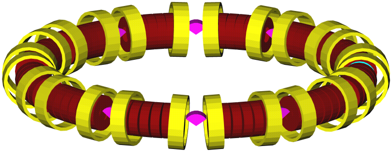
Guggenheim Cooling Channel Simulations

Pavel Snopok

April 6, 2009

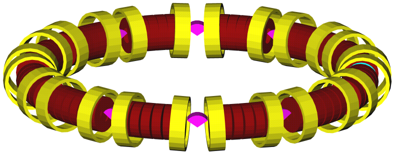
RFOFO ring & helix



- RFOFO ring

- Advantages:
  - Fast cooling.
  - Compact design.
  - RF reuse.

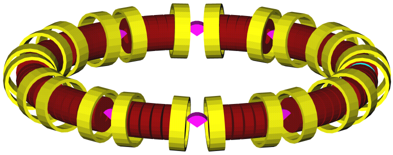
RFOFO ring & helix



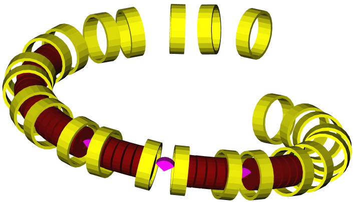
- RFOFO ring

- Advantages:
  - Fast cooling.
  - Compact design.
  - RF reuse.
- Challenges:
  - Absorber overheating.
  - Injection/extraction.
  - Continuous operation.

RFOFO ring & helix



- RFOFO ring



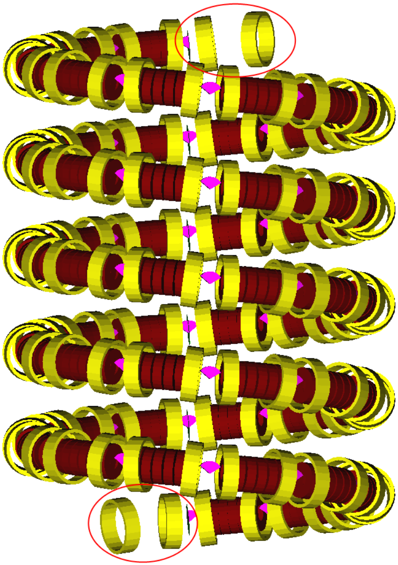
- RFOFO helix

RFOFO ring & helix

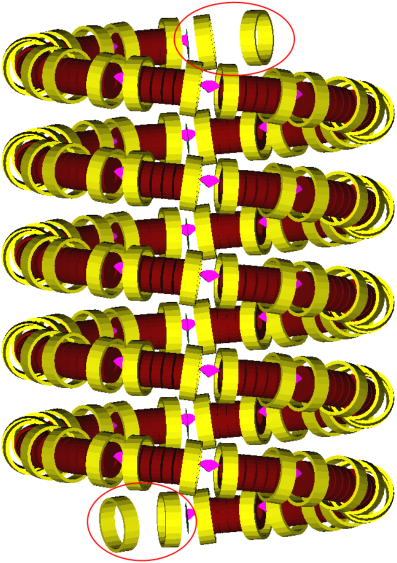
Table: RFOFO and Guggenheim parameters

	RFOFO	Guggenheim
Circumference, [m]	33.00	33.00
RF frequency, [MHz]	201.25	201.25
RF gradient, [MV/m]	12.835	12.621
Maximum axial field, [T]	2.77	2.80
Pitch, [m]	0.00	3.00
Pitch angle, [deg]	0.00	5.22
Radius, [mm]	5252.113	5230.365
Coil tilt (wrt orbit), [deg]	3.04	3.04
Average momentum, [MeV/c]	220	220
Reference momentum, [MeV/c]	201	201
Absorber angle, [deg]	110	110
Absorber thickness on beam axis, [cm]	27.13	27.13

Multilayer scheme with no shielding

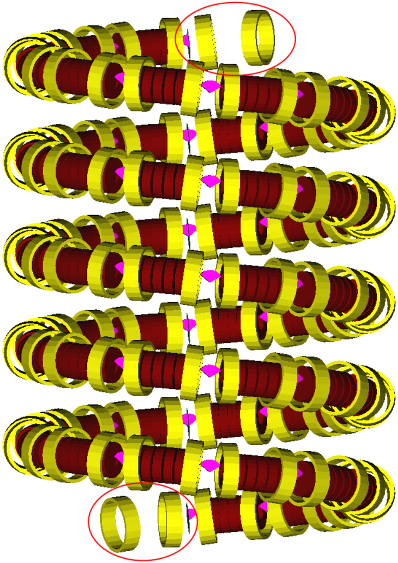


Multilayer scheme with no shielding



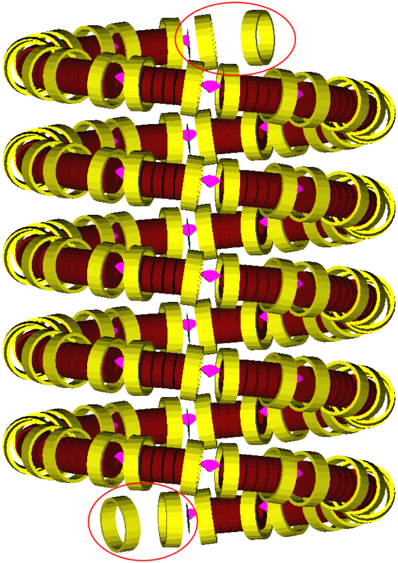
- 5 layers = 165 m

Multilayer scheme with no shielding



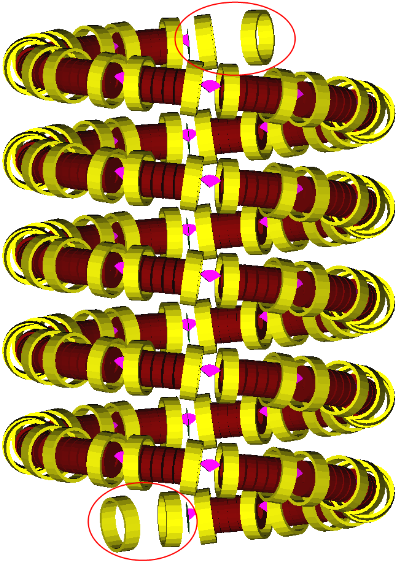
- 5 layers = 165 m
- no shielding between layers

Multilayer scheme with no shielding



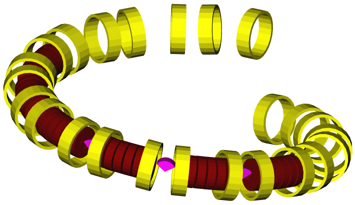
- 5 layers = 165 m
- no shielding between layers
- the magnetic field at any point of the trajectory is generated by all the coils

Multilayer scheme with no shielding



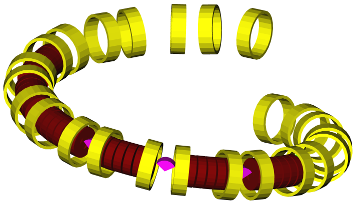
- 5 layers = 165 m
- no shielding between layers
- the magnetic field at any point of the trajectory is generated by all the coils
- compared to the case with shielding between layers

Multilayer scheme with shielding



- Characteristic half-turn of the multilayer Guggenheim with shielding

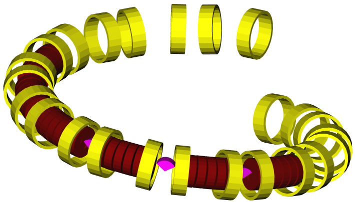
Multilayer scheme with shielding



- Characteristic half-turn of the multilayer Guggenheim with shielding

- any number of layers, up to 15 studied = 495 m

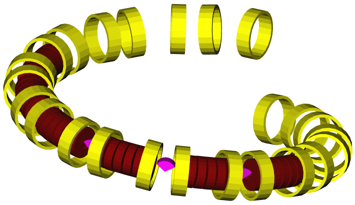
Multilayer scheme with shielding



- Characteristic half-turn of the multilayer Guggenheim with shielding

- any number of layers, up to 15 studied = 495 m
- shielding between layers

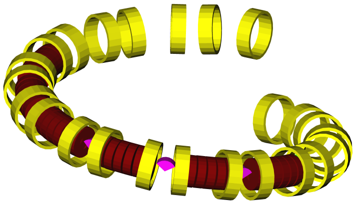
Multilayer scheme with shielding



- Characteristic half-turn of the multilayer Guggenheim with shielding

- any number of layers, up to 15 studied = 495 m
- shielding between layers
- the magnetic field at any point of the trajectory is generated only by the coils in the same turn

Multilayer scheme with shielding



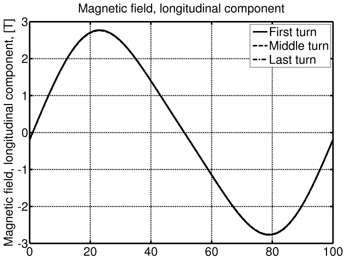
- Characteristic half-turn of the multilayer Guggenheim with shielding

- any number of layers, up to 15 studied = 495 m
- shielding between layers
- the magnetic field at any point of the trajectory is generated only by the coils in the same turn
- used for comparison to the case with no shielding

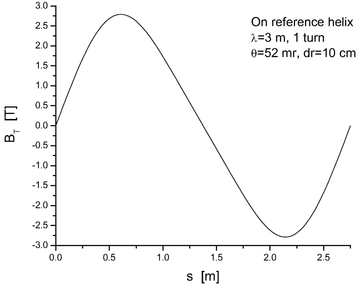
UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Neutrino Factory Muon Collider

Longitudinal component

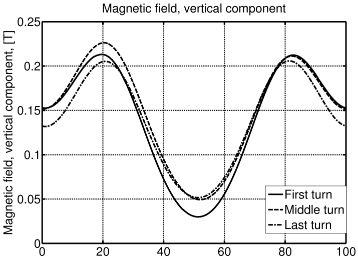


- G4Beamline

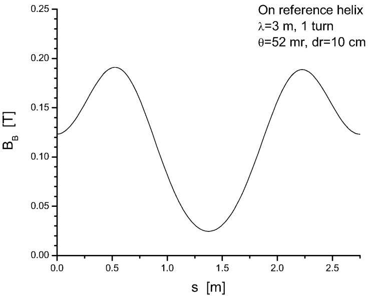


- ICOOL

Vertical component

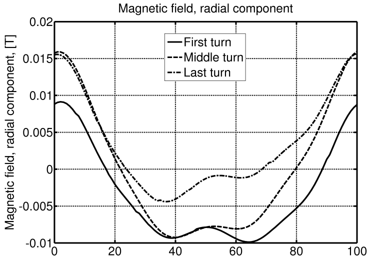


- G4Beamline

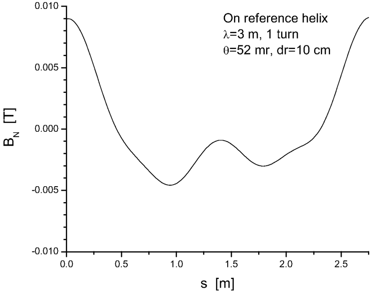


- ICOOL

Radial component



- G4Beamline



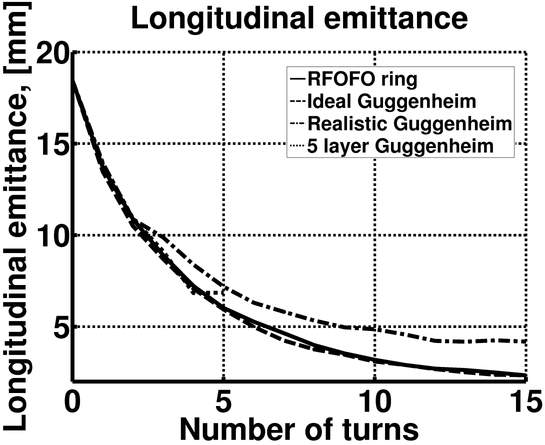
- ICOOL

Performance characteristics compared

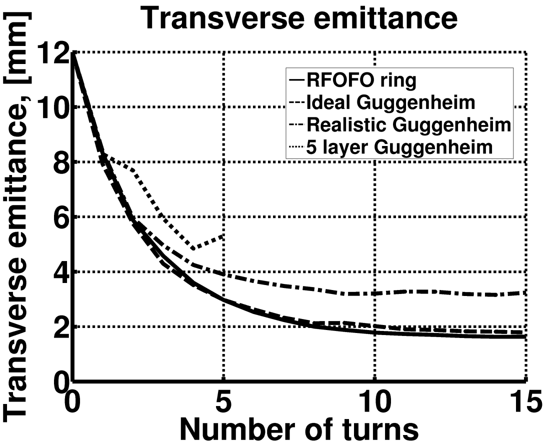
Four simulations are considered:

- Original RFOFO lattice
- Ideal Guggenheim (shielding between layers, single turn)
- "Realistic" Guggenheim (shielding between layers, single turn, RF cavities with windows, absorbers with windows)
- 5-layer Guggenheim (no shielding, all 5 layers contributing, all windows)

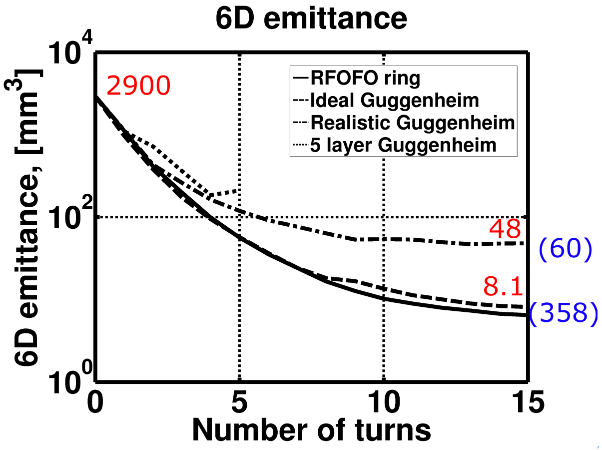
Longitudinal emittance



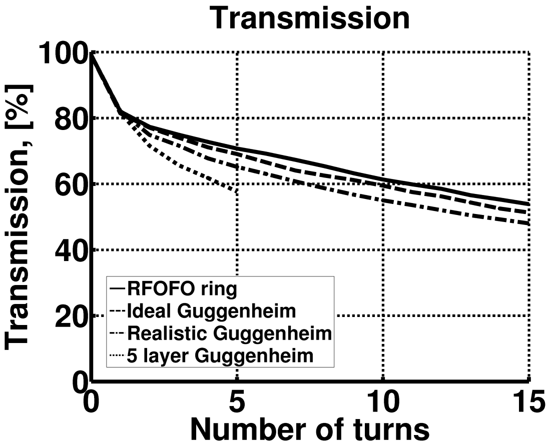
Transversal emittance



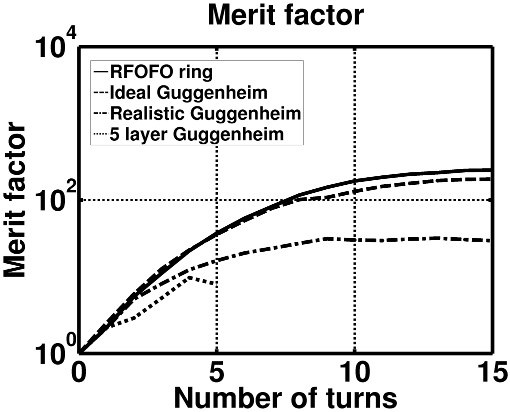
6D emittance



Transmission



Merit factor



$$M(s) = \frac{\varepsilon_{6D}(0)}{\varepsilon_{6D}(s)} \frac{N(s)}{N(0)}$$

		Structure			
Parameter	Turn #	RFOFO ideal	Guggenheim ideal	Guggenheim realistic	Guggenheim 5 layers
σ_x [mm]	0	41.79	41.79	41.79	41.79
	5	25.48	27.05	28.81	30.72
	10	19.62	20.74	25.58	-
	15	18.71	19.47	26.60	-
σ_y [mm]	0	42.86	42.86	42.86	42.86
	5	24.14	27.72	30.10	38.08
	10	18.61	21.74	27.77	-
	15	18.24	20.81	26.73	-
σ_p [MeV/c]	0	27.85	27.85	27.85	27.85
	5	11.80	12.00	13.58	12.79
	10	7.98	8.40	11.55	-
	15	7.37	7.45	10.83	-
σ_t [ns]	0	0.298	0.298	0.298	0.298
	5	0.235	0.237	0.261	0.364
	10	0.171	0.166	0.201	-
	15	0.143	0.144	0.185	-

Table: Decrease in variance for different models

6D Cooling

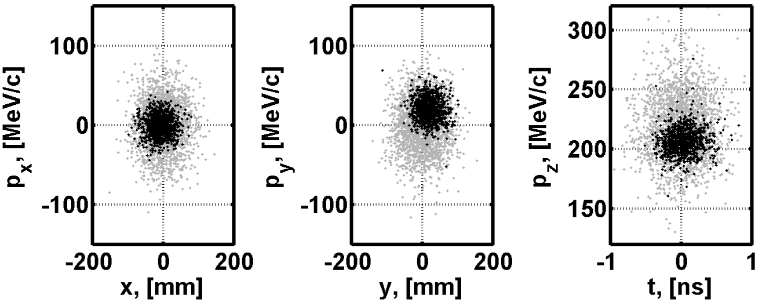
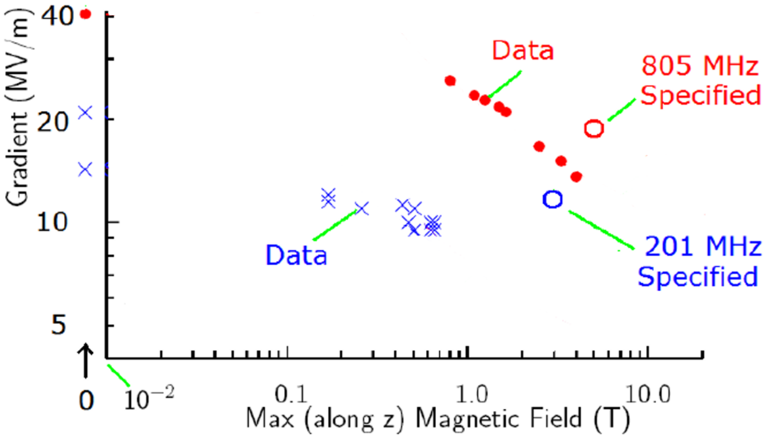


Figure: Reduction in the 6D phase space due to cooling. Gray – initial distribution, black – after 15 turns in the realistic Guggenheim cooling channel (495 m).

rf Breakdown problem

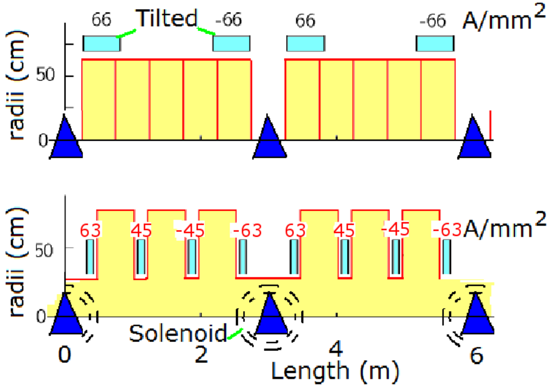


10

Magnetically insulated RFOFO lattices

Old RFOFO
with coils outside

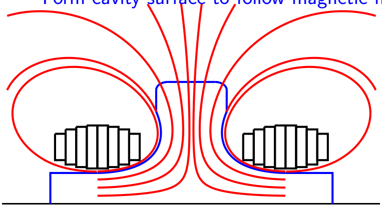
Approximated
lattice using
coils in open irises

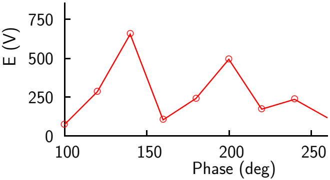


This is not quite the magnetically insulated lattice, since it does not have the outer reverse coils, but the fields on axis will be very similar

Magnetic Insulation

Form cavity surface to follow magnetic field lines





- All tracks return to the surface
- Energies are very low
- No dark current, No X-Rays !
- No danger of melting surfaces
- But secondary emission $\longrightarrow$ problems ?
- Grateful to SLAC for help
- This cavity is inefficient $\mathcal{E}_{\rm surface} \approx 4 \times \mathcal{E}_{\rm acc}$
  Not acceptable

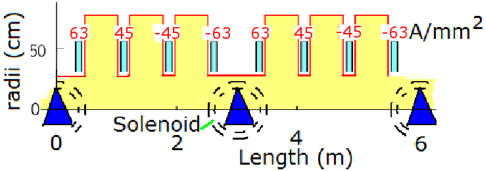
Conclusions on rf breakdown in magnets problem

- Beryllium is the ideal material
  - Would probably solve the problem even at room temperature
  - Would certainly solve it at nitrogen temperature
- Aluminum is significantly better than Copper
  - If cold, it would probably solve the problem
  - If multipacter is a problem, a thin copper layer would be ok

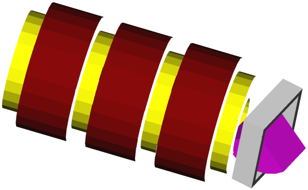
Advantages over Magnetic Insulation

- Pillbox cavities have better Shunt Impedance
- Pillbox cavities give more acceleration for same surface fields
- Muon transmission is better with less rapid field changes
  - Simulations of RFOFO Guggenheim 6D cooling gives unacceptable losses
  - A Neutrino Factory front end using magnetic insulation appears difficult

One cell of the open cavity lattice as simulated

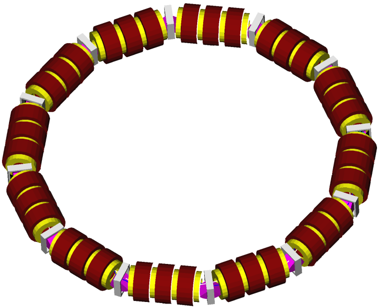


- Scheme



- G4BL Simulation

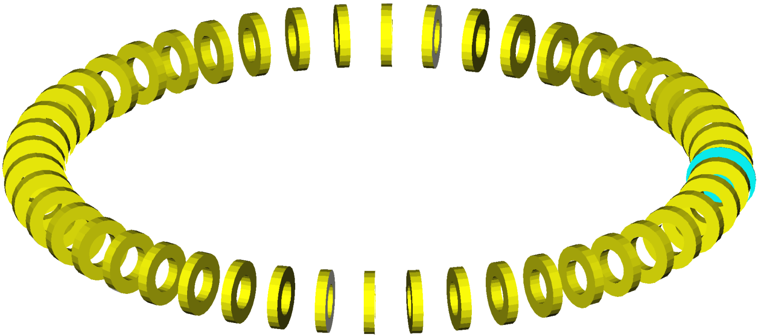
Local bending vs uniform bend



- Straight cells + 30 deg bend

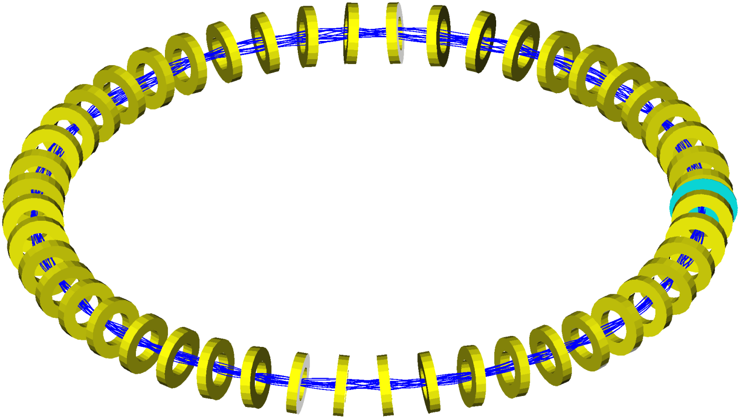
- Curved cells + uniform bend

Magnetic coil tilt



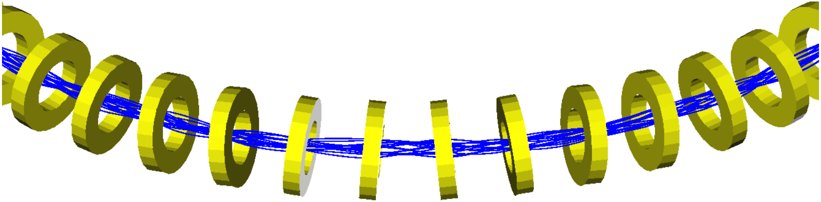
- No tilt + uniform field of 0.136 T

Magnetic coil tilt



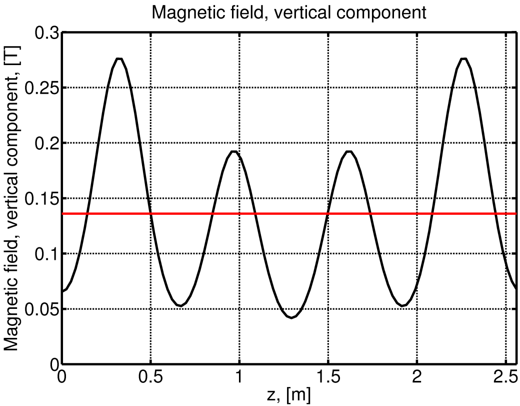
- 4.9 degree tilt generating 0.136 T

Magnetic coil tilt

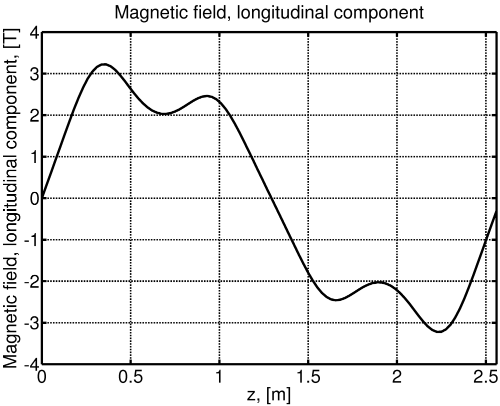


- 4.9 degree tilt generating 0.136 T, magnified

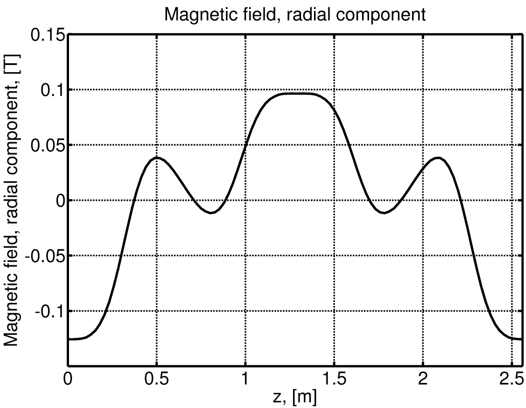
Magnetic field, vertical component



Magnetic field, longitudinal component



Magnetic field, radial component



Parameters

- Average vertical field of 0.136 per cell is generated by tilting the coils
- Tilting coils requires some more space ⇒ shorter RF cavities ⇒ 7.1 MeV/c gain per cell
- 100 degree absorbers ⇒ 9.58 MeV/c loss per cell ⇒ need shorter absorbers ⇒ 90 degree absorbers
- Tweaking absorber positions/tilts might help

Transmission

- Magnetic coils only: 88% after 15 turns (450 m) with no decay/stochastic processes
- Magnetic coils only: 62.5% after 15 turns with decay and stochastic processes
- As soon as the RFs and absorbers are turned on, the transmission drops to 50% after just 5 turns

Summary

Current results:

- A number of issues with the lattice of the RFOFO helix, commonly known as Guggenheim addressed: transmission and magnetic field profile discrepancies between G4BL and ICOOL resolved.
- Guggenheim cooling channel studied in detail, simulated with and without shielding, with and without absorber and RF windows.
- Quantitative results: 50% transmission, 60 times 6D emittance reduction with shielded layers + RF windows + absorber windows.

Summary

Plans:

- Open cavity lattice studies.
- Magnetic field only: transmission of 88% with no decay and stochastic processes, 62.5% with decay and stochastic processes.
- RFs + absorbers: require further studies.
- Studies of the sensitivity to the RF gradient and magnetic field strength.