Collider Scheme with Bunch Merging

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Collaboration and MuTac

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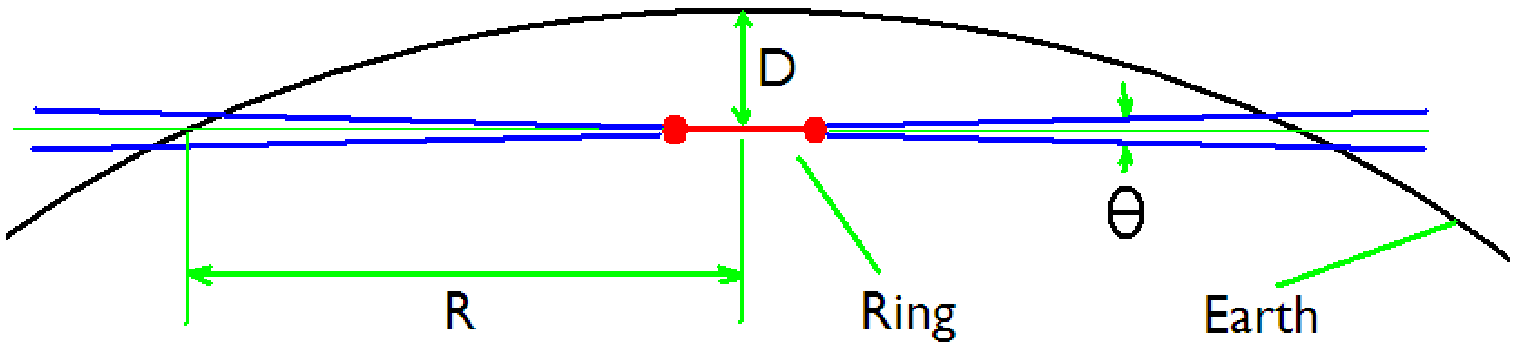
- New Collider Parameters
- Scheme
- Pre-Merging RFOFO Cooling
- Merging
- Post-merging RFOFO Cooling
- HTS Solenoid Cooling
- Acceleration with ILC Linacs
- Collider Ring and Detector

Assumptions

- Energy is the physicists highest priority
  Consider center of mass E of both 4 TeV and 8 TeV
- Luminosity/S can be relaxed a factor of 2 relative to Snowmass 96
- Tune shift $\approx$ 0.1 probably ok (instead of 0.044 in Snowmass 96)
  Concensus at Fermilab Low emittance Workshop Feb 06
- A depth of 135 m "straight forward"
  This is the depth proposed for ILC
- Fix Neutrino radiation $\leq$ 10 mrem/year
  1/10 of Federal limit $\leq$ 100 mrem/year
- Use same proton driver and muon cooling for both phases
- Allow higher field magnets, and greater depth for 8 TeV case
  ave. bending of 10 T vs 5 T, depth of 540 m vs 135 m
- Use same Collider Ring design as in Snowmass 96 Study

Neutrino Radiation Constraint

Not discussed in 96 report but notes soon after (King)



$$\text{Radiation} \;\propto\; \frac{I_\mu\ \sigma_\nu}{\theta\ R^2} \;\propto\; \frac{I_\mu\ \gamma^2}{D} \;\propto\; \frac{\mathcal{L}\ \beta_\perp}{\Delta\nu\ \ <\mathrm{B}>}\ \frac{\gamma}{D}$$

For fixed $\Delta\nu$, $\beta_\perp$ and $< B >$; and $\mathcal{L} \propto \gamma^2$:

$$\text{Radiation} \;\propto\; \frac{\beta_\perp}{\Delta\nu\ \ < B >\ \ D}\ \gamma^3$$

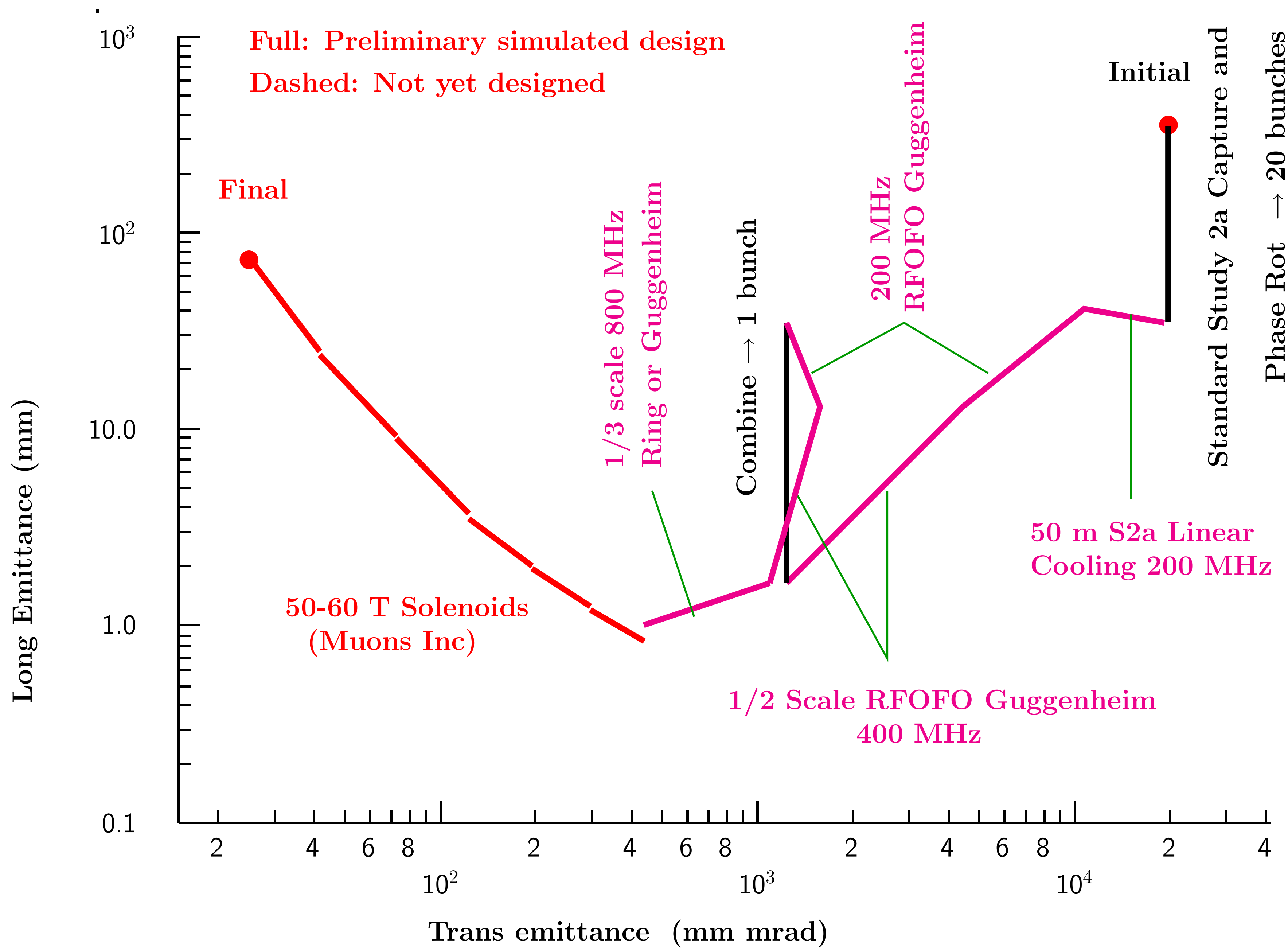
For D=135 m R=40 Km
For D=540 m R=80 Km

	Phase 1	Phase 2	cf 97	
C of m Energy	4	8	3	TeV
Luminosity	5	20	7	10^{34} cm^{2}sec^{-1}
Tune Shift	0.1	.1	.05	
Bunches	$1+1$	$1+1$	$2+2$	
Muons/bunch	2	2	2	10^{12}
Ring <bending field>	5.18	10.36	5.18	T
Ring circumference	8.1	8.1	6.1	km
Trans Emittance	25	25	50	pi mm mrad
rms momentum spread	0.12	0.06	0.16	%
Beta at intersection	3	3	3	mm
Beam sigma at IP	2.8	2.0	3.2	μm
Long Emittance	72	72	72	pi mm rad
Repetition Rate	7.5	7.5	15	Hz
Muon Beam Power	9	9	37	MW
Required depth for ν rad	135 (ILC)	540	300	m
Proton Driver power	$\approx 2^*$	$\approx 2^*$	4	MW

* Dependent on losses in cooling and acceleration

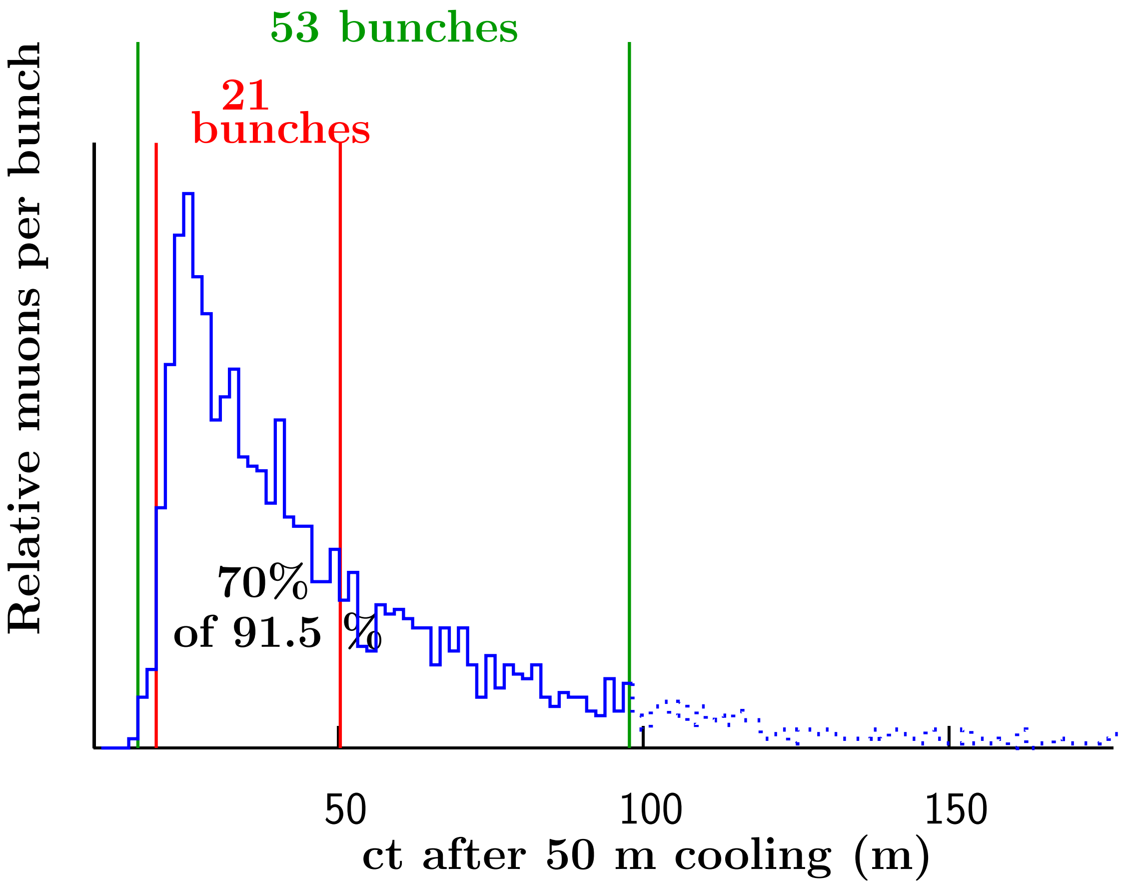
Capture and Cooling Scheme

1. 20 T Capture with Study 2a Phase Rotation
2. Use best 21 bunches (70% of Study 2a)
3. Pre-Cool with Study 2a lattice
4. Continue with RFOFO at 200 MHz
5. Lower Long emittance with 400 MHz
6. Merge 21 bunches into one
7. Cool and exchange with RFOFO at 200 MHz
8. Cool and exchange with RFOFO at 400 MHz
9. Cool and exchange with RFOFO at 800 MHz
10. Cool with 50-60 T Solenoids
11. Accelerate in recirculating ILC
12. Circulate in Collider



Note: No dashed section

Use only 21 of Study 2a Rotated bunches

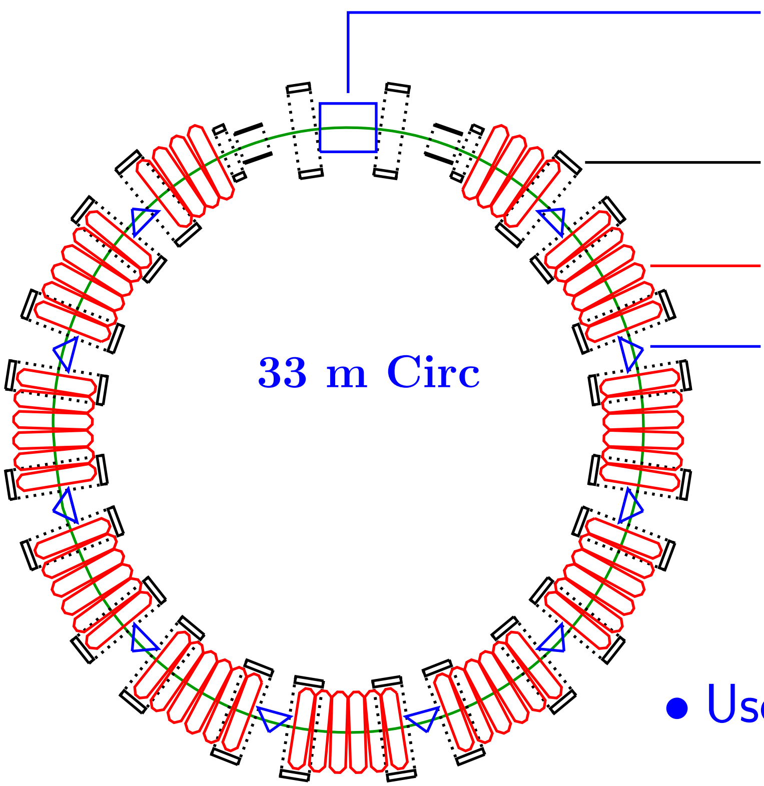


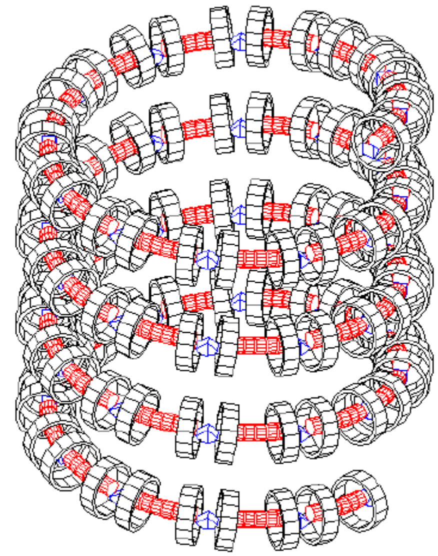
50 m of Study 2a Linear Cooling

Reduces Transverse emittance from 20 to 10 pi mm
Longitudinal emittance rises from straggling

6 D cooling in "RFOFO" Ring with Wedges

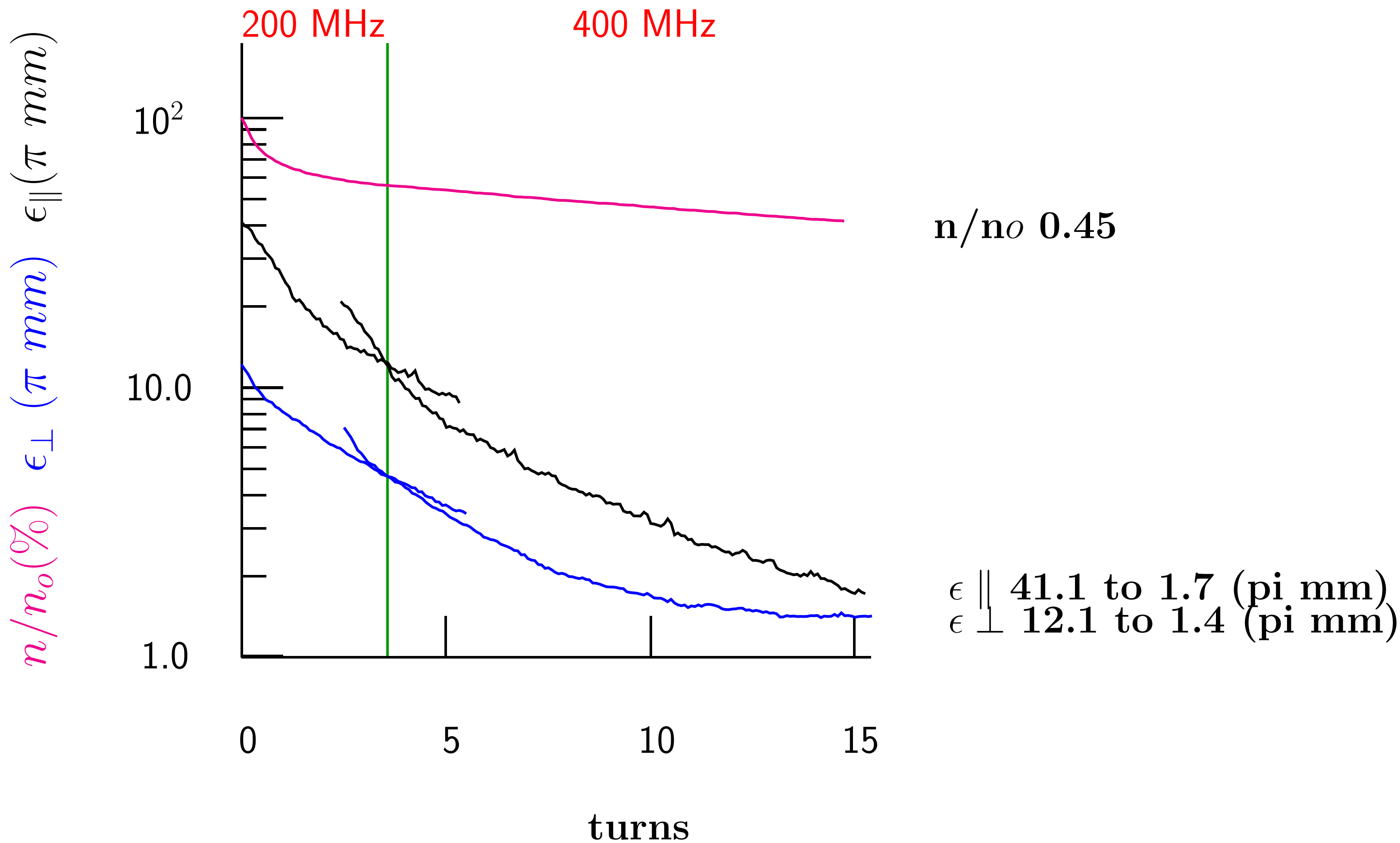
- Bending gives dispersion
- Wedge absorbers: Cooling also in longitudinal





- Use as 'Guggenheim' helix
  - Because bunch train fills ring
  - Avoids difficult kickers
  - Better performance possible by tapering
    Not yet assumed

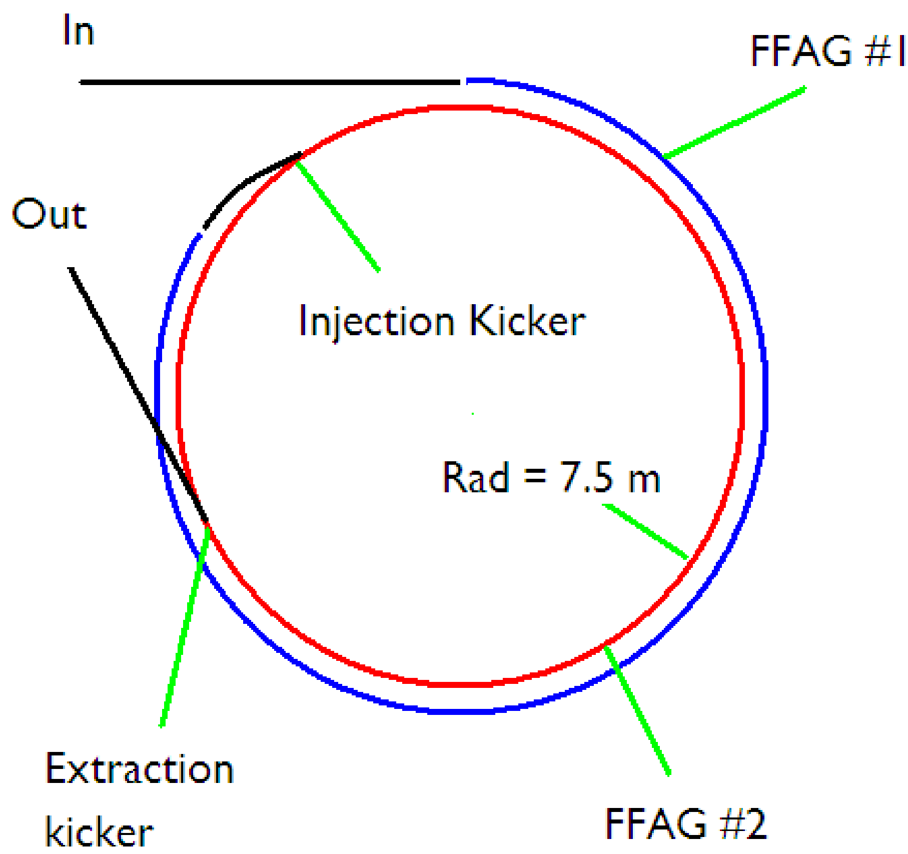
Pre-Merging Cooling with 2 RFOFOs



- 200 MHz RFOFO as published, but Guggenheimed (B=3 T)
- 400 MHz RFOFO has all dimensions halved (B=6 T)
- Equilibrium emittances both halved

Bunch Merging

Using negative k FFAG's
to maximize momentum
compaction



- Initial bunches from RFOFO are short (Long Emit=1.7 pi mm)
- First rotation with sawtooth RF rotates all bunches individually
- Second rotation with single ramp rotates all bunches
- Merged bunches captured with standard 200 MHz RFOFO RF

- If negative k FFAG's impractical, use long linear drifts
  this will double decay losses

First Rotation

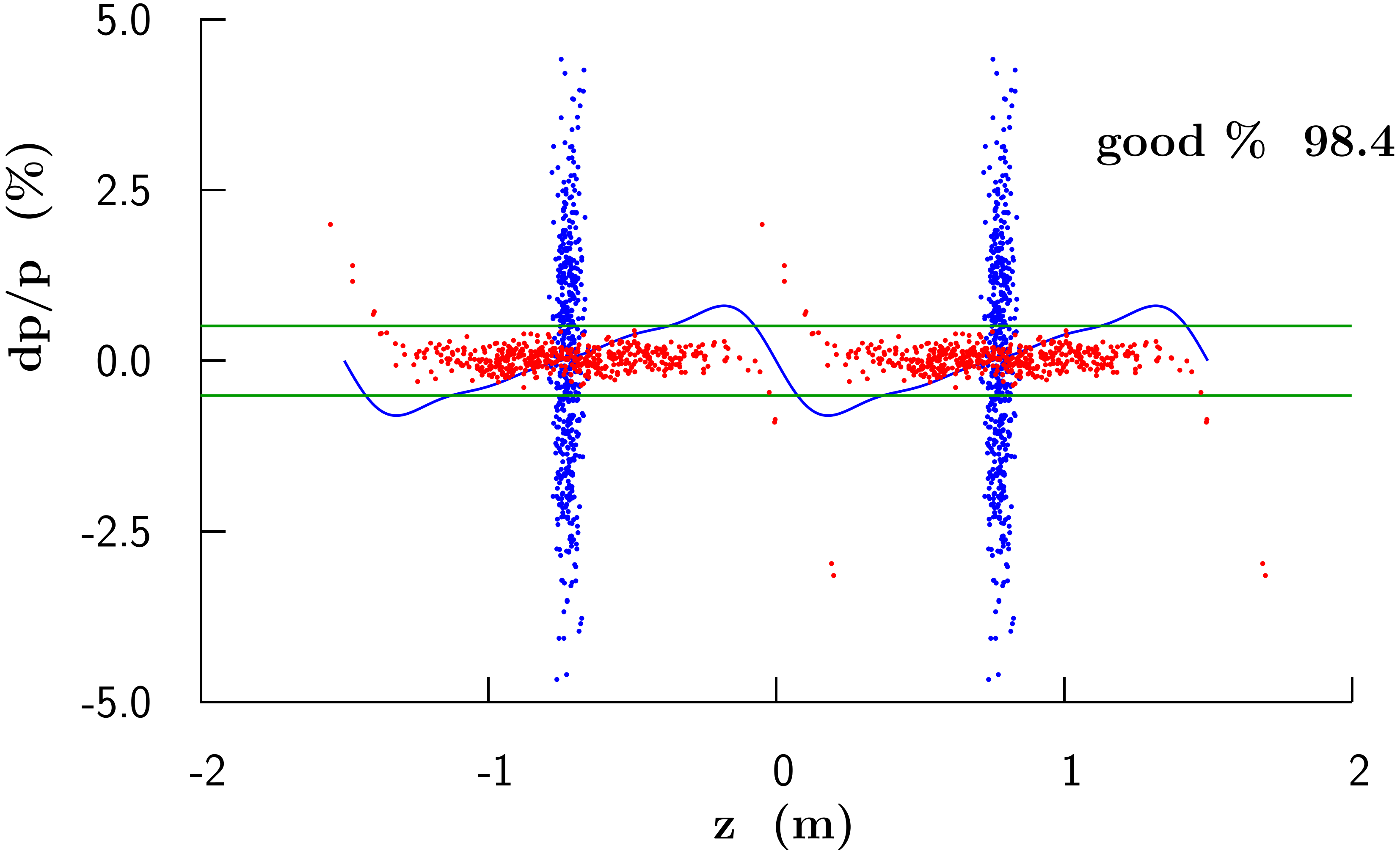
Length	38	m
Circumference	45	m
Turns	0.85	
k	-3	
width	$\pm$ 80	cm
RF Freq.	201	MHz
Harmonics	402 603 805	MHz
Average Gradient	0.3	MV/m
Momentum	200	MeV/c
Initial Long Emittance	1.7 $\times$ 21	mm
Decay Loss	3.0	%

Second Rotation

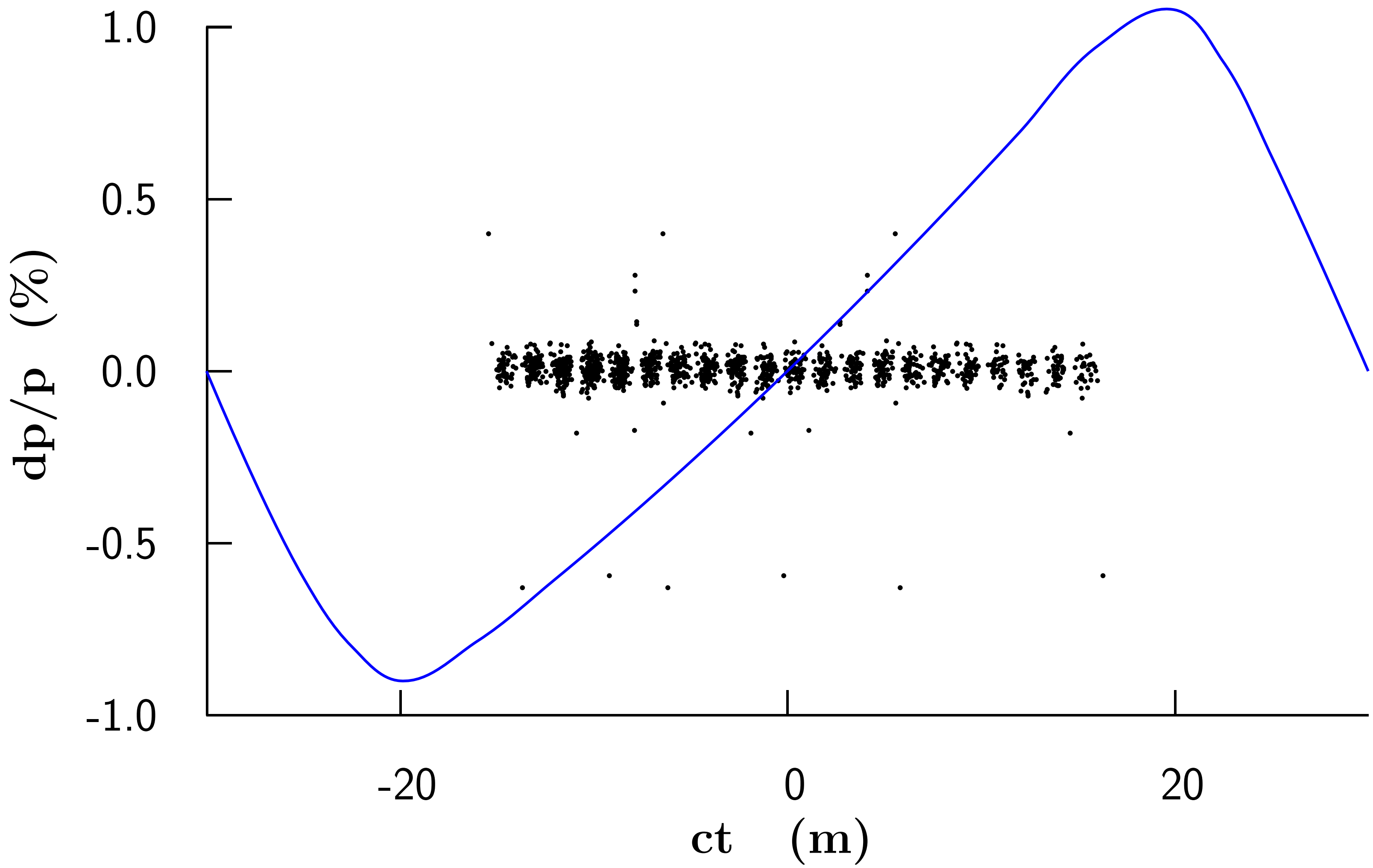
Length	169	m
Circumference	45	m
Turns	3.7	
Kicker rise time	50	nsec
k	-3	
width	$\pm$ 80	cm
RF Freq.	5	MHz
Wave form generator		
Average Gradient	0.3	MV/m
Momentum	200	MeV/c
Decay Loss	12.3	%
Scraping Loss	5.5	%
Final Long Acceptance	134	pi mm
Final Long Emittance	23	pi mm

Probably easier to drift first in FFAG rings without RF, correct energies with RF in linear lattice before first rotation and after second rotation,
but simulations done with RF in ring

First Rotation

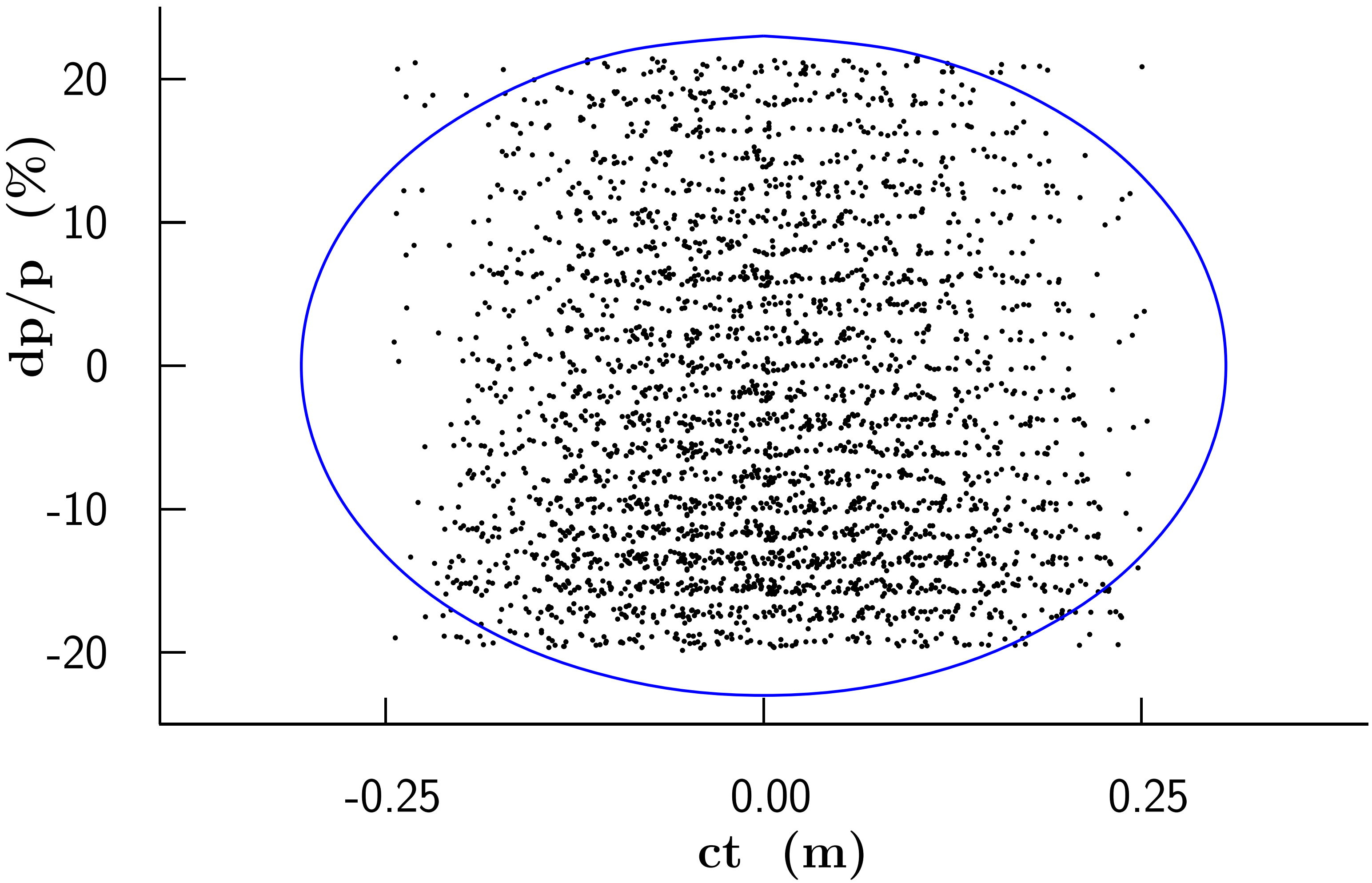


Before Second Rotation



After Rotations

not decayed (%) 97.09896 87.72808
in accept (%) 94.57606 eff (%) 80.56277
long acceptance (pi mm) 134.0572
long beta (m) 1.330435 emitlong (mm) 23.18362

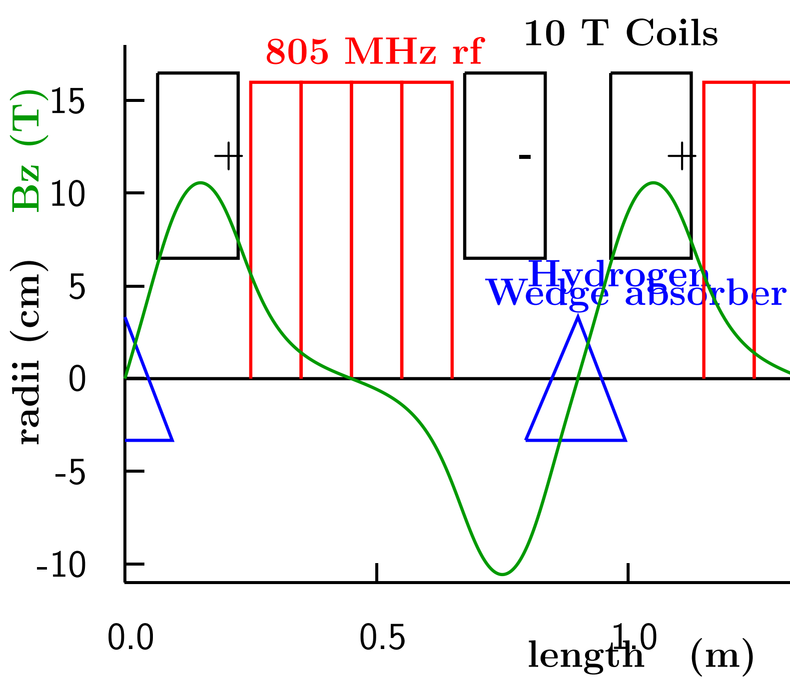


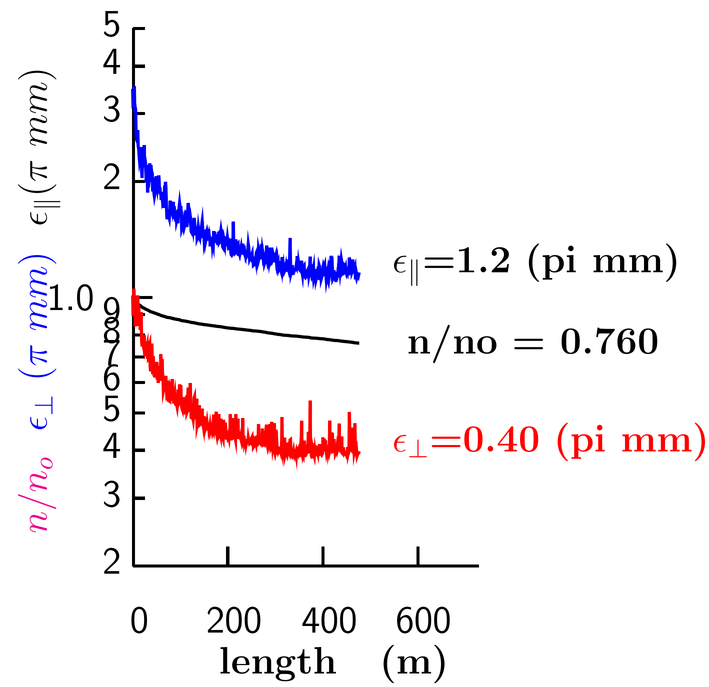
Post Merge Cooling

Cooling in rings now possible because

- Single bunch allows time for kicker rise
- small transverse emittance assures low kicker energy

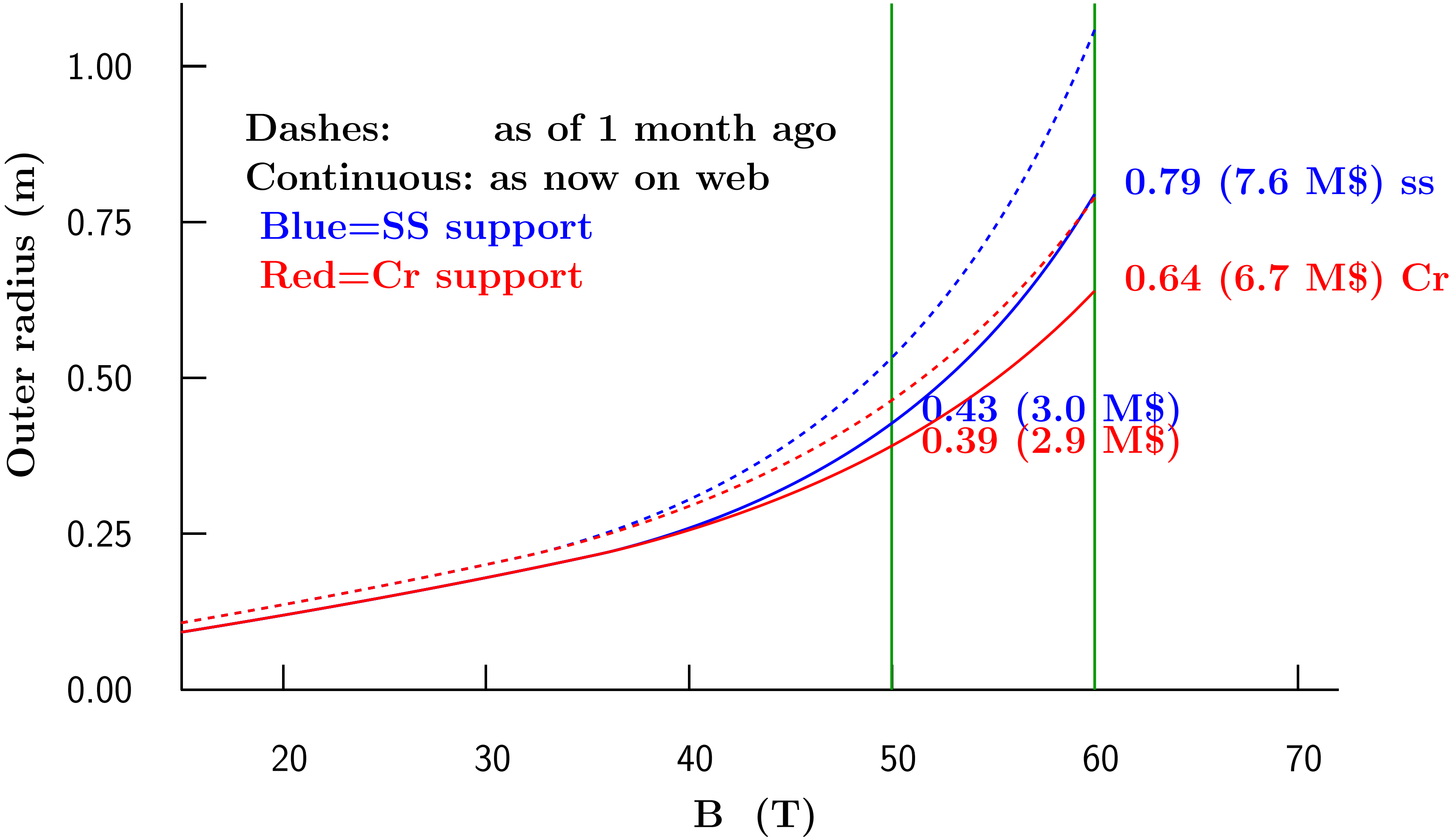
1. Cool longitudinally with 200 MHz RFOFO Ring
   Transverse emittance rises slightly, but longitudinal cools fast
2. Cool further longitudinally with 400 MHz 1/2 scale RFOFO Ring
   Slight transverse cooling, strong longitudinal cooling
3. Cool in new low beta 800 MHz RFOFO Ring





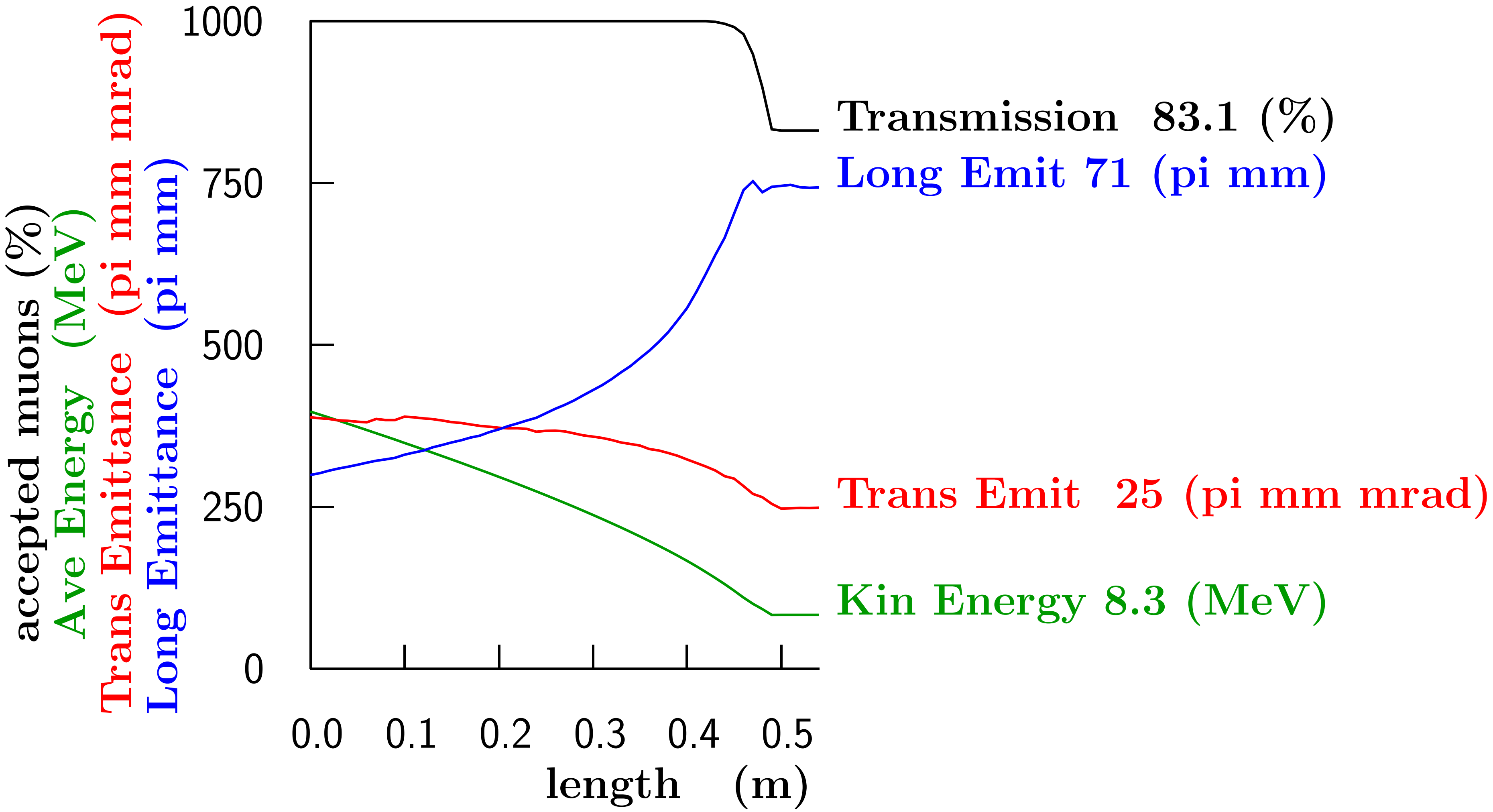
50-60 T Solenoids (S. Kahn, Muons Inc)

- Using American Superconductor HTS cable parameters as published
- Vary current per layer and ss, or chromium, support per layer
- Keep same current margin and same strain for all layers



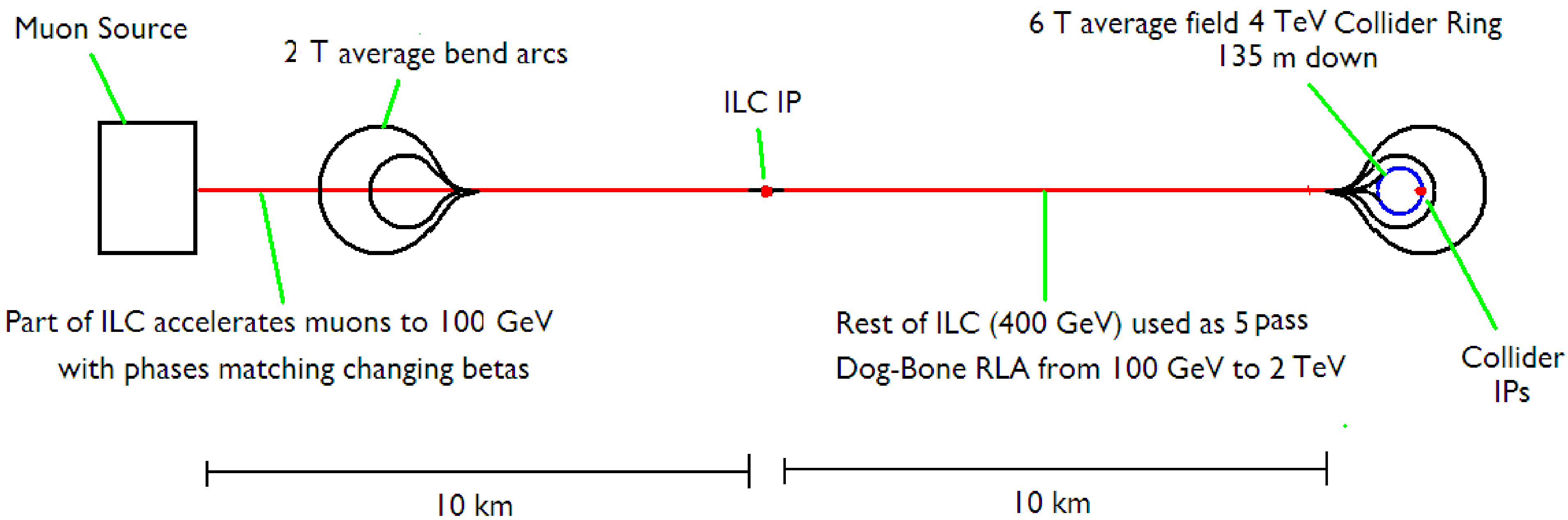
- Costs only of superconductor, assuming 20$ per m

ICOOL Simulation of Final Solenoid Cooling



- Simulation only of hydrogen in solenoid
- No design or simulation of matching and re-acceleration
- Better performance if more than current 6 stages used

Acceleration using ILC



- ILC cavities spaced 1/2 integer wavelengths to accelerate in both directions

- 4 TeV design assumes 500 TeV ILC gradients (30 MV/m)
- Decay losses from 1 GeV to 2 TeV only 8 %

- 8 TeV design will depend on exitance/nature of 1 TeV ILC upgrade

Muon Survival (a first guess)

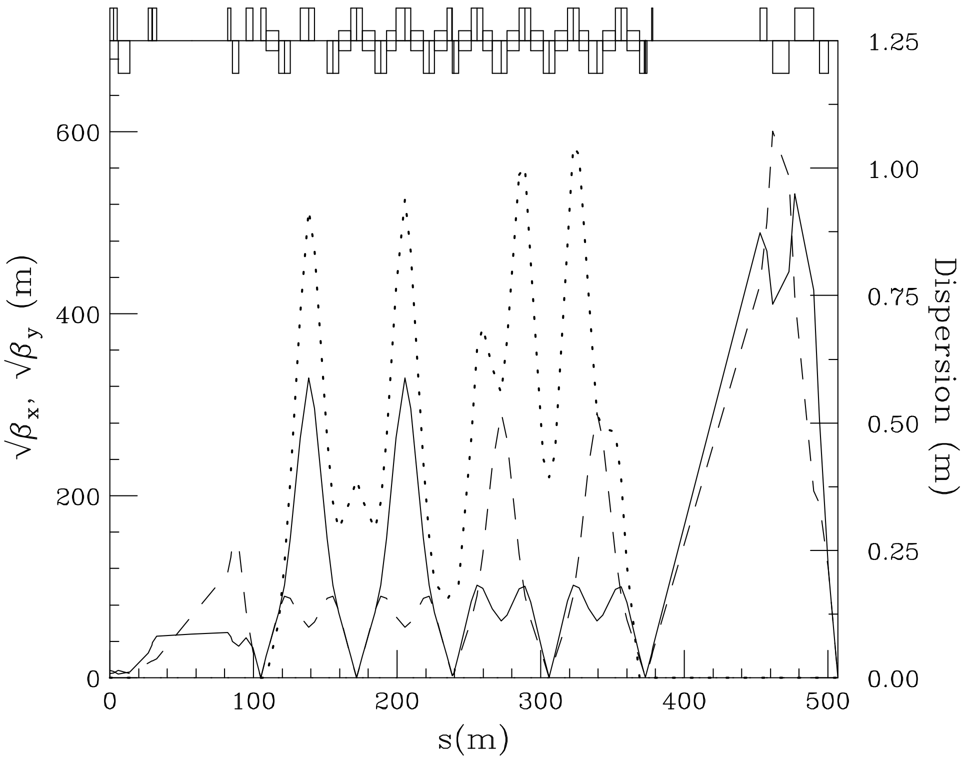
	Transmission	Cumulative
21 vs 54 bunches	.7	.7
Pre-merge RFOFO cooling	$\approx$ .5	.35
Merging	0.8	0.28
Post-merge RFOFO cooling	$\approx$ 0.5	0.14
Final 50 T solenoid cooling	.7	0.1
Acceleration to 2 TeV	0.7	0.07

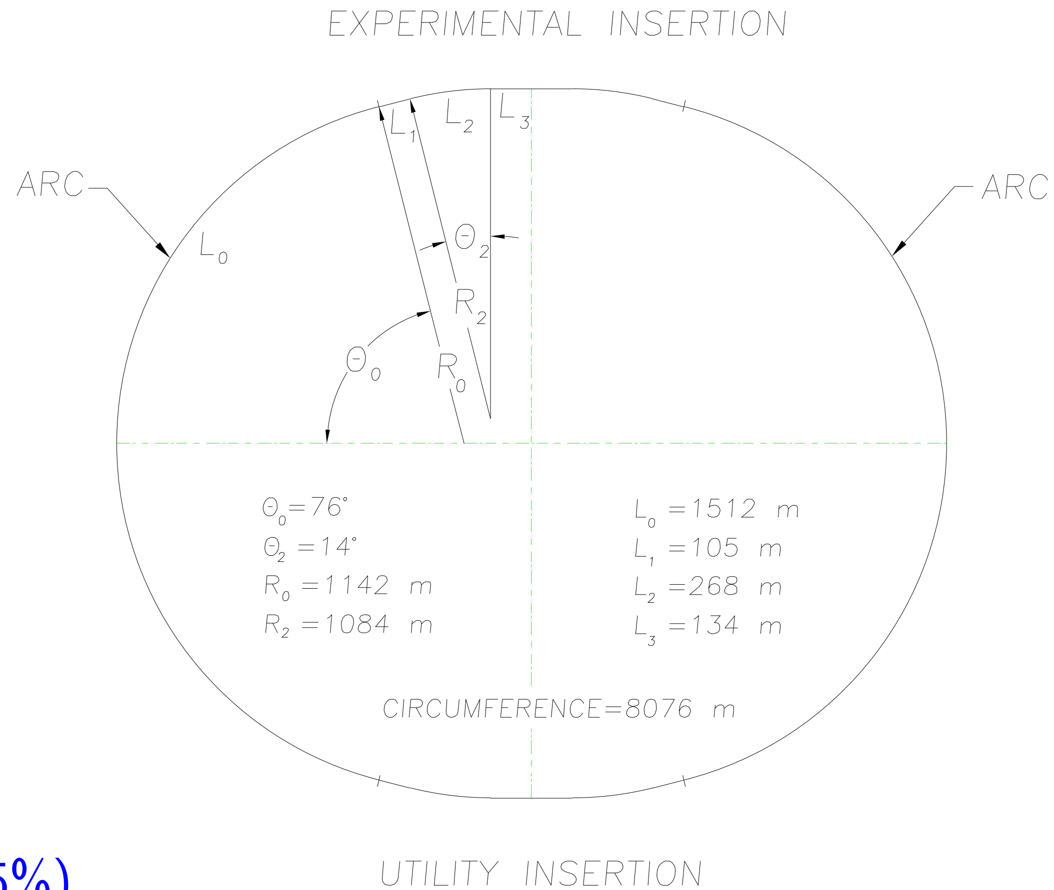
Required Muons per bunch	2 10^{12}
Muons per bunch after merge	8 10^{12}
Initial Muons per bunch	2.8 10^{13}
Initial muons per 24 GeV proton	0.4
Initial 24 GeV protons	7 10^{13}
Proton power (MW)	**2**

- Proton power $<$ Neutrino Factory
- But hard to get 1 ns proton bunch of 7 10^{13}
  Reason I used 24 GeV
- Possible loading problems with 8 10^{12} muons per bunch

Collider Ring

From 96 study (Garren, Johnstone et al)



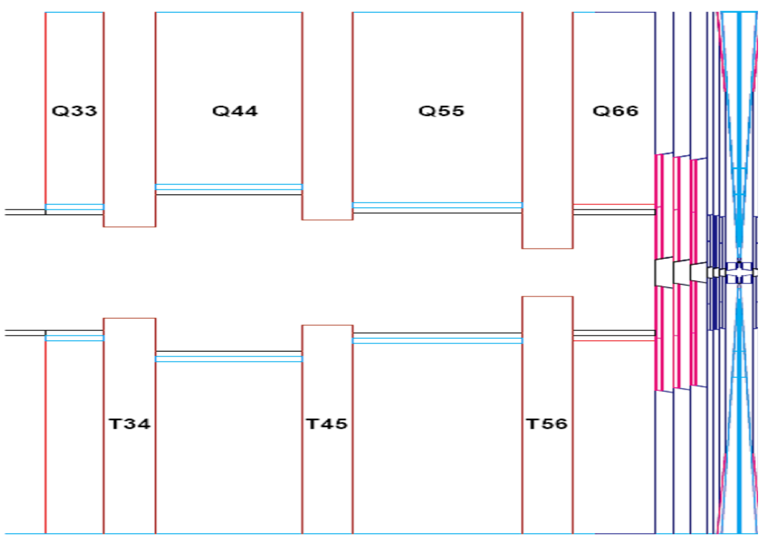


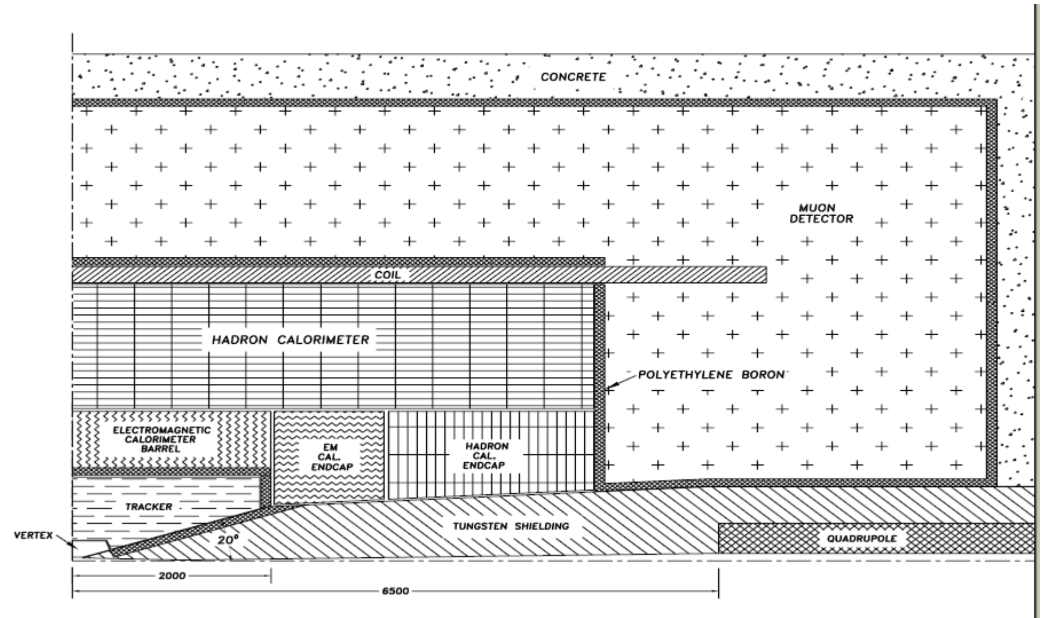
- Large momentum acceptance ($\pm$ 0.5%)
- Very low beta at intersection (3 mm)
- Insertion design follows Linear Collider concepts

Decay losses in Ring

- Heavy shielding only needed for Collider Ring
- 180 W/m for phase 1   360 W/m for phase 2
- 3 cm of water cooled tungsten appear sufficient

Detector Shielding Studied in 96





- Detailed study in 96 (Stumer)
- Gave acceptable detector rates and occupancies
- But Shielding obscured 20 degrees about axis

Conclusion

- Interesting Muon Colliders at 4 and 8 TeV defined
  Consistent with Neutrino radiation and Tune shifts
- First complete cooling scheme
  Preliminary simulations of all components

To Do

- Design negative k FFAG
- Design matching and accel between final solenoid coolings
- Study loading problems
- Optimize
- End to end simulate