V. PHYSICS AT A HIGGS FACTORY

A. Skrinsky, Chair

V. PHYSICS AT A HIGGS FACTORY, *A. Skrinsky* (INP, Novosibirsk), Chair

Overview of the Higgs Factory $\mu^+\mu^-$ Collider Concept - *D. Cline* (UCLA)

Higgs Boson Mass/Physics - *G. Kane* (U Mich)

Progress Report Detector Backgrounds - *I. Stumer* (BNL)

Beam Halo vs Beam Decays in $\mu^+\mu^-$ Colliders: Effect on Detector and Machine Designs - *N. Mokhov* (FNAL)

Determining the Energy Scale of the 50-GeV First Muon Collider Using g-2 Precession - *R. Raja/A. Tollestrup* (FNAL)

Tracking Concepts of High-Luminosity Muon Colliders - *M. Atac* (FNAL/UCLA)

OVERVIEW OF THE HIGGS FACTORY
$\mu^+\mu^-$ COLLIDER CONCEPT

David B. Cline

UCLA

Center for Advanced Accelerators

1. **The Scientific Case for The Higgs Boson**
2. **Higgs Factory (HF) $\mu^+\mu^-$ Collider Concept**
3. **Mass Range of Interest for HF and SUSY Higgs Bosons**
4. **Precision Electro Weak Parameters – LHC-CMS Prospects**
5. **When might we know M_H Range for Planning H.F.**
6. **Study of Exotic Physics with Higgs Boson – NFC/FCNC**

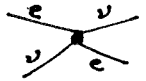
THESIS _____SUMMARY_____

TO GET A NEW FACILITY IN THE US IT WILL BE ESSENTIAL TO DEMONSTRATE IT'S PHYSICS NEED

WHY SHOULD THERE BE A FUNDAMENTAL SCALAR PARTICLE OR INTERACTION

A LITTLE HISTORY

~ 1932 FERMI INVENTS THEORY OF WEAK INTERACTION



4 Fermion Point like (Spin ½)

~1937 HEISENBERG AND OTHERS SHOW THEORY DIVERGENT $\sigma_{\nu e} \sim E^2_{cm}$

$\sigma_{\nu e} \to \infty$ $E \to \infty$ and Violates Unitarity at ~ 300 GeV incm

~ 1938 - 48 Concept of W (Weakon) (Spin 1)
Klein → Low
$\sigma_{\nu e} \to \ln E$, $E \gg M_W$

But theory still Divergent since now
$W+W \to W+W$ $\sigma_{WW} \to \infty$ like previous

~ 1966 - 68 Ward, Salam, Glashow, weinberg etc Show how divergences can be cured (Using ~ 1965-67 Higgs Mechanism) P. Higgs

Relate M_Z and M_W

i) Invent Neutral ~~Vector~~ Vector ?° { WWC 73, 2° disc 83 at CERN }
cure divergence - $W_L + W_L \to W_L + W_L$

ii) Need Neutral Scalar to cure divergence in $W_L+W_L \to W_L+W_L$ H_o ??
- Most likely $M_H < 1$ TeV - But could be cut not pole?

NC 1973 ↓ W/Z 1983

Natural conservation laws for neutral currents* ⇒ NFC

Sheldon L. Glashow and Steven Weinberg
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138
(Received 20 August 1976)

We explore the consequences of the assumption that the direct and induced weak neutral currents in an SU(2) ⊗ U(1) gauge theory conserve all quark flavors *naturally*, i.e., for all values of the parameters of the theory. This requires that all quarks of a given charge and helicity must have the same values of weak T_3 and $\vec{T}^2$. If all quarks have charge $+2/3$ or $-1/3$ the only acceptable theories are the "standard" and "pure vector" models, or their generalizations to six or more quarks. In addition, there are severe constraints on the couplings of Higgs bosons, which apparently cannot be satisfied in pure vector models. We also consider the possibility that neutral currents conserve strangeness but not charm. A natural seven-quark model of this sort is described. The experimental consequences of charm nonconservation in direct or induced neutral currents are found to be quite dramatic.

NO FCNC SO FAR

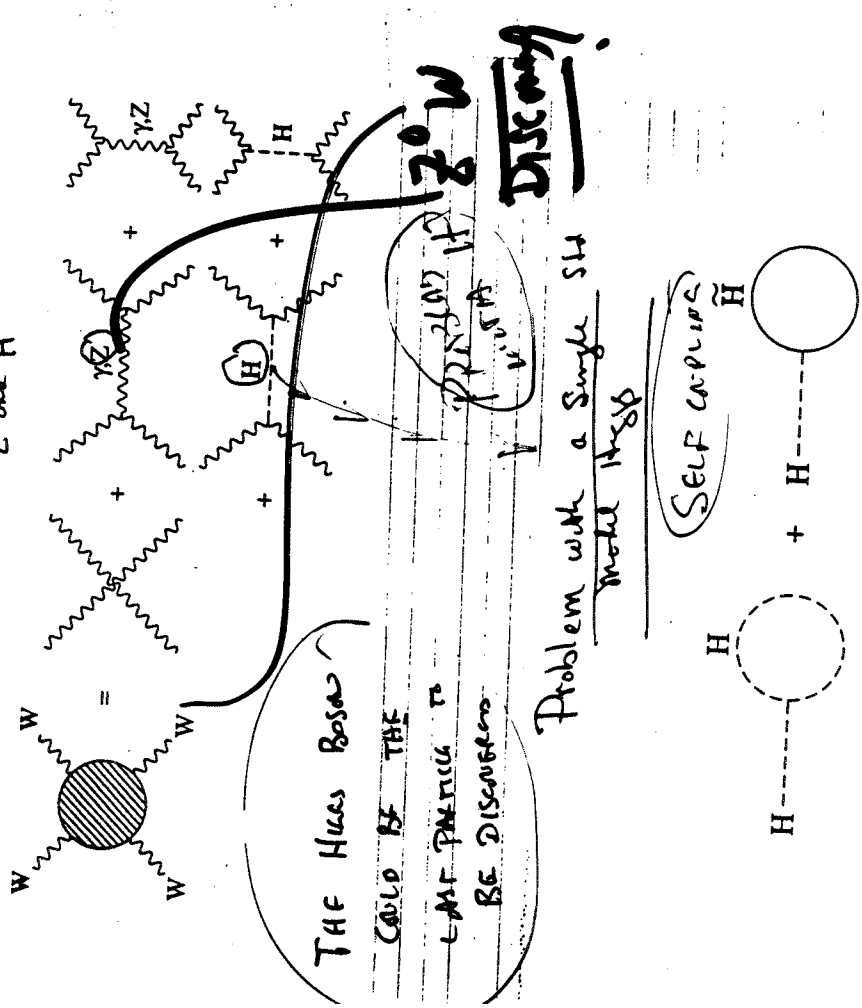
Natural Flavor Conservation NFC

1) 1 Higgs Boson
2) All quark ⇒ $\begin{pmatrix} +2/3 \\ -1/3 \end{pmatrix} = \begin{pmatrix} u \\ d \end{pmatrix}\begin{pmatrix} c \\ s \end{pmatrix}\begin{pmatrix} t \\ b \end{pmatrix}$

Has Never been tested directly –
IS KEY COMPONENT of STANDARD MODEL!

S Willenbrock ITP Thy Fermi

CURE FOR DIVERGENCES WITH Z and H



THE Higgs Boson Could BE THE LAST Particle To BE Discovered

Problem with a Single SU Neutral Higgs

SELF CAPTURE

WHAT CUTS OF THIS DIVERGENCE??

Figure 5: (a) Quadratically-divergent one-loop correction to the Higgs vacuum-expectation value from a Higgs loop; (b) the quadratic divergence is cancelled by a Higgsino loop in a supersymmetric theory.

FROM VIEWPOINT OF EXPERIMENT!

Table 4. The scalar sector.

With a high-mass t quark, precision LEP/SLD data and the theorists' dreams of a SUSY world, the scalar (pseudo-scalar sector) is possibly very complex and may require several types of colliders.[7] Consider:

- If the low-mass Higgs has $m > 130$ GeV, MSSM is not allowed.
- If $m > 200$ GeV, there are constraints from the requirement that perturbation theory be useful up to very high energy and from the stability of the vacuum.
- If $m < 130$ GeV, MSSM is possibly ok, but we may expect other particles (H, A), and the width of the low mass Higgs may change.
- The scalar sector may be extremely complex, requiring pp (LHC) and $\mu^+\mu^-$ colliders (and possibly NLC and $\gamma\gamma$ colliders).
- In high energy collisions, vector states are allowed unless a special method is used. Consider $\mu^+\mu^-$ colliders with polarized $\mu^\pm$:

$\mu^+\mu^-$ → (100-500) GeV - scalars (H, A, ...) W^+W^-

$\mu^+\mu^-$ → ≥ 2 + TeV Z^0Z^0 production in scalars

This cannot be done for pp or e^+e^- colliders.

- A $\mu^+\mu^-$ collider is complimentary to the LHC/CMS detector.

- NLC still untested for many processes -

Std Model Higgs

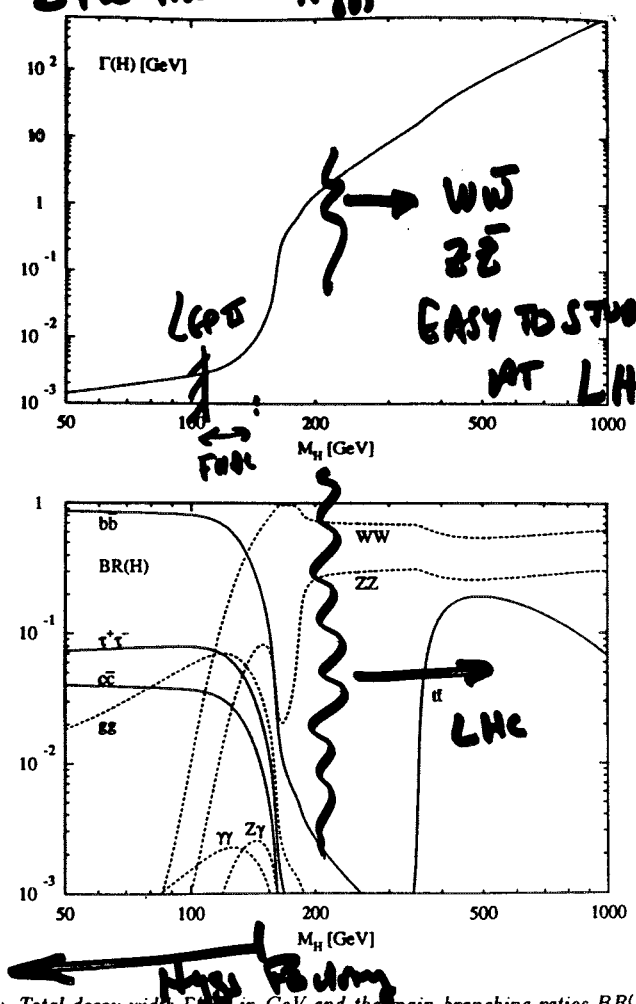


Figure 2: *Total decay width $\Gamma(H)$ in GeV and the main branching ratios $BR(H)$ of the Standard Model Higgs decay channels, using the inputs of Tab. 2.*

Concept of a Higgs Factory (I)

μ(92) → (~1992 Napa $\mu^+\mu^-$ Collider meeting) was first to enunciate the specific use to measure the properties of the Scalar Sector) (1st Meeting in this Series)

In the Standard model the H^0 couples mainly to WW and ZZ

if $M_H < M_{2W}$, M_{2Z} the ~~coupling~~ coupling is very weak — Hence $\Gamma_{H^0} \sim$ MeV–50 MeV

if $M_H >> M_{2W}$ $\Gamma_{H^0} \sim$ GeV → 10 GeV

$H^0 \to WW, ZZ$

Thus a low mass Higgs is hard to discover and difficult to study

In contrast for $H^0 > M_{2Z}$ it is fairly

trivial - ie $p+p \to \cdots H^0$

$\hookrightarrow Z+Z$

The Compact Muon Solenoid Detector (1989) was invented to study this mode $\hookrightarrow \mu\mu$ $\hookrightarrow \mu\mu$

So a Higgs Factory is mainly interesting for

$M_H < M_{2W}$ or $M_{2Z} < 180$ GeV

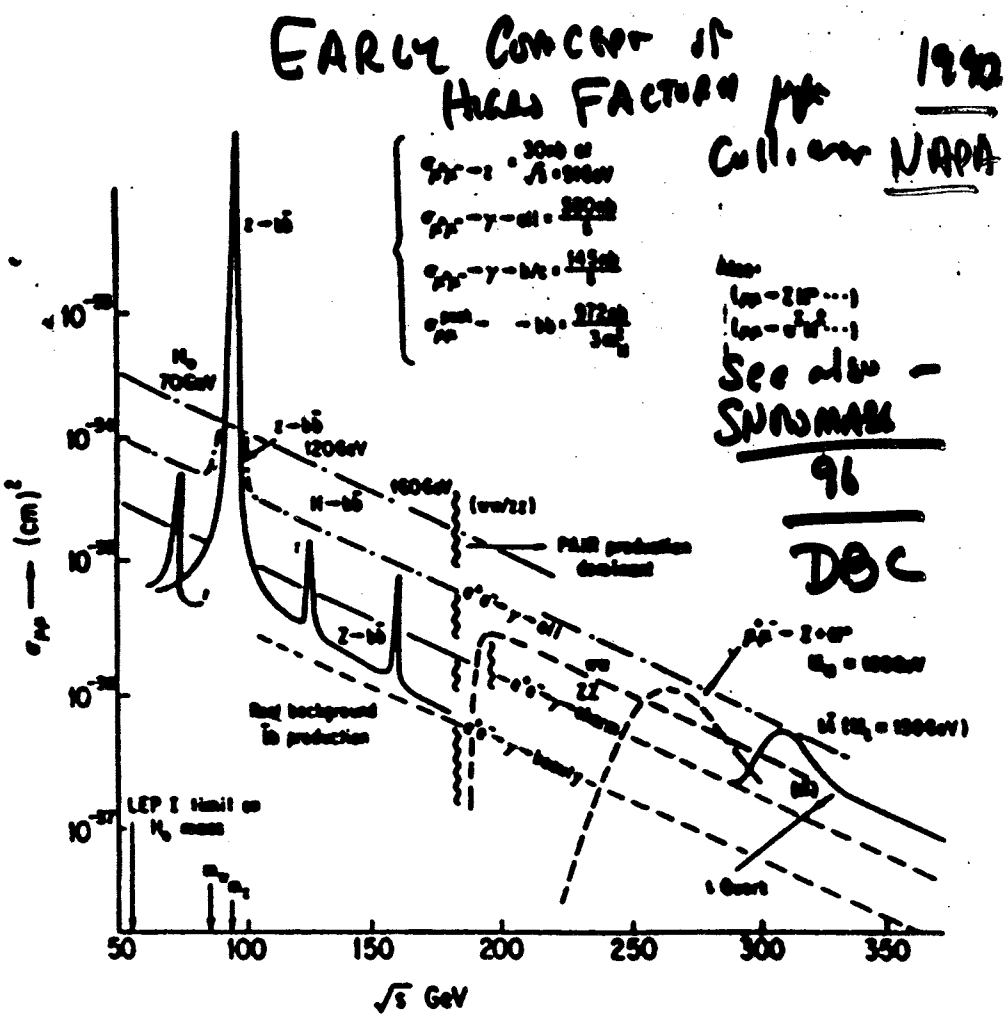


Fig. 1. The first concept of a Higgs factory $\mu^+\mu^-$ collider from the Napa Workshop.[1]

Table 6. Examples of the scan for the Higgs at different mass.

(A) m_H ~ GeV - $H \sim b\bar{b}$ - Background from $Z \sim b\bar{b}$ reduced.

$\sigma_{H\text{-}b\bar{b}} = 8 \times 10^{-36}$ cm^2 $\qquad$ $\sigma_{Z\text{-}b\bar{b}} = 4 \times 10^{-36}$ cm^2

$\delta p/p = 0.01\%$ $\qquad$ $\Sigma\, \sigma_Z + \sigma_H = 12 \times 1^{-36}$ cm^2 at resonance

Known position within 1 GeV. For each scan point, a 5σ is to be observed.

[Assume $\mathcal{L} = 10^{32}$; $\Delta t = 5 \times 10^4$ s for 100 scan points]

(B) m_H ~ 100 GeV

$\sigma_{H\text{-}b\bar{b}} = 9 \times 10^{-36}$ cm^2 $\qquad$ $\sigma_{Z\text{-}b\bar{b}} = 12 \times 10^{-36}$ cm^2

$\frac{\delta p}{p} = 0.01\%$ $\qquad$ $\Sigma\, \sigma_H + \sigma_t = 21 \times 10^{-36}$ cm^2

Same scan method.

$\geq 3\sigma$ effect

Conclude that $\mathcal{L} = 10^{32}$ cm^{-2} sec^{-1} and that $\delta p/p = 0.01\%$ is adequate to find the Higgs.

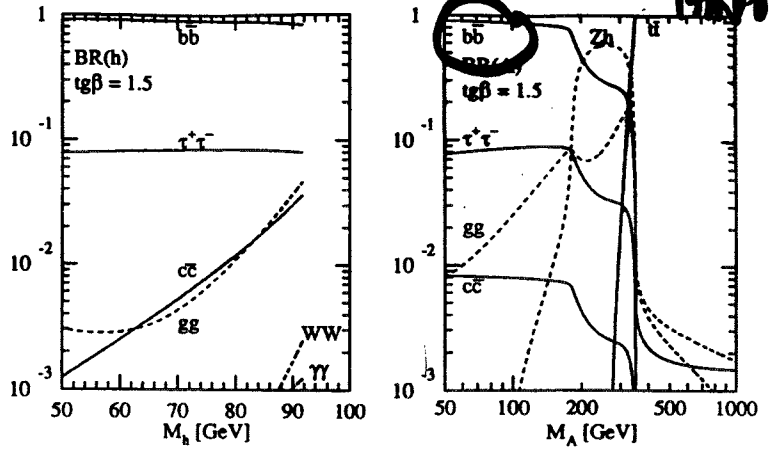


Fig. 3a

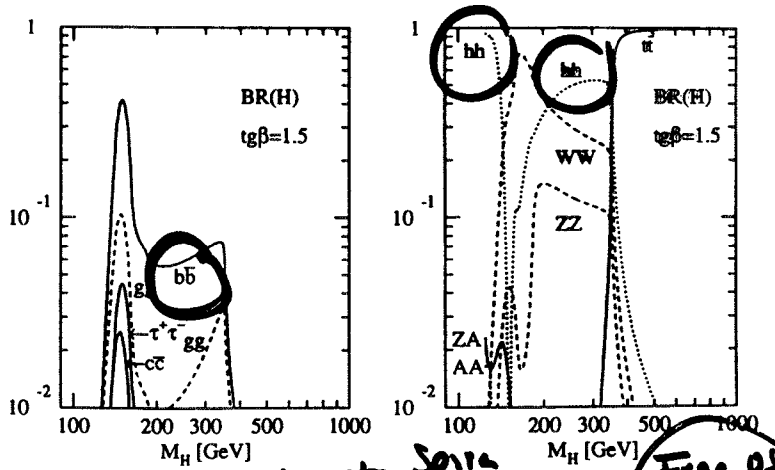


Fig. 3b

Figure 3: *Branching ratios of the MSSM Higgs bosons h, A(a), H(b), H$^\pm$(c) and the total decay widths Γ(Φ)(c), using the inputs of Tab. 2.*

CURRENT

LIMITS ON HIGGS MASSES

Updated Limits

H^0_{SM} $m > 77.1$ GeV 95% CL (LEPWG) $e^+e^- \to ZH$

EW fit: $m = 115^{+116}_{-66}$ GeV

$m < 420$ GeV 95% CL

NOW ~~$\approx$~~ GeV

SUSY h, A $m_h > 64.5$ GeV (ALEPH) $e^+e^- \to hZ$

$m_A > 64.5$ GeV $\tan\beta > 1$ $e^+e^- \to hA$

– may exist fine-tuned escapes from limits

$H^\pm$ $m > 54.5$ GeV $e^+e^- \to H^+H^-$

$p\bar{p} \to t\bar{t} \to H^\pm X$ CDF & DØ limits

New LEP limits on parameter space for

charginos neutralinos $m_{\chi^\pm_1} \geq 91$ GeV

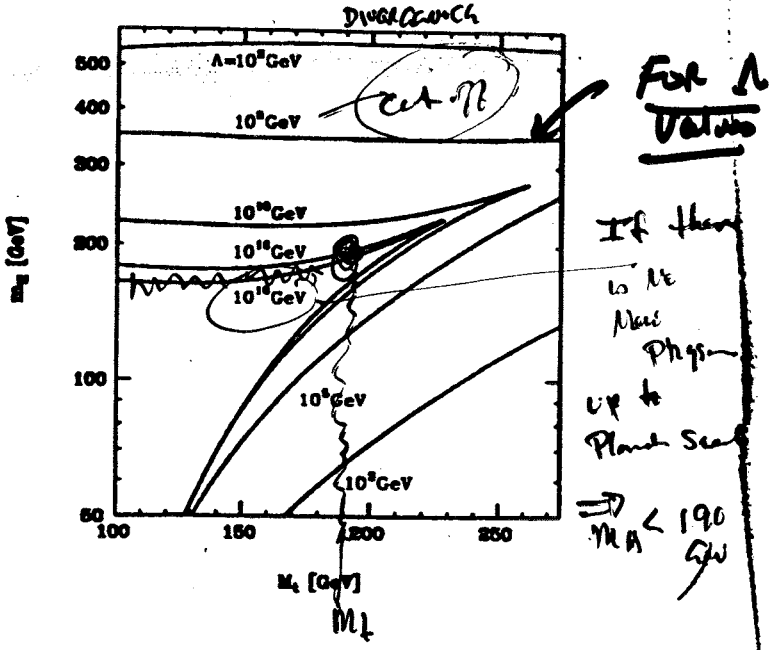
sleptons $\tilde{e}$ $\tilde{\mu}$ $m_{\tilde{\chi}} > 80$, $m_{\tilde{\mu}} > 73$ for small m_0

stop sbottom

We heard more on Wed –

THERE ARE BOUNDS OF HIGGS MASS

WHAT COMES OFF THE DIAGRAM



FOR Λ VALUES

IF THERE IS NEW PHYSICS UP TO PLANCK SCALE

$\Rightarrow M_H < 190$ GeV

Figure 1: *Bounds on the Higgs mass as a function of the top quark mass for different values of the scale Λ, at which new physics is expected to appear.*

OTHER "EVIDENCE" FOR LOW MASS HIGGS

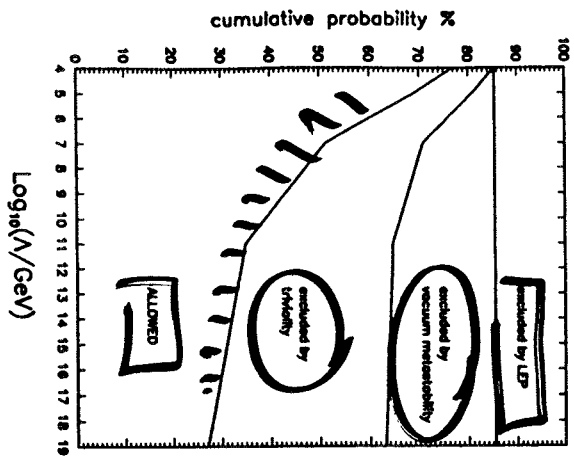
- USING PRECISION ELECTROWEAK DATA
  (Z^0 parameters, $m_{W^\pm}$, m_t, $\sin^2\theta_W$ etc etc)

  Current fits suggest $m_H < 300$ GeV

  After LEP 2 provides precision m_W this bound could improve

- By ~ 2000 we may have a limit with an error of ± 10 GeV that is believable (or 50 ???)

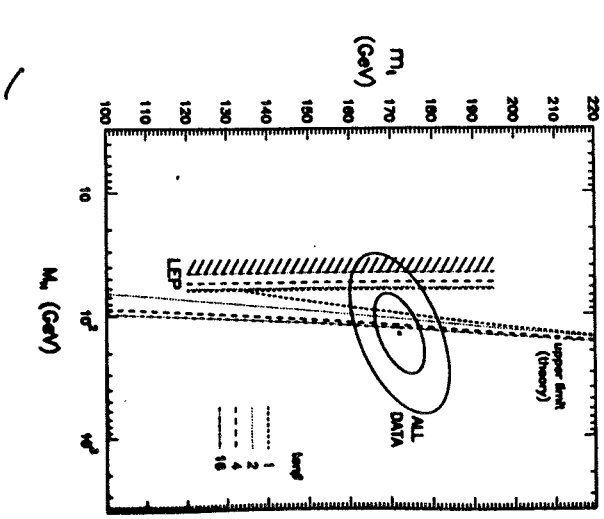
{All in All it is a good but that [of the Higgs Exists] AT LEAST ONE WILL BE AT LOW MASS



LIMITS ON HIGGS MASS

THIS HAS BEEN RULED OUT BY LEP

2. Cumulative (integrated) probabilities in the various zones excluded or allowed in the d Model by one-sided bounds. No value of Λ can be excluded.



LAST YEAR

THIS YEAR

FIG. 2. Indirect bounds on (M_H, m_t) and one-sided experimental and theoretical limits in the Minimal Supersymmetric Standard Model. Apart from the Higgs sector, the MSSM spectrum is assumed to be decoupled. Solid ellipses represent the 1-σ and 2-σ contours as in Fig. 1. The vertical lines are the LEP lower bounds on M_H [99], which depend slightly on $\tan\beta$. The other

3d

EW Data

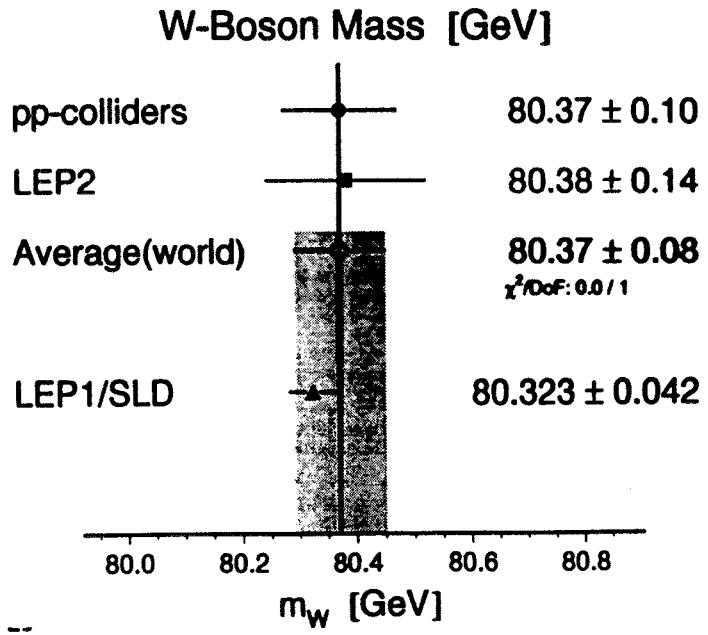
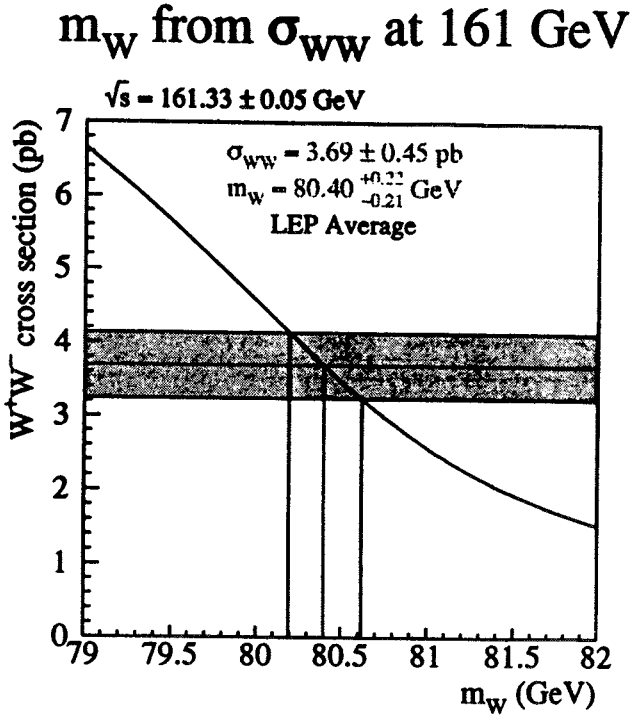


Figure 5: Comparison of the direct W mass measurements at the Tevatron and LEP2 and the indirect determination using LEP1 and SLD data.

EW Data

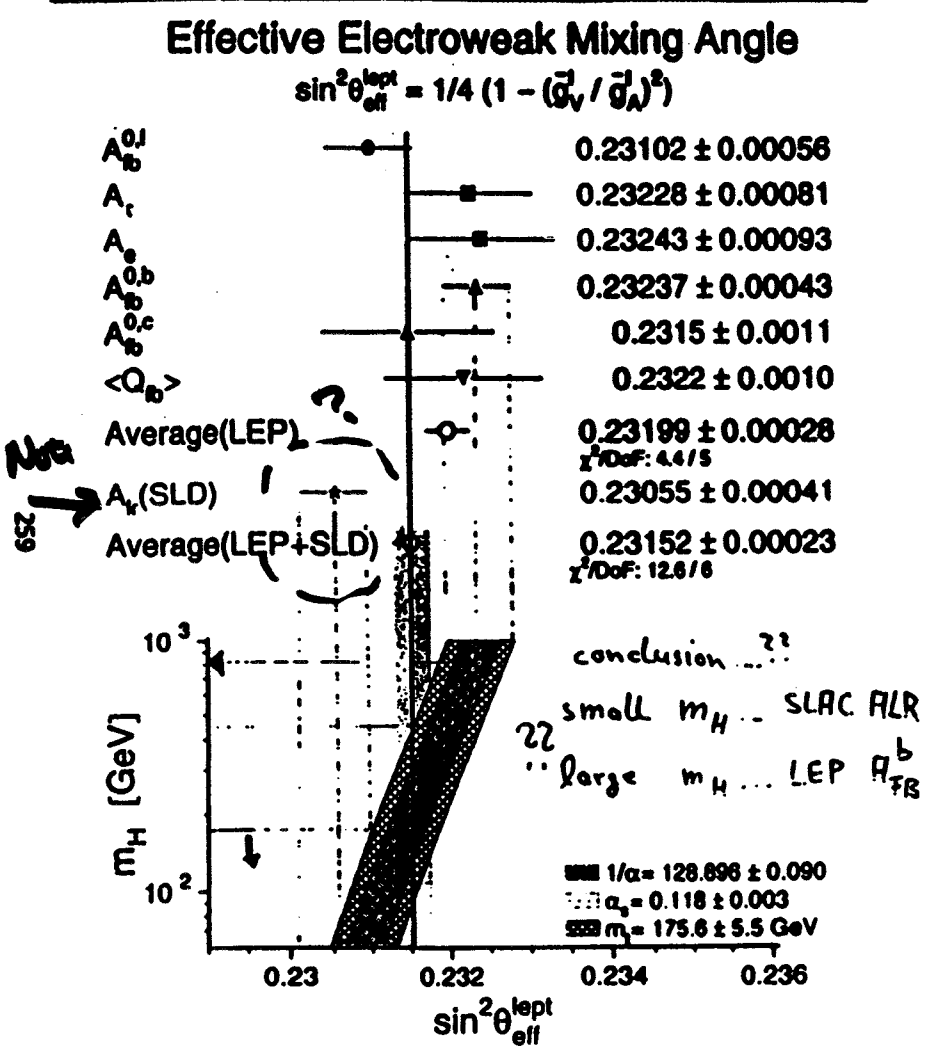


Final LEP 161 GeV W mass
LEP EW Working Group

9

Figure 3: WW cross section at $\sqrt{s}$ = 161.3 GeV as a function of W mass. The band represents the experimental measurement.

Summary of $\sin^2\theta^{lept}_{eff}$



Note 259

conclusion ...??

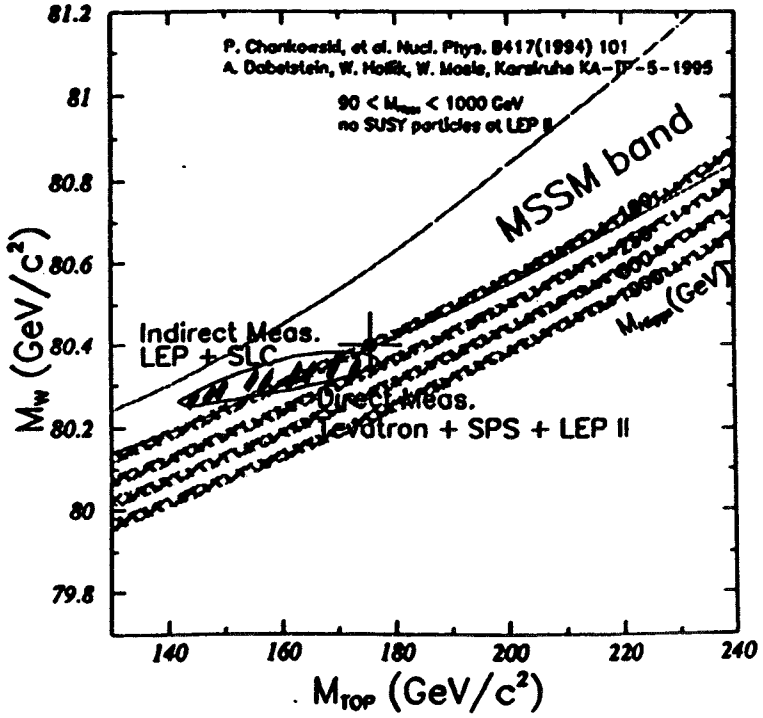
?? small m_H .. SLAC ALR

?? large m_H ... LEP A^b_{FB}

all precision data ...

$m_H = 115 \pm \begin{smallmatrix}116\\66\end{smallmatrix}$ < 420 GeV (95% c.l.)

attention: (1987) $m_{top} < 190$ GeV U. Amaldi et al.
(1988) $m_{top} < 169$ GeV G. Costa et al. (90% c.l.)
(1991) $m_t = 132 \pm \begin{smallmatrix}27\\31\end{smallmatrix} \pm \begin{smallmatrix}18\\19\end{smallmatrix}$ LEP Coll.



Most Recent Fits to EW Parameters Suggest

— Low Mass Higgs —

Davier & Hocker 97: $M_h = 129^{+103}_{-92}$ GeV

Erler & Langacker 97: $M_h = 122^{+184}_{-77}$

EW Fit CERN 97: $M_h = 115^{+116}_{-66}$ GeV

$M_h < 420$ GeV 95% C.L.

NEW LEP II Limit → $M_h > 88$ GeV

We may be tempted to assume M_h is small! ⇒ Higgs Factory!

October 7, 1997

LBNL-40877
hep-ph/9710308

Combining real and virtual Higgs boson mass constraints[1]

Michael S. Chanowitz[2]

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Berkeley, California 94720

Abstract

Within the framework of the standard model we observe that there is a significant discrepancy between the most precise Z boson decay asymmetry measurement and the limit from direct searches for Higgs boson production. Using methods inspired by the Particle Data Group we explore the possible effect on fits of the Higgs boson mass. In each case the central value and the 95% confidence level upper limit increase significantly relative to the conventional fit. The results suggest caution in drawing conclusions about the Higgs boson mass from the existing data.

- Recall years ago $Z \to bb$ Problem → Disagreed the Fits

UNTIL EW PARAMETERS ARE CONSISTENT WE CAN'T TRUST M_h ESTIMATION !

Tables

Table 1. Values for $sin^2\theta_{eff}^{lepton}$ from asymmetry measurements[1] with 1σ experimental errors. The corresponding Higgs boson masses, the 95% CL upper and lower limits, and the confidence level for $m_H < 77$ GeV are given for each measurement.

	$\sin^2\theta_{eff}^{lepton}$ (1σ)	m_H (GeV)	$m_{95}^{>}$, $m_{95}^{<}$	P(< 77GeV)
A_{LR}	0.23055 (41)	16	3, 80	0.95
A_{FB}^b	0.23236 (43)	520	100, 2700	0.03
A_{FB}^l	0.23102 (56)	40	5, 290	0.71
A_τ	0.23228 (81)	440	30, 6700	0.14
A_e	0.23243 (93)	590	28, 13000	0.14
Q_{FB}	0.23220 (100)	380	14, 10000	0.21
A_{FB}^c	0.23140 (111)	83	2, 3000	0.48

Is there a conflict

WHY IS MASS of h IMPORTANT FOR HIGGS FACTORY

Logic of Higgs Study @ NF FUTURE

Why a Higgs Factory

Table 3. Logic of detailed study of the Higgs sector.

If particles in the scalar sector are ever discovered, it will be essential to determine their properties, which will give direct information about the nature of the particle and the underlying theory. Three simple examples can be cited:

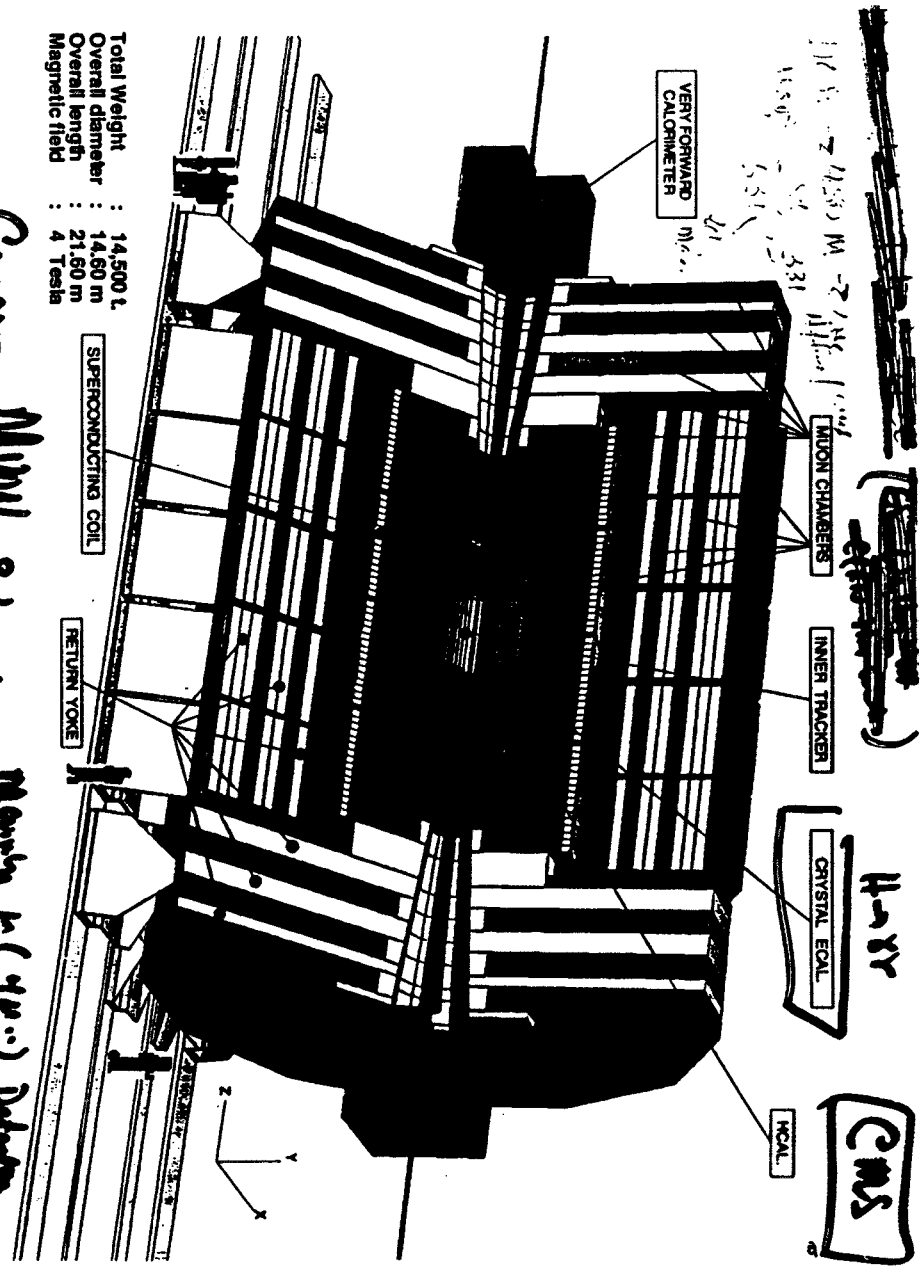
1. Suppose a Higgs-like particle is discovered with mass 110 GeV. This could either be the Standard Model (SM) Higgs or an MSSM Higgs. A measurement of the width of the state would presumably tell the difference. However, the SM width is 5 MeV – a formidable measurement!

2. Suppose a Higgs-like particle is discovered with a mass of 150 GeV. This is presumably beyond the MSSM bound, but it could be an NMSSM or an SM Higgs. A measurement of the width could presumably resolve the issue.

3. Suppose a Higgs-like particle of mass 165 GeV is discovered. This is presumably even beyond the NMSSM limits. If this is an SM Higgs, can we learn more by the study of the rare decay modes?

1) $M_h > 150$ GeV – Susy out

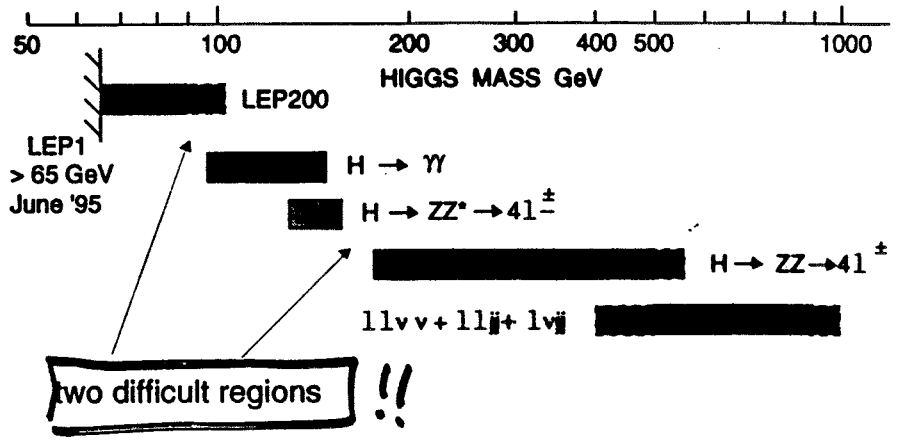
2) $m_h > 2M_W$ – LHC may do All important physics



SM Higgs search at LHC

i) mass range explorable at $\sqrt{s}$ =14 TeV with $3 \cdot 10^4$ pb^{-1} taken at 10^{33} cm^{-2}s^{-1}

CMS



ii) explorable mass range with 10^5 pb^{-1} taken at 10^{34} cm^{-2}s^{-1}

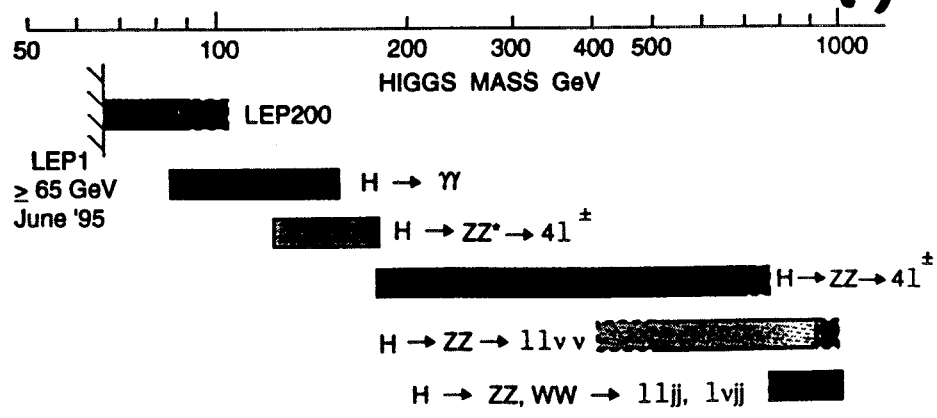


Table 12.4a
Signal significance for H → 4 charged leptons for m_H =130, 150, 170 GeV at $10^5 pb^{-1}$ without lepton isolation.

	m_H = 130 GeV	m_H = 150 GeV	m_H = 170 GeV	$t\bar{t}$	$Zb\bar{b}$	ZZ*
Events in $m_H \pm 2\sigma_H$	41.7	108.3	29.3	4.8/GeV	0.97/GeV	1.8/GeV
Significance	6.1	12.1	4.1			

Table 12.4b
Signal significance for H → 4 muons for m_H =130, 150, 170 GeV at $2 \times 10^5 pb^{-1}$ with muon isolation.

	m_H = 130 GeV	m_H = 150 GeV	m_H = 170 GeV	$t\bar{t}$	$Zb\bar{b}$	ZZ*
Events in $m_H \pm 2\sigma_H$	31.3	74.1	20.3	0.9/GeV	0.3/GeV	1.3/GeV
Significance	7.4	15.2	5.0			

12.1.6 H → ZZ → 4 Charged Leptons

The H → ZZ → 4 $l^{\pm}$ channel is sensitive, even with only $10^4 pb^{-1}$, over a wide mass range, from $2m_Z$ up to about 400 GeV [19]. The main background is non-resonant ZZ production. For $m_H \leq 300$ GeV, the natural width of the Higgs is small (e.g. Γ_H = 1.5 GeV for m_H = 200 GeV), and a good four-lepton mass resolution will facilitate an early observation.

For the ZZ continuum background, the $q\bar{q} \rightarrow ZZ$ subprocess was simulated. The $gg \rightarrow ZZ$ contribution was accounted for by multiplying the $q\bar{q} \rightarrow ZZ$ cross-section by a factor of 1.33 [20]. No k-factors were included for the signal or background.

Internal bremsstrahlung was included using PHOTOS. The fraction of Zs falling outside the $(m_Z \pm 6)$ GeV window, due to the internal bremsstrahlung alone, is 12% for $Z \rightarrow e^+e^-$ and 7% for $Z \rightarrow \mu^+\mu^-$. To account for external bremsstrahlung, a full GEANT simulation of the response to electrons was performed [17] and electron energies were measured in the calorimeter, as discussed in Sect. 11.4. The muon momenta were smeared according to parametrized resolutions obtained from a full GEANT simulation [18]. With m_H = 300 GeV, the Z mass resolution in the Gaussian peak region for $Z \rightarrow e^+e^-$ events is 2.2 GeV, and for $Z \rightarrow \mu^+\mu^-$ events, 2.1 GeV. In calculating the expected number of events, a reconstruction efficiency of 95% per lepton was included. No lepton isolation cuts were applied as the $t\bar{t}$ background is negligible.

The p_t and η [illegible] cuts are the same as for the ZZ* channel. At m_H = 400 GeV, the overall (η and p_t) 4-lepton acceptance is in the electron channel, 55%, and [illegible] m_H = 600 GeV, the acceptances are 77% and 79% respectively. Two e^+e^- or $\mu^+\mu^-$ pairs with an invariant mass consistent with a Z were required. The Z mass window is large, $(m_Z \pm 6)$ GeV, since there are [illegible] backgrounds which are critically affected by the two-lepton mass cut. Due to bremsstrahlung and momentum resolution, ≈ 40% of the events are lost due to this cut (see Sect. 11.4). A more sophisticated method, using the fine granularity of the ECAL, could allow the recovery of a fraction of the radiative losses in the future.

Figure 12.11 shows the expected 4-lepton mass spectrum for m_H = 300, 500 and 600 GeV, with the ZZ background. The event rates shown are for $2 \times 10^5 pb^{-1}$ and $10^5 pb^{-1}$.

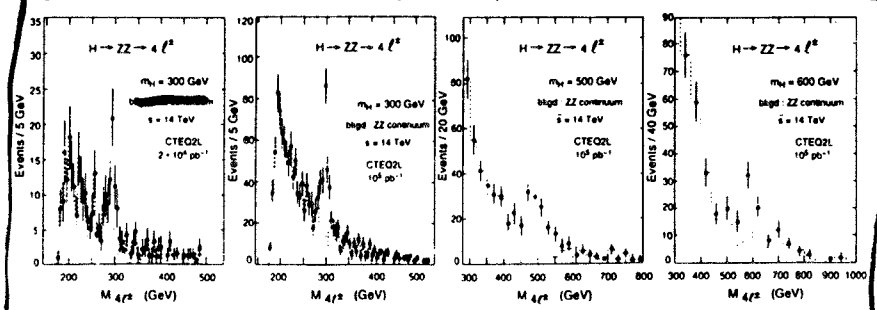


Fig. 12.11. The four-lepton mass distributions for H → ZZ → 4$l^{\pm}$ superimposed on the ZZ continuum background for m_H = 300 and 2×10^4 pb^{-1} and for m_H = 300, 500 and 600 GeV with $10^5 pb^{-1}$.

The crystal calorimeter was assumed to have an energy resolution given by $\Delta E/E = 2\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ in the barrel and $\Delta E/E = 5\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ in the endcap, where there is a preshower detector. At high luminosity, a barrel pre-shower detector covers $|\eta| < 1.1$, resulting in a resolution of $\Delta E/E = 5\%/\sqrt{E} \oplus 0.5\% \oplus 0.200/E$ and an ability to measure the photon direction with resolution $\Delta\alpha = 40\ \text{mrad}/\sqrt{E}$ in this region. For more details concerning both the [illegible] configurations and the breakdown of the mass resolution, see Sect. 4.1.

The background to the H → γγ signal may be divided into three categories:

- prompt diphoton production from quark annihilation and gluon fusion diagrams, which gives an irreducible background,
- prompt diphoton production from significant higher-order diagrams – primarily bremsstrahlung from the outgoing quark line in the QCD Compton diagram,
- background from jets, where an electromagnetic energy deposit originates from the decay of neutral hadrons in a jet or from 1 jet + 1 prompt photon.

The prompt diphoton background was generated using CTEQ2L structure functions in PYTHIA. For the bremsstrahlung background, a previous PYTHIA calculation for $\sqrt{s}$ = 16 TeV, m_{top} = 150 GeV, and HMRSB structure functions, was rescaled to take account of the new parameters. The resulting cross-sections are given in Table 12.1. It is assumed that the jet background is reduced to an insignificant level (< 10%) by the combination of isolation and π^0 rejection cuts.

Figure 12.3 shows a background-subtracted two-photon effective mass plot for a simulated single experiment, for an integrated luminosity of 10^5 pb^{-1} (taken at high luminosity) with signals at m_H = 90, 110, 130 and 150 GeV. Figure 12.4 shows a similar plot, for an integrated luminosity of 3×10^4 pb^{-1} taken at low luminosity.

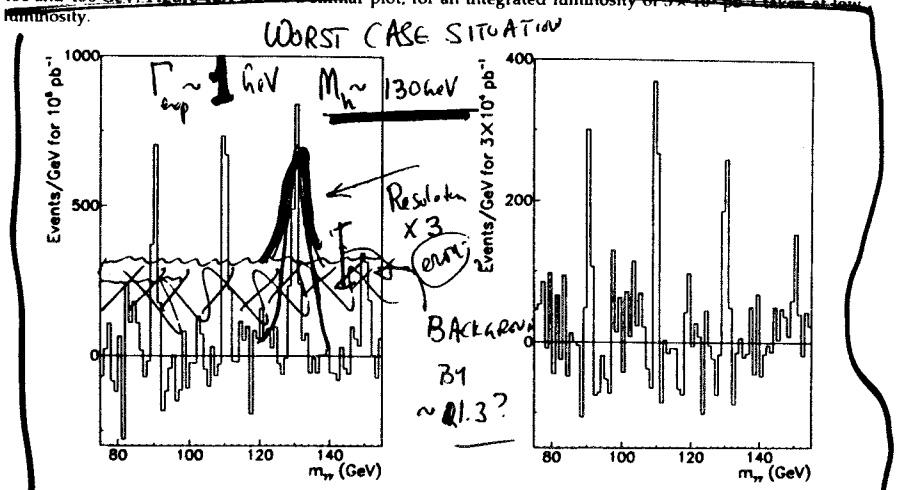


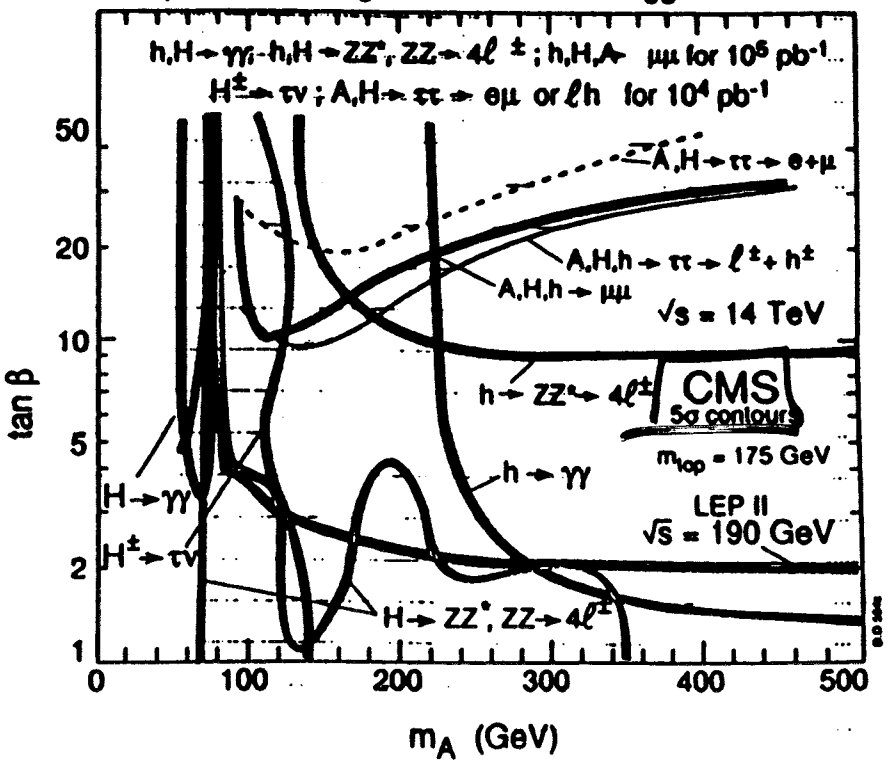
Fig. 12.3: Background-subtracted 2γ mass plot for 10^5 pb^{-1} with signals at m_H = 90, 110, 130 and 150 GeV, in the $PbWO_4$ calorimeter.

Fig. 12.4: Background-subtracted 2γ mass plot for 3×10^4 pb^{-1} with signals at m_H = 90, 110, 130 and 150 GeV, in the $PbWO_4$ calorimeter.

Figures 12.5 and 12.6 show contours giving the cross-section times branching ratio required to give specified signal significances $\left(N_S / \sqrt{N_B}\right)$, as a function of mass. The significances were calculated by counting events within a mass window of optimum width, corresponding to the width containing about 75% of the signal. After a single year of running at 10^{34} $cm^{-2}s^{-1}$ (10^5 pb^{-1}, Fig. 12.5), an SM Higgs could be discovered across the full range 85 to 150 GeV. After only 3×10^4 pb^{-1} (Fig. 12.6), taken at low luminosity, an SM Higgs could be discovered between 95 and 150 GeV.

Significance contours for MSSM Higgs bosons

WHAT ABOUT "TOTAL SUSY" AT LHC



THESE ARE FOR LIMITS BUT IF THERE IS A SUSY THRESH...

HIGGS-FACTORY SCAN ~130 GeV

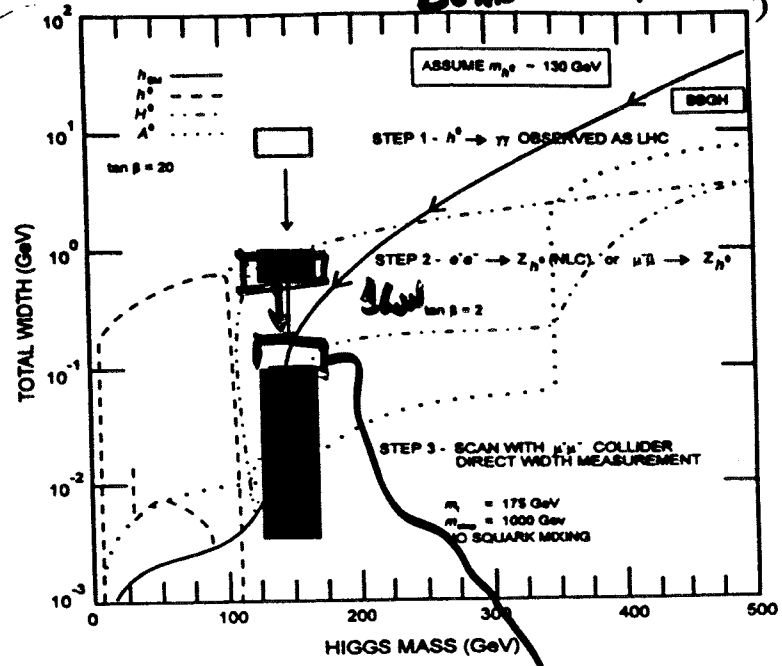
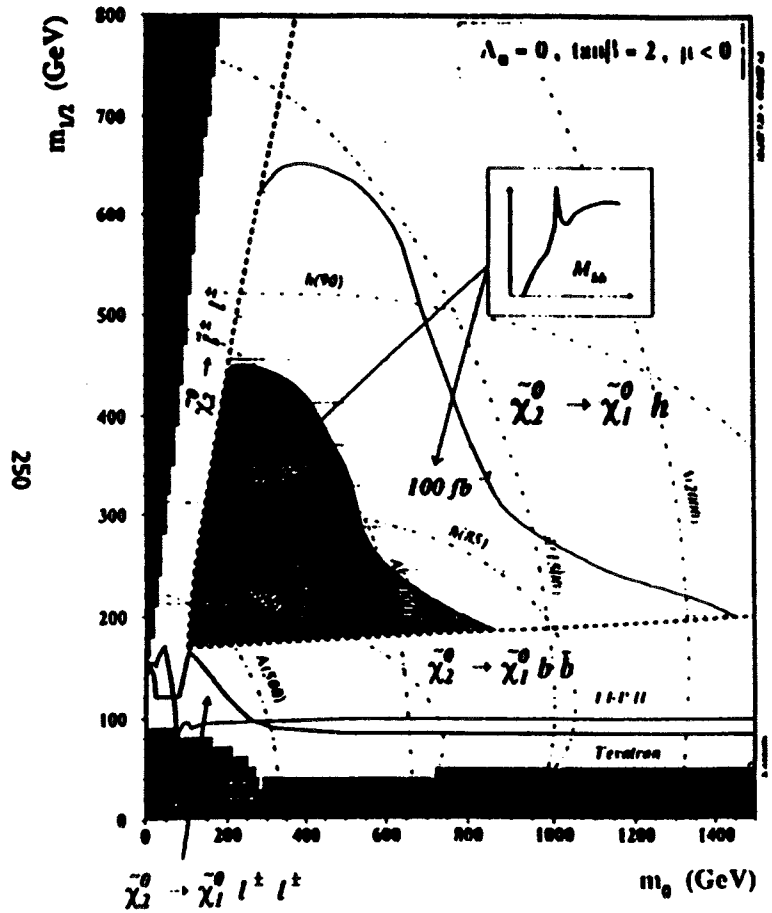


Fig. 2. Higgs-factory $\mu^+\mu^-$ collider concept. The Higgs is discovered at the LHC (CMS) and the width further reduced at the NLC or at a $\mu^+\mu^-$ collider. The final stage is to scan for the Higgs at the $\mu^+\mu^-$ collider. Existing models can be distinguished by their widths. [Adapted from Ref. 12 (BBGH = Barger, Berger, Gunion, Han) and Ref. 14.]

Conclusions from Weak Tests

IN THIS CASE A HIGGS FACTORY MAY NOT BE NECESSARY !!

Domains of $h \to b\bar{b}$ peak visibility in the framework of mSUGRA model



WHEN MAY WE KNOW THAT A HIGGS FACTORY IS ESSENTIAL

1) EW Measurements ~ Soft
   ~ 2001 — LEP II
   — TEV 2 + Main Injector
   may "Prove" $m_h < 180$ GeV
   OR LEP II → $m_h \lesssim 105$ GeV

2) FNAL may Discover $m_h < 180$ GeV
   ~ 2003 ?

3) LHC Discover Higgs but not total Susy
   ~ 2007 ?

2001 - early
2003 - realistic
2007 - Latest

Example of masses and branching ratios at one point in $m_0, m_{1/2}$ space :

- $m_0 = 500$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$, $\tan\beta = 2$, $\mu < 0$

  $m_{\tilde{g}} = 1224$ GeV $m_{\tilde{q}} \leq m_{\tilde{g}}$ $m_{\tilde{t}_1} = 852$ GeV

  $m_{\tilde{\chi}_1^0} = 217$ GeV

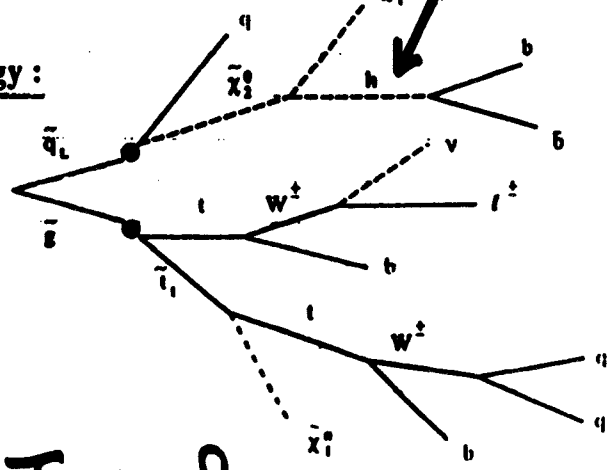
  $m_{\tilde{\chi}_1^\pm} = 427$ GeV $m_{\tilde{e}_L} = 611$ GeV $m_h = 89.7$ GeV

dominant decays :

- $\tilde{g} \longrightarrow \tilde{q}\bar{q}$ ($\tilde{t}_1\bar{t} \sim 49\%$, $\tilde{b}_1\bar{b} \sim 17\%$)
- $\tilde{q}_L \longrightarrow \tilde{\chi}_1^\pm q \sim 2/3$, $\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^\pm \sim 100\%$; $\tilde{\chi}_1^0 q \sim 1/3$, $\tilde{\chi}_1^0 \to \tilde{\chi}_1^0 h \sim 96\%$ ($h \to b\bar{b} \sim 88\%$), $\tilde{\chi}_1^0 Z \sim 3\%$
- $\tilde{q}_R \to \tilde{\chi}_1^0 q \sim 100\%$
- $\tilde{t}_1 \longrightarrow \tilde{\chi}_1^0 t \sim 94\%$, $t \to W^+ b$

Recent CMS Simulation

event topology :



- *4 b-jets*
- *+ 3 non-b jets*
- *+ $\not{E}_T^{miss}$*

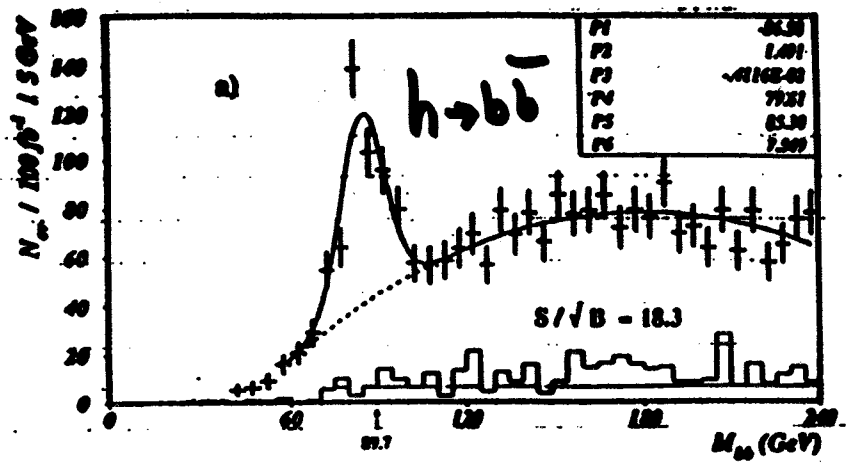
S. Abdullin
D. Denegri

— TOTAL SUSY AT LHC —

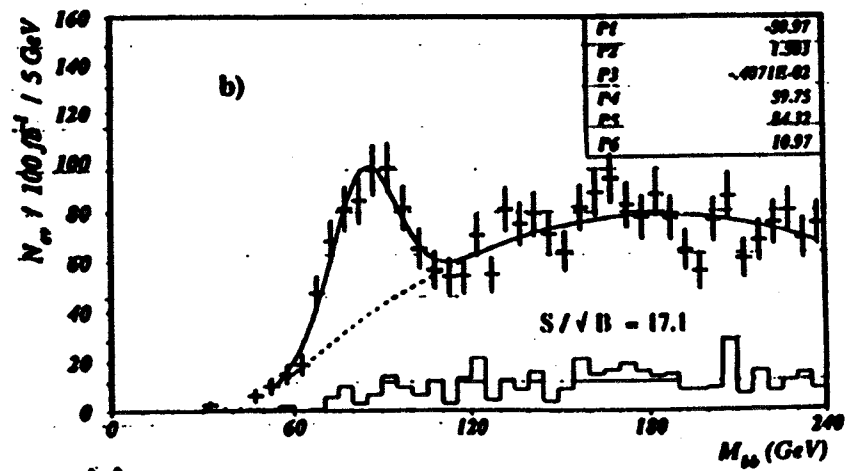
$h \to b\bar{b}$ in mSUGRA

E_T Cuts

nominal CMS performance

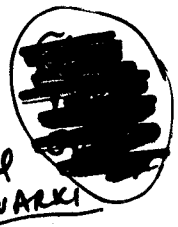


HCAL : $\sigma/E = 120\% / \sqrt{E} \oplus 10\%$



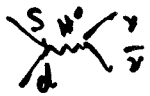
HIGGS OBSERVED IN $b\bar{b}$ OR NOMINAL BR STATE!!

SEARCH FOR FCNC HIGGS DECAY AT A HIGGS FACTORY



- THE ABSENCE OF FCNC IN (2nd QUARK) TRANSITIONS COMES FROM GIM MECHANISM – THERE IS NO KNOWN REASON FOR THE SUPPRESSION IN THE SCALAR SECTOR (EXCEPT FOR THE GLASHOW–WEINBERG ASSUMPTION IN SM)

- $K \to \pi^+ \nu\bar{\nu}$ ... ARE INSENSITIVE TO THE HIGGS SECTOR SINCE $H \to \nu\bar{\nu}$ NFC $\to l\bar{l}$ (e, μ) is small



- IN ADDITIVE MODELS OF A COMPOSITE HIGGS $t\bar{t}$ COULD HAVE FCNC – (Atwood + Soni)

- AT A HIGGS FACTORY ONE CAN SEARCH FOR $H \to q_a \bar{q}_b$ $\to s\bar{b}$, $c\bar{u}$] Low mass Higgs

$\to t\bar{c}$ or $t\bar{u}$ for $M_H > M_t$

Probably to the level of $\sim 10^{-4} - 10^{-5}$

TESTING NFC at a $\mu^+\mu^-$ Higgs Factory

(If $M_H > 150$ GeV)

Fig. [illegible] can.[15]

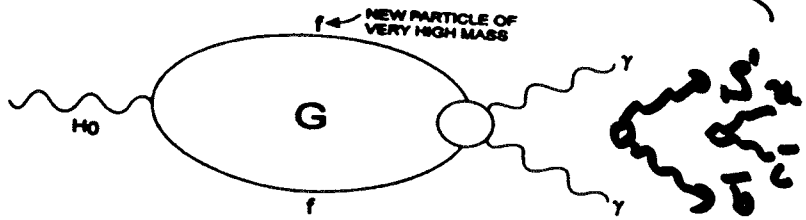


Fig. 6. Possible probe of new physics in a rare Higgs decay mode.

8

This same new Physics may cut off the divergence in the Higgs Sector

Summary

1) All of our current success ~ Weak Interaction Physics has come from AVOIDING DIVERGENCES → (Fermi Theory 1933 → W, Z 1983 CERN pp Col.; WSG 1967)

2) The Higgs sector has a serious "sickness"
- Susy cures

a) Susy cures → $M_h < 150$ GeV
divergences → HA ....

b) Some unknown physics cures divergences (study NP at HF)

3) A Higgs Factory is to study the Higgs Sector
- If $M_h > 2M_W$ the LHC (CMS/Atlas will do a very good job!)
- $150\,GeV < M_h < 2M_W$ - Susy Higgs out HF
- $M_h < 150$ GeV - Higgs Factory essential HF

4) If the LHC crosses a threshold so that Susy is dominant — Higgs study is likely done for Susy → decays — HF Not Necessary

WHEN AT HIGGS FACTORY IS NEEDED AND WHY

M_{Higgs}	Standard Model or Susy	HF Collider Necessary	Comments
~ 88 → 150 GeV → LEP II Limit	Susy Higgs mass Range - Higgs very similar	Yes (?)	However if Mass is low LHC may be flooded with h → bb̄ (CMS Study)
~ 150 ~ 200 GeV	Outside of Susy Higgs - but Still Couplings strikingly similar to expected	Yes !!	In difficult mass range to study at LHC
200 – 300 GeV	Outside Susy Range - but can be observed at LHC	No ? for h	If Low mass Susy observed and even if no LHC flooded will be difficult to study
> 300 GeV	For Std Model Higgs	→ No for h	
	For A, H .. Susy Higgs	→ Yes for A, H	

Higgs Factory "Crown Jewel" of pp Colliders

BUT MUST BE JUSTIFIED!

HIGGS BOSON MASS/PHYSICS

DISCUSS:

- HOW LIKELY IS A HIGGS BOSON TO EXIST?
- HOW LIKELY IS IT TO HAVE A PARTICULAR MASS?
- SEVERAL HIGGS BOSONS? MASSES?
- PRODUCTION? DECAYS?
- WHEN IS h^0 LIKELY TO BE DETECTED DIRECTLY?
- WHAT WILL BE KNOWN ABOUT h^0 BEFORE μC?

G. KANE, μC 97

- HIGGS PHYSICS -- TECHNICALLY OK, CONCEPTUAL MYSTERY

- VERY DIFFICULT TO CONSTRUCT ALTERNATIVES TO HIGGS MECHANISM, IN ORDER TO GIVE MASSES TO GAUGE BOSONS AND FERMIONS AND HAVE RENORMALIZABLE THEORY

- HIGGS PHYSICS ORIGIN CENTRAL PROBLEM OF STANDARD MODEL

- HIGGS PHYSICS POINTS WAY TO HOW TO EXTEND SM, SINCE SM ALONE IS NOT STABLE TO RADIATIVE CORRECTIONS, NOR CAN THE EW SYMMETRY BE BROKEN INTERNALLY

- CURRENTLY STILL (BARELY) CONCEIVABLE THAT NO HIGGS BOSON EXISTS

HOW LIKELY IS h^0 ?

- THERE IS GOOD EVIDENCE THAT BREAKING OF EW SYMMETRY IS PERTURBATIVE, AND GOOD EVIDENCE THAT NATURE IS SUPERSYMMETRIC

  (PREDICTED BY SUSY)

  - **--UNIFICATION OF GAUGE COUPLINGS** --THEY CHANGE AS GO TO SMALLER DISTANCES BECAUSE OF SUPER PARTNERS IN LOOPS
  - **--AGREEMENT OF PRECISION MEASUREMENTS WITH SM**--SUSY ONLY ENTERS THROUGH LOOPS SO EFFECTS SMALL
  - **--PERTURBATIVE DERIVATION OF HIGGS MECHANISM** --$M^2_{H_{top}} < 0$ BECAUSE OF TOPLOOP IF m_{top} LARGE

    (PREDICTED BY SUSY)

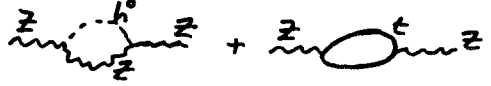
- IF SUSY, THEN h^0 EXISTS

- ANALYSIS OF LEP DATA

  ($m^{SUSY}_{h^0} \leq m^{SM}_{h^0}$)

  $\Rightarrow m_{h^0} = 100^{+100}_{-50}$ GeV

ALL PARTICLES ARE SOMETIMES COMBINATIONS OF ALL OTHERS --PROPERTIES OF VIRTUAL PARTICLES AFFECT BEHAVIOR OF OBSERVED ONES -- LAMB SHIFT ~1947, TOP QUARK AT LEP 1991



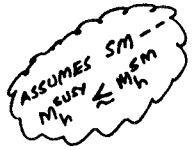
$\Rightarrow \delta(\text{OBSERVABLES}) \sim ( ) G_F m_t^2 + ( ) g_2^2 \ln(m_h/m_Z)$

$\Rightarrow$ VERY LIKELY h^0 EXISTS

--MAYBE DON'T BET YOUR HOUSE ON IT, BUT SURELY DON'T BET AGAINST IT WHEN PLANNING

NCE KNOW h^0 EXISTS, CAN CONSTRAIN Macc

M_{h^0}?



- EXPERIMENTAL CONSTRAINT

$$M_{h^0} \approx 100^{+100}_{-50} \text{ GeV}$$

--WILL IMPROVE A LITTLE -- COUPLE OF THEORETICAL CORRECTIONS, THEN ALL WILL BE INCLUDED THAT COULD HAVE AN EFFECT ~ EXPERIMENTAL SENSITIVITY
-- SOME REVISION OF PRECISION MEASUREMENTS IN PROGRESS -- BETTER M_t ACCURACY -- BETTER UNDERSTANDING OF α_s

- THEORETICAL CONSTRAINTS -- DEPEND ON:
  - ▲ WHICH THEORY -- SM, MSSM, GENERAL SUSY, X
    -- SM OFTEN USED AS TOY MODEL, TO CALIBRATE DETECTORS, BUT UNLIKELY TO DESCRIBE NATURE BECAUSE OF HIERARCHY PROBLEM -- SOME EXTENSION OF SM NEEDED, USUALLY AFFECTS HIGGS SECTOR
  - ▲ WHETHER THEORY IS PERTURBATIVE UP TO ~ UNIF SCALE, OR INSTEAD NEW STRONGLY INTERACTING PHYSICS APPEARS AT LOWER SCALES -- EVIDENCE FOR PERTURBATIVITY, DON'T BET AGAINST IT IN PLANNING
  - ▲ IN SM, STABILITY OF VACUUM

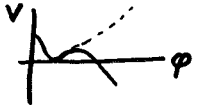
CONSIDER SM $\left(V = \mu^2\varphi^2 + \lambda\varphi^4,\ \lambda \sim m_h^2\right)$

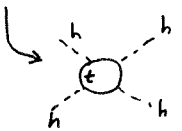
-- ASSUME PERTURBATIVE TO $\gtrsim 10^{16}$ GeV

$$\Rightarrow 130 \lesssim M_h \lesssim 190 \text{ GeV}$$

- UPPER LIMIT -- IF M_h TOO LARGE THEN λ LARGER AT SCALE $\sim M_h$ -- THEN AS EXTRAPOLATE λ TO HIGH SCALE IT BLOWS UP

- LOWER LIMIT -- λ HAS TOP LOOP -- CAN GO NEGATIVE





SO WORLD DOES NOT STAY IN STABLE MINIMUM
-- IF M_h TOO SMALL THEN λ STARTS SMALL -- $\lambda \sim 0$ AS GOES NEGATIVE SO PERTURBATIVE, CALCULABLE -- BUT POTENTIAL ONLY GAUGE INVARIANT AT EXTREMA, SO INTRINSIC UNCERTAINTY

NOTE -- IN SM, M_h NOT CALCULABLE -- DEPENDS ON λ -- λ NOT MEASUREABLE OUTSIDE OF HIGGS SECTOR

MSSM -- h^0 EXISTS

$$30 \lesssim M_{h^0} \lesssim 130 \text{ GeV}$$

(EXPT NOW $75 \lesssim M_{h^0}$)

$$M_h^2 \leq \underbrace{M_Z^2 \cos^2 2\beta}_{\text{TREE LEVEL}} + \underbrace{\frac{3}{4\pi}\alpha_2 \frac{m_t^4}{m_W^4} \ln\left(\frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4}\right) + \cdots}_{\text{LOOP CORRECTIONS}}$$

-- NOTE -- IF $\tan\beta \sim 1$ THEN $\cos 2\beta \sim 0$ -- IF $m_{\tilde{t}}^4 \simeq m_t^4$ THEN $\ln(\,) \simeq 0$

-- NO VACUUM STABILITY LOWER BOUND -- RUNNING OF λ GETS CONTRIBUTIONS FROM TOP AND STOPS -- THEY APPROXIMATELY CANCEL -- POTENTIAL ALWAYS STABLE

[MSSM = THEORY WITH SM PARTICLES AND THEIR SUPERPARTNERS, SM $SU(3) \times SU(2) \times U(1)$ SYMMETRY, 2 HIGGS DOUBLETS -- GENERAL SOFT SUSY BREAKING]

NOTE -- IN SUSY, m_h CALCULABLE IN TERMS OF PARAMETERS THAT CAN BE MEASURED OUTSIDE THE HIGGS SECTOR ($\tan\beta$, $m_{\tilde{t}}$, $m_{\tilde{G}}$ ---)

GENERAL SUSY

-- ANY HIGGS SECTOR, ANY SUSY BREAKING, NO ASSUMPTIONS BUT PERTURBATIVITY

$$\Rightarrow M_{h^0} \lesssim 150 \text{ GeV}$$

(PRESENTLY $\pm \sim 10\%$)

e.g.

$$M_{h^0}^2 \leq M_Z^2\left(\cos^2 2\beta + \frac{2\lambda^2}{g_Z^2}\cos^2\theta_W \sin^2 2\beta\right) + (\,) m_t^4 \ln M_{\tilde{t}}/m_t$$

EXTRA TERM BOUNDED IF ALL COUPLINGS PERTURBATIVE -- BOUND CALCULABLE

X

- IF NO SUSY, MAYBE NO h^0 -- NO MODEL OR UNDERSTANDING OF WHAT TO EXPECT -- MAYBE GAUGE BOSONS INTERACT STRONGLY, IF SO MAY OR MAY NOT BE OBSERVABLE -- MAYBE TOP INTERACTS STRONGLY -- IF WW INTERACT STRONGLY, COULD BE ABOVE ~8 TeV

- INTERESTING APPROACH -- JIM WELLS -- MAYBE TOP GETS PART OF MASS FROM NORMAL HIGGS MECHANISM, PART FROM CONDENSATE DUE TO (NEW) STRONG INTERACTION -- ALSO GET SCALAR ($t\bar{t}$ BOUND STATE) -- SCALAR MAY OR MAY NOT MIX WITH h^0 -- PROPERTIES OF "h^0" CAN BE VERY DIFFERENT -- CAN HAVE REDUCED COUPLING TO Z, W -- COUPLINGS TO $b\bar{b}$ CAN BE SMALLER -- VERY DIFFERENT PRODUCTION CROSS SECTIONS (COUPLING TO $\mu^+\mu^-$ CAN BE MUCH SMALLER)

SO

$\Rightarrow$ UNLESS BEING MISLEAD BY BOTH DATA AND THEORY, AND GAUGE COUPLING UNIFICATION JUST UNLUCKY ACCIDENT,

$$m_{h^0} \lesssim 150\ (\pm 10\%)\ \text{GeV}$$

AND

PROBABLY $m_{h^0} < 130$ GeV

- ALSO -- THERE ARE SOME HINTS THAT $\tan\beta \lesssim 2$, $m_{\tilde{t}} \lesssim m_t$

$\Rightarrow m_{h^0} < 100$ GeV

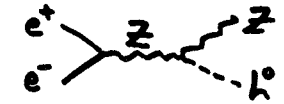
ONCE h^0 FOUND -- WOULD LIKE TO CONFIRM CONSISTENT WITH SUSY

- SM --- ONE DOUBLET OF COMPLEX FIELDS $\begin{pmatrix}\phi^+\\ \phi^0\end{pmatrix}$ → 4 REAL STATES, 3 BECOME $W^\pm_{LONG}$, Z_{LONG} ⇒ 1 PHYSICAL BOSON
- SUSY --TWO COMPLEX DOUBLETS → 8 REAL STATES -- STILL 3 BECOME $W^\pm_{LONG}$, Z_{LONG} ⇒ 5 PHYSICAL BOSONS
  $h^0, A^0, H^0, H^\pm$
  -- POSSIBLY ADDITIONAL STATES
  -- ONLY ONE COMBINATION GIVES MASS TO W, Z -- MASS EIGENSTATES LINEAR COMBINATIONS -- SO ALL "HIGGS BOSONS"

- ONLY SURE WAY TO TELL IS TO DETECT ADDITIONAL STATES $A^0, H^0, H^\pm$
- POSSIBLY CAN SHOW $\Gamma^{h^0}_{TOT}$ OR $g(VV h)/g(ZZh)$ DIFFERENT FROM SM
- PROBABLY $m_{h^0} <$ SM LOWER LIMIT
- PROBABLY PRECISE MEASUREMENT OF m_{h^0} NOT DEFINITIVE SINCE CALCULATION OF m_{h^0} HAS SCALE, SCHEME DEPENDENCE (~1 GeV?)

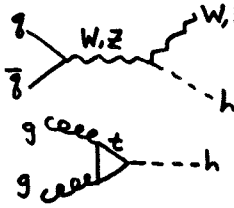
WHEN WILL h^0 PROBABLY BE DETECTED? WHAT WILL BE MEASURED?

- LEP



-- SEARCH FOR $m^{SM}_{h^0} \lesssim 100$ GeV BY ~2000
-- MEASURE $g(ZZh)\,g(hb\bar{b})$
-- OBSERVE DECAY TO $b\bar{b}$ ONLY
-- SOME PRODUCTION, DECAY DISTRIBUTIONS →

- FNAL



$\sigma \simeq \frac{3}{4}$ pb

$\sigma \simeq$ pb

-- USE W, Z TRIGGER, OR τ's

$W(\to \ell^\pm\nu)\, h(\to b\bar{b})$
$W(\to jj)\, h(\to \tau^+\tau^-)$
$Z(\to \nu\bar{\nu}, \ell^+\ell^-)\, h(\to b\bar{b})$
$Z(\to jj)\, h(\to \tau\tau)$

GUNION HAN MARCIANO, STANGE, WILLENBROCK } MRENNA, GK

⇒ OBSERVE h^0_{SM} IF $m_h \lesssim 120$ [$W(\to \ell^\pm\nu)\, h$]
$m_h \lesssim 135$ [ALL MODES]
(STILL SOMEWHAT CONTROVERSIAL)

-- SUSY SITUATION UNDER STUDY -- COULD BE SAME
-- COUPLINGS CHANGE -- IF σ REDUCED THEN m_A NOT TOO LARGE, SEE $h^0 + A \to b\bar{b}\,b\bar{b}$, $b\bar{b}\,\tau^+\tau^-$

NOTE --- AT FNAL, BY 2006 EXPECT

$\gtrsim 50\ fb^{-1}$ (2 DETECTORS)

$\Rightarrow N_{\text{EVENTS OF } h^0 \text{ PRODUCED}} \approx 1.75\ pb \times 50\ fb^{-1} \gtrsim 85{,}000$

$\Rightarrow$ ONCE MASS MEASURED, CAN DETECT $BR(\tau\bar{\tau})$, $BR(\gamma\gamma) \sim 10^{-3}$, $BR(\mu^+\mu^-) \sim \frac{1}{3} 10^{-3}$

- CAN TRY FOR $g(t\bar{t}h)$, $g(c\bar{c}h)$
  - $\sigma(h^0+X) \sim g(t\bar{t}h)$ ....
  - $BR(h^0 \to \text{hadrons}) \approx \underbrace{BR(c\bar{c}) + BR(gg) + BR(b\bar{b})}_{\sim g(VVh^0)}$
  - $\sigma(h^0+\gamma) \sim g(t\bar{t}h^0)$ DICUS, REPKO ET AL

WHAT MIGHT PREVENT DETECTION AT LEP, FNAL:

- $\sin^2(\beta-\alpha) \ll 1$ SO ZZh, WWh SMALL
  -- PROBABLY h^0+A^0 OK AT FNAL, CERTAINLY OK AT NLC(400)
- MIX SINGLETS INTO h^0

  W, Z MASS FROM $D_\mu h = (\partial_\mu - i g_2 \underbrace{\vec{W}\cdot\vec{\tau}}_{(\cdot\cdot)(\cdot)})h$

  FERMION MASS FROM $\underbrace{\bar{L} H}_{(\cdot\cdot)(\cdot)} c_R$

  SO SINGLETS UNCOUPLED FROM Z, W, FERMIONS -- BUT CAN MIX IN WAVE FUNCTIONS OF MASS EIGENSTATES (LIKE STERILE ν)

  -- BUT OK IN PRINCIPLE -- MUST GET $M_{W,Z,\text{FERMION}}$ -- IF "h^0" MAINLY SINGLET, THEN NEXT STATE SATISFIES BOUND $M \lesssim 150$ GeV, AND IT CAN BE PRODUCED -- NOT AT LEP OR FNAL, OK AT NLC(400) -- PRESUMABLY OK AT HEμC

  OKADA ET AL, ELLWANGER, SAVOY ET AL, GUNION, HABER ET AL

- WELLS SCENARIO

CONCLUDE

- PROBABLY h^0 EXISTS
- $M_{h^0} \lesssim 150$ GeV
- PROBABLY $M_{h^0} < 130$ GeV
- SOME INDICATION $M_{h^0} < 100$ GeV
- PROBABLY $\gtrsim 75{,}000$ h^0 PRODUCED AT FNAL, BR($\gamma\gamma$, $\mu\mu$) DETECTED
- HEAVY HIGGS BOSONS? -- CHANCE FOR A^0 AT FNAL
- LHC? -- PRODUCE LOTS OF $A^0, H^0, H^\pm$
  - -- DETECTION? -- HARD TO SAY UNTIL KNOW SPARTICLE MASSES, SINCE BR(SPARTICLES) IS LARGE IF ALLOWED

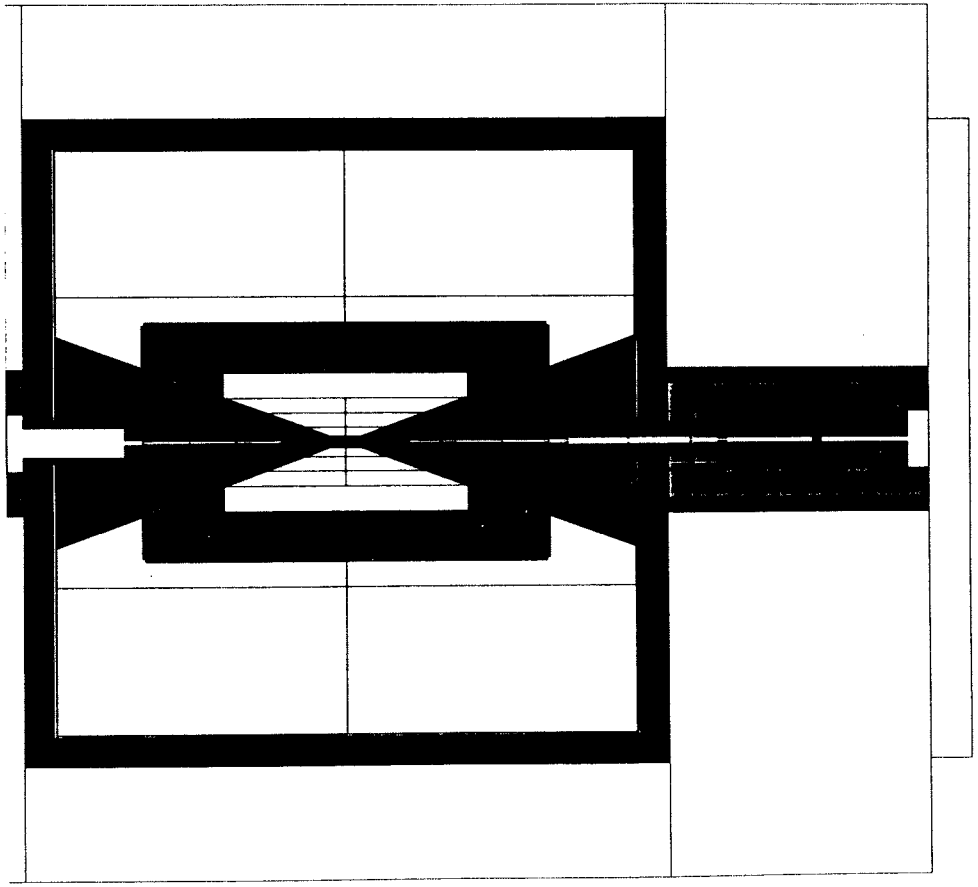
SF DEC 97
STUMER

PROGRESS REPORT

DETECTOR BACKGROUNDS

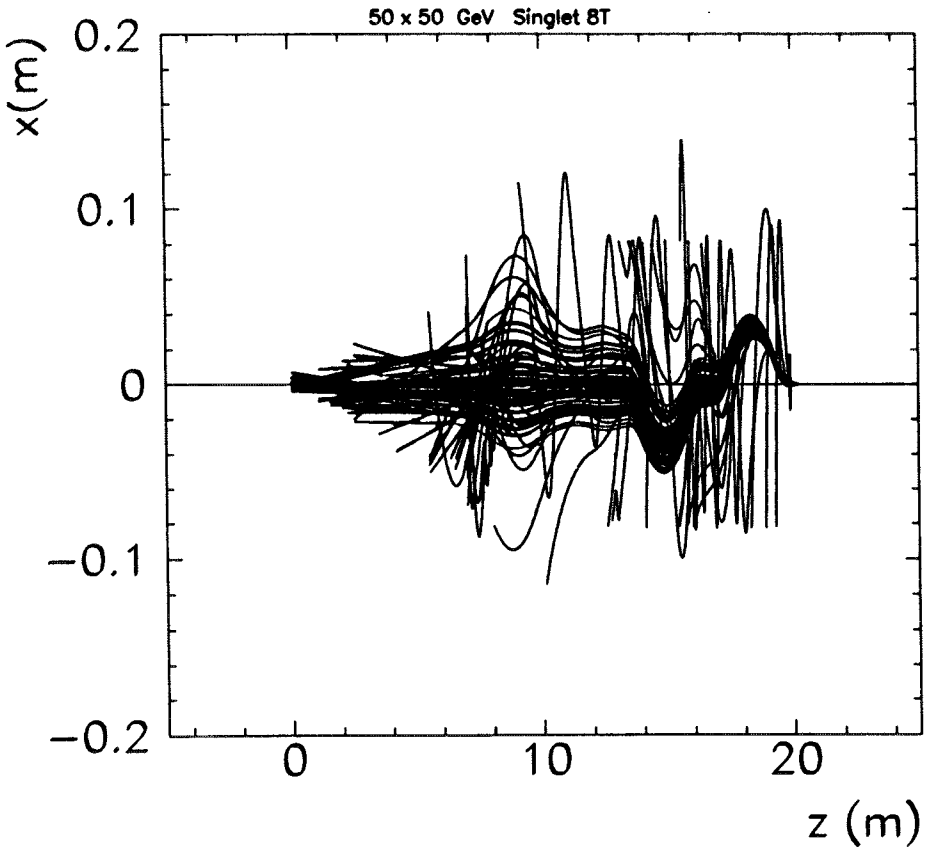
BENARY
KAHN
PALMER
STUMER

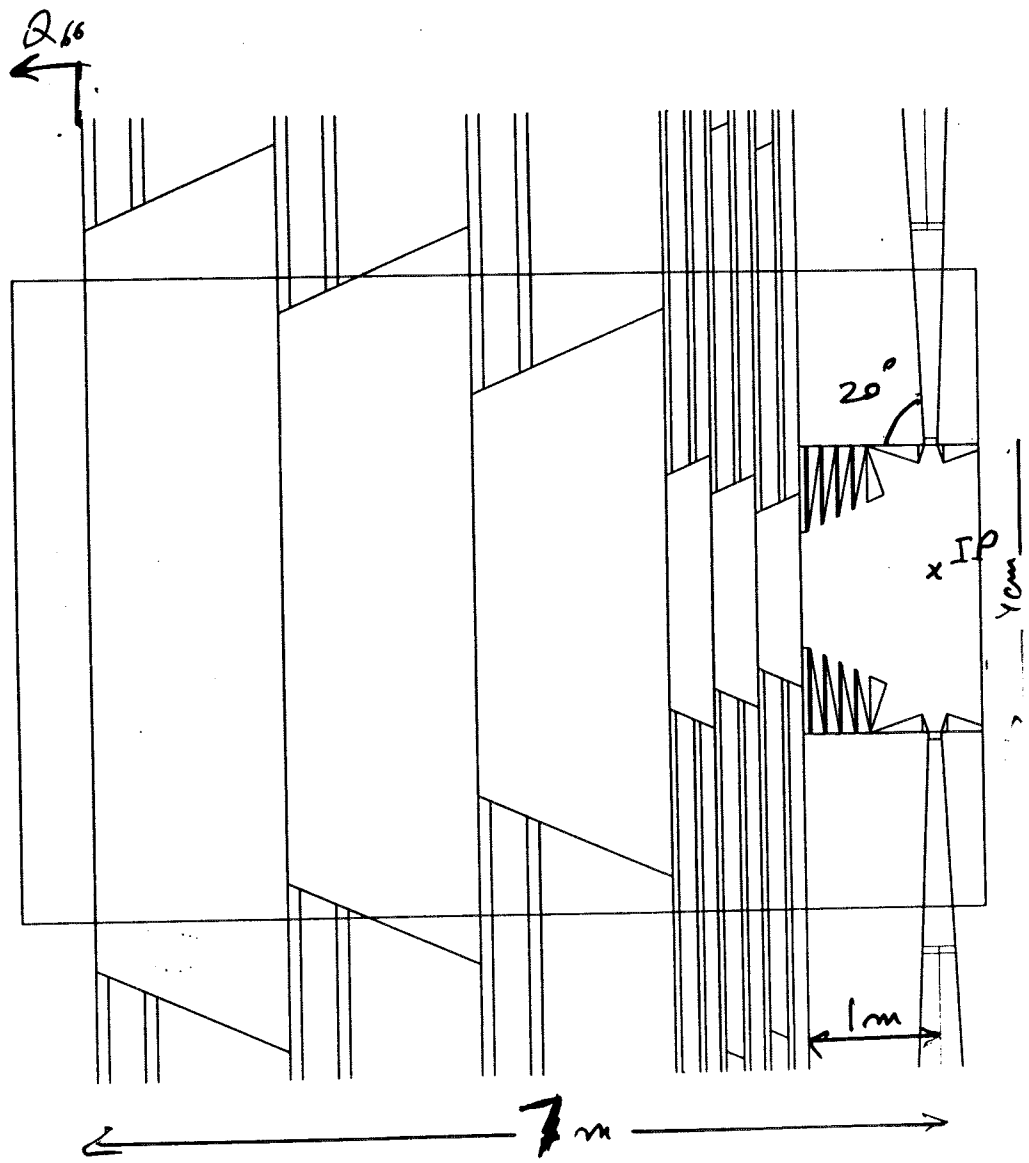
50 × 50 GeV

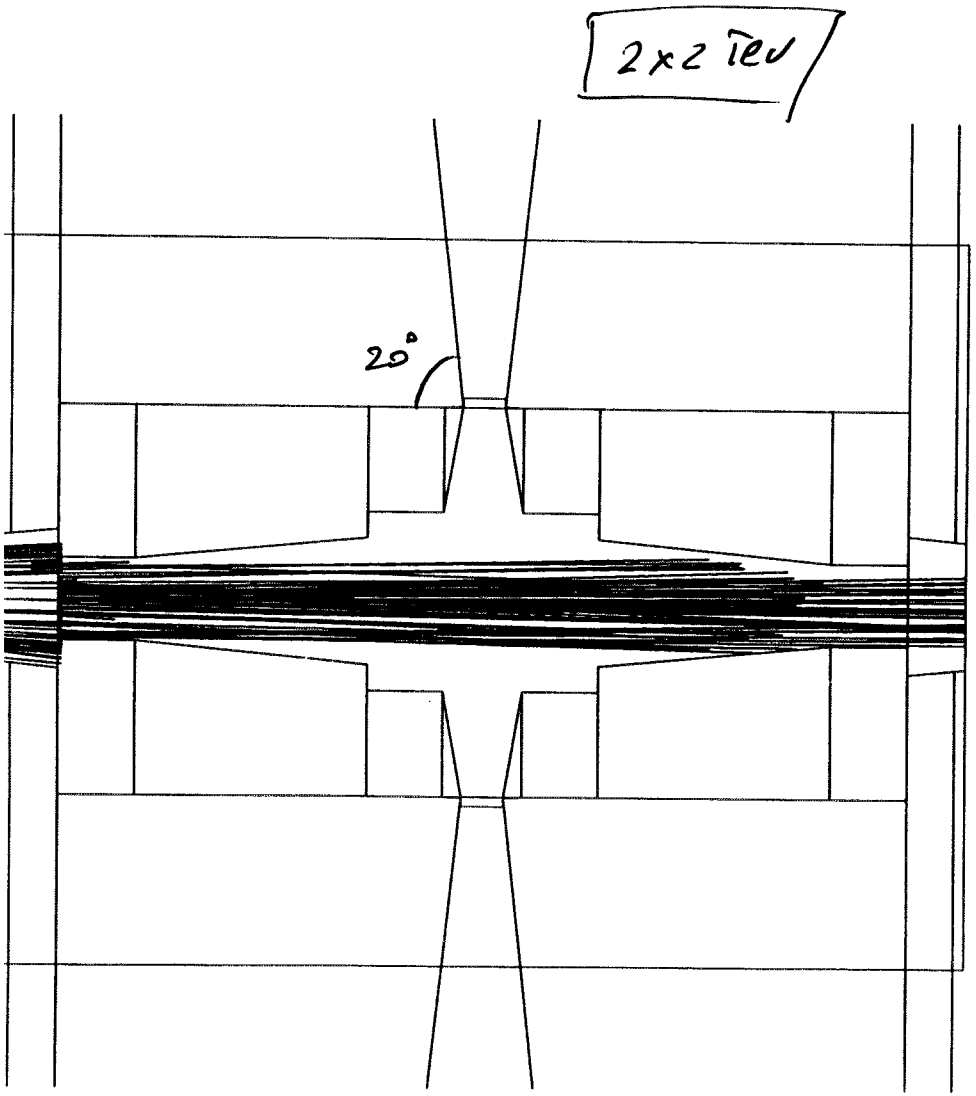


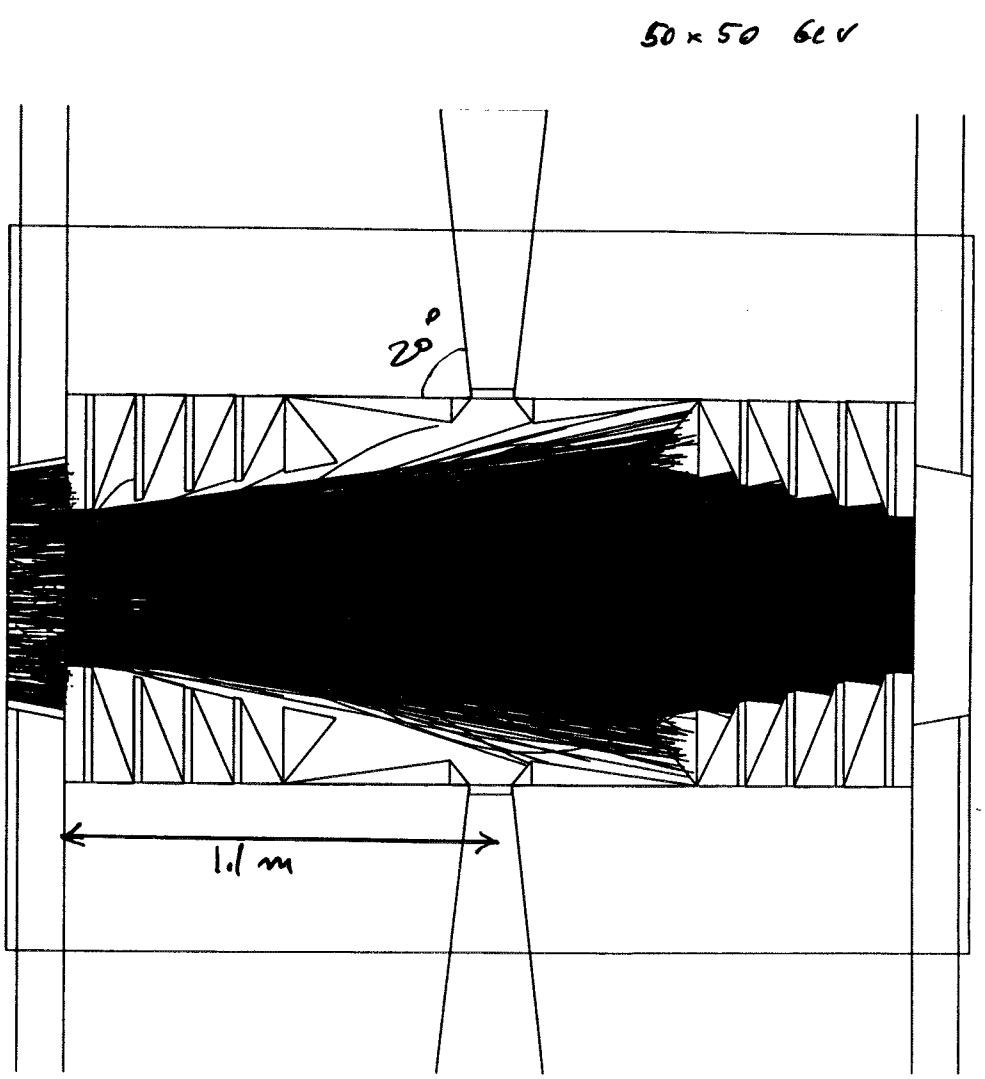
OUTLINE

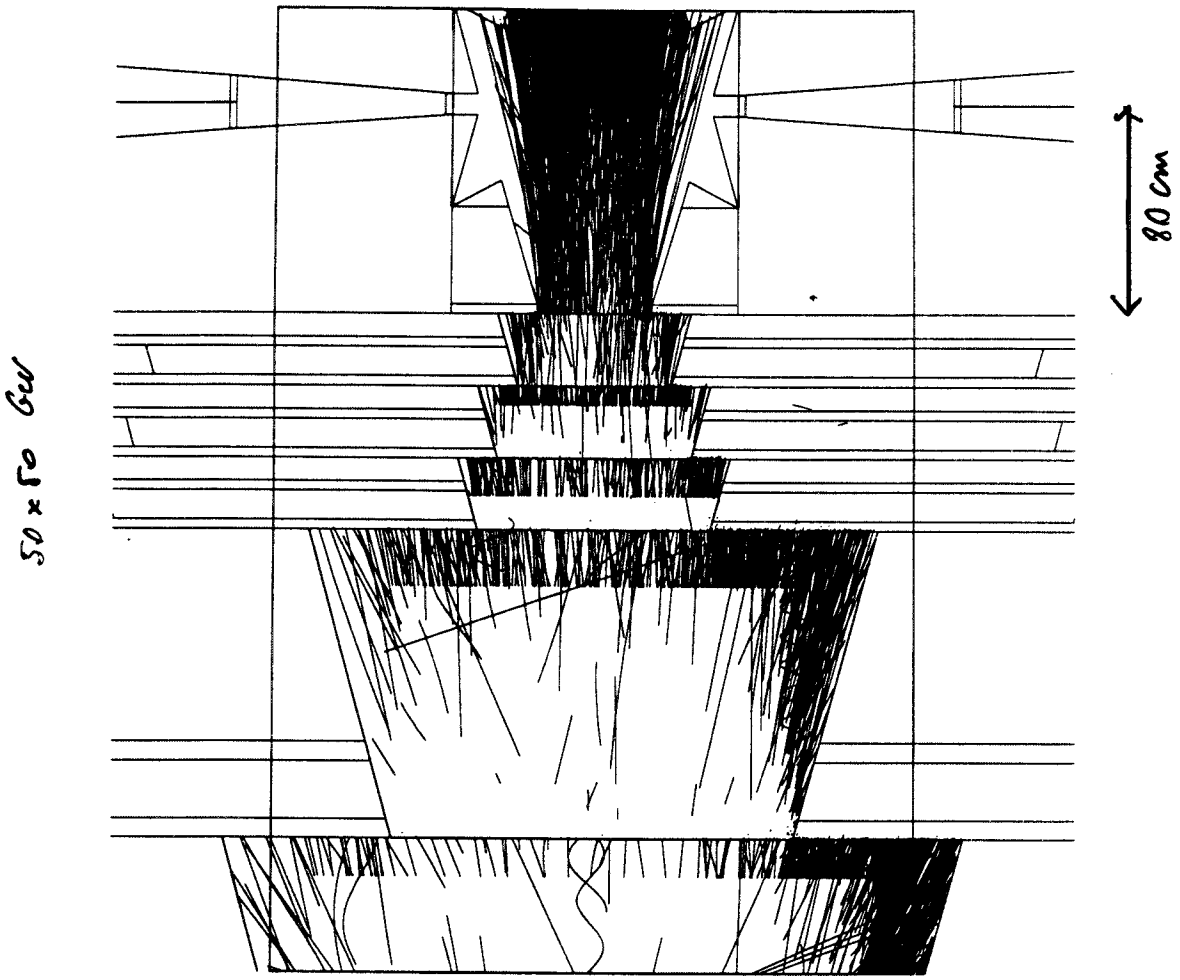
- IMPROVEMENTS ON 50×50 GeV
  1. MOVE THE FIRST LIP TO 80 cm
  2. ADD 4T DIPOLE AT 2.5-4 m
  3. RAISE SOLENOID TO 4T
  4. ADD FINS TO INNER CAVITY
- FLUENCES AT 2×2, 250×250, 50×50
- OCCUPANCIES "
- RADIATION DAMAGE "
- BETHE HEITLER μ's PROBLEM AND SOLUTIONS ??
- CONCLUSIONS

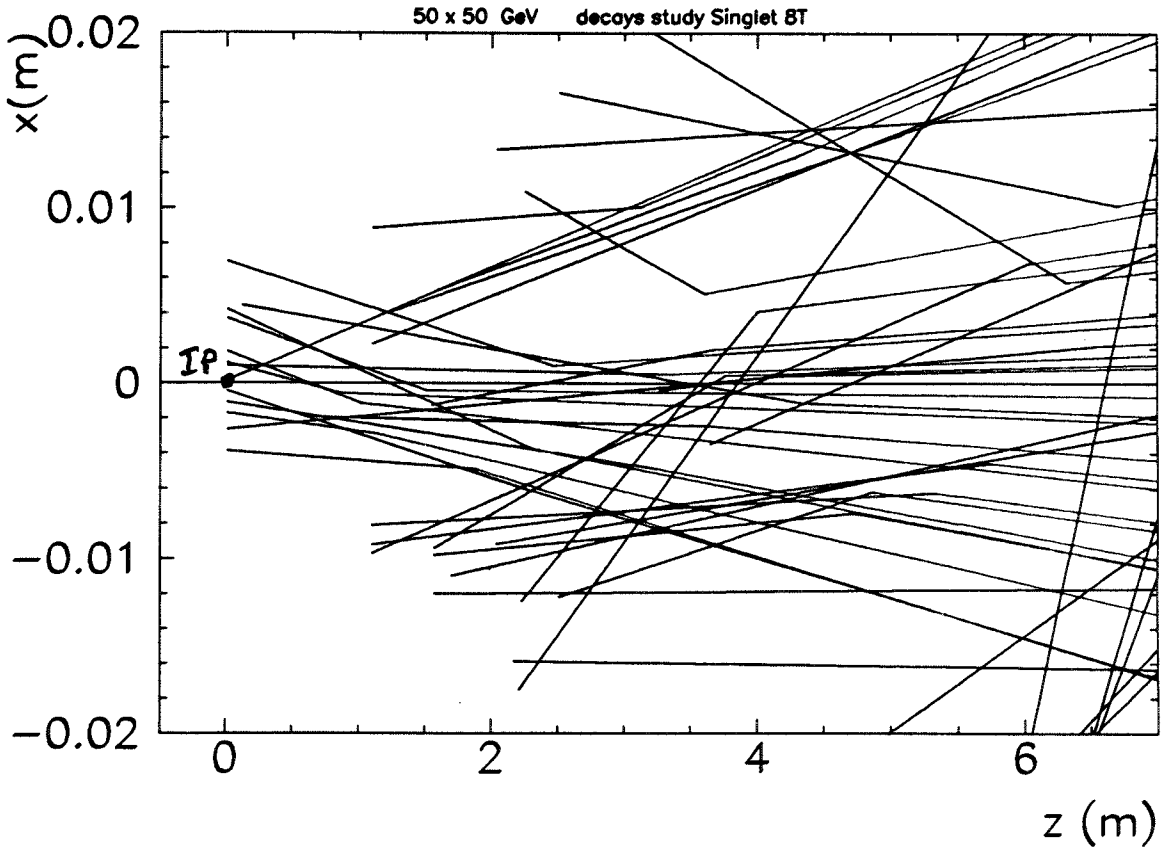

50 x 50 GeV Singlet 8T
x(m)
0.2
0.1
0
−0.1
−0.2
0
10
20
z (m)

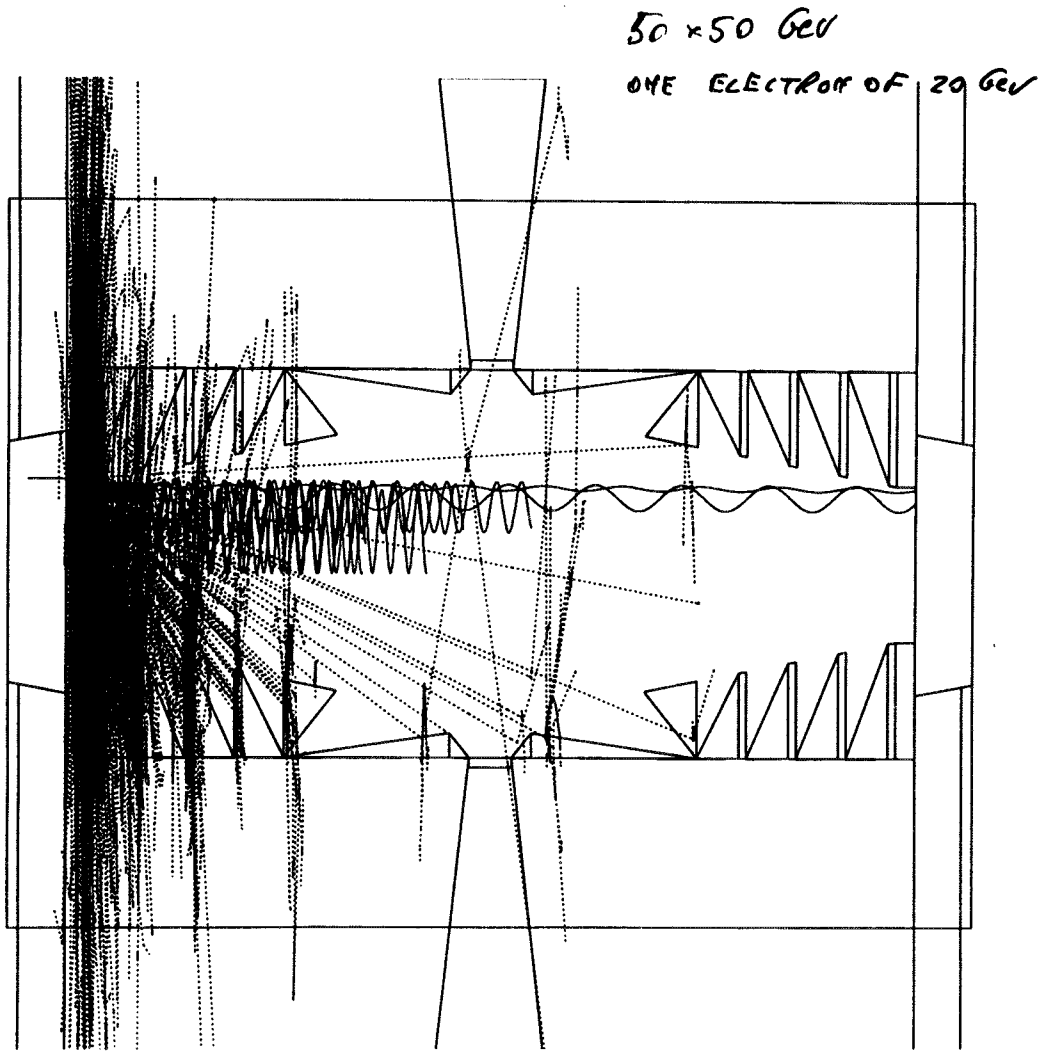

Q16
20°
x IP
Y cm
1m
7m

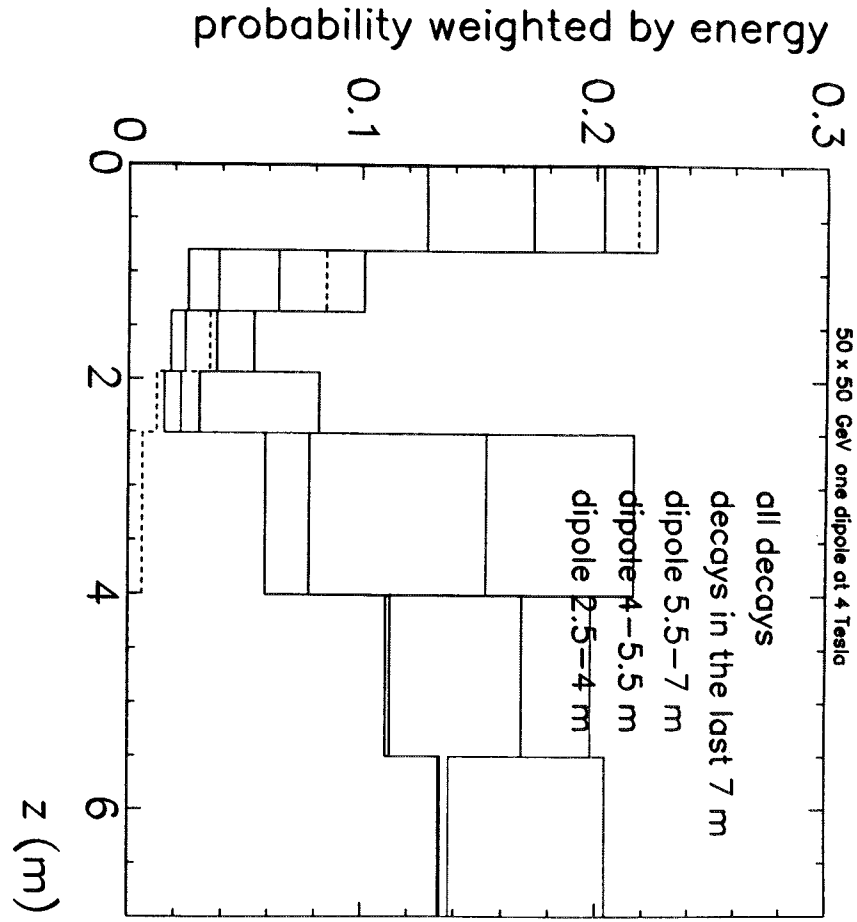

2×2 TeV
20°

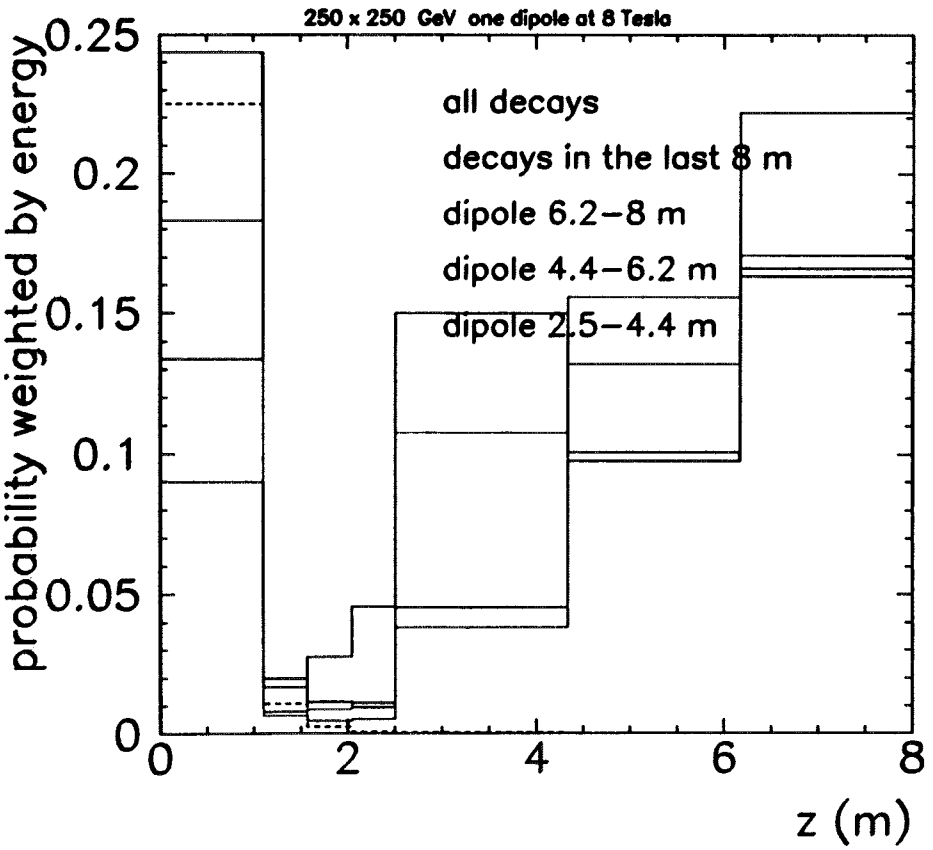

50×50 GeV
20°
1.1 m

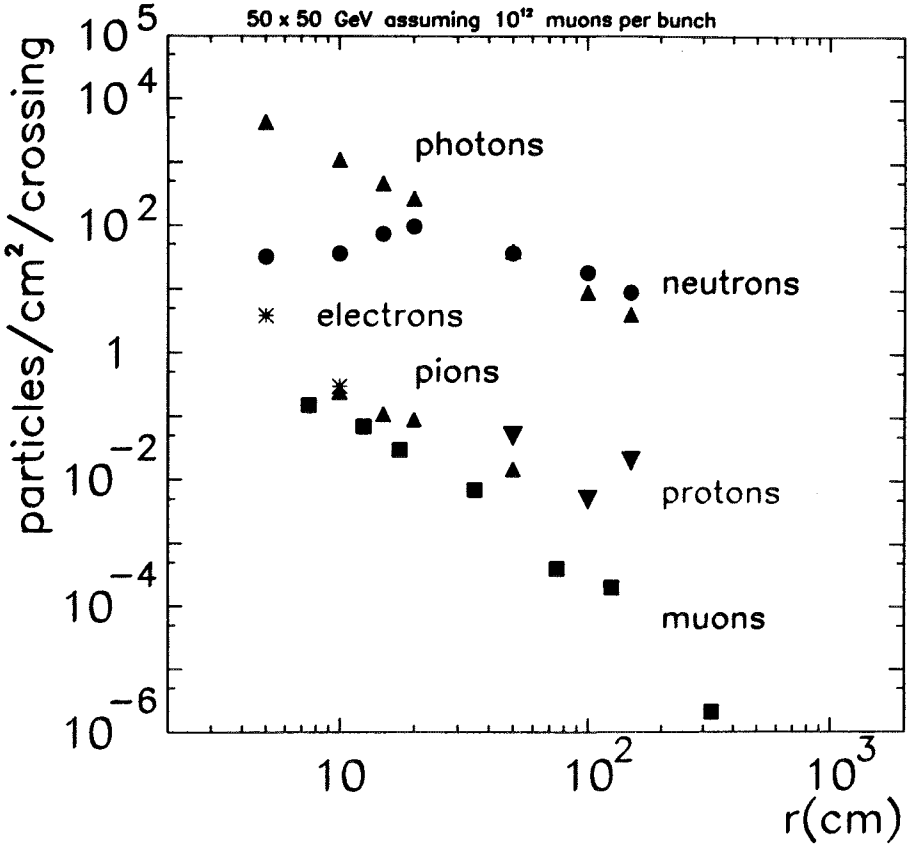

50 x 50 Gev
80 cm

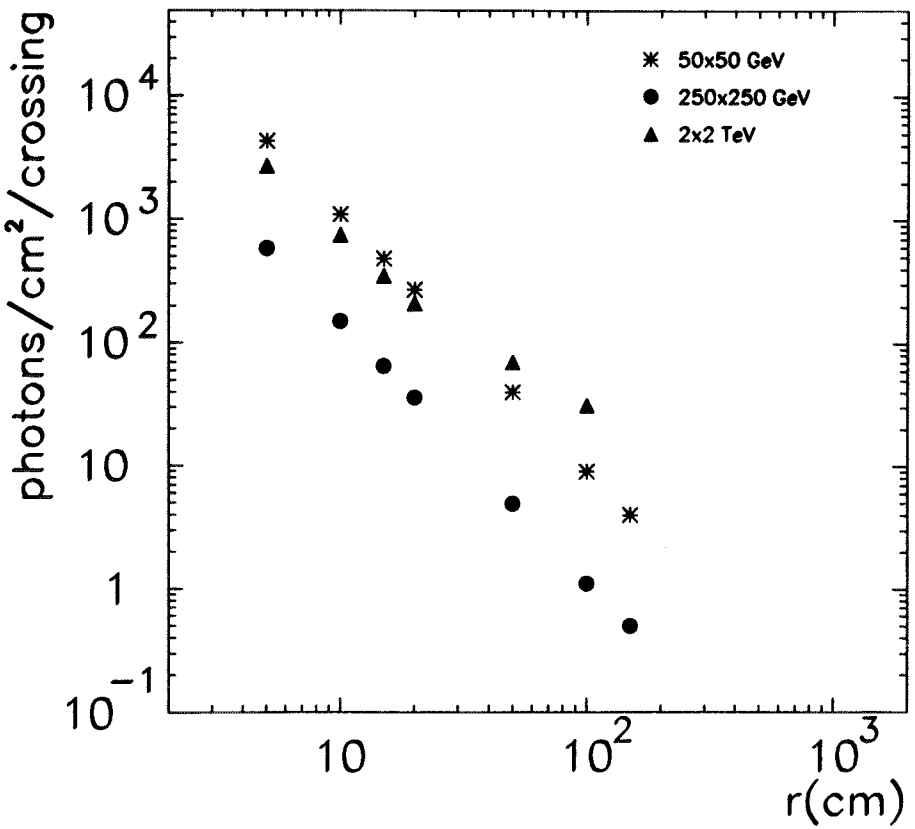

50 x 50 GeV decays study Singlet 8T
x(m)
0.02
0.01
0
−0.01
−0.02
IP
0
2
4
6
z (m)

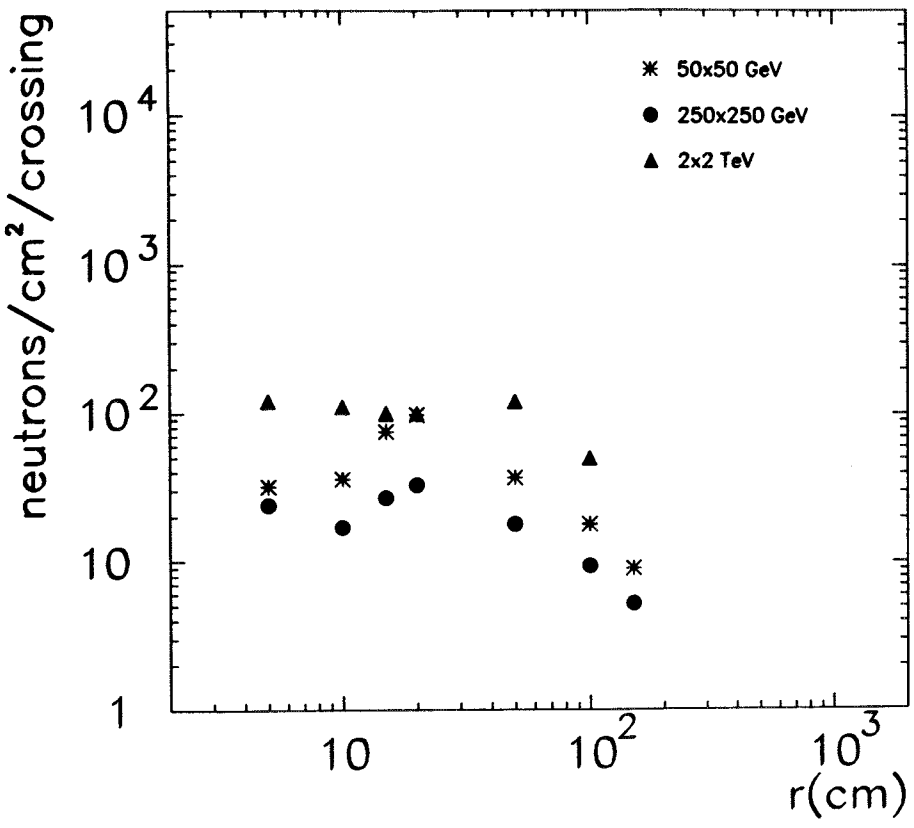

50 x 50 GeV
ONE ELECTRON OF 20 GeV


probability weighted by energy
0.3
0.2
0.1
0
0
2
4
6
z (m)
50 x 50 GeV one dipole at 4 Tesla
all decays
decays in the last 7 m
dipole 5.5–7 m
dipole 4–5.5 m
dipole 2.5–4 m


250 x 250 GeV one dipole at 8 Tesla
probability weighted by energy
z (m)
all decays
decays in the last 8 m
dipole 6.2–8 m
dipole 4.4–6.2 m
dipole 2.5–4.4 m
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8


50 x 50 GeV assuming 10^12 muons per bunch
particles/cm²/crossing
r(cm)
photons
neutrons
electrons
pions
protons
muons
10^5
10^4
10^2
1
10^-2
10^-4
10^-6
10
10^2
10^3


photons/cm²/crossing
10⁴
10³
10²
10
1
10⁻¹
10
10²
10³
r(cm)
50x50 GeV
250x250 GeV
2x2 TeV


neutrons/cm²/crossing
10⁴
10³
10²
10
1
10
10²
10³
r(cm)
50x50 GeV
250x250 GeV
2x2 TeV

Background hits and occupancy at 50x50 TeV

Assume 2 bunches of $10^{12}\mu$'s each for hits, 4×10^{12} for occupancy

For silicon vertex assume 300x300 micron^2 pads

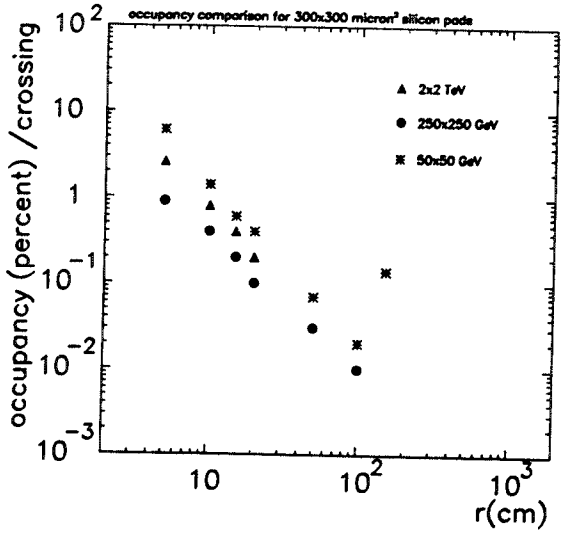
rad (cm)	*photons* (/cm^2)	*neutrons* (/cm^2)	*charged* (/cm^2)	*Hits* (/cm^2)	*Occup all*	*Occup charged*
5	13	0.03	4	17	6.1 %	1.4 %
10	3.3	0.04	0.6	4	1.4 %	0.2 %
15	1.4	0.07	0.14	1.6	0.6 %	0.05 %
20	0.8	0.1	0.10	1.0	0.4 %	0.04 %
50	0.1	0.03	0.065	0.2	0.07 %	0.02 %
100	0.03	0.02	0.005	0.06	0.02 %	0.002 %
150	0.01	0.01	0.02	0.04	0.014 %	0.007 %

Radial Fluences at 50x50 GeV

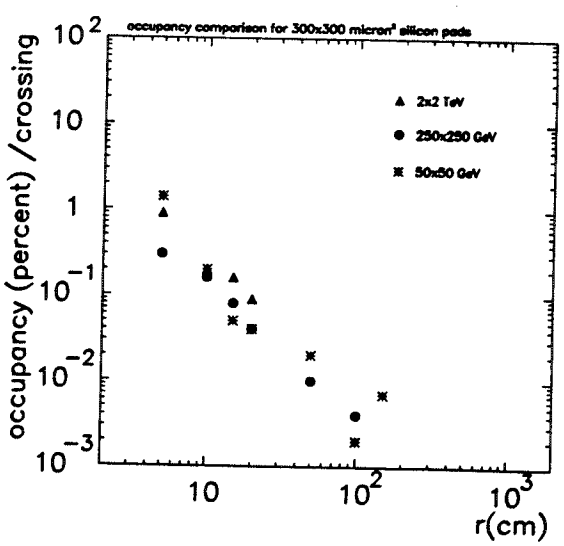
particles/cm^2/crossing for two bunches of $10^{12}\mu$'s each

radius (cm)	*photons*	*neutrons*	*protons*	*pions*	*electrons*	*muons*
5	4300	32			3.8	0.15
10	1100	36		0.24	0.3	0.07
15	480	75		0.11		0.03
20	270	98		0.09		0.007
50	40	37	0.05	0.015		0.0004
100	9	18	0.005			0.0002
150	4	9	0.02			.21e-5
muon						.24e-6
threshold	40 keV	40 keV	10 MeV	10 MeV		

Occupancy



Charged Occupancy

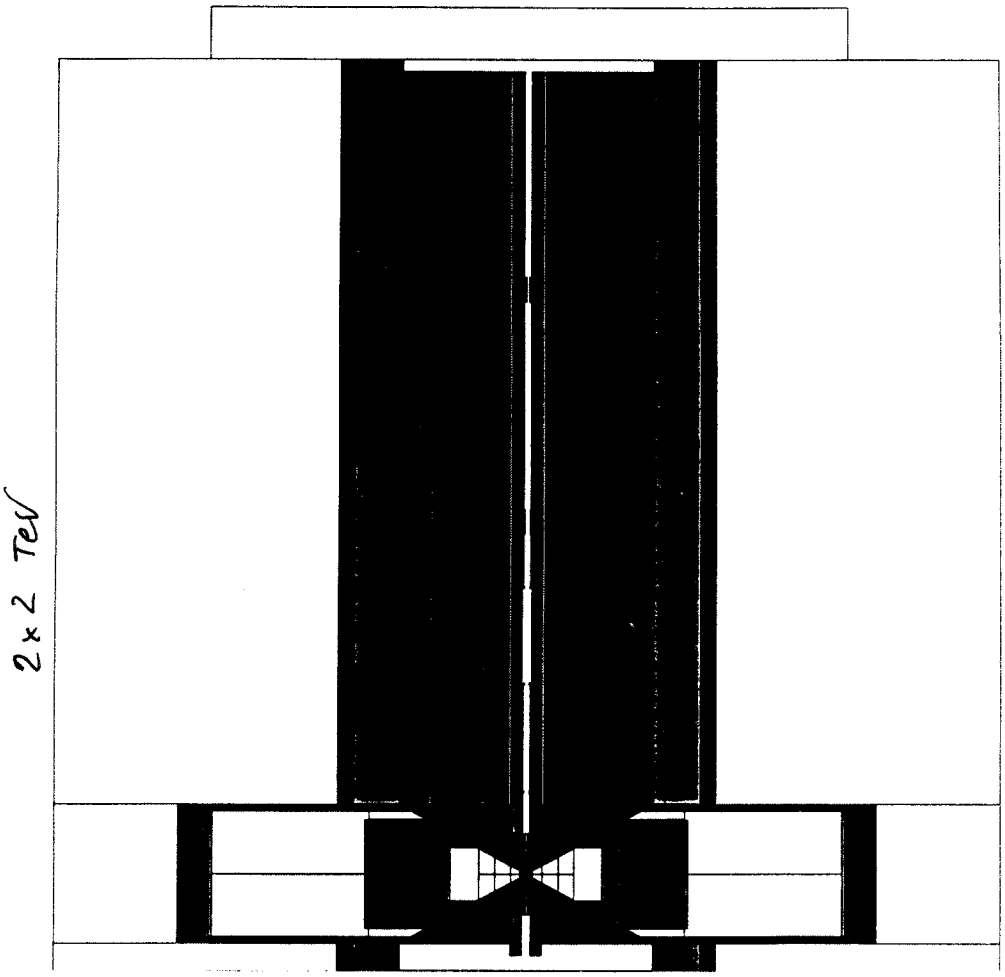


Radiation damage by neutrons on silicon detectors

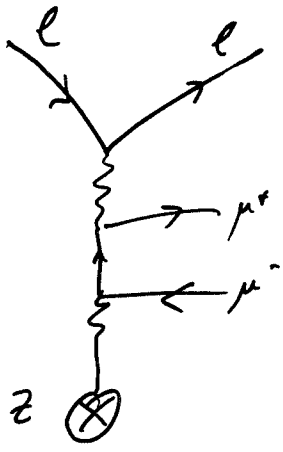
assume 1000 loops , 15 Hz , 1 year = 10^7 seconds

acceptable hits per year = 1.5 10^{14}

c.m.	μ's/bunch	neutrons/cm^2/crossing	Hits/year	*Lifetime*
Tev	10^{12}	above 100 Kev	10^{13}	years
4	2	100	3.	5
.5	4	50	3.	5
.1	4	30	1.8	8



BETHE-HEITLER PROBLEM !!



$P(e + Z \to \mu^+\mu^- + X) = 10^{-3}$ 500 GeV

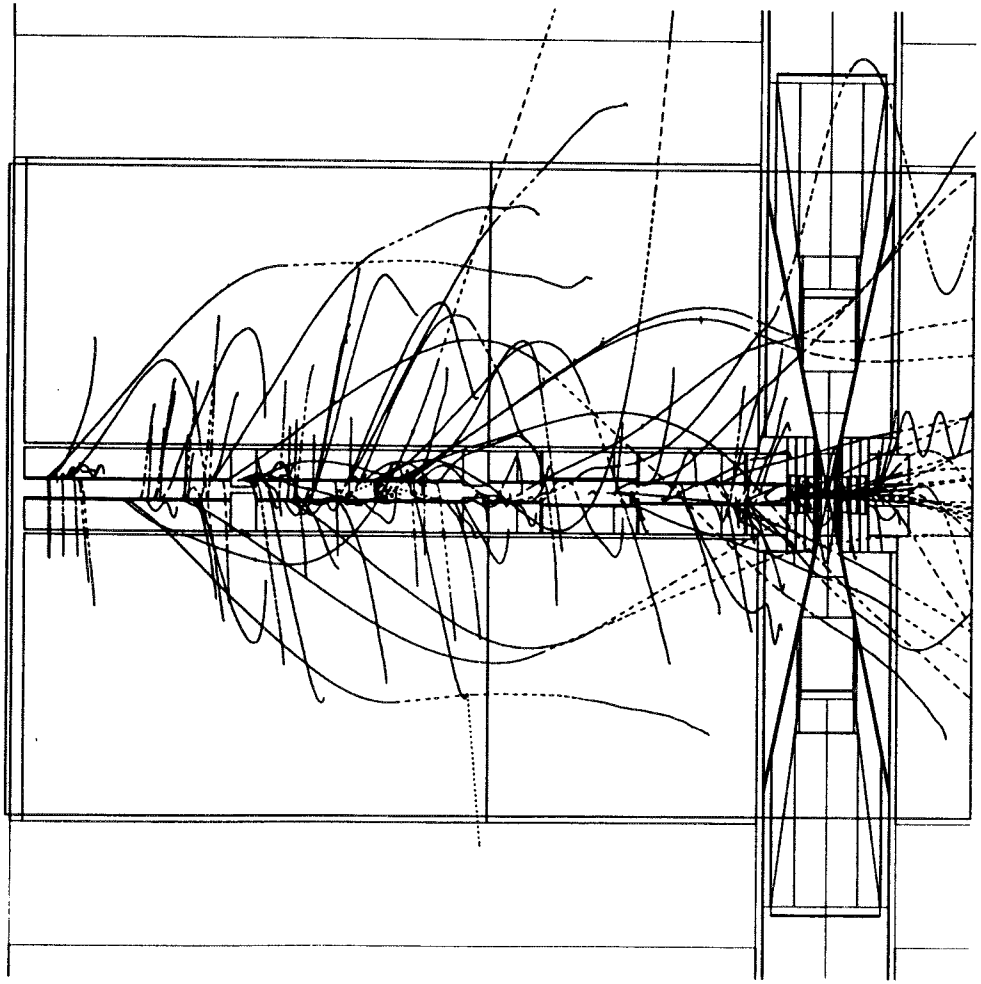
100 GeV $= 10^{-4}$

20 GeV $= 10^{-5}$

SIMULATION REQUIRES ALL MAGNETIC FIELDS : QUADS, DIPOLES, TOROIDS, SOLENOIDS AND THE RETURN YOKES.

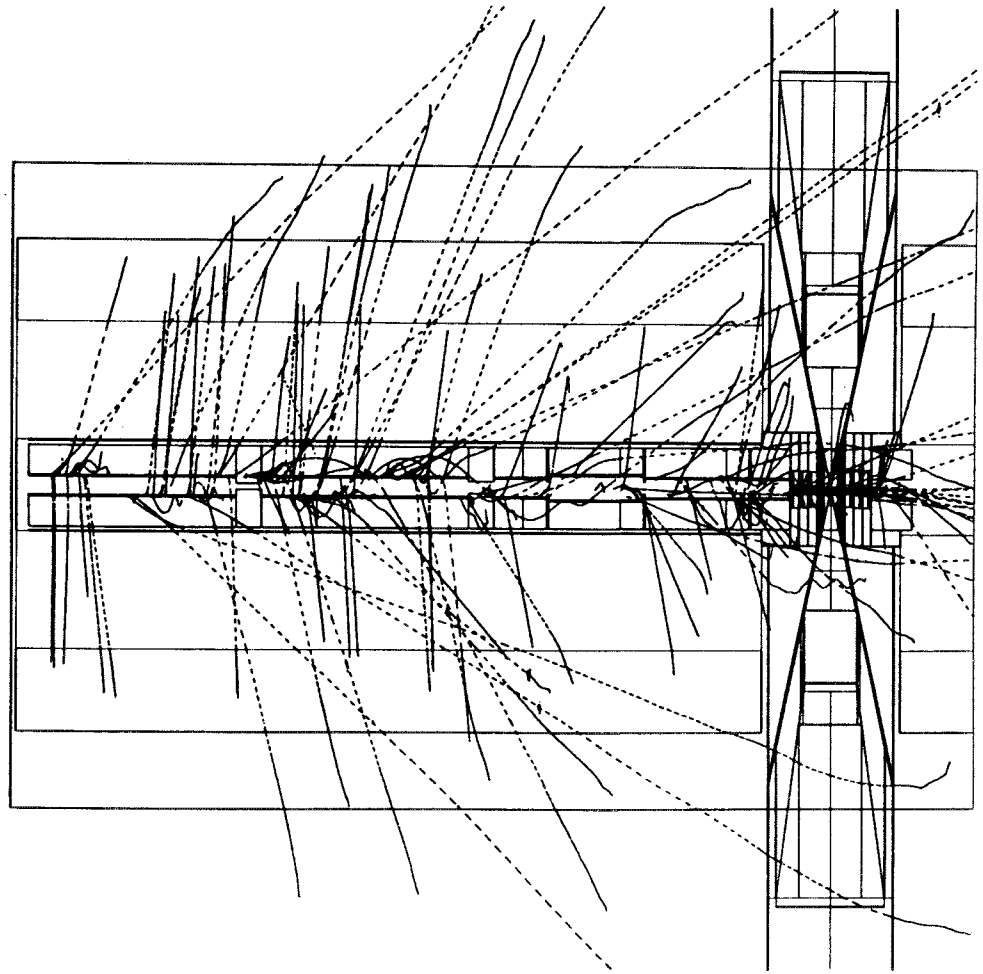
2 x 2 TeV

~~250 x 250 GeV~~ Fe Toroid 2 Tesla

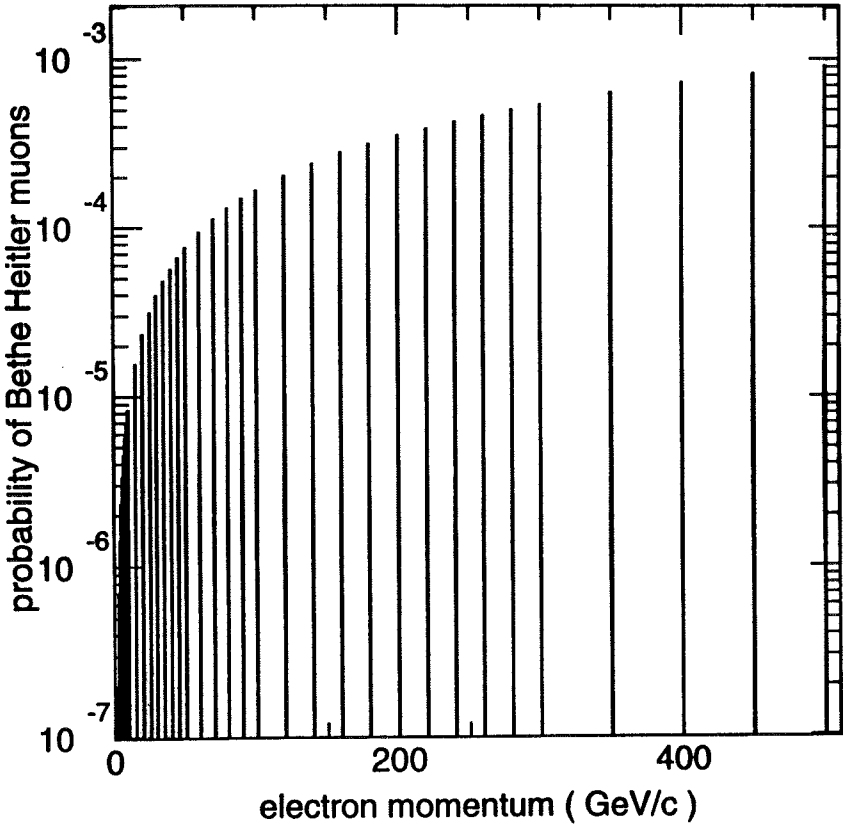


2 x 2 TeV

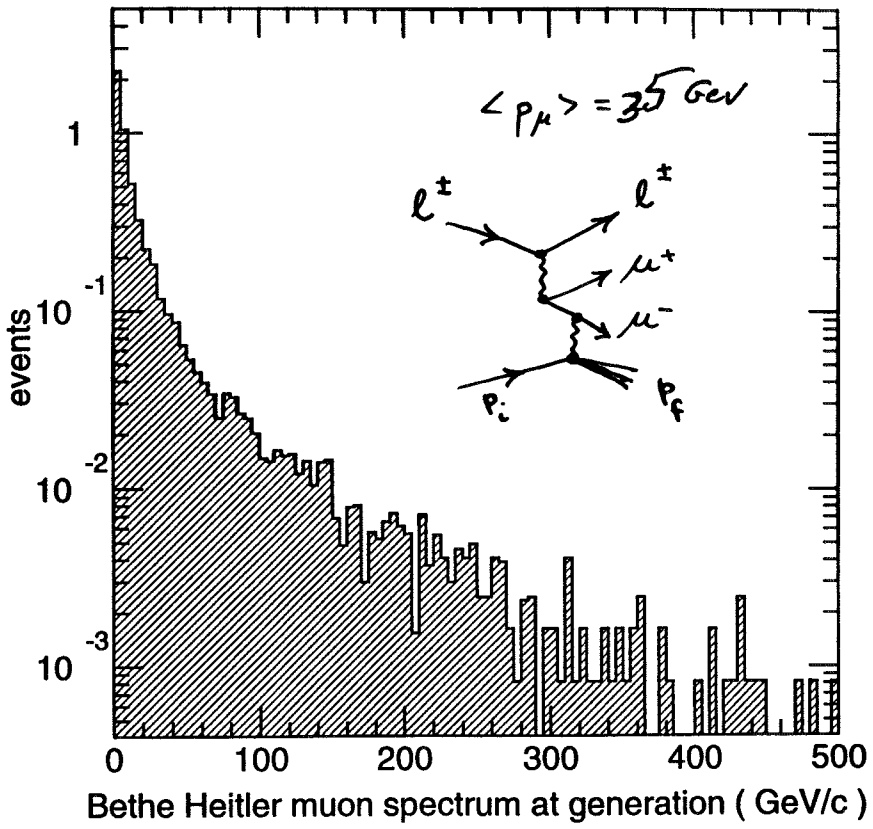
BETHE HEITLER μ's REGULAR QMFTG.



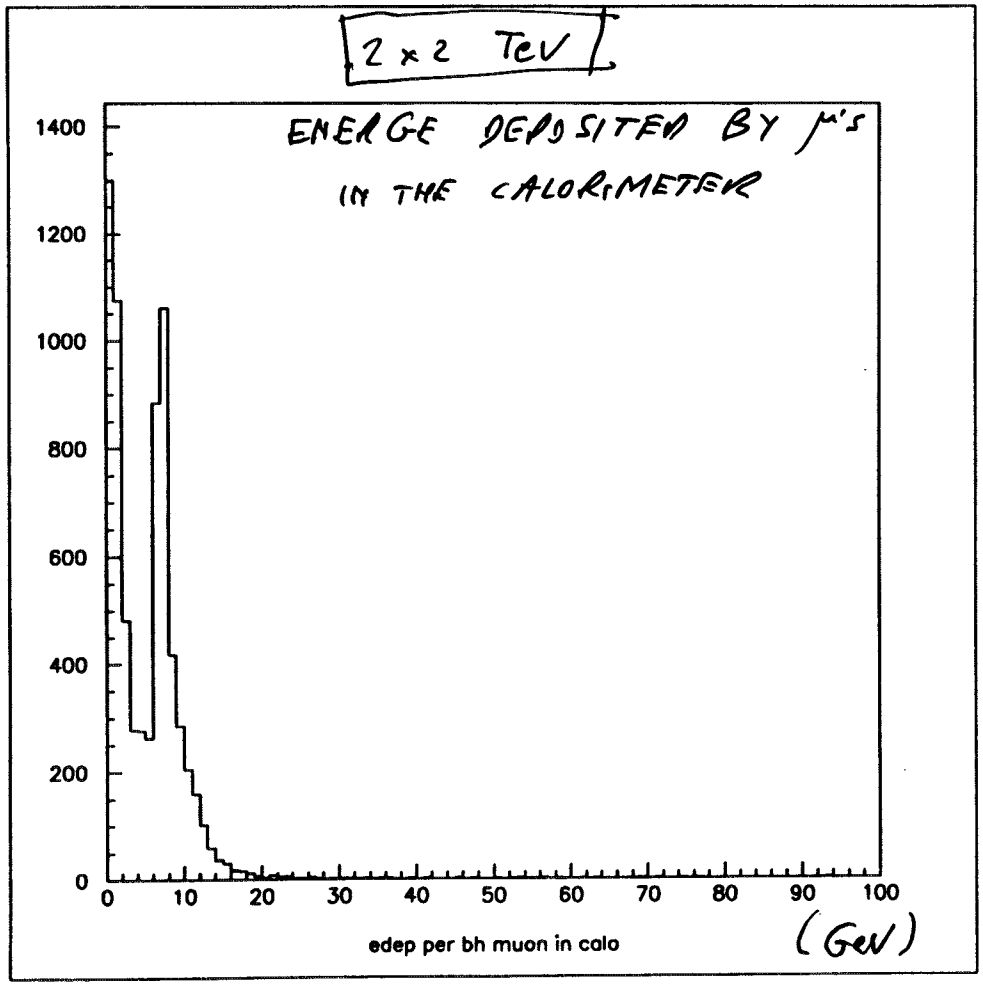
BETHE - HEITLER MUONS

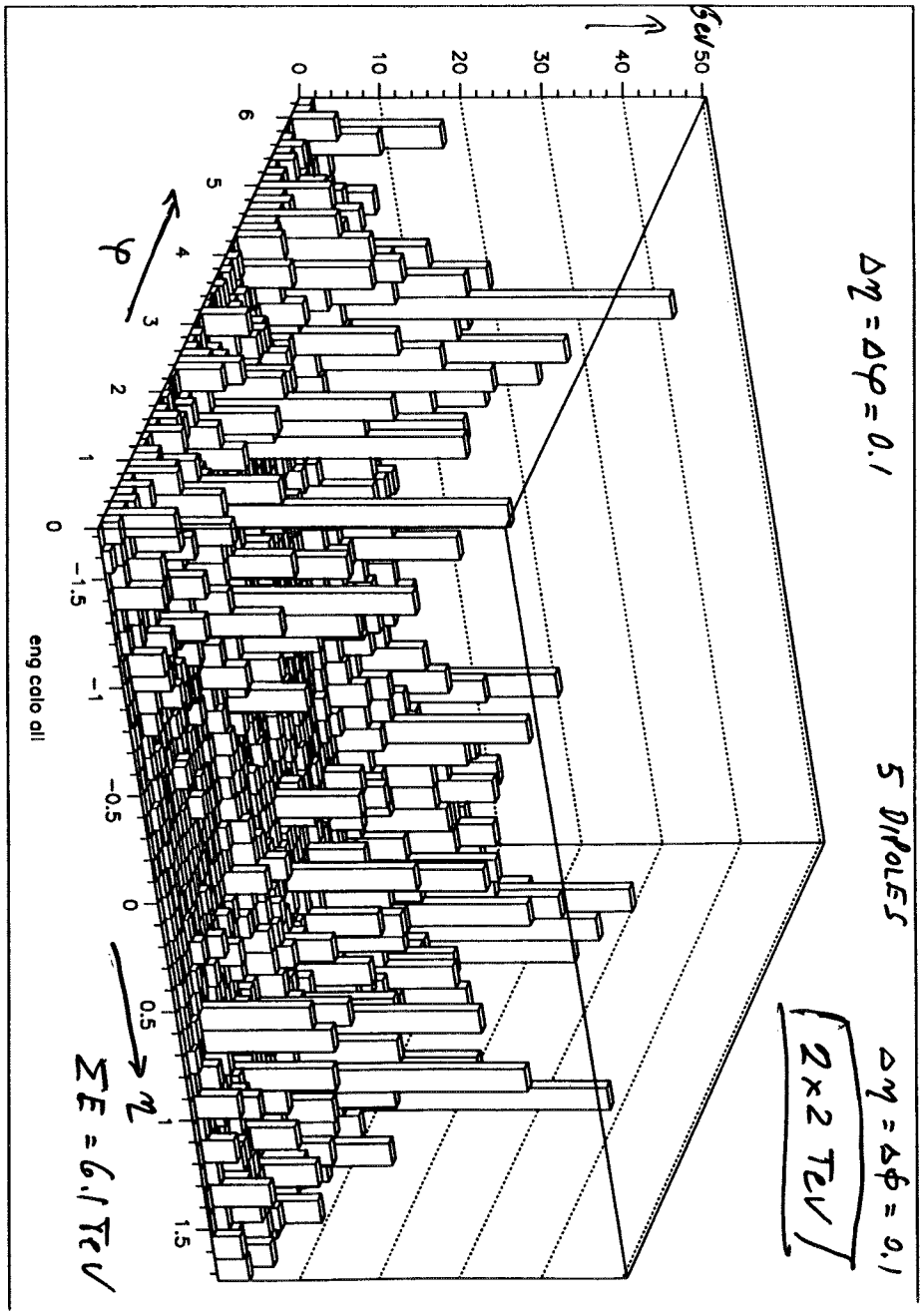


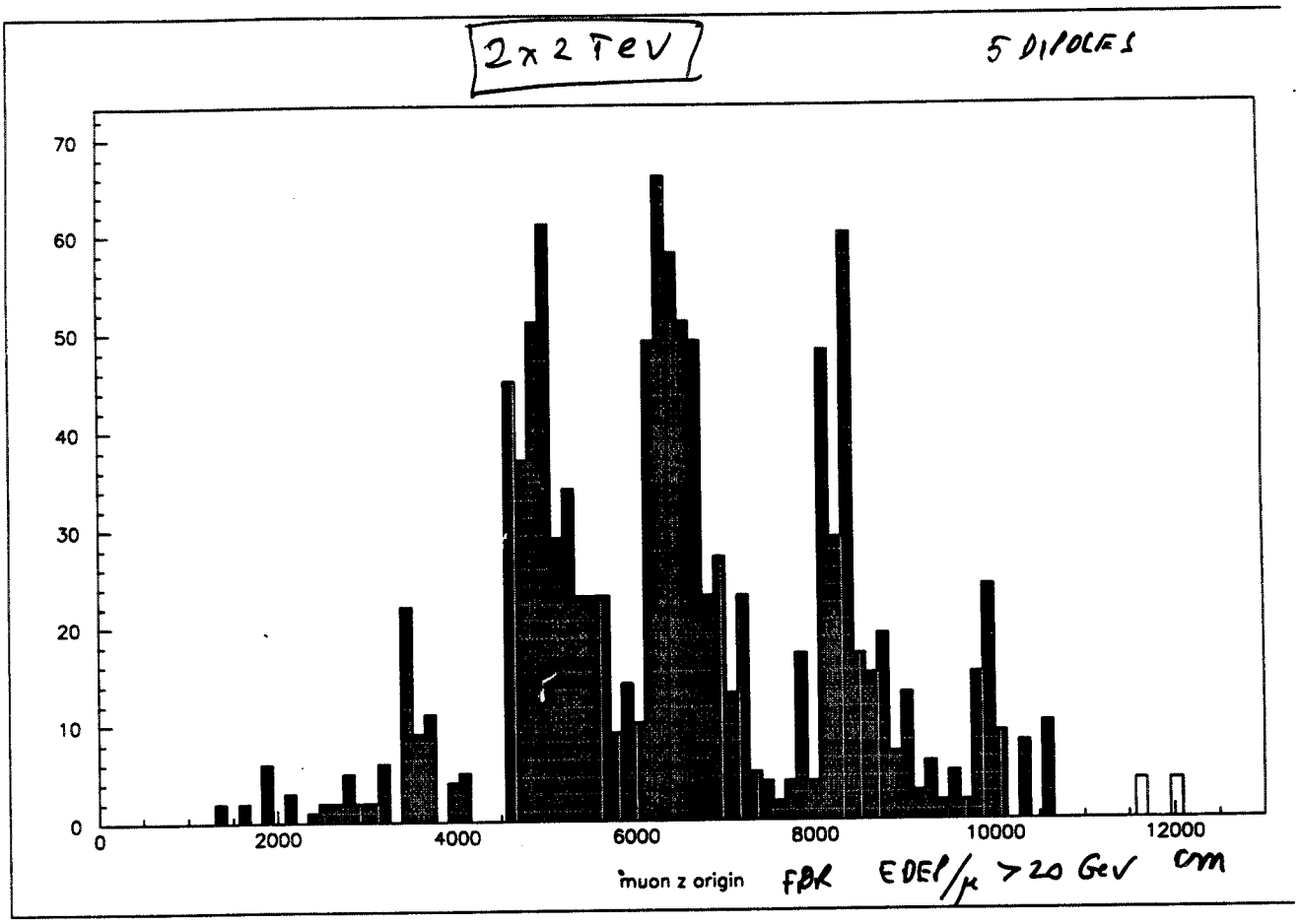
2 × 2 TeV



- NOTE: PROBABILITY FOR A 500 GeV e^- INCIDENT ON TUNGSTEN BLOCK TO PRODUCE A MUON IS $\sim 10^{-3}$
- THE BETHE-HEITLER MUONS ARE $\approx$ PARALLEL TO THE BEAM DIRECTION


2 x 2 TeV
ENERGE DEPOSITED BY μ's
IN THE CALORIMETER
1400
1200
1000
800
600
400
200
0
0 10 20 30 40 50 60 70 80 90 100
edep per bh muon in calo
(GeV)


Δη = Δφ = 0.1
5 DIPOLES
Δη = Δφ = 0.1
2 x 2 TeV
ΣE = 6.1 TeV
eng calo all
φ
η
GeV
0 10 20 30 40 50
0 1 2 3 4 5 6
-1.5 -1 -0.5 0 0.5 1 1.5



- WAYS TO IMPROVE THE SECONDARY MUONS PROBLEM

(1) MOVE THE CALORIMETER AT $\lambda_0 = 2.5$ m

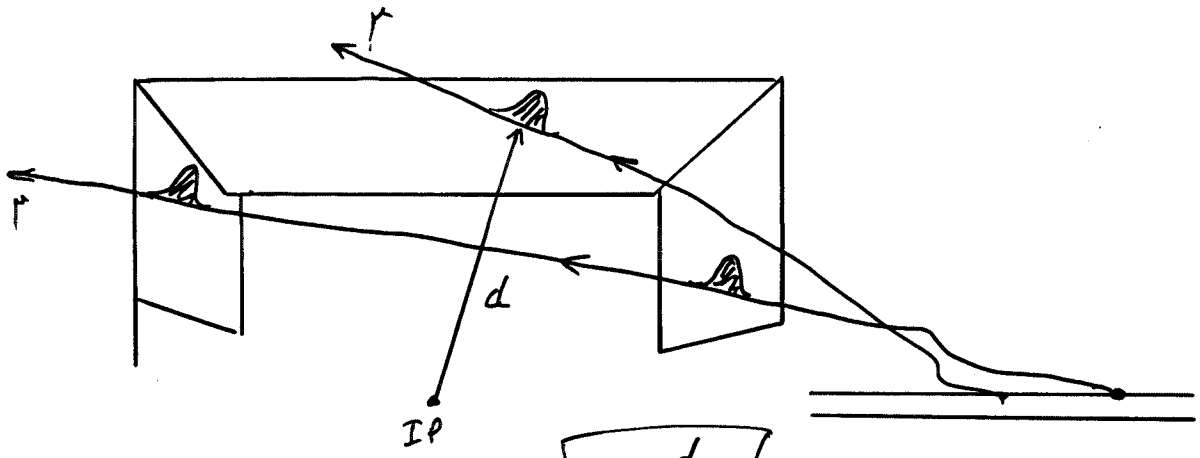
(2) TIME OF FLIGHT CUT.

(3) LOWER THE η OF HARMONIC CALORIMETER
Al + Li Argon

(4) USE A HIGH Z ABSORBER (Pb)
AROUND THE FF.

(5) INSTALL A Fe TOROID (2 Tesla)

(6) ---

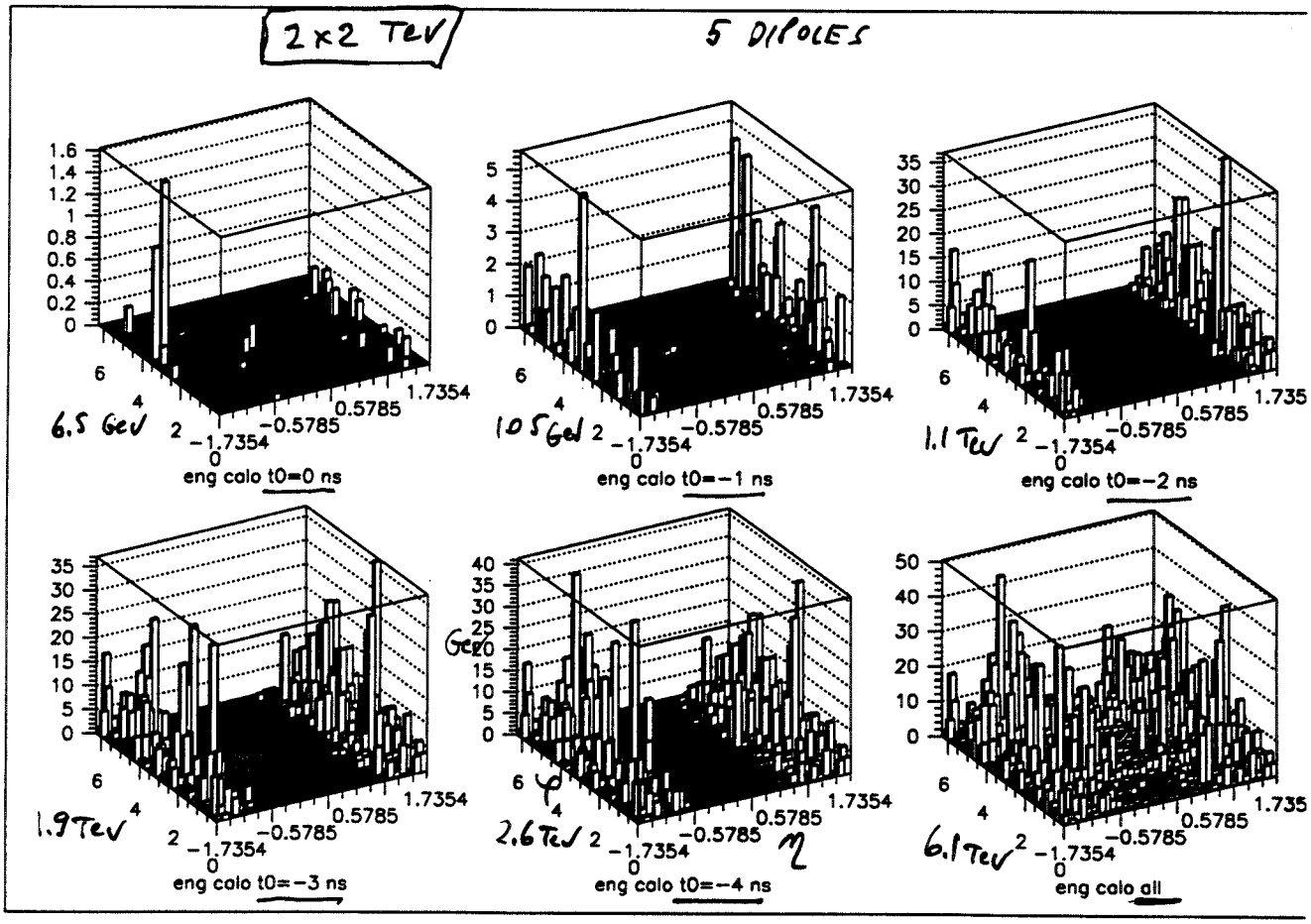


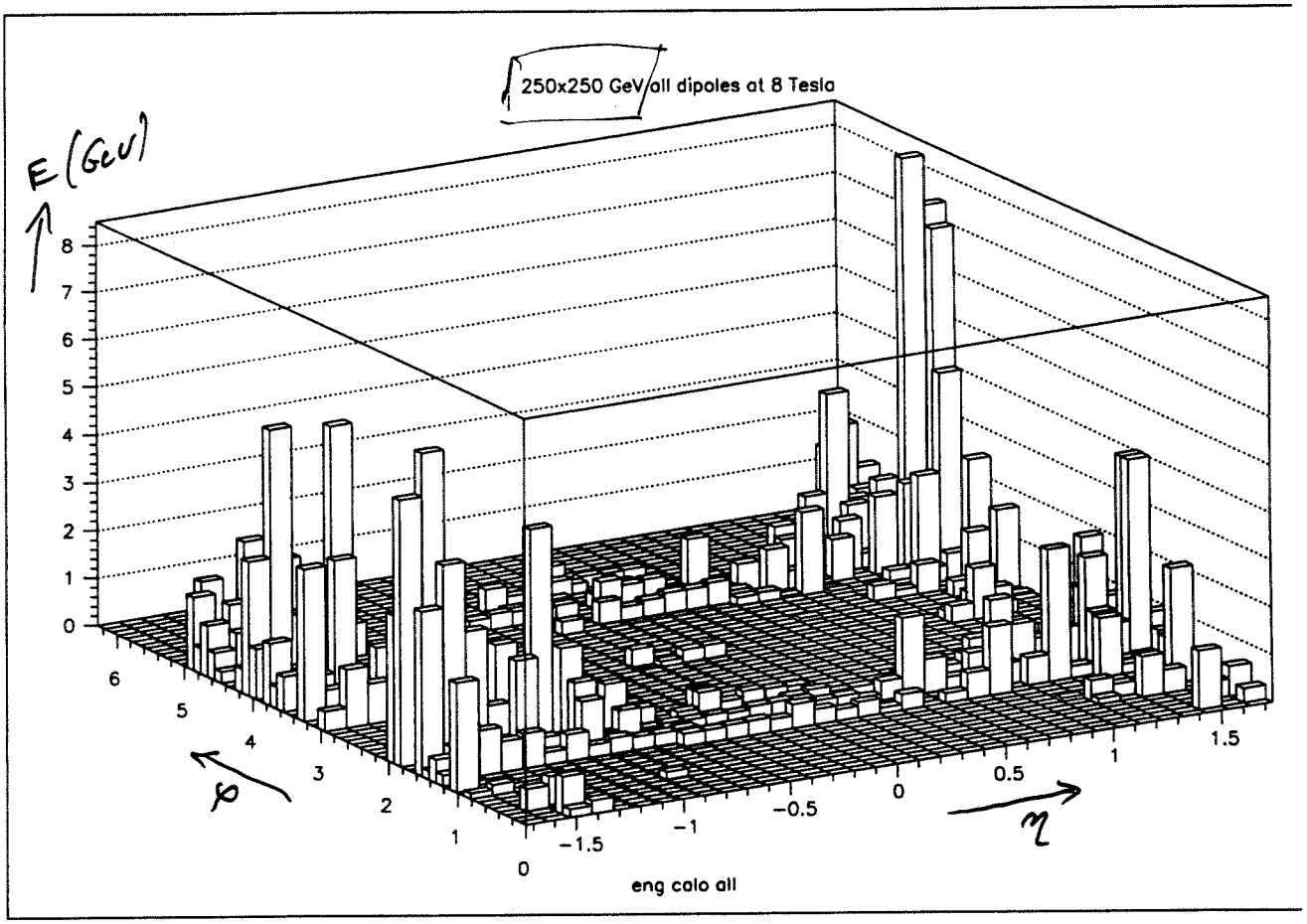
$t_0 = \frac{d}{c}$

— USE 1 nsec AS TIME UNIT

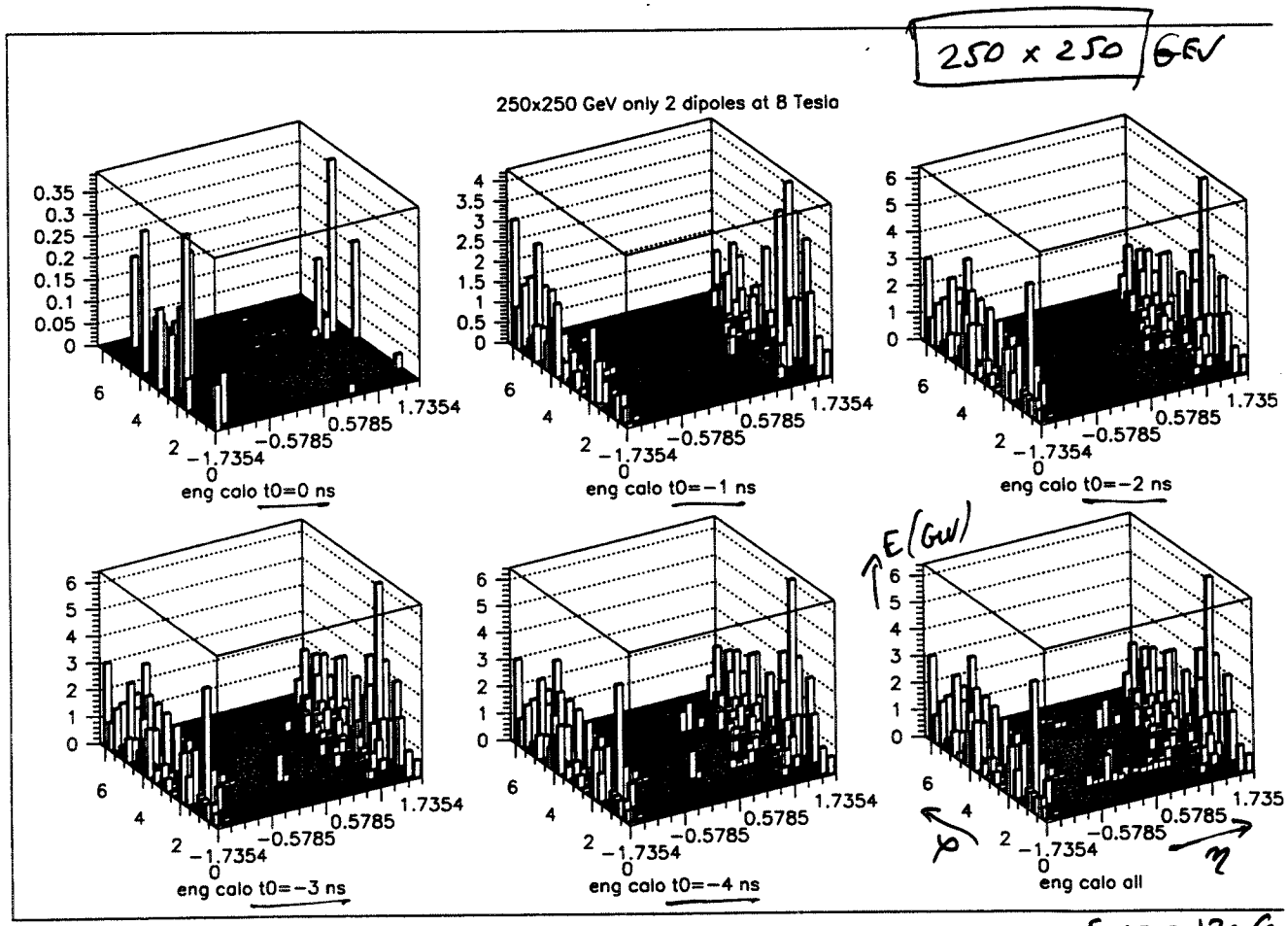
1 nsec ≈ TIME DEVELOPMENT OF ECM SHOWER

≈ SIZE OF A HADRONIC CALORIMETER CELL

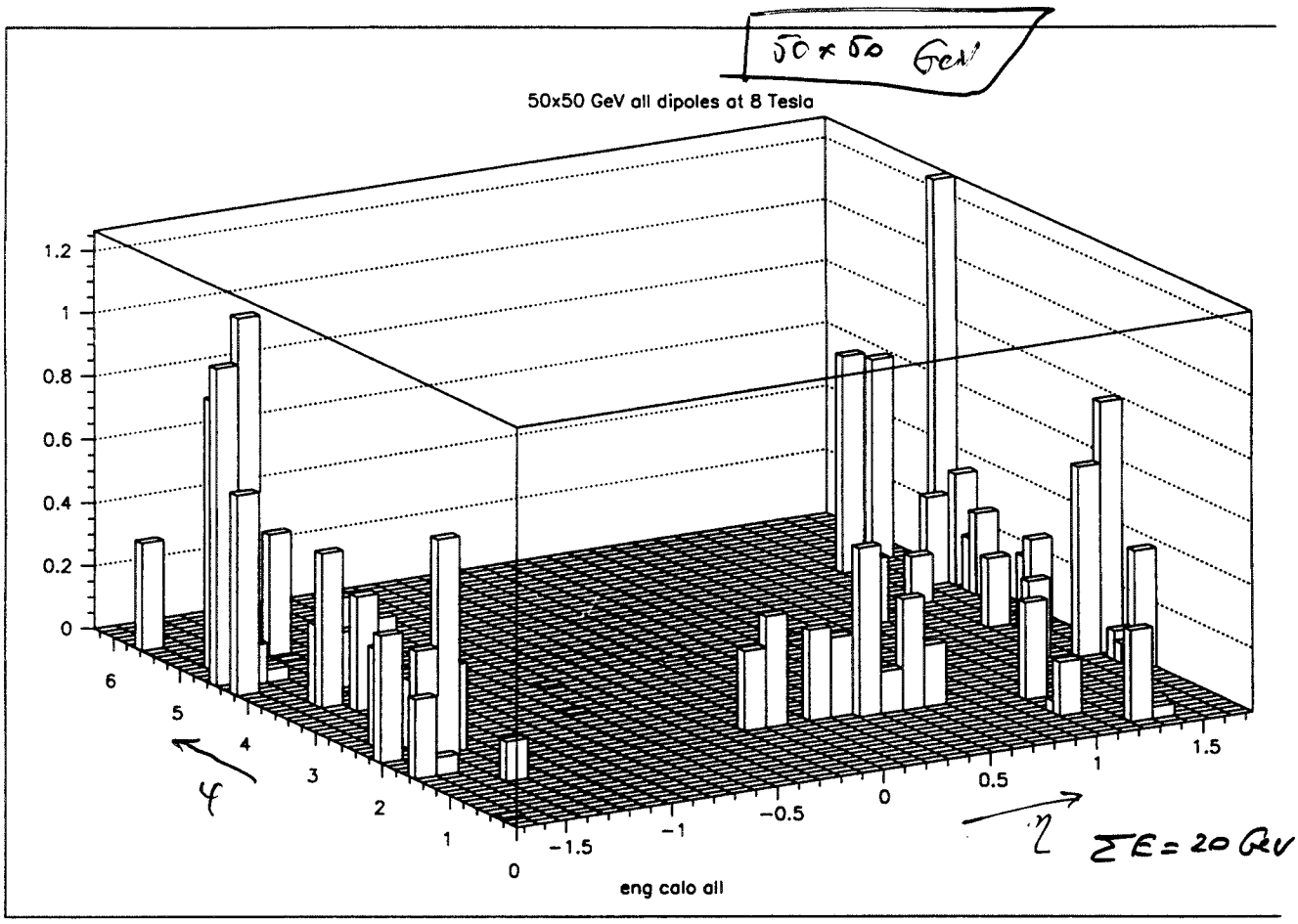


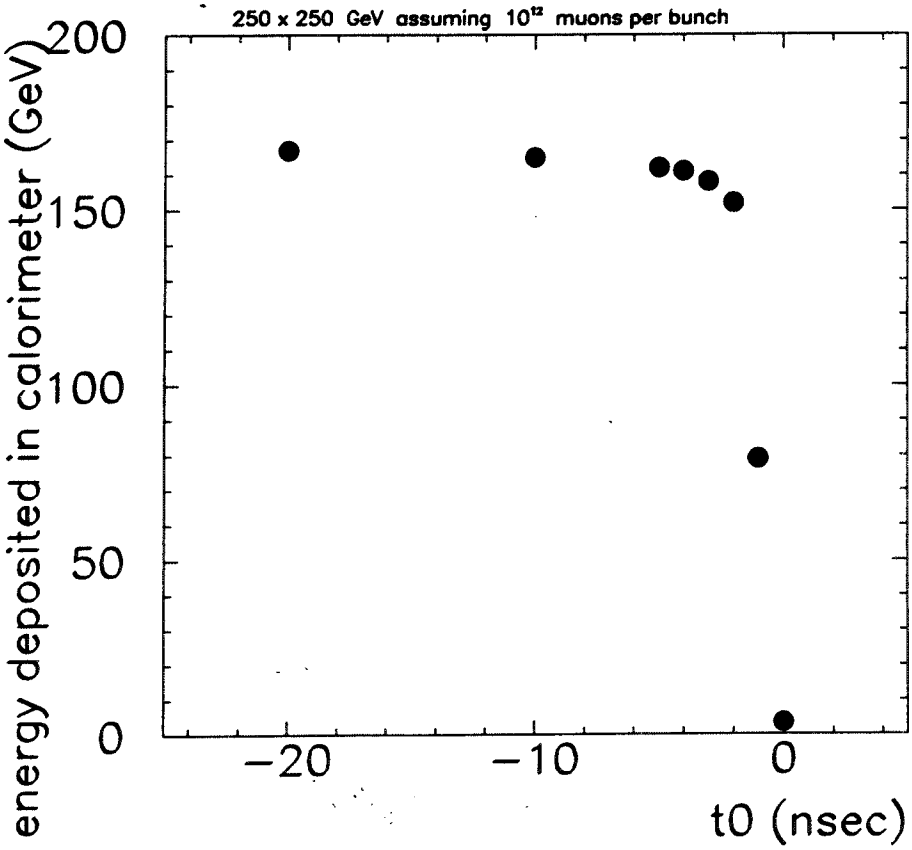


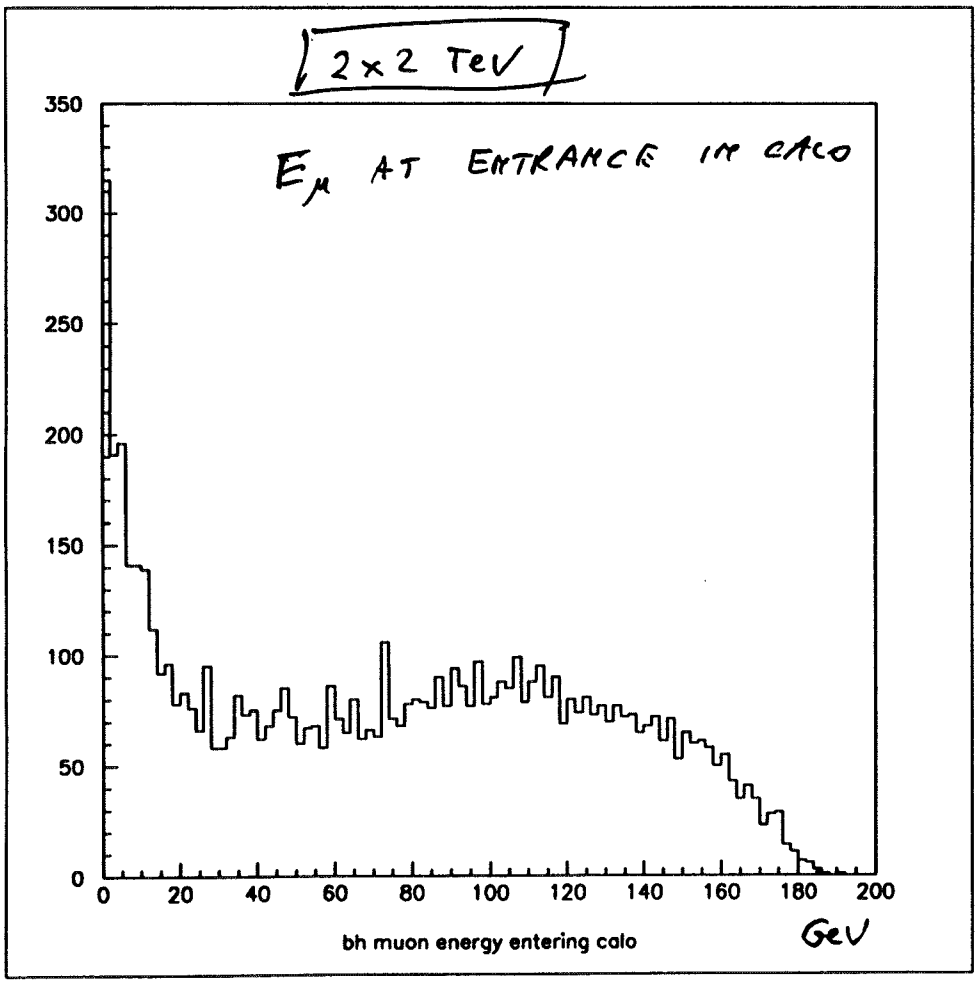
250 x 250 GeV

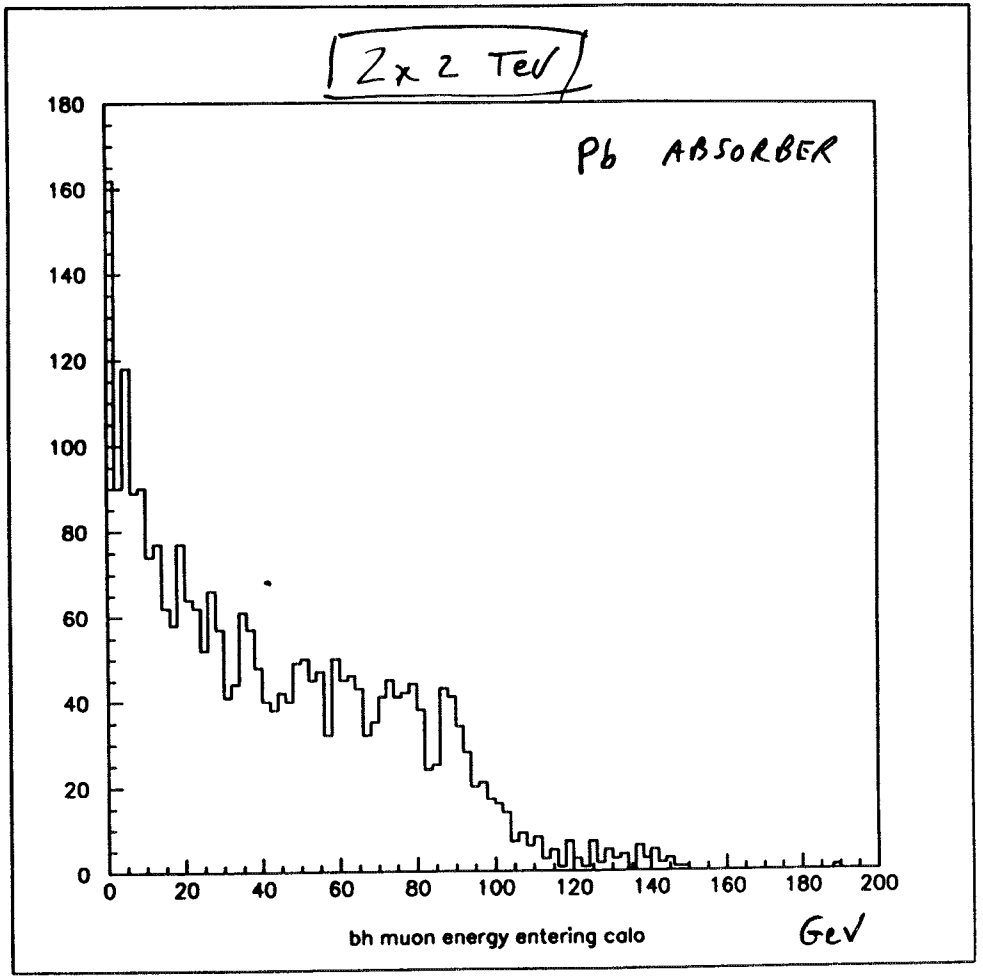


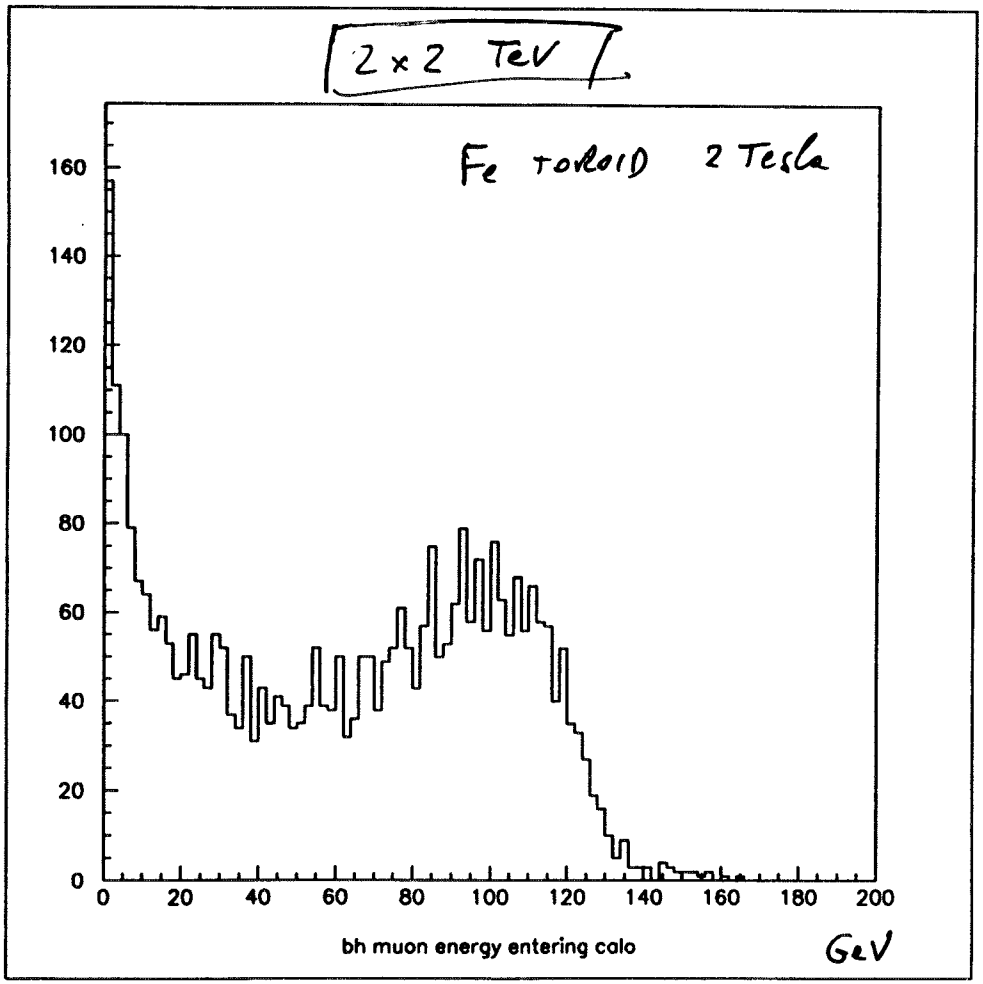
$E_{TOT} = 170$ GeV


50 x 50 GeV
50x50 GeV all dipoles at 8 Tesla
1.2
1
0.8
0.6
0.4
0.2
0
6
5
4
3
2
1
0
φ
−1.5
−1
−0.5
0
0.5
1
1.5
η
ΣE = 20 GeV
eng calo all

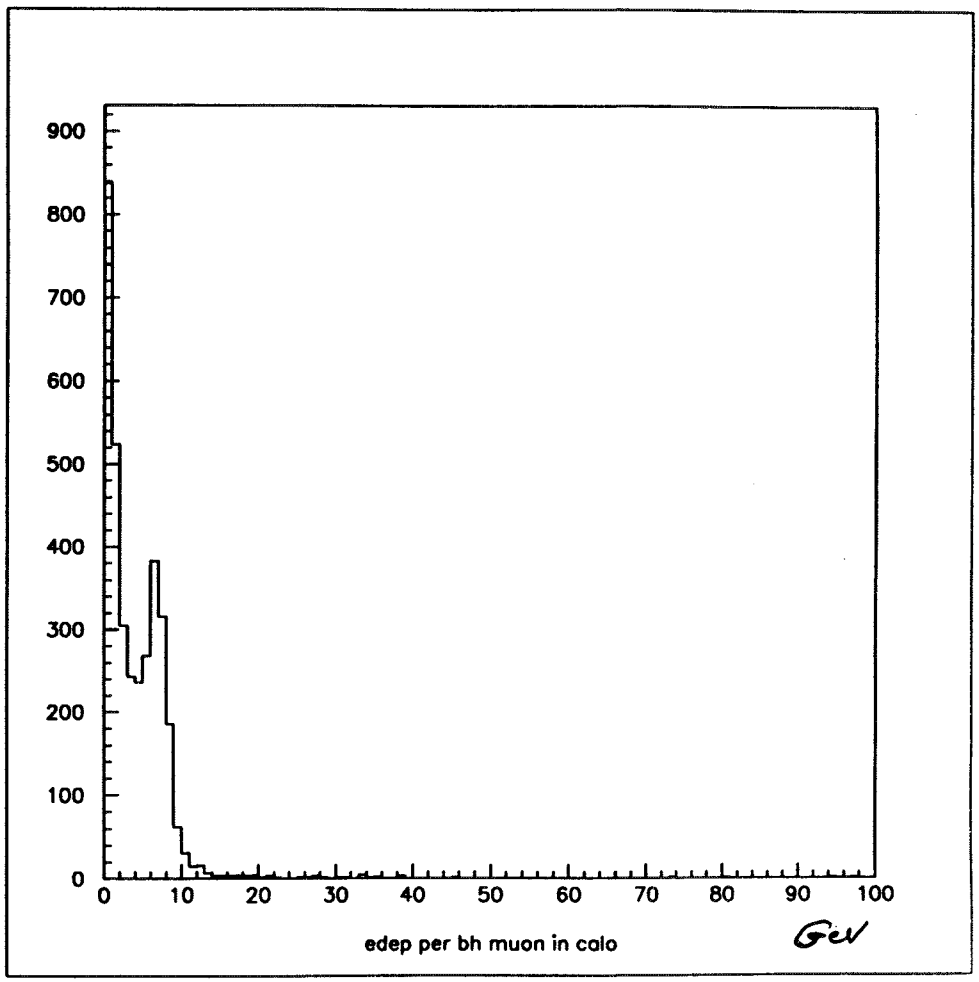

250 x 250 GeV assuming 10^12 muons per bunch
energy deposited in calorimeter (GeV)
200
150
100
50
0
−20
−10
0
t0 (nsec)


2x2 TeV
E_μ AT ENTRANCE IN CALO
350
300
250
200
150
100
50
0
0 20 40 60 80 100 120 140 160 180 200
bh muon energy entering calo
GeV

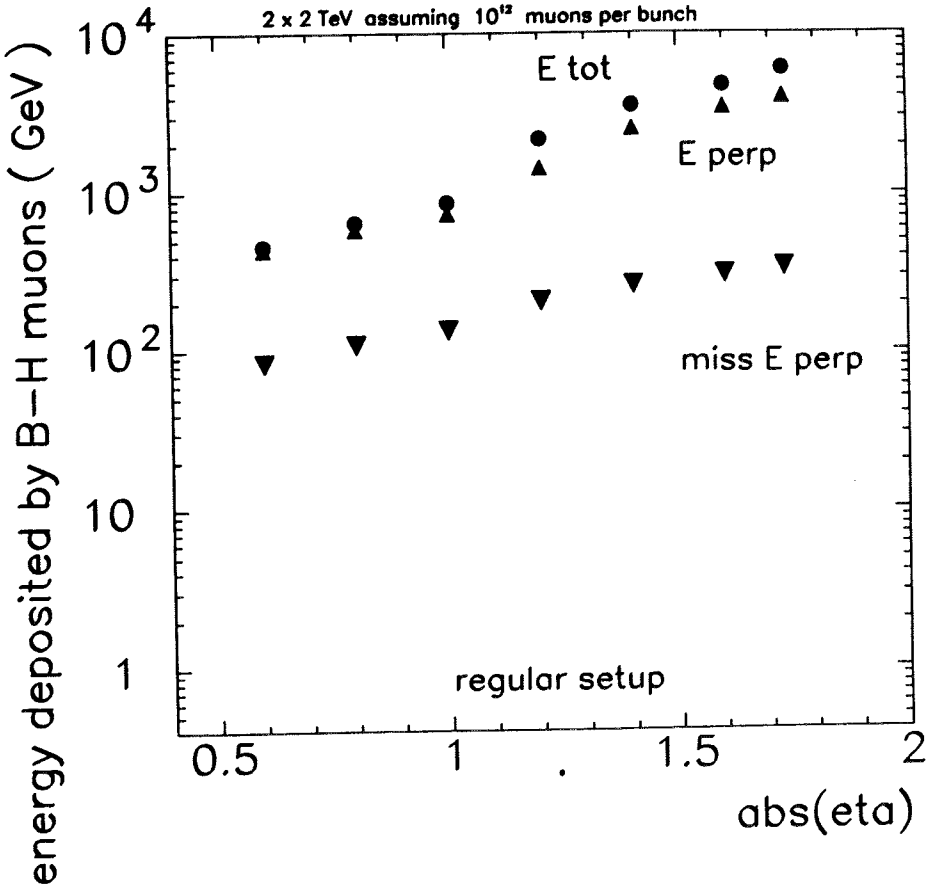

2x2 TeV
Pb ABSORBER
180
160
140
120
100
80
60
40
20
0
0 20 40 60 80 100 120 140 160 180 200
bh muon energy entering calo
GeV

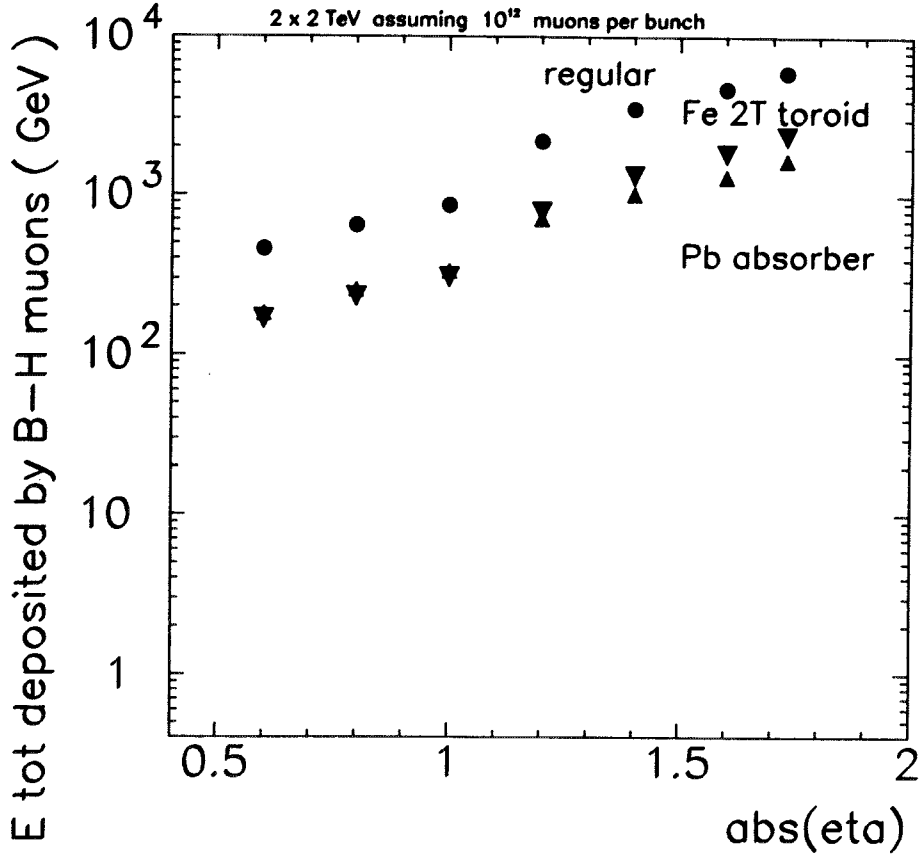

2 x 2 TeV
Fe TOROID 2 Tesla
0
20
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160
180
200
bh muon energy entering calo
GeV

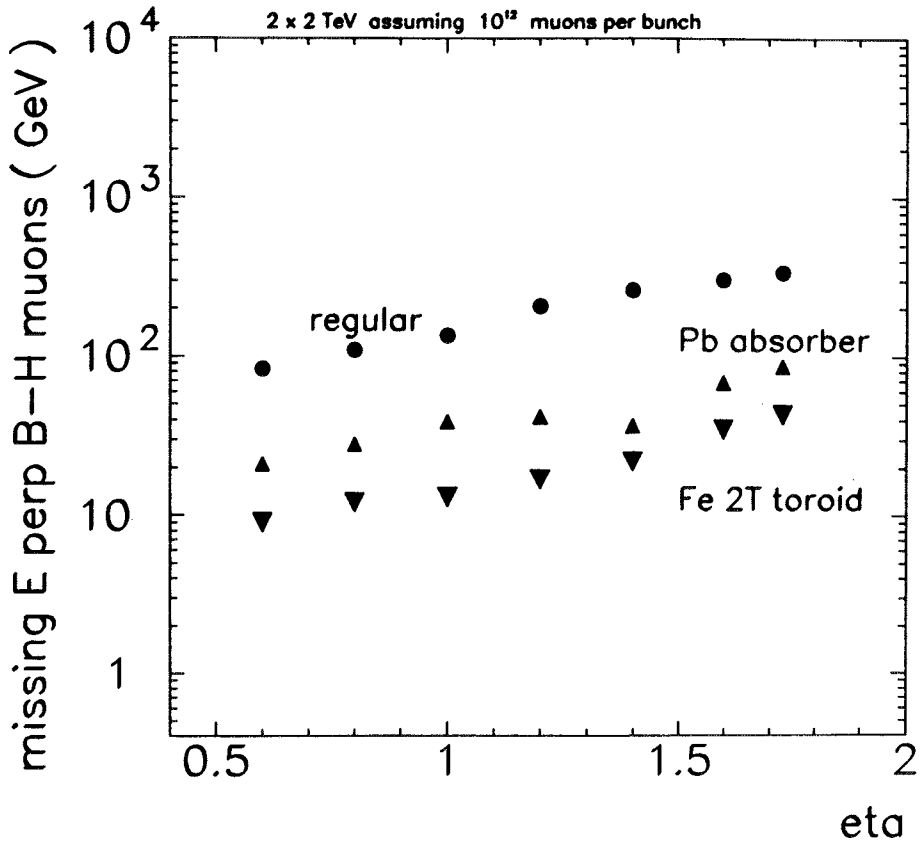
2 x 2 TeV

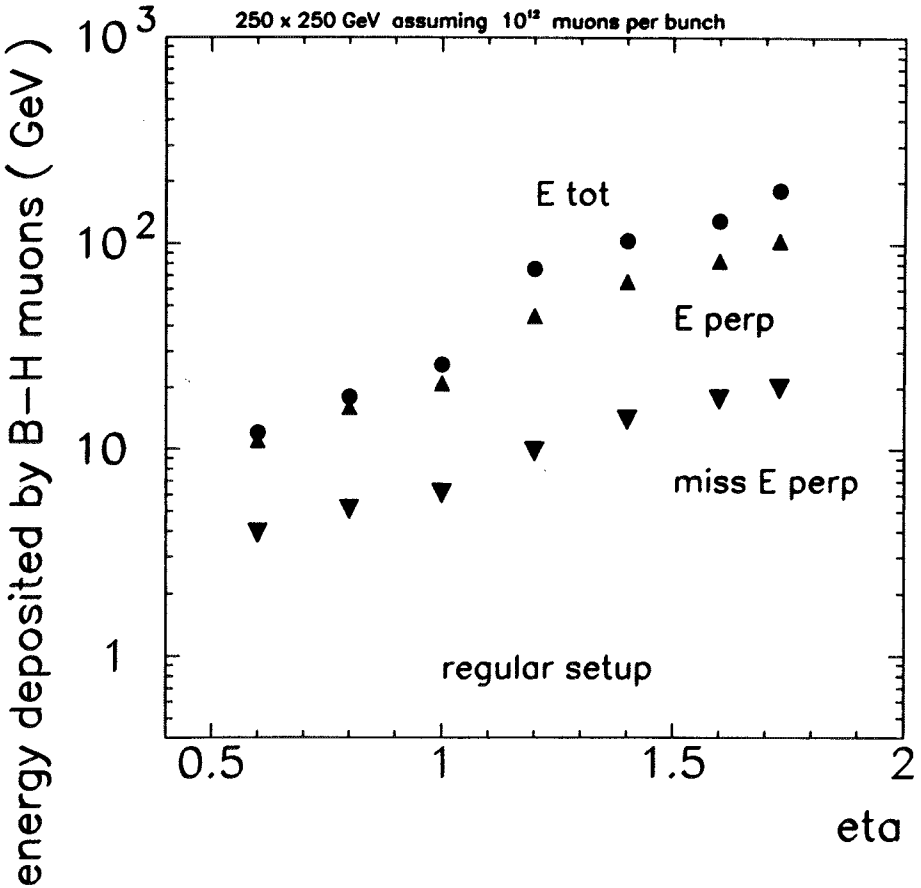

0
100
200
300
400
500
600
700
800
900
0
10
20
30
40
50
60
70
80
90
100
edep per bh muon in calo
GeV

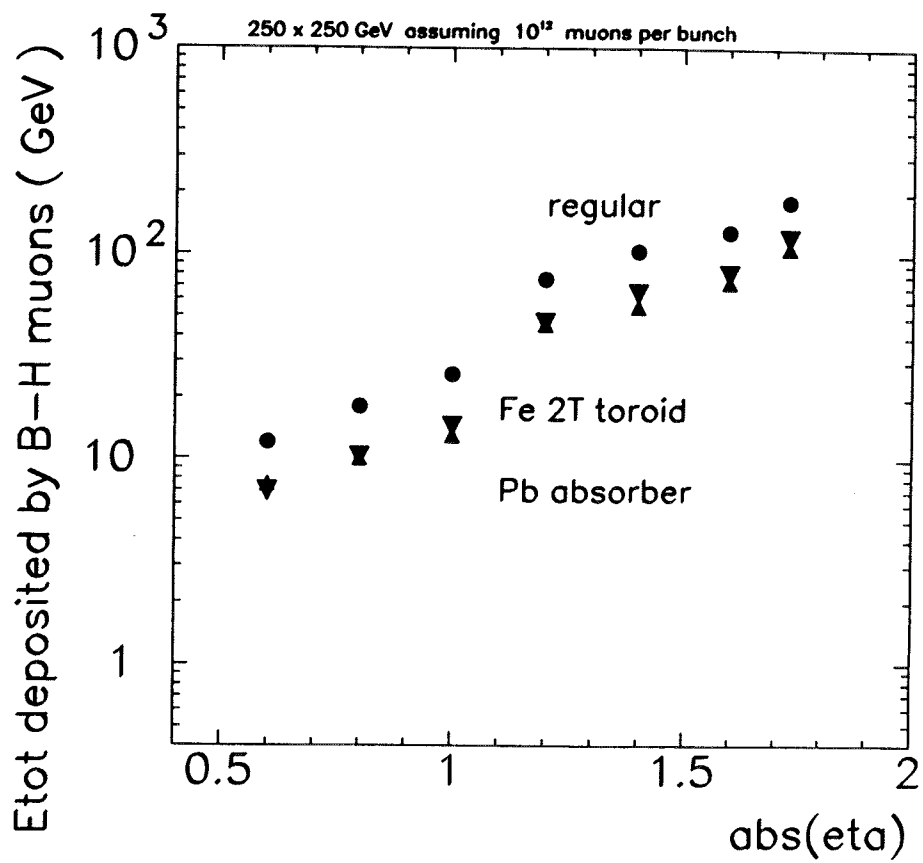
	2×2 TeV	250×250 GeV	50×50 GeV
#μ's GENERATED	18.5 K	5.1 K	1K
<p_μ>	35 GeV	16 GeV	
#μ's ENTER CALO.	1.3 K	94	58
<p_μ>	76 GeV	11.2 GeV	1.8 GeV
<$E_{DEPOSITED}$>	5.4 GeV	2.6 GeV	0.8 GeV
<E_{TOT}>	6 TeV	200 GeV	20 GeV
Pb ABSORBER			
#μ's ENTER CALO.	500	70	
<p_μ>	42 GeV	11. GeV	
<E_{dep}>	3.9 GeV	2 GeV	
<E_{TOT}>	1.6 TeV	109 GeV	
Fe TOROID (2T)			
#μ's ENTER CALO	640	74	
<p_μ>	62 GeV	10.9 GeV	
<E_{dep}>	4.2 GeV	2 GeV	
<E_{TOT}>	2.4 TeV	121 GeV	

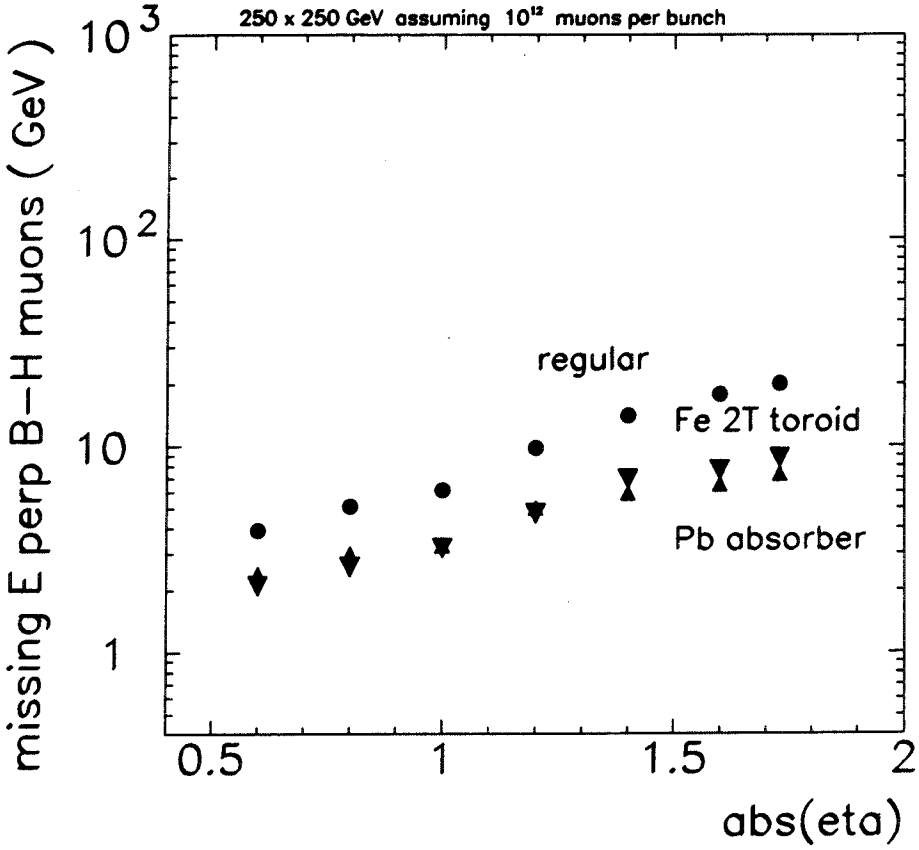



2 x 2 TeV assuming 10^12 muons per bunch
regular
Fe 2T toroid
Pb absorber
E tot deposited by B-H muons (GeV)
abs(eta)
10^4
10^3
10^2
10
1
0.5
1
1.5
2


2 x 2 TeV assuming 10^12 muons per bunch
regular
Pb absorber
Fe 2T toroid
missing E perp B-H muons (GeV)
eta
10^4
10^3
10^2
10
1
0.5
1
1.5
2


250 x 250 GeV assuming 10^12 muons per bunch
energy deposited by B-H muons (GeV)
10^3
10^2
10
1
E tot
E perp
miss E perp
regular setup
0.5
1
1.5
2
eta


250 x 250 GeV assuming 10^12 muons per bunch
Etot deposited by B-H muons (GeV)
10^3
10^2
10
1
regular
Fe 2T toroid
Pb absorber
0.5
1
1.5
2
abs(eta)



CONCLUSIONS NOW ~~MAY-97~~ ~~JULY-97~~ DEC 97

	BACK GROUNDS				DETECTORS
RANGE	SHORT	MEDIUM	LONG	VERY LONG	
	γ, e	n, π, p	BH μ's	μ HALO, $\nu, \bar{\nu}$	
< 2 TeV	V	V	!	?	V SIL VTX, TPC, **CALO**
50 x 250 GeV	~~V~~ V	V	~~!~~ !	?	V SIL ~~VTX~~ VTX, CALO
OVER 50 x 50 GeV	~~V~~ V	V	V	?	V SIL ~~VTX~~ VTX, CALO

BEAM HALO VS BEAM DECAYS IN $\mu^+\mu^-$ COLLIDERS: EFFECT ON DETECTOR AND MACHINE DESIGNS

by N. Mokhov

A.I. Drozhdin, C.J. Johnstone, N.V. Mokhov
Fermilab

A. Garren
LBNL

OUTLINE

- Beam halo handling
- Extraction of 2 TeV halo
- Extraction and collimation at 50 GeV
- Beam loss and backgrounds
- Protection of lattice components
- Conclusion

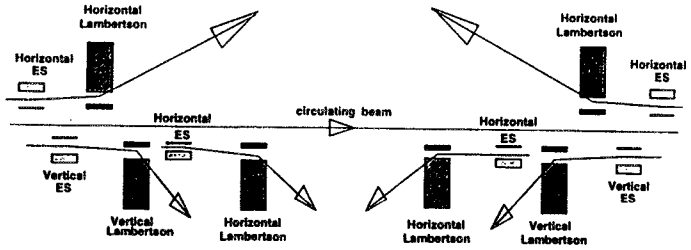


Figure 1: General view of the muon collider beam collimation system.

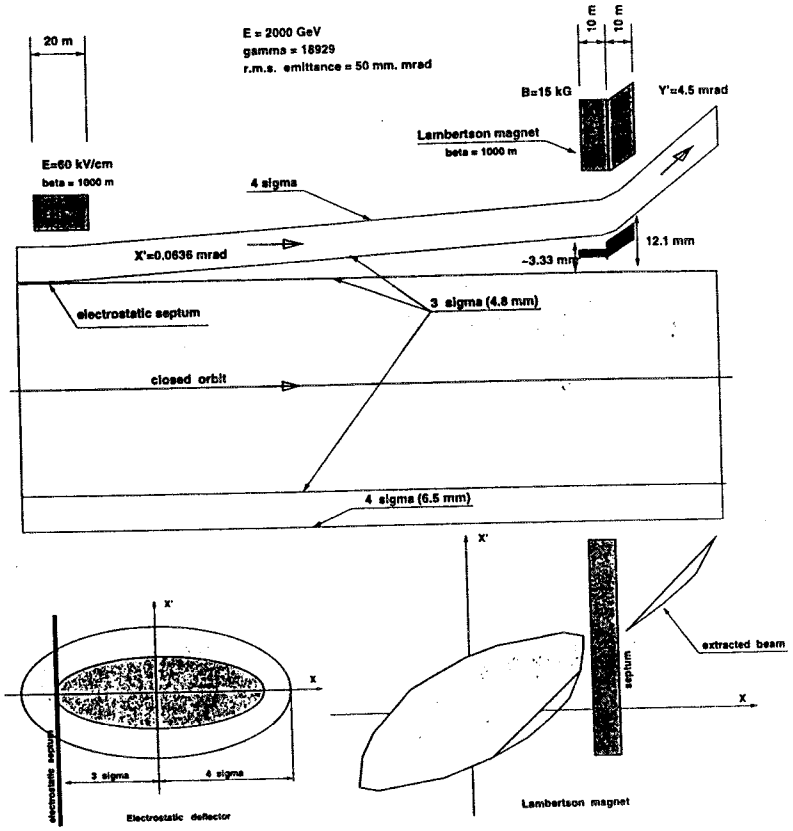


Figure 2: Halo cleaning scheme.

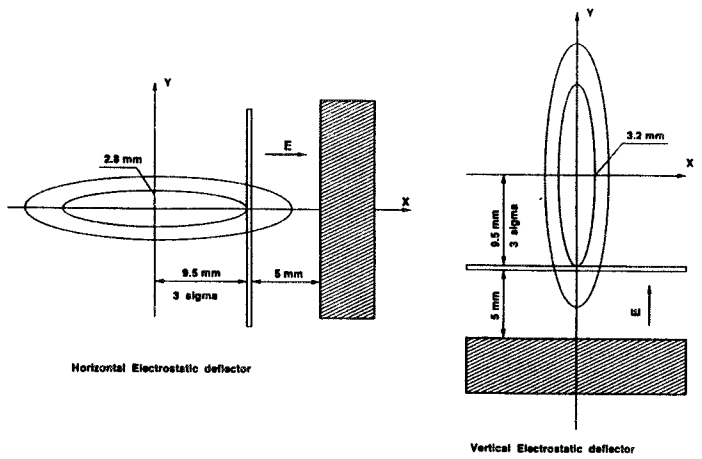


Figure 2: Electrostatic deflectors cross section.

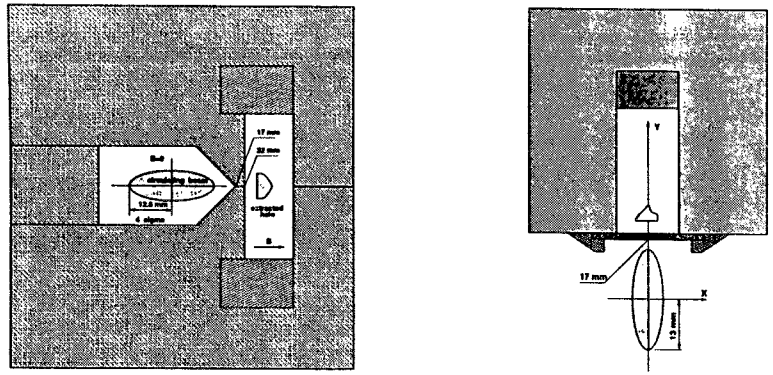


Figure 3: Lambertson and septum-magnet cross section.

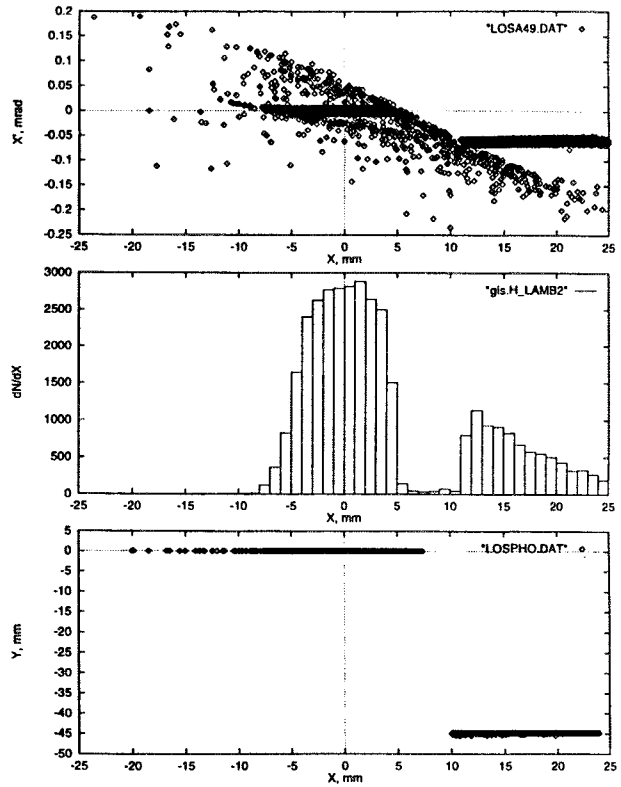


Figure 15: Halo phase plane at the second Lambertson magnet entrance (top and middle), and exit (bottom).

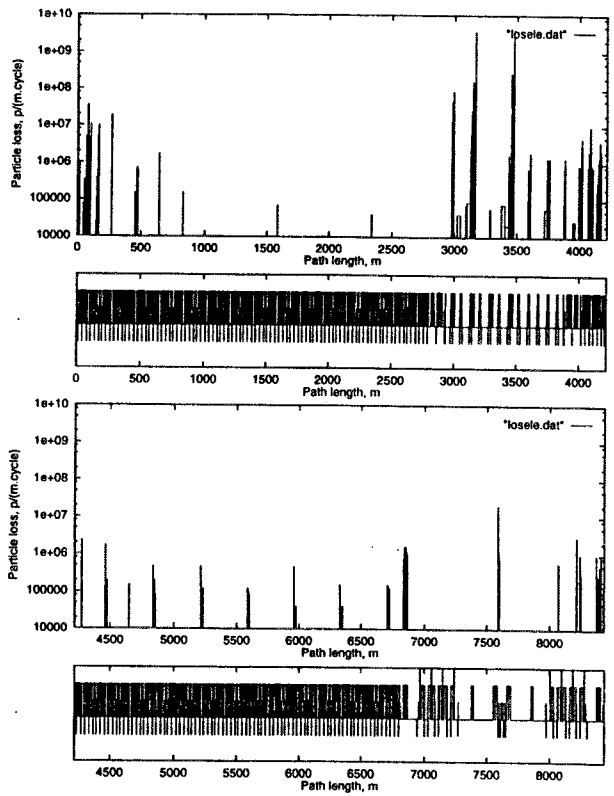


Figure 16: Beam loss at collimation.

50 X 50 GeV $\mu^+\mu^-$ Collider Beam Collimation System*

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P.O. Box 500, Batavia, Illinois 60510

A. Garren

Lawrence Berkeley National Laboratory

Berkeley, CA 94720

December 8, 1997

1 Abstract

Summary of studies is presented towards the possibility of beam halo collimation in the 50 X 50 GeV $\mu^+\mu^-$ collider using absorbers or electrostatic deflector for scrapping the circulating beam. It is shown based on Monte-Carlo simulations that traditional scheme with $5m$ long steel absorber permits to suppress losses in the IP by three order of magnitude, to 0.07% of the scraped beam.

2 Introduction

The halo originated background in the detector arise from muons which come to the aperture restrictions of the collider. In proton and electron accelerators particles which are lost away from the interaction region do not produce considerable background in the detector as they can be intercepted locally. High-energy muons can traverse several tens meters of lattice or shielding. Therefore, muons lost from the beam anywhere along the collider are candidates for background production in the detector. Muons which induce electromagnetic or hadronic showers either upstream or inside of the detector

*Presented at the *International Conference on Physics Potential and Development of $\mu^+\mu^-$ Colliders.* San Francisco, California, December 10-12, 1997

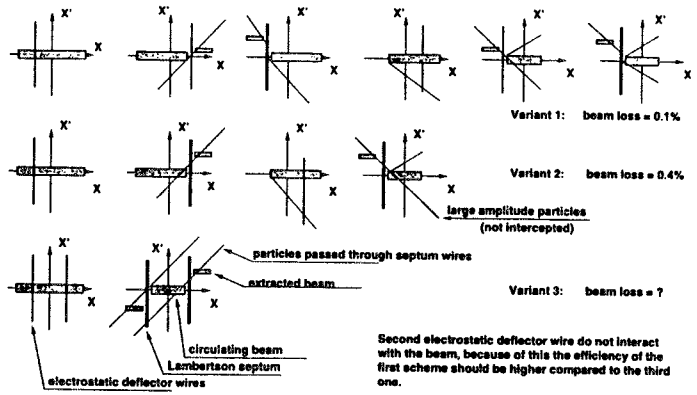


Figure 4: Different schemes of muon collider beam collimation.

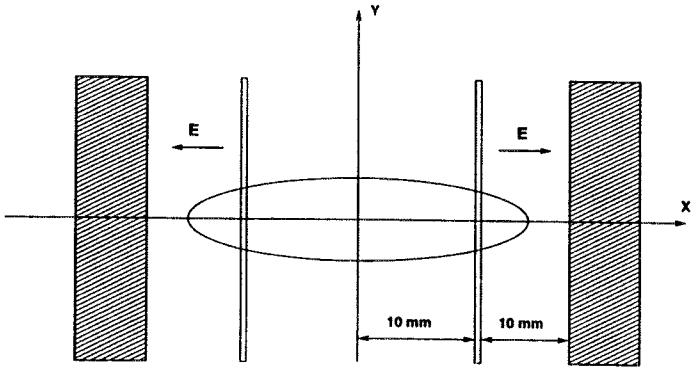


Figure 5: Symmetric electrostatic deflectors cross section.

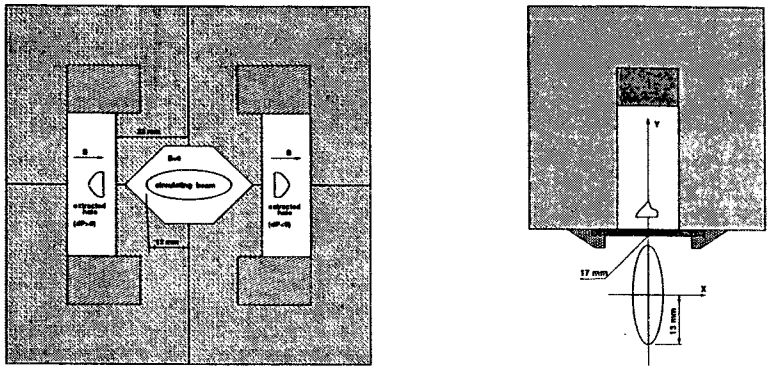


Figure 6: Symmetric Lambertson and septum-magnet cross section.

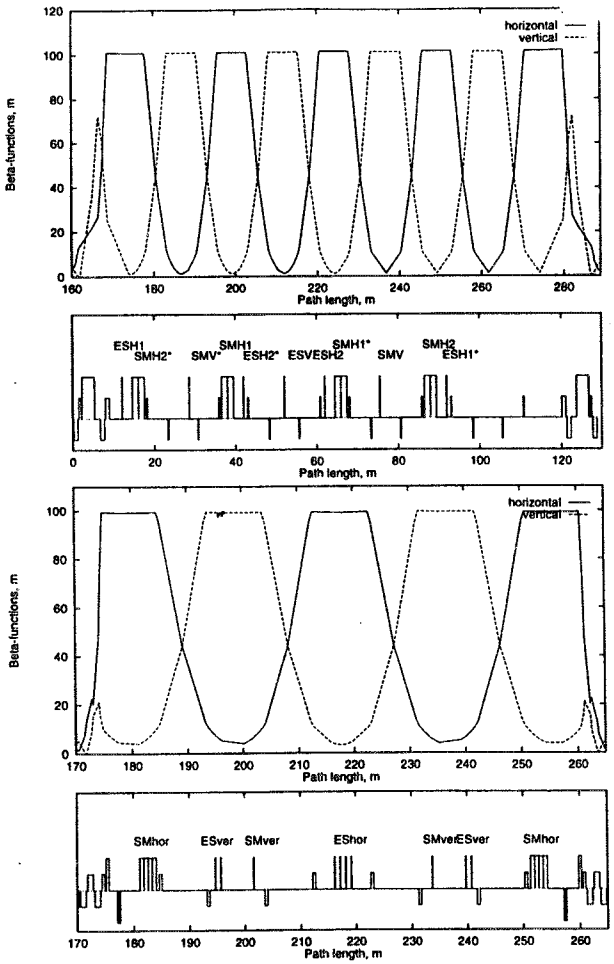


Figure 8: Collimation section beta functions and possible collimation schemes.

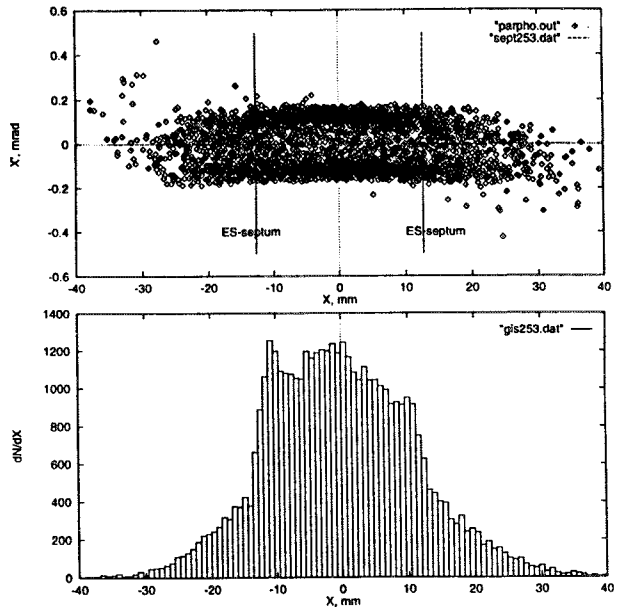


Figure 9: Halo phase plane at the horizontal electrostatic deflector entrance in the symmetric scheme.

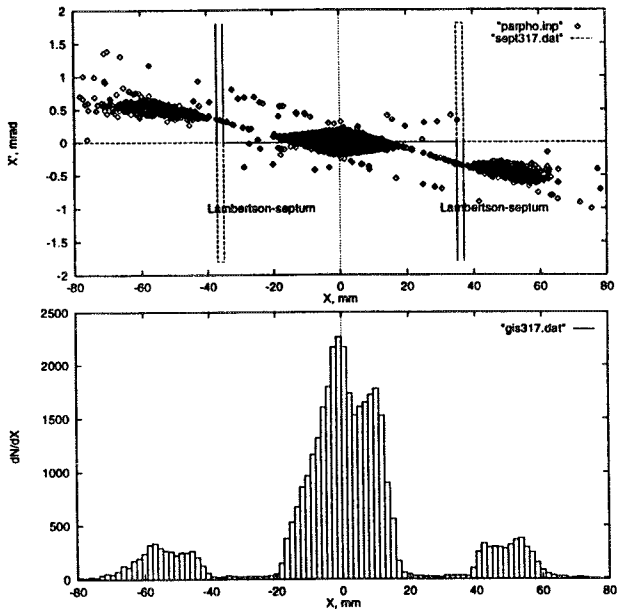


Figure 10: Halo phase plane at the Lambertson magnet entrance in the symmetric scheme.

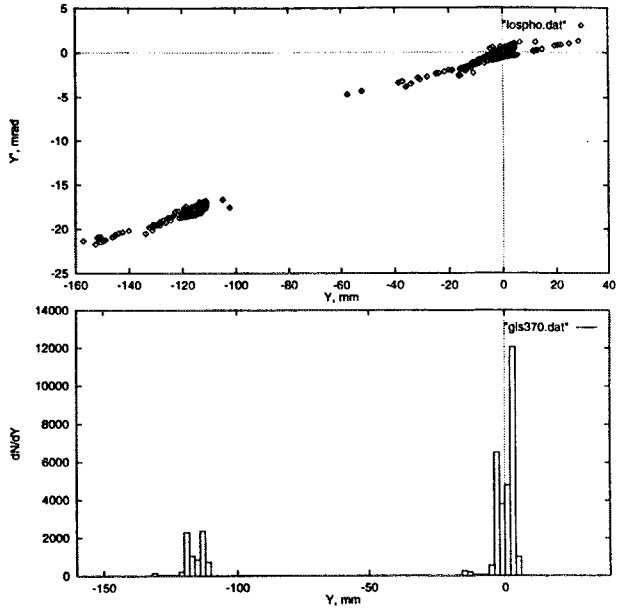


Figure 11: Halo phase plane at the the Lambertson magnet exit in the symmetric scheme.

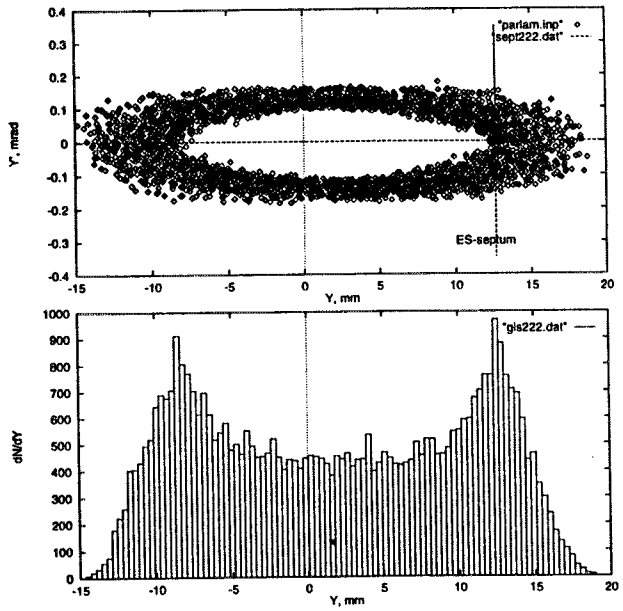


Figure 12: Halo phase plane at the vertical electrostatic deflector entrance in the symmetric scheme.

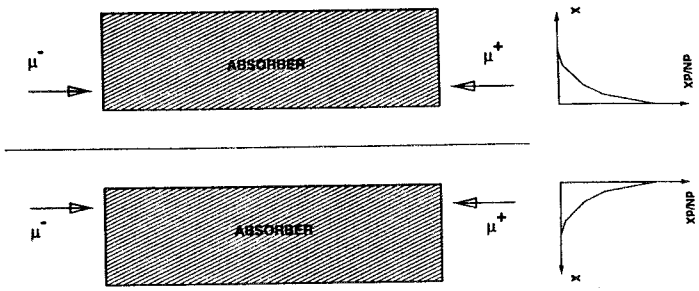
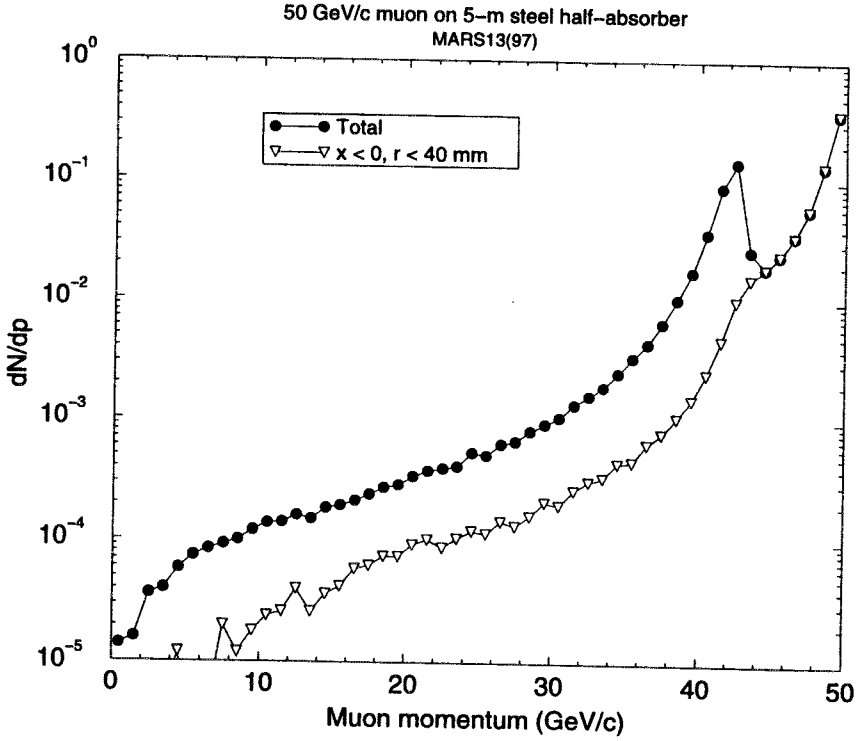
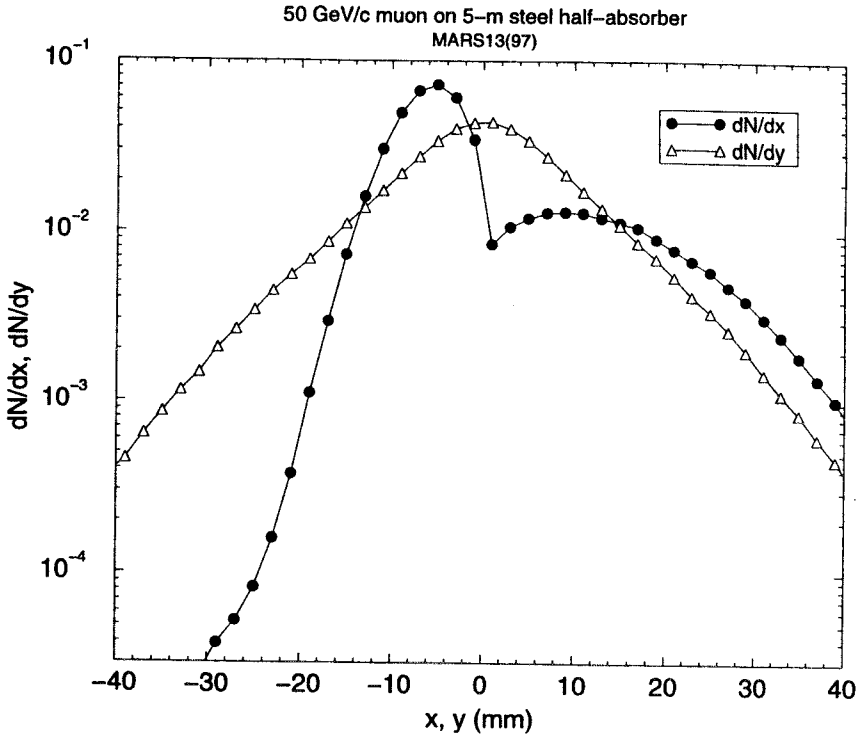
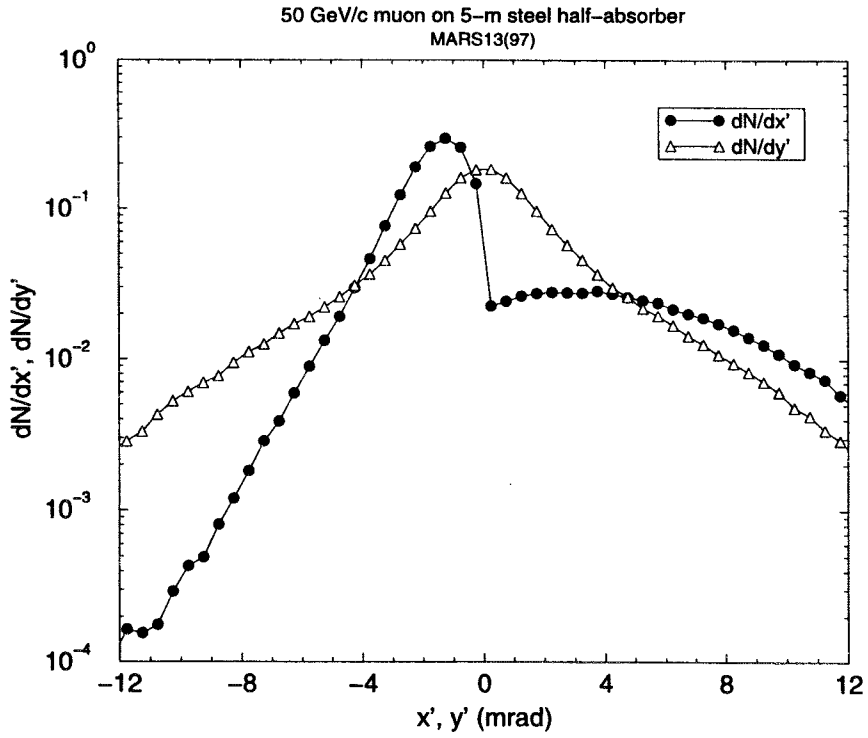


Figure 15: Halo collimation with $5m$ steel absorber.


50 GeV/c muon on 5–m steel half–absorber
MARS13(97)
Total
x < 0, r < 40 mm
dN/dp
Muon momentum (GeV/c)


50 GeV/c muon on 5–m steel half–absorber
MARS13(97)
dN/dx
dN/dy
dN/dx, dN/dy
x, y (mm)



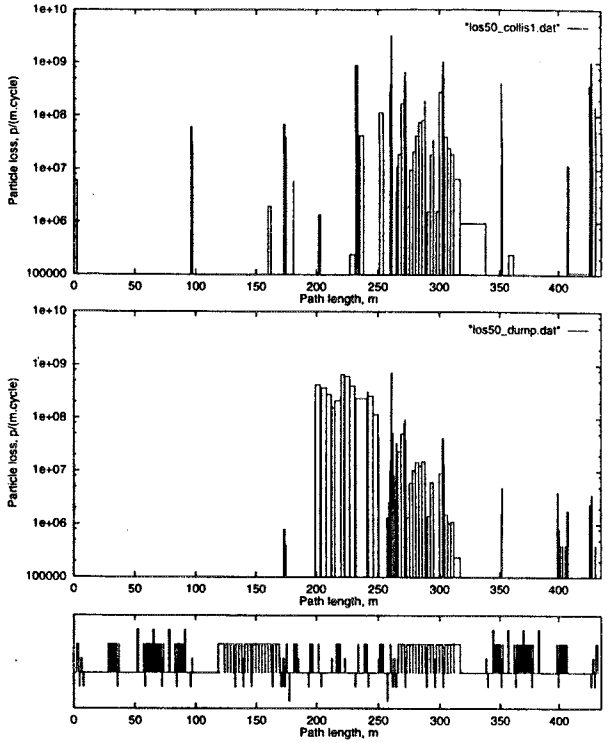


Figure 16: Beam loss at collisions with halo extraction (top) and halo dumping at internal absorber (bottom). One percent of the beam intensity is collimated at collisions.

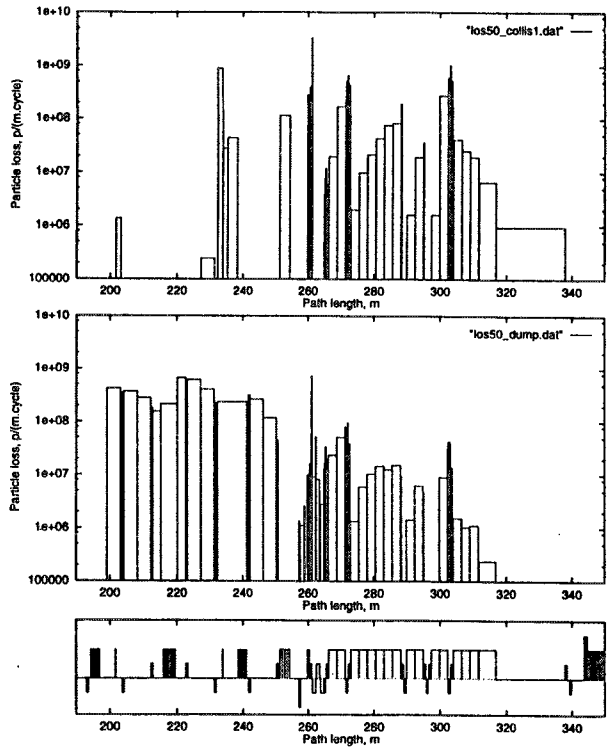
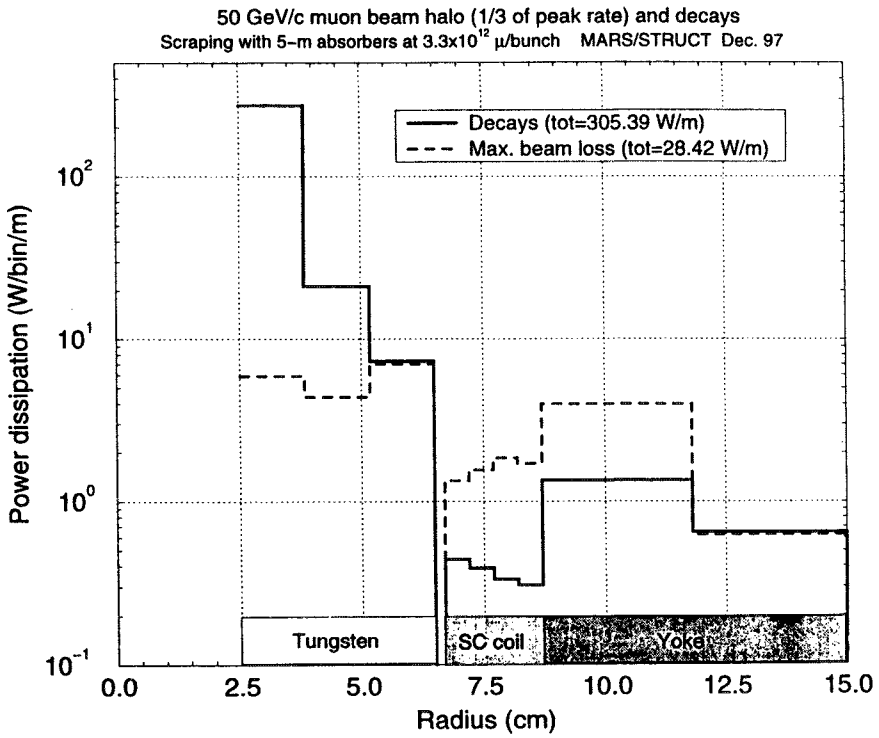
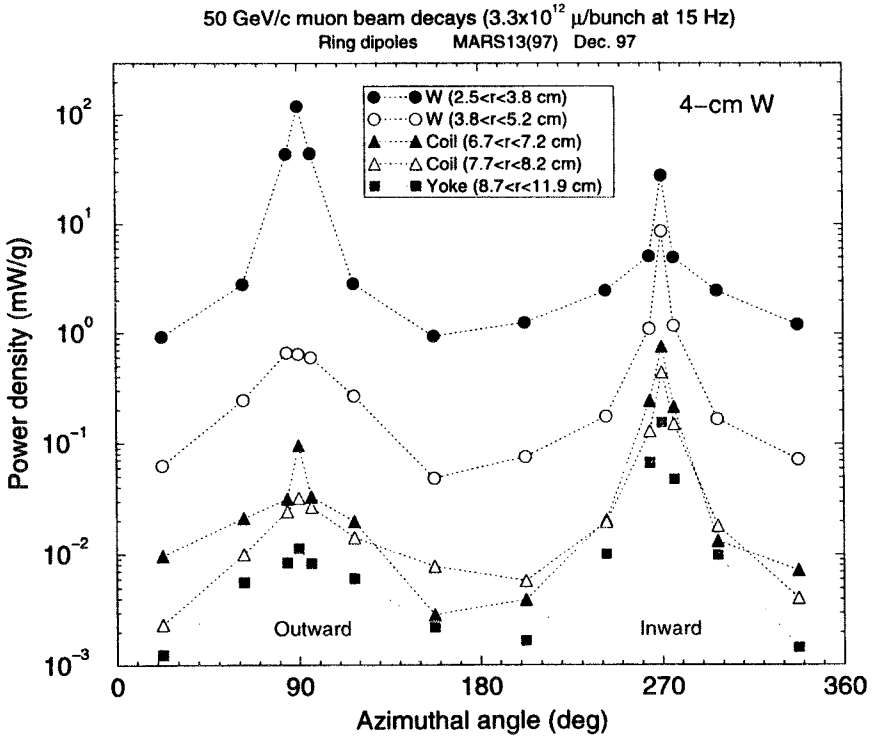
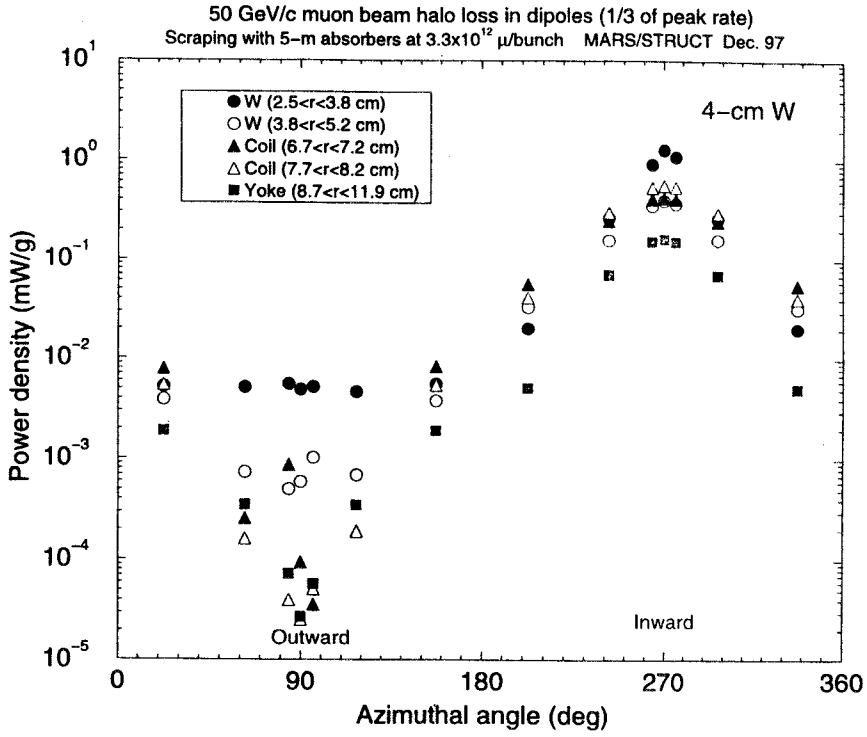
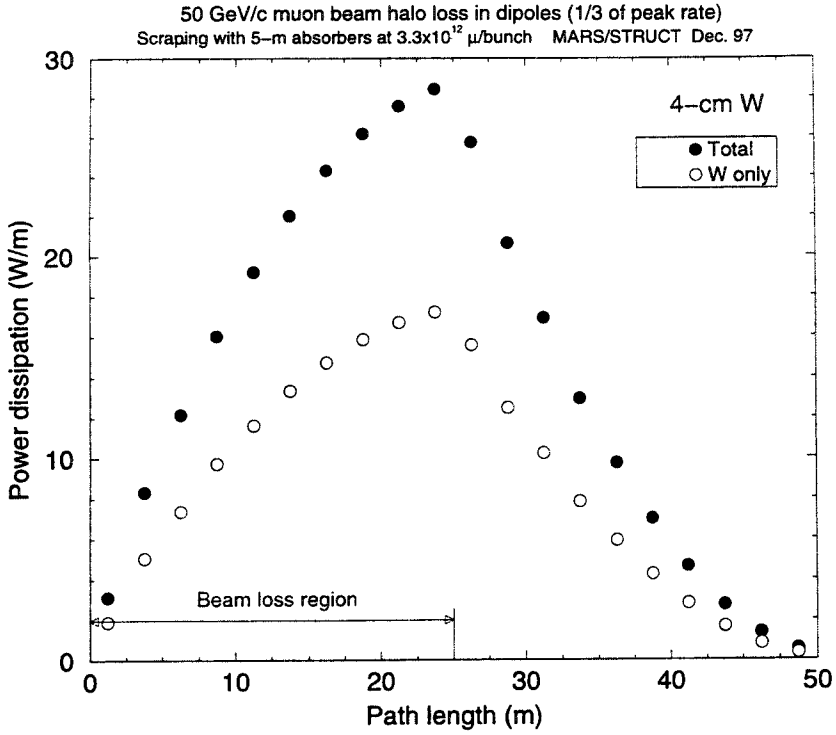


Figure 17: Beam loss at collisions with halo extraction (top) and halo dumping at internal absorber (bottom). One percent of the beam intensity is collimated at collisions.




50 GeV/c muon beam decays (3.3x10^12 μ/bunch at 15 Hz)
Ring dipoles MARS13(97) Dec. 97
W (2.5<r<3.8 cm)
W (3.8<r<5.2 cm)
Coil (6.7<r<7.2 cm)
Coil (7.7<r<8.2 cm)
Yoke (8.7<r<11.9 cm)
4-cm W
Outward
Inward
Power density (mW/g)
Azimuthal angle (deg)


50 GeV/c muon beam halo loss in dipoles (1/3 of peak rate)
Scraping with 5-m absorbers at 3.3x10^12 μ/bunch MARS/STRUCT Dec. 97
W (2.5<r<3.8 cm)
W (3.8<r<5.2 cm)
Coil (6.7<r<7.2 cm)
Coil (7.7<r<8.2 cm)
Yoke (8.7<r<11.9 cm)
4-cm W
Outward
Inward
Power density (mW/g)
Azimuthal angle (deg)



CONCLUSION

- Beam cleaning system is a mandatory in muon colliders
- At 2 TeV, extraction of beam halo reduces loss rate in IR by three orders of magnitude; efficiency of an absorber-based system is much much lower
- At 50 GeV, a five meter long steel absorber does an excellent job, eliminating halo-induced backgrounds in detectors
- At 50 GeV, a 4-cm tungsten liner or a design with iron/coils completely separated on the mid-plane are needed to protect SC magnets against both beam halo (locally!) and beam decays

Determining the energy scale of the 50 GeV First Muon Collider using g-2 precession

Rajendran Raja,Alvin Tollestrup
Fermilab

Workshop on Physics at the First Muon Collider and Front end of the FMC ,
November 6-9, 1997

Format of talk

- Describe g-2 method.
- Planar ideal accelerator
- Explore fractional error in measurement Lorentz factor $\delta\gamma/\gamma$ of muon as a function of number of electrons sampled and polarization.
- Explore variation of $\delta\gamma/\gamma$ as a function of momentum spread $\delta p/p$ of muons
- Examine effects of departures from ideal case.
- Assume that a)Polarized muons can be delivered to the collider ring and b)The polarization can be adequately maintained for 1000 turns.

Bargmann-Michel-Telegdi equation

$$\frac{d\vec{S}}{dt} = \vec{\Omega} \times \vec{S}$$

$$\vec{\Omega} = -\frac{e}{m\gamma}((1+a\gamma)\vec{B}_{\perp} + (1+a)\vec{B}_{\parallel} - (a\gamma + \frac{\gamma}{1+\gamma})\vec{\beta} \times \frac{\vec{E}}{c})$$

$$\vec{\Omega} = \vec{\Omega}_{cyc}(1+a\gamma)$$

$$a = (g-2)/2$$

$B_{\perp}, B_{\parallel}$ are the components of magnetic field perpendicular and parallel particle direction

This equation controls the evolution of the spin vector $\vec{S}$. Polarization is the average of the spin vectors over the muon ensemble. Per revolution spin rotates by $a\gamma 2\pi$ radians more than momentum

Definitions

In the muon rest frame, E is the energy of the electron. Its fractional energy

expressed in terms of the maximum energy ($m_{\mu}/2$) is x. N is the number of muon decays. θ is the angle of the electron in the muon center of mass

w.r.t muon direction. <E> is the average electron energy and <PL> is the average longitudinal electron momentum in the muon rest frame.

P is the z component of the muon polarization along the muon direction. $\hat{P}$ is charge*P of the muon.

Electron energy distribution

$$x = 2E / m_\mu$$

$$\frac{d^2N}{dx d\cos\theta} = N(x^2(3-2x) - \hat{P}x^2(1-2x)\cos\theta)$$

$$< E >= \frac{m_\mu}{2N} \iint x \frac{d^2N}{dx d\cos\theta} dx d\cos\theta = \frac{7}{10}\frac{m_\mu}{2}$$

$$< P_L >= \frac{m_\mu}{2N} \iint x\cos\theta \frac{d^2N}{dx d\cos\theta} dx d\cos\theta = \frac{\hat{P}}{10}\frac{m_\mu}{2}$$

Decay distributions

$$< E_{lab} >= \frac{7}{20} E_\mu (1 + \frac{\beta}{7}\hat{P})$$

$$E(t) = Ne^{-\alpha t}(\frac{7}{20} E_\mu (1 + \frac{\beta}{7}(\hat{P}\cos\omega t + \phi)))$$

$$\omega = \gamma \frac{g-2}{2} 2\pi$$

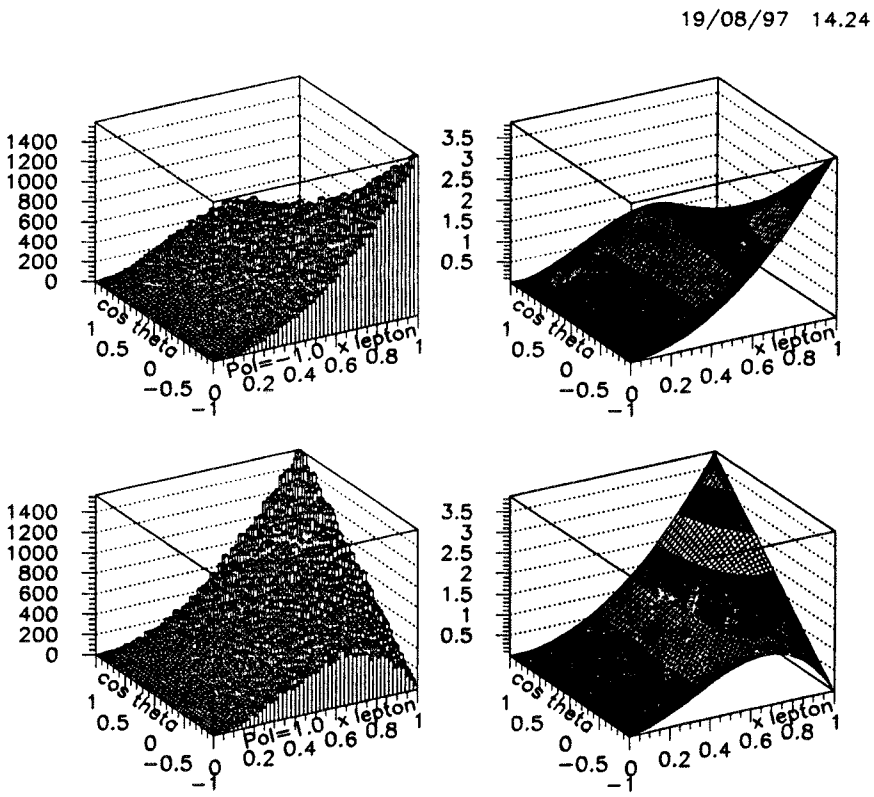
$$\alpha = \frac{t_{circ}}{\gamma t_{life}} = \frac{2\pi m_\mu}{0.3 B c t_{life}}$$

$$f(t) = Ae^{-Bt}(C\cos(D + Et) + F)$$

$<E_{lab}>$ is the average electron energy in lab. E(t) is the total electron energy during turn t. Determine ω to get γ. γ information also present in α.

f(t) is the fitting function. MINUIT used to fit and extract information.

Electron energy and angle distributions in muon rest frame
Polarization = -1.0 and 1.0

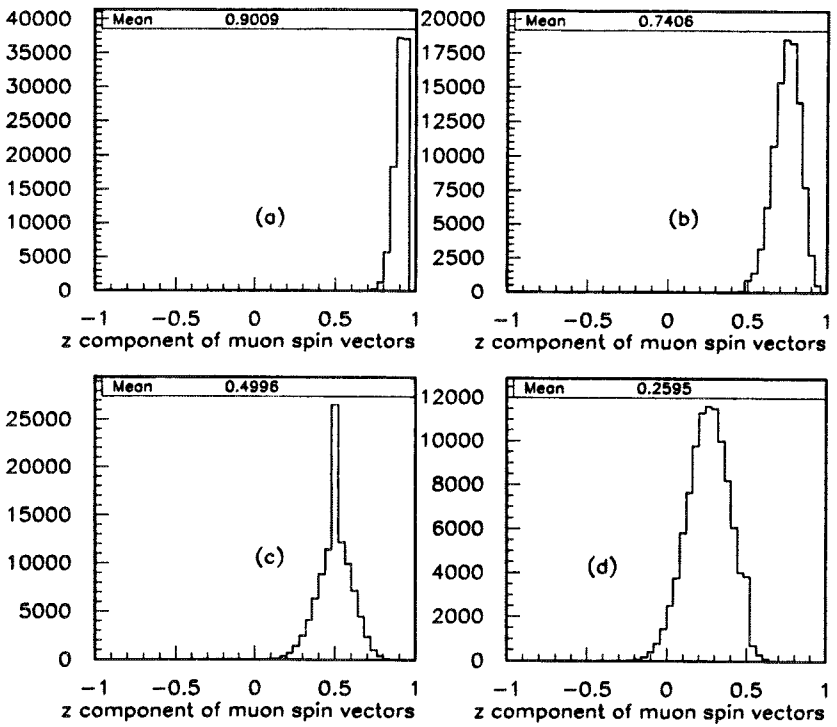


Variation in spin vectors

The electron energy sampled depends only on $\hat{P}$ which the average of the z component of the individual spin vectors. If all the muons had the same momentum, then the variation of the individual spin vectors is unimportant. Only the average matters. However, $\delta p/p$ is non-zero and the individual spins precess slightly differently turn to turn and a dilution in polarization results. We generate $\hat{P}$ as a binomial distribution about a given average.

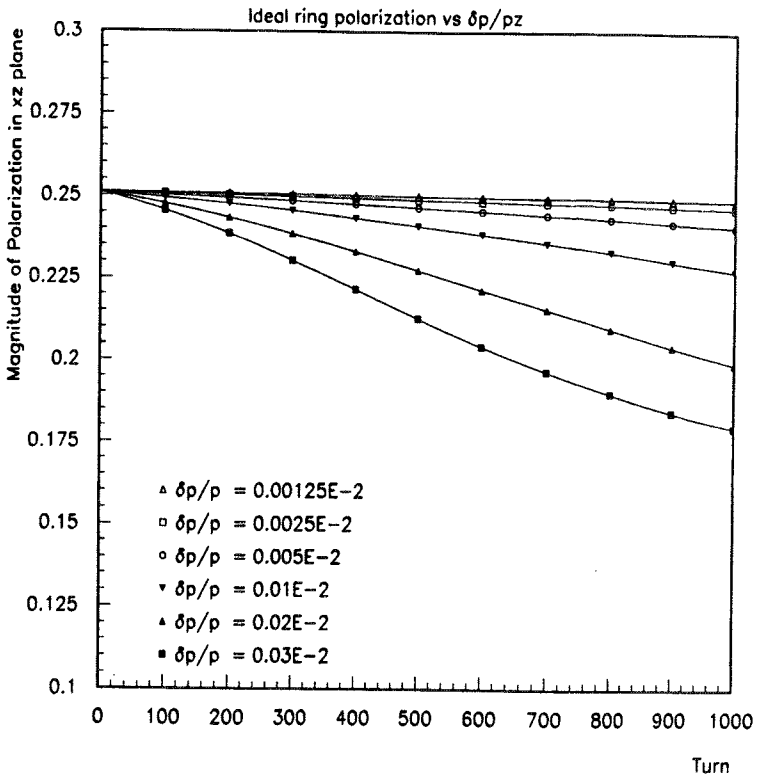
Muon Spin vector generation

05/09/97 10.28



Polarization vs turn for various δp/p

05/11/97 10.57



Idealized collider ring model

In order to simulate the decays, we assume an idealized planar collider ring made up of 4.0 Tesla average bending field. This results in the following parameters.

Muon Energy	= 50 GeV
Lorentz factor γ	= 473.22
Spin precession per turn	= 3.4667 radians
Magnetic field	= 4 Tesla
Ring Radius	= 41.667 meters
Circulation time	= 0.873E-6 sec
Dilated muon life time	= 0.104E-2 sec
Turn by turn decay constant α	= 0.8399E-3

Generation of decays

We generate an ensemble of 100K muons with appropriate spin and momentum vectors, precess them and decay them for 1000 turns. The measurement errors are added later as appropriate.

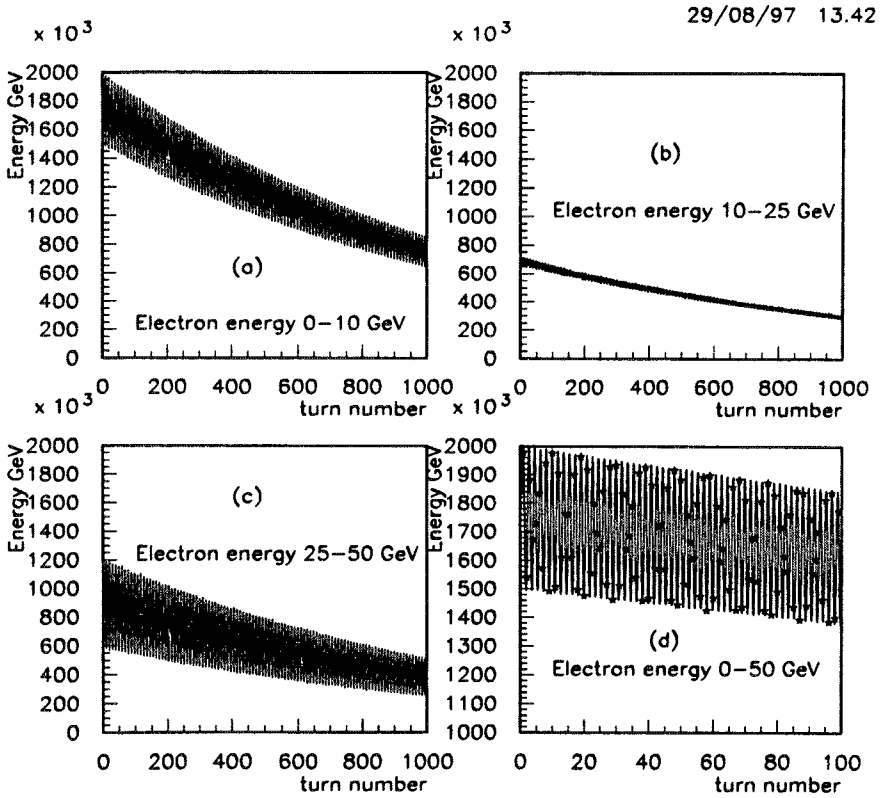
The 100K ensemble of muons represent the beam and are re-used every turn, after precessing. Each individual muon is precessed by the appropriate amount determined by its individual γ. After each turn, the number of muons is reduced by the amount expected by exponential decay. No fluctuations in this are made at this point.

We will generate muons with $\delta p/p$=0.03E-2 for most of the study and then will explore the dependence of the results on $\delta p/p$.

We will explore the effect of measurement errors due to sampling fluctuations in the number of electrons.

We will explore the accuracy obtainable in $\delta\gamma/\gamma$ from measuring α, the turn by turn decay constant.

Electron lab energy spectrum Pol=1.0, 100K decays



Explanation of previous plot

The variation of the total lab electron energy seen in a calorimeter will depend on the electron energy cut made. Figure (d) has no electron energy cut. For 100 turns, we compare the predictions of the theory with the generated events. Excellent agreement. The amplitude of the oscillations depend on the polarization as well as the average value of cos θ sampled. A cut on lab electron energy imposes a selection on cos θ. Electron energy 10-25GeV for 50 GeV muons samples cos θ =0, i .e. 90 degrees in muon rest frame.

Measurement errors

We need an EM calorimeter that measures total energy deposited per bunch from turn to turn. In addition, it would also be useful to have the number of particles going into the calorimeter. This can be done by having a scintillating fiber front end to the calorimeter that measures mips. This can lead to two sets of measurements. Total Electron energy and average electron energy.

We would also like to make cuts on the momenta of elctrons being summed over. This can be done by a spectrometer in front of the calorimeter. With such a device,

we can show that...

Measurement errors

For total energy E, N electrons and average individual electron energy <e>,

for a calorimeter with Constant Sampling and Noise terms (C,S,η)

the fractional resolution in E is given by

$$\frac{\sigma_E^2}{<E>^2} \approx \frac{1}{N}\left(1+\frac{\sigma_e^2}{<e>^2}\right)+C^2+\frac{S^2}{N<e>}+\frac{\eta^2}{N^2<e>^2}$$

For 50 GeV muons, <e>=34.05 GeV,

σ_e =6.046 GeV. For calorimeter,

S=0.15GeV $^{1/2}$ and η may be neglected for large N. If C=0, then

Measurement errors

$$\frac{\sigma_E^2}{< E >^2} \approx \frac{1}{N}(1 + 0.03153 + 0.000661)$$

Neglecting sampling term,

$$PERR^2 \equiv \frac{\sigma_E^2}{< E >^2} \approx \frac{1.03153}{N}$$

PERR=0.5E-2, 1.0E-2, 2.0E-2, 3.0E-2

imply, N=41261, 10315, 2579 and 1146 electrons sampled with e>25 GeV.

For a beam intensity of 10^{12} muons,

there are 3.2E6 decays per meter.

Constant term has to be of order 0.32E-2 for100,000 electrons sampled.

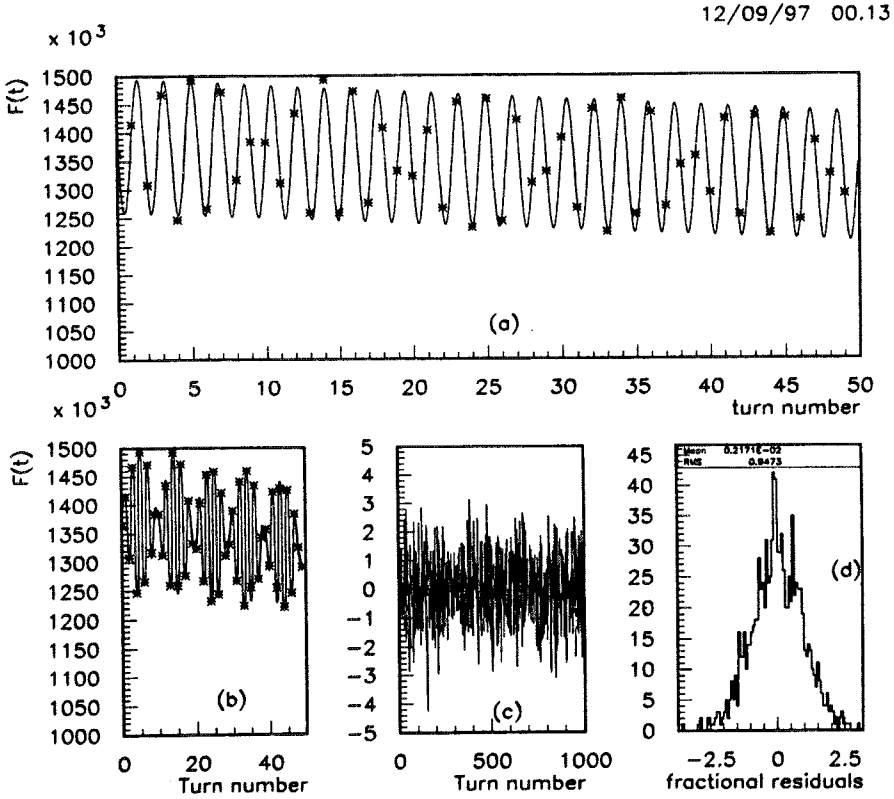
Measurement errors, using average energy

If the number of electrons as well as their total energy is measured, then one can use the average energy. Average energy has lower percentage error, since the error due to the fluctuations in N are removed.

$$\frac{\sigma_{Eav}^2}{< Eav >^2} \approx \frac{1}{< N >}\left(\frac{\sigma_e^2}{< e >^2}\right)... \approx \frac{0.03153}{N}$$

The other advantage of using average energy is that one does not have to model the intensity decay function.

Fit to 50 GeV μ⁻, P=0.26 δp/p=0.03E-2



δγ/γ vs measurement error and Polarization δp/p=0.03E-2

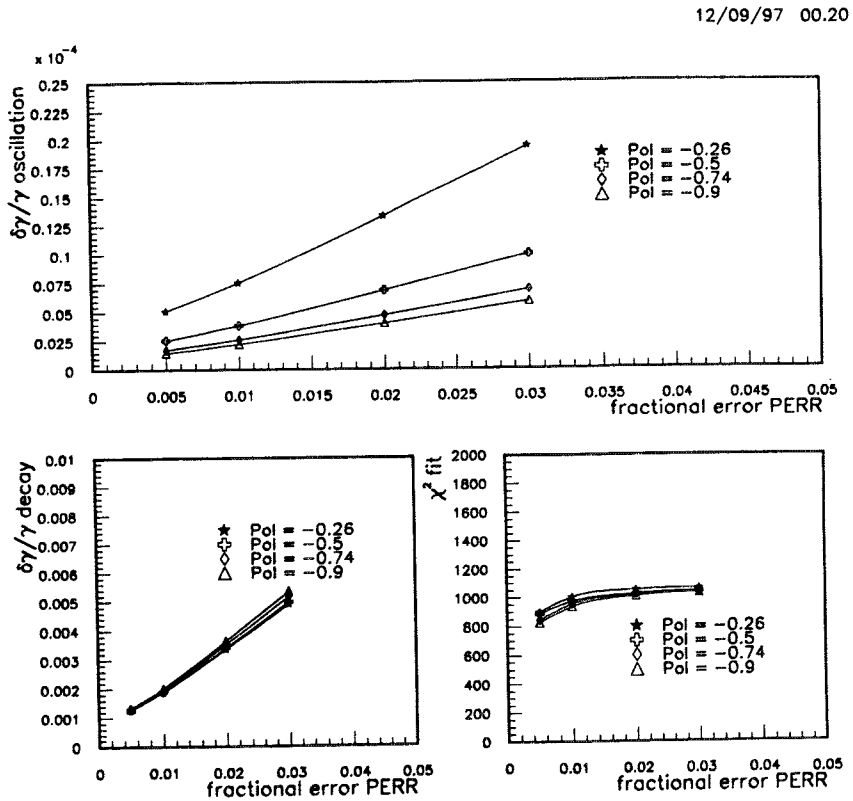
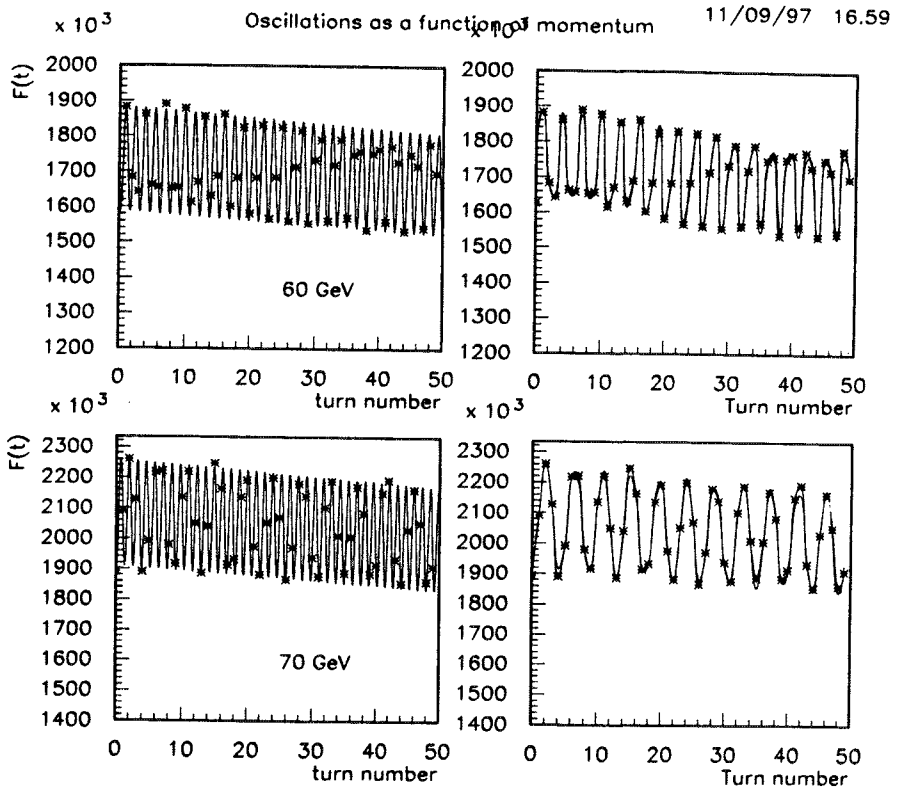


Table of fit parameters

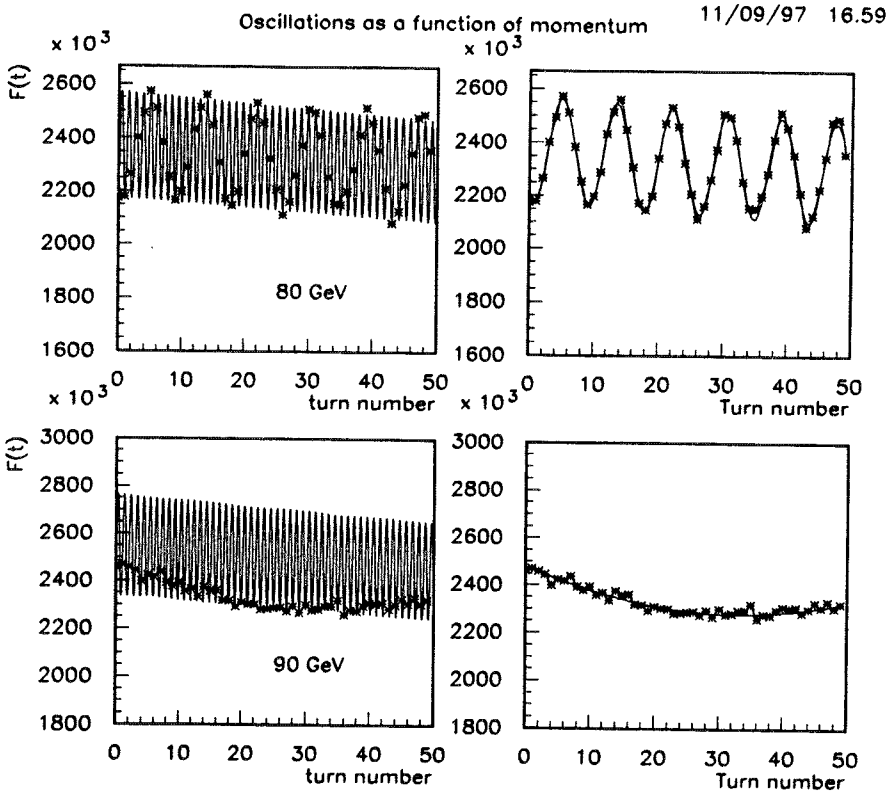
$\hat{P}$	PERR	Number of electrons sampled	$\delta\gamma/\gamma$ *oscillations*	$\delta\gamma/\gamma$ *decay*	χ^2 for NDF=1000
-0.90	0.50E-02	41261	0.14568E-05	0.13227E-02	824.
-0.90	0.10E-01	10315	0.22147E-05	0.20124E-02	936.
-0.90	0.20E-01	2579	0.39999E-05	0.36398E-02	1009.
-0.90	0.30E-01	1146	0.58659E-05	0.53457E-02	1030.
-0.74	0.50E-02	41261	0.17418E-05	0.13019E-02	843.
-0.74	0.10E-01	10315	0.26183E-05	0.19591E-02	954.
-0.74	0.20E-01	2579	0.46981E-05	0.35229E-02	1021.
-0.74	0.30E-01	1146	0.68765E-05	0.51672E-02	1039.
-0.50	0.50E-02	41261	0.25903E-05	0.12813E-02	888.
-0.50	0.10E-01	10315	0.38407E-05	0.19029E-02	973.
-0.50	0.20E-01	2579	0.68338E-05	0.33972E-02	1026.
-0.50	0.30E-01	1146	0.99744E-05	0.49749E-02	1041.
-0.26	0.50E-02	41261	0.51242E-05	0.12688E-02	898.
-0.26	0.10E-01	10315	0.75317E-05	0.18791E-02	1004.
-0.26	0.20E-01	2579	0.13324E-04	0.33447E-02	1053.
-0.26	0.30E-01	1146	0.19380E-04	0.48950E-02	1061.

TABLE I. Results of fits for $\delta\gamma/\gamma$ as a function of polarization $\hat{P}$ and noise PERR. Also shown is the χ^2 of the fit for 1000 turns.

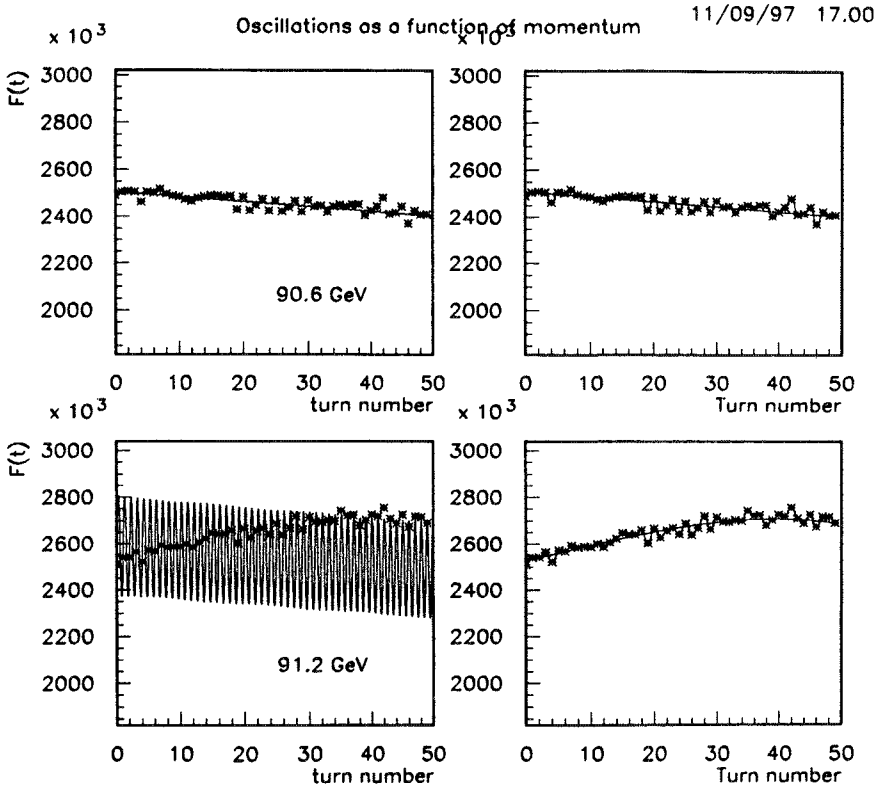
Fits for 60Gev/c and 70 Gev/c muon momenta



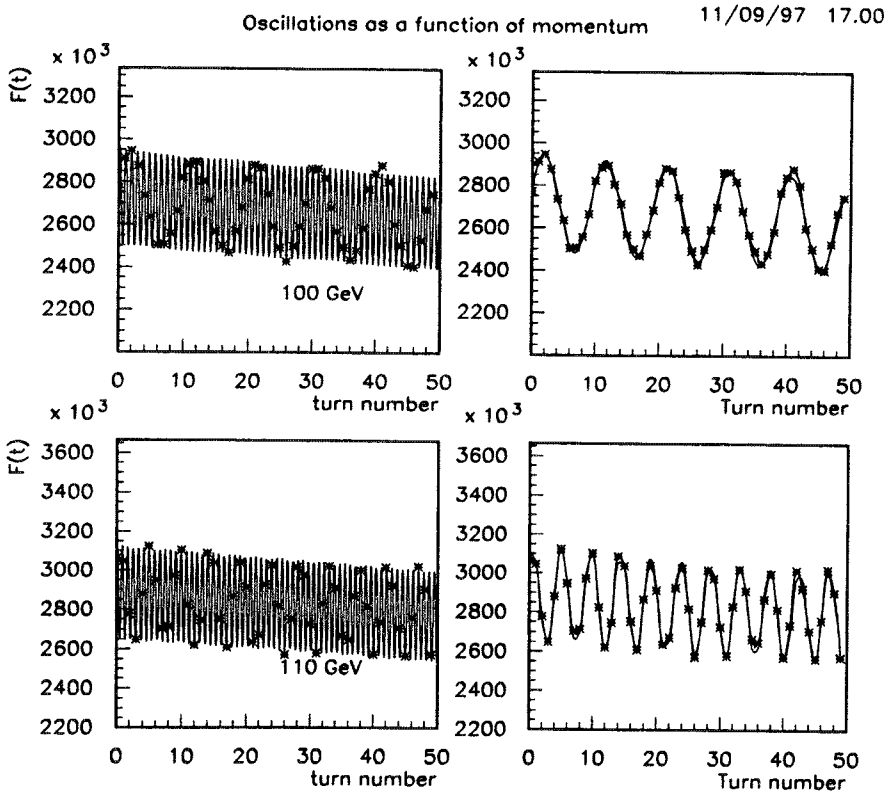
Fits for 80 GeV/c and 90 GeV/c muon momenta



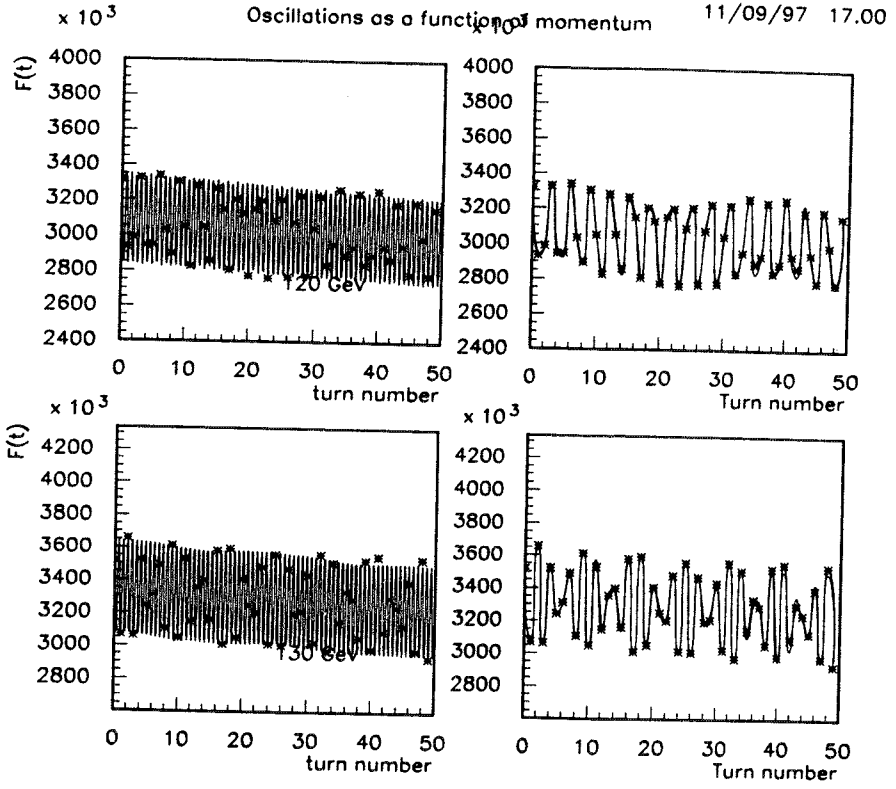
Fits for 90.622 GeV/c and 91.2 GeV/c muon momenta



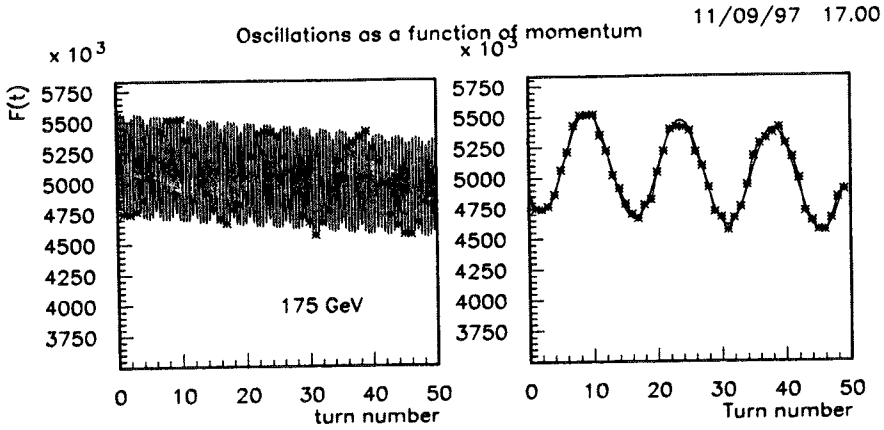
Fits for 100 GeV/c and 110 GeV/c muon momenta



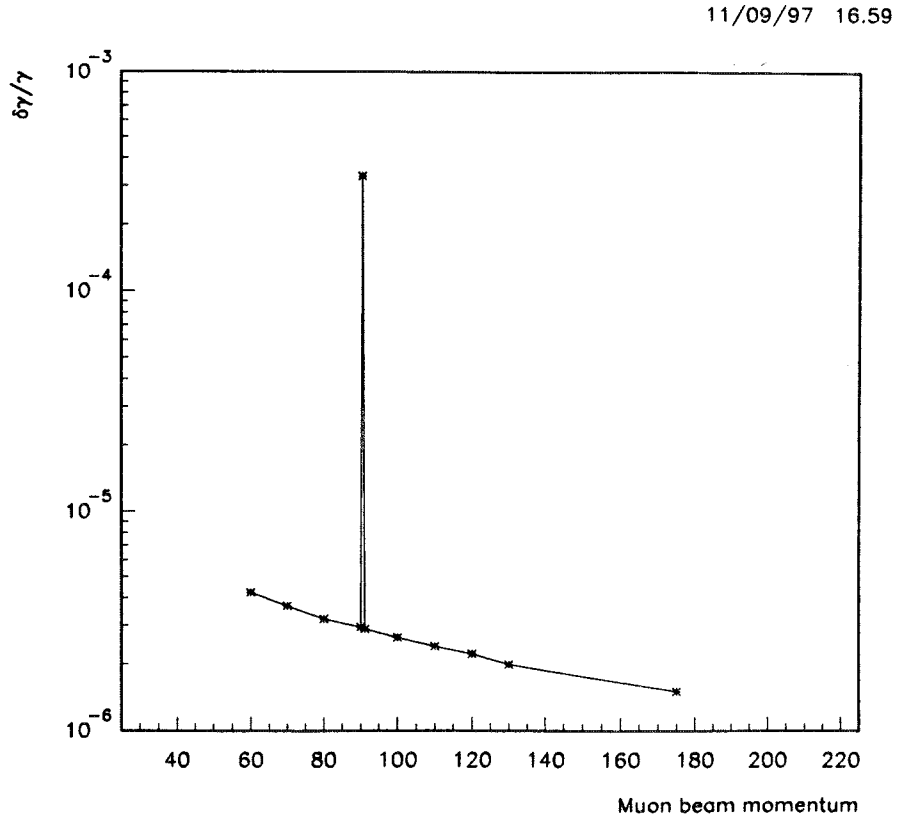
Fits for 120 GeV/c and 130 GeV/c muon momenta



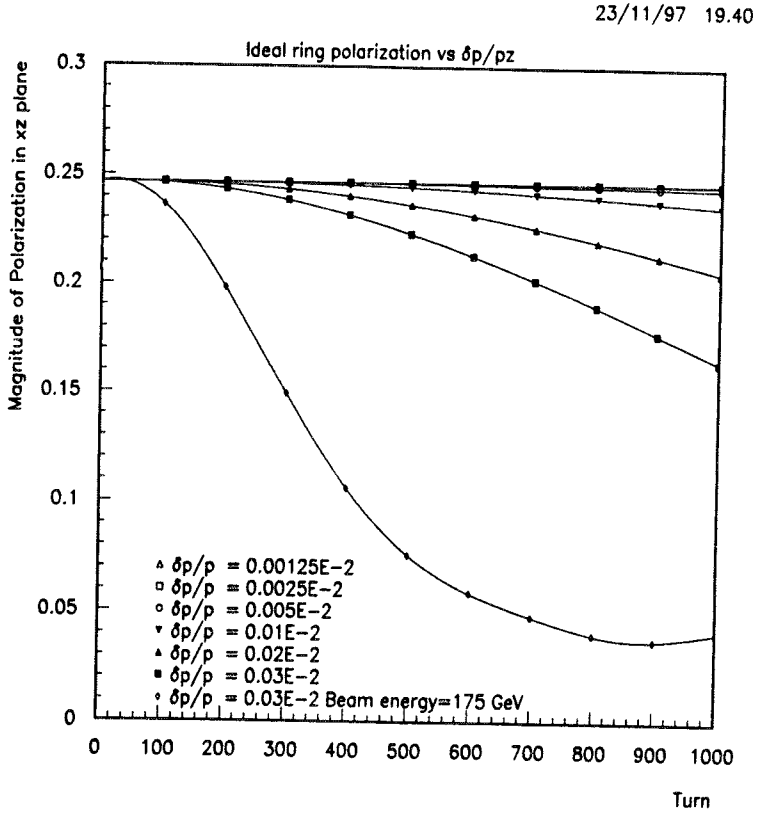
Fit for 175 GeV/c muon momenta



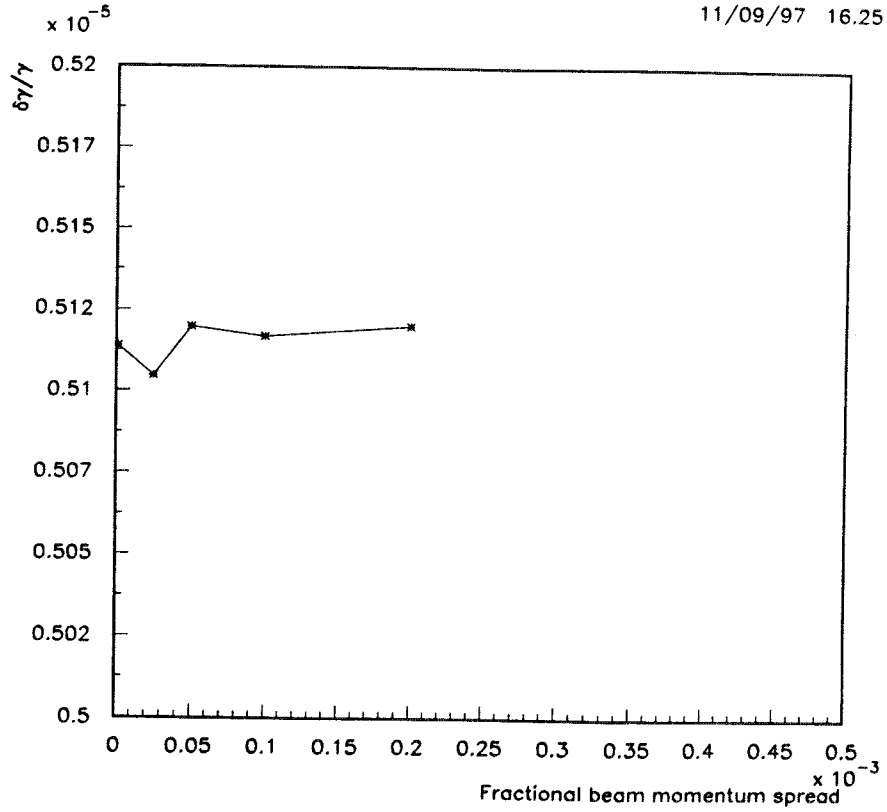
δγ/γ vs muon beam momentum



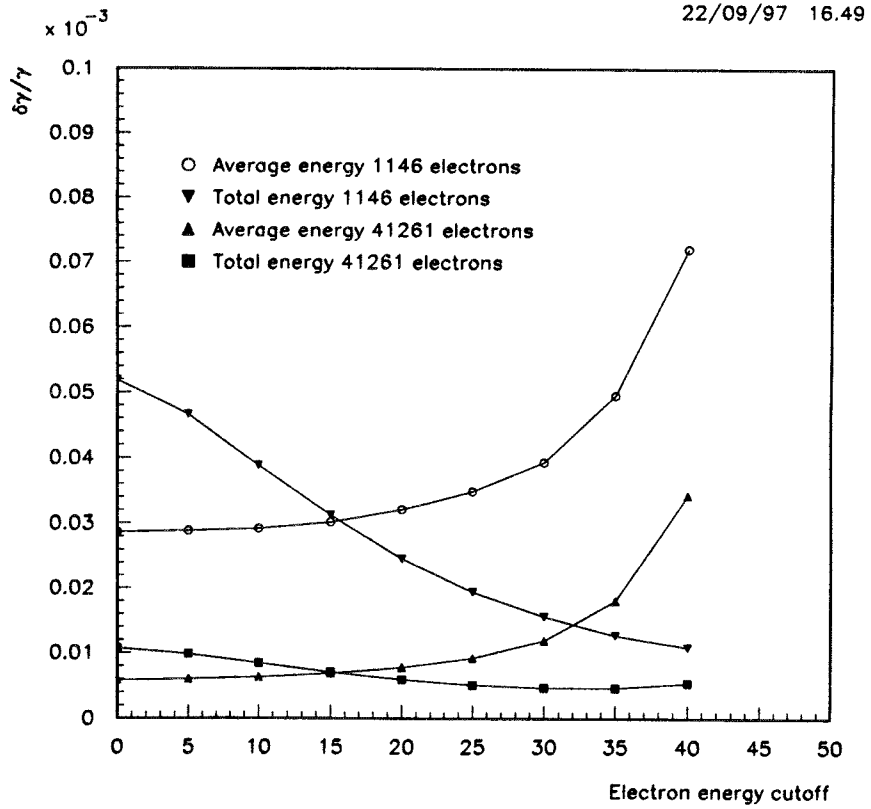
Polarization vs turn for various δp/p



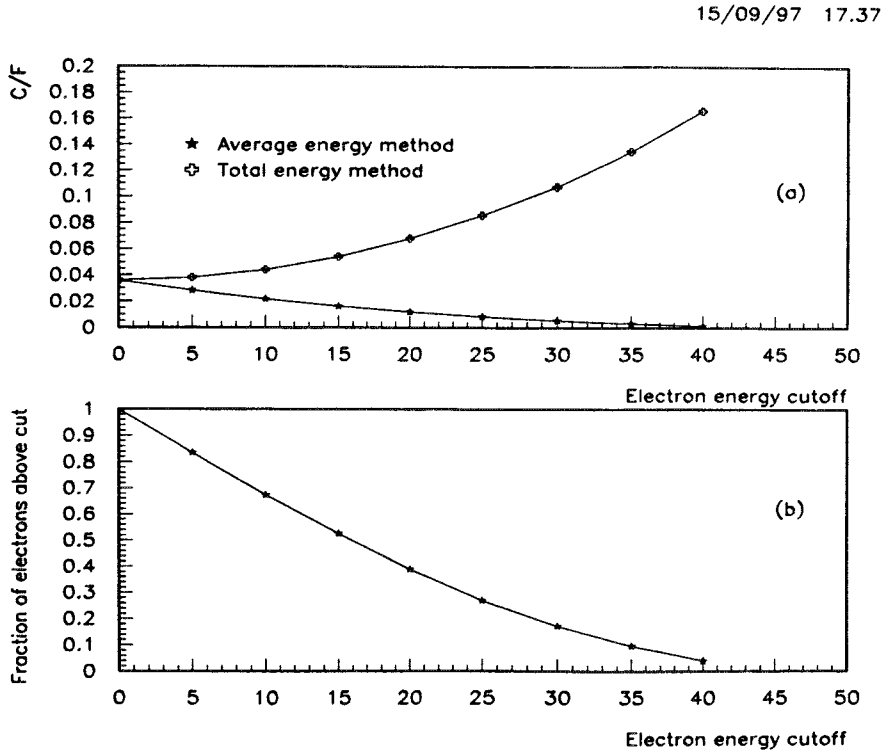
δγ/γ vs δp/p for 50 GeV/c μ⁻. Perr=.5e-2 P=.26



$\delta\gamma/\gamma$ vs electron energy cut for a sample of 40K and 1.1K electrons



a) Variation of C/F vs electron energy cut
b) fraction of electrons that survive cut



Departures from ideal case

- Electric fields. Collider ring will have RF but electrostatic separators are not envisaged at present. BMT equation tells that that longitudinal electric fields have no spin precession effect since $\vec{\beta}\times\vec{E}=0$
- Effects of radial magnetic fields
  - » Quadrupole misalignments. FODO
  - » Quad radial magnetic field followed by Horizontal dipole bend followed by reverse quad radial field has a net effect. (Assmann and Koutchouk LEP)

$$\nu_0 = \gamma(g-2)/2$$

$$<\partial\nu> = \frac{\cot \pi\nu}{8\pi}\nu_0^2\left(n_Q (Kl_Q)^2 \sigma_y^2 + n_{cv}\sigma_{\theta cv}^2\right)$$

$$\sigma_{\partial\nu} = \frac{<\delta\nu>}{\cos \pi\nu_0}$$

Departures from ideal case

- Correction elements may be neglected. These effects are less for the muon collider than for LEP because a)LEP has more quadrupoles b)Muon is 200 times heavier than electron.

Machine	Spin tune ν_0	Quadrupoles	RMS Kl_Q meters^{-1}	σ_y meters	$\delta\nu$	$\sigma_{\delta\nu}$
46 GeV LEP	100.47	≈ 600	0.032	0.5E-3	5.7E-6 ≡ 3KeV	6.1E-5 ≡ 30KeV
50 GeV Muon Collider	0.5517	70	0.274	0.5E-3	-0.26E-8 ≡ -0.24KeV	1.66E-8 ≡ 1.46KeV

TABLE I. Predictions for spin tune shift $\delta\nu$ and spread in spin tune shift $\sigma_{\delta\nu}$ caused by quadrupoles for LEP compared to the 50 GeV muon collider ring

Effects due to Experimental area solenoid

- Consider a solenoid 1.5 Tesla - 6 meters long = 9Tesla -meters.

$$\theta_s = -\frac{e}{\gamma m_\mu}(1+a)B_s = -(1+a)\frac{B_s l}{B\rho}$$

$$\nu + \delta\nu = \frac{1}{\pi}\arccos(\cos(\pi\nu)\cos(\frac{\theta}{2}))$$

θ is the angle of rotation due to solenoid. For 9 Tesla-meters, this is 3.09 degrees per turn. This yields $\delta\nu/\nu$ =-1.72 MeV. LEP will have 200 times less effect, since the tune is 200 times larger. LEP corrects with vertical bumps and horizontal bends. 200 times harder to do for muons. Bucking solenoids optimal.

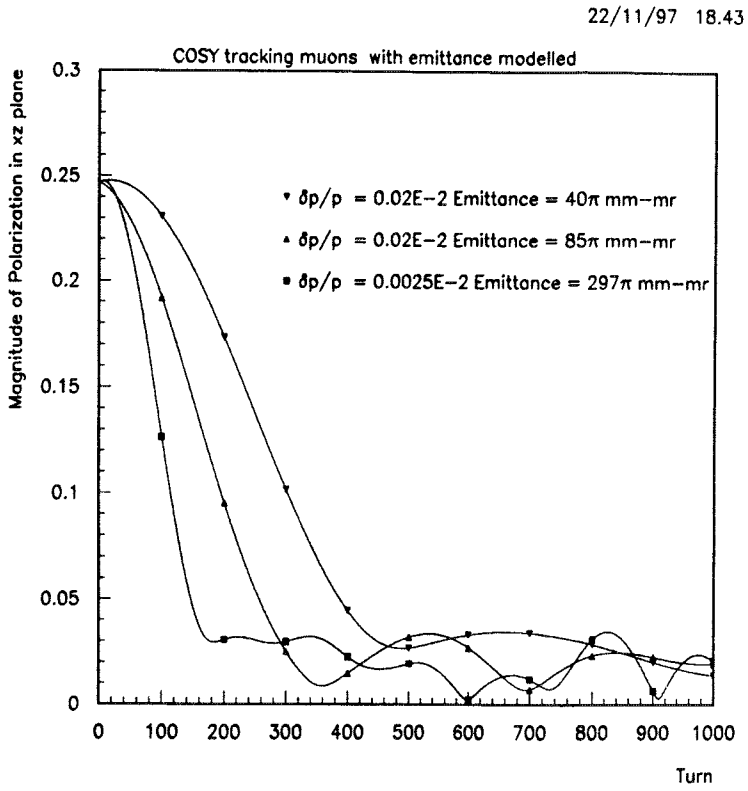
COSY studies

- COSY- Infinity has spin precession in it as well as higher order effects. Differential algebra techniques. Usin current 50 GeV design (C. Johnstone, W. Wan)
- 3 cases
  - » emittance = 297 π mm-mr, δp/p=0.0025E-2
  - » emittance=85 π mm-mr, δp/p = 0.02E-2
  - » emittance=40 π mm-mr, δp/p=0.02E-2
- Spin tune studied as a function of 5 variables
  - » x = x position ; x' = p_x/p
  - » y = vertical position; y' = p_y/p
  - » κ = δ kinetic energy/nominal kinetic energy
- Spin tune is then given by $\nu = 0.5517 + 0.5915\kappa - 64{,}61x^2 - 0.1017x'^2 - 69.81y^2 - 0.1088y'^2 - 8.341x\kappa - 0.3921\kappa^2$ to second order

Cosy Studies

- Track 1000 muons in COSY with
- polarization of 0.25 and emittance and δp/p modelled for the three cases.
- Conclude that the non-linear aperture causes polarization loss for large emittances rather tha momentum spread. Need to optimize design.

Polarization of 1000 muons vs turn number in COSY



Conclusions

- We have shown that IF
  - » it is possible to deliver polarized muons to the ring
  - » and that it is possible maintain the polarization for 1000 turns
- g-2 precession can be used to obtain precisions of the order of a few parts per million in the energy of the bunches.
- This is true for a range of $\delta p/p$that covers the two options considered here.
- Method can be used to scan a narrow Higgs, Measure the W mass etc...

Dec.11, 1997

M.Atac,FNAL/UCLA

TRACKING CONCEPTS OF HIGH LUMINOSITY MUON COLLIDERS

OUTLINE

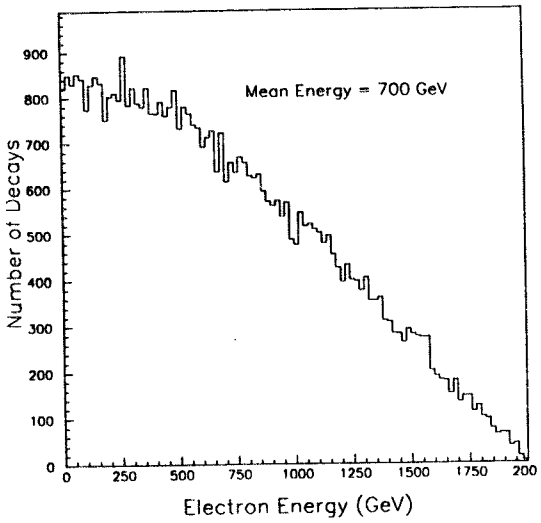
1. FINAL FOCUS DESIGN AND COMPUTED BACKGROUNDS
2. SHIELDING FOR NEUTRONS AND GAMMAS
3. GENERAL PURPOSE STRAWMAN DETECTOR CONCEPTS
   a. VERTEX TRACKING
   b. INNER TRACKING
   c. OUTER TRACKING
   d. EM AND HADRON CALORIMETERS
   e. MUON CHAMBERS
4. CONCLUSION

DETECTORS AND BACKGROUND

- Since muons decay, background levels at a muon collider are expected to be high.
- Understanding the backgrounds levels and how these backgrounds affect the performance of a strawman detector is a crucial part of assessing the feasibility of doing physics at a muon collider.
- Therefore, within the muon collider collaboration, there has been a significant effort devoted to:
  (i) Designing the final focus to minimize backgrounds in the detector.
  (ii) Understanding the remaining backgrounds in the detector, and identifying the critical background-related detector issues.
  (iii) Developing a feasible strawman detector and assessing its performance in the predicted backgrounds.

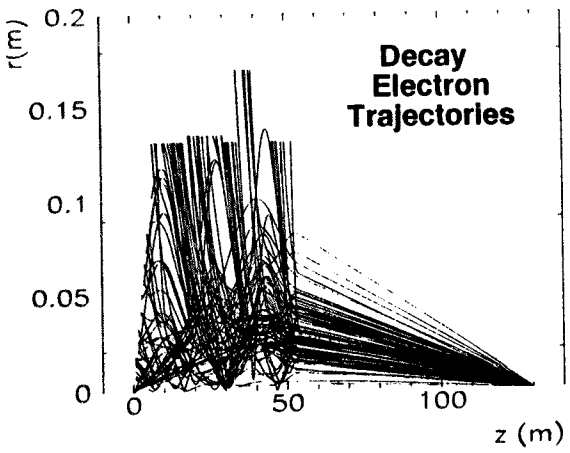
Fermilab people (M. Atac, A. Bross, T. Diehl, S. Geer, C. Johnstone, P.Lebrun, N. Mokhov, R. Rajendran, A. Tollestrup) in collaboration with BNL people (D. Benary, S. Kahn, D. Lissauer, M. Murtagh, F. Paige, V. Polychronakos, P. Rehak, I. Stumer, V. Tchernatine), and R. Roser (Univ. Illinois).

Muon Decay Backgrounds



2 x 2 TeV Muon Collider

- **2 x 10^{12} muons/bunch**
- **2 x 10^{5} decays / m**
- **Mean decay electron energy = 700 GeV**



Electron decay angles are O(10) microradians.

Therefore, in the final focus section, decay electrons tend to stay in the beampipe until they see the final focus Quad fields etc.

Background List

- **Decay Backgrounds:**

  Two detailed complementary calculations have been performed: GEANT calculation (I. Stumer, BNL), MARS calculation (N. Mokhov, FNAL). The assumed final focus system and shielding configurations assumed for the two calculations are similar in general, but the details are very different.

  Both the GEANT and MARS calculations track all particles through the final focus and 2 Tesla detector solenoidal fields and fully simulate:

  - **Electron showers**
  - **Synchrotron radiation**
  - **Photonuclear interactions**
  - **Bethe–Heitler muon pair production**

- **Beam Halo:**

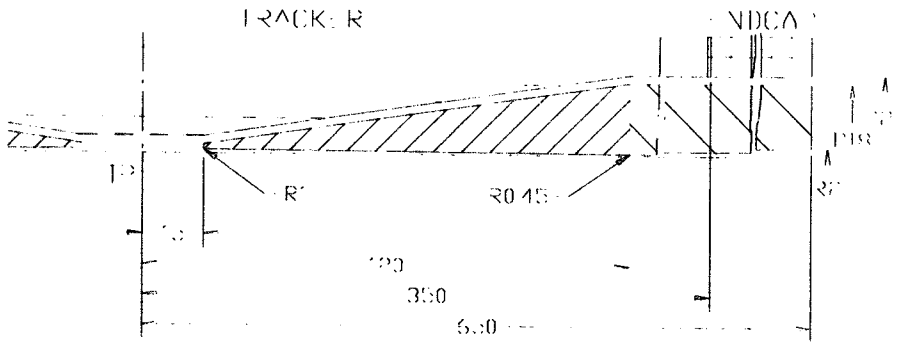
  Beam halo model and beam scraping design being developed, but no results yet.

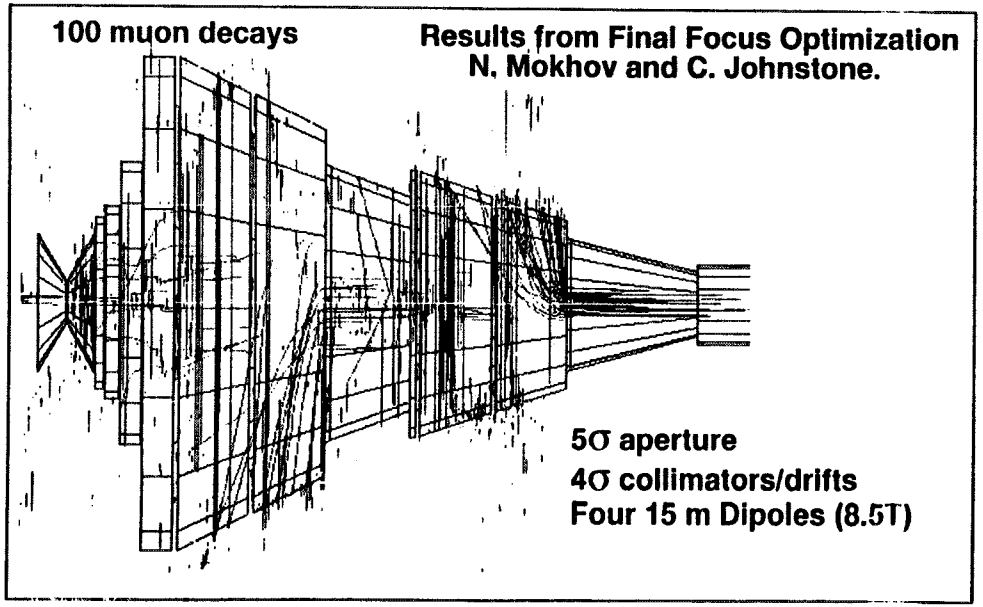
- **Beam–Beam Interactions:**

  Believed to be small compared with other backgrounds

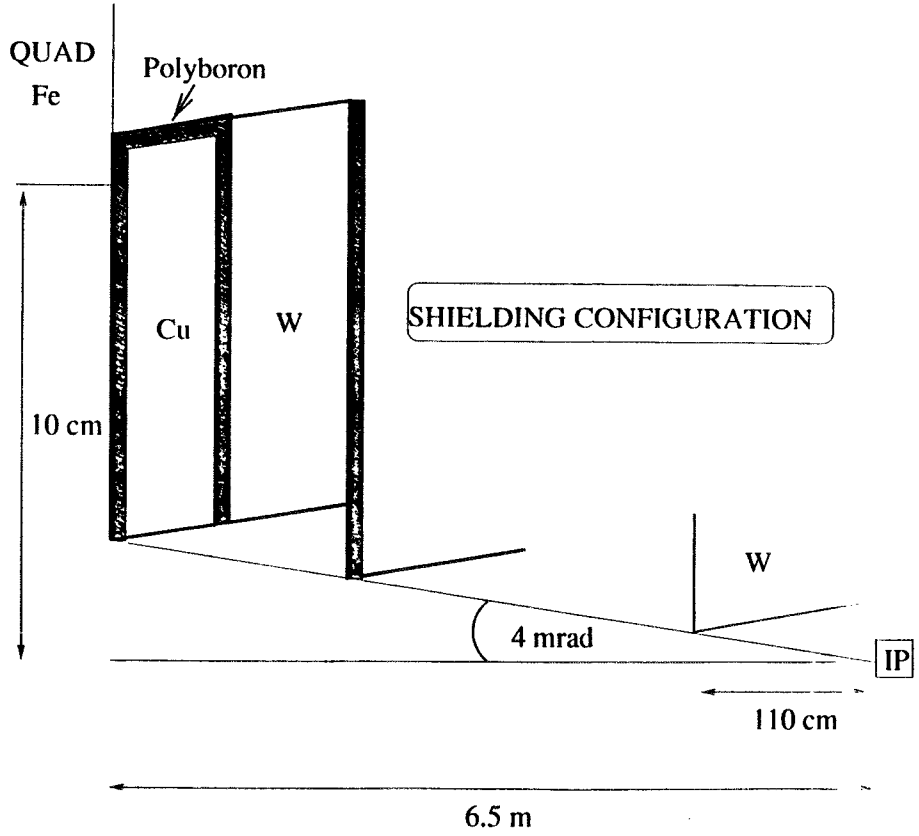
MARS Calculation

Uses a somewhat different shielding configuration than the GEANT calculation:





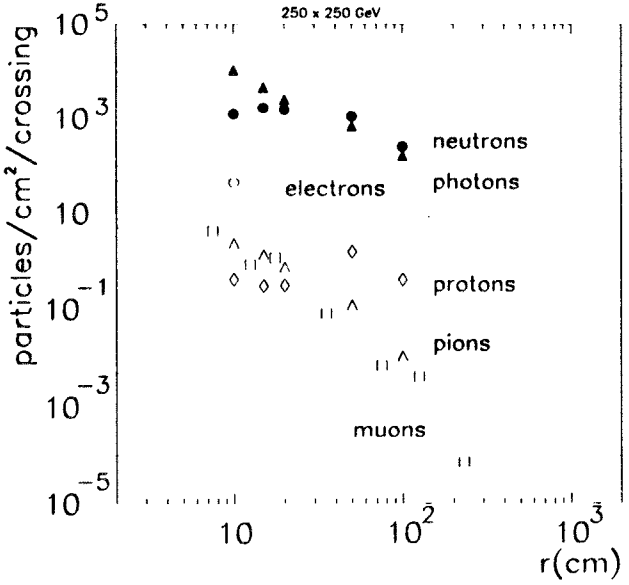
Shielding Configuration Implemented in GEANT Background Calculation



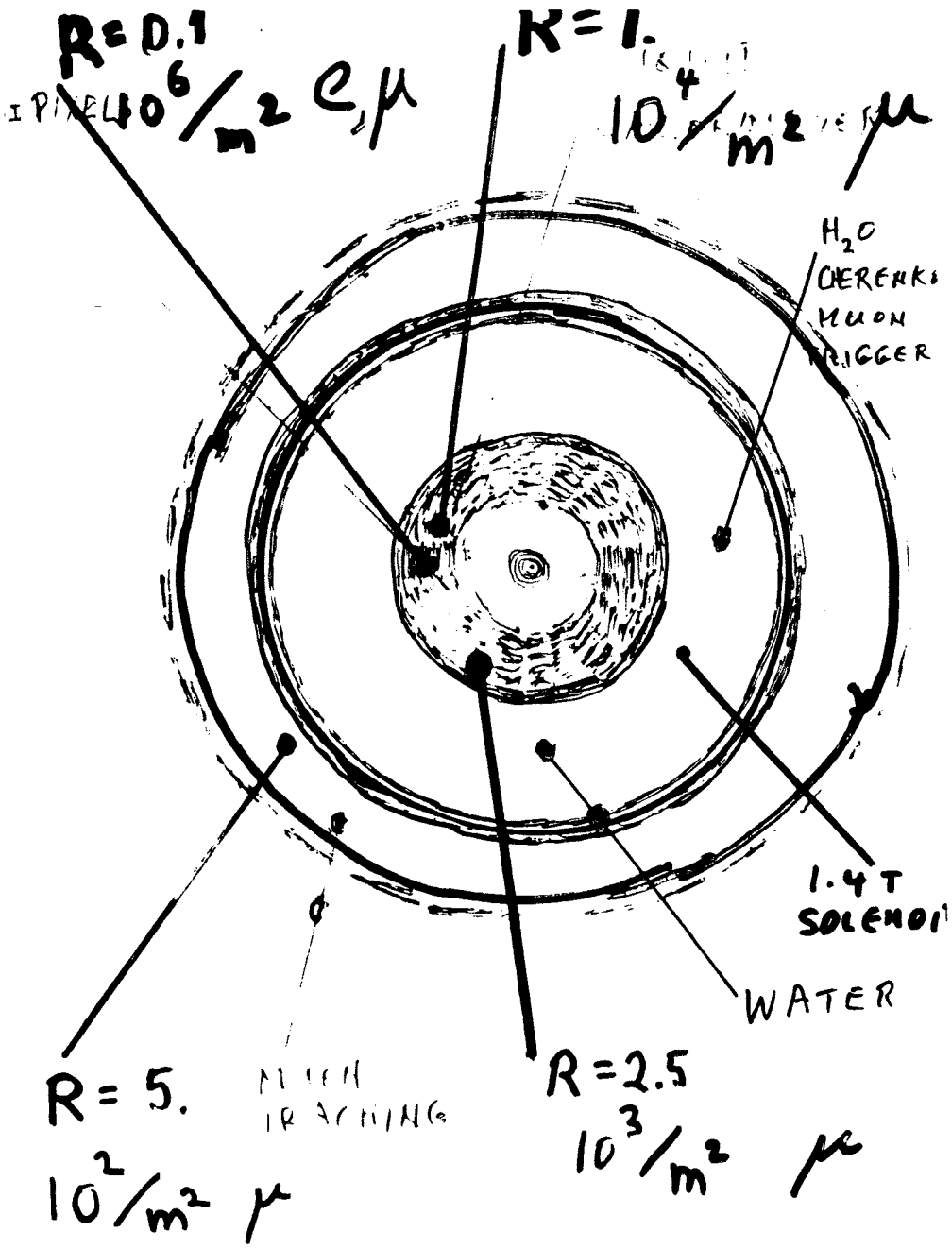
First Muon Collider

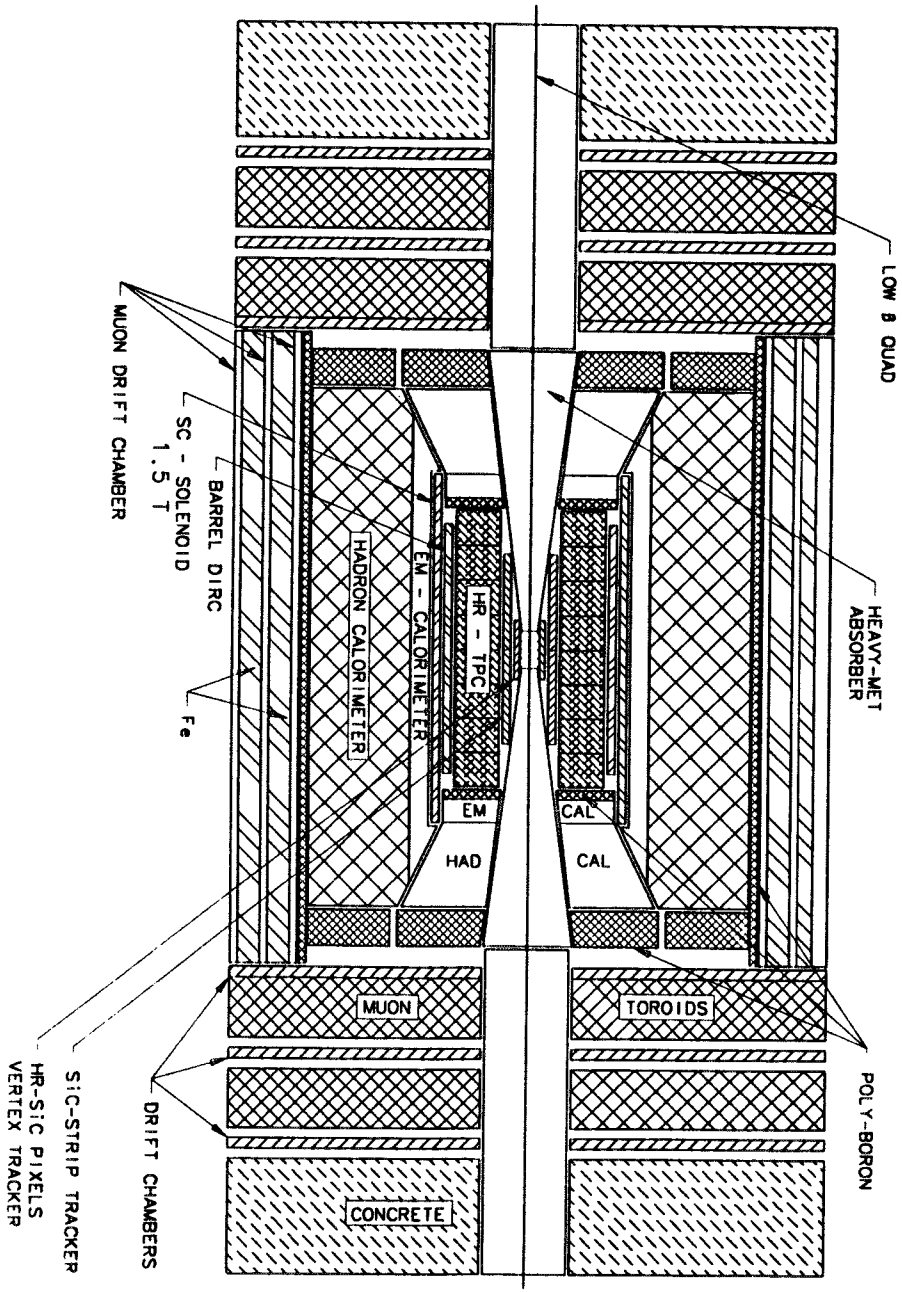
- **Some GEANT work has been done to calculate backgrounds at a lower enerhy muon collider –> 250 x 250 GeV. This was before the recent improvements to the final focus which led to an order of magnitude reduction in backgrounds:**

250 x 250 GeV –> 1.5 x 10^6 decays / m



- **These background fluxes are comparable to those computed for a 2 x 2 TeV collider .... so we anticipate that the backgrounds at a lower energy machine will be similar to those at the 2 x 2 TeV machine .... EXCEPT the Bethe–Heitler muon background which is much better. A more detailed calculation is being done at BNL.**





Hit Density in a Vertex Detector

- Consider a layer of Silicon at a radius of 10 cm. The GEANT results for the radial particle fluxes per crossing yield:

750 photons/cm^2	–>	2.3 Hits/cm^2
110 neutrons/cm^2	–>	0.1 Hits/cm^2
1.3 charged tracks/cm^2	–>	1.3 Hits/cm^2
TOTAL		3.7 Hits/cm^2

- –> 0.4% occupancy in 300 x 300 μm^2 pixels.
- **The corresponding numbers at 5cm radius are 13.2 Hits/cm^2 –> 1.3% occupancy.**
- **This doesnt sound too bad. For comparison, SLD has about 40 Hits/cm^2 on the inner layer of their CCD detector.**

PAVEL REHAK

Radiation Dose in Silicon Vertex Detector

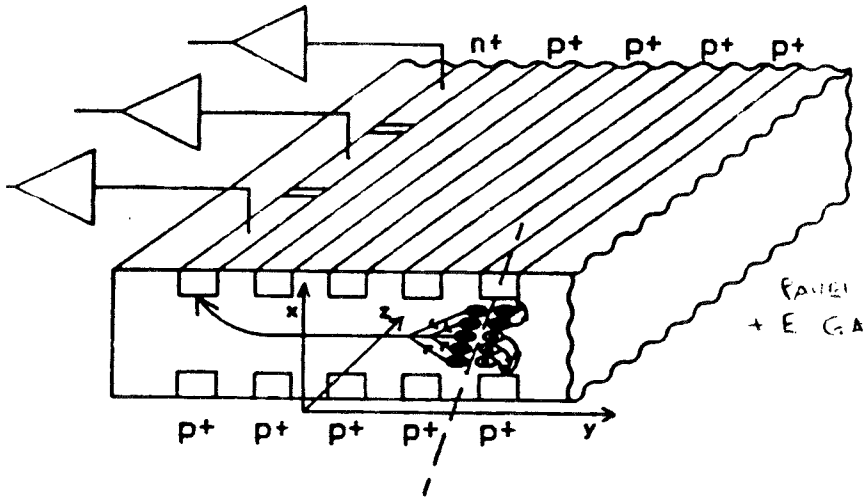
- **Consider a silicon layer at a radius of 10 cm. The dose due to non–ionizing energy loss can be calculated from the MARS or GEANT results (which give consistent results) taking into account particle type, energy spectra, and fluxes.**

$$\phi_{NIEL} = \phi_p + \phi_\pi + 0.5\phi_\mu + 0.1\phi_e + \phi_{n>0.1\,MeV} + 0.01\phi_\gamma$$

- **-> ϕ_{NIEL} = 240 per cm^2 per crossing.**

MARS predictions for 1 year (= 10^7 secs) of operation:	
2 x 2 TeV muon collider	7 x 10^{13} cm^{-2}
LHC at 10^{34} cm^{-2}s^{-1}(CMS)	8 x 10^{13} cm^{-2}

Silicon Drift Detector (SDD)



PAVEL REHAK + E. GATTI

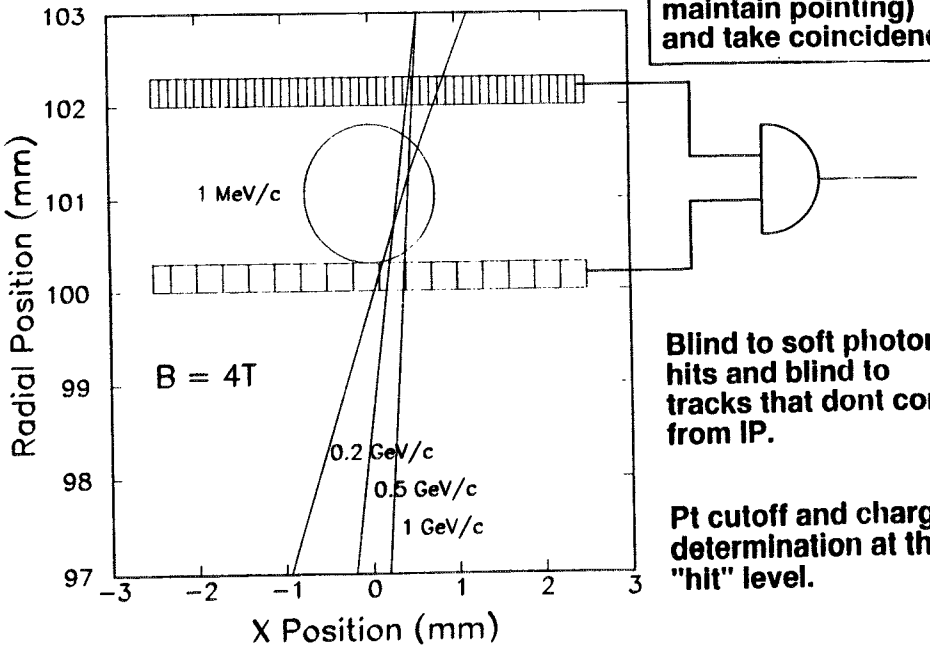
- EXPLOIT 10 μs BETWEEN BEAM CROSSINGS ⇒ FEW MICRON RESOLUTION IN DRIFT DIRECTION
- WITH 50 μm x 300 μm DETECTORS & 6 LAYERS ⇒ 2 x 10^9 CHANNELS
- EACH 10 μs CLEAR IF NO TRIGGER, ABORT BEAMS IF TRIGGER & TAKE 100 mS (?) TO READ OUT DEVICE.

Type inversion in Si-microstrip detectors occur around a fluence of 10^{13} /cm^2. To collect the charge we need to increase the bias voltage from 30 V to 200-300 V for a 300 micron thick detector. This would make the Si drift chamber unusable in high fluences.

Steve Geer
Jay Chapman

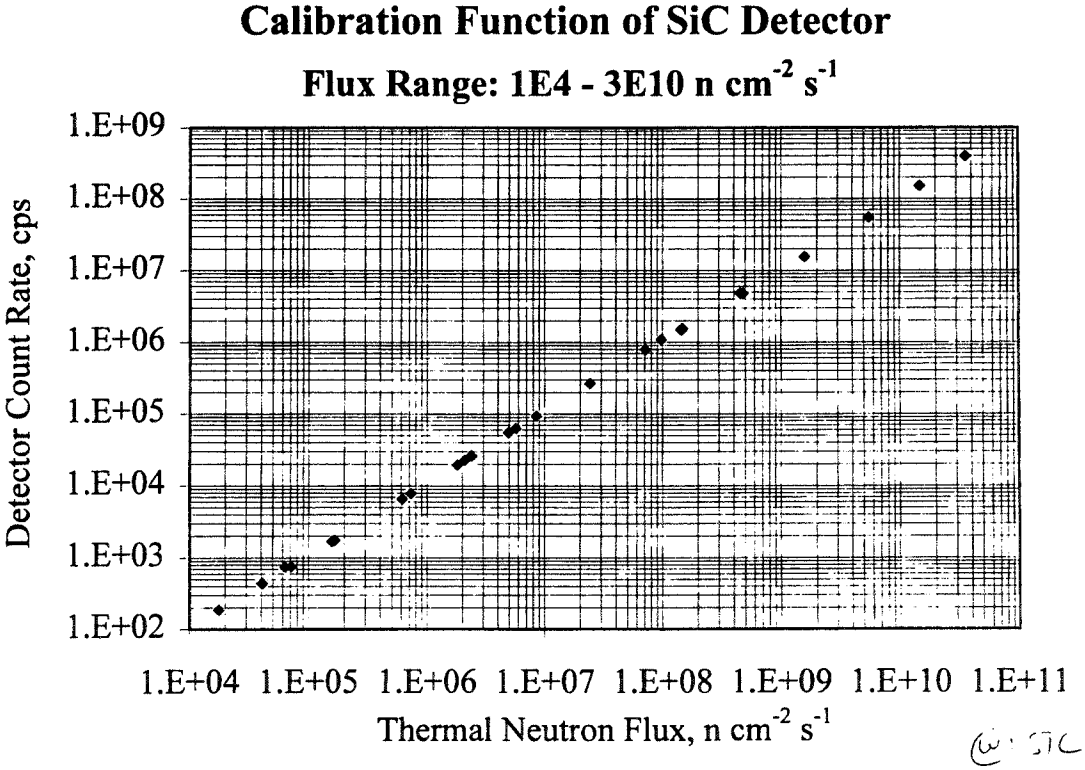
Pixel Microtelescope

- **Most of the background hits in a silicon vertex detector close to the muon collider IP arise from very low energy (~ 1 MeV) photon interactions.**
- **At Snowmass we thought of a possible way of screening out these background hits to facilitate:**
  - **Getting the first layer at the smallest viable radius**
  - **Developing a track trigger**

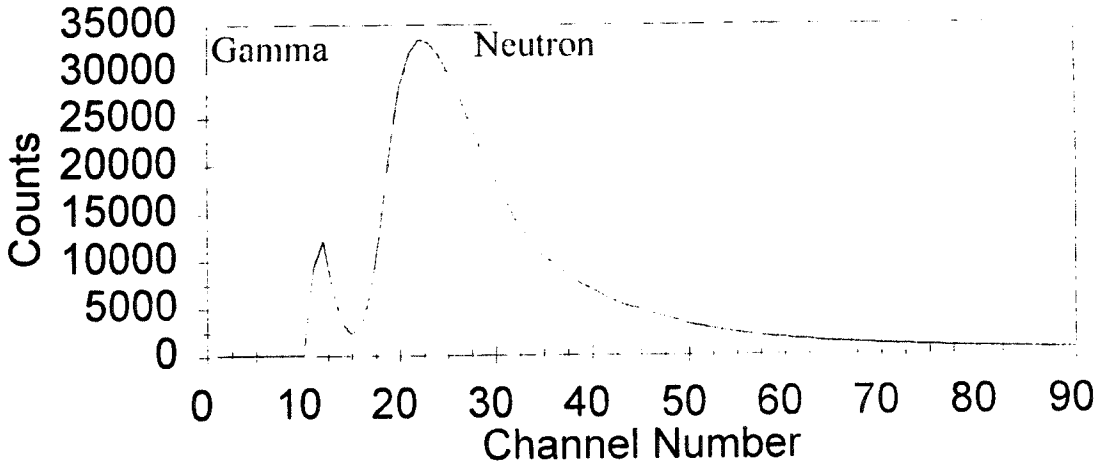


Material property	Silicon	GaAs	3C SiC	4H SiC	Diamond
Bandgap (eV)	1.1	1.43	2.3	3.2	5.5
Resistivity (Ω-cm)	$\sim 10^5$	$\sim 10^8$	-	$\sim 10^7$	$>10^{11}$
Breakdown field (V/cm)	$\sim 10^5$	$\sim 10^5$	1.5×10^6	3×10^6	10^7
Electron mobility (cm^2/V-s)	1350	6000	750	800	1800
Hole mobility (cm^2/V-s)	~480	~400	40	115	1200
Saturation drift velocity (cm/s)	10^7	10^7	2.5×10^7	2×10^7	2.2×10^7
Dielectric constant	11.9	13.1	-	-	5.7
Cohesive energy (eV/atom)	4.63	-	-	-	7.37
Energy to create e-h pair (eV)	3.6	4.2	8.3 (est'd.)	8.3 (est'd.)	13
Ave. Ionized signal/100 μm (# e^-)	9200	13000	6400 (est'd.)	6400 (est'd.)	3600

Table I. Comparison of potential particle detector material properties



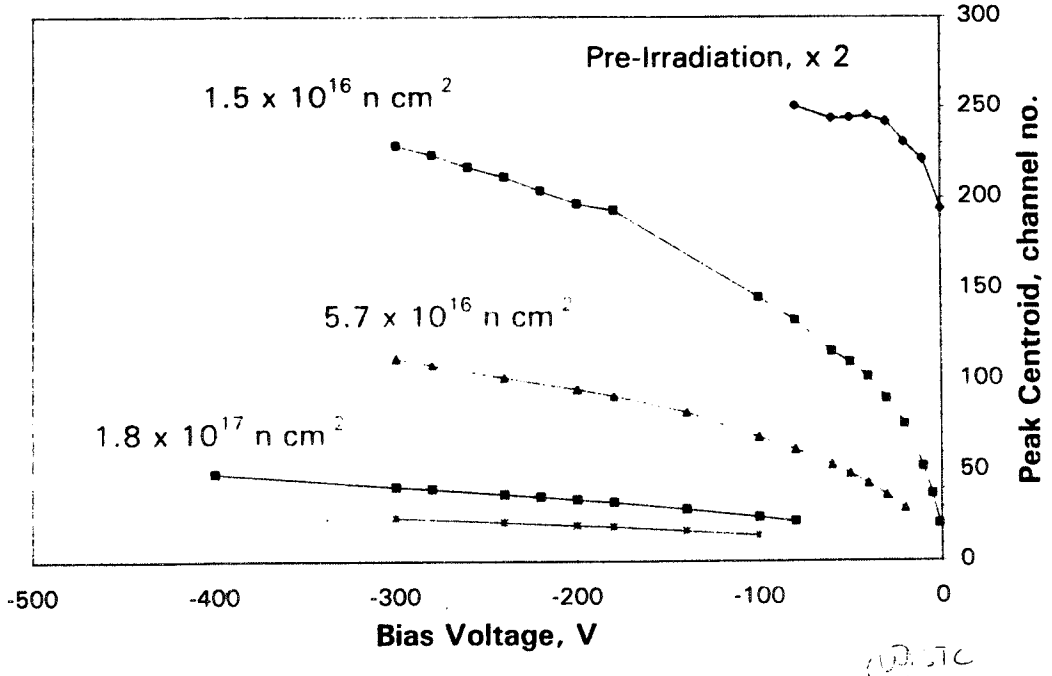
Separation of Neutron and Gamma Signals



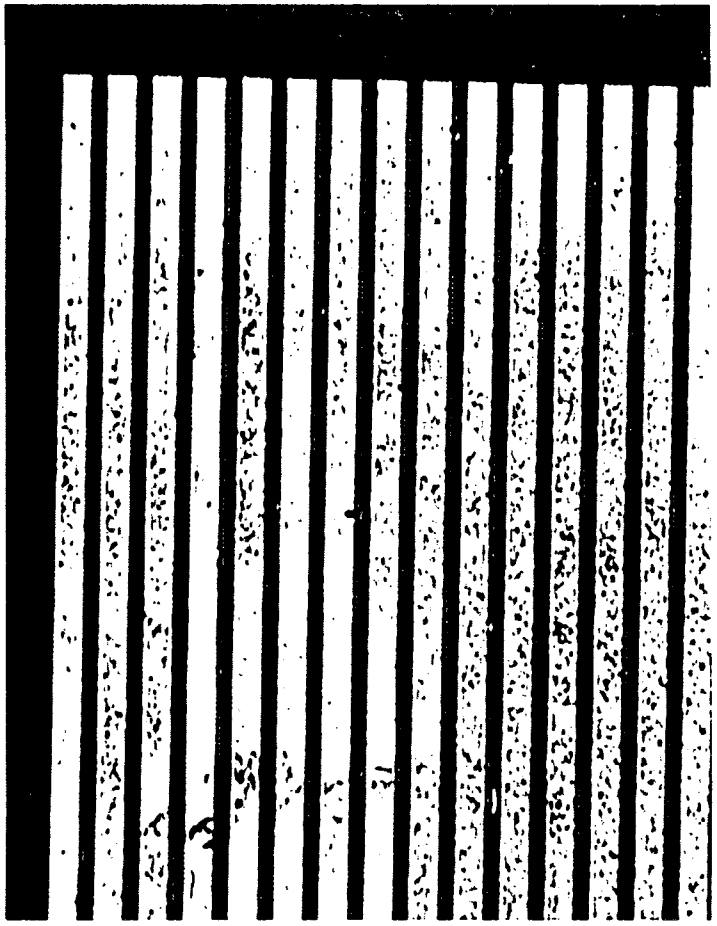
Thermal neutron flux = 3.2E 10 n/sq. cm/s
Gamma field = 50.000 R/h

520

Peak Centroid versus Applied Voltage for PN-Junction Diode L12-4



SiC

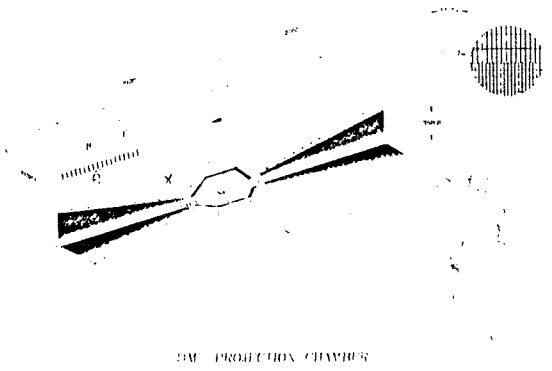


M.ATAC

Outer Tracker

Option 1: Silicon strips or large pixels

Option 2: TPC

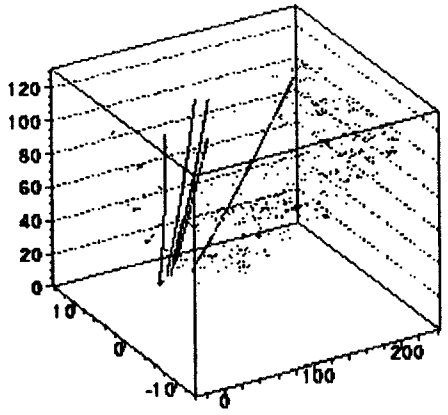


He + 10% CF_4

-> 6 cm/μs at E = 1500 V/cm

(Note: time between crossings = 10 ms)

Ion buildup -> $\Delta E/E = 0.7\%$



Y VS X VS Z

The background occupancy of O(1%) can be reduced by rejecting large pulse heights from photon and neutron induced recoils.

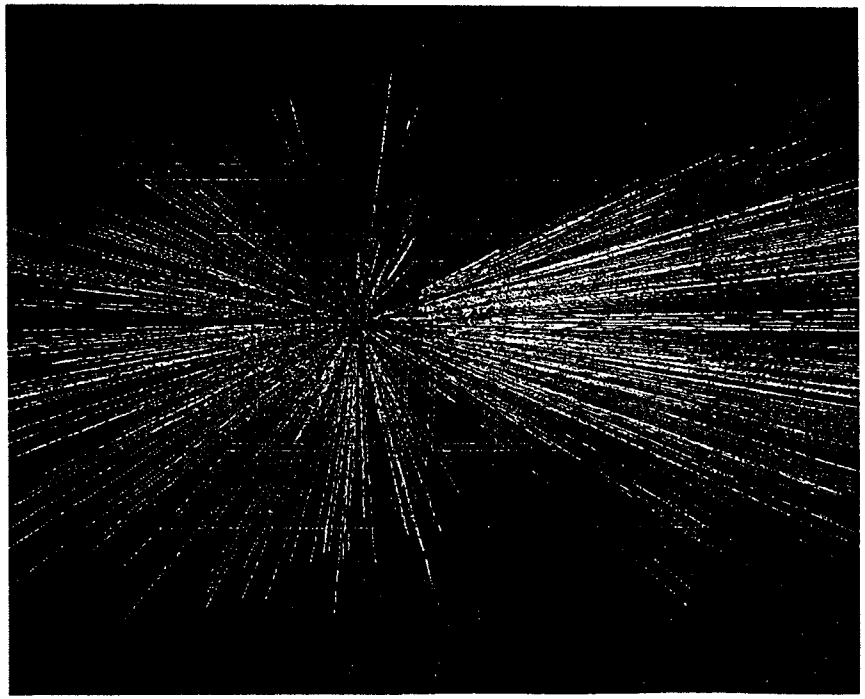
Performance of the Large Scale TPC System in the Heavy Ion Experiment NA49

S. Wenig

CERN

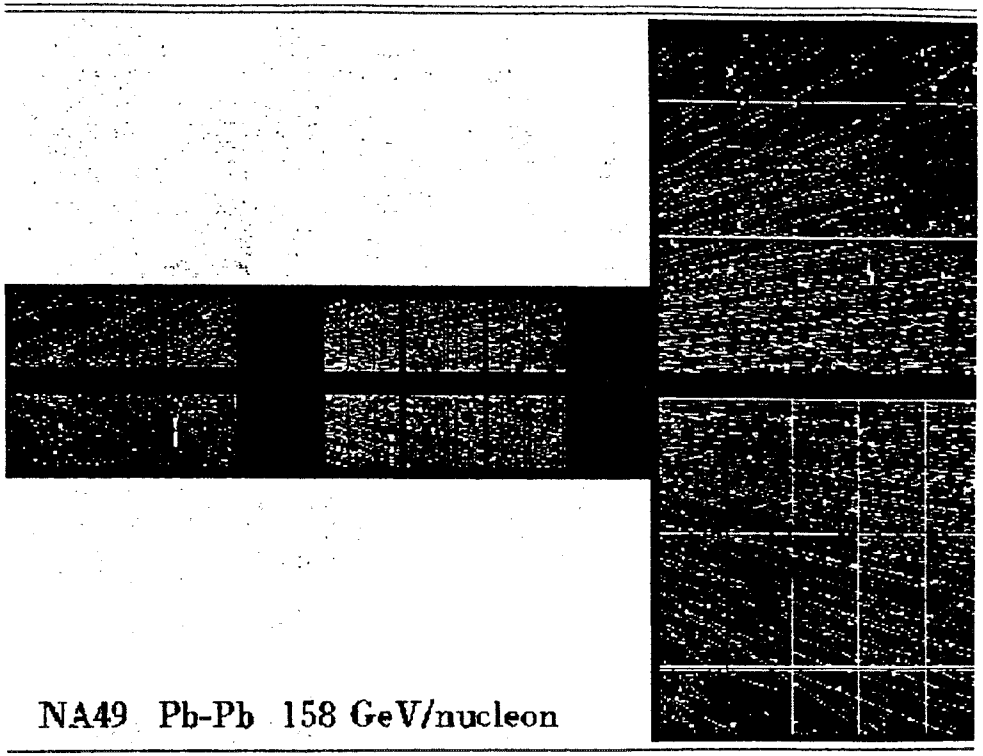
for the NA49 Collaboration

Athens - LBNL - Birmingham - Bratislava - Budapest - CERN - GSI - UCD - Dubna - IKF - Krakow - UCLA - Marburg - MPI - Yale - Seattle - Warsaw - Zagreb



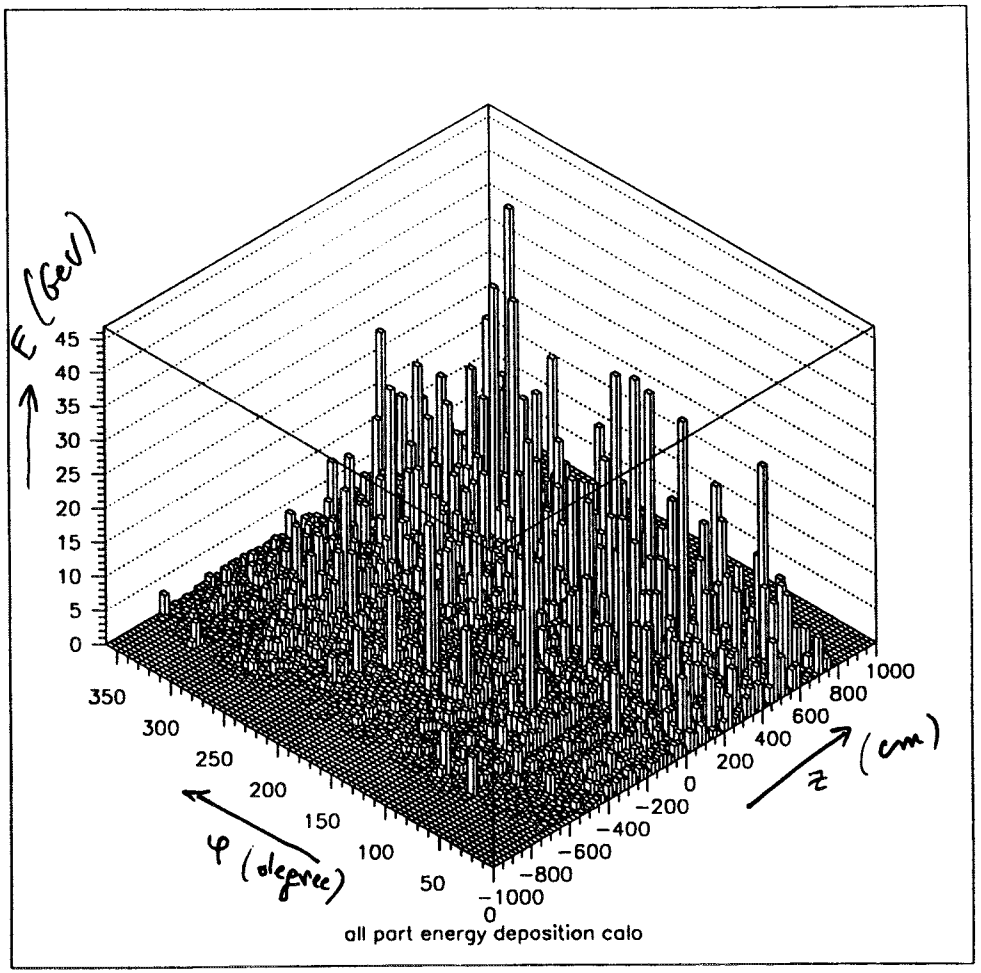
TOP VIEW

- 7 mm high slice around beam



- extreme high track density
  - ~ 1200 tracks in total
  - 400 - 600 tracks per TPC

FEBR - 97



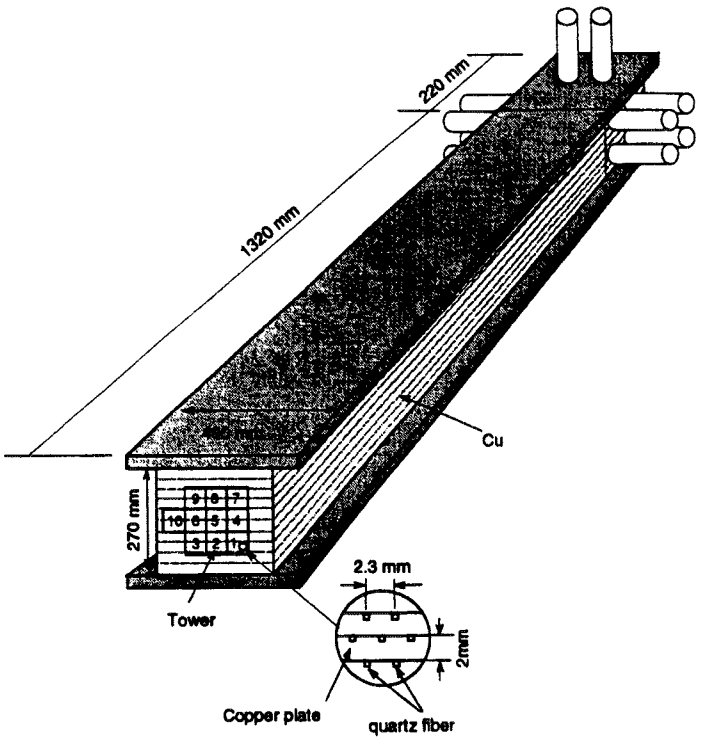
BEAM TEST RESULTS FROM A FINE-SAMPLING QUARTZ FIBER CALORIMETER FOR ELECTRON, PHOTON AND HADRON DETECTION

N. Akchurin[1], S. Ayan[2], G. Bencze[3], K. Chikin[9], H. Cohn[4], S. Doulas[5]†, I. Dumanoğlu[6], E. Eskut[6], A. Fenyvesi[3], A. Ferrando[7], M.C. Fouz[7], O. Ganel[8], V. Gavrilov[9], Y. Gershtein[9], C. Hajdu[3], J. Iosifidis[11], M.I. Josa[7], A. Khan[7], S.B. Kim[5], V. Kolosov[9], S. Kuleshov[9], J. Langland[1], D. Litvintsev[9], J.-P. Merlo[5]‡, J. Molnar[3], A. Nikitin[9], Y. Önel[1], G. Önengüt[6], D. Osborne[5], N. Özdeş-Koca[6], A. Penzo[10], E. Pesen[2], V. Podrasky[11], A. Rosowsky[5]*, J.M. Salicio[11], C. Sanzeni[11], R. Sever[2], H. Silvestri[11], V. Stolin[9], L. Sulak[5], J. Sullivan[5], A. Ulyanov[9], A. Umashev[9], S. Uzunian[9], G. Vesztergombi[3], R. Wigmans[8], D. Winn[11], R. Winsor[1], P. Zalan[3] and M. Zeyrek[2]

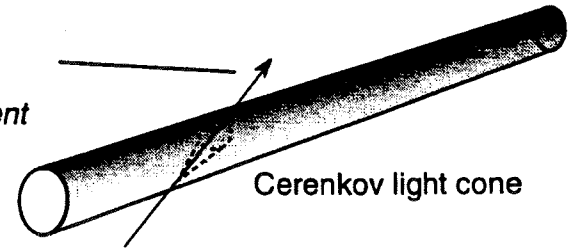
1) *University of Iowa, Iowa City, U.S.A.*
2) *Middle East Technical University, Ankara, Turkey.*
3) *KFKI-RMKI, Budapest, Hungary.*
4) *Oak Ridge National Laboratory, Oak Ridge, U.S.A.*
5) *Boston University, Boston, U.S.A.*
6) *Çukurova University, Adana, Turkey.*
7) *CIEMAT, Madrid, Spain.*
8) *Texas Tech University, Lubbock, U.S.A.*
9) *ITEP, Moscow, Russia*
10) *Università di Trieste and INFN, Ses. Trieste, Trieste, Italy*
11) *Fairfield University, Fairfield, U.S.A.*

† Now at Northeastern University, Boston, U.S.A.
‡ Now at University of Iowa
* Now at C.E.N. Saclay, Gif-sur-Yvette, France

Prototype of very forward hadronic calorimeter



Shower secondary particle produced in Copper by an incident particle.



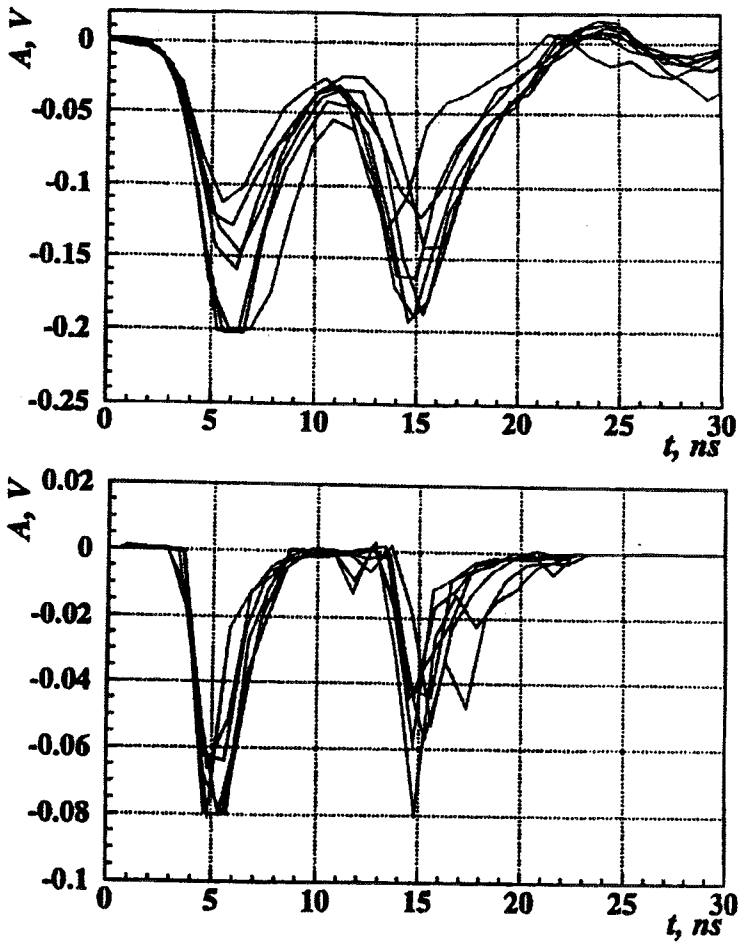


Figure 21

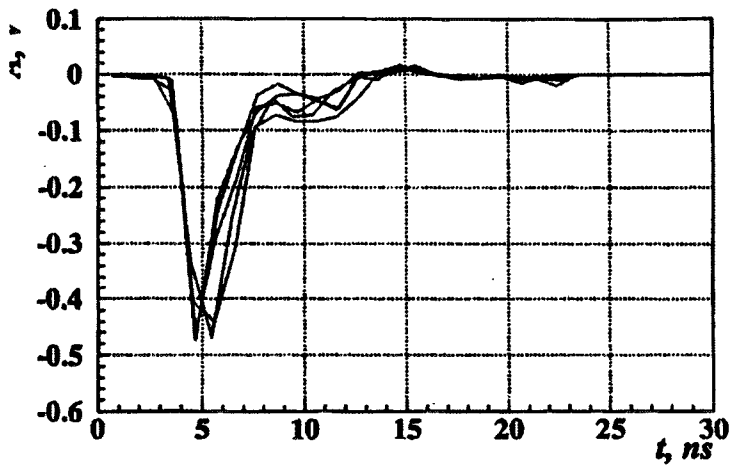
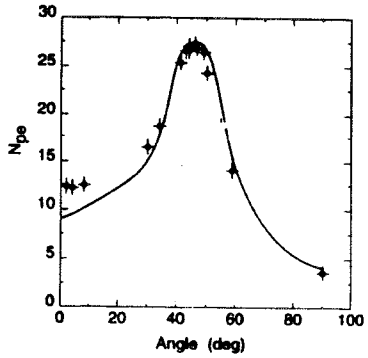


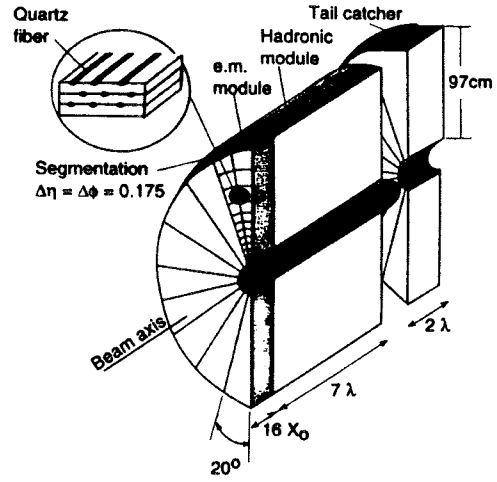
Figure 22

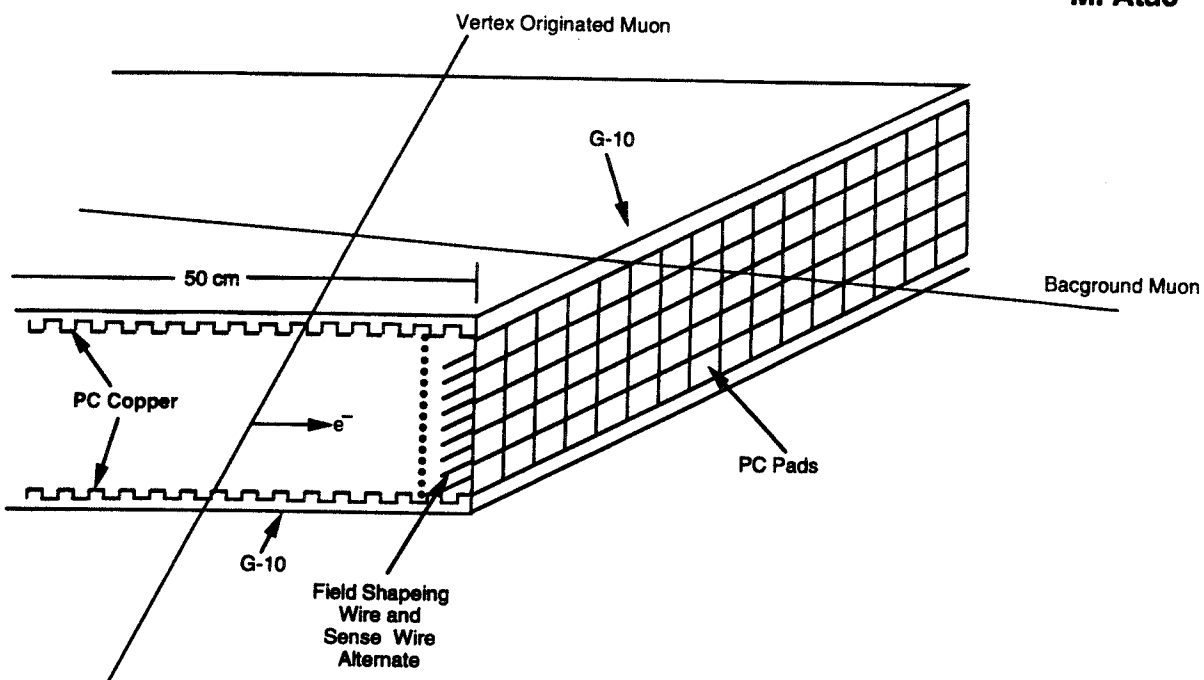
Quartz Fibre VF

Light is generated by Cerenkov effect
- fast and sensitive to relativistic charged particles
- insensitive to low energy n's, slow hadrons, induced radioactivity
- narower and shorter hadronic showers predominantly sensitive to e.m. component



Choose configuration in which fibres run almost parallel to the incident particles





- Read Pads only
- t coordinate provides Z , pads provide r-phi coordinate
- Pipeline readout and majority coincidence can eliminate background tracks and accepts vertex originated muons
- Wires are there to provide avalanche

HAVE NO FEAR

DETECTOR

TECHNOLOGIES ARE NEAR