

Photocathode research at UCLA Pegasus Laboratory

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Astronomy*

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The UCLA logo, consisting of the letters "UCLA" in white, bold, sans-serif font, centered within a dark blue rectangular background.

Acknowledgements

- UCLA Pegasus Laboratory group

X. Shen, J. Giner Navarro. Postdocs.

E. Pyrez, E. Curry, D. Cesar, E. Cropp, P. Denham Graduate students.

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- Collaborators: R. K. Li, J. Maxson, D. Alesini, G. Andonian, F. Carbone, D. Filippetto, J. Luiten, S. Karkare, J. B. Rosenzweig, J. Spence

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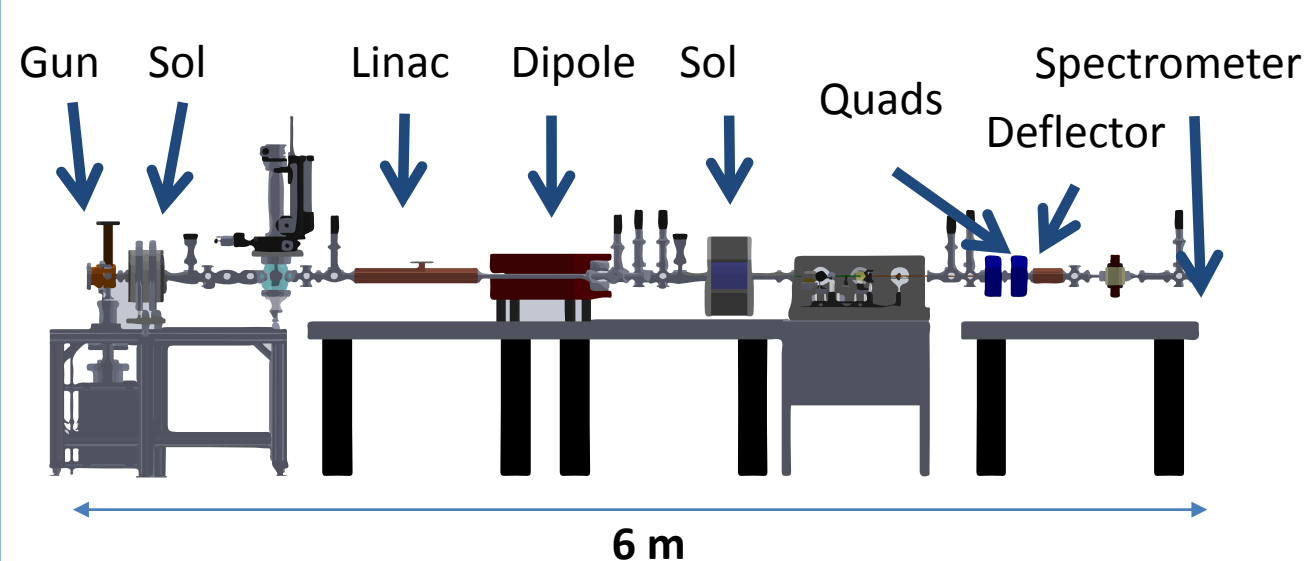
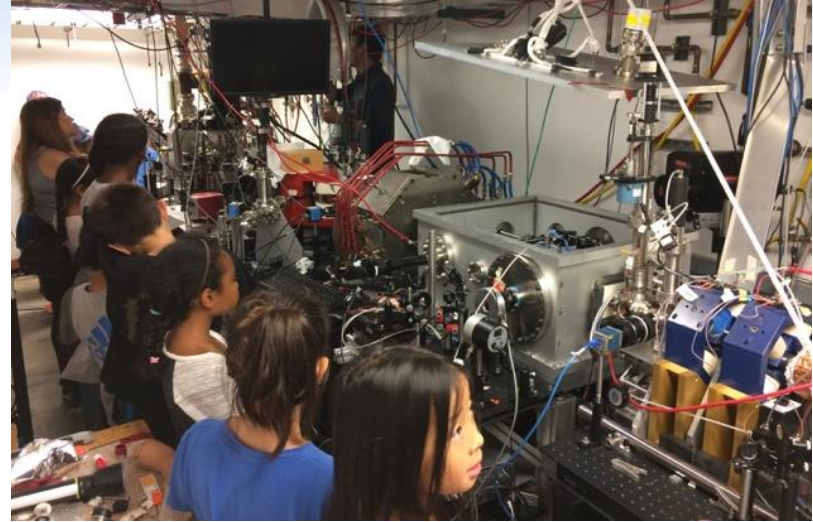


Outline

- Load-lock chamber for high gradient S-band RF gun
- Symplectic camels and magnetized beams
- DC gun test stand for photocathodes
 - Laser heating
 - Pump-probe reflectivity
 - Cold gun and new NSF MRI with University of Colorado: HyRes

High peak brightness low charge beam research at UCLA Pegasus Laboratory

- **3-14 MeV student-run university-size accelerator beamline optimized for sub-pC beams**
- Ultralow charge beams with high peak brightness or phase space density:
 - *DLA: few fs acceleration bucket, sub-micron aperture*
 - *High resolution ultrafast electron diffraction*
 - *Single shot imaging / UEM*
 - *THz acceleration / amplification*



E. Curry et al. Meter-scale THz-driven acceleration of a relativistic electron beam. *Phys. Rev. Lett.* **120**, 094801 (2018)

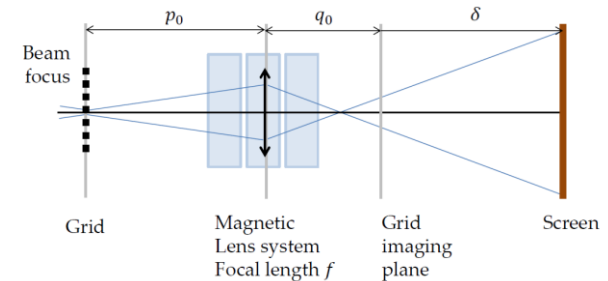
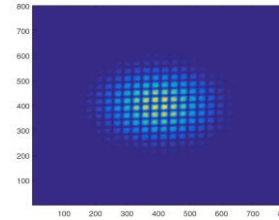
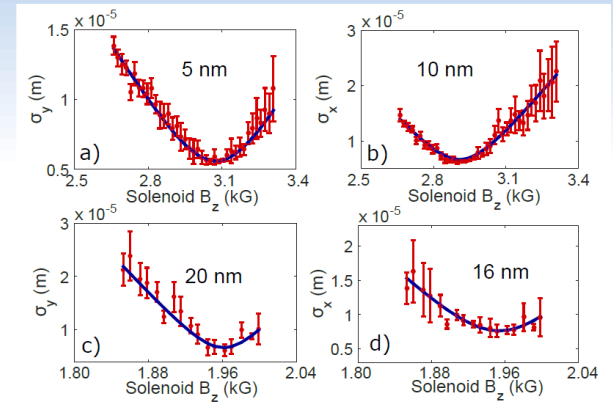
D. Cesar et al., Onset of non-linear effects in high gradient dielectric laser accelerator. *Communications Physics* **1**, 46 (2018)

D. Cesar, et al., Demonstration of single-shot picosecond time-resolved MeV electron imaging using a compact permanent magnet quadrupole based lens. *Phys. Rev. Lett.*, **117**, 024801 (2016)

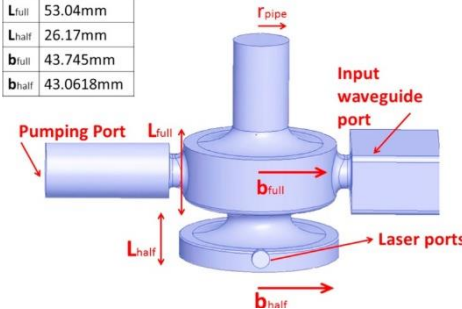
J Maxson, et al., Direct measurement of sub-10 fs relativistic electron beams with ultralow emittance. *Phys. Rev. Lett.*, **118** 154802 (2017)

Current Pegasus beam performances

- 5 nm transverse emittance, 20 fC, $\sim 10 \mu\text{m}$ spot on cathode
- Various emittance diagnostics techniques being developed
 - Single-shot 4D transverse emittance diagnostics based on TEM grid
 - Electron microscope-based setup for single-shot 4D trace space reconstruction
 - Knife-edge beam-matrix reconstruction (with LBNL, D. Filippetto and F. Ji).
- 1.4 cell gun with braze-less design to maximize launch phase/field
- High power RF system upgrade. Solid state modulator and 7.5 MW klystron



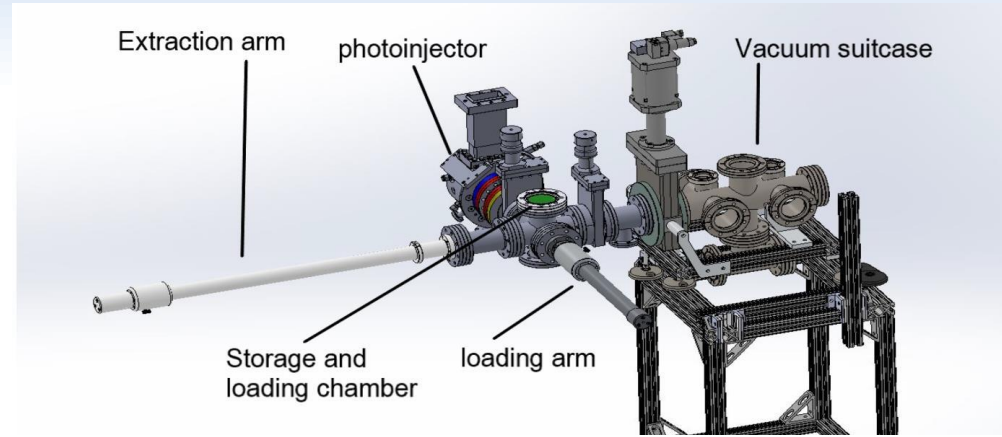
r_{pipe}	18mm
L_{full}	53.04mm
L_{half}	26.17mm
b_{full}	43.745mm
b_{half}	43.0618mm



How to further improve brightness: advanced photocathodes in high gradient RF guns

- Many open questions:

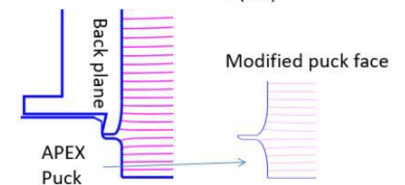
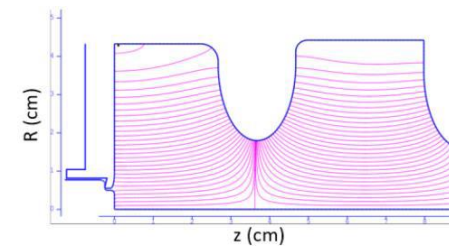
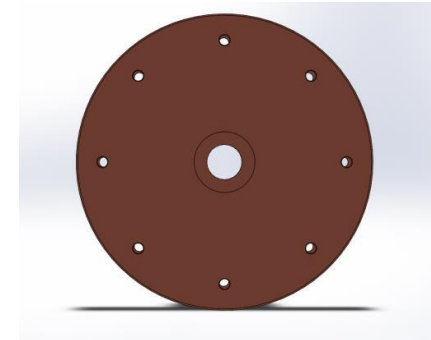
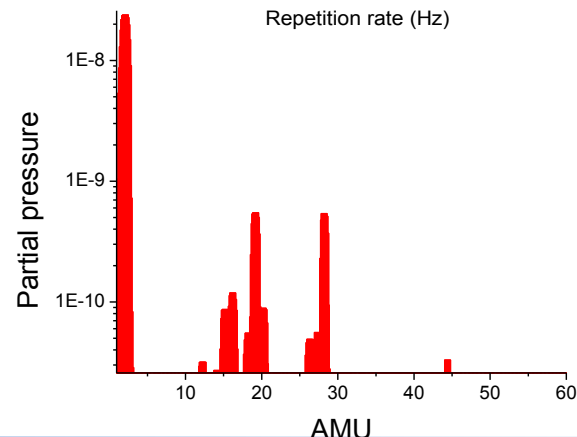
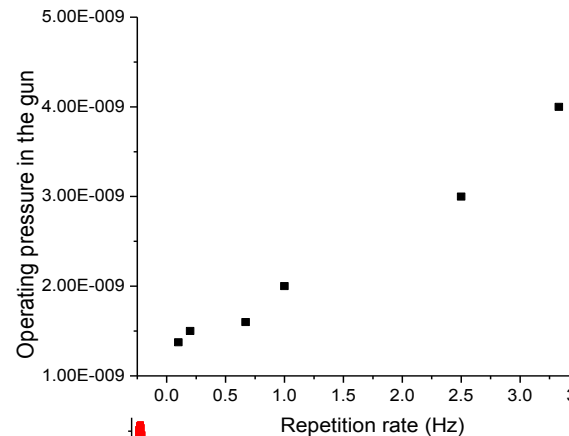
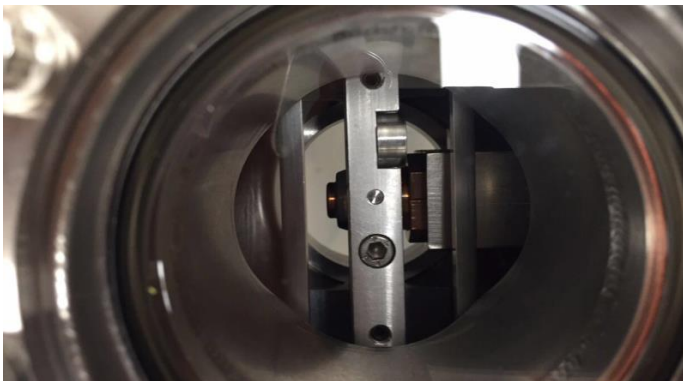
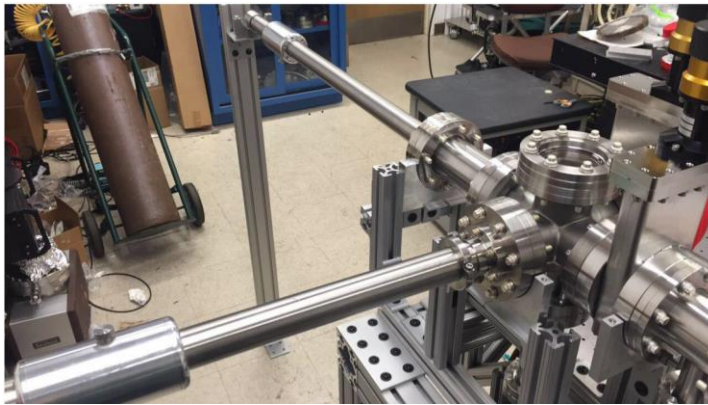
- Vacuum and life-time
- Effect of roughness at high field
- Brightness scaling



- Developed a 1.4 cell photoinjector load–lock system compatible with “APEX-style vacuum suitcase” to deliver substrate-grown photocathodes from the preparation chamber into the injector without breaking vacuum.
- Cathodes being considered for testing:
 - High QE semiconductors. Alkali-antimonide photocathodes.
 - Single crystal cathodes / atomically clean metals.

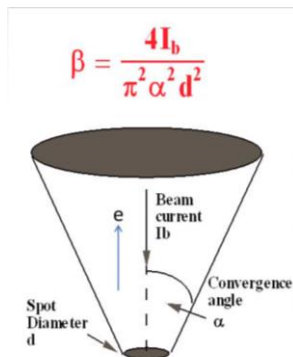
UCLA gun Load-Lock chamber

- Tested spring-less RF contact for cathode back-plane in a preliminary setup.
- Full system ready to be attached to the gun
- NEG pumping being installed
- Aiming at 10^{-10} vacuum in loadlock region
- Gun vacuum more of an issue, but all diagnostics work single-shot
- Cathodes from LBNL/ASU (end of 2018)

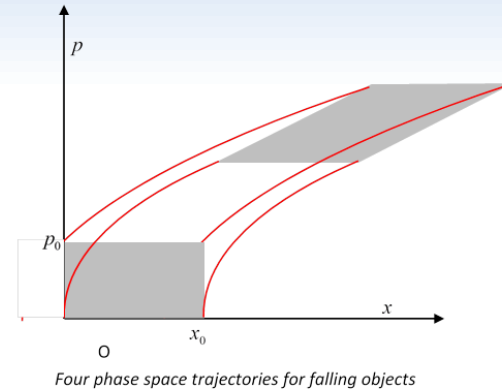


Some general considerations on 6D brightness and Liouville theorem

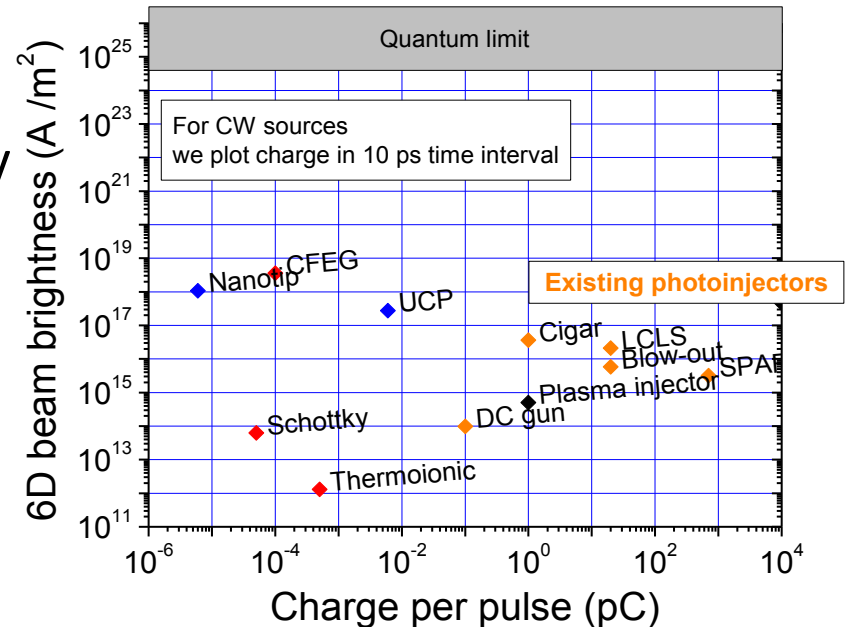
- Hamiltonian flow is a volume preserving transformation
- Liouville invariant = phase space volume: $\det(\sigma)$
- 6D brightness is a good measure of beam quality
- Using very strong lenses we can always shape the beam to fit a very small (arbitrarily small) aperture in x-y space...



$$\beta = \frac{4I_b}{\pi^2 \alpha^2 d^2}$$



◆ Electron sources 6D beam brightness



Symplectic camels and the non squeezing theorem (Gromov, 1985)

- ...but we can't fit an arbitrary small aperture in x - p_x space !!!
- Liouville volume is not the only invariant in symplectic transformations.
- 'Lagrangian' invariants : $Tr((J\sigma)^n)$
 - In 2D (4D phase space) $\det(\sigma) = \epsilon_1^2 \epsilon_2^2$ $Tr((J\sigma)^2) \propto \epsilon_1^2 + \epsilon_2^2$
- B. Carlsten, PRSTAB, 14, 050706 (2011): eigenemittances

The Symplectic Camel: *It is impossible to move a ball of radius ≥ 1 symplectically from one side of the wall to the other.*

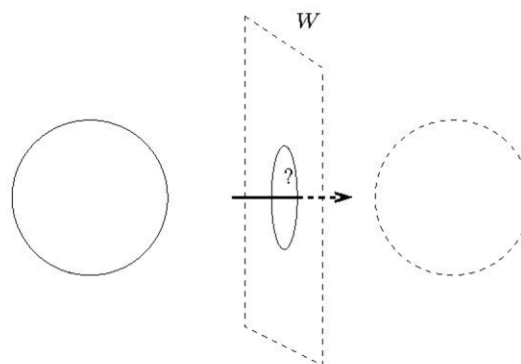
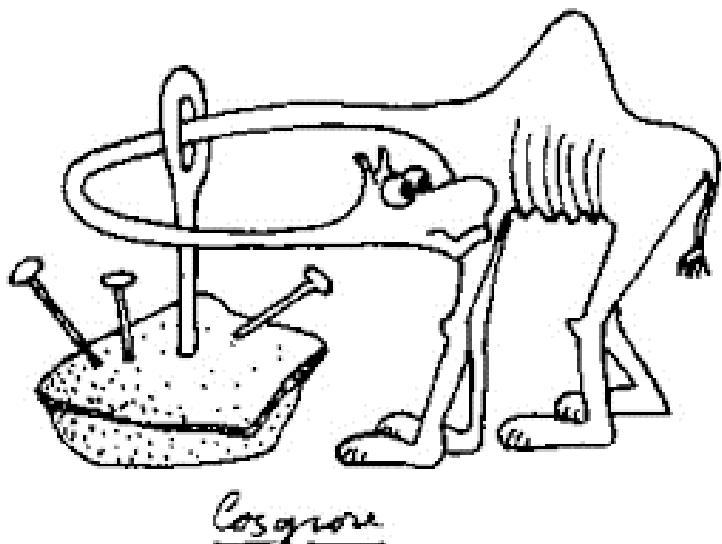
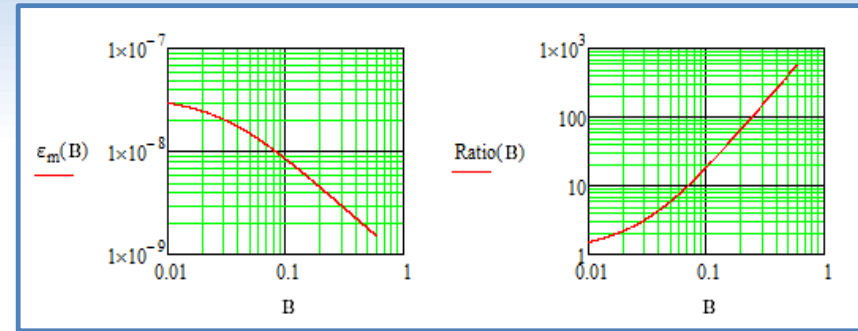


FIGURE 2.3. Can the ball go through the hole?

⁶The name of this problem is a somewhat "in" joke, of the kind appreciated by many mathematicians. The reference is to the saying that it would be easier for a camel to go through the eye of needle than for a rich man to get into heaven. (This saying is probably a mistranslation of a sentence in the bible.)

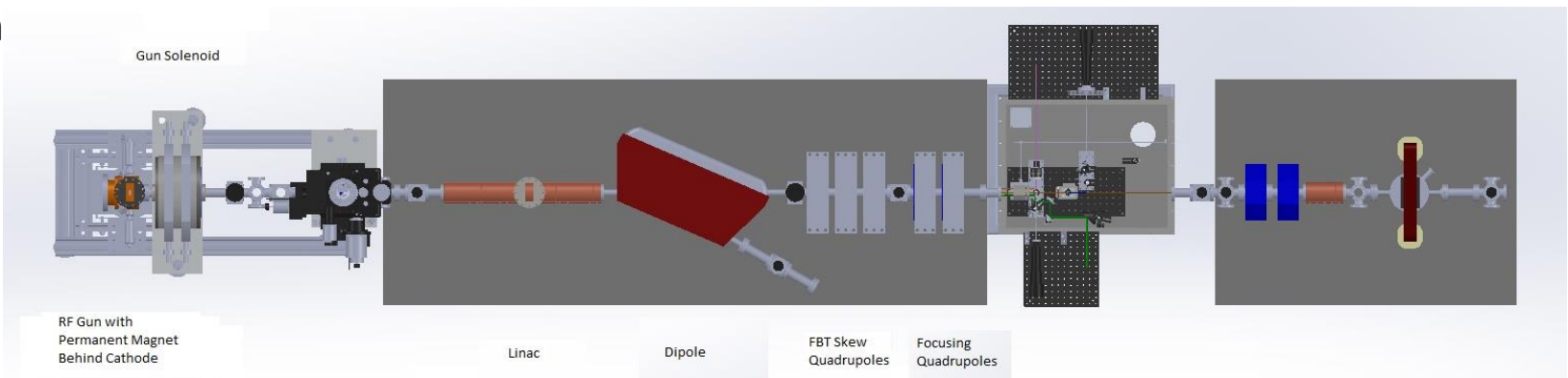
Consequences of Gromov theorem for beam physics: Flat beam transforms and emittance exchange beamlines

- A beam with a smaller eigenemittance can always be transformed into a round beam (by adding correlation/angular momentum)
- At the same time it can fit into a smaller phase space hole than a round beam with the same 4D emittance.
- Critical for some applications (DLA, microscopy, etc.) !
- Magnetized beam + Skew quadrupole beamline implemented at Pegasus
- Permanent magnet to tune B on cathode
- Simulations predict 2 nm x 200 nm emittances and 1.5 um x 10 um spot sizes at DLA en



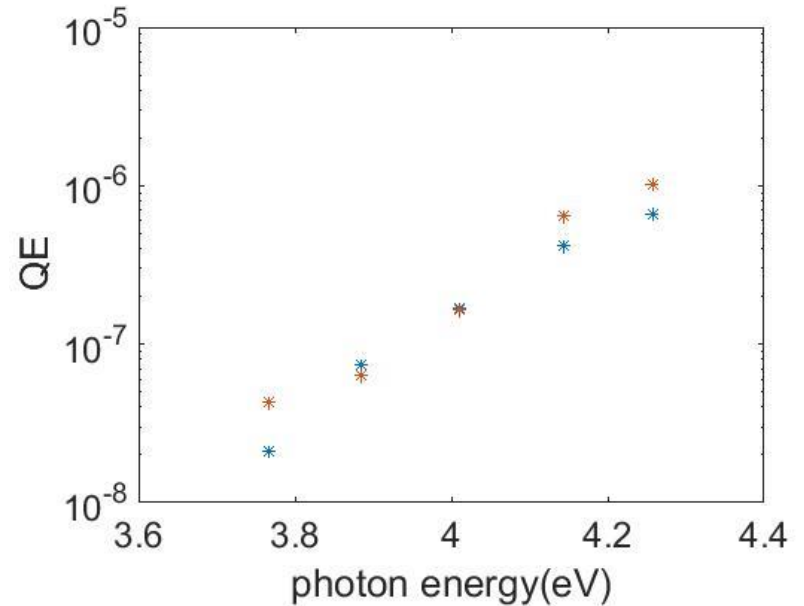
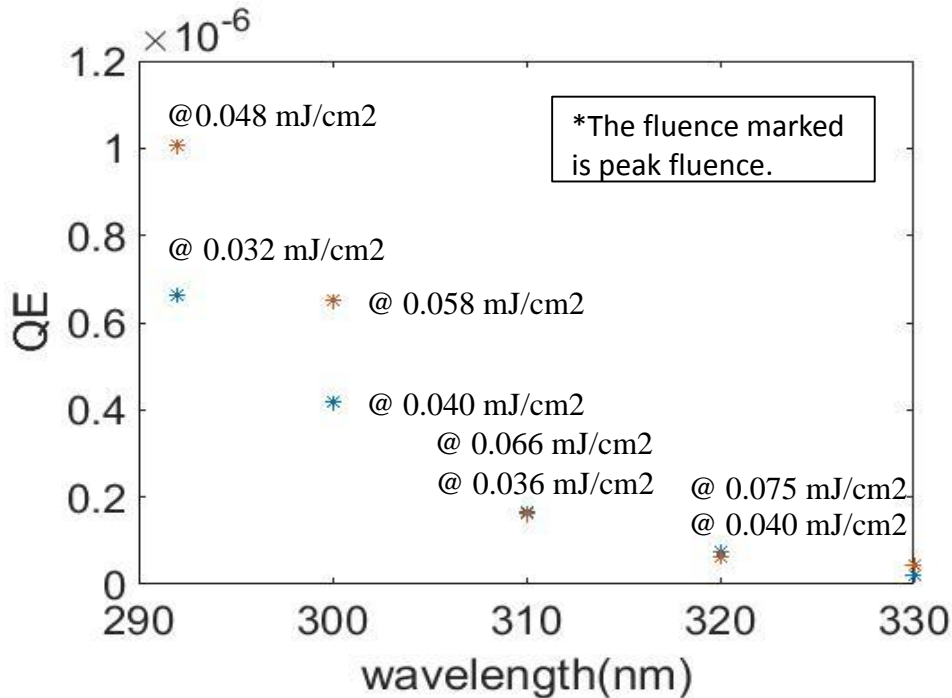
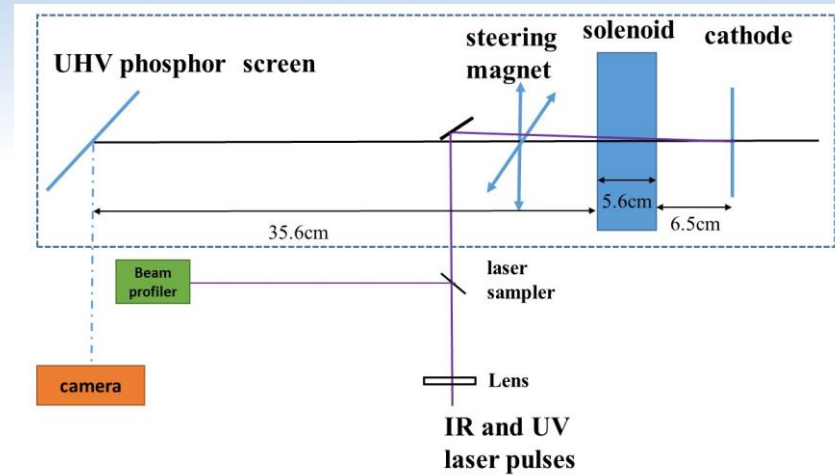
$$\epsilon_{\pm} = \epsilon_{eff} \pm L \quad \epsilon_{eff} = \sigma_x \sqrt{\frac{MTE}{m_0 c^2} + (\kappa_0 \sigma_x)^2}$$

$$\epsilon_{-} \cong \frac{MTE}{e_0 B c} \quad \epsilon_{-}(\text{nm}) = \frac{0.033 * MTE(\text{meV})}{B(\text{kG})}$$



DC gun test stand

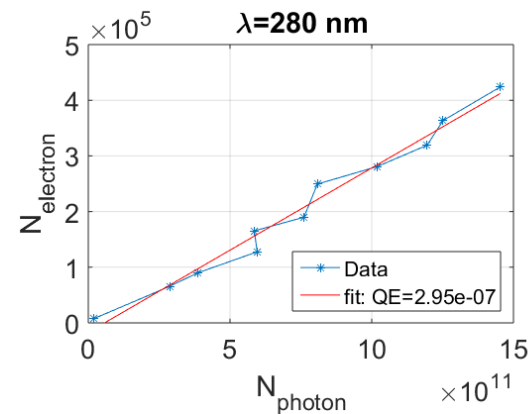
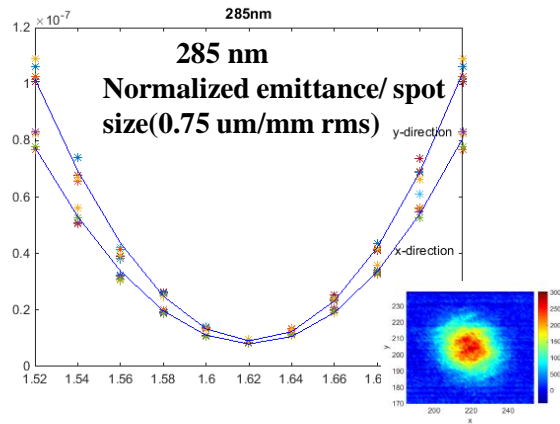
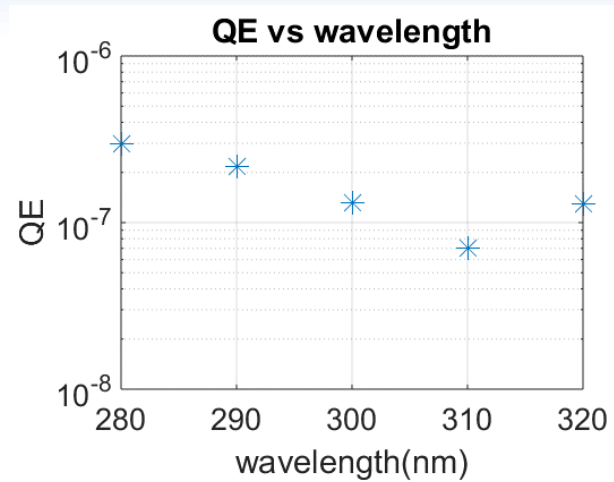
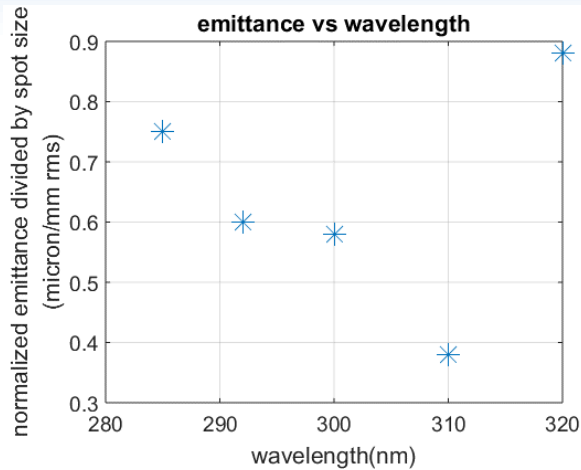
- 30 kV test stand for cathode studies
- Easy-to-exchange cathode plugs
- Solenoid scan for emittance measurements
- OPA for tunable UV
 - QE and emittance vs. wavelength



Emittance and QE measurements at high fluence (mJ/cm² incident)

After replacing cathode plug, not reproduced

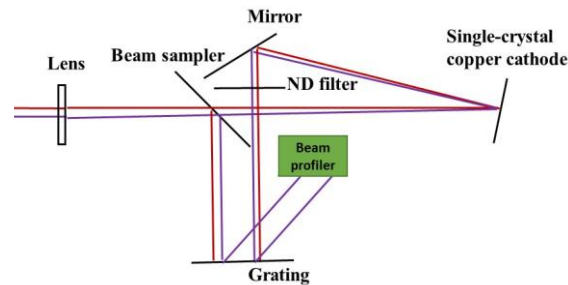
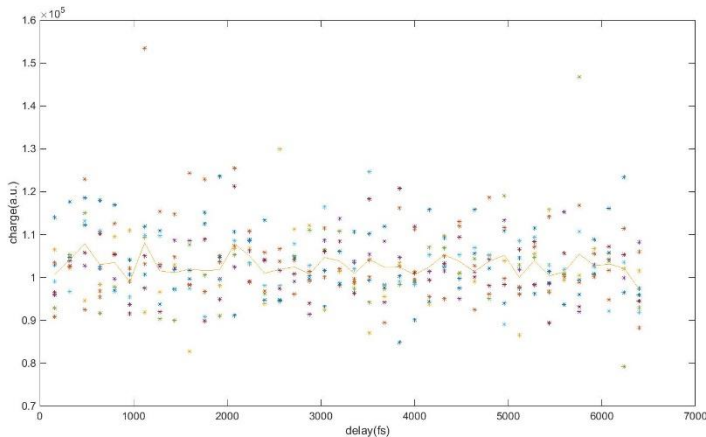
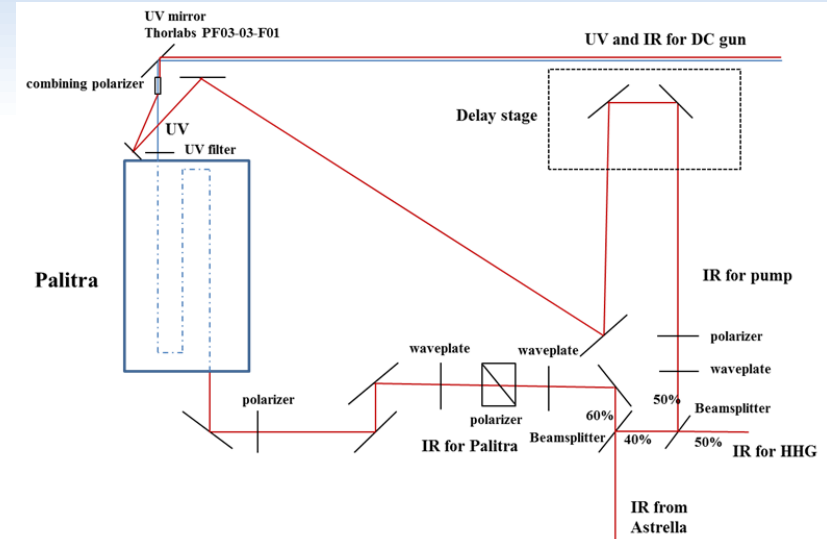
Measurements to be validated using single-crystal plug



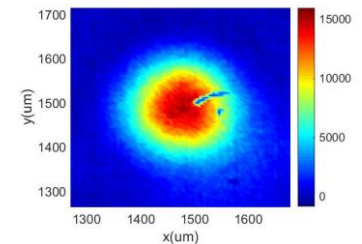
Laser heating for metal cathodes

800 nm pump and tunable UV probe

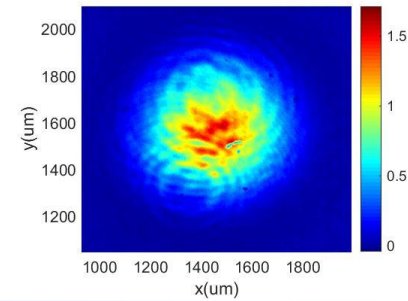
- Measuring charge yield vs. time-delay
- No signal yet
- Strong 800 nm emission at the fluences where laser heating should be observed. Hard to disentangle
- Emittance measurements require deflector
- Pump-probe reflectivity setup being implemented.



UV spot virtual cathode

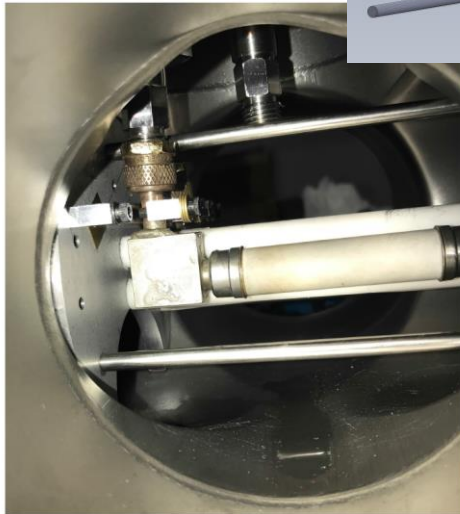
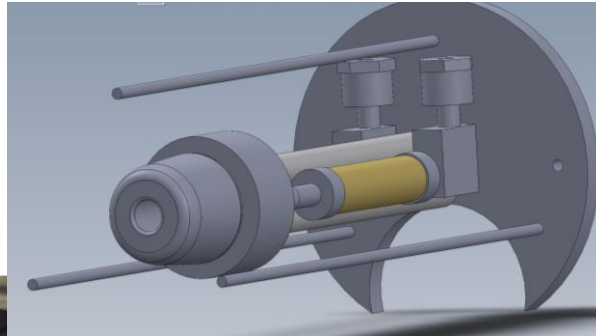


IR spot virtual cathode



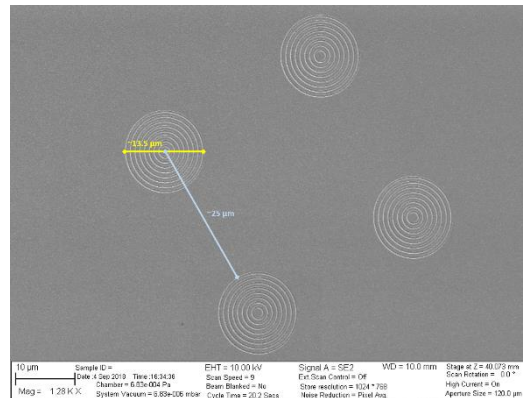
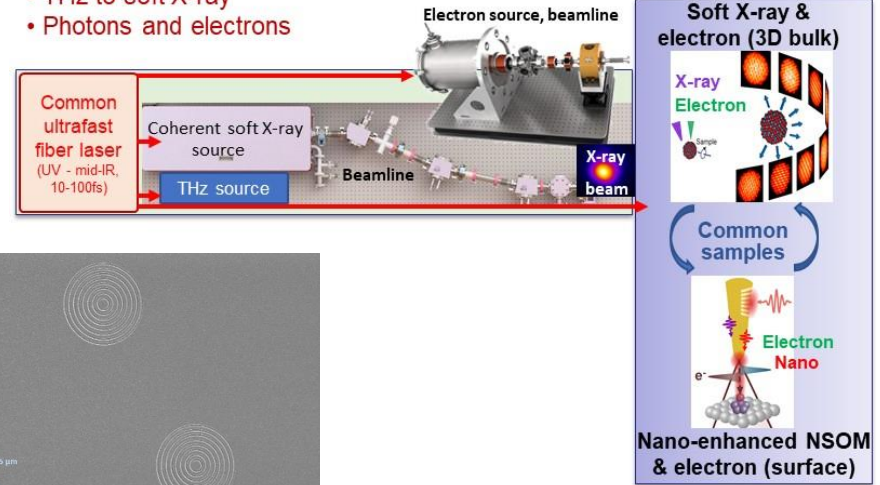
Other UCLA DC gun developments

- Plasmonic cathode studies (with D. Filippetto et al. LBNL)
- High brightness beamline for new NSF MRI with Colorado putting together HHG and UED
- Cold (liquid nitrogen) gun being tested for metal cold cathode yield and emittance measurements



Ultrafast illumination beams:

- THz to soft X-ray
- Photons and electrons



Conclusions

- Beam Brightness and Photocathode Physics relevant for all Pegasus beamline applications : DLA, THz, UED and UEM
- Load-lock for high gradient S-band injector coming soon !
- Magnetized beams have unique advantages (small emittance linearly benefits from improvements in MTE)
- DC gun test stand(s) + tunable UV source to investigate laser heating / plasmonic photocathodes / cold metal cathode sources