Update on the Helical Cooling Channel

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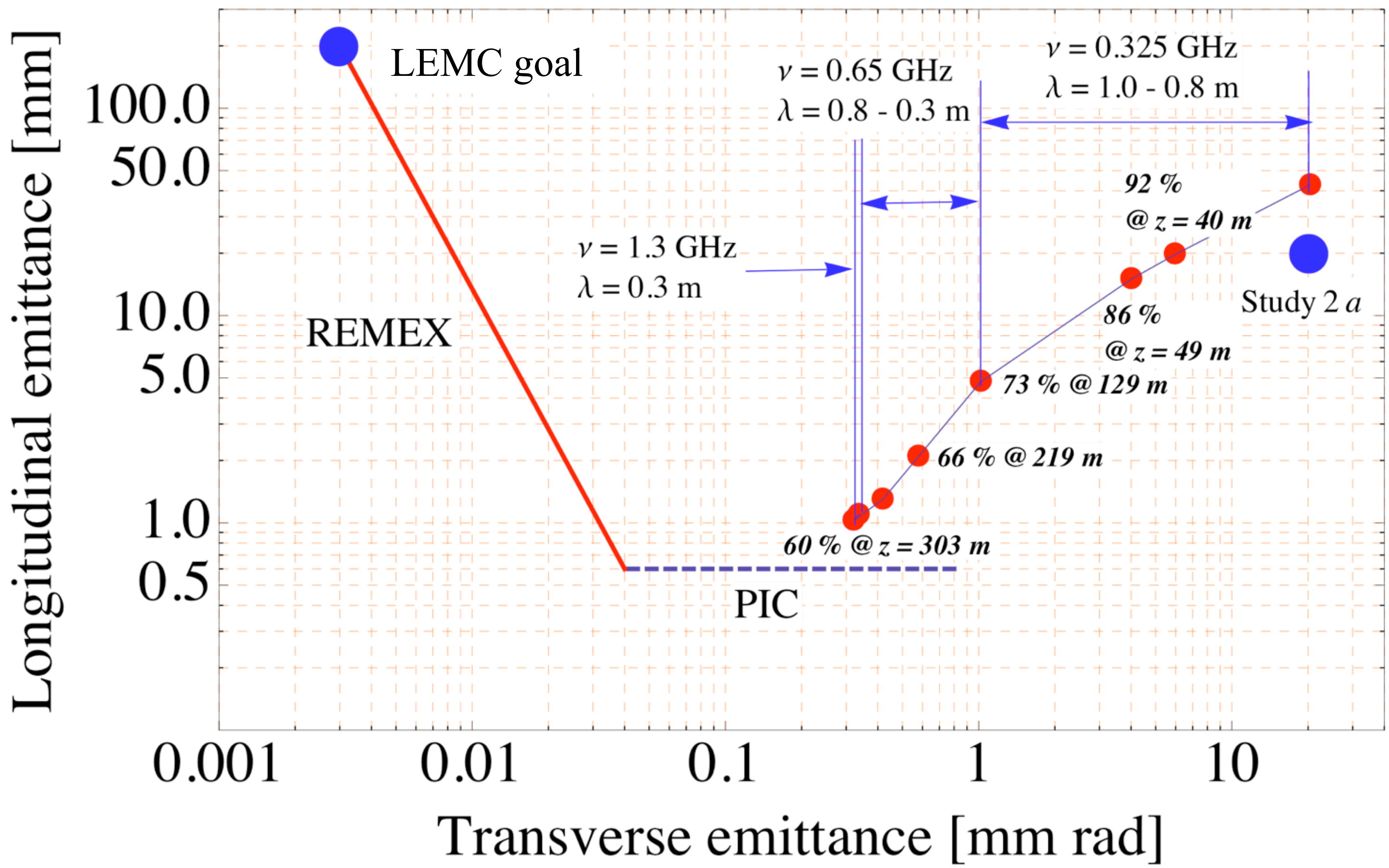
Introduction

- Studied capability of helical solenoid magnet how to design embedded RF cavity into the magnet
  - Try to make larger bore coil
  - In this talk, the occupancy of coil is 50 % in longitudinal direction (gap between coils = coil length)
- Found some successful design
- Then designed adiabatic matching section based on helical solenoid coil

Latest emittance evolution curve in HCC

Simulation result by using analytical EM field expression

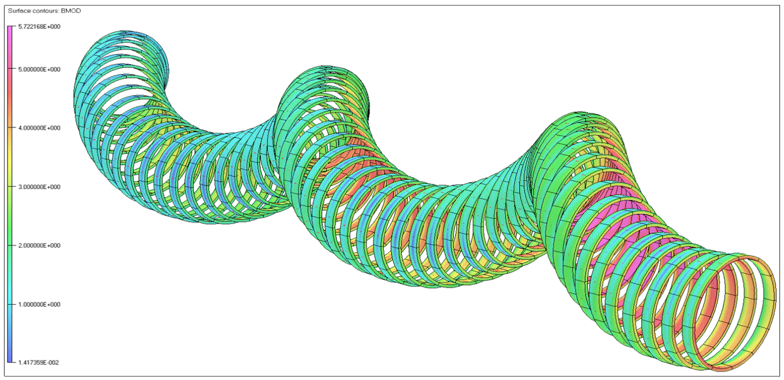


Parameter list

	z	b	b'	bz	λ	N	ε_T	ε_L	ε_{6D}	ε
unit	**m**	**T**	**T/m**	**T**	**m**	**GHz**	**mm rad**	**mm**	**mm^3**	**Transmission**
1	0						20.4	42.8	12900	1.00
2	40	1.3	-0.5	-4.2	1.0	0.325	5.97	19.7	415.9	0.92
3	49	1.4	-0.6	-4.8	0.9	0.325	4.01	15.0	10.8	0.86
4	129	1.7	-0.8	-5.2	0.8	0.325	1.02	4.8	3.2	0.73
5	219	2.6	-2.0	-8.5	0.5	0.65	0.58	2.1	2.0	0.66
6	243	3.2	-3.1	-9.8	0.4	0.65	0.42	1.3	0.14	0.64
7	273	4.3	-5.6	-14.1	0.3	0.65	0.32	1.0	0.08	0.62
8	303	4.3	-5.6	-14.1	0.3	1.3	0.34	1.1	0.07	0.60

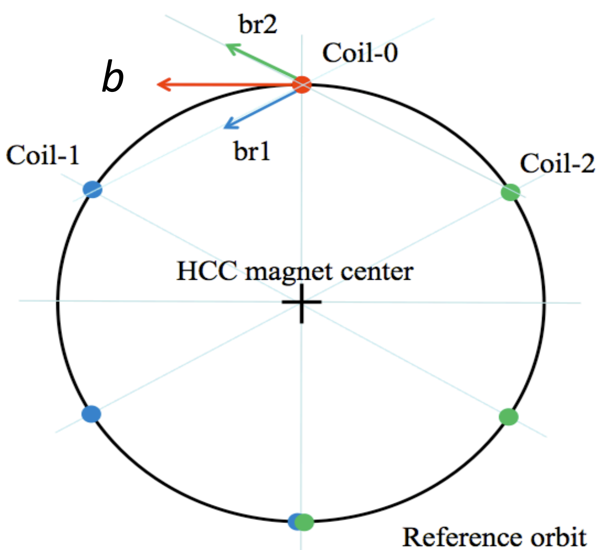
- Lattice parameter is designed for μ^+ with left-handed helicity beam
- Average momentum = 200 MeV/c
- *b* is a helical dipole, *b'* is a helical field gradient (=$\partial b/\partial \rho$), and *bz* is a solenoid field on the reference orbit

Helical solenoid magnet



Helical Solenoid (HS) magnet

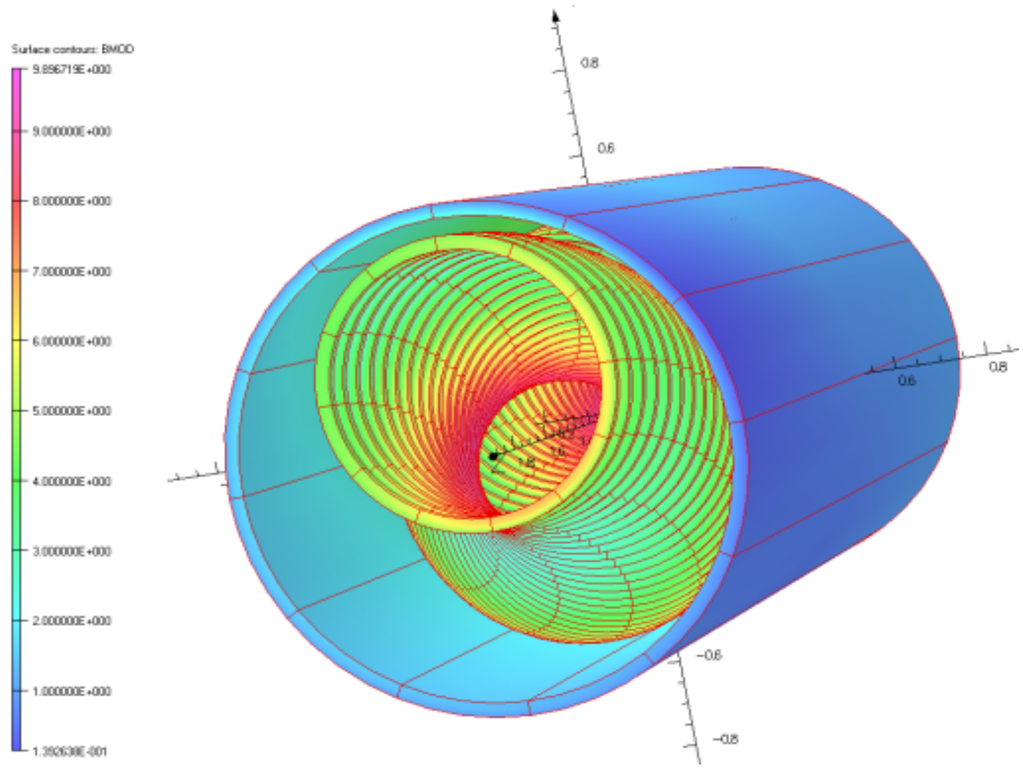
- Consists of a small pancake coil
- Coil center locates on the reference orbit
- Gap between coils is designed the same as the coil length in this presentation



Schematic front view of HS magnet

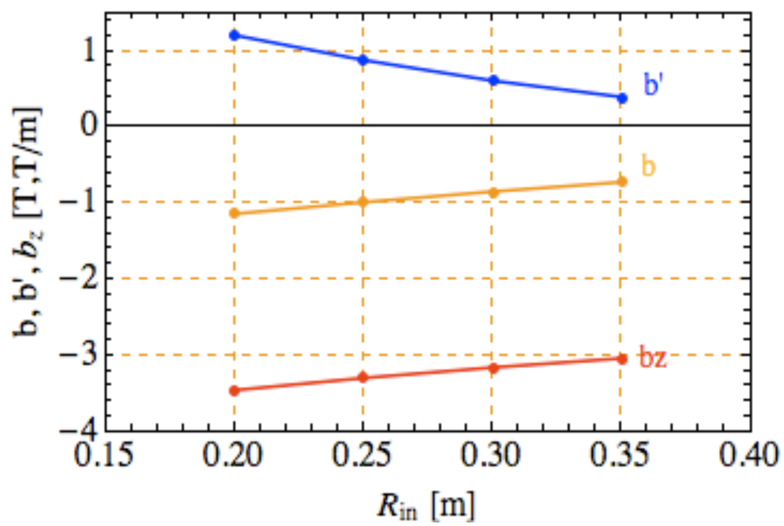
- Shows coil center located on the reference orbit
- Let us find the field map at coil-0 center
- *bz* is mainly produced by coil-0
- *b* is produced by *br1* and *br2* that are generated from neighbor coils (coil-1 and coil-2)
- *b'* is tuned by adjusting coil size

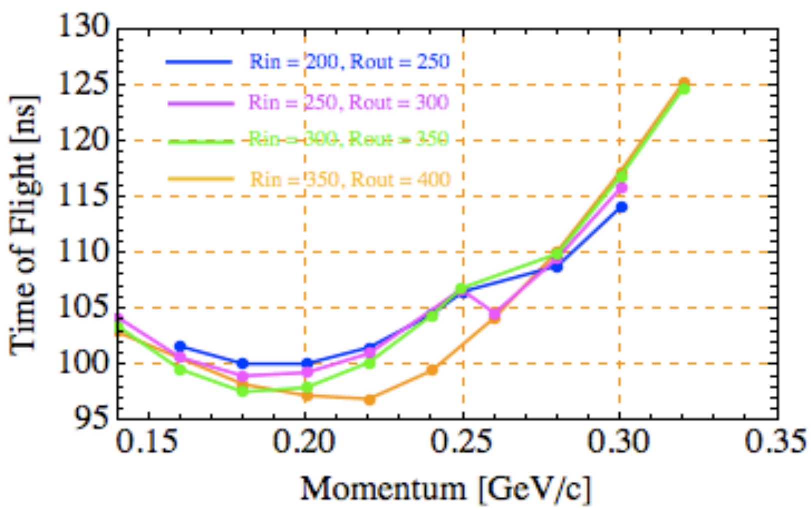
Add pure solenoid magnet



All three lattice parameters (*b*, *bz*, *b'*) can be tuned easily by adding a pure solenoid magnet

Tune bore radius of HS coil





Variation of b, bz, b' as a function of inner radius of HS coil

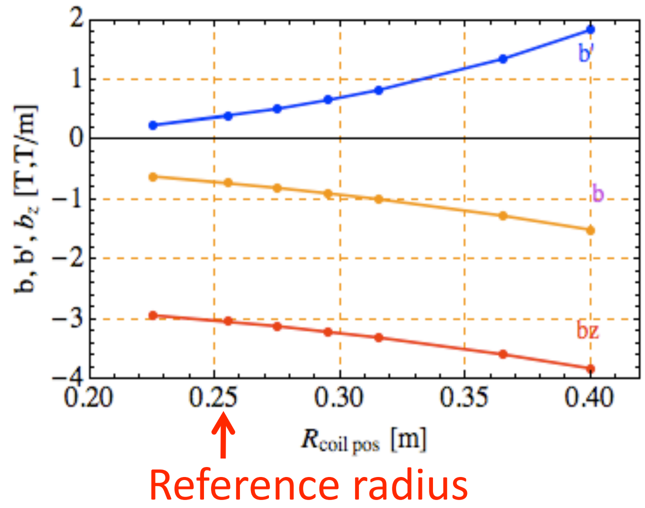
- b and bz are adjusted by current density to satisfy the same designed momentum at each lattice condition
- No solenoid applied in this study
- b' is monotonically reduced at larger coil bore

Variation of acceptance of HS magnet as a function of inner radius of HS coil

- Inject pencil beam with large momentum spread ($0.1 < p < 0.4$ GeV/c)
- No absorber no RF
- Larger bore coil has larger momentum acceptance
- Interestingly, the zero phase slip factor ($=p/\tau\ \partial\tau/\partial p$) is shifted

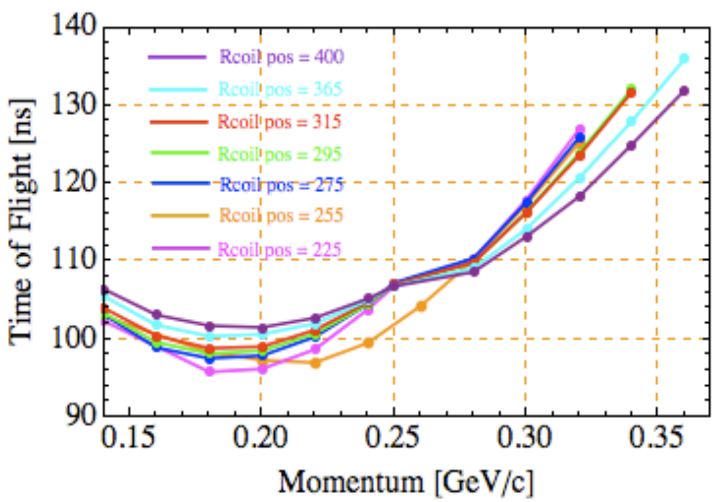
→ Dave Neuffer brough up a new rebuncher (not covered in this talk)

Coil center position dependence



Variation of b, bz, b' as a function of HS coil center position

- Larger b' is needed for cooling
- I asked by myself why coil center position must be on the reference orbit
- By moving coil outward from magnet center, b' can be enhanced significantly

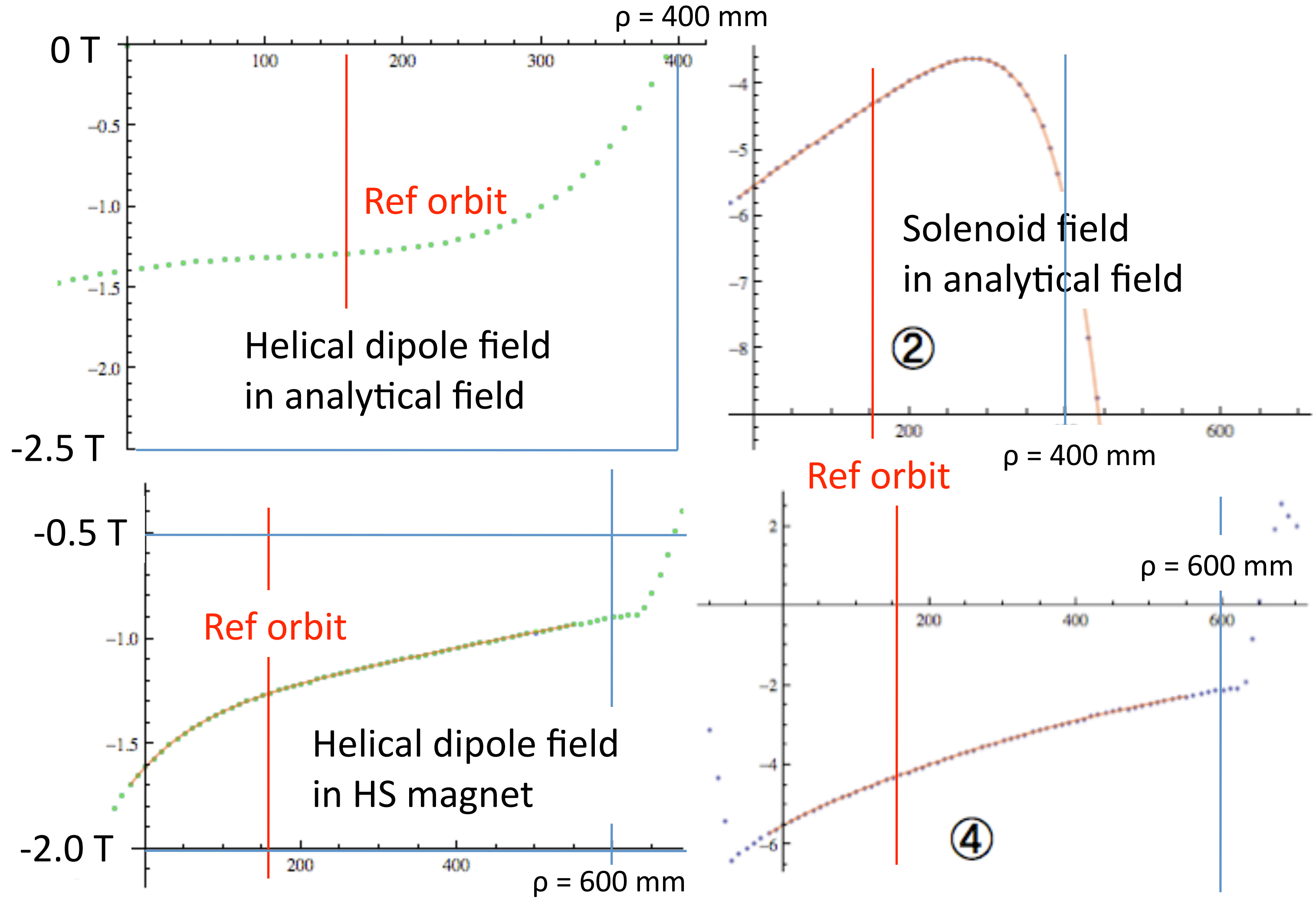


Variation of HS magnet as a function of HS coil center position

- Larger HS coil displacement generates larger momentum acceptance

Field uniformity in HS magnet

Compare analytical field expression (Bessel) vs HS magnet



b and bz in HS magnet are uniformly distributed at large radius

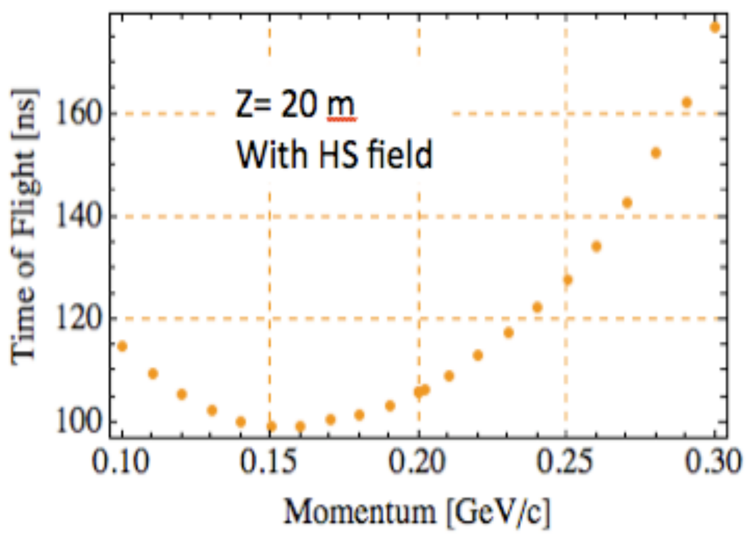
→ good for high p particle

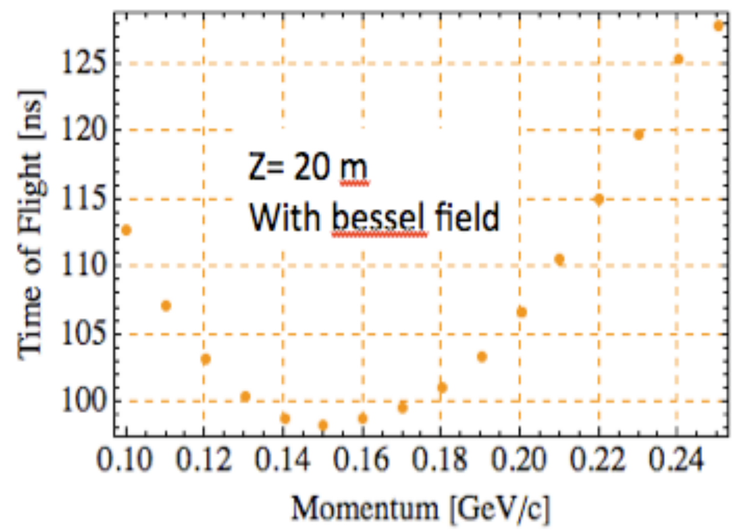
Design 1st HCC

Size of 325 MHz RF cavity: r = 0.35 m

	a_{ref}	R_{coil}	R_{in}	l_{coil}	n_{coil}	R_{out}	b	b'	b_{sol}	b_z	D	p	b/b'	I
Unit	m	m	m	m		m	T	T/m	T	T	m	GeV/c		A/mm^2
HS	0.16	0.28	0.35	0.025	20	0.40	1.31	0.53	0.55	-4.31	0.23	0.202	2.45	-194
Bessel							1.31	0.55		-4.32	0.28	0.2	2.38	

Table 4: Parameter list for first HS magnet





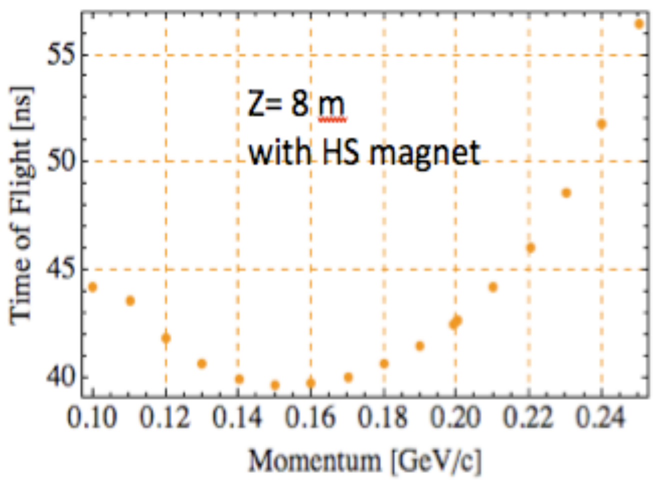
- No absorber, no RF
- HS magnet has larger momentum acceptance than analytical field

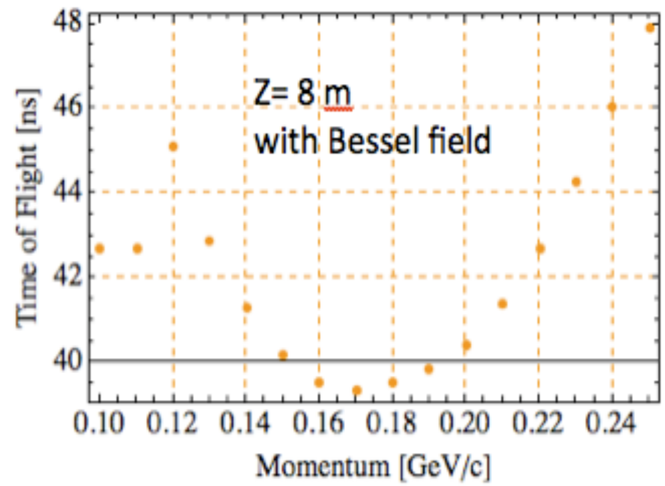
Design near end HCC

Size of 650 MHz RF cavity: r = 0.18 m

	a_{ref}	R_{coil}	R_{in}	R_{out}	l_{coil}	n_{coil}	B	b'	b_{sol}	b_z	D	P	b/b'	I
Unit	m	M	m	m	m		T	T/m	T	T	m	GeV/c		A/mm^2
HS	0.063	0.158	0.18	0.28	0.0125	16	3.26	4.56	6.73	-10.7	0.083	0.20	0.71	-332.9
Bessel							3.22	3.14		-10.6	0.093	0.2	1.02	

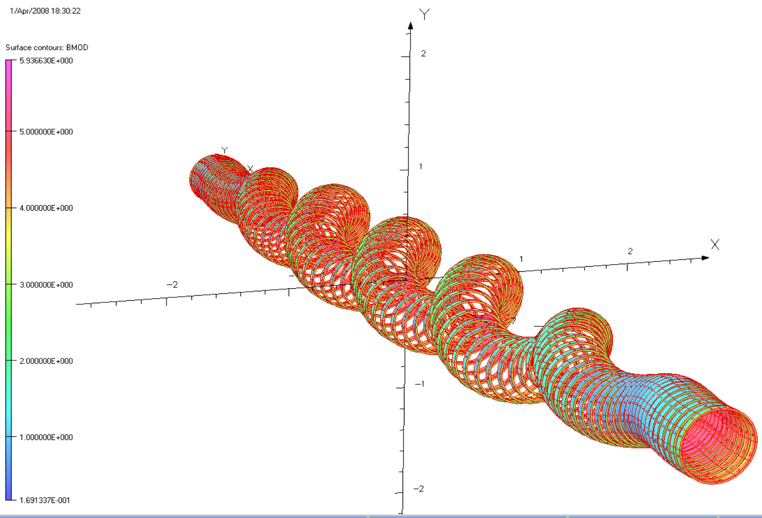
Table 5: Field parameter for second final HCC magnet (λ = 0.4 m)





- No absorber, no RF
- No big difference between HS magnet and analytical field (why??)

Matching section



Schematic view of HS with matching section

- Matching section locates between straight channel and helical magnet
- Matching must generate proper transverse kick and position offset
- HS matching magnet is designed
- HS coil center radius is linearly increased

	Coil center	R_{in}	R_{out}	Current density	Length
Unit	M	m	m	A/mm²	m
Upstream matching section	0 → 0.28	0.35	0.40	-220 →-193.6	5.5
Cooling section	0.28	0.35	0.40	-193.6	12
Downstream matching section	0.28 → 0	0.35	0.40	-193.6 → -220	5.5

Table 6: Parameter for matching section

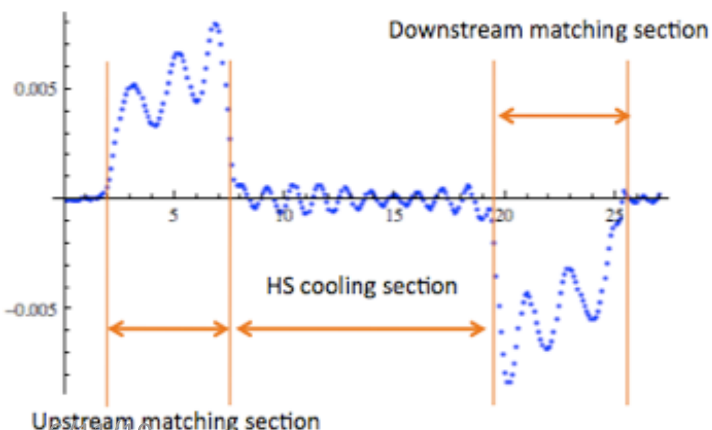
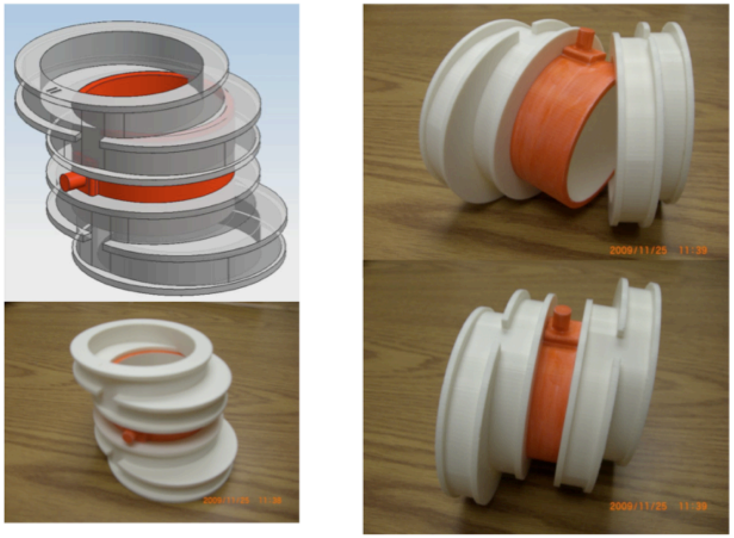


Figure 21: Amplitude of perturbative oscillation in matching section.

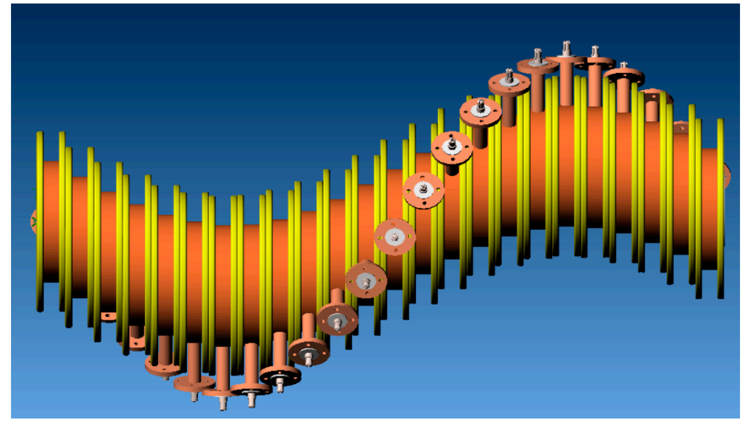
Analyze perturbation in matching section

- Plot shows perturbation oscillation
- By tuning coil geometry and current density, perturbation oscillation in the HS cooling section can be minimized
- Analytical investigation of this design is underway
- From preliminary study, matching section has larger acceptance than the HS cooling channel

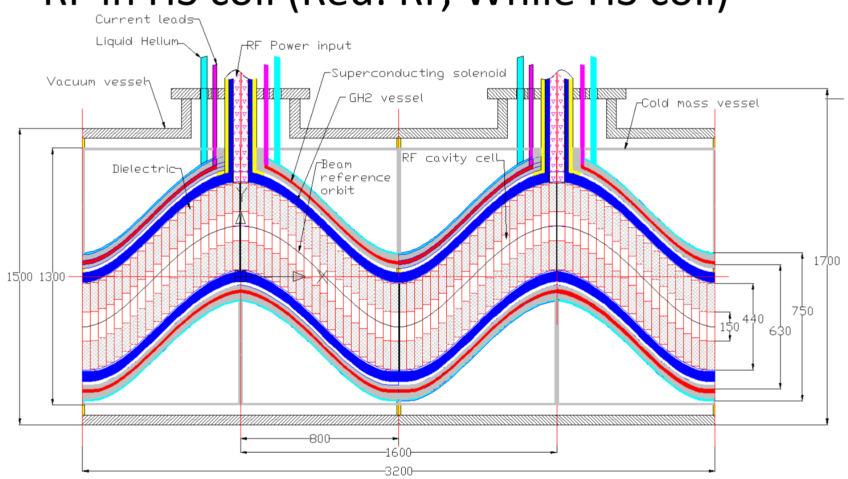
Integrate RF and HS magnet



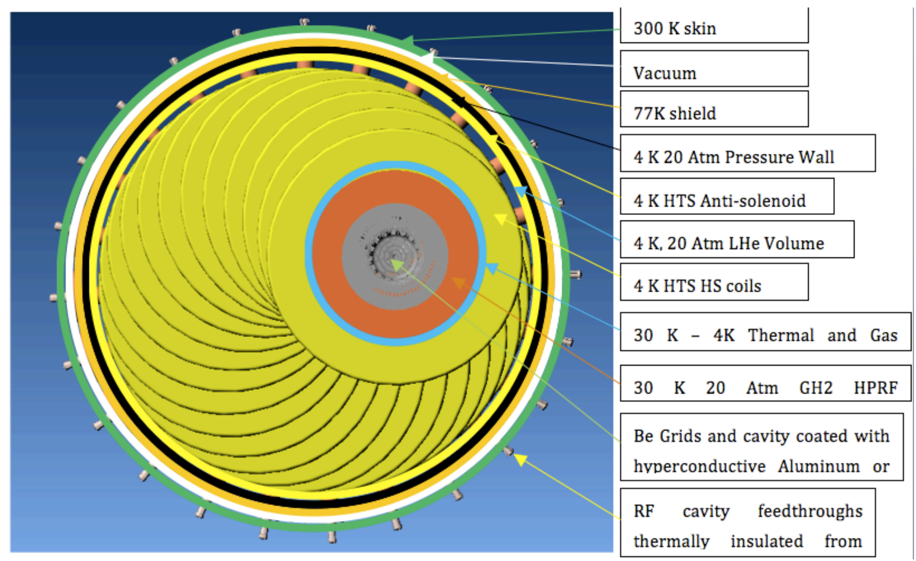
RF in HS coil (Red: RF, While HS coil)



RF in HS coil



Other design to integrate RF into HS magnet



Include with infrastructures

Conclusion

- Studied HS magnet and found its great capability to apply for muon cooling
- Cooling simulation in HS magnet is on going
- First matching design has been done
  – Frontend group works hard to find better matching design that has larger momentum acceptance
- Investigated some other applications
  – Rebuncher by Dave N.