RADIO FREQUENCY CRABBING SYSTEM FOR AN ELECTRON-ION COLLIDER

ALEJANDRO CASTILLA

Center for Accelerator Science

Old Dominion University

October 2nd 2012

Outline

- **Accelerator Physics at Old Dominion University.**
- **Niowave-ODU SBIR/STTR Projects Overview.**
- **Crabbing Cavities for an Electron-Ion Collider:**
  - The MEIC at 12 GeV Jlab.
  - Crabbing Crossing Concept.
  - Our Design and Results.
  - Future Work.

ODU- Center for Accelerator Science

- **Research Experience:**
  - Superconducting Radio Frequency Accelerating, Deflecting, Crabbing Structures.
  - Novel Accelerator Designs High Current, High Polarization Electron Guns.
  - Detectors for Nuclear and Particle Physics.
- **National and International Research Internships:**
  - Israel.
  - France.
  - Mexico.
  - USA.

CENTER FOR ACCELERATOR SCIENCE

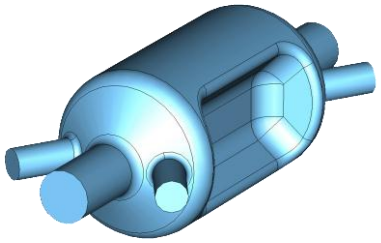
ODU- Center for Accelerator Science

- **Current Grad-Students:**
  - Subashini de Silva (SBIR-STTR/NP, HEP).
  - Mahmoud Mohamad Ali.
  - Christopher Hopper. (DOE/ NP).
  - HyeKyoung Park (SBIR-STTR/NP).
  - Michael Moore (SBIR-STTR/HEP).
  - Ahmad Sheikzada.
  - Alejandro Castilla (SBIR-STTR/NP).
  - Kirsten Deitrick (SBIR-STTR/BES).
  - Randika Gamage (SBIR-STTR/BES).
- **Current Post Doctoral Fellows:**
  - Rocío Olave (SBIR-STTR/BES).
  - Julius Nfor (SBIR-STTR/HEP).
  - Fareh Pei-Jen.
- **Current International Interns:**
  - Karim Hernandez (SBIR-STTR/BES).

CENTER FOR ACCELERATOR SCIENCE

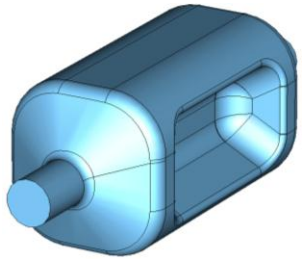
NIOWAVE-ODU SBIR/STTR PROJECTS

- **From Nuclear Physics:**
  - 500 MHz Spoke Cavity (Completed!).
  - 499 MHz JLab Deflector (Completed!).
  - 750 MHz Crab Cavity for the MEIC/JLab (Phase II).



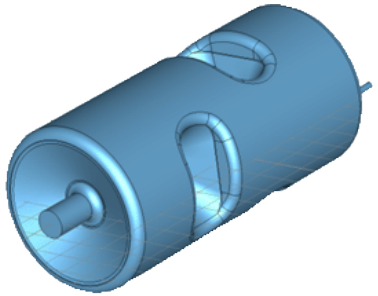
750 MHz Crab

- **From High Energy Physics:**
  - 400 MHz Crab Cavity for the LHC HiLumi Upgrade (Phase II).
  - 365 MHz Deflecting/Crabbing Cavity for Project X (Phase I, Completed).



400 MHz Crab

- **From Basic Energy Sciences:**
  - 700 MHz Multi Spoke Cavity with Cryomodule for a 4G X-Ray Source (Phase I & II).

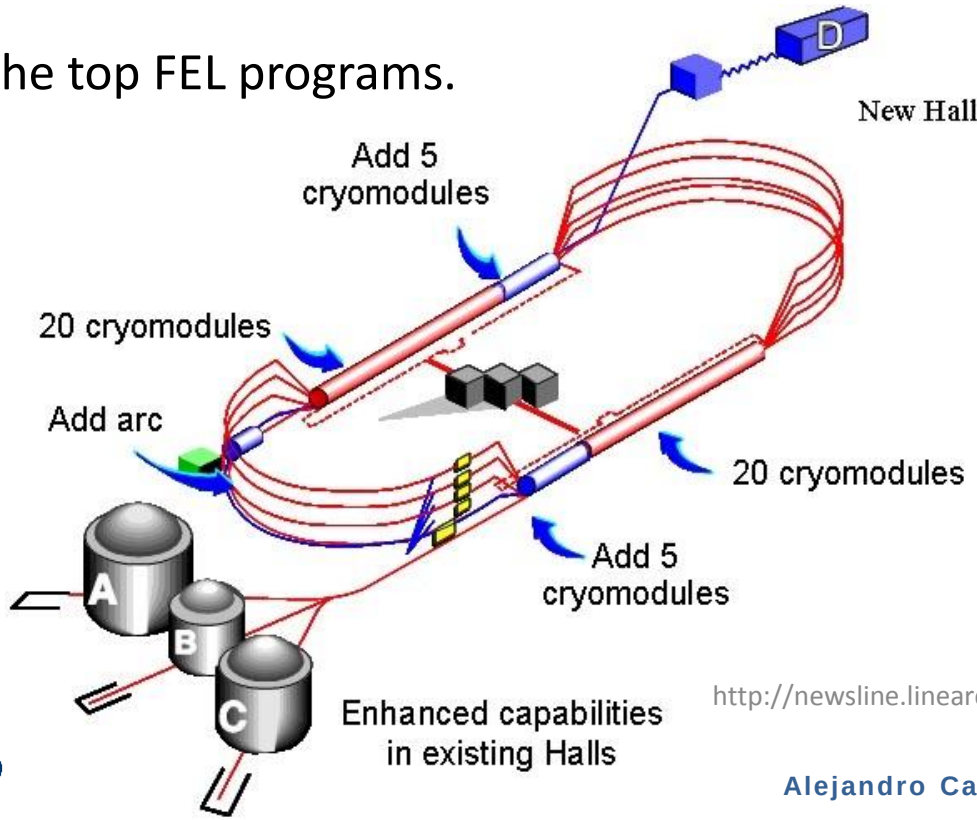


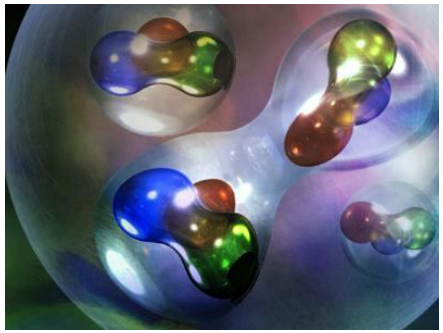
700 MHz Spoke

Jefferson Lab
Thomas Jefferson National Accelerator Facility

12 GeV Upgrade

- **Is JLab just a *Nuclear Physics* facility?**
  - A world leader in *Superconducting Radio Frequency* accelerators.
  - Designs, build and process components for facilities *around the world*.
  - One of the top FEL programs.

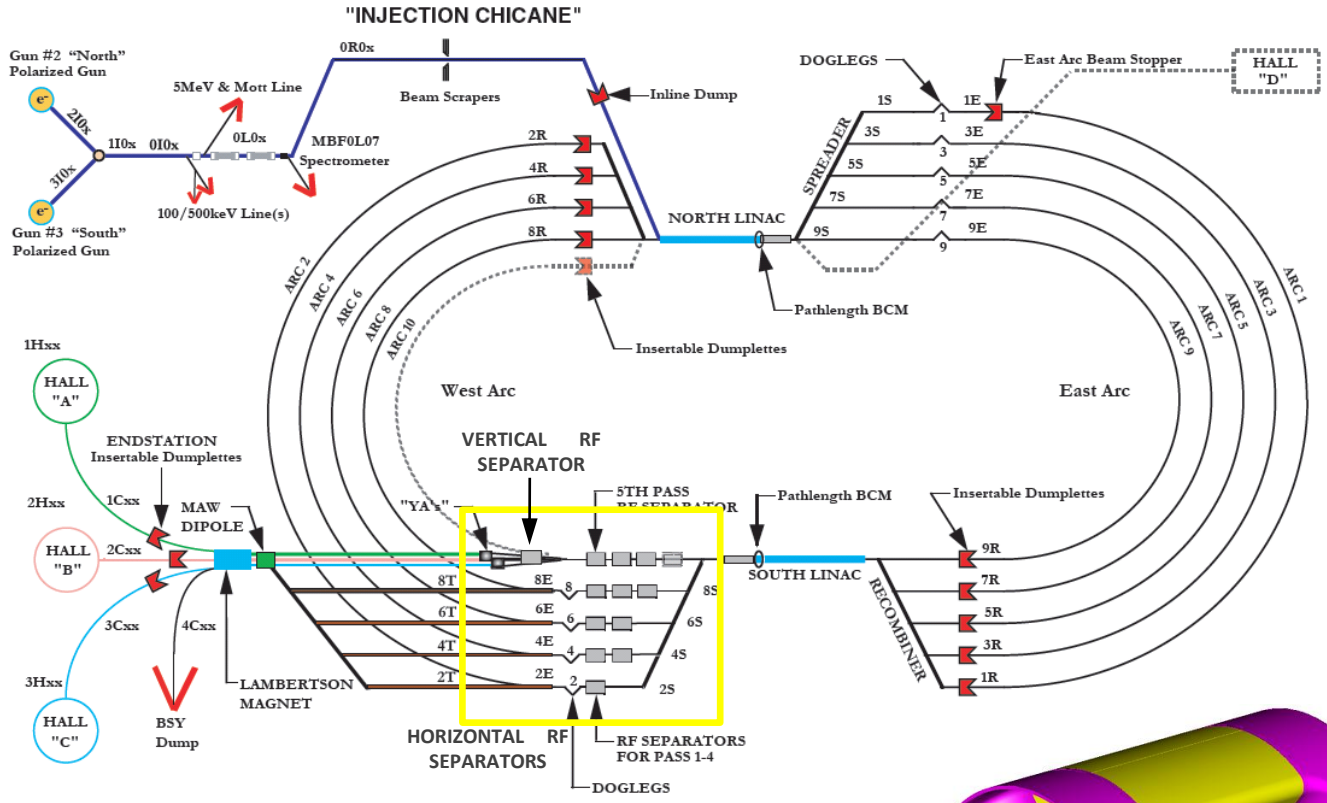


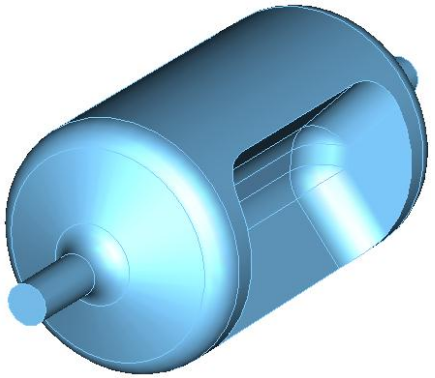


http://newsline.linearcollider.org

Jefferson Lab
Thomas Jefferson National Accelerator Facility

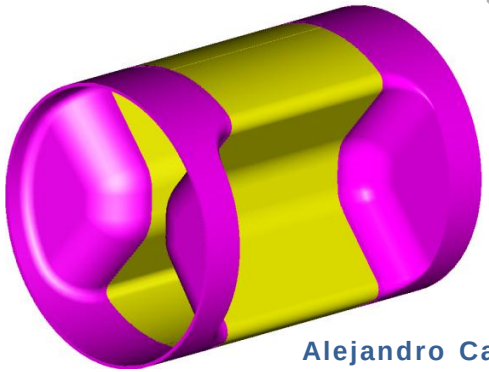
12 GeV Upgrade





*Subashini de Silva, ODU.

499 MHz Deflector*



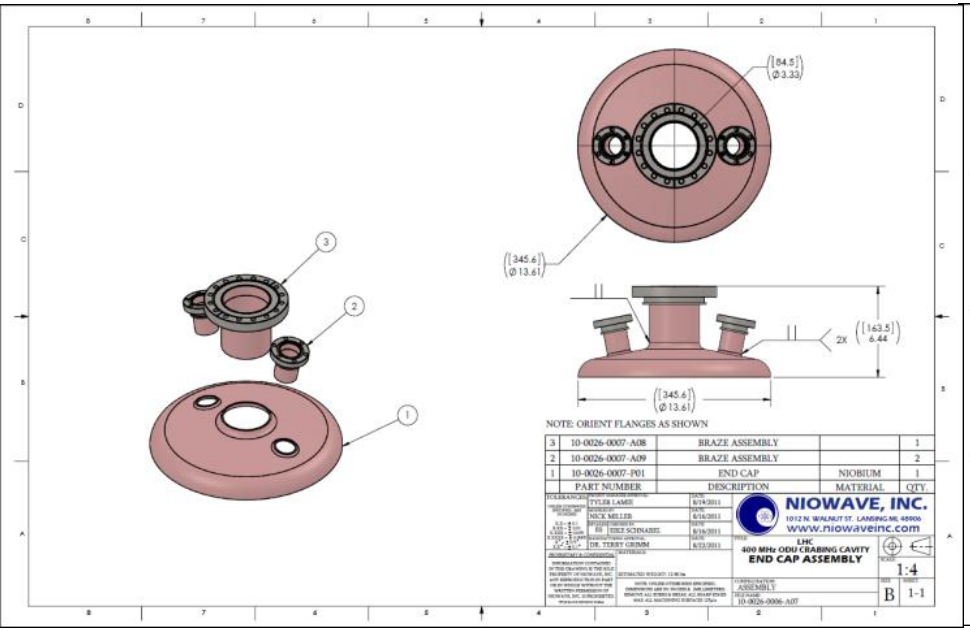
Jefferson Lab
Thomas Jefferson National Accelerator Facility

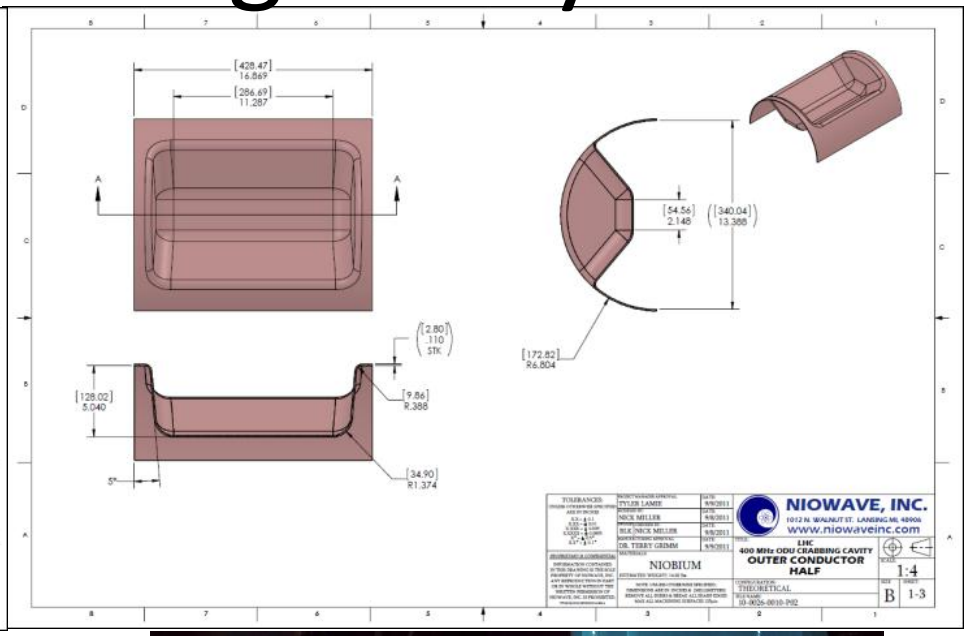
12 GeV Upgrade

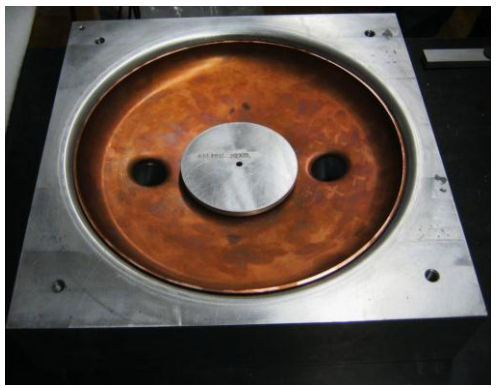
499 MHz Deflector*

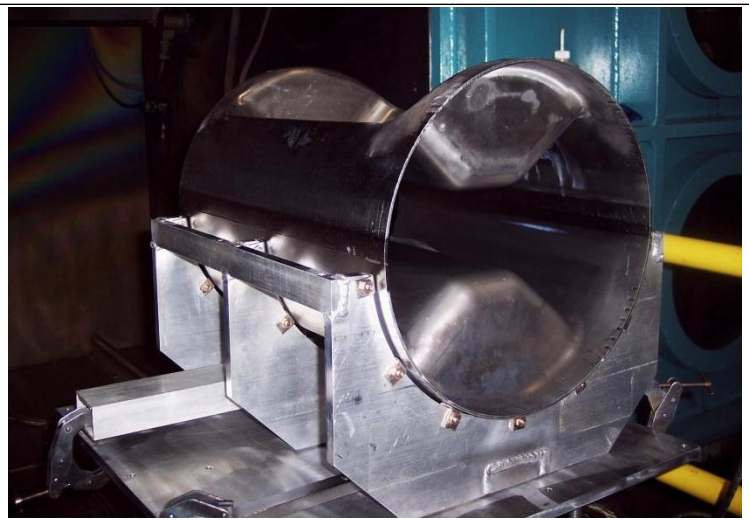
*Subashini de Silva, ODU.

400 MHz Crabbing Cavity





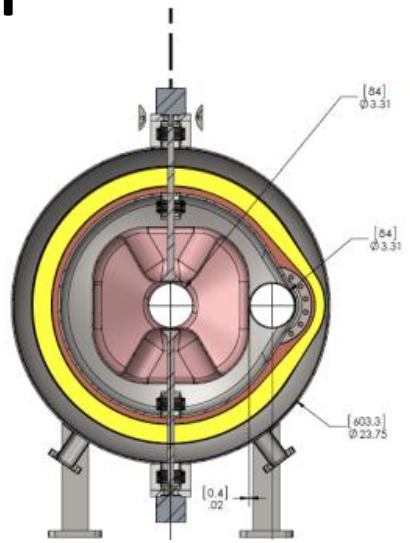


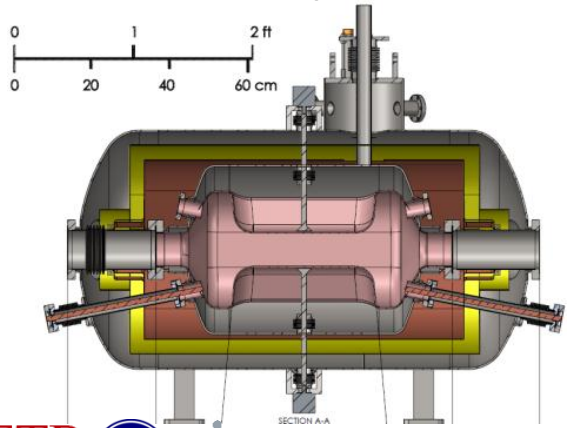


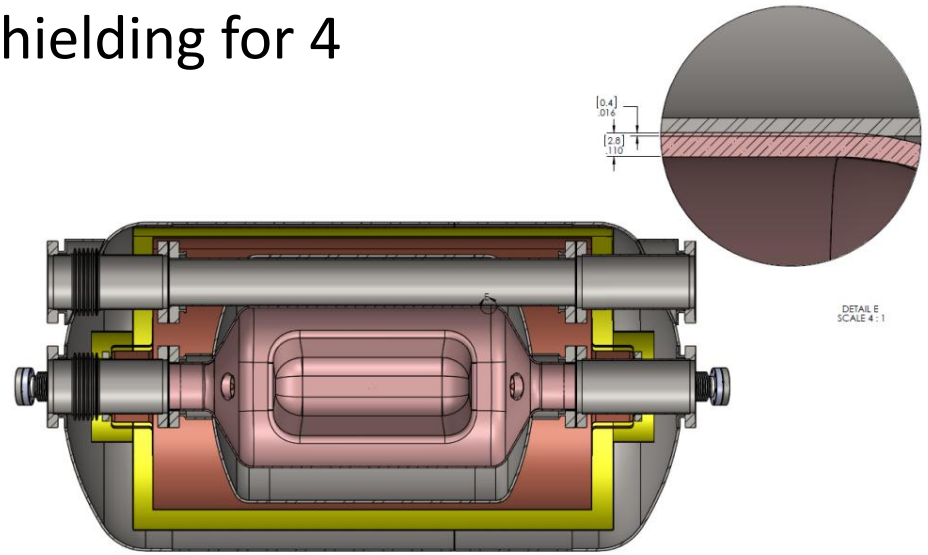
400 MHz LHC Crabbing Cavity

LHC Deflecting/Crabbing Cavity Cryomodule Design

- Power and HOM Couplers.
- Frequency Tuners.
- Physical Space Constrictions (Twin Beam Chambers 194 mm Center-to-Center).
- Horizontal and Vertical Deflection Allowance.
- Thermal and Magnetic Shielding for 4 K or 2 K Operation.

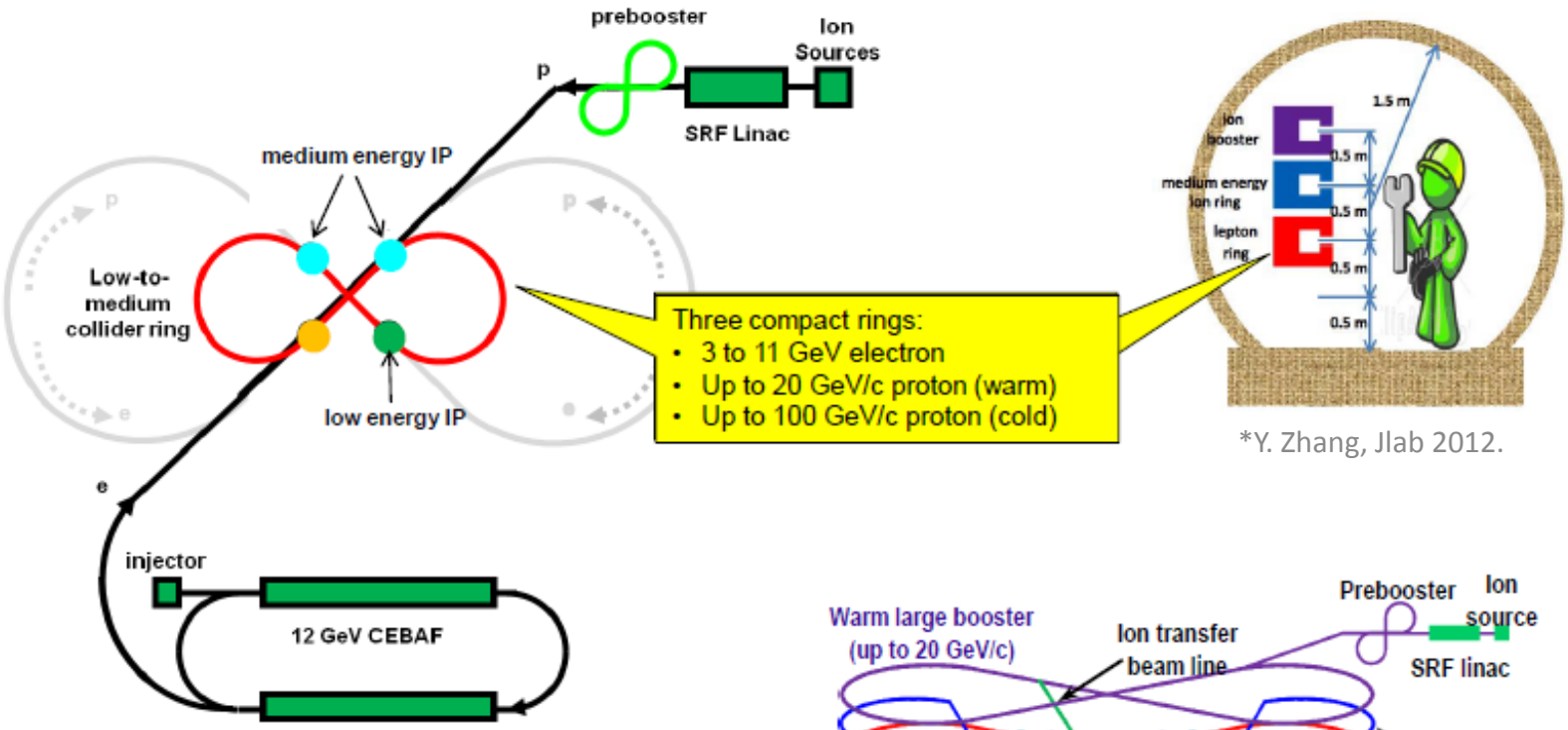




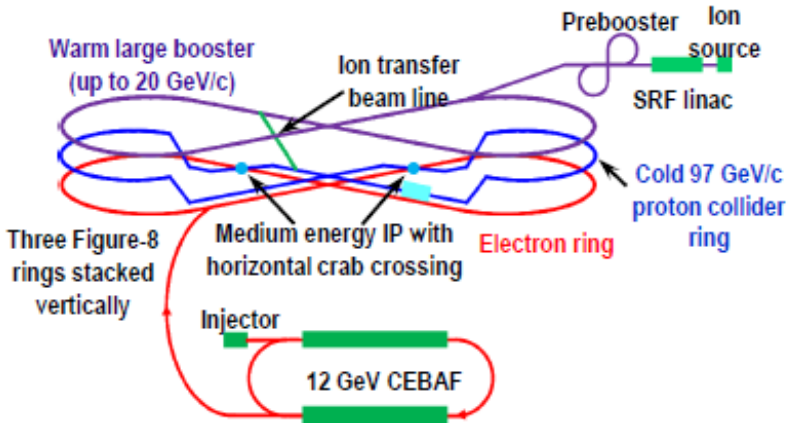


SBIR/STTR
SMALL BUSINESS INNOVATION RESEARCH
SMALL BUSINESS TECHNOLOGY TRANSFER

Jlab 12 GeV Upgrade and the MEIC*



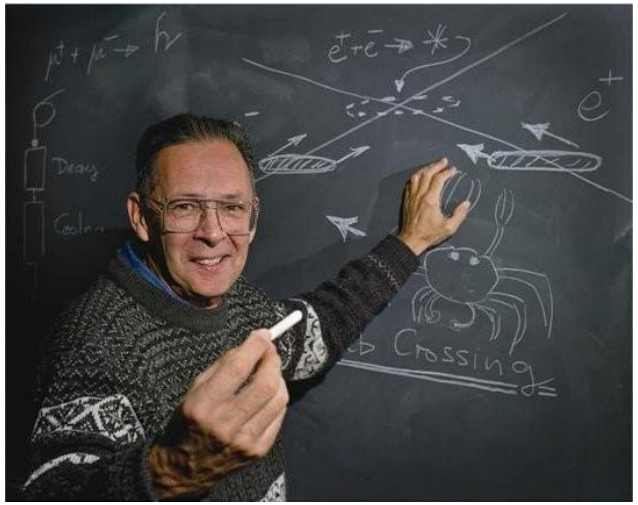
*Y. Zhang, Jlab 2012.

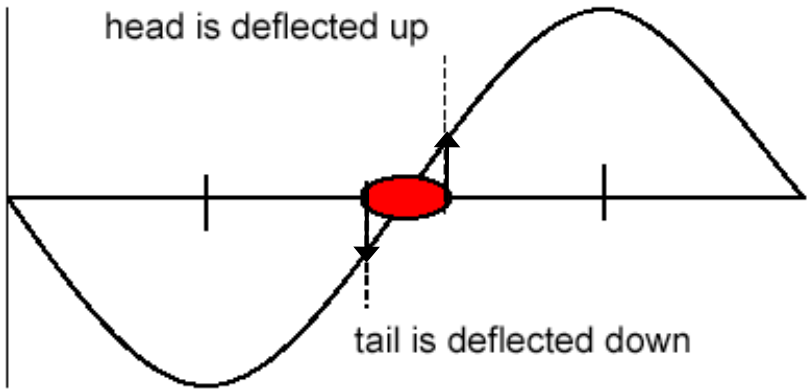


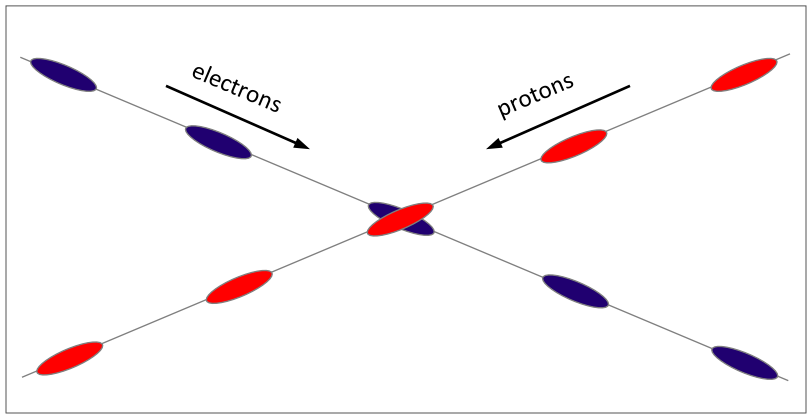
*Medium-Energy Electron-Ion Collider.

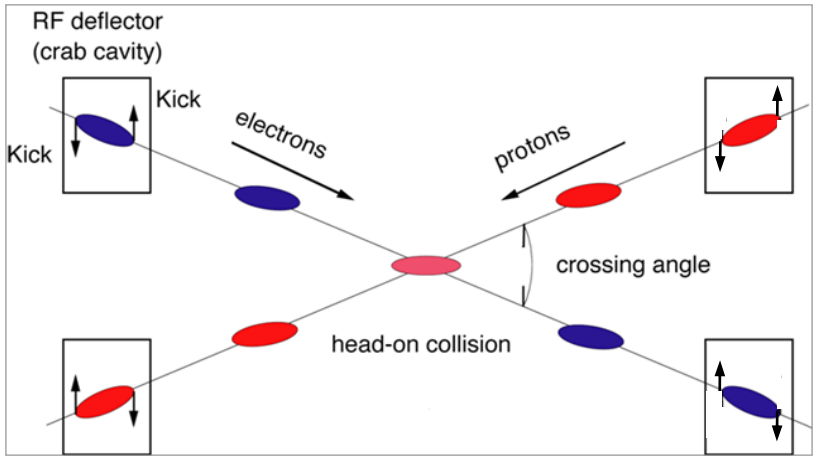
Crabbing Concept

*R. Palmer, SLAC-PUB-4707 (1988).

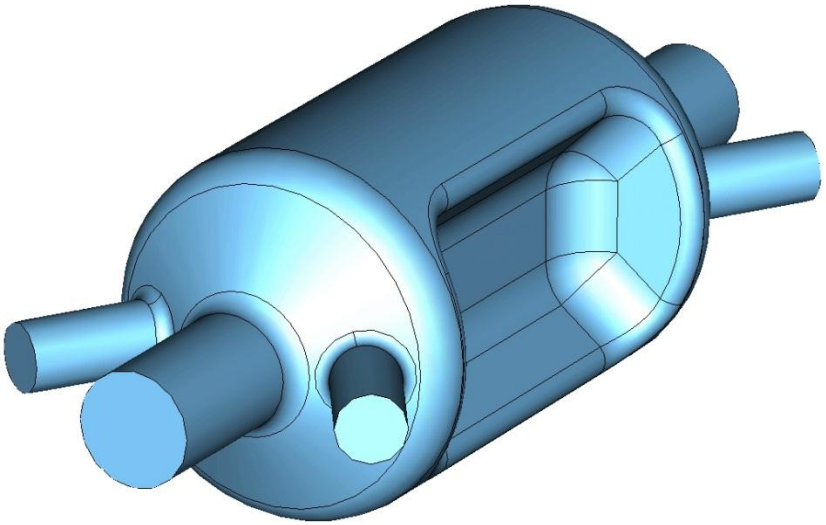


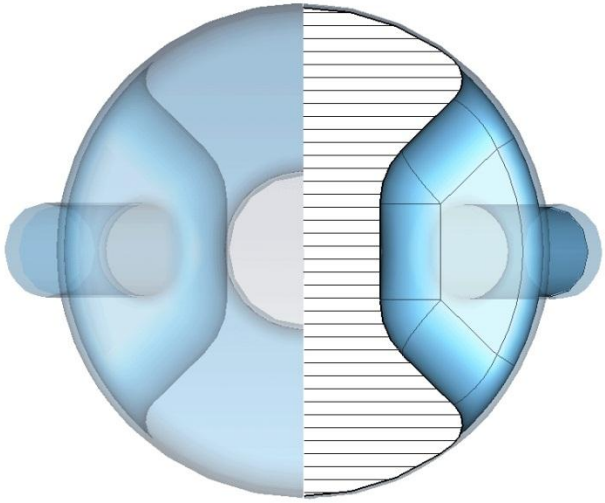






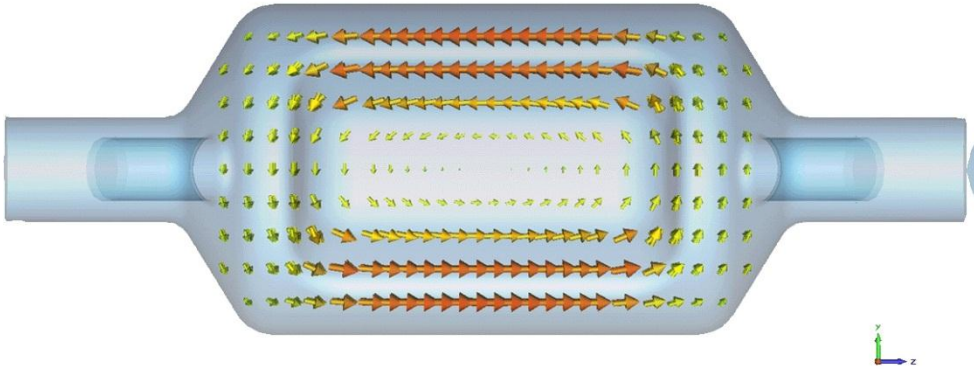
750 MHz Crabbing Cavity Design

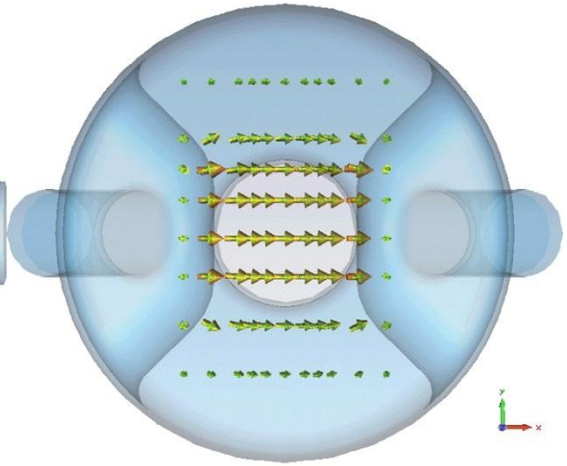




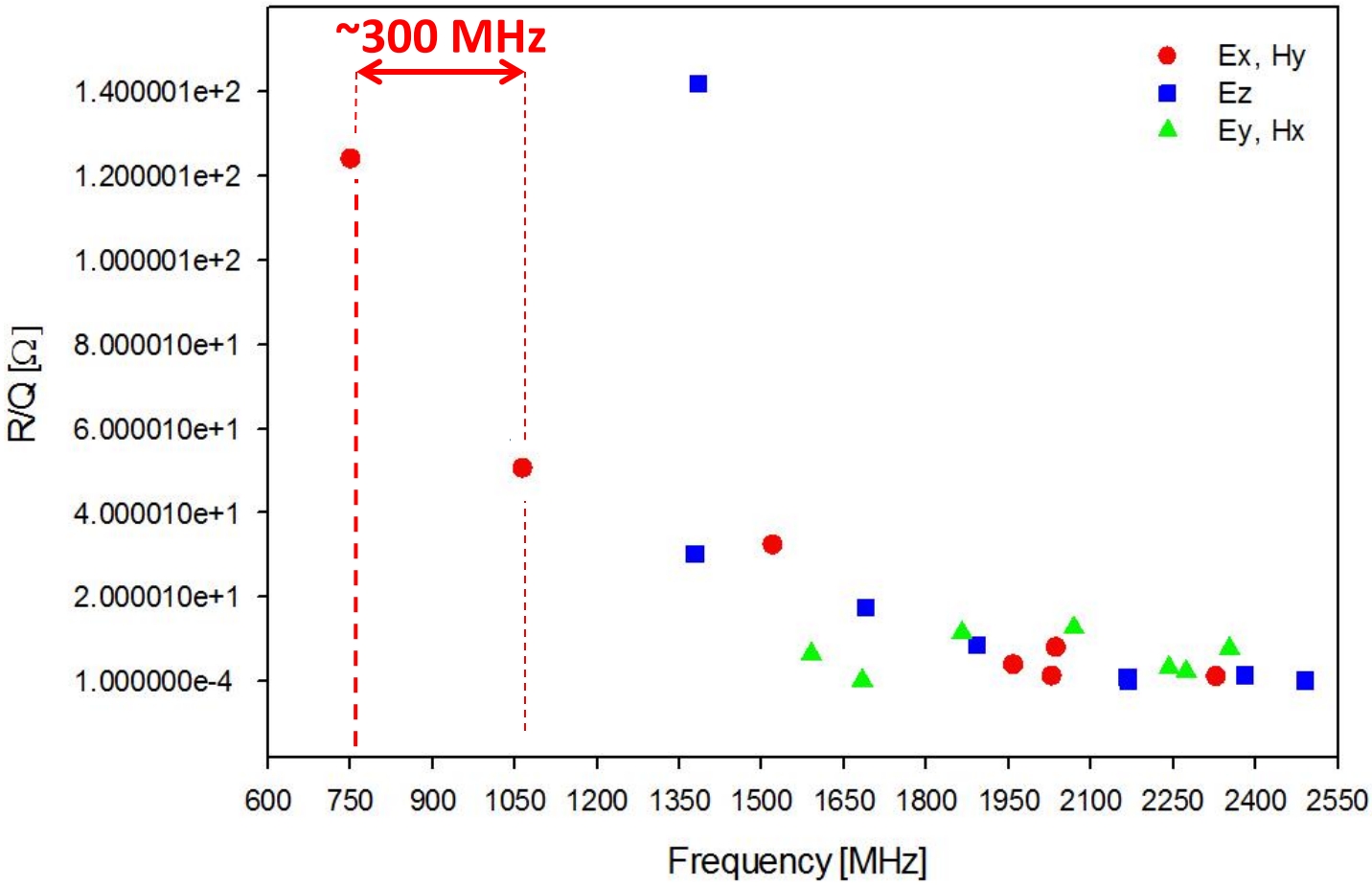
Magnetic Field

Electric Field





750 MHz CC Higher Order Modes

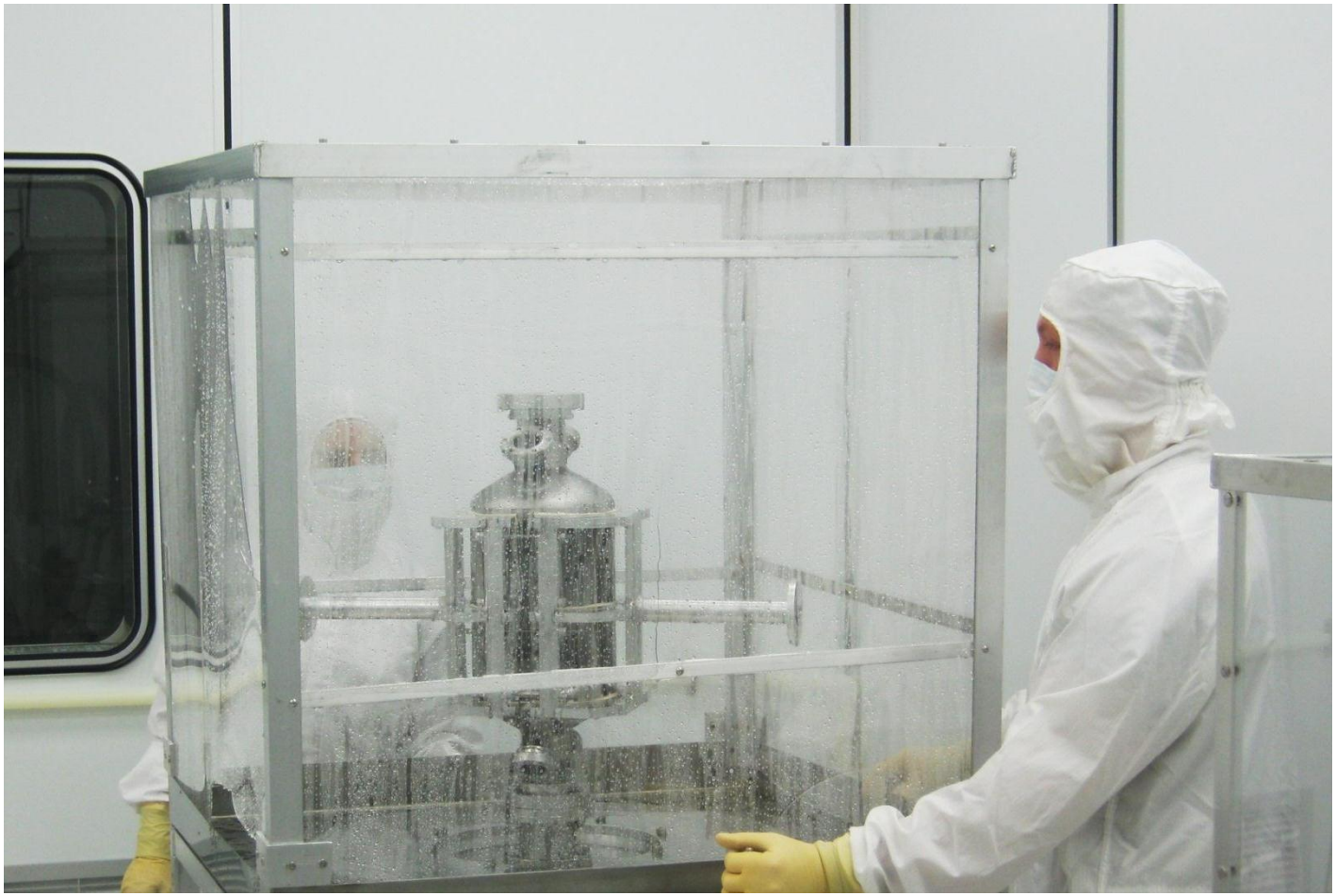


Assembling and Electron-Welding

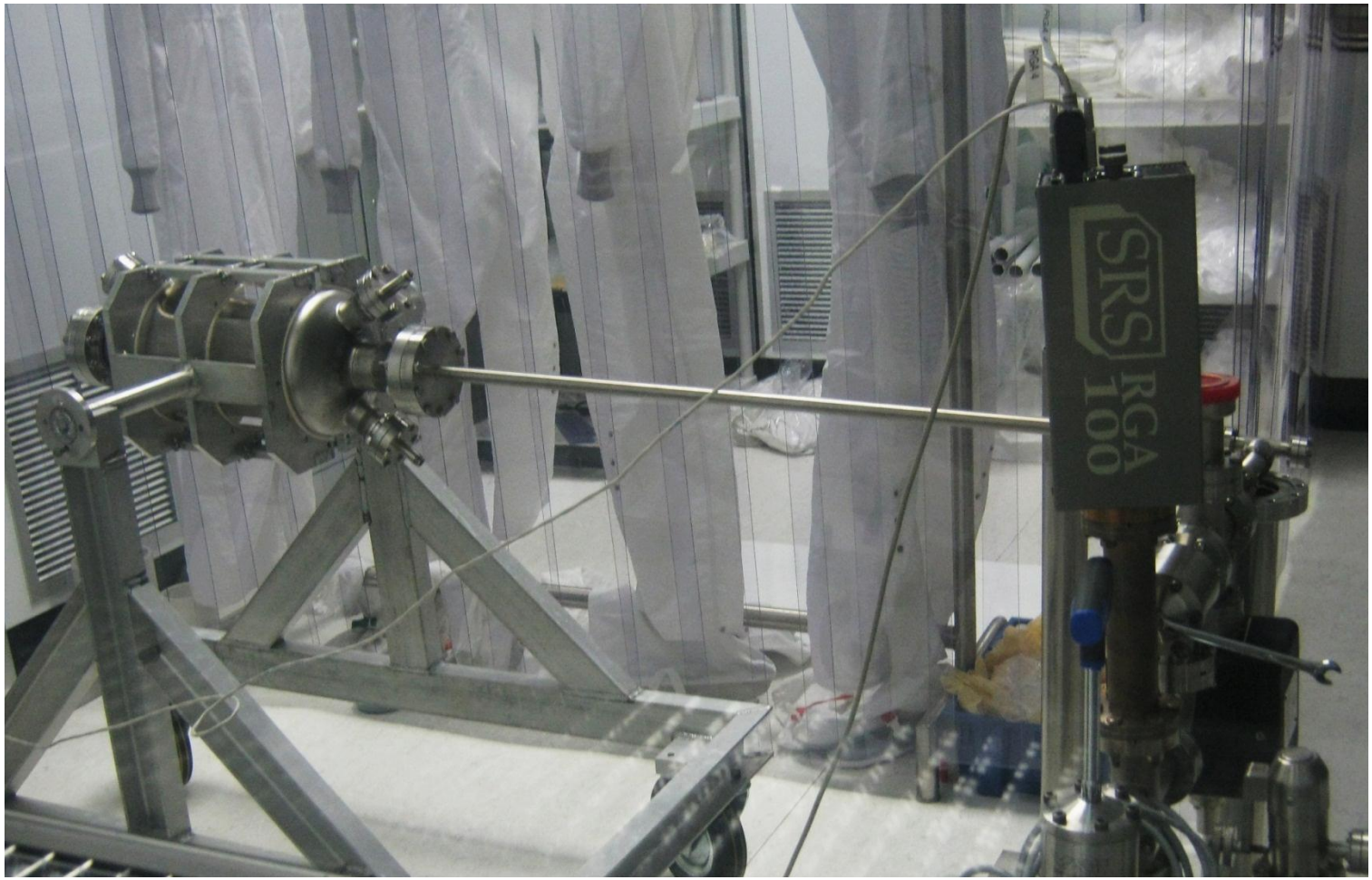
Buffer Chemical Polishing

–150 µm etch with standard BCP solution.

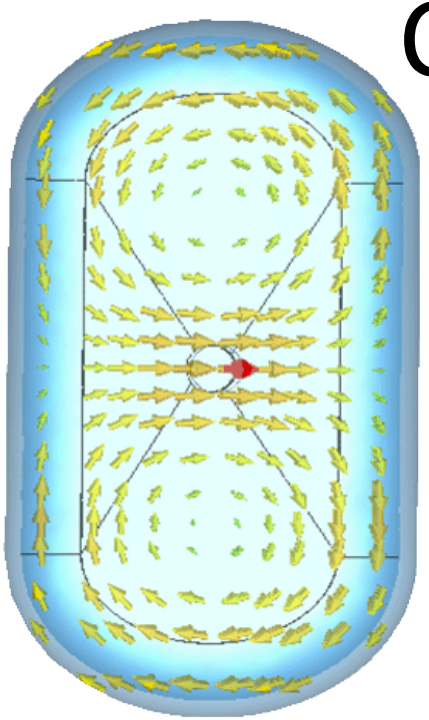
High Pressure Rinsing



After Etch Pumping Down



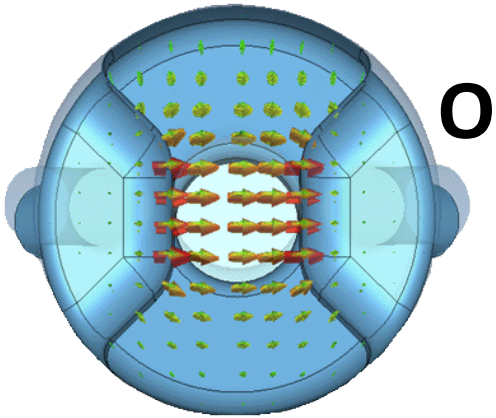
Comparing Crabs



KeK

Parameter	750 MHz	KEK[4] MHz	Units
Freq. of π mode	750.1	501.7	MHz
λ/2 of π mode	200.0	299.8	mm
Freq. of 0 mode	1350.6	~700.0	MHz
Cavity length	300.0	299.8	mm
Cavity width	190.1	866.0	mm
Cavity height	190.1	483.0	mm
Bars width	67.0	-	mm
Angle	45	-	deg
Aperture diameter	60.0	130.0	mm
Deflecting voltage (V_T^*)	0.200	0.300	MV
Peak electric field (E_P^*)	4.45	4.36	MV/m
Peak magnetic field (B_P^*)	9.31	12.45	mT
Geometrical factor	131.4	220	Ω
$[R/Q]_T$	124.15	46.70	Ω
$R_T R_S$	1.65×10^4	1.03×10^4	Ω^2

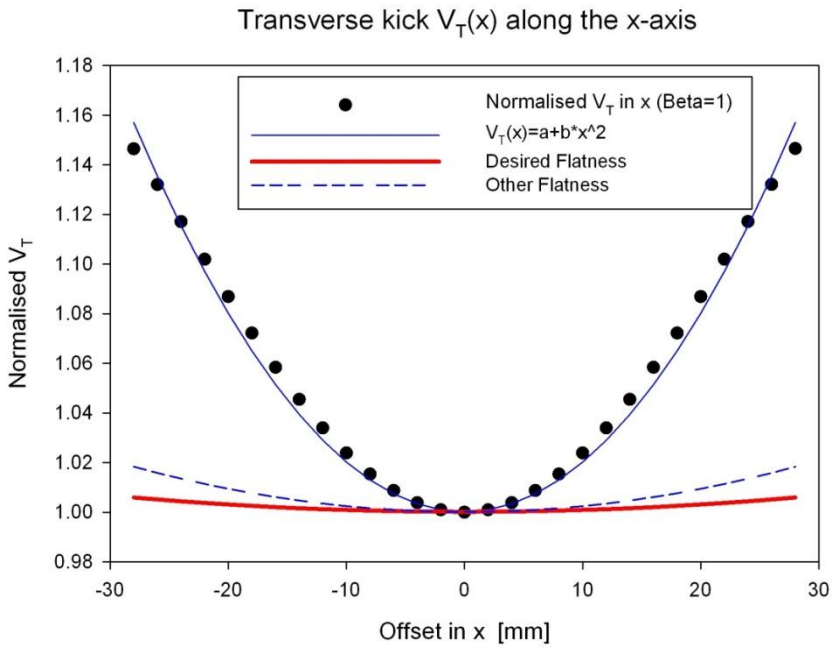
At E_T^* = 1 MV/m

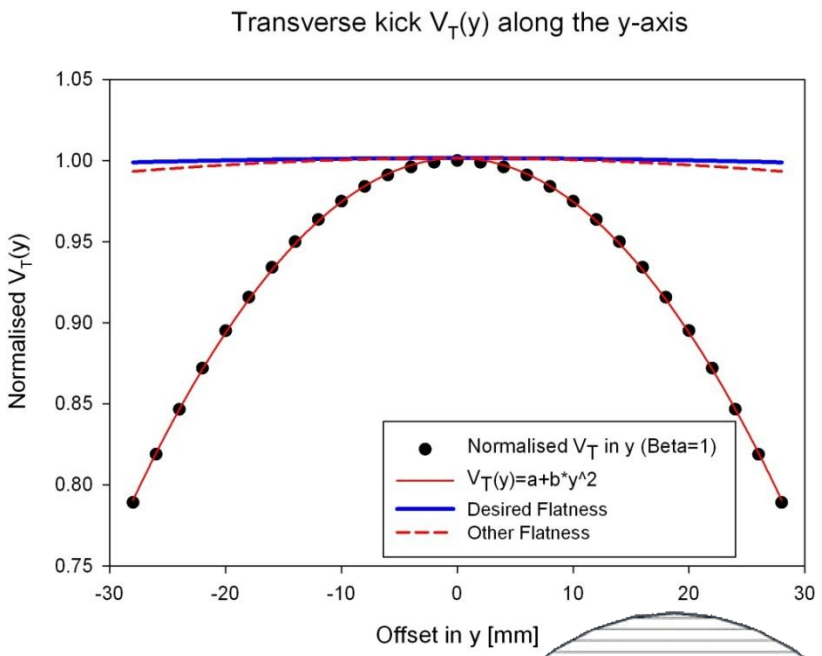


ODU-NIOWAVE

with JLab.

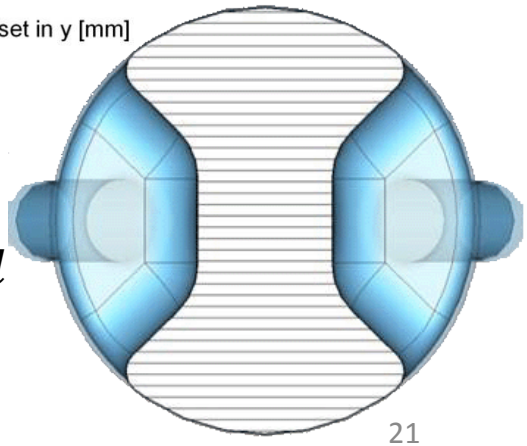
Field Uniformity and Emittance



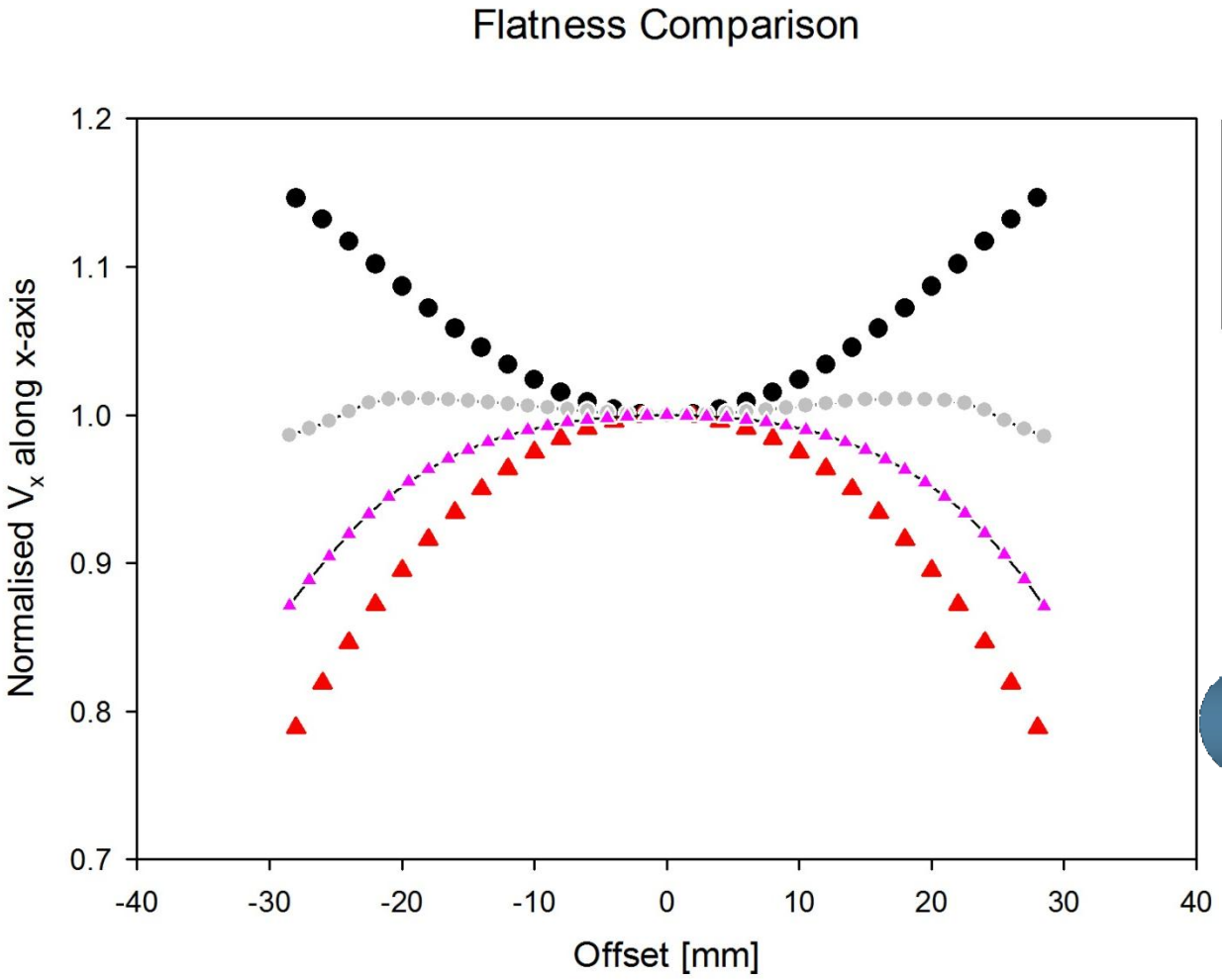


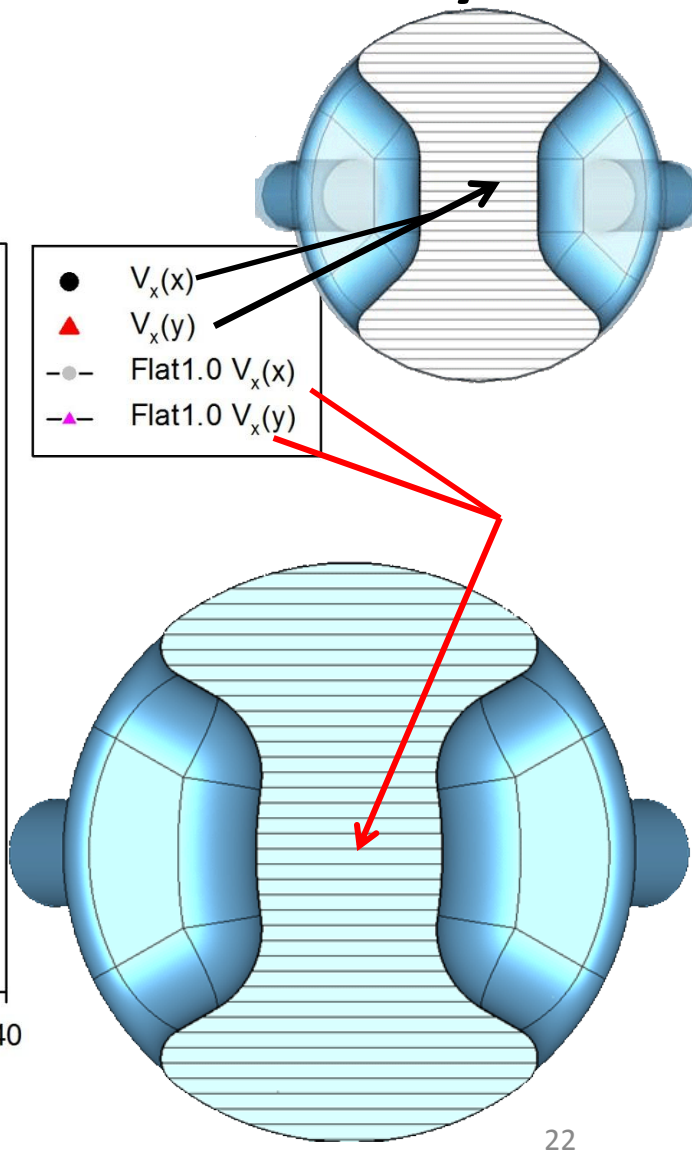
$$\epsilon^2{}_{n,rms} \equiv \epsilon^2{}_{0n,rms} + \frac{x^2{}_{0,rms}(\overline{\Delta p_x{}^2} - \overline{\Delta p_x}^2)}{m^2c^2}$$

For a proton beam on axis coming with $\epsilon_{0n,rms}(y) = 0.07\mu m - rad$ then leaves with $\epsilon_{n,rms}(y) = 0.13\mu m - rad$ after 1 pass.



Correcting Field Non-Uniformity





References

- PRST-AB
  - Beam Dynamics Studies for Transverse Electromagnetic Mode-type RF Deflectors – Phys. Rev. ST Accel. Beams **15**, 022001 (2012) - S. Ahmed, et.al.
- PAC 2011 – NewYork, USA
  - Design of Superconducting Parallel-bar Deflecting/Crabbing Cavities with Improved Properties – J.R. Delayen, S.U. De Silva
  - Fundamental and HOM Coupler Design for the Superconducting Parallel-Bar Cavity – S.U. De Silva, J.R. Delayen
  - Multipacting Analysis of the Superconducting Parallel-bar Cavity – S.U. De Silva, J.R. Delayen
  - Beam Dynamics Studies of Parallel-Bar Deflecting Cavities – S. Ahmed, et.al.
- SRF 2011 – Chicago, USA
  - Compact Superconducting Cavities for Deflecting and Crabbing Applications – J.R. Delayen – Inivted Talk
  - Designs of Superconducting Parallel-Bar Deflecting Cavities for Deflecting/Crabbing Applications – J. R. Delayen, S.U. De Silva
  - Analysis of HOM Properties of Superconducting Parallel-Bar Deflecting/Crabbing Cavities – S.U. De Silva, J.R. Delayen
  - Mechanical Study of Superconducting Parallel-Bar Deflecting/Crabbing Cavities – H. Park, S.U. De Silva, J. R. Delayen
- IPAC 2011 – San Sebastián, Spain
  - Design of Superconducting Parallel-bar Deflecting/Crabbing Cavities – J.R. Delayen, S.U. De Silva
  - Crab Crossing Schemes and Studies for Electron Ion Collider – S. Ahmed, et.al.

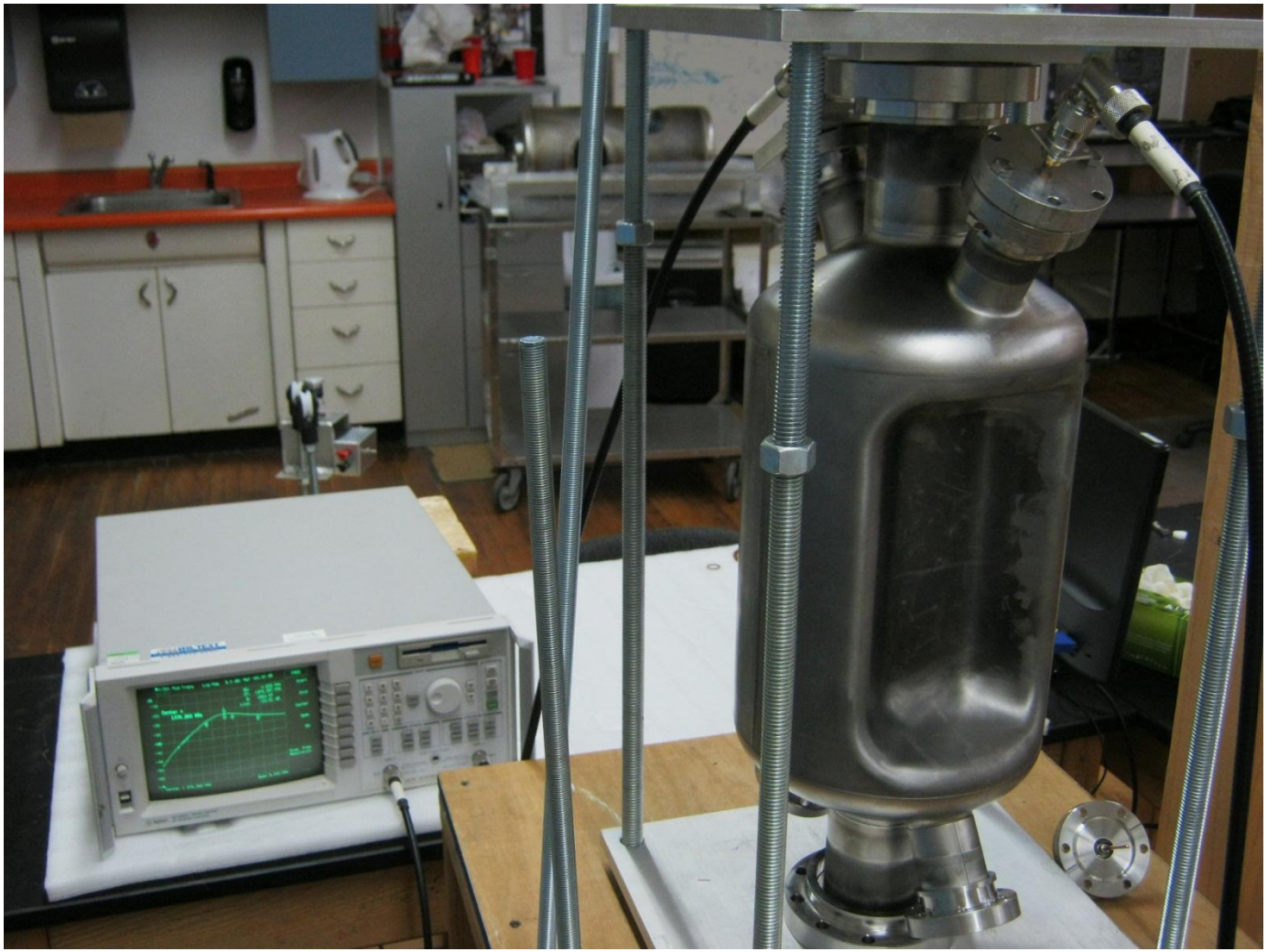
References

- PRST-AB
  - Evolution and Properties of Parallel-Bar Deflecting/Crabbing Cavities – S.U. De Silva, J.R. Delayen
- IPAC 2012 – New Orleans, USA
  - Design and Development of Superconducting Parallel-bar Deflecting/Crabbing Cavities – S.U. De Silva, J.R. Delayen
  - Characteristics and Fabrication of a 499 MHz Superconducting Deflecting Cavity for the Jefferson Lab 12 GeV Upgrade – H. Park, S.U. De Silva, J. R. Delayen
  - Engineering of a Superconducting 400 MHz Crabbing Cavity for the LHC HiLumi Upgrade – D. Gorelov, T. Grimm (Niowave, Inc., Lansing, Michigan), S.U. De Silva, J.R. Delayen
  - RF Modeling Using Parallel Codes ACE3P for the 400-MHz Parallel-Bar/Ridged-Waveguide Compact Crab Cavity for the LHC HiLumi Upgrade – Z. Li, L. Ge (SLAC, Menlo Park, Ca*li*fornia), J.R. Delayen, S.U. De Silva
  - Simulation of a TEM-mode Crab Cavity in the SPS – H.J. Kim, T. Sen (Fermilab, Batavia), K. Li (Stony Brook University, Stony Brook)
  - Impedance Budget for MEIC Electron Ring – S. Ahmed et.al.
- LINAC 2012 – Tel Aviv, Israel
  - Compact Superconducting Crabbing and Deflecting Cavities – S.U. De Silva – Invited Talk
  - Multipole Field Effects of Parallel-Bar Deflecting/Crabbing Cavities – S.U. De Silva, J.R. Delayen

Acknowledgements

- Terry Grimm (Niowave)
- Dmitry Gorelov (Niowave)
- Jean Delayen (ODU/JlLab)
- Subashini de Silva (ODU/JLab)
- Rocío Olave (ODU)
- Christopher Hopper (ODU)
- Karim G. Hernández (DCI-Ugto)

Thank you !

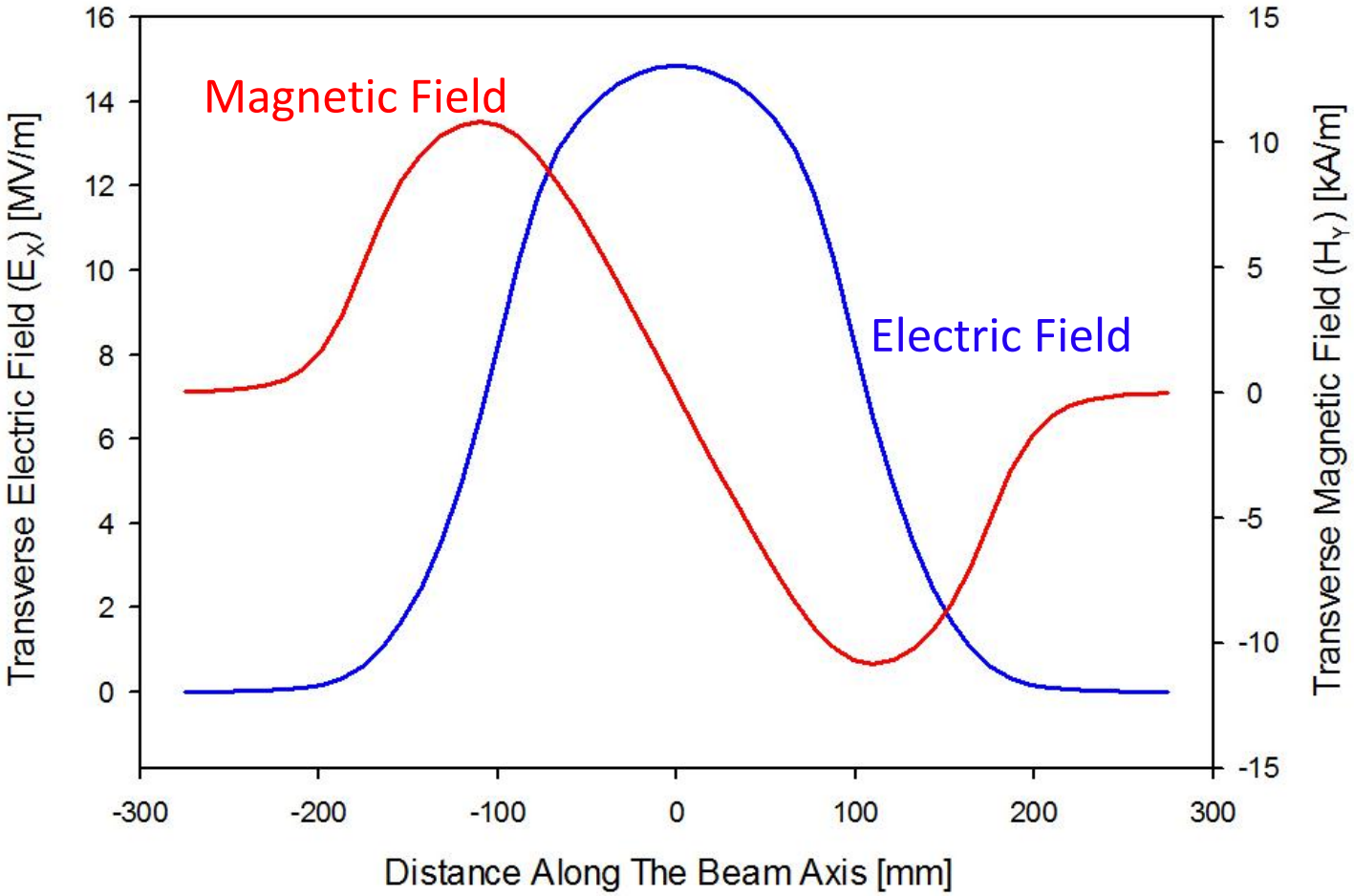


Contacts

Name	E-mail
Jean Delayen	<delayen@jlab.org>
Subashini De Silva	<sdesilva@jlab.org>
Christopher Hopper	<chopp002@odu.edu>
Rocio Olave	<rolave@odu.edu>
Alejandro Castilla	<acast020@odu.edu>
Terry Grimm	<grimm@niowaveinc.com>
Tyler Lamie	<lamie@niowaveinc.com>
Dmitry Gorelov	<gorelov@niowaveinc.com>

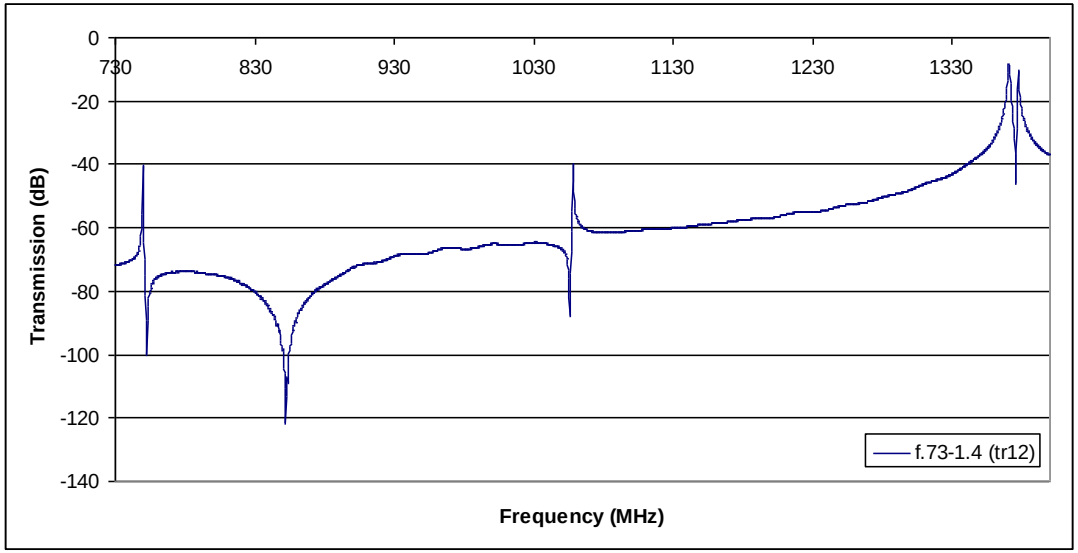
750 MHz CC Transverse Fields

(Fundamental Mode)



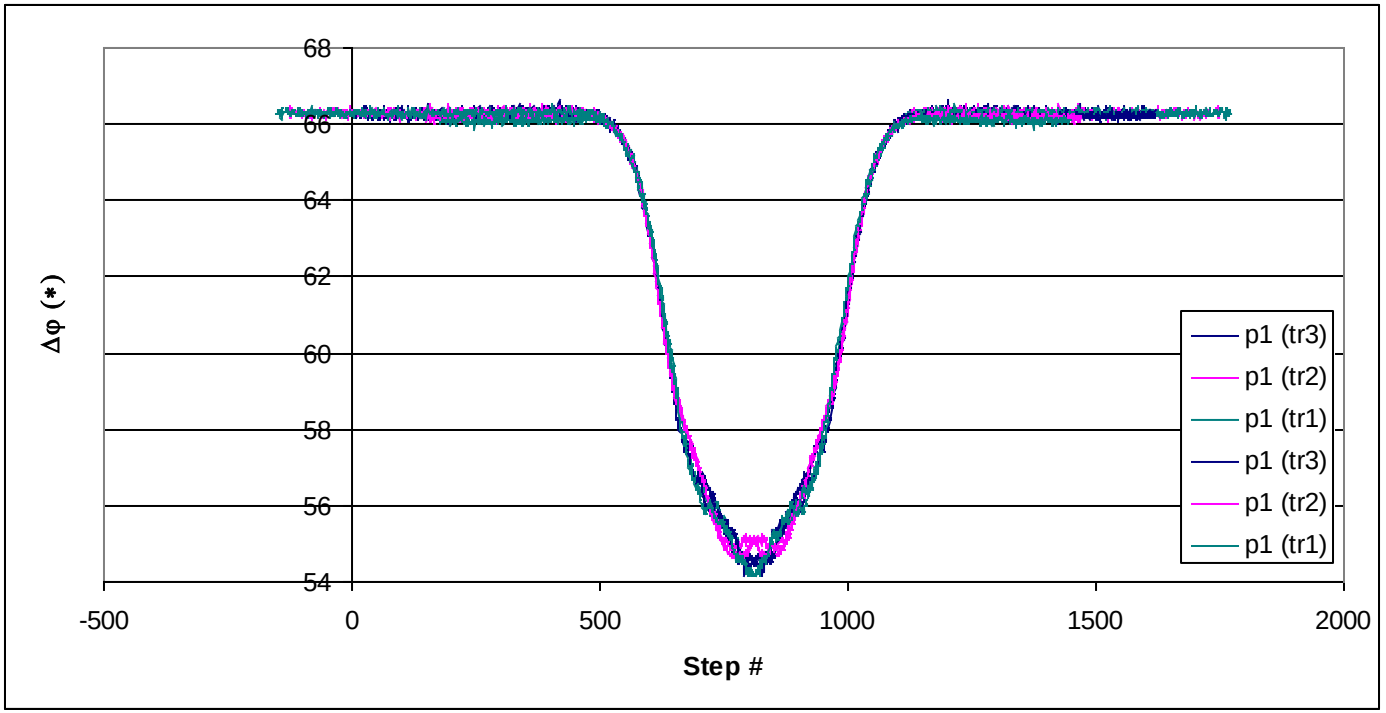
750 MHz CC Trimming Results

Mode	f (MHz)	Q	Loss (dB)
1	749.492	5600	-53
2	1058.027	6900	-37
3	1370.410	1200	-16
4	1377.506	2000	-19



- **df/dz per total length**
  - calculated: -0.46769 MHz/mm
  - measured: -0.46299 MHz/mm

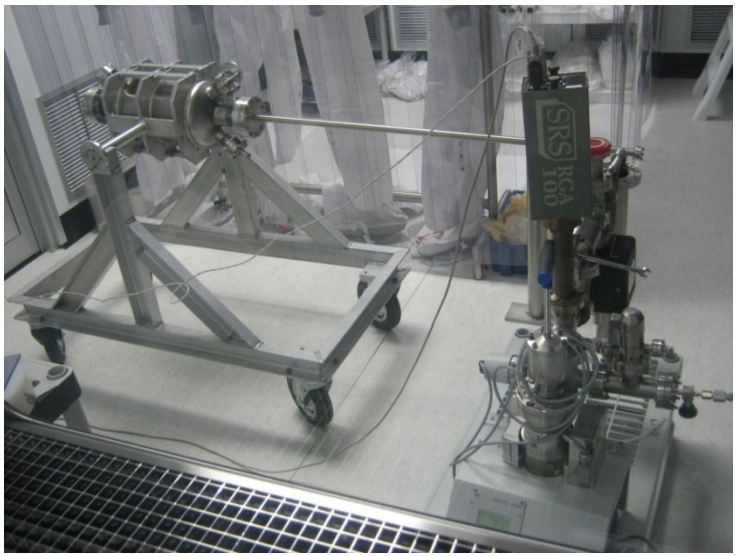
750 MHz CC Asymmetry



- ~0.025” measured difference in the end-cells gaps produce ~ 55% difference in the magnitude of the longitudinal modes #3 and #4, but no measurable asymmetry in the deflecting fundamental mode

750 MHz CC Pump Down

- Install blanks, antennas, and long vacuum tube
- Pump down on cavity horizontal in etch cart
- At this stage, a vacuum leak was detected and traced to the braze joint on one of the HOM ports



750 MHz CC Repaired Cavity

- To seal the leak on the braze flange, that port was removed and a niobium plug was welded in its place.
- Cavity etch was repeated (15 µm) followed by a second high pressure rinse and clean room dry period.

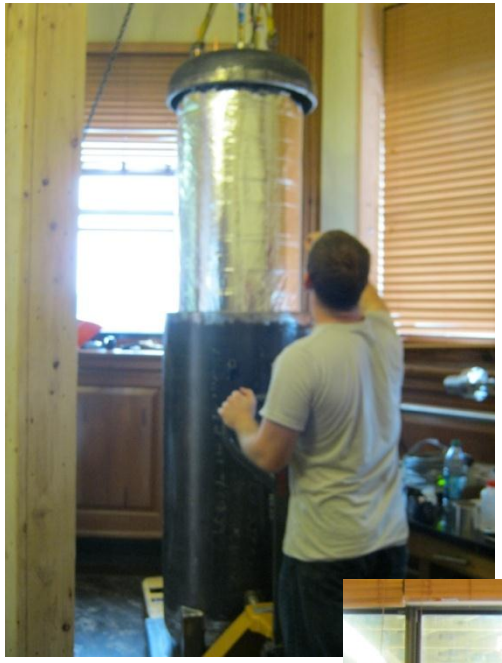
Temperature Sensors and Antennas

750 MHz CC Helium Vessel

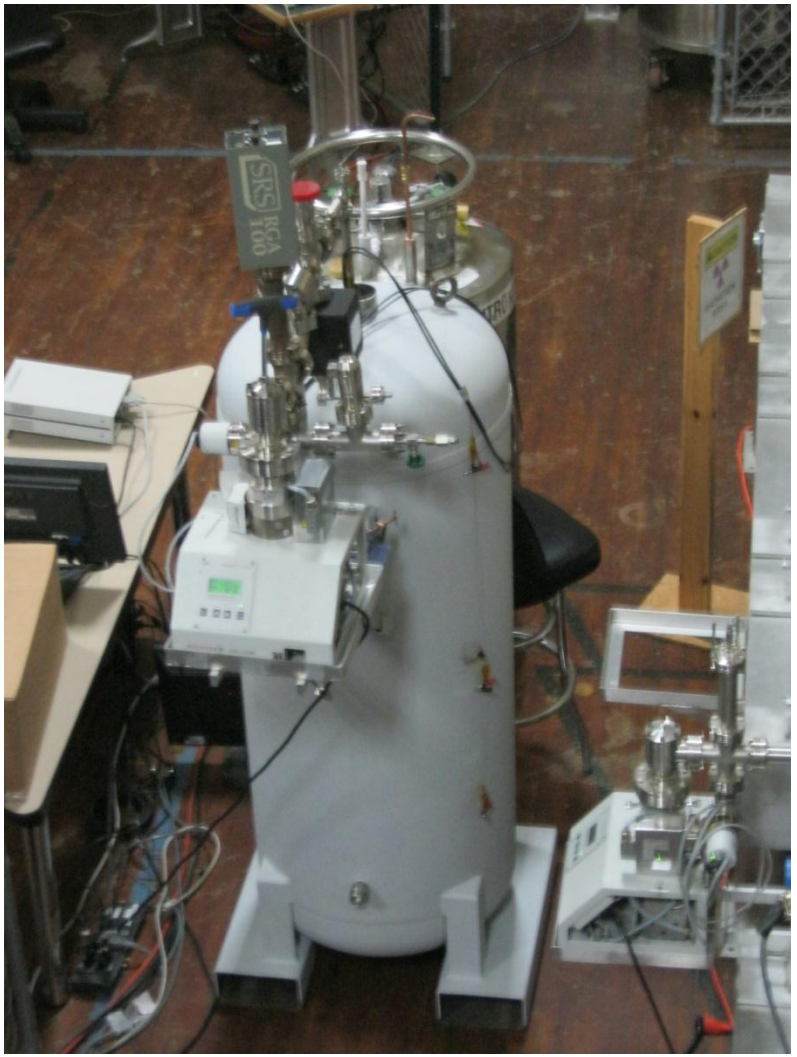
750 MHz CC Cu Nitrogen Shield

750 MHz CC Mu Shield

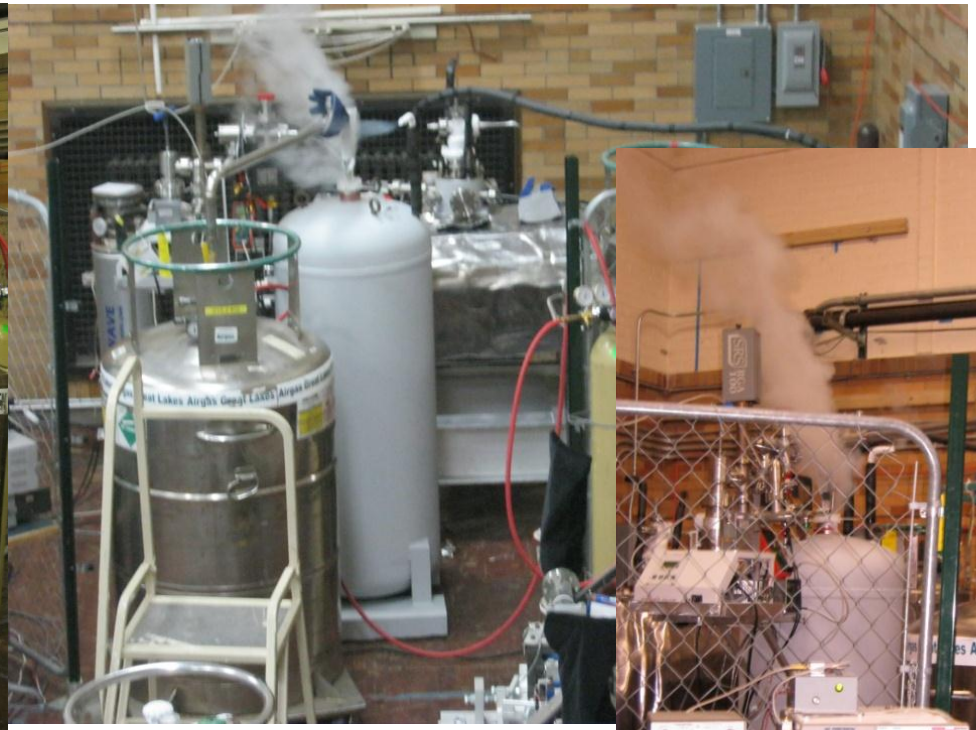
750 MHz CC Vacuum Vessel



Complete Cryomodule



750 MHz CC Cryotest Setup



750 MHz CC Preliminary Tests

- For the cavity after removing $150\ \mu m$ etch with standard BCP solution:

$$Q_0 = \frac{G}{R_s} \approx 3 \times 10^8 \text{ (measured 4K)}$$

- Geometrical factor:

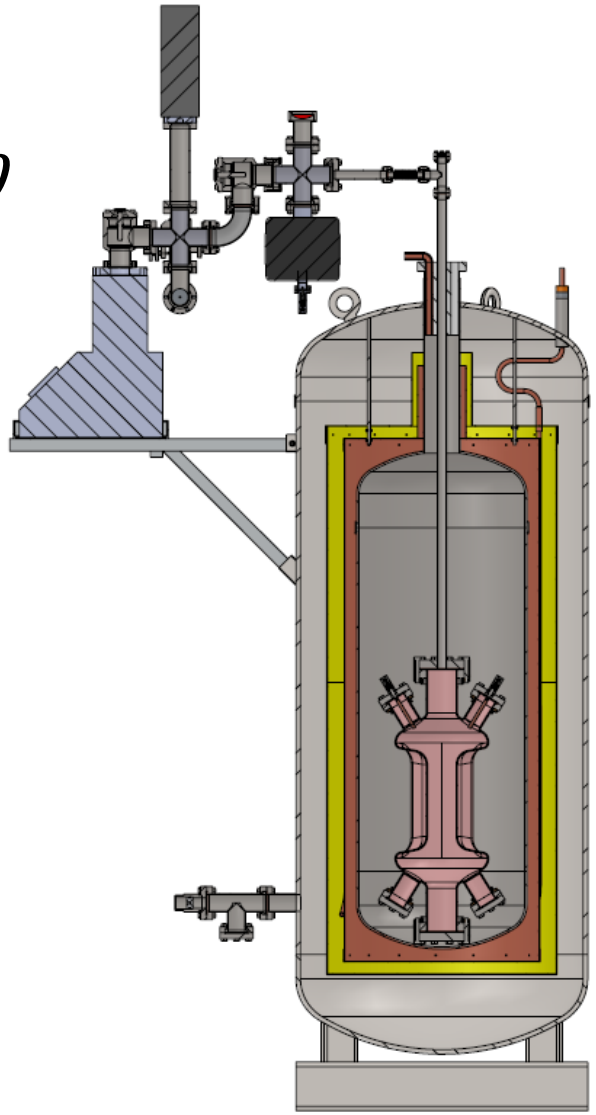
$$G = 131.4\ \Omega \text{ (design)}$$

- Now, for the shunt impedance:

$$R_s = 438\ n\Omega$$

- For the power dissipated:

$$P_{dis} = 10\ W \text{ (measured 4K)}$$



750 MHz CC Preliminary Tests

- And so, for $R_T = \frac{{V_T}^2}{P_{dis}}$ (deflecting voltage):

$$R_T R_s = 1.65 \times 10^4\ \Omega^2 \text{ (design)}$$

$$R_T = 37.67 \times 10^9\ \Omega$$

- We can estimate the deflecting Voltage:

$$\boldsymbol{V \sim 0.6\ MV}$$

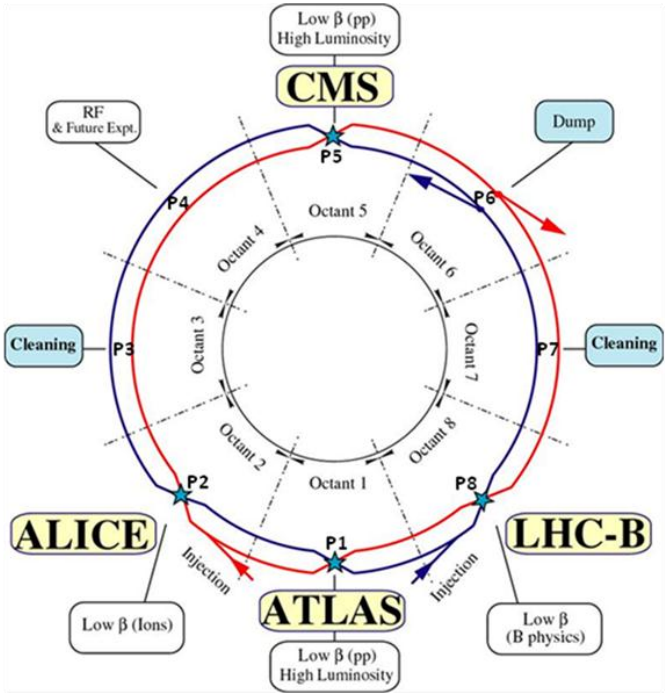
- Using this we recalculate:

$$E_p = 13.35\ {}^{\mathrm{MV}}/_{\mathrm{m}}$$

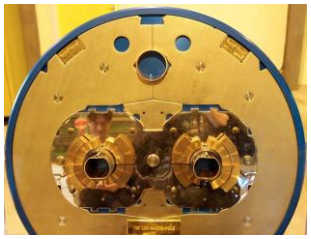
$$B_p = 27.93\ \mathrm{mT}$$

RF Crab Cavity Requirements

- Local scheme requires crab cavities on either side of the interaction point (IP).
- Requires vertical and horizontal crabbing at the two interaction points (IP1 and IP5).
- Operating rf frequency – 400 MHz.
- Transverse voltage requirement - 10 MV per beam per side.

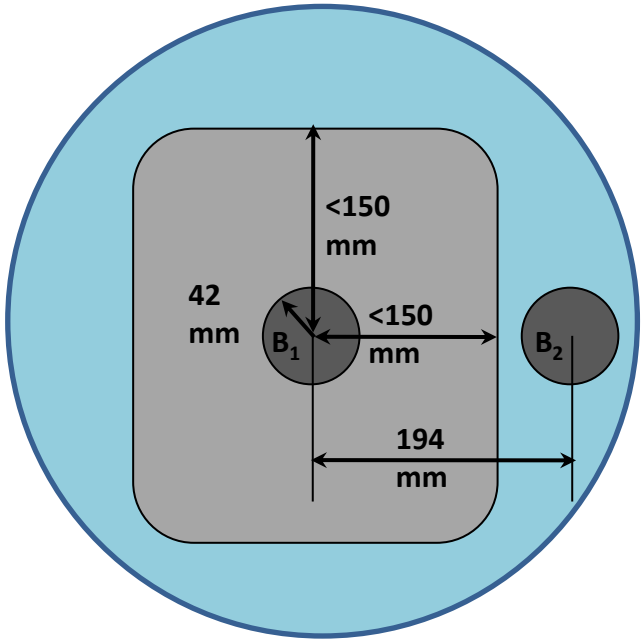


L. Rossi, LHC-CC 10



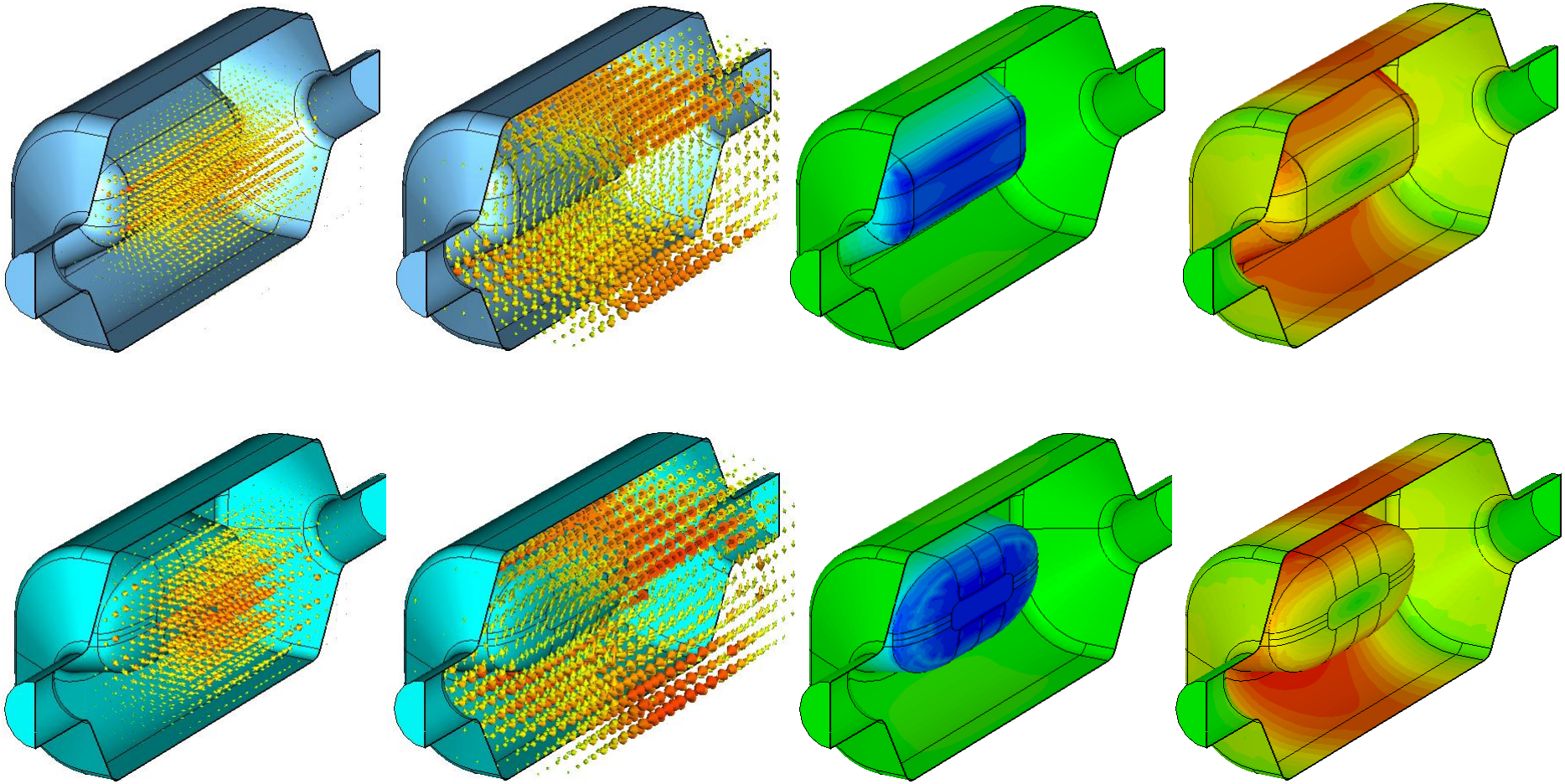
27 km @1.9K to accelerate protons to 7TeV

Dimensional Constraints



Field Distribution / Surface Fields

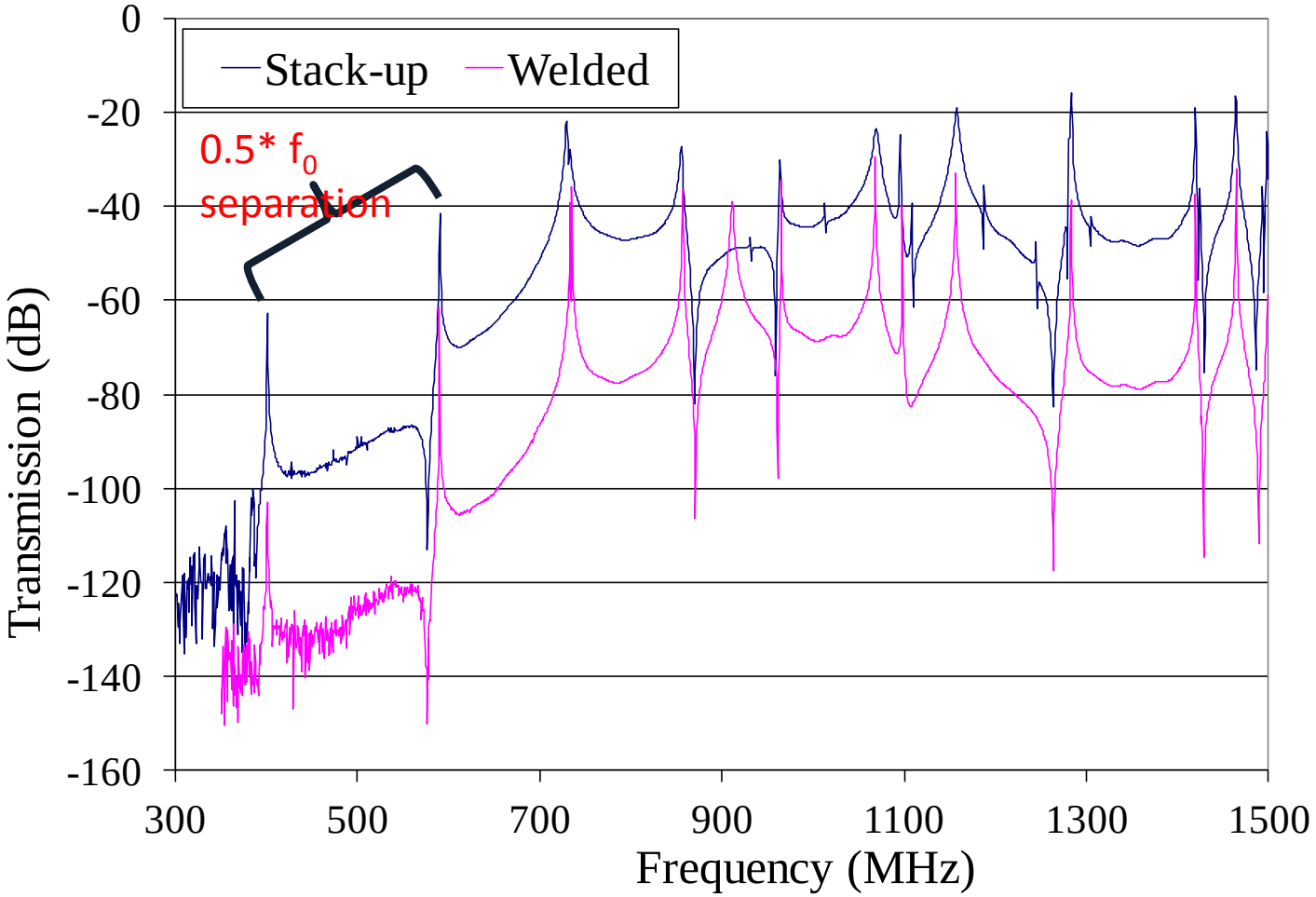
E Field | H Field | Peak E Field | Peak H Field



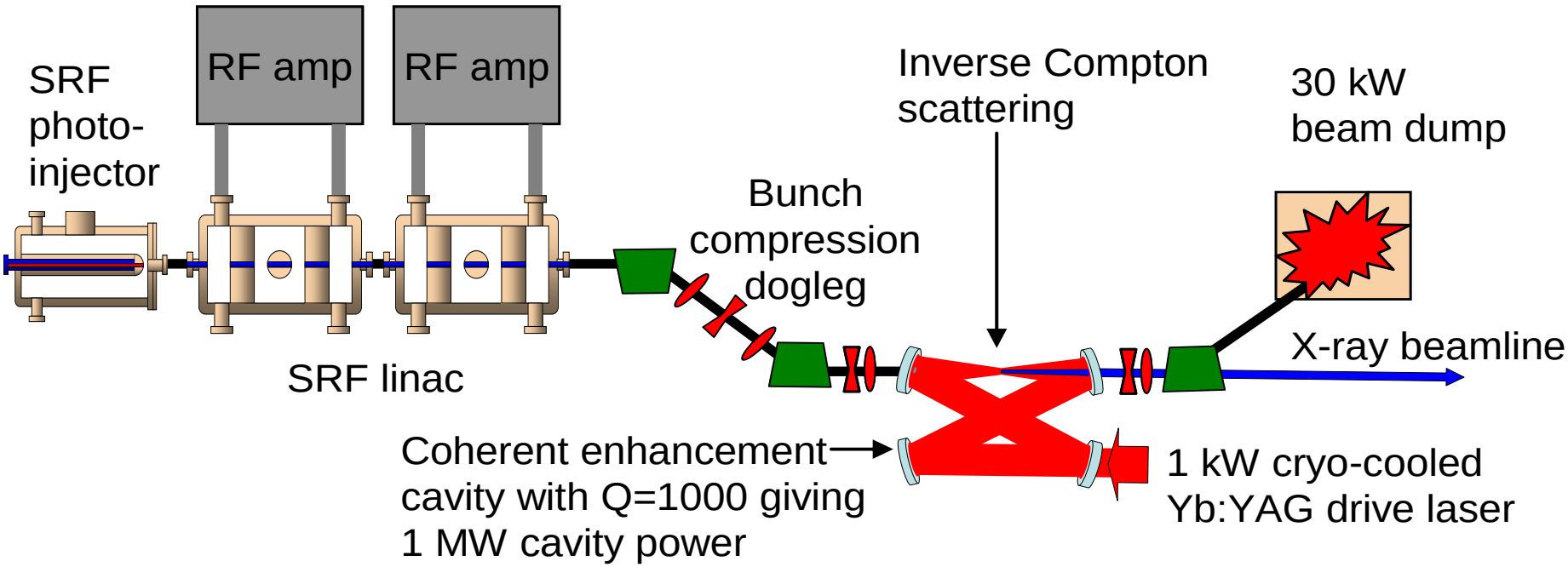
End Cap Fabrication – 400 MHz

400 MHz Room Temperature

400 MHz Frequency Measurements

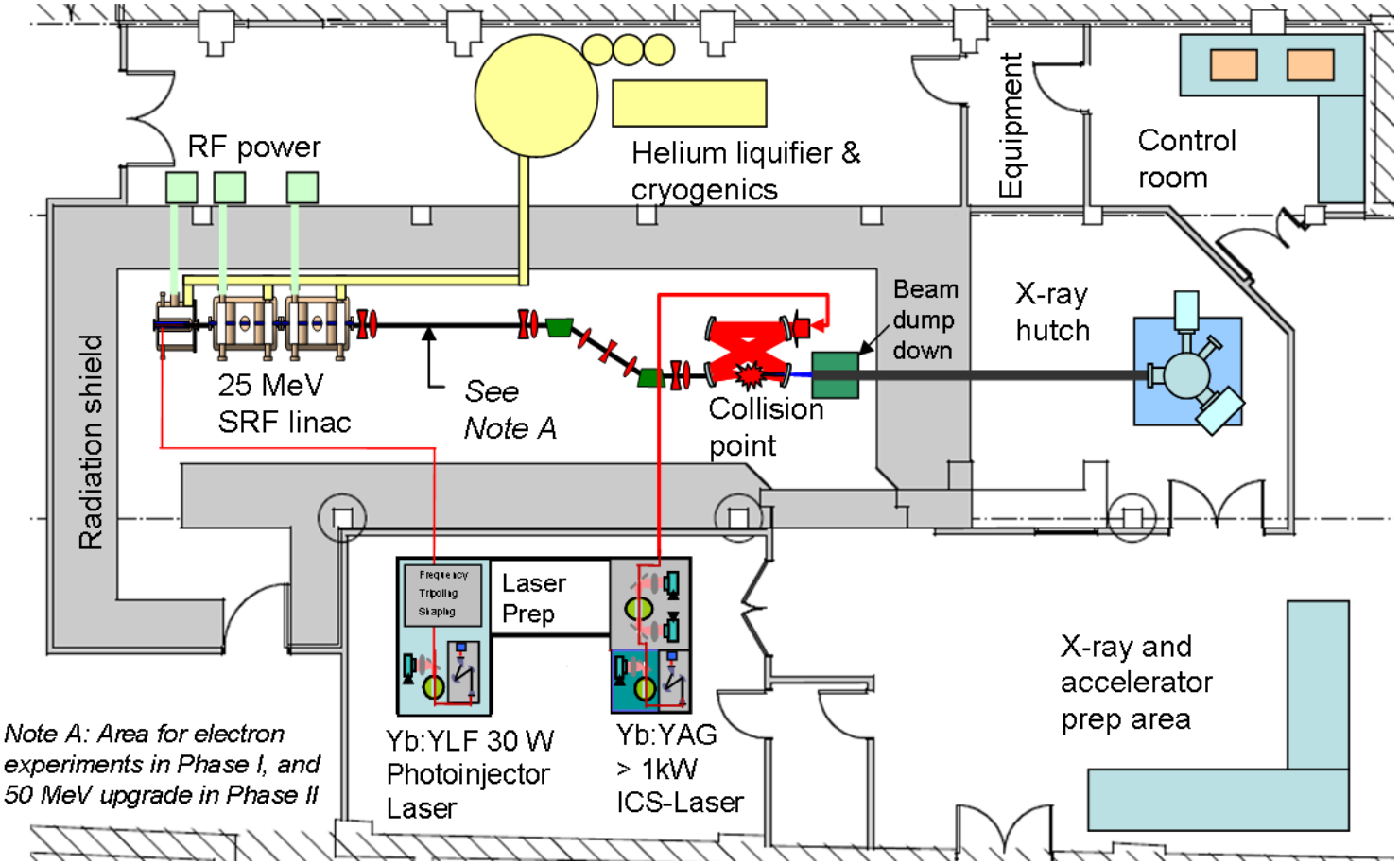


4rd Generation X-Ray Source



*Goeff Kraft, Jlab 2011.

4rd Generation X-Ray Source



*Goeff Kraft, Jlab 2011.

4rd Generation X-Ray Source

- **What do we want?**

-X-Ray specs

Parameter	Quantity	Unit
X-ray energy	Up to 12	keV
Photons/bunch	1.6×10^{6}	
Flux	1.6×10^{14}	photon/sec
Average Brilliance	1.5×10^{15}	photon/(sec mm^2 mrad^2 0.1%BW)

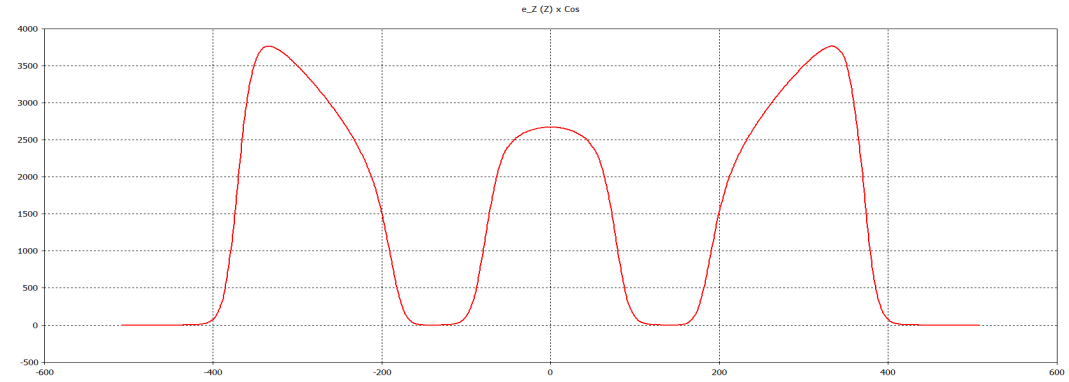
- **What do we need?**

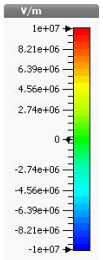
-Beam specs

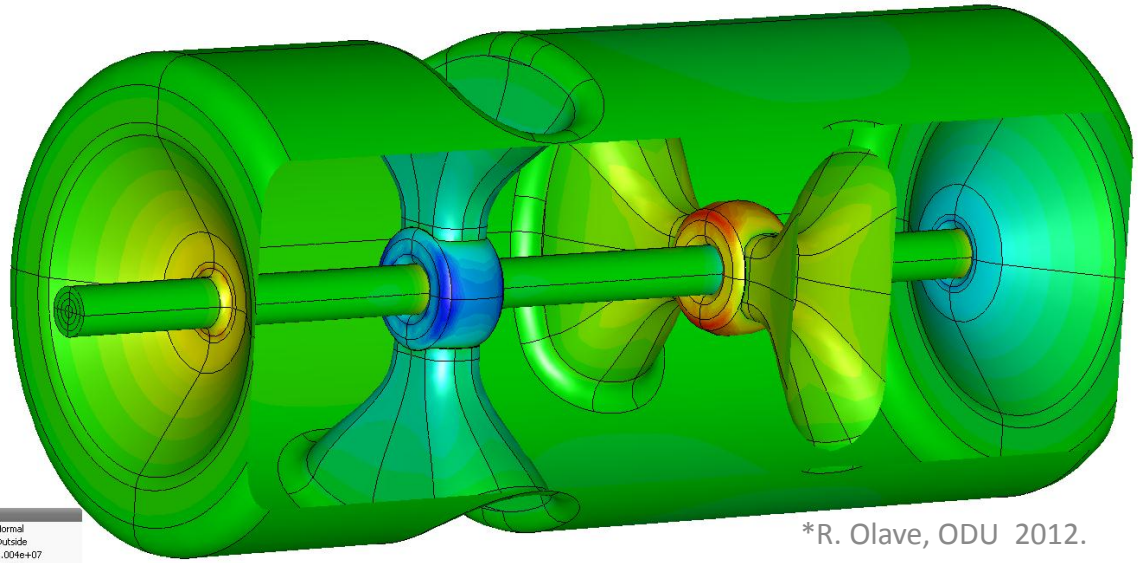
Parameter	Quantity	Unit
Energy	25	MeV
Bunch charge	10	pC
Repetition rate	100	MHz
Average current	1	mA
Normalized emittance	0.1	mm-mrad
β	5	mm
FWHM bunch length	3.0(0.9)	psec(mm)
RMS energy spread	7.5	keV

*Goeff Kraft, Jlab 2012.

4rd Generation X-Ray Source







*R. Olave, ODU 2012.