Surface Properties of LHC Vacuum Chambers

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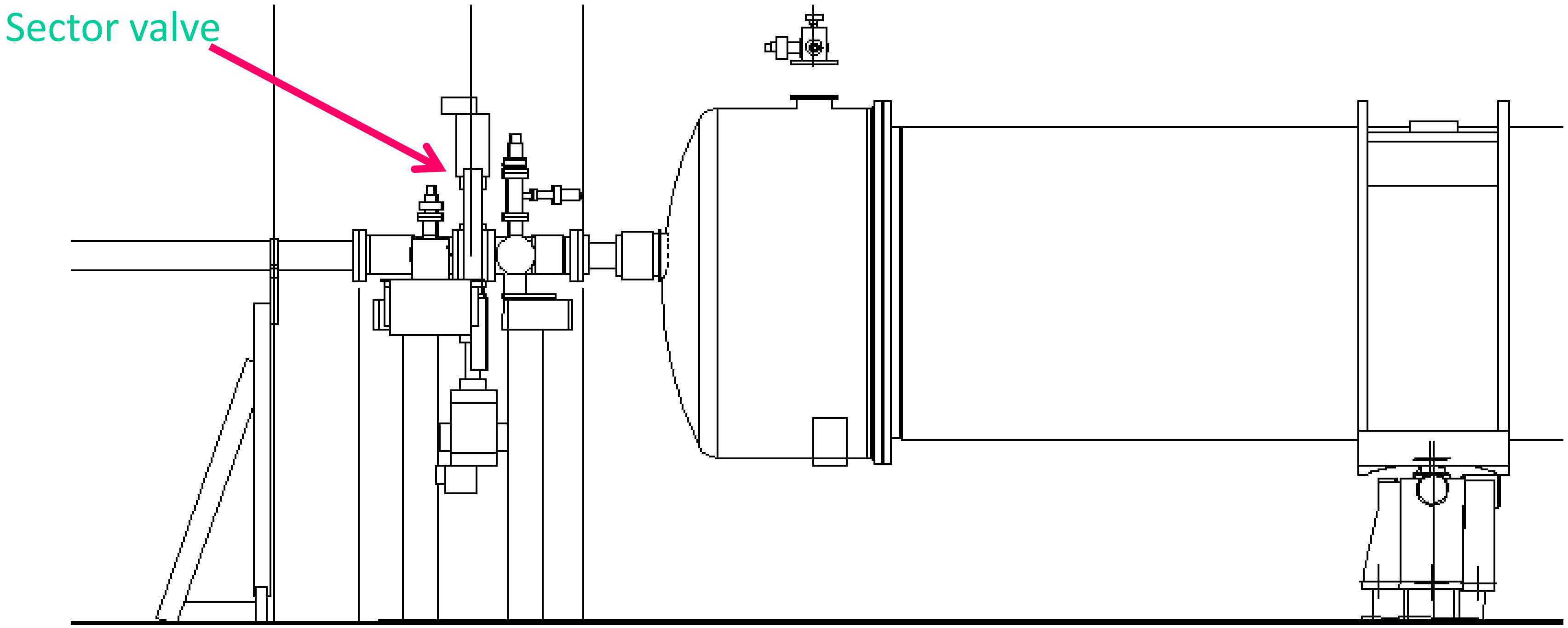
1. Vacuum chambers types in LHC
2. Electron related surface properties
3. Photon related surface properties

1. Vacuum Chamber Types in LHC

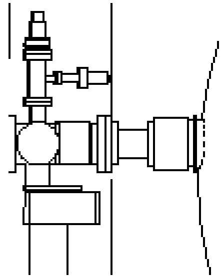
Cryogenic temperature areas : what's this ?

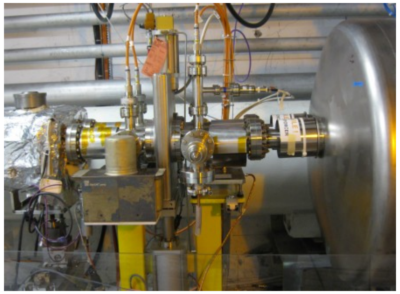
- LHC arcs,
- Stand Alone Magnets : triplets, quadrupoles, D1, D2
- At each extremity of EACH cryostat, a vacuum sector valve is installed.
- It defines a so called "cryogenic vacuum" sector
- By definition, a cryogenic vacuum sector is unbaked.



Cryogenic temperature areas : what's there ?

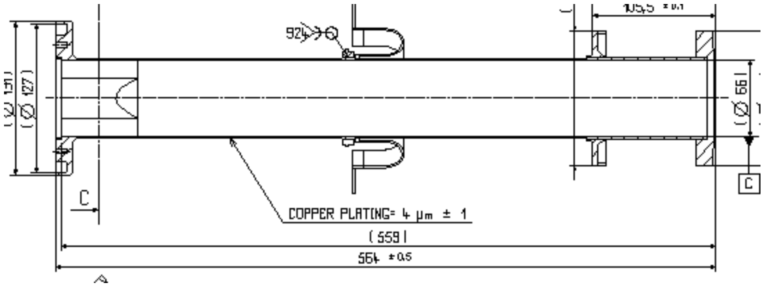
- Unbaked copper chambers operating at room temperature





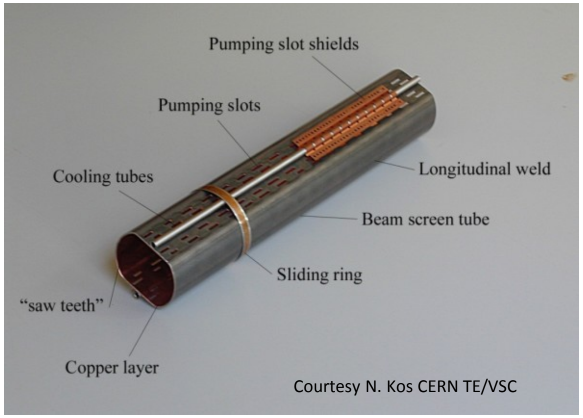
- Unbaked copper plated cold warm transitions from RT to 1.9 K

1.9 K



300 K

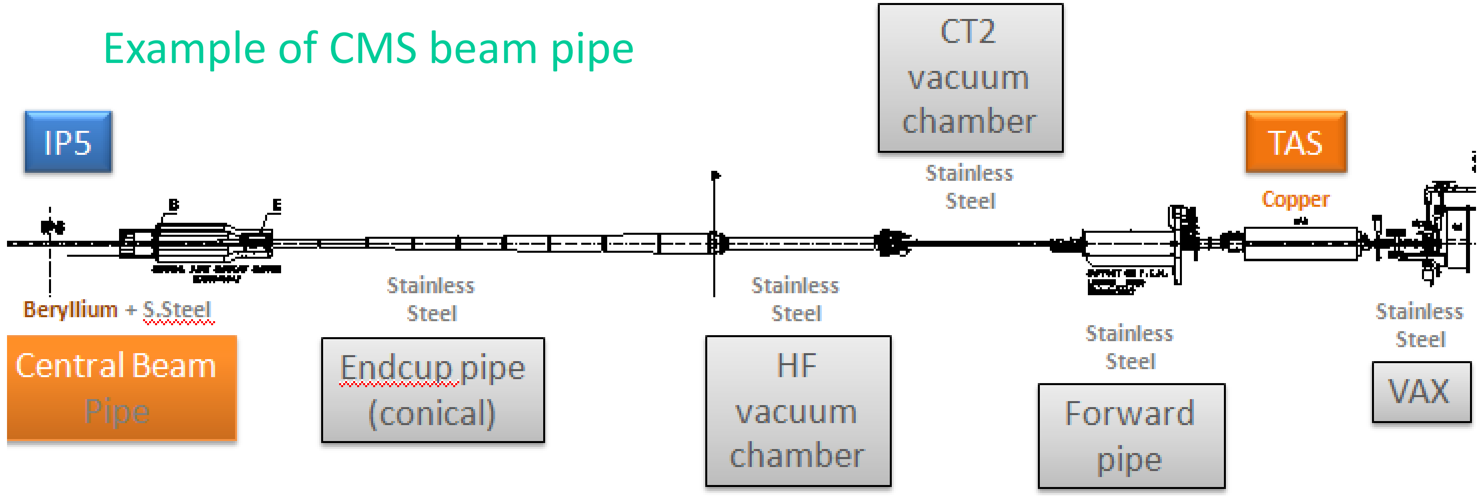
- Unbaked beam screens operating at 5-20 K



Room temperature areas : what's this ?

- LHC experiments : ATLAS, CMS, ALICE, LHC-B

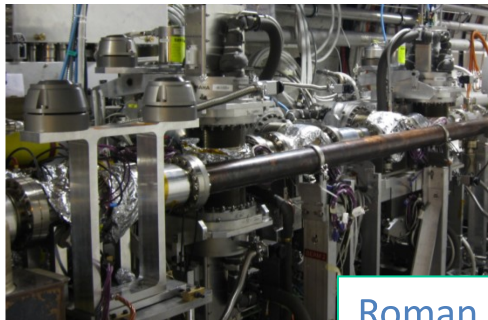
Example of CMS beam pipe



- Room temperature vacuum system between sector valves

Room temperature areas : what's there ?

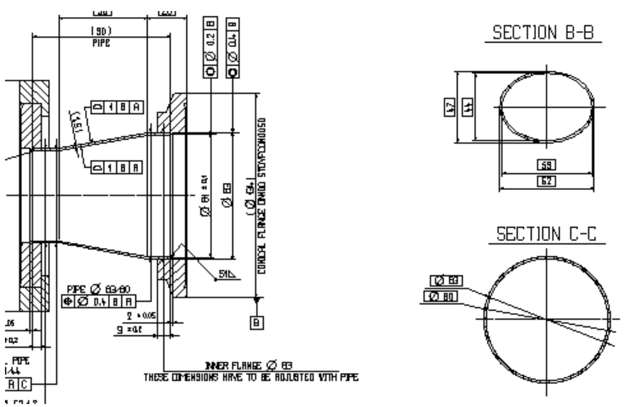
- BI equipment, collimators, kickers, roman pot ….. all baked



Roman pot

Collimators

- LHC experiments, circular, elliptical vacuum chambers, warm magnets, septa …. all NEG coated and activated
- Several geometries :
  - ID 52, 63, 80, 100, 130, 212.7, 797
  - Ellipses 52x30, 59x44, 128x53 can be H or V
  - Experimental chambers !!
  - Transition chambers



Warm magnets

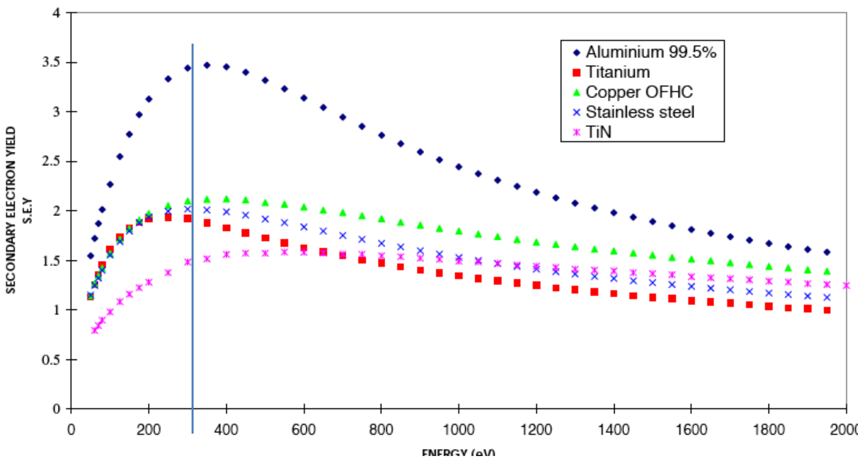
2. Electrons related surface properties

Secondary electrons curve

$$\delta = \frac{number of\ produced electrons}{incident electrons}$$

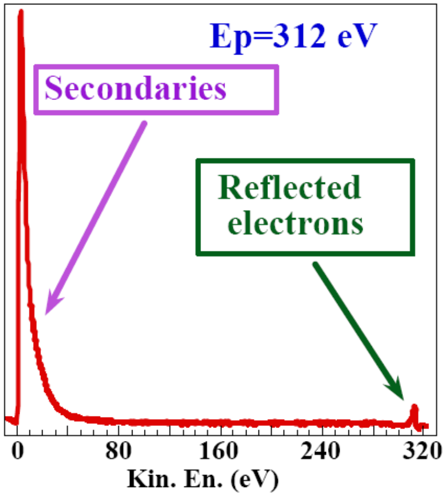
- Technical material
- Maximum around 200-300 eV
- δ_{max} ~ 2 to 3.5

"as received"



312 eV

N. Hilleret *et al.*, LHC Project Report 433 2000, EPAC 00



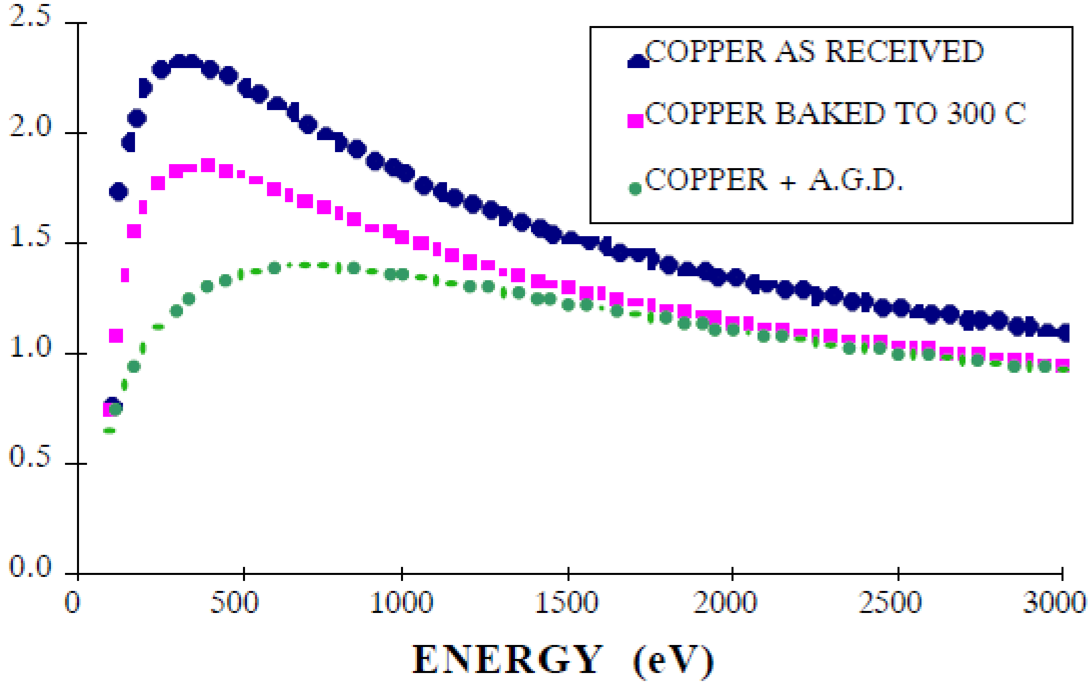
R. Cimino , I.R. Collins, App. Surf. Sci. 235, 231-235, (2004)

- The electron distribution curve (EDC) shows :

  - Component at reflected electron energy
  - Secondary electrons with low energy

  Most of the emitted electrons have low energy

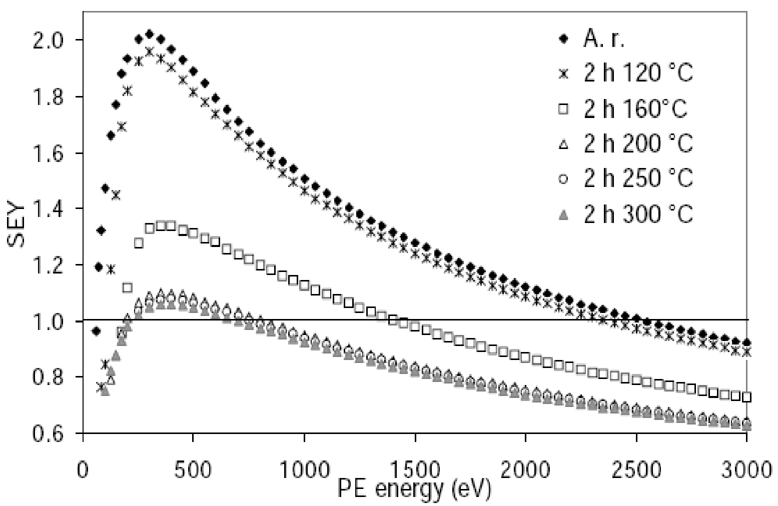
Cu surface : unbaked, baked, pure Cu

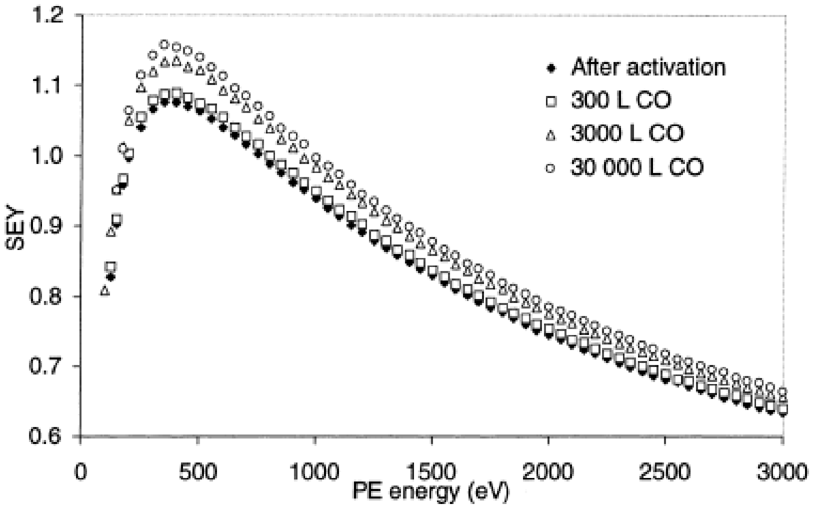


N. Hilleret *et al.*, LHC Project Report 433 2000, EPAC 00

- δ_{max} :
  ~ 2.3 in the unbaked case
  ~ 1.8 with *in-situ* bakeout at 300 deg
  1.3 with *in-situ* glow discharge (value of pure Cu)

Activated NEG





C. Scheuerlein *et al.* Appl.Surf.Sci 172(2001)

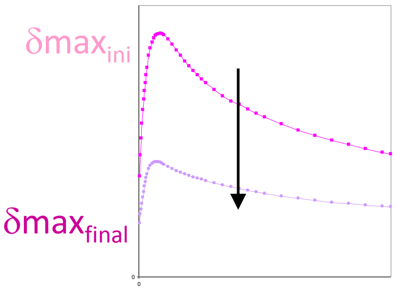
- Activated TiZrV film :
  - $\delta_{max} \sim 1.1$

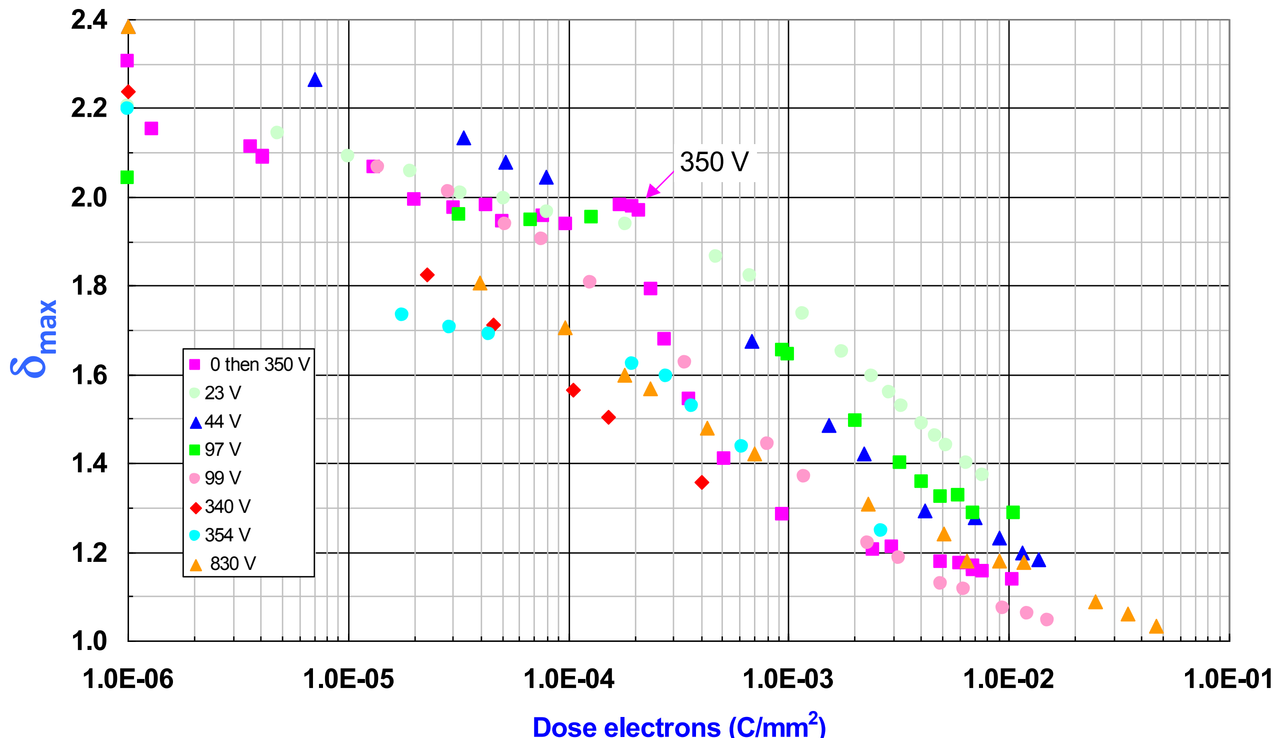
- Saturated TiZrV film :
  - $\delta_{max} < 1.3$
  - H_2, H_20, CO, CO_2
  - But $\delta_{max} > 2$ when exposed to air !

Since δ_{max} is very low, there are no multipacting in NEG vacuum chambers

LHC : scrubbing under electrons irradiation

- Reduction of SEY under electron irradiation
- 1 to 10 mC/mm^2 is required to have $\delta_{max} < 1.3$
- Growth of a carbon layer (AES, XPS)



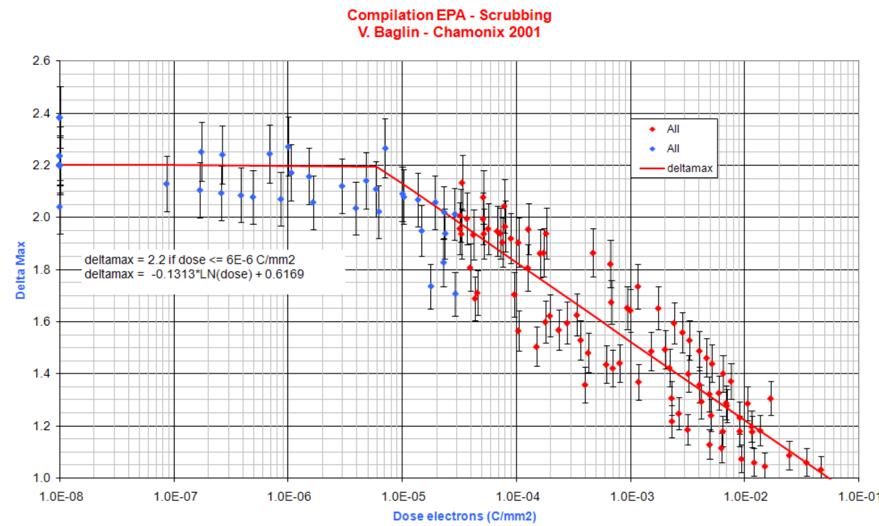


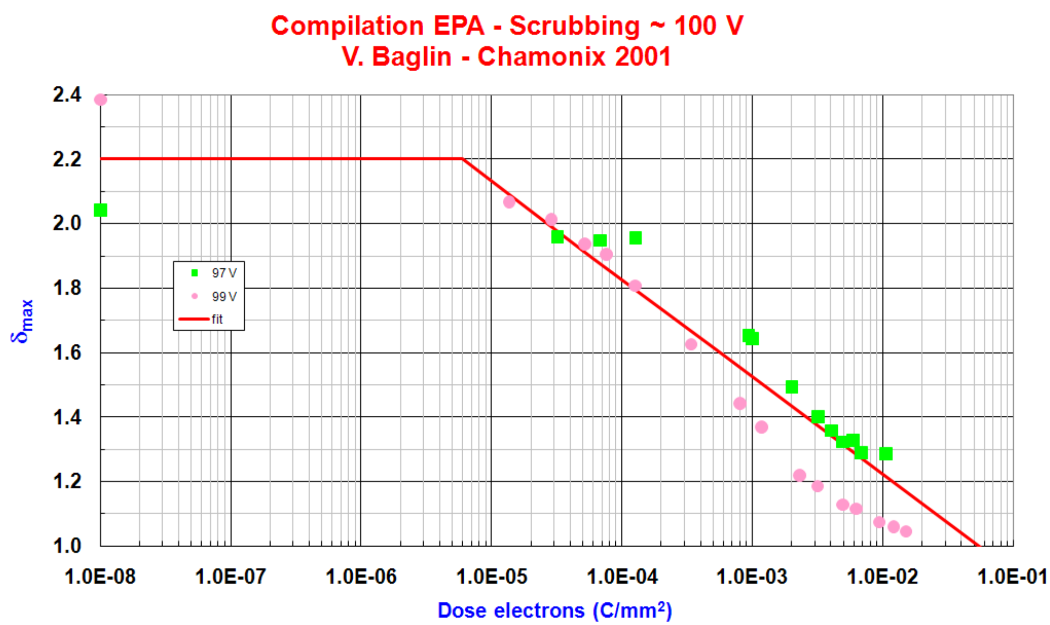
V. Baglin *et al.*, Chamonix, 2001

A very simple curve fit

- Fit well 100 eV curve

$$\begin{cases}\delta_{\max} = 2.2 \text{ if } \mathrm{dose} \leq 6\,10^{-6}\ \mathrm{C/mm^2} \\ \delta_{\max} = -0.1313\ln(\mathrm{dose}) + 0.6169\end{cases}$$



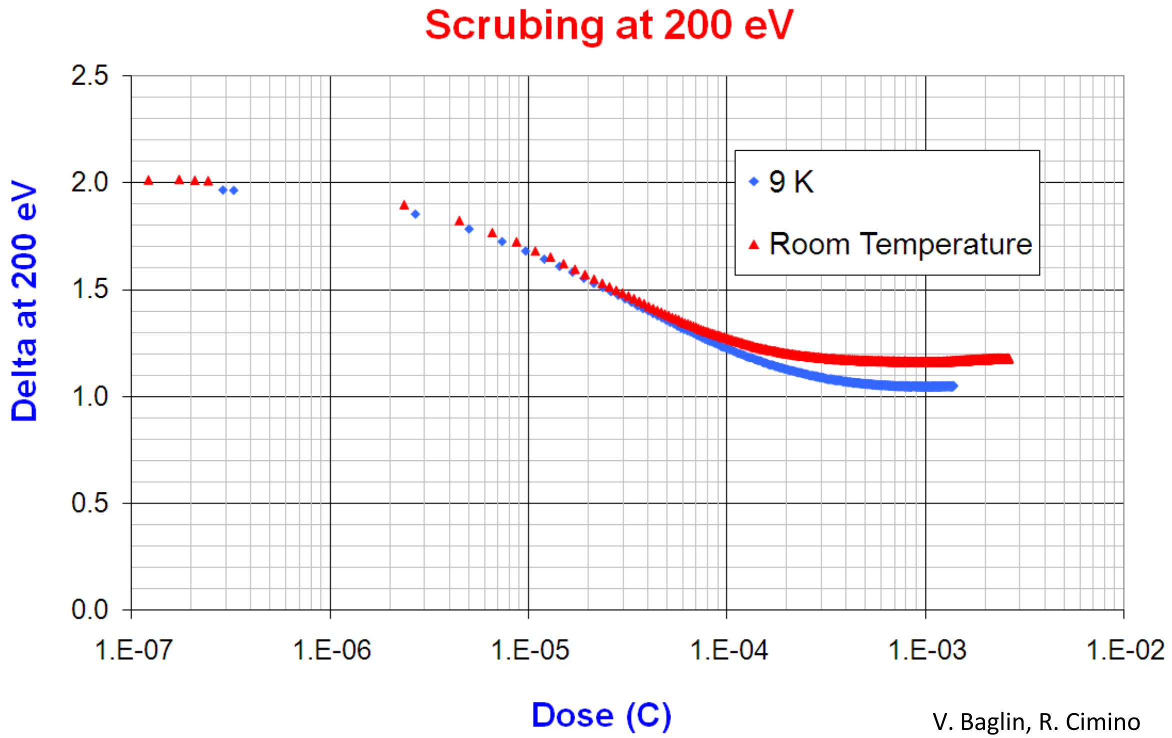


Scrubbing works also in cryogenic areas !!

- Unbaked by design

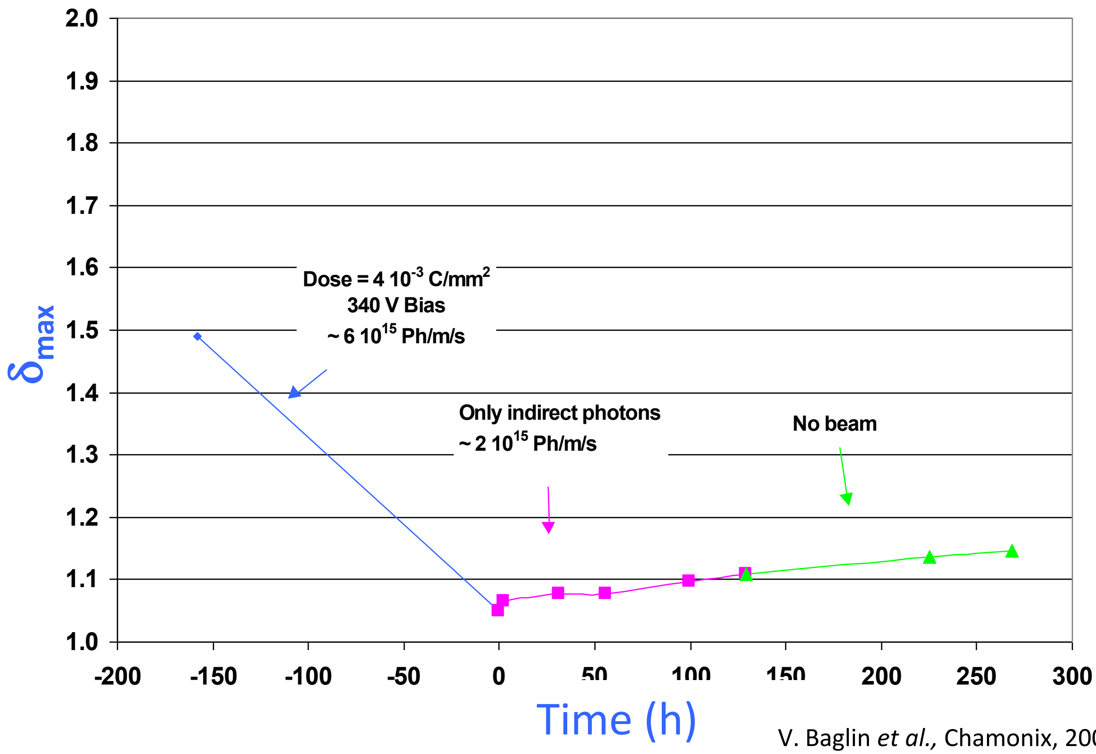
- Providing that the beam screen's surface coverage stays below a monolayer : cool down CB first

- Scrubbing at cryogenic temperature is as much efficient as at room temperature



V. Baglin, R. Cimino

After a stop : slight re-conditioning required



V. Baglin *et al.,* Chamonix, 2001

- Re-conditioning is necessary after a significant stop ~ 0.1 / 10 days for P ~ 10^{-9} Torr

- Expected to be much faster than the initial conditioning (to be quantified)

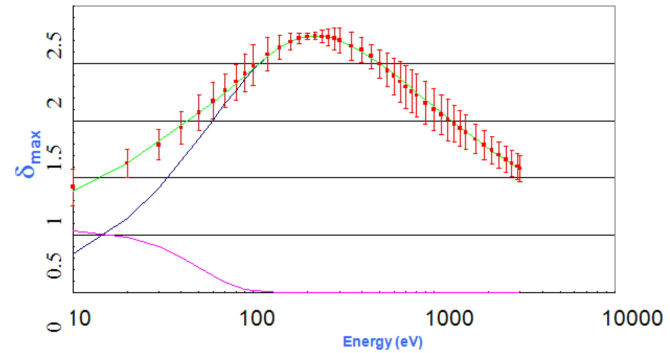
What happen to the low energy electrons ?

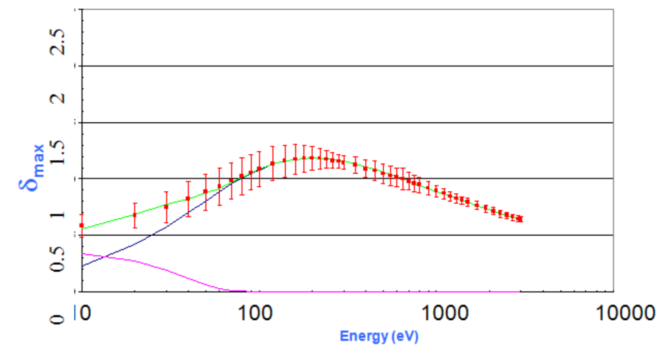
- Detailed analysis of the SEY curves, revealed the presence of reflected electrons at low energy

- Low energy electrons are present in as received and scrubbed state

- The reflected part might be described by an exponential behaviour

$$\delta(E) = \delta_{max} \frac{s\, E/E_{max}}{s-1+\left(E/E_{max}\right)^{s}} + a \exp\left(-\frac{E^2}{2\sigma^2}\right)$$

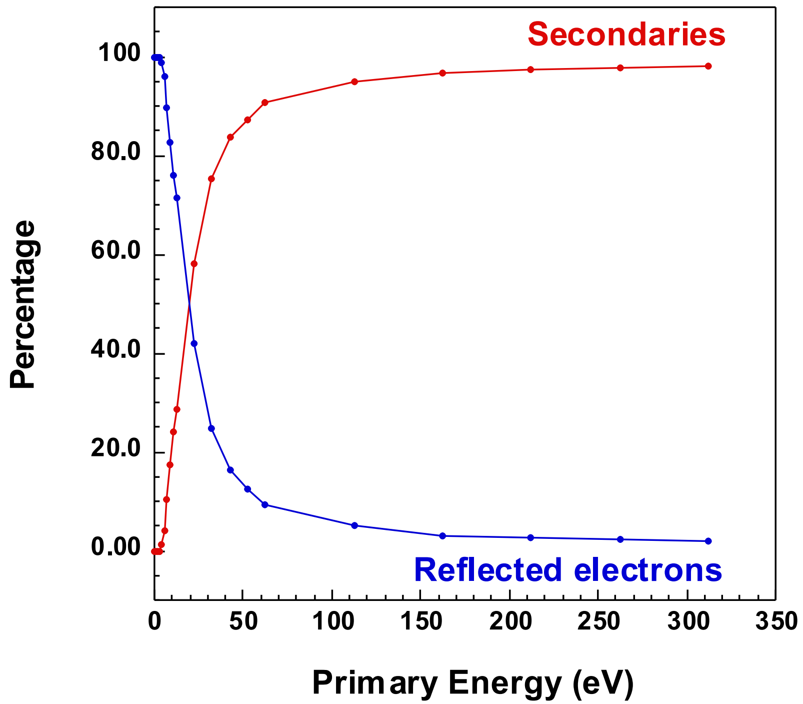




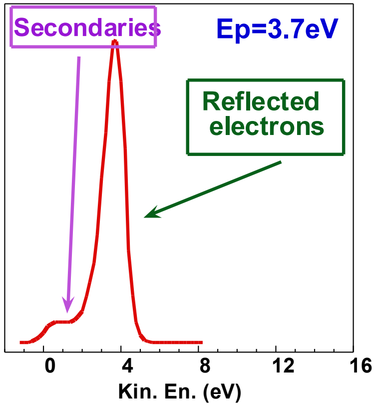
V. Baglin *et al.*, Chamonix, 2001

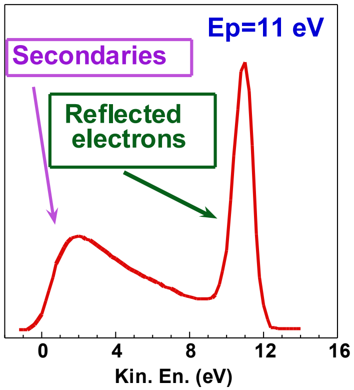
Electron reflectivity of Cu

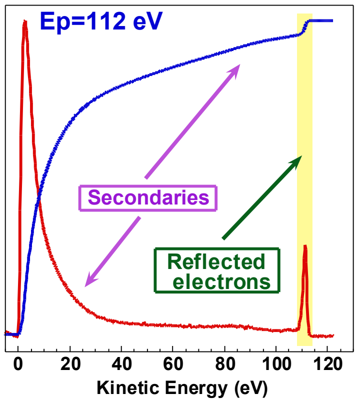
- Measure of the EDC for several primary energies (Ep)
- Electrons with energy below 20 eV have large reflectivity (> 50 %)

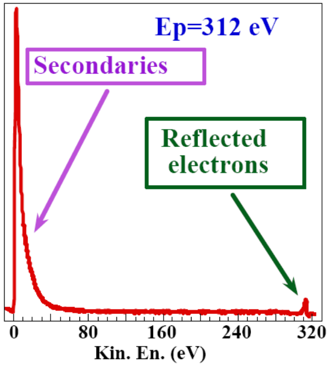


R. Cimino , I.R. Collins, App. Surf. Sci. 235, 231-235, (2004)



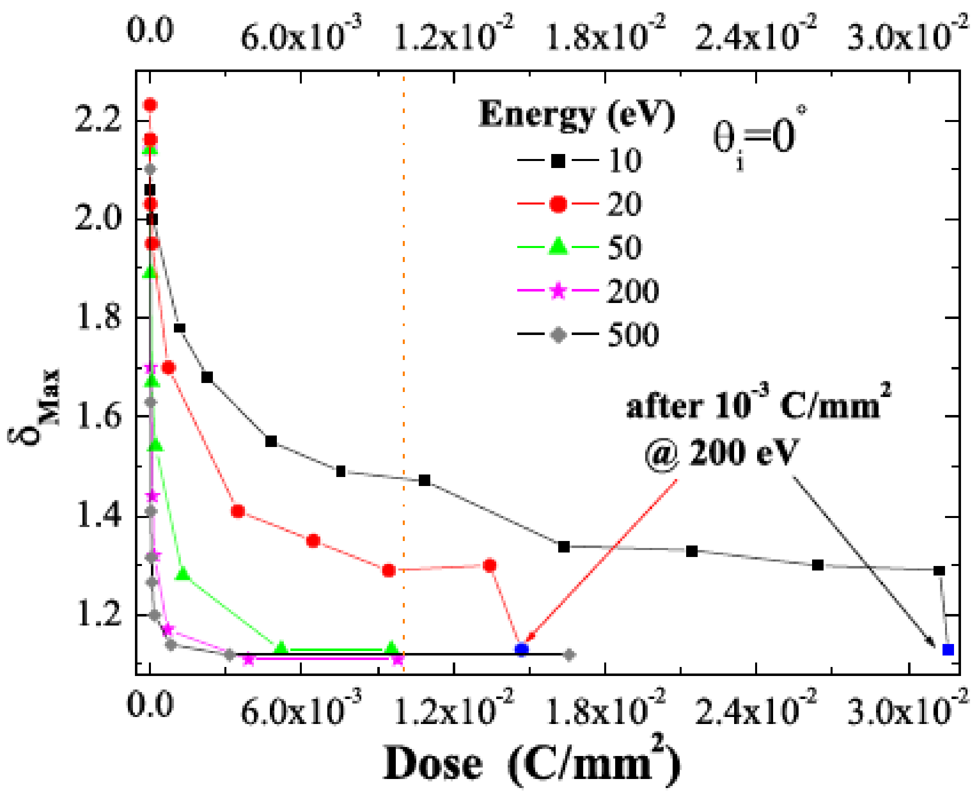






A consequence : impact on conditioning efficiency

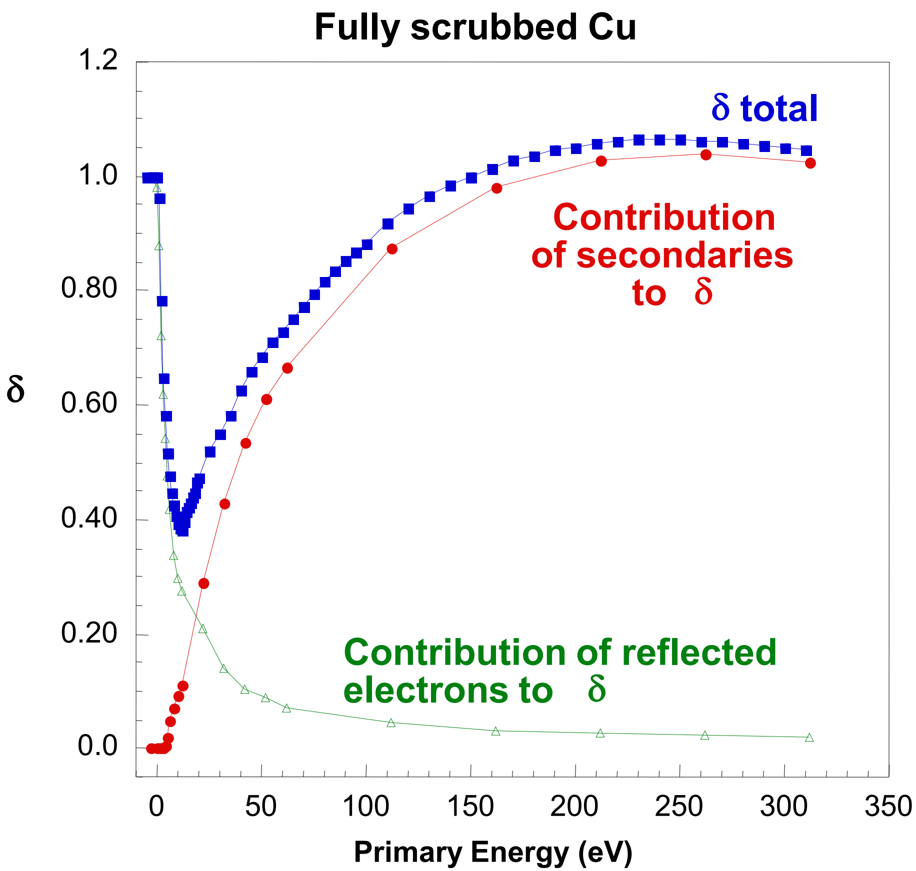
- The conditioning rate is less efficient for electrons below 50 eV



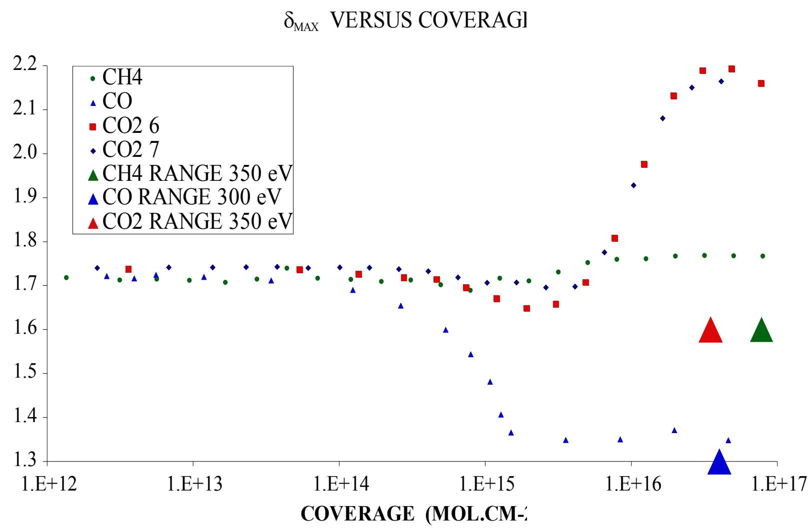
R. Cimino *et. al.* EPAC 2008, Genoa, Italy

SEY at cryogenic temperature

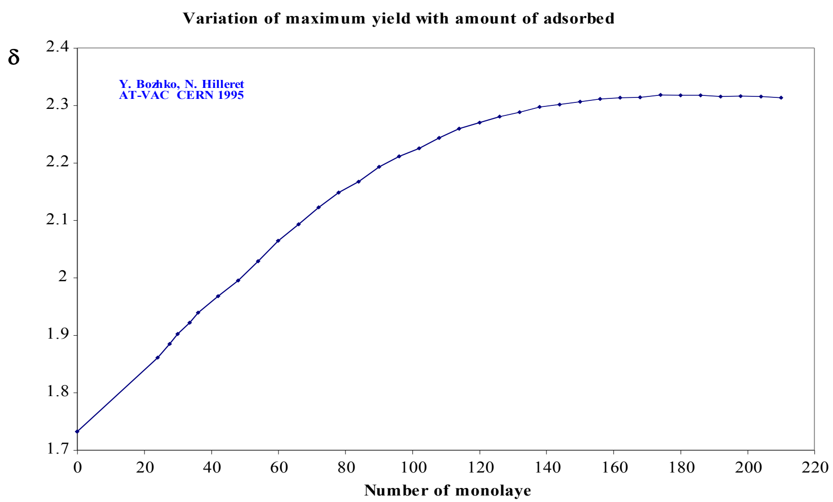
- Cu can be scrubbed **BUT**
- avoid gas condensation (H_2O, CO_2)



R. Cimino , I.R. Collins, App. Surf. Sci. 235, 231-235, (2004)



N. Hilleret. LHC MAC December 2004

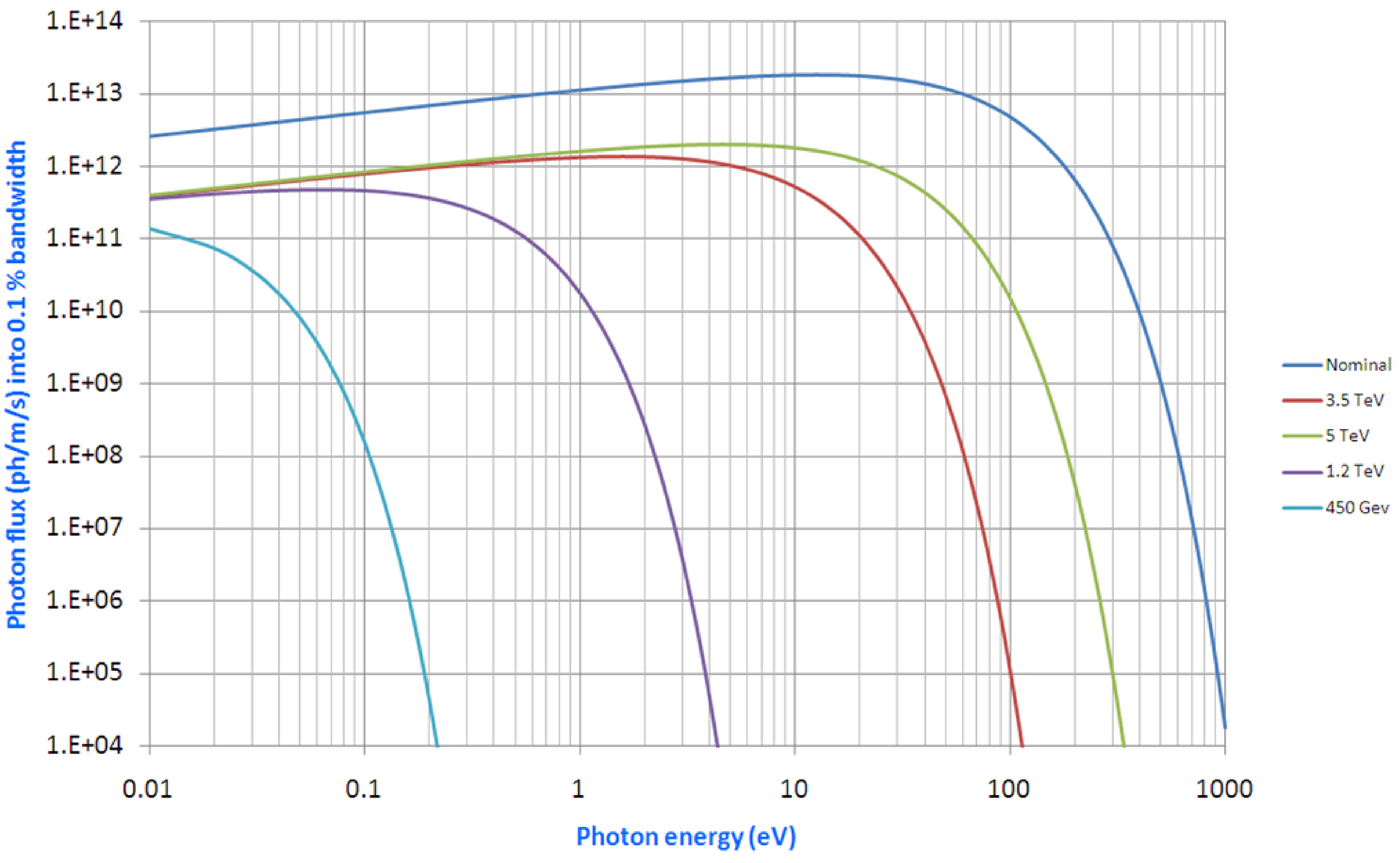


N. Hilleret *et. al.* Chamonix 2000

3. Photons related surface properties

LHC SR spectrum : UV

- With nominal parameters : 7 TeV and 585 mA
- With reduced beam current, 90 mA, and reduced beam energy

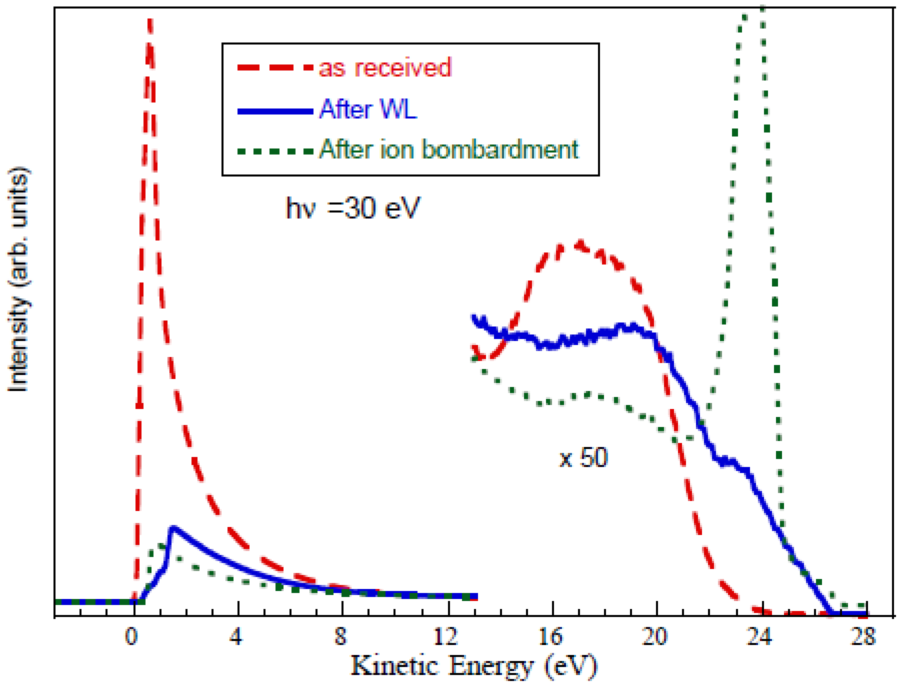


Energy of emitted photoelectrons

- Most of the photoelectrons have energies below 10 eV

- A conditioning is observed under SR or glow discharge

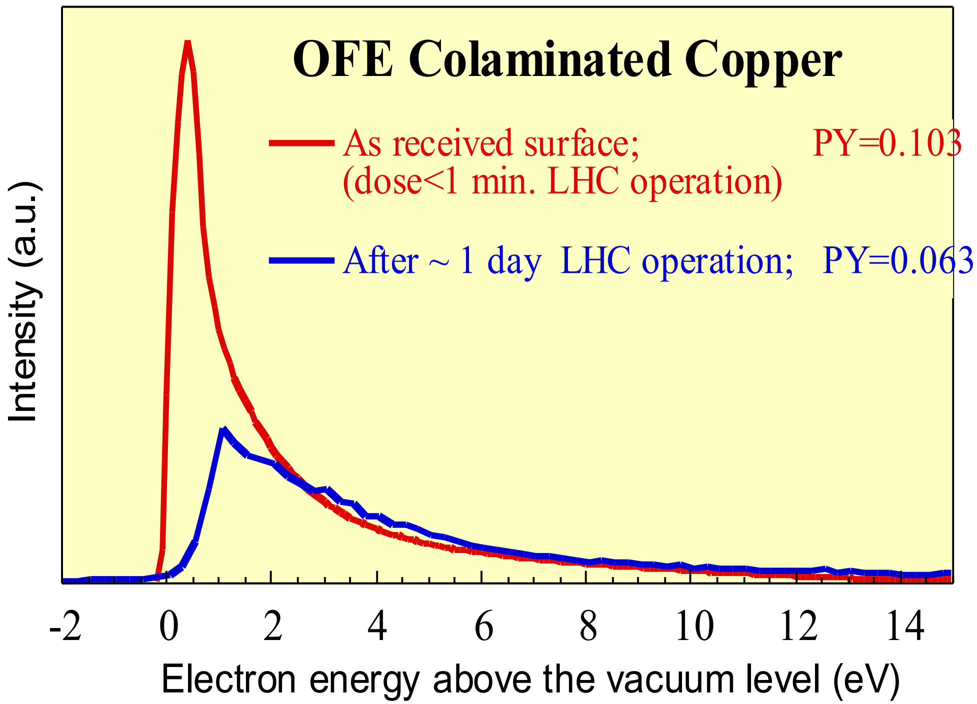
Cu colaminated



R. Cimino *et al.* Phys. Rev. AB-ST 2 063201 (1999)

EDC under SR irradiation

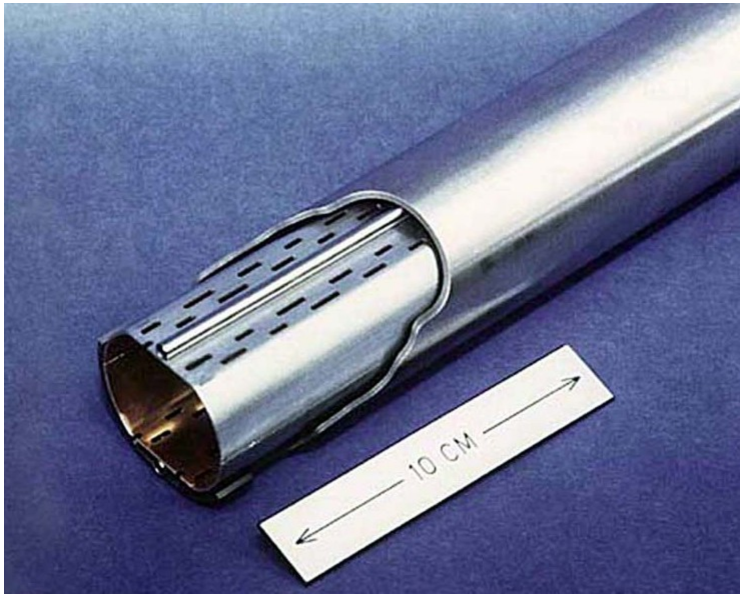
- SR irradiation reduce the amount of low energy photoelectrons
- The total yield is decreased by 40 % after 1 day of nominal LHC operation



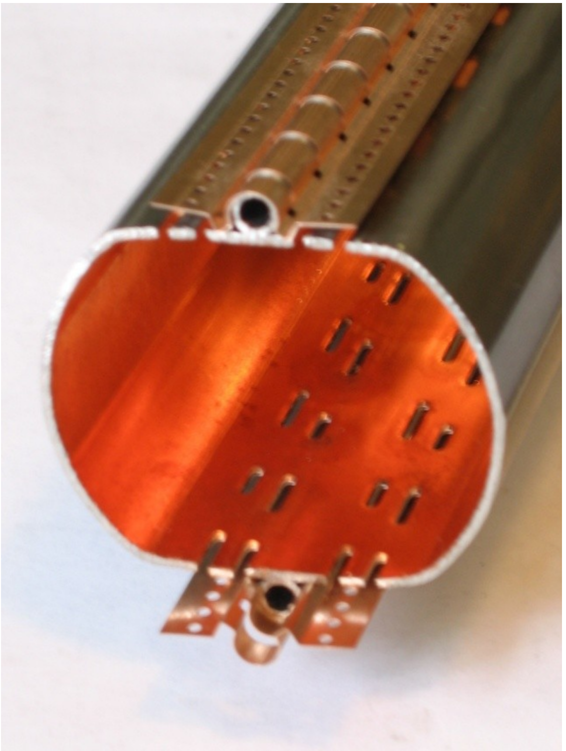
R. Cimino *et al.* Phys. Rev. AB-ST 2 063201 (1999)

LHC design

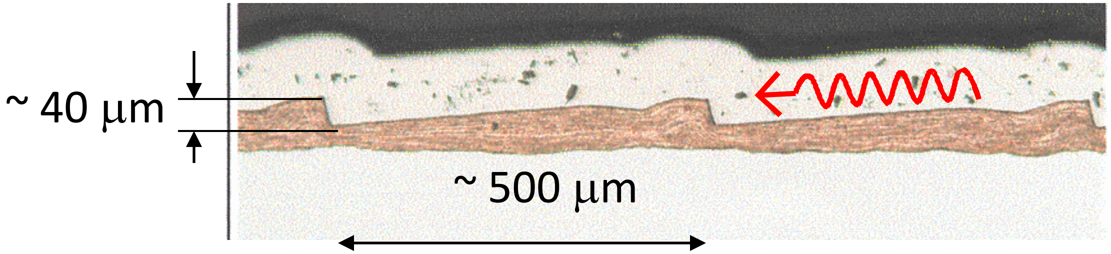
- Sawteeth are provided in the LHC beam screen to reduce the photoelectron yield and the forward reflectivity



Courtesy N. Kos CERN TE/VSC



Courtesy N. Kos CERN TE/VSC



Photon reflectivities of Cu materials

- Measured at ELLETRA with SR of 26 mrad grazing incidence (4.5 mrad in LHC)

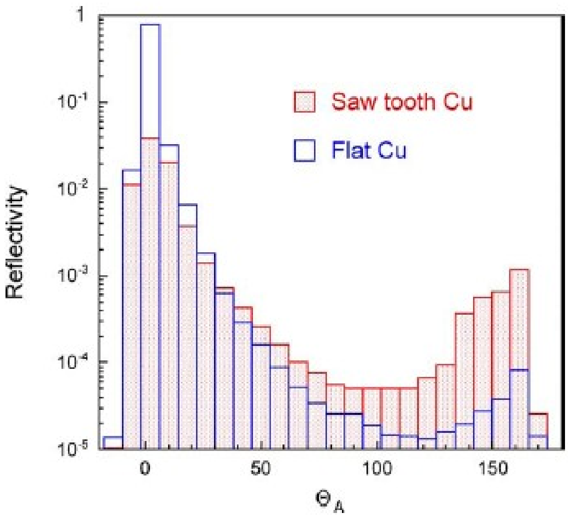


Fig. 2. Measured reflectivity, on the scattering plane, from a flat Cu sample (blue empty bars) and from the saw-tooth sample (red bars). Each point measure the reflectivity collected by the diode (whose angular dimension in the scattering plane was 8°).

Table 1
Measured values of the forward scattering, back scattering and diffused light expressed in percentage of the incoming light

	Flat sample	Saw-tooth sample
Forward scattering (%)	80	4
Back scattering (%)	0	2
Diffused (%)	2	4
Total	82	10

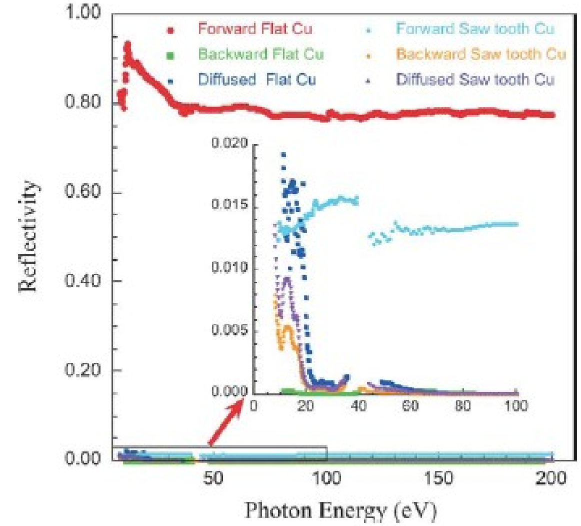
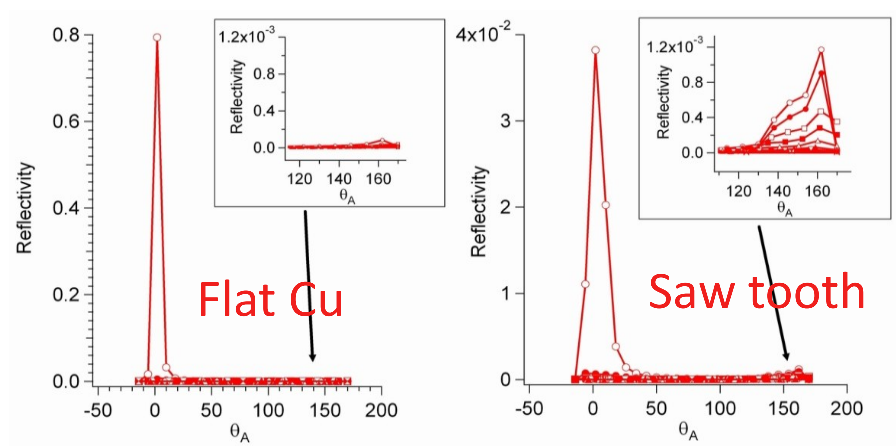


Fig. 3. Reflectivity of the measured flat and saw-tooth Cu surface vs. impinging monochromatic photon energy between 8 and 200 eV.

- LHC sawtooth provides low :
  - forward reflection
  - back scattering
  - diffuse light

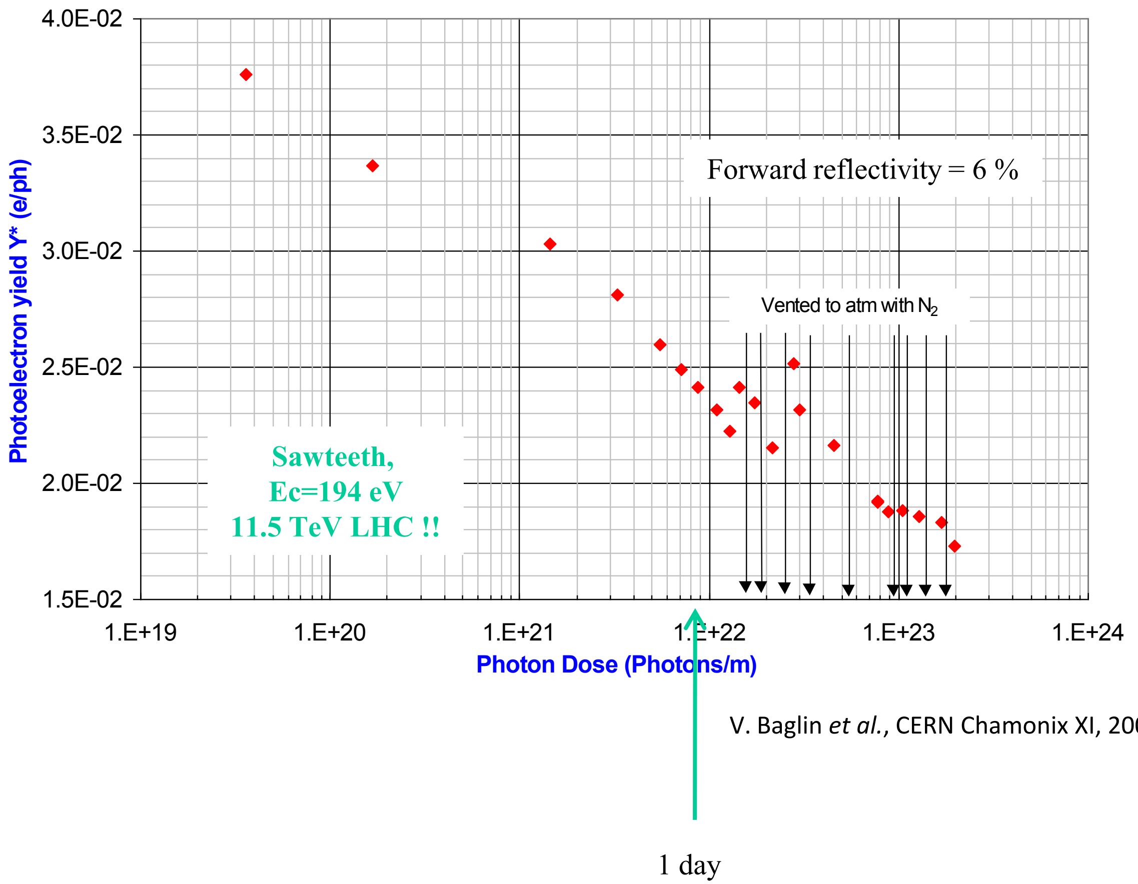


N. Mahne *et al*. App. Surf. Sci. 235, 221-226, (2004).

LHC Beam Screens

- SR irradiation at EPA
- The photoyield decrease with **beam conditioning**
- It varies from 4 to 1 % under perpendicular incidence

PEY, Reflectivity



V. Baglin *et al.*, CERN Chamonix XI, 2001

Behaviour with critical energy ?

- SR irradiation at EPA
- Grazing incidence, 11 mrad
- The photoyield increases when increasing critical energy.
- Photon reflectivity slightly decreases when increasing critical energy

		45 eV		194 eV	
Material	Status	R (%)	PY* (e/ph)	R (%)	PY* (e/ph)
Al	unbaked	-	0.11	-	0.32
Cu-smooth	unbaked	81	0.11	77	0.32
Cu-electrodeposited	unbaked	5	0.08	7	0.08
Cu-sawtooth	unbaked	8	0.03	7	0.04
TiZr	unbaked	20	0.06	17	0.08
TiZr	activated at 350°C	20	0.02	17	0.03

I.R. Collins *et al.* EPAC 1998,Stockholm, Sweeden

NB : molecular desorption yields are linear in the range, 10 – 300 eV. So the photoelectron yield should be also proportional to critical energy

$$PY^* \sim E_c$$

Behaviour of technical materials under different treatments ?

- WL irradiation at BESSY
- Value ranges from 4 to 10 %
- Al exhibit the highest yield
- Colaminated Cu is 6 %

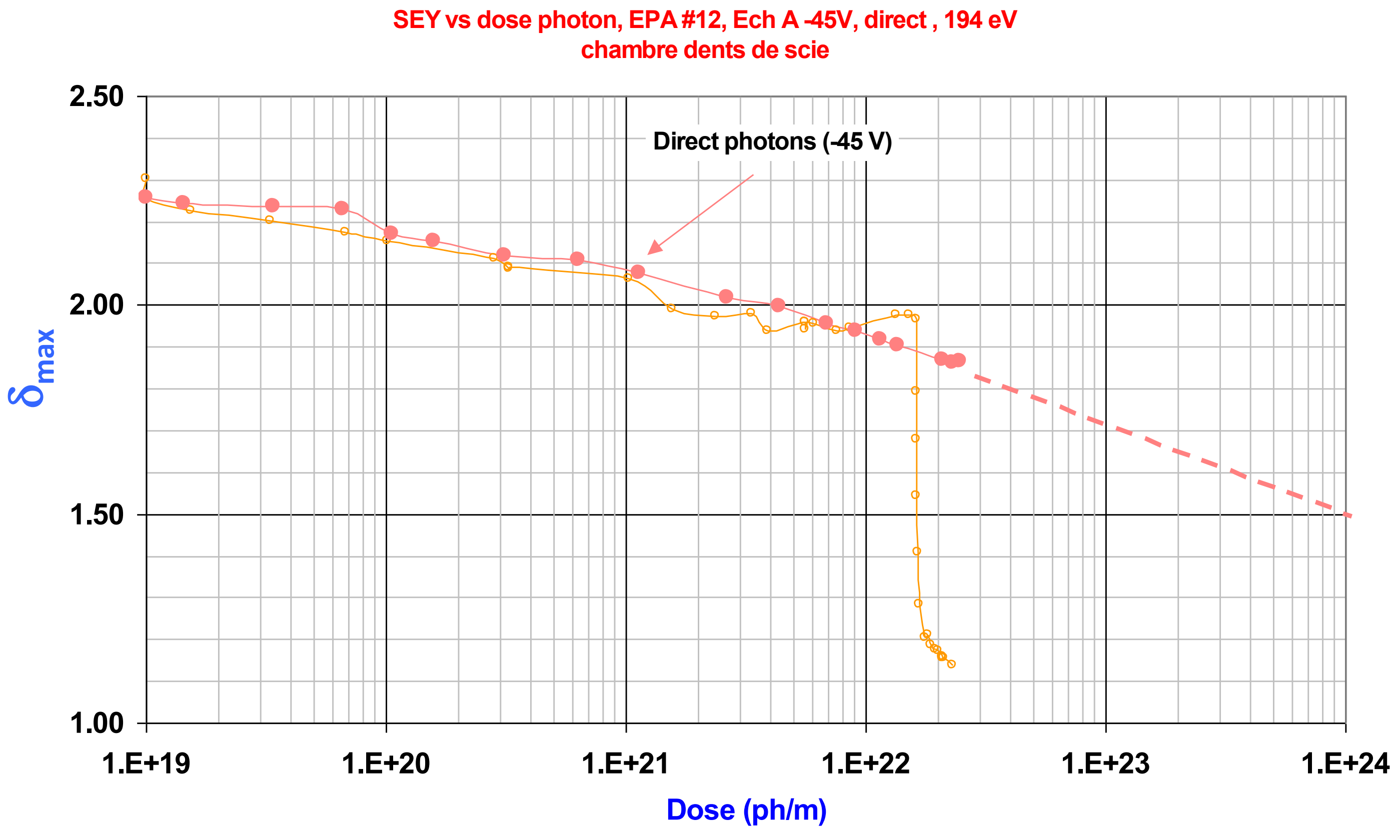
Sample	WL yield (electrons/photon)
Au	0.041 ± 0.002
Cu	0.063 ± 0.002
Cu-sp.	0.053 ± 0.002
Cu-ab.	0.093 ± 0.002
TiN	0.080 ± 0.002
TiN-sp.	0.120 ± 0.002
TiZr	0.088 ± 0.002
TiZr-ac.	0.055 ± 0.002
TiZr II	0.084 ± 0.002
TiZr II ac.	0.057 ± 0.002
Cu-el.	0.070 ± 0.002
Cu-el.-an.	0.062 ± 0.002
Pd	0.072 ± 0.002
Pd-an.	0.080 ± 0.002
St 707	0.053 ± 0.002
St 707-ac.	0.035 ± 0.002
Al	0.106 ± 0.002
Al-sp.	0.835 ± 0.002

R. Cimino *et al.* Phys. Rev. AB-ST 2 063201 (1999)

Photon scrubbing vs photon dose

- A minor reduction of the SEY due to SR can be observed
- Cannot rely on SR to scrub the LHC

1 year of nominal LHC operation yields to ~ 1.5



Thank you for your attention !!!