Material Science for next generation Accelerator Vacuum systems

Roberto Cimino
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Material Science for next generation Accelerator systems

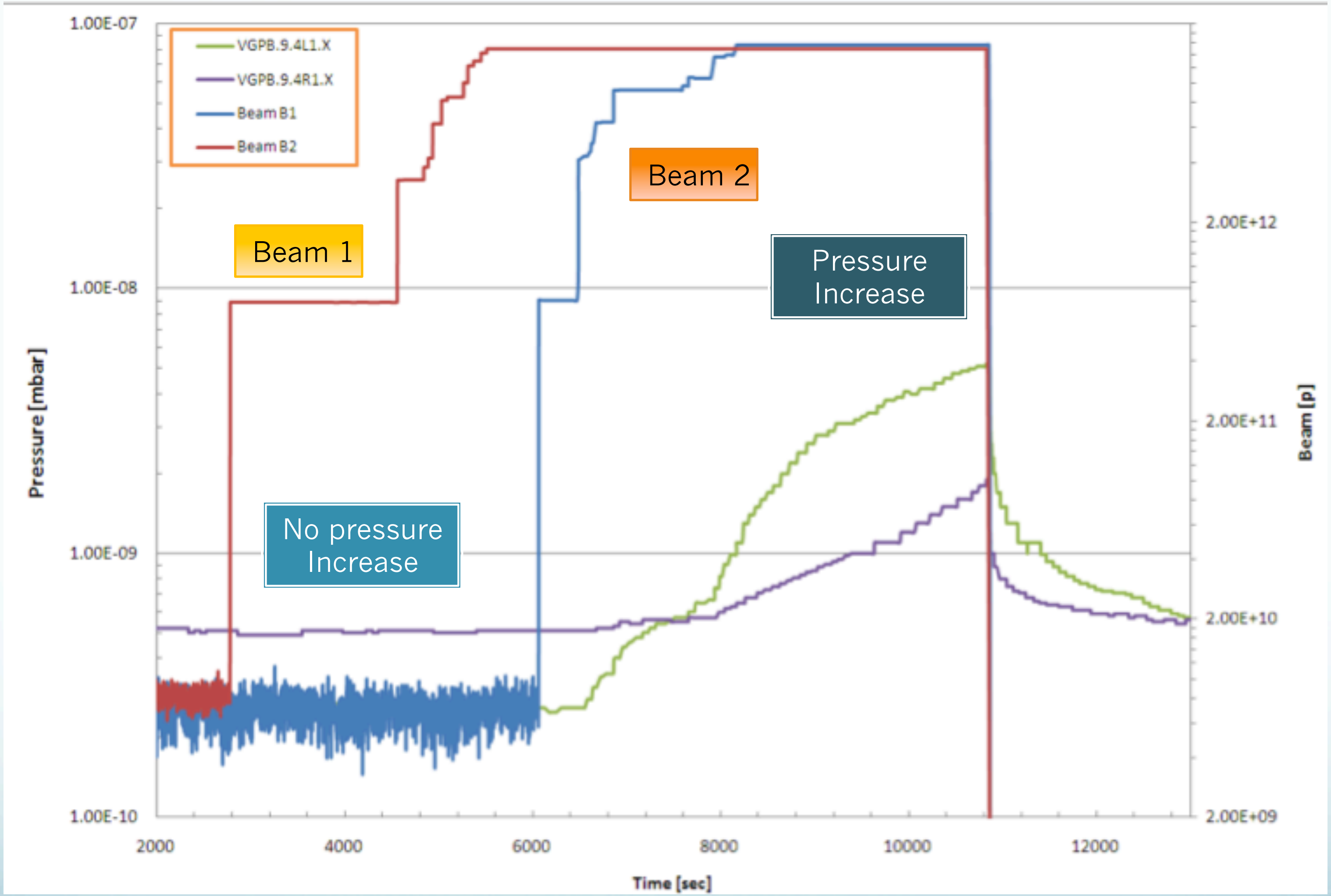
- Introduction
  - Interplay between Beam and Surfaces: some real examples (LHC)
  - What happens to the Vacuum beam pipe in presence of the beam?
- The Surface Science properties of relevance: SEY, PY, R
- Mitigation strategies
- conclusion

One real example to see it:

8-10-2010

450 GeV – 150 ns bunch spacing:
Merged vacuum @ LHC

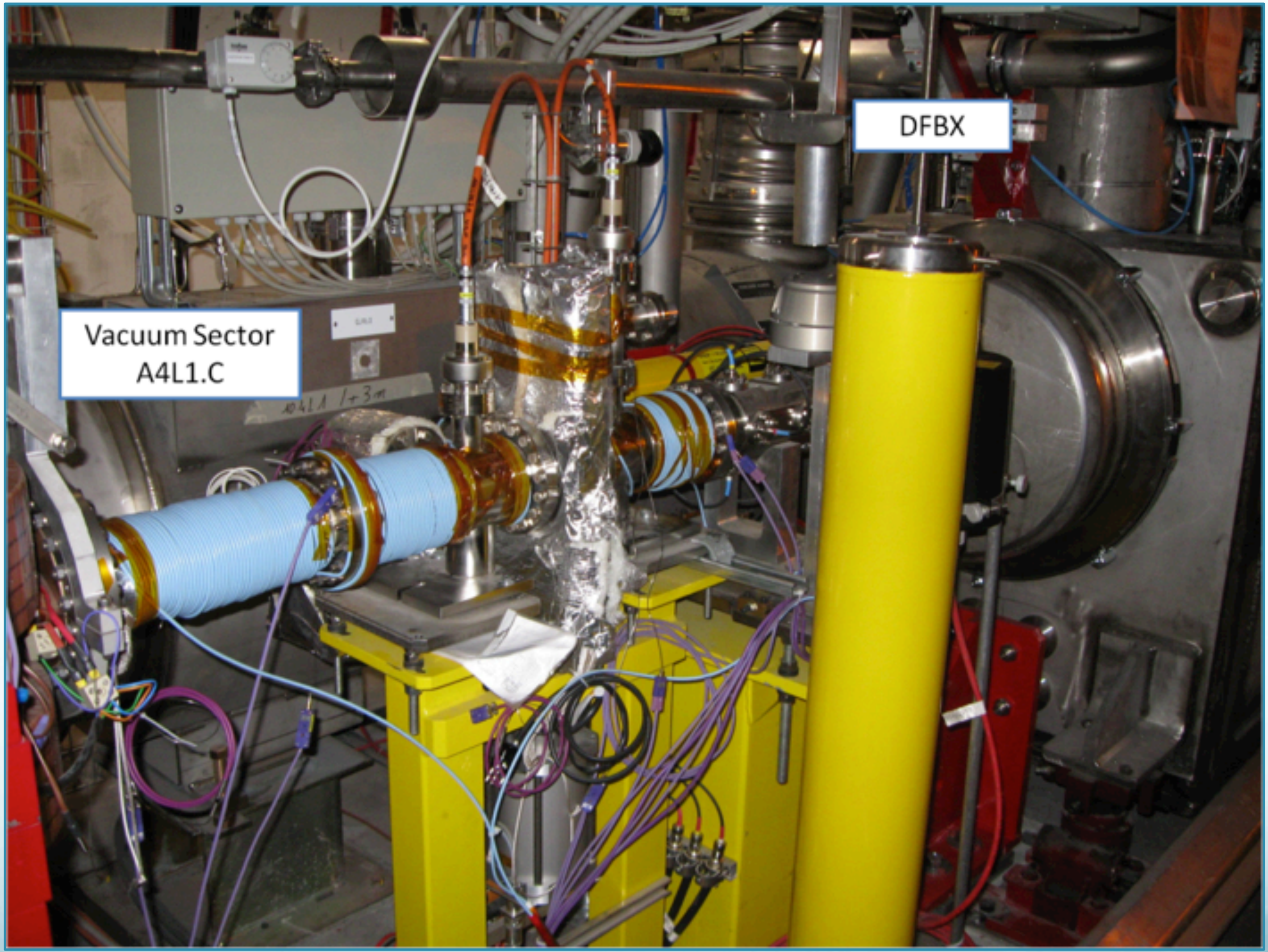
Exotic Vacuum behavior @ LHC:



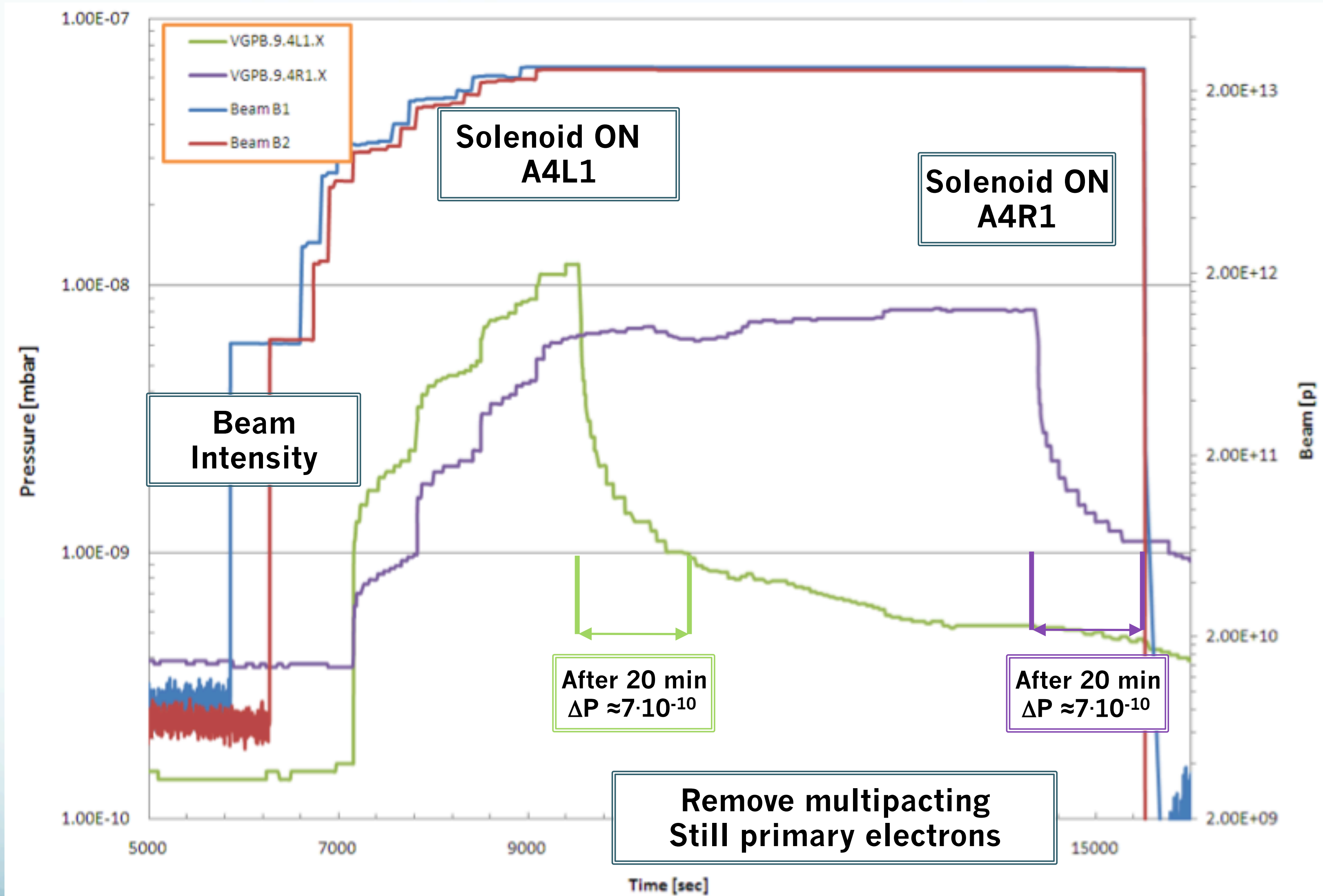
450 GeV – 150 ns bunch spacing: Merged vacuum

8-10-2010

Easily solved: Installation of Solenoids



Solenoids effect on pressure



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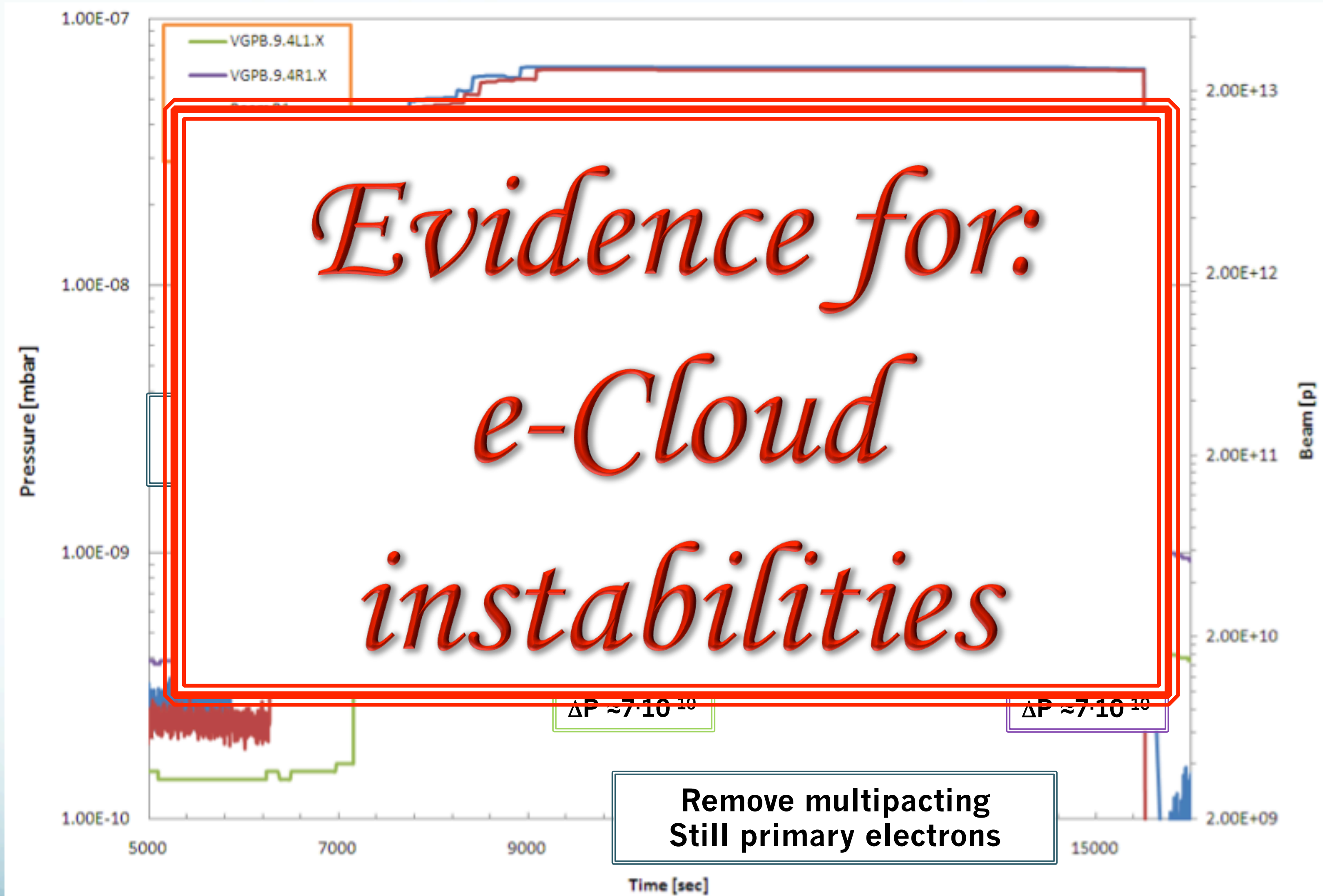
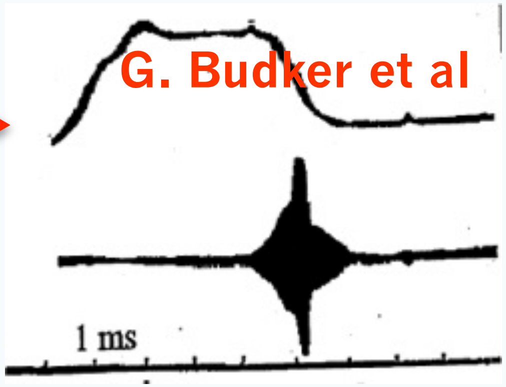


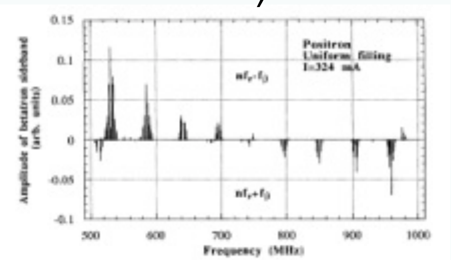
E-cloud history

- *1965 INP PSR Transverse instability & beam loss*
- *1971 ISR e-p, 1977 Beam induced multipacting*
- *1988 LANL PSR vertical instability &beam loss*
- *1988 KEK PF multibunch instability*
- *Since 1996 BEPC IHEP-KEK collaboration*
- *1997 LHC crash program launched*
- *1997 CESR "anomalous anti-damping" explained*
- *1997/98 APS e^- cloud study start*
- *Since 1998 SPS e^- cloud with LHC beam*
- *2000 PS e^- cloud with LHC beam*
- *Since 1999 e^- cloud at KEKB and PEP-II*
- *Since October 2001 evidence for e^- cloud at RICH*
- *Since december 2002 e^- cloud at TEVATRON*
- *Etc etc…*

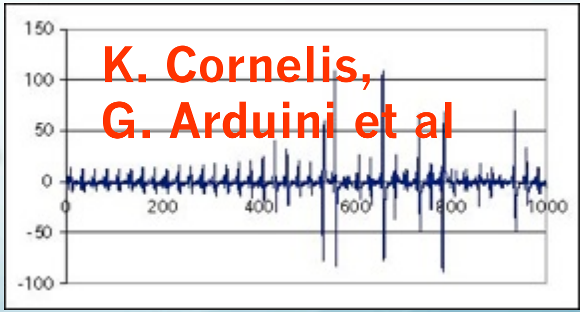


G. Budker et al

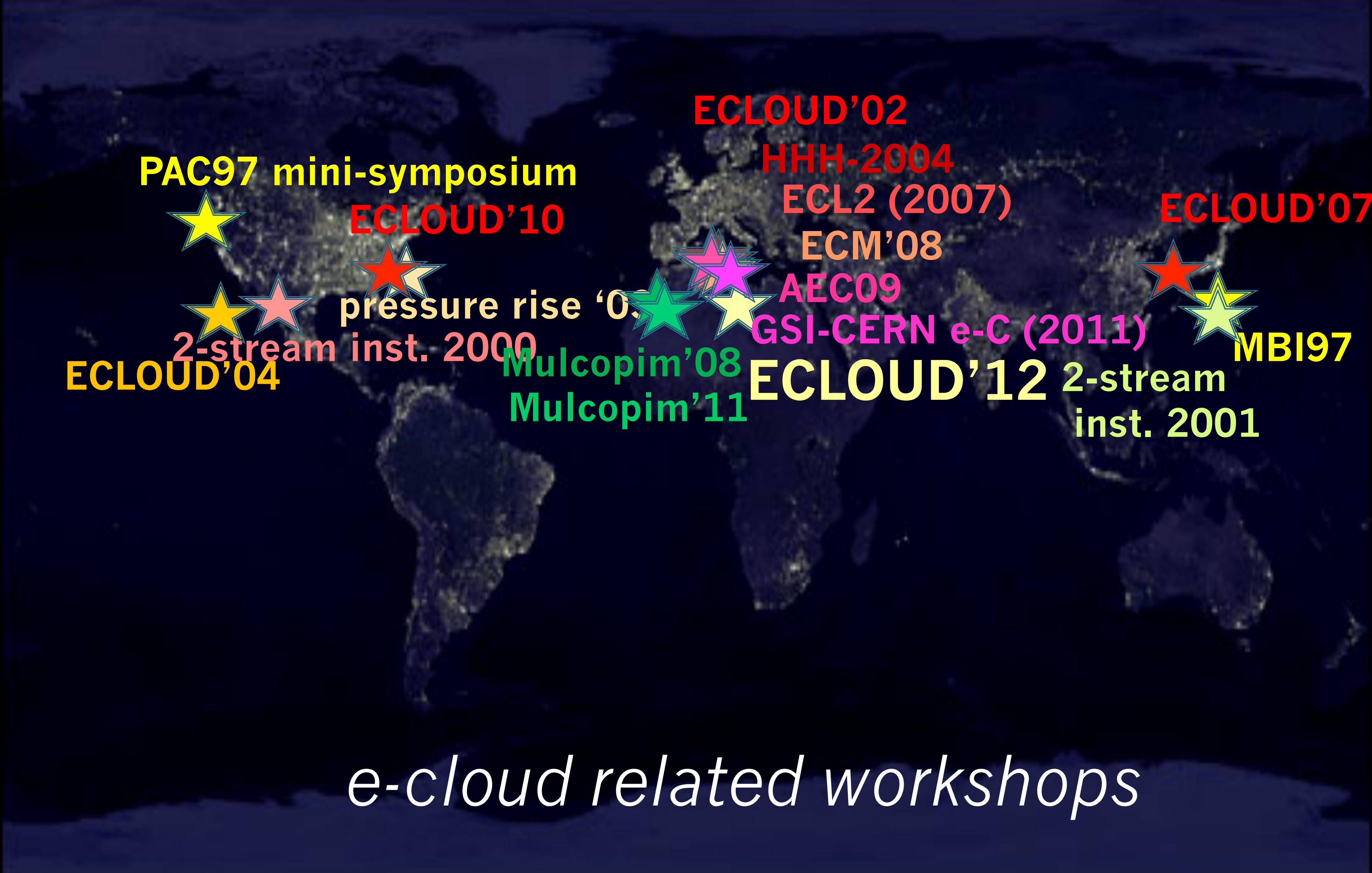
KEK PF, 1988



M. Izawa, Y. Sato, T. Toyomasu



K. Cornelis, G. Arduini et al



e-cloud related workshops

ECLOUD12 sheds light on electron clouds

INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS
CERN COURIER
VOLUME 52 NUMBER 7 SEPTEMBER 2012

A recent workshop reviewed the latest experiences with the phenomenon of electron clouds at the LHC and other accelerators.

Electron clouds – abundantly generated in accelerator vacuum chambers by residual-gas ionization, photoemission and secondary emission – can affect the operation and performance of hadron and lepton accelerators in a variety of ways. They can induce increases in vacuum pressure, beam instabilities, beam losses, emittance growth, reductions in the beam lifetime or additional heat loads on a (cold) chamber wall. They have recently regained some prominence: since autumn 2010, all of these effects have been observed during beam commissioning of the LHC.

Electron clouds were recognized as a potential problem for the LHC in the mid-1990s (*CERN Courier* July/August 1999 p29) and the first workshop to focus on the phenomenon was held at CERN in 2002 (*CERN Courier* July/August 2002 p15). Ten years later, the fifth electron-cloud workshop has taken place, again in Europe. More than 60 physicists and engineers from around the world gathered at La Biodola, Elba, on 5–8 June to discuss the state of the art and review recent electron-cloud experience.

Valuable test beds

Many electron-cloud signatures have been recorded and a great deal of data accumulated, not only at the LHC but also at the CESR Damping Ring Test Accelerator (CesrTA) at Cornell, DAΦNE at Frascati, the Japan Proton Research Complex (J-PARC) and PETRA III at DESY. These machines all serve as valuable test beds for simulations of electron-cloud build-up, instabilities and heat load, as well as for new diagnostics methods. The latter include measurements of synchronous phase-shift and cryoeffects at the LHC, as well as microwave transmission, coded-aperture images and time-resolved shielded pick-ups at CesrTA. The impressive resemblance between simulation and measurement suggests that the existing electron-cloud models correctly describe the phenomenon. The workshop also analysed the means of mitigating electron-cloud effects that are proposed for future projects, such as the High-Luminosity LHC, SuperKEKB in Japan, SuperB in Italy, Project-X in the US, the upgrade of the ISIS machine in the UK and the International Linear Collider (ILC).

An international advisory committee had assembled an exceptional programme for ECLOUD12. As a novel feature for the series, members of the spacecraft community participated, includir aerospa ogy, the Polytec space su in accel termeas through satellite perform Intrigui emissio lyse elec constru emission ures for ings and ECLOU involved at this m emission first app at the Ur effects in

Severa first time ... from Cornell, for photon tracking, modelling surface properties and 3D geometries; OSMOSEE from Onera, to compute the secondary-emission yield, including at low primary energies; PyECLOUD from CERN, to perform improved and faster build-up simulations; the latest version of WARP-POSINST from Lawrence Berkeley National Laboratory, which allows for self-consistent simulations that combine build-up, instability and emittance growth, and is used to study beam-cloud behaviour over hundreds of turns through the Super Proton Synchrotron (SPS); and BI-RME/ECLOUD from a ▷

Several powerful new simulation codes were presented for the first time at ECLOUD12.

chairs of ECLOUD12

Roberto Cimino, LNF/INFN
and
Frank Zimmermann, CERN

Vacuum in new generation accelerators is "more" complex than just "Vacuum"

- Let us see what may cause such beam and/or pressure instabilities .
- The case of the:

LHC arcs

LHC

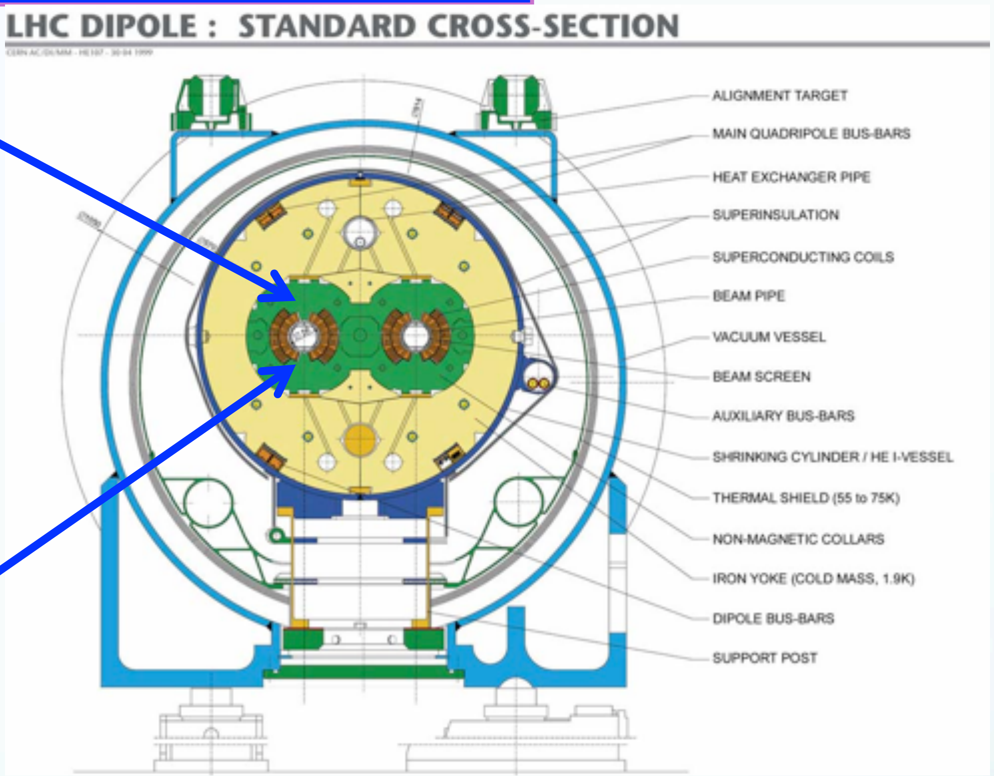
The LHC (Large Hadron Collider) is a the particle accelerator being built at CERN. Two beams of protons fly around a ring of 27km in circumference.

LHC arcs

Static

Radial Distance

Cold Bore @ 1.9 K



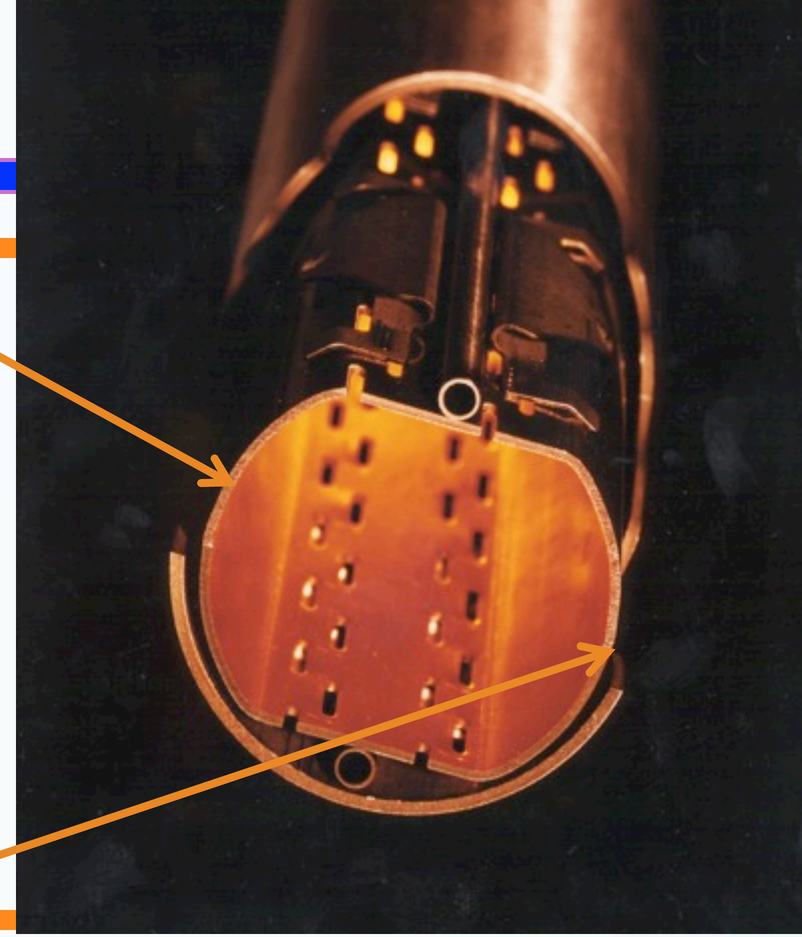
Extreme High Static Vacuum (<< 10^{-13} Torr)

Cold Bore @ 1.9 K

Need of a Beam Screen

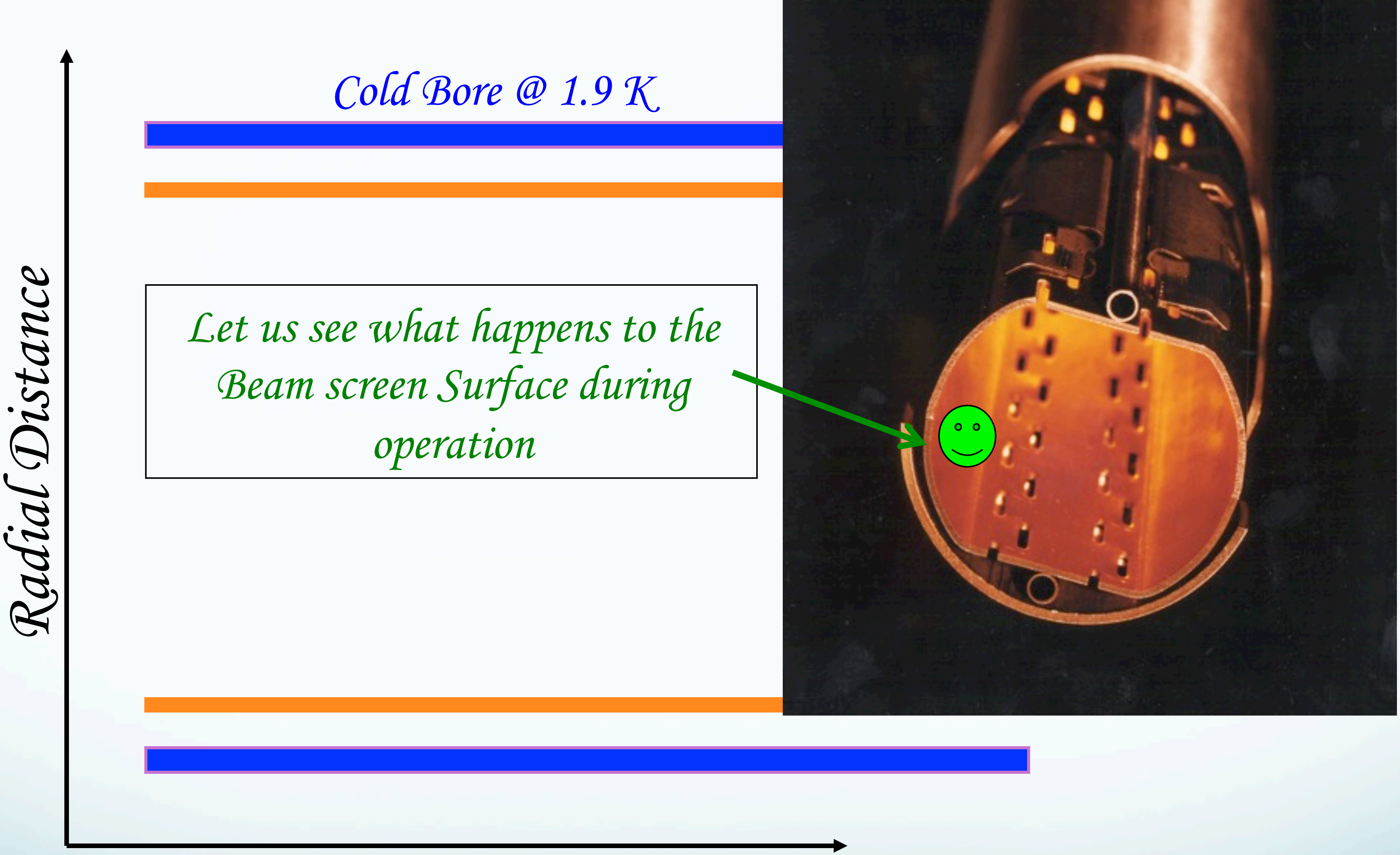
@ 5K< T <20K

to reduce heat load (SR, Eddy current, Impedance, etc…) on Cold bore for thermal load issues



Radial Distance

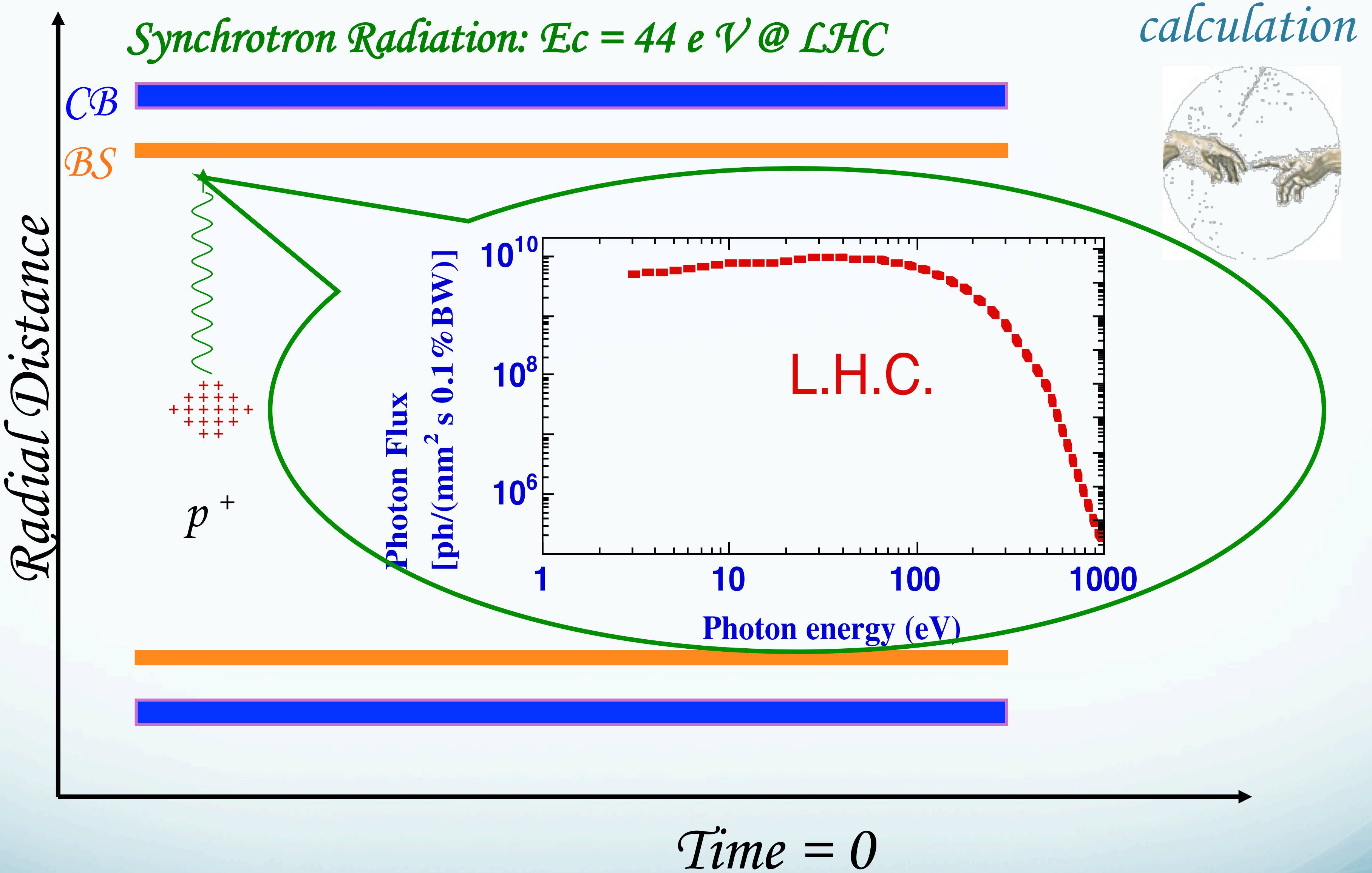
T=0, without beam



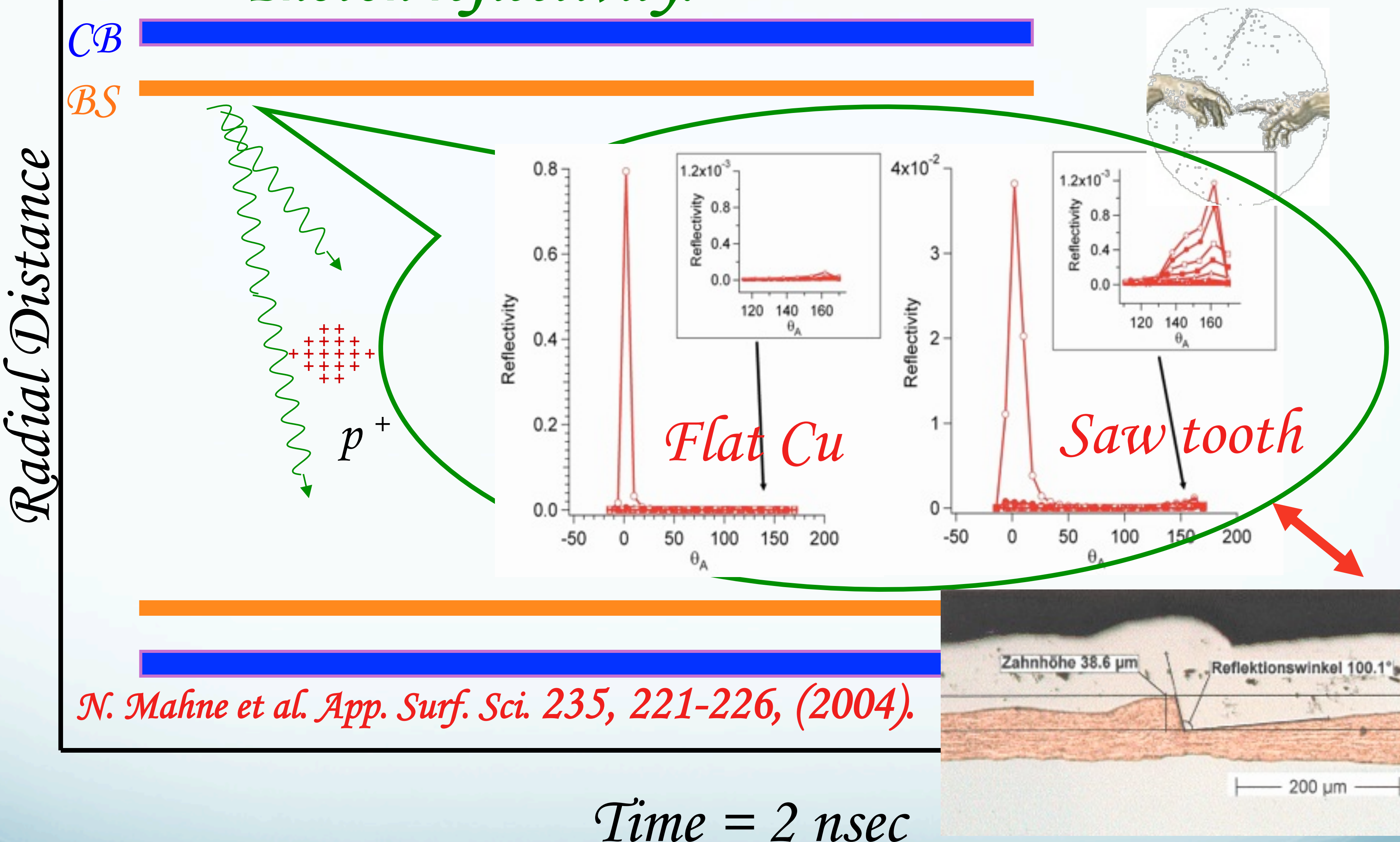
T=0, without beam

Synchrotron Radiation: Ec = 44 e V @ LHC

calculation

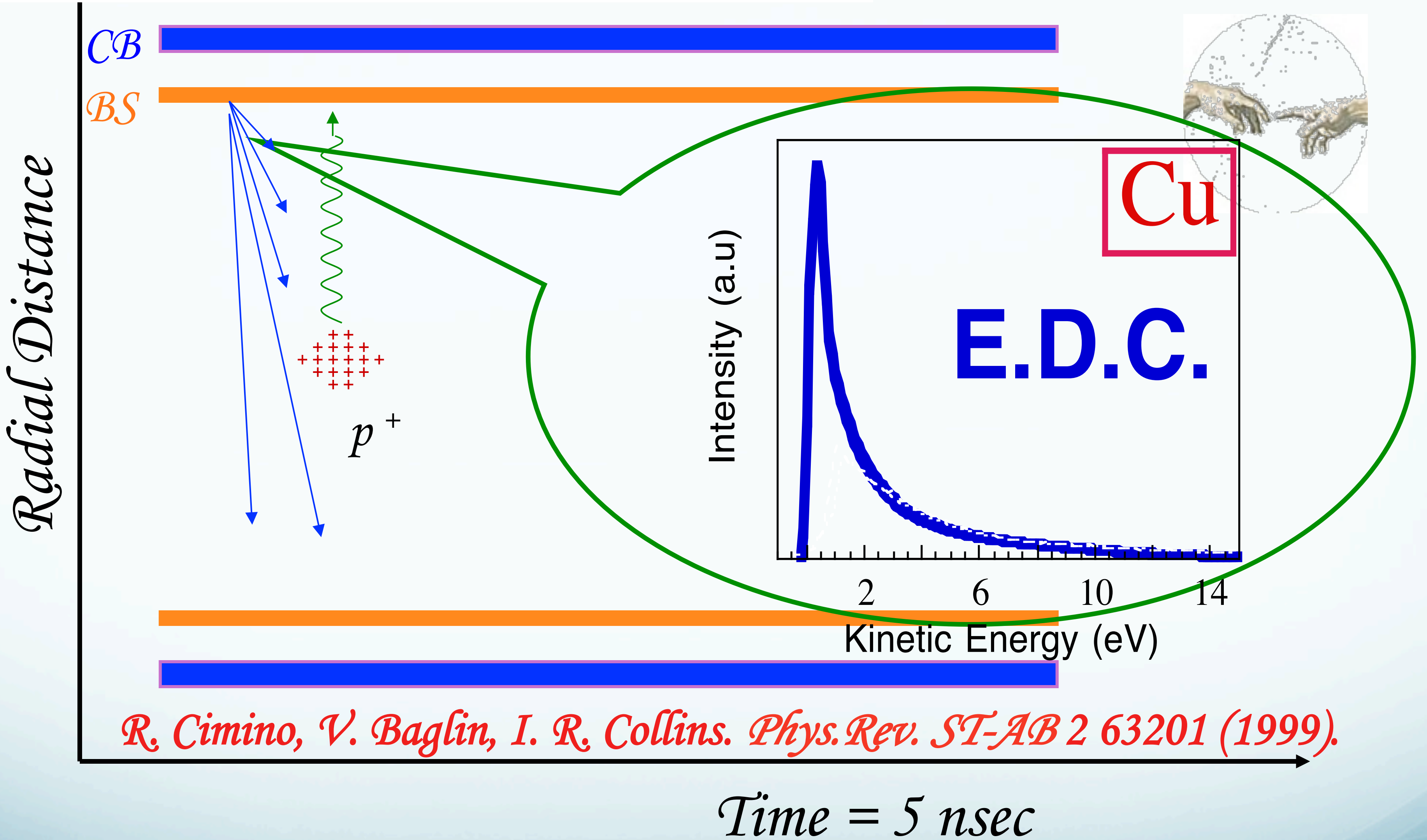


Photon reflectivity:



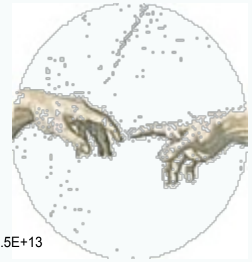
N. Mahne et al. App. Surf. Sci. 235, 221-226, (2004).

Photoemission:(vs. hν, Θ, E,T, B)



R. Cimino, V. Baglin, I. R. Collins. Phys.Rev. ST-AB 2 63201 (1999).

Produced e⁻ (PY): very important for single beam instabilities



Even in absence of SR:

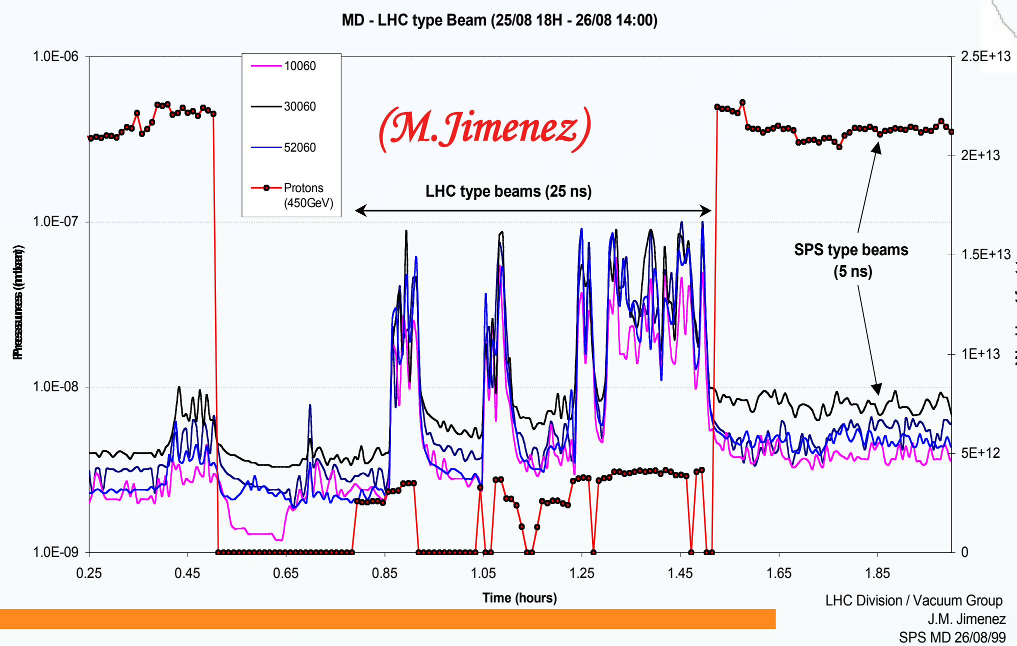
e⁻ from ionization of residual gas… etc

SPS

Radial Distance

e^-

p^+

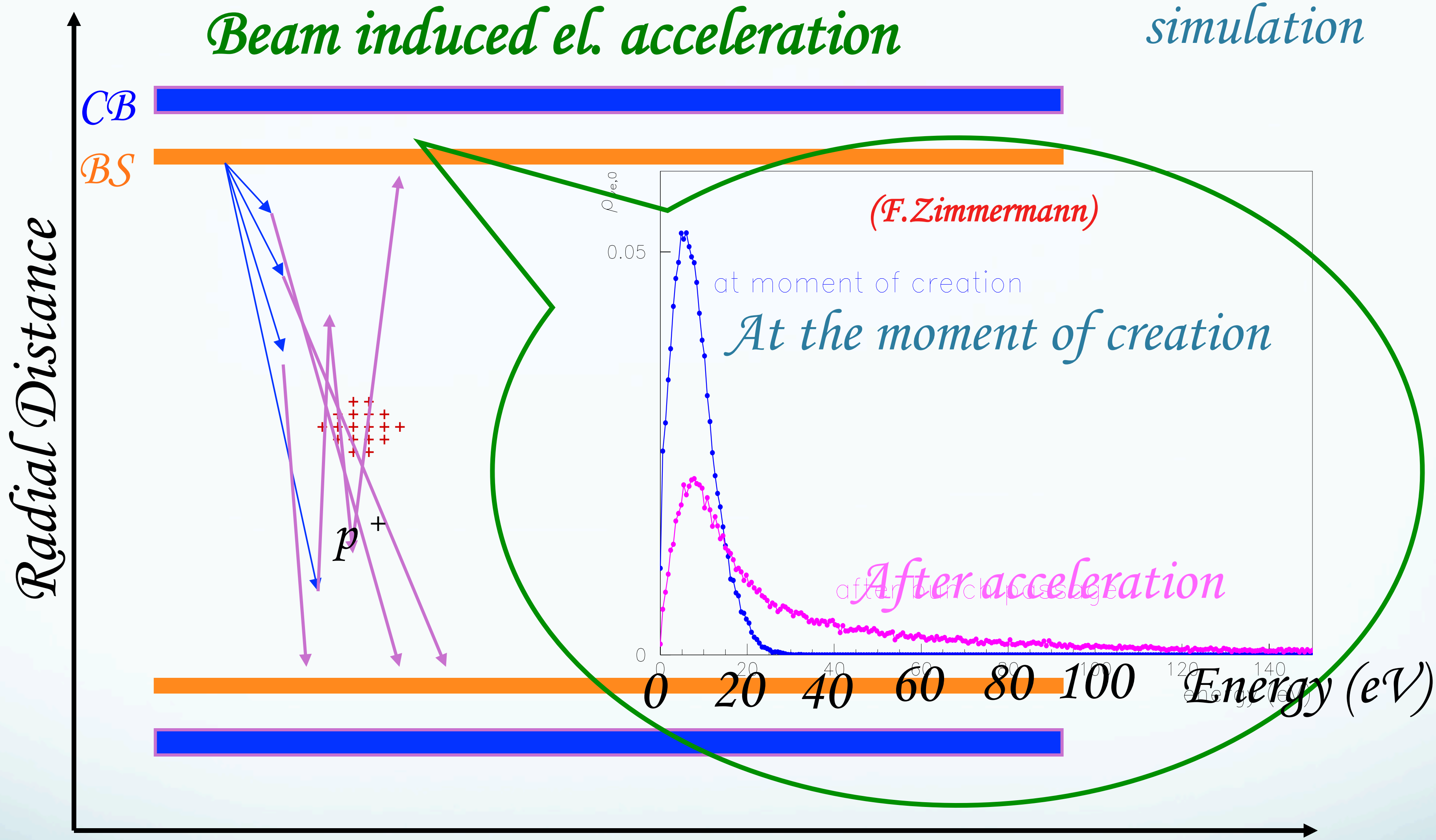


Beam induced multipacting is observed in SPS where no e⁻ are photoemitted.

Time = 5 nsec

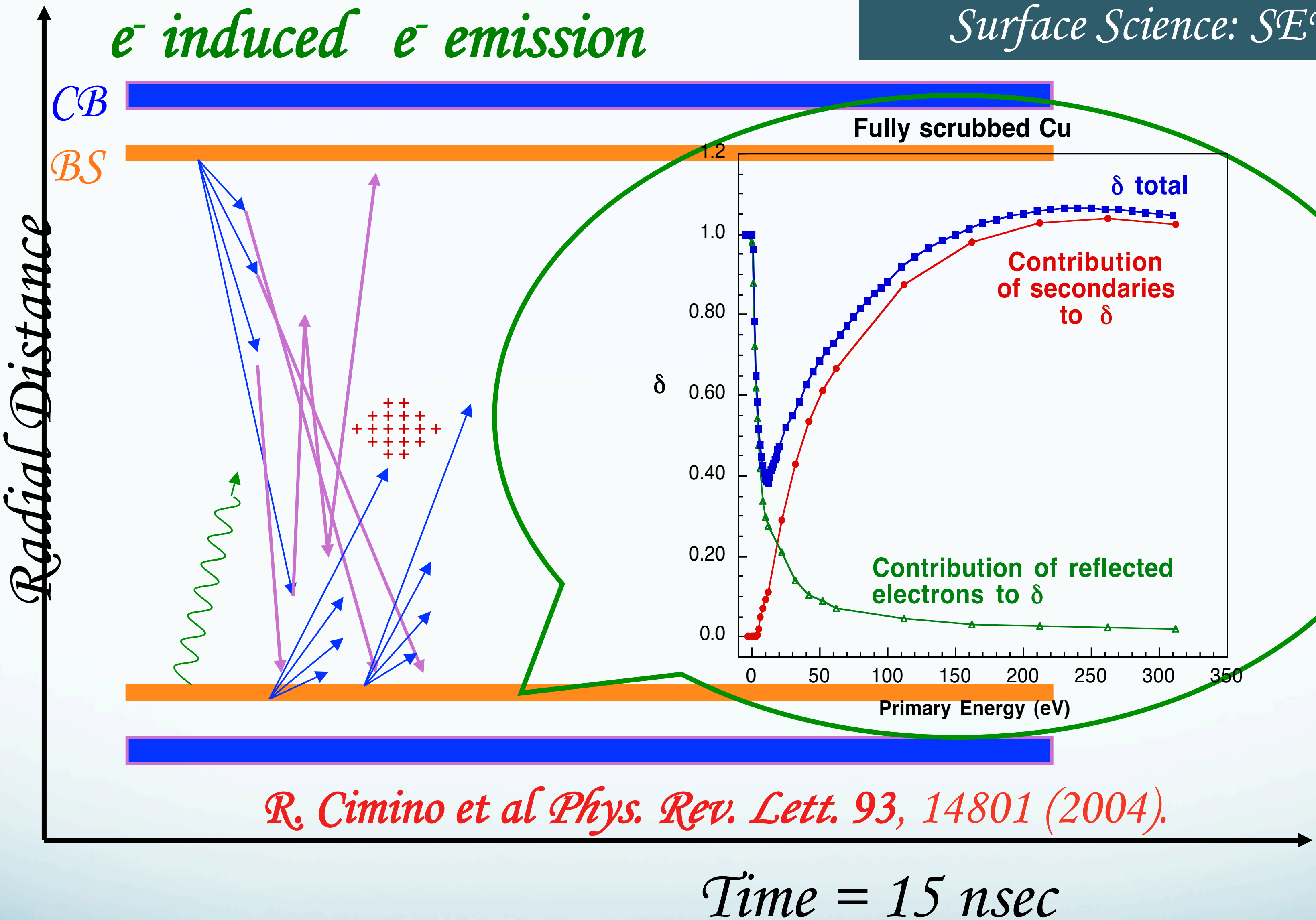
Beam induced el. acceleration

simulation



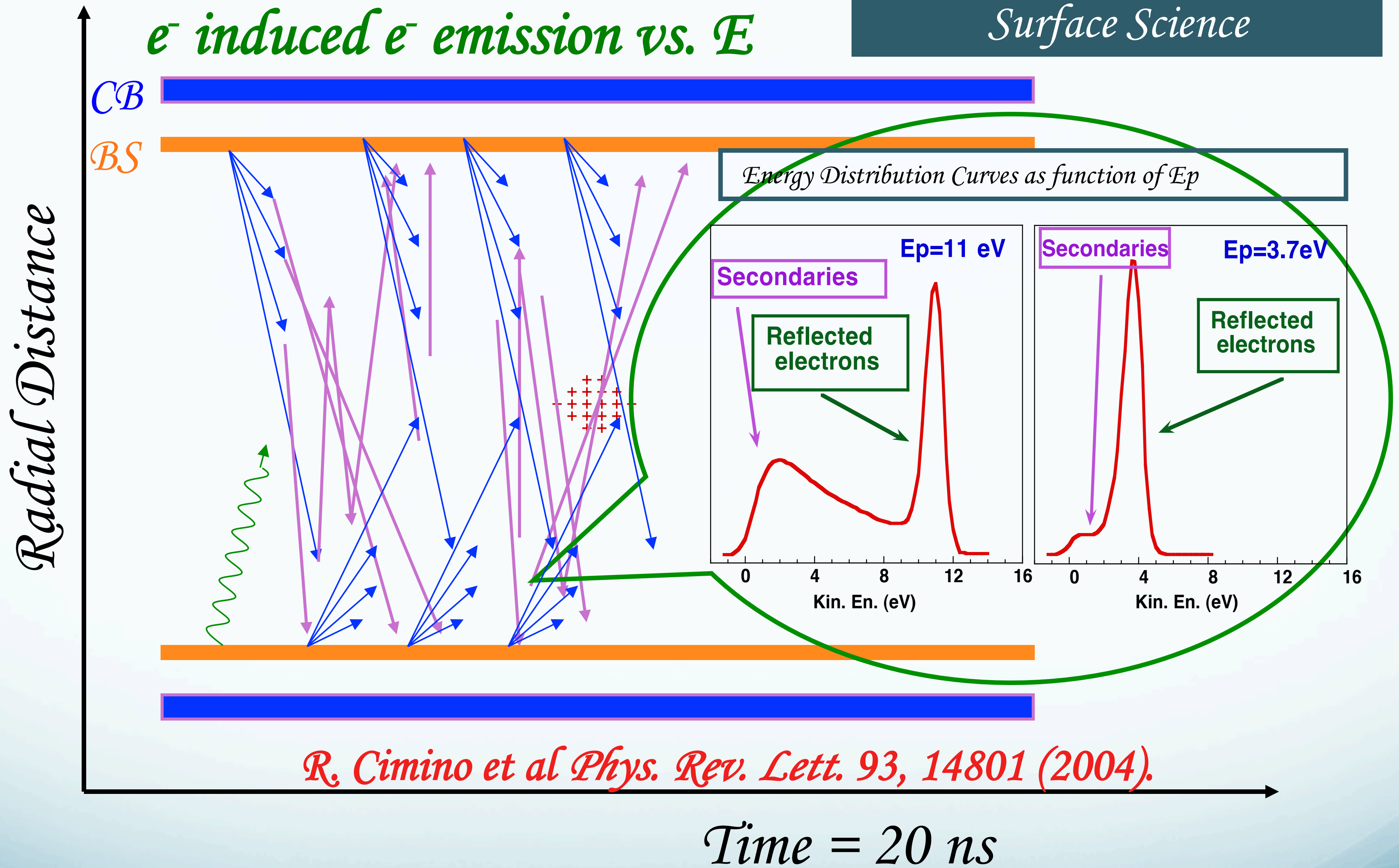
Time = 10 nsec

e^- induced e^- emission

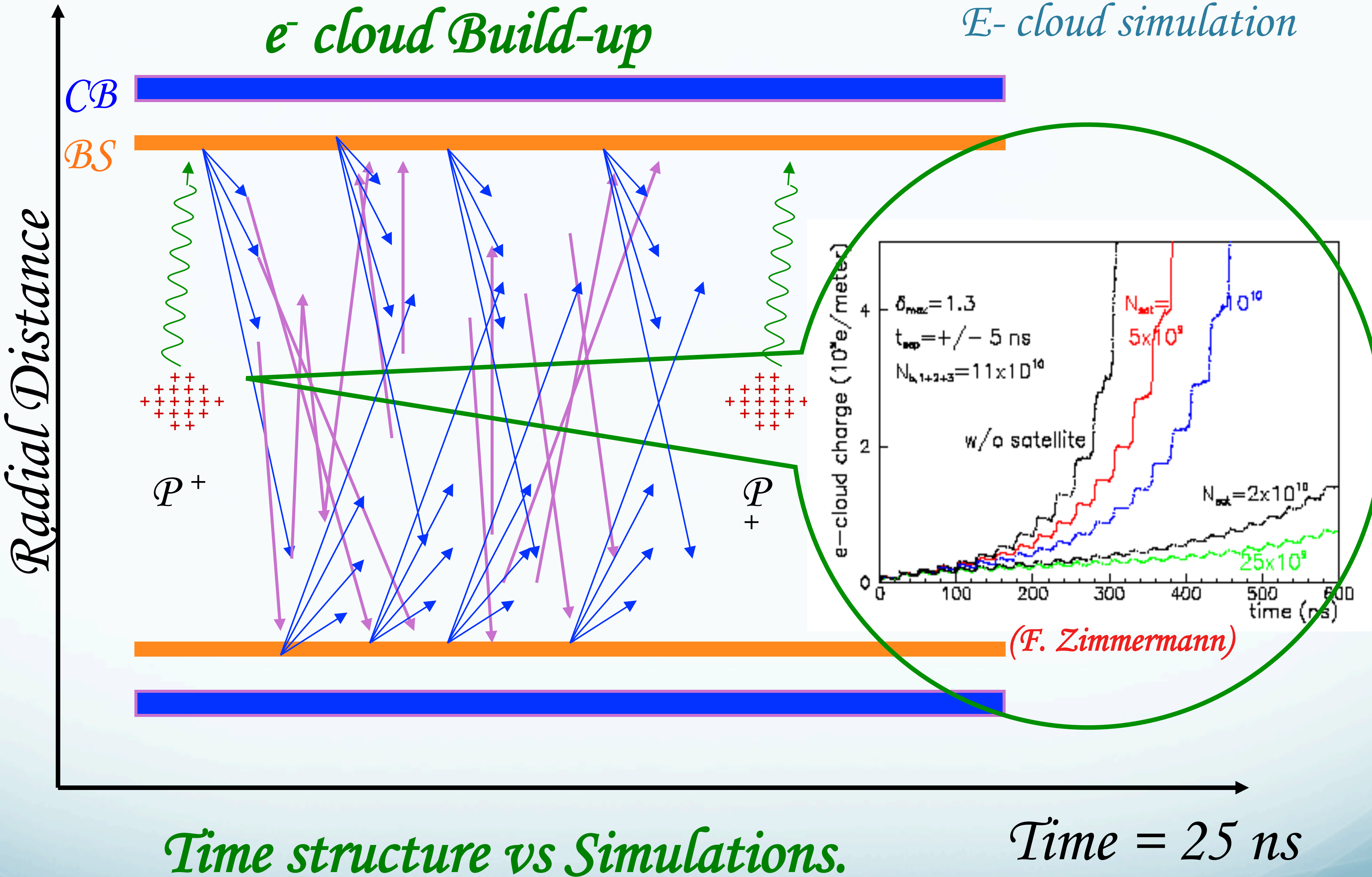


R. Cimino et al Phys. Rev. Lett. 93, 14801 (2004).

e^- induced e^- emission vs. E



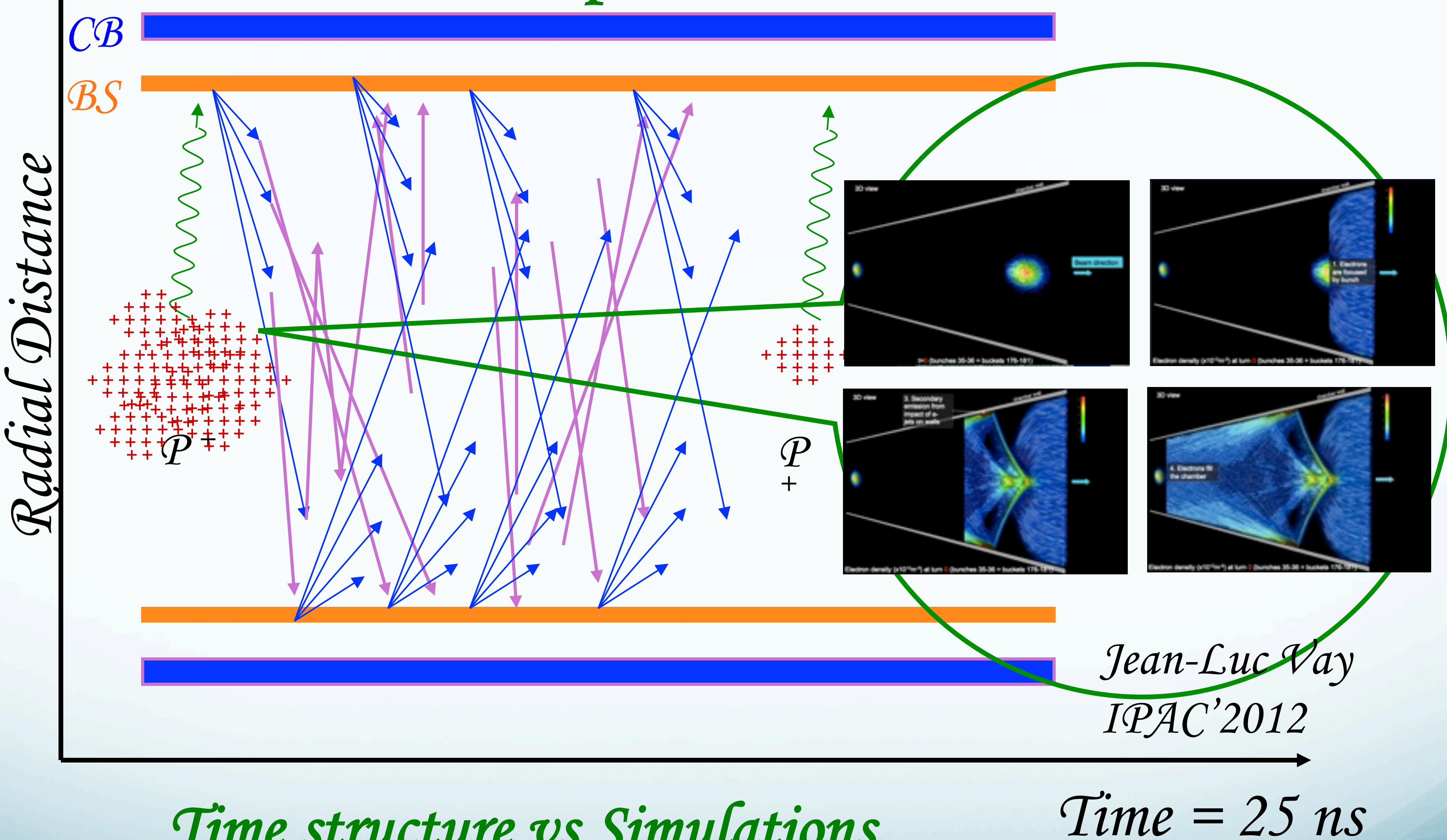
e⁻ cloud Build-up



Time structure vs Simulations.

Beam blow up

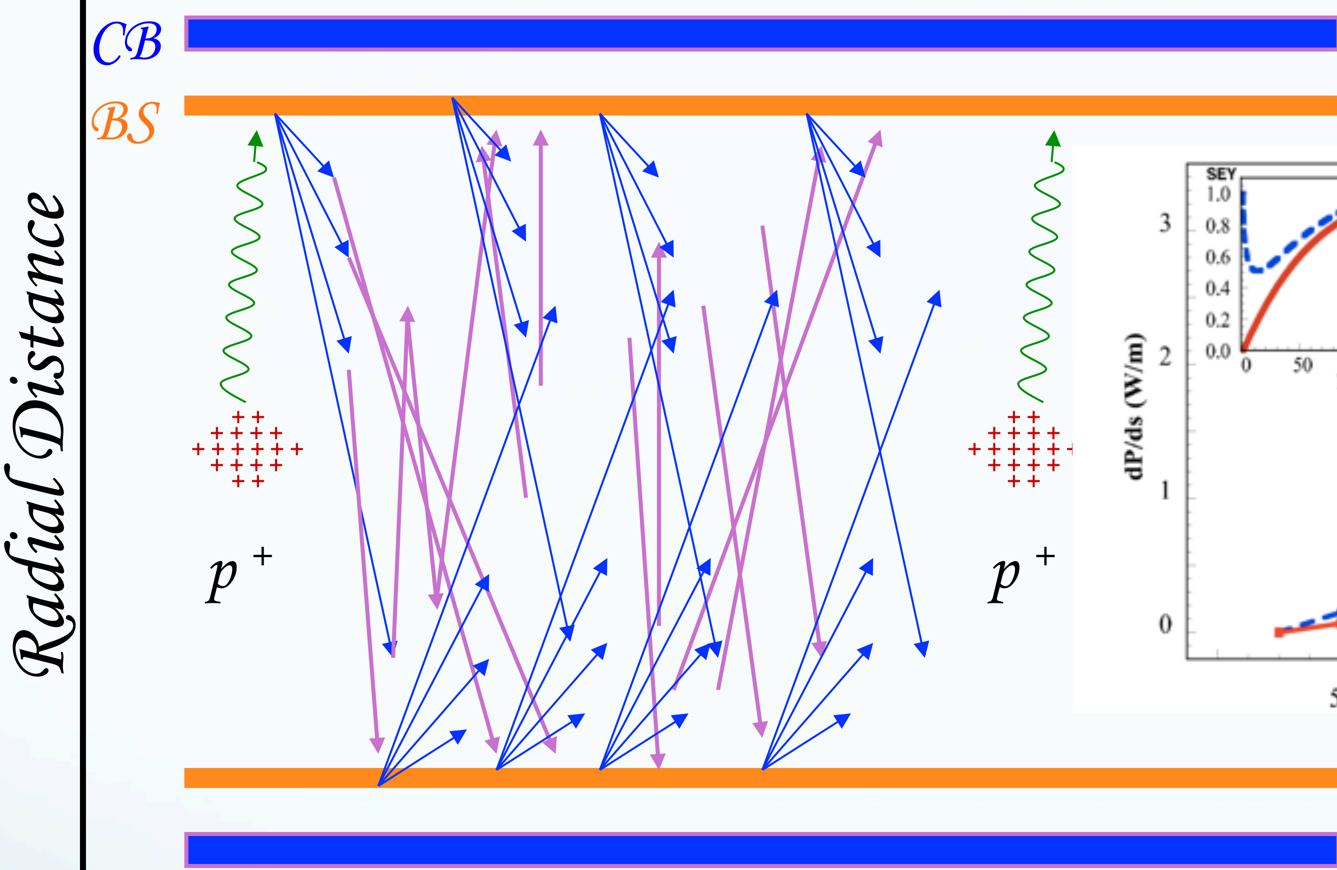
E- cloud simulation

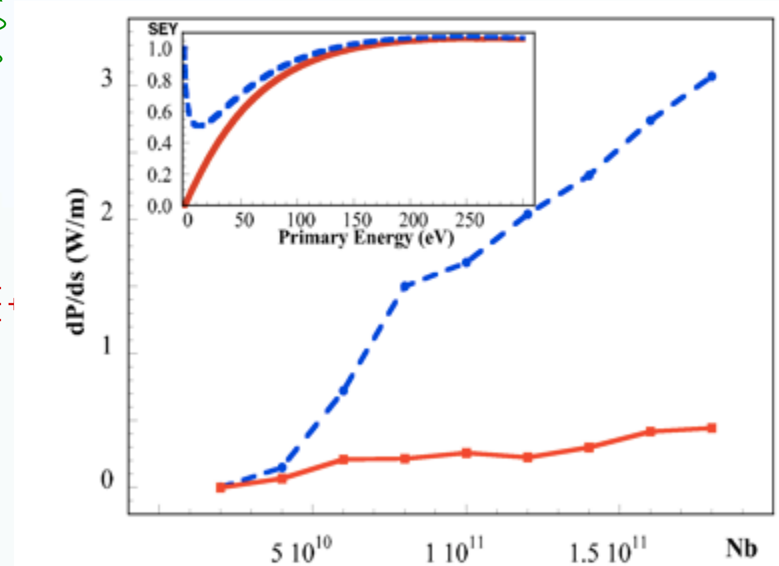


Time structure vs Simulations.

Simulation

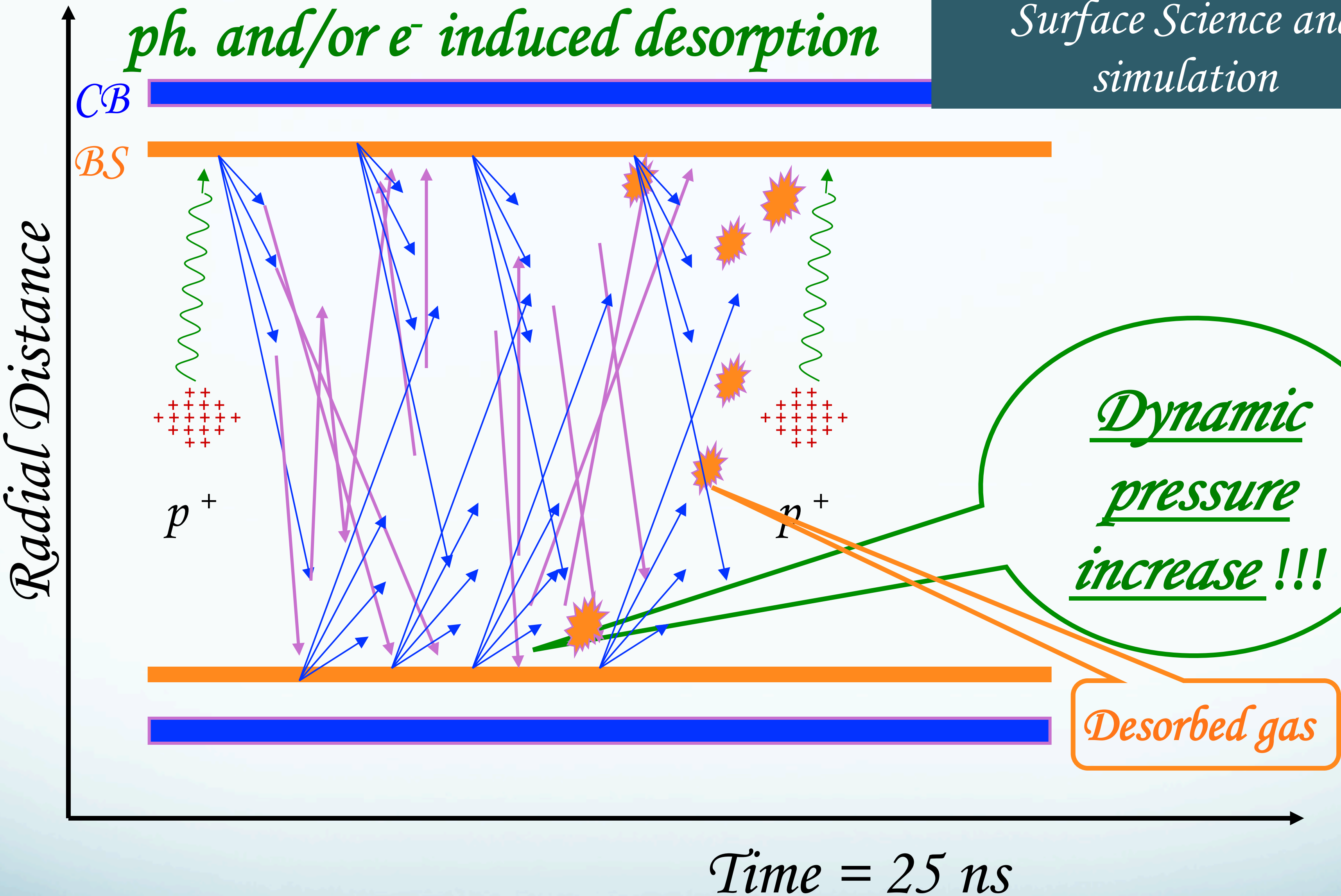
e^- induced heat load





R. Cimino et al Phys. Rev. Lett. 93, 14801 (2004).

Time = 25 ns



It is a beam/Vacuum issue!

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  - What happens to the Vacuum beam pipe in presence of the beam?
- The Surface Science properties of relevance: SEY, PY, R
- Mitigation strategies
- conclusion

The Surface Science Actors:

- Secondary Electron Yield (the number of electrons created after bombardment of a single electron.)
- Photoelectron Yield (the number of electrons created after bombardment of a single photon)
- Photo-reflectivity (the number of photons reflected by the surface)

And their dependence on:

material, Energy, angle, temperature, magnetic field, Conditioning etc etc….

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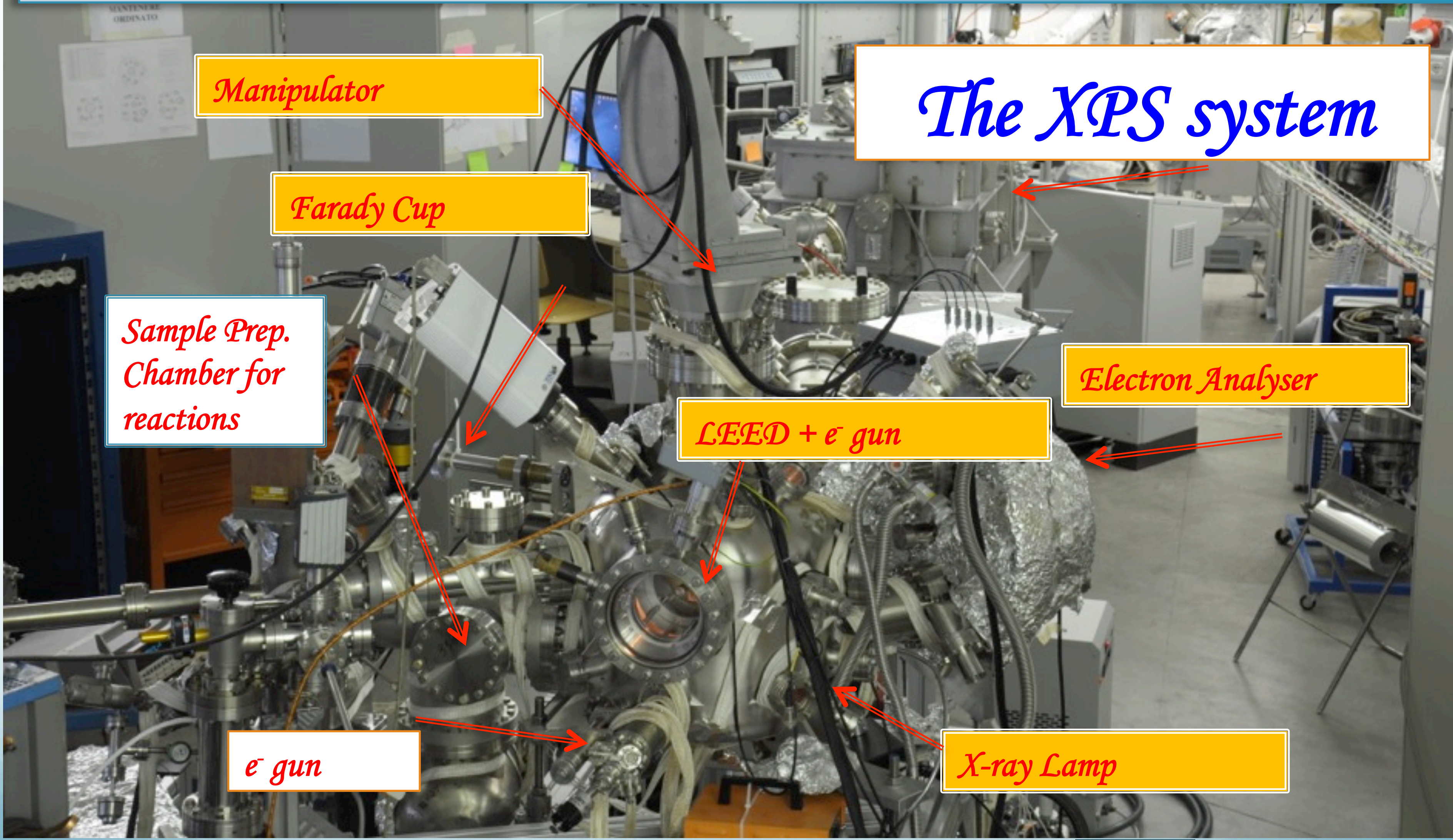
We set up and are working on two Surface Science "state of the art" systems to study, produce and test low SEY films @ Daϕne Light Laboratory



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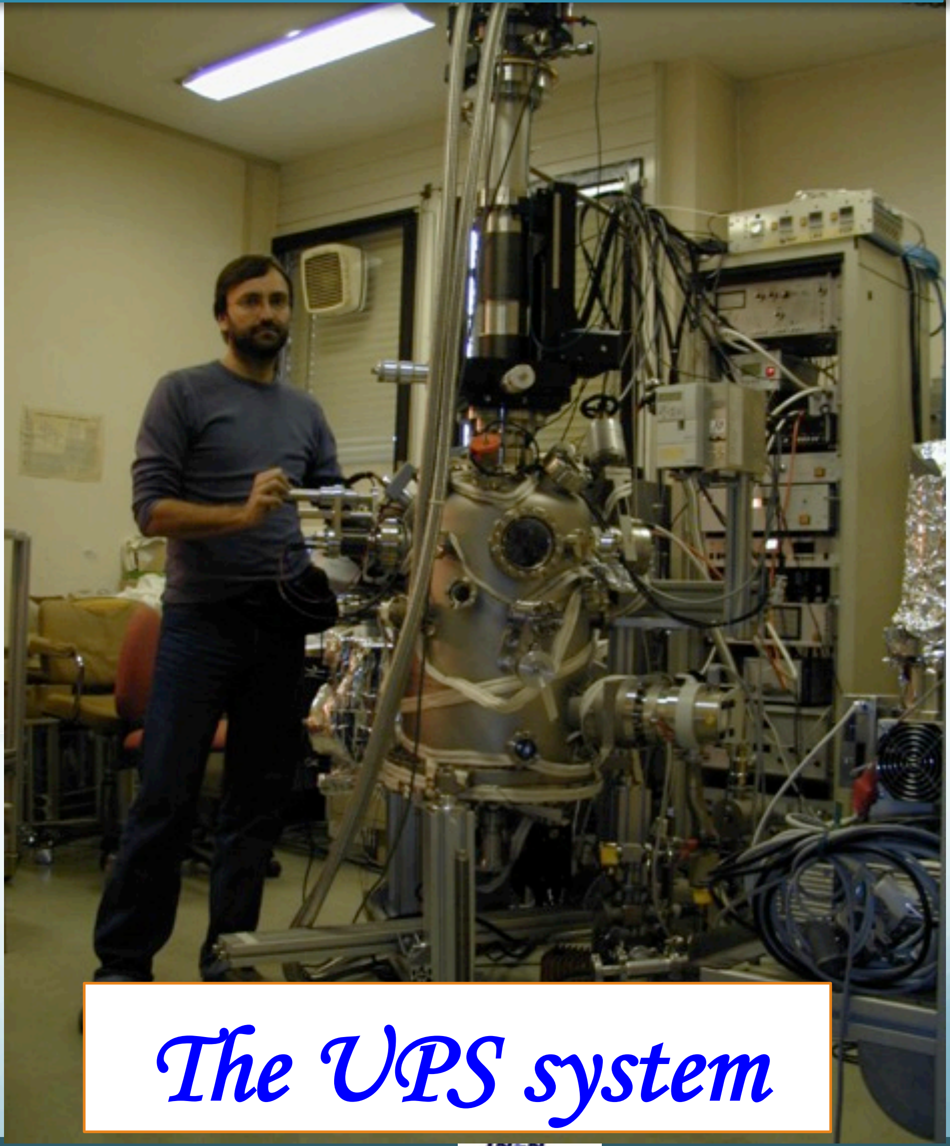
- μ-metal chamber;
- En. & angle res. analyser;
- Low T manipulator;
- LEED - Auger RFA;
- Faraday cup.
- Low energy electron gun
- Mass spectrometer
- Sample preparation
- Monocromatic high flux-high resolutionVUV Lamp



The UPS system

Activity of the LNF Material Science Laboratory

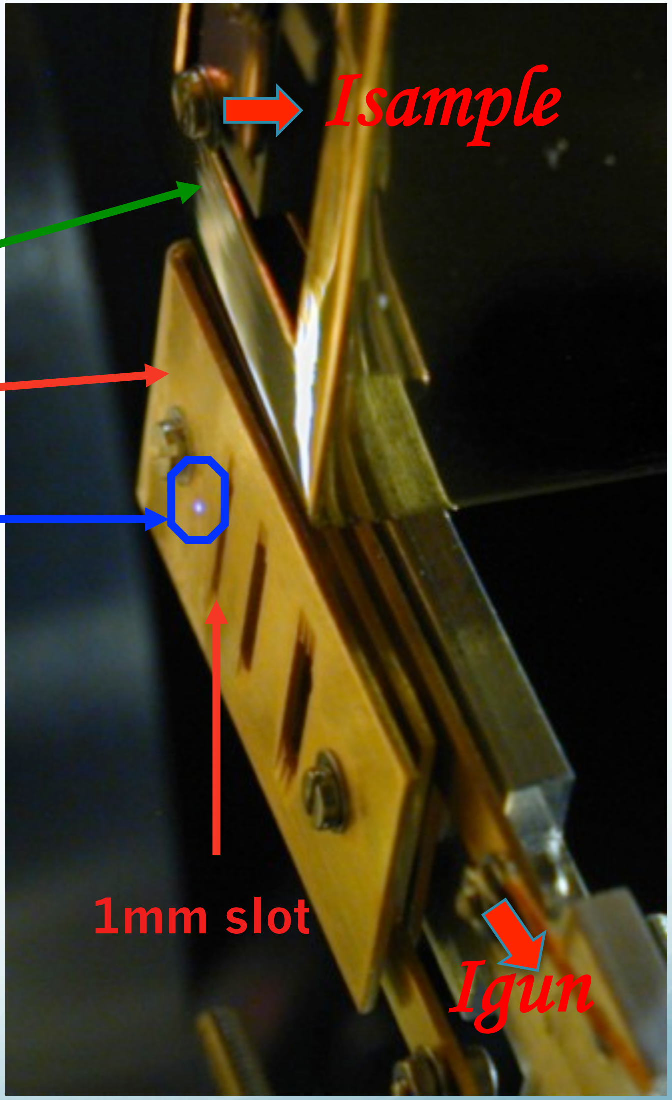
- Our Laboratory is becoming an internationally recognized reference Lab for material science analysis and tests of relevance for e-cloud studies.
- We are studying (in collaboration with international labs):
  - CERN- LHC (Dipole chamber) Cu Samples
  - CERN – SPS SS and a-C Coatings
  - Al from DAFNE and PETRA 3 (DESY)
  - Stainless Steal (from RICH, Brookhaven)
  - TiN "test" samples produced at LNF and from PEP

… and we are learning a lot!!!

Measure of Secondary e^- Yield

What we have now @ LNF:

- 2 μ-metal chamber;
- (2 different En. & angle res. analyser)
- 2 sample manipulators (1 for Low T)
- 2 LEED - Auger RFA;
- 2 Faraday cup.
- 2 Low energy electron gun
- 2 Mass spectrometer
- 2 (different) Samples preparation systems.



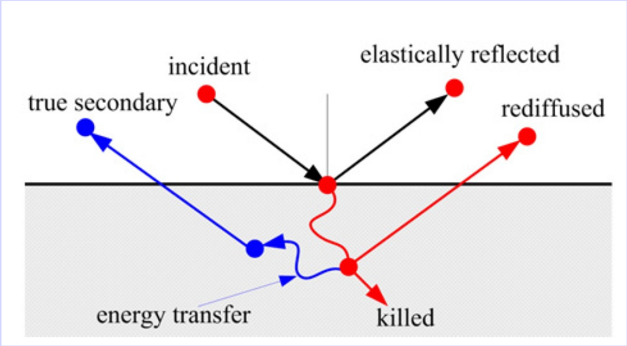
- e^- beam Stable between 30 - 500 eV
- Currents from few nA to μA (20μC/h/mm^2 - 20mC/h/mm^2)
- Intense spot (ϕ < 0.5 mm) with low background

$$SEY = \delta = \frac{I_{out}}{I_{in}} = \frac{I_{gun} - I_{sample}}{I_{gun}}$$

Measure of Secondary e^- Yield

$$SEY = \delta = \frac{Iout}{Iin} = \frac{Igun - Isample}{Igun}$$

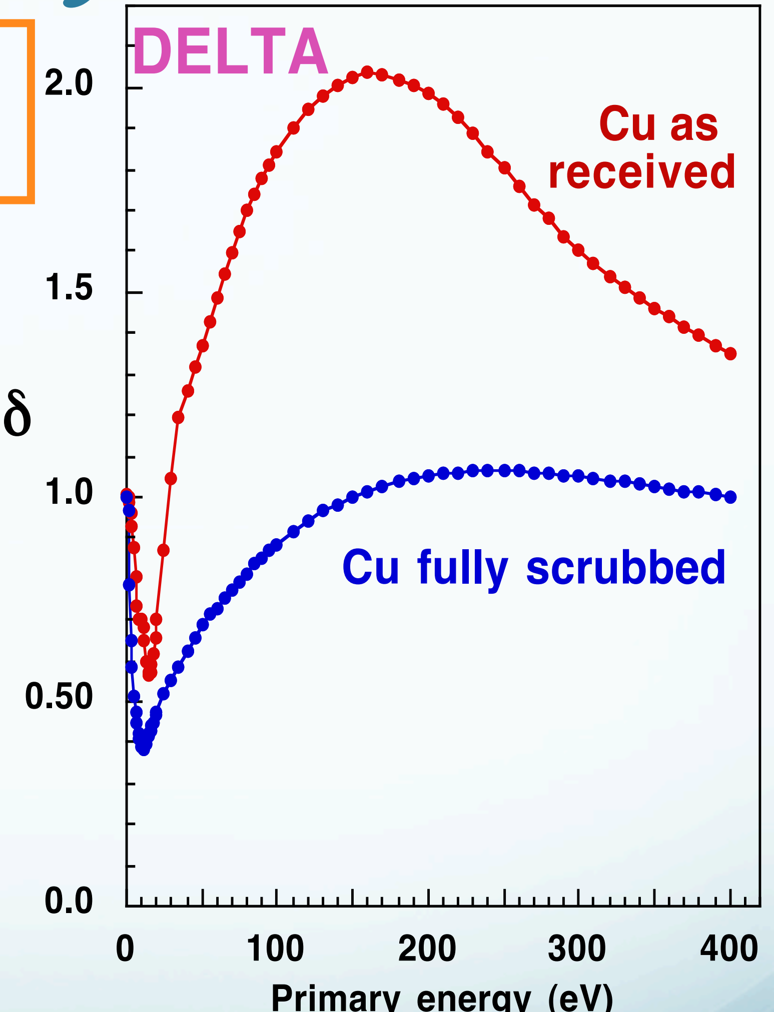
At each Primary energy we can measure Igun (with the Faraday cup) and Isample.



secondary electron emission

three-step process:

- *production of SEs at a depth z*
- *transport of the SE toward the surface*
- *emission of SE across the surface barrier*



R. Cimino et al Phys. Rev. Lett. 93, 14801 (2004).

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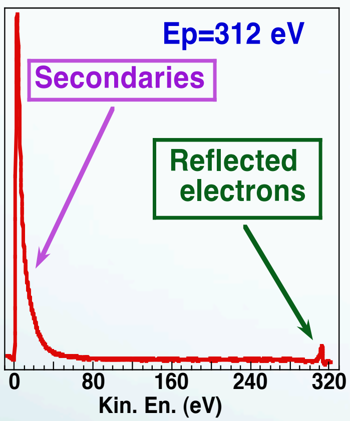
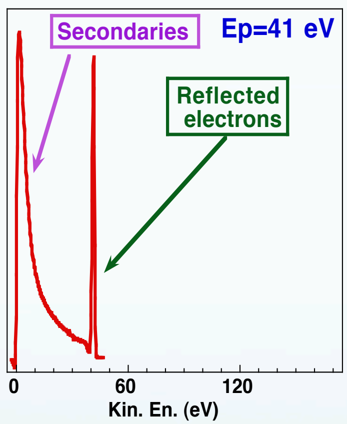
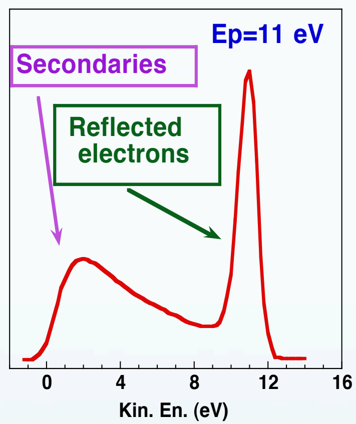
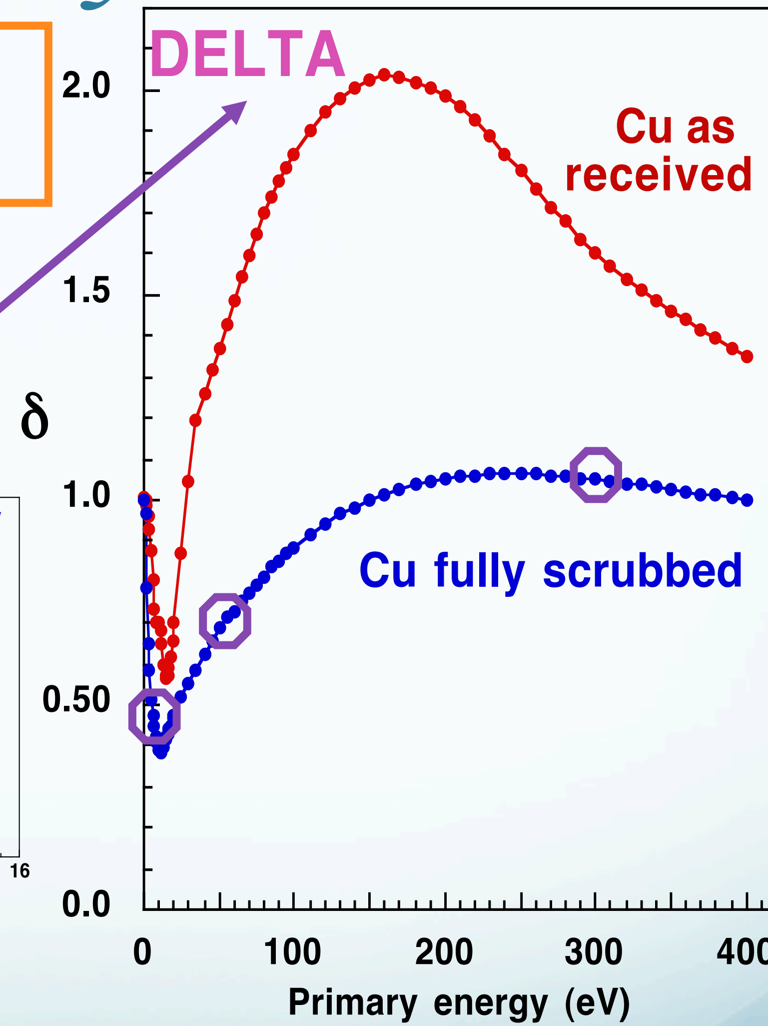






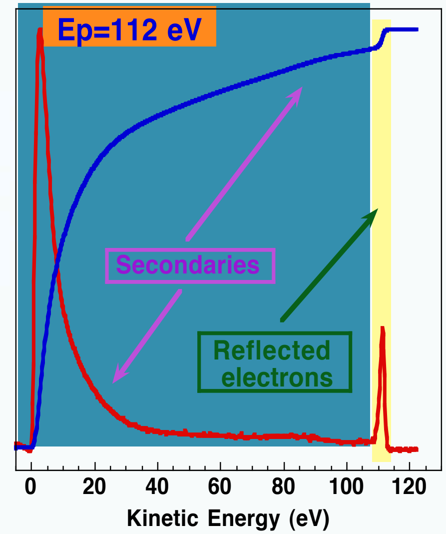


- *Each point in δ is the integral of the energy distribution of the emitted electrons*

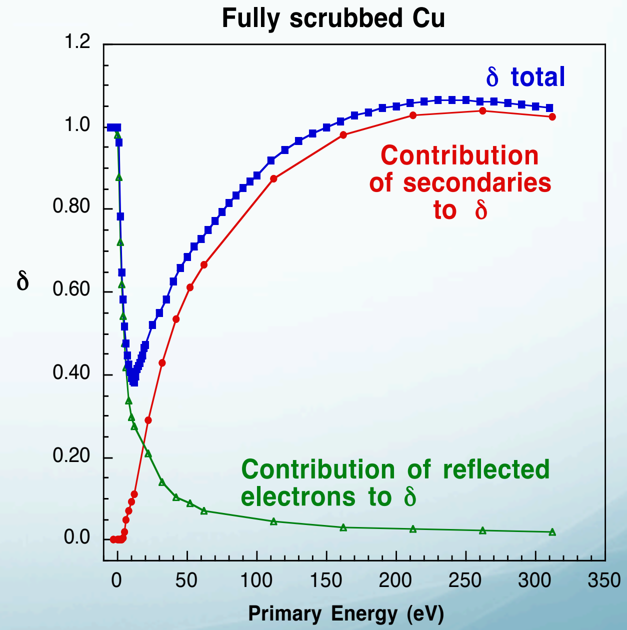
R. Cimino et al
Phys. Rev. Lett. 93, 14801 (2004).

SEY on LHC Cu @ Low energy

- Integrating the curves gives the Percentage of Secondaries and Reflected electrons
- To separate "true secondaries" from "re-diffused electrons" is arbitrary and has not been considered in this analysis.

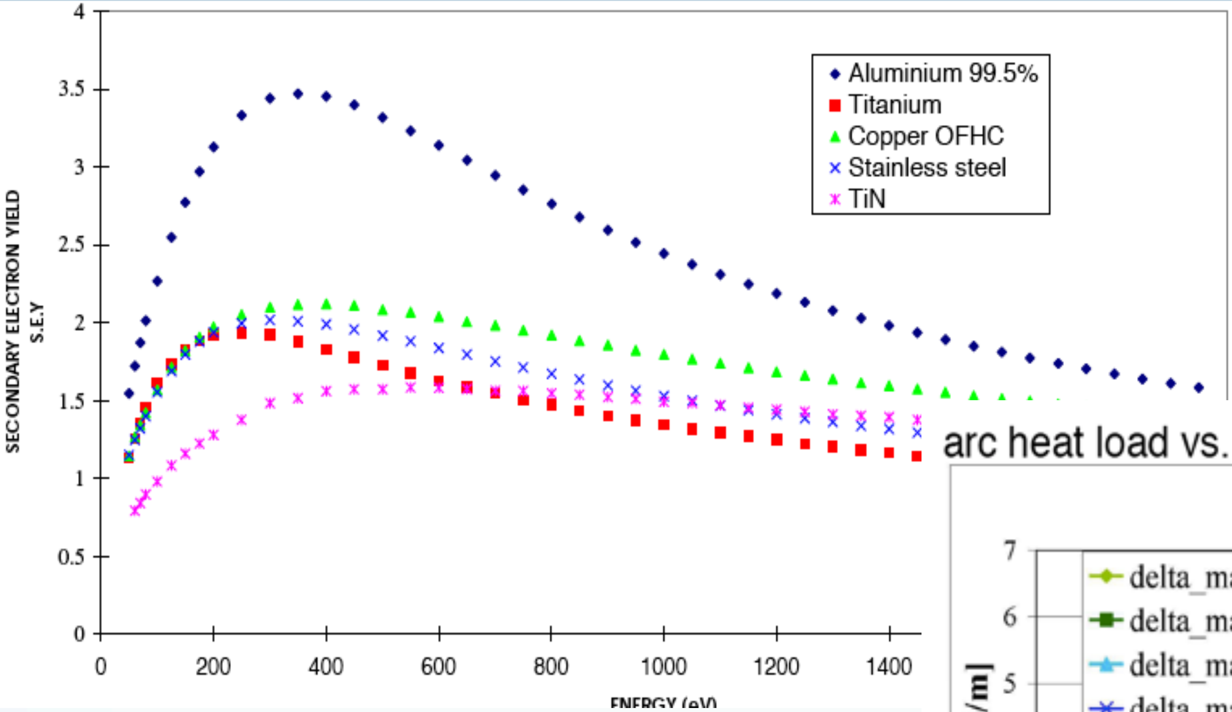


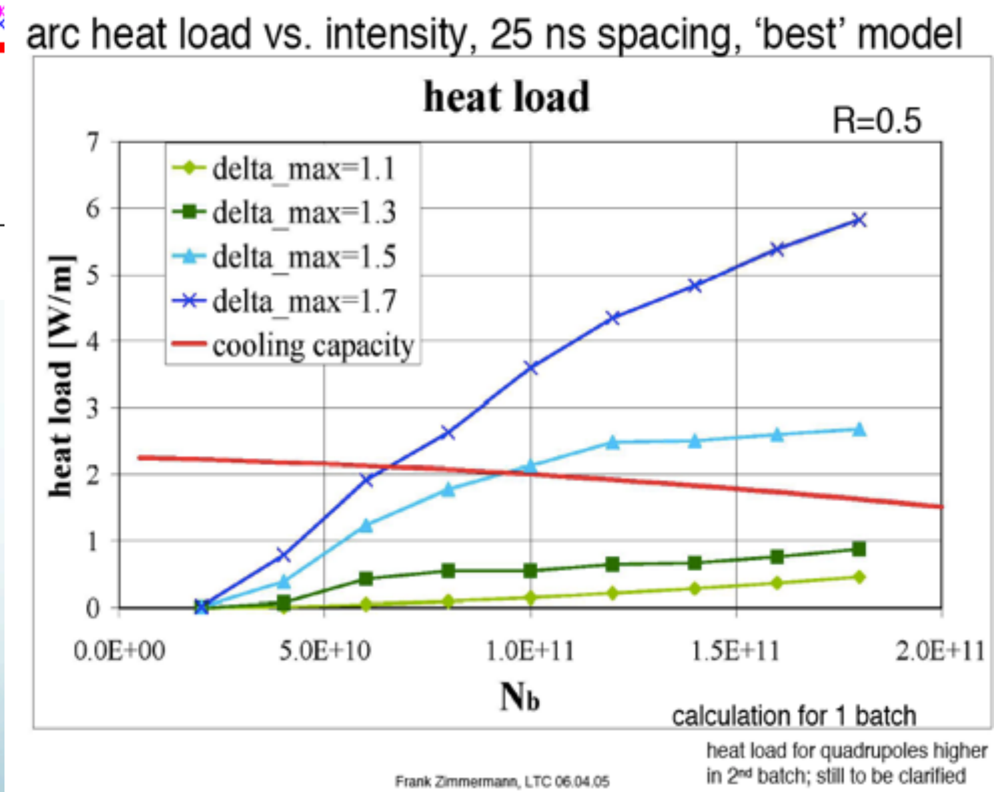
We observe that the contribution to δ of the reflected electrons at very low primary energy is, in this material, very high.



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

The Secondary e⁻ Yield depends on the surface type and condition:





…. *And has a tremendous impact to simulations (see calculation 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!

Mitigation Strategies

Surface Scrubbing (or conditioning)

Intrinsically low SEY material

Geometrical modifications

Electrodes in the lattice.

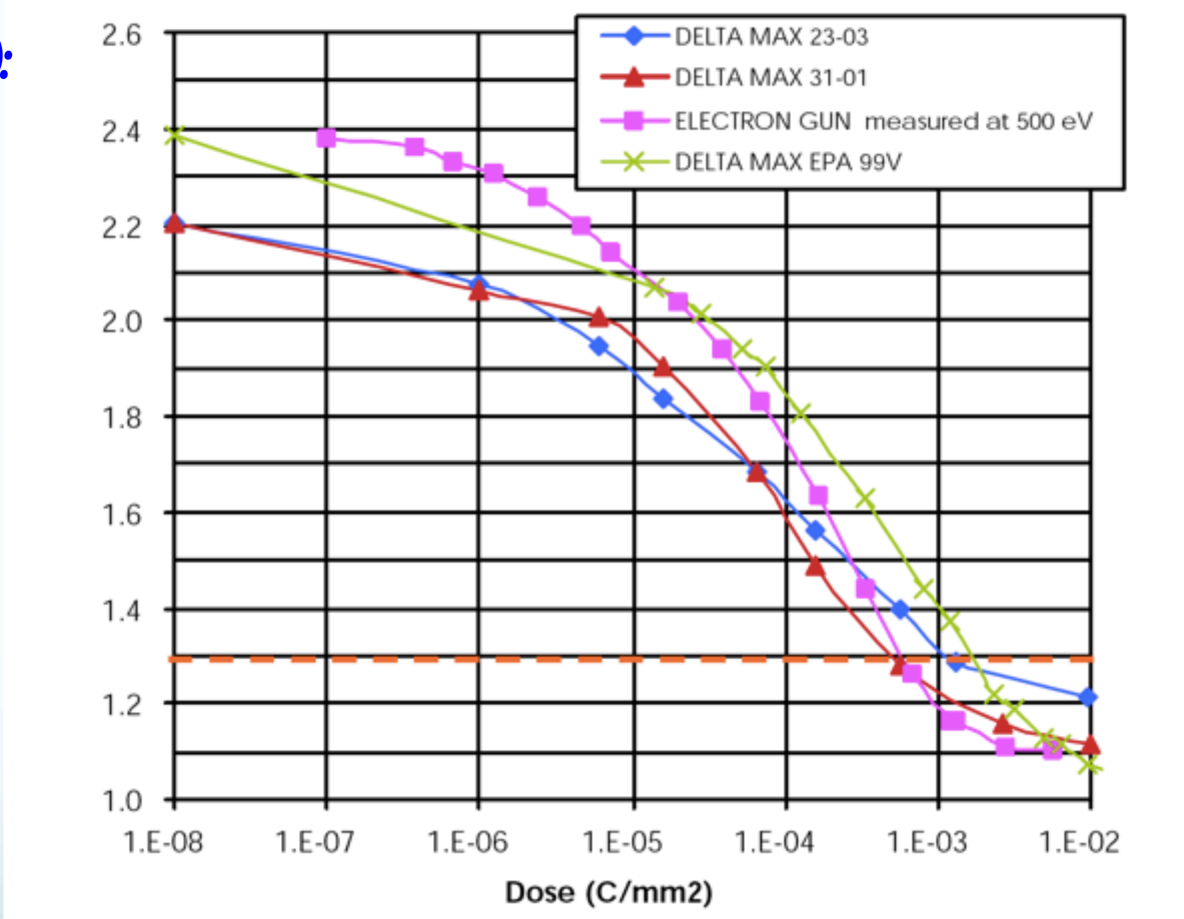
External solenoid field

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…*

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

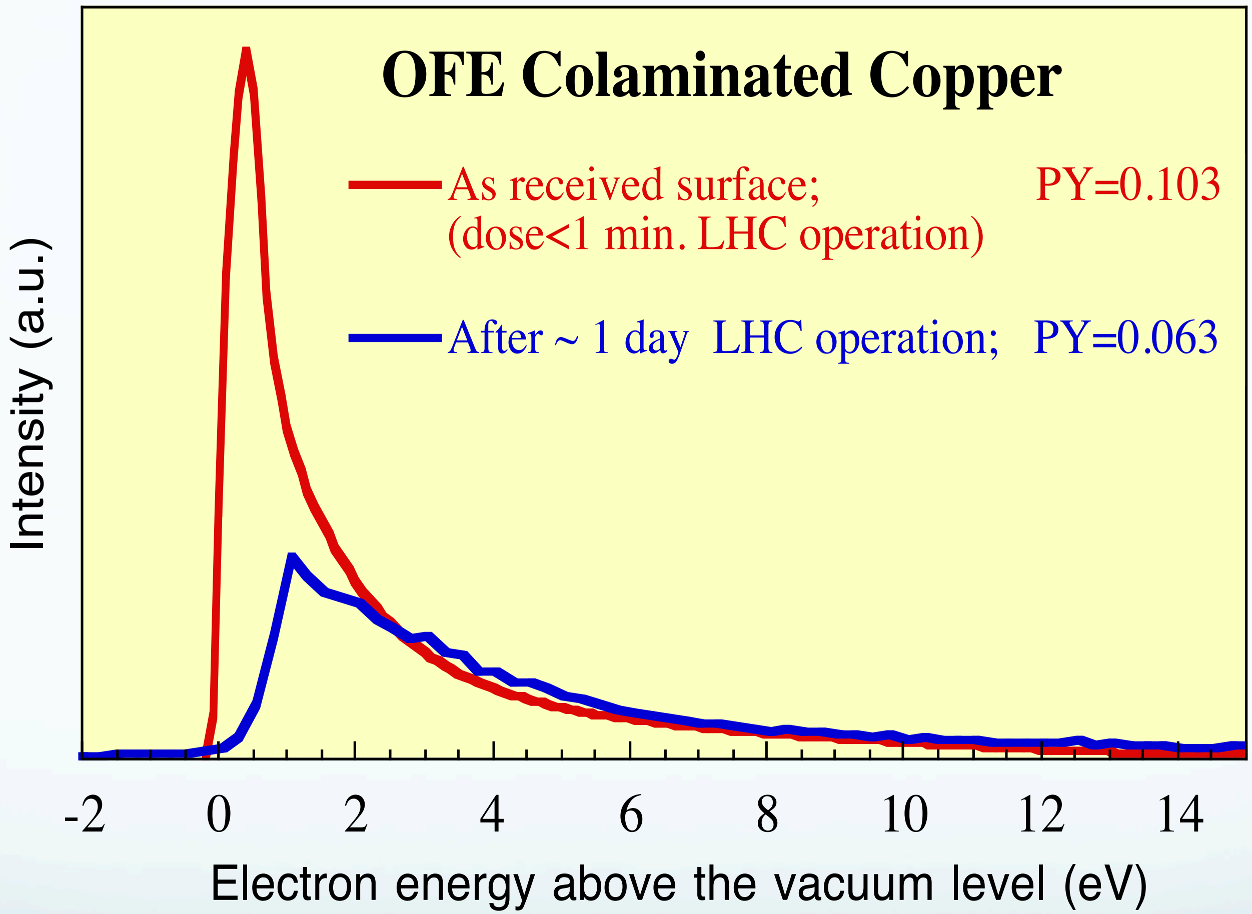
from LHC PR 472 (Aug. 2001):

"…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.

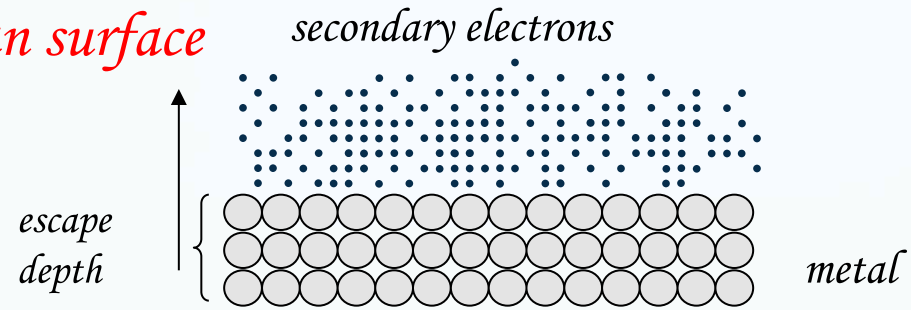
Beam scrubbing effect with photon

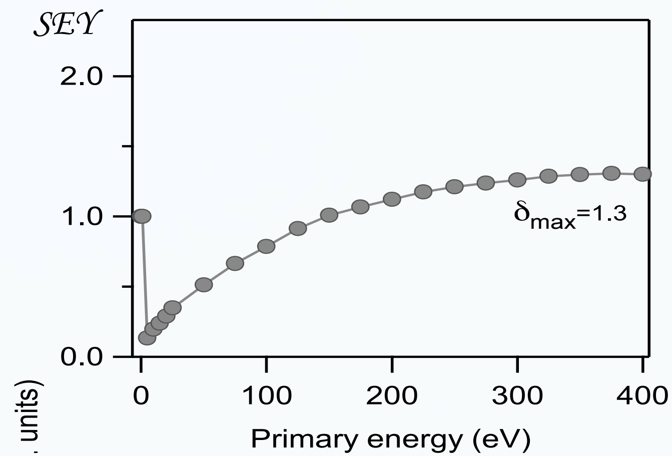


See: R. Cimino et al Phys. Rew. AB-ST 2 063201 (1999)

Study the Chemistry governing the SEY with X ray photoelectron spectroscopy

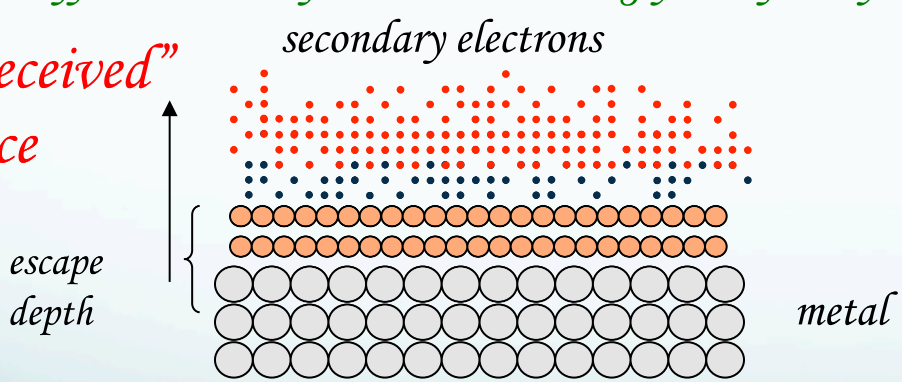
Atomically clean surface

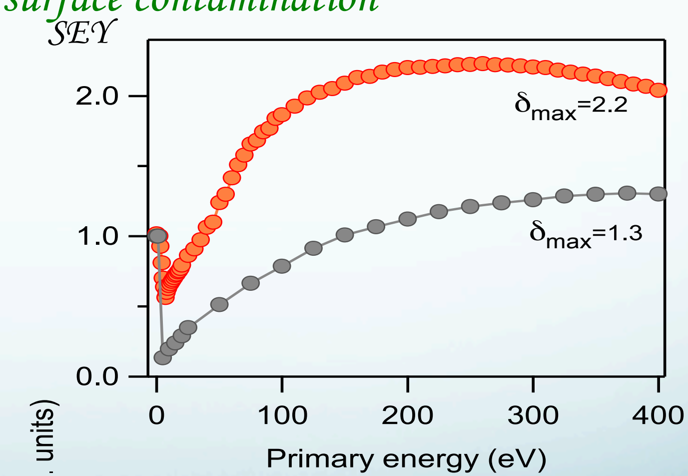




- *the effective SEY of the metal is strongly modified by the surface contamination*

"As received" surface

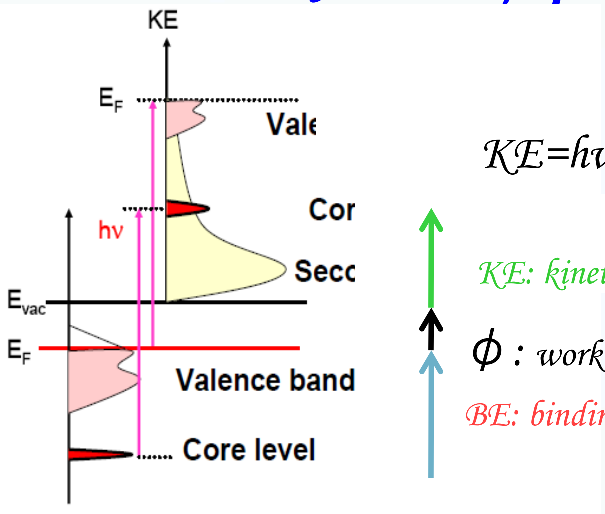




- ***SEY is very Surface sensitive and XPS is a powerful tool to study its chemistry dependence***

X-ray photoelectron spectroscopy

$\theta_{emiss}=0°$



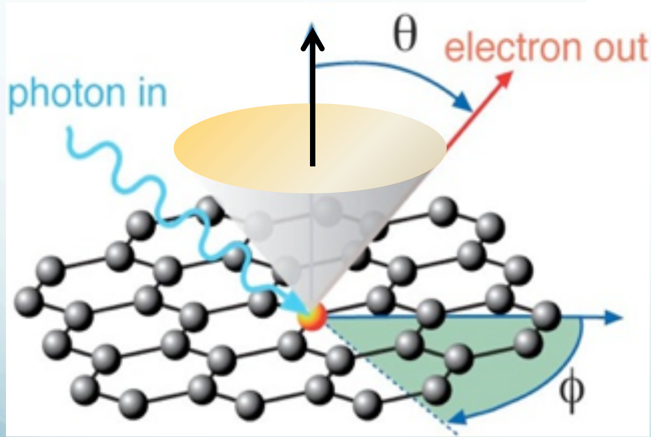
KE=hv-BE-ϕ

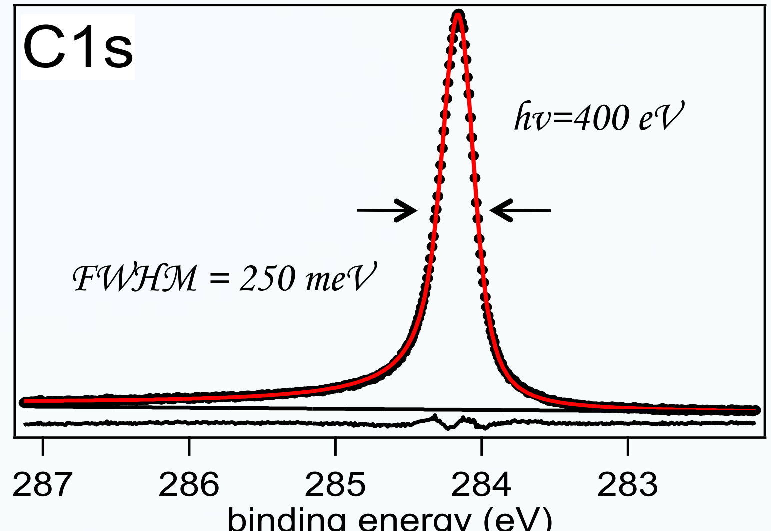
KE: kinetic energy

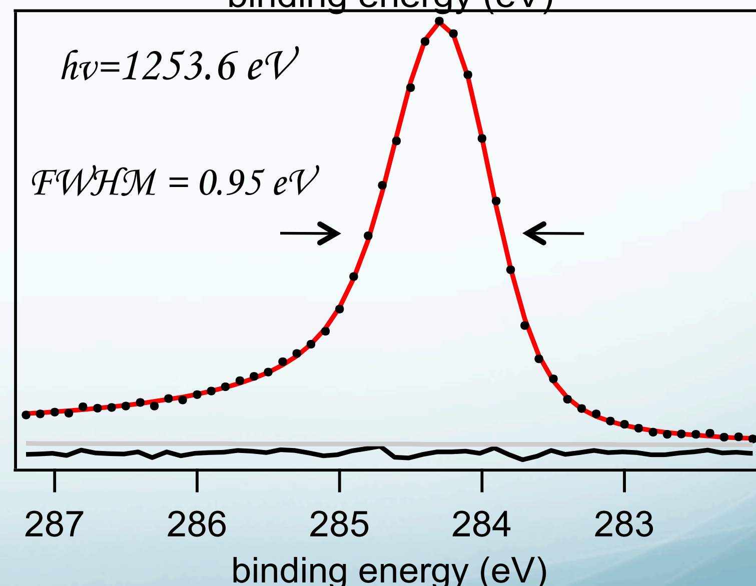
ϕ : work function

BE: binding energy

electron analyzer

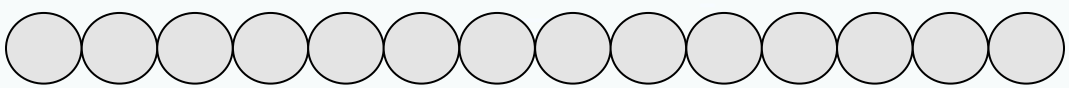


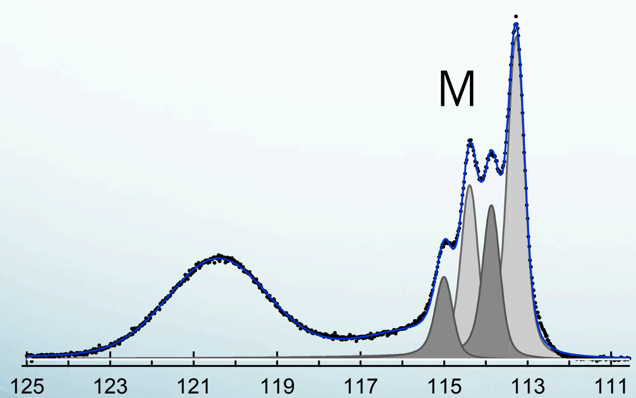




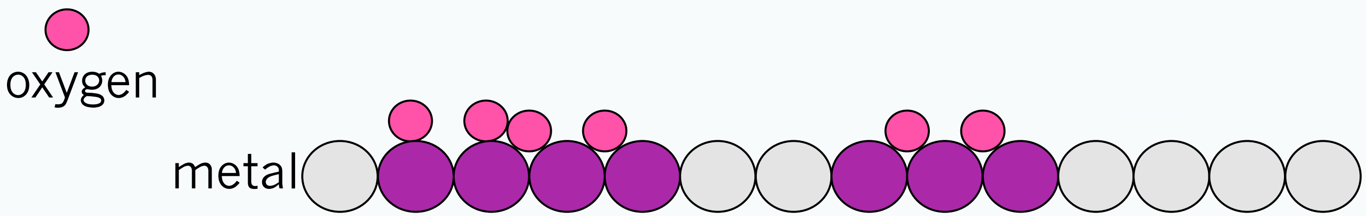
XPS spectroscopy of technical samples

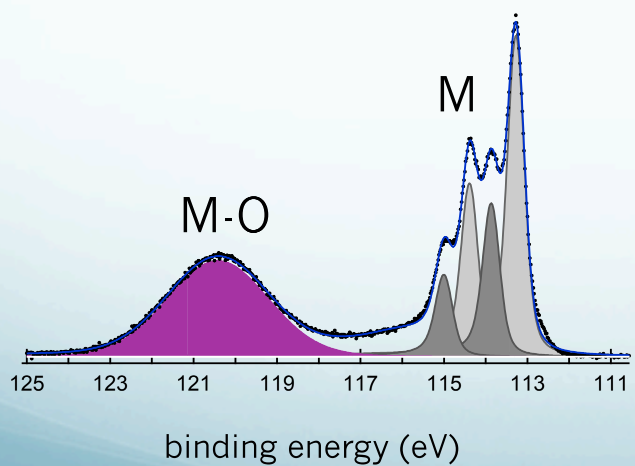
metal



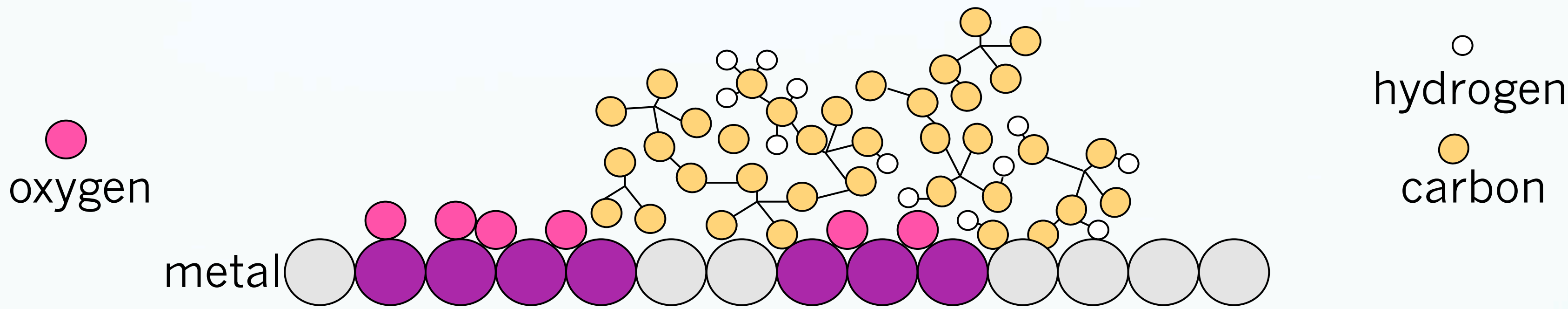


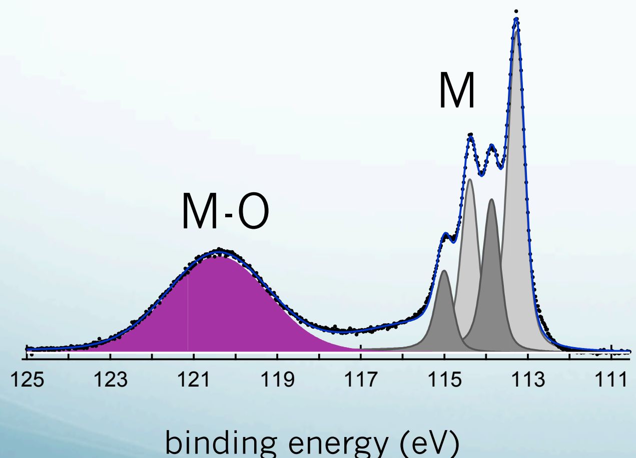
XPS spectroscopy of technical samples

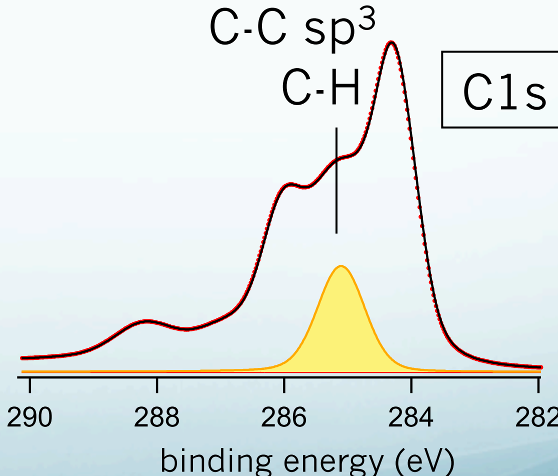




XPS spectroscopy of technical samples

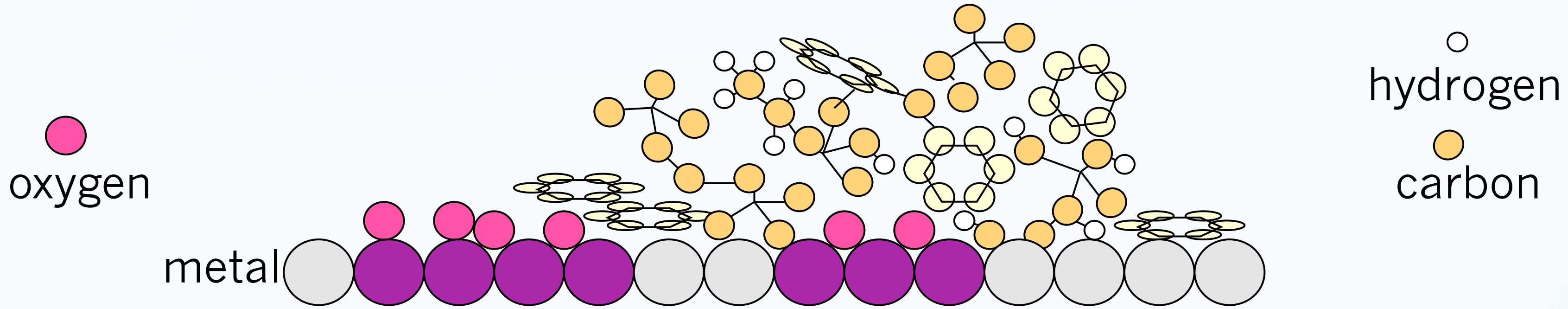


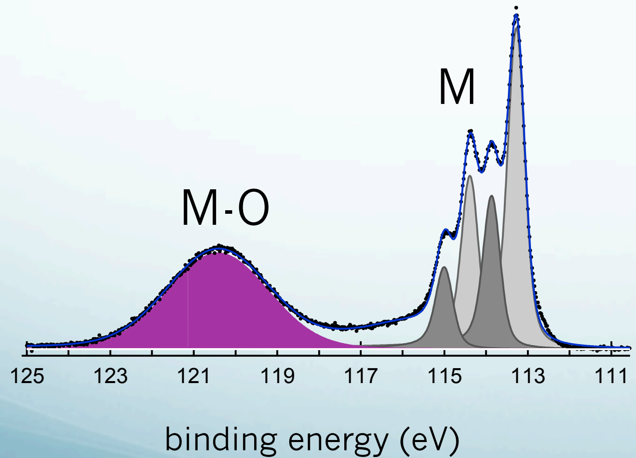


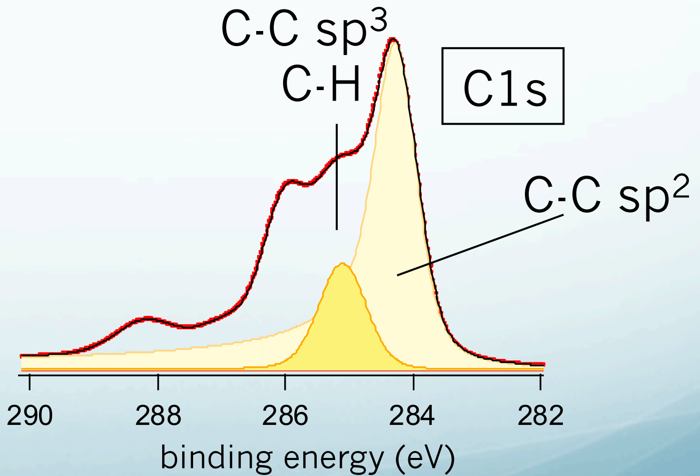


R. Cimino

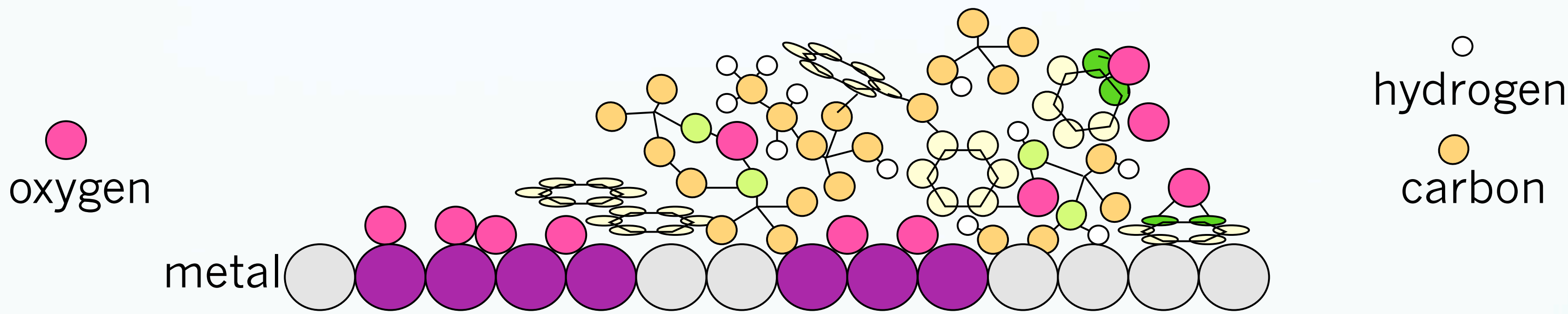
XPS spectroscopy of technical samples

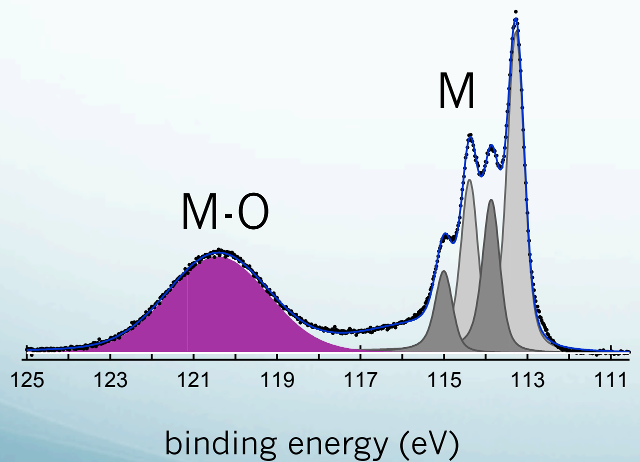


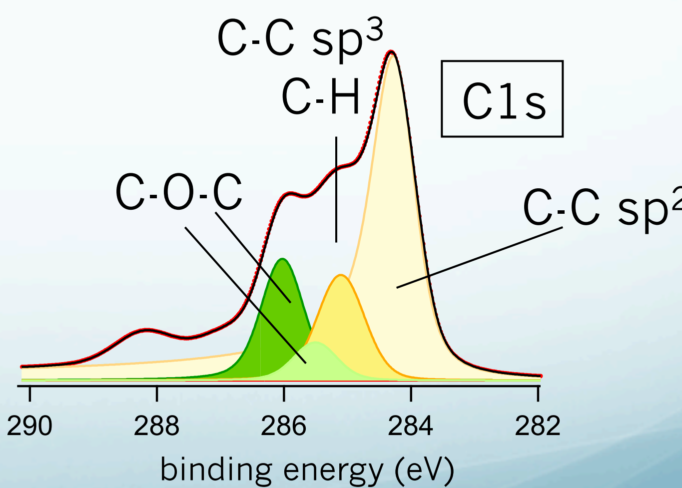




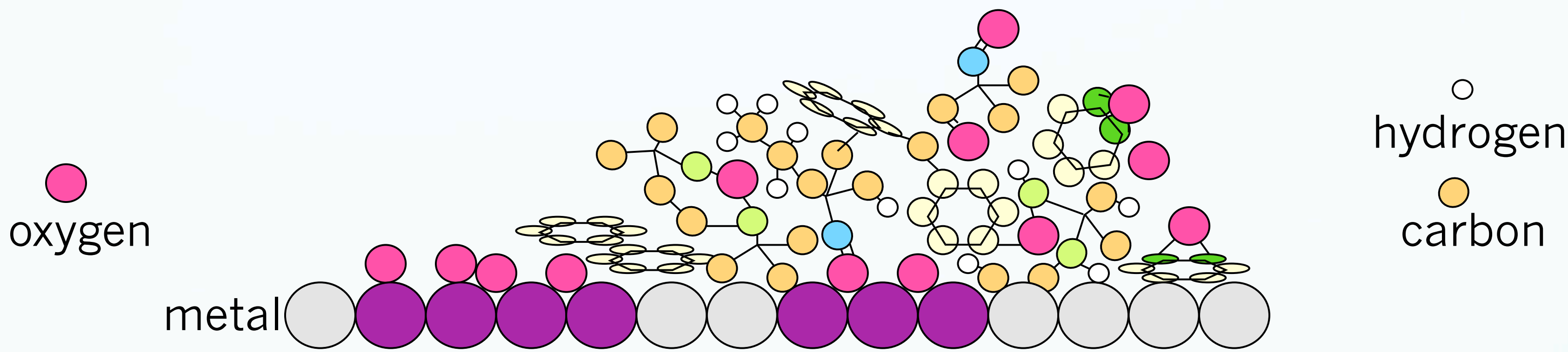
XPS spectroscopy of technical samples

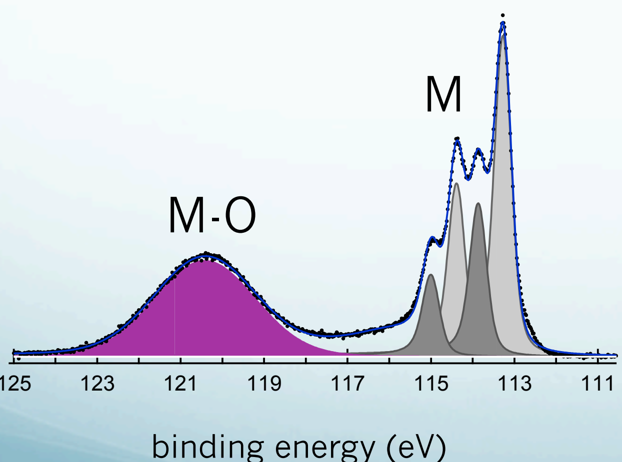


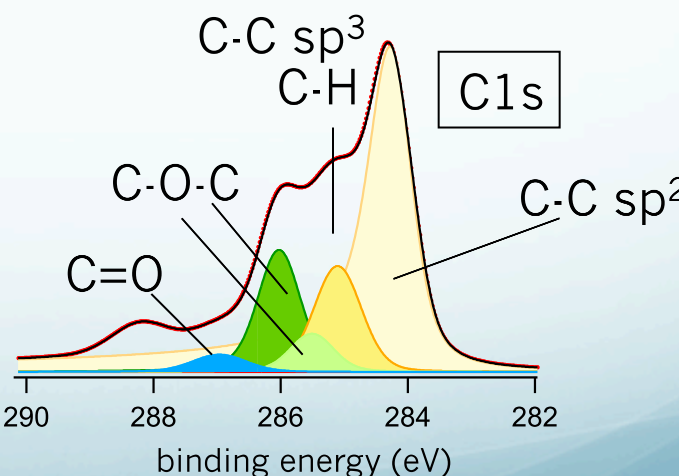




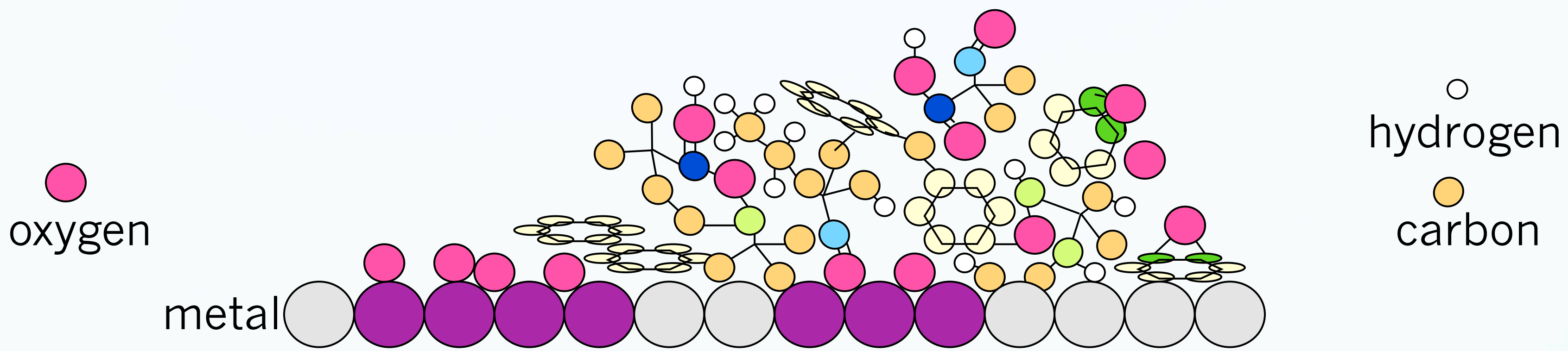
XPS spectroscopy of technical samples

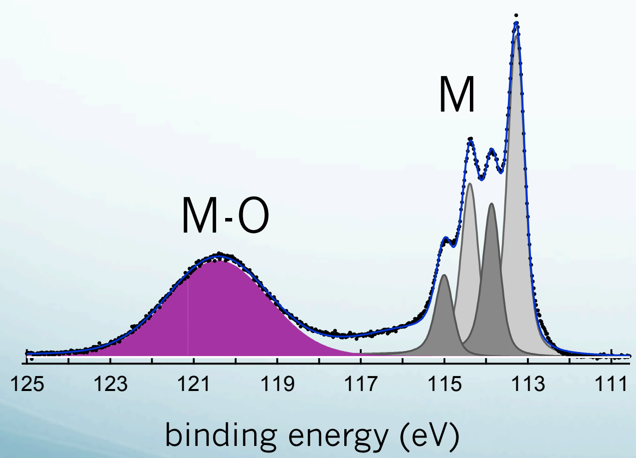


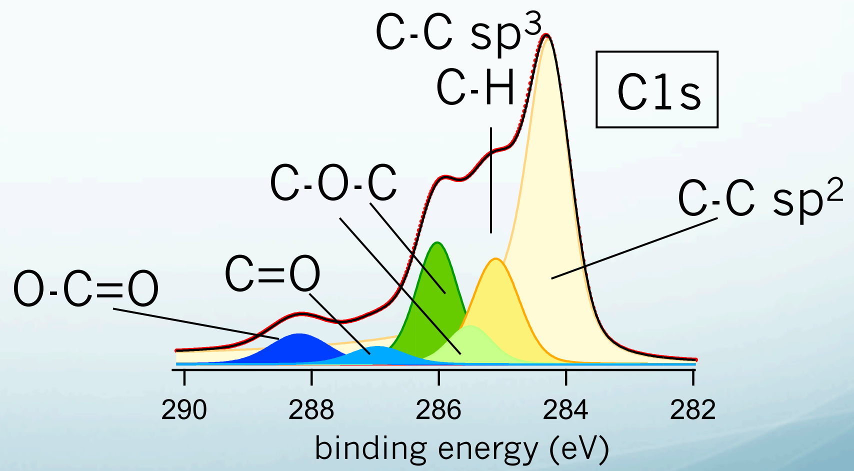




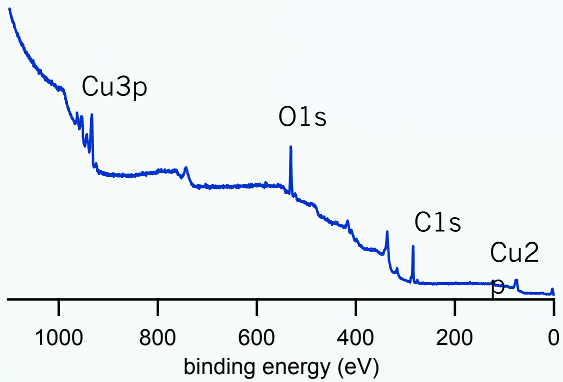
XPS spectroscopy of technical samples

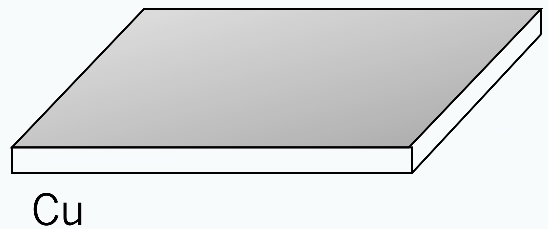


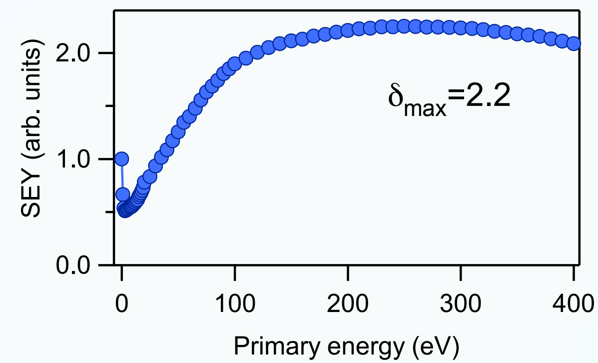




co-laminated Cu for LHC beam screen



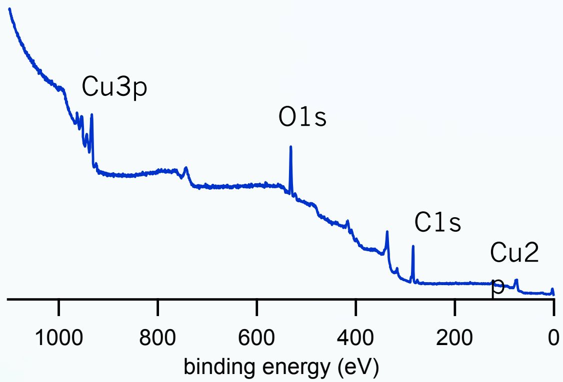


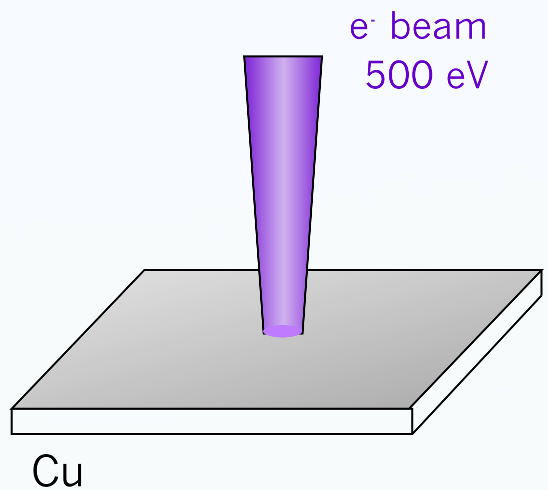


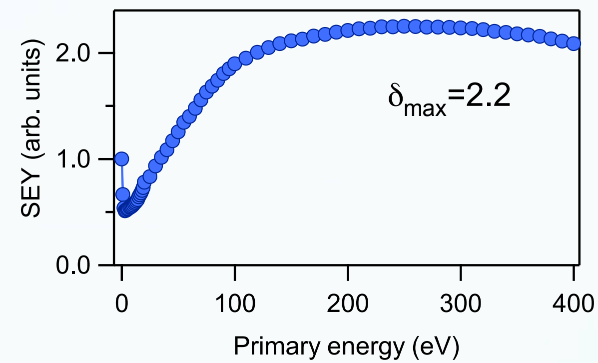
Understanding chemistry (XPS) and SEY

co-laminated Cu for LHC beam screen

R. Larciprete et al. Ecloud-12 and PRST: 16 (2013) 011002

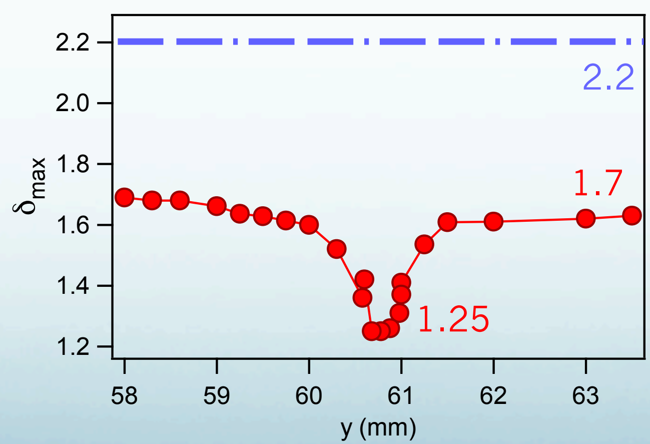






I=5μA

Q=1.2×10^{-3} C/mm^2

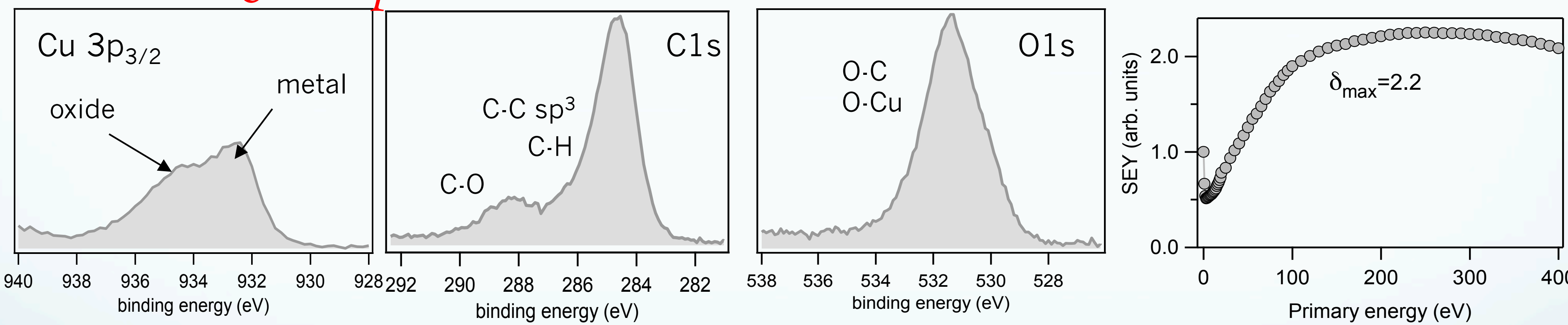


SEY decreases also outside the beam spot

co-laminated Cu for LHC beam screen

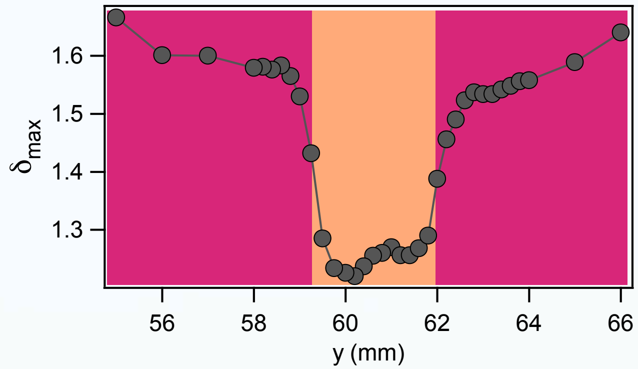
R. Larciprete et al. Ecloud-12 and PR ST: 16 (2013) 011002

as received Cu sample



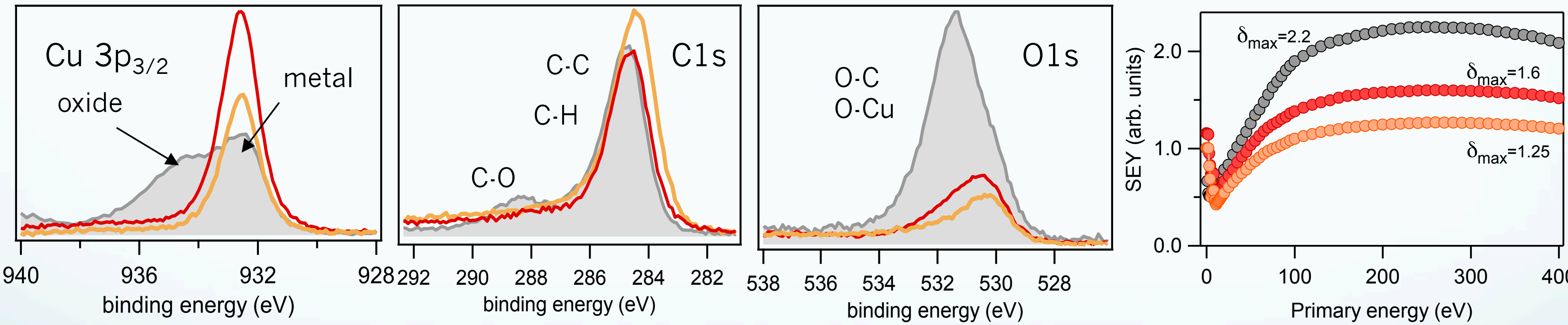
co-laminated Cu for LHC beam screen

R. Larciprete et al. Ecloud-12 and PR ST: 16 (2013) 011002



E=500 eV
I=5μA

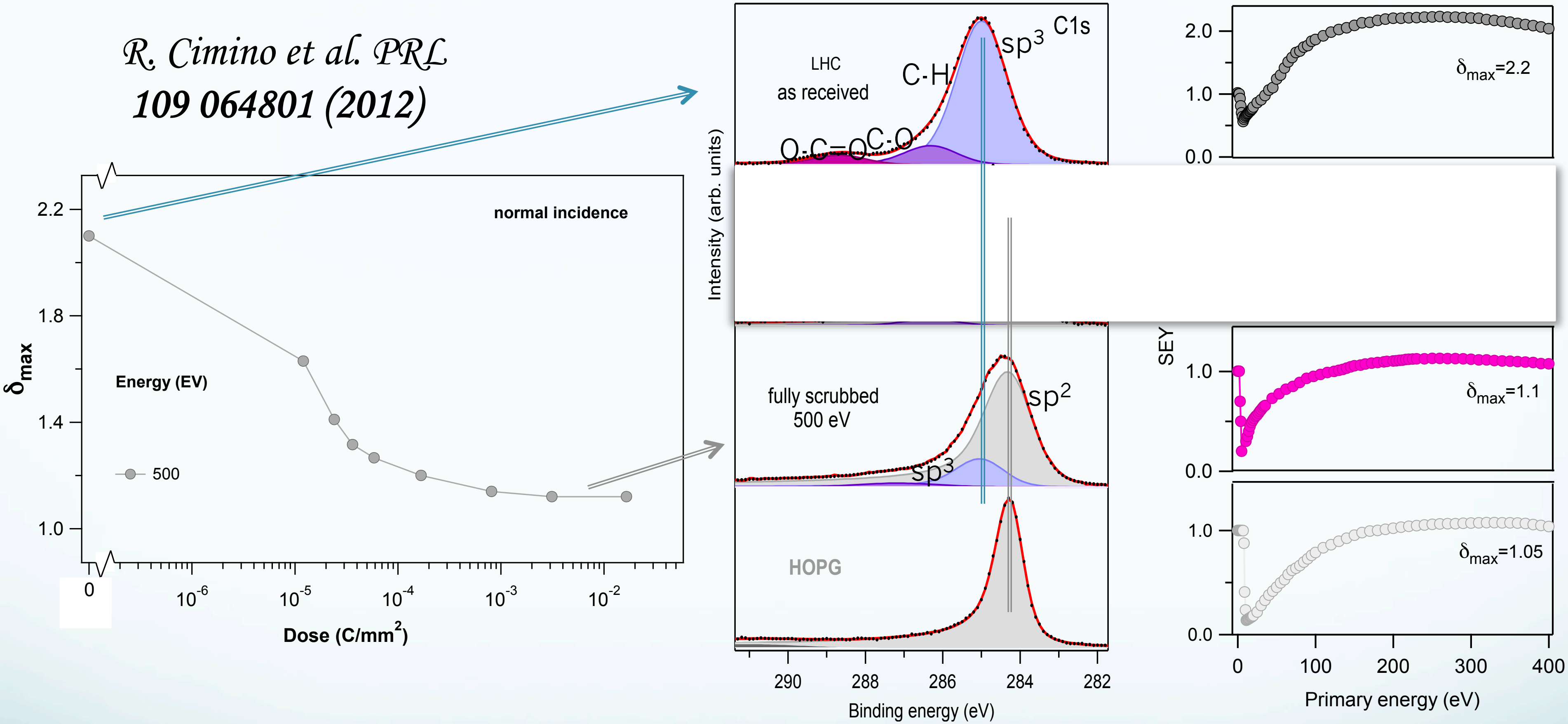
Q=1.2x10^{-3} C/mm^2



- the beam spot but also the surrounding area is modified
- in the beam spot the quantity of surface C increases → graphitic film growth

co-laminated Cu for LHC: fully scrubbed

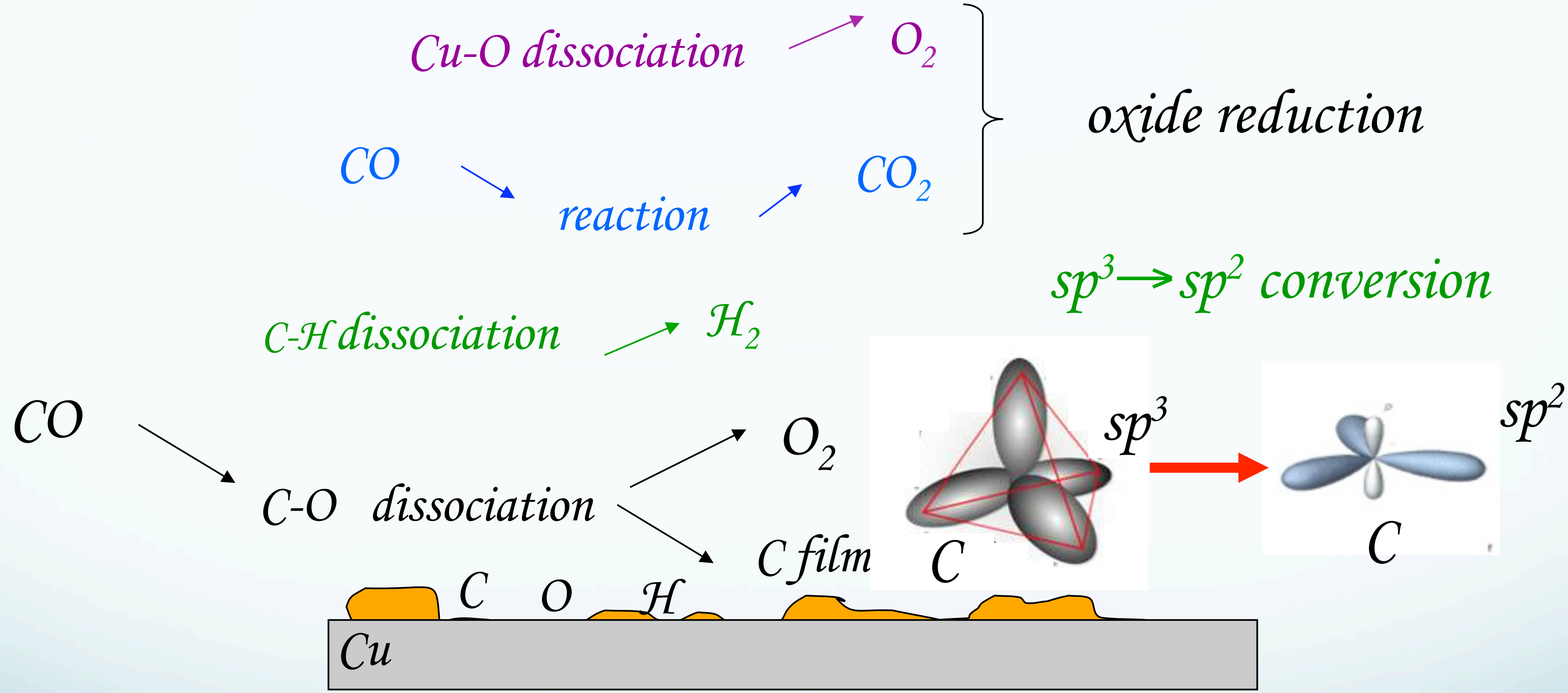
R. Cimino et al. PRL
109 064801 (2012)



SEY and XPS are directly related

e^- beam induced surface reactions

R. Larciprete et al. Ecloud-12 and PR ST: 16 (2013) 011002



the contribution of all electron-induced surface reactions reduces δ_{max} from 2.2 to 1.1

- The chemical origin of the scrubbing is now clear: it is due to the Electron induced surface graphitization!
- It occurs (with small differences) for many technical surface like Cu, SS, TiN etc. (noticeably not for Al)
- BUT: it is a phenomenon which intrinsically need energy to occur: do all electrons induce it?

PRL 109, 064801 (2012) PHYSICAL REVIEW LETTERS week ending 10 AUGUST 2012

Nature of the Decrease of the Secondary-Electron Yield by Electron Bombardment and its Energy Dependence

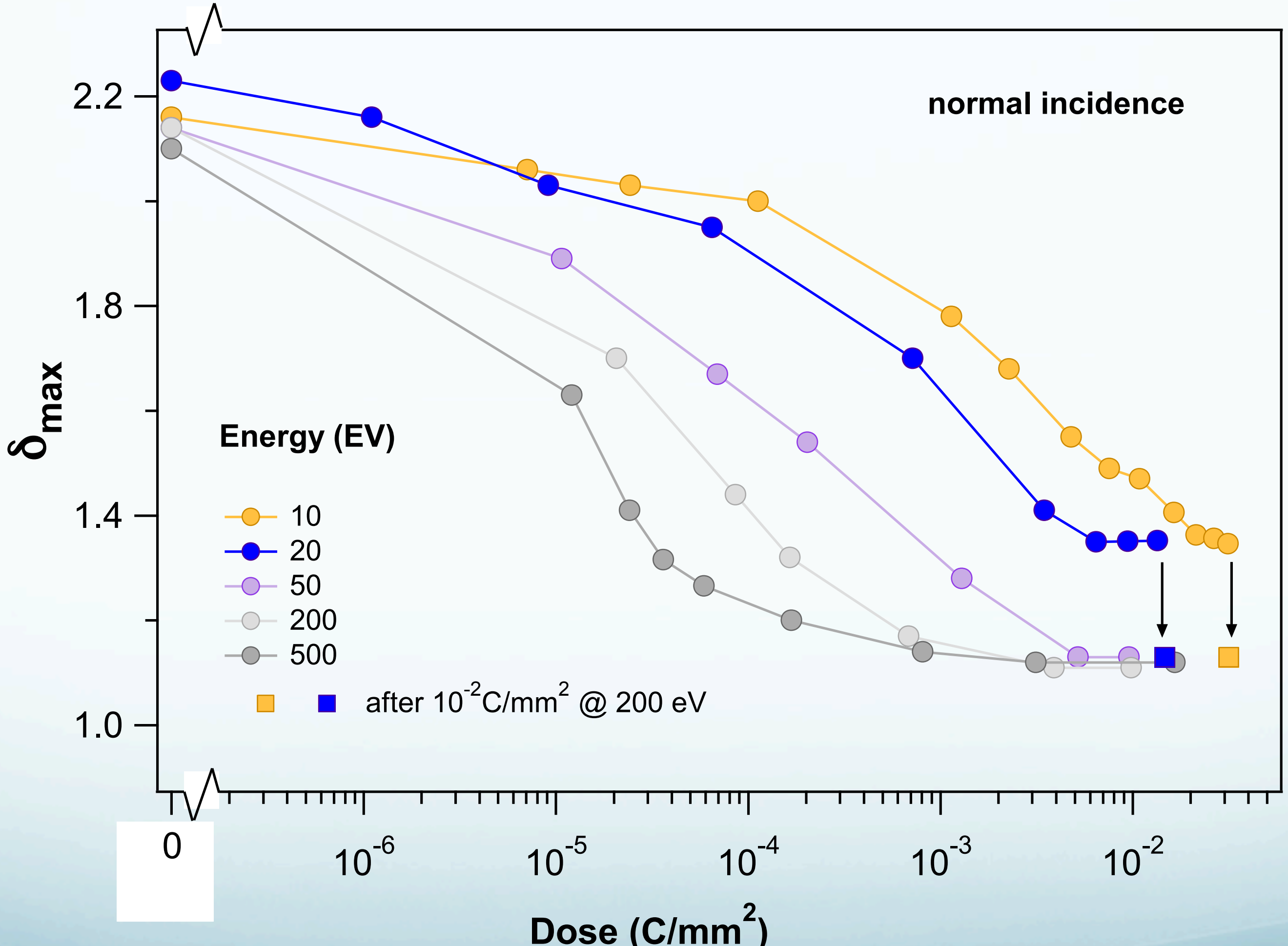
R. Cimino,[1] M. Commisso,[1] D. R. Grosso,[1] T. Demma,[2] V. Baglin,[3] R. Flammini,[1,4] and R. Larciprete[1,5]
[1]LNF-INFN, Via E. Fermi 40, 00044 Frascati (Roma), Italy
[2]Laboratoire de l'Accélérateur Linéaire, CNRS-IN2P3, Université Paris-Sud 11, Orsay, France
[3]CERN, Geneva, Switzerland
[4]CNR-IMIP Istituto Metodologie Inorganiche e Plasmi, Via Salaria Km. 29.300, 00019 Monterotondo Scalo (RM), Italy
[5]CNR-ISC Istituto dei Sistemi Complessi, Via Fosso del Cavaliere 100, 00133 Roma, Italy
(Received 26 April 2012; published 10 August 2012)

We performed a combined secondary electron yield (SEY) and x-ray photoelectron spectroscopy study as a function of the electron dose and energy on a Cu technical surface representative of the LHC accelerator walls. The electron bombardment is accompanied by a clear chemical modification, indicating an increased graphitization as the SEY decreases. The decrease in the SEY is also found to depend significantly on the kinetic energy of the primary electrons. When low-energy primary electrons are employed ($E \leq 20$ eV), the reduction of the SEY is slower and smaller in magnitude than when higher-energy electrons are used. Consequences of this observation are discussed mainly for their relevance on the commissioning scenario for the LHC in operation at CERN (Geneva), but are expected to be of interest for other research fields.

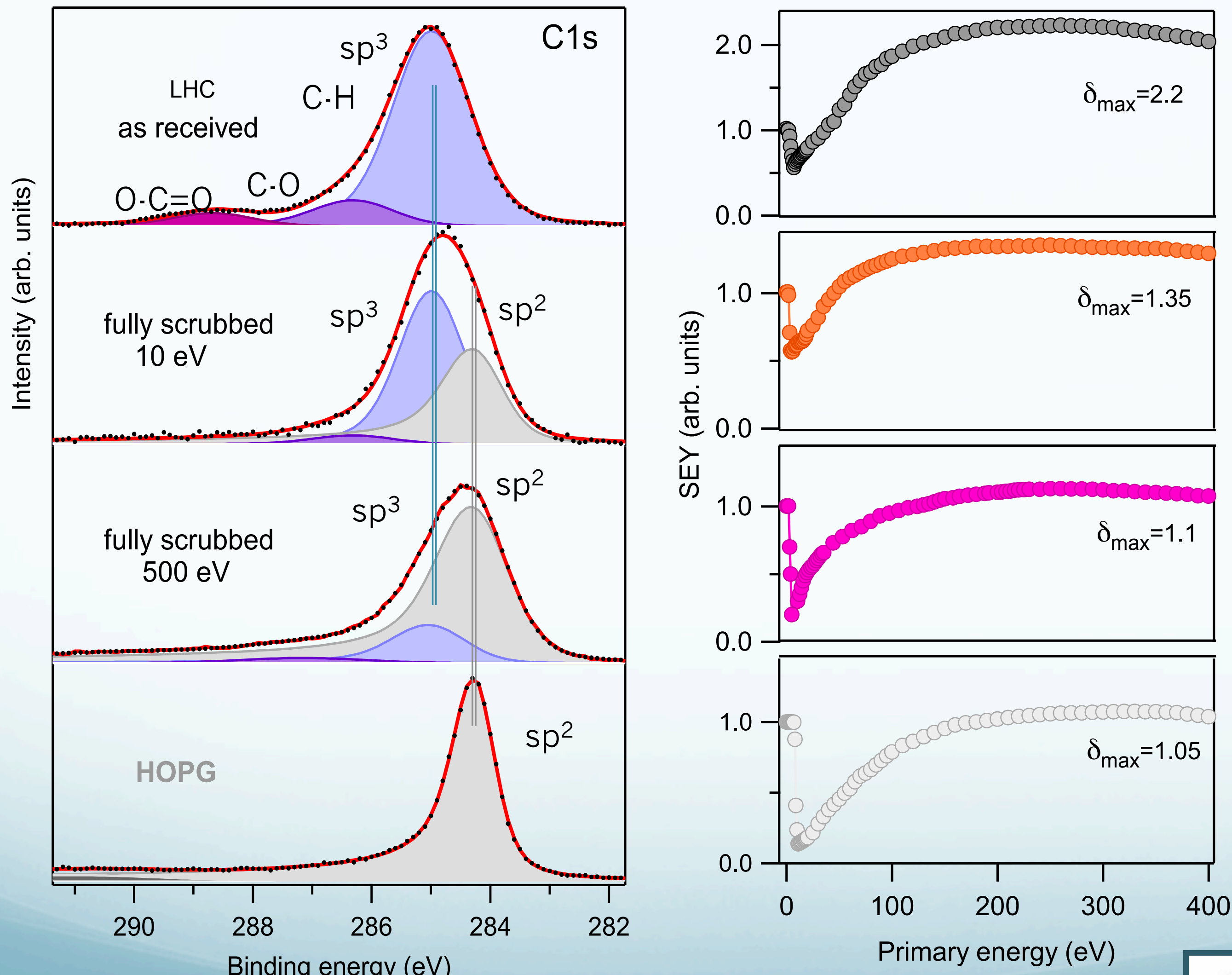
DOI: 10.1103/PhysRevLett.109.064801 PACS numbers: 29.20.−c, 79.20.Hx, 07.30.−t, 29.27.Bd

co-laminated Cu for LHC beam screen

R. Cimino et al. PRL ***109 064801 (2012)***



co-laminated Cu for LHC beam screen



R. Cimino et al. PRL
109 064801 (2012)

Theo Demma (LAL) simulation :

R. Cimino et al. PRL **109 064801 (2012)**

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	-	$7.98 \cdot 10^{-4}$
maximum SEY δ_{max}	-	1.2(0.2)2.0
energy for max. SEY E_{max}	eV	237

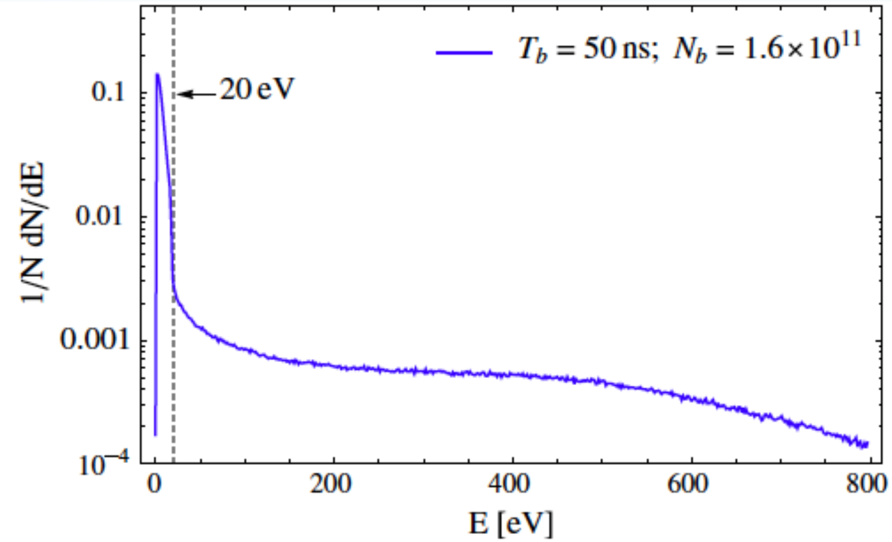
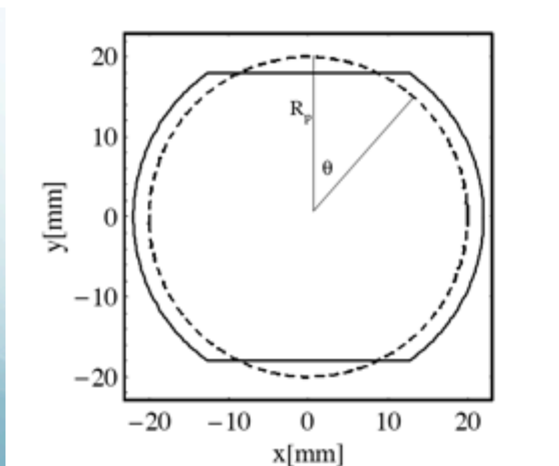


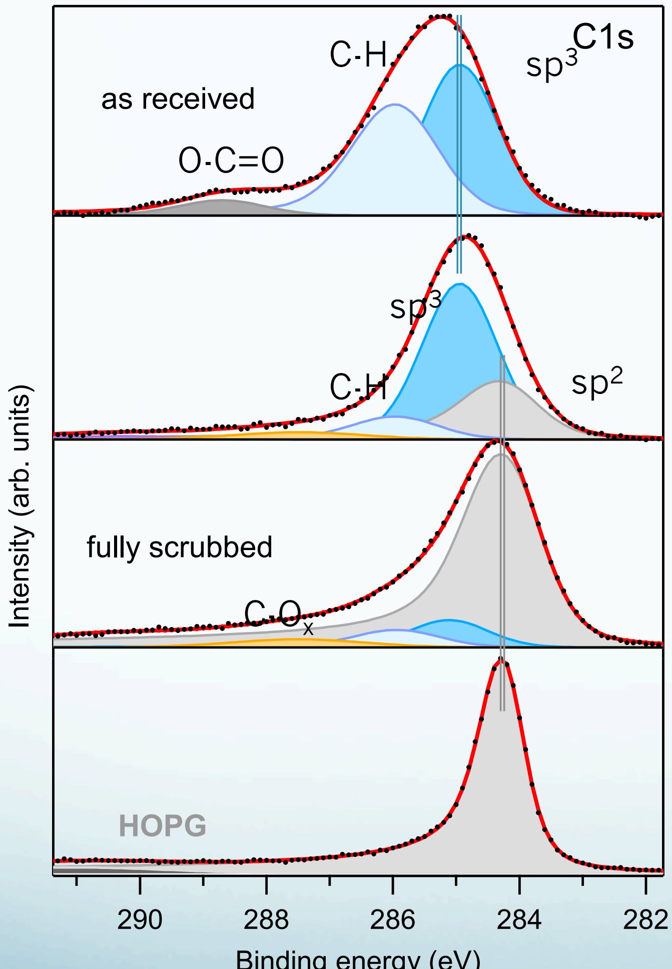
FIG. 3 (color online). Calculated electron energy distribution at the LHC accelerator wall. The number of electrons below and above 20 eV (dotted line) is nearly equal.

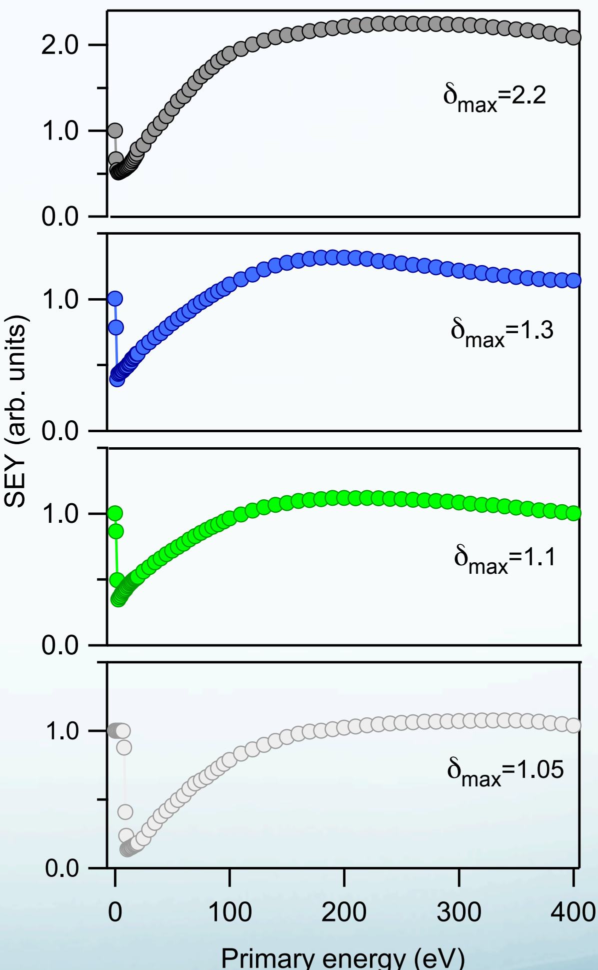


- *optimize the "scrubbing" process @ LHC with beam parameters enhancing the presence, in the cloud, of higher energy el.*
- *Give a more reliable estimate of the needed scrubbing time.*

Similar results for Stainless steel samples from RICH@BNL

E=500 eV



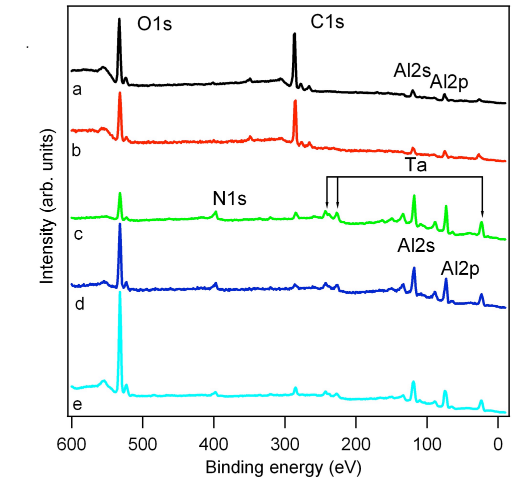


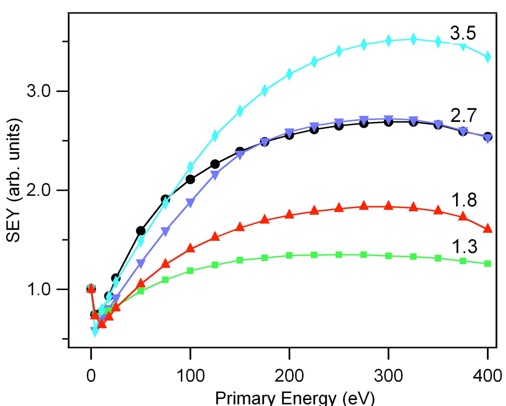
R. Cimino et al to be published

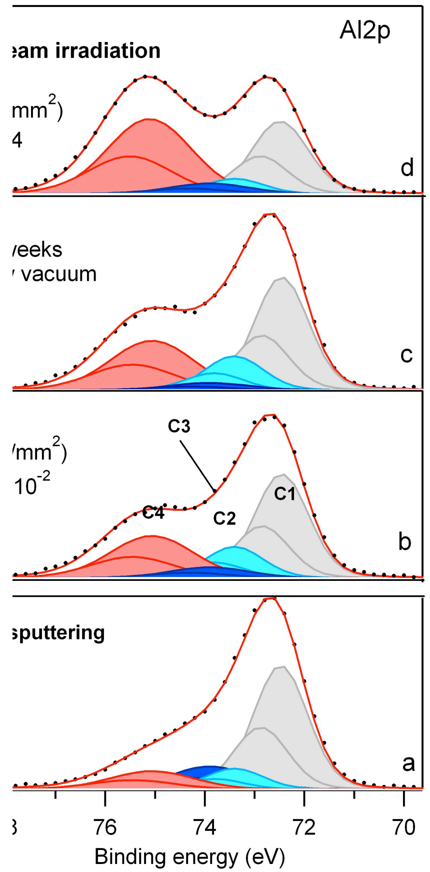
… BUT not for Al (from Petra III)

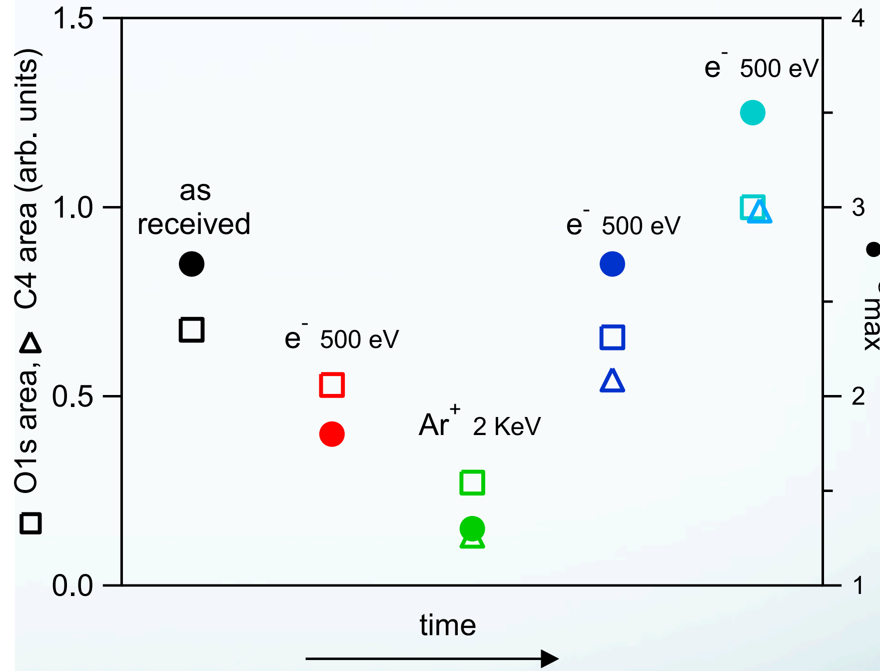
dipole chamber of Petra III at DESY

D. Grosso et al. submitted to PR-ST





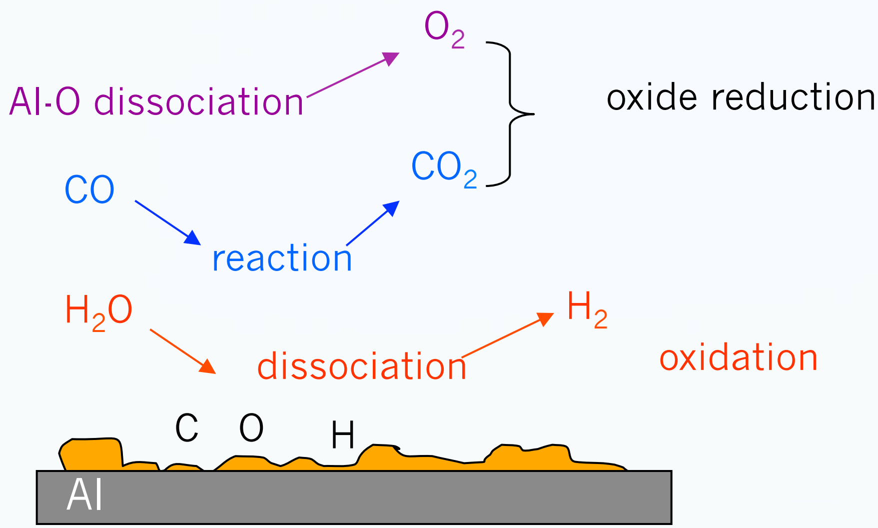




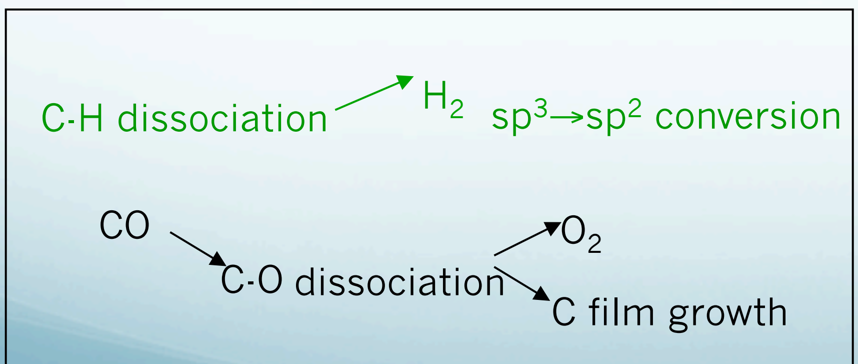
On Al: dramatic enhancement exclusively of the most oxidized Al_2O_3 phase

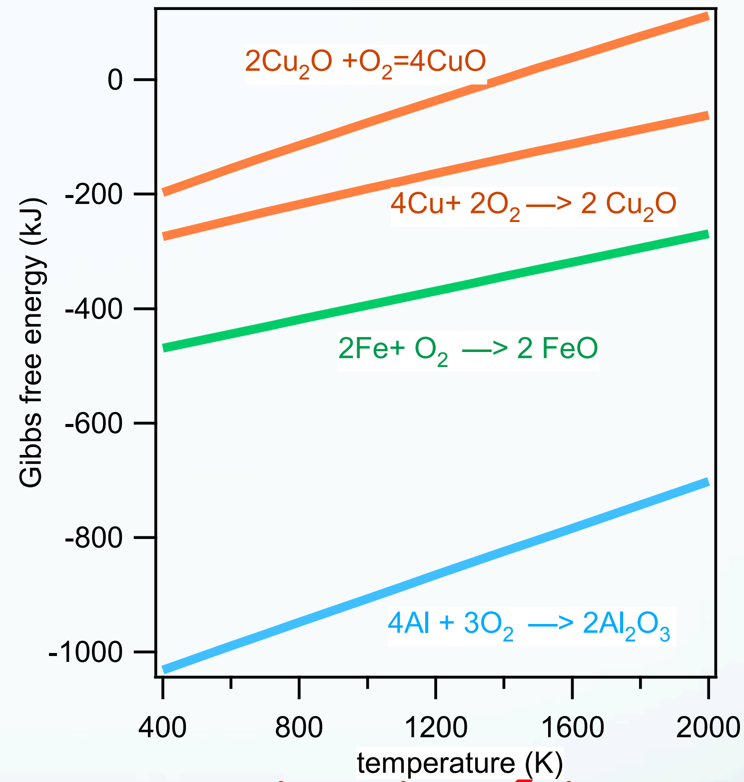
the SEY variation follows the O content of the Al surface

e^- beam induced surface reactions in Al



SEY is determined by the rates of Al oxidation and reduction





reactions involving C play a minor role

D. Grosso et al. submitted to PR-ST

The Surface Science Actors:

- Secondary Electron Yield (the number of electrons created after bombardment of a single electron.)
- Photoelectron Yield (the number of electrons created after bombardment of a single photon)
- Photo-reflectivity (the number of photons reflected by the surface)

And their dependence on:

material, Energy, angle, temperature, magnetic field, Conditioning etc etc….

Why?

- Not only to study the input parameters used in simulations of multipacting and e-cloud build-ups, related instabilities
- But also to simulate and prevent single bunch instabilities just connected to the mere existence of a certain density of e^- in the accelerator chambers.

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}

- Also for ILC DR, LHC-upgrade etc. the problem **of single bunch instabilities is a very serious one and does not only depend on the SEY of the accelerator walls nor by the subsequent e-cloud buildup, but also by the number of primary photoelectrons directly produced**. This number depends on **wall photo-reflectivity** (i.e. the number of photons actually hitting the wall) and **by the relative quantum efficiency (PEY)**

- We (ILC-collaboration, LHC Upgrade, APS, ANKA etc) launched an experimental campaign to measure with Synchrotron Radiation, such values of Photo-reflectivity and PEY for the different materials of interest.

- **LNF is leader in this working package.**

We performed preliminary measurement and we intend to continue measuring photon reflectivity using the reflectometer at BESSY II in Berlin.

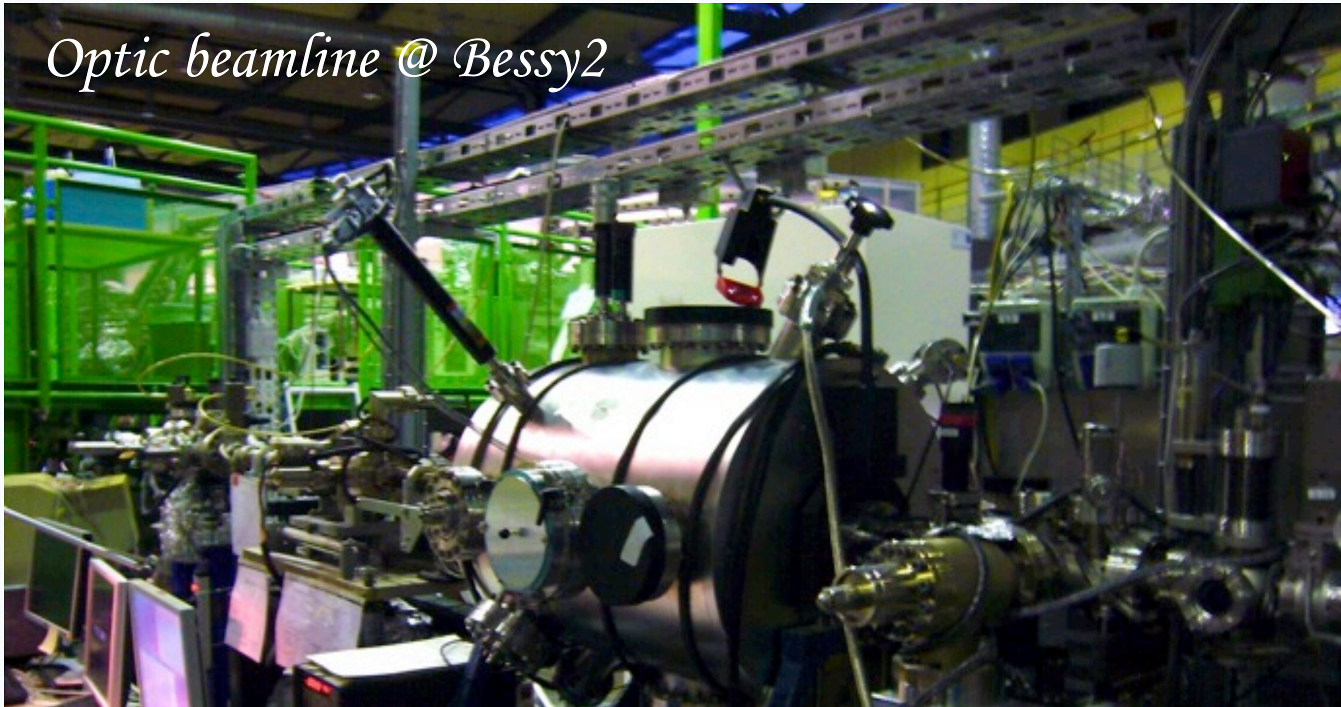
ECLOUD-12 proceeding and to be submitted to Phys. Rev. Special Topics

SOFT X-RAY REFLECTIVITY: FROM QUASI-PERFECT MIRRORS TO ACCELERATOR WALLS

F. Schäfers, Institute for Nanometre Optics and Technology, HZB BESSY-II, Berlin, Germany
R. Cimino, LNF / INFN, Frascati, Italy

Abstract

Reflection of light from surfaces is a very common, but complex phenomenon not only in science and technology, but in every day life. The underlying basic optical principles have been developed within the last 5 centuries using visible light available from the sun or other laboratory light sources. X-rays were detected in 1895, and the full potential of soft- and hard-x ray radiation for material analysis and characterisation is available only since to the advent of synchrotron radiation sources some 50 years ago. On the other hand high-energy machines and accelerator-based light sources suffer from serious performance drop or limitation due to the interaction of the light with the accelerator walls, thus producing photoelectrons which in turn interact with the accelerated beam. Thus the suitable choice of accelerator materials and its surface coating which determines its x-ray optical behaviour is of utmost importance to achieve ultimate emittance performance. Basic principles and examples on reflectivity are given here.



- Photon energy: 20-1600 eV
- a low grating (150 l/mm)
- is used for 20-150 eV
- a high grating (1228.1 l/mm) is used for 130-1600 eV
- Samples: aluminum, copper, and stainless steal
- Spot size:
- 0.25 mm in vertical,
- 1.1 mm in horizontal

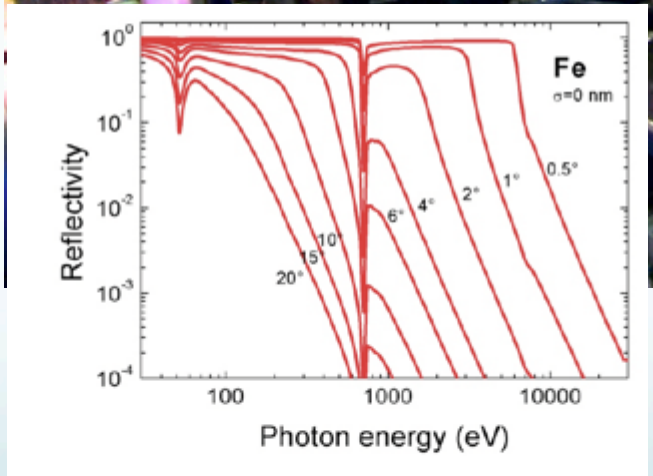


Figure 3: Fresnel-reflectivity of a smooth Fe surface as function of photon energy for various incidence angles.

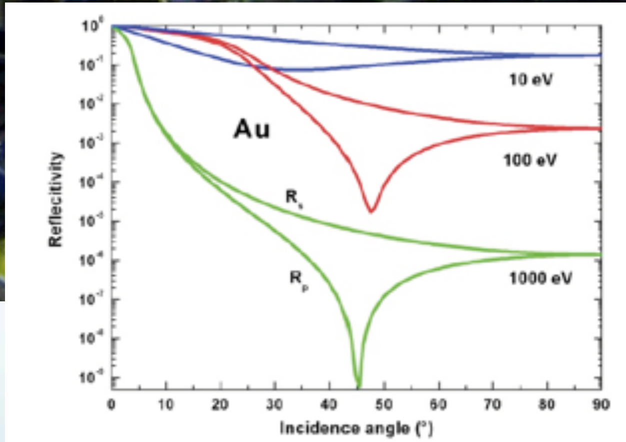
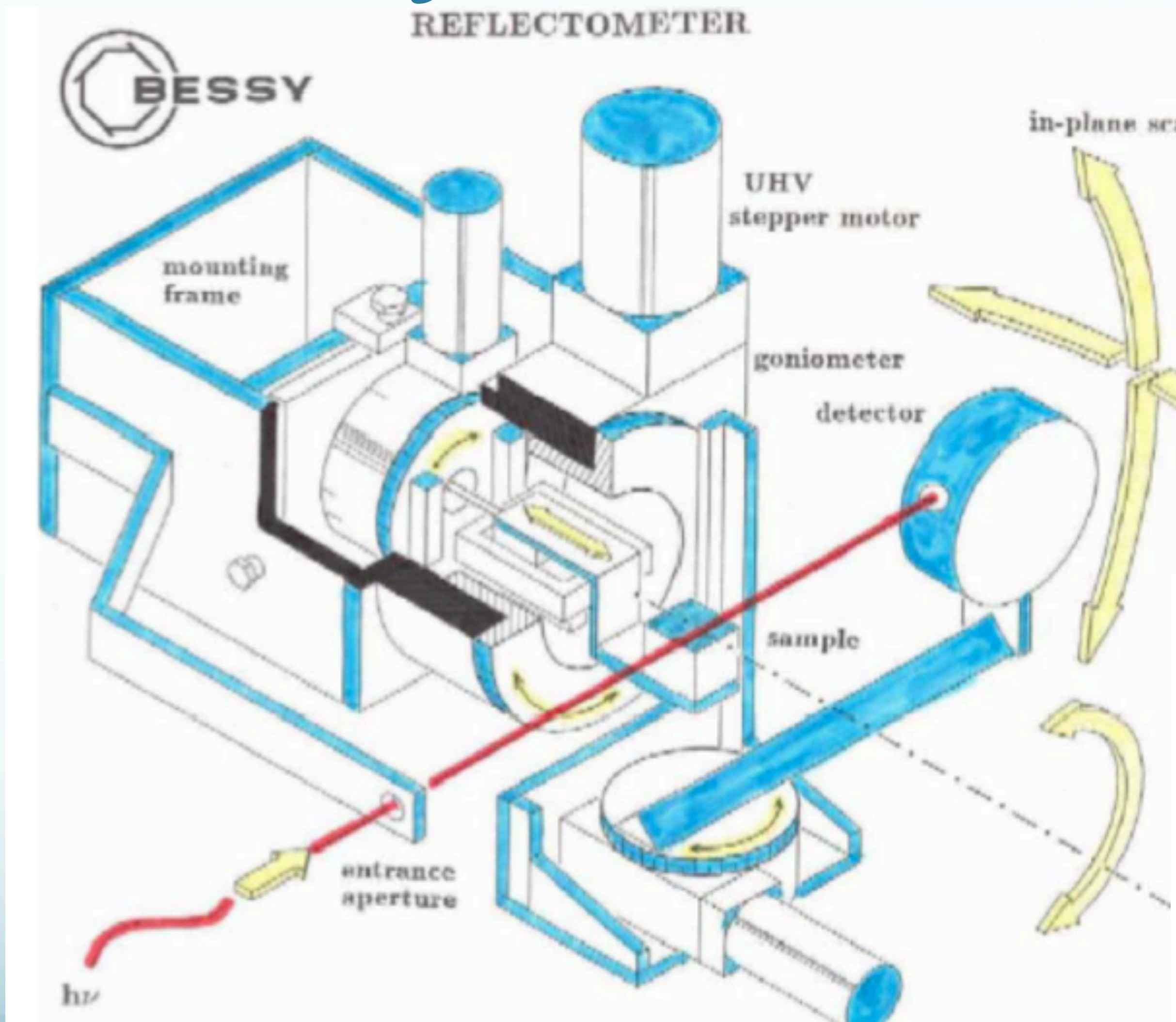


Figure 2 Reflectivity R_s and R_p of a perfect Au-coating as function of incidence angle in the UV and soft x-ray range.

F. Schäfers and R. Cimino
ECLOUD-12 proceeding and to be submitted to Phys. Rev. Special Topics

Reflectometer at BESSY II



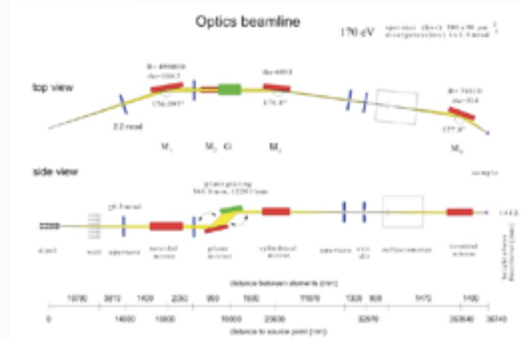


Figure 7: The soft x-ray optics beamline for at-wavelength metrology at BESSY-II [44]

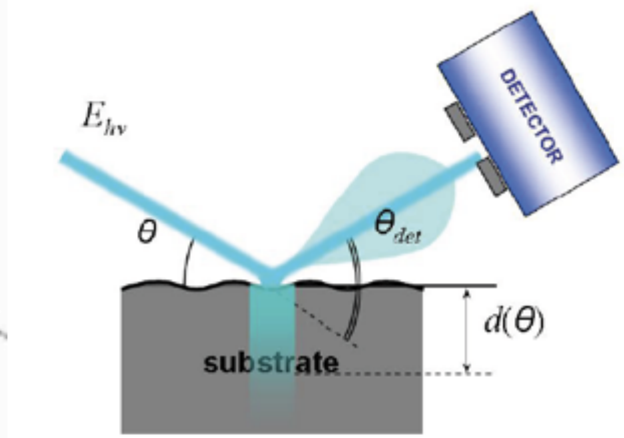


Figure 9: Geometry in reflectometry experiments.

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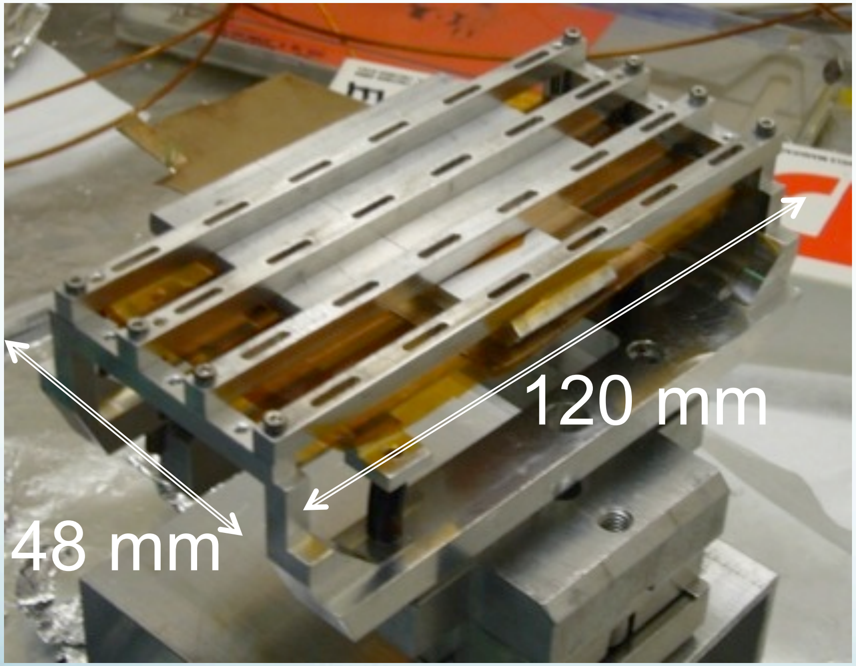
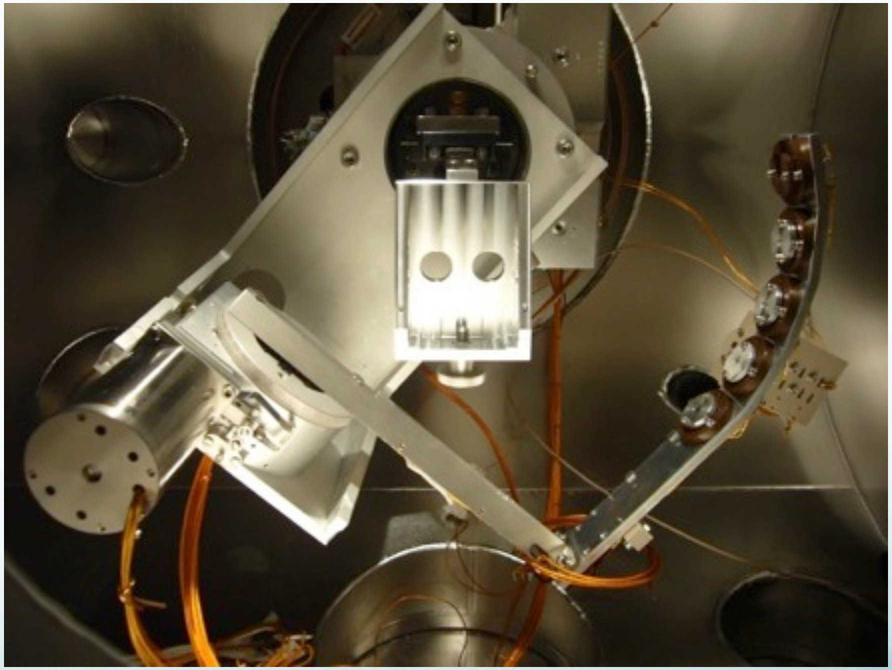
Samples and Sample holder

- During the preliminary beam period, we measured different samples:
  - as example here we show CU from LHC beam screen
- The samples are isolated from the sample holder by Kapton to also measure the photo yield.





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Reflectivity from LHC Cu

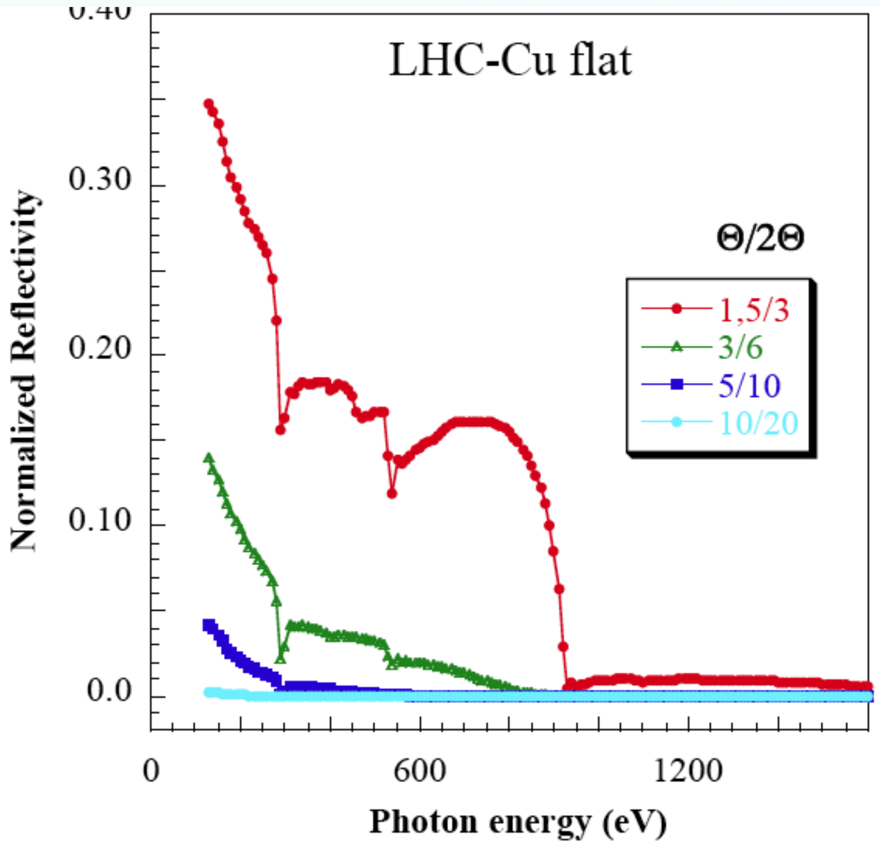

Figure 10: Reflectivity of LHC-Cu sample representative of the flat part of the beam screen, as function of photon energy for various incidence angles Θ and emission angle 2 Θ.

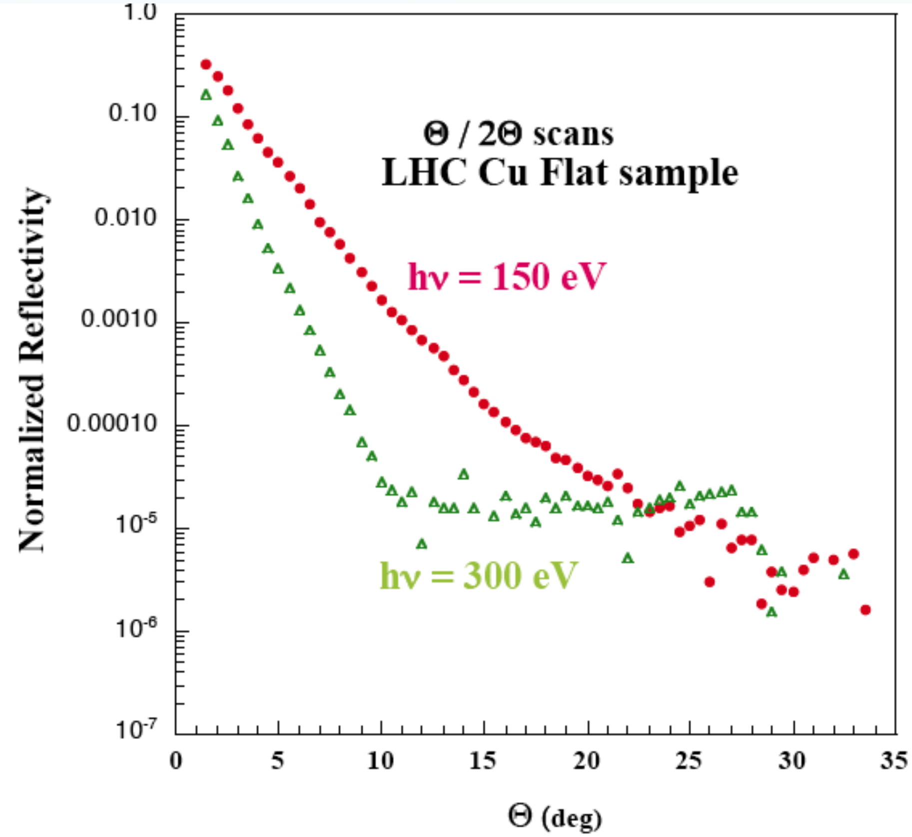

Figure 14: Normalized Reflectivity of LHC- Cu Flat sample as function of incidence angles Θ and emission angle 2Θ, for two photon energies of 150 and 300 eV, respectively.

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Roughness produce scatter light

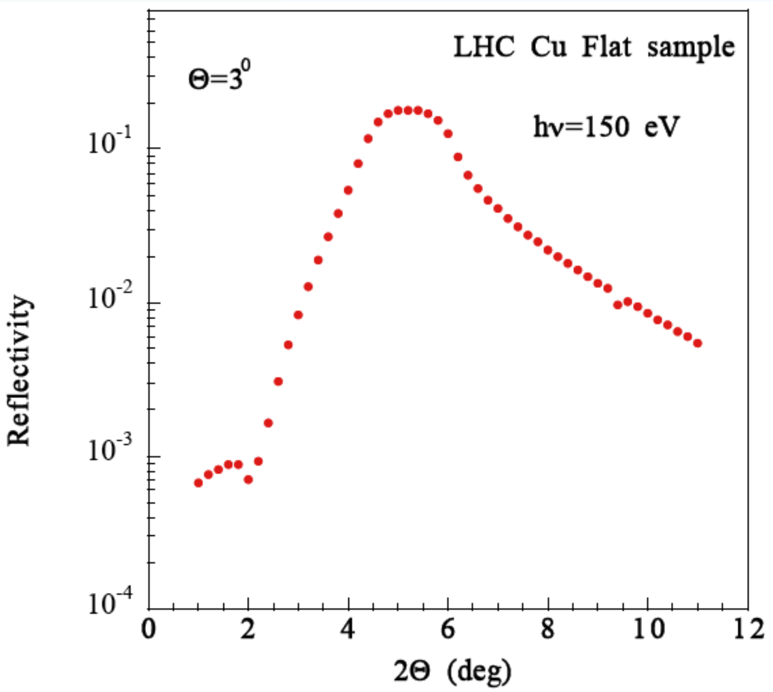

Figure 11: Normalized reflectivity of LHC- Cu Flat sample as function of emission angle 2Θ, for a given photon energy hν=150 eV and incidence angle of Θ=3°.

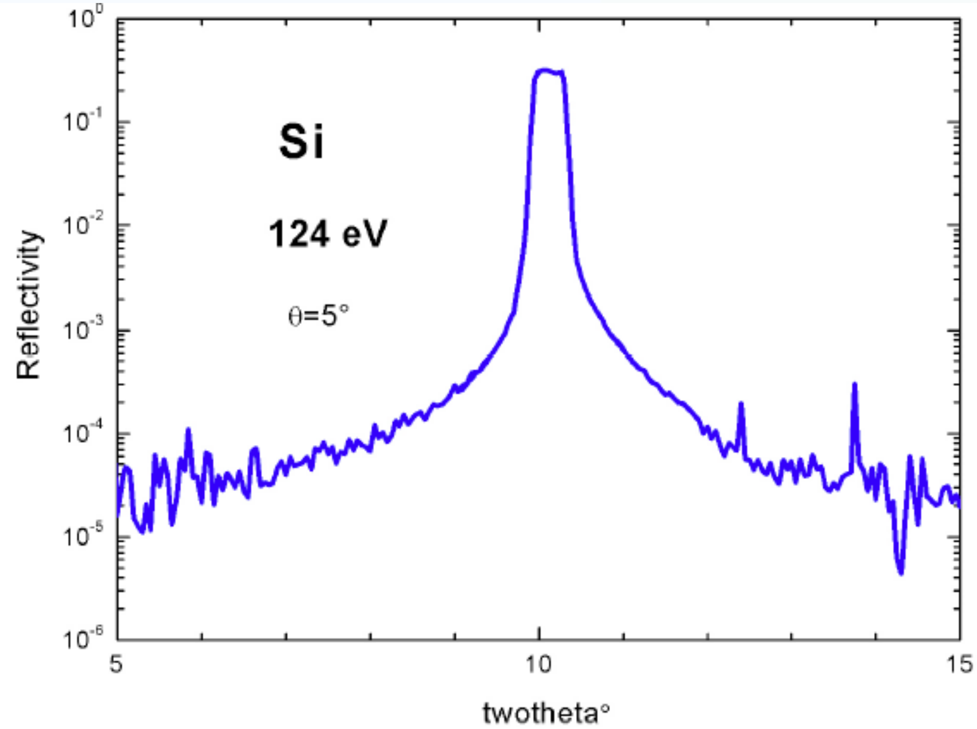

Figure 12: Scattering from a quasi-perfect Si mirror surface taken at 5° incidence angle and at 124 eV (10 nm). Data taken with a 4x4mm photodiode.

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Photo Yield

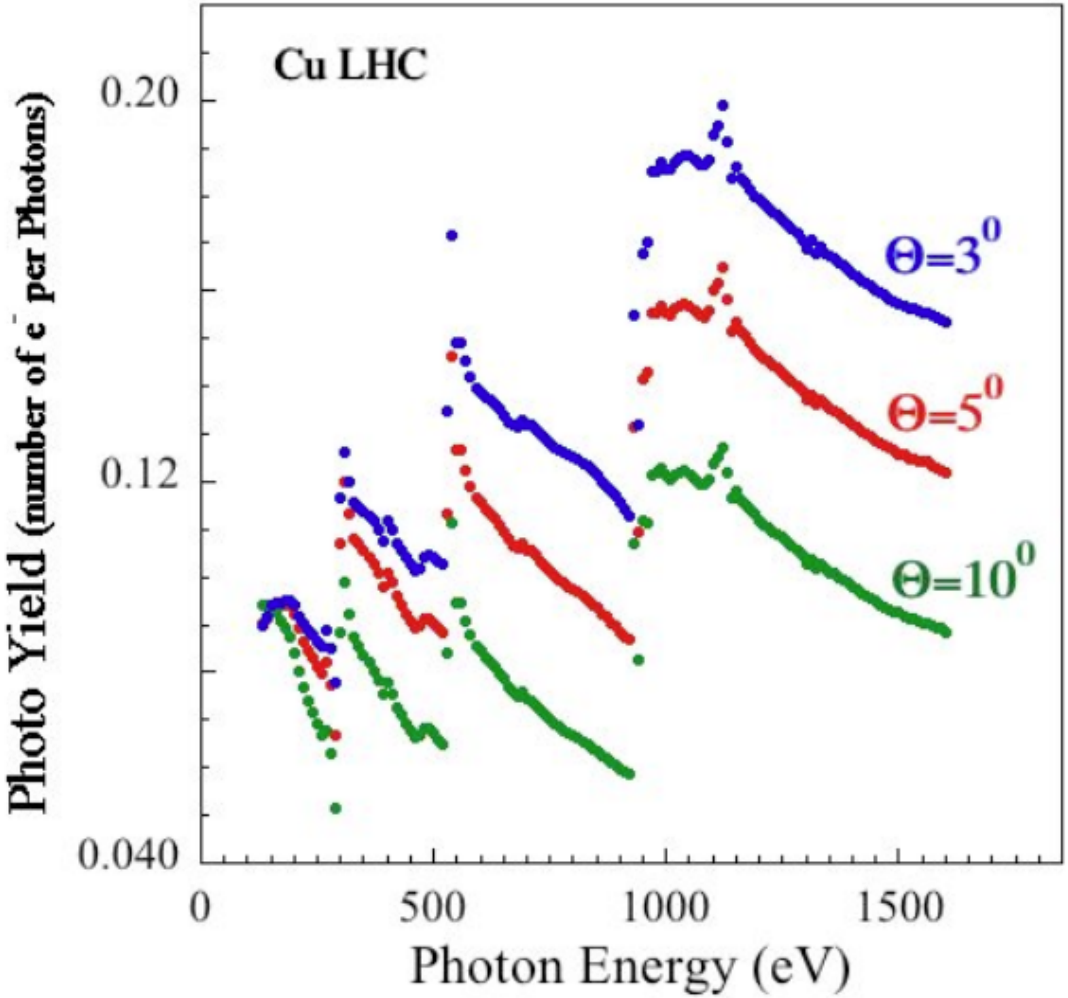

Figure 15: Photo yield (number of electron emitted per incident photon) from a Cu Technical surface of LHC beam screen, as function of photon energy at different incidence angles.

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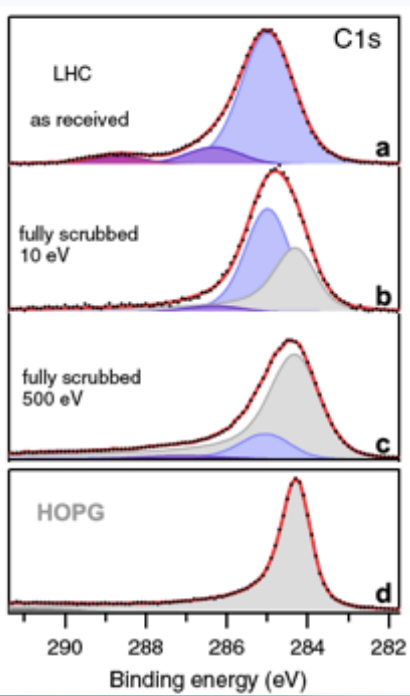
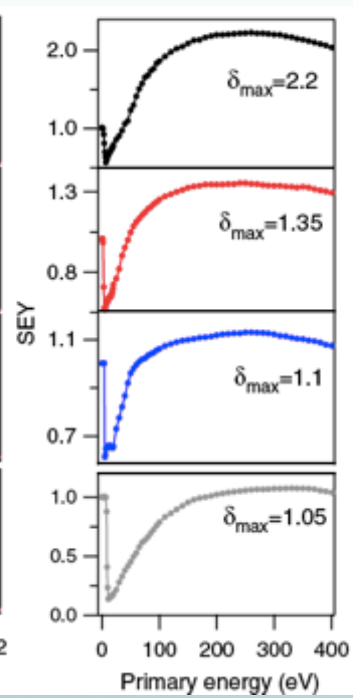
Towards mitigation Strategies….

- ✓ We measure and feed material parameters (R, PY, and SEY) into simulations.
- ✓ Understand their profound nature to:
- ✓ Optimize chemical (mechanical) process to reduce their detrimental influence on beam.
- ✓ Search for new material / coatings with intrinsically "good" parameters.

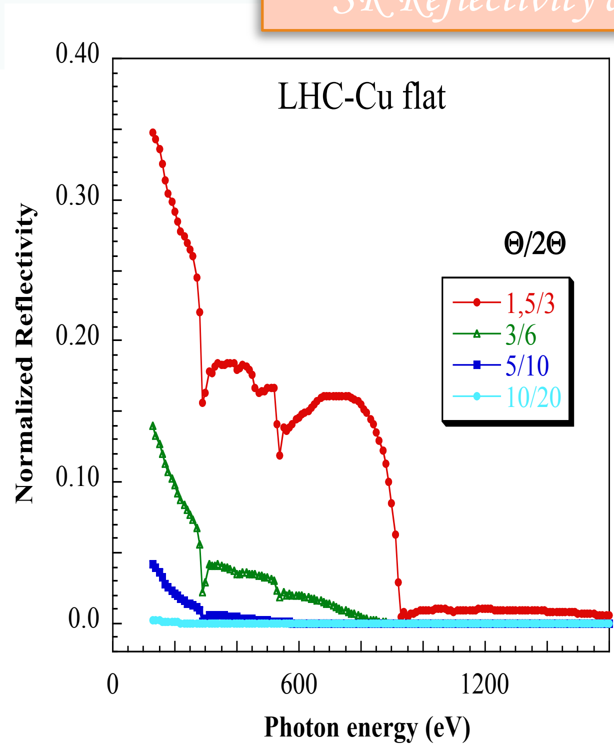
XPS

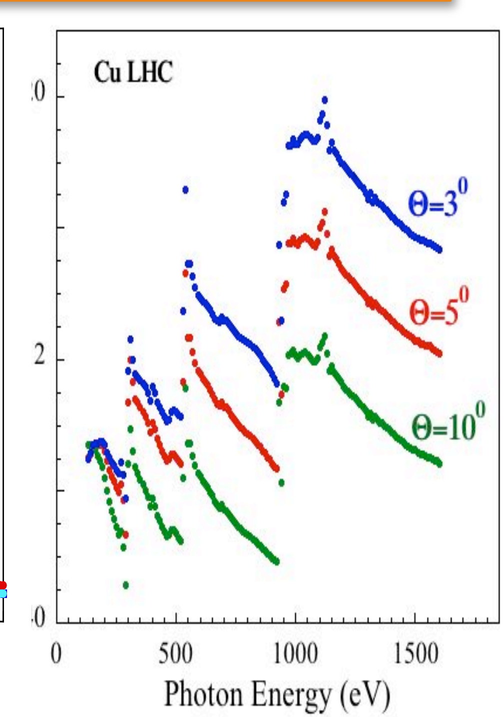


SEY



SR Reflectivity and PY (@BESSY-II)





One research line 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.

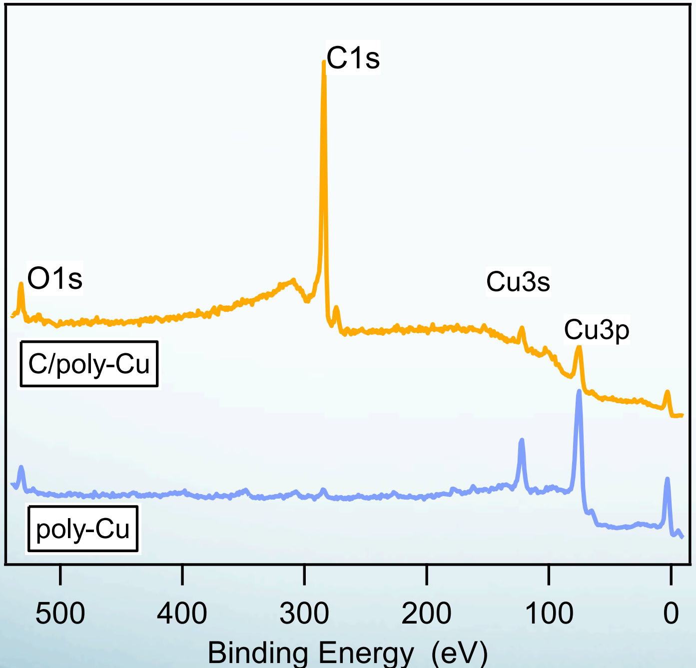
C films on polycristalline Cu

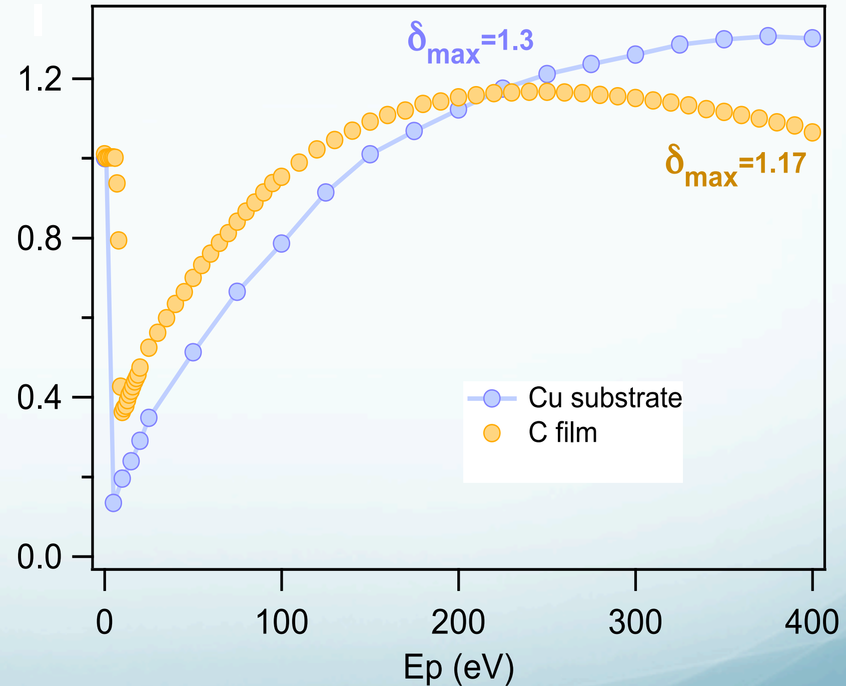
a-C films

magnetron sputtering @ RT

p(Ar)= 10^{-2} mbar Δt = 2min

C film thickness 2-3 nm





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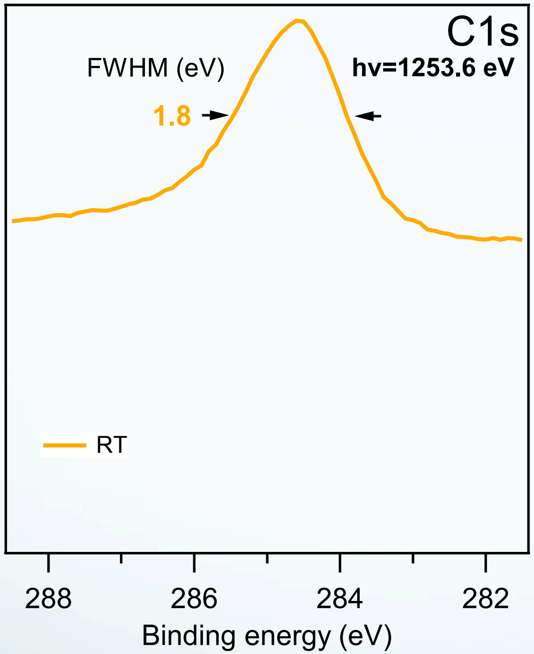
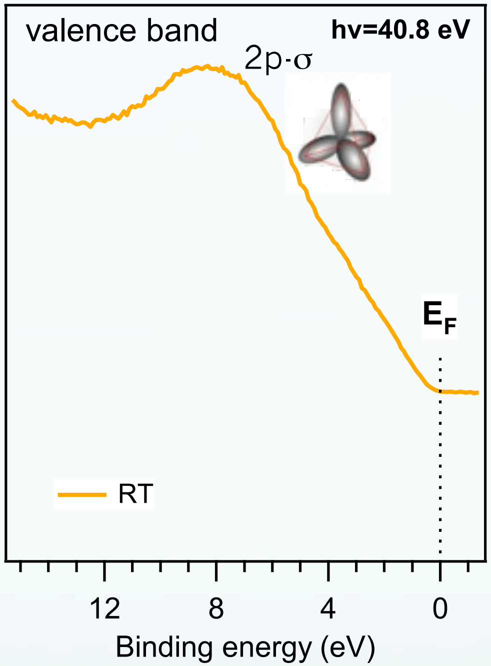
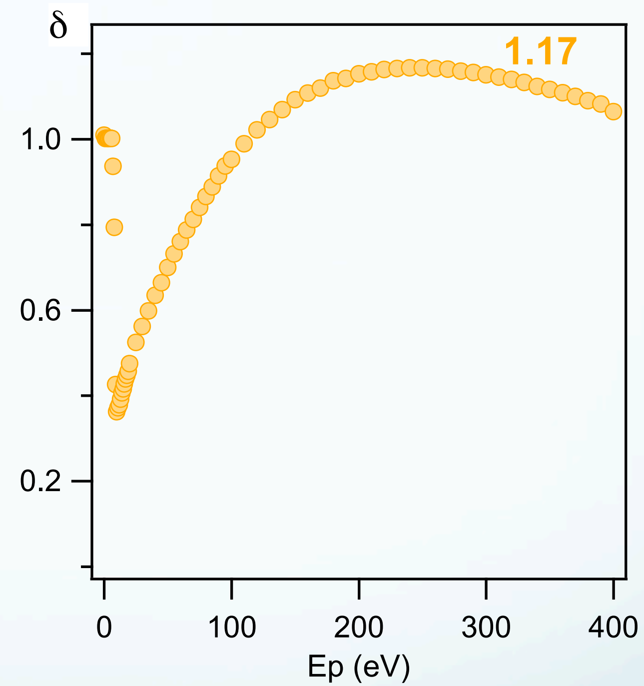
C films on polycristalline Cu

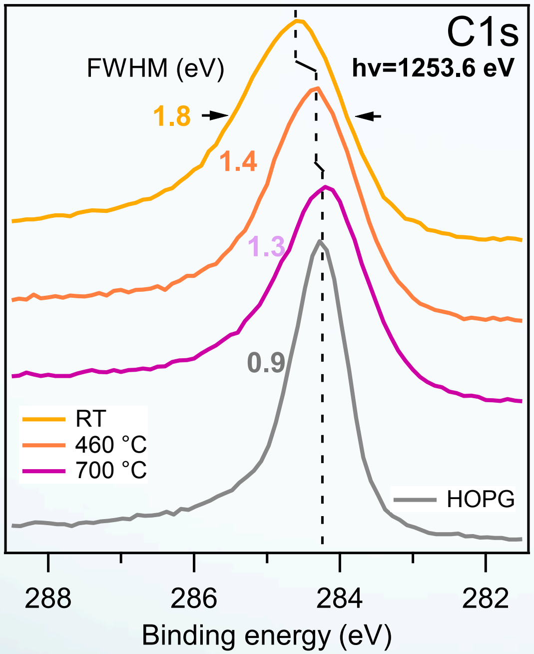


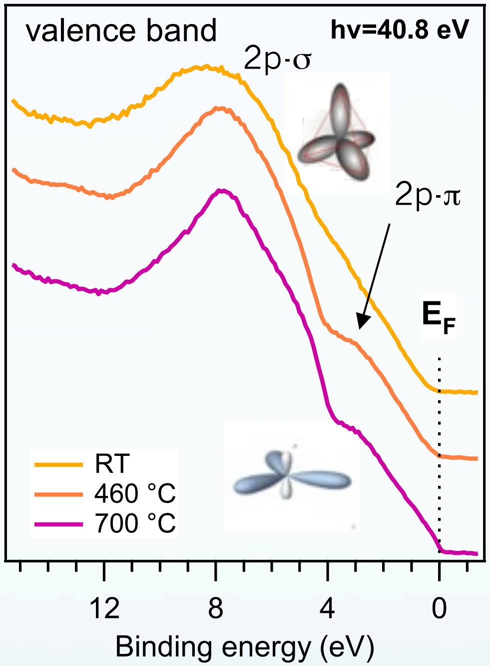


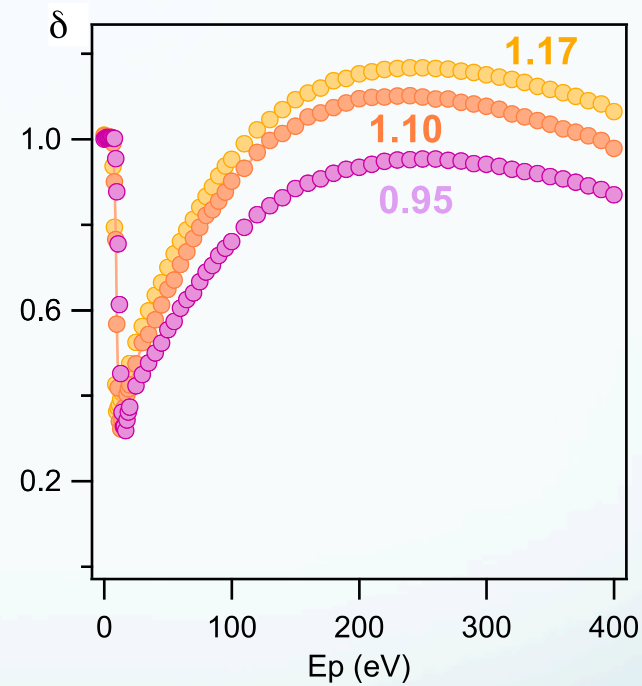


D. R. Grosso R. Larciprete, A. di Trolio and R. Cimino: in preparation

C films on polycristalline Cu







the graphitization of the C films corresponds to a lower SEY

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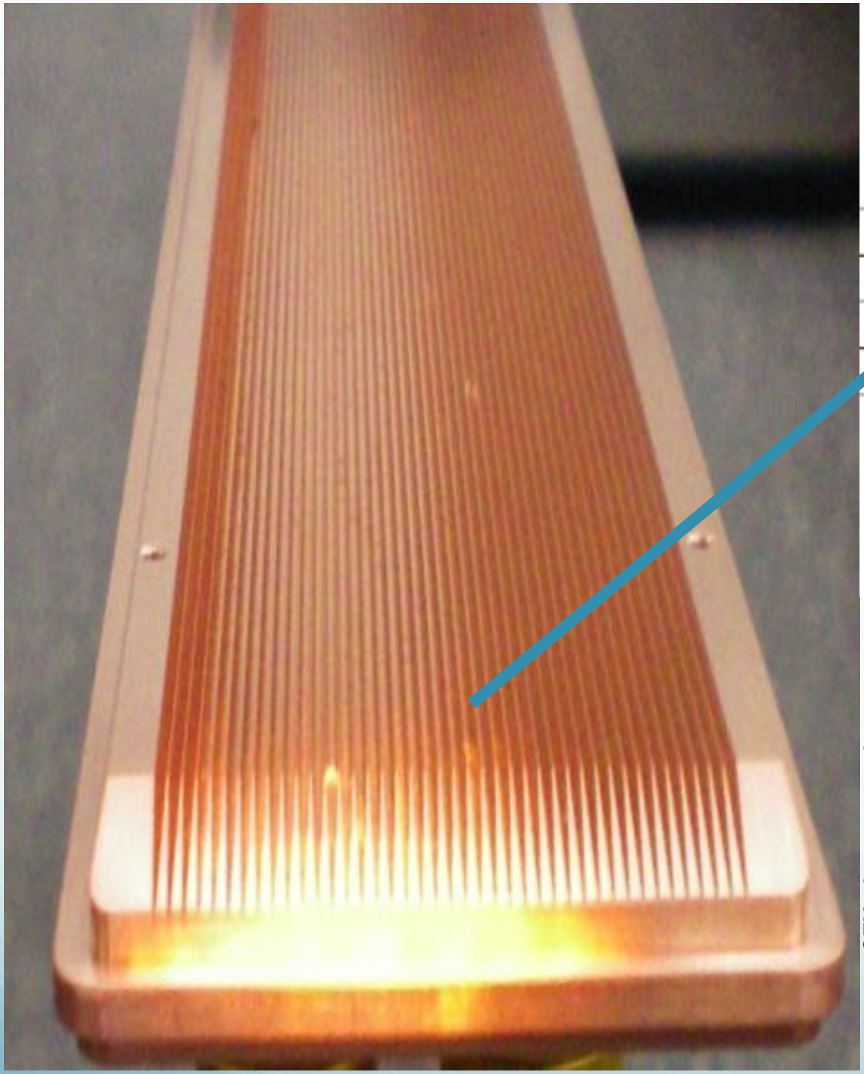
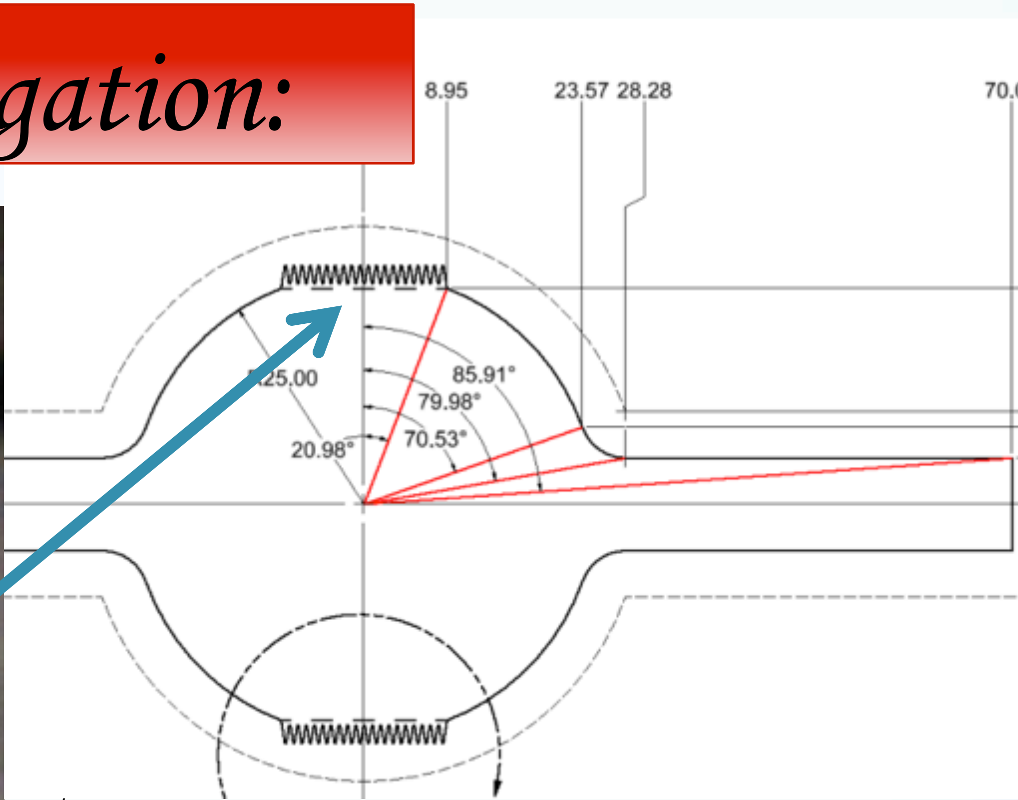
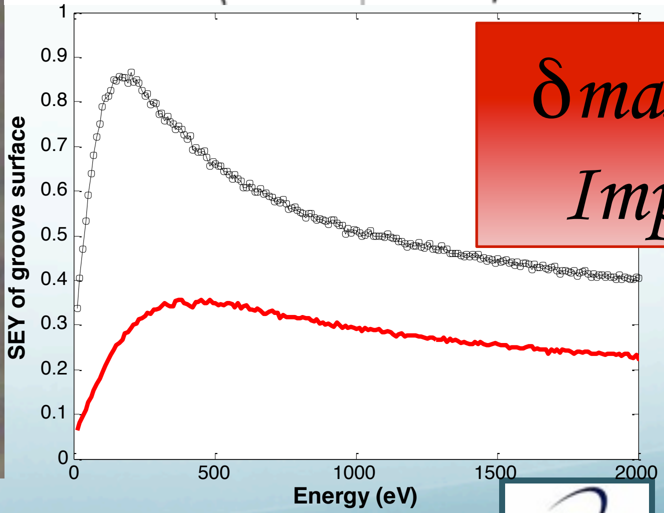
Geometrical Mitigation:







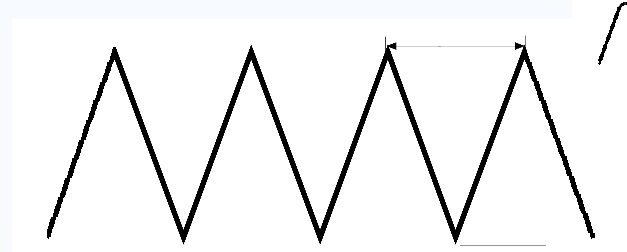
δmax < .8 …

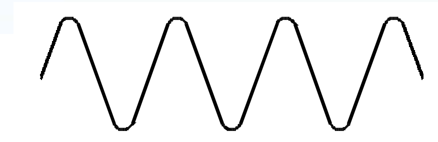
Impedence?

Impedance enhancement factor

(Code : Finite Element Method, PAC07 THPAS067, L Wang)

$$\eta = \frac{Z_{grooved surface}}{Z_{smooth surface}} = \frac{\int H^2 ds}{H_0^2 W}$$





The total impedance enhancement= η * *percentage of grooved surface*

p=1.25mm (period)
d=2.5mm (depth)
t=0.125mm (thickness)

$$\eta = 1.64$$

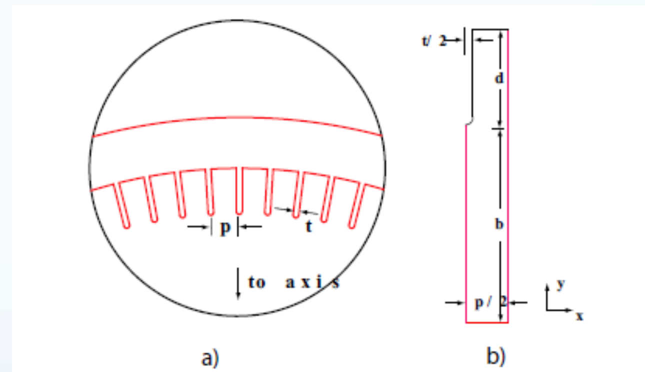


Figure 1: a)—detail of the grooved vacuum chamber wall; dimensions shown are period p and fin thickness t; b)—

p=1.25mm
d=2.5mm
t=0.25mm

$$\eta = 1.42$$

Work in progress@INFN: interesting results

Conclusion

- Vacuum for accelerators is becoming a very multidisciplinary science!
- There is still a lot to do and to learn
- Synergic efforts, dedicated Surface, Material and Vacuum science laboratory are required to reach desired understanding and performances.

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Dafne-L and Dafne Ac...

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Roberto Fl...

ISC istituto dei sis...

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...Nat. Lab., USA

HZB Hel... Zentrum

...e for Nanometre Optics
...I) Berlin