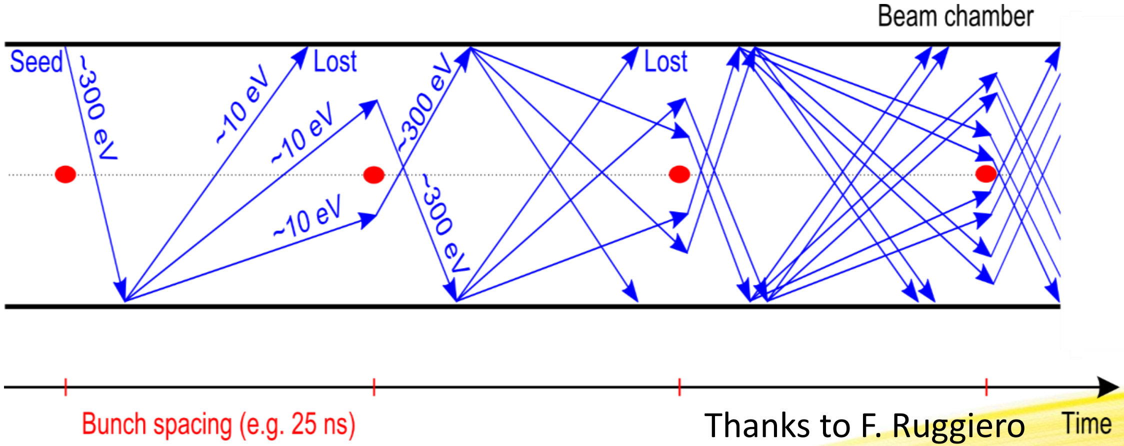
SURFACE EFFECTS FOR ELECTRON CLOUD

R. Cimino LNF-INFN



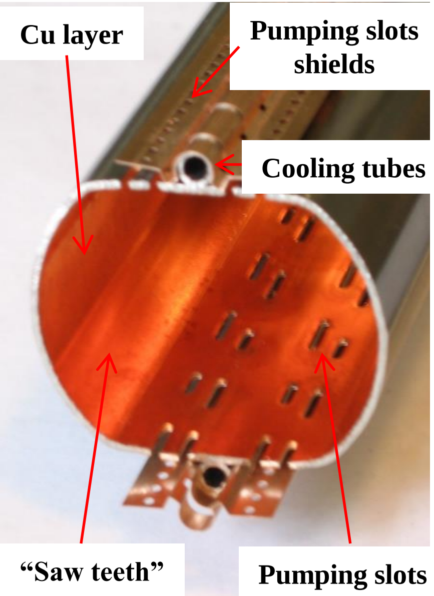
Thanks to F. Ruggiero

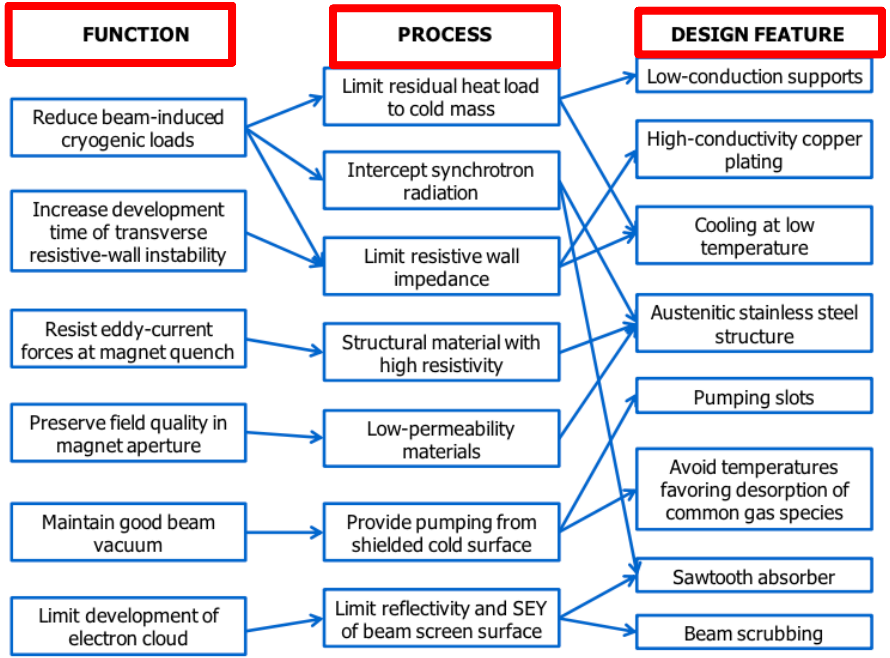
OUTLINE

- ~~Introduction~~:
- E-cloud mitigation methods in a global scenario: compatibility with impedance, vacuum, etc.
- The seed of e^-cloud: number of photoelectrons (PY) and their effect to the surface.
- How surface sensitive is SEY?
  - Role of Temperature, overlayer thickness, etc
- Conclusions

The global scenario: e^- cloud methods must be compliant with all BS features.

For LHC:





FUNCTION

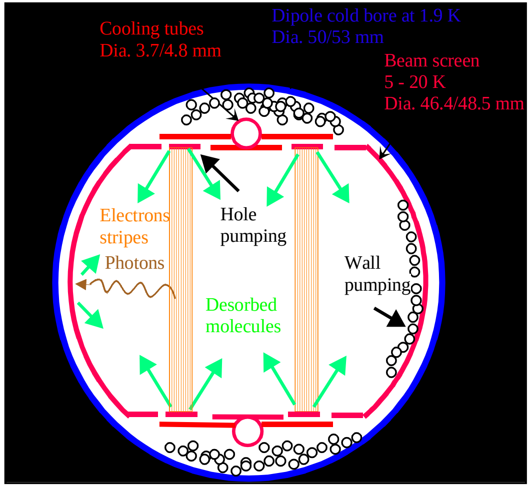
- Reduce beam-induced cryogenic loads
- Increase development time of transverse resistive-wall instability
- Resist eddy-current forces at magnet quench
- Preserve field quality in magnet aperture
- Maintain good beam vacuum
- Limit development of electron cloud

PROCESS

- Limit residual heat load to cold mass
- Intercept synchrotron radiation
- Limit resistive wall impedance
- Structural material with high resistivity
- Low-permeability materials
- Provide pumping from shielded cold surface
- Limit reflectivity and SEY of beam screen surface

DESIGN FEATURE

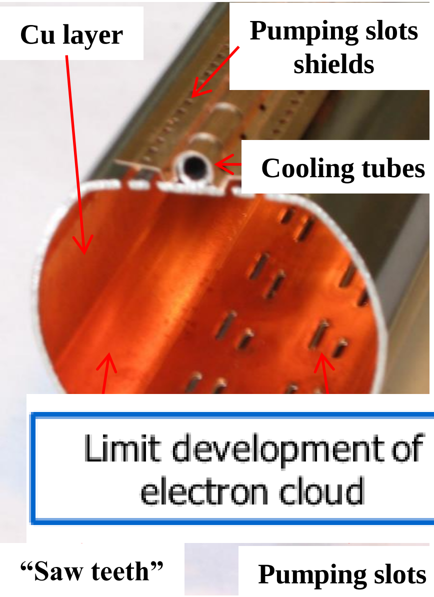
- Low-conduction supports
- High-conductivity copper plating
- Cooling at low temperature
- Austenitic stainless steel structure
- Pumping slots
- Avoid temperatures favoring desorption of common gas species
- Sawtooth absorber
- Beam scrubbing

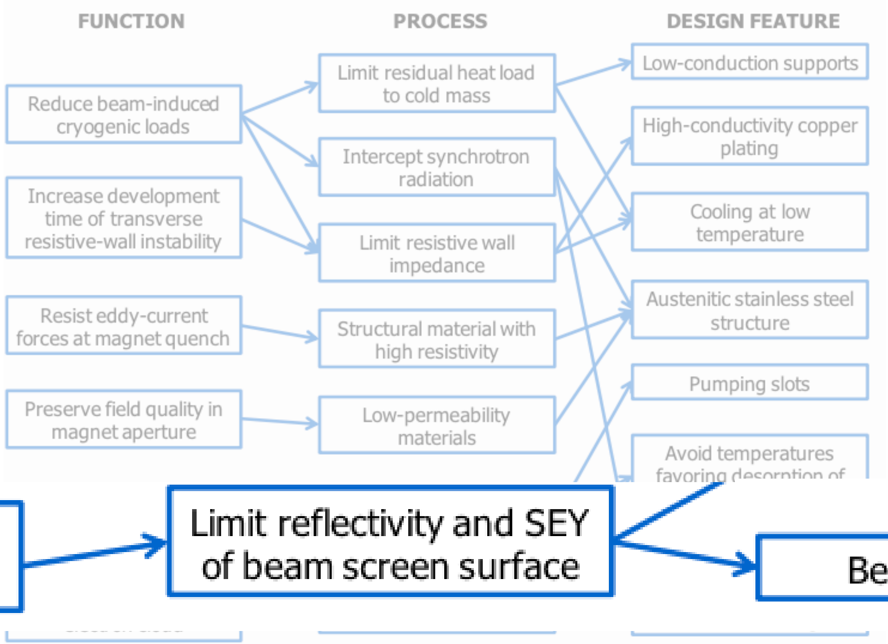


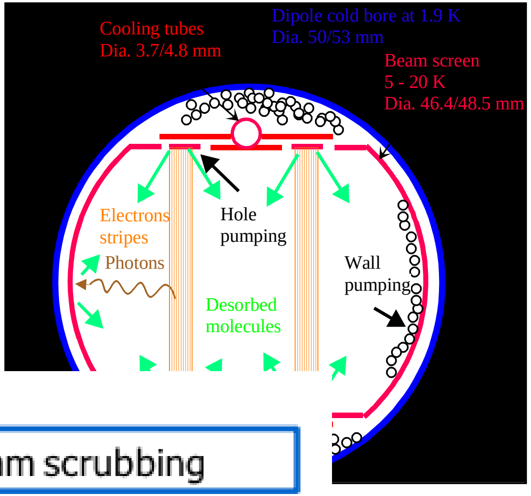
V. Baglin et al. CERN-ATS-2013-006

The global scenario: e cloud methods must be compliant with all BS features.

For LHC:







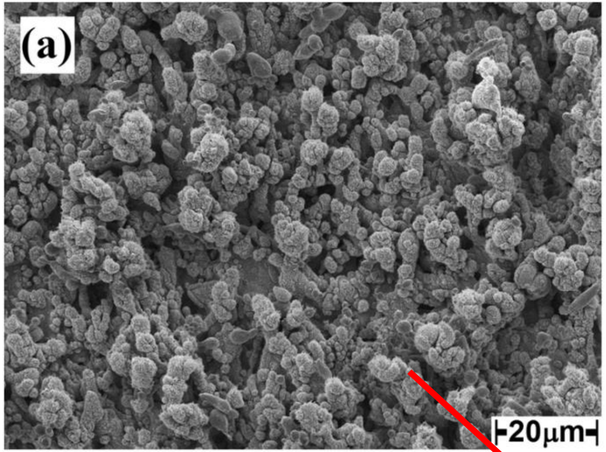
Limit development of electron cloud → Limit reflectivity and SEY of beam screen surface → Beam scrubbing

V. Baglin et al. CERN-ATS-2013-006

Alternative solution: Laser treated materials (see: Oleg Talk)

Limiting SEY with LASE-Cu

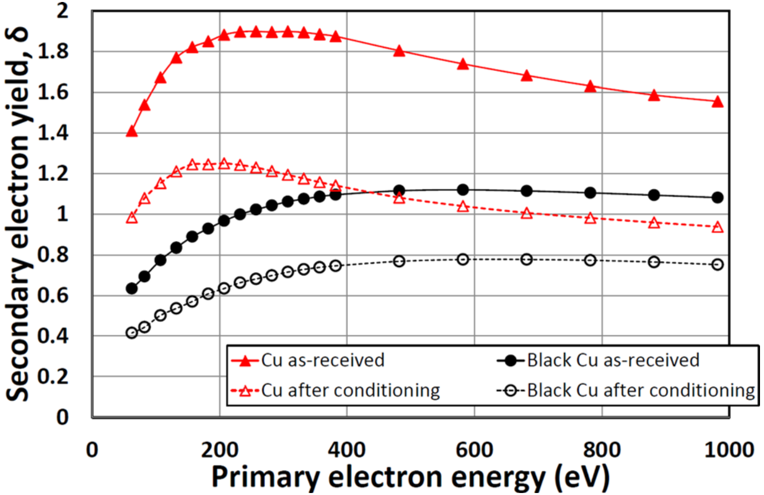
surface morphology of LASE



R. Valizadeh et al. , Appl. Surf. Sci. (2017)

Very low SEY

R. Valizadeh et al. , Appl. Phys. Lett. (2014)



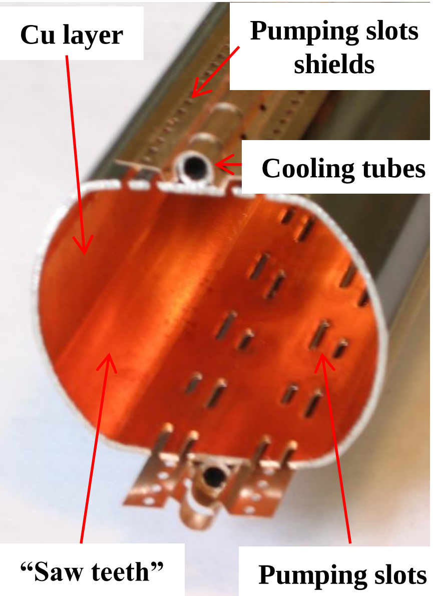
R. Valizadeh, et al. Appl. Phys. Lett. 105, 231605 (2014)

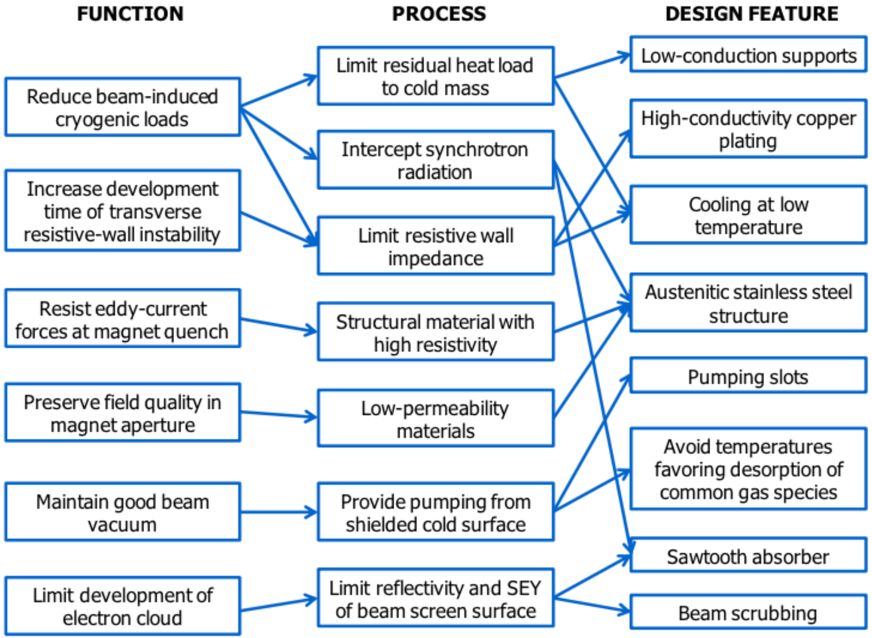
See Oleg Talk

Is it compliant with all BS functionalities?

The global scenario: e cloud methods must be compliant with all BS features.

For LHC:





FUNCTION

- Reduce beam-induced cryogenic loads
- Increase development time of transverse resistive-wall instability
- Resist eddy-current forces at magnet quench
- Preserve field quality in magnet aperture
- Maintain good beam vacuum
- Limit development of electron cloud

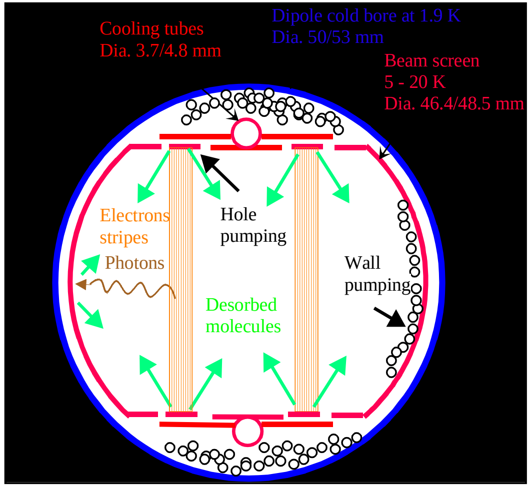
PROCESS

- Limit residual heat load to cold mass
- Intercept synchrotron radiation
- Limit resistive wall impedance
- Structural material with high resistivity
- Low-permeability materials
- Provide pumping from shielded cold surface
- Limit reflectivity and SEY of beam screen surface

DESIGN FEATURE

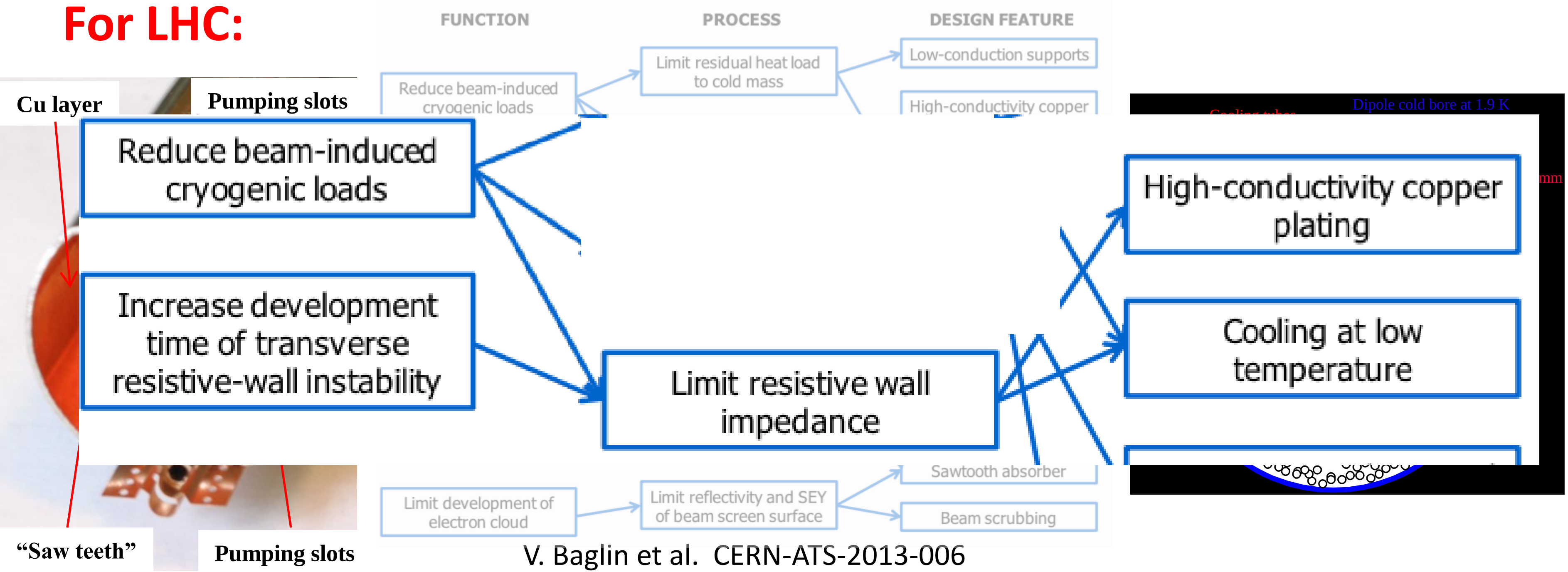
- Low-conduction supports
- High-conductivity copper plating
- Cooling at low temperature
- Austenitic stainless steel structure
- Pumping slots
- Avoid temperatures favoring desorption of common gas species
- Sawtooth absorber
- Beam scrubbing

V. Baglin et al. CERN-ATS-2013-006



The global scenario: e cloud methods must be compliant with all BS features.

For LHC:



FUNCTION

PROCESS

DESIGN FEATURE

Limit residual heat load to cold mass

Low-conduction supports

Reduce beam-induced cryogenic loads

High-conductivity copper

Reduce beam-induced cryogenic loads

Increase development time of transverse resistive-wall instability

Limit resistive wall impedance

High-conductivity copper plating

Cooling at low temperature

Sawtooth absorber

Limit development of electron cloud

Limit reflectivity and SEY of beam screen surface

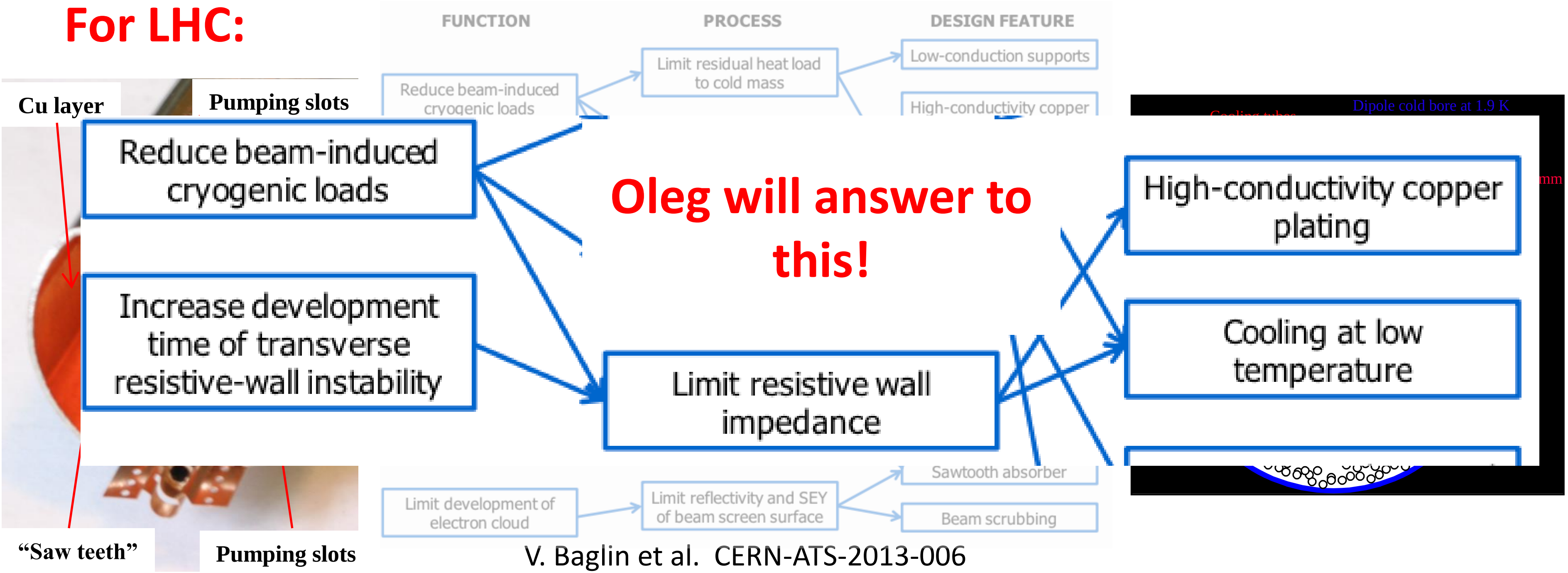
Beam scrubbing

V. Baglin et al. CERN-ATS-2013-006

Impedance issues?

The global scenario: e cloud methods must be compliant with all BS features.

For LHC:



FUNCTION

PROCESS

DESIGN FEATURE

Reduce beam-induced cryogenic loads

Limit residual heat load to cold mass

Low-conduction supports

High-conductivity copper

Reduce beam-induced cryogenic loads

Increase development time of transverse resistive-wall instability

Limit resistive wall impedance

High-conductivity copper plating

Cooling at low temperature

Sawtooth absorber

Limit development of electron cloud

Limit reflectivity and SEY of beam screen surface

Beam scrubbing

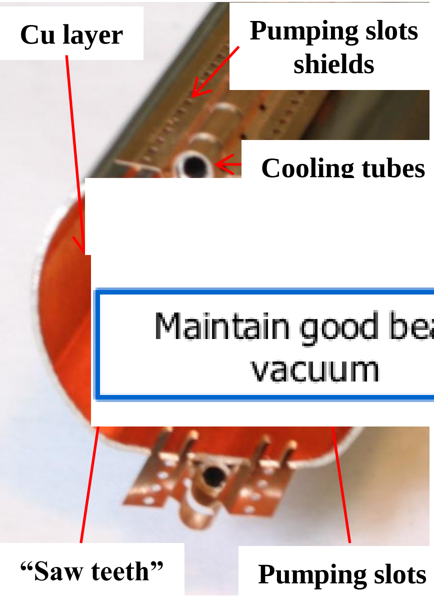
Oleg will answer to this!

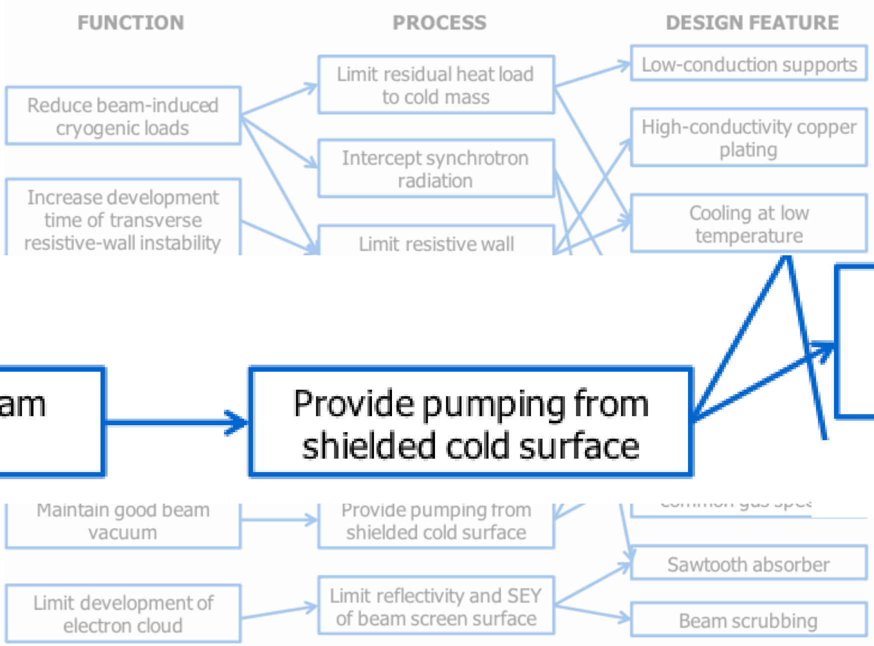
V. Baglin et al. CERN-ATS-2013-006

Impedance issues?

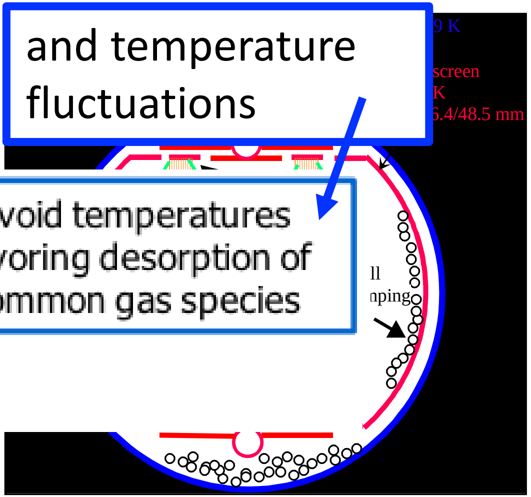
The global scenario: e cloud methods must be compliant with all BS features.

For LHC:





Maintain good beam vacuum → Provide pumping from shielded cold surface → Avoid temperatures favoring desorption of common gas species



and temperature fluctuations

V. Baglin et al. CERN-ATS-2013-006

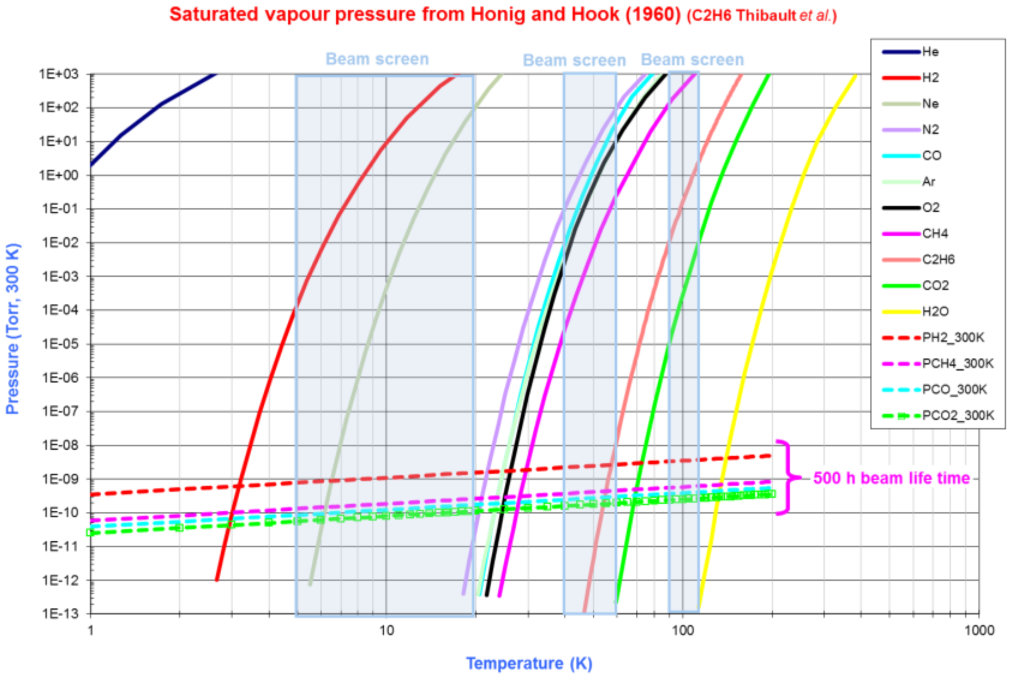
Vacuum issues?

WHEN OPERATING AT LOW TEMPERATURE

LHC
Synchrotron Radiation Power = 0.13 W/m
FCC
Synchrotron Radiation Power = 40 W/m

Working Pressure
($<10^{-11}$ mbar)

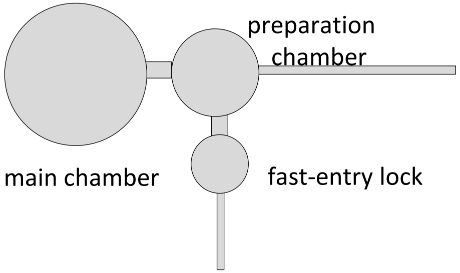
Beam screen
Temperature Range



Independently on the substrate treatment, the thermal stability against small BS T fluctuation has to be guaranteed

We studied thermal stability @ LNF within EuroCirCol collaboration

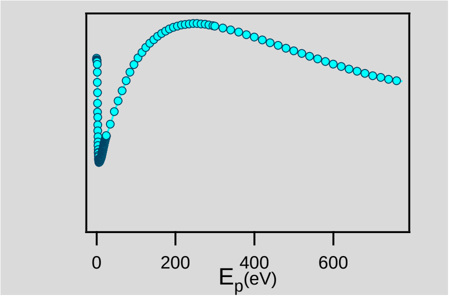
Ultra high vacuum systems

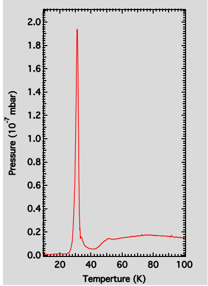


- LNF-cryogenic manipulator
- Sample at **15-300 K**

Secondary Electron Yield (SEY) measurements

Equipment : Electron gun, Faraday cup

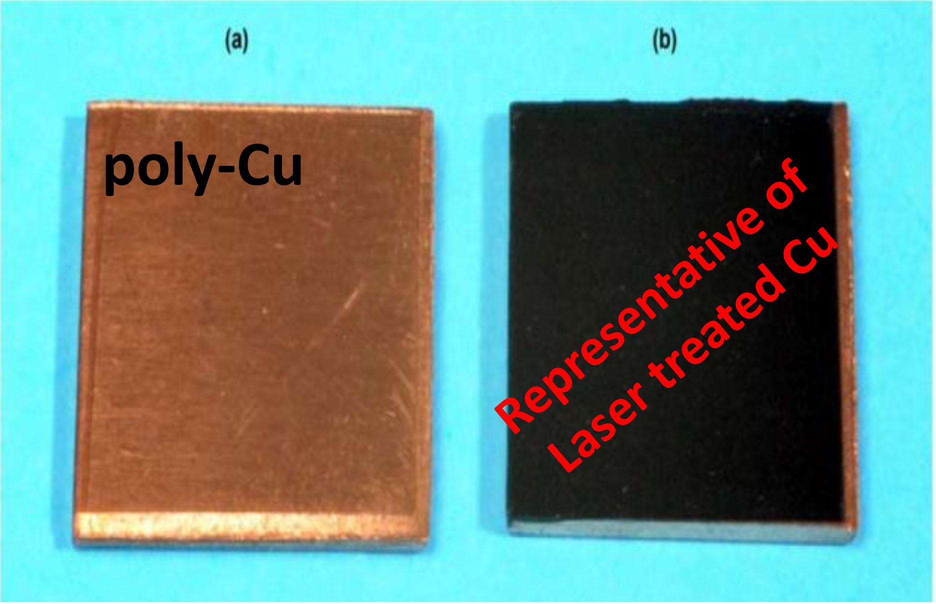




Temperature Programmed Desorption (TPD) and Mass Spectrometry measurements

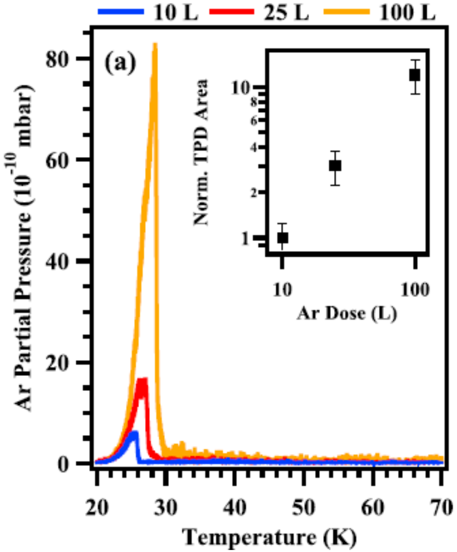
Equipment : QMS (Hiden HAL 101 Pic)

TPD from unbaked lase-Cu for temperature induced vacuum transients study



Comparative study of TPD from flat poly-Cu and LASE-Cu unbaked samples using different gases (Ar, CH_4, CO and H_2)

TPD from unbaked lase-Cu for temperature induced vacuum transients study: Ar



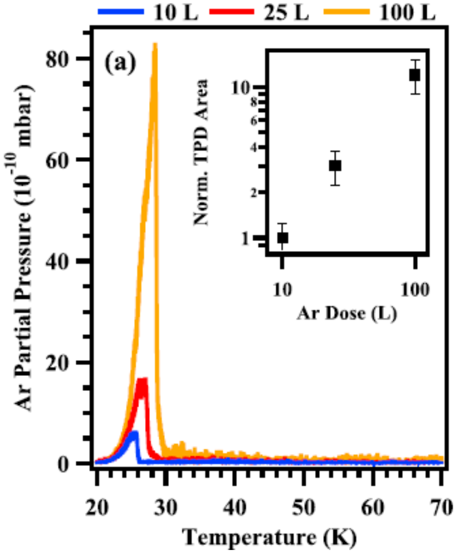
Ar on poly-Cu

Single TPD peak at ~30 K corresponding to the desorption of a condensed thick Ar layer

Desorption temperature determined by the weak Ar-Ar van der Waals interaction energies

L. Spallino, M. Angelucci, R. Larciprete, R. Cimino,
Appl. Phys. Lett. 114, 153103 (2019)

TPD from unbaked lase-Cu for temperature induced vacuum transients study: Ar



Single TPD peak at ~30 K corresponding to the desorption of a condensed thick Ar layer

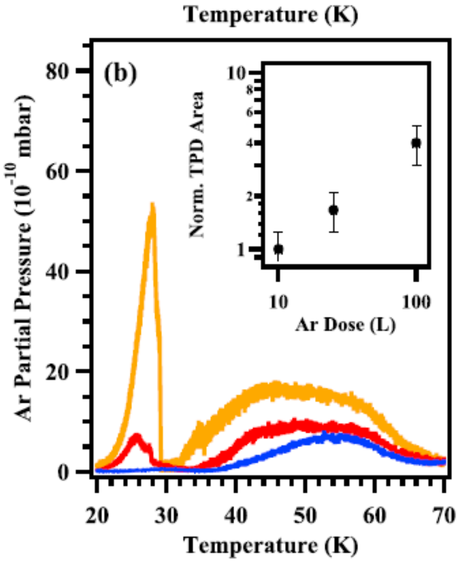
Desorption temperature determined by the weak Ar-Ar van der Waals interaction energies

Ar on poly-Cu

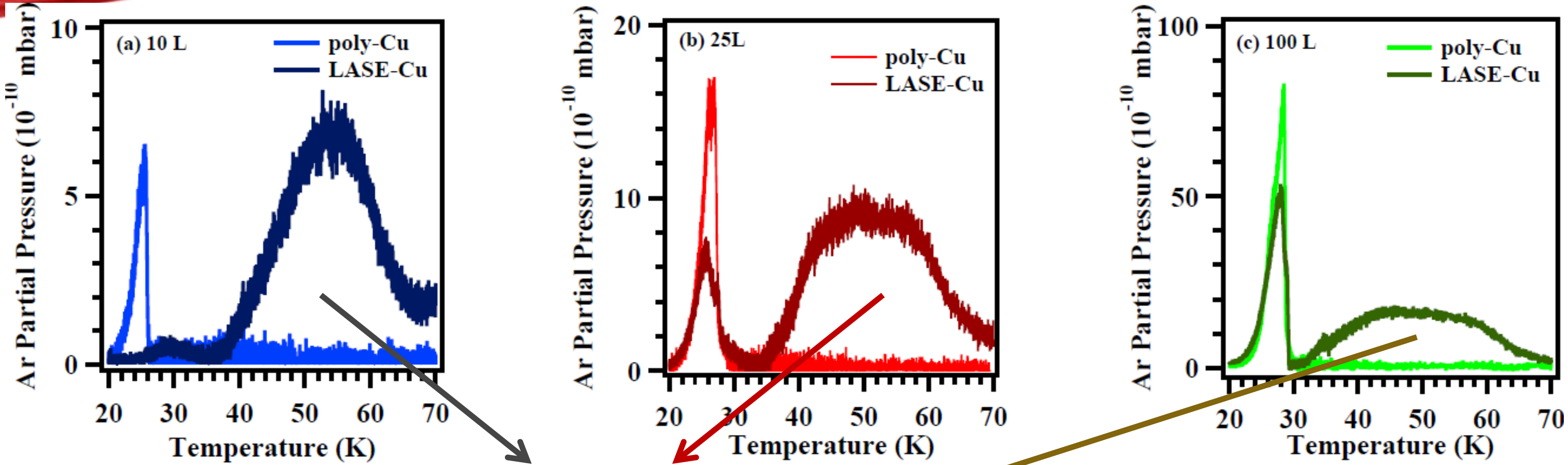
L. Spallino, M. Angelucci, R. Larciprete, R. Cimino, Appl. Phys. Lett. 114, 153103 (2019)

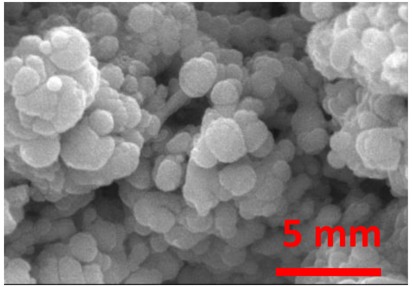
Ar on LASE-Cu

TPD peak at ~30 K corresponding to the desorption of a condensed thick Ar layer together with a broad TPD profiles, whose peak temperatures and widths depend on the Ar dose



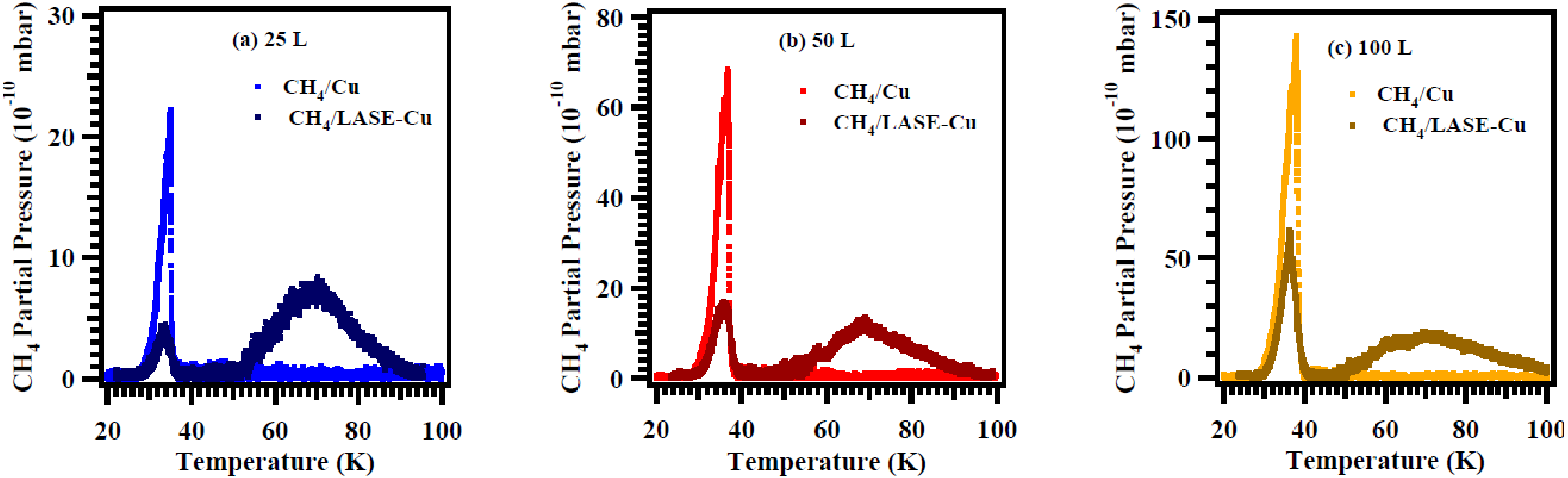
TPD from unbaked lase-Cu for temperature induced vacuum transients study: Ar





TPD characteristics determined by the sponge-like structural features of LASE-Cu

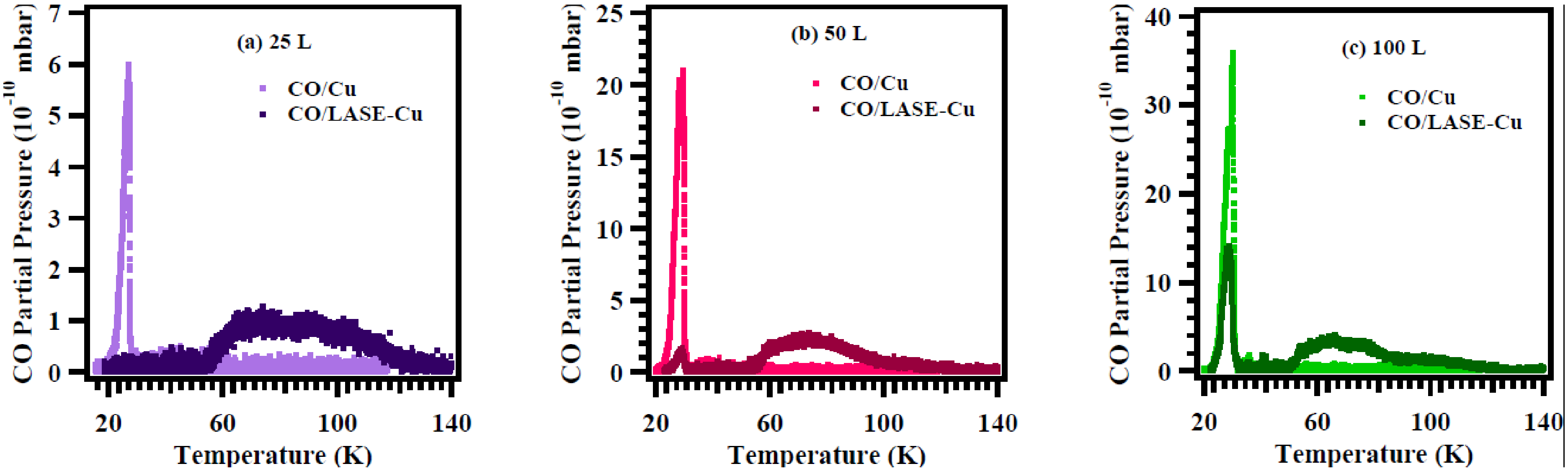
TPD from unbaked lase-Cu for temperature induced vacuum transients study: CH_4



L. Spallino, M. Angelucci and R. Cimino, to be published

Conceptually identical results have been obtained with CH_4

TPD from unbaked lase-Cu for temperature induced vacuum transients study: CO



L. Spallino, M. Angelucci and R. Cimino, to be published

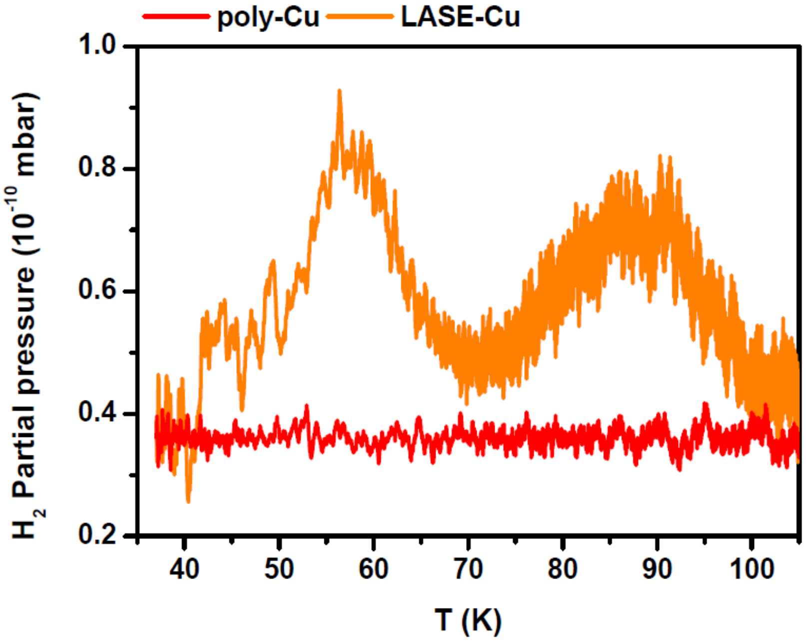
Conceptually identical results have been obtained with CO

TPD from unbaked lase-Cu for temperature induced vacuum transients study: H_2

TPD of 100 L H_2 dosed on poly-Cu and LASE-Cu samples held at T~15-18 K

No TPD signal should be observed by considering the H_2 vapor suture pressure curve!!!

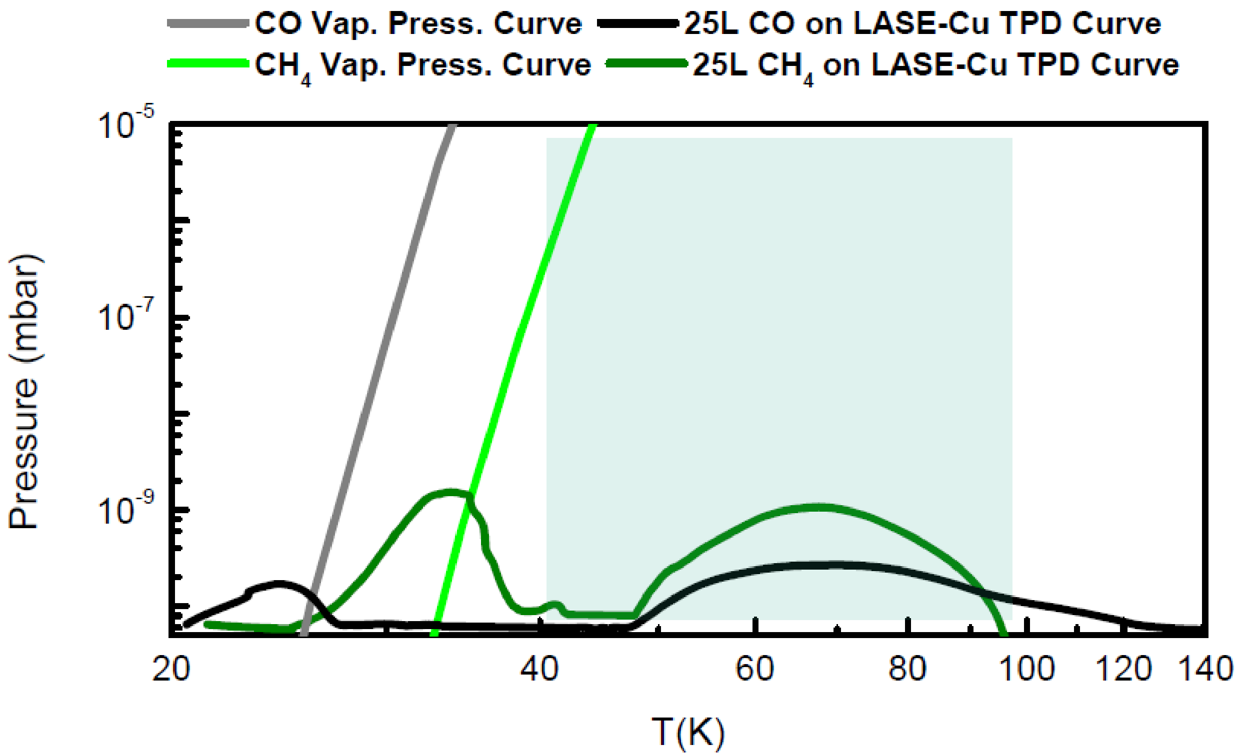
The wide distribution of high energy adsorption sites within the inner pore is responsible for the H_2 TPD signal from LASE-Cu sample



L. Spallino, M. Angelucci and R. Cimino, to be published

TPD from unbaked lase-Cu for temperature induced vacuum transients study

Saturated vapour pressure from Honig and Hook (1960)



L. Spallino, M. Angelucci and R. Cimino, to be published

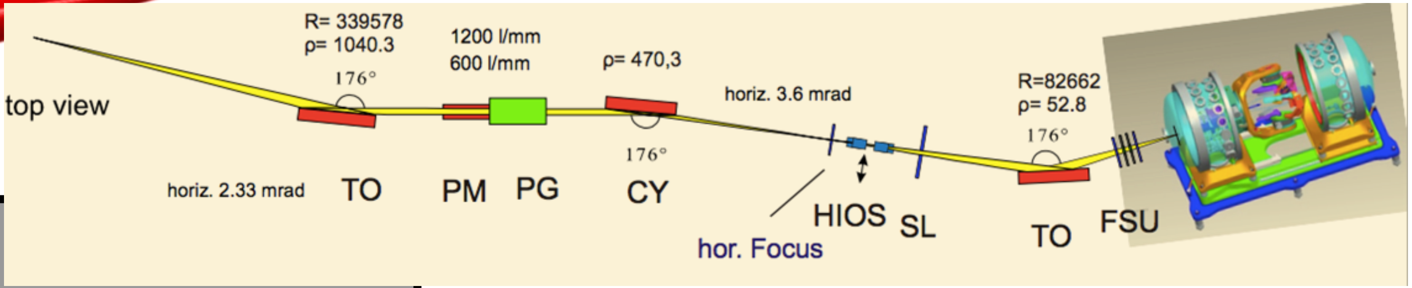
Further studies and electron/photon stimulated desorption are necessary to validate/optimize LASE-Cu at low T.

Low SEY AND Low impedance AND Vacuum compatibility, etc. must be granted!

OUTLINE

- ~~Introduction~~:
- E-cloud mitigation methods in a global scenario: compatibility with impedance, vacuum, etc.
- **The seed of e$^-$cloud (and of single bunch inst.): number of photoelectrons (PY) and their effect to the surface.**
- How surface sensitive is SEY?
  - Role of Temperature, overlayer thickness, etc
- Conclusions

We can measure PY and R in operational conditions



Experimental Parameters

- Phot. Energy range 35÷1800 eV
- Beam height h=0.3 mm
- Incident Beam measurement
- GaAsP Photodiodes (4x4mm) (0.1*4mm)
- Incident angle 0.25, 0.5, 1°

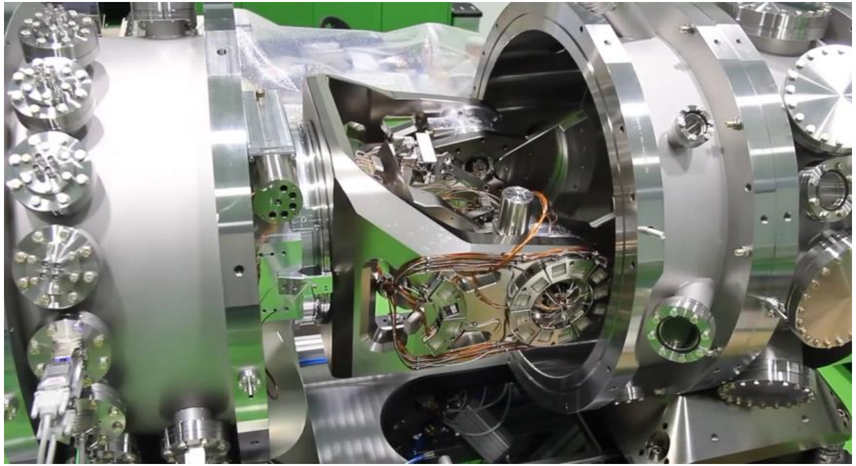
The Beamline

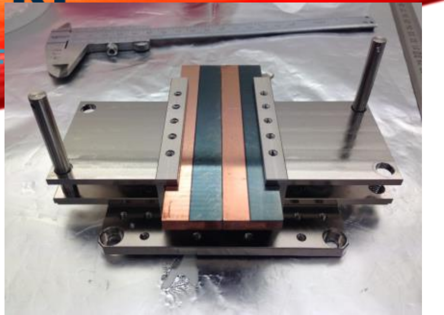
A. Sokolov, et al., Journal of Synchrotron Radiation 25, 100 (2018).

The Reflectometer

A.A.Sokolov,et al,Proc.of SPIE92060J-1-13(2014)

Axis	Hardware	Range	Pos. accuracy
Azimuth angle β	HUBER 430	-180° - 180°	3.6“
Sample angle θ	HUBER 411	-90° - 270°	3.6“
Detector angle 2θ	HUBER 411	-180° - 180°	3.6“
Detector off-plane (2 axes)	Ceramic motors	-25 mm – 25 mm (-4° - 4°)	50 nm
Sample Adjustment Tx, Ty, Tz	Ceramic motors	-20 mm – 20 mm (not simul.)	500 nm
Sample Adjustment Rx, Ry, Rz	Ceramic motors	-10° - 10° (not simul.)	1“





The sample studied:

Cu (different Roughness)

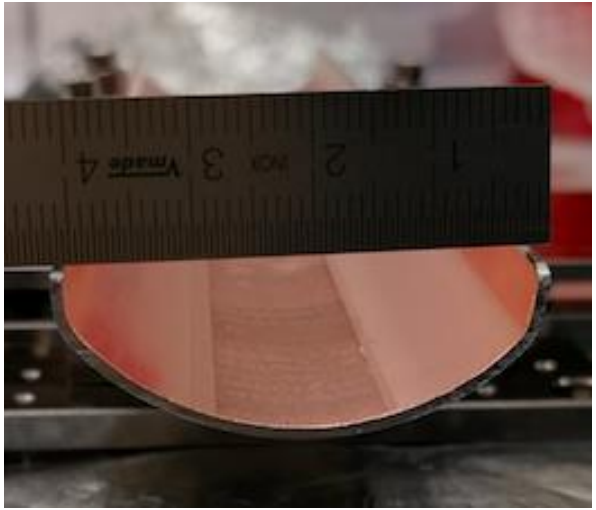
LHC - Saw Tooth

LASE

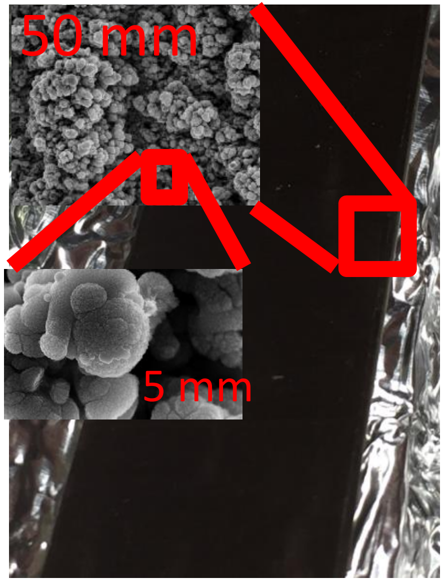
Cu+ amorphous Carbon Thin Film

And: NEG, Stainless Steel, ...

Cu LHC



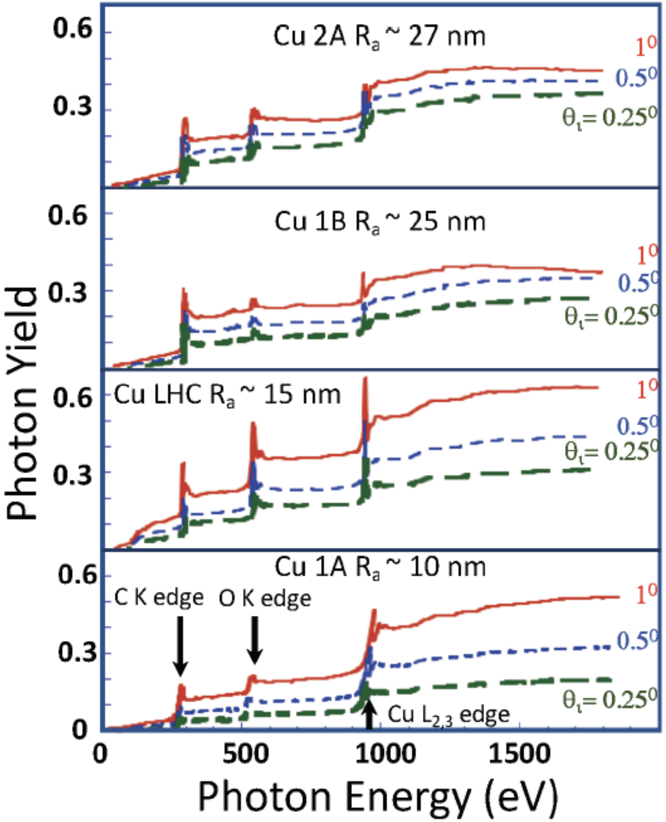
LHC Saw Tooth



LASE Cu

Selected results: Photo Yield

- In all cases, PY is higher at higher photon energies.
- The PY dependence on θ_i is consistently dimmed and finally washed out when surface Ra is increasing.
- In all cases, the Cu-L2-3 absorption edge at 930-950 eV is visible and cause an increase in the measured PY.
- In all spectra we measure a significant effect due to the C K-edge at 280 eV and O K-edge at 530 eV (surf. Contaminants)
- Roughness does influence the PY. The lower is Ra, the highest is the measured PY.



E. La Francesca et al: submitted to PR ST

Photon interaction studies (RT) @ DAΦNE-L

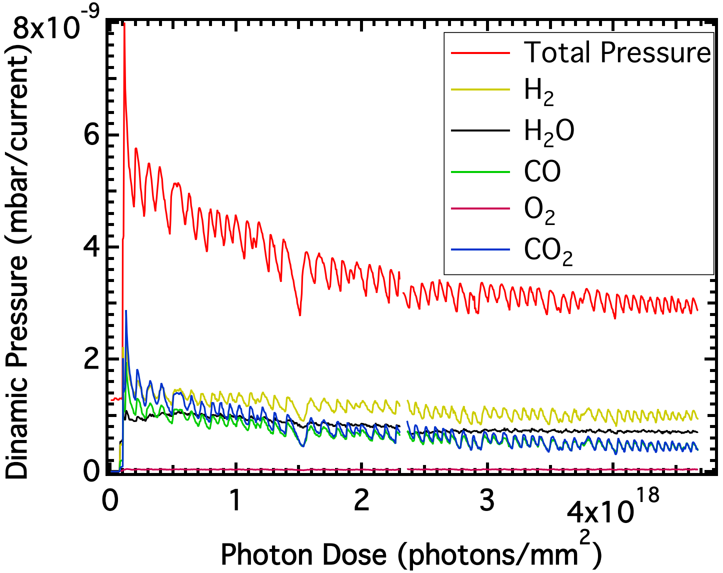
Photo Stimulated Desorption

Pressure Evolution

Surface Chemistry Changes
(Conditioning)

Photon / Electron Scrubbing comparison

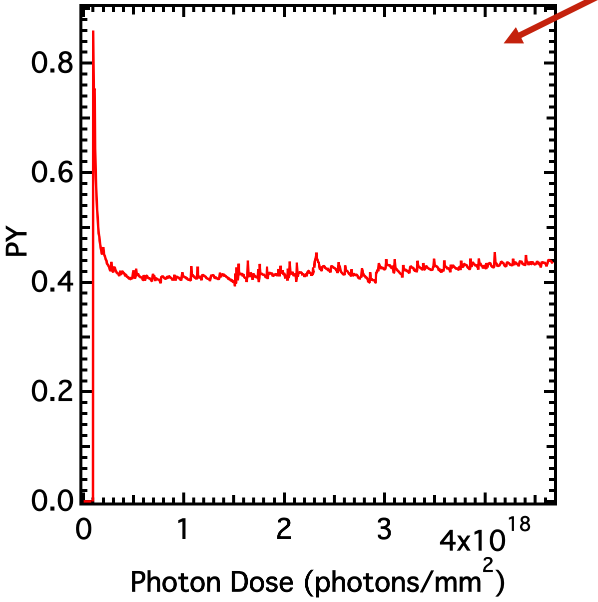
Preliminary results on PSD from small samples @ DAΦNE

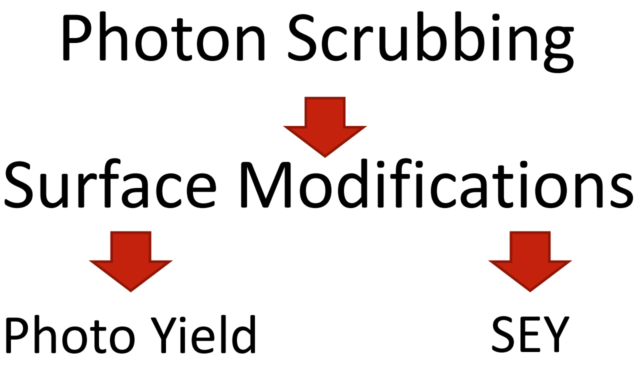


Photon interaction studies (RT) @ DAΦNE-L

<u>Preliminary results</u>
from small samples

Studied on the same surface





Photon Scrubbing

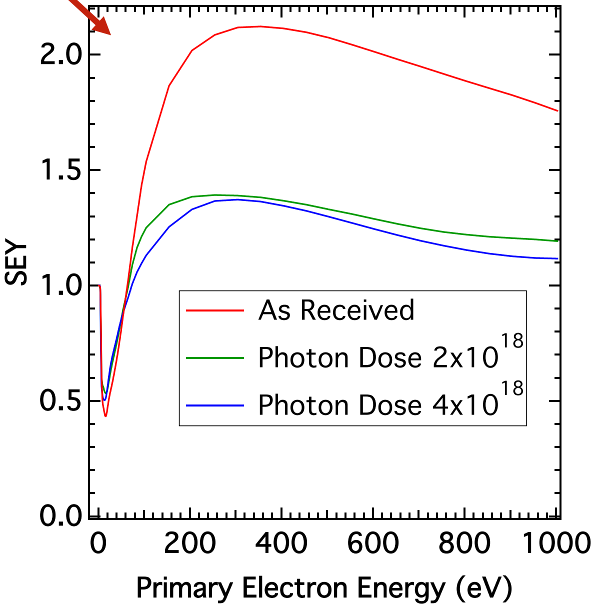
Surface Modifications

Photo Yield

SEY

Strong variation of surface conditions at “low dose”

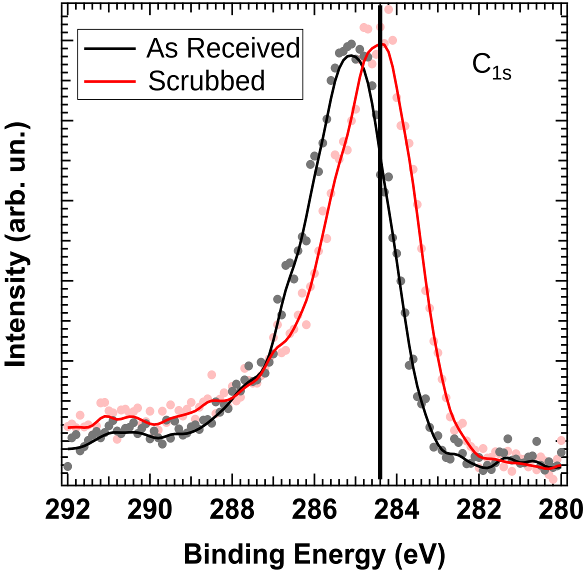
Slow variations at “high doses”



Finale State <u>SEY=1.3</u>

Photon interaction studies (RT) @ DAΦNE-L

XPS



Still in progress!

Surface Modifications

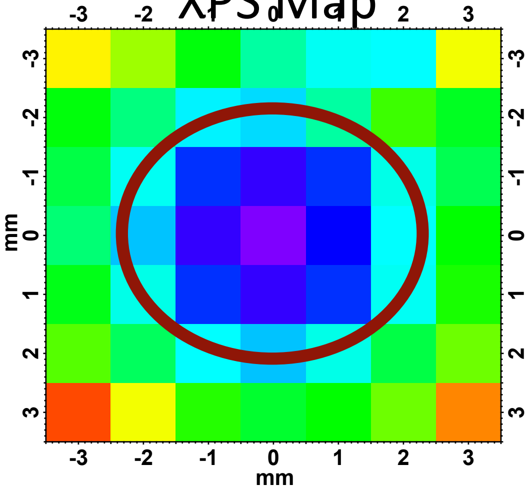
Modification of Carbon C-1s
From sp^3 to sp^2

Same chemical process of Electron Scrubbing

But SEY_{Max} Decreases to 1.3 as for low energy electrons

Preliminary results

XPS Map



Scrubbing Area

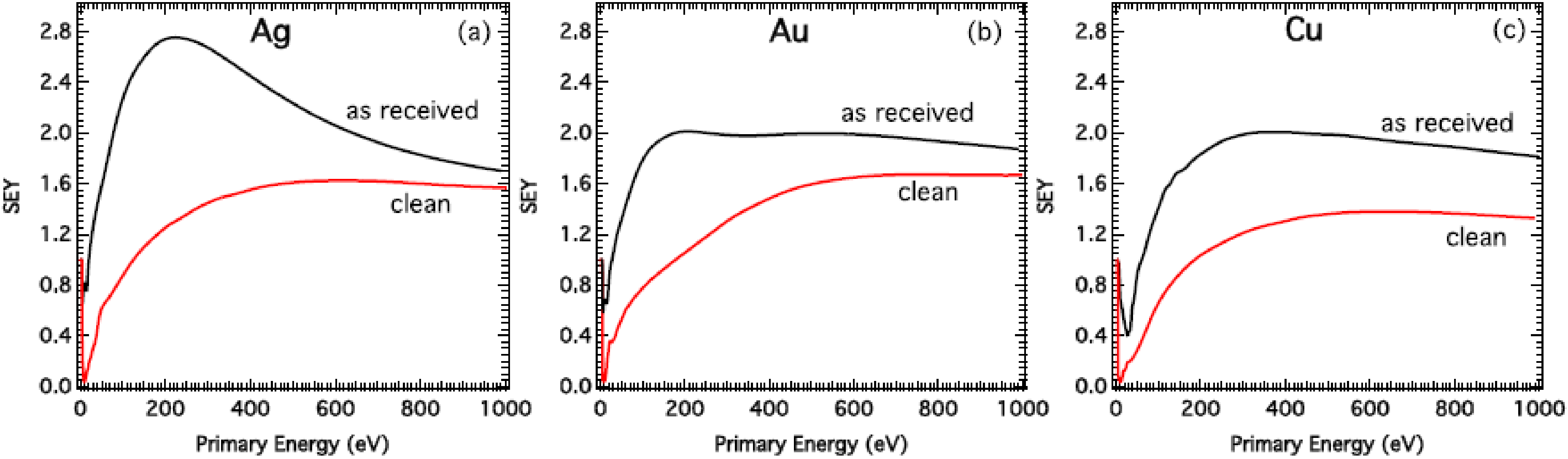
Spot Dimension

OUTLINE

- ~~Introduction~~:
- E-cloud mitigation methods in a global scenario: compatibility with impedance, vacuum, etc.
- The seed of e^-cloud: number of photoelectrons (PY) and their effect to the surface.
- How surface sensitive is SEY?
  - Role of Temperature, overlayer thickness, etc
- Conclusions

SEY behavior is strongly influenced by the chemical state of the surface

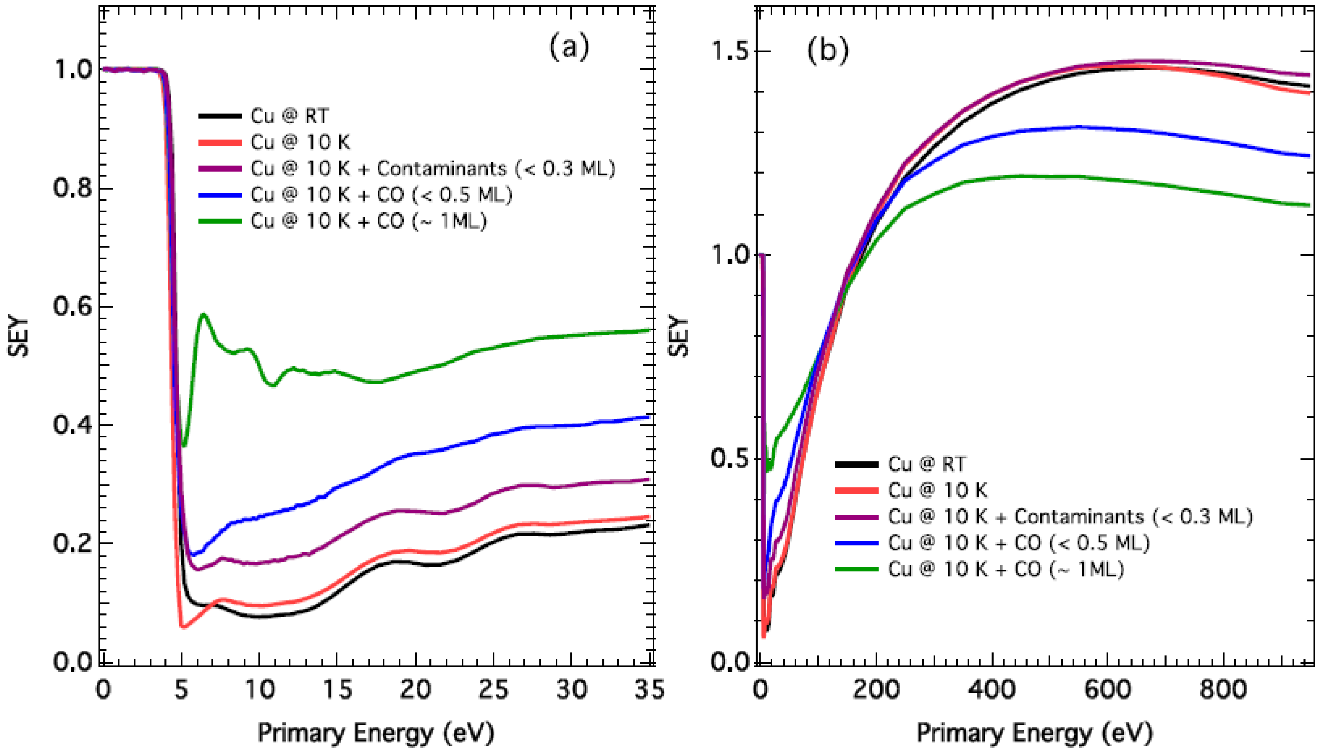
L. A. Gonzalez et al., AIP Adv. (2017)



Contaminants from atmosphere ~ 5 - 20 nm

SEY at LT (20 K) ~ SEY at RT but...

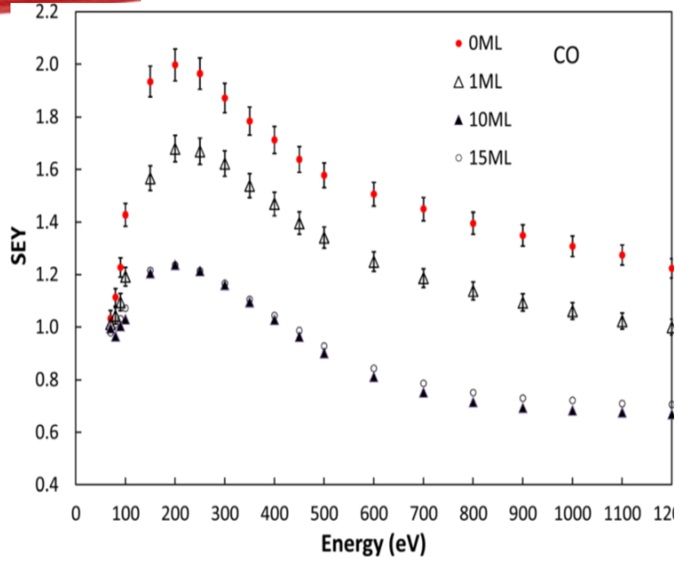
L. A. Gonzalez et al., AIP Adv. (2017)



- ➢ SEY is highly sensitive to the presence of adsorbates, even at sub-monolayer coverages
- ➢ SEY of cold surfaces influenced by gas physisorption

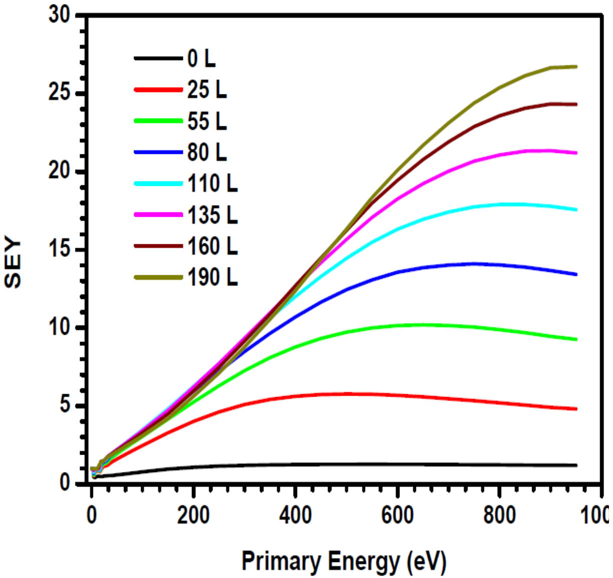
SEY Surface sensitivity: gases on LT Cu

CO thick layer coverage



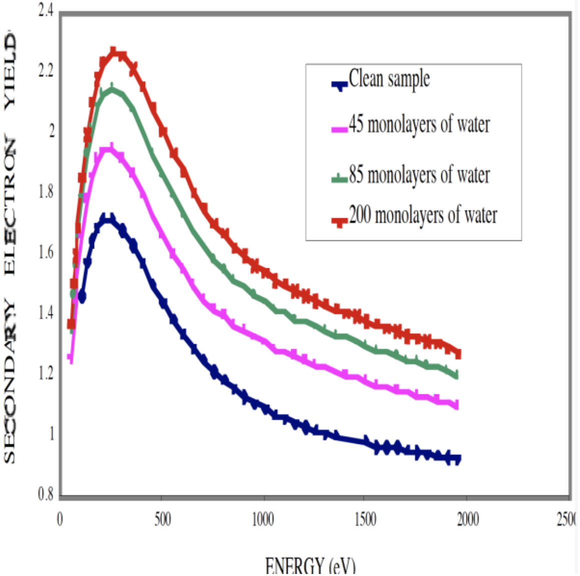
Kuzucan et al., J. Vac. Sci. Technol. A (2012)

Ar thick layer coverage



L. Spallino, M. Angelucci and R. Cimino, to be published

H_2O thick layer coverage



V . Baglin, et al Proceedings of EPAC 2000, Vienna, Austria

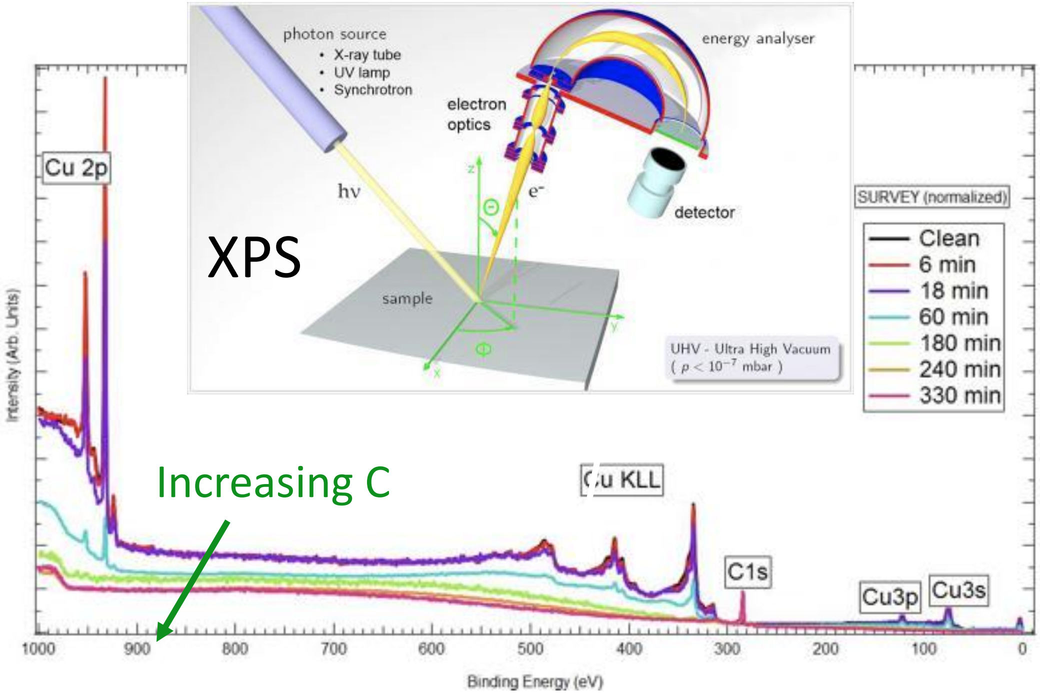
SEY is an intrinsic material property strongly sensitive to the surface composition and chemical state

Element and coverage specific

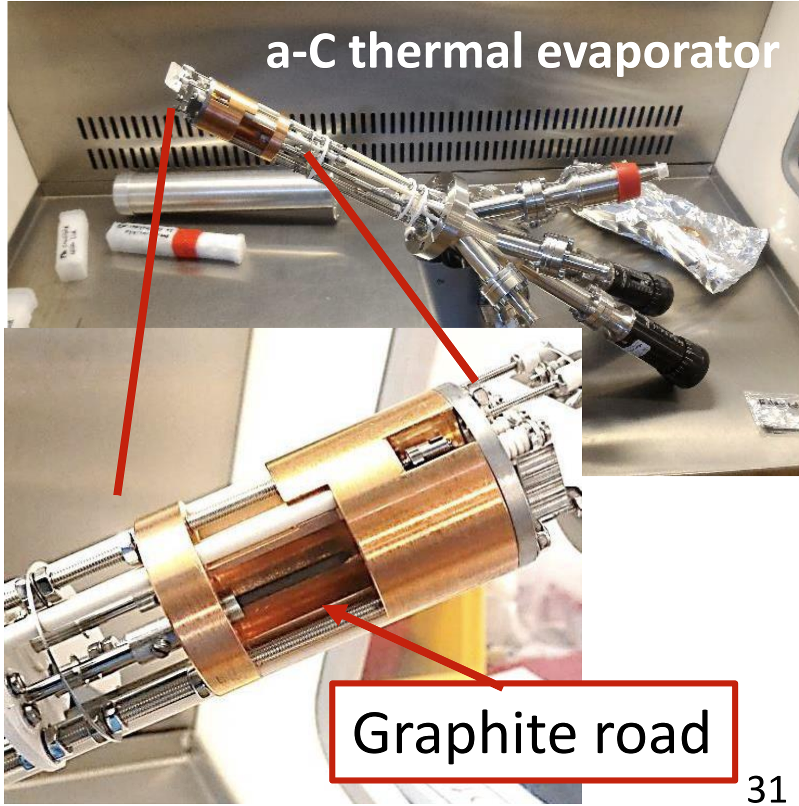
HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-*Preliminary*-

We followed the growth of thin a-C layers on Cu with XPS to measure its thickness



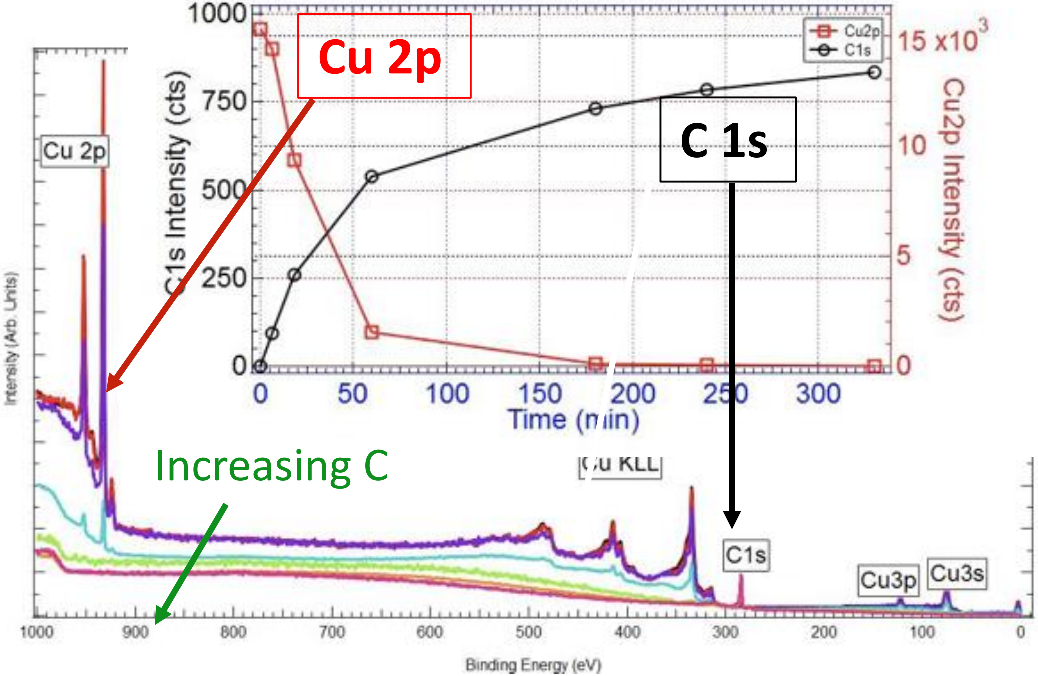
A. Novelli et al., in preparation



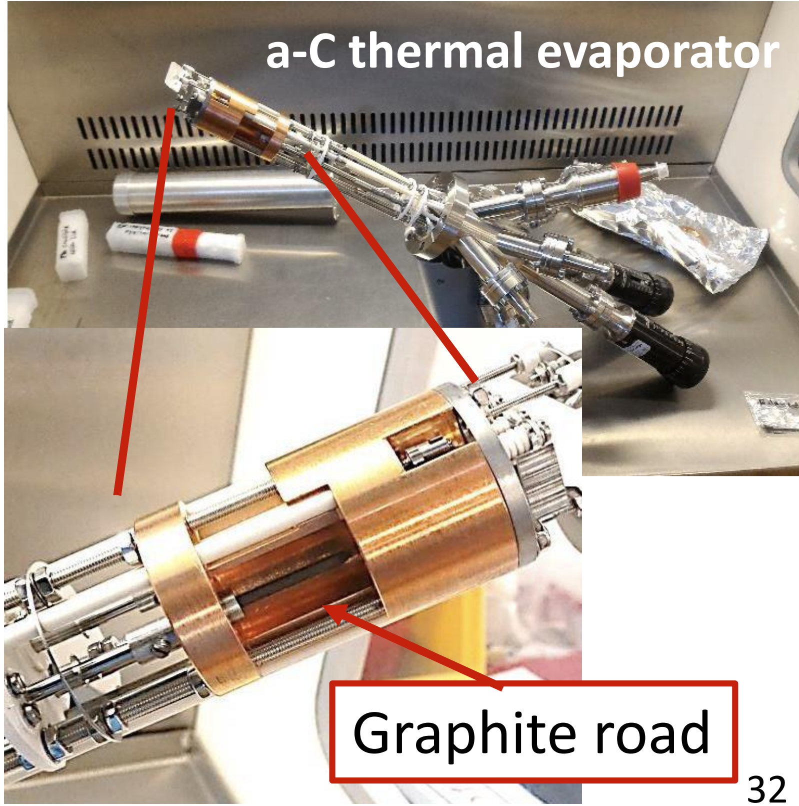
HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-Preliminary-

We followed the growth of thin a-C layers on Cu with XPS to measure its thickness



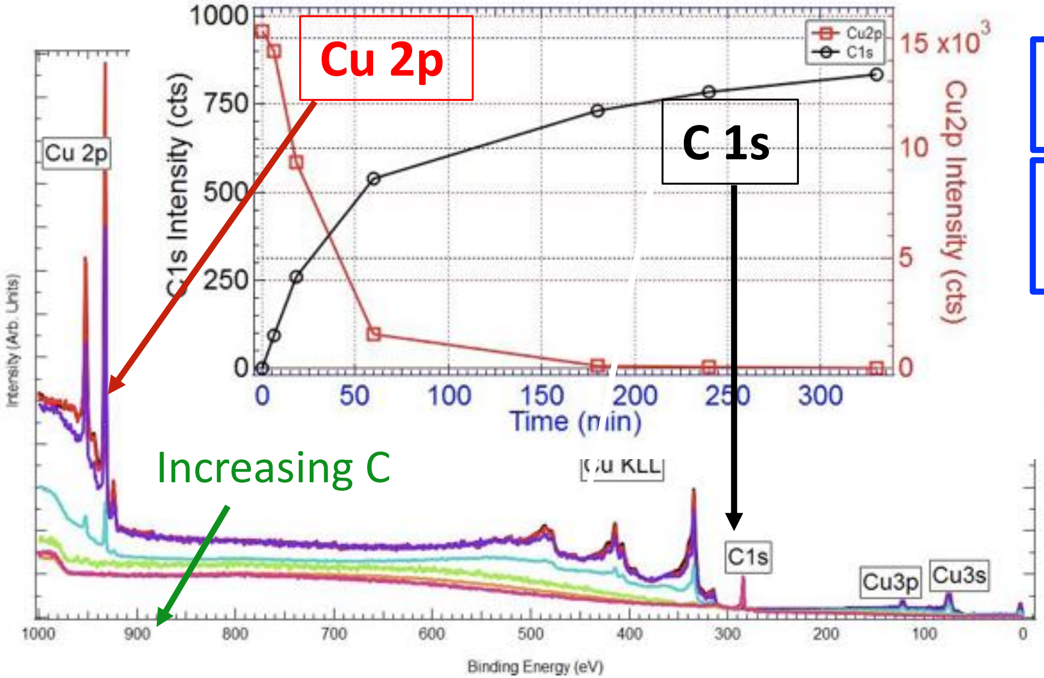
A. Novelli et al., in preparation



HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-*Preliminary*-

We followed the growth of thin a-C layers on Cu with XPS to measure its thickness



A. Novelli et al., in preparation

In XPS:

$$I_{Cu}^{C} = (I_{Cu,bulk}^{C})*\exp(-d/\lambda_{Cu,C})$$

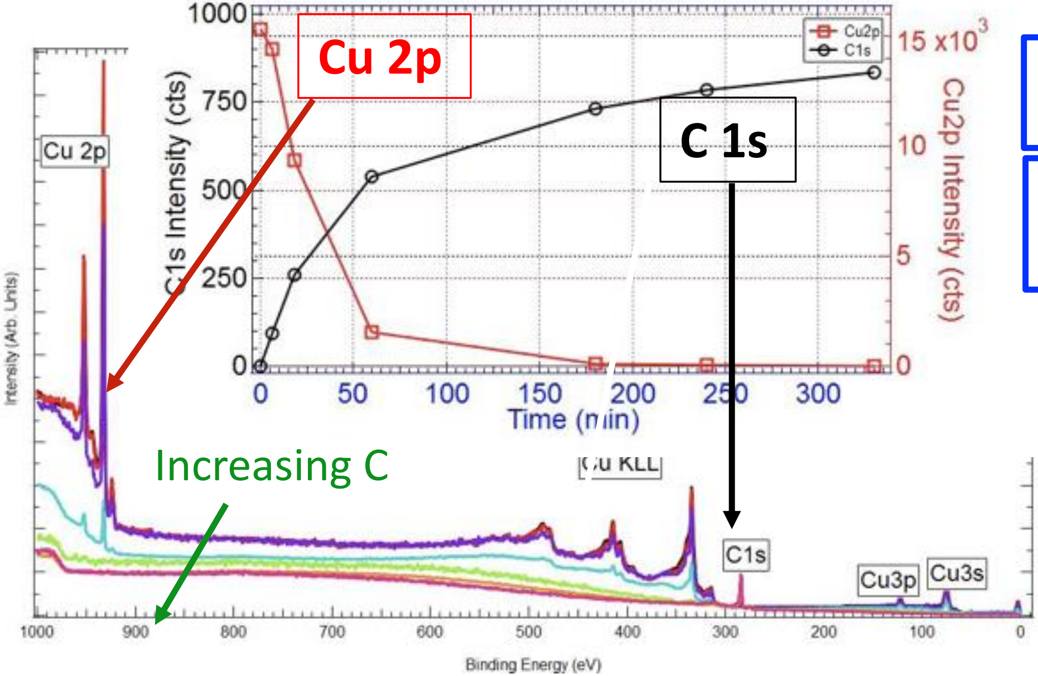
$$I_{C}=I_{C,bulk}*(1-\exp(-d/\lambda_{C,C}))$$

where **d** is the unknown thickness and λ is the inelastic mean free path.

HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-Preliminary-

We followed the growth of thin a-C layers on Cu with XPS to measure its thickness



A. Novelli et al., in preparation

In XPS:

$$I_{Cu}^{C} = (I_{Cu,bulk}^{C})*\exp(-d/\lambda_{Cu,C})$$

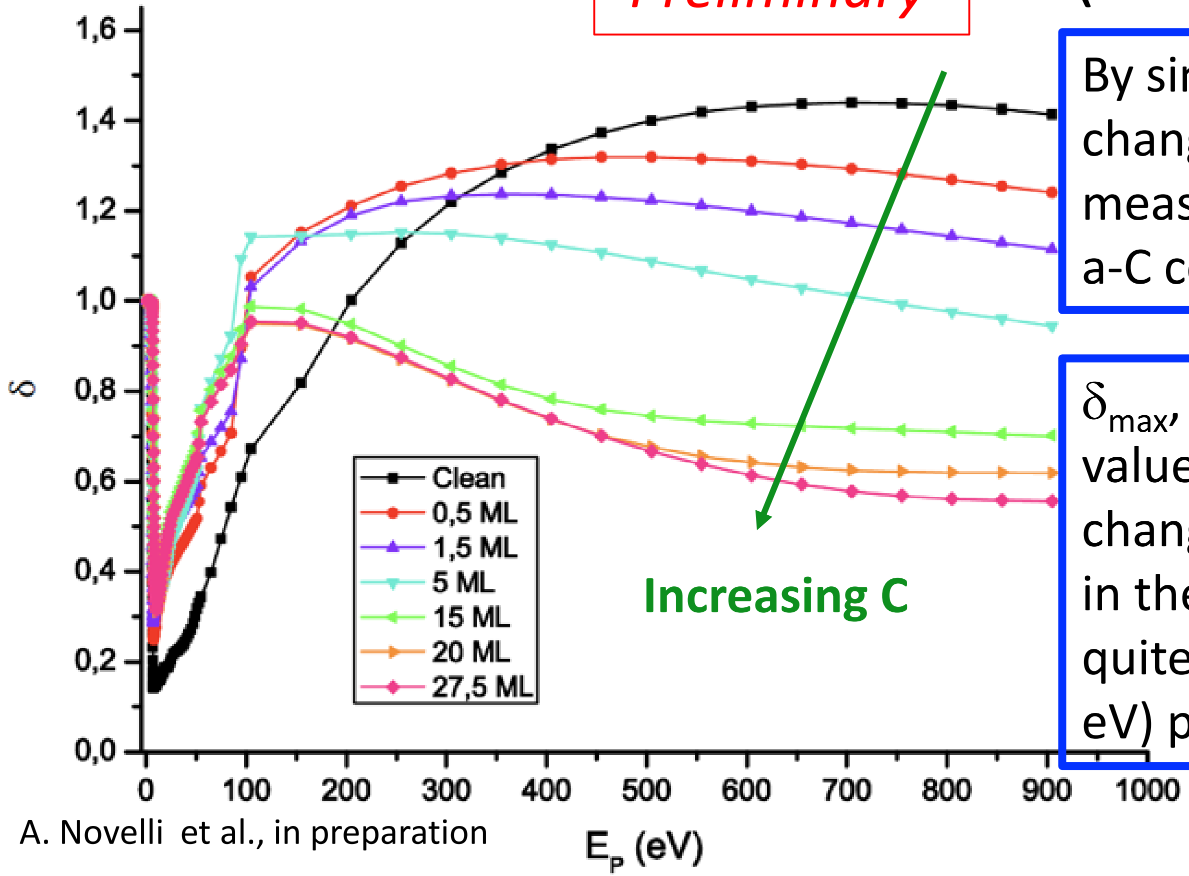
$$I_{C}=I_{C,bulk}*(1-\exp(-d/\lambda_{C,C}))$$

where **d** is the unknown thickness and **λ** is the inelastic mean free path.

We also calibrate the 1ML Carbon signal with the one emitted from Gr/Cu (1 Ml)

HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-Preliminary-



Increasing C

A. Novelli et al., in preparation

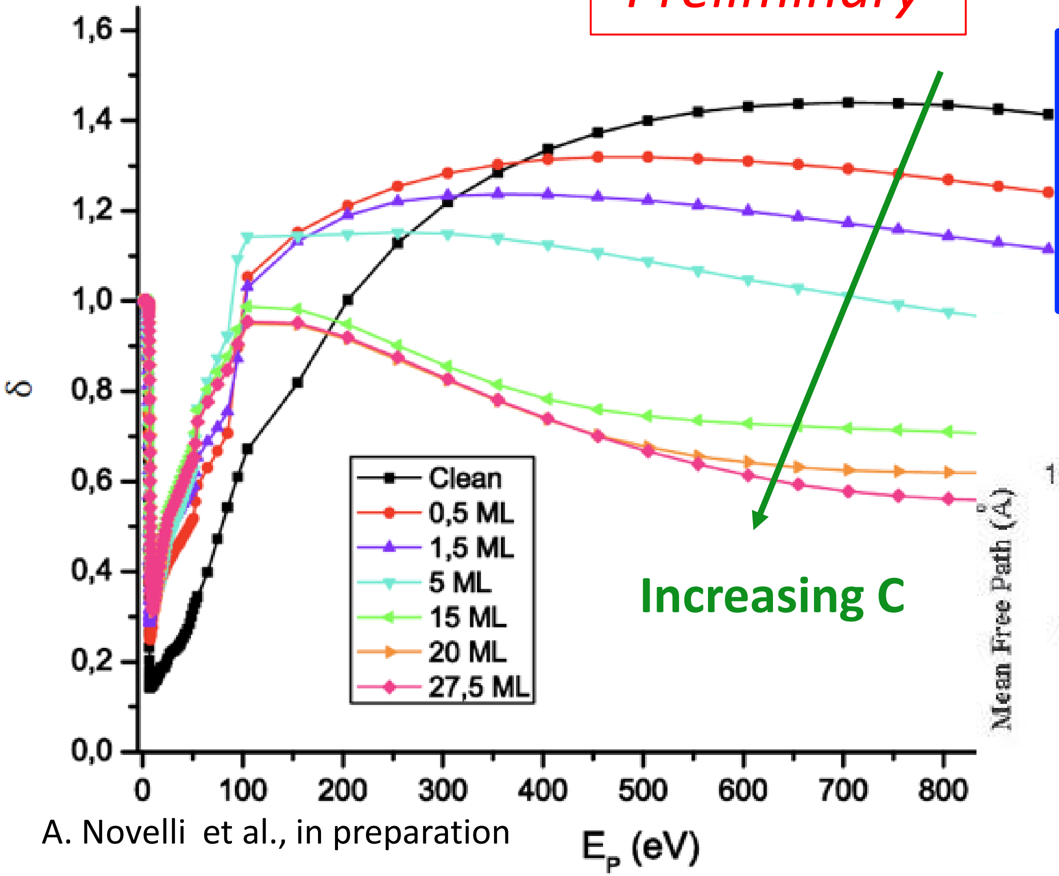
By simultaneously follow SEY changes with a- C thickness we can measure SEY dependence on actual a-C coverage.

δ_{max}, E_{max} sets to their (a-C) final values quite soon, while minor changes still occurs at higher doses in the very low (< ~ 20 eV) and quite high primary energy (> ~400 eV) part.

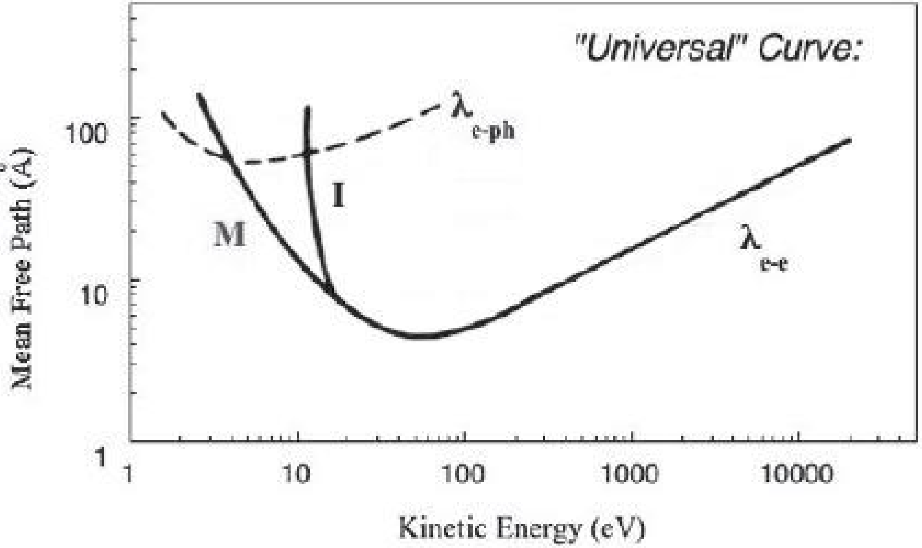
HOW A COATING MODIFY SEY?
(the case of a-C on Cu)

-*Preliminary*-

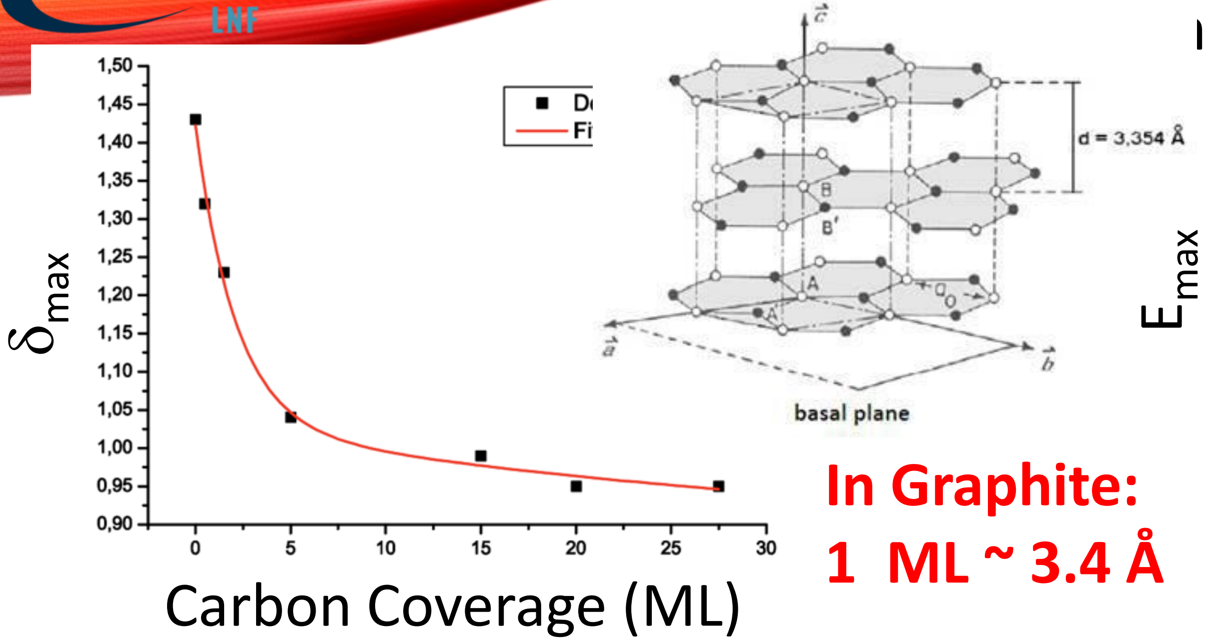
By simultaneously follow SEY changes with a- C thickness we can measure SEY dependence on actual a-C coveradge.



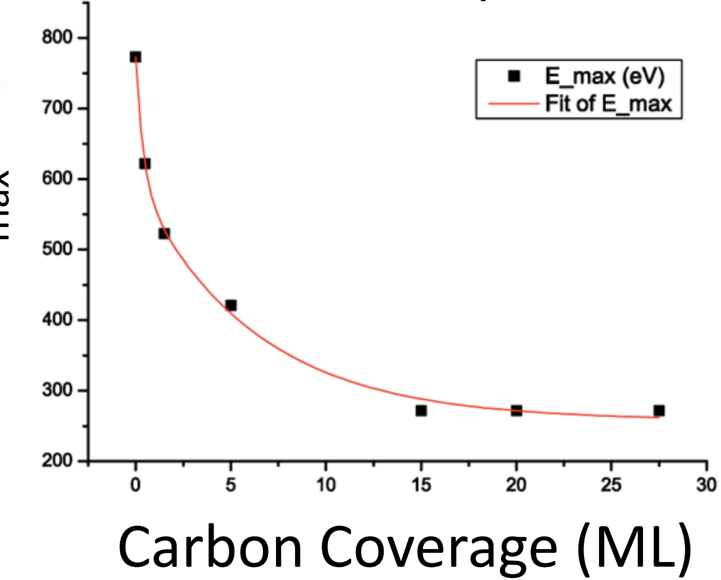
A. Novelli et al., in preparation



HOW A COATING MODIFY SEY?
ıe case of C on Cu)



In Graphite:
1 ML ~ 3.4 Å



Could follow d_{max} vs C coverages

Could follow E_{max} vs C coverages

➔ 15-20 Ml (~ 5-6 nm) of a-C determines SEY properties.

A. Novelli et al., in preparation

DO WE LEARN SOMETHING ON SCRUBBING?

- To have a fully scrubbed Surface, we need more than 5-6 nm of (low SEY) a- C covering our surface.
- Original Contaminant thickness depends on the material and material cleaning. (can be between 4 to 20 nm)
- During irradiation (ph and e^-) both desorption and substrate chemical modifications occurs.
- Are we always sure that we are left with the minimum C coverage to reduce SEY below 1.1 ?
- Why photons and low energy electrons (below 50 eV) behaves differently than high energy electrons (above 50 eV up to 3keV)?

CONCLUSIONS

- All new materials should be validated in all aspects in a global approach.
- Laboratory experiments have been and must be refined.
- Material studies in conditions as close as possible to operating ones (preparation, Low Temperature & geometry) is mandatory.
- There are still open aspects in the scrubbing process.
- Very thin coatings (about 6 nm for a-Carbon) are enough to completely reduce clean poly - Cu SEY to the one of a-C.

Thank you for your attention

Thanks to the low temperature team at LNF:
M. Angelucci, A. Liedl, R. Larciprete e L. Spallino.

Tanks to the technical support of
DAΦNE-L Team:
A. Grilli, M. Pietropaoli, A. Raco, V. Tullio, V. Sciarra and G. Viviani

Istituto Nazionale di Fisica Nucleare
Divisione Ricerca: DAFNEL

Thanks to EuroCirCol project and to its scientific community

Thanks to MICA supporting project funded by INFN-SNC5

Thanks to CERN-INFN bilateral agreement KE3724 /TE/HL-LHC-Addendum No.4 to Agreement TKN3083