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Status of the APS SPX R&D

A. Nassiri

Ultrafast SIG Meeting, Thursday July 16, 2009

U.S. Department of Energy

UChicago Argonne LLC

Office of Science
U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

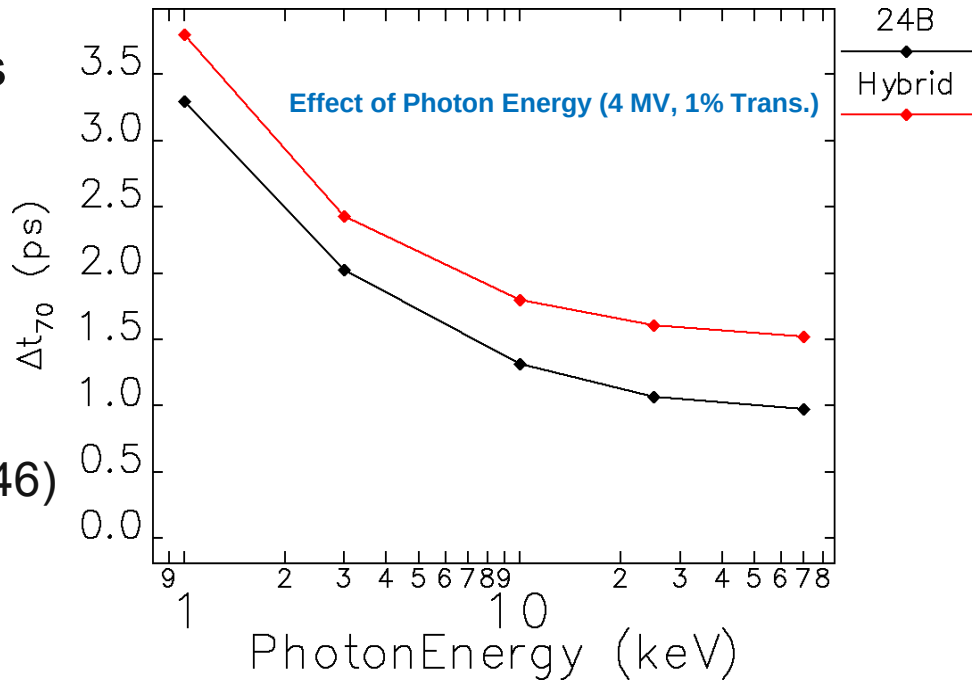
Outline

- SPX deliverables
- Beam and RF parameters
- ANL/JLab collaboration
- Continuing P&DV
- Summary

SPX Deliverables

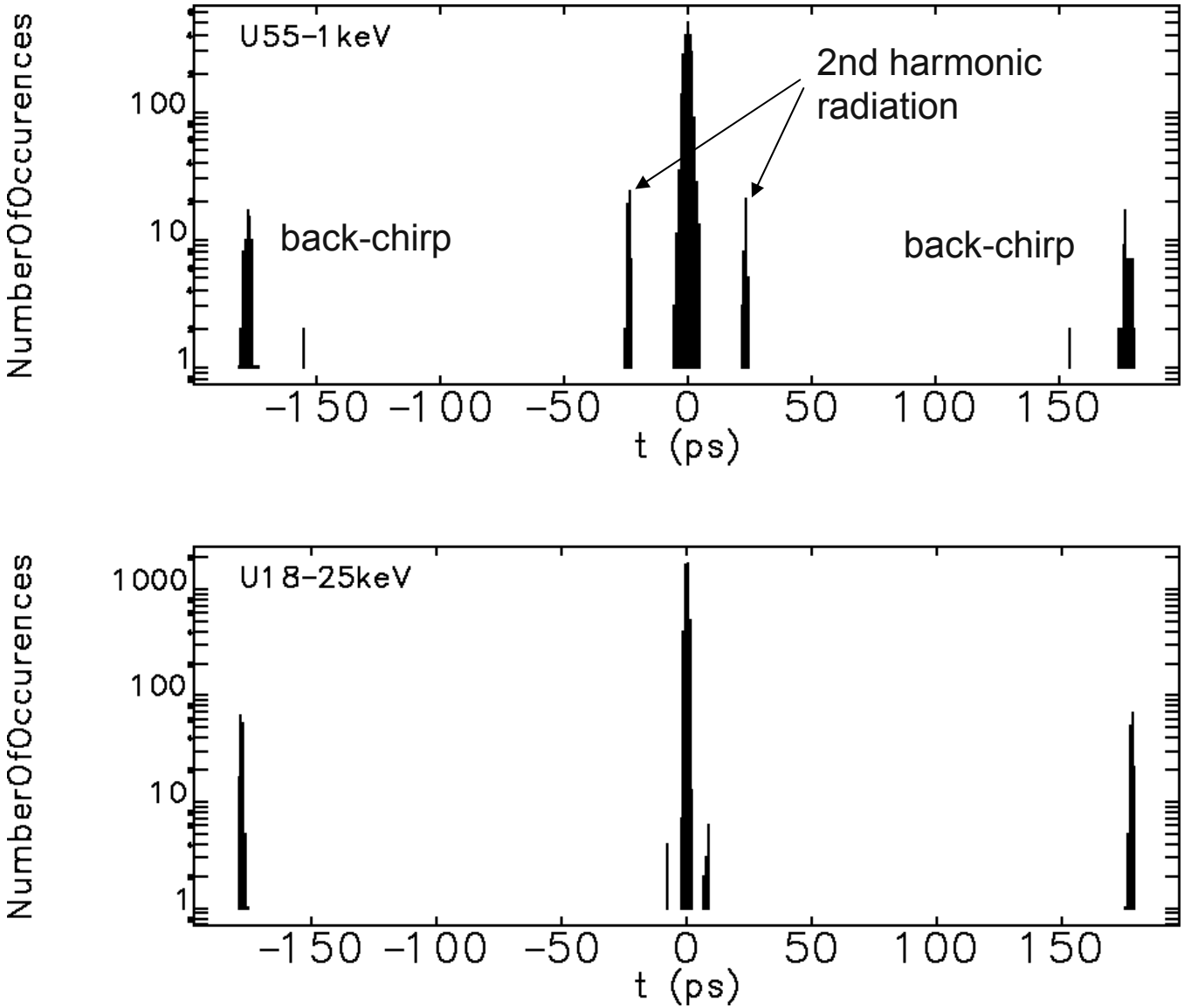
- X-ray pulses of less than 2 ps ("FWHM")
- 1% of normal intensity
- High repetition rate up to CW
- Can accommodate at least two fill patterns
  - *24 B and Hybrid*
  - Deflecting voltage of 4 MV (emittance below 50 pm, 2%coupling)

- Looked at several undulator options spanning this range
  - U55 at 1 keV (K=3.86)
  - U33 at 3 keV (K=2.73)
  - U33 at 10 keV (K=0.91)
  - U18 at 25 keV (K=0.26)
  - U18 3rd harmonic at 70 keV (K=0.46)
- In all cases we considered 2.4 m devices



M. Borland, OAG-TN-2007-016, 3/16/07.

Details of X-ray Slicing Results for Hybrid Mode

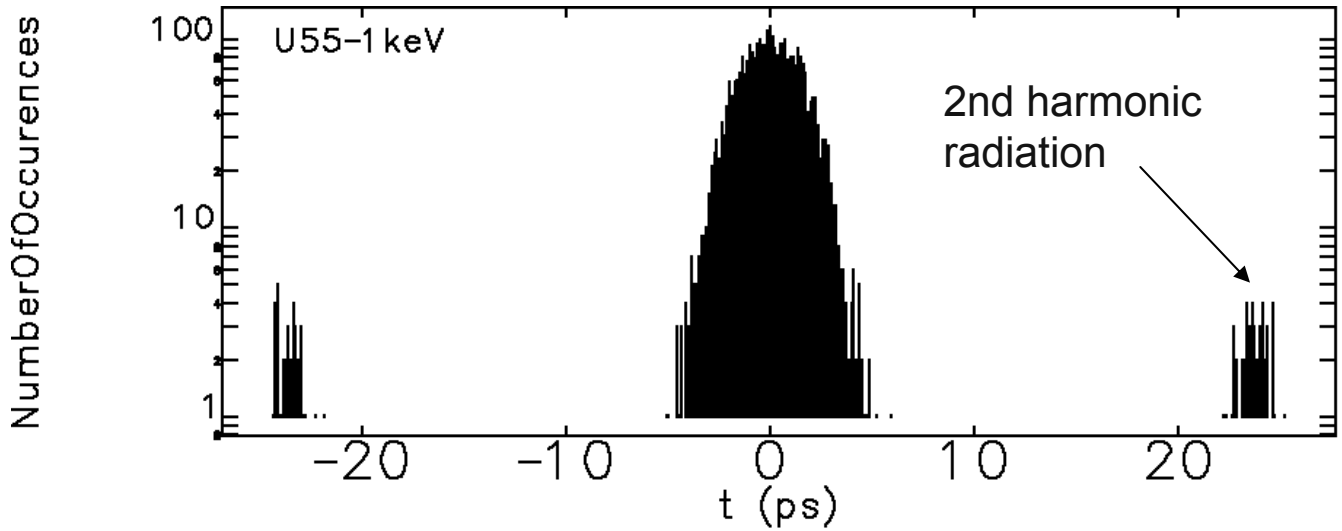


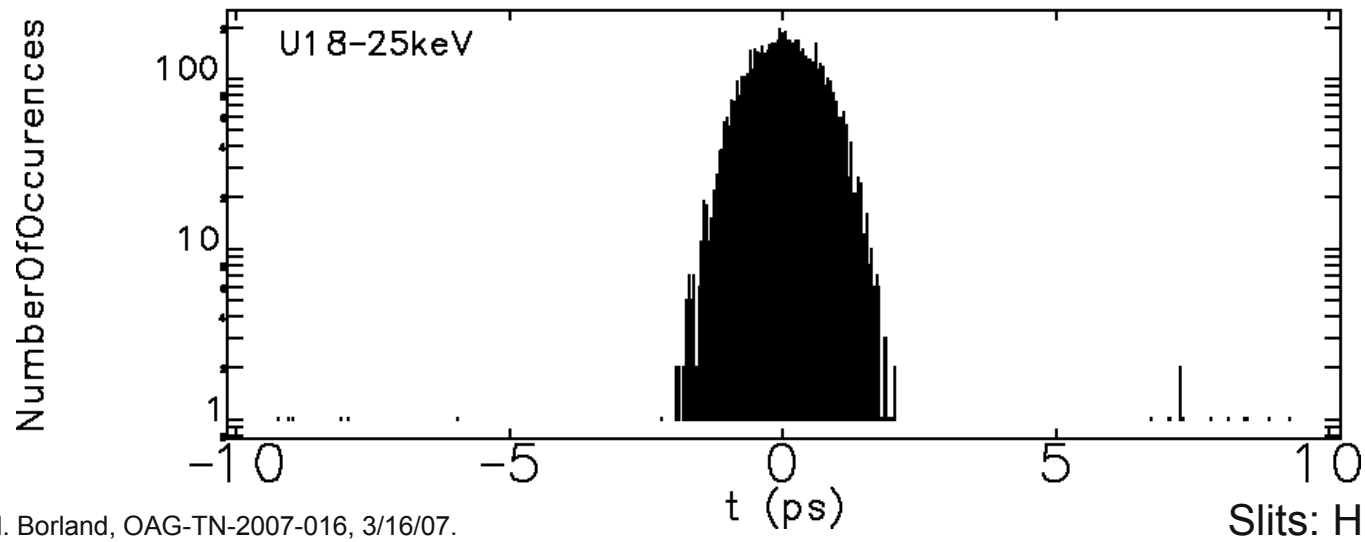
Back-chirp pulses have about 2.5% of the intensity of the central pulse.

M. Borland, OAG-TN-2007-016, 3/16/07.

Slits: H=0.5 mm, V=0.2 mm

Details of X-ray Slicing Results for 24 Bunch Mode





Back-chirp pulses have about 0.02% of the intensity of the central pulse and are not seen here.

[1]M. Borland, OAG-TN-2007-016, 3/16/07.

Slits: H=0.5 mm, V=0.2 mm

Beam Parameters

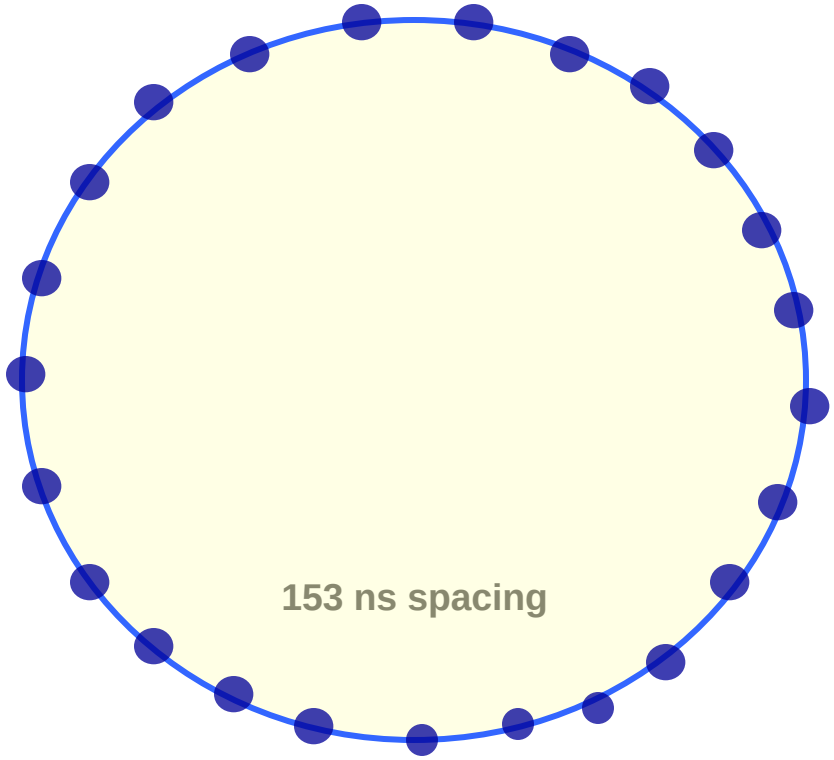
Nominal operating total current	102 mA
Maximum operating total current	132 mA
Total design current	202 mA
Energy	7 GeV
Revolution frequency	271.55 kHz
Synchrotron frequency	2.1 kHz
Momentum compaction	2.8×10^{-4}
Cavity β_x	20 m
Cavity β_y $\alpha_p = \frac{p}{L}\frac{dL}{dP}$	5 m
RMS bunch length for 2 mA	37 ps

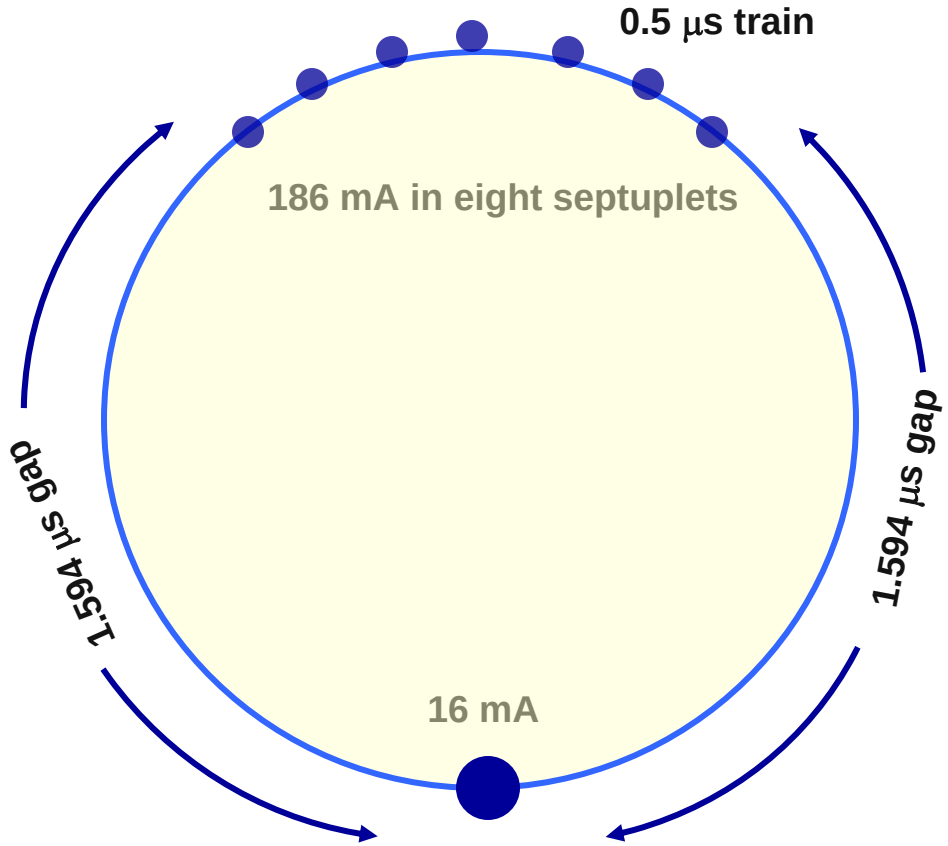
Planes	Growth rate	Synch. Radiation	Coherent
Longitudinal	60 S^{-1}	208 S^{-1}	208 S^{-1}
Horizontal	5 S^{-1}	104 S^{-1}	>600 S^{-1}
Vertical	200 S^{-1}	104 S^{-1}	> 600 S^{-1}

L. Emery

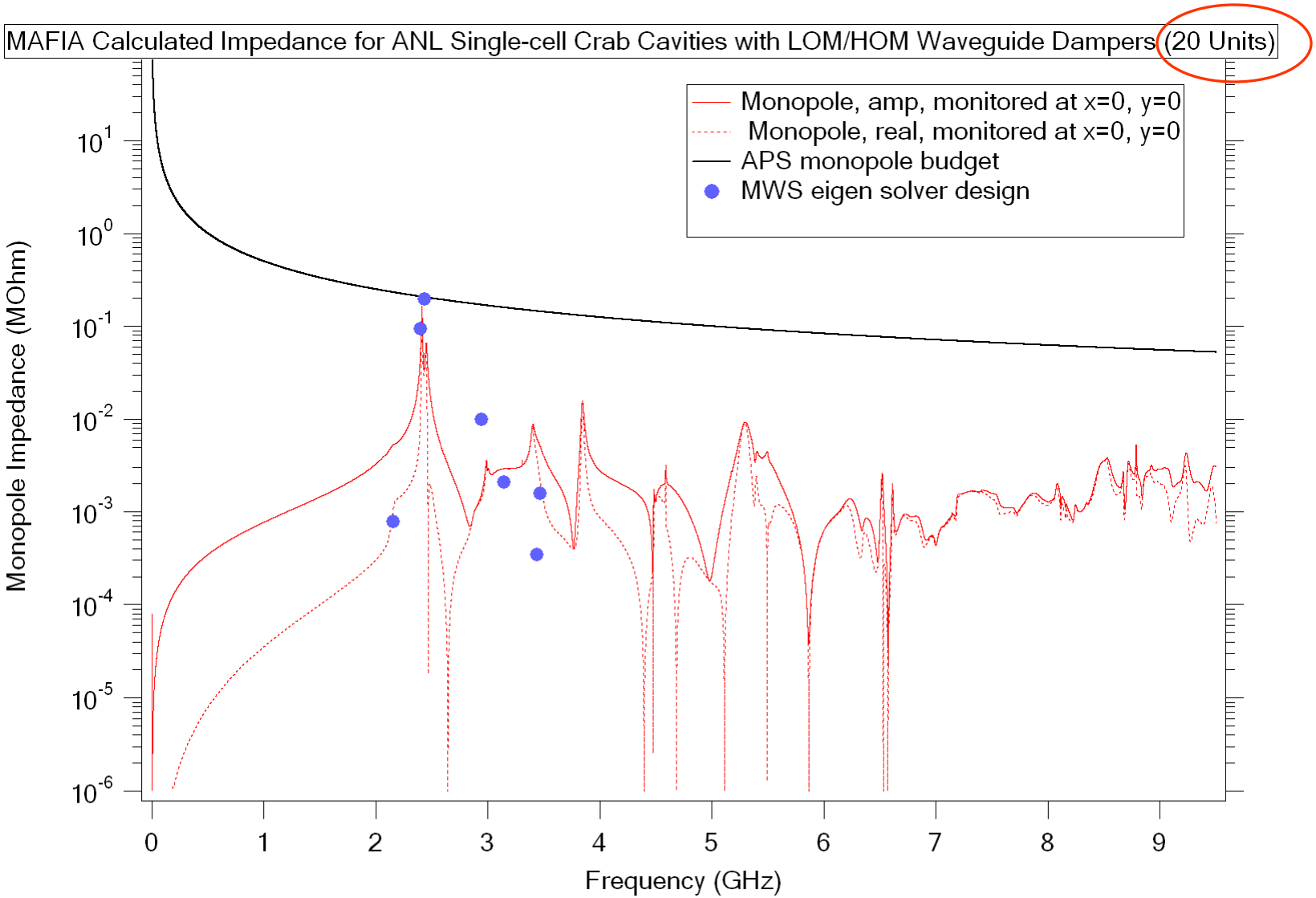
Bunch Patterns

- Symmetric
  - 202 mA in 24 bunches
- Hybrid (single bunch + a bunch train)
  - 202 mA I Hybrid: 1+8×7 (higher growth rates)



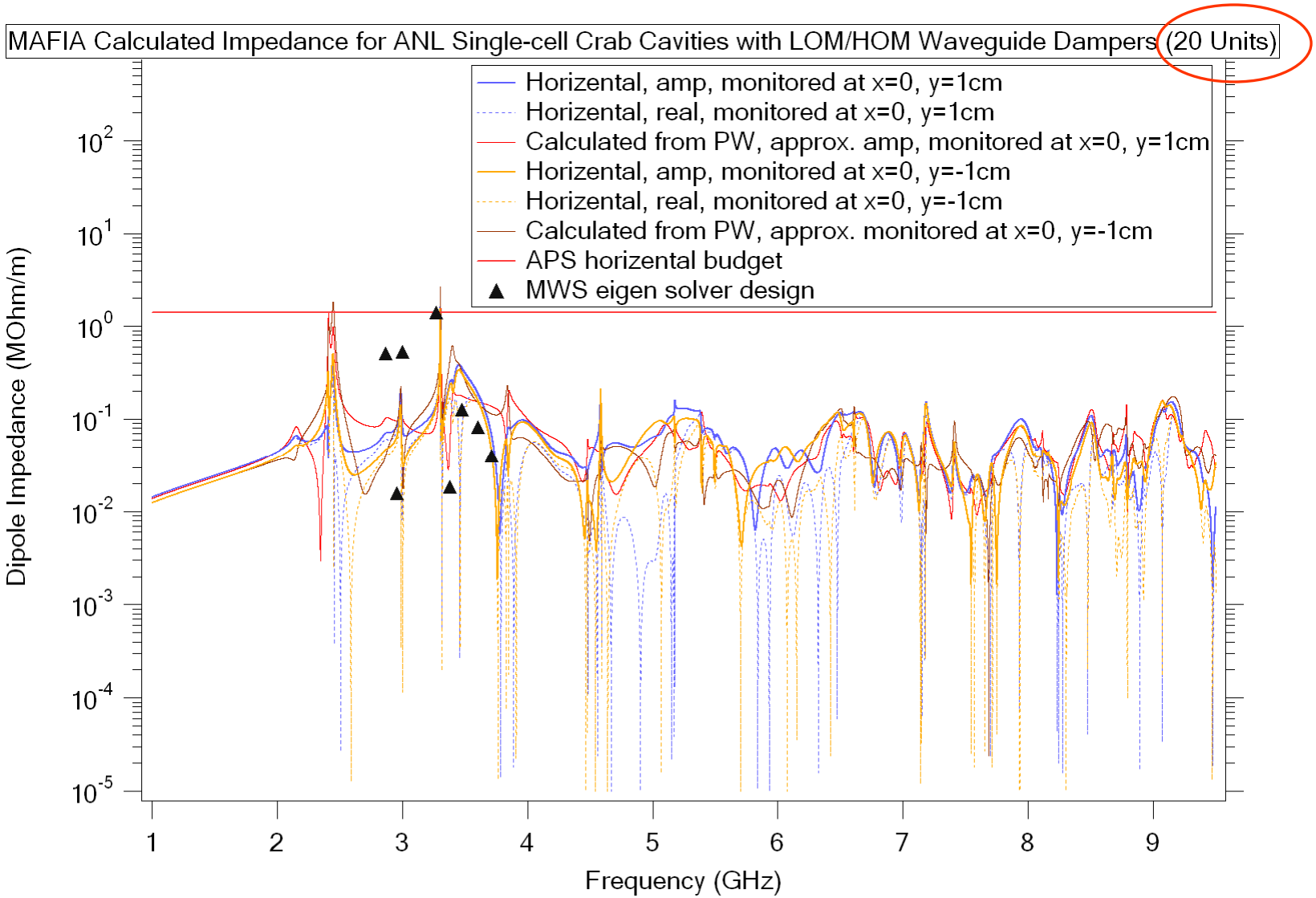


Single-cell Crab Cavity Unit Design with LOM and HOM Waveguide Dampers



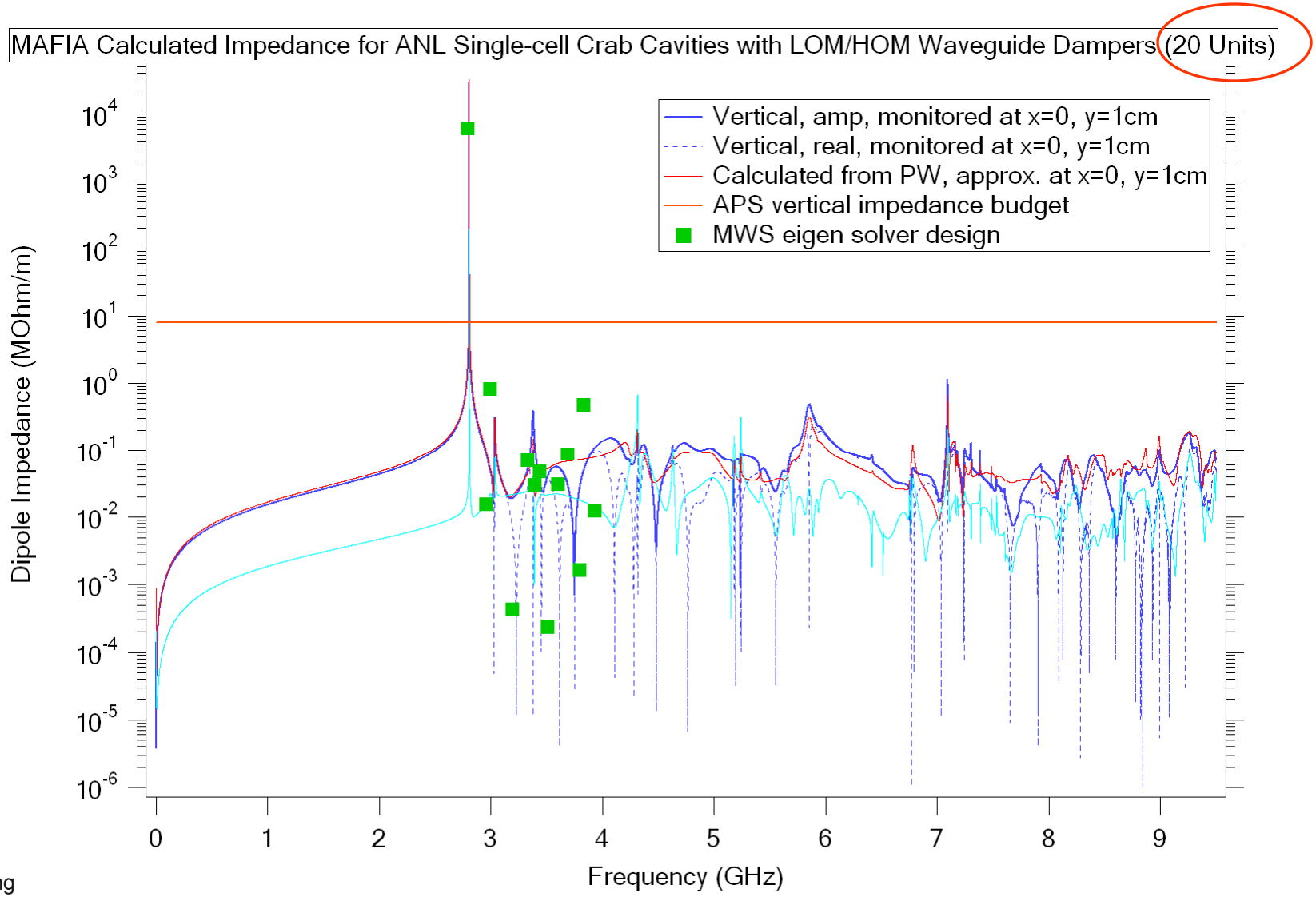
H. Wang

Single-cell Crab Cavity Unit Design with LOM and HOM Waveguide Dampers



H. Wang

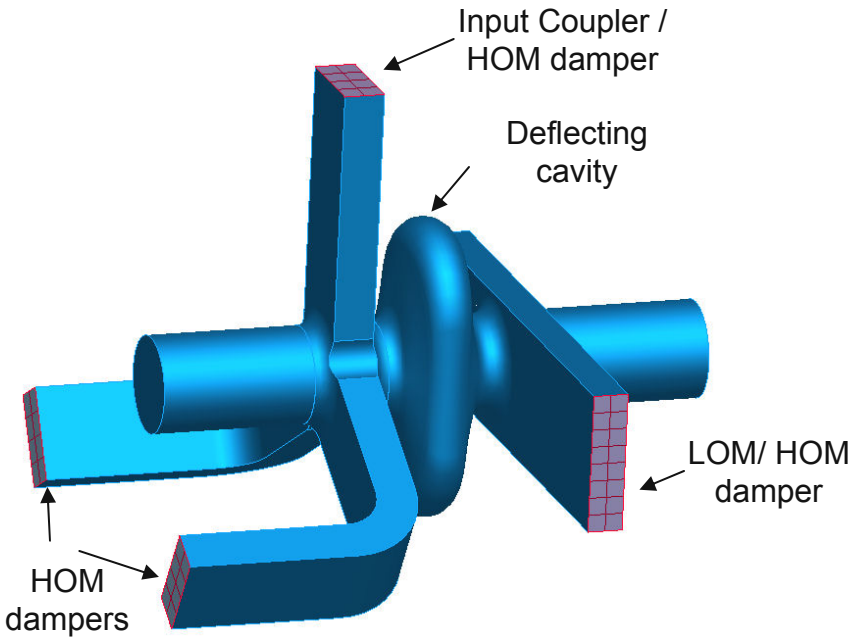
ANL's Single-cell Crab Cavity Unit Design with LOM and HOM Waveguide Dampers



H. Wang

RF Parameters

Frequency (GHz)	2.815
Deflecting Voltage	4 MV * 2
Qo (2K)	$3.8 * 10^9$
G	235
R_T / Q (Ω/m)	37.2
Beam Radius	2.5 cm
No. Cavities	12 * 2
Operation	CW
Nominal Beam Current (mA)	100
E_{sp}/V_{defl} (1/m)	83.5
B_{sp}/V_{defl} (mT/MV)	244.1



TM110+TE111, both contribute to the transverse kick

$$\vec{F}_\perp = q\left[\vec{E}_\perp + \left(\vec{v}\times\vec{B}\right)_\perp\right]$$

$$V_y(\phi) = e^{-i\phi}\int_{-L/2}^{L/2}\left[E_y(z)e^{-i\kappa z} - icB_x(z)e^{-i\kappa z}\right]dz$$

Panofsky-Wenzel:

$$V_y = -\frac{i}{\kappa}\frac{\partial}{\partial y}V_z = -\frac{iV_z(x=0,y=y_0)}{\kappa y_0}$$

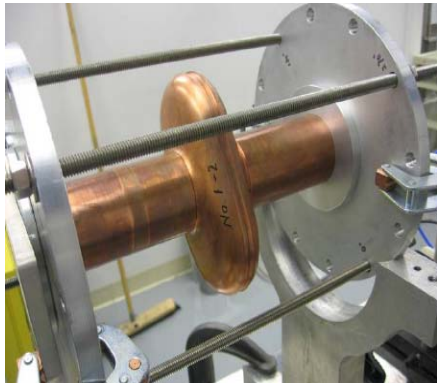
$$\left(\frac{R}{Q}\right)_\perp = \frac{V_d^2}{\omega U} = \frac{\left[\int_{-L/2}^{L/2} E_z(x=0,y=y_0)e^{-i\kappa z}dz\right]^2}{\omega U(\kappa y_0)^2}$$

ANL/JLab Collaboration

- RF structure design, simulation and analysis
- Prototyping
- “Cold” Cavity measurement
- Cryomodule

Prototyping

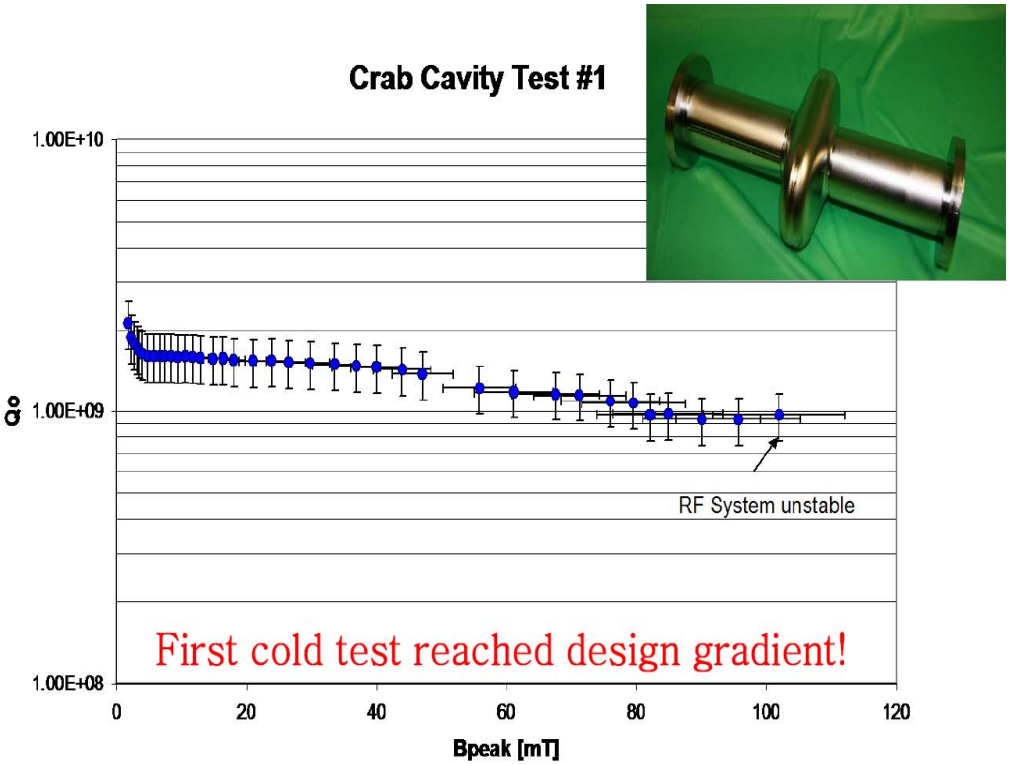
- Design of single-cell Nb cavities

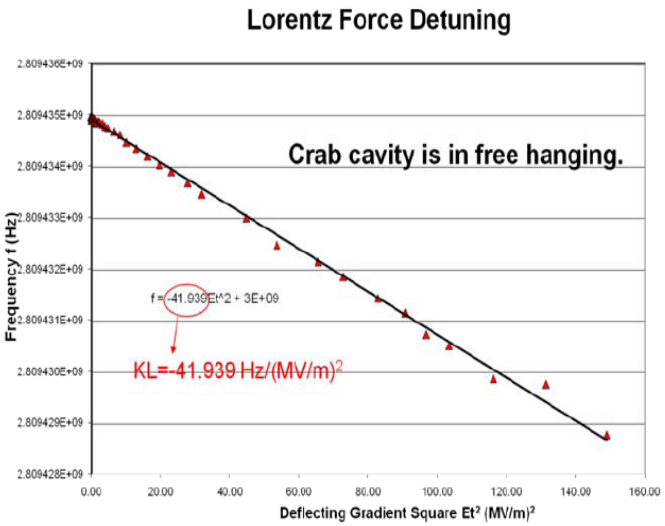


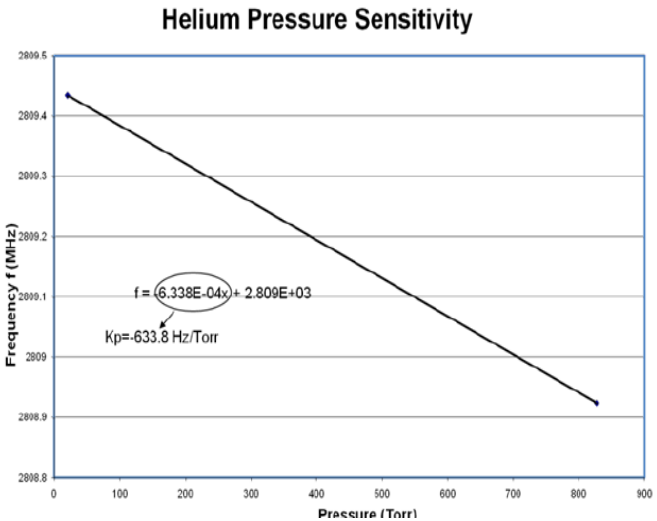
R (race-track) (mm)	44
D (race-track) (mm)	33.6
Ratio (R+D)/R	1.76
Frequency (GHz)	2.815
R_T / Q (Ω)	37.8
E_{sp}/V_{defl} (1/m)	~72
B_{sp}/V_{defl} (mT/MV) without damping	~160

ANL/JLab collaboration

Cold Measurements







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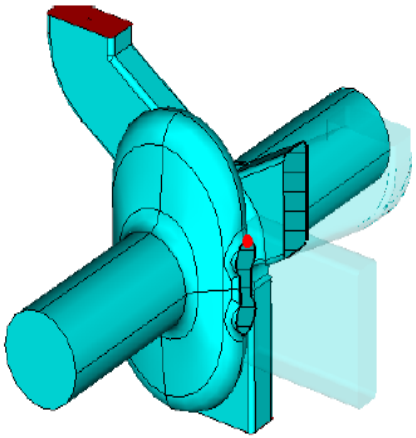
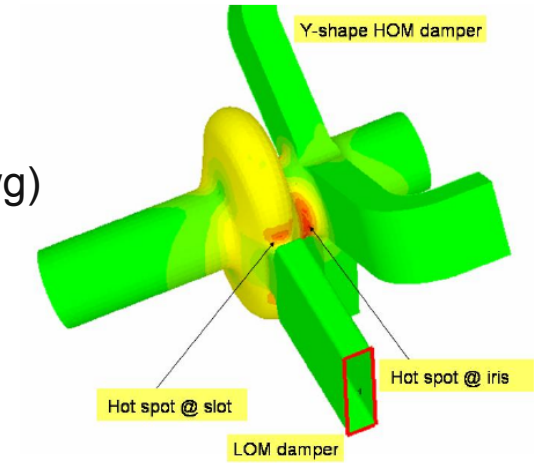
On-Cell Coupling

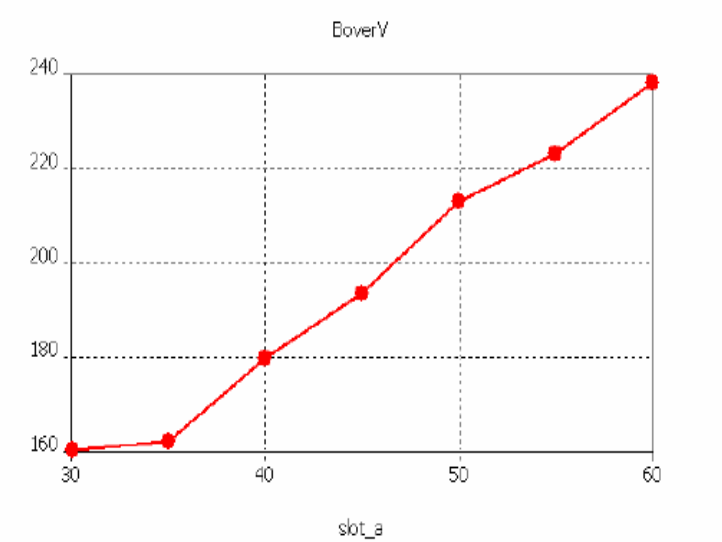


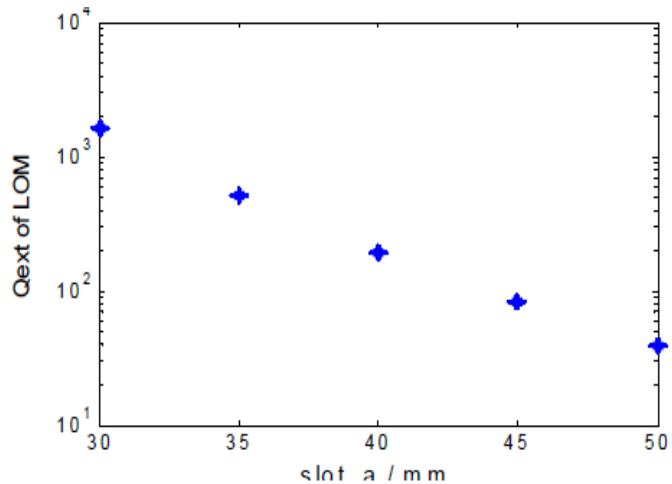
B_{neck}/B_{iris}~0.8

B_{max}/V_{def}= 157 mT/MV (single-cell)

= 240 mT/MV (sc+end wg)





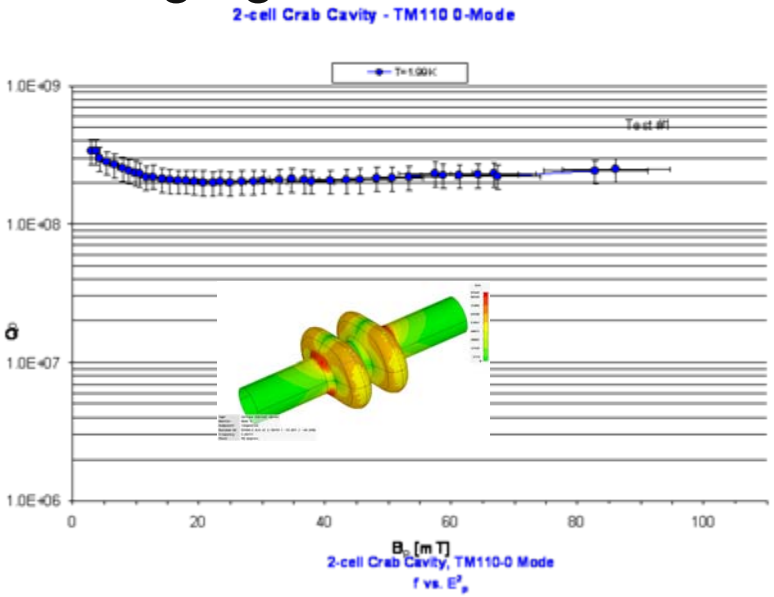


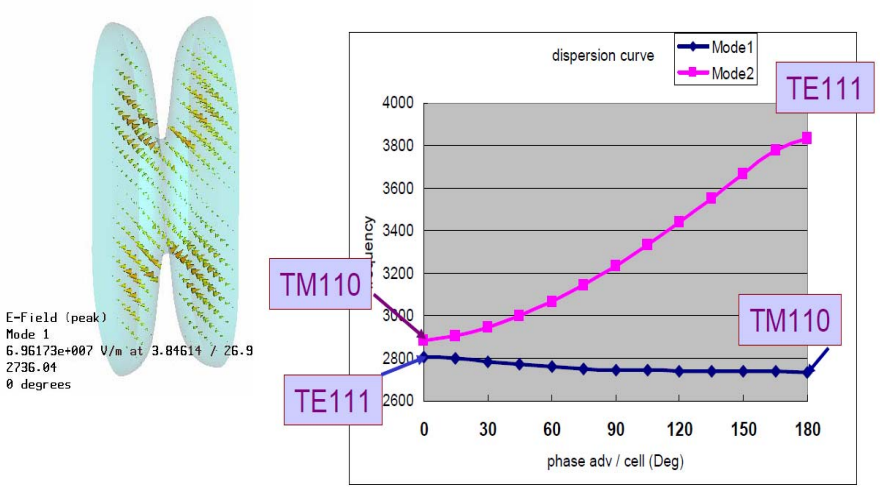
B_{max}/V_{def} and Q_{ext} with on=cell damper (w/o end group waveguide)

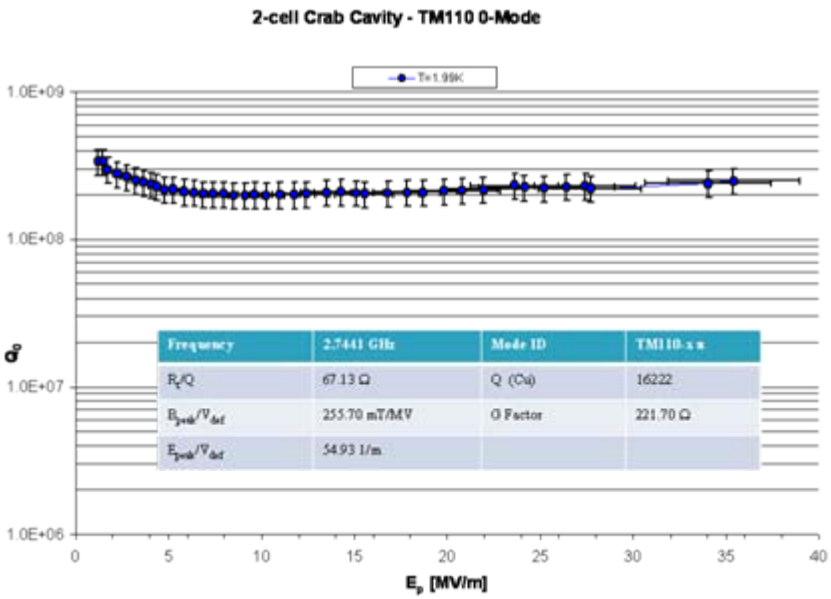
ANL/JLab collaboration

Multi-cell

- A 2-cell structure
  - Large grain Niobium





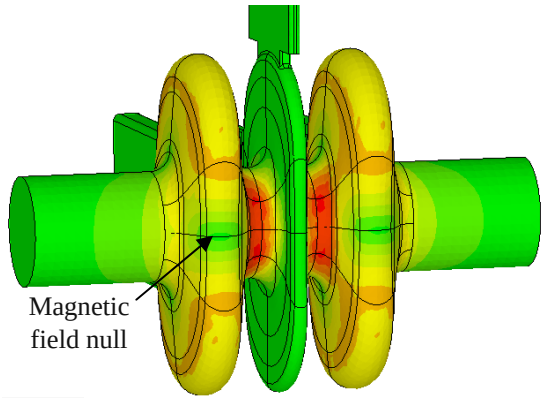


Frequency	2.7441 GHz	Mode ID	TM110-x x
R_t/Q	67.13 Ω	Q (Cu)	16222
B_{peak}/V_{def}	255.70 mT/MV	G Factor	221.70 Ω
E_{peak}/V_{def}	54.93 1/m		

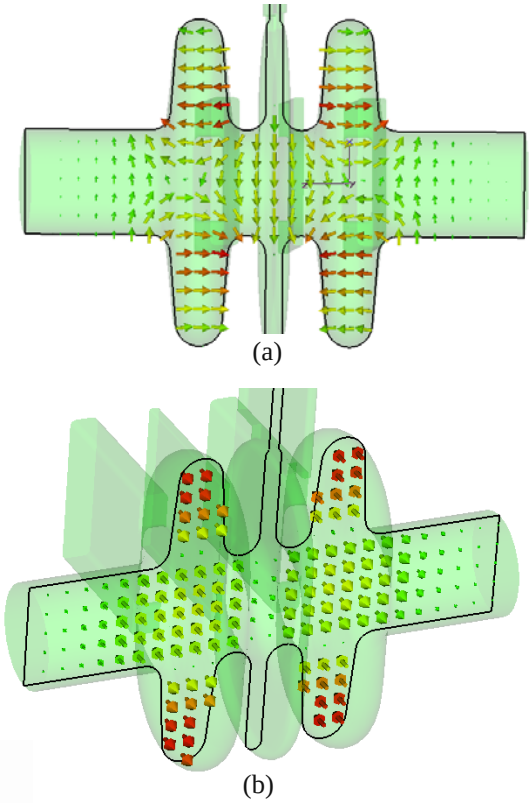
ANL/JLab collaboration

Continuing P&DV

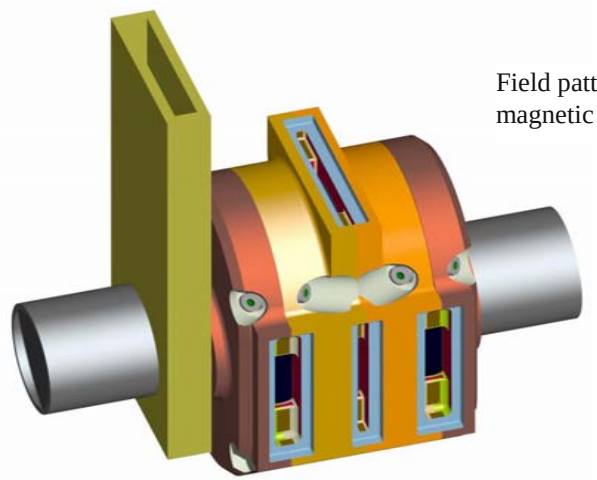
- 3-cell in $\pi/2$ mode
  - The dipole mode impedance in the passband of the operating modes are heavily damped by on-cell waveguide damper.
  - Stable across bandwidth up to 200 mA.
  - Worse case: 24B:
    - *1.2 kW parasitic loss @100 mA*
    - *5 kW @200 mA*
  - Promising



Provides improved packing factor



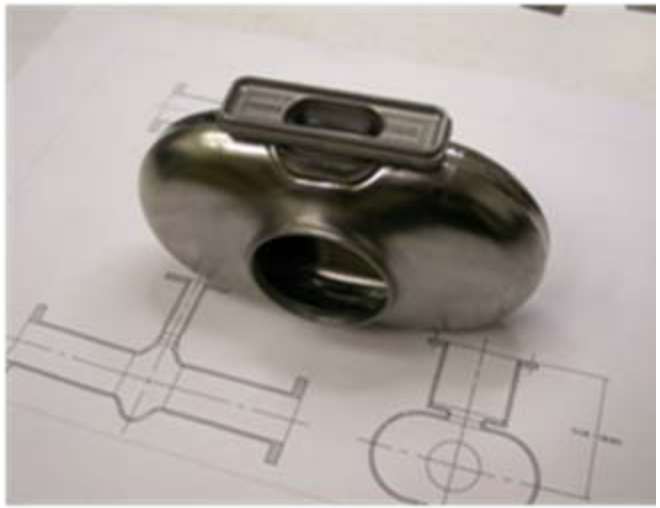
Field pattern for the $\pi/2$ dipole mode: (a) electric field (b) magnetic field.



Waldschmidt, Nassiri

Continuing P&DV (2)

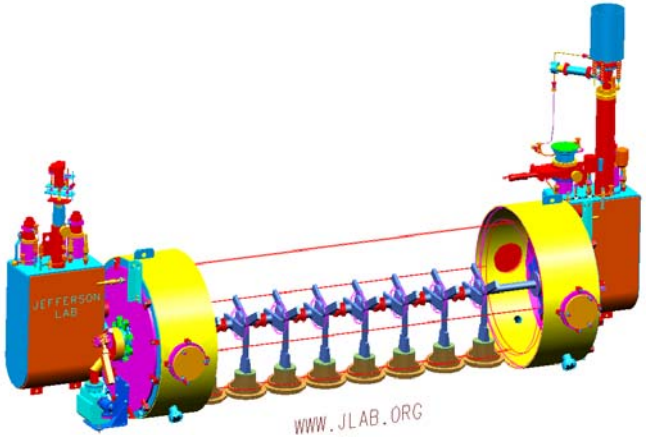
- Single-cell with on-cell damper
  - First cold test in early June 2009
    - *Significant multipacting*
    - *He processing underway*
    - *3D multipacting analysis underway*
      - *Tech-X*
      - *SLAC*

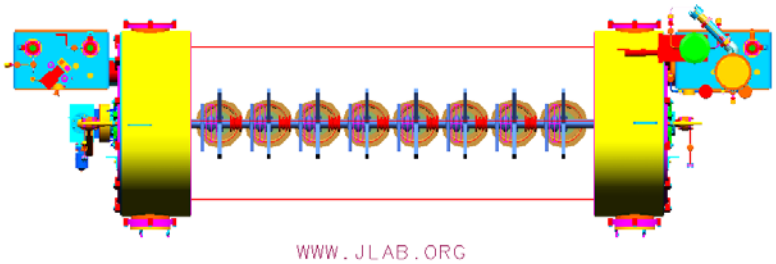


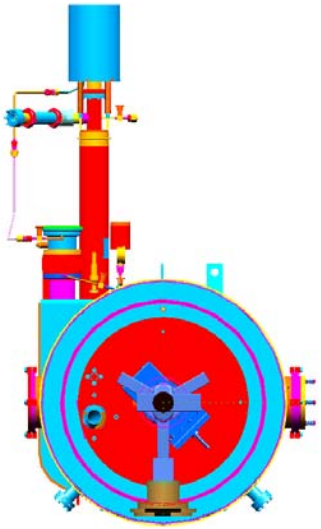
ANL/JLab collaboration

Continuing P&DV (3)

- Cryomodule concept







- 8 units per cryomodule
- 1 LOM damper per unit
- 3 HOM dampers per unit
- 1 FPC (combine with 1 HOM WG) per unit
- 5 kW klystron power (for 300mA@r=1mm) per unit
- 0.55 MV crabbing voltage (B_p=100mT) per unit
- 4.4 MV crabbing voltage per cryomodule
- 8 MV crabbing/un-crabbing voltage needed?
- 16 units needed on APS=2 cryomodules

ANL/JLab collaboration

Summary

- Significant progress since January 2007 on cavity design
  - Very encouraging results
  - On-going effort to improve cavities rf performance
- Continuing with prototyping and detailed simulation and analyzes
  - Debug and refine design
  - Valuable experimental data for computer modeling
    - *Multipacting and field breakdown*
  - Started to address other technical challenges
    - *Cryomodule*
    - *Low-level rf and control*
      - *Phase stabilized link*
        - *Transmitter, receiver and phase detector temp sensitivity have been measured. 300 meters of fiber optic cable tested in an environmental chamber. T, R and optical components in a temp controlled box @27degrees C.*
        - *Preliminary results: for a 3 degree C temp rise of the cable*
        - *Open loop: 6 degree, closed loop: 0.5 degrees @352MHz*
    - *Beam diagnostics*

Summary (2)

- SPX is part of the APS Renewal Plan.
  - CD0
- Initial cost estimate is done.
- Preparing for CD0-level cost profile.
- We hope to get FY10 LDRD fund to be able to continue on.
- Our goal:
  - First passive test of a fully assembled cryomodule in FY12.
    - *Local cooling*
    - *Some rf power (quasi-active)*
    - *Beam test*