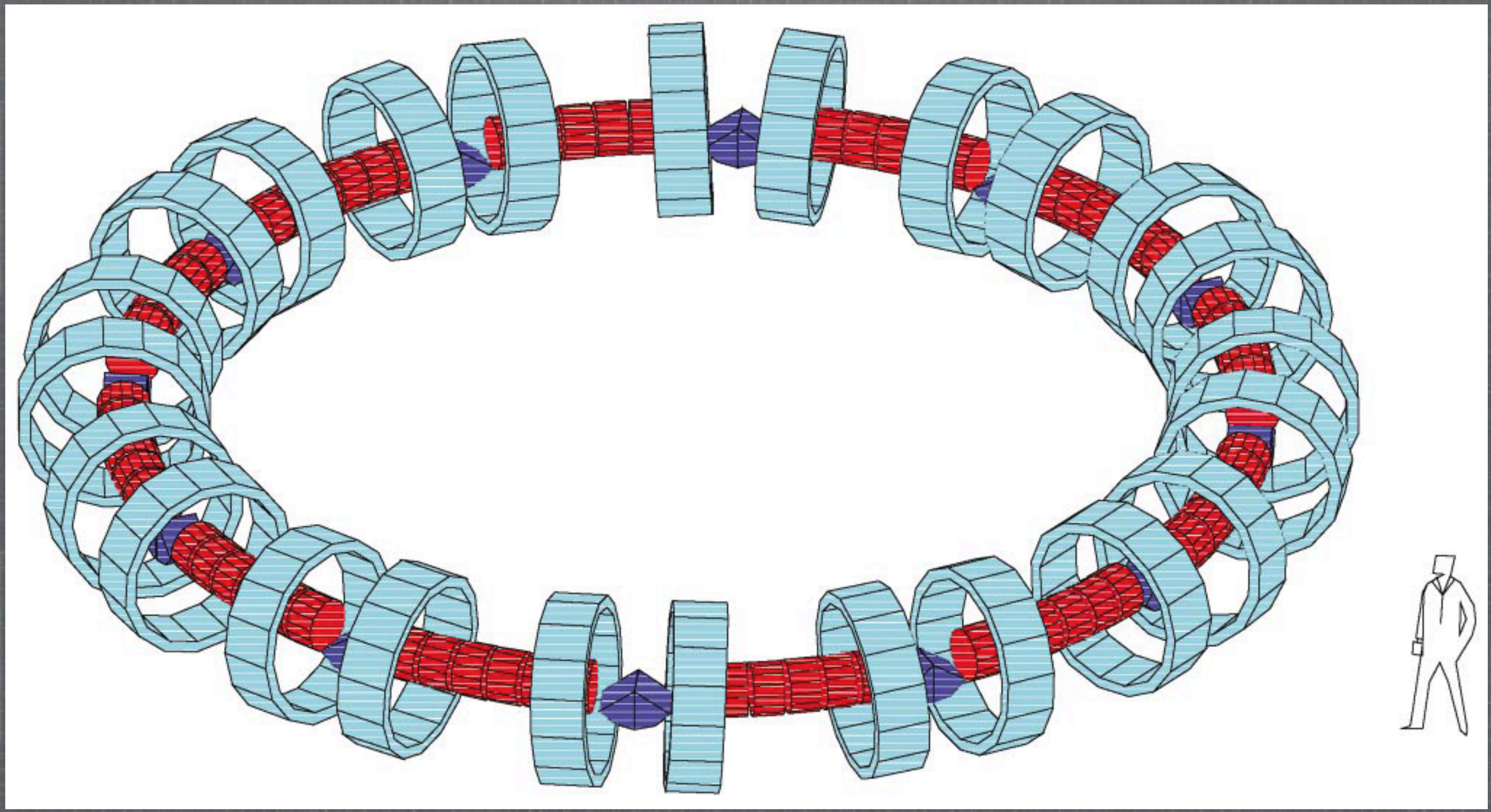
FINAL COOLING STUDIES

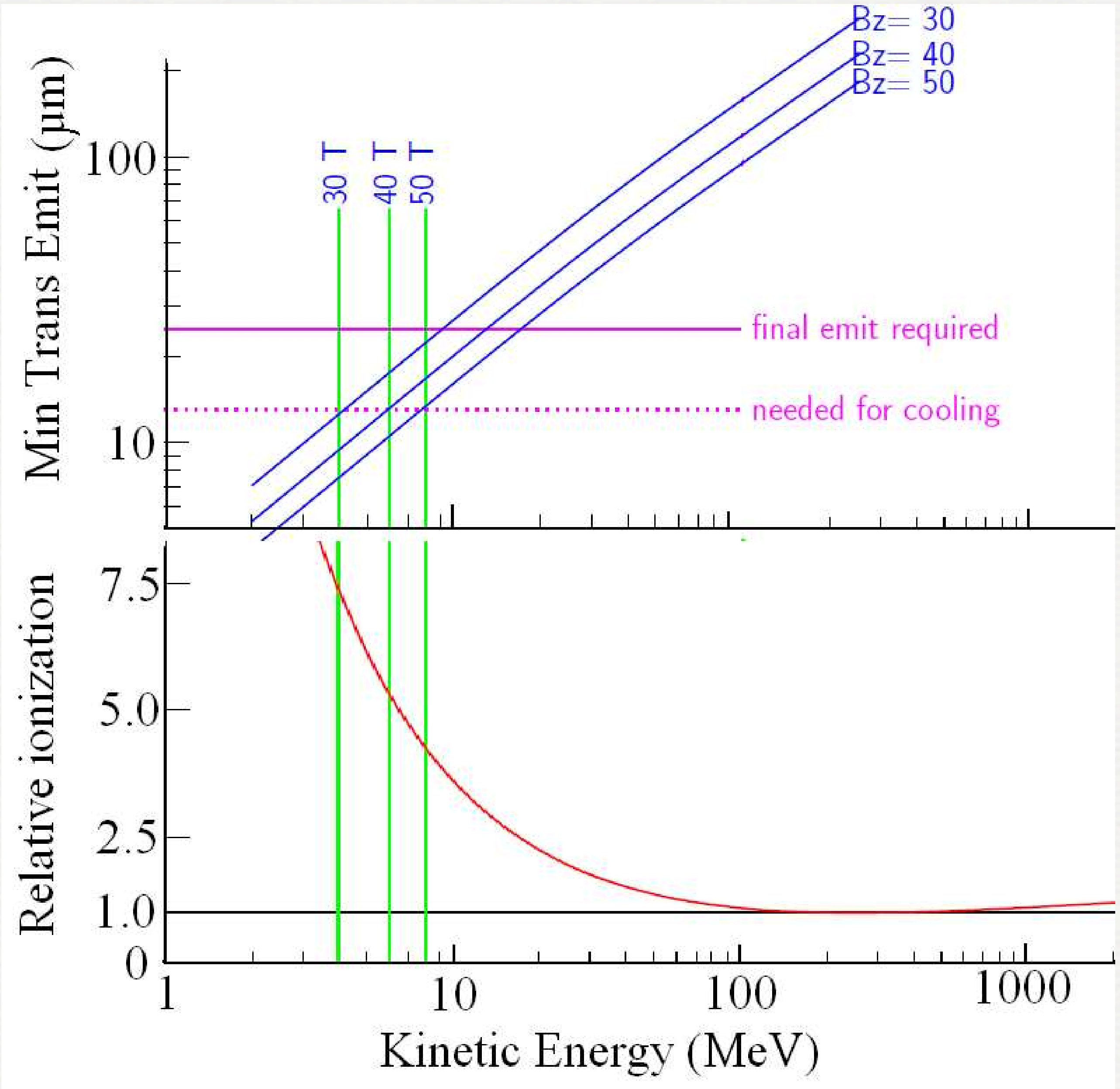
Jon Lederman



MAXIMIZE LUMINOSITY

- To maximize luminosity:
  - reduce transverse emittance without blowing up longitudinal emittance too much.
  - since transverse emittance is proportional to beta function, reduce beta function.

MINIMIZE TRANSVERSE EMITTANCE



$$\epsilon_{x,y}(min) \propto \frac{E}{BL_R \frac{dE}{dz}}$$

- Operate at lower energy for larger dE/dz.
- Negative slope of dE/dz increases momentum spread and longitudinal emittance.

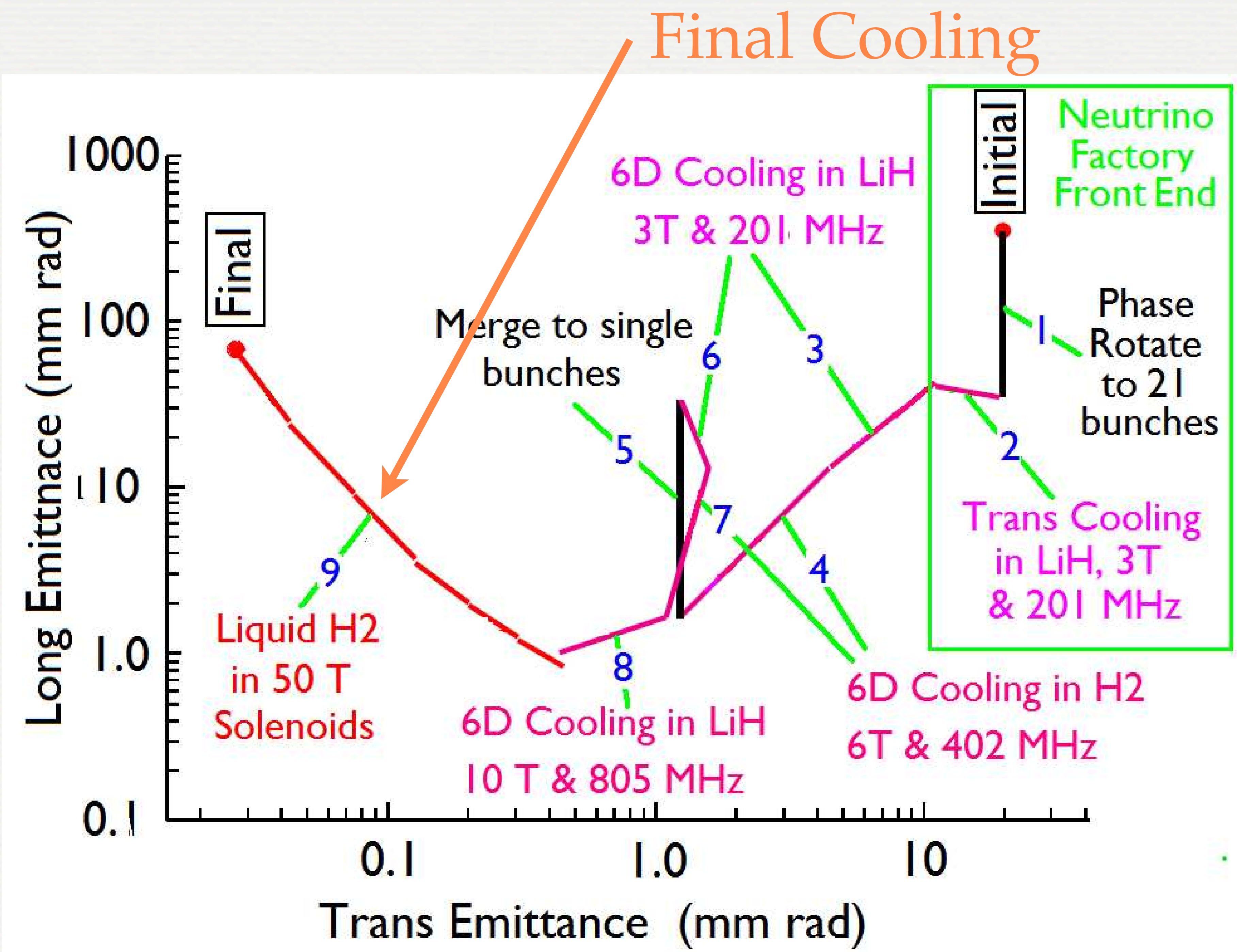
FINAL COOLING

- To achieve required final transverse emittance, final stage requires stronger focusing than is achievable in 6D cooling of earlier stages
- Using lower momenta, it can be achieved using liquid hydrogen and strong solenoids.
- Reduce transverse emittance by using progressively higher solenoid fields to drive down beta function.
- Beta function may also be reduced by lowering energy.

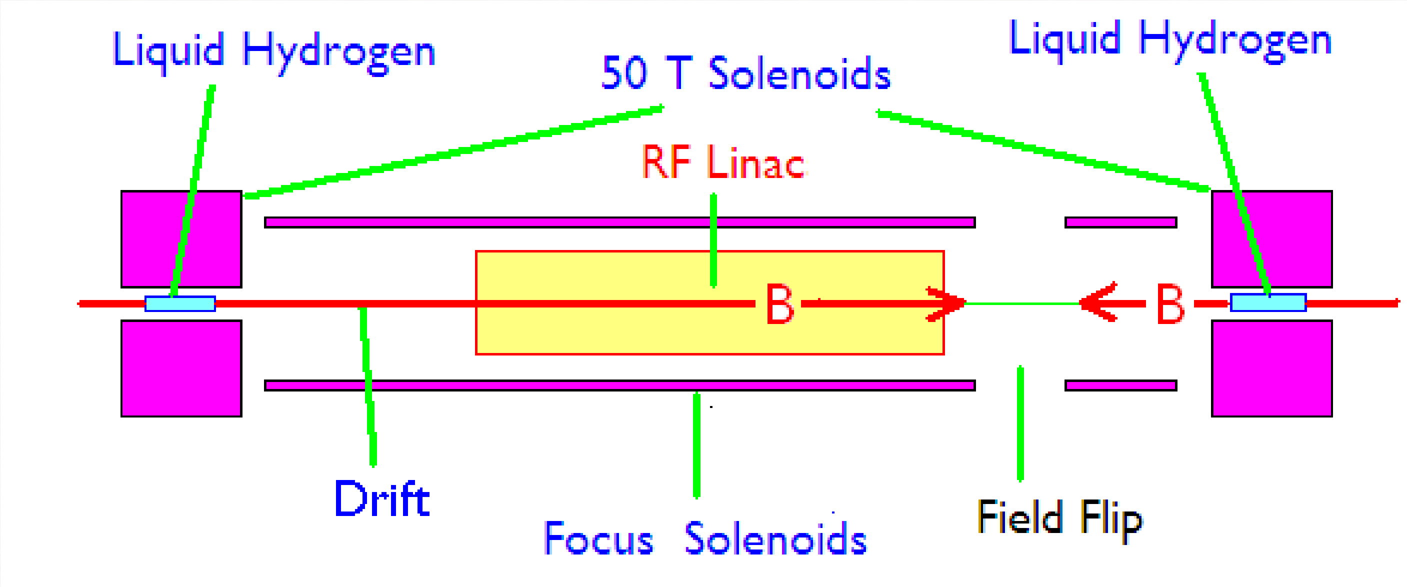
LONGITUDINAL EMITTANCE GROWTH

- Tradeoff between operating at lower momenta and longitudinal emittance growth:
  - Operating at lower momenta allows for reduction in transverse emittance.
  - However, this introduces longitudinal heating b/c operating at progressively higher negative slope on dE/dx curve.
- Final cooling lattice introduces growth of longitudinal emittance through:
  - Longitudinal heating.
  - Energy straggling.
  - Bunch length growth due to TOF effects.

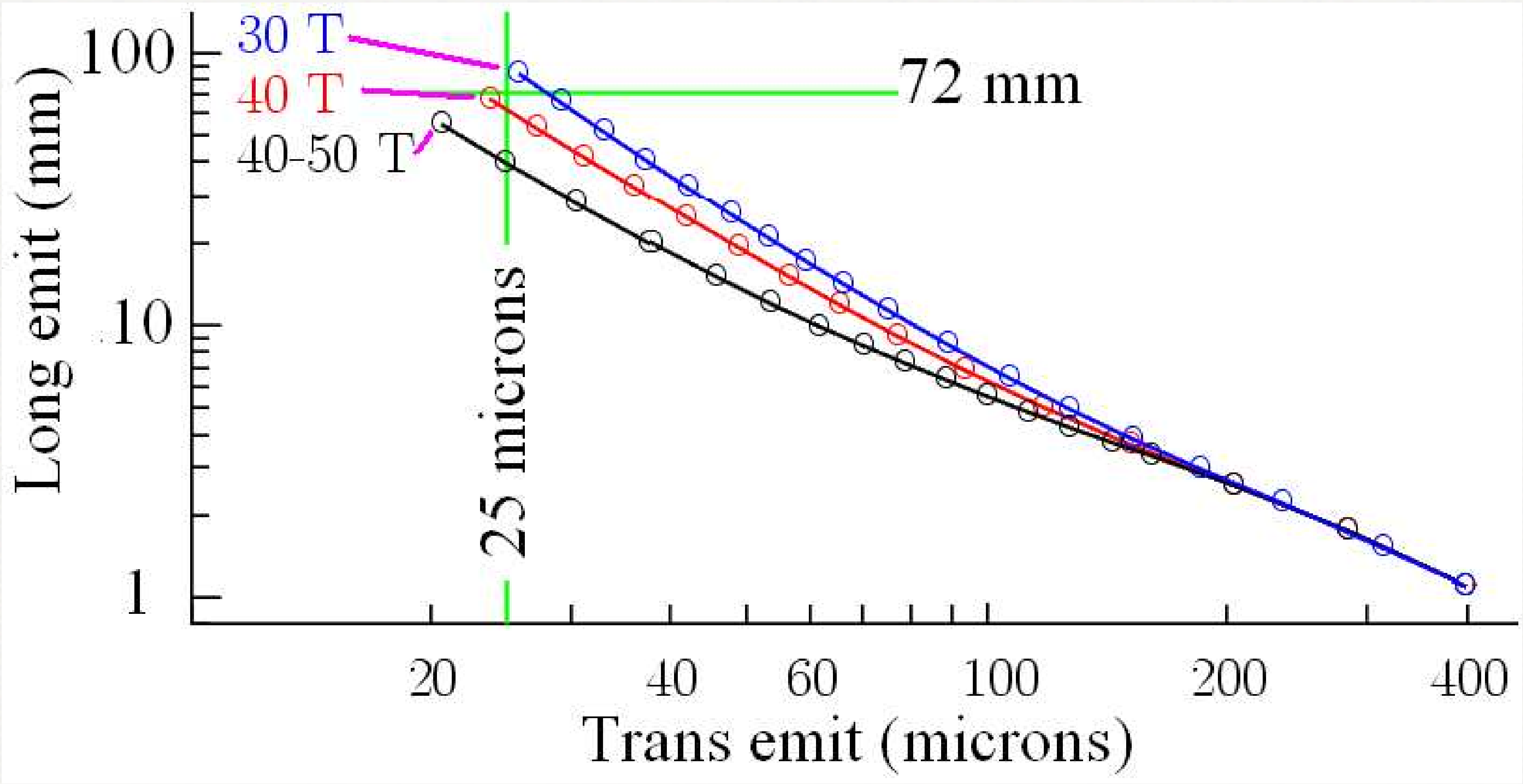
LONGITUDINAL VS. TRANSVERSE EMITTANCE



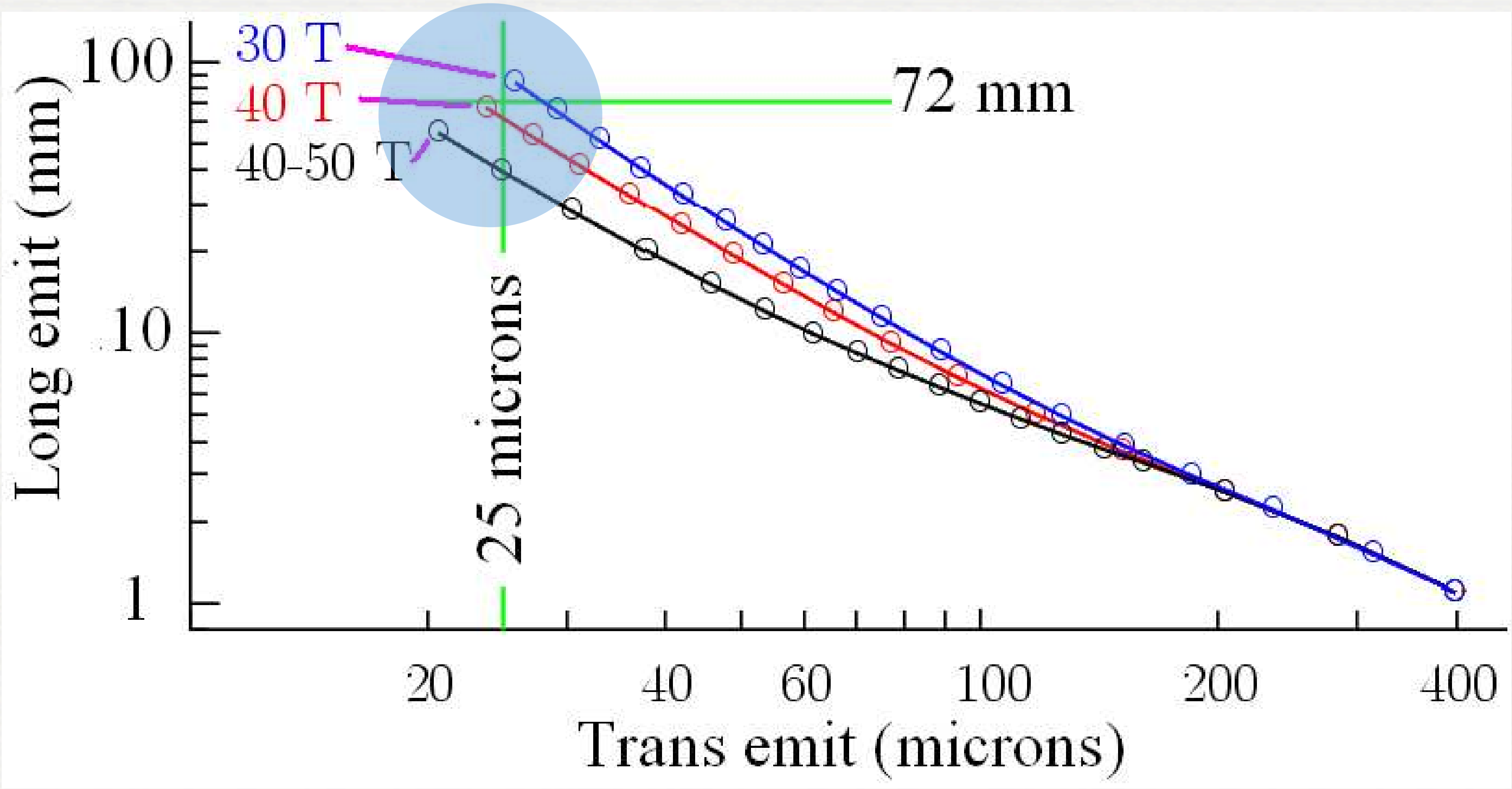
FINAL COOLING STAGE



EMITTANCE BEHAVIOR

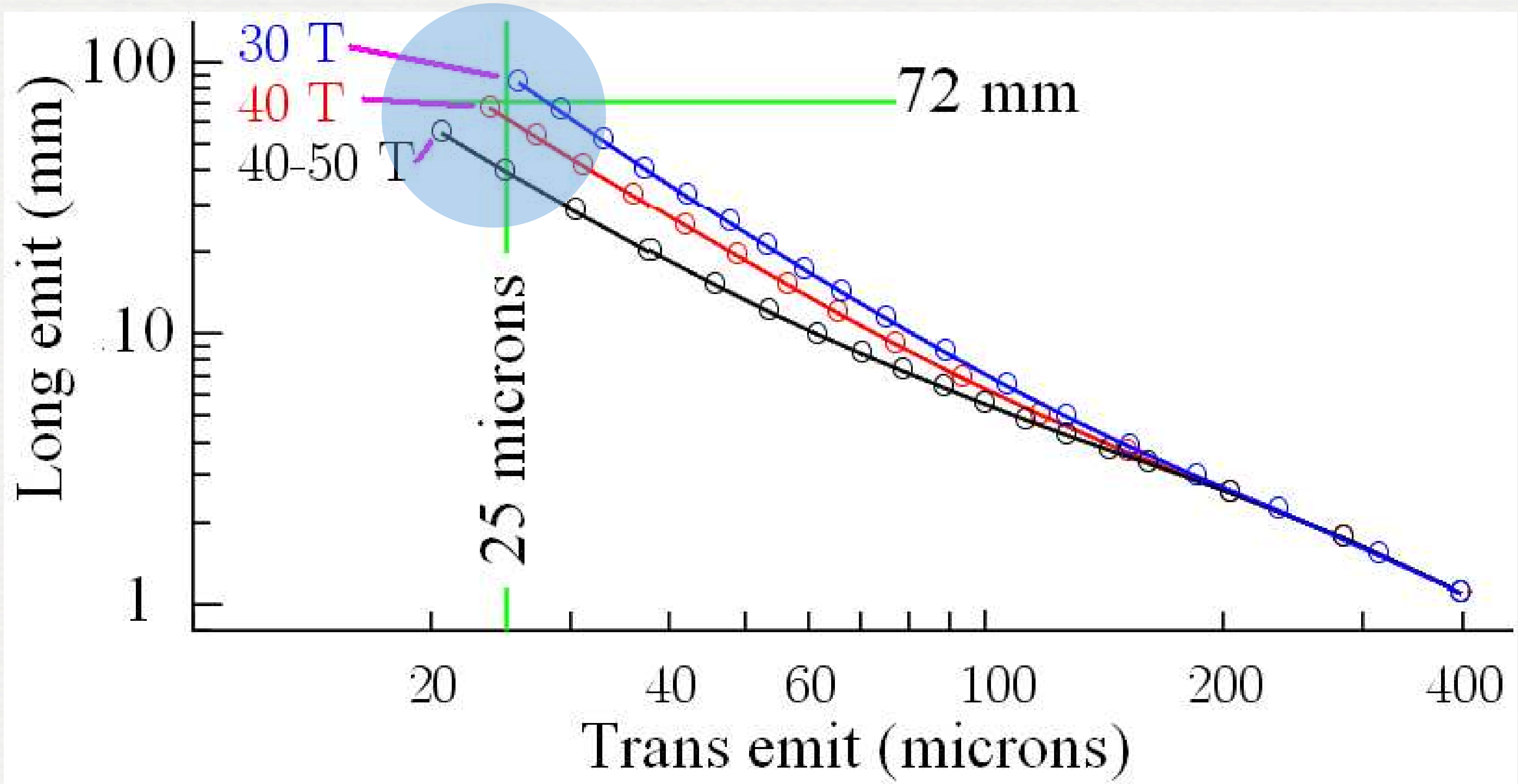


EMITTANCE BEHAVIOR



- Emittance goals can be achieved with 40 T solenoids. Possibly with 30 T solenoids.

EMITTANCE BEHAVIOR



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- Higher field curves have lower slope - lower longitudinal emittance growth.

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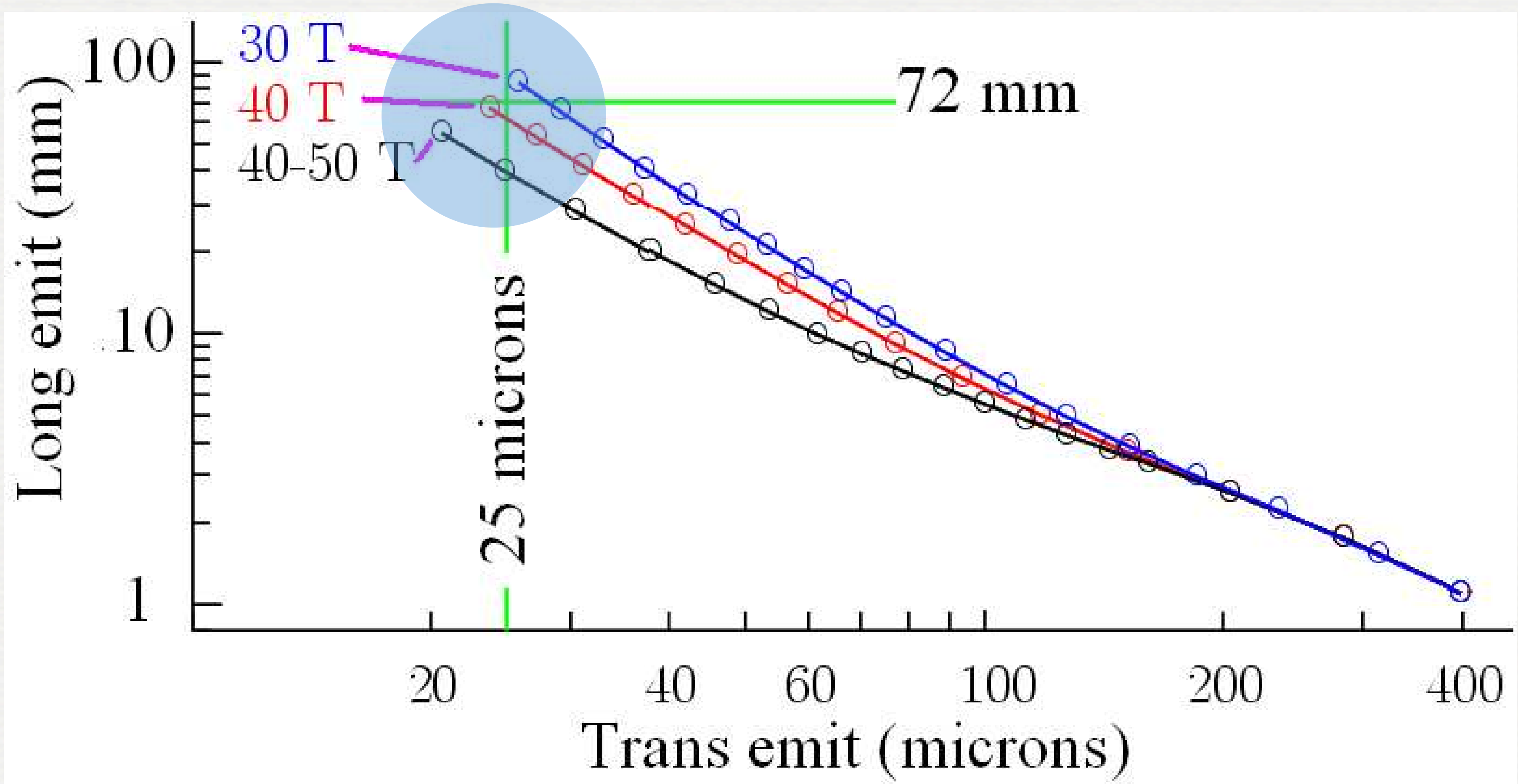

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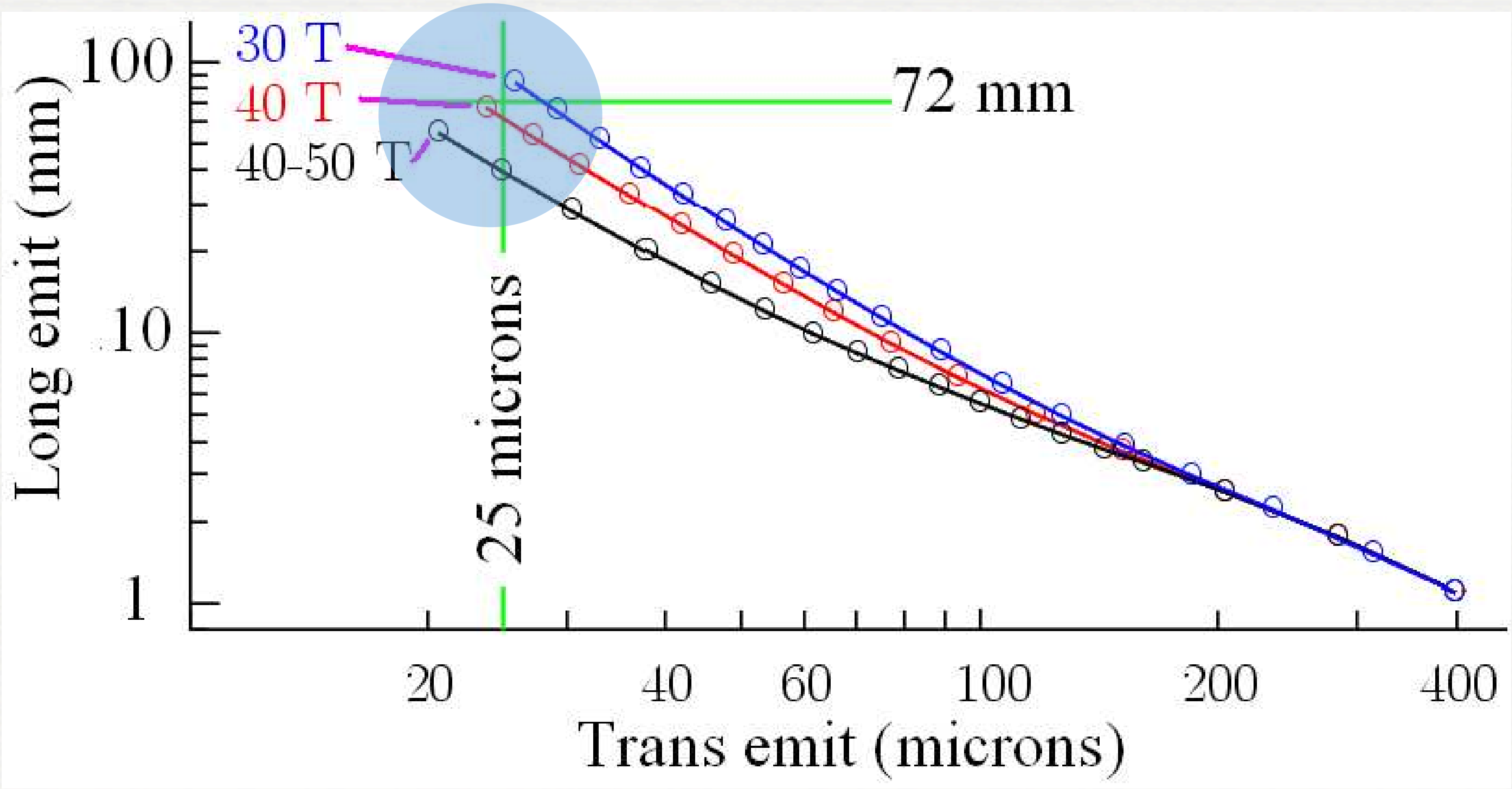
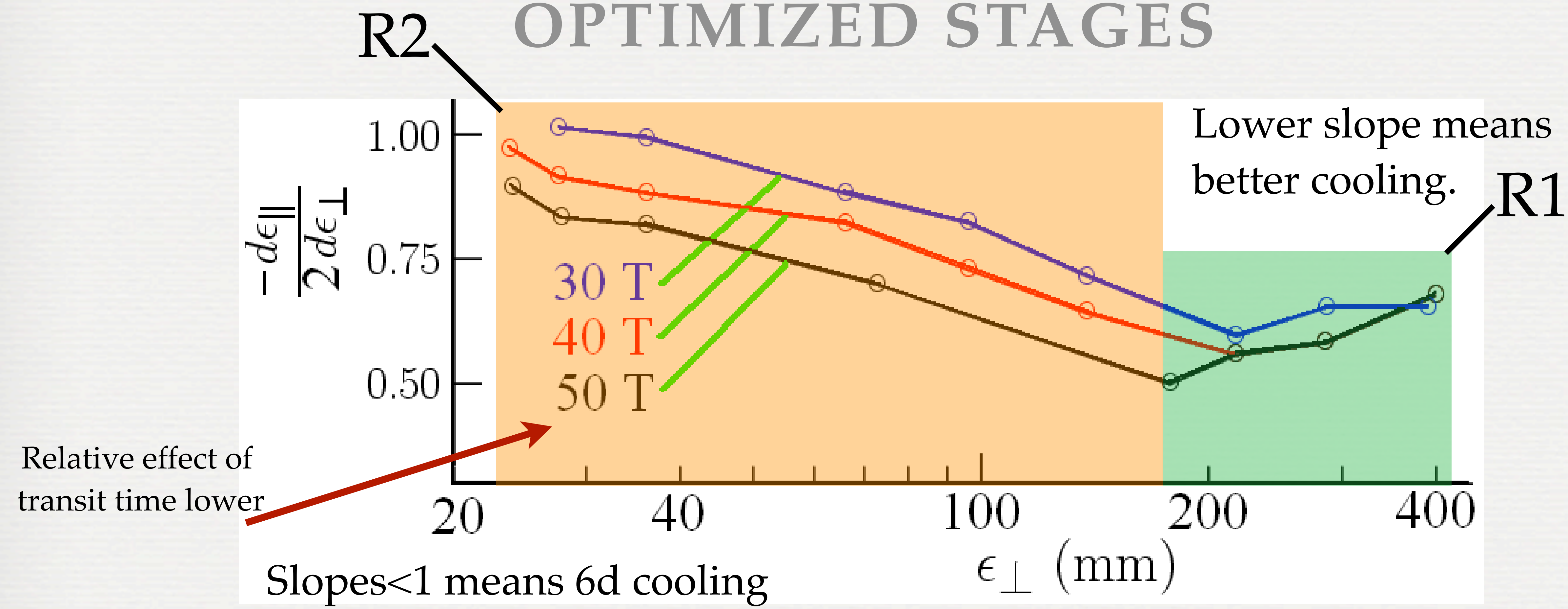


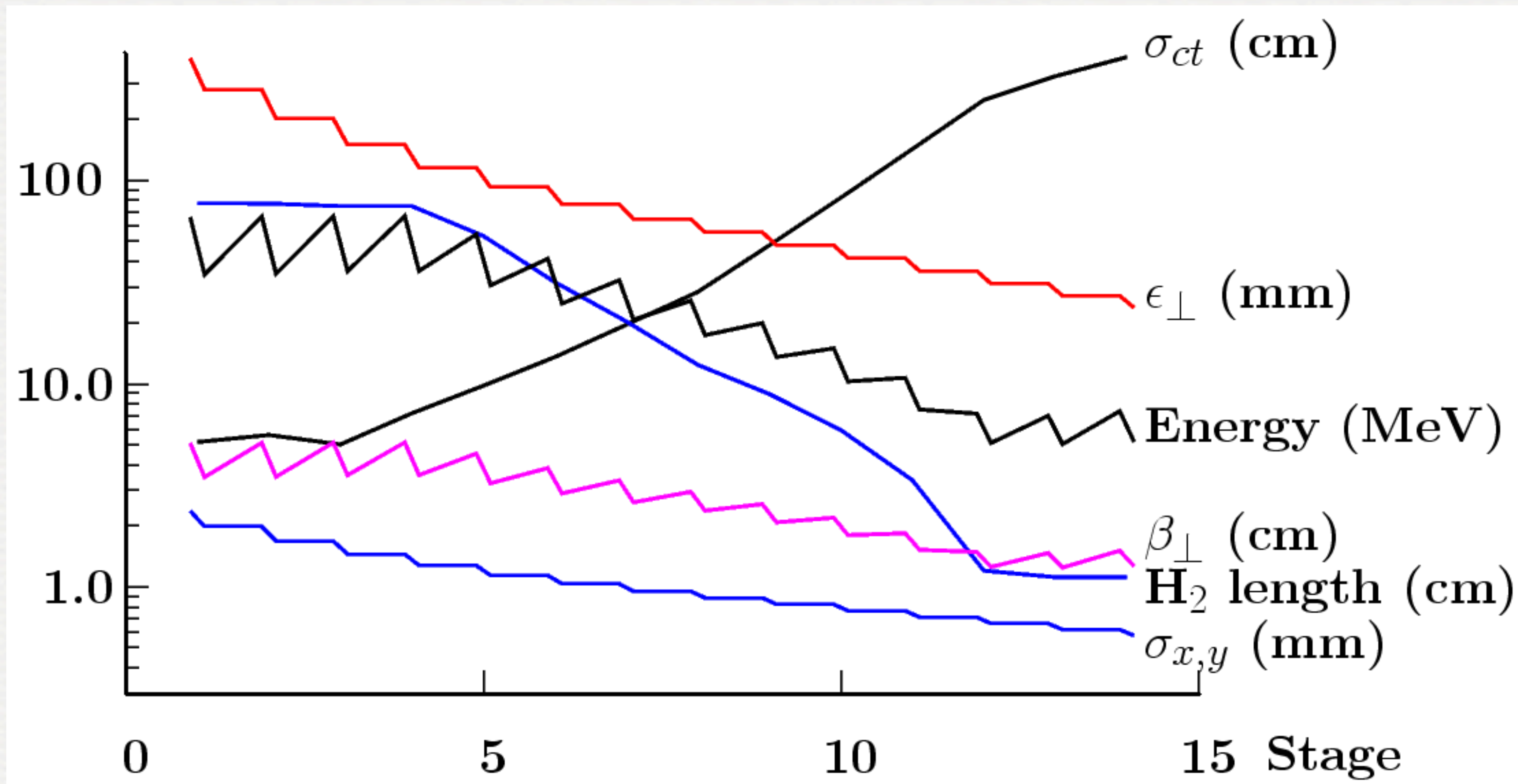
- Emittance goals can be achieved with 40 T solenoids. Possibly with 30 T solenoids.
- Higher field curves have lower slope - lower longitudinal emittance growth.
- Only two stages have been simulated with full RF.
- Generated by interpolation of the graph on the following slide.

SIMULATED SLOPES FOR MANUALLY OPTIMIZED STAGES



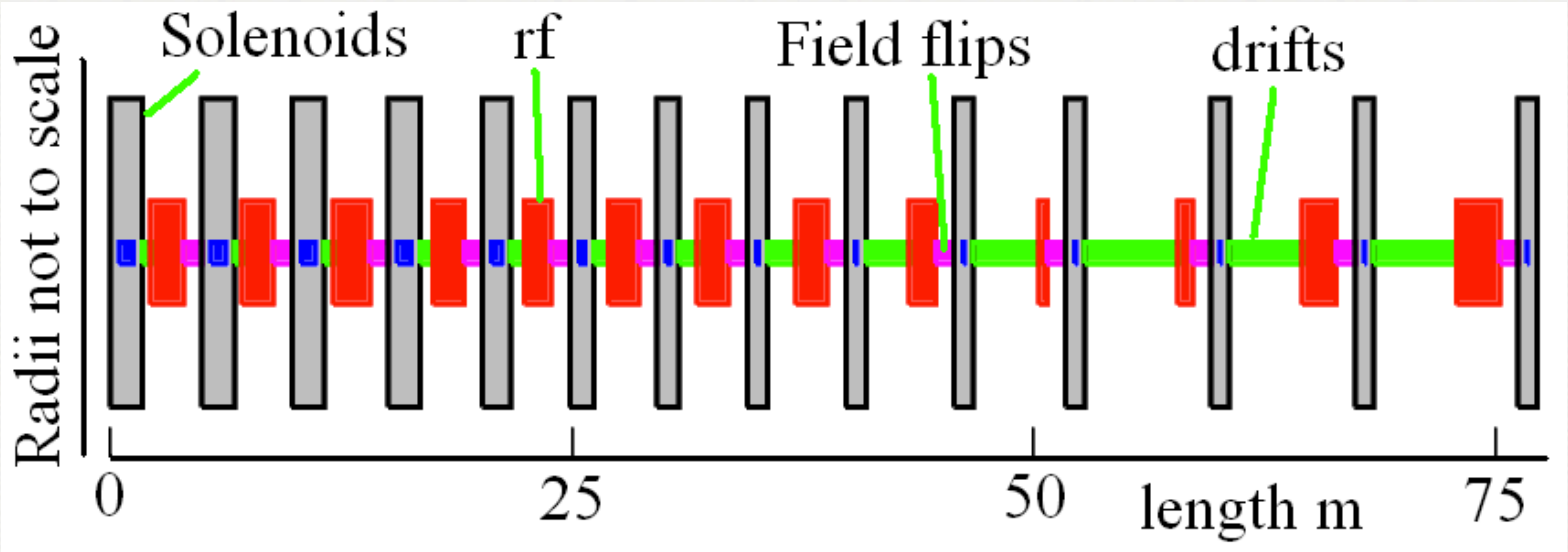
- Going to higher negative dE/dx slopes makes longitudinal heating worse.
- Relative effect of TOF heating becomes less significant as bunch length increases. Also, absorbers shorter.

40T PARAMETERS VS. STAGE



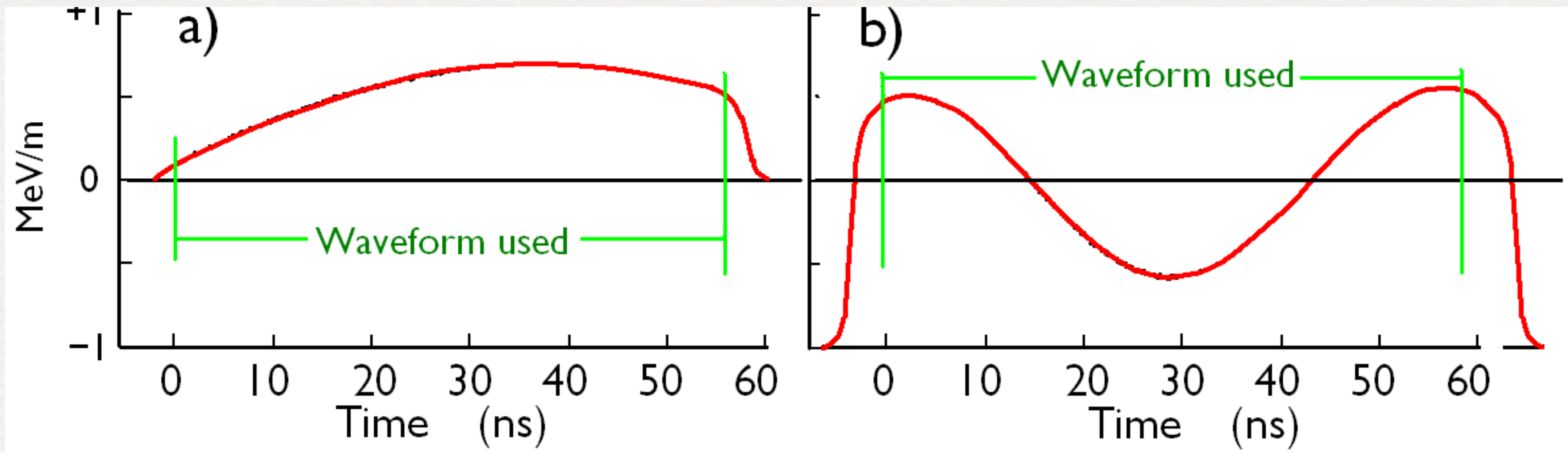
- Bunch length rises from 5 cm-400 cm.
- Energy falls from 66 MeV to 5 MeV.
- H2 absorber length falls from 77 cm to 11 cm.
- Beta is reduced to 1.5 cm w/RMS beam size of 0.6 mm.
- dE/dZ rises
- For bunches larger than 0.75 m, induction linacs were assumed with gradients of 1 MV/m

LENGTHS OF ELEMENTS FOR 40T EXAMPLE



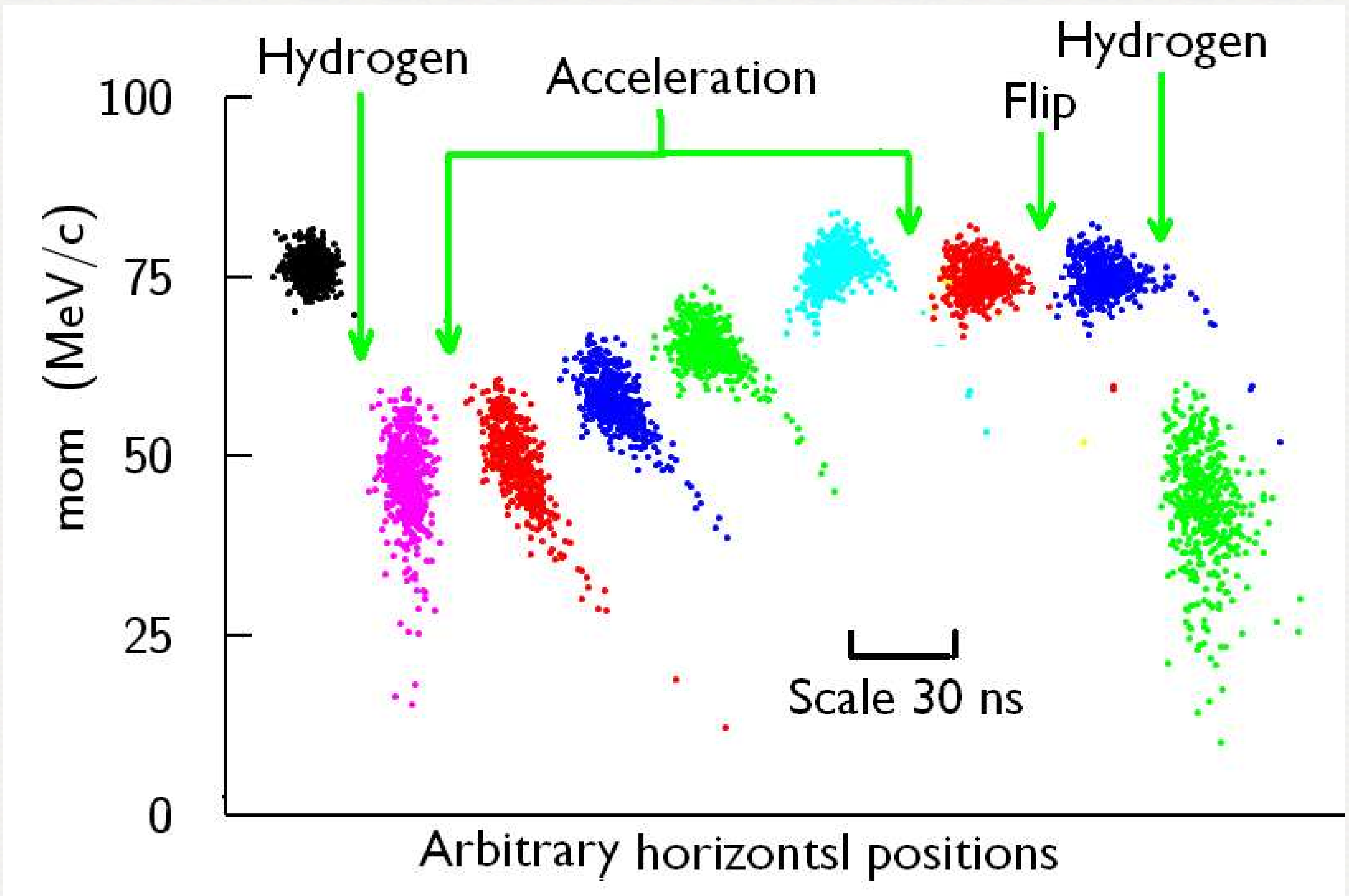
INDUCTION LINAC WAVEFORMS

Induction Linac Waveforms

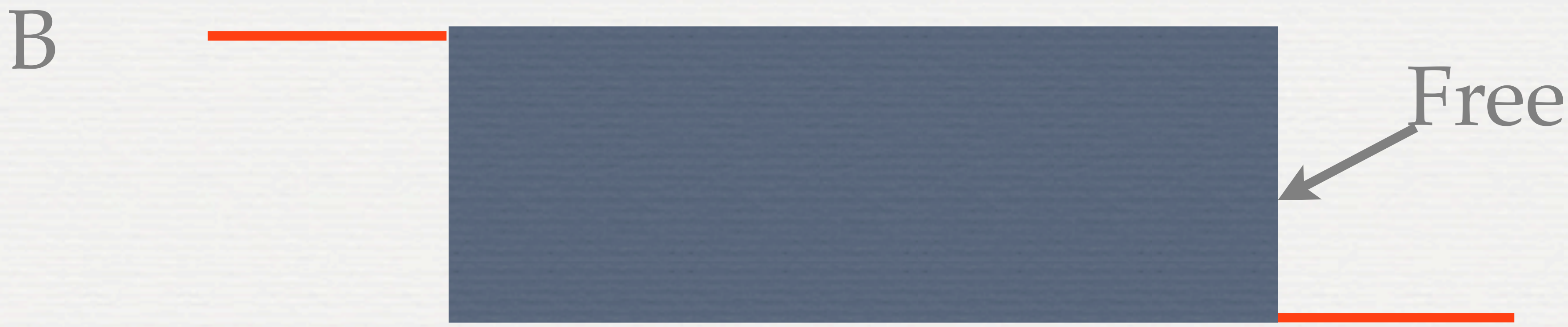


Pulse shape adjusted to maintain elliptical profile in longitudinal phase space.

LONGITUDINAL PHASE SPACE EVOLUTION

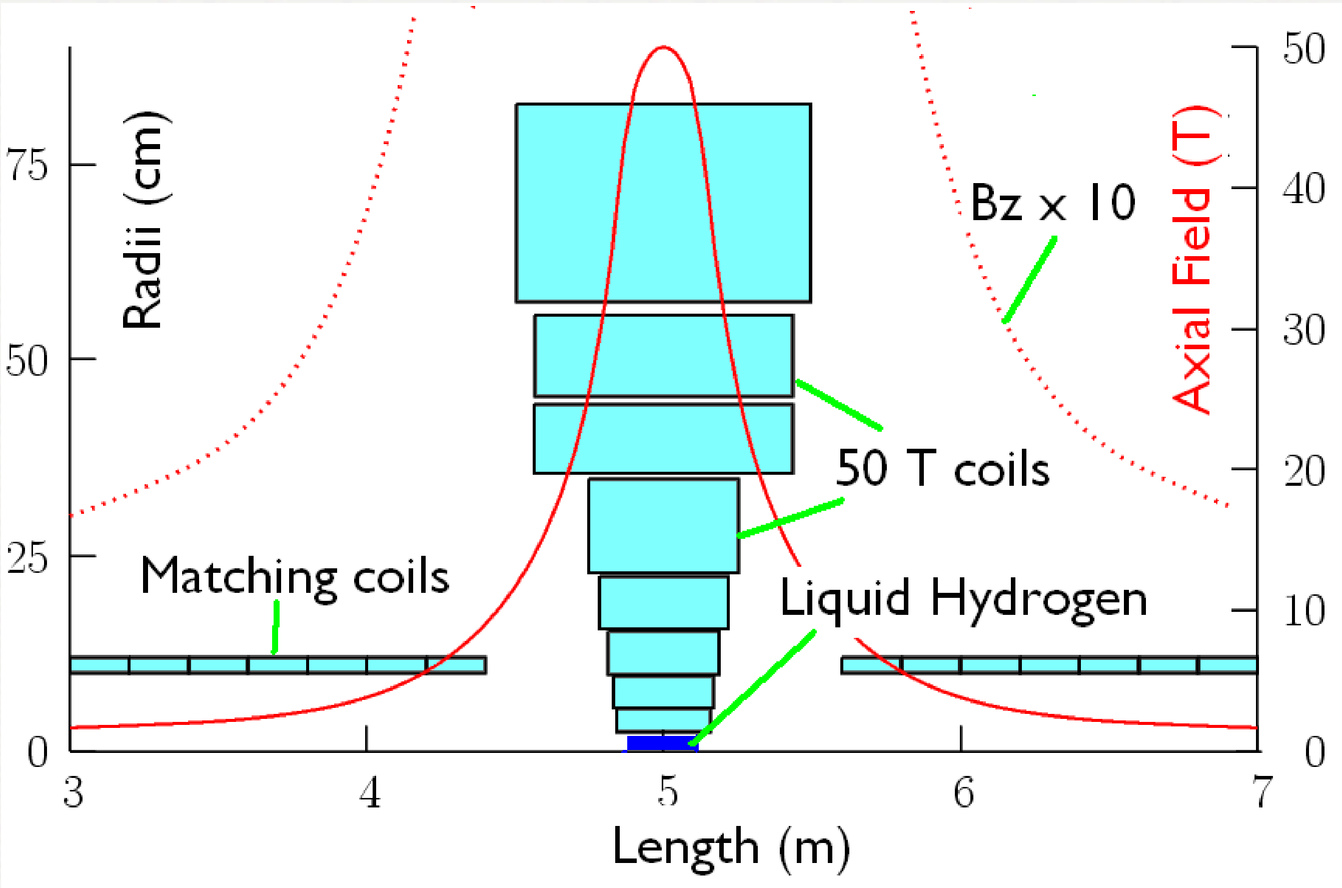


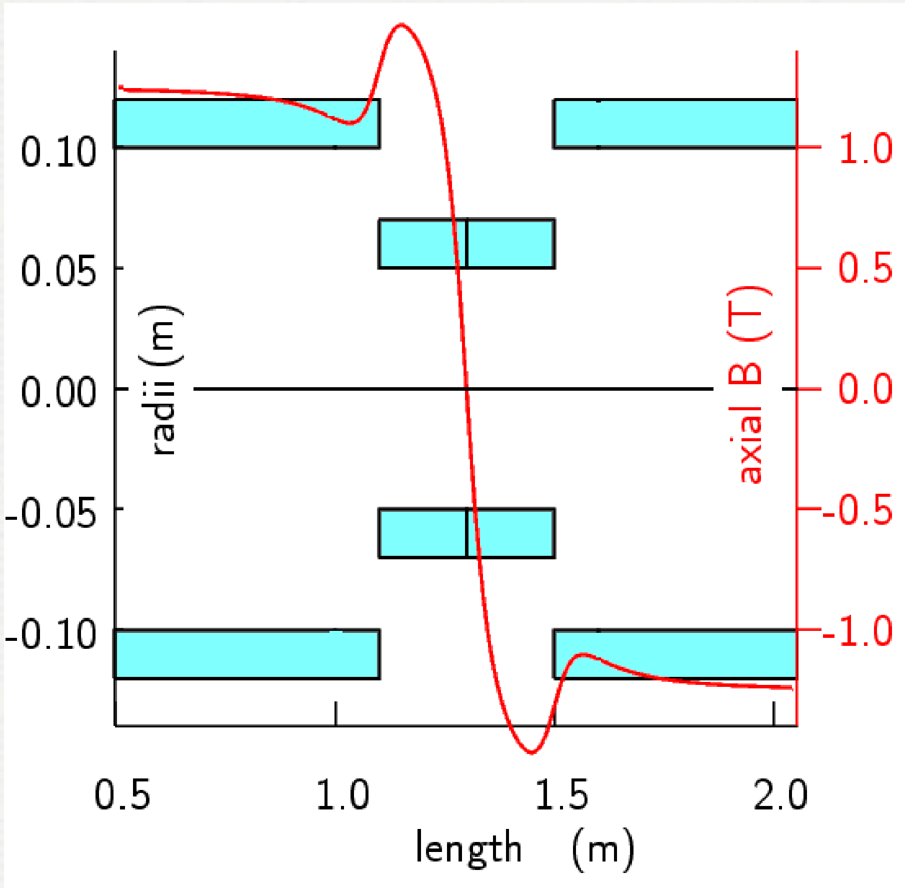
MATCHING PROBLEM



- Field flip defines boundary conditions for B.
- What is the optimal shape of B in the free region to achieve best beta mapping?
- Methodology:
  - Calculate transfer map in free region by integrating Hamiltonian.
  - Evaluate match using appropriate metric.
  - Using numerical optimizer determine optimal B
  - in free region.

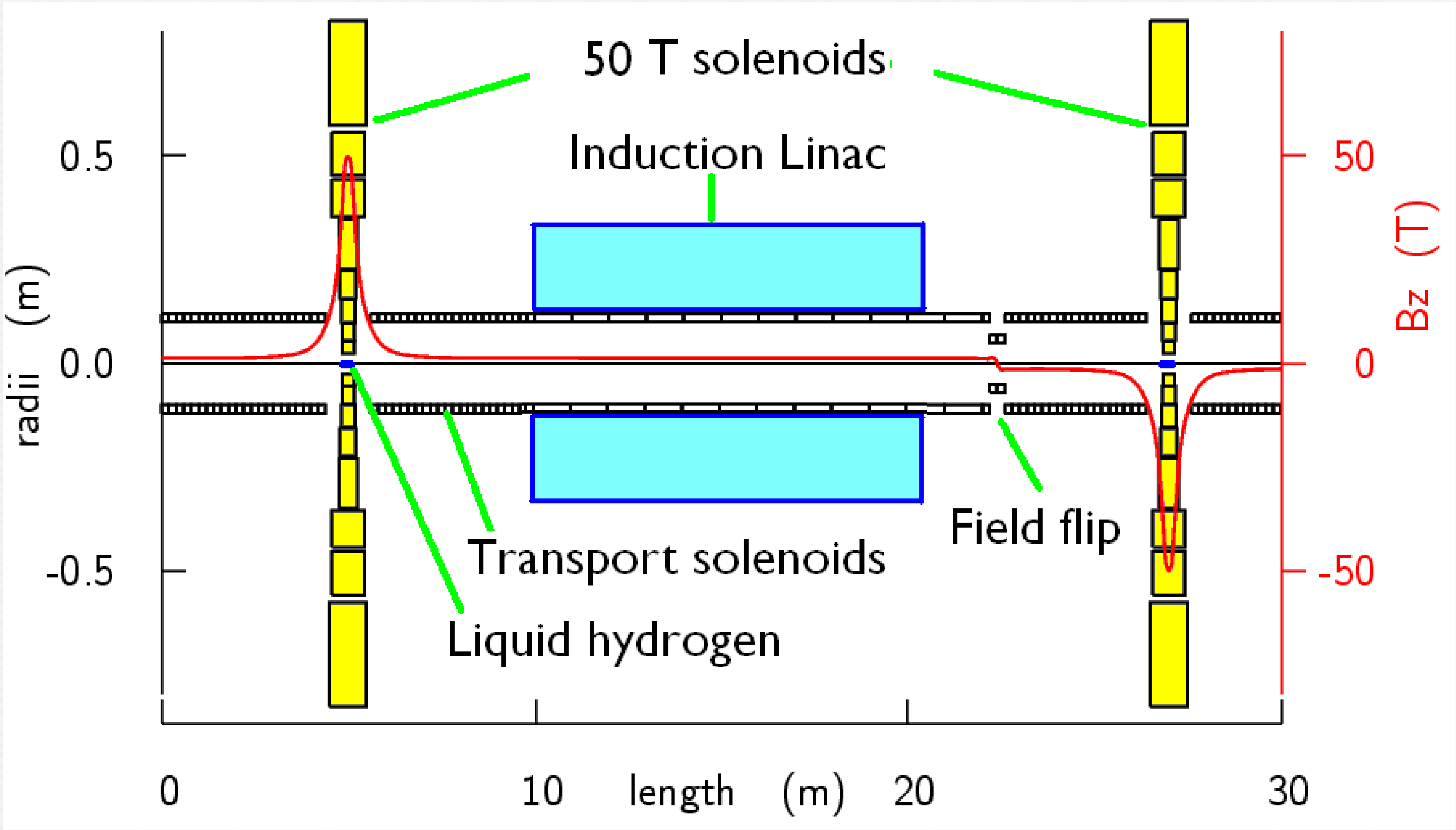
50T MATCHING AND FIELD FLIP





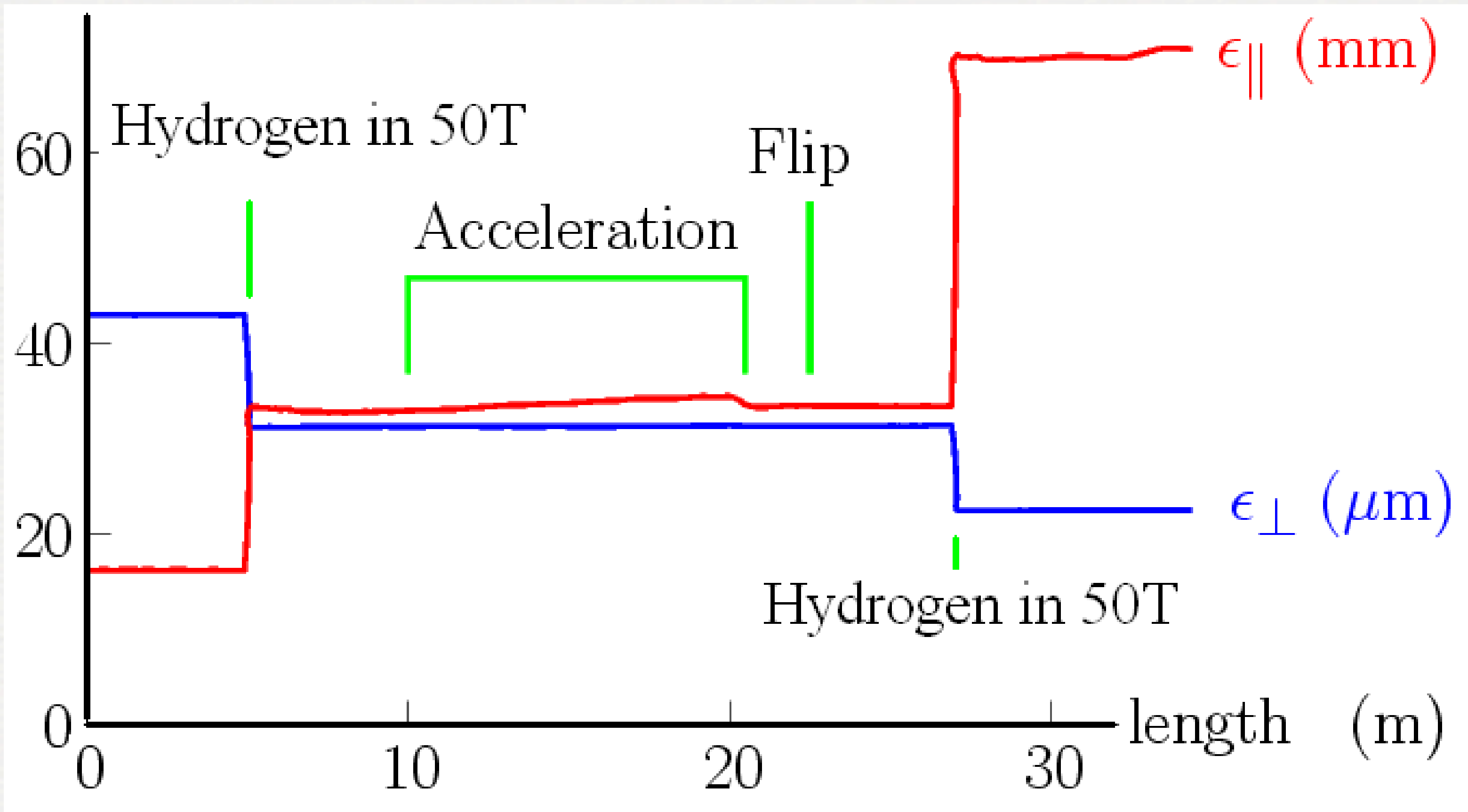
- Field profile determined heuristically.

SIMULATION OF LAST TWO STAGES



- Bunch length is long (approx. 3 meters).
- RF is induction linac.

SIMULATION OF MATCHING AND ACCELERATION FOR FINAL TWO STAGES (50T SEQUENCE)



CONCLUSION

- As muon energy E falls in conjunction with rising dE/dz, minimum emittance can fall below 25 um.
- Although longitudinal emittance rises, due to increasingly negative dE/dz slope, a satisfactory longitudinal emittance can be achieved.
  - This can be achieved by restricting $-\frac{d\epsilon_{\parallel}}{2d\epsilon_{\perp}}$