Muon Collider Progress

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PAC09

5/5/09

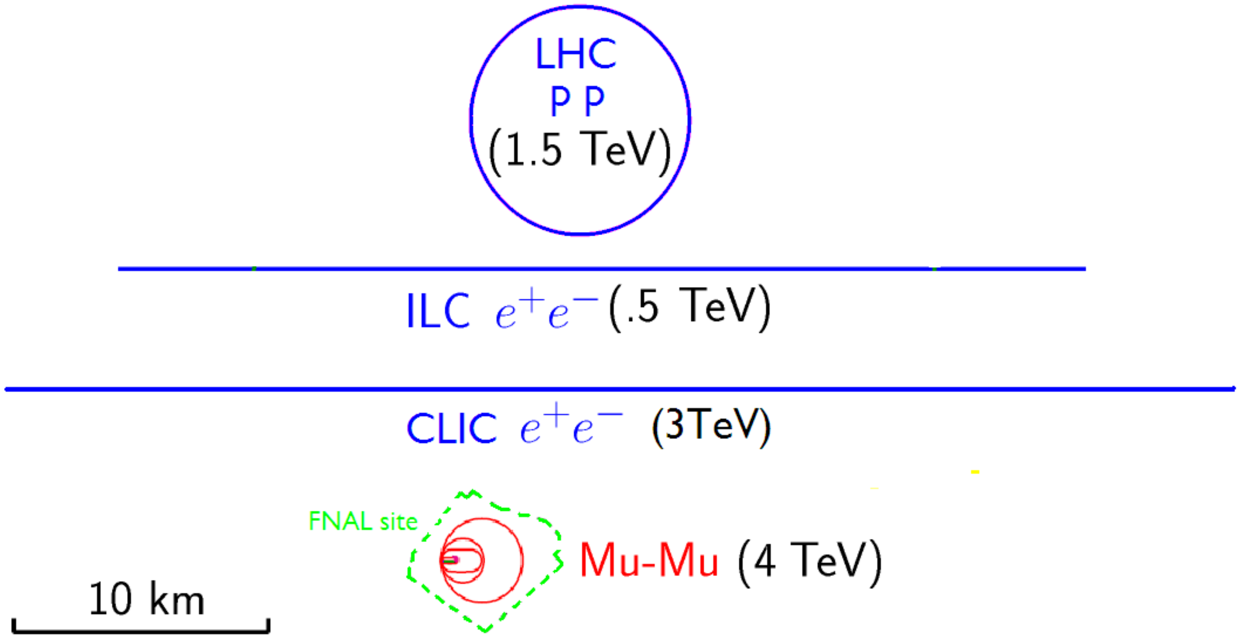
Vancouver

- Driver
- Target & capture
- Acceleration
- Collider ring ***
- Matching between 50T solenoid cooling ***
- rf breakdown problem for 6D cooling
  - ALD or other surface preparation
  - Magnetic insulation ***
  - High pressure gas ***
  - Cold cavities ***
- Conclusion

*** New results since last year

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

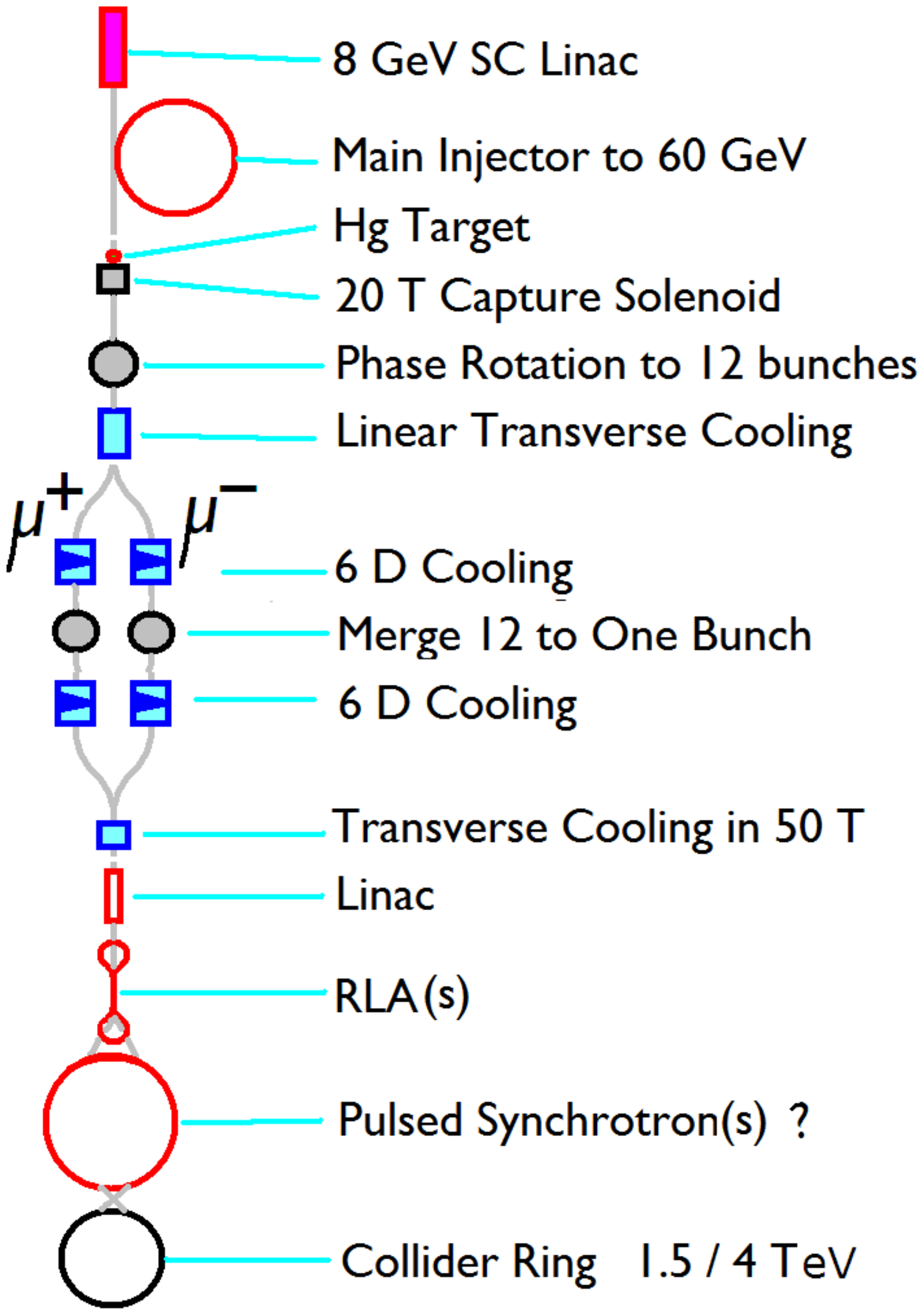


Schematic

$$\mathcal{L} = n_{\rm turns}\, f_{\rm bunch}\, \frac{N_\mu^2}{4\pi\sigma_\perp^2}$$

$$\Delta\nu \propto \frac{N_\mu}{\epsilon_\perp}$$

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



8 GeV SC Linac

Main Injector to 60 GeV

Hg Target

20 T Capture Solenoid

Phase Rotation to 12 bunches

Linear Transverse Cooling

6 D Cooling

Merge 12 to One Bunch

6 D Cooling

Transverse Cooling in 50 T

Linac

RLA(s)

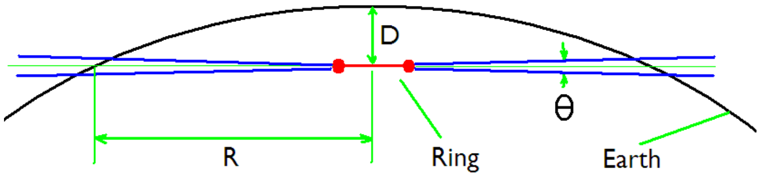
Pulsed Synchrotron(s) ?

Collider Ring 1.5 / 4 TeV

Collider Parameters

C of m Energy	1.5	4	TeV
Luminosity	1	4	10^{34} cm^{2}sec^{-1}
Muons/bunch	2	2	10^{12}
Ring circumference	3	8.1	km
Beta at IP $= \sigma_z$	10	3	mm
rms momentum spread	0.1	0.12	%
Required depth for ν rad	13	135	m
Repetition Rate	12	6	Hz
Proton Driver power	≈4	≈ 1.8	MW
Muon Trans Emittance	25	25	pi mm mrad
Muon Long Emittance	72,000	72,000	pi mm mrad

- Emittance and bunch intensity requirement same for both examples
- Luminosities are comparable to CLIC's
- Depth for ν radiation keeps off site dose < 1 mrem/year



$$\text{Radiation} \propto \frac{\mathcal{L}\ \beta_\perp}{\Delta\nu\ \ <\mathrm{B}>}\ \frac{\gamma^2}{D}$$

Proton driver

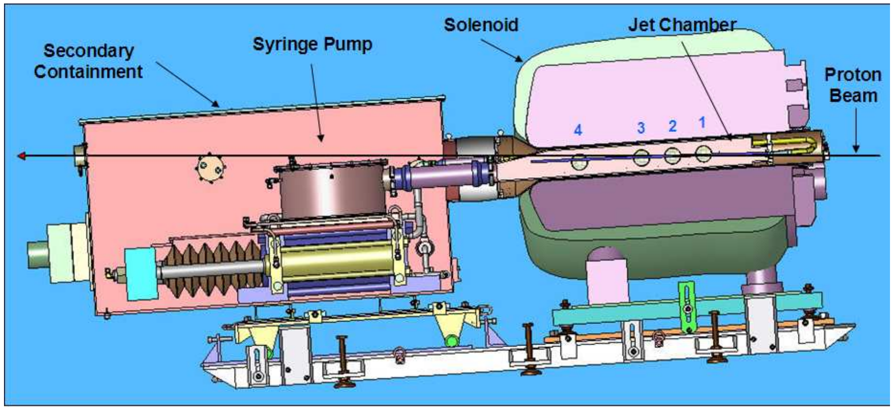
- Project X (8 GeV H^- linac),
  - Accumulation in the Re-cycler
  - Acceleration to 56 GeV in the Main Injector
  - Stack and re-bunch in new ring
  - 1.7 x 7 = 12 Hz x 40 Tp = 4 MW
- Alternatives
  - Doing it all at 8 GeV
  - Sequence of synchrotrons

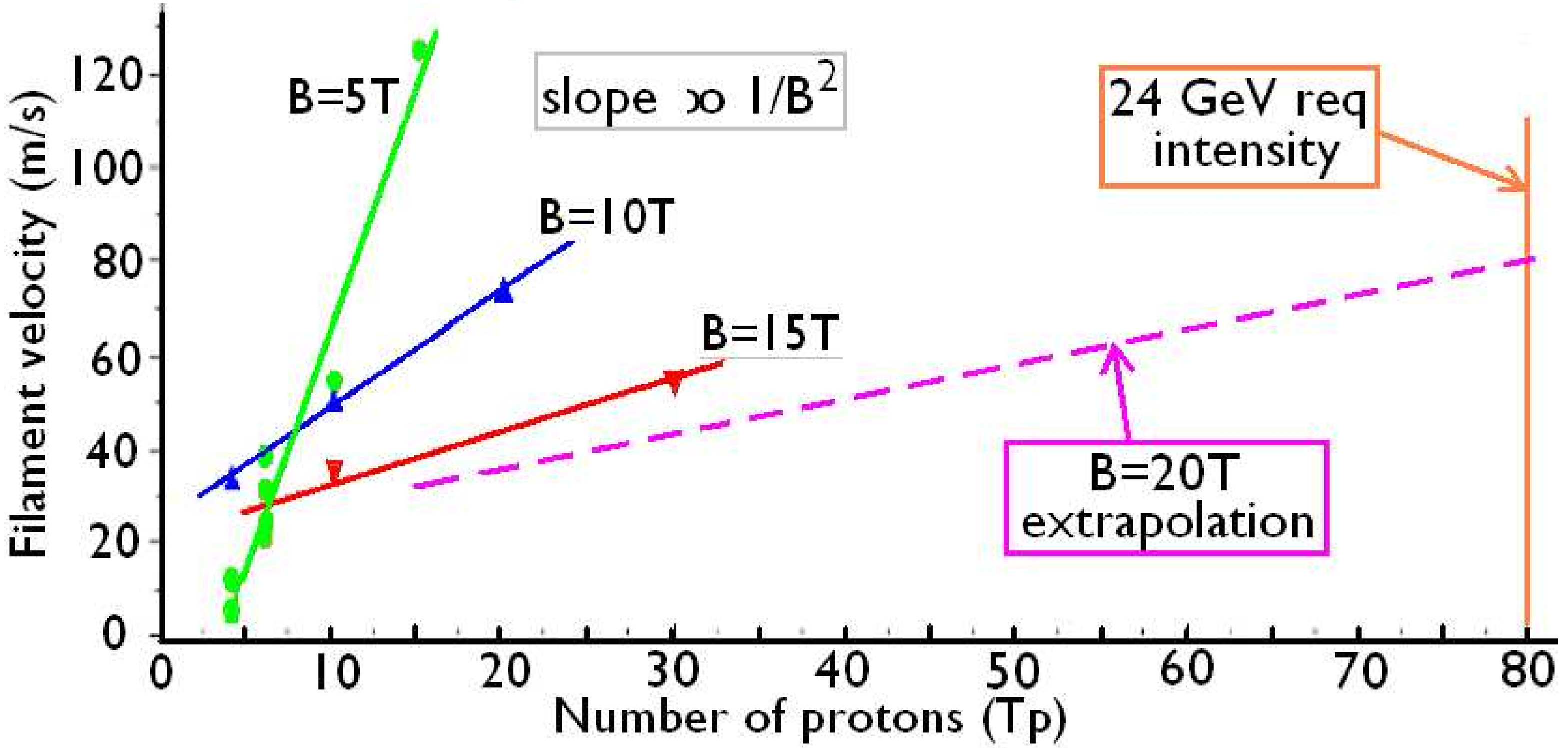
Target & Capture

- Mercury Jet Target
- 20 T capture
- Adiabatic taper to 2 T
- MERIT Experiment at CERN H. Kirk (BNL) &K. McDonald
  - No problems seen up to 30 Tp
  - (cf 40 Tp for 56 GeV $\approx$ 300 Tp for 8 GeV)

MERIT Experiment at CERN

- 15 T pulsed magnet
- 1 cm rad mercury jet
- Up to 30 Tp at 24 GeV
- Magnet field lowers splash velocities

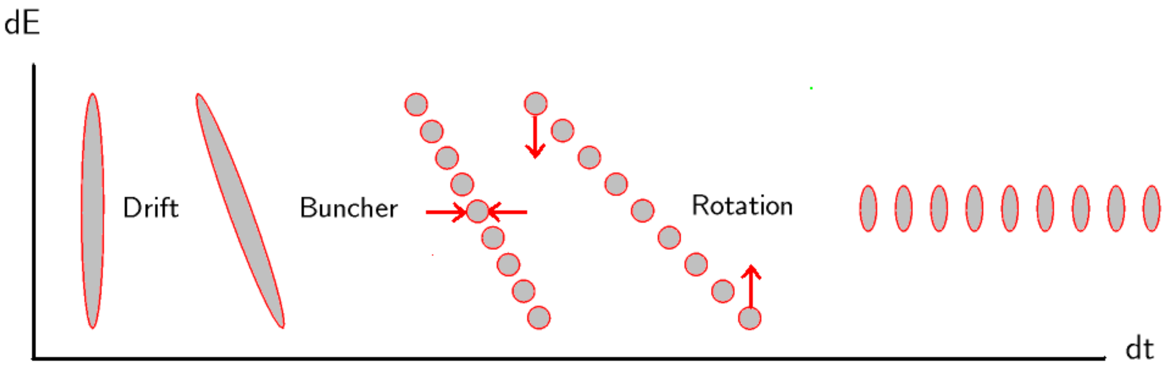




Extrapolation to Collider parameters looks ok
no current proton source intense enough to test

Phase Rotation

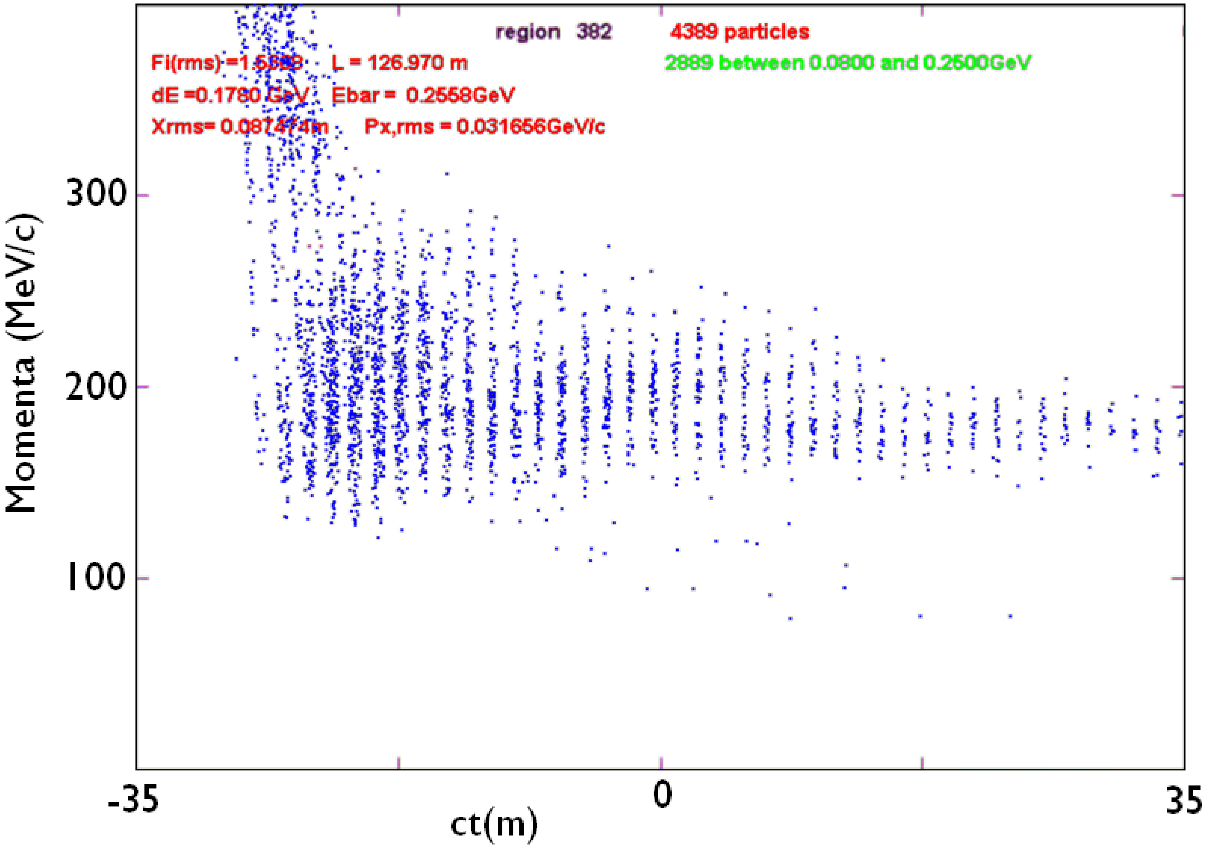
- Neuffer method:
  - Bunch first
  - then Rotate



- New optimization generates 12 vs. 21 bunches makes merging easier

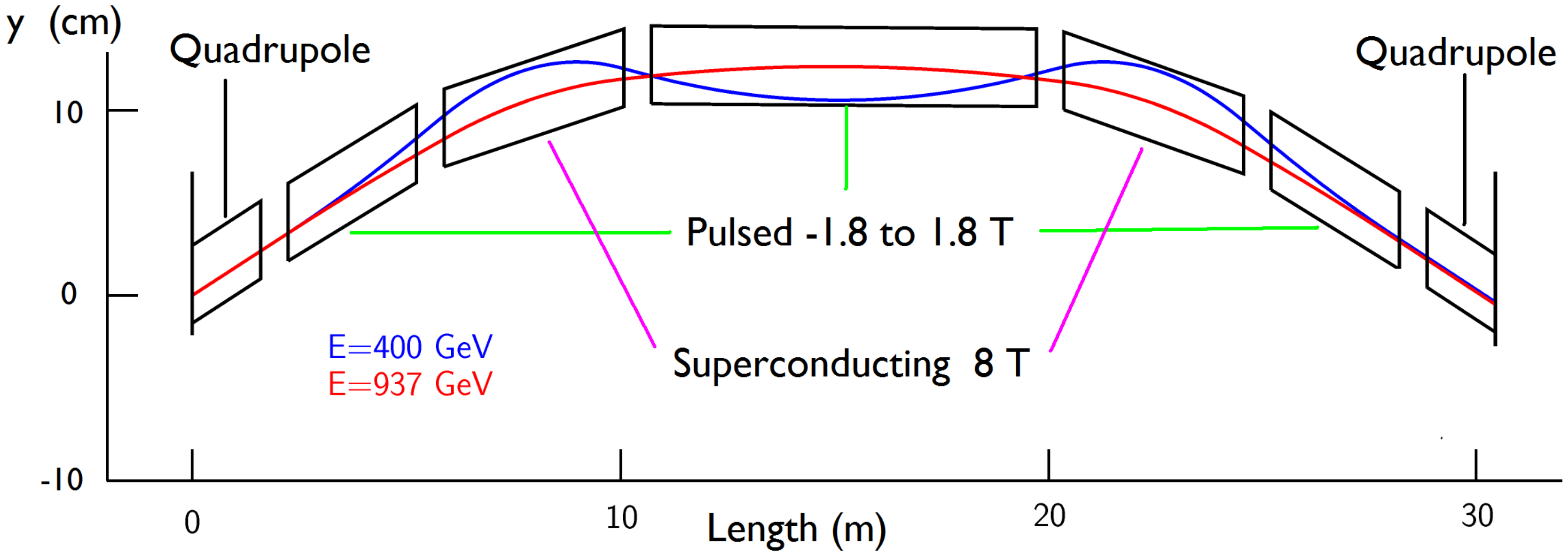
- Simulations assume rf in magnetic fields

Drift (m)	57
Bunch (m)	31
Rotate (m)	36
rf grad (MV/m)	15



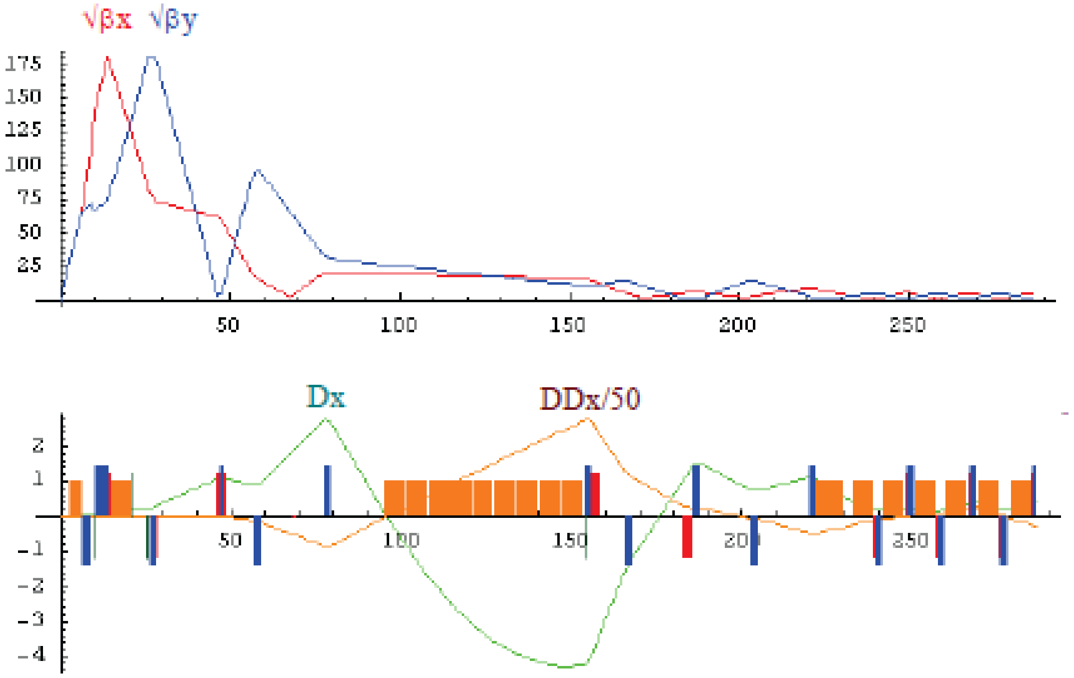
Acceleration

- Sufficiently rapid acceleration is straightforward in Linacs and Recirculating linear accelerators (RLAs)
  Using ILC-like 1.3 GHz rf
- Lower cost solution would use Pulsed Synchrotrons
  - Pulsed synchrotron 30 to 400 GeV (in Tevatron tunnel)
  - SC & pulsed magnet synchrotron 400-900 GeV (in Tevatron tunnel)
  - SC & pulsed magnet synchrotron 900-2000 GeV (in new tunnel)



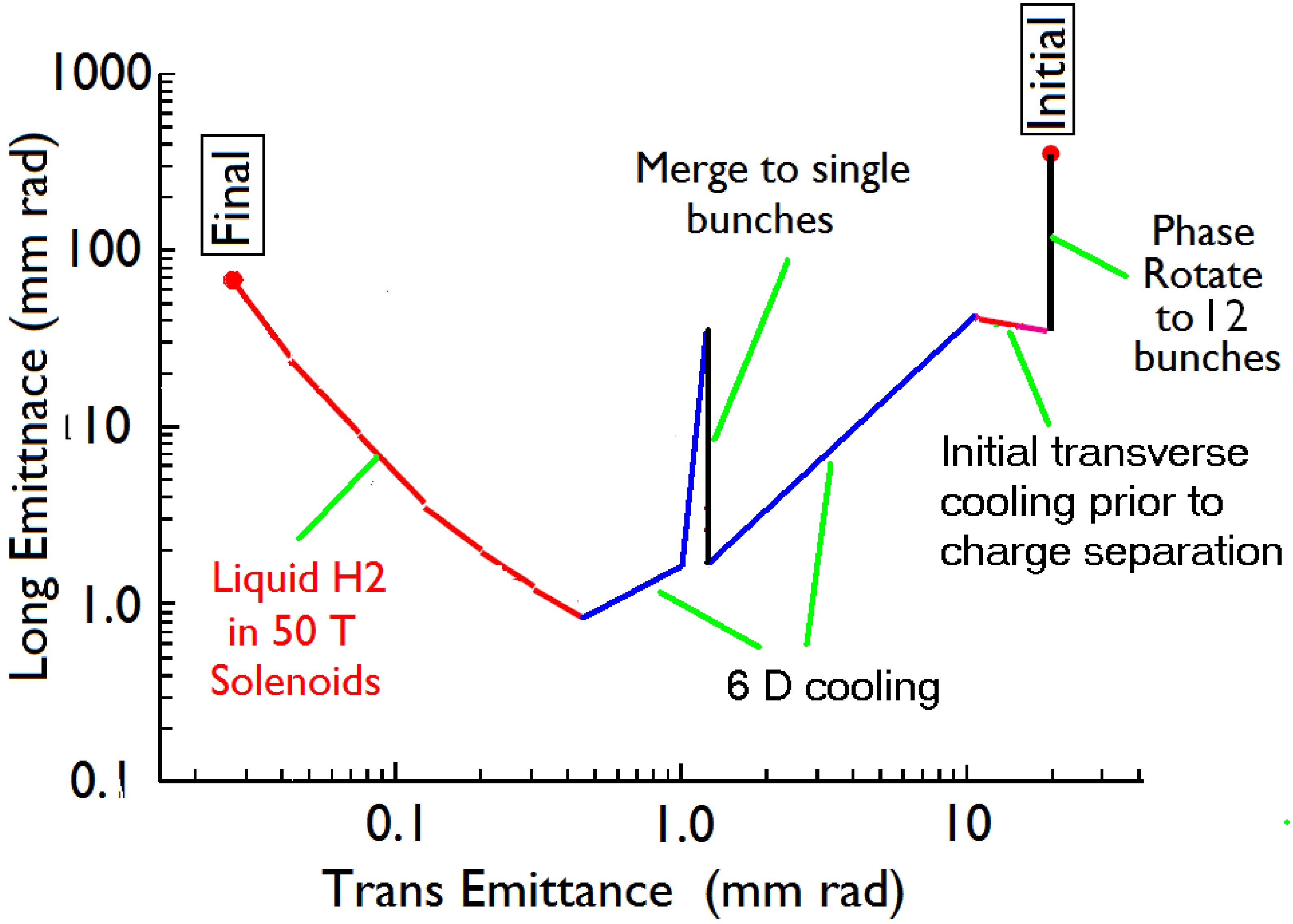
Collider Rings

- 1.5 TeV (c of m) Design by Alexahin & Gianfelice-Wendt
  - Now meets β^* and acceptance requirements ***
  - But early dipole may deflect unacceptable background into detector



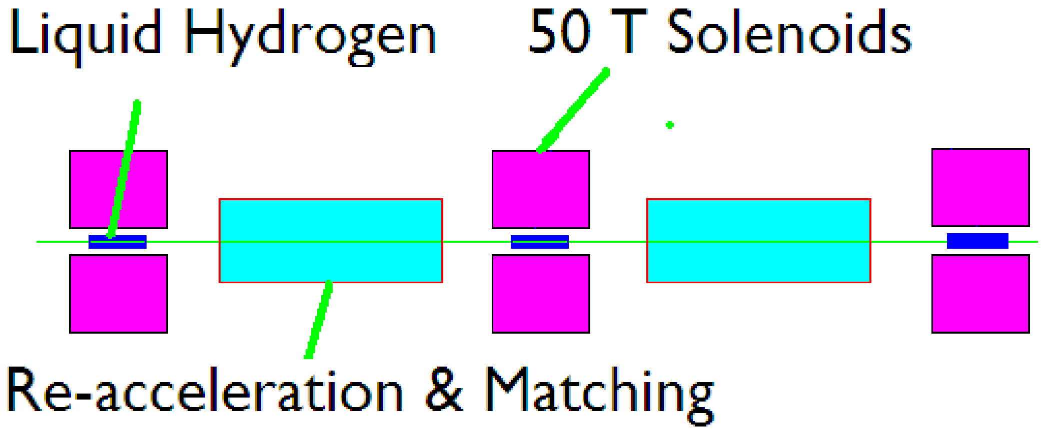
- 4 TeV (c of m) 1996 design by Oide
  - Meets requirements in ideal simulation
  - But is too sensitive to errors to be realistic

Muon Cooling



- All parts simulated as some level

Final Cooling in 50 T Solenoids

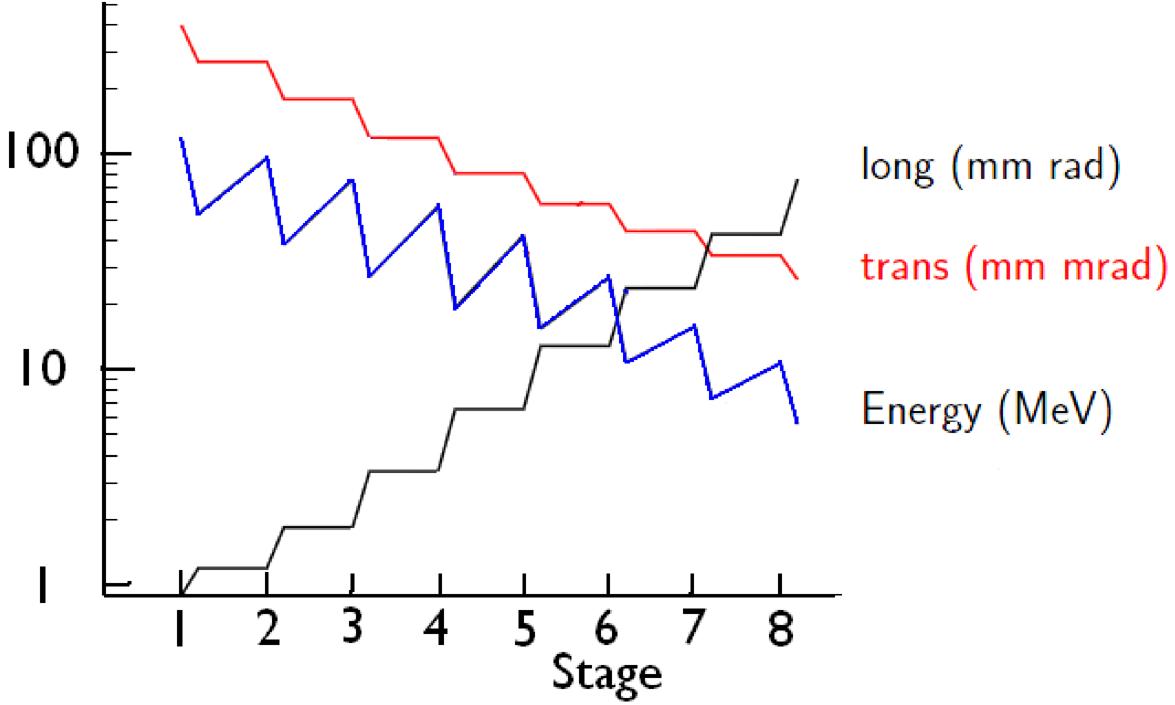


Liquid Hydrogen

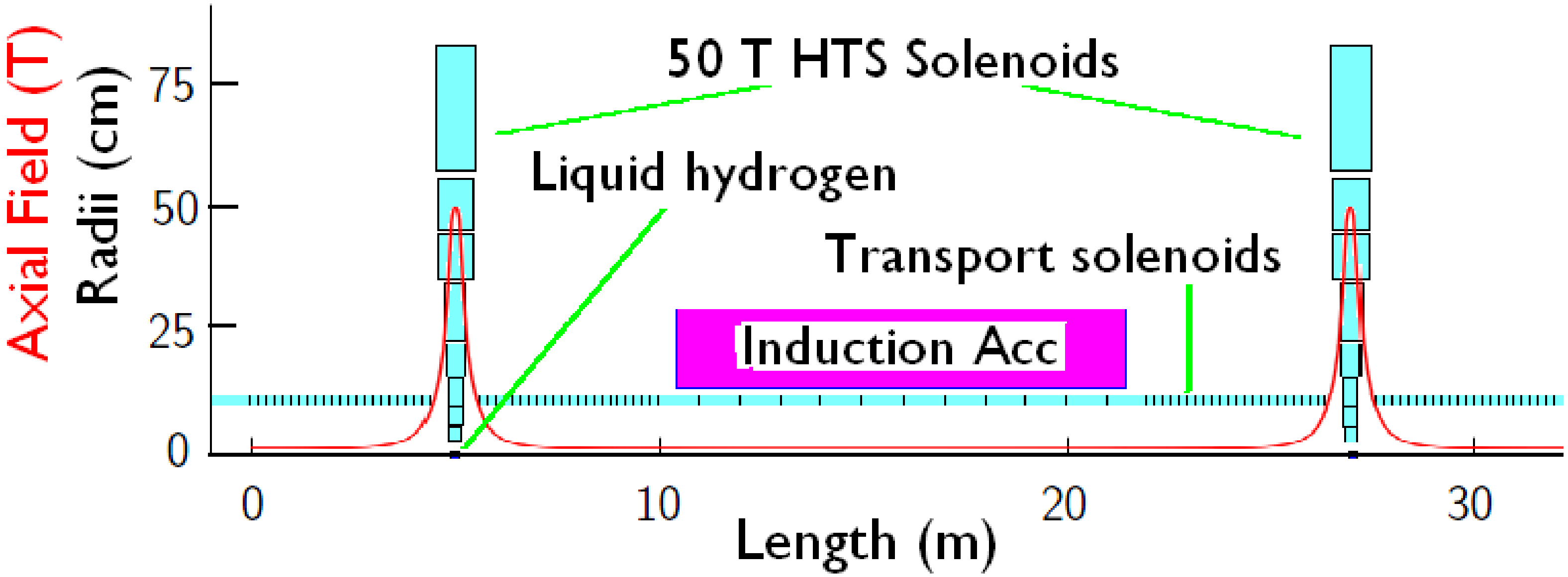
50 T Solenoids

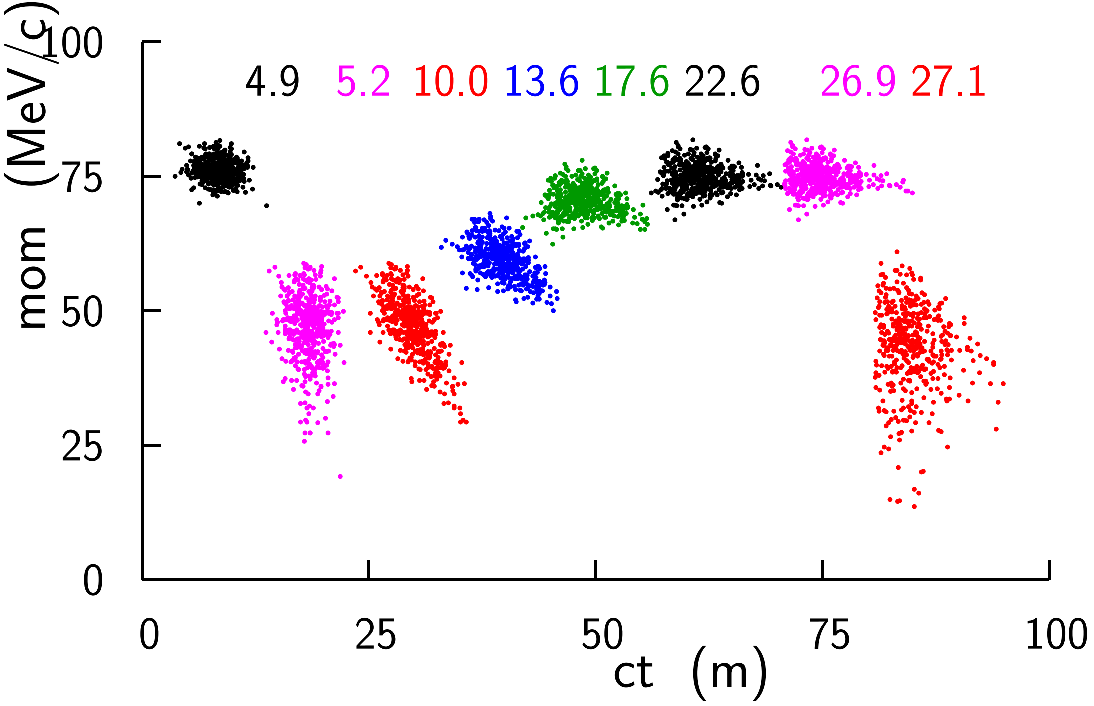
Re-acceleration & Matching

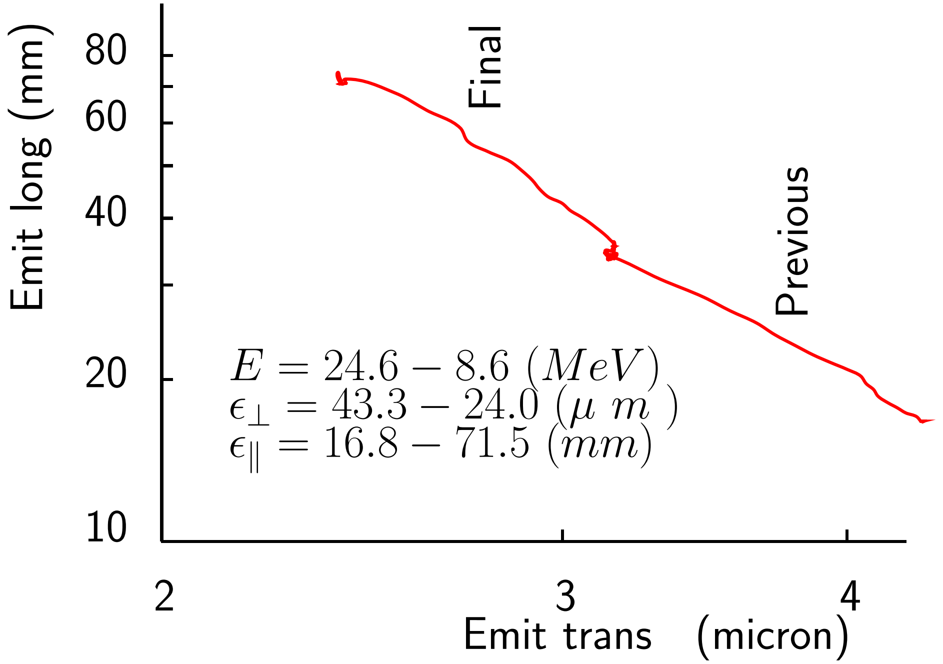
ICOOL simulate all stages, minus matching and re-acceleration



Simulation, including matching, of last two solenoids



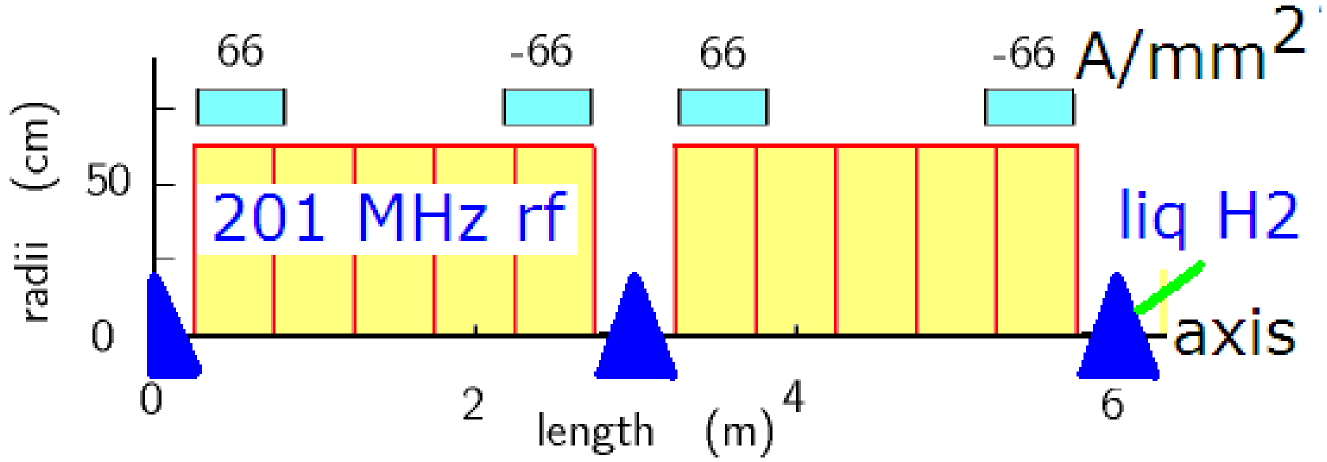




- Little loss in matching
- Transmission 85%

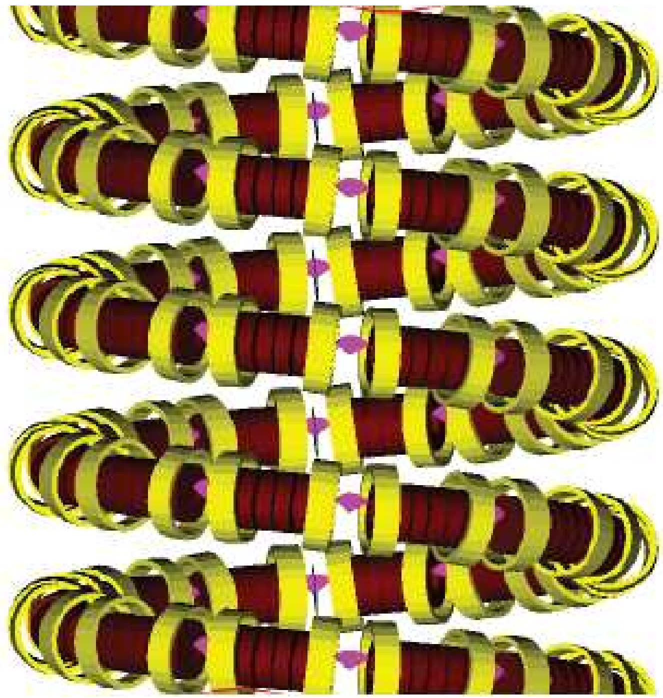
6D cooling in Guggenheim Lattices

Lattice
without
bending



Bending added

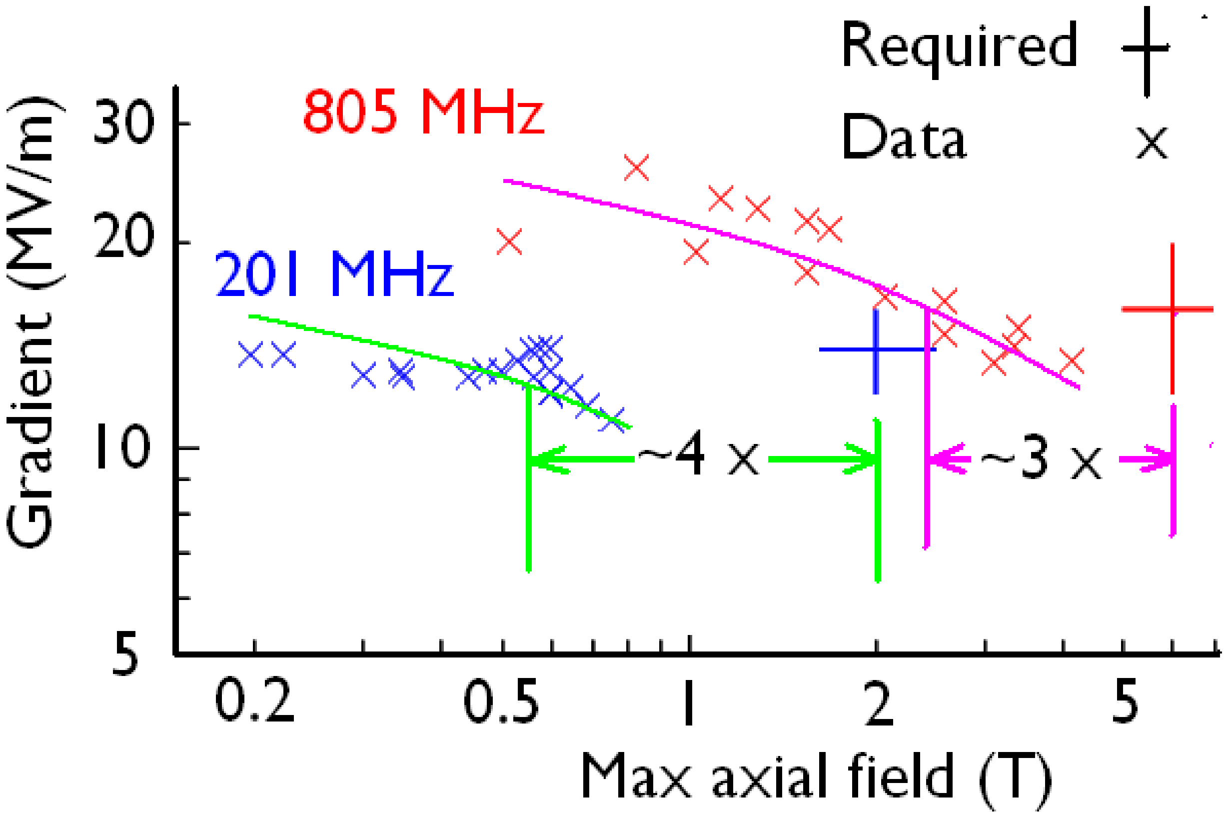
to generate dispersion for 6D-cooling
Guggenheim geometry



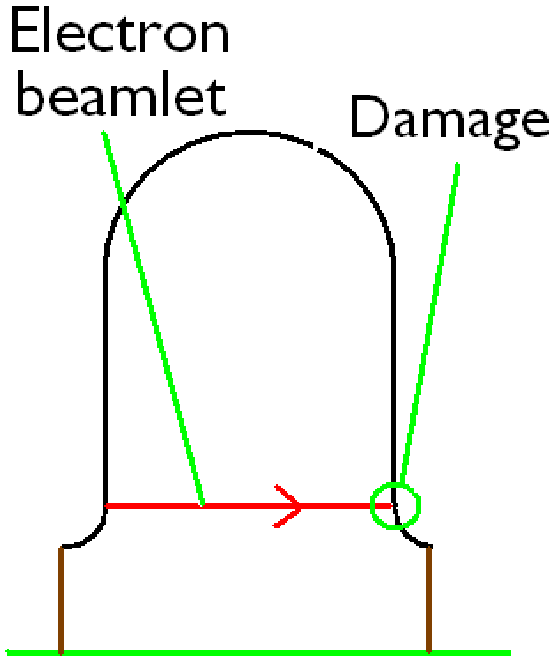
Parameters

Stage	freq (MHz)	Grad MV/m	Mag (T)
Initial	201	12	3
Mid	402	17	6
Final	805	20	12

Experimental results on breakdown in fields



Some problems in this data
Conclusions are preliminary
Lines to guide the eye

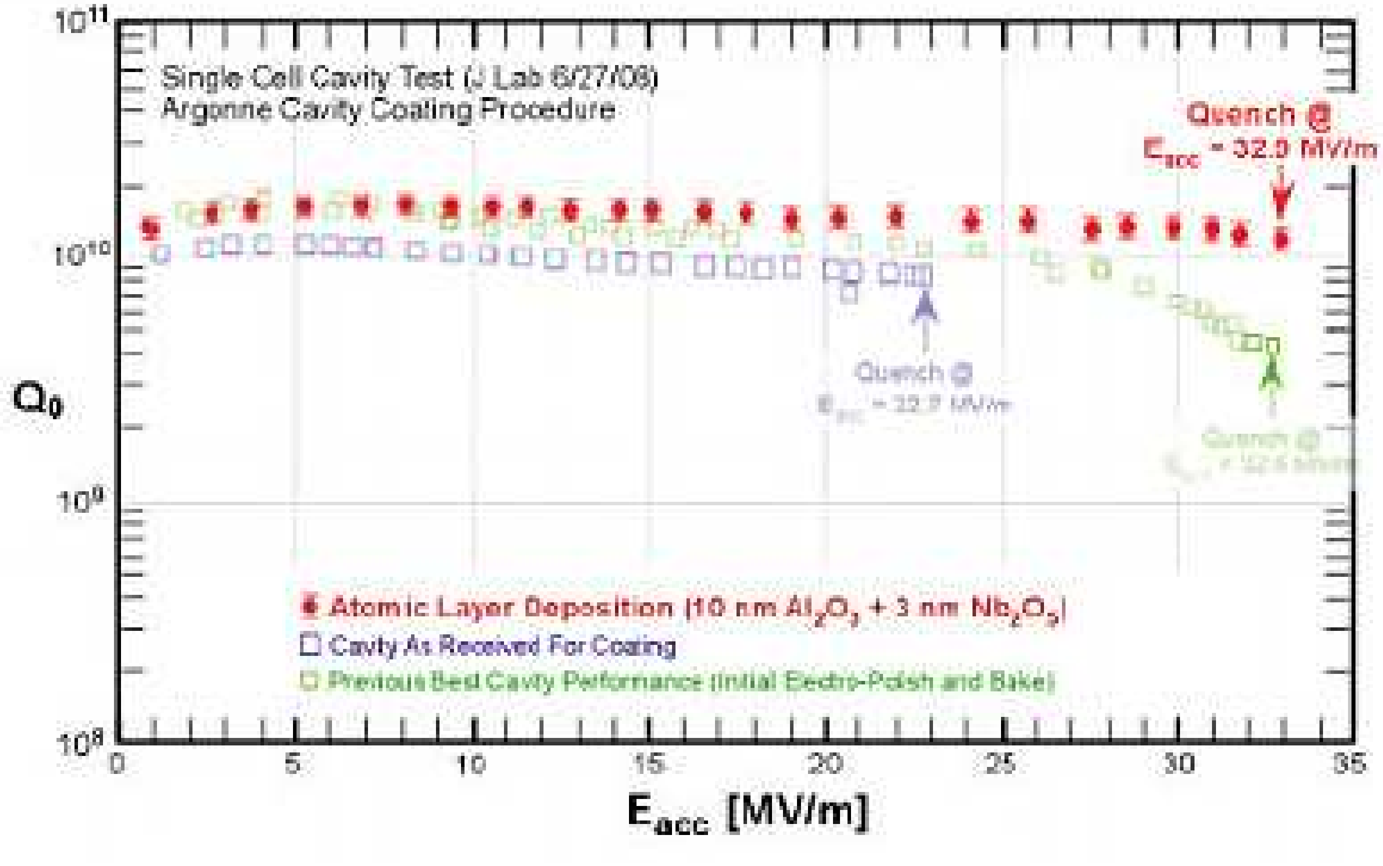


Theory
(Palmer Fernow
Gallardo Li Stratakis)

Possible solutions

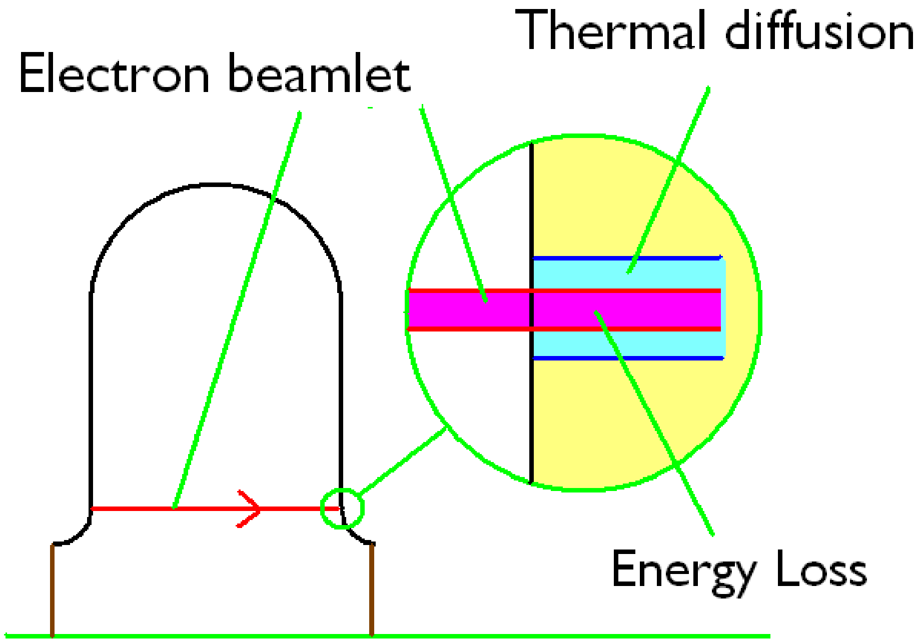
1. ALD, other surface treatment
2. Cold Beryllium, or Al cavities
3. Magnetic Insulation
4. High pressure gas

1) ALD or other surface treatment



- Substantial improvement in super-conducting cavity
- Will it improve magnetic field damage ?

2) Cold Beryllium or Aluminum Cavities

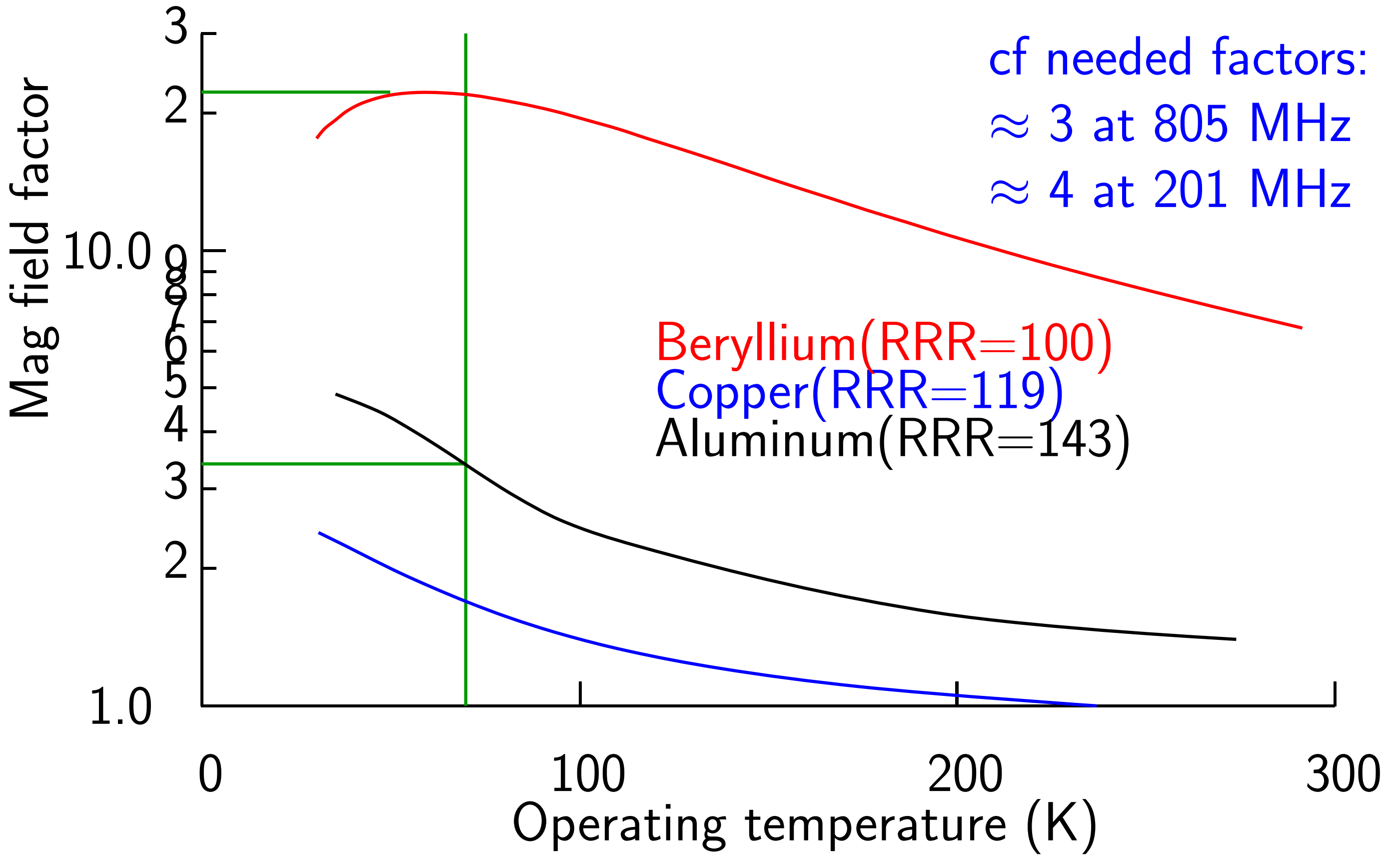


- SLAC observes copper surface damage with cyclical heating of only 45 degrees
- Focused field emission currents should damage with similar temperatures
- Breakdown will follow if the damage is on a high gradient surface
- Strains depend on magnetic field, material properties, and initial temperature

For fixed rf gradient

$$S \propto \int_{t=0}^{\tau} \frac{\alpha(T)\; dE/dx}{B^2\; \rho\; C_p(T)\; \sqrt{\frac{\tau\;\; K(T)}{\rho\;\; C_p(T)}}} dt$$

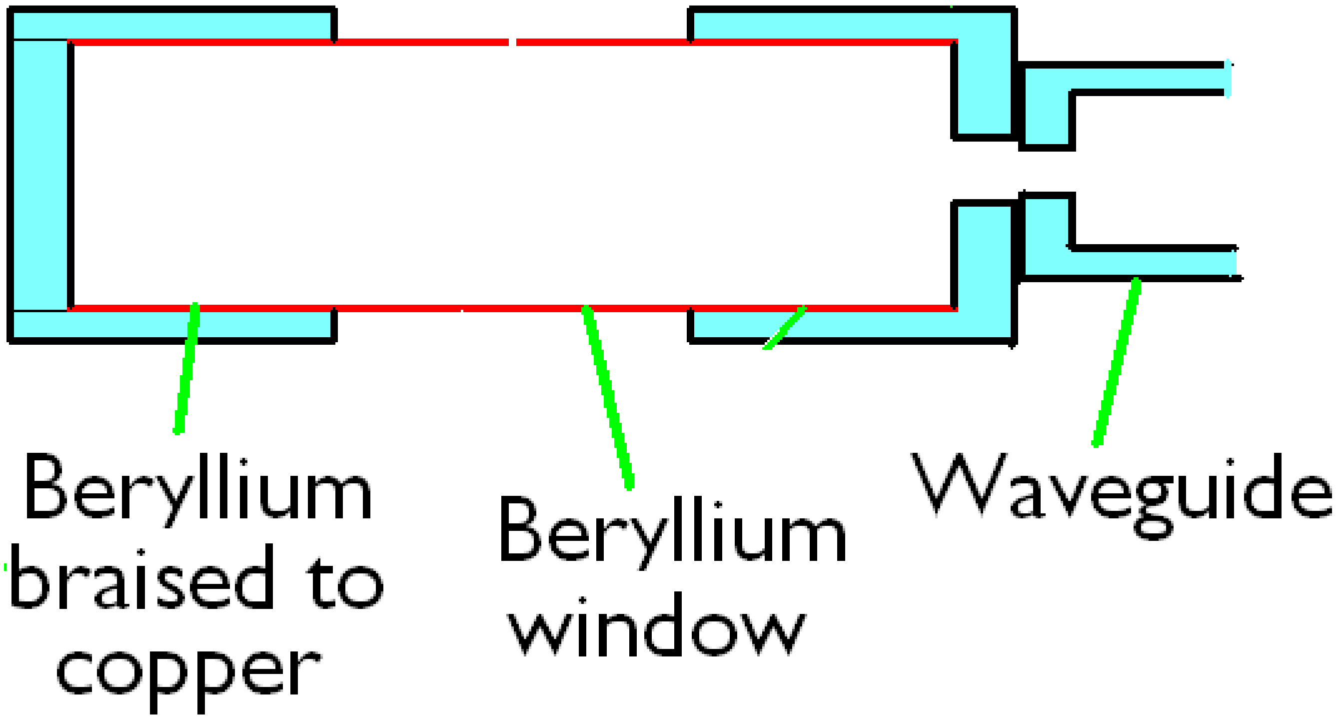
Relative B for same strain



cf needed factors:
$\approx$ 3 at 805 MHz
$\approx$ 4 at 201 MHz

- Cold beryllium gives reduction $B_{damage} \approx 22$ (certainly sufficient)
- Warm beryllium gives reduction $B_{damage} \approx 7$ (probably sufficient)
- Cold aluminum gives reduction $B_{damage} \approx 3$ (possibly sufficient)
- WARNING: Several assumptions in this calculation
  But test of cooled copper cavity will check the hypothesis

Beryllium Cavity using sheet material

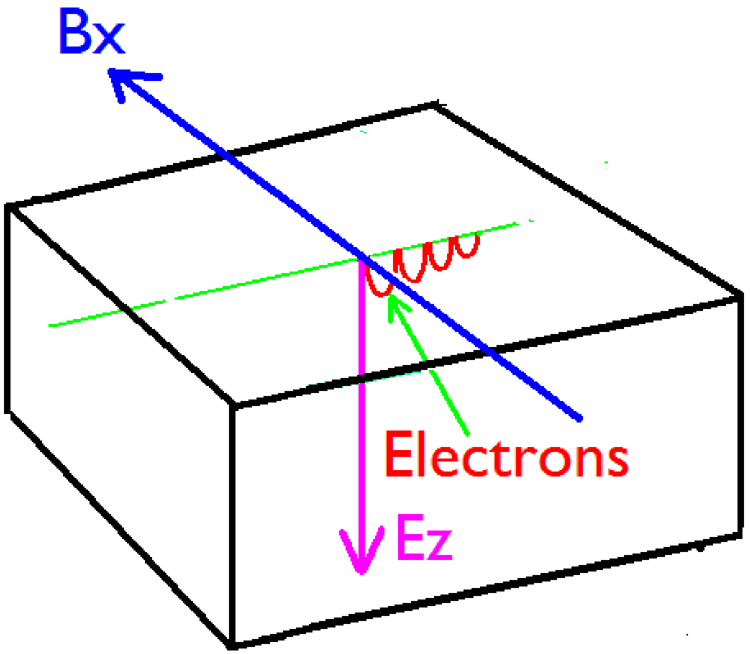


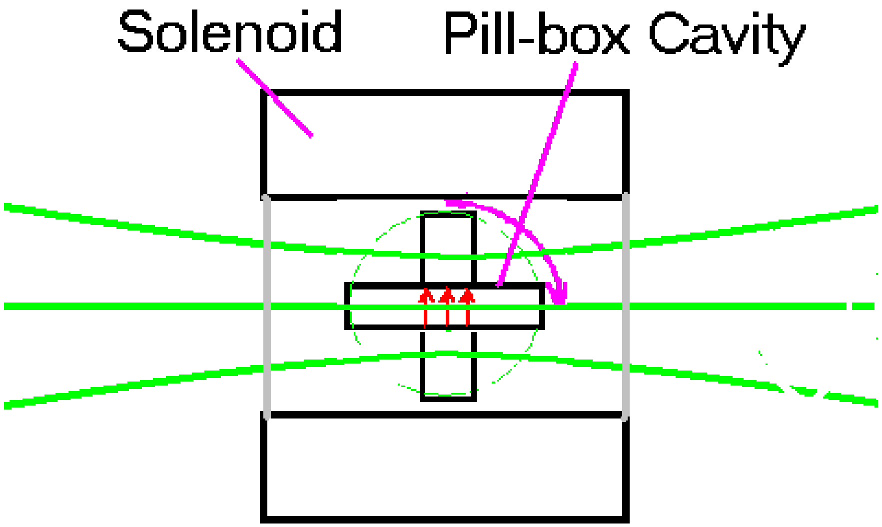
Beryllium can also be deposited on other materials - used at ITR

3) Magnetic Insulation Concept

- If magnetic field lines are parallel to an emitting surface
- All field emitted electrons will return to the surface with low energies and do no damage

A first experiment (Under construction at FNAL)

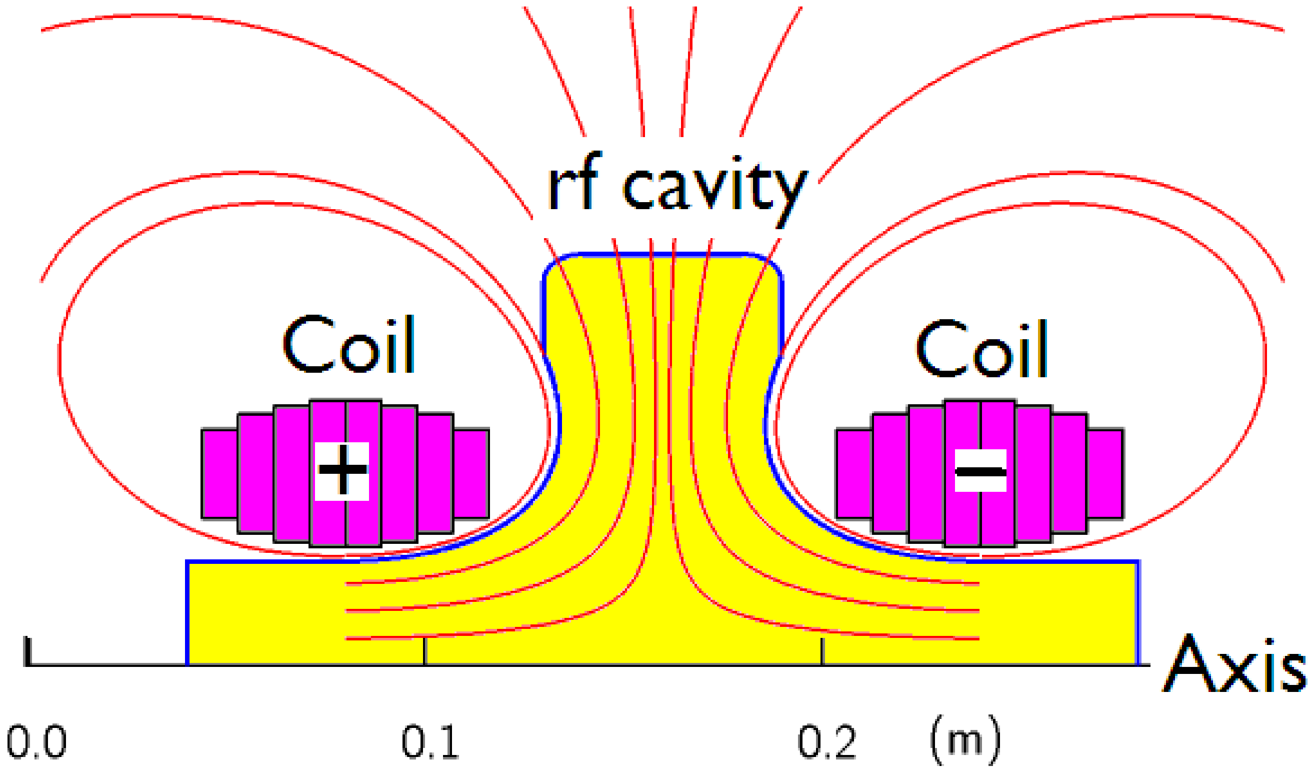




. Simulation

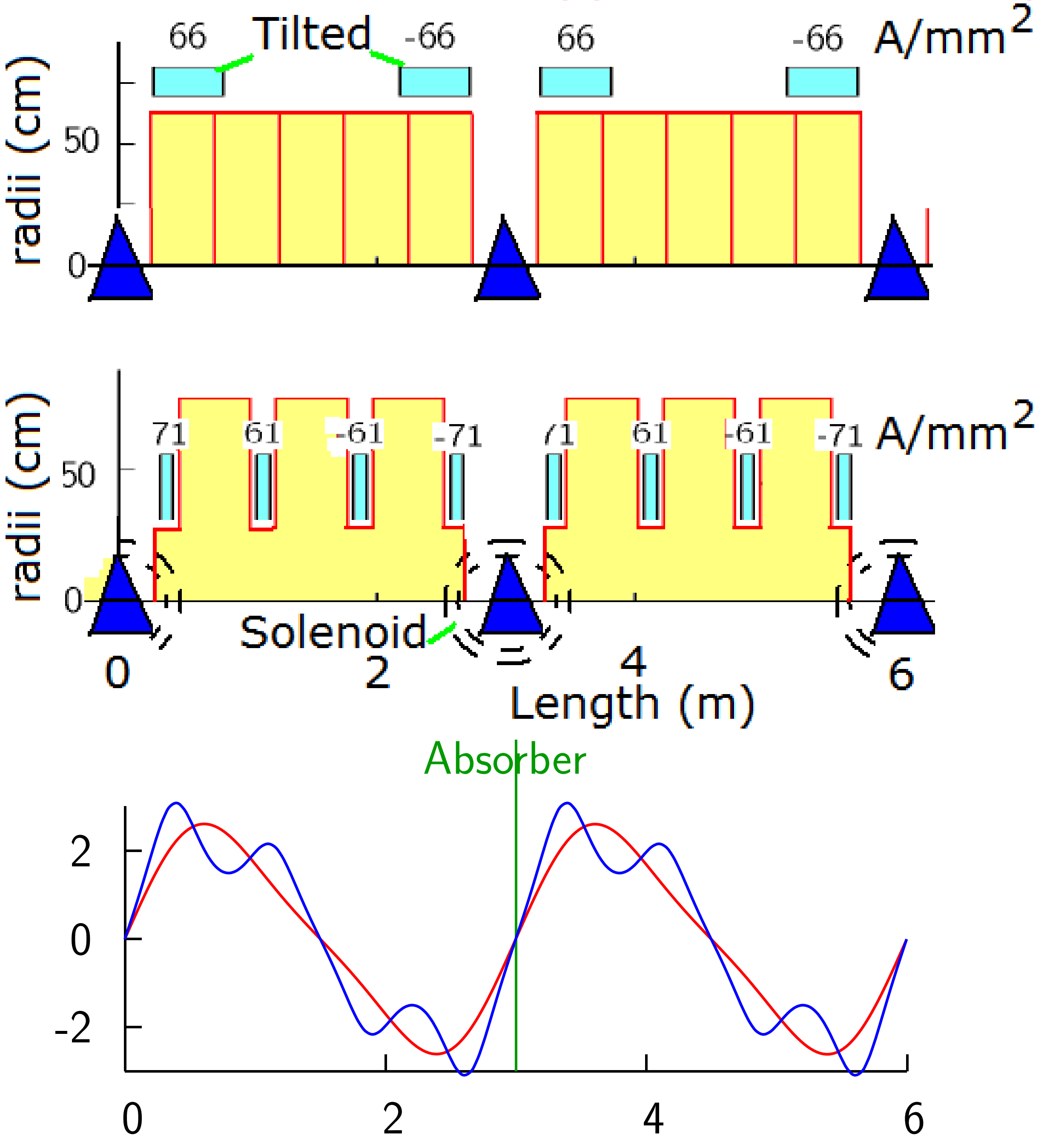
Experiment in 4 T solenoid

Example of Mag. Insulated Accelerating Cavity



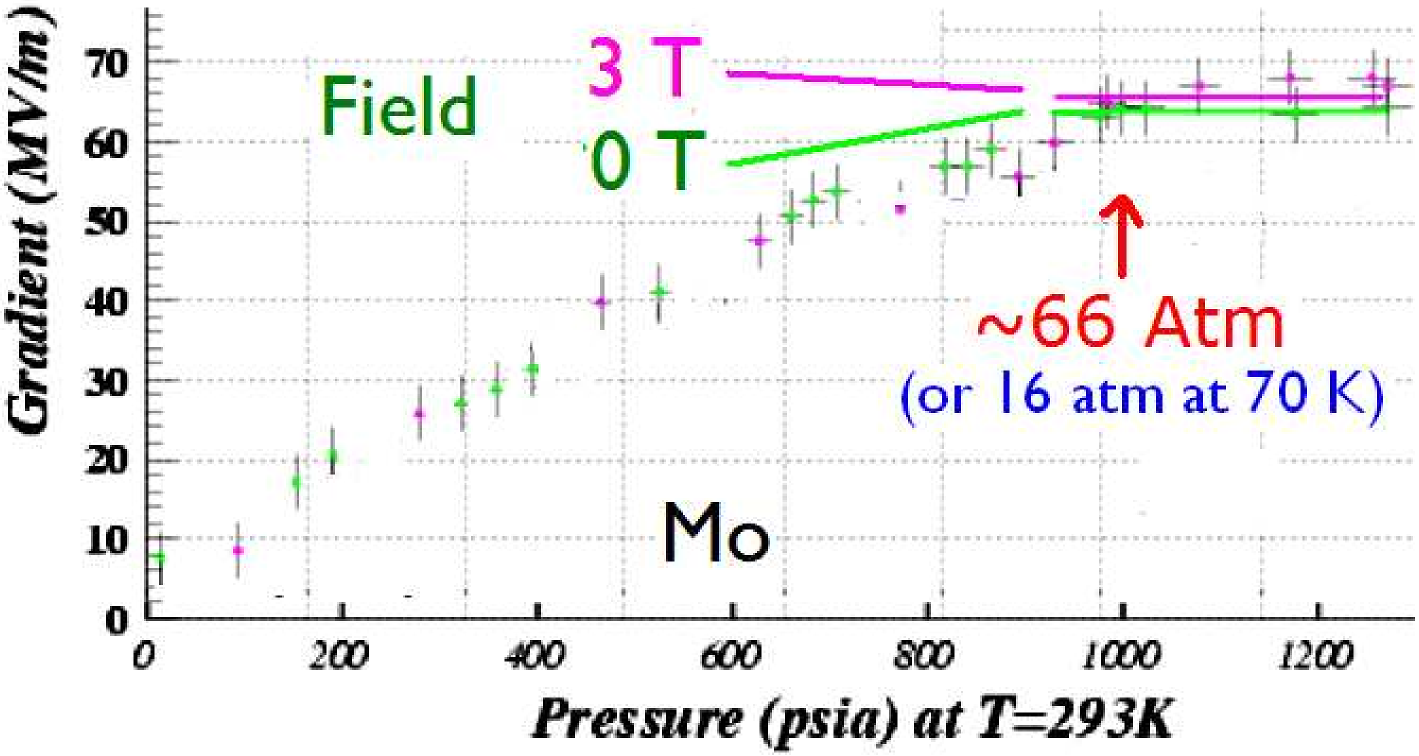
With extra coils, solutions possible without field flip

RFOFO 6D Guggenheim Cooling



- Surface fields now ≈ 2 times acceleration
- Shunt impedance worse
- Higher content of Fourier content in B vs z
- → Greater losses

4) High pressure gas filled rf (Mucool & Muons Inc)

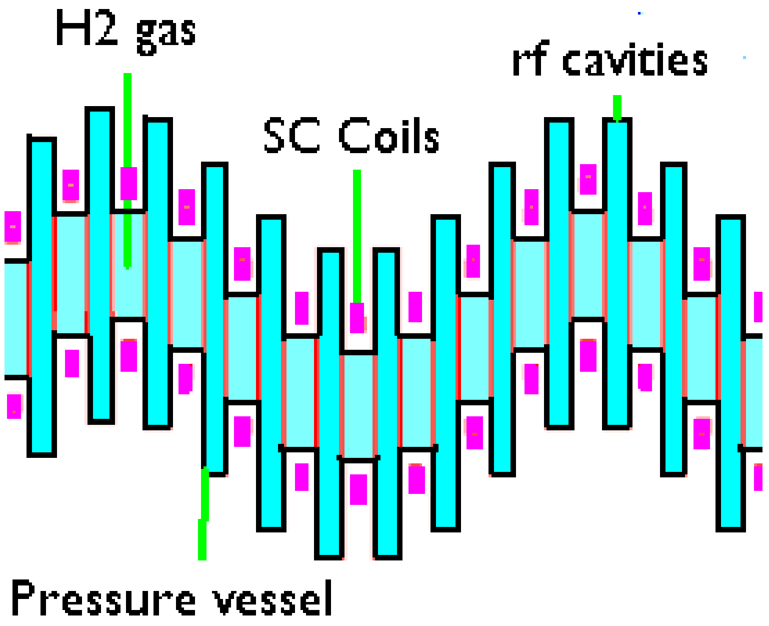


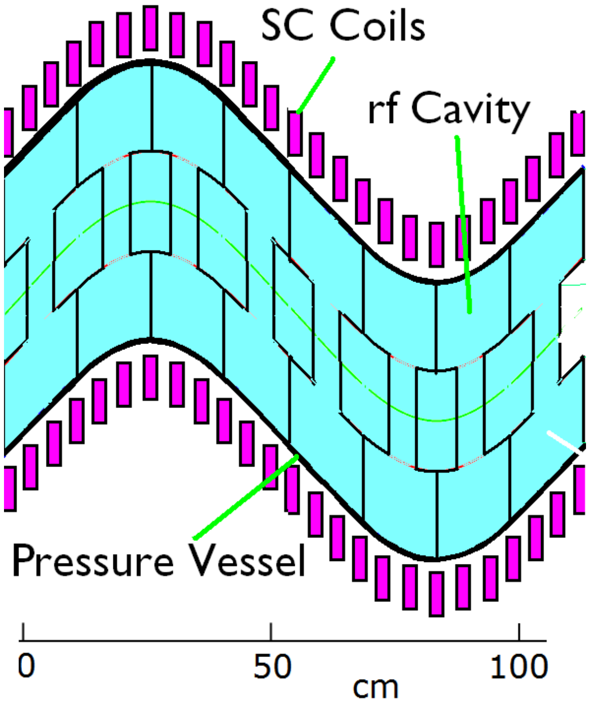
- High pressure hydrogen gas suppresses breakdown
- And can be used as primary absorber
- Lattices must have low $\beta_\perp$ everywhere
- Emittance exchange using LiH wedges
- Or systems with longer paths for higher momenta (e.g. HCC)

Helical Cooling Channel (HCC)

(MCTF, & Muons Inc)

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

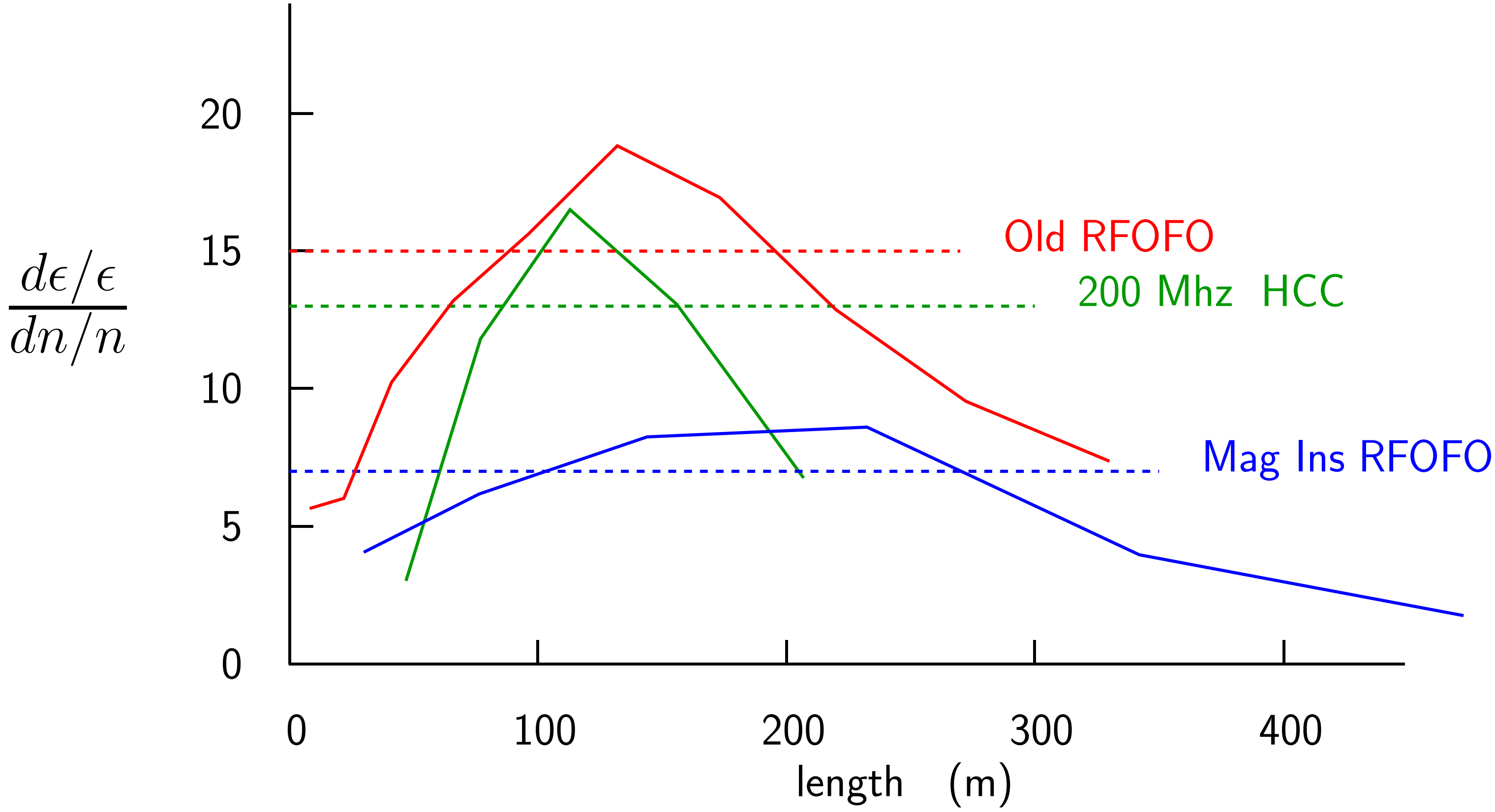




- Required Fields 50-100% higher than in Guggenheim
- But transmission better

- Engineering integration of rf difficult
  Easier with lower average gradient
  but where are the waveguides?
- Possible problem of rf breakdown with intense muon beam transit

ICOOL Simulations



- Mag Insulation transmission is poor
- HCC with ideal fields is better, even with low gradient
- But original RFOFO Guggenheim is best

Conclusion

- All stages for a "baseline" design have been simulated at some level
- 1.5 TeV Collider design now has acceptance for 25 mm mrad emittance
- Example of matching for final 50 T cooling done

- Significant technical problem is rf breakdown in magnetic fields
- But several possible solutions
  - ALD or other surface treatment
  - Cooled Al or Be cavities ← preferred solution
  - Magnetically insulated cavities
  - High pressure hydrogen gas filled cavities