Material science and accelerator R&D: Reflectivity and Photo Yield measurements of vacuum chamber technical surfaces

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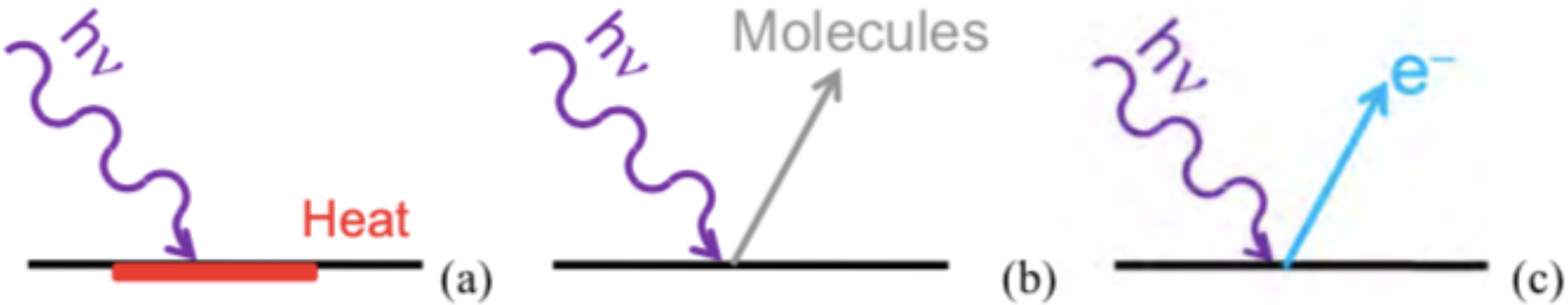
OUTLINE

- Synchrotron radiation detrimental effects
- Reflectivity and Photo Yield
- Bessy II measurements
- Conclusions

Synchrotron Radiation detrimental effects

- Heat load on the accelerator walls
- Gas load
- Production of photo emitted electrons (e^- cloud effect)
- Beam instability



Synchrotron Radiation interaction with Matter

Reflected + Absorbed + ~~Transmitted~~

Specular reflected

Scattered

Synchrotron Radiation interaction with Matter

Reflected + Absorbed + ~~Transmitted~~

Photo-electrons generation

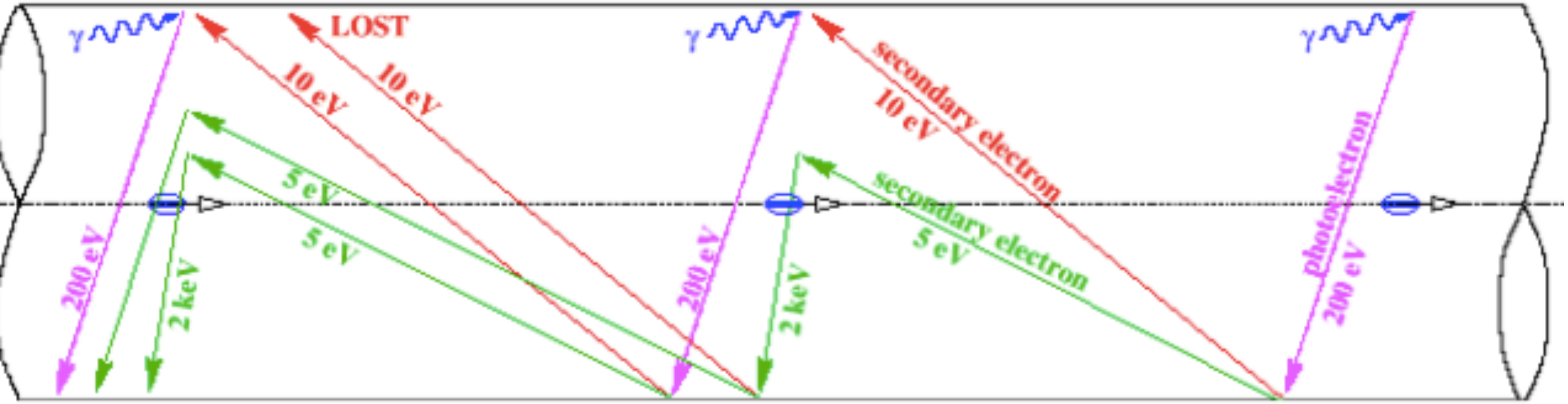
Electron cloud effect

SR and electron cloud generation

Photo-emitted electrons can be:

- Produced directly by SR (dipoles): emitted in the orbit plane (not participate to electron cloud build up).

- Produced by the reflected or scattered light (dipoles and free field zone): emitted perpendicularly to the orbit plane



Original representation F. Ruggero

Beam instability

To model the generation of photoelectrons i
PyECLOUD bu
up simulations
needed paramte
like PY and R

Synchrotron Radiation interaction with Matter

Reflected + Absorbed + ~~Transmitted~~

Photo-electrons generation

Heat Load

Electron cloud effect

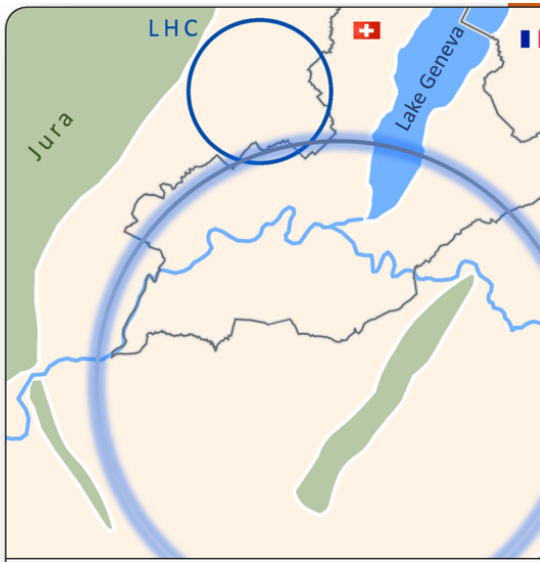
FCC Parameters

http://tlep.web.cern.ch/content/fcc-hh

Version 1.0 (2014-02-11)

Parameters	LHC	H-L LHC	FCC-hh
c.m. Energy [TeV]	14		100
Circumference *C* [km]	26.7		100 (83)
Dipole field [T]	8.33		16 (20)
Injection energy [TeV]	0.45		3.3
Peak luminosity $[10^{34}\ cm^{-2}s^{-1}]$	1.0	5.0	5.0
Stored beam energy [GJ]	0.392	0.694	8.4 (7.0)
SR power per ring [MW]	0.0036	0.0073	2.4 (2.9)
Arc SR heat load [W/m/aperture]	0.17	0.33	28.4 (44.3)
Critical photon energy [keV]	0.044		4.3 (5.5)

Total Power to dissipate such HL at cold bore temperature: 3 GW



Schematic of an 80 – 100 km long tu

FCC-hh SR incide
angle: 0.077 deg
(0.62 mrad)

Dipoles at 1.9 K

Synchrotron Radiation interaction with Matter

Arc SR Heat Load = 28.4 (44.3) W/m/aperture

=

Reflected + Absorbed + ~~Transmitted~~

ecular
flected

Scattered

To be increased in high temperature parts

To be increased in cold parts (Superconductor Magnets)

. Cimino, V. Baglin and F. Schäfers, PRL. 115 (2015) 264804

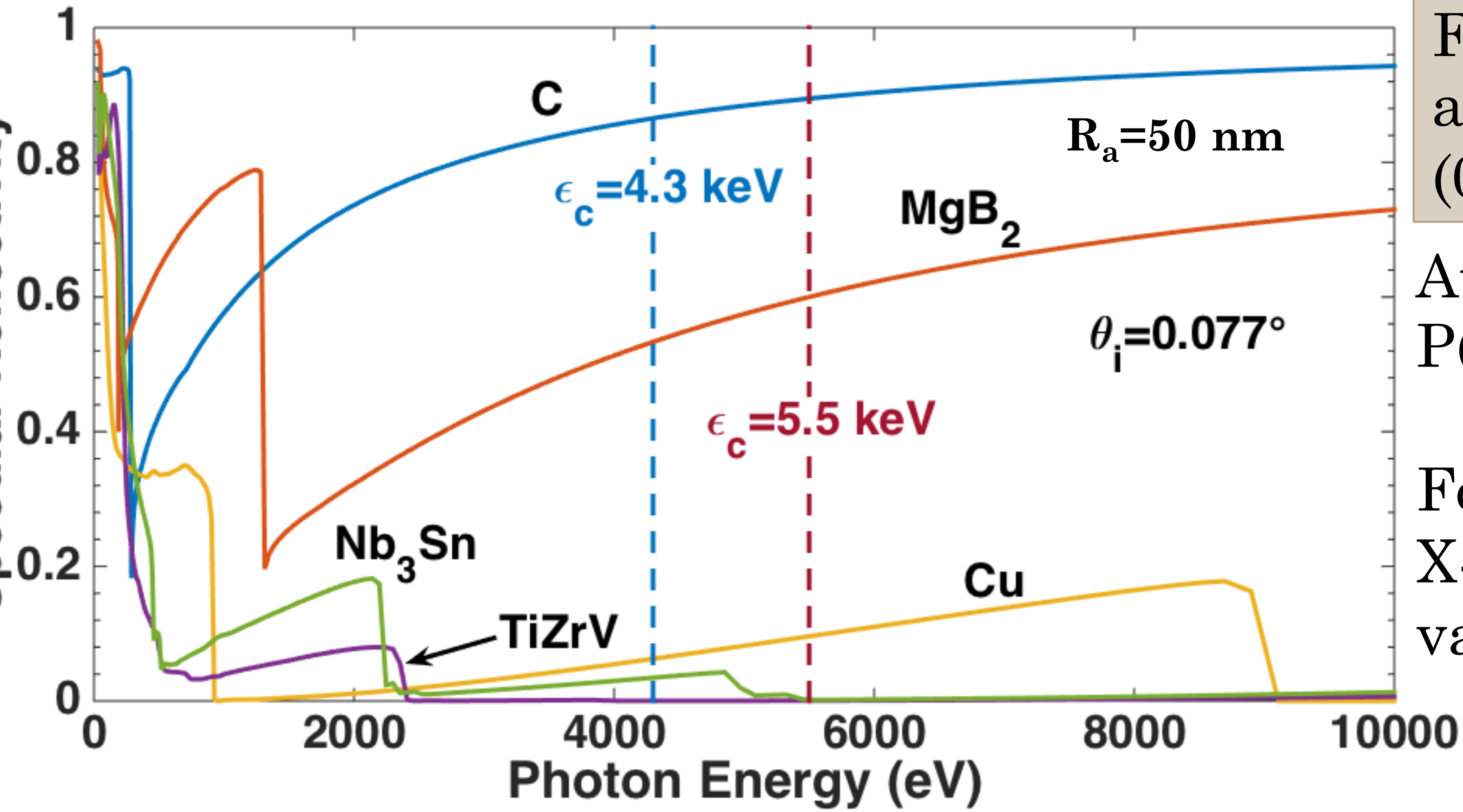
Reflectivity

X-Ray Reflectivity depends on a limited number of parameters:

- Photon energy and light polarization
- Angle of incidence
- Surface roughness
- Material

Specular Reflectivity: the case of Carbon

REFLEC simulations



R. Cimino, V. Baglin and F. Schäfers, PRL. 115 (2015) 264804

FCC-hh SR incidence angle: 0.077 deg (0.62 mrad)

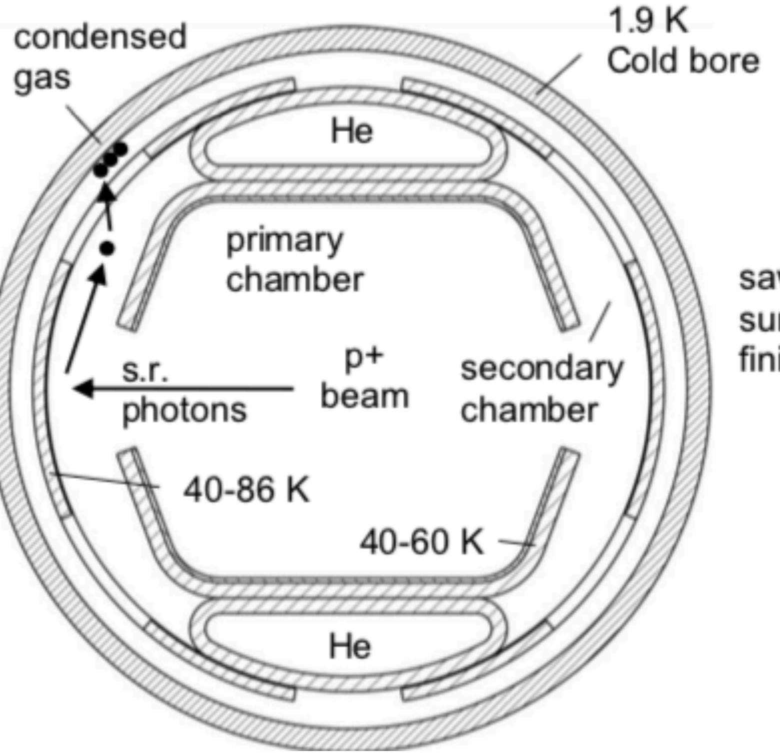
Attenuation depth (λ): $P(x)=\exp(-x/\lambda)$

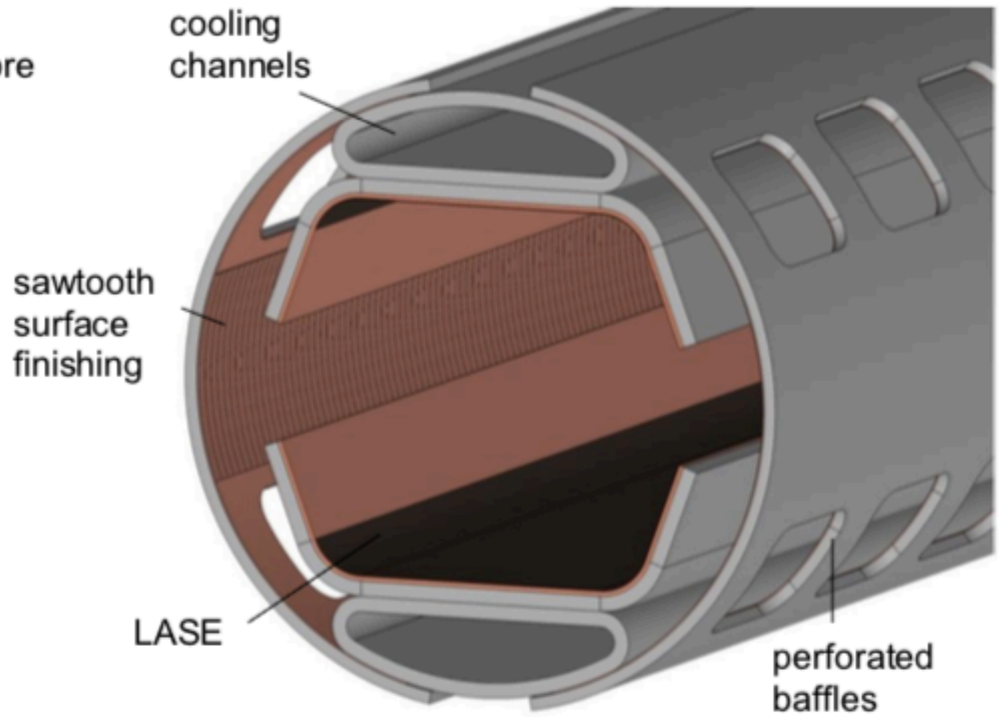
For x= λ the intensity of X-rays falls to 1/e of its value at the surface.

λ(C) ~ 3.5 nm (X-ray range)

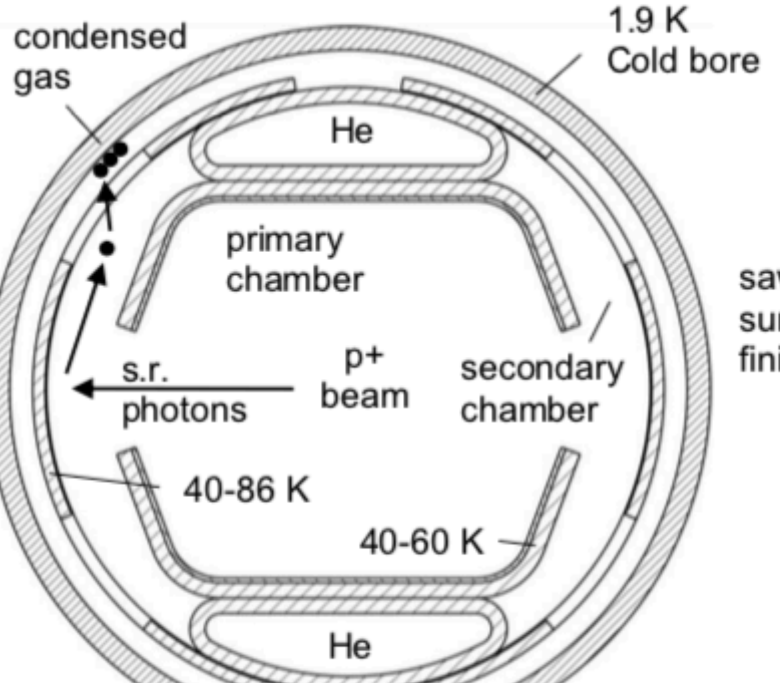
20 nm of C can reflect all photons

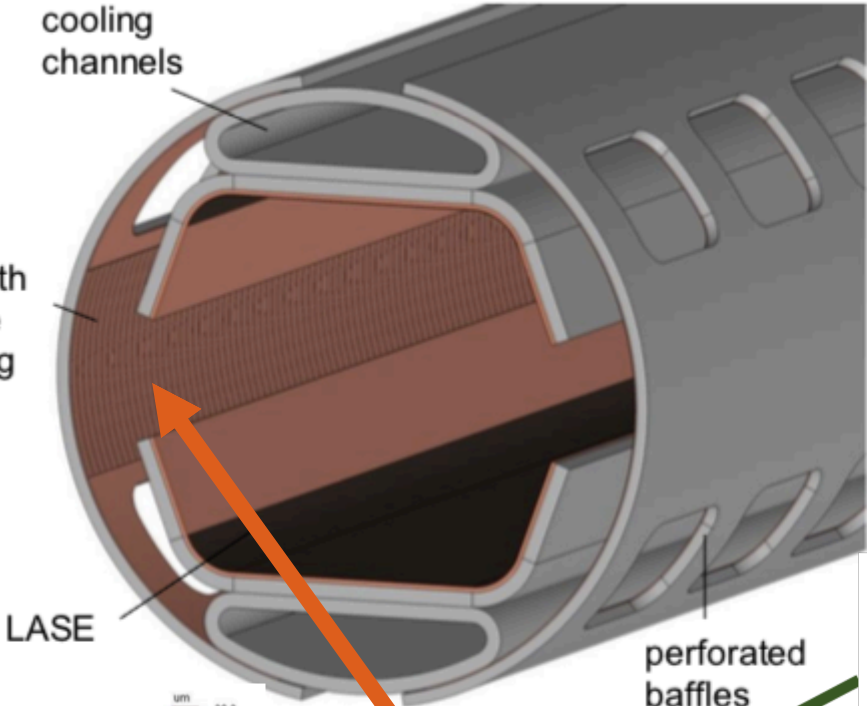
FCC-hh Beam Screen

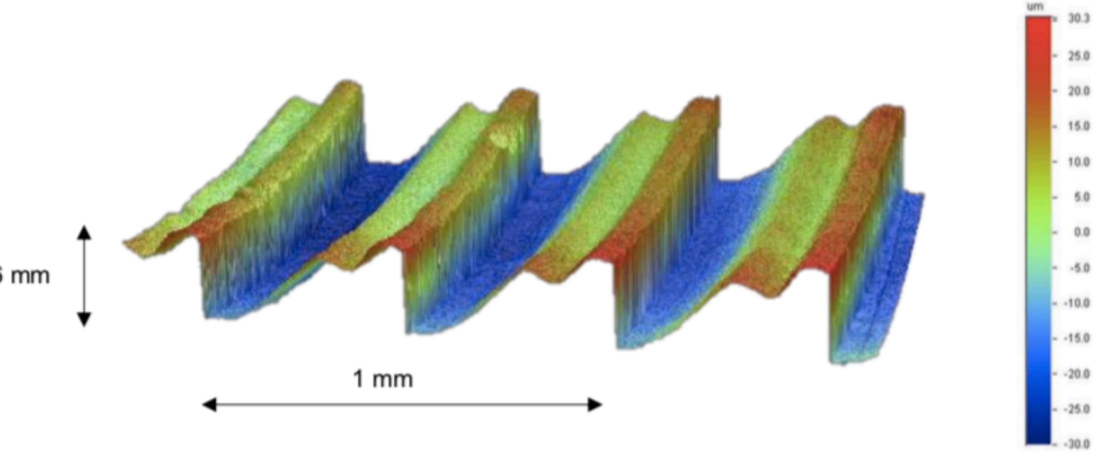


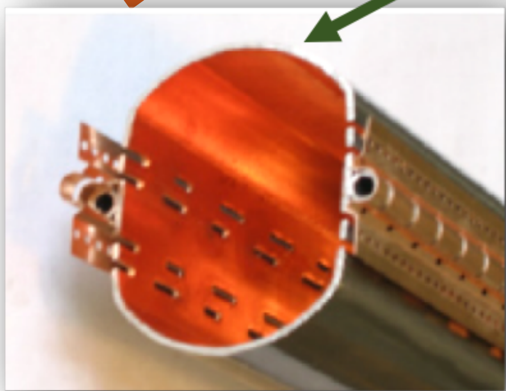


FCC-hh Beam Screen

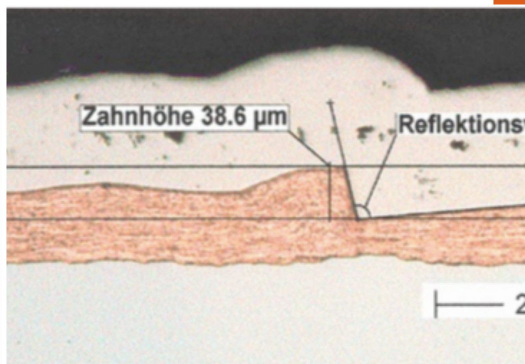




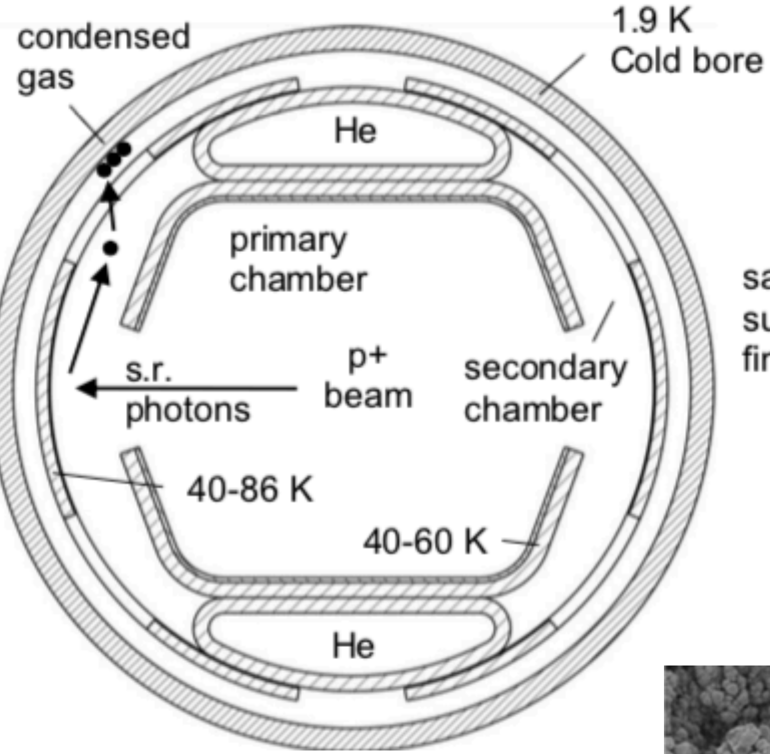


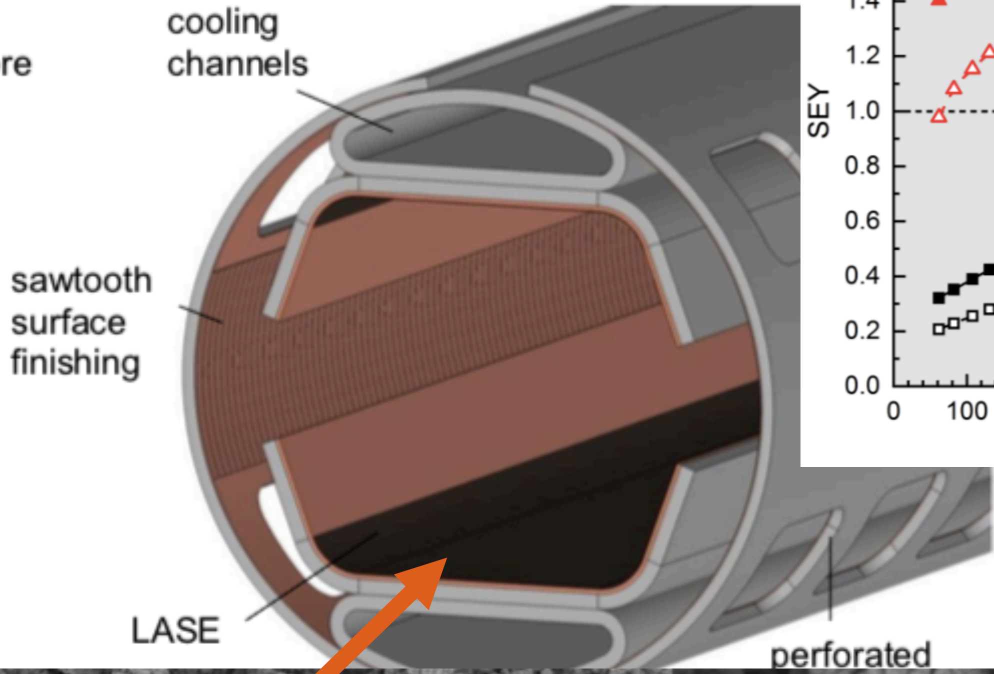


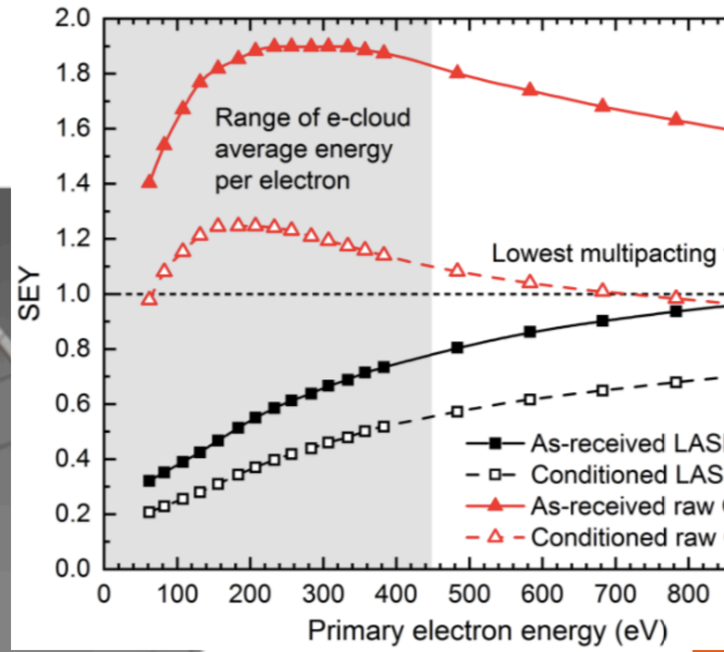
Saw-Toot

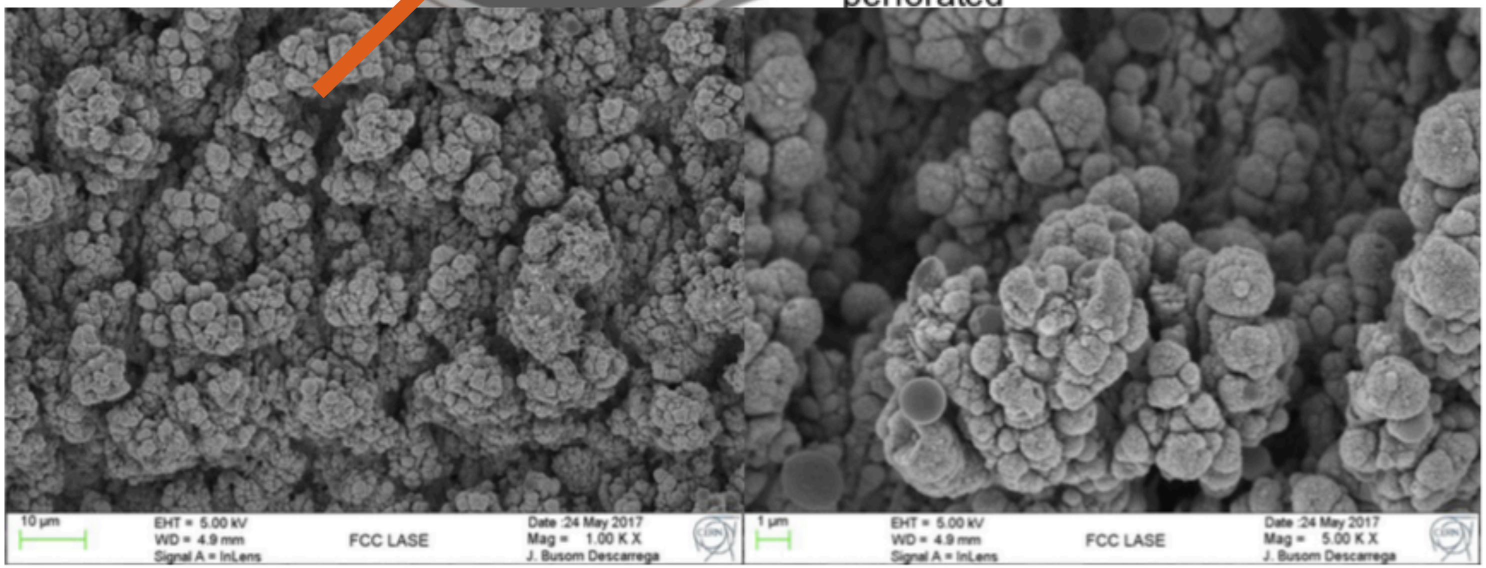


FCC-hh Beam Screen







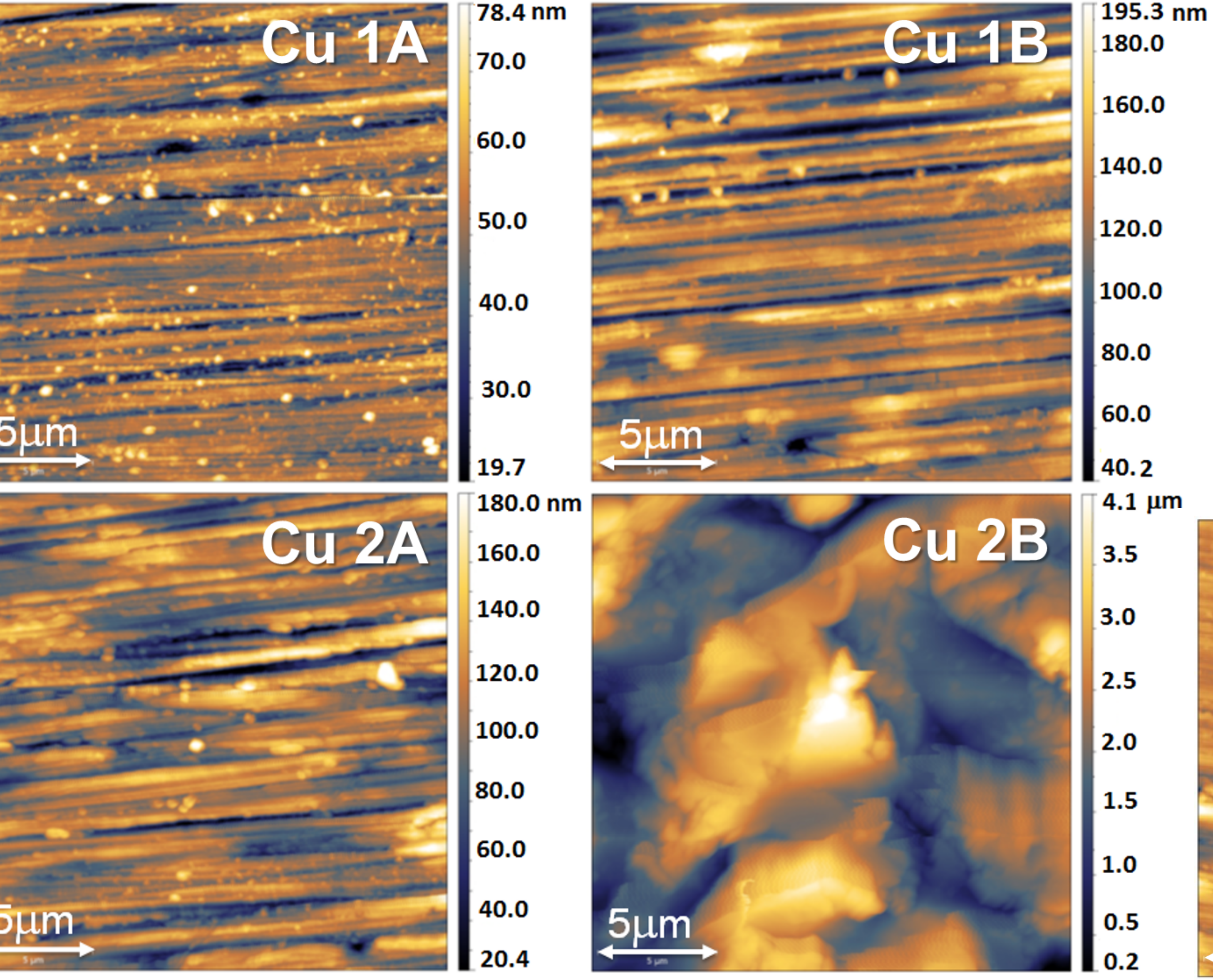


The Science & Technology Facility Council (STFC)

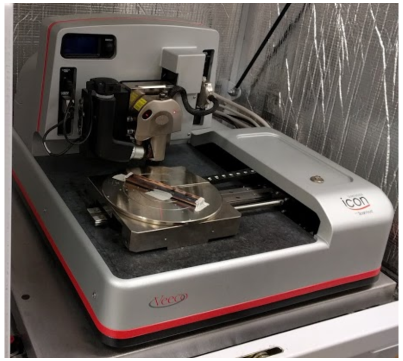
Samples

- two copper sample polished, Cu 1A and Cu 2A (10 cm long), with and without a-C coating;
- two copper sample lapped, Cu 1B and Cu 2B (10 cm long), with and without a-C coating;
- LHC Beam Screen (BS), flat zone (30 cm long), with and without a-C coating;
- LHC Beam Screen (BS), Saw-Tooth zone (30 cm long);
- Cu sample treated by Laser Ablation Surface Engineering (LASE, made by the Science & Technology Facility Council (STFC))(30 cm long).

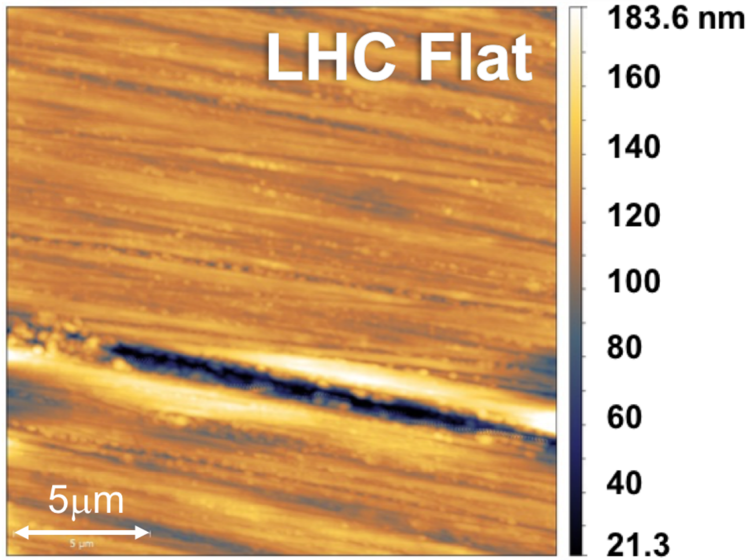
AFM measurements



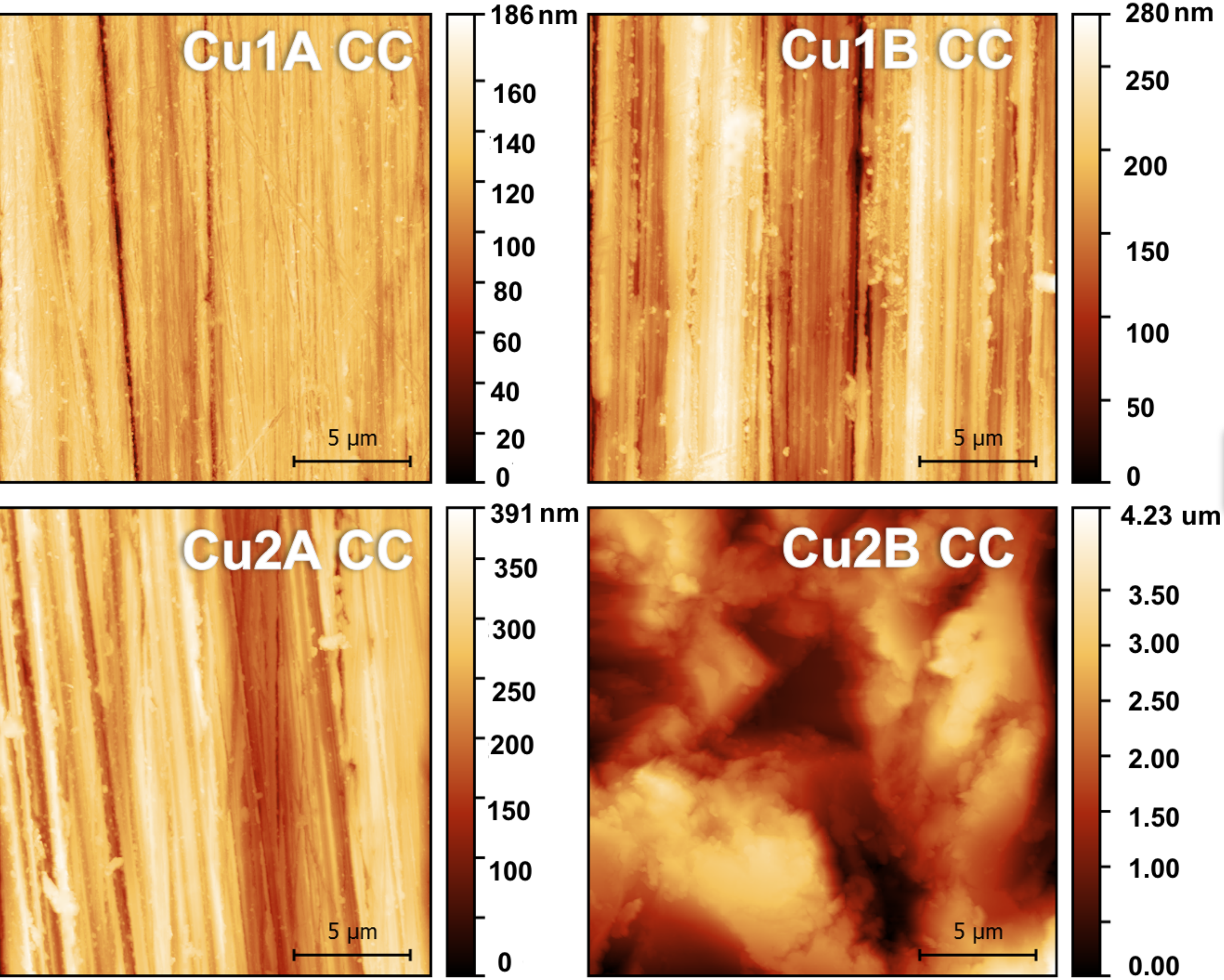
CNIS
CENTER OF NANOTECHNOLOGY FOR ENGINEERING OF SAPIENZA



AFM (20x20µm²)



AFM measurements



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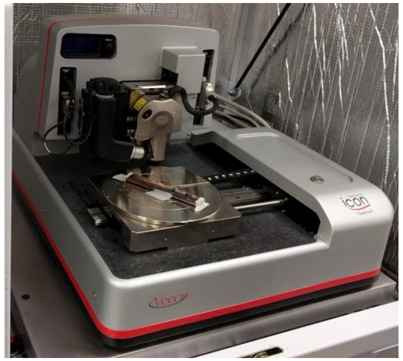
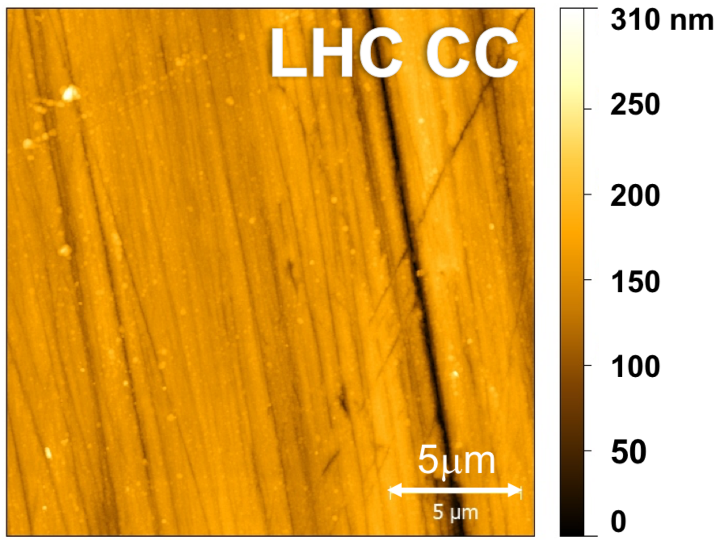
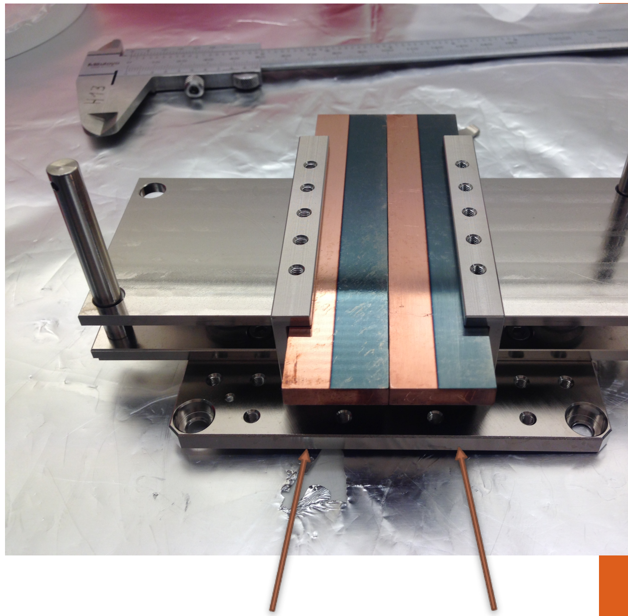


AFM (20x20µm²)



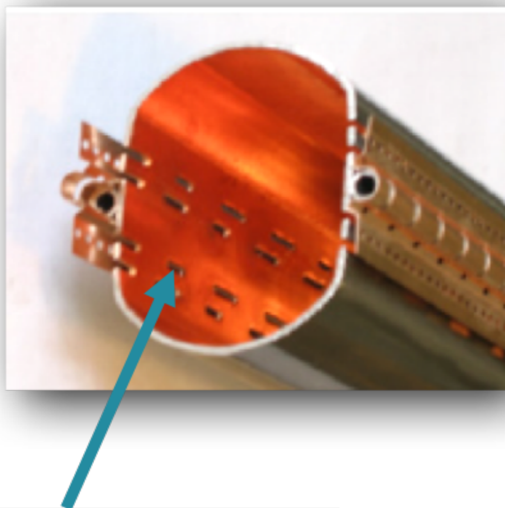
Measured roughness

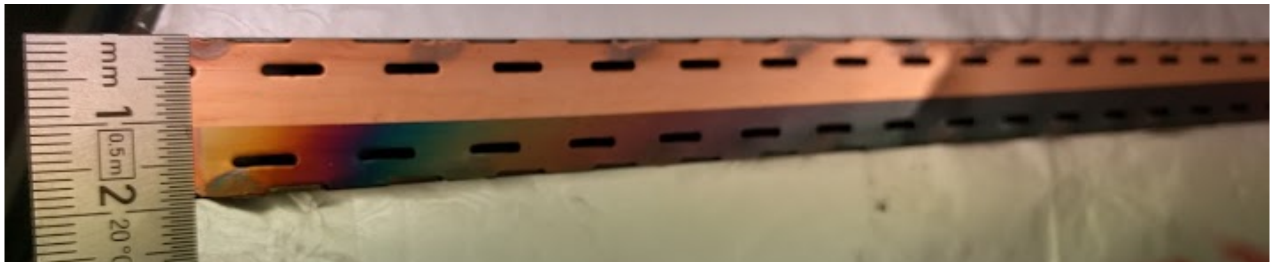
Sample	RMS Roughness (R_a)	RMS Roughness (R_a) (Carbon Coating)
Cu 1A	9.6 nm	13.4 nm
Cu 1B	25 nm	31.3 nm
Cu 2A	27 nm	28.6 nm
Cu 2B	643 nm	648 nm
LHC-Flat	14.9 nm	20.1 nm



Side A – means polished
Side B – means lapped

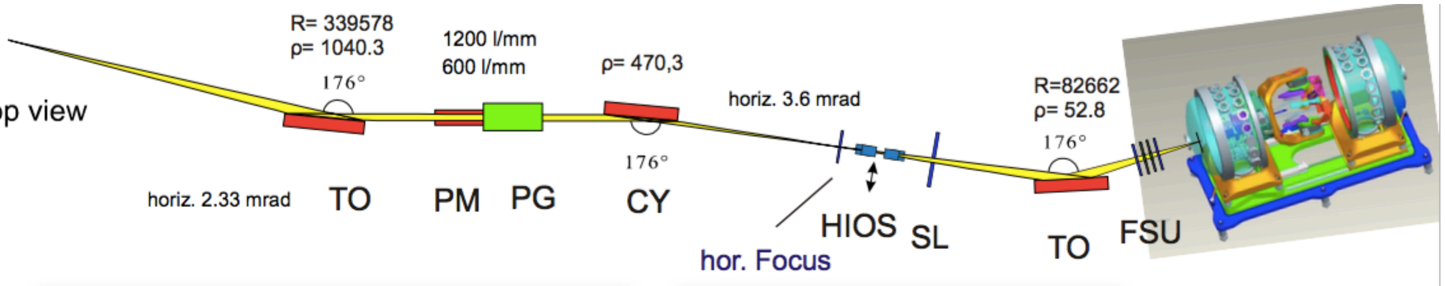
50 nm CC made by Magneto-sputtering



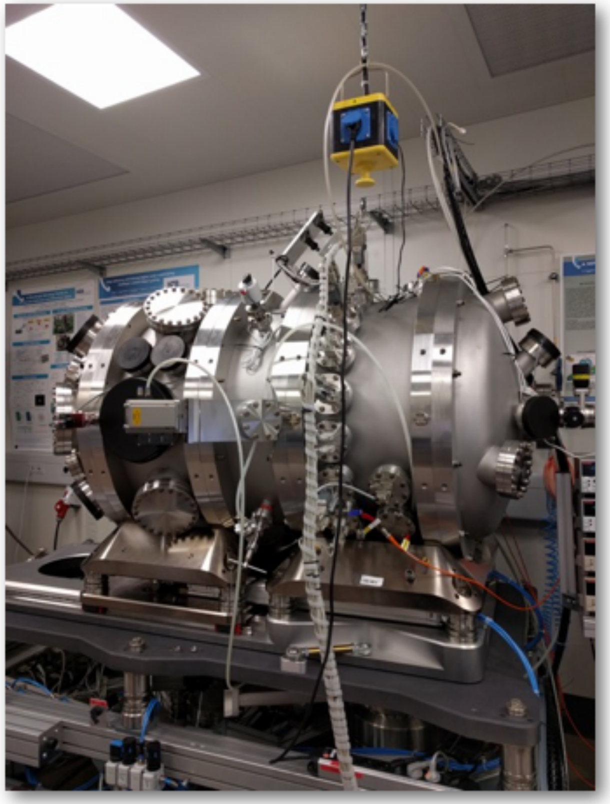


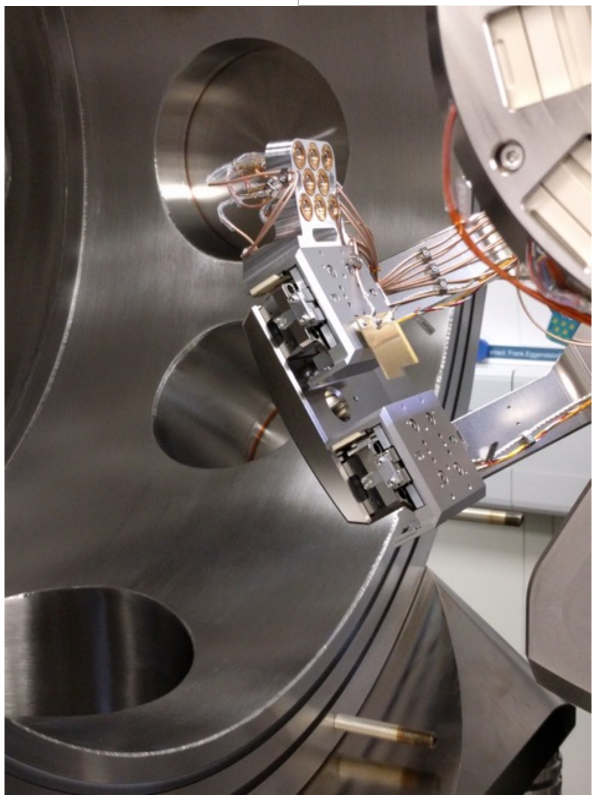
BESSY-II Optic Beamline and Reflectometer

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



HZB Helmholtz Zentrum Berlin





BESSY-II Optic Beamline and Reflectometer

- Incidence angle θ: -90° – 90°
- Detector in-plane 2θ: -180° – 180°
- Detector off-plane χ : -4° – 4°
- Sample – detector: 310 mm
- Six axes sample positioning
- Sample current measurement
- GaAsP-Photodiodes
- Detector slits, pinholes

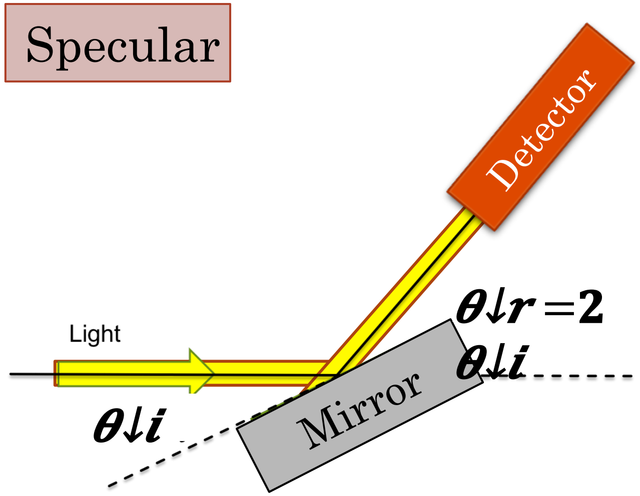
A.A.Sokolov,et al,Proc.of SPIE92060J-1-13(2014)

Bessy II Measurements

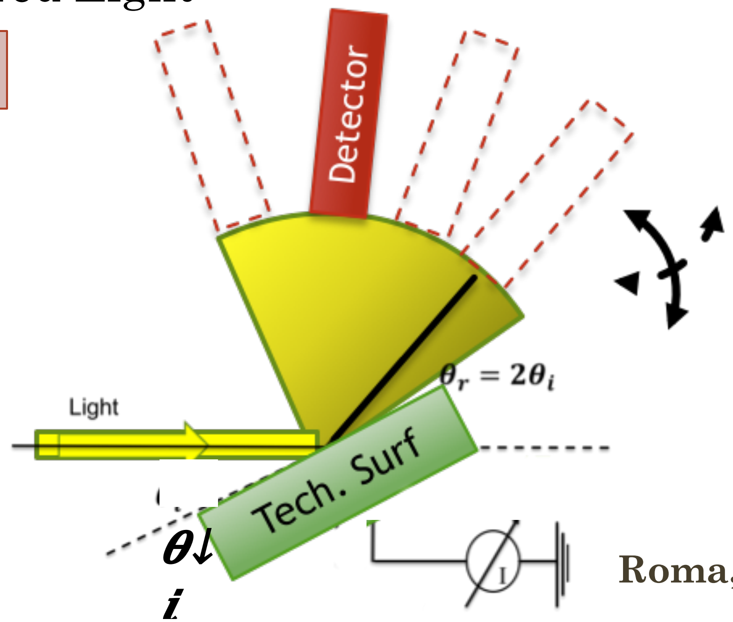
- Photon Energy range 35÷1800 eV
- Beam height h=0.3 mm
- Incident Beam measurement
- GaAsP Photodiodes (4x4mm) (0.12*4mm)
- Incidence angle 0.25, 0.5, 1 deg
- Reflectivity measurement → Specular Reflectivity; Scattered Light

Photo Yield:
PY= N_e/N_γ

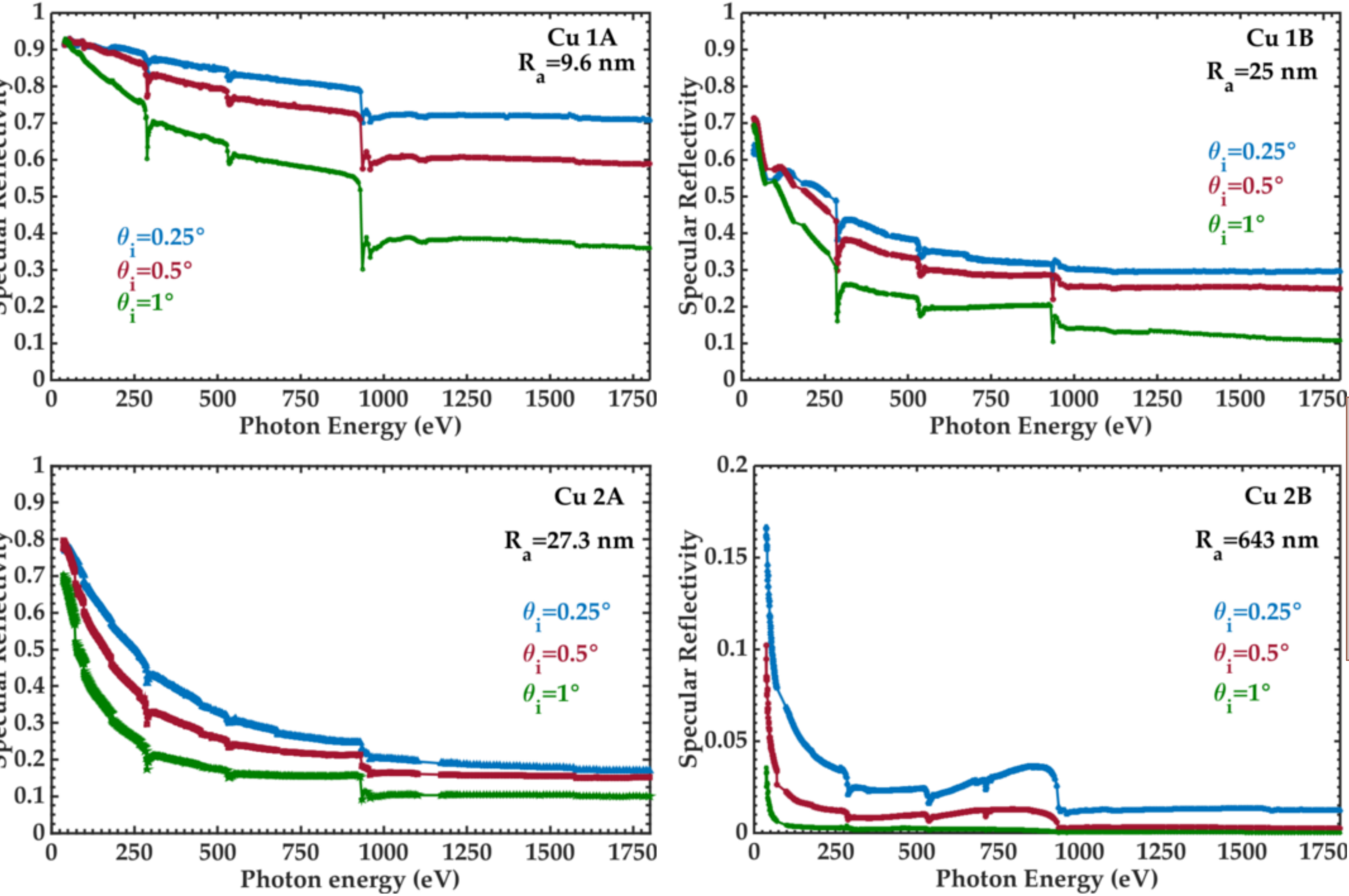
Specular

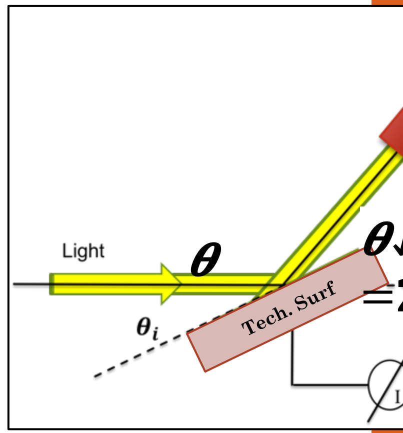


Total



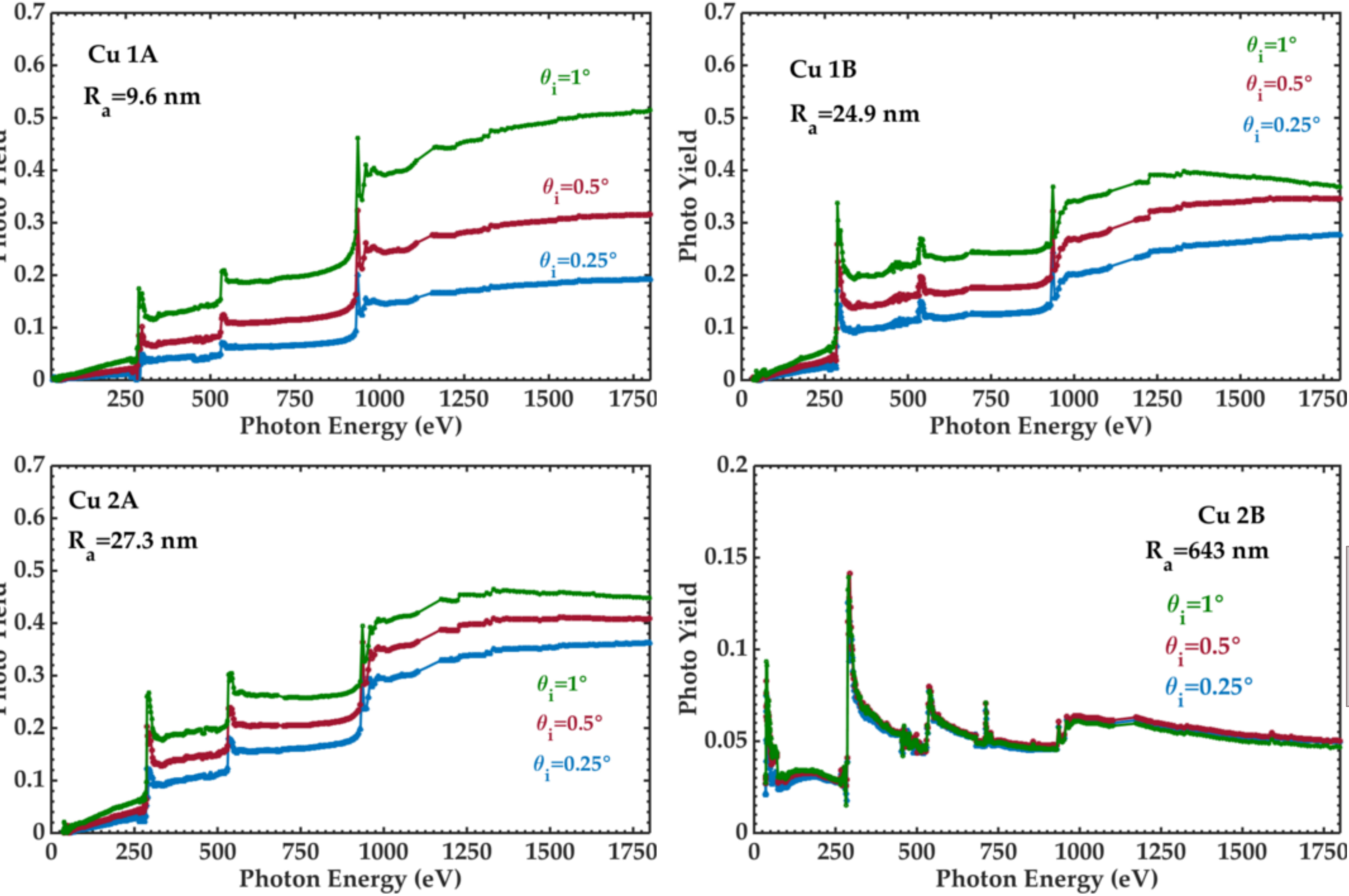
Flat Copper Samples





At grazing inciden angle contaminant are influencing Cu Reflectivity

Flat Copper Samples



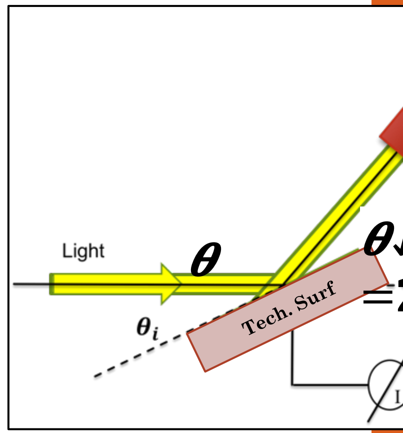
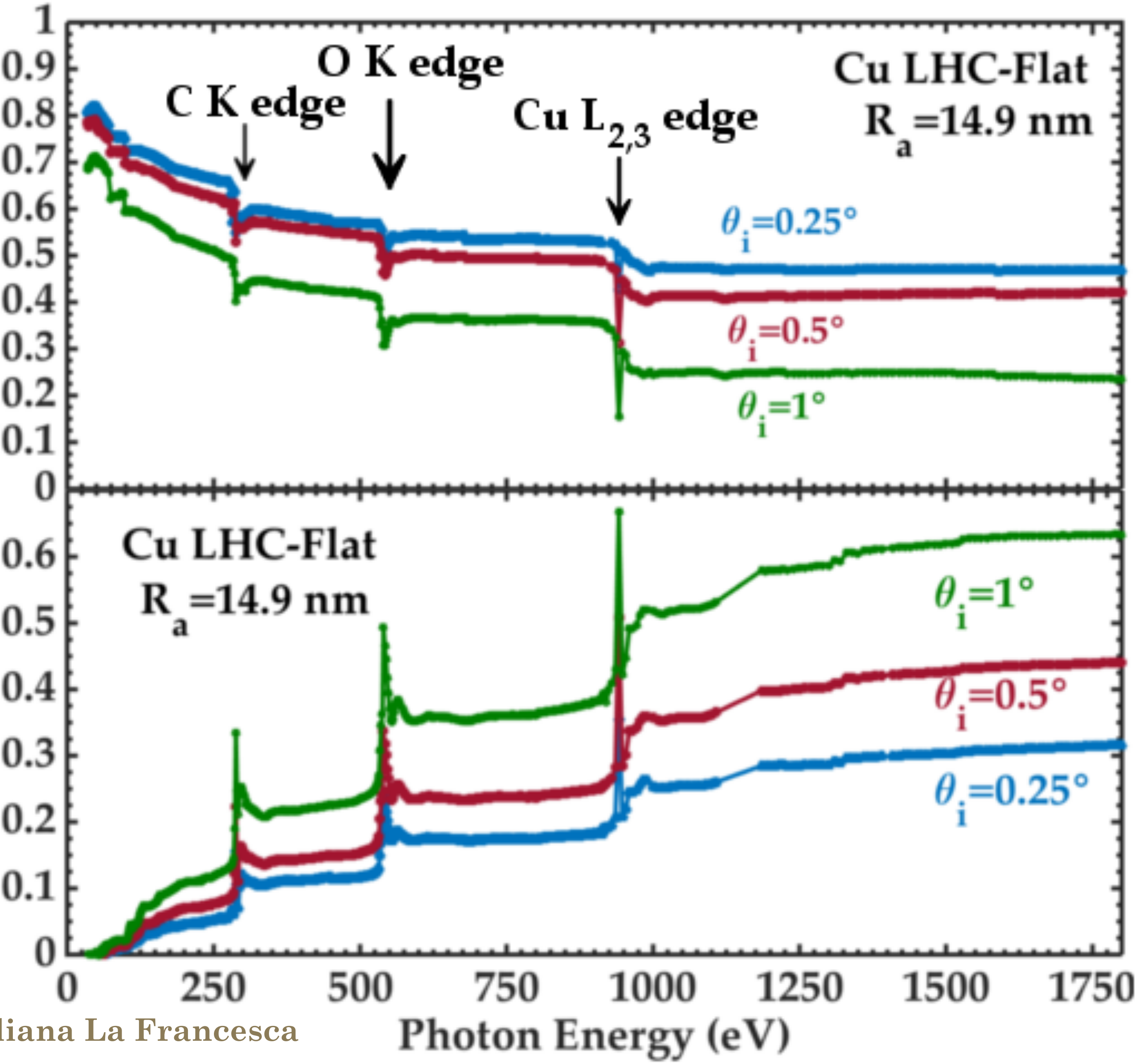


Photo Yield:
PY= N_e/N_γ

Peaks correspor
to absorption ed

LHC-Flat



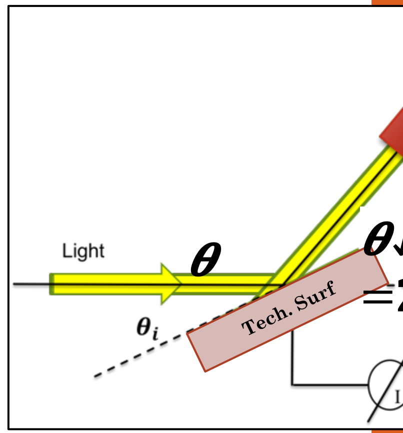
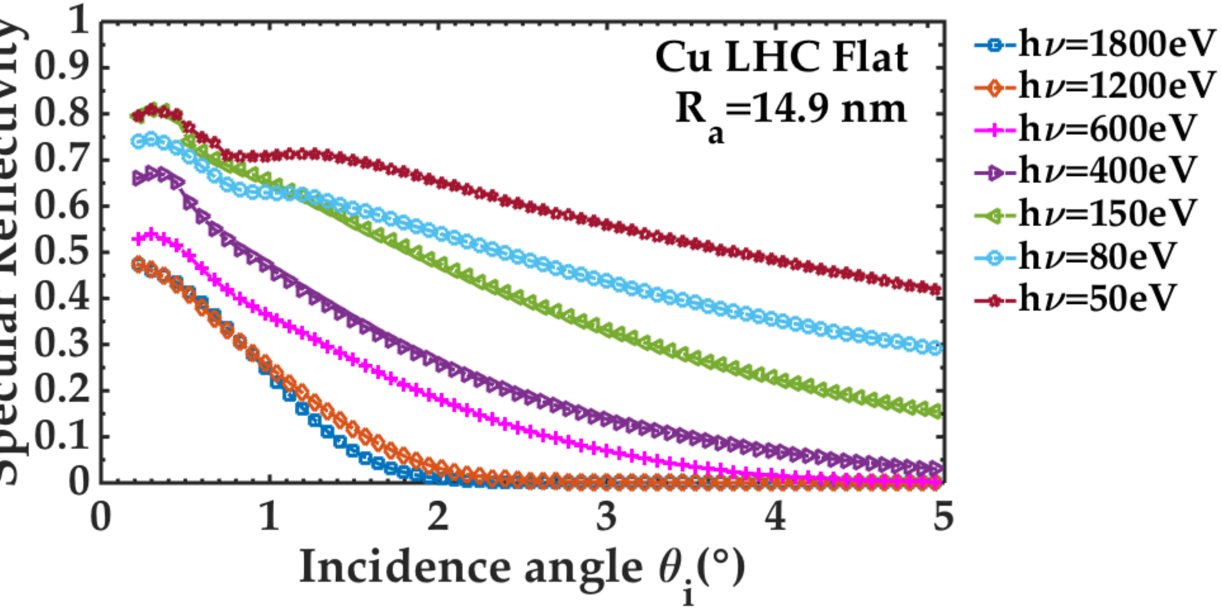


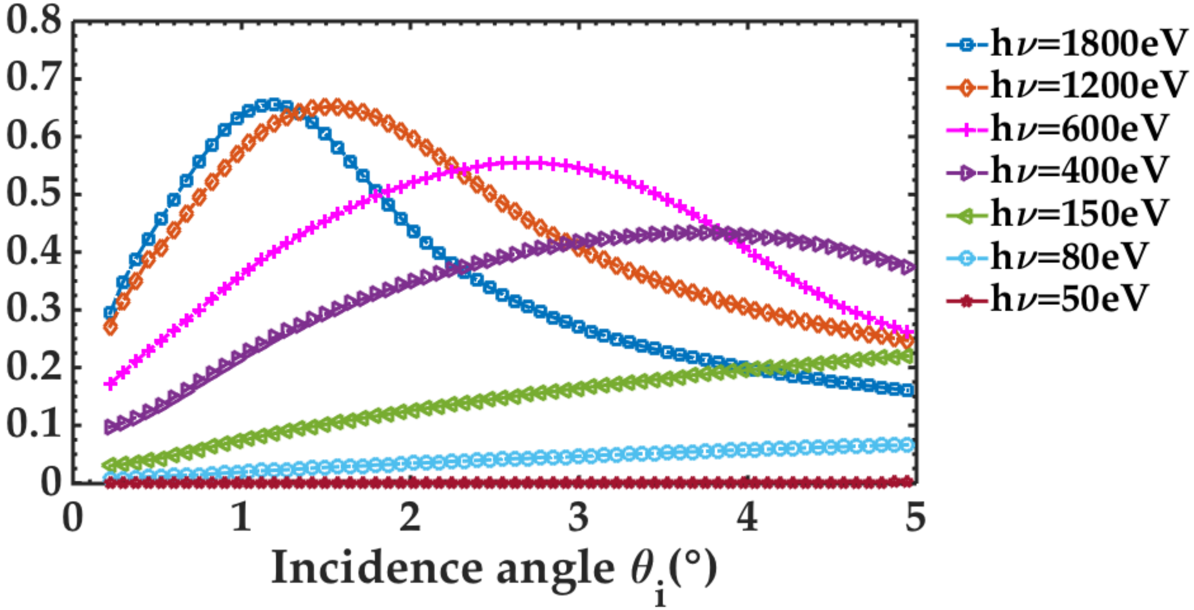
Photo Yield:
PY= N_e/N_γ

At grazing incidence angle contaminants are influencing Cu Reflectivity

Peaks correspond to absorption edges

LHC-Flat





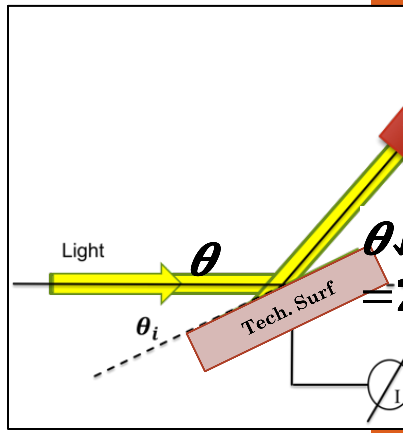
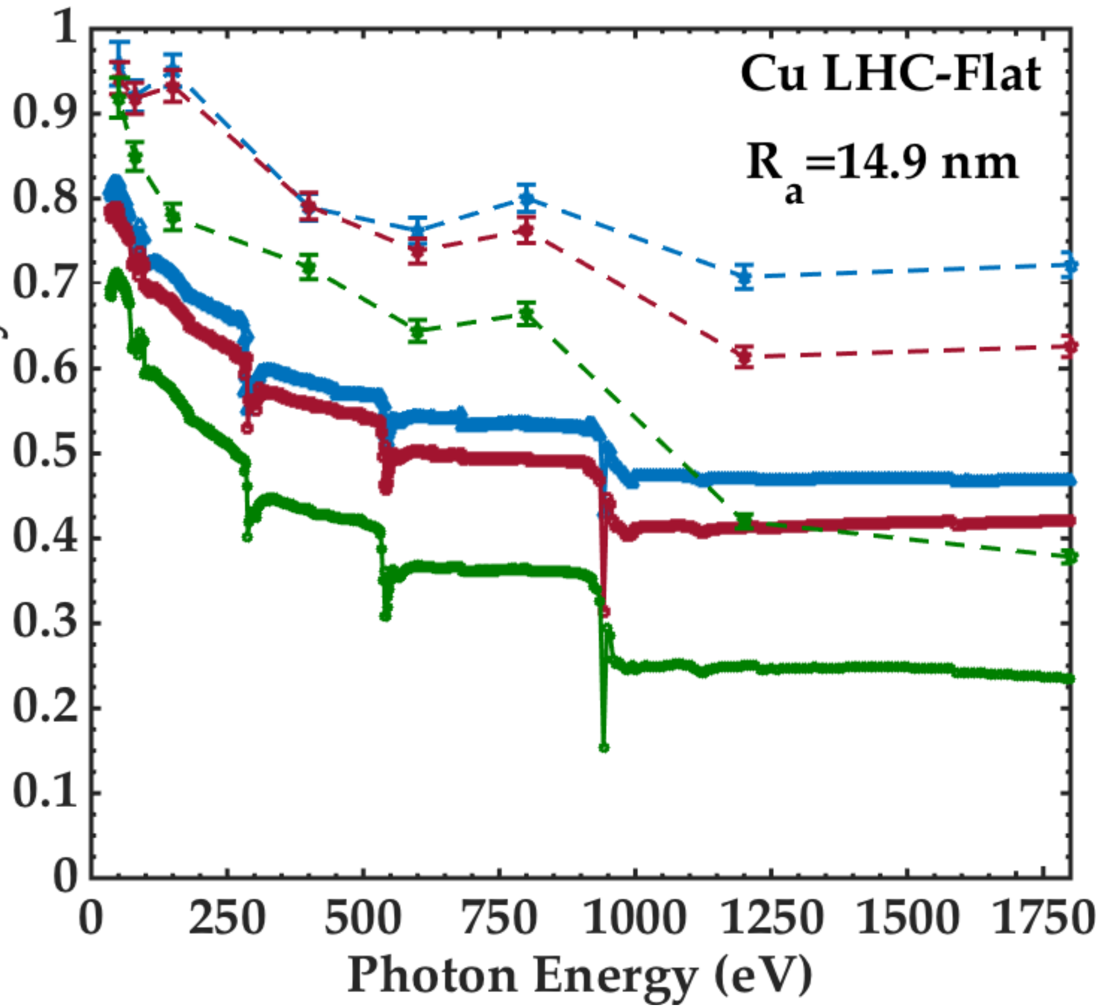
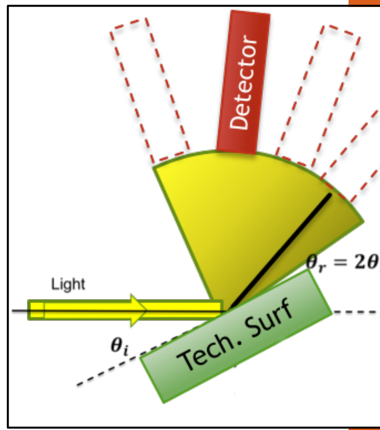


Photo Yield:
PY= N_e/N_γ

Low energy photons can be reflected even at high incidence angles

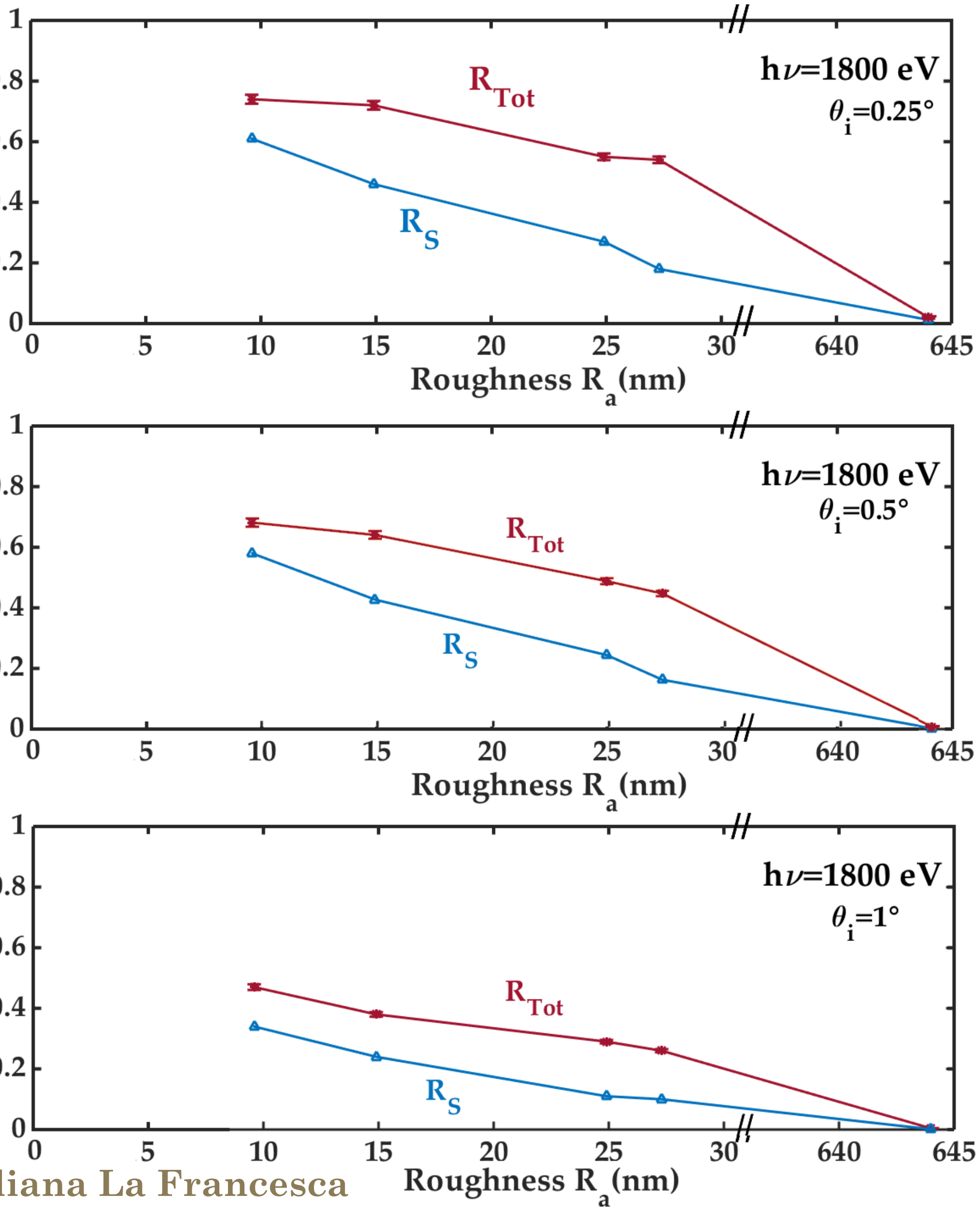
Specular and Total Reflectivity

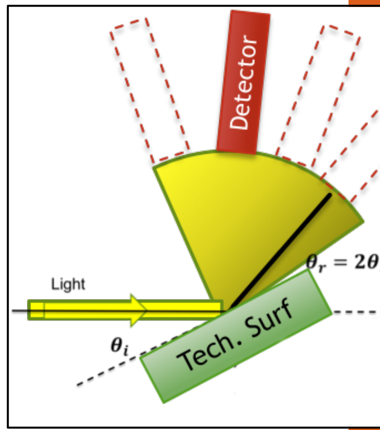


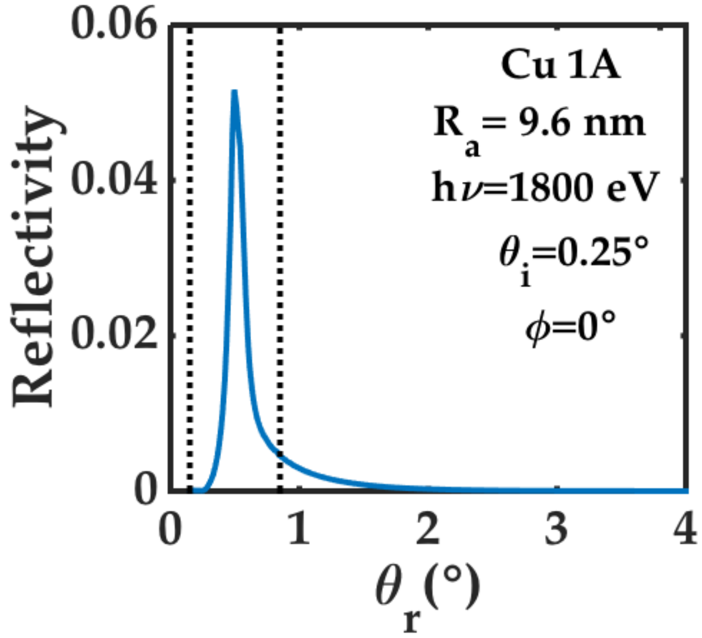


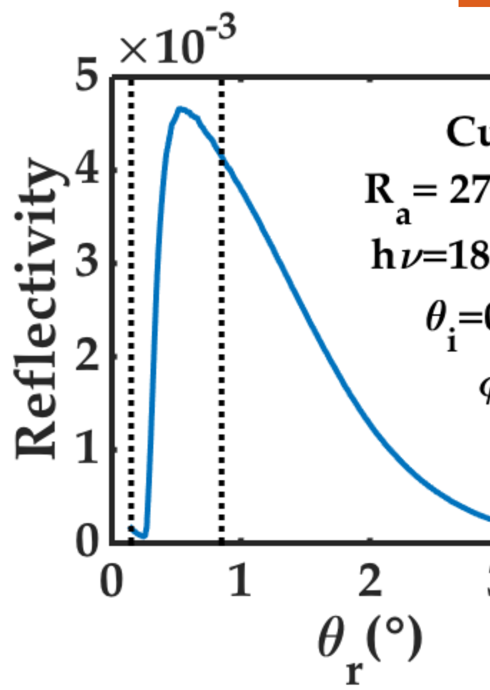
Photon energy $h\nu$(eV)	Total Reflec. $\theta_i = 0.25°$ ($\pm 2\%$)	Specular Reflec. $\theta_i = 0.25°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 0.5°$ ($\pm 2\%$)	Specular Reflec. $\theta_i = 0.5°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 1°$ ($\pm 2\%$)
1800	0.722	0.468	0.627	0.421	0.378
1200	0.708	0.470	0.614	0.413	0.420
800	0.801	0.535	0.763	0.494	0.664
600	0.762	0.543	0.738	0.503	0.644
400	0.790	0.586	0.791	0.560	0.720
150	0.951	0.712	0.933	0.678	0.778
80	0.921	0.755	0.918	0.725	0.850
50	0.959	0.815	0.942	0.785	0.919

Specular and Total Reflectivity

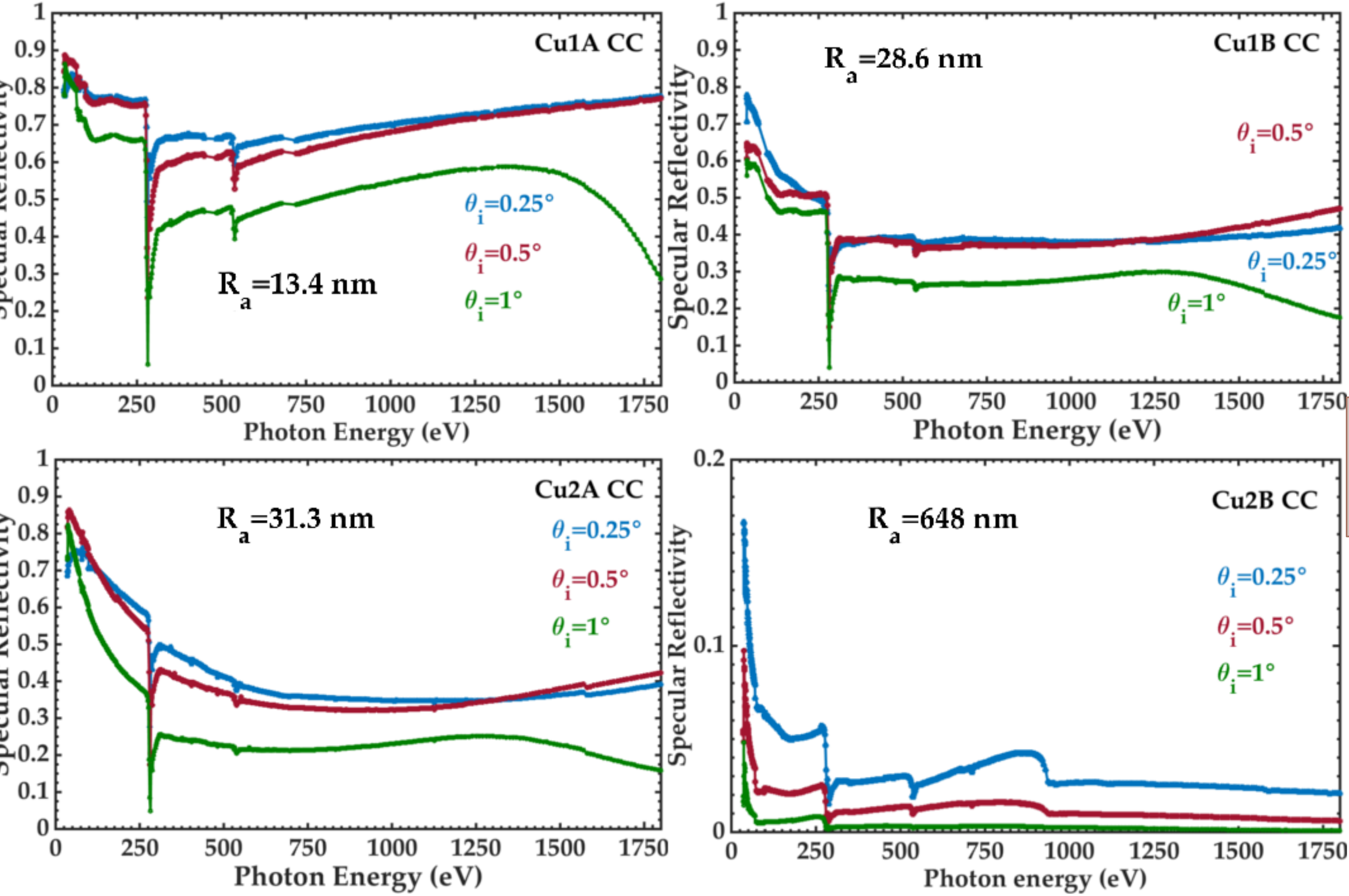


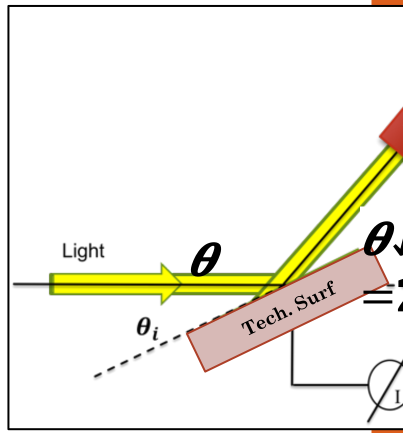






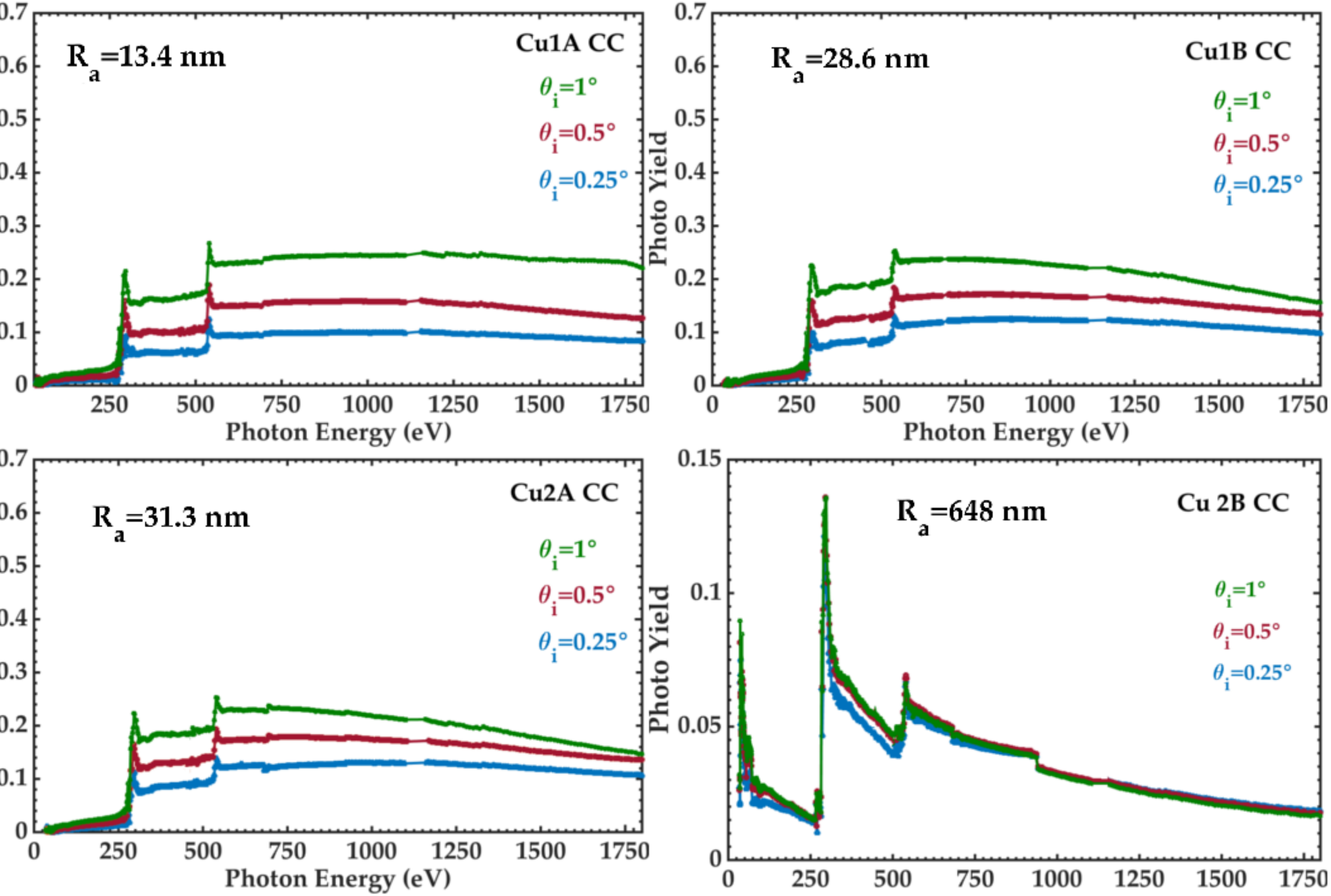
Cu Samples with C Coating

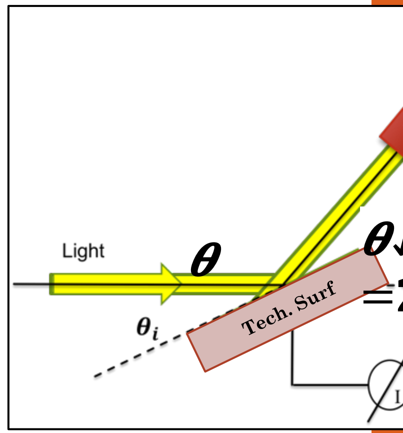




Coating process increased roughne

Cu Samples with C Coating

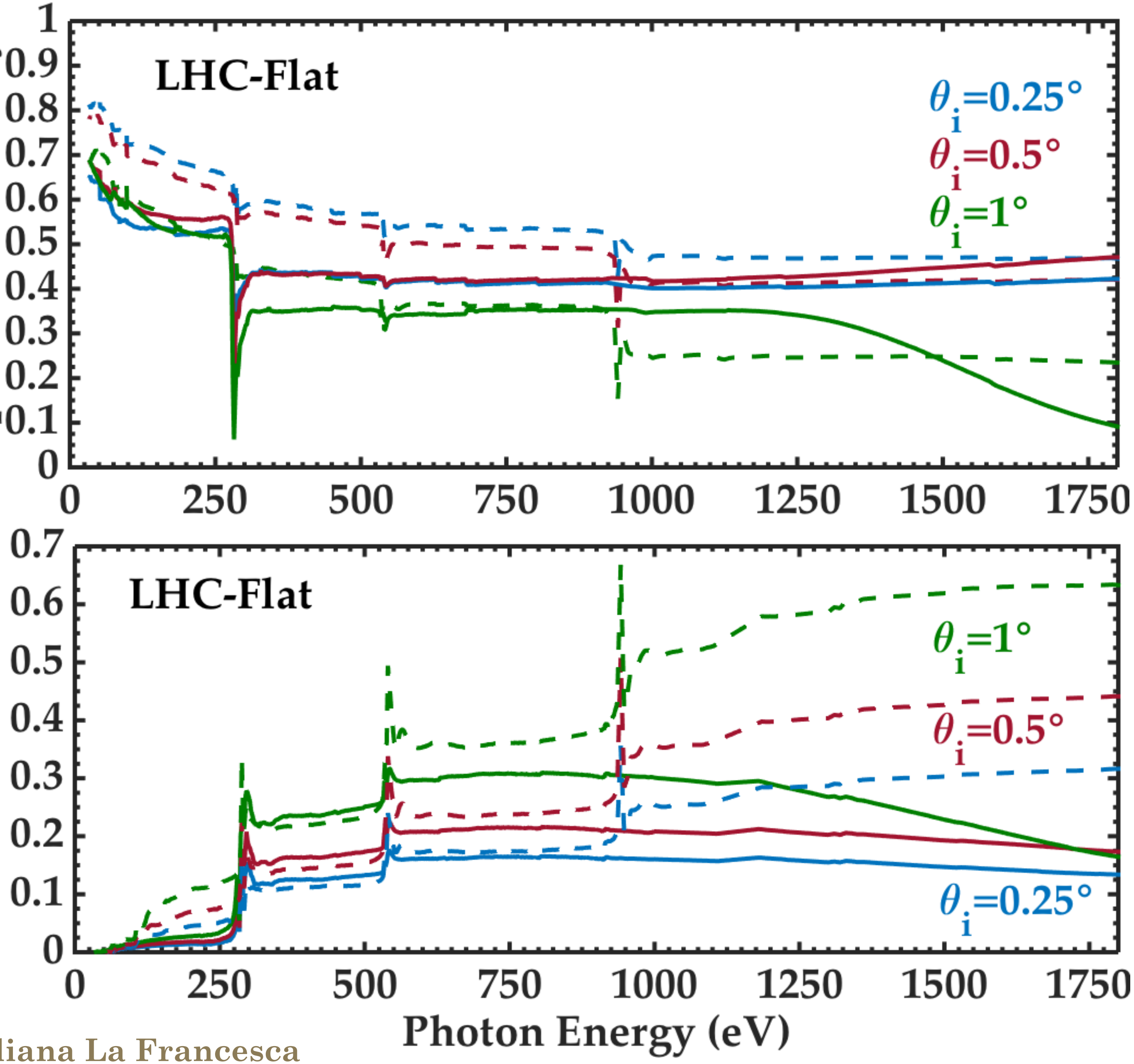


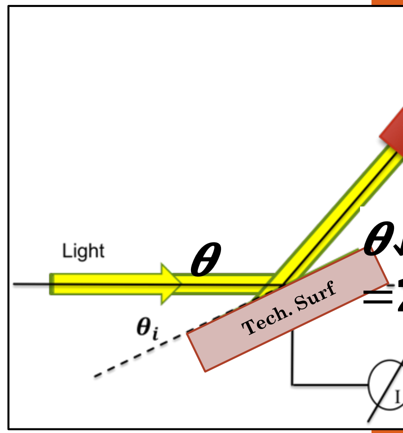


Peaks correspon
to absorption ed

Carbon coating
reduces
Photo Yield at h
energy

LHC-Flat with C Coating





Decreasing of reflectivity at $\theta_i=1°$ is due to the achievemer of the critical angle.

Peaks correspond to absorption edges

LHC-Flat with C Coating

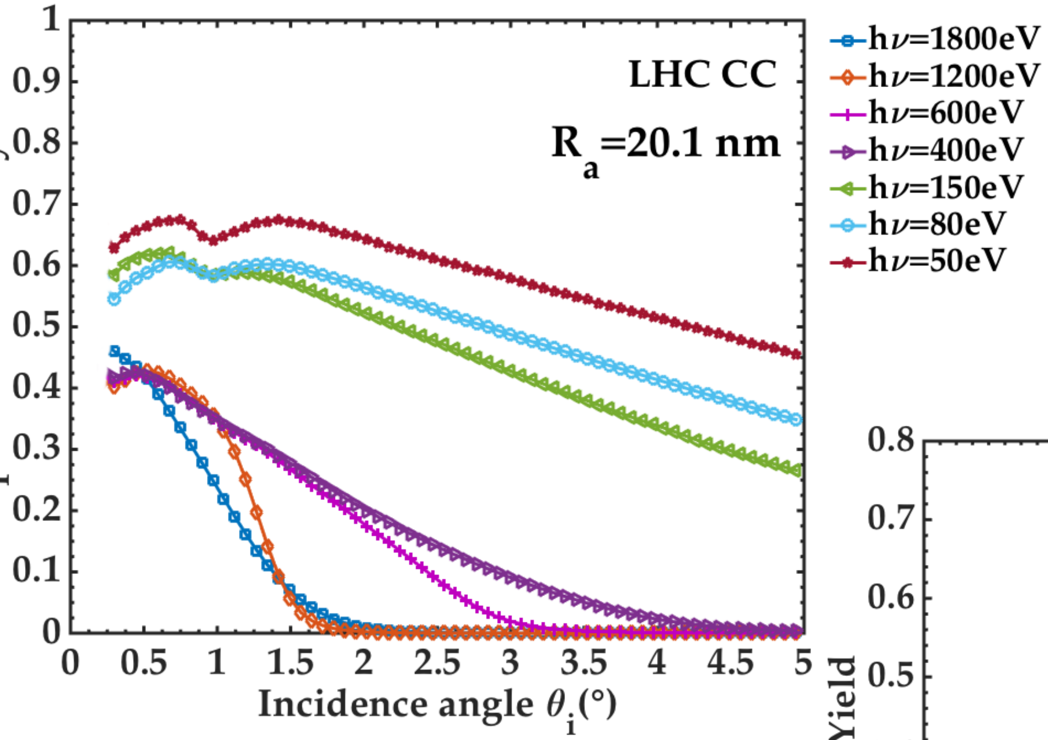
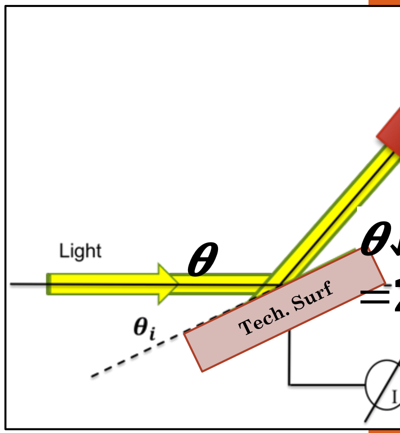
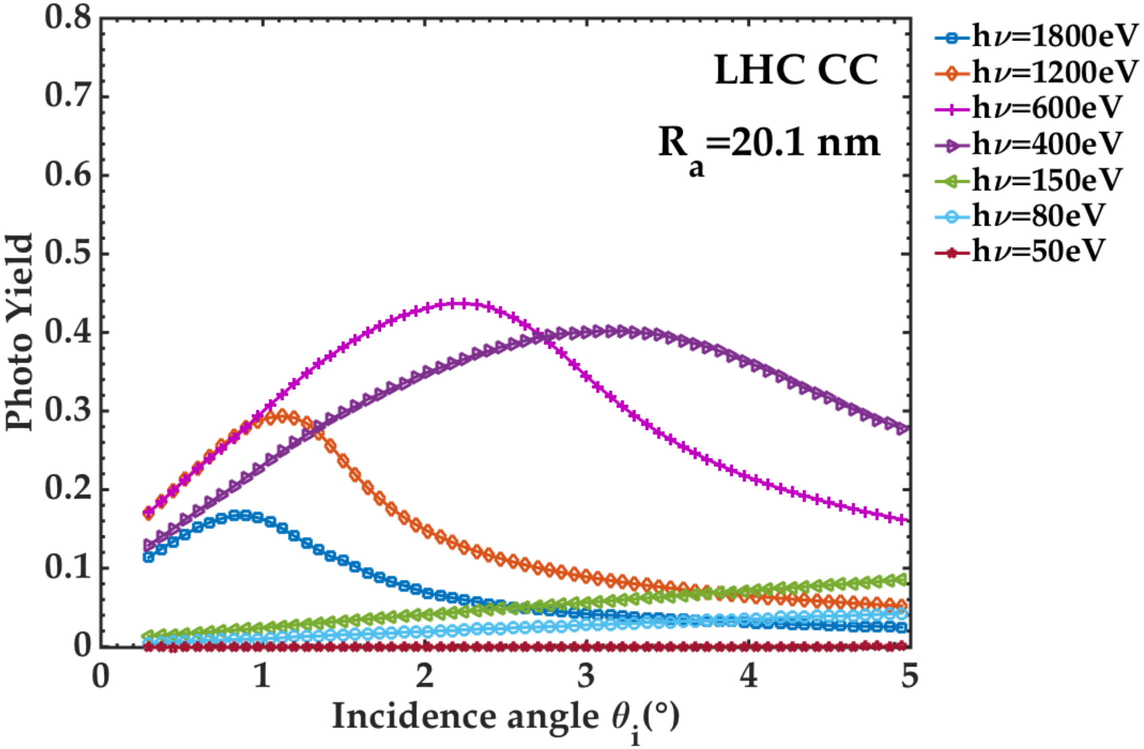
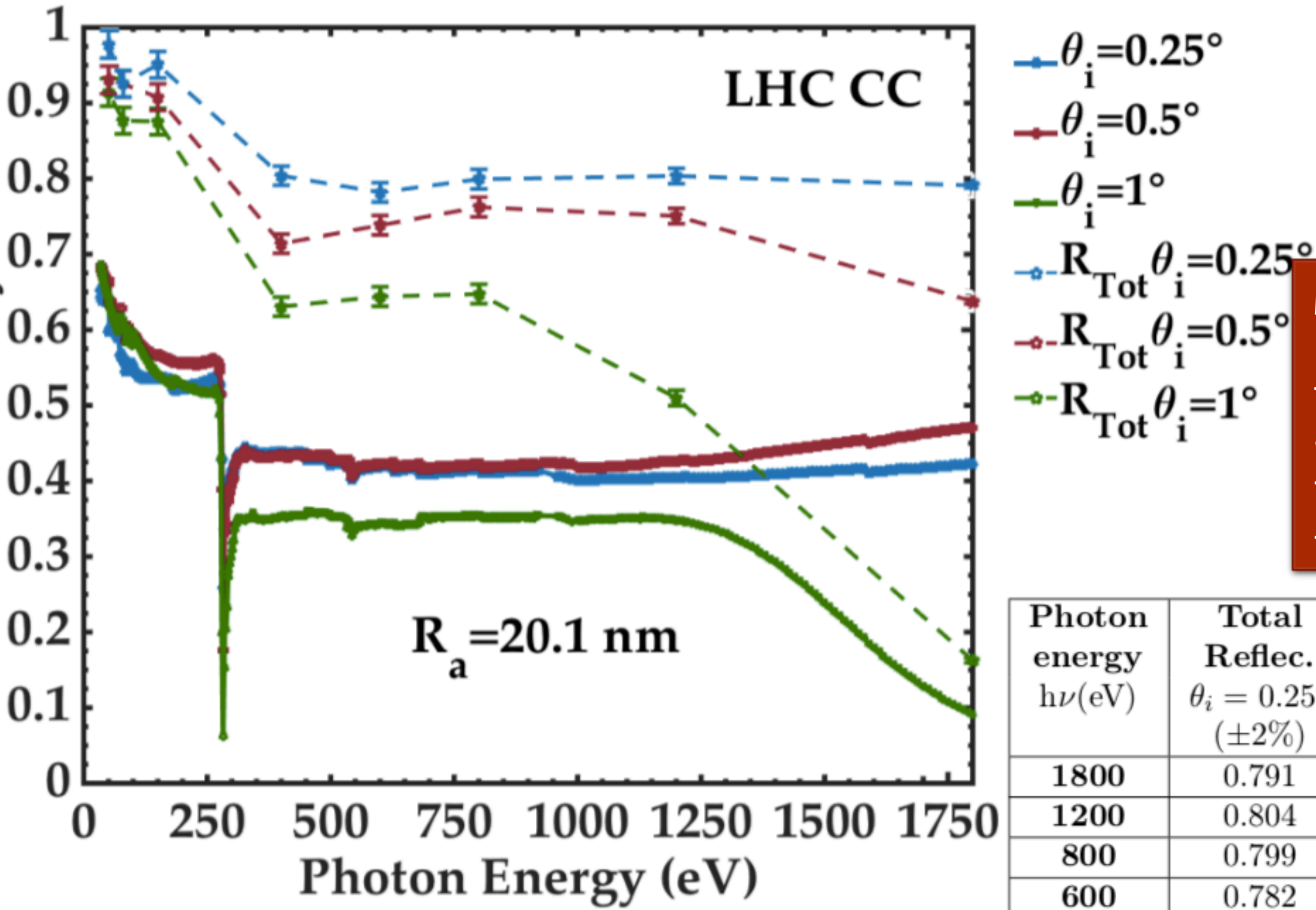


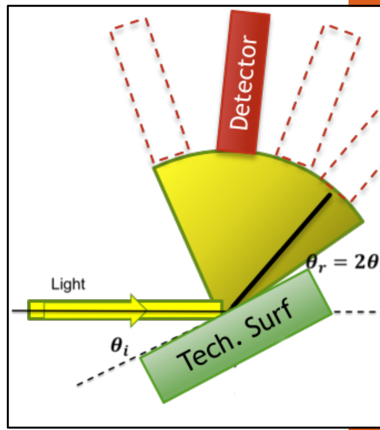
Photo Yield:
PY= N_e/N_γ





Specular and Total Reflectivity

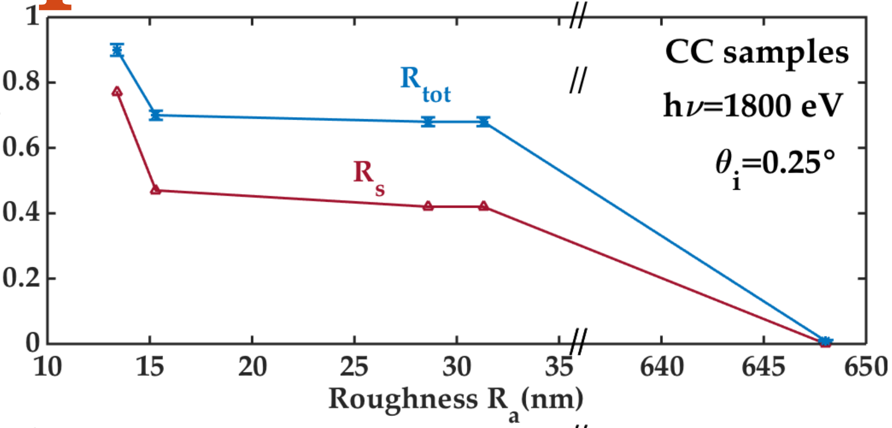


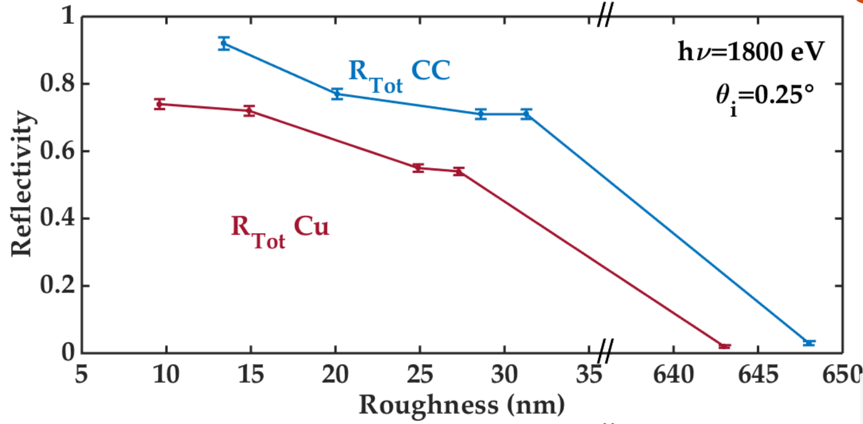


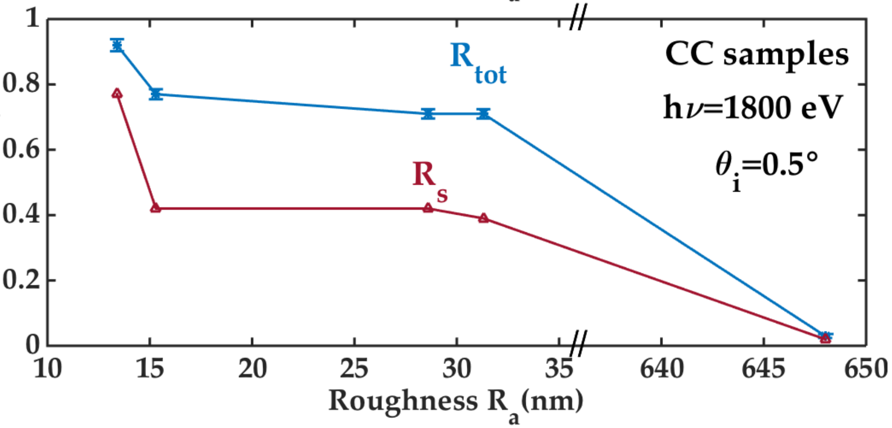
Total Reflectivity higher than Specular Reflectivity

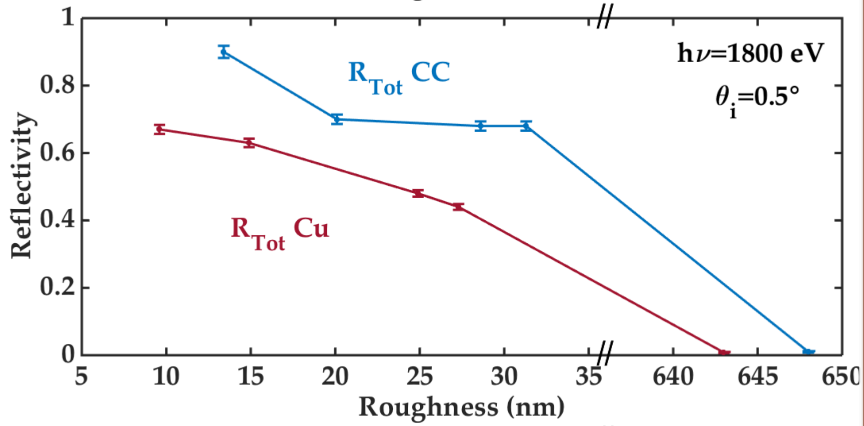
Photon energy hν(eV)	Total Reflec. $\theta_i = 0.25°$ (±2%)	Specular Reflec. $\theta_i = 0.25°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 0.5°$ (±2%)	Specular Reflec. $\theta_i = 0.5°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 1°$ (±2%)	Sp R θ (±
1800	0.791	0.422	0.670	0.471	0.453	
1200	0.804	0.426	0.751	0.405	0.510	
800	0.799	0.423	0.762	0.415	0.647	
600	0.782	0.419	0.738	0.423	0.644	
400	0.804	0.438	0.714	0.434	0.631	
150	0.951	0.541	0.908	0.540	0.876	
80	0.926	0.561	0.925	0.605	0.877	
50	0.977	0.636	0.931	0.663	0.914	

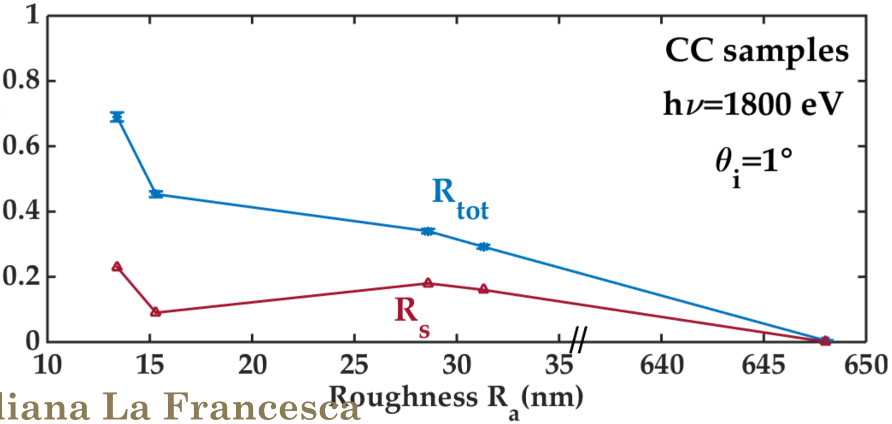
Specular and Total Reflectivity

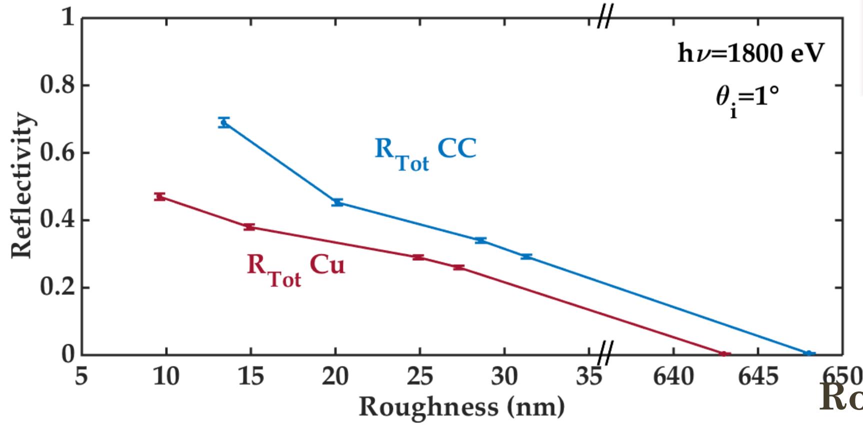


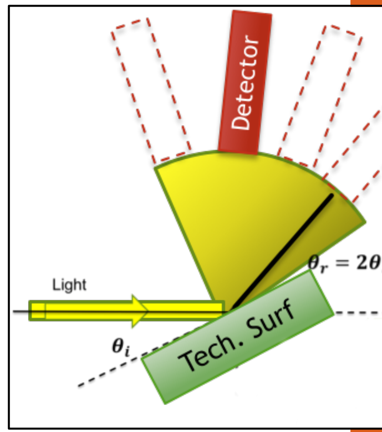






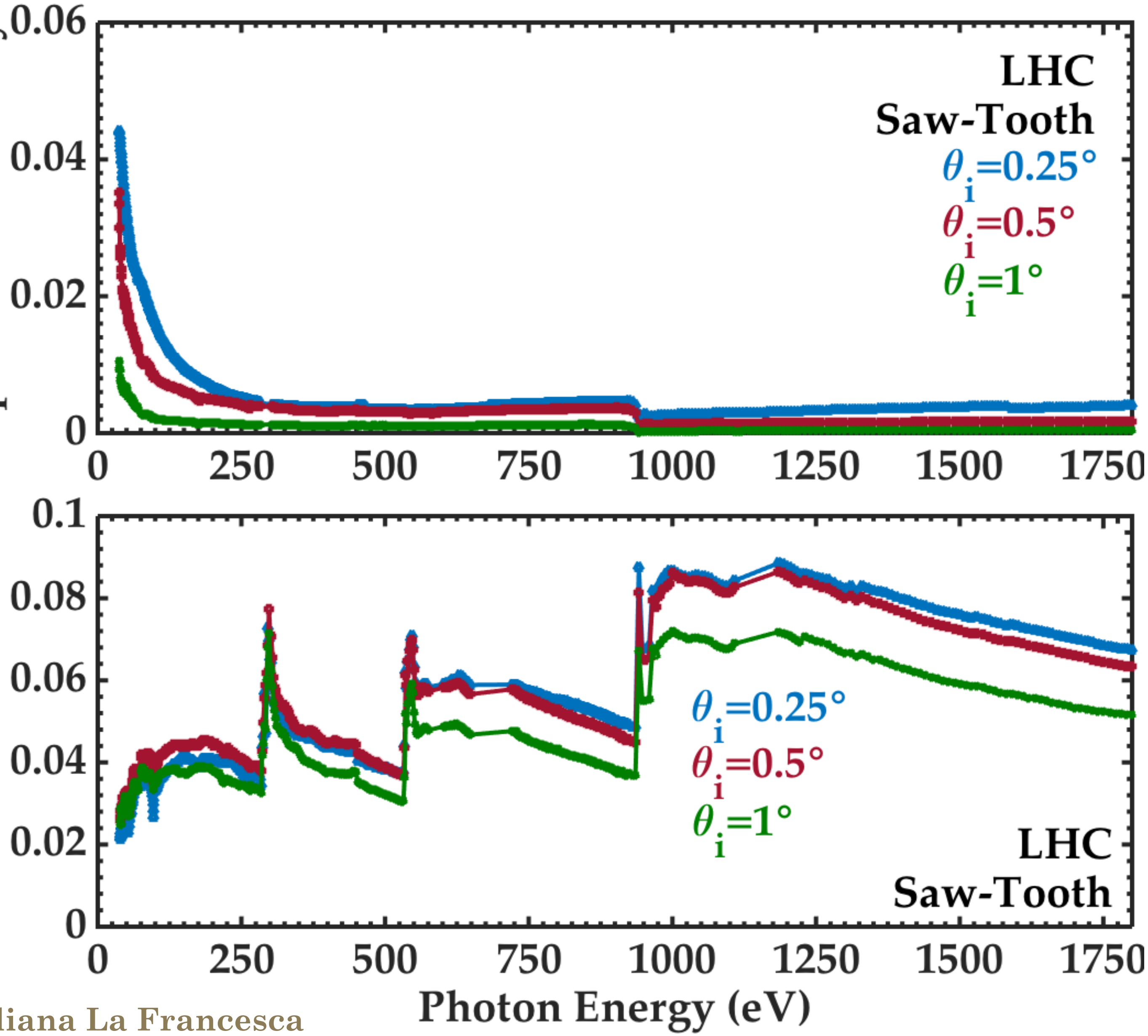


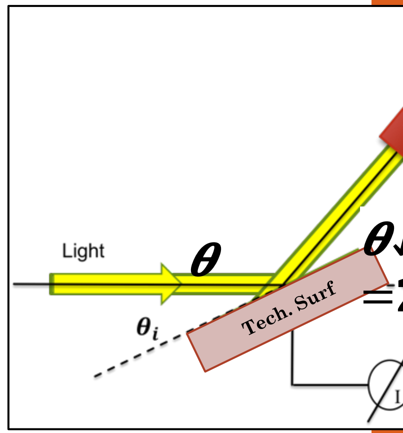




CC increases Total Reflecti
and reduce absorption an
related Heat Load.

LHC Saw-Tooth

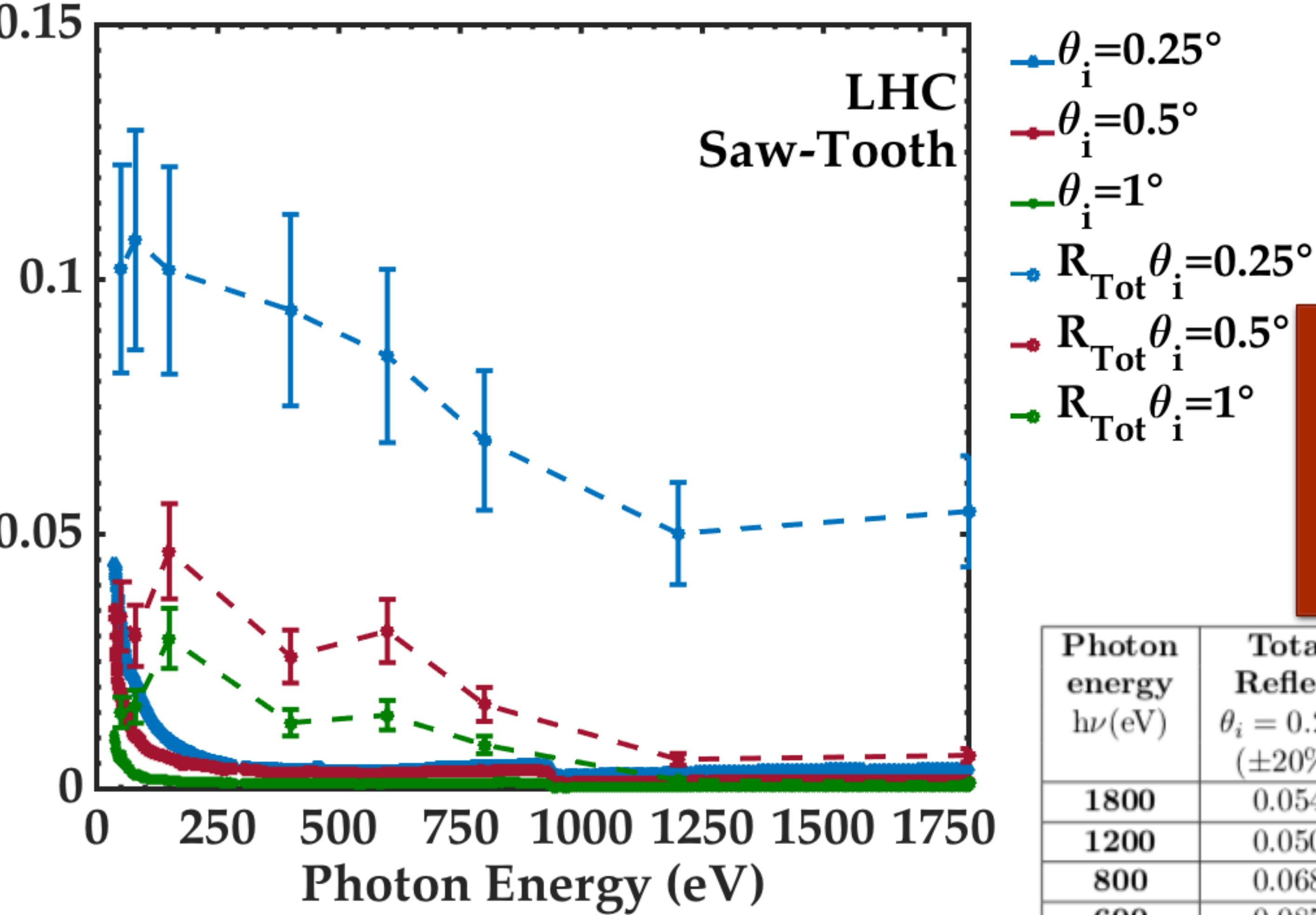


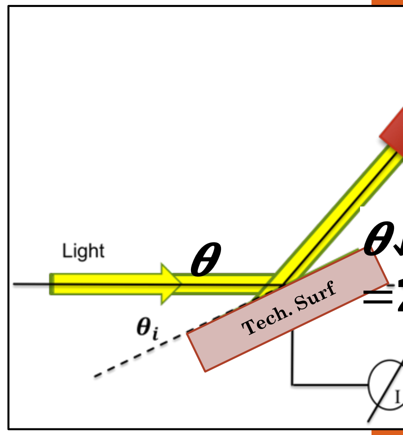


PY peaks confirm the contaminants presence

Little difference in PY for the three incidence angle

LHC Saw-Tooth

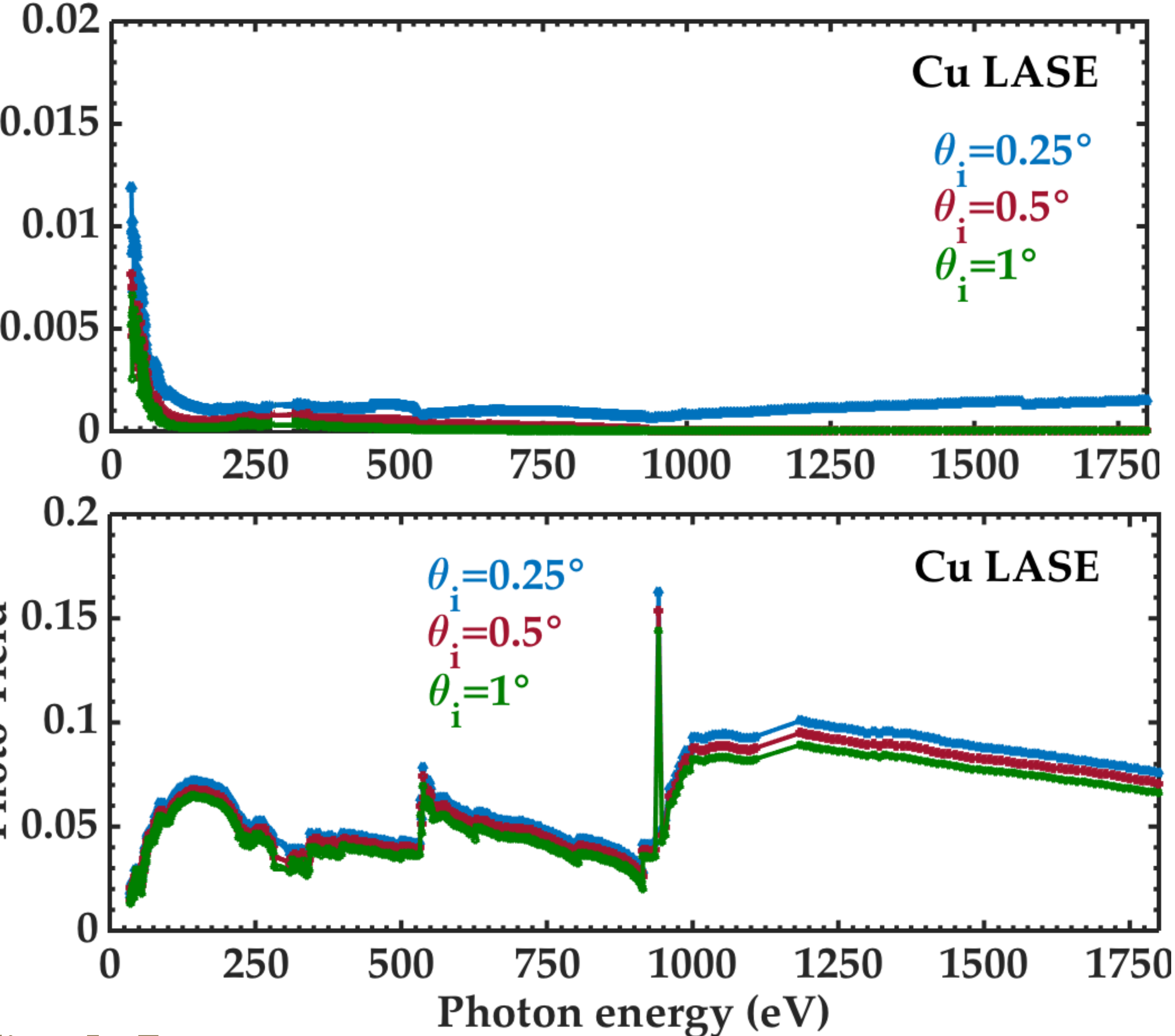


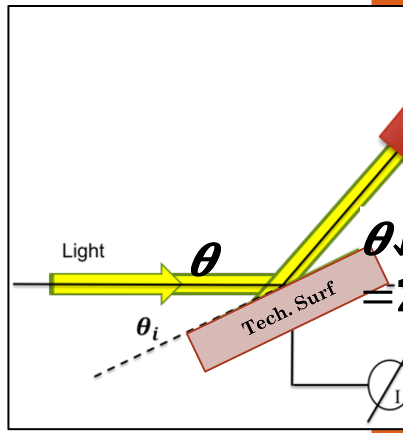


Total Reflectivity higher than Specular Reflectivity

Photon energy $h\nu$(eV)	Total Reflec. $\theta_i = 0.25°$ ($\pm$20%)	Specular Reflec. $\theta_i = 0.25°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 0.5°$ ($\pm$20%)	Specular Reflec. $\theta_i = 0.5°$ ($\pm 10^{-5}$)	Total Reflec. $\theta_i = 1°$ ($\pm$20%)	S…
1800	0.054	0.0004	0.007	0.0017	0.001	
1200	0.050	0.0030	0.006	0.0015	0.002	
800	0.068	0.0044	0.017	0.0035	0.009	
600	0.085	0.0035	0.031	0.003	0.014	
400	0.094	0.0038	0.026	0.003	0.013	
150	0.102	0.0096	0.047	0.006	0.029	
80	0.108	0.021	0.030	0.010	0.016	
50	0.102	0.032	0.034	0.019	0.015	

LASE

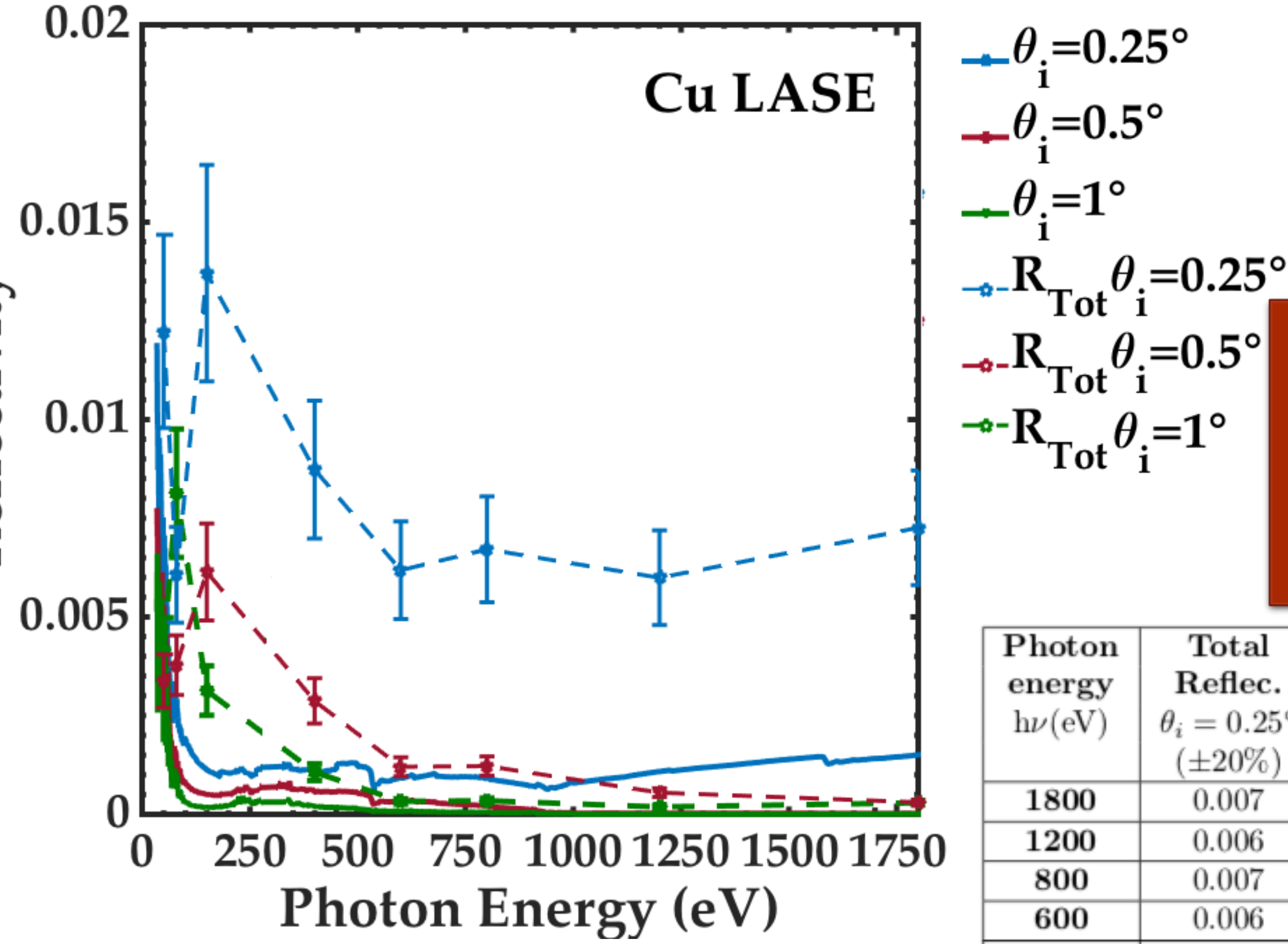


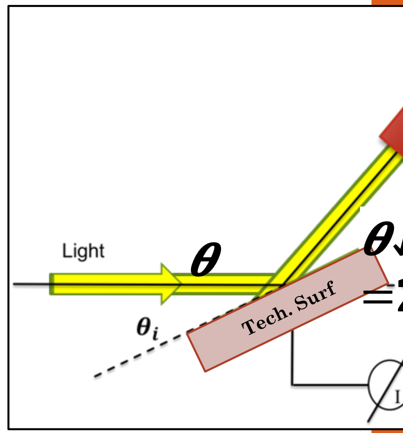


No difference in PY for the three incidence angle

No carbon evidence

LASE

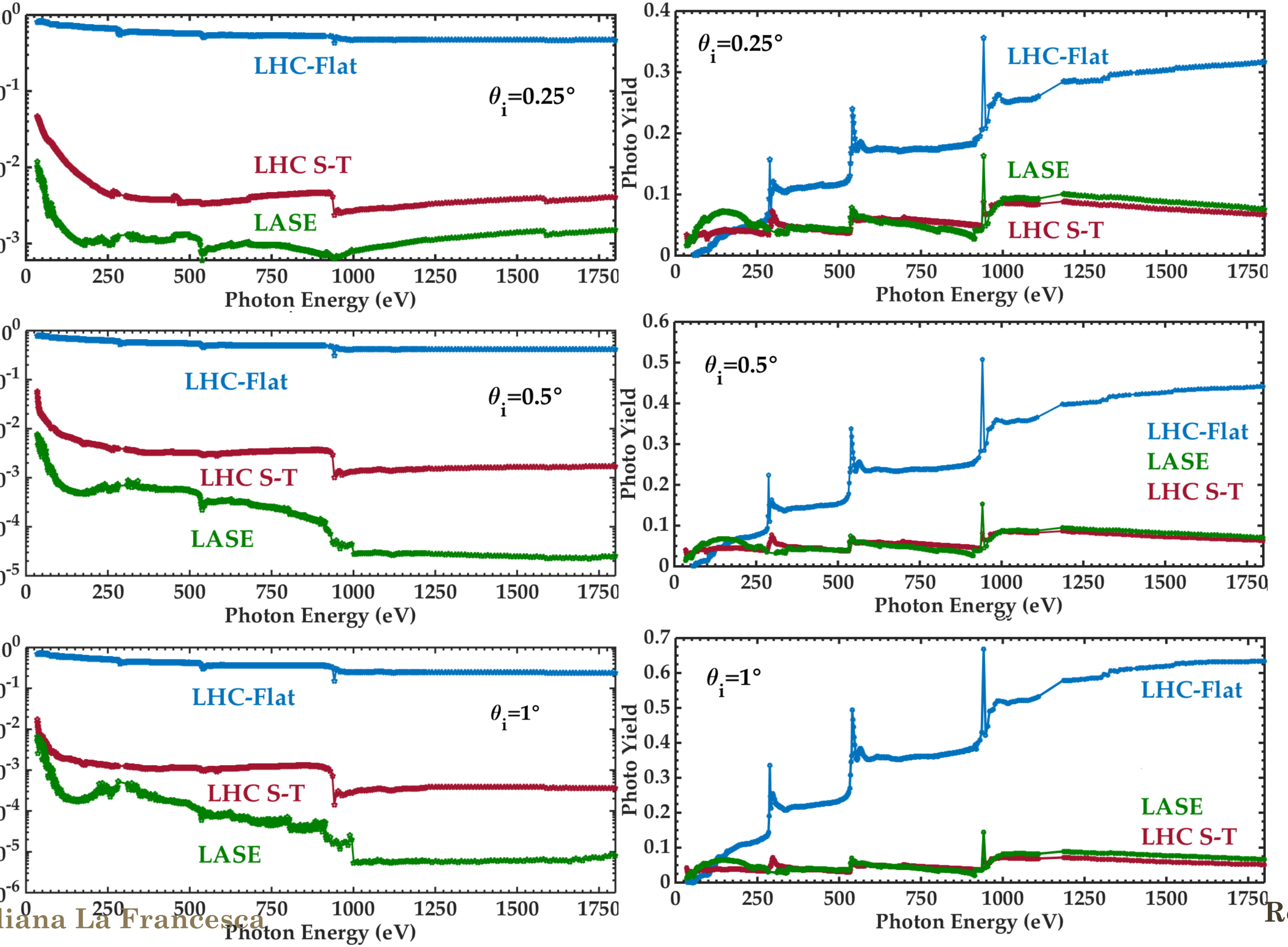




Total Reflectivity higher than Specular Reflectivity

Photon energy $h\nu$(eV)	Total Reflec. $\theta_i = 0.25°$ (±20%)	Specular Reflec. $\theta_i = 0.25°$ ($\pm10^{-5}$)	Total Reflec. $\theta_i = 0.5°$ (±20%)	Specular Reflec. $\theta_i = 0.5°$ ($\pm10^{-5}$)	Total Reflec. $\theta_i = 1°$ (±20%)	Spe Re θ_i (±
1800	0.007	0.0015	0.0003	$2.5 \cdot 10^{-5}$	0.0003	8.1
1200	0.006	0.0011	0.0005	$2.8 \cdot 10^{-5}$	0.0002	6.1
800	0.007	0.0009	0.001	0.0002	0.0003	5.3
600	0.006	0.0009	0.001	0.0003	0.0003	7.6
400	0.009	0.001	0.003	0.0005	0.001	0.
150	0.014	0.001	0.006	0.0005	0.002	0.
80	0.011	0.003	0.004	0.001	0.008	0.
50	0.012	0.006	0.005	0.004	0.004	0

Surface modification effects



LHC S-T Specular Reflectiviy one order o magnitude lower than LASE.

Photo Yield of LHC S-T and LASE are the sar

Conclusions

- At grazing incidence angle air contaminants deeply influence Reflectivity.
- For technical surfaces scattered light cannot be neglected.
- Photo Yield does not significantly depend on roughness.
- Carbon coating increases Total Reflectivity and reduce absorption and related Heat Load (as long as incidence angle is below its critical angle).
- Cu LASE Reflectivity is substantially lower than for untreated copper and for LHC Saw-Tooth sample.
- The Photo Yield of Saw-Toothed copper and LASE are the same.
- Experimental data are important to characterize SR behaviour and HL for all materials to be used in FCC-hh dipoles and IP.

Thank you for your attention.