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Secondary Electron Emission from Niobium at Cryogenic Temperatures

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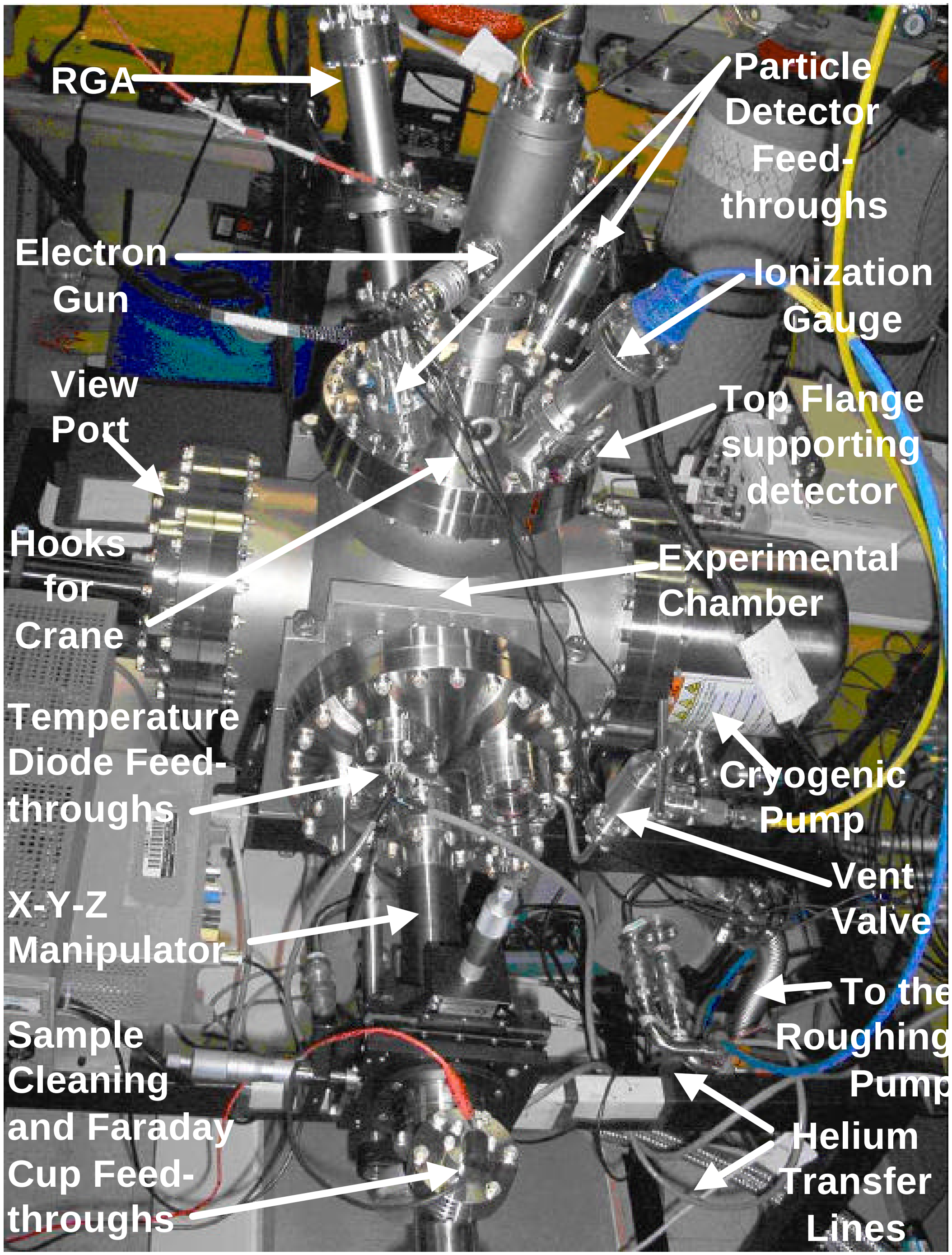
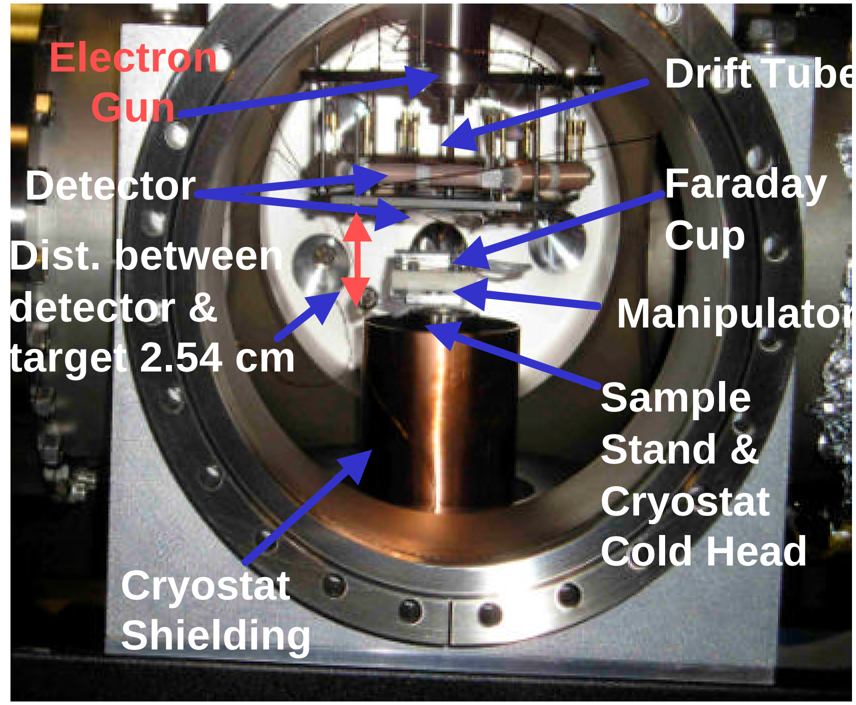
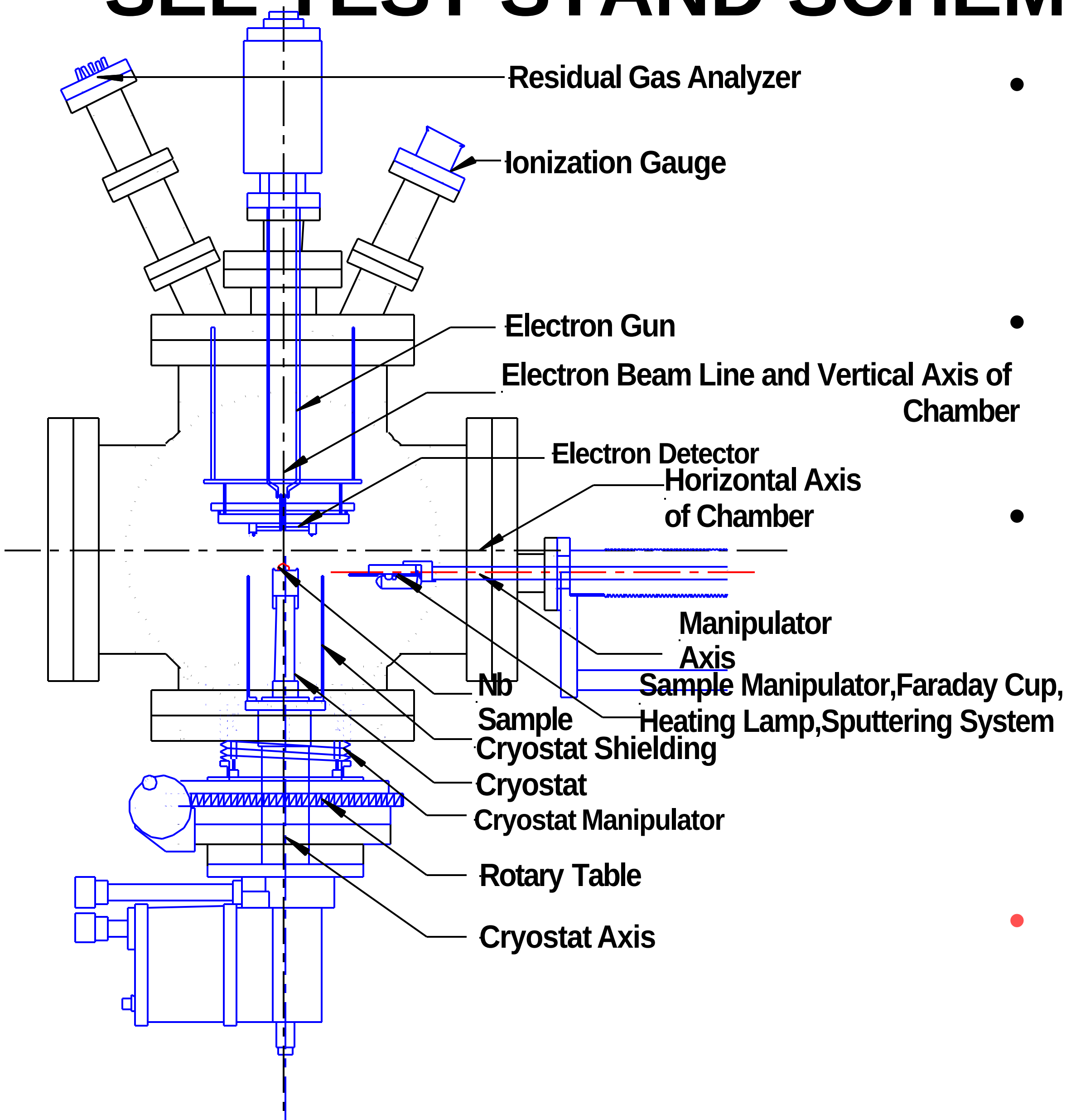


SEE TEST STAND



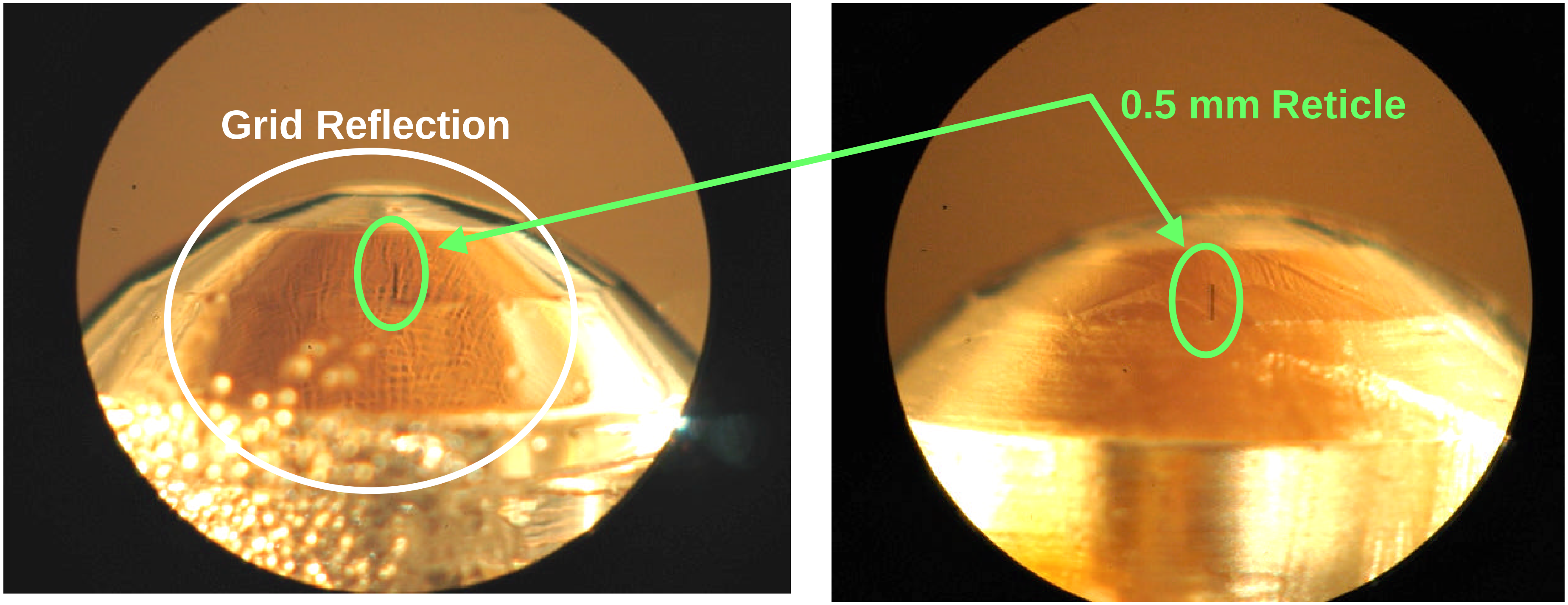
- Electron Gun
- Particle Position Detector
- Manipulator Arm
- Cryostat & Rotary Table
- RGA & Pressure Gauges
- Rough/Turbo/Cryo Pumps

SEE TEST STAND SCHEMATIC DRAWING



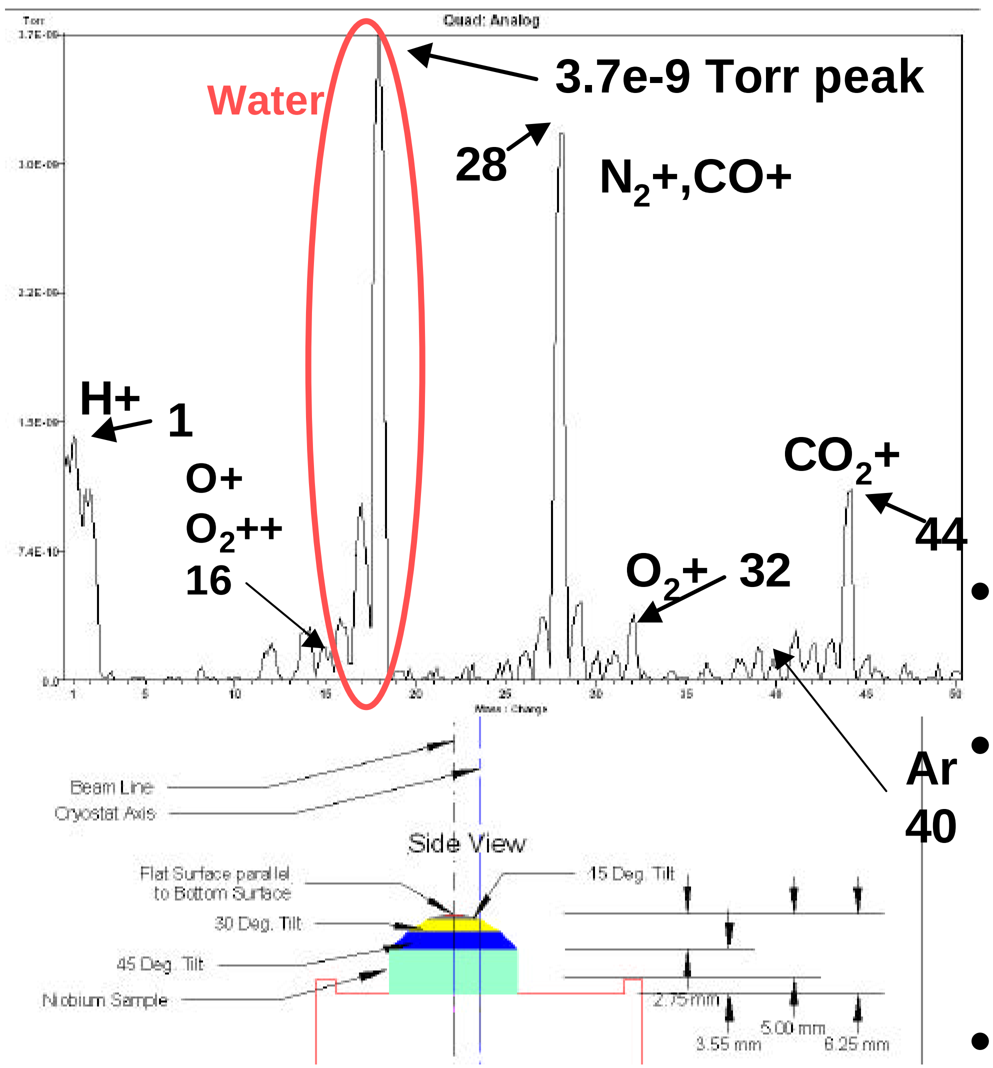
- Gun-Detector Geometry
  - Electron beam passes through center of particle detector via beam drift tube
- Grid (72% transmission)
  - 75x200µm wire; 1mm^2 hole
  - Covers MCP of detector
- Cryostat
  - First stage of cryostat partially surrounded by a second stage oxygen free high conductivity (OFHC) copper shield
  - Mounted on rotary table
- Transfer Engineering Inc.
  - Built vacuum system & manipulator arm with diagn.

SURFACE SAMPLE POLISHING



- Electropolish Technique
  - Cornell Univ. - Two samples
  - Surface removal no less than 125 microns everywhere except inside grooves
- Buffered Chemical Polish
  - LANL - Six samples
  - Surface removal - 98 microns
  - 1:1:2 ratio hydrofluoric acid, nitric acid, phosphoric acid
  - Temp. 8 - 10 ^{o}C

TYPICAL OPERATING CONDITIONS



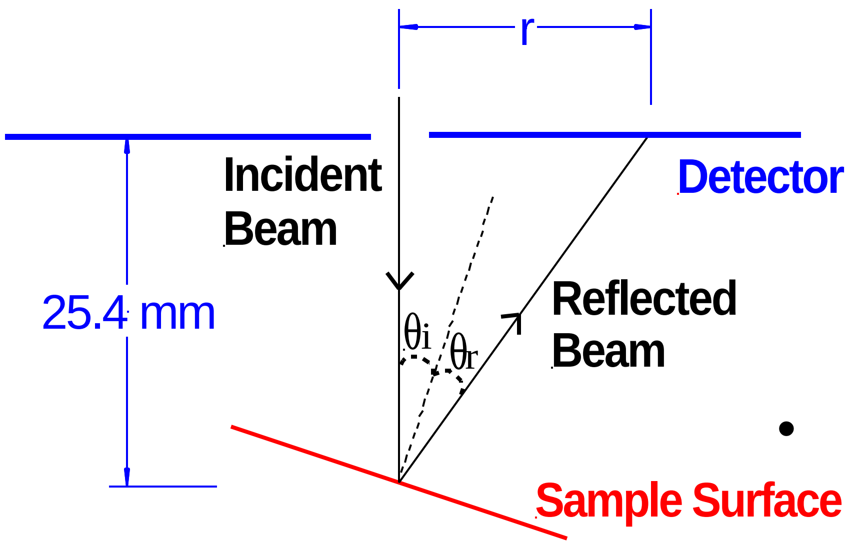
Cryostat axis 2 mm off beam axis
Cylindrical sample - 4 beveled surfaces

- Pressure (RGA - 5e-9 Torr)
  - Water Vapor- Abundant
    - 1 H+,16 O+,17 HO+,18 H_2O+
  - Atm.Leak (4 x more N_2 than O_2)
    - 16 O+, 28 N_2+,32 O_2+,40 Ar+
      - UHV epoxy used on pin-hole in welded bellows
    - 44 CO_2+ elastomeric O-rings
    - Typ. Pres.-**5e-9 to 9e-10Torr**
- Cryostat Temp. (Grease)
  - Side 9^{o}K; Top **23^{o}K**(no pressure)
- Electron Beam Parameters
  - Energies: 0.1-3 keV (**1 keV typ.**)
  - Dia. / Duration - **150 mm** / **100ms**
  - Current: 80pA-3.7nA (**2.2nA typ**)
- Grid Potential ~ **100** & **150** V
- Alignment and Sample Geom.

EXPERIMENTAL PROCEDURE

- Sample placement
  - Crudely by hand
- Pumps on
  - Finer placement with manipulator arm, electron gun (EG) & Faraday cup at 5e-9 Torr
- Cryostat on at 5e-9 Torr
- Diagnostic measurement on primary electron beam
- RGA measurements & pressure measurements
- RGA & pres. gauges off - particle position detector (PPD) on
- Determined location of each bevel surface using PPD & EG - position recorded
- Perform exp. on virgin sample surf. at particular beam energy
- Between each change in primary beam energy - PPD turned off and RGA, pressure, and beam characteristics recorded

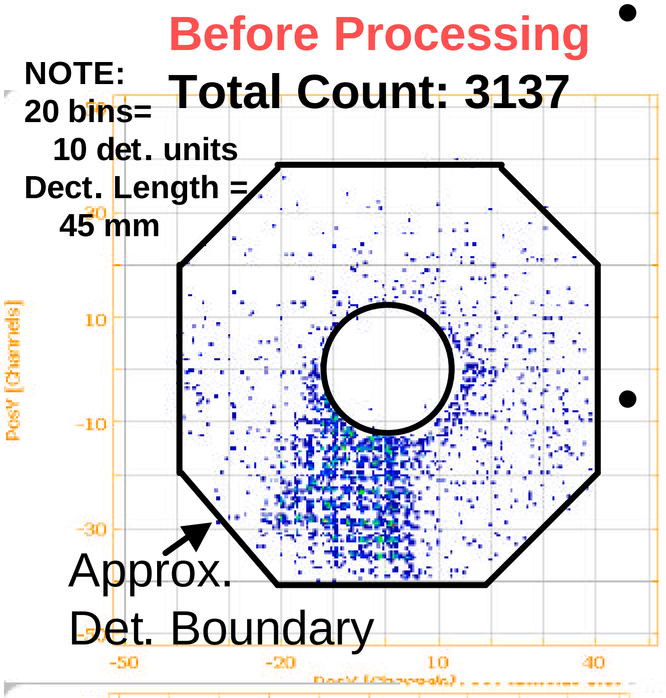
‘Specular’ Backscattered Electron Location

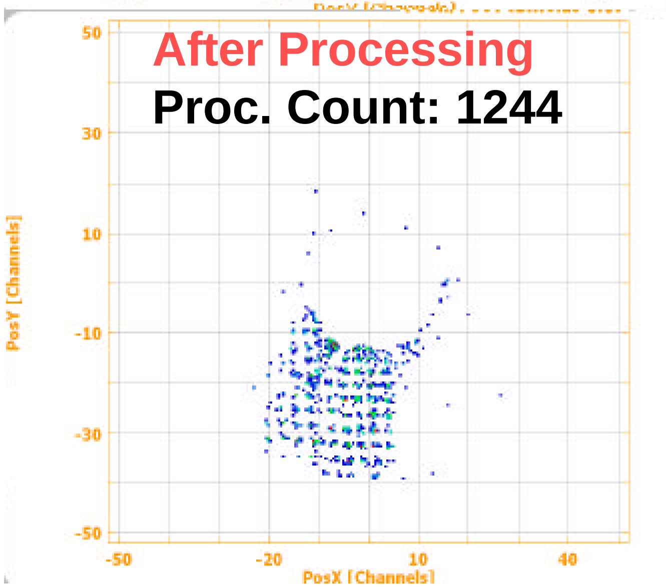


Specular Reflection: q_r= q_i

- Motivation
  - Quantum mechanics - electron is treated as a wave function
  - Wave function has properties of an electromagnetic (EM) wave
  - An EM wave obeys Snell’s law of reflection
  - Backscattered electron (BSE) energy is nearly the same as the incident primary electron
- Location of ‘Specular’ BSE for Different Beveled Surfaces
  - 0^o and 15^o beveled surface
    - Lost in aperture opening (r=12 detector units or 6.8 mm for 15^o)
  - 30^o beveled surface
    - Location r=26.6 detector units or 15 mm, nearly in middle of cluster

DATA PROCESSING & PRESENTATION

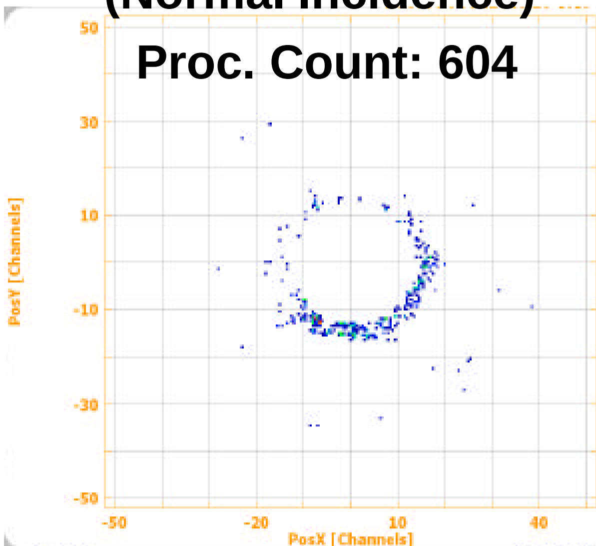




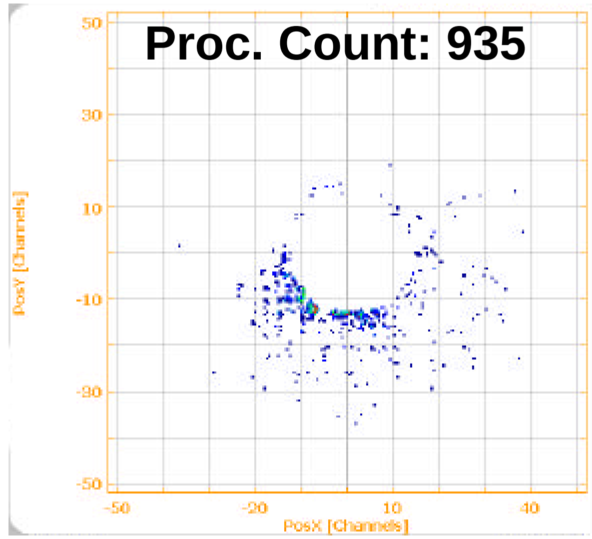
- Scattered Plots - Color and Location
  - Detected SE count over a 281μm x 281μm sq.
  - Pixel color signifies the number of electrons detected in a bin; 1 pixel is 281 x 281 μm sq.
  - Aperture opening visible in scattered plots
- Data Processing - Count
  - One is subtracted from all bins; bins with counts less than one are omitted
    - Enhance the visibility of the BSE
    - Removes dark counts (sparse & random)
      - Negligible dark counts due to short pulse duration (2% - 6% total count)
  - Total count detected offers information on relative change in SEE
  - Other forms of measure
    - Center of gravity (CG) of SEE spatial distr.
    - Standard deviation(SD) from CG

ELECTRO-POLISHED - 1 keV Prim. Beam

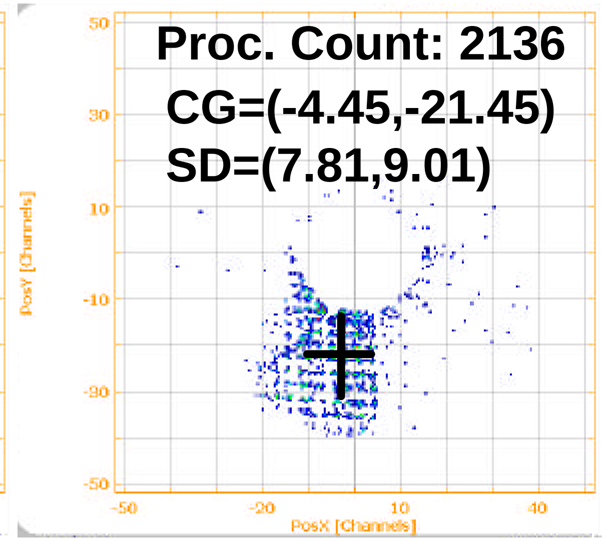
0^{O} Beveled Surf. (Normal Incidence)



15^{o} Beveled Surf.

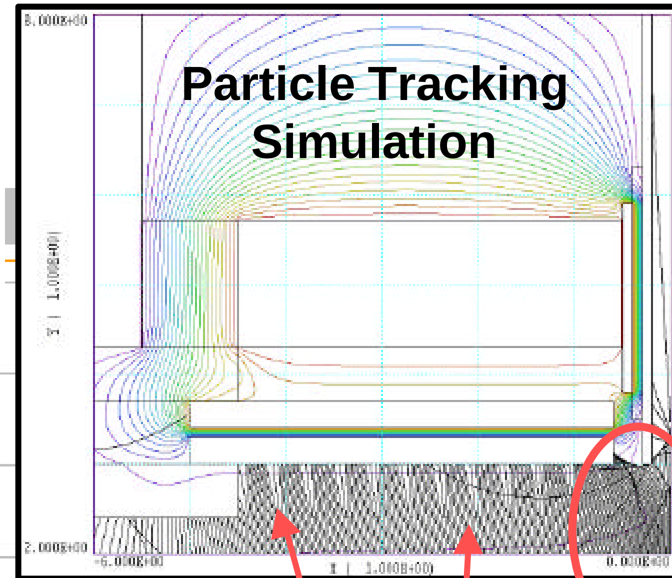


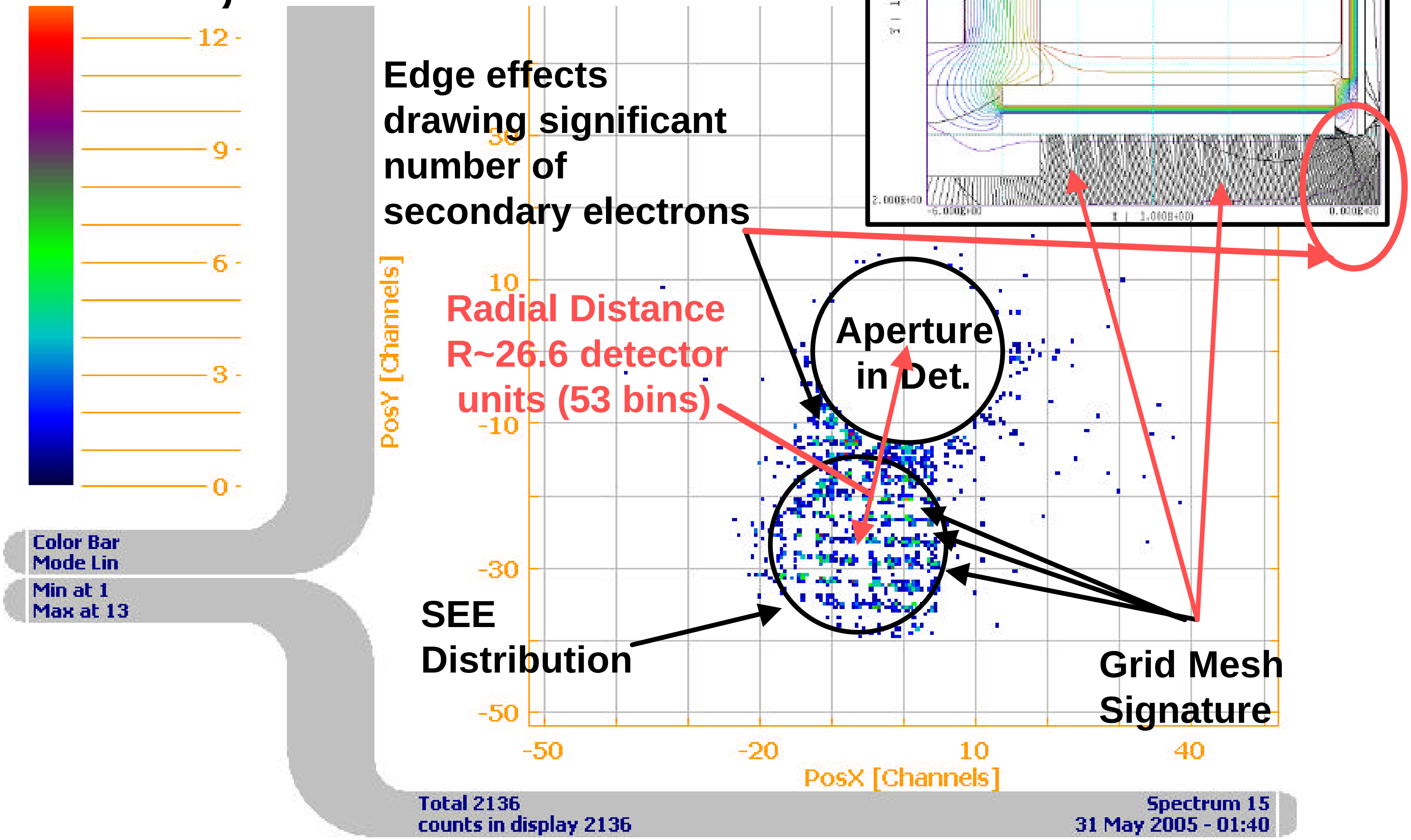
30^{o} Beveled Surf.



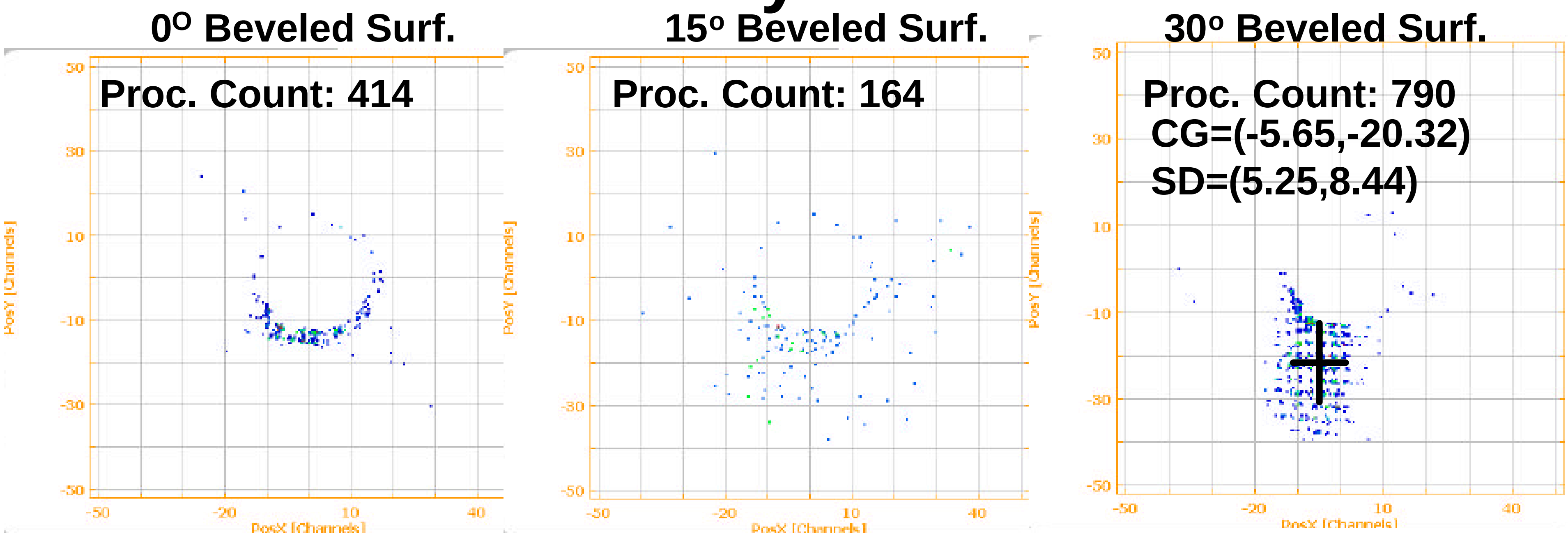
- As the angle of incidence increases, the distribution of SEE shifts radially outward along the detector surface
- Aperture opening in the detector may be observed
- 0^{o} & 15^{o} incidence - most SEE lost to the aperture opening
- Aperture masks the SEE spatial distribution allowing for study of the tail ends of the momentum distribution.
- 30^{o} Center of Gravity (CG) of SE distr. and standard deviation (SD)

DETAILS: SEE FROM 1 keV PRIMARY ELECTRON BEAM, 30^{O} EP SAMPLE



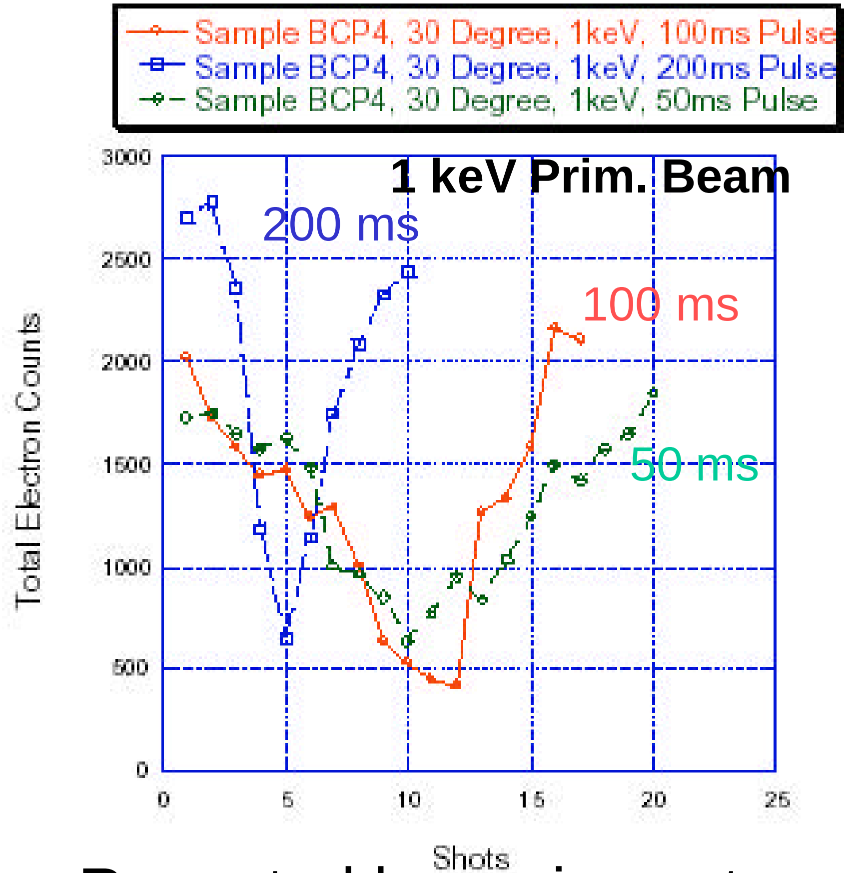


BUFFERED CHEMICAL POLISHED (BCP) - 1 keV Primary Electron Beam



- Observations - (Same trends as from the EP sample)
  - Significant loss of count for 15° incidence compared to normal.
- 30° Beveled Surface
  - On ave., proc. EP count is 2.3 times larger than proc. BCP count
    - Based on six BCP and five EP shots
  - Lit. - rough surf. on a micro. level min. SEE. Electr. emitted from the surf. inside of a micro. groove may be recaptured by its walls.

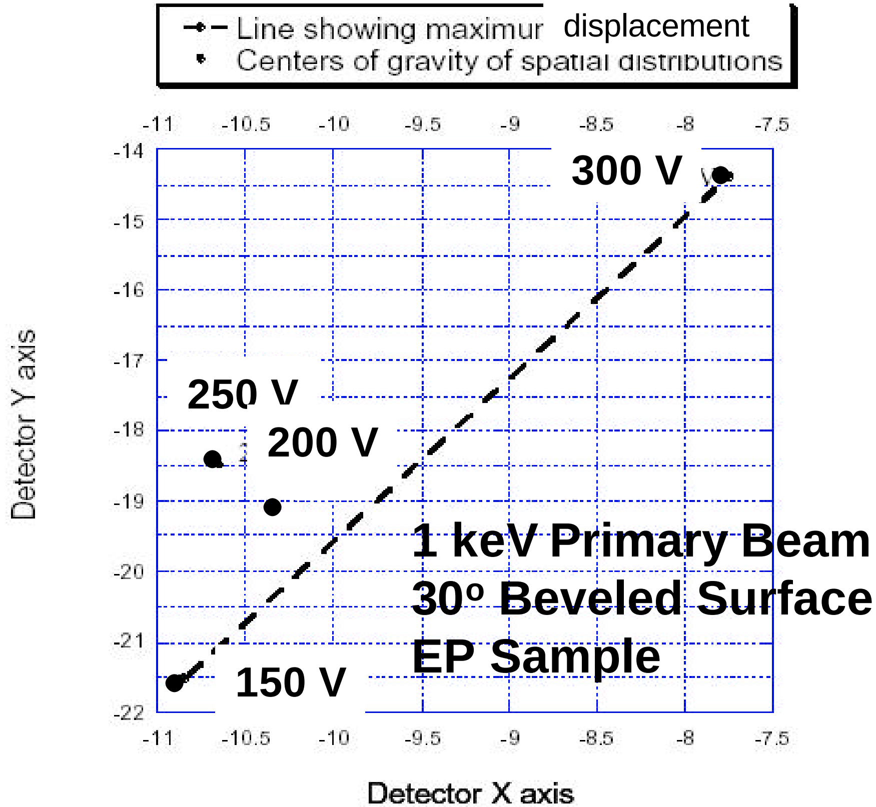
SURFACE CONDITIONING BCP - PULSE WIDTHS & NUMBER SHOTS

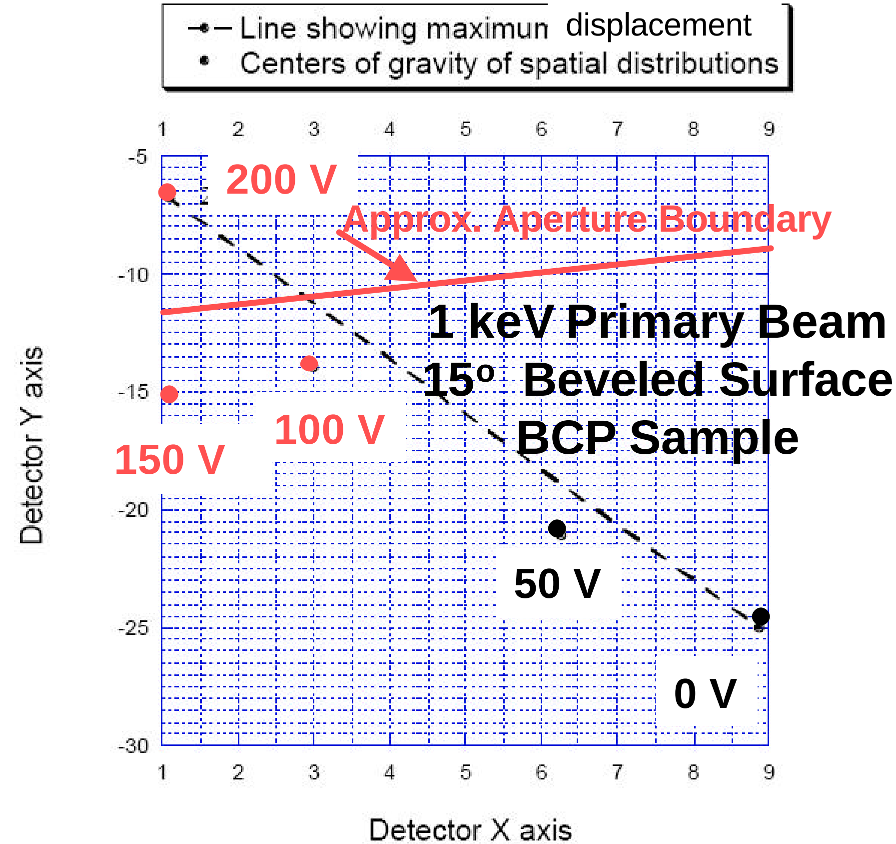


- Repeated beam impacts on single spatial location
  - ~30 s between each impact
  - 1 keV primary beam, pulse current 2.2 nA

- Pulse Width vs Rep. Rate
  - Five 200 ms pulses yield a similar min. conditioning effect as ten 100 ms pulses
  - Ten 50 ns pulses yield a conditioning minimum slightly higher than ten 100 ns pulses
  - Fall and rise rates for a particular pulse width is similar.
- EP Conditioning Rate is Slower than BCP but SEE Minimum are Similar

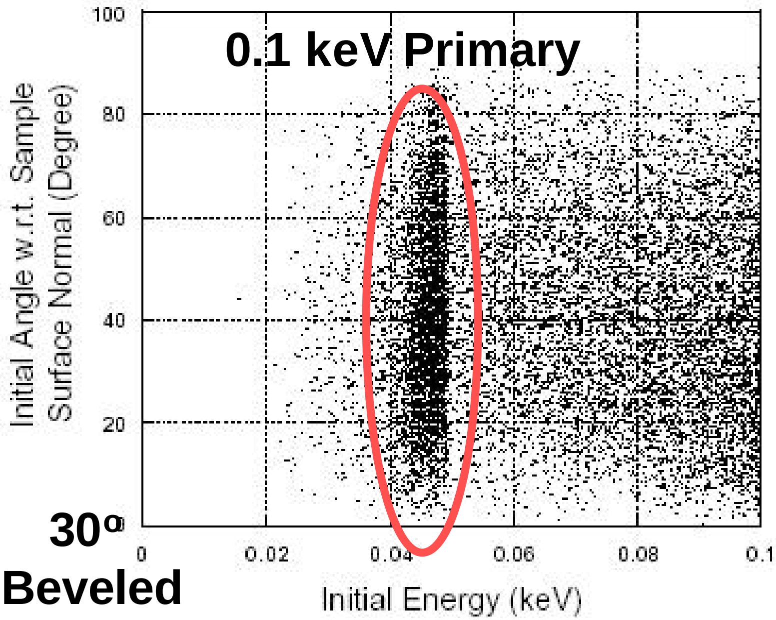
TRACKING SEE DISTR. VARYING GRID VOLT.



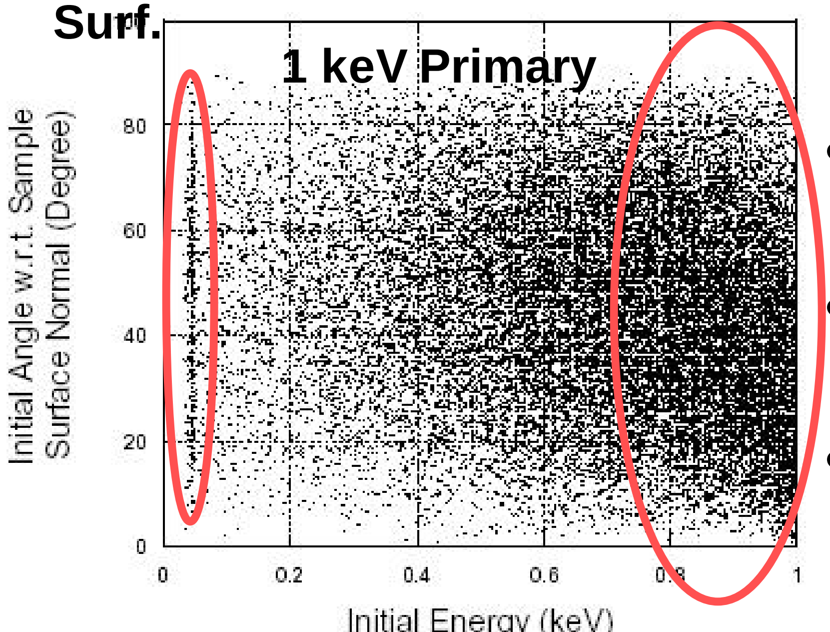


- Controlling Grid Properties - EP
  - Increasing the pot. displaces the center of gravity of the distribution towards the detector center.
  - For a 150 V change, the distribution traverses 16 bins or 4.4 mm
- Controlling Grid Properties - BCP
  - ‘Specular’ cal. indicate the CG of the SEE distri. for the **100 V** & higher grid pot. is lost to the detector aperture.
  - At 50 V, the entire distribution is visible to the detector.
  - Δ200 V-displaced by 40 bin / 11.3 mm

MONTE CARLO SIMULATION RESULTS



30º Beveled Surf.



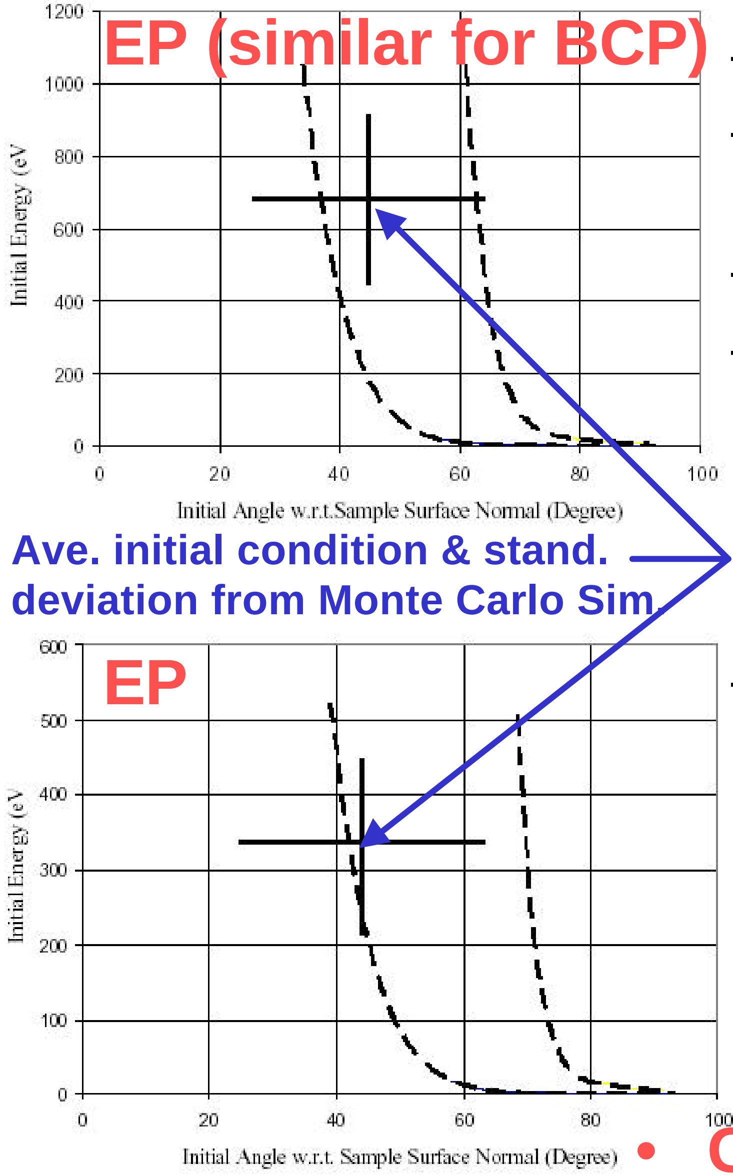
- Monte Carlo Code
  - Original Version (valid > 50 eV)
    - Dr. David Joy, Univ. of Tenn.
  - Modified Vers. (added near surf. Effects; tracks of all SE generations)
    - Dr. Richard Kant, UNLV
  - Microscopic, single scatterer approach to follow the primary and all generations of secondaries through the collision cascade
  - Output - Initial energy/mom. dir. cos.
- Logistics
  - 100,000 primary electr. launched
- 100 eV – large concentration between 40-50 eV
- 1keV – large concentration between 0.9 and 1 keV, and structure around 50 eV

SIMULATION LIMITATIONS

- SEE Monte Carlo Code-Limitations
  - Model provides estimates for energies between 50 eV and 1 keV in the collision cascade
  - Once below 50 eV, the charge is no longer tracked
  - If near the surface and the SE energy is betw. 20 eV and 50 eV, a random generator decides if the particle is emitted from the surface
  - Important Observations
    - Literature suggests that *true* secondary electrons typically have energies *less than* 50 eV
    - SEE Monte Carlo Code in its present form may not adequately predict the *true* secondary electron emission
    - Since the primary electron beam is low, tracking results obtained from the SEE Monte Carlo code should provide reasonable estimates for the backscattered secondary electron (BSE) (Note: BSE have energies comparable to primary electron)

SIMULATION vs EXPERIMENT

30º Beveled Surf.



- **Logic**
  - The SE Monte Carlo code predicts BSE
  - Based on specular arguments, exp. data has been masked to observe the BSE
  - Anticipate- SEs favor emission in specular dir.
  - All initial particle trajectory conditions (energy/ mom. dir. cos.) for the standard deviation extrema from the average final position of the SEE distr. as measured on the detector are determined with a particle tracking code.
  - Initial conditions of final extrema positions are plotted. All possible initial conditions should lie in between these curves. If SEE is uniformly distributed about the detected specular electron, the ave. initial conditions of the Monte Carlo BSE distri. should be central to experimental curves.
- **Good agreement shown**

CONCLUSION

- A SEE test stand has been designed to study the initial conditions of secondary electrons emitted from niobium in cryogenic state.
- Secondary electron particle distributions have been studied for 0^o, 15^o, and 30^o beveled surfaces
- BCP and EP samples have been compared showing that the EP count is over twice as large as the BCP count
- Electron beam surface conditioning was examined. Conditioning appears to be sensitive to pulse duration and the number of impacts
- Good comparison have been shown between experiment and simulation

ACKNOWLEDGEMENTS

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