Alkali antimonide photocathode performance in ultrafast electron microdiffraction

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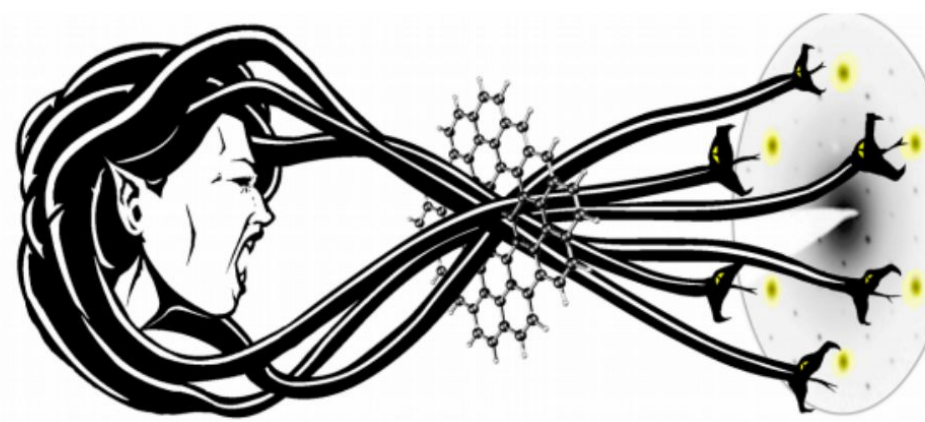
MEDUSA

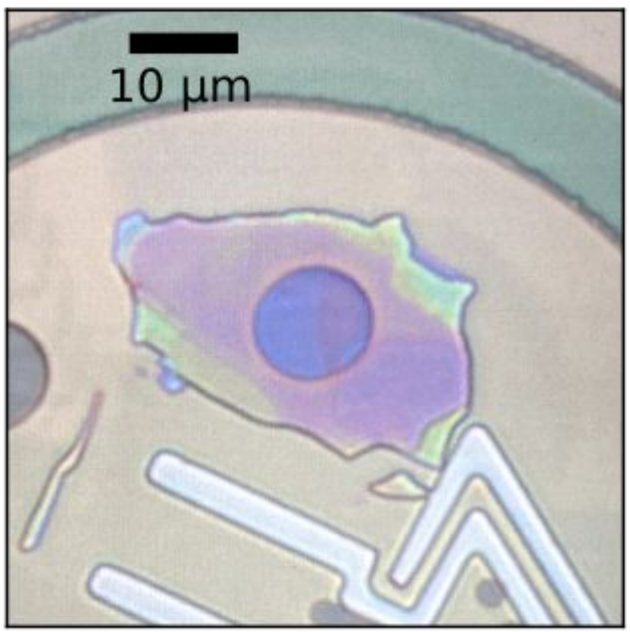
- Ultrafast Electron Diffraction (UED) is a time-resolved technique for studying materials out of equilibrium
- Conservation of six-dimensional brightness imposes a trade-off between spatial and temporal resolution in UED
- Machines that deliver 100 fs or shorter electron pulses typically produce rms transverse beamsizes 25 um or greater
- With a low MTE electron source, we form single micron size probes while maintaining 100s of femtosecond temporal resolution

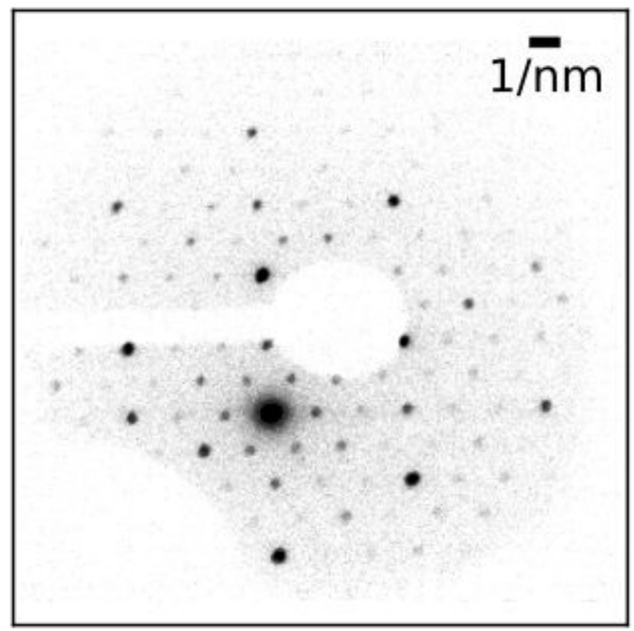
MICRO
ELECTRON
DIFFRACTION FOR
ULTRAFAST
STRUCTURAL
ANALYSIS



Microdiffraction

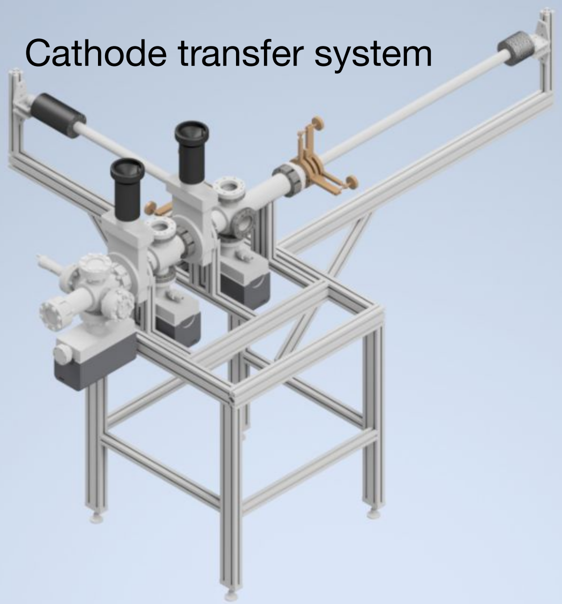
- Small probes make possible the study of small samples, e.g., flakes of materials that are challenging to prepare as large single crystals



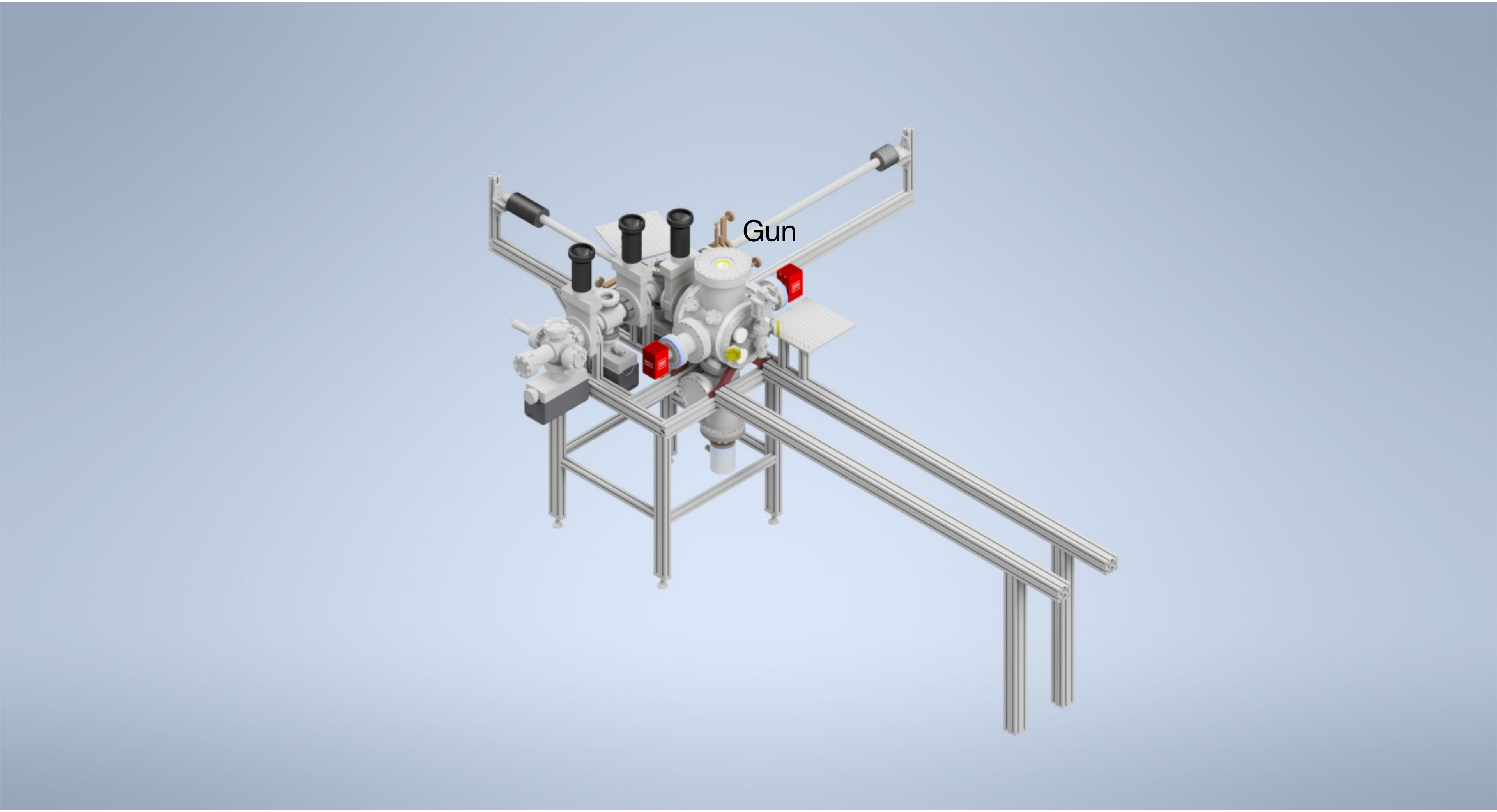


Diffraction sample, Nb_3Br_8

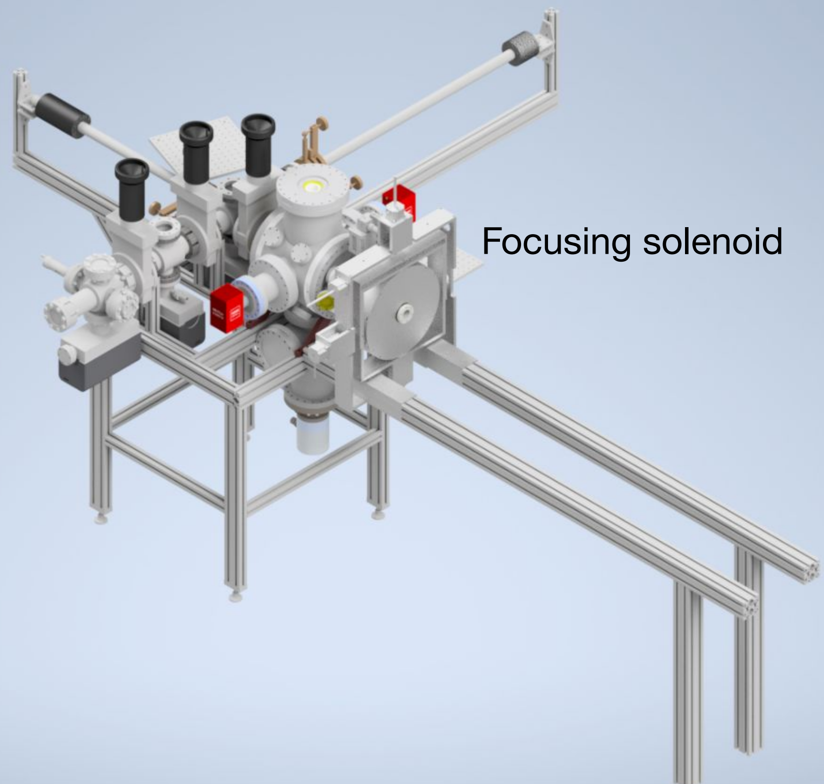
Beamline overview



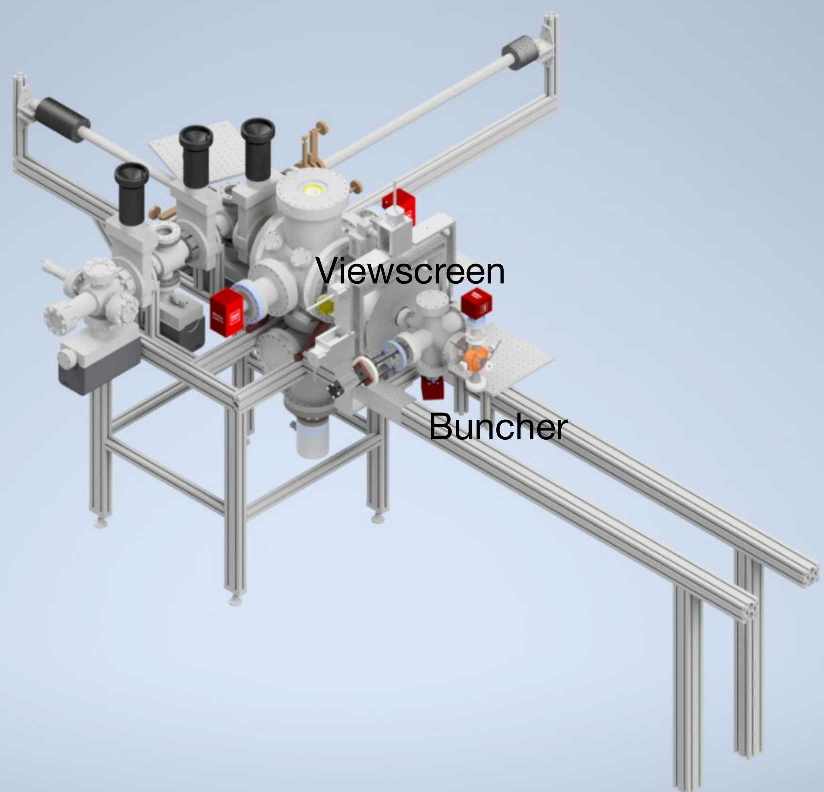
Beamline overview



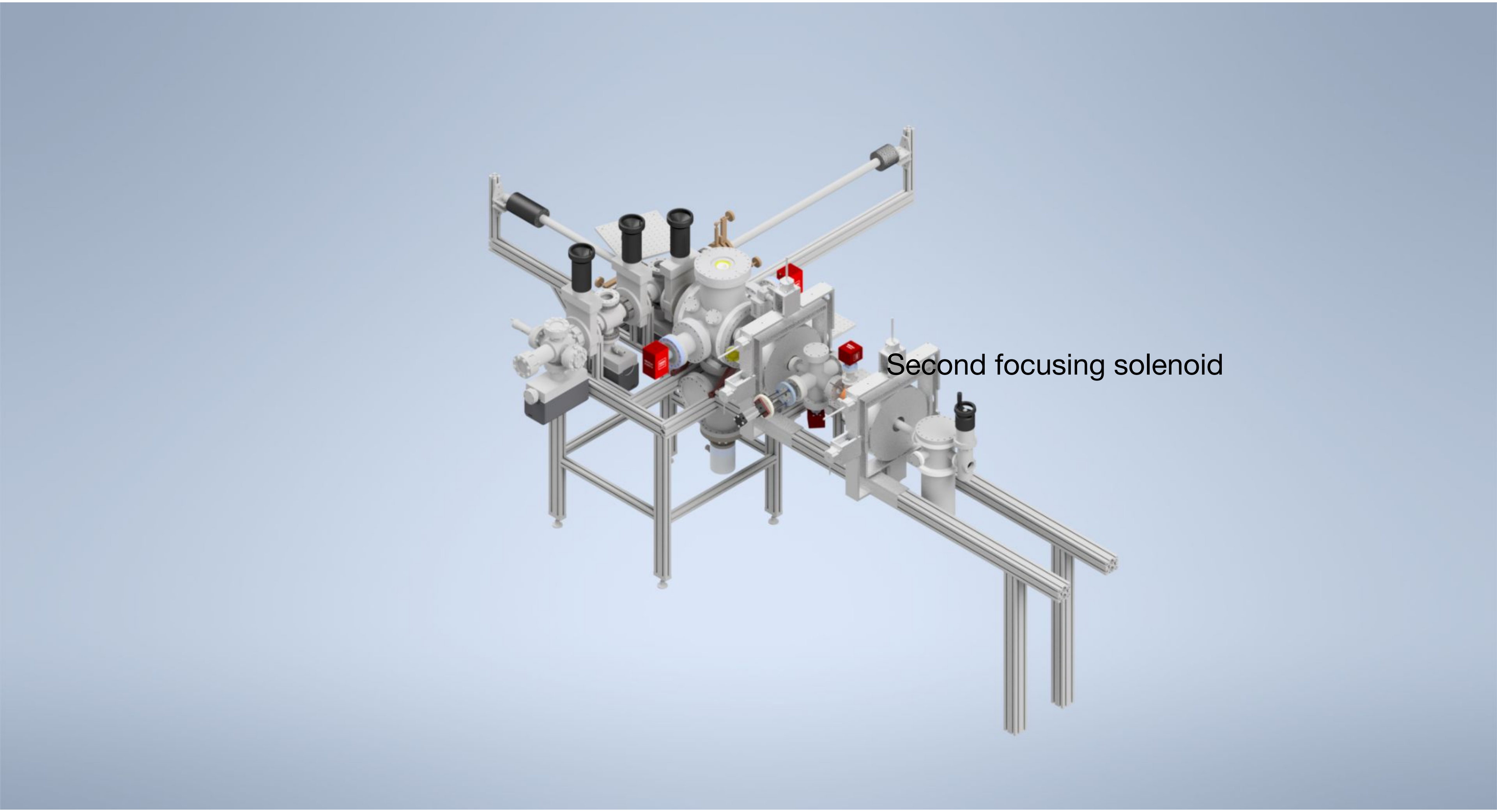
Beamline overview



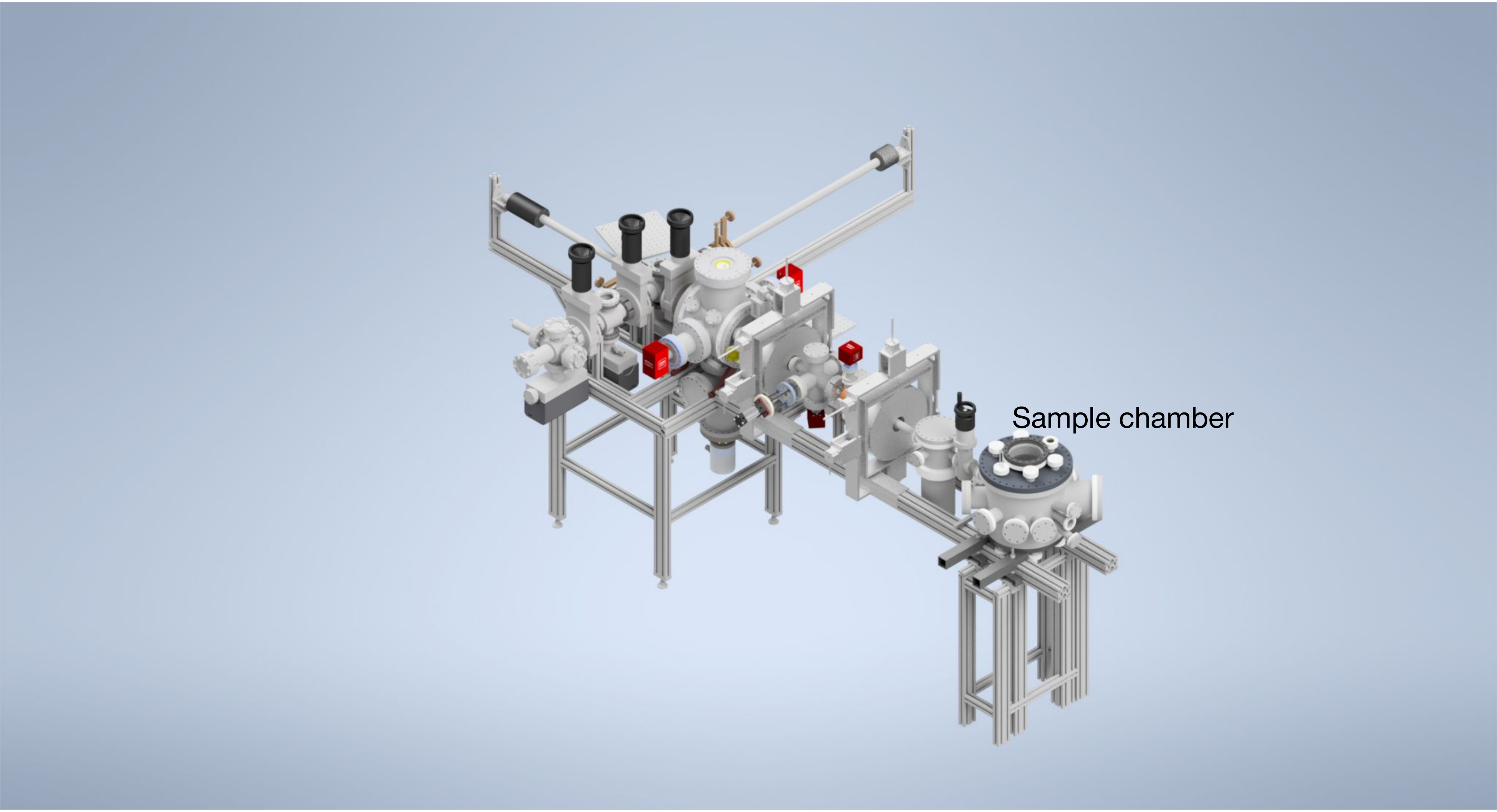
Beamline overview



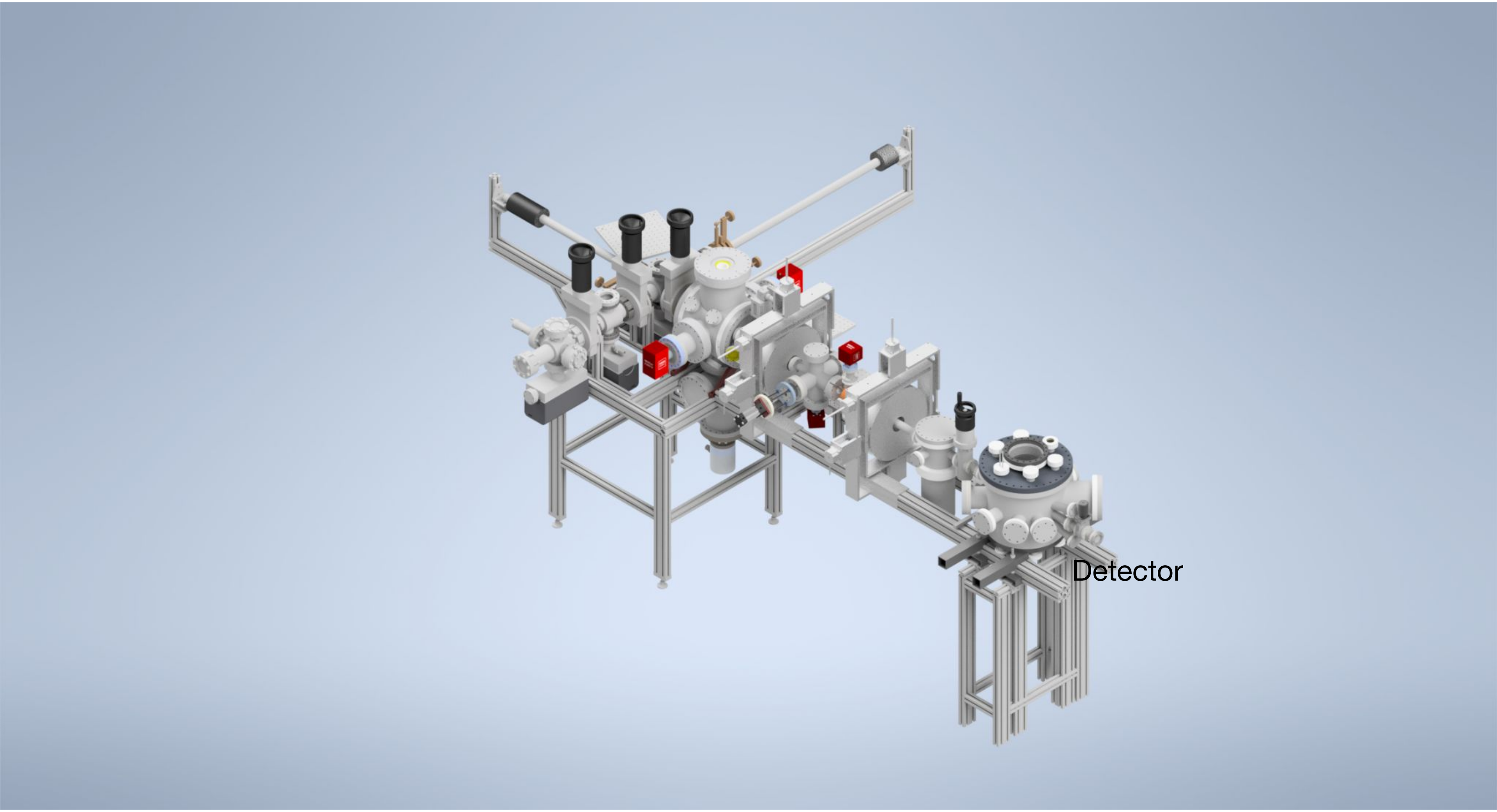
Beamline overview



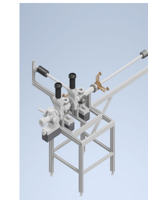
Beamline overview



Beamline overview

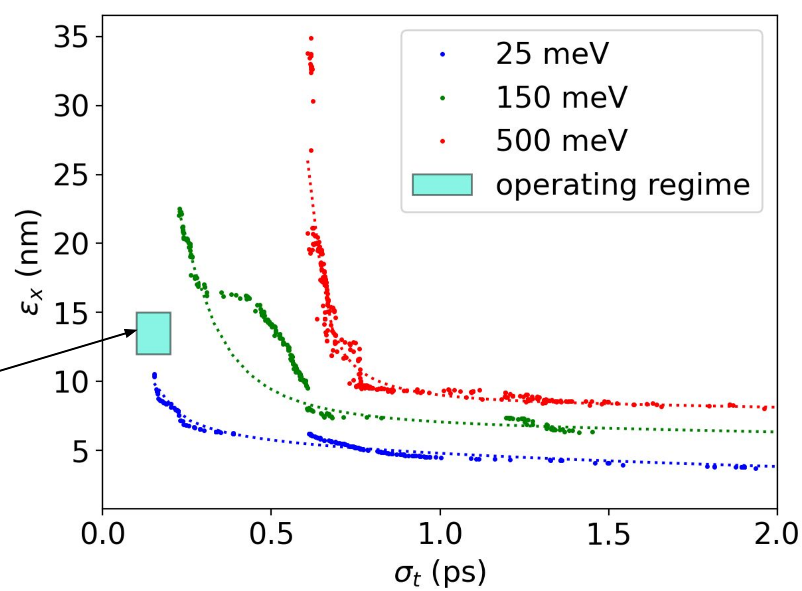


Cathode



- Na-K-Sb cathode grown at Cornell
- These cathodes have previously been measured to have high (percent-level) QE in the green and low (~35 meV) MTE at threshold
  - In simulation, decreasing MTE has a noticeable effect on emittance at the sample, around a factor of 2 at sub-picosecond bunches

10^5 electrons/bunch

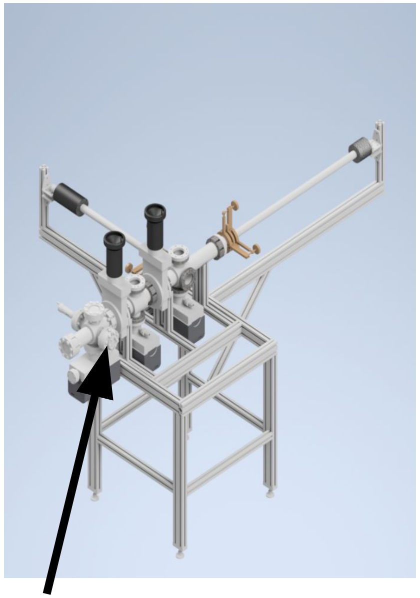


more on this a little later

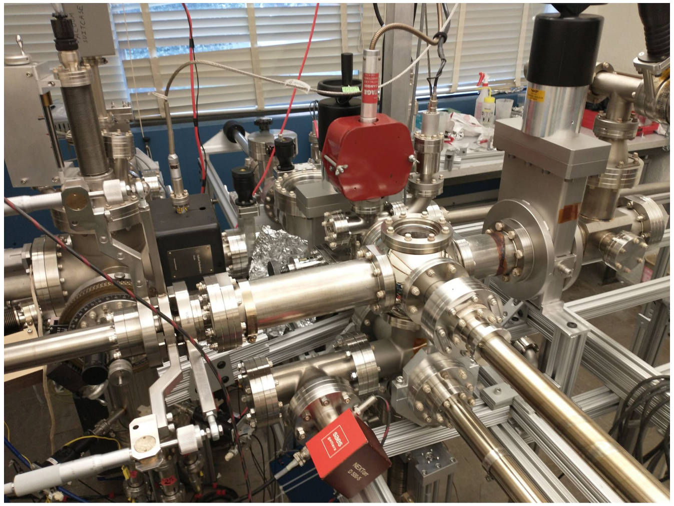
Cathode transfer

- The vacuum in all components of the cathode transfer process is kept under 10^{-10} Torr
- Compact suitcase fits inside the beamline's lead shielding
- Our Na-K-Sb photocathodes retain QEs in the 10^{-4} level at 650 nm after transfer to the gun

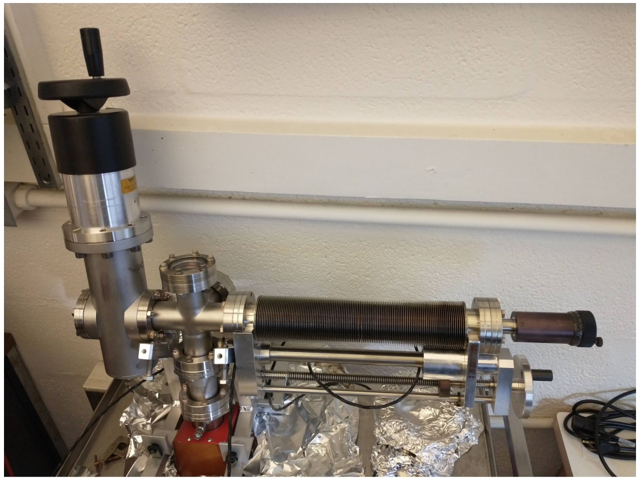
Cathodes grown on INFN/DESY/LBNL style miniplug



Suitcase attachment



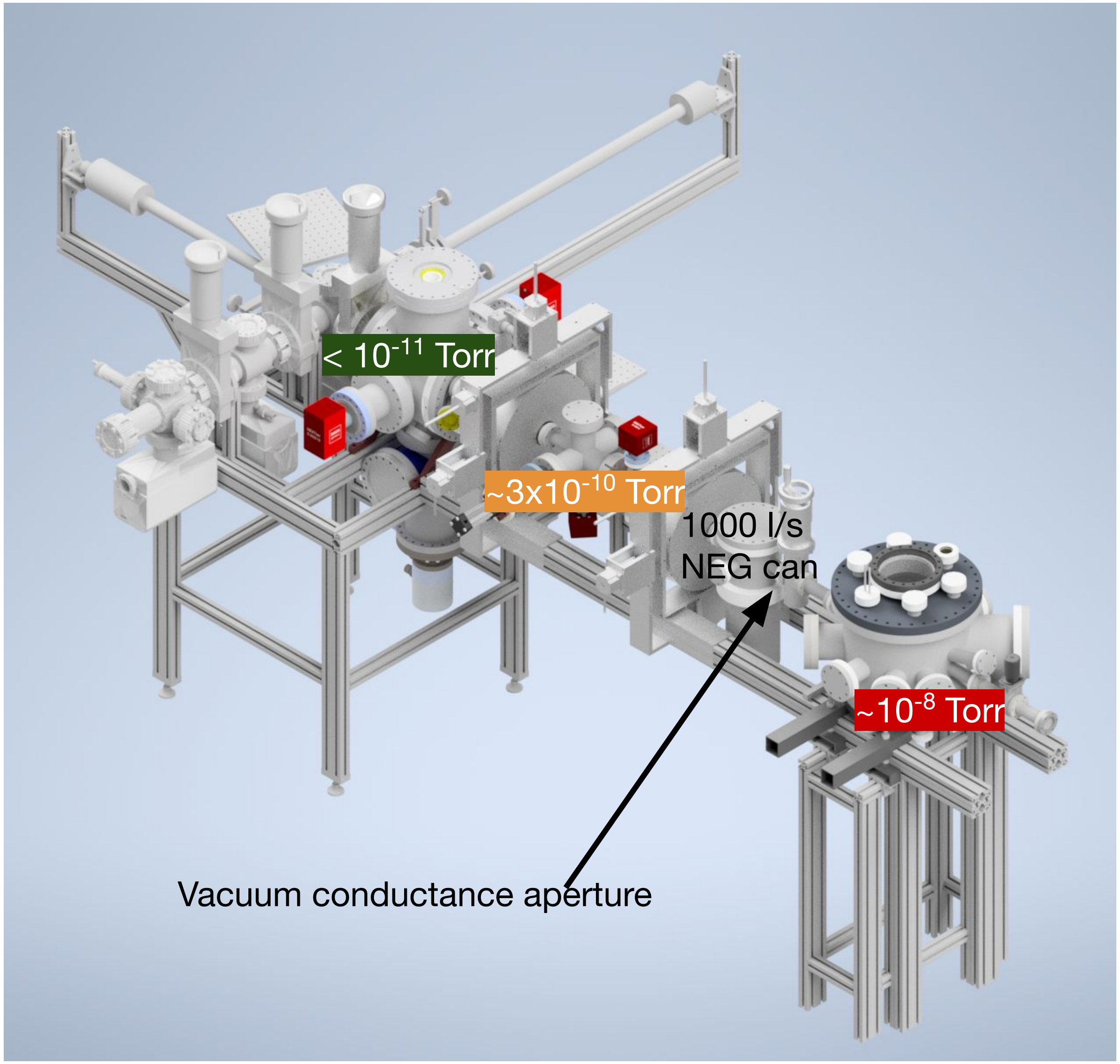
Growth chamber



Vacuum suitcase

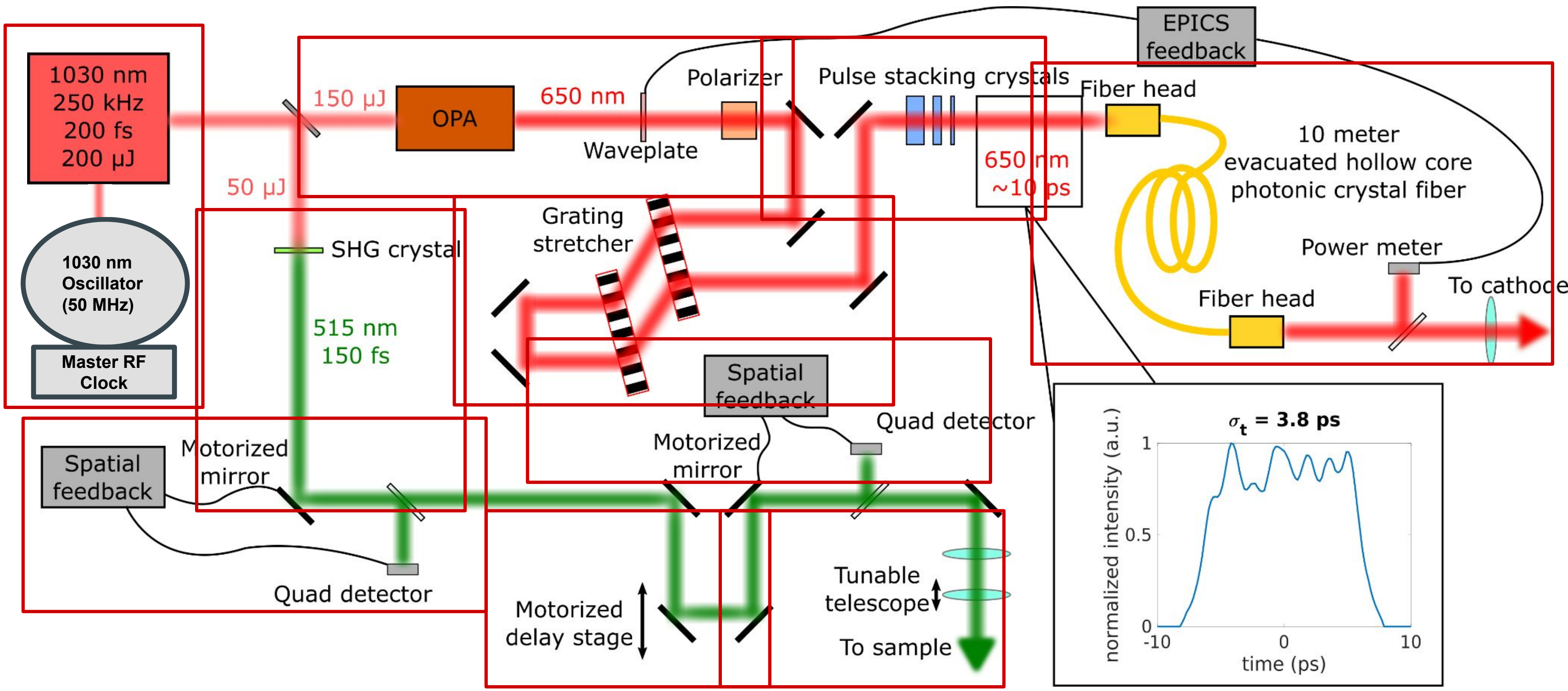
Vacuum

- Baking out sample chamber is impractical
- Conductance aperture and NEG can between sample chamber and beamline
- Gun remains below 10^{-11} Torr even with the sample chamber at 10^{-8} Torr.
- We've been able to use same photocathode for >800 hours of runtime



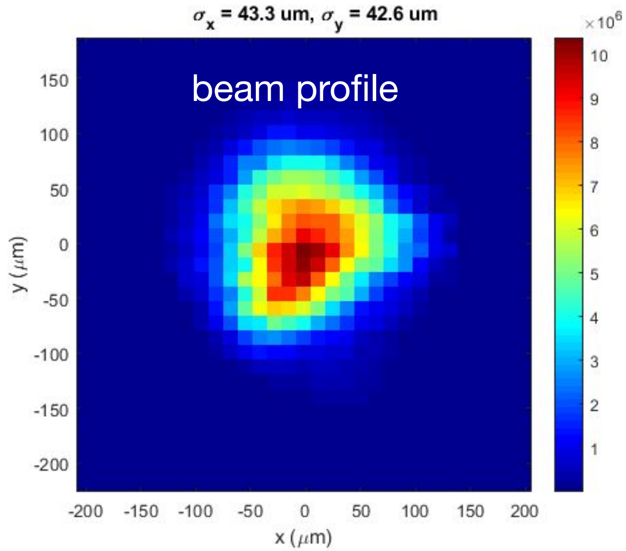
Laser setup

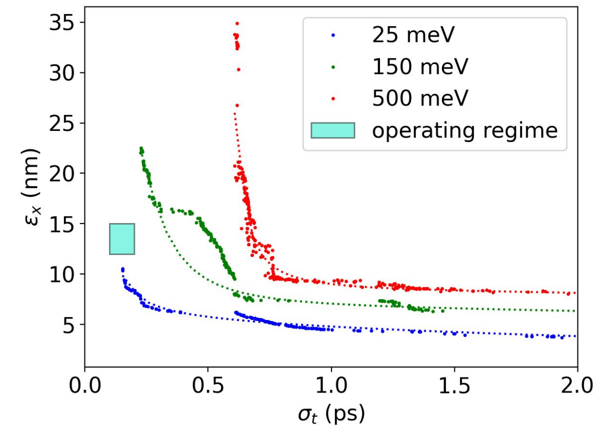
- We split a 1030 nm seed, generating 515 nm light for the pump and 650 nm light for the cathode
- 650 nm is chosen as it is near threshold but remains in the linear photoemission regime

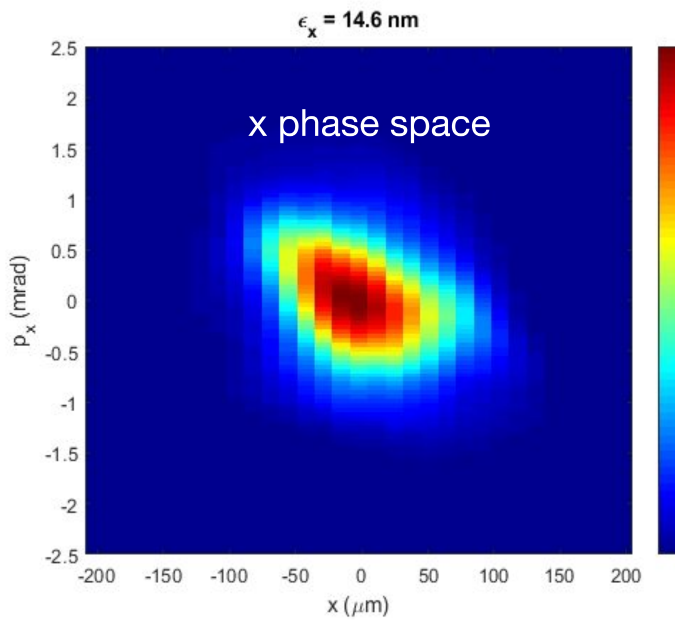


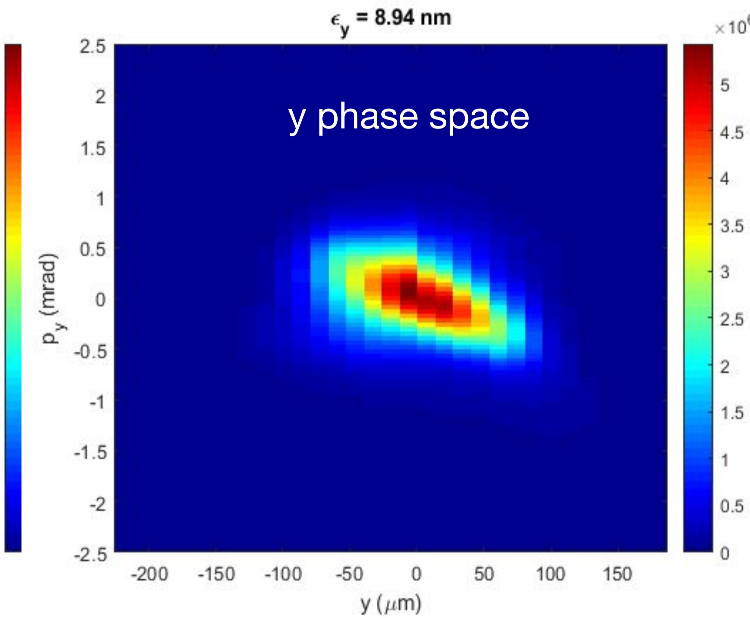
Emittance

- We can measure the emittance at the sample plane with a knife edge
- <15 nm normalized emittance in x
- 9 nm normalized emittance in y
- Right in the blue rectangle





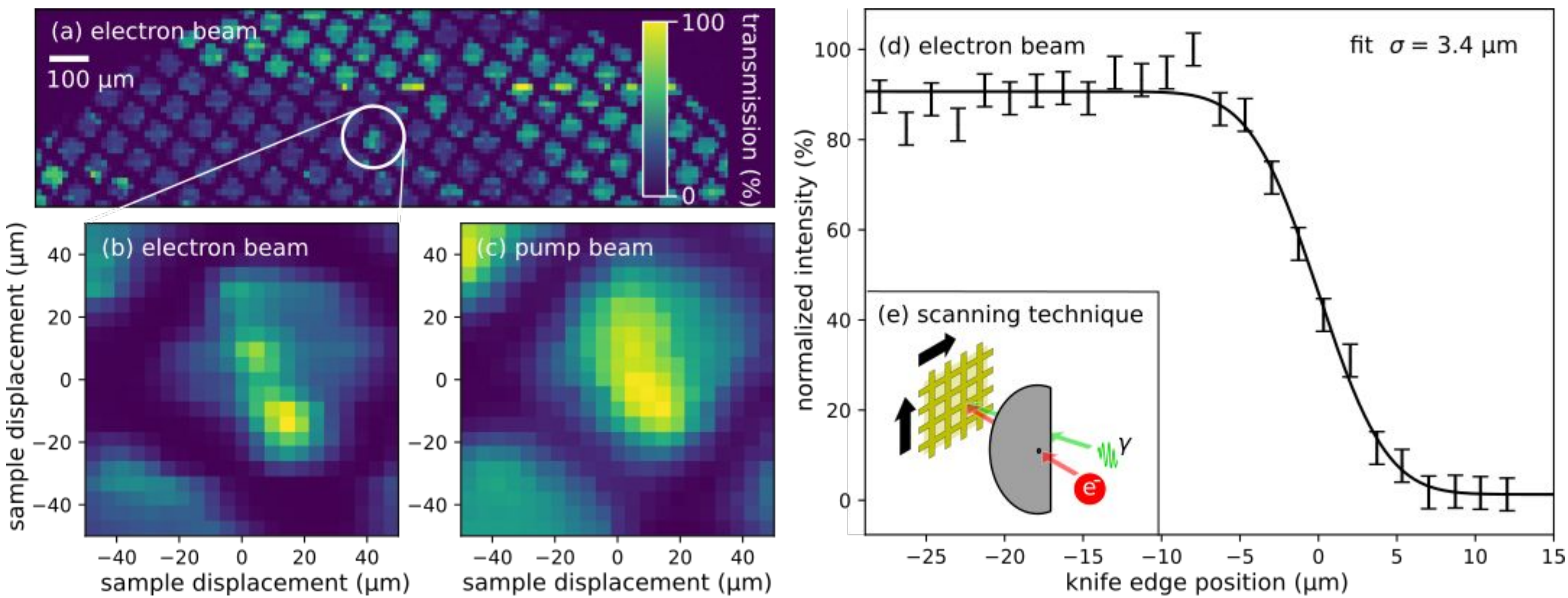




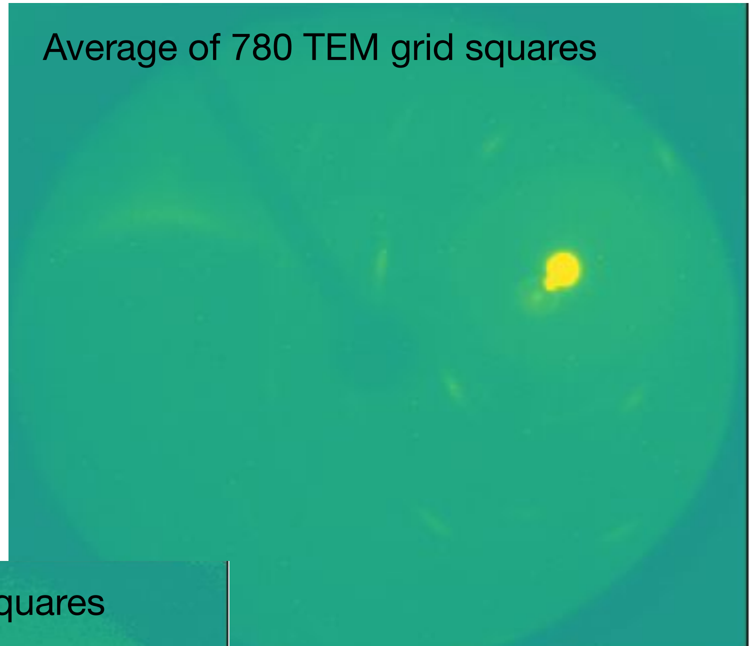
Spatial resolution

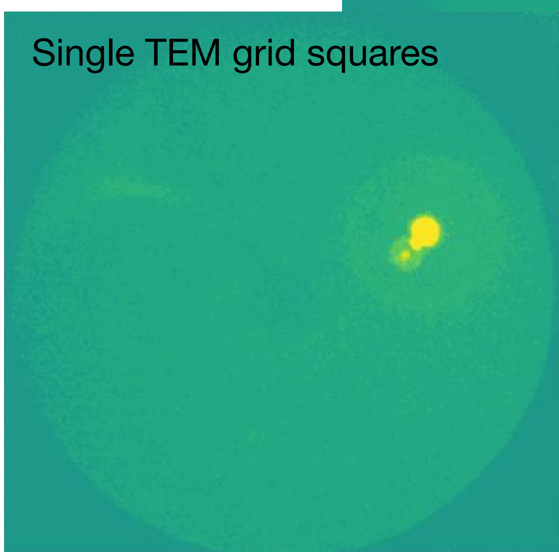
- 10 µm aperture placed just before sample (~500 electrons through)
- We characterize the size of the electron beam in two different ways

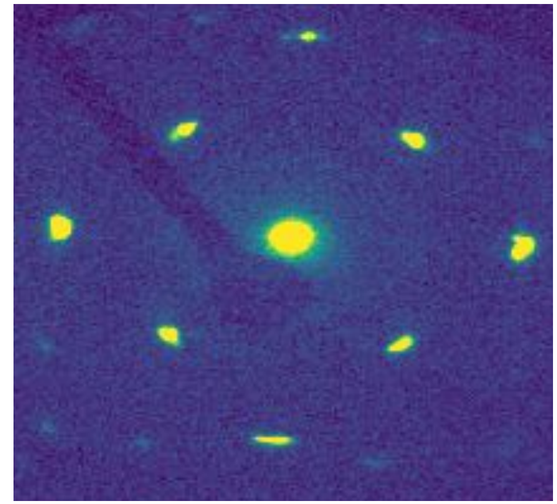
1. TEM grid scan (a)-(c)
   a. Also gives us spatial overlap with pump beam
2. Direct knife edge scan (d)



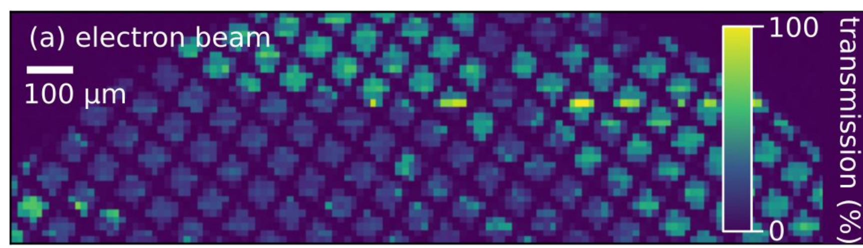
Spatial resolution







Single TEM grid square

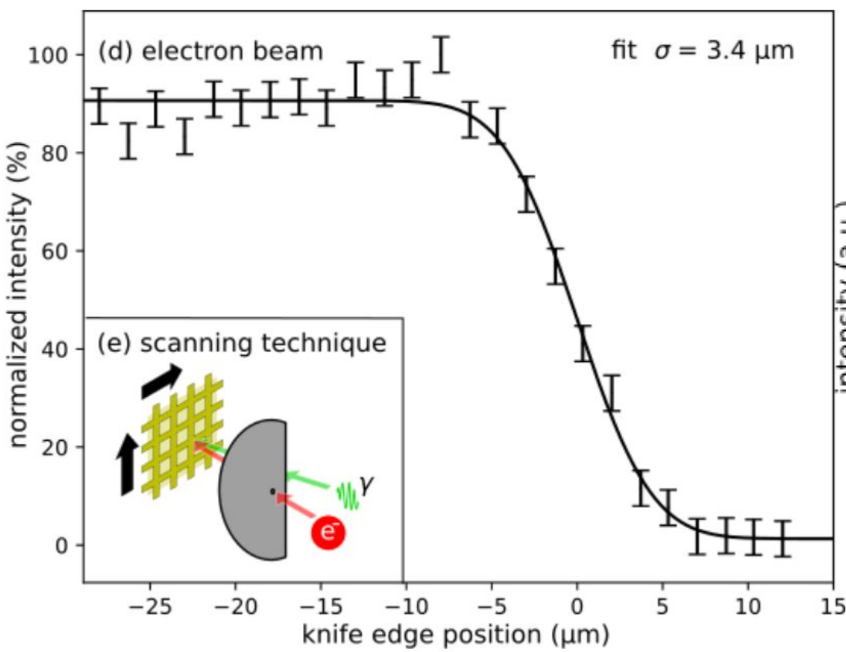


Transmission scan of TEM grid

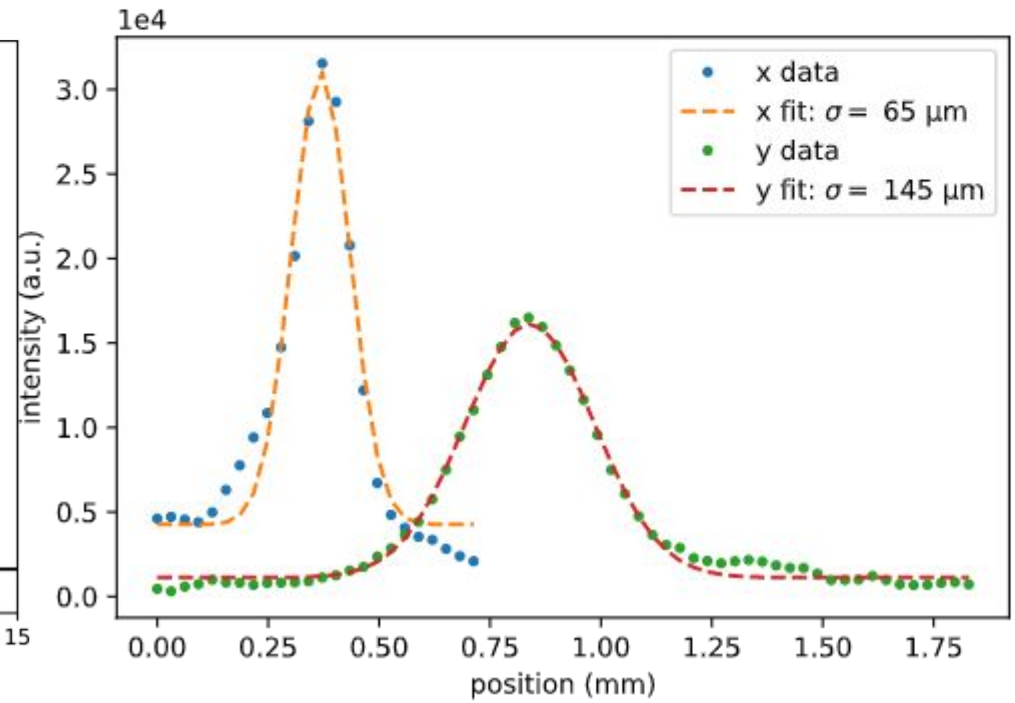
Emittance (apertured)

- At waist, $\varepsilon = \sigma_x \sigma_{x'}$
- For the ~500 electrons passing through aperture:
  0.7 nm normalized emittance!

Size measured with knife edge

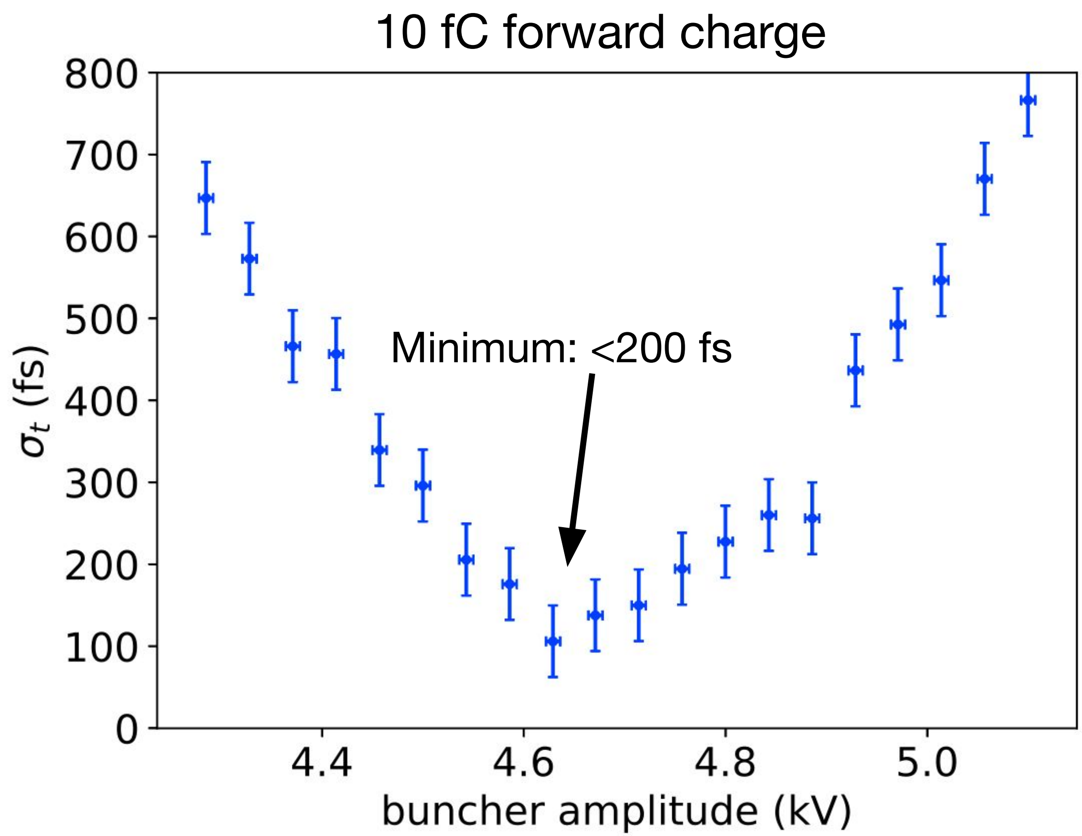


Momentum spread measured with size on final screen

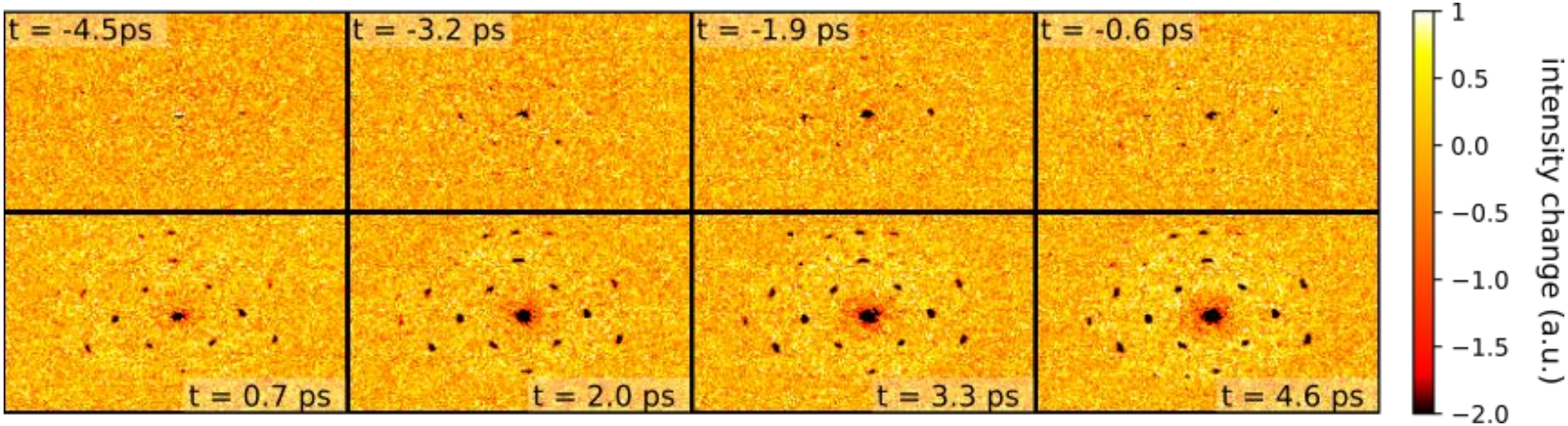


Bunch length

- The bunch length can be obtained by measuring the beam size along an rf deflection axis.

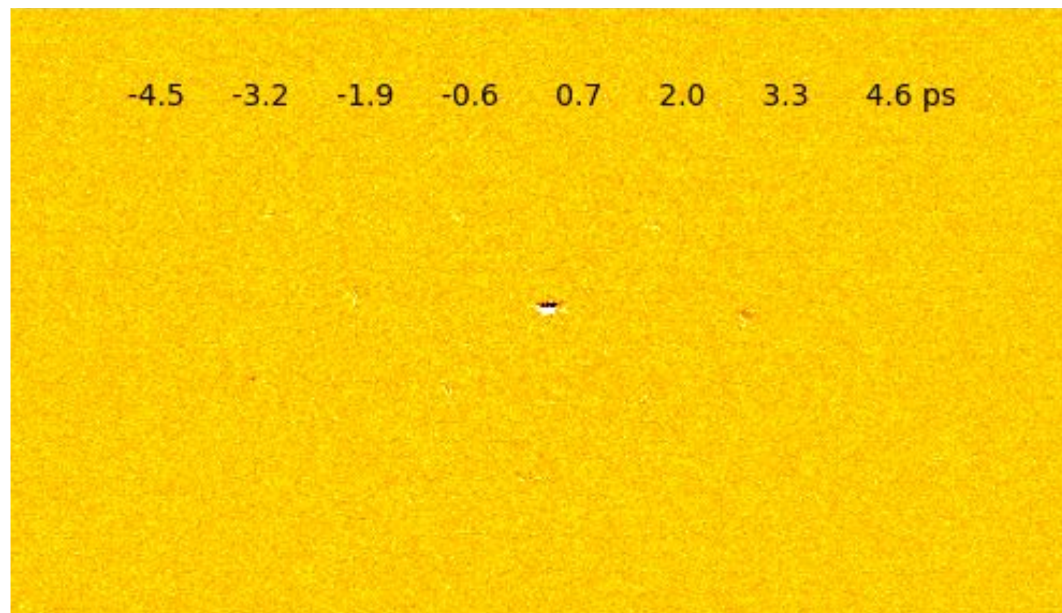


Gold UED



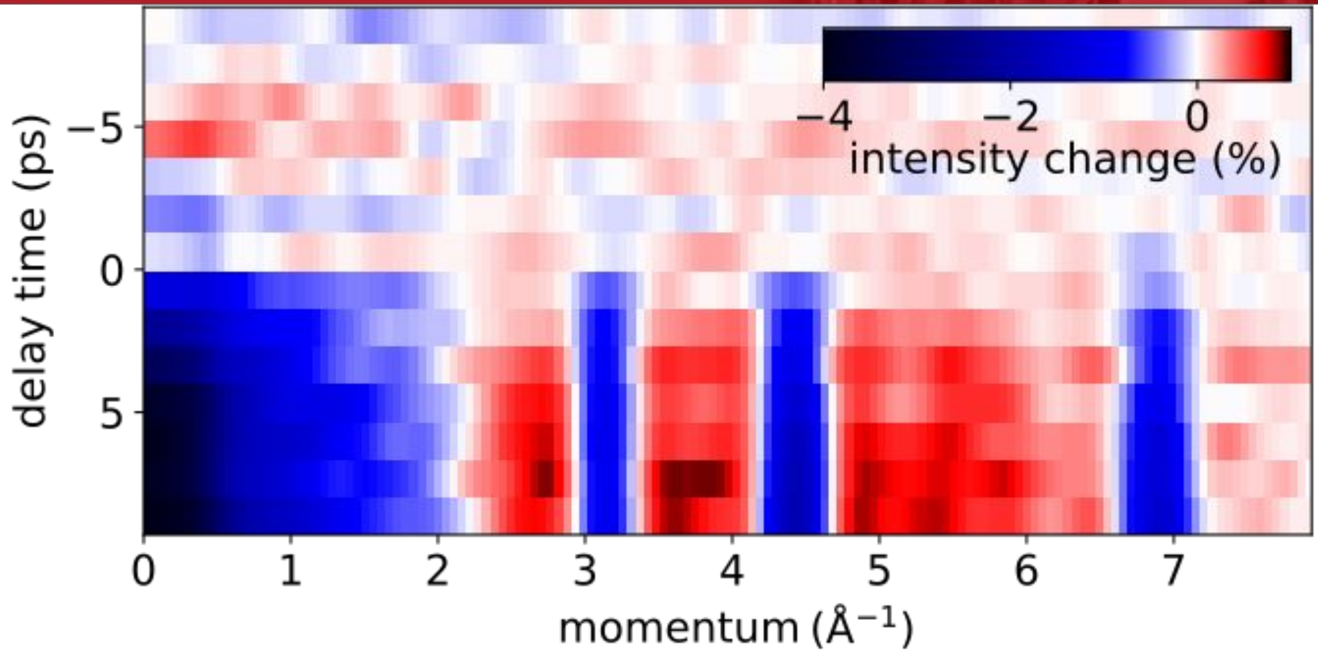
Signal S is the *relative* change in intensity I:

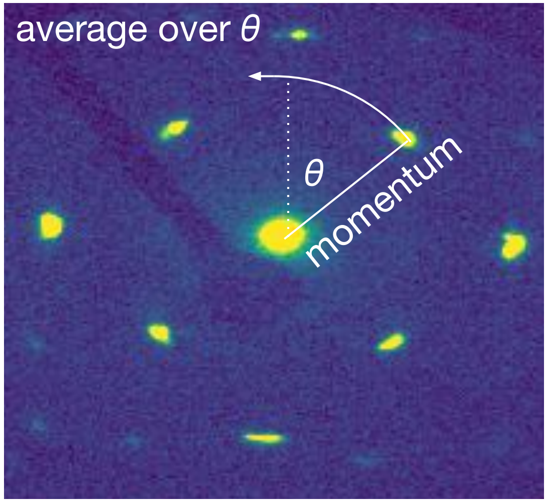
$$S = \frac{I_{hot} - I_{cold}}{I_{cold}}$$



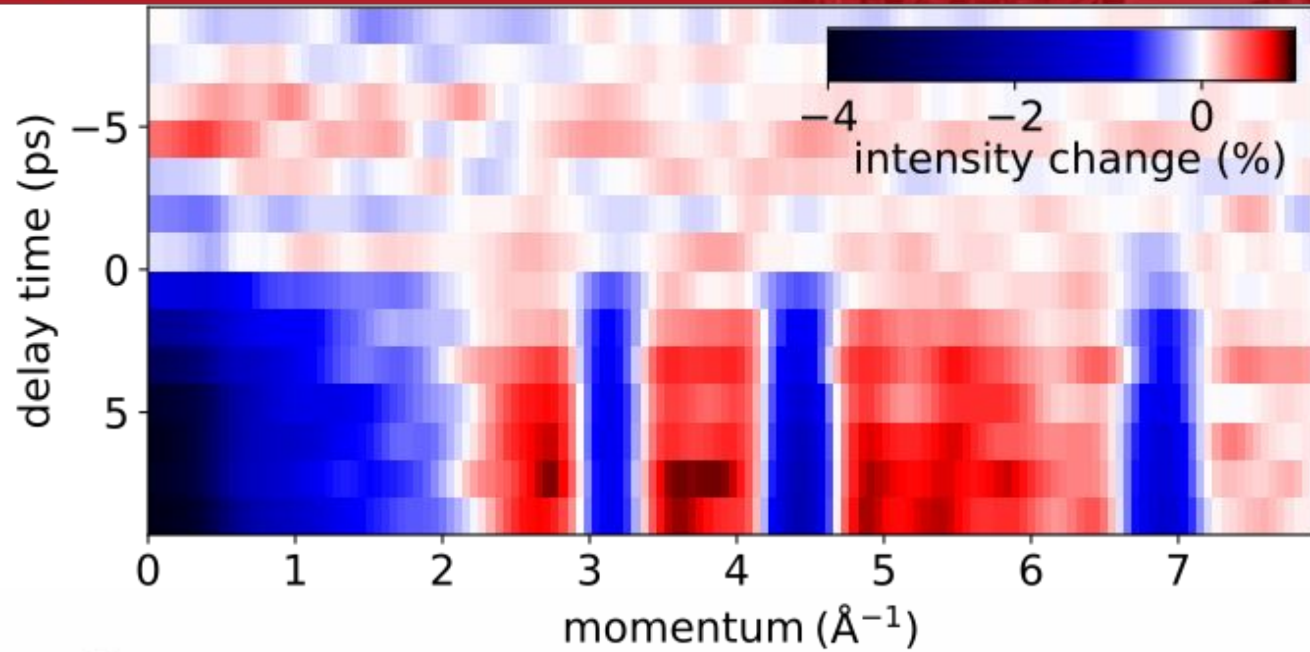
In our experiment, $|S| \sim 1\%$

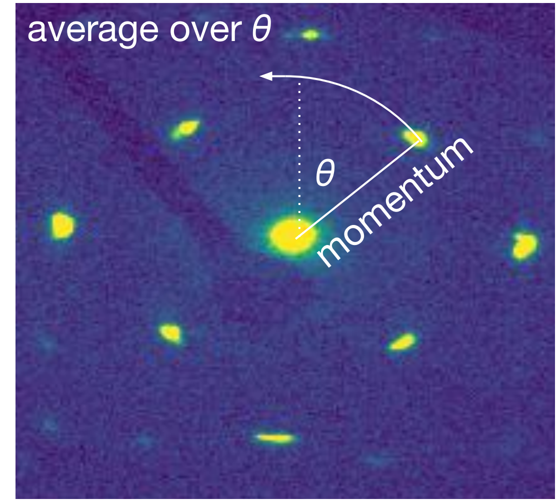
Gold UED

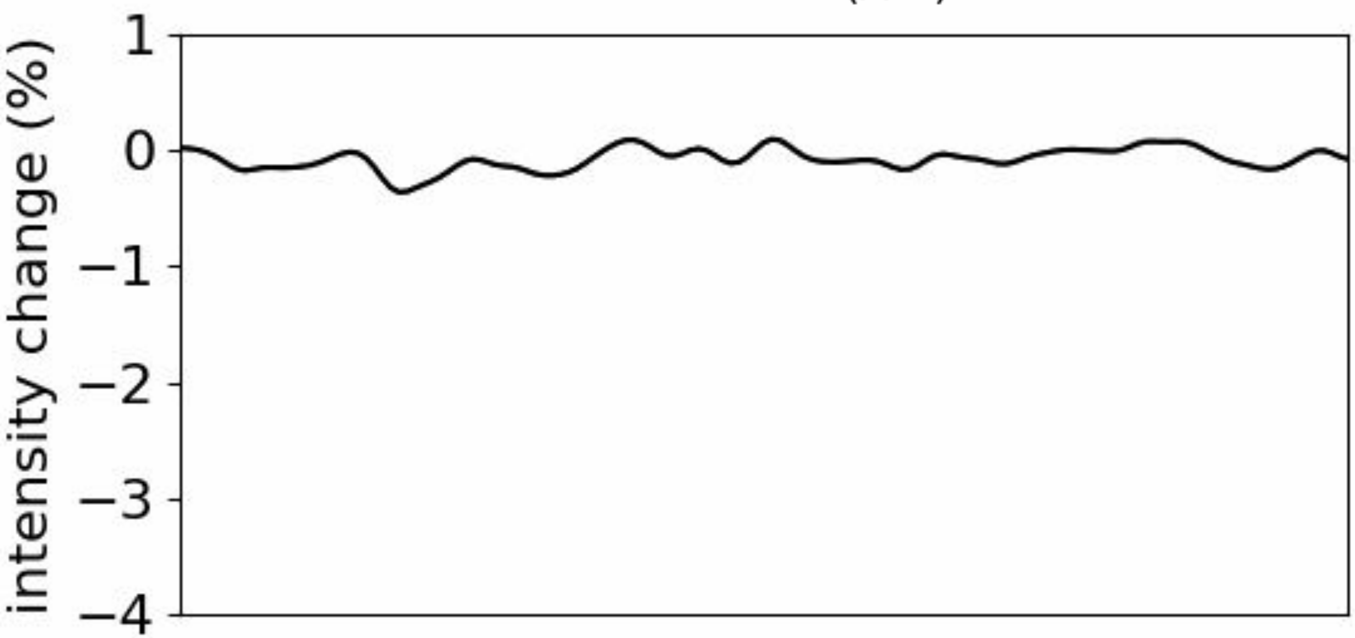

−4
−2
0
intensity change (%)
delay time (ps)
−5
0
5
0
1
2
3
4
5
6
7
momentum (Å^{-1})


average over θ
θ
momentum

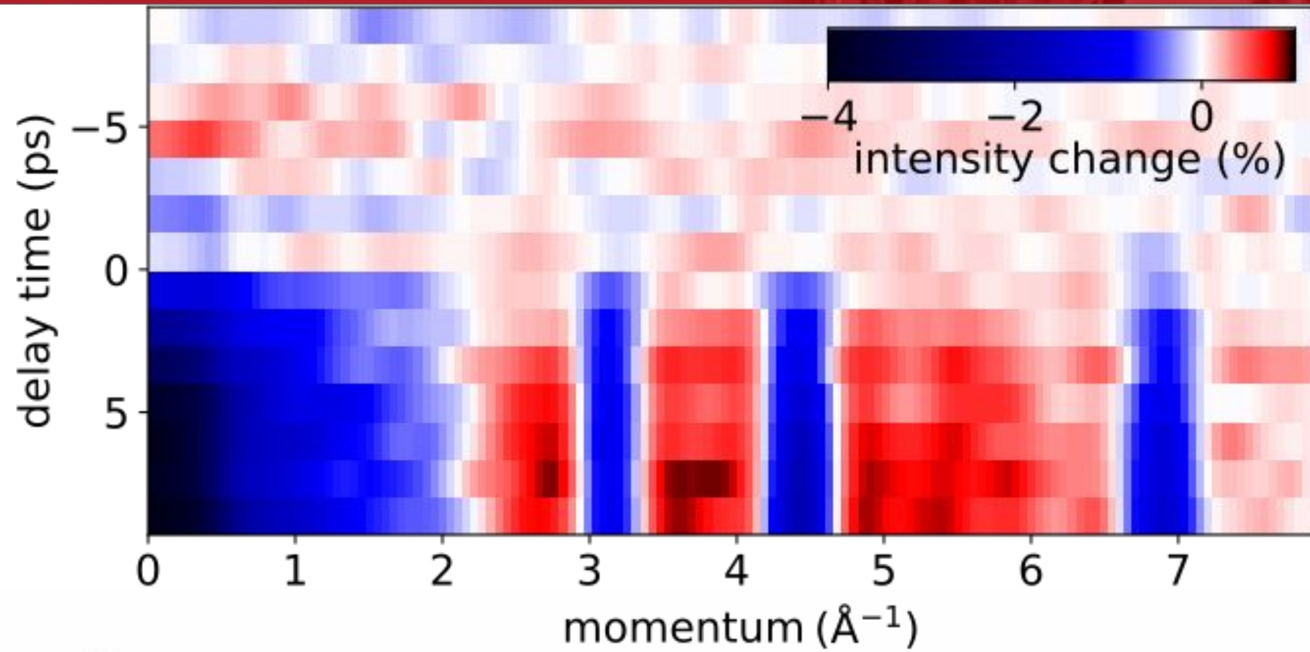
Gold UED

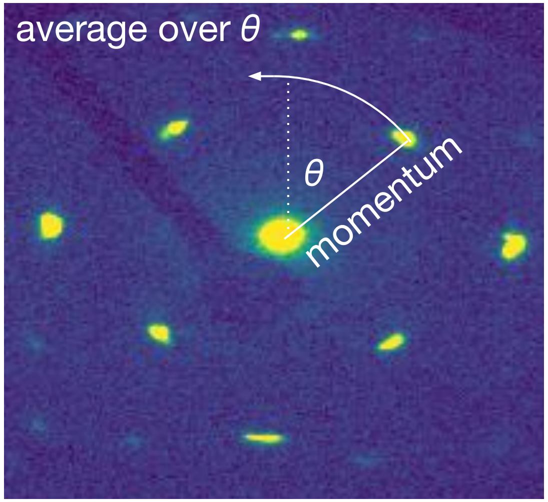

−4
−2
0
intensity change (%)
delay time (ps)
−5
0
5
0 1 2 3 4 5 6 7
momentum (Å^{-1})

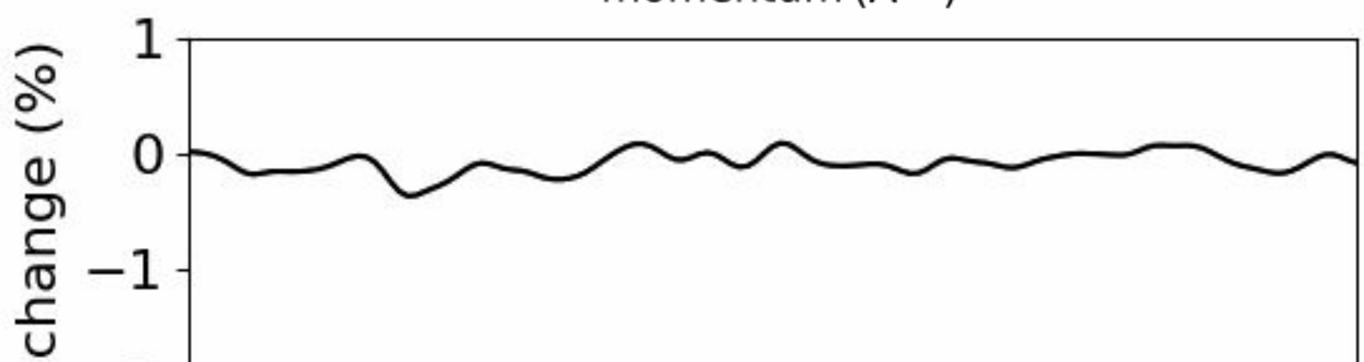

average over θ
θ
momentum


intensity change (%)
1
0
−1
−2
−3
−4

Gold UED





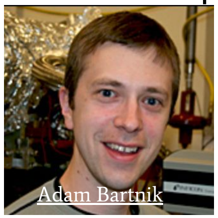


Data taken at:

- 5 kHz repetition rate
- 5 s exposures
- 100 exposures per delay
- 100 < e$^-$ per shot < 1000

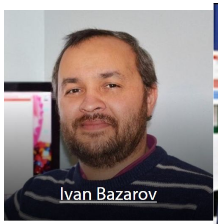
Acknowledgements

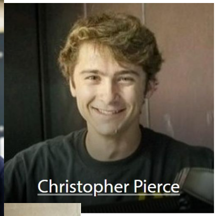
Maxson Group



Now at U. Salerno.

Bazarov Group





Now at BNL

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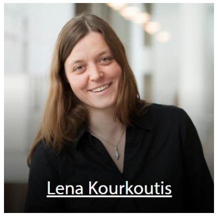
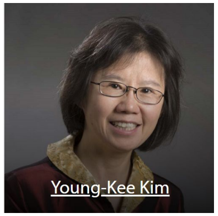
Cornell Electron Microscopy

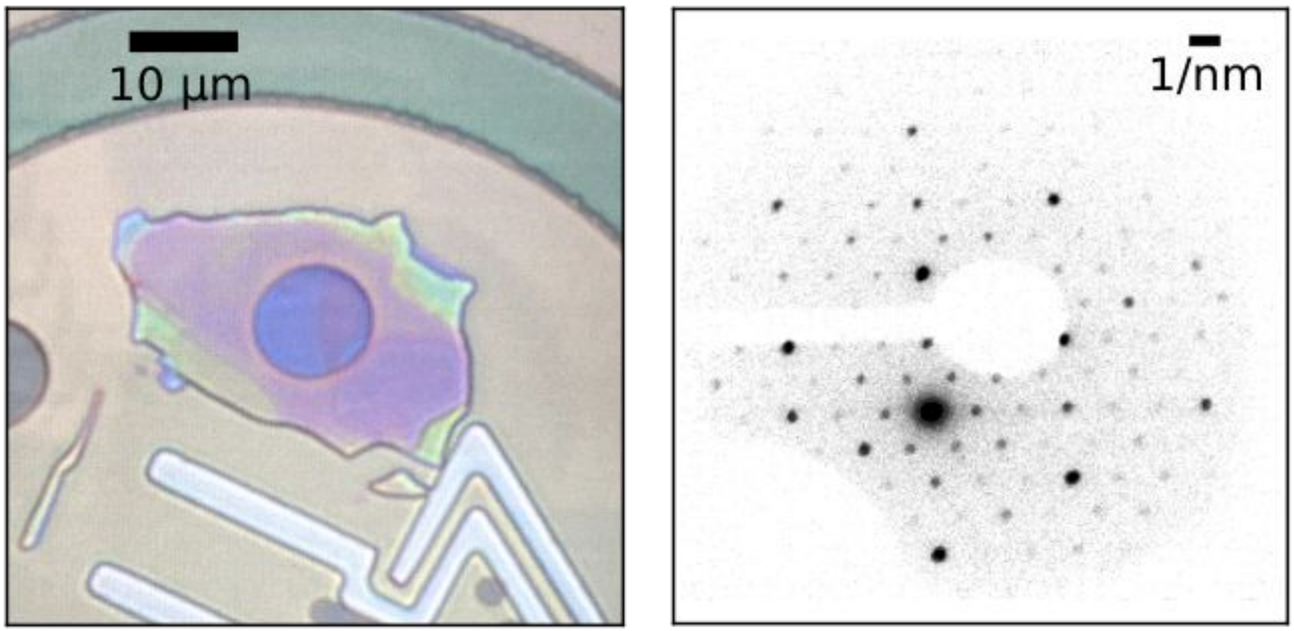


U. Chicago Beam Dynamics



Conclusion

- MEDUSA is an operational UED beamline running low MTE Na-K-Sb photocathodes at threshold, in the linear photoemission regime
- Low MTE enables subpicosecond, micron scale bunches with hundreds of electrons per bunch and fine reciprocal space resolution



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