NEW 1.4 CELL RF PHOTOINJECTOR DESIGN FOR HIGH BRIGHTNESS BEAM GENERATION

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OUTLINE

- Introduction
- SPARC 1.6 cell photoinjector
- Beam dynamics
- Clamping technique
- 1.4 cell photoinjector design
- Future plans
- Conclusion

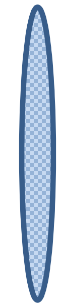
INTRODUCTION

Goal: To improve beam brightness in several operating regimes by increasing the extraction field, $E_o = E_{peak} * sin(\square_o)$, while maintaining a low breakdown probability

- High brightness beams needed for X-FEL, ultrafast electron diffraction, inverse Compton scattering, high power THz generation, etc..

"PANCAKE"

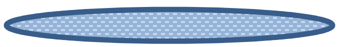
$L_T \gg L_Z$



- In pancake regime, the 4D beam brightness, $B_{n,4D} = \frac{mc^2 \epsilon_o \boldsymbol{E_o}}{2\square k_B T}$.

"CIGAR"

$L_Z \gg L_T$



- In cigar regime, the 4D the emitted charge $\square \boldsymbol{E_o^{1.5}}$

- Use new fabrication techniques.

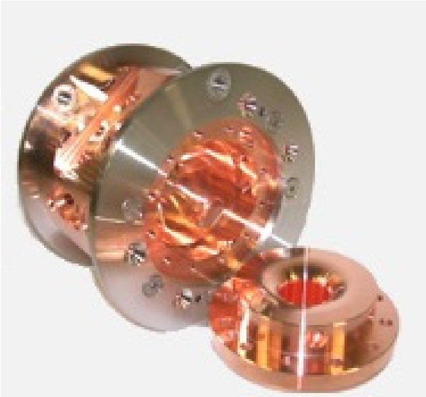
Approach: Increasing the optimal launch phase.

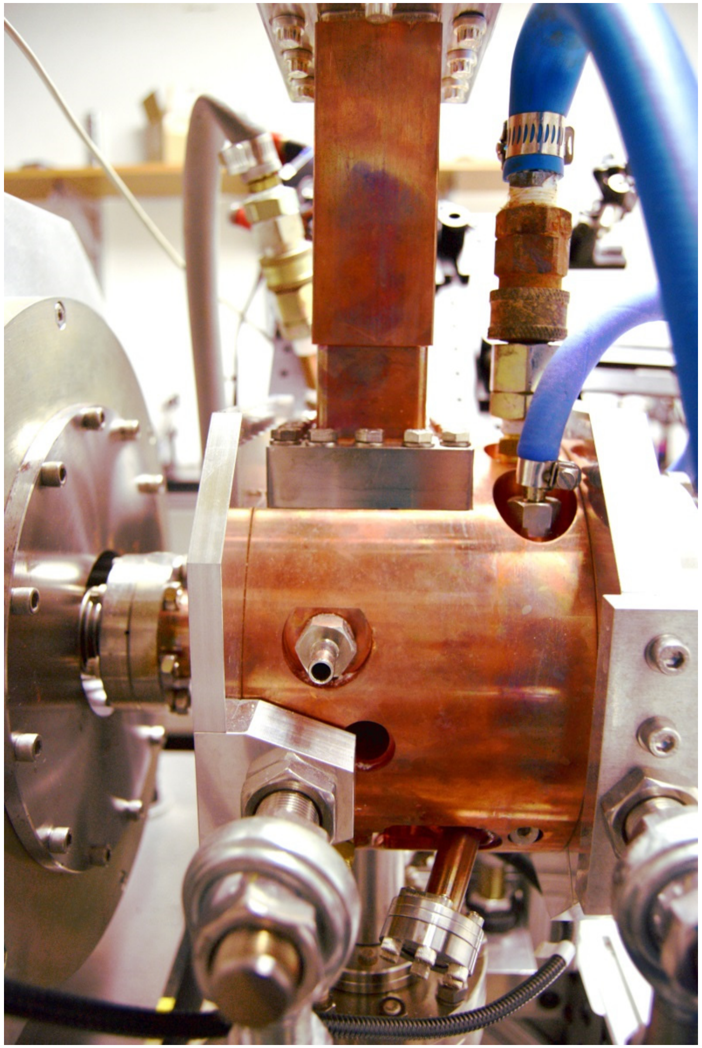
- Shortening the first cell minimizes the phase slippage.

SPARC S-BAND 1.6 CELL PHOTOINJECTOR

The SPARC 1.6 cell photoinjector was realized and tested at the Pegasus Lab (UCLA).

- Designed for operating gradient of 120MV/m
- High power tests were performed with XK5 klystron. Maximum power of 10MW at a repetition rate of 5Hz. Commissioned up to 95 MV/m
- Conditioned with pulses down to 1.5μs.
- New fabrication technique. Lower breakdown probability.
- New geometries improved electromagnetic design.

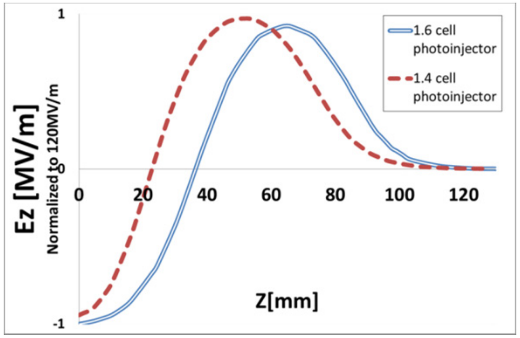


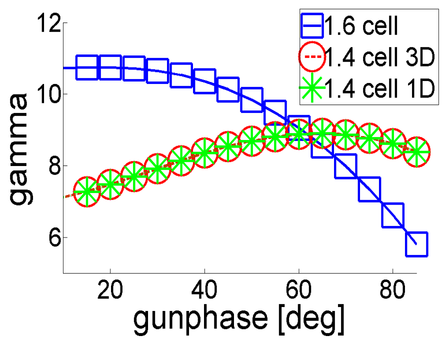


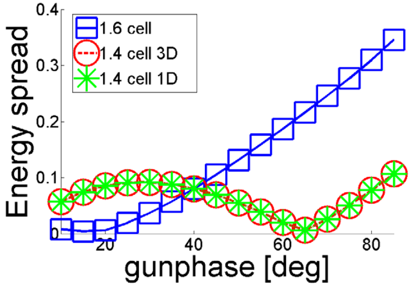
BEAM DYNAMICS

- SPARC first cell length is 36.45mm with an optimal launch phase of $\square_o = 30^o$, typical of 1.6 cell photoinjectors .

- The new shortened 1.4 cell photoinjector has a first cell length of 22mm with an optimal launch phase of $\square_o = 70^o$.







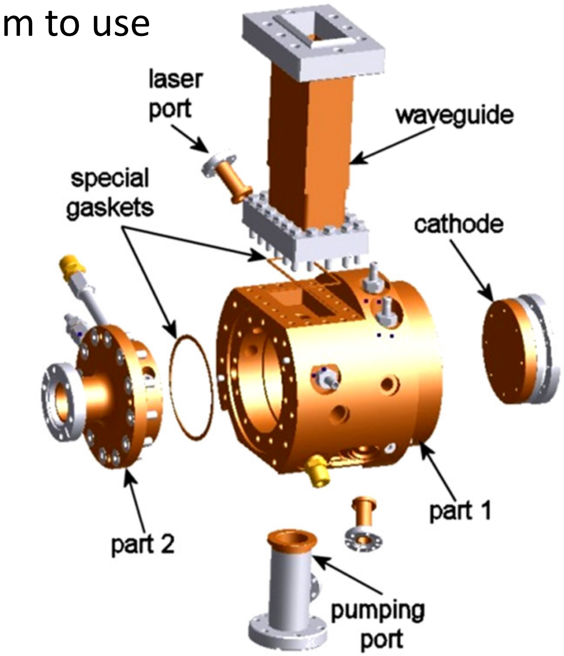
- The extraction field improves by a factor of $\frac{\sin 70^o}{\sin 30^o} = 1.9$.

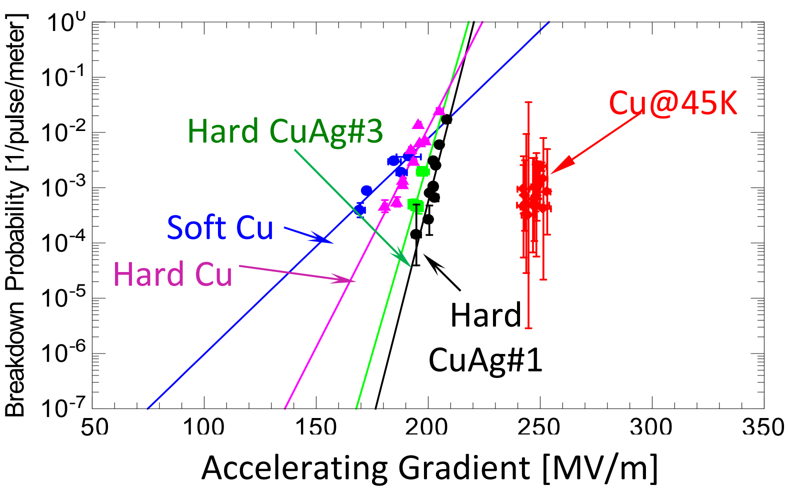
- The energy spread is minimum between $65^o - 70^o$ as expected.

CLAMPING TECHNIQUE

LNF developed special gaskets that guarantee RF contact and seal vacuum to use a clamping technique and avoid brazing. Why?

- Expensive
- Requires large vacuum furnaces
- High-risk procedure
- Makes copper 'soft'





Courtesy of *V. Dolgashev, S. Tantawi*

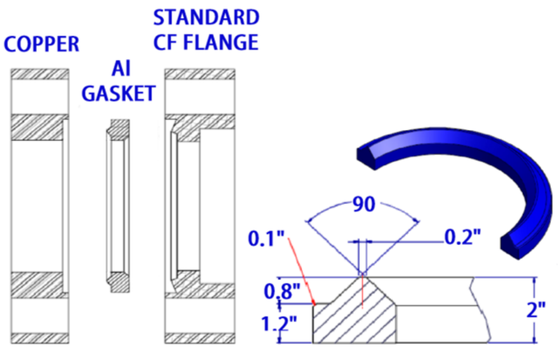
- The material properties in structures operating at high gradients affect the breakdown probability.
- Hard copper shows significant improvement over 'soft' copper at the operating gradient of 120MV/m.

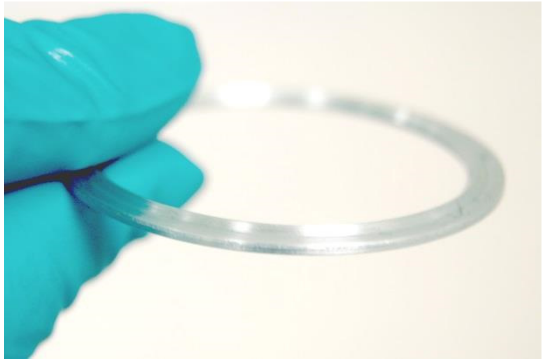
MECHANICAL DESIGN

- Main cavity is made of a central single piece of OFHC copper
- Part 1 belongs to the body of the central piece and contains space for fitting the cathode.
- Part 2 seals the full cell using a special gasket designed at LNF-INFN. The gasket guarantees RF contact and vacuum sealing.
  Patent: PCT/IB2016/051464

- Aluminum vacuum sealing gaskets were designed at UCLA. Seals copper and stainless steel.

- Compatible with standard CF flanges of various sizes.





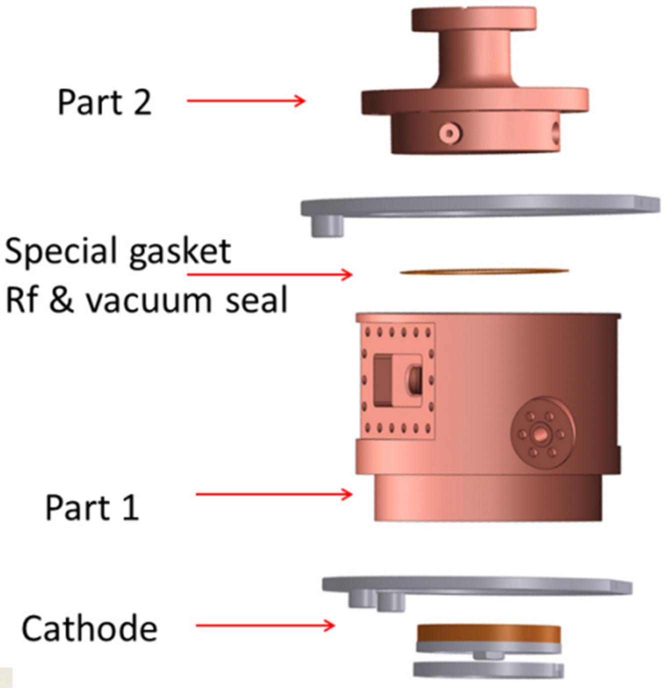
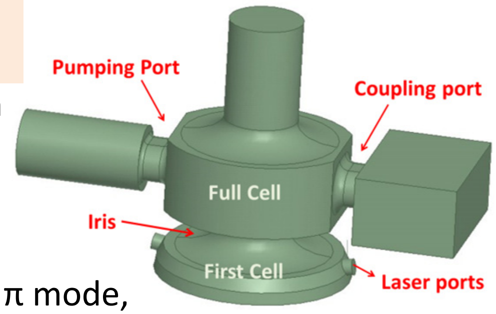


Fig. 1 Assembly Schematic

ELECTROMAGNETIC DESIGN

Main Cavity Features

- Operating gradient of 120MV/m with pulses ~2µs.
- Iris shape is elliptical with ratio $\frac{b}{a} = 2$.
- Iris diameter of 36mm.
- Mode separation between the 0 and π mode, $\Delta 50MHz$.



Full Cell Ports

- Ports have racetrack shape.
- Strongly rounded edges for max H_{surf} of 420kA/m.
- Pulse Heating for 2µs pulse, ΔT <60^{o}C.
- Coupling β=1.7
- Two ports : Coupling port and additional pumping port. Symmetric to compensate for dipole moment.

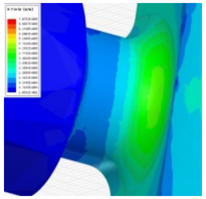
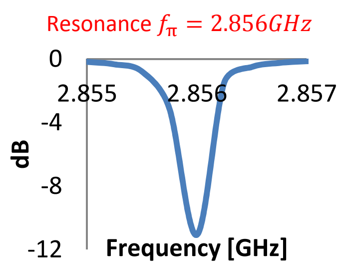


Fig. Surface plot of H_{surf}



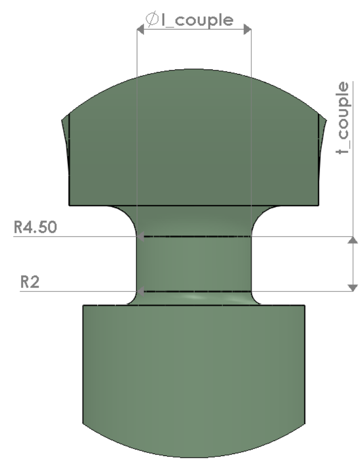


Fig. Coupling hole schematic

Full Cell Design

- Non-cylindrical geometry.
- Flat walls at both ports locations eases fabrication demands.

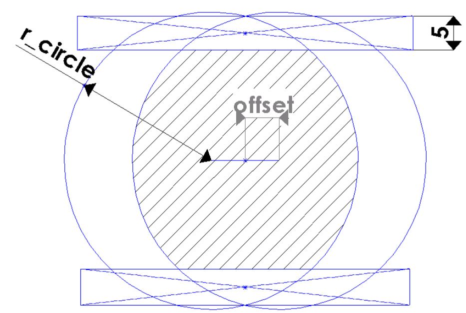
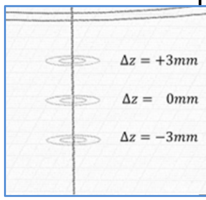


Fig. Full cell cross section

- Quadrupole moment, A(z) reduced up to factor ~4 near the central axis.

$$A(z) = (H_{\max} - H_{\min})/(2r)$$



r_o [mm]	A(z) $[\frac{kA}{m^2}]$	A(z) $[\frac{kA}{m^2}]$	A(z) $[\frac{kA}{m^2}]$	RF Structure
	$z = -3mm$	$z = 0mm$	$z = +3mm$	
2	375	361	365	1.4 cell
2	1156	1259	1214	1.6 cell
4	355	382	385	1.4 cell
4	583	555	586	1.6 cell

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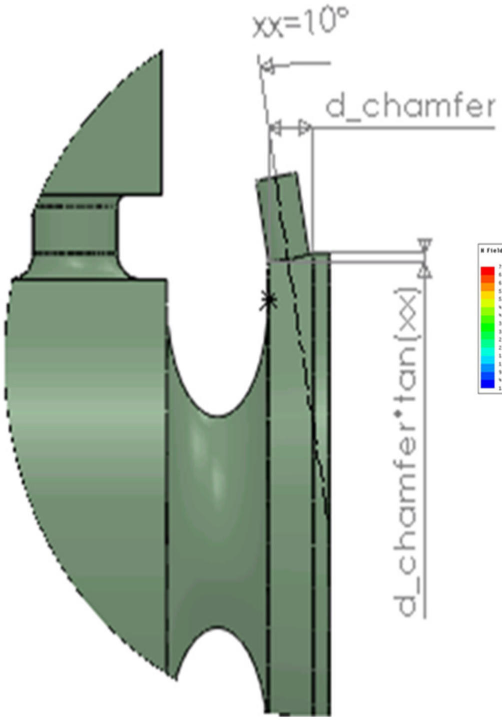
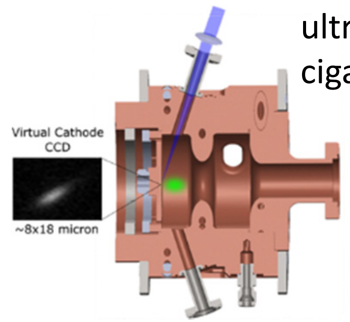
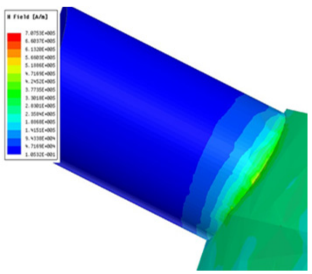
ELECTROMAGNETIC DESIGN

Laser Ports

- First cell truncation creates surface normal to the laser ports. Ease of fabrication demands.
- $H_{surfacepeak}$ at 120MV/m is 440kA/m
- Pulse Heating for 2µs pulse , $\Delta T < 60^{o}$C

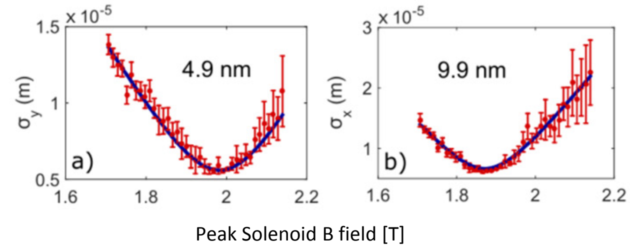






Oblique Incidence

- Very small drive laser spot size on the cathode generates ultralow emittance beams (~5nm-rad). ~20fC bunch in cigar regime.

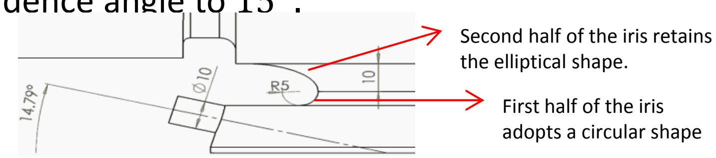


D. Cesar ,Phys. Rev. Lett. 117, 024801 (2016)

- Shortened cell restricts oblique illumination angle to 10^{o}. Laser wavelength 266nm. Minimum spot projection ~6µm

Illumination Angle : θ_{inc}	$\mathbf{10^{o}}$
Numerical Aperture: NA	0.083
Beam Waist: $w_o = \frac{\lambda_o}{\pi NA}$	$1.020\mu m$
Projection: $w_o/tan(\theta inc)$	$5.78\mu m$

- Solution involves simple iris re-design.
- Beam spot projection down to ~3.5µm with an oblique incidence angle to 15^{o}.



ADVANCED PHOTOCATHODES

Load Lock Mechanism:

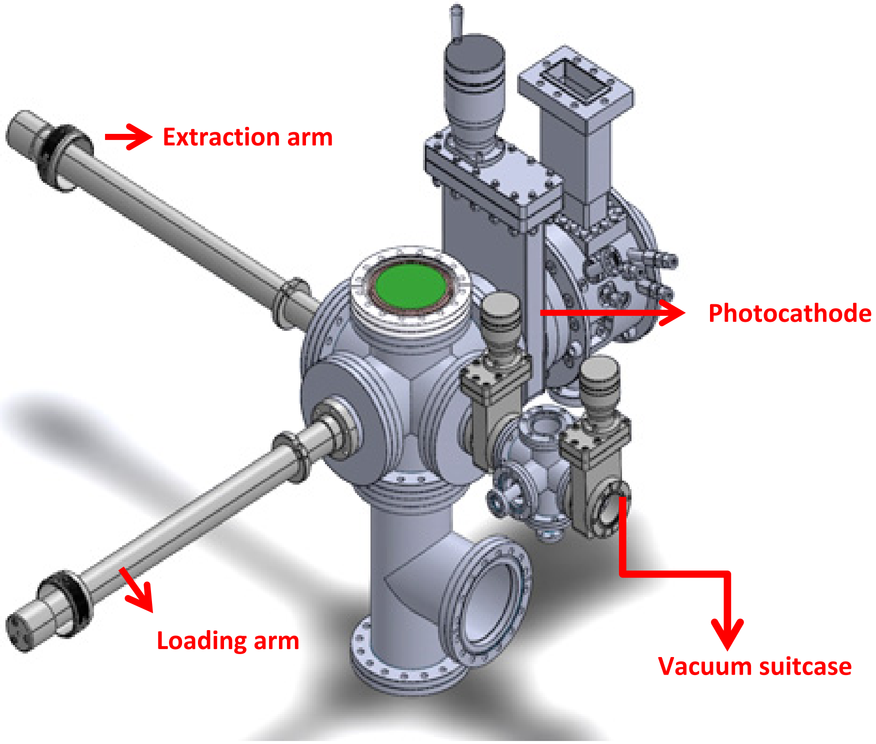
Goal: Test advanced photocathodes to achieve ultra high peak beam brightness

❖ 1.4 cell photoinjector load–lock system compatible with "vacuum suitcase" to deliver pregrown photocathodes from the preparation chamber into the injector without breaking vacuum.

❖ Never tested in high gradient structures.

❖ Possible cathodes:
- Single crystal cathodes / atomically clean metals
- High QE semiconductors like Alkali-antimonide photocathodes.

❖ Challenges include RF sealing, reproducibility and vacuum during operation.

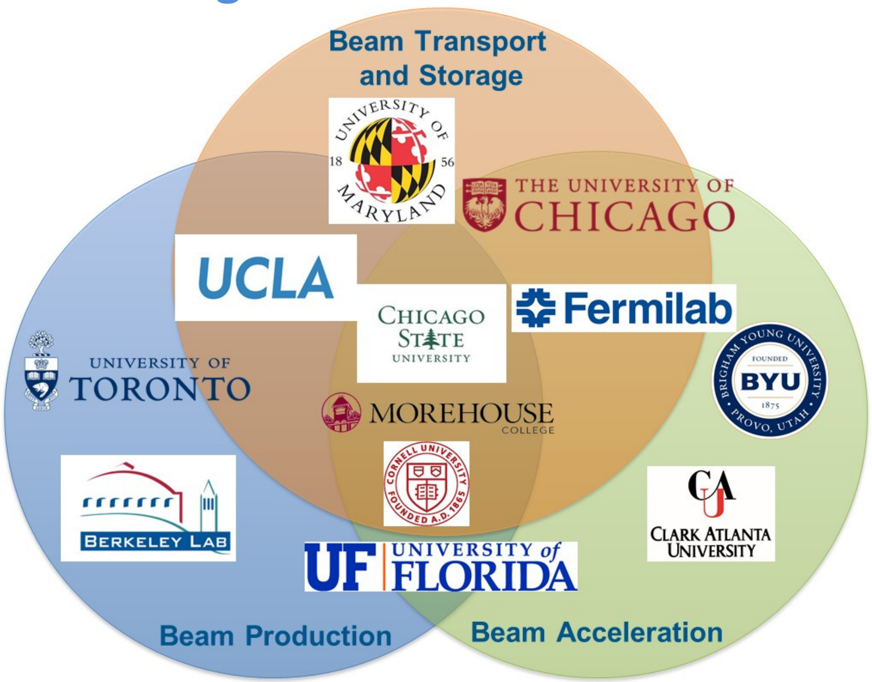


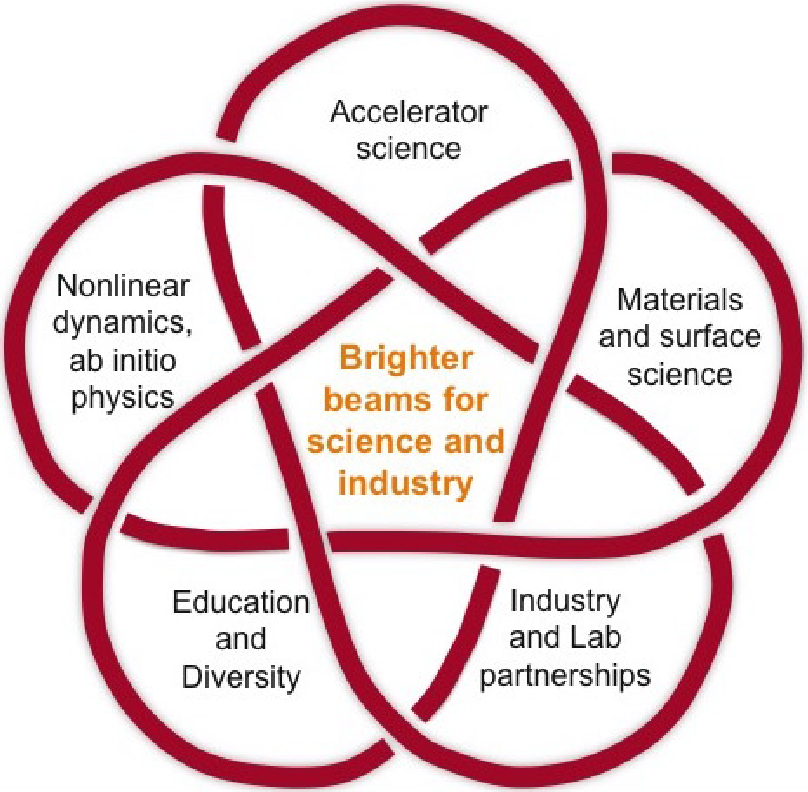
CENTER FOR BRIGHT BEAMS (CBB)

Research Objectives

Transform the reach of electron beams by

- **Increasing brightness x100**
- **Reducing the cost and size of key enabling technologies.**





CONCLUSION

- The simple solution of shortening the first cell minimizes the phase slippage to increase the optimal launch phase to 70^o for the S-band 1.4 cell photoinjector operating at a gradient of 120 MV/m achieving higher beam brightness regardless of the operating regime.

- The new full cell geometry was optimized to lower the quadrupole moment along the central axis achieving up to one order of magnitude lower than the SPARC gun.

- No brazing/welding fabrication reduces cost, manufacturing time, preserves the material properties of copper and lowers the breakdown probability.

- New features on the 1.4 cell photoinjector target the generations of for ultralow emittance beams and the use of advanced photocathodes for extremely high peak beam brightness.