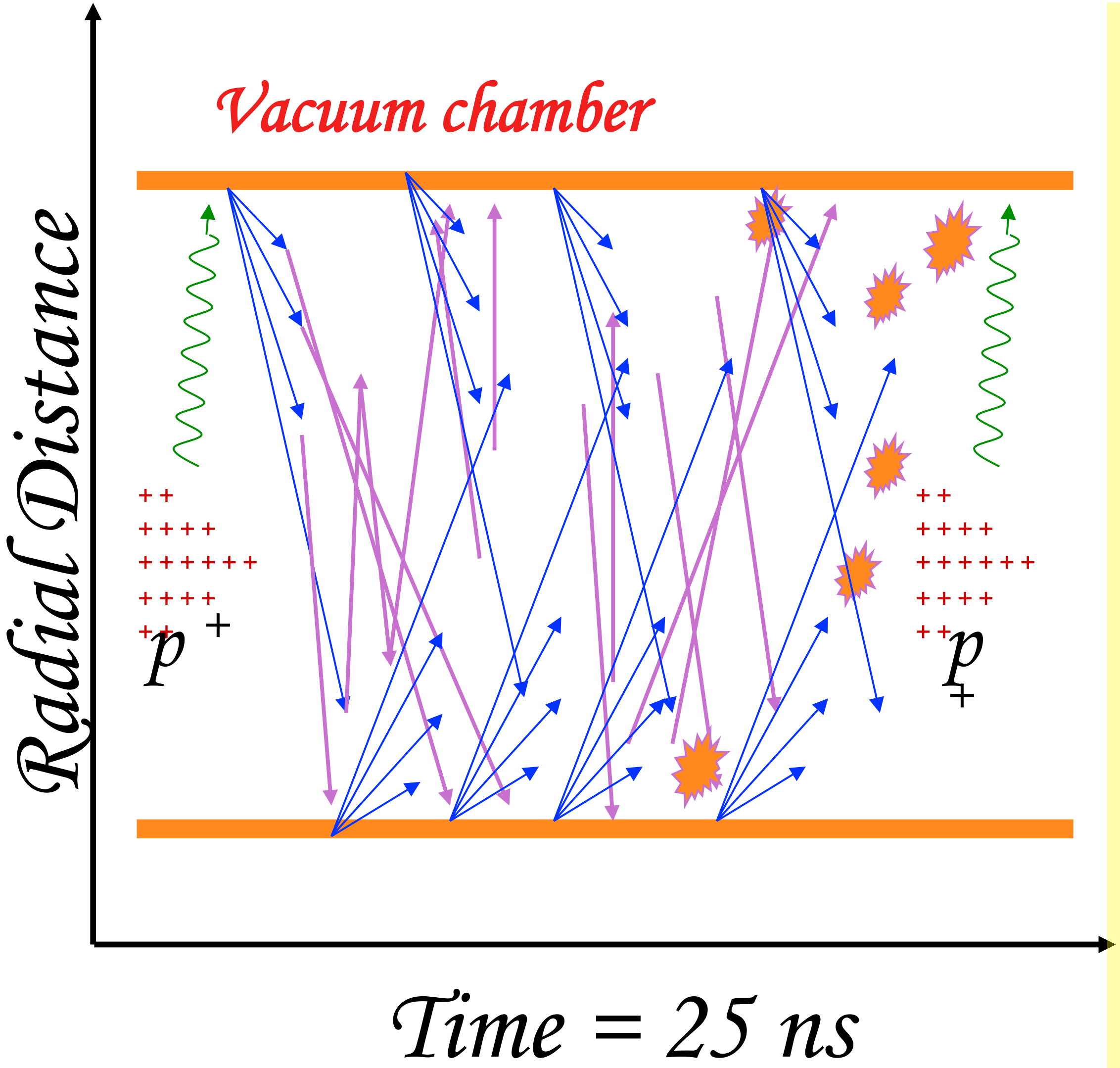
Developement and Characterization of new Pipe Material and Coatings for e-cloud mitigation @ LNF.

Roberto Cimino LNF-INFN

For the NTA-IMCA and Nuvola-GrV collaboration

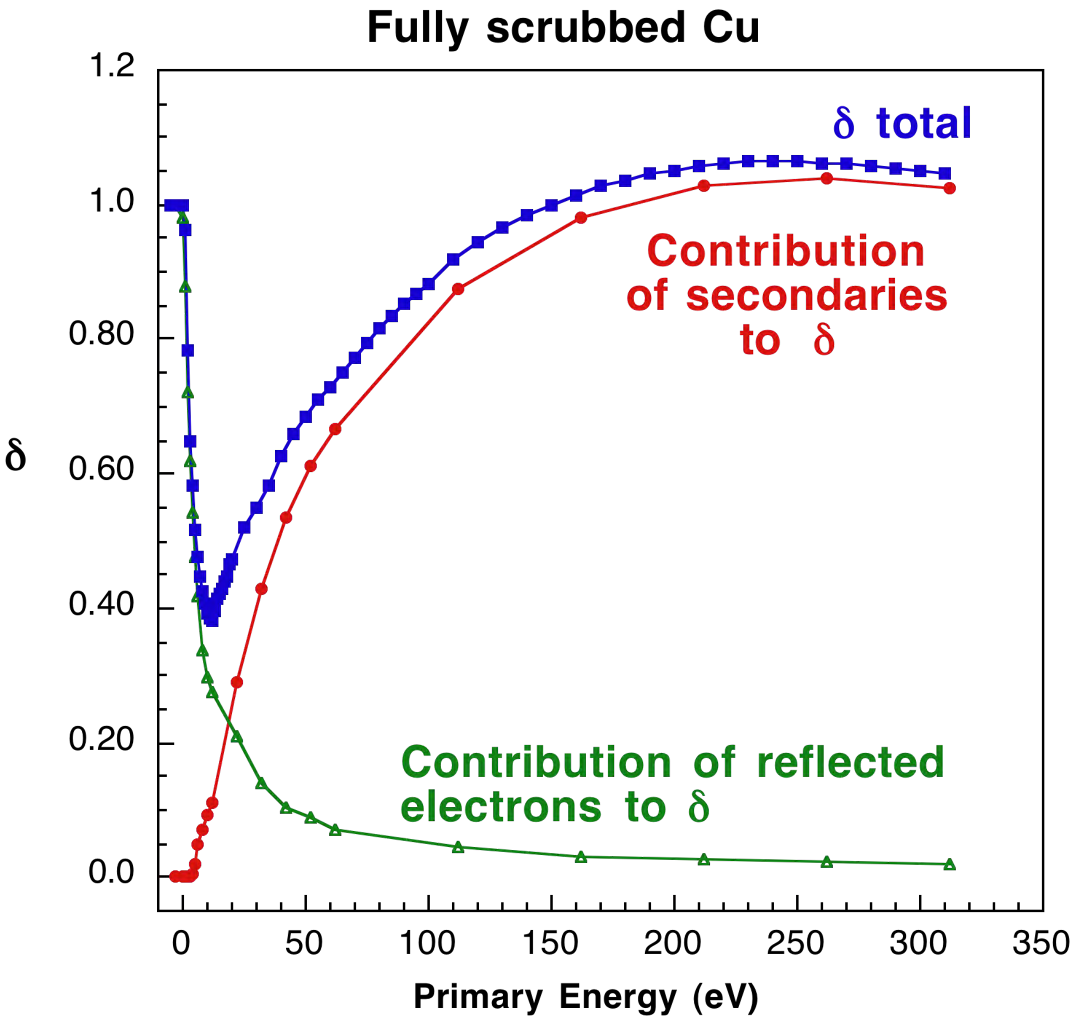
- *Introduction to the e-cloud problem*
- *Ongoing work in other Laboratories (state of the art)*
- *Material Science Laboratory@LNF first results.*
- *Conclusion.*

The "e-cloud" phenomenon (in pils)



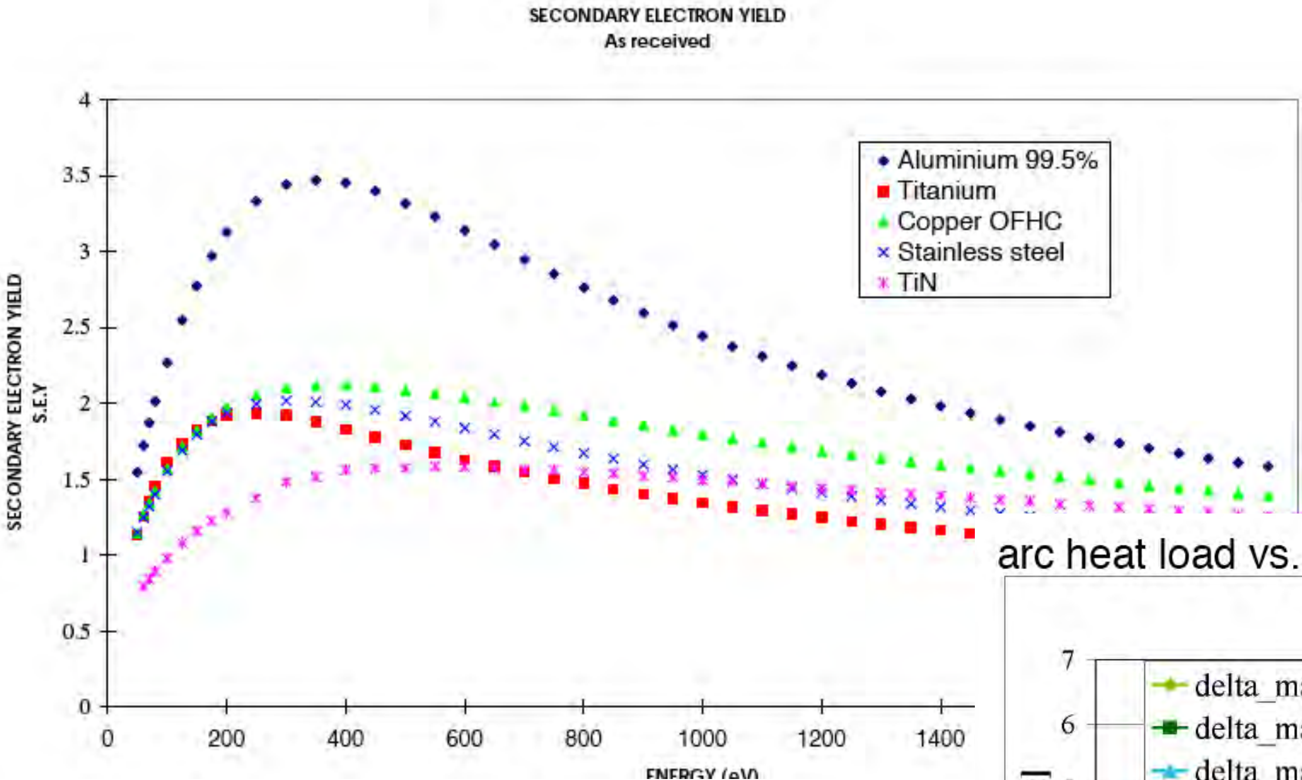
The accelerated particle beam produces SR and/or e^- that, by hitting the accelerator's walls generate photo-e^- or secondary-e^-.
Such e^- can interact with the beam (most efficiently for positive beams) and multiply, inducing additional heat load on the walls, gas desorption and may cause severe detrimental effects on machine performance.

One of the most relevant parameter for e-cloud studies is: S.E.Y. (or δ)



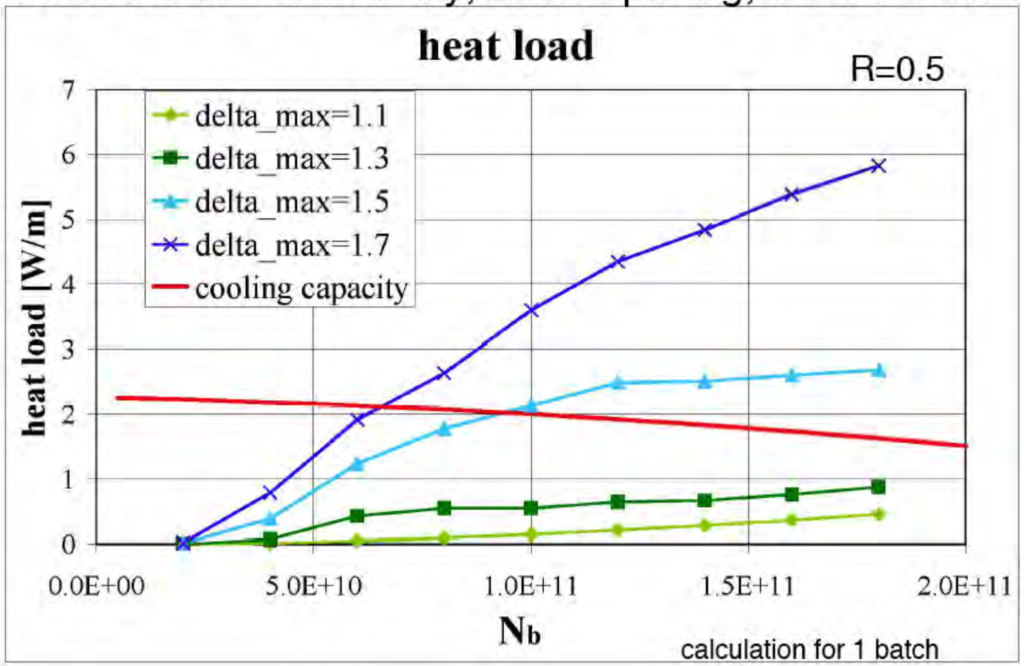
I.e.: the number of electrons created after bombardment of a single electron.

R. Cimino, et al.,
Phys. Rev. Lett.
93 (2004) 014801



Measure of Secondary e^- YIELD

arc heat load vs. intensity, 25 ns spacing, 'best' model



heat load for quadrupoles higher in 2nd batch; still to be clarified

Frank Zimmermann, LTC 06.04.05

…. And its impact to simulations (see calculaion for LHC).

Most of the existing and planned accelerator machines base the reaching of their design parameters to the capability of obtaining walls with a SEY ~1.3 or below!

Surface Scrubbing (or conditioning)

Intrinsically low SEY material

Geometrical modifications

Electrodes in the lattice.

External solenoid field

Surface Scrubbing (or conditioning)	⇨	*-Efficiency (time & final SEY)…*
Geometrical modifications	⇨	*Impedance. Machining costs.*
Intrinsically low SEY material	⇨	*Stability and material choice…*
Electrodes in the lattice.	⇨	*If possible… (Impedance, costs.)*
External solenoid field.	⇨	*Not always possible…*

Ongoing work in other Laboratory (state of the art)

@ KEK for Super KEKB

@ CERN for SPS, LHC and LHC Upgrade

3. Plans for Super KEKB

Y. Suetsugu, KEK
on behalf of KEKB Vacuum Group

- Required electron density to avoid single bunch instability

K. Ohmi , KEK Preprint 2005-100 (2006)

$$\rho_{e,th} = \frac{2\gamma\nu_s\omega_{e,y}\sigma_z/c}{\sqrt{3}KQr_e\beta L}.$$

Here,

$$\omega_{e,y} = \sqrt{\frac{\lambda_+ r_e c^2}{\sigma_y(\sigma_x+\sigma_y)}}$$

E [GeV]	= 4.0				
γ	= 7828	N_b	= 6.25E+10		
ν_s	= 0.0185	Q_b[C]	= 1.4E-08	(1.4 mA/bunch)	
		S_b [m]	= 1.2	(4ns)	
σ_z [m]	= 6.E-03	λ [C/m]	= 5.2E+12	($Q_b/2/\sigma_z$)	
c [m/s]	= 3.E+08	σ_y [m]	= 2.E-05		
K	= 11	σ_x [m]	= 2.E-04		
Q	= 7				
r_e [m]	= 2.80E-15	ω_e	= 5.46E+11	$K = \omega_e\,\sigma_z/c$	
β_y [m]	= 25	$\omega_e\,\sigma_z/c$	= 10.9	$Q = \mathrm{Min}(Q_{nl},\ \omega_e\,\sigma_z/c)$	
L [m]	= 3016			Q_{nl} ~7	

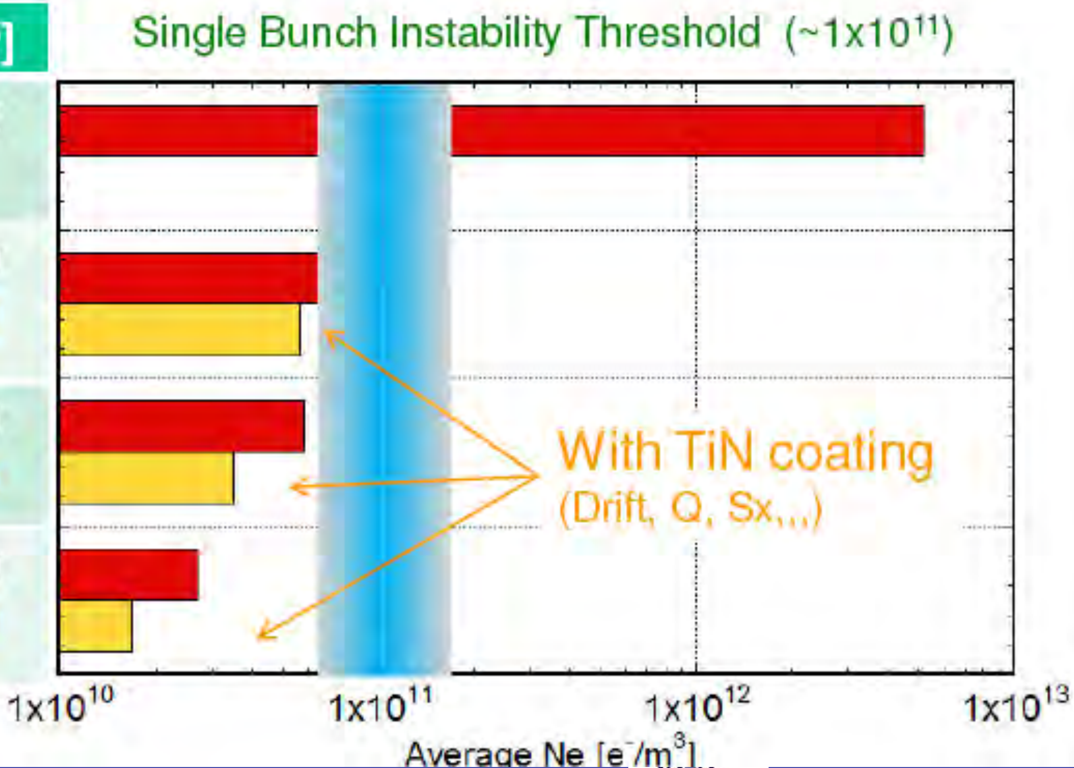
ρ [m^{-3}] =1.13E11 ➔ Our target =1E11 m^{-3}

3. Plans for Super KEKB

Y. Suetsugu, KEK
on behalf of KEKB Vacuum Group

- Summary
  - Major electron cloud will be reduced by antechamber scheme and solenoid field at arc section. But it seems still insufficient.
  - Electrodes in wiggler and grooves in bending magnets will decrease EC further and increase the safety margin.
  - The groove in B is still under consideration → further R&D.

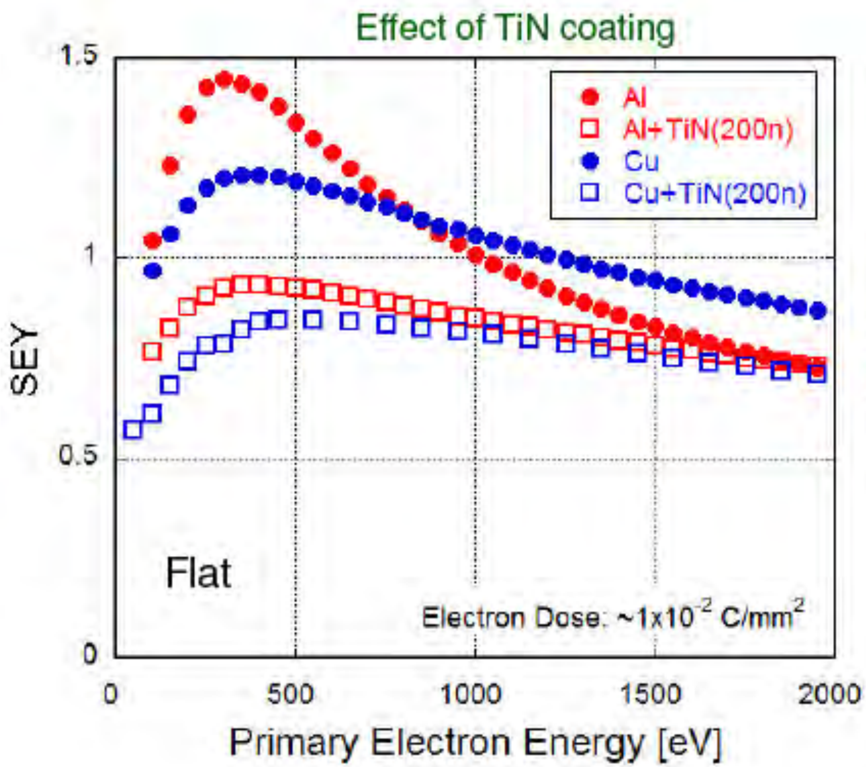
Condition	ne [m^{-3}]
Circular Cu chamber [KEKB beam pipe]	5.2E12
Solenoid at Drift (1/50) +Cu Antechamber (1/4)	9.4E10 5.7e10
+Electrode in Wiggler (1/200)	5.8E10 3.5E10
+Groove in B (1/10)	2.7E10 1.7e10

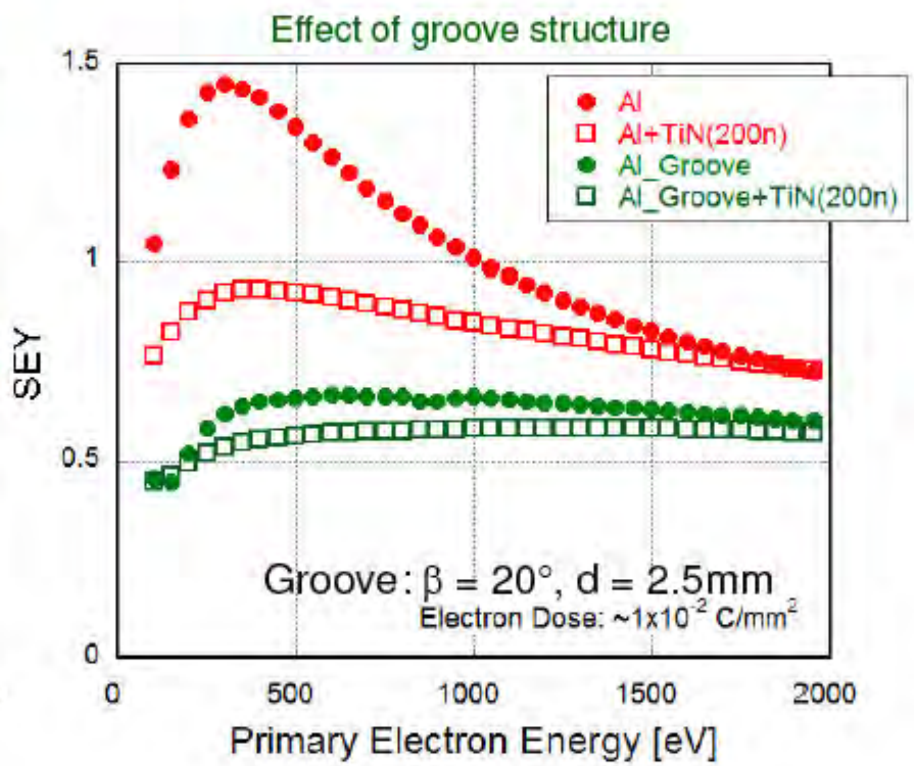


2.3 Grooved surface

Y. Suetsugu, KEK
on behalf of KEKB Vacuum Group

- SEY Measurement at Laboratory (B = 0): Effect of structure
  - The TiN coating decrease Max. SEY to 0.9~0.8.(Al, Cu)
  - Groove structures decrease it to ~0.7 even without TiN (Al); the effect of groove structure seems larger even for aluminum (if $\beta = 20°$).
  - Grooved surface seems effective even without B field.

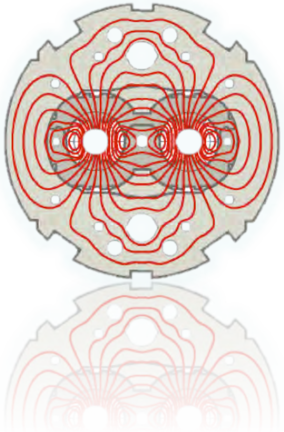




Ongoing work in other Laboratory (state of the art)

@ KEK for Super KEKB

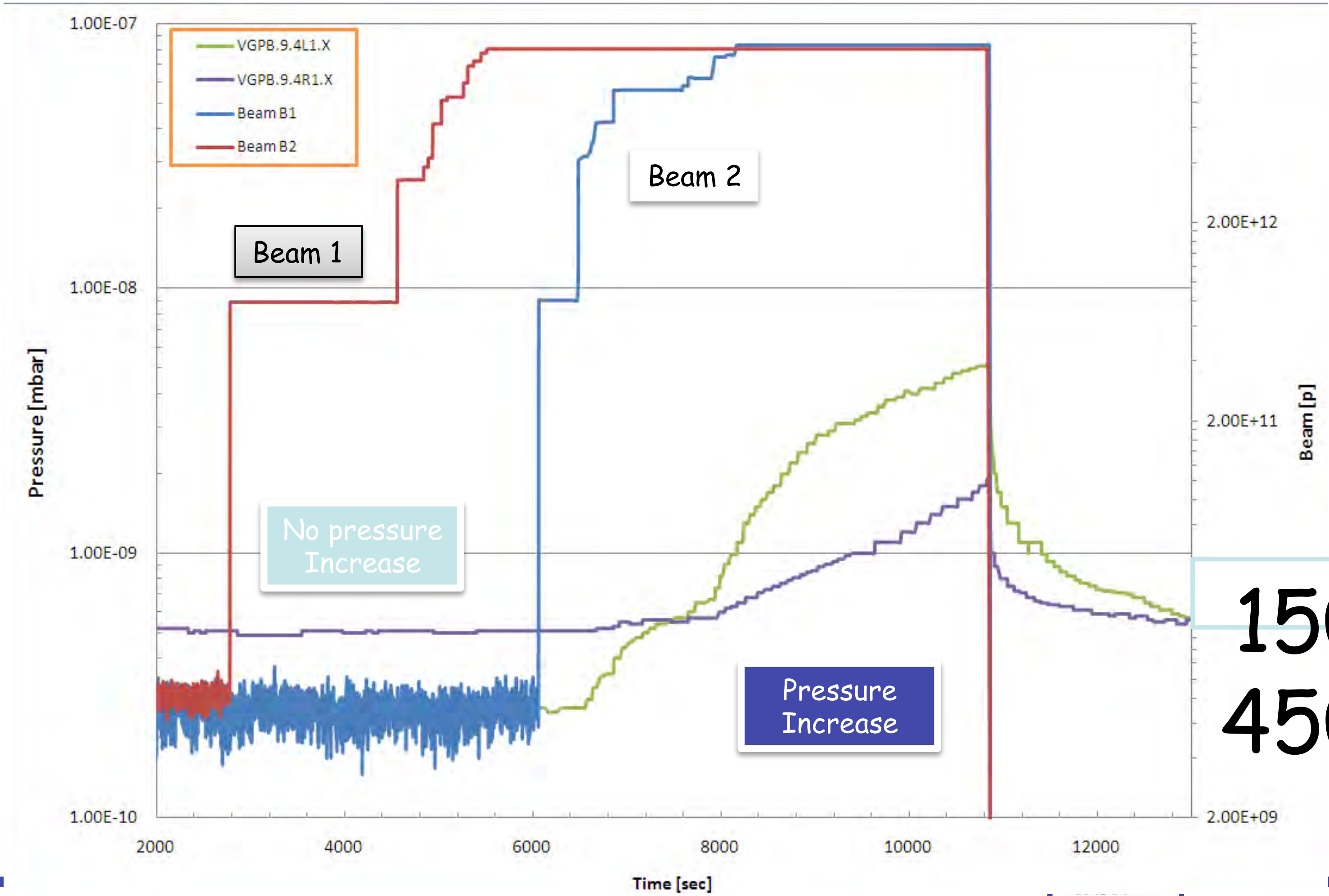
@ CERN for SPS (and future LHC Upgrade)



See: CERN-GSI Electron Cloud Workshop. CERN 7-3-2011

e-cloud @ LHC: a Real Issue

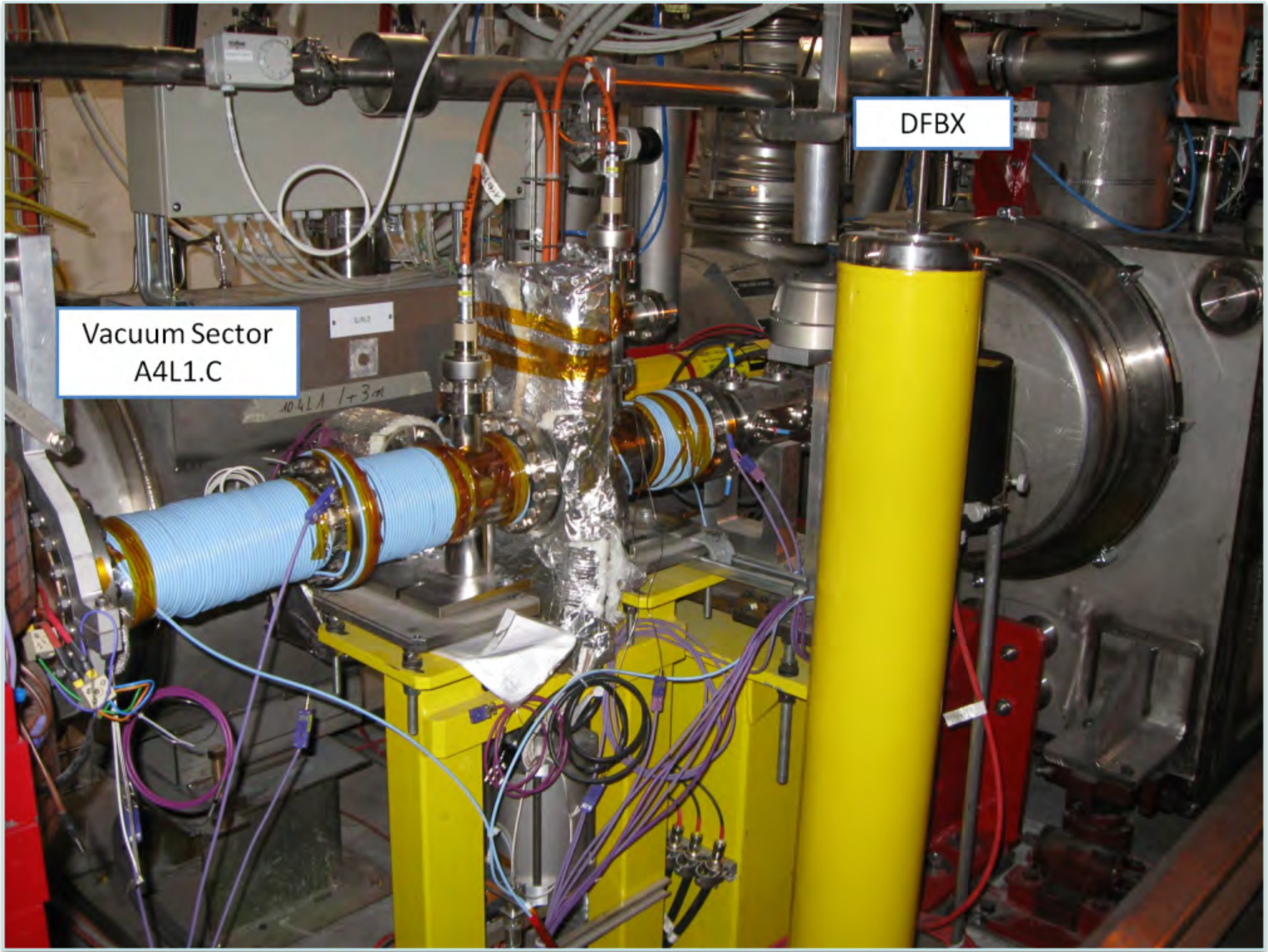
First observation of e-cloud activity @ LHC: 8-10-2010. 150 ns bunch spacing: Merged vacuum



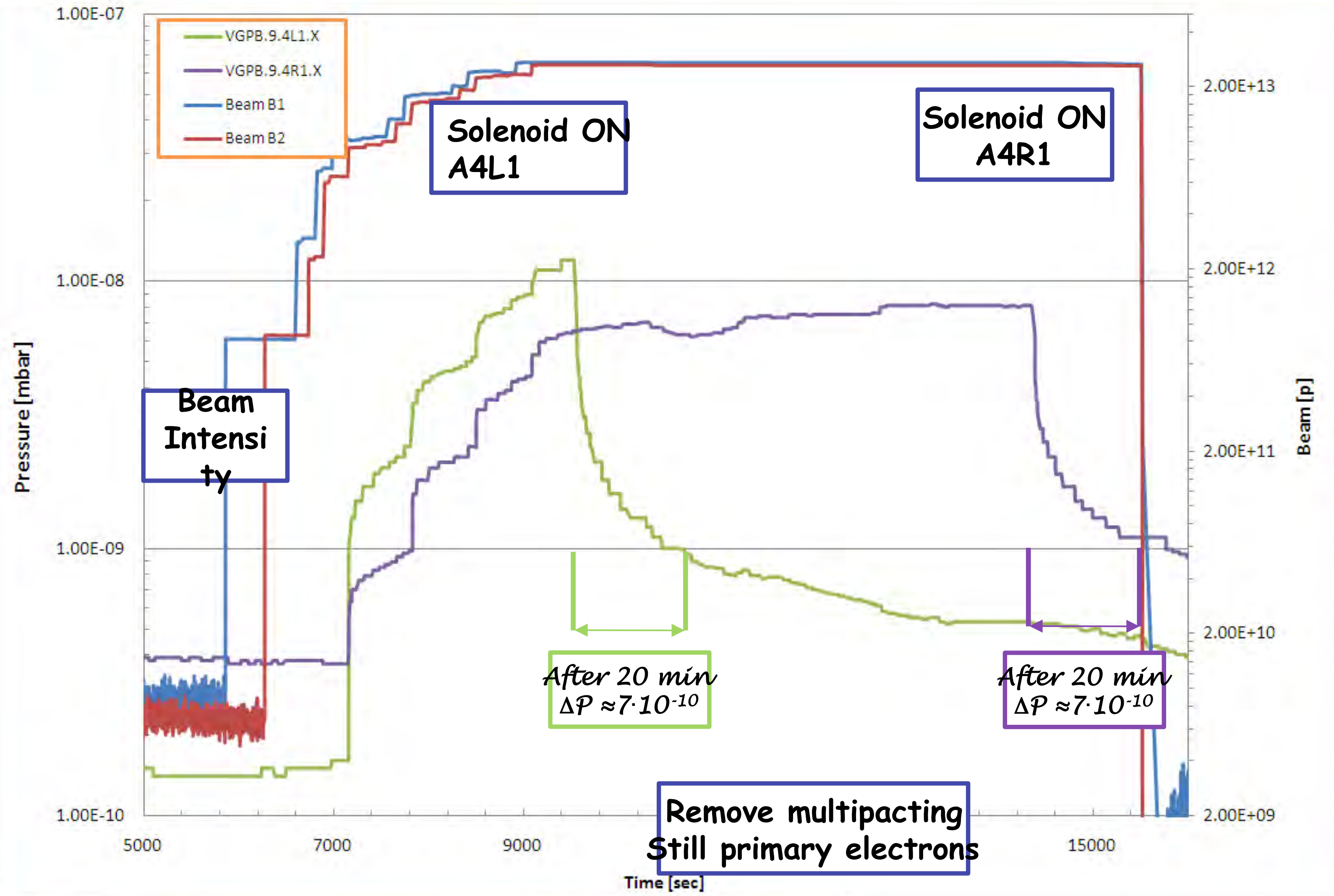
150 ns - 450 GeV

R. Cimino

Easily solved: Installation of Solenoids

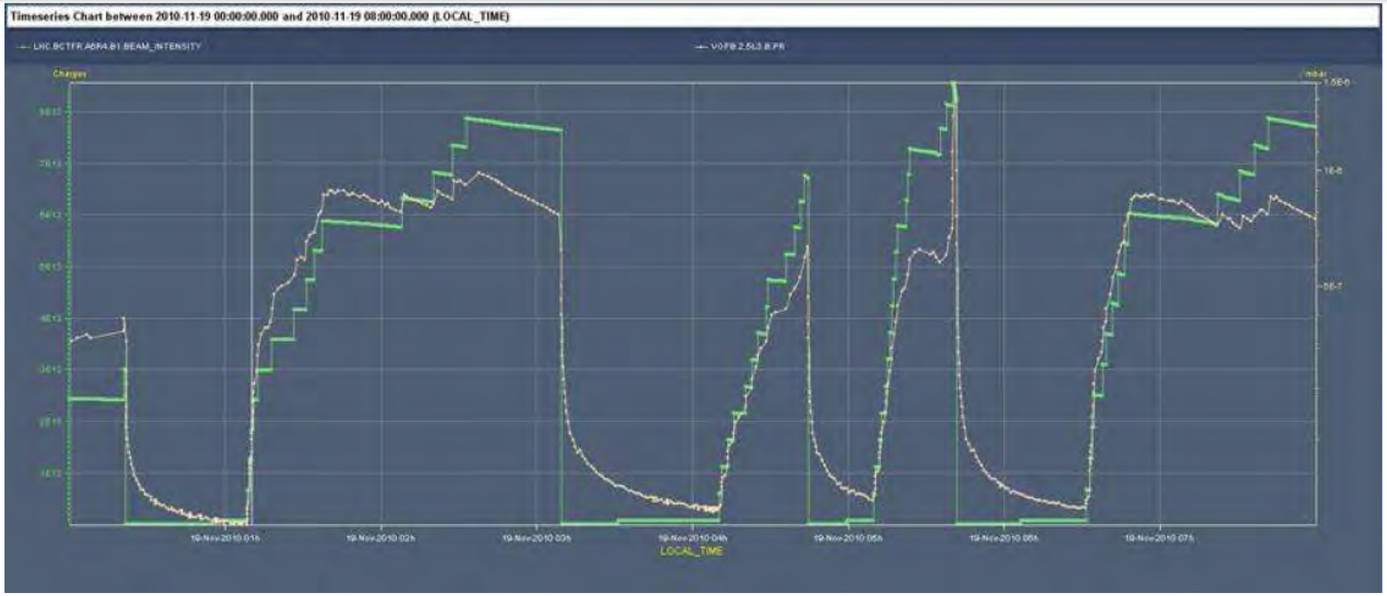


Solenoids effect on pressure



R. Cimino

➔*OBSERVATIONS IN 2010 @ LHC:*



Pressure rises with 75ns bunch spacing were observed in IR3
Even though P~10^-6mbar, 936 bunches could be filled in

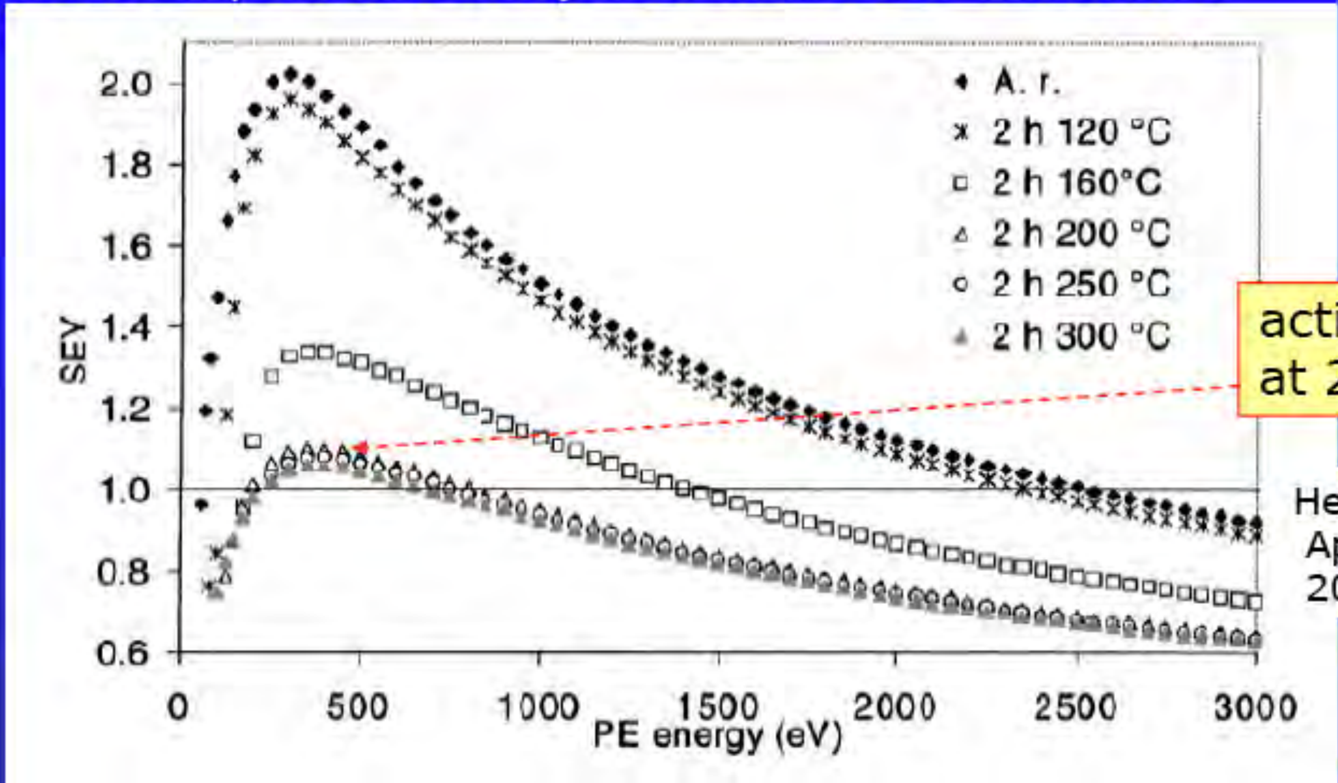
➔**PLAN FOR 2011:** Scrubbing using 50ns bunch trains
Physics operation using 75ns

➔**GOAL:** Investigate SEY parameters such that e-clouds do not limit physics operation

Bakeable system

NEG coatings

TiZrV NEG thin films can provide a surface with low δmax after heating at the lowest temperature compared with other materials:



Henrist et al. Appl.Surf.Sci, 2001

-2h at 200C or 24h at 180C

-data for 8 re-activations of 2h at 250C after air-venting show an SEY below 1.3

-LHC long straight sections (6 km, more than 1000 chambers) to provide pumping and low SEY

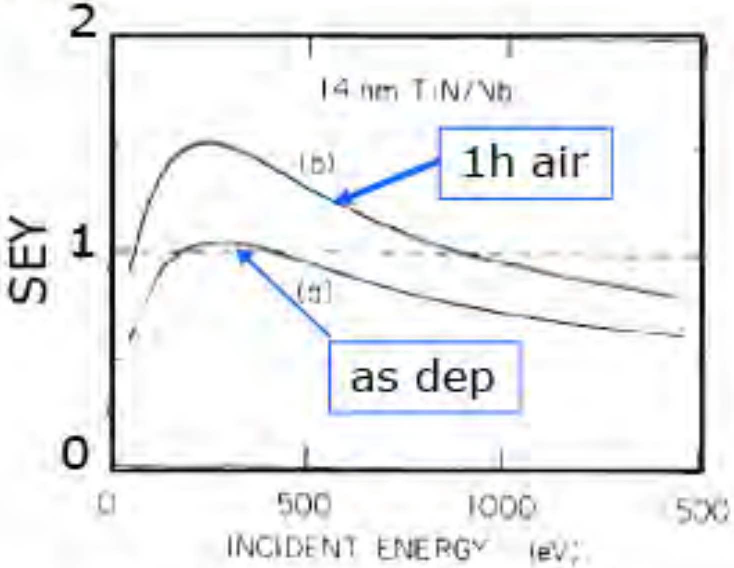
No bake

Surfaces with initially low SEY: TiN and effect of air exposure

As deposited TiN has a δmax = 0.9-1.1 ; **clean copper** has 1.3

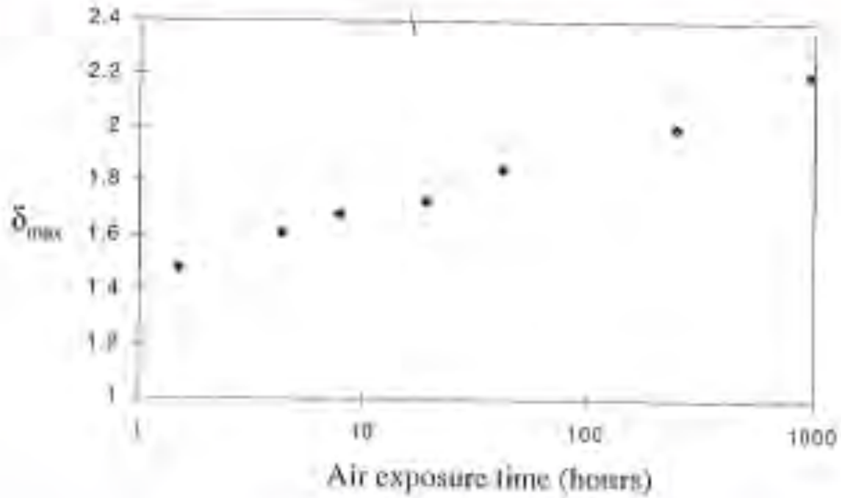
Upon air exposure the TiN yield increases to **δmax** = 1.5-2.5 and the one of copper to δmax =1.6-2.2

TiN



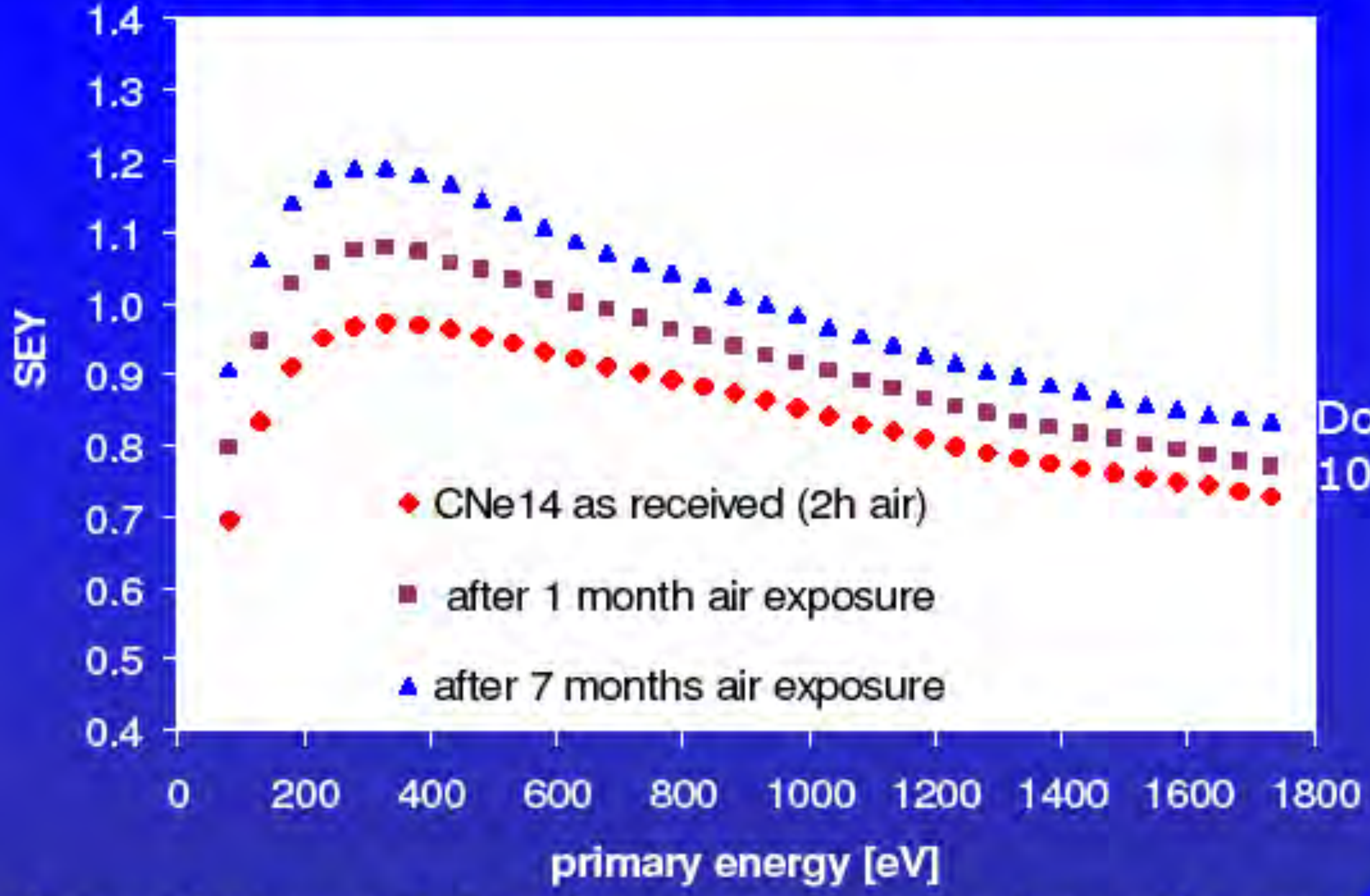
(E.L.Garwin et al. 1987)

Copper: air exposure



(Scheuerlein, 1999)

SEY of a-C carbon coatings (no bake):



Dose below 10^{-6} Clb/mm^2

-initial δmax between 0.9 and 1.1, some scattering in the aging values for air exposure

-No change with thickness above 50 nm

-Aging is difficult to study by surface analysis since it is difficult to distinguish adsorbed hydrocarbons..... on carbon

Activity of the LNF Material Science Laboratory:

Our Laboratory is becoming a reference Lab for material science analysis and tests of relevance for e-cloud studies.

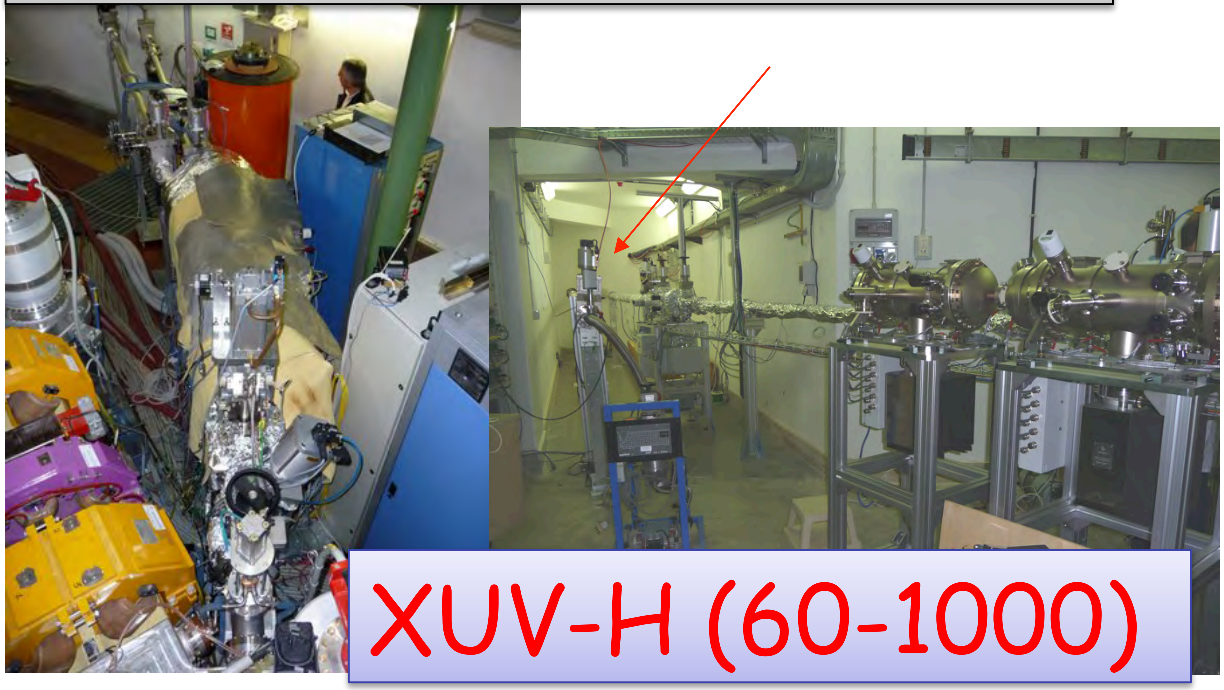
We are studying (in collaboration with the respective institutes):

- *CERN- LHC (Dipole chamber) Cu Samples*
- *CERN – SPS a-C Coatings*
- *Al from DAFNE and PETRA 3 (DESY)*
- *Stainless Steal (from RICH, Brookhaven)*
- *TiN "test" samples produced at LNF and from PEP*
- *……*

… and we are learning a lot!!!

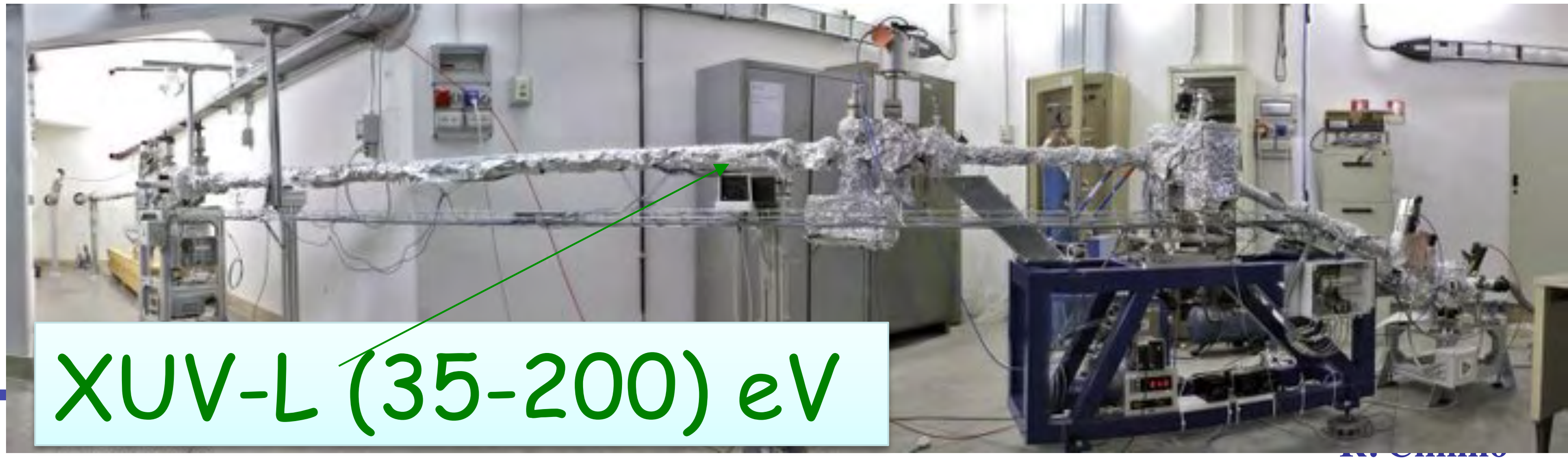
- *Together with the SEY experiments, @ LNF, we are able to "see" the chemical modification at the surface. This will be more effective by using two SR beamlines from a DAΦNE BM which we are now carefully aligning and commissioning!*

LNF XUV Beam Lines



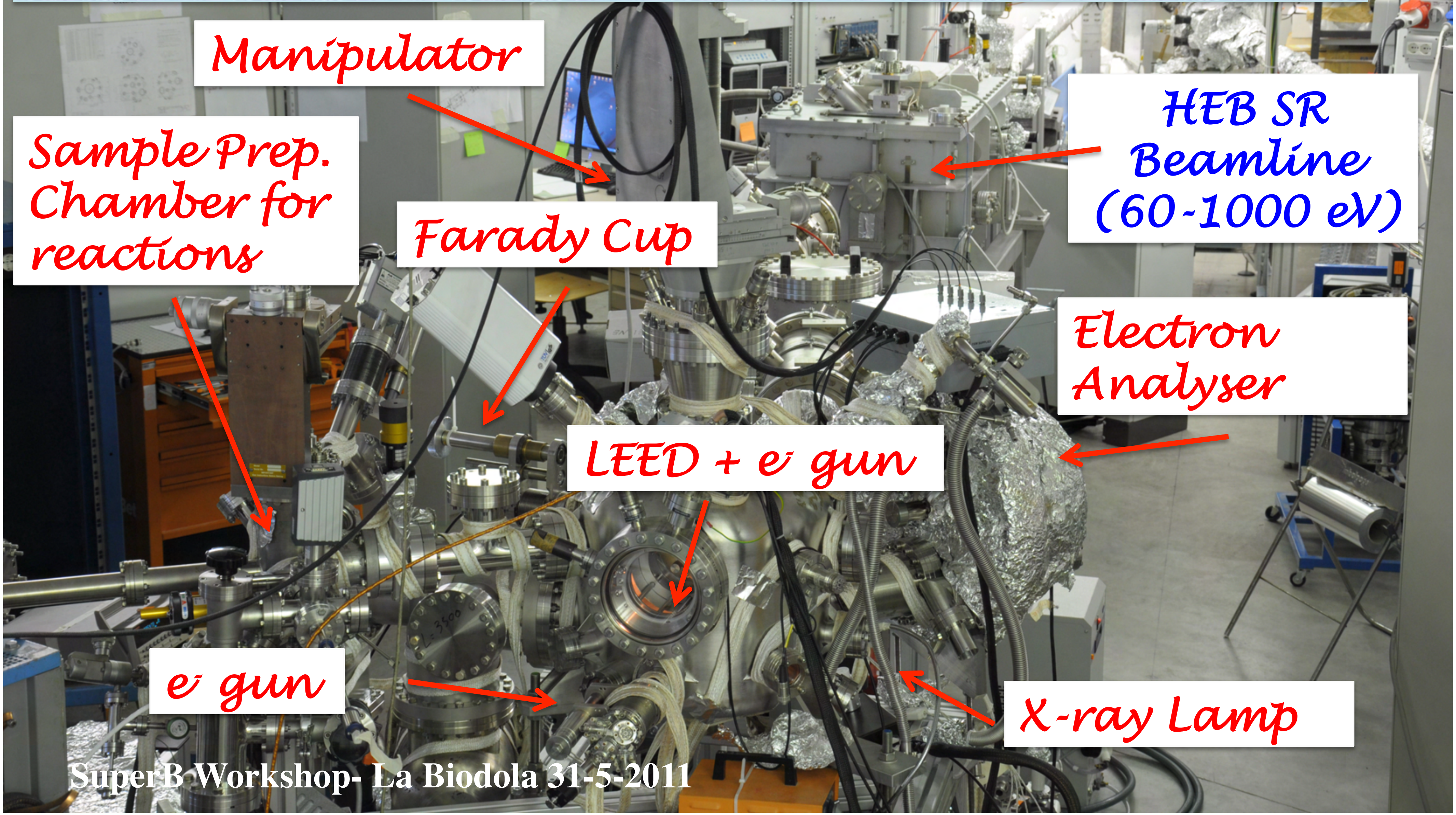
XUV-H (60-1000)

When ready we will be one of the few laboratory in the wolrd to be able to analyse SEY (PEY) variation after electron and photon scrubbing on the same samples. This is a situation which does occur in real accelerators, but it has never been studied in a laboratory experiment.

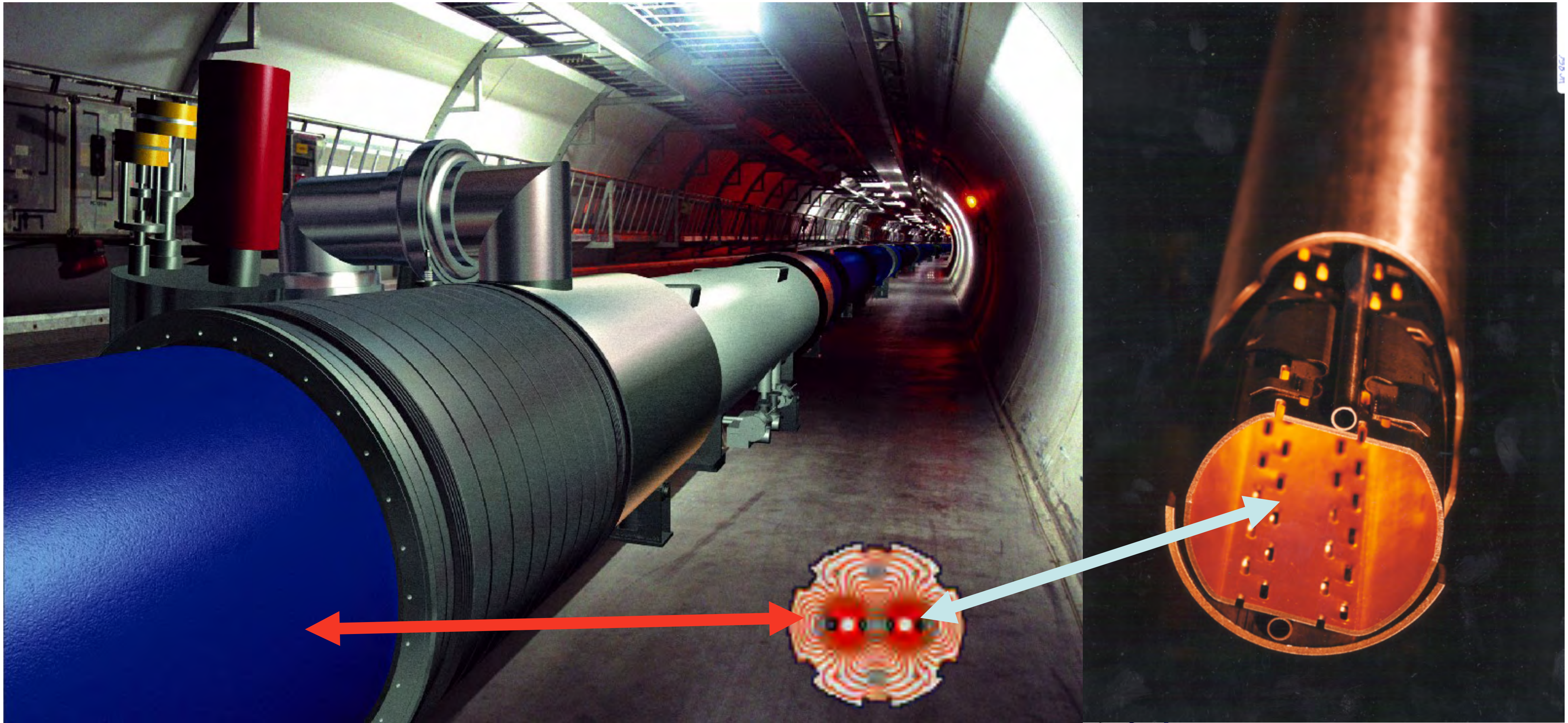


XUV-L (35-200) eV

We are sworking on up a State of the art Surface Science system to study, produce and test low SEY films.

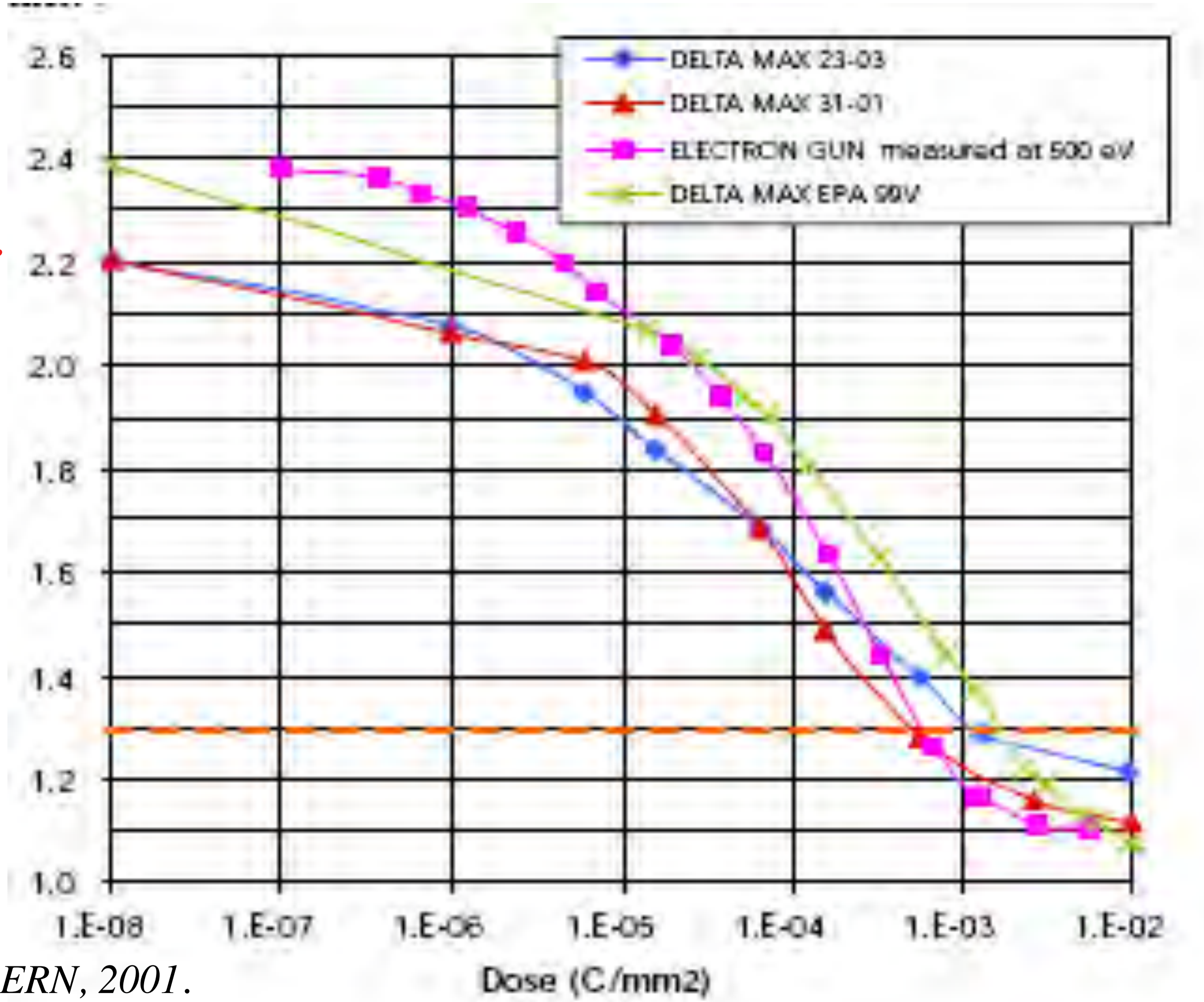


Our study on the Cu surfaces of the LT dipole regions of LHC: "scrubbing" and chemical modifications



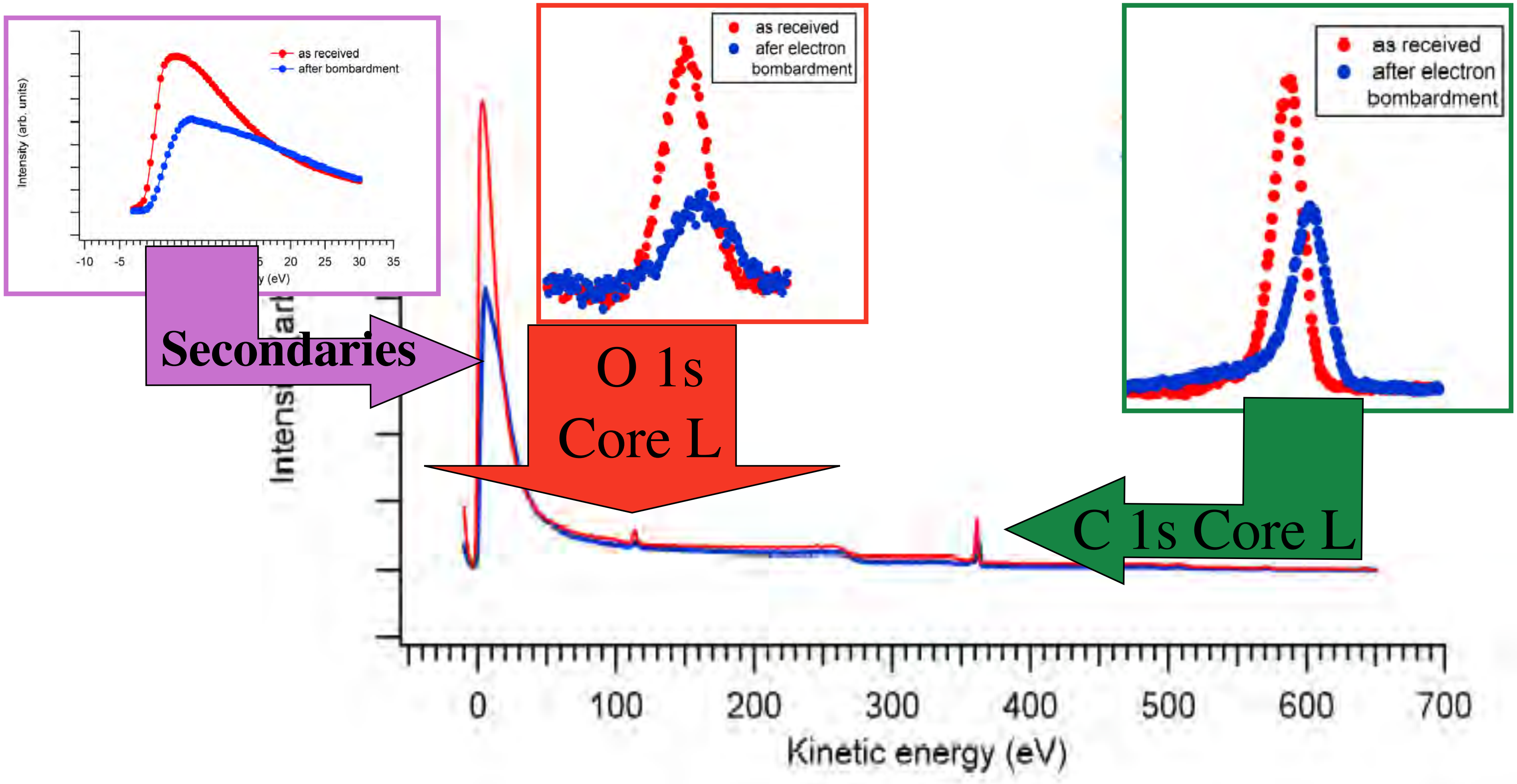
The Beam "scrubbing" effect is the ability of a surface to reduce its SEY after e^- bombardment.

from LHC PR 472 (Aug. 2001): "…Although the phenomenon of conditioning has been obtained reproducibly on many samples, the exact mechanism leading to this effect is not properly understood. This is of course not a comfortable situation as the LHC operation at nominal intensities relies on this effect…"



V. Baglin et al, LHC Project Report 472, CERN, 2001.

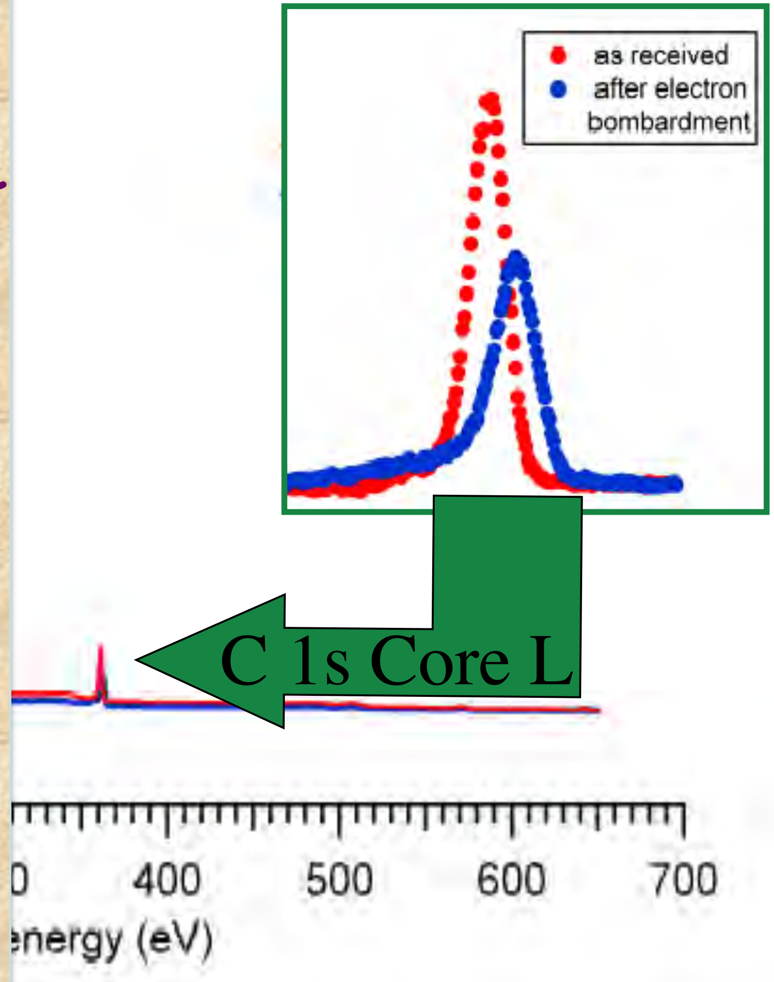
Photoemission spectroscopy during electron scrubbing.



*Cimino et al. not published

Photoemission spectroscopy during electron scrubbing.

From photoemission spectra we notice that on LHC copper samples, oxigen does not vary significantly with electron bombardment, and carbon levels shows a clear formation of a sp^2 layer indicating a graphitization of the sample.



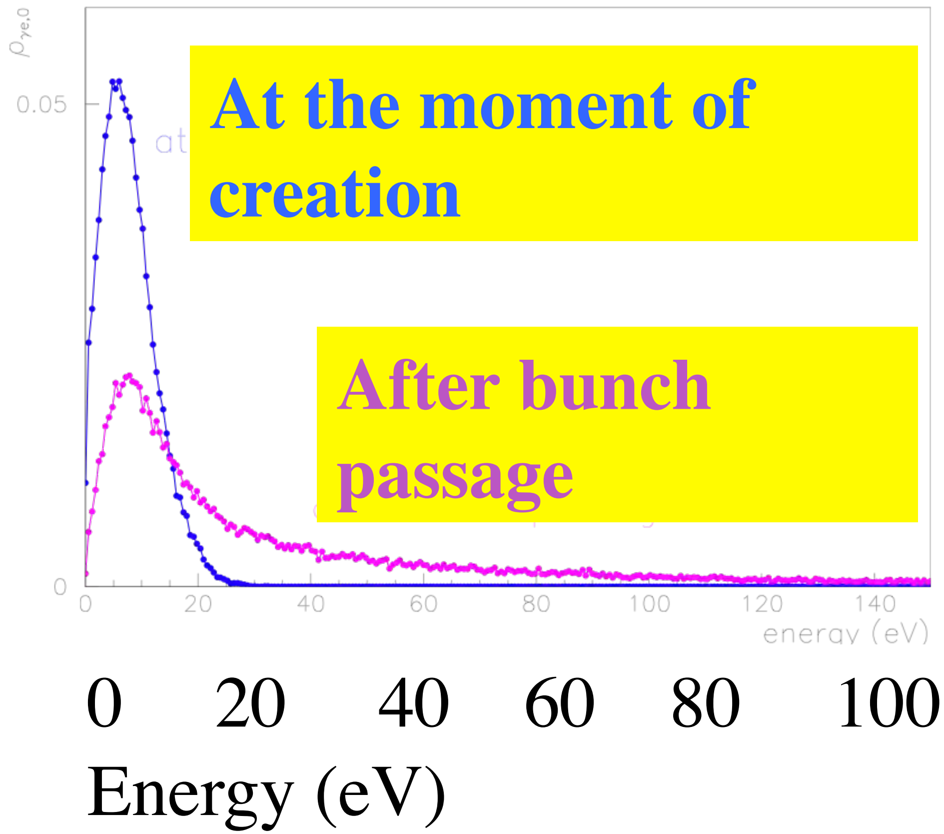
*Cimino et al. not published

a little (but useful) detour on the scrubbing process

Most of the data on "scrubbing" have been obtained in laboratory experiments by bombarding surfaces with 500 eV electrons for increasing Time (i.e: dose)

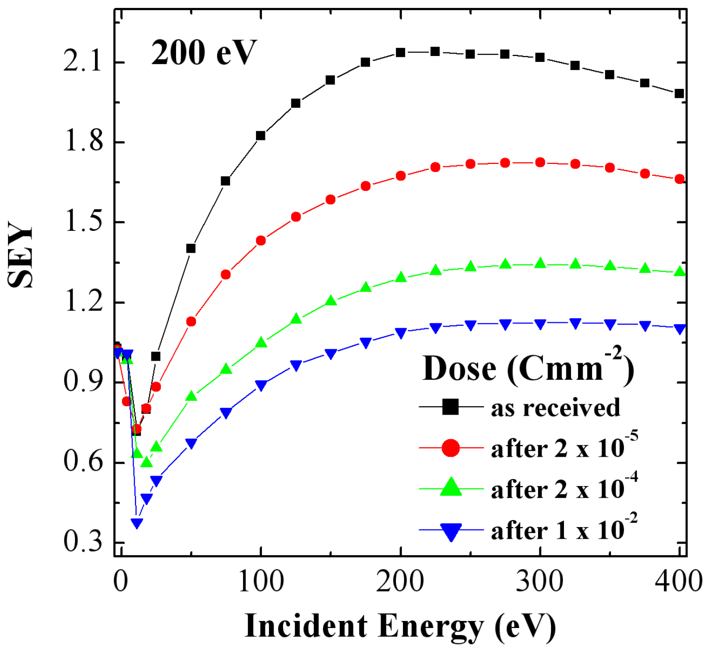
Dose= N°e⁻ x t(s) x A (mm²)

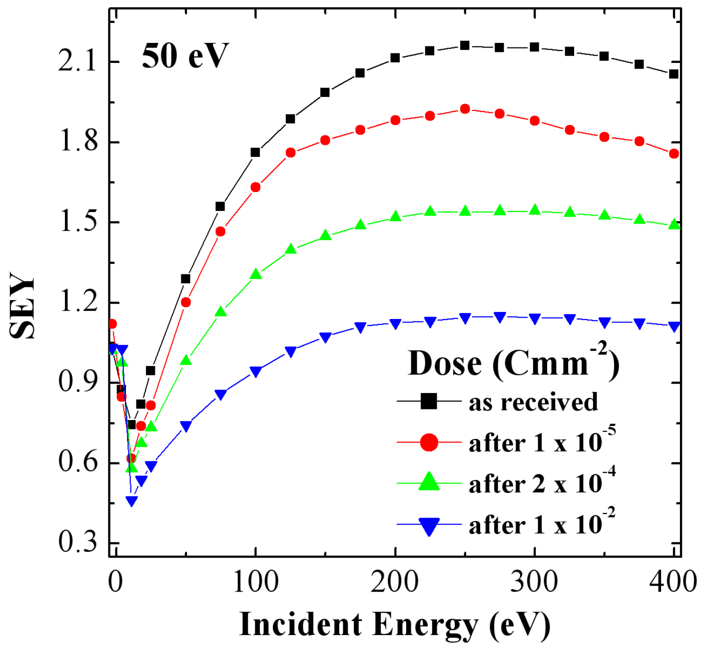
- *What energy do the e⁻ participating in the cloud have in the accelerator? Simulation by F. Zimmermann (2001) shows that the main contribution lies at low energy!*
- *do 10 e⁻ @ 500 eV scrub as*
  - *10 e⁻ @ 10 eV?*

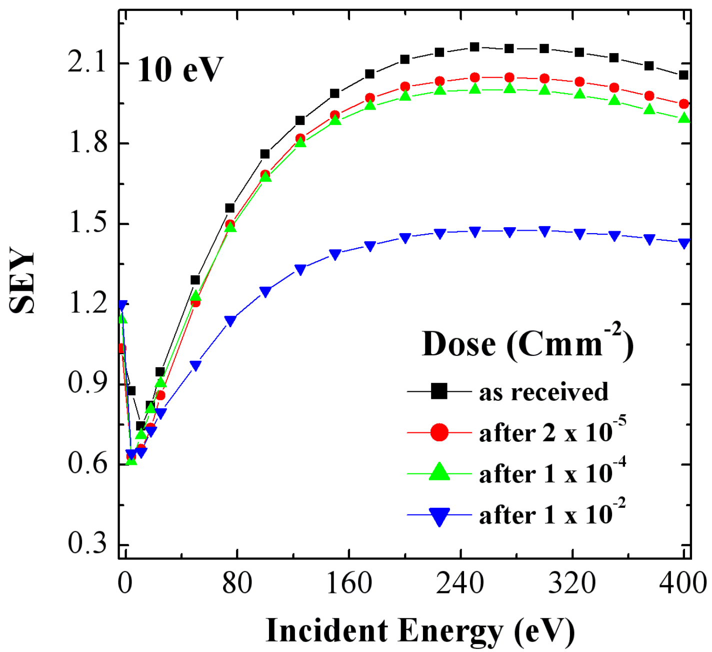


Scrubbing vs impinging electron energy

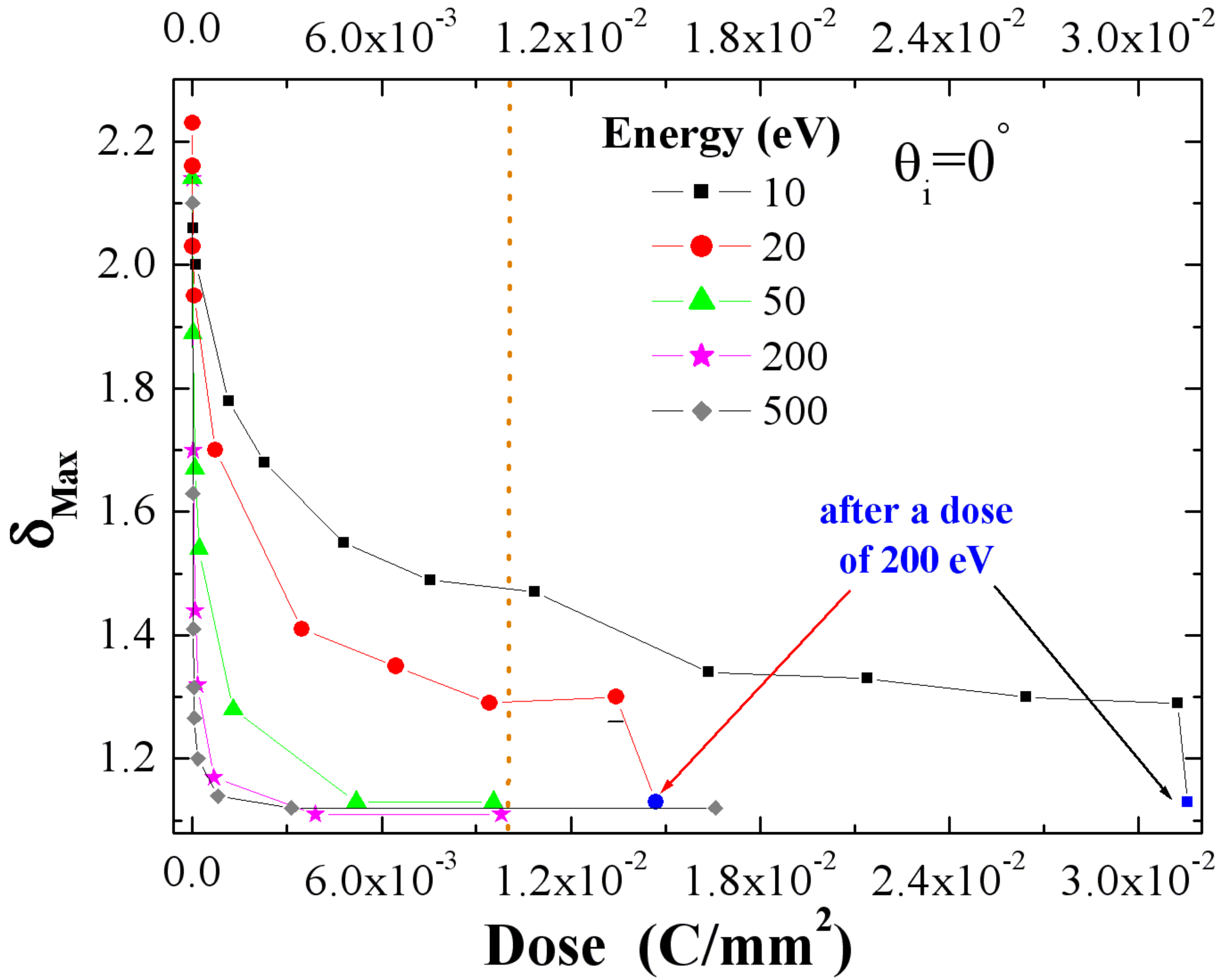
Comisso et al in preparation







SEY measurements for 200 eV, 50 eV and 10 eV impinging electron energy at normal incidence



δ_{max} versus dose for different impinging electron energies at normal incidence.

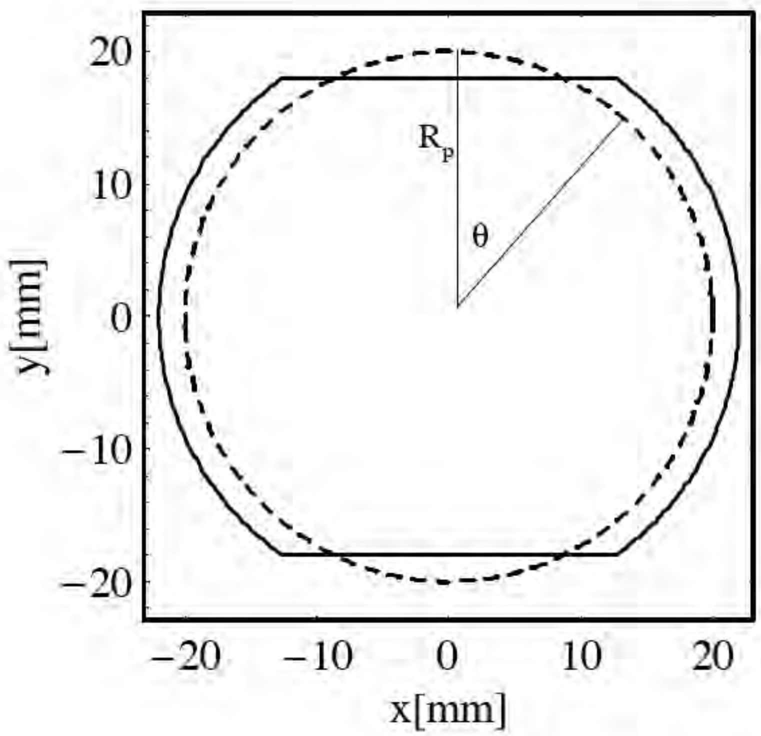
Commisso et al in preparation

We demonstrate that the potentiality of an electron beam to reduce the SEY does not only depend on its dose, but also on hits energy.

Theo DEMMA performed some preliminary simulation to see if one can optimize the "scrubbing" process @ LHC

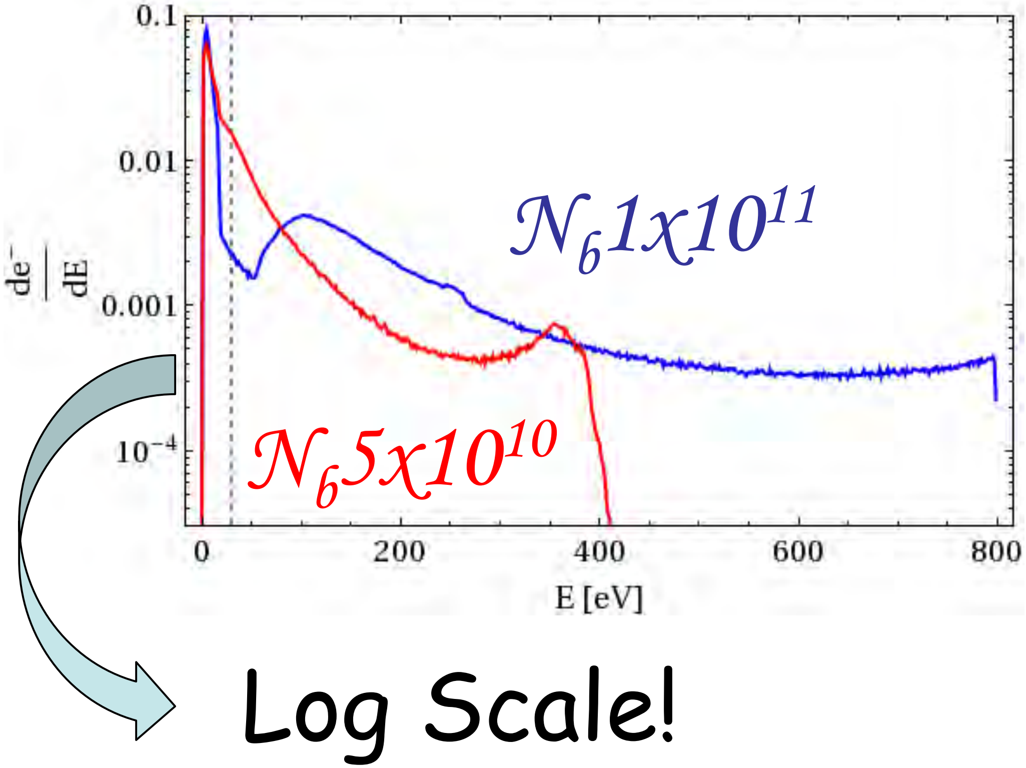
Table 1: Parameters used for ECLOUD simulations.

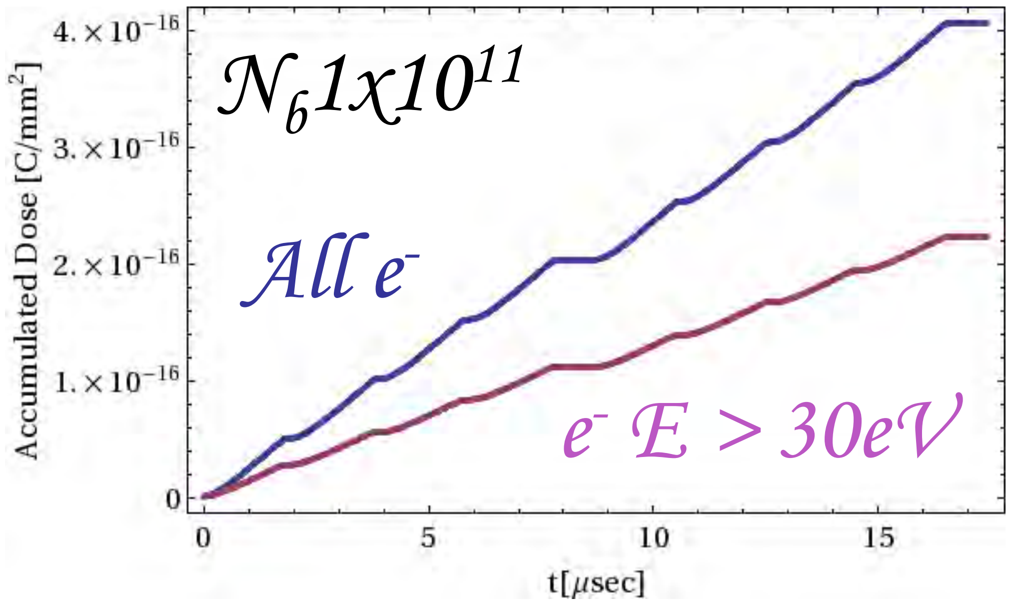
parameter	units	value
beam particle energy	GeV	7000
bunch spacing t_b	ns	$25; 50; 75$
bunch length	m	0.075
number of trains N_t	-	4
number of bunches per train N_b	-	$72; 36; 24$
bunch gap N_g	-	8
no. of particles per bunch	10^{10}	$10; 3.0$
length of chamber section	m	1
chamber radius	m	0.02
circumference	m	27000
primary photo-emission yield	-	$7.98 \cdot 10^{-}$
maximum SEY δ_{max}	-	1.2(0.2)2.0
energy for max. SEY E_{max}	eV	237



• *Potential consequences of these measurements on the commissioning of LHC: calculation of the e^- dose hitting the walls versus beam parameter and energy (preliminary).*

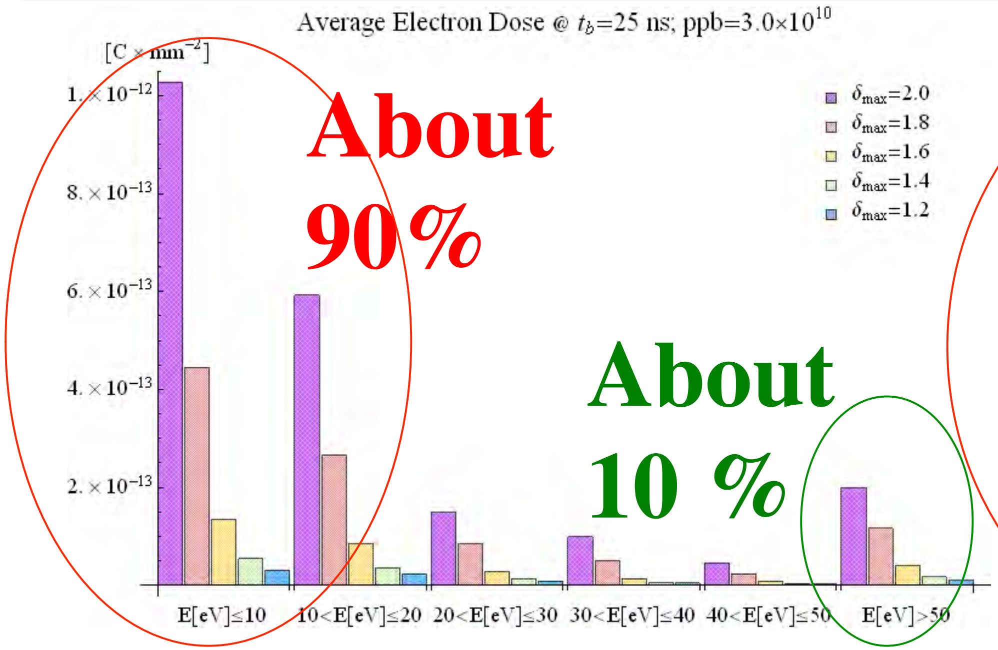
@ 50ns, δ_{max}=1.4

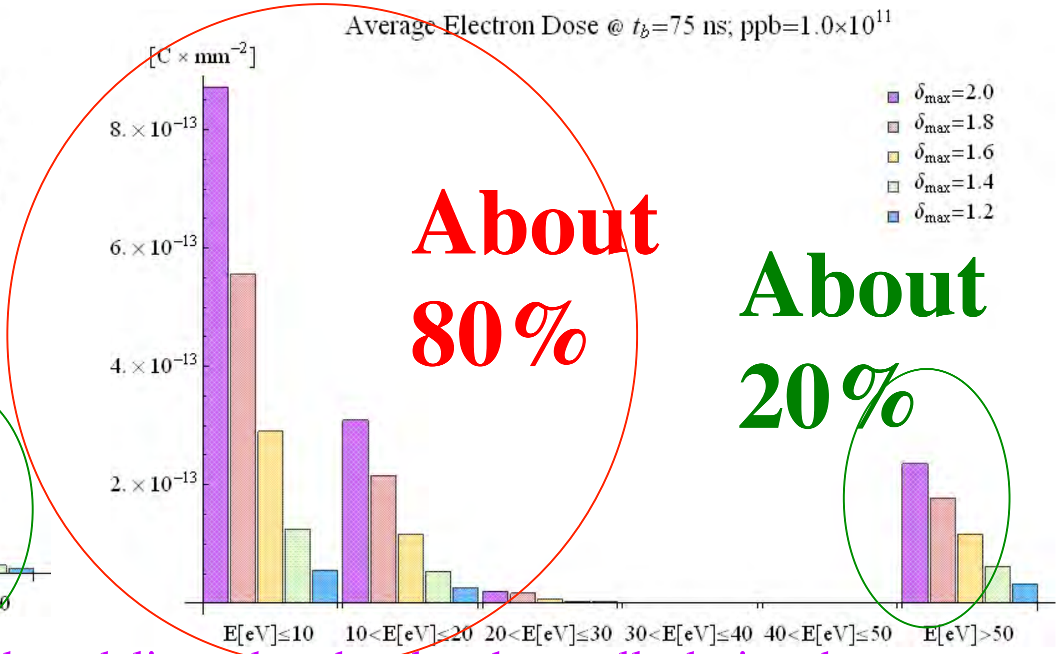




T. Demma et al. in preparation.

• *Potential consequences of these measurements on the commissioning of LHC : calculation of the real e⁻ energy of the cloud (EC) hitting the walls versus beam (preliminary).*

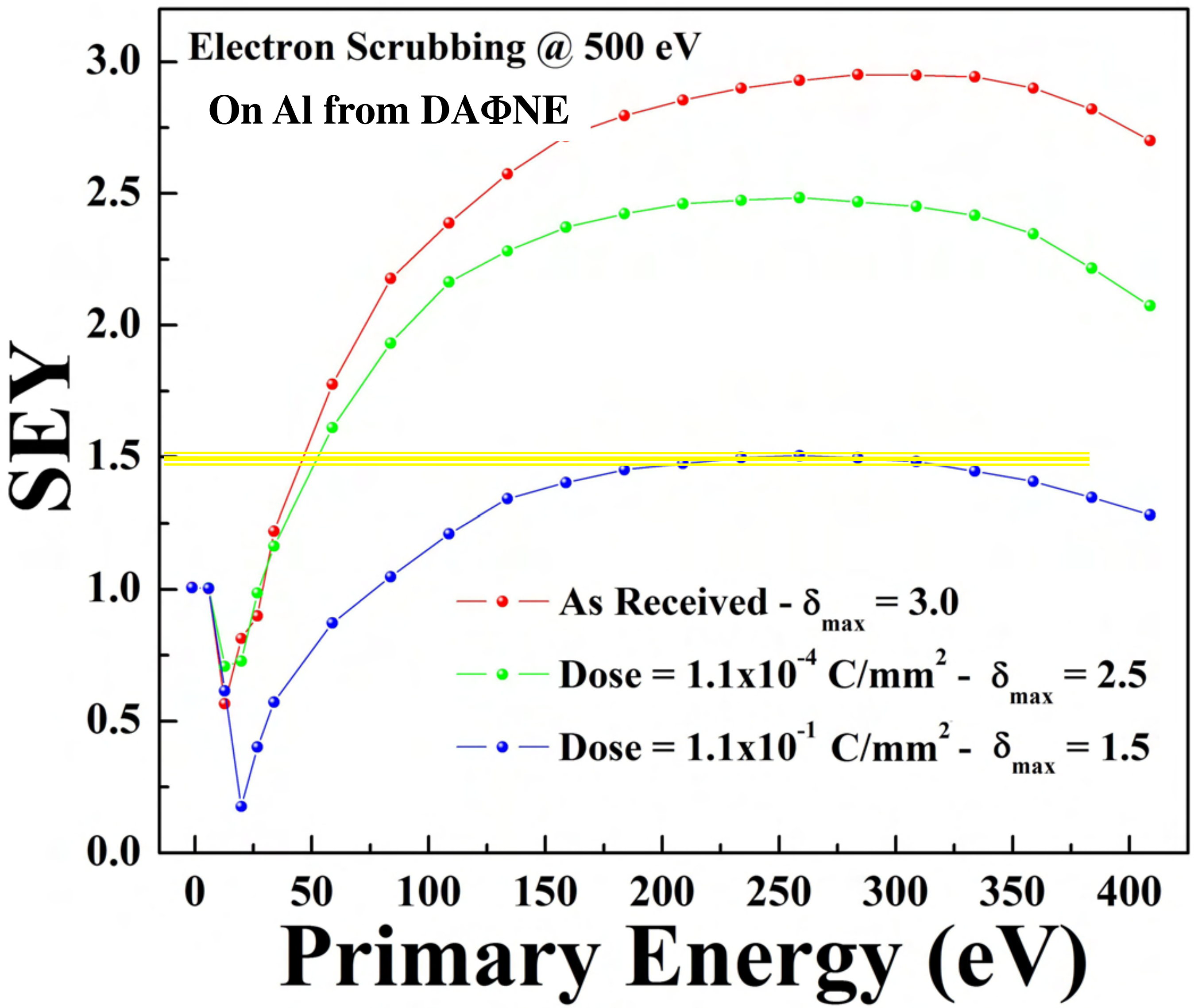




Simulated energy components of electron dose delivered to the chamber walls during the passage of a bunch train for different value of δ_{max}

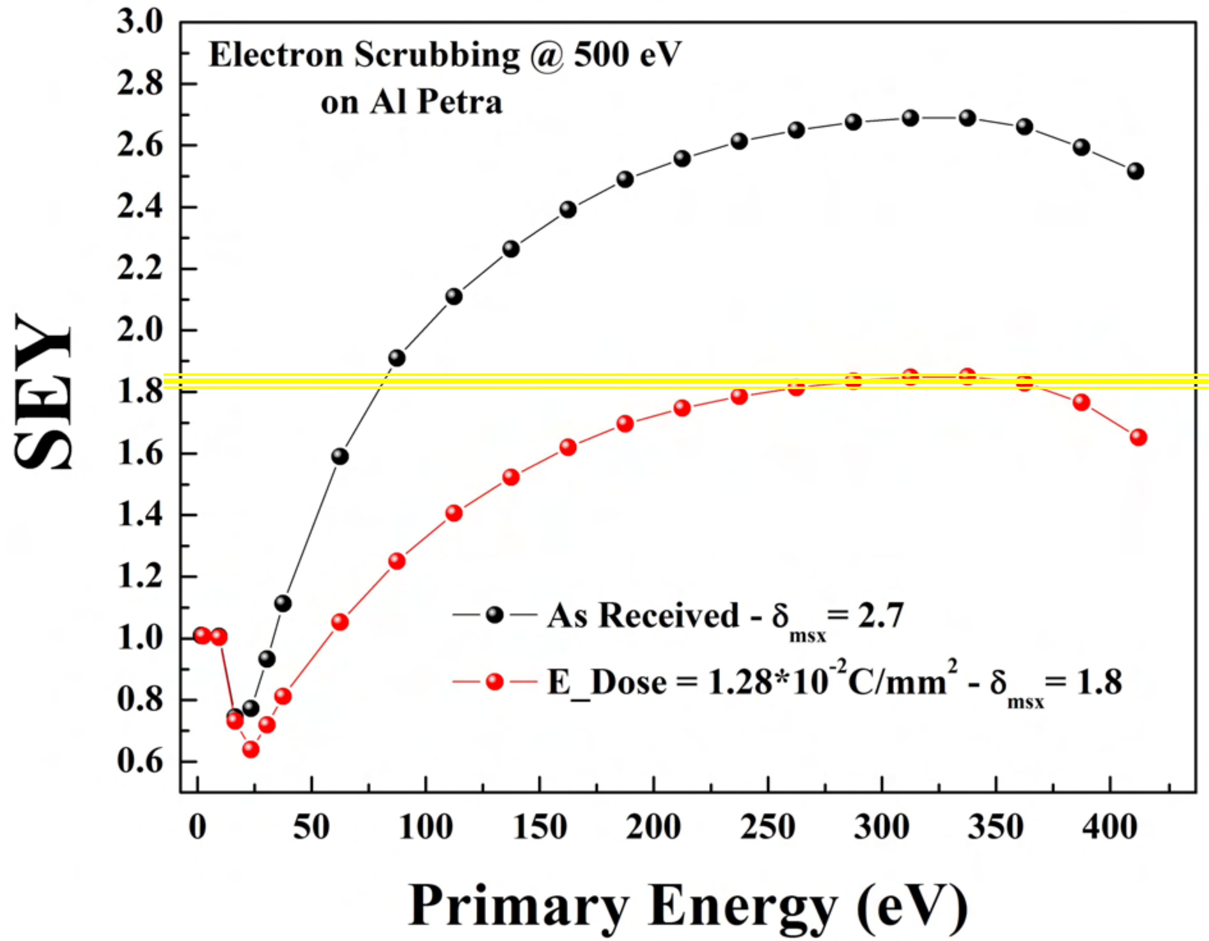
M.Commisso, R. Cimino, T. Demma, V. Baglin in preparation.

Back to our SEY and XPS studies: Al from DAΦNE



D. R. Grosso et al
in preparation

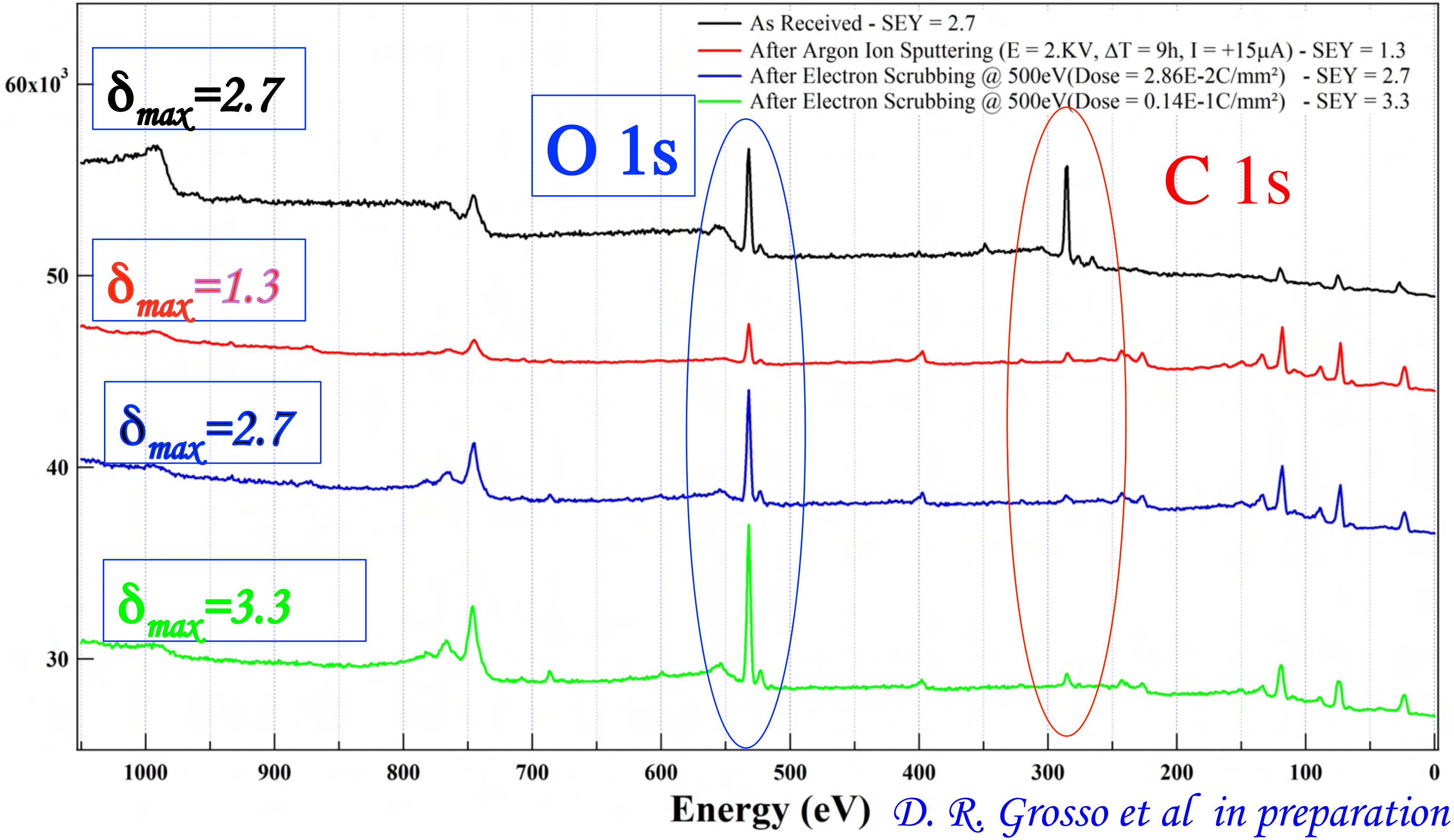
Back to our SEY and XPS studies: Al from Petra III (difficulties in reaching low emittance)!



General note: when one deal with industrially prepared materials: **Not all the materials are what they are called!**

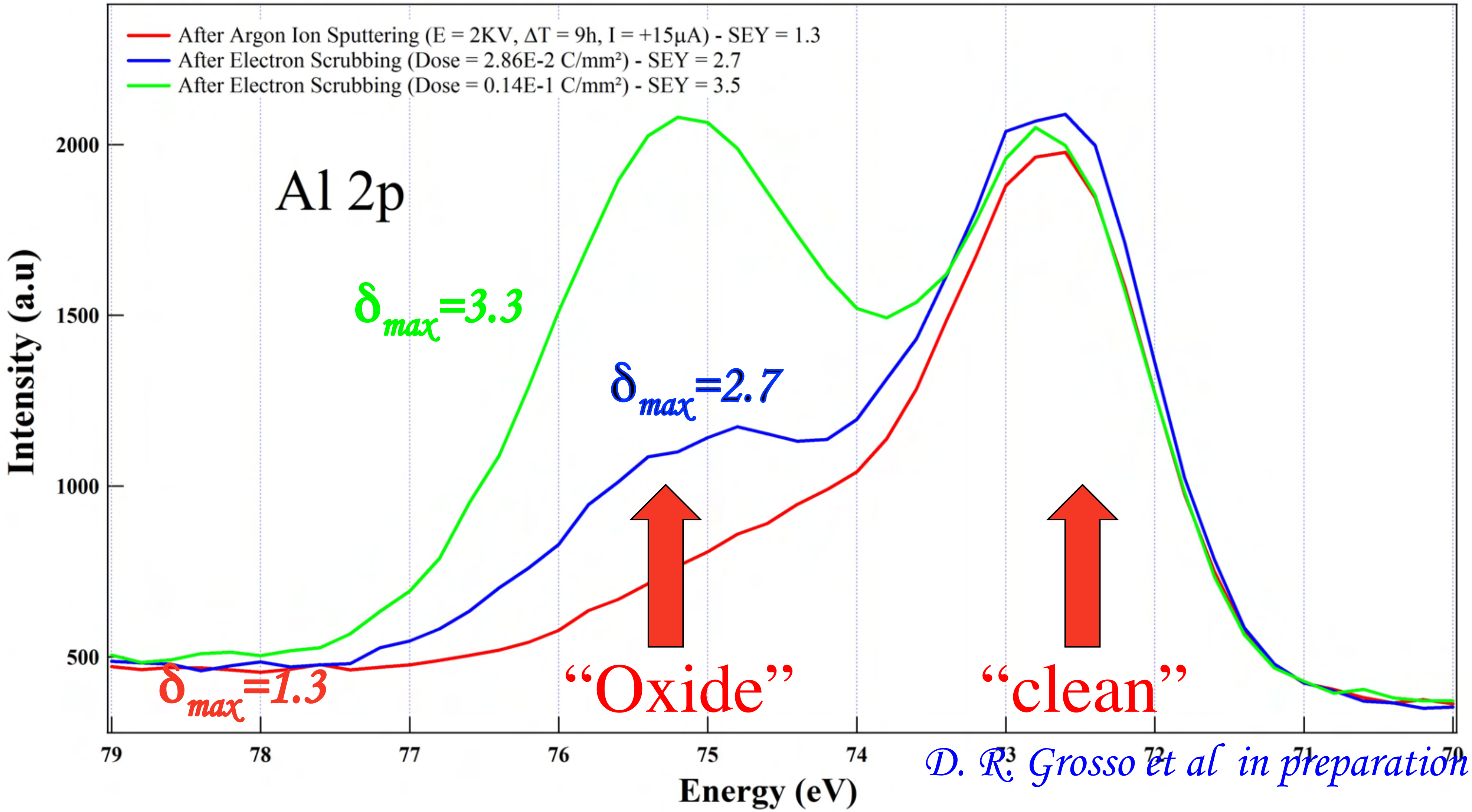
:so et al in preparation

XPS studies on Al as received, sputtered clean and e^- dosed in 10^{-8} - 10^{-9} mbar:



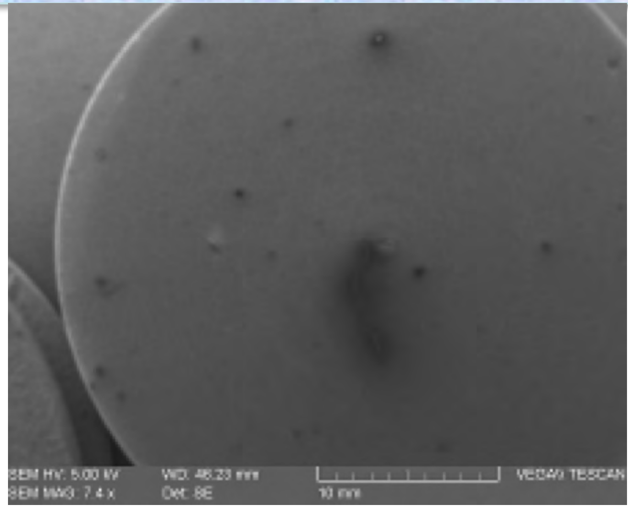
D. R. Grosso et al in preparation

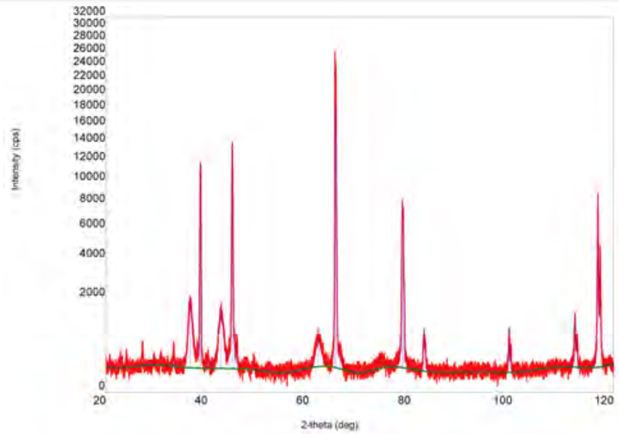
XPS studies on Al:



D. R. Grosso et al in preparation

New results on TiN (done by S. Bini & the LNF Vacuum Group).

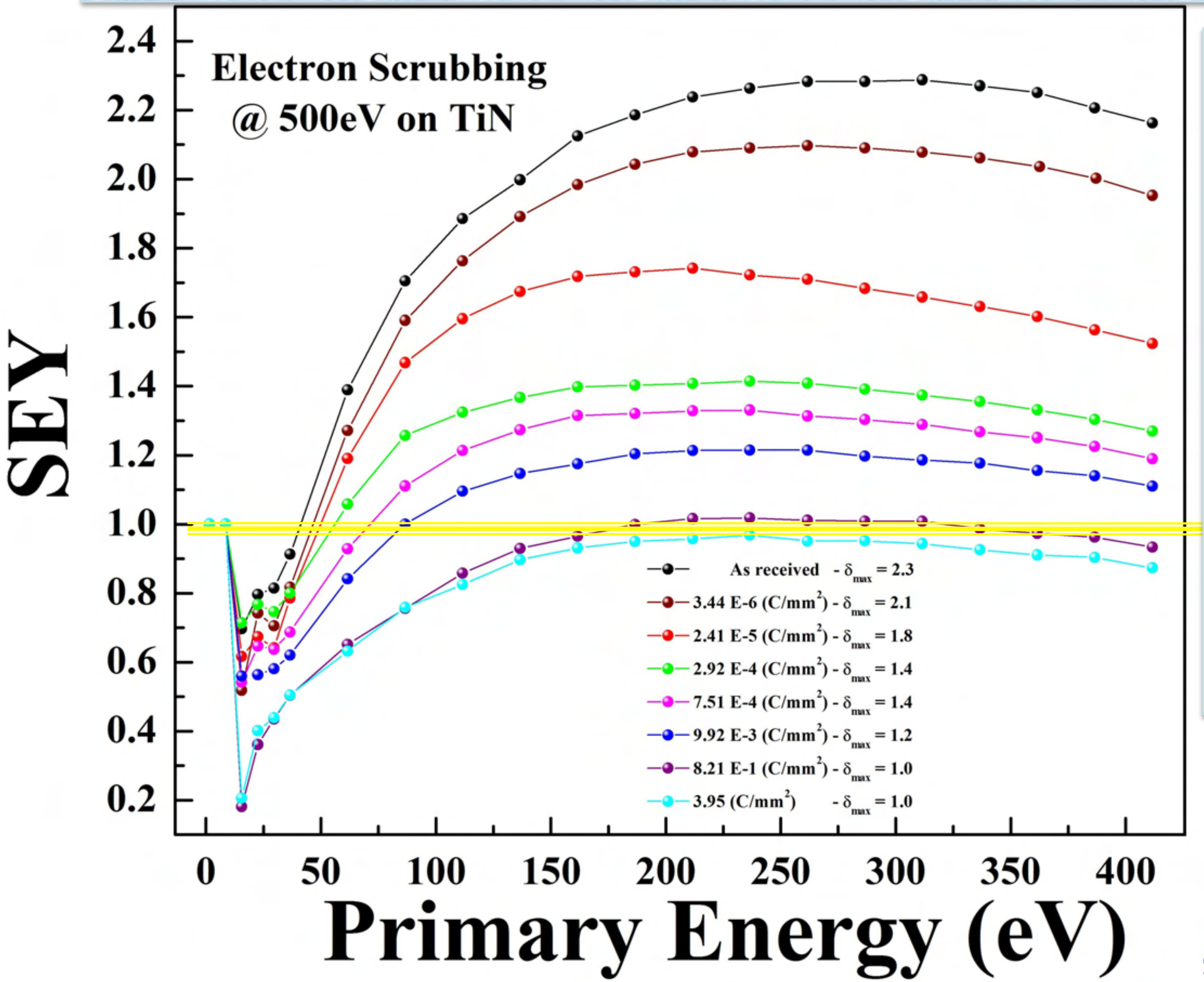




Nanocrystalline TiN thin films has been deposited on aluminum substrates by RF-magnetron sputtering. The "good" quality of the film in terms of microstructural morphology and texture was characterized by SEM and FE SEM and by X – Ray Diffraction.

*Bini et al. in preparation

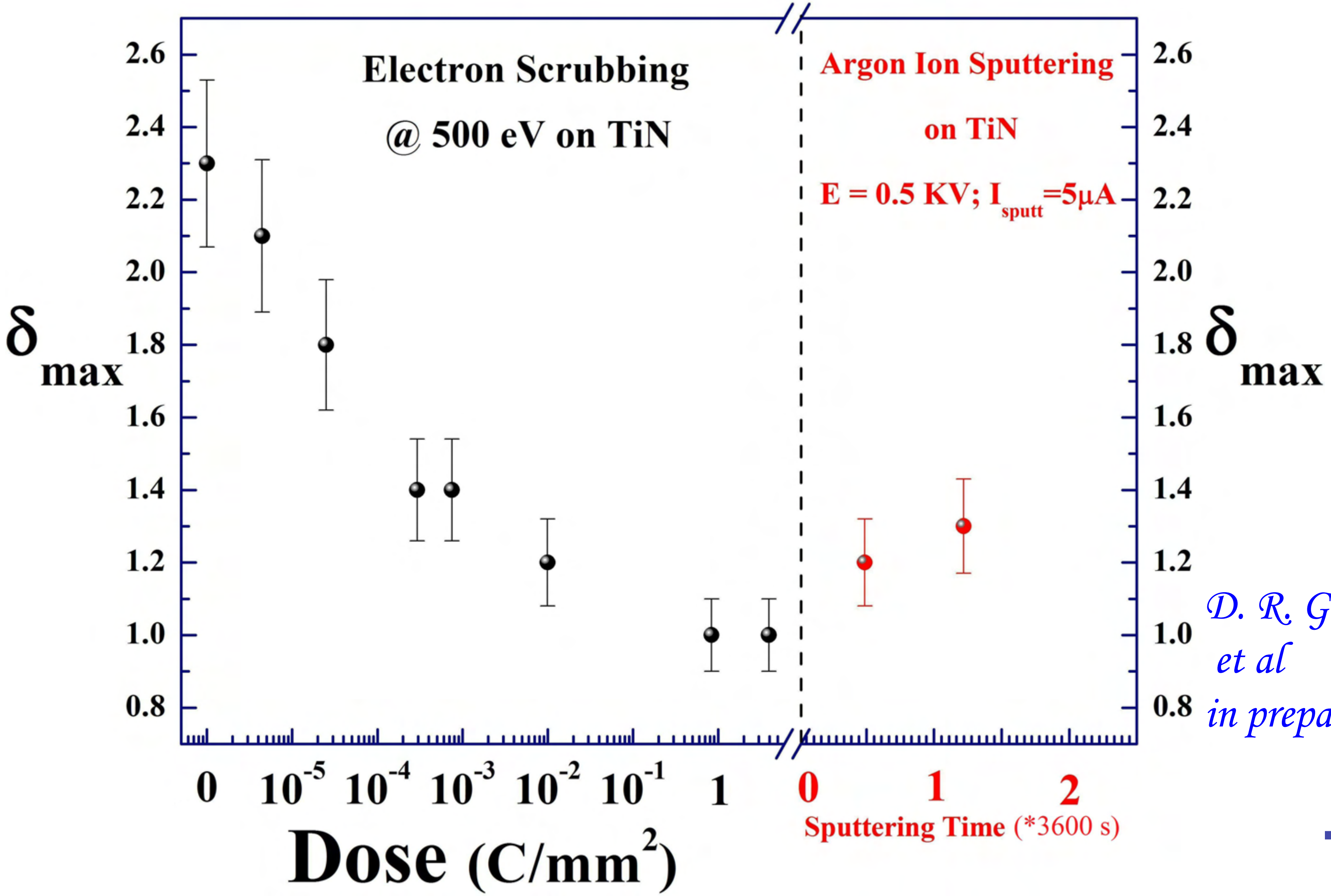
On such TiN we measured SEY vs. electron Dose and….



TiN (at least "our") needs scrubbing: then it reaches δ_{max} ~ 1, which is the value quoted at KEK

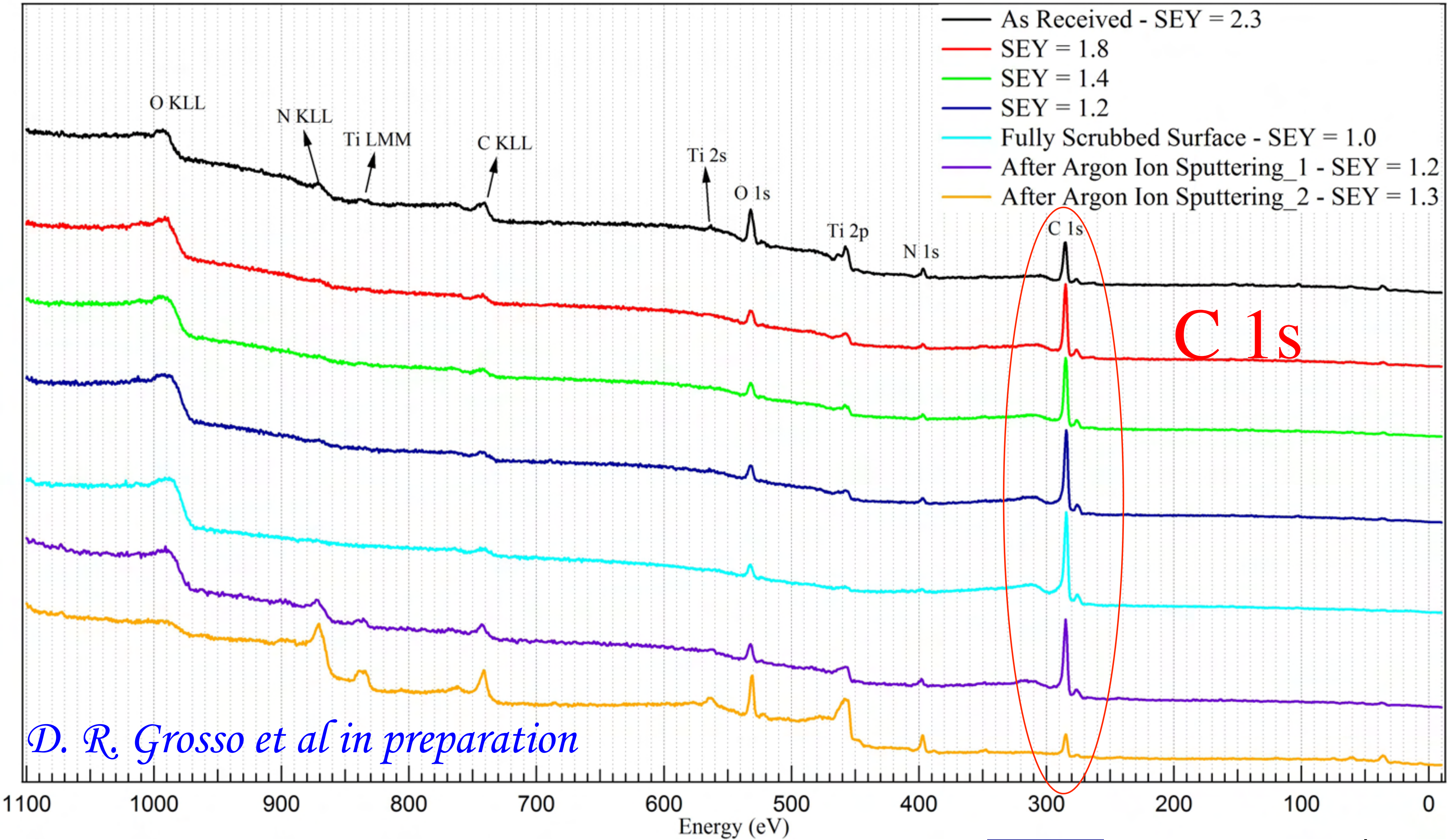
D. R. Grosso et al in preparation

We measured δ_{max} vs. e^- Dose and Ion sputtering and..

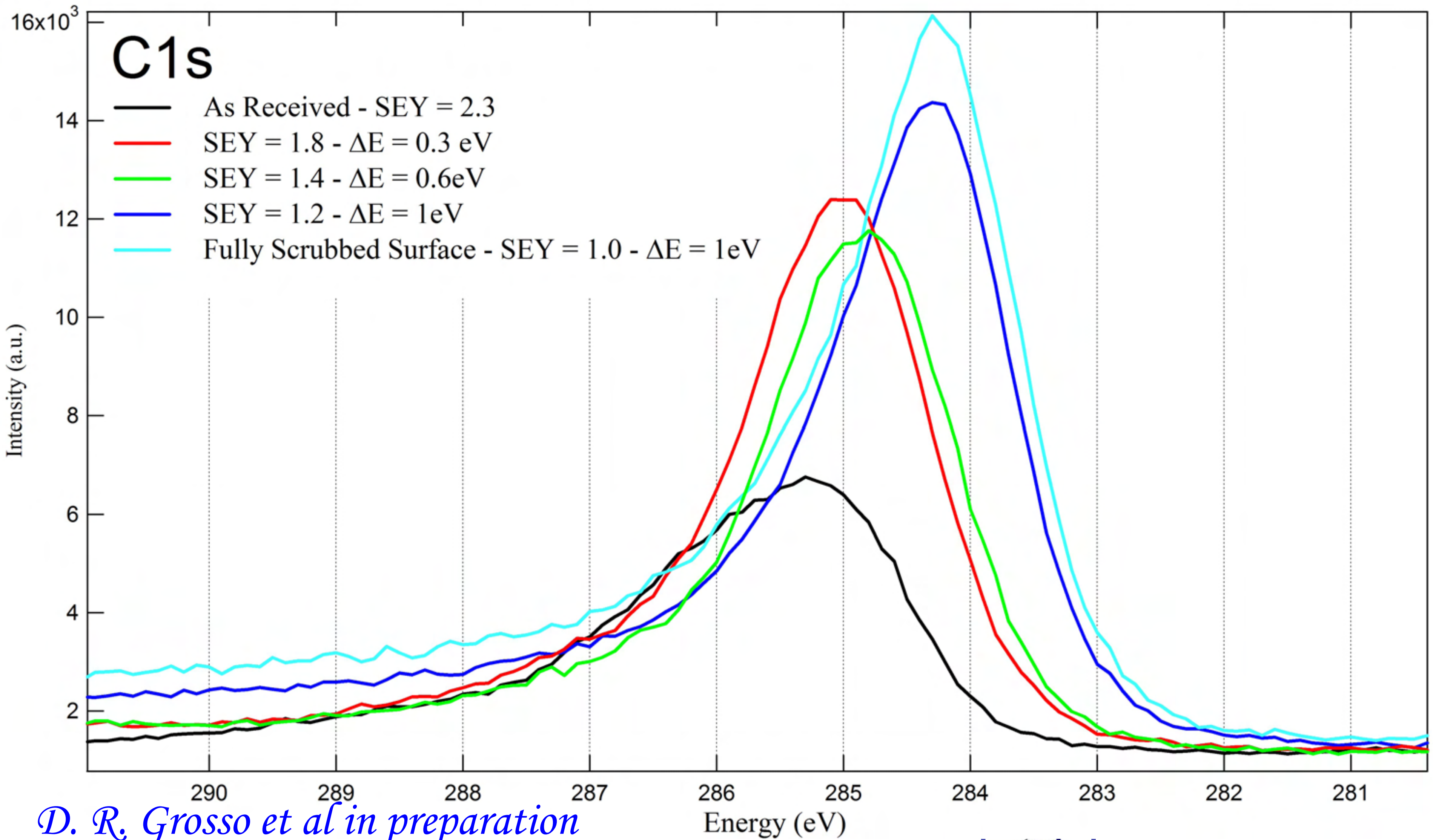


D. R. Grosso et al in preparation

We measured XPS vs. e⁻ Dose and Ion sputtering and..



Also in TiN the SEY reduction is accompanied by C-sp² formation



D. R. Grosso et al in preparation

What did we learn so far?

Al, is very reactive, ageing etc. produce Oxides with very high SEY! (If used should be coated)

From Surface Analysis we learn that when C on the surface forms an sp^2 layer, then scrubbing is efficient and the δ_{max} goes below 1.2!!

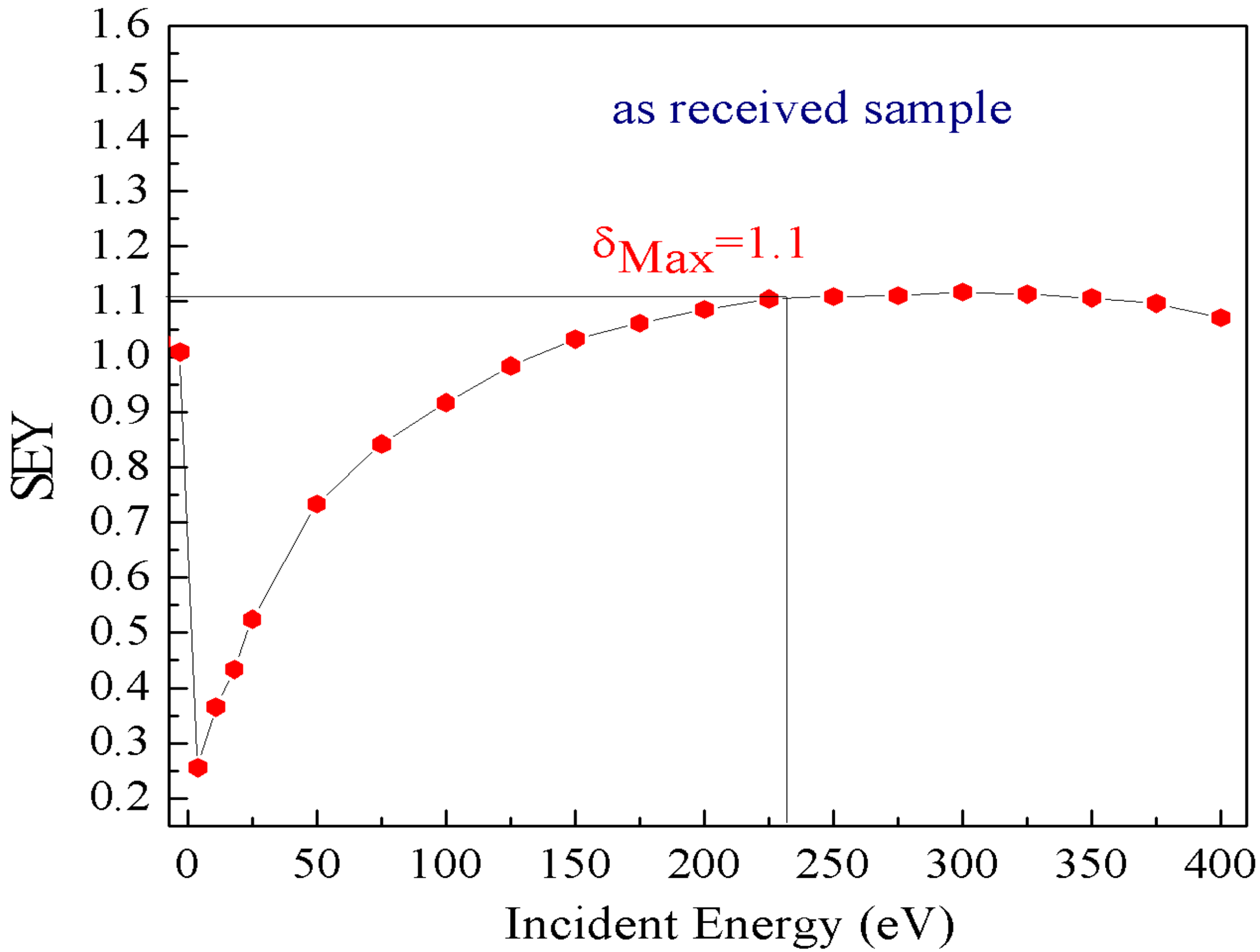
Graphitization is an essential (and quite general, but Al) ingredient in SEY reduction!

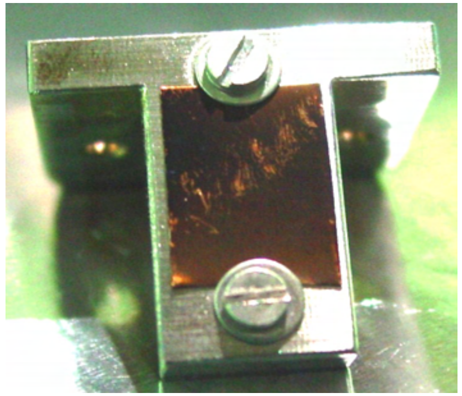
Is there an alternative way to graphitize samples in order to have low SEY surfaces? Can we deposit stable carbon or graphite coatings ?

CERN uses magneto-sputtering technique to grow a thick (1-10 μm) of a-C film on accelerator wall surfices.
Results are promising and under study in terms of stability versus time, adhesion etc.

Our line of work is concentrated on creating very thin (some layers) "graphene" - like coatings on metal substrates to be used in accelerator to mimic what is actually happening during scrubbing.

PRELIMINARY





R. Cimino

Not only we start to understand what is actually happening during SEY reduction, but also using it to develop conceptually new material and coatings.

Results are promising and suggest that this could be the right research direction!

Other accurate studies are necessary to optimize growth parameters, to test the performance of material in terms of stability vs time, adhesion, cost effectiveness etc..
We need to be able to produce these material in large scale for accelerators……. A lot of work!!!

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- Attention: there is a worring color code:

  in green …. Non staff… (At risk!)

  In blue….. LNF staff (very very busy)

  in Red……….. People from other institutions

  in black…….. People gone