Optical Imaging of Ultra-small Electron Beams

Bryce Jacobson
RadiaBeam Technologies, LLC
1 October, 2013
NA-PAC 2013

Outline

- Motivation and approach
- Optical imaging system
- Electron beam target
- Bench-top calibration
- Installation on Pegasus beamline @ UCLA
- Initial tests and setup
- Recent measurements
- Upcoming plans
- Conclusion

Motivation and Approach

radiabeam TECHNOLOGIES

- Small electron beams: 100's nm ~ 10's um
  - Low resolution with working distances of typical optical systems
  - Larger than diffraction limit at optical wavelengths
  - Can use high numerical aperture imaging
- Needed in many machines and applications
  - Dielectric laser accelerators
  - Plasma wakefield accelerators
  - High brightness light sources
- New novel transverse diagnostic techniques becoming available, but optical imaging is well understood
  - Simple interpretation and analysis
- Instrumentation for tune-up and commissioning

Optical Imaging System

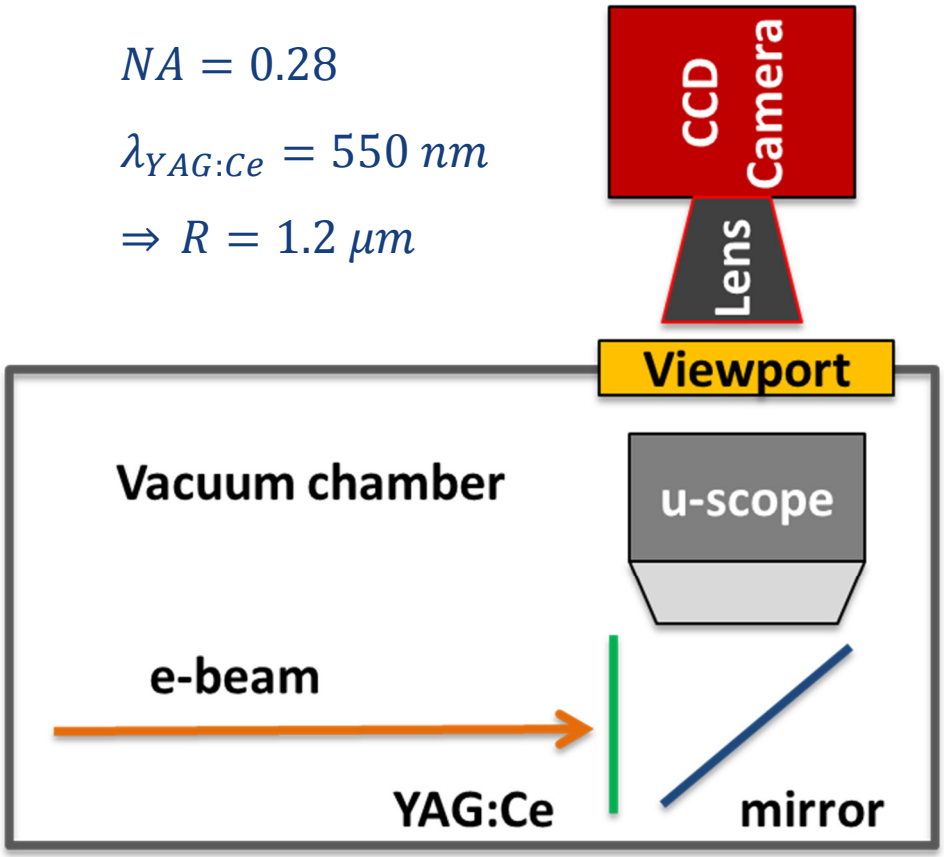
- Increase numerical aperture of optical system
- Infinity corrected microscope
  - Large spacing between lenses
- Schwarzschild reflective objective
  - Free of spherical and chromatic aberration, coma, astigmatism,
- ReflX Objective from Edmund Optics
  - ¼ wave
  - 15x magnification
  - 0.28 N.A.
  - ~ 24 mm working distance
  - 13.3 mm effective focal length
  - Infinite conjugate
- YAG:Ce scintillator target
  - Radiates over 4π
- Normal incidence object plane
  - Short depth of focus for high NA

$$R = \frac{0.61\,\lambda}{NA}$$

$$NA = 0.28$$

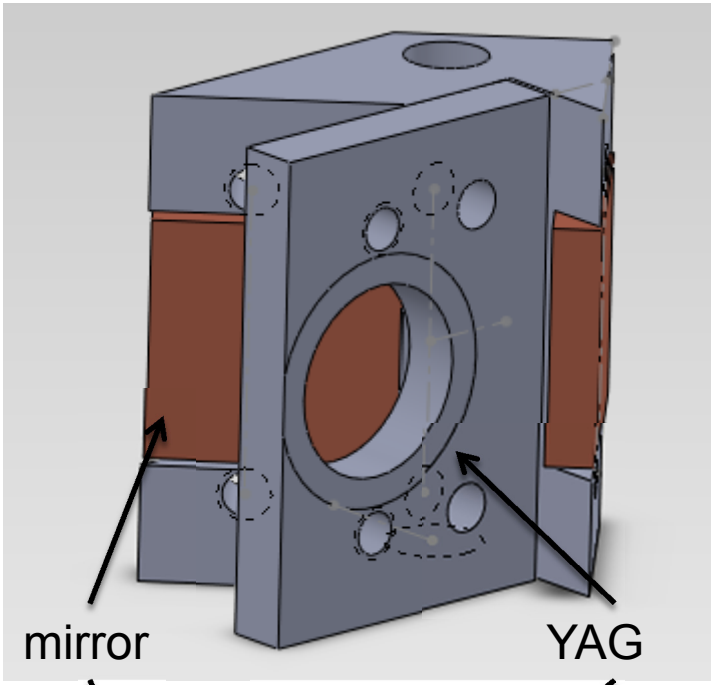
$$\lambda_{YAG:Ce} = 550\ nm$$

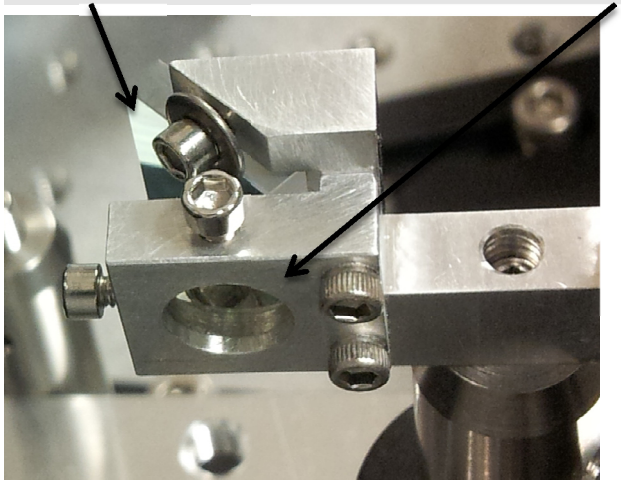
$$\Rightarrow R = 1.2\ \mu m$$



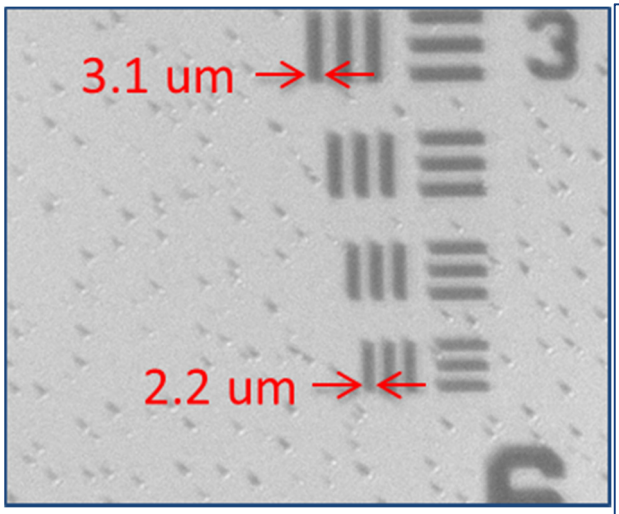
Electron Beam Target

- UCLA designed multi-purpose assembly
  - Normal incidence YAG
  - 45 degree incidence COTR
  - Pass-through for e-beam
- YAG:Ce crystal scintillator
  - 30 µm thickness
  - Thinnest sold by vendor
  - Limits blooming, scattering, and other diffractive effects
- 24 mm working distance
  - Small (~ ½”) YAG and mirror

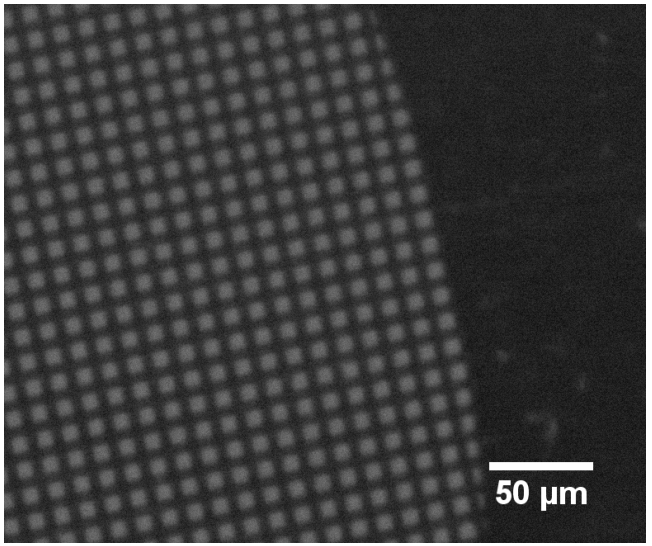




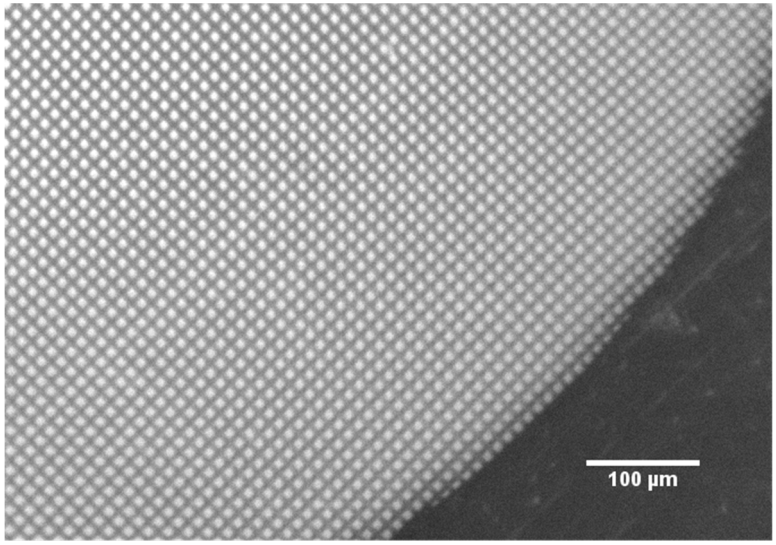
Bench-top Calibration

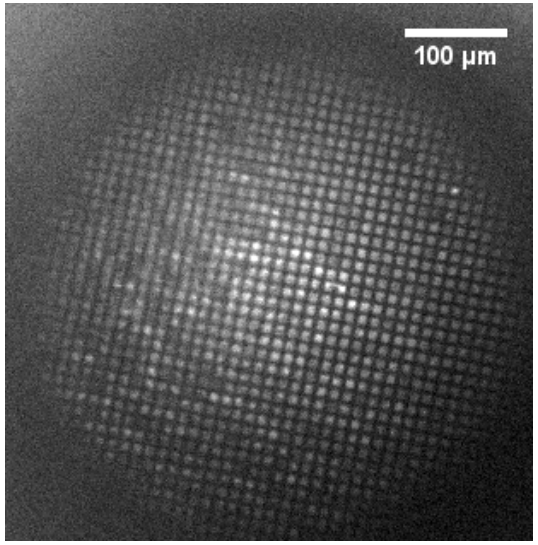


12.5 µm pitch TEM grid used for focusing and alignment . High mag image taken at RBT. →
Low mag image taken at RBT. ↓
Low magnification (3.75x) image of screen on YAG installed at UCLA Pegasus↘

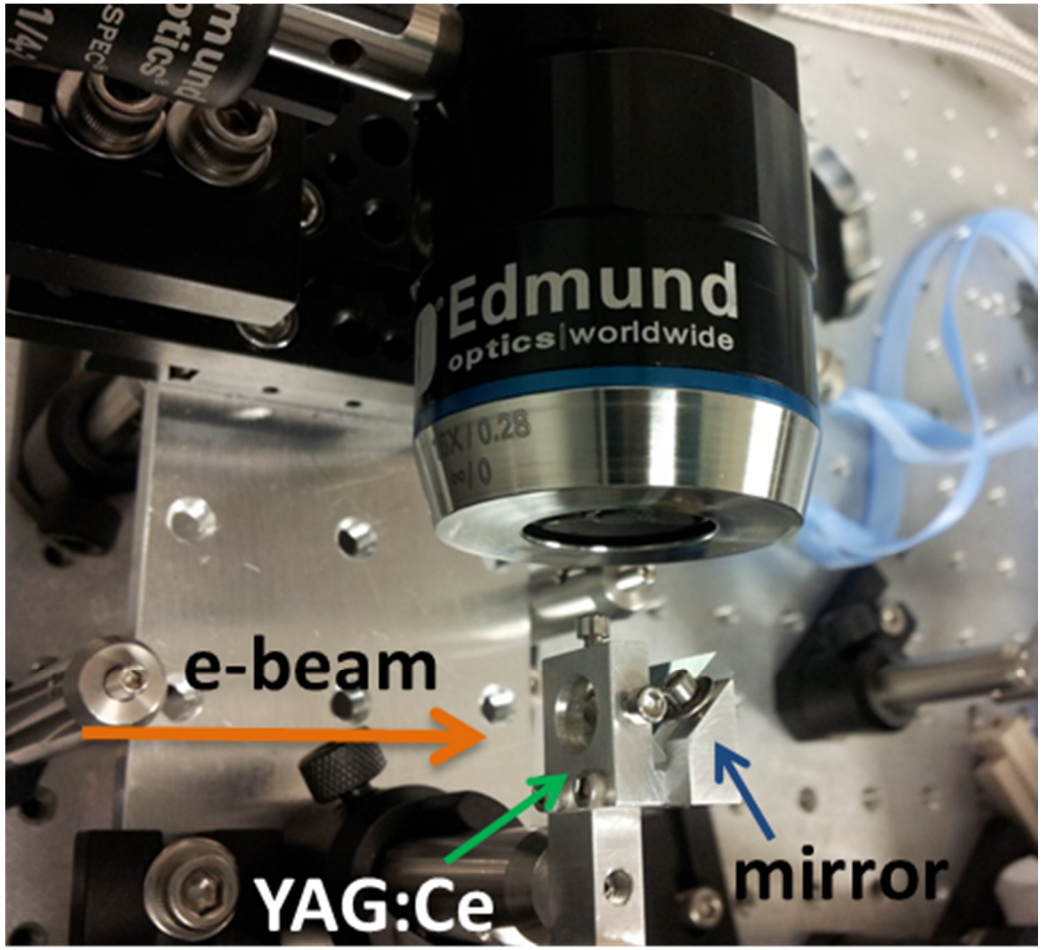


↑ Resolution test done at RadiaBeam: 2.2 µm lines on the USAF 1951 Test Target are clearly resolvable. Imaged here by 250 mm focal length tube lens and 4.7 µm pixel array CCD.





Installation at UCLA Pegasus

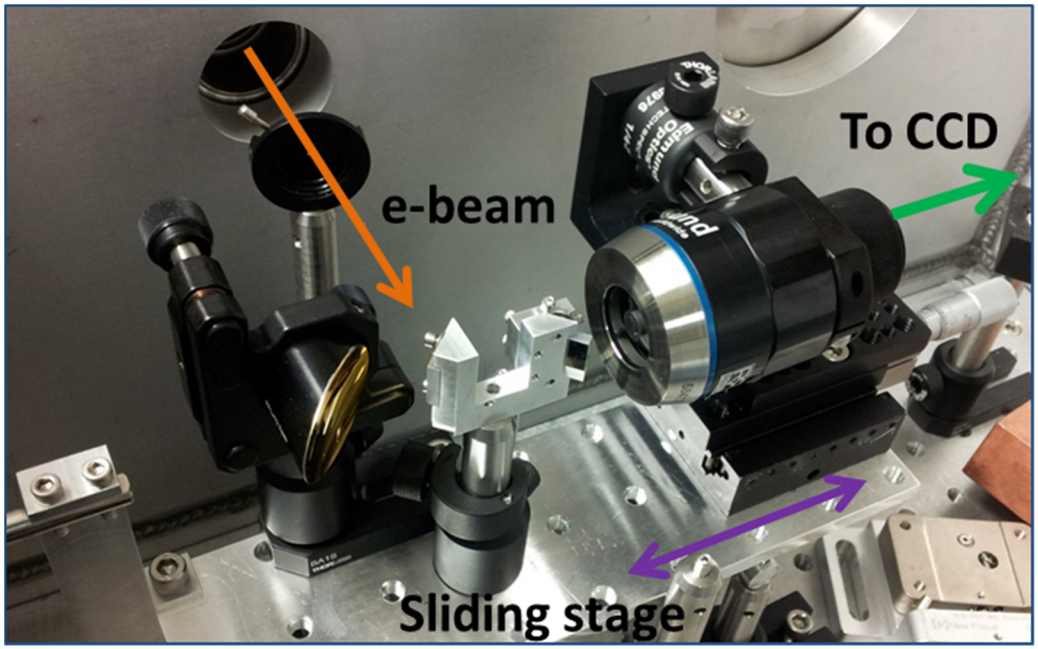


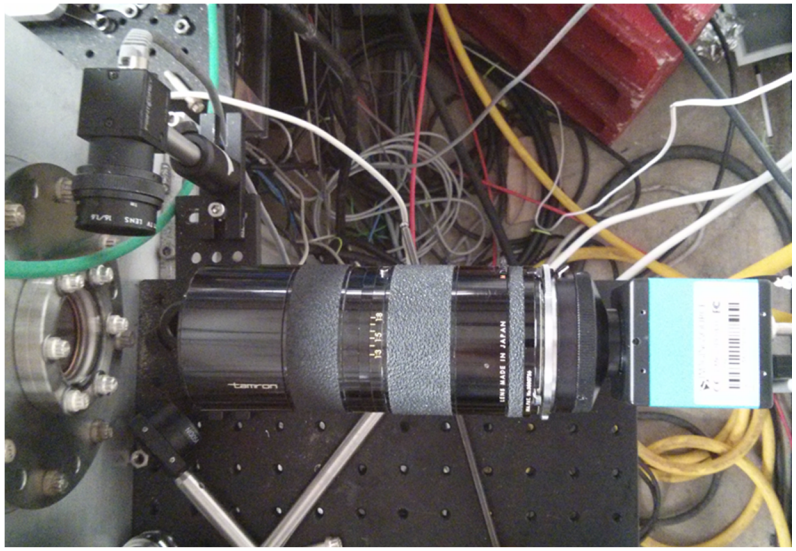
- Scintillator and mirror assembly installed in Pegasus test cell at UCLA in July
- Alignment between microscope objective and YAG/mirror assembly critical
  - Transverse small field of view
  - Longitudinal small depth of field

Installation at UCLA Pegasus

radiabeam TECHNOLOGIES

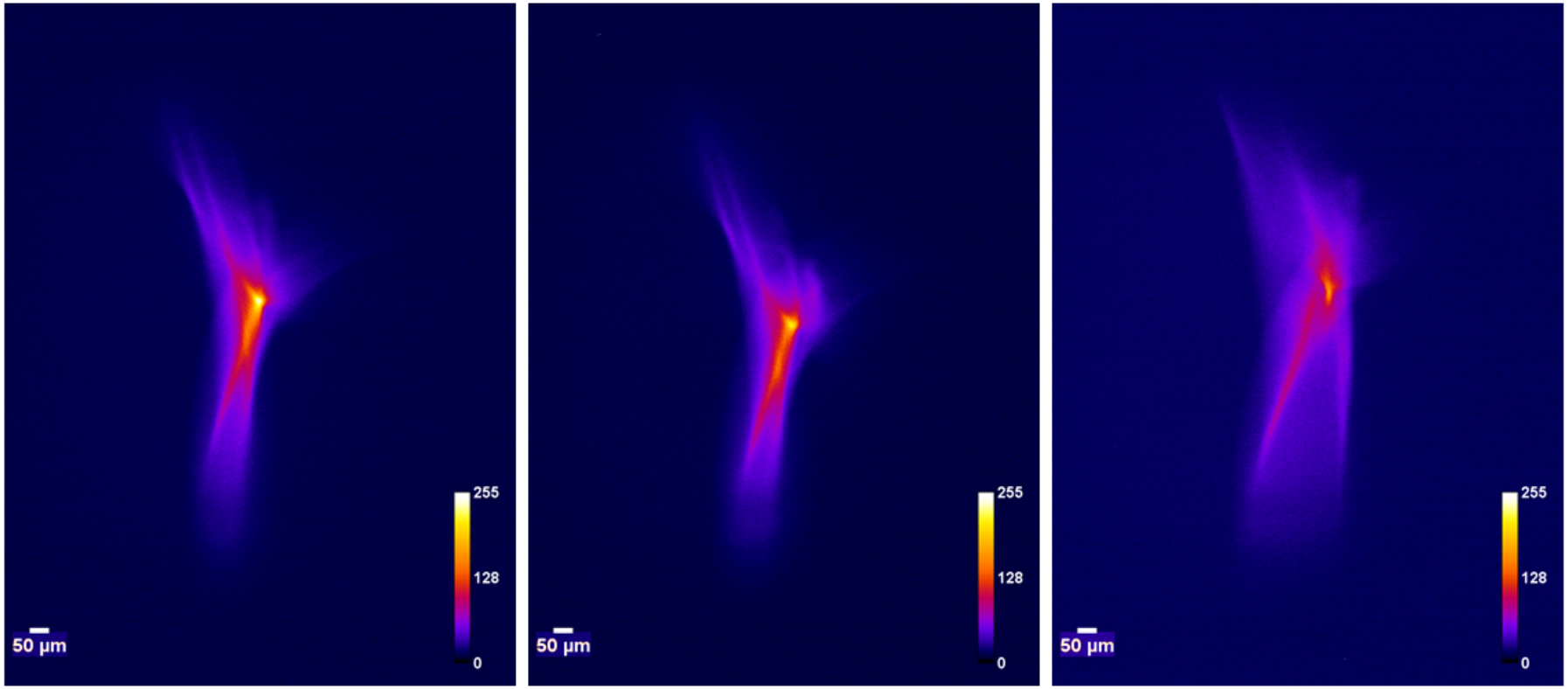
↓ Installation inside of Pegasus vacuum chamber. Stage moves to allow beam access for three separate experiments.





↑ Out of vacuum components: ImageSource CCD camera (5.6μm pixel size) and 200 mm camera lens.

First Beam Test at Pegasus

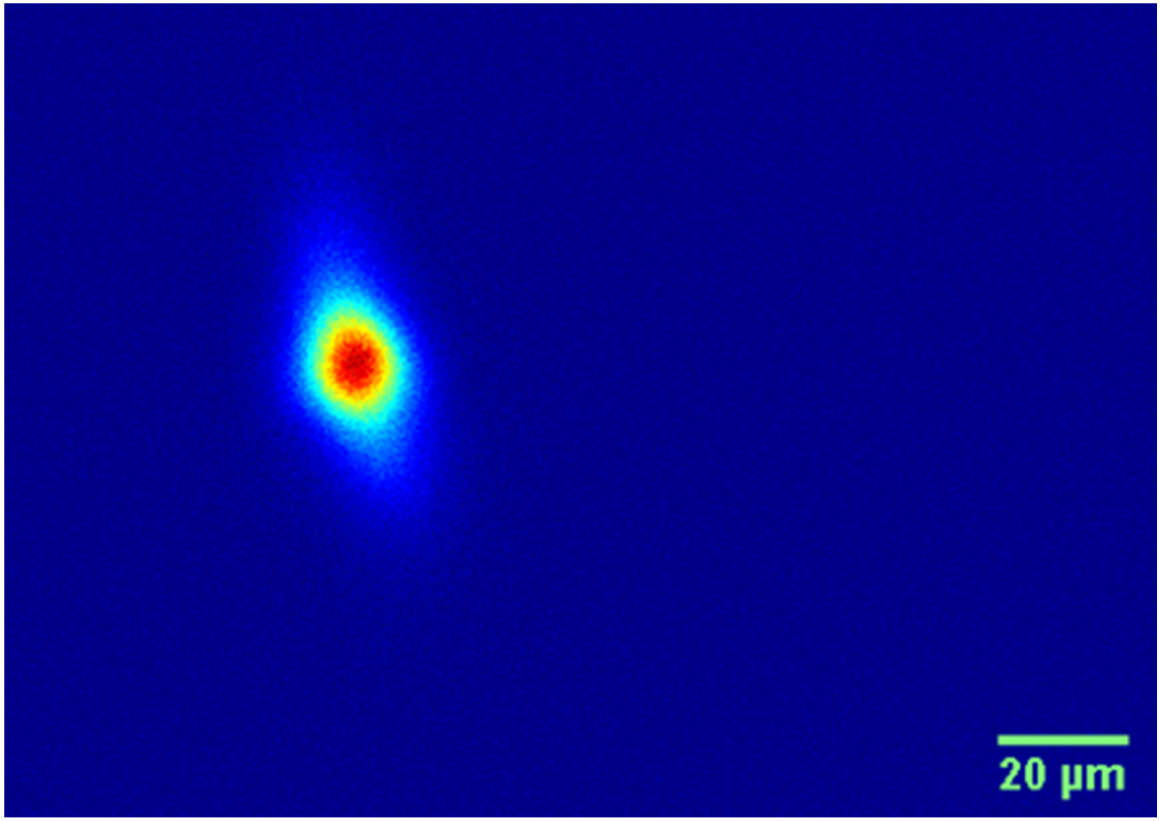


↑ 1st beam images taken in late July at Pegasus: 1.2 pC single bunch and wide FOV setup, 50 mm camera lens and 3.75x magnification. Even at this low magnification, ~ 10 µm features are evident in the beam. Spot sizes smallest achievable during recent Pegasus beamline re-commissioning.

Latest Beam Test at Pegasus

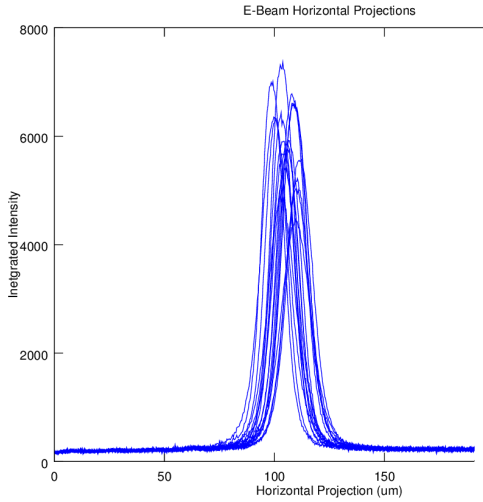
radiabeam TECHNOLOGIES

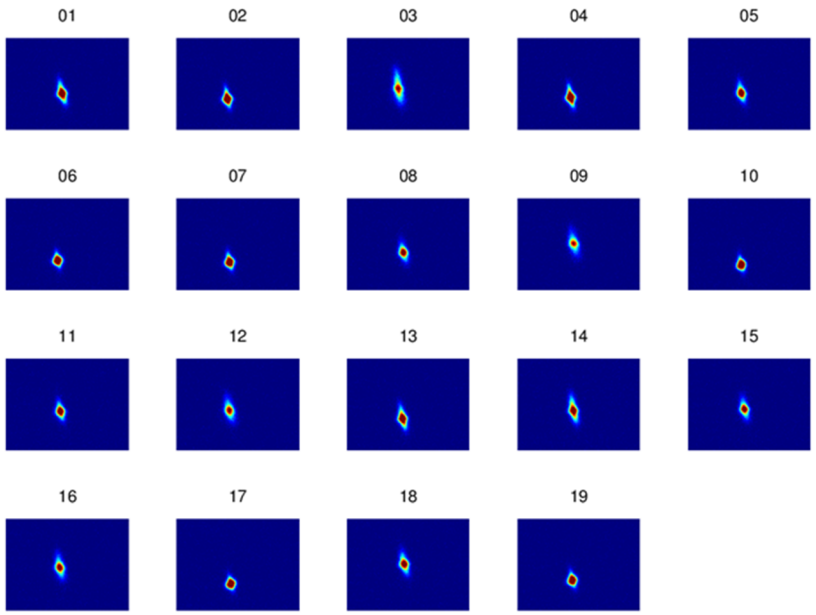
- Pegasus beamline been re-commissioned
- Much smaller spot sizes achievable
- 0.5 pC single bunch charge
- Narrow FOV setup
- 200 mm camera lens
- 15x magnification
- FWHM spot sizes of ~15 µm visible.

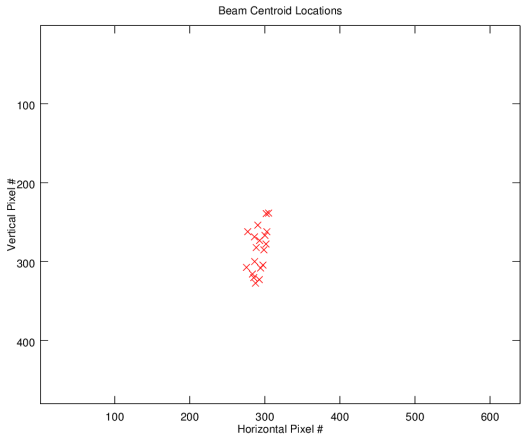


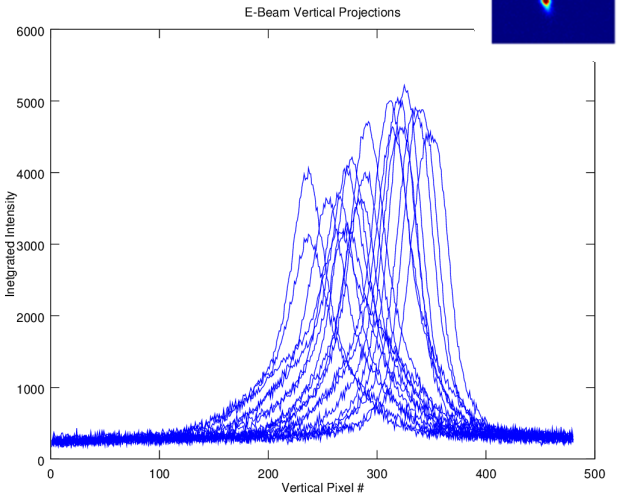
↑ Beam image of small spot size taken last week at UCLA Pegasus. Spot sizes smallest achievable currently at UCLA.

Recent Measurements at UCLA

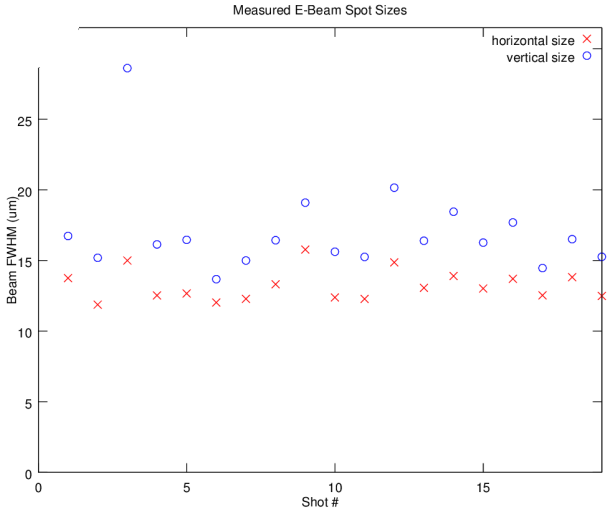




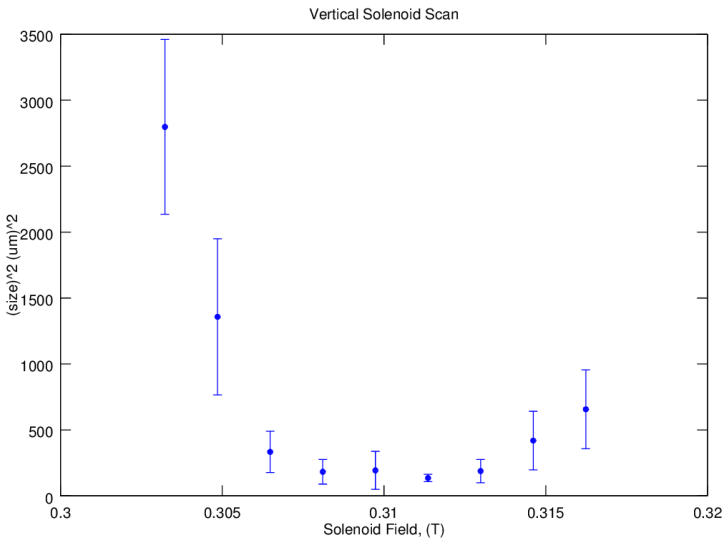


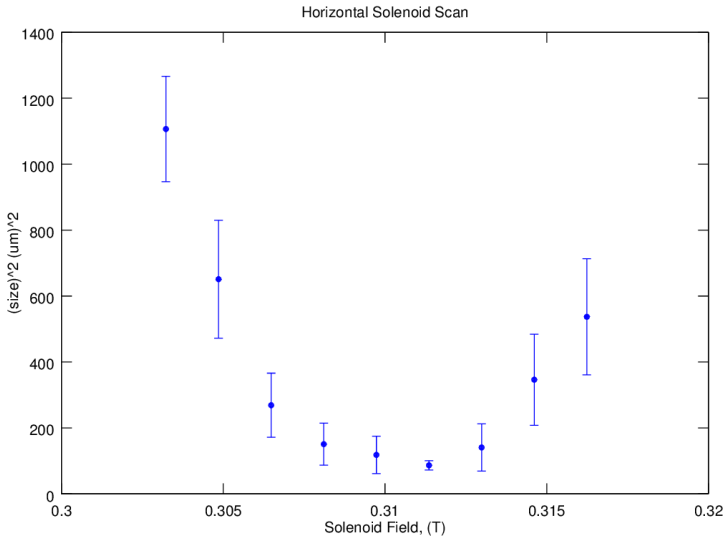


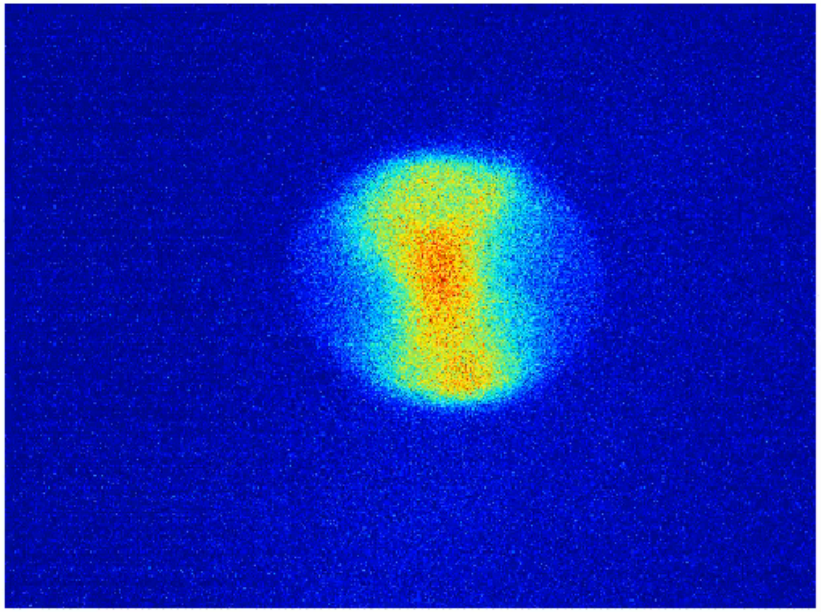
- Can see beam stability and shot-to-shot variations
- Projections are well sampled with many pixesl



Solenoid Scan Data



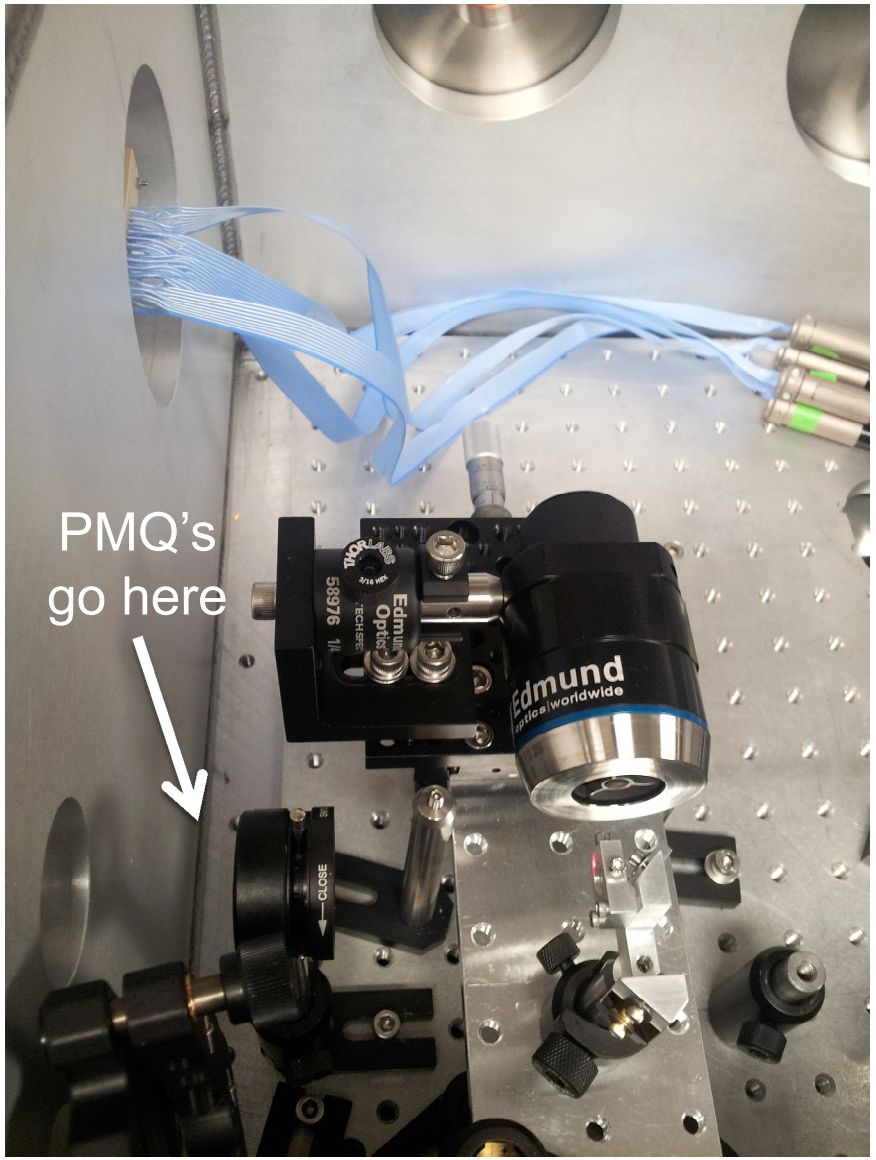




- Sample solenoid current scan through ~15 µm beam waist

Next Experimental Tests

- Want to achieve even smaller spot size to test resolution limit of optics
- Install permanent magnetic quadrupoles in front of YAG screen
- Quadrupoles are ready
- New stage in fabrication at UCLA
- RBT actuator ready to integrate into system
- Will achieve < 5µm spot sizes



Conclusions

- We have assembled a high numerical aperture imaging system based on reflective infinite conjugate microscope design at UCLA Pegasus
- We have achieved low and high magnification beam imaging under various machine conditions
- We have designed and will shortly install PMQ's in order to achieve < 5µm spot for subsequent imaging

Acknowledgements

- The work presented here was done by a coordinated team of members from RadiaBeam Technologies and UCLA Particle Beam Physics Laboratory (PBPL).
- RadiaBeam Technologies
  - Amber Bechtel
- UCLA-PBPL
  - Pietro Musumeci
  - Renkai Li
  - Kevin Roberts
  - Hoson To
  - Xianhai Lu