Experimental Results of Electron Method for Remote Spacecraft Charge Sensing

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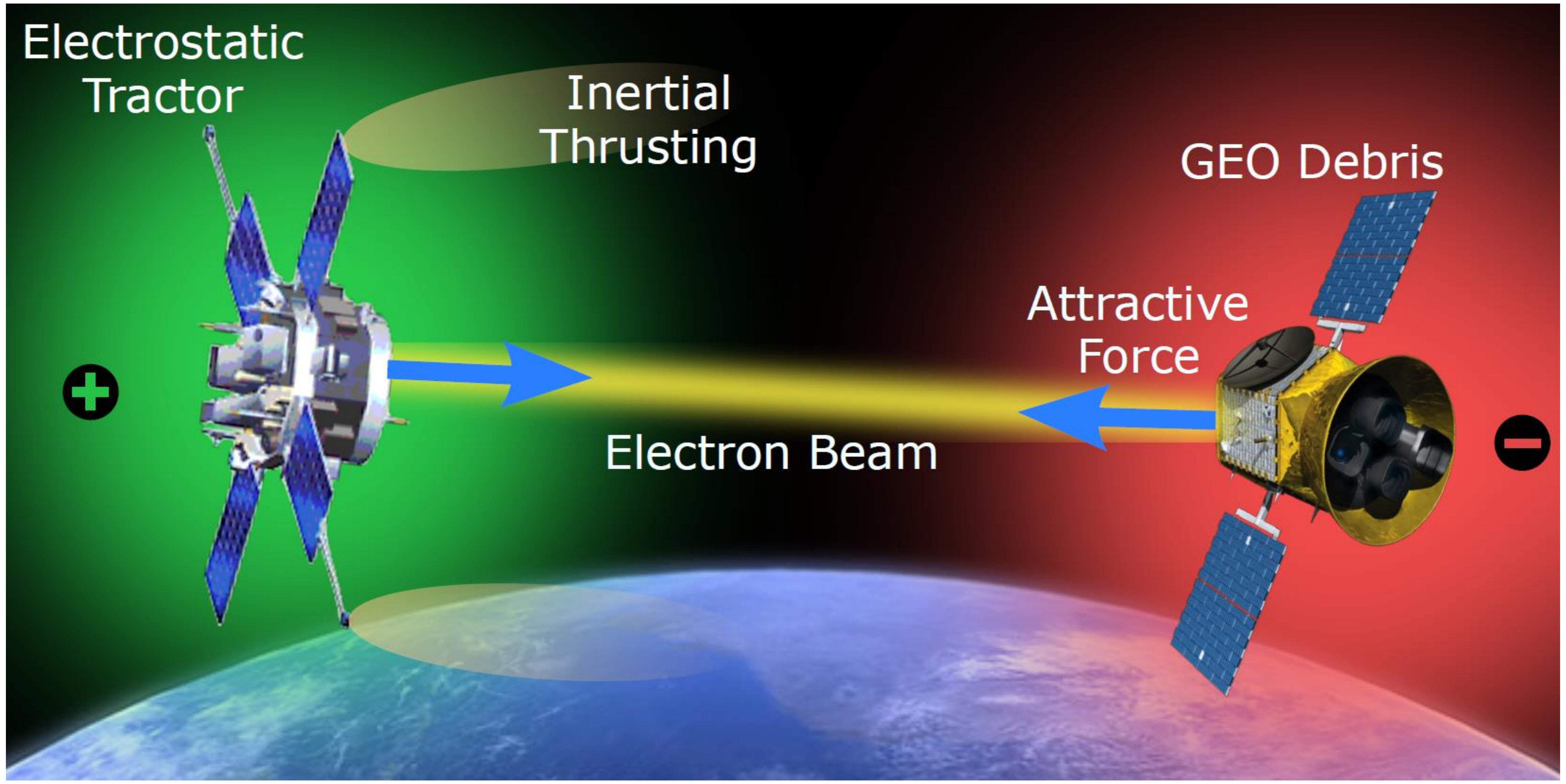
Motivation for Touchless Sensing

Mitigation of unwanted effects

- On orbit experiments to study:
  - Spacecraft charging
  - Material surface evolution
- ESD prevention during docking/contact operations

Enabling new capabilities

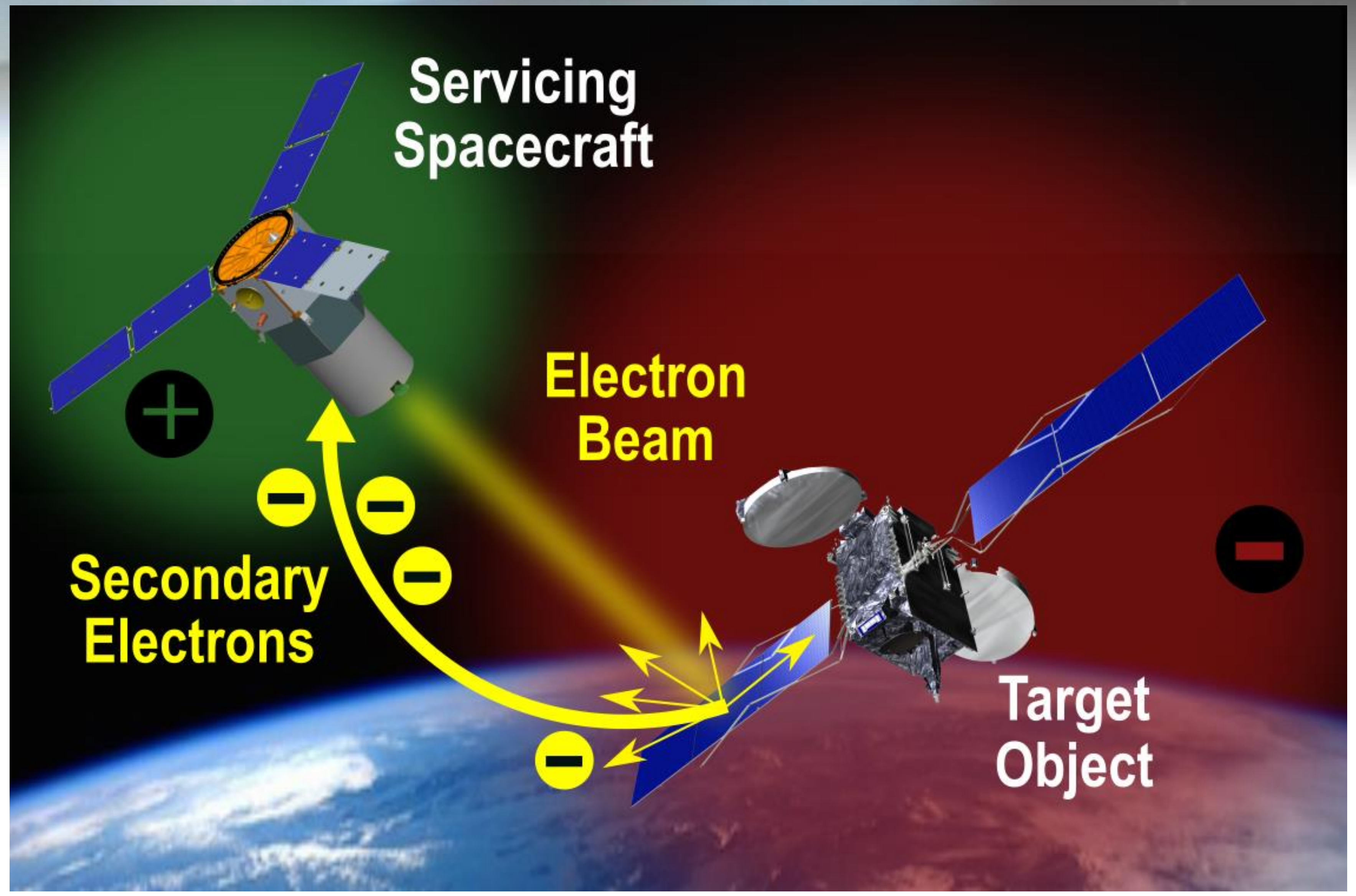
- Electrostatic Tractor
- Detumbling of space debris
- Coulomb formations
- Lunar/asteroid surface characterization
- Material identification for SSA

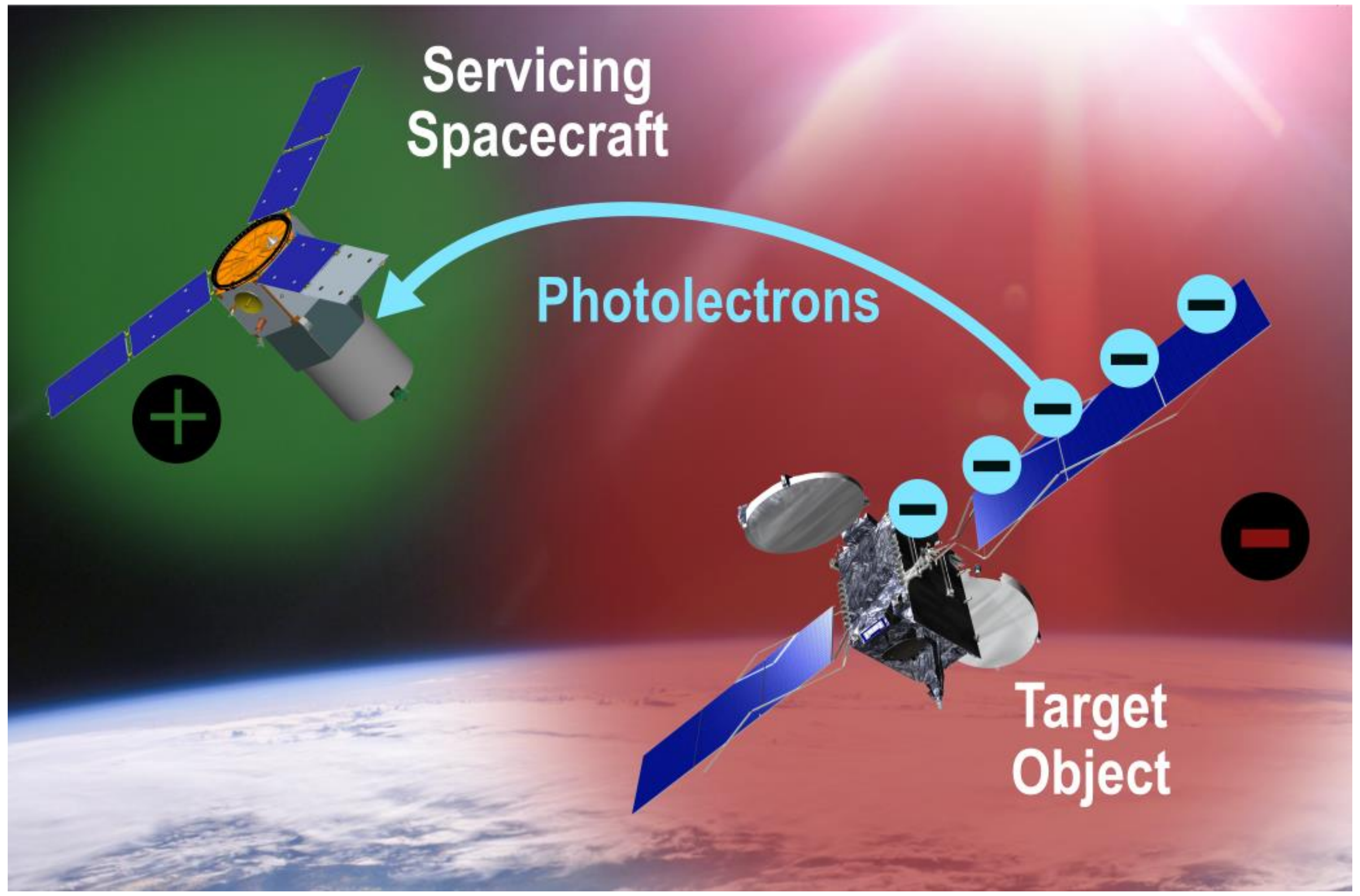


Concept for Touchless Potential Sensing

Concept:

- Electrons generated on surface of target object
  - Secondaries from an active electron beam
  - Photoelectrons from sunlight
- Accelerated toward servicing craft which is at high positive potential
- Arrive with energies equal to potential difference between craft plus small initial energy
- Electron energies can be easily measured

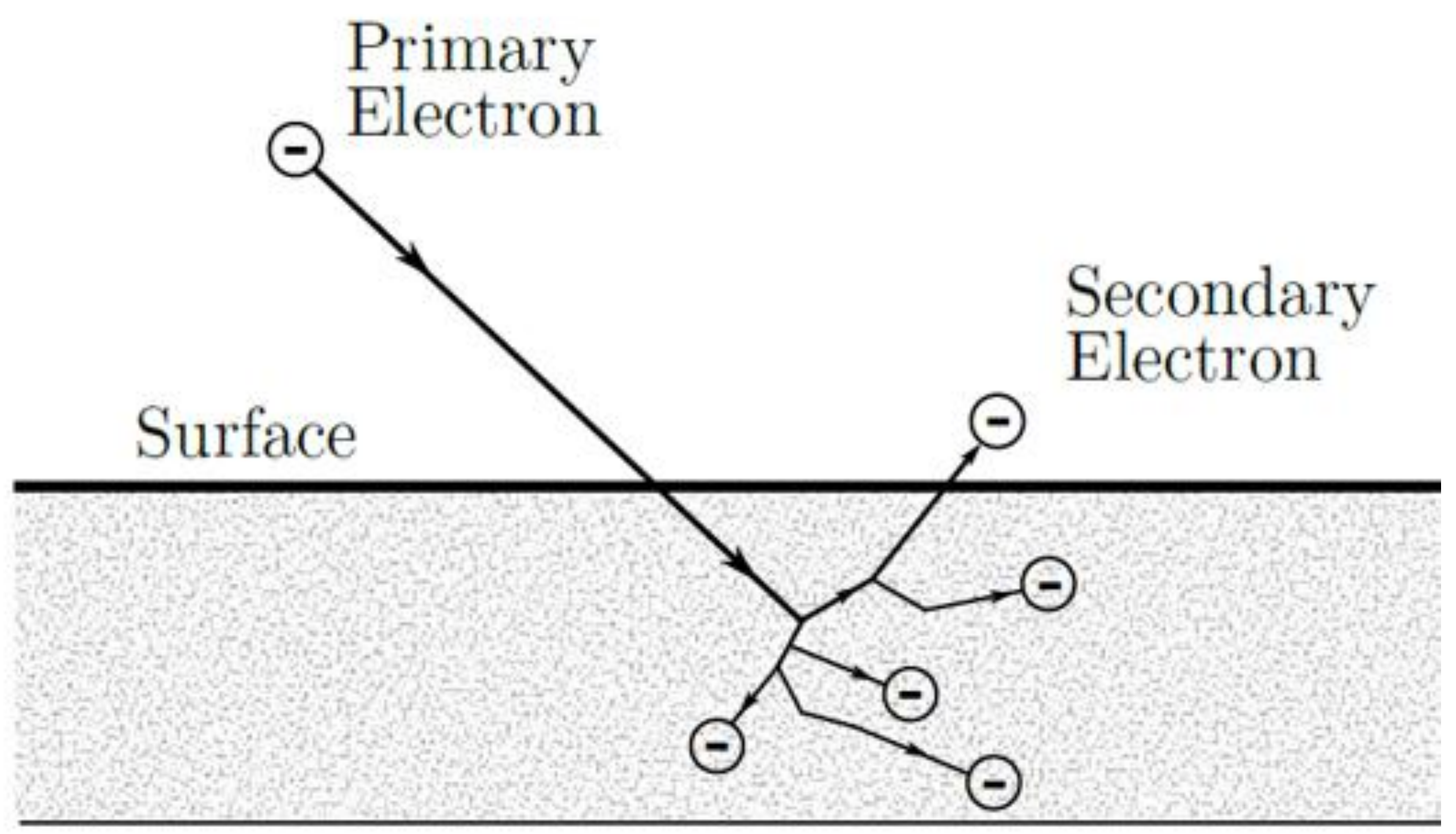


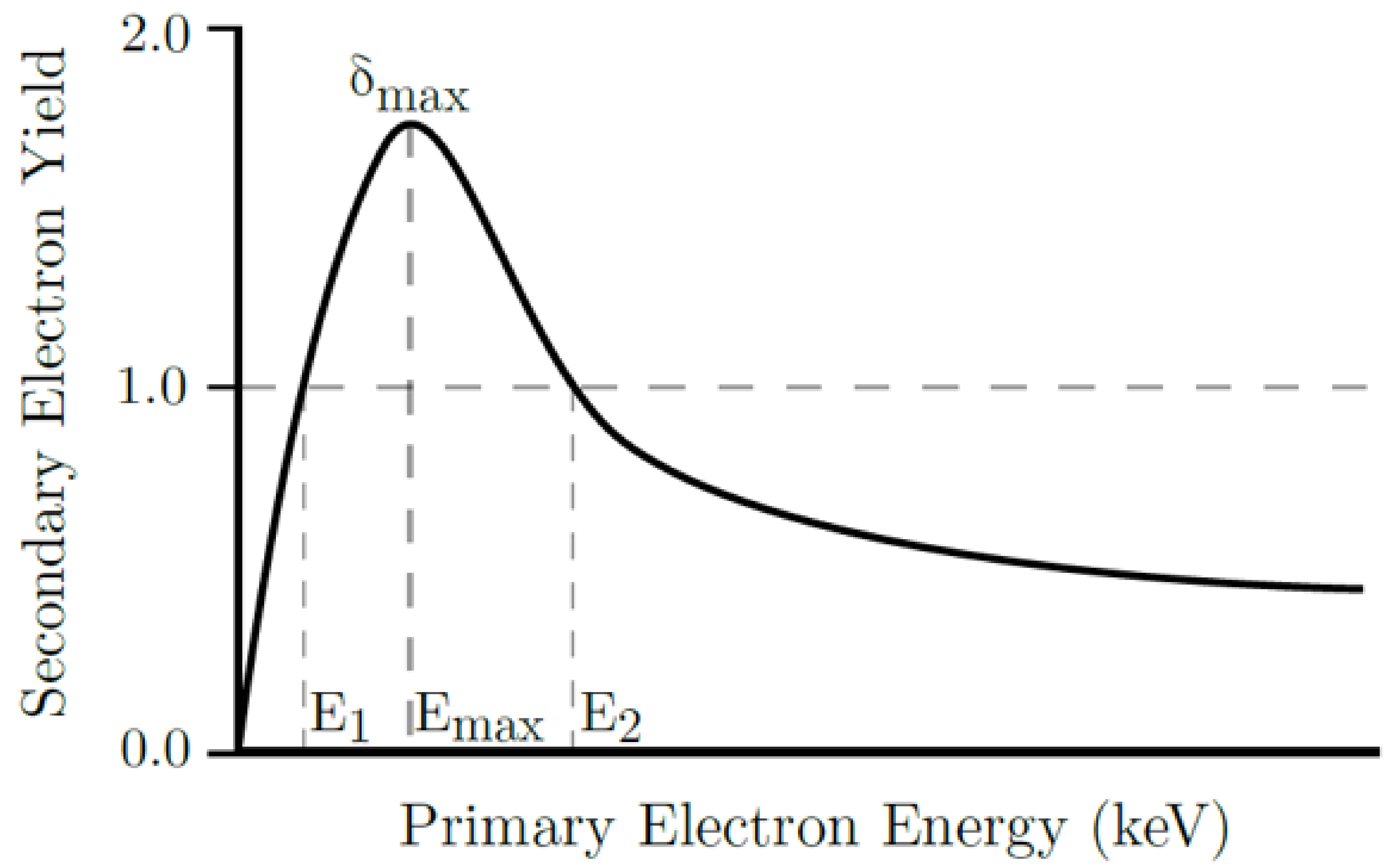


Secondary and Photoelectrons

Key fact: secondary and photoelectrons emitted from surface with very low energies

Backscattered electrons carry no information about the target potential





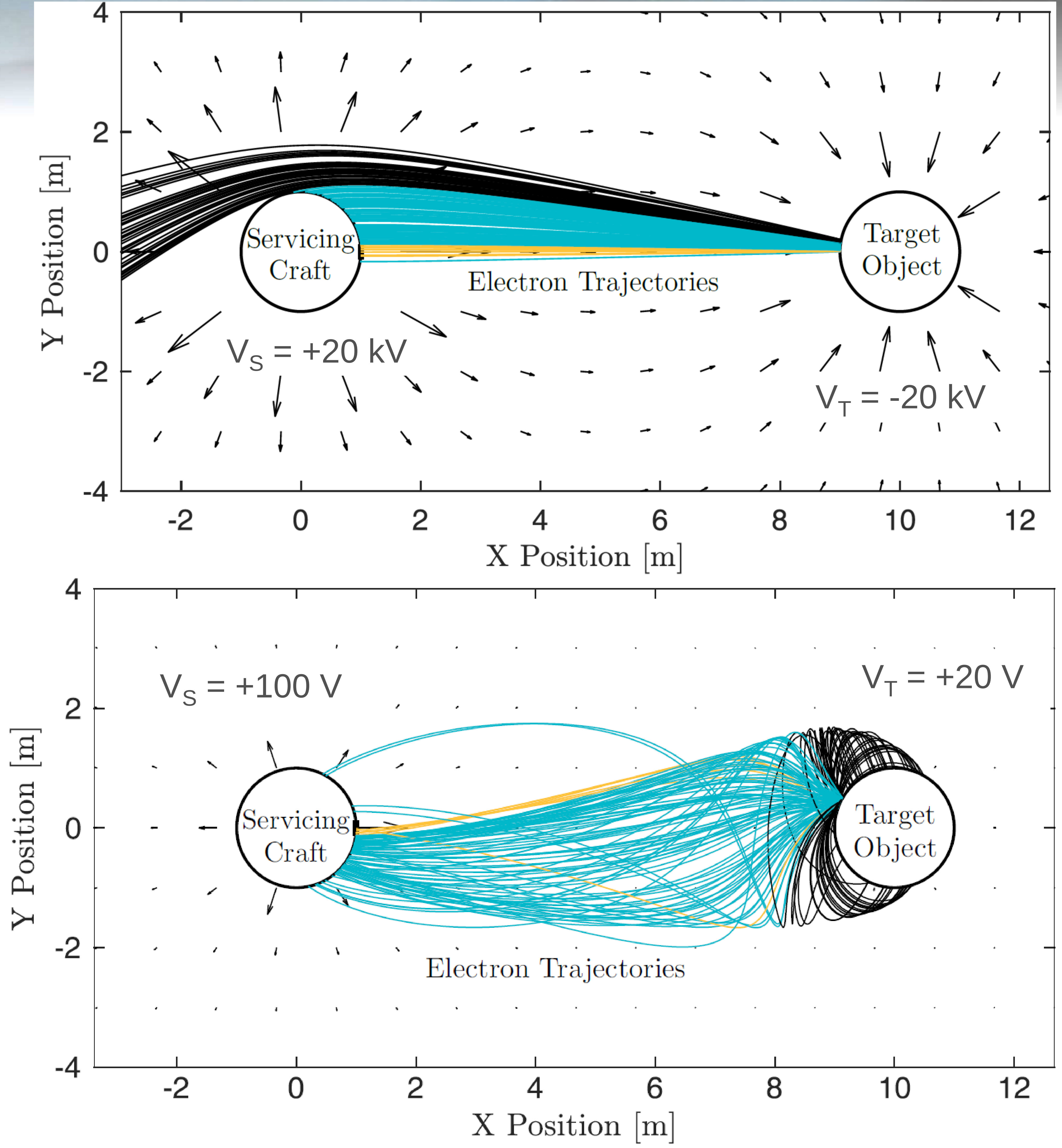
Method

Goal: Investigate accuracy of electron sensing method and determine effect of relative geometries

Approach: Measure potential of target plate in vacuum for range of voltages and angles

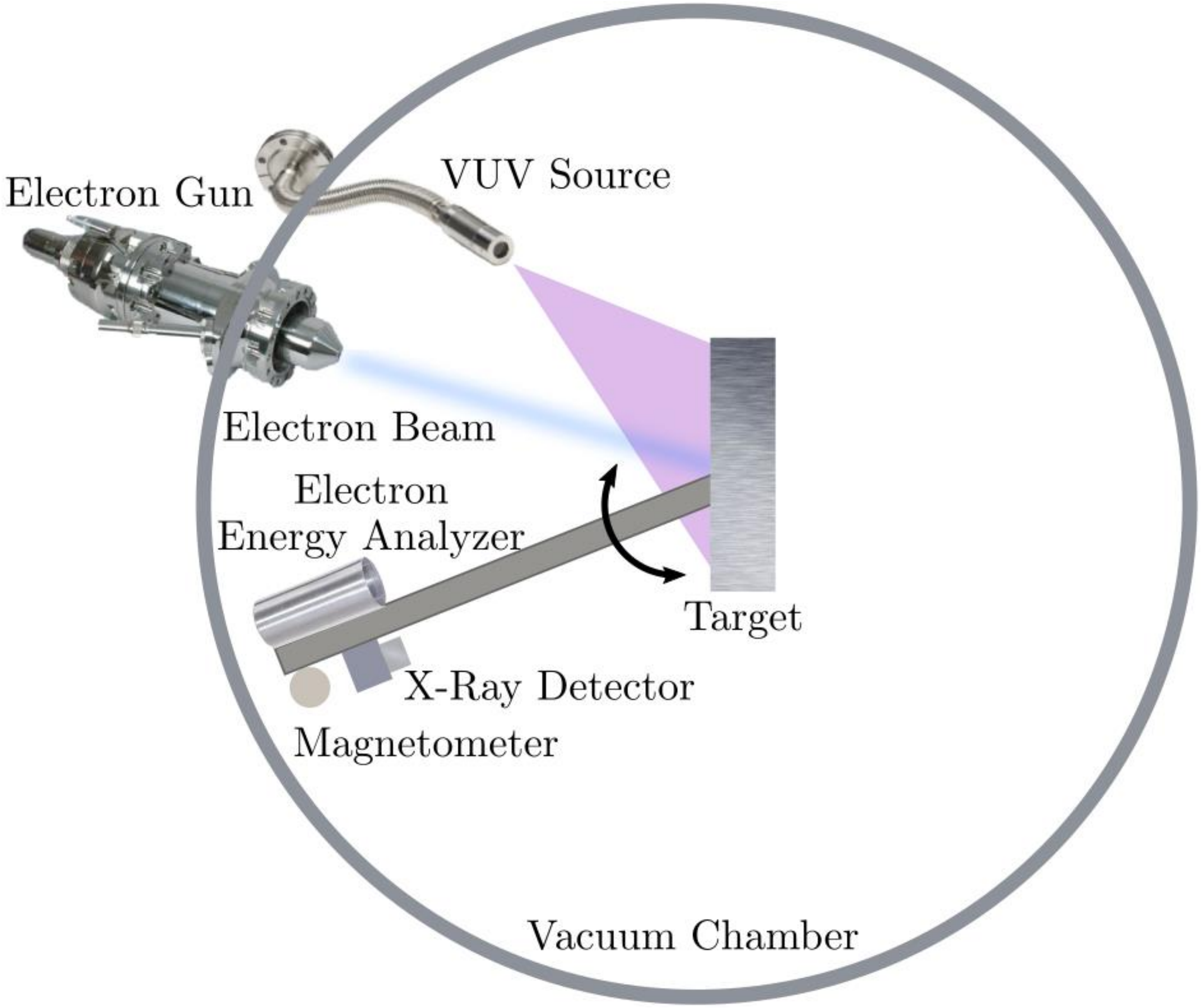
Improvements from previous work:

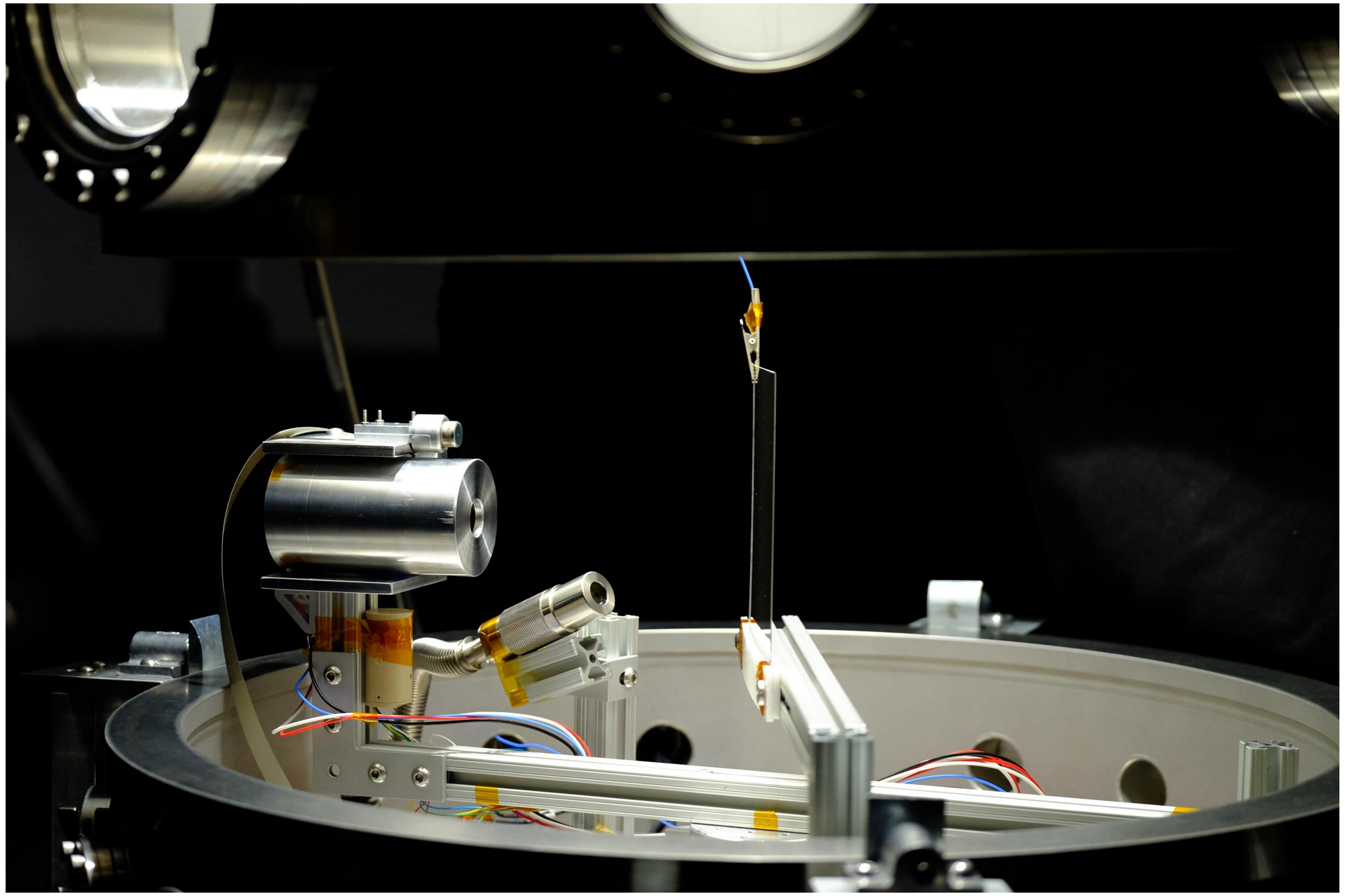
- Ability to test in 100-1000s V range + rotational stage
- Simulations extended to 3D
- Simulations can model electric field around arbitrary shapes using Method of Moments



Experiment Setup

- Gridded Faraday cup used to measure energy distribution of electrons
- Obtained measurements of secondary and photo electrons from charged plate (100s of volts to kilovolts)
- Copper, Aluminum, and Inconel samples tested



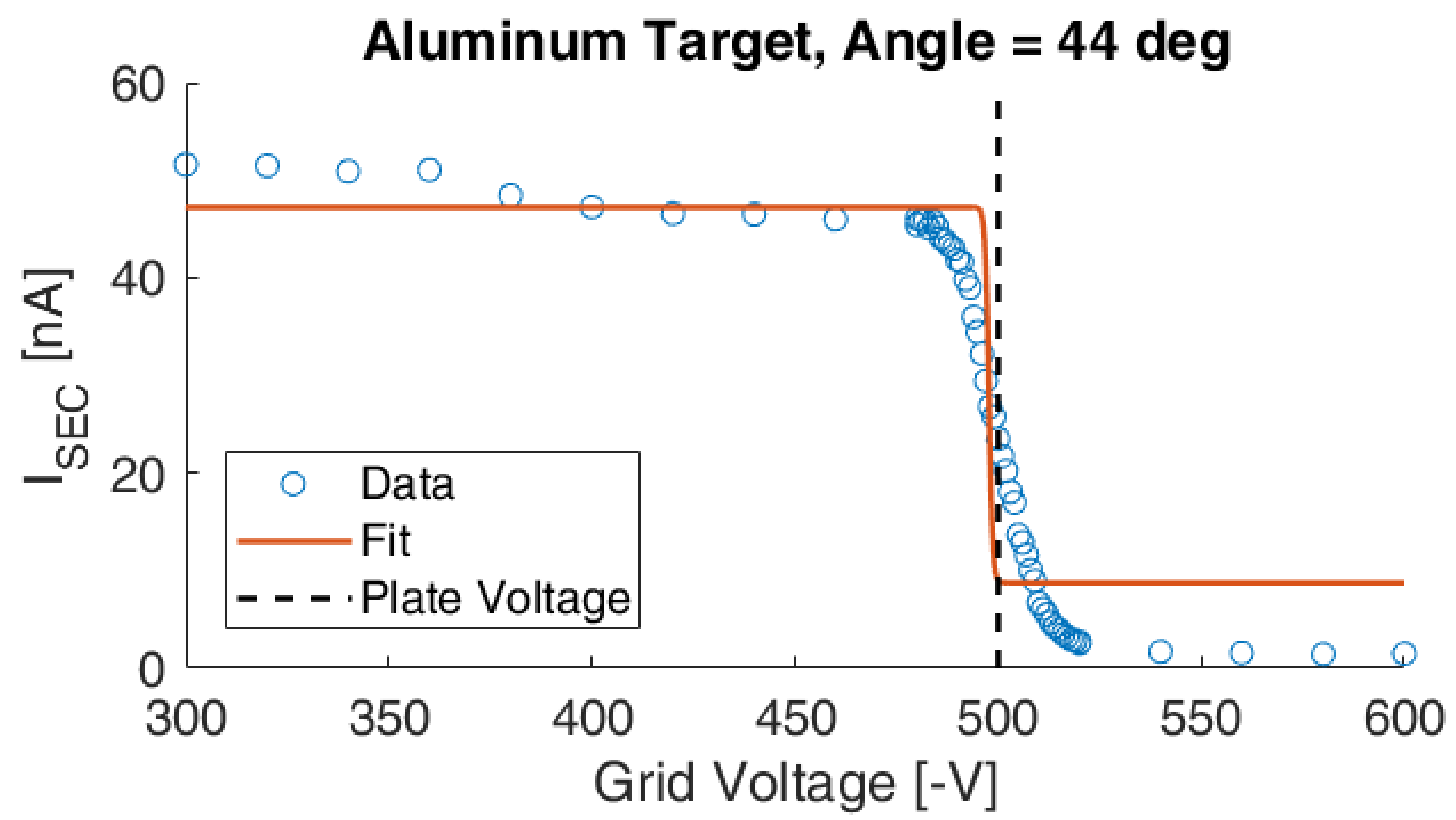


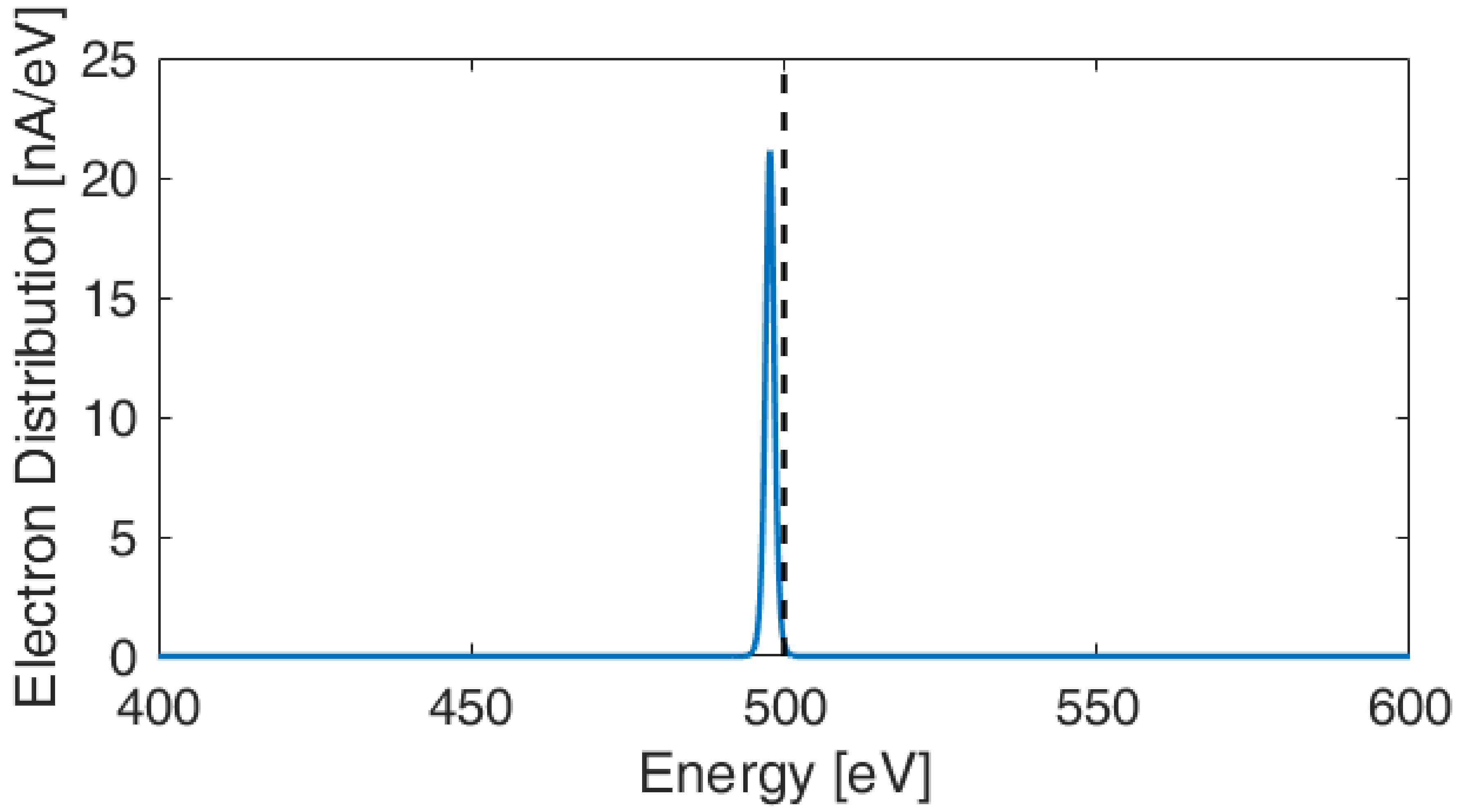
Experiment Results

- Smooth step-function fit to raw data using nonlinear regression
- a, b, c, and d are fitting parameters
- I is the electron current and Vg is the grid voltage
- Electron energy distribution found by taking derivative
- Nonlinear fit requires decent initial guess

$$I = a - b\tanh\left(cV_g + d\right)$$

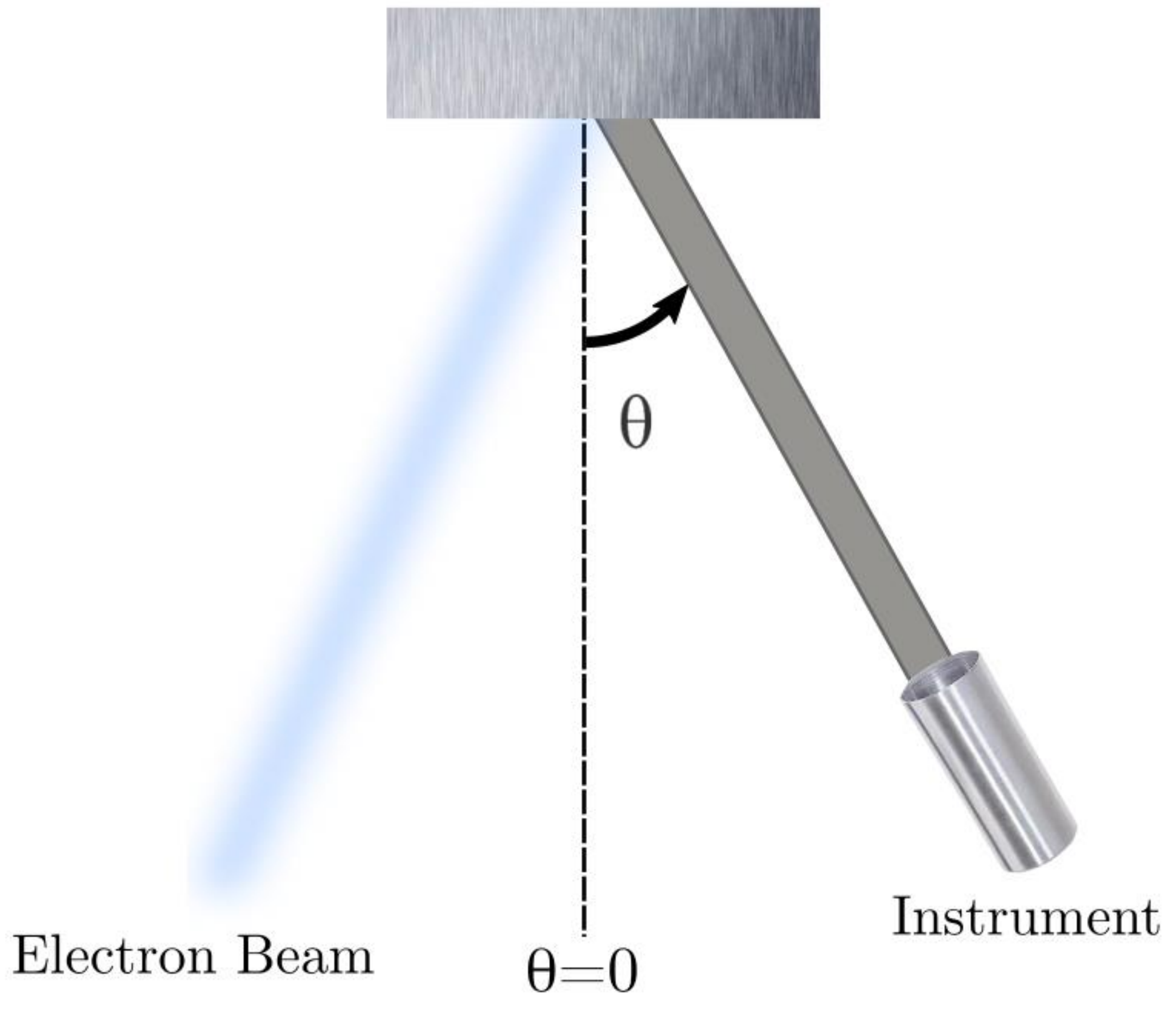
$$-\frac{dI}{dV_g} = bc\left(1 - \tanh^2(cV_g + d)\right)$$

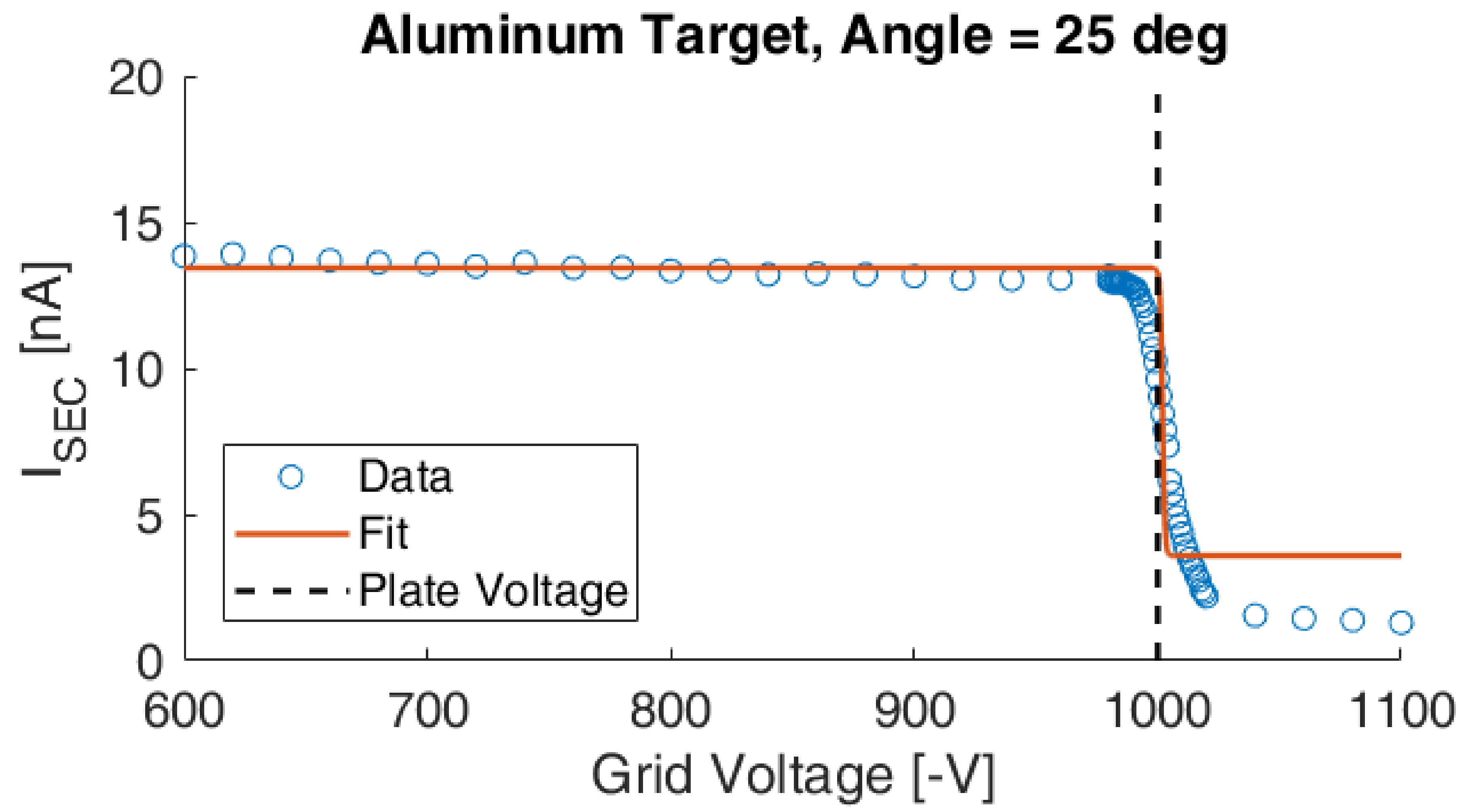


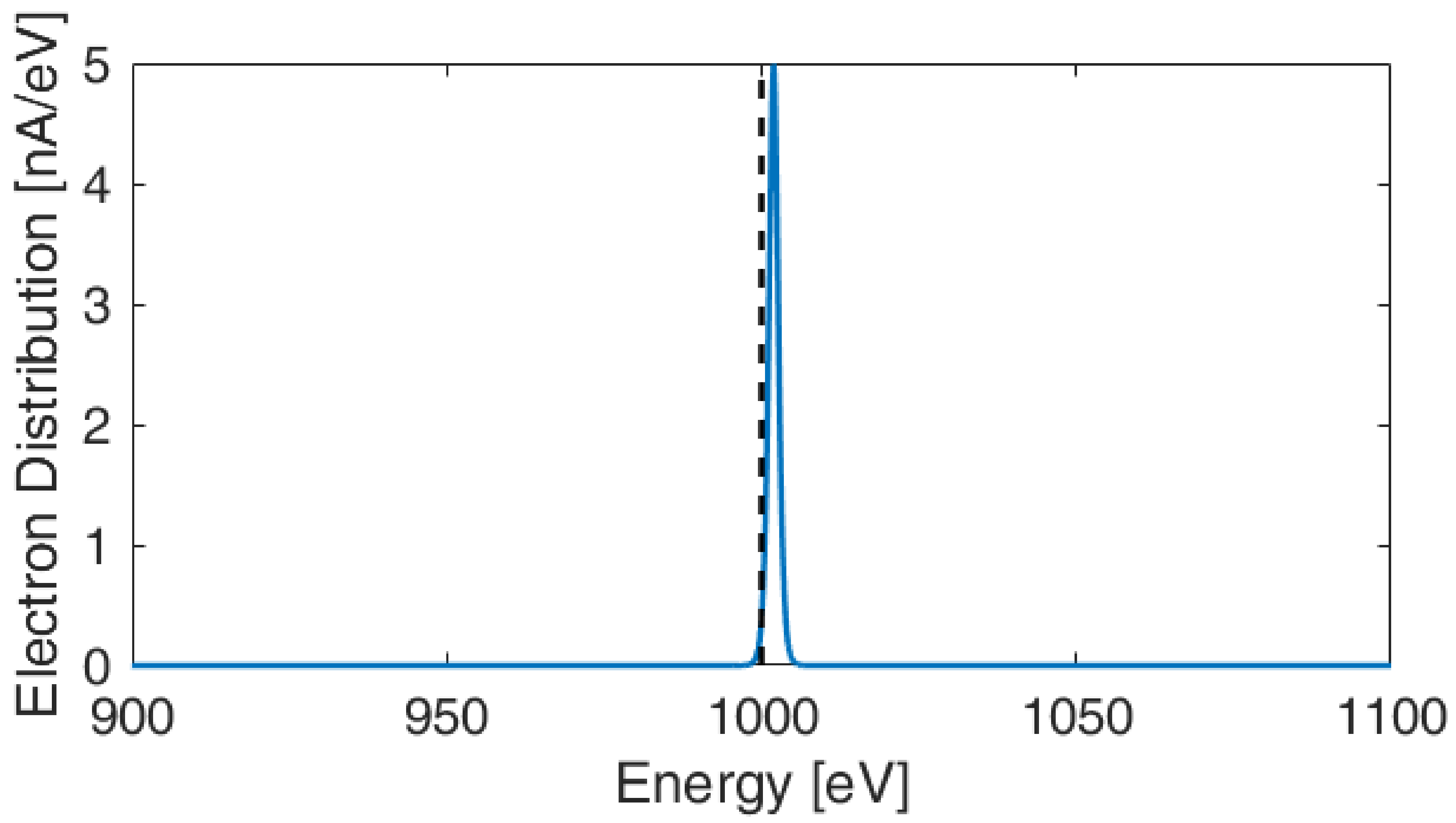


Experiment Results – Electron Beam

Rotational stage allows data collection over 110°, from -20° to +90°

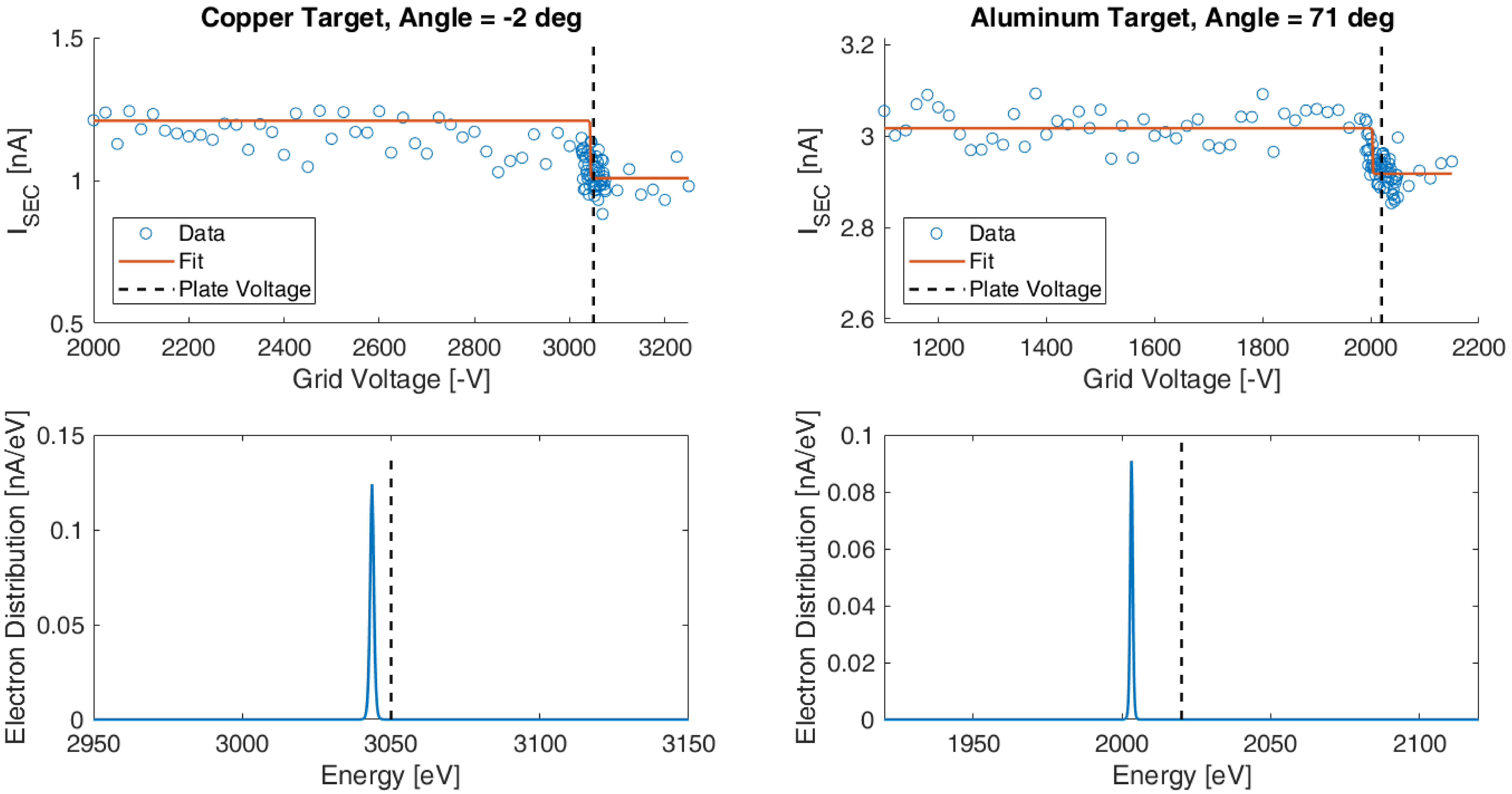






Experiment Results – Electron Beam

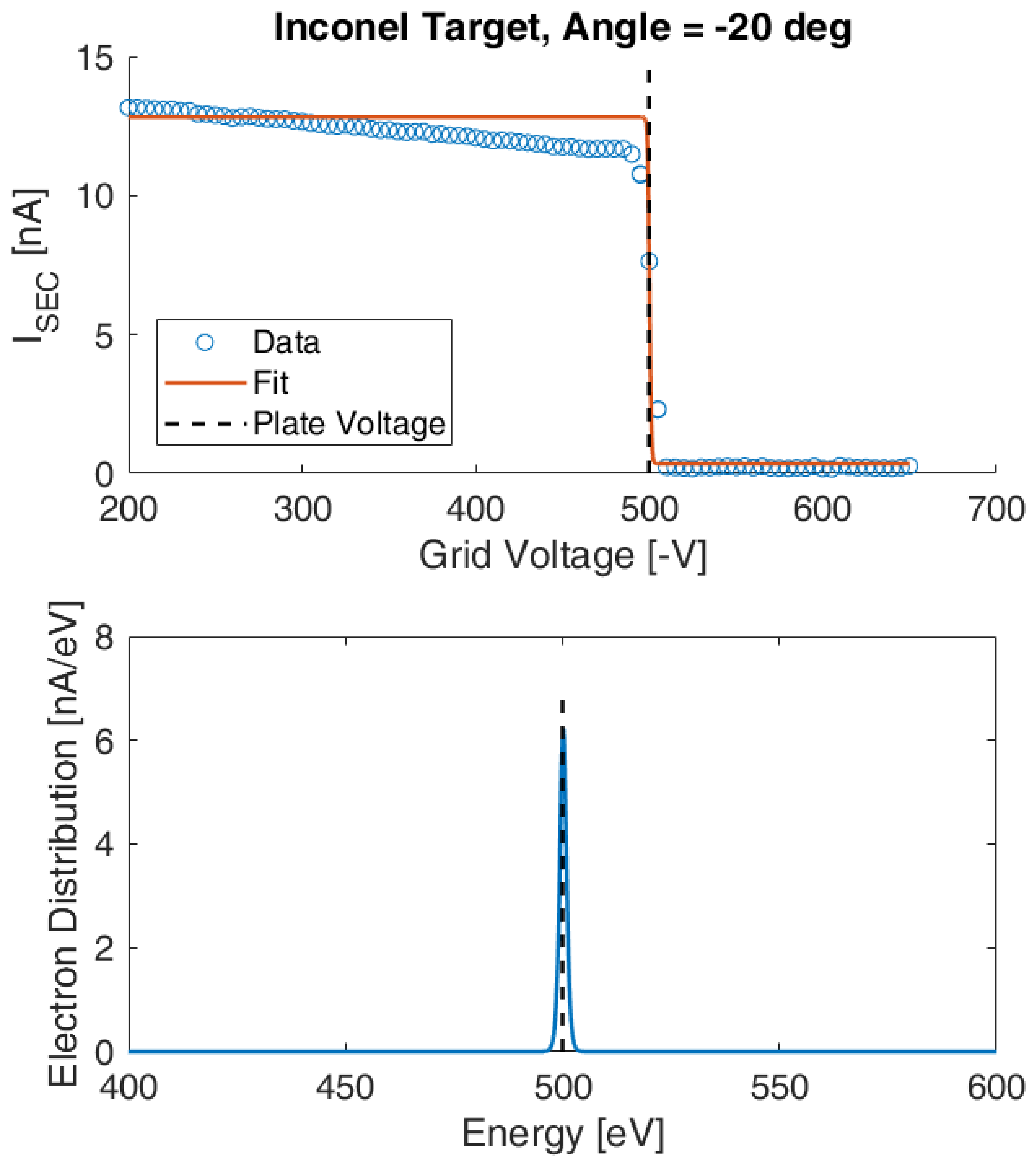
- Electron sensing method is extremely accurate
- Wide range of plate voltages
- Even for low signals and large angles



Experiment Results – Photoelectrons

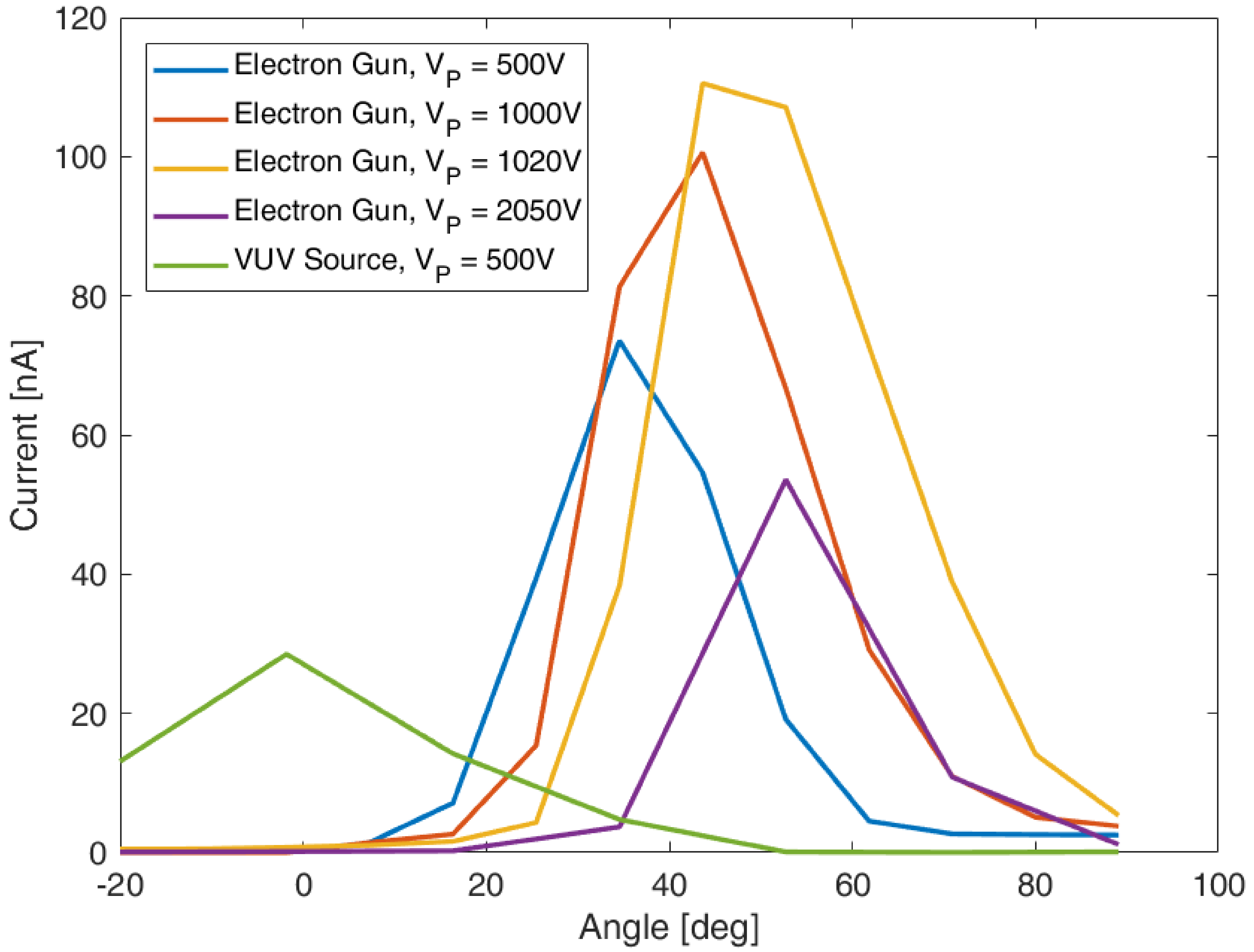
- Photoelectron current from VUV light also gives excellent touchless measurement of plate potential

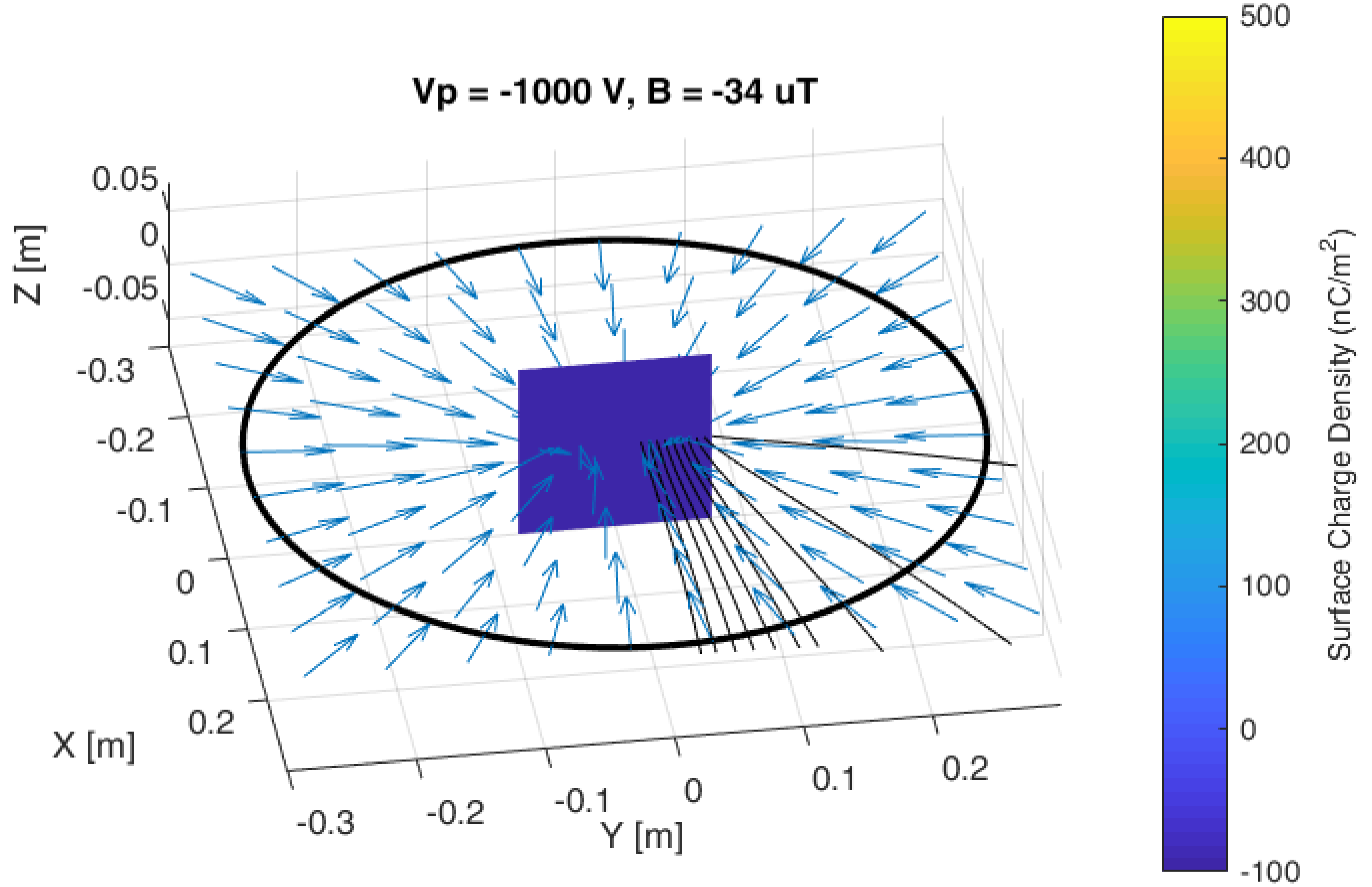
- All materials tested give consistent results
  - Current experiments: Copper, Aluminum, Inconel
  - Previous experiments: Aluminized mylar, ITO



Experiment Results – Geometry

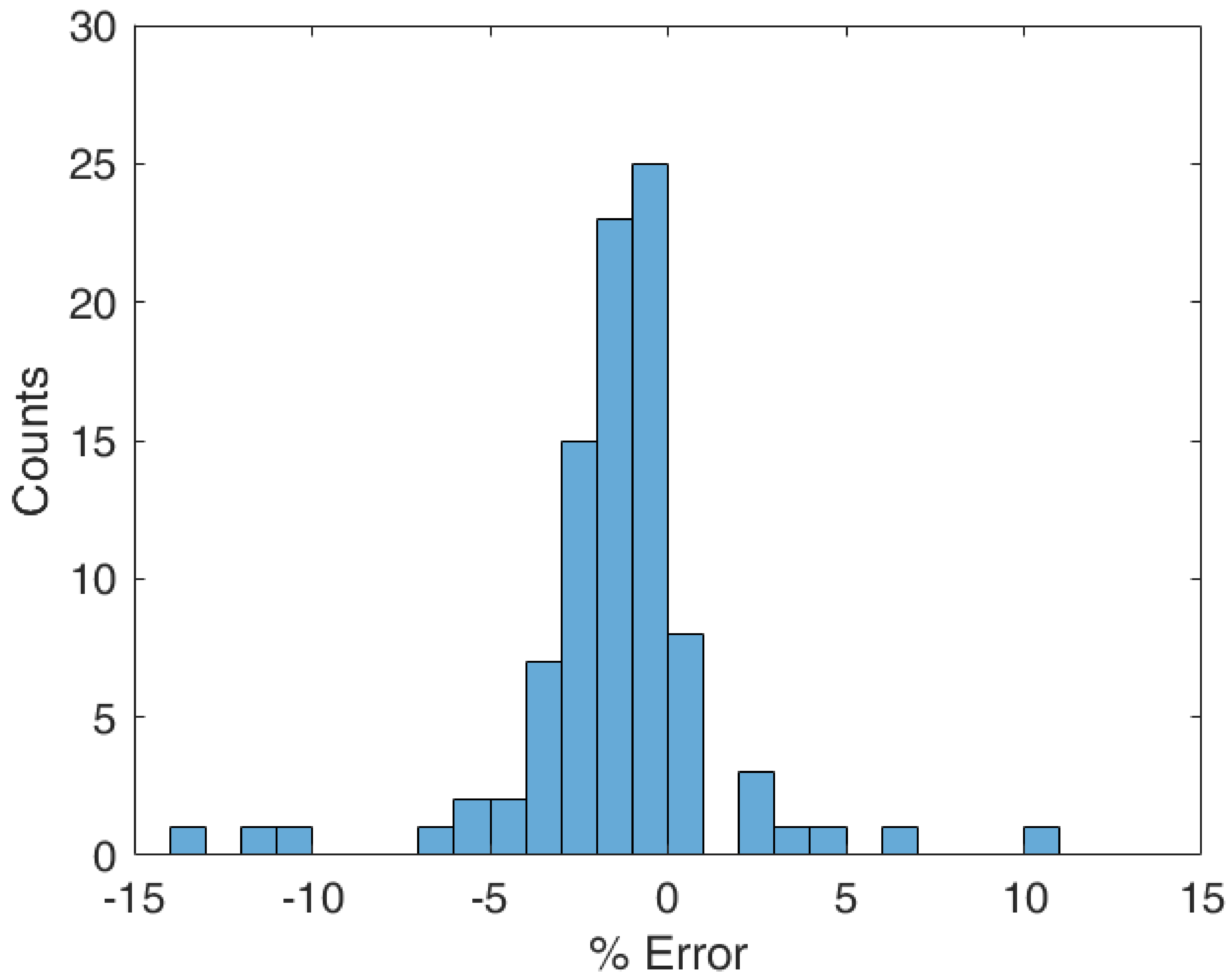
- Largest current for electron gun tests actually occurs at an angle of 35-50° off normal
- Photoelectron tests centered about normal





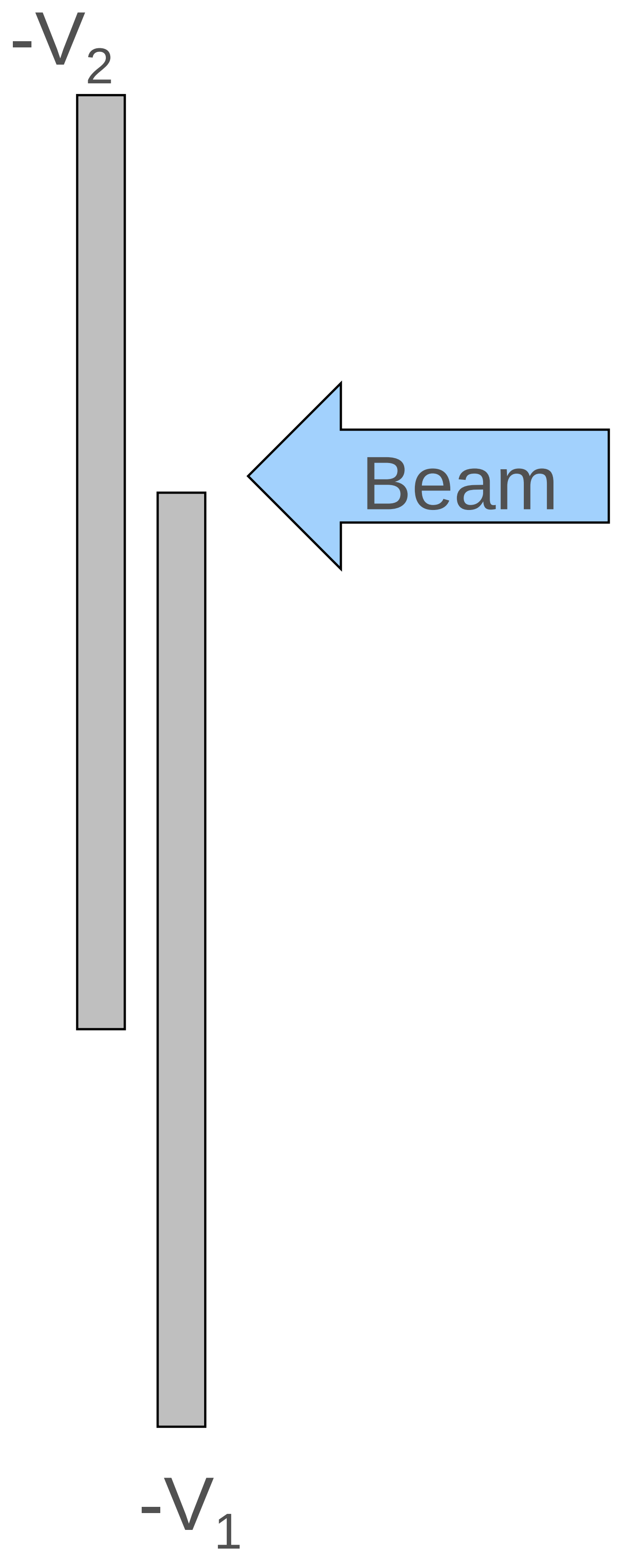
Experiment Results – Error

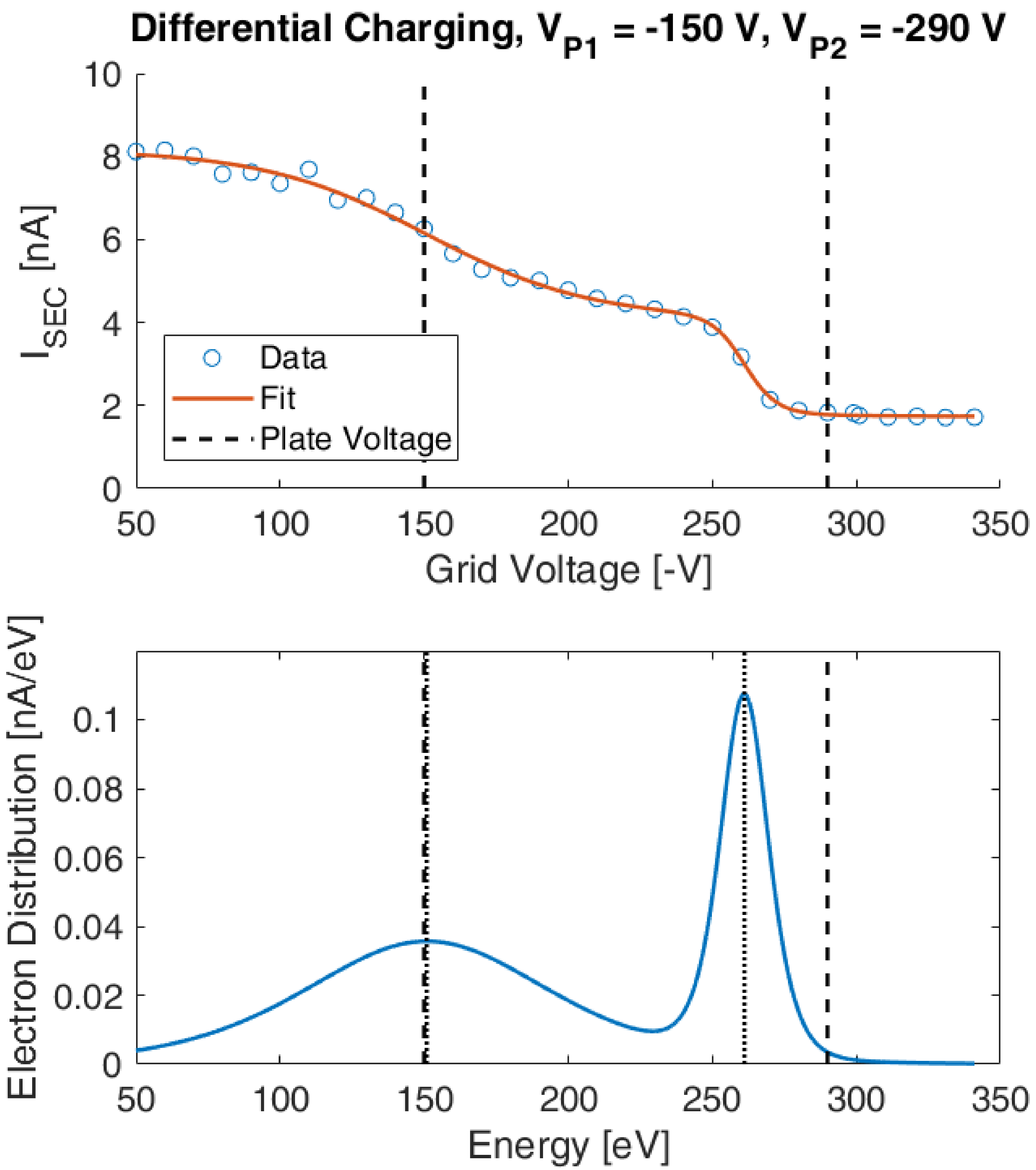
- Excluded cases where -dI/dV < 0.1 nA/eV
- Average error across all materials/angles/voltages = -0.257%
- Mode at ~7% is from single test with V_P= -130V
- Reason to suspect accuracy of HVPS at low voltages
- Average error is now = -1.42%

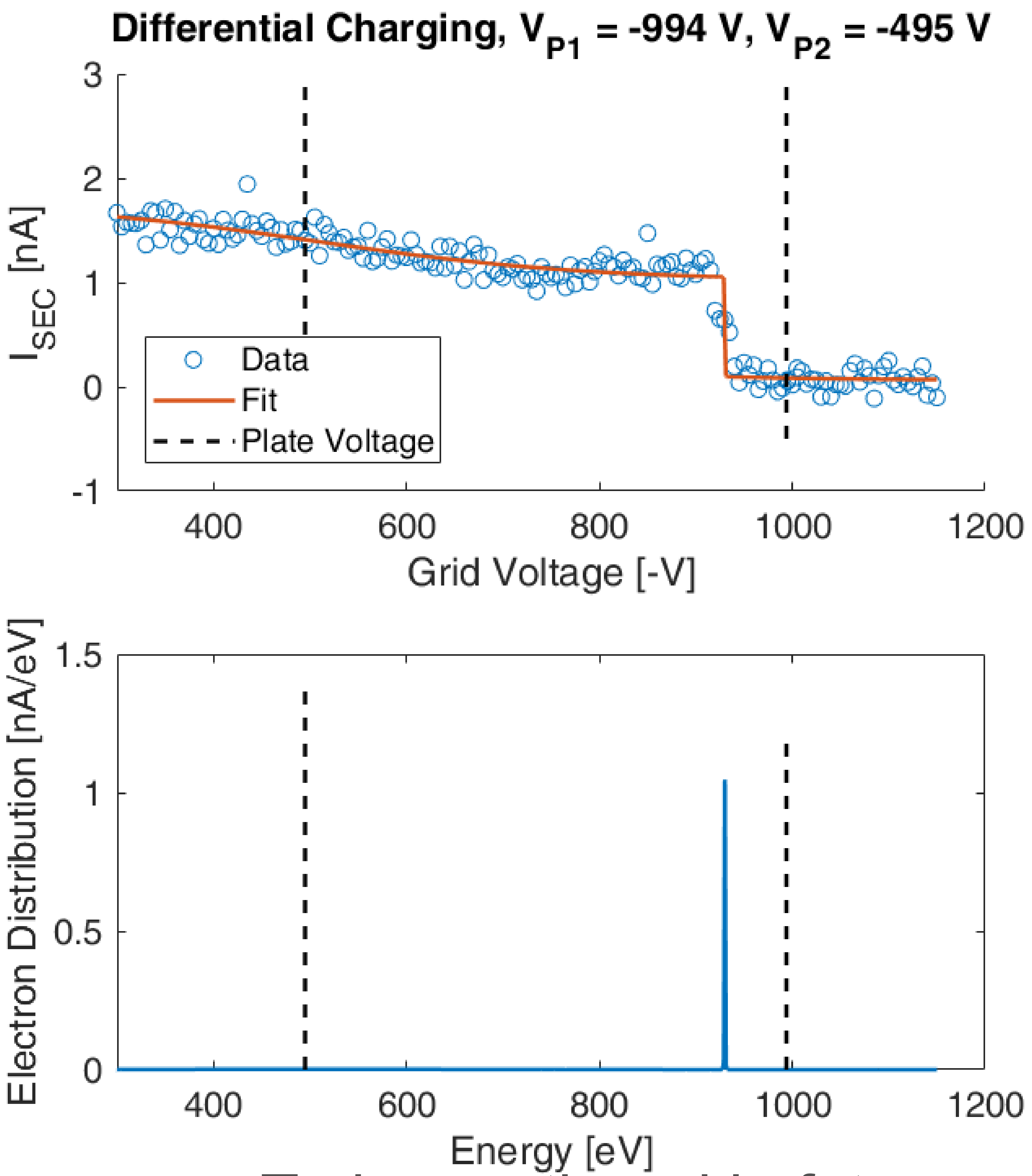


Experiment Results – Differential Charging

- Differential charging results always find peak at larger voltage, even when voltage on plates is switched
- Electric field at edge of plate 1 drives electrons straight up?







To be continued in future work…

Comparison of Methods

Electron Sensing	X-Ray Sensing
Photoelectrons provide passive sensing option	Requires electron beam (?)
Servicing craft must be positive	Signal independent of servicing craft potential
Material identification not straightforward (auger peaks?)	Characteristic peaks allow identification of material
Demonstrated use sensing lunar potential surface	Demonstrated use for asteroid surface characterization
Prolific on-orbit	Less common in Earth orbit

- Future missions could incorporate both methods for a robust potential sensing instrument
- Future work will compare the methods in more detail and develop data fusion algorithms

Conclusions and Future Work

Conclusion:

Touchless potential sensing works

- Over a large range of spacecraft potentials
- With both secondaries and photoelectrons
- For a variety of common spacecraft materials
- Over a wide range of relative attitudes
- With readily-available instrumentation
- Accurate to within a few % error

Future work:

- Conduct experiments and simulations with realistic spacecraft shapes and differential charging
- Develop filter to determine electron distribution without prior knowledge
- Data fusion from multiple sensors
- Implement system on experimental testbed with tumbling model spacecraft

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