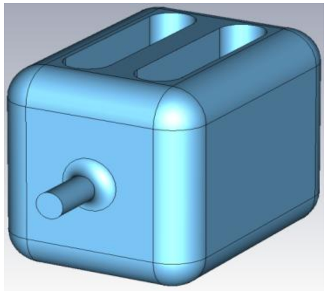
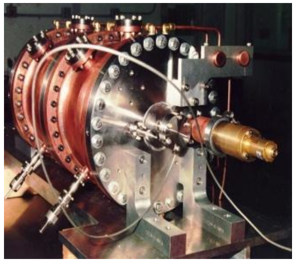
An Overview of My Recent Studies





Shahid Ahmed

Center for Advanced Studies of Accelerators
JLab

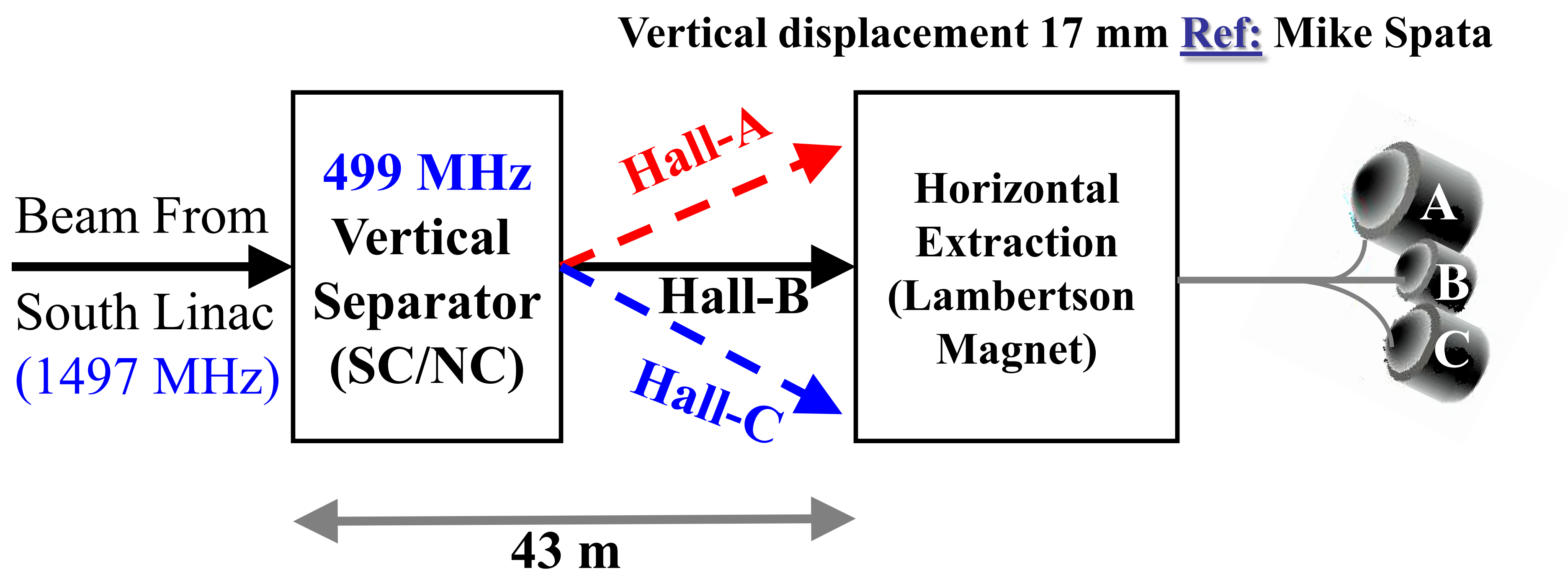
Layout of Presentation

- Beam Dynamics of TEM-type 499 MHz Deflecting Cavities (NC/SC)

- Status of NC RF Deflector for High Power Test

- More Interesting Activities:
  - HOM Survey
  - Electron-Ion Collider Design Studies
  - Beam Break-up Studies
  - Plasma Cleaning of RF Cavities
  - G4beamline Computer Code Development

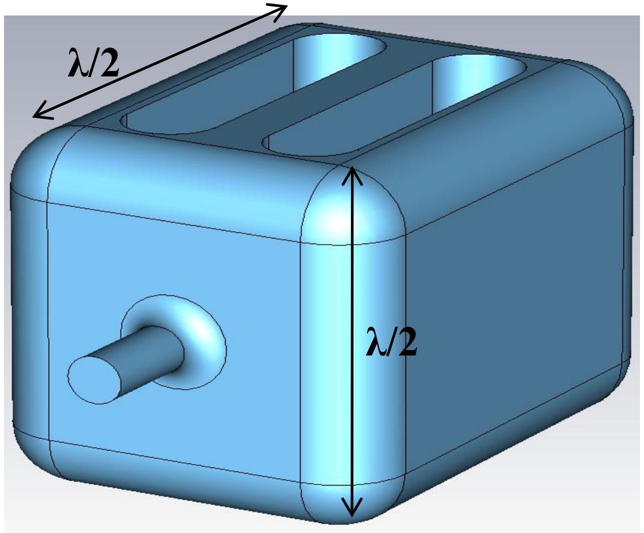
Schematic of Separation Plus Extraction System



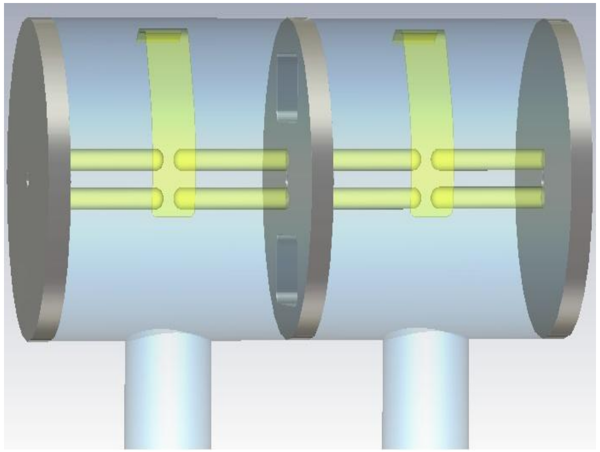
Noteworthy Points:

- Utilize existing horizontal extraction magnet (Lambertson)
- Vertical separation followed by horizontal extraction
- 17 mm vertical displacement at entrance of extraction magnet

Deflecting Cavities – NC & SC



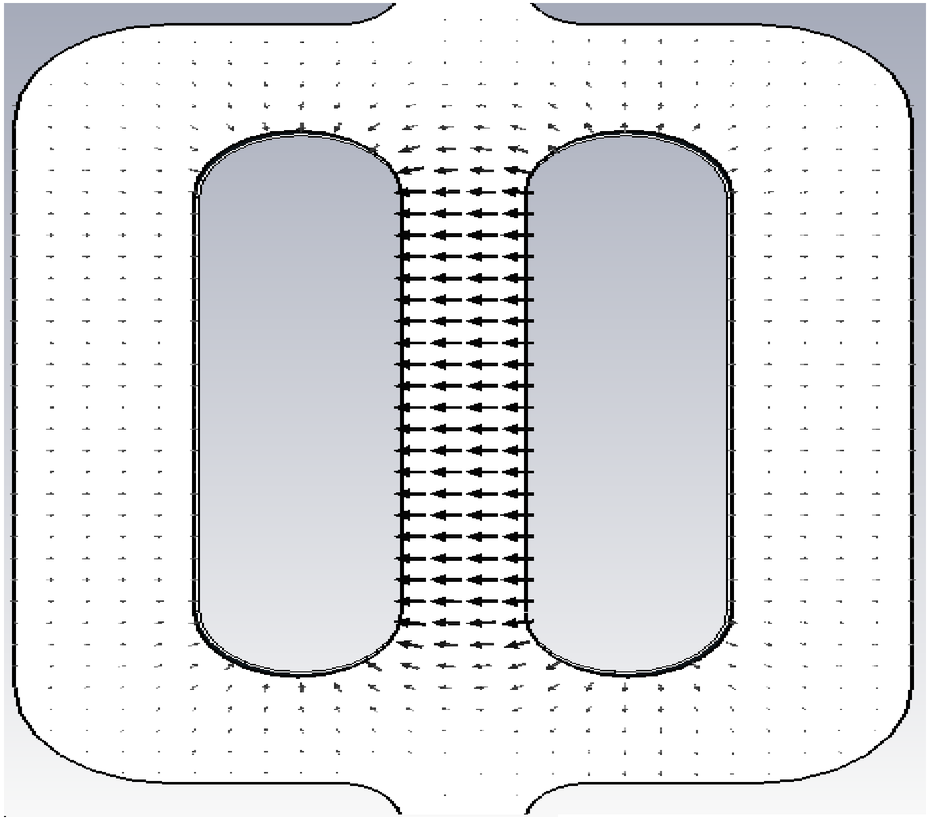
Superconducting (SC)



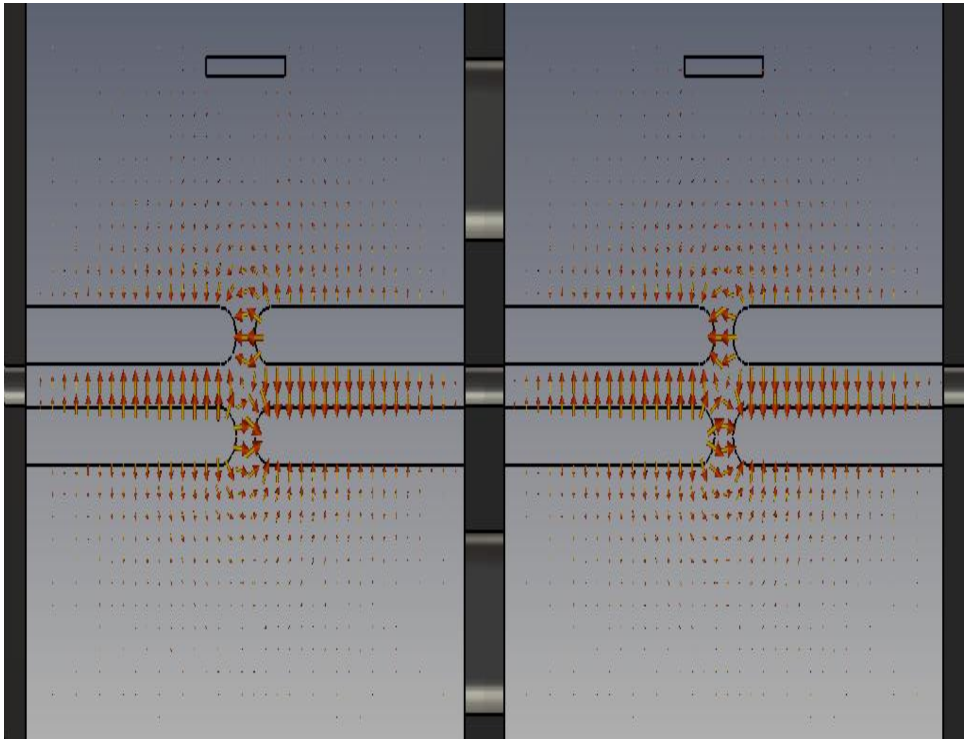
Normal Conducting (NC)

Parameter	SC	NC	Unit
Frequency of π mode	499.2	499	MHz
λ/2 of π mode	300.4	300.4	mm
Cavity length	394.4	300	mm
Bars width	67	20	mm
Bars length	284	135	mm
Aperture diameter	40.0	15	mm
V_{def}^*	0.3	0.3	MV
E_p^*	1.85	3.39	MV/m
B_p^*	6.69	8.87	mT
$G = QR_S$	67.96	34.9	Ω
$[R/Q]_T$	933.98	24921	Ω
At E_T^* = 1 MV/m			

EM Field Distribution of Deflecting Mode



SC Structure



NC Structure

- ❖ Fields strongly concentrated within rods
- ❖ Strong deflection to beams

Why Need Simulations ?

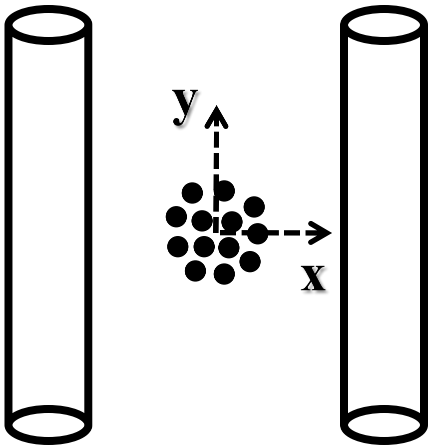
- Two different deflecting cavities :
  - Normal conducting (exists for 6 GeV CEBAF operation)
  - Superconducting (EM design available)

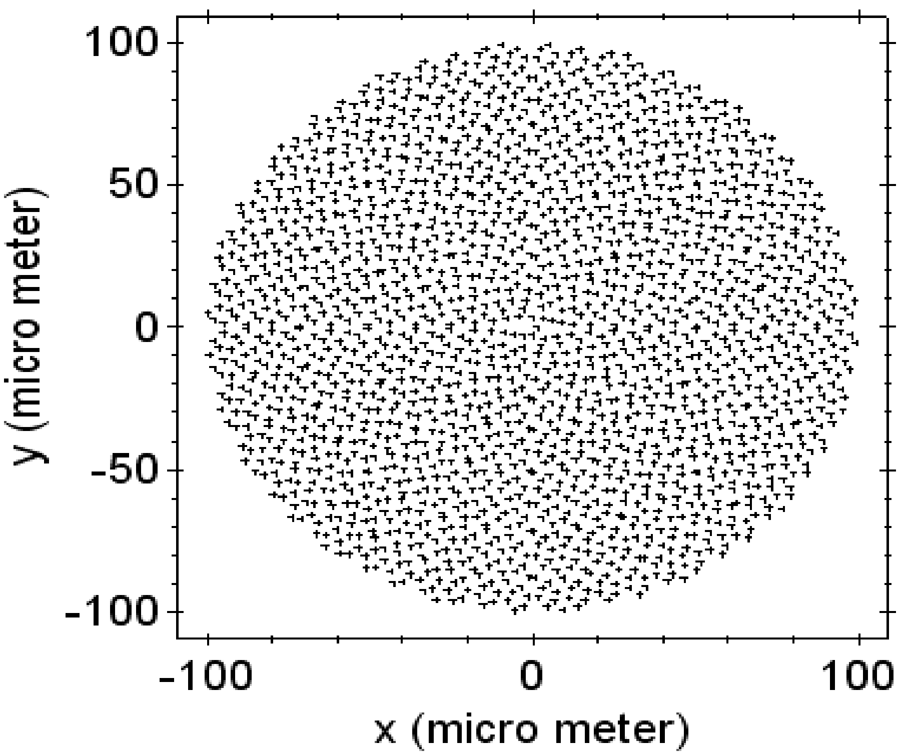
- No beam dynamics predictions available

- Require one/two SC but six/eight NC structures
  - Aperture diameter : 40 mm for SC and ~ 15 mm for NC
  - Beam stay clear condition requires 6.5 mm from either wall (SC is OK but NC may not enough)
  - Alignment tolerance for NC arrangement
  - Emittance dilution needs to know

Beam Dynamics : Simulation Schematic

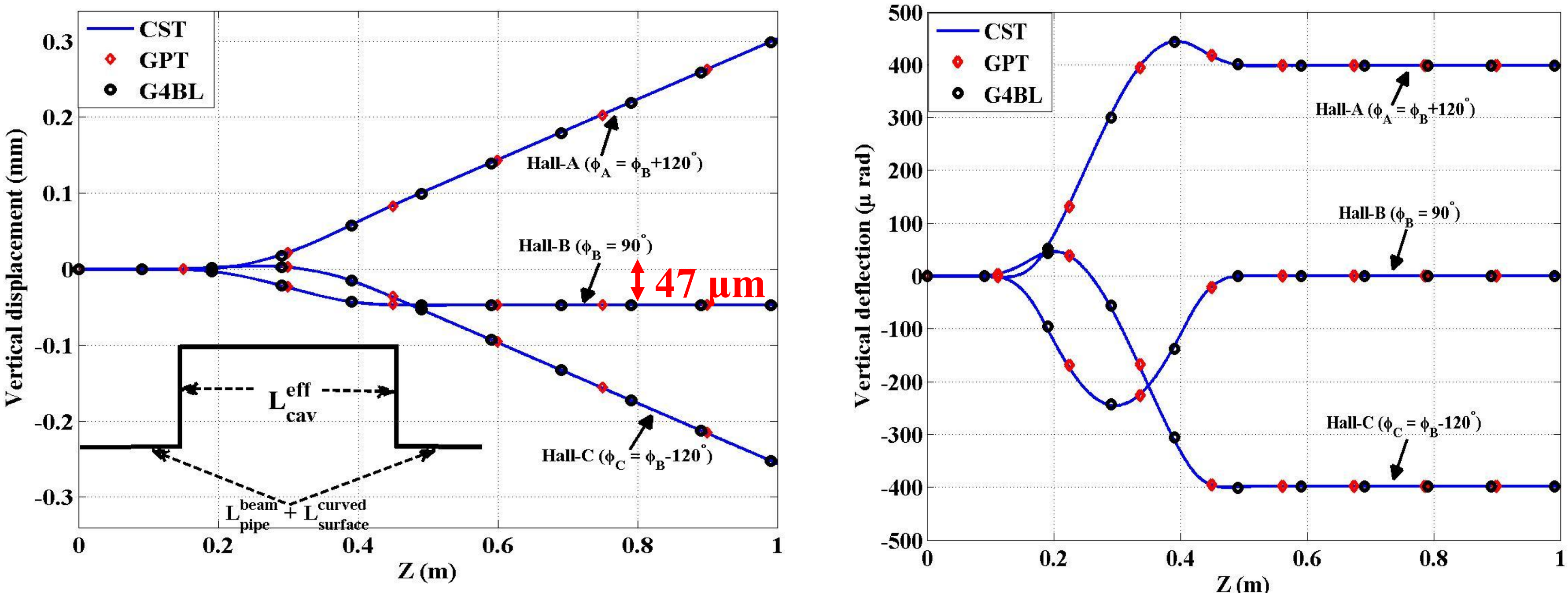
- Particle : 1000 electron ($m_e = 5.11 \times 10^{-4}$ GeV), Q = 1 pC
- E : 11 GeV , $p = \sqrt{(E^2 - m_e^2)} \sim 11$ GeV/c
- $\beta = E / p \sim 1$, $\gamma = E / m \sim 2.15264 \times 10^4$





First discussion for SC structure followed by comparison with NC

Transverse Displacement & Deflection



❖ Three distinct tracks for hall A, B and C

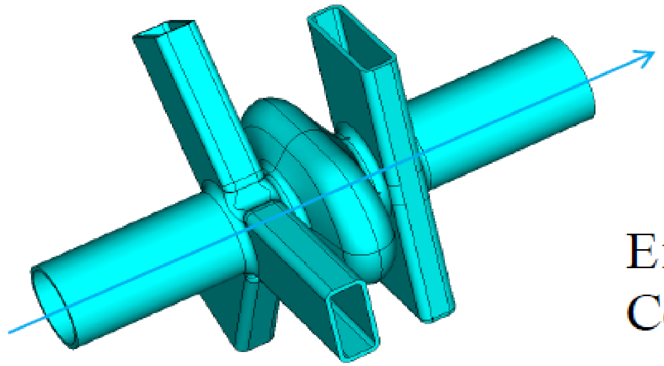
❖ Non zero residual offset in position (~ 47 µm) but not in angle

❖ All nonlinear phenomena occur inside cavity

❖ Results confirmed by CST, GPT and g4beamline simulations

APS Crab Cavity

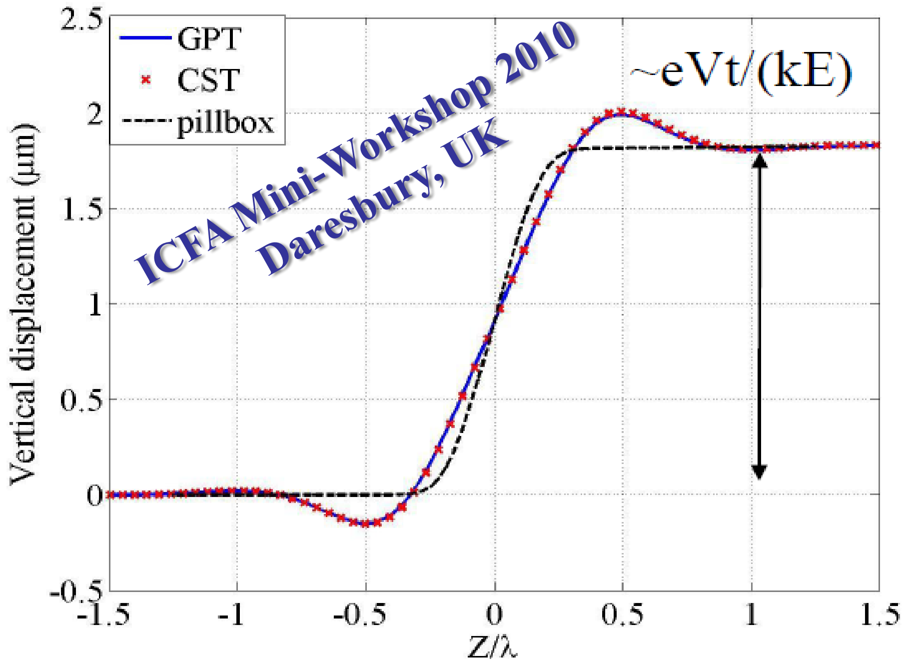
Presenter: H. Wang

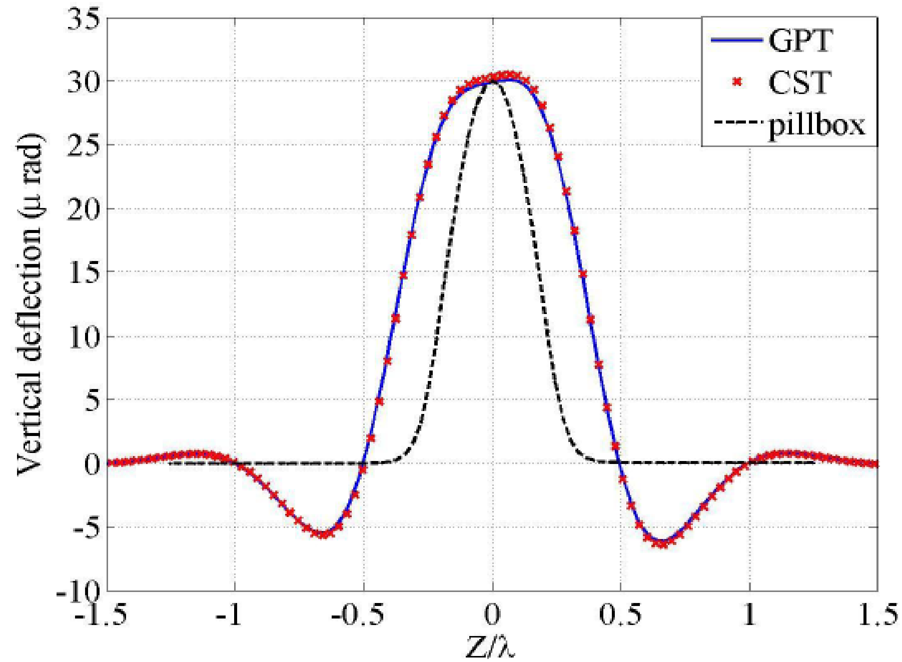


Vt=0.5MV
E=7GeV

Courtesy to Dr. Shahid Ahmed in CASA, JLab

Effect of RF kick/tilt due to LOM /HOM Couplers is very small to the reference particle with “zero” crabbing phase.



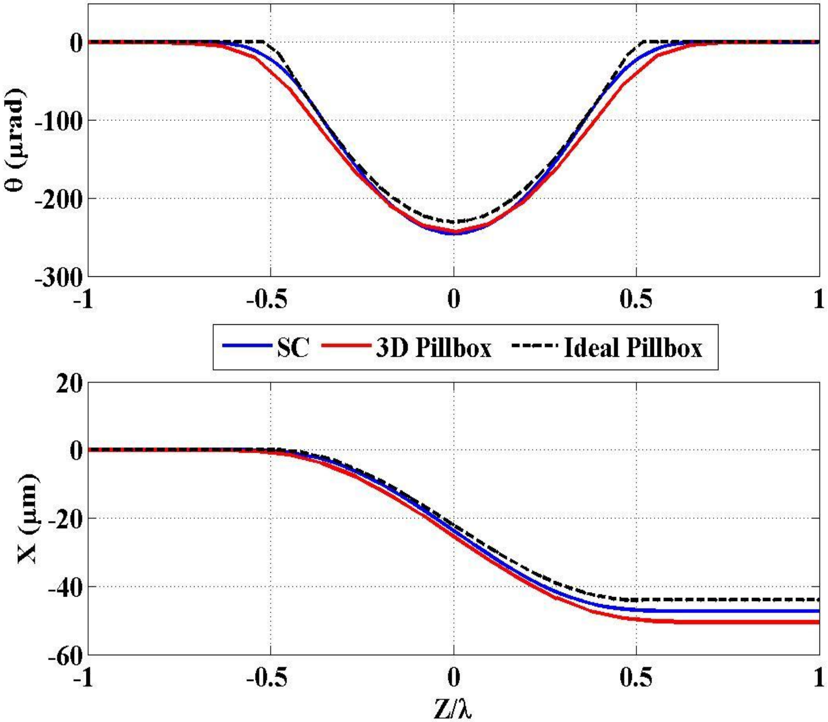


Non-Zero Residual Orbit Offset for Reference Phase

The deflection and the displacement at the exit of a thick ideal pillbox cavity are expressed as follows.

$$x_f = x_0 + \frac{L}{2}\left(x_0' + x_f'\right) + \frac{q_e V_{def}}{k E_b} Sin\phi$$

$$x_f' = x_0' + \frac{q_e V_{def}}{E_b} Cos\phi$$



Note: $\varphi_{ref} = 90^o$

$\mathbf{x_0 = 0,\ x'_0 = 0,\ V_{def} = 5.06\ MV,\ E_b = 11\ GeV}$

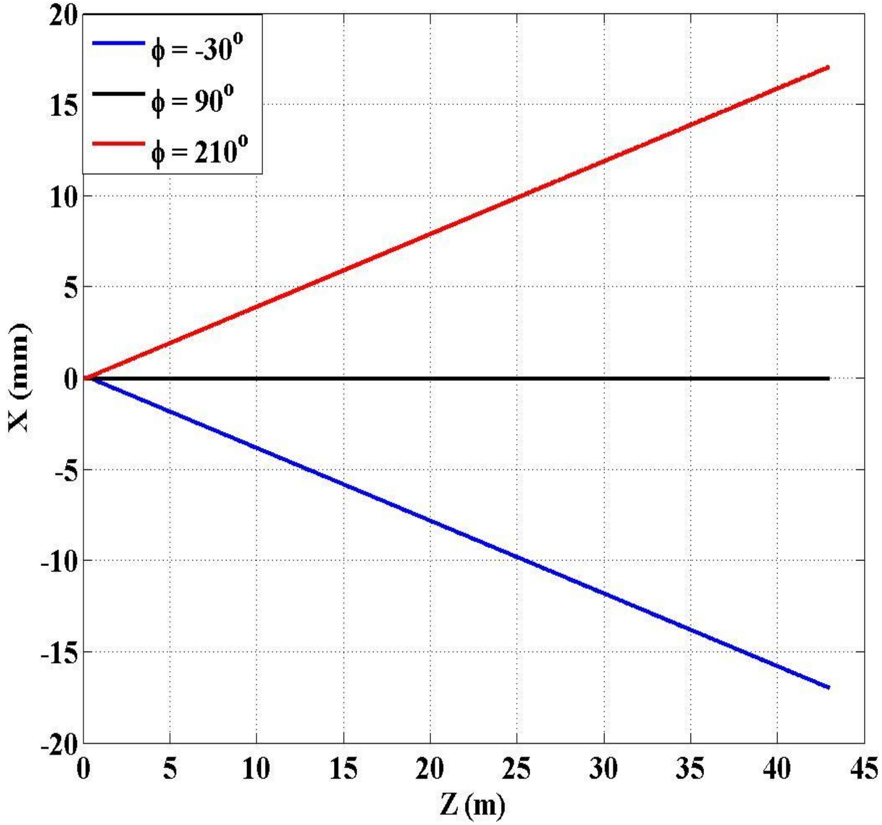
Simulation Results (X):

44 µm (Ideal Pillbox) : comparable to analytical value 43.97 µm.

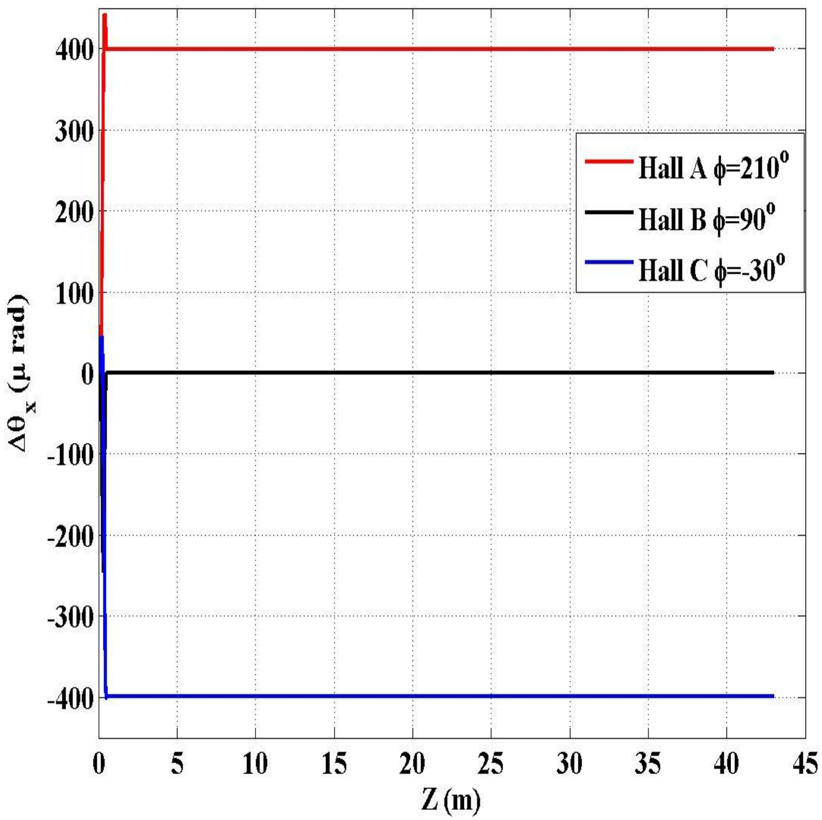
47.3 µm (SC), 50 µm (3D Pillbox) : (7-13)% of the ideal pillbox cavity.

Displacement & Deflection @ Lambertson Magnet

Displacement



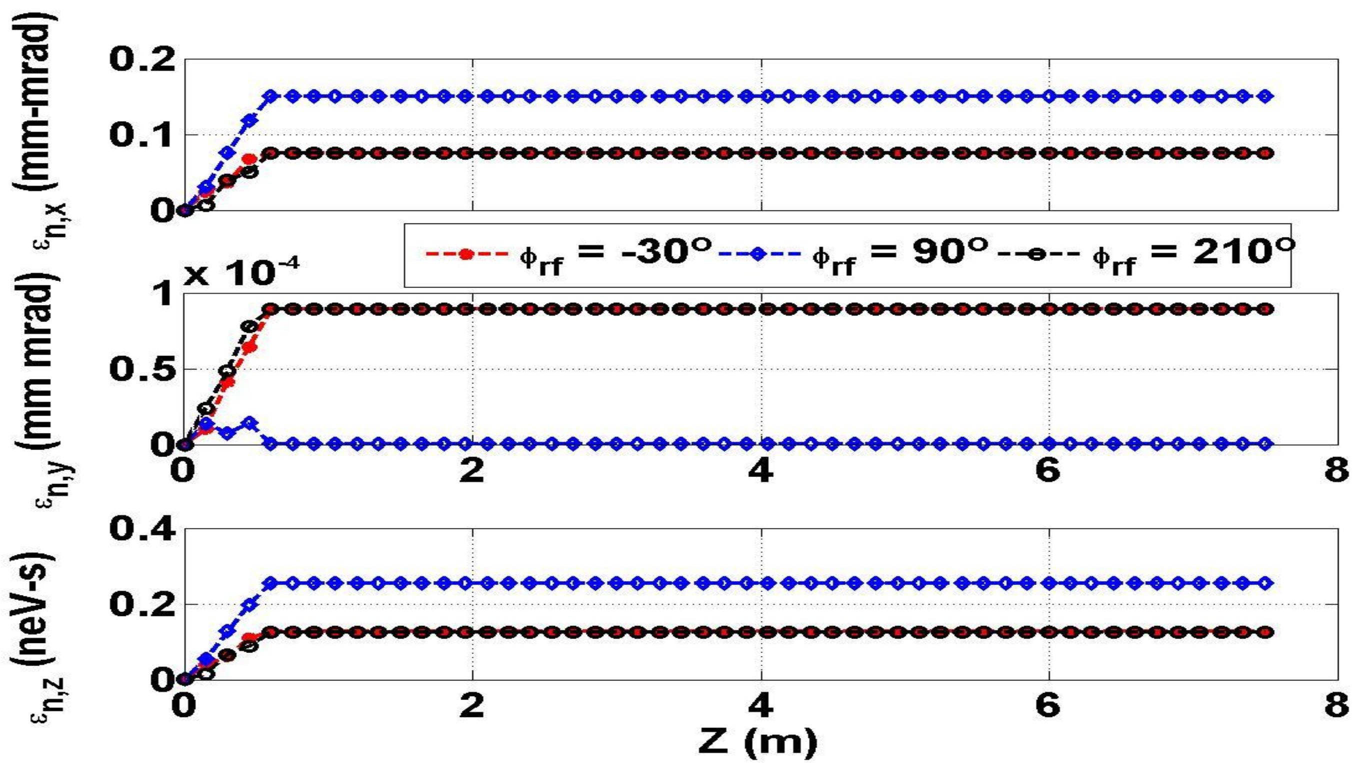
Deflection



Noteworthy points:

- **Three distinguishable tracks**
- **Non-linear effects vanish**

Normalized RMS Emittance

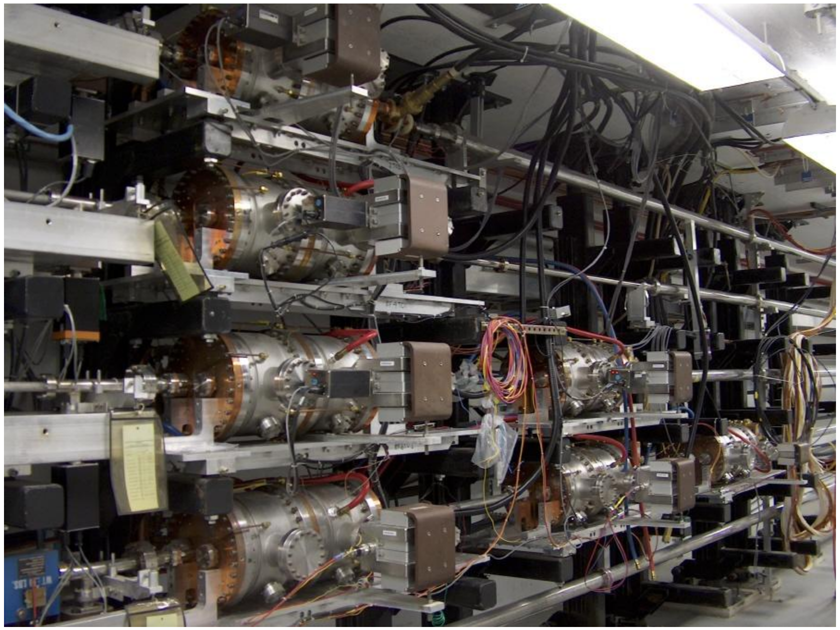


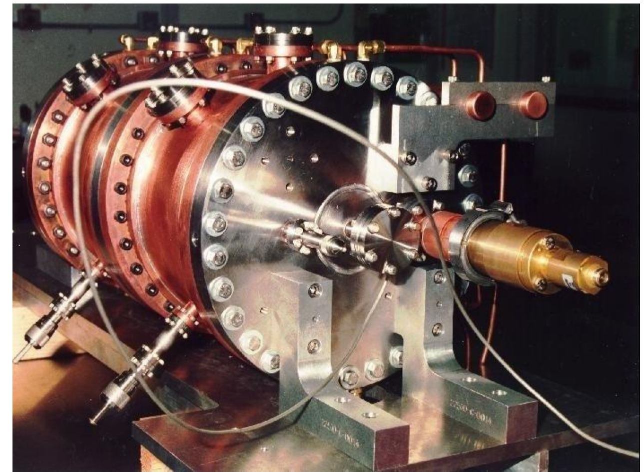
For uniform distribution corresponding to $\varphi = \varphi_{ref}$:

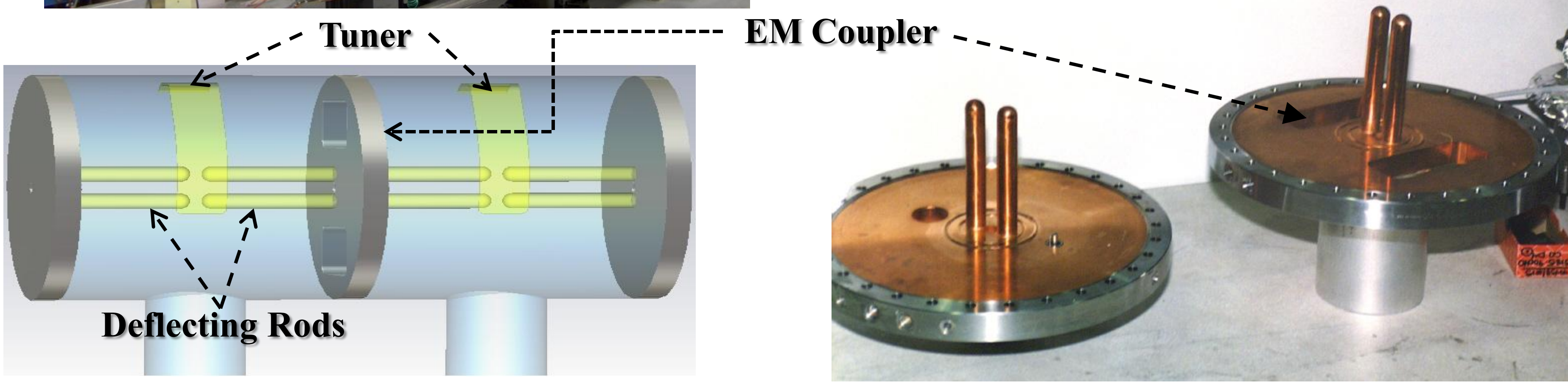
$$\varepsilon_{\mathrm{n,\,rms}} = \frac{q_e V_{def}}{4\sqrt{3} m_e c^2} k r_b l_b = 0.15 \text{ mm-mrad}$$ **agrees with simulation**

$\varepsilon^{def}_{\mathrm{n,\,rms}} = 0.5 \times \varepsilon^{ref}_{\mathrm{n,\,rms}}$; as deflecting gradient is half.

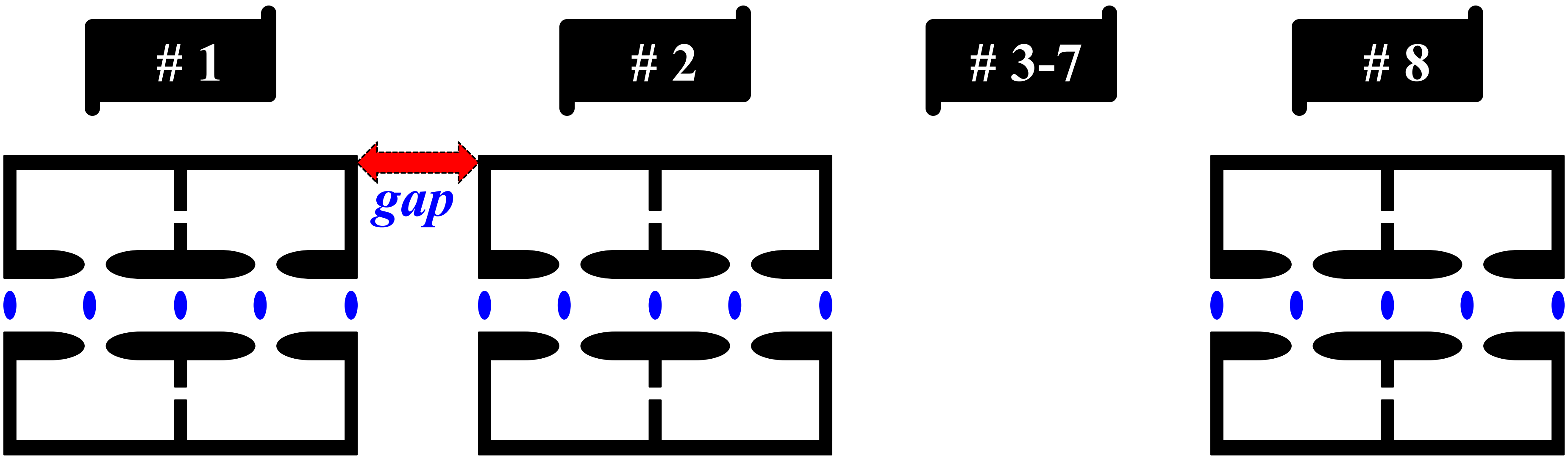
Normal Conducting Cavity







8-Cavity Arrangement



Cavity Length = 601.2 mm @ f = 499 MHz , *c* = 3 x 10^8 m/s

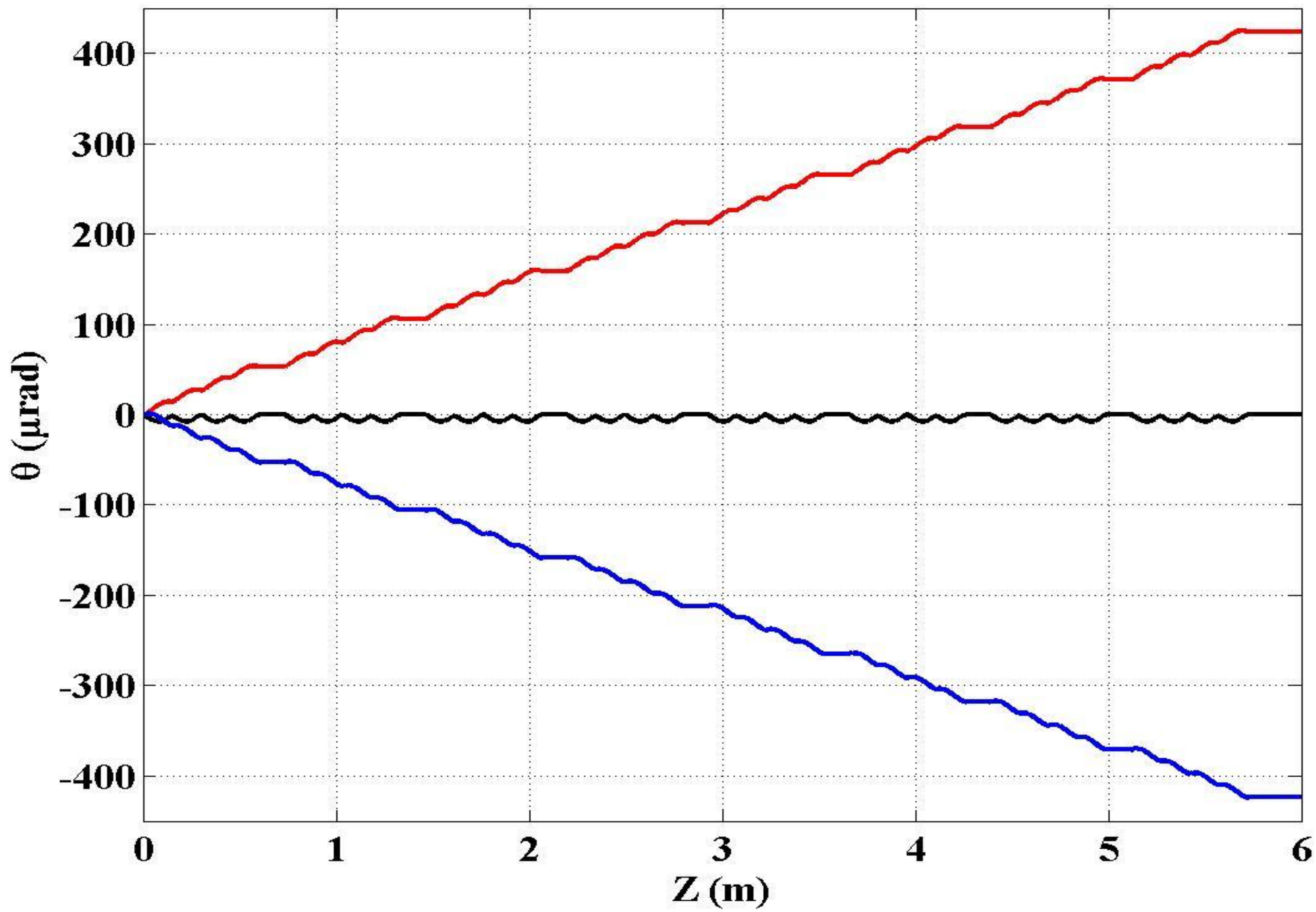
Gap = 130.06 mm

Center-to-center distance = 731.26 mm

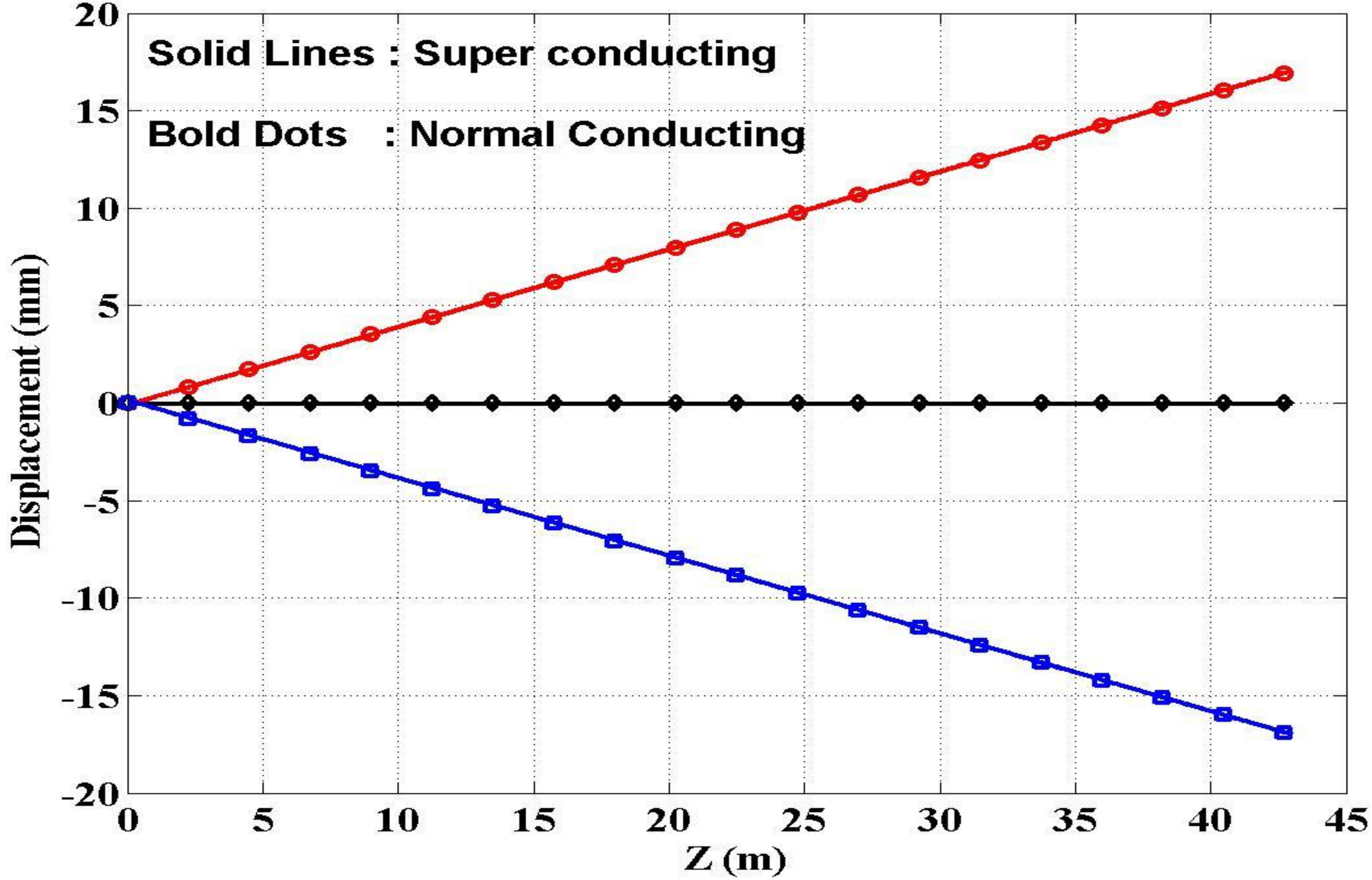
Time-Delay = (731.26 x 10^{-3})/ (3 x 10^8) = 2.44 ns

Phase Delay = 2πf x Time-Delay = 437.88 deg

Evolution of Deflection

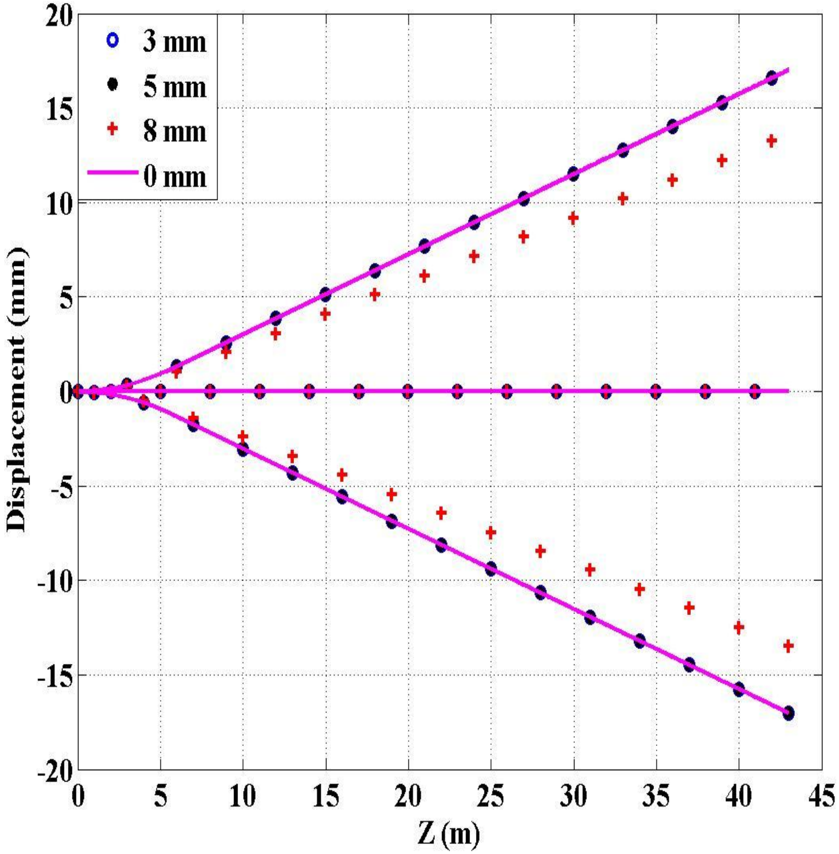


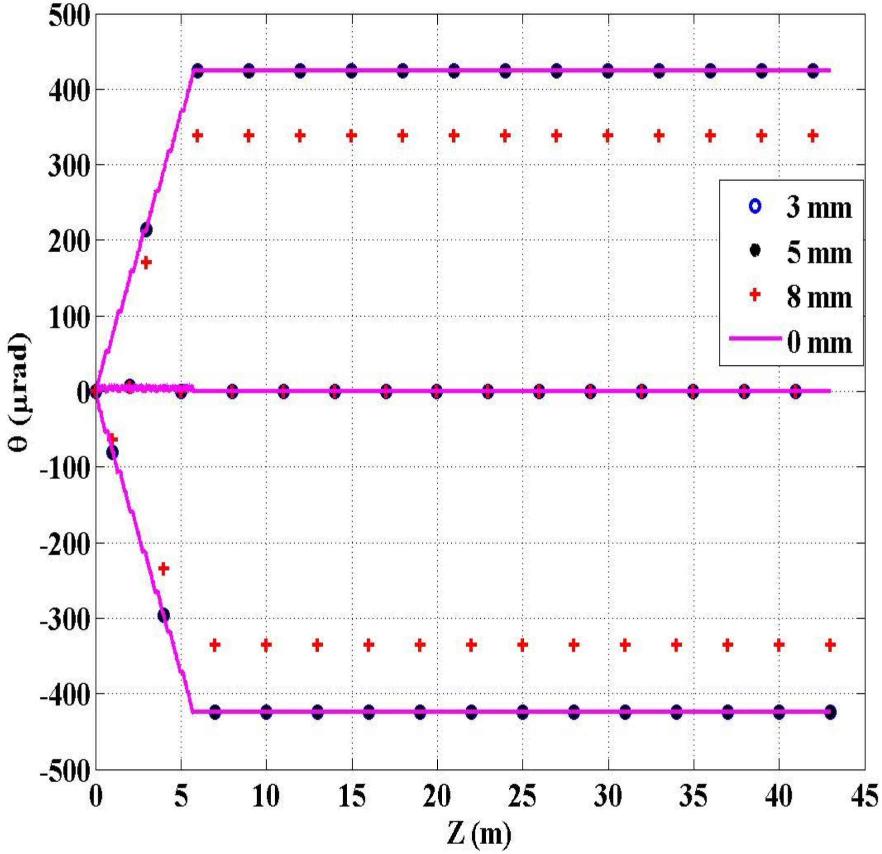
NC Versus SC



Solid Lines : Super conducting
Bold Dots : Normal Conducting
Displacement (mm)
Z (m)
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
35
40
45

Mechanical Vibration : Displacement & Deflection

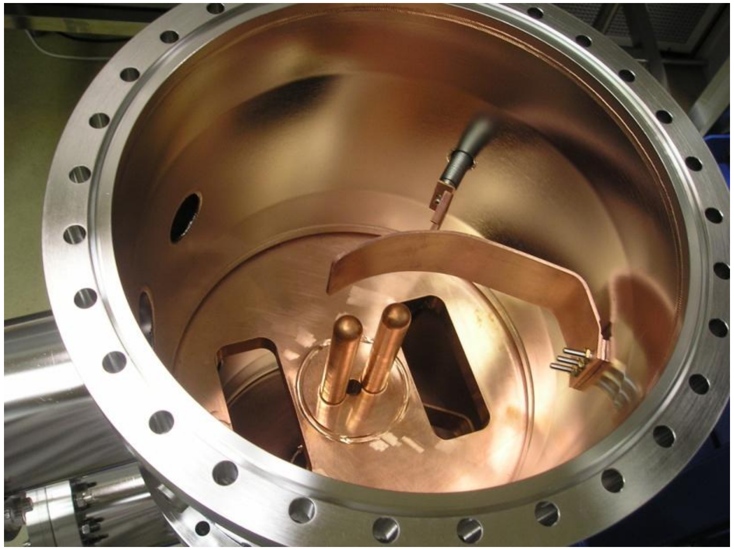




Conclusion

- One/two SC or an array of NC structures can be used to provide required vertical displacement
- Emittance dilution is small
- Array of NC cavities demonstrated stability against mechanical vibration
- Both SC and NC structures are suitable for 11 GeV RF separation in 12 GeV upgrade of CEBAF
- Results published in PAC'11 and a PRST-AB paper under review

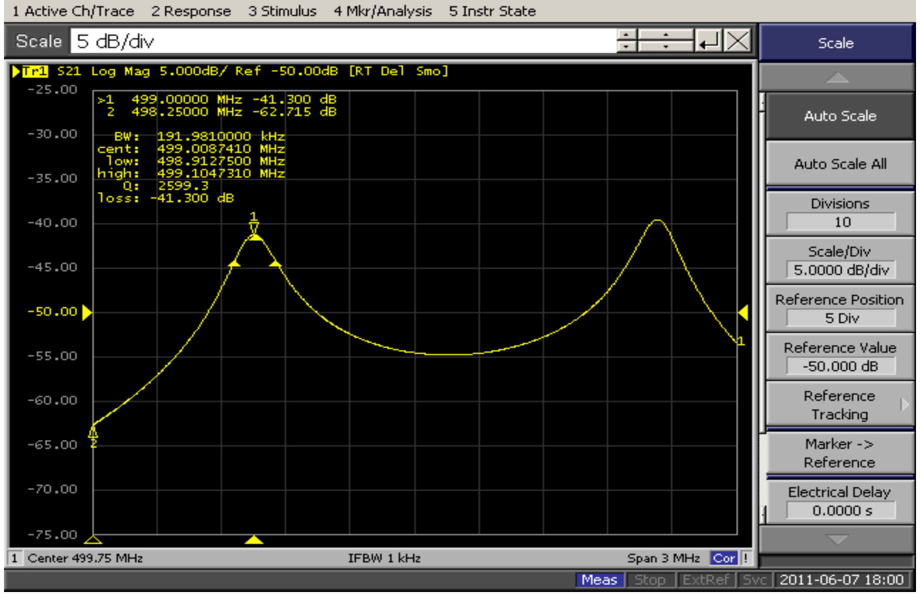
NC Deflecting Cavity High Power Test



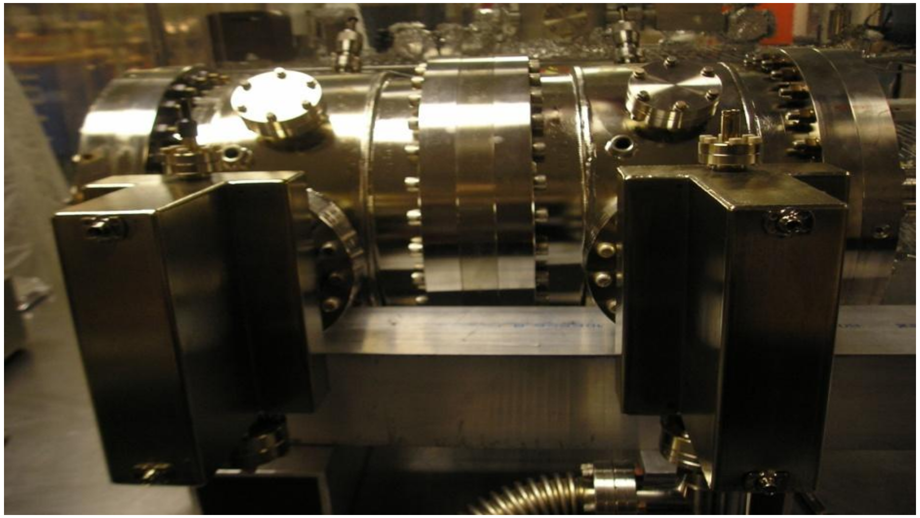
CST Simulation:

Changed body material from Cu to SS

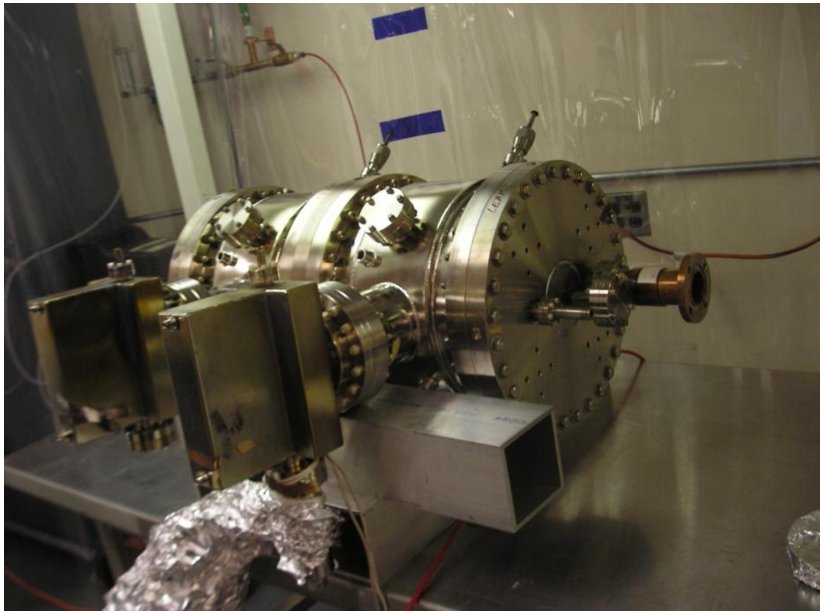
Q (~ 5200) remains unchanged confirming field concentration mainly near rods



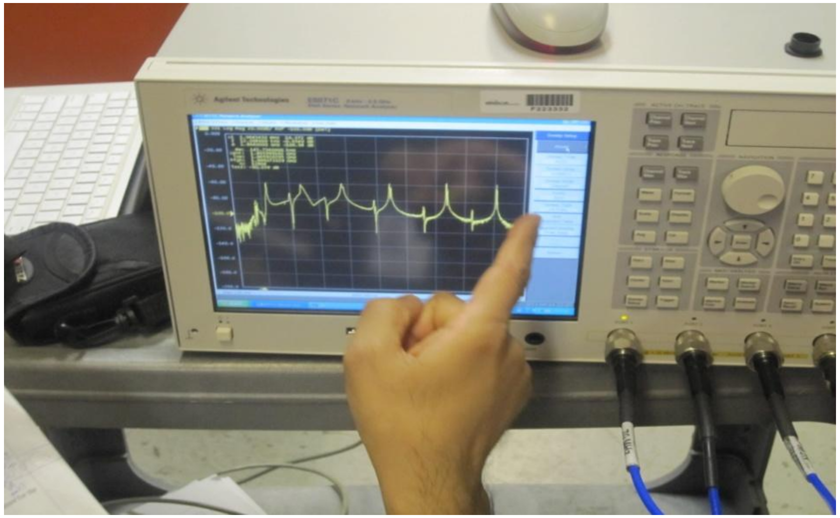
NC Deflecting Cavity …. Cont'd

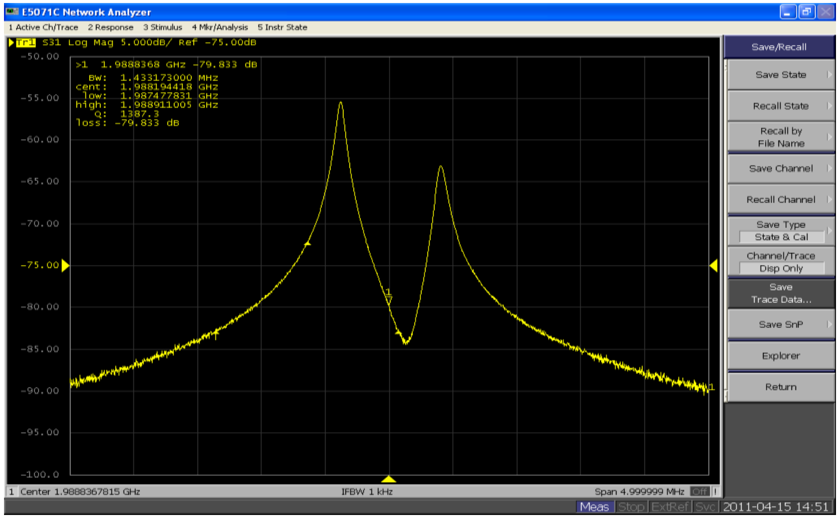


- Cavity needs under vacuum to connect ion pump
- Folks in vacuum group baked after no leak confirmed
- Gasket change confirms leak tight, leaks found on joints after baking
- No baking required
- HP test sometime end of September or early next month



HOM Measurement

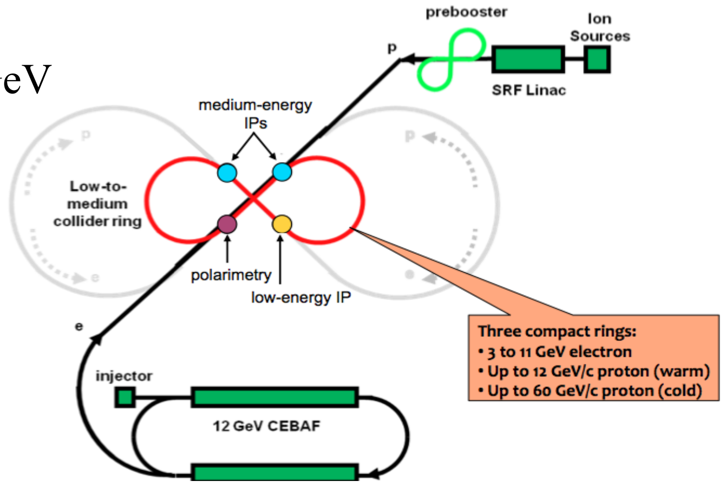




- Providing support to SRF Lab
- Helping for BBU study

MEIC Design Study

- Medium Energy Electron Ion Collider (MEIC) at JLab -- future high energy particle accelerator beyond 12 GeV upgrade of CEBAF
- Utilize existing polarized electron source complex with 12 GeV upgrade + new ion complex (light to medium ions)
- Collision frequency of 750 MHz with small charge per bunch and large crossing angle
- Increased beam stability and high luminosity



Parameters	MEIC	KEKB	PEPII
Beam energy E_b (GeV)	60/5	8/3.5	9/3.1
Collision freq (MHz)	748.5	509	238
Circumference (m)	1000	3016	2200
h (harmonic no.)	2500	5120	3492
K_B (# of bunches)	2500	5120	1658
Particle/bunch N_e (10^{10})	0.416/2.5	1.4/3.3	2.6/5.6
Bunch length σ_l (mm)	10/7.5	4/4	10/10
Total current I (A)	0.5/3	1.1/2.6	0.99/2.14
Rad. power P_{rad} (MW)	6	4/2.1	3.6/2.4
SR loss/turn (MeV)	2	3.5/0.81	3.58/1.14
RF voltage (MV)	9.0	10-20/5-10	18.5/5.9
Energy spread σ_E (10^{-4})	3/7.1	6.7/7.1	
Norm. hor. emit. ϵ_x^n (μm-rad)	0.35/54	123/281	390/850
Norm. vert. emit. ϵ_y^n (μm-rad)	0.07/11	2.5/5.6	15.8/33.5
Hor. beta-star β_x^* (cm)	10	33	50/37.5
Vert. beta-star β_y^* (cm)	2	1	2/1.5
Luminosity per IP (10^{33} cm^{-2} s^{-1})	5.6	10	3

- Beam Dynamics and Instabilities in MEIC Design
- Impedance Budget for MEIC
- Study of Electron Cloud Effect for MEIC
- Crab Crossing Studies

Publications: 2-IPAC'11, 2-PAC'11

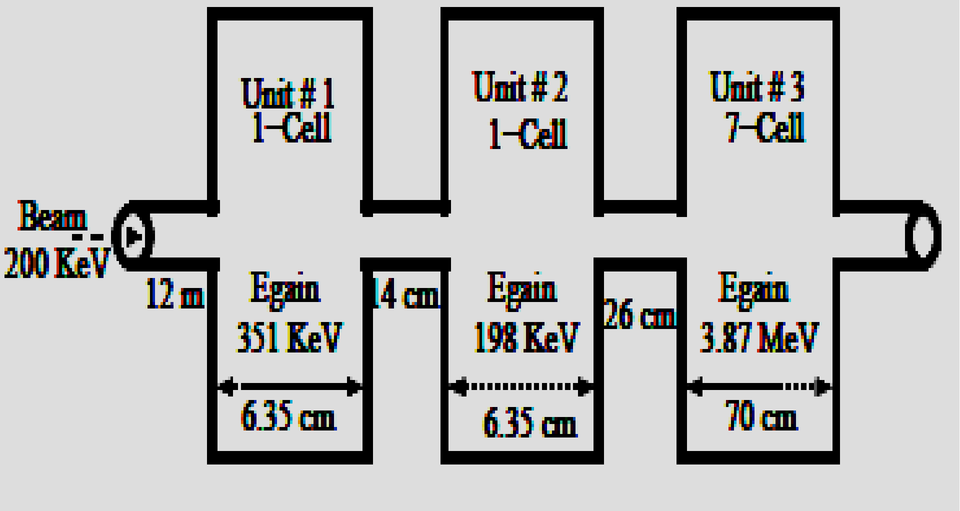
More Activities

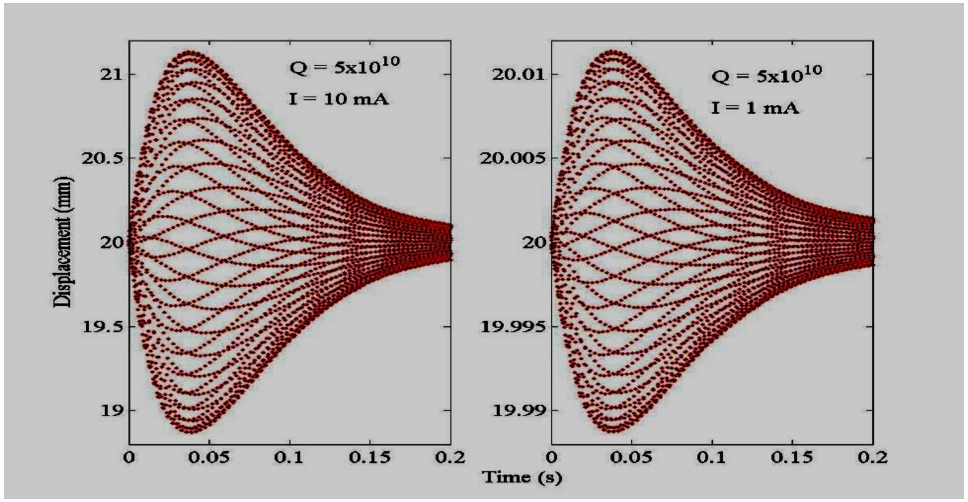
Beam Break-up (BBU) Studies:

- CEBAF injector upgrade
- Single-pass BBU – cumulative effect
- Caused due to offset of beam or elements
- Nature of effect: random

TDBBU simulations:

$$\begin{bmatrix} V_r \\ V_i \end{bmatrix}_{t'} = \exp\left(-\frac{\omega_H \Delta t}{2Q_H}\right) \begin{bmatrix} \cos(\omega_H \Delta t) & -\sin(\omega_H \Delta t) \\ \sin(\omega_H \Delta t) & \cos(\omega_H \Delta t) \end{bmatrix} \begin{bmatrix} V_r \\ V_i \end{bmatrix}_t$$





Noteworthy points:

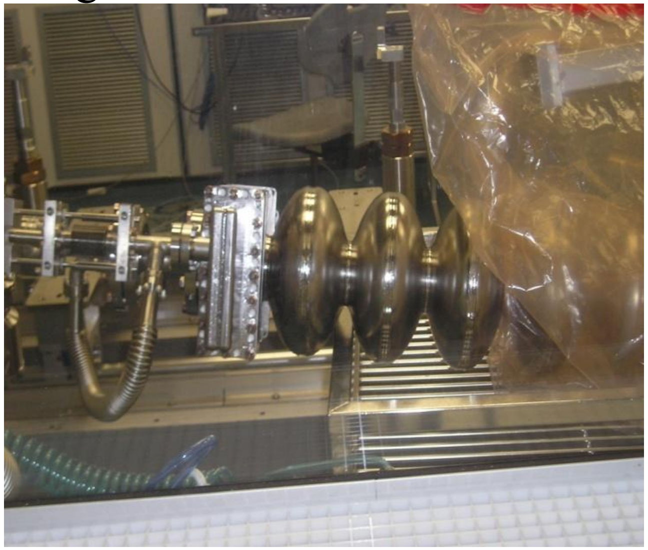
- Transient onset of beam blowup, settles down with damping time of HOMs
- Blow-up displacement amplitude varies linearly with initial offset and quadratically with current
- Stability for wide range of current 1-100 mA with Q = 5 x 10^{10}

Publications: 2-PAC'11

Plasma Cleaning of RF Cavity

Improve cavity performance

- Removal of surface contaminants causing field emission
- Removal of hydrogen from bulk Nb
- Vacuum performance by removing absorbed contaminants from surface



- Gas bottles are available
- Vertical test of cavity needs to be done
- Working on RF source
- Safety procedure and talk with Radcon folks
- Purchase a compact plasma processing chamber to test small samples

G4Beamline Software Development

Publication: PAC'11

Modeling of Space Charge

A cylindrical beam having laminar, parallel beam particles with uniform density propagating in a drift tube (i.e. no external field).

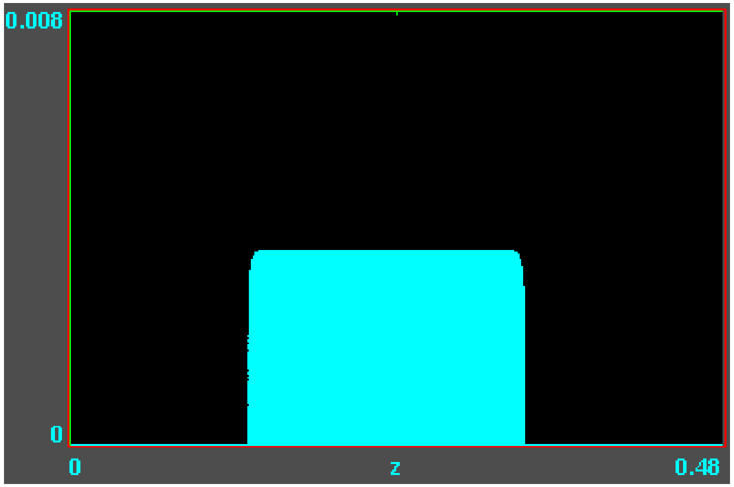
Parameters of study:

Particles = electron
Number of macro-particles = 500
Each macro-particle = 2.0 x 10^7 particles
P_z = 0.4 MeV/c
β = 0.615
γ = 1.27
Bunch shape = cylindrical
Bunch length = 200.0 mm
Initial radius = 2.0 mm

Ref: Theory and Design of Charged Particle Beams – Martin Reiser

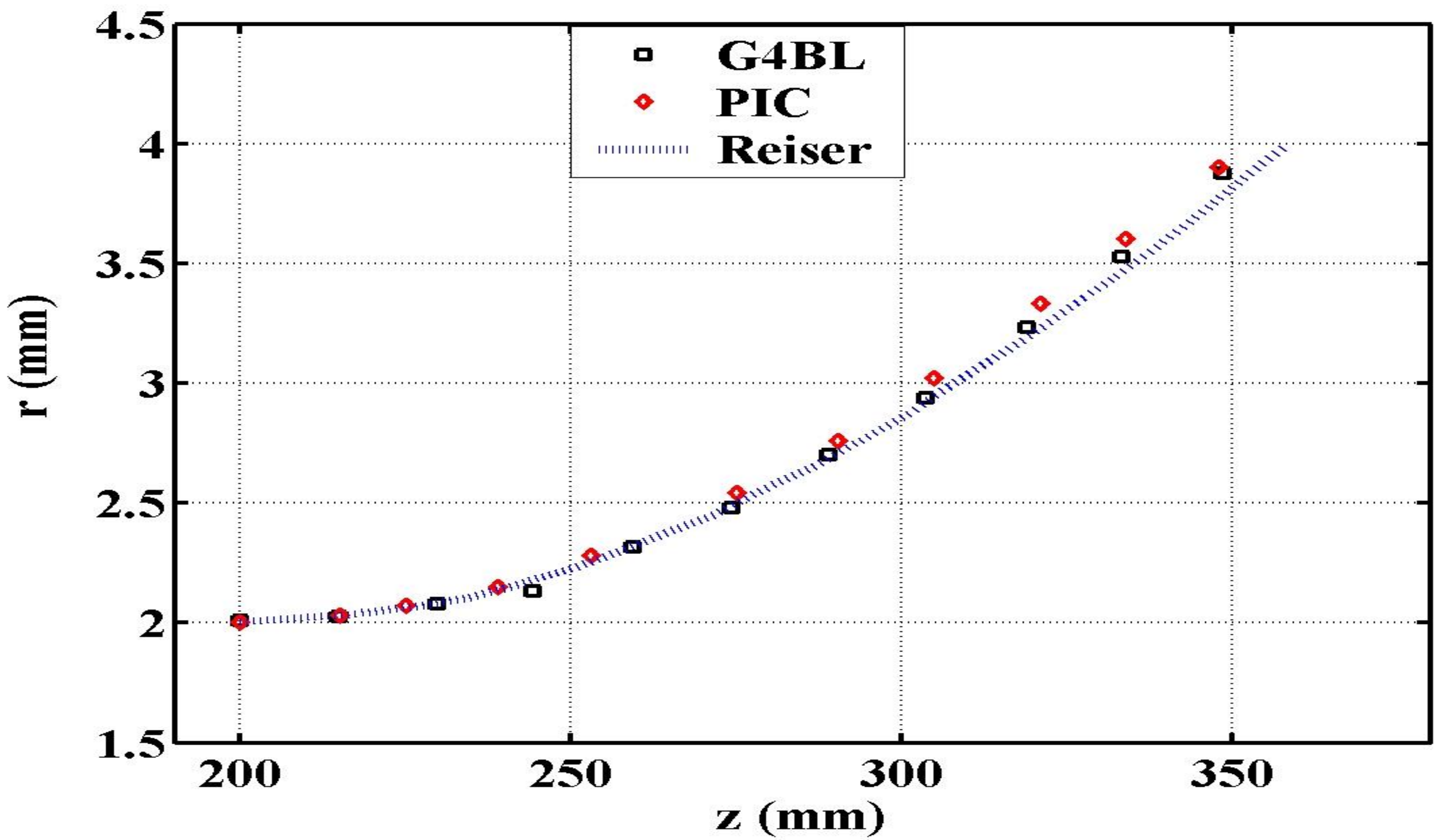
Time Evolution of Beam Envelope

PIC Simulation



Martin Reiser estimates doubling of beam size (r = 4 mm) when beam-centre reaches at z = 248 mm, PIC simulation gives 3.9 mm

Comparison of Results



PIC and G4BL Simulations agree well with the analytical result

Thanks!