Design and simulation of 6D ionization cooling lattices for Muon Accelerators

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Thanks to: V. Balbekov, J. S. Berg, R. Fernow, S. Khan, R. Palmer, P. Snopok, H. Witte

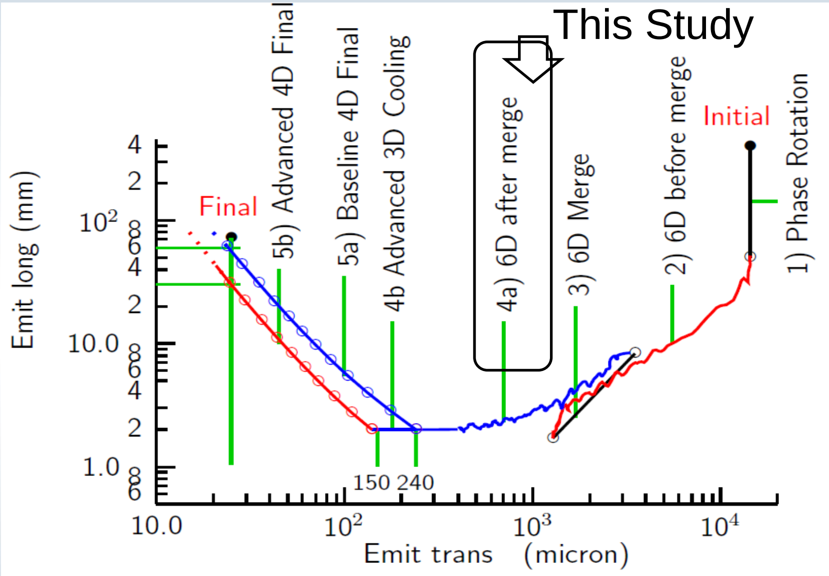
MAP Collaboration Meeting

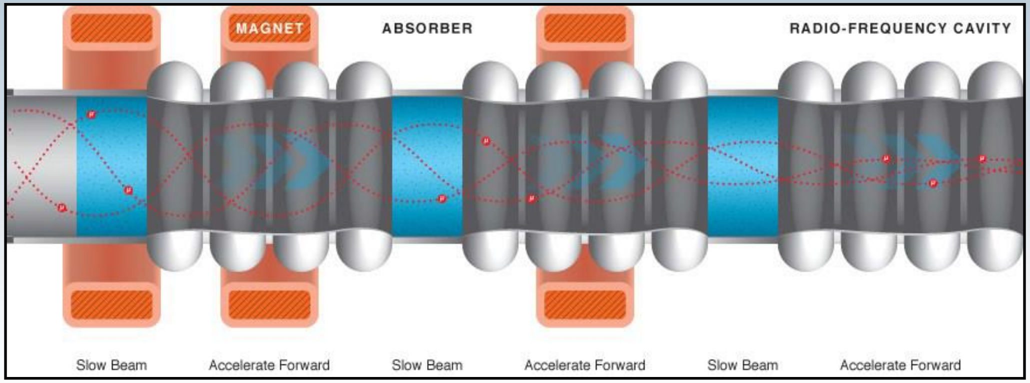
June 21, 2013

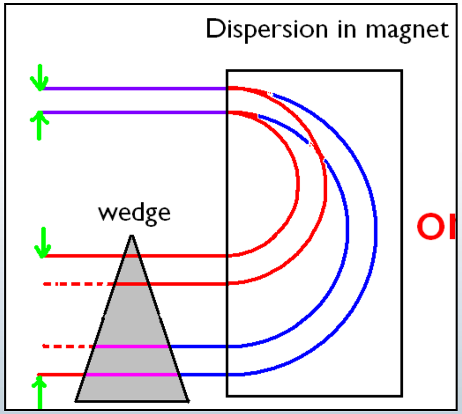
Outline

- Introduction to the tapering concept
- Present a promising 6D cooling lattice
  - A <u>tapered</u> Guggenheim Lattice
- **Evolution to a straight (snake-type) Guggenheim**
  - I will show that you I can transform the Guggenheim to a straight lattice with no parameter changes! Yes, it works!
- Lattice Details
  - Identify the required rf, voltage, B-field, radius, absorber length
- Evaluate Performance
  - Track particles : Carry out a full “front-to-end” simulation
- Review magnet & engineering feasibility

Cooling Requirement

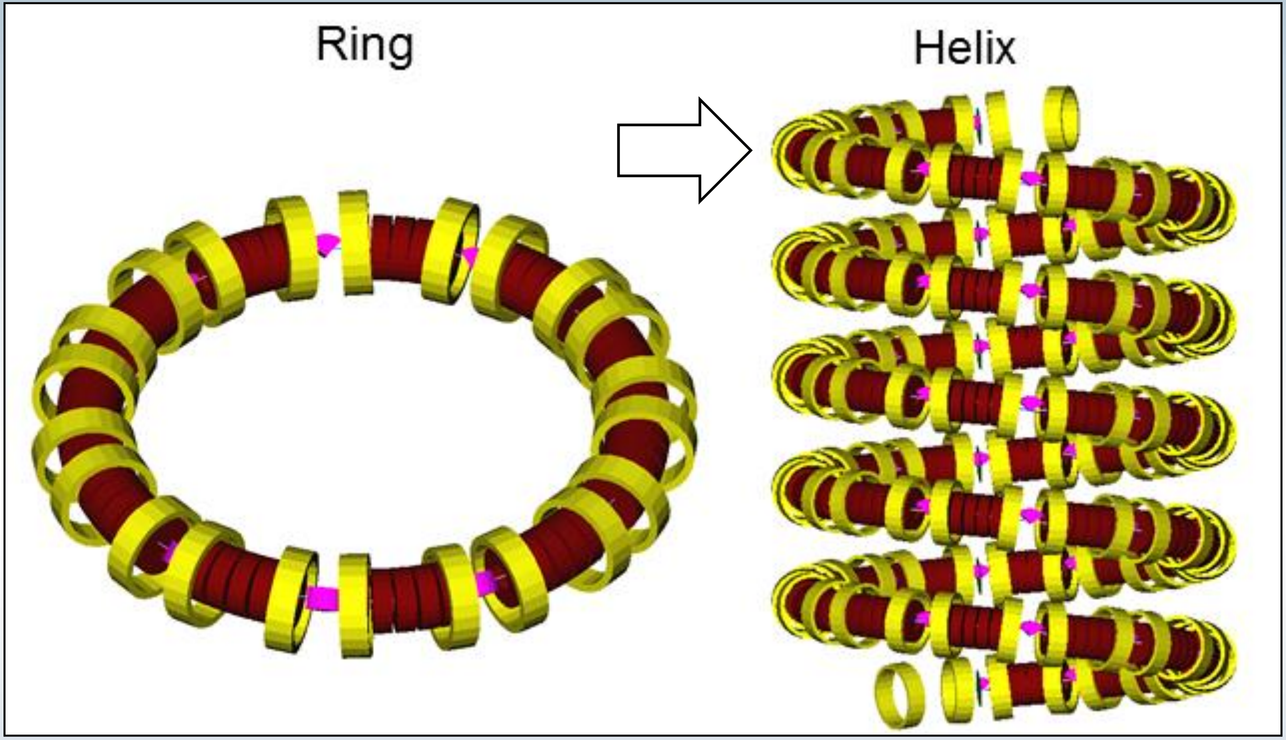


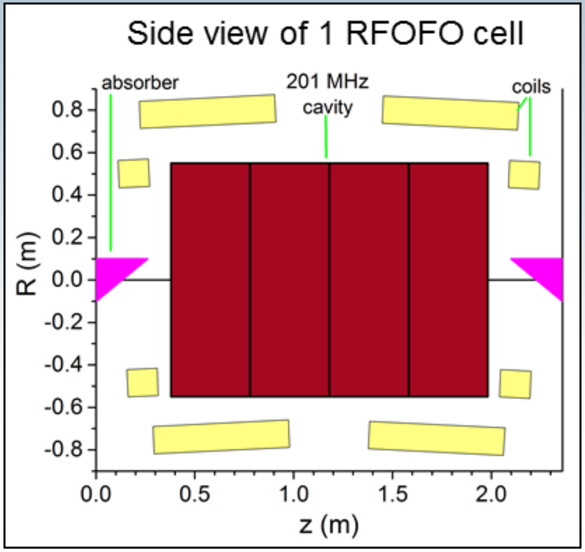


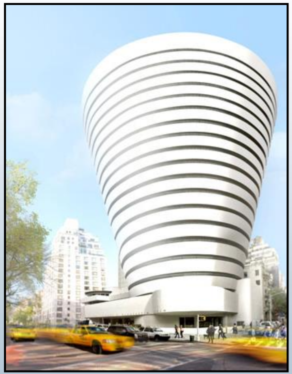


- Ionization cooling is the only feasible option
- Longitudinal cooling through emittance exchange
- Simultaneous transverse & longitudinal cooling

RFOFO Cooling Concept



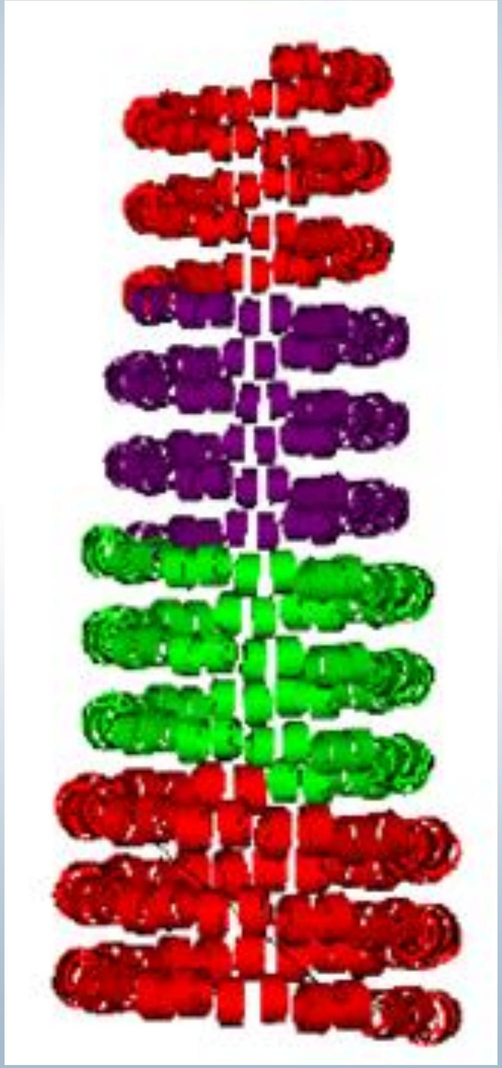




- Tilt coils to generate dispersion
- Emittance exchange on a wedge absorber
- Ring evolved to a helix to avoid injection/extraction issues

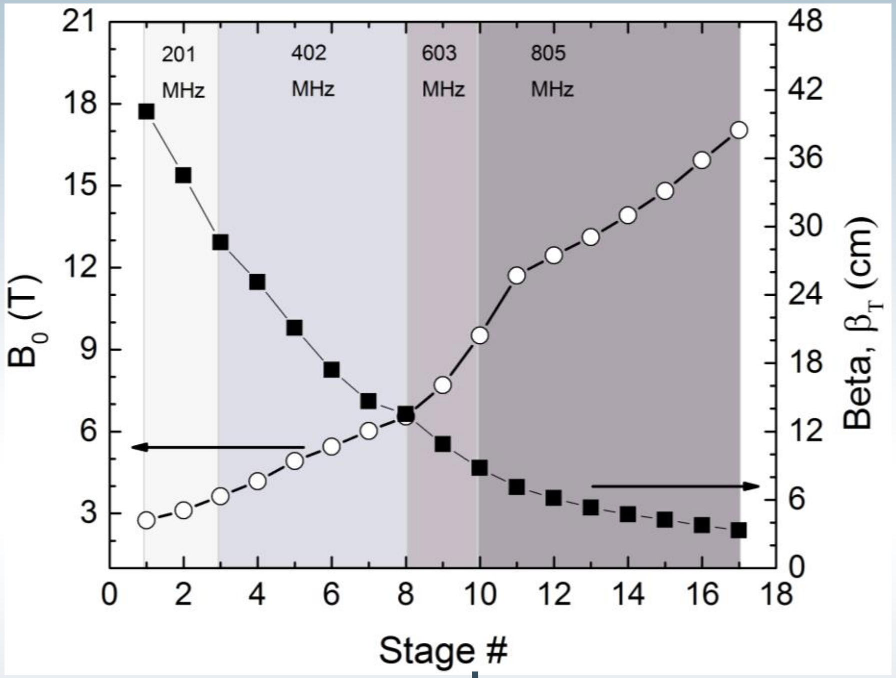
Palmer et al., PRST-AB 8, 021021 (2005); Snopok & Hanson , IJMPA 8, 021021

Tapering



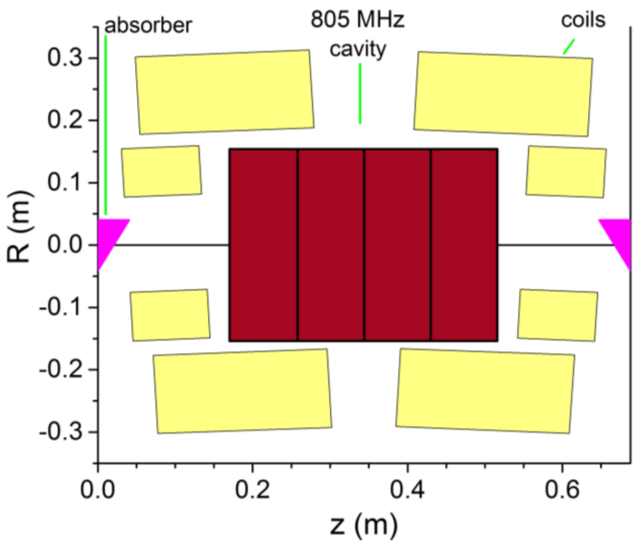
- Lattice parameters such as rf freq., cell length, focusing strength, absorber length, change with distance
- Keep emittance above equilibrium
- Tapering pros:
  - More dispersion, faster cooling
  - Impressive constant cooling efficiency
  - Shorter than untapered channels
  - Method is not restricted to a Guggenheim
- We can transform it to a straight lattice with no changes (R_FOFO)

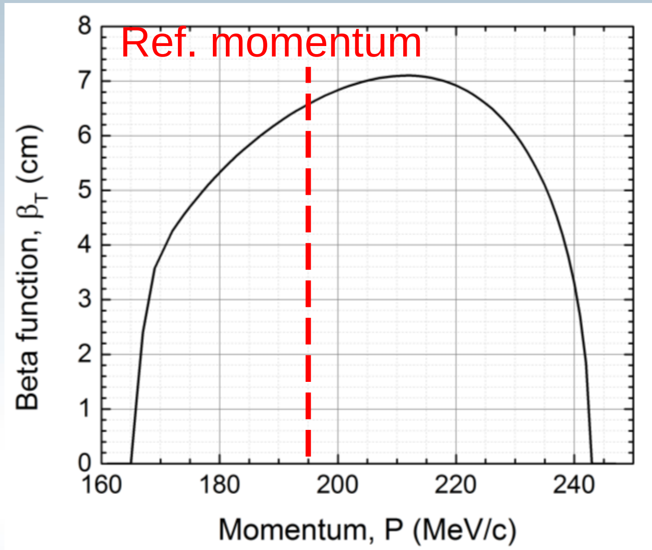
Stages of the Guggemheim

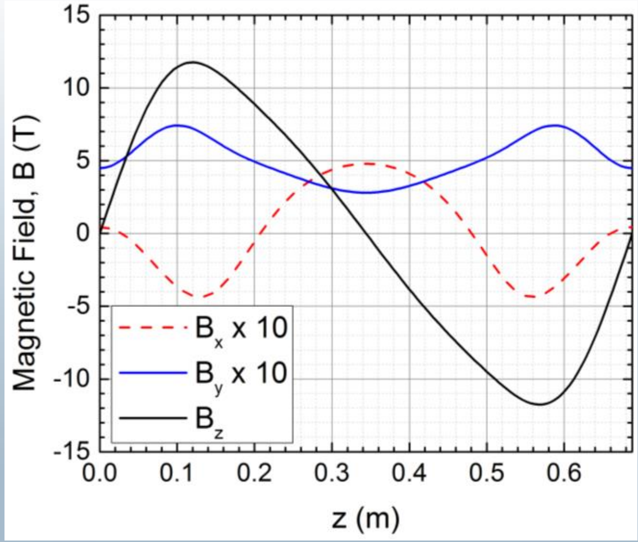


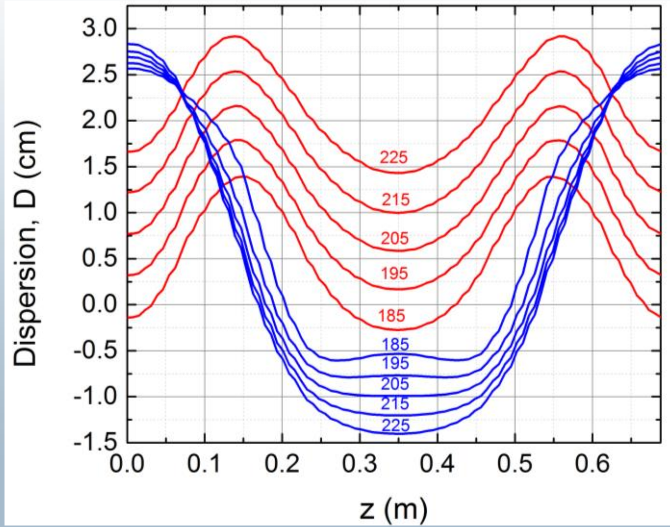
- 17 tapered stages are enough
- Each stage consist of a series of identical cells
- Only four different frequencies are necessary
- **Highest B is ~18T, conservative grad.~23 MV/m for 805 MHz**

Example: Stage 11

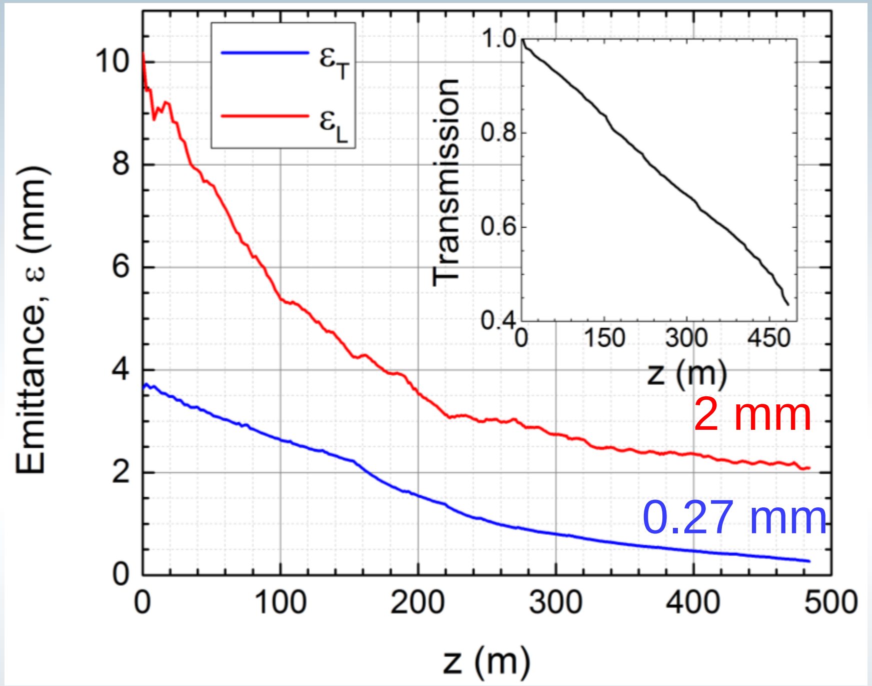


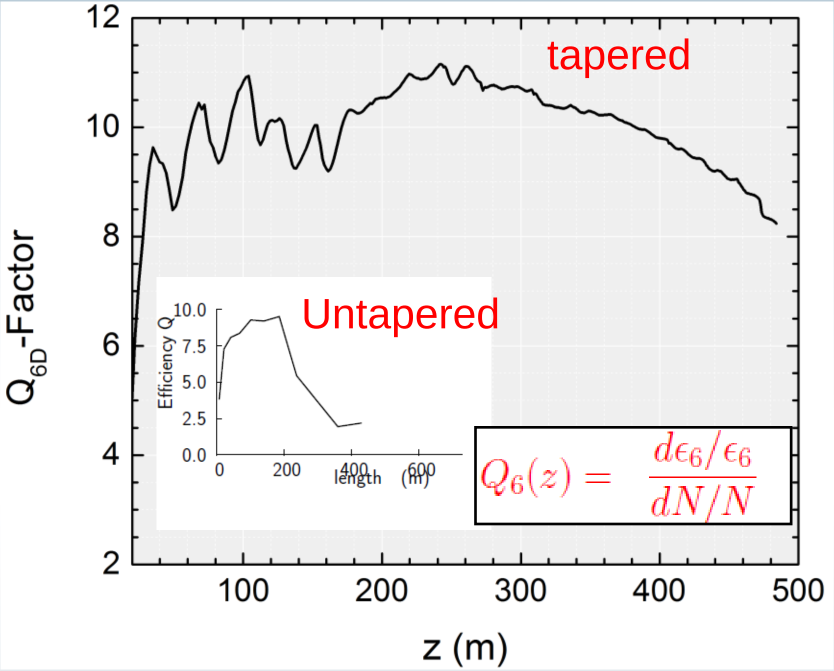






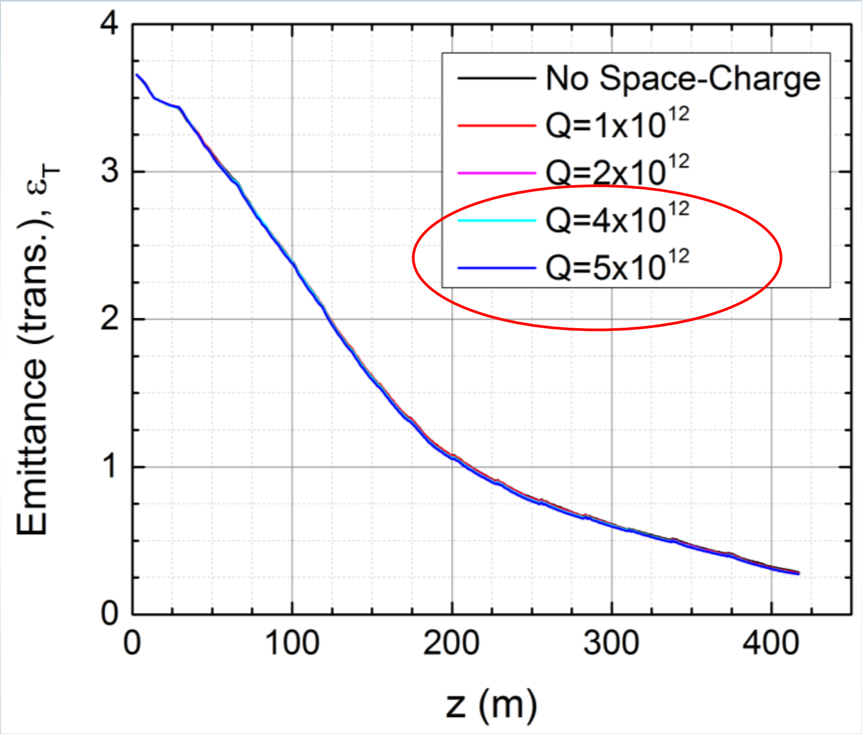
Particle Tracking & Performance

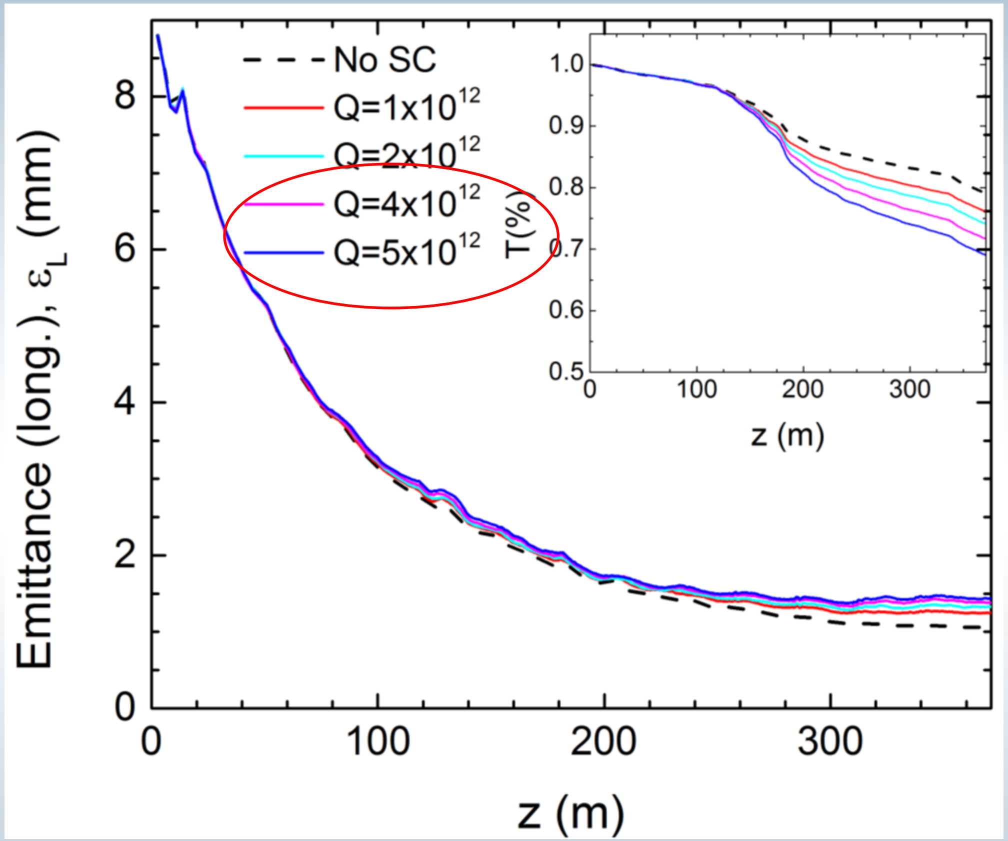




- Cools to MC baseline parameters. We start with a real distribution from the post-merger (100,000 particles)
- Notice that Q is flat all the way (importance of tapering)
- Transmission ~45% with decays, windows, stochastics.

Cooling Limitations due Space-Charge

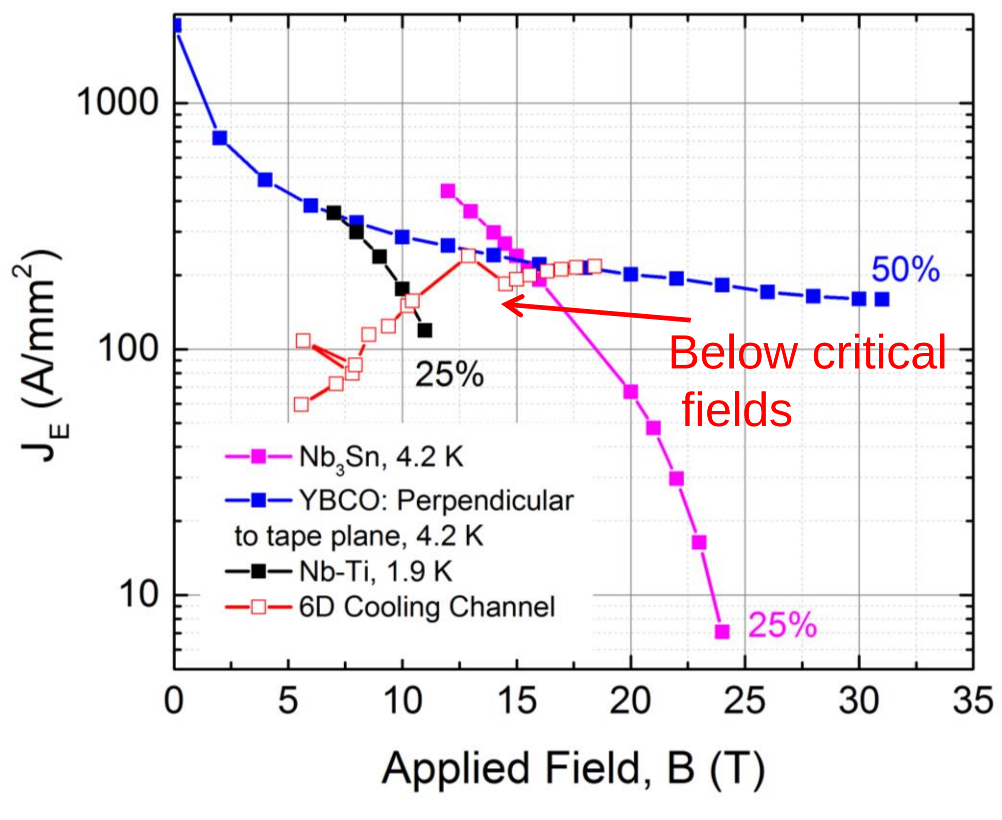




- 20% particle loss after z>200 m due space-charge
- Thus, we avoid cooling longitudinally below 2 mm

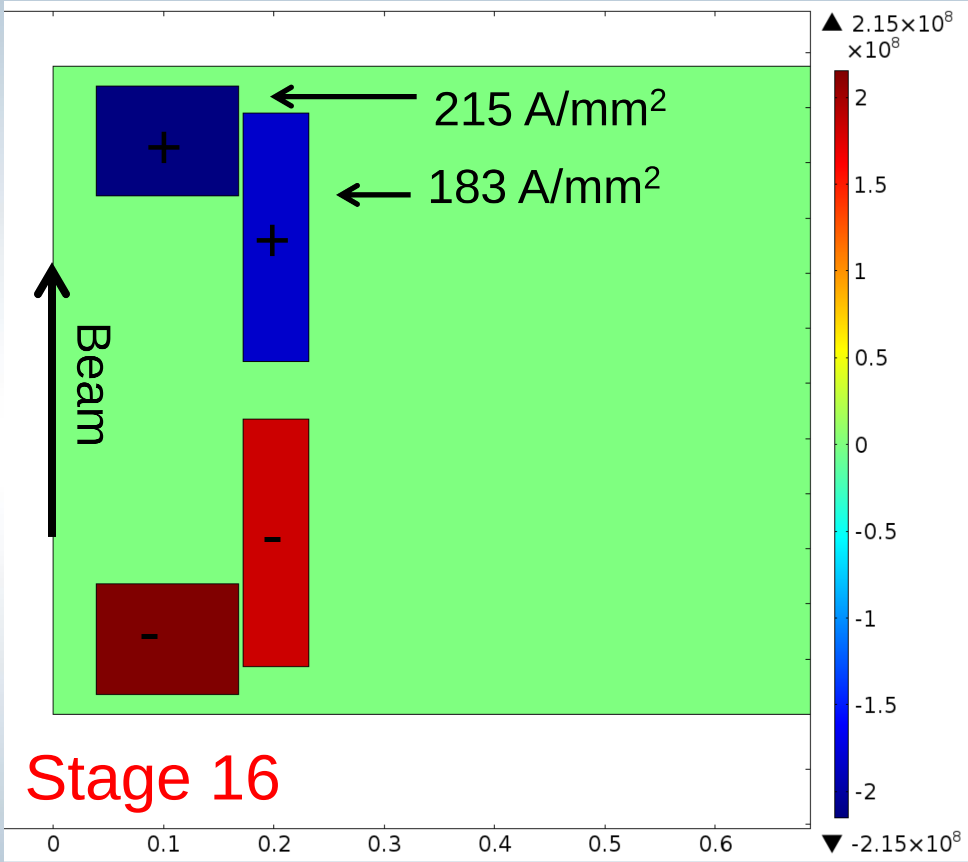
D. Stratakis, R. Palmer and D. Grote, Proc. of IPAC 2013, p. 759

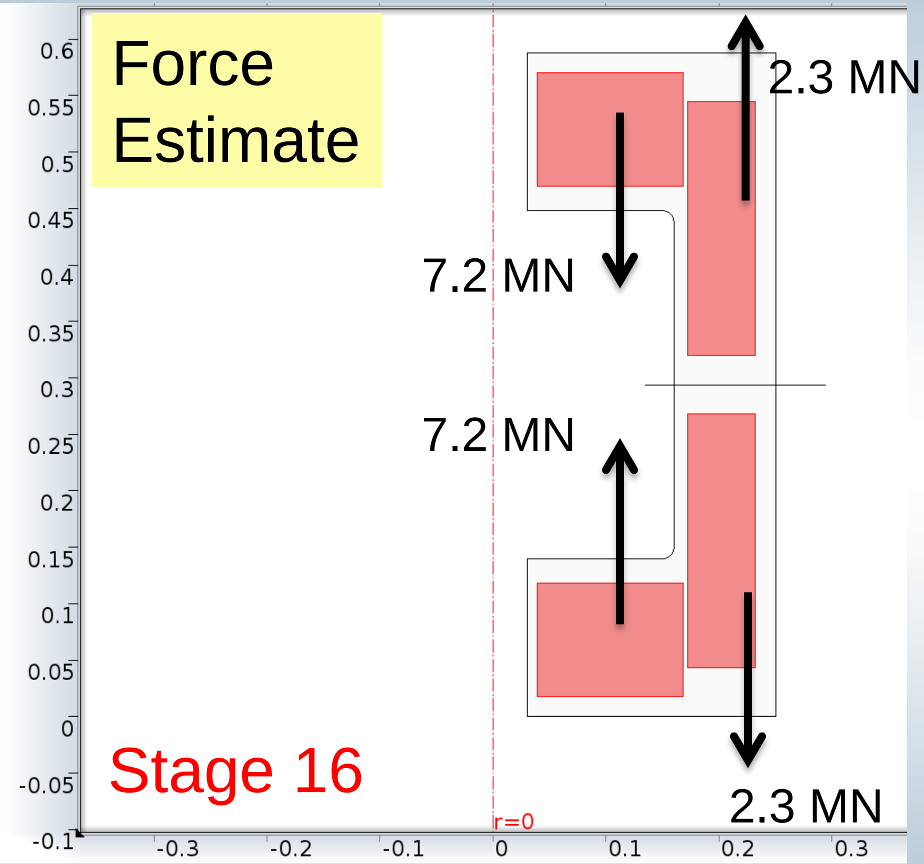
Critical B-Field limits



- All simulations use realistic fields calculated from coils.
- Our lattice fields are below or close to the critical limits of existing magnet technology.

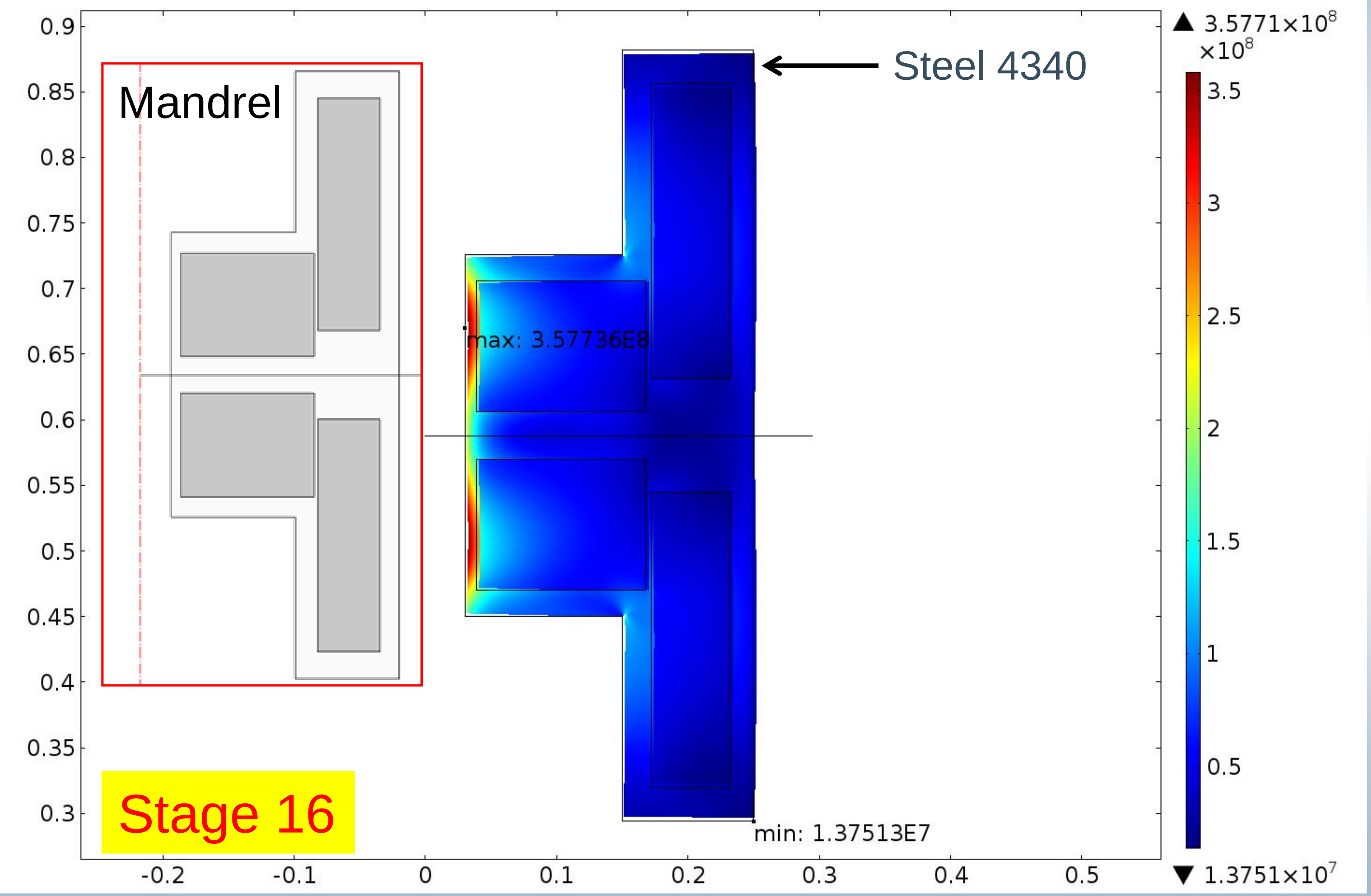
Engineering Studies (H. Witte)





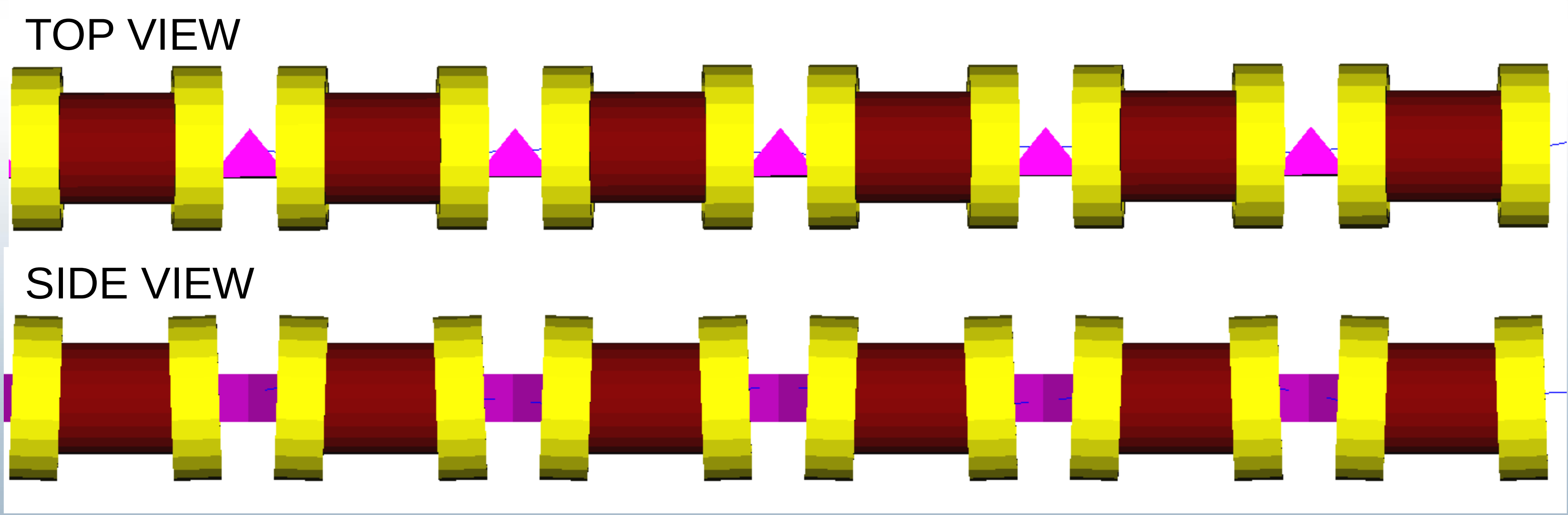
- Preliminary studies with COMSOL

Von-Mises Stress (H. Witte)

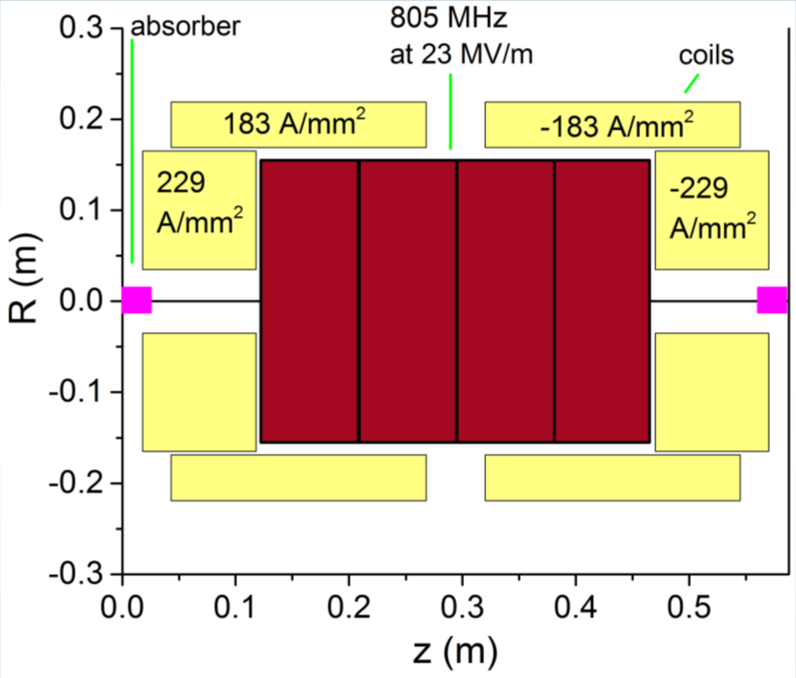


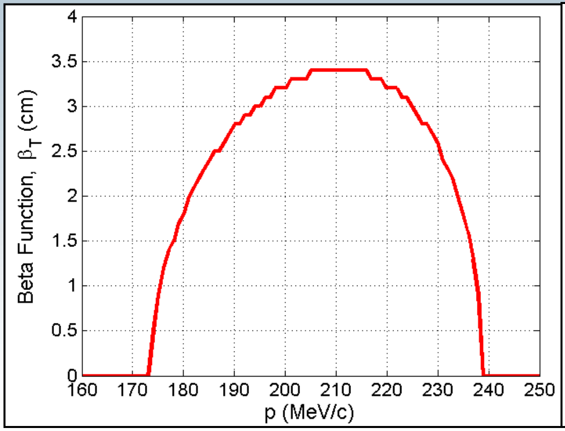
Convert to a straight Guggenheim

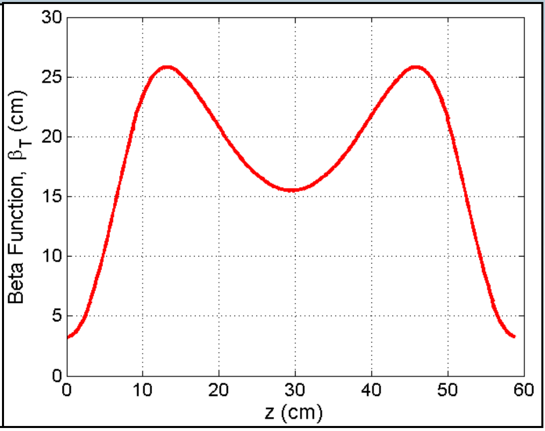
- Conversion from Guggenheim to Rectilinear_FOFO
  - Good news: Only minor variations of the Guggenheim lattice parameters are needed



Design a late stage with R_FOFO



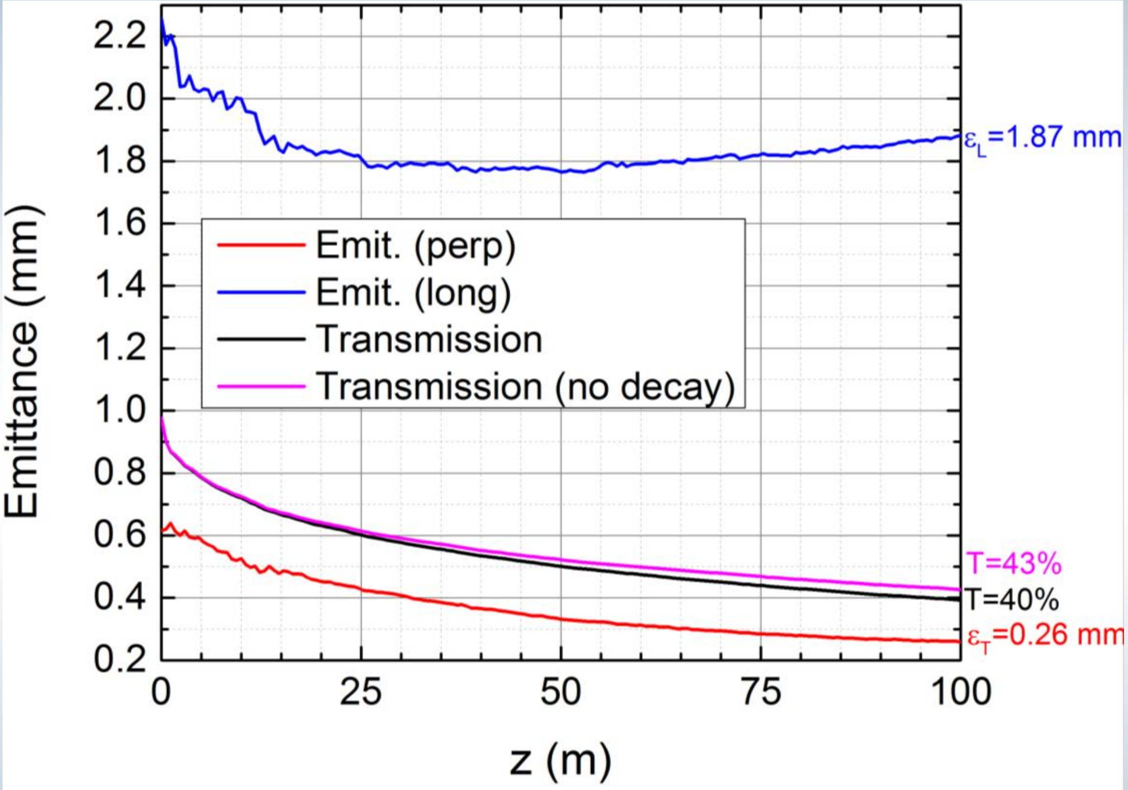




This is the worst case!

Property	Value
Cell period	0.588 m
RF Frequency/ RF number	805.0 MHz / 4
RF voltage	**23.6 MV/m**
Synchronous phase	32 deg.
Absorber	LH2
Minimal beta function	3.2 cm
Max Field on Coil	**18.6 T**
Max Field on Axis	**17.0 T**

Last Stage with a R_FOFO



- Cools towards the baseline requirements for a MC with a >40% transmission!
- Initial distribution is the output of Stage12 of Guggenheim

Summary

- Some additional things to remember:
  - A Guggenheim can become **straight** with the <u>same</u> parameters!
  - This is a front-to-end complete simulation. We include rf and absorber windows, muon decays and stochastics.
  - We reach close to the baseline MC requirements with T>45%!
  - We use realistic fields calculated from coils
  - **“Low” < 19 T** fields (worse case is 18.6 T on coil and 17 T on axis)
  - Current densities within limits including a <u>moderate</u> safety factor
  - Only 4 rf: 201,402,603,805 MHz. Conservative 23 MV/m 805 MHz
  - Notable <u>flat & high</u> cooling efficiency. 6D drop by a 1/1000 factor.
  - Encouraging results look encouraging from preliminary studies!
  - This work is submitted to Phys. Rev. ST-AB