PRECISION Measurements of SM parameters at the ν fact F. End.

(M. Mangano for WG2)

- $\sin^2\theta_W$ from νe & νN

  M. Chanowitz, K. Mc Farland, J. Yu

- V_{CKM}

  I. Bigi, L. Gibbons

- D-$\bar{D}$ mixing

  H. Nelson, D. Harris, I. Bigi

M. Chanowitz

Current Status

After 10 years of beautiful precision EW studies at LEP, SLAC, FNAL

- No clear sign of new physics
- BUT agreement with SM is MARGINAL at the stated precision

- **EWWG** global SM fit: $\chi^2 = 23/15$ CL $= \underline{0.08}$
- $x_W^{\ell,\mathrm{eff}}$: $A_{LR}, A_{FB}^{\ell}, A_e, A_\tau + A_{FB}^{b}, A_{FB}^{c}, Q_{FB}$

m_H

$$\chi^2 = 12.4/6 \qquad CL = \underline{0.05}$$

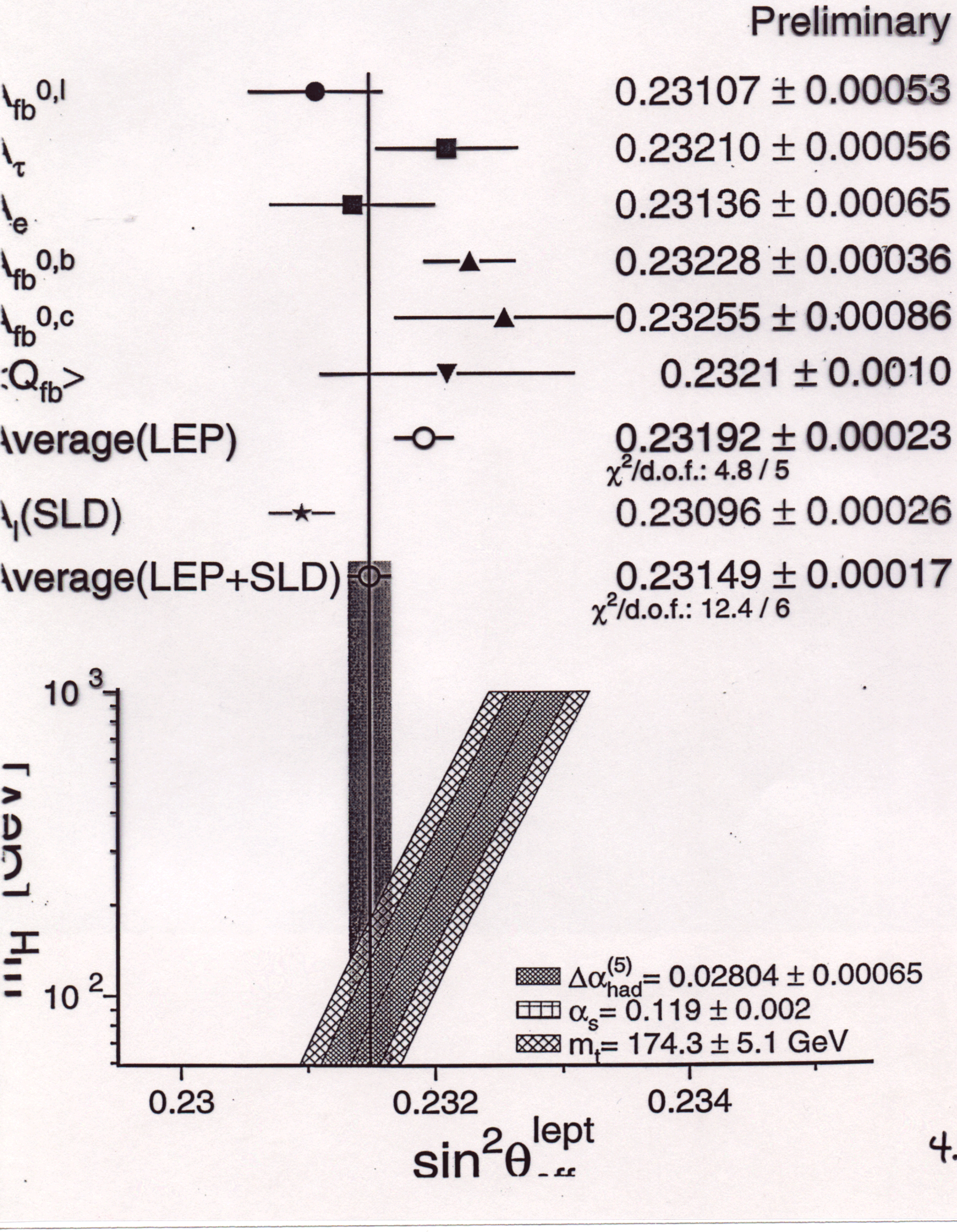
Most precise: A_{LR} vs A_{FB}^{b} 3σ CL $= \underline{0.003}$

Leptonic: $A_{LR}, A_{FB}^{\ell}, A_e, A_\tau$ $\chi^2 = 3.4/3$

- $\underline{A_b}$ $A_b^{SLC} = A_{FBLR}^{b} \oplus A_b^{LEP} = \frac{4}{3} A_{FB}^{b}/A_\ell$

$$\Rightarrow A_b^{SM} - A_b = 2.6\,\sigma \qquad \underline{CL = 0.01}$$

$$(\& \quad A_c^{SM} - A_c = 2.1\,\sigma \qquad CL = 0.04)$$


Preliminary
0.23107 ± 0.00053
0.23210 ± 0.00056
0.23136 ± 0.00065
0.23228 ± 0.00036
0.23255 ± 0.00086
0.2321 ± 0.0010
Average(LEP)
0.23192 ± 0.00023
χ²/d.o.f.: 4.8 / 5
(SLD)
0.23096 ± 0.00026
Average(LEP+SLD)
0.23149 ± 0.00017
χ²/d.o.f.: 12.4 / 6
10³
10²
Δα(5)had= 0.02804 ± 0.00065
αs= 0.119 ± 0.002
mt= 174.3 ± 5.1 GeV
0.23
0.232
0.234
sin²θlept

4.1

Potential Impact

Two scenarios

I. $(\Delta x_W^l)_{NUFAC} \sim 2 \cdot 10^{-4}$

$\oplus$

Current data

II. $(\Delta x_W^l)_{NUFAC} \sim 1 \cdot 10^{-4}$

$\oplus$

Projected Run 2 data (m_t)

I. $(\Delta x_W)_{NUFAC} \sim 2\cdot 10^{-4}$

	Lepton Asyms	All
LEP/SLC		
Δx_W^ℓ (10^{-5})	0.23117 (20)	0.23149 (17)
m_H	$58 \times 1.69^{0\pm1}$	$106 \times 1.63^{0\pm1}$
⊕ NUFAC		
Δx_W^ℓ	14	13
m_H	$58 \times 1.56^{0\pm1}$	$106 \times 1.56^{0\pm1}$

~10-20%

$\Rightarrow$ little impact on nominal precision, but may illuminate conflict in existing data between leptonic & hadronic asyms.

II $(\Delta x_W^\ell)_{NUFAC} \sim 1 \cdot 10^{-4}$

Assume $\Delta m_t = 2.5$ GeV, $\Delta m_W = 25$ MeV

	Lepton Asyms	All
NUFAC m_H	$58 \cdot 1.34^{0 \pm 1}$	$106 \cdot 1.34^{0 \pm 1}$
95% CL	< 94	< 174

$\oplus$ LEP/SLC

m_H $\sim$ No Change

$\oplus$ m_W (Run 2)

m_H $\sim$ No Change

($\Delta m_W \sim 20$ MeV $\Rightarrow$ same $\Delta(\ln m_H)$ as from $\Delta x_W^\ell \sim 2 \cdot 10^{-4}$)

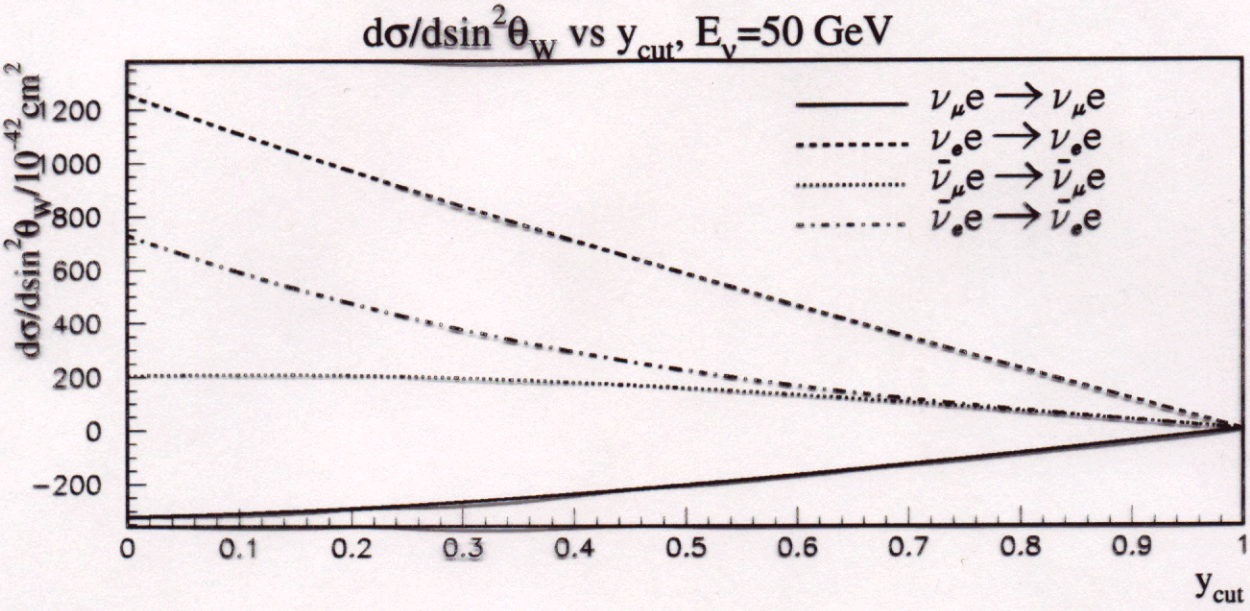
$\Longrightarrow$ factor 2 gain in $m_H(x_W^\ell)$

+ crisper resolution of existing discrepancies.

& D. Harris

νe Scattering: Cross-Sections II

Sensitivity to $\sin^2\theta_W$

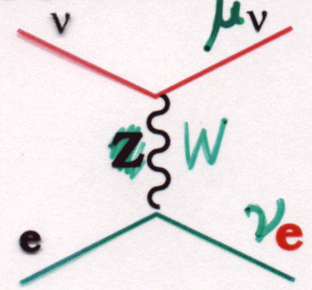


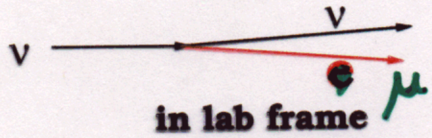
- μ^+ beam, $\nu_e e \to \nu_e e$ varies by 0.1% for $\delta\sin^2\theta_W \sim 0.0005$
- μ^- beam: neutrino flavors summed less sensitive than flavor-separate case

νe Scattering: Normalization

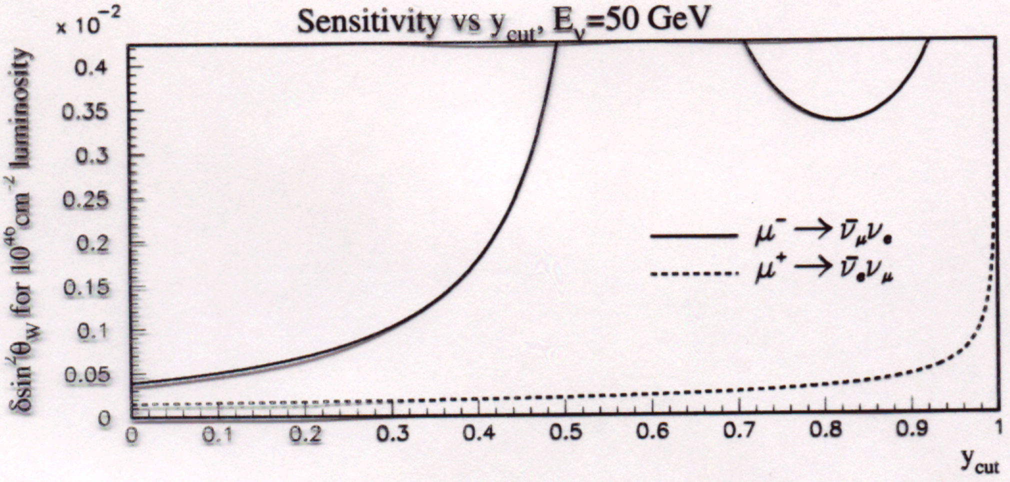
$\mu^- \to e^- \nu_\mu \overline{\nu_e}$ Beam Has Charged-Current Normalization Processes

- $\nu_\mu e^- \to \nu_e \mu^-$
- $\overline{\nu_e} e^- \to \overline{\nu_\mu} \mu^-$





$\mu^+ \to e^- \overline{\nu_\mu} \nu_e$ Beam Has None!

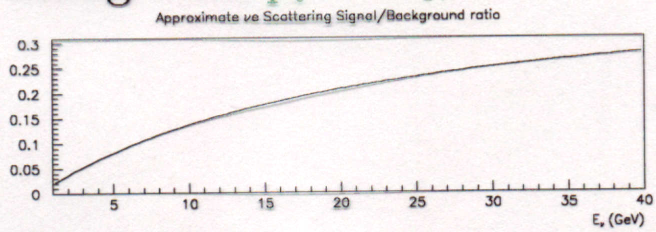


- Sensitivity for an integral analysis $y > y_{\rm cut}$
- Normalizable beam is much less sensitive
- Remember: μ^+ beam, $\nu_e e \to \nu_e e$ varies by 0.1% for $\delta \sin^2\theta_W \sim 0.0005$

νe Scattering: Backgrounds II

Quasi-Elastic ν_e Scattering

- p_t separation
  - ▷ $\sigma_{\mathrm{QE}}/\sigma_{\nu e} \sim \frac{4000\ \mathrm{GeV}}{E_\nu}$
  - ▷ Signal $p_t^2 \sim m_e E_\nu \oplus m_\mu^2$ (reaction $\oplus$ beam)
    - ∗ p_t Resolution in Li Ar (ICARUS) ~ 400 MeV
    - ∗ c.f.: $E_\nu \sim 30$ GeV $\Rightarrow p_t^{\nu e^-} = 200$ MeV
  - ▷ Background $p_t \sim m_N$



$\mu^- \to \nu_\mu \overline{\nu_e}$ and e^+/e^- important!

- ▷ Background very well measured (high p_t)

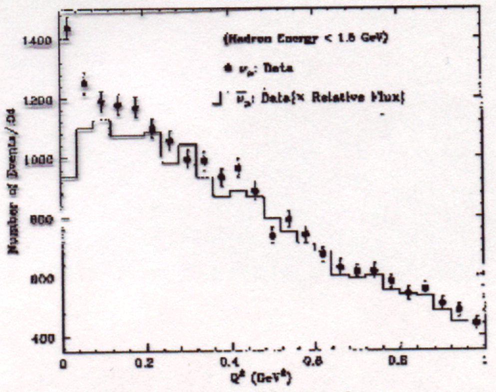


FIG. 2. Distribution of $Q^2 = E_\nu E_\mu \theta_\mu^2$ for events with $E_{\mathrm{HAD}} \le 1.5$ GeV. The ν_μ events are shown by solid circles. The $\bar{\nu}_\mu$ events, scaled up by the relative ν_μ to $\bar{\nu}_\mu$ flux, are shown by the solid line.

Statistical subtraction possible but painful

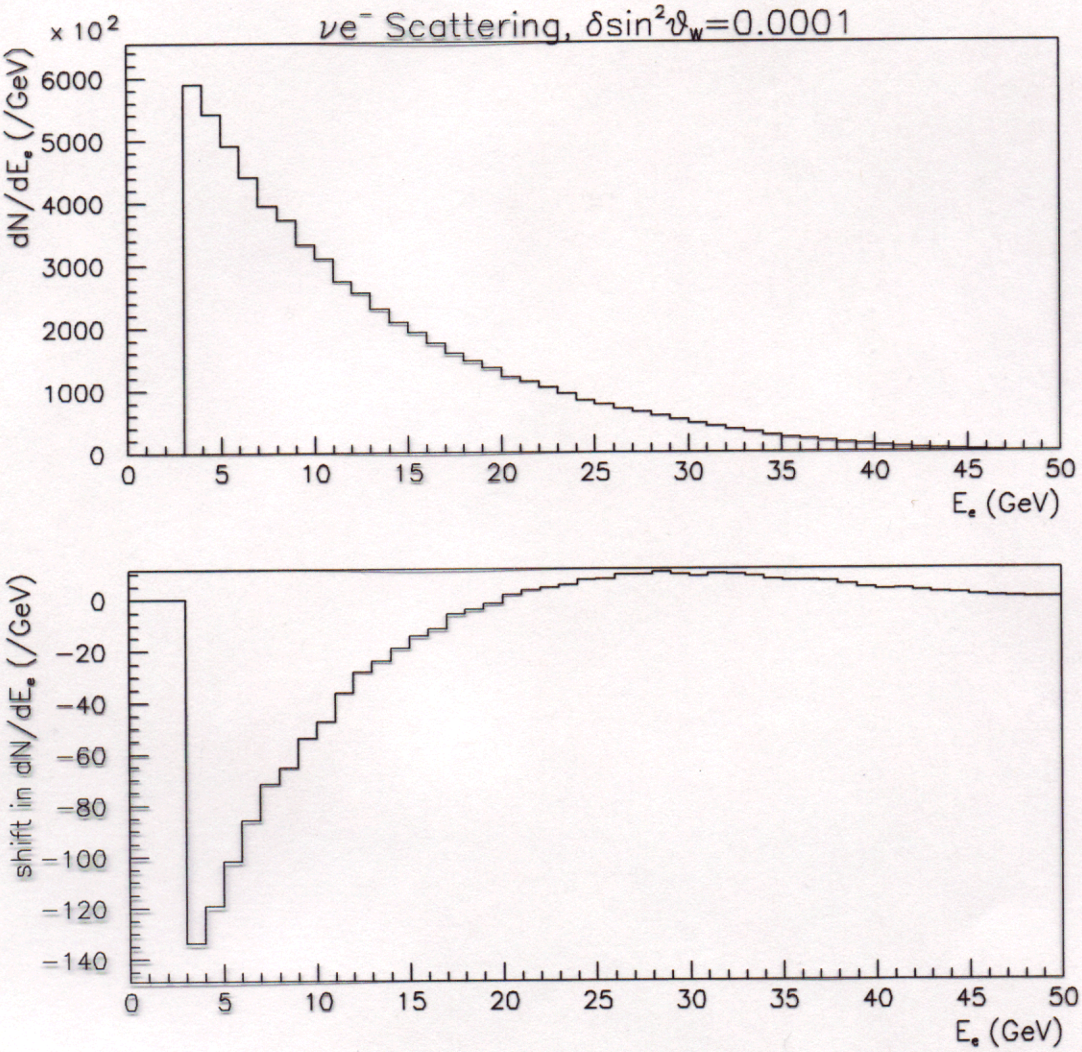
νe Scattering: Statistics II

Take detector as a liquid argon TPC

- Vary depth and radius
- Start of detector is 40 meter baseline
- 50 GeV μ^- beam, 10^{20} μ, 800 meter straight section

Radius	Depth	Tons	g/cm^2	νe^- Events, $E_e > 3GeV$
10 cm	10 m	0.43	1400	3.2×10^5
20 cm	10 m	1.9	1400	7.5×10^5
50 cm	10 m	10	1400	2.0×10^6
10 cm	100 m	4.3	14000	1.8×10^6
20 cm	100 m	19	14000	6.0×10^6
50 cm	100 m	100	14000	1.9×10^7
50 cm	30 m	33	4200	6.4×10^6

νe Scattering: Statistics II



$$\delta \sin^2\theta_{W(\text{stat})} \approx 0.0002$$

Conclusions

1. νe^- Scattering:
   Theoretically Clean, Experimentally Hard
2. Sensitive beam to $\sin^2\theta_W$ (μ^+) is hard to normalize
3. Backgrounds are a concern
4. Requires a dedicated detector
5. High flux, high energy a must
6. $\delta\sin^2\theta_W \sim 0.0002$ is probably achievable
   - 10^{21} muons for $\delta\sin^2\theta_W < 0.0001$?

νN $\sin^2\theta_W$ Measurement at Present

- Charm Production $\Rightarrow$ Need techniques insensitive to Sea Quarks
  Paschos-Wolfenstein: $R^- = \frac{\sigma^\nu_{NC}-\sigma^{\bar\nu}_{NC}}{\sigma^\nu_{CC}-\sigma^{\bar\nu}_{CC}} = \rho^2\left(\frac{1}{2}-\sin^2\theta_W\right)$

  Minimize sea quark contributions.
- Clever beam design $\Rightarrow$ Minimize uncertainties in N_{ν_e} by reducing neutral secondary contents, such as K_L

  But $\Longrightarrow$

- Still needed to understand the ν beam from the secondaries well.
- Statistical uncertainty dominates.
- Relies on statistical separation of NC and CC events based on longitudinal energy deposition in the calorimeter ("event length").
- Radiative correction a rather large theoretical uncertainty.

Experimental Technique

Indistinguishable NC events prohibits R^- Style measurements $\Rightarrow$ But we could measure $R^{\nu(\overline{\nu})}$ Style

Linear combinations of Llewellyn-Smith ratios:

For $\nu_\mu\overline{\nu}_e$ beam

$$R_\nu^{\mu^-} = \frac{\sigma(\nu_\mu, NC) + \sigma(\overline{\nu}_e, NC)}{\sigma(\nu_\mu, CC) + \sigma(\overline{\nu}_e, CC)} = \frac{R^\nu + grR^{\overline{\nu}}}{1+gr} \tag{1}$$

For $\nu_e\overline{\nu}_\mu$ beam

$$R_{\overline{\nu}}^{\mu^+} = \frac{\sigma(\overline{\nu}_\mu, NC) + \sigma(\nu_e, NC)}{\sigma(\overline{\nu}_\mu, CC) + \sigma(\nu_e, CC)} = \frac{R_{\nu_\mu} + g^{-1}rR_{\overline{\nu}_\mu}}{1+g^{-1}r} \tag{2}$$

where,

$$r = \frac{\sigma(\overline{\nu}, CC)}{\sigma(\nu, CC)} \simeq 0.5$$

and

$$g \equiv \frac{\int \Phi(E_{\overline{\nu}_e})E_{\overline{\nu}_e}dE_{\overline{\nu}_e}}{\int \Phi(E_{\nu_\mu})E_{\nu_\mu}dE_{\nu_\mu}} = \frac{\int \Phi(E_{\nu_e})E_{\nu_e}dE_{\nu_e}}{\int \Phi(E_{\overline{\nu}_\mu})E_{\overline{\nu}_\mu}dE_{\overline{\nu}_\mu}}. \tag{3}$$

the energy-weighted flux ratio between ν_μ and ν_e

The above assumes lepton universality and no beam polarization

Uncertainty Comparisons

For $E_\mu = 50GeV$ and $10^{20}\mu$-decays/yr, 40m straight section, on a 1m long CCD (iso-scalar) target would yield $\sim 30M$events/yr, assuming 100% fiducial coverage

SOURCE of UNCERTAINTY	NuTeV	νMC
Data Statistics	0.0019	$\sim 3.5 \times 10^{-4}$
ν_e flux	0.00045	**Irrelevant**
Transverse Vertex	0.0004	negl.
Energy Measurement		
Energy Scale	0.00049	negl.
Muon Energy Loss in Shower	0.00012	negl.
Energy Resolution	0.00006	negl.
Primary lepton ID	N.A.	negl.?
Event Length		**Irrelevant**
Hadron Shower Length	0.00022	
Counter Fiducial Size	0.00024	
Counter Efficiency & Noise	0.00011	
Vertex Determination	0.00012	
TOTAL EXP. SYST.	0.00078	negl.?
Charm Production, $\overline{s}$ ($m_c = 1.31 \pm 0.24$ GeV)	negl.	~~negl.?~~ 0.0004
Higher Twist	0.00011	negl.?
Longitudinal Cross-Section	0.00004	negl.
Charm Sea, ($\pm$100%)	0.00002	negl.
Non-Isoscalar Target	0.00017	0 (D_2 Target) 9×10^{-5} (CCD + Al Circuit)
Structure Functions	0.0001	~~negl.~~ <0.0001
Rad. Corrections	0.00051	< 0.0005
$\sigma^{\overline{\nu}}/\sigma^{\nu}$	0.00021	negl.
TOTAL PHYSICS MODEL	~0.00069	< 0.000~~5~~6
TOTAL UNCERTAINTY	0.0022	< 0.000~~6~~7
ΔM_W	$0.11GeV/c^2$	< 0.03~~0~~5GeV/c^2

Conclusions

- It is very feasible to achieve ΔM_W<30MeV, thanks to high neutrino flux
  - Add valuable information to understanding SM
  - Contribute significantly to LHC's Higgs search
- Charm production uncertainty seems to be controllable but need improvements in measurement systematics
- Better study on radiative correction error
- Better understanding of the different techniques
- Particle ID can be under control but it's time to use more realistic tools for more detailed estimate (eg. π^0 production rate)
- Trigger capability in the target is important not only for P-ID but also due to pile up events in the calorimeter.
- Need to input this measurement's requirement into a detector design

Dear Santa:
Heavy Flavour Physics at nuMC's -- Theoretical Desires

I.I. Bigi

University of Notre Dame du Lac

Which info on HFlPh missing + interesting in 2010?

3 classes

- (more precise) measurements of SM parameters
- calibration of theoretical tools
  (control over hadronization)
- probe for NP

(A) Measurements of SM Parameters

1) CKM Parameters

$$
\begin{array}{cccc}
 & d & s & b \\
|V_{CKM}| = & \left(\begin{array}{ccc}
0.9742 - 0.9757 & 0.219 - 0.226 & 0.002 - 0.005 \\
0.219 - 0.225 & 0.9734 - 0.9749 & 0.037 - 0.043 \\
0.004 - 0.014 & 0.035 - 0.043 & 0.9990 - 0.9993
\end{array}\right) & \begin{array}{c} u \\ c \\ t \end{array}
\end{array}
$$

with 3-family unitarity!

$$
|V_{CKM}| = \begin{pmatrix}
0.9722 - 0.9748 & 0.216 - 0.223 & 0.002 - 0.005 & \cdots \\
0.199 - 0.233 & 0.784 - 0.976 & 0.037 - 0.043 & \cdots \\
0.0 - 0.09 & 0 - 0.55 & 0 - 0.9993 & \cdots \\
\cdots & \cdots & \cdots & \cdots
\end{pmatrix}
$$

without 3-family unitarity!

$|\Delta V_{cd}|_{PDG00} = 17\%$ [3%]

$|\Delta V_{cs}|_{PDG00} = 20\%$ [2%]

$|\Delta V_{ub}|$ ″ $= 40\%$

$|\Delta V_{cb}|$ ″ $= 8\%$

L. Gibbons

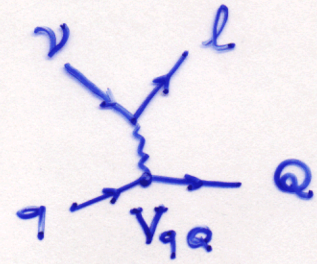
Summary

- a variety of techniques to extract $|V_{ub}|$ w/ uncertainties 10-15% or less at $\Upsilon(4S)$

- complementary systematics:
  we'll want them all to verify we really know $|V_{ub}|$ at 10% level!

challenge for nuMC

extract $\begin{pmatrix} |V_{cd}| \\ |V_{ub}| \\ |V_{cs}| \\ |V_{cb}| \end{pmatrix}$ with uncertainty $\begin{pmatrix} \mathcal{O}(1\%) \\ \mathcal{O}(1\%) \\ \mathcal{O}(\text{few } \%) \\ \mathcal{O}(\text{few } \%) \end{pmatrix}$



- appears feasible experimentally
- theoretical uncertainties?
  - actually measure ratios |V(cd)/V(ud)|

    uncertainties in PDF's drop out
  - threshold suppression

    lab for duality studi

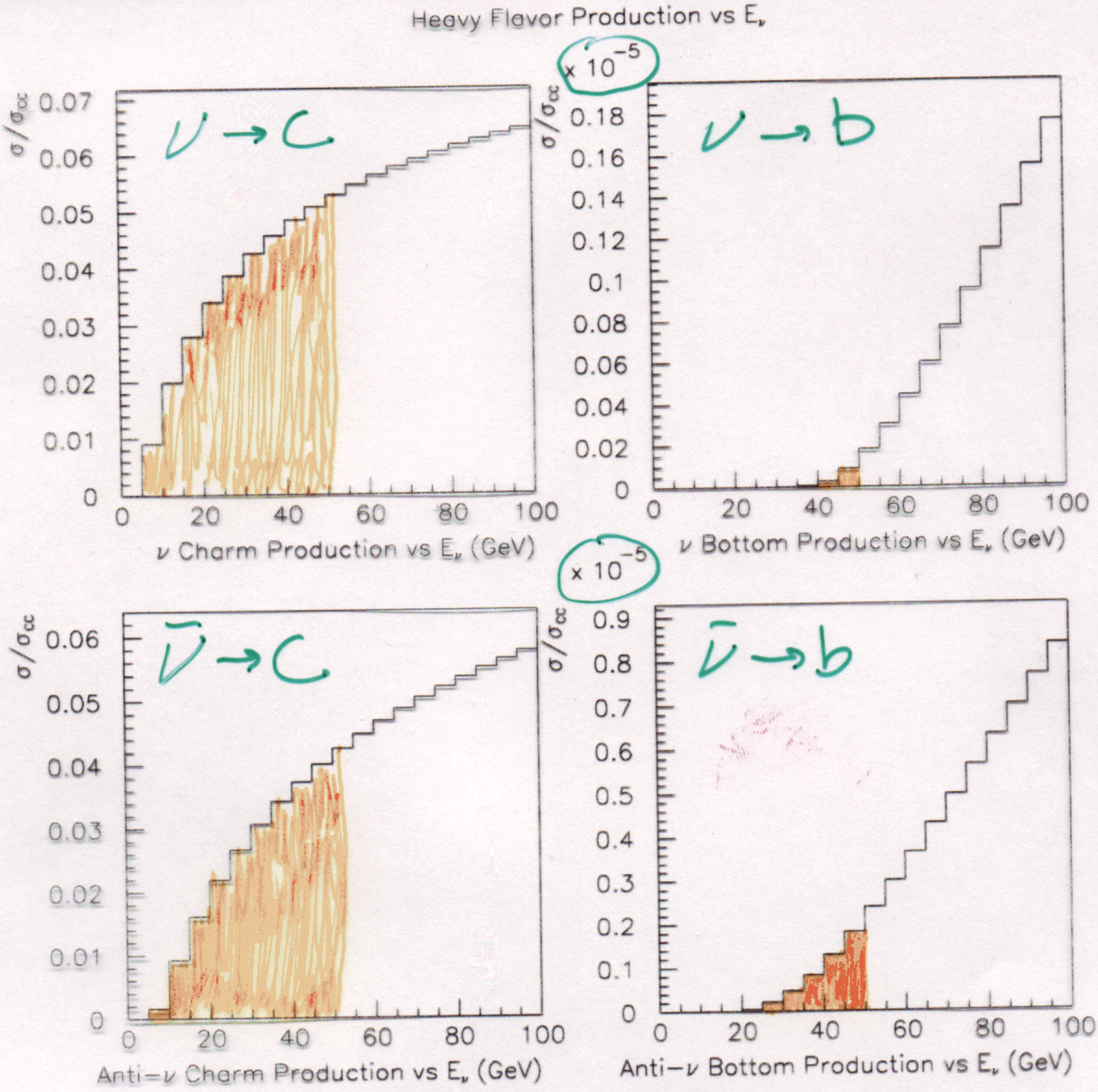
    central challenge

    involves nonperturb. definit. of quark mass

    ≠ " " of " " in decays

    could use |V(cs)| and |V(cb)| as calibrators!

Neutrino Charm Factory: By-Products



$$\frac{\sigma_{\text{charm}}}{\sigma_{\text{CC}}} \qquad\qquad \frac{\sigma_{\text{bottom}}}{\sigma_{\text{CC}}}$$

- Charm Production averages ≈ 3% of cross-section
- Bottom Production not accessible at 50 GeV

  ▷ precise measure of $|V_{ub}|$ at high E_ν? (B. King)

2) D^0 - D^0 oscillations

- **basic quantities**

$$x_D = \frac{\Delta M_D}{\Gamma_D} \qquad\qquad y_D = \frac{\Delta \Gamma_D}{2\Gamma_D}$$

$\uparrow$ sensitive to NP $\qquad$ $\uparrow$ hardly sensitive to NP

- **flavour tag**

initial state

– $D^{+*} \longrightarrow D^0 \pi^{+}$

– $D^{+} \bar{D}^0$, $D^{-} D^0$

– $\nu N \longrightarrow \mu^{-} D X$

$\bar{\nu} N \longrightarrow \mu^{+} \bar{D} X$ $\qquad$ νMC $\quad \Delta C = -\Delta Q_\ell$ rule

final state

$D^0 \longrightarrow K^{-} X$ $\qquad$ SM backgrd: DCSD

$D^0 \longrightarrow \ell^{+} X$ $\qquad$ " $\quad$ " $\quad$ none – but check!

- experim. landscape

$$r_D = \frac{\Gamma(D^0 \to \ell^- X)}{\Gamma(D^0 \to \ell^+ X)} \simeq \frac{1}{2}\left(x_D^2 + y_D^2\right)$$

$$D^0 \to K^+ \pi^- \quad \text{vs.} \quad D^0 \to K^- \pi^+$$

$$y_D' = y_D \cos \delta_{K\pi} - x_D \sin \delta_{K\pi}$$

$r_D \leq 5 \times 10^{-4}$ 95% C.L. CLEO

$-0.04 \leq y_D \leq 0.06$ 90% C.L. E791

$-0.058 \leq y_D' \leq 0.01$ 95% C.L. CLEO

$y_D = 0.0342 \pm 0.0139 \pm 0.0074$ FOCUS

- theoret. landscape

folklore

$y_D, x_D \sim 10^{-4} - 10^{-3}$ dominated by LDD

my (& Uraltsev's) opinion

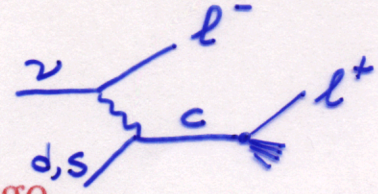
$y_D, x_D \sim \mathcal{O}(10^{-3})$ can be obtained from OPE

& D. Harris

$D^0 - \overline{D}^0$ Mixing

- $D^0 - \overline{D}^0$ is a clean signature of new physics if seen above 10^{-6} level
- e^+e^- and Fixed Target currently at few$\times 10^{-3}$ level (BaBar estimates few10^{-4} sensitivity with years at design luminosity)
  - ▷ Stuck on systematics/backgrounds
  - ▷ Reconstructed flavor from $D^0 \to K^-\pi^+$ (but $D^0 \to K^+\pi^-$ is 1% of this rate)
  - ▷ Proper lifetime analysis required to get below 10^{-2}

One idea for $D^0 - \overline{D}^0$ Mixing in a Neutrino Factory Beam:



- High momentum lepton is tag
- Measure (inclusive) second lepton charge
  - ▷ about 30% from neutral D mesons
  - ▷ 10% efficient, assuming only $e^\pm$ useful
    - ∗ There is a few$\times 10^{-2}$ background from light meson decays in showers for the case of muons
  - ▷ probe 5×10^6 D^0 decays
- $D^0 - \overline{D}^0$ mixing gives $\ell^\pm_{\rm tag}\ell_{\rm charm^\pm}$
  - ▷ vs dominant $\ell^\pm_{\rm tag}\ell^\mp_{\rm charm}$

Target for Charm Experiment

CCD'S : 300 μm thick

spaced every 600 μm

2 m long

$\Rightarrow$ 210 g / cm^2

(3300 planes!)

$9.6\, X_0$, $2.0\, \lambda_{INT}$

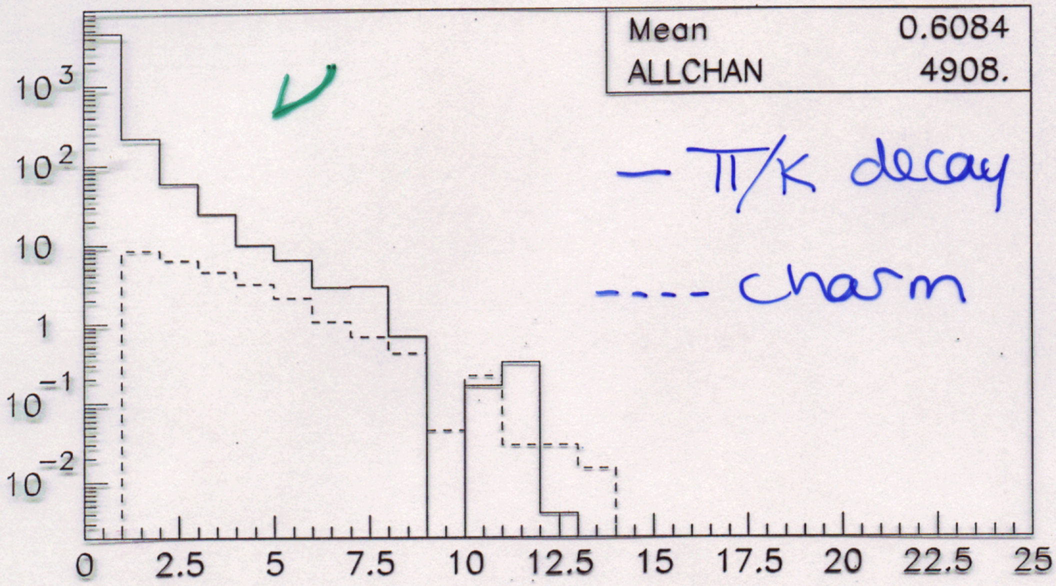
$\lambda c\tau$ for charm from 25-50 GeV ring is between .5 $\rightarrow$ 2.5 mm

But Beware: Density of this target only 1/2 that of SiO_2 .... $\left(\frac{2.2}{2}!!!\right)$

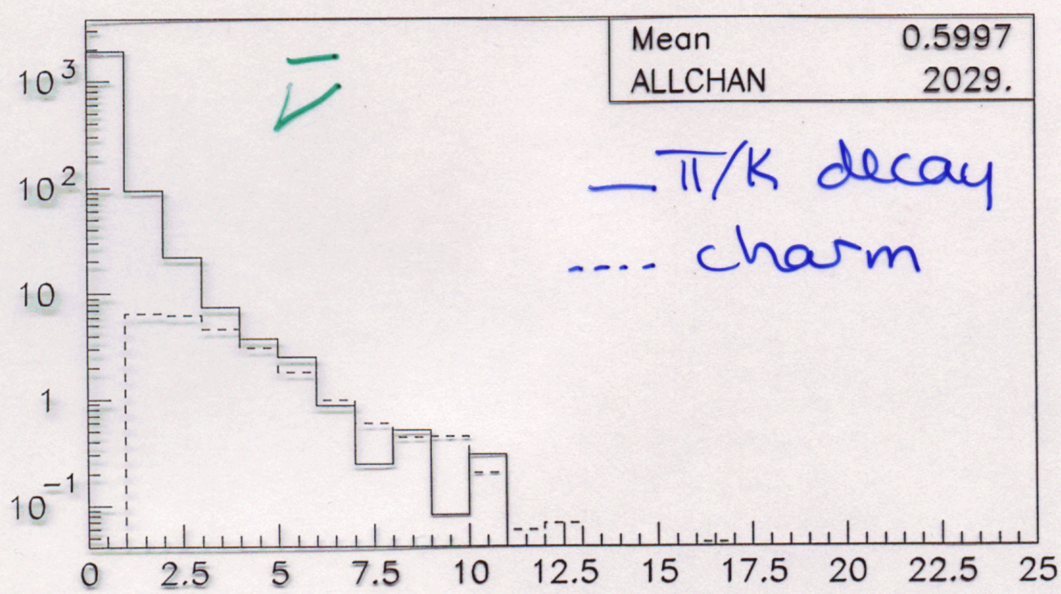
Backgrounds enter....

5cm
25GeV

Second Muon Momenta exp1



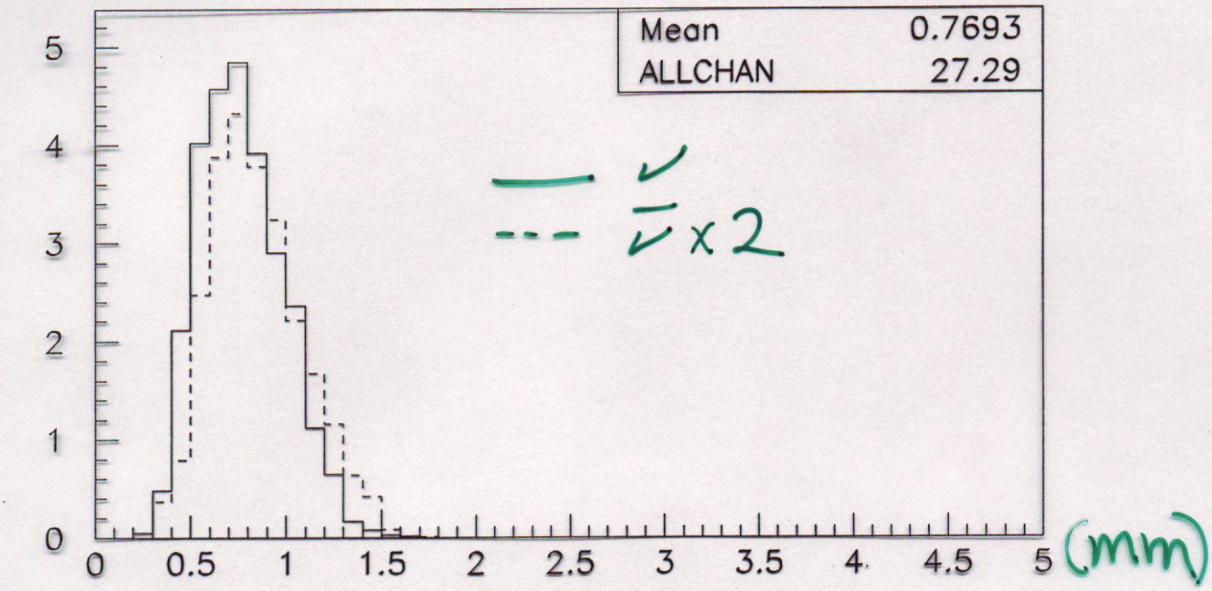
Second Muon Momentum nu no charm



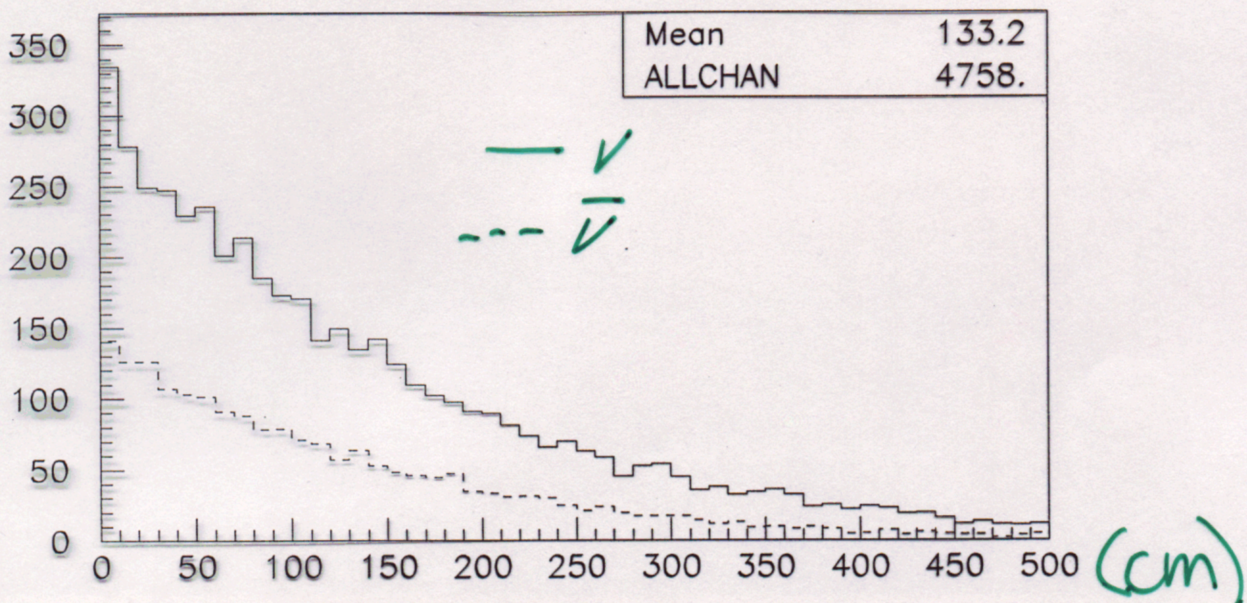
Second Muon Momentum nubar no charm

Second Muon vertex exp1

25GeV
5cm

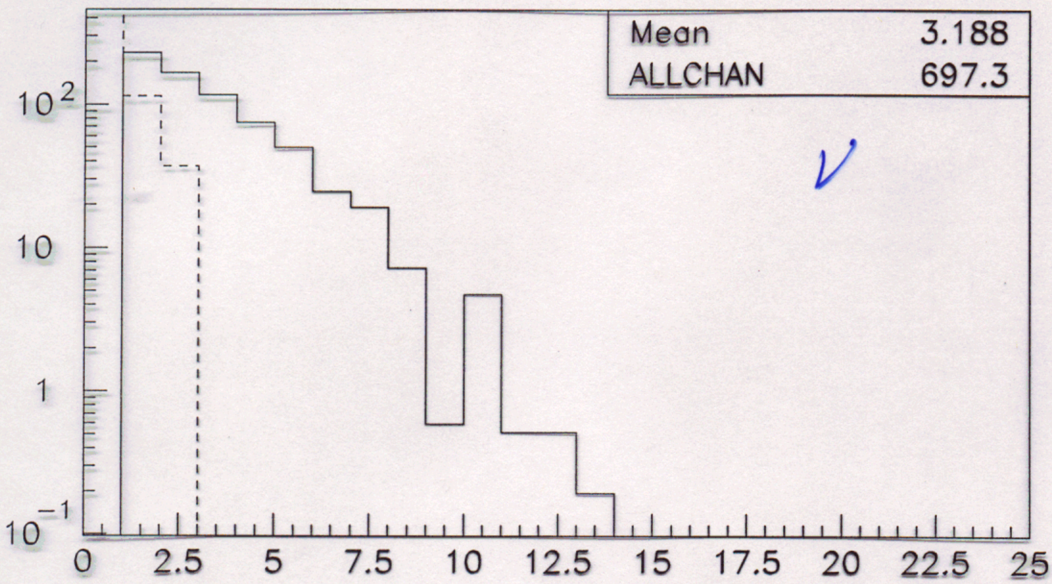


Second Muon $\gamma c\tau$ nu charm

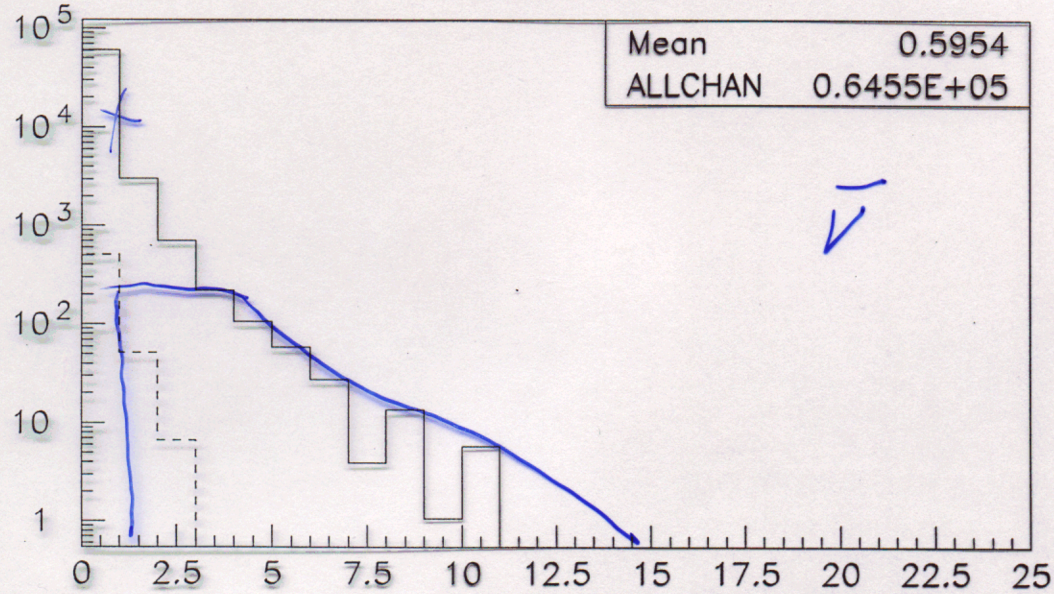


Second Muon z nu not charm

New Signal vs Background exp2



Second Muon Momentum nu charm



Second Muon Momentum nubar no charm

CONCLUSIONS

For 10^{20} μ decays,

E_μ Ring (GeV)	Radius (cm)	$c\to\mu$ Rate/g/cm^2 $\times 200\,g/cm^2$	$\times$ 4 (?)
25	5	5.4K	22K
25	50	140K	560K
50	5	80K	320K
50	50	1.4M	5.6M

x10 rate

X4 means: Use $(\nu_\mu, \bar{\nu}_e)^{\mu^+} + (\bar{\nu}_\mu, \nu_e)^{\mu^-}$ Ring

and $c\to\mu$ with $c\to e$.

* Using $\bar{\nu}$ as well as ν would add another ~40% rate.

* Using more than just $c\to\ell$ could also gain factor of N, $N \lesssim 5$

Backgrounds to $c\to\mu$: $\lesssim 1\%$ for 5mm cut + 5GeV muon momentum cut....

Backgrounds to $c\to e$??? $\pi\to e$ less π^0 production more!

Conclusions

First studies w. some elements of realism (e.g. bg's!) reported at this Workshop:

- $\sin^2\theta_W^{eff}$ from νe — K. McFarland, D. Harris, B. King

  ($\Delta_{achieved} \sim 2\times10^{-4}$, $\Delta_{goal} \lesssim 1\times10^{-4}$)

  cfr polar. Møller fixd tgt e-scatt. exp. @ Tesla $\delta\sin^2\theta_W \sim \boxed{6\times10^{-5}}$

  cfr GigaZ $\delta\sin^2\theta_W \sim \boxed{10^{-5}}$

- $\sin^2\theta_W$ from νN — J. Yu

  ($\Delta M_W^{achieved} \sim 35$ MeV, $\Delta_{goal} \lesssim 10$ MeV)

  cfr GigaZ $\delta M_W \sim 6$ MeV

- $D\bar{D}$ mixing — D. Harris, K. McFarland

  ($B/S \lesssim 10^{-2}$ goal: $\sim 10^{-3\div-4}$)

  cfr Bfact $\sim \frac{7\times10^{-3}}{[\mathcal{L}/10^3 fb^{-1}]^{1/2}}$

This work should now be extended to other observables, defining accuracy benchmarks & determining beam & detector specs needed to achieve them.

It already seems clear, though, that we need $\boxed{E^\mu \gtrsim 50\ \text{GeV}}$