Muon Colliders

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MuTAC

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FNAL

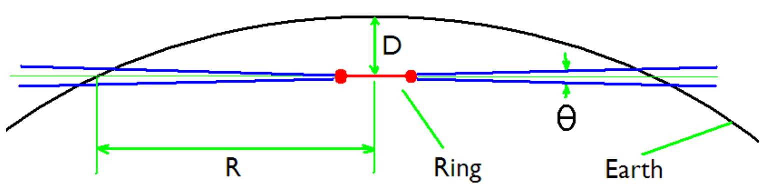
- Driver
- Target & capture
- Acceleration
- Collider ring ***
- Matching between 50T solenoid cooling ***
- rf breakdown problem for 6D cooling
  - Magnetic insulation ***
  - High pressure gas ***
  - Cold cavities ***
- Conclusion

*** New results since last year

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



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

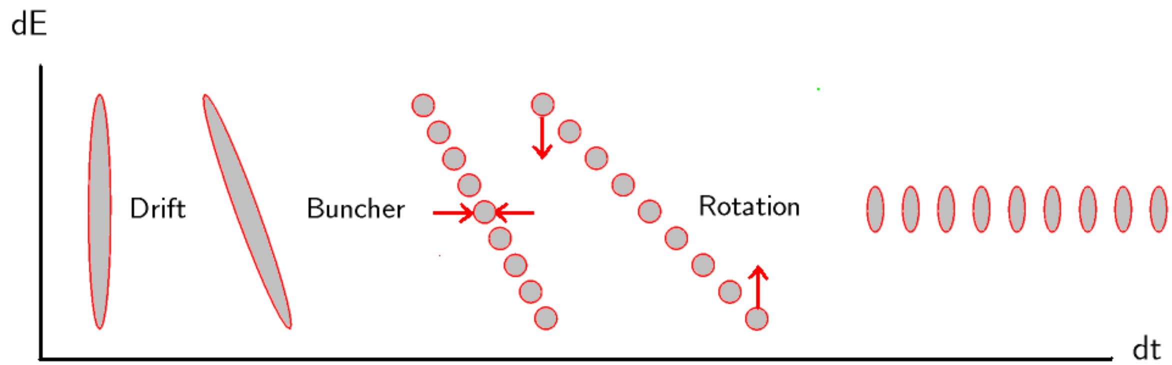
Proton driver

- 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
  - Up to 30 Tp (cf 40 Tp for 56 GeV $\approx$ 300 Tp for 8 GeV)
  - No problems seen

Phase Rotation



- Neuffer method:
  - Bunch first
  - then Rotate
- Frequencies of bunching and rotation must change as function of drift
- Current simulation used rf in magnetic fields ***

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)

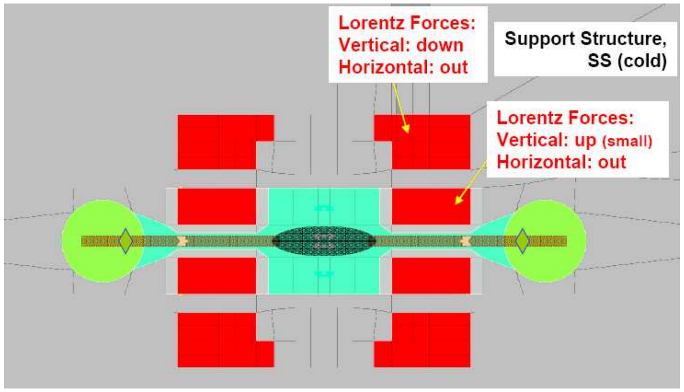
Collider Rings

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

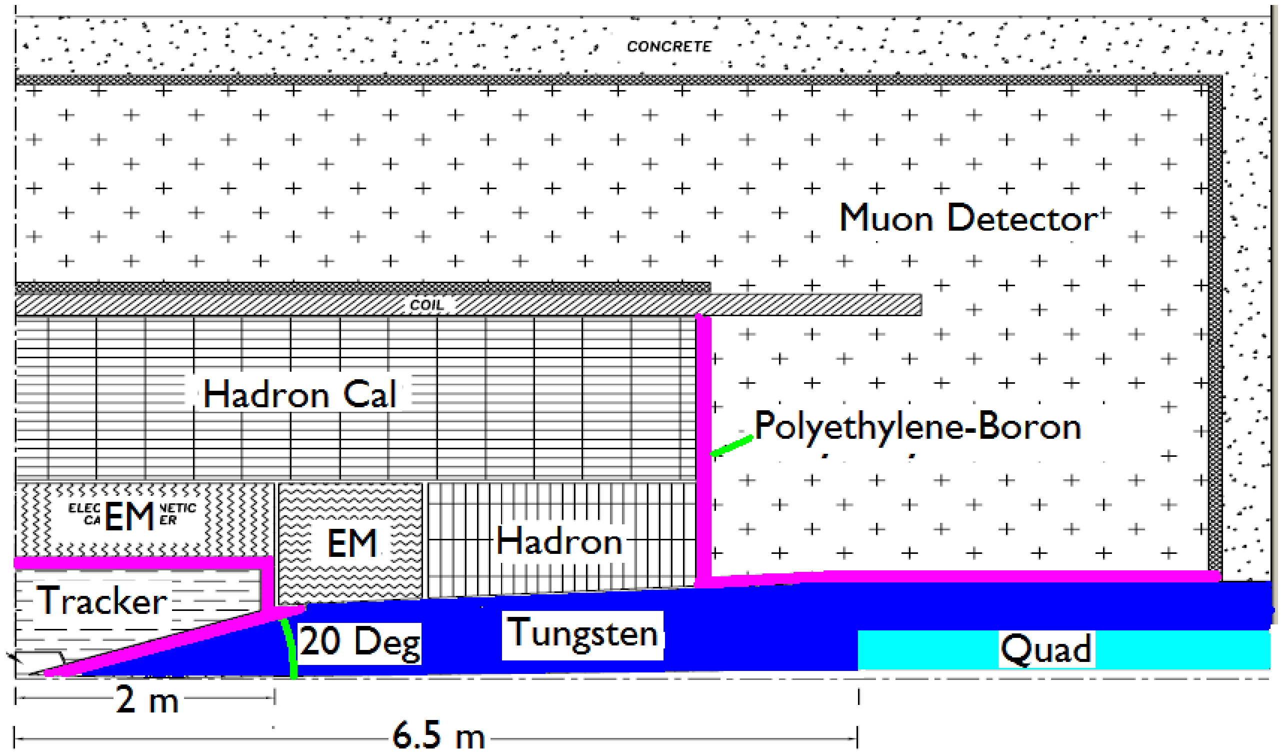
- 4 TeV (c of m) 1996 design by Oide
  - Meets requirements in ideal simulation
  - But is too sensitive to errors to be realistic

Collider Ring Dipole Magnets

- Luminosity $\propto 1/$circumference $\propto < B >$
  So very high field dipoles desirable
- $1/3$ of beam energy given to decay electrons
  Means to absorb their energy required
- 15 T HTS Open Mid-plane dipole good option



Detector   From 1996 Study of 4 TeV Collider

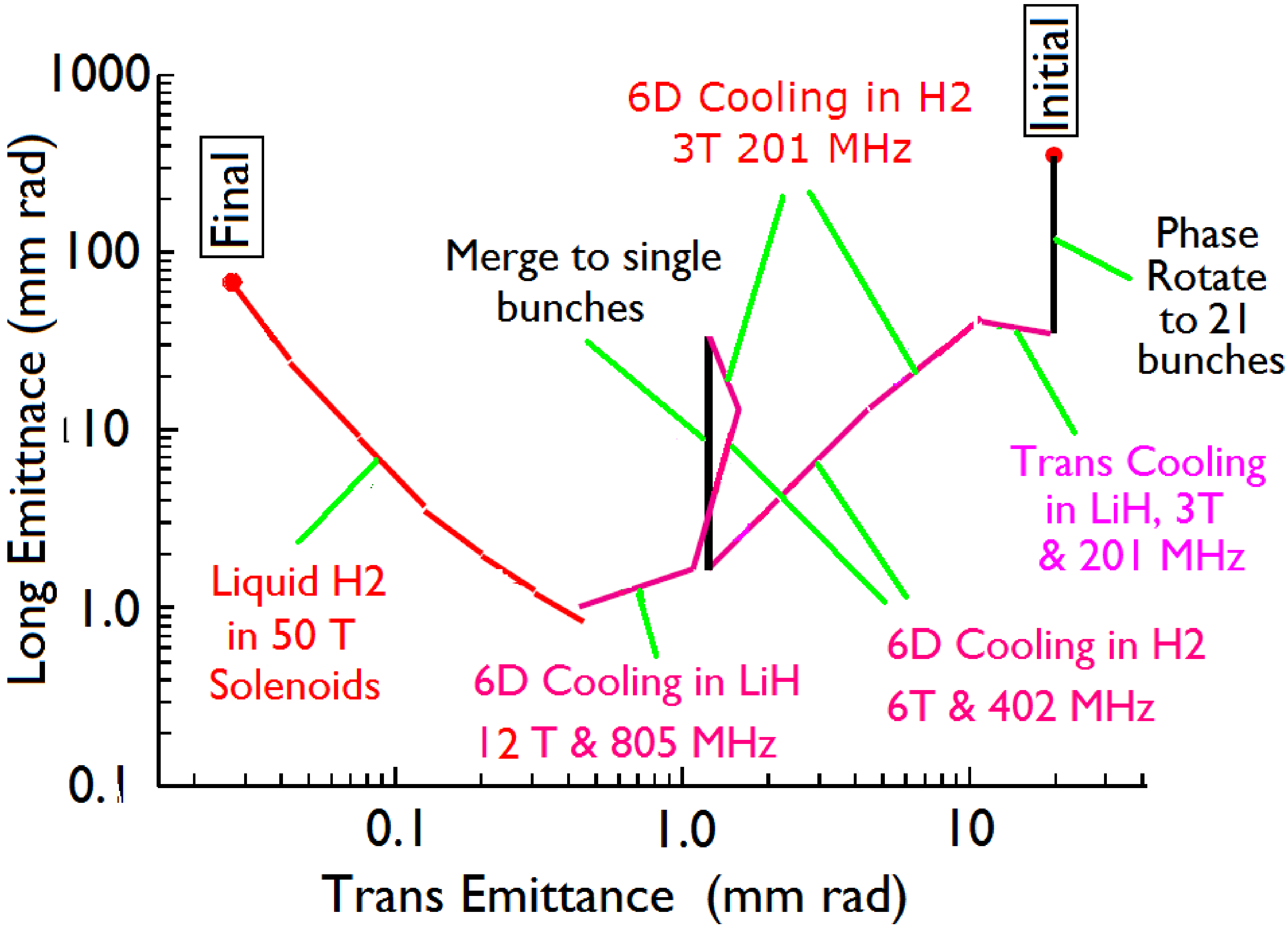


- Sophisticated shielding designed in 1996 4 TeV Study
- GEANT simulations then indicated $\leq\ 10^{34}$ LHC backgrounds

  BUT

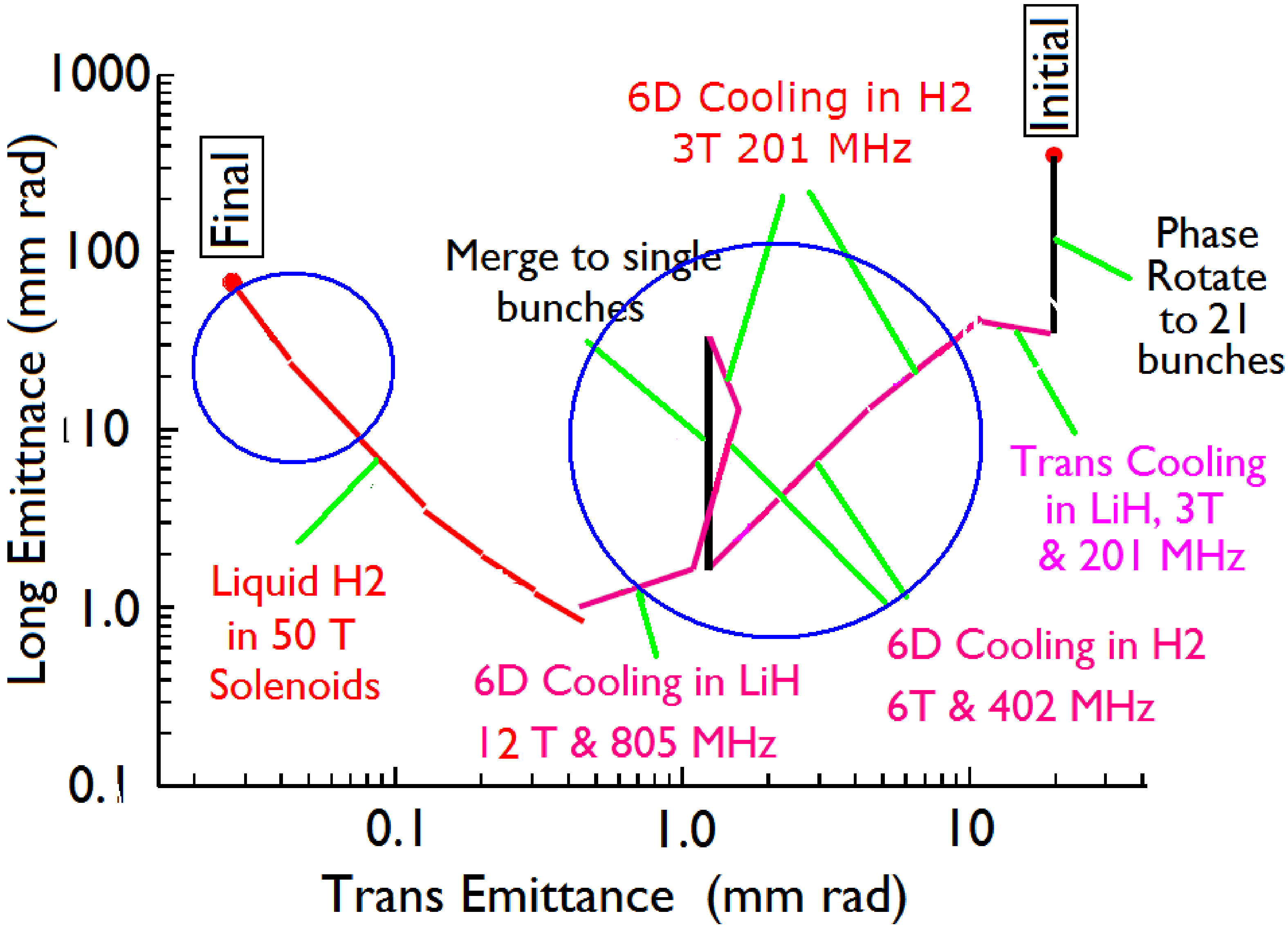
- Tungsten shielding takes up 20 degree cone
- Can we do better? (New effort being organized)

Muon Cooling



- All parts simulated as some level

Muon Cooling



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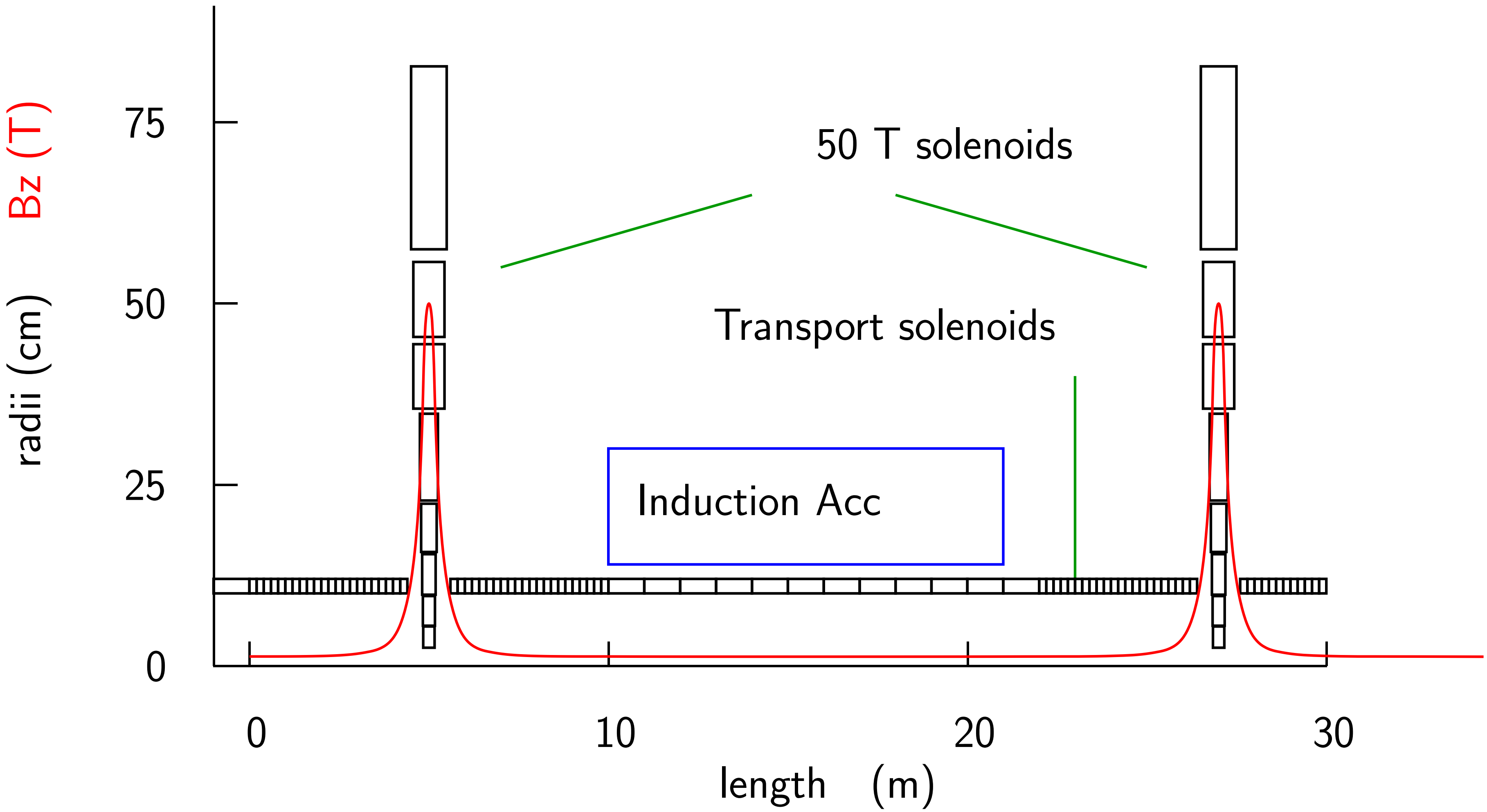
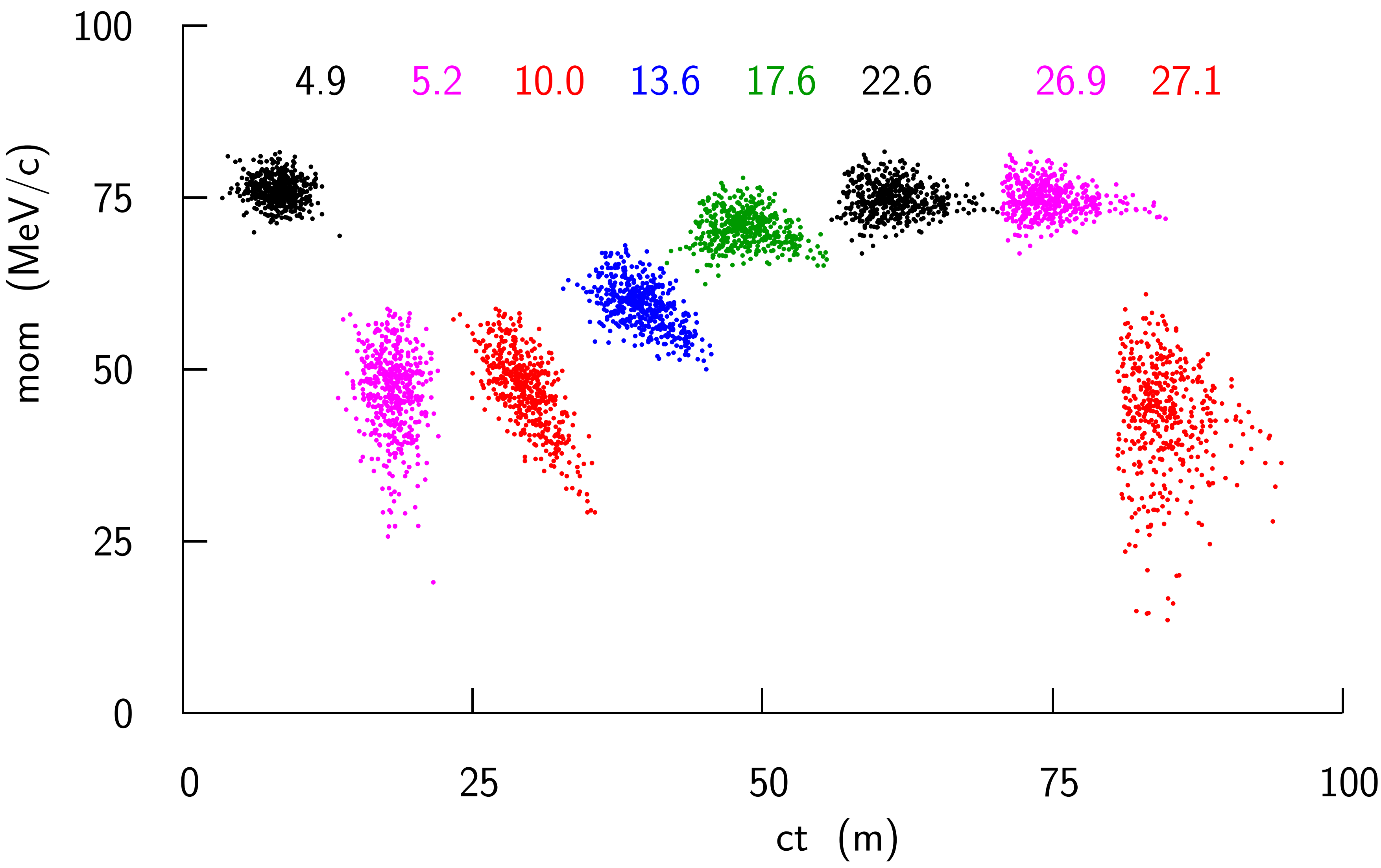
Final Cooling in 50 T Solenoids

ICOOL simulation, including matching, of last two solenoids

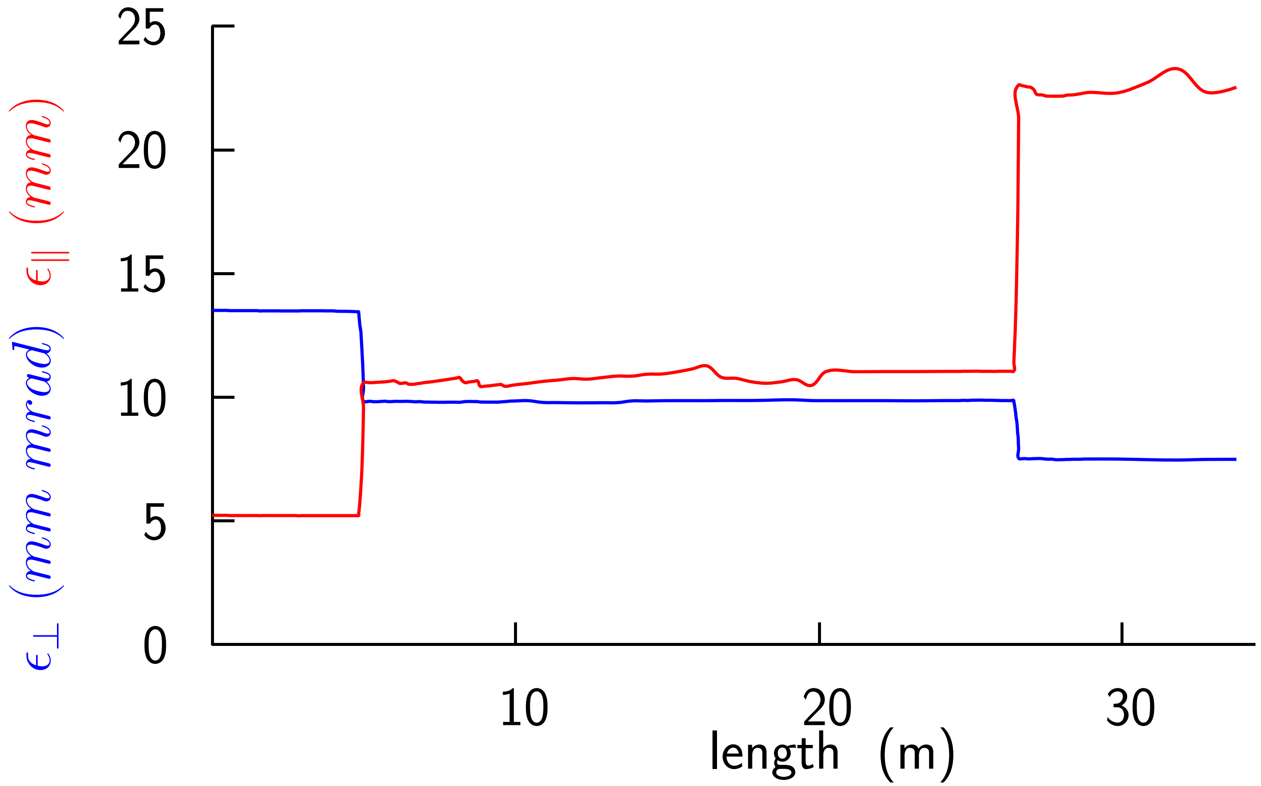


- 50 T design from PBL SBIR phase 1
- 1.4 MV/m Induction

ICOOL Simulation



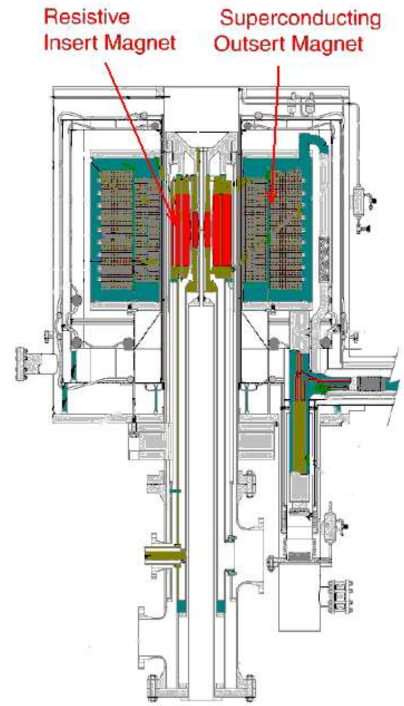
Emittances



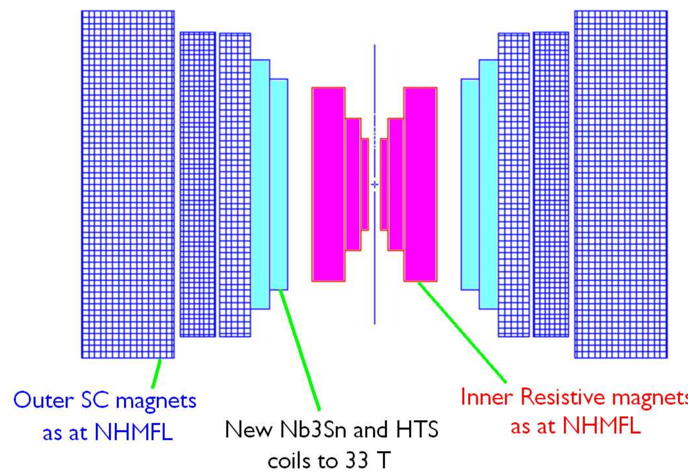
- Little loss in matching
- Transmission 85%

Is 50 T Realistic ?

- 45 T hybrid at NHMFL, but uses 25W
  - We need $\approx$ 5 solenoids
  - 125 MW not crazy
- Conservative (PBL SBIR) hybrid approach
  - Replace outer (17 T) resistive coil with Nb3Sn
  - Replace next (33T) resistive coil with HTS
  - Power now 10 MW per 50T
  - 5 coils use acceptable 50 MW
- 50 T all HTS solenoid preferable
  - but not essential
- If less field used $\mathcal{L} \propto 1/\epsilon_\perp \propto \mathrm{B}$



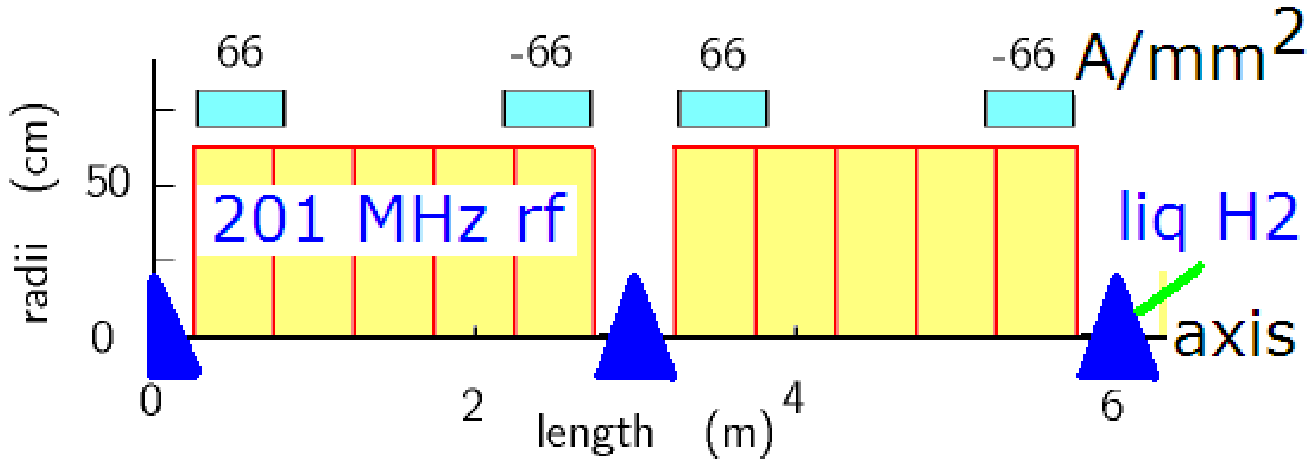
NHMFL 45 T Hybrid Magnet



PBL 50 T hybrid

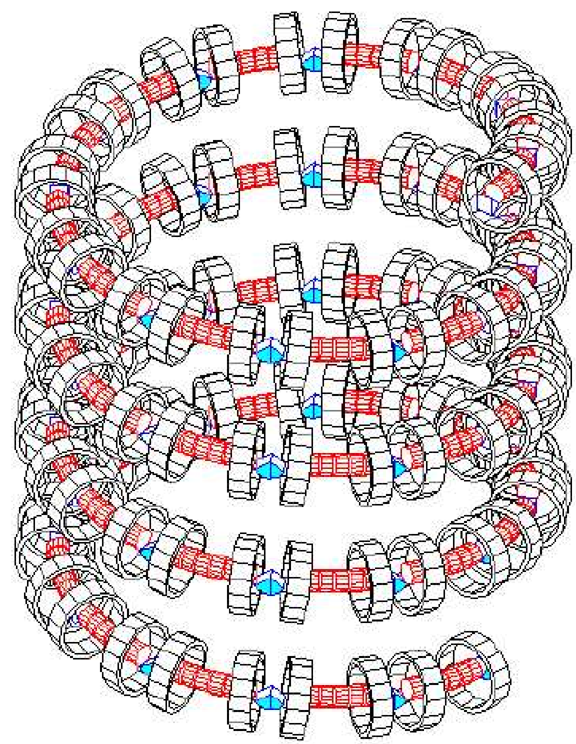
6D cooling in Guggenheim Lattices

Lattice without bending



Bending added

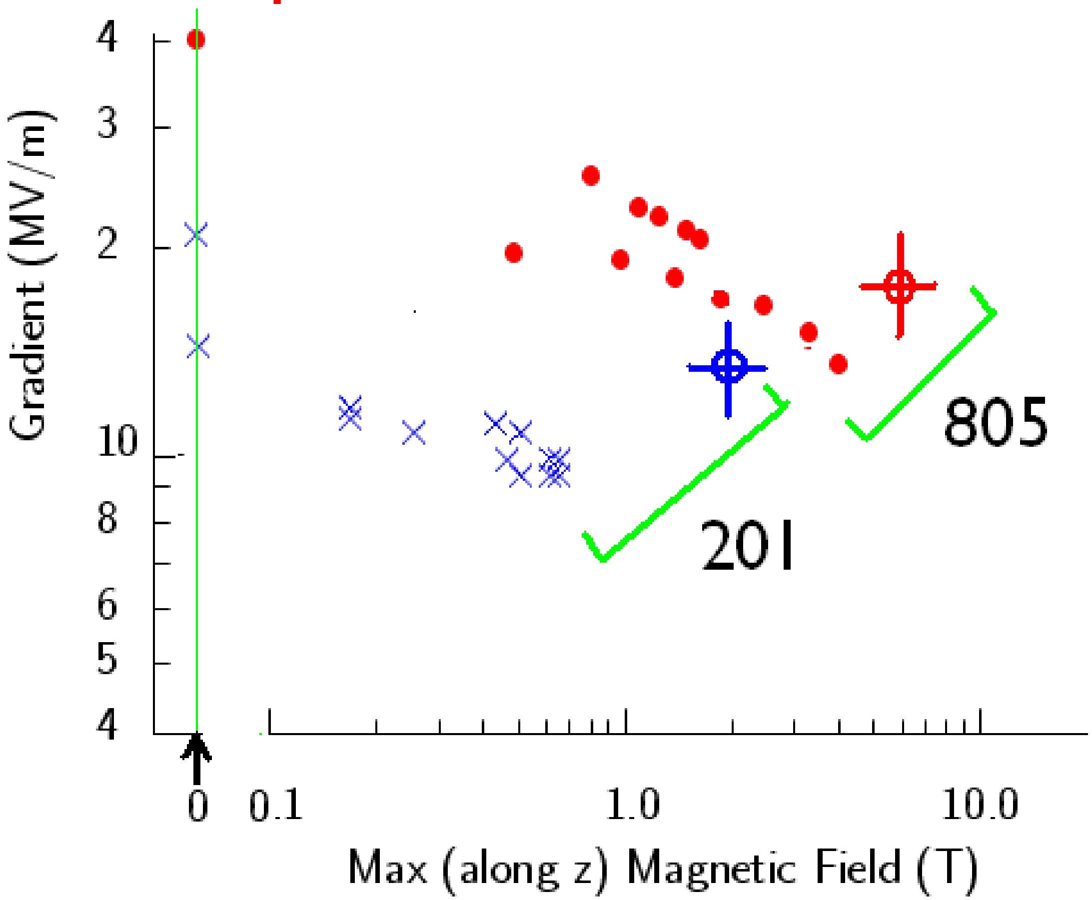
to generate dispersion for 6D-cooling
Guggenheim geometry



Parameters

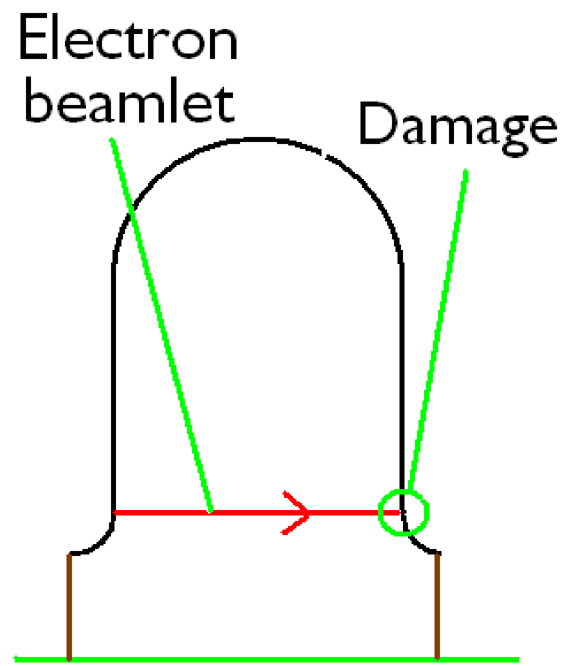
Stage	freq (MHz)	Grad MV/m	Mag (T)
Initial	201	12	3
Mid	402	17	6
Final	805	20	12

Experimental results on breakdown in fields



Some problems in this data

Conclusions are preliminary



Theory
(Palmer Fernow
Gallardo Li Stratakis)

Possible solutions

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

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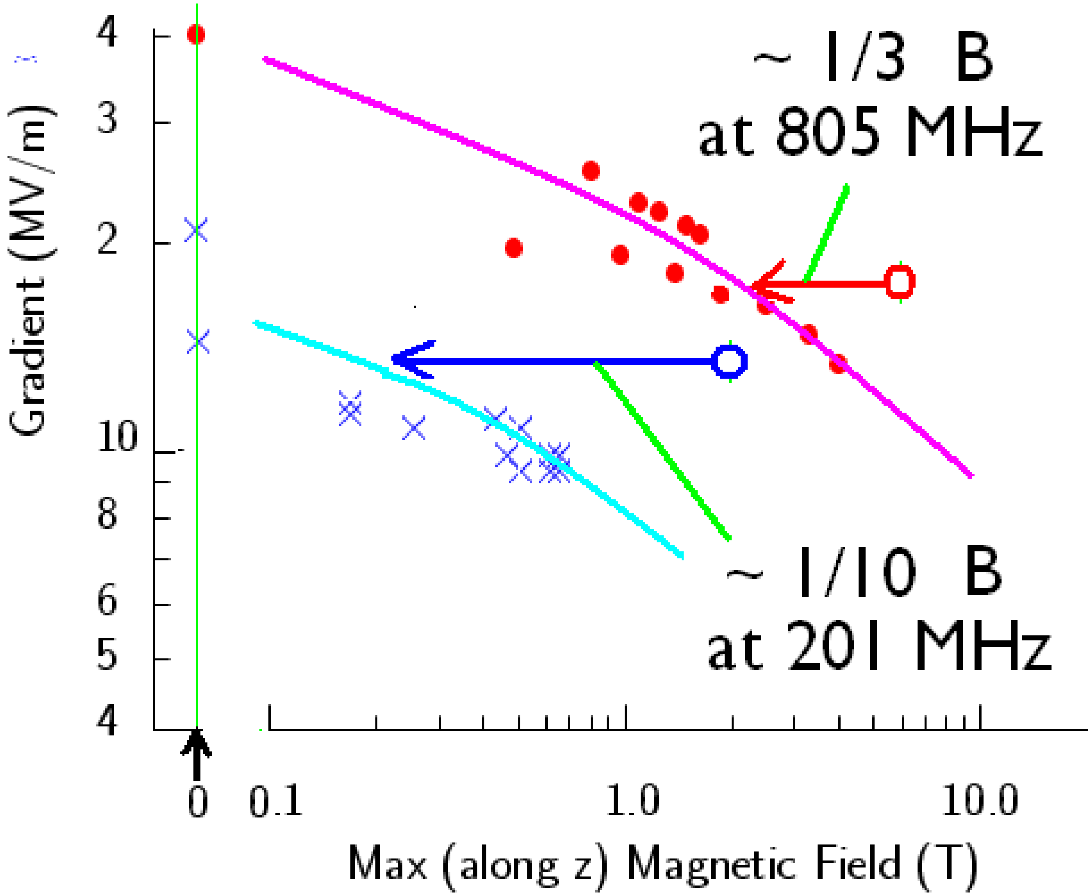

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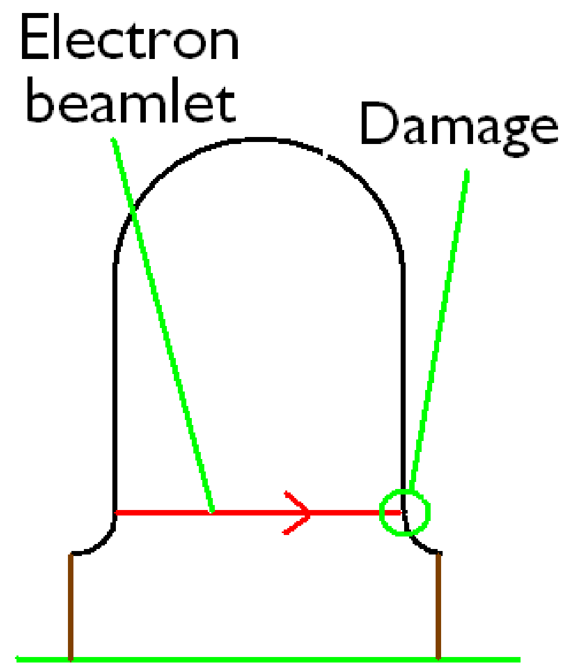

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1. ALD or other surface treatment
2. Magnetic Insulation
3. Beryllium or Cold Al cavities ?
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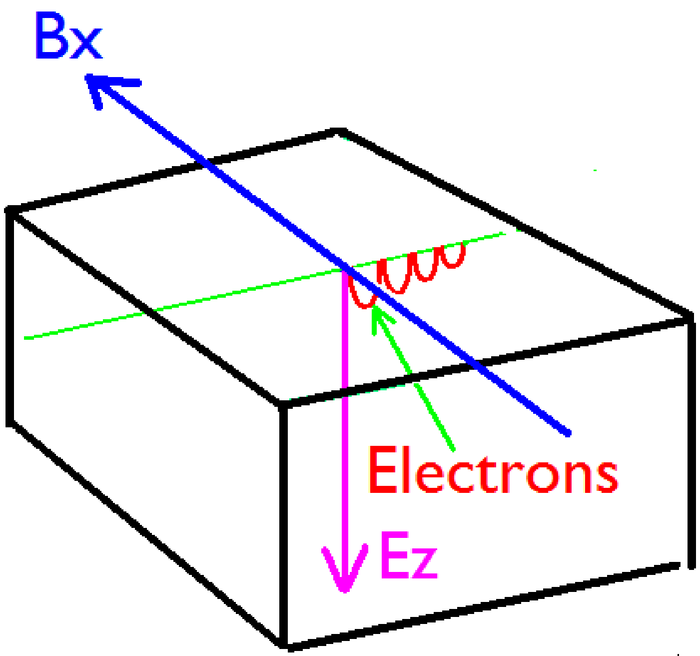
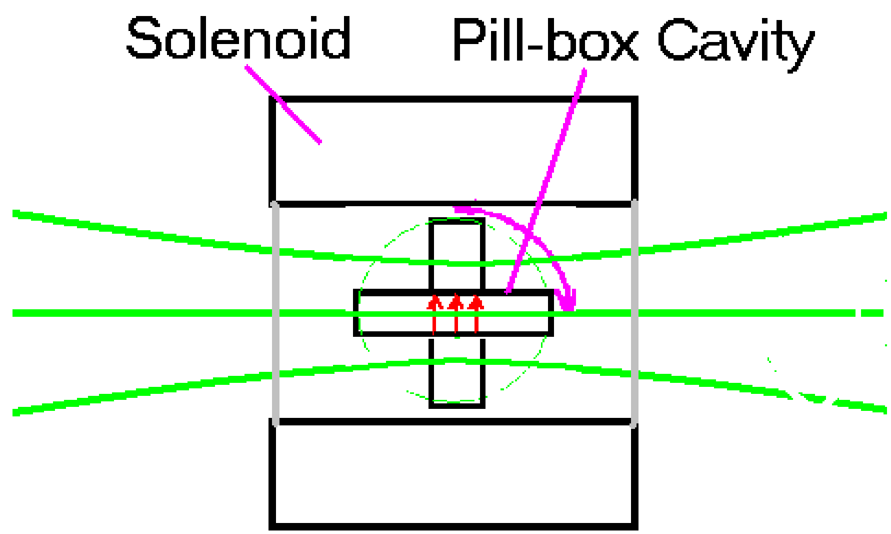
2) Magnetic Insulation Concept

- 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)

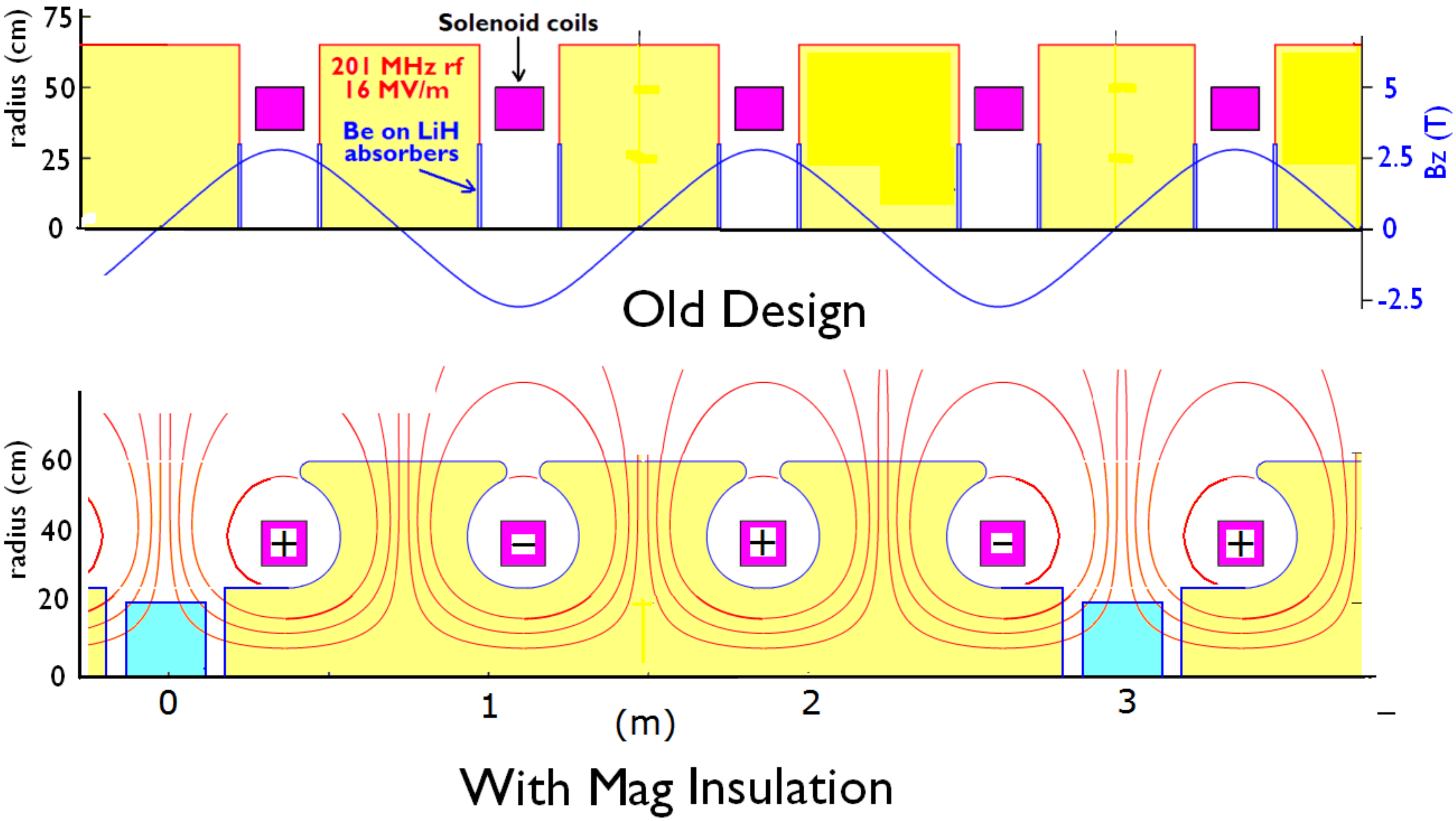




. Simulation

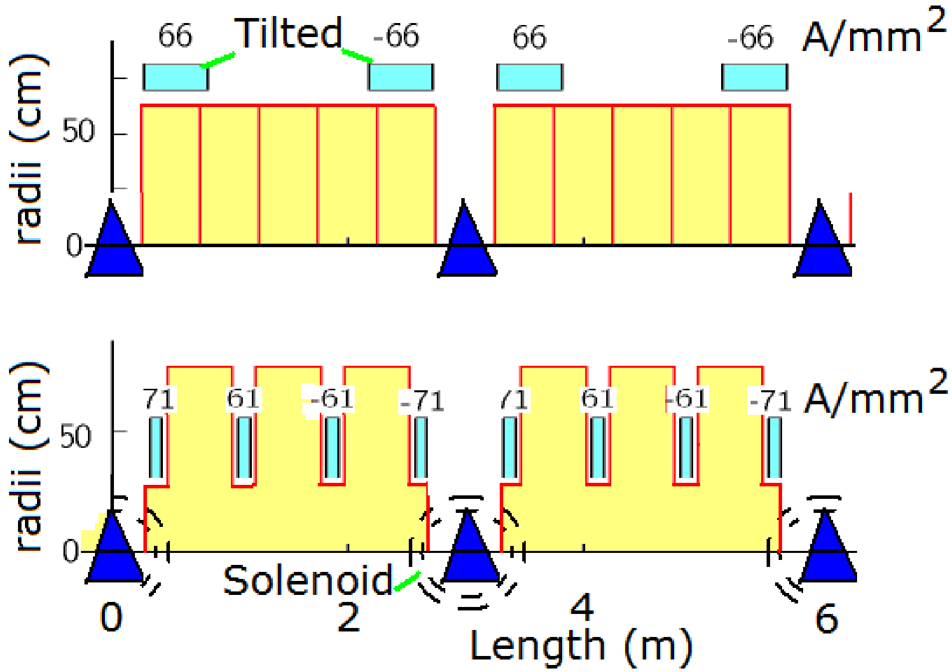
Experiment in 4 T solenoid

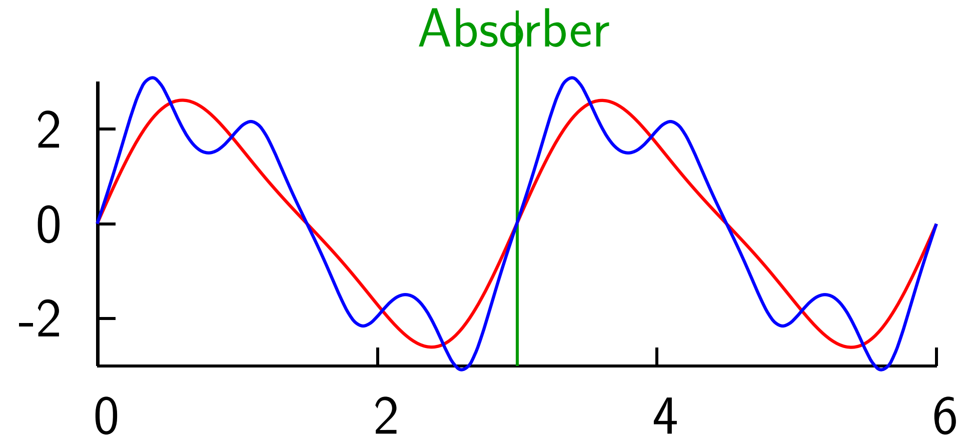
Magnetically Insulated Pre-Cooling Lattice

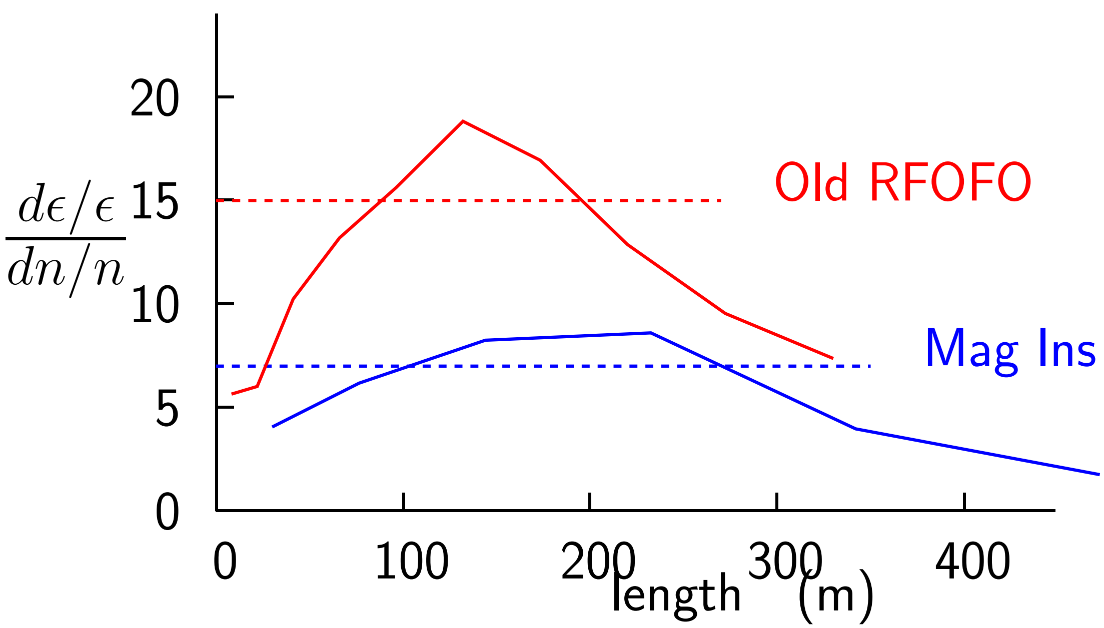


- Good solution for Pre-Cooling
- Difficult engineering

RFOFO 6D Guggenheim Cooling

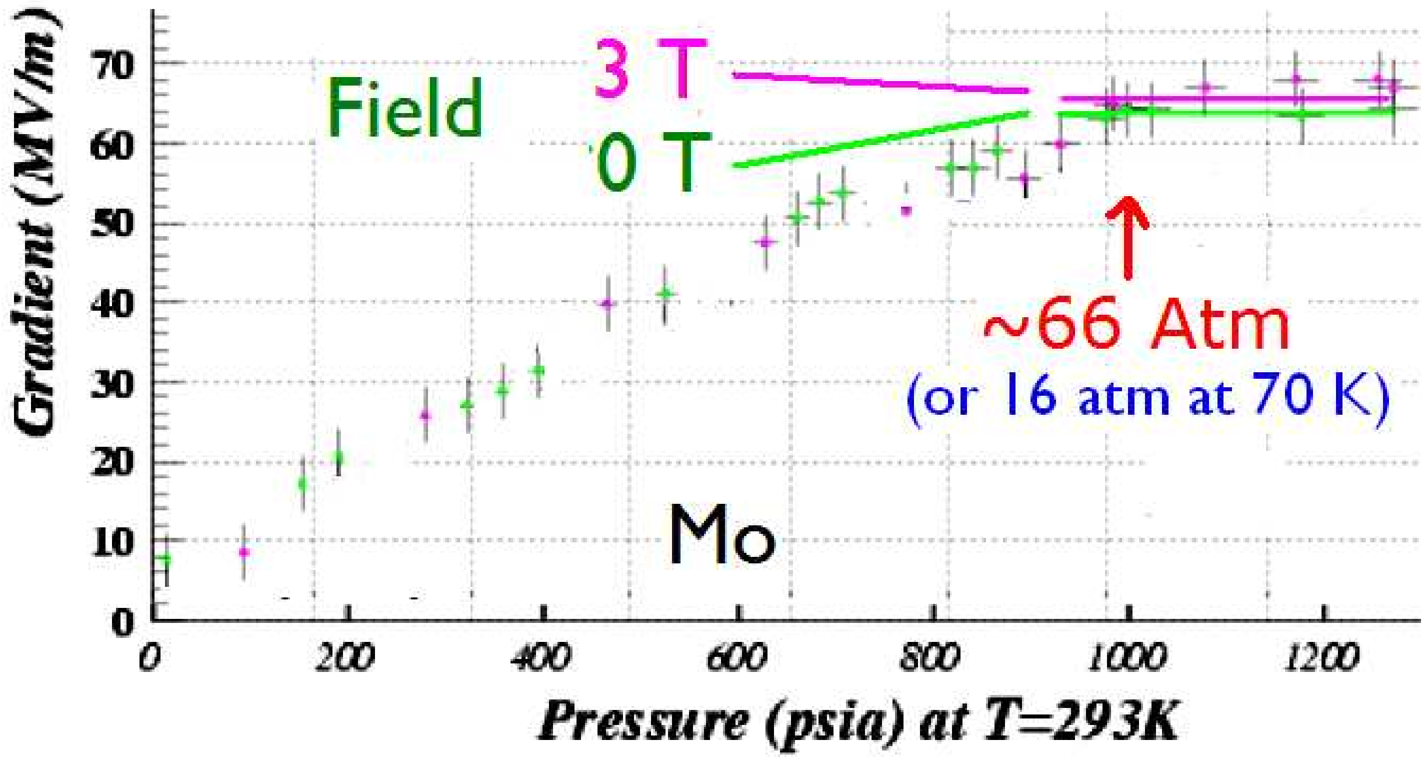






- Because used for so much cooling losses are unacceptable (3% vs 7% transmission)
- Surface fields now $\approx$ 2 times acceleration
- Shunt impedance worse

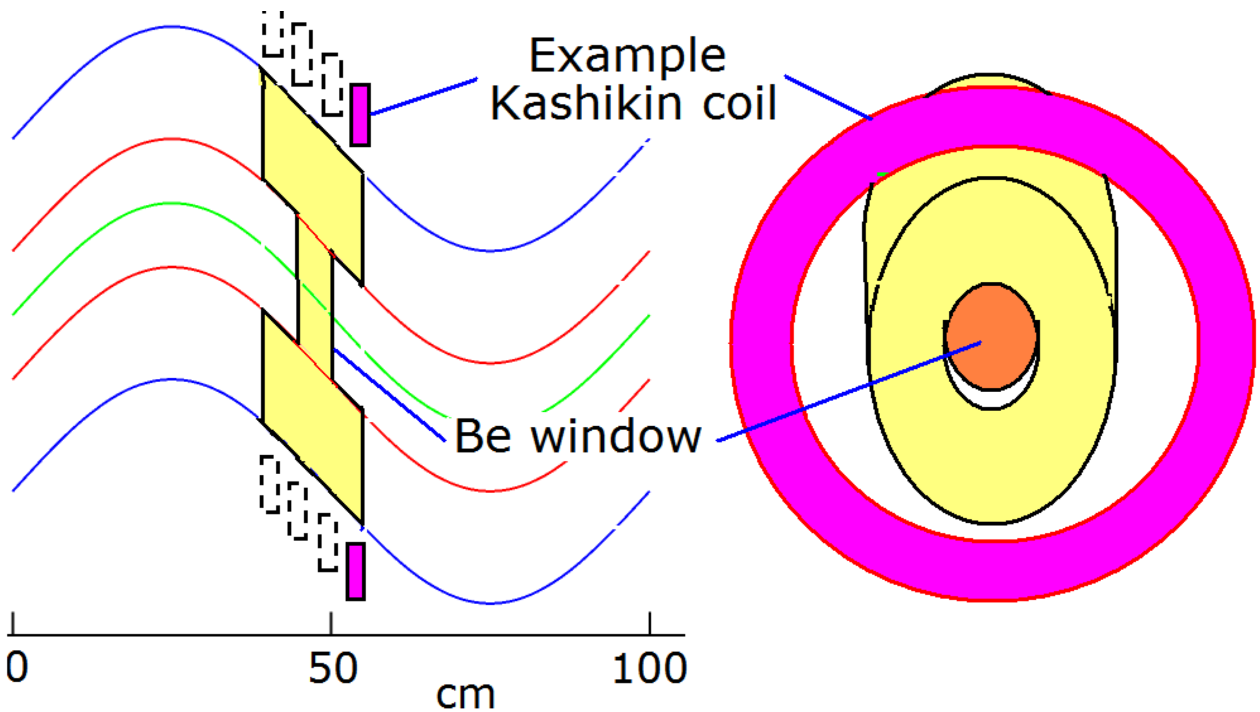
3) High pressure gas filled rf (Mucool & Muons Inc)



- 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)
(NFMCC, MCTF, & Muons Inc)

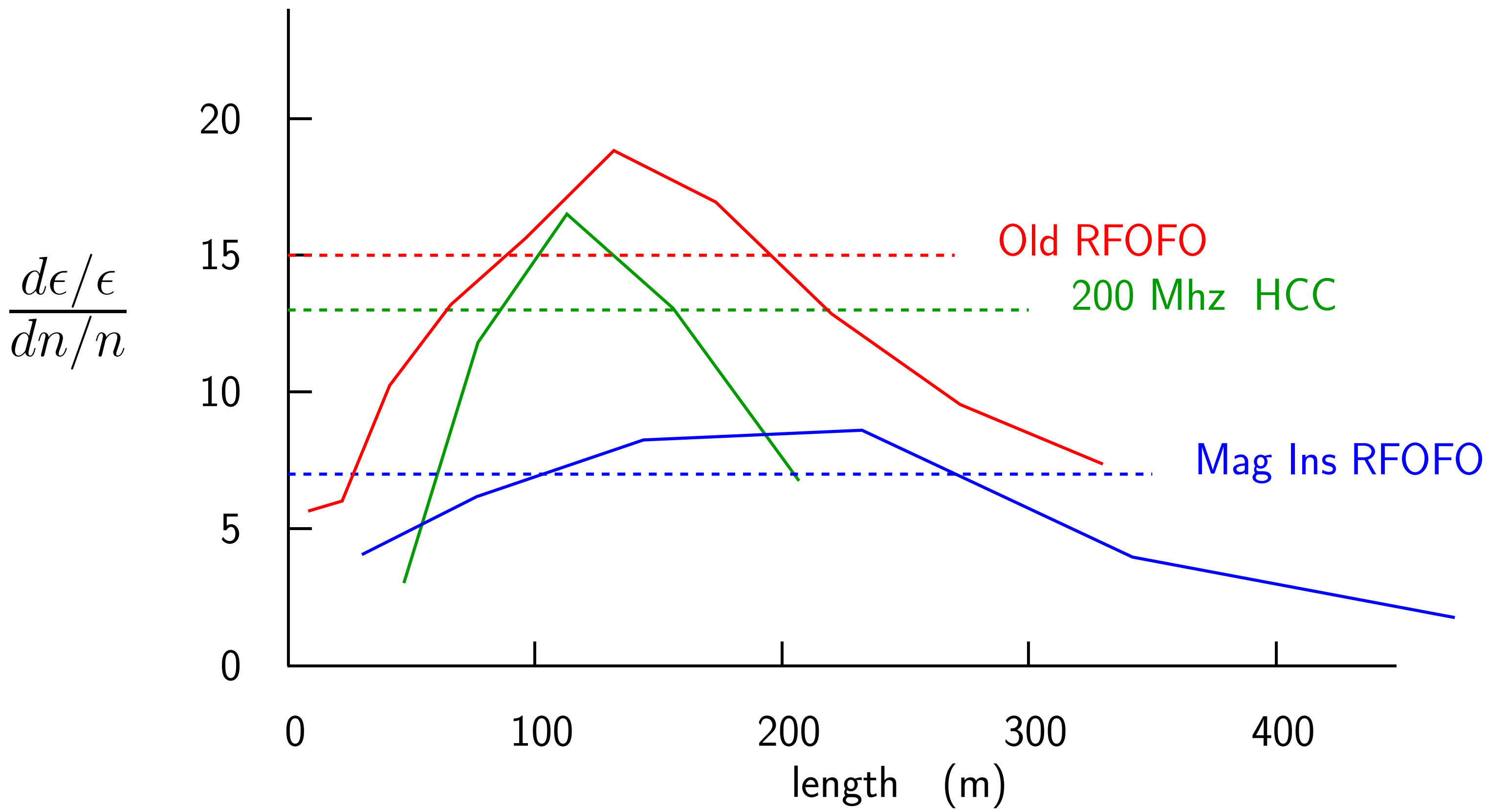
- Muons move in helical paths in high pressure hydrogen gas
- Higher momentum tracks have longer trajectories giving momentum cooling (emittance exchange)



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

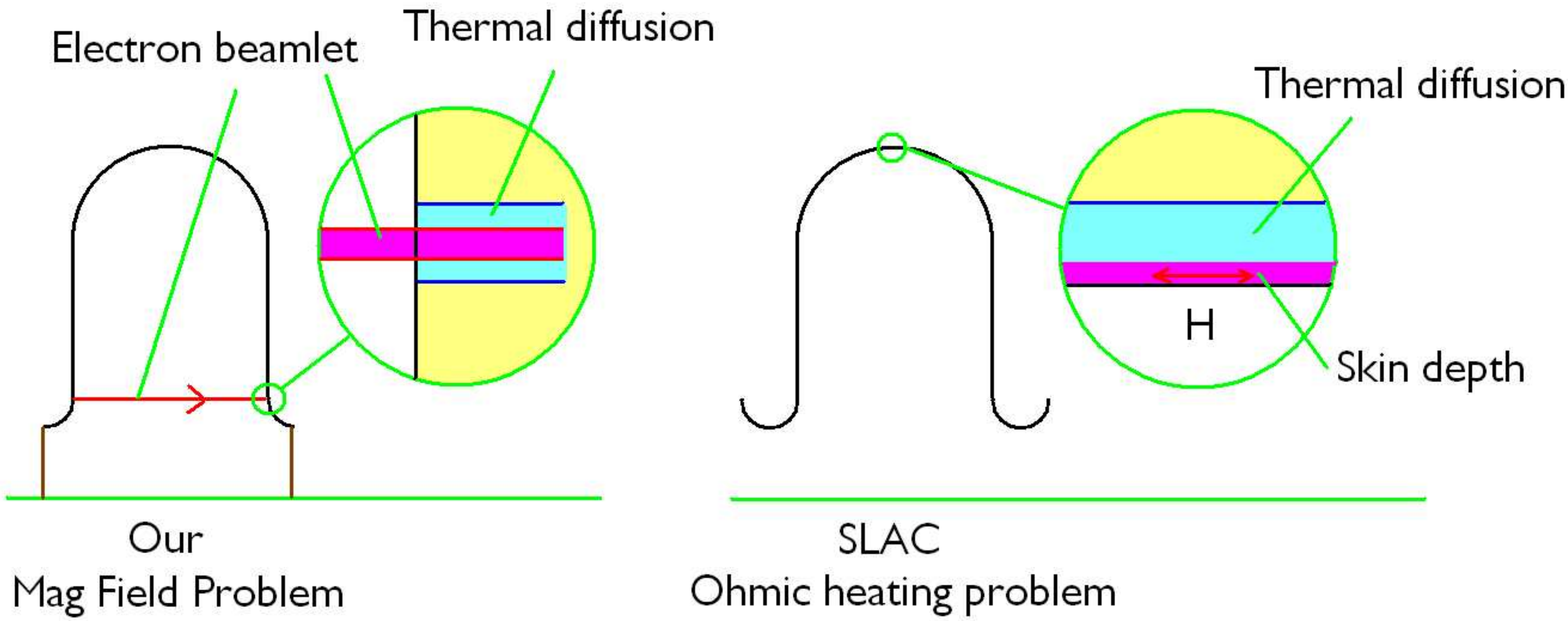
- Engineering integration of rf difficult
  but possible with lower average gradient
- Possible problem of rf breakdown with intense muon beam transit

ICOOL Simulation of HCC for 201 MHz Cooling



- Transmission is better than Mag Insulation
- But not as good as old Guggenheim
- Engineering, safety and effects of beam to be resolved

4) Beryllium/Aluminum Cold Cavities

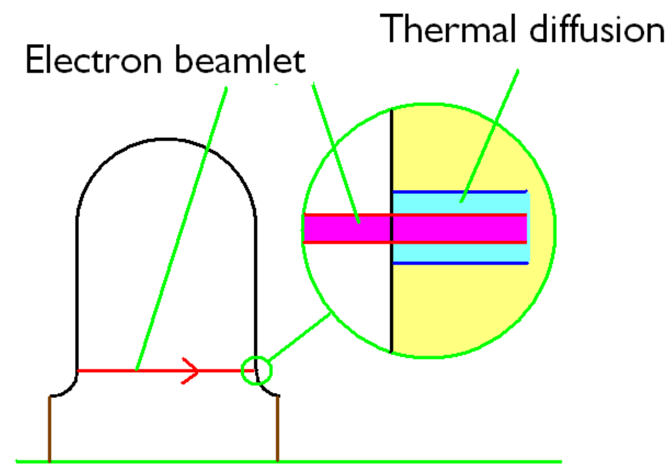


- SLAC observes copper surface damage with cyclical surface heating of only 45 degrees
- Focused field emission currents could also heat copper to such temperatures
- Breakdown will follow if the damage is on a high gradient surface

Assume damage is from cyclical strains S due to Beamlets

$$S \;\propto\; \frac{dE}{dx}\int_o^t \frac{I(\mathcal{E})\;\alpha(\mathrm{T})}{\mathrm{A_{beam}}\;\rho\;\mathrm{C_p(T)}}dt$$

$\alpha(T)$ expansion, ρ density, $C_p(T)$ specific heat.

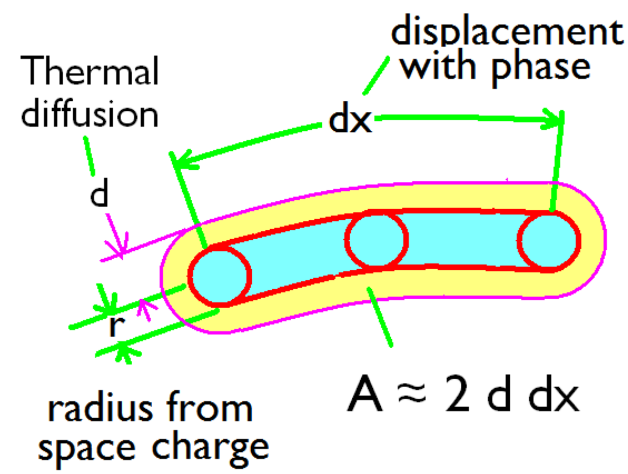


Assume $r \;<\; d(T) \;<\; dx$

e.g. 805 MHz, $B = 3T$, $\mathcal{E} = 17$ (MV/m)

$dx = 100(\mu m), d = 48(\mu m), r = 10(\mu m)$

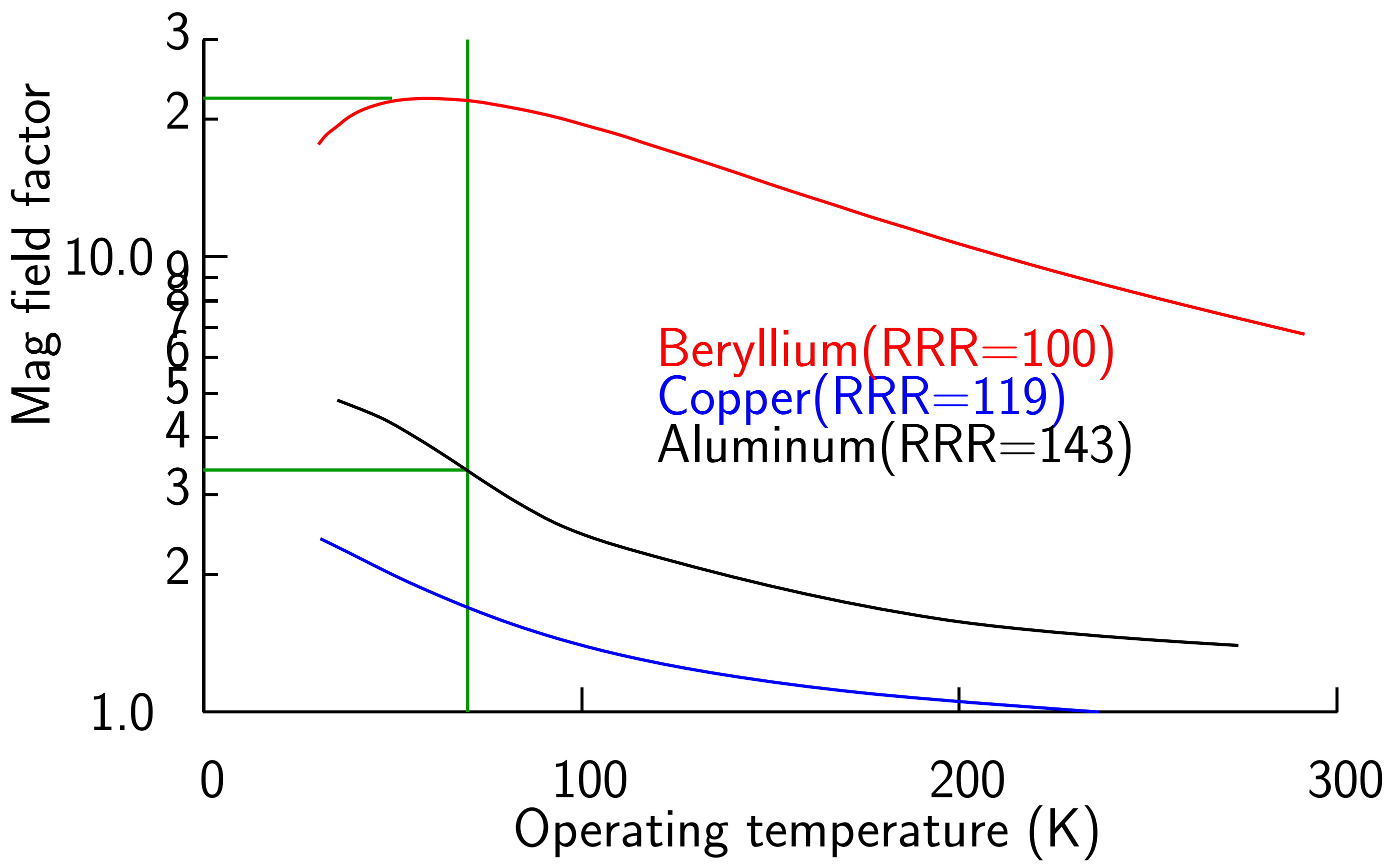
$$A_{beam} \approx 2d(T)\;dx \;\propto\; \frac{d(T)}{B} \qquad d(T) \;=\; \sqrt{\frac{K(T)\tau}{\rho C_p(T)}}$$

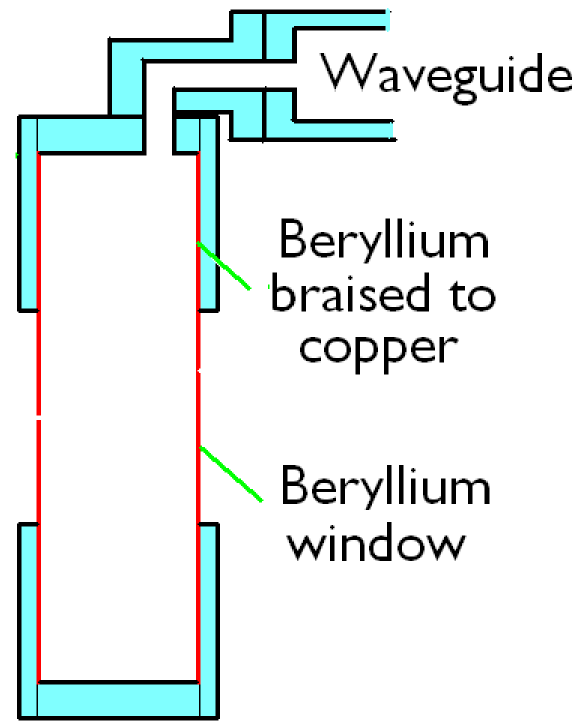


$$S \;\propto\; \frac{dE}{dx}\int_o^t \frac{I(\mathcal{E})\;\mathrm{B}\;\alpha(\mathrm{T})}{\mathrm{d(T)}\;\rho\;\mathrm{C_p(T)}}dt$$

- We will assume the rf pulse length t is NOT increased even when low temperatures give longer decay times τ

Relative B for same strain





- Cold beryllium gives reduction $B_{damage} > 10$
  should solve the problem for all cases
- Cold aluminum gives reduction $B_{damage} \approx 3$
  might solve the problem for 805 case
- Test of cooled copper cavity will test the hypothesis

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
  - Magnetically insulated cavities
  - High pressure hydrogen gas filled cavities
  - Cooled Al or Be cavities ← preferred solution