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Normal-Conducting Radio-Frequency (NCRF) Deflecting Cavities at RadiaBeam Technologies

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Outline

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- **Company Overview**

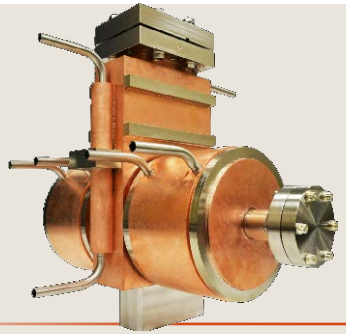
- **X-Band Traveling-wave Deflector (XTD)**
  - RF design
  - Machining, Cleaning, Tuning
- **S-Band Deflector for the Pohang Accelerator Laboratory (PAL)**
  - RF design
  - Machining, Cleaning, Tuning
  - Installation and initial beam measurements
- **Deflecting Cavity for "streaked"-UED project**
  - Normal-Conducting (RF design)
  - Dielectric (RF design)

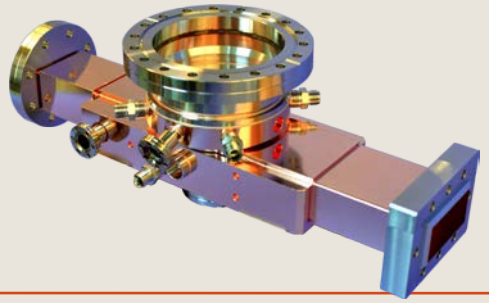
- **Dielectric Photonic Band Gap (PBG) Deflector**

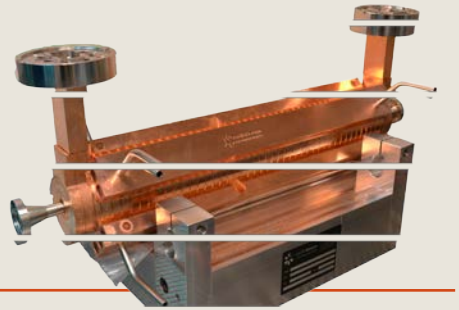
- **RadiaBeam resources and capabilities**

Company Overview

- RadiaBeam Technologies, LLC. is a small business with core expertise in accelerator physics.
- Spin-off from UCLA (2003)
- Extensive R&D Program (DOE, DOD, DHS, NSF)
- Growing products line for research laboratories and industrial customers (magnets, diagnostics, RF structures, complete systems)







Applications of RF Deflectors (or TCAVs)

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- Fourth-generation light sources (from VUV to hard X-rays) have achieved a dramatic improvement in important beam parameters such as brightness, coherence, and pulse duration.

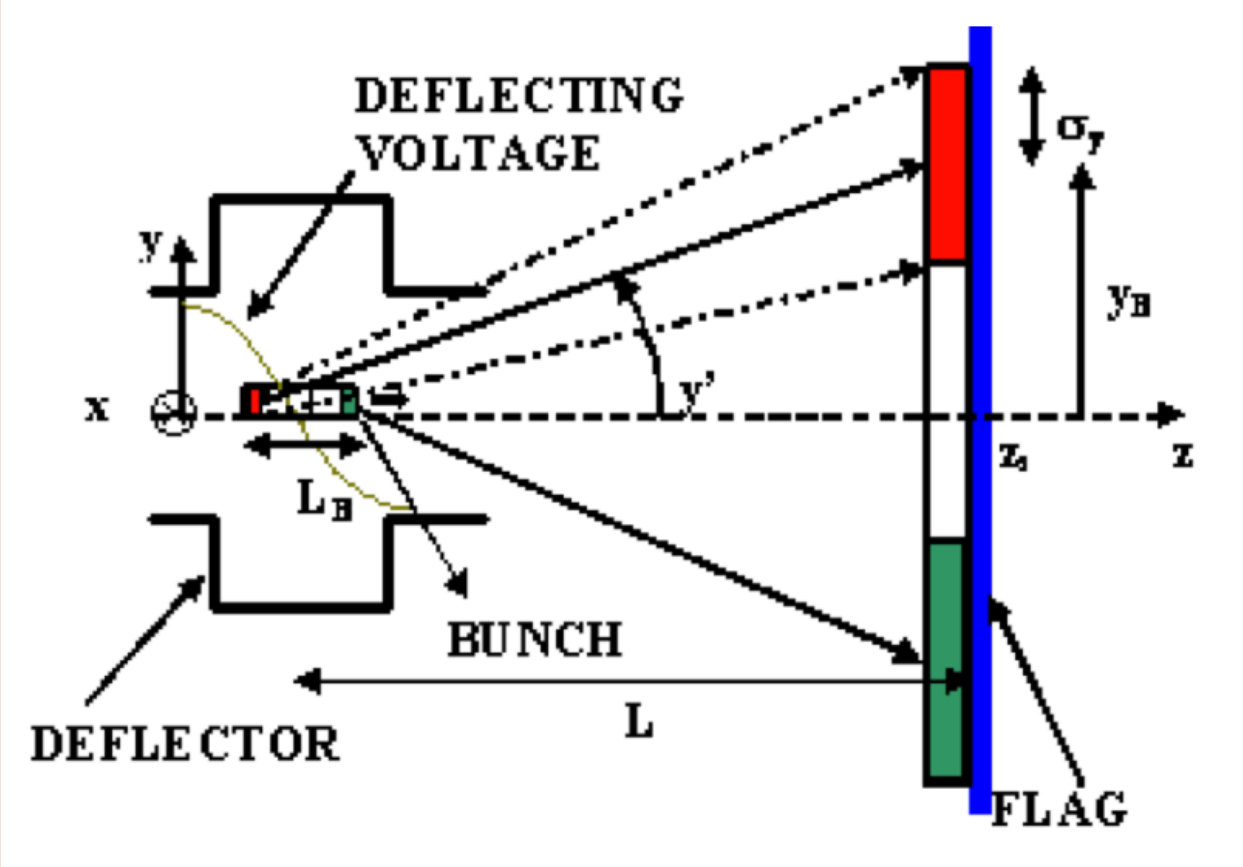
- In Linac-driven FELs, electron bunches have a typical length of a few hundred fs. Therefore, high-resolution (10's of fs) needs to be achieved by a certain device in order to clearly picture the longitudinal beam profile.

- RF Deflectors (or TCAVs) represent very powerful tools for the characterization of the longitudinal and transverse phase space and beam manipulation in advanced accelerators.

- TCAVs are fast and can achieve resolutions of the order of 1 fs.

Bunch length measurements
Longitudinal phase space measurements
Horizontal slice emittance measurements
Ultra-short bunch generation
Diagnostics with a circular polarized TCAV
Crab cavities for linear colliders
RF kickers
RF separators for $\pm$ particles
Etc…

Longitudinal to transverse correlation



$$\sigma_y = \sqrt{\sigma_{y0}^2 + \sigma_z^2 \beta_d \beta_s \left(\frac{2\pi e V_0}{\lambda p c} \sin(\Delta\psi)\cos(\varphi) \right)^2}$$

X-Band Traveling-wave Deflector (XTD)

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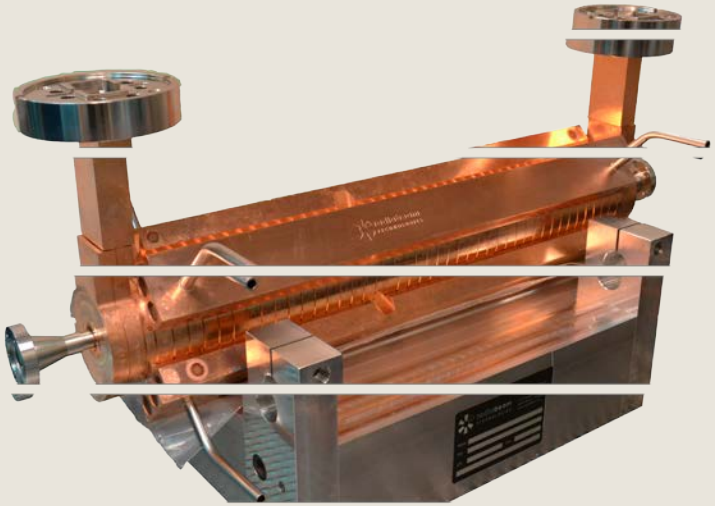
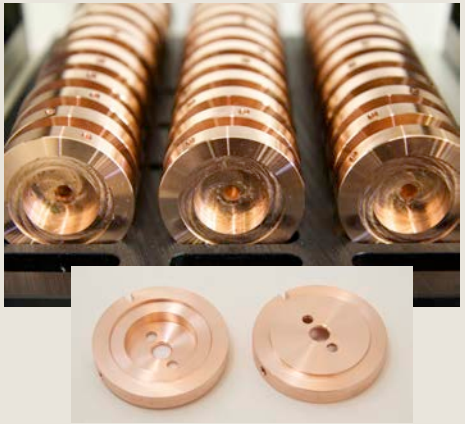
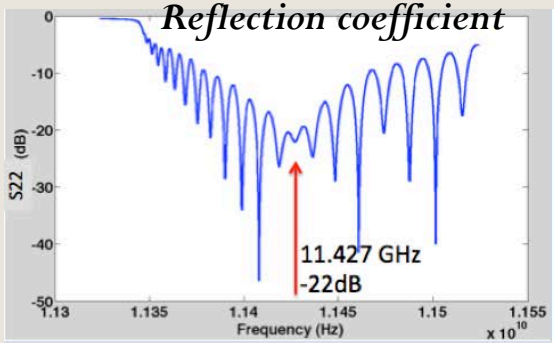
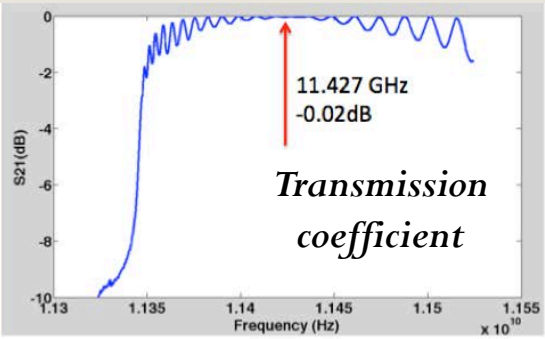


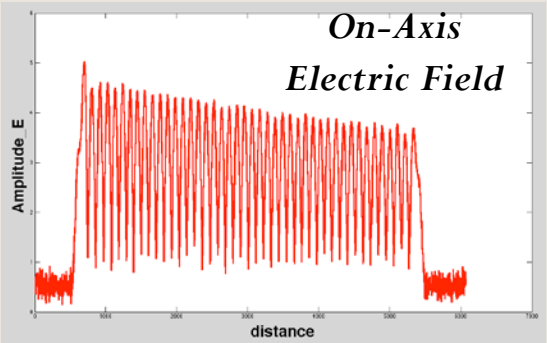
- In-house RF design and machining
- Brazing: close-by company
- Tuning at SLAC (Sept2012)
- At BNL waiting for high-power tests (spring 2014)

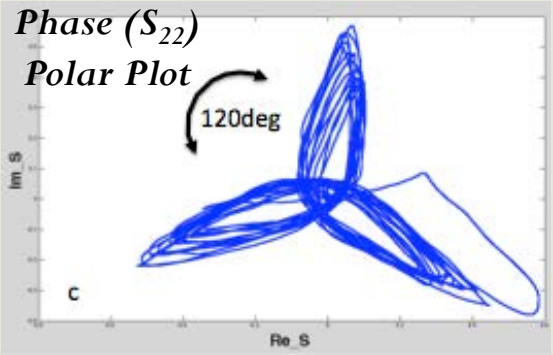


2π/3-mode frequency	11.424 GHz
Deflection Kick	8.5 kV/m/W$^{1/2}$
Attenuation	0.66 m^{-1}
Group velocity	0.027 c
Length	45 cm
Max. input peak power	20 MW



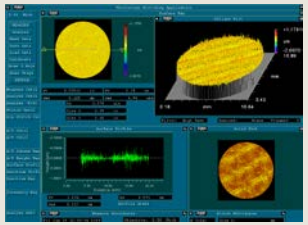


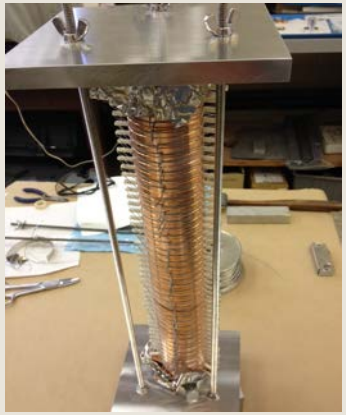




XTD: Machining and cleaning

43 main cells
2 couplers





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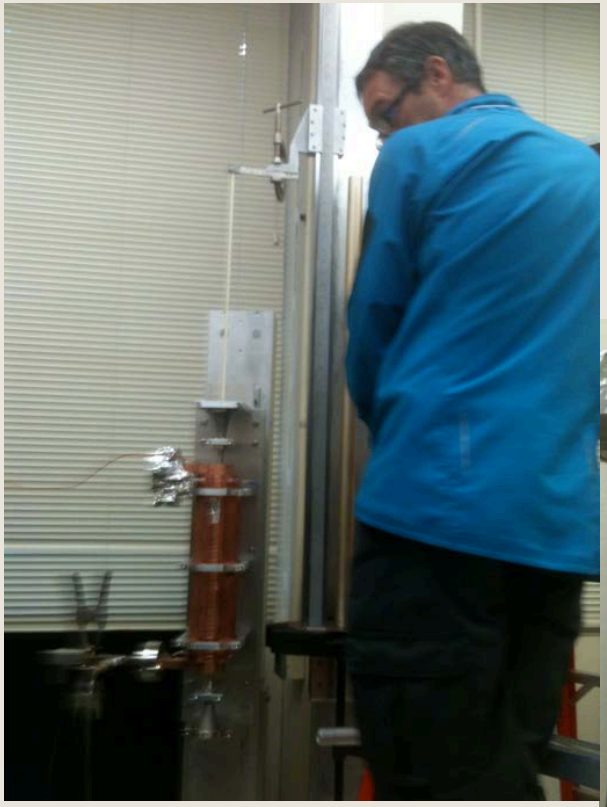
Plunger system

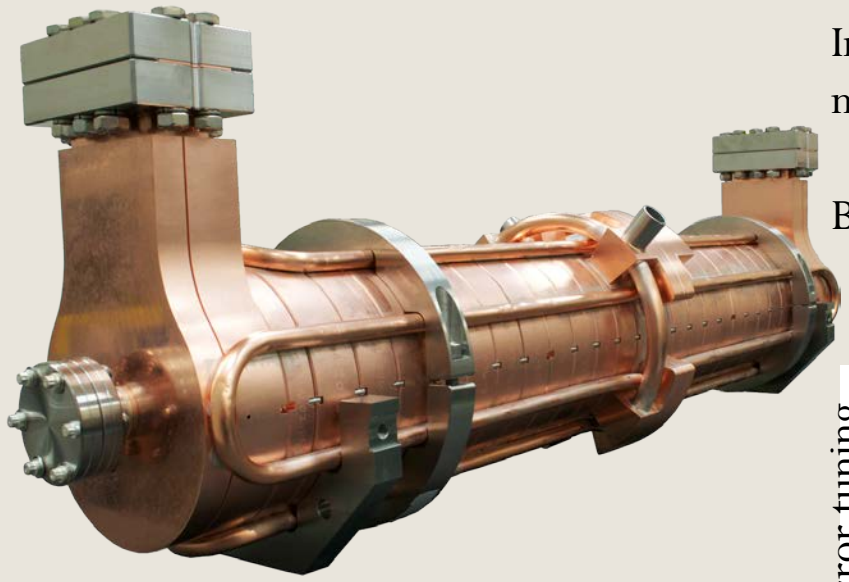
Alignment system



Bead-pull system

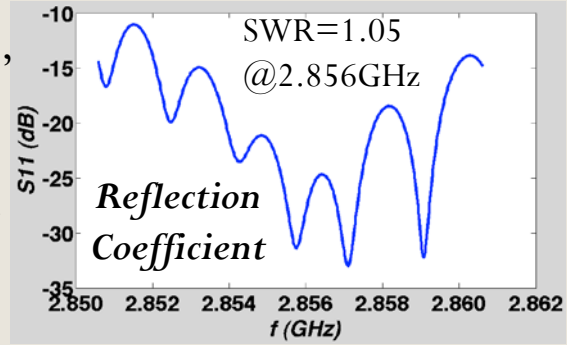
X-Band Deflector Tuning process

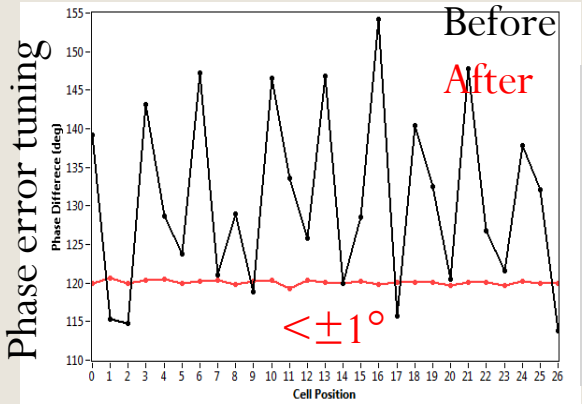
S-Band Deflector for the Pohang Accelerator Laboratory (PAL)

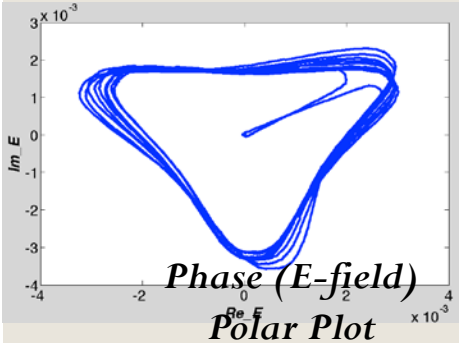


In-house RF design, machining and tuning

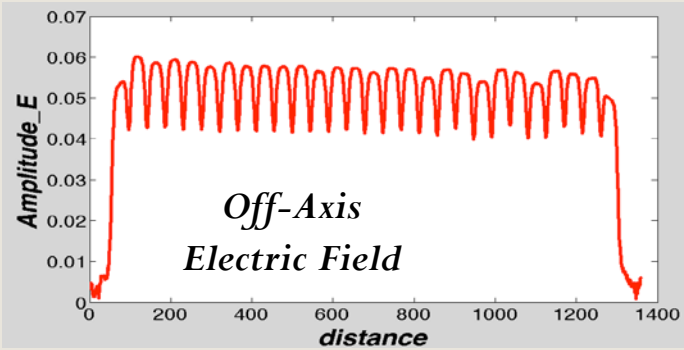
Brazing: close-by company



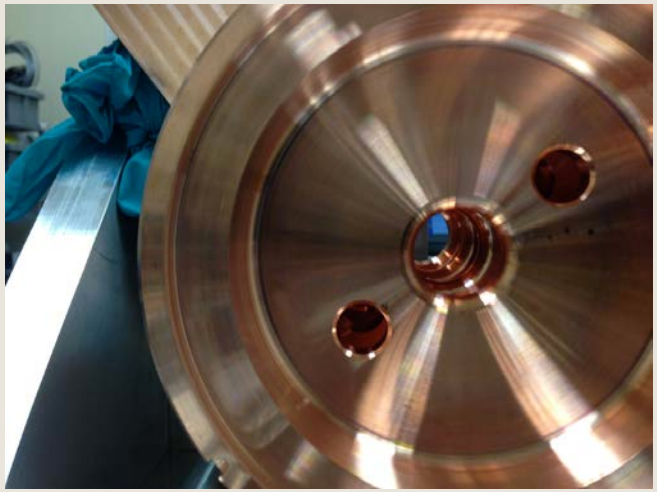




2π/3-mode frequency f	2.856 GHz
Transverse Shunt Impedance r_T	28.7 MΩ/m
Unloaded Q	13400
Attenuation α	0.15 m^{-1}
Group velocity v_g	0.014 c
Kick/√Power	2.7 MV/√MW
Length	1 m



PAL deflector : Machining and cleaning



23 main cells
2 couplers

PAL deflector – initial beam measurements

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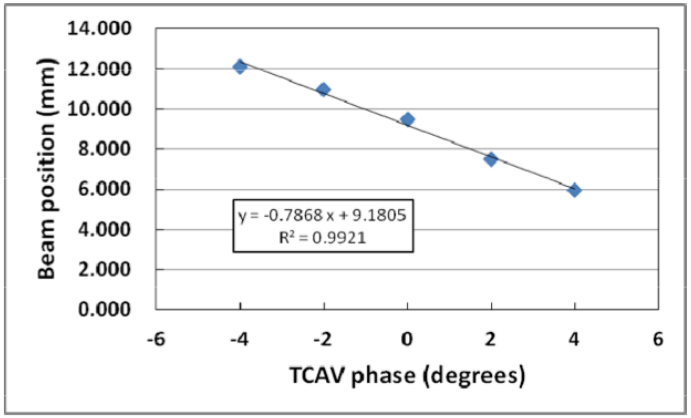
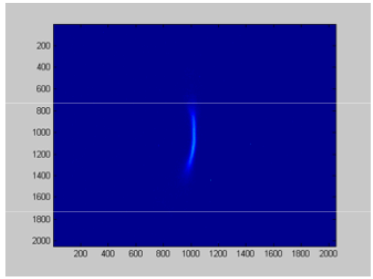
S-Band deflector installed at the Injector Test Facility (ITF) for the PAL XFEL

Bunch Length measurement at ITF

Initial low power (few kW) measurements of a 1.53 ps long beam.



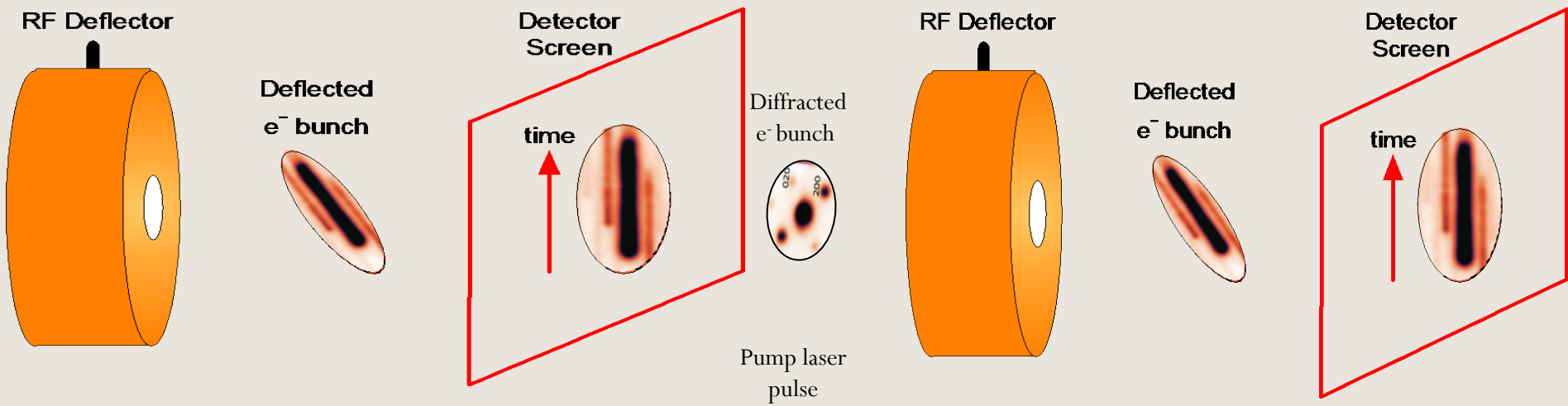
parameter	value
Laser inj. ph.	35 °
Beam energy	85.6 MeV
Beam charge	200 pC
TCAV RF power	0.137 MW



TCAV phase (degrees)	CM in Y (pixel)	beam position in Y (mm)	beam size in Y (μm)
4	716	5.943	1268.55
2	901.2	7.480	1267.40
0	1139.7	9.460	1238.08
-2	1317.9	10.939	1226.97
-4	1455.6	12.081	1262.24

(rms bunch length)
~ 1.53 ps
~ 0.456 mm
~ 1.57 degS

Streaked-UED (SUED) System



Originally proposed by P. Musumeci et al., P. Musumeci et al. *RF streak camera based ultrafast relativistic electron diffraction*. Review of Scientific Instruments (2009) vol. 80 pp. 013302

Ultrafast electron diffraction (UED) has the potential for real-time imaging of structural changes on atomic length scales, thus promising to make a profound impact on a large area of science including biology, chemistry, nano and material sciences

Innovations

- Compromise between Conventional and Relativistic UED systems
- Same physics of current UED systems but cheaper and more compact
- UED measurements in small laboratories

Main Parameters

Electron Energy	100 keV
Number of electrons/pulse	10^7
Pulse Length (at the sample)	20 ps
Deflector RF power	1 kW
Deflector Nominal Voltage	20 kV
Temporal Resolution of System	30 fs

NCRF Deflecting Cavity for SUED: RF design

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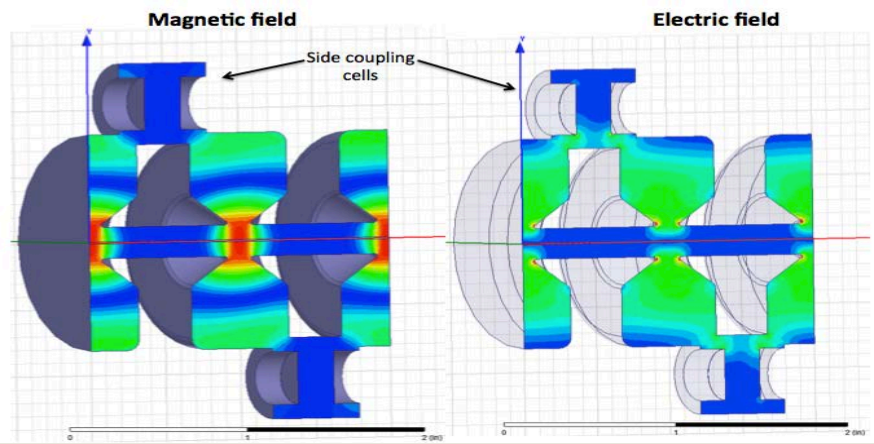
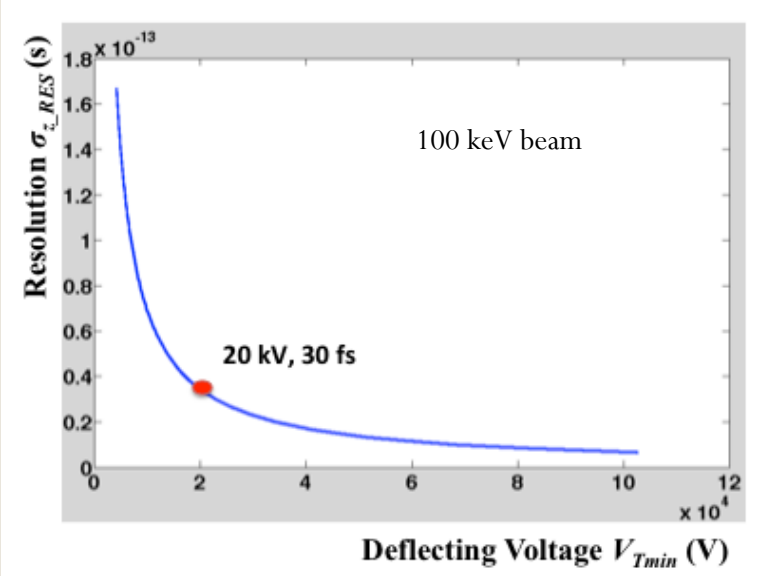
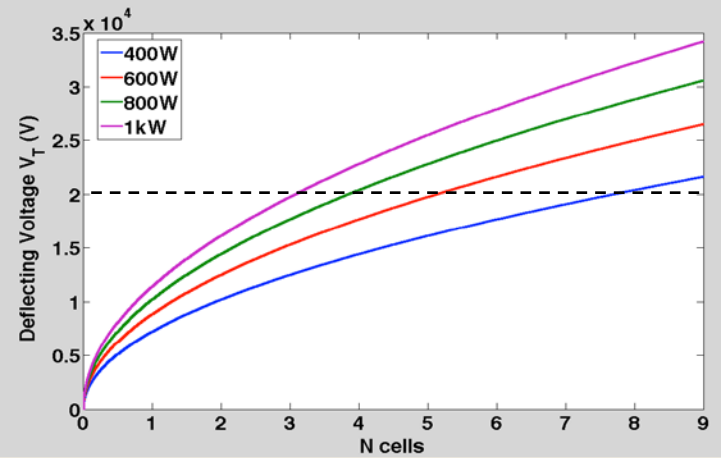


Optimized cell geometry. The use of nose cones allows the concentration of the field toward the center of the deflecting gap, which creates a stronger field and better deflection, especially in our case of slow electrons (β=0.54).



RF parameters (single cell)	Value
Frequency	9.3 GHz
β (E=100keV)	0.54
Transverse Shunt Impedance R_T	0.13 MΩ/cell
Q unloaded	9,200
Beam Pipe aperture (dia)	0.22in
Kick/sqrt(power)	0.36 kV/sqrt(W)

Number of cells	Required input RF Power
N=3	P_{in}=1kW
N=5	P_{in}=600W
N=7	P_{in}=400W



Deflecting Cavity for SUED : engineering

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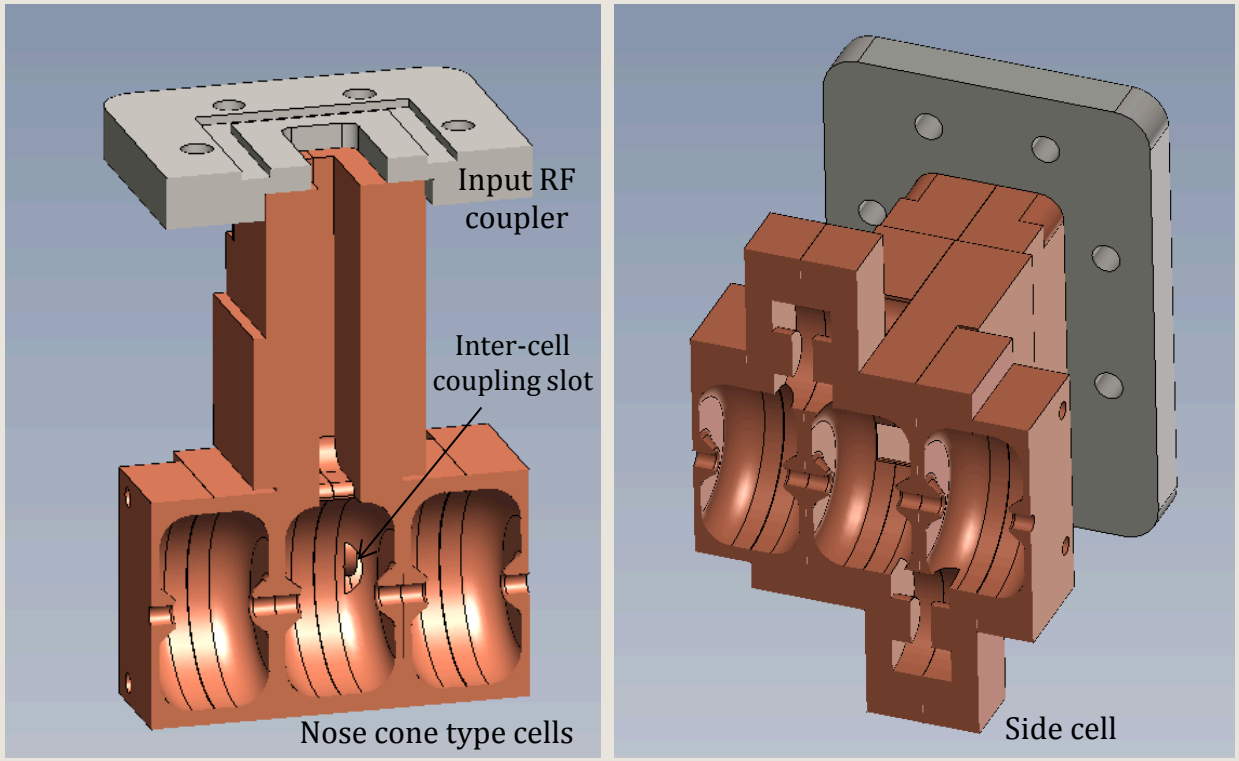
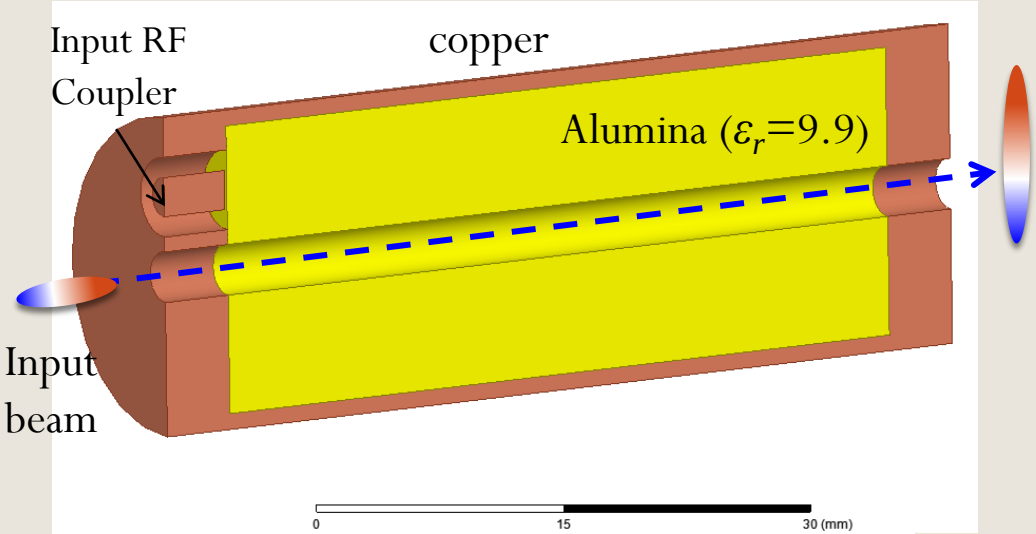
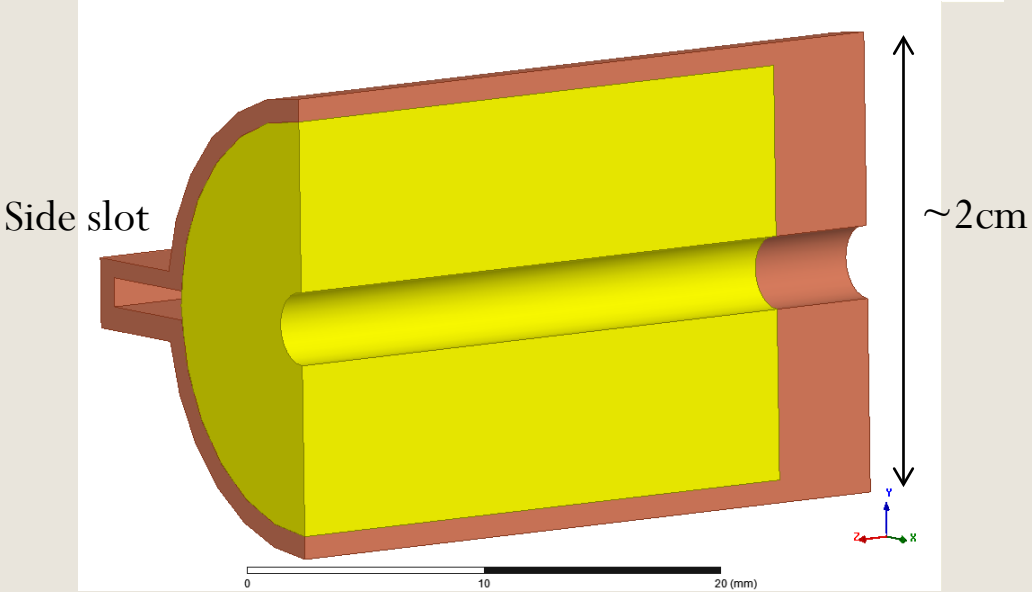
Sub-task	Objective
1. Engineering	Complete engineering of deflector, based on design generated in Phase I.
2. Fabrication	Fabricate the deflector
3. Cold-testing	Ensure proper RF performance during fabrication process
4. Cleaning	Prepare parts for brazing
5. Brazing	Braze deflector
6. Tuning	Tune deflector
6. Power tests	Deflector conditioning



3D model of the X-Band Deflector, from SolidWorks

Dielectric Deflecting Cavity for SUED

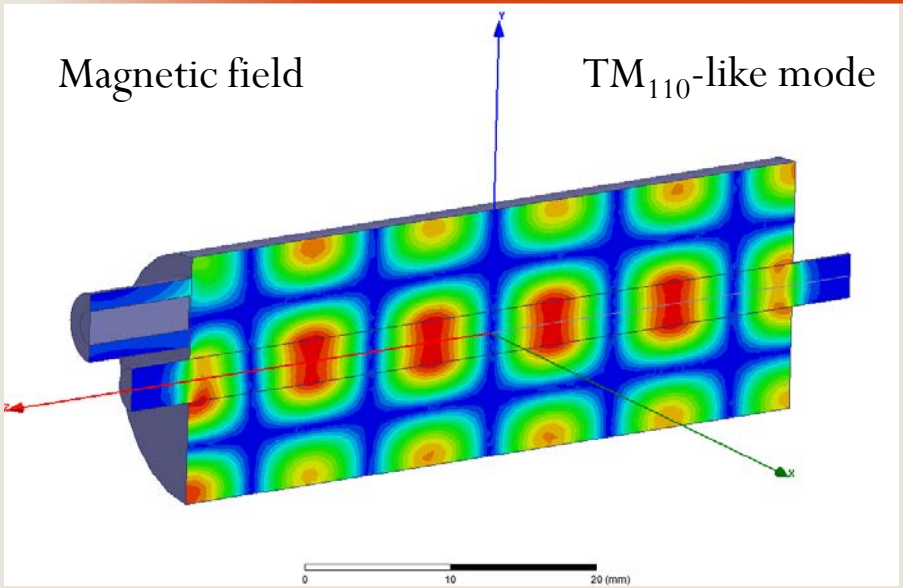


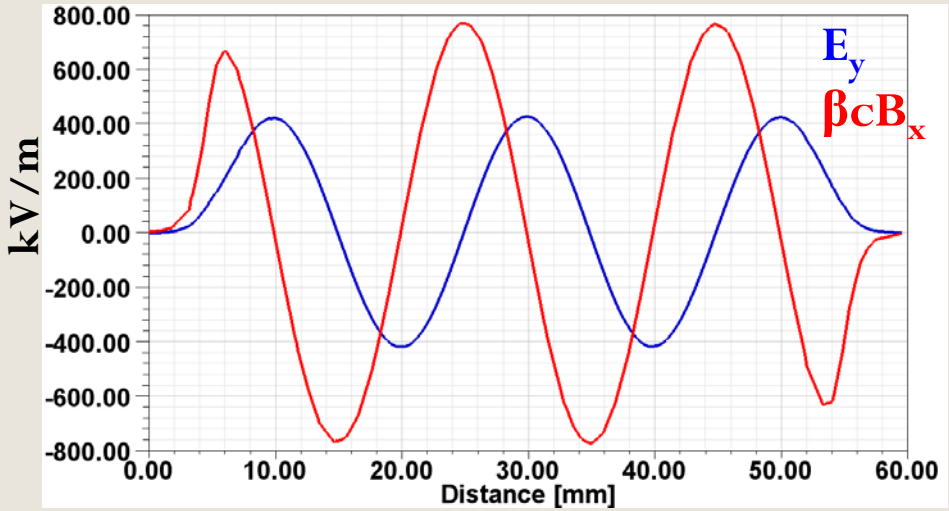


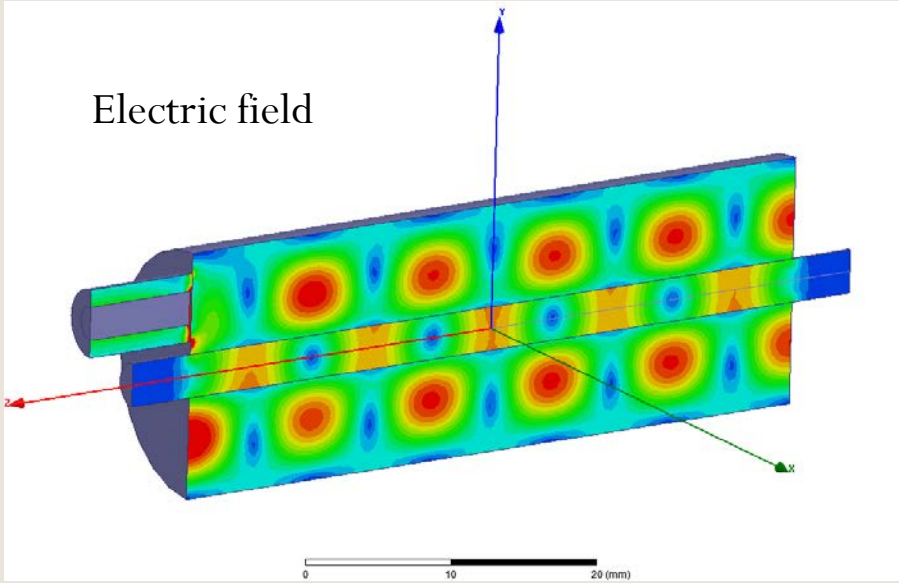
- SW cavity
- Input RF power: SMA cable+ RF probe
- Side slot for stabilization of desired mode polarization
- Copper electroformed around alumina tube
- Alumina: 99.5% purity, +/- 0.05 mm tolerance

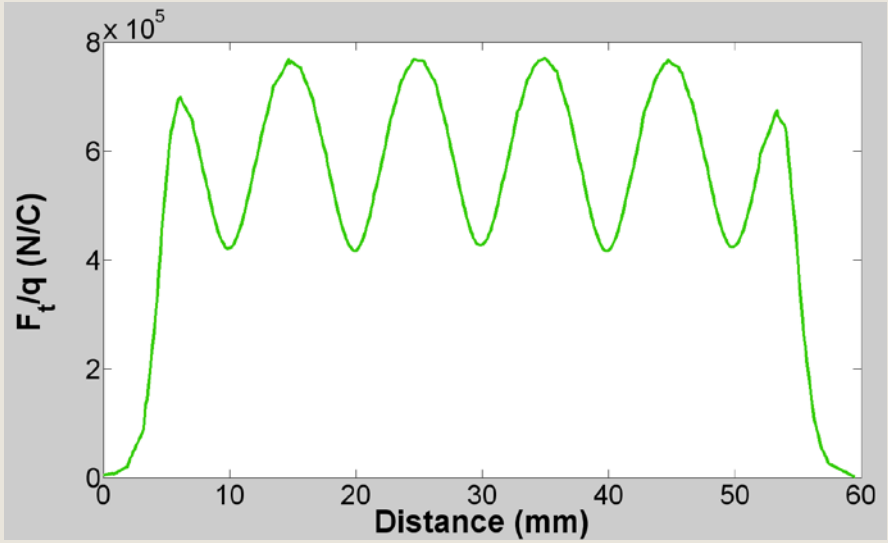
Frequency	8.2 GHz
Unloaded Q_0	10,000
Beam energy	100 keV (β=0.54)
Beam bore diameter	3.17 mm
Length	6 cm
Deflecting Voltage	30 kV
Kick/Power$^{1/2}$	1.57 keV/W$^{1/2}$
RF input power	400 W

Dielectric Deflecting Cavity for SUED: RF design









Dielectric PBG deflector

- Photonic band gap structure: a one-, two- or three-dimensional periodic metallic and/or dielectric system (for example, of rods), which acts like a filter, reflecting and then trapping RF fields in some frequency range and allowing RF fields at other frequencies to transmit through.

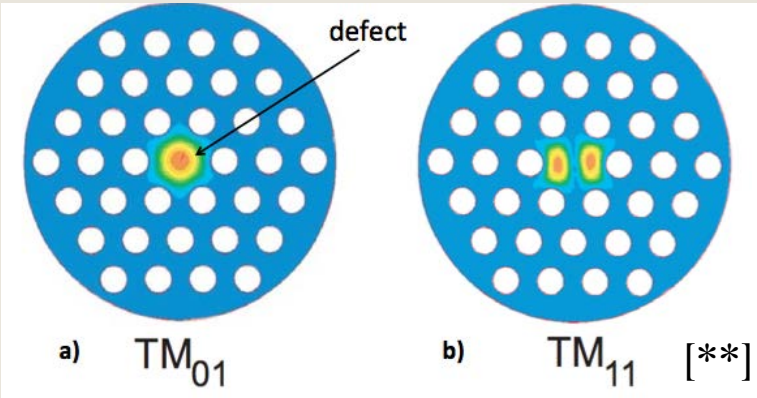
- ***Band Gap***: the range of frequencies which does not propagate through the periodic structure.

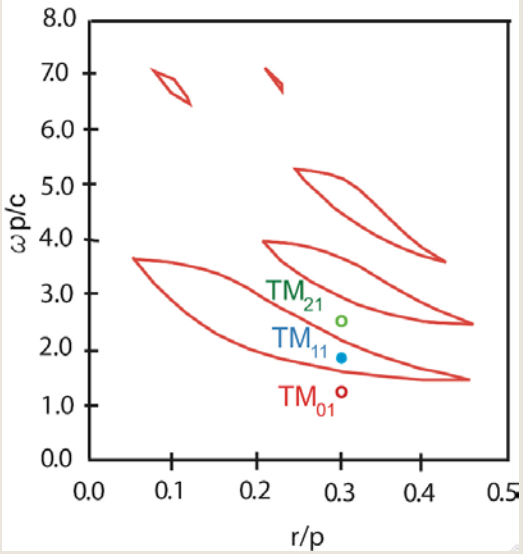
- Suppression of not only HOMs but also LOMs by varying the size of the rods by using dielectric rods instead of metallic inside a PBG device [*].

- Biggest advantage of the PBG structures: more effective with regards to filtering out parasitic modes.

- Breakdown and charging can be mitigated with the proper choice of dielectric material

- Collaboration with Evgenya Simakov (LANL)





band-gap diagram of a dielectric PBG. The frequency of the operating mode (dipole TM_{11}) as a function of the ration r/p together with the LOM and the first HOM [courtesy of E. Smirnova].

* M.A. Shapiro et *al.*, Theoretical Analysis of Overmoded Dielectric Photonic Band Gap Structures for Accelerator Applications, Proceedings of the 2003 Particle Accelerator Conference.
** E. I. Smirnova, *Novel Photonic Band Gap structures for accelerator applications*, PhD Thesis, MIT 2005

Dielectric PBG deflector: preliminary RF simulations

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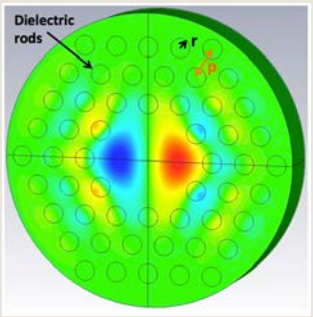
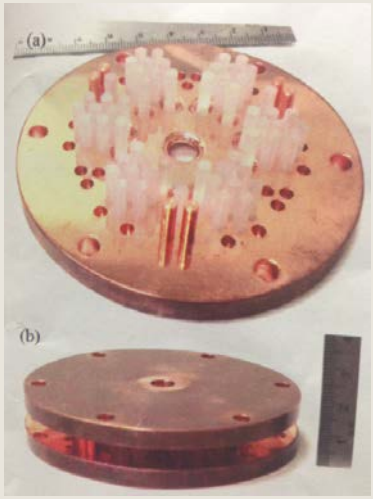
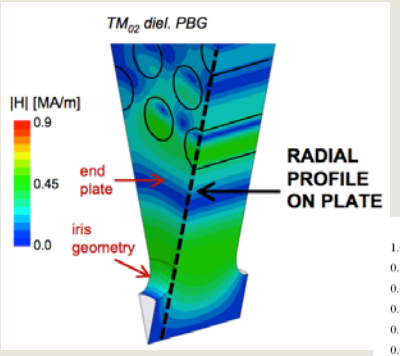
- 3D surface model of a standing-wave deflecting cell unit (from CST Studio, courtesy of E. Simakov)

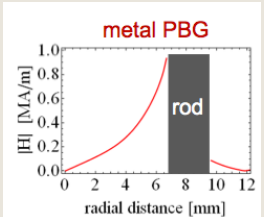


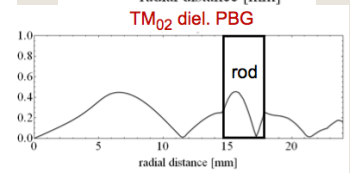
- hybrid PBG (metal and dielectric rods) accelerating structure recently machined at MIT [NAPAC13 paper]. This structure was cold-tested with a clamped set-up but not brazed yet for high-power tests.

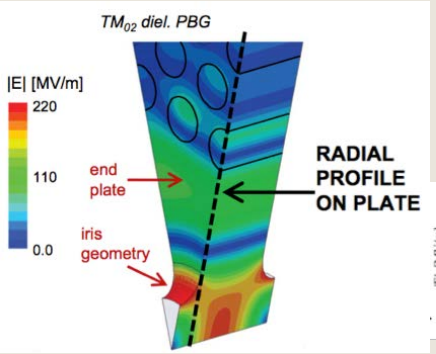


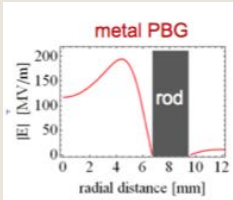
- by using dielectric rods instead of metallic, it is possible to decrease the surface peak magnetic field on the rods themselves by more than a factor of 2 !!!

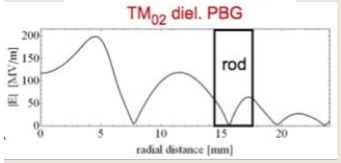












M. Shapiro et al., Design of dielectric and metallic PBG structures, at US High Gradient Research Collaboration Workshop 2011, SLAC

RESOURCES AND CAPABILITIES

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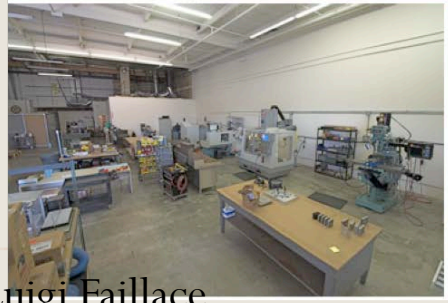
- Enhanced engineering/manufacturing capabilities
  - New Facility + recent expansion
  - New Equipment
- Studied and Developed RF manufacturing process workflows
- Increased RF testing/validation capabilities
- Developed custom UHV/RF component cleaning and assembly facilities
  - Following SLAC developed guidelines
  - Presents us with full control over *almost* all critical processes (no oven)
- Collaborations with Universities and National Laboratories



Cell Machining and Cleaning

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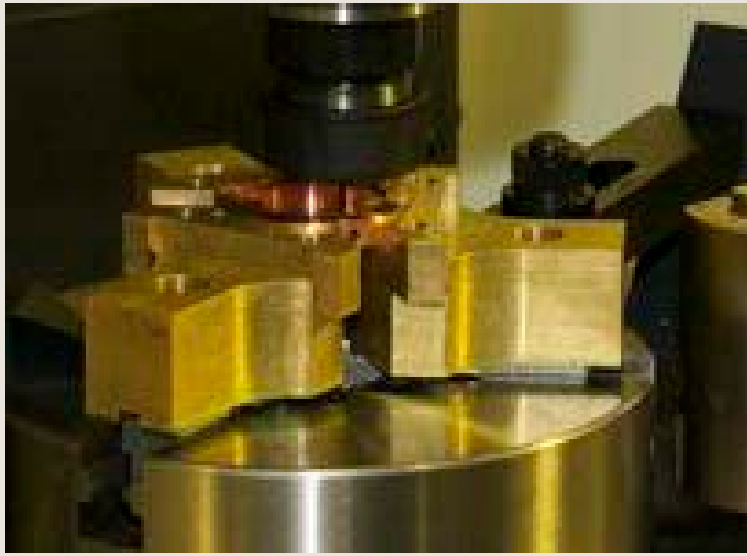
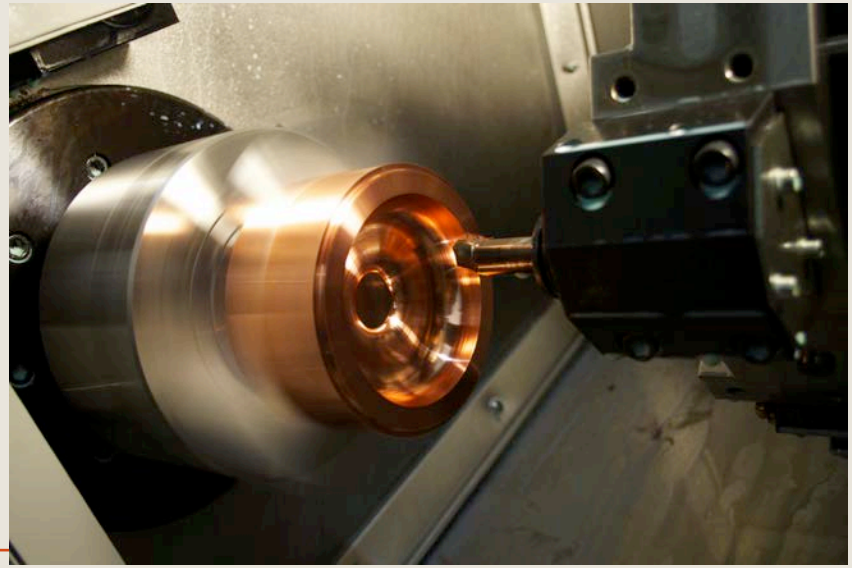
- CNC mills and lathes
  - Capable of 0.0002" precision and repeatability (lathe)
  - 2-4 micron flatness
  - 4-6 micro-inch surface finishes (100-150nm)
  - Developed specialized workholding tooling
  - Optimized cutting tooling (PCD)
  - Refurbished or manufactured storage and travel containers
  - Considerable man-hours invested into process and handling systematics
- Chemical cleaning room
  - With guidance from SLAC MFD
  - Utilize a modified version of SLAC cleaning processes
- Clean Assembly / Testing Room
  - Class 100 / Class 1000





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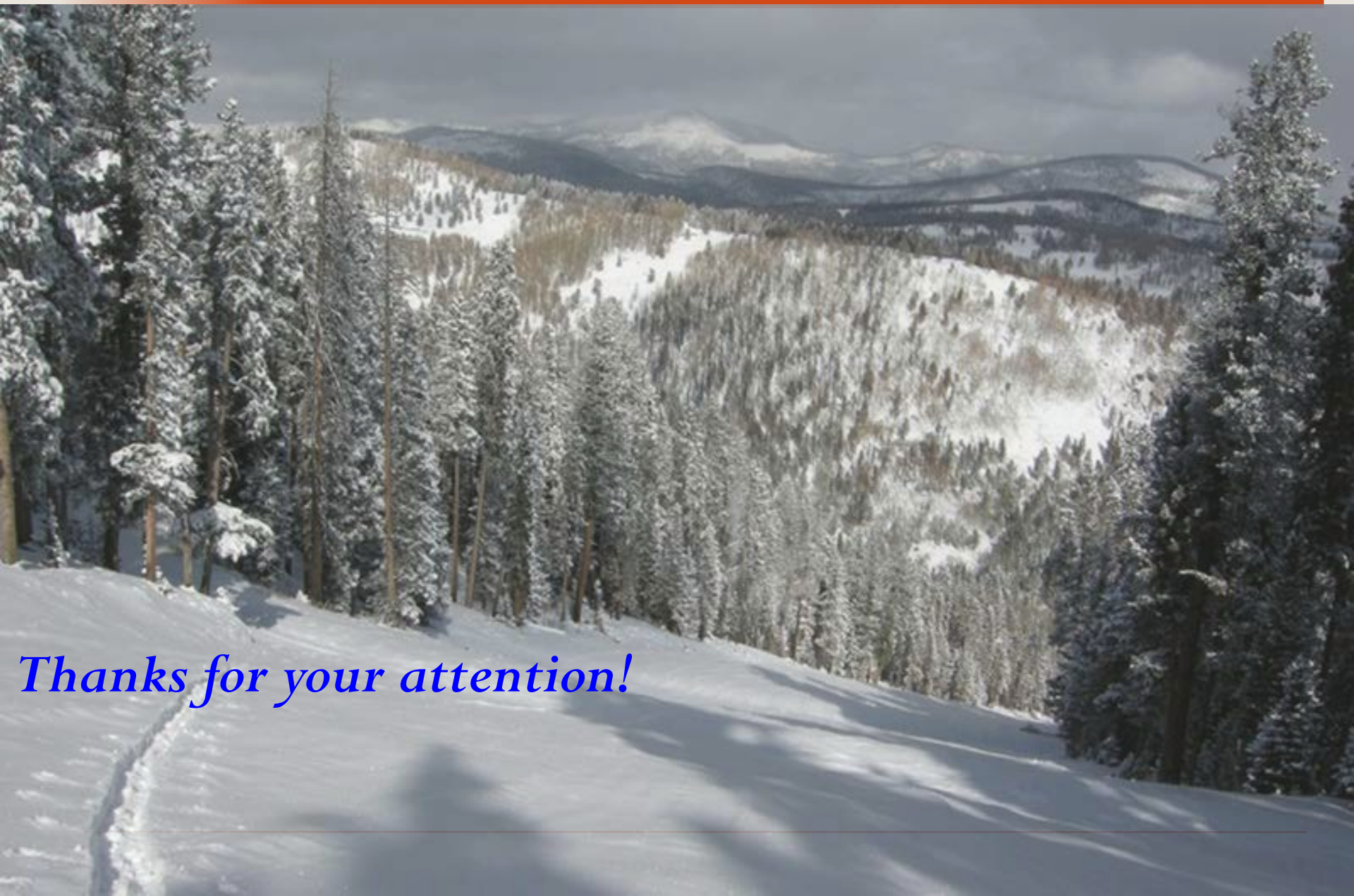

Thanks for your attention!