MUON COLLIDERS

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1 Introduction

1.0.1 Collaboration

- $>$ 100 Collaborators (30-40 FTE's)
- Lead Spokesperson :Bob Palmer (BNL)
- Associate Spokesmen:
  A. Sessler (LBNL), A. Tollestrup (FNAL)
- Lead Institutions
  BNL, FNAL, BINP, LBNL,
  Mississippi, Princeton, UCLA
- Members also from :
  ANL, CERN, Ecole Poly., Fairfield, Indiana, KEK, Oak Ridge, Saclay
- Experiments
  - Cooling Exp: S. Geer
  - Target & Capture Exp K. McDonald
  - BNL E910 (Pion Prod) H. Kirk
  - BNL E932 (Proton compression) J. Norem

1.0.2 WHY A MUON COLLIDER

μ is a High mass Lepton

- Lepton Energy advantage
- Suppressed Synchrotron Rad
  ($\propto\ \gamma^4\ \propto\ m^{-4}$)
  - Circular and Smaller

  - Luminosity $\propto n_{turns} \approx 1000$
  - Easier Tolerances
  - Narrow Energy Spread $\rightarrow$ 0.003%

- Less Initial State Radiation
- Direct Higgs Production
  $\mu^+ \mu^- \rightarrow h, A, H \quad (\sigma \propto m^2)$
- μ p Interactions
  - 200 GeV μ + 1 TeV p
    $\approx 3 \times$ HERA

1.1 COMPARISON of COLLIDERS

1.1.1 e vs. μ Comparison

1.1.2 BUT

μ's in diffuse phase space
and μ's Decay

1.1.3 Need

- Efficient μ Production
- Rapid Cooling
- Rapid Acceleration

1.1.4 Deal With

- Beam Pipe Heating
- Detector Background
- Neutrino Radiation

1.2 History

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1.3 Luminosity

Interaction Rate dn/dt for cylindrical bunch of area A and with uniform distribution:

$$\frac{dn}{dt} = N_1 \ f \ \rho \ \ell \ \sigma_{int}$$

$$\rho_2 = \frac{N_2}{\ell \ A}$$

Define Luminosity $\mathcal{L}$ by

$$\frac{dn}{dt} = \mathcal{L} \ \sigma_{int}$$

then

$$\mathcal{L} = \frac{N^2 \ f}{A} = < I_\mu > \ \frac{N}{A}$$

For Gaussian beams:

$$\mathcal{L} = \frac{N^2 \ f}{4\pi \ \sigma_r^2} = < I_\mu > \ \frac{N}{4\pi \ \sigma_r^2} \tag{1}$$

We need high average muon current, many muons per bunch, and a small spot size.

1.4 PARAMETERS

CoM energy	TeV	3	0.4	0.1	
p energy	GeV	16	16	16	
p's/bunch		2.5×10^{13}	2.5×10^{13}	5×10^{13}	
Bunches/fill		4	4	2	
Rep. rate	Hz	15	15	15	
p power	MW	4	4	4	
μ/bunch		2×10^{12}	2×10^{12}	4×10^{12}	
Wall power	MW	204	120	81	
Collider circ.	m	6000	1000	350	
Ave bend B	T	5.2	4.7	2	
Rms $\frac{\Delta p}{p}$	%	0.16	0.14	0.12	0.003
6D ϵ_6	$(\pi \mathrm{m})^3$	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}	1.7×10^{-10}
Rms ϵ_n	$\pi \ 10^{-6} m$	50	50	85	290
β^*	cm	0.3	2.6	4.1	14.1
σ_z	cm	0.3	2.6	4.1	14.1
σ_r spot	μm	3.2	26	86	294
σ_θ IP	mrad	1.1	1.0	2.1	2.1
Tune shift		0.044	0.044	0.051	0.015
Luminosity	$cm^{-2}s^{-1}$	7×10^{34}	10^{33}	1.2×10^{32}	10^{31}
Higgs/year				1.9×10^3	3.9×10^3

1.5 100GeV HIGGS COLLIDER

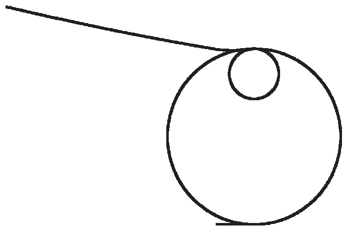
1.5.1 3 TeV COLLIDER

1.6 Pion Production

Fig π vs p Energy ***

Fig π's vs. their E ***

1.7 PROTON SOURCE



NEED:

- Proton Beam Power 2-4 MW
- Very short bunch: rms 1-2 nsec

FNAL PROPOSAL: 4 MW

- Upgraded linac (.4 $\rightarrow$ 1 GeV)
- Higher field operation in Booster
- New Pre-Booster

BNL PROPOSAL: 2 MW

- Upgraded linac (.2 $\rightarrow$ .6 GeV)
- Increased AGS rep rate: 2.5 Hz

1.8 Target, Capture, Decay and Phase Rotation

[R.B.Palmer: Lec.1] 1.8 Target, Capture, Decay and Phase Rotation

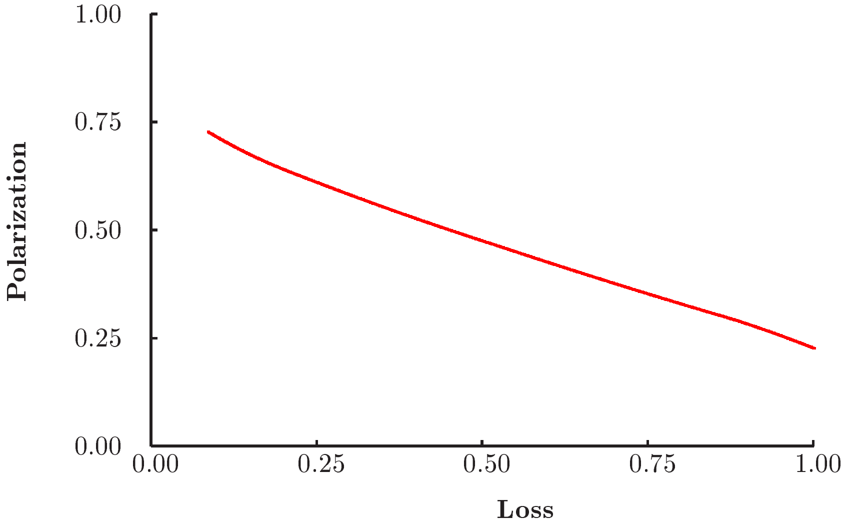
- TARGET: Liquid Metal Jet
- CAPTURE: 20 T Solenoid
- DUMP
- MATCHING
- DECAY & PHASE ROT.: 1.25 T

liquid target picture ***

1.8.1 Simulation of Capture and Phase Rotation

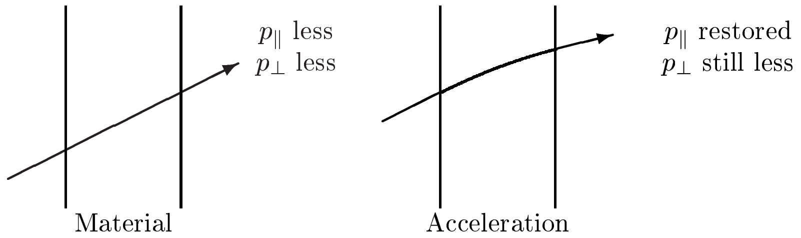
low B polarization
file: pol
Sec 12

1.8.2 Initial Polarization vs Loss

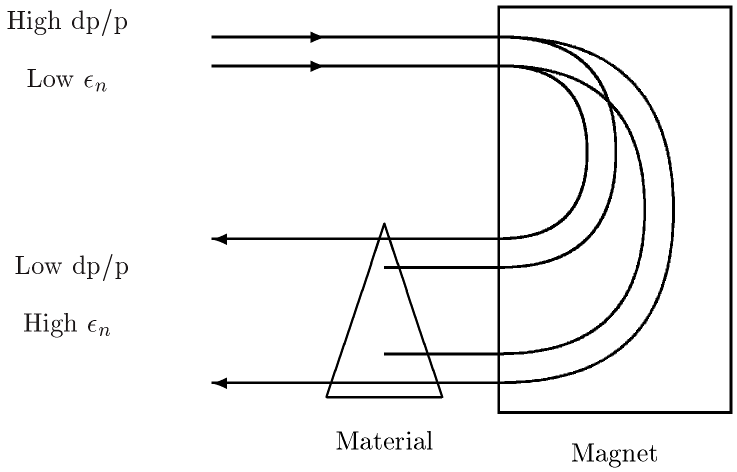


1.9 IONIZATION COOLING

- TRANSVERSE



- LONGITUDINAL EMIT EXCH



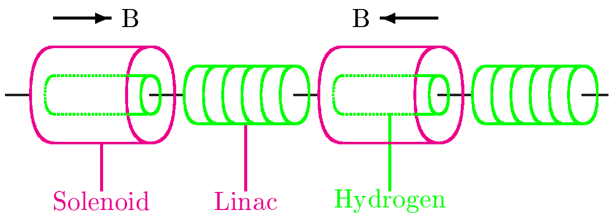
1.9.1 TRANSVERSE COOLING

- Energy Loss lowers $\epsilon_\perp$
- Coulomb Scattering Increases $\epsilon_\perp$
- Equilibrium:

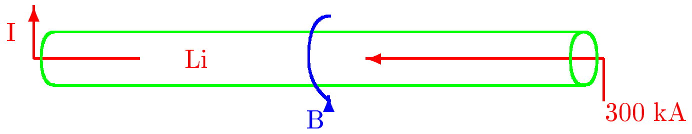
$$\epsilon_\perp \propto \beta_\perp \frac{1}{\beta_v L_R \, dE/dx} \propto \beta_\perp$$

HOW TO GET LOW $\beta_\perp$

- Alternating solenoids (Early Stages)



- Lithium Lens (Late Stages)



1.9.2 SIMULATION at 15 T

1.9.3 FINAL STAGE

Higgs Collider parameters Achieved at 30 T, but Lithium Lenses may be more economical.

1.9.4 LONGITUDINAL EMIT EXCH

Horizontal Bend → Vert Dispersion
Wedge removes Disp. → increases y
Vertical Bend Horizontal → Dispersion
Wedge removes Disp. → increases x

- dp/p reduced
- Emittance x and y increased

1.10 EMIT EXCH SIMULATION

1.10.1 One Bend

1.10.2 Both Bends

1.11 COOLING SYSTEM

- 6D emit reduction/stage ≈ 2
- Typical length 20 m/stage
- Trans Cool & Long Exch Alternate

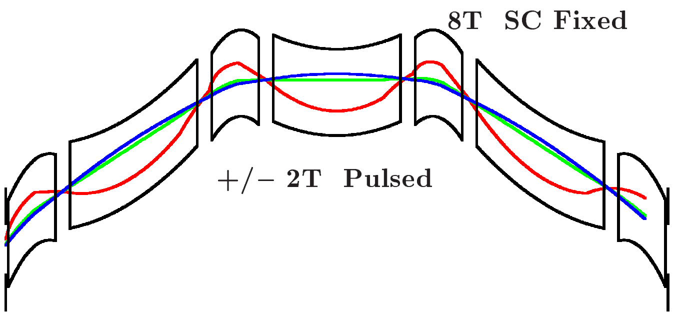
Required 6D reduction $\approx 10^6$
Number of stages ≈ 20
Total Length ≈ 500 m
Momentum ≈ 180 MeV/c
Decay Loss ≈ 36 %

1.12 ACCELERATION

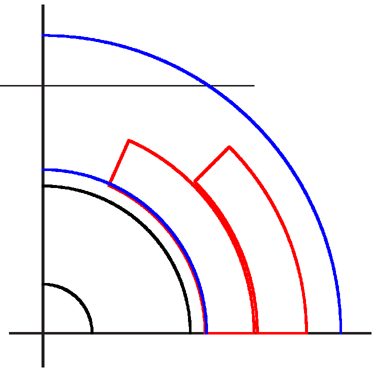
Acceleration must be rapid

- At very low Energies:
  Linacs (one pass)
- Intermediate Energies:
  Recirculating-Linac (or FFAG)
  ($\approx$ 10 turns)

- High Energies:
  Hybrid Pulsed & SC Synchrotron
  ($\approx$ 40 turns)

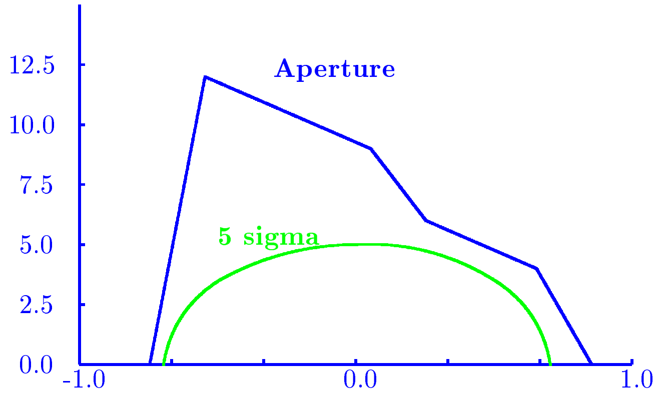


1.13 COLLIDER RING



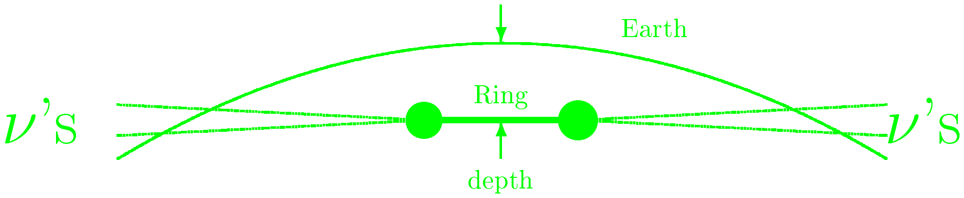
- Low beta
  Local chromatic corr.
- Short Bunches
  Isochronous ring
  Flexible Momentum Compaction
- Tungsten Beam Shield
  6 cm at 3 TeV,
  3 cm at 100 GeV
- Status
  - feasibility demonstrated at 4 TeV
  - 100 GeV Lattices: Good Aperture

Aperture (sigma)



Momentum spread (%)

1.14 NEUTRINO RADIATION



- Radiation $\propto \; E^3/length^2 \;\propto\; E^3/depth$
- Use: 1/10 Federal limit = 10 mR/year

THEN

- Negligible problem at 1.5 TeV
  - ≈ 1 mR/year
- E = 3 TeV OK at 300 m depth
  - ≈ 10 mR/year
- E > 3 TeV Requires:
  - Beam wobbles, and/or
  - Special Locations, and/or
  - Better Cooling (Optical Stochastic?)

1.15 BACKGROUND

- at 5 cm rad
- Si Pixels
- $60 \times 150\ \mu m$

- acceptable n dose= 5×10^{14}
- 1 year = 10^7 sec

Energy	TeV	100	500	4000
Occupancy all	%	0.6	0.1	0.3
Occupancy Charged	%	0.14	0.1	0.1
neutron > 100 KeV	n/cm^2	100	50	30
neutron dose	Hits/year	$3\ 10^{13}$	$3\ 10^{13}$	$1.8\ 10^{13}$
Lifetime	years	15	15	25

Significant Bethe Heitler Muons at Higher E's
Calorimeter Timing and Subdivision?

1.16 CONCLUSION

MOTIVE

- Small size (e.g. 3 TeV fits at FNAL)
- Easier Tolerances ?
- Lower \$/TeV ?
- Very low dE/E (e.g. 3 $\times 10^{-5}$)
- Precision E Det ($\approx 10^{-6}$)
- S Coupling to Higgs ($\propto m^2$)

PROGRESS

- Theory well understood
- Simulations progressing well
- No "Fatal Flaw" found
- Experimental Program Starting