Muon Colliders

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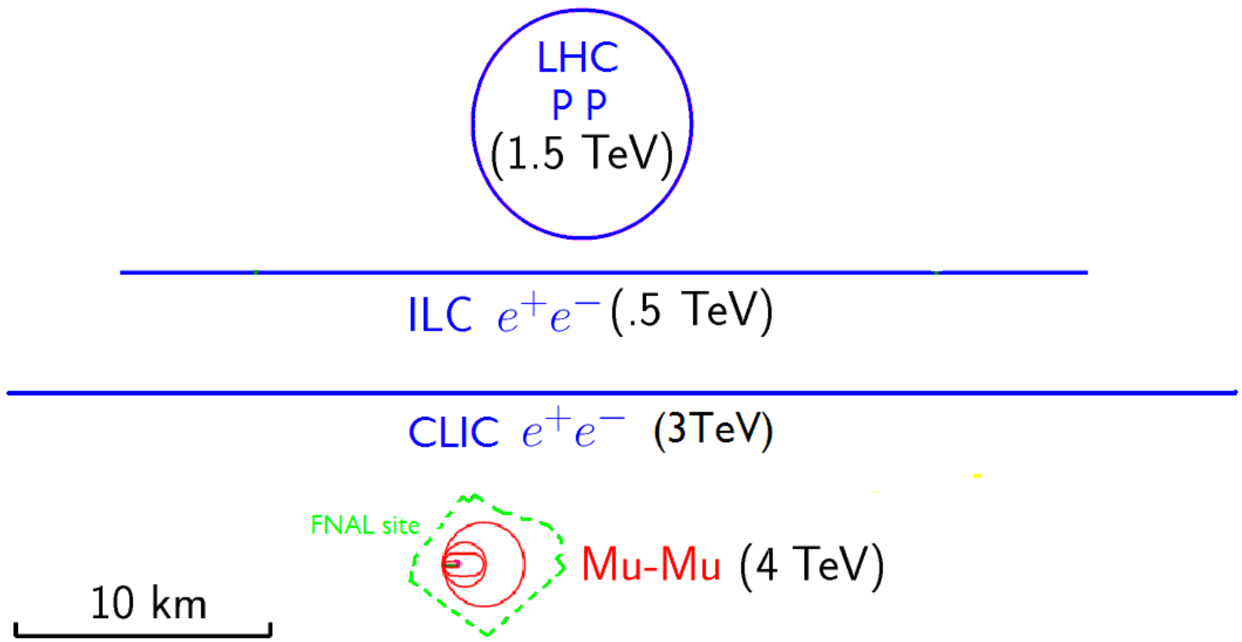
High Intensity workshop

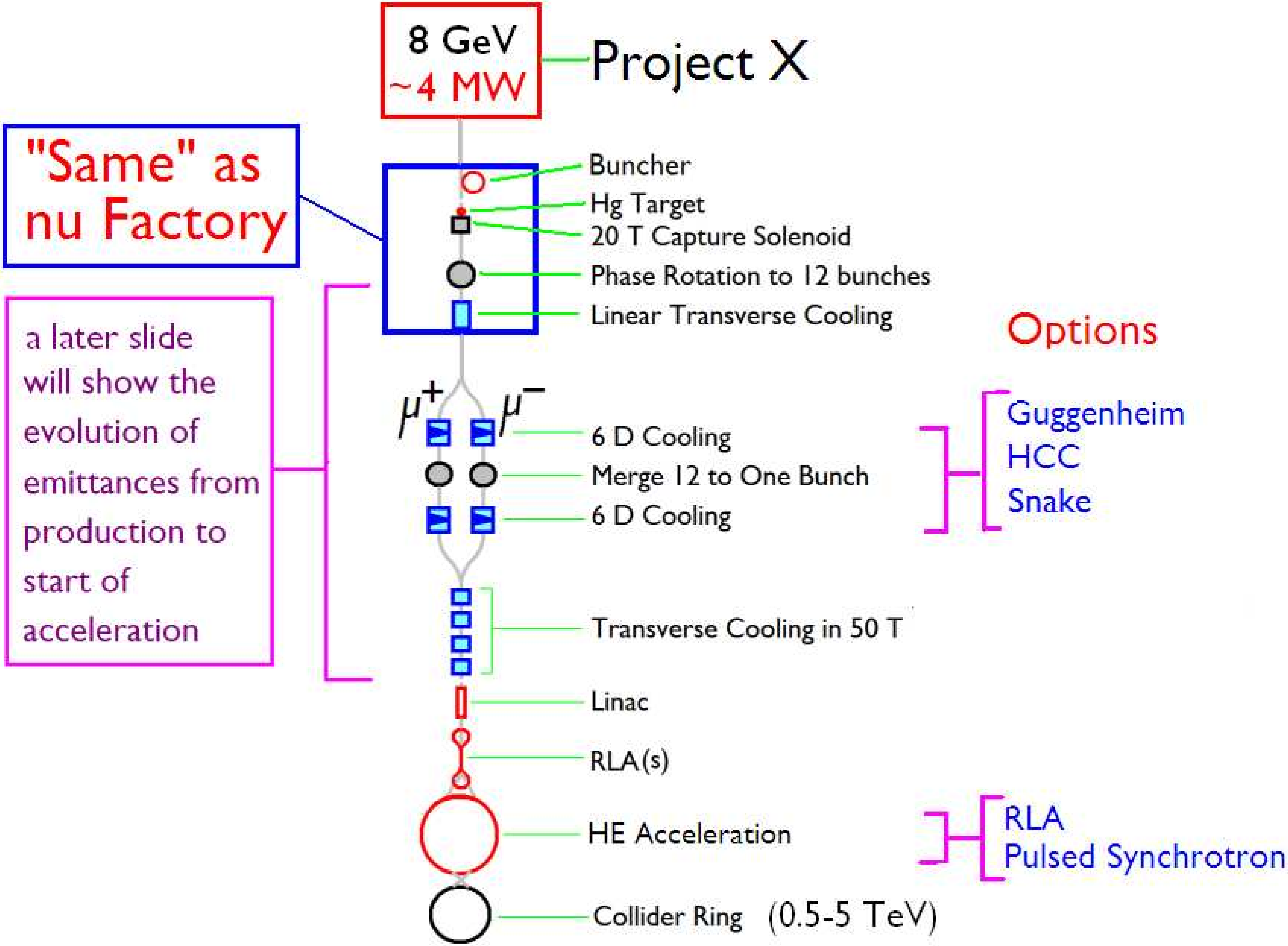
FNAL 10/19/09

- Introduction
- Baseline Designs
- R&D
- Conclusion

Why a Muon Collider?

- Point like interactions as in linear e^+e^-
- Negligible synchrotron radiation:
  Acceleration in rings Small footprint Less rf Hopefully cheaper
- Collider is a Ring
  $\approx$ 1000 crossings per bunch Larger spot Easier tolerances 2 Detectors
- Negligible Beamstrahlung Narrow energy spread
- 40,000 greater S channel Higgs Enabling study of widths



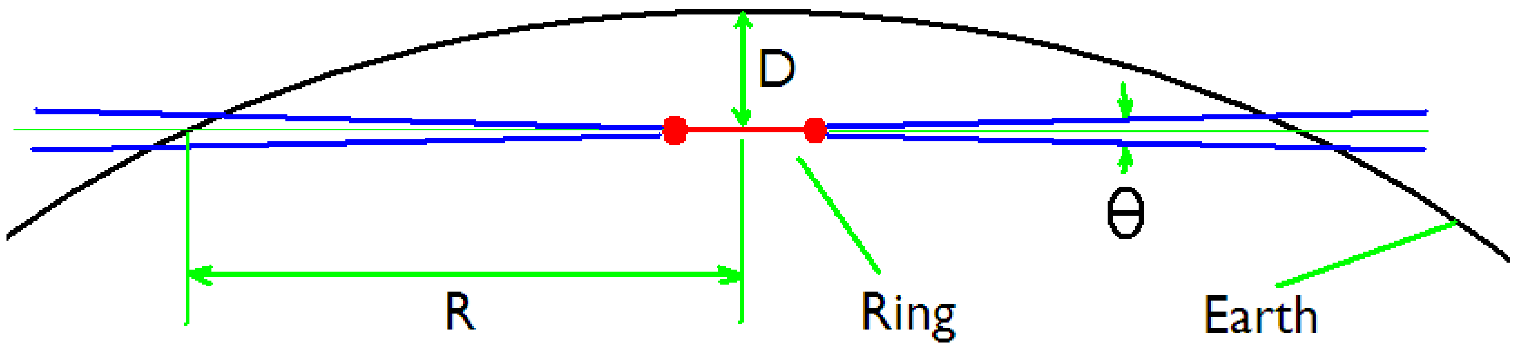

8 GeV
~4 MW
Project X
"Same" as nu Factory
Buncher
Hg Target
20 T Capture Solenoid
Phase Rotation to 12 bunches
Linear Transverse Cooling
Options
a later slide will show the evolution of emittances from production to start of acceleration
μ^+
μ^-
6 D Cooling
Merge 12 to One Bunch
6 D Cooling
Guggenheim
HCC
Snake
Transverse Cooling in 50 T
Linac
RLA(s)
HE Acceleration
RLA
Pulsed Synchrotron
Collider Ring
(0.5-5 TeV)

Current Baseline Parameters (Y Alexahin)

C of m Energy	1.5	3	TeV
Luminosity	0.92	3.4	10^{34} cm^{2}sec^{-1}
Beam-beam Tune Shift	0.087	0.087	
Muons/bunch	2	2	10^{12}
Total muon Power	9	15	MW
Ring <bending field>	6	8.4	T
Ring circumference	2.6	4.5	km
β^* at IP $= \sigma_z$	10	5	mm
rms momentum spread	0.1	0.1	%
Muon per 8 GeV p	0.008	0.007	
Repetition Rate	15	12	Hz
Proton Driver power	3.5-4.8	3-4.3	MW
Muon Trans Emittance	25	25	pi mm mrad
Muon Long Emittance	72,000	72,000	pi mm mrad

- Lower power estimate based on MARS15
- Emittance and bunch intensity requirement same for both examples
- 3 TeV luminosity (3.4 10^{33}) compared to CLIC's (2 10^{33} for dE/E $<$ 1%)
- Luminosities should be higher due to 'Disruption' enhancement

Neutrino Radiation Constraint (B King)



$$\text{Radiation} \propto \frac{E_\mu \; I_\mu \; \sigma_\nu}{\theta \; R^2} \propto \frac{P_{\text{beam}} \; \sigma_\nu}{\theta \; R^2}$$

Since

$$\mathcal{L} \propto B_{\text{ring}} \; P_{\text{beam}} \; \Delta\nu \; \frac{1}{\beta^*}$$

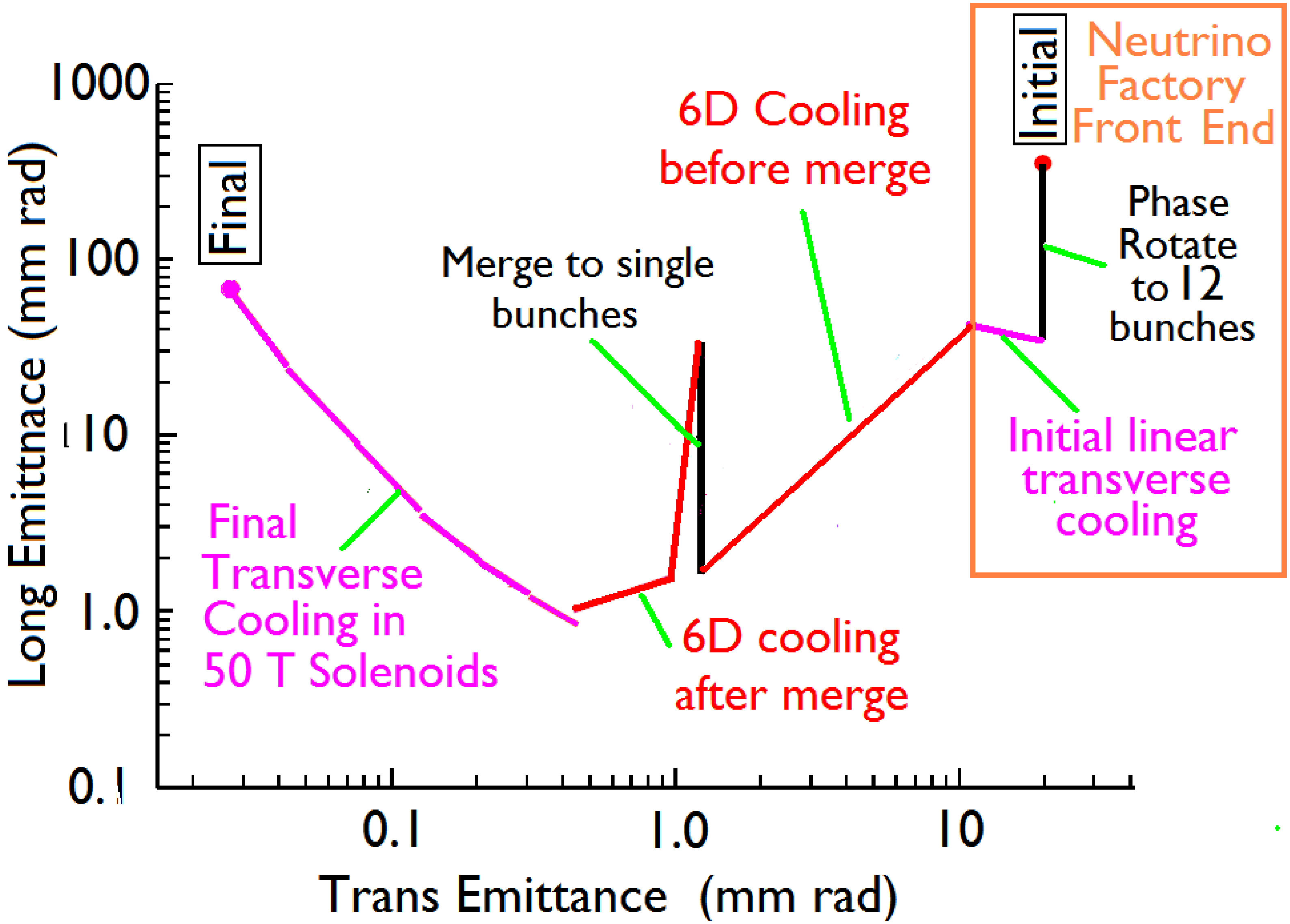
And we need

$$\mathcal{L} \propto \mathrm{E}^2$$

$$\text{Radiation} \propto \left(\frac{\beta^*}{\Delta\nu \; B_{\text{ring}}}\right) \; \frac{\gamma^4}{D}$$

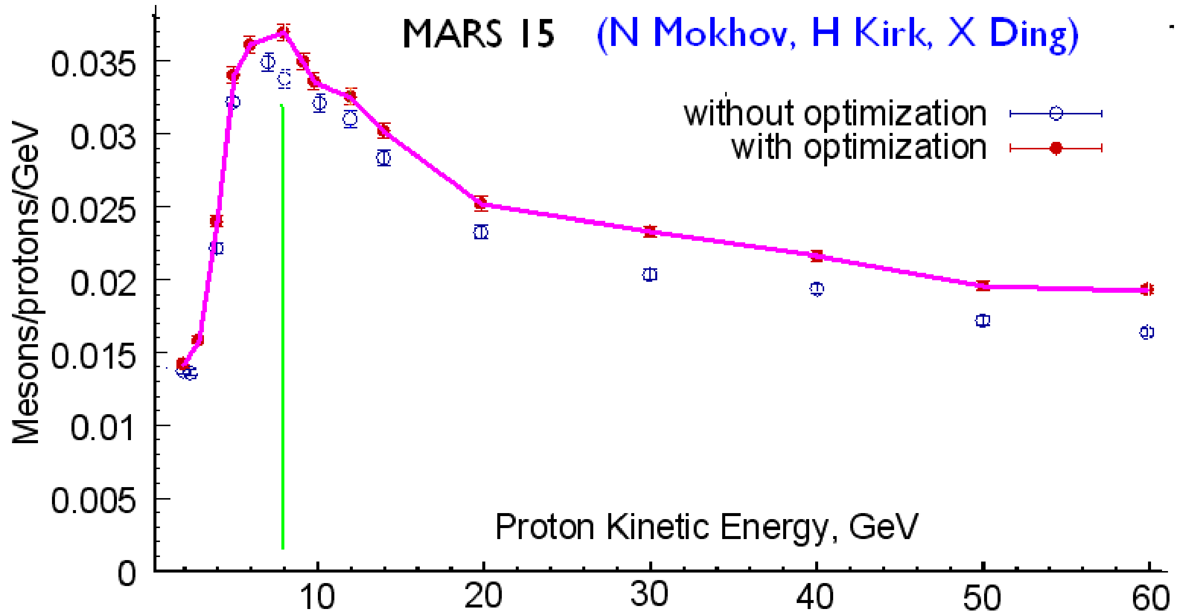
- Little problem at 1.5 TeV
- Required depth of order 200 m for 3 TeV
  and straight sections must be minimized or aimed at owned locations

Emittances vs. Stage

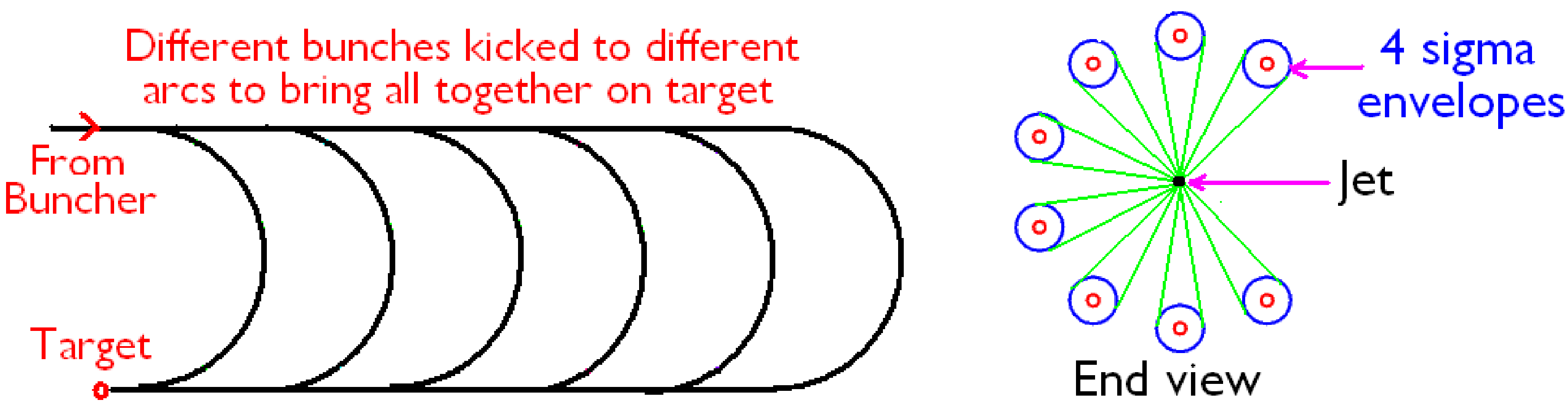


- Every stage simulated at some level,
- But with many caveats

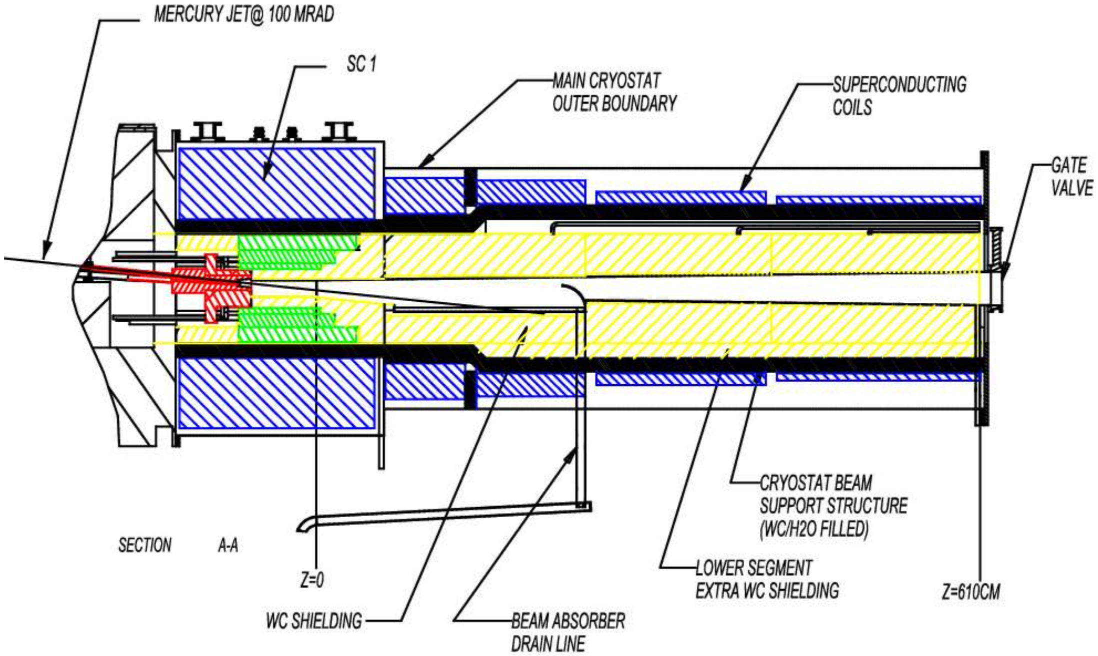
Proton driver



- Clear advantage in proton energy $\approx$ 8 GeV
  - But requires 170-280 Tp in 3 nsec
  - Bunching ok with multiple ($\approx$ 8) bunches (Ankenbrandt)

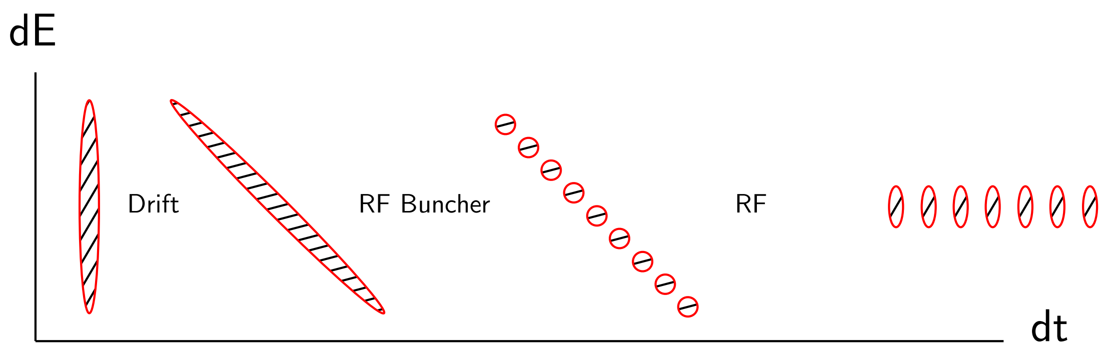


Target and Capture



- Mercury Jet Target, 20 T capture
- Adiabatic taper to 2 T
- Discussed by Geer

Phase Rotation (D Neuffer)



- Drifts
- Multiple frequency rf
- Bunch
- Then phase to rotate
- Discussed by Geer

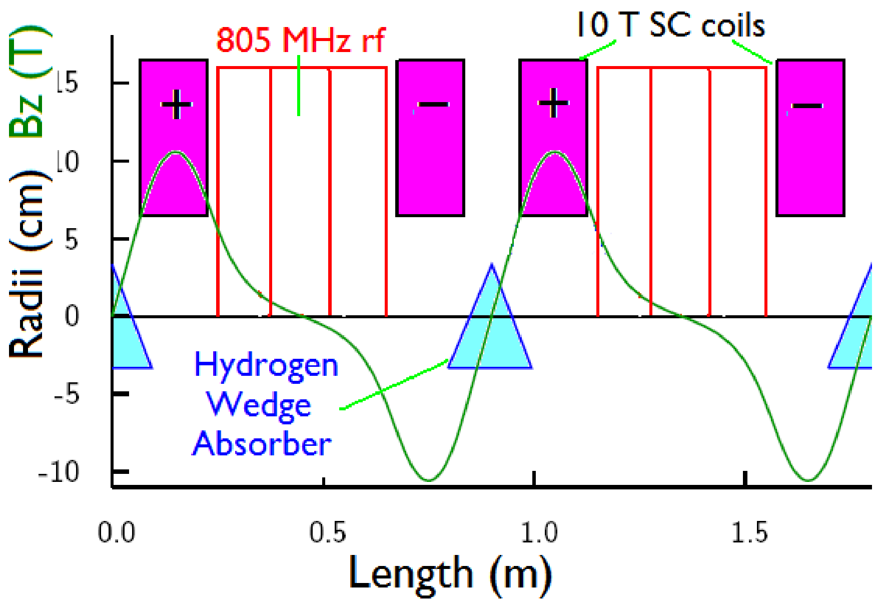
Both of these would be substantially the same as for a Neutrino Factory

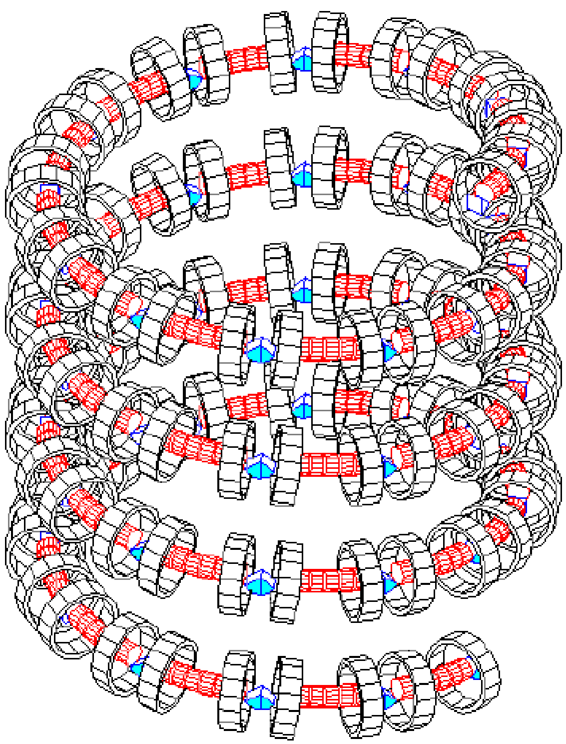
6D Cooling Several methods under study

a) "Guggenheim" Lattice (R Palmer)

- Lattice arranged as 'Guggenheim' upward helix
- Bending gives dispersion
- Higher momenta pass through longer paths in wedge absorbers giving momentum cooling (emittance exchange)
- Starting at 201 MHz and 3 T, ending at 805 MHz and 10 T

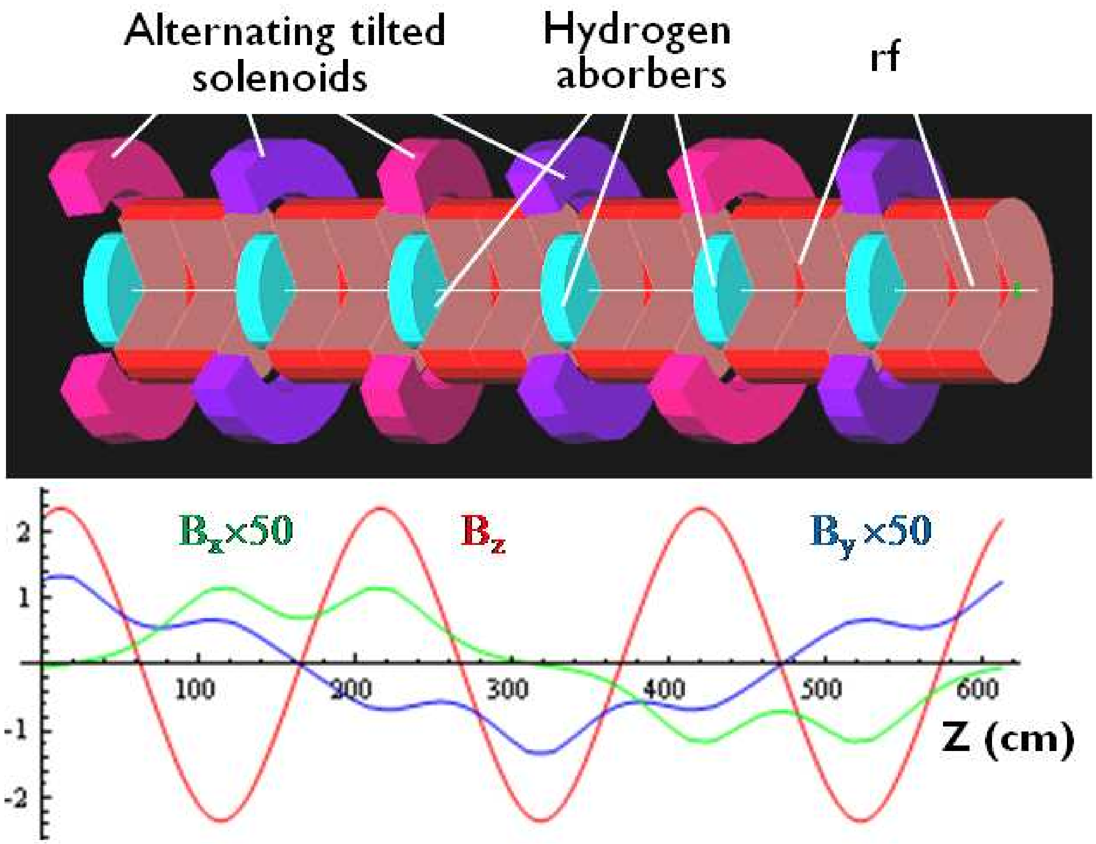
e.g. 805 MHz 10 T cooling to 400 mm mrad





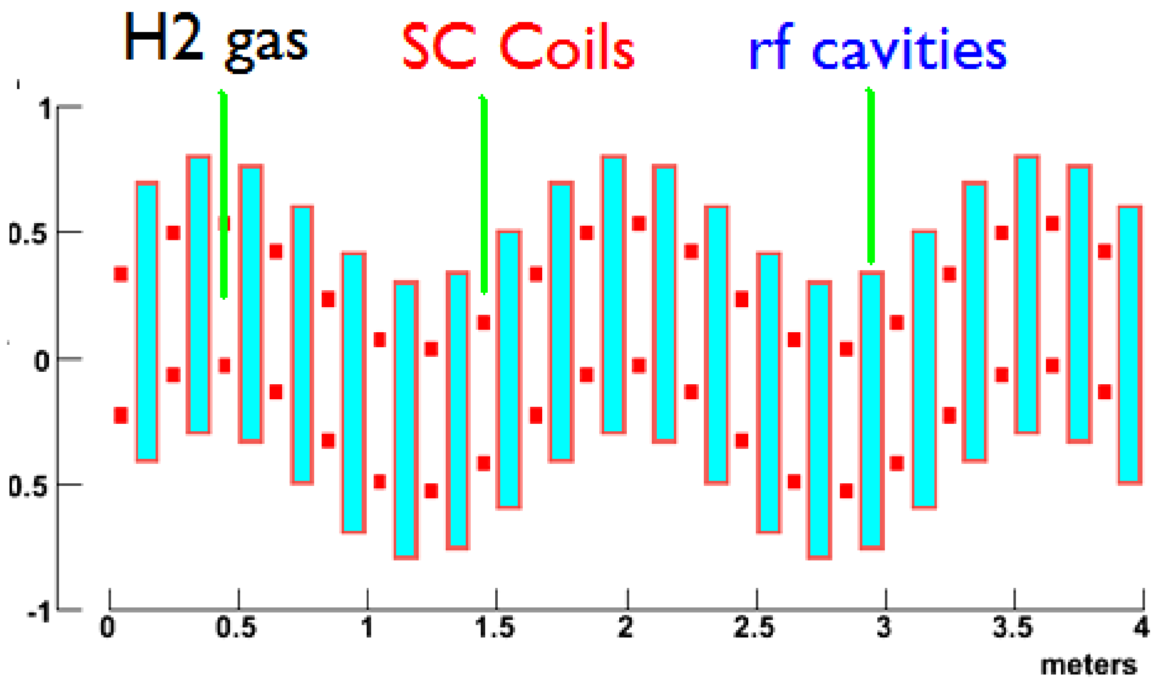
b) Snake (Y Alexahin)

- Tilted alternating solenoids generate dispersion
- Higher momenta pass through absorbers at steeper angles giving momentum cooling (emittance exchange)
- Lattice accepts both signs
- Starting at 201 MHz and 2.5 T, ending at 805 MHz and 10 T



c) Helical Cooling Channel (HCC) Derbenev)

- Muons move in helical paths in high pressure hydrogen gas
- Higher momentum tracks have longer trajectories giving momentum cooling (emittance exchange)

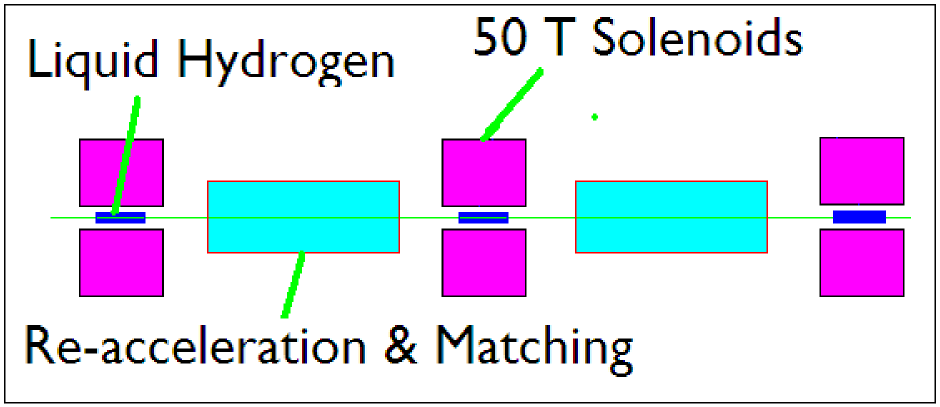


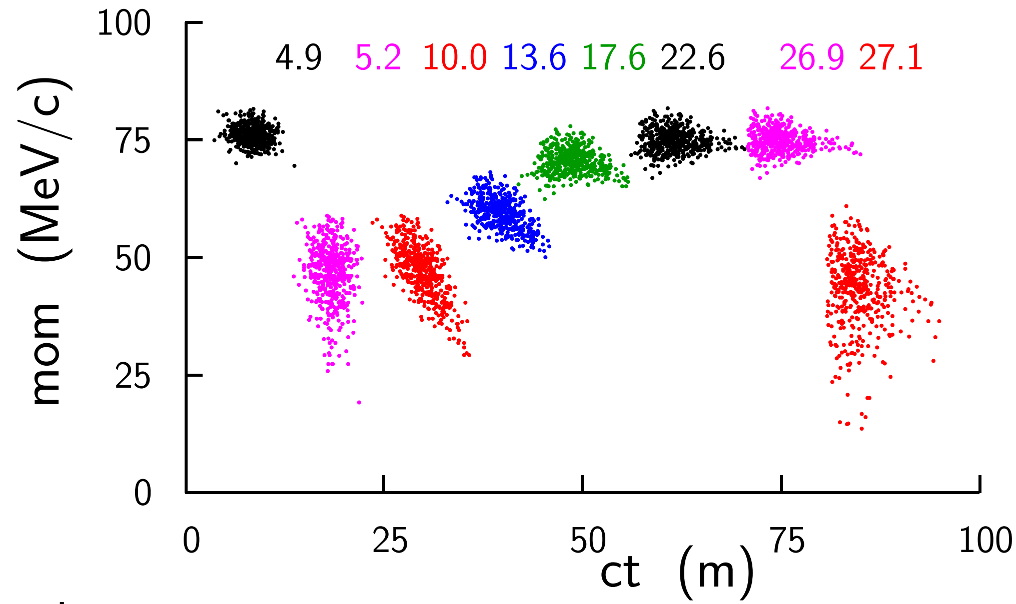
- Initial Bz=4.3 T
- Final Bz=17.2 T (Higher than snake or guggenheim)

- Engineering integration of rf difficult
- Possible problem of rf breakdown with intense muon beam transit

Final Transv. Cooling in High Field Solenoids (Palmer)

- Lower momenta allow transverse cooling to lower transverse emittances, but longitudinal emittance rises: Effectively reverse emittance exchange

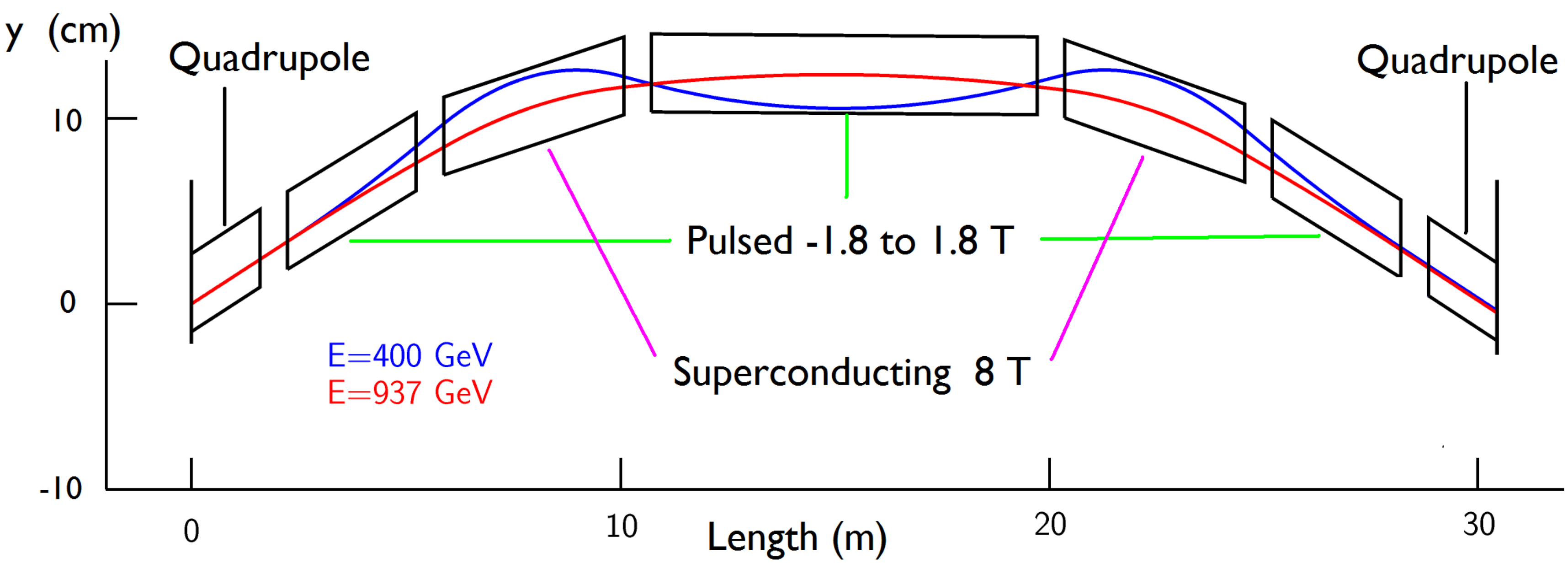




- Need 5-8 50 T solenoids
- ICOOL Simulation of cooling in solenoids
- Simulation of re-acceleration & matching only for last two stages
- 50 T Solenoid technology
  - 45 T hybrid at NHMFL, but uses 25W
  - 40 T HTS experiment under construction (later)
  - 50 T 'all HTS' designs

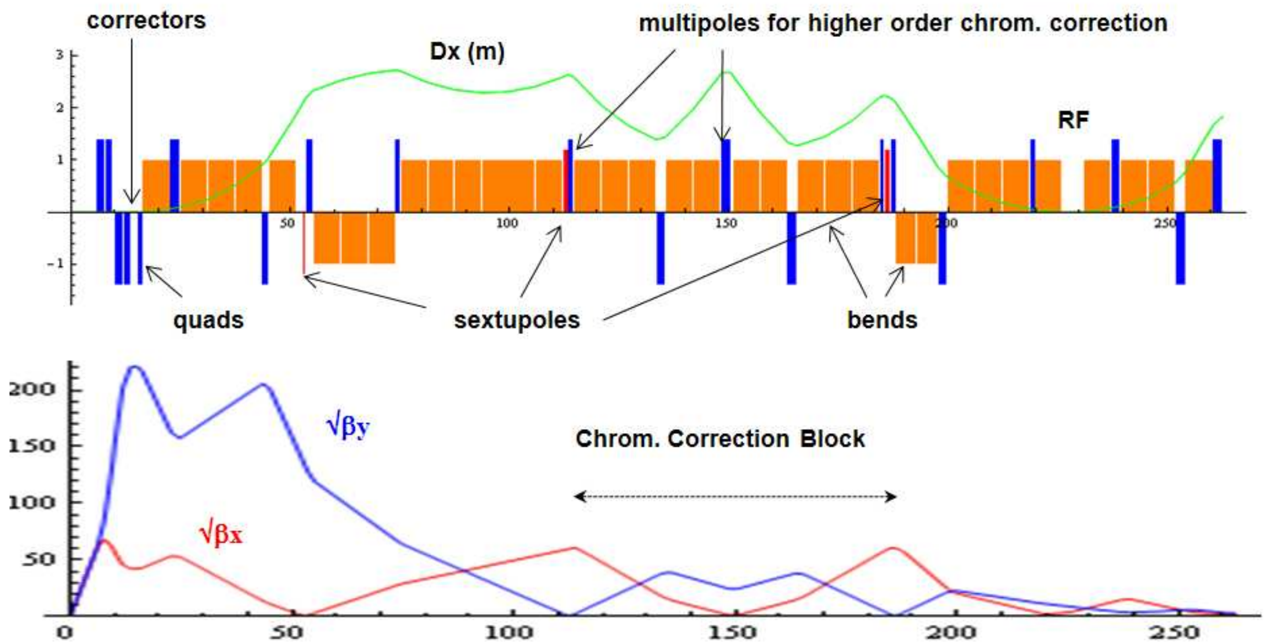
Acceleration

- Sufficiently rapid acceleration is straightforward in Linacs and Recirculating linear accelerators (RLAs)
  Possibly using ILC-like 1.3 GHz rf
- Lower cost solution would use Pulsed Synchrotrons (D Summers)
  - Pulsed synchrotron 30 to 400 GeV (in Tevatron tunnel)
  - Hybrid SC & pulsed magnet synchrotron 400-900 GeV (in Tevatron tunnel) For $\lesssim$ 1.8 TeV
  - Hybrid SC & pulsed magnet synchrotron 900-1500 GeV (in new tunnel For 3 TeV



Collider Ring

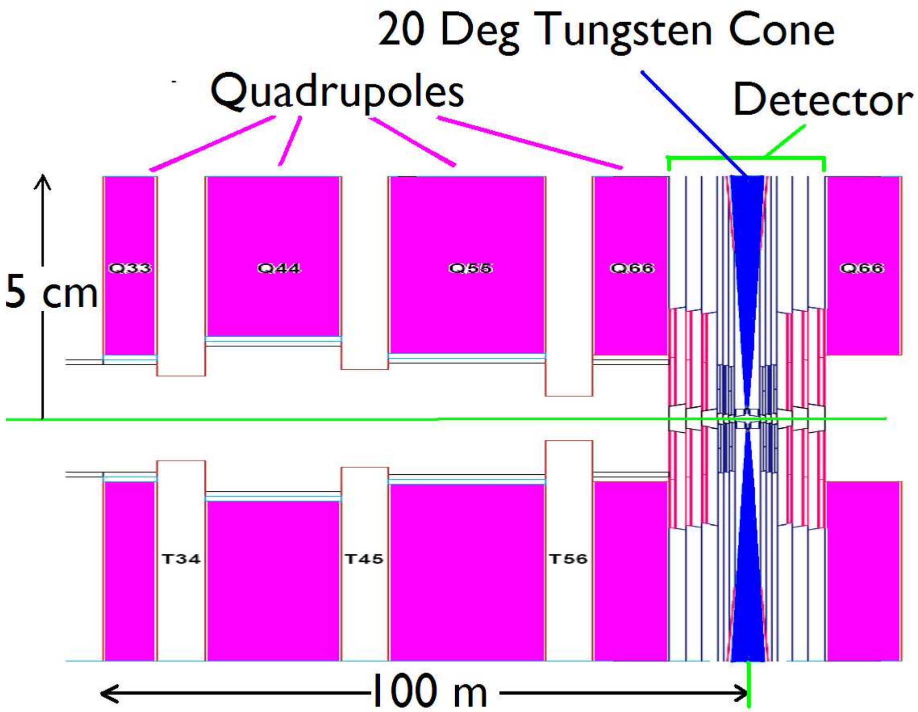
- 1.5 TeV new lattice (Y Alexahin, E Gianfelice-Wendt)



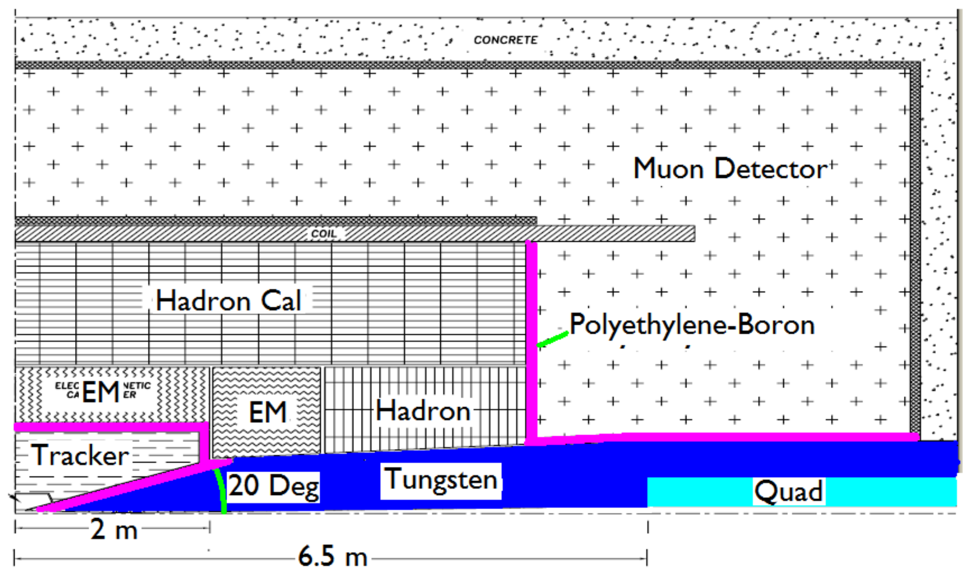
  - 4.5 sigma dynamic aperture
  - 0.8% dp/p (need only 0.3%) May allow greater $\epsilon_{\parallel}$ and thus smaller $\epsilon_{\perp}$
  - Smaller circumference (2.6 km vs 3.1 km) increasing luminosity

- 4 TeV (c of m) 1996 design (Oide)
  - Meets requirements in ideal simulation
  - But is too sensitive to errors to be realistic - needs work

Detector   From 1996 Study of 4 TeV (I Stumer N Mokhov)



Shielding



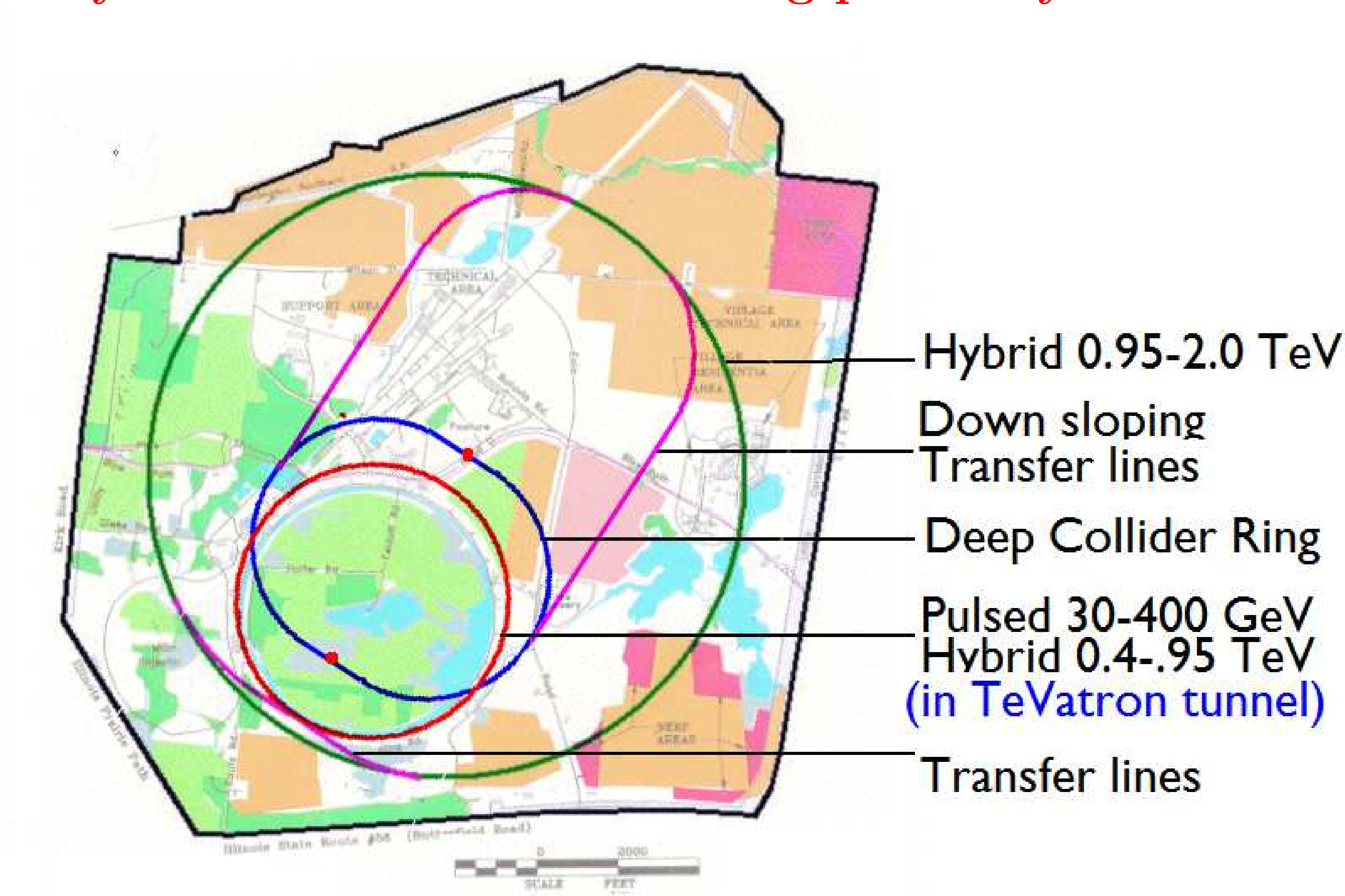
Detector

- Sophisticated shielding of decay electron background designed for 1996 4 TeV
- GEANT simulations then indicated acceptable backgrounds
- Would be less of a problem now with finer pixel detectors

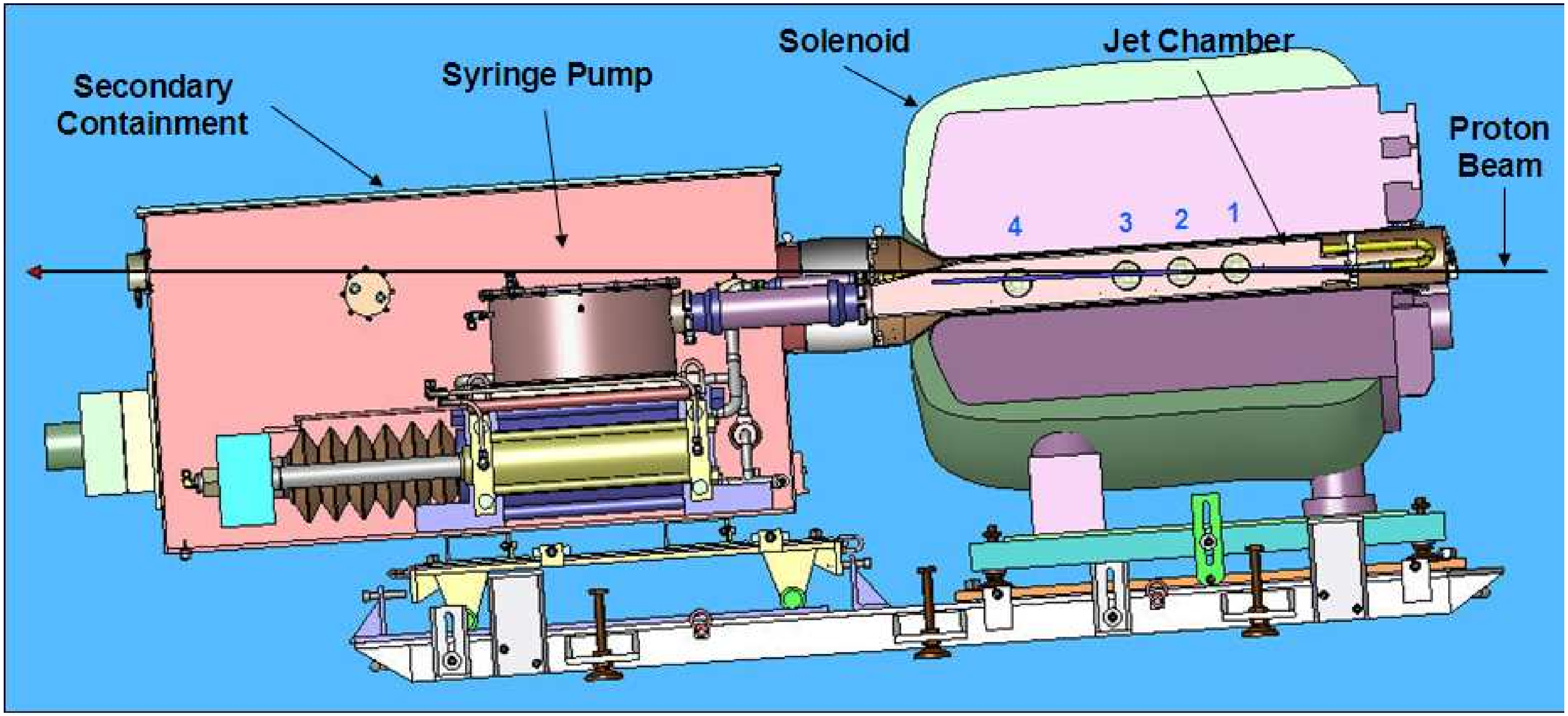
BUT

- Tungsten shielding takes up 20 degree cone
- Simulation now re-started

Layout of 3 TeV Collider using pulsed synchrotrons



R&D AND EXPERIMENTS
1) MERIT Experiment at CERN

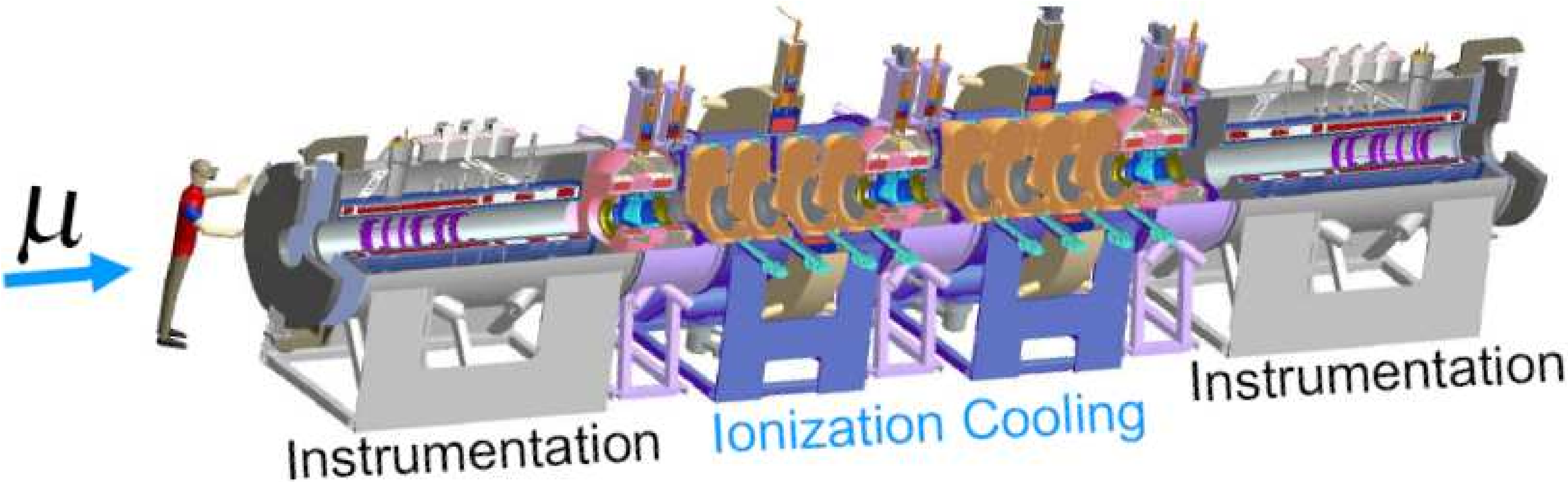


Discussed by Geer

2) Muon Ionization Cooling Experiment (MICE)

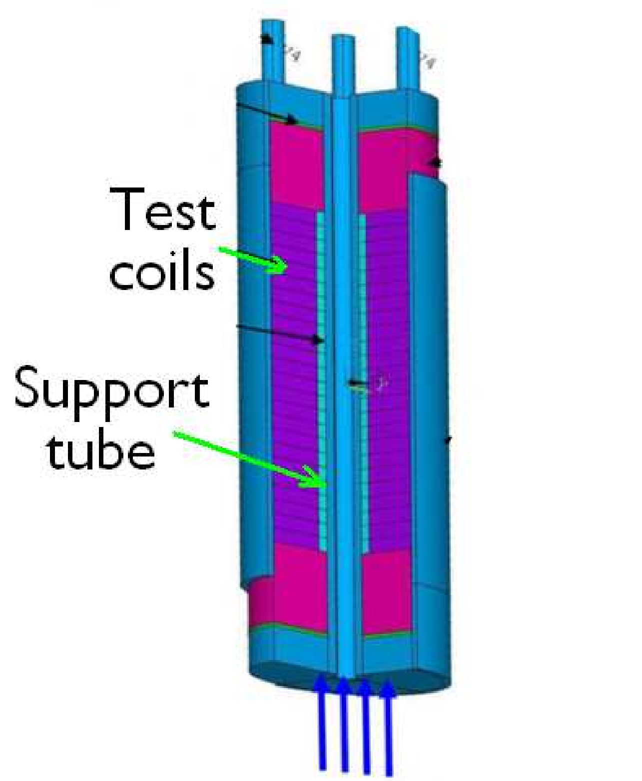
International collaboration at RAL, US, UK, Japan (Blondel)

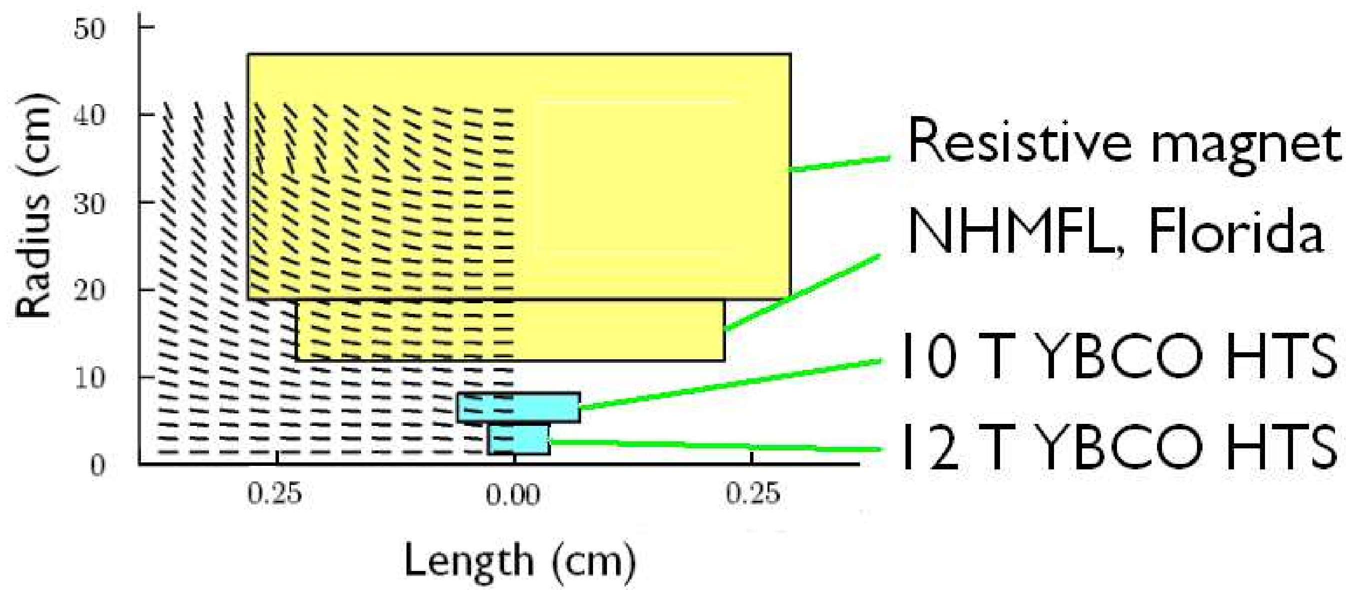
- Will demonstrate transverse cooling in liquid hydrogen, including rf re-acceleration
- Uses a different version of 'Guggenheim' lattice
  But, as now configured, has no bending or emittance exchange



- Possible test of emittance exchange in single wedge absorber

3) HTS R&D towards a 50 T solenoid





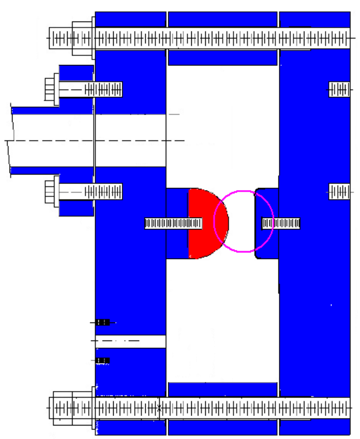
- FNAL program
- Testing multiple small coils in existing 12 T facility
- Fields up to 25 T

- BNL/PBL Program (SBIR)
- Nested YBCO HTS coils under construction
- 12 + 10 T = 22 T stand alone
- Approx 40 T in 19 T NHMFL magnet
- Design for 19 T NbTi + Nb_3Sn design is straightforward

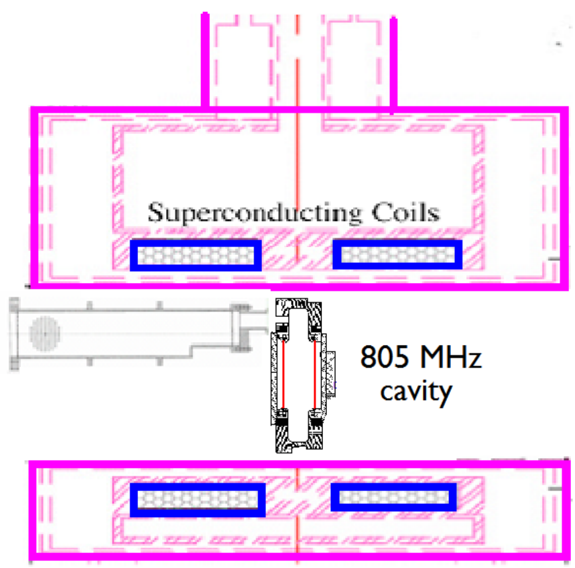
4) MuCool, and MuCool Test Area (MTA) at FNAL

International collaboration US, UK, Japan (Bross)

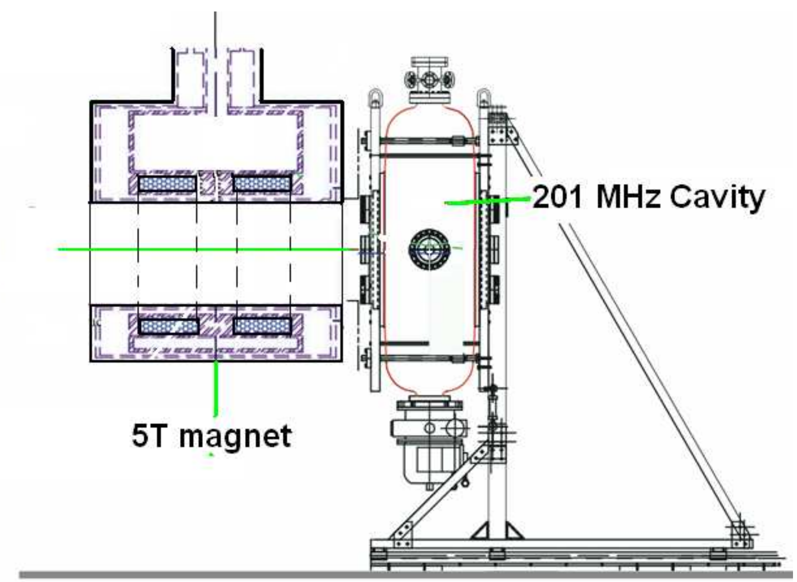
- Liquid hydrogen absorber tested
- Open & pillbox 805 MHz cavities in magnetic fields to 4 T
- 201 MHz cavity tested in stray magnetic field of 0.7 T
  Later, with coupling coil, to 2T
- High pressure H2 gas 805 MHz pillbox cavity tested
- Soon: 805 MHz gas Cavity with proton beam



HP Gas cavity

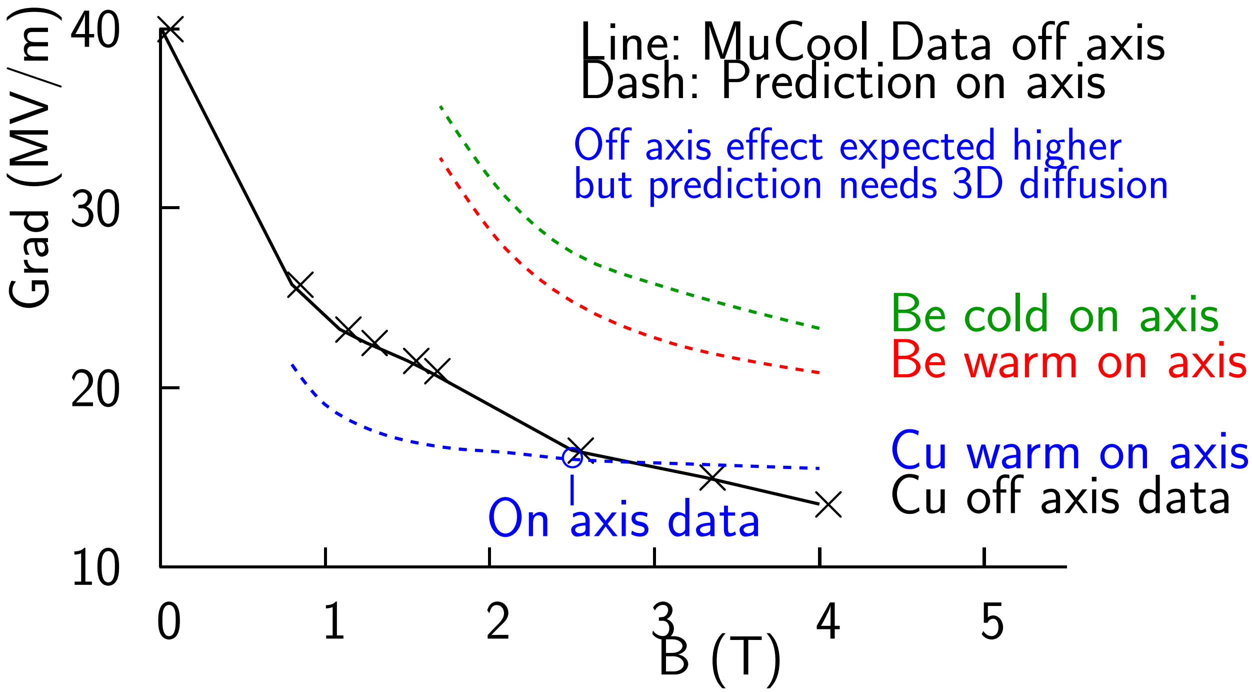


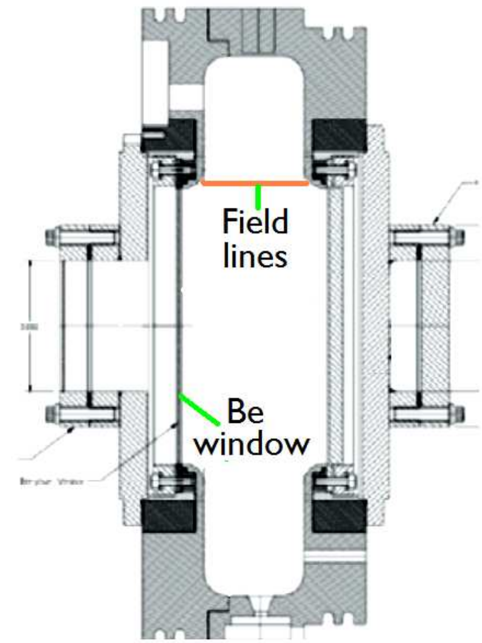
805 MHz in 4 T magnet



201 MHz next to magnet

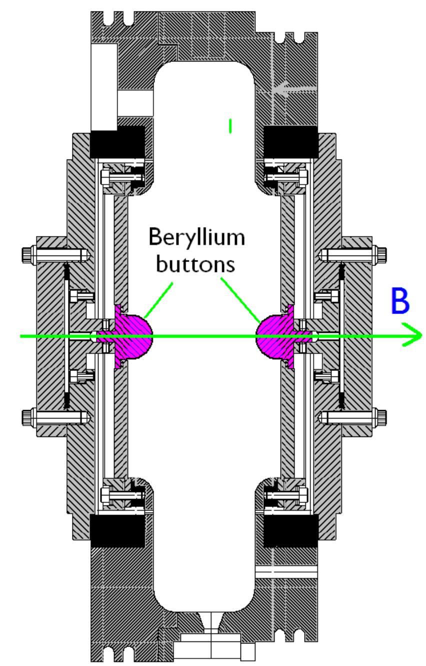
rf breakdown in magnetic fields



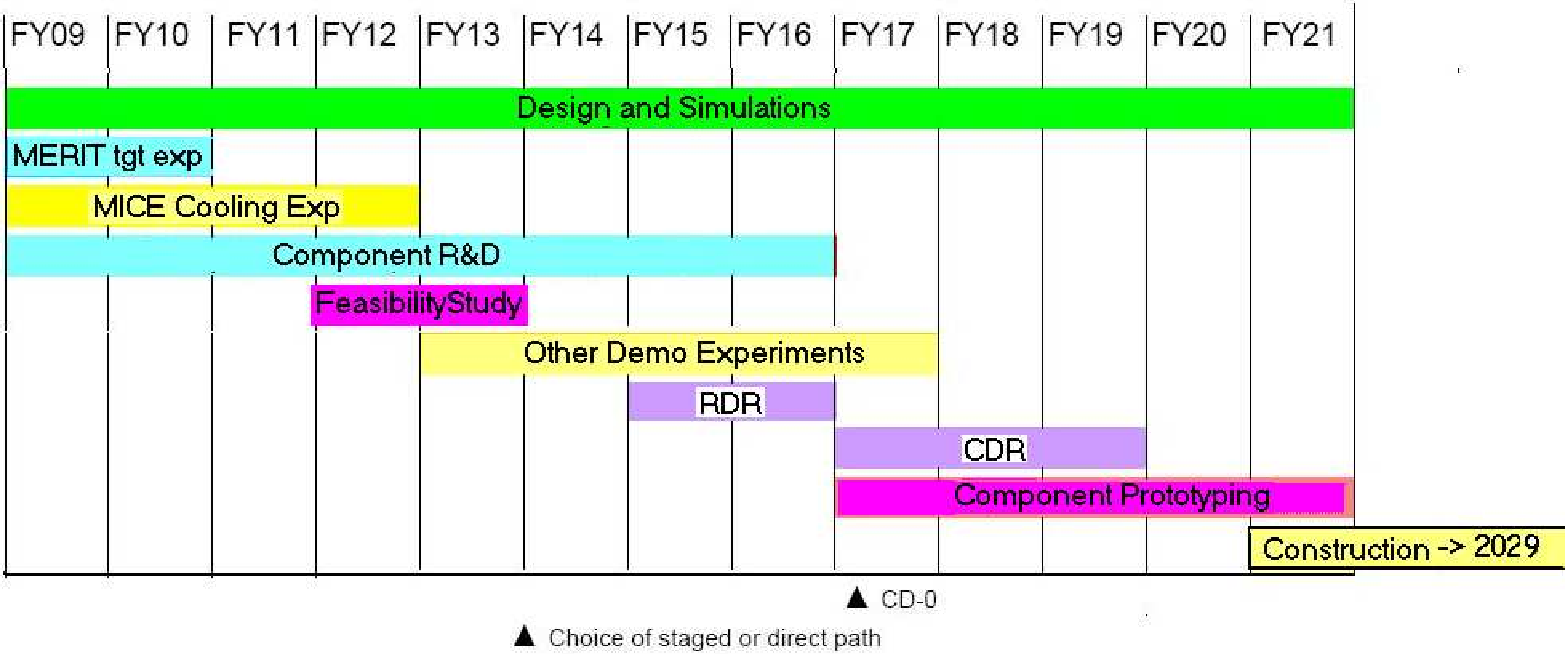


Solutions under study

1. Improved surface preparation e.g. ALD (ongoing) (J Norem)
2. HP Gas filled cavities (in beam in few months) (R Johnson)
3. Magnetic insulation: B $\perp$ E (in 1 month) (Palmer, Stratakis)
4. Use of Beryllium (button in a few months) (Palmer Stratakis)



R&D plan submitted to DoE



8	11	13	20	25	25	25	35	40	40	R&D Funds M$/year

Delayed 1 year from P5 presentation

Conclusion

- Muon Colliders have significant advantages vs. $e^+ - e^-$ linear colliders
  - smaller footprint
  - easier tolerances
- But also challenges
  - neutrino radiation
  - new technologies for ionization cooling
  - decay electron backgrounds in detector
- It also needs a challenging proton driver
  - 4-5 MW at 8 GeV
  - few very intense (170-280 Tp) bunches
  - compressed to short pulses (σ_t=3 ns)
- Full 8 GeV SC linac would be a good candidate
  - Solutions using a lower energy SC linac need study
- R&D started on target, cooling, HTS solenoids, rf
  - Problem with rf in magnetic fields being addressed