APPENDIX

J. Gallardo, Organizer

APPENDIX, *J. Gallardo* (BNL), Organizer

Speakers and Conference Organization - *J. Wurtele* (UC Berkeley/LBNL)
Superconducting Magnets for a Muon Collider - *R. Scanlan* (LBNL)
Pion Production and Targetry at $\mu^+\mu^-$ Colliders (see p. 578) - *N. Mokhov* (FNAL)
The AGS E910 Experiment: Measurement of π Production - *H. Kirk* (BNL)
Liquid Jet Targets - *K. McDonald* (Princeton)
Target Materials - *D. Summers* (U Mississippi)
ICOOL Simulations of Alternating Solenoid Transverse Cooling - *R. Palmer* (BNL)
ICOOL: Recent Developments (after v1.61) - *R. Fernow* (BNL)
Theory of Emittance Exchange - *R. Palmer* (BNL)
A New Scheme of Linear Accelerator - *Y. Zhao* (BNL)
Temperature Distribution on Beryllium Windows in $\mu^+\mu^-$ Cooling RF Cavity - *D. Li, W. Turner, J. Corlett* (LBNL)
Linear Orbit Recirculators - *F. Mills* (FNAL)
Cooling Experiment - *S. Geer* (FNAL)
An Update on a Cooling Scenario - *J. Norem* (FNAL/ANL)
Longitudinal Impedance Tuner Using High Permeability Material - *K. Koba, Y. Mori*, ... (KEK)
Vertex Tagging - *B. King* (BNL)
Matching and Emittance Exchange Section for Ionization Cooling with Li Lenses - *V. Balbekov* (FNAL)

SPEAKERS & CONFERENCE ORGANIZATION

PROBLEM: ENSURE REPRESENTATION OF MUON COLLIDER AT IMPORTANT WORKSHOPS AND CONFERENCES

INCREASE THE NUMBER OF PEOPLE GIVING TALKS

J. WURTELE

SPEAKERS COM. (JW, J. Gunion, A. Tollestrup, B. Palmer)

GOALS

* POST LIST OF CONFERENCES, WORKSHOPS, AND SPEAKERS
* CONTACT ORGANIZING COMMITTEES TO FIND OUT WHAT TALKS ARE REQUESTED.
* FIND SPEAKERS

NOTES

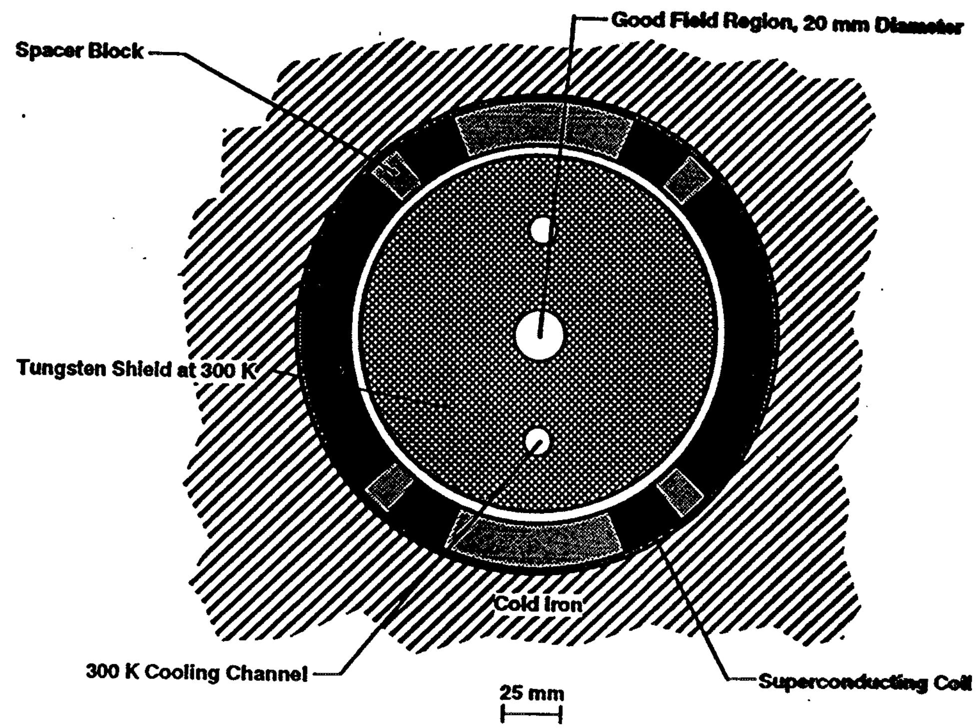
* PLEASE LET US (ME) KNOW OF UPCOMING TALKS YOU MAY HAVE.
* PLEASE LET US KNOW OF POSTERS AS WELL.
* PLEASE LET US KNOW OF TALKS YOU DECLINE
* WE ONLY TRY TO COORDINATE IMPORTANT MEETINGS, NOT SEMINARS AT UNIVERSITIES.

Superconducting Magnets for a Muon Collider

R. SCANLAN

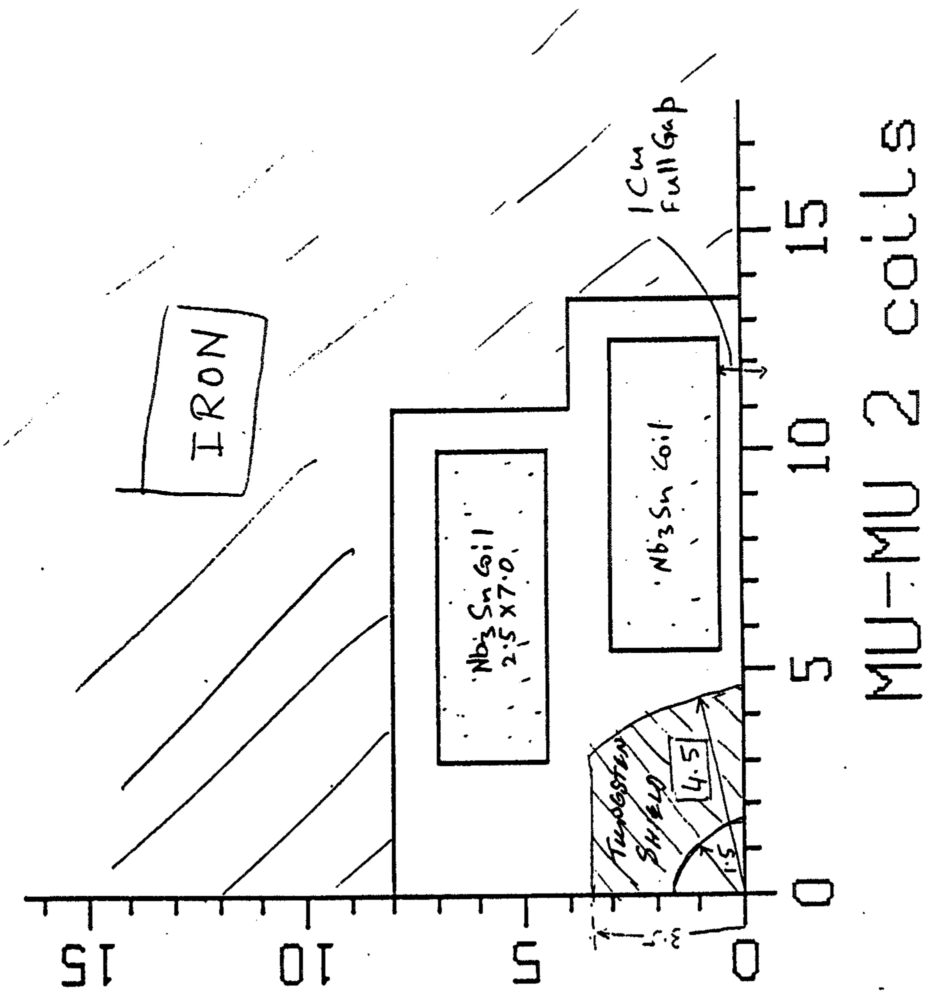
• Outsert Solenoid for Pion Capture	7 - 13 T
• Phase Rotation Cavity Solenoids	~5 T
• Solenoids for the Muon Cooling System	5 - 14 T
• Dipoles for the Muon Cooling System	1 - 4 T
• Dipoles and Quadrupoles for the Acceleration Rings	up to 7 T
• Collider Ring Bending Section Dipoles	8 - 12 T
• Collider Interaction Region Quadrupoles	8 - 12 T

NbTi Cos θ Dipole for Muon Collider



NbTi (1.8K)
9.5-10 T

Nb3Sn Block Coil Dipole for Muon Collider



Preliminary Cross section for muon collider *(Nb_3Sn, 4.3 K)*
(other side of the coil is not yet included)

- Conductors not graded (grading would give higher field)
- Performance at 4.3 K (1.8 K would give higher field)
- Loss in Jc due to stress is not included

- Cross section uses two blocks of coil, each is 25mm X 70 mm. (Pl. see attached POISSON model for more details.)
- The calculations are done for an overall current density of 400 Amps/mm^2

Current Densities in Amps/mm^2		
Joverall		400
Jmetal		571
%Cu	30	
%SC	70	
Jcu		1905
Jsc		816
Measured Jc@15T in TWCA		814
Jcu in D20 (LBL Nb3Sn magnet)		1630

Field in Tesla	
Bo	13.6
Bpeak(block#1)	14.4
Bpeak(block#2)	15.2

Note : All field harmonics are 10^{-5} at 10 mm reference radius.

Preliminary Conclusions:
A 14T magnet is possible with the coils developed for the proposed LBL common coil magnet.

Status for muon collider ring dipoles:

- Both 9.5-10 T NbTi and 13-14 T Nb3Sn dipoles look feasible
- Heat deposition calculations need to be done for both NbTi (1.8 K) and Nb3Sn (4.3 K) cases
  - -25 W/m for Nb3Sn epoxy impregnated coils look O.K (D20 results).
  - -for significantly higher heat loads, we may need to go to ICCS conductor
- Structure still needs to be designed
- Nb3Sn block coil design uses similar coils to 14 T common coil magnet—can combine R&D work

Pion Production and Targetry at $\mu^+\mu^-$ Colliders - *N. Mokhov* (FNAL)

(see page 578)

H. Kirk

preliminary

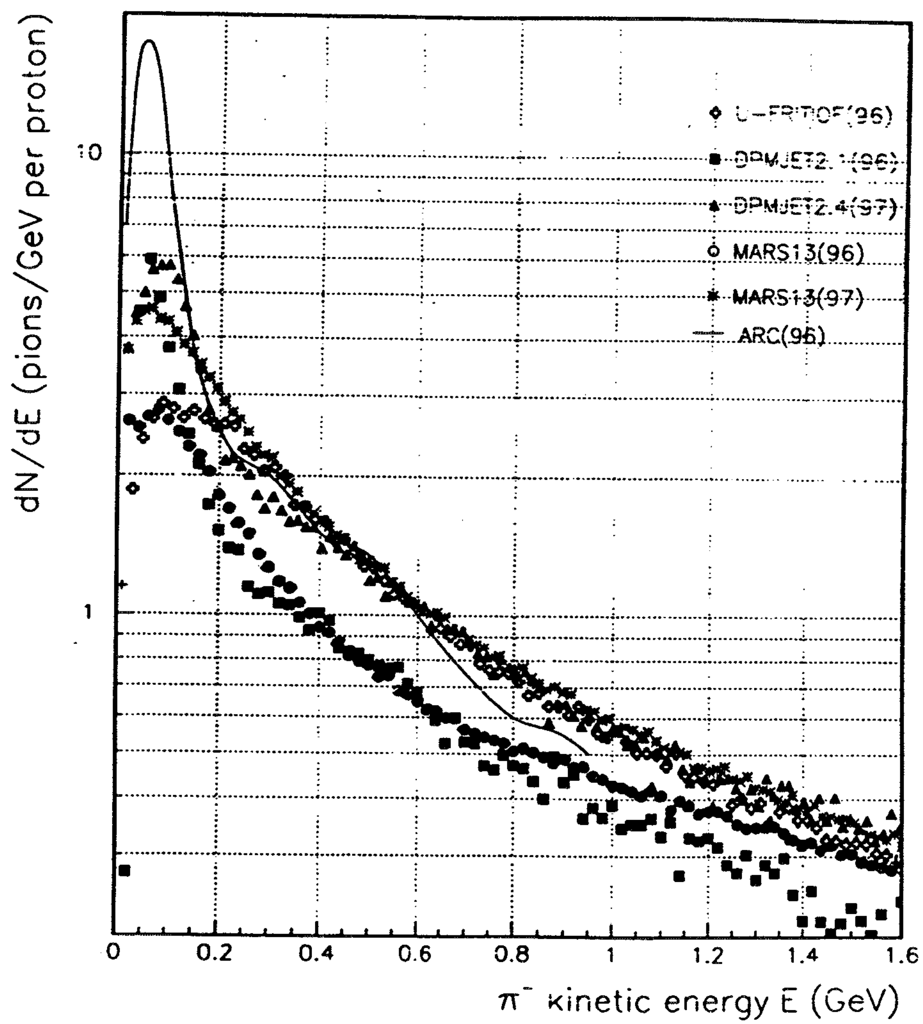
97/09/26 15.24

The AGS E910 experiment

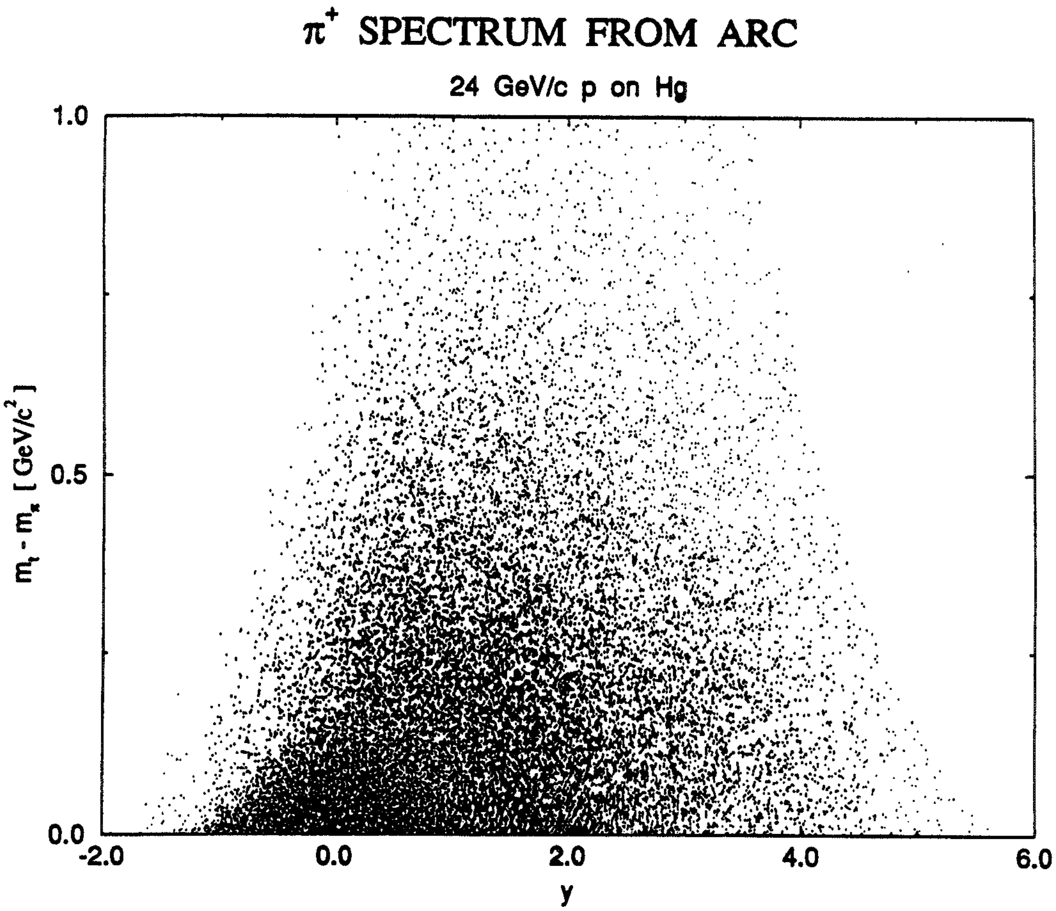
Measurement of π production

The experiment features:

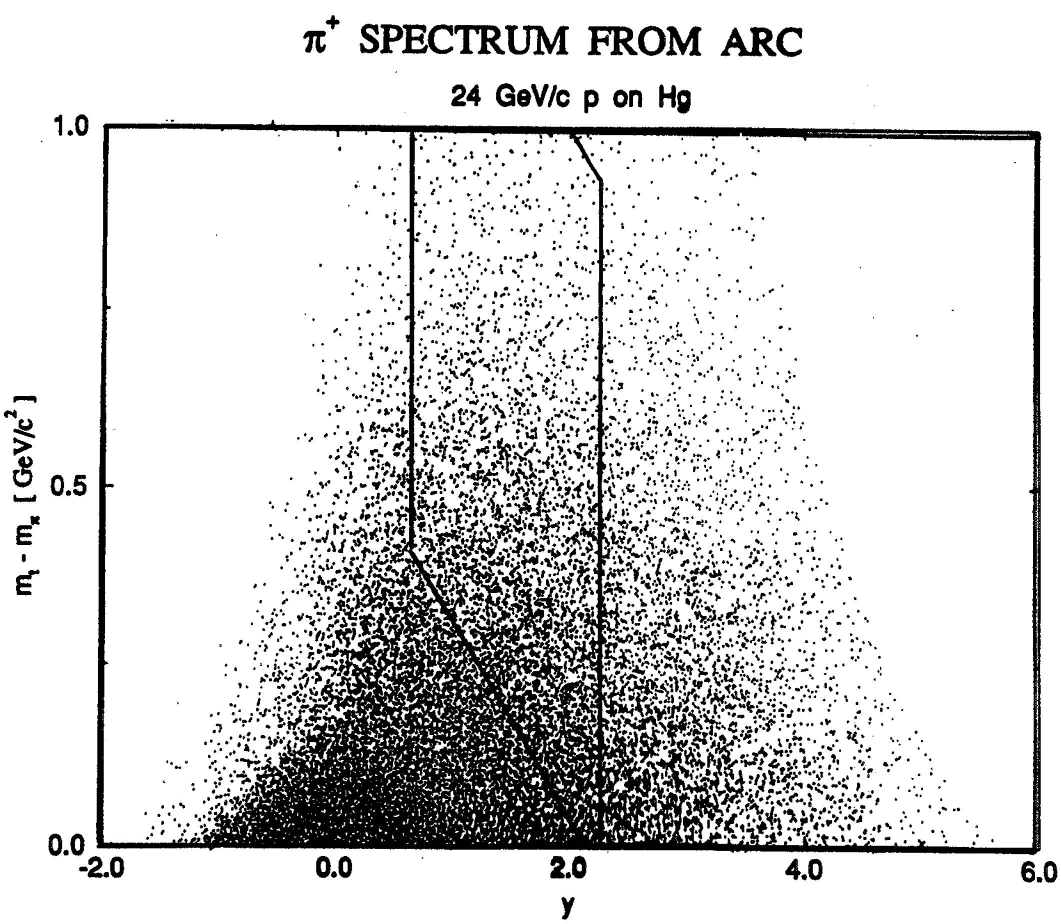
- Proton beams of 6, 12.5 , and 18 GeV/c
- Various target material (Be, Cu, Au)
- High acceptance TPC for particle momenta down to 30 MeV/c
- Good particle identification in TPC by dE/dx
- Measurement of low-energy pion production cross-sections



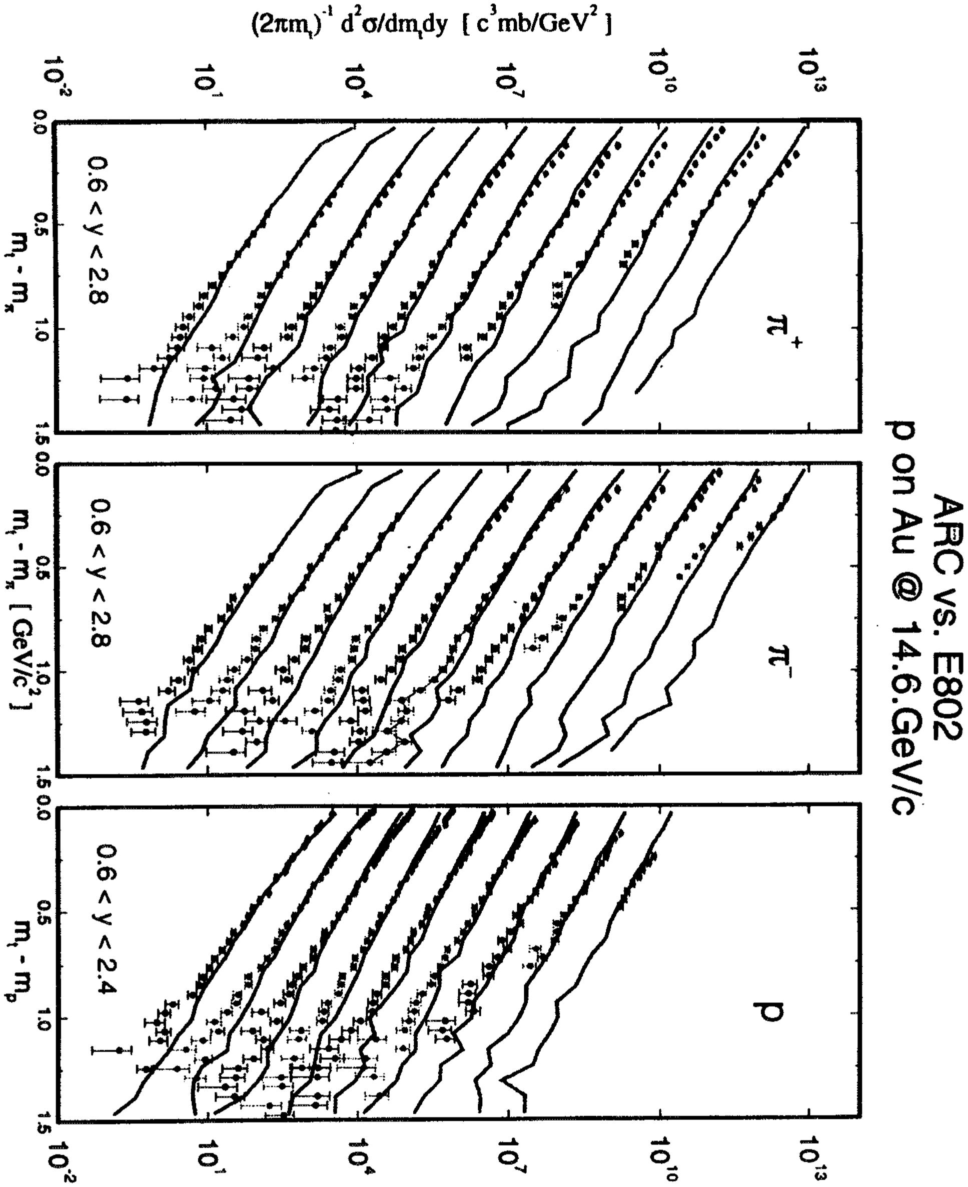
24 GeV/c protons on Hg

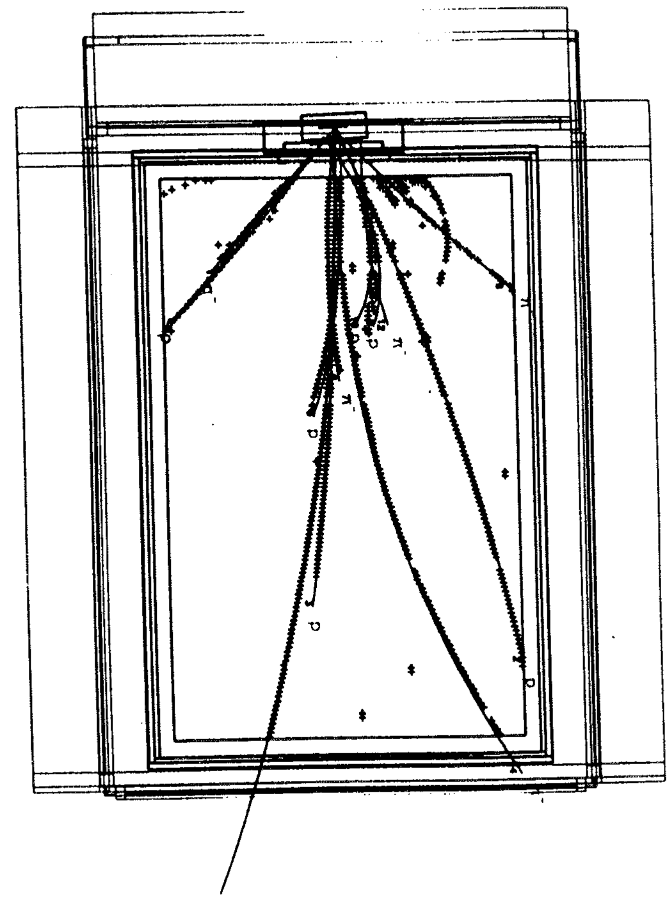


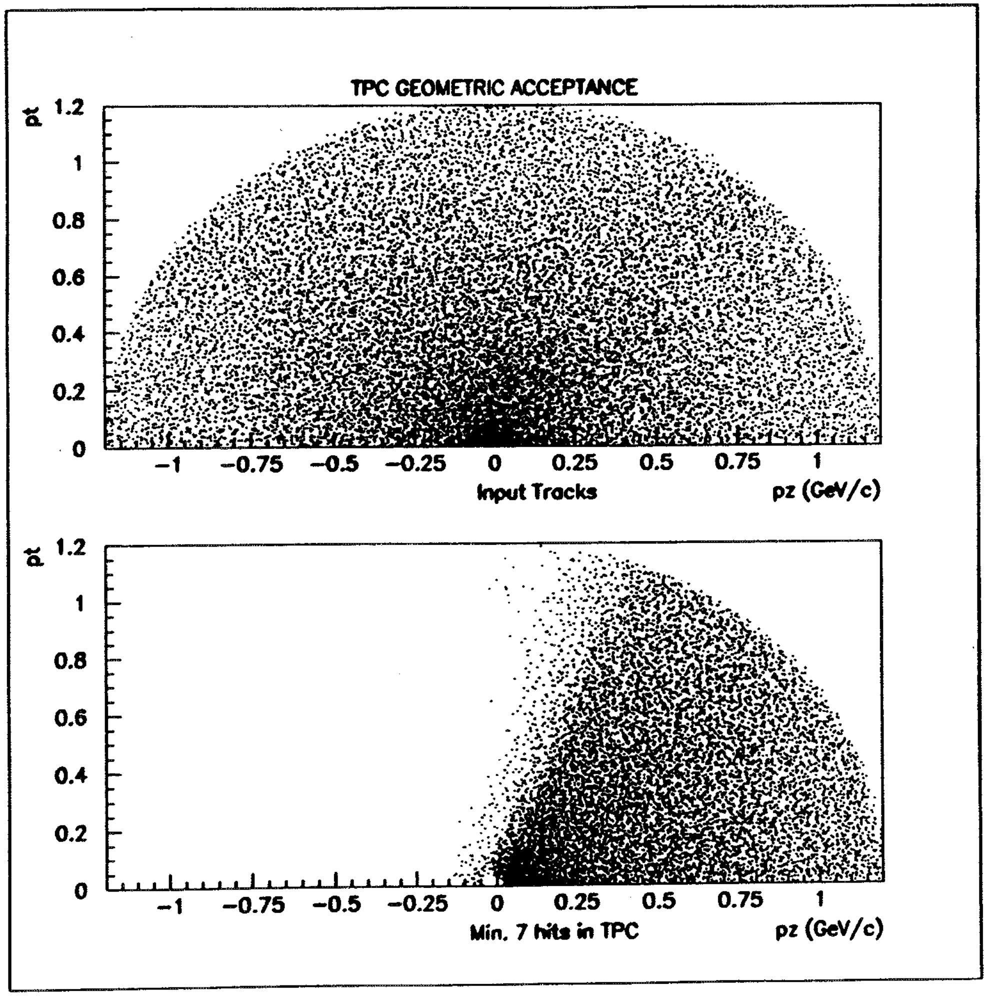
π+ SPECTRUM FROM ARC
24 GeV/c p on Hg
1.0
0.5
0.0
mt - mπ [GeV/c2]
-2.0
0.0
2.0
4.0
6.0
y



π+ SPECTRUM FROM ARC
24 GeV/c p on Hg
1.0
0.5
0.0
mt - mπ [GeV/c2]
-2.0
0.0
2.0
4.0
6.0
y


ARC vs. E802
p on Au @ 14.6.GeV/c
$(2\pi m_t)^{-1}\, d^2\sigma/dm_t dy$ [c^3mb/GeV^2]
π^+
π^-
p
0.6 < y < 2.8
0.6 < y < 2.8
0.6 < y < 2.4
$m_t - m_\pi$
$m_t - m_\pi$ [GeV/c^2]
$m_t - m_p$

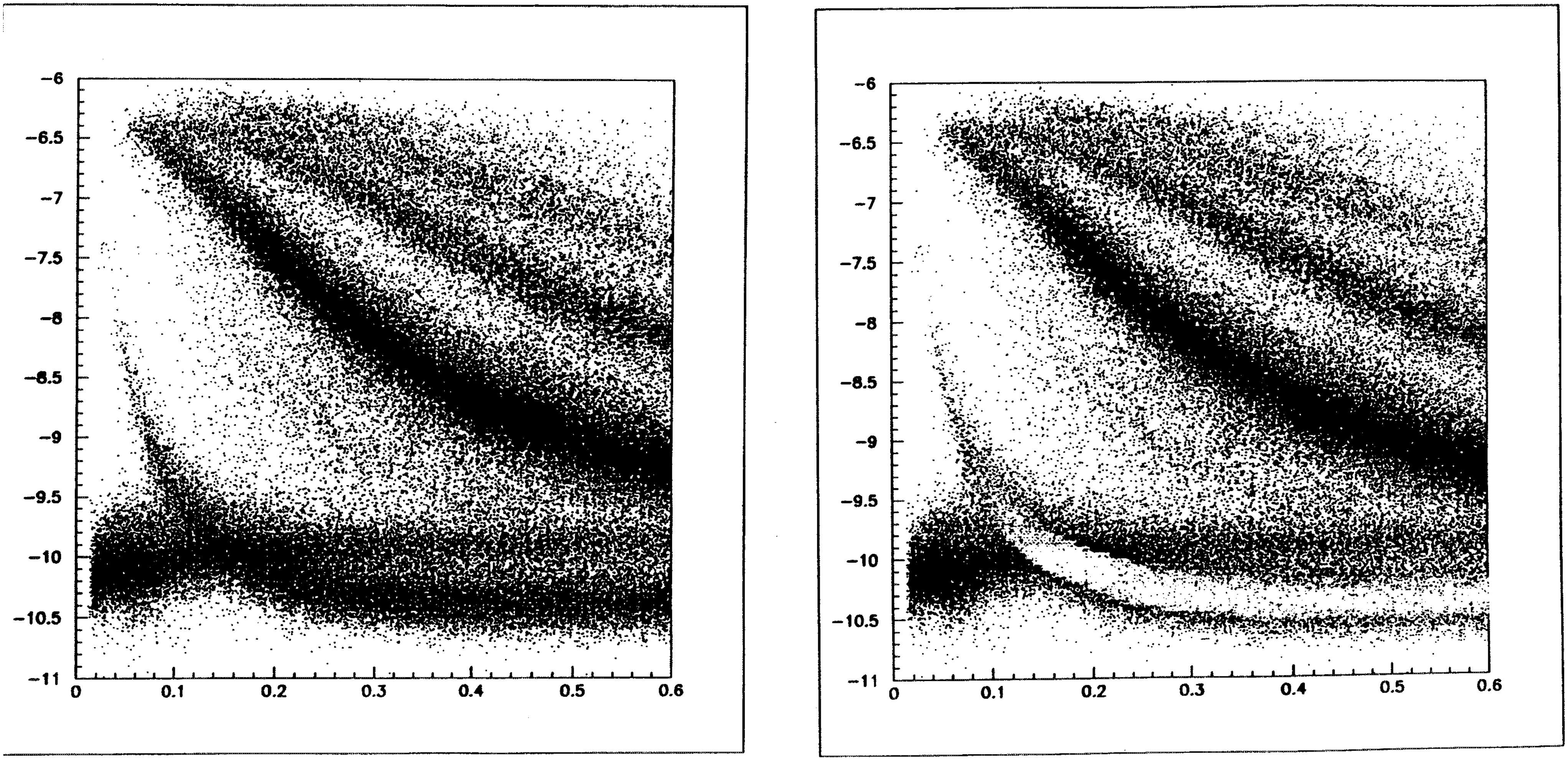


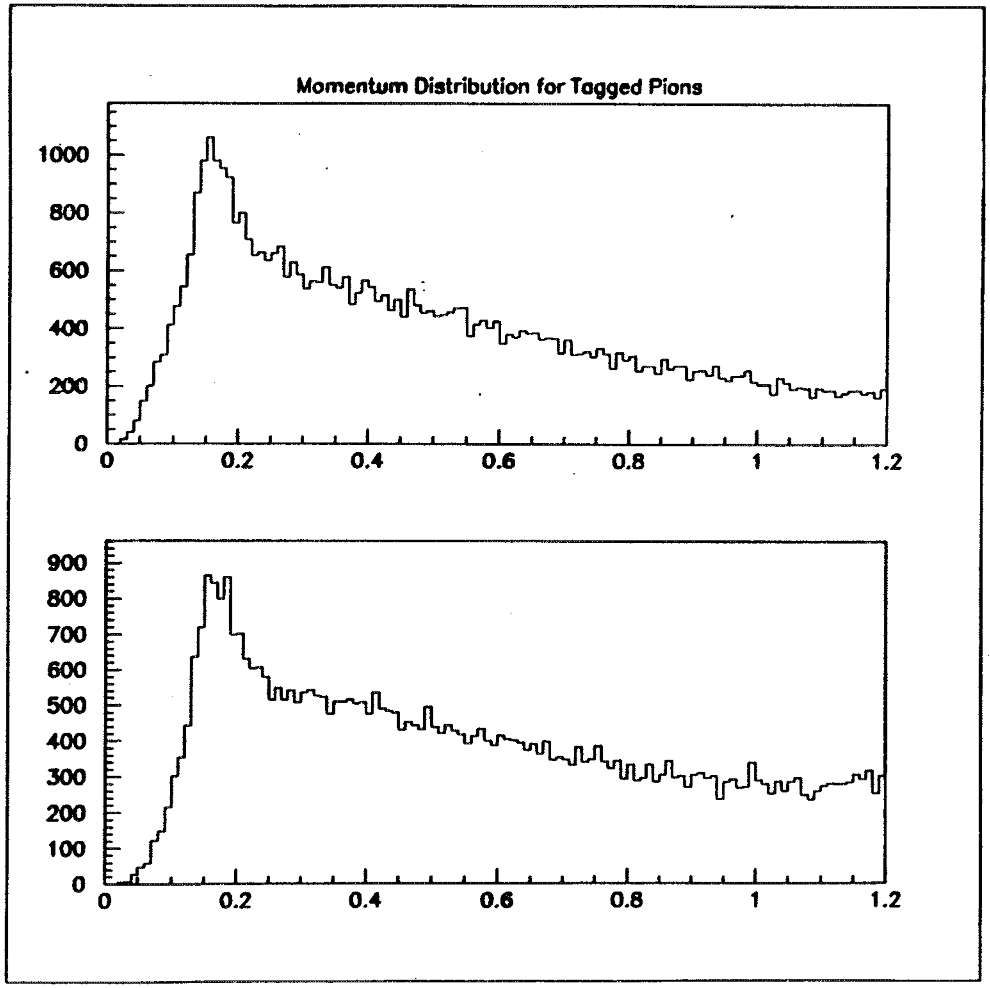


Pion Production Experiment

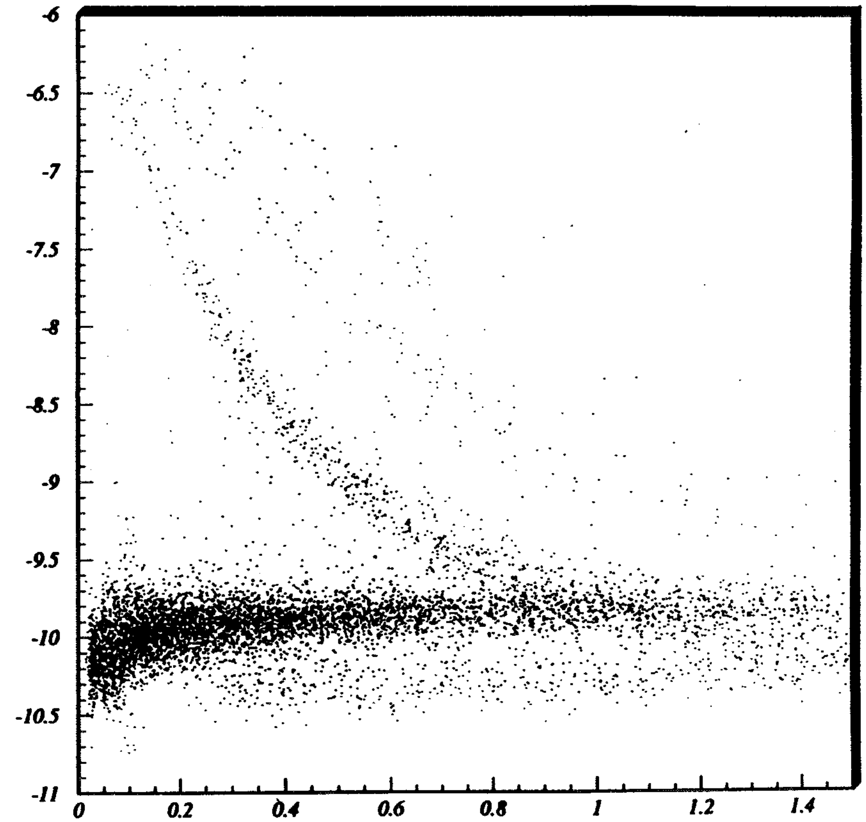
Milestones

- Winter-Spring 96: E910 Run at BNL
- Summer 96: Quick Analysis of 10 % data
- Fall-Winter 96: Code Fine Tuning
  Hit Finding and Tracking
  Calibrations
- Spring 97: Data Reduction of 2 % data
- Summer 97: Data Analysis of 2 % data

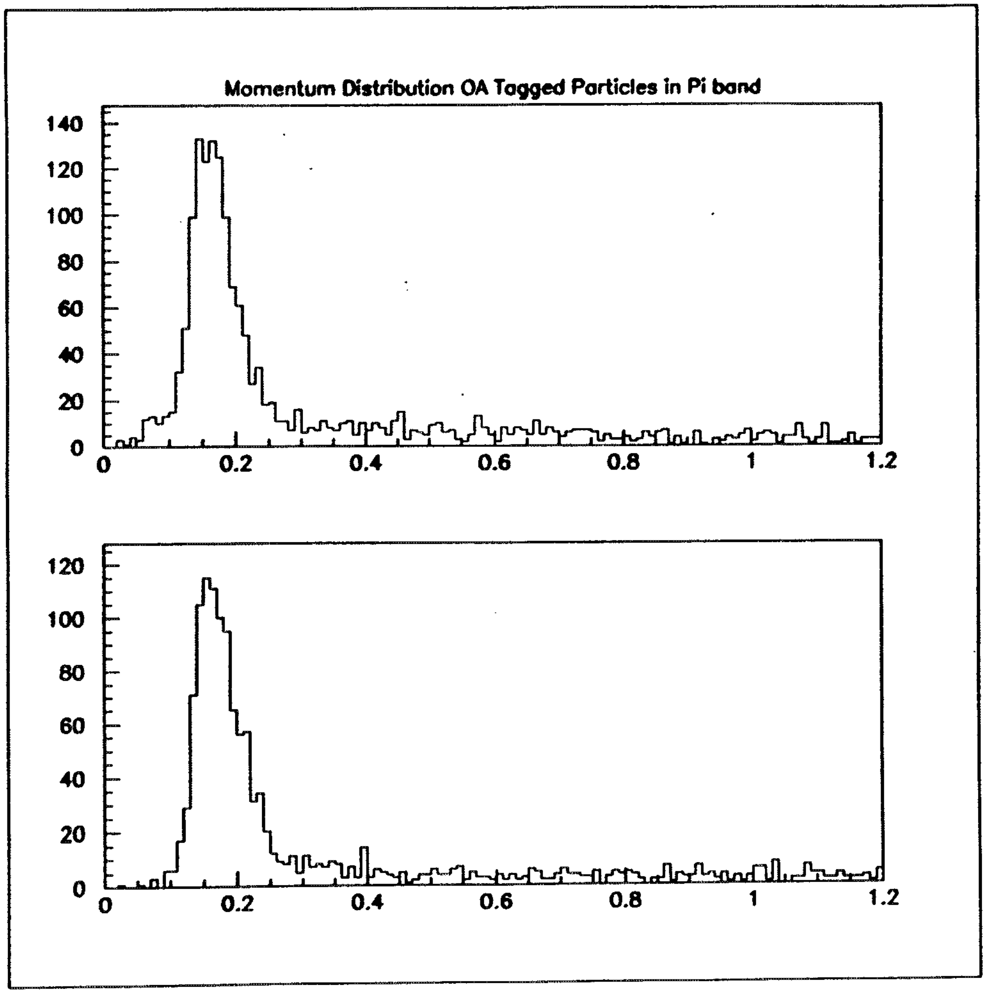

-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
0
0.1
0.2
0.3
0.4
0.5
0.6
-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
0
0.1
0.2
0.3
0.4
0.5
0.6



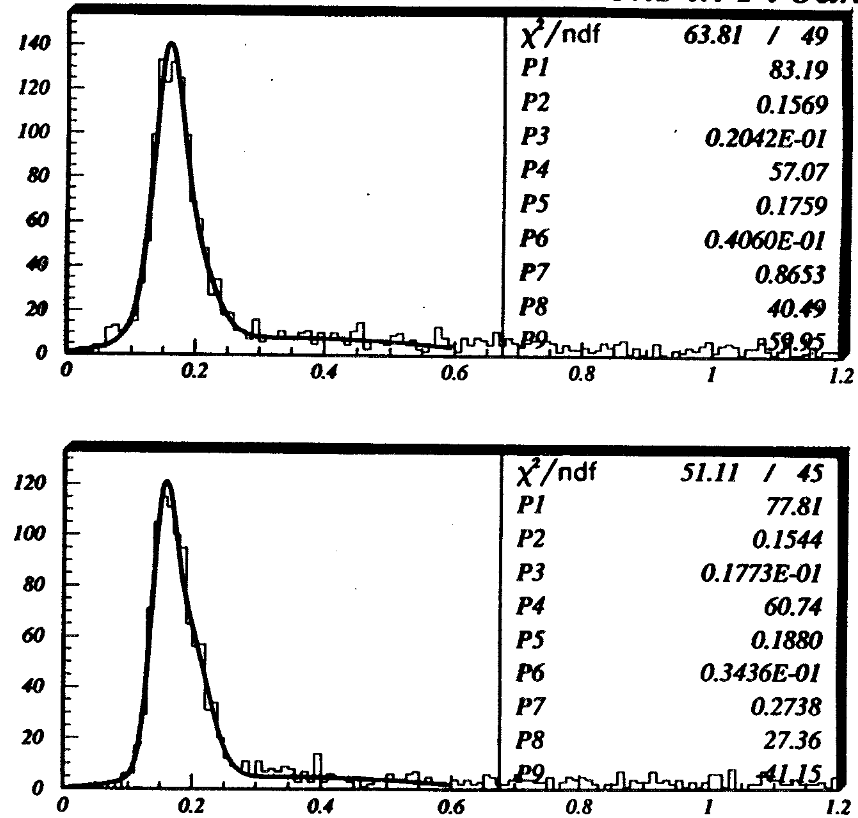
Momentum Distribution for Tagged Pions
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
1.2
900
800
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2



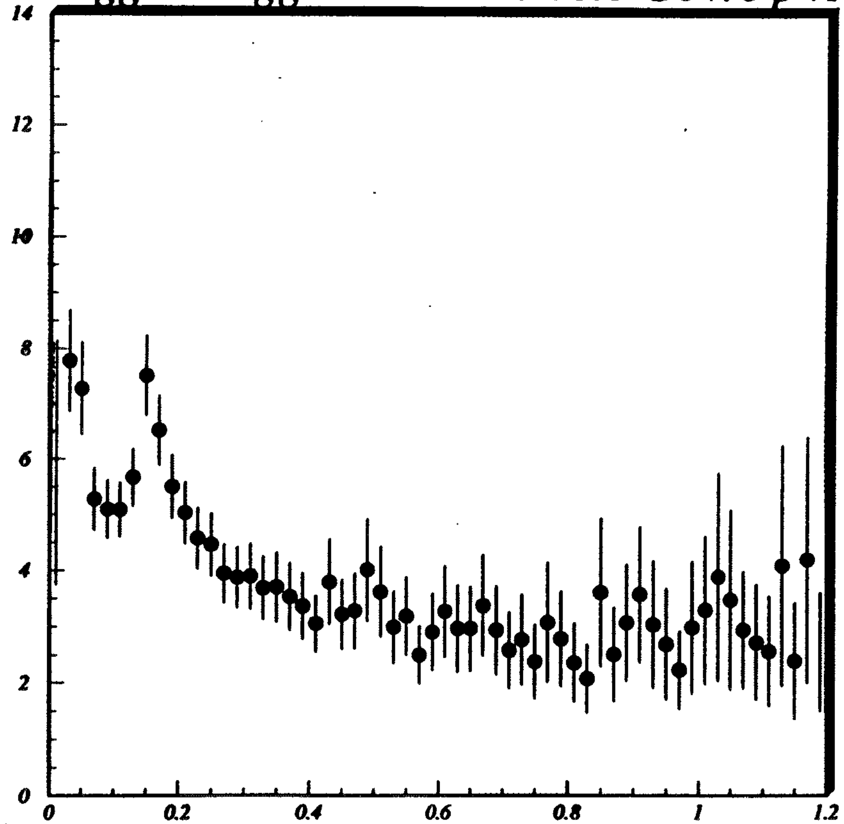
-6
-6.5
-7
-7.5
-8
-8.5
-9
-9.5
-10
-10.5
-11
0
0.2
0.4
0.6
0.8
1
1.2
1.4

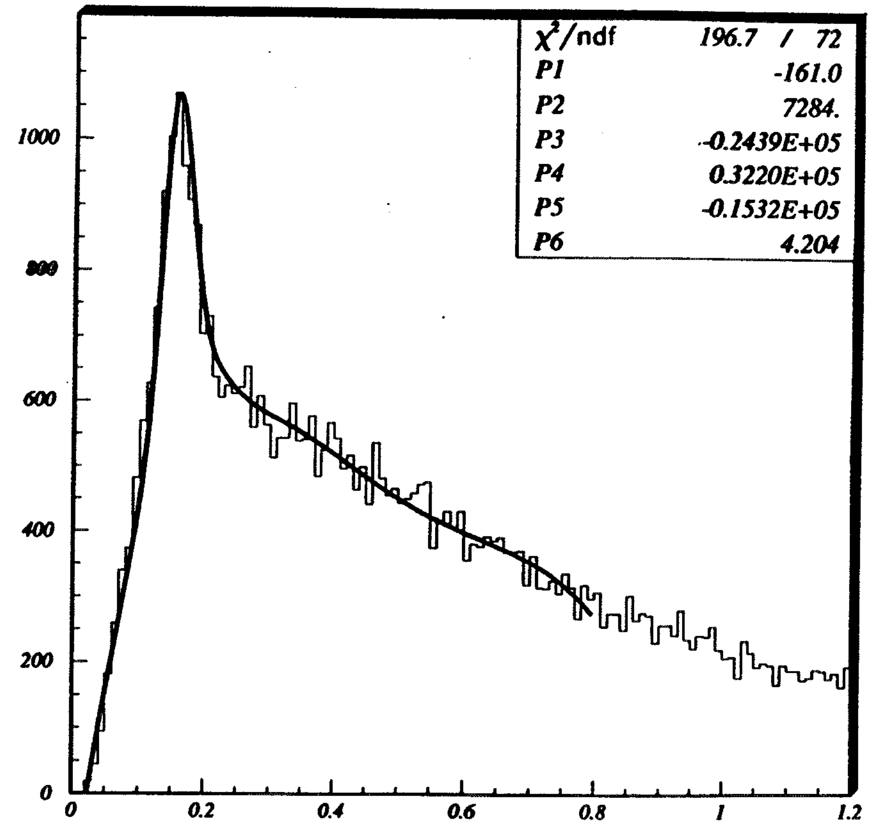


Momentum Distribution electrons in Pi band

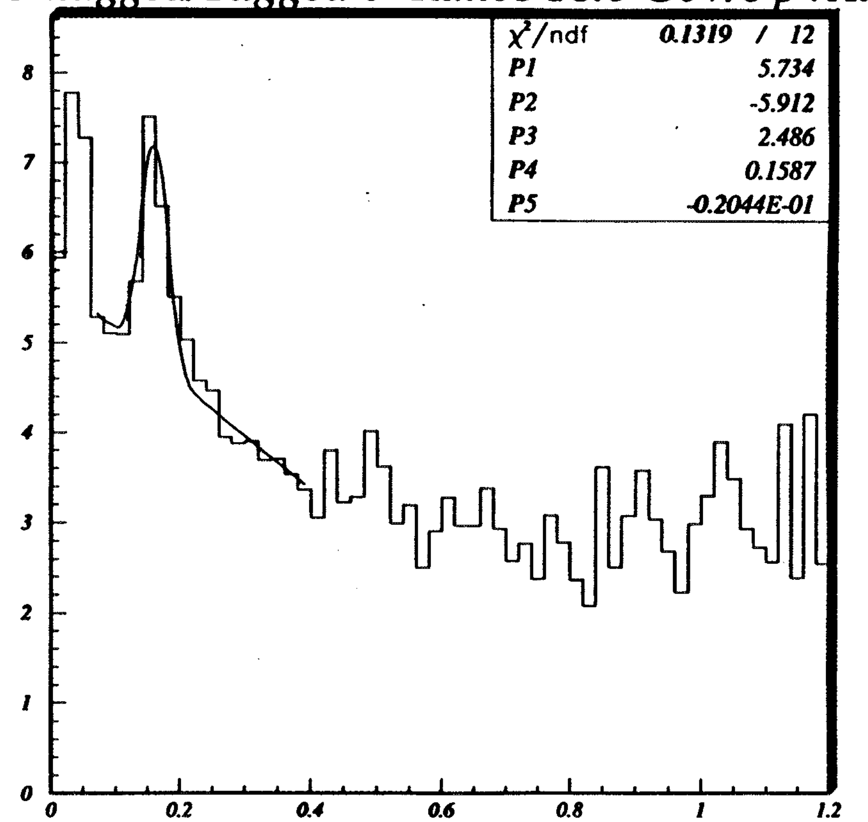


TOTAL
~~Untagged~~/Tagged e- Ratios 18.0 GeV/c p+Au

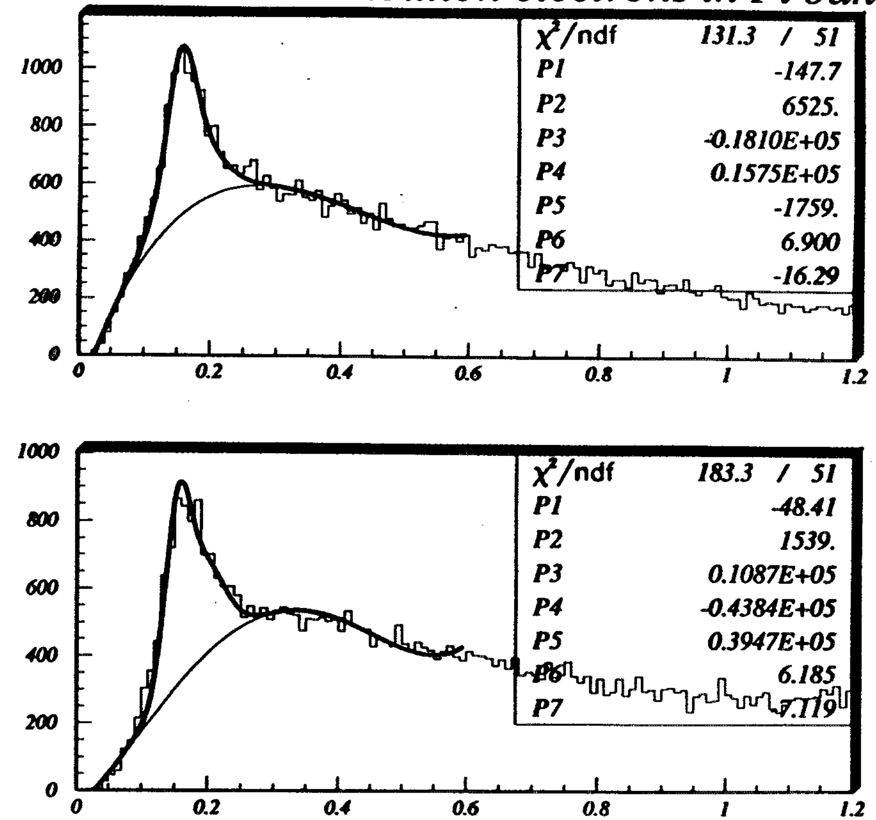


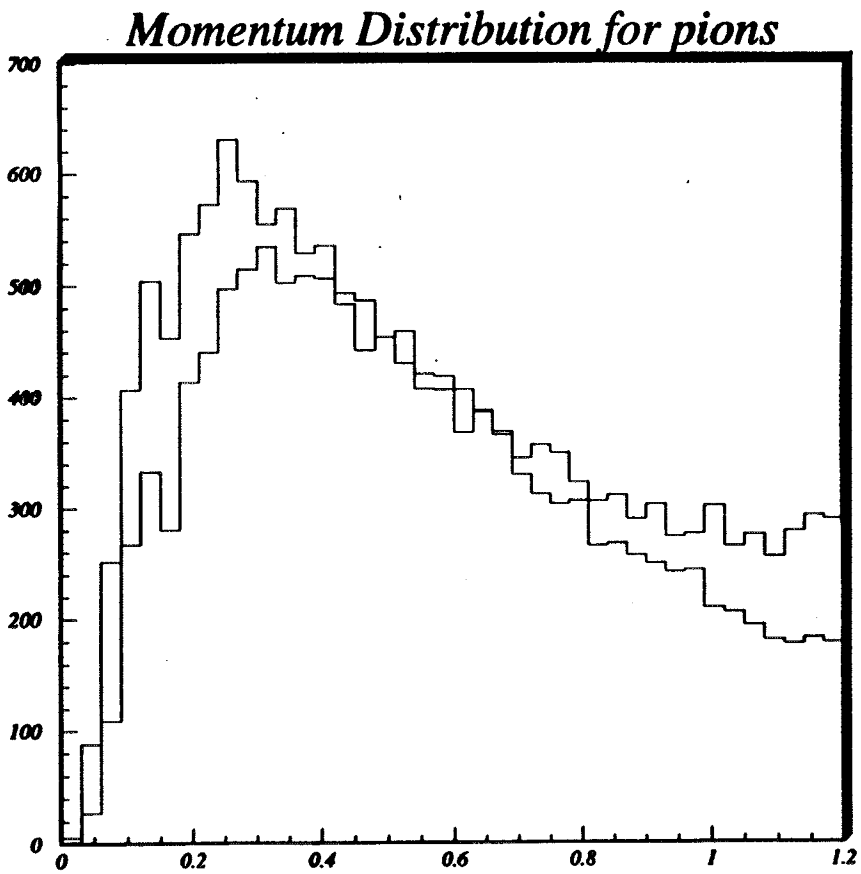


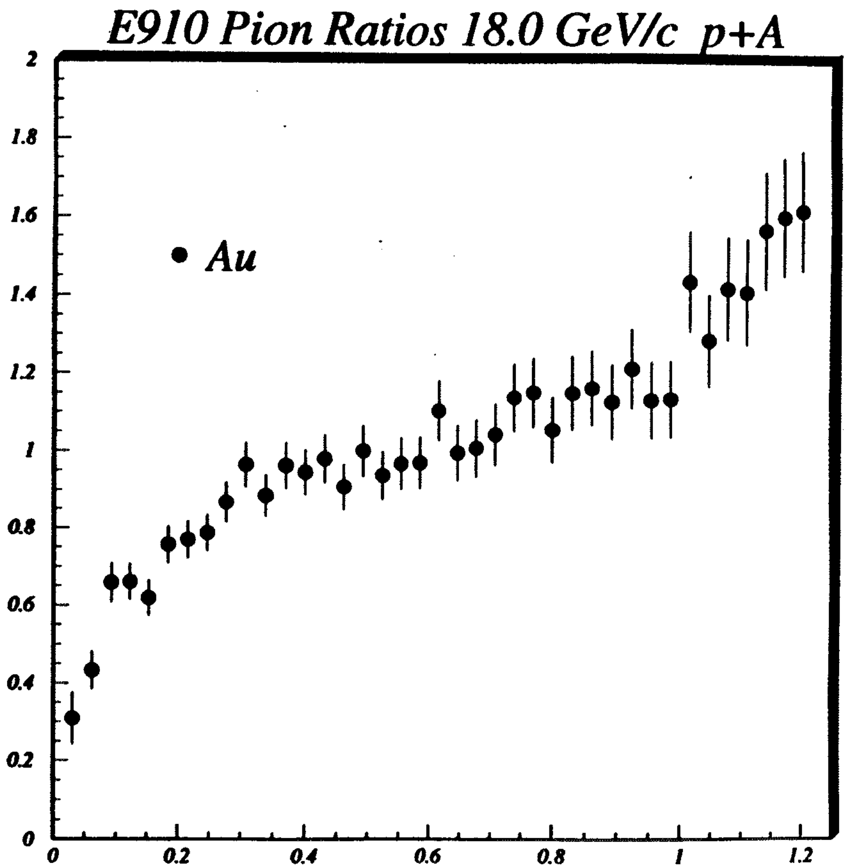
~~Untagged~~ TOTAL/Tagged e- Ratios 18.0 GeV/c p+Au

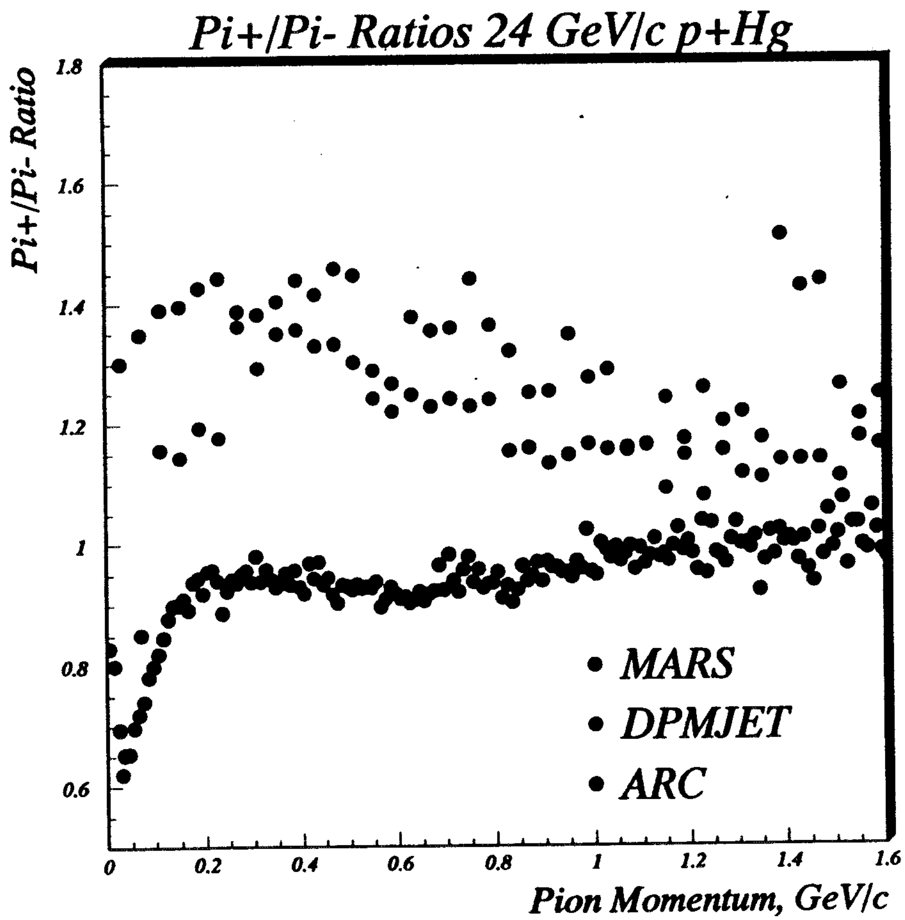


Momentum Distribution electrons in Pi band




Momentum Distribution for pions
700
600
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2


E910 Pion Ratios 18.0 GeV/c p+A
Au
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2


Pi+/Pi- Ratios 24 GeV/c p+Hg
Pi+/Pi- Ratio
1.8
1.6
1.4
1.2
1
0.8
0.6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Pion Momentum, GeV/c
MARS
DPMJET
ARC

LIQUID JET TARGETS

K. McDONALD 12/13/97
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See MuMu-97-3 at http://puhep1.princeton.edu/~mcdonald/mumu
especially sec. 2.

PRIMARY TARGET: HIT BY ~ 10^{15} PROTON/SEC AT 15-30 GeV
15-Hz BEAM
~2 INTERACTION LENGTH TARGET
⇒ ~ 100 JOULES/PULSE DEPOSITED
⇒ SHOCK THAT CRACKS SOLID TARGET,
OR PIPE SURROUNDING LIQUID TARGET
(AT ~ONLY ~ 1°C/PULSE)

SOLUTION: LIQUID JET TARGET

CANDIDATE METALS: In-Pb-Sn ALLOYS (~~Bi~~)

ex: In/Sn 50/50 M.P. = 120°C ($Z_{In}=49$, $Z_{Sn}=50$)

Pb/Sn 38/62 M.P. = 183°C ($Z_{Pb}=82$)

$\rho \approx 10\ g/cm^3$, $\sigma \sim \frac{1}{50}\sigma_{copper}$

BUT, TARGET IS SURROUNDED BY 20-T SOLENOID
FOR GOOD PION CAPTURE

⇒ CONDUCTING LIQUID DEVELOPS BODY CURRENT
AS IT ENTERS THE $\vec{B}$ FIELD.

MAGNETO HYDRODYNAMICS!

WILL A STRONG MAGNETIC FIELD REPEL A METAL JET?

MAGNETO-HYDRODYNAMICS § 3.13

infinitely conducting plasma column. Even the growth rates agree within a factor of 2 (Murty, 1960, 1961). On the other hand, when an axial magnetic field is present, a high or low conductivity makes a considerable difference.

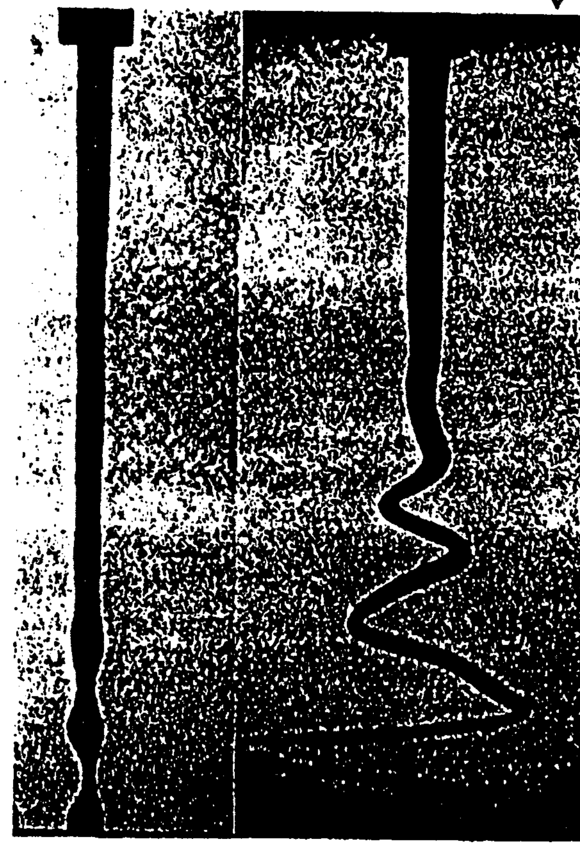
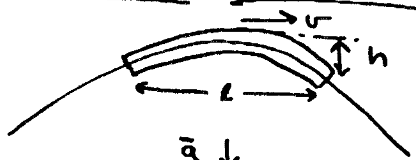


FIG. 3.19. Pictures of falling mercury jet carrying electric current. (a) In the absence of an axial magnetic field, sausage instabilities develop. (b) When an axial magnetic field (300 gauss) is present, the column is deformed into a spiral.

Gravitational Curvature



$\bar{g}\downarrow$

$$h = \frac{1}{2} g t^2 = \frac{g(l/2)^2}{2v^2}$$

$$\Rightarrow \quad v = \sqrt{\frac{g l^2}{8h}}$$

EX: $l \sim 30\,\text{cm} \sim 2\lambda_{INT}$

DESIRE $h \approx \frac{1}{8}$ cm

$\Rightarrow \quad v \sim 1000$ cm/s $=$ 10 m/s

COMPARE: IF EACH PROTON PULSE SEES A DIFFERENT JET,

15-Hz REP RATE, $l = 30$ cm $\Big\} \Rightarrow v > 15 \cdot 30 = 450$ cm/s $= 4.5$ m/s

Magnetic Reynolds Number

LAB FRAME: JET HAS VELOCITY $\bar{v}$

LAB FIELDS $\bar{E}, \bar{B}$ (= SUM OF EXTERNAL + INDUCED FIELDS)

JET REST FRAME: $E' = \bar{E} + \bar{v} \times \bar{B}$ ($v \ll c$, MKSA UNITS)

$\Rightarrow$ EDDY CURRENTS $\bar{J} = \sigma E' = \sigma(\bar{E} + \bar{v} \times \bar{B})$

σ = CONDUCTIVITY

MAXWELL: $\bar{\nabla} \times \bar{E} = -\frac{\partial \bar{B}}{\partial t}$, $\quad \bar{\nabla} \times \bar{B} = \mu_0 \bar{J}$

(NEGLECTING DISPLACEMENT CURRENT)

ELIMINATE $\bar{J}, \bar{E}$: $\quad \underbrace{\frac{\partial \bar{B}}{\partial t} = \frac{\nabla^2 \bar{B}}{\mu_0 \sigma}}_{\text{DIFFUSION EQUATION}} + \underbrace{\bar{\nabla} \times (\bar{v} \times \bar{B})}_{\text{SMALL IF } \bar{v} \text{ SMALL}}$

$\Rightarrow$ DIFFUSION TIME $\tau \approx \mu_0 \sigma r^2$ FOR JET OF RADIUS r.

$$\approx (4\pi \times 10^{-7})(10^6)(10^{-2})^2 \approx 10^{-4}\,\text{s}$$

FOR $\sigma = 2\%$ OF Cu, $r = 1$ cm

COMPARE TO TIME DURING WHICH MAGNETIC FIELD VARIES APPRECIABLY: $\frac{D}{v}$, D = DIAMETER OF SOLENOID

$R = \frac{\tau v}{D} \approx \frac{10^{-4} \cdot 10}{0.3} \approx 0.003$ = MAGNETIC REYNOLD'S #

$R \gg 1 \Leftrightarrow \bar{B}$ DOESN'T PENETRATE CONDUCTOR

$\ll 1 \Leftrightarrow \bar{B}$ DOES PENETRATE

ANOTHER VIEW: CONSIDER SKIN DEPTH

FREQUENCY $\omega \lesssim \frac{v}{D}$

$$\delta = \sqrt{\frac{2}{\mu_0 \omega \sigma}} \approx \sqrt{\frac{2D}{\mu_0 \sigma v}}$$

COMPARE TO RADIUS OF CONDUCTOR:

$$\left(\frac{r}{\delta}\right)^2 = \frac{\mu_0 \sigma r^2 v}{2D} = \frac{R}{2}$$

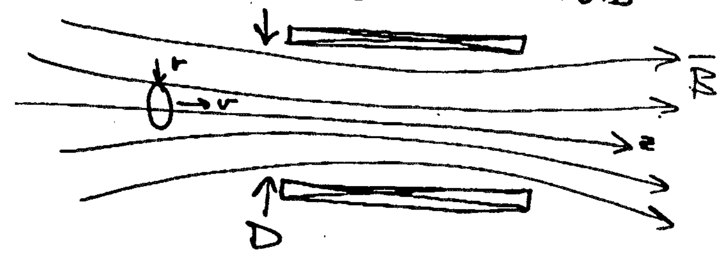
LOW MAGNETIC REYNOLD'S # $\Leftrightarrow$ CONDUCTOR IS SMALL COMPARED TO SKIN DEPTH.

OUR CANDIDATE METALS DO NOT EXCLUDE THE SOLENOID FIELD (VIA SURFACE CURRENTS)

$\Rightarrow B_{INTERNAL} \approx B_{SOLENOID}$

SIMPLE ANALYSIS OF EDDY CURRENTS AND $\vec{J} \times \vec{B}$ FORCE

I. JET MOVES ALONG AXIS OF SOLENOID



CONSIDER LOOP OF RADIUS r, WITH VELOCITY v ALONG z

RADIAL EXTENT Δr

LONGITUDINAL EXTENT Δz

$\Rightarrow$ RESISTANCE $R = \frac{2\pi r}{\sigma \Delta r \Delta z}$ AROUND LOOP.

$\Rightarrow$ INDUCED CURRENT $I = \frac{\mathcal{E}}{R} = \frac{\dot{\Phi}}{R} \approx \frac{\pi r^2 \dot{B}_z(0,z)}{R} = \frac{\pi r^2 B_z' v}{R}$

$$= \frac{\sigma r v B_z' \Delta r \Delta z}{2}$$

RETARDING FORCE DUE TO $\bar{I}_\phi \times \bar{B}_r$, WHERE $B_r \approx \frac{r}{2} B_z'$

ΔF_z ON LOOP $= 2\pi r I B_r = -\pi \sigma r^3 (B_z')^2 v \frac{\Delta r \Delta z}{2}$

INTEGRATE OVER RADIUS: $F_z = -\pi \sigma r^4 (B_z')^2 \frac{v \Delta z}{8}$

$$= m\dot{v} = \pi r^2 \Delta z \rho v' v$$

$$\Rightarrow \quad v' = -\frac{\sigma r^2 (B_z')^2}{8\rho}$$

CONFIRMATION: WEGGEL, WALKER & WELLS (ORNL, 1979)

For solenoid of diameter D, $B_{z,max}' \approx \frac{B_0}{D}$

⇒ $v' \approx \frac{\Delta v}{D} \approx -\frac{\sigma r^2 B_0^2}{8 \rho D^2}$

or $\Delta v \approx -\frac{\sigma r^2 B_0^2}{8 \rho D}$

⇒ Jet won't reach center of solenoid if initial velocity too small!

Ex: $\sigma = 10^6$, $r = 1\,cm$, $B_0 = 20T$, $\rho = 10\,\frac{gm}{cm^3} = 10^4\,\frac{kg}{m^3}$

$D \approx 0.3\,m$

⇒ $v_{min} \approx 2\,m/s$

Compare: If each jet pulse is ~30 cm long (2 λ), and have 15 pps, must have $v > 5\,m/s$ so that each beam pulse sees a different jet pulse.

Also, radial forces! $\Delta F_r = -2\pi r I B_z$

⇒ radial pressure gradient

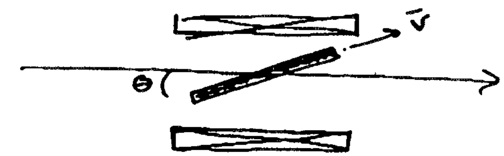
$$\Delta P_r = \frac{\Delta F_r}{2\pi r \Delta z} = -\frac{I B_z}{\Delta z} = -\frac{\sigma r v B_z B_z'}{2} \Delta r$$

Integrate from $r=0$: $\Delta P_r = -\frac{\sigma r^2 v B_z B_z'}{4} \approx -\frac{\sigma r^2 v B_0^2}{4D}$

≈ 3 atm for $v = 10\,m/s$

? Not a problem?

L. Jet at Angle to Solenoid Axis



Full equation of motion for incompressible fluid:

$$\rho \frac{d\vec v}{dt} = -\vec\nabla P + \rho \vec g + \eta \nabla^2 \vec v + \vec J \times \vec B$$

(pressure, gravity, viscosity)

If eddy effects dominate, use $\vec J = \sigma(\vec E + \vec v \times \vec B)$

$$\rho \frac{d\vec v}{dt} = \sigma(\vec E + \vec v \times \vec B) \times \vec B = \sigma(\vec E_\perp \times \vec B - B^2 \vec v_\perp)$$

⊥ ⇔ perp to $\vec B$. [Cowling, 1957 'Magnetohydrodynamics']

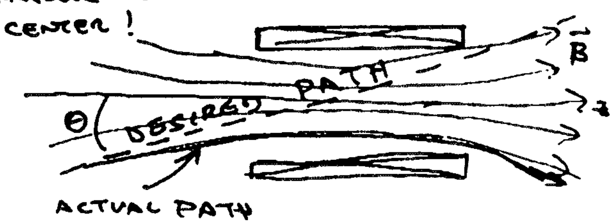
⇒ $\rho \frac{d\vec v}{dt}\Big|_\perp \approx \rho \frac{d\vec v_\perp}{dt} = -\sigma B^2 \vec v_\perp$ A diffusion equation

⇒ Damping time $\tau_\perp \approx \frac{\rho}{\sigma B^2} \approx \frac{10^4}{10^6 (20)^2} \sim 2.5 \times 10^{-5}\,s$

for velocity ⊥ to $\vec B$. ['Magnetic viscosity', Chandrasekhar]

⇒ Jet will tend to follow field lines during time $\frac{D}{v} = \frac{0.3}{10} = 0.03\,s$, as it enters the solenoid

⇒ Jet will be parallel to solenoid axis when at solenoid center!



Compare to Ordinary Viscosity

Magnetic viscosity volume force $\approx \sigma B^2 v_\perp$

Ordinary viscosity volume force $\approx \eta \frac{v_\perp}{r^2}$ for jet of radius r.

Hartmann Number (1937) $= \sqrt{\frac{\sigma B^2 v_\perp}{\eta v_\perp / r^2}} = rB\sqrt{\frac{\sigma}{\eta}} \approx (0.01)(20)\sqrt{\frac{10^6}{10^{-3}}}$

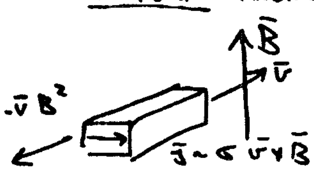
$\approx 6\times 10^4$ ⇒ can neglect ordinary viscosity

using $\eta \approx 10^{-3}$ MKS, as for mercury.

But is Cowling's Argument Relevant?

It implies a strong retarding force on a conductor moving at right angles to a uniform magnetic field

(??) $\bar{F} \sim \bar{J}\times\bar{B} \sim -\bar{v}B^2$



$\bar{J} \sim \sigma \bar{v}\times\bar{B}$ (??)

But the current $\bar{J}$ would quickly lead to a charge separation

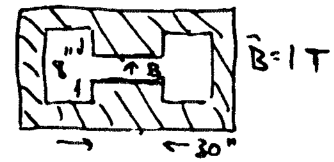
⇒ static field $\bar{E}$ that opposes $\bar{v}\times\bar{B}$

Then $\bar{J} = \sigma(\bar{E} + \bar{v}\times\bar{B}) \to 0$!!

Laboratory Observations of Eddy Currents

Princeton cyclotron magnet

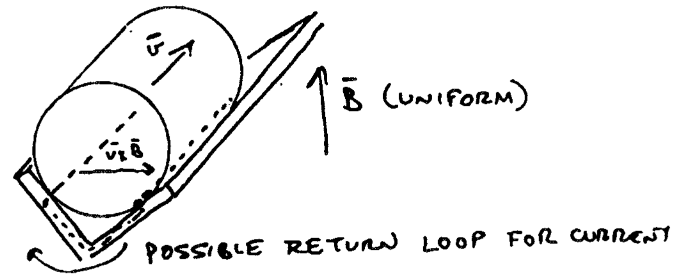
Brass spheres, discs, rods



Spheres: no drag force for linear motion, either in fringe or central field; drag torque when rotation

Discs, rods; drag force for linear motion only in fringe field;
drag force for curved motion
strong drag torque when rotation.

Attempt to display Cowling's effect

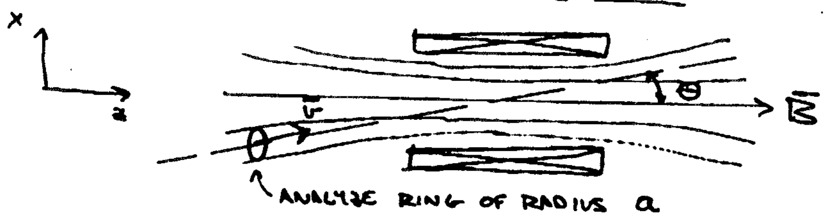


But, no drag detected!

⇒ field gradients can produce drag on jet, but not a uniform field;

ignore $-\bar{v}B^2$ term!

Jet at Angle Θ to Solenoid Axis

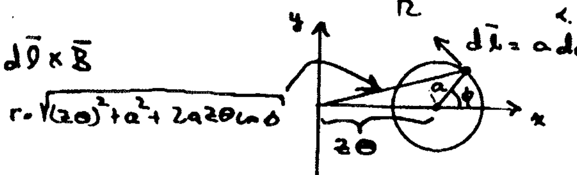


EDDY CURRENTS FLOW IN LOOPS ⊥ TO $\vec{B}$

IDEALIZATION: CIRCULAR LOOPS ⊥ TO $\hat{z}$ = SOLENOID AXIS

AS BEFORE, EDDY CURRENT $I = -\frac{\dot{\Phi}}{R} \approx -\frac{\sigma a v_z B_z'}{4} \Delta r \Delta z$

$F = \int I\, d\vec{l} \times \vec{B}$



$B_z(r,z) \approx B_z - \frac{r^2}{4} B_z''$; $B_r(r,z) \approx -\frac{r}{2} B_z'$

↖ ON AXIS

$\vec{B} = (B_x, B_y, B_z(r,z)) = \left(-\frac{B_z'}{2}(z\Theta + a\cos\phi), -\frac{B_z'}{2} a\sin\phi, B_z - \frac{(z\Theta)^2 + a^2 + 2az\cos\phi}{4} B_z''\right)$

INTEGRATE FORCE OVER DISC OF RADIUS a:

$$\vec{F} = \frac{\pi \sigma a^4 v_z B_z' \Delta z}{8}\left(\hat{x}\frac{z\Theta B_z''}{2} - \hat{z} B_z'\right)$$

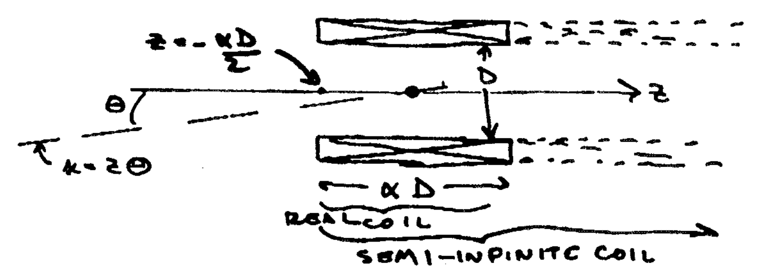
↖ FOUND IN PREVIOUS ANALYSIS

TRANSVERSE DRAG FORCE ↗

$\vec{F} = m\dot{\vec{v}} = \pi a^2 \Delta z\, \rho\, v_z \vec{v}\,'$

$\Rightarrow \quad v_x' = \frac{\sigma a^2 z \Theta B_z' B_z''}{16\rho} \qquad v_z' = \frac{-\sigma a^2 (B_z')^2}{8\rho}$

Approximate Real Solenoid by Semi-Infinite Solenoid



FIELDS ON AXIS: $B_z = \frac{B_0}{2}\left(1 + \frac{w}{\sqrt{1+w^2}}\right)$, $w = \frac{2z}{D} + \alpha$

$B_z' = \frac{B_0}{D} \frac{1}{(1+w^2)^{3/2}}$ $\qquad \alpha = \frac{\text{LENGTH}}{\text{DIAMETER}}$

$B_z'' = -\frac{6 B_0}{D^2} \frac{w}{(1+w^2)^{5/2}}$

INITIAL VELOCITY $v_{z,-\infty}$, $v_{x,-\infty} = \Theta v_{z,-\infty}$

$$\Rightarrow \quad v_x(z) = \Theta\left\{v_{z,-\infty} - \frac{3\sigma a^2 B_0^2}{1024\rho D}\left[\frac{\pi}{2} + \tan^{-1} w + \frac{w}{1+w^2} + \frac{2w}{3(1+w^2)^2} - \frac{16z}{3D(1+w^2)^3}\right]\right.$$

$$v_z(z) = v_{z,-\infty} - \frac{3\sigma a B_0^2}{128\rho D}\left[\frac{\pi}{2} + \tan^{-1} w + \frac{w}{1+w^2} + \frac{2w}{3(1+w^2)^2}\right]$$

≈ π WHEN z = 0 ← CENTER OF MAGNET

EXAMPLE : α = 2

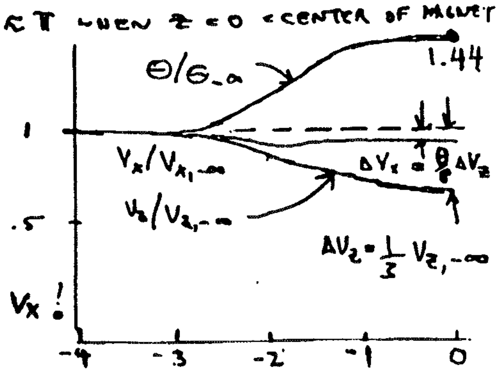
$v_{z,-\infty} = 3\Delta v_z$

$\Delta v_x = \frac{1}{8}\Theta \Delta v_z$ SMALL

$\Rightarrow \Theta = \frac{v_x}{v_z}$ ACTUALLY INCREASES

SINCE v_z DECREASES MORE THAN v_x !

⇒ CAN USE CONDUCTING JET



OTHER OPTIONS

1. REDUCE EDDY CURRENT EFFECTS BY USING SLURRY OF METAL POWDER.
   EX: TUNGSTEN READILY AVAILABLE IN 1 μm GRAINS.
   APPARENTLY A WATER SLURRY WITH 80% TUNGSTEN (BY WEIGHT) IS STILL A LIQUID (90% ⇒ TOOTHPASTE).

   ? 'MAGNETIC VISCOSITY' ANALYSIS DID NOT DISPLAY A LENGTH SCALE. WILL IT BE REDUCED FOR A METAL POWDER?

2. TUNGSTEN CARBIDE SLURRY ($\rho_{WC} = 15 g/cm^3$)

   COULD USE $SnCl_4$ (M.P. = −33°C, B.P. = 120°C)
   OR $SnBr_4$ (M.P. = +33°C, B.P. = 200°C)
   AS SLURRY BASE. (SOME IONIC CONDUCTIVITY)
   [ALSO: C. RUBBIA, C. JOHNSON]

3. LOW-MELTING TEMP OXIDES (SUMMERS)

R & D AT PRINCETON

HAVE Bi:Pb (MP = 255 F) & Bi:PbSnIn (MP = 137 F)
OBTAINING POWDERED W & WC FOR SLURRIES
(+ $SnCl_4$, $SnBr_4$, $TiCl_4$, $TiBr_4$)

RECENTLY FOUND OUR 'MISSING' 8-T MAGNET, WITH 1" DIAMETER ROOM TEMP HORIZONTAL BORE BUILT BY JANIS (1970).

WILL ATTEMPT TO RECOMISSION FOR JET STUDIES (& FOR LOW-PRESSURE TPC).

TARGET MATERIALS

D. Summers - Mississippi

13 DEC 1997 San Francisco
Muon Collider Collaboration
MEETING

NON-CONDUCTIVE

Mat.	Z	ρ	MP	BP	
PtO_2	78	10.2	450°C		$250/oz
Re_2O_3	75	8.4	145°C		NO SOURCE
WBr_6	74	6.9	19°C	48°C	"
ReF_6	75	6.2	19°C	48°C	
I	53	4.9	114°C	184°C	
Xe	54	3.5	-112°C	-107°C	

CAVEATS: DISSASSOCIATION TEMP.
SUBLIMATION

LOOK INTO ZINC DIE CAST INJECTORS

HIGH RESISTIVE

Mat.	Z	ρ	MP	BP	μΩcm
Hg	80	13.5	-39°C	357°C	Poison 98
Pb	82	11.3	327°C	1744°C	340°C @ 98
37Pb/63 Sn	82		182°C		
52In/48Sn	50		118°C		
Ga	31		30°C	2403°C	

Notes:

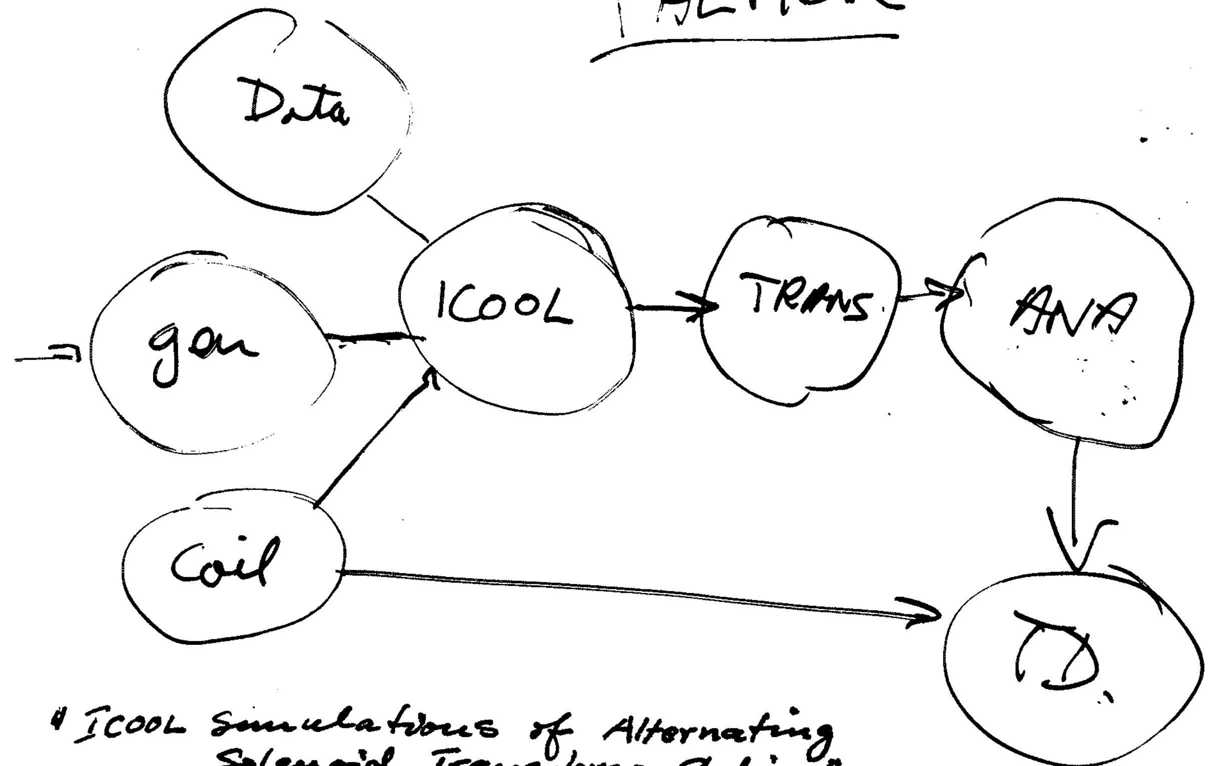
Liquid Pb has 5x RESISTANCE of the solid

Solders May too.

2 I.L. of LEAD = 34 cm

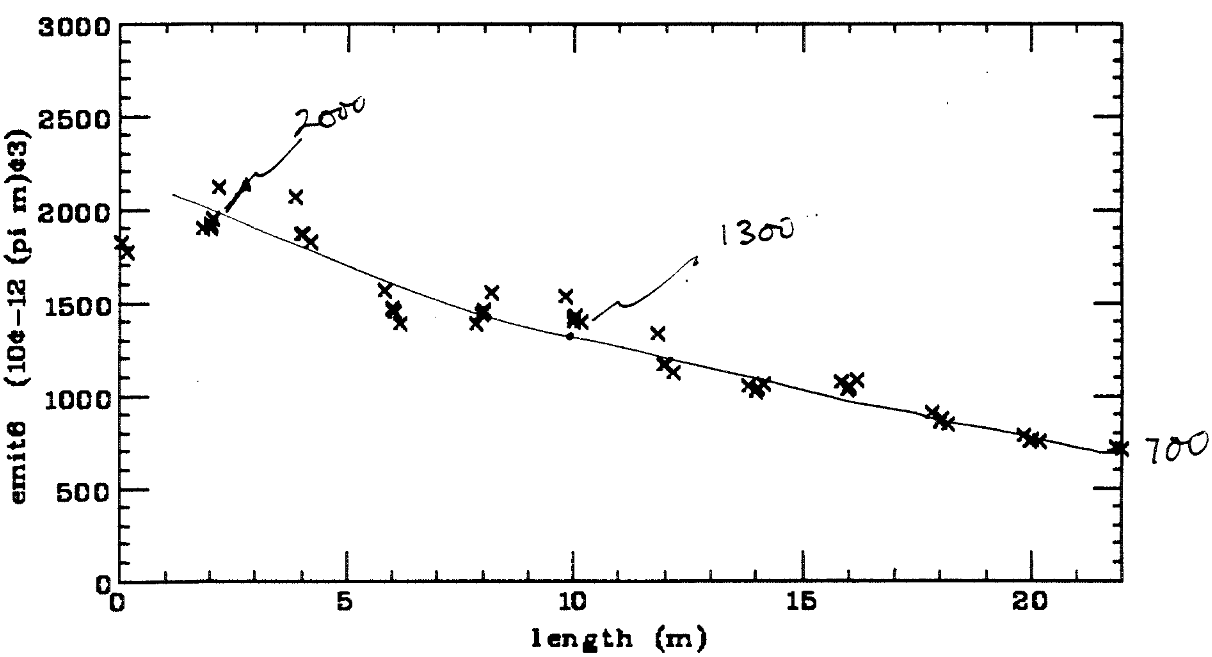
ICOOL Simulations ...

PALMER

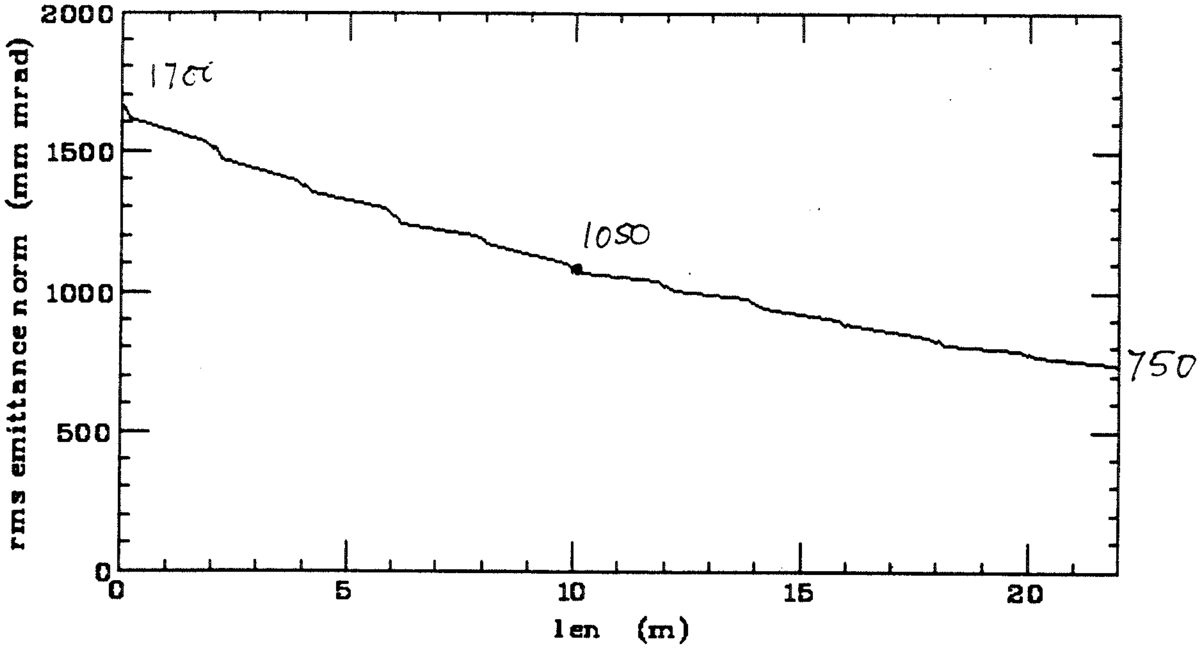


"ICOOL Simulations of Alternating Solenoid Transverse Cooling"

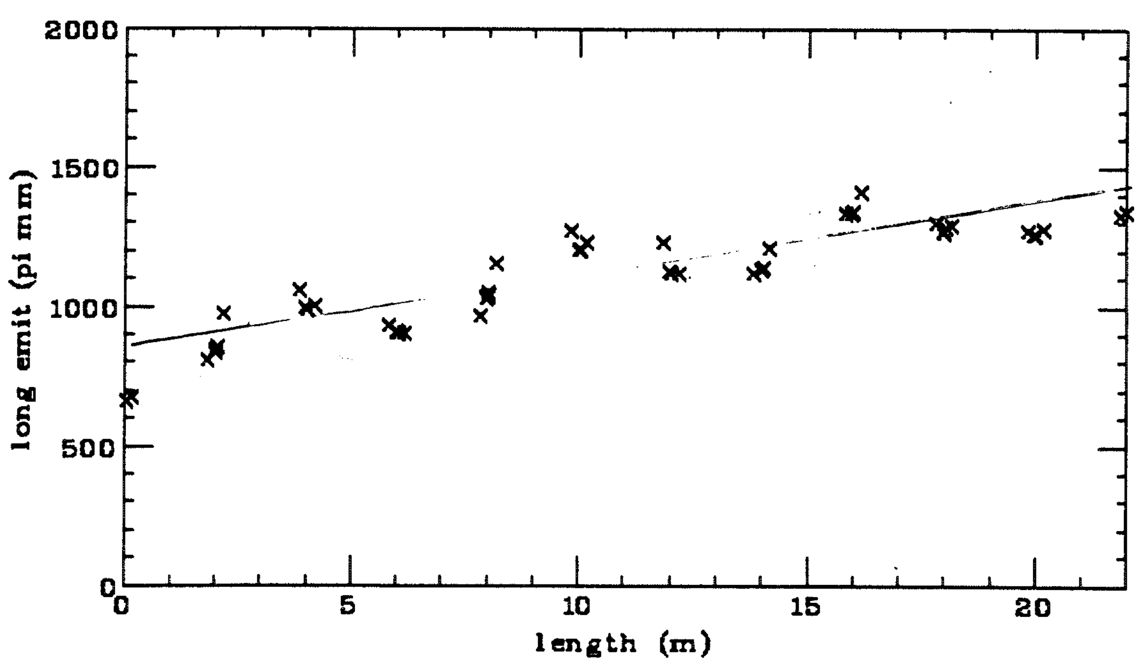
Alternating 15 T solenoids + LH (LH4)

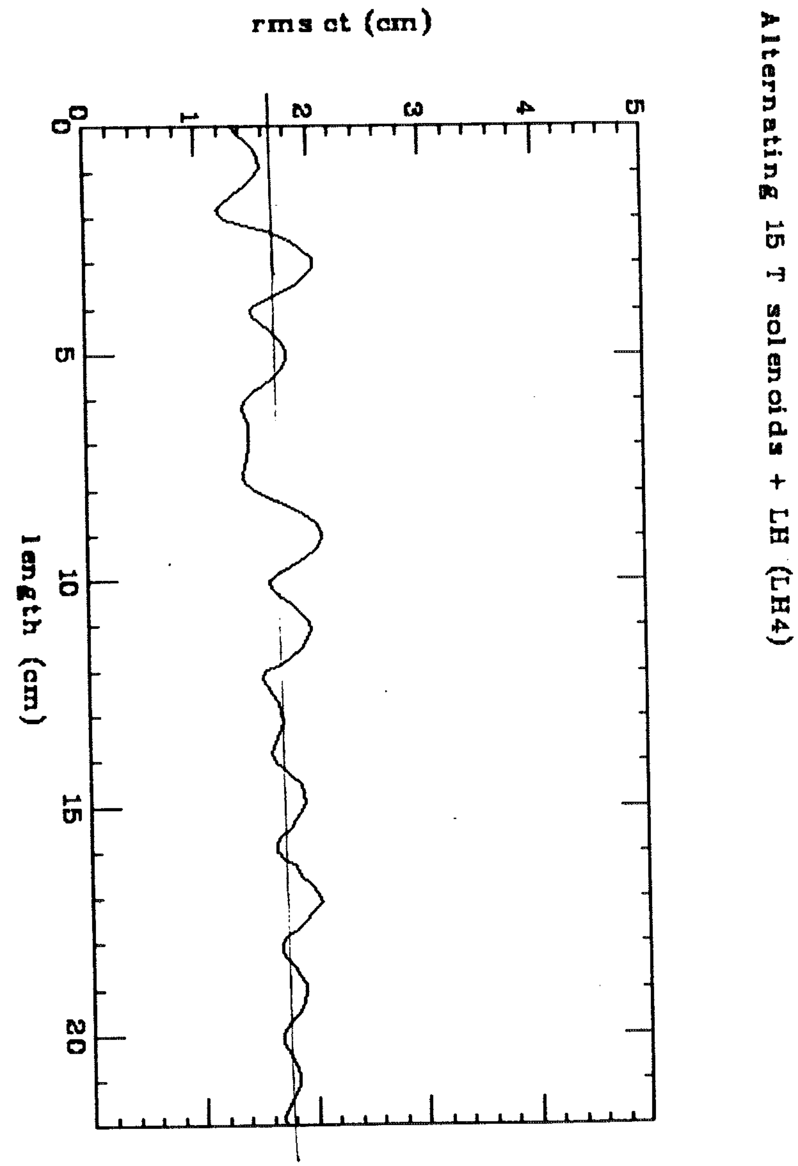


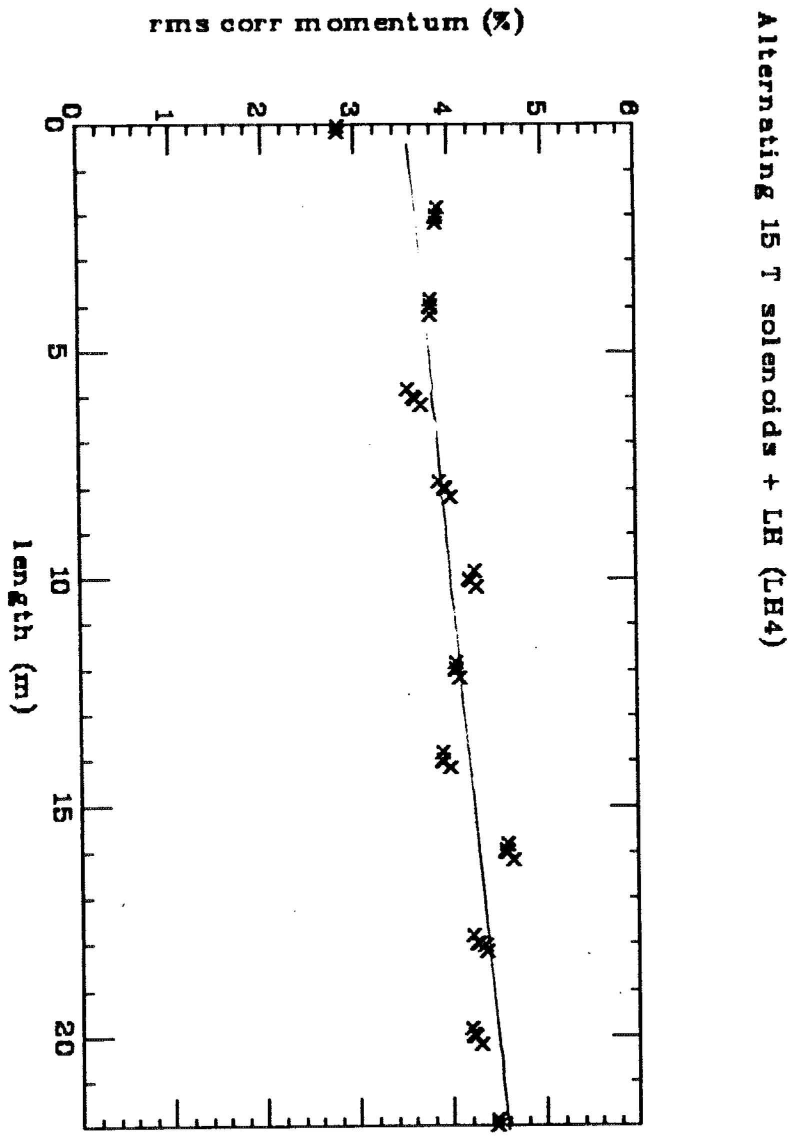
Alternating 15 T solenoids + LH (LH4)



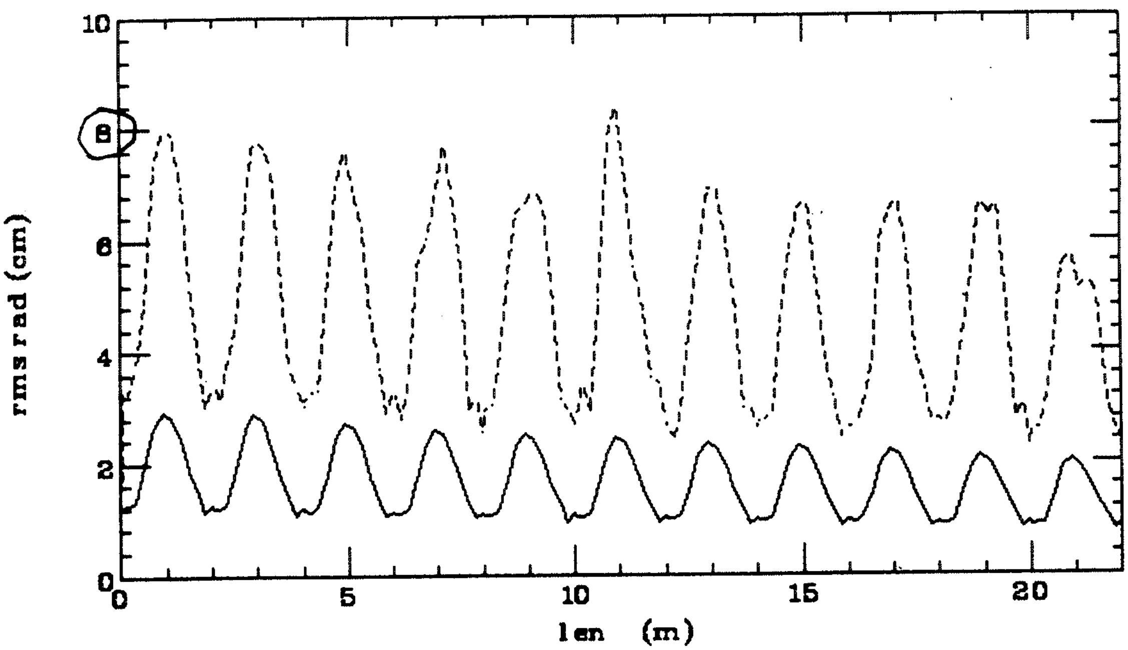
Alternating 15 T solenoids + LH (LH4)



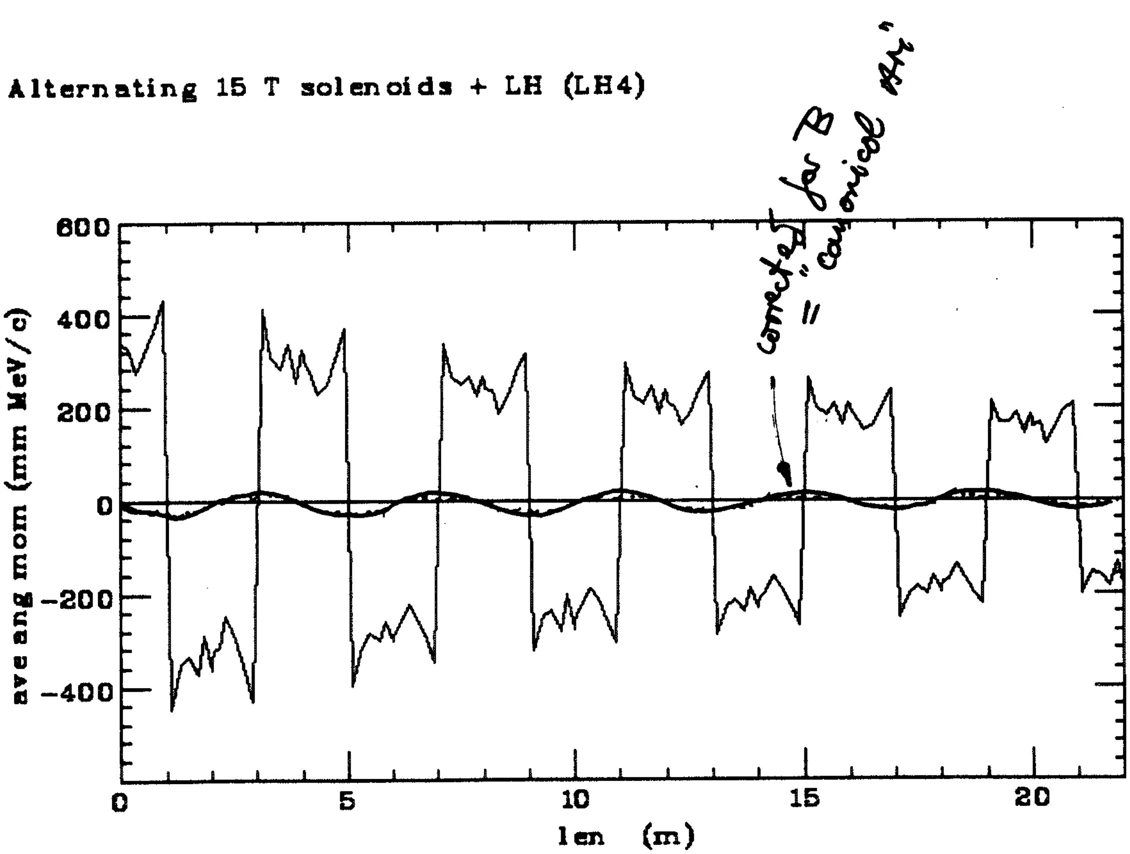

Alternating 15 T solenoids + LH (LH4)
rms ct (cm)
length (cm)
0
1
2
3
4
5
0
5
10
15
20

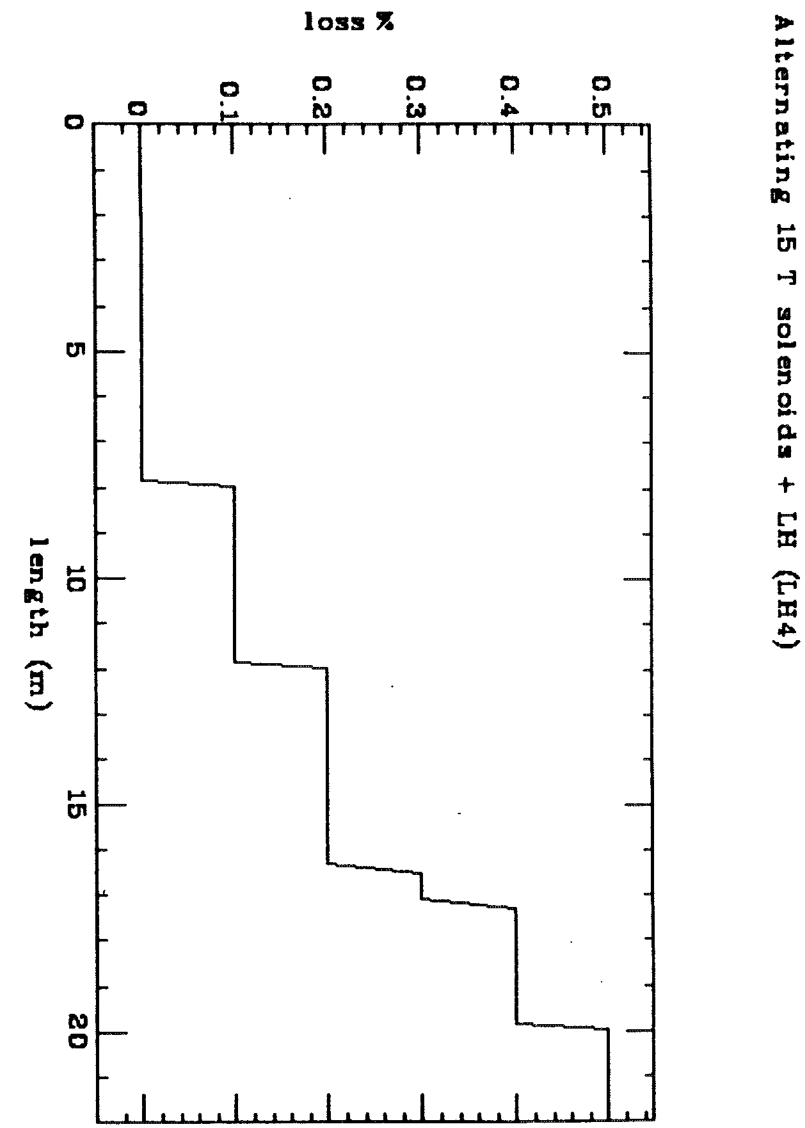

Alternating 15 T solenoids + LH (LH4)
rms corr momentum (%)
length (m)
0
1
2
3
4
5
6
0
5
10
15
20

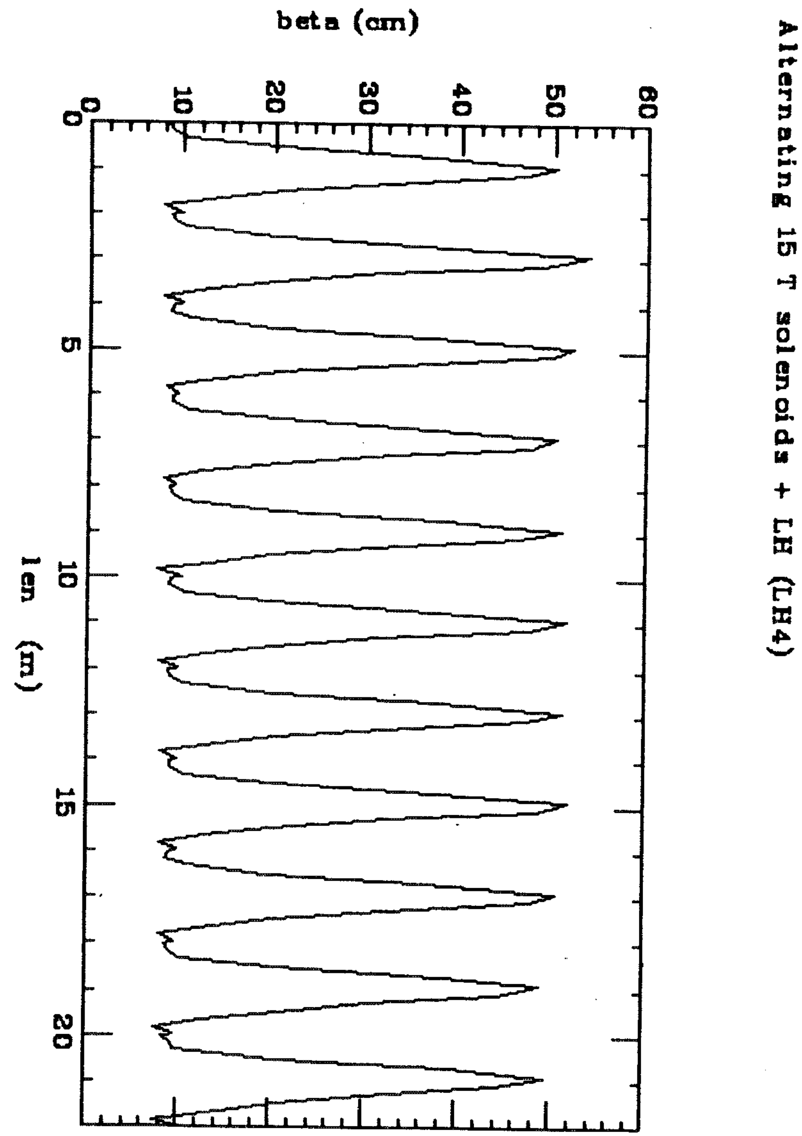
Alternating 15 T solenoids + LH (LH4)

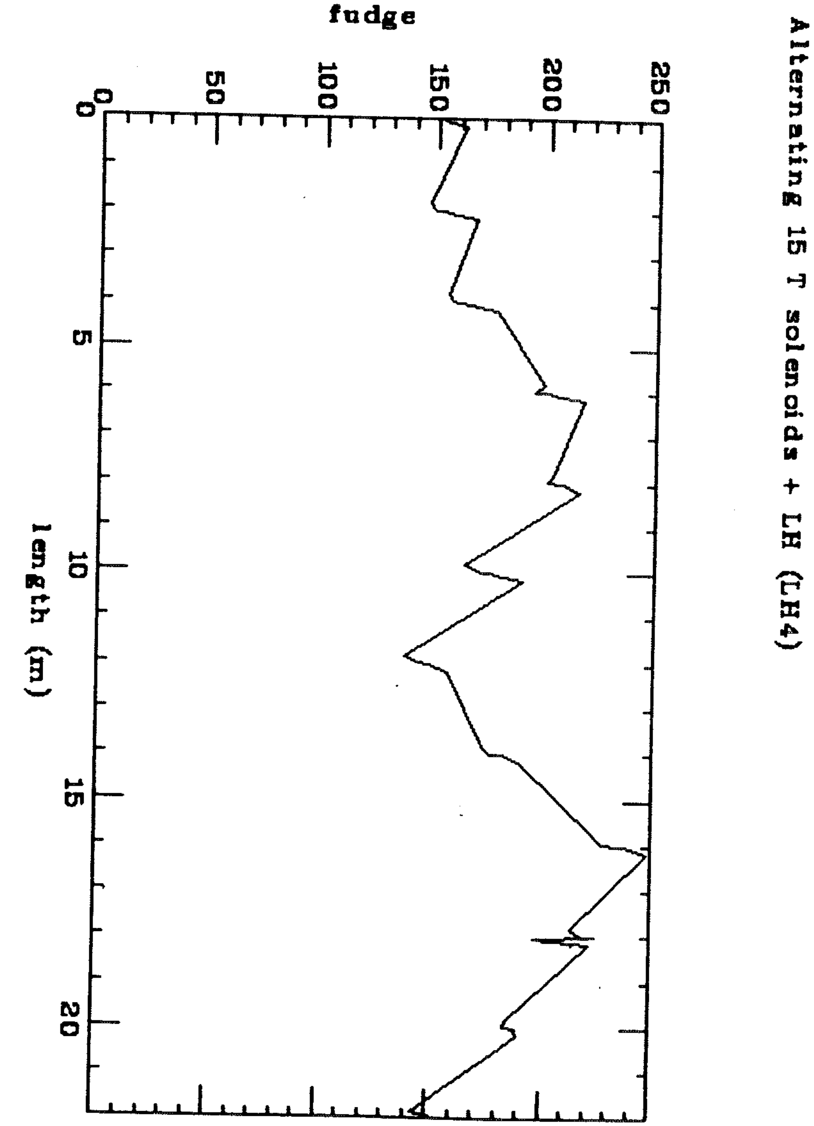


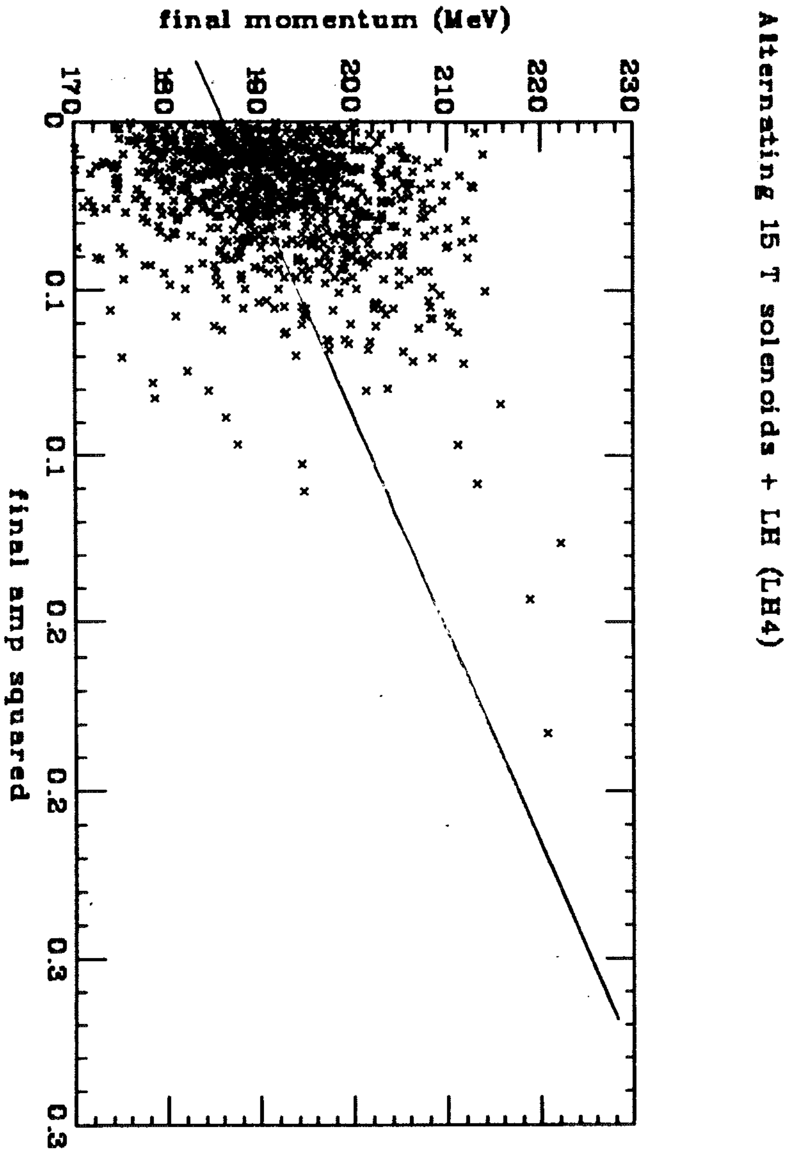
Alternating 15 T solenoids + LH (LH4)

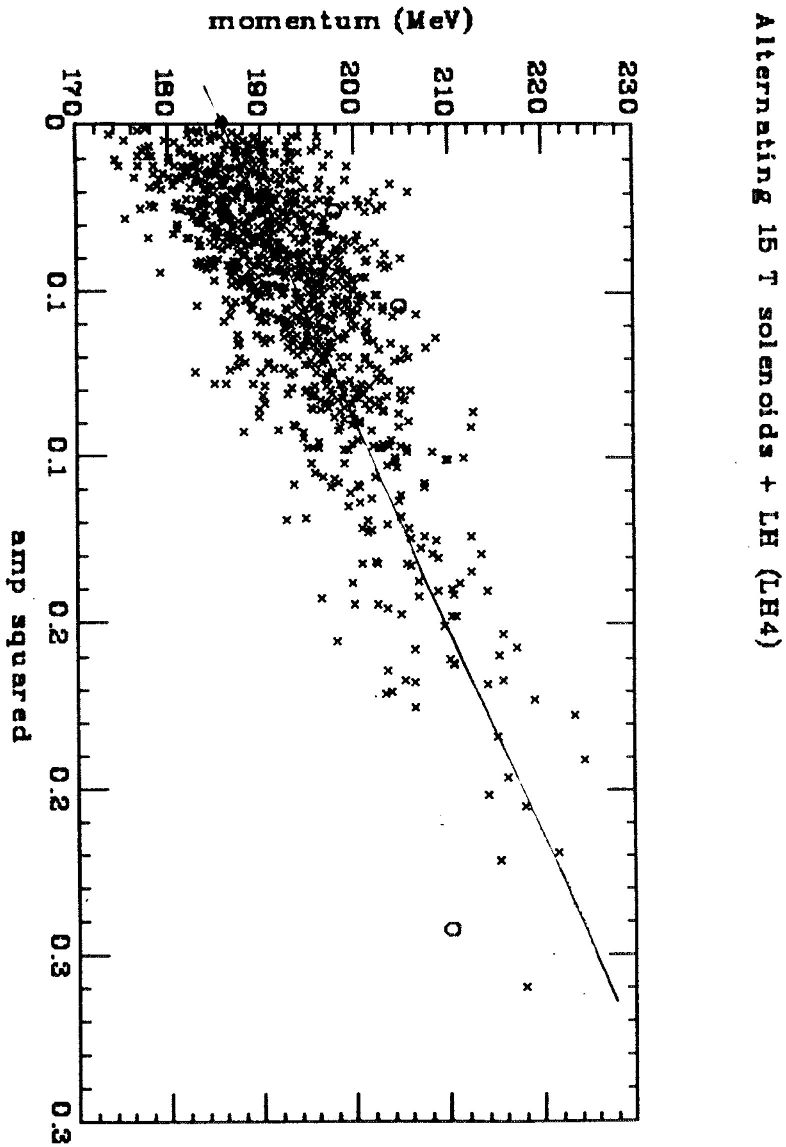


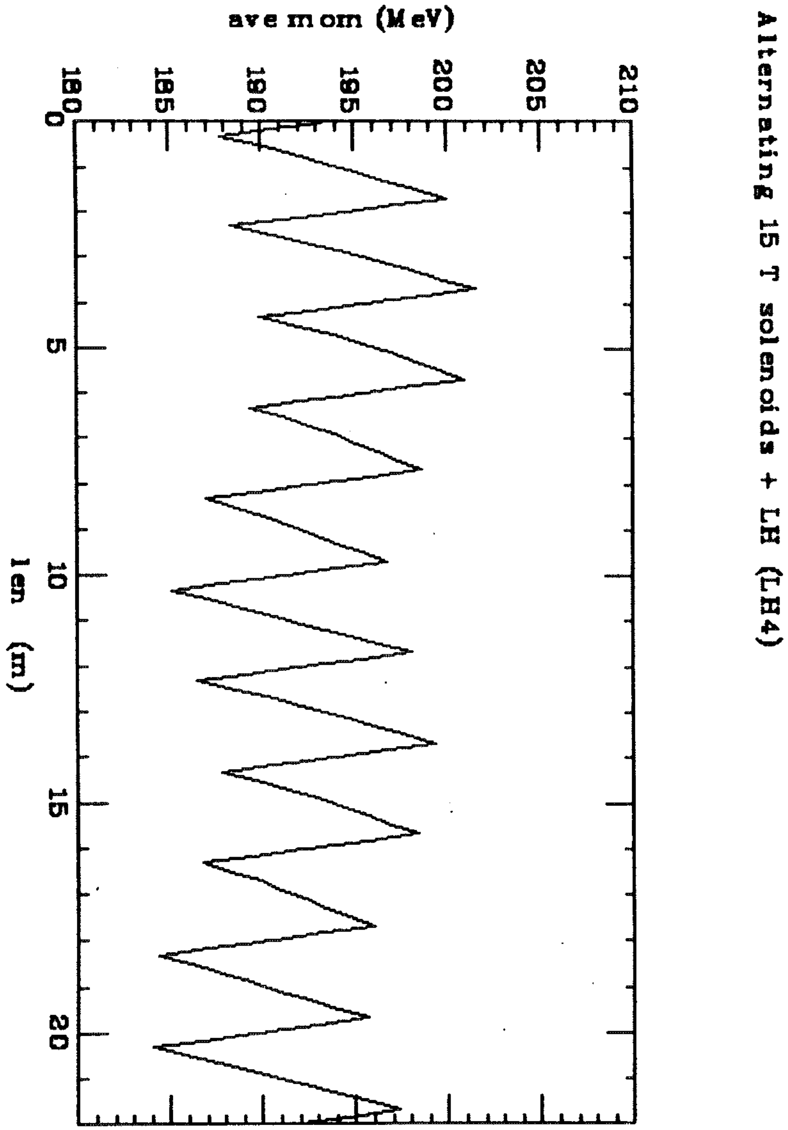

Alternating 15 T solenoids + LH (LH4)
loss %
length (m)
0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20


Alternating 15 T solenoids + LH (LH4)
beta (cm)
len (m)
0
10
20
30
40
50
60
0
5
10
15
20

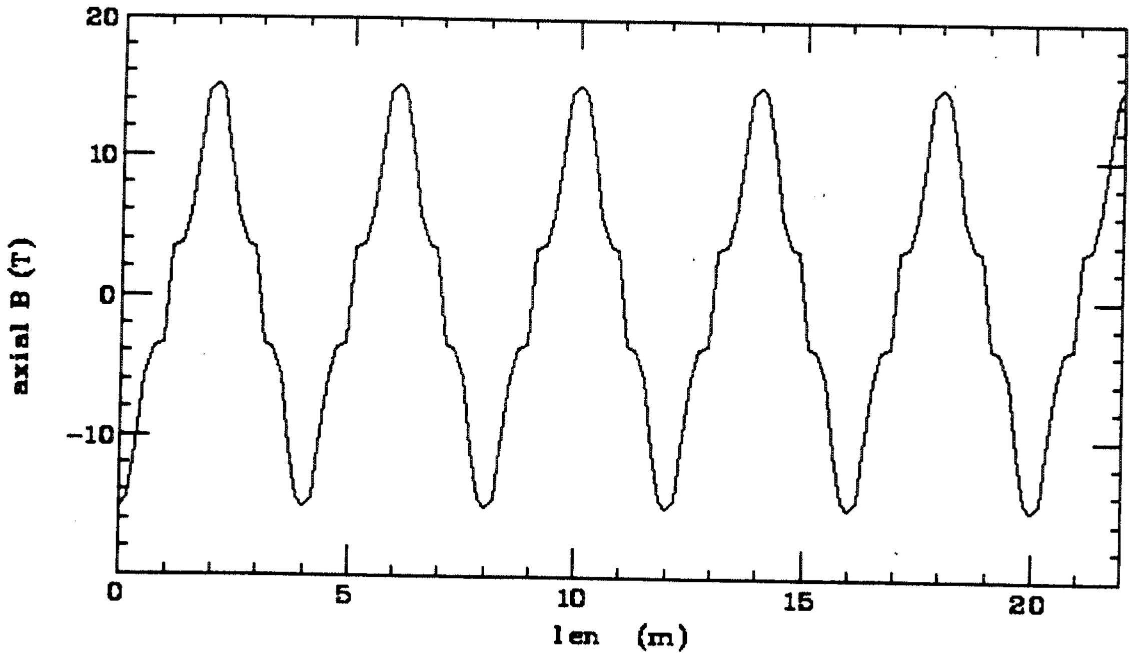

Alternating 15 T solenoids + LH (LH4)
fudge
length (m)
0
5
10
15
20
50
100
150
200
250

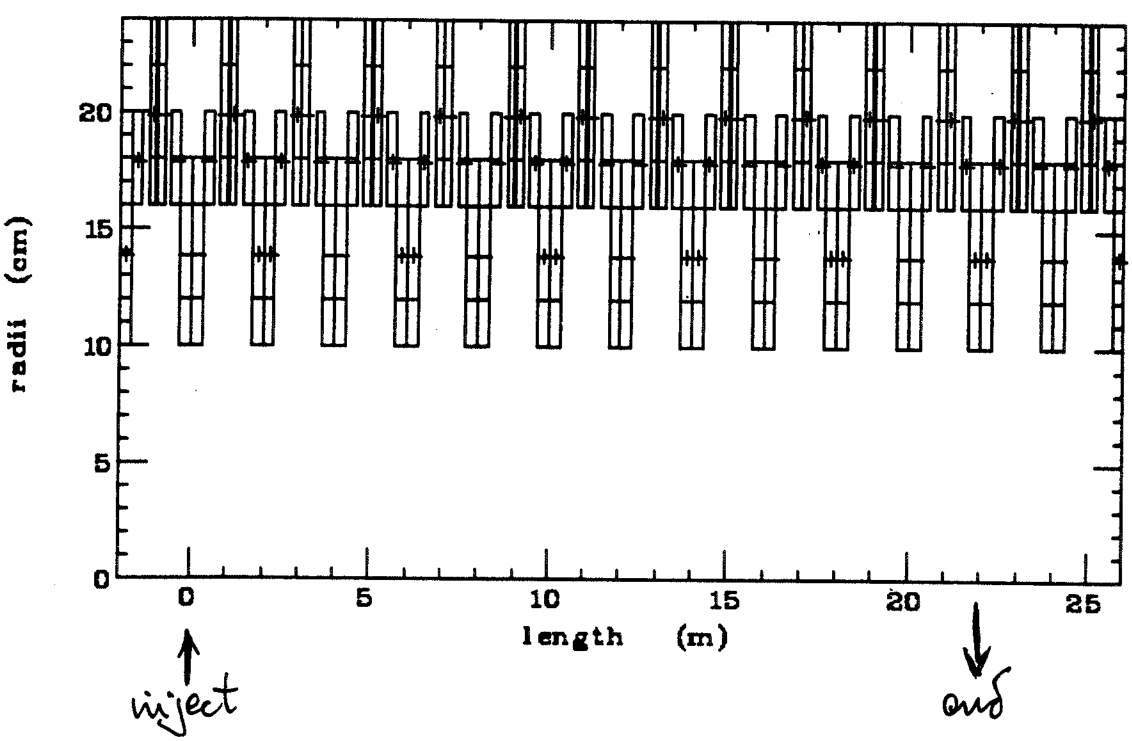

Alternating 15 T solenoids + LH (LH4)
final momentum (MeV)
final amp squared
170
180
190
200
210
220
230
0
0.1
0.2
0.3

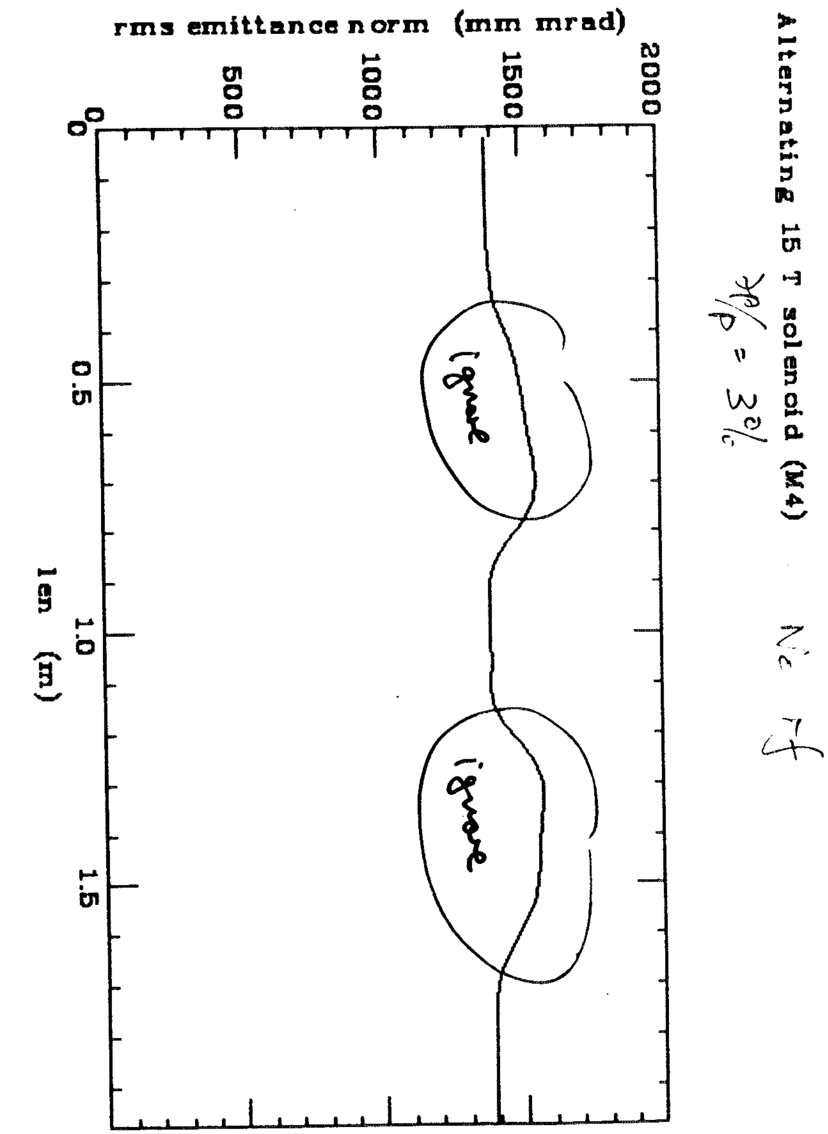

Alternating 15 T solenoids + LH (LH4)
momentum (MeV)
170
180
190
200
210
220
230
0
0.1
0.1
0.2
0.2
0.3
0.3
amp squared

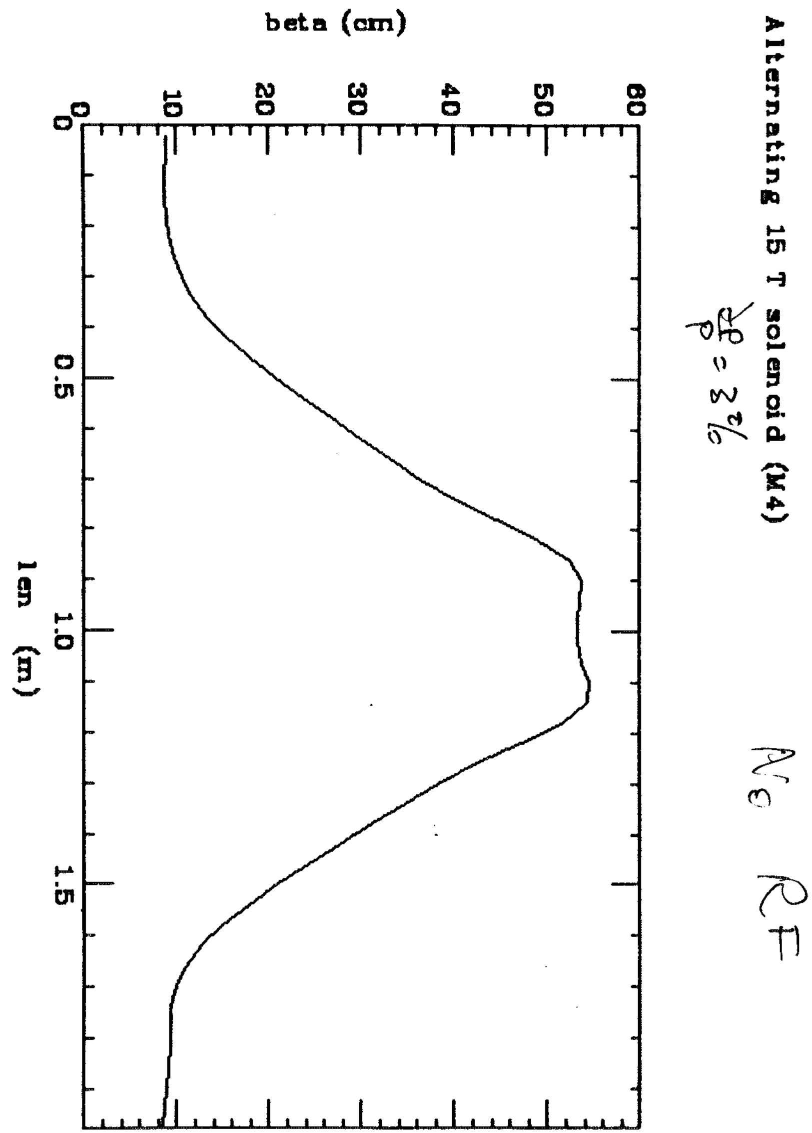

Alternating 15 T solenoids + LH (LH4)
ave mom (MeV)
180
185
190
195
200
205
210
0
5
10
15
20
len (m)

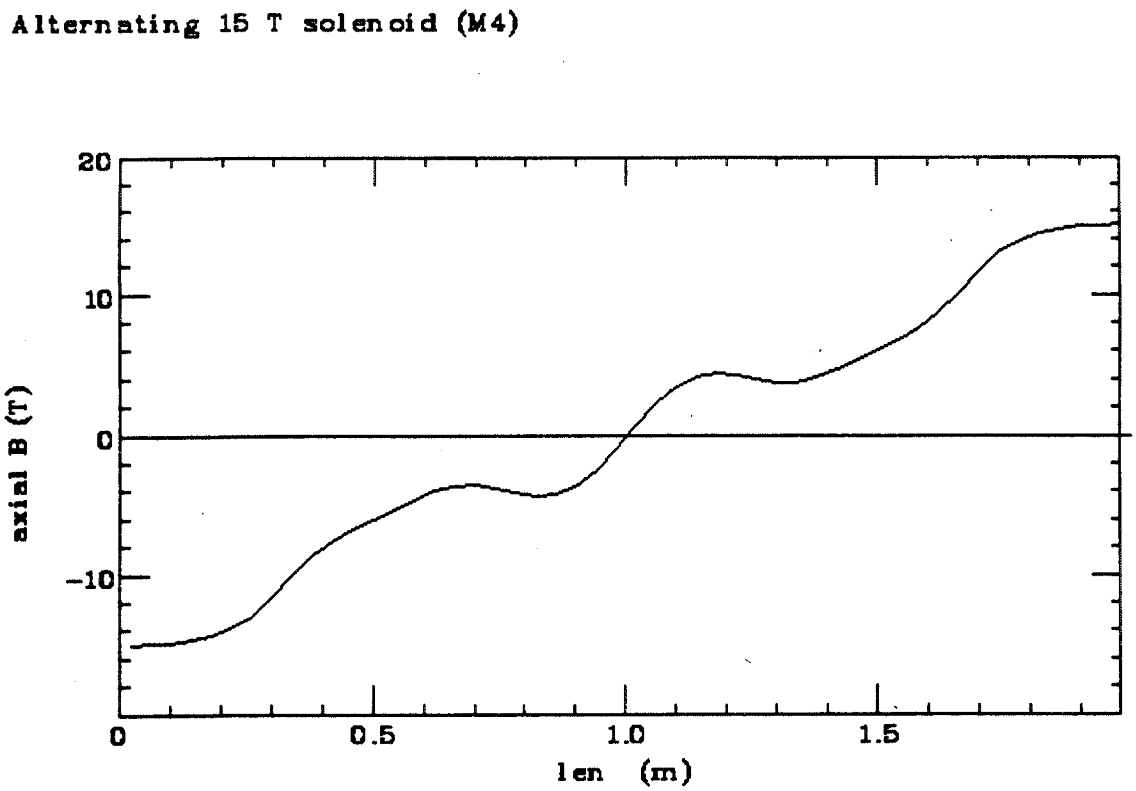
Alternating 15 T solenoids + LH (LH4)

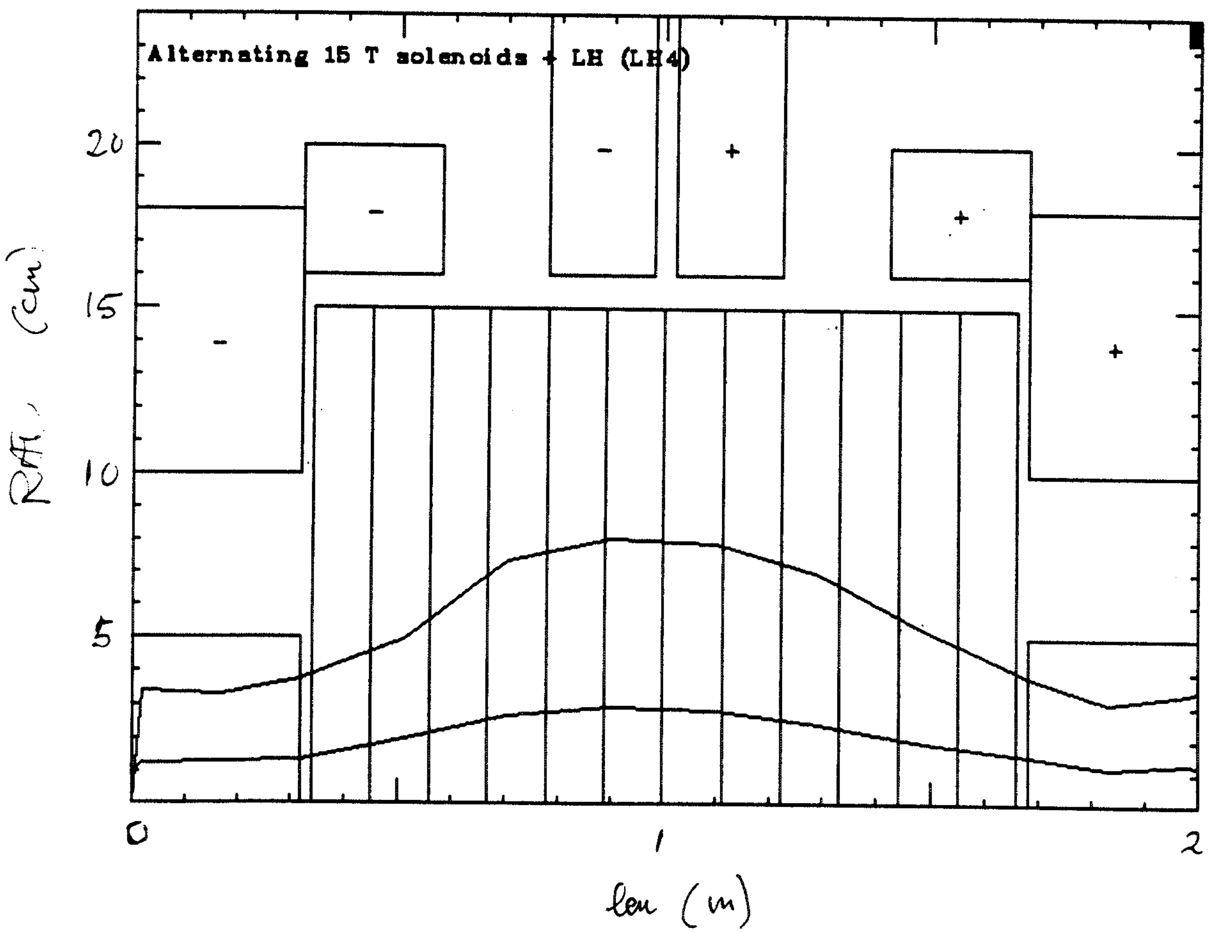





Alternating 15 T solenoid (M4)
∂p/p = 3%
No rf
rms emittance norm (mm mrad)
0
500
1000
1500
2000
0.5
1.0
1.5
len (m)
ignore
ignore


Alternating 15 T solenoid (M4)
∂p/p = 3%
No RF
beta (cm)
0
10
20
30
40
50
60
0.5
1.0
1.5
len (m)


Alternating 15 T solenoid (M4)
axial B (T)
20
10
0
-10
0
0.5
1.0
1.5
len (m)


Alternating 15 T solenoids + LH (LH4)
RAD (cm)
20
15
10
5
-
-
-
+
+
+
0
1
2
len (m)

R. FERNOW

ICOOL: Recent developments
(after v1.61)

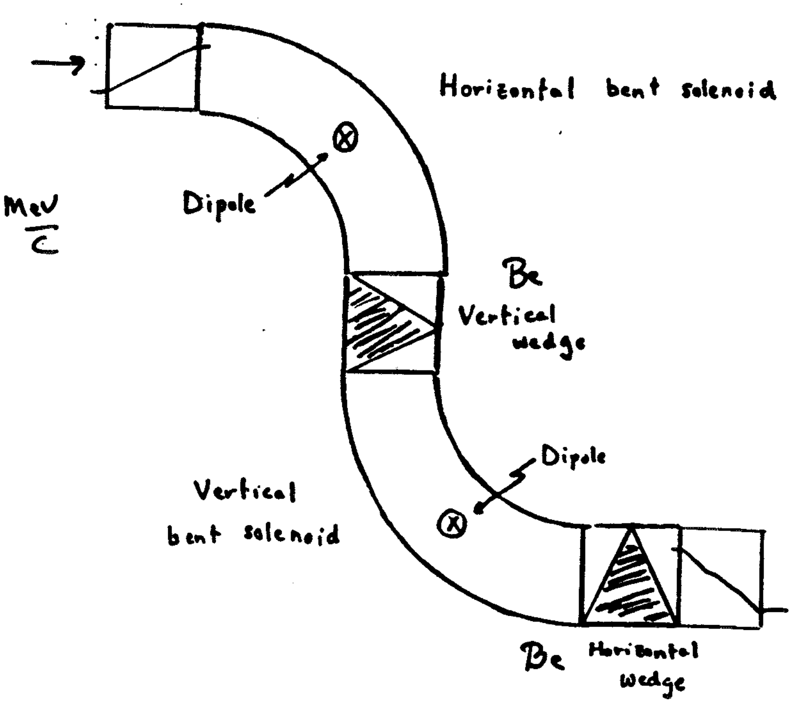
- exclusively uses spatial stepping in accelerator coordinates
- reversed the region - particle loop order
- added code to define background magnetic field on a grid
- added azimuthally adjustable wedge region
- added current sheet fields
- added 2nd order bent solenoid fields
- stopped tracking phasemodel=3,4 reference particles

ICOOL: future work

- debug background grid code
- ability to read in user-defined field map
- generalize equations of motion for bends in arbitrary planes
- correct neighbor fields for accelerator coordinates
- improve step-size logic inside materials
- speed

Case 4

$p = 200$ MeV/c



Example parameters

Beam distributions

σ_X , σ_Y	10	mm
σ_{PX}, σ_{PX}	15	MeV/c
σ_Z	10	mm
σ_{PZ}	7	MeV/c

Solenoids

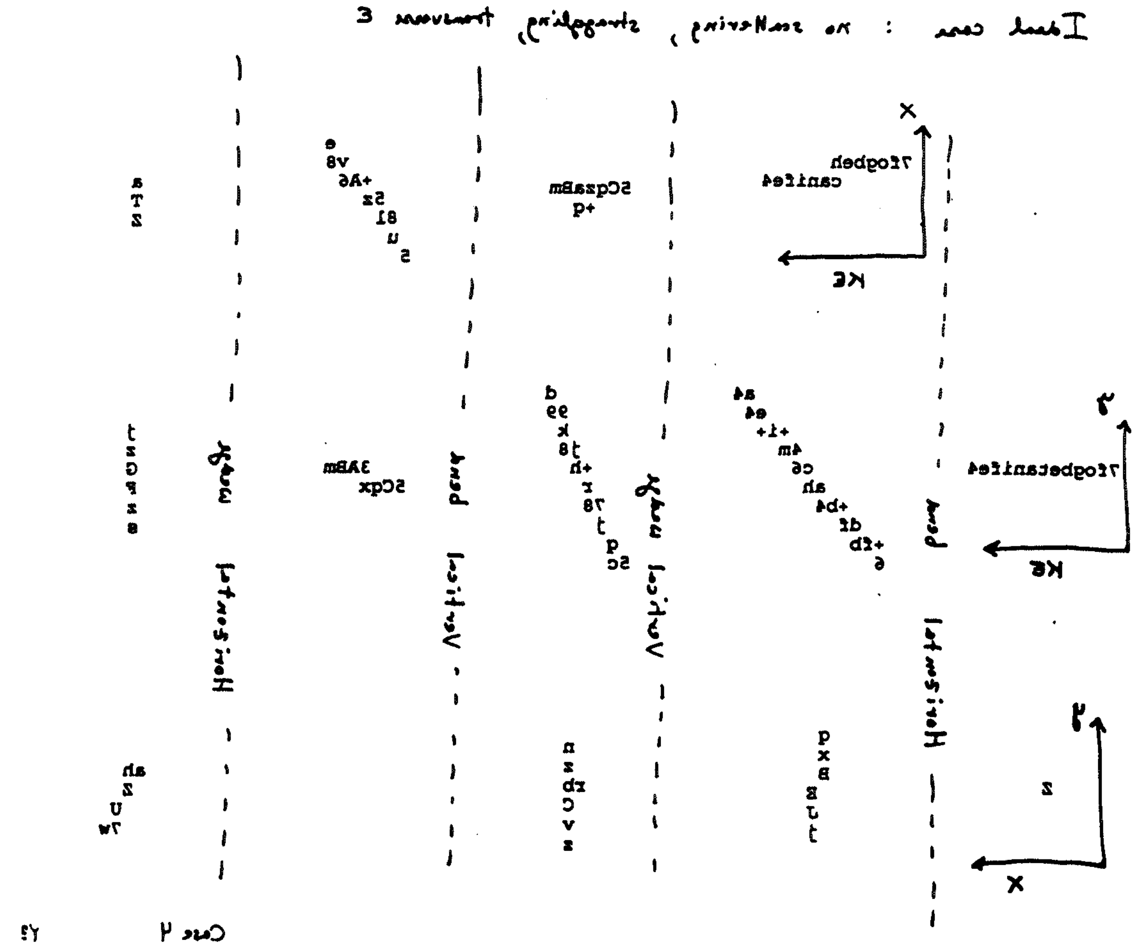
	horizontal	vertical	
p_o	200	193.5	MeV/c
B_S	7	7	T
B_D	-1.75	1.69	T
L	0.599	0.599	m

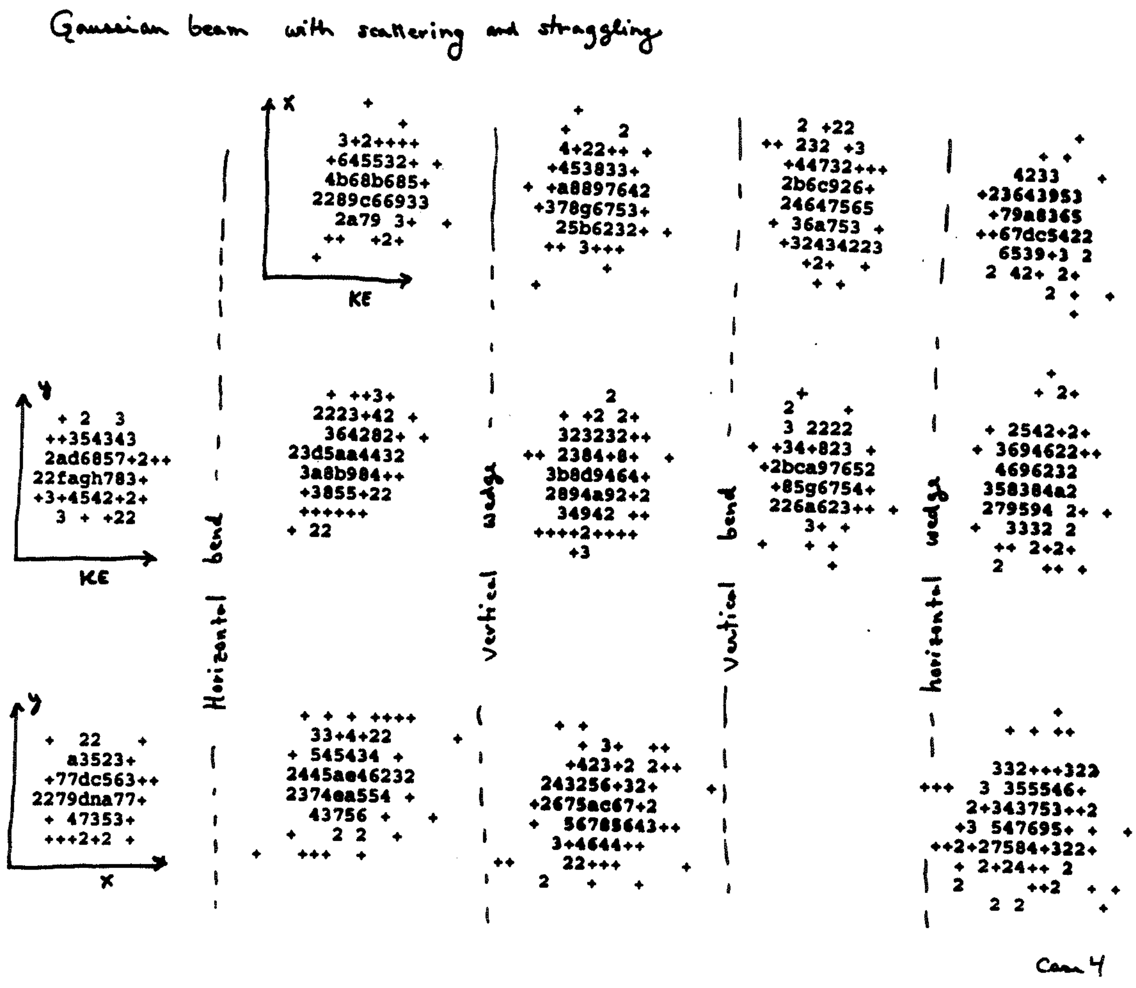
Wedges

	vertical	horizontal	
α	20	30	degrees
w	0.10	0.10	m
h	0.10	0.10	m
L_o	0.04	0.06	m

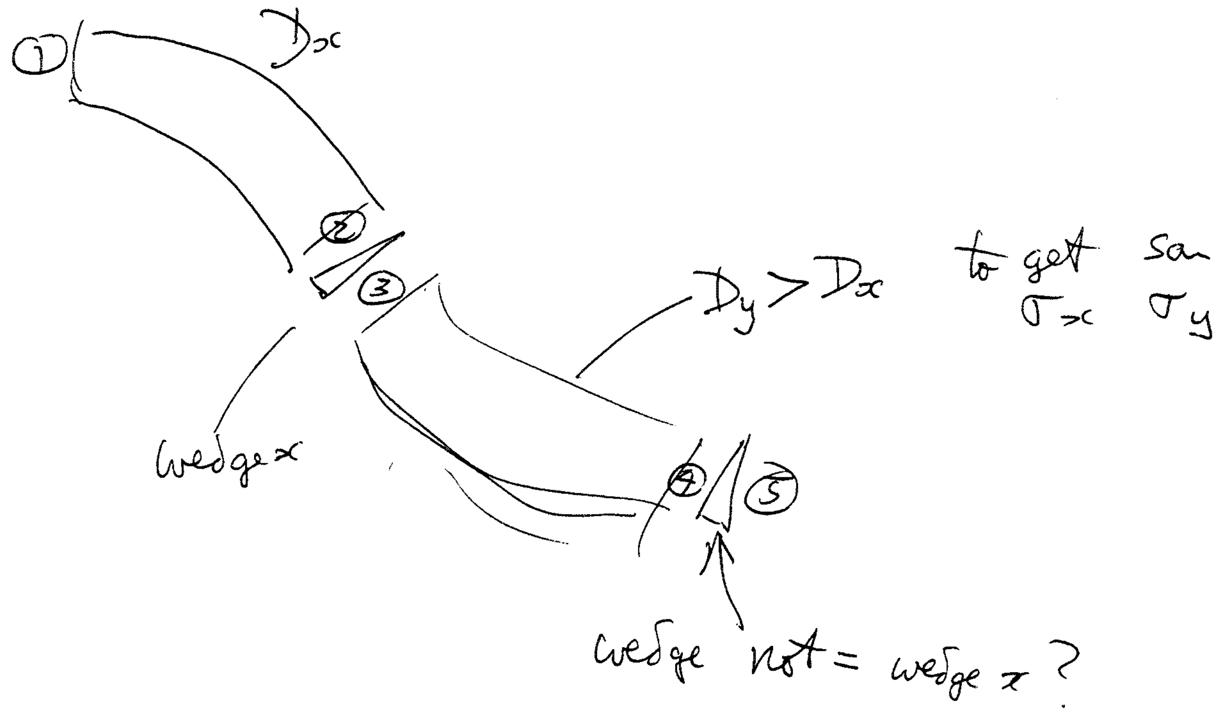
Results

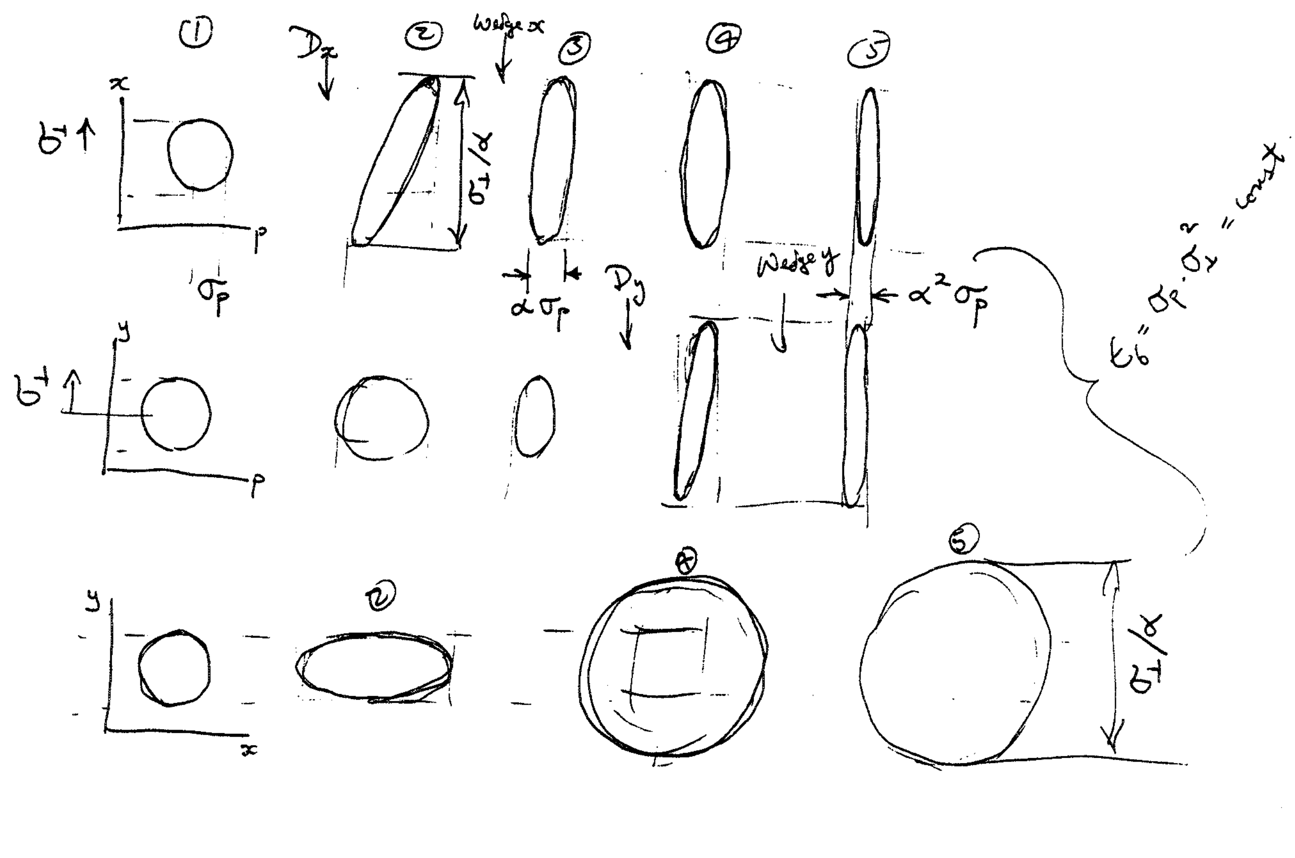
$f\epsilon T$	1.21
$f\epsilon L$	1.43
$f\epsilon 6$	2.09




Gaussian beam with scattering and straggling
Horizontal bend
Vertical wedge
Vertical bend
horizontal wedge
Case 4

B. PALMER
"Theory of Emittance Exchange"





A NEW SCHEME OF LINEAR ACCELERATOR

Yongxiang Zhao
Nov. 1997

WHY?

Standing Wave Structure – π-mode: $v_g = 0$,
Mode separation problem

Side Coupling Structure – RF: π/2-mode, Beam: π-mode
Complex Structure

Traveling Wave Structure -- Need damper and waste power

TW with outer recycling loop – Need two ports,
(TW Resonator Ring) Phase sensitive

NEW SCHEME

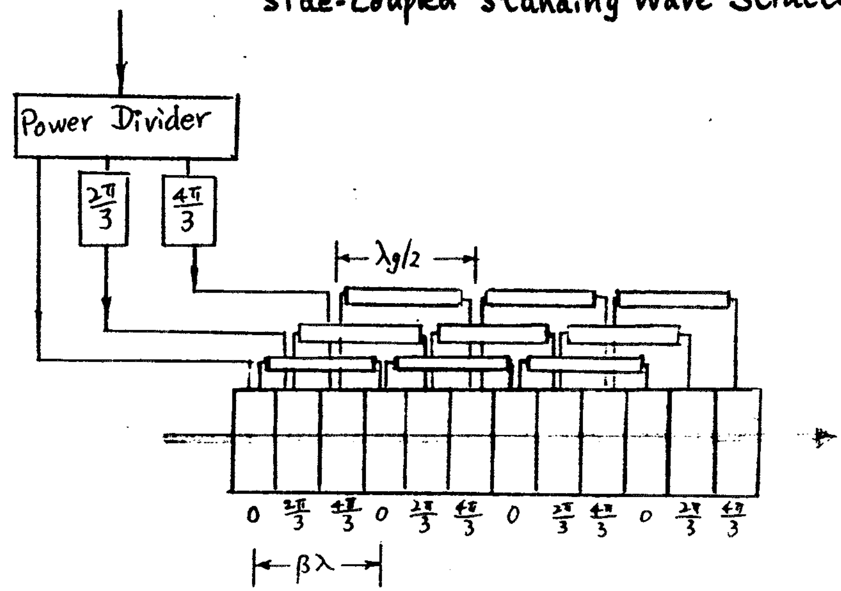
Combine both advantages of TW and SW

From viewpoint of beam: 2π/3-mode, or 2π/4-mode

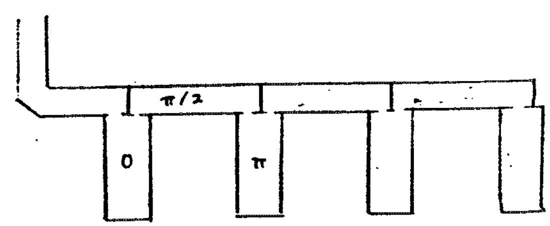
From viewpoint of power feed: π/2-mode, Standing wave

Suitable for different β value.

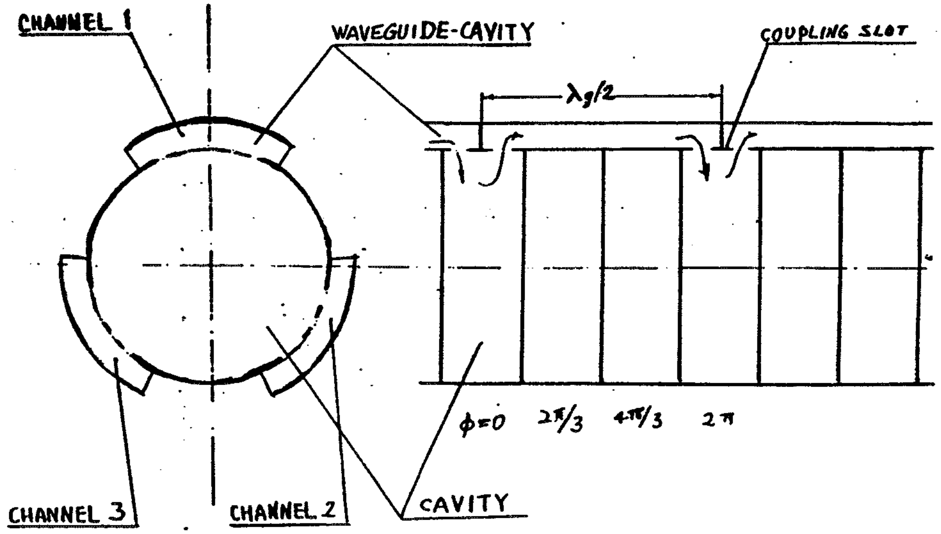
The Principle Scheme of
Multi-Channel Interleaved
side-coupled standing Wave Structure



For One Channel

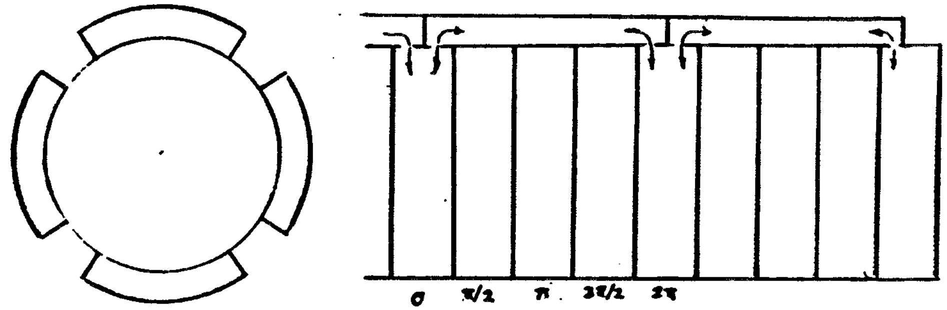


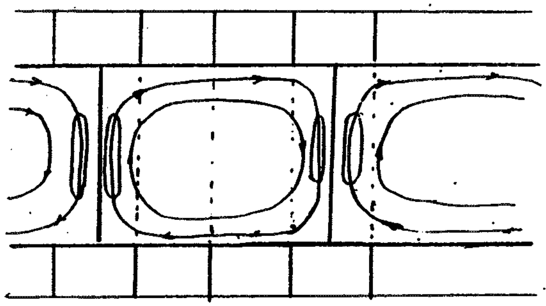
RF: π/2-mode
Beam: 2π/3-mode

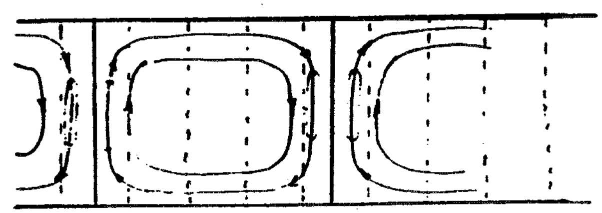


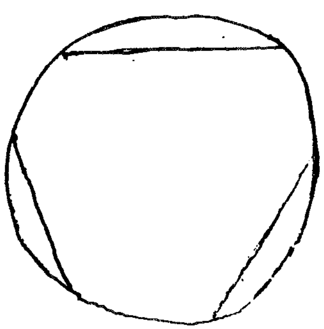
$2\pi/4$-mode

4-Channel side-coupling Standing Wave Structure









ADVANTAGES

- Beam sees $2\pi/3$-mode, or $2\pi/4$-mode, higher efficiency than π-mode.
- RF system is of standing wave, no damper needed, no power wasted.
- Working on $\pi/2$-mode, the best for stability, least sensitivity for errors
- Structure is relatively simple. Compact size
- Both constant gradient and constant impedance avalable simutenously.
- Easy match for different β value.

Using uniform waveguide to form
side-coupling cavity
reduce tranverse size

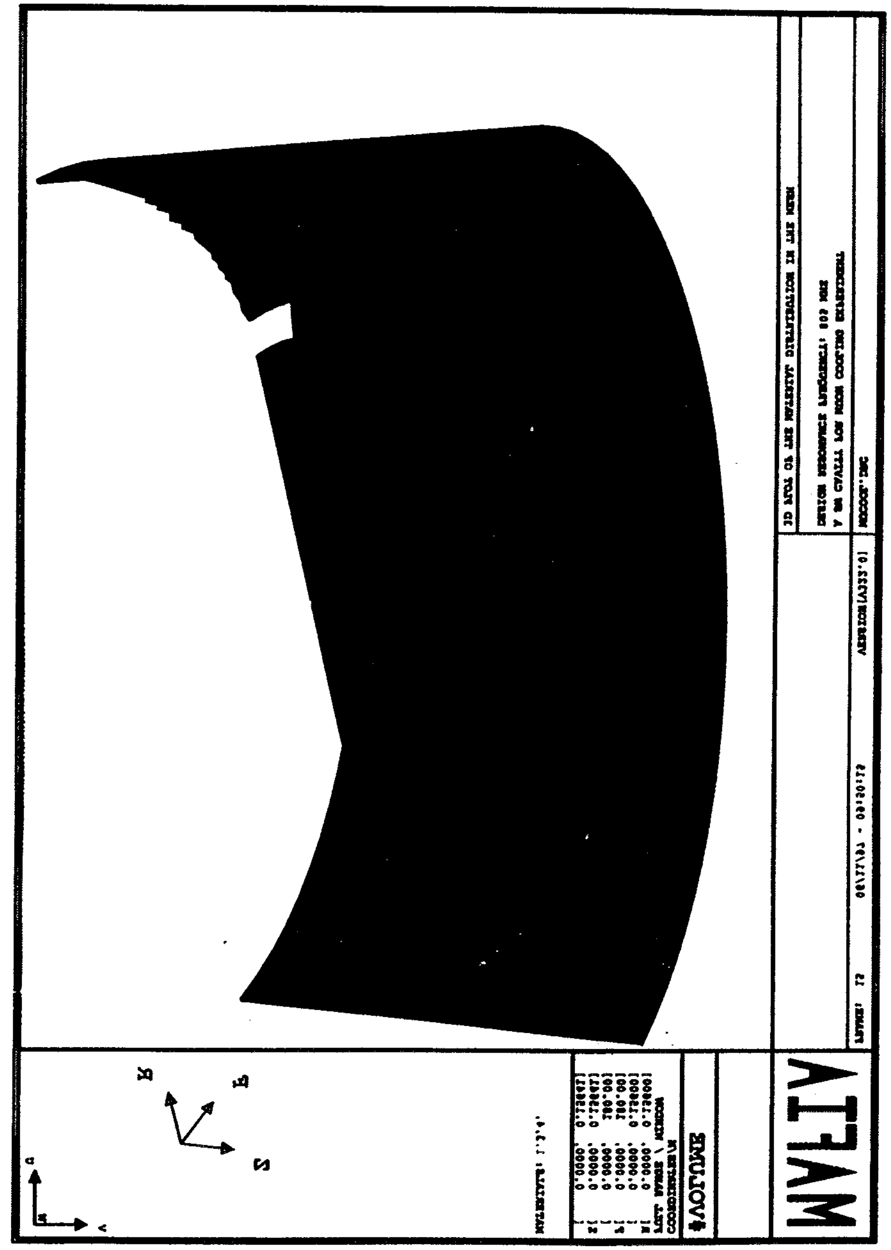
$\pi/2$-mode is possible.

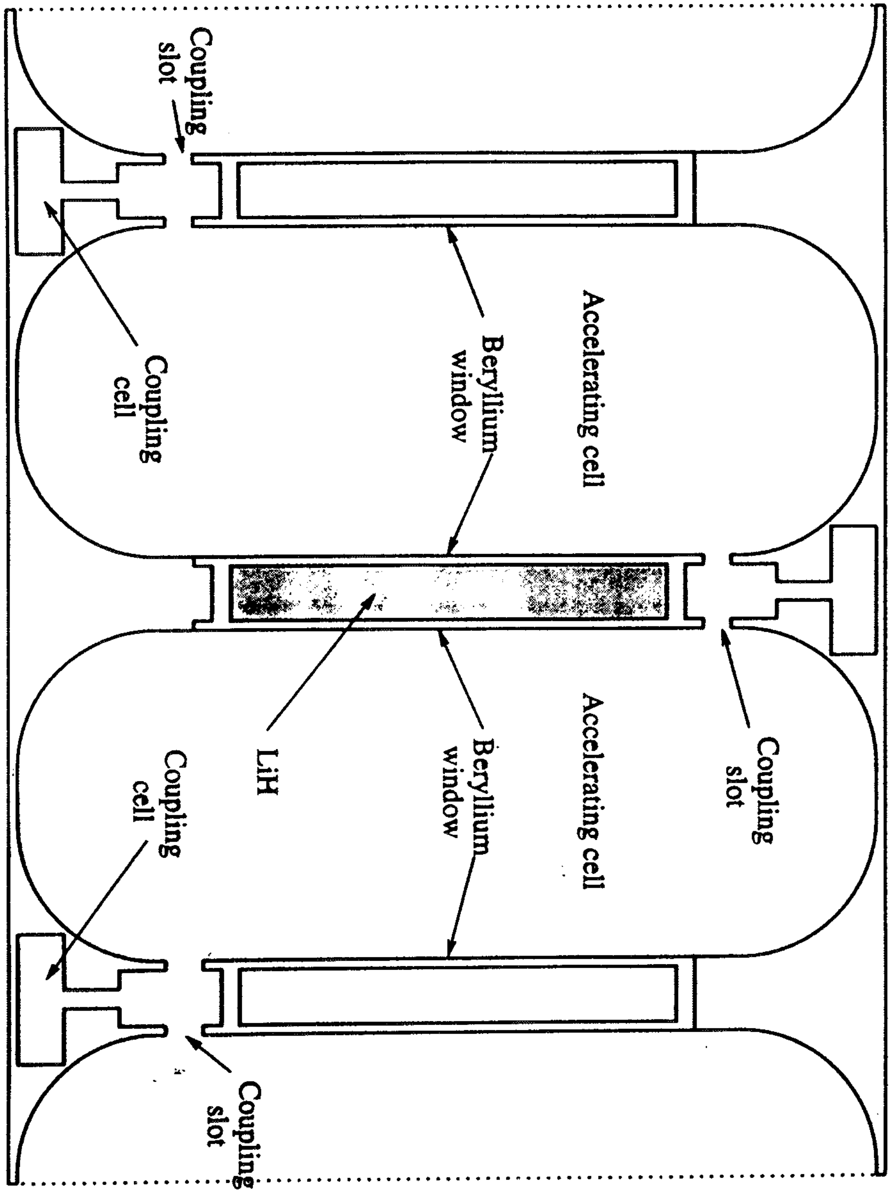
12/13/97

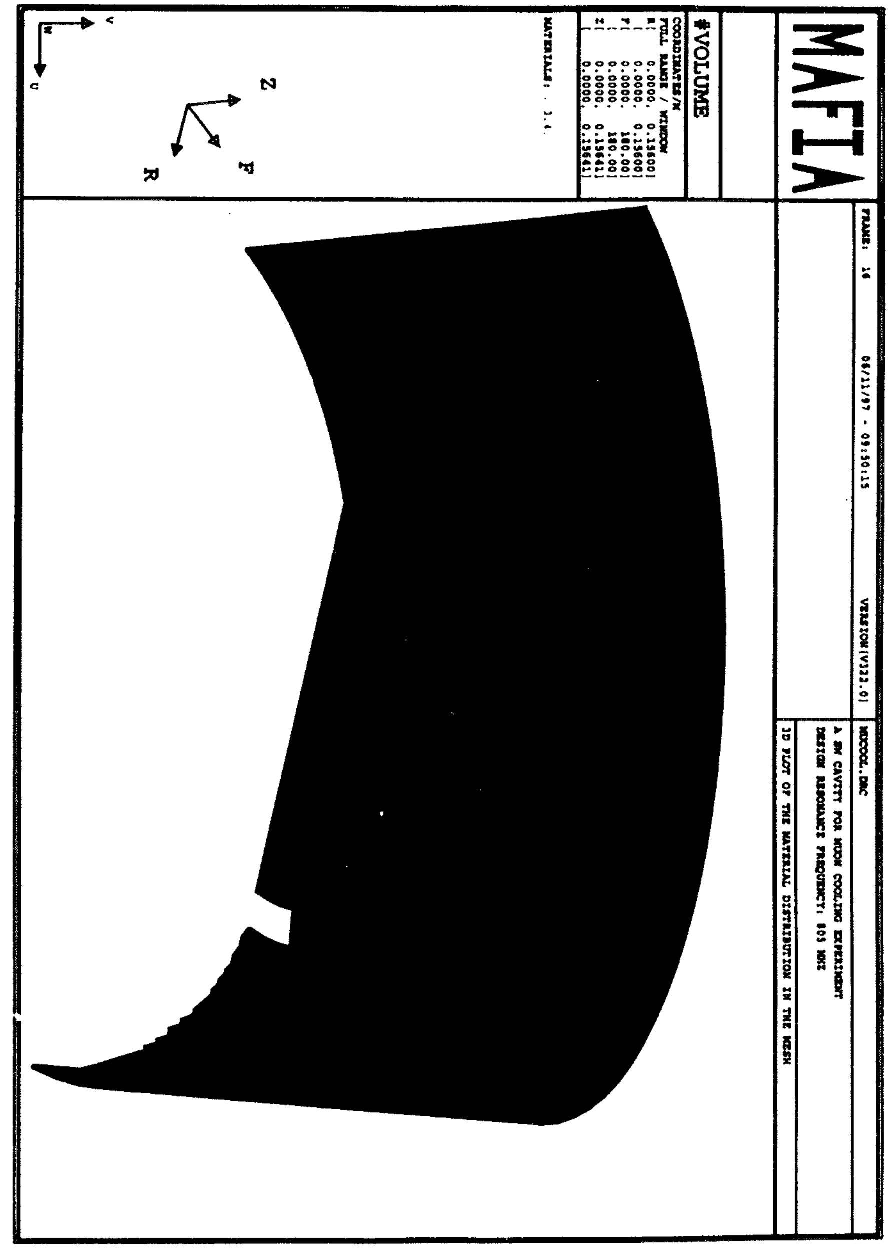
Temperature Distribution on Beryllium Windows in $\mu^+\mu^-$ cooling RF Cavity

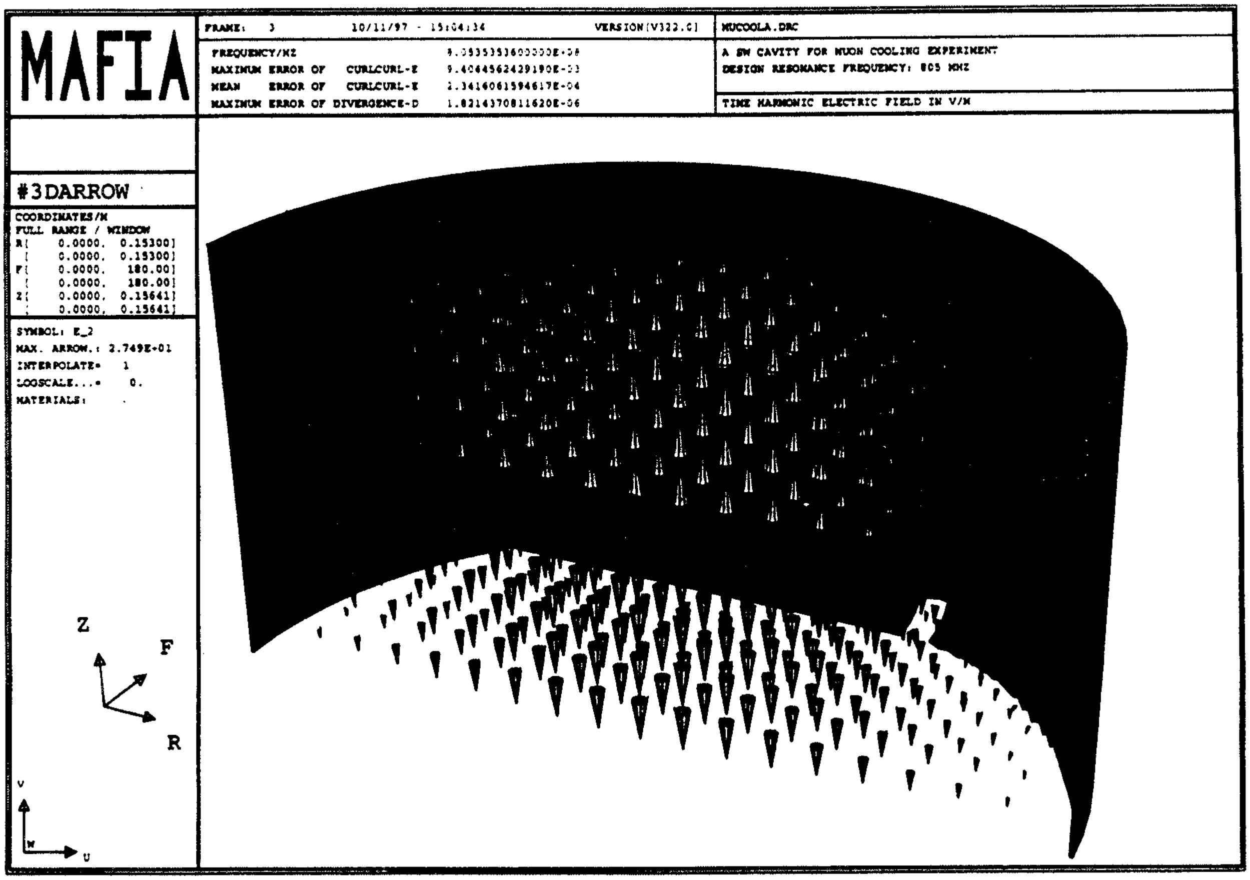
D. Li, W. Turner, J. Corlett

LBNL




Coupling slot
Coupling cell
Accelerating cell
Beryllium window
LiH
Accelerating cell
Beryllium window
Coupling slot
Coupling cell
Coupling slot

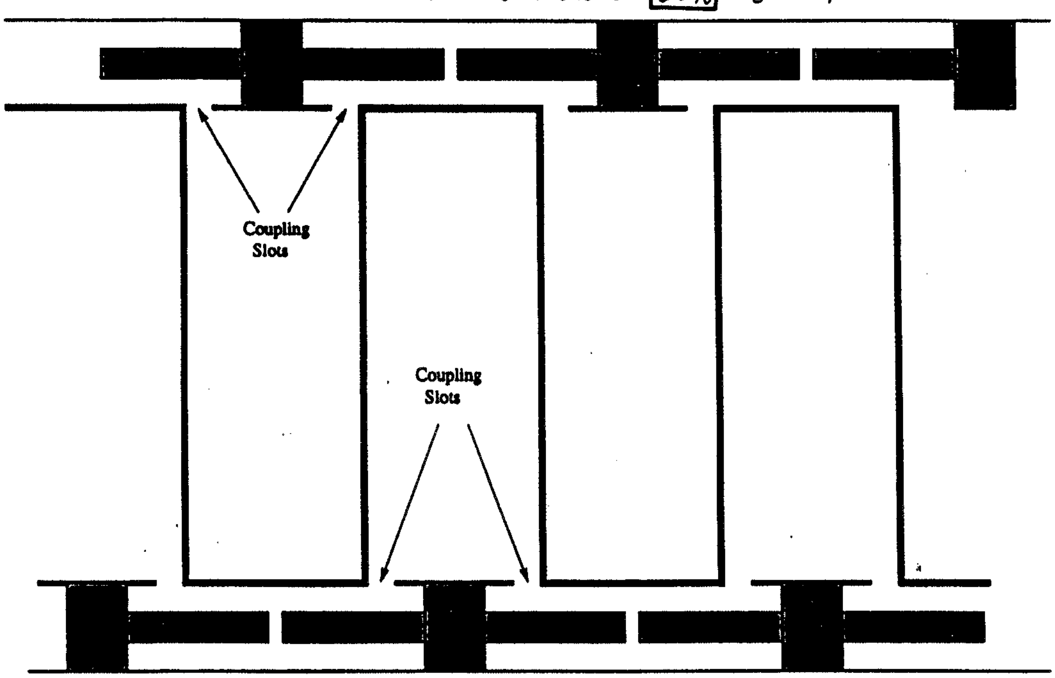

MAFIA
#VOLUME
Z
F
R



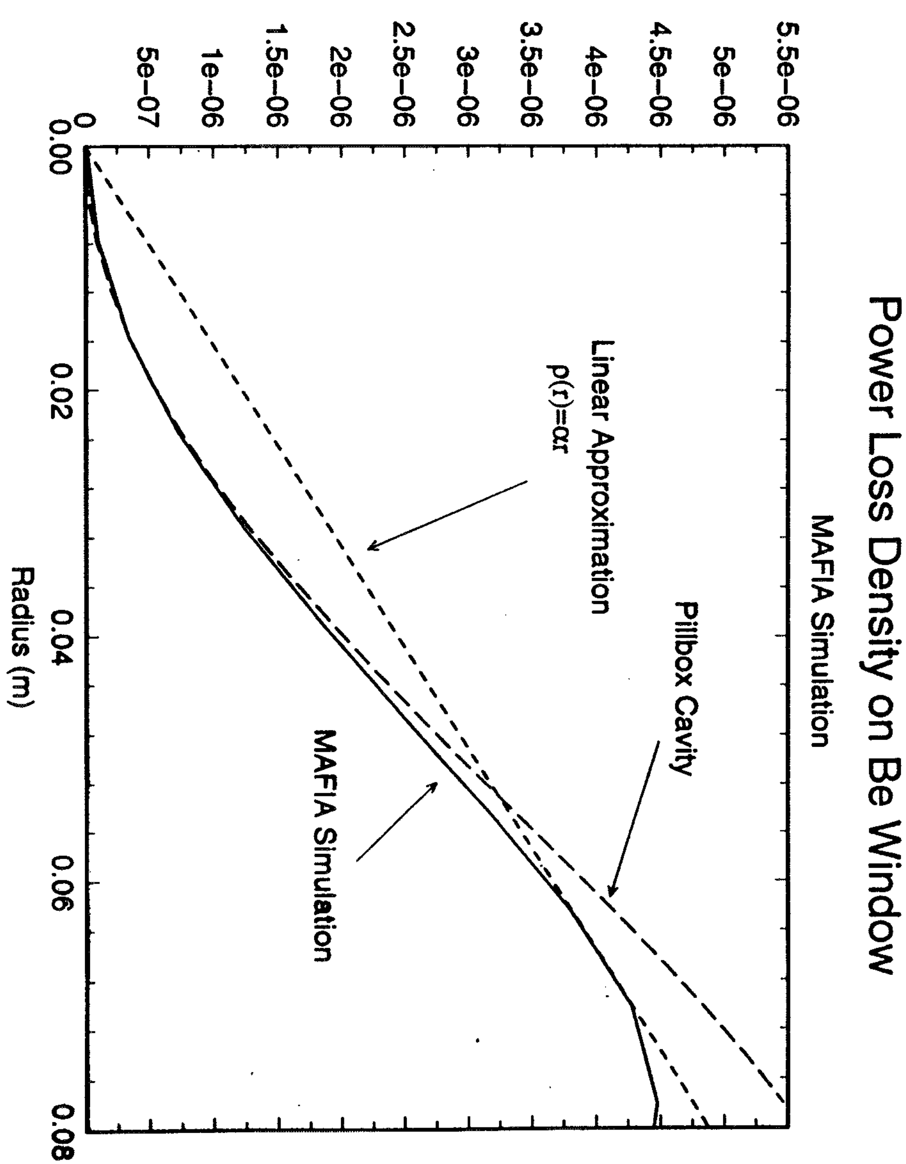
PB formula → $ZT^2 \sim 46$ MΩ/m, $Q \sim 22{,}000$ 12/01/97

Al's structure for muon collider

ZT^2 should be [20%] higher,



However, if we move the coupling cavity in to reduce outter diameter, ZT^2 will be lower, + beam does not go through the center



12/13/97

Cavity with Be Window

$r_{Be} = 7.8$ cm	Copper
$ZT^2 \sim 35\ M\Omega/m$ $(\beta = 0.84)$	$(37\ M\Omega/m)$
$Z \sim 64\ M\Omega/m$	$(68\ M\Omega/m)$

Using $\sqrt{\dfrac{\sigma_{Cu}}{\sigma_{Be}}} = \sqrt{3}$

Assume $E_{acc} \sim 30$ MV/m
pulse length $\sim 15\ \mu s$
repetition rate ~ 15 Hz

⇓

Power loss on one window

14 Watts at LN assuming

$$\sqrt{\frac{\sigma_{LN}}{\sigma_{RT}}} = 2$$

If we consider heat conduction in beryllium only, $k = 200 \frac{W}{m \cdot K}$
& $d = 0.0254$ mm

12/13/97

Linear model gives,

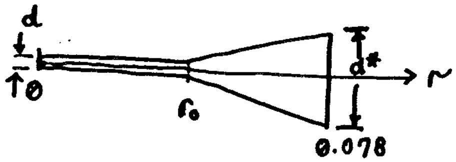
$$T_{max} = T_R + \frac{1}{6\pi}\left(\frac{P}{kd}\right)$$

(T_R = 77 K; P = Power loss on the window)

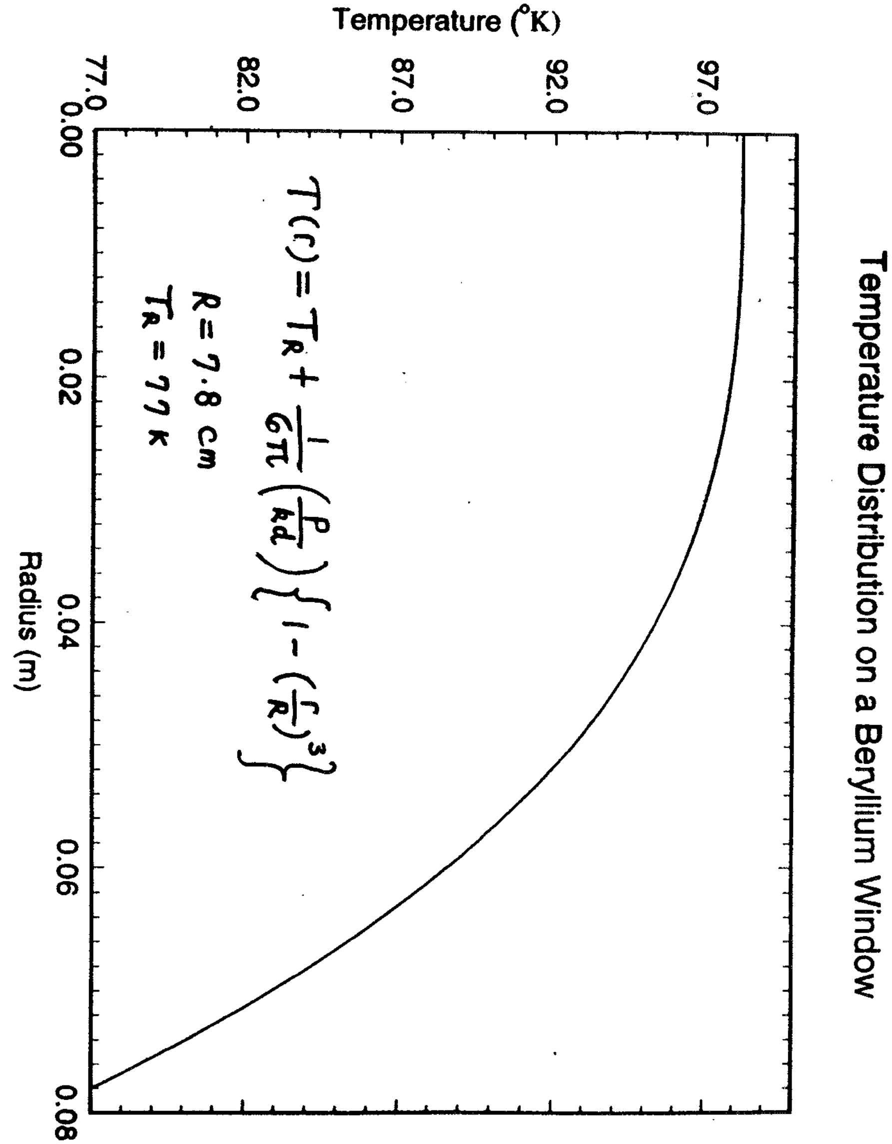
→ flat window

$$\boxed{T_{max} = 77 + 146 = 223\ K}$$

For better heat conduction,



T_{max}	d^*/d	T_{max}
133 K	6	
138 K	5	126 K
146 K	4	134 K
157 K	3	147 K
177 K	2	170 K
$r_0 = 3.9$ cm		$r_0 = 2.6$ cm



Draft Agenda Muon Cooling RF
Mini Workshop @ LBNL

Date: 9-10 Feb or 16-17 Feb TBD next wk.

Goal: Agree on configuration and time table for FY98 cooling rf work @ FNAL + BNL + LBNL

Agenda:

Review cooling simul. and expt. config.	Palmer and/or Kirk
Be resis./thermal cond.	Zhao
$\frac{2\pi}{3}$ interleaved cell concept	Zhao
Be window design	Moretti
$\pi/2$ interleaved cell concept	Moretti
Be window htg.	Li
Mafia cavity sim.	Li
Rf cavity test plans	Corlett
Plans for this year	group discussion.

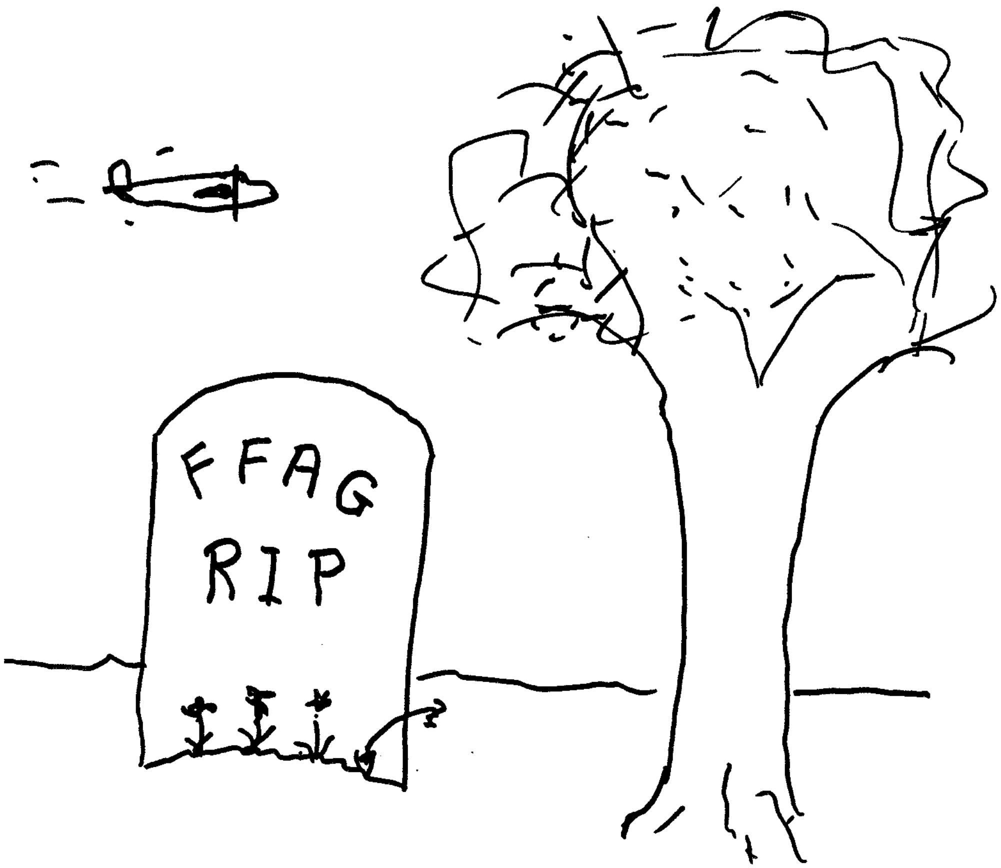
Tentative List of Attendees rf mini workshop:

BNL	Kirk, Palmer, Zhao
FNAL	Moretti, Norem
LBNL	Corlett, Li, Rimmer, Turner, Celata, Sessler, Wurtele
SLAC	Miller, Wilson, Hoag + ?

all to be confirmed.

Others welcome.

Contact: wcturner@lbl.gov



F. Mills 12/13/97

Linear Orbit Recirculators
F. E. Mills
October 2, 1997

Introduction

It has been proposed to use FFAG geometry for linac recirculator arcs to accelerate muons for a muon collider.[1] The difficulties with this come about in the following way. FFAGs are usually thought of as accelerators in which the particles are accelerated slowly, as in any synchrotron. In order to contain the beam it is necessary to keep the tune constant during acceleration, i. e. the chromaticity is zero, or at least very small, to avoid crossing resonances. To achieve this one employs the "scaling" geometry in which orbits of different momenta are similar in shape (possibly rotated) and the vertical mid plane fields along a radial line θ = const., or spiral $r = r_0 e^{w\theta}$ vary as r^k. The result is usually a very large radial magnet aperture. Until recently, it was not possible to incorporate long, dispersion free straight sections[2]. Finally it is not clear how to achieve the necessary orbit lengths so as to maintain phase stability during acceleration.

Further reflection suggests the following: For only, say, ten orbits, it is not essential to maintain the zero chromaticity requirement, and one might be able to use stronger , but linear, focusing systems. It is known that quadrupole channels can be built which accept a large range of momentum. Adding bending should not change that fact. In fact the limit of stability (occurring at the lowest momentum) will occur when the phase advance per cell exceeds π. At higher momentum the phase advance decreases, but by while β_{min} increases, β_{max}, determined primarily by the structure length, does not change much. In fact, as $2\pi/3$ is exceeded, β_{max} increases somewhat (beating near the stopband). Scaling simple AG orbits, we note that the typical β is about R/ν, while the typical dispersion is about R/ν^2. Then we can win on aperture by maintaining the strongest focusing possible. We need to employ the strongest gradients possible.

There are two reasons for using separated function geometry, as opposed to combined function geometry. In the first place, in curved magnets with gradient, there is a cubic term in the vector potential[3] which provides a sextupole-like field which will give

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[1] This was suggested at the Sausalito Workshop in 1994 by Bob Palmer, and discussed there by Philip Meads. Recently, Bruce King at BNL has published a report "Variable field bending magnets for recirculating linacs." 16 January, 1997

[2] At Sausalito, Meads showed a radial sector geometry which included such straight sections.

[3] See next section.

additional chromaticity. While this may or may not be important, it is well known that most efficiency in focusing is achieved by concentrating the focusing, as in a separated function geometry. Since our goal will be to have small dispersion, we will wish to obtain the strongest possible focusing.

Lowest Order Fields with Field and Gradient of Field

We employ usual accelerator coordinates. First we define a curve in space $\mathbf{r}_o(s)$ where s is the arc length along the curve. $\alpha, \beta, \& \gamma$ are unit vectors in the tangent, outward(opposite to radius of curvature), and vertical directions. The curvature is Ω. We will not consider situations with torsion (out of plane bends). The dipole field

$$B = -\frac{P_0 c\Omega}{e},$$

which provides the curvature (bending) is accompanied by a quadrupole field, that is, the bend field depends on position, its spatial derivative at $\mathbf{r}_o(s)$ being

$$B' = -\frac{P_0 c\kappa}{e}.$$

These fields can be described by a single component of vector potential A_s Maxwell's equations require

$$[\nabla \times \nabla \times \mathbf{B}]_s = 0$$

In the (s,x,z) coordinate system, this yields

$$(1+\Omega x)\frac{\partial^2 A_s}{\partial x^2} - \Omega\frac{\partial A_s}{\partial x} = 0$$

Now we attempt a solution

$$A_s = \sum_{\substack{j=1...n \\ n=1...\infty}} A_{jn} x^{n-j} z^j$$

leading to recursion relations for the A_{jn}. We can solve them for the lowest order potential which has bending Ω and gradient κ. It becomes

$$\frac{eA_s}{P_0 c} = -\left[\Omega x + \frac{\Omega^2 x^2}{2} + \frac{\kappa}{2}\left(x^2 - z^2\right) + \frac{\Omega\kappa}{6}x^3\right]$$

The second and forth term are "curvature terms" required to satisfy Maxwell's equations. The cubic term gives a chromatic tune shift in the horizontal motion for combined function magnet systems, which is not present in separated function systems.

Approximate Hamiltonian

The Hamiltonian G, with s as independent variable, is given by

$$G = -P_s = -\mathbf{P}\bullet\alpha(1+\Omega x) = -(1+\Omega x)\sqrt{P^2 - P_x^2 - P_z^2} + P_0\left[\Omega x + \frac{\Omega^2 x^2}{2} + \frac{\kappa}{2}\left(x^2 - z^2\right) + \frac{\Omega\kappa}{6}x^3\right]$$

We now expand the radical and drop terms of order greater than two. Then the approximate Hamiltonian is

$$G = -P(1+\Omega x) + \frac{P_x^2 + P_z^2}{2P} + P_0\left[\Omega x + \frac{\Omega^2 x^2}{2} + \frac{\kappa}{2}\left(x^2 - z^2\right)\right]$$

From this Hamiltonian we can obtain the equations of motion:

$$x'' + \frac{P_0}{P}\left(\Omega^2 + \kappa\right)x = \Omega\left(\frac{P - P_0}{P}\right) \qquad z'' - \frac{P_0}{P}\kappa z = 0$$

Now there is no requirement that $\left(\frac{P - P_0}{P}\right)$ be small. The principal approximation was that the squares of P_x and P_z be small compared to the square of P, that is, that the angles must be small.. In all cases of interest Ωx will be small compared to 1. The third term dropped was the cross term with curvature and gradient, which is zero for separated function lattices.

Now we recognize that these are the usual equations (except for the momentum ratio factor of the focusing terms) solved by orbit programs like SYNCH, MAD,IDA, etc., but they are useful over large ranges of momentum, so long as the angles are small.

Scaling Orbits with Momentum

Now we need to learn how to use the presently existing programs to calculate orbits for large factors in momentum. We can see in the differential equations of motion that if arc lengths are scaled as the square root of momentum while keeping Ω and κ the same, the free (betatron) oscillations will be described accurately. The particular integral (dispersion) will have the correct form but must be multiplied by an additional factor P/P_0. Angles are scaled by the square root of the same factor. We can accomplish this most easily with a scale transformation

$$s^* = \sqrt{\frac{P_0}{P}}s$$

keeping the action differential constant

$$dA = P_s ds + P_x dx + P_z dz - Hdt = P_s\sqrt{\frac{P}{P_0}}ds^* + P_x dx + P_z dz - Hdt$$

Then the new Hamiltonian G^* is the old one multiplied by the factor $\sqrt{\frac{P}{P_0}}$.

This leads to new equations of motion as indicated above.

$$\ddot{x} + (\Omega^2 + \kappa)x = \Omega\left(\frac{P}{P_0} - 1\right) \qquad \ddot{z} - \kappa z = 0$$

Orbit Lengths

The length of an orbit is

$$C = \oint \sqrt{(1+\Omega x)^2 + x'^2 + z'^2}\, ds \approx \oint (1 + \Omega x)\, ds$$

since the angles x' and z' are small. The incremental change in length due to x is

$$\Delta C = \oint \Omega x\, ds = \oint \Omega x_p^* \left(\frac{P}{P_0} - 1\right) ds = \left(\frac{P}{P_0} - 1\right)\sqrt{\frac{P}{P_0}} \oint \Omega x_p^* ds^*$$

Now the programs calculate

$$\alpha^* = \frac{\oint \Omega x_p^* ds^*}{\oint ds^*}$$

so we can substitute to find

$$\Delta C = C\alpha^* \left(\frac{P}{P_0} - 1\right) = C\alpha^* \frac{P}{P_0}\left(\frac{P - P_0}{P}\right)$$

When P is near P_0,

$$\Delta C = C\alpha\left(\frac{P - P_0}{P}\right)$$

so that

$$\alpha = \alpha^* \frac{P}{P_0}$$

The question of whether that can be made true in general is addressed below. If it is true, then if on successive orbits j,

$$P_j = \frac{jP_0}{n}, \qquad \Delta C = C\alpha\left(1 - \frac{n}{j}\right)$$

There does not seem to be any obvious way to obtain successive orbit length differences equal to integer numbers of RF wavelengths for equal increments in momentum. Since there are only several bunches, it may be possible to shift the RF phase sufficiently between bunch passages.

Long Dispersion-free Straight Sections

In order to accelerate in long linear accelerator sections, it is necessary to have zero dispersion straight sections. One of the failures of FFAG accelerators was the inability to devise such straight sections. Recently, as noted above, Philip Meads found a way to make such straight sections in a machine accelerating by a momentum ratio of three. Carol Johnstone is working on applying his method to the linear systems considered here. In case this is not successful, there are two other methods that might be employed. First, the circulation time is long enough that individual passages can be steered by pulsed magnets. Second, it may be possible to devise a simple chicane to accomplish the same thing.

A Numerical Example

It is instructive to consider a specific case with specific magnet technology. Let us consider the 70 GeV RLA in the current scenario. In the first place, we will use 5 T bends, so since $B\rho = 233$Tm, we can take $\rho = 50$ m. We will take $B' = 20$ T/m so $\kappa = 0.08$ m^{-2}. The program IDA[4] has been used to calculate lattices. First one must obtain the proper magnet lengths. To do this, the lengths are changed to get a phase advance as large as possible but less than π. This length is the equal to the actual length divided by R, where

$$R = \sqrt{\frac{P}{P_0}} \leq 1$$

P_0 having been chosen as the highest momentum. We then recalculate as $1/R^2$ takes on the values 2,3,4,...,9. When the tunes, momentum compaction factors, and chromaticities are calculated by IDA, the curvature is automatically adjusted so that the cell length fits into a closed orbit with an integer number of cells. This jogs the data a bit, and the tune and chromaticity need to be divided by R to get the actual value. In the table below, the raw tune is multiplied by R, yielding approximately a constant.. This means the tune is inversely proportional to P until the stopband is approached, as may be anticipated. The momentum compaction factor α indeed turns out to be nearly proportional to P. In the table below, L is the scaled half-quadrupole length, and the data are raw results from IDA.

P_0/P	L	$x_{p\,max}$	β_{max}	β_{min}	α	ν_x	$-\zeta_x$	α/R^2	ν_x/R
1	0.6	6.007	26.17	22.00	.0575	4.175	3.35	.0575	4.175
2	.8584	3.278	20.67	14.45	.0296	5.837	5.27	.0592	4.127
3	1.039	2.313	18.83	11.03	.0199	7.153	6.81	.0597	4.130
4	1.2	1.839	18.08	8.70	.0153	8.225	8.16	.0613	4.113
5	1.342	1.526	18.05	7.02	.0121	9.378	9.73	.0603	4.194
6	1.470	1.334	18.62	5.68	.0101	10.40	11.38	.0607	4.246
7	1.588	1.186	19.92	4.56	.0086	11.51	13.51	.0602	4.350
8	1.697	1.0711	22.33	3.57	.0074	12.69	16.60	.0591	4.486
9	1.8	1.003	27.20	2.60	.0066	14.17	21.60	.0592	4.724

[4] This program was written and distributed by Mark Barton of BNL and IBM.

The expected small variation of β_{max} is observed. The factor by which we should multiply X_p to get the offset of the lowest energy orbit is -8/9, so the required aperture is 89 cm.

Conclusions

Althiugh the results are interesting,the required aperture is still a bit large. Higher fields will improve this. Nevertheless, the amount of hardware to recirculate the beam is certainly smaller than would be required by 9 separate channels. Some attention should be placed on designing magnets of sufficient aperture for this purpose, particularly with higher fields and gradients.

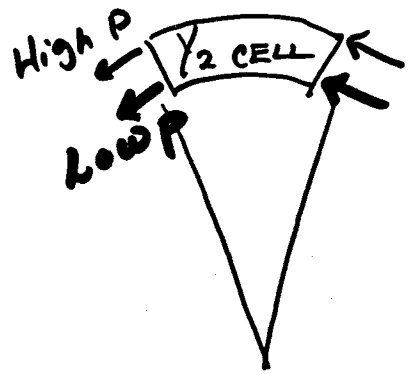
Effort should be applied to finding a solution for zero dispersion straight sections, and for describing the alternate solutions of chicanes or pulsed magnets.

The structure here has a length of 630m, which must be augmented by about 800m of linac, so the revolution time is about 5 μsec, which sounds a bit short to shift the phase of the nominal 350 MHz Linac indicated for this RLA in the scenario.. Since the bunch lengths are only several cm, perhaps higher frequency would be better.

FFAG Cardinal Rules

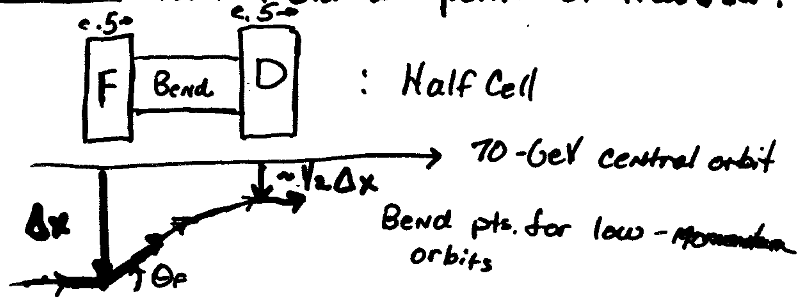
→ Use FODO structure; lattice functions close for largest momentum range (factor of 2-3 over other structures)

→ Different momenta beams are parallel every half cell / whole cell symmetry points



i.e. Total Bend Angles is equal for all momenta at cell symmetry points

START with FODO High momentum (70GeV) defines closed orbit. Low momentum traverses far off axis in F quad; **ASSUME** ~12T field at point of traversal.



At 10GeV $\theta_F = \frac{.5_m(.3)(12T)}{10\text{ GeV}} = \mathbf{.18\ rad}$

The geometry DICTATES the low momentum beam crosses the D quad off-axis at approximately half the distance as in the F quad. Therefore one can solve for the bend angle required to match 70 + 10 GeV orbits at symmetry points.

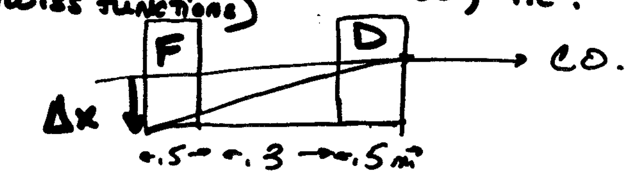
$$\theta_{DIPOLE} = \frac{\theta_{DIPOLE}}{7} = \theta_{DIPOLE} - (\theta_F - \theta_D) \quad \text{BUT } \overline{\theta_D = ½\theta_F}$$

(θ_{DIPOLE} at 70 GeV; $\frac{\theta_{DIPOLE}}{7} = \theta_{DIPOLE} - (\theta_F - \theta_D)$ at 10GeV)

$\Rightarrow \theta_{DIPOLE} = .105$ rad @ 10 GeV $\qquad \theta_{DIPOLE} = .015$ rad @ 70 GeV

At 12T; dipole length = .292 m

Now THAT WE HAVE A CELL LENGTH, the F QUAD APERTURE IS DETERMINED BY THE CONDITION FOR CLOSING THE LATTICE (twiss functions) AT 10GeV; i.e.

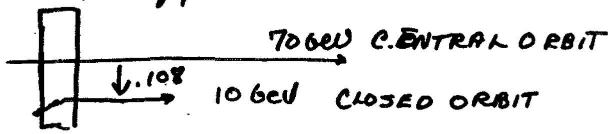


$\Delta x = .18\text{ rad } (1.3m) = .23\ m$

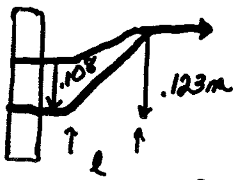
[FOR A .25m half-aperture F quad (1-m LONG) the poletip field is 13T]

THE ARC REQUIRES 209 modules (× 2.6m/module) is ~544 m

To GENERATE A STRAIGHT, start at center of D quadrupole which is the point of closest approach of the 2 beams



⇒ Need a pair of bucked dipoles to bring both orbits together.

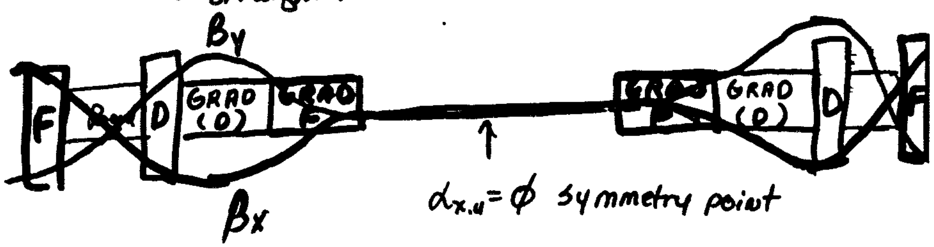


$$\Rightarrow .123\text{m} = \theta l = \frac{l^2(.3)(2T)}{10\,\text{GeV}}$$

(Total length of bucked dipoles = 2l)

$$l = .58\ \text{m}$$

Now the 1.2 m of bucked dipoles either side of straight will have to be gradient magnets to make a beam waist, the required symmetry point at the center of the straight.



COOLING EXPERIMENT

S. GEER

MAY 1997 : ORCAS IS. DECISION TO FORM IONIZATION COOLING COLLAB.

JULY 7-8 1997 : COOLING EXPT. MEETING AT FNAL

JULY 28-29 1997 : COOLING EXPT. MEETING AT BNL

} PREPARATION FOR GILMAN PANEL

AUGUST 1997 : GILMAN PRESENTATION AT FNAL →

FOFO COOLING HARDWARE
LIQUID Li - LENS HARDWARE
COOLING TEST FACILITY
EXPTAL PROGRAM AT FACILITY

} DRAFT R&D PROPOSAL 50 PEOPLE!

OCTOBER 20 - 22 1997 : COOLING EXPERIMENTAL, THEORETICAL & SIMULATION MEETING AT FNAL

THESE MEETINGS HAVE BEEN VERY EFFECTIVE & WE PLAN TO CONTINUE THEM

JAN 20-24 1998 : NEXT COOLING EXPERIMENT & THEORY MEETING AT BNL

- ITS IMPORTANT TO GET THE COOLING R&D PROPOSAL COMPLETED AND THE SMALL-SCALE GENERIC PART OF THE R&D PROGRAM BEGUN AS SOON AS POSSIBLE.
- THE TIMESCALE FOR COMPLETING THE PROPOSAL IS COUPLED TO PROGRESS ON THE COOLING SIMULATION WORK
- AT SOME POINT WE WILL NEED TO UPDATE OUR IDEAS ABOUT THE COOLING R&D PROGRAM & THE EXPERIMENT(S) REQUIRED ... THE JANUARY MEETING MAY BE THE RIGHT TIME.

An EXCEL Program is being written with goals:

- A complete cooling scenario
- A consistent set of all numbers
- detailed writeups
- many colors (+ shades of gray)
- . . .

J. NOREM

"An Update on a Cooling Scenario"

Writing the code is instructive - one confronts questions like:

What parts are required?

→ Trans cooling module
→ $\varepsilon_L \to \varepsilon_T$ (wedges)
→ Li lens

} Overall structure?

What does the wedge abs system look like?

→ adiabatic bends
→ distributed wedge absorbers

} Tradeoffs: length (drags) ⟷ emittance growth

Emittance dilution?

→ how to parametrize transitions

Where do losses come from?

→ required apertures, f_RF, a_z

Muon Cooling Algorithm

Initial

e_L =	1	m
e_x =	0.05	m rad
p =	105	MeV/c
dE/E =	1	
B_sol =	5	T
n =	5.E+12	muons/p
E =	196	MeV
K E =	90	MeV

Final

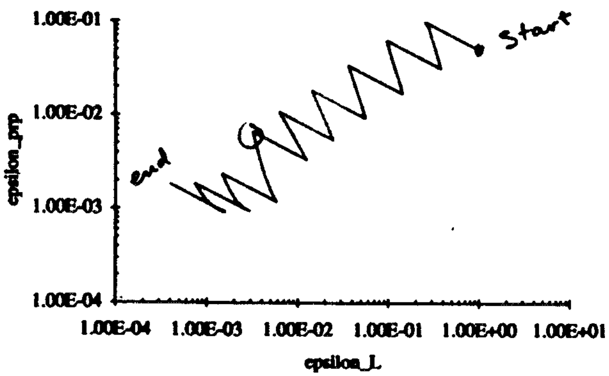
e_L =	0.00040	
e_x =	0.00182	
e_6 =	5.23E-07	X initial
Trans =	27.6	%

Absorber

Mat'l =	LH	
L_R =	0.871	m
rho =	0.82	g/cc
dE/dx =	100	MeV/m
<dE/dx> =	10	MeV/m
beta_prp =	0.1	m
[illegible] =	0.0625	
e_equil,N =	0.000700	m-rad
e_equil =	0.000454	m-rad

Constants

m_mu =	105.6	MeV
c =	3.E+08	m/s
tau_d =	2.20E-06	s
e_0 =	8.90E-12	
mu_0 =	1.26E-06	



Type	e_L	e_x	e_y	e_prp	e_6	dL	L	E	p	v/c	dE/dx	L_c	M. S.	de_l/m	s(E)	f	decay
	m	m-rad	m rad			m	m	MeV									
Initl	1.00E+00	5.00E-02	5.00E-02	5.00E-02	2.50E-03	0	0	196									1.000
L > x	[redacted]		5.00E-02	7.07E-02	2.50E-03	4	4	196									0.997
L > y	[redacted]	1.00E-01	[redacted]	1.00E-01	2.50E-03	4	8	196									0.993
cool	2.70E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	[illegible]	[illegible]	1.000	0.90		0.990
cool	3.00E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	0.942	10	33.30	[illegible]	1.111	0.90		0.987
cool	3.43E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	[illegible]	10	33.30	[illegible]	1.111	0.90		0.984
cool	3.80E-01	3.14E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.111	0.90		0.981
L > x	[redacted]		3.14E-02	6.29E-02	3.70E-04	4	20	196									0.977
cool	1.60E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	33.90	[illegible]	1.111	0.90		0.974
cool	1.17E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	0.942	10	33.90	[illegible]	1.111	0.90		0.971
cool	1.30E-01	[illegible]	1.18E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	0.942	10	33.90	[illegible]	1.111	0.90		0.968
cool	1.45E-01	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33.90	[illegible]	1.111	0.90		0.965
L > y	[redacted]	3.29E-02	[redacted]	3.37E-02	4.10E-05	4	48	196									0.962
cool	4.00E-02	[illegible]	2.40E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	0.942	10	33.90	5.1E-05	1.122	0.90		0.958
cool	4.34E-02	1.70E-02	1.70E-02	1.74E-02	1.30E-05	[illegible]	[illegible]	[illegible]	105	0.942	10	33.90	5.1E-05	1.118	0.90		0.955
cool	3.00E-02	1.20E-02	1.20E-02	1.20E-02	[illegible]	[illegible]	[illegible]	[illegible]	105	0.942	10	33.90	5.1E-05	1.116	0.90		0.952
cool	2.84E-02	8.95E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	33.90	5.1E-05	1.113	0.90		0.949
L > x	[redacted]		9.39E-03	1.84E-02	4.70E-06	4	68	196									0.946
cool	1.84E-02	2.56E-02	[illegible]	[illegible]	[illegible]	[illegible]	72	[illegible]	105	[illegible]	10	33.90	5.1E-05	1.163	0.90		0.943
cool	1.40E-02	1.80E-02	3.11E-03	[illegible]	[illegible]	[illegible]	[illegible]	196	105	0.942	10	33.90	5.1E-05	1.155	0.90		0.940
cool	2.17E-02	1.34E-02	[illegible]	7.31E-03	1.12E-06	4	[illegible]	[illegible]	105	0.942	10	33.90	5.1E-05	1.148	0.90		0.937
cool	2.40E-02	[illegible]	2.94E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.142	0.90		0.934
L > y	[redacted]	9.77E-03	[redacted]	1.07E-02	7.14E-07	4	88	196									0.931
cool	7.30E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	105	[illegible]	10	33.90	[illegible]	1.200	0.90		0.928
cool	8.90E-03	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	[illegible]	105	0.942	10	33.90	[illegible]	1.198	0.90		0.924
cool	1.07E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10	33.90	[illegible]	1.198	0.90		0.921
cool	1.25E-02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.175	0.90		0.918
L > x	[redacted]		3.56E-03	6.58E-03	1.36E-07	4	108	196									0.915
cool	3.00E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	107	[illegible]	10	7.37	1.1E-04	1.175	0.29		0.887
cool	4.32E-03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.170	0.29		0.883
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.165	0.29		0.880
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.160	0.29		0.876
L > y	[redacted]	1.40E-03	[redacted]	2.34E-03	7.90E-09	4	128	150									0.872
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	107	0.710	10	7.37	[illegible]	1.200	0.29		0.868
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.194	0.29		0.865
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.188	0.29		0.861
cool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	107	0.710	10	7.37	1.1E-04	1.182	0.29		0.857
L > x	[redacted]		9.92E-04	1.80E-03	2.53E-09	4	148	150									0.854
cool	8.97E-04	2.00E-03	[illegible]	[illegible]	[illegible]	4	[illegible]	150	107	0.710	10	7.37	1.1E-04	1.223	0.29		0.850
cool	1.00E-03	7.40E-04	8.79E-04	1.12E-03	1.30E-09	4	156	150	107	0.710	10	7.37	1.1E-04	1.218	0.29		0.847
cool	1.32E-03	1.12E-03	8.57E-04	8.78E-04	1.20E-09	4	160	150	107	0.710	10	7.37	1.1E-04	1.208	0.29		0.843
cool	1.50E-03	8.71E-04	8.40E-04	[illegible]	1.31E-09	4	164	150	107	0.710	10	7.37	1.1E-04	1.203	0.29		0.839
L > y	[redacted]	9.71E-04	[redacted]	1.82E-03	1.31E-09	4	168	150									0.836
																	0.276

c=0.52*U^0.66

f_rf	V_rf	A_rf	fr/b	bucket dE/m	bucket dt	bunch dE/m	bunch dt	aper	beta	sig	Loss_tr	U_B	U_rf	I	perv.	L_char	E_prp	E_pll
MHz	MV/m	m			ns		ns	m	m	m		MJ	J	A		m	MV/m	MV/m
								0.4	0.3	0.122								
								0.4	0.3	0.173		15.9						
								0.4	0.3	0.173		15.9						
350	45	1.17	0.24	1.05	1.17	0.51	0.57	0.3	0.3	0.160	0.8808	15.9	3611	1406	1.2E-07	644.2	0.18	0.05333
350	45	1.17	0.26	1.05	1.17	0.54	0.60	0.3	0.3	0.136	0.9468	15.9	3611	1334	1.2E-07	557.4	0.18	0.05333
350	45	1.17	0.29	1.05	1.17	0.57	0.63	0.3	0.3	0.115	0.9823	15.9	3611	1266	1.1E-07	484.0	0.18	0.05333
350	45	1.17	0.33	1.05	1.17	0.60	0.67	0.3	0.3	0.097	0.9960	15.9	3611	1201	1.1E-07	420.7	0.18	0.05333
								0.4	0.3	0.194	0.9226	15.9						
350	45	1.17	0.09	1.05	1.17	0.32	0.35	0.3	0.3	0.164	0.8695	15.9	3611	2279	2.0E-07	516.0	0.18	0.05333
350	45	1.17	0.10	1.05	1.17	0.33	0.37	0.3	0.3	0.139	0.9398	15.9	3611	2163	1.9E-07	447.8	0.18	0.05333
350	45	1.17	0.11	1.05	1.17	0.35	0.39	0.3	0.3	0.117	0.9790	15.9	3611	2052	1.8E-07	388.8	0.18	0.05333
350	45	1.17	0.12	1.05	1.17	0.37	0.41	0.3	0.3	0.099	0.9950	15.9	3611	1947	1.7E-07	337.9	0.18	0.05333
								0.3	0.3	0.099	0.9950	15.9						
350	45	1.17	0.03	1.05	1.17	0.20	0.22	0.3	0.3	0.084	0.9993	15.9	3611	3677	3.3E-07	208.4	0.18	0.05333
350	45	1.17	0.04	1.05	1.17	0.21	0.23	0.3	0.3	0.071	0.9999	15.9	3611	3477	3.1E-07	181.9	0.18	0.05333
350	45	1.17	0.04	1.05	1.17	0.22	0.24	0.3	0.3	0.061	1.0000	15.9	3611	3292	2.9E-07	159.1	0.18	0.05333
350	45	1.17	0.05	1.05	1.17	0.23	0.26	0.3	0.3	0.052	1.0000	15.9	3611	3120	2.8E-07	139.5	0.18	0.05333
								0.3	0.3	0.104	0.9923	15.9						
805	45	0.15	0.11	0.43	0.37	0.14	0.12	0.13	0.3	0.088	0.7427	3.0	683	6556	5.8E-07	163.1	2.16	0.12267
805	45	0.15	0.13	0.43	0.37	0.15	0.13	0.13	0.3	0.075	0.8453	3.0	683	6099	5.4E-07	143.5	2.16	0.12267
805	45	0.15	0.15	0.43	0.37	0.16	0.14	0.13	0.3	0.063	0.9218	3.0	683	5692	5.1E-07	126.3	2.16	0.12267
805	45	0.15	0.17	0.43	0.37	0.18	0.15	0.13	0.3	0.054	0.9683	3.0	683	5327	4.7E-07	111.4	2.16	0.12267
								0.2	0.3	0.054	0.9996	3.0						
805	45	0.15	0.05	0.43	0.37	0.10	0.08	0.13	0.1	0.027	1.0000	3.0	683	9692	8.6E-07	40.8	2.16	0.12267
805	45	0.15	0.06	0.43	0.37	0.11	0.09	0.13	0.1	0.023	1.0000	3.0	683	8856	7.9E-07	36.7	2.16	0.12267
805	45	0.15	0.07	0.43	0.37	0.12	0.10	0.13	0.1	0.020	1.0000	3.0	683	8127	7.2E-07	33.2	2.16	0.12267
805	45	0.15	0.08	0.43	0.37	0.13	0.11	0.13	0.1	0.017	1.0000	3.0	683	7487	6.6E-07	30.3	2.16	0.12267
								0.13	0.1	0.035	0.9996	3.0						
1300	45	0.07	0.05	0.187	0.41	0.04	0.09	0.08	0.1	0.025	0.9977	1.2	262	8613	1.7E-06	26.9	9.11	0.1981
1300	45	0.07	0.06	0.187	0.41	0.05	0.10	0.08	0.1	0.018	1.0000	1.2	262	7964	1.6E-06	20.6	9.11	0.1981
1300	45	0.07	0.07	0.187	0.41	0.05	0.11	0.08	0.1	0.014	1.0000	1.2	262	7379	1.5E-06	16.7	9.11	0.1981
1300	45	0.07	0.08	0.187	0.41	0.05	0.12	0.08	0.1	0.012	1.0000	1.2	262	6851	1.4E-06	14.4	9.11	0.1981
								0.08	0.1	0.012	1.0000	1.2						
1300	45	0.07	0.02	0.187	0.41	0.03	0.06	0.08	0.1	0.011		1.2	262	12510	2.5E-06	9.4	9.11	0.1981
1300	45	0.07	0.03	0.187	0.41	0.03	0.07	0.08	0.1	0.010		1.2	262	11450	2.3E-06	9.2	9.11	0.1981
1300	45	0.07	0.03	0.187	0.41	0.03	0.08	0.08	0.1	0.009		1.2	262	10505	2.1E-06	9.3	9.11	0.1981
1300	45	0.07	0.04	0.187	0.41	0.04	0.08	0.08	0.1	0.009		1.2	262	9661	1.9E-06	9.5	9.11	0.1981
								0.08	0.1	0.019		1.2						
1300	45	0.07	0.01	0.187	0.41	0.02	0.05	0.08	0.1	0.014		1.2	262	17475	3.5E-06	11.0	9.11	0.1981
1300	45	0.07	0.01	0.187	0.41	0.02	0.05	0.08	0.1	0.012		1.2	262	15848	3.1E-06	9.5	9.11	0.1981
1300	45	0.07	0.02	0.187	0.41	0.03	0.06	0.08	0.1	0.011		1.2	262	14411	2.8E-06	8.9	9.11	0.1981
1300	45	0.07	0.02	0.187	0.41	0.03	0.06	0.08	0.1	0.010		1.2	262	13139	2.6E-06	8.6	9.11	0.1981
								0.08	0.1	0.010	0.3302	1.2						
												319	51933					

you write it / you rate it

Interface * * *

Completeness * *

Neatness * *

Usefulness ?

Reliability  ↔ *

LONGITUDINAL IMPEDANCE TUNER USING HIGH PERMEABILITY MATERIAL

K. KOBA, Y. MORI, ...

[HIGH INTENSITY PROTON SYNCHROTRON]

SPACE CHARGE FORCE ↗ WEAKENS

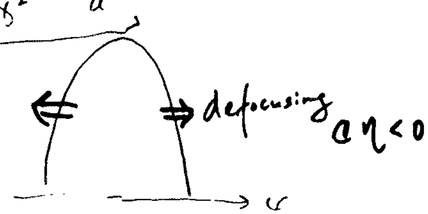
⇒ "RF FOCUSING FORCE" ↘
below transition
longitudinal phase space

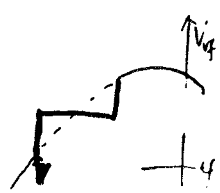
ⓐ BELOW TRANSITION

S.C. IMPEDANCE ⇒ CAPACITIVE
CAN BE CANCELED BY INDUCTANCE

$$Z_0''(\omega) = i Z_0 \frac{R\omega}{c\gamma^2} \ln\frac{b}{a}$$

(Sessler, ...) '60.

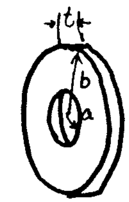




INDUCTANCE (RF)

- ferrite $\mu \lesssim 400$, $f \sim < 100 MHz$
  $Q \approx 30-50$, $H_c \gtrsim 1000 A/m$
- magnetic alloy
  FINEMET $\mu \sim \underline{4000}$, $f \sim 10-50$ MHz
  $Q \sim 1$, $H_c \sim 10$ A/m

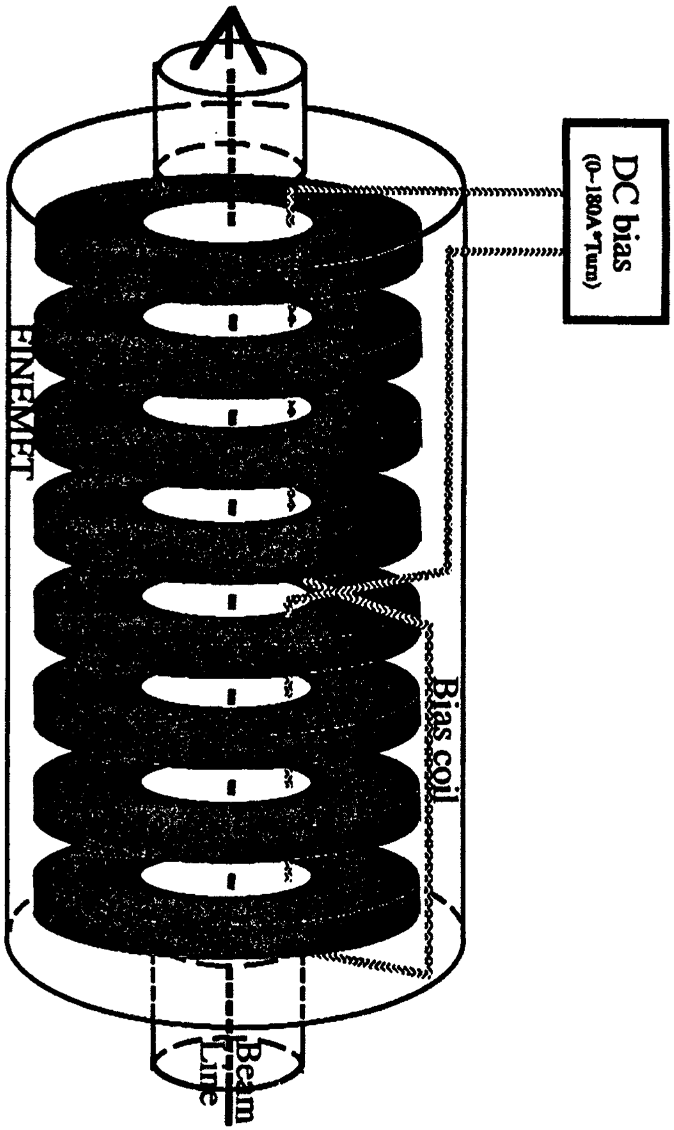
$$L = \frac{\mu_0 \mu}{2\pi} \cdot t \cdot \ln\frac{b}{a}$$



total length

FINEMET ~ 1/10 ferrite

compact !



MEASUREMENT

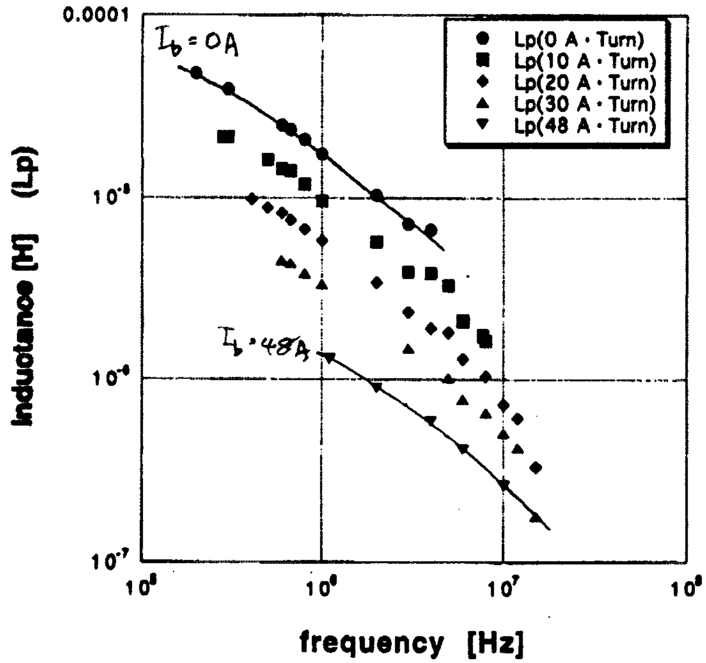
ω_s shift

X dipole motion ⇐ incoherent Potential Well Distortion

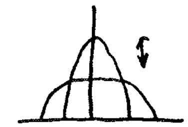
o Quadrupole motion

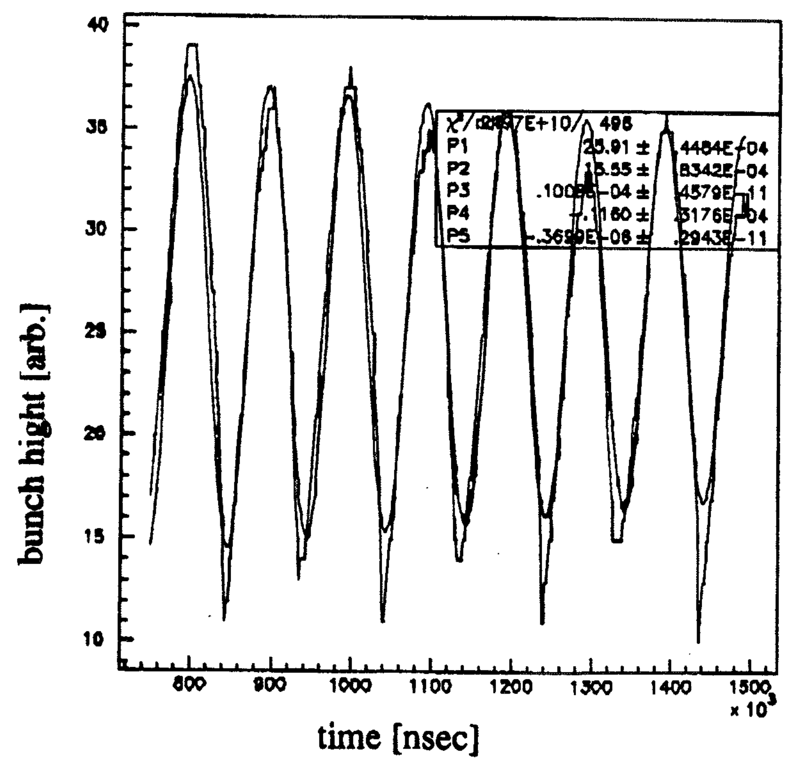
$$\frac{\Delta f_{2s}}{f_{2s}} = \frac{1}{4}\,\frac{\Delta f_s}{f_s} \qquad (\text{ Sacherer })$$

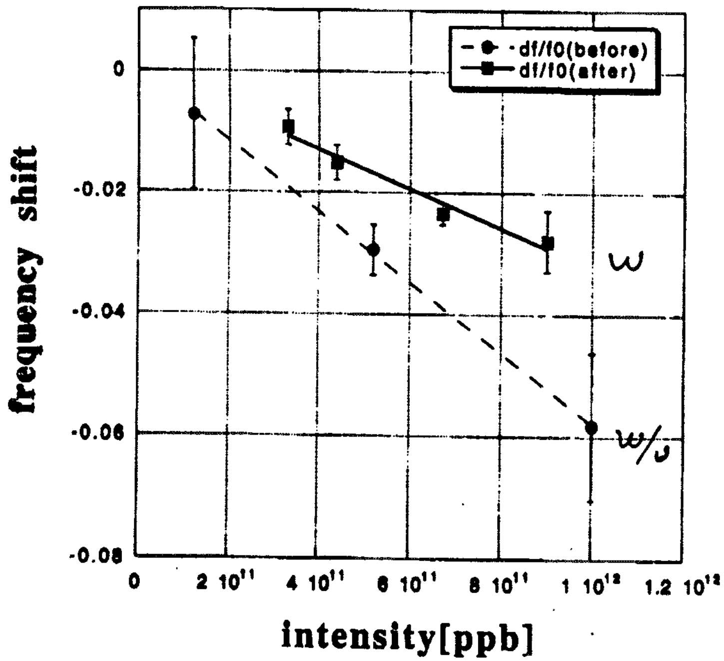
$$\frac{\Delta f_s}{f_s} = -\frac{3 e f_0}{2\pi^2 h V_0 \cos\phi_0}\left(\frac{2\pi R}{1}\right)^3\left[\frac{g_0 Z_0}{2\beta\gamma^2} - \left|\frac{Z}{n}\right|\right] N$$



@ envelop of bunch height






df/f0(before)
df/f0(after)
frequency shift
0
-0.02
-0.04
-0.06
-0.08
0
2 10^11
4 10^11
6 10^11
8 10^11
1 10^12
1.2 10^12
intensity[ppb]
w
w/o

Vertex Tagging

Bruce King

BNL

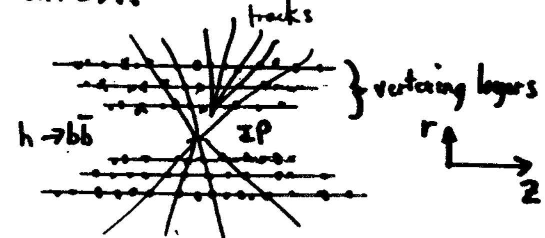
bking@sun2.bnl.gov

μμ Collaboration Meeting   13 December, 1997

Can We Do B Tagging? Yes!!

Comparision with LHC...

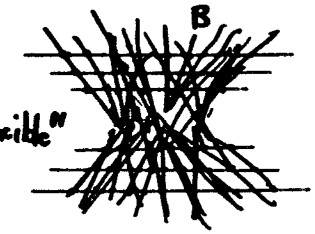
- many many hits
- few tracks



μμ

[pictures are illustrative only]

~same # hits
most from tracks → "irreducible"



LHC

⇓

LHC vertexing <u>much</u> harder

LHC claims can do b tagging

∴ μμ certainly can.

Q.E.D.

Brief Recap of Calc^{n} of Tagging Efficiencies
(see BJK talk at FNAL November workshop)

b & c tagging

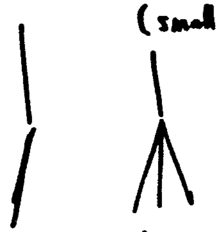
Scaling of Petra Huntermeier study for DESY LC

- uses Active Pixel Sensors (APS's) ✓
- inner layer of vertex detector at 2 or 3.5 cm → extrapolate to 5 cm (~20% effect)
- LC has better cond^{n}s : small spot size, fewer background hits

assess as small effects → 20% reduction in effic.

τ tagging for Higgs factory

$h^0 \to \tau\tau$ is same topology as $Z^0 \to \tau\tau$ at LEP, SLD
usually 2 ~ back-to-back stiff tracks, no other tracks
(small miss at vertex - optional)



1-vs-1 (70%) 1-vs-3 (30%)

"sticks out like a sore thumb"
⇓
70% efficiency from

Conclusions

- Confidence in vertex tagging at μ collider:

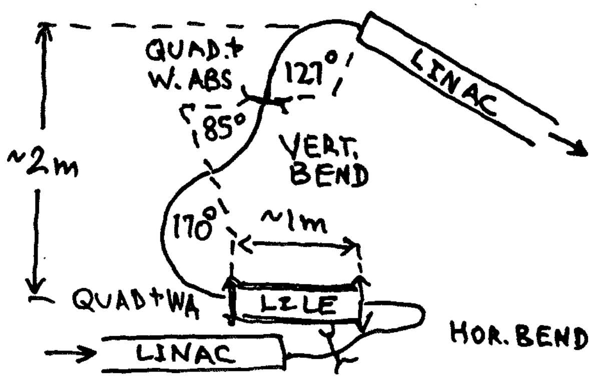
b tagging	✓✓✓	(Bob Palmer rating system)
c tagging	✓✓	
τ tagging	✓✓	

- Quick estimate of b, c, τ tagging efficiencies was presented at Nov. FNAL workshop. Detailed estimate would need ~final beam parameters, shielding design, detector design, pattern recognition & vertexing algorithm – not yet practical / useful.

Matching and emittance exchange section for ionization cooling with Li lenses

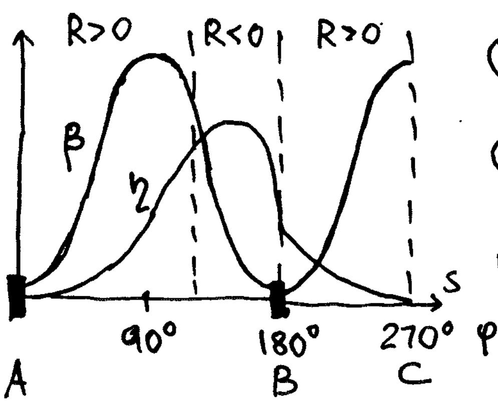
Valeri Balbekov

1. Schematic



- Bending magnets: field index 0.5, $R \simeq 0.5\,m$
- Phase advances: 120°, 60°, 90°
- Length of the bend $\frac{3\pi}{2} R\sqrt{2} \simeq 3\,m$

2. Beta-function and dispersion

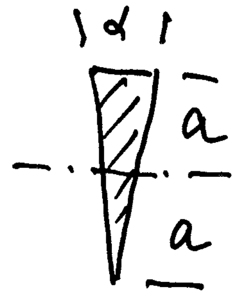


Ⓐ $\beta = \beta_L \sim 1\,cm$
$\eta = 0$

Ⓑ $\beta = \beta_L$
$\eta = 2R \sim 1\,m$

Ⓒ $\beta = \frac{2R^2}{\beta_L} \sim 50\,m$
$\eta = 0$

3. Wedge



$$\frac{\eta}{a}\Delta E \simeq \frac{\beta^2}{3}(E_{max} - E_{min})$$

$$\Delta E \simeq \frac{0.15\,m}{1\,m}\,\frac{100\,MeV}{3} = 5\,MeV$$

(~2.5 cm Be)

$$\alpha \simeq \frac{2.5\,cm}{15\,cm} = \frac{1}{6} \simeq 10^\circ$$

710 Blank