# Developement and Characterization of Materials 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)*

Vacuum chamber

Radial Distance

p^+ p_+

Time = 25 ns
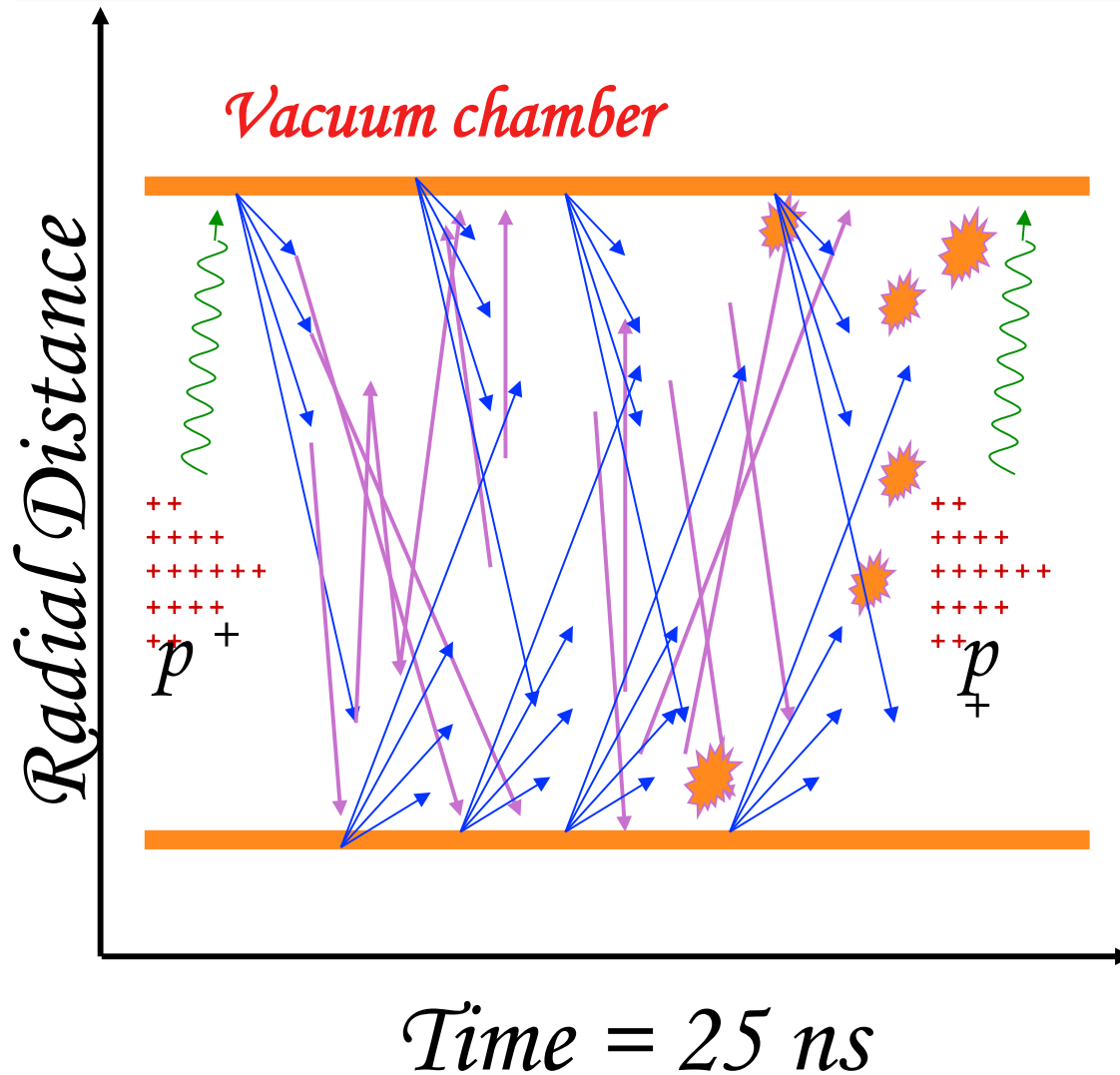
The accelerated particle beam produces SR and/or e^- that, by hitting the accelerator's walls generate photo-e^- or secondary-e^-.

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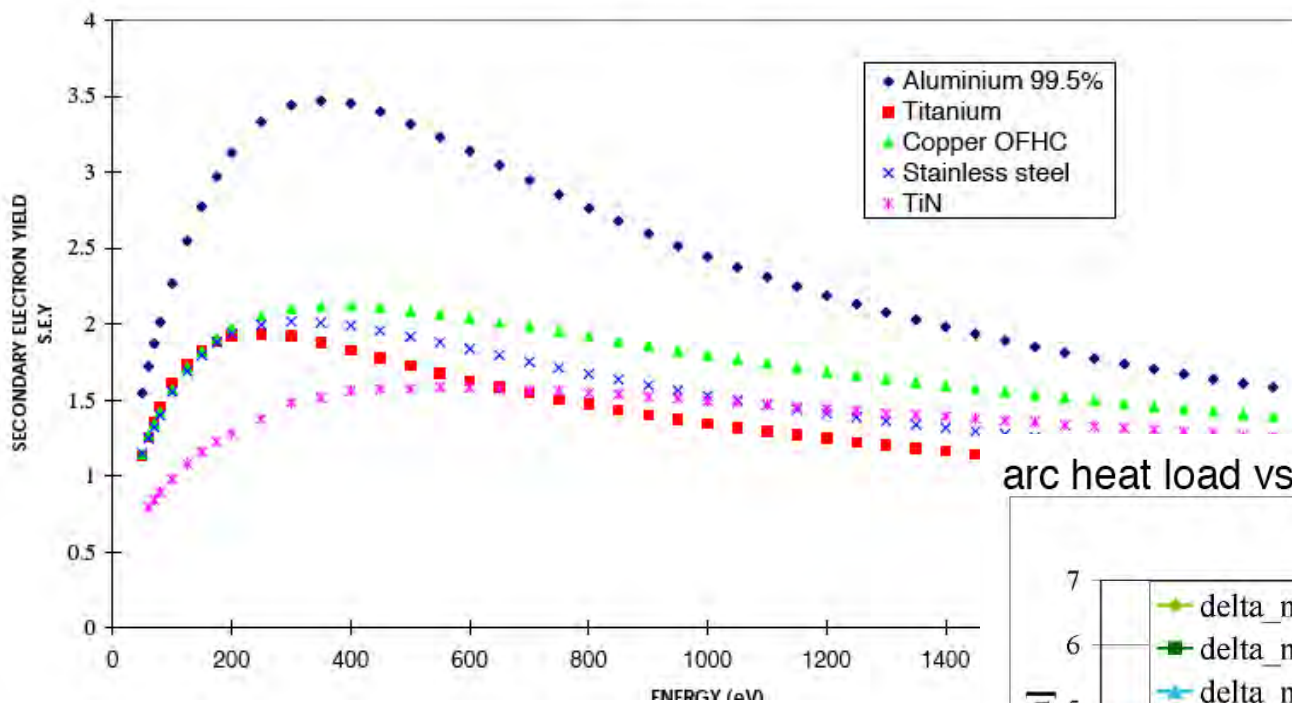
One of the most relevant parameter for e-cloud studies is: S.E.Y. (or δ)

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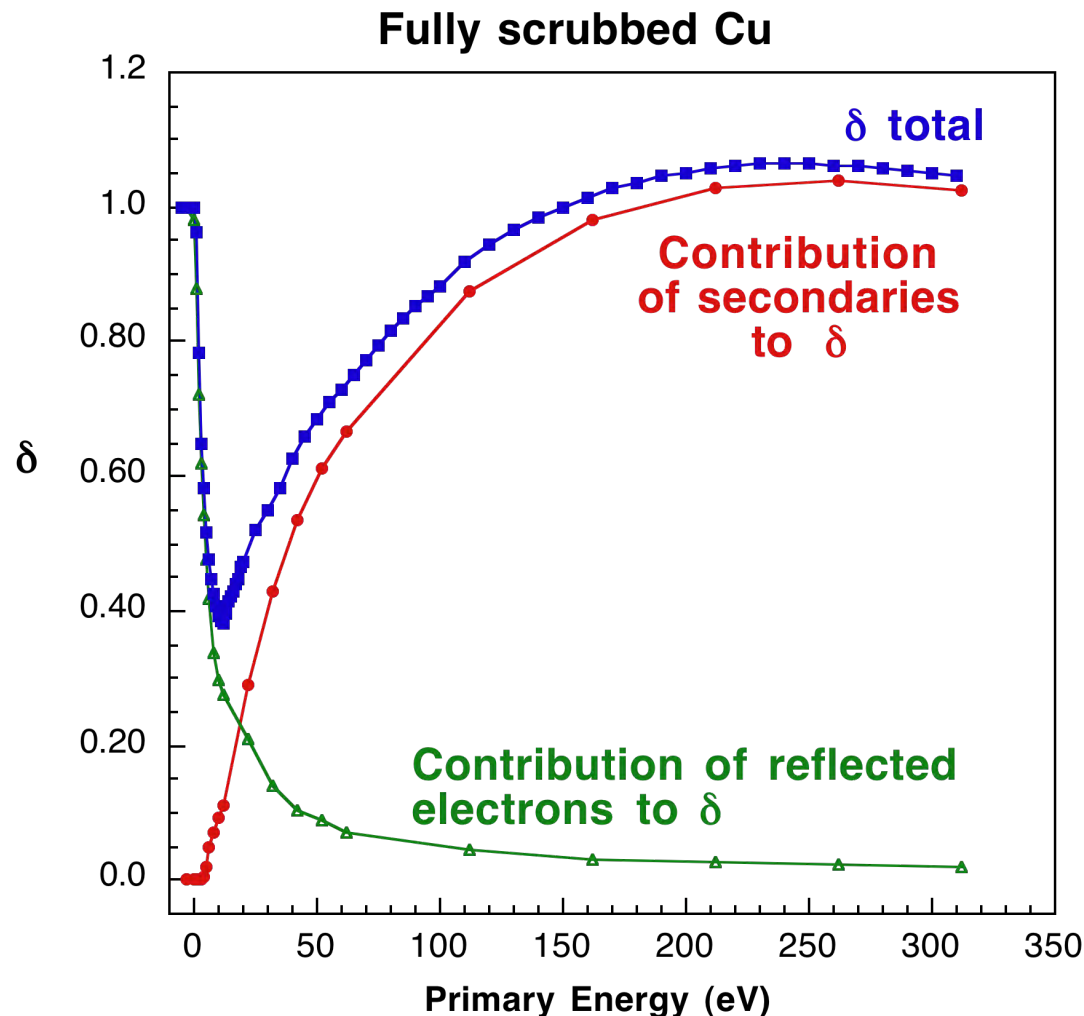
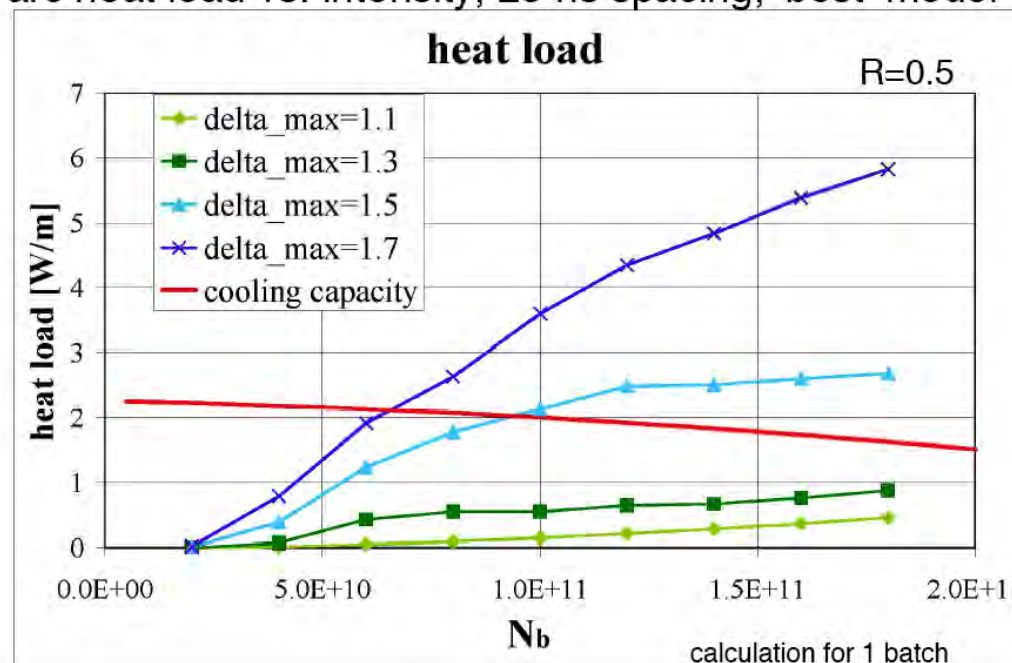I.e.: the number of electrons created after bombardment of a single electron.

R. Cimino, et al., Phys. Rev. Lett. 93 (2004) 014801
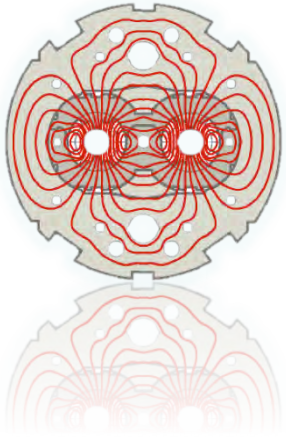
SECONDARY ELECTRON YIELD
As received

Legend:
- Aluminium 99.5%
- Titanium
- Copper OFHC
- Stainless steel
- TiN

Measure of Secondary e⁻ YIELD

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

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

heat load   R=0.5

- delta_max=1.1
- delta_max=1.3
- delta_max=1.5
- delta_max=1.7
- cooling capacity

calculation for 1 batch

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

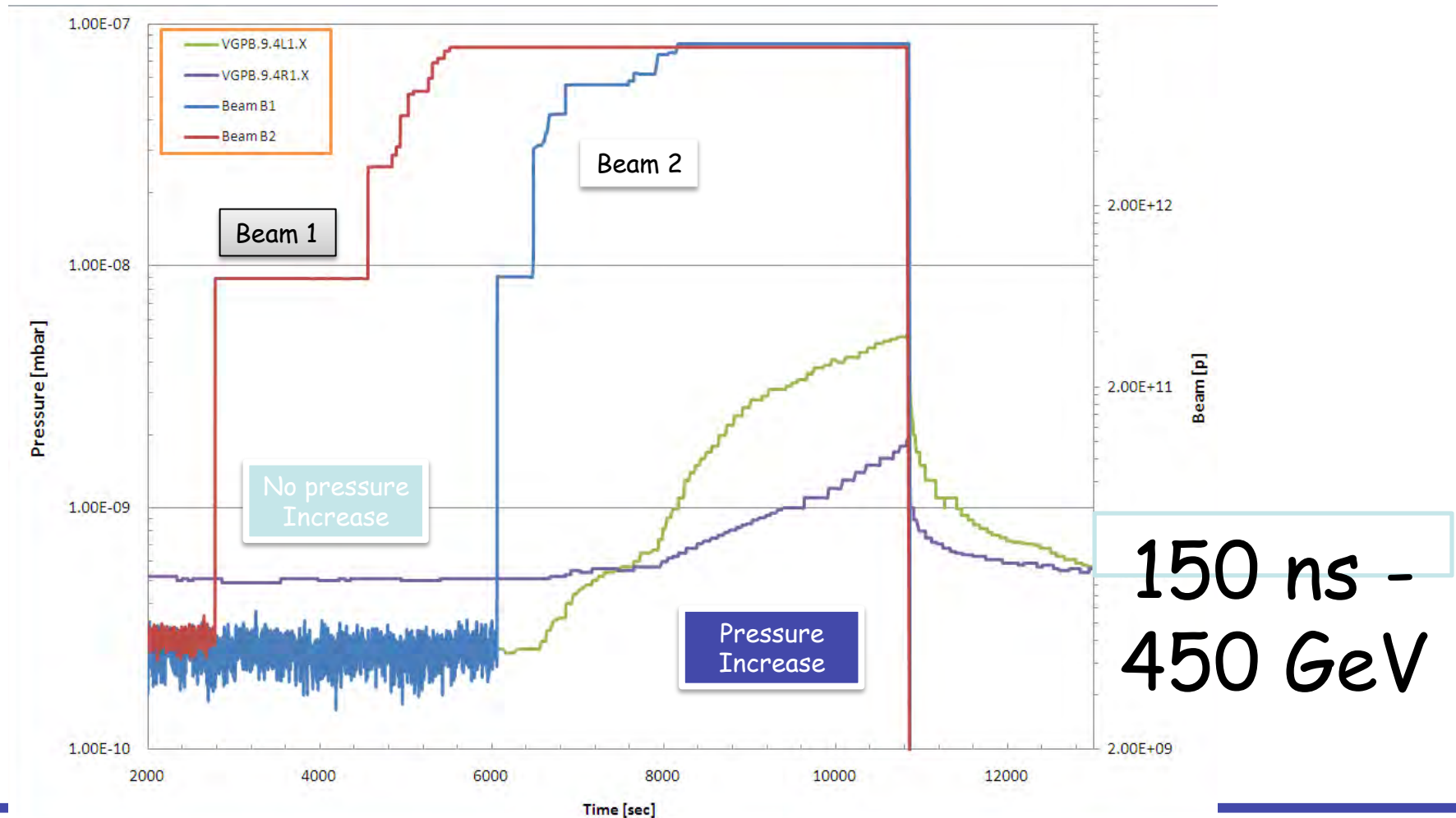Frank Zimmermann, LTC 06.04.05

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

e-cloud @ LHC: a Real Issue

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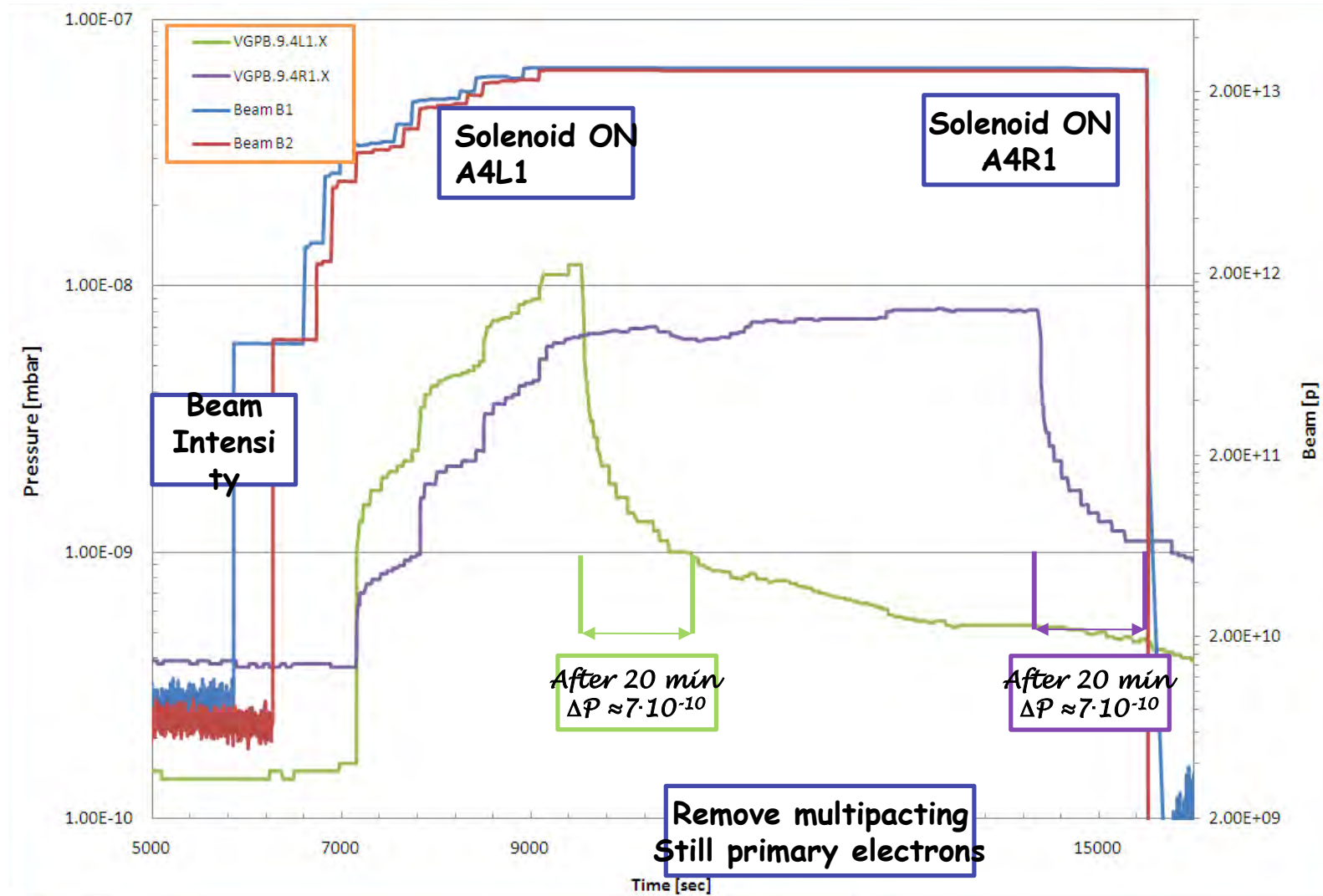

150 ns - 450 GeV

R. Cimino

Easily solved: Installation of Solenoids
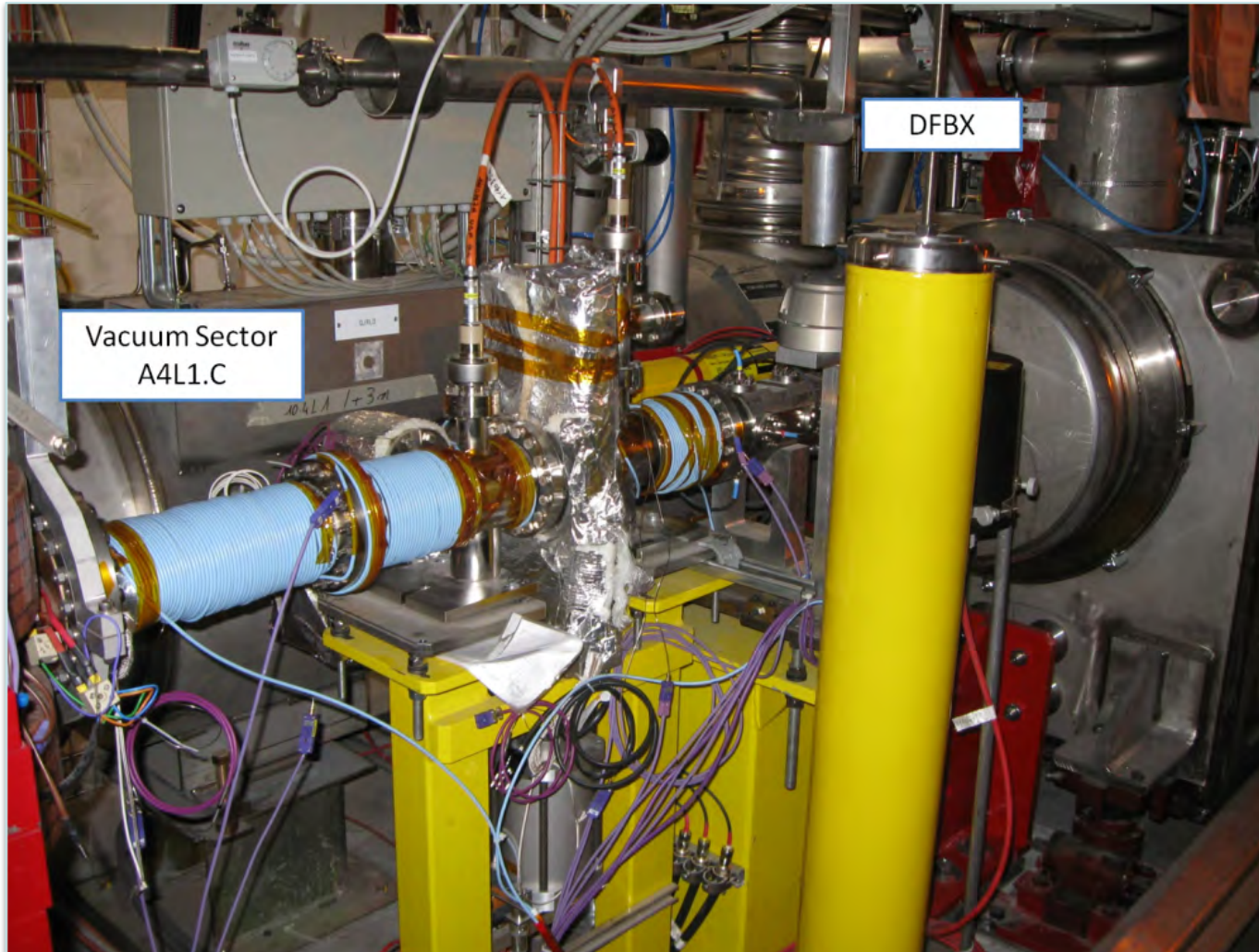
Solenoids effect on pressure

R. Cimino
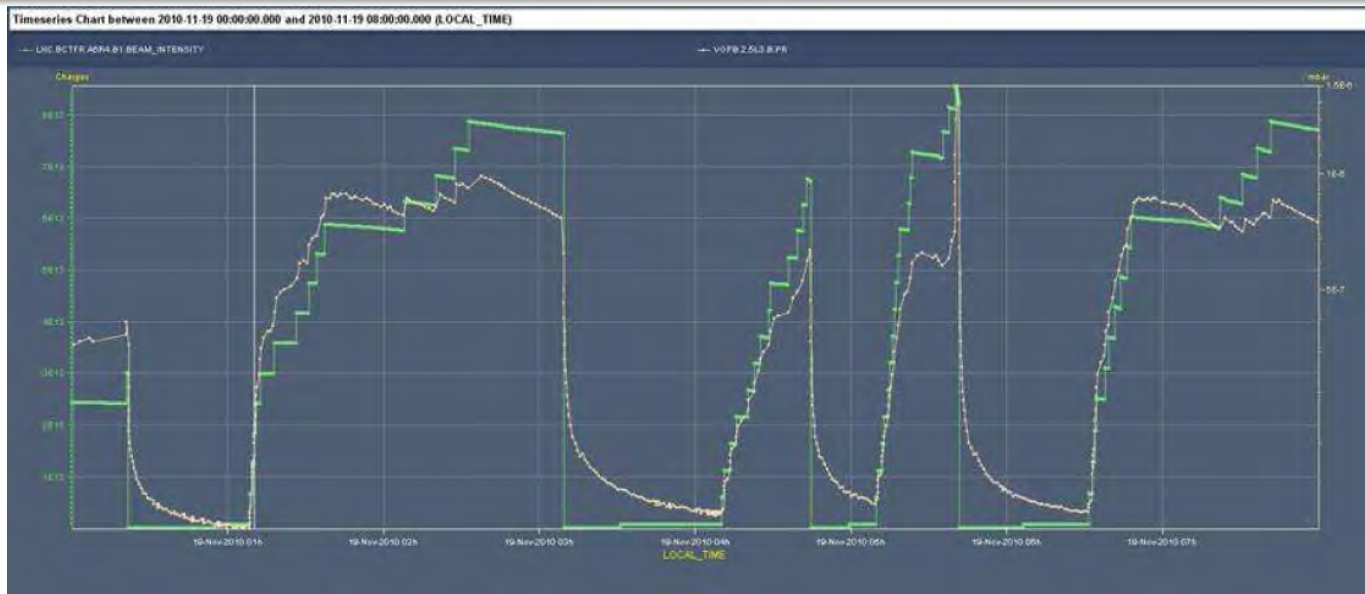
Pressure rises with 75ns bunch spacing were observed in IR3
Even though P~10^{-6}mbar, 936 bunches could be filled in
➔**PLAN FOR 2011:** Scrubbing using 50ns bunch trains
Physics operation using 75ns
➔**GOAL:** Investigate SEY parameters such that e-clouds do not limit physics operation

3. Plans for Super KEKB

Y. Suetsugu, KEK
on behalf of KEKB Vacuum Group

- Required electron density to avoid single bunch instability

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

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

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			$Q_{nl} \sim 7$

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

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Single Bunch Instability Threshold for Super-B (courtesy of T. Demma)

		June 2008		January 2009		March 2009		Sep.2009
		ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{int} [$10^{15}m^{-2}$] solenoids	ρ_{int} [$10^{15}m^{-2}$] no solenoids	ρ_{center}
SEY=1.1	95%	0.06	2.1	0.09	2.5	0.22	2.7	0.1
	99%	0.02	0.25	0.04	0.3	0.04	0.7	0.07
SEY=1.2	95%	0.22	2.8	0.27	3.2	0.45	6.5	0.3
	99%	0.045	0.71	0.06	0.82	0.07	2.4	0.1
SEY=1.3	95%	2.7	20.2	2.9	25.7	5.4	25	2.0
	99%	0.94	3.2	1.3	4.1	4.5	13	0.7

Most of the existing and planned accelerator machines base the reaching of their design parameters to the capability of obtaining walls with a SEY ~1.2 or below!

(This includes the Damping Rings of interest to this workshop!)

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…*

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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
- NEGs ……

… 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 ΔΑΦΝΕ BM which we are now carefully aligning and commissioning!*
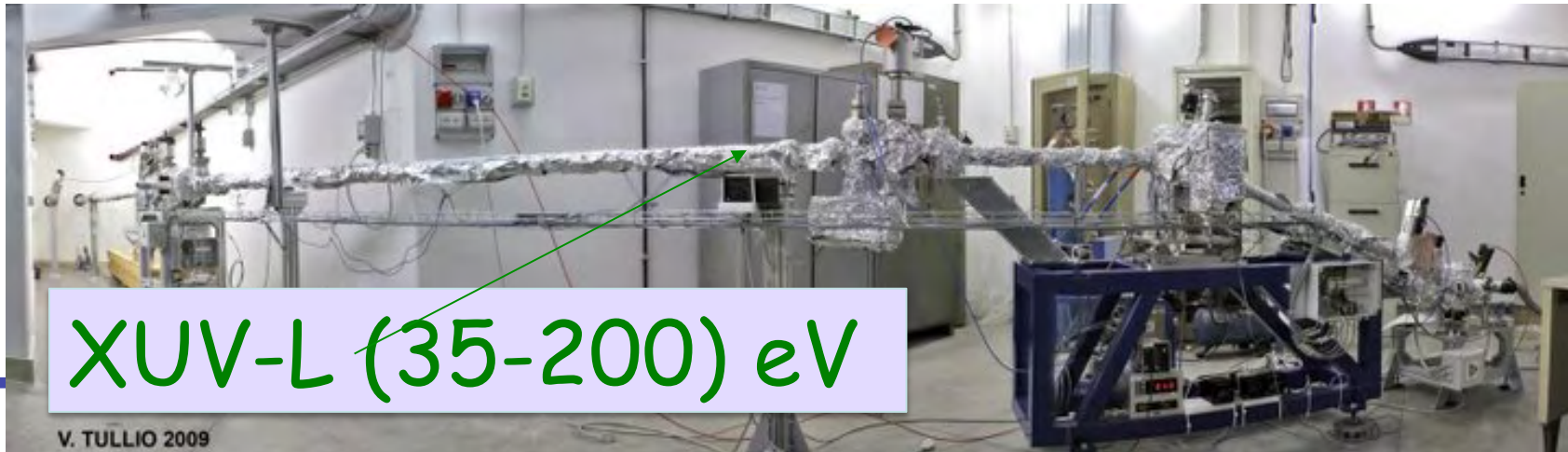
R. Cimino

LNF XUV Beam Lines
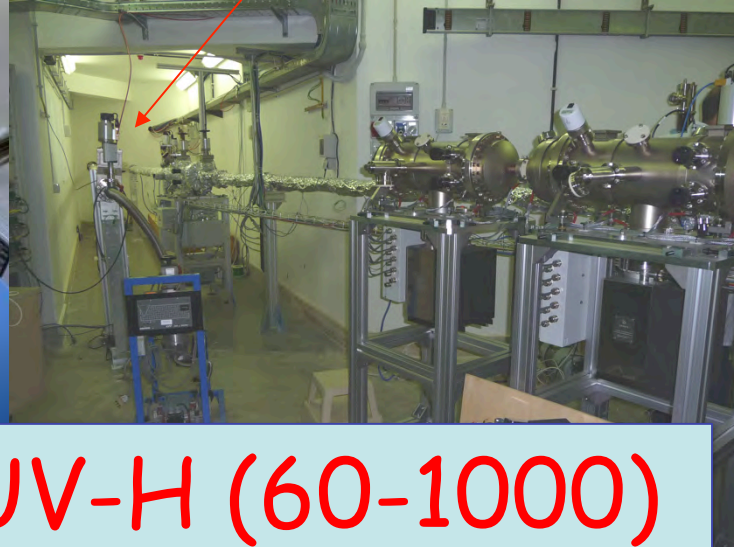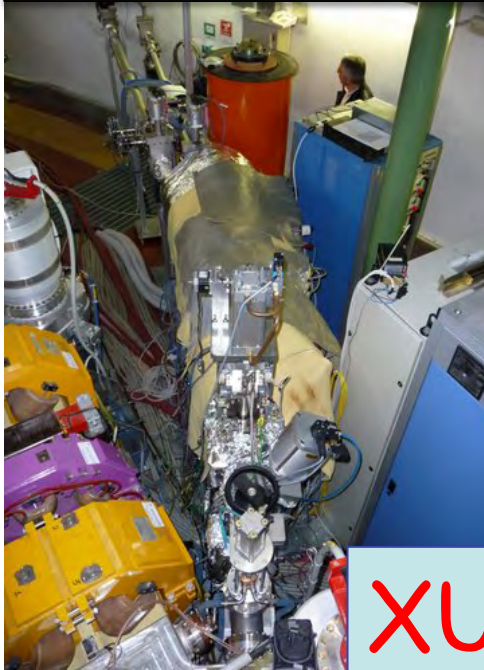
XUV-H (60-1000)

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

V. TULLIO 2009

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

Manipulator

Sample Prep. Chamber for reactions

Farady Cup

HEB SR Beamline (60-1000 eV)

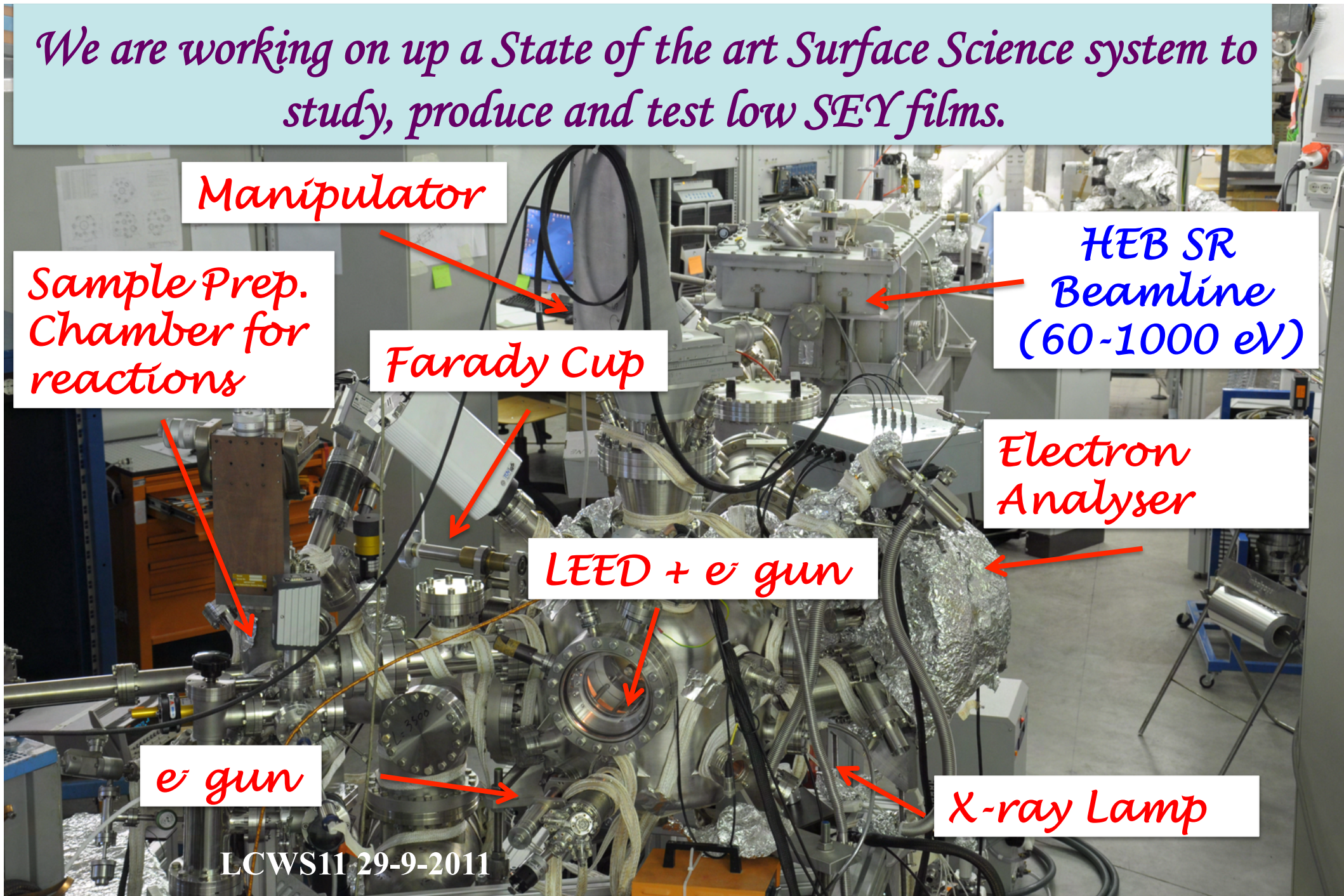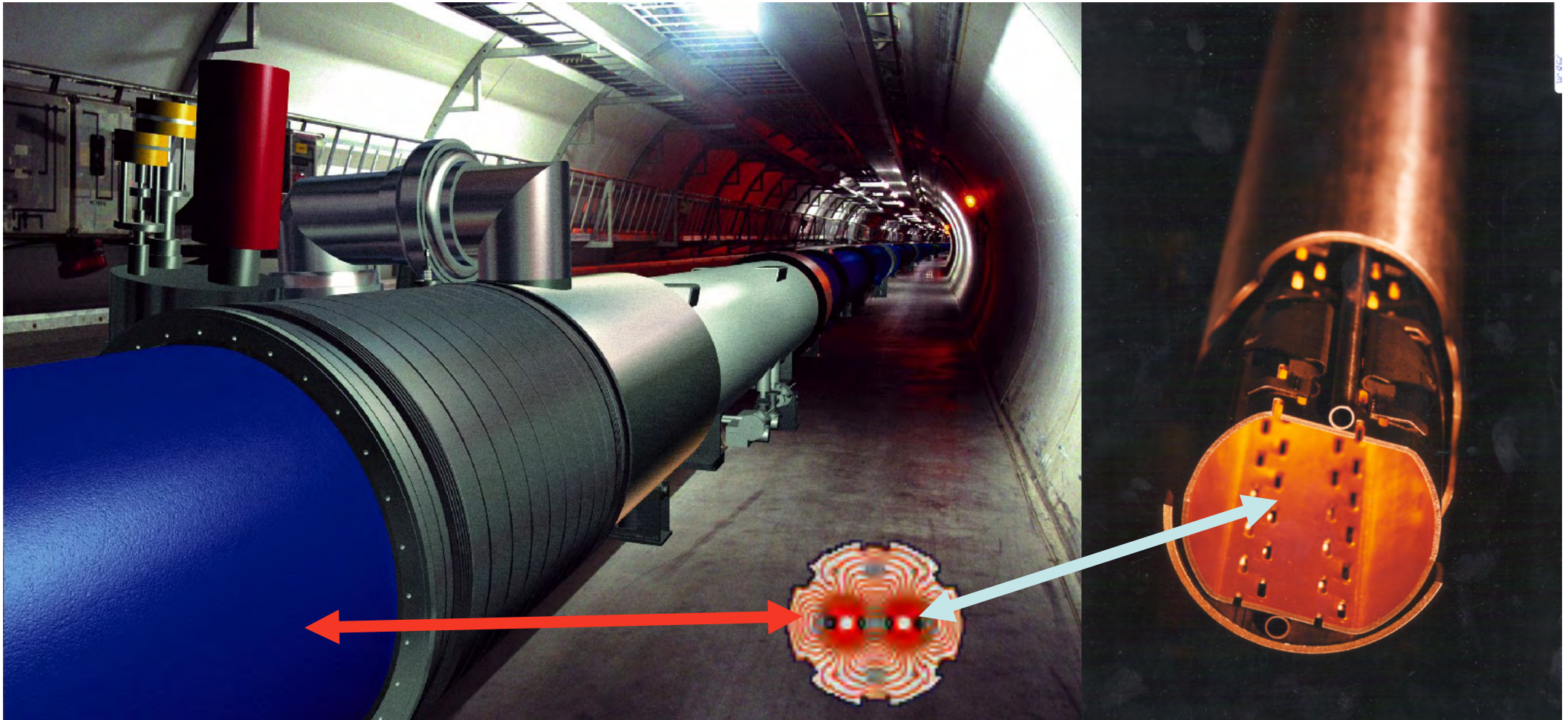Electron Analyser

LEED + e⁻ gun

e⁻ gun

X-ray Lamp

LCWS11 29-9-2011

Our study on the Cu surfaces of the LT dipole regions of LHC: "scrubbing" and chemical modifications
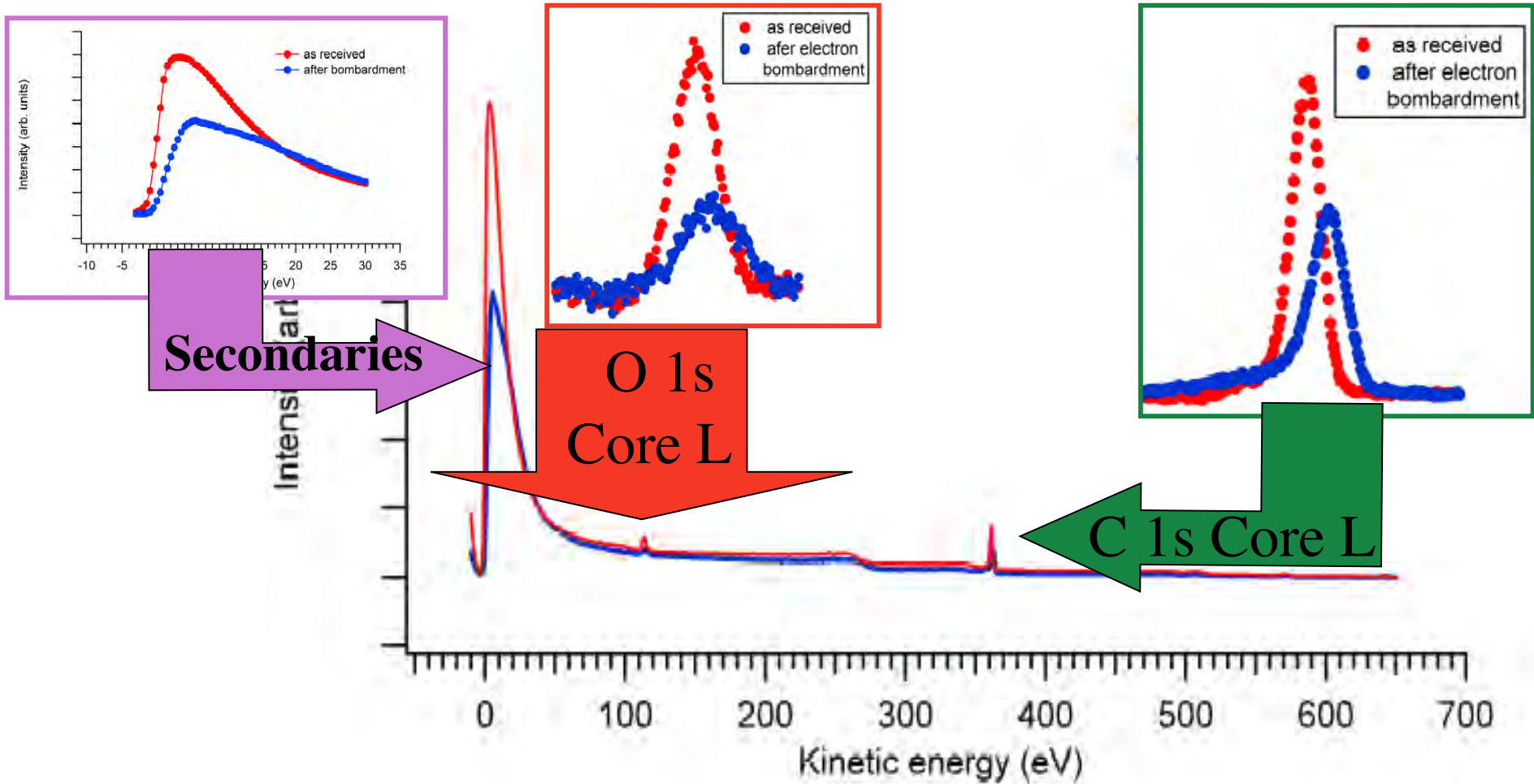
The Beam "scrubbing" effect is the ability of a surface to reduce its SEY after e⁻ bombardment.

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..."
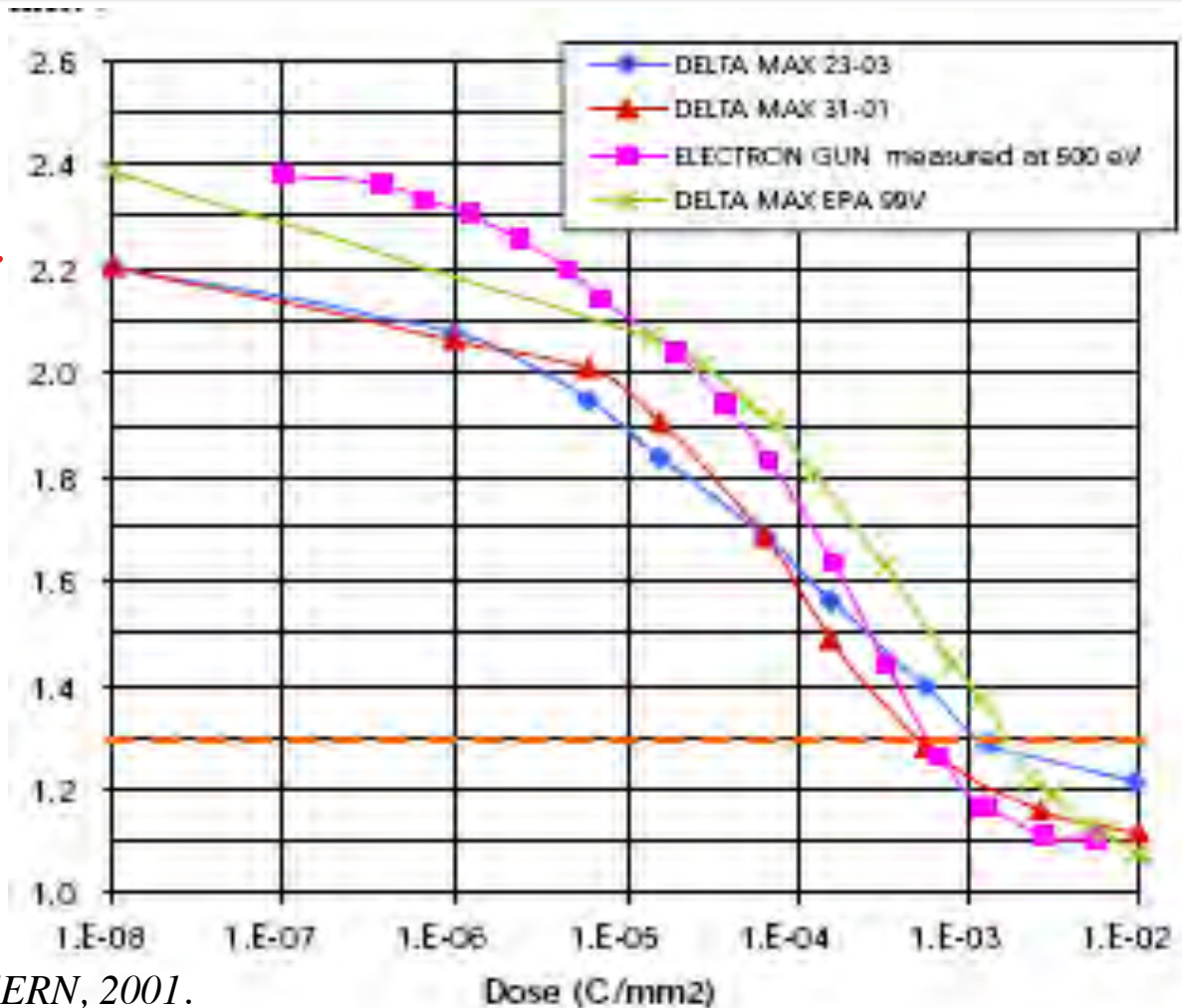

V. Baglin et al, LHC Project Report 472, CERN, 2001.

# *Photoemission spectroscopy during electron scrubbing.*

R. Cimino

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.

as received
after electron bombardment

C 1s Core L

400   500   600   700

energy (eV)
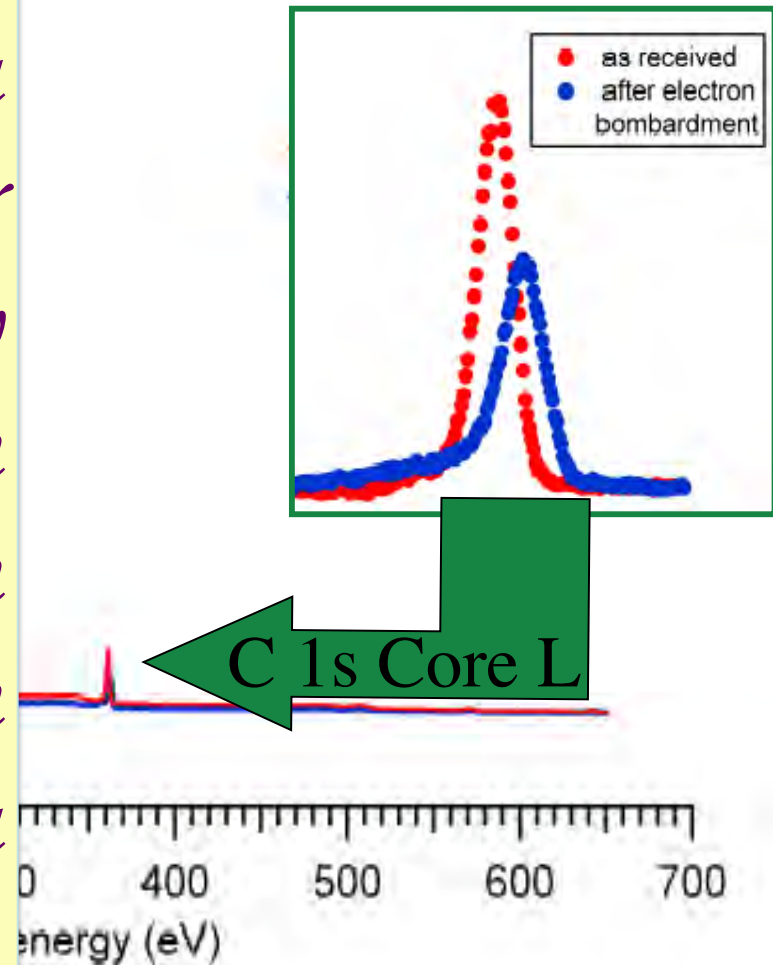
*Cimino et al. not published

Separation of the sp^3 and sp^2 components in the C1s photoemission spectra of amorphous carbon films

Javier Díaz,[*] Guido Paolicelli,[†] Salvador Ferrer, and Fabio Comin

European Synchrotron Radiation Facility, Boîte Postal 220, 38043 Grenoble Cedex, France
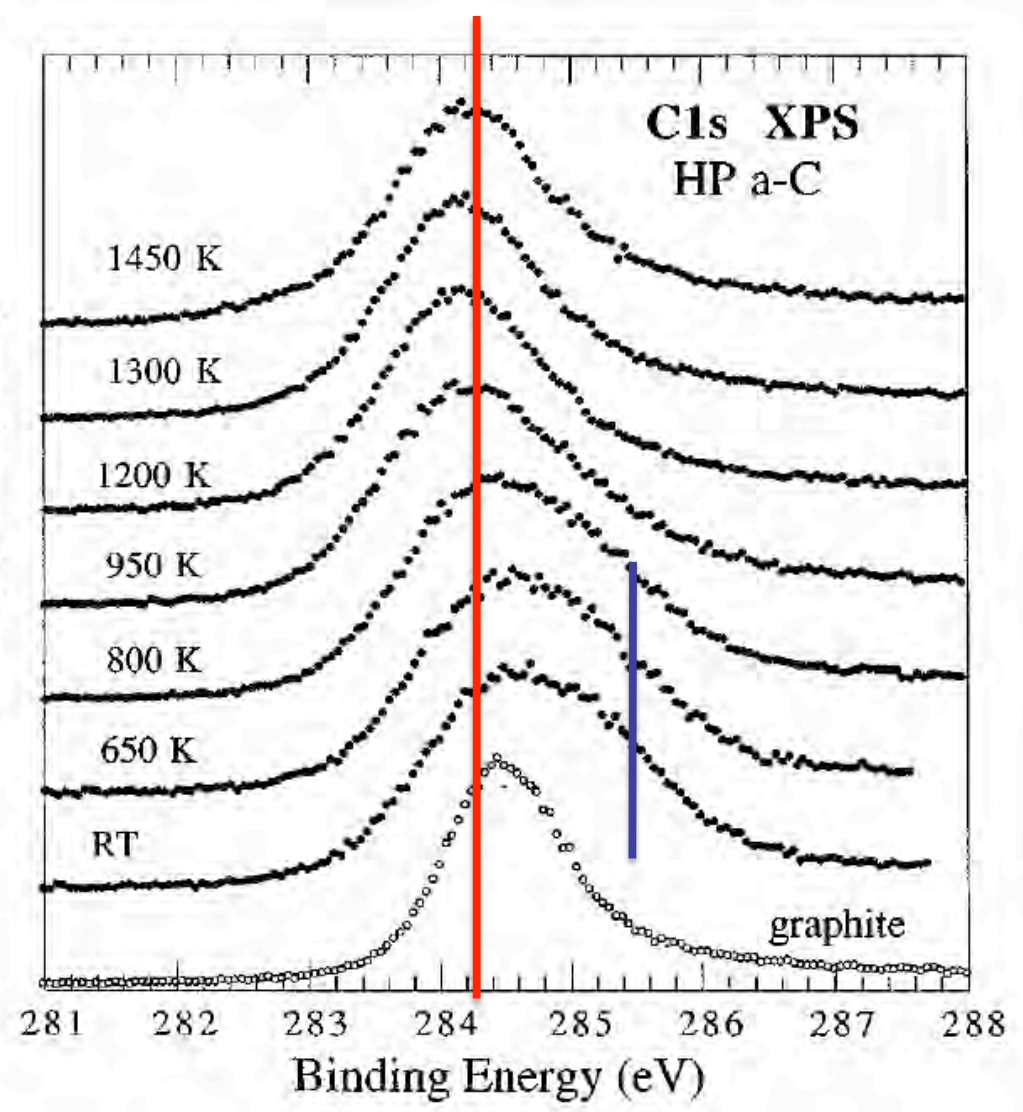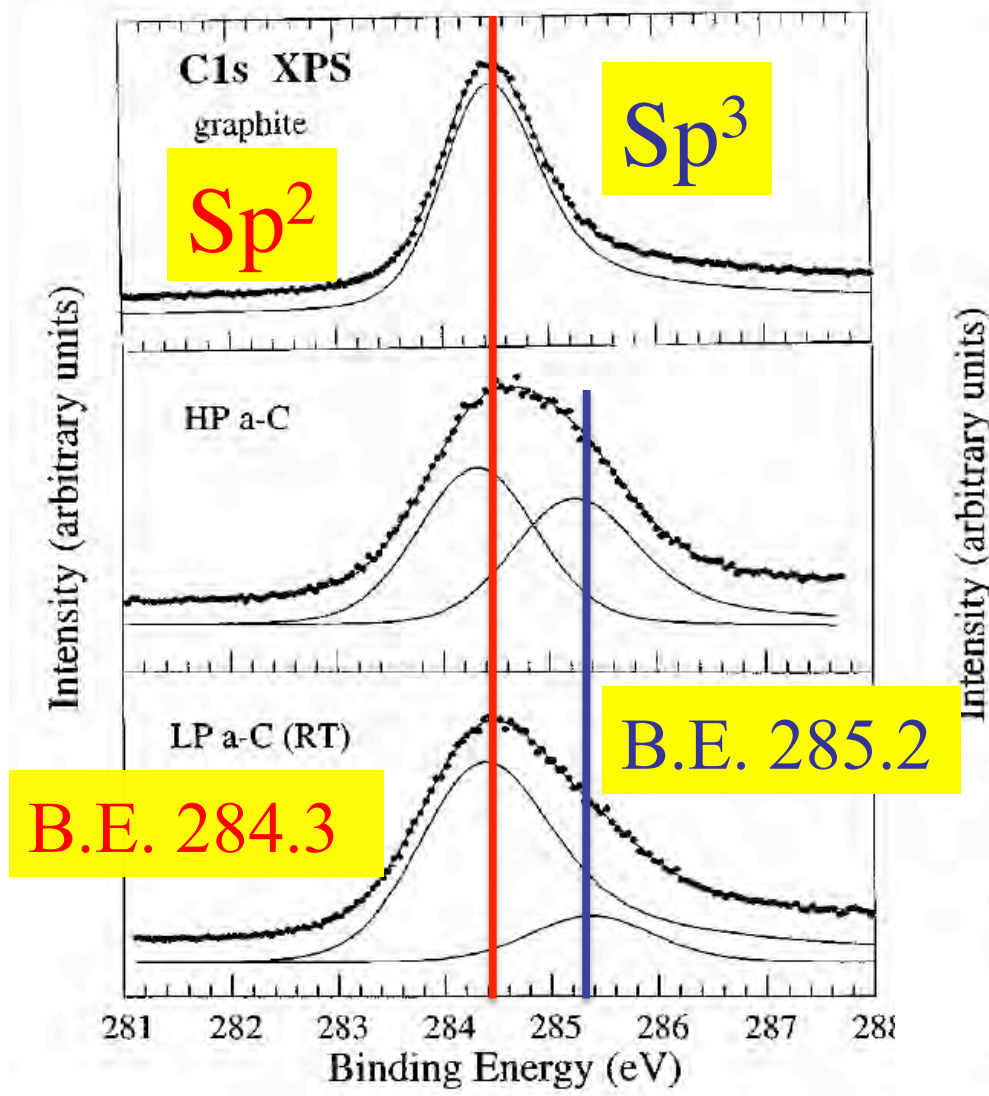
SEY and XPS studies: Al from DAΦNE and Petra III (difficulties in reaching low emittance)

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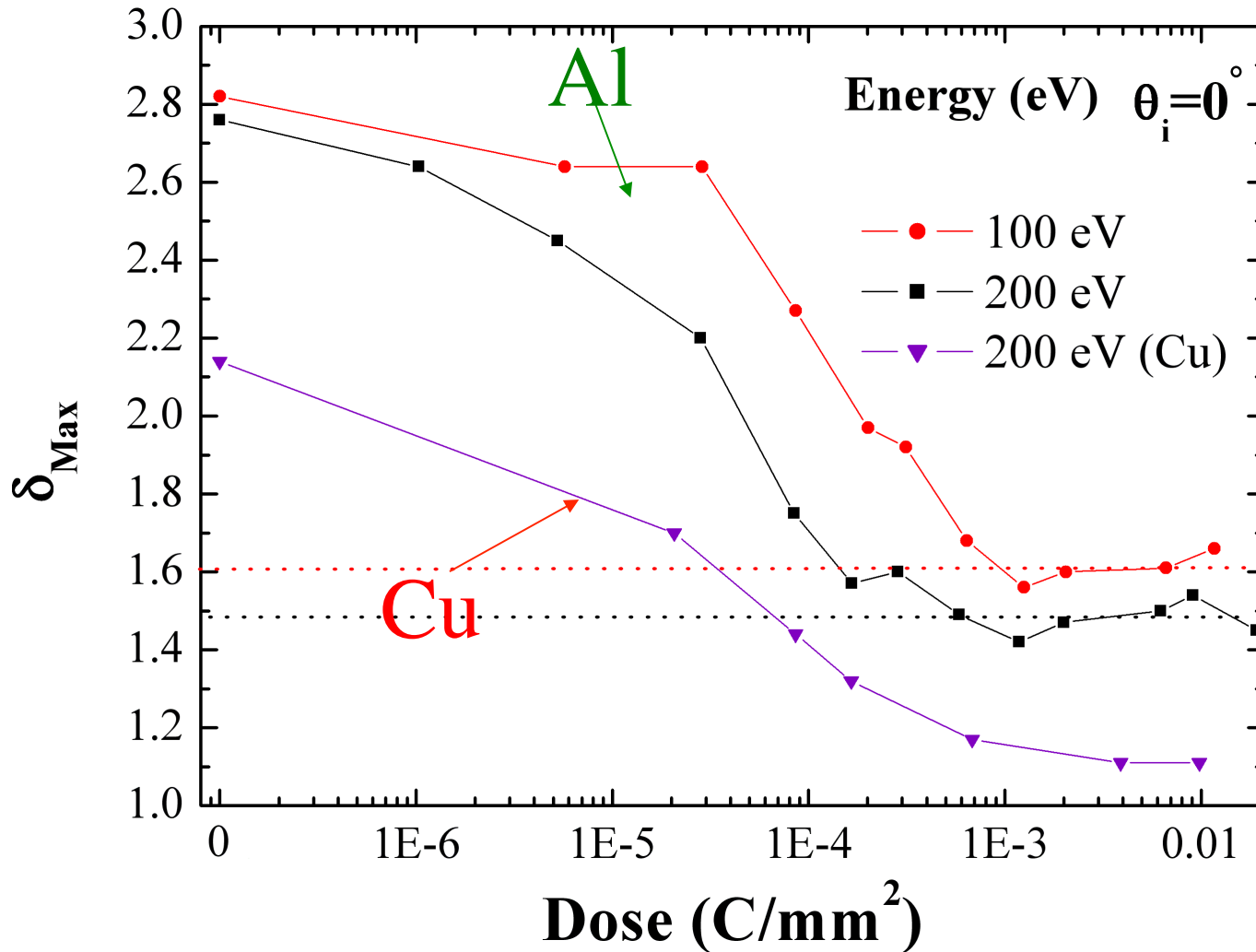
When you deal with industrially prepared materials:
Not all the materials are what they are called!

D. R. Grosso et al in preparation

SEY and XPS studies: Al from Petra III (difficulties in reaching low emittance)
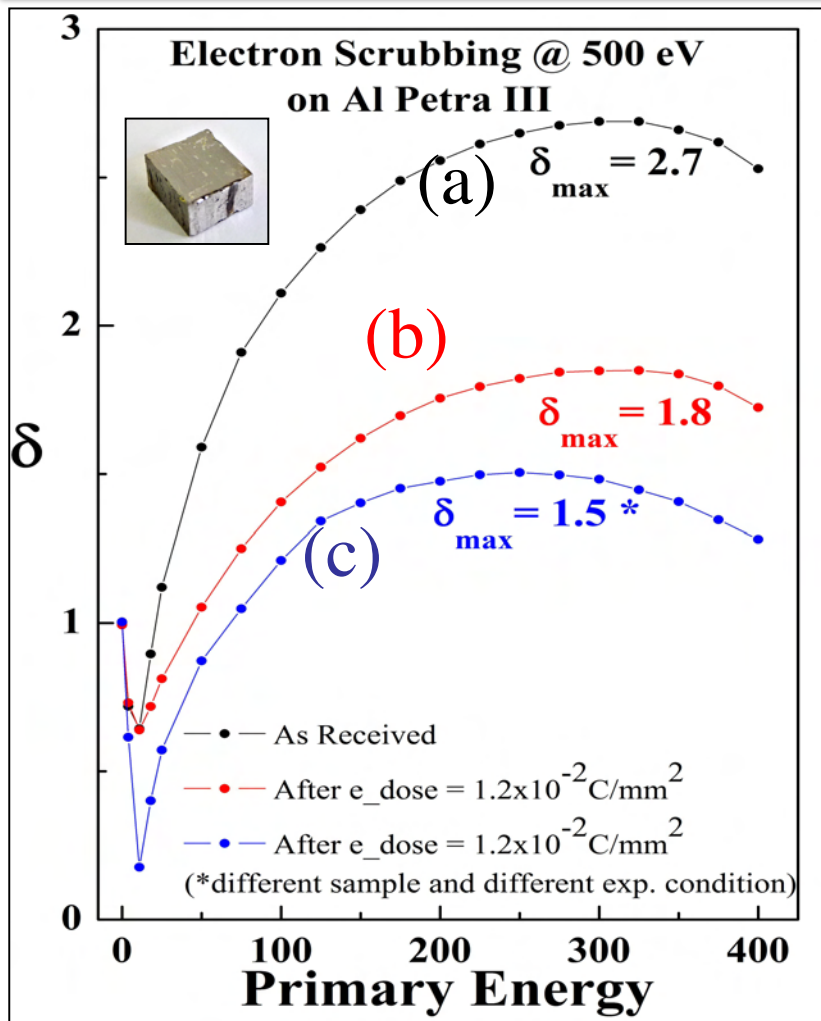
Three SEY spectra recorded in different conditions on Al technical samples cut from the inner walls of the Petra III storage ring,

(a) "as received"

(b) after electron scrubbing at 500 eV KE in UHV at background pressures of low 10^{-9}

(c) after electron scrubbing at 500 eV KE in UHV at background pressures of low 10^{-10} mbar

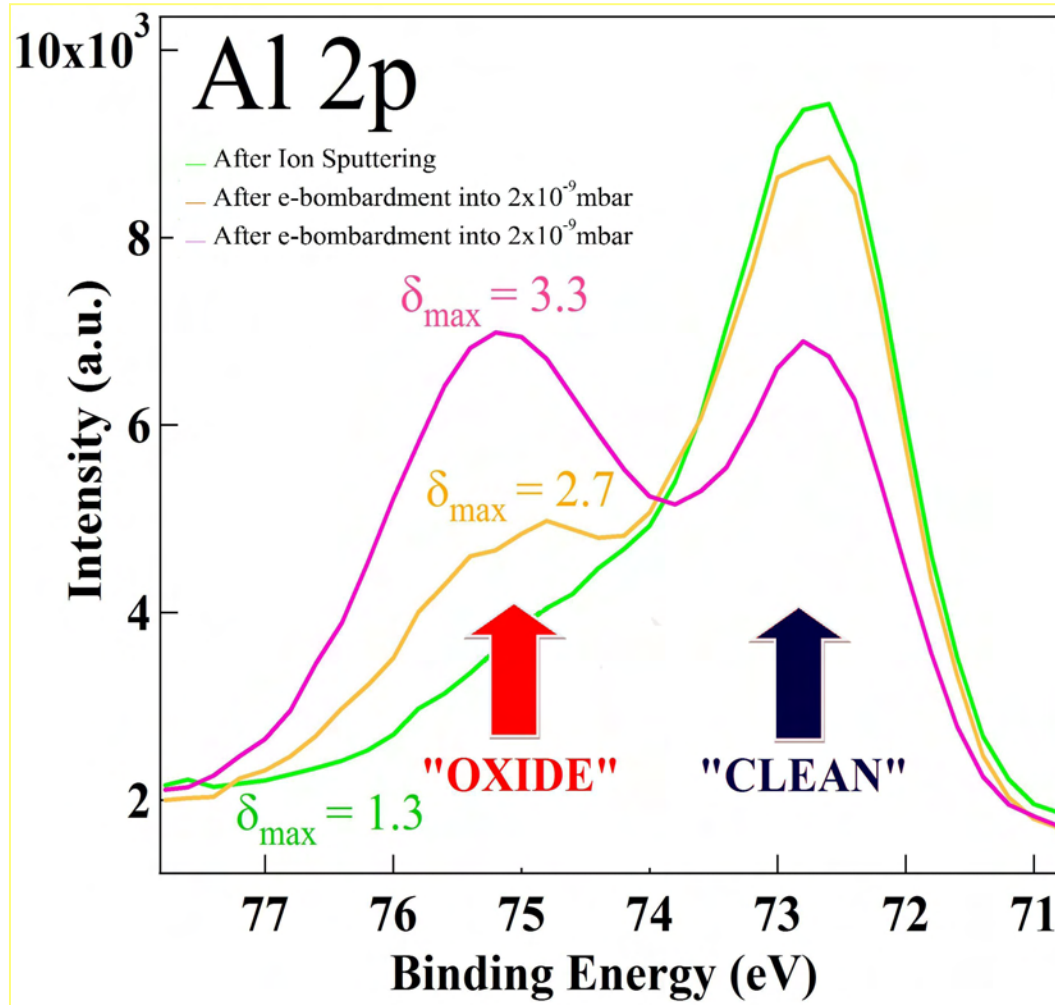# XPS studies on Al as received, sputtered clean and e⁻ scrubbed in 10^{-8} - 10^{-9} mbar:

Al 2p

— After Ion Sputtering
— After e-bombardment into 2×10^{-9} mbar
— After e-bombardment into 2×10^{-9} mbar

$\delta_{max} = 3.3$

$\delta_{max} = 2.7$

$\delta_{max} = 1.3$

"OXIDE"   "CLEAN"

Intensity (a.u.)

Binding Energy (eV)

The XPS characterization of the sample surface, after several cycles of ion sputtering and e⁻ bombardments, shows clearly that the SEY variation is closely related to the oxidation state of the Al sample, reaching a δ_{max} value as low as 1.3 for our cleanest surface.

D. R. Grosso et al in preparation

XPS and SEY studies on Al : conclusion

- Also in the case of Al the SEY decreases upon electron scrubbing.
- **The SEY measurements may be influenced by the base vacuum at which they are performed**
- **Presumably little role of C and dominant role of Oxidation state to determine SEY**
- **The extreme reactivity of Al surface, makes Al chambers not suitable for their e-cloud related performances unless coated with a more stable compound.**

D. R. Grosso et al in preparation

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TiN

Of interest for SuperB, Super KEKB, ILC Damping Rings, etc.

R. Cimino

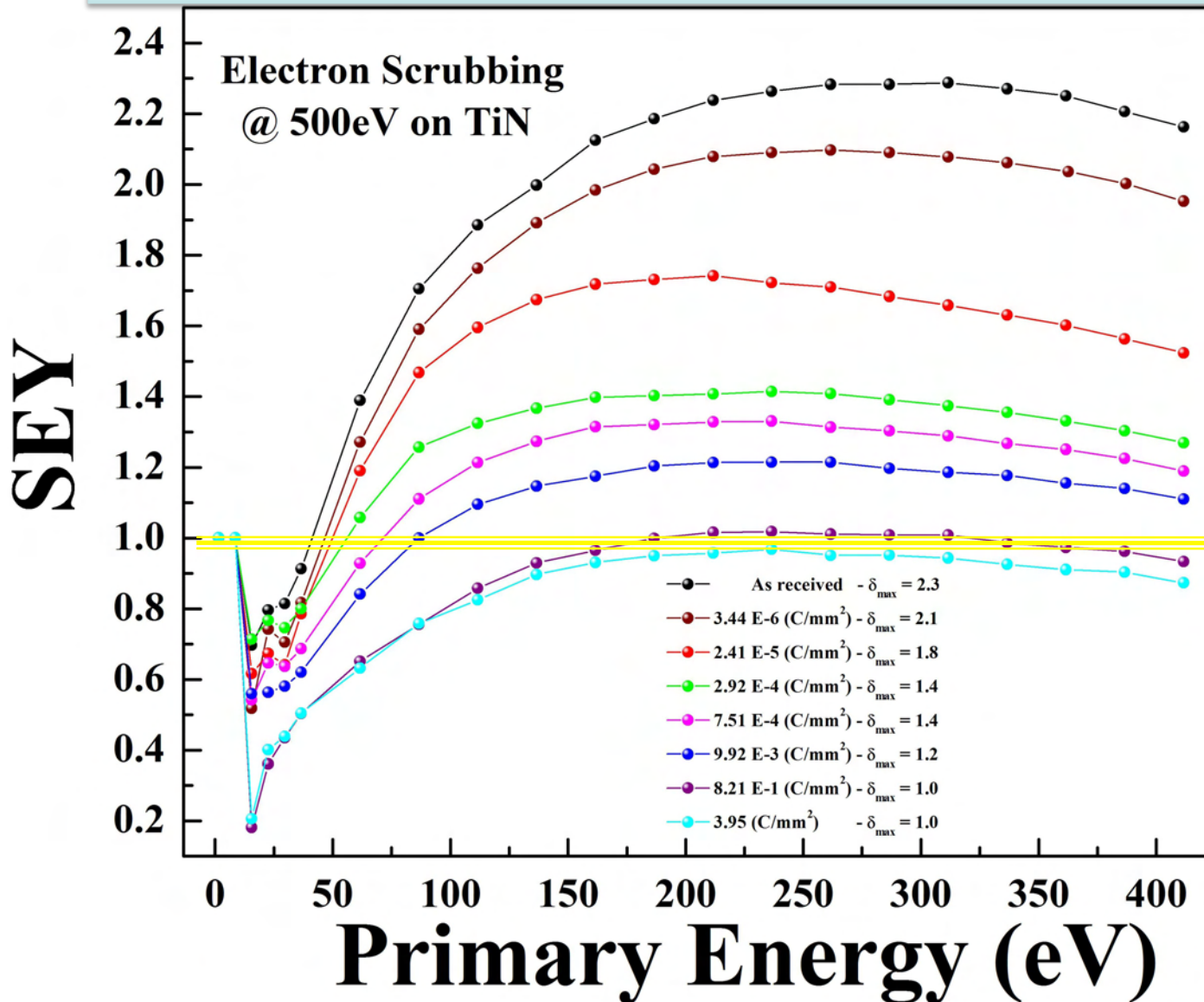# TiN (done by S. Bini & the LNF Vacuum Group).
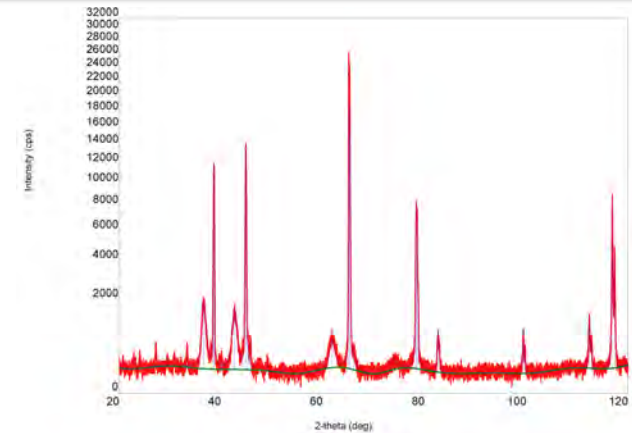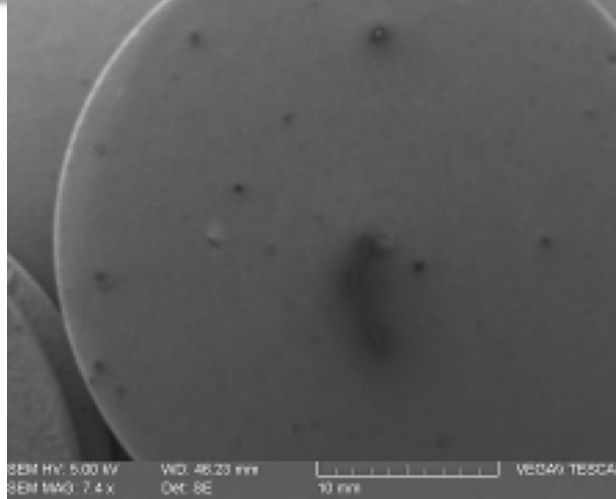
Nanocrystalline TiN thin films has been deposited on aluminum substrates by RF-magnetron sputtering. The "good" quality of the film in terms of microstructural morphology and texture was characterized by SEM and FE SEM and by X – Ray Diffraction.   *D.R. Grosso et al. in preparation
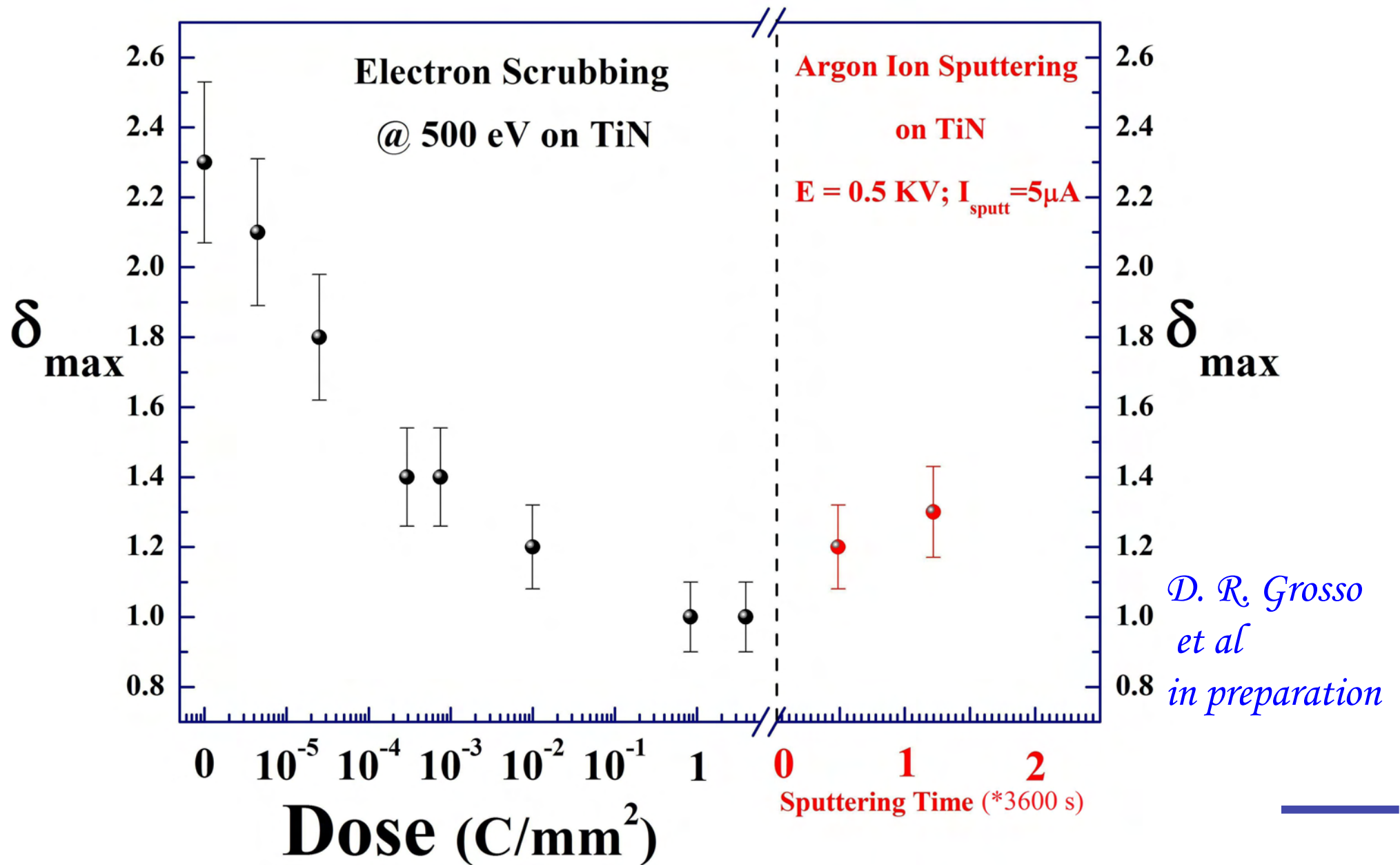
On such TiN we measured SEY vs. electron Dose and….

Electron Scrubbing @ 500eV on TiN

Legend:
- As received - δ_{max} = 2.3
- 3.44 E-6 (C/mm^2) - δ_{max} = 2.1
- 2.41 E-5 (C/mm^2) - δ_{max} = 1.8
- 2.92 E-4 (C/mm^2) - δ_{max} = 1.4
- 7.51 E-4 (C/mm^2) - δ_{max} = 1.4
- 9.92 E-3 (C/mm^2) - δ_{max} = 1.2
- 8.21 E-1 (C/mm^2) - δ_{max} = 1.0
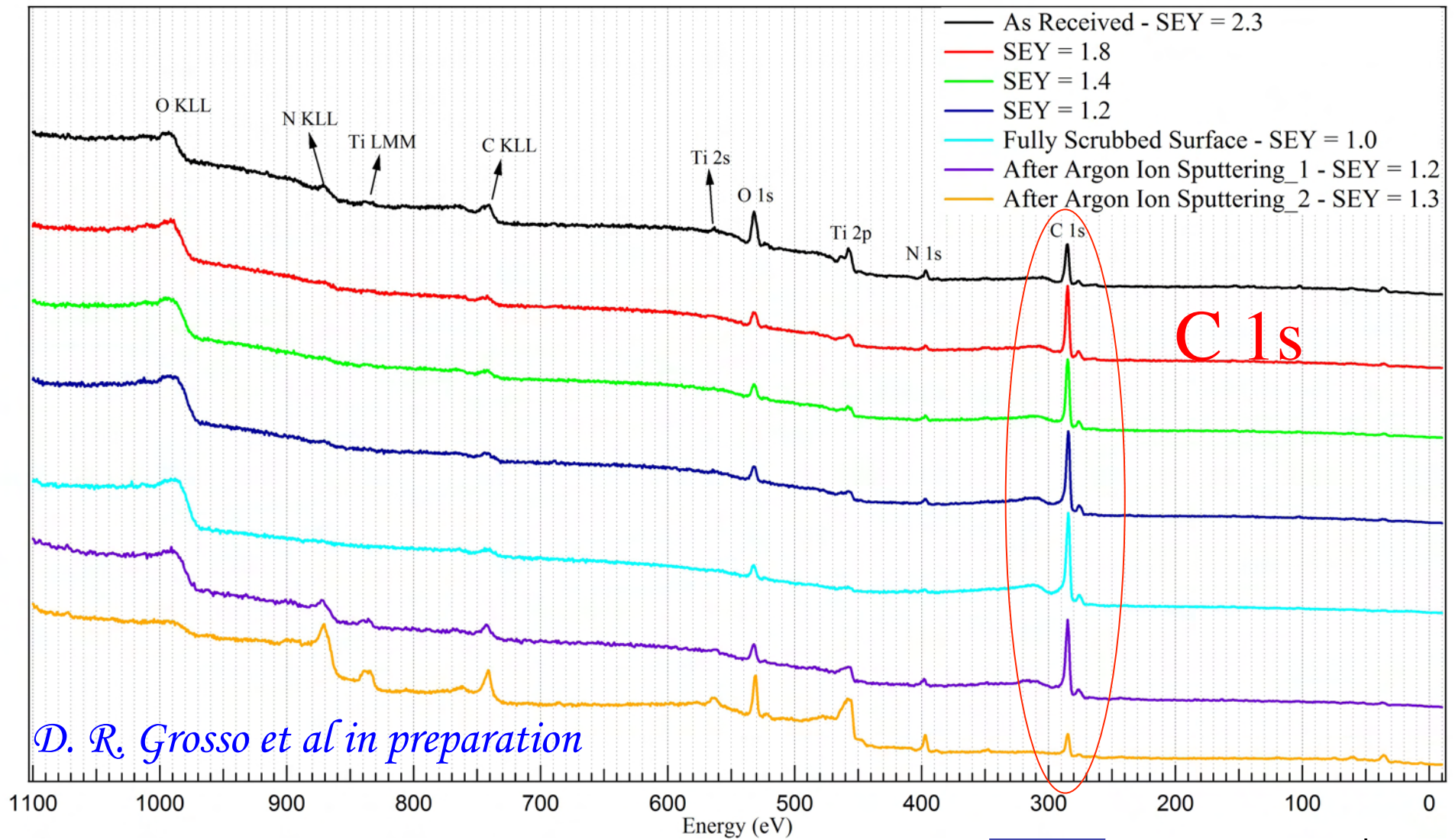- 3.95 (C/mm^2) - δ_{max} = 1.0

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

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Electron Scrubbing @ 500 eV on TiN

Argon Ion Sputtering on TiN

E = 0.5 KV; I_{sputt} = 5 μA

δ_{max}

Dose (C/mm^2)

Sputtering Time (*3600 s)

D. R. Grosso et al in preparation

D. R. Grosso et al in preparation

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

C1s
- As Received - SEY = 2.3
- SEY = 1.8 - ΔE = 0.3 eV
- SEY = 1.4 - ΔE = 0.6eV
- SEY = 1.2 - ΔE = 1eV
- Fully Scrubbed Surface - SEY = 1.0 - ΔE = 1eV

Sp³   Sp²

Intensity (a.u.)

Energy (eV)

D. R. Grosso et al in preparation
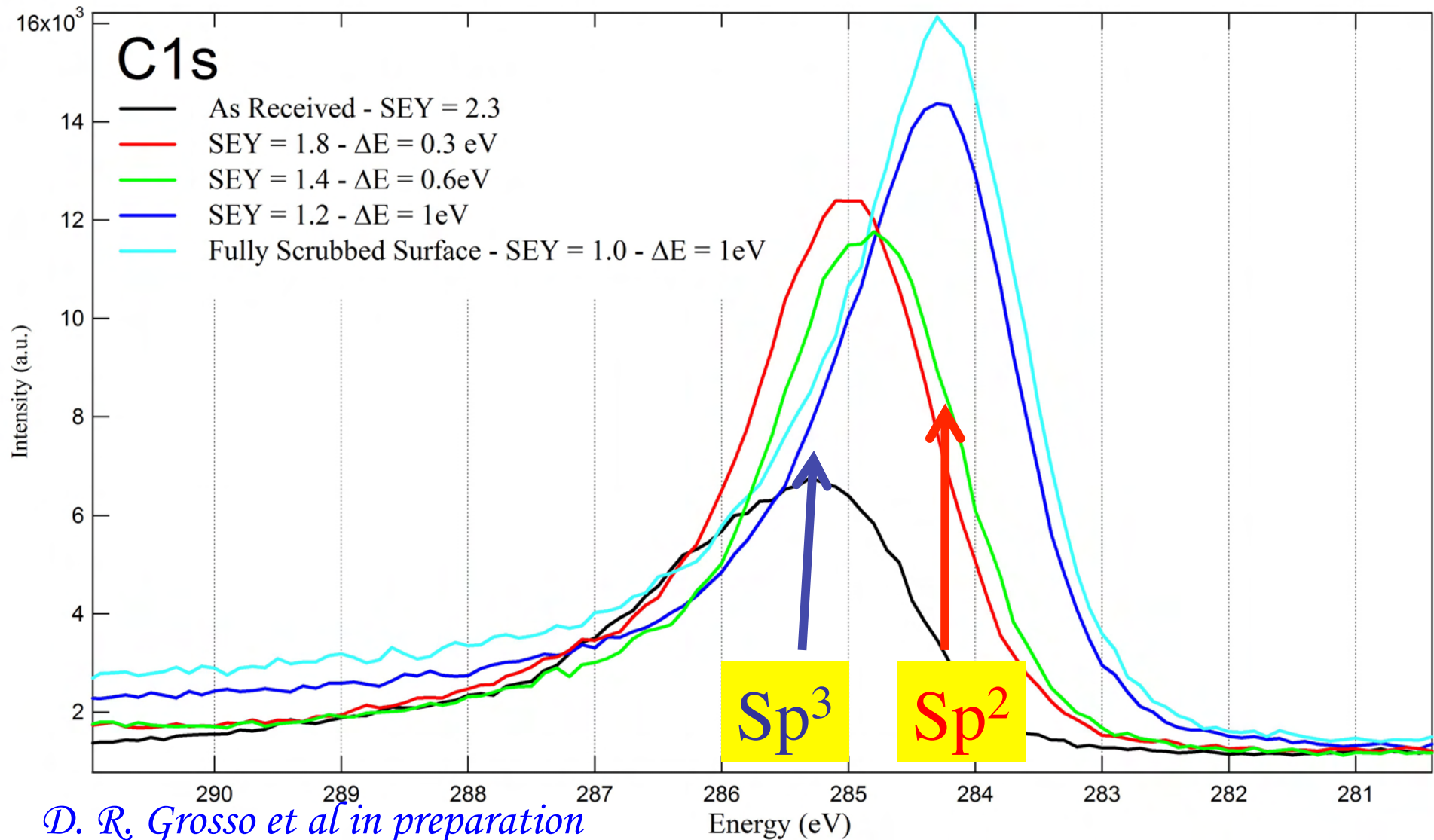
a little (but useful) detour on the scrubbing process

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)
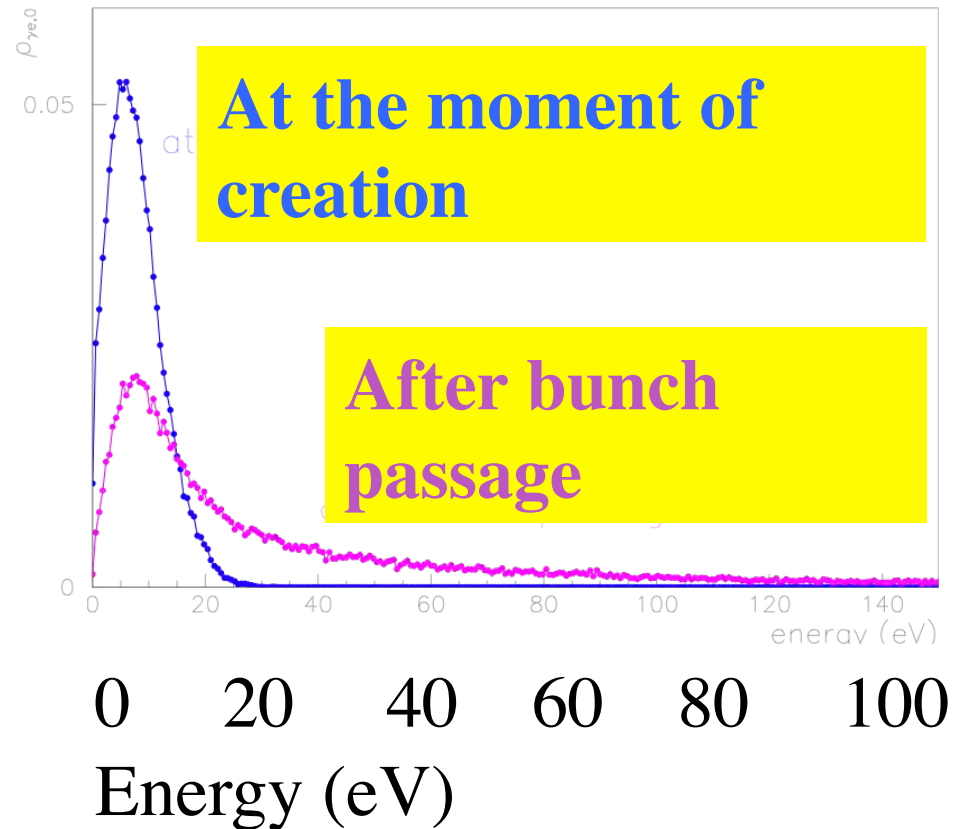
Dose= N°e⁻ x t(s) xA (mm²)

- *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!*
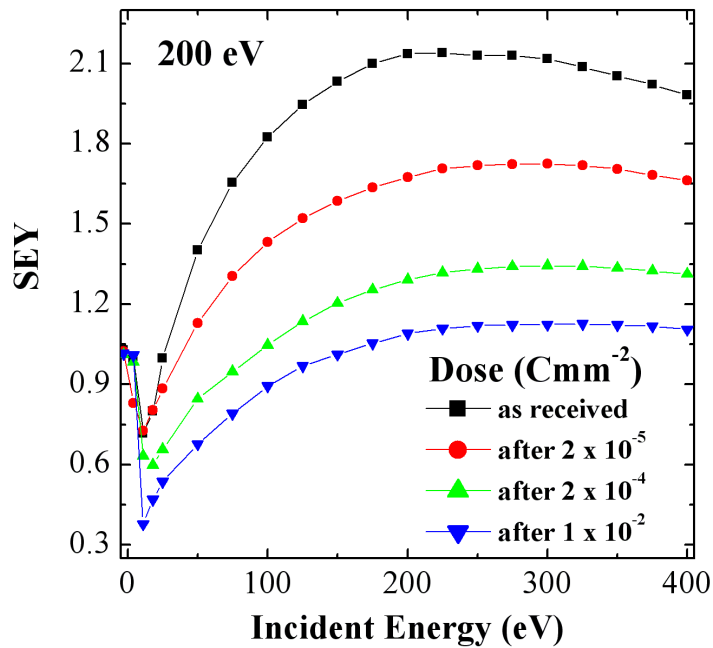
- *do 10 e⁻ @ 500 eV scrub as*
  - *10 e⁻ @ 10 eV?*

At the moment of creation
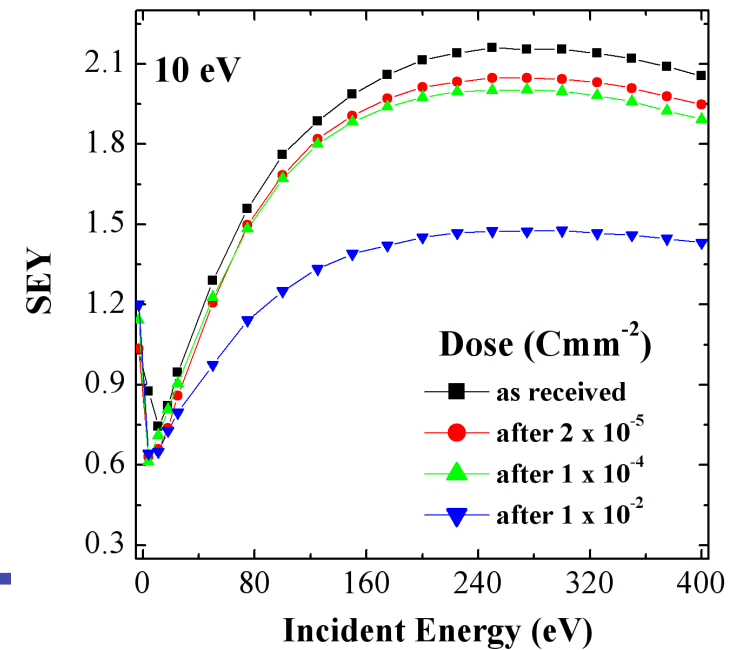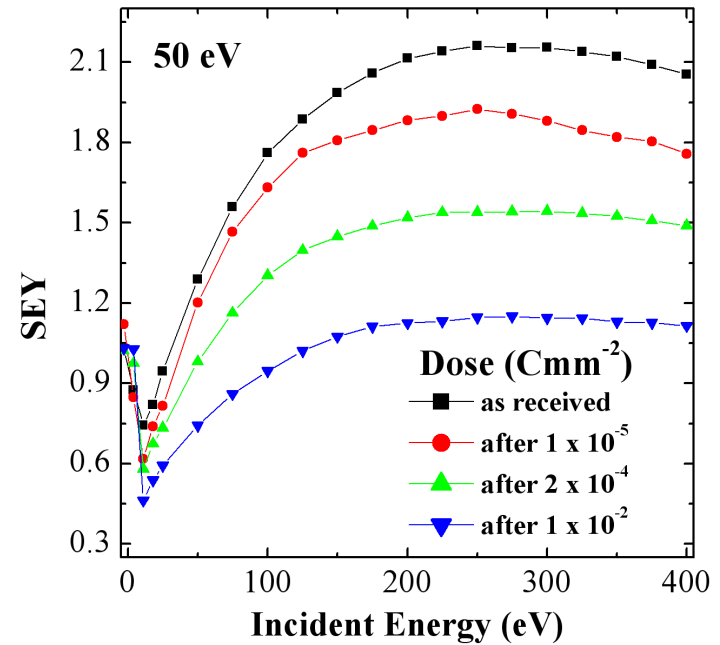
After bunch passage

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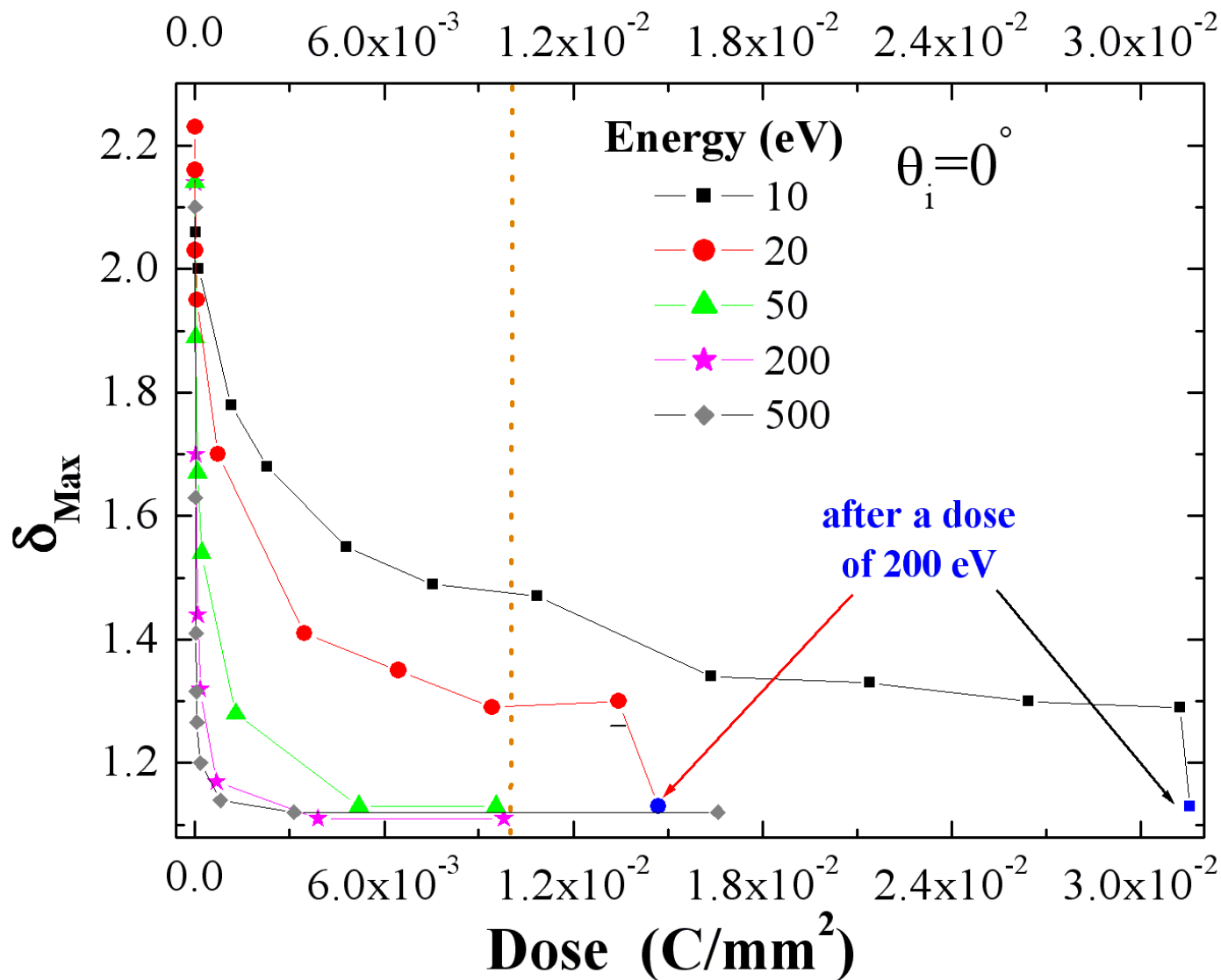
δ_{max} versus dose for different impinging electron energies at normal incidence.

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 its energy.

We repeated the experiment to confirm it and to do XPS.

We repeated the experiment to confirm it and to do XPS.

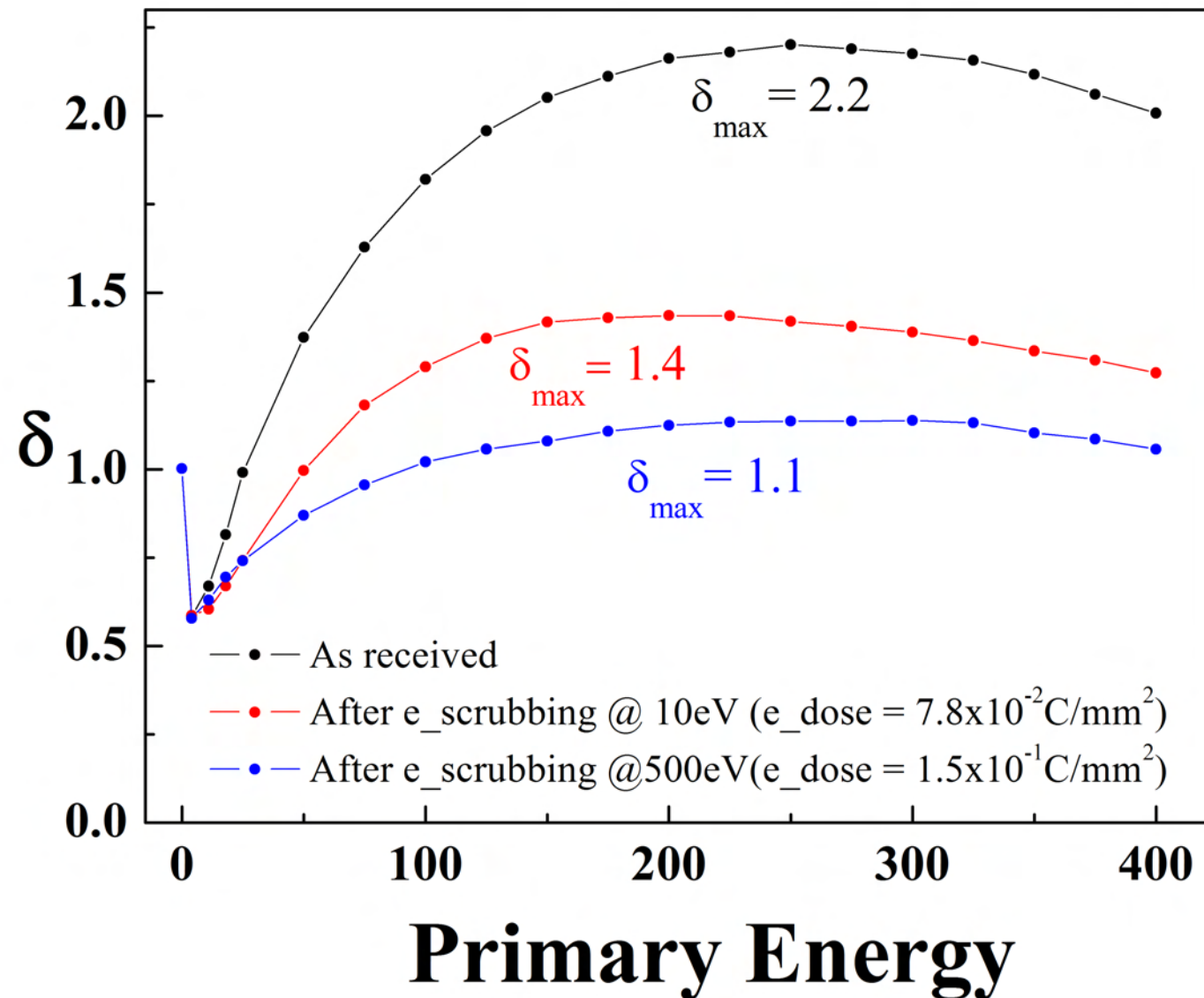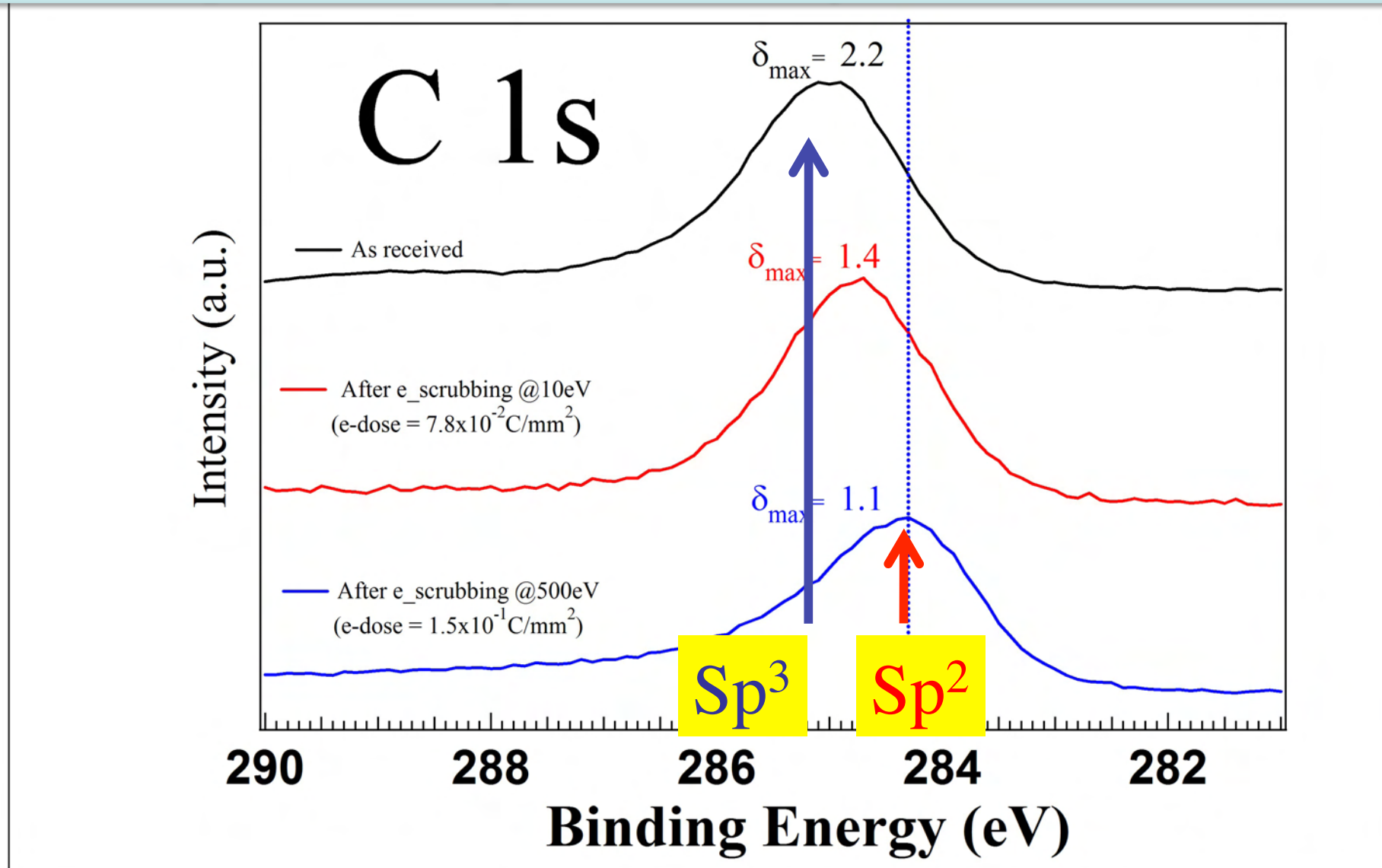*Theo DEMMA performed some preliminary simulation to see if one can optimize the "scrubbing" process @ LHC*

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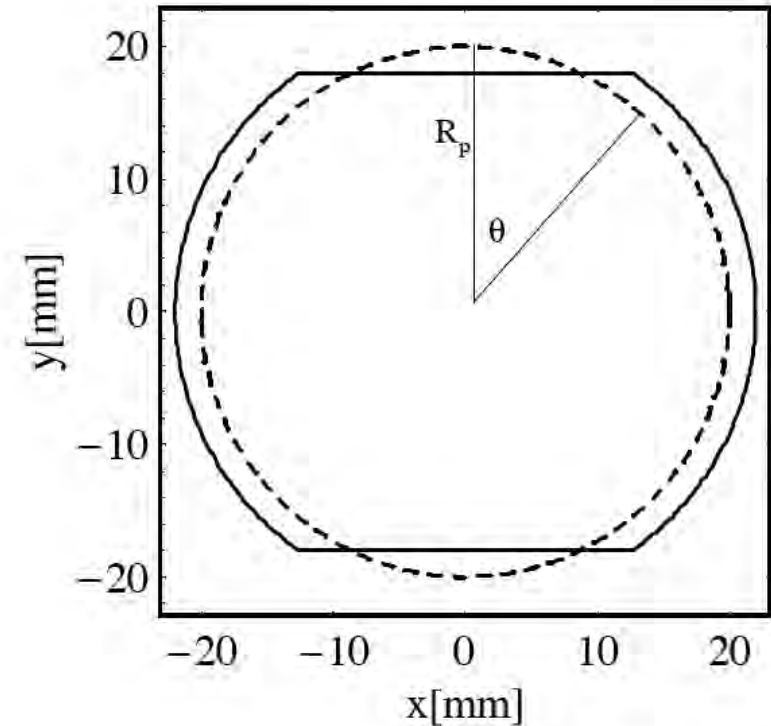
- *Potential consequences of these measurements on the commissioning of LHC: calculation of the e⁻ dose hitting the walls versus beam parameter and energy (preliminary).*

@ 50ns, δ_{max}=1.4 equal e⁻ density
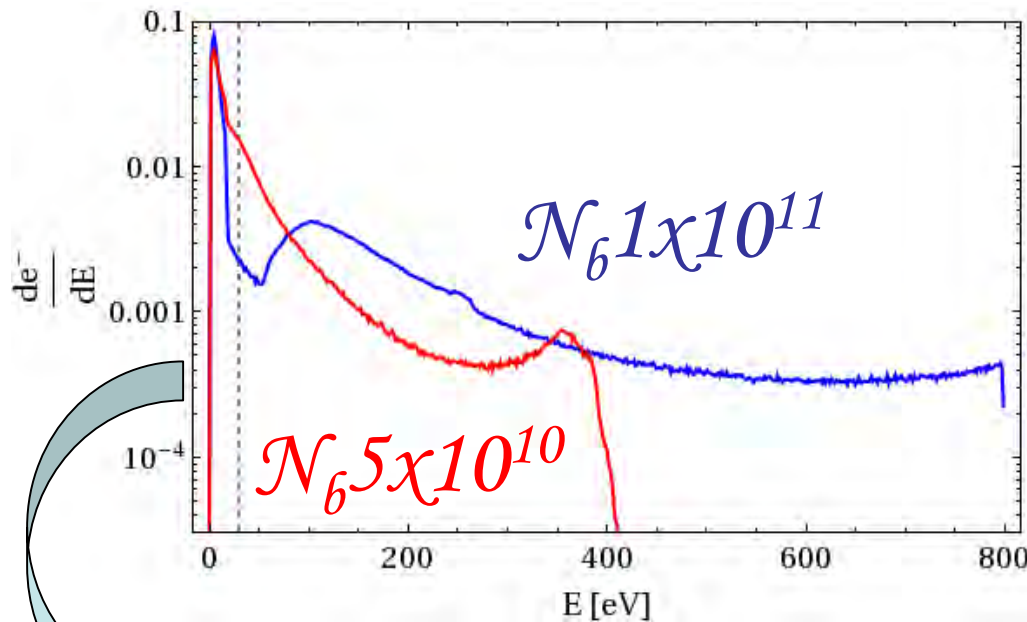
Log Scale!
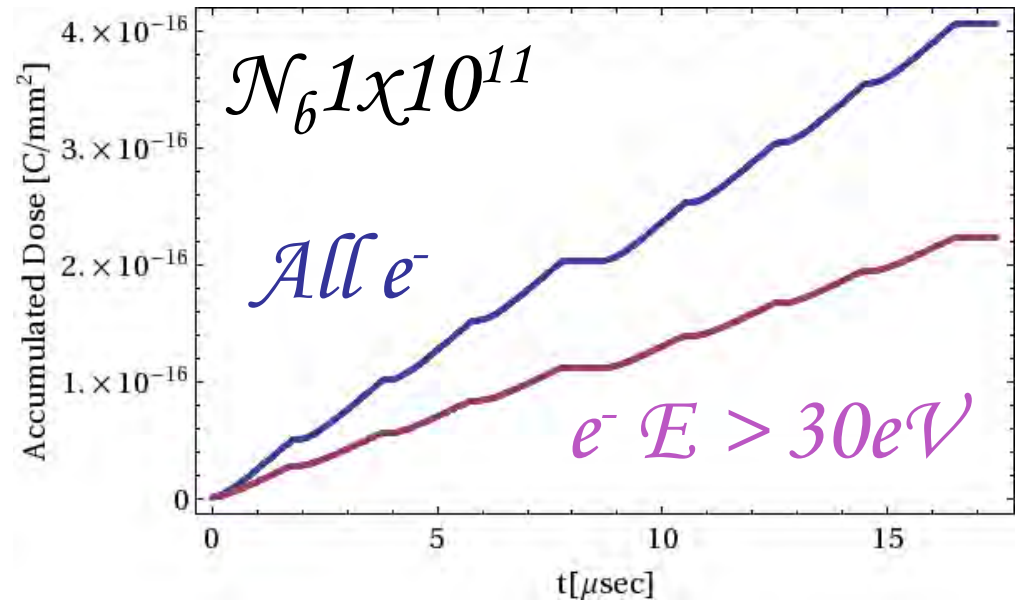
T. Demma et al. in preparation.

- *Potential consequences on the commissioning of LHC: optimizing beam parameters to increase $e^->30$ eV. Could be important to determine optimal n. of bunchs and bunch pattern for DR.*

Simulated energy components of electron dose delivered to the chamber walls during the passage of a bunch train for different value of δ_{max}
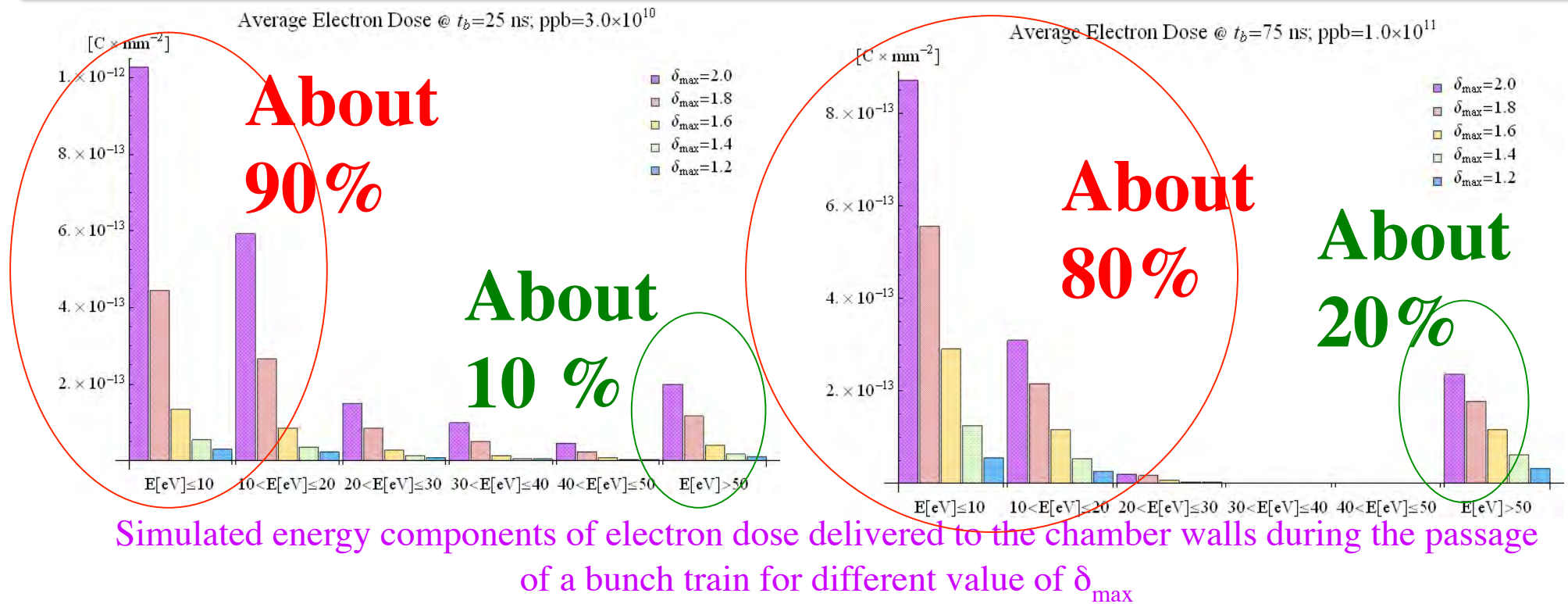
M.Commisso, R. Cimino, T. Demma, V. Baglin in preparation.

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!

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

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CERN uses magneto-sputtering technique to grow a thick (0.2-10 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.

Cu Sample

δ_{max} = 1.3
δ_{max} = 1.3
δ_{max} = 1.17
δ_{max} = 1.10
δ_{max} = 0.95

SEY
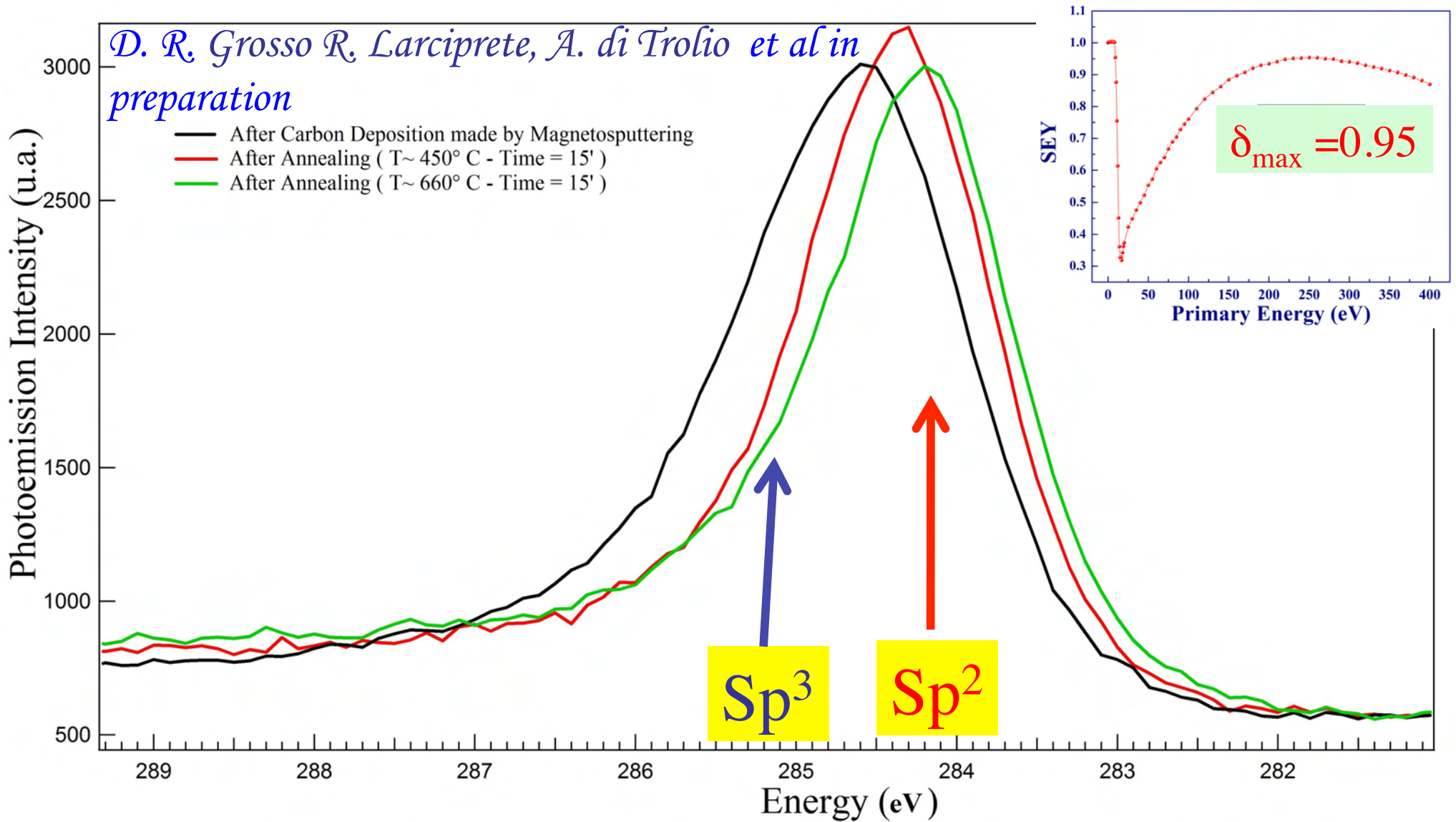
— · — After Argon Ion Sputtering (Clean Surface)
— · — After Annealing (T $\cong$ 750°C - ΔT = 15')
— · — After Carbon Deposition made by Magnetosputtering (ΔT = 4')
— · — After Annealing (T $\cong$ 450°C - ΔT = 15')
— · — After Annealing (T $\cong$ 660°C - ΔT = 15')

Primary Energy (eV)

D. R. Grosso R. Larciprete, A. di Trolio et al in preparation

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D. R. Grosso R. Larciprete, A. di Trolio et al in preparation

After Carbon Deposition made by Magnetosputtering
After Annealing (T~ 450° C - Time = 15')
After Annealing (T~ 660° C - Time = 15')

Sp³

Sp²

δ_{max} =0.95

It confirms that the best Graphene/Graphite layer we grow the lowest the SEY is !

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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<u>Last but not least : the e-cloud community</u>

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F. Zimmermann, M. Palmer, R. Wanzenberg and many others…..

announcement & invitation

ECLOUD'12

La Biodola, Isola d'Elba, Italy
From 5/6 to 9/10 June 2012

ECLOUD workshop series started at CERN in 2002.
After 10 years and stops in Napa Valley/CA (2004), Daegu/Korea (2007), and Cornell University/NY (2010), ECLOUD'12 returns to Europe!

Topics: SEY models, e-cloud build & e-cloud effects in accelerators, beam induced multi-pactoring, surface properties, mitigation measures, microwave diagnostics, …

more info will be posted at https://cern.ch/ecloud12

we hope to see you there!
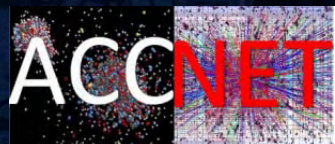
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