Collider Cooling Scheme with Bunch Merging

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- New Collider Parameters
- Scheme
  - Neutrino Factory Front End
  - Pre-Merging RFOFO Cooling
  - Merging
  - Post-merging RFOFO Cooling
  - HTS Solenoid Cooling
  - Acceleration with ILC Linacs
- A Potential problem
- Conclusion

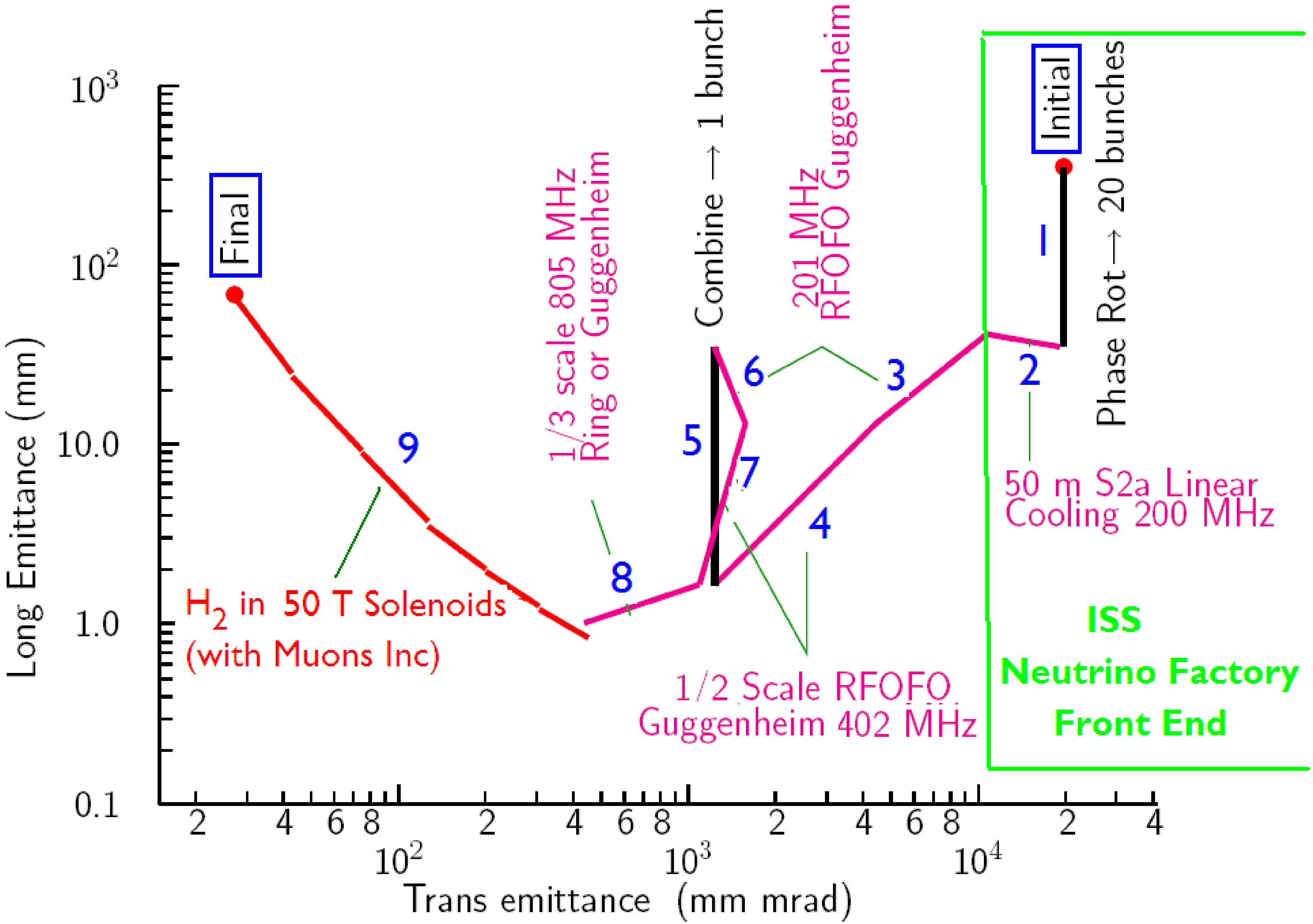
Example Collider Parameters

$$\mathcal{L} \propto B_{\mathrm{ring}} P_{\mathrm{beam}} \Delta\nu \frac{1}{\beta_{\perp}}$$

4 TeV Collider Ring Parameters from 98 Study, 8 TeV pushed

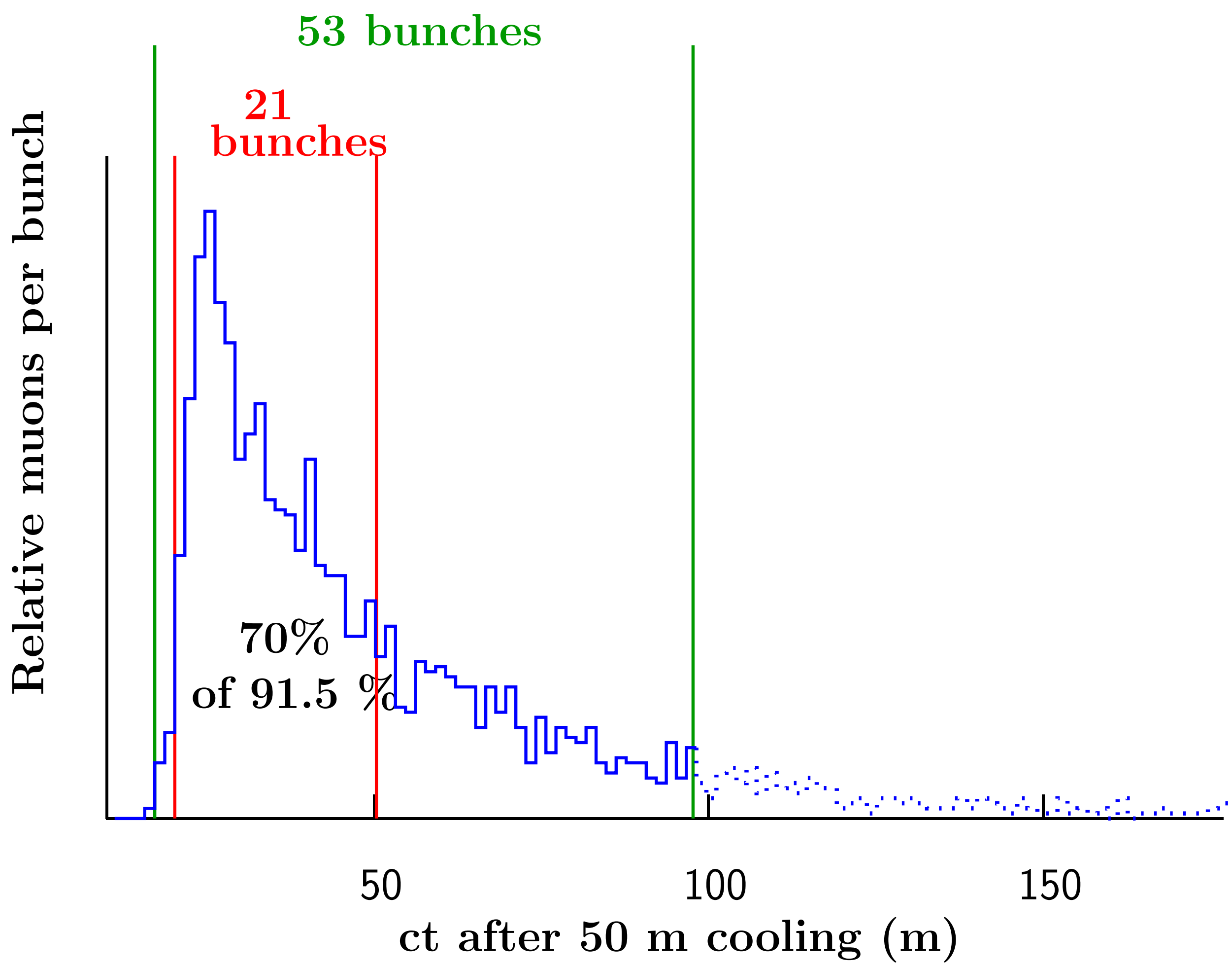
	Phase 1	Phase 2	
C of m Energy	4	8	TeV
Luminosity	4	8	10^{34} cm^{2}sec^{-1}
Tune Shift	0.1	.1	
Muons/bunch	2	2	10^{12}
Ring <bending field>	5.18	10.36	T
Ring circumference	8.1	8.1	km
Beta at intersection	3	3	mm
rms momentum spread	0.12	0.06	%
Muon Beam Power	9	9	MW
Required depth for ν rad	135 (ILC)	540	m
Repetition Rate	6	3	Hz
Proton Driver power	$\approx$ 1.8	$\approx$ 0.8	MW
Trans Emittance	25	25	pi mm mrad
Long Emittance	72,000	72,000	pi mm mrad

Cooling Scheme



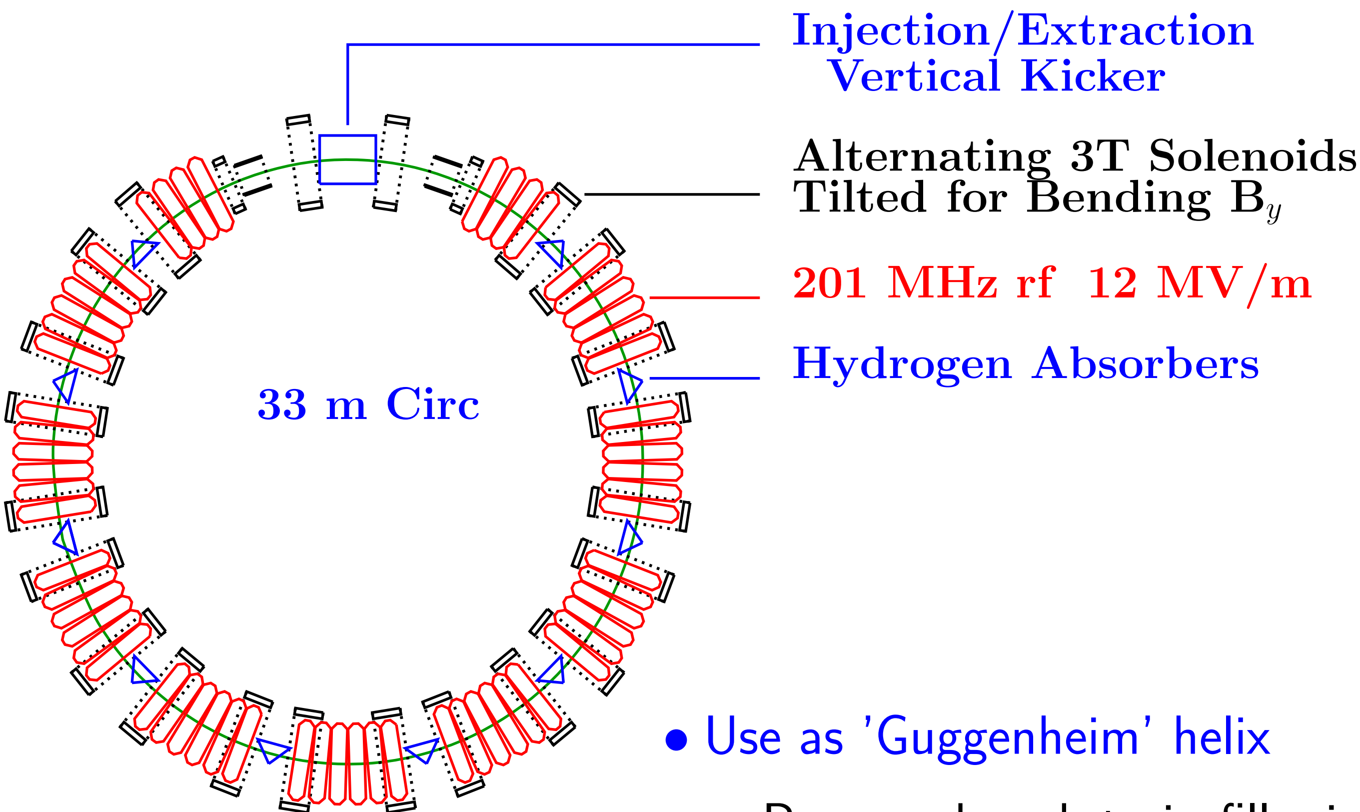
1 & 2) Bunched Beam Phase Rotation and Initial Cooling as in Neutrino Factory

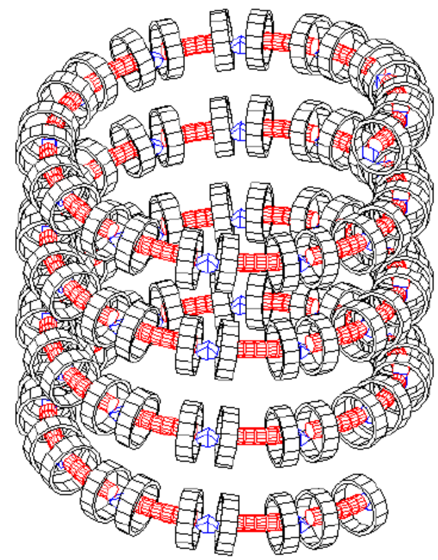
But use only 21 of 56 used in Study 2a



3) & 4) 6 D cooling in "RFOFO" Rings with Wedges

- Bending gives dispersion
- Wedge absorbers give memittance exchange: Cooling also in longitudinal

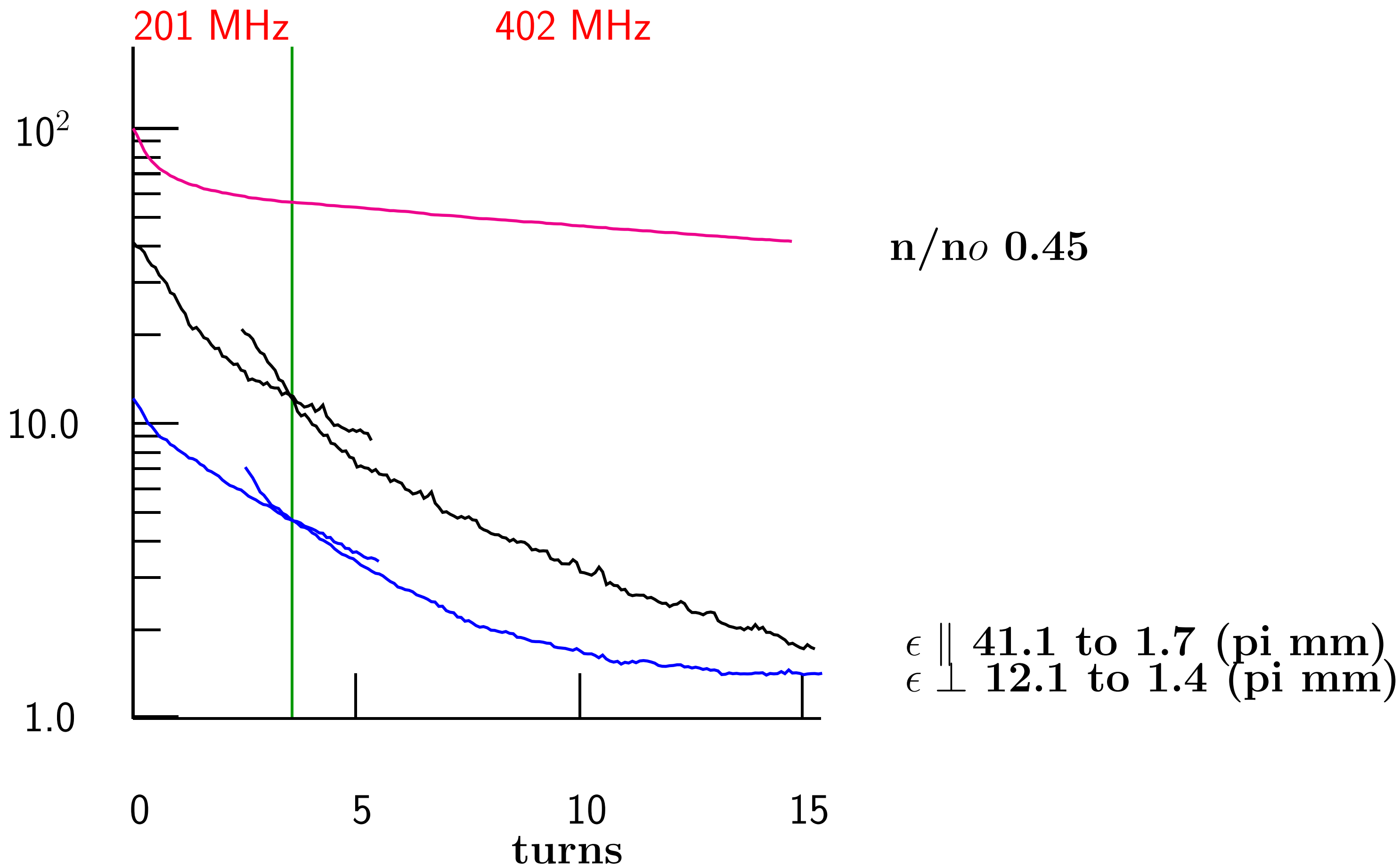




- Use as 'Guggenheim' helix
  - Because bunch train fills ring
  - Avoids difficult kickers
  - Better performance possible by tapering
    Not yet assumed

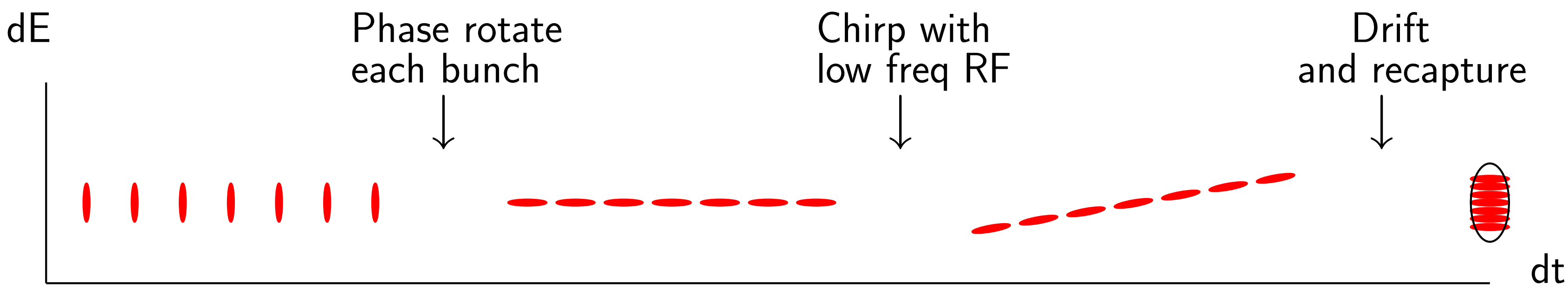
3) with 201 MHz   4) 402 MHz and 1/2 scale

ICOOL Simulations of real fields Balbakov was first

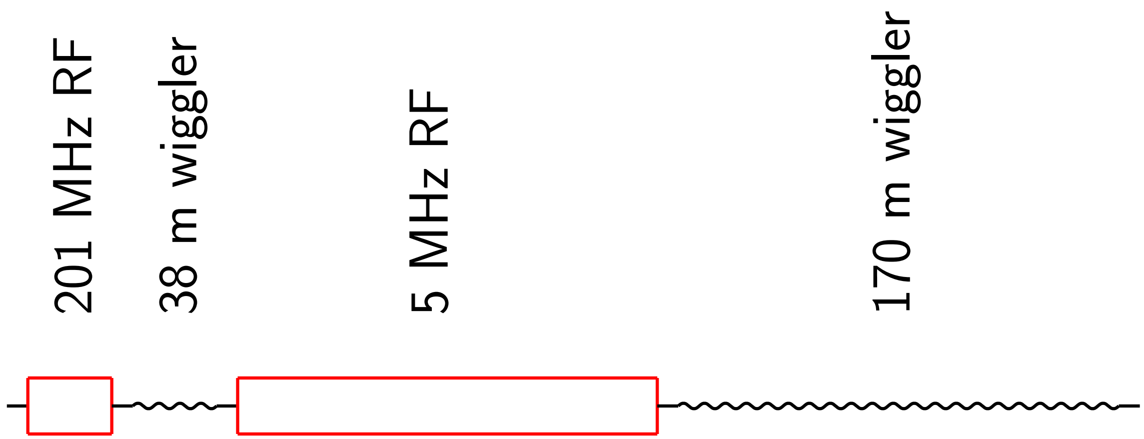


- 201 MHz RFOFO as published, but Guggenheimed (B=3 T)
- 402 MHz RFOFO has all dimensions halved (B=6 T)
- Equilibrium emittances both halved

5) Bunch Merging



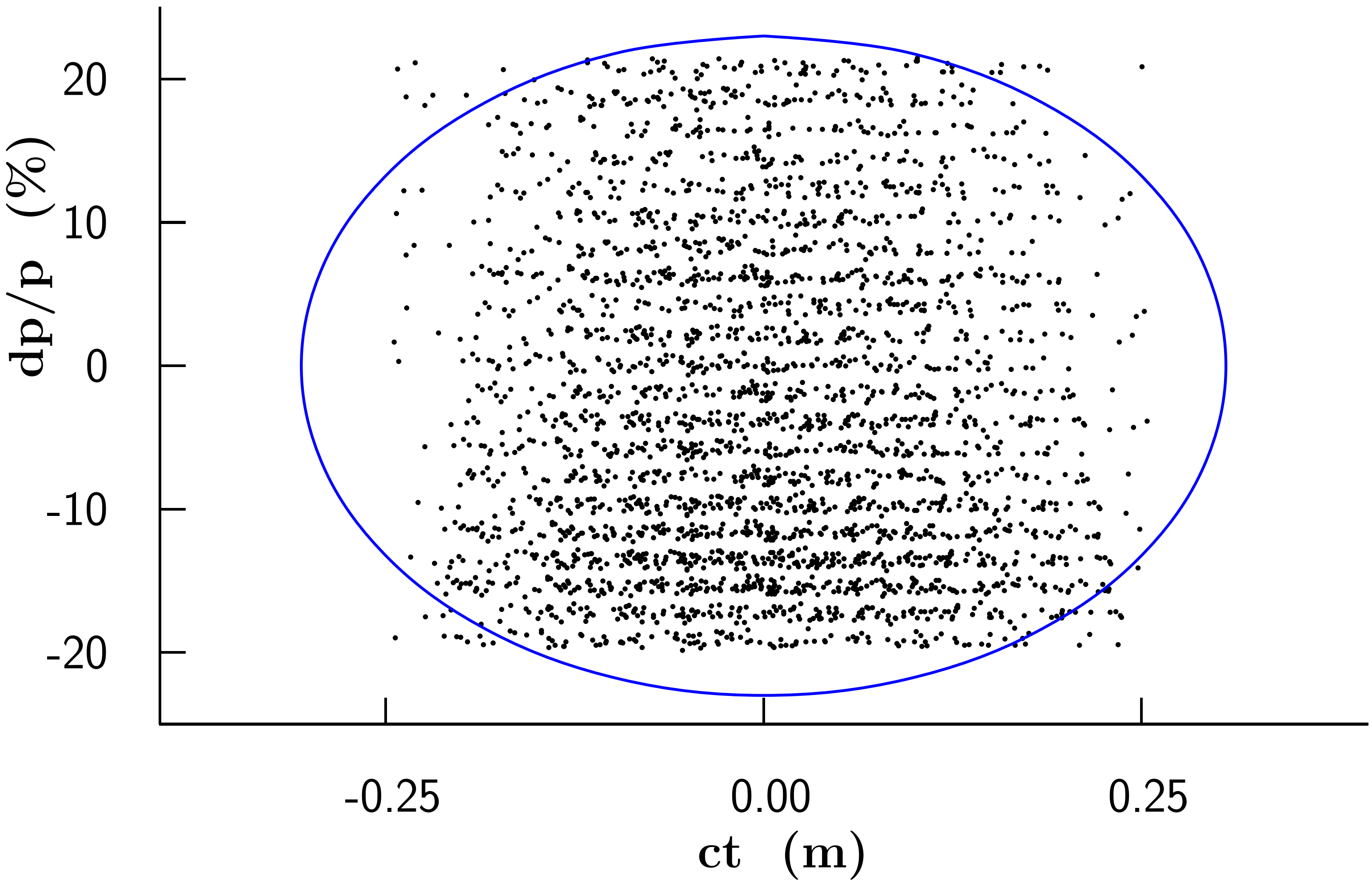
- First rotation with sawtooth RF rotates all bunches individually
- Second rotation with single ramp rotates all bunches
- Merged bunches captured with standard 201 MHz RFOFO RF



Using ICOOL simulated wigglers to maximize momentum compaction

After Both 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



6) and 7) 201 MHz and 402 MHz RFOFOs

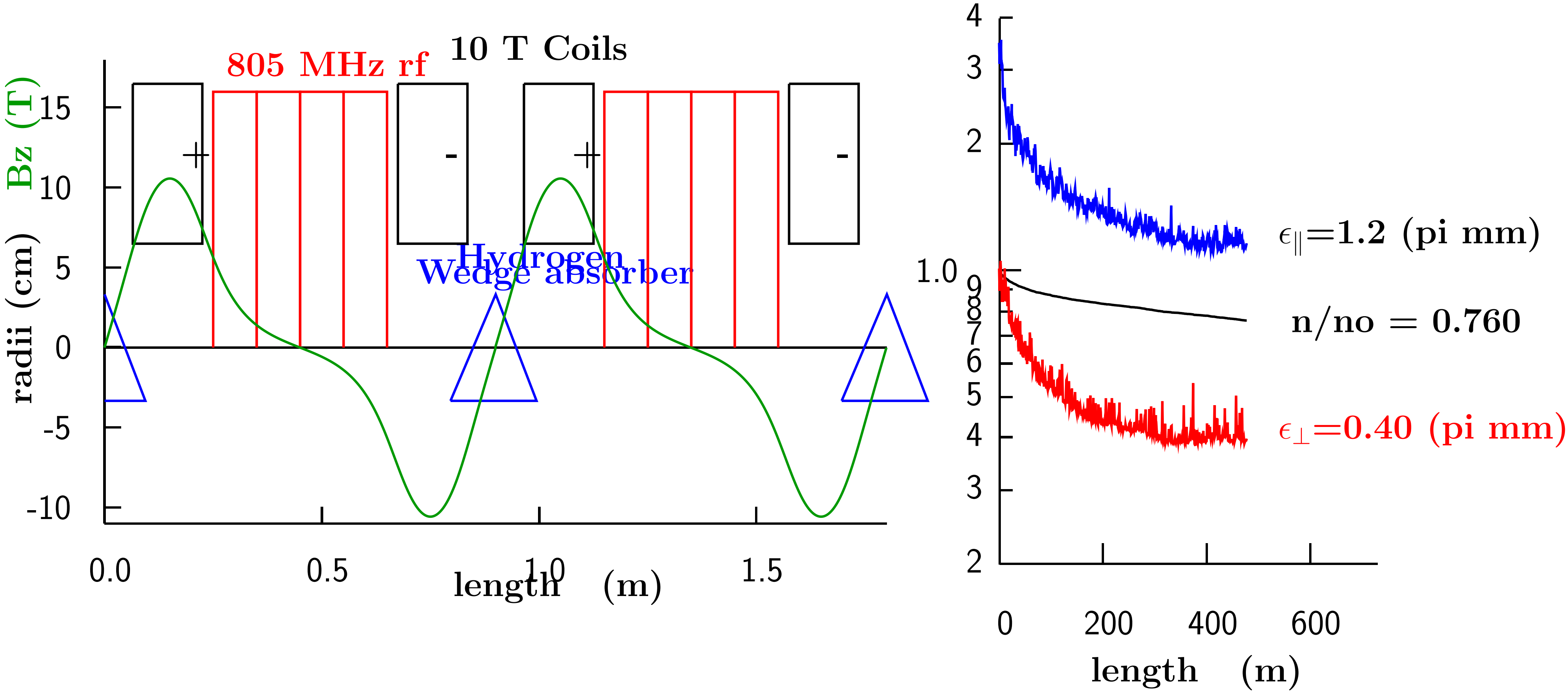
Cooling in rings now possible because

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

6) Cool longitudinally with 201 MHz RFOFO Ring
Transverse emittance rises slightly, but longitudinal cools fast

7)Cool further longitudinally with 402 MHz 1/2 scale RFOFO Ring
Slight transverse cooling, strong longitudinal cooling

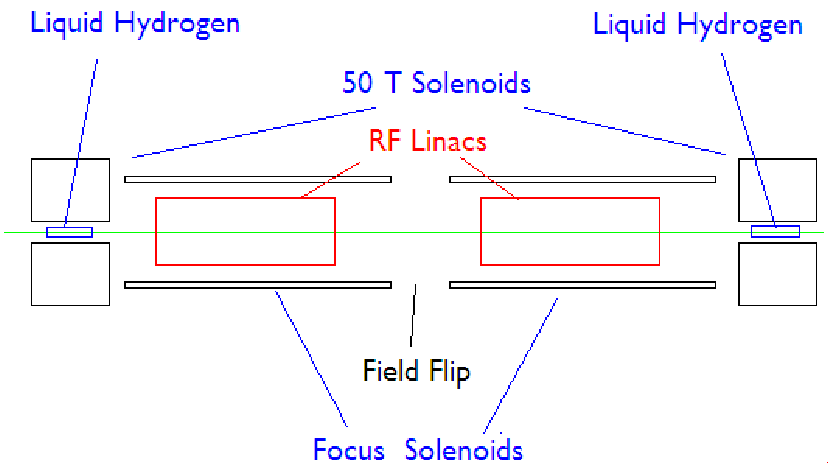
8)New low beta 805 MHz RFOFO Ring

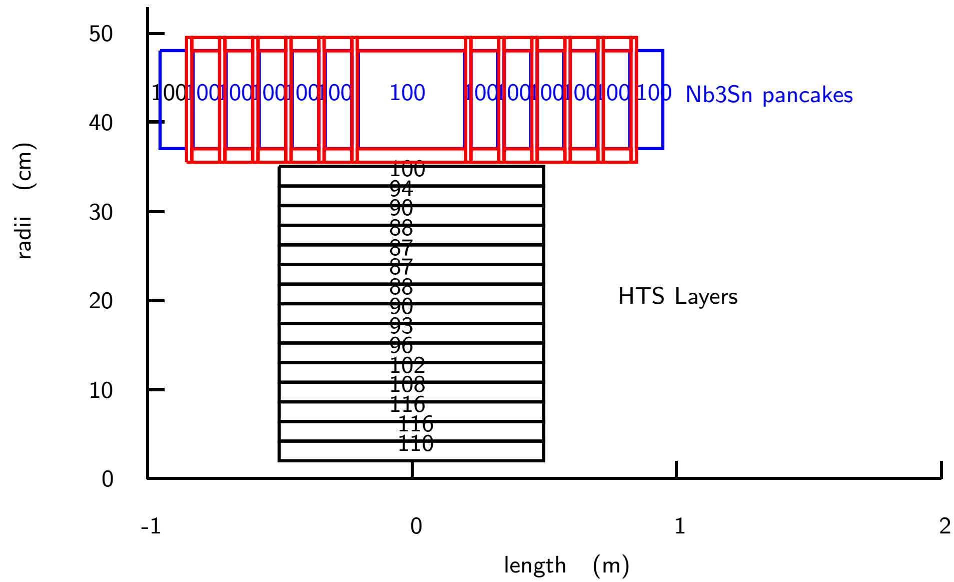


- Uses 10 T high current density (150 A/mm^2) solenoids
- Higher field HTS solenoids (Summers) would allow further cooling and reduced muon charge at a higher rep rate. But not less muon beam power per luminosity. e.g. 20 T and 600 A/mm^2

9) Cooling in linear sequence of 50 T solenoids

With Muons Inc.





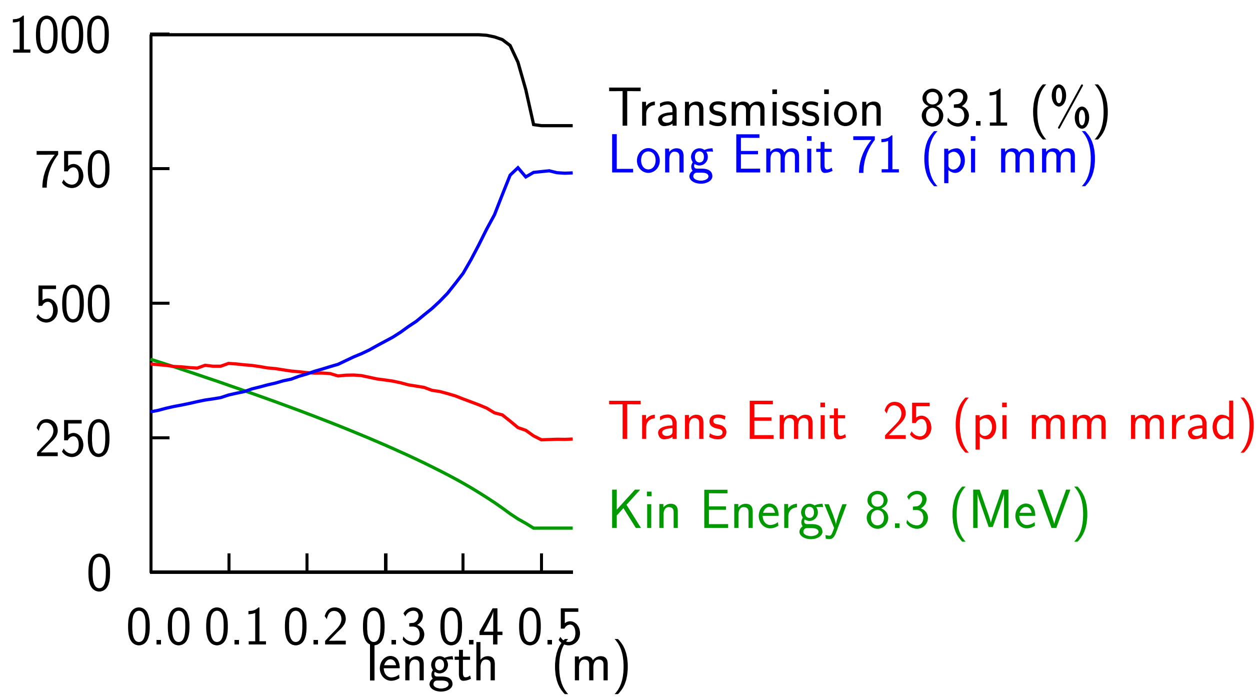
- Layer wound allowing current to vary with radius
- Vary ss support with radius to keep strain constant
- e.g. use existing American superconductor HTS tape

- Much work needed, but 50 T seems practical

ICOOL Simulations (without matching & accel.)

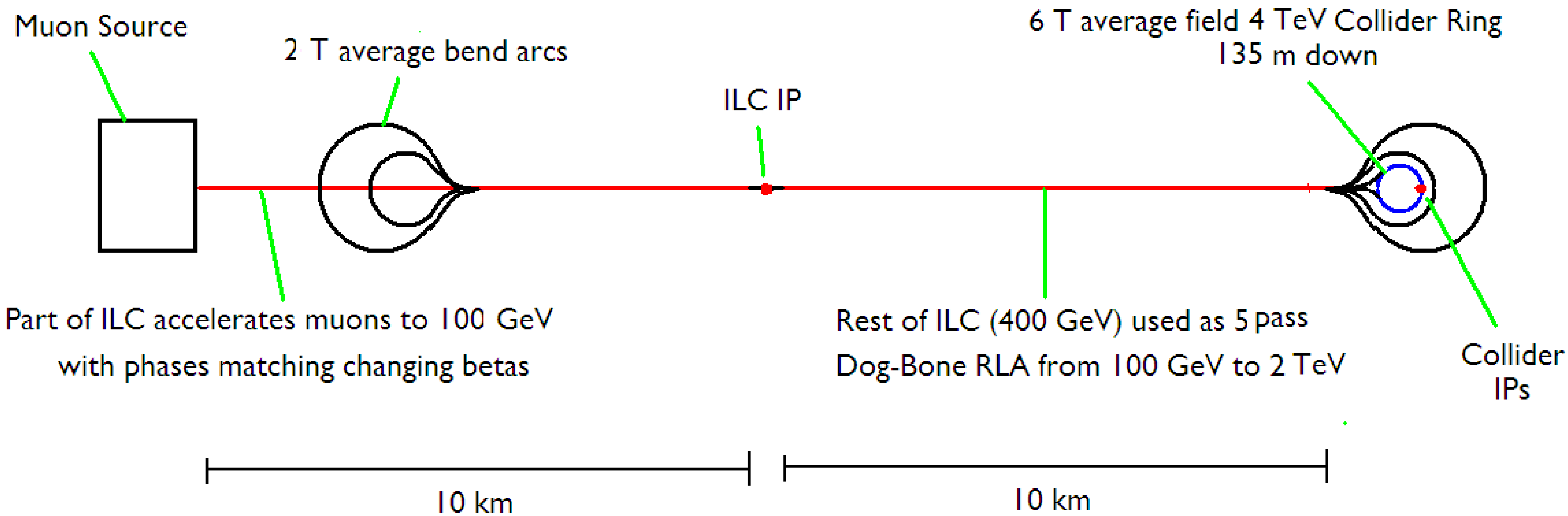
- 6 Solenoids with hydrogen absorbers inside
- Better performance if more than current 6 stages used
- Matching and acceleration not yet done
- But adiabatic solenoid matching should be easy

e.g. Simulation of Final Solenoid Cooling



- Lengths up to 1 m in earlier stages

9) Acceleration using ILC



- 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 nature of 1 TeV ILC upgrade
- If no ILC, then RLA to 1 TeV, then pulsed synchrotron (Summers)

Muon Survival (a first guess)

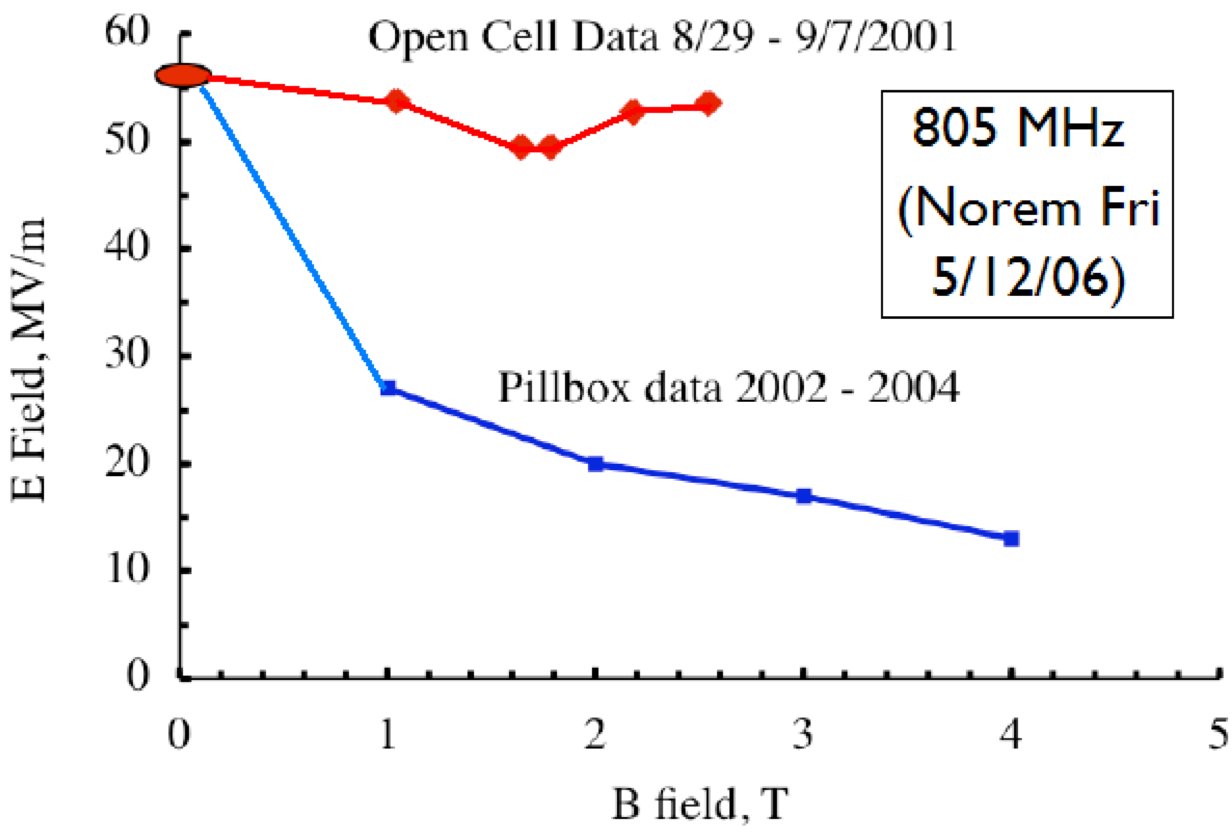
	Transmission	Cumulative
21 vs 54 bunches	.7	.7
Pre-merge RFOFO cooling	$\approx$ .5	.35
Merging	0.8	0.28
Post-merge RFOFO cooling	$\approx$ 0.5	0.14
Final 50 T solenoid cooling	.7	0.1
Acceleration to 2 TeV	0.7	0.07

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 for 4 TeV (MW)	**1.5**
Proton power for 8 TeV (MW)	**0.8**

- Proton power $<$ ISS Neutrino Factory
- But lower rep rate $\rightarrow$ more charge/bunch
  Need E$>$ 8 GeV to get 1-3 ns proton bunch of 7 10^{13}
- Loading with 8 10^{12} muons per bunch needs study

Potentially Problem in above SFOFO Lattices

- In above RFOFO Guggenheims: RF in high Mag Fields
- Inconsistent data: may/may not be a problem



- If it is a problem, all RFOFOs need redesign to lower fields or develop other methods

Conclusion

- Good Muon Colliders at 2, 4, and 8 TeV defined
  Consistent with Neutrino radiation and Tune shifts
- First complete cooling scheme
  Preliminary simulations of all components

To Do

- Design matching and accel between final solenoid coolings
- Study loading, wake, space charge and impedance problems
- Design lattices with lower fields on RF
- Consider alternative technologies
  - Gas filled Helices vs. RFOFO Rings
  - PIC and Similar lattices vs. High Field Solenoids
  - Lithium Lenses Vs. High Field Solenoids
  - Reverse emittance exchange with wedges vs. High Field Solenoids