MUON COLLIDERS

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LBNL

COLLABORATION

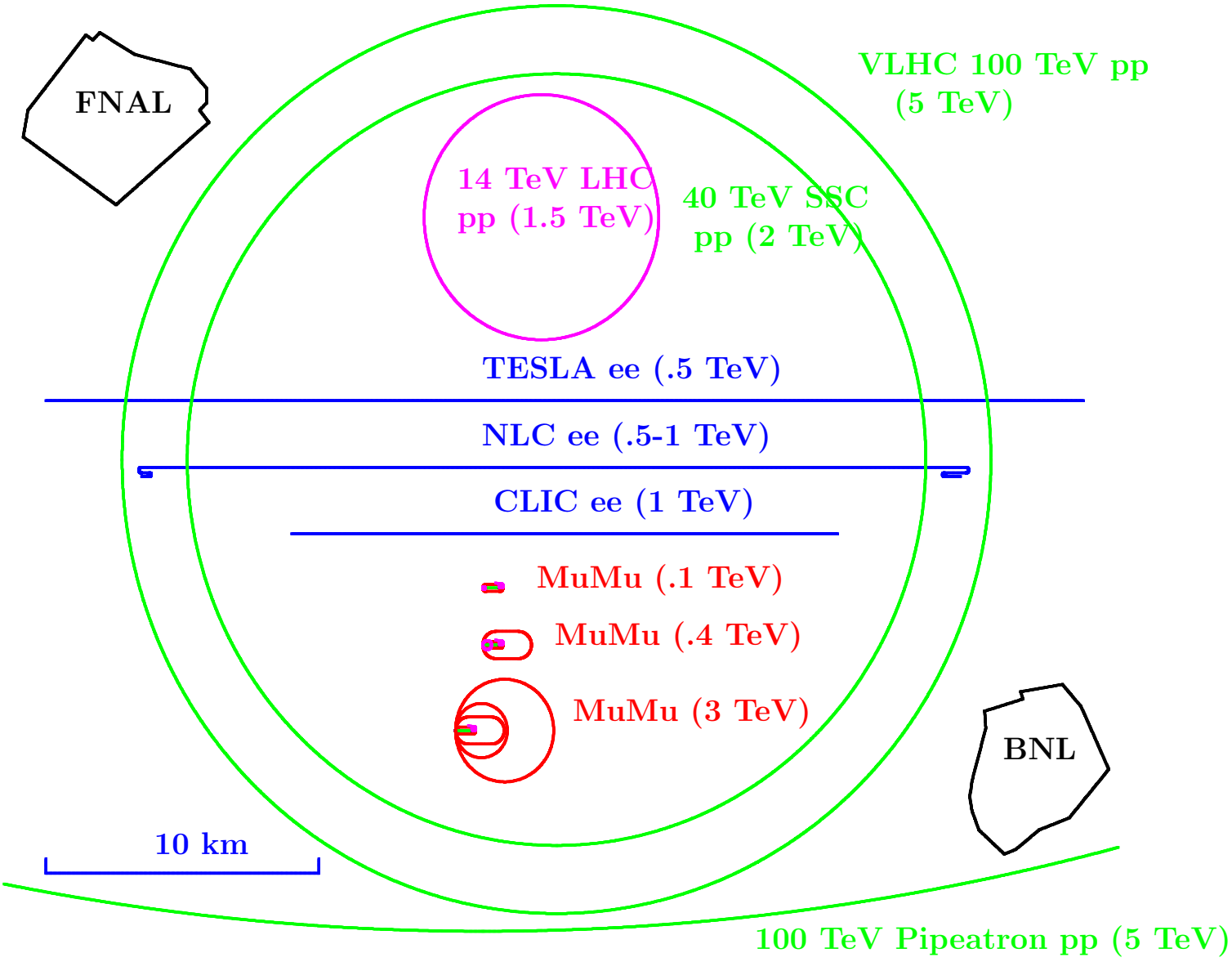
- $>$ 100 Collaborators (30-40 FTE's)
- Lead Spokesperson :Bob Palmer (BNL)
- Associate Spokesmen:
  A. Sessler (LBNL), A. Tollestrup (FNAL)
- Lead Institutions
  BNL, FNAL, BINP, LBNL,
  Mississippi, Princeton, UCLA
- Members also from :
  ANL, CERN, Ecole Poly., Fairfield, Indiana,
  KEK, Oak Ridge,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

WHY A MUON COLLIDER

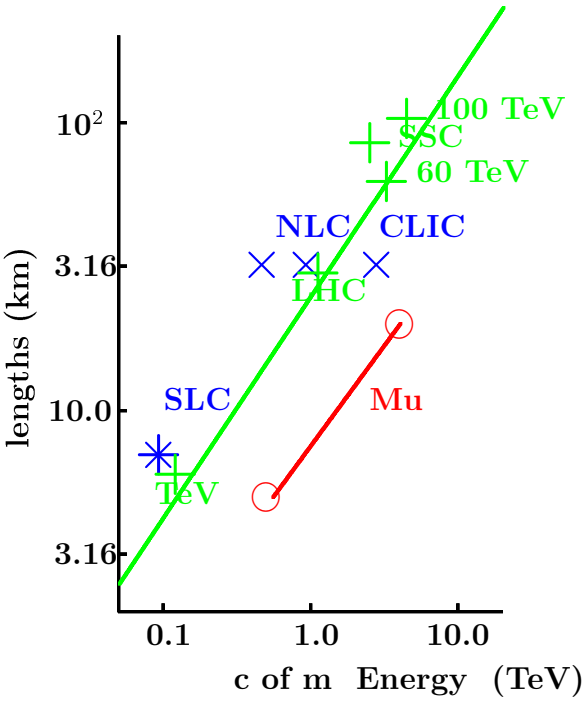
μ is a High mass Lepton

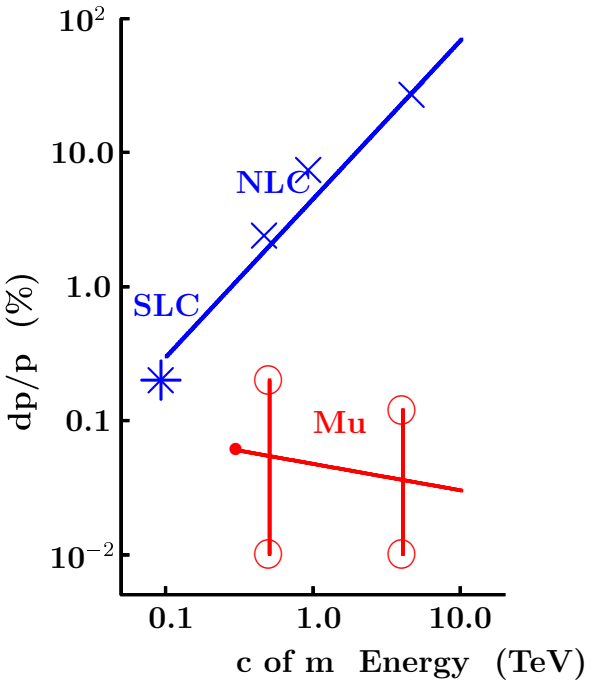
- **Lepton Energy advantage**
- **Suppressed Synchrotron Rad**
  $(\propto \ \gamma^4 \ \propto \ m^{-4})$
  - **Circular and Smaller**
  - **Luminosity** $\propto \ n_{turns} \ \approx$ **1000**
  - **Easier Tollerances**
  - **Narrow Energy Spread** $\rightarrow$ **0.003%**
- **Less Initial State Radiation**
- **Direct Higgs Production**
  $\mu^+ \ \mu^- \ \rightarrow \ h, A, H \ \ (\sigma \ \propto \ m^2)$
- μ **p Interactions**
  - **200 GeV** μ **+ 1 TeV** p
    $\approx$ **3** $\times$ **HERA**

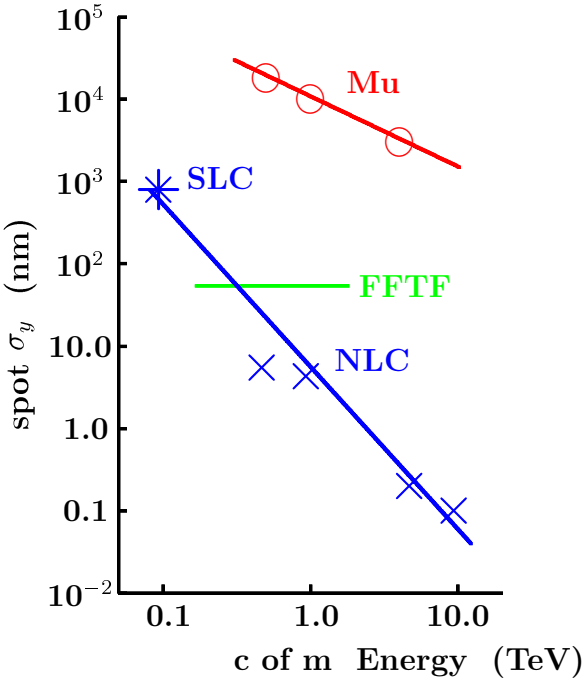
COMPARISON of COLLIDERS

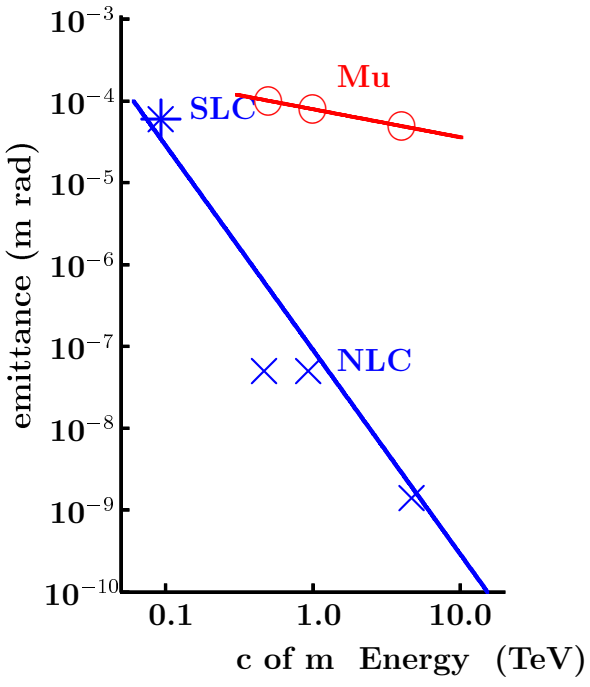


COMPARISONS e vs. μ









BUT:

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

Need

- Efficient μ Production
- Rapid Cooling
- Rapid Acceleration

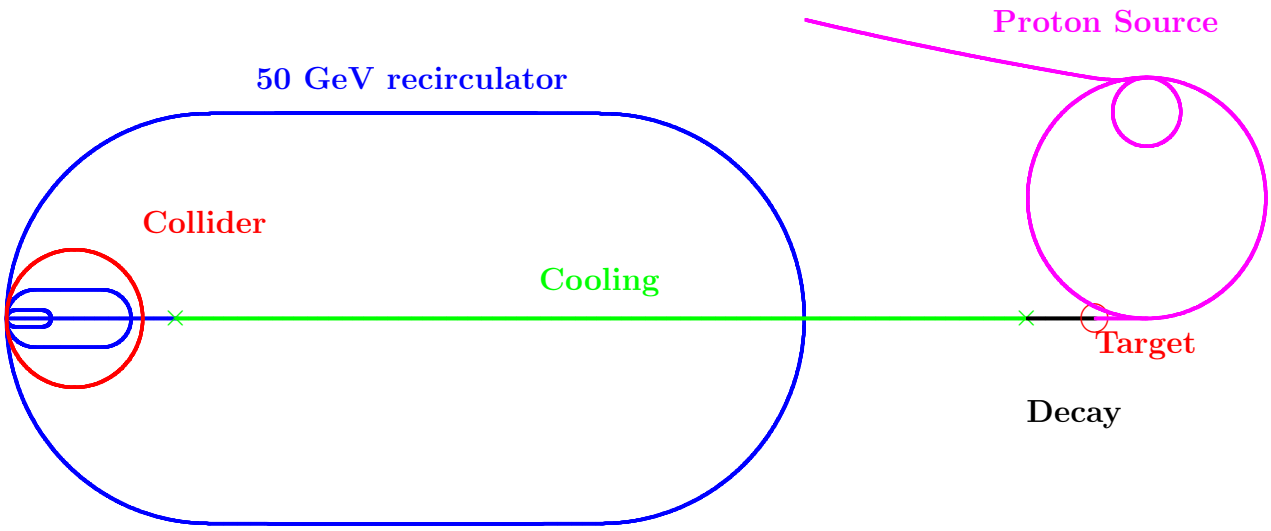
Deal With

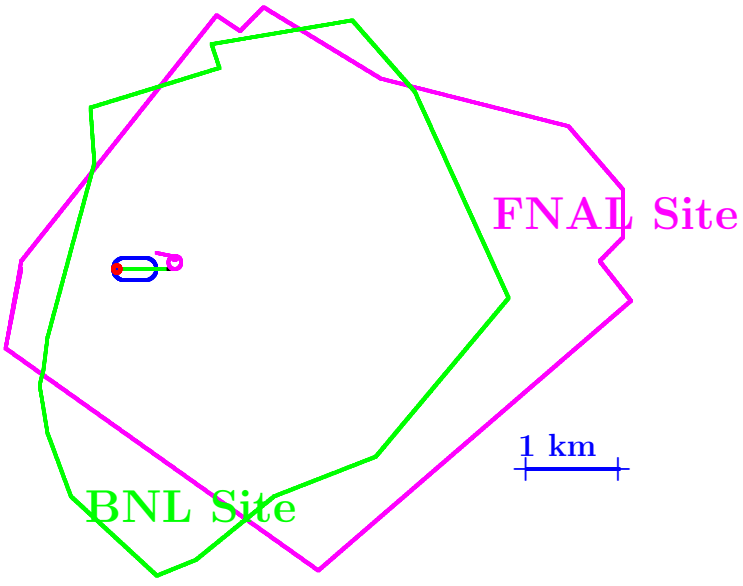
- Beam Pipe Heating
- Detector Background
- Neutrino Radiation

PARAMETERS

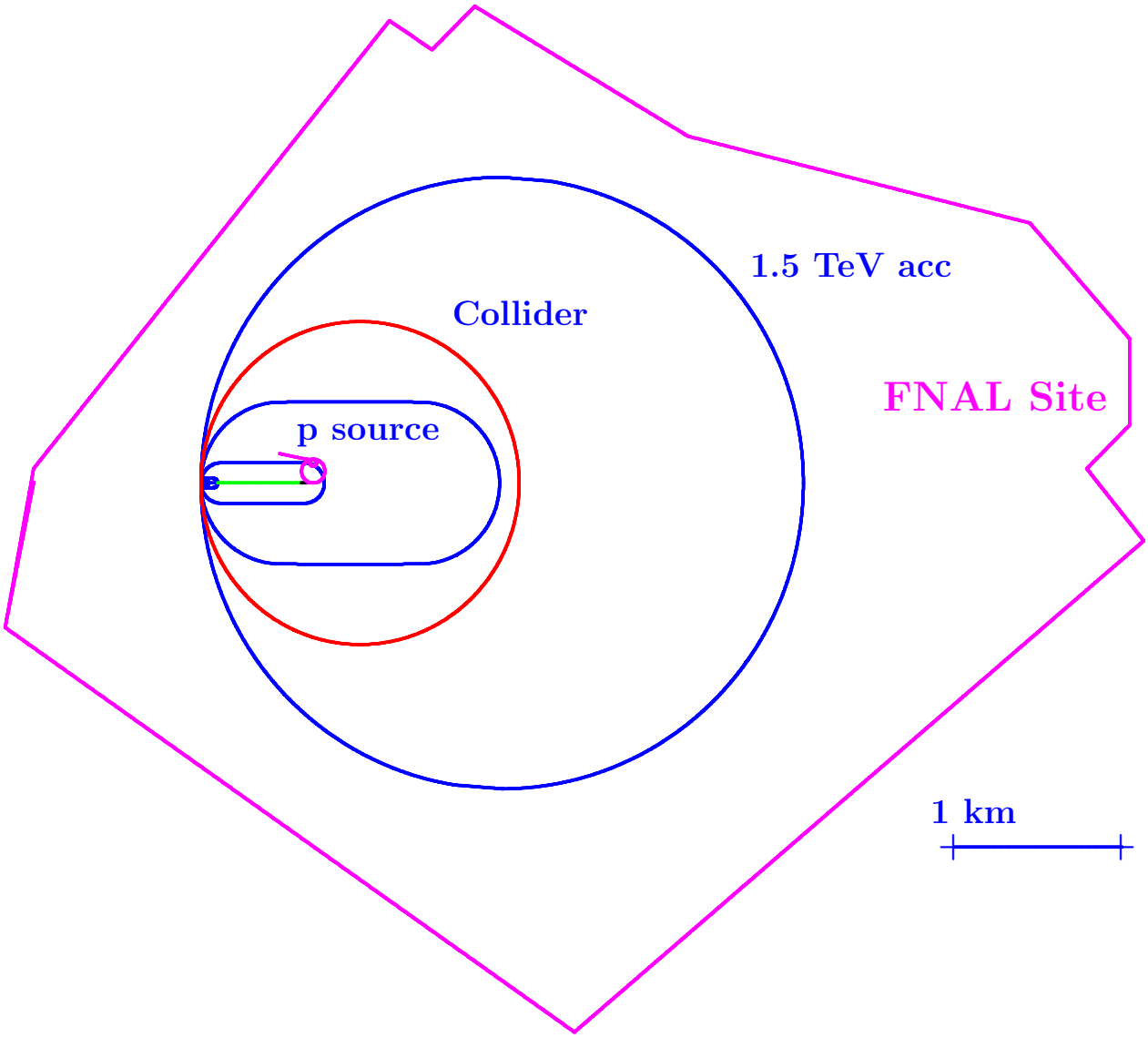
CoM energy	TeV	3	0.4	0.1	
p energy	GeV	16	16	16	
p's/bunch		2.5×10^{13}	2.5×10^{13}	5×10^{13}	
Bunches/fill		4	4	2	
Rep. rate	Hz	15	15	15	
p power	MW	4	4	4	
μ/bunch		2×10^{12}	2×10^{12}	4×10^{12}	
Wall power	MW	204	120	81	
Collider circ.	m	6000	1000	350	
Ave bend B	T	5.2	4.7	2	
Rms $\frac{\Delta p}{p}$	%	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

100GeV HIGGS COLLIDER

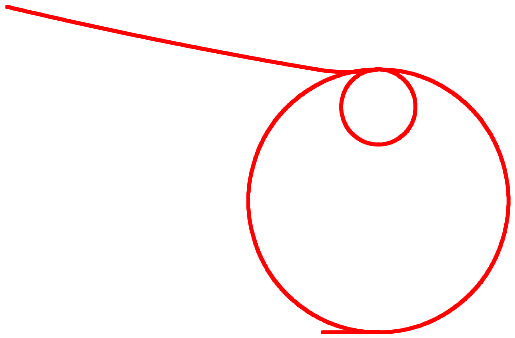




3 TeV COLLIDER



PROTON SOURCE



NEED:

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

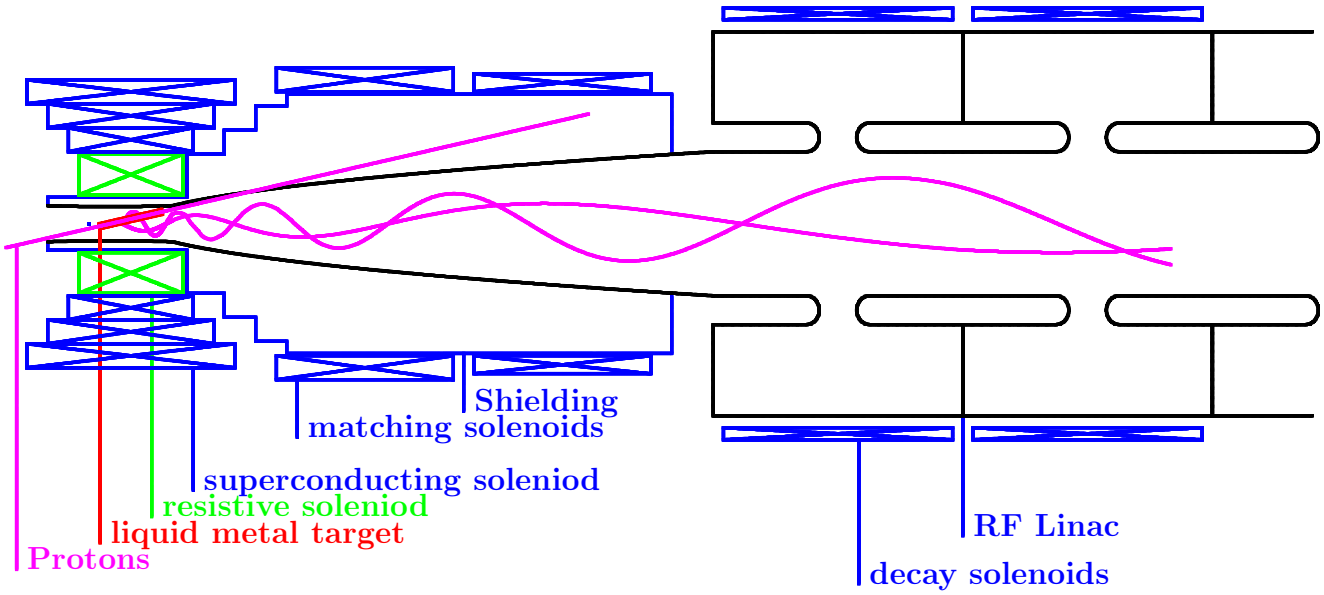
FNAL PROPOSAL: 4 MW

- **Upgraded linac (.4 → 1 GeV)**
- **Higher field operation in Booster**
- **New Pre-Booster**

BNL PROPOSAL: 2 MW

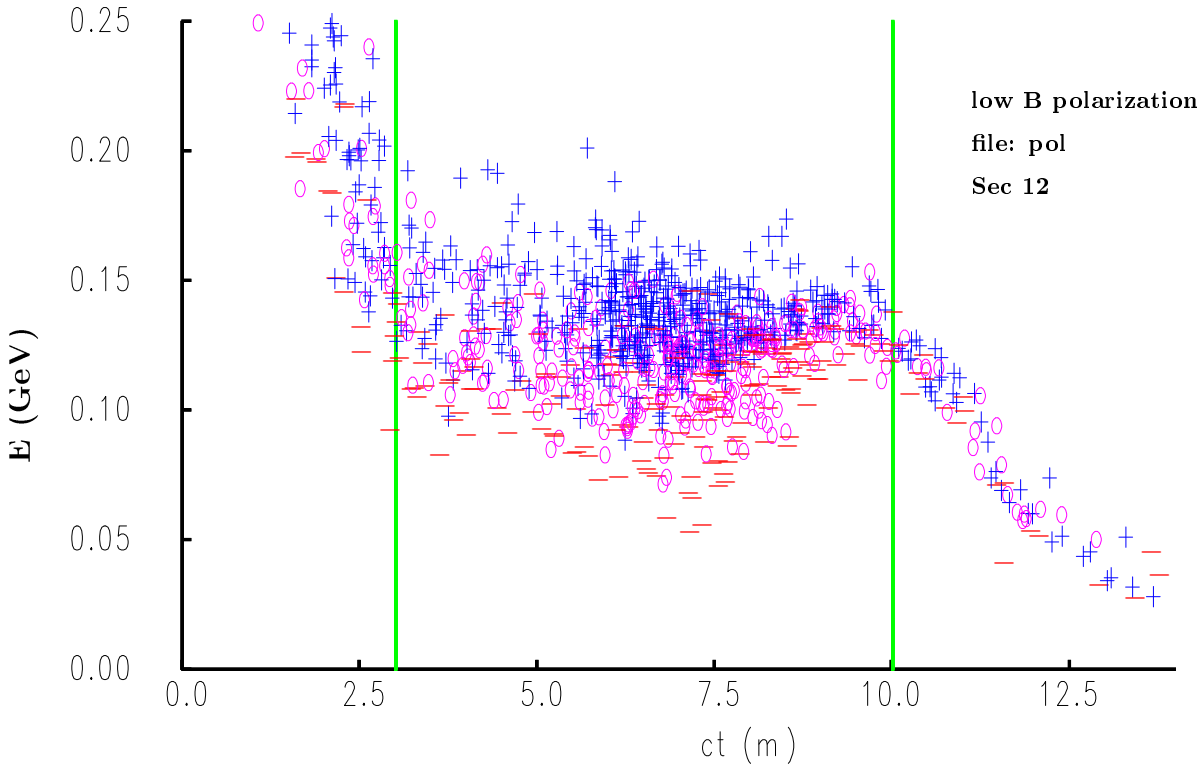
- **Upgraded linac (.2 → .6 GeV)**
- **Increased AGS rep rate: 2.5 Hz**

TARGET, CAPTURE & DECAY

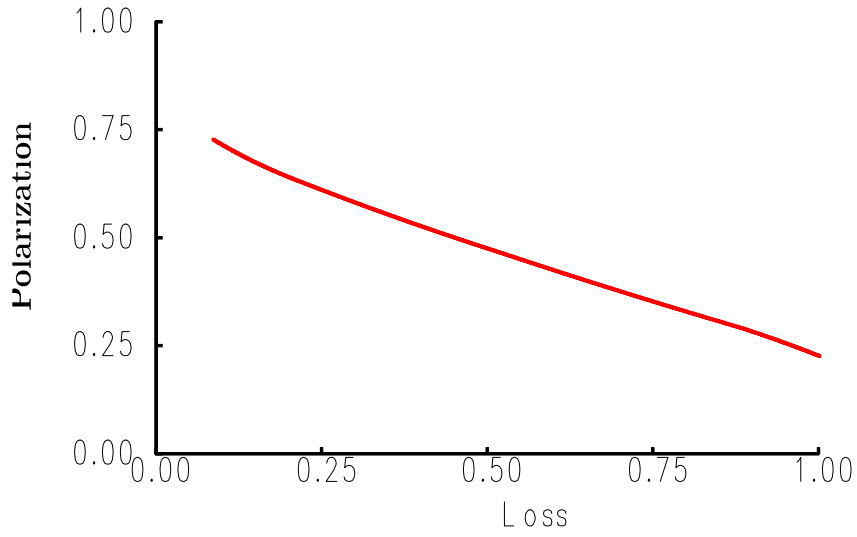


- **TARGET: Liquid Metal Jet**
- **CAPTURE: 20 T Solenoid**
- **DUMP**
- **MATCING**
- **DECAY & PHASE ROT.: 1.25 T**

SIMULATION
Capture and Phase Rotation

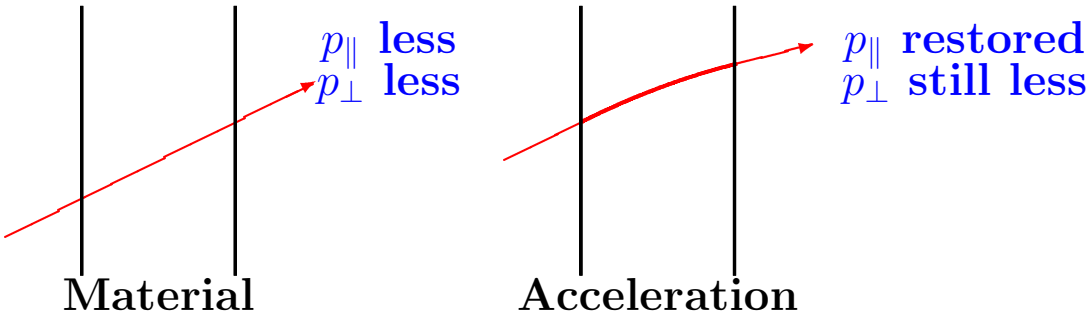


Initial Polarization vs Loss

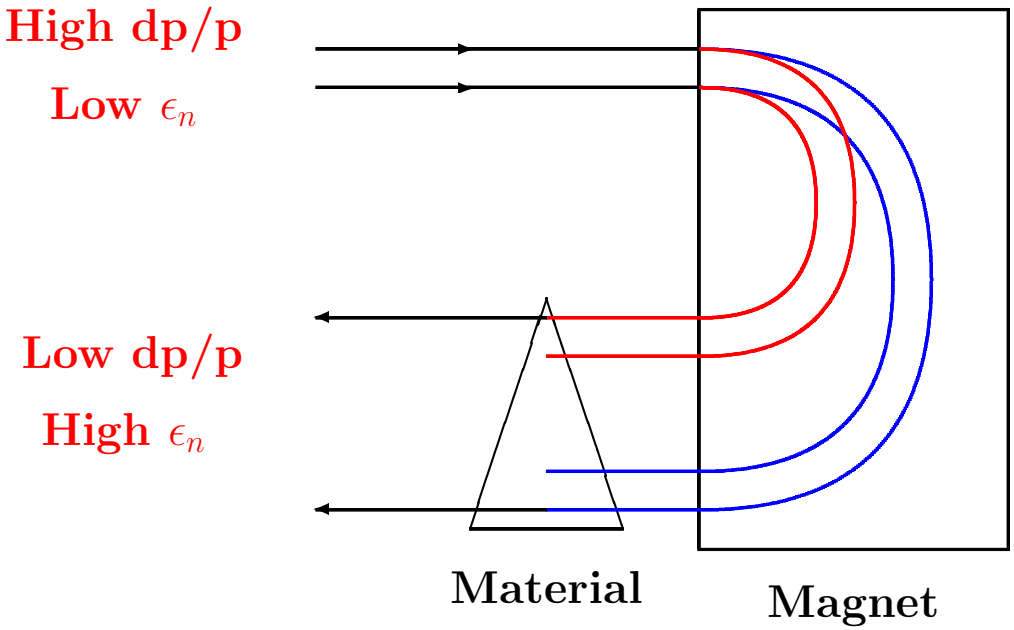


IONIZATION COOLING

- **TRANSVERSE**



- **LONGITUDINAL EMIT EXCH**



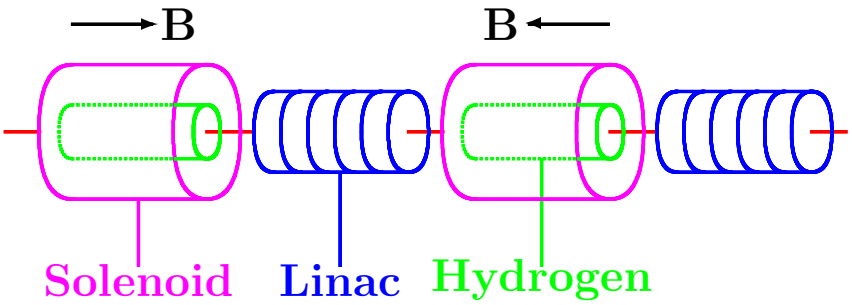
TRANSVERSE COOLING

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

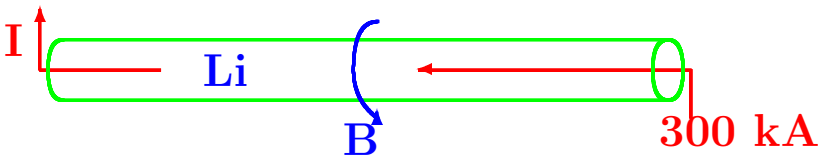
$$\epsilon_\perp \;\propto\; \beta_\perp \frac{1}{\beta_v L_R \; dE/dx} \;\propto\; \beta_\perp$$

HOW TO GET LOW $\beta_\perp$

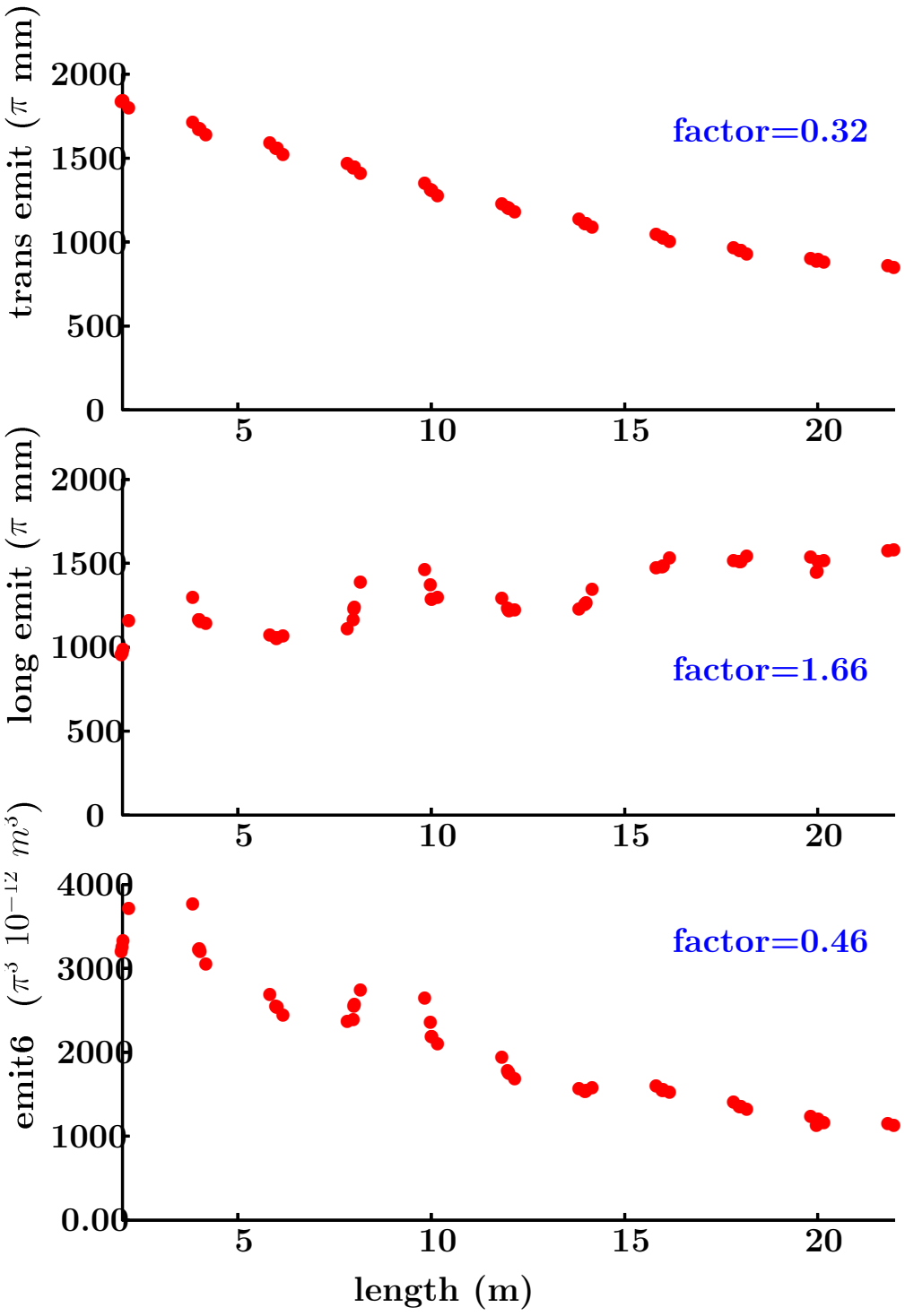
- **Alternating solenoids (Early Stages)**



- **Lithium Lens (Late Stages)**

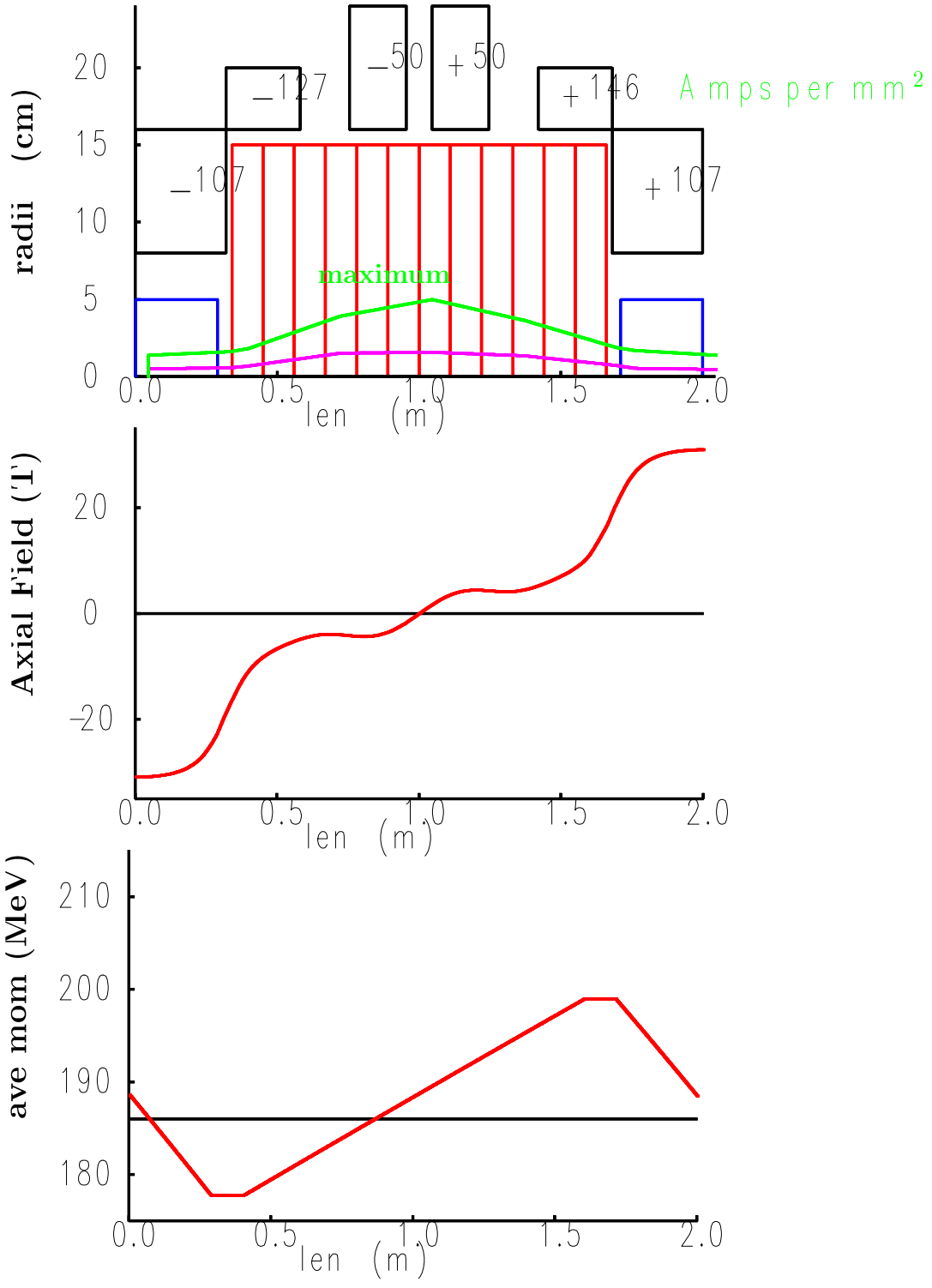


SIMULATION at 15 T

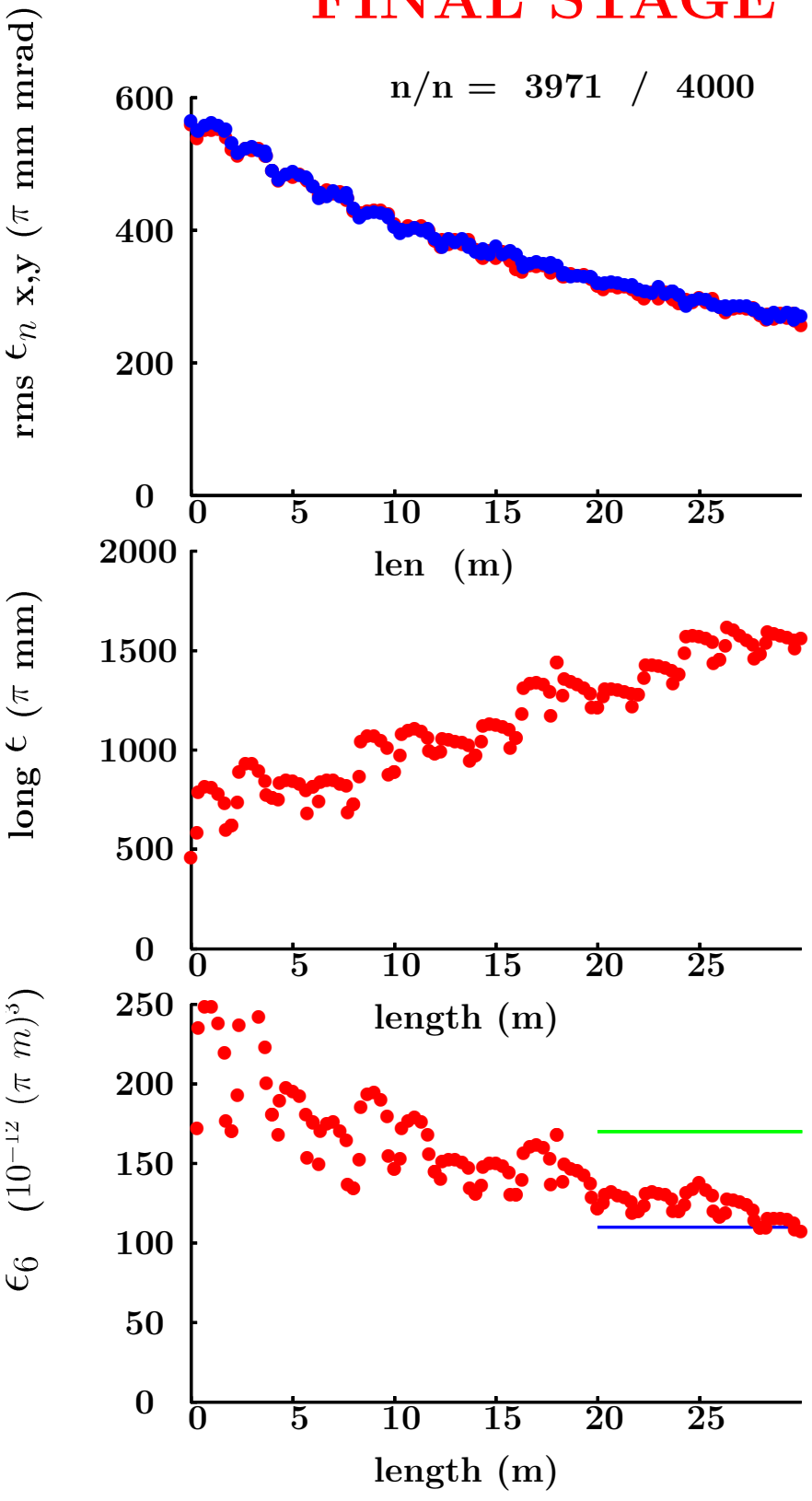


Higgs Collider Params Achieved at 30 T, but Lithium Lenses may be more economical.

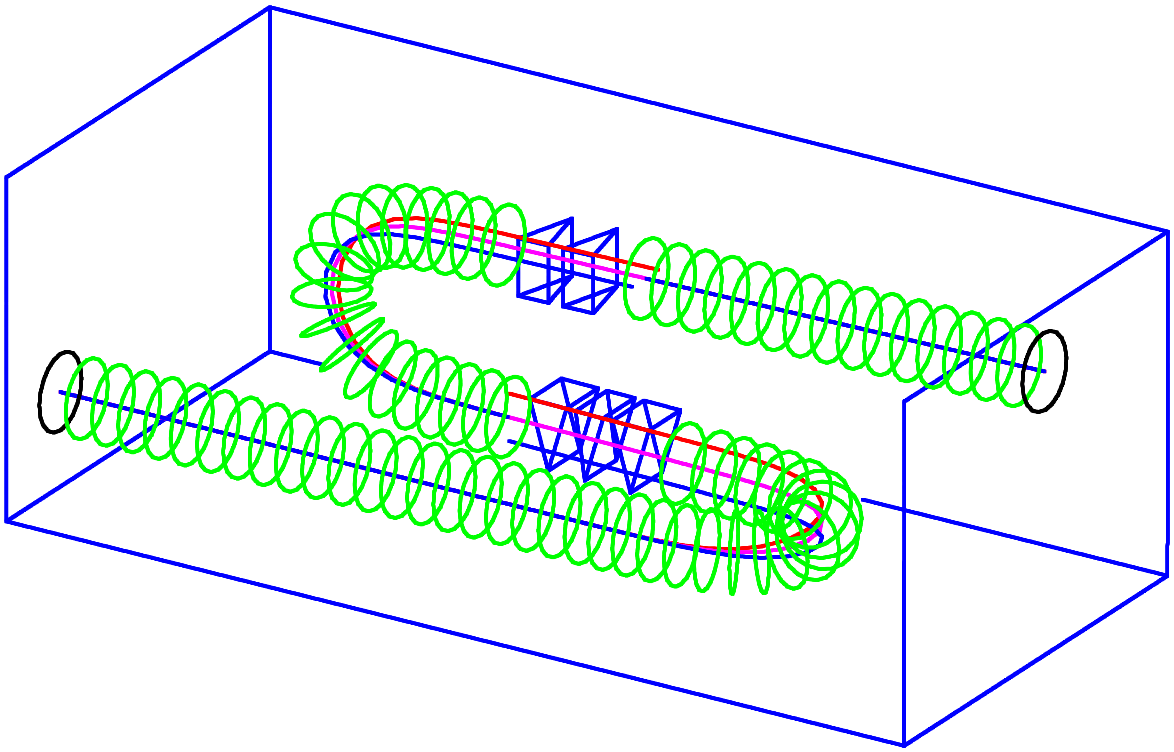
30T COOLING CELL



FINAL STAGE


n/n = 3971 / 4000
rms ϵ_n x,y (π mm mrad)
600
400
200
0
0
5
10
15
20
25
len (m)
long ϵ (π mm)
2000
1500
1000
500
0
0
5
10
15
20
25
length (m)
ϵ_6 (10^{-12} (π m)^3)
250
200
150
100
50
0
0
5
10
15
20
25
length (m)
Spec. in Collider
Spec. at End of Coo

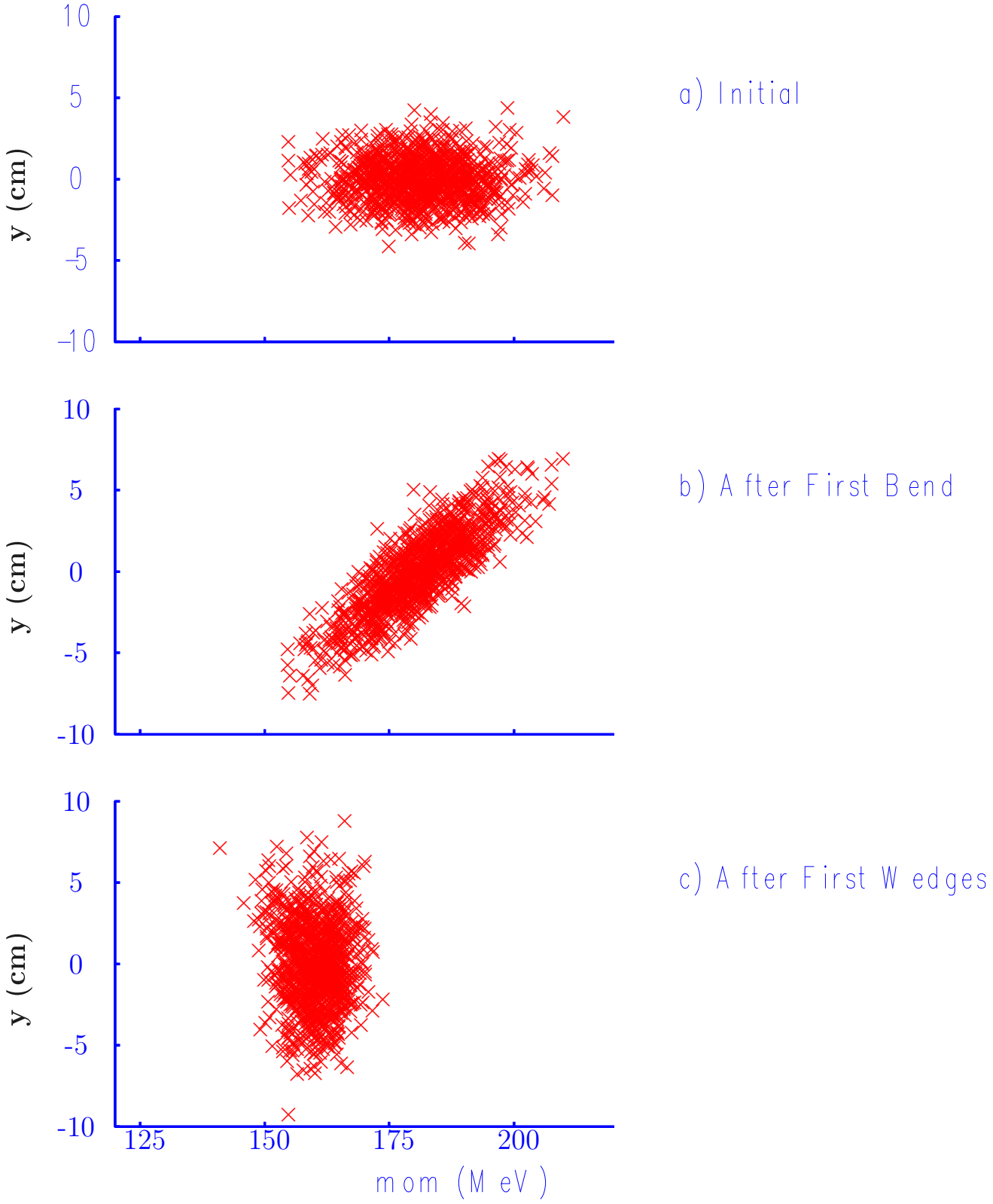
LONGITUDINAL EMIT EXCH



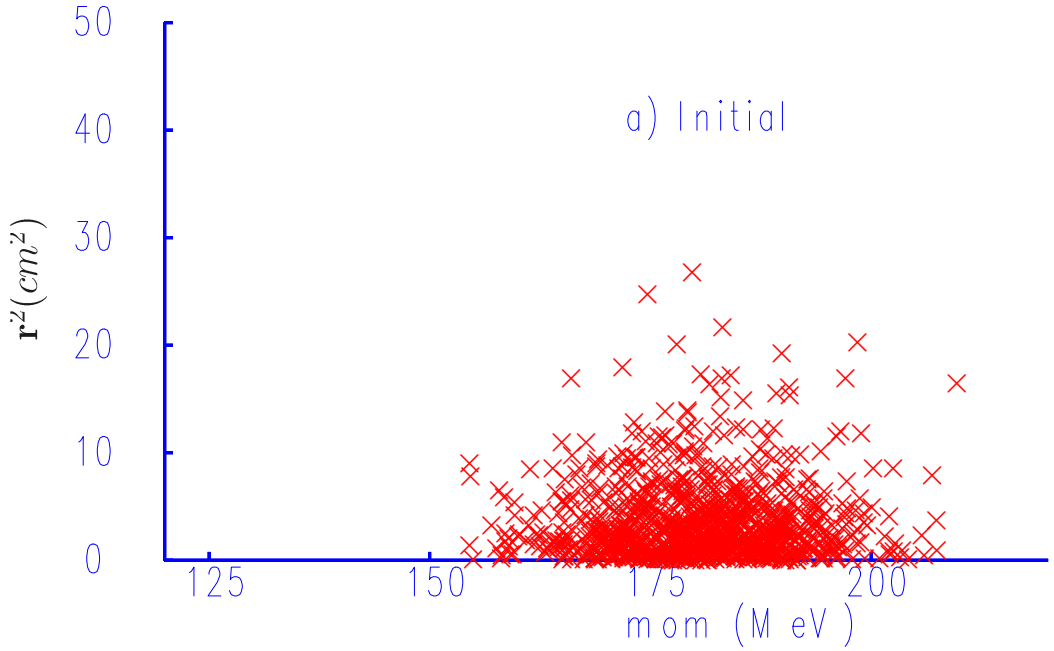
Horizontal Bend → Vert Dispersion
Wedge removes Disp. → increases y
Vertical Bend Horizontal → Dispersion
Wedge removes Disp. → increases x

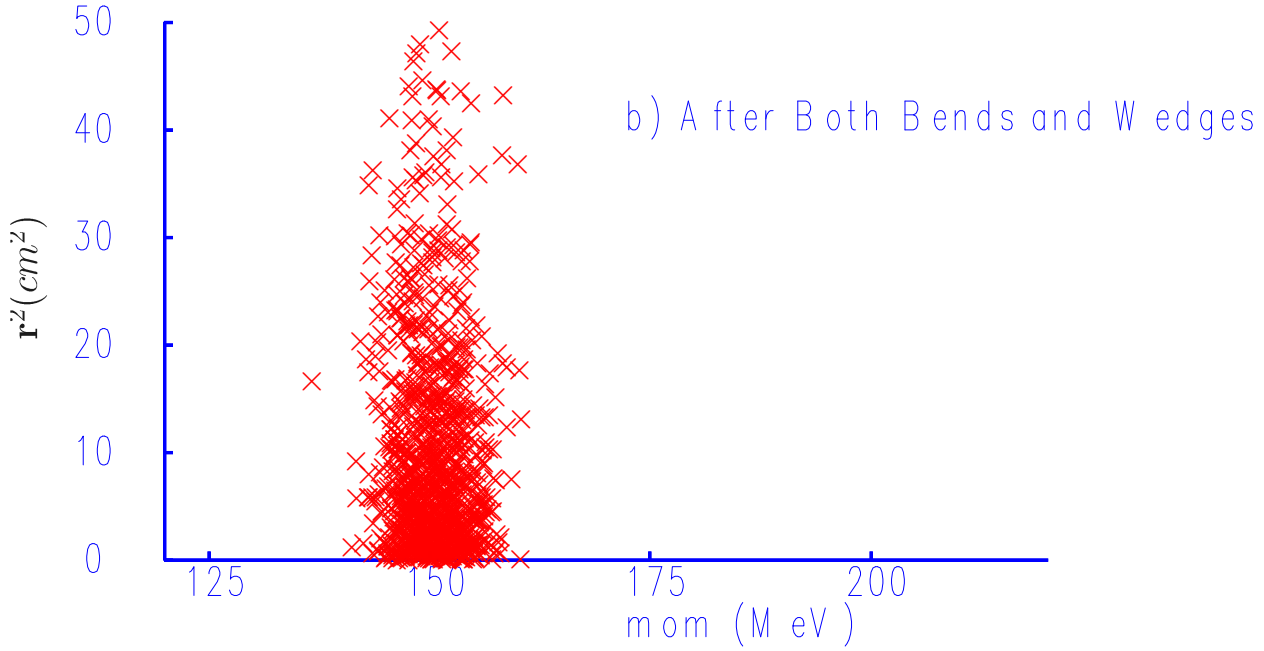
- dp/p reduced
- Emittance x and y increased

EMIT EXCH SIMULATION

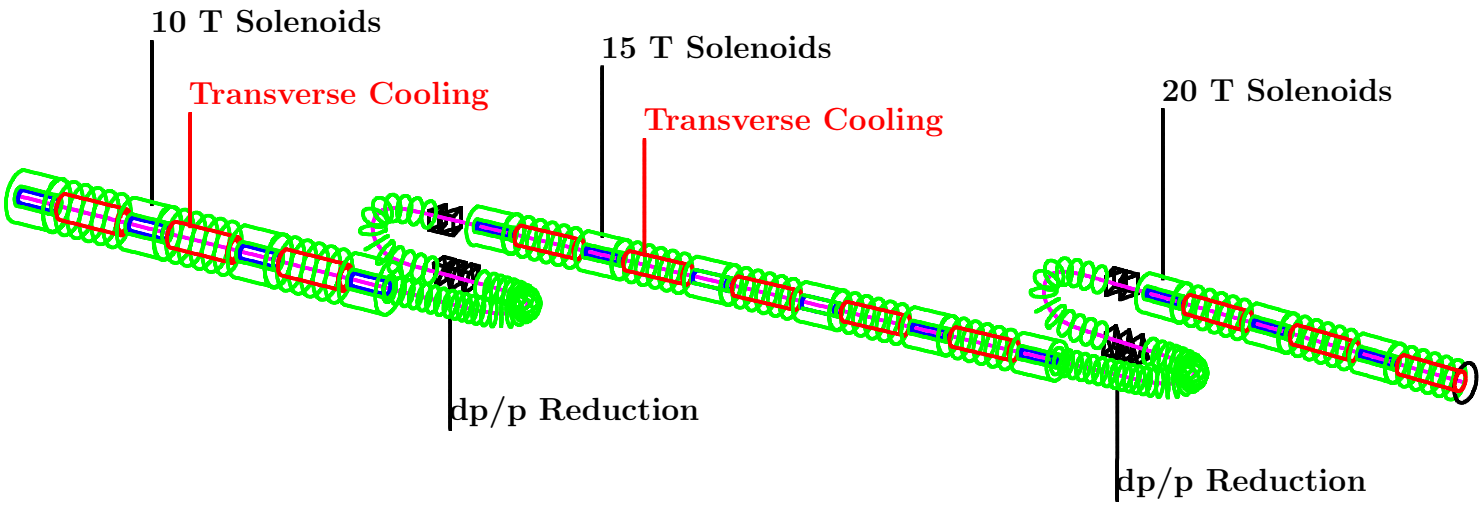


EMIT EXCH SIMULATION





COOLING SYSTEM



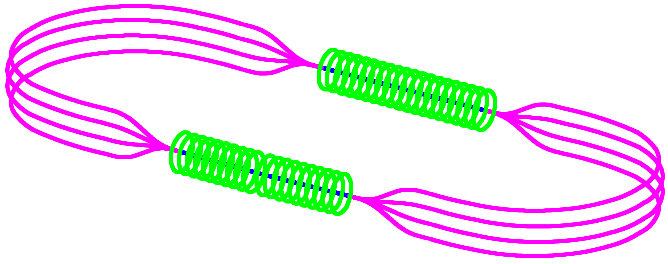
- 6D emit reduction/stage ≈ 2
- Typical length 20 m/stage
- Trans Cool & Long Exch Alternate

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

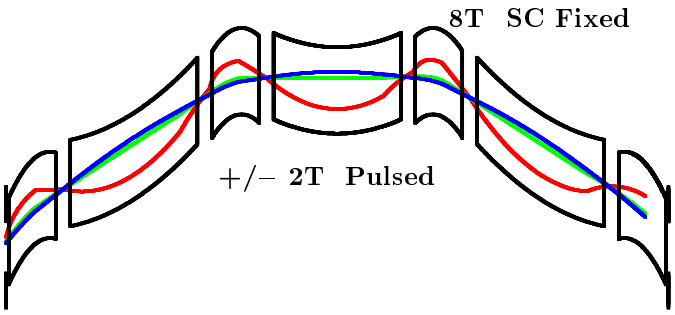
ACCELERATION

Acceleration must be rapid

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

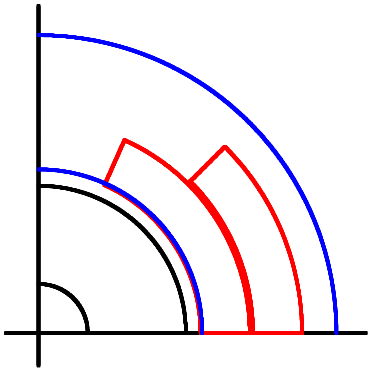


- High Energies:
  Hybrid Pulsed & SC Synchrotron
  ($\approx$ 40 turns)

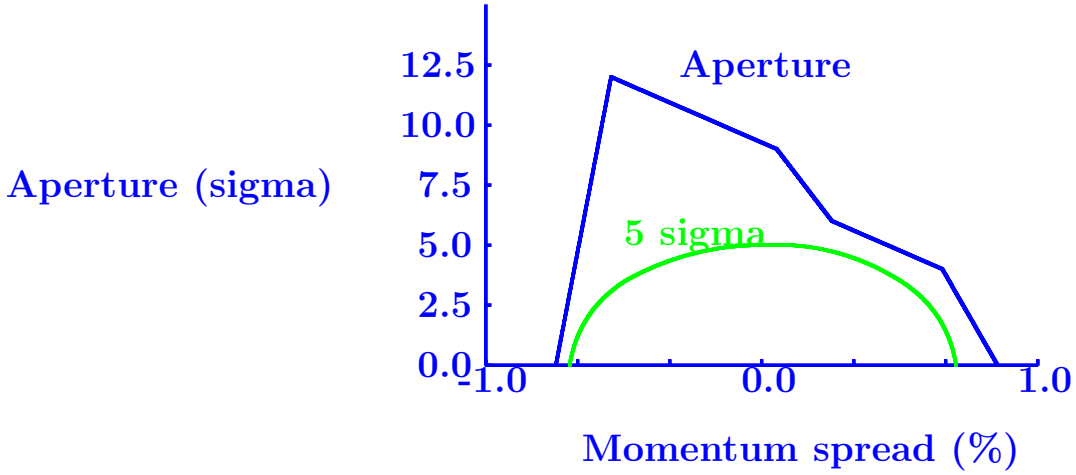


COLLIDER RING

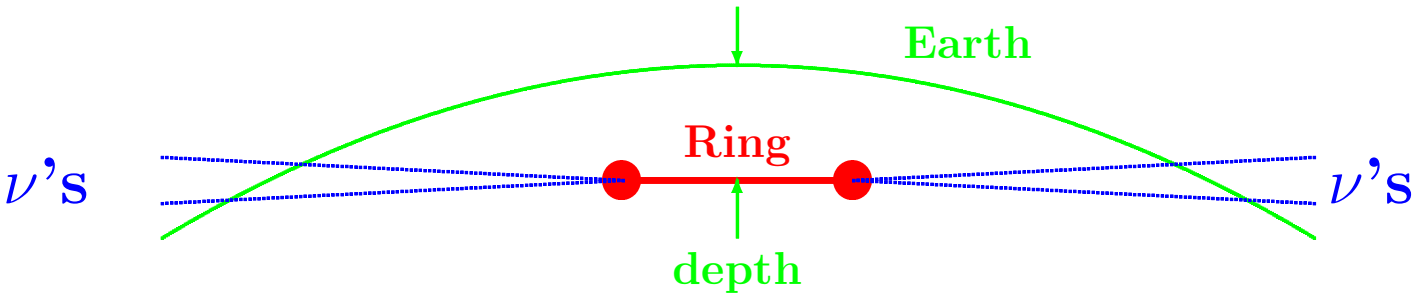
- **Low beta**
  Local chromatic corr.
- **Short Bunches**
  Isochronous ring
  Flexible Momentum Compaction
- **Tungsten Beam Shield**
  6 cm at 3 TeV,
  3 cm at 100 GeV



- **Status**
  - feasibility demonstrated at 4 TeV
  - 100 GeV Lattices: Good Aperture



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**
  - $\approx$ **1 mR/year**
- **E = 3 TeV ok at 300 m depth**
  - $\approx$ **10 mR/year**
- **E > 3 TeV Requires:**
  - **Beam wobbles, and/or**
  - **Special Locations, and/or**
  - **Better Cooling (Optical Stochastic?)**

BACKGROUND

- **at 5 cm rad**
- **Si Pixels**
- **60 $\times$ 150 μm**
- **acceptable n dose= 5 $\times$ 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 Subdivion?

THE MOST CRITICAL ISSUES

Target

- Heating → liquid metal?
- Splash?
- Motion in Magnet

Capture RF

- Low Frequency (30-90 MHz)
- High Gradient (3-6 MV/m)
- High Radiation

Cooling RF

- Higher Frequency (800 MHZ)
- Very High Gradient (36 MV/m)

Cooling Demonstration

R & D PLAN

Gilman Subpanel:

- "Expanded Program"
- "Simulation and Experiment"
- "Project Management"
- "Review in About Two Years"

In Two Years

- Maintain Simulation Effort
- Start Project Management
- Test rf for Cooling
- Test Liquid metal Target in Beam (no mag, no rf)

Longer Term

- Expand Simulation Effort
- Demonstrate 10 m of Cooling System
- Test Target with solenoid and rf
- Start Modeling Other Components

THEORETICAL STUDIES

Ongoing

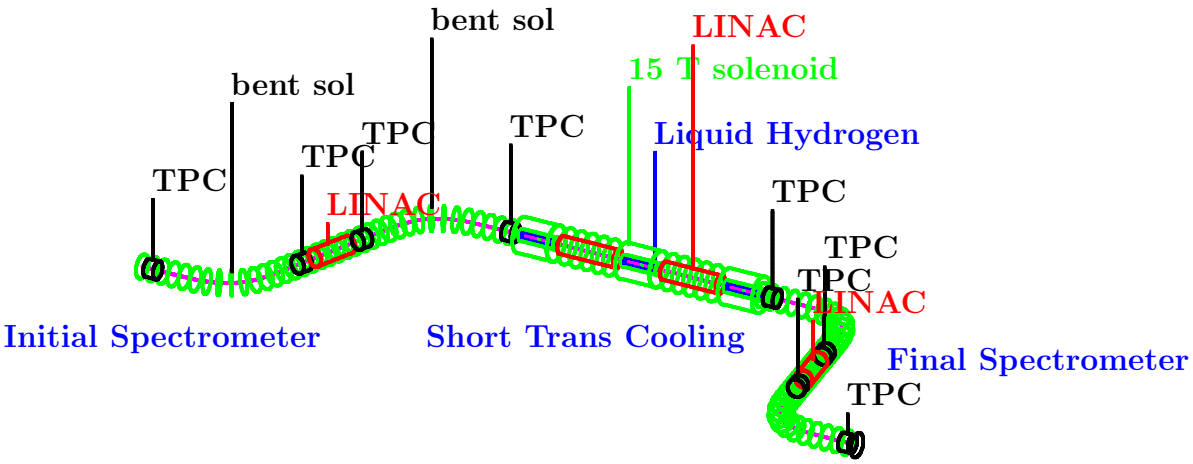
- Proton Driver Design
- Liquid Target Dynamics *
- Pion Capture Design *
- Phase Rot RF Design *
- Initial Cooling Simulation ●
- Cooling RF Design *
- Li Lens simulation *
- Add Space Charge & Wakes ●
- Acceleration Lattices ●
- FFAG Accleration ●
- Collider Lattice
- Beam-Beam with Lattice ●
- IR Shield & Background

* Linked to Experimental Program

● Recently started

COOLING EXP

(Proposed to FNAL)



In 2 Years

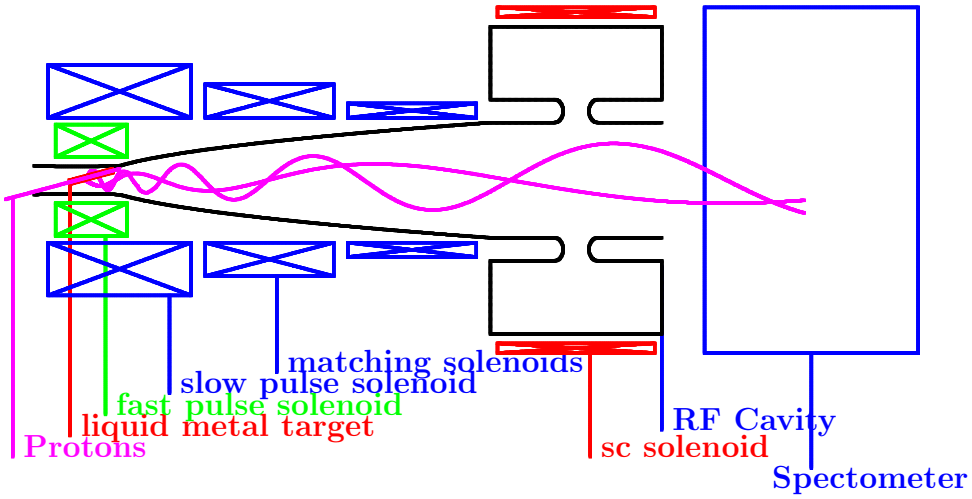
1. Low Power RF Cavity Test (LBL)
2. High Power RF Cavity Test (FNAL)
3. Add Solenoidal Field

In $\approx$ 3 Years

4. Build 10 m of channel
5. Measure 6D Cooling
6. Build Bent Sol ϵ exch.
7. Measure dp/p reduction
8. Develop liquid Li Lenses
9. Measure Cooling in Li Lenses

TARGET EXP

(To be Proposed to BNL Aug)



In 2 Years

1. Beam on static liquid (AGS)
2. Jet in Magnetic Field (FSU)
3. Beam in jet (AGS)

In $\approx$ 3 Years

4. Low Frequency rf offline
5. Beam in jet in Pulse Field (AGS)
6. LF rf in Beam
7. Add Field over RF
8. (Measure particle Flux ?)

OTHER EXP/TECH R&D
Needed Later

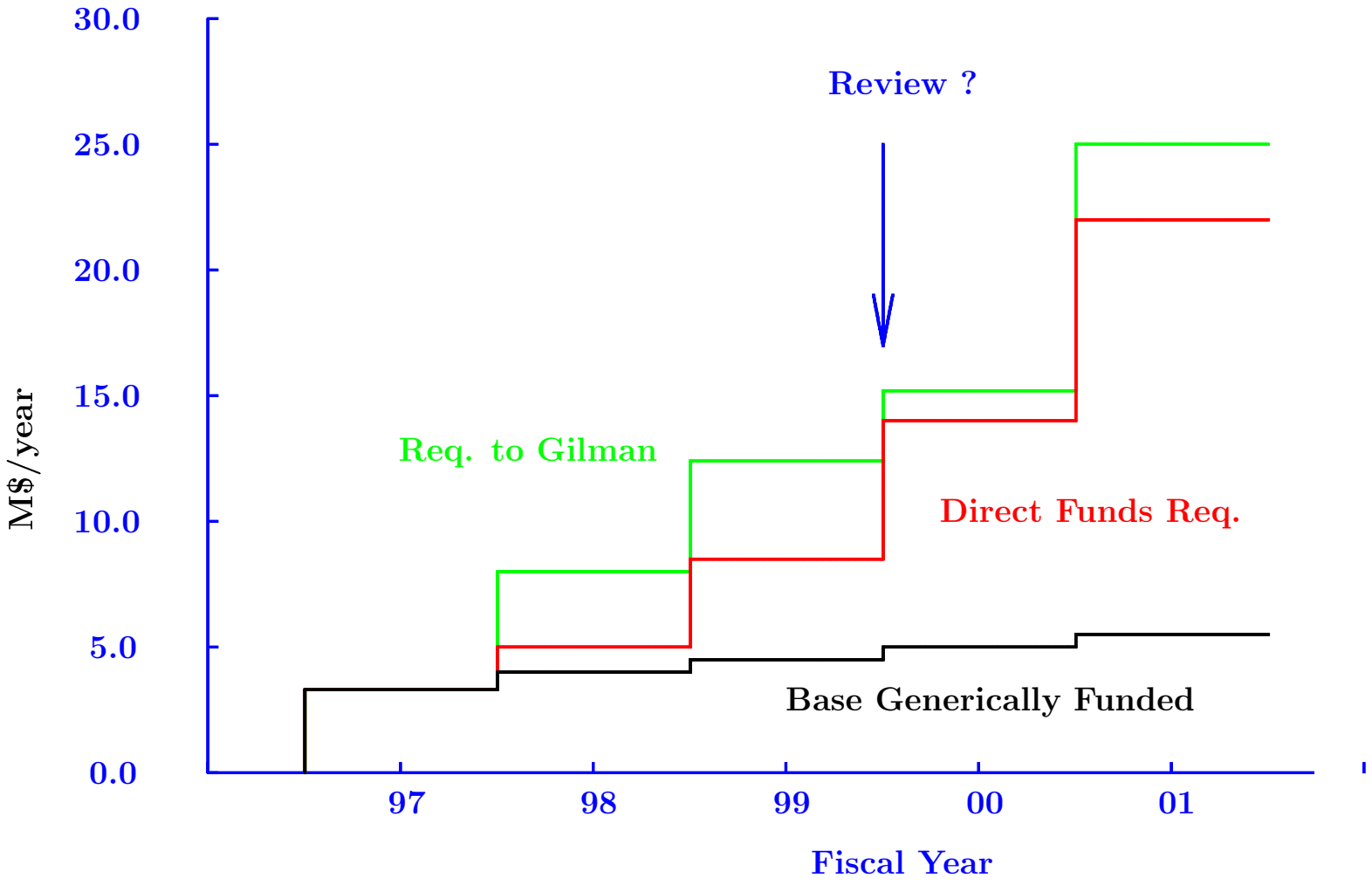
- Droton Driver
- π Production vs. p Energy
- rf Power Sources
- Multi-hole Magnets
- Kickers for Recircirc. Acc.
- Accelerator Pulse Dipoles
- Accelerator SC Linacs
- Superconducting Collider Magnets
- Detector

MANAGEMENT PLAN

Under Discussion by
T.Kirk, J.Peoples, P.Oddone

- **Muon Collider Oversite Group (MUCOG)**
  - **The 3 "Directors"**
- **Technical Advisory Committee (TAC)**
  - **Lab/University/International**
  - **Reports to MUCOG**
- **Project Manager (PM)**
  - **Member of Collaboration**
  - **Reports to MUCOG**

LONGER TERM NEEDS



FY 99 DIRECT FUNDING NEEDED

FY	97	98	99
Current Salaries		280 [1]	400[2]
Project Manager			200[2]
Cooling Experiment		550[1]	2100[2]
Target Experiment		120[1]	900[2]
Other R & D + Contingency		0	300[2]
Total Direct		1000[1]	3900[2]
Approx Base Salaries	3300	4000	4500
Approx Grand Total	3300	5000	8400
cf Gilman Req.	3300	8000	12400

Notes:

1 For ≈ half of year 2 for full year

WHAT IF

We get Only $ 1 M ?

- Half our current rate of direct funding
- Reduce manpower
- Slow initial experiments
- Stop preparations for later exp's
- No Contingency
- No Results in "about two years"

CONCLUSION

MOTIVE

- **Small size** **(e.g. 3 TeV fits at FNAL)**
- **Easier Tollerances ?**
- **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**