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Electron Yield Measurements of Bulk Lunar Simulants

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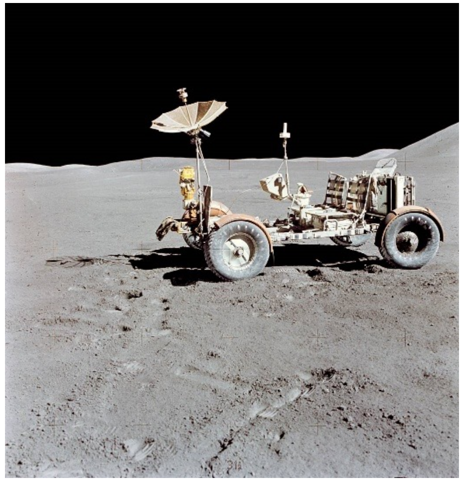
Dust Charging Effects

- Localized and global dust lofting activity
- Engineering requirements for Lunar surface, instrumentation and equipment operations
- Surface removal methods for gear, habitat, optical, and mechanical surfaces
- Dust shields/barriers in Lunar bases
- Prototyping aerosol coatings for instrumentation and spacecraft development
- Habitat air filtration
- Astronaut health effects
- Water-regolith separation
- Better understanding of insulative grains used in instrumentation
- Planetary formation, interstellar dust aggregation and other charged-induced dust processes
- Dust induced charge transport magnitudes and approximations

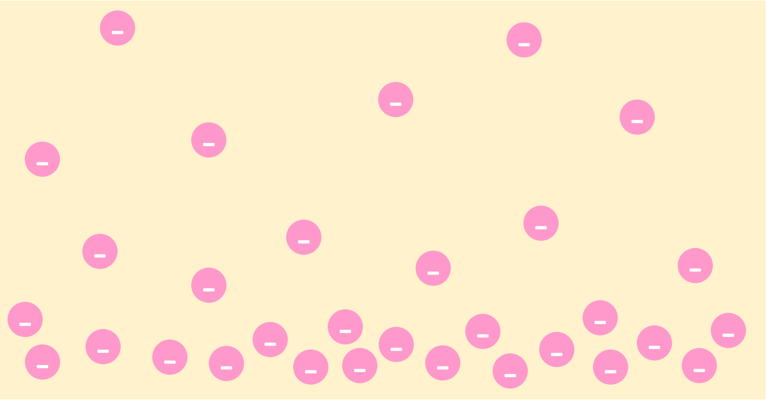
Launch of Spacehab, 1993 - Credit: NASA



Lunar Rover Vehicle on Apollo 15, 1971 - Credit: NASA

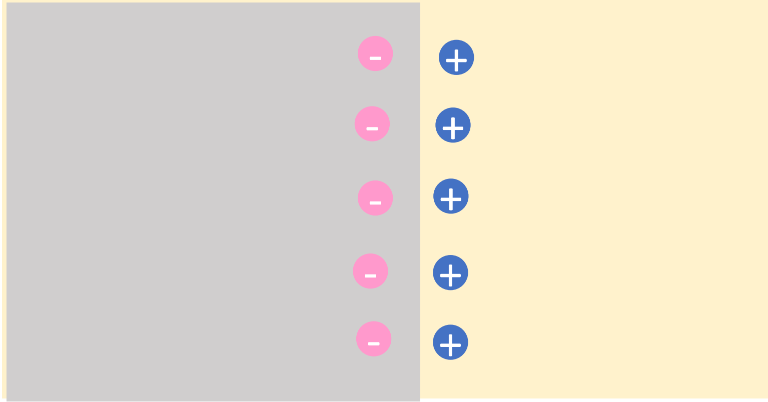
Relevance of Electron Yields to Dust Charging Effects

Levitation



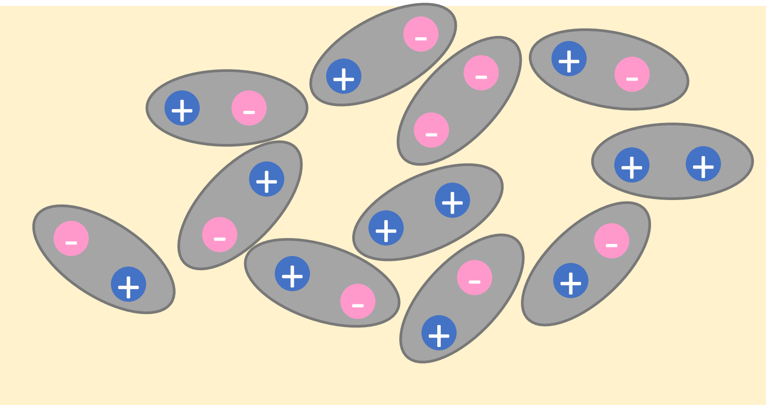
Charge Repulsion of Like Charges

Electrostatic Adhesion



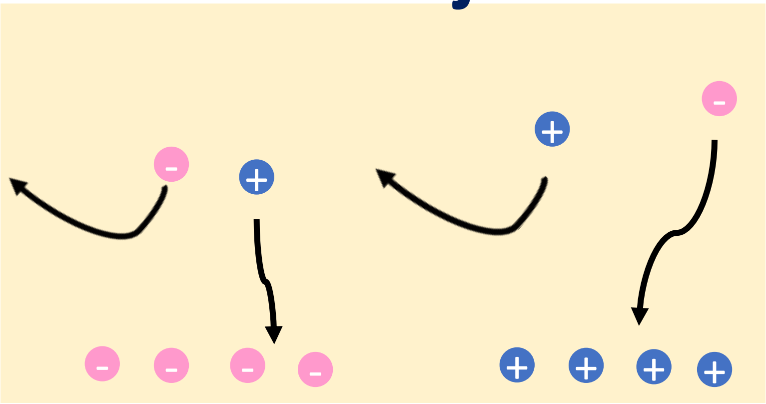
Charge Attraction of Opposite (or Mirror) Charges

Dust Agglomeration



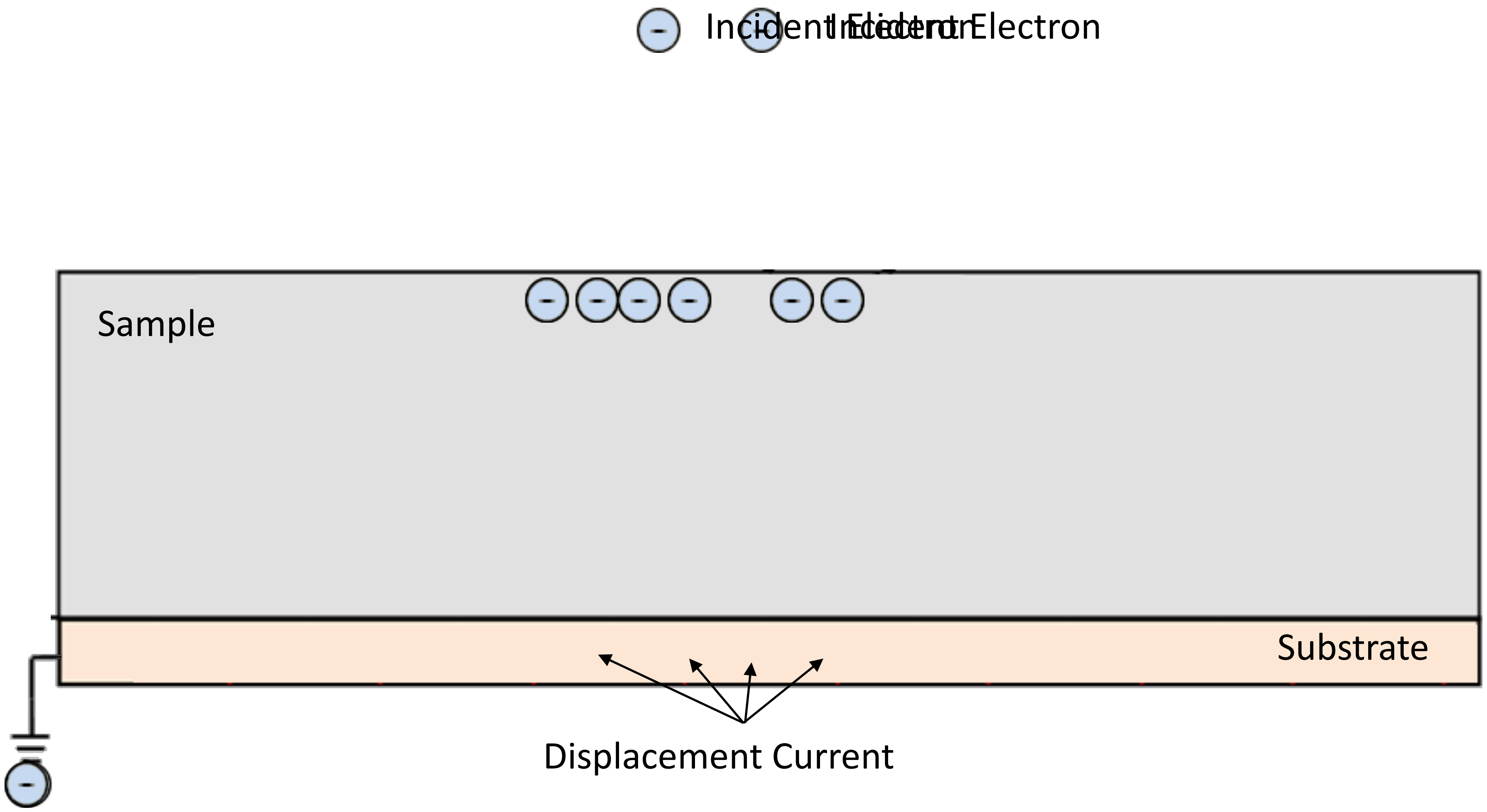
Alignment of Dipole Charges

Modified Trajectories



Charge Deflection

Electron Yields for Insulators



Yield Definitions

$$\textbf{Electron Yield} \equiv \frac{\#\text{ of } e^{-}\text{out}}{\#\text{ of } e^{-}\text{ in}}$$

TEY ≡ $\boldsymbol{\sigma}$ ≡ Total yield of all emitted e^{-}

BSEY ≡ $\boldsymbol{\eta}$ ≡ Backscattered yield of e^{-} reflected from sample surface

SEY ≡ $\delta \equiv \boldsymbol{\sigma} - \boldsymbol{\eta}$ ≡ Secondary yield of emitted e^{-} from inside of sample

Energies & Yields

Neutral e^{-} yield: $\delta_1(E_1) = \delta_2(E_2) \equiv 1$

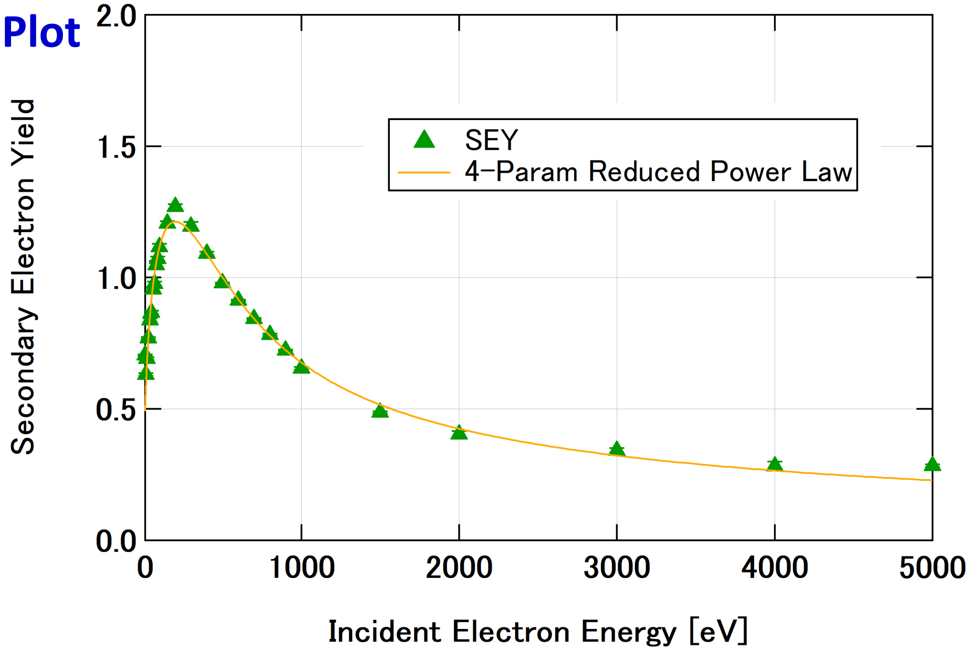
E_1 ≡ First crossover energy

E_2 ≡ Second crossover energy

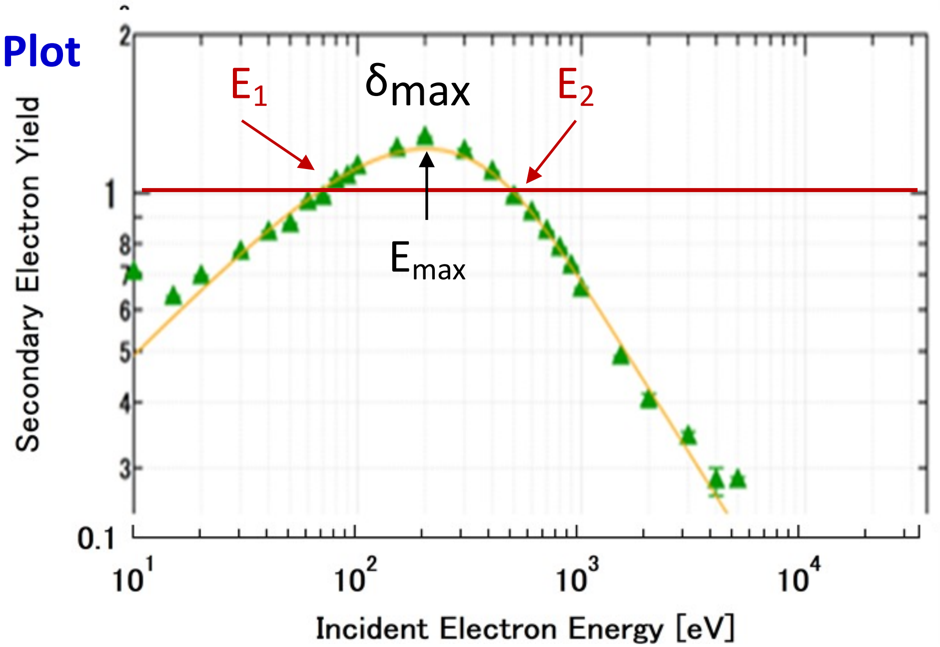
Maximum e^{-} yield: δ_{max}

E_{max} ≡ e^{-} energy at $\delta_{max}(E_{max})$

Linear Plot

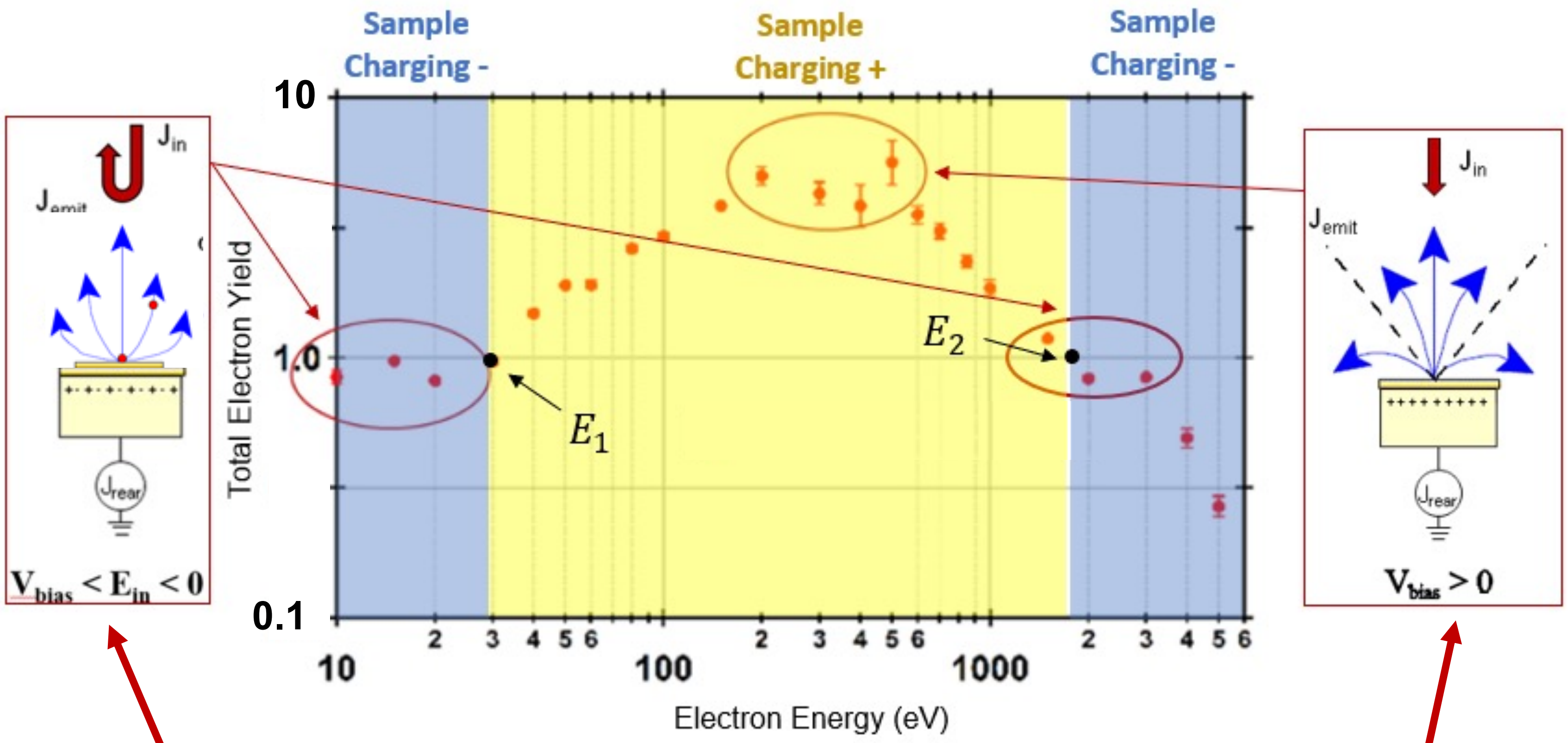


Log-log Plot



Yield curves of conducting HOPG graphite

Charging Effects



Negative charging suppresses TEY<1 through repulsion of incident electrons from negative surface

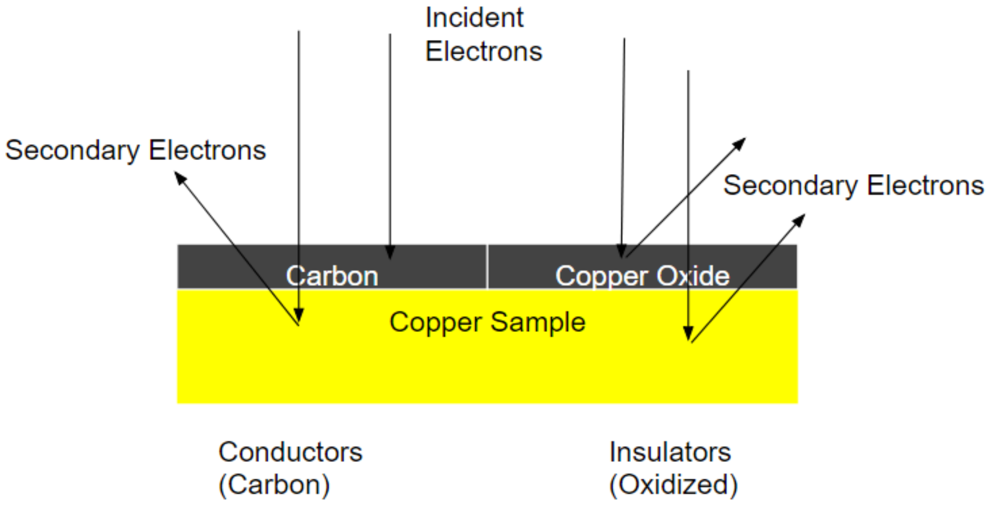
Positive charging suppresses TEY>1 through reattraction of low energy SEY to positive surface

Things Affecting EY

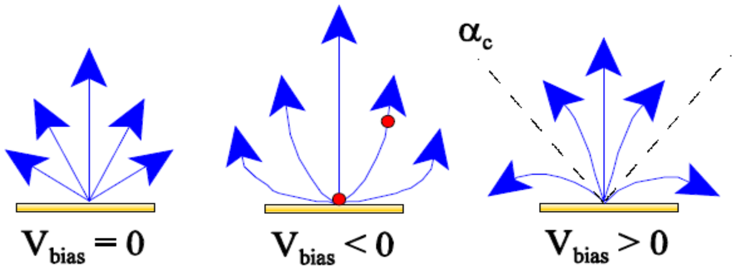
Incident Energy*	Incident Angle
Incident Species	Target Material
Charge*	Conductivity*
Coatings	Contamination*
Roughness*	Porosity* .

*Can change due to Environment Effects

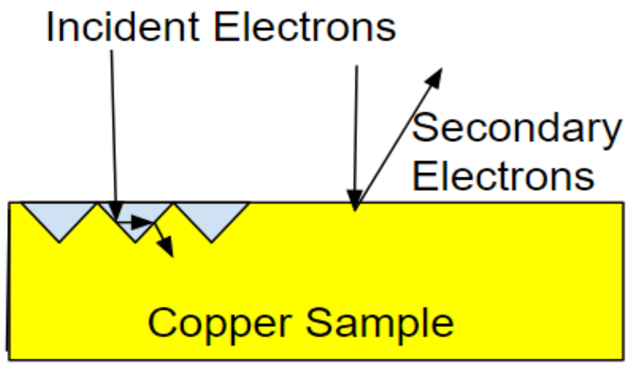
Contamination and Layers



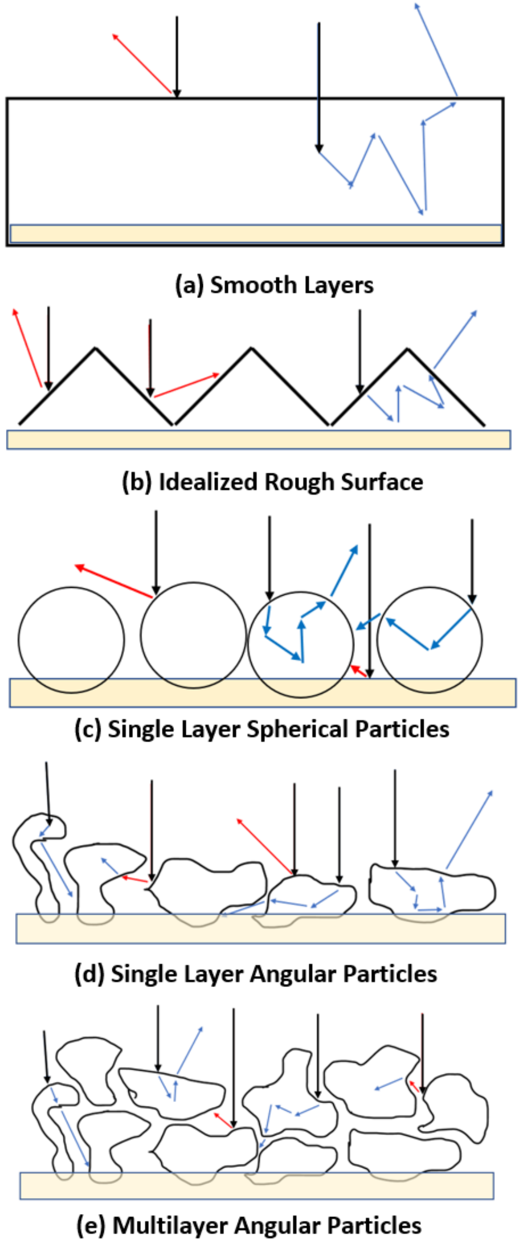
Charging



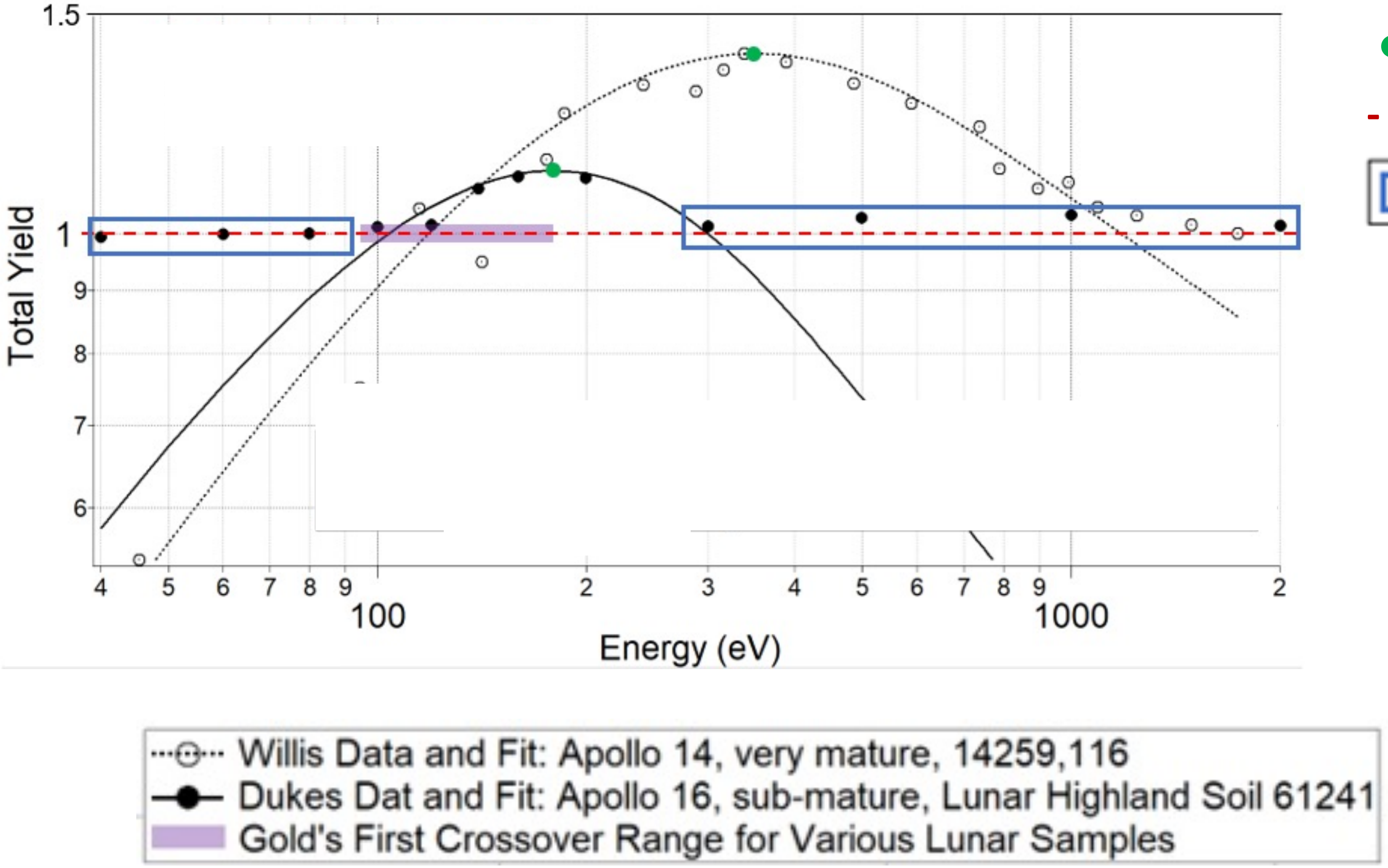
Surface Morphology



Roughness and Porosity



Review of Previous Lunar Dust EY Studies



● Peak Yield Points [E_m , $\delta_{max}(E_m)$]

- - - - Charging Limit

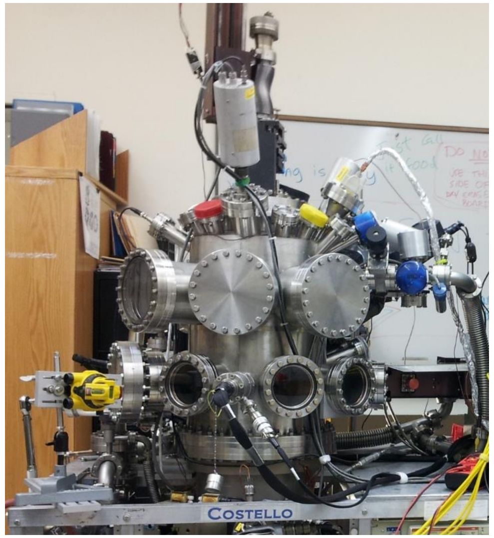
Charged Data

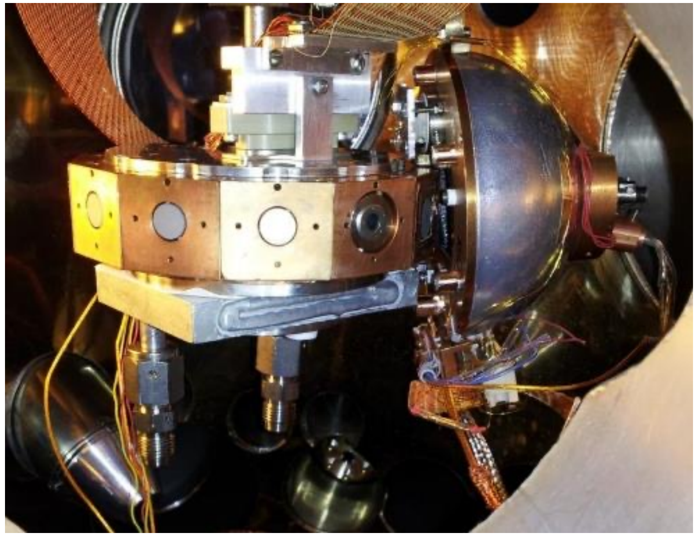
References

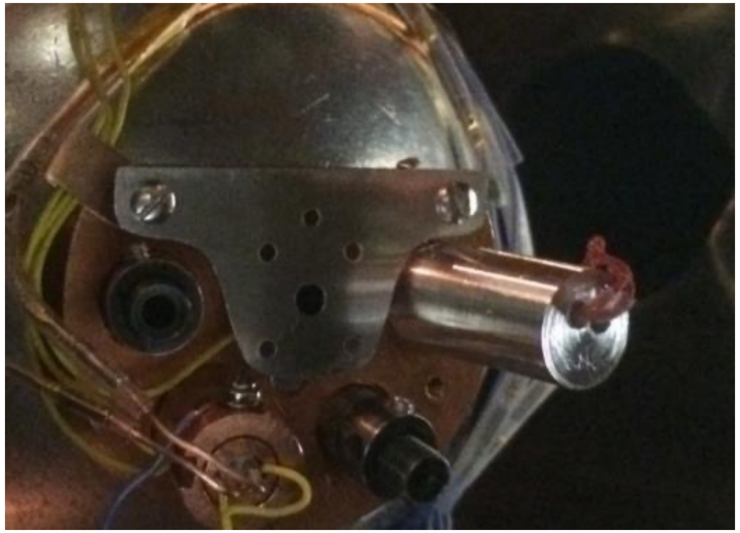
Anderegg, M., 1972;
Gold, T., 1979; Meyer C., 2010
Dukes, C., 2013

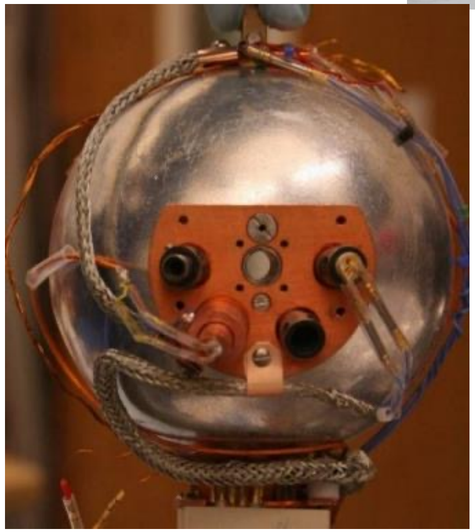
There are additional studies of beam-induced charging of individual grains: Abbas, 2010 and Horanyi, 1998

Hemispherical Grid Retarding Field Analyzer Electron Emission Detector







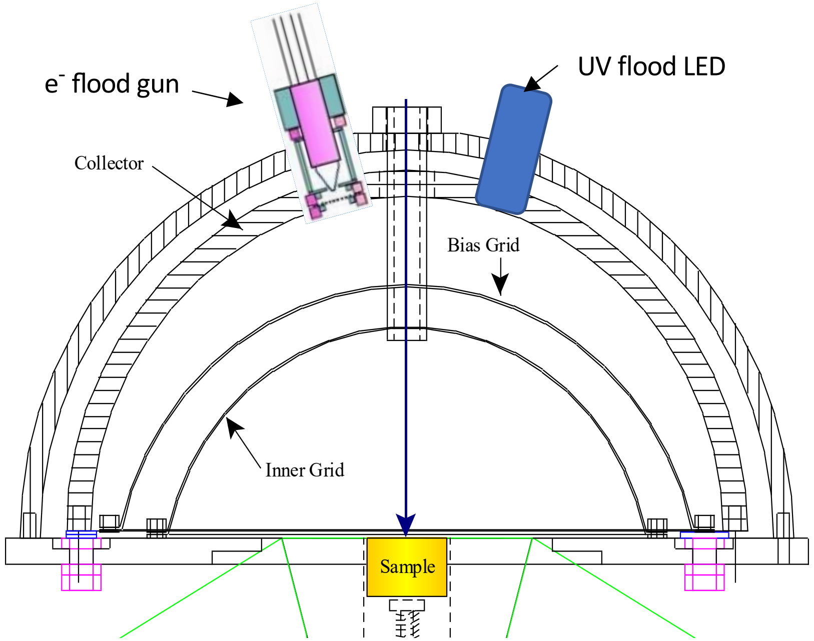


EY Instrumentation

- 10 eV to 80 keV incident electrons
- fully enclosed HGRFA for emission electron energy discrimination.
- Precision absolute yield by measuring all currents
  - ~1-2% accuracy with conductors
  - ~2-5% accuracy with insulators
- *in situ* absolute calibration
- multiple sample stage
- ~40 K < T < 400 K
- reduced S/N

Enhanced Low Fluence Methods for Insulator Yields

- low current (<1 nA-mm^{-2}), pulses (<4 μs) with <1000 e^{-}-mm^{-2}
- Point-wise yield method charge with <30 e^{-}-mm^{-2} per effective pulse
- neutralization with low energy (~6 eV) e^{-} and UV and VUV and thermal dissipation
- *in situ* surface voltage probe

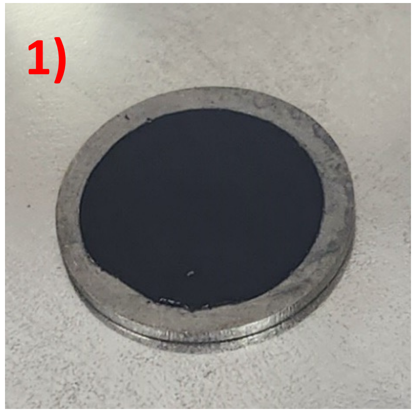


Granular Sample Preparation Methods

1. Prepared a conducting substrate* mounted on a stainless steel 14 mm diameter disc (Fig.1)
2. Placed disc underneath sieves
3. Fractions of the LHS-1# particle size distribution selected with sieves are deposited randomly on the adhesive substrate discs (Fig. 2)
4. Blew off loose dust between each level

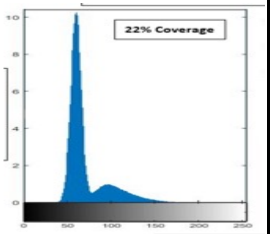
- **LHS-1 Sample 2:** All particles on substrate are placed randomly via sieves

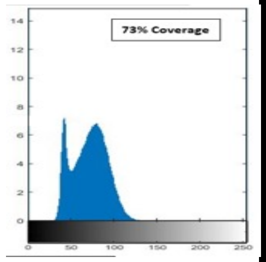
- **LHS-1 Sample 1:** Manually place largest sized particles >100 um in a grid pattern on substrate

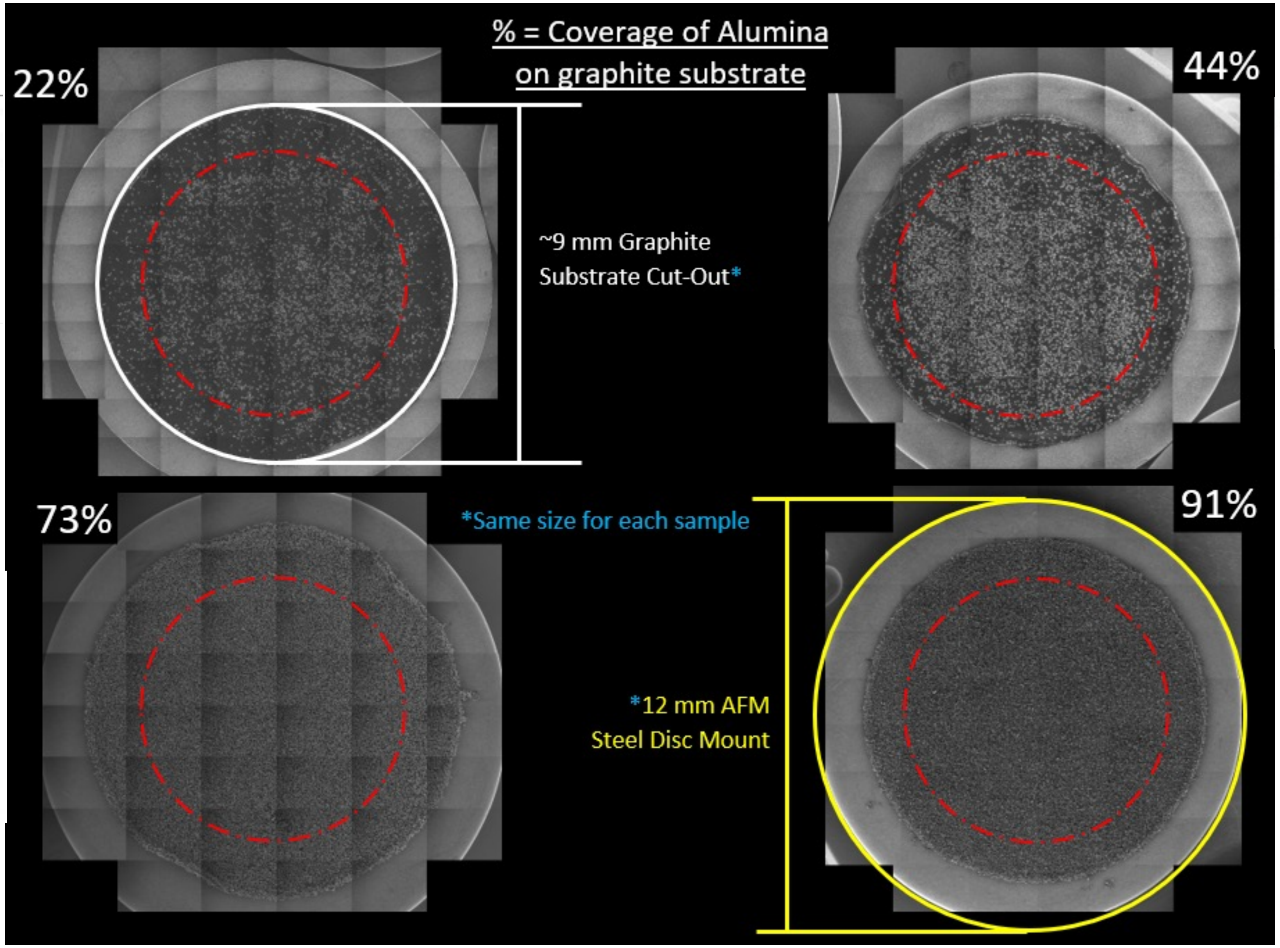


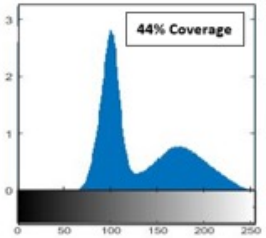
* *Ted Pella* SEM graphitic carbon mounting tape with adhesive and Al core
\# *Exolith Labs* Lunar Highland Simulant (LHS-1)

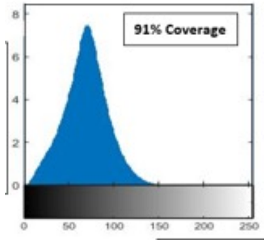
Coverages of Single Layer Al_2O_3 Grains

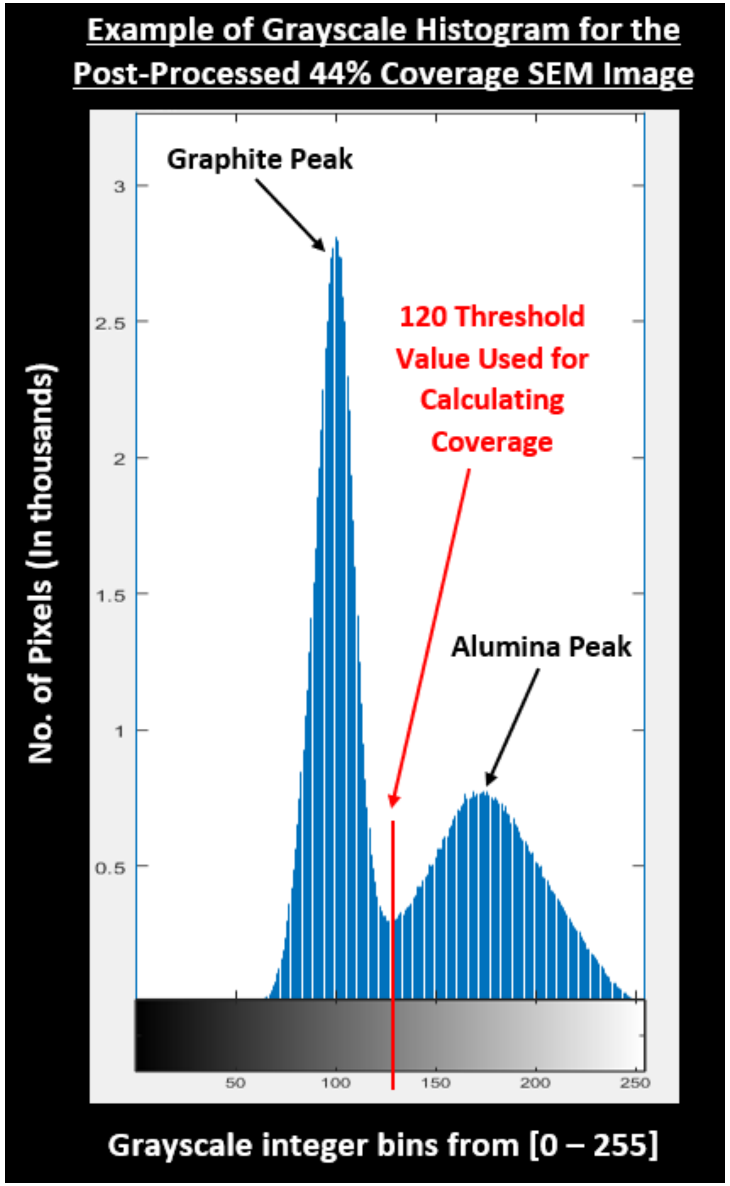






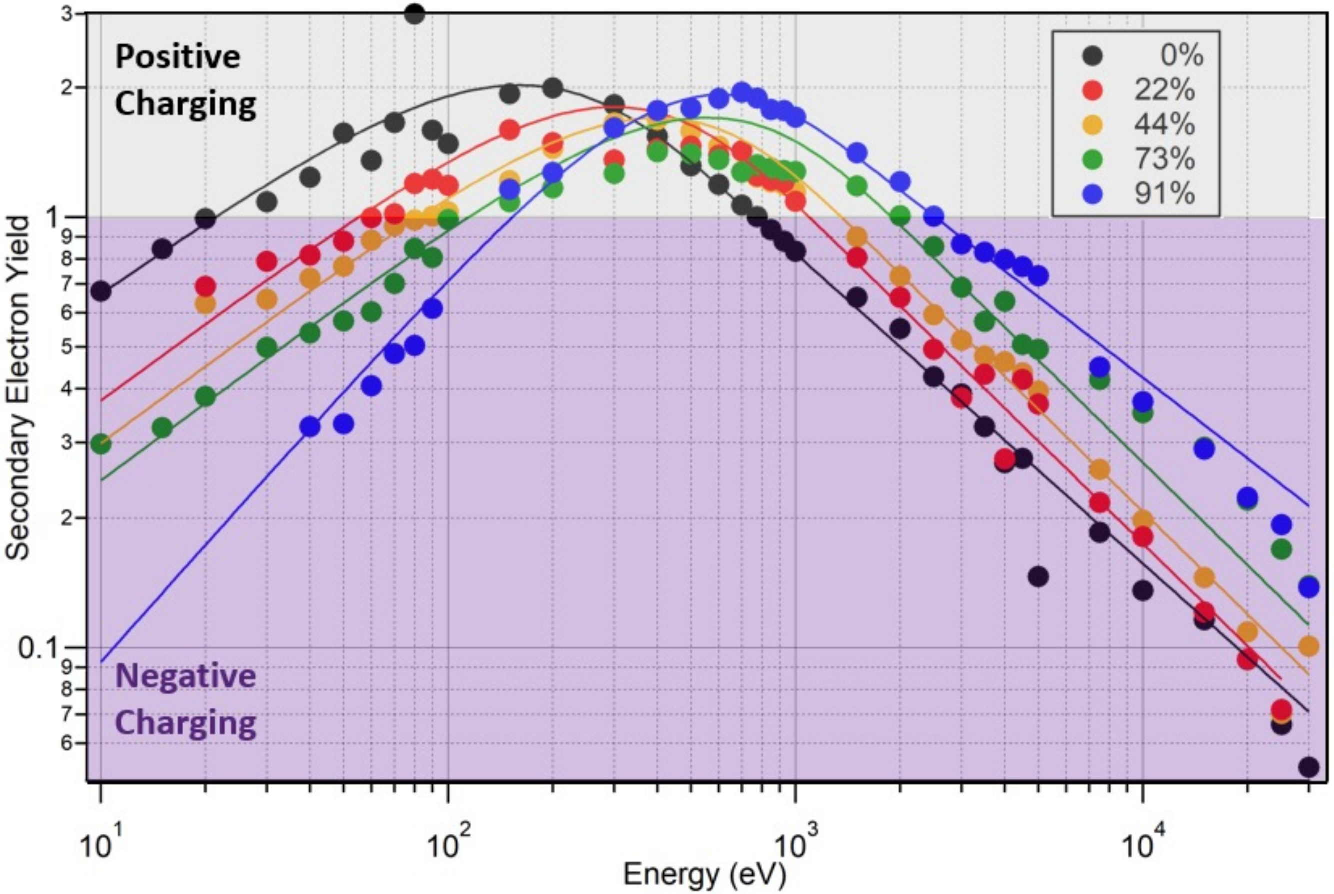


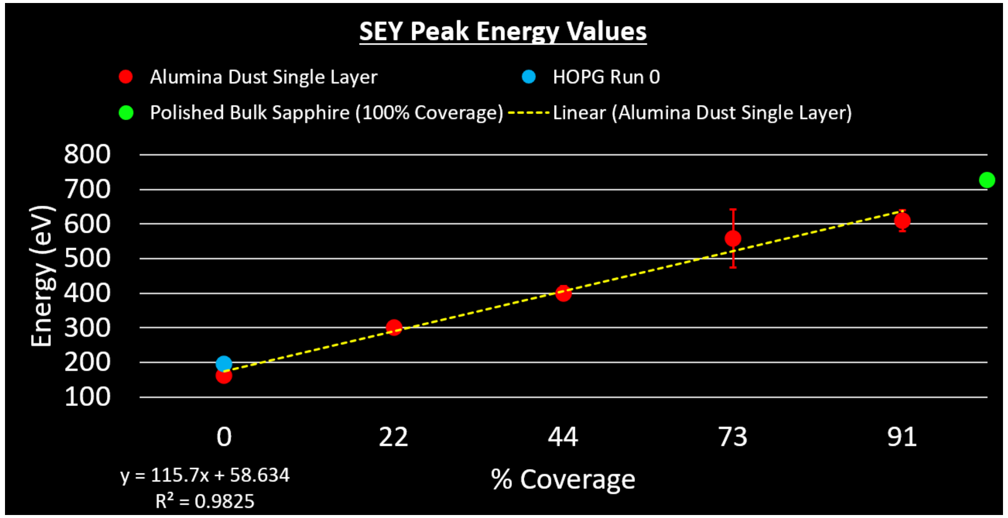


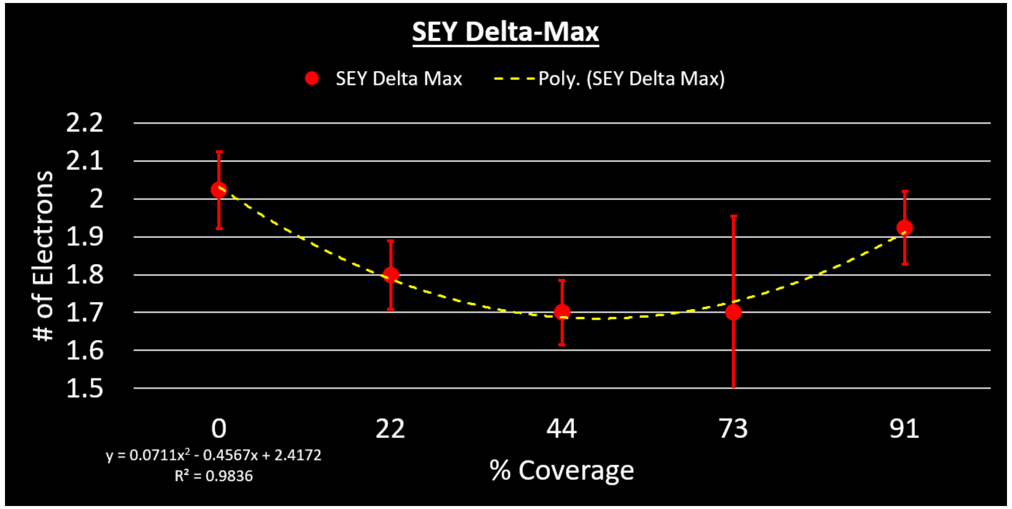


Secondary Electron Yield (SEY) Fits

SEY = TEY – BSEY







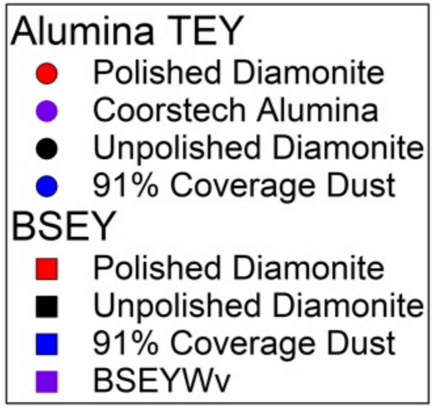
- E_{max} increases linearly from C to rough Al_2O_3 values
- δ_{max} depressed at intermediate coverages when E_{max} for a polished C and Al_2O_3 contributions are both present

Comparison of Different Alumina Types

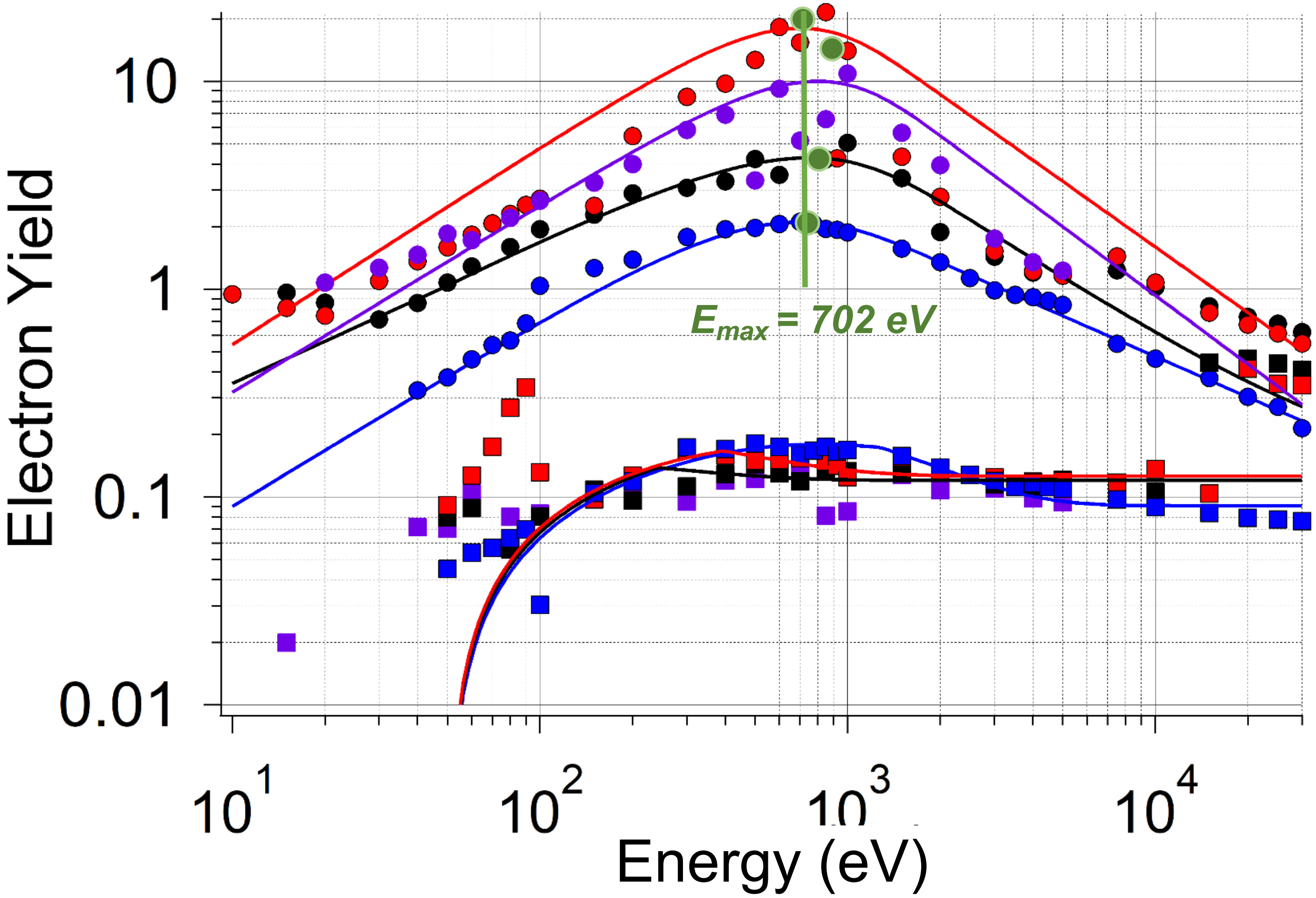
- ***Surface roughness greatly supresses δ_{max}, here by >9X***

- **Does not significantly affect E_{max}, *n* or *m***

- **BSEY largely unaffected by roughness**



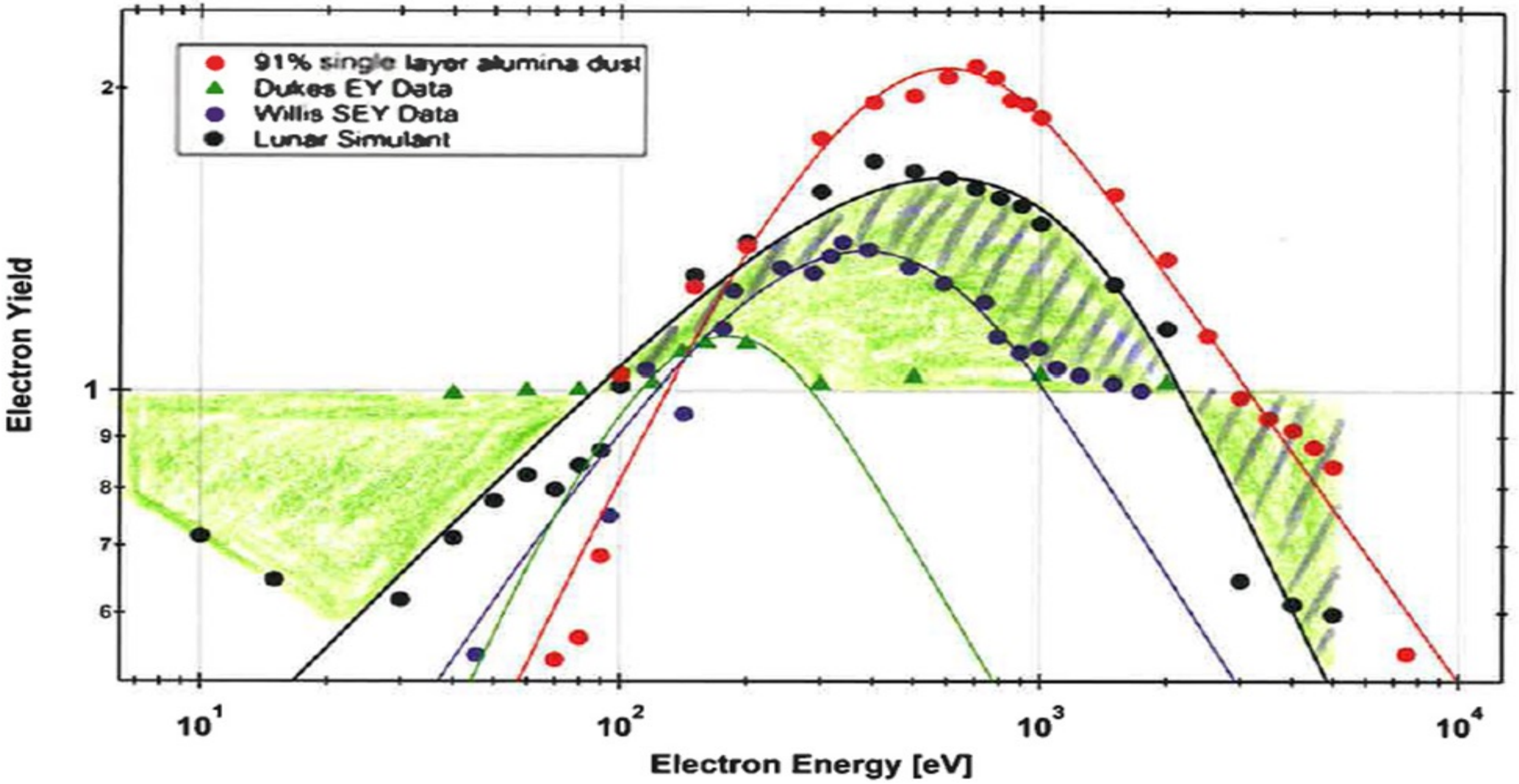
Al_2O_3 Materials	δ_{max}	E_1 (eV)	E_2 (eV)
Polished Diamonite	18	19	15000
Coorstech Alumina	10	36	9500
Unpolished Diamonite	4.2	47	5700
67 μm Al_2O_3 Dust	2.1	150	3000



Alumina and Lunar Simulant vs Lunar Dust Data

USU Data:

- Alumina dust and Lunar Simulant are similar, with much higher yields than previous lunar dust studies
- (δ_{max}-1) ~4X Willis and >20X Dukes and Gold
- Do not exhibit charging below E_1 and above E_2
- E_1 largely consistent among all studies
- E_2 increases 3X Willis and 10X Dukes
- E_{max} increases >2X Willis and >5X Dukes
- USU results predict much more + and – charging, with + charging over much broader energy range
- USU data is not for lunar dust (yet)!
- Green and purple dashed regions roughly illustrate the extent of charging for the Dukes and Willis studies



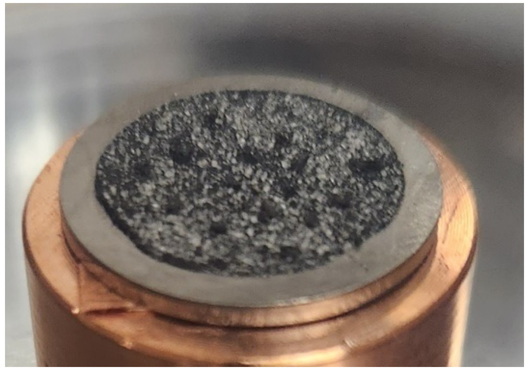
Dust Studies	δ_{max}	E_{max} (eV)	E_1 (eV)	E_2 (eV)
USU Al_2O_3 Dust	2.1	702	150	3000
USU LHS-1 Simulant	1.54	540	100	2550
Willis Lunar Dust	1.4	320	115	1100
Dukes Lunar Dust	1.1	185	97	290
Gold Lunar Dust	1.0	--	100-150	--

LHS-1 Lunar Simulant—Sample 1

Bulk Chemistry
Relative abundances.
Measured by XRF.

Oxide	Wt.%
SiO_2	51.2
TiO_2	0.6
Al_2O_3	26.6
FeO	2.7
MnO	0.1
MgO	1.6
CaO	12.8
Na_2O	2.9
K_2O	0.5
P_2O_5	0.1
LOI*	0.4
Total**	99.4

* Loss on ignition
** Excluding volatiles and trace elements



LHS-1 Sample 1

LHS1,90,G6,0 100x 15kV 0.08Torr

Gold Lunar Dust Sample: 10084 [Apollo 11]

% Weight	Compound
43	SiO2
16	FeO
13	Al2O3
~28	Other

Gold Lunar Dust Sample: 15005 [Apollo 15]

% Weight	Compound
N/A	SiO2
N/A	Al2O3
N/A	Other

Gold Lunar Dust Sample: 60009 [Apollo 16]

% Weight	Compound
46.4	SiO2
27.8	Al2O3
16.2	CaO

Gold Lunar Dust Sample: 61500 [Apollo 16]

% Weight	Compound
44.66	SiO2
26.5	Al2O3
15.33	CaO
~13.51	Other

Willis Lunar Dust Sample: 14259,116

% Weight	Compound
46.94	SiO2
17.31	Al2O3
11.06	CaO
~23.684	Other

Dukes Lunar Dust Sample: 61241

% Weight	Compound
45.32	SiO2
27.15	Al2O3
15.69	CaO
~12.57	Other

LHS-1 Dust:

% Weight	Compound
51.2	SiO2
26.6	Al2O3
12.8	CaO
~8.9	Other

Anderegg, M., 1972;
Gold, T., 1979; Meyer C., 2010
Dukes, C., 2013;

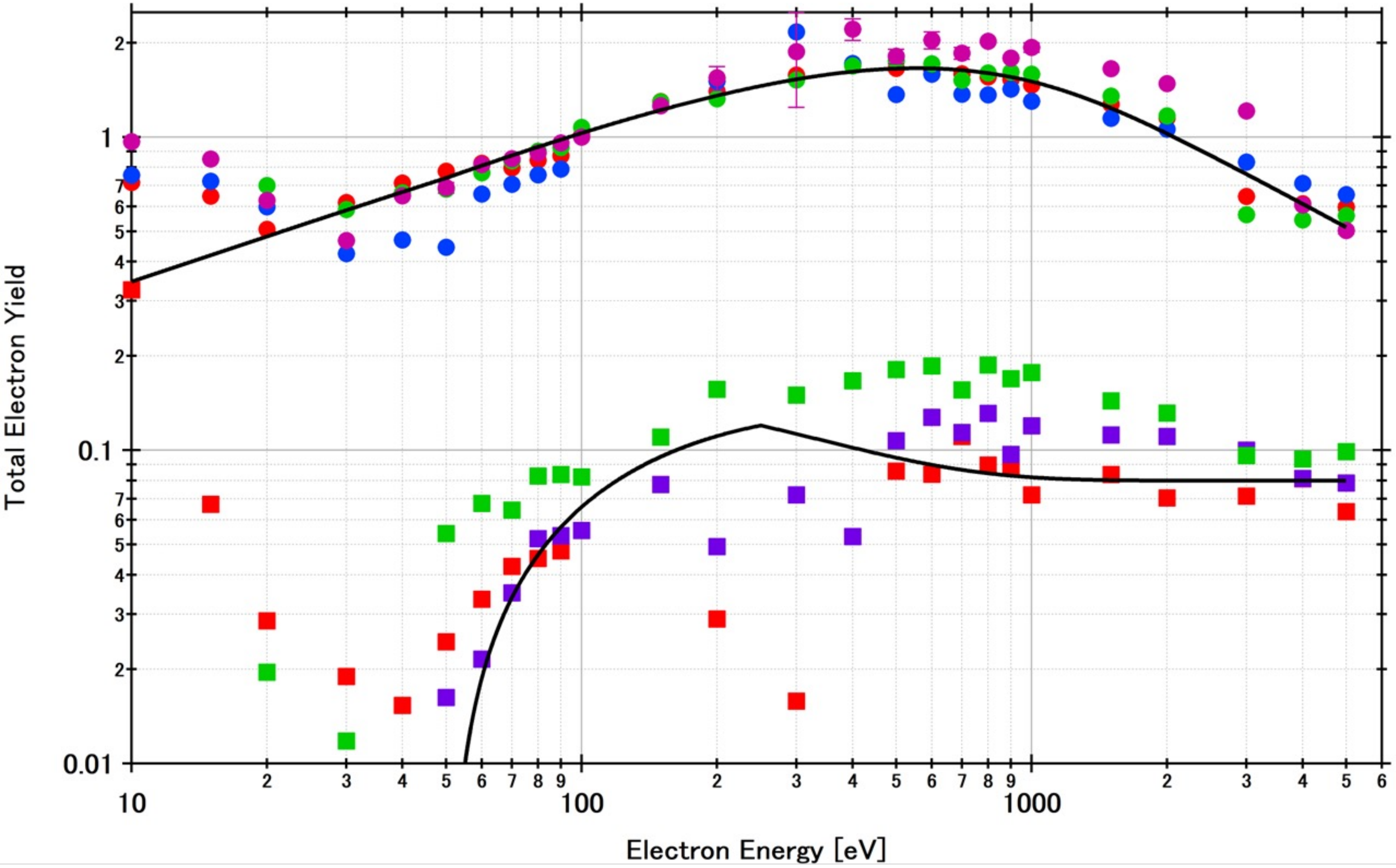
Lunar Simulant Yield Data

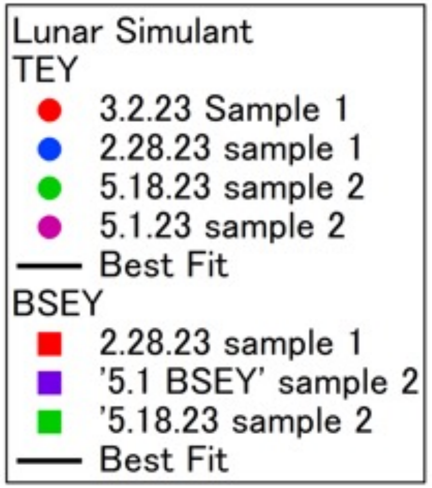
- Comparison of EY curves for two LHS-1 samples, both measured twice.
- Sample 1 has more particulates >100 µm
- TEY/SEY/BSEY all agree within small uncertainties.

Single fits are shown for TEY and BSEY:

δ_{max} = 1.58 ± 0.3 E^{δ}_{max} = 540 ± 40 eV
n = 1.264 ± 0.07 m = 0.515 ± 0.05
E^{σ}_{1} = 100 ± 10 eV E^{σ}_{2} = 2250 ± 200 eV

η_{peak} = 0.12 ± 0.3 E_{peak} = 250 ± 50 eV
η_{0} = 0.08 ± 0.2





Lunar Simulant Yield Decay Curve

DAP-2023

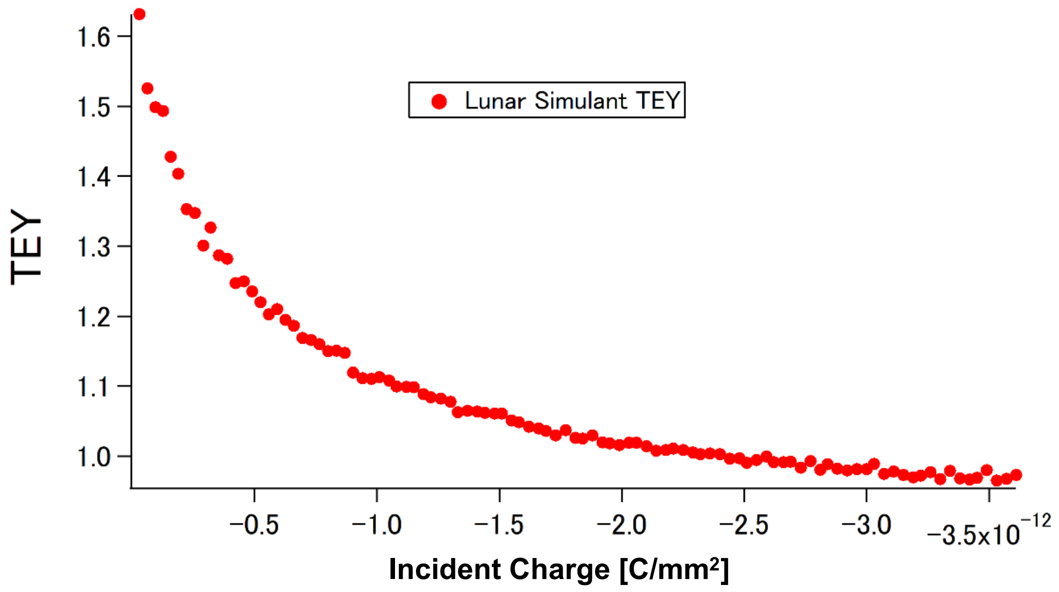
Yield Decay Curve show the evolution of TEY with successive charge pulses without intervening charge dissipation

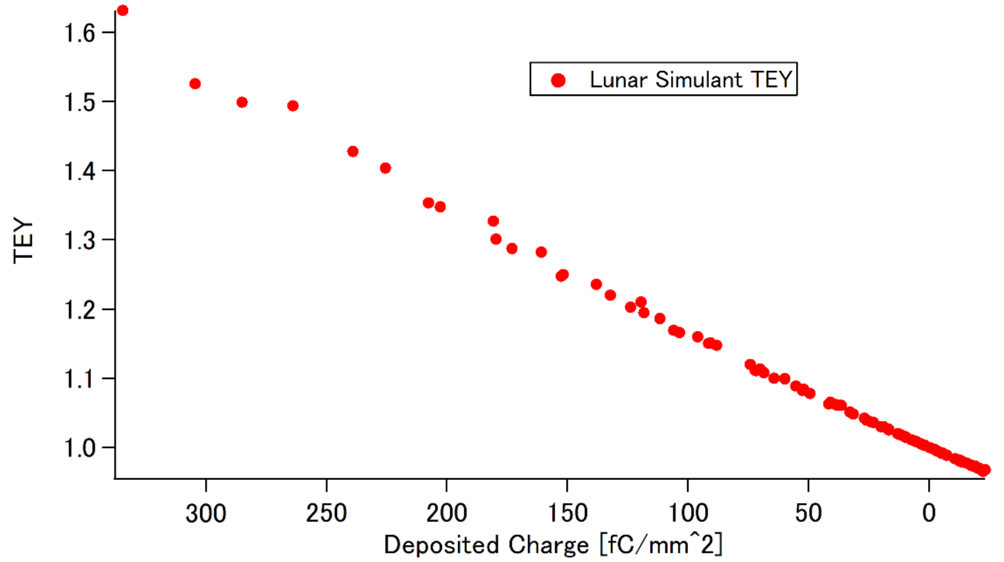
Plot shows 100 pulse sequence with ~3.6 pC/mm^2 (~$2 \cdot 10^7$ e$^-$ / mm^2)

Charge density per pulse:

- **USU: ~40 fC/mm^2-pulse (~$3 \cdot 10^5$ e$^-$ / mm^2)**
- ***Willis: >1 µA continuous beam**
- ***Gold: >1 µA continuous beam**
- ***Dukes: >10 µC/mm^2-pulse (~30MX USU)**

* No charge dissipation between pulses





Key Takeaways

- EY dust data are critical for myriad theory, simulations and engineering applications for lunar surface activities
- Previous EY measurements were significantly affected by charging, layering, angularity, roughness and porosity
- USU granular sample preparation methods developed and validated
- Accurate and precise EY data for highly-insulating, angular, rough, porous, homogeneous Al_2O_3 granular and inhomogeneous LHS-1 lunar simulant samples at USU
- TEY/BSEY/SEY results consistent with models for materials, roughness, and coverage
- Need to extend studies to include:
  - More homogeneous SiO_2 and Al_2O_3 granular data for additional particle sizes, shapes, and coverages
  - Multilayer porous dust samples
  - Other types of simulants
- **Clearly demonstrates we are able to acquire high quality electron yield and charge decay curves of lunar dust samples**

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