Surface Chemical and Photo-Physical Analysis Of Alkali Antimonide Photocathodes

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EWPAA

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Conclusions
(From Daniele's Talk)

- Surface science tecniques essential in understanding the cathode properties
- Once the growth process is stable and reproducible, it might be moved to the production
- Continous improvements during the cathode production are essential to guarantee reliable photocathode properties.
- Important is the interplay between cathode improvement and gun development

MOTIVATION FOR PHOTOCATHODE R&D

Photoinjectors for new accelerators require

High brightness	Determined by	Cathode's intrinsic emittance Cathode's QE (and launch gradient)
High average current	Feasible if	Cathode has high QE (and c.w. operation possible)

HIGH-CURRENT PHOTOINJECTORS

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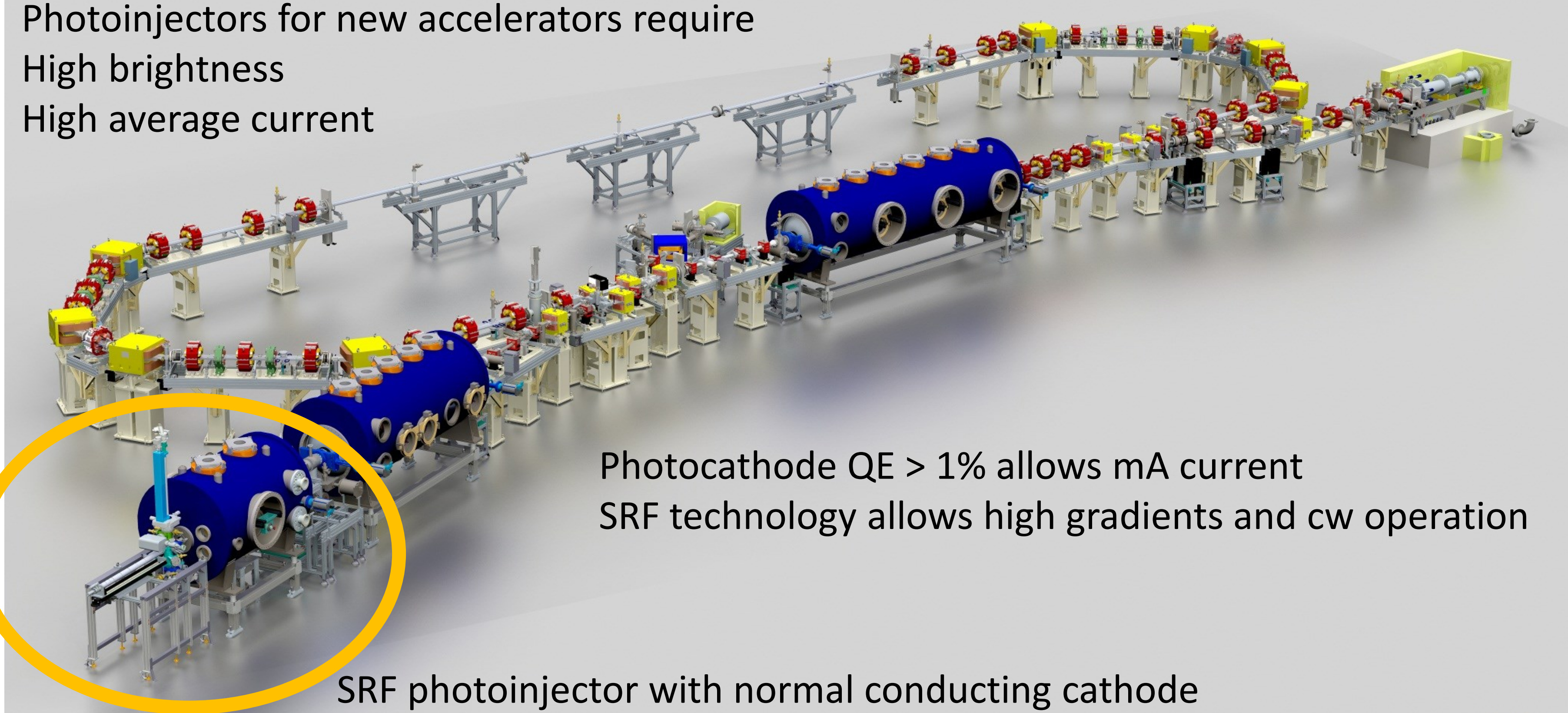
Photoinjectors for new accelerators require
High brightness
High average current



Photocathode QE > 1% allows mA current
SRF technology allows high gradients and cw operation

SRF photoinjector with normal conducting cathode
Photocathode exchange system

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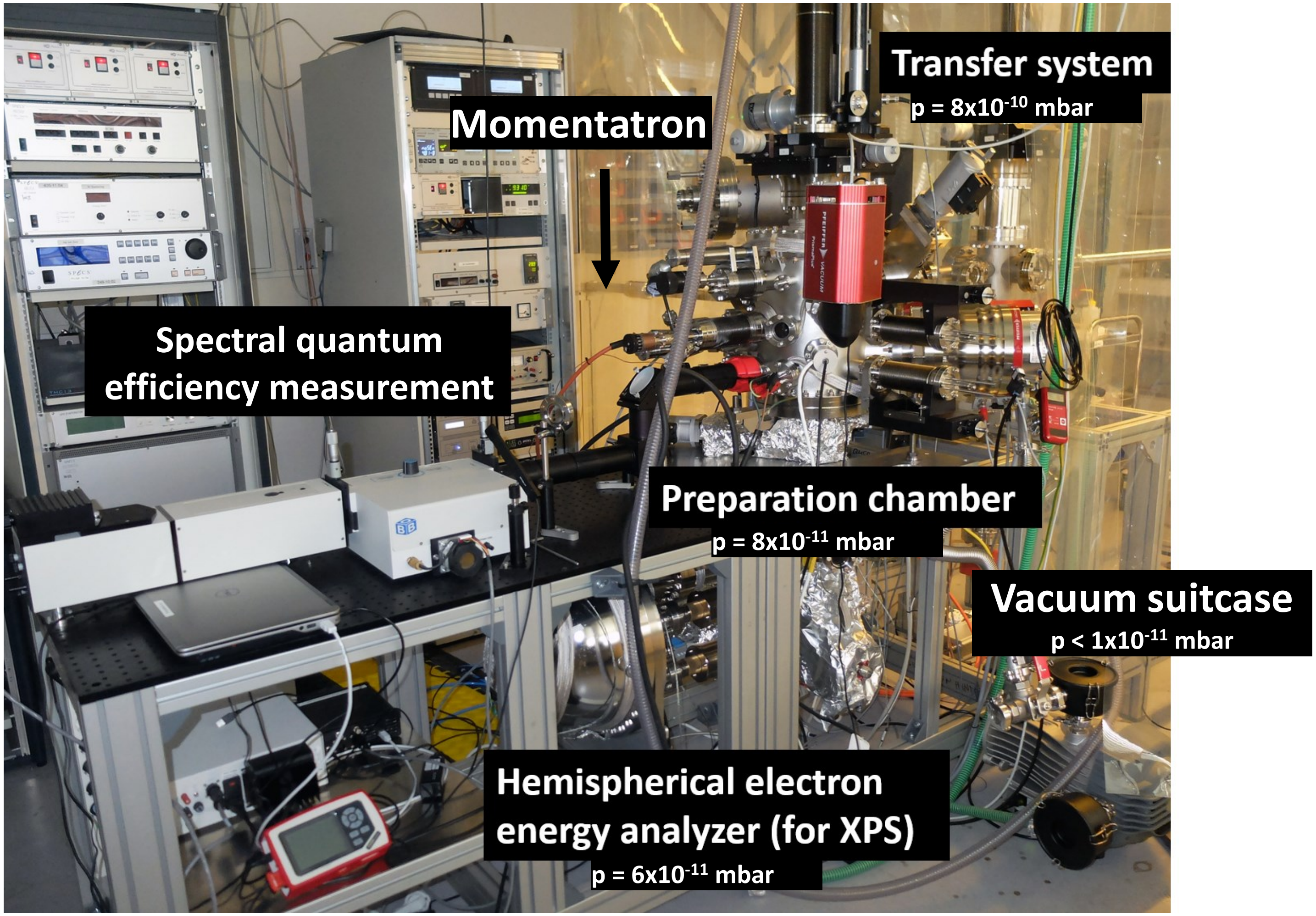
XPS measurements

- Lessons learned from XPS (and mass spectrometry)
- Path from sequential growth to Alkali co-deposistion

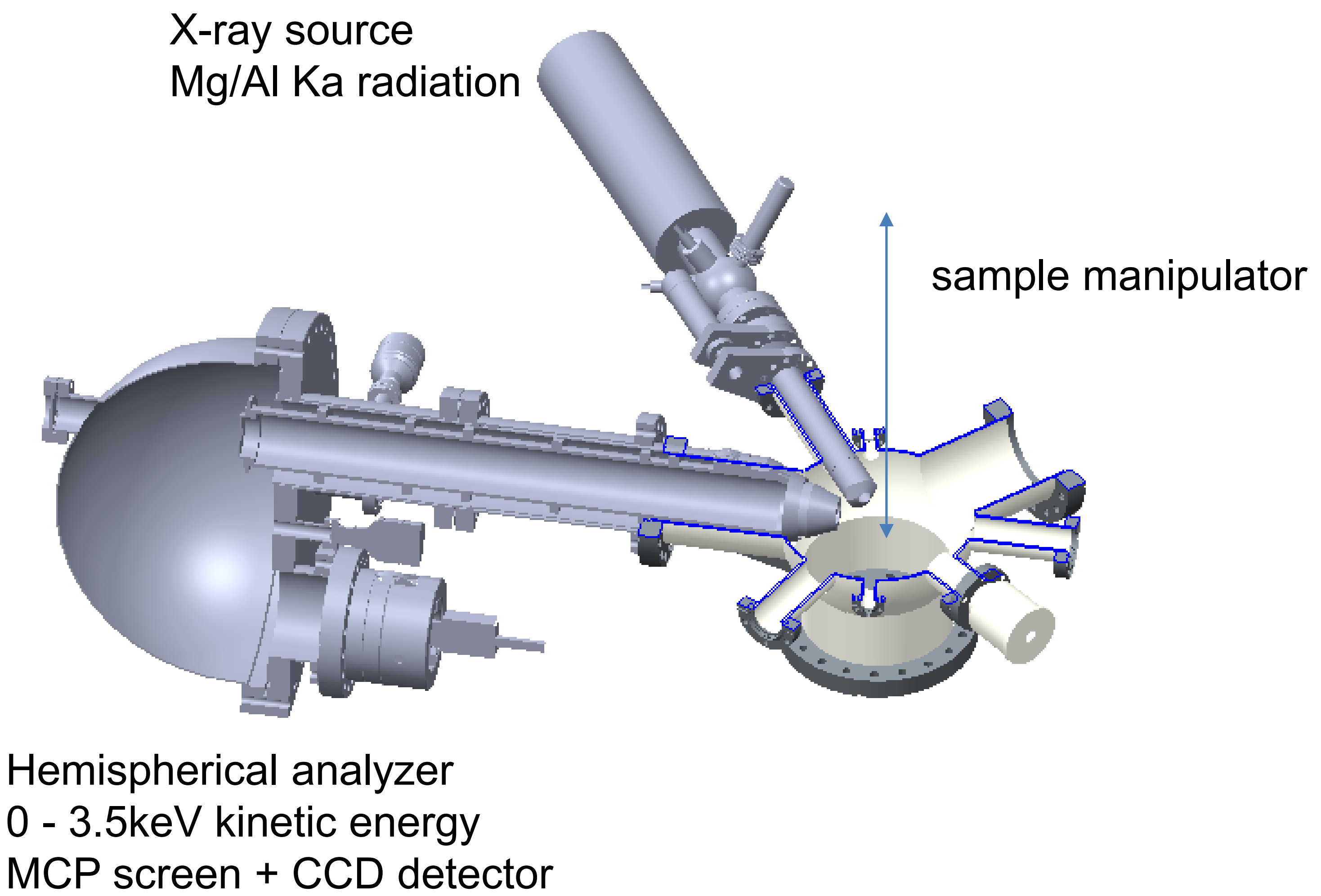
Spectral response measurements

Intrinsic emittance

PHOTOCATHODE LAB



XPS SYSTEM

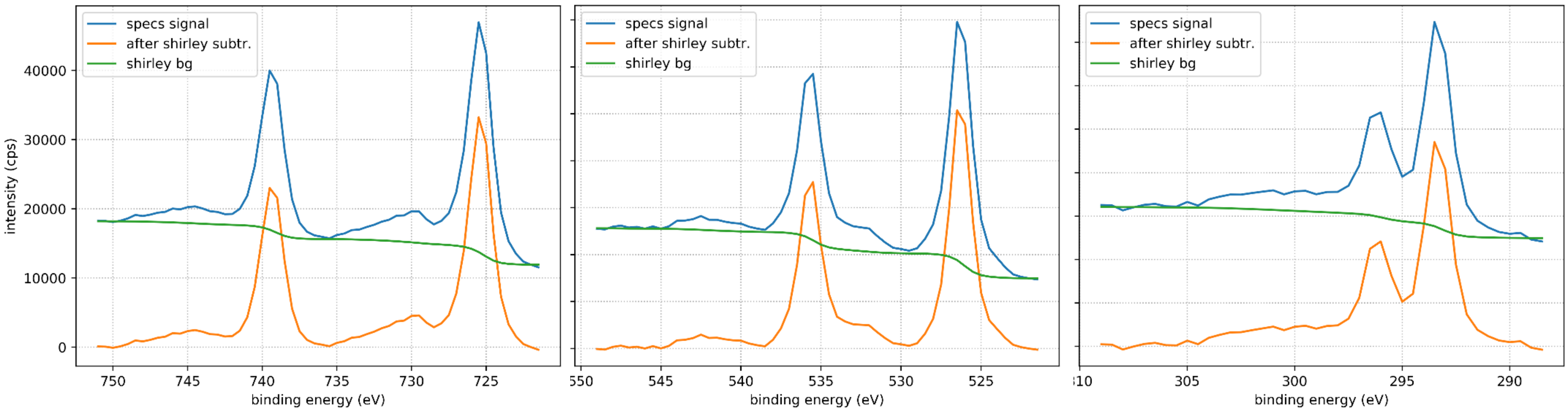


X-ray source
Mg/Al Ka radiation
sample manipulator
Hemispherical analyzer
0 - 3.5keV kinetic energy
MCP screen + CCD detector

XPS - QUANTIFICATION

Surface stoichiometry of the sample

- Signal of a Peak proportional to atomic concentration * cross section * IMFP
- Signal = Area under Peak after Shirley subtraction



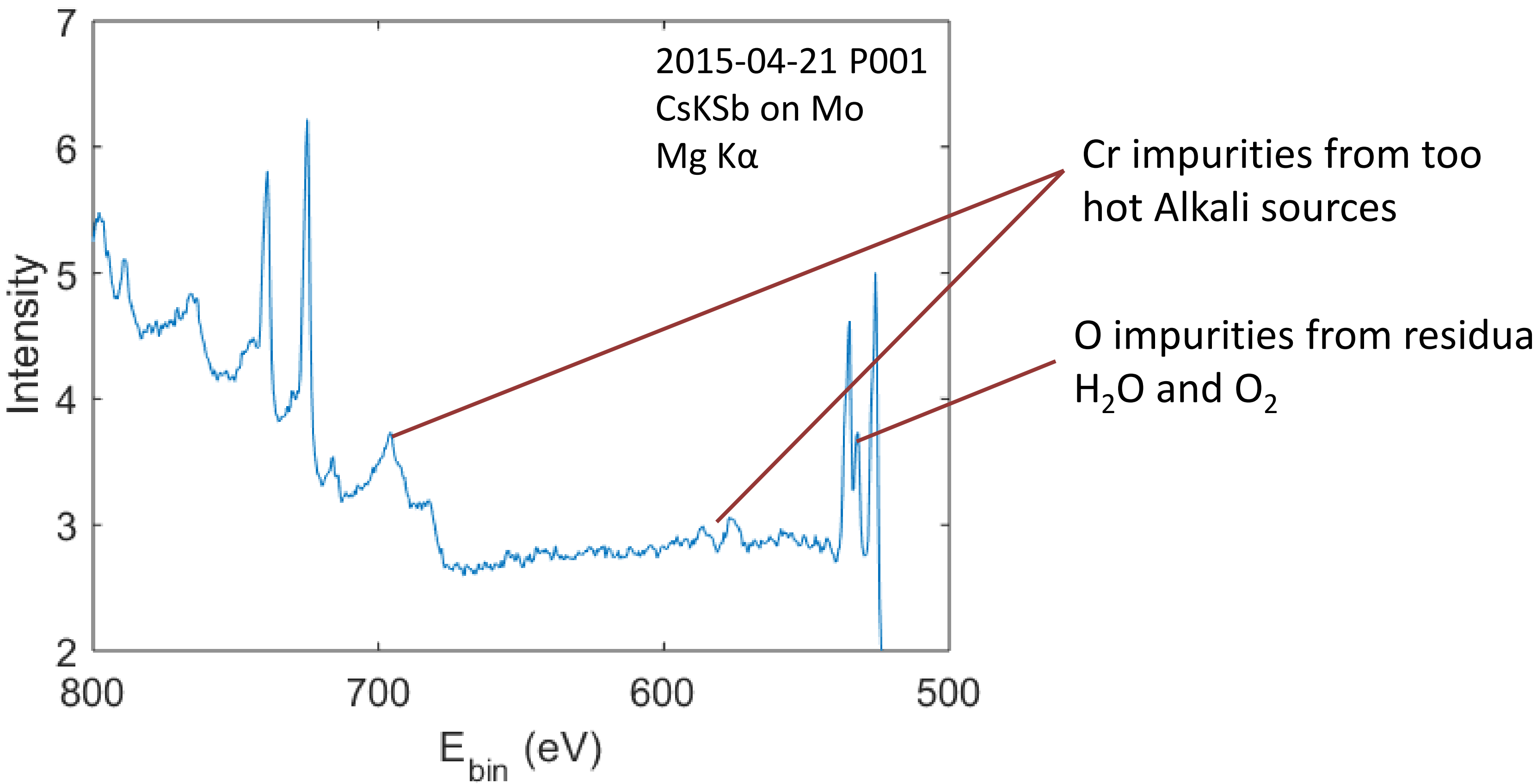
Cross section from Scofield

IMFP from SESSA (formula by Tanuma, Powell, Penn)

	area	area/(IMFP+CS)		
K 2p	30617.41	187.38		
Cs 3d	152060.48	130.46		
Sb 3d	99373.15	103.43		
Cs K Sb : 0.310	0.445	0.246	relative peak intensities	
Cs K Sb : 1.261	**1.812**	**1.000**	**stoichiometry**	

Scofield, Journal Electron Spectroscopy and Related Phenomena, 8, 129-137 (1976) .
Tanuma, Powell, Penn, Surf. Interf. Analysis, 21, 165 (1994).

BENEFIT FROM MATERIALS SCIENCE APPROACH



XPS allows quick assessment of chemical composition, quantification.

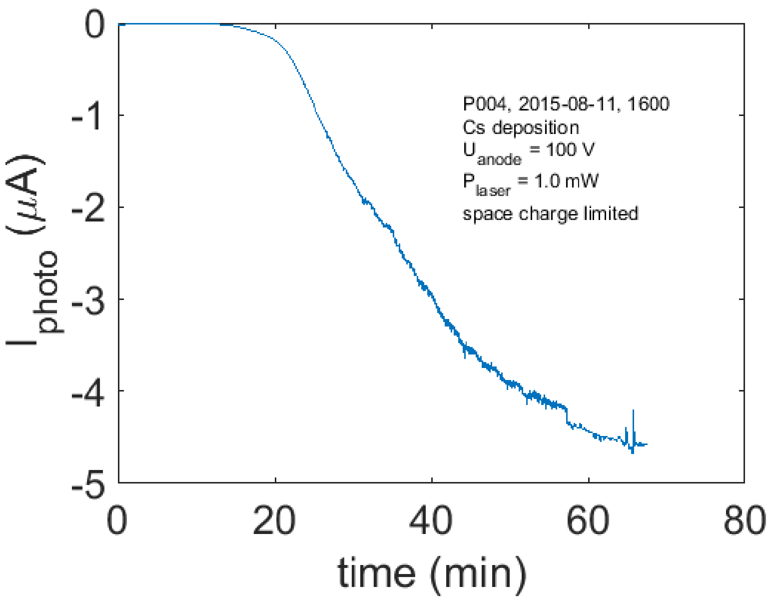
Thus teaches us to work accurately and carefully.

BENEFIT FROM MATERIALS SCIENCE APPROACH

Results P004 :

- Polished Mo substrate
- 10 nm Sb film evaporated at 100°C
- Surface composition KSb after K deposition
- zero QE for green light, small QE for daylight

- Surface composition Cs_2KSb after Cs deposition
- **~5% QE**
- 3.8% and 3.6% QE after 1 and 2 days



Results P005 :

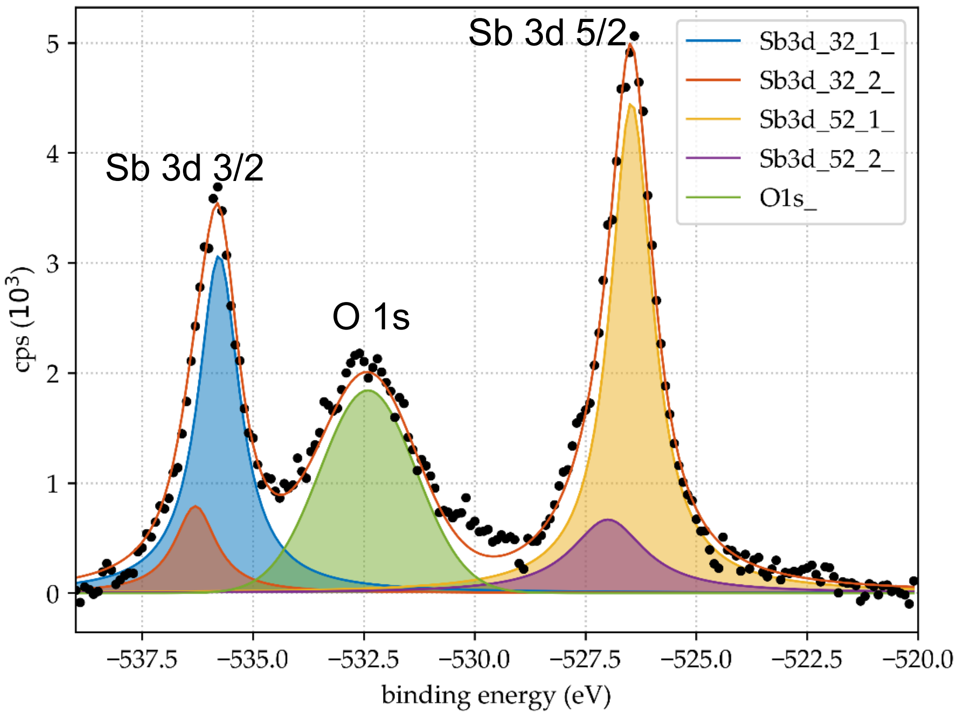
- < 10nm Sb film evaporated at 100°C
- $K_{2.4}Sb$ surface composition after K deposition, strong Oxygen impurities
- K rich composition after Cs deposition, strong Oxygen impurities
- 0.175% QE

BENEFIT FROM MATERIALS SCIENCE APPROACH

The difference between a good and a bad cathode :

- Same substrate, same cleaning, low contaminations confirmed by XPS
- Same sequential growth procedure, same type of sources

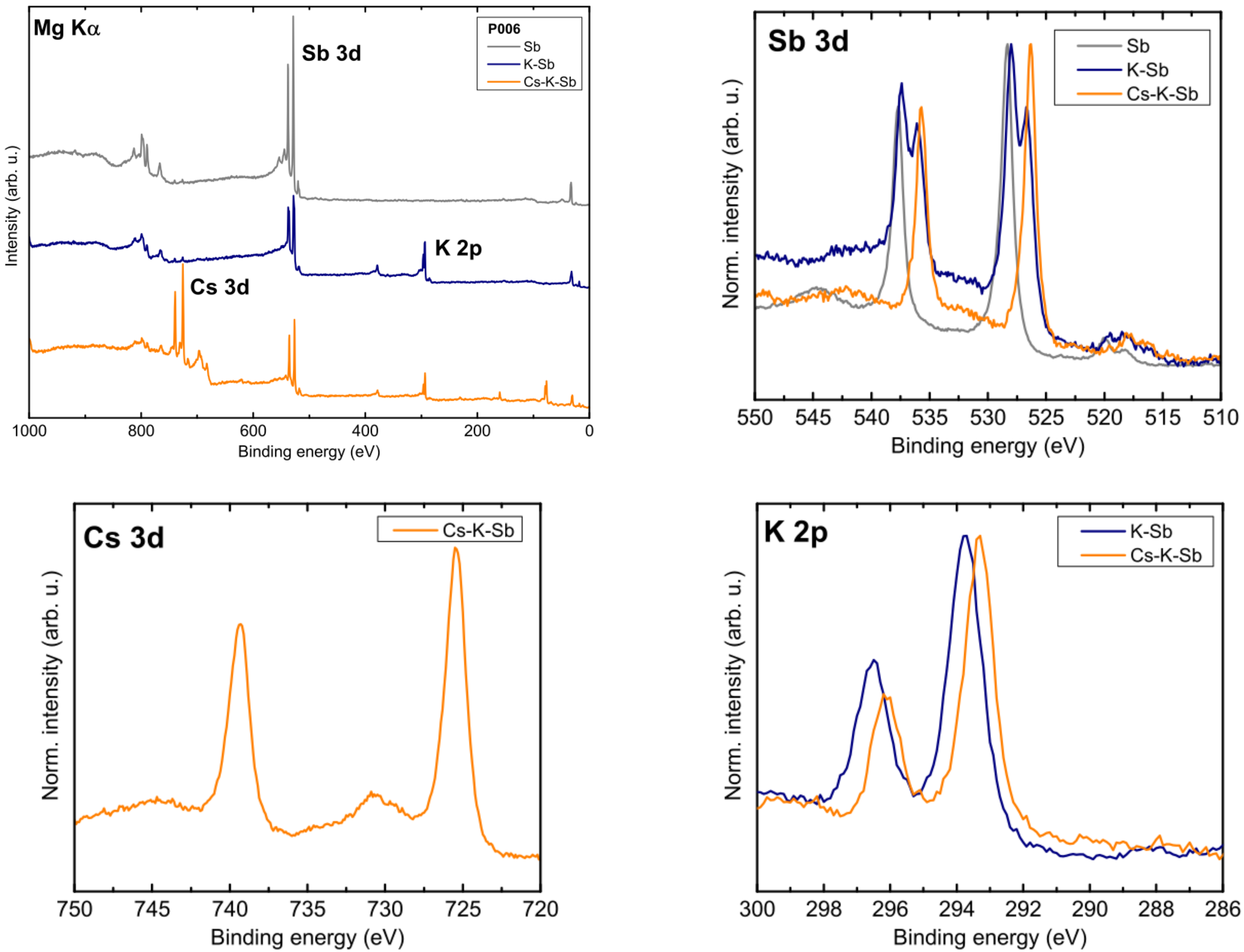
- P005 Sb layer not as thick
- Water and Oxygen partial pressure worse by 10^2



Strong degasing of K source due to first use
→ Need to degas at higher temperatures

Control over vacuum conditions is essential.
Mass spectrometer allows to ensure low residual gas pressures.

BENEFIT FROM MATERIALS SCIENCE APPROACH



ALKALI CO-DEPOSITION PROCESS

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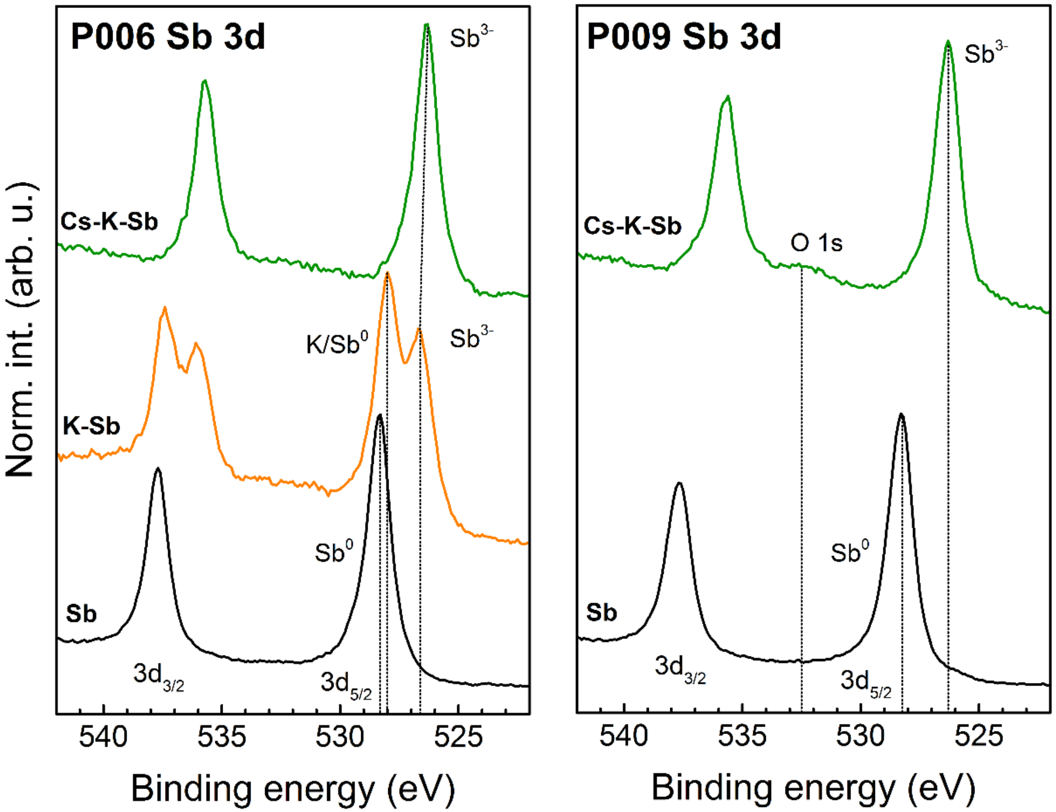
- Conventional process (sequential growth of Sb, K, Cs) leads to good results when K-Sb material has only partially reacted
- Alkali co-deposition (K+Cs on Sb) yields good sample performance and is easier to reproduce



RECENT RESULTS (P013)

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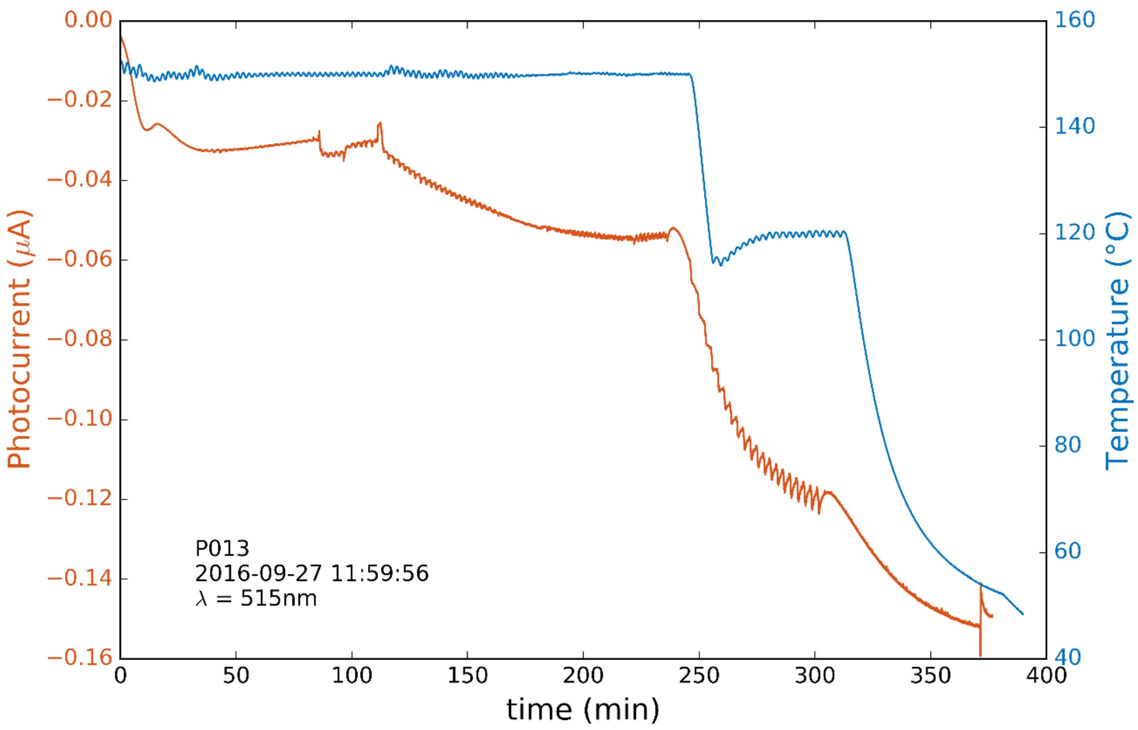
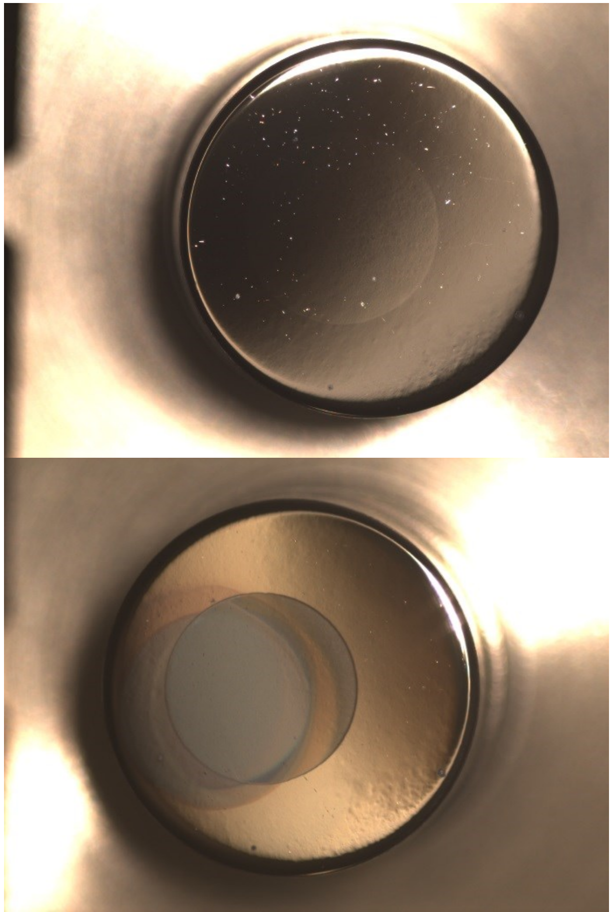
Photocathode P013 grown on a Mo substrate:
30nm Sb deposition at 150°C
K + Cs co-deposition at 150°C, reduce to 120° after 250min, finally let cool





XPS measurements

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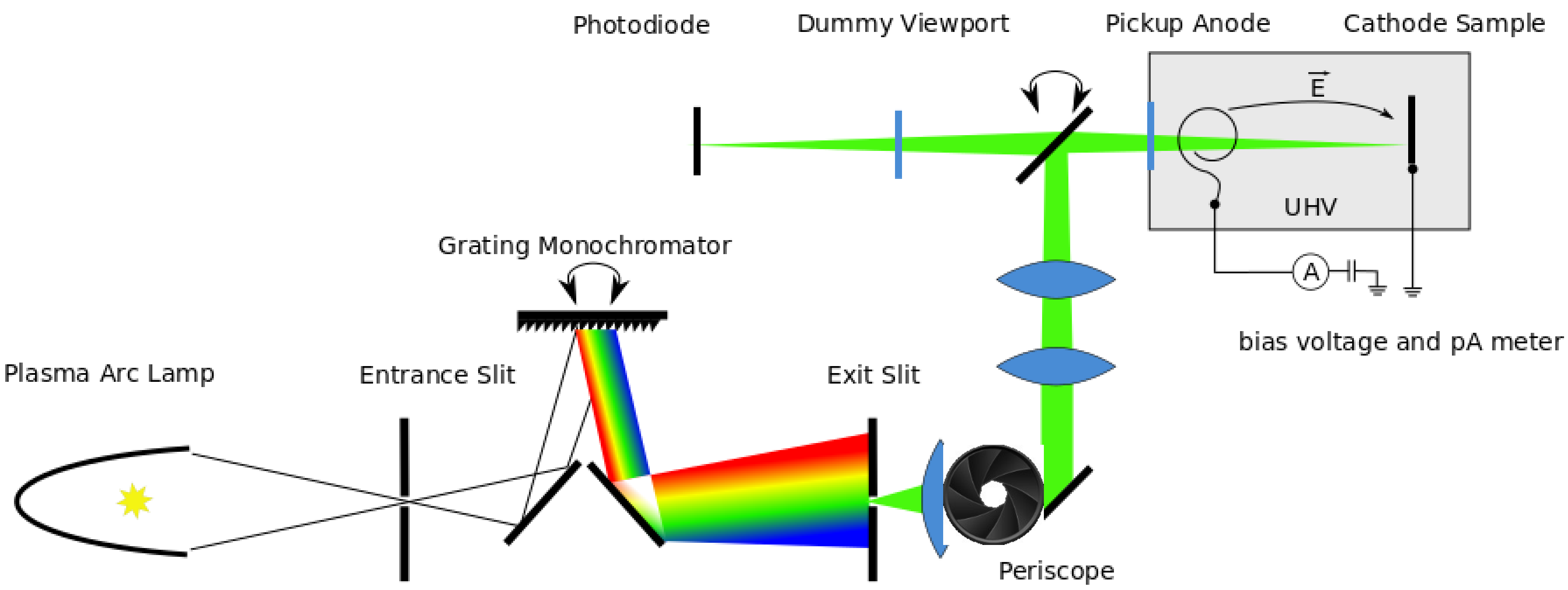
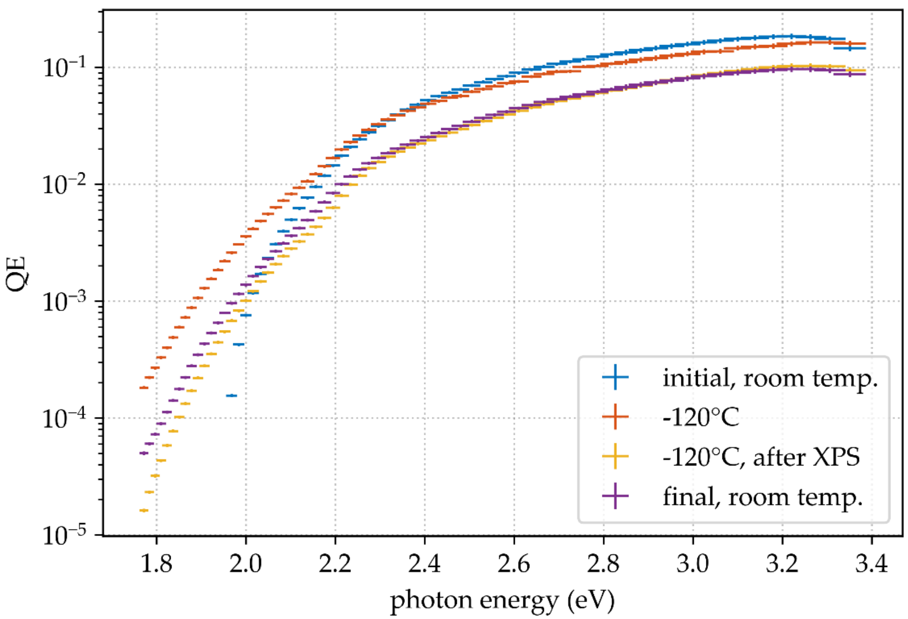
Intrinsic emittance

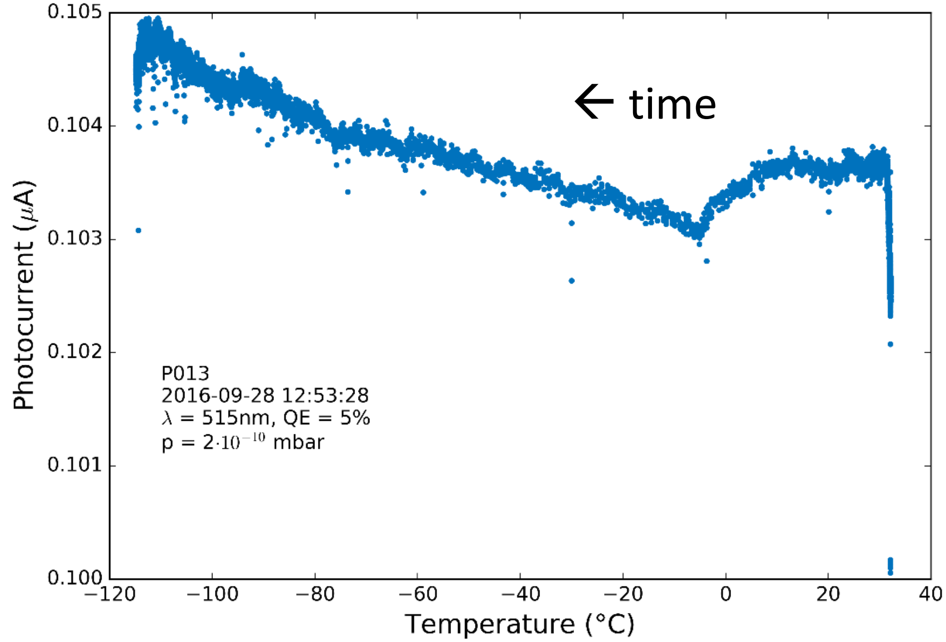
SPECTRAL RESPONSE



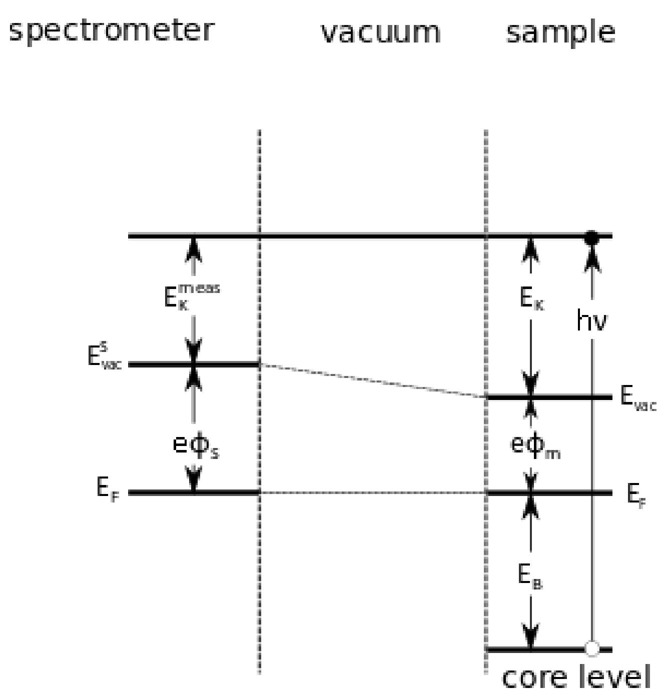
RECENT RESULTS (P013)

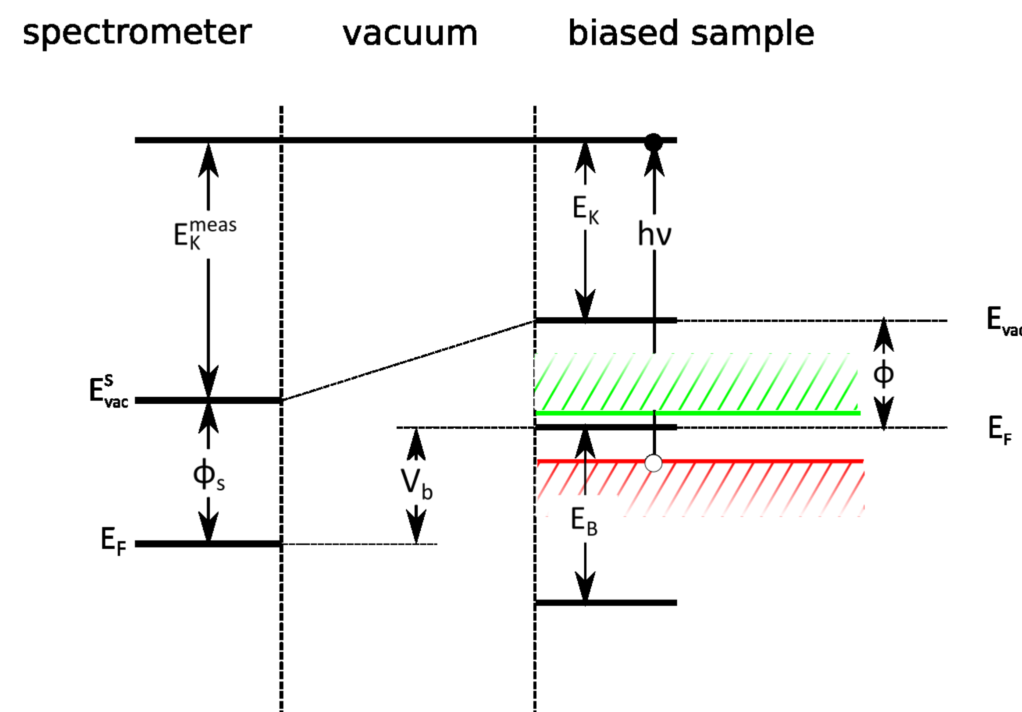
No degradation of the performance was observed during cooling to –
Movement of the cold sample (exposure to p > 10^{-9} mbar) results in loss of QE.





Spectral behavior (loss in blue QE, increase in red QE) not understood.
Still want to reproduce measurement.





Discussion : how to define work function for semiconductors?
Kelvin Probe definition version Photoemission definition?

See e.g. Helander, et al. (2010). *Appl. Surf. Sc.*,*256*(8),10.1016/j.apsusc.2009.11.002

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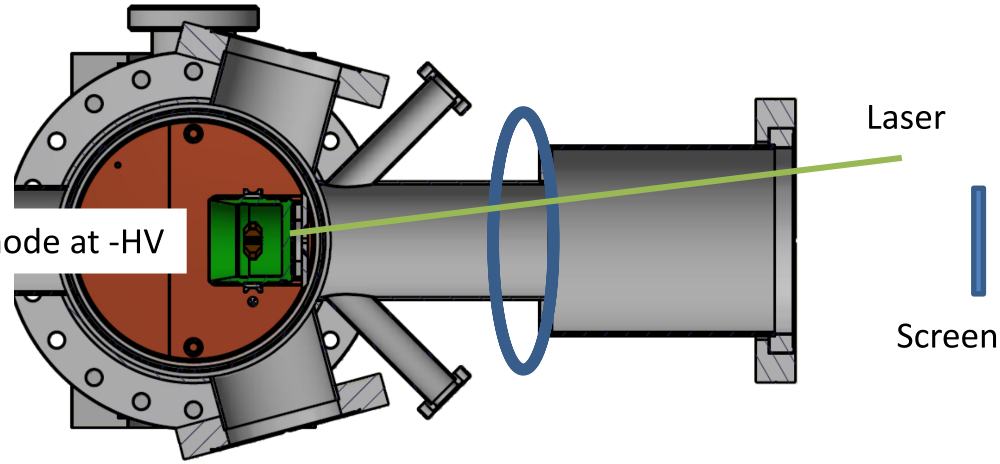
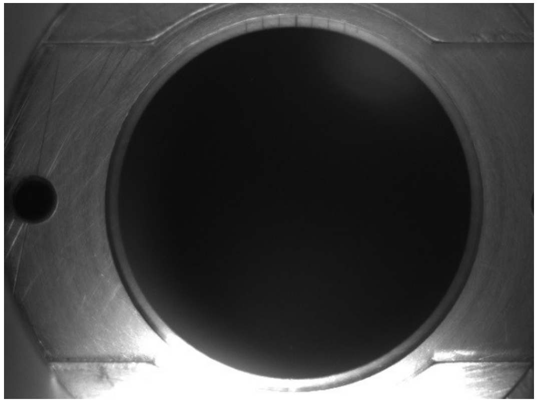
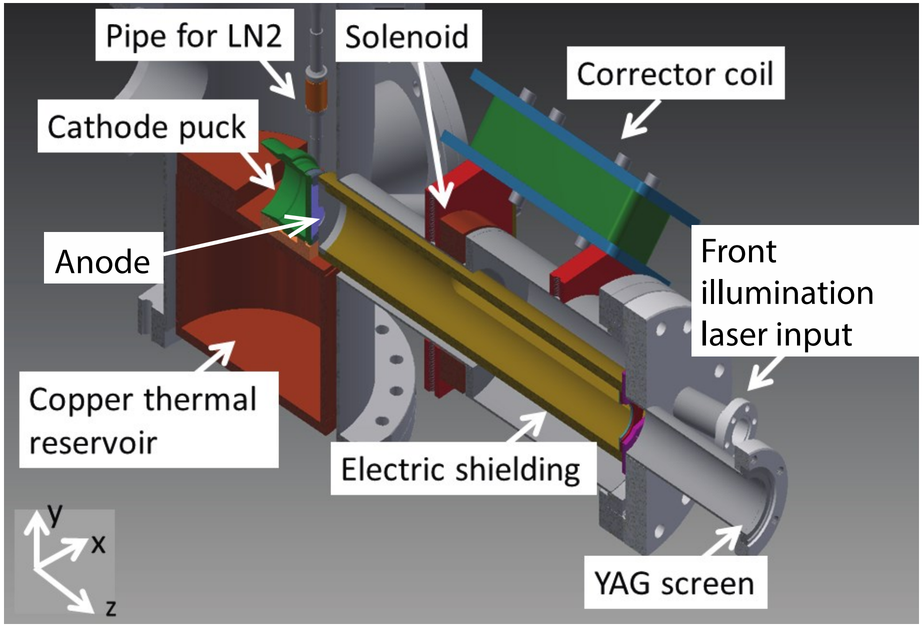
REPORT CORNELL MEASUREMENTS

TE meter

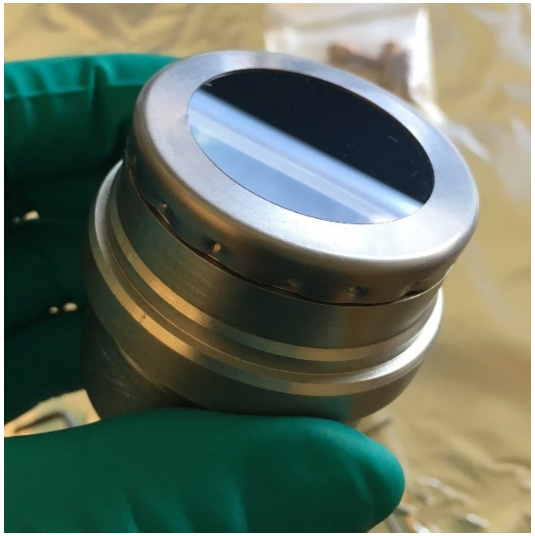


Screen

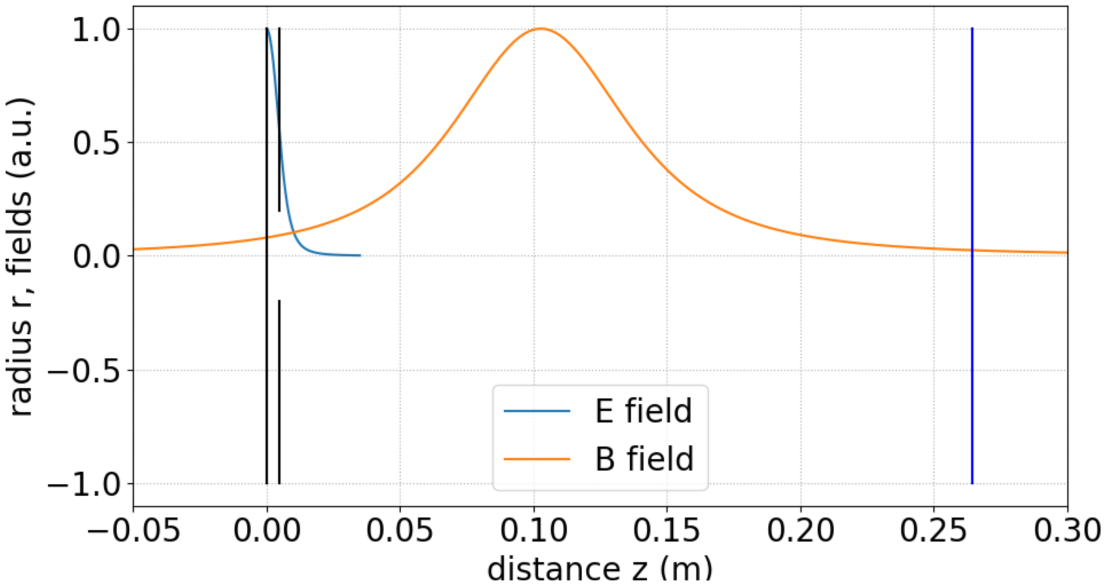


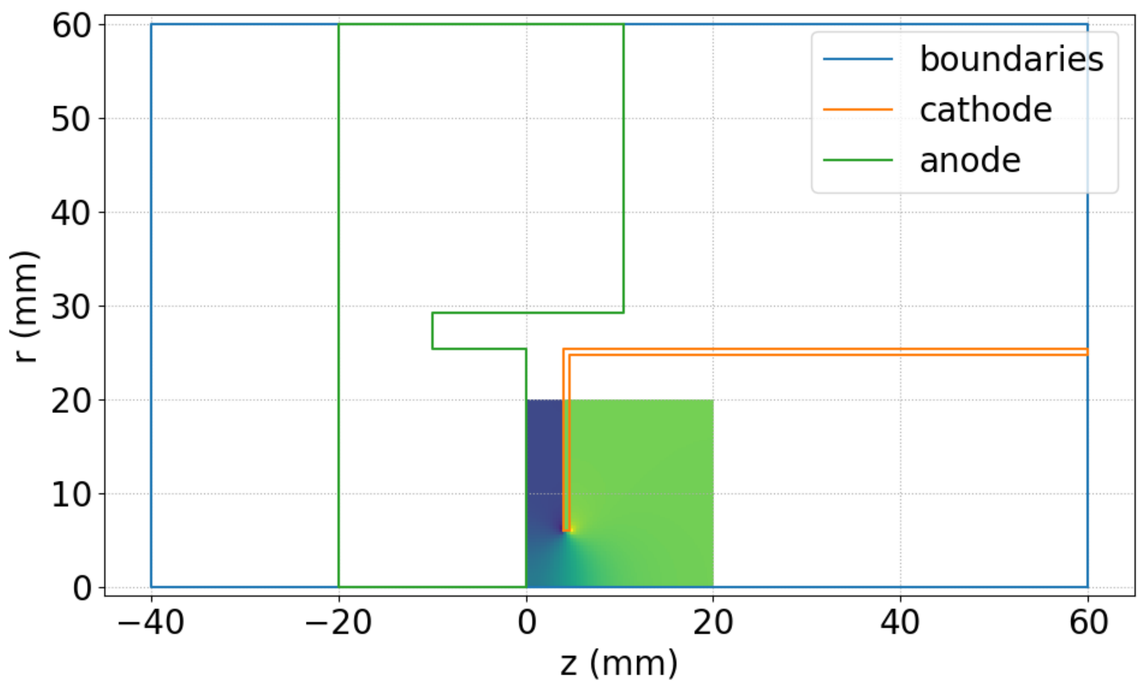


Cornell plug (Si wafer clamped on 2“ Mo plug)



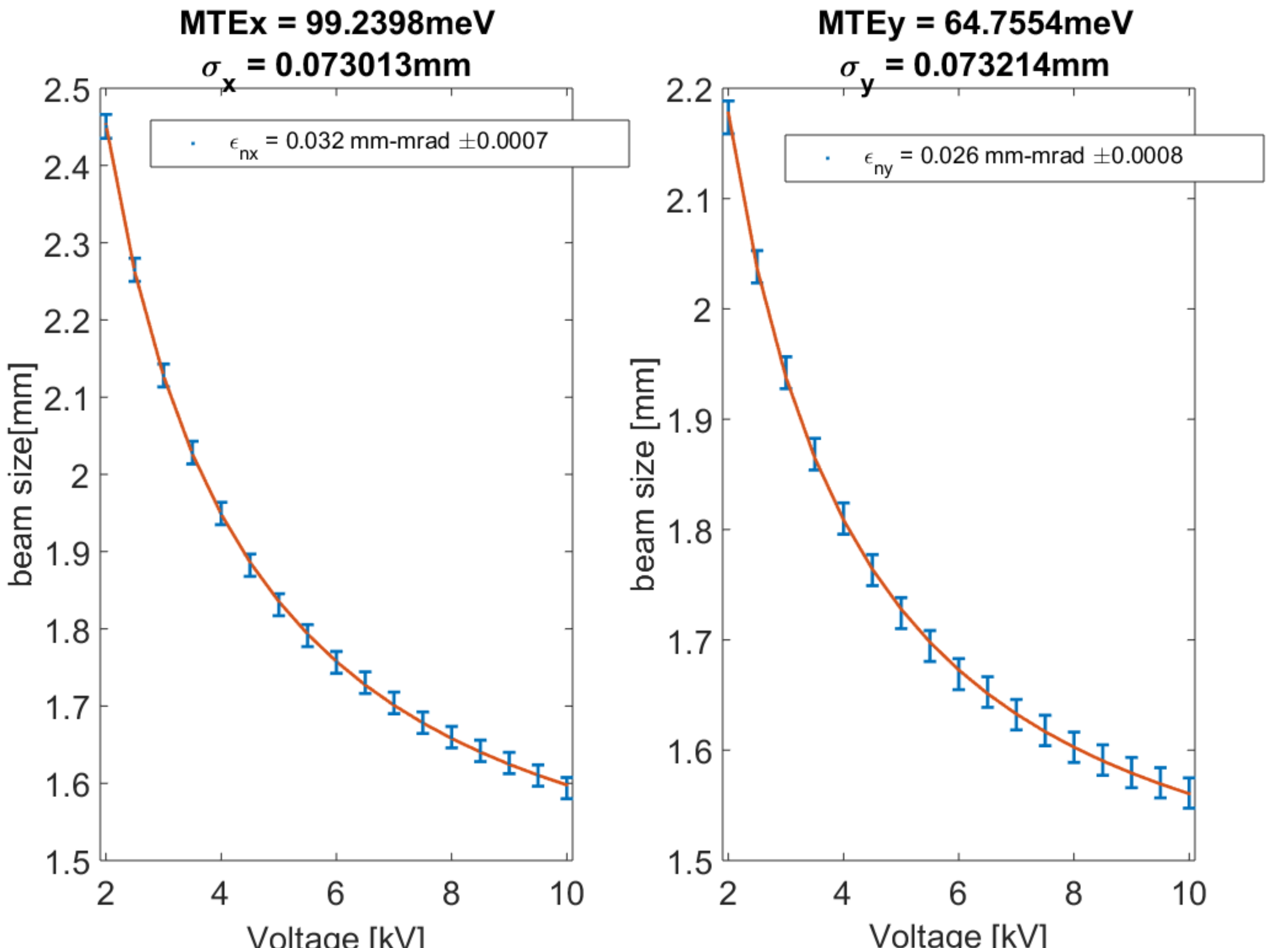
Principle of the measurement





Voltage Scan or Solenoid Scan

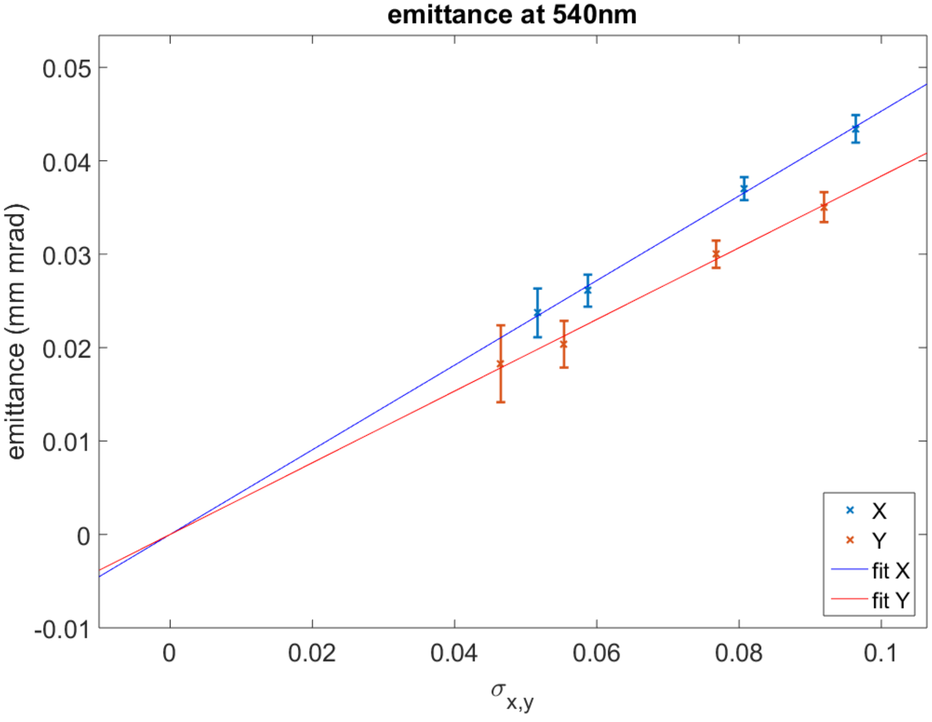
- Take a screen image for many settings
- Simulated field maps are scaled for actual settings and transfer matrices calculated
- least squares fit to obtain MTE and initial beam size

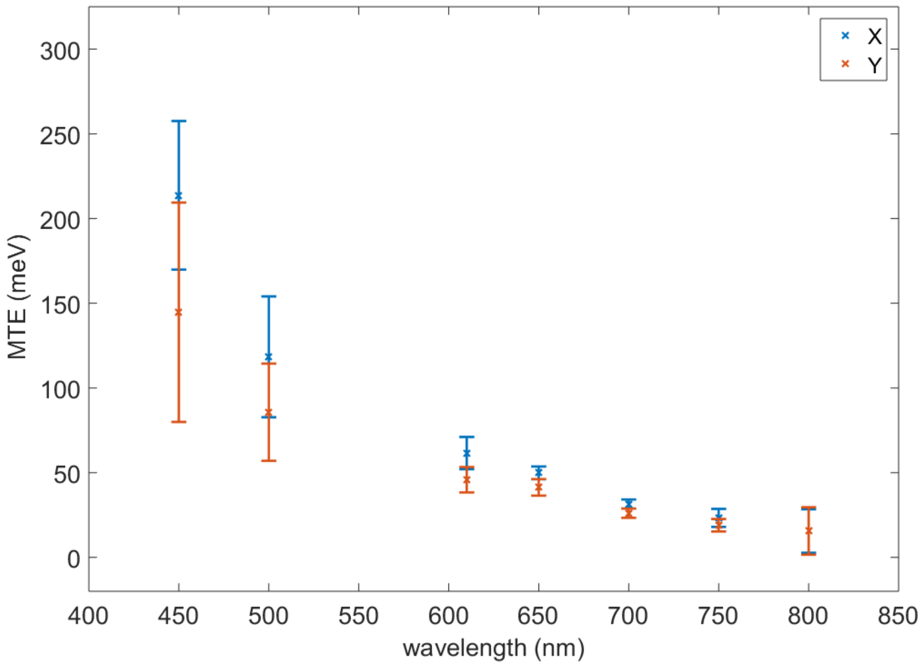


Gulliford, C., & Bazarov, I. (2012). *PRSTAB 15(2).*
Lee, H. *Thesis, 2017*

Data for Cs_3Sb on Si(100)

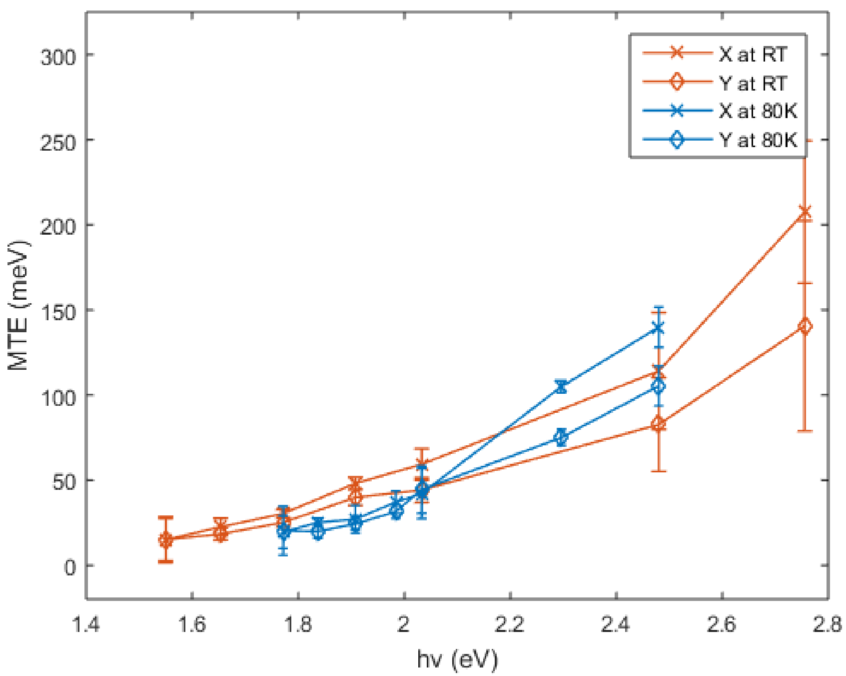
- Take a voltage scan at each laser spot size (pinholes)
- Lin. regression of emittance for each wavelength

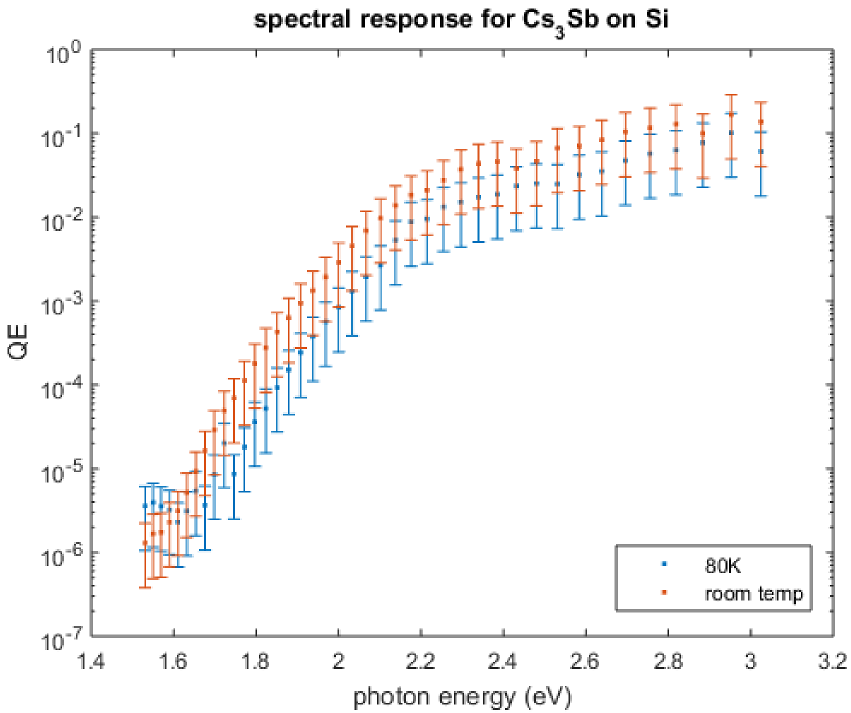




Data for Cs_3Sb on Si(100)

- MTE for sample at RT approaches limit at ~25meV
- QE drops during cool down (at $2*10^{-10}$ mbar vacuum)
- MTE for cold sample approaches the same limit!





Data for Cs_3Sb on Si(100)

- Work function shifts about 0.1 eV

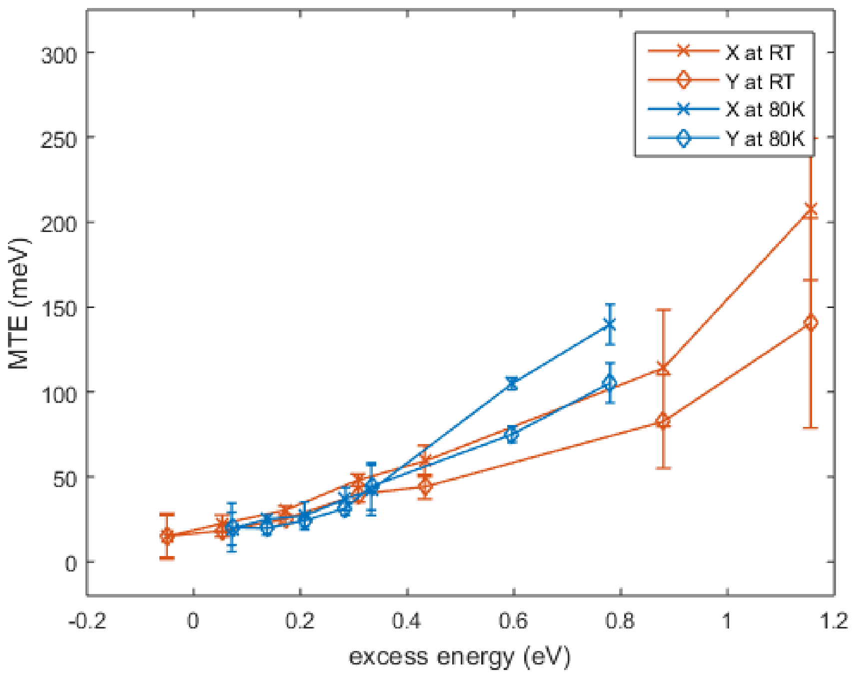
- Measured MTE rises slower than model
- Does not approach zero

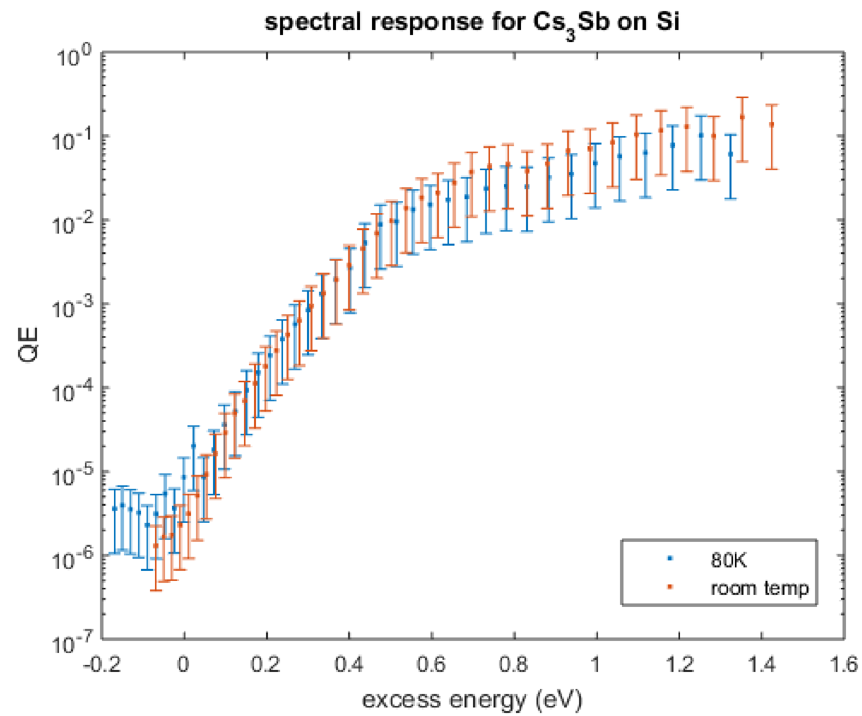
Most simple model:

$$E_{excess} = h\nu - E_G - E_A$$

$$MTE = \frac{1}{3} E_{excess}$$

$$\varepsilon_{semi} = \sigma_x \sqrt{E_{excess} / 3mc^2}$$





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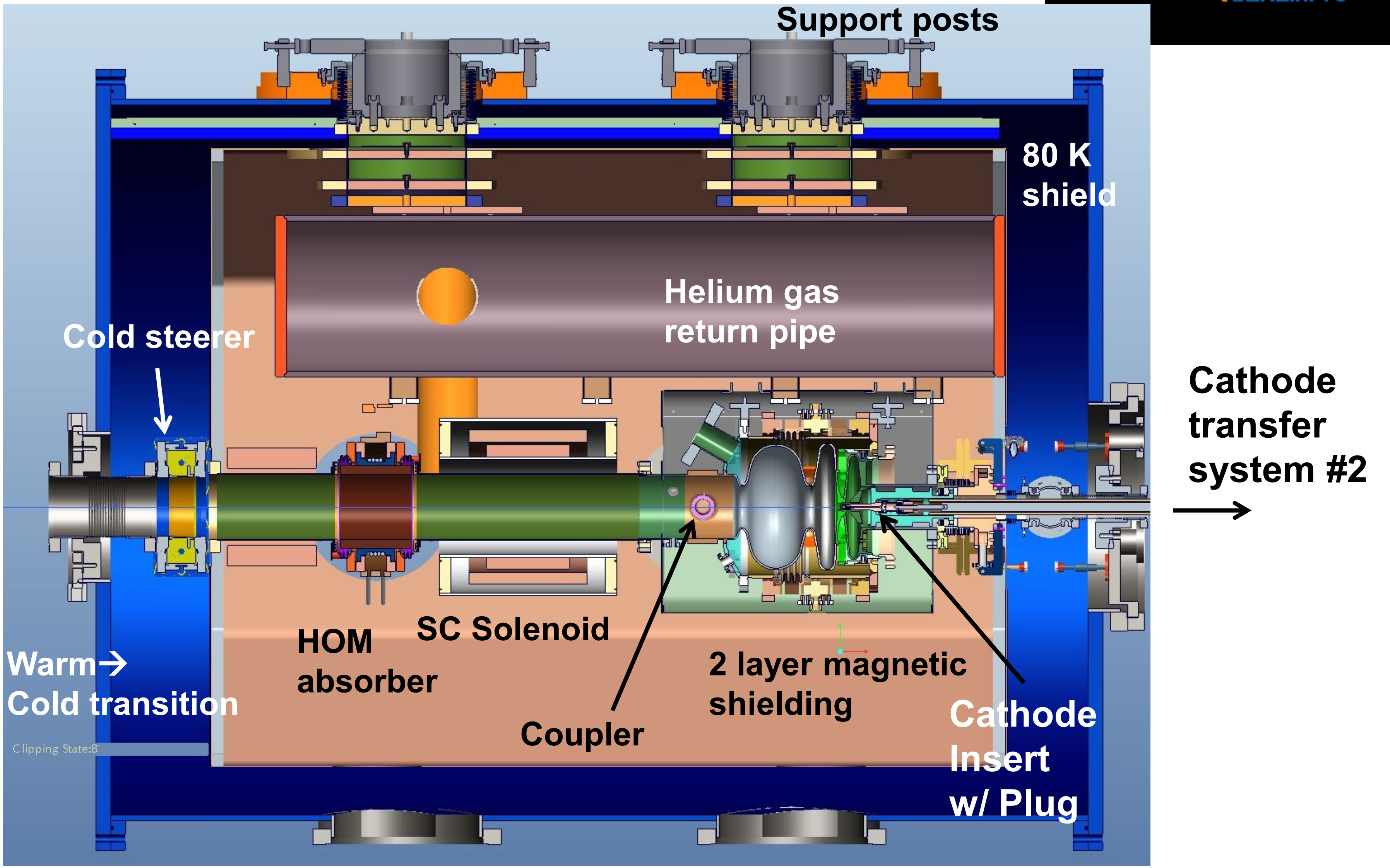
John Smedley, Zihao Ding, Menjia Gaowei

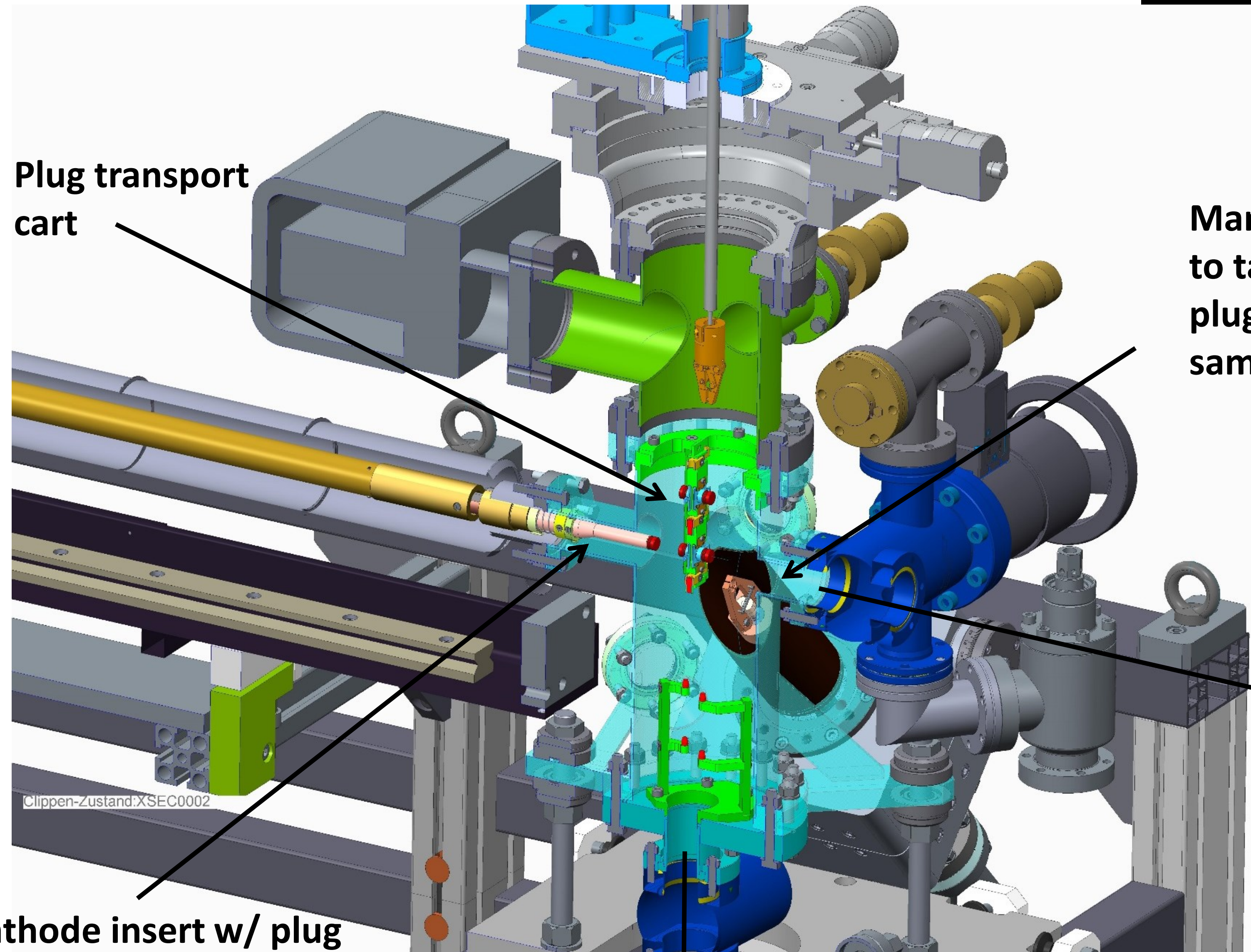
Thank you for your attention!

CROSS-SECTION OF THE GUN MODULE



with courtesy of A. Neumann (HZB)

CROSS-SECTION TRANSFER SYSTEM #2



Plug transport cart

Manipulator to take the plugs off the sample holder

Gun Module

Cathode insert w/ plug

Vacuum suitcase