Cooling for Higgs Factory

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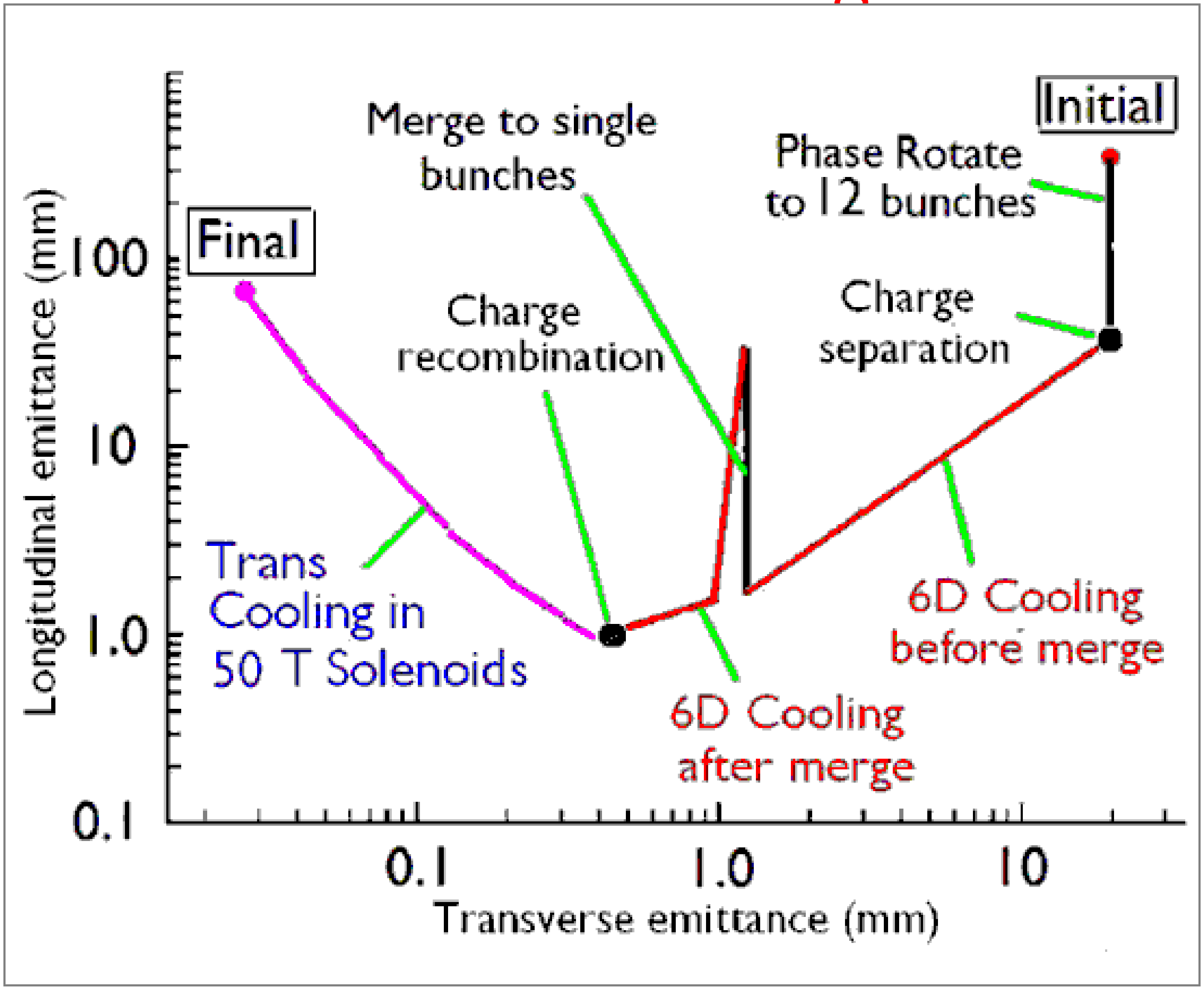
- Bunch Merge
- Space Charge
- Candidates
- Performance
- Super Conductor Requirements
- Conclusion

Concepts for Muon Collider cooling

As shown, merge is only in longitudinal (dp) direction, i.e. in 2D

For Higgs Factory we will skip 'Final cooling'



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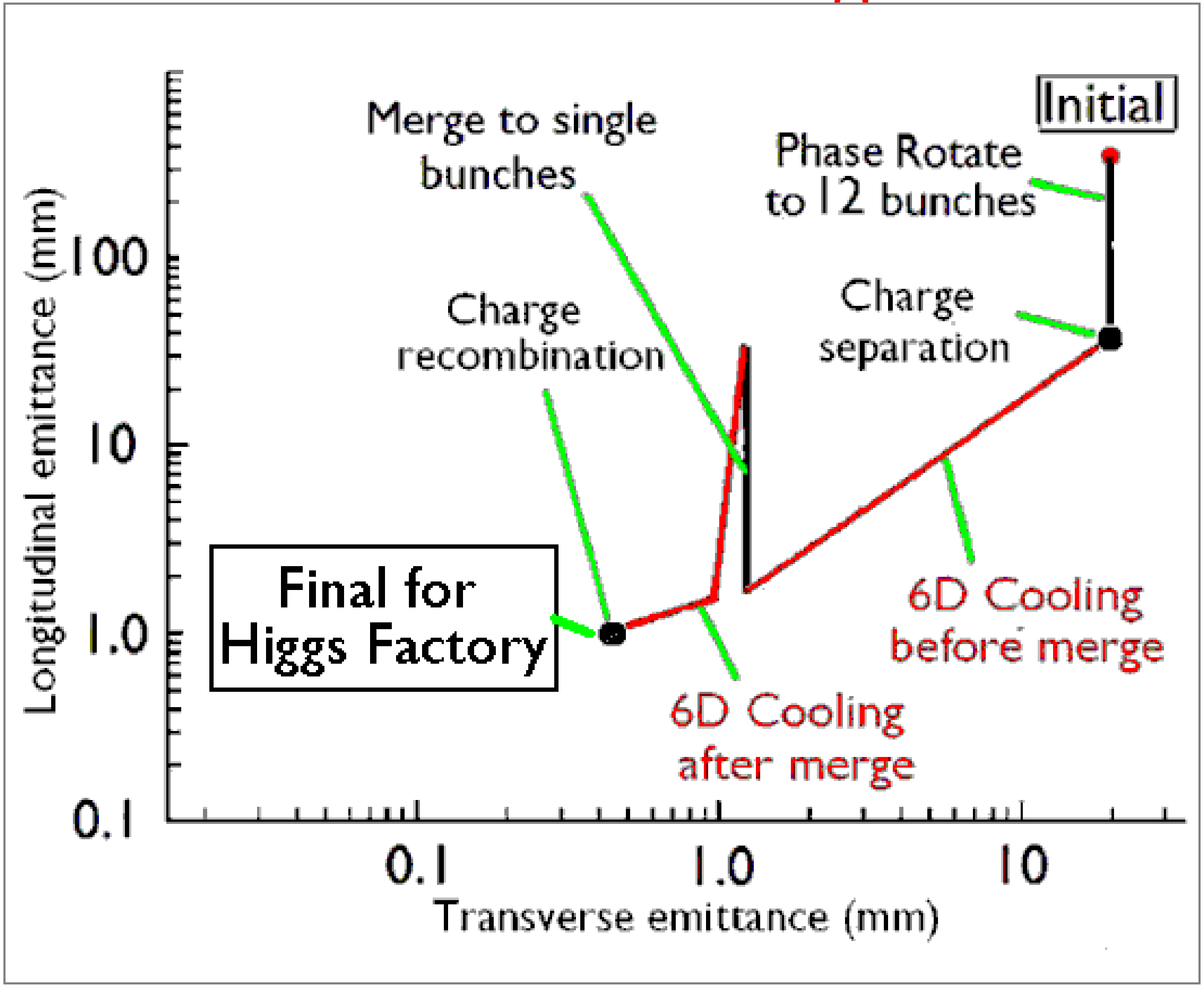
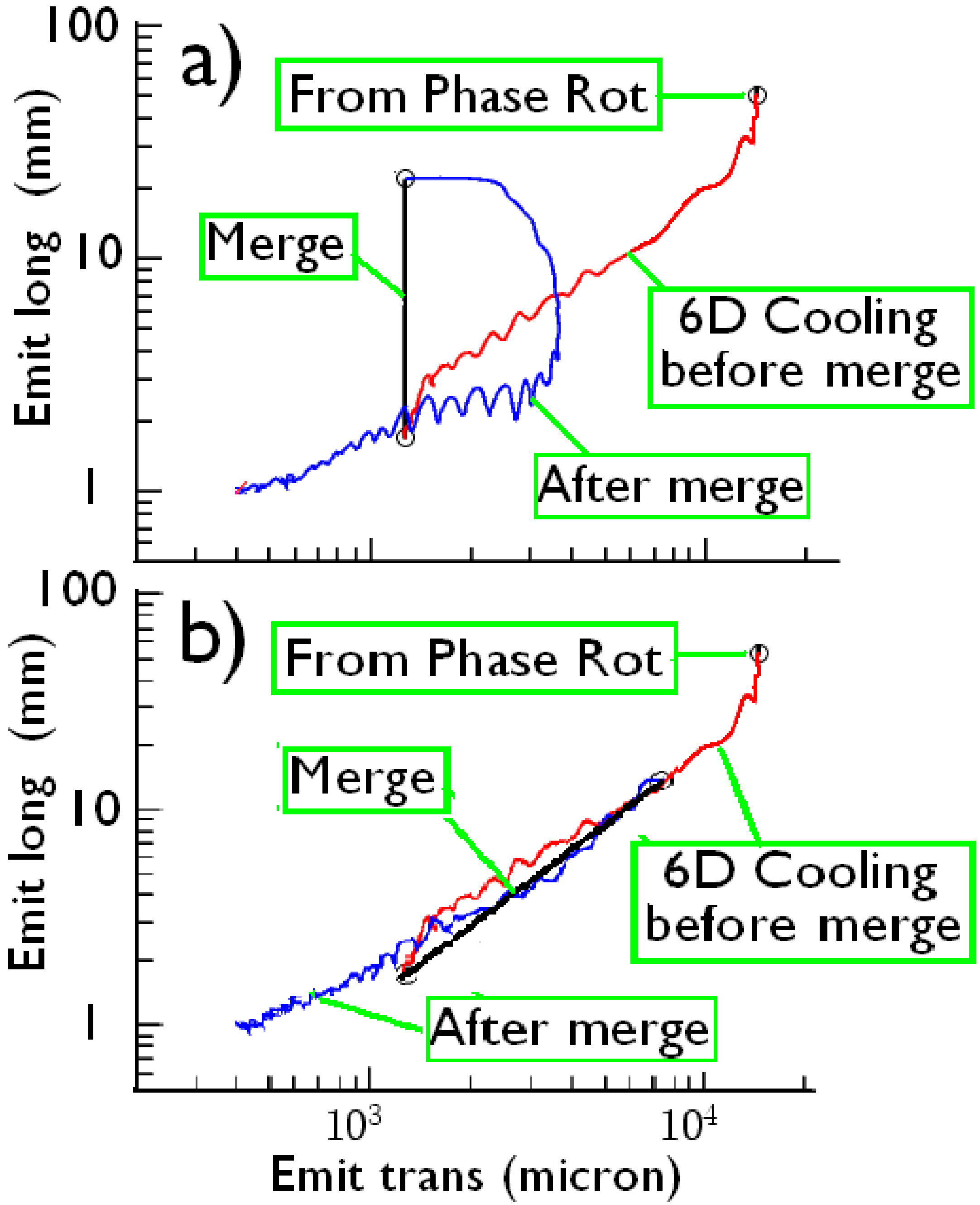


2D vs. 6D Bunch Merge

Matching back into 6D cooling after a 2D merge is unnatural, and, in this simulation inefficient

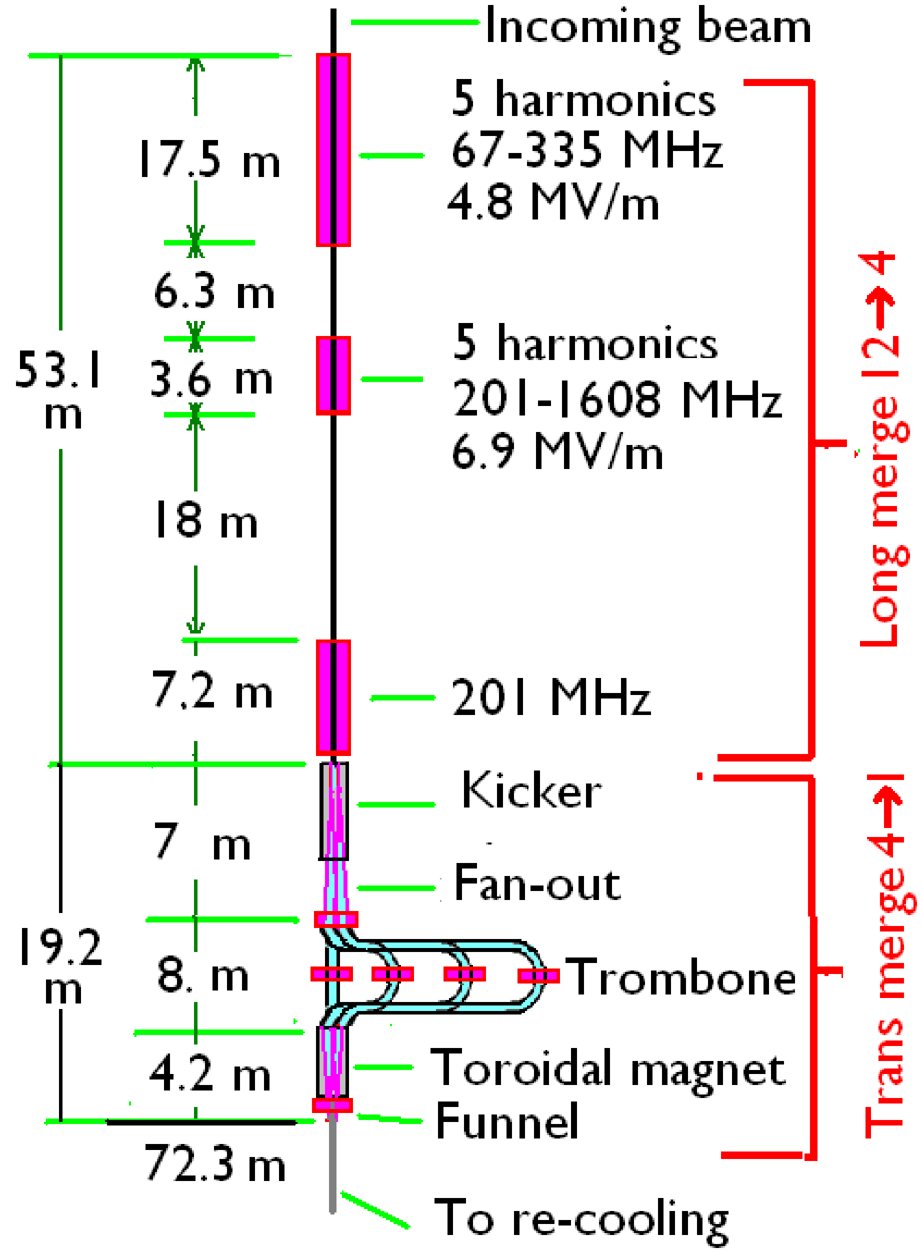
This early 6D merge was more efficient



6D merge

Merge in longitudinal space by rf stacking of groups of 3 bunches

Merge in transverse space by kicking stacked bunches into 4 (trombone) transports with differing lengths then stacking the outputs in x and y before capturing in the larger transverse phase space



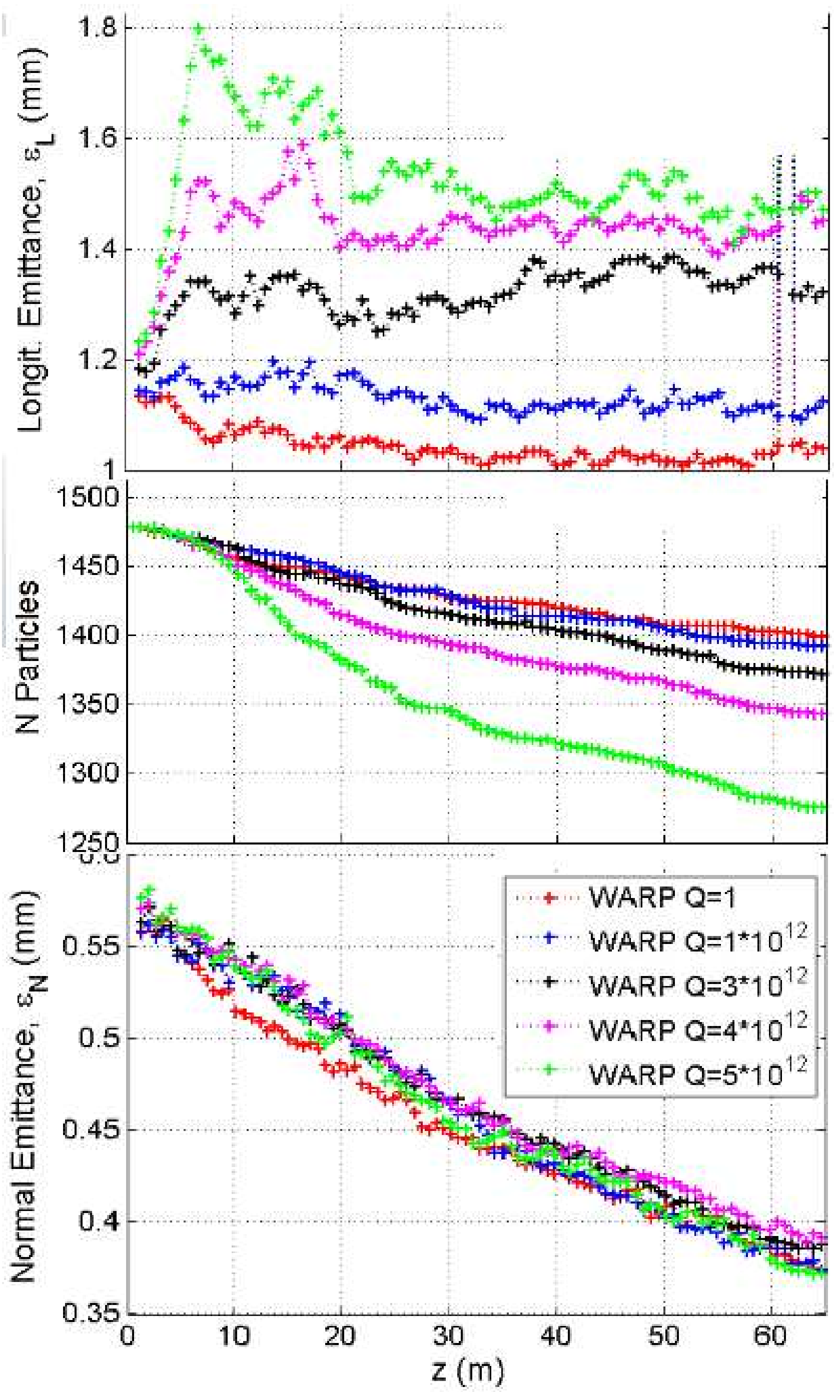
Space Charge

For 2 10^{12} μs at 1.5 TeV,
we need $\approx\ 5 10^{12}$
at end of 6D cooling

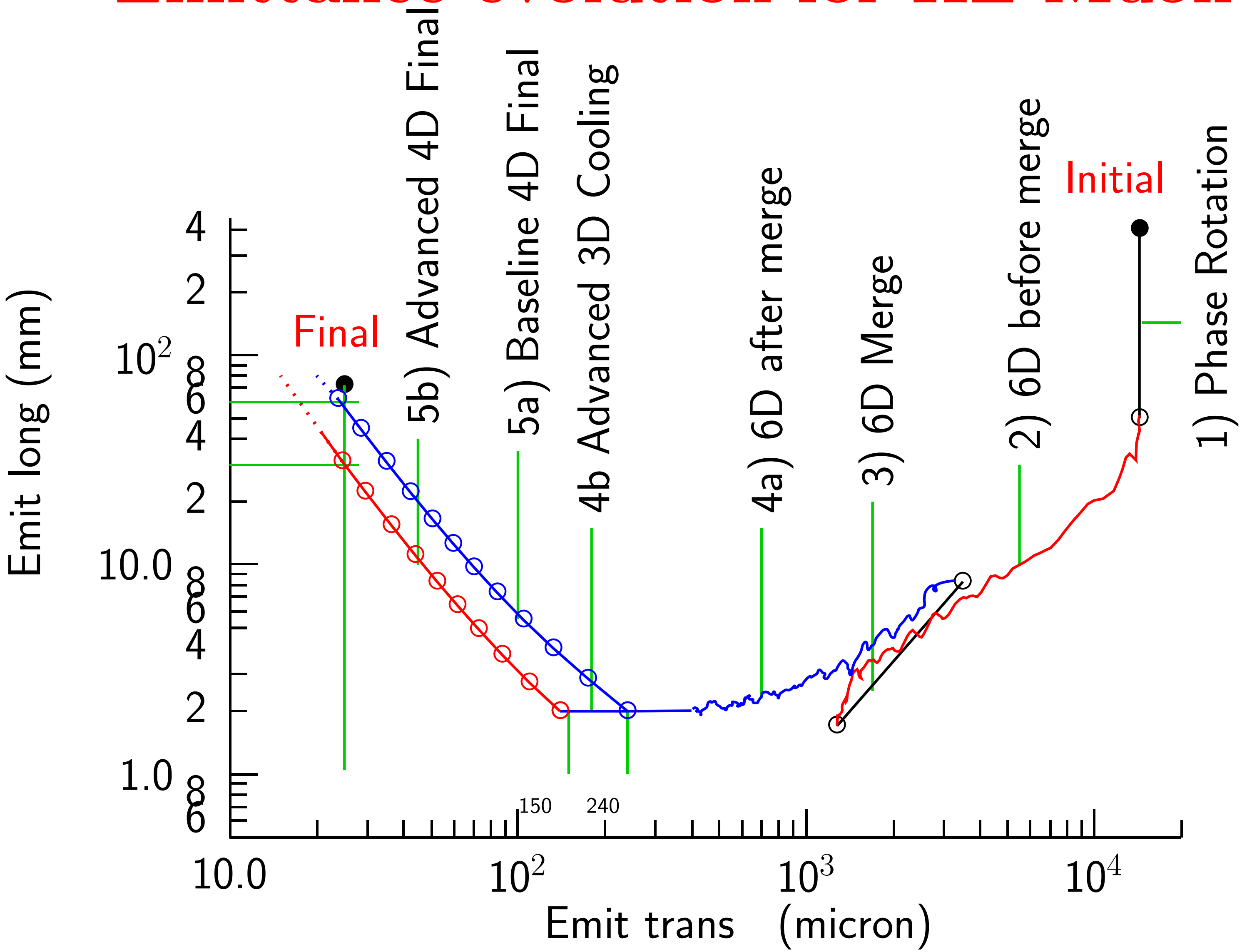
For 2 10^{12} at the Higgs,
we need $\approx\ 2.5 10^{12}$
at end of 6D cooling

Analytic (Palmer & Gallardo) and
WARP Simulation (D. Stratakis)
show that for 2.5 10^{12} $(2 10^{12})$
$\epsilon_\parallel$=1.2 mm may be ok

But for 5 10^{12} $(4 10^{12})$
we are limited to $\epsilon_\parallel\ \geq$2 mm

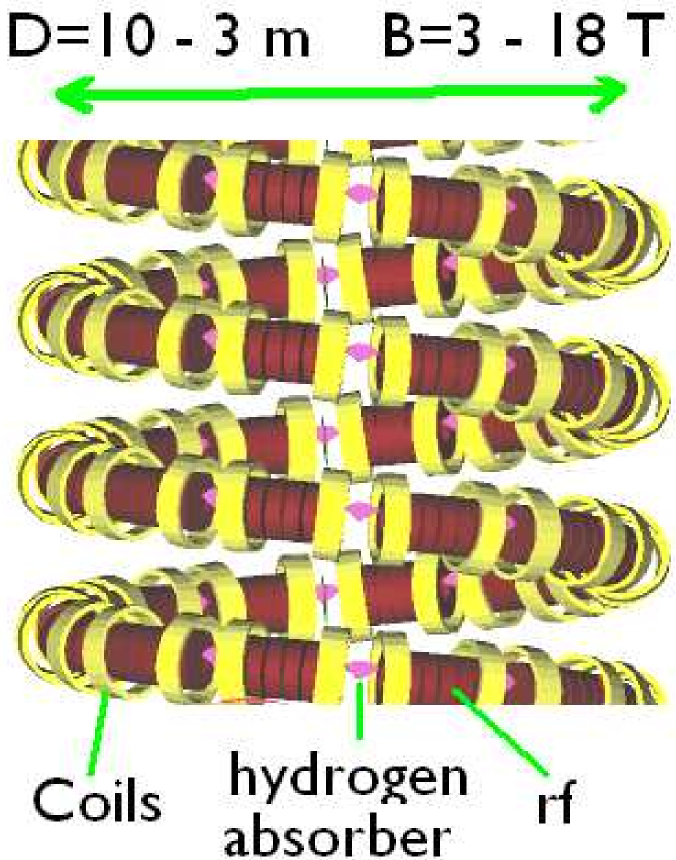


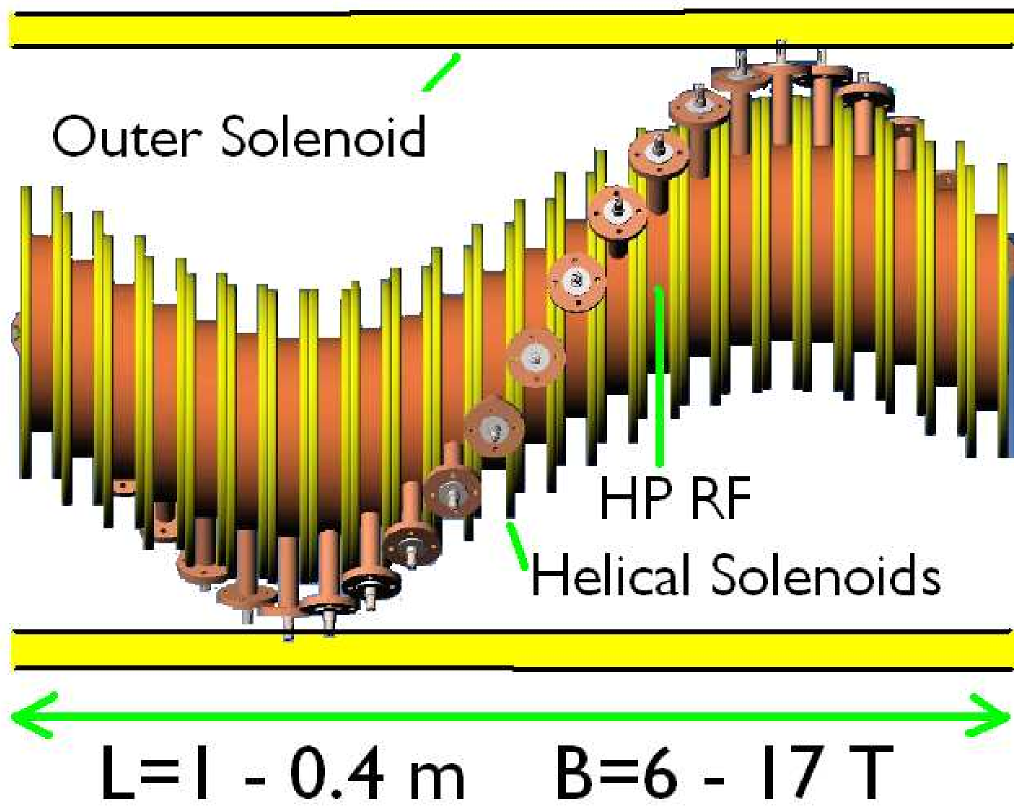
Emittance evolution for HE Muon Collider



Assume we use the same phase rotation, 6D cooling before the merge, and the same merge

Candidates for 6D cooling





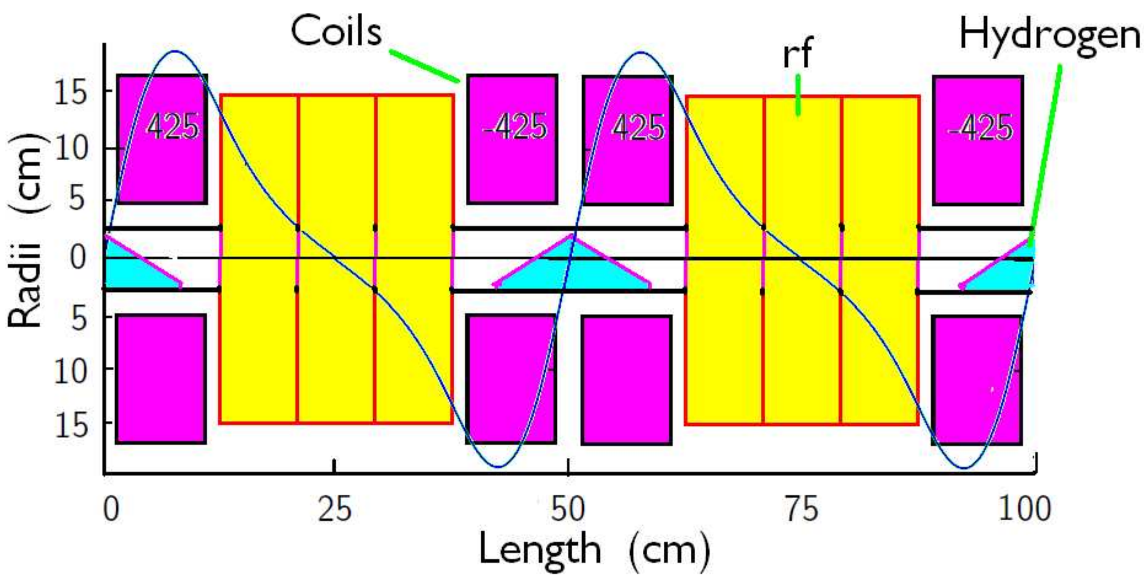
Guggenheim
Vacuum rf

Helical Cooling Channel
High pressure gas rf

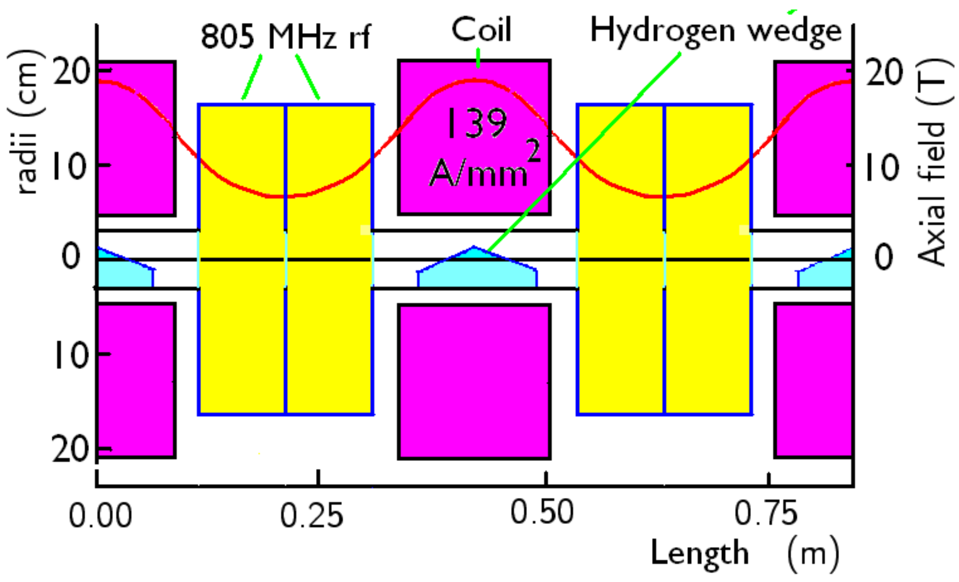
- 'The Snake' (not shown) does not cool to low emittances, but cools both signs. Advantage to use at start of 6D cooling

RFOFO vs. Fernow (Non-flip) Guggenheims

(rbk9h1)



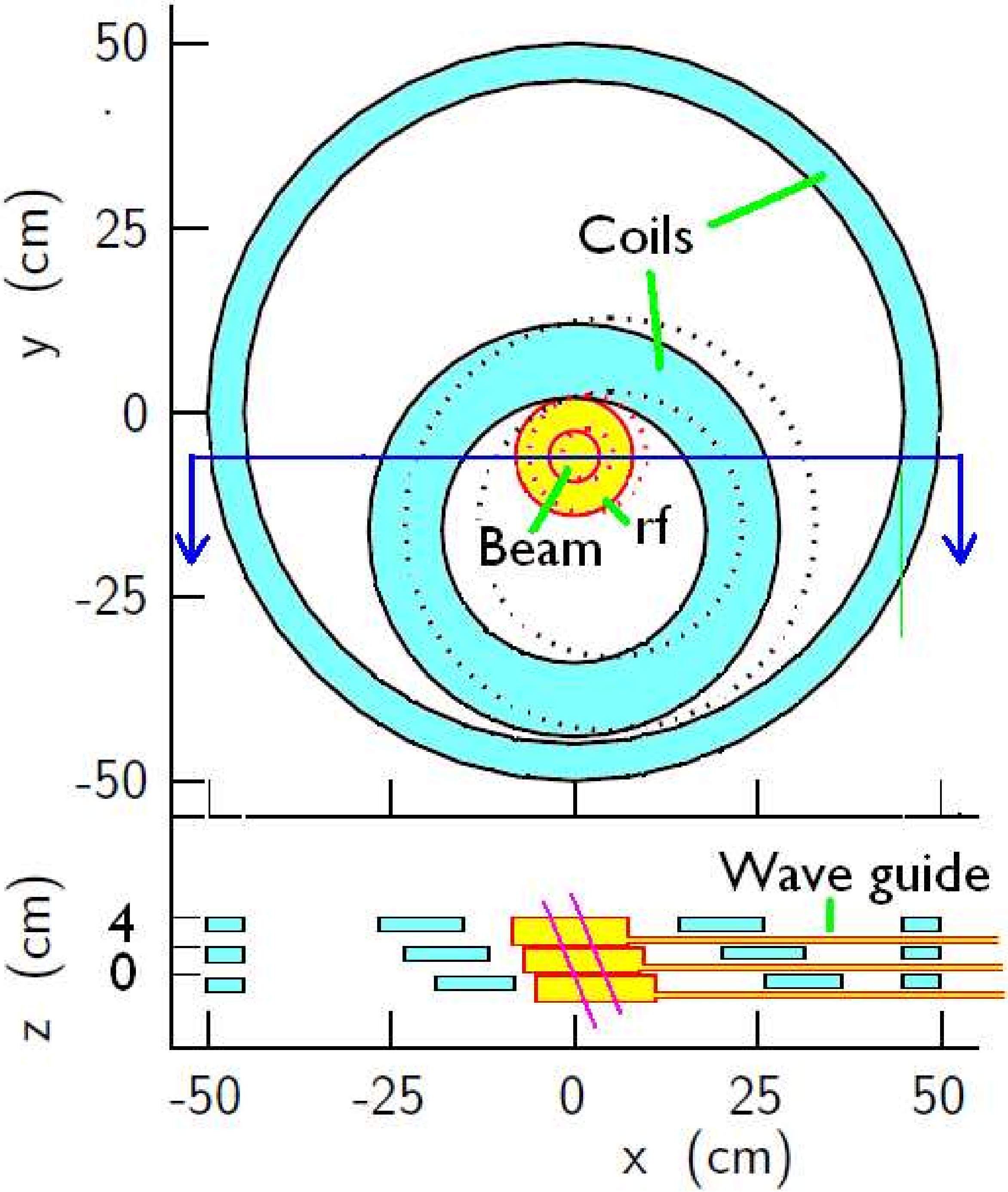
(nf102a)



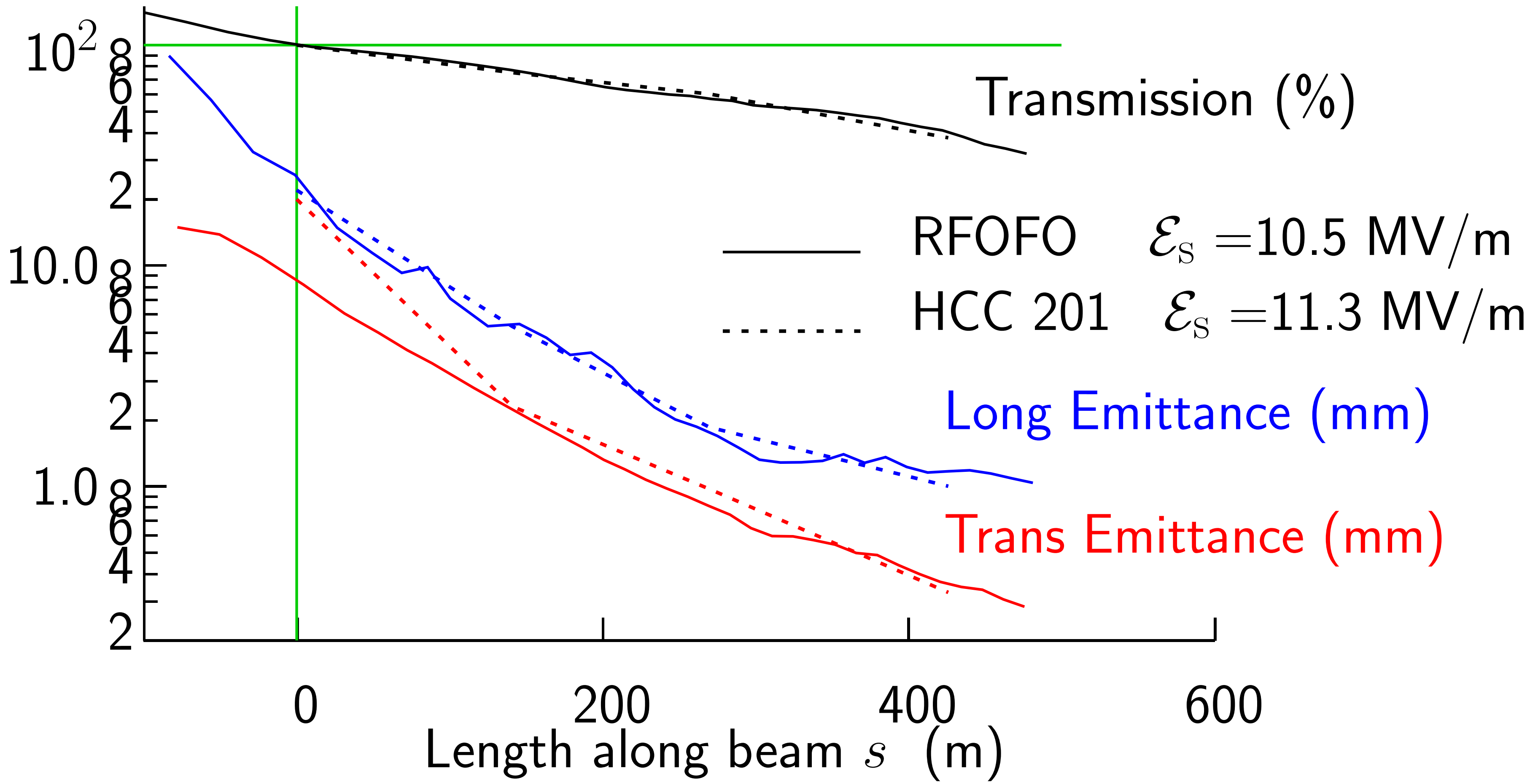
HCC
Stage 6 section

Cools to $\epsilon_{\perp}$ =0.4 mm Peak field on conductor 17.2 T

stage 7, for 0.3 mm would presumably be smaller with higher fields

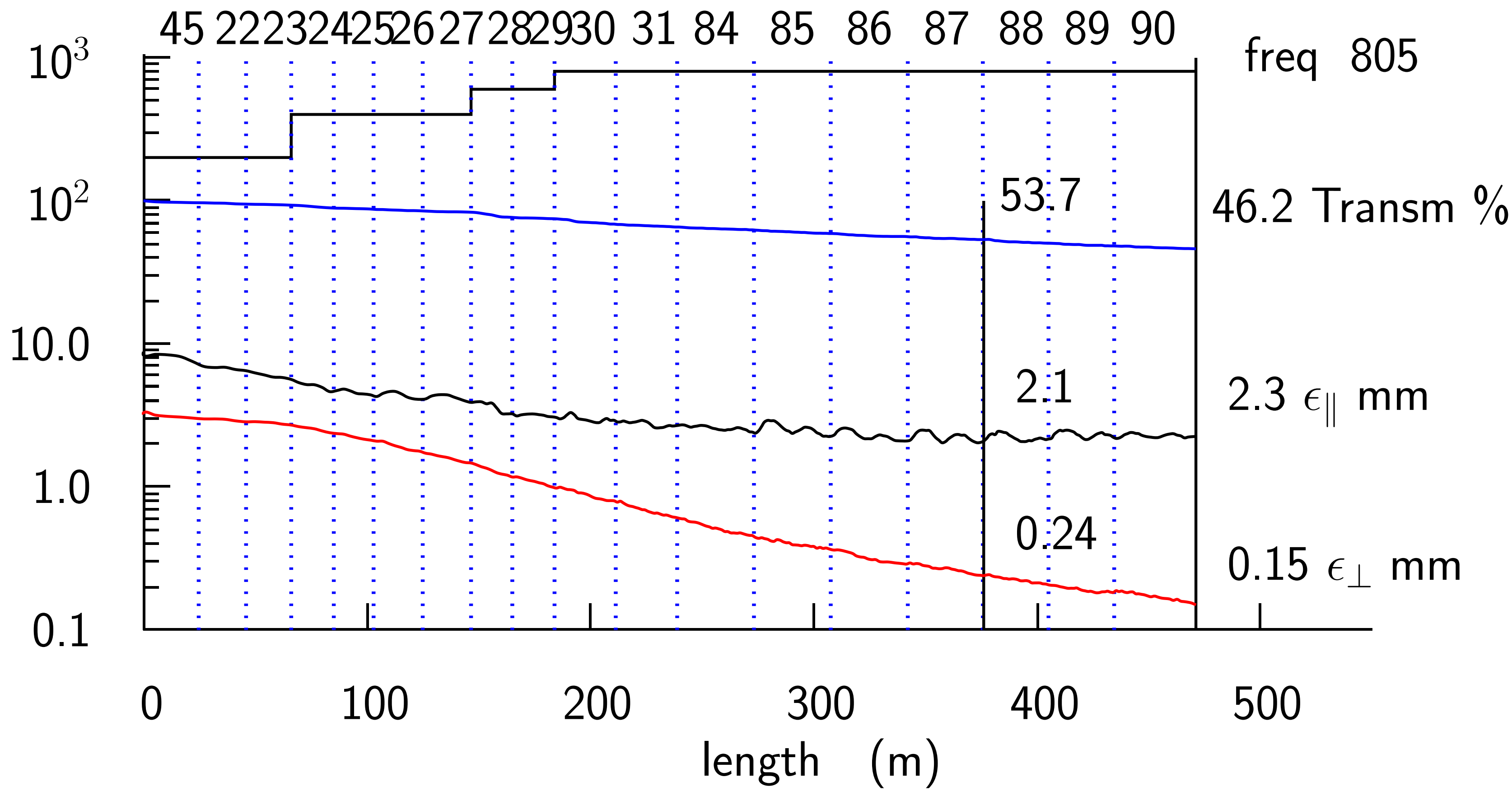


Guggenheim and HCC Performances



- Emittances are vs. length along the beams (not the helix axes)
- Cooling rates similar
- Transmissions also similar for similar rf gradients

ICOOL Simulation (using matrices) of 6D cooling after merge for H.E Collider



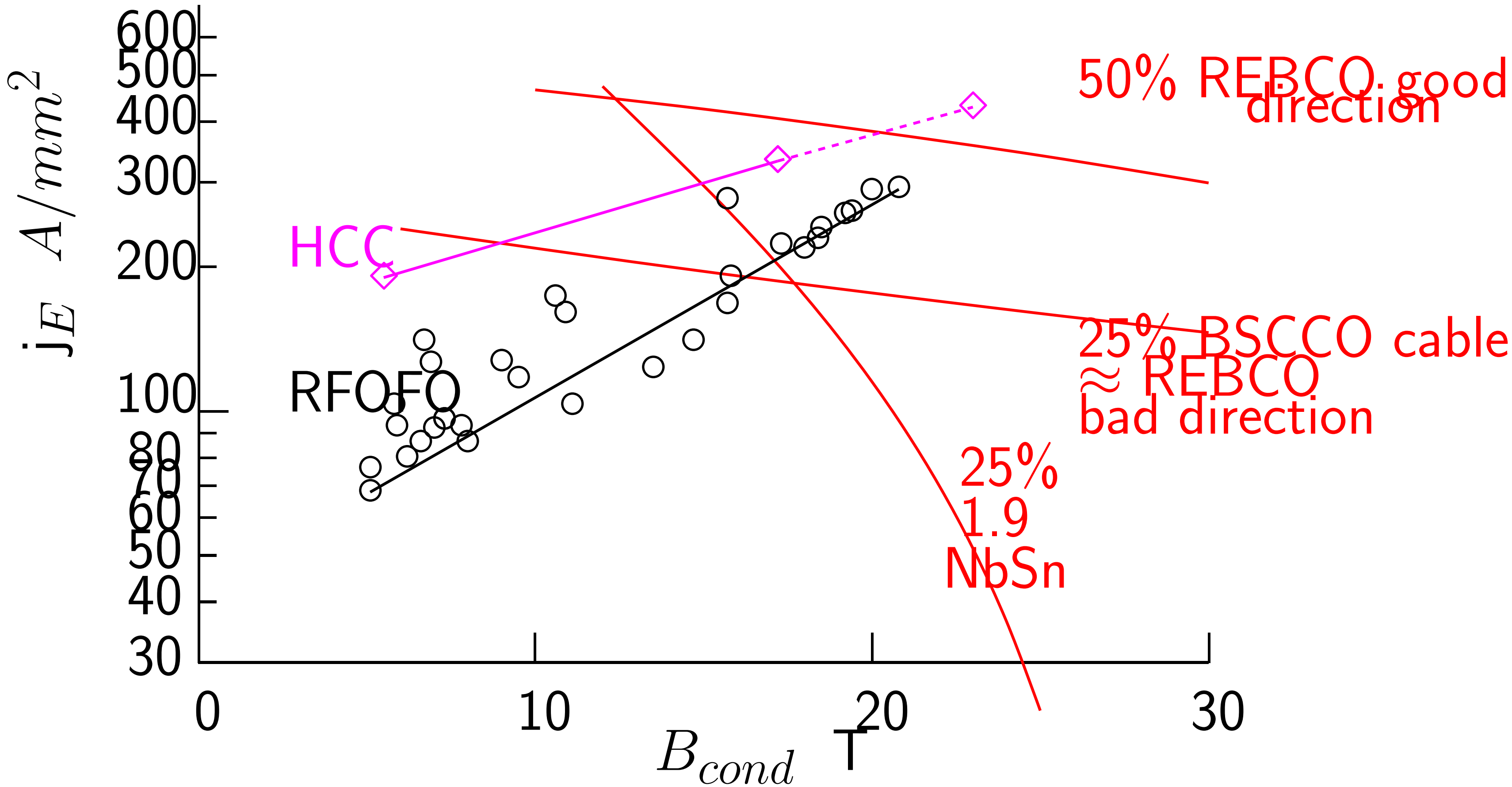
- Longitudinal emittance kept above 2 mm for space charge
- Cooling down to 0.15 mm transverse with HTS conductors

Required SC Current Densities

a) for HCC and RFOFO Guggenheim

Both have rapidly changing fields

in the bad direction for REBCO

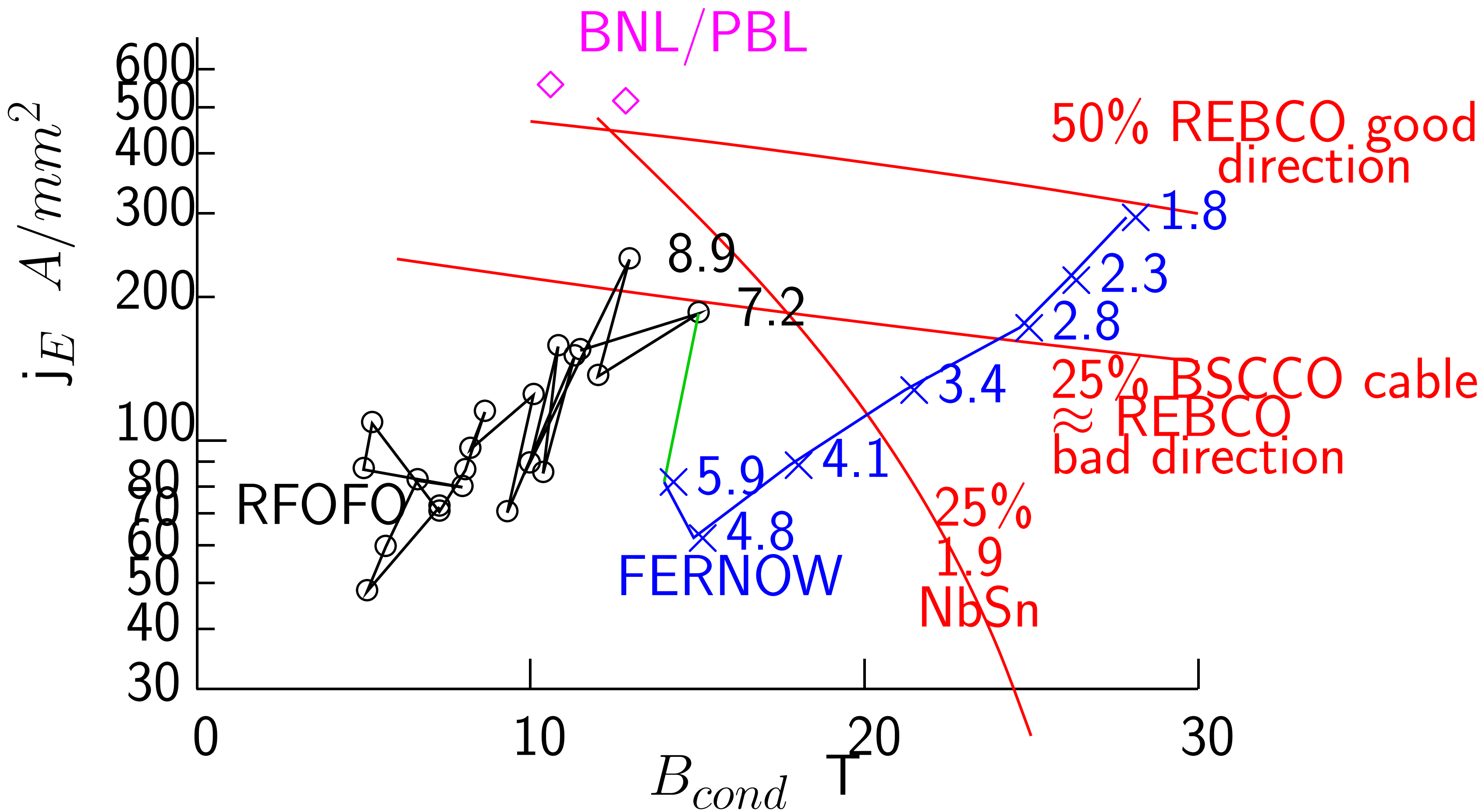


Neither look plausible

Required SC Current Densities

b) For Guggenheim using Fernow Non-flip lattices

Non flip lattices even better than single coils for field direction



This looks more plausible

And goes to lower betas if HTS used

Conclusion

- Lower acceleration losses and no final cooling means fewer muons need be cooled for a Higgs Factory
  - 2.5 10^{12} for 1.5-2 10^{12} colliding in Higgs
  - cf 5 10^{12} for 1.5-2 10^{12} colliding at 3 TeV
- We still need cooling before and after a bunch merge
- 6D merge is likely more efficient than a 2D version
- Space charge is probably significant:
  - Long emittance of 1 mm almost ok if $N_\mu = 2\ 10^{12}$ (Alexahin)
  - Long emittance of 1 mm not ok if $N_\mu = 4\ 10^{12}$ (Neuffer 2)
- Simulations of three 6D cooling systems can meet requirements
- RFOFO Guggenheim & HCC have challenging SC requirements
- Guggenheim with Fernow Non-Flip lattice appears more plausible