Guggenheim channels with realistic fields in ICOOL

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Cooling Mini-Workshop
FNAL

22 October 2009

Introduction

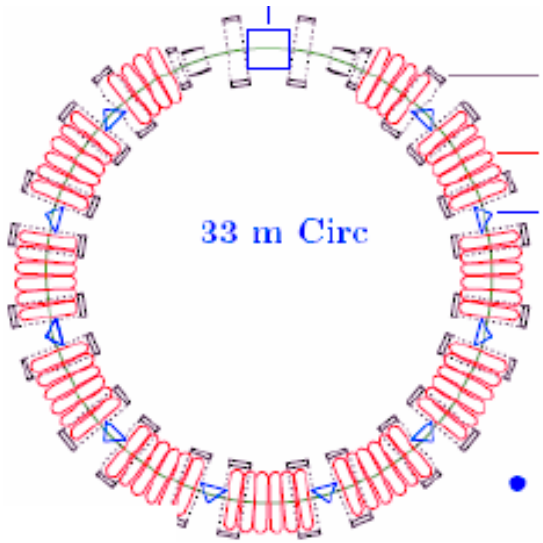
- first realistic modeling of Guggenheim channel
  - done by Amit Klier in 2006 using G4Beamline
  - work continued by Pavel Snopok et al
- ICOOL simulations of Guggenheim channels
  - 1) ignore helical nature of channel (assume Gug ≈ ring)
  - 2) use skew dipole term in a multipole expansion
- found inconsistencies using multipole expansion technique
- => use 3D map feature in ICOOL
- developed program for creating accurate 3D Guggenheim maps

GUGMAP

- wrote new code to make maps from RFOFO-like lattices
- starts with simple user input of lattice parameters
- positions and orients solenoids along a reference helix
- makes superposition of fields from solenoids on cylindrical grid
  => no magnetic shielding considered
- solenoid field calculated using elliptic integrals
- calculates fields in Frenet and cylindrical coordinates
- has a Biot-Savart routine for checking results
- checks Maxwell's equations at all interior grid points
- checked that pitch=0 reproduces RFOFO fields
- field results agree very well with G4Beamline
- made new maps for 201, 402, and 805 MHz lattices

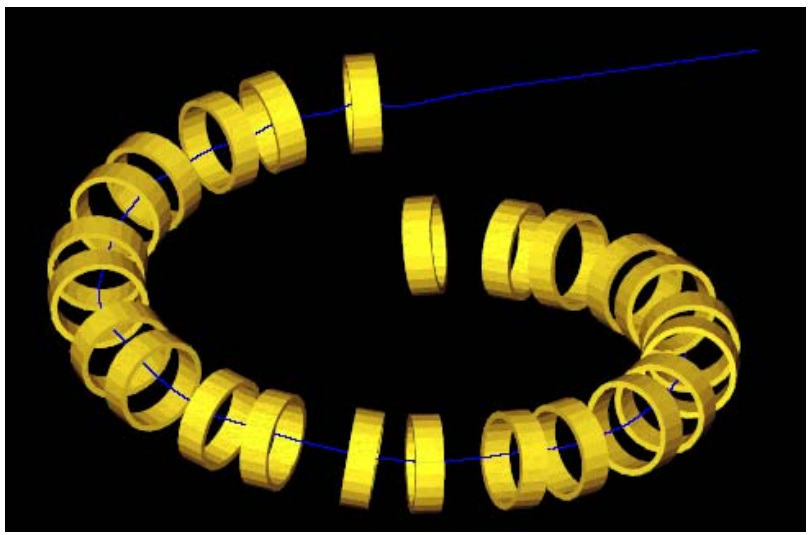
Guggenheim channel

- design starts with RFOFO cooling ring lattice



note coils outside
RF cavities

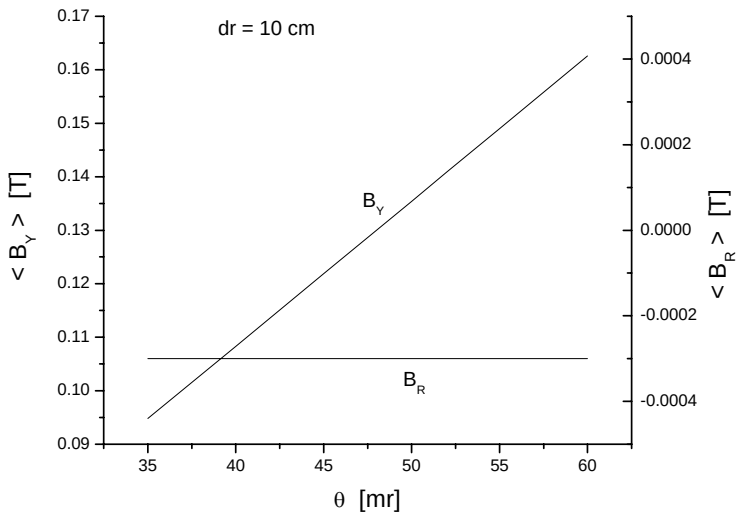
- G4Beamline model of one turn of the 201 MHz channel
- pitch = 3 m

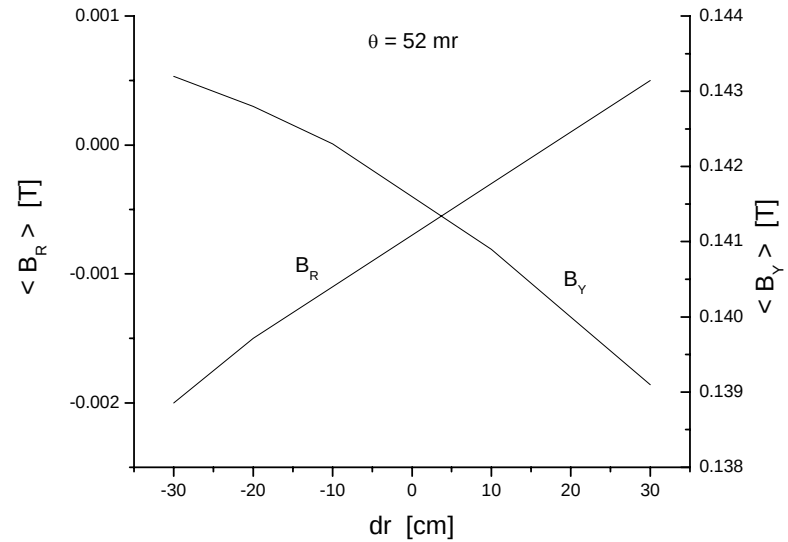


(Amit Klier)

Tuning the field map

- adjust dip angle to get $\langle B_Y \rangle$ to correspond to geometric radius of helix
- adjust radial offset of coils from helix axis to adjust $\langle B_R \rangle$

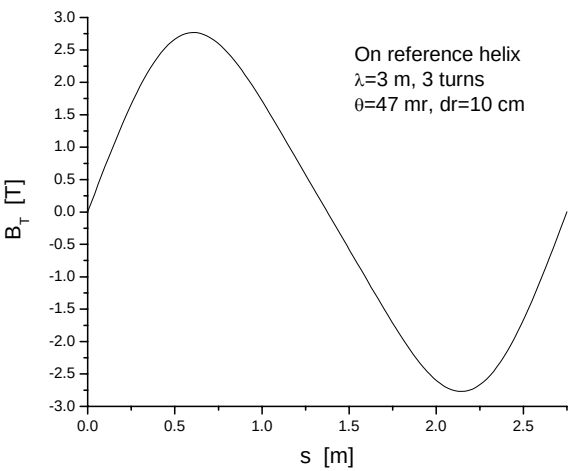


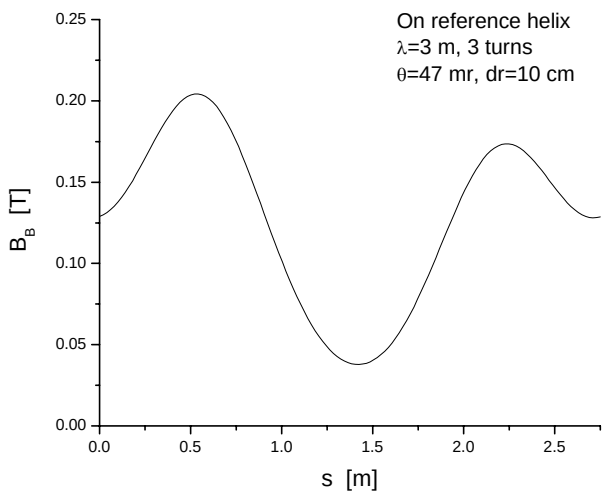


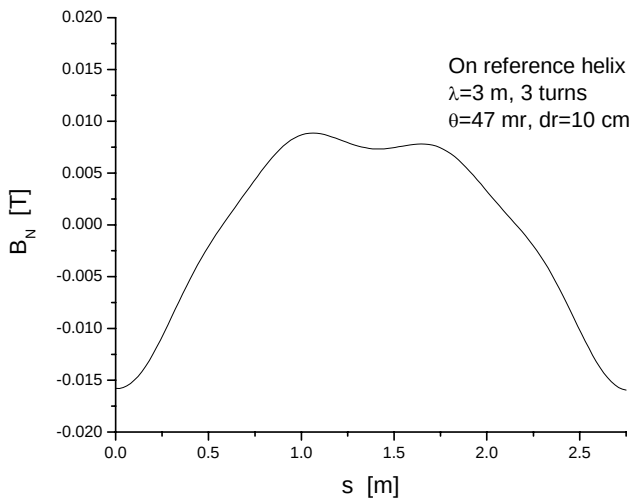
- radial offset adjustment used to set $\langle B_R \rangle = 0$ for RFOFO ring

Cylindrical grid

- for 201 MHz lattice we computed field on 1 cm cylindrical grid
- use field in central cell in middle of 3-turn lattice to satisfy symmetry conditions
- takes ~3 hours to make a grid



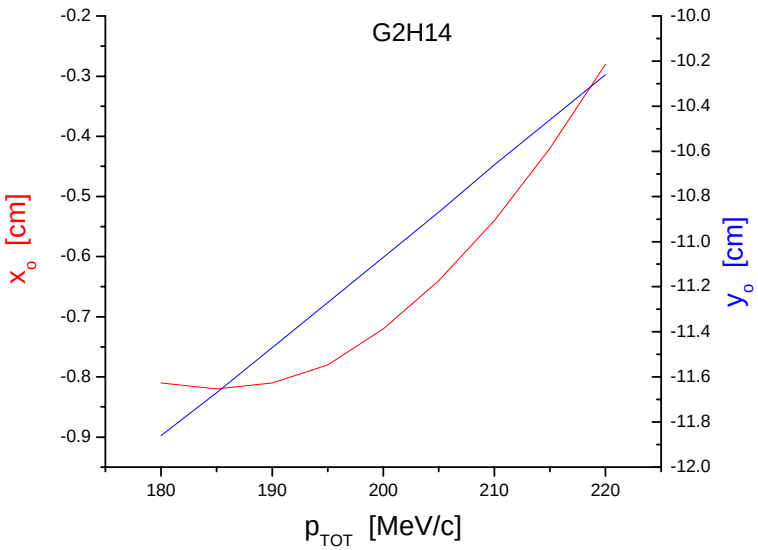


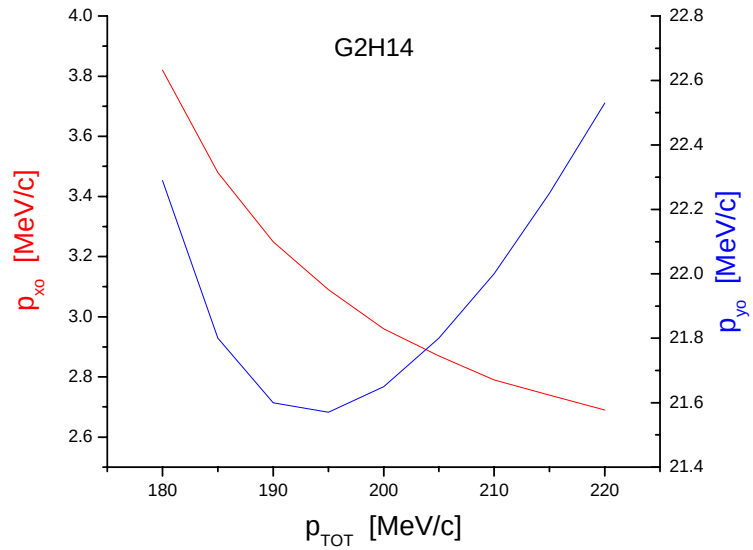


- on-axis components at center of grid

Periodic orbits

- periodic orbits determined with a root-finding routine
- routine uses ICOOL tracking with the 3D map

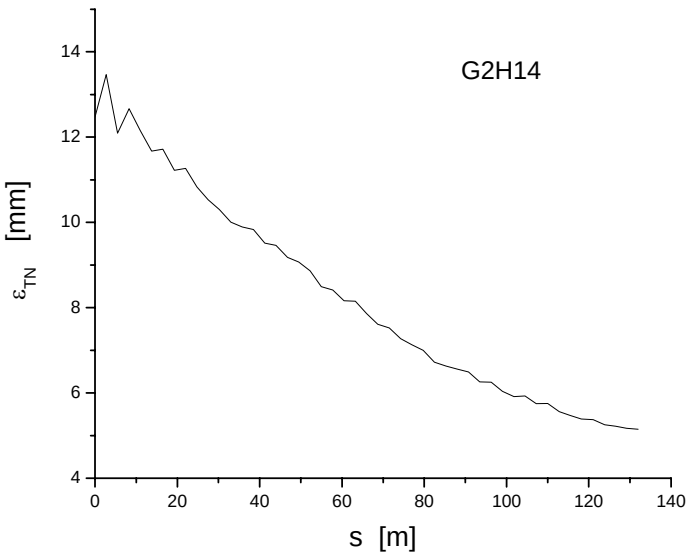


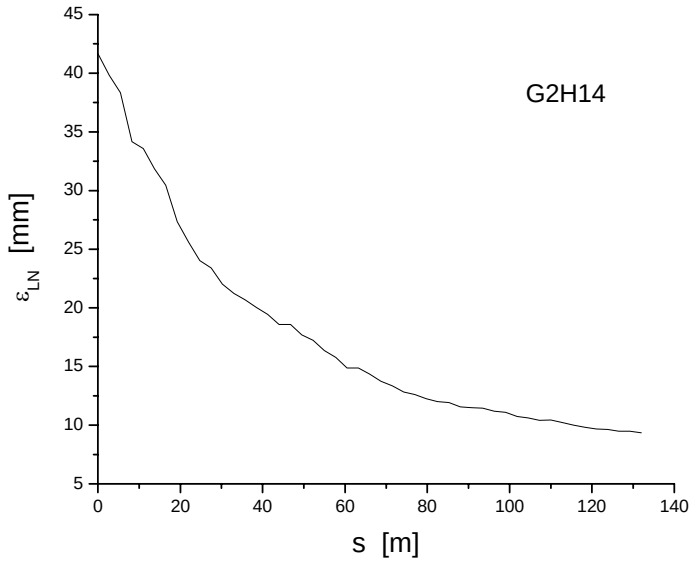


- finds good periodic orbits over wide range of p
- 3 m pitch => 25 cm vertical offset per cell
- large initial vertical offset ~ -12 cm
- minimum β ~38 cm at 200 MeV/c

201 MHz Performance

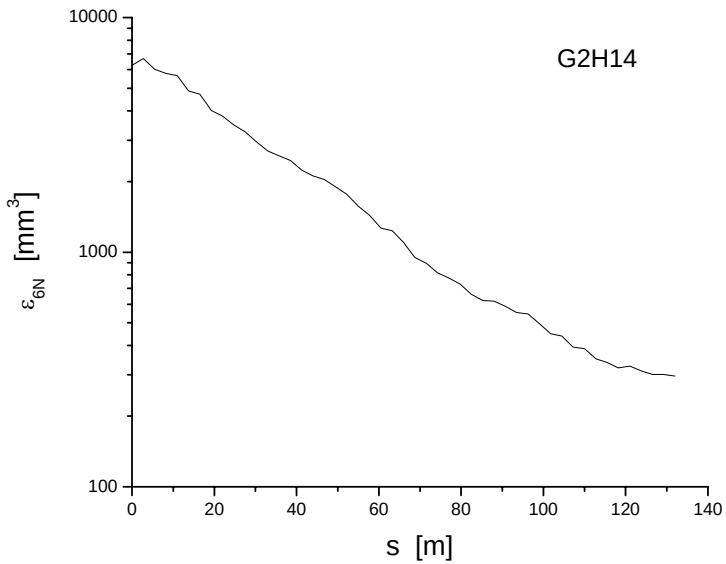
- look at 1st Guggenheim channel in Bob Palmer's collider scenario
- run ICOOL by repeatedly using new 3D map
- adjust vertical position of all particles by 25 cm after each cell
- OK for interior of long channel, but ignores differences in end-cell fields
- the G4Beamline procedure of using all coils is more realistic

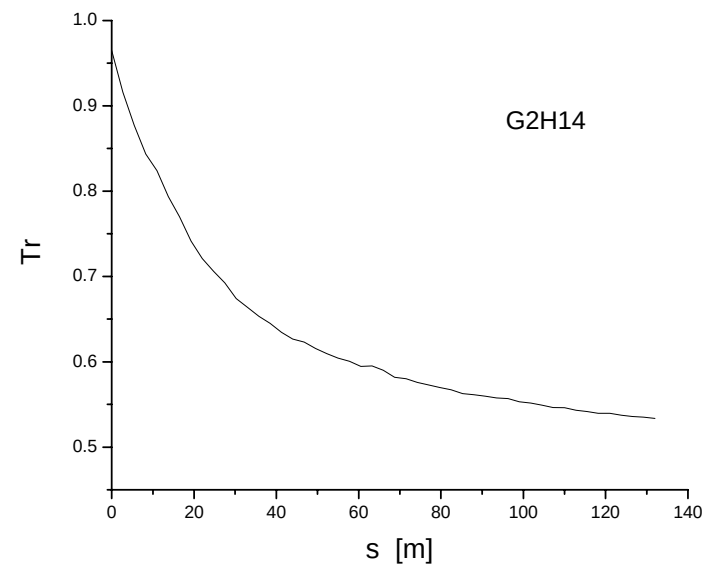




- transverse and longitudinal emittances reach scenario goal after 4 turns

201 MHz Performance

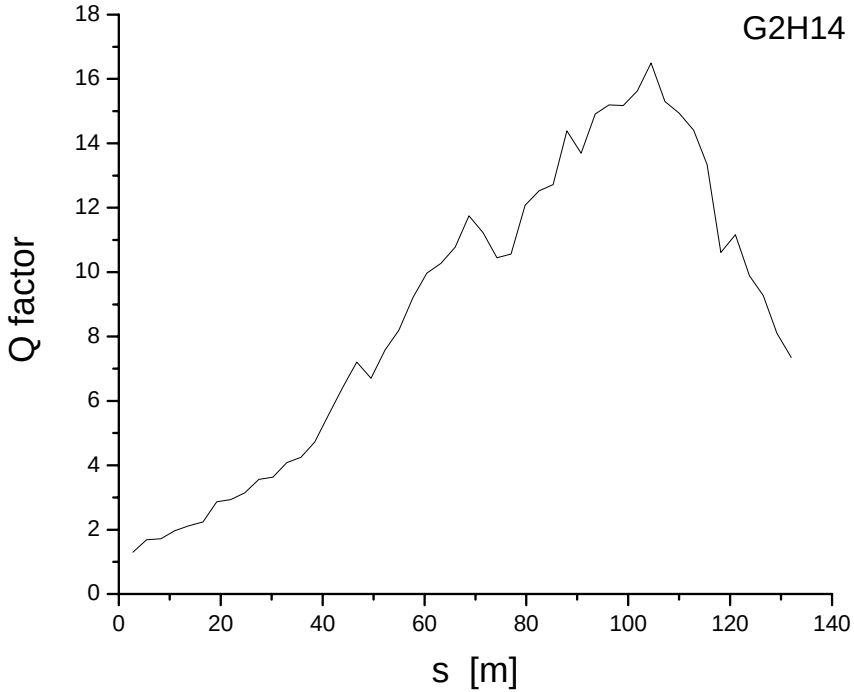




- 6D emittance reduced by factor of ~20 without windows
  => good ideal cooling
- overall transmission is ~53%
  => needs improvement

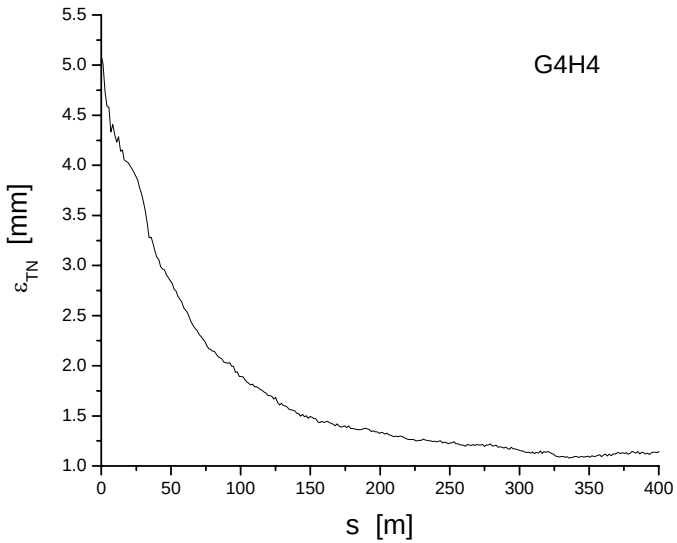
201 MHz Performance

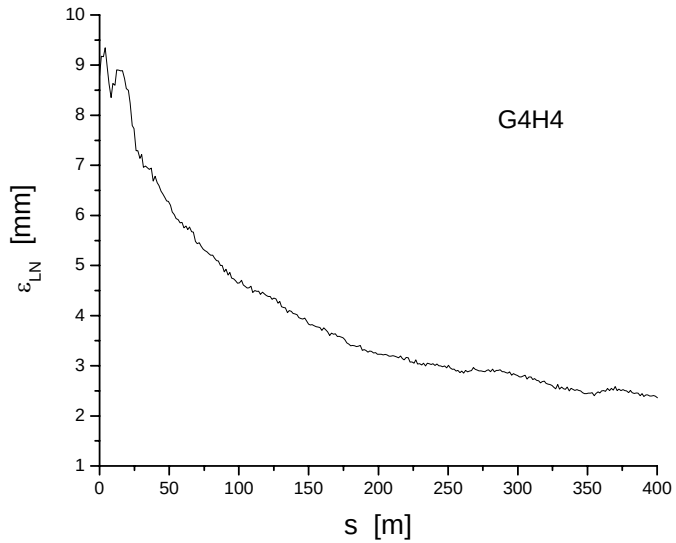
$$Q(s) = \frac{(d\varepsilon_{6N}/ds) / \varepsilon_{6N}}{(dN_\mu/ds) / N_\mu}$$



- peak Q~16, average Q~10
- takes ~70 m of channel for optimal matching to develop
- needs careful initial matching and tapering for peak efficiency

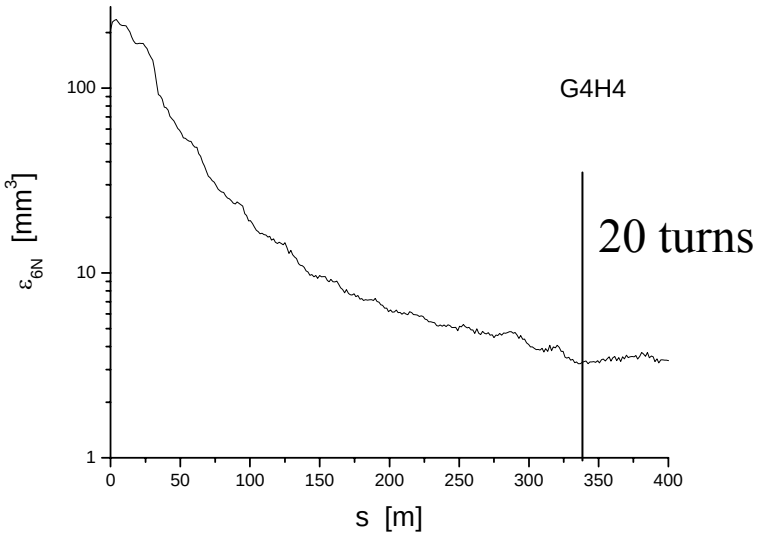
402 MHz Performance

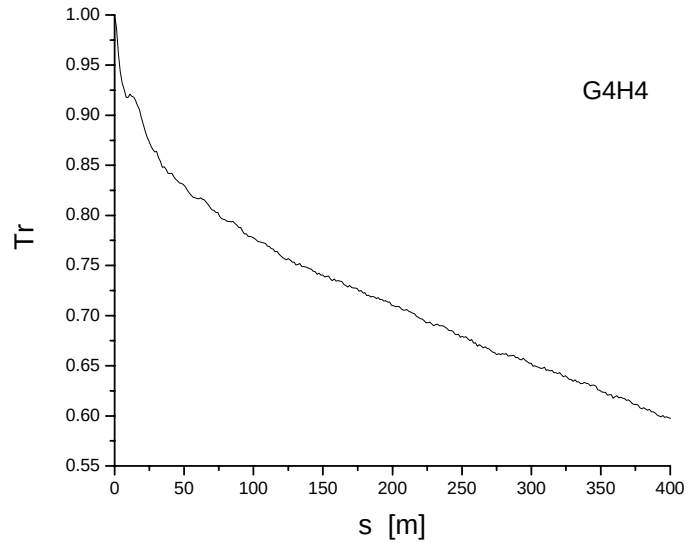




- this lattice is exactly scaled down by 2 from the 201 MHz lattice
- probably not acceptable because of peak field and hoop stress on coils
- good cooling without windows
- beta function ~19 cm at 200 MeV/c

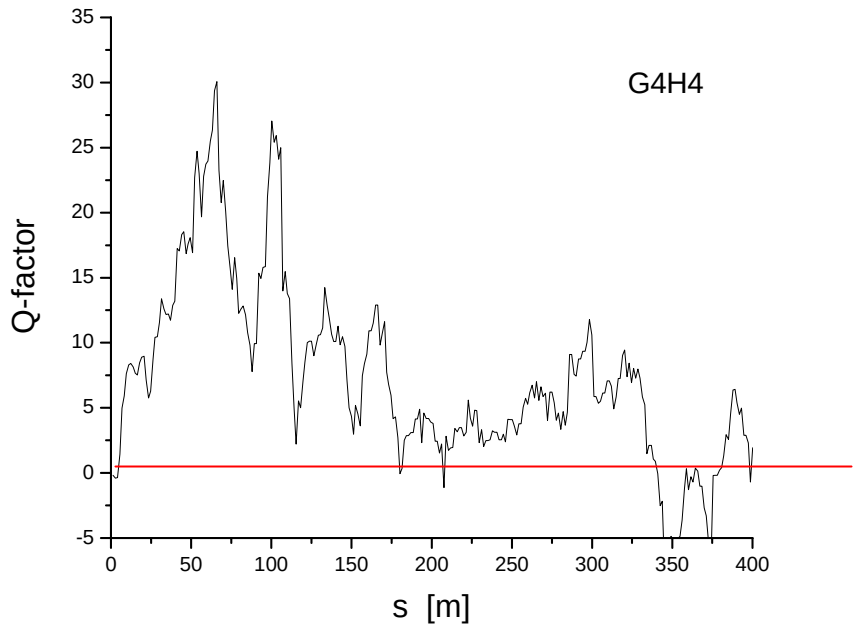
402 MHz Performance





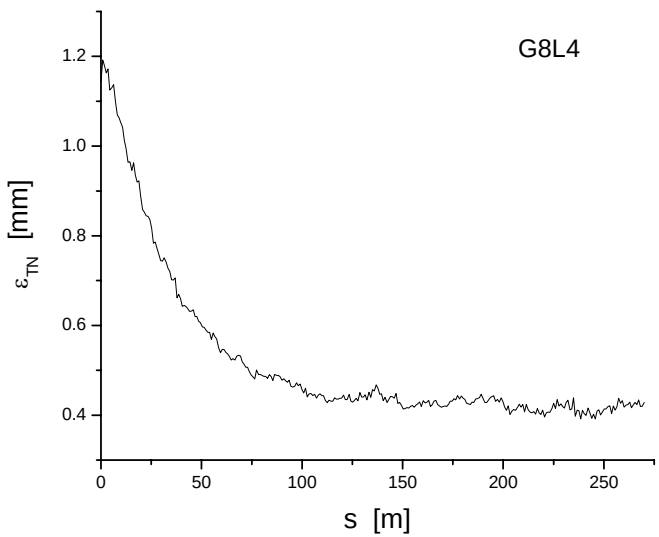
- 6D emittance reduced by factor of 60 after 20 turns
- transmission ~63%

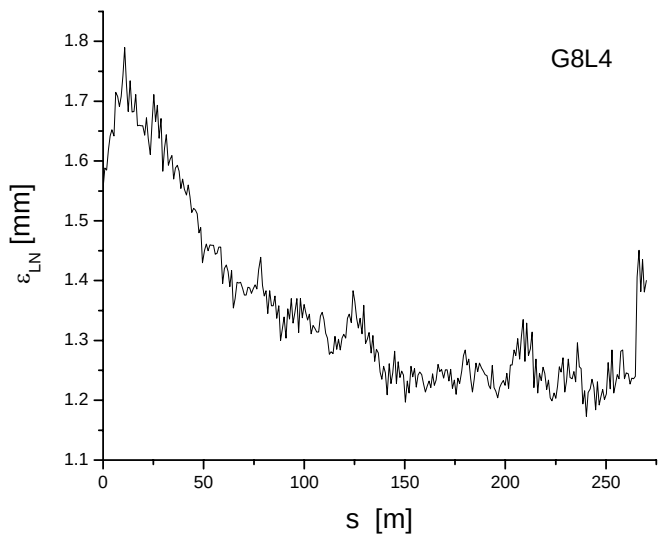
402 MHz Performance



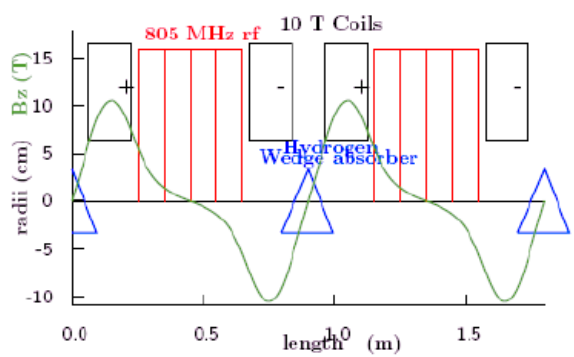
- efficiency is more dependent on local conditions than the 201 MHz lattice
- peak Q~28, average Q~10
- needs tapering for peak efficiency

805 MHz Performance

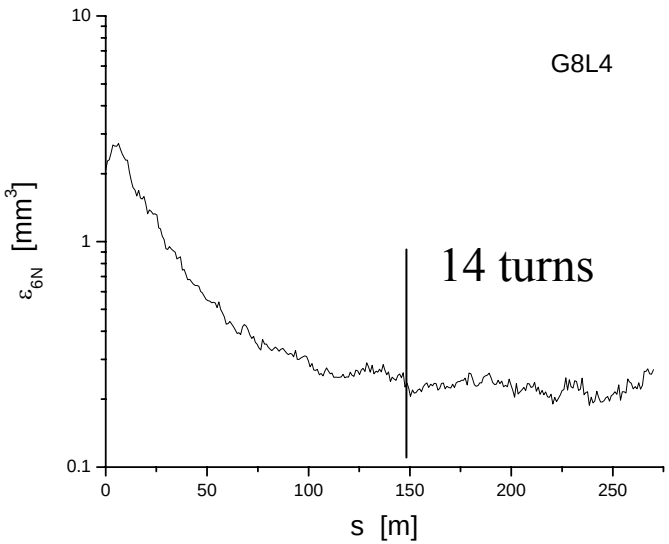


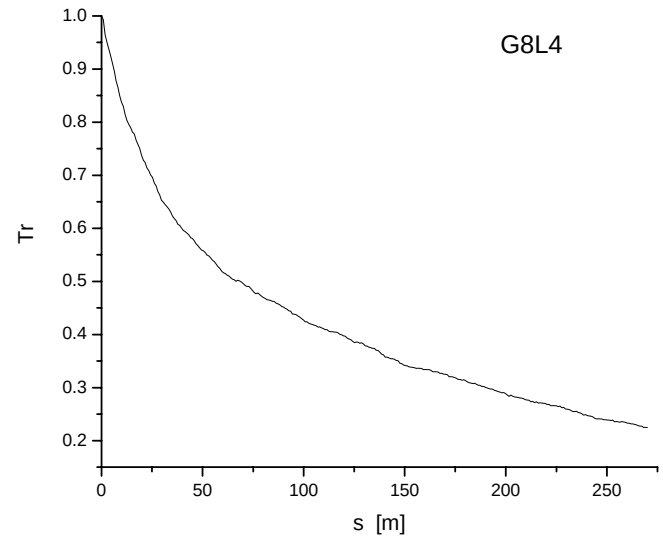


- different lattice design with coils near RF irises
- pitch = 60 cm, $\Delta r = 0$
- beta function ~5 cm at 200 MeV/c
- has some initial longitudinal mismatch
- good cooling for ~14 turns



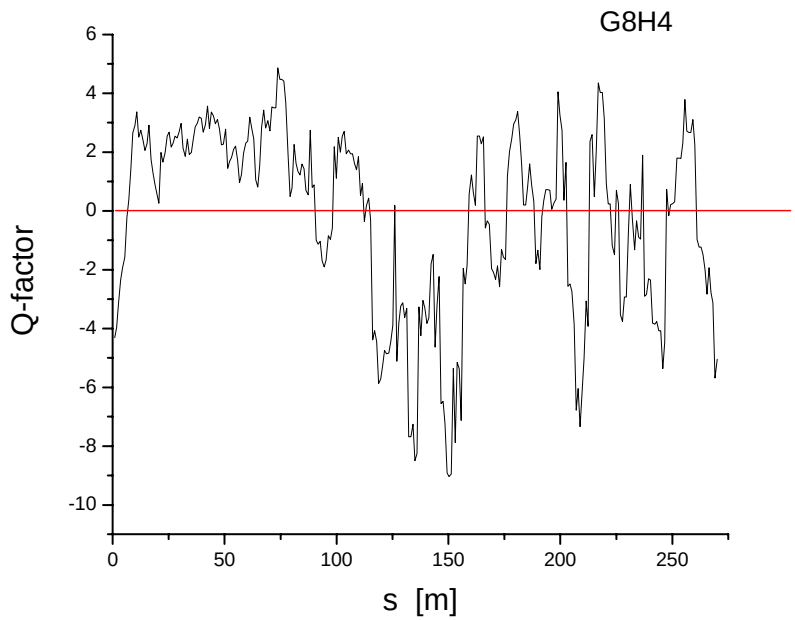
805 MHz Performance





- 6D emittance reduced by factor of 10 after 14 turns
- transmission is poorer than in earlier approximate simulations
- may not be at the global optimum (simulations have ~15 adjustable parameters)
- previous 805 simulations used <u>constant</u> dipole field (not tipped solenoids)

805 MHz Performance



- efficiency is small and dependent on local conditions
- peak Q~4, average Q~2
- this channel needs a lot more work

Improved simulations

- modify GUGMAP to handle tapered channels
- need two new Guggenheim channel designs
  1) tapered 201-402 MHz lattice before bunch merging
  2) tapered 201-805 MHz lattice after bunch merging
- may be easier to start this work with G4Beamline
- add windows to tapered lattice simulations
- alternate tapered design with open cavities ?
- must demonstrate required cooling with good transmission

Summary

- can now study Guggenheim performance in ICOOL with realistic fields
- found good agreement with G4Beamline field components
- found periodic orbits over wide range of momenta using 3D field maps
- found good cooling for Guggenheim channels in Palmer collider scenario
- tapered channels are needed to improve overall transmission