p-p Collider Costs and Luminosity Considerations

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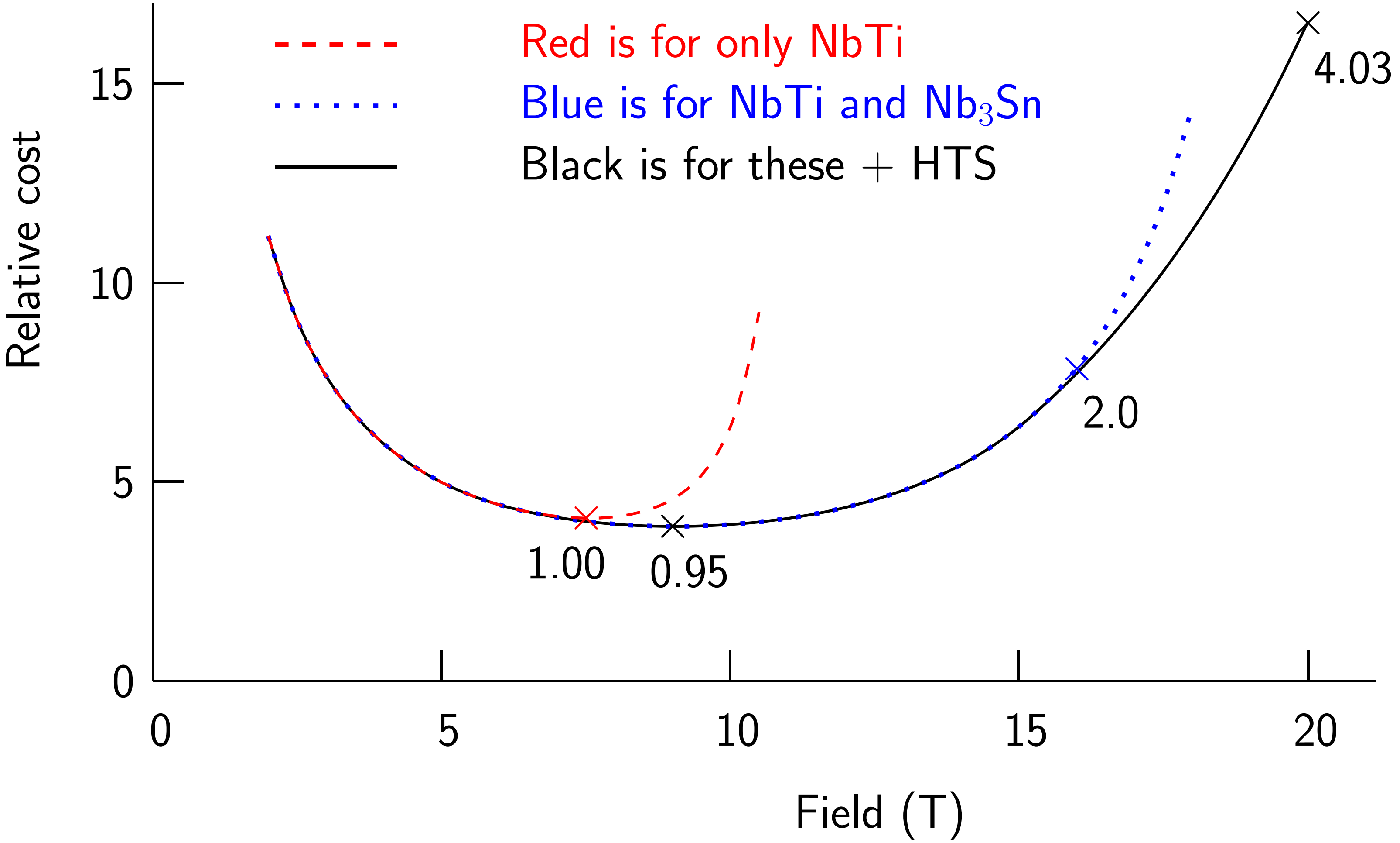
1. Estimated Costs vs. Dipole Magnetic Fields
2. Luminosity Evolution with high Dipole Magnetic Fields
3. Appendix on Earlier Study

Part I
Total Costs vs. Dipole Fields
Earlier Study (see appendix)

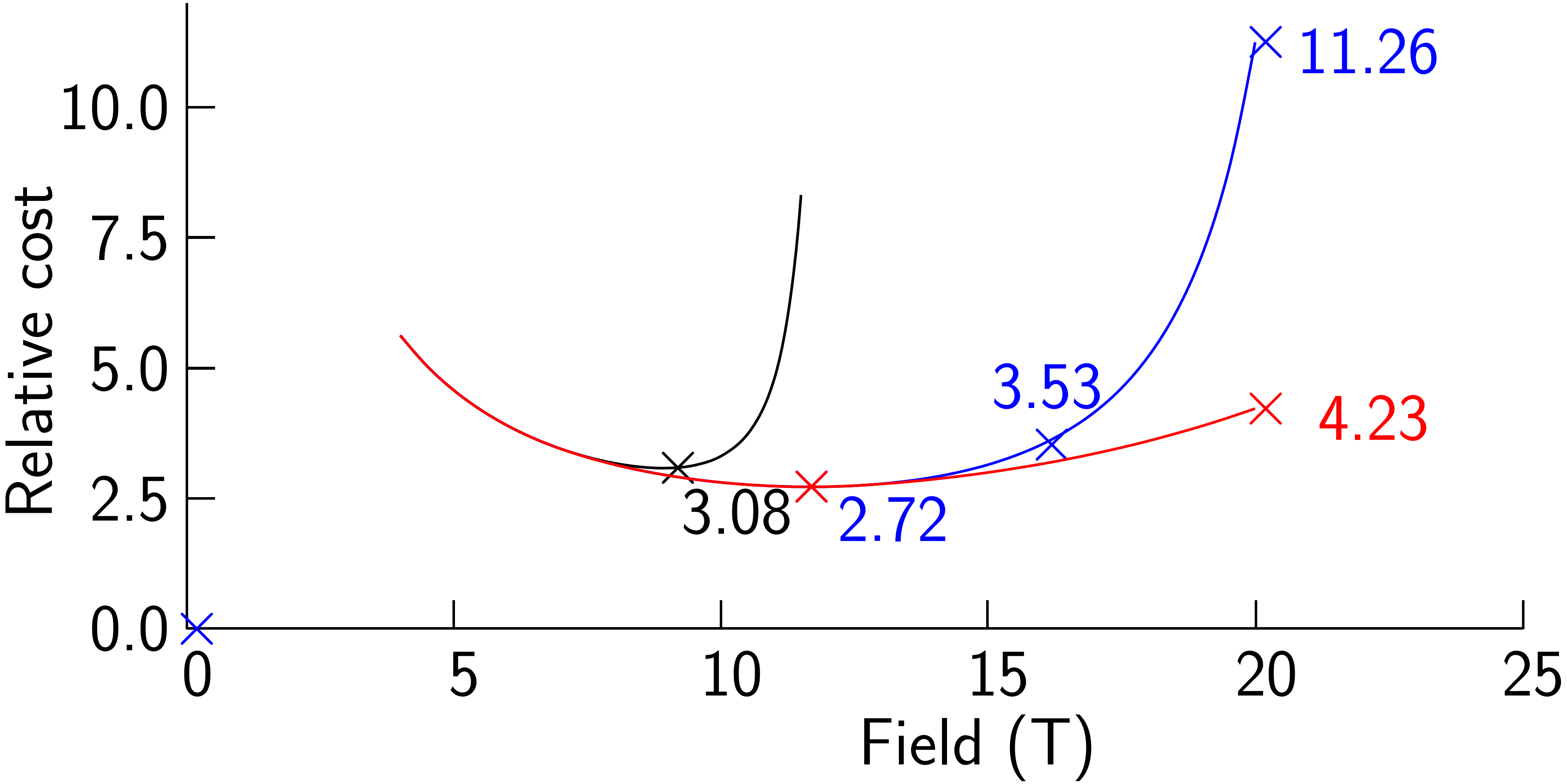


Exploration of more optimistic Assumptions

- Allow saturation for Yoke diam approx 72 cm
  Program protests the high level of saturation
- Assume BSCCO cost 7.5 times NbTi (c.f. factor 15)
- Nb3Sn still 4 times NbTi
- BSCCO latest 100 atmosphere processed current densities
- Collars to hold forces

These assumptions chosen to favor the high field case

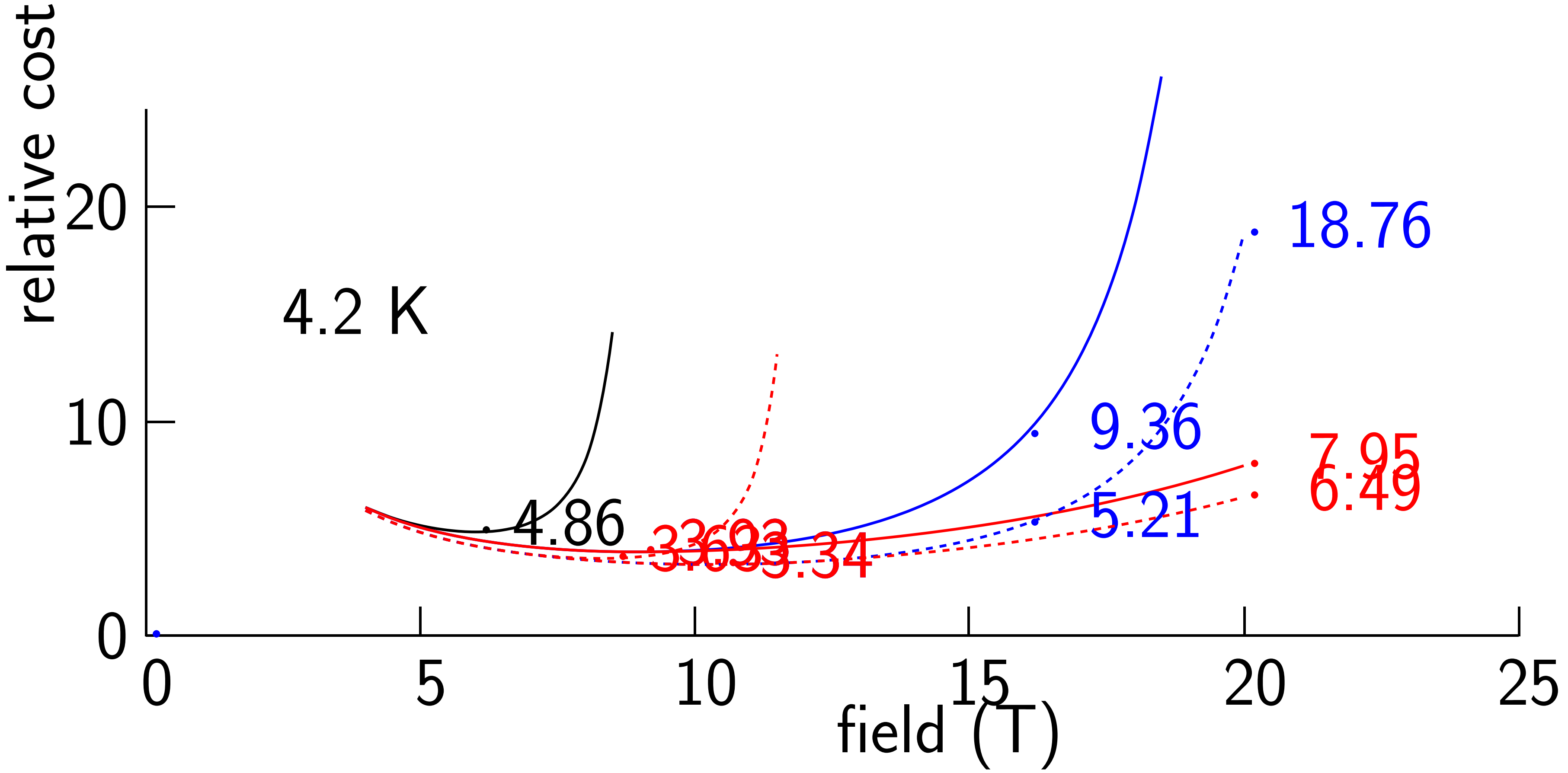
Cost vs. Dipole Field



20 T + HTS: cost 1.20 times 16 T with Nb3Sn

and 1.55 times 12 T with Nb3Sn minimum

Cost at 4.2 K



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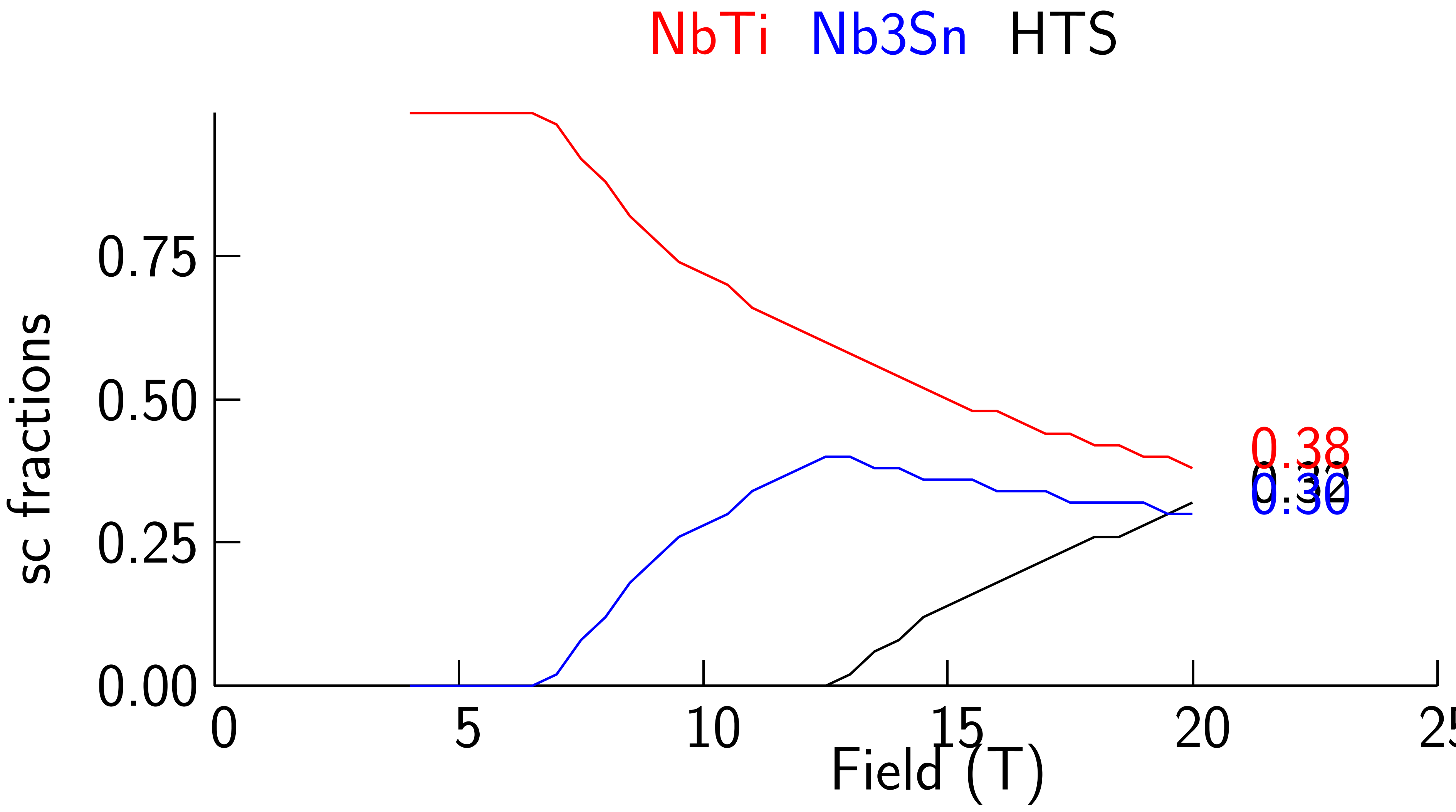
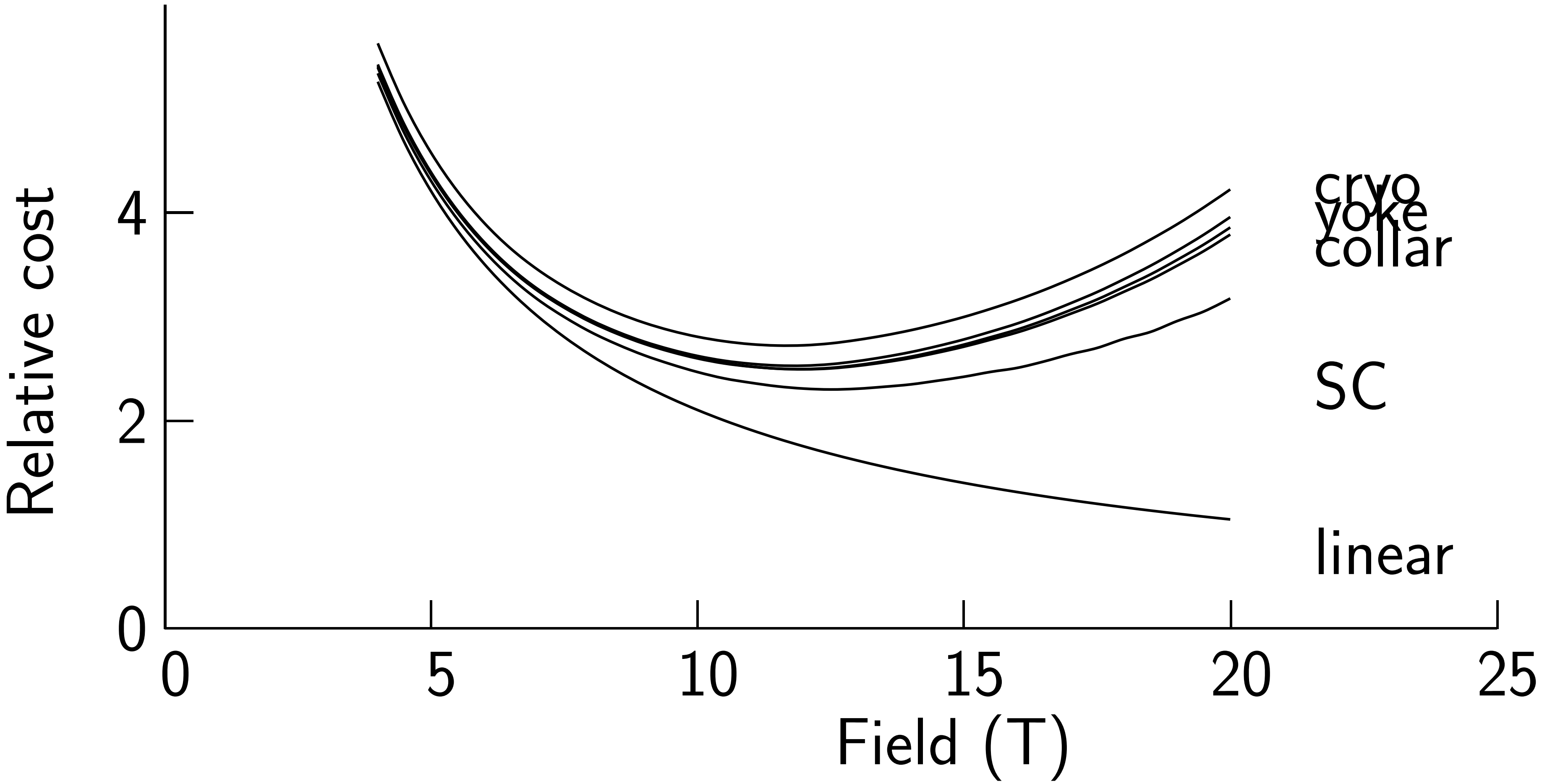
Superconductor Fractions

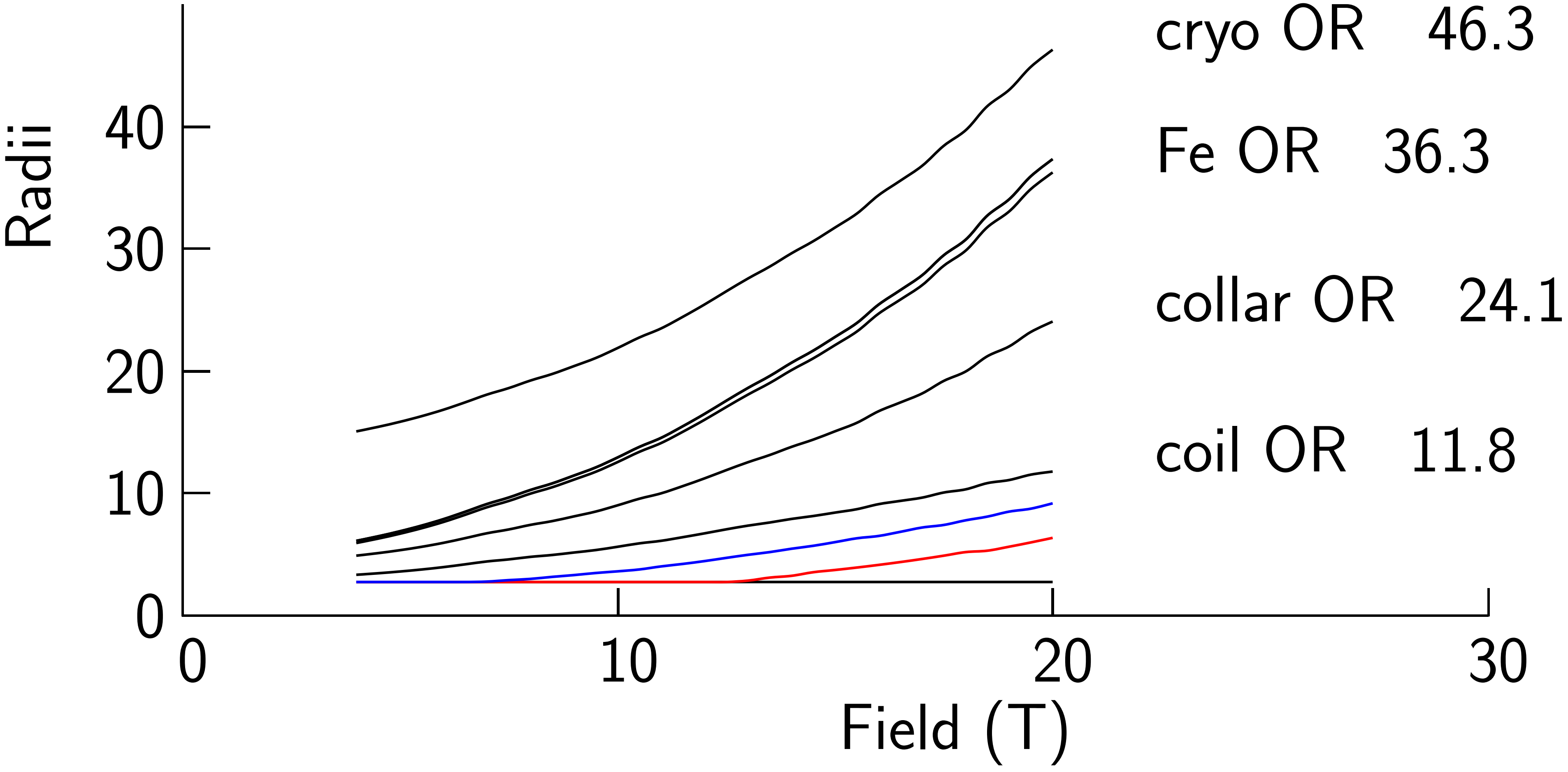


Relative Costs of Components

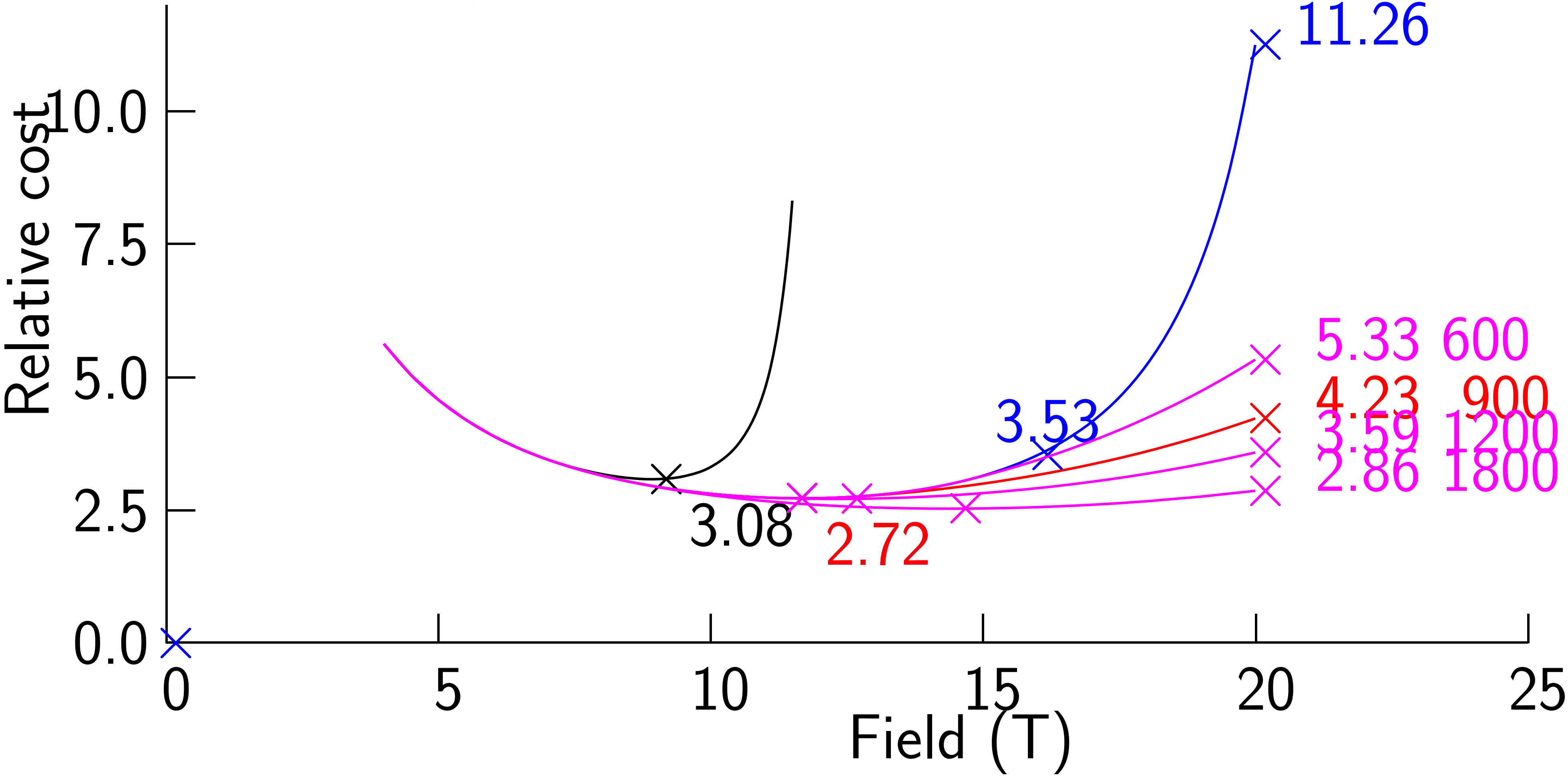


Dominated by superconductor costs

Radii of Components



vs. HTS current densities



If j(HTS) 1.5 times: cost 1.02 times 16 T with Nb3Sn

If j(HTS) 2.0 times: cost 0.81 times 16 T with Nb3Sn

and only 1.05 times 12 T Nb3Sn min

Conclusion

- With optimistic assumptions:
  - Costs could favor the use of HTS
  - Costs could be insensitive to field chosen
  - But minimum total cost is still probably in the 10-15 T range
- With almost any assumptions
  - It is cheaper to run at 1.8 K for the improved current densities in NbTi and Nb3Sn outer coils.

Part II

Study of Peak and average Luminosity

In collaboration with Tang Jingyu at IHEP

Discussing an advantage of using of high magnetic fields

Introduction I

The Chinese IHEP is proposing a two stage project:

1. CEPC: Circular Electron-Positron Collider
2. SPPC: Super Proton-Proton Collider in same tunnel

Circumference	54	km
Center of mass Energy	70.6	TeV
Dipole Fields	20	T
Peak Initial Luminosity	1.2	10^{35} $cm^{-2}s^{-1}$
Beta function at IP (β^*)	75	cm
Bunch Separation	25	nm
Protons per bunch	2	10^{11}
Initial normalized emittance ($\epsilon_\perp$)	4.1	μm
rms bunch length	7.5	cm

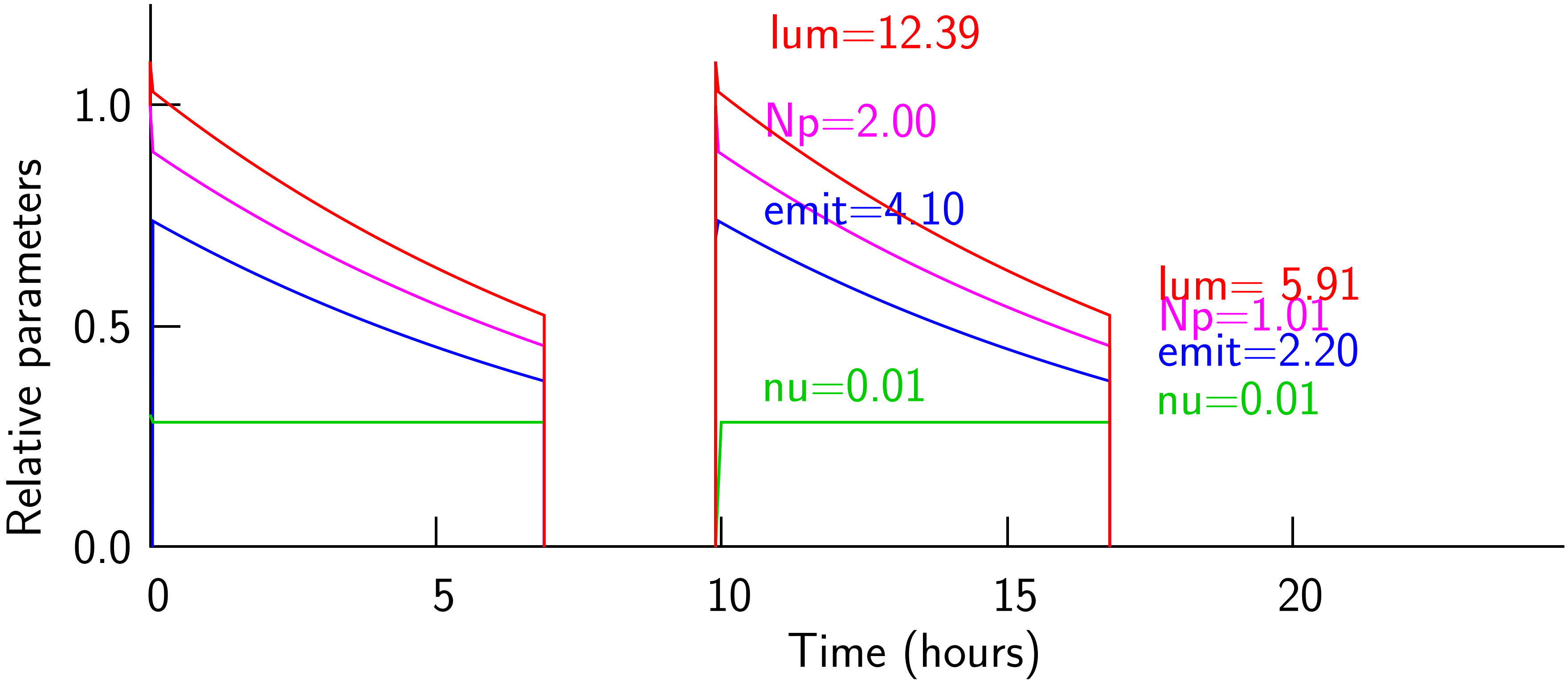
Introduction II

- Runs will start with electron bunches of $2\ 10^{11}$
- The initial normalized emmittsnce is $\epsilon = 4.1 \ \ \mu$m,
- These will give initial luminosity 12.4 $10^{34} \ \ cm^{-2}s^{-1}$, and initial tune shift $\xi = 0.01$
- Interactions will reduce N_p decreasing the tune shift

$$\xi \propto N_p/\epsilon_\perp$$

- But synchrotron radiation (that is higher with high B) can reduce the emittances ($\epsilon_\perp$) that would excessively increase the tune shift
- A transverse noise source is required to limit the emittance cooling and could control tune shifts as required

a) Fixed Tune Shift $\xi = .01$



turnaround time= 3 hr run time= 6.9 hr

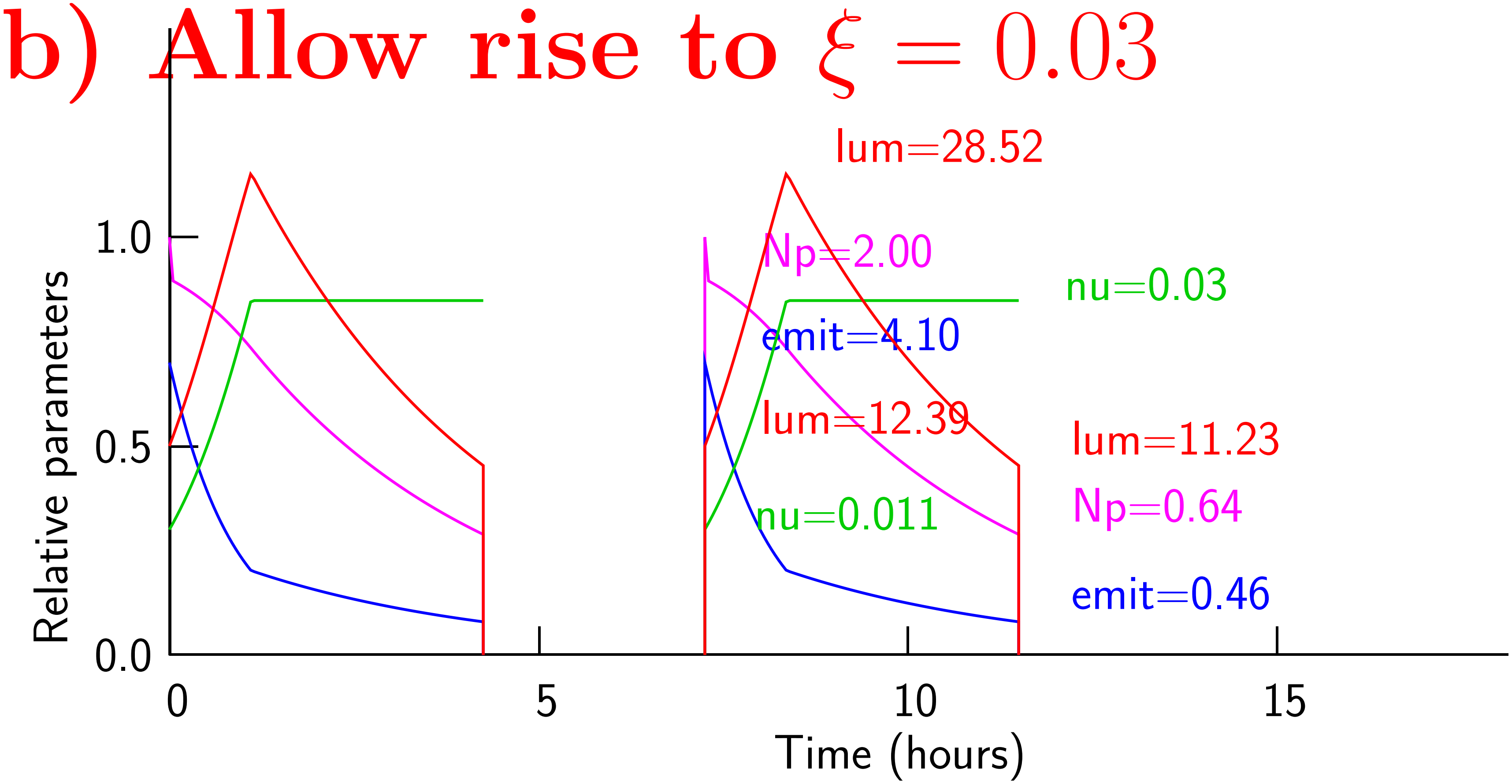
Average Luminosity 5.89 $10^{34}\ cm^{-2}s^{-1}$

Only about half the initial value

490 interactions per crossing

Considered ok as technology improves

b) Allow rise to $\xi = 0.03$



turnaround time= 3 hr run time= 4.25 hr

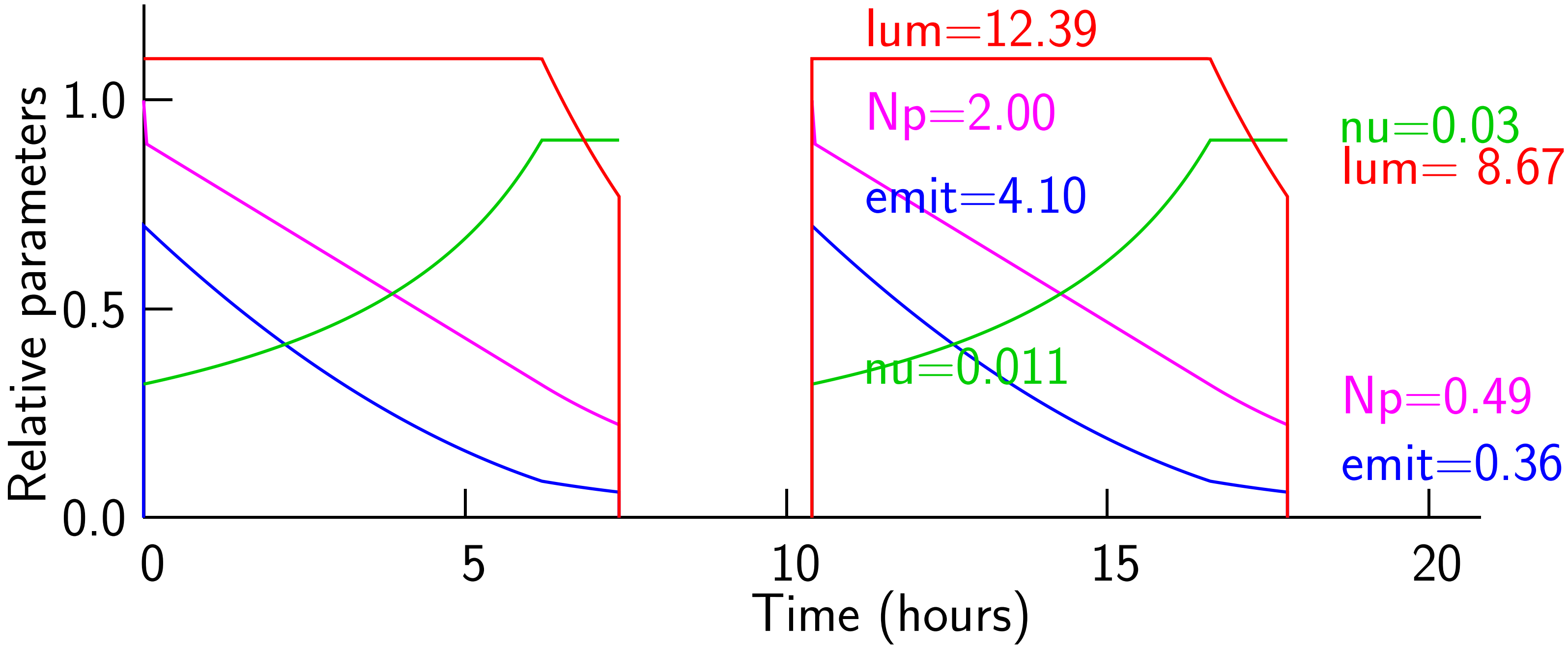
Average Luminosity 11.12 $10^{34}\ cm^{-2}s^{-1}$

1120 interactions per crossing

Definitely too high

c) Level Luminosity $\mathcal{L} = 12.4\ 10^{34}$

Use noise to control emittance drop and limit luminosity



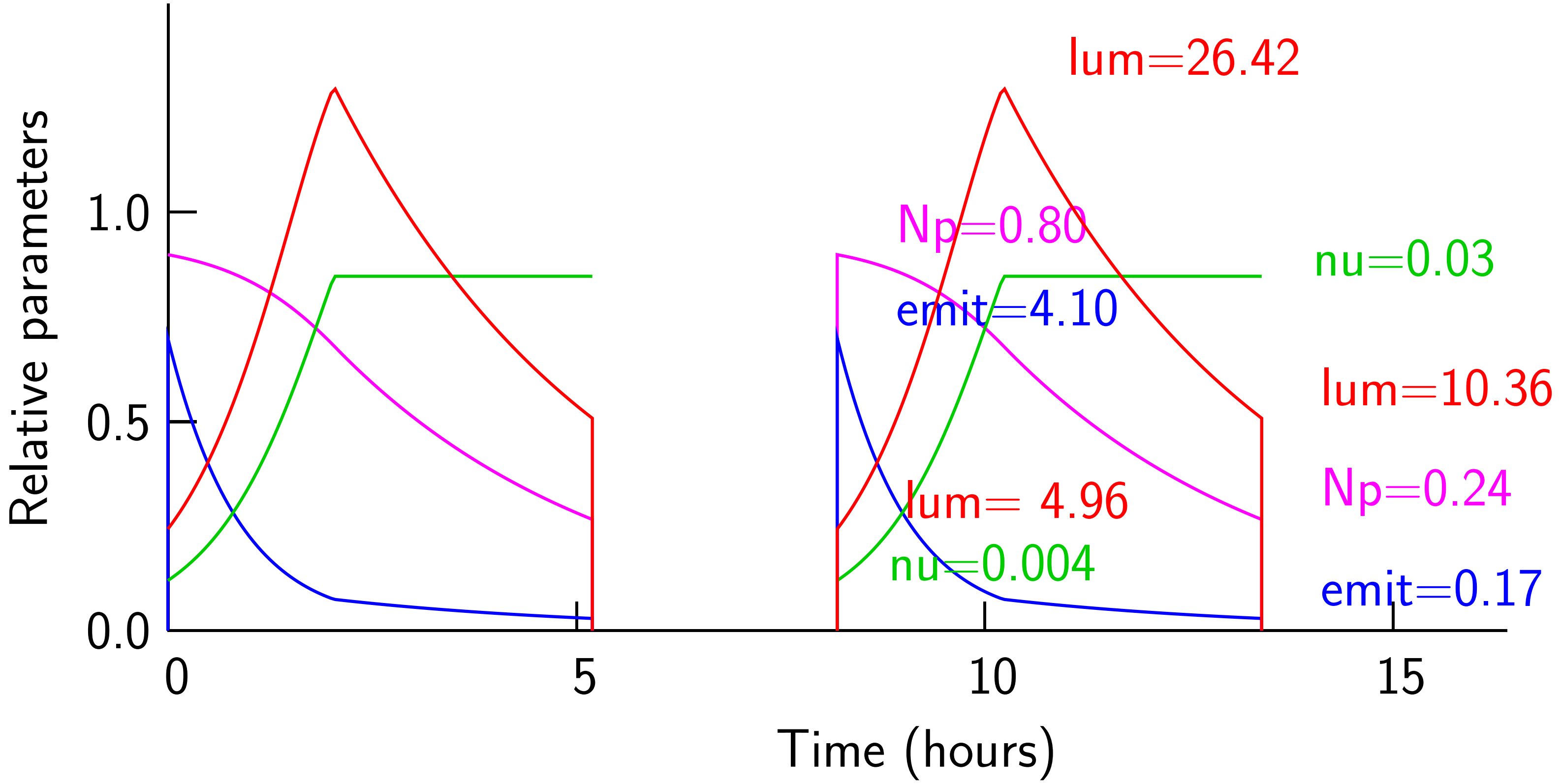
turnaround time= 3 hr run time= 7.4 hr

Average Luminosity 8.58 $10^{34}\ cm^{-2} s^{-1}$

490 interactions per crossing, considered ok in future

d) Lower sep $\Delta t: \ 25 \rightarrow 10$ ns

Lower N_p to keep same current: reduces initial luminosity



turnaround time= 3 hr run time= 5.2 hr

Average Luminosity 10.23 $10^{34}\ cm^{-2}s^{-1}$

415 interactions per crossing, certainly ok

Stronger focusing: reduced β^*

The luminosity starting lower, never reaches the maximum events per bunch crossing, but we can increase it if we can lower β^*. But a lower β^* implies an increase in angular spread from the IP

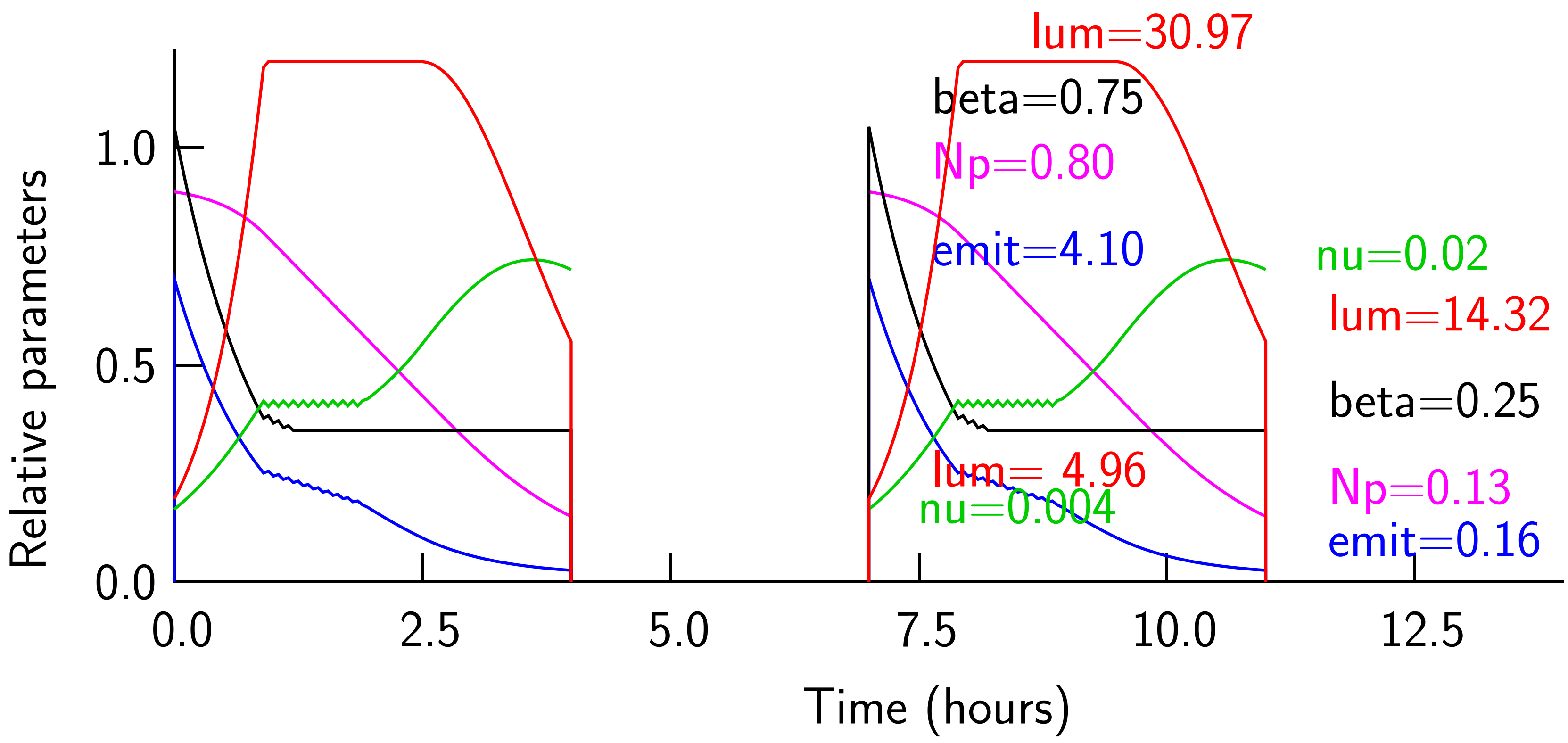
$$\theta^* = \sqrt{\frac{\epsilon_\perp}{\beta^*\ \beta_v\gamma}}$$

increasing the beam size at the final focusing triplet

$$\sigma_{R\ in\ triplet}\ \approx\ L\ \theta^*\ \propto\ \sqrt{\frac{\epsilon_\perp}{\beta^*}}$$

But if β^* is only reduced in proportion to the synchrotron reduced emittance $\epsilon_\perp$, then the beam radius at the triplet is not increased

e) β^* reduced + leveling



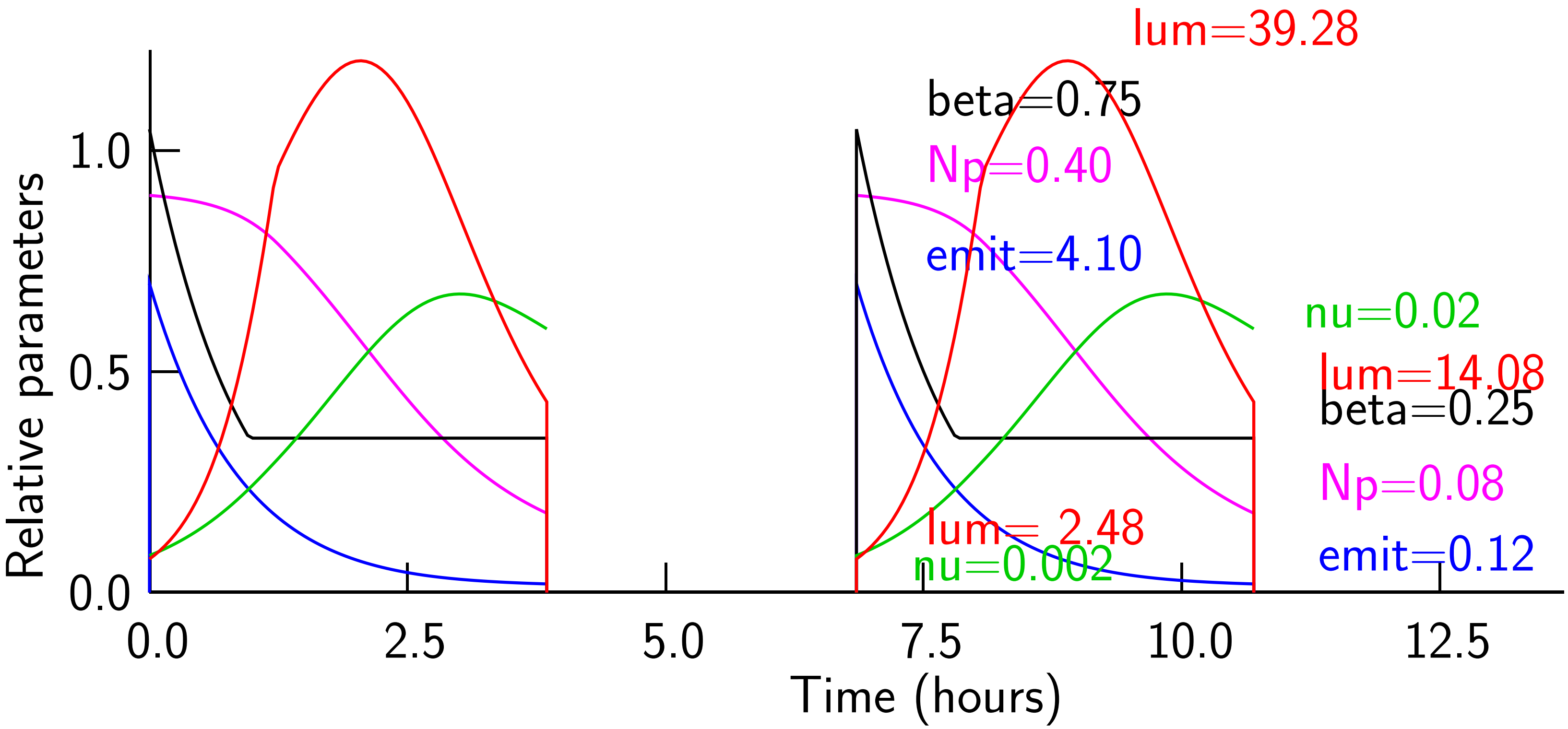
turnaround time= 3 hr run time= 4 hr

Average Luminosity 14.18 $10^{34}\ cm^{-2}s^{-1}$

490 interactions per crossing again

ok

f) Bunch separation $\Delta t = 5ns$



turnaround time= 3 hr run time= 3.85 hr

Average Luminosity 13.96 $10^{34}\ cm^{-2}s^{-1}$

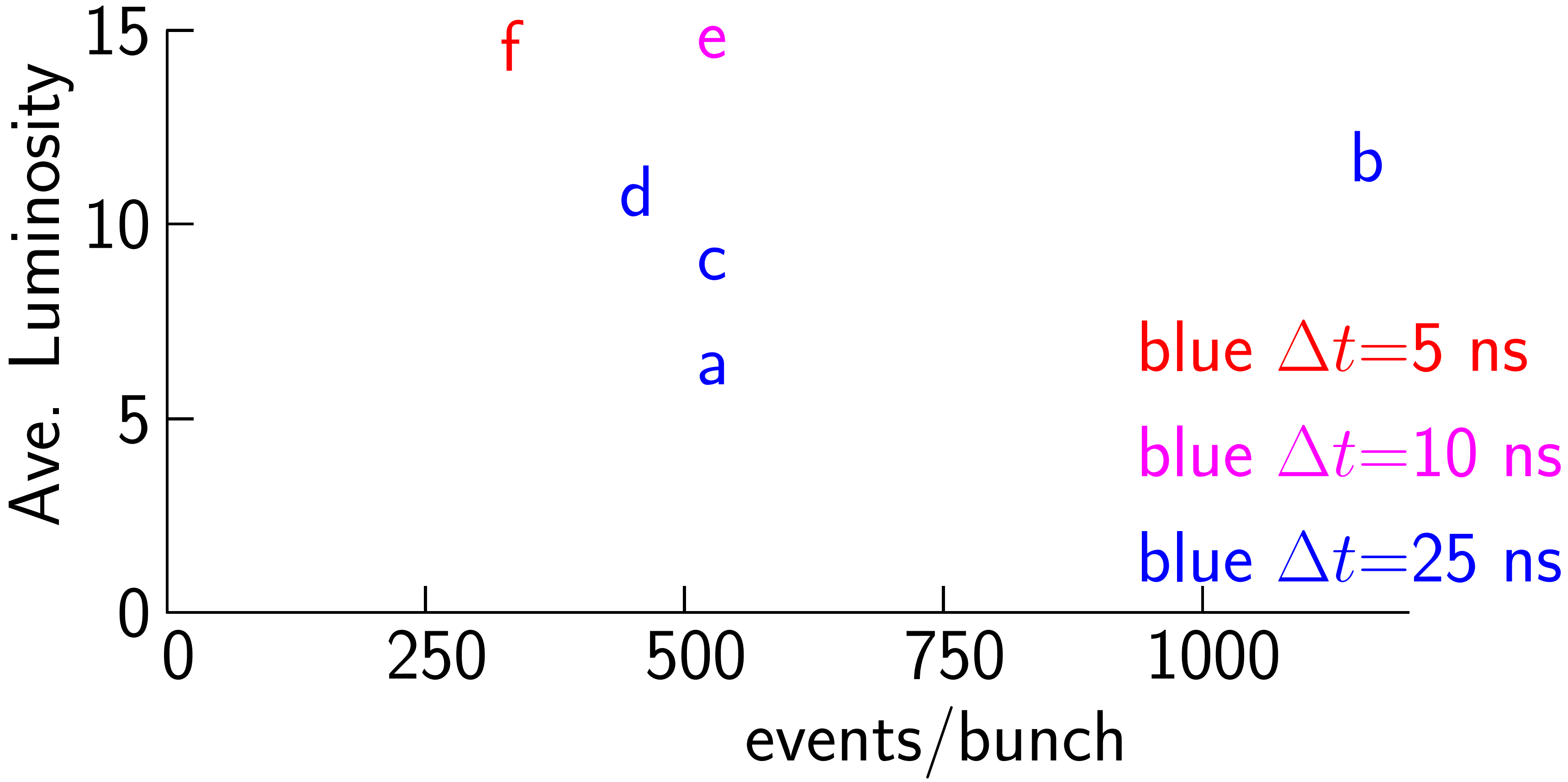
almost the same luminosity but fewer (300 vs 490) interactions per bunch crossing and electron cloud may be less

Summary

For turnaround times = 3 hr. except those in parentheses for 0.77 hr.

	Run hr	endϵ μm	end Np 10^{11}	endβ^* cm	n/cross	Ave Lum $10^{34}\ cm^{-2}s^{-1}$
Initial		4.1	2	75	12.4	3 (0.77)
a) Conservative	6.9	2.2	0.64	75	490	5.89 (8.08)
b) $\xi \rightarrow$ 0.03	4.25	0.46	0.64	75	1120	11.12 (16.93)
c) Level lum	7.4	0.36	0.49	75	490	8.58 (11.05)
d) $\Delta t = 10$ ns	5.2	0.17	0.24	75	415	10.23 (14.49)
e) $\beta^* \rightarrow$ 25 cm	4.05	0.16	0.13	25	490	14.30 (21.21)
f) $\Delta t = 5$ ns	3.85	0.12	0.08	25	300	13.96 (21.13)

Luminosity vs. Pile-up



Conclusion

- Even Conservative SPPC Average Luminosity is high
- But can perhaps be further increased ≈ 3 times by:
  - allowing synchrotron damping to reduce the beam emittance, and
  - reducing the intersection point (IP) β^* as the emittance falls
- Reducing the turnaround time would further increase the average luminosity
- These ideas will need further study

Appendix: Earlier Cost Study

$$U \;\propto\; circ\; B^2\; R_{ave}^2$$

$$R_{ave} \;\approx\; \propto B \qquad circ \;\propto\; \frac{1}{B}$$

$$U \;\propto\; \frac{B\; B^2}{B} \;\propto\; B^2$$

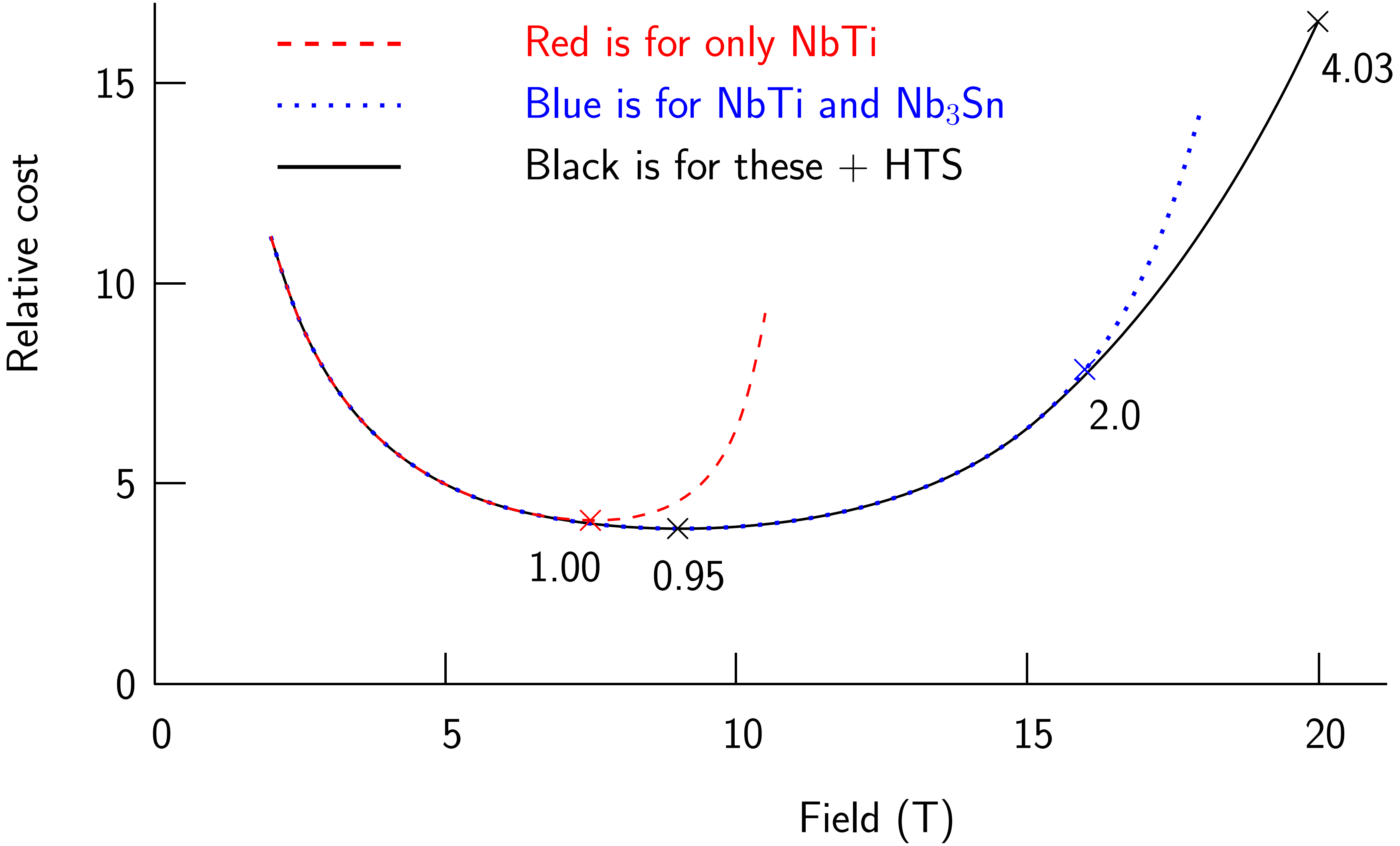
$$M_{sc} \;\propto\; circ\; B\; R_{ave} \propto \frac{B^2}{B} \;\propto\; B$$

Method

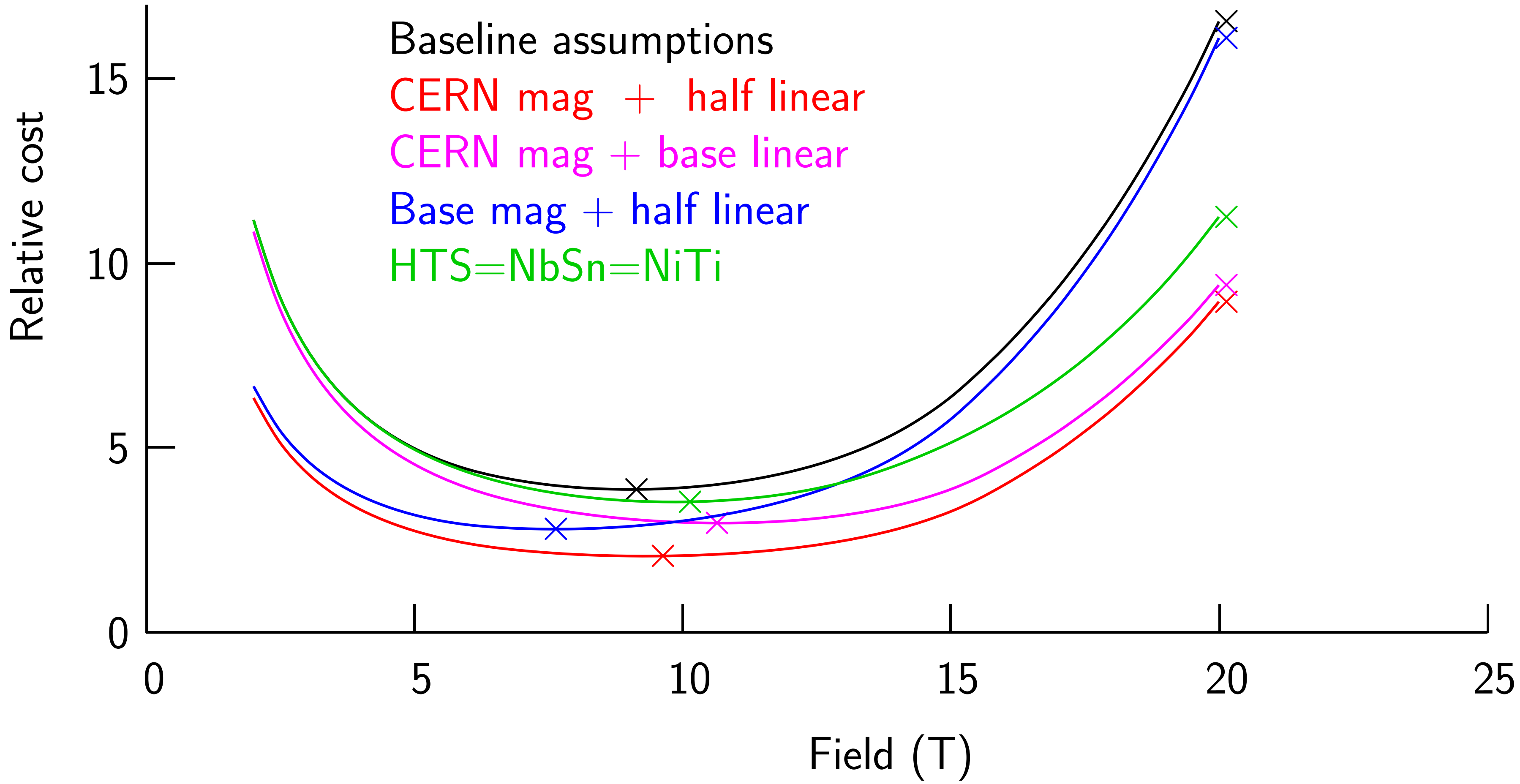
- For different bending fields and different fractions of NbTi, Nb_3Sn, & HTS conductors:
  - Calculate Yoke cross section for minimal saturation
  - Find collar dimensions to hold coil forces
  - Use CERN estimated sc costs and SSC data for support, yoke, cryogenic, and tunnel costs
- Find fractions of conductors to minimize magnet costs
- Determine total magnet and tunnel costs vs. field

At low fields tunnel and other 'linear' costs dominate. At high fields super-conductor and other magnet costs dominate. Between these is a minimum

Costs vs. Bending fields



Sensitivity to Assumptions



CONCLUSION

- This analysis suggests that 20 T is significantly more expensive than $\leq$ 16 T
- This conclusion does not seem sensitive to the assumptions
- But the result may not be relevant if the development of very high field technology is a significant motivation