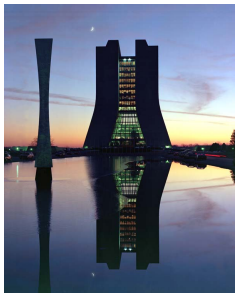


Recent progress of HCC D&S

K. Yonehara

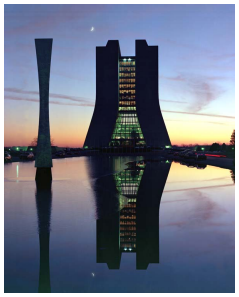
APC, Fermilab

On Behalf of HCC/HPRF simulation group

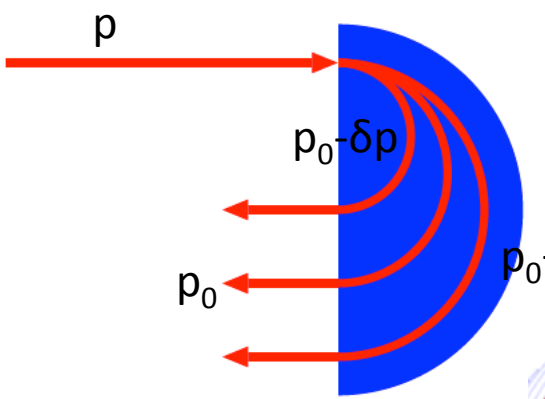


Contents

- Design helical cooling channel
- RF power loading
- Feasibility
- Summary



Helical Cooling Channel



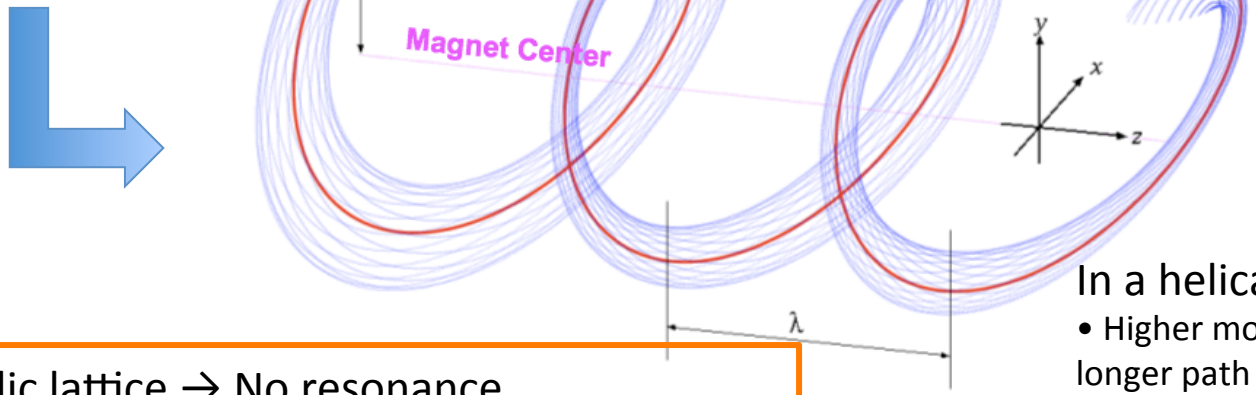
Homogeneous absorber filled dipole magnet

New concept accelerating system

Key elements

- Dense hydrogen gas distributed homogeneously in a continuous helical lattice

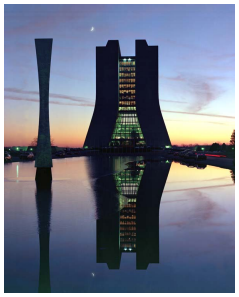
Ya.S. Derbenev & R.P. Johnson, PRSTAB 8 041002 (2005)



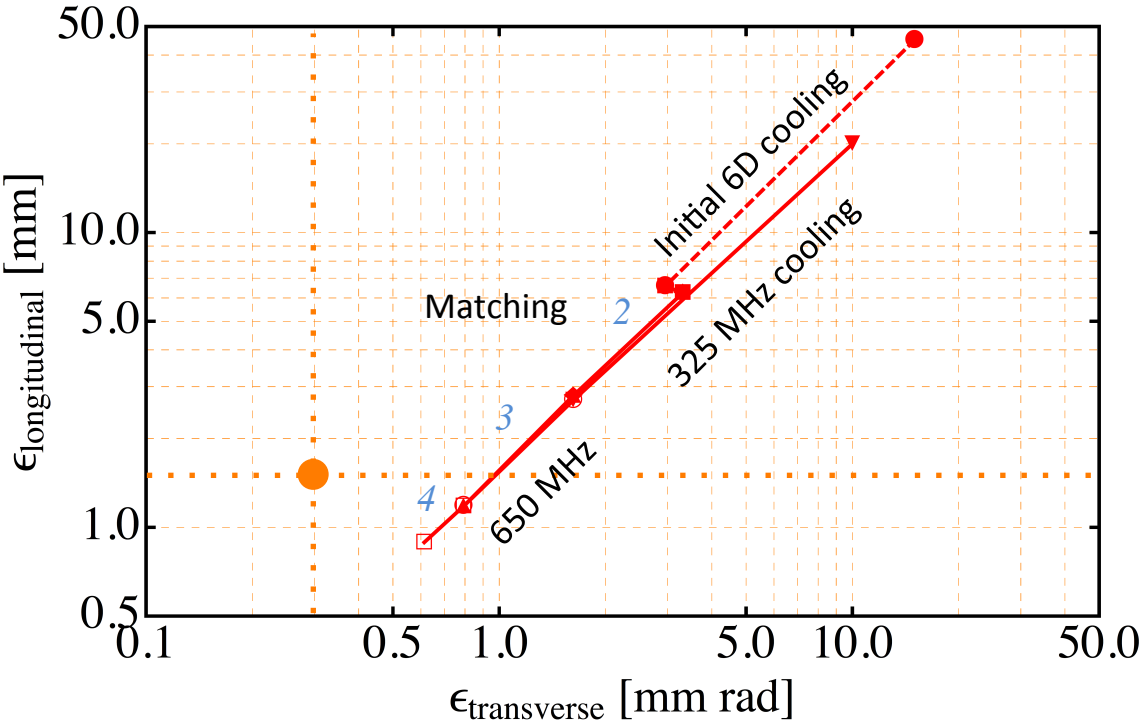
In a helical cooling channel

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

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



6D equal cooling decrement HCC



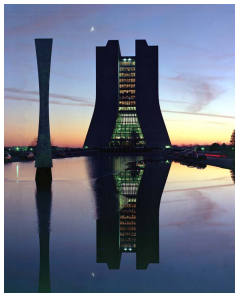
Matching

Transmission: 56 % → 80 %

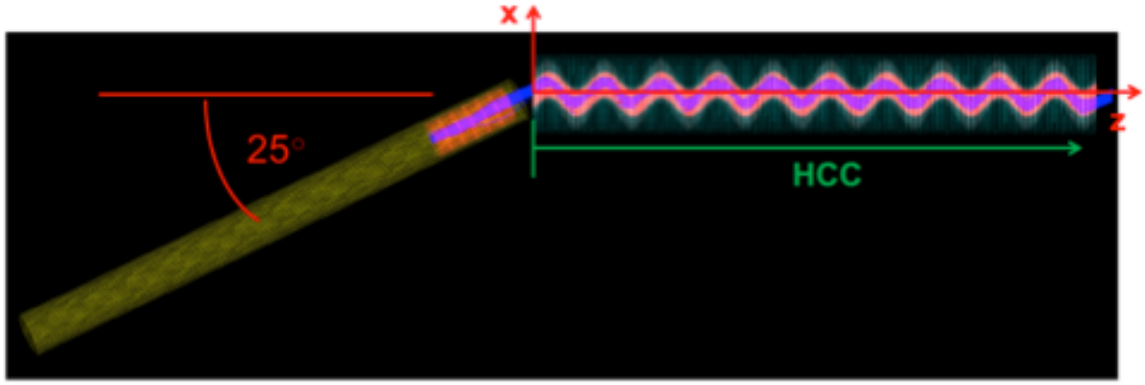
C. Yoshikawa

6D HCC

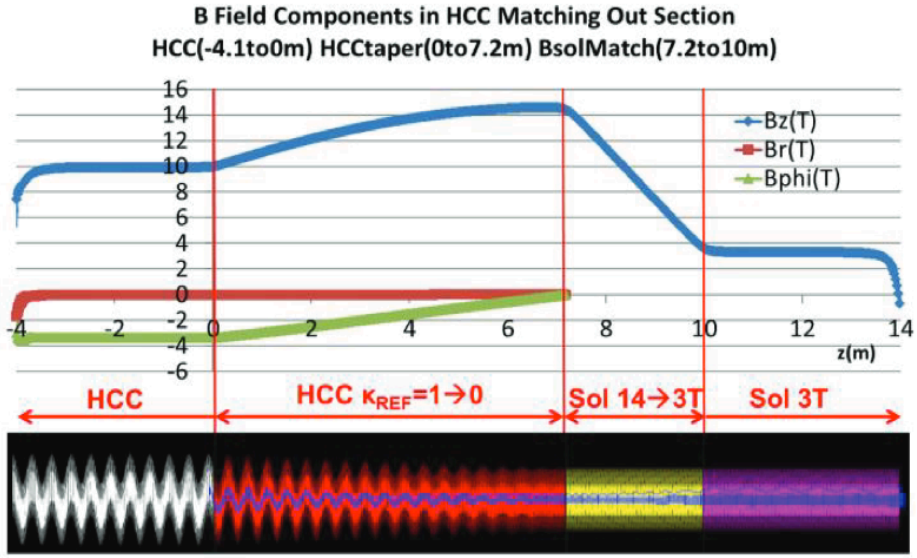
- RF parameter
  - E = 20 MV/m
  - ν = 325 & 650 MHz
- Gas pressure
  - 160 atm at 300 K
  - 43 atm at 80 K
- Magnetic fields
  - Bz = 4 – 12 Tesla
- Equilibrium emittance
  - ε_T = 0.6 mm (goal: 0.3 mm)
  - ε_L = 0.9 mm (goal: 1.5 mm)
- Transmission (one cooling cycle)
  - 60 %
- Channel length (one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



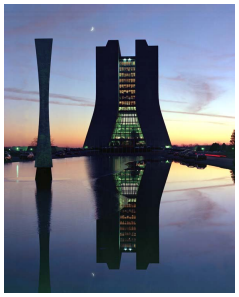
Matching In and Out



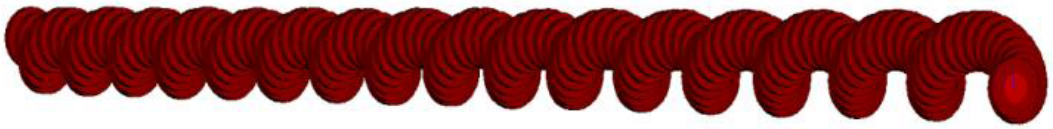
- HCC is a positive phase slip while a solenoid channel is a negative phase slip
- Need a phase transition
- Phase jump at the gap for matching in
- Transmission efficiency 80 %



- Adiabatic channel for matching out
- It also induces an emittance exchange



Bunch merge channel



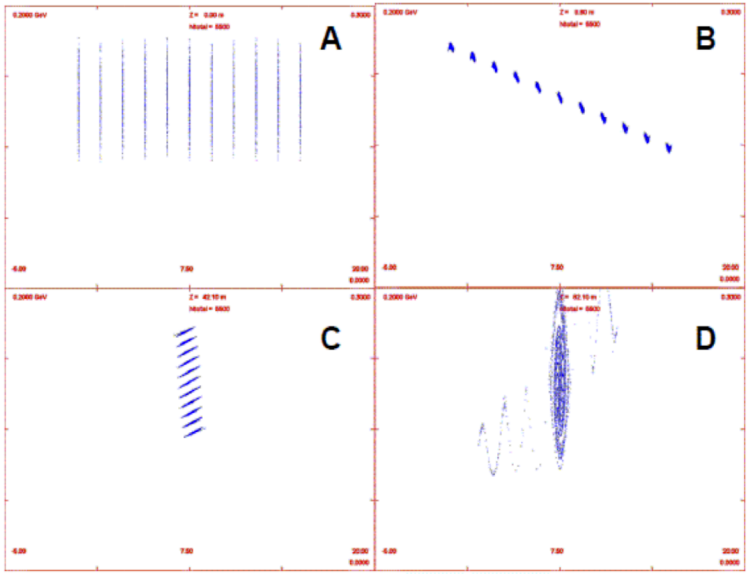
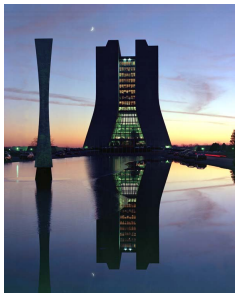
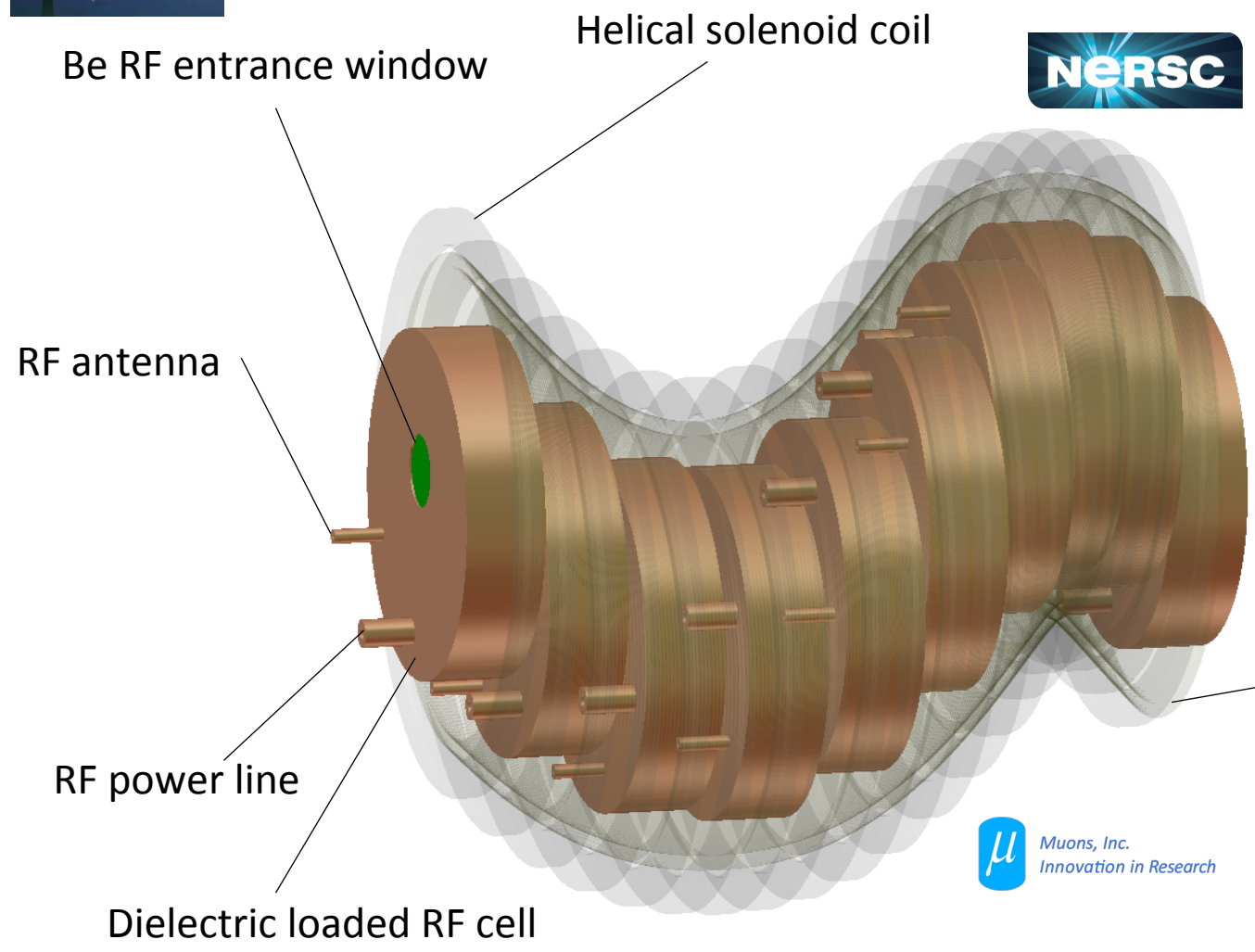


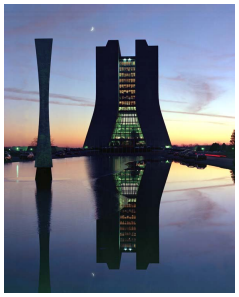
Figure 4: Overview of bunch recombiner with initial quasi-isochronous bunch formation.

- Need muon beam acceleration for beam relativistic velocity to be more constant
- Acceleration in a gas-filled HCC
- Start momentum 209.2 MeV/c to 286.8 MeV/c in 12 m
- Observed emittance growth during acceleration since beta function is changed in the by modulating helical period (λ = 0.5 m to 1.0 m)
- Use phase rotation (B), drifting (C), and capturing into a RF bucket
- No major particle loss observed



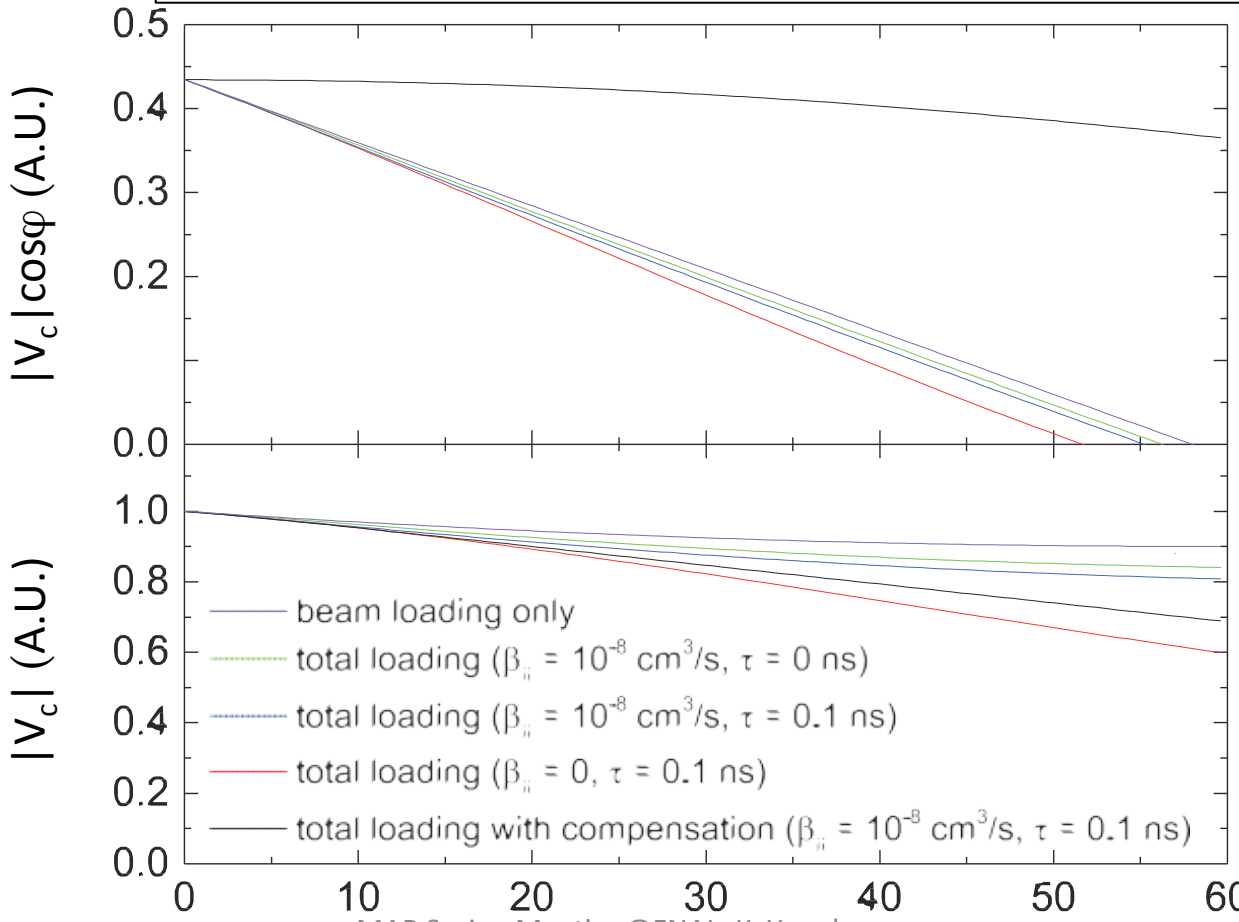
Integrated helical beam element





RF power loading in gas-filled RF

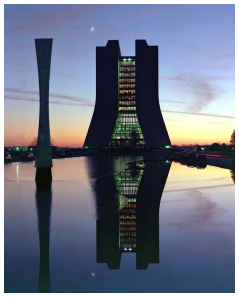
- Overall RF power dissipation
  = Plasma loading + Beam loading
- RF gradient drops 80 % with compensation



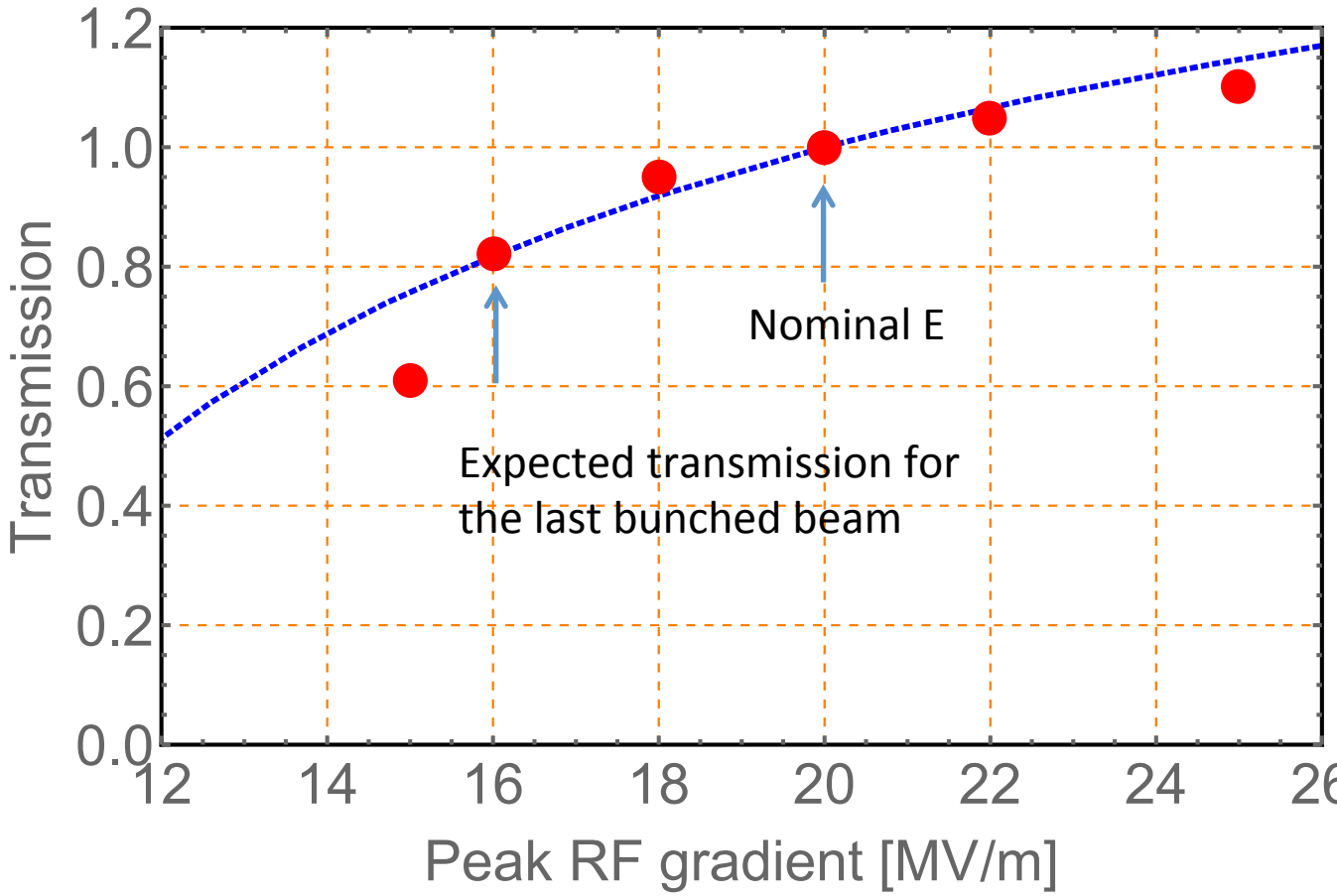
M.Chung
IPAC'13

$n_\mu = 10^{13}/12$

f = 805 MHz
Pillbox cavity



Transmission efficiency vs RF amplitude



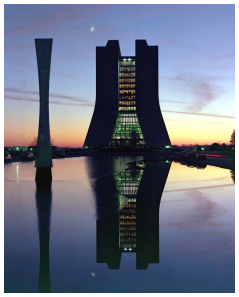
Analytical estimation

$I_{adm} \propto \eta^{-1/2} \propto \beta_L$

η: slip factor

K. Yonehara
IPAC'14, TUPME015
Eqs. (8), (10)

f = 650 MHz



Design HCC beam element

Muons, Inc.
Innovation in Research

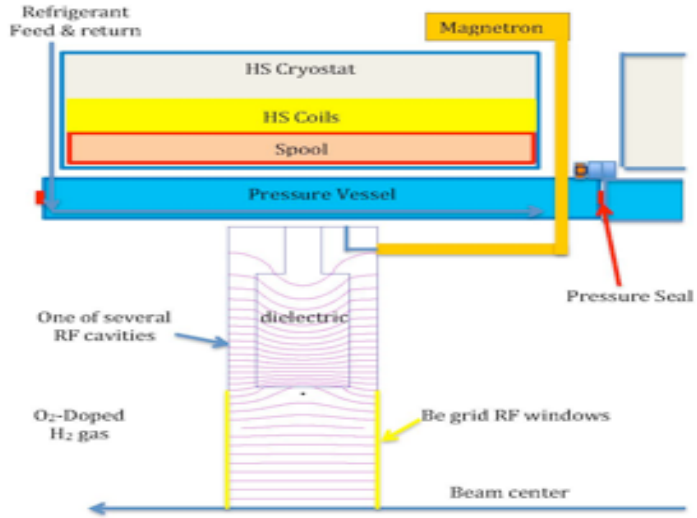
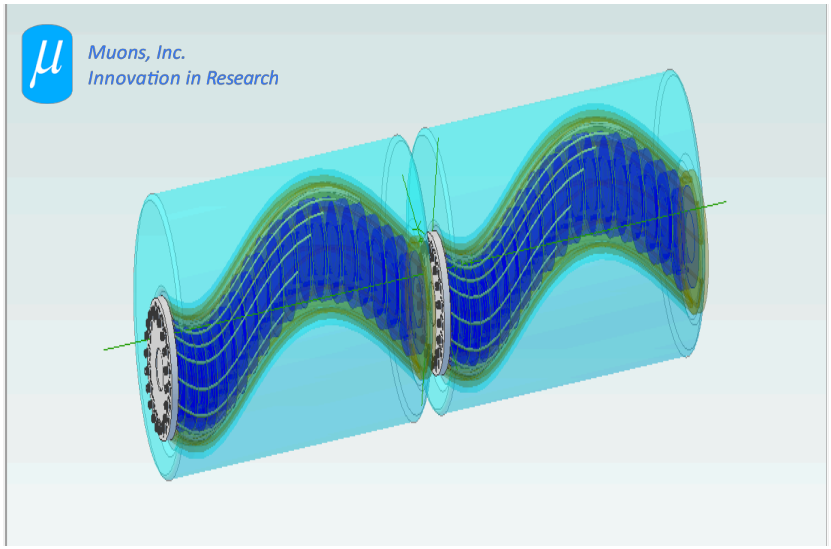
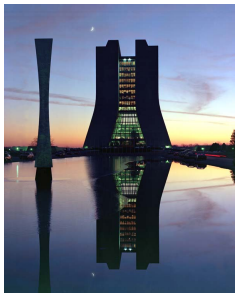


Figure 3: Conceptual diagram showing the features of a dielectric-loaded cavity with Be RF windows, pressure vessel wall, and the HS coil and its cryostat.



Each RF cell is powered by a magnetron

Access RF power line at the gap between two HCC segments



Power estimation

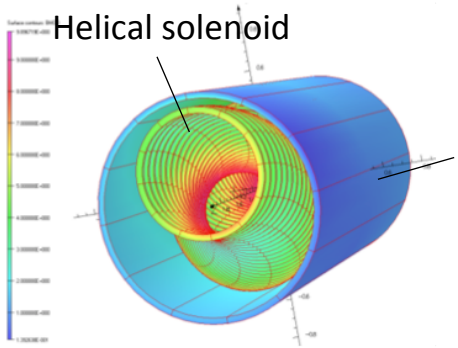


Table 1: Power estimation for helical RF system

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

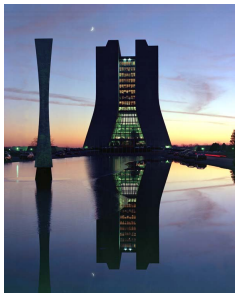
Section 2, 3, 4 are shown in slide 4

- 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

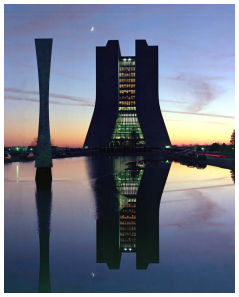
Section	Unit	2	3	4
HS R_{in}	mm	217	105	100
HS R_{out}	mm	247	195	190
Coils/λ		10	10	10
Coil L	mm	80	50	40
Cur. D	A/mm^2	271	149	189
Dipole b on beam	T	1.61	2.58	3.22
Gradient b' on beam	T/m	-0.79	-2.01	-3.14
Straight B_{sol}	T	-3.21	-8.78	-7.15
B_z	T	5.32	8.51	10.6
Stored B	MJ/m	4.7	10.7	10.5

- Magnetic energy including with a straight solenoid magnet is extremely high (Giga Joules!)



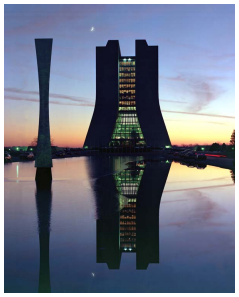
Feasibility of HCC (I)

- Helical RF system
  - DLRF cell requires higher peak power by factor two than a pillbox
  - Need RF power source for each cell
  - Magnetron is a possible solution but it requires phase stability
  - Collaborate with the SRF group
  - Resistive heat is acceptable with a LN2 chiller
  - Need engineering investigation to design Be window

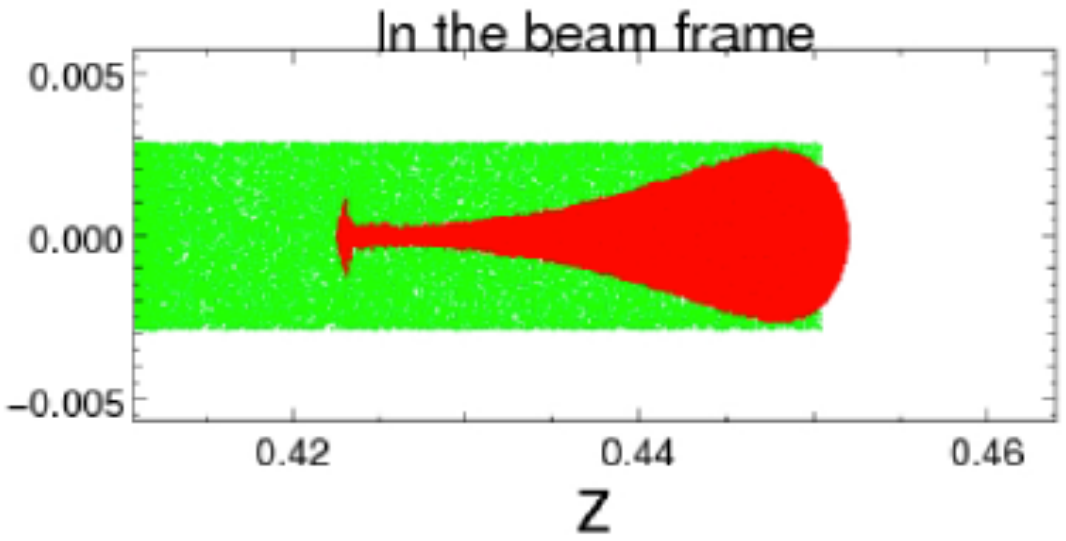


Feasibility of HCC (II)

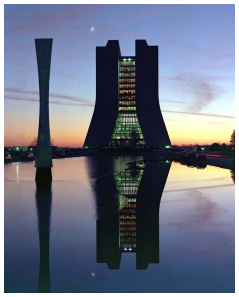
- Helical magnet
  - Huge system comparable with expensive Mu2e magnet system
  - Too tight space to put correction coil
  - It is very challenging to design the final section
    - Recent DLRF cell study shows the possibility to design smaller cell size (a half from a pillbox)
    - We found other cooling path that significantly mitigates field requirements
    - No engineering investigation for other cooling option has been made yet



Possible plasma lens effect



- If muon beam is very intense it generates a dense gas-plasma in a gas-filled RF cavity
- Wakefield generated by beam excites the ionized electron oscillation
- As a result, the internal electric field in the beam is neutralized and the beam induces the axial magnetic field
- The axial field makes beam focusing
- Simulation effort is on-going



Summary

- We found the excellent agreement between the helical cooling theory and the numerical simulation
- We found a very engineering challenge for the final cooling stage
- If the plasma lens is real we can go lower emittance