100 keV DC Gun Test Stand

1st PSI-FEL/LEG Advisory Committee Meeting

March 29-30, 2006

Topics

- Motivation Behind this Test Stand
- Implementation
- First Results
- Outlook

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Motivation Behind this Test Stand

Back in 2003, we considered a FEA based gun and asked ourselves...

- Can we minimize emittance by choosing special field configurations?
  → Shape non-linear electro-static field components to counteract non-linear space charge forces (van der Geer, de Loos, Botman, Luiten, van der Wiel / TU Eindhoven)

- Emittance minimization by space charge compensation?
  → Solenoid magnet (Carlsten / LANL)
  → Simulations for PITZ (Cee, Krassilnikov, Setzer, Weiland / TU Darmstadt)
  → TTF Beam Transport Lines (Zhang / DESY)

- Phase space properties of a bunch of beamlets coming from a pulsed FEA?

- What kind of diagnostics are required to resolve such low emittances?

Motivation Behind this Test Stand

So we decided to investigate these questions with a 100 keV DC gun test stand

- 100 kV DC gun with a pulsed FEA
  → can still be handled in DC mode (peak electric field strength < 20 MV/m)
  → only gate voltage needs to be pulsed → inexpensive pulser
  → capable of delivering a space-charge dominated beam
- Modular gun design
  → diode configuration can be further optimized
  → diode configuration can be easily exchanged (optimization, FEA mounting)
  → simple electrode replacement in case of surface damage (HV breakdown)
- In-vacuum solenoid magnet
  → delivers high field strength → beam can be focussed at desired location
  → field well confined through iron yoke → no bucking coil required
- Dedicated diagnostics module directly following solenoid
  → measure transverse phase space properties and Q(t)
  → reconstruct transverse phase space and measure projected emittance
  → compare different measurement techniques (slits, pinholes, pepper-pot)

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Implementation

- MAFIA 2.5D simulations and particle tracking
  - Emittance optimized gun geometry
  - Solenoid and diagnostics specifications

- Infrastructure
  - EPICS as control system with fiber-optic links to hot deck
  - Digital power supplies, pulser
  - Dedicated vacuum system (ion getter and turbo molecular pumps, RGA, ...)
  - Bunker with LAC for radiation protection & safety in WSLA exp. hall

- Diagnostics Module
  - FC
  - YAG screen, zoom optics, CCD camera
  - Slits and pinholes
  - P43 screen, zoom optics, CCD camera
  - Pepper-pot

Emittance Optimized Gun Geometry

- Input parameters:
  Cathode potential: $U = -100$ kV
  Active emitter radius: $r_{act} = 500\ \mu m$
  Pulse: Gaussian, cut-off at $\pm 3\sigma_t$, $\sigma_t = 20$ ps
  Peak current: $I_{peak} = 100$ mA
  Initial energy: $\gamma_0 = 1.0001$, initial divergence set 0
  Iris: $r_{iris} = 750\ \mu m$
  Tracked macro-particles: N = 20000

- Tracked Path: From the cathode surface to end of the drift section at z = 342 mm

- Variation: Electrode angle, accelerating gap, r_{iris}, peak electric field strength

  → Peak electric field strength 19 MV/m
  → Emittance can be minimized to ~ $2 \cdot 10^{-8}$ m·rad
  → Solenoid strength tunable in order to produce focus at any location within diagnostics module

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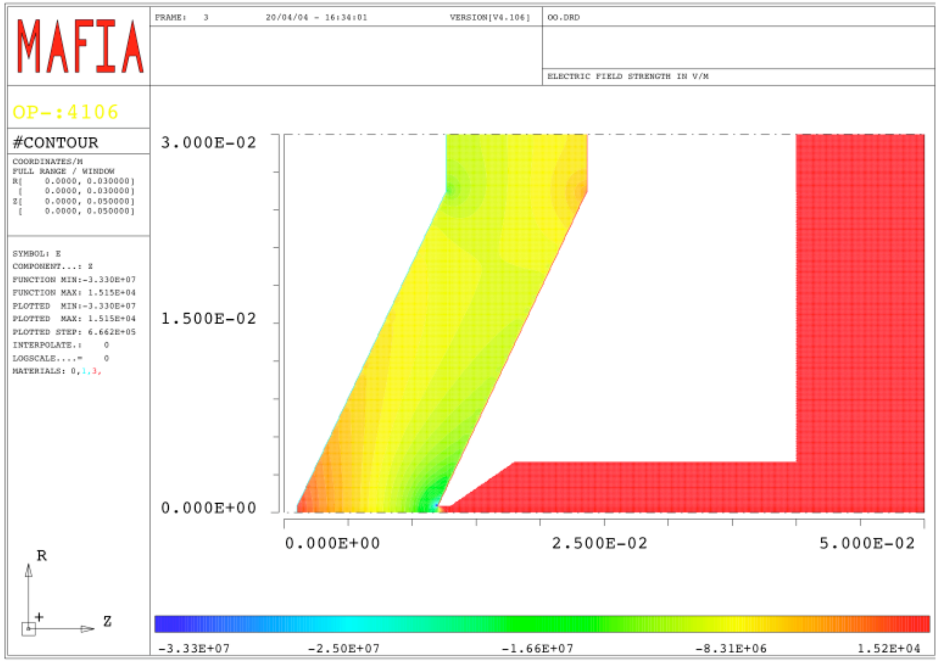
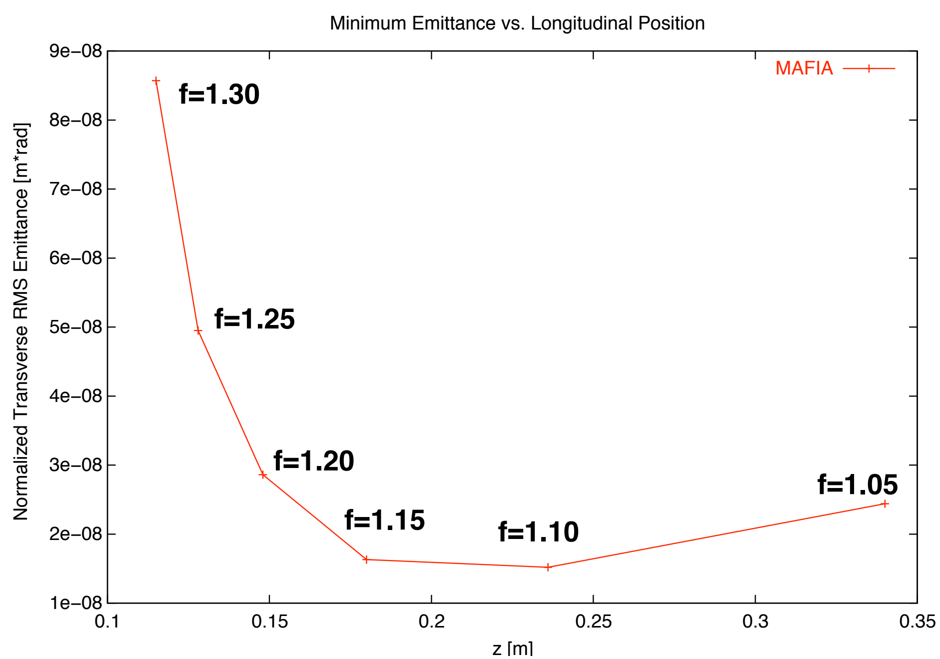
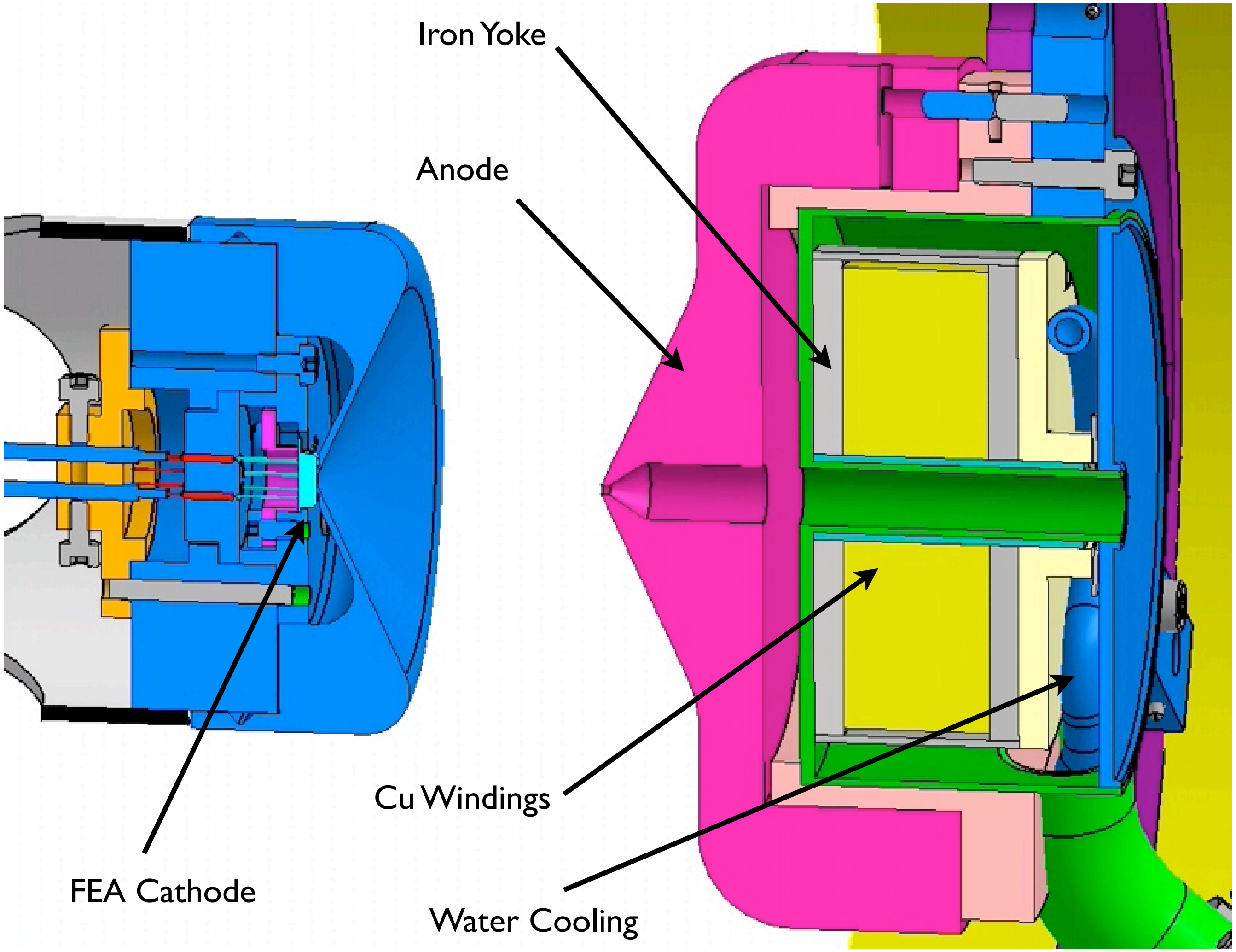




Solenoid Specifications

- DC solenoid right behind anode provides focussing to emitted beam
- Solenoid is built in-vacuum and actively cooled through an in-vacuum cooling water circuit (~50 W heat dissipation)
- 200 mT of magnetic field on beam axis
- Magnet iron yoke confines field outside of diode region
- Digital power supply control is integrated in EPICS
- Anode electrically isolated; feedthrough for readout



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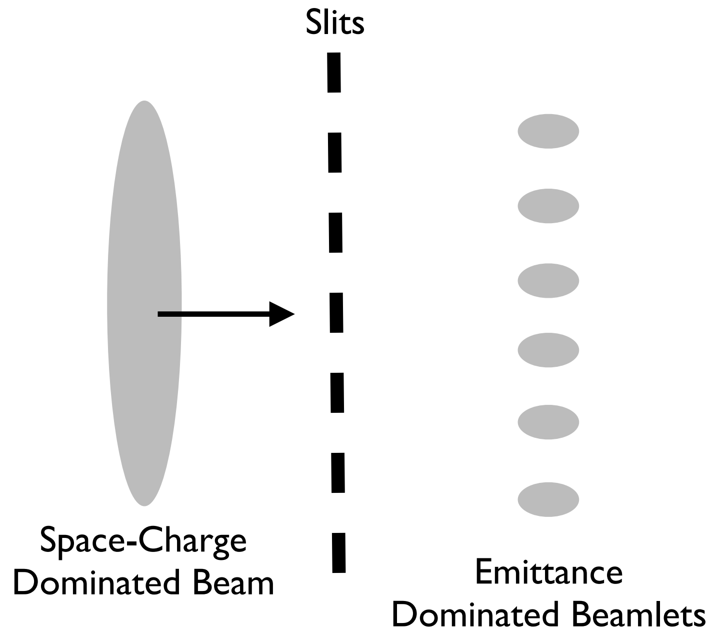
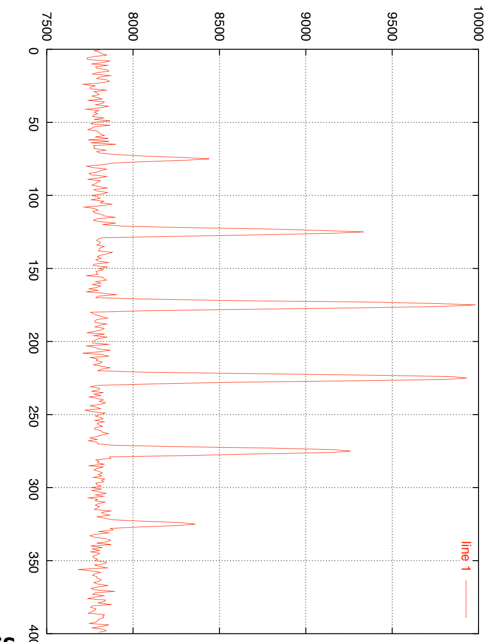
Emittance / Phase Space Reconstruction

- Slit/pinhole masks and pepper-pot obstruct part of the beam
- Beamlets emerge from holes and are imaged on a screen downstream
- Broadening of the beamlet image with respect to the hole gives uncorrelated divergence information
- Position of beamlet images with respect to center of gravity gives correlated divergence information

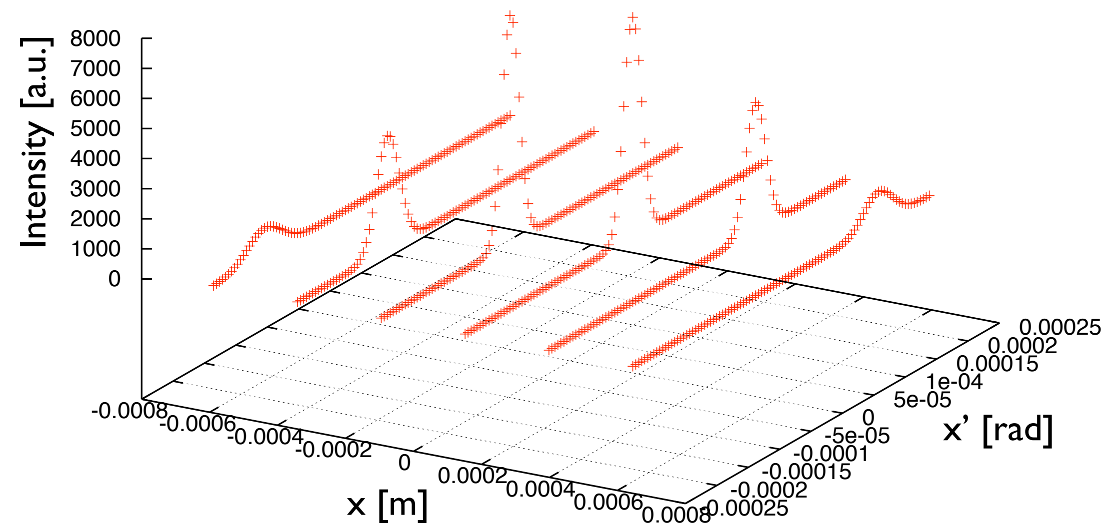
  → reconstruct transverse phase space

  → determine projected transverse emittance





Beamlet Intensity Profile on Screen



Implementation

- MAFIA 2.5D simulations and particle tracking
  - Emittance optimized gun geometry
  - Solenoid and diagnostics specifications

- Infrastructure
  - EPICS as control system with fiber-optic links to hot deck
  - Digital power supplies, pulser
  - Dedicated vacuum system (ion getter and turbo molecular pumps, RGA, ...)
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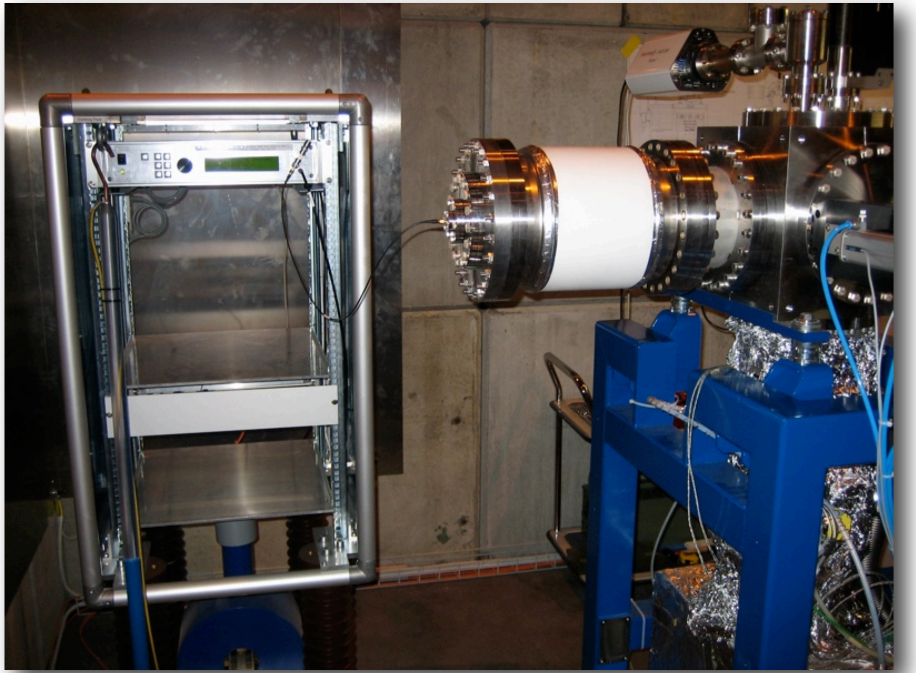
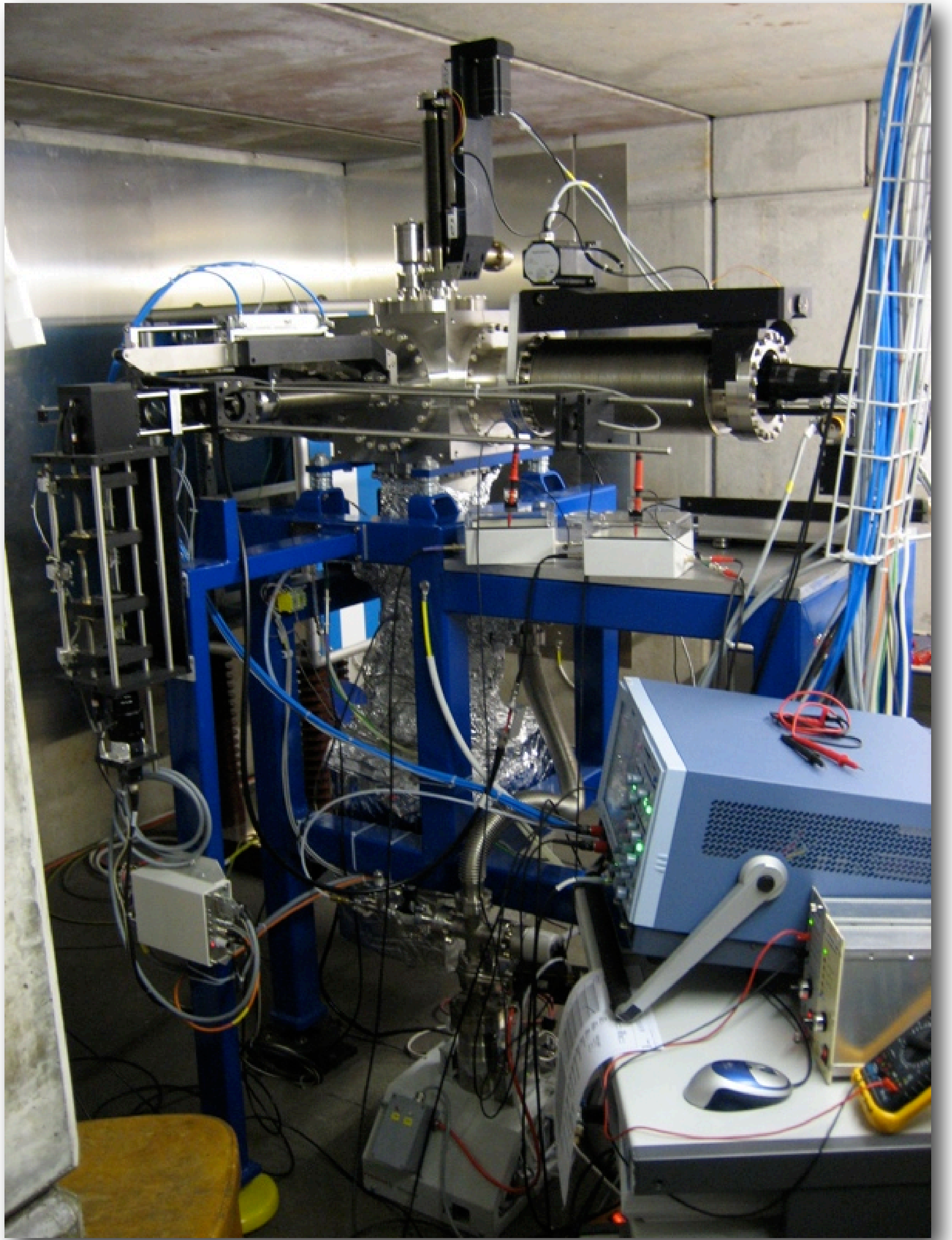
- Diagnostics Module
  - FC
  - YAG screen, zoom optics, CCD camera
  - Slits and pinholes
  - P43 screen, zoom optics, CCD camera
  - Pepper-pot

Infrastructure





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- Diagnostics Module
  - Movable Coaxial Faraday Cup
  - YAG screen, zoom optics, CCD camera
  - Slits and pinholes
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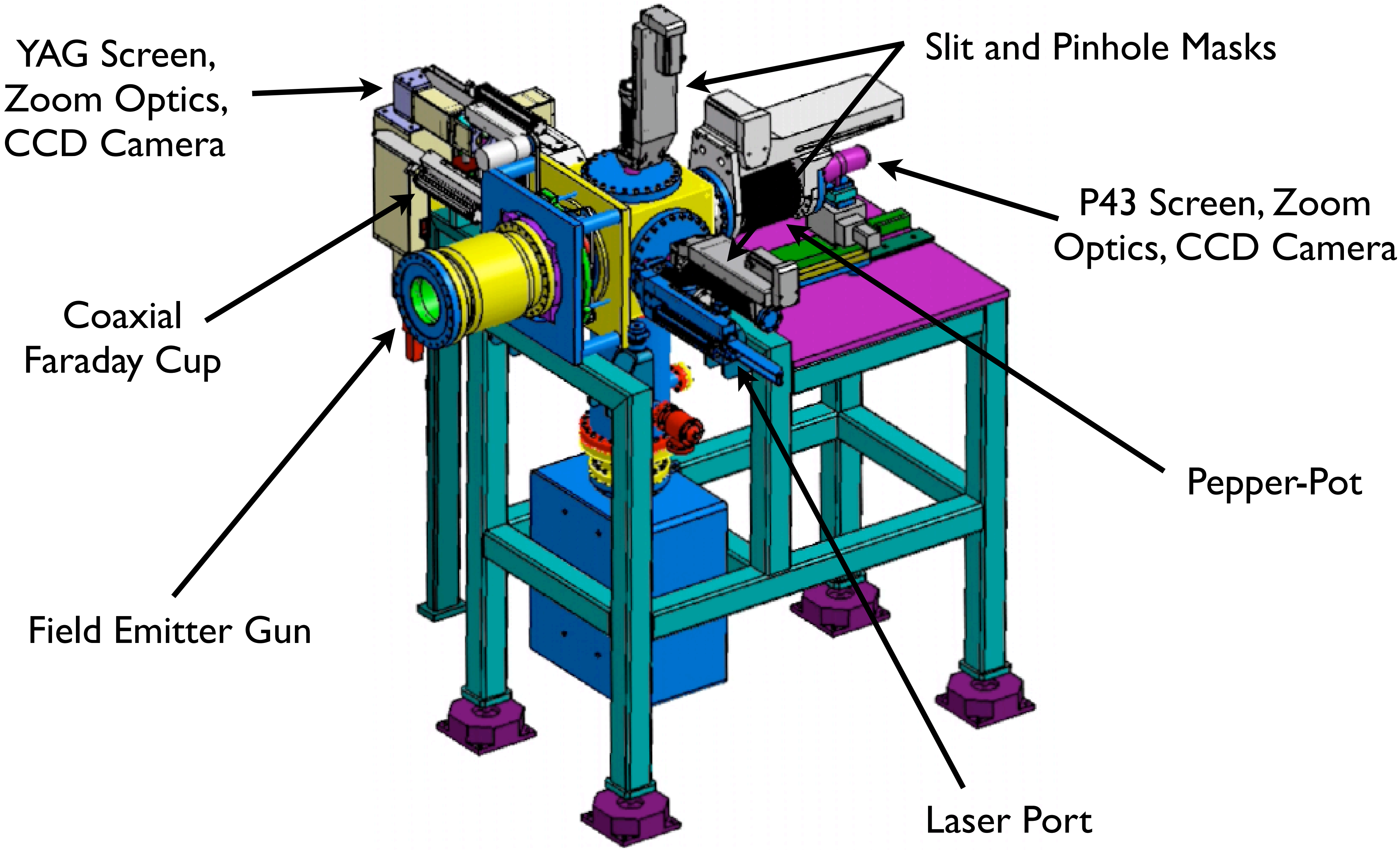
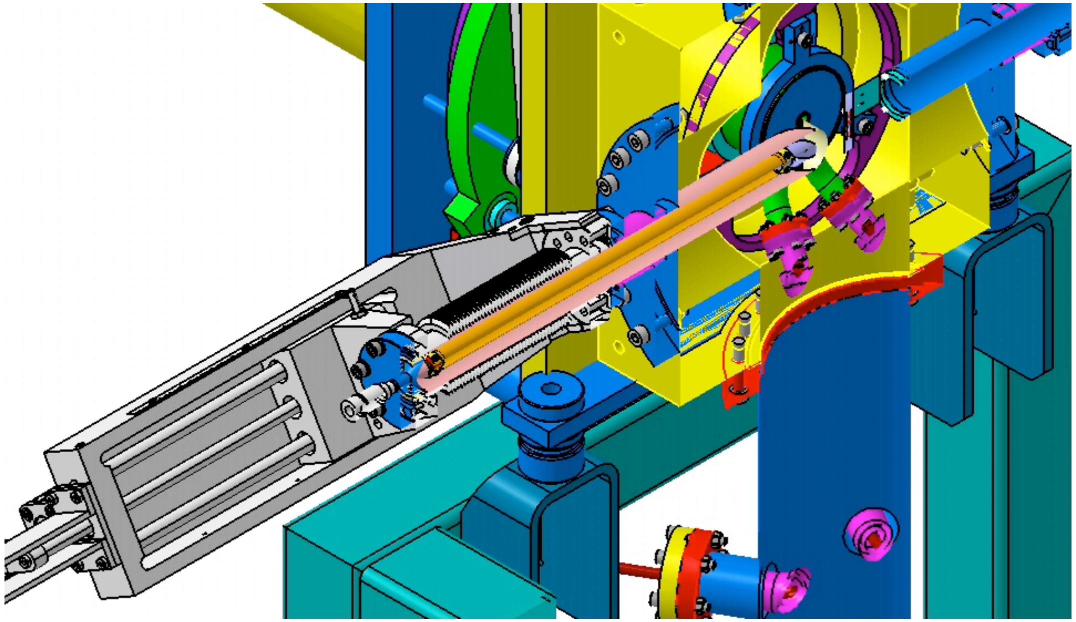
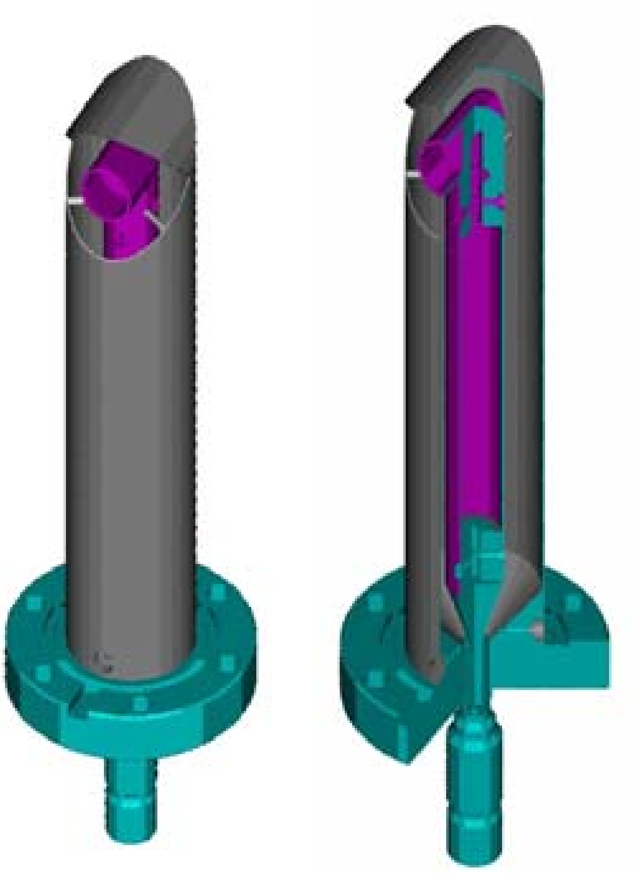
Diagnostics Overview



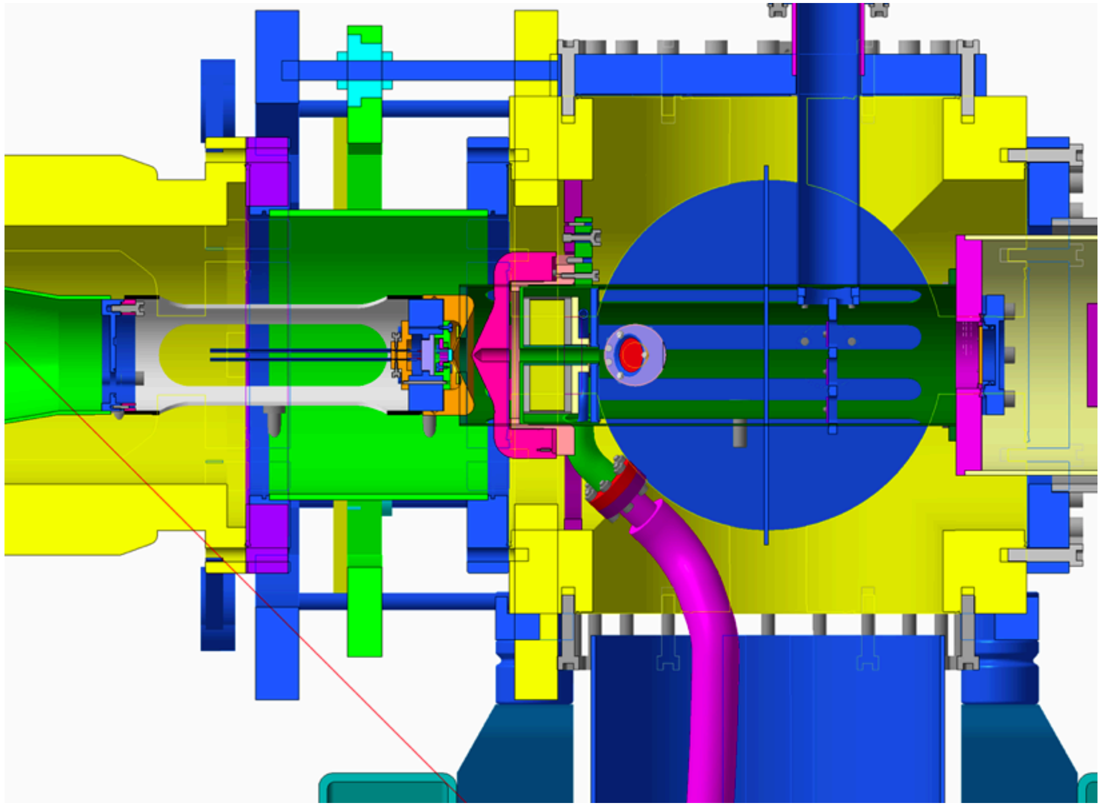
Movable Coaxial Faraday Cup

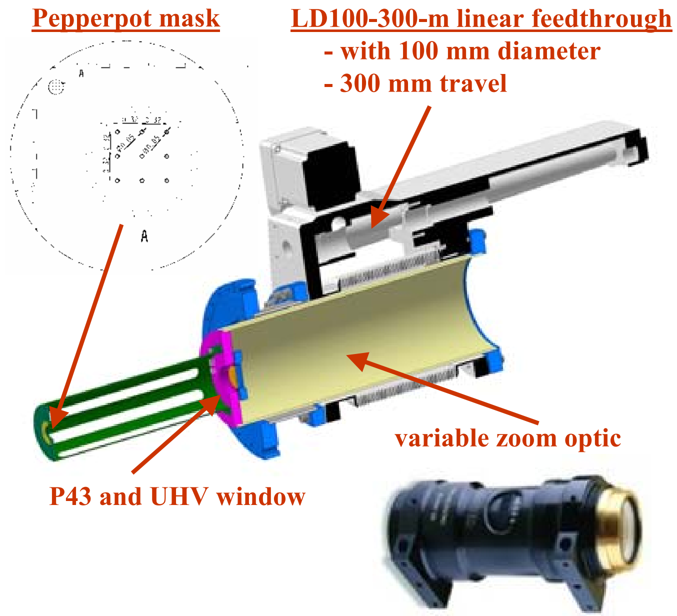
- Measures field emitted current and transient beam signals
- 20 mm diameter cup; coaxial design provides high bandwidth (>4 GHz)
- Moved into beam directly behind solenoid through pneumatic actuator
- Controlled through EPICS; readout through high bandwidth scope (2 GHz, 20 GS/s)
- Design successfully used behind SLS Linac gun (90 keV)

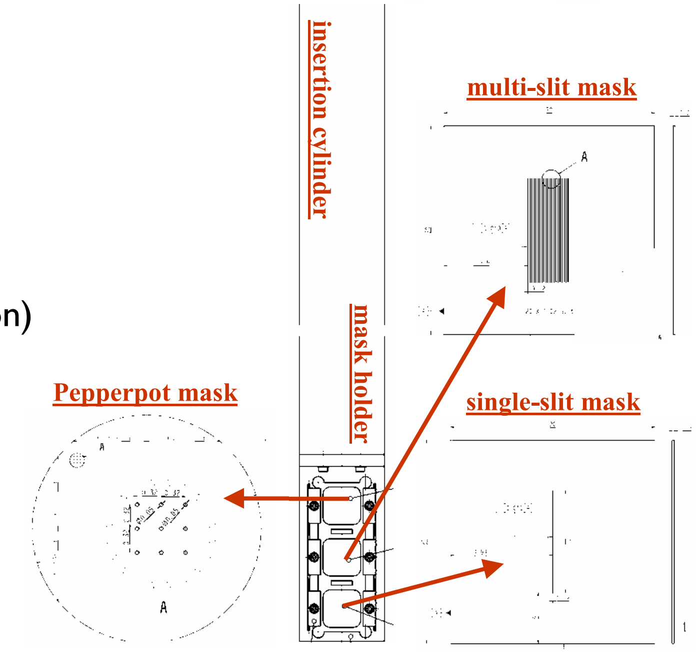




Slit and Pinhole Masks, Pepper-Pot



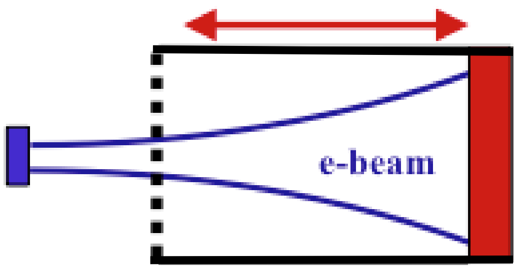




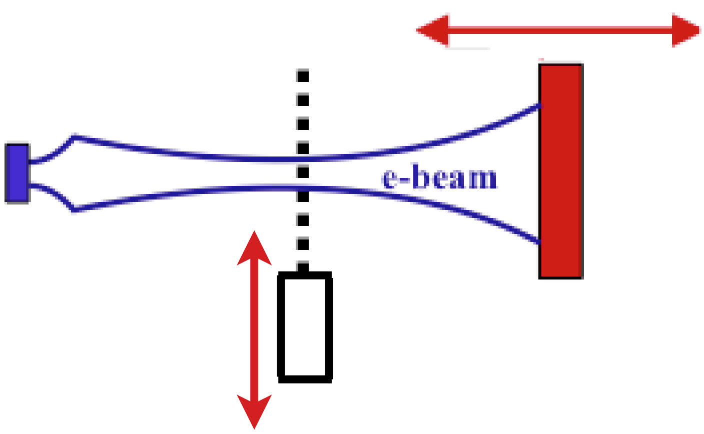
- Laser eroded masks of 100 μm tungsten substrate (exchangeable)
- Slit/pinhole (width 20 μm, pitch 170 μm) array inserted at solenoid focal point by motorized UHV feedthrough; position measured with linear encoder (0.5 μm resolution)
- Pepper-pot (diameter 50 μm, pitch 320 μm) arrangement with fixed distance to P43 screen to characterize unfocussed beam
- P43 (6-8 μm, aluminized) screen at variable distance from mask for visualization of beamlets
- CCD camera and zoom optics (calibration scale on UHV quartz window) read out through EPICS

Measurement Modes

- Unfocussed case
  Movable pepper-pot arrangement (300 mm travel) with fixed distance (300 mm) between pepper-pot and P43 screen



- Focussed case
  Fixed slit/pinhole array insert with movable P43 screen (300 mm travel)



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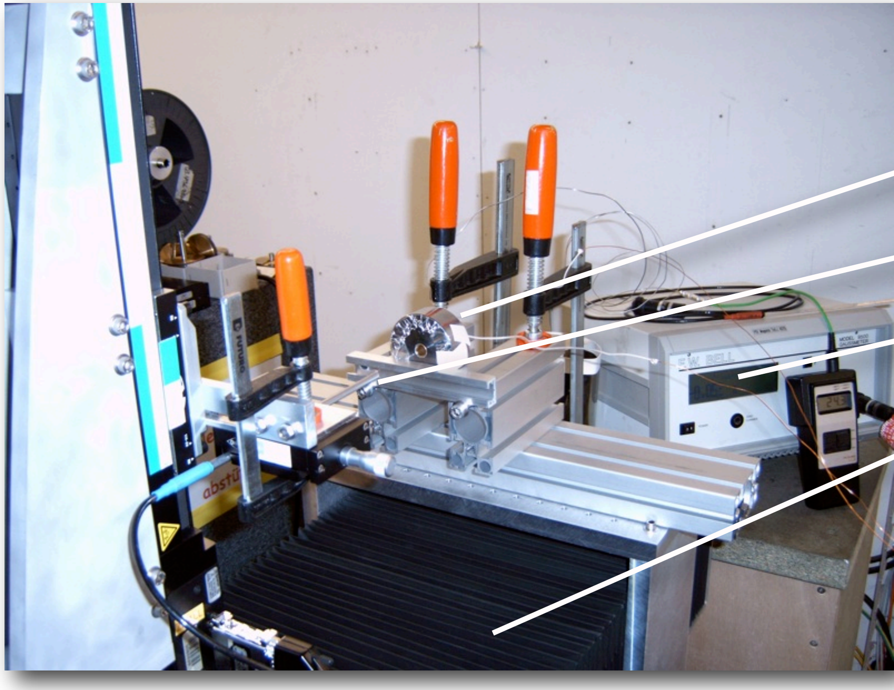
First Results

- Magnetic field measurements of the in-vacuum solenoid
- Optical resolution of our screen monitor imaging system
- FEA Calibration
- HV Conditioning → FEA damage and replacement

Solenoid Field Measurements



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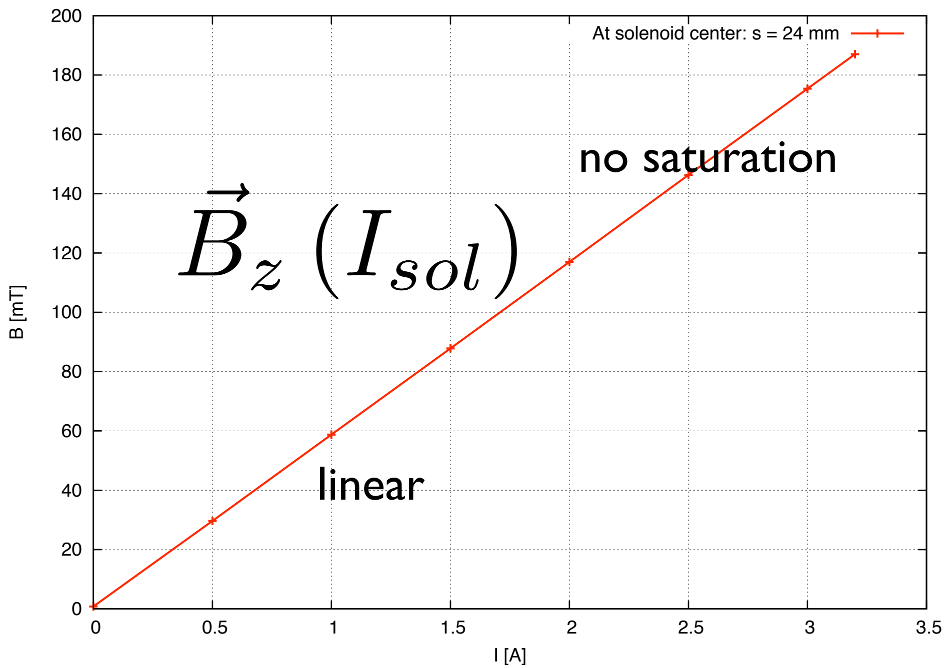

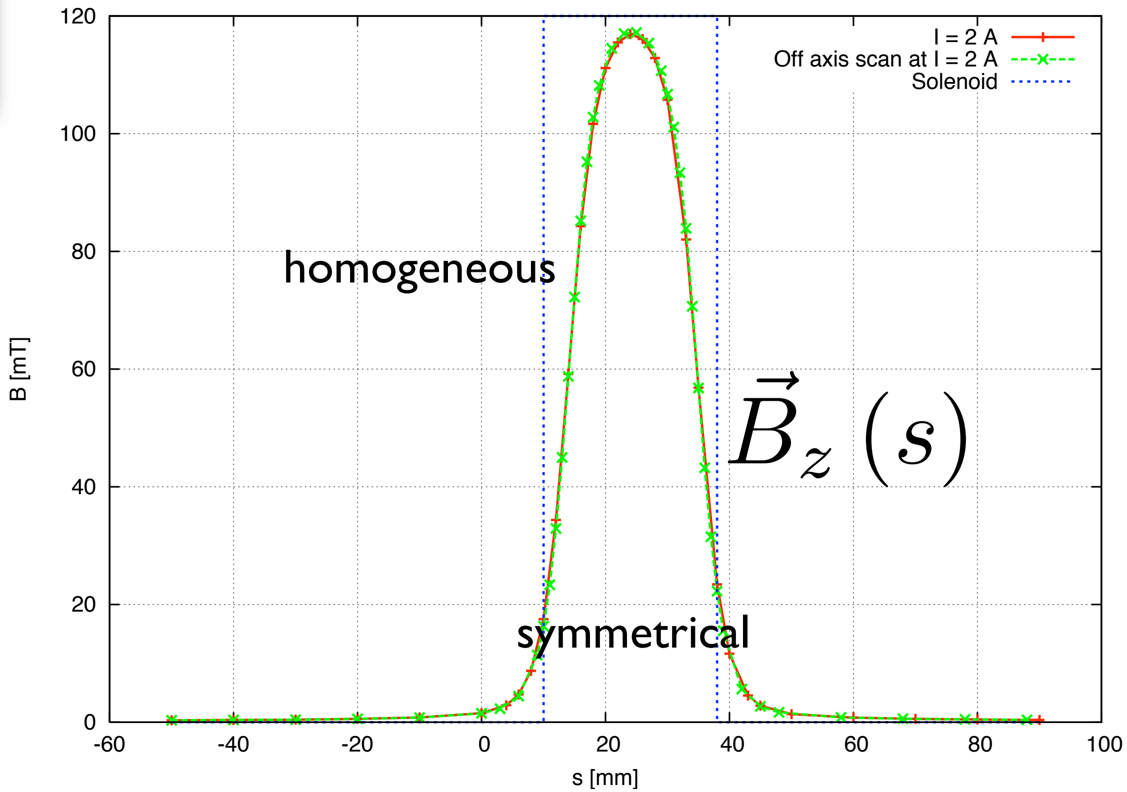

Optical Resolution of our Imaging System

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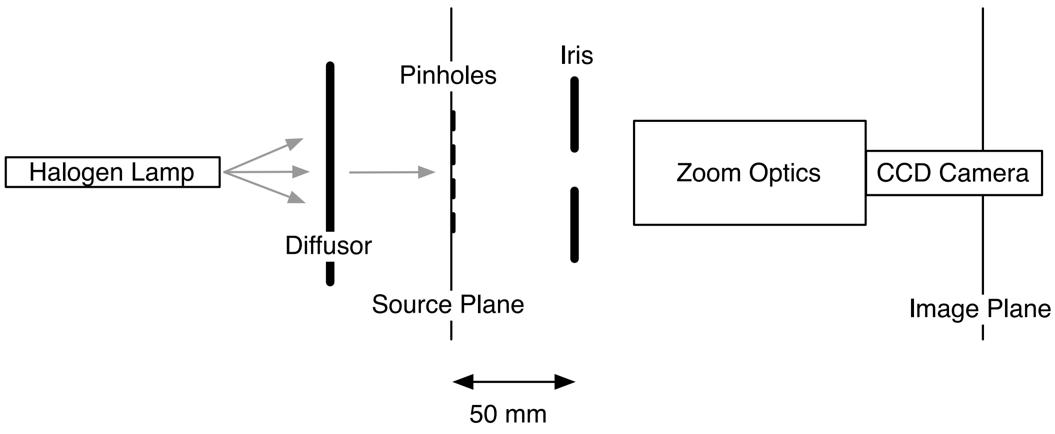
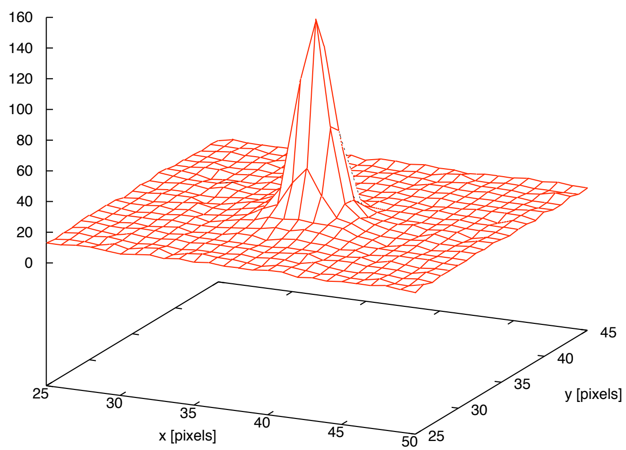
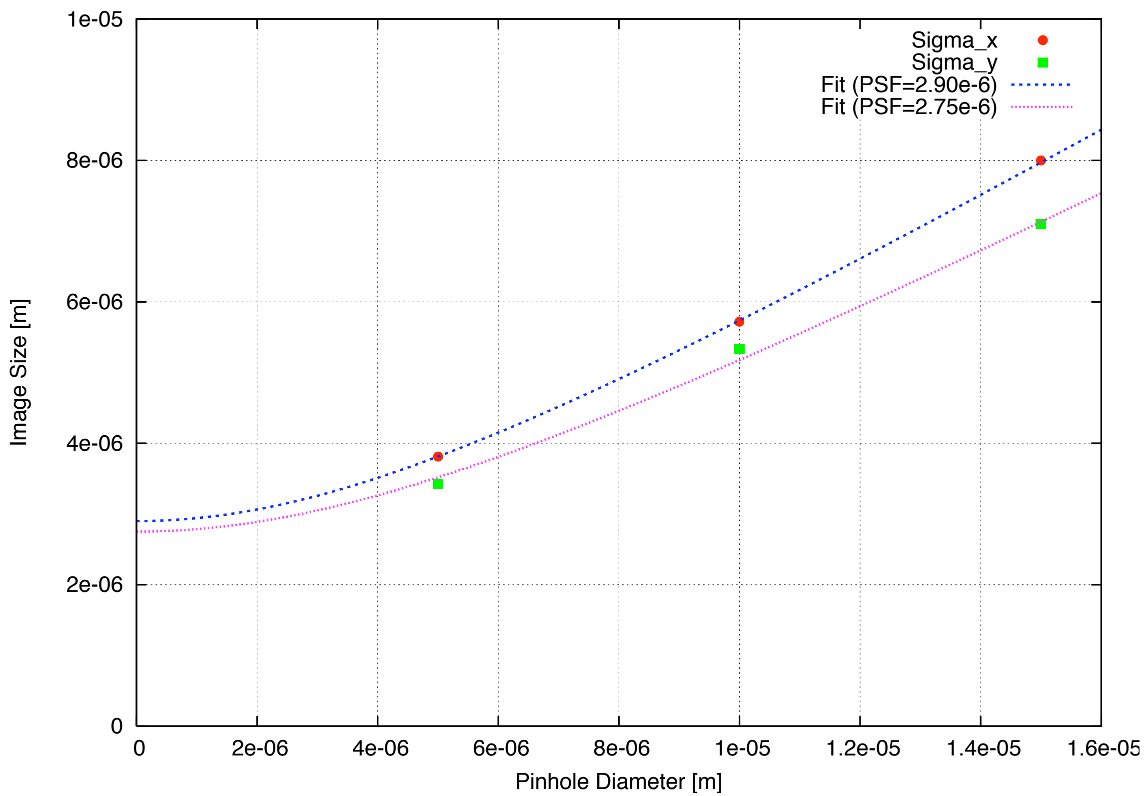


- Point-Spread Function = measure 2D intensity distribution in image plane produced by a point source in source plane (use pinhole arrays)

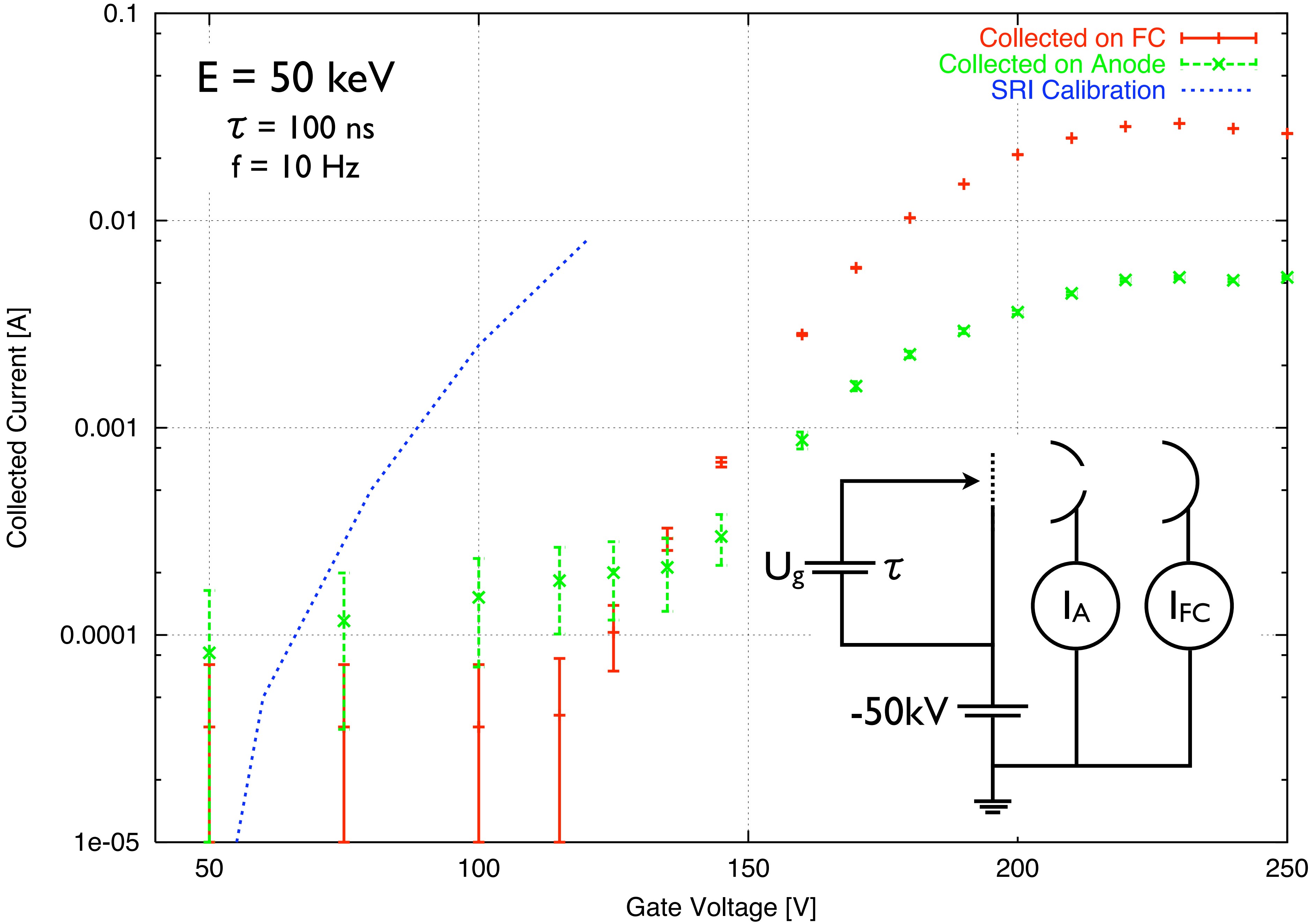
- We measured PSF of entire imaging unit (CCD, zoom optics, frame grabber) in order to include all diluting contributions

  → Ultimate resolution is ~3μm

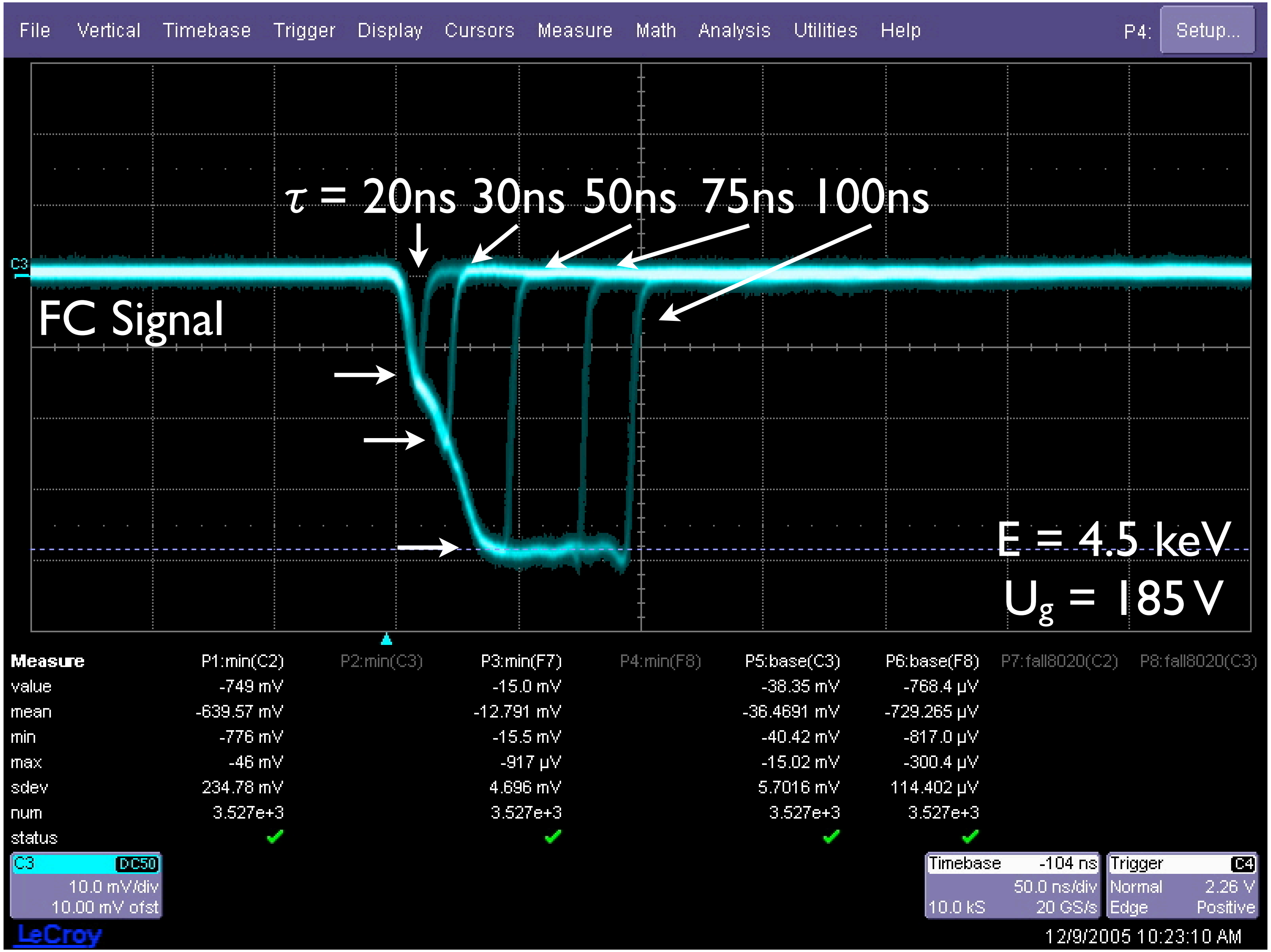




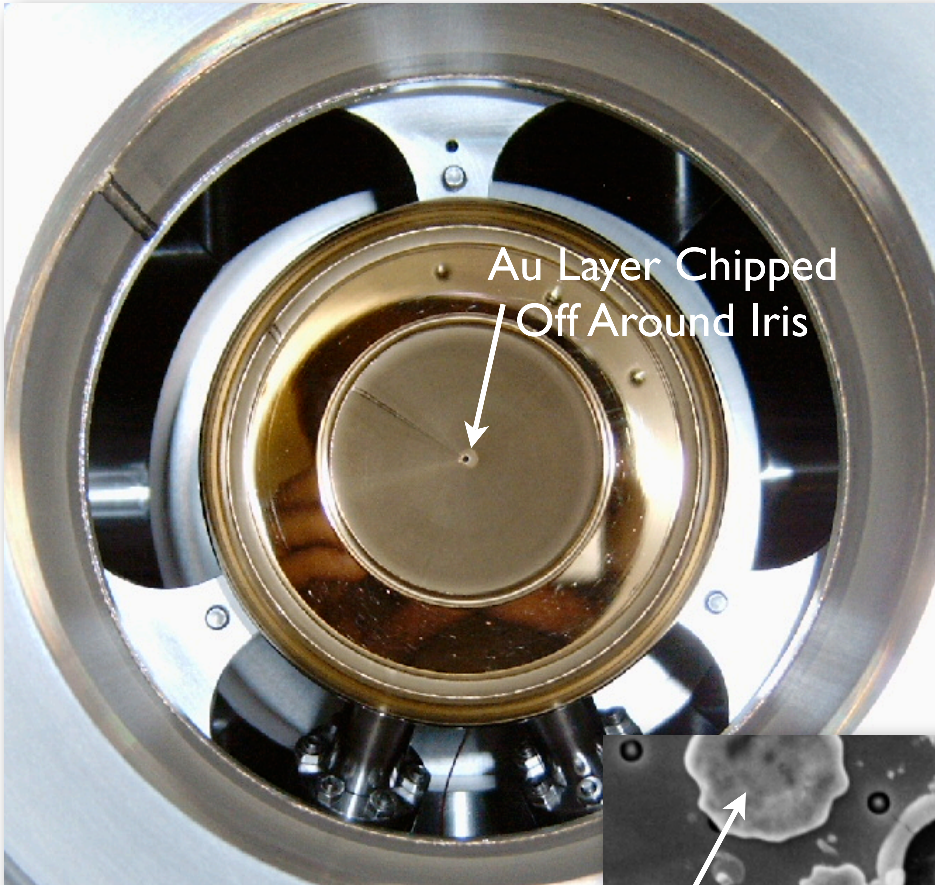
FEA Calibration (SRI-1257E)

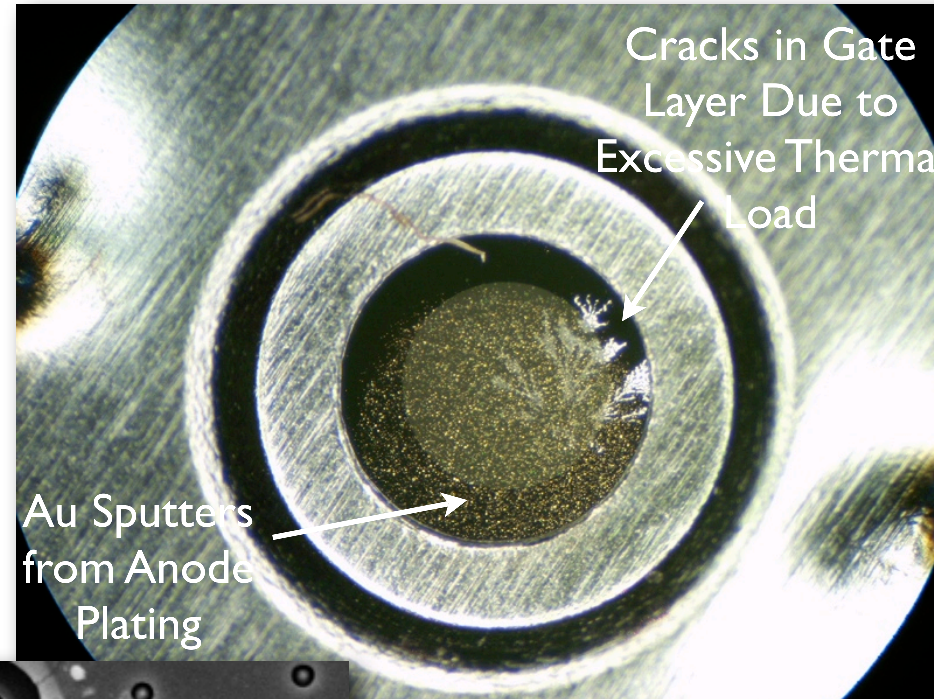


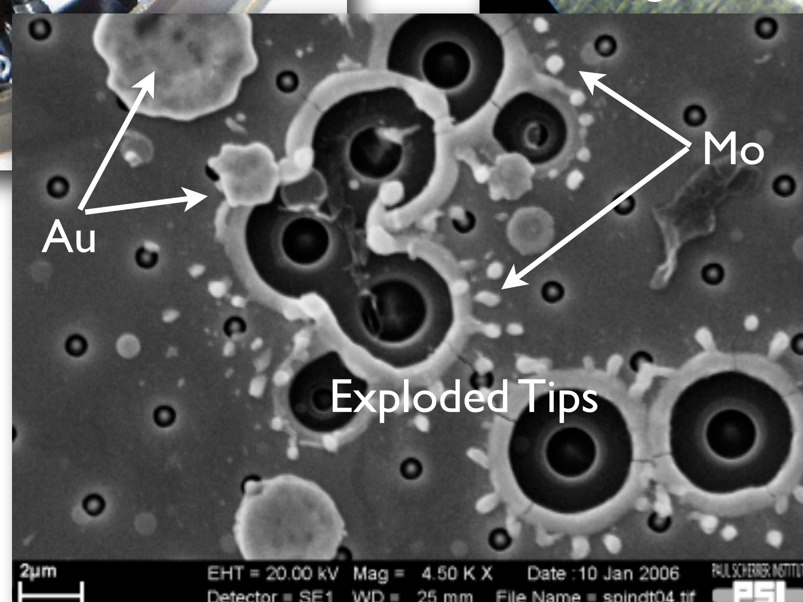
Pulse Width Variation



FEA Damage (SRI-1257E)







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Outlook

- Measurement program for upcoming months (with new FEA)
  - $I(t)$ vs. U_g and τ → $Q_{tot}(U_g)$
  - Beam size vs. Q_{tot} and I_{sol}
  - Divergence vs. Q_{tot} and I_{sol}
    → projected emittance
    → full transverse phase space reconstruction
    → benchmark slit/pinhole/pepper-pot diagnostics
    → tomographic phase space reconstruction

- Installation of a 3D mover system for optimized alignment

- Photo-assisted field emission (Laser on FEA)