Surfaces and Electron Clouds

Valentine Petit

TE-VSC-SCC

With many inputs from

M. Himmerlich, H. Neupert, M. Taborelli, P. Costa Pinto, L. Mether, B. Bradu, S. Fiotakis…

Joint Accelerator Performance Workshop Montreux 2023

Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab

- Pressure limitation in SPS kickers, what could be the cause?

- Summary and conclusions

Outline

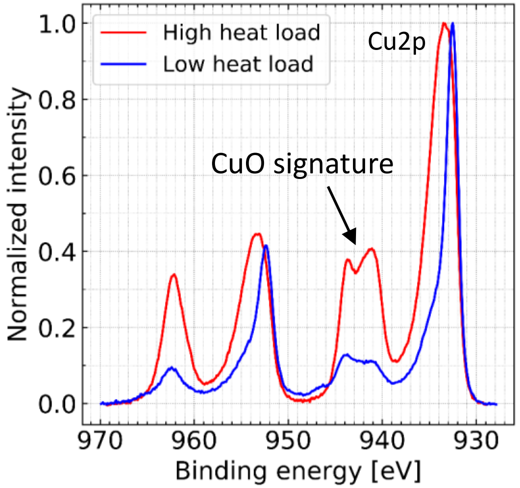
- LHC surfaces
  - **Previous results and open questions**
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab

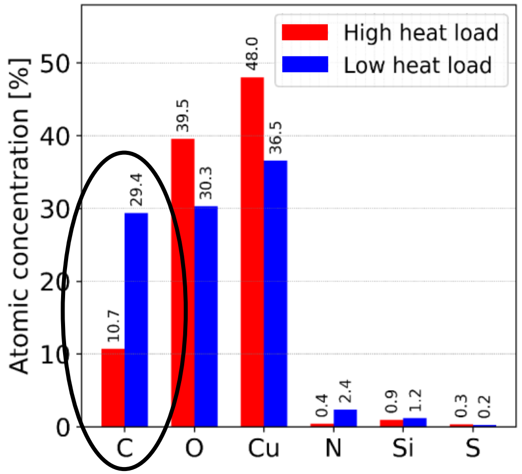
- Pressure limitation in SPS kickers, what could be the cause?

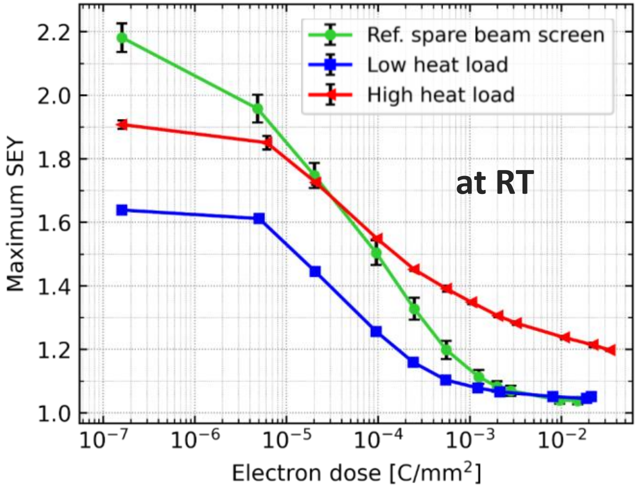
- Summary and conclusions

Previous results and open questions

Surface analysis at RT of **low and high heat load beam screens** extracted from the LHC during LS2 have suggested **CuO and low carbon amount as responsible for high heat loads**







- Surface studies at cryogenic temperature
  - → validate the key role of **CuO** and **low carbon coverage**
  - → understand the **origin** and the **history** of the **LHC beam screen surface state**
- Development of mitigation solutions
  - → recover an **efficient conditioning** and **low heat loads**

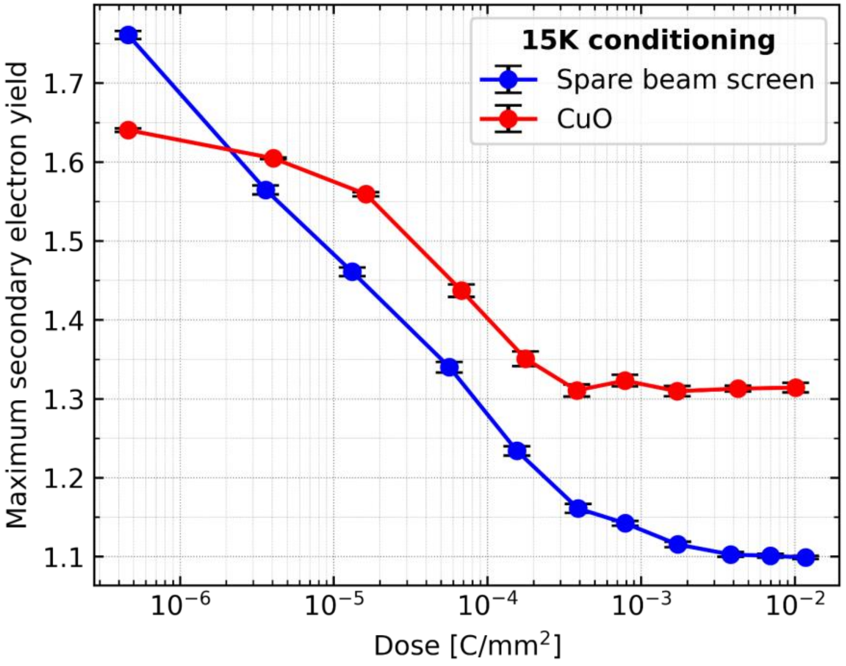
Outline

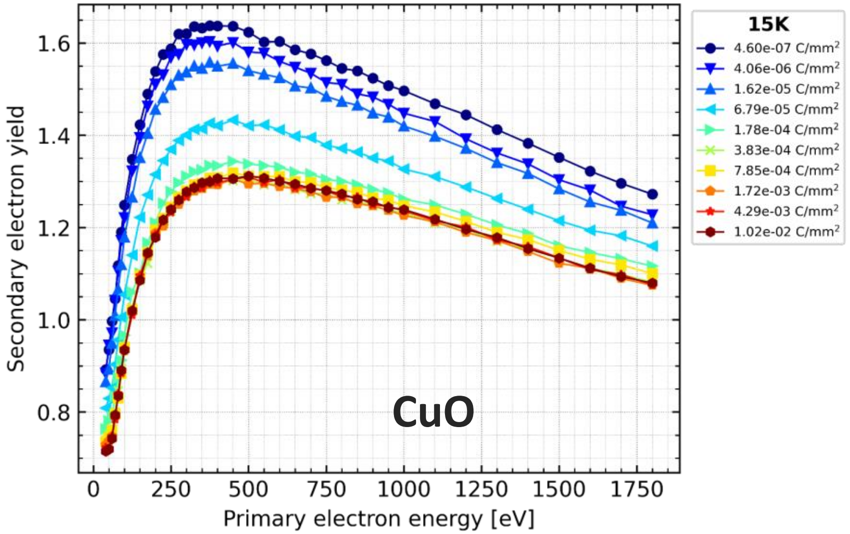
- LHC surfaces
  - Previous results and open questions
  - **Cryo-conditioning of CuO versus spare beam screen**
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab

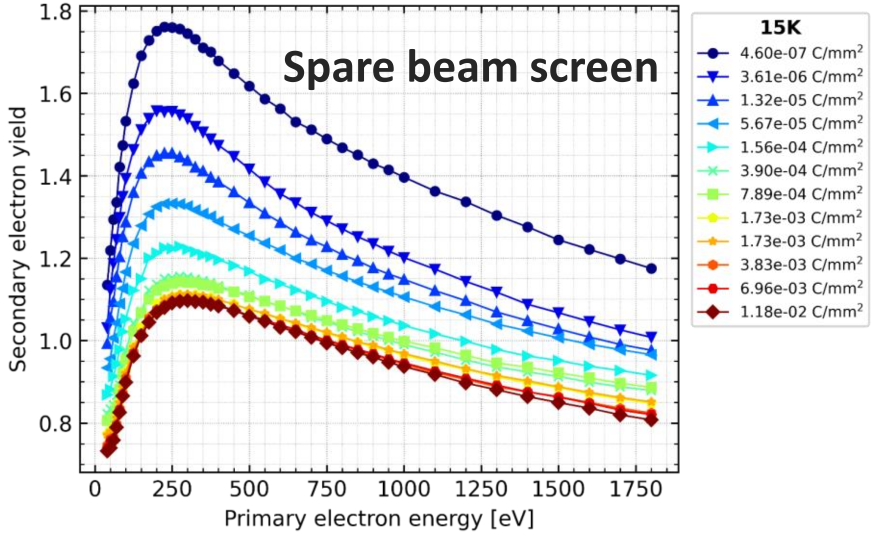
- Pressure limitation in SPS kickers, what could be the cause?

- Summary and conclusions

Cryo-conditioning of CuO vs spare beam screen







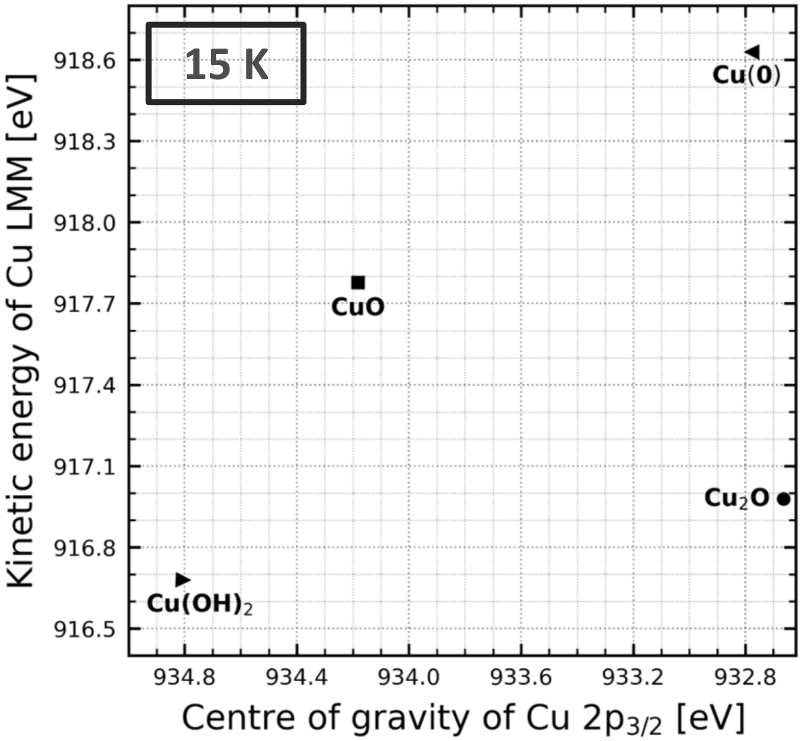
- At saturation of SEY decrease: **δ_{max}(CuO) = 1.3 > δ_{max}(Spare BS) = 1.1**
- Saturation of SEY decrease requires **less dose for CuO** than for the spare beam screen
- 15K conditioning of low and high heat load LHC extracted beam screen to be performed

Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - **Origin of the difference of surface state**
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab
- Pressure limitation in SPS kickers, what could be the cause?
- Summary and conclusions

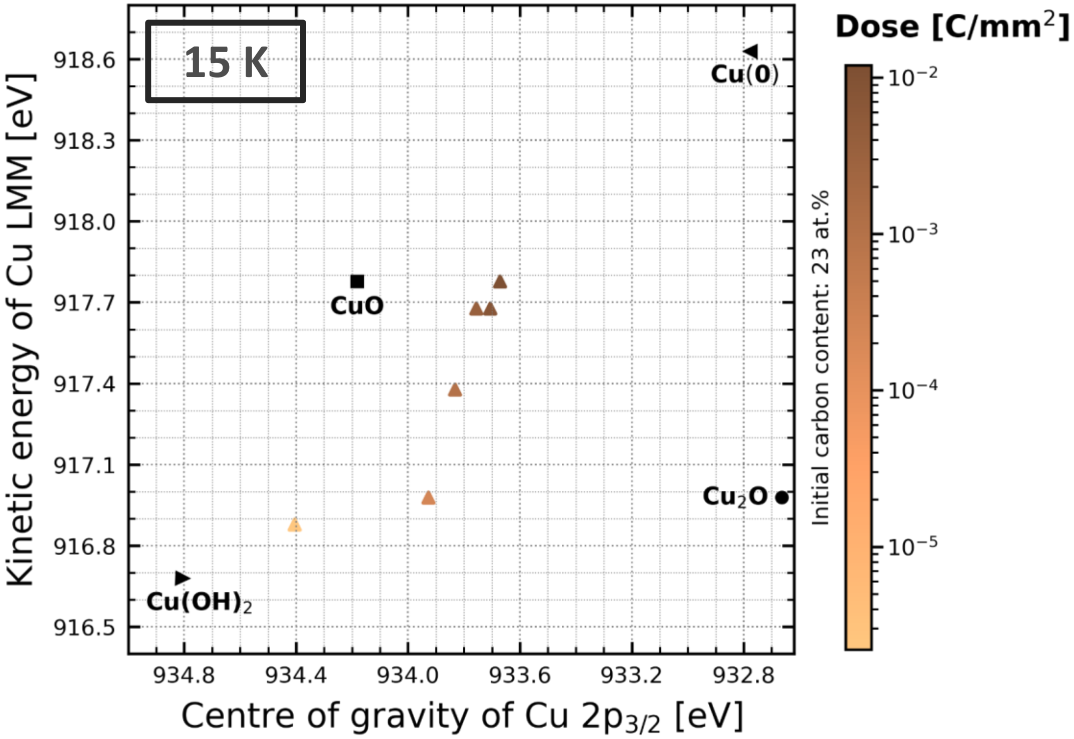
Origin of CuO build-up and influencing factors

Chemical mapping of copper, based on X-ray Photoelectron Spectroscopy data



Origin of CuO build-up and influencing factors

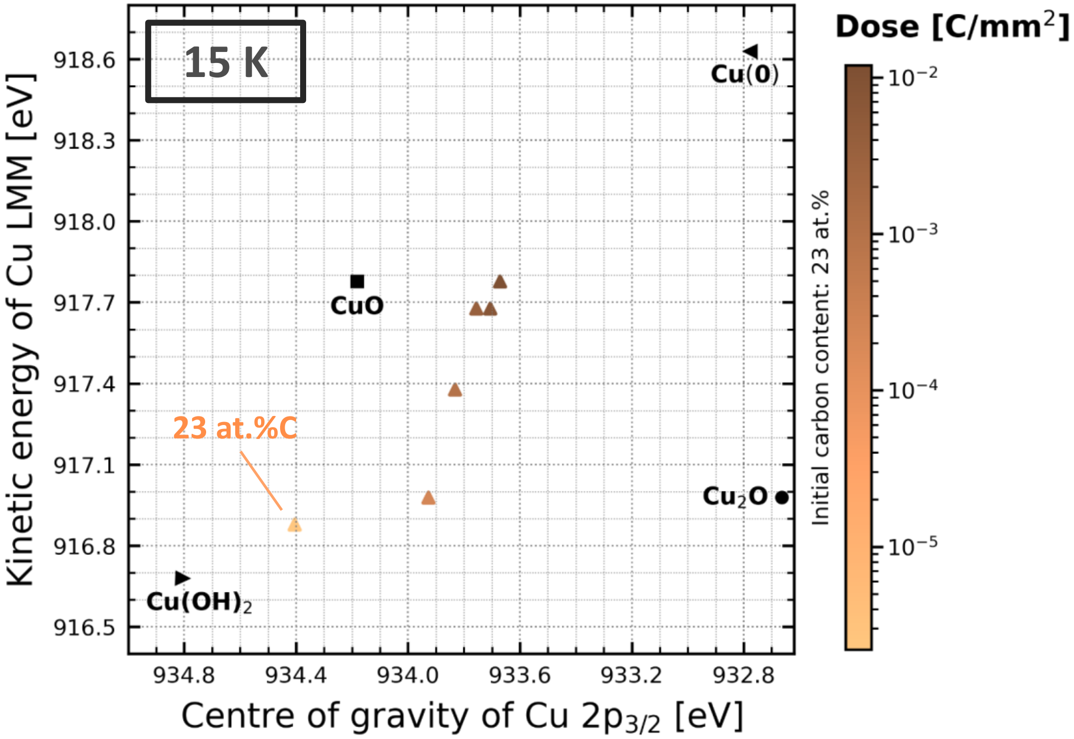
Chemical mapping of copper, based on X-ray Photoelectron Spectroscopy data



- During electron irradiation at 15K, **airborne $Cu(OH)_2$ converts into CuO**

Origin of CuO build-up and influencing factors

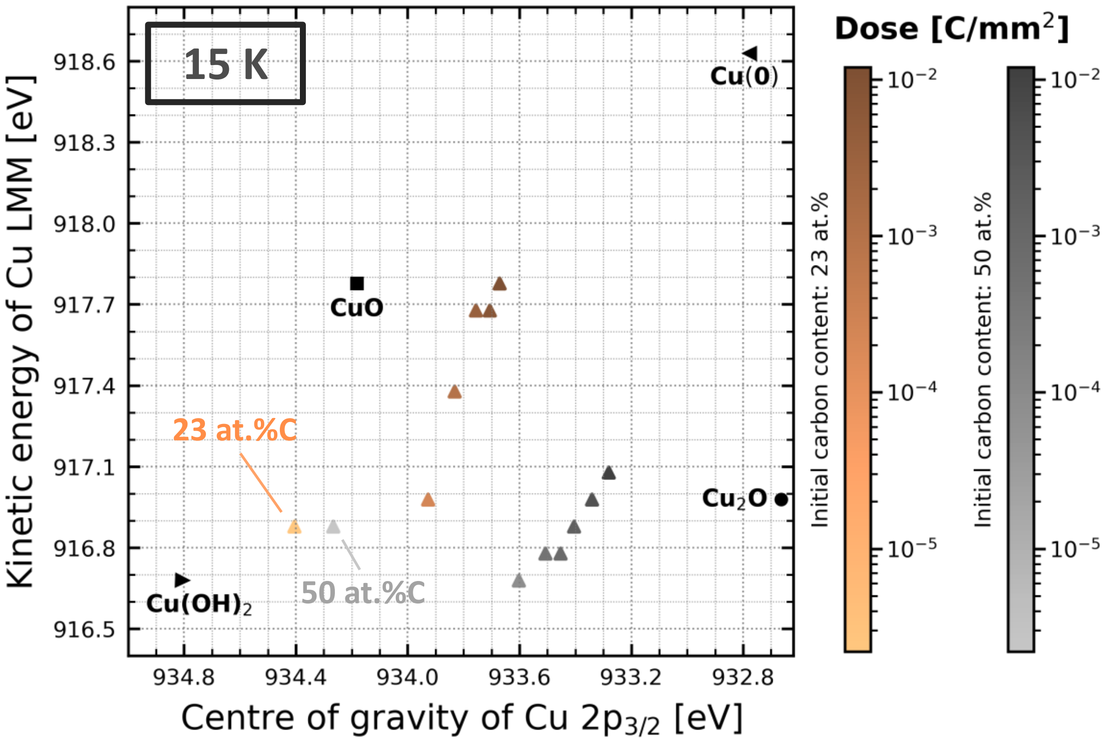
Chemical mapping of copper, based on X-ray Photoelectron Spectroscopy data



- During electron irradiation at 15K, **airborne $Cu(OH)_2$ converts into CuO**

Origin of CuO build-up and influencing factors

Chemical mapping of copper, based on X-ray Photoelectron Spectroscopy data



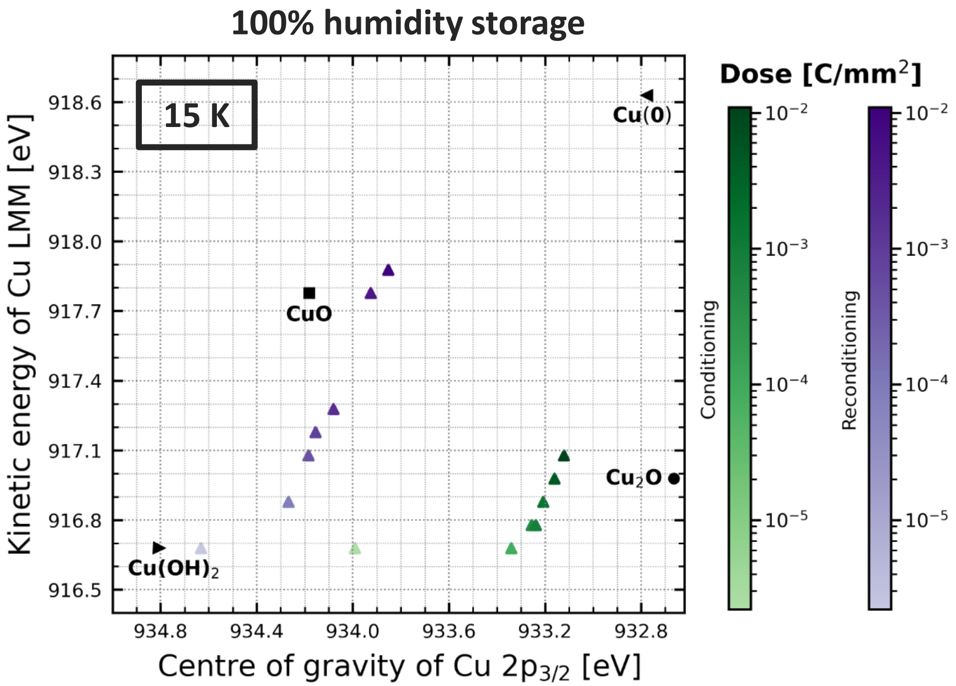
- During electron irradiation at 15K, **airborne Cu(OH)$_2$ converts into CuO**
- Airborne carbon contamination is limiting the conversion to CuO and helps reducing to Cu_2O

Origin of CuO build-up and influencing factors

Conditioning 15K → 2.5 months storage → Reconditioning 15 K

Origin of CuO build-up and influencing factors

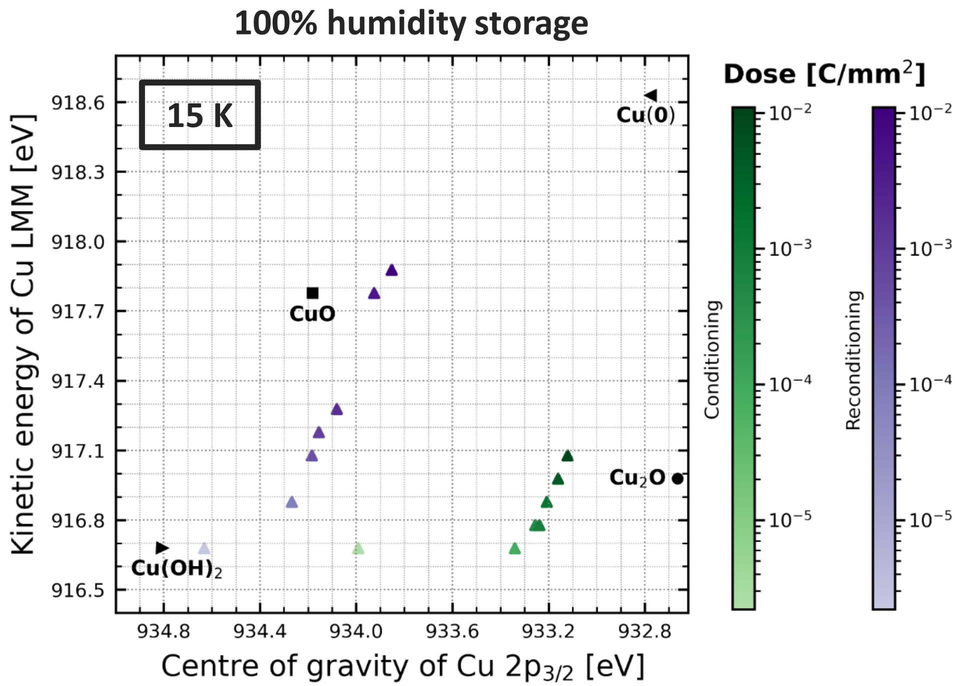
Conditioning 15K → 2.5 months storage → Reconditioning 15 K

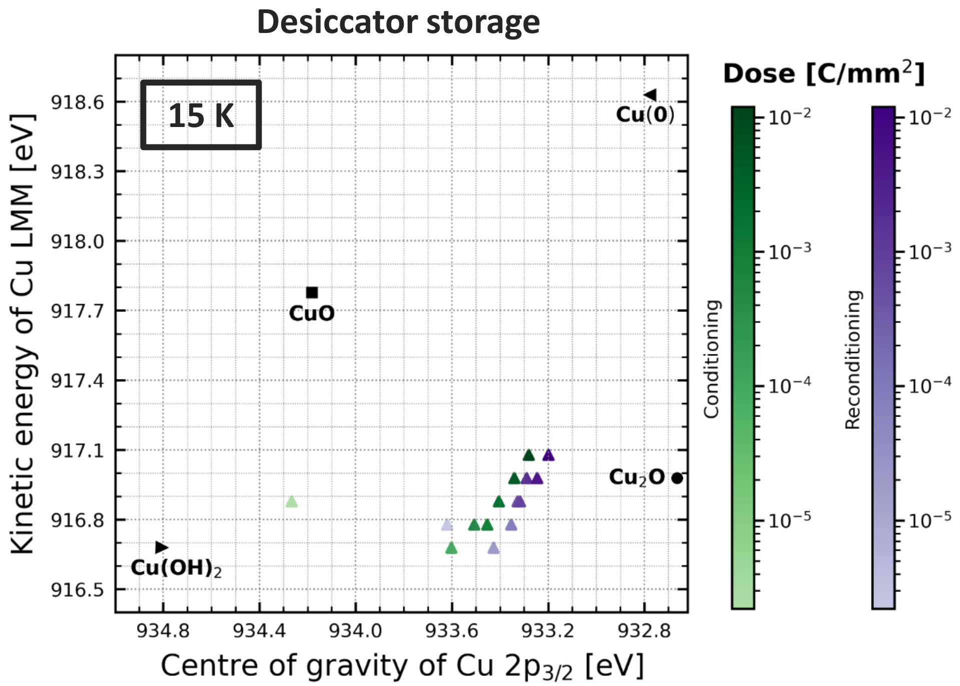


- First conditioning: **CuO-free**
- Increased surface reactivity → **massive $Cu(OH)_2$ uptake** in humid atmosphere
- **CuO build-up** during reconditioning of sample with **large $Cu(OH)_2$ coverage**

Origin of CuO build-up and influencing factors

Conditioning 15K → 2.5 months storage → Reconditioning 15 K





- First conditioning: **CuO-free**
- Increased surface reactivity → **massive $Cu(OH)_2$ uptake** in humid atmosphere, only **limited in dry atmosphere**
- **CuO build-up** during reconditioning of sample with **large $Cu(OH)_2$ coverage only**

Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - **Beam screen treatment: what surface properties could we expect?**
  - Photo-electron yield measurement in the lab

- Pressure limitation in SPS kickers, what could be the cause?

- Summary and conclusions

Investigating mitigation solutions

- ## Objectives
  - Remove CuO and/or increase surface carbon concentration on selected beam screens to reduce heat loads and recover cooling margins
  - Ensure the passivation of the beam screen surface (robustness against re-oxidation)

- ## Processes under evaluation
  - Carbon deposition by **plasma discharge in C_xH_y**

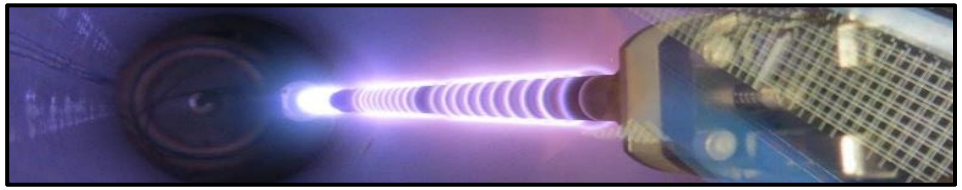
    \+ ≈ 1 day/53m/beam line of coating

    \- as-coated SEY ≈ 1.8

  - **Thin aC coating** by Physical Vapor Deposition (sputtering)

    \+ expertise available, as-coated SEY ≈ 1.4

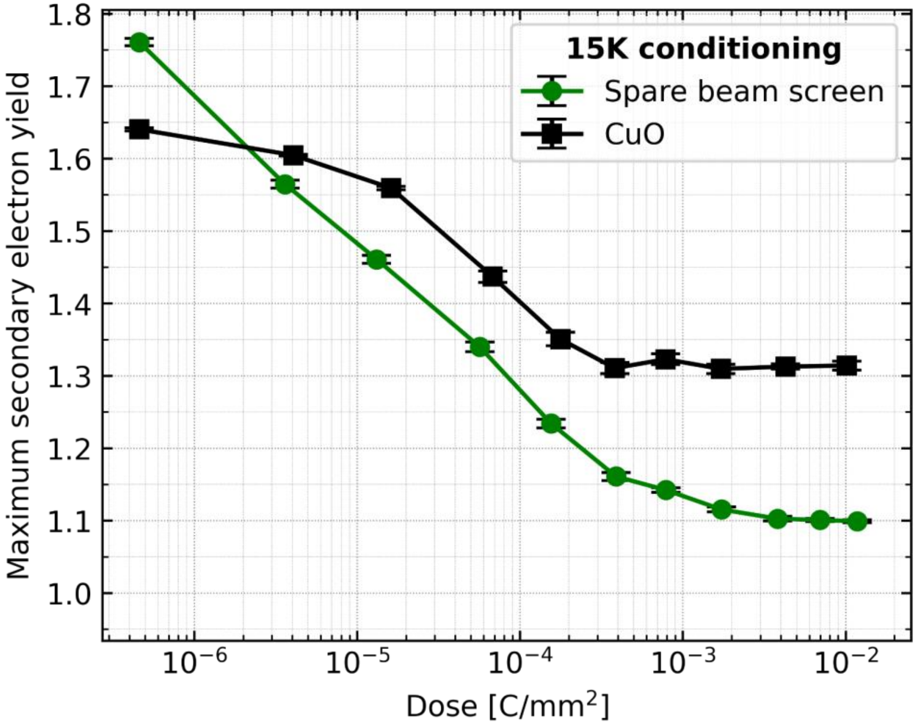
    \- ≈ 4 days/53m/beam line of coating

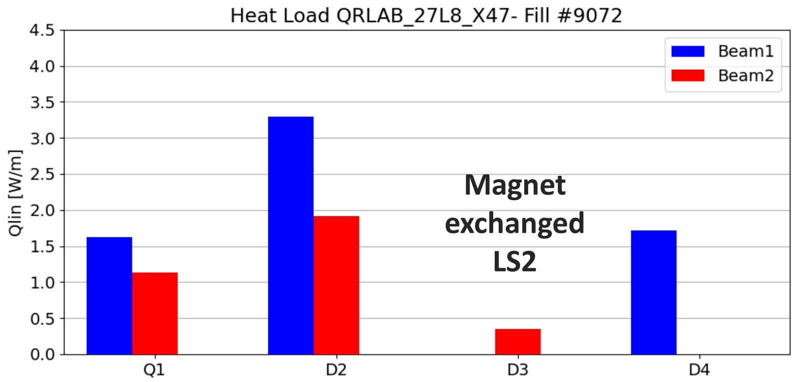


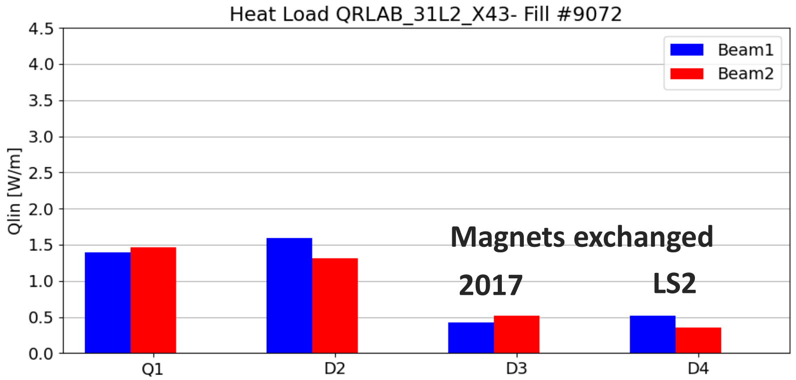
- ## Sample qualification

SEY as coated and after 15K conditioning, Photo-electron yield, robustness against reoxidation during ventings (ageing), adhesion, Electron Stimulated Desorption…

15K conditioning of treated surfaces

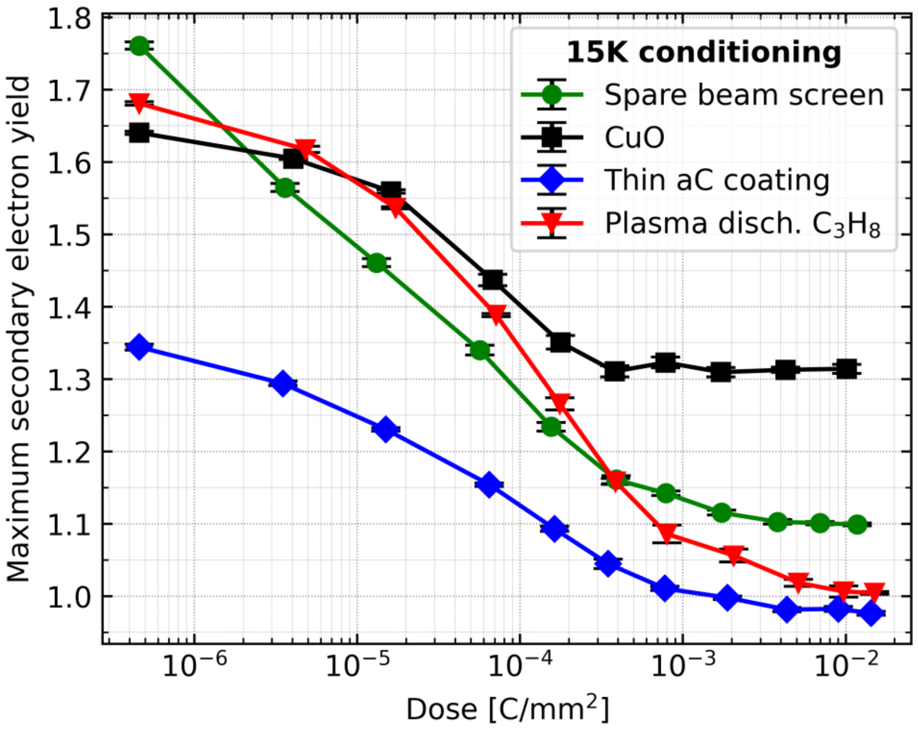


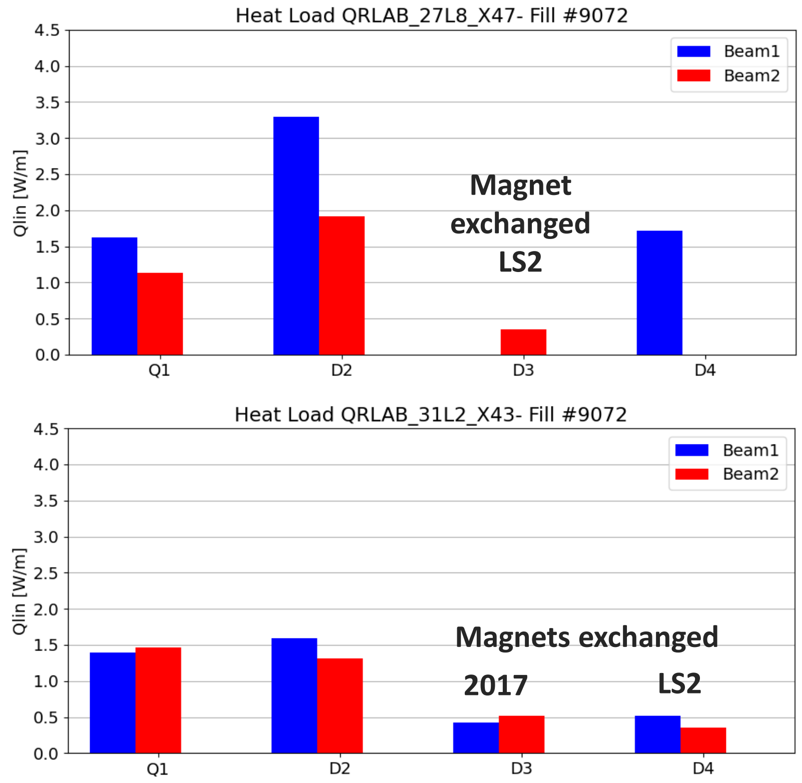




See L. Delprat's presentation

15K conditioning of treated surfaces





See L. Delprat's presentation

- **15K conditioning validated at 250 eV** for both types of carbon layer on CuO
- Limit for the LHC: **conditioning is not possible below electron cloud build-up threshold** but comparing with conditioning a spare beam screen, **the treated surfaces condition very well**

Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - **Photo-electron yield measurement in the lab**
- Pressure limitation in SPS kickers, what could be the cause?
- Summary and conclusions

Photoelectron yield estimates in the lab

- Photoelectron yield determinant in ecloud seeding and is thus of paramount importance for **building an accurate simulation model**. However, it is reduced to a single value for a multi-variable parameter (angle of incidence, photon energy)

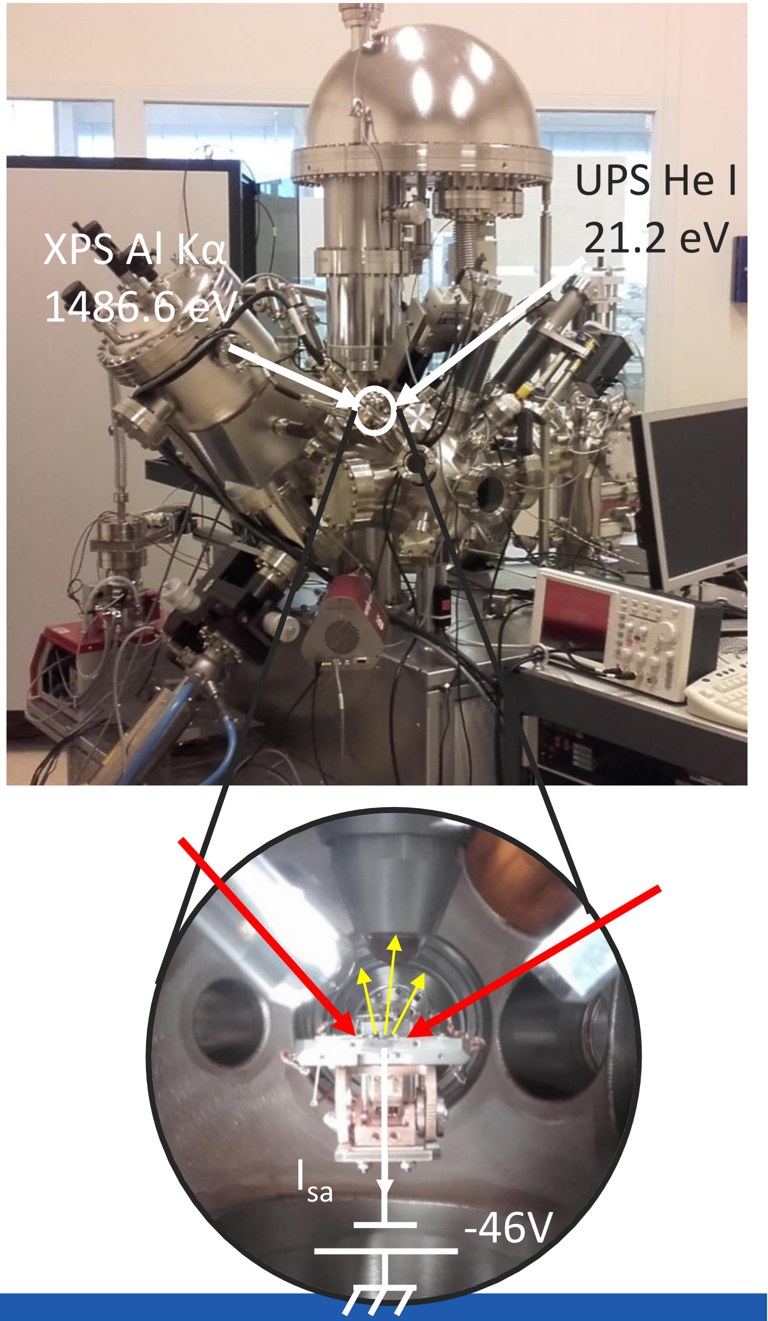
- Photoelectron yield measurement in the laboratory, capabilities and limitations
  - Only possible on **RT system**:
    - critical for conditioned state (in particular CuO),
    - but **PEY (as SEY) is not influenced by temperature :** E(hν or e^-) >> E(kT)=26 meV

  - Sources for Photoelectron Spectroscopy: He I (**21.22 eV**), Al Kα (**1486.6 eV**)

  - **Geometry limitations**: incidence angle limited by sample manipulator and positioning of sources (LHC: 5.1 mrad incidence, not achievable), spread of light spot at grazing incidence…

    → Still requires modifications for operating at full potential

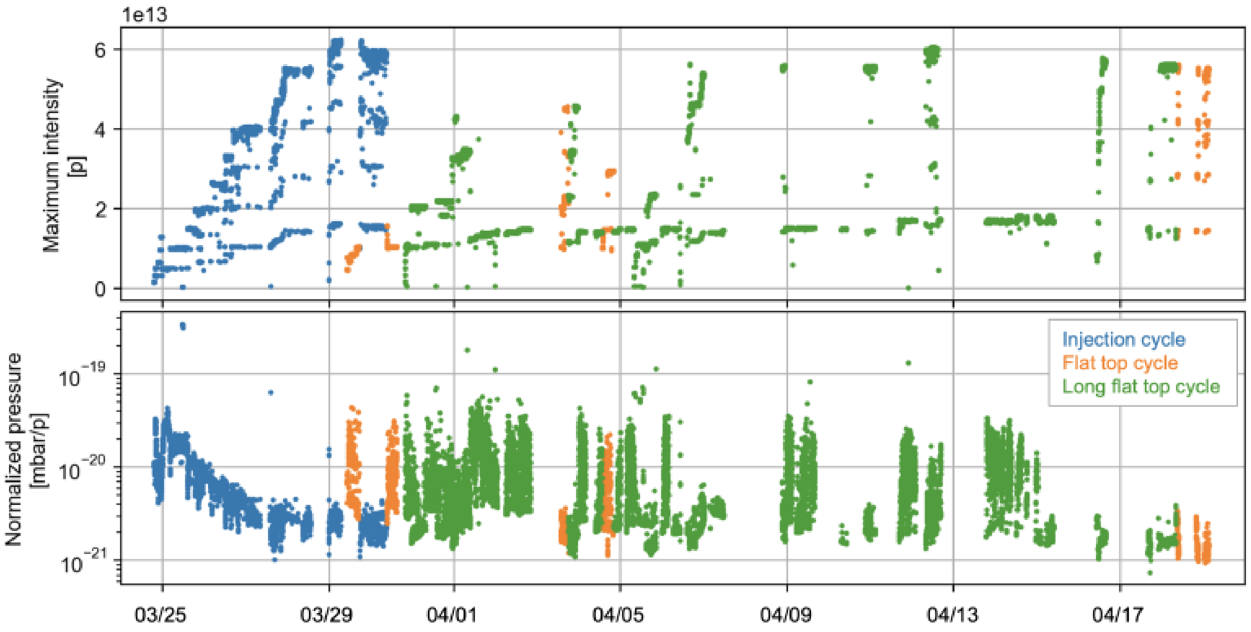
  - No absolute photon flux measurement: relative estimates, **comparative measurements**

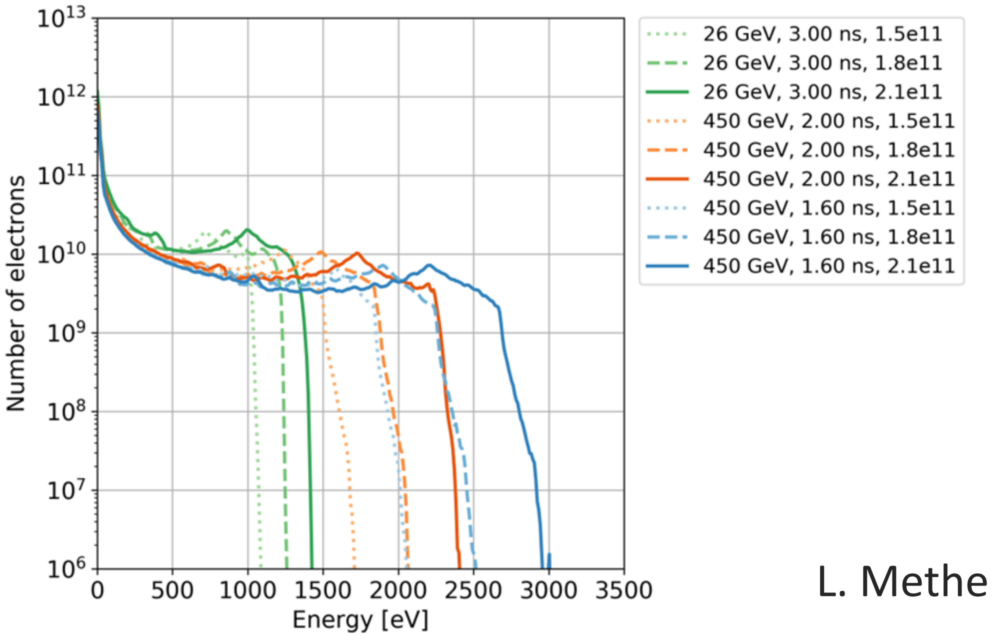


Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab
- **Pressure limitation in SPS kickers, what could be the cause?**
- Summary and conclusions

Pressure limitation in SPS kickers



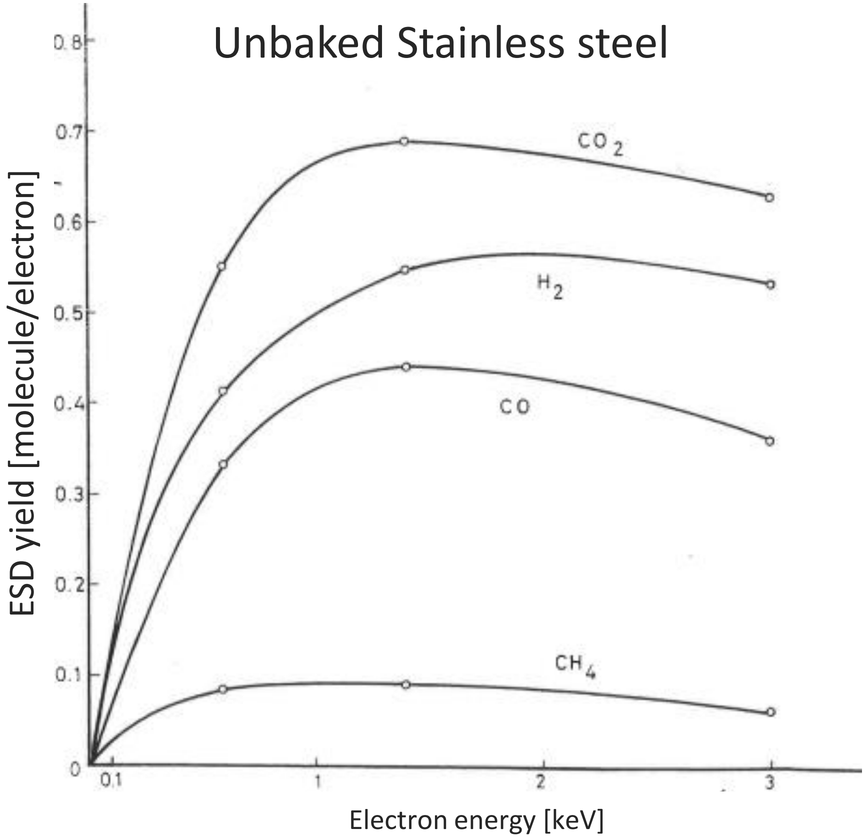


L. Mether

- Pressure limitation in SPS kickers. Clear scrubbing at 26 GeV, but **massive (× 5-10) pressure increase** when bringing the beam to **450 GeV** with **short bunch length** and difficult scrubbing.

- The increase of beam energy and decrease of bunch length push the electron energy distribution to higher energies.
  → Can this affect the **E**lectron **S**timulated **D**esorption from the surrounding surface and how?

ESD dependence on energy – as received surface



M-H. Achard, CERN-ISR-VA/76-34

- ESD yield of as received surface (i.e. with airborne contamination) is **slightly decreasing** for energies between 1 and 3 keV

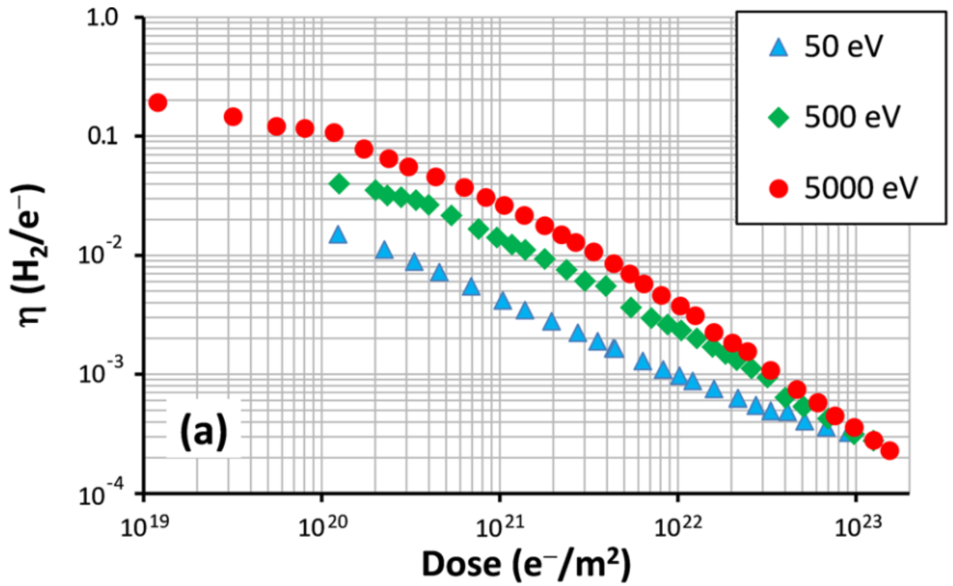
  → Cannot explain the kickers observation

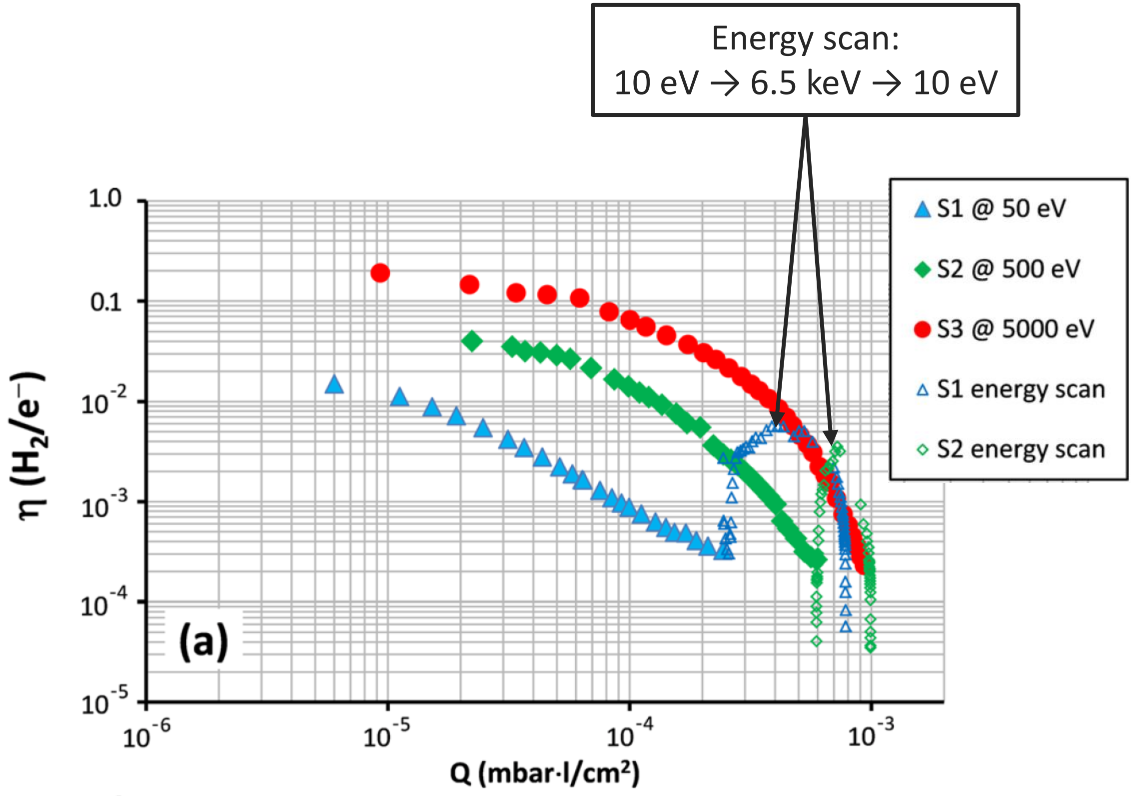
- Visible effect of secondary electrons on ESD yield: the SEY also decreases in this energy range

ESD dependence on energy – effect of conditioning

Stainless steel, after 24h bake out at 250 °C

O. Malyshev *et al.,* J. Vac. Sci. Technol. A 31, 031601 (2013)





- ESD yield as a function of desorbed quantities varies differently for different energies → the **energy impacts the conditioning state**
- Increasing the electron energy after low energy conditioning increases the ESD yield

ESD dependence on energy – tentative explanation

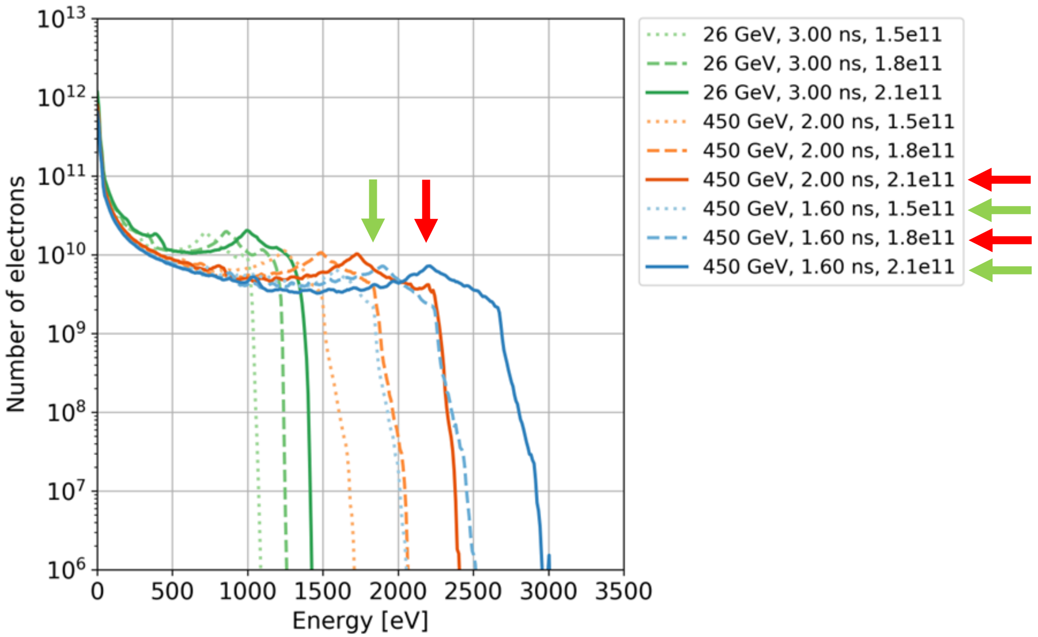
- For an **"as received"** surface, the **dominant contribution to ESD** comes from the **topmost surface contaminants.** ESD yield is therefore mostly independent of the electron energy, above a threshold of few tens of eV, since all impinging electrons reach the surface layer

- For a **conditioned** surface, for which the number of molecules at the topmost surface is reduced, the contribution from **atoms from deeper layers** could start to play a role. Therefore, by **increasing the energy**, which results in an **increase of mean free path** of electrons, results in a **deeper contributing volume**.

  For Fe: λ(1.5 keV) = 2.3 nm while λ(3 keV) = 4.1 nm Tanuma *et al.* Surf. Inter. Anal. 17, 1991, 911-926

  No strong dependance on material for conductors

- A **comparison of pressure behavior** with **different beams** leading to the **same electron energy spectrum** could help confirming this hypothesis



Outline

- LHC surfaces
  - Previous results and open questions
  - Cryo-conditioning of CuO versus spare beam screen
  - Origin of the difference of surface state
  - Beam screen treatment: what surface properties could we expect?
  - Photo-electron yield measurement in the lab
- Pressure limitation in SPS kickers, what could be the cause?
- **Summary and conclusions**

Summary and conclusions

- Presence of **CuO and low carbon coverage** clearly lead to **high SEY** after 15K conditioning compared to a spare beam screen

- **Mechanisms for CuO formation** are clarified: **$Cu(OH)_2$** acts as a precursor; **carbon** plays a key role in determining the Cu oxidation state after conditioning. Its non-uniform presence from one beam screen to another may explain the different heat loads

- Experiments are on going for **selecting a process** for recovering **efficient conditioning of LHC beam screens** and the **15K conditioning** of these surfaces is **validated**

- **Photo-Electron Yield** measurements have started on lab setup, results need to be confirmed and the data set needs to be extended for covering all relevant surfaces, both for the understanding of the machine state and for prediction of its state after treatment

- A tentative explanation is proposed for the pressure behavior observed in the SPS kickers, which involves the **probed depth variation** due to the **change of energy of the electrons**

Thank you for your attention

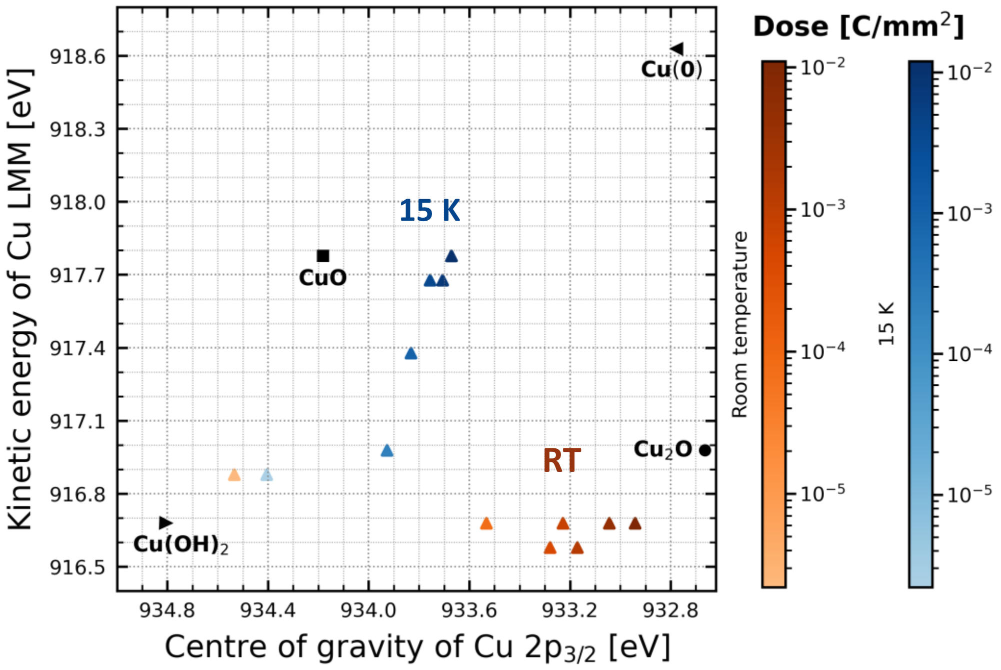
Backup slides

Conditioning of $Cu(OH)_2$: 15 K versus RT

Airborne copper hydroxide $Cu(OH)_2$ could be a precursor for CuO build-up by electron irradiation:

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

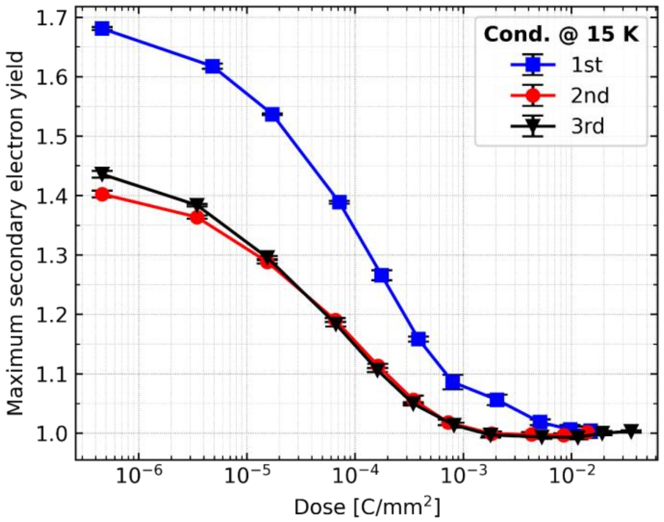
Chemical mapping based on X-Ray Photoelectron Spectrum (XPS)

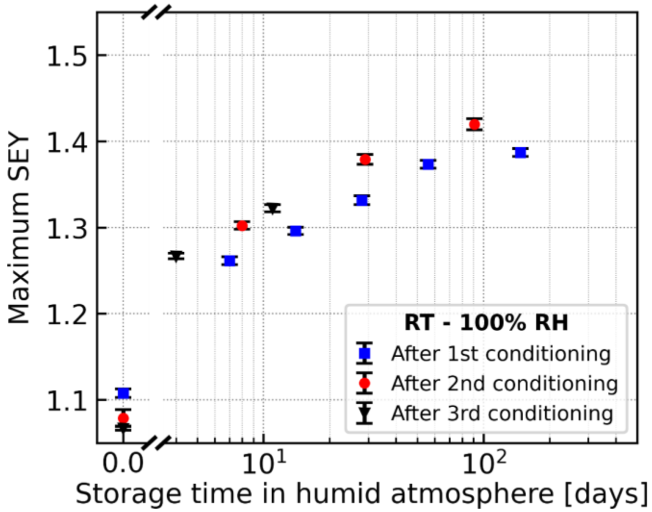


- At RT, $Cu(OH)_2$ is reduced to Cu_2O
- **$Cu(OH)_2$** seems to be a precursor for **CuO build-up at 15 K**

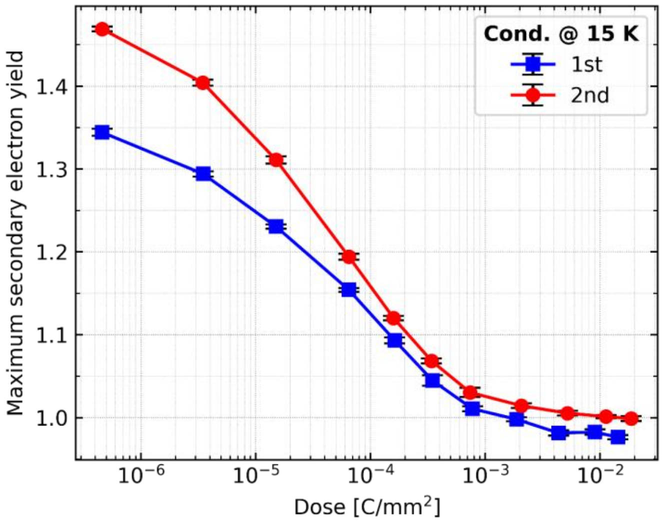
Beam screen treatments - ageing cycles

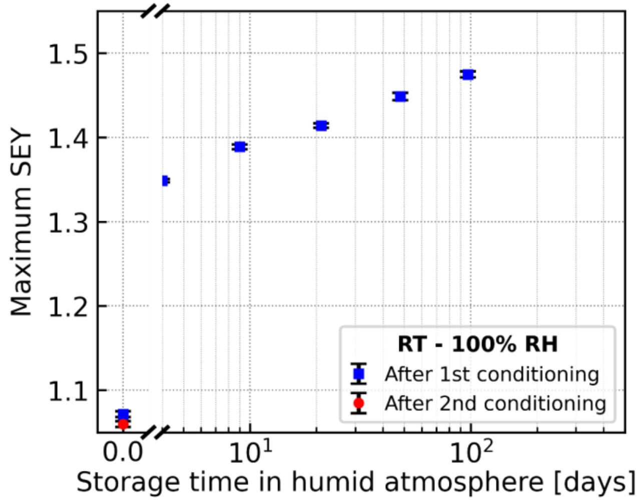
Plasma discharge in C_3H_8



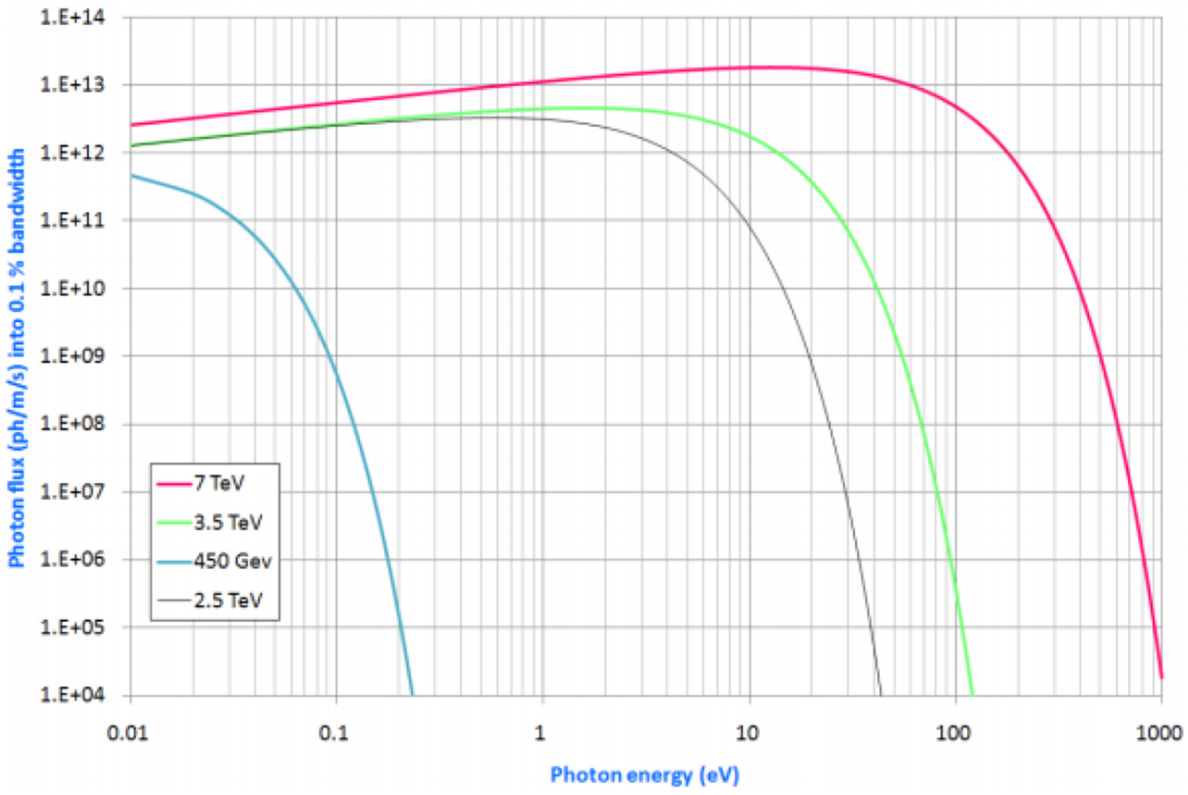


Thin aC coating





Synchrotron radiation spectrum in the LHC



V. Baglin, IPAC 2011

Photoelectron yield – Si wafer at 120 eV

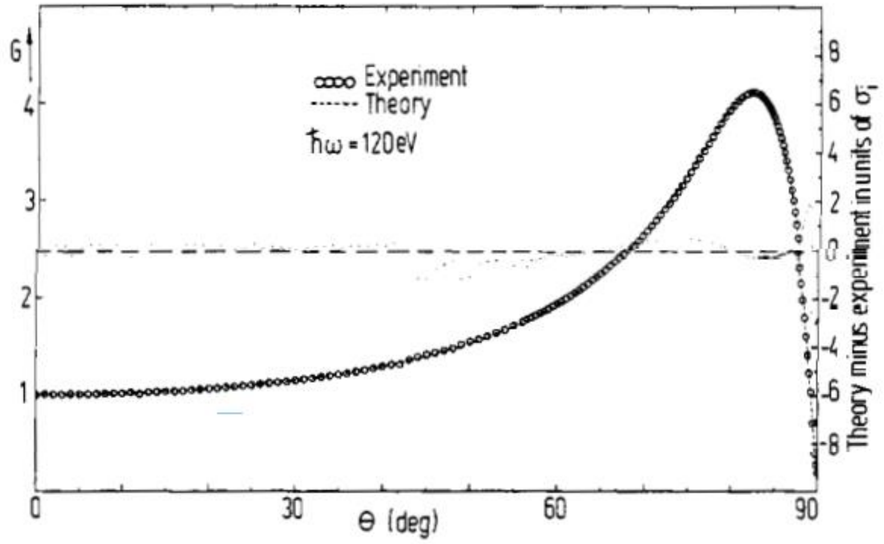


Figure 4. Total photoelectric yield $G(\theta)$ against angle of incidence at $\hbar\omega$ = 120 eV. (○), experimental curve; (---), theory; (···), deviation of theory minus experiment in units of σ_i.

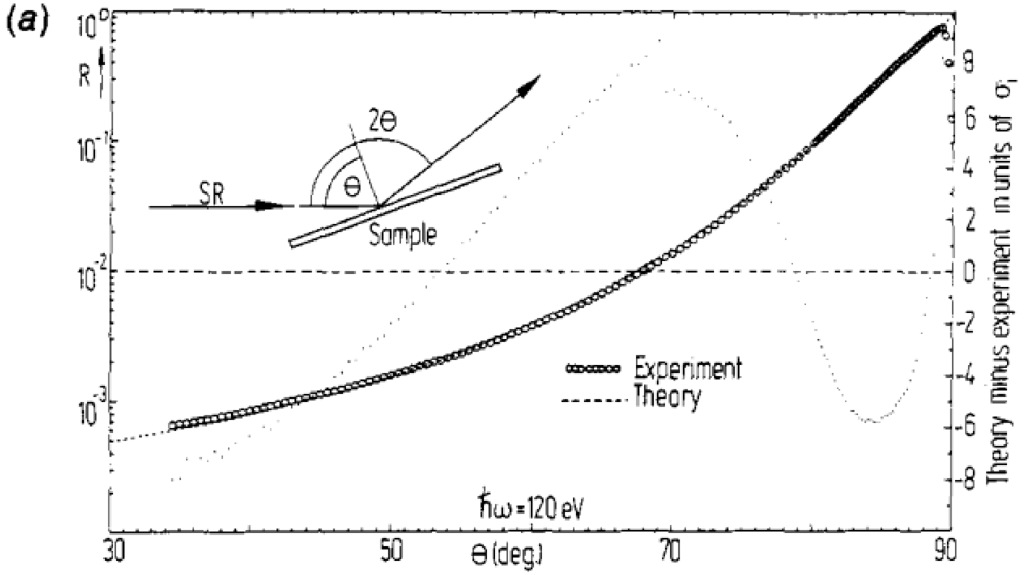


Figure 2. (a) Reflectance $R(\theta)$ against angle of incidence θ at $\hbar\omega$ = 120 eV. (○), measured reflectance of unprepared wafer; (---), fit to experimental curve with bulk model; (···) deviation of theory minus experiment in units of σ_i. Inset shows the principle of reflectance spectra.

F -R Bartsch et al 1990 Semicond. Sci. Technol. 5 974

Kicker beam line material SEY and conditioning

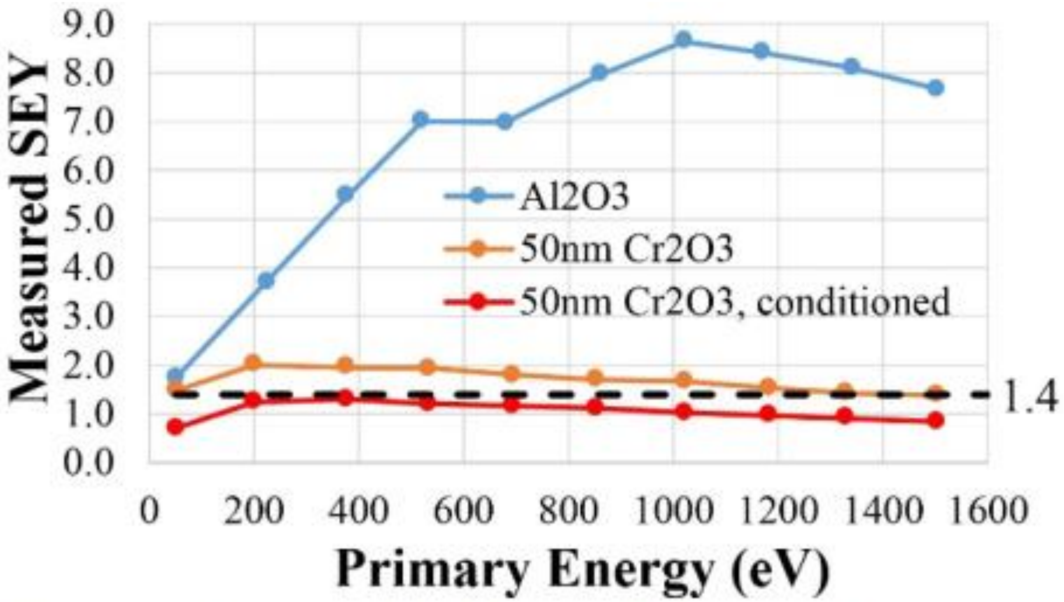


Figure 4: Measured SEY of high purity alumina and alumina with a 50 nm Cr_2O_3 coating: bombarding Cr_2O_3 with electrons reduces δ_{max} to below 1.4 [Measurements courtesy of E. Garcia-Tabares Valdivieso and H. Neupert].

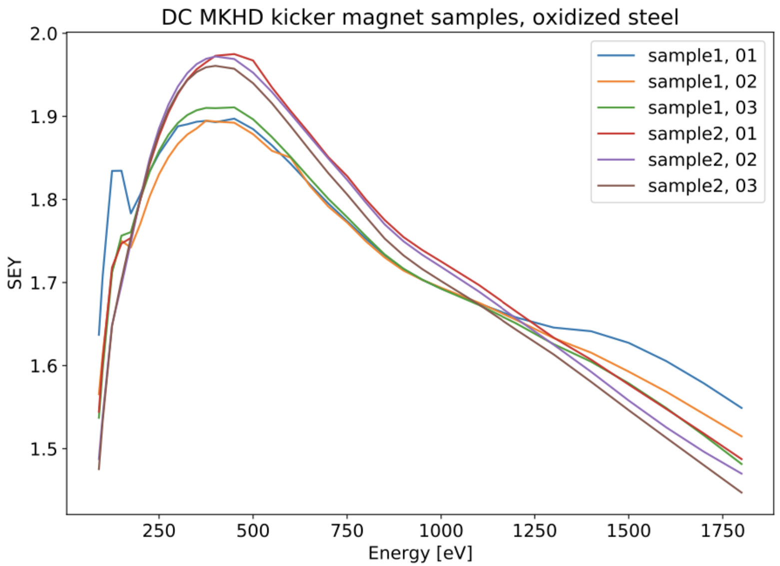


Figure 1: SEY spectra on samples 1 and 2

M. Barnes *et al.* , *J.Phys.Conf.Ser.* 874 (2017) 1, 012101

H. Neupert, SEY measurement report