Guggenheim simulations

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Muon Collider Design Workshop
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Outline

- use of guggenheims in Palmer cooling scenario
- modeling the helical nature of the channel
- modeling shielding between the layers
- channel topology
- new guggenheimed collider simulations
- work that needs to be done

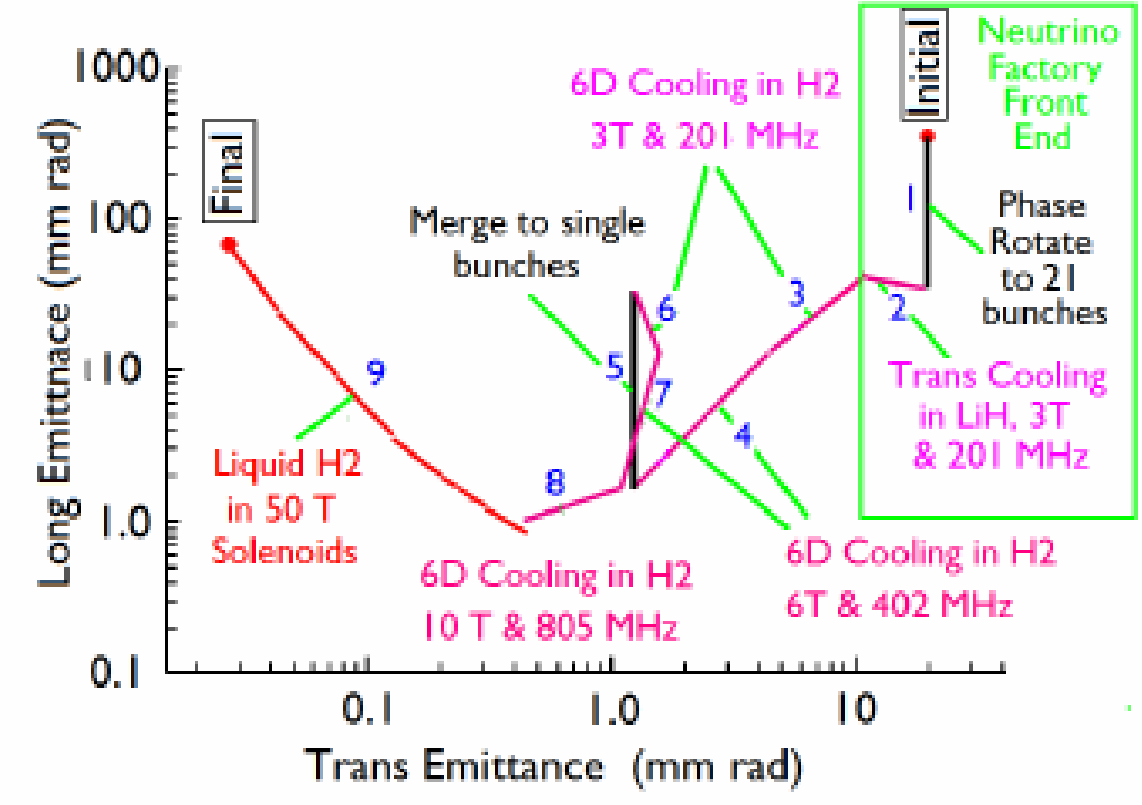
Our inspiration

Palmer cooling scenario

- used to do intermediate cooling in Palmer scenario
- provides <u>all</u> the longitudinal cooling

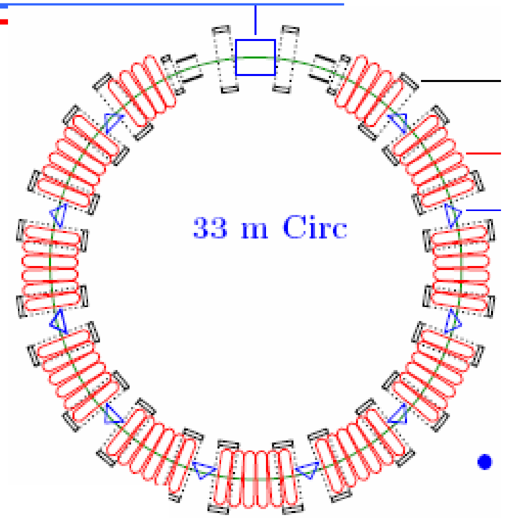
gets down to ε_{TN} = 0.4 mm and ε_{LN} = 1 mm

Cooling scenario plot

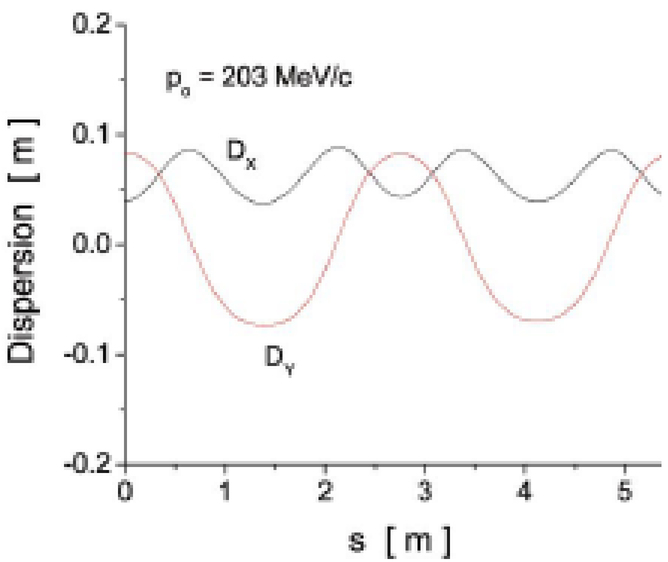


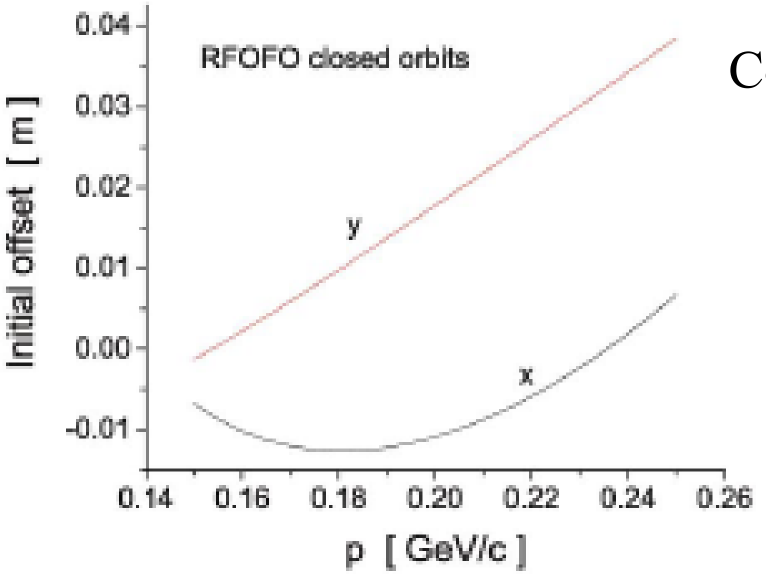
RFOFO ring

- channel based on turning RFOFO ring into helix
- focusing using alternating solenoid lattice
- bending from tipping the solenoids
- used 201 MHz, 12 MV/m
- wedge-shaped LH_2 absorbers



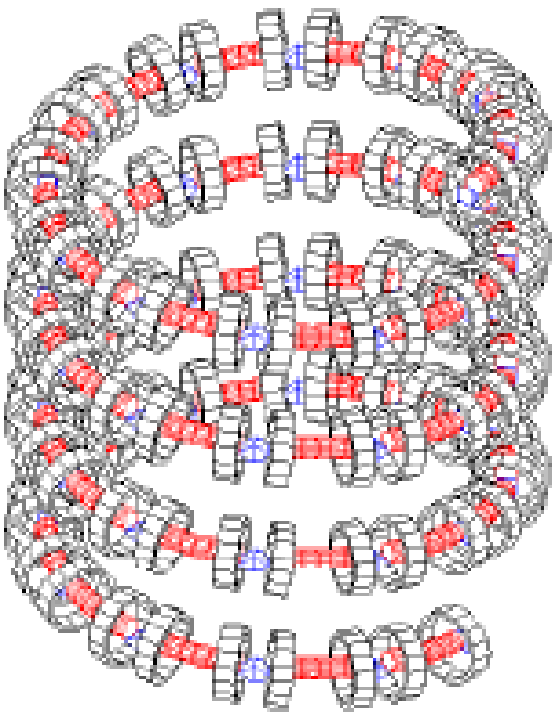
Coils outside RF





Gugenheim layout

- advantages over ring configuration
  - no restriction on bunch train length
  - no injection or extraction
  - tapering is possible
  - relieves heat load on absorber
- disadvantages
  - more hardware needed ($)
  - may need magnetic shielding

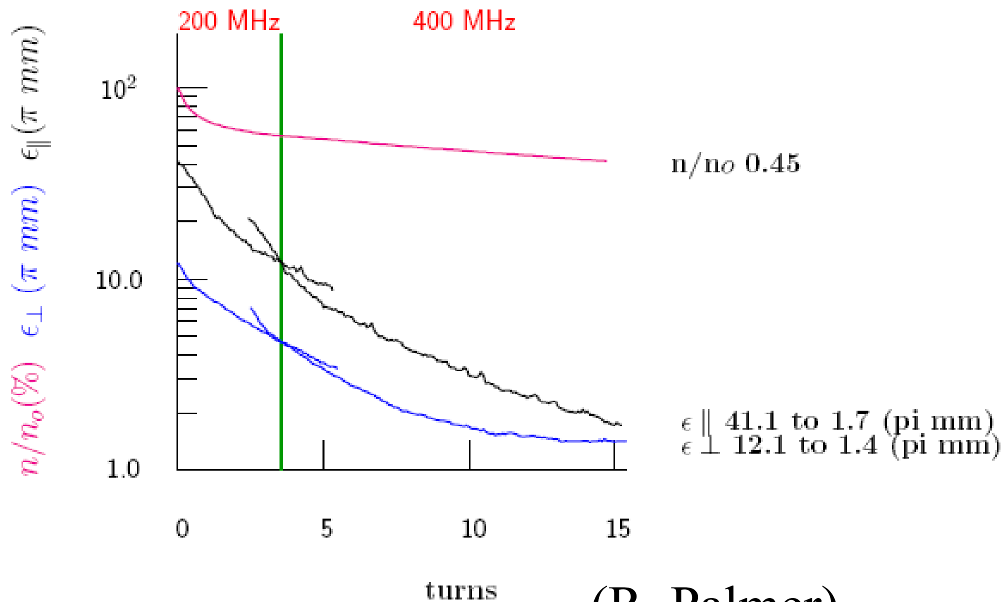


Reference 201 MHz simulation

- reference simulations used to estimate cooling performance
- used twice in the scenario
- could be same channel with different initial beam conditions
- used same parameters as the RFOFO ring

  C=33 m, B_S=3 T, G=12 MV/m, $\beta_\perp$= 40 cm

Before merge

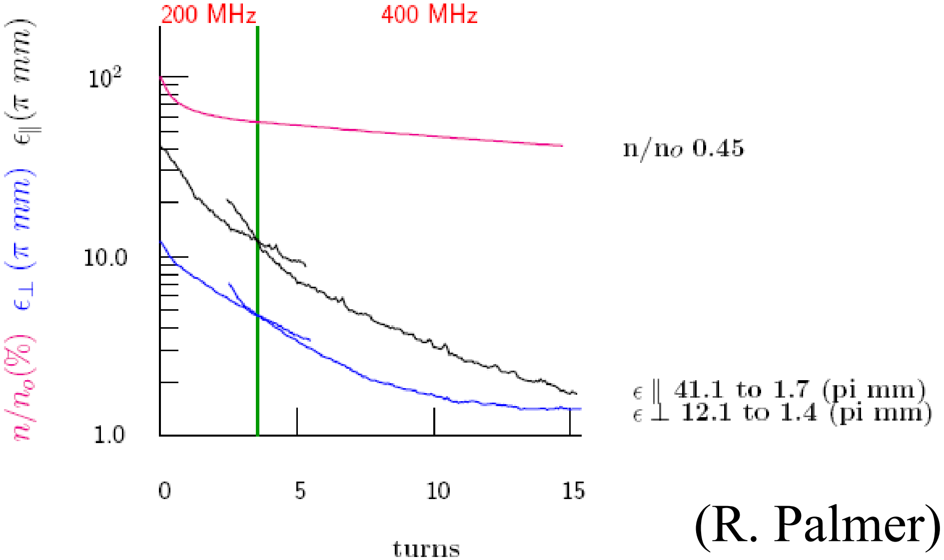


(R. Palmer)

Reference 402 MHz simulation

- also used twice in the scenario
- could be same channel with different initial beam conditions
- scaled dimensions of 201 MHz ring by ½

  $C=17$ m, $B_S=6$ T, $G=14$ MV/m?, $\beta_\perp= 20$ cm
- assumed smooth transition from 201 → 402 channels

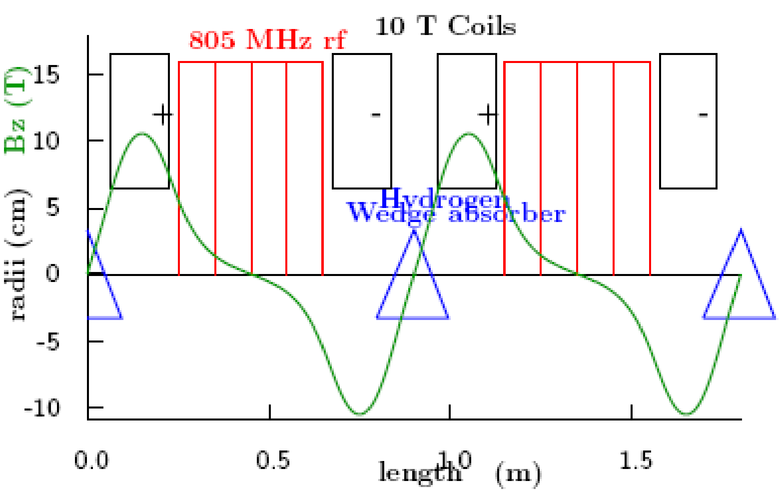


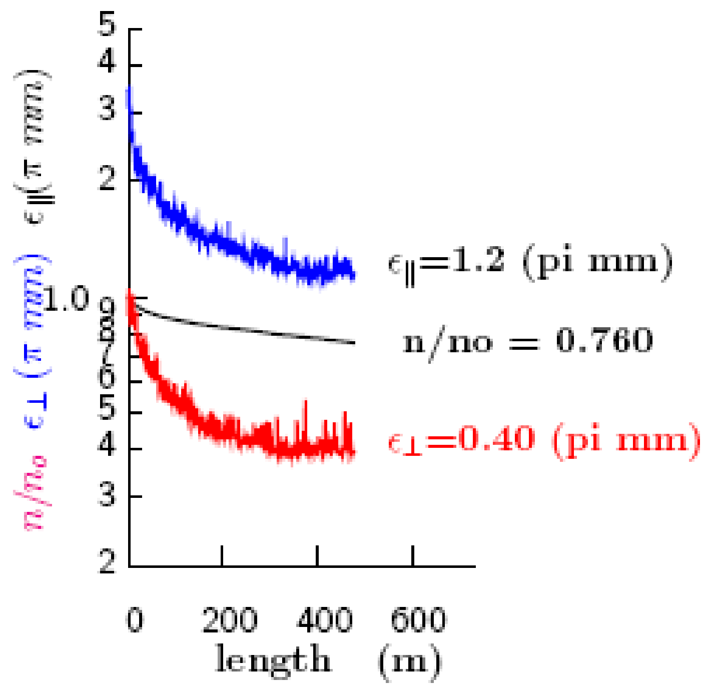
(R. Palmer)

Reference 805 MHz simulation

- had to design modified lattice (“1/3 scale”)
- coils moved closer to axis

C=11 m, B_S=10 T, G=16 MV/m , $\beta_\perp$= 5 cm





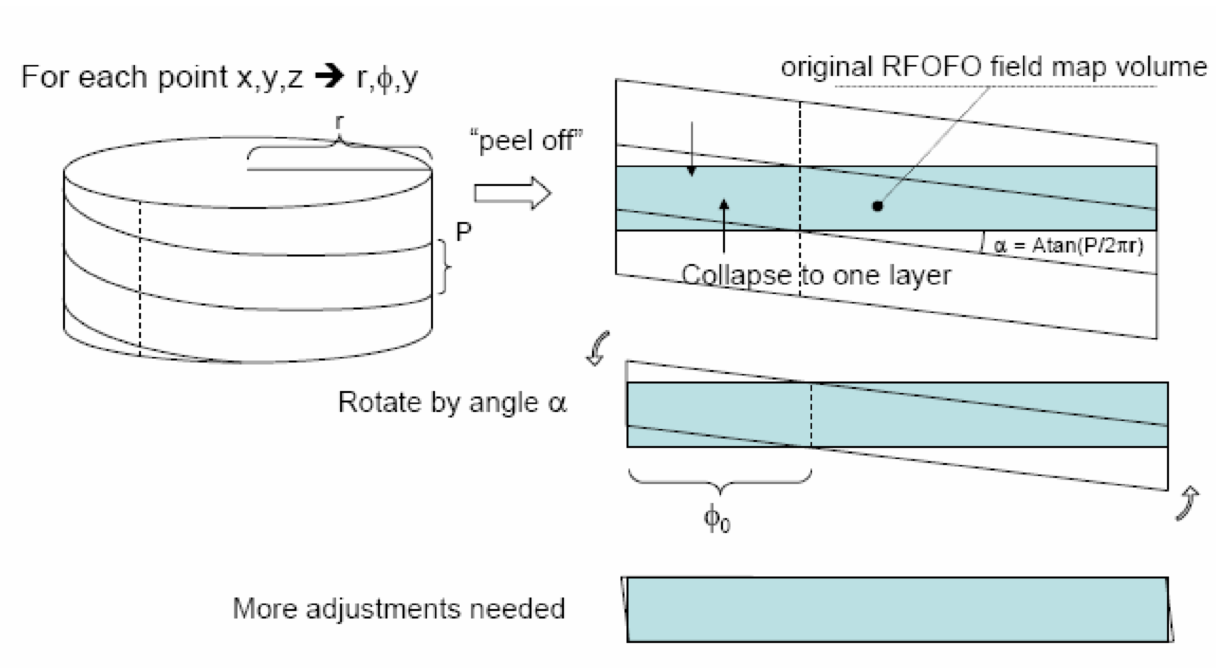
(R. Palmer)

Simulating the guggenheimness

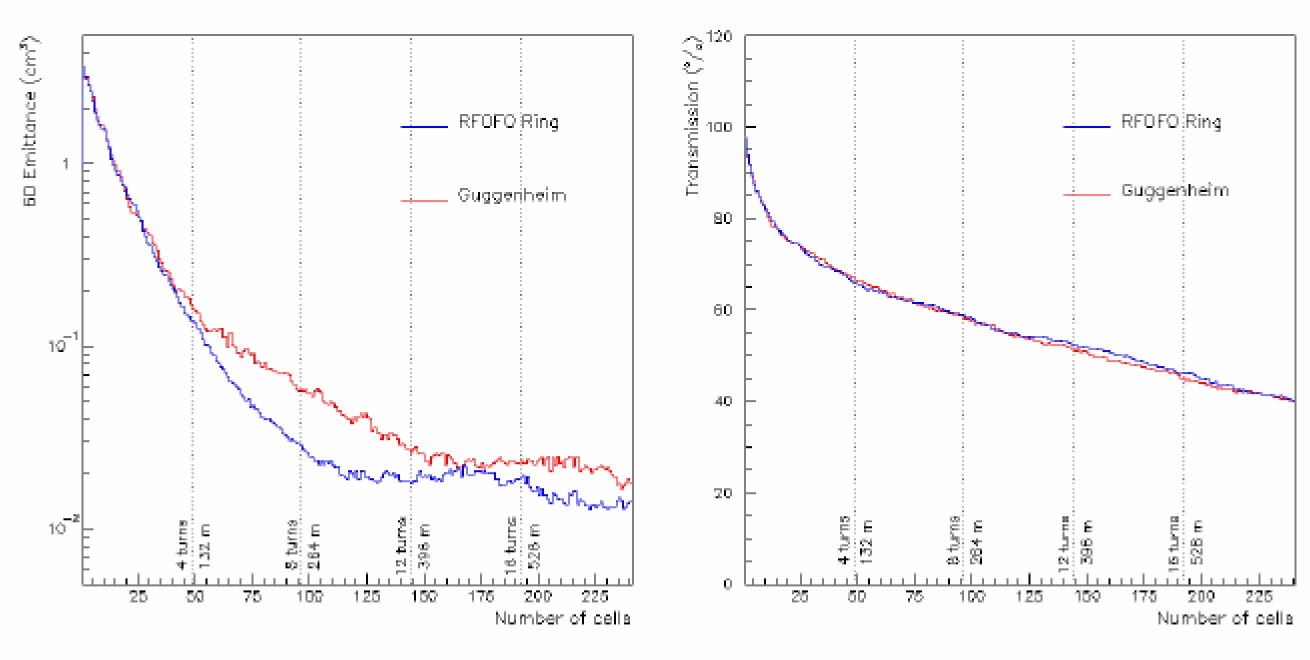
- preceding simulations actually used ring configurations
- investigate effects of helical channel
- at minimum we need to include bending out of the plane
- some possible approaches tried so far
    1) transformed ring field map
    2) placing coils in 3D space
    3) including the a_0 multipole

Transformation of ring field map

- procedure for mapping slice of helical field onto RFOFO ring map
  (A. Klier, LEMC workshop, Feb. 2006)
- location in map depends on pitch and azimuthal position
- need to rotate initial beam by pitch angle around x axis



Comments on Klier transformation



(A. Klier)

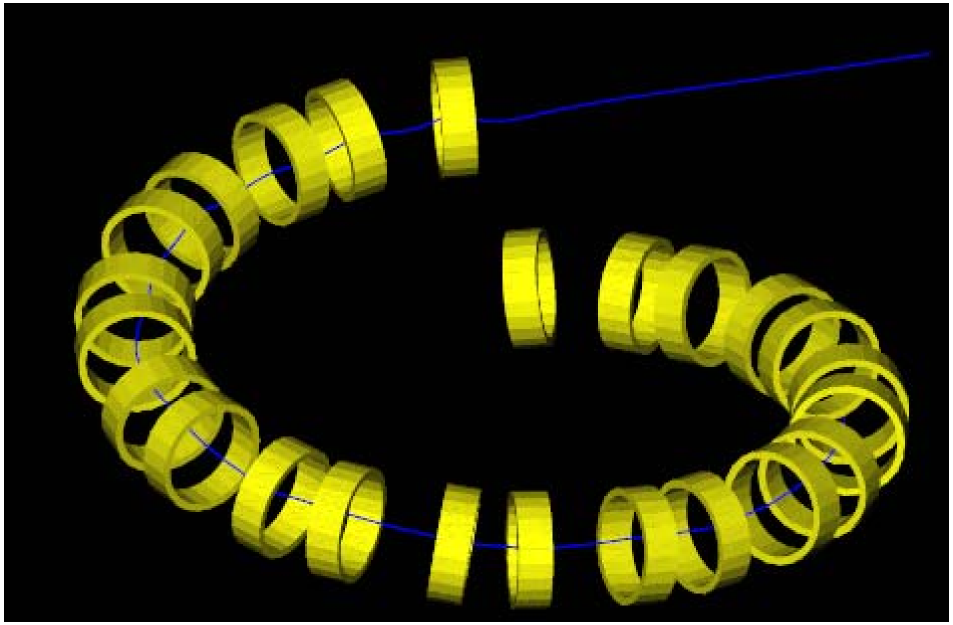
- cooling is still observed with 3 m pitch
- but …

  transformed field map is <u>not Maxwellian</u>

  ignores influence of coils in adjacent layers

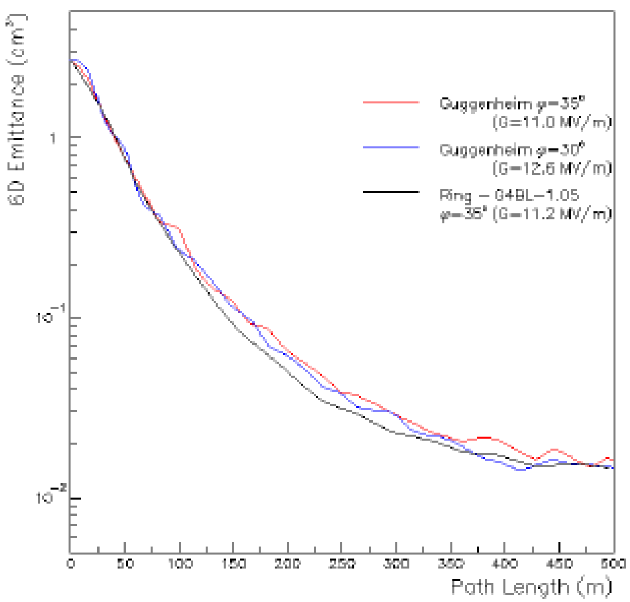
Coils in 3D space

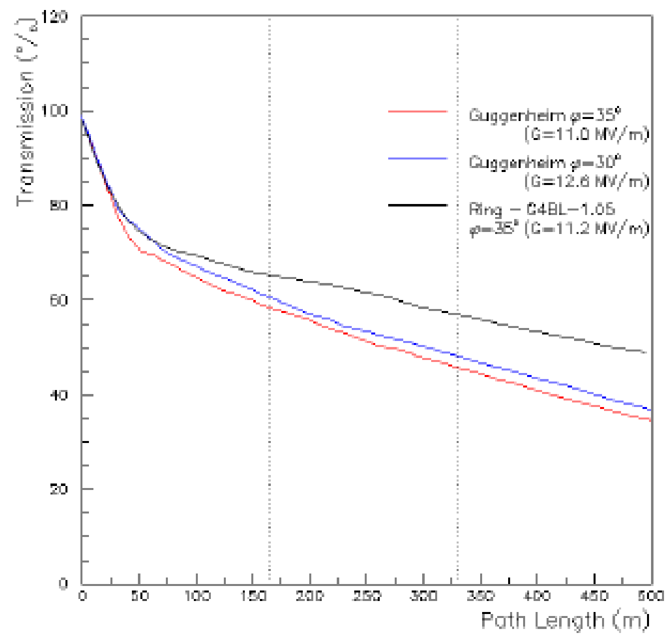
- place coils with G4BL, A. Klier, July 2006
- this method is Maxwellian
- one layer was modeled this way before Amit left



Single 3D layer simulation

- recirculated beam thru same layer: output -> input
- emittance reduction similar to RFOFO ring
- transmission after 15 turns was a lot worse (38% vs 51%)
- loss is even worse (Tr=27%) for 6 m pitch
- caveat: only had RF and absorbers in 6 of 12 cells in the layer (and ring?)

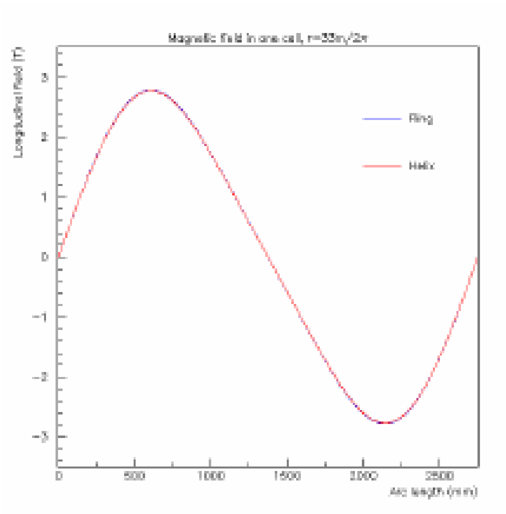




3 m pitch

(A. Klier)

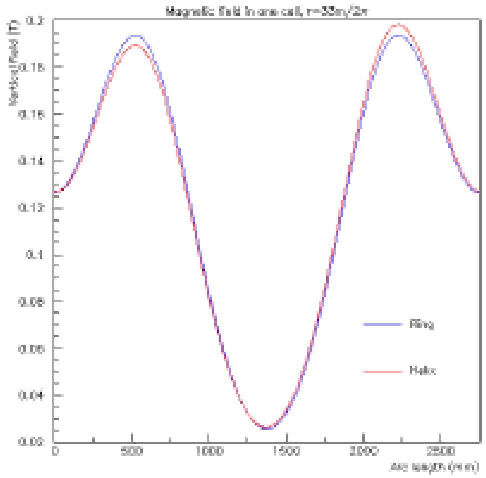
Difference between ring and helix fields



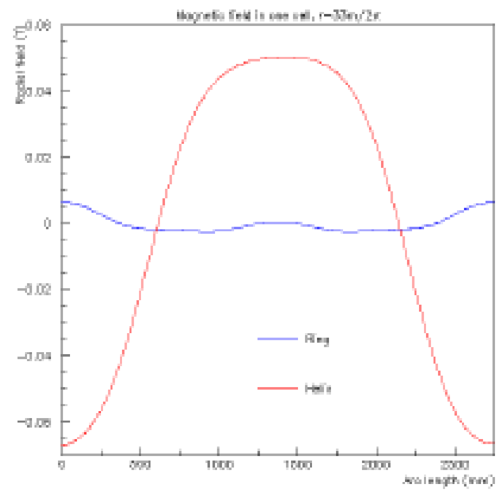
Slight difference in B_Y

Major difference is in radial field

=> add a_0 multipole

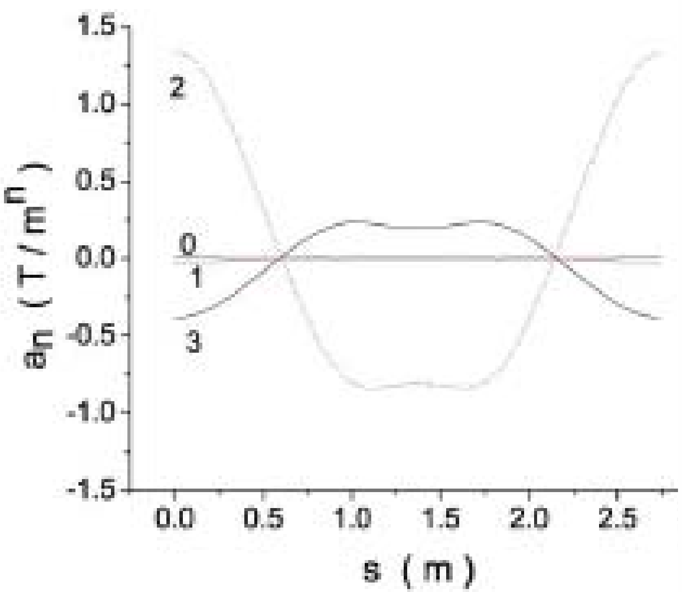


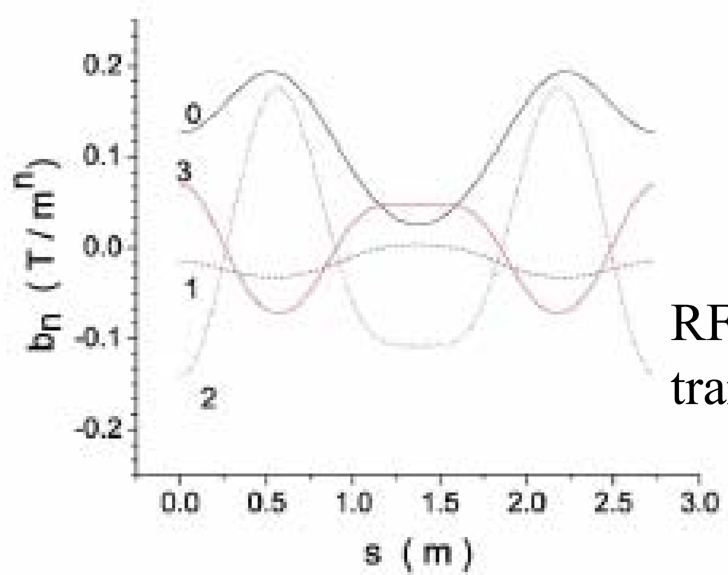
(A. Klier)



Multipole approach

- one mode in ICOOL gets B from multipole expansion
- input: Fourier decomposition of multipoles along reference orbit
- off-axis fields from ≤5th order expansion of Maxwell equations
- advantages: fast, easy to study effect of individual multipoles
- disadvantage: field accuracy decreases farther from reference orbit



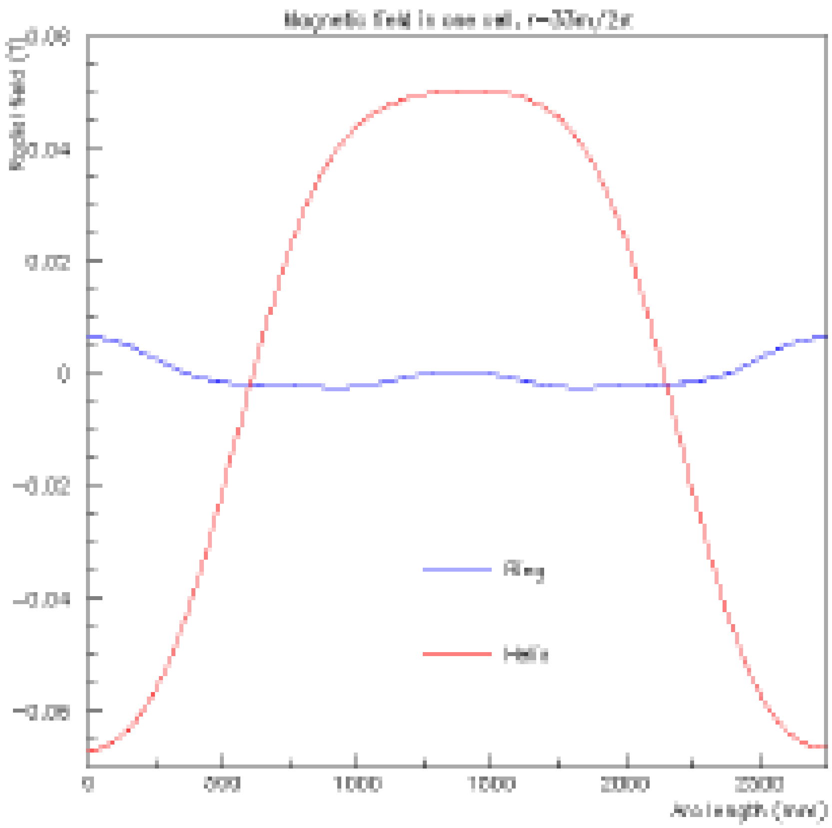


RFOFO ring
transverse multipoles

Skew dipole term

From G4BL field maps we need $a_0 \sim 0.03$ T for 3 m pitch

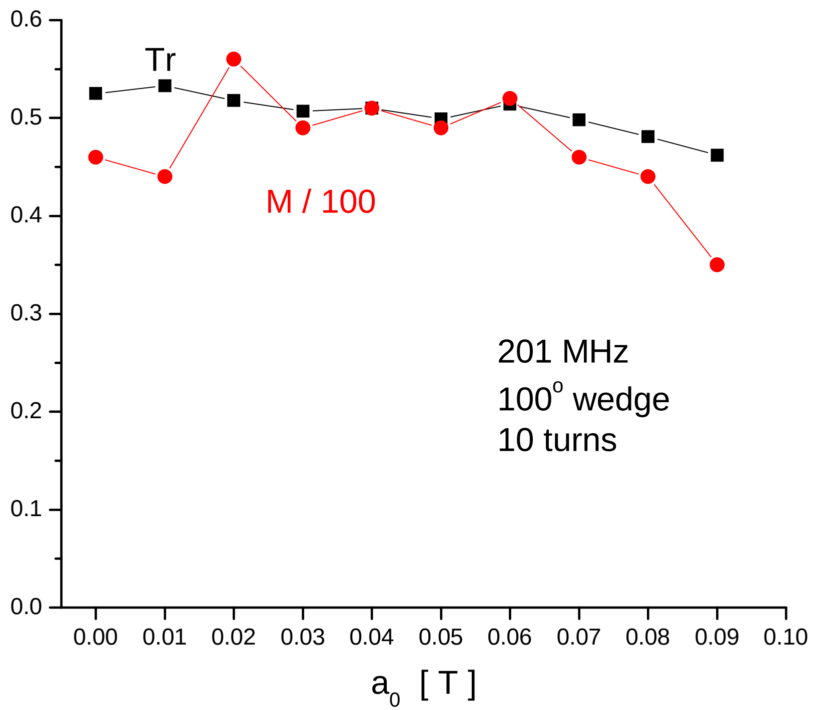
Radial field



(A. Klier)

Constant a_0

- examine effect of a_0 on a reference case in ICOOL
- 201 MHz guggenheim with large input emittance



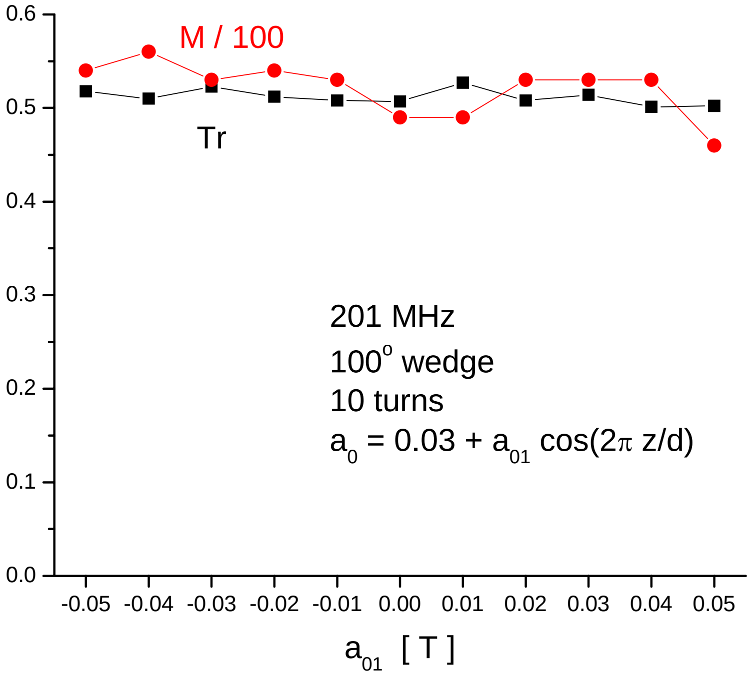
Tendency to decrease at large a_0
Not a large effect

Varying a_0

- actual field is ≈ sinusoidal
- examine effect of sinusoidaly varying a_0 on reference case

$$a_0 = 0.03 + a_{01} \, \mathrm{COS}(2\pi \, z / d)$$

- 201 MHz guggenheim with high input emittance



Small decrease for large positive a_{01}

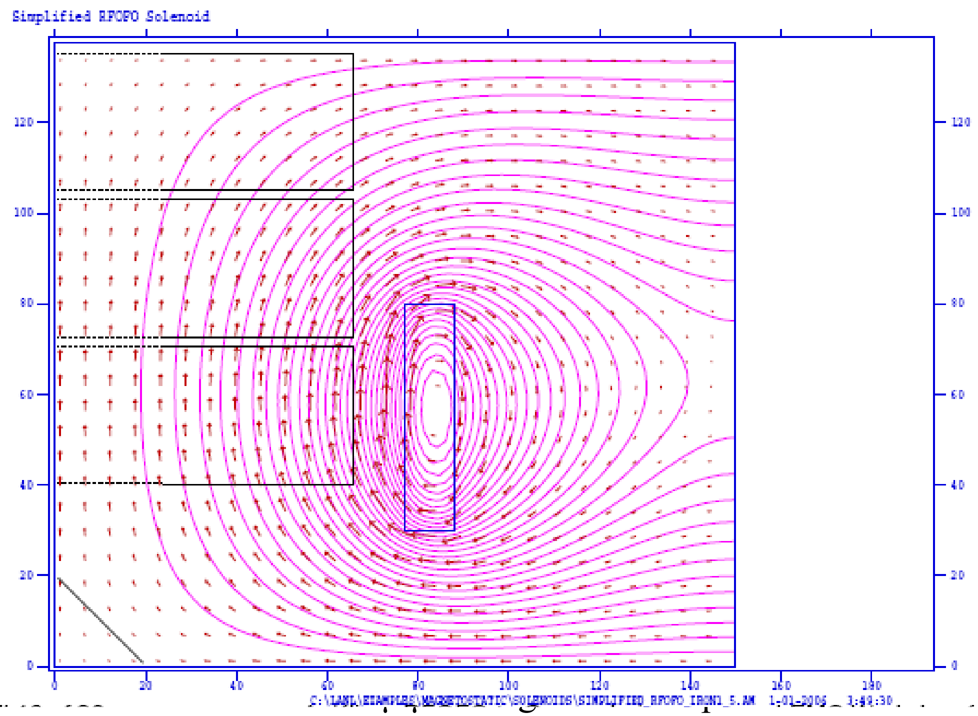
Not a large effect

Review

Method	cooling	transmission
Klier transform	G < R	G ≈ R
3D coils	G ≈ R	G < R
multipoles	G ≈ R	G ≈ R

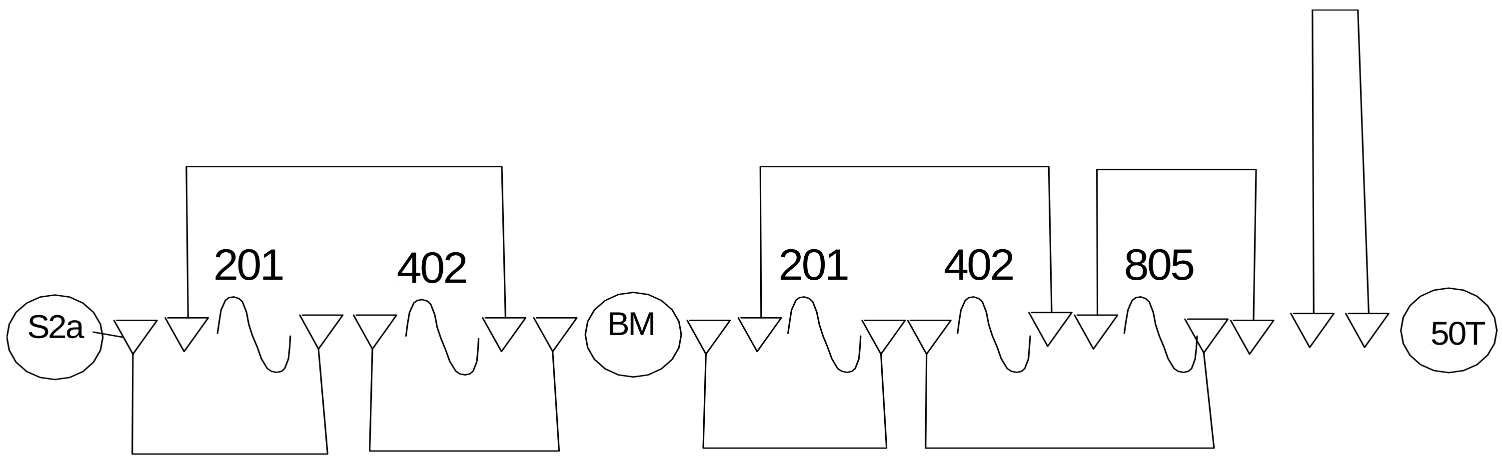
Shielding between the layers

- studied by A. Klier
- used simplified B map for RFOFO ring with no bending
- used Poisson to simulate external boundary shield
- found little effect on field near the axis
- effect of shielding on cooling performance not done(?)



Can we use same channel for both signs?

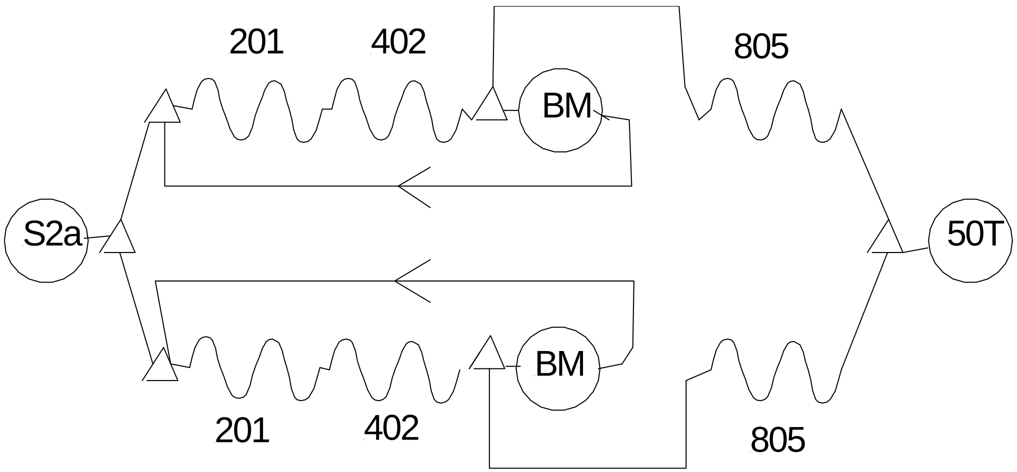
- we want to run with both signs of μ simultaneously
- injection at opposite ends of the channel is theoretically possible



- needs 16 switchyards, 8 long transfer lines
- tapering not possible
- not practical => need separate channels for each charge

Can we reuse the 201 & 402 channels?

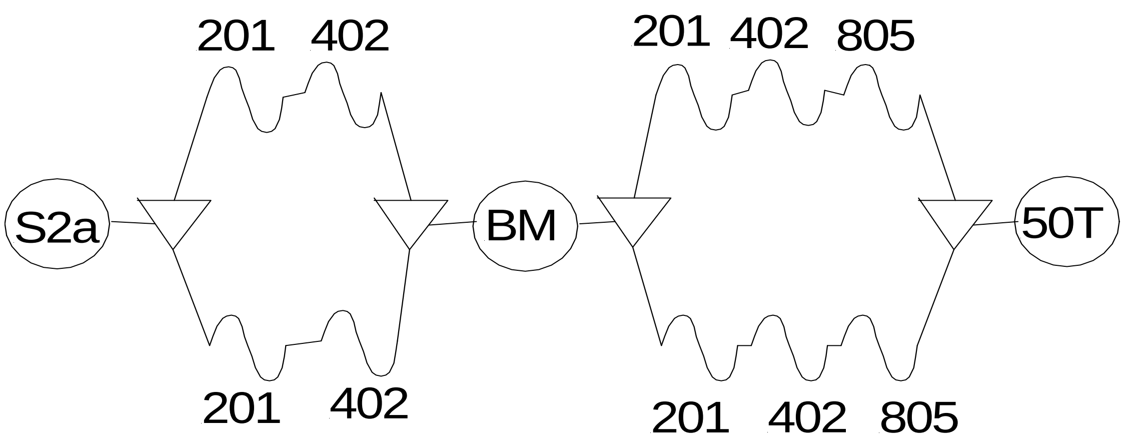
- still trying to save some money



- needs 6 switchyards (2 time-dependent), 4 long transfer lines
- 201 & 402 tapering not optimal, 805 is OK
- probably impractical => need separate 201 & 402 channels

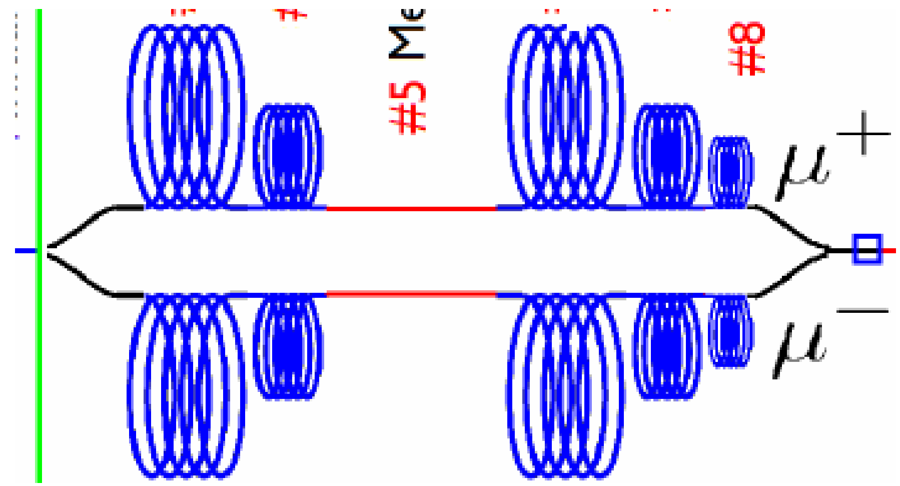
Practical layouts

• maybe we can use the same bunch merging for both signs



Needs 2 extra switchyards

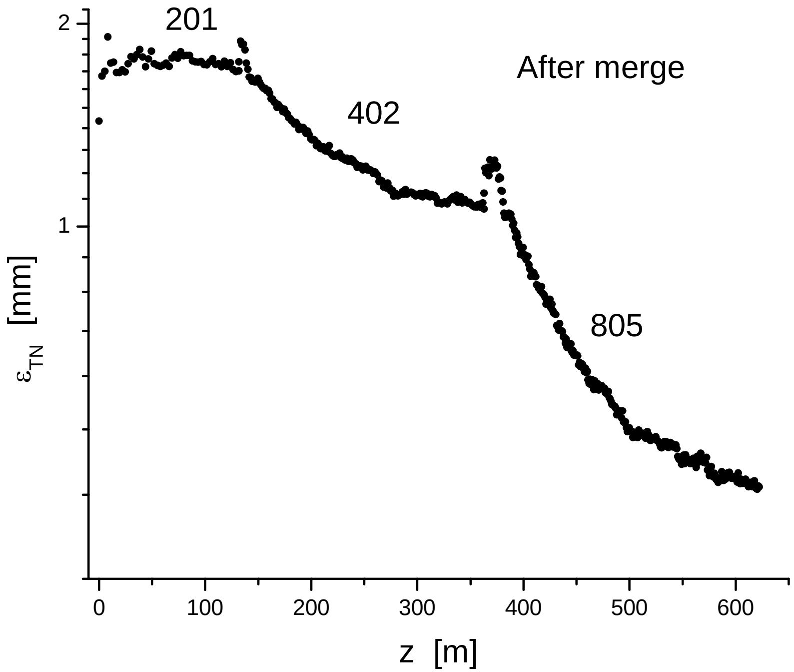
• if not, then we're left with

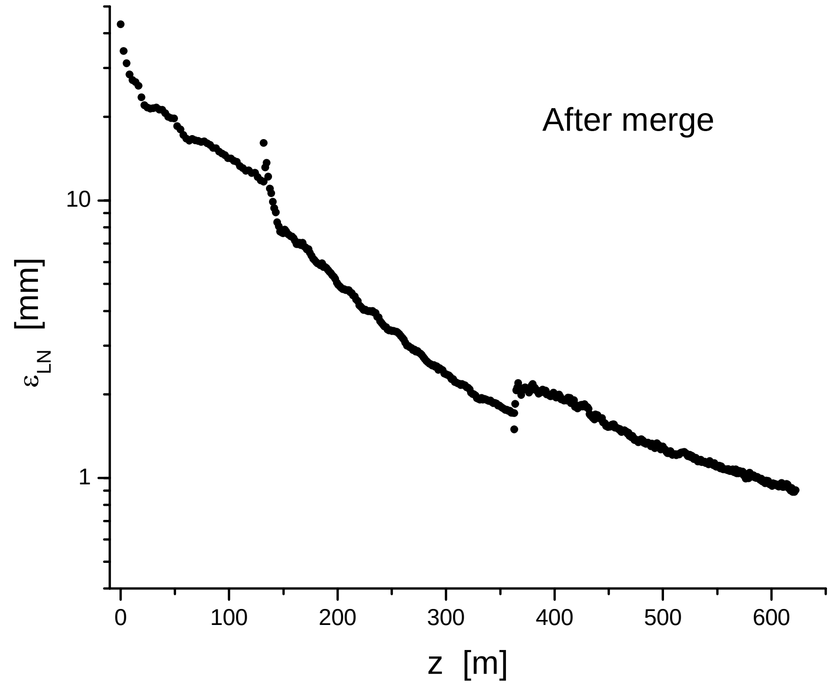


Guggenheim cooling simulations

- look at the 5 guggenheim channels in Palmer scenario
- 201: RFOFO ring multipoles + a_0=0.03 T
- 402: 2 x RFOFO ring multipoles + a_0=0.06 T
- 805: Fourier fit to B_S + b_0=0.38 T + a_0=0.08 T
- use optimized liquid hydrogen wedges
- use independent initial beam distributions

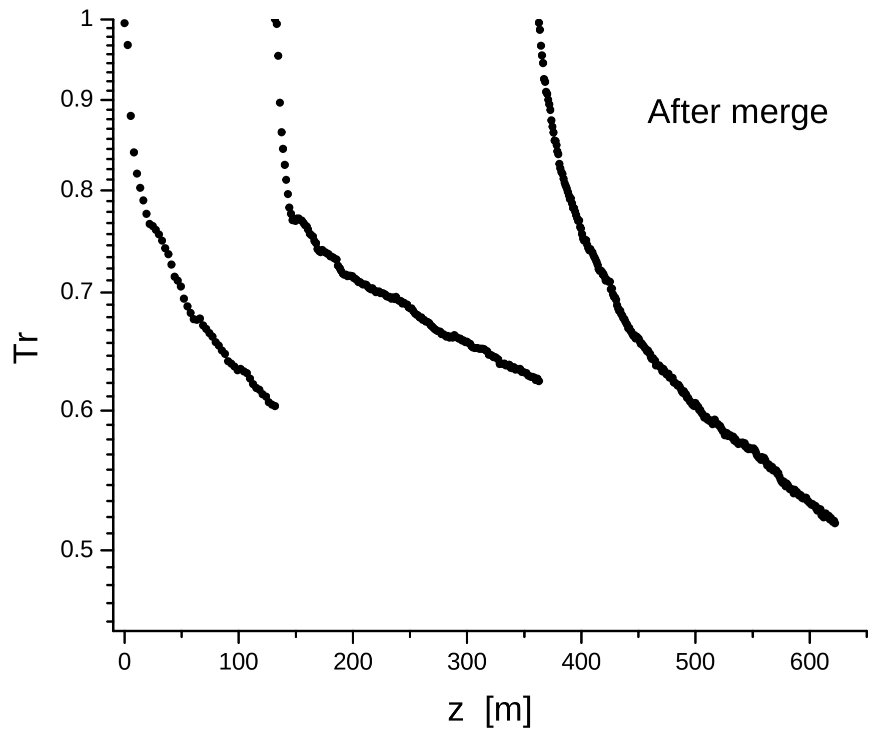
Guggenheim performance





Cooling meets scenario specs

Guggenheim performance



- each section started with new beam
- matching problems, particularly at 201 and 402

ICOOL simulation results

f [Mhz]	turns	a_0 [T]	ε_{TN} [mm]	ε_{LN} [mm]	Tr_d	Tr_s
201	4	0.03	5.0	10	0.90	0.62
402	14	0.06	1.2	1.7	0.83	0.66
201	4	0.03	1.7	12	0.90	0.67
402	14	0.06	1.1	1.7	0.83	0.75
805	24	0.08	0.41	0.9	0.81	0.64

- scenario allows total Tr=25% for guggenheims
- this simulation has total Tr~6%
- it is imperative that we improve efficiency
- with given turns, we need Tr_s~0.89 for each guggenheim

Work that needs to be done

- improve transmission of the current channels
  - design matching into each channel
  - or replace with two tapered channels
- improve realism of simulations
  - start with beam coming from linear precooler
  - use actual beam from previous section
  - create accurate field maps & associated multipoles
    - (get beyond using constant a_0 or b_0)
  - add windows to simulations
- get G4BL model working again
  - check accuracy of multipole method
  - investigate influence of other layers on cooling

More work that needs to be done

- design the first charge switchyard
- find practical design for wedge-shaped LH_2 absorber
- do we need to design a whole new lattice?
  - open-cell, bucked-coil, or gas-filled lattices?
  - what are the actual constraints on RF gradients?
    - from B field
    - or muon beam
  - how much optimization to do now?
  - need MuCOOL experimental results ASAP!!!

Summary

- not practical to use same channel for both charges
- probably not practical to reuse 201 and 402 channels
- G4BL simulations
  - most accurate to date
  - showed guggenheim transmission worse than ring (?)
- multipole simulations have unacceptable transmission losses
- we have good ideas for improving the efficiency
- this system involves a lot of hardware
  - total length of guggenheims ~ 2 **x** 1 km
- still have more work to show this is a practical method of 6D cooling