Magnets for Final Collider cooling

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(& S. Kahn (Muons Inc.) for magnet)

Friday 11/18/05 Meeting

- **60 T HTS Magnet** but not in detail
- Snowmass Requirements for Collider
- Calculated Emittances vs. Energy
- ICOOL Simulations
- Complete Cooling Concept

Magnet design

- Assume all Lorentz forces taken by hoop stress
- windings have alternate superconductor and ss
- Layer winding allows currents and ss thicknesses to vary with radius
- Assume Young's Modulus for conductor = T/S
- Limit strain in superconductor to 0.35 %
- Engineering current density from 'American Superconductor'
  - Use "compression tolerant wire" : .3 mm x 4.85 mm
  - Take best current specification of 100 A/mm^2 at 77 degrees
  - operate at 85% of maximum current
  - Allow 10% for insulation
  - Use linear fit to "Scale Factor" at 4.4 deg. = 2.2 - 0.23 B(T)

Cases Considered

(colors correspond to those of lines in following plots)

1. **Keep current density and thickness of ss constant**
   Allow current margin and strain to vary
2. **Keep current density constant,**
   Allow ss thickness to vary so as to keep strain in ss constant
   Note that if the strains are everywhere the same, all dimensions rise by the same fraction and there is no distortion or increase in radial pressure
3. **Vary current density to keep fixed current margin**
   allow ss thickness to vary
4. **As above, but use Chromium instead of ss**
5. **As above but impose an initial compression on conductor of 0.15 %**

Calculation for variable stainless thickness

$$T = j\ \alpha\ r\ \ B = ((1-\alpha)Y_{ss}\ +\ \alpha\ Y_{sc}\ )S$$

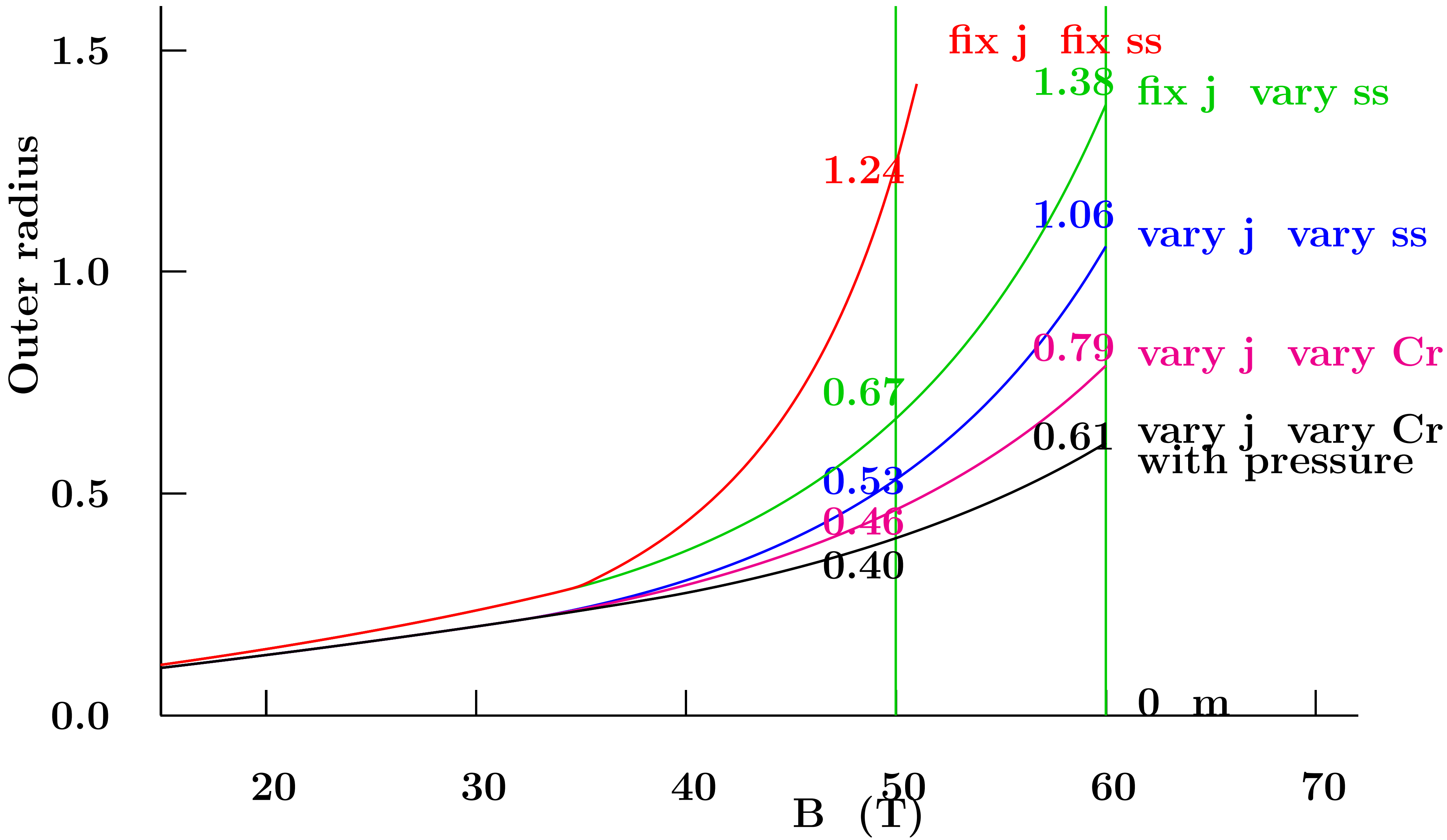
$$r_o = 3(\mathrm{cm}) \qquad \frac{dB}{dr} = j\ \alpha\ \ \mu_o$$

$$\frac{j}{j_o}\ =\ 2.2 - 0.023 \times B$$

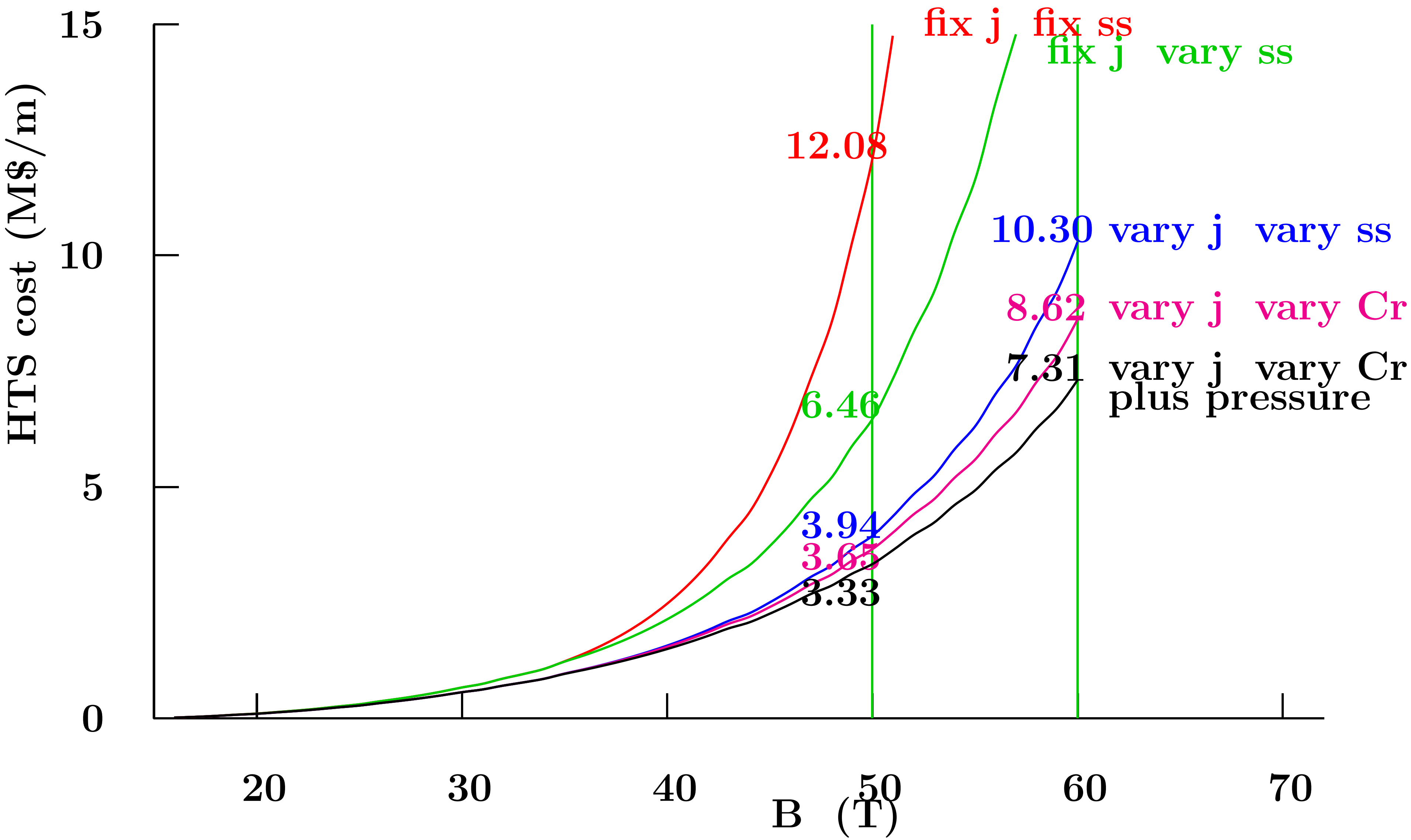
$$j = 100 \times 0.85 \times 0.9\ =\ 76.5(\mathrm{A/mm}^2)$$

Y$_{ss}$**= 192** (GN/m^2) **Y**$_{Cr}$**= 192** (GN/m^2)
Y$_{sc}$**= 85.71429** (GN/m^2)
Max Strain S= .35 (%)
Assumed cable dimensions and cost:
width 4.9 (mm), Thickness 0.30 (mm), Packing 0.90, Cost 20 \$/m

Magnet Radii



HTS Costs


HTS cost (M$/m)
15
10
5
0
20
30
40
50
60
70
B (T)
fix j fix ss
fix j vary ss
12.08
6.46
10.30 vary j vary ss
8.62 vary j vary Cr
7.31 vary j vary Cr
plus pressure
3.94
3.65
3.33

3 TeV Collider requirements

$$\mathcal{L} \propto n_{\rm turns}\ f_{\rm bunch}\ \frac{N_\mu^2}{\sigma_\perp^2} \qquad \Delta\nu \propto \frac{N_\mu}{\epsilon_\perp}$$

$$\mathcal{L} \propto \ < B_{\rm ring} > \ P_{\rm beam}\ \Delta\nu\ \frac{1}{\beta_\perp} \qquad \epsilon_\perp \propto \frac{N_\mu}{\Delta\nu}$$

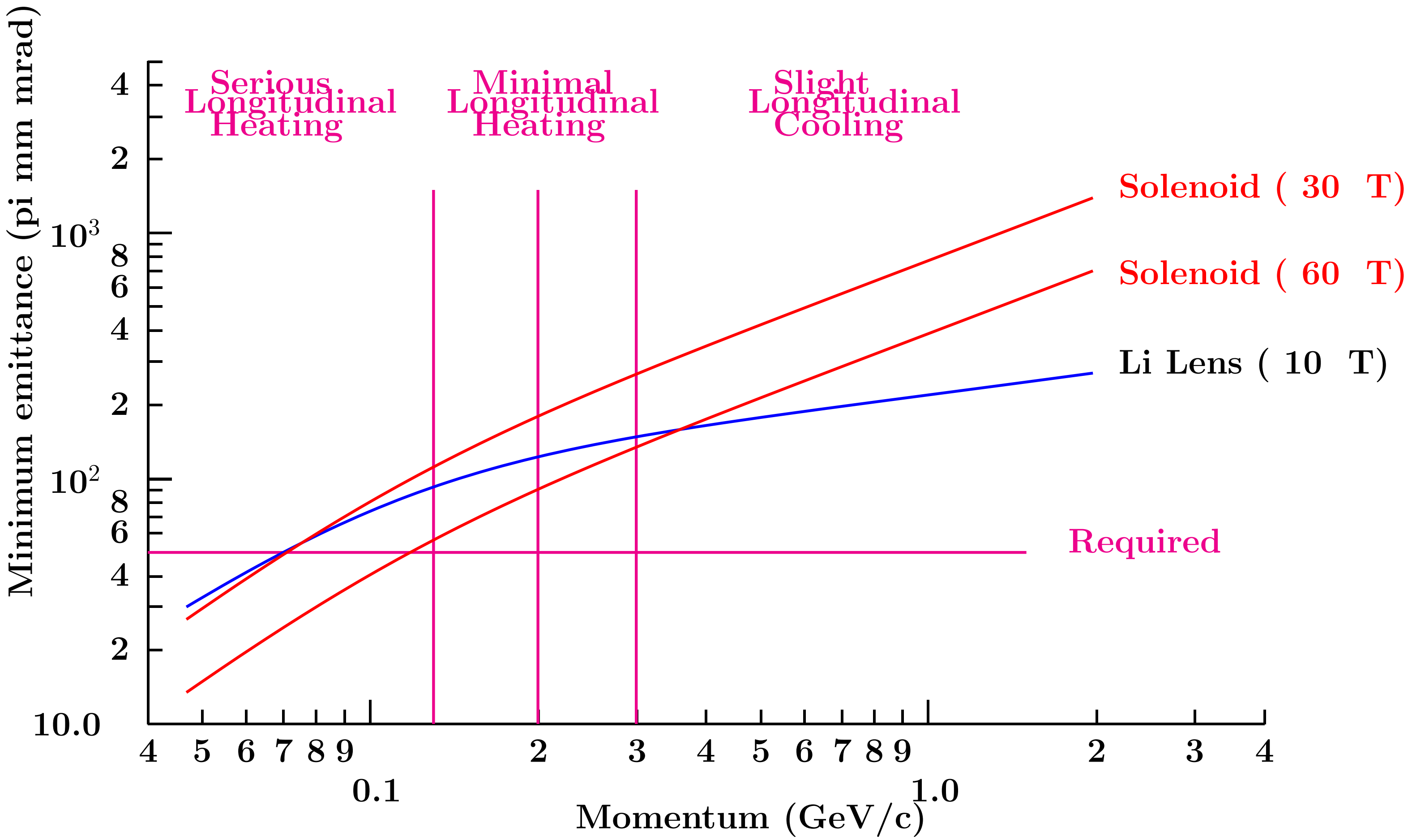
- **Luminosity limited independent of emittance:**
- **Higher $\mathcal{L}/P_{\rm beam}$ requires lower $\beta_\perp$ or correction of $\Delta\nu$**

Snowmass 98 Assumed

Average bending field	**T**	**5.2**
Tune Shift (from e rings)		**0.044**
Luminosity	$10^{33} cm^{-2}$	**70**

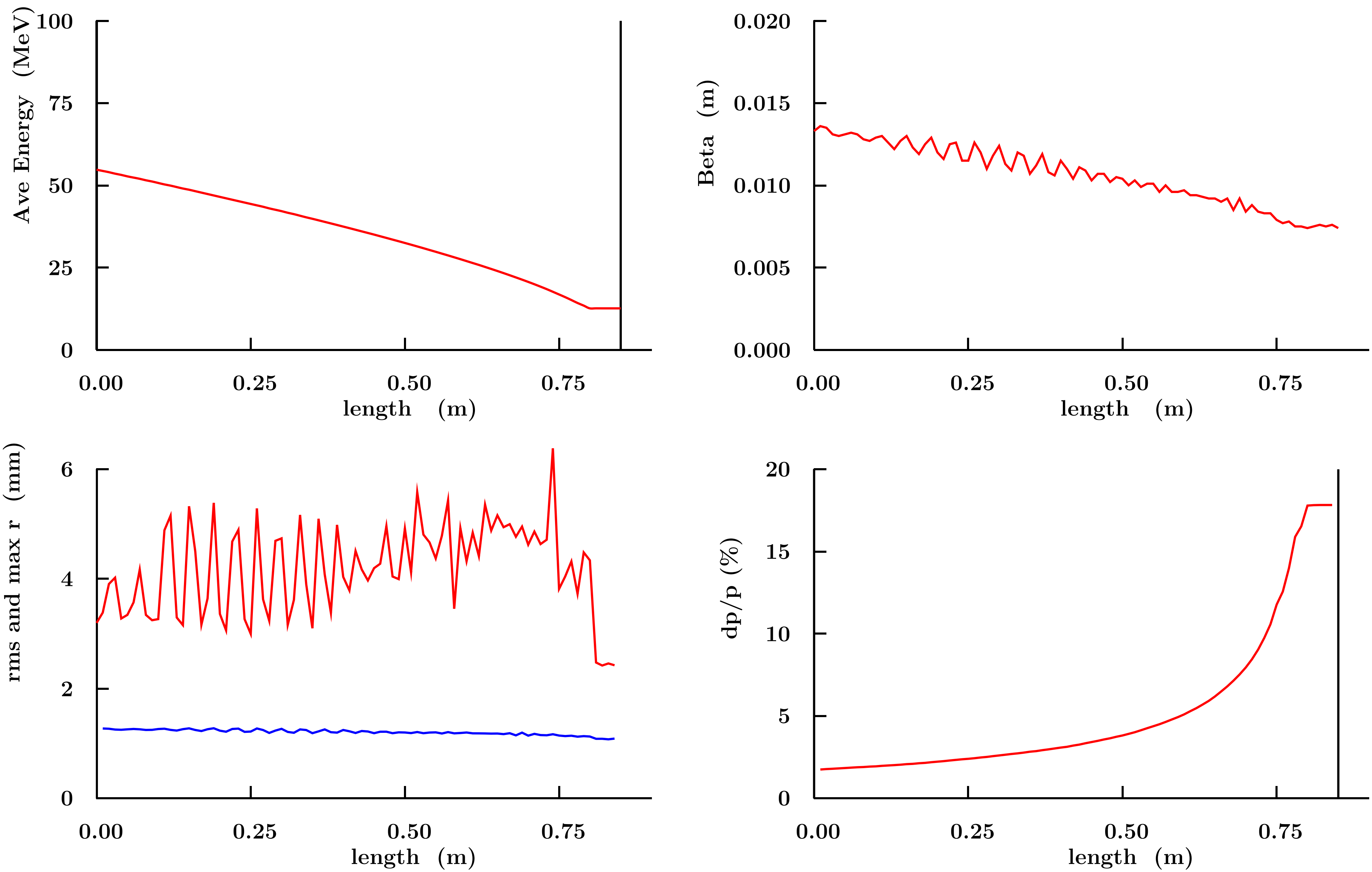
	E_{cm} TeV	N_μ 10^{12}	f Hz	P_μ MW	$\beta_\perp = \sigma_z$ mm	dp/p %	$emit_\perp$ π mm	$emit_\parallel$ π mm	ϵ_6 $(\pi\ mm)^3$
Required	3	2	30	28	3	0.16	.05	72	170
Initial							20	2000	10^9
Factor							400	30	$6\ 10^6$

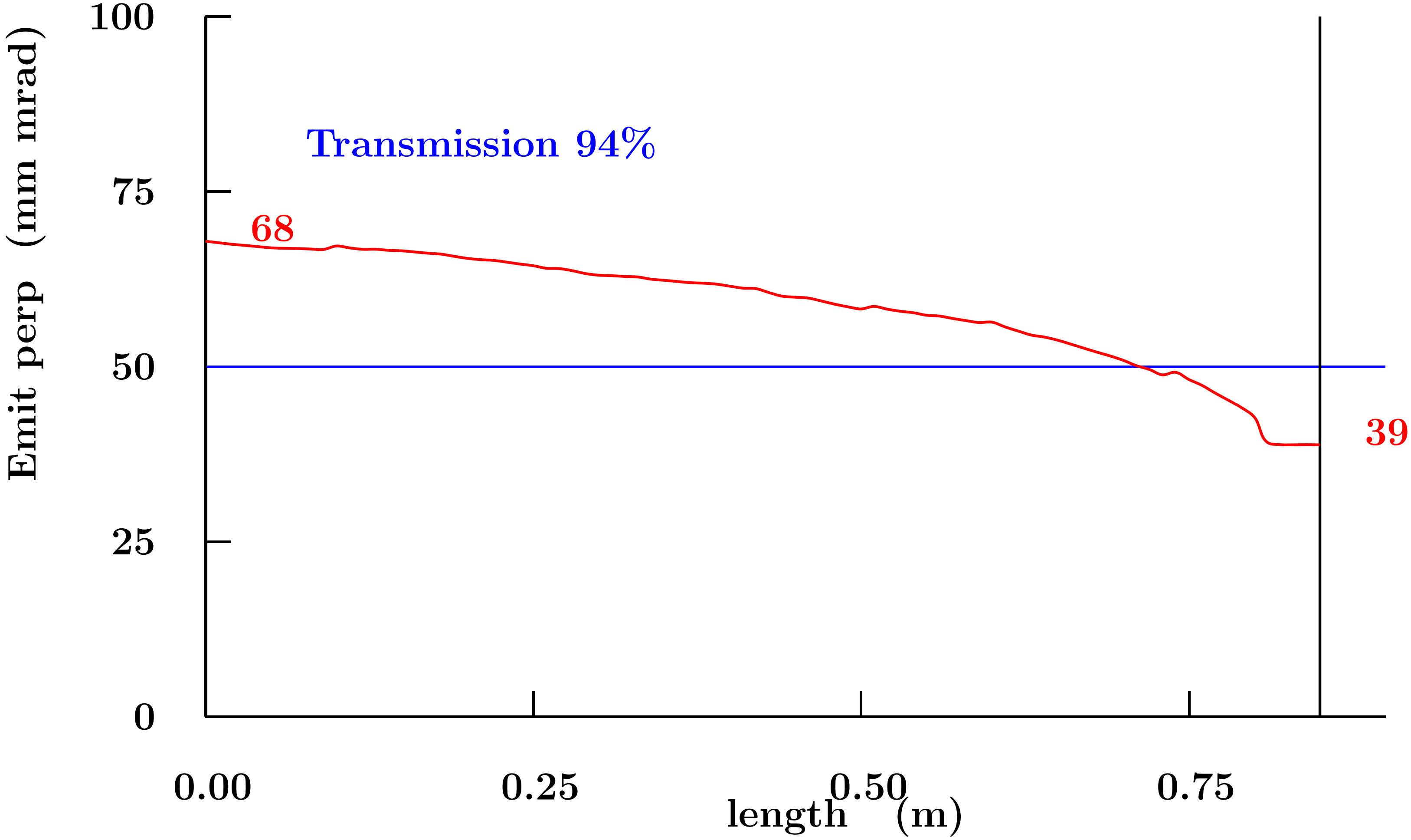
Calculated Minimum Emittance vs. Momentum



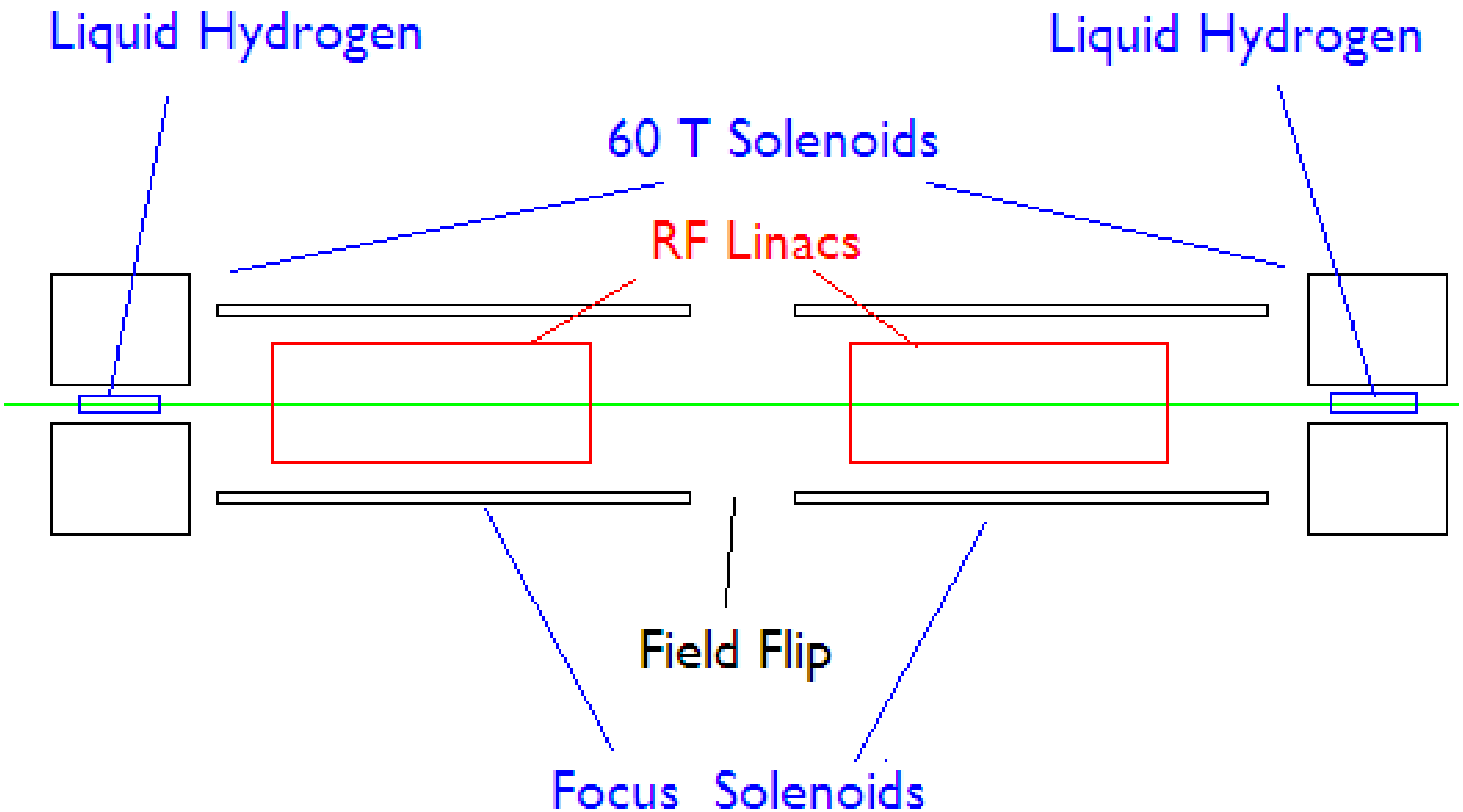
- To reach 50 pi mm, the momentum must be very low and the length of each section must be relatively short
- 30 T Solenoid appears roughly equivalent to 10T Li Lens

ICOOL Simulation of Final Stage

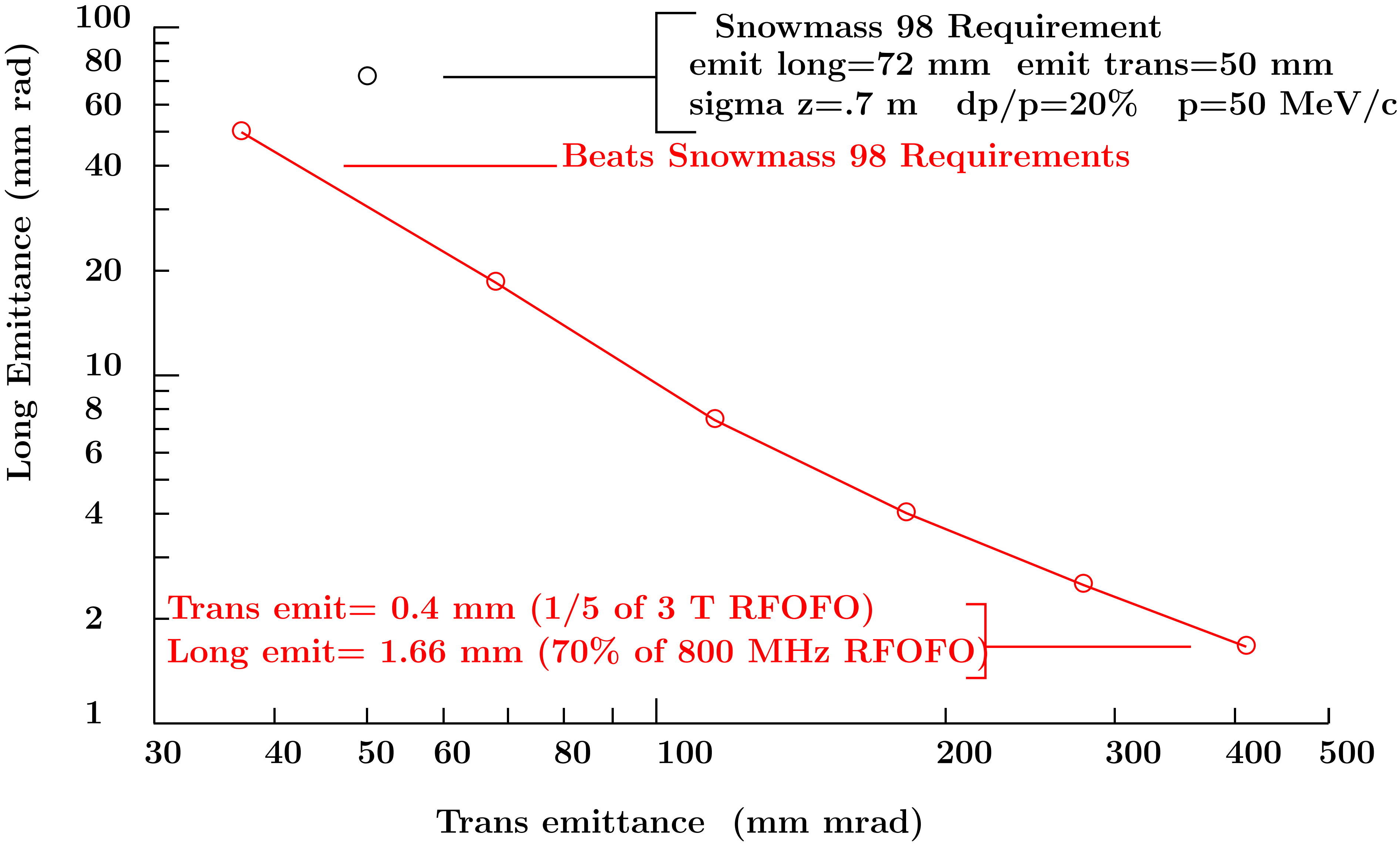



Emit perp (mm mrad)
100
75
50
25
0
Transmission 94%
68
39
0.00
0.25
0.50
0.75
length (m)

Concept of Final cooling Stages



Cooling in Last Five 60 T Magnets



Parameters of Stages

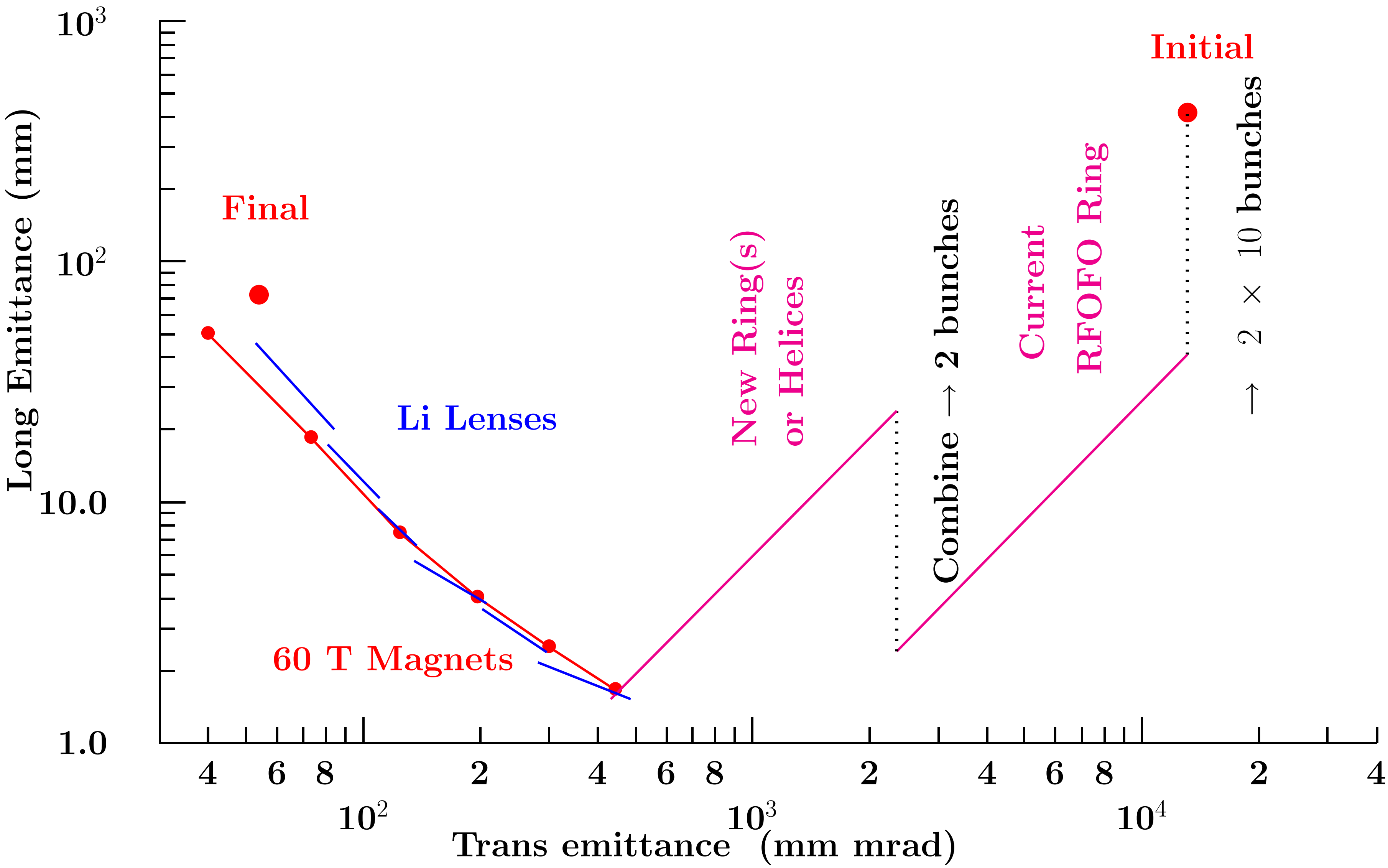
Emittances are at ends of each stage

	emit trans mm mrad	emit long mm	dp/p 1 %	dp/p 2 %	E1 MeV	E2 MeV	dE MeV	sigmaz cm	min freq MHz
1	278	2.5	3.3	8	53	11	42	3.5	800
2	182	4	2.7	8	57	15	41	6.1	400
3	115	7.4	2.5	11	60	22	38	9.4	200
4	68	18.5	2	15	64	28	36	21	100
5	37	50	2	20	68	33	35	50	100

Note

- dp/p increases in each stage
  and must be reduced by phase rotation in linacs
- Bunch lengths are increasing
- Acceleration Frequencies must fall
- But acceleration required is small

Full System & Li Lens comparison



Conclusion

- 60 T HTS Solenoids may be feasible
- ICOOL simulation shows emittance of order 40 pi mm mrad after 0.8 m at 60 T
  Meets Snowmass 98 Requirement
- Five Magnets can cool from beam plausibly obtained from 6 D Ring
- Performance seems similar to Li Lenses
  But Transmission 92% vs 67% = 2 times luminosity
  R&D being done for us
  and Li Lens matching much harder