Optimized Quads for Collider IP

R. B. Palmer (BNL)

MCTF Thursday

5/28/09

- Motivation
- Super-conductor properties
- Cos theta quadrupole optimization
- Aside on "block" design
- Use in Collider final focus
- Open mid-plane dipole
- New Collider Parameters
- Conclusion

Motivation

Luminosity

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

$$\mathcal{L} \;\propto\; \frac{< B > P_{\rm beam}\; N}{\epsilon_\perp\; \beta^*}$$

- We may have trouble getting $N = 2\;10^{12}$
- We may have trouble getting $\epsilon \;=\; 25\;10^{-6}$ m
- We may have trouble getting 7% cooling transmission
- Beam beam tune shift $\Delta\nu$ may not be a constraint

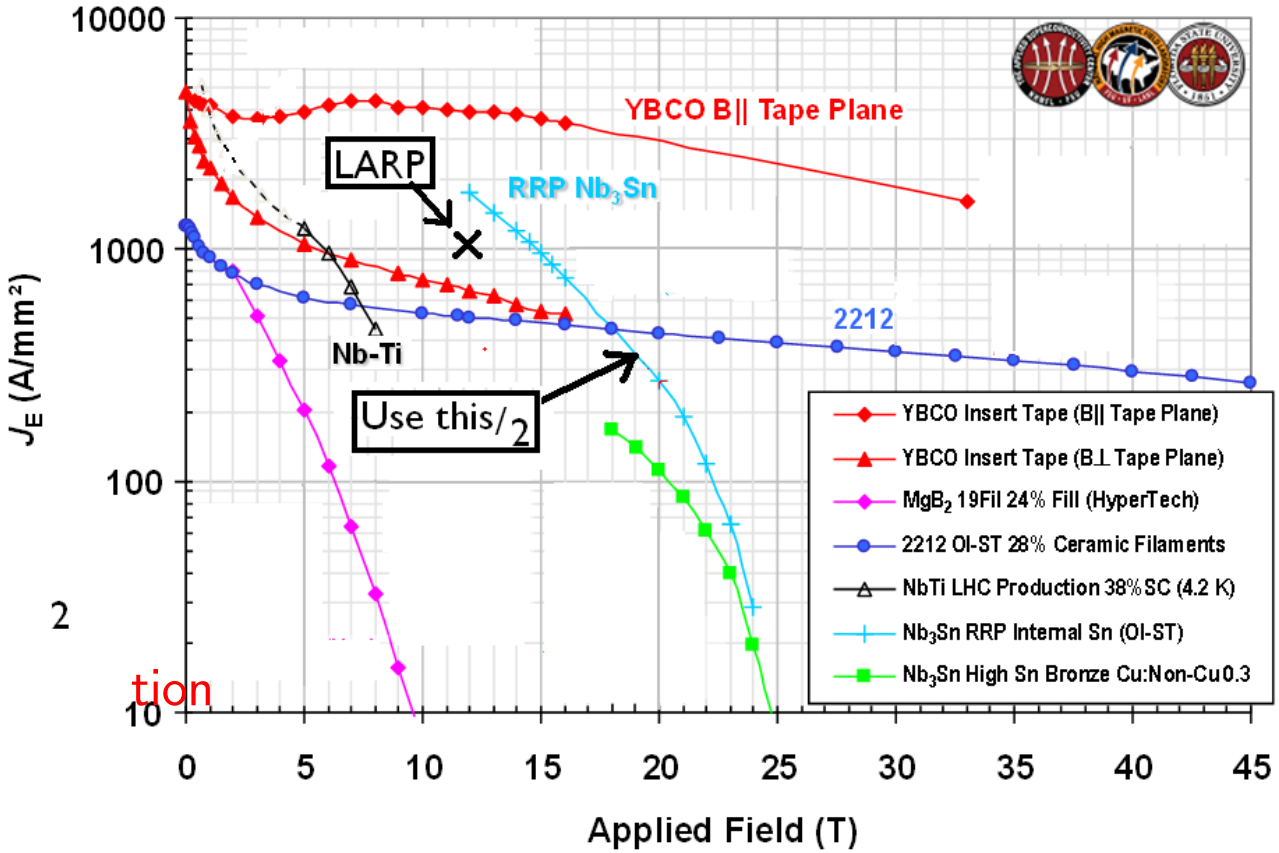
- Look for other ways to recover Luminosity
  - More proton power (Chuck)
  - Higher $< B >$ <<<<<<<<
  - Lower β^* <<<<<<<

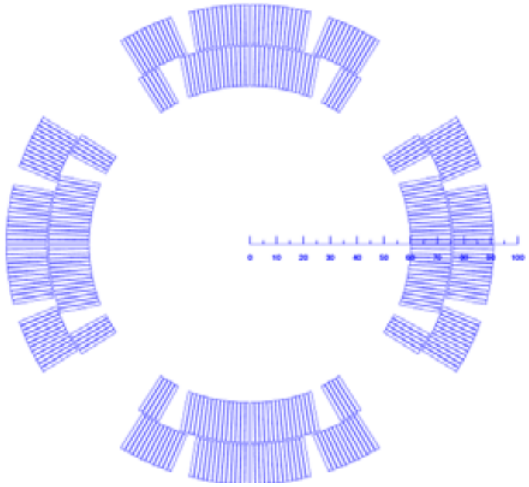
Advances in SC Quadrupole Design

Design of HQ – a High Field Large Bore Nb_3Sn Quadrupole Magnet for LARP

H. Felice, G. Ambrosio, M. Anerella, R. Bossert, S. Caspi, D. Cheng, D. Dietderich, P. Ferracin, A. K. Ghosh, R. Hafalia, C. R. Hannaford, V. Kashikhin, J. Schmalze, S. Prestemon, G.L. Sabbi, P.Wanderer, A.V. Zlobin

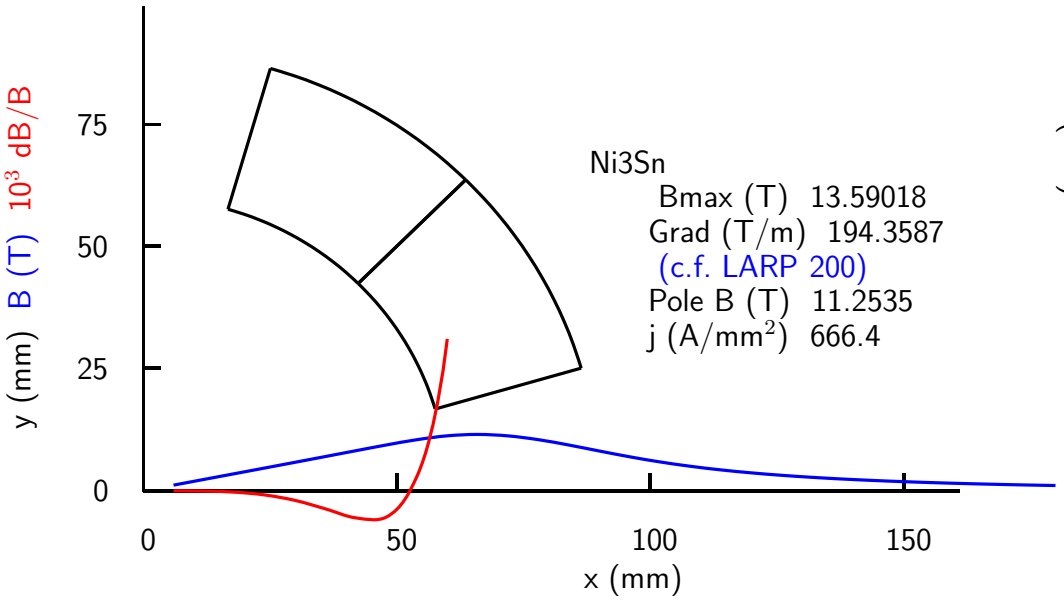
Above magnet now under construction uses conductor performance:

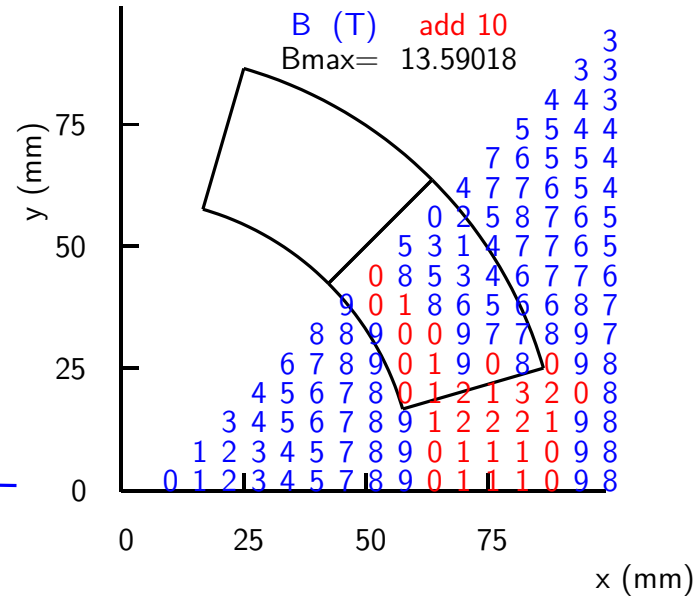


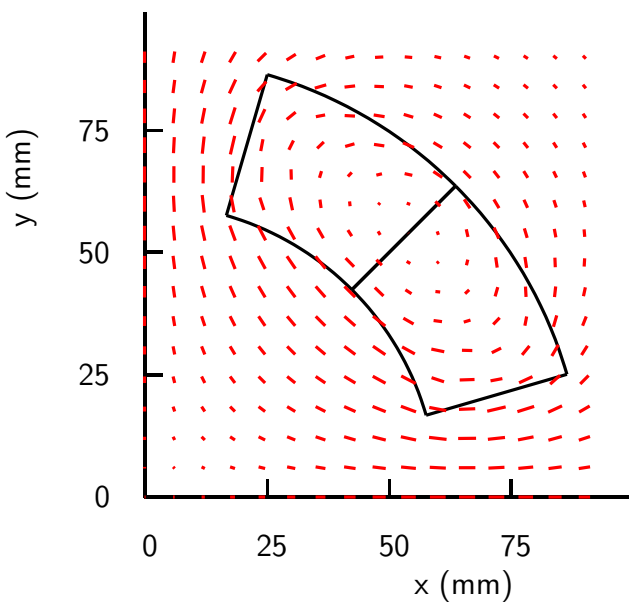


LARP Quad Cross section

Reproduce LARP Design



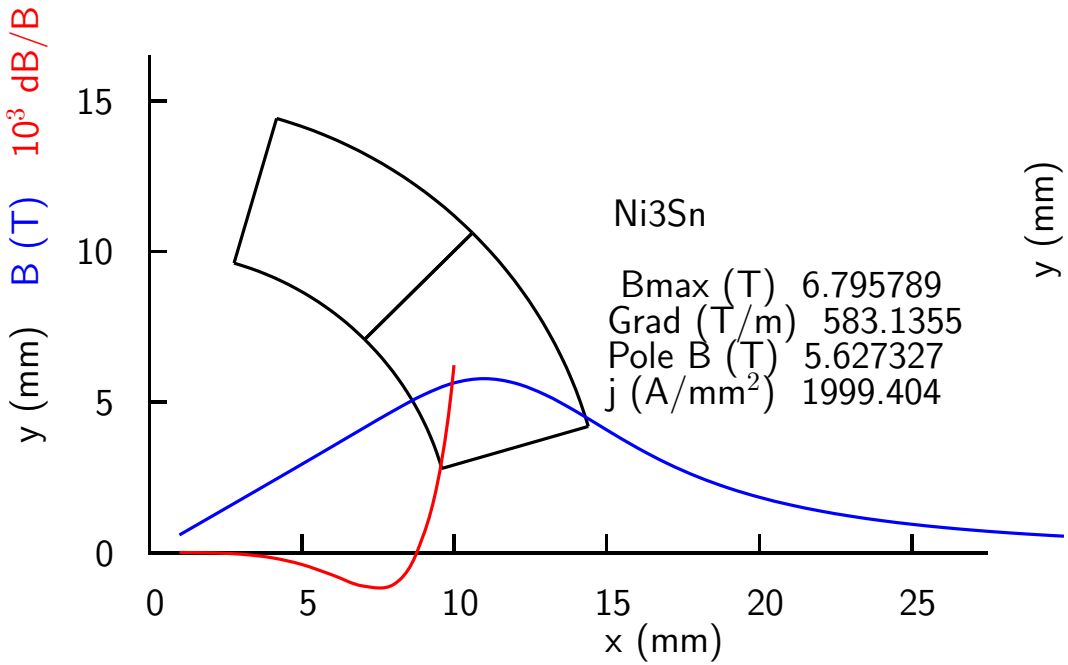




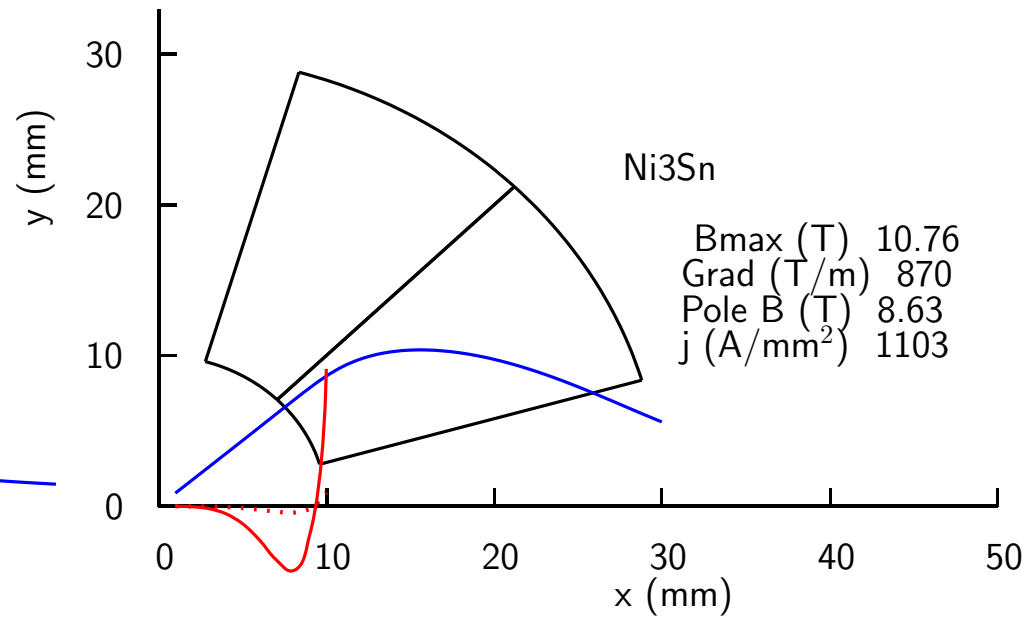
- Gradient found of 194 T/m
  c.f. LARP's 203 T/m
  Good agreement

- Note field at all angles
- So YBCO is not suitable

Scale R down to 1 cm



Small dR/R=0.5
Grad=583

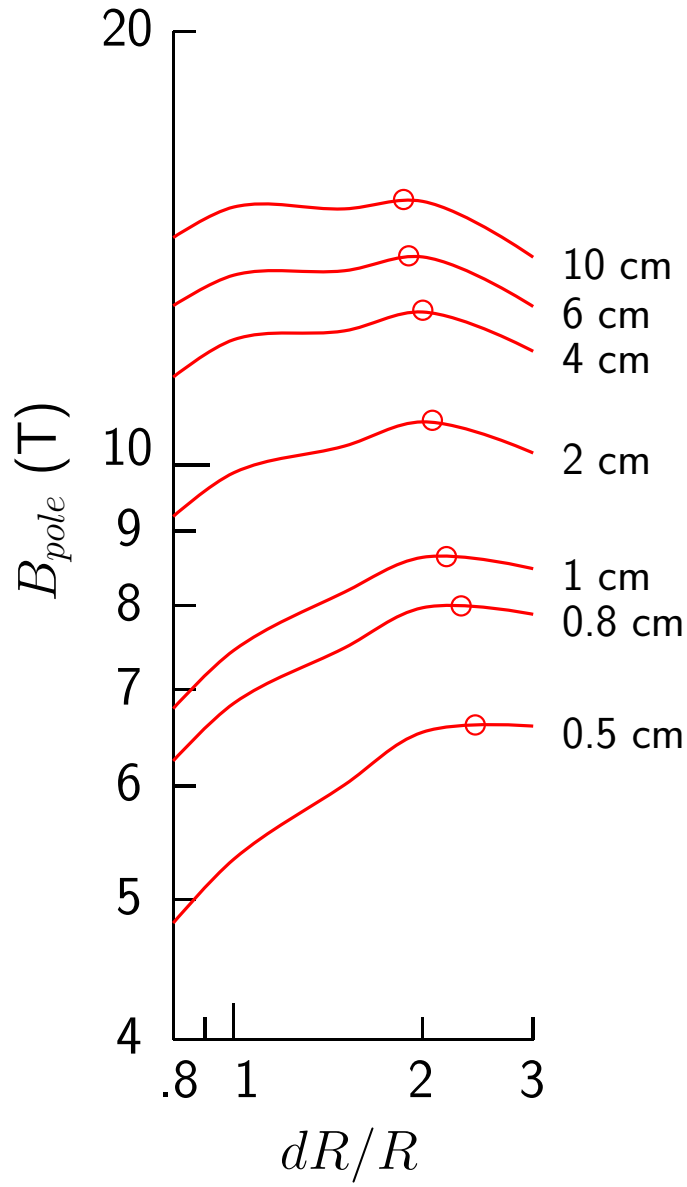


Large dR/R=2.0
Grad=870

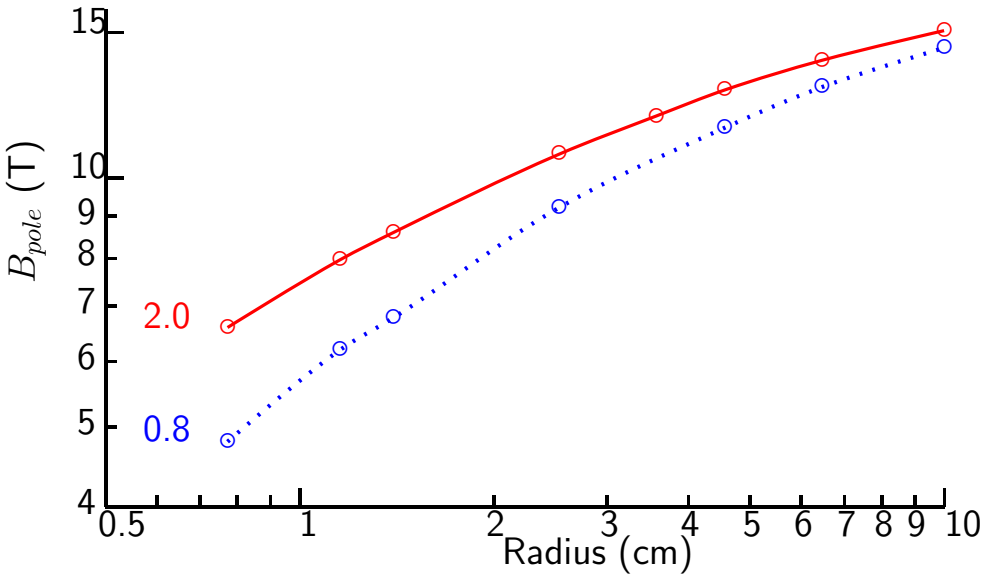
- Max fields higher in dR/R=2.0, current densities lower, but gradient still higher
- dR/R=0.5: Radial width of conductor (0.5 cm) much less than LARP (3 cm)
- dR/R=2.0: Radial width of conductor (2 cm) still less than LARP (3 cm) but key-stoning is more severe and will need R&D

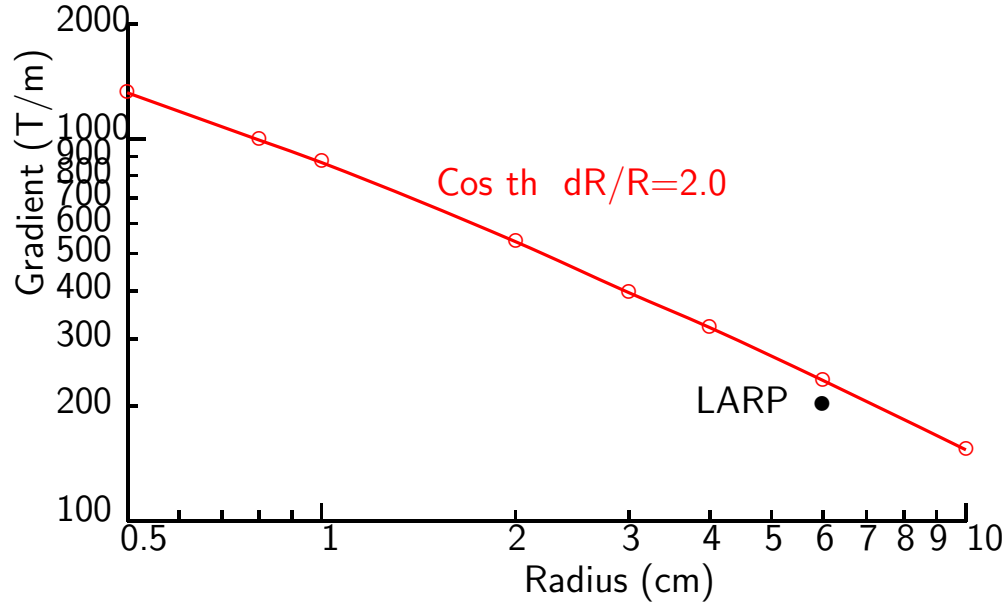
Search for optimum dR/R for different R

- Optimum always near $dR/R = 2$
- But Large dR/R more useful at low radii



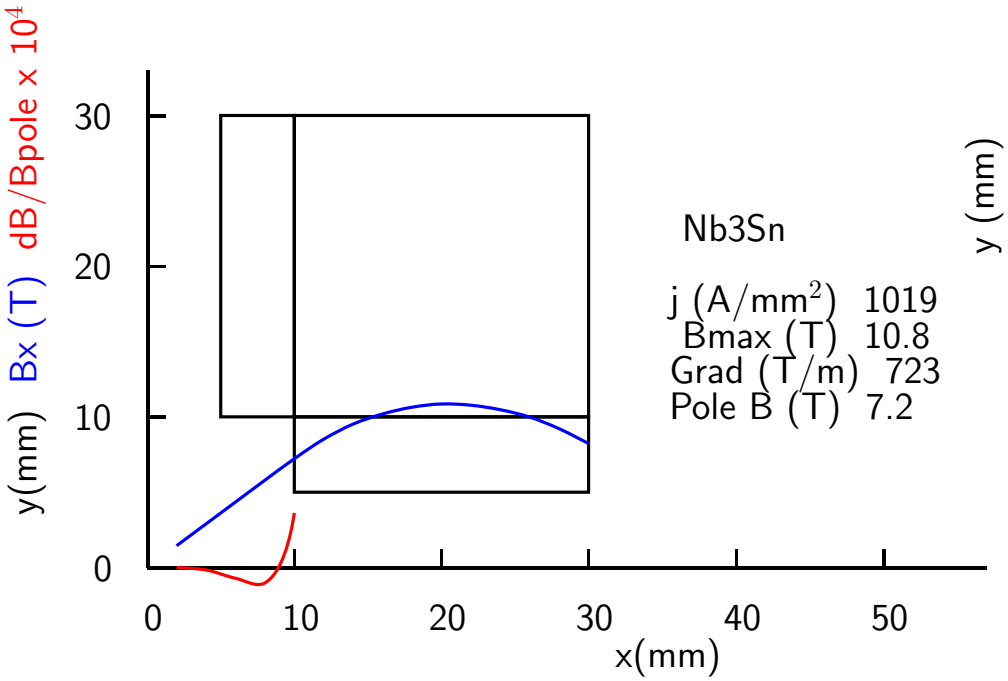
B_{pole} and Gradient vs. R

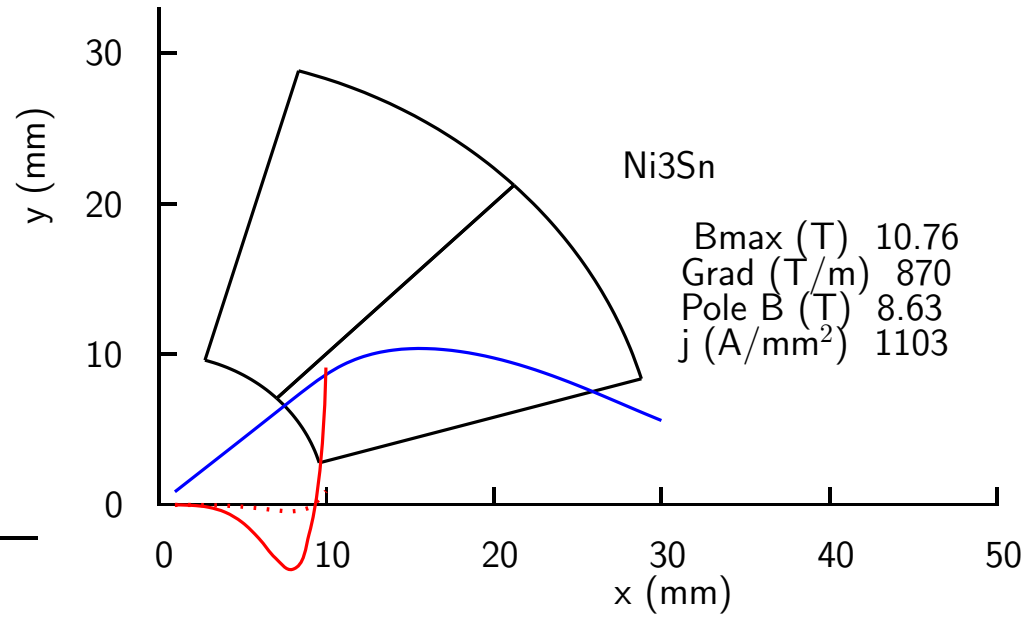




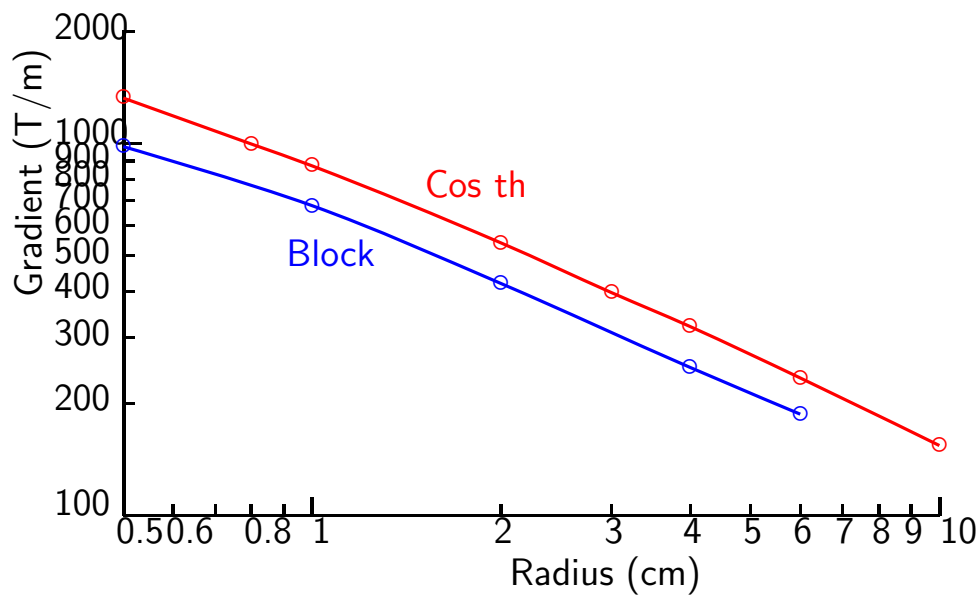
- Huge gains if radius reduced

Aside: "Block" Cross Section vs. Cos θ

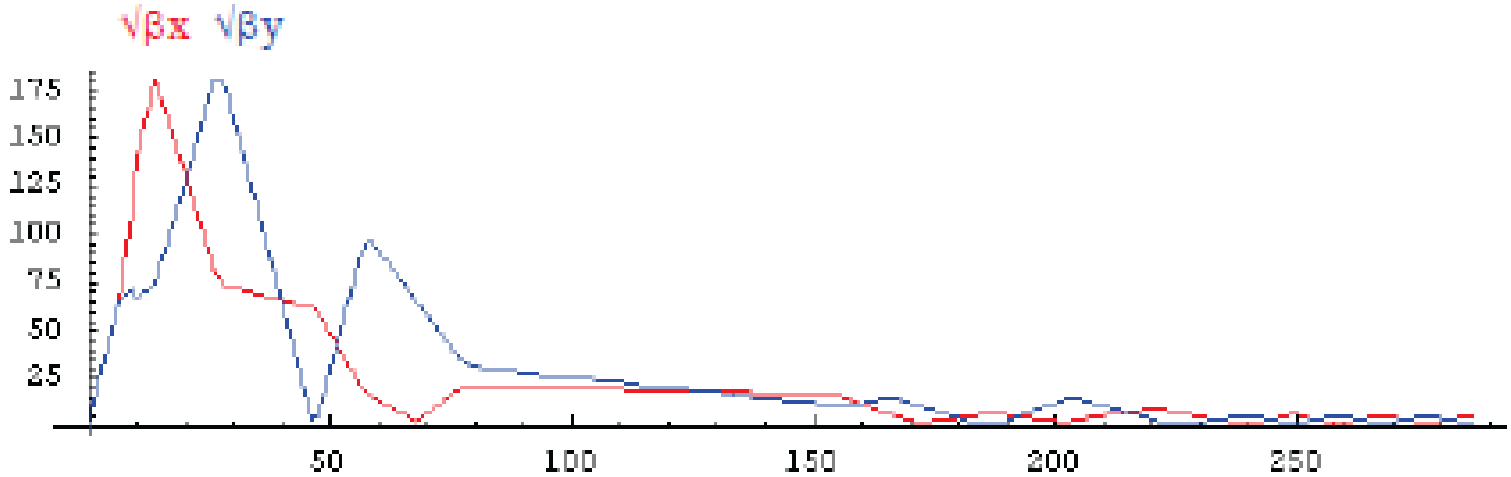


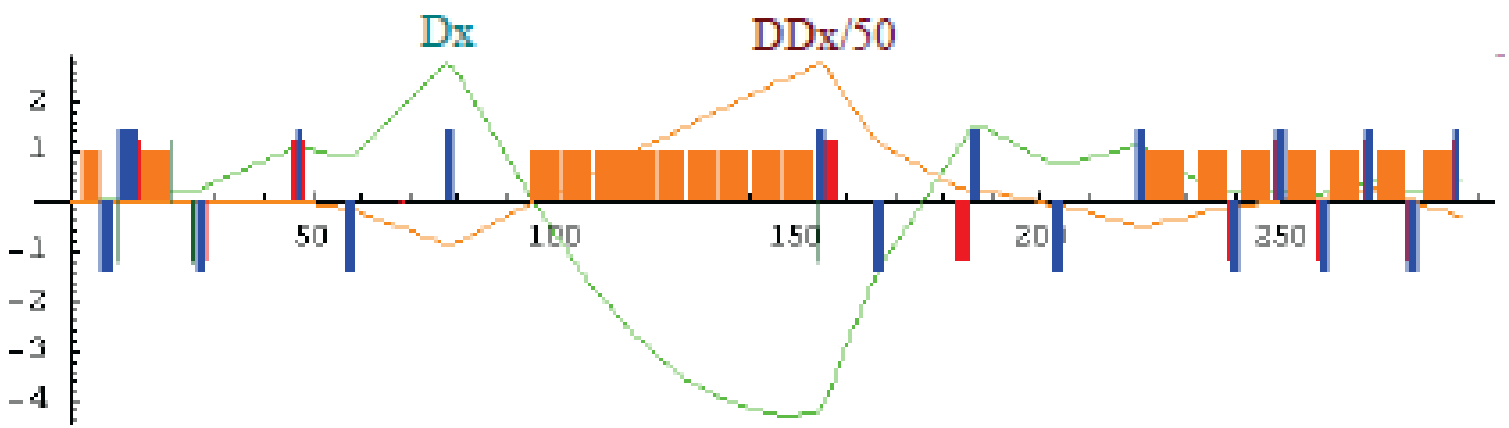


- Blocks shape easier to wind, but
- 20% loss of gradient using L shape



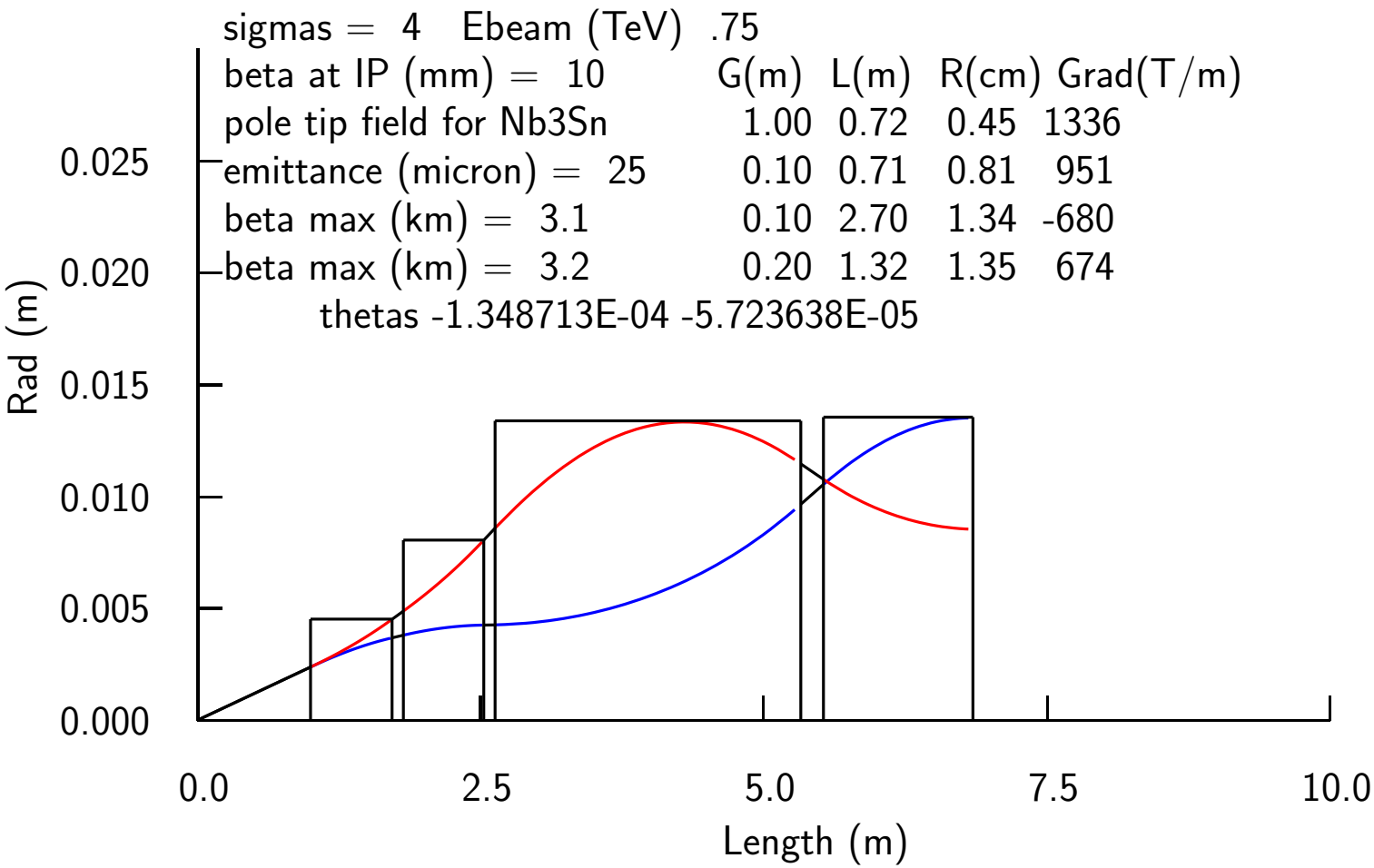
Collider Final focus design





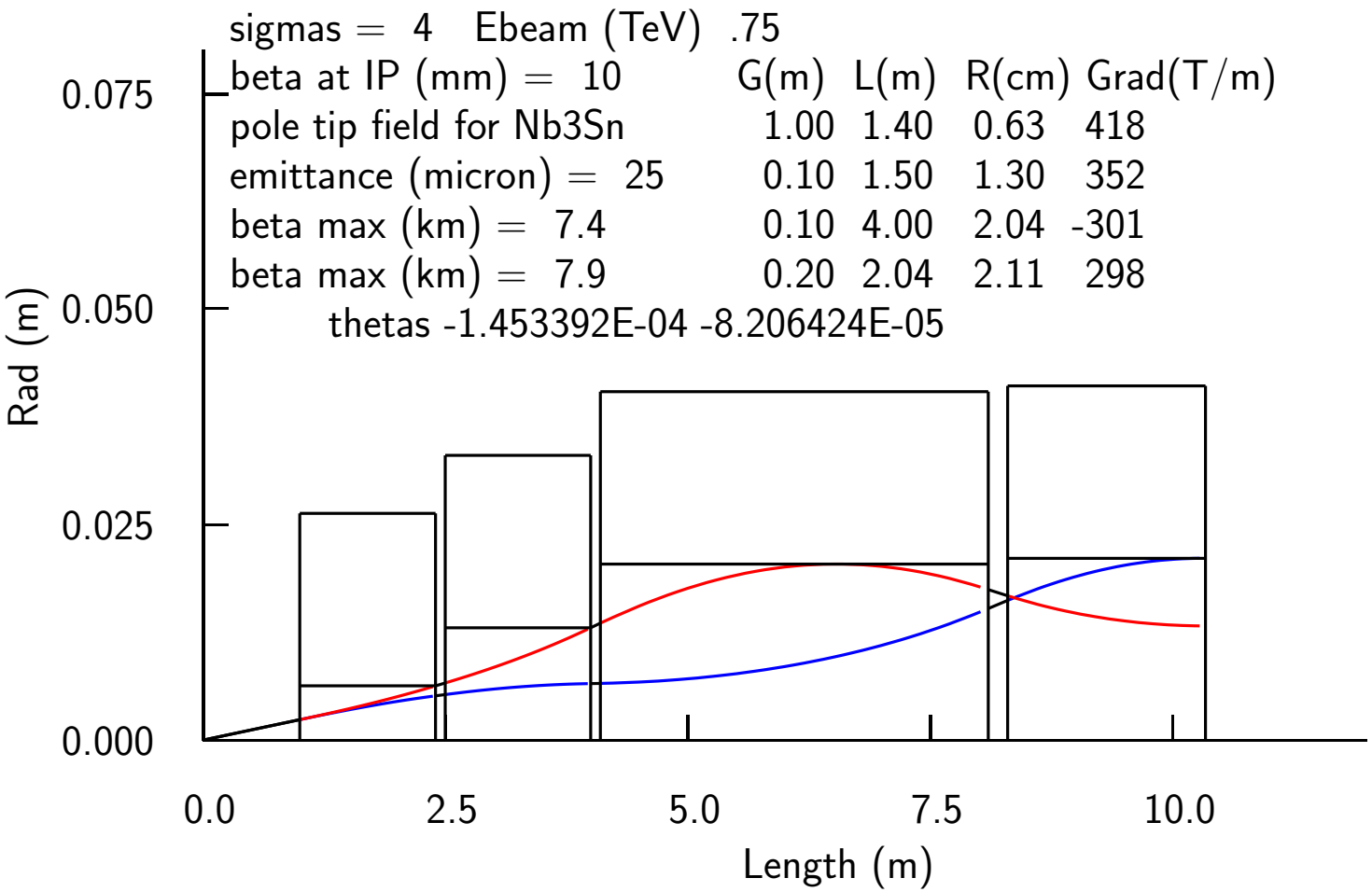
- Yuri and Eliana's Dipole First design
- $\beta_{max} = 175^2$ m $\approx$ 30 km
- Aim to keep $\beta_{max} \leq 30\ (km)$, but with lower $\beta*$ for higher luminosity

Final focus design with high gradient quads



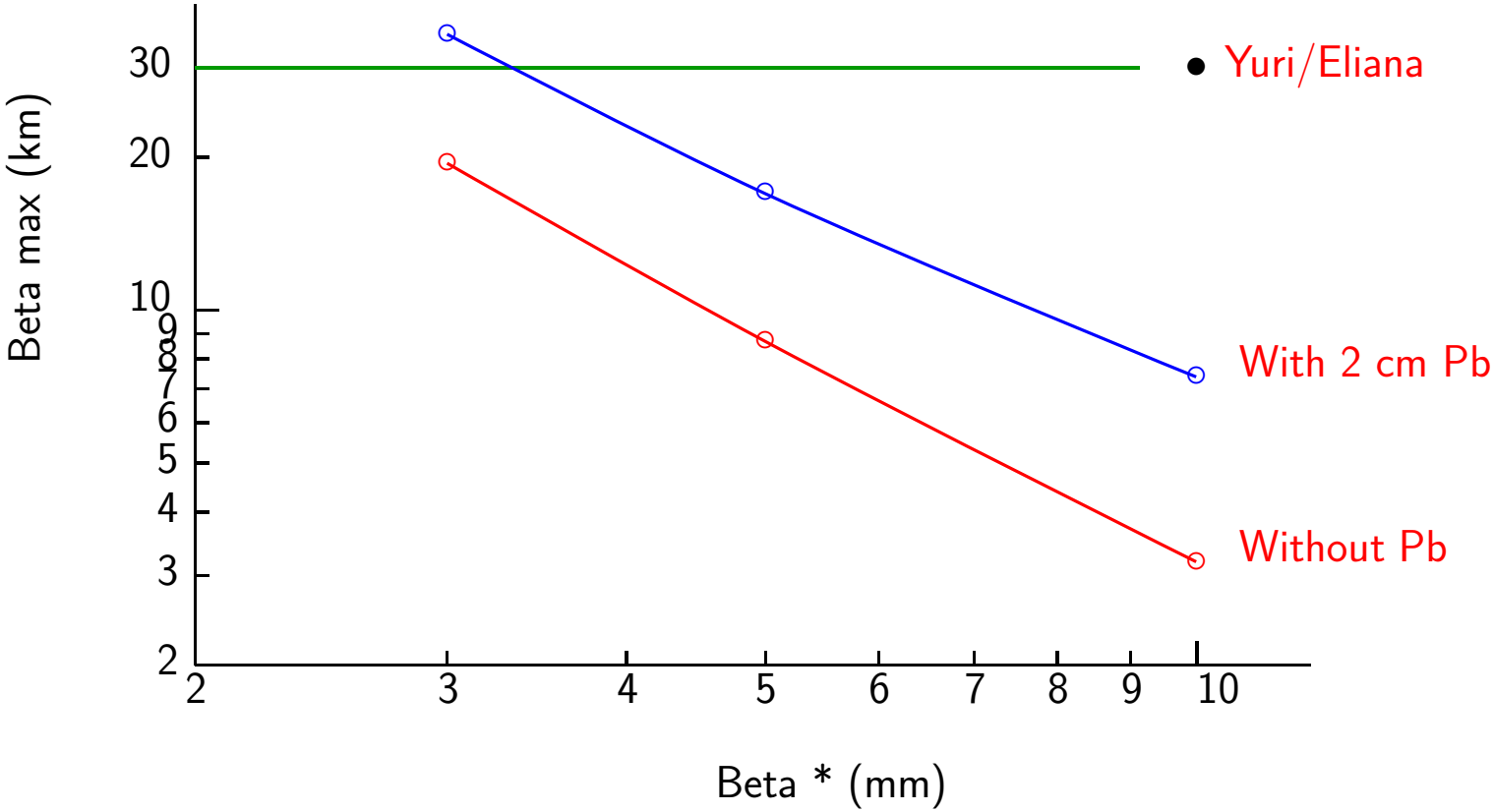
- For the same β *: $\beta(max) \approx 1/10$ Yuri/Eliana's (3.2 vs. 30 km)
- But heating from decay electrons probably unacceptable

With 2 cm lead shielding



- Not as good, but $\beta(max)$ still $\approx$ 1/4 Yuri/Eliana's (7.4 vs. 30 km)
- Magnet #1 Max field at 4 sigma = 2.6 T so this magnet could be substituted by a Holmium or Gadolinium magnet (Summers)
  but others have higher pole fields so sc magnets plus Pb are better

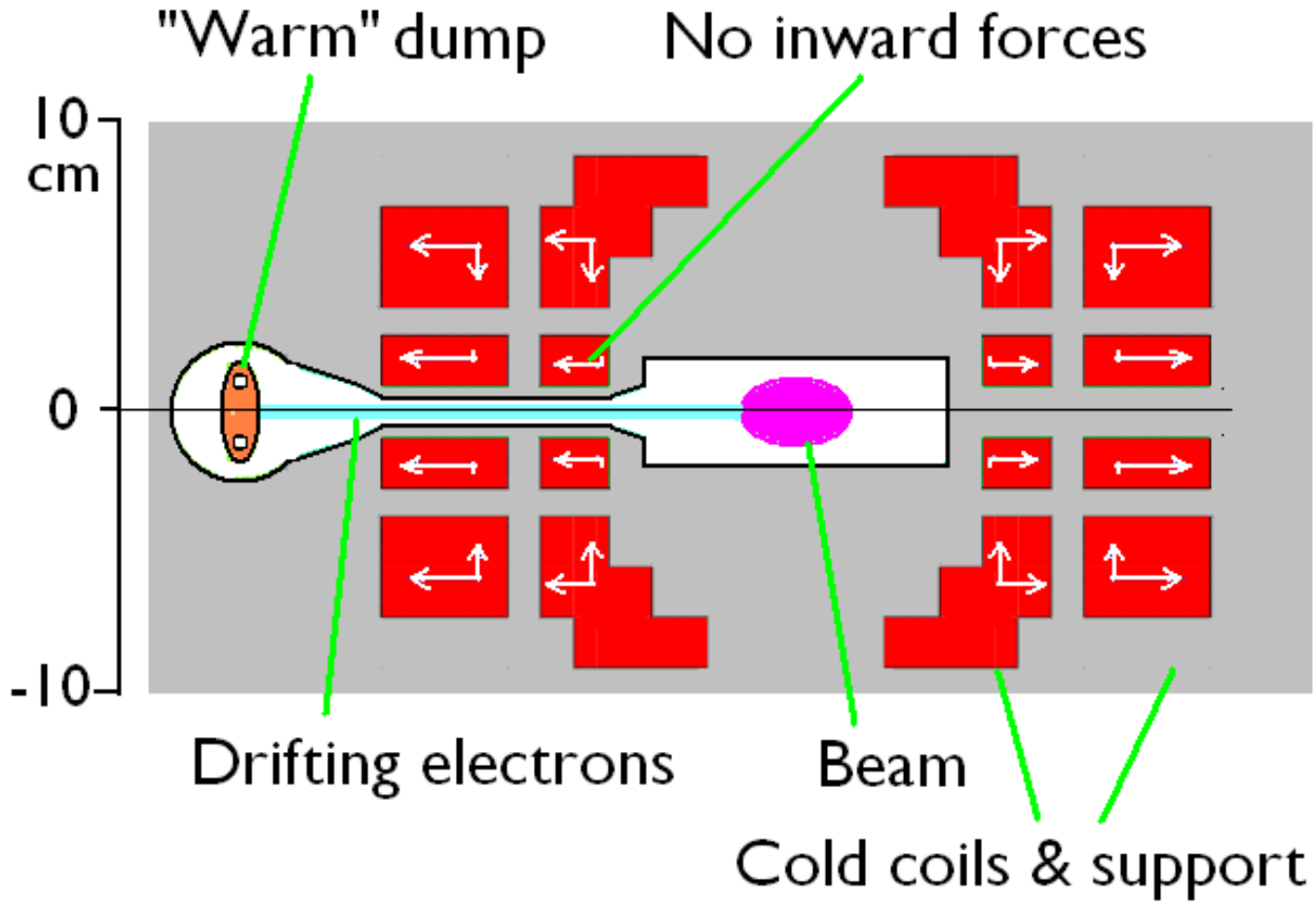
Beta max vs. Beta*



- Even with 2 cm PB: $\beta* = 3.5$ mm vs. 10 mm for same βmax
  $\beta* = 5$ mm has βmax $= 17$ (km)
- Hopefully ok without dipole first (for which there is no room)

HTS/Nb_3Sn Open Mid-Plane Dipole (Gupta)

- HTS Dipoles should allow ave bending field $\approx$ 10 T
- It makes no sense to stay with LTSC dipoles
- 13 T design with Nb3Sn 15 T with HTS



Possible New Parameters

	Current Base	New Ideal	Compromise	
Luminosity	1.0	4.0	1.0	10^{34} cm^{2}sec^{-1}
Beam-beam Tune Shift	0.1	0.1	0.03	
Muons/bunch	2	2	1	10^{12}
Ring <bending field>	5.2	10.4	10.4	T
Beta at IP $= \sigma_z$	10	5	5	mm
rms momentum spread	0.1	0.2	0.1	%
Muon survival	0.07	0.07	0.05	
Repetition Rate	12	12	17	Hz
Proton Driver power	4	4	4	MW
Trans Emittance	25	25	35	pi mm mrad
Final solenoids	50	50	40	T
Long Emittance	72,000	72,000	36,000	pi mm mrad
6D Emittance	45	45	45	10^{-12} (m rad)^3

- 6 D emittance the same
- 15 T open mid-plane dipoles (Gupta)
- 5 mm beta* using high grad quads
- 0.2 % rms mom spread

- Reduced transmission (5% vs. 7%)
- Cooling in 40 T solenoids to 35 μm
- Fewer Muons per bunch (1 vs 2 10^{12})
- Same momentum spread (0.1 % rms)

Conclusion

- 200 T/m Nb_3Sn Quad under construction by LARP
- Using this material: optimize conductor thickness vs radius
- Gradients much higher than assumed now
- Use of such quads could lower $\beta*$
- Also reasonable to use 15 T HTS open mid-plane dipoles
- Allows either
  1. Four times luminosity, or
  2. Easier parameters for same luminosity (Chuck)
- To Do
  - Try grading the super conductor
  - Add a 'First Dipole'
  - Optimize locations and number of steps
  - MARS study of needed shielding
  - Plasma (for μ^-) and e beam (for μ^+) focusing