International
UON Collider
Collaboration

Helical FOFO & Helical cooling channel

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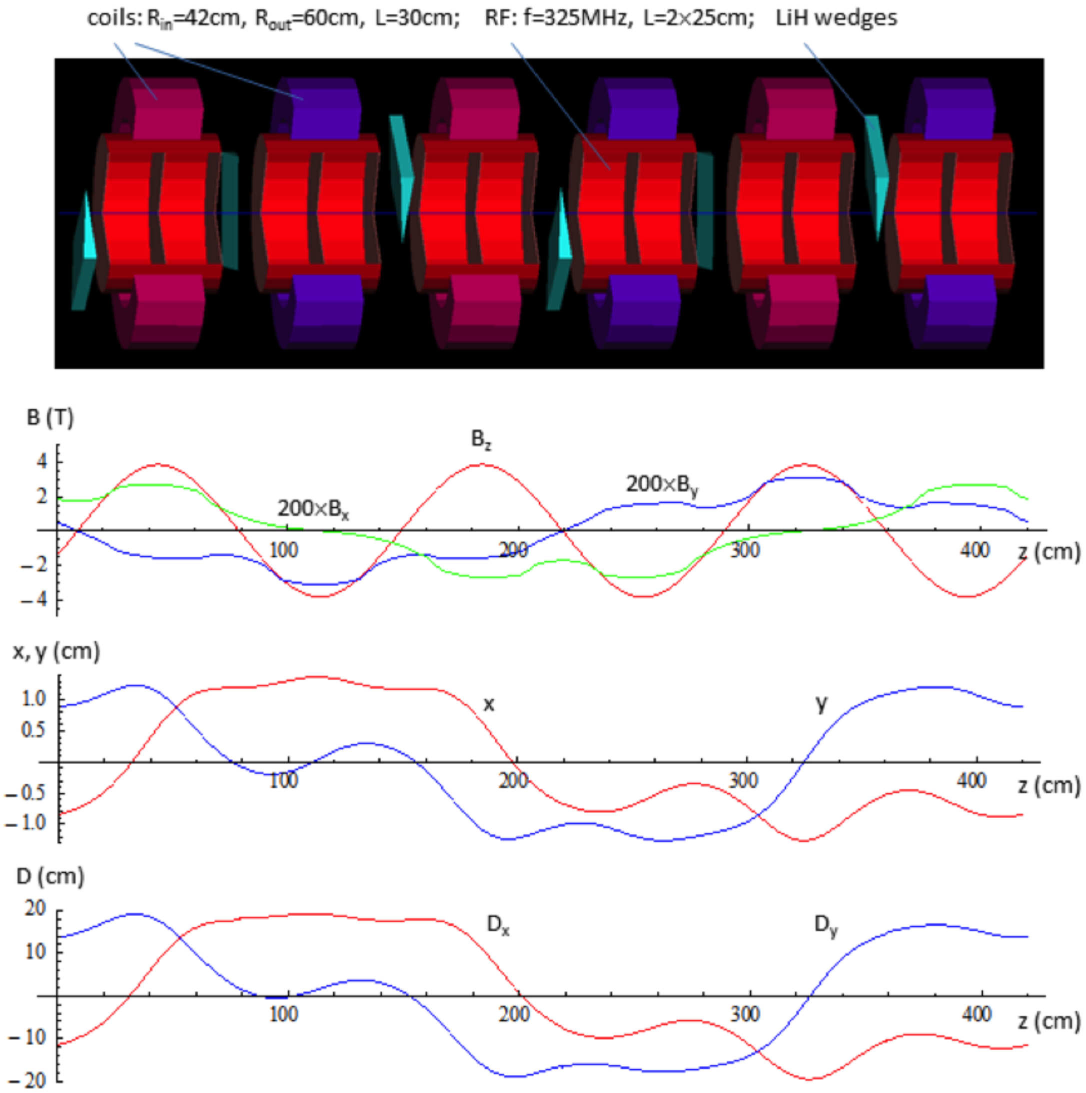
Outline

- Concept of Helical FOFO and Helical Cooling Channel
- Simulation result
- Lattice parameter & RF gradients
- Technology challenge

Concept of Helical FOFO



- Generate resonant dispersion by using alternating solenoid focusing
- Rotation plane

$$x cos(\phi_k) + y sin(\phi_k) = 0$$

$$\phi_k = \pi(1 - 2/N_s)(k + 1)$$

$$k = 1,2, \dots , N_s$$

N_s is the number of solenoids per period
If $N_s = 2(2 \cdot j + 1)$, μ^+ and μ^- orbits are identical with a half period off
($j = 1, N_s = 6$ in this example)

- Thus, HFOFO cools both signs

Simulation result

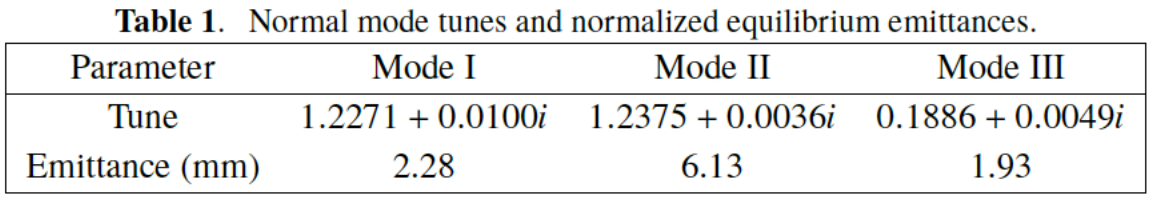
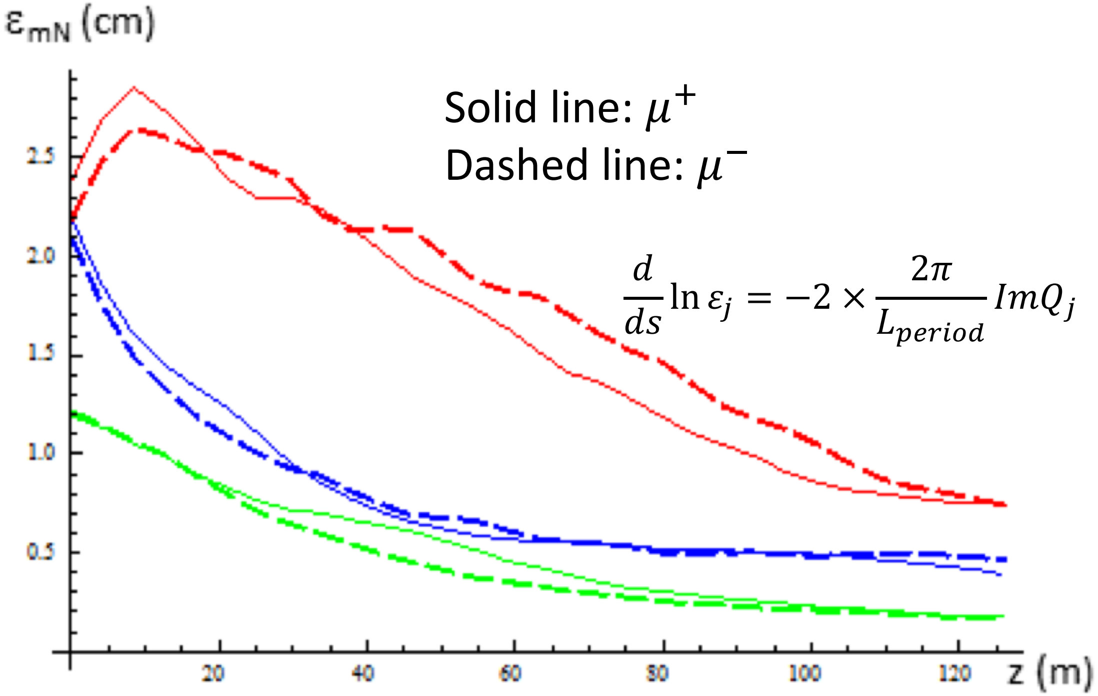


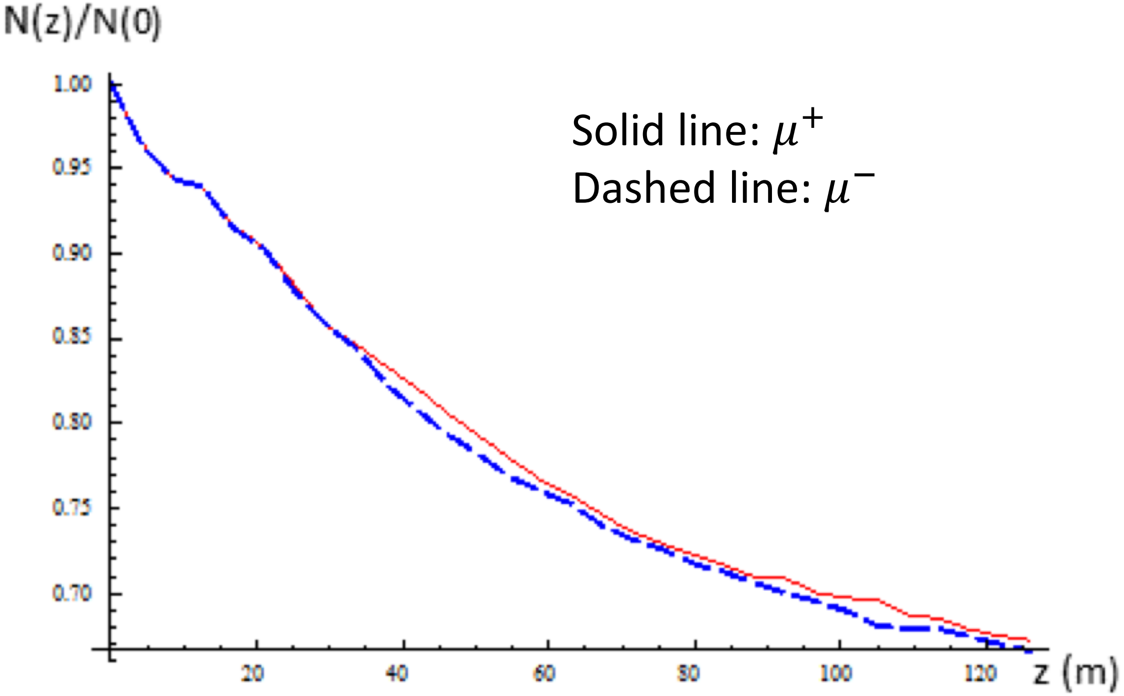
Table 1. Normal mode tunes and normalized equilibrium emittances.

Parameter	Mode I	Mode II	Mode III
Tune	$1.2271 + 0.0100i$	$1.2375 + 0.0036i$	$0.1886 + 0.0049i$
Emittance (mm)	2.28	6.13	1.93



Solid line: μ^+
Dashed line: μ^-

$$\frac{d}{ds}\ln\varepsilon_j = -2\times\frac{2\pi}{L_{period}} ImQ_j$$



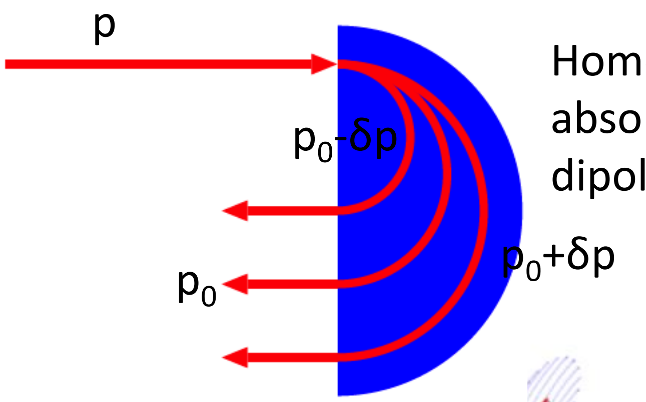
Solid line: μ^+
Dashed line: μ^-

- RF gradient = 25 MV/m, RF frequency = 325 MHz, filled with 50-atm hydrogen gas
- Matching and Beam window are included in the result

Next step for Helical FOFO

- Reoptimize lattice
  - RF gradient down to 20 MV/m
- Engineering design
  - Solenoid coil tilted by 2.5 mrad: Need a stress analysis
  - Either gas-filled or vacuum RF cavities: Need to add a waveguide
  - Integrate beam elements
  - Cold channel vs Room Temperature channel

Concept of Helical Cooling Channel (HCC)



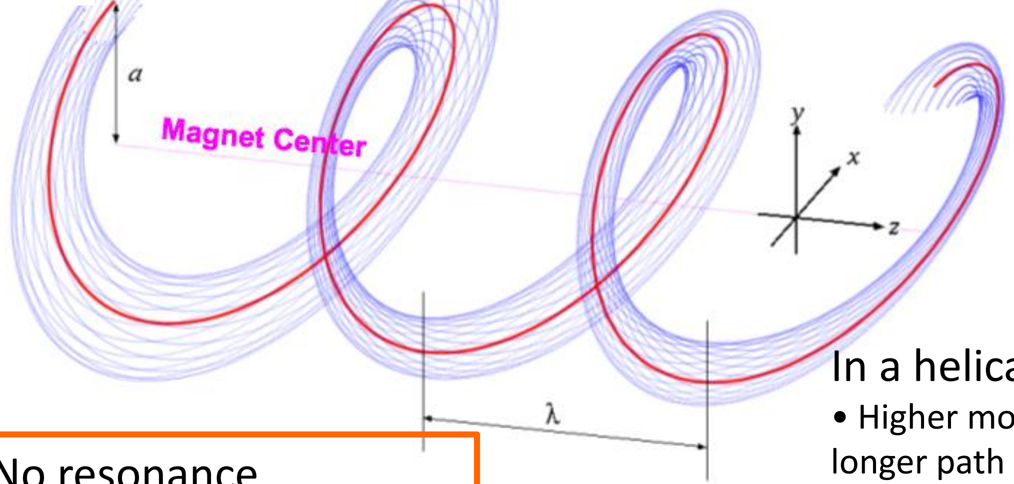
Homogeneous absorber filled dipole magnet

New concept accelerating system

Key elements

- Dense hydrogen gas distributed homogeneously in a continuous helical lattice

Ya.S. Derbenev & R.P. Johnson, PRSTAB 8 041002 (2005)

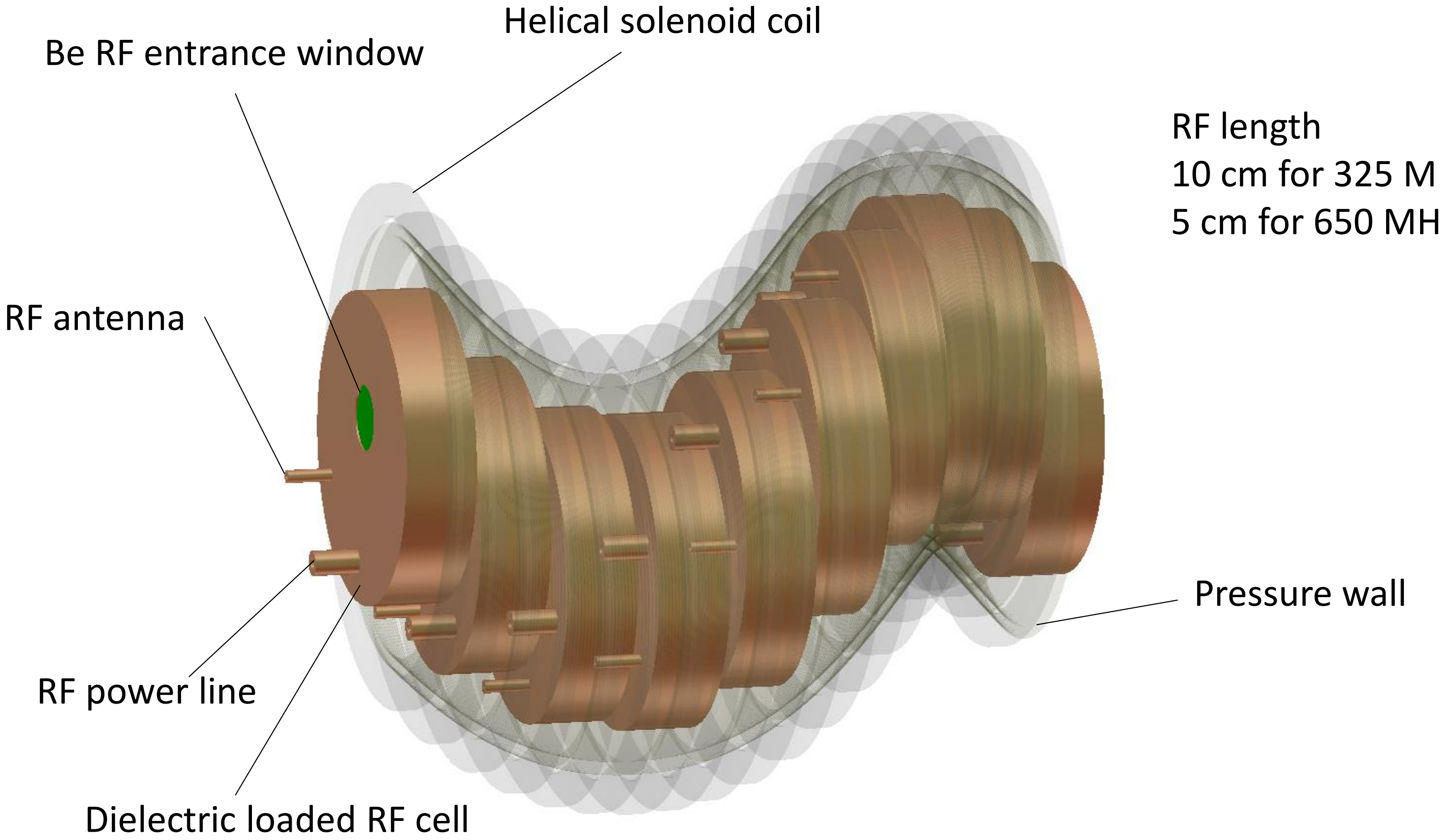


No periodic lattice → No resonance
→ Large acceptance
Continuous ionization cooling → Short length

In a helical cooling channel

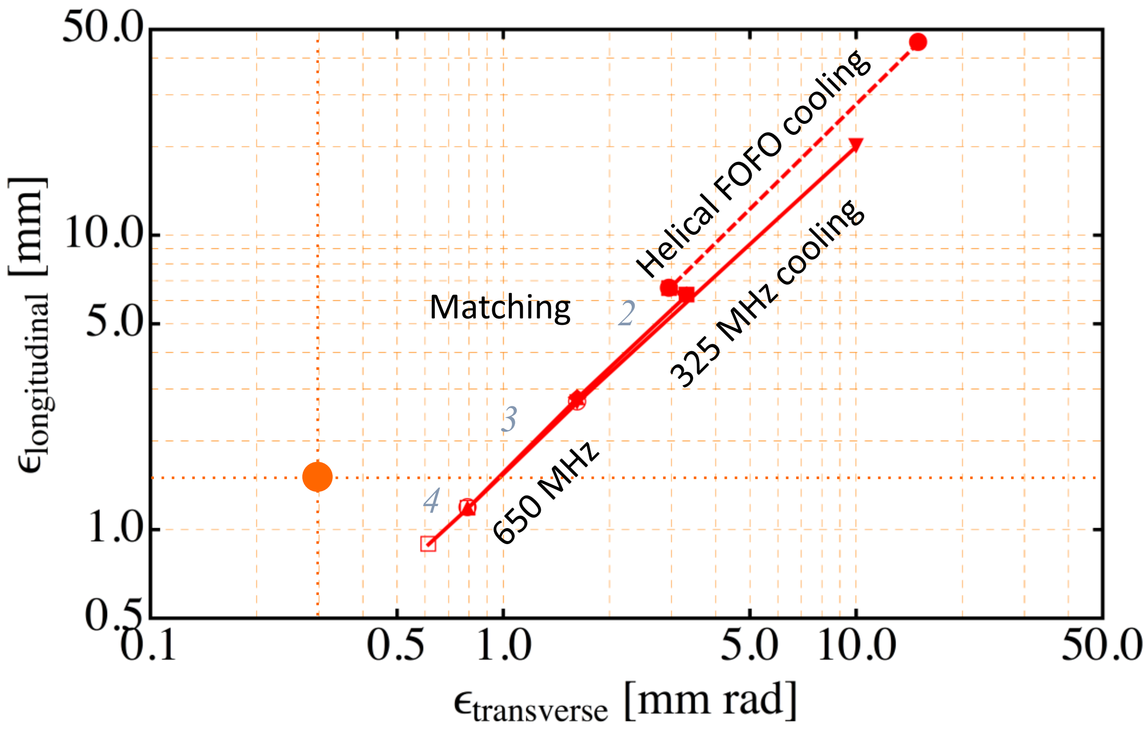
- Higher momentum spiral orbits have longer path length and hence higher energy loss resulting in dispersion

Helical beam element



RF length
10 cm for 325 MHz
5 cm for 650 MHz

Simulation result



Matching

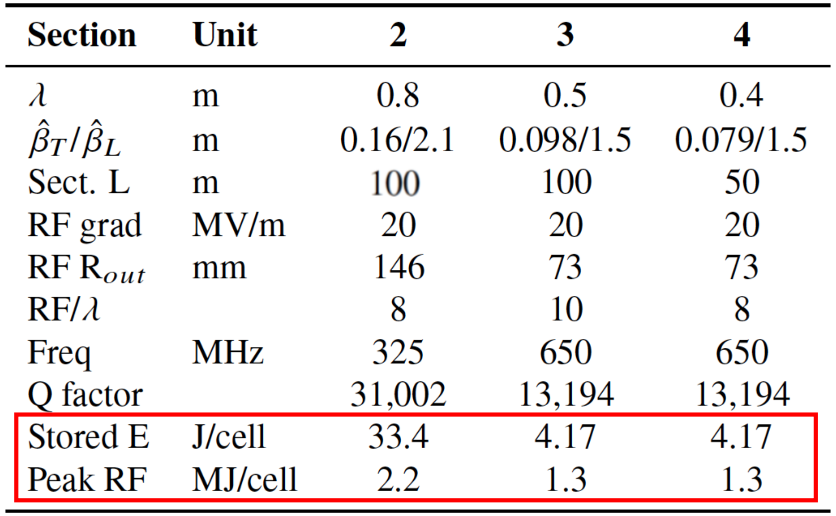
Transmission: 80 %

6D HCC

- RF parameter
  - E = 20 MV/m
  - ν = 325 & 650 MHz
- Gas pressure
  - 160 atm at 300 K
  - 43 atm at 80 K
- Magnetic fields
  - Bz = 4 – 12 Tesla
- Equilibrium emittance
  - ε_T = 0.6 mm (MAP goal: 0.3 mm)
  - ε_L = 0.9 mm (MAP goal: 1.5 mm)
- Transmission (one cooling cycle)
  - 60 %
- Channel length (one cooling cycle)
  - 250 m

Engineering design

Table 1: Power estimation for helical RF system



Section	Unit	2	3	4
λ	m	0.8	0.5	0.4
$\hat{\beta}_T/\hat{\beta}_L$	m	0.16/2.1	0.098/1.5	0.079/1.5
Sect. L	m	100	100	50
RF grad	MV/m	20	20	20
RF R_{out}	mm	146	73	73
RF/λ		8	10	8
Freq	MHz	325	650	650
Q factor		31,002	13,194	13,194
Stored E	J/cell	33.4	4.17	4.17
Peak RF	MJ/cell	2.2	1.3	1.3

Section 2, 3, 4 are shown in slide 4

- Dielectric loaded RF cell can store higher RF energy than a pillbox cell
- But, it requires higher peak RF power than a pillbox cell

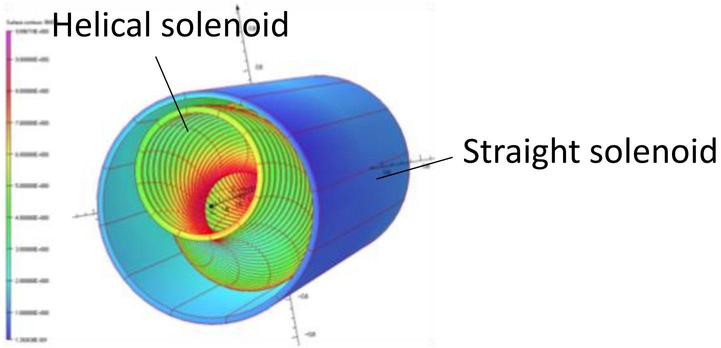
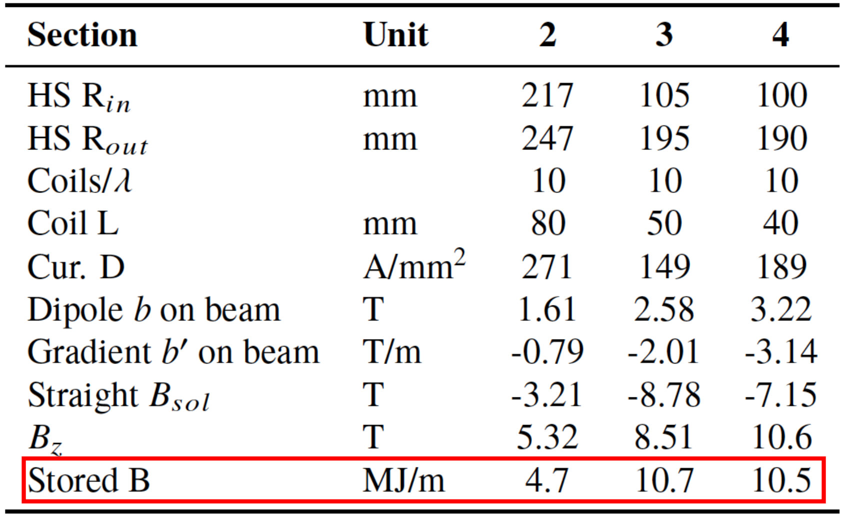


Table 2: Power estimation for helical magnet



Section	Unit	2	3	4
HS R_{in}	mm	217	105	100
HS R_{out}	mm	247	195	190
Coils/λ		10	10	10
Coil L	mm	80	50	40
Cur. D	A/mm^2	271	149	189
Dipole b on beam	T	1.61	2.58	3.22
Gradient b' on beam	T/m	-0.79	-2.01	-3.14
Straight B_{sol}	T	-3.21	-8.78	-7.15
B_z	T	5.32	8.51	10.6
Stored B	MJ/m	4.7	10.7	10.5

- Magnetic energy including with a straight solenoid magnet is extremely high

Next step

- Beam dynamics: Need a beam adapter to match muon beam into HCC
- Reoptimize beam lattice
- Technological challenge
  - Helical solenoid magnet:
  - Integrate RF into helical solenoid
  - Cold channel vs Room temperature channel