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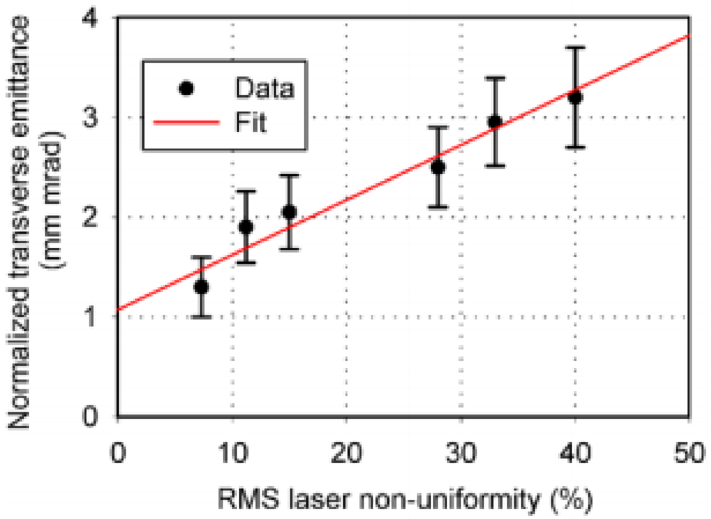
In collaboration with: D. Dang, K. Kabra, D. Ratner, S. Li and P. Musumeci

MAPPING PHOTOCATHODE QUANTUM EFFICIENCY USING GHOST IMAGING

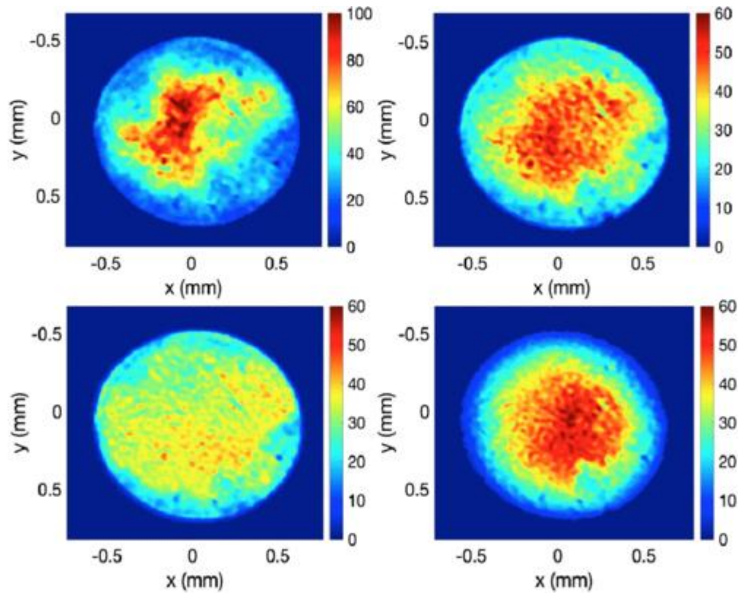
Motivation

- Beam quality (low emittance) can only degrade from cathode
  - Good beam at cathode is critical
- Local quantum efficiency nonuniformities can cause nonlinear spacecharge effects that degrade beam quality
  - Often due to chemical and/or morphological roughness at single to few tens of um scale



F. Zhou et al. Phys. Rev. ST Accel. Beams 5, 094203, 2002

- Mapping such hotspots is critical
- Quantum efficiency map informs:
  - Avoidance
  - Laser shaping

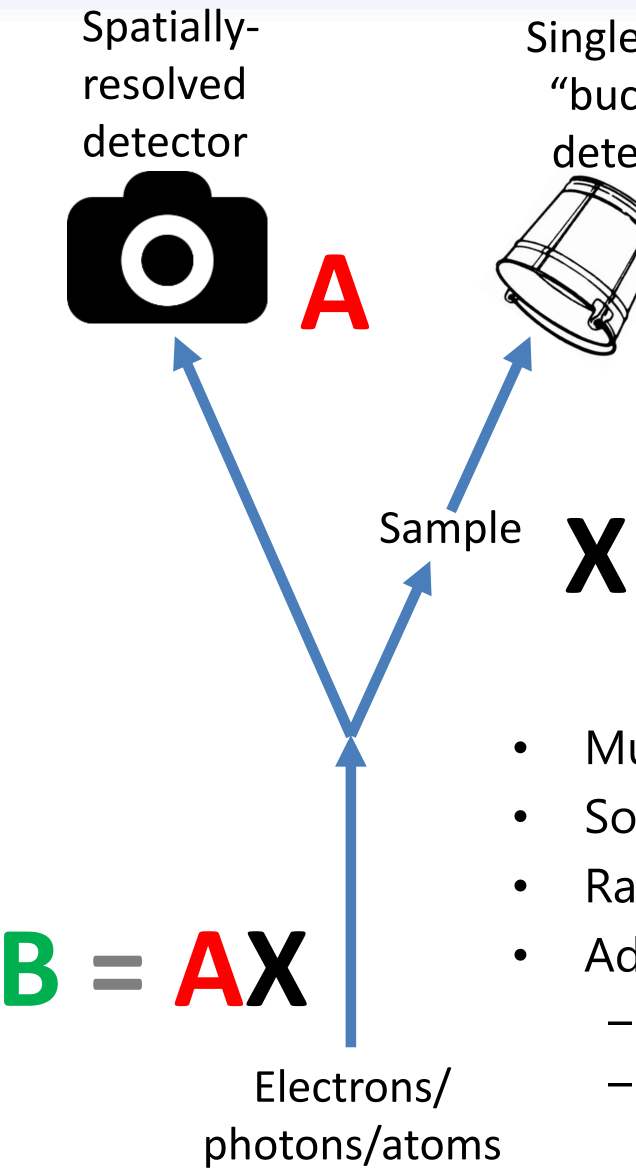


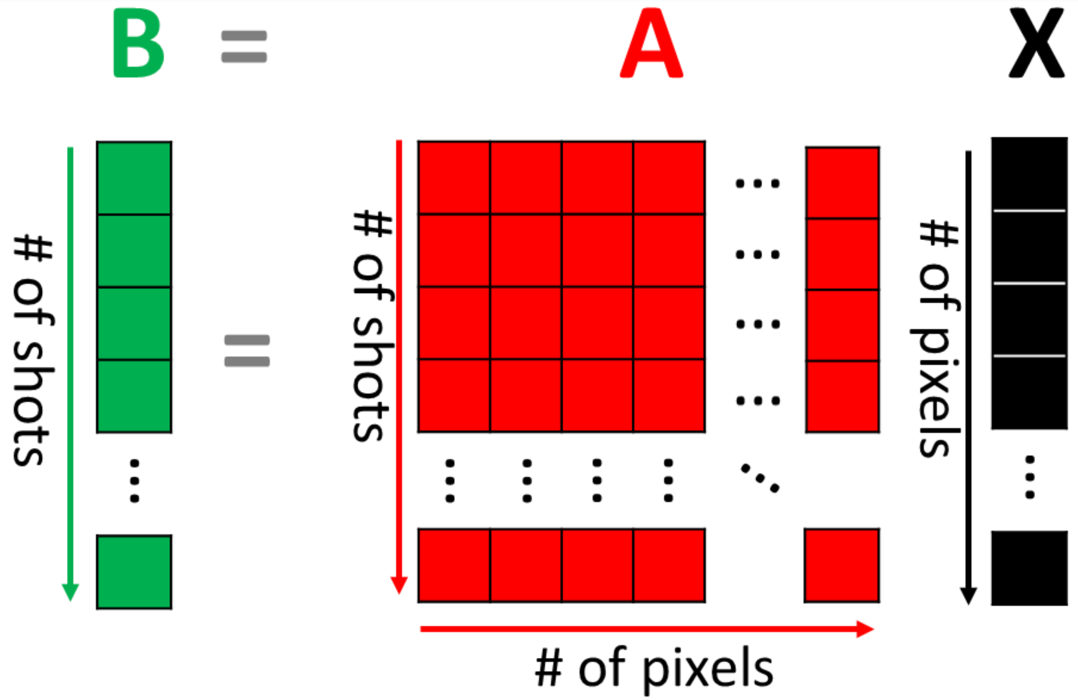
S. Li et al. Phys. Rev. Accel. Beams 20, 080704, 2017

Outline

- Overview of Ghost Imaging (GI)
- Demonstration of electron GI
  - Benefits and discussion
- Application of GI to photocathode mapping
  - Benefits to the mapping process
- In Progress: extension to the super-resolution regime
  - Subpixel/small laser shift background
  - In simulation
  - Experimental outlook

Ghost Imaging Overview





- Multishot technique
- Solve for **X**, effect of sample on each pixel
- Raster scan is special case where A is proportional to identity matrix
- Advantages of GI framework:
  - Compressed Sensing (using prior knowledge → Ridge, ADMM)
  - Multiplexing/Fellgett's advantage

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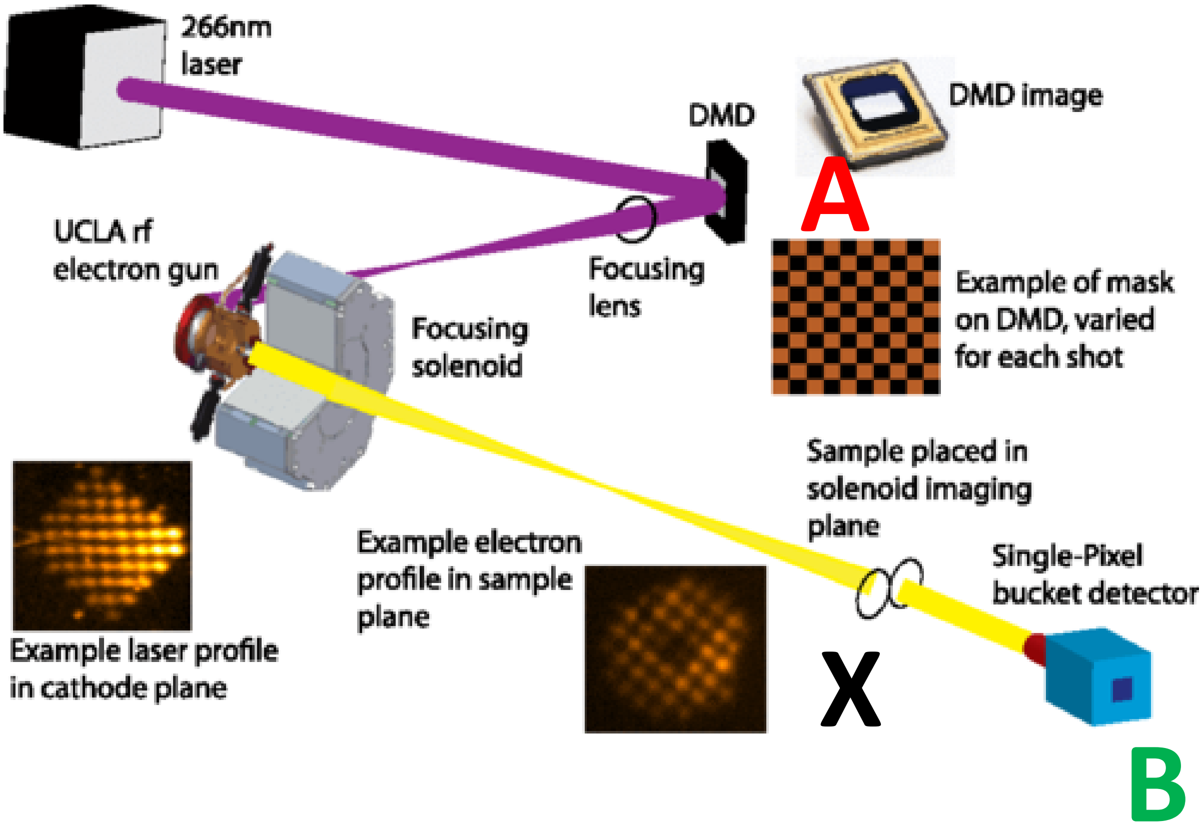
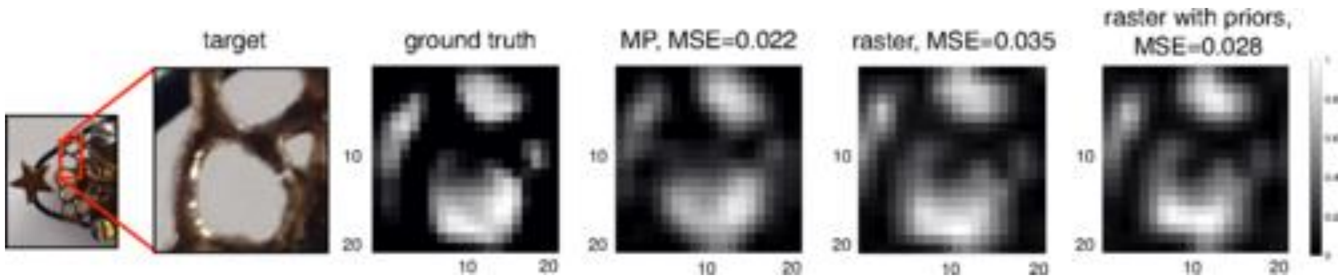
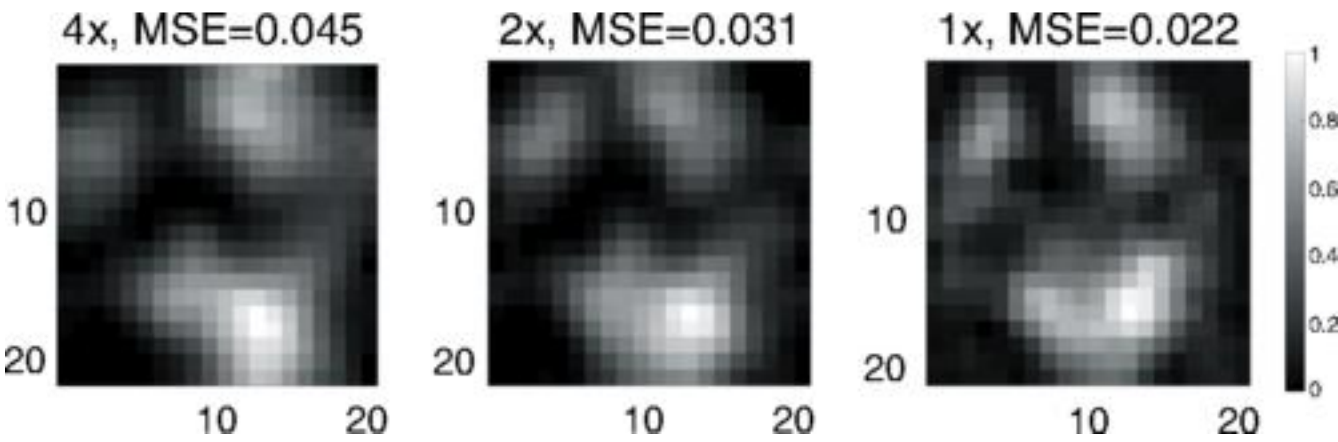
First Experimental Demonstration of Electron Ghost Imaging





Advantage of Multiplexing: Fellgett’s Advantage



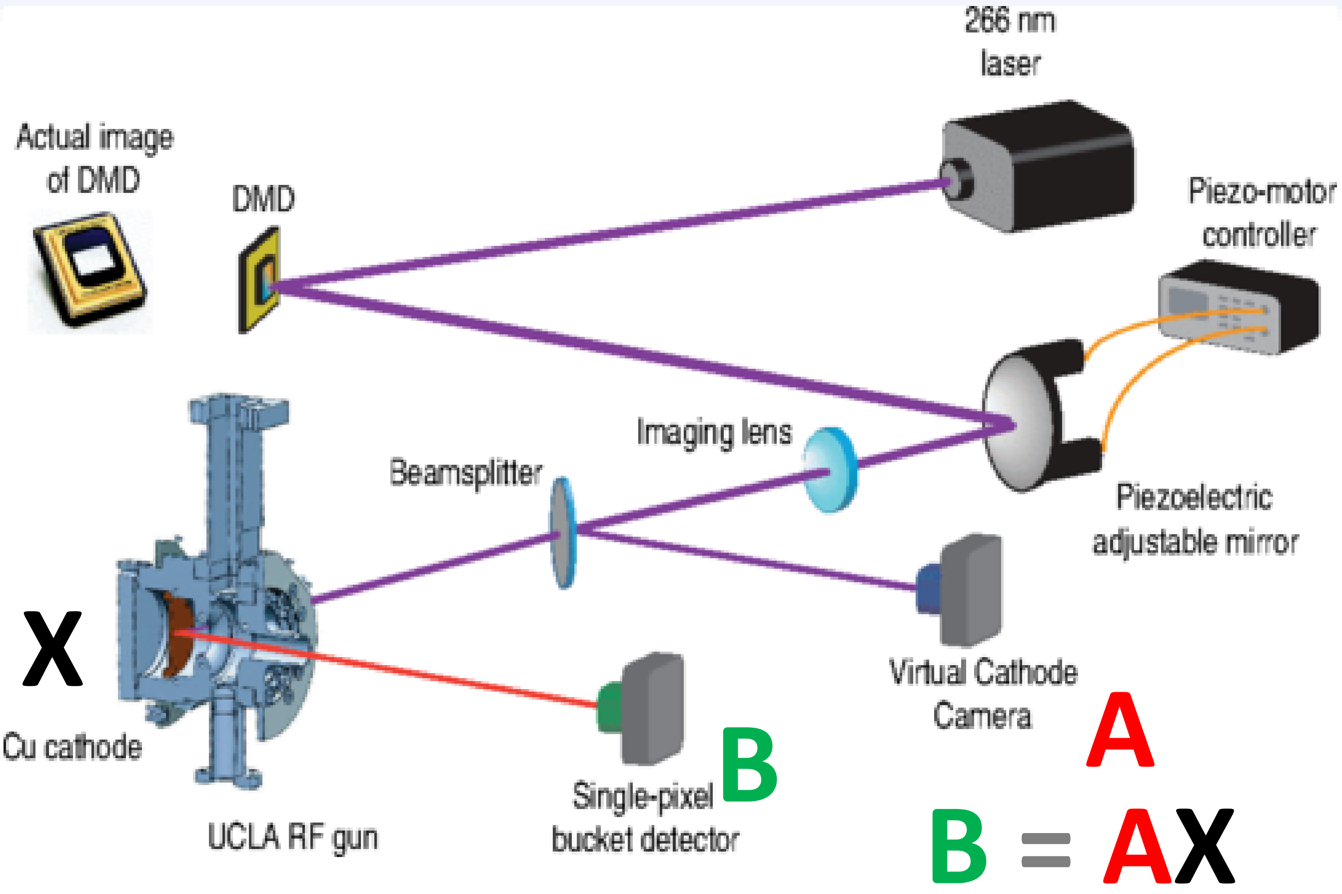
Demonstration of Compressed Sensing

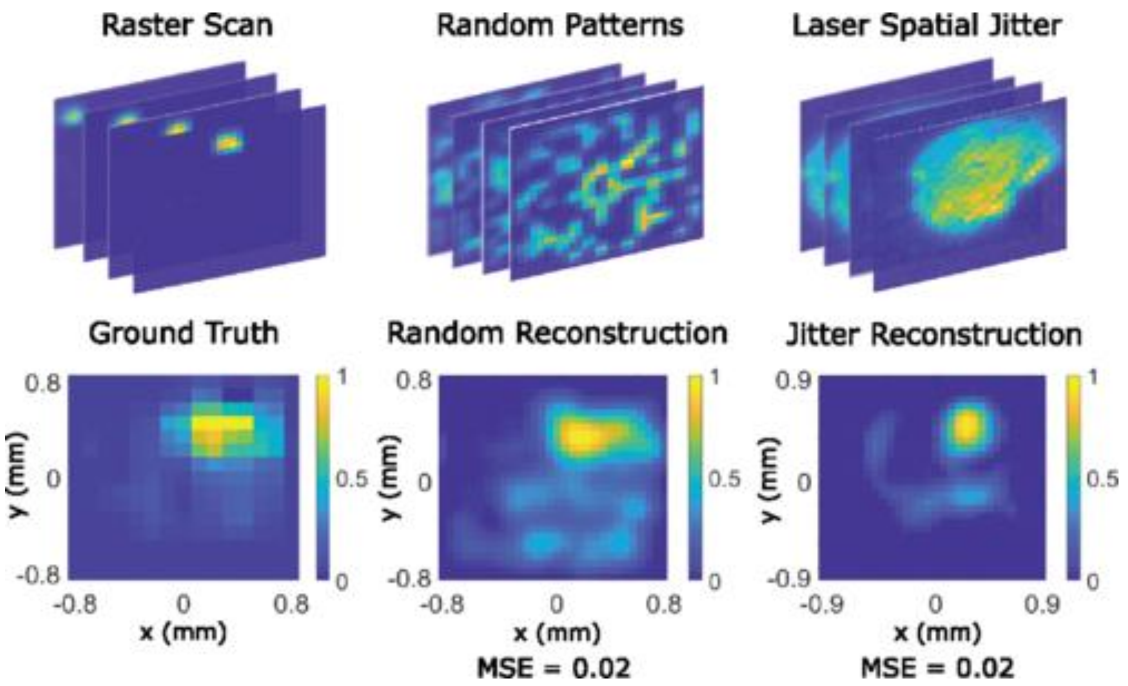
SLAC

B = AX

S. Li, **F. Cropp**, K. Kabra, T. J. Lane, G. Wetzstein, P. Musumeci, and D. Ratner, Phys. Rev. Lett. **121**, 114801 (2018)

Photocathode Ghost Imaging





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Major benefits:

1) Increased QE map accuracy (Fellgett's advantage)
2) Fewer shots needed (faster) for same resolution as raster scan (compressed sensing)
3) **Data can be taken parasitically**
4) **Framework leads to possibility of higher resolution**

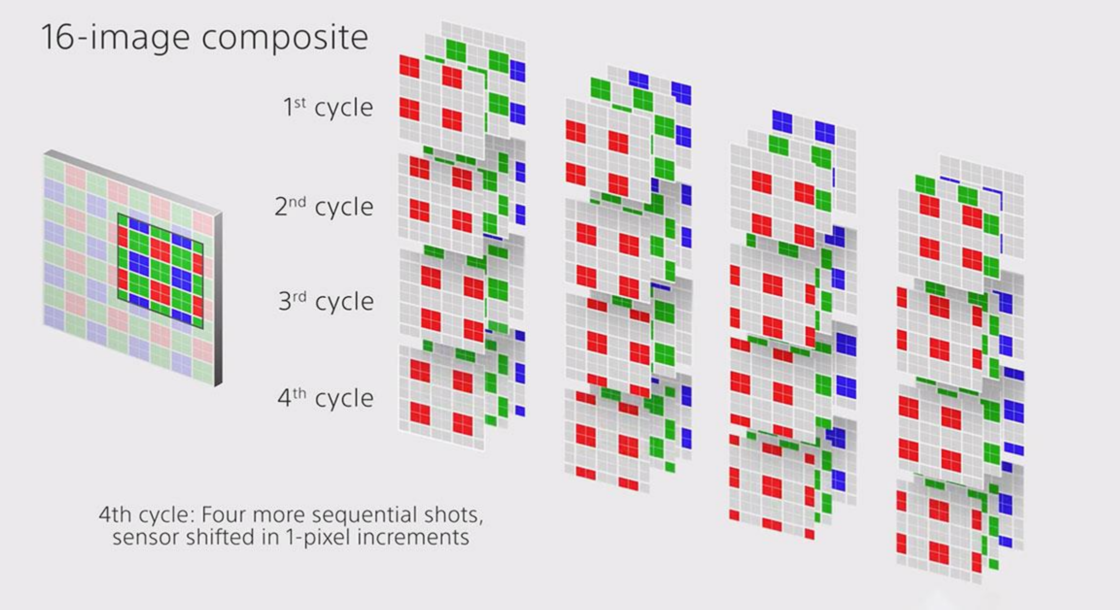
Super-Resolution

- Sub-pixel shift has been applied to commercially-available cameras, such as Sony α7R IV
- Similarly, apply the laser shift to electron ghost imaging, particularly of photocathode QE
- Promises resolution determined by shift, rather than optical resolution limit

Sony α7R IV

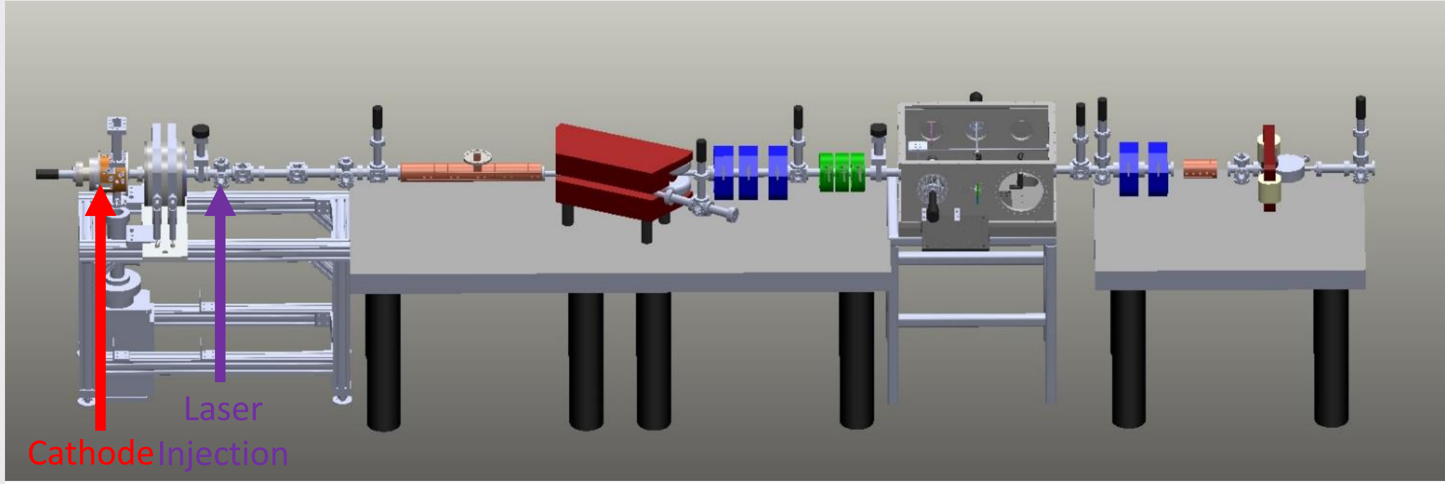
Optical Resolution Limit:

$$\Delta l = 1.22\frac{\lambda f}{D}$$



https://briansmith.com/sony-a7r-iv-16-shot-pixel-shift-produces-240-8-mp-raws/

Example: Pegasus beam line



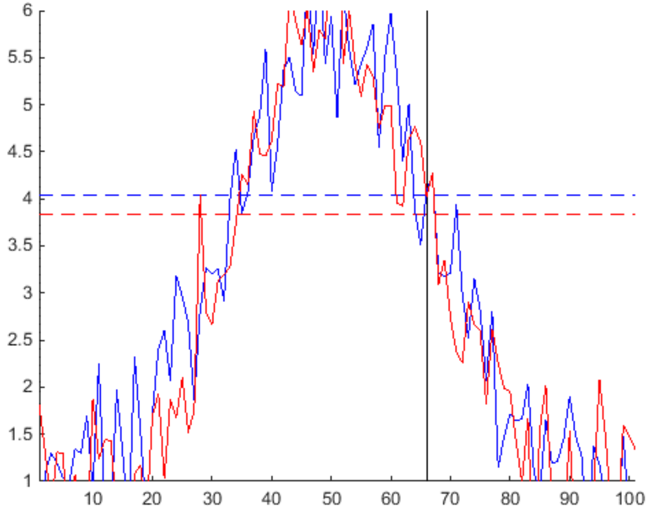
Normal incidence injection, lens must be outside vacuum chamber → 75cm lens → ~25um optical resolution limit

In Simulation

$$\mathbf{B} = \mathbf{A}\mathbf{X} + \varepsilon$$

Sensing matrix blur and noise – well understood if it corresponds with real sample illumination

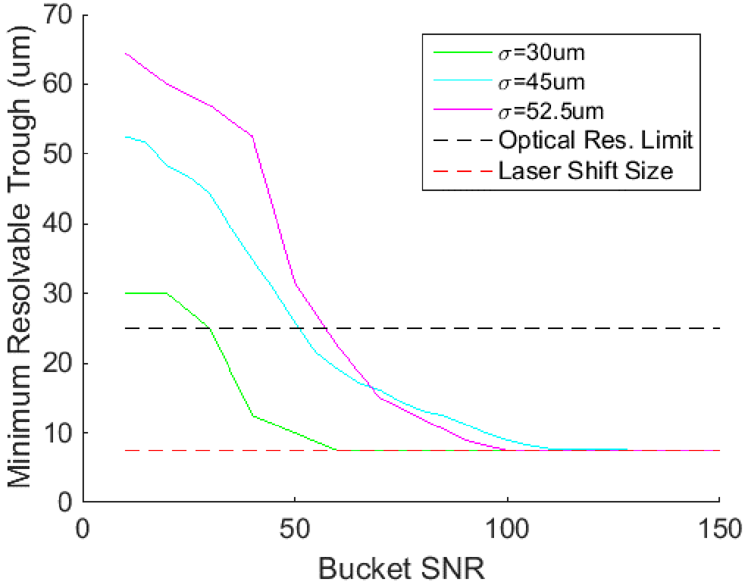
Shot noise – vector of noise on each shot – regularized penalty function helps

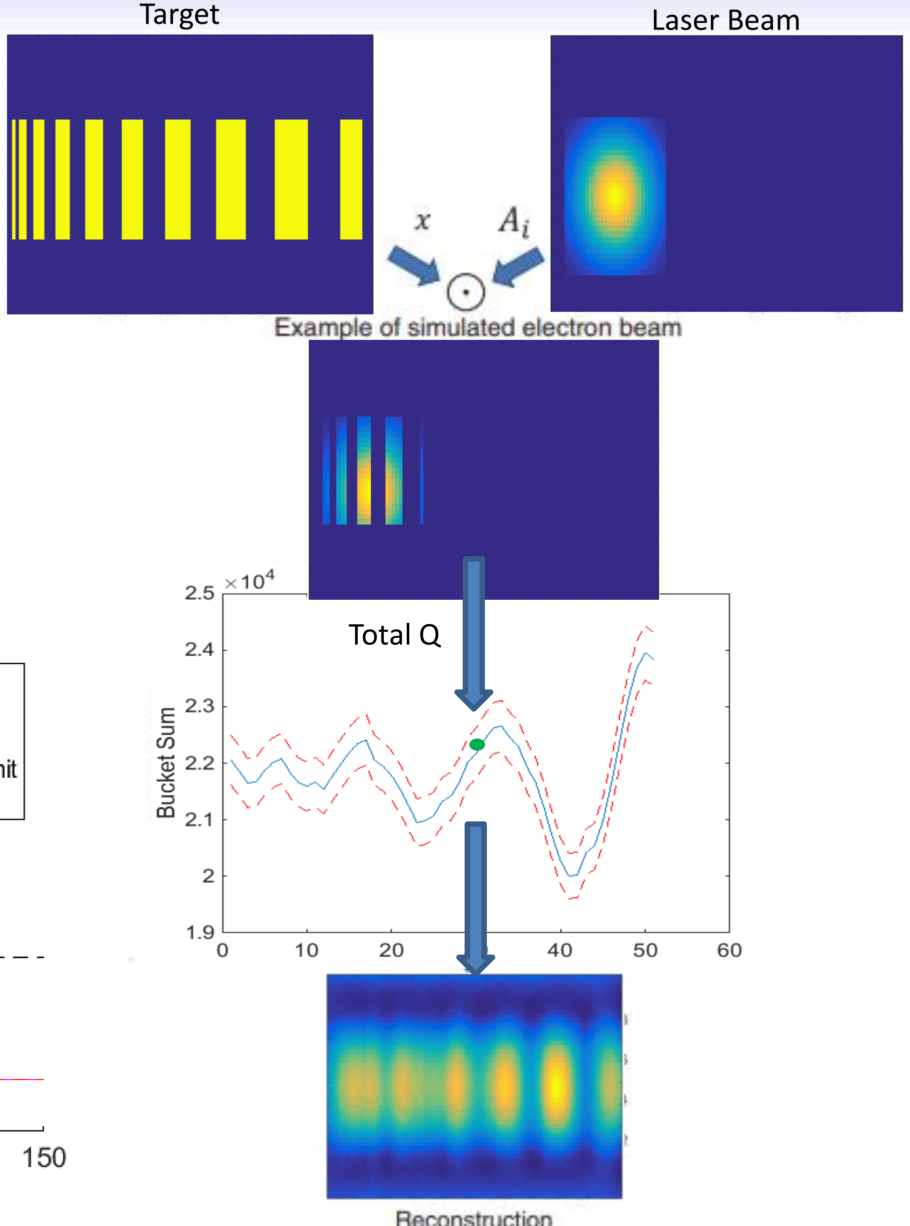


$$\frac{\delta}{\sigma} > \frac{e^{1/2}}{\sqrt{2}\mathrm{SNR}}$$

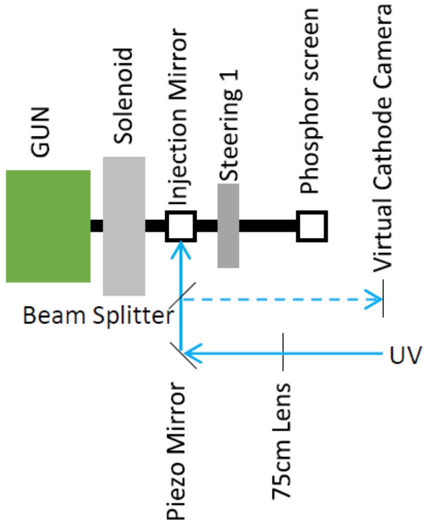
δ: Laser shift length
σ: RMS beam size
SNR: Signal-to-noise ratio

Laser Shift: 7.5um





Experimental and Future Outlook



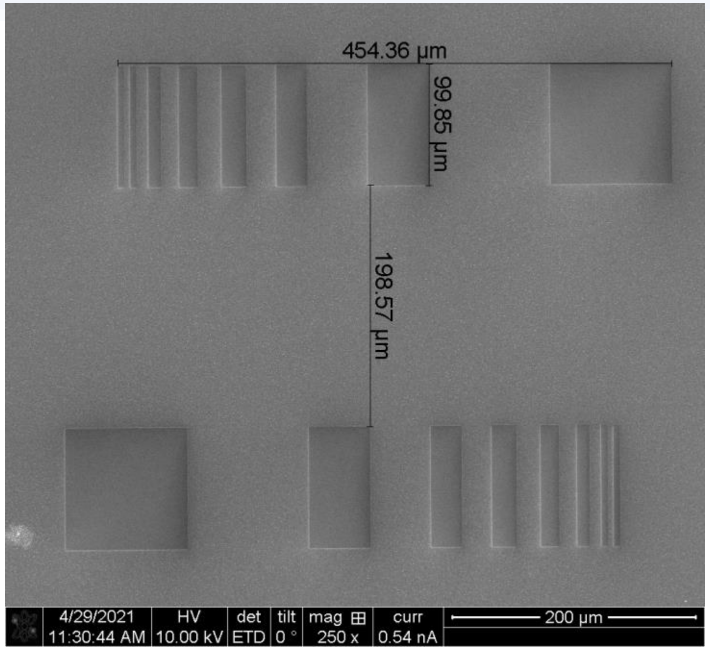
Optical Resolution Limit:

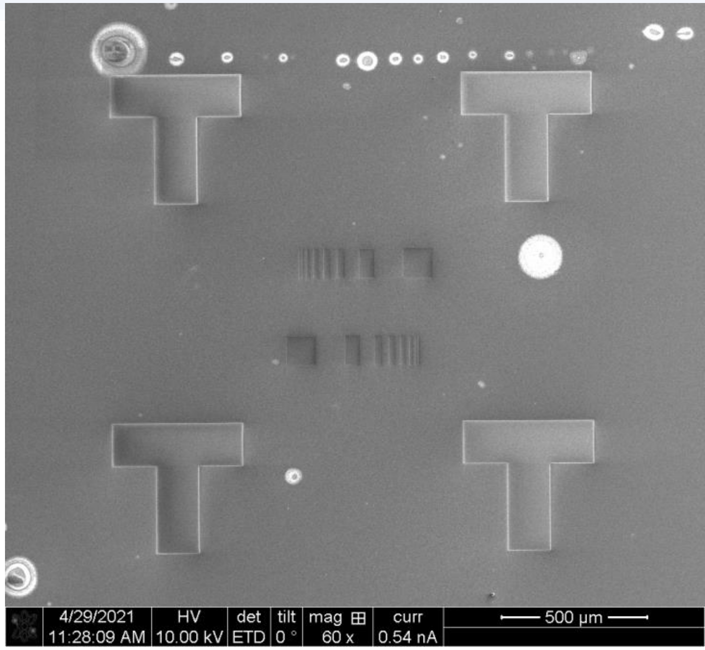
$$\Delta l = 1.22\frac{\lambda f}{D} \approx 25um$$

$$f = 75cm$$

$$\lambda = 266nm$$

$$D = 1cm$$

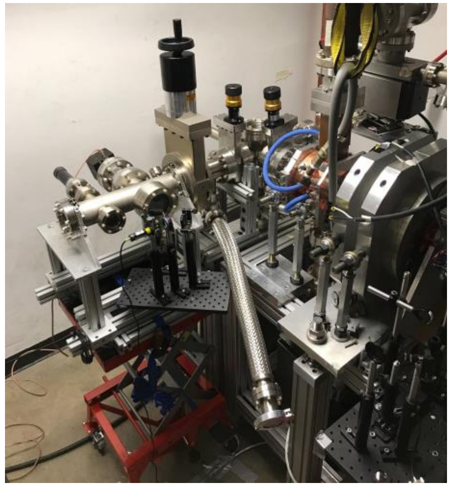


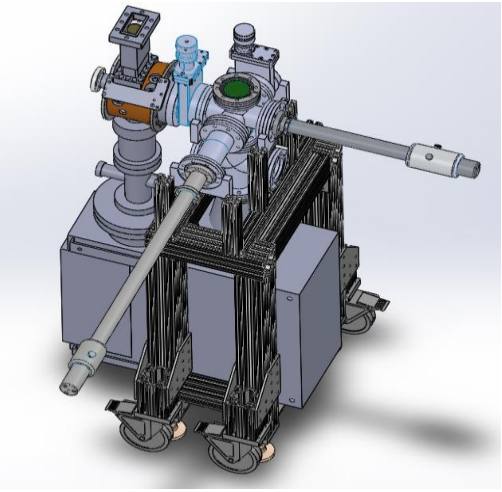


Experimental constraints on resolution:

VCC pixel size: 3.75um
Piezo step size: ~250nm
Piezo range: 3.5mm

Possible future extension: High resolution imaging of alkali-antimonide cathodes (grown at Cornell University)





Conclusion

- Ghost Imaging has been shown to be a viable method using electrons
  - Useful for the problem of QE mapping
    - Fewer shots
    - Better resolution
    - Passive data collection
- In progress: improving spatial resolution beyond optical resolution limit
  - Simulations suggest major resolution improvement with experimental SNR
  - Useful for studies of advanced photocathodes

- Thank you to the following scientists:
  - Pietro Musumeci (UCLA)
  - Krish Kabra (UCLA)
  - David Dang (UCLA)
  - Daniel Ratner (SLAC)
  - Siqi Li (SLAC)
  - Chad Pennington (Cornell)
  - Jared Maxson (Cornell)

Questions?

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