CERN

In-situ a-C coating performance and status of LESS & tunnel implementation

P. Costa Pinto, V. Baglin, S. Calatroni, P. Chiggiato, P. Cruikshank, P. Demolon, H. Fjierli,C. Garion, B. Di Girolamo, L. Leggiero, H. Kos, N. Kos, H. Neupert, R. Salemme, M. Sitko, M. Taborelli, E. Valdiviesco, I. Wevers.

Outline

1. Introduction
2. In-situ a-C coating
3. Status of LESS
4. Status of tunnel implementation
5. Summary

1 – Introduction

Motivation: Reduce the heat load to the beam screens.

Lower the SEY
<1.1

Reduce e-cloud
Without scrubbing

Decrease
heat load

Coat with a low SEY
carbon thin film

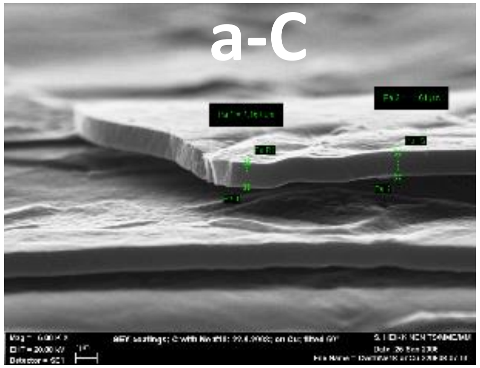
LESS
Laser Engineered Surface
Structures

1 – Introduction

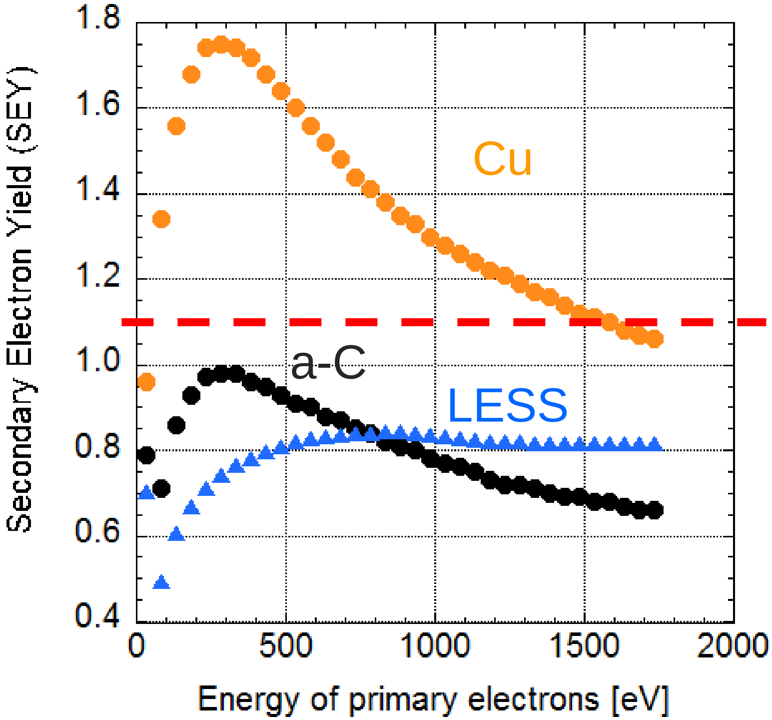
Motivation: Reduce the heat load to the beam screens.

Lower the SEY <1.1 → Reduce e-cloud → Decrease heat load

Without scrubbing



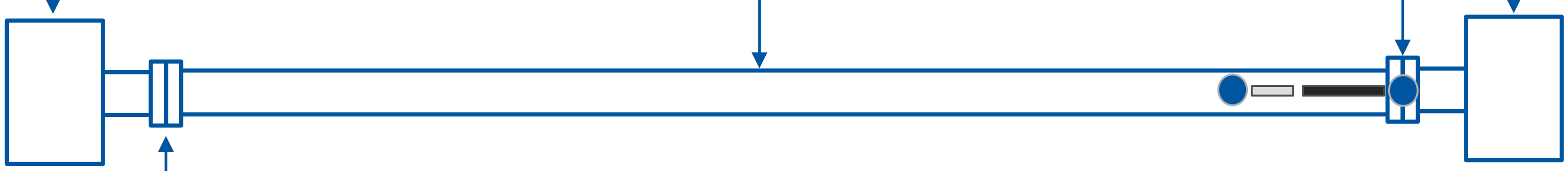
Low SEY results from the electronic properties

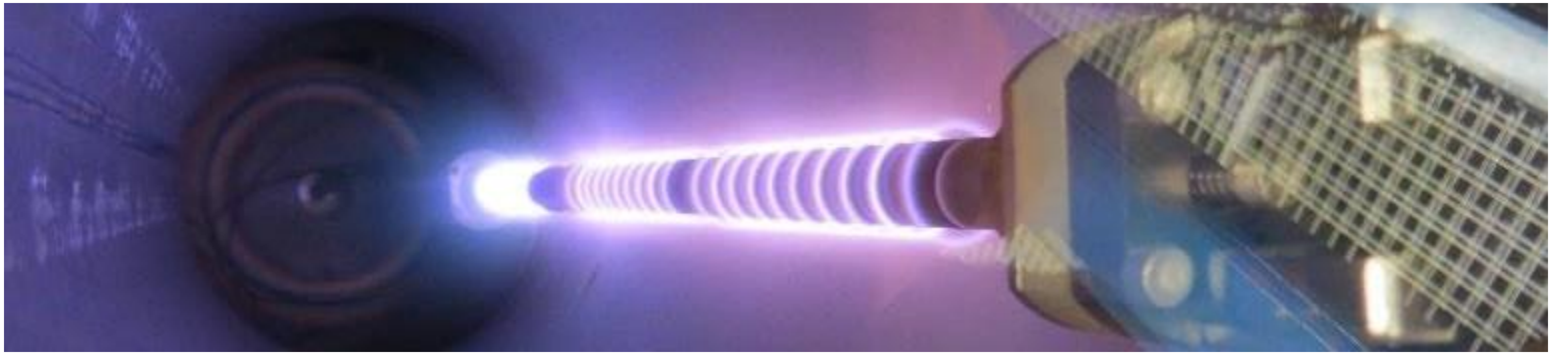


Low SEY is a morphological effect

2 – In-situ a-C coating

How it is done





2 – In-situ a-C coating

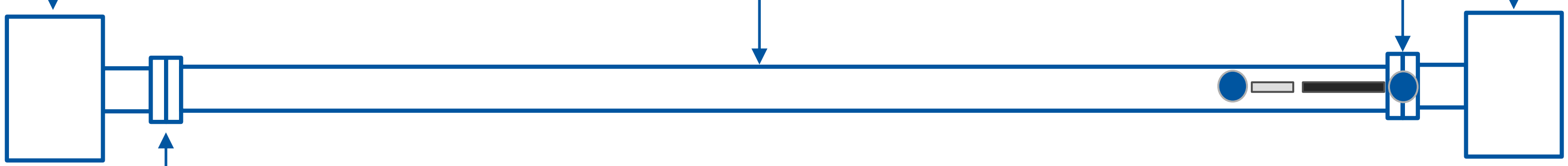
How it is done

1 spool for mechanical cable
+
2 spools for electrical cables

Cold bore + beam screen

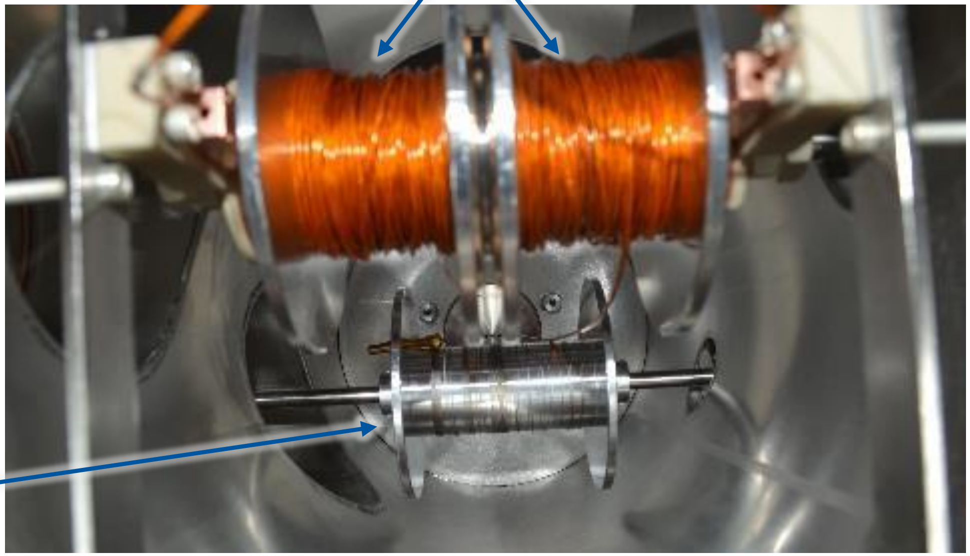
Ar injection

1 spool for mechanical cable



Turbo molecular pump

Electrical cables



mechanical cable

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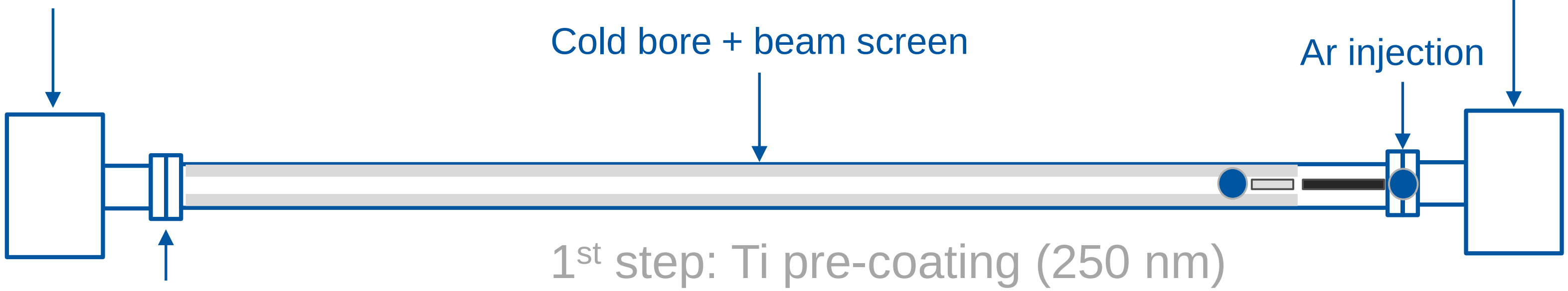
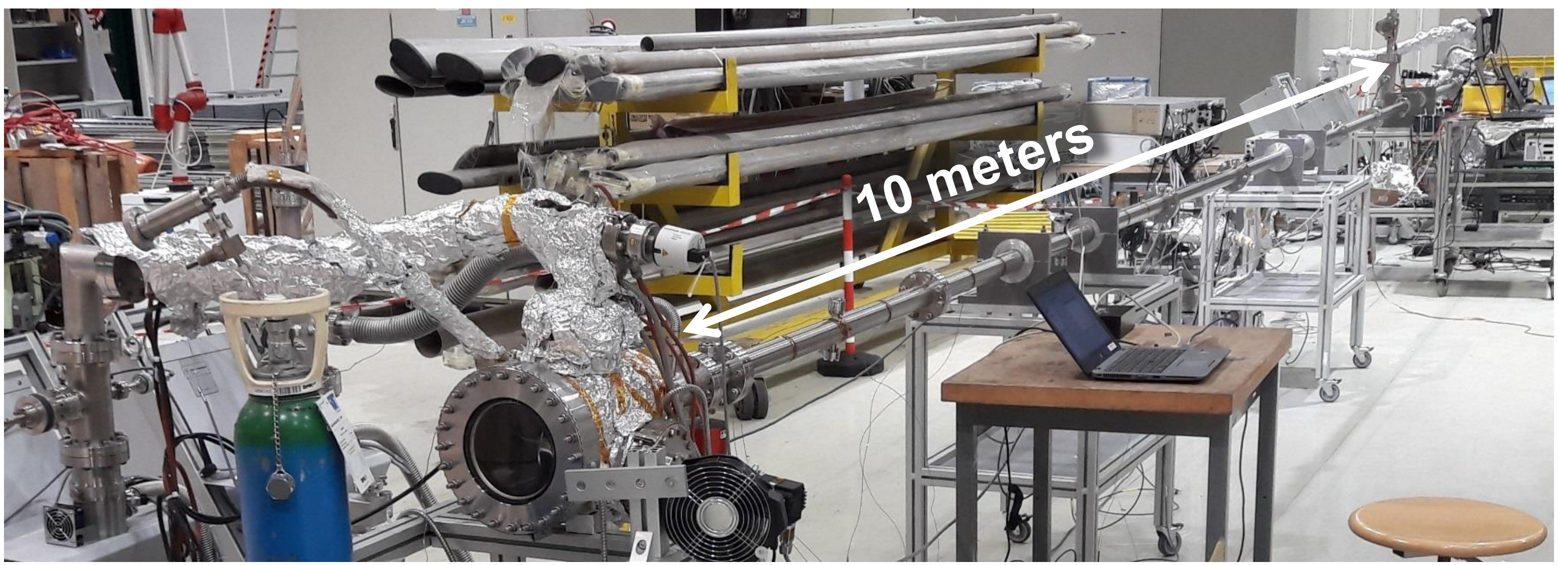
1 spool for mechanical cable



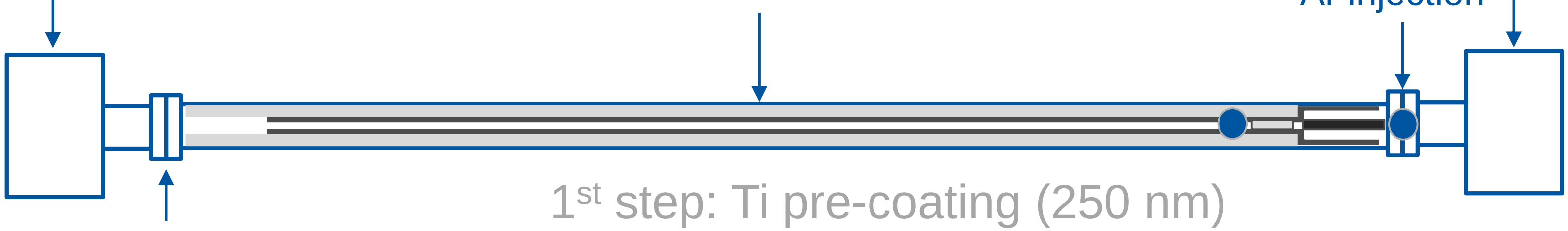
Turbo molecular pump

1^{st} step: Ti pre-coating (250 nm)



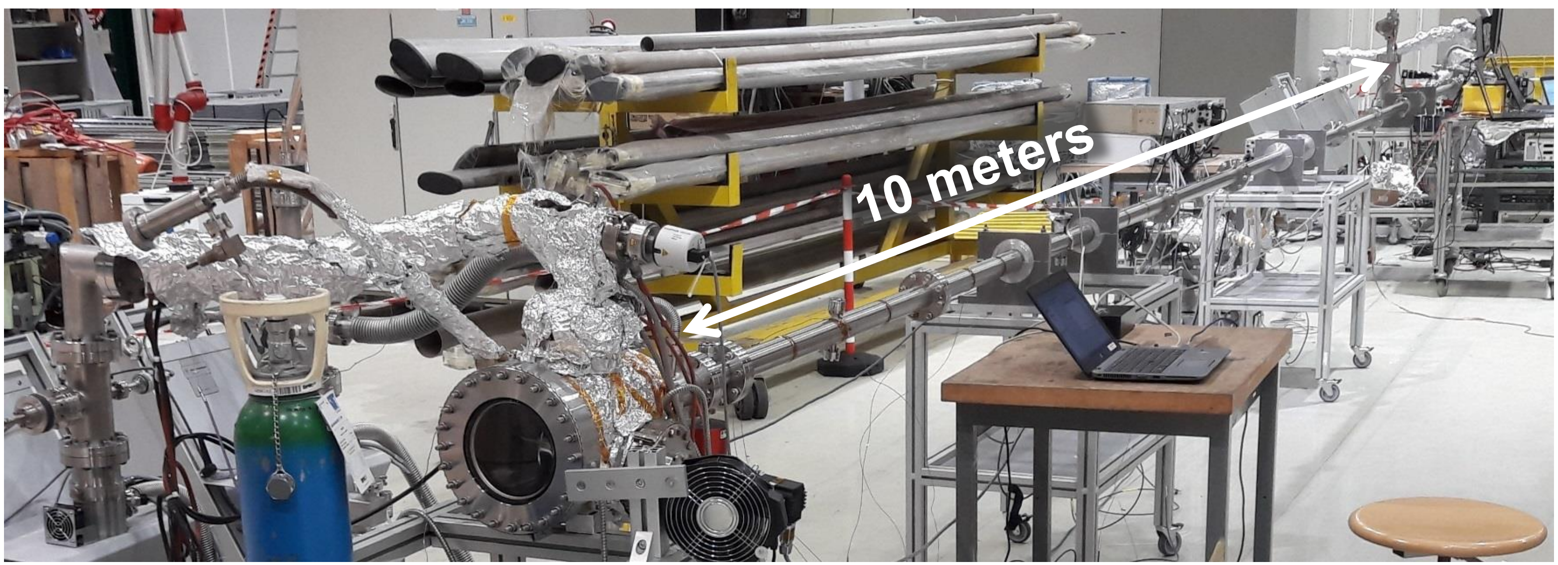
2 – In-situ a-C coating

How it is done



1st step: Ti pre-coating (250 nm)

2st step: carbon coating ~90 nm (with Ti flashes ~250nm)



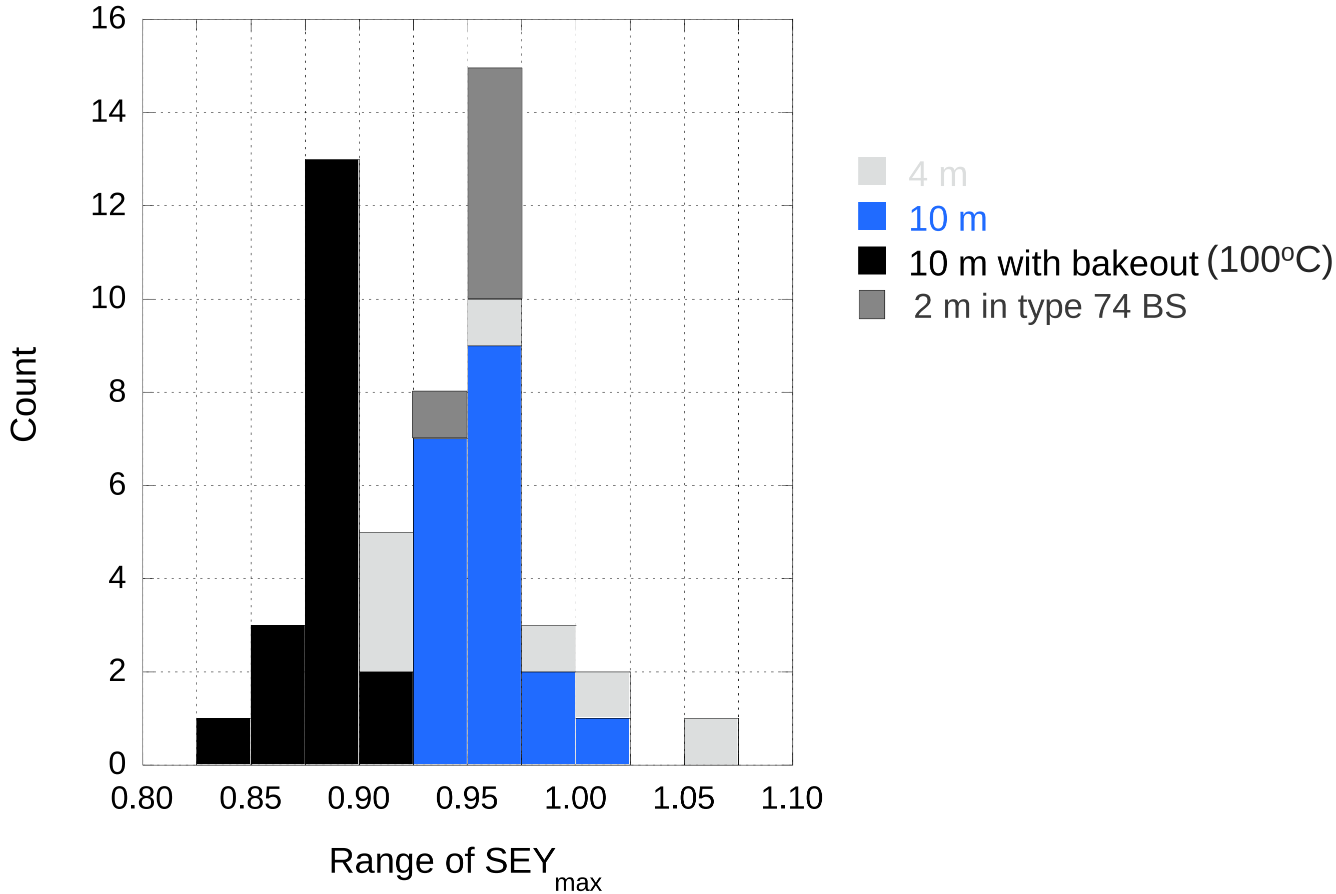
2 – In-situ a-C coating

Performance:

- ☑ SEY along 10 meters
- ☑ Tests in accelerators (e-Cloud detectors + COLDEX+ LHC Pilot sector)
- ☑ Control of particulates **OK. To be confirmed in final recipe for LHC (2018)**
- ☑ Vacuum: pump down, Isotherms, Photodesorption yield.
  OK but a new BS operation temperature is proposed (between 60K and 80K). To be confirmed in final recipe for LHC (2018). Photodesorption yield ok at 77 K. (@KEK)
- ☑ Impedance: calculations and measurement. **Calculation ok: the increase is acceptable. To be measured in 2018**
- ☑ Adhesion. **Ok in all trials, after 10 thermal quenches. To be confirmed in a BS already exposed to the beam. (MB3409 Q4 2017)**
- ☑ Resistance to radiation **Ok for IP2 & IP8 (up 200 MGy). To be measured in 2018 with final recipe.**

Performance: SEY along 10 meters

Maximal SEY_{max} < 1.1 along 10 meters of arc type BS

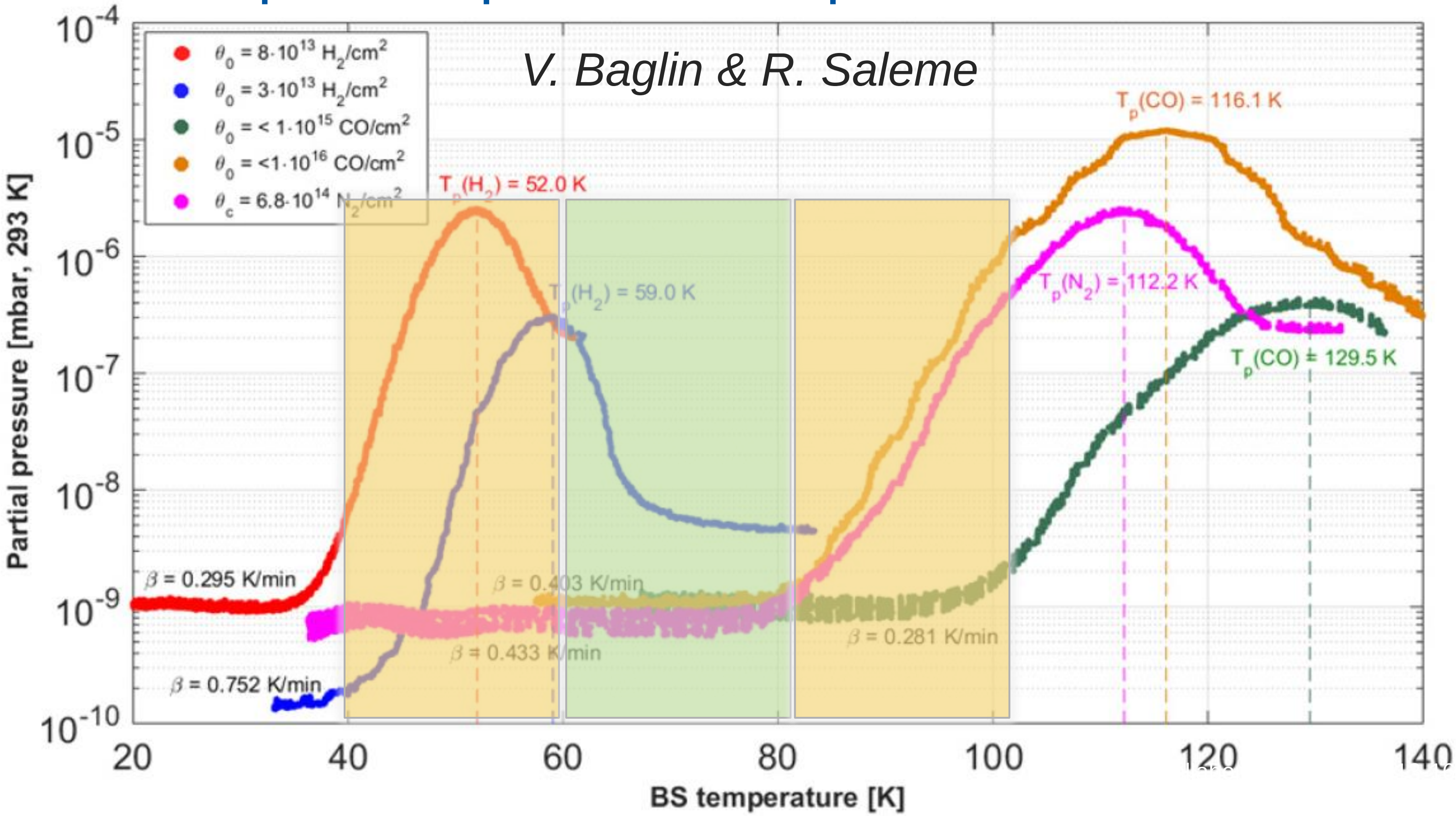


Performance: Vacuum at low temperatures

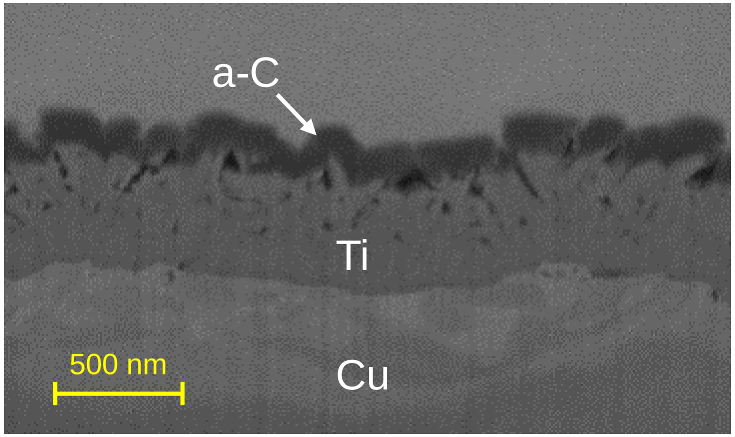
Surface capacity of a-C ~100x that of metal surfaces

Thermal Desorption Spectroscopy in COLDEX (& lab)

Proposed operation temperature: 60K -> 80K



Performance: Adhesion



C / Ti[M] → Gradient of composition and carbide bonding: Good adhesion and stable.

Ti / Cu oxide → Ti mixes with Cu oxide: good.

Thinner the Ti, lower the stresses, better the adhesion

Cu oxide

Performance: Adhesion

Good adhesion: peel-off never observed even after 10 thermal quenches from RT to 77K (dipping in LN2)

coating

↓

10 x quench to 77K

↓

Glue dollies

↓

Cure 2h@150ºC

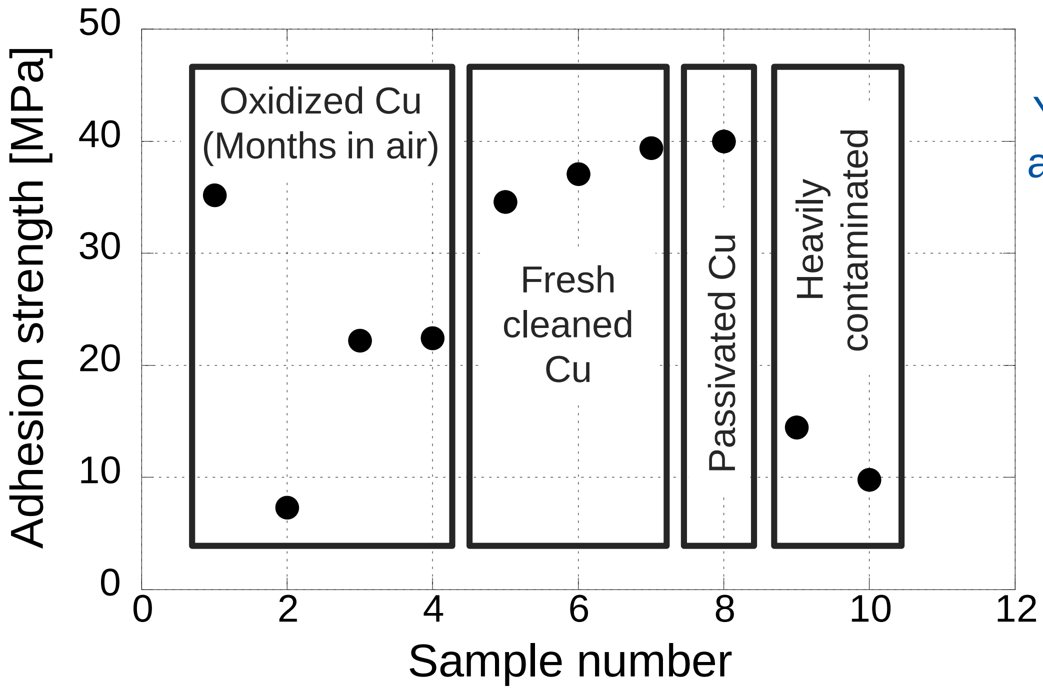
↓

pull test

Performance: Adhesion

Good adhesion: peel-off never observed even after 10 thermal quenches from RT to 77K (dipping in LN2)

- coating
- 10 x quench to 77K
- Glue dollies
- Cure 2h@150ºC
- pull test



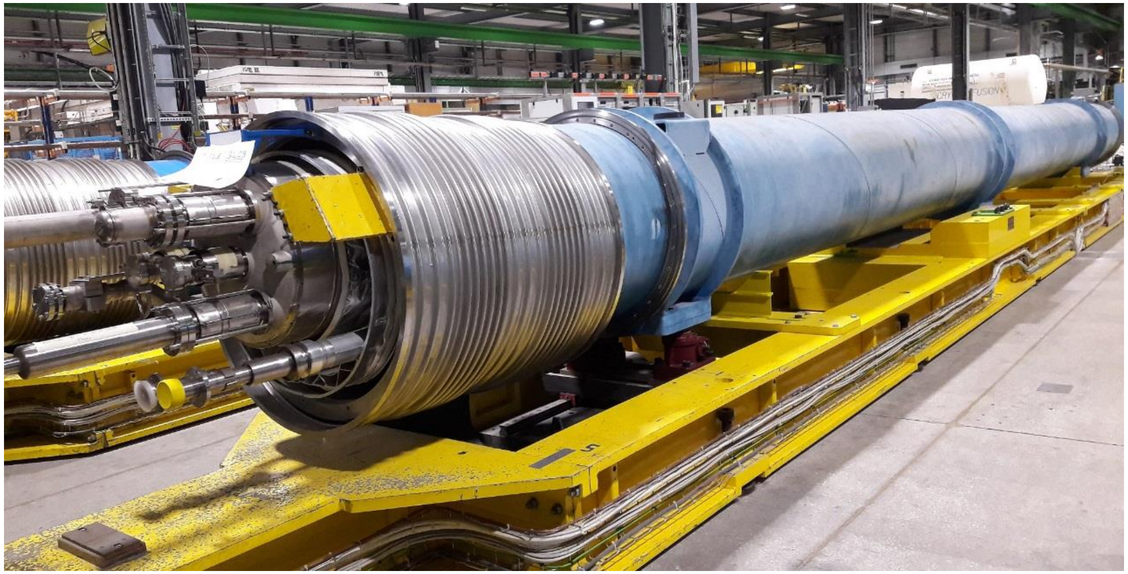
Yield strength of annealed copper ~50 MPa

5 MPa = 500 N/cm²

Performance: Adhesion

Test adhesion on a BS already exposed to the beam and remained in air for long time.

MB3409 removed from LHC in LS1 and kept in air since then.
Before end of 2017



If adhesion fails, implement in-situ surface pre-treatments: ion etching, UV cleaning or Ti^{+} implantation.

Performance: Resistance to radiation

Doses calculated by F. Cerutti (whole life of HiLumi):

- 1 GGy for triplets in IR1 and IR5
- 100 MGy for triplets in IR8 (and negligible for IR2)

No impact on the SEY

Performance: Resistance to radiation

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- 1 GGy for triplets in IR1 and IR5
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Adhesion. (At the time Ti layer was not yet available, so we tested C on Cu)

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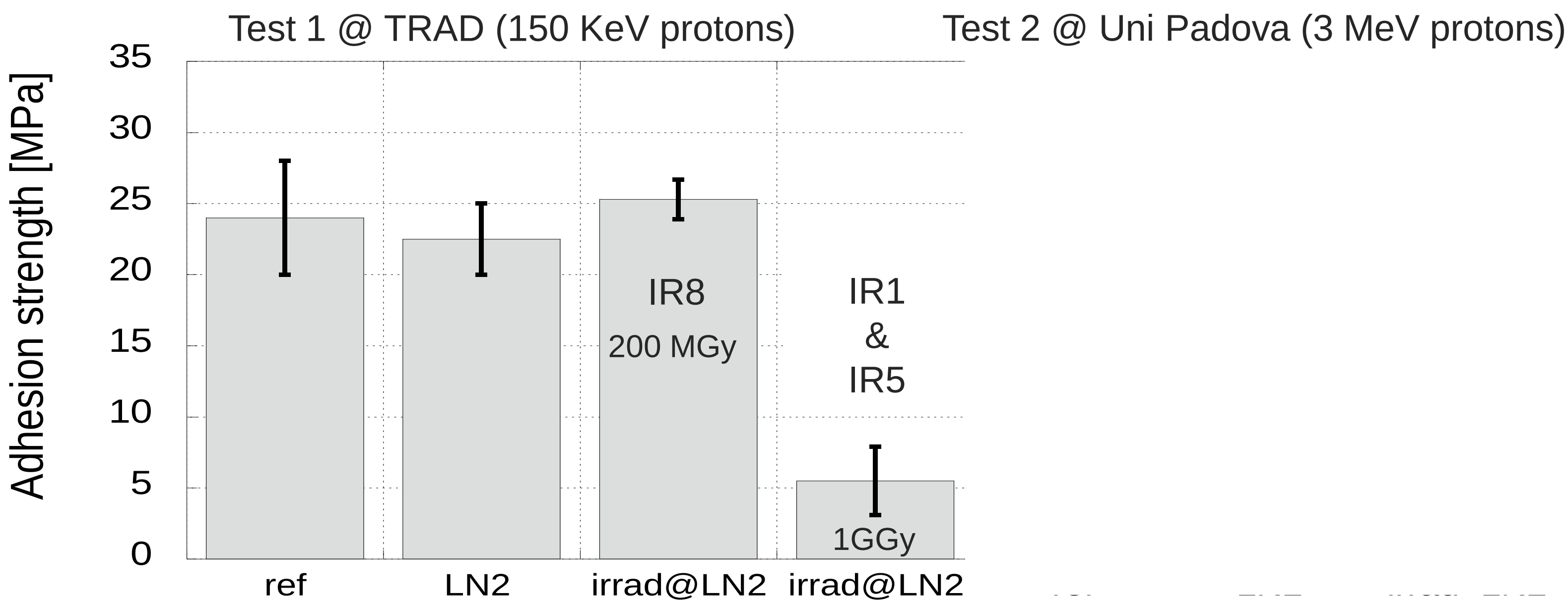
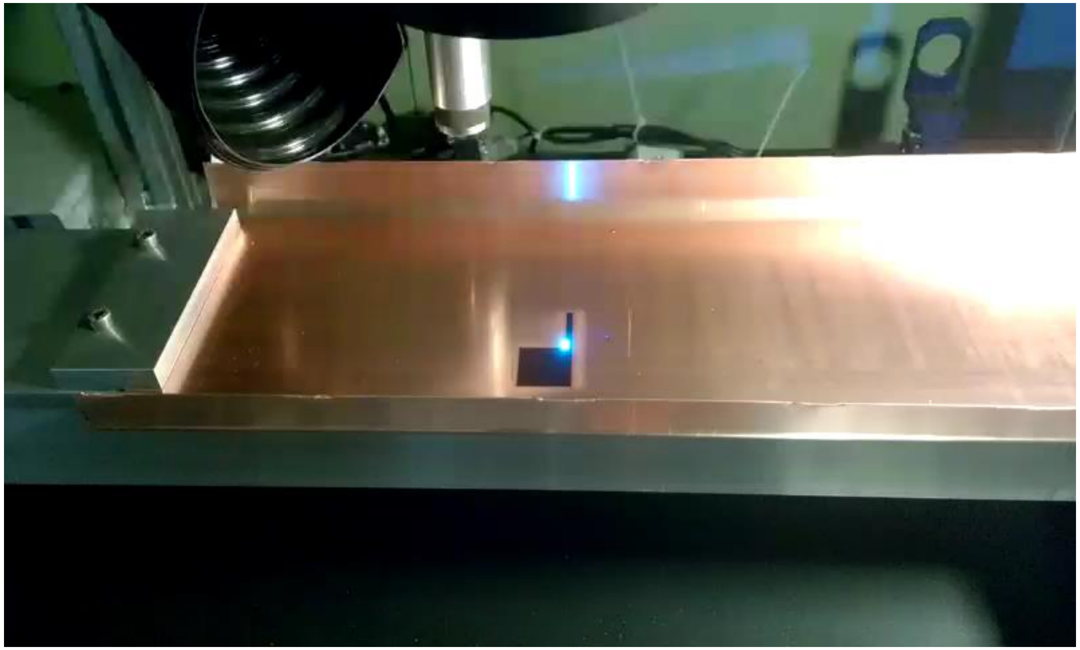


To be repeated with Ti layer

3 – Status of LESS

Collaboration with UK partners: University of Dundee and ASTeC-STFC

Laser treatment of metals just above ablation threshold.



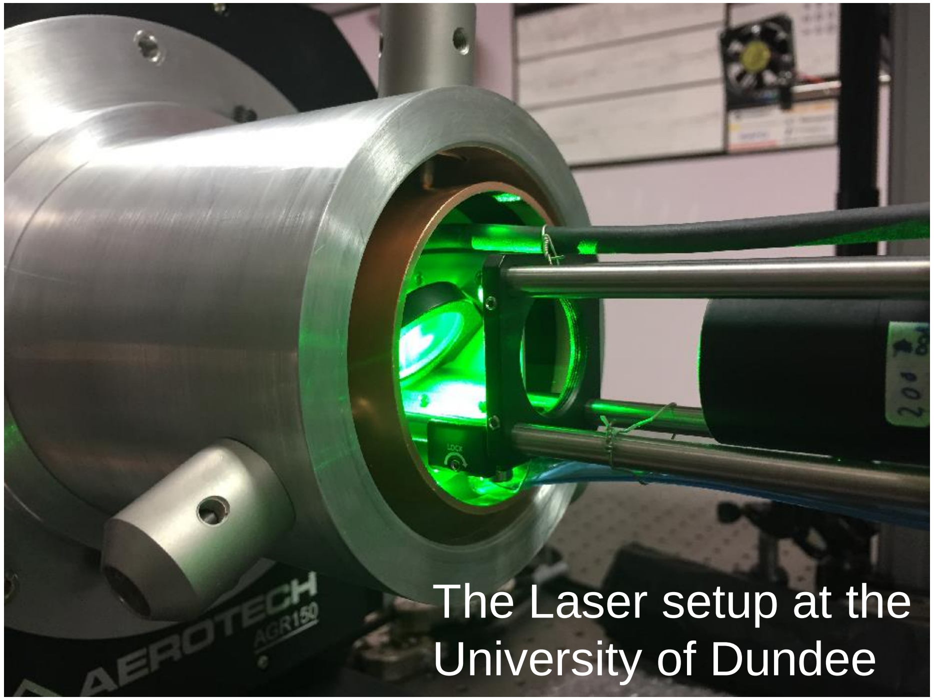
Courtesy Reza Valizadeh, ASTeC, STFC Daresbury Laboratory

3 – Status of LESS

Collaboration with UK partners: University of Dundee and ASTeC-STFC

Laser & optics

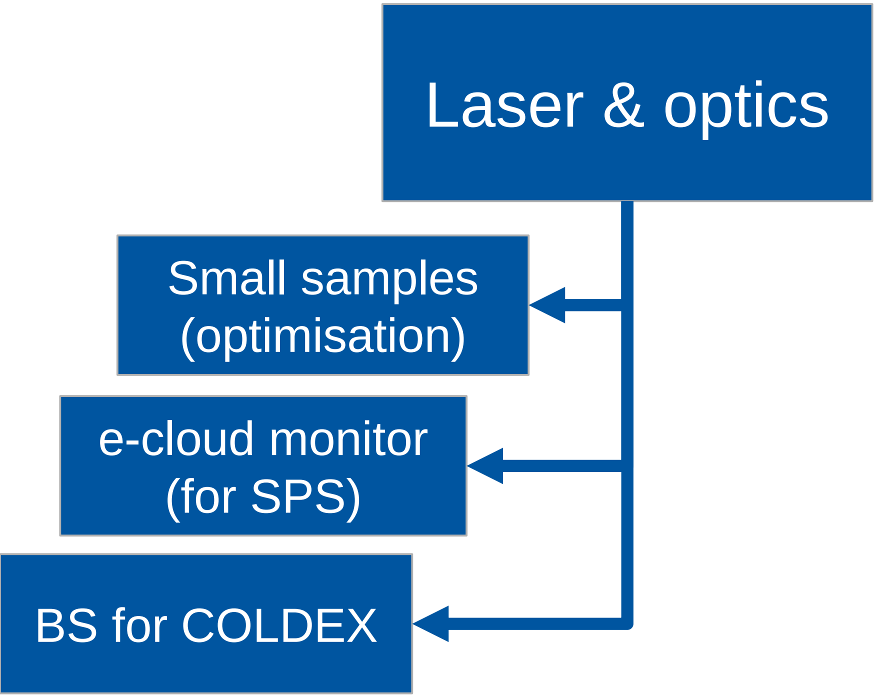
- Small samples (optimisation)
- e-cloud monitor (for SPS)
- BS for COLDEX

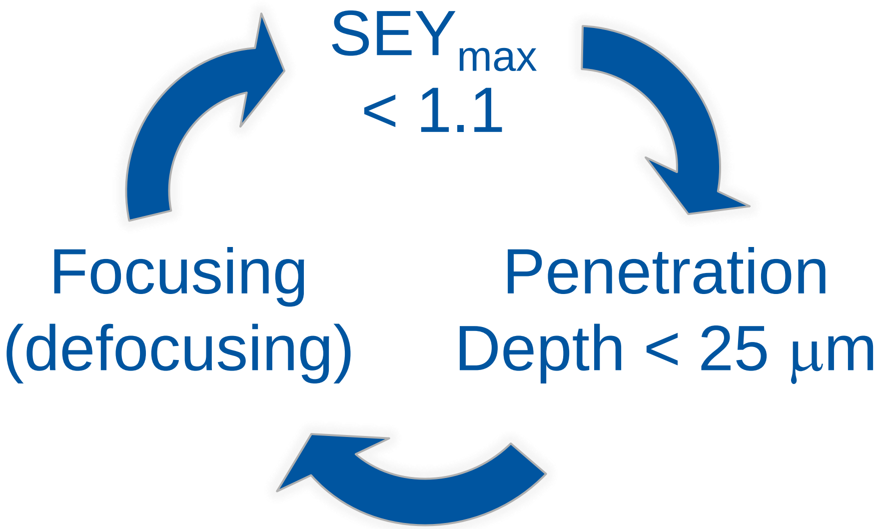


The Laser setup at the University of Dundee

3 – Status of LESS

Collaboration with UK partners: University of Dundee and ASTeC-STFC





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Courtesy of Amin Abdolvan

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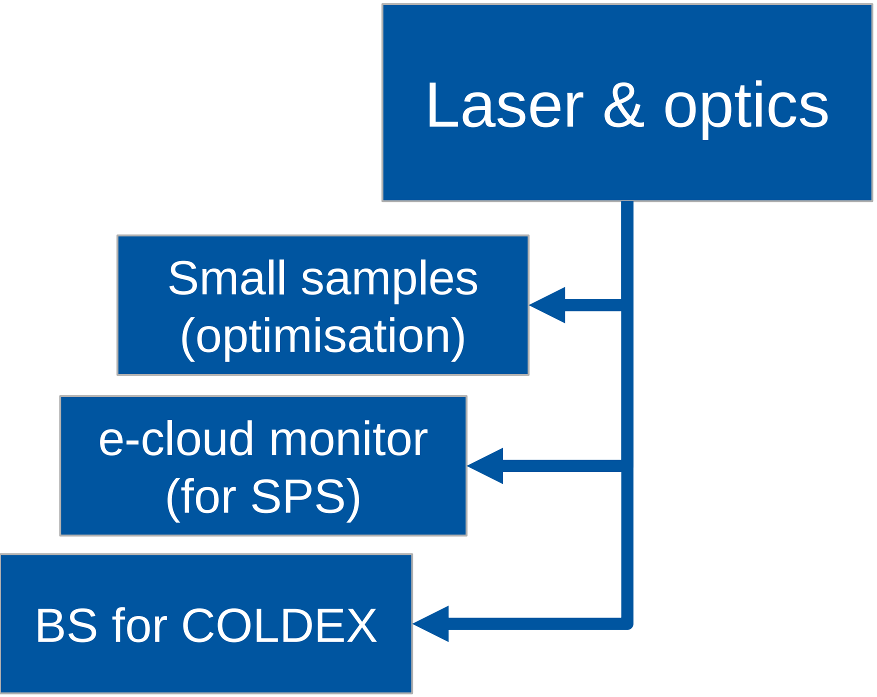

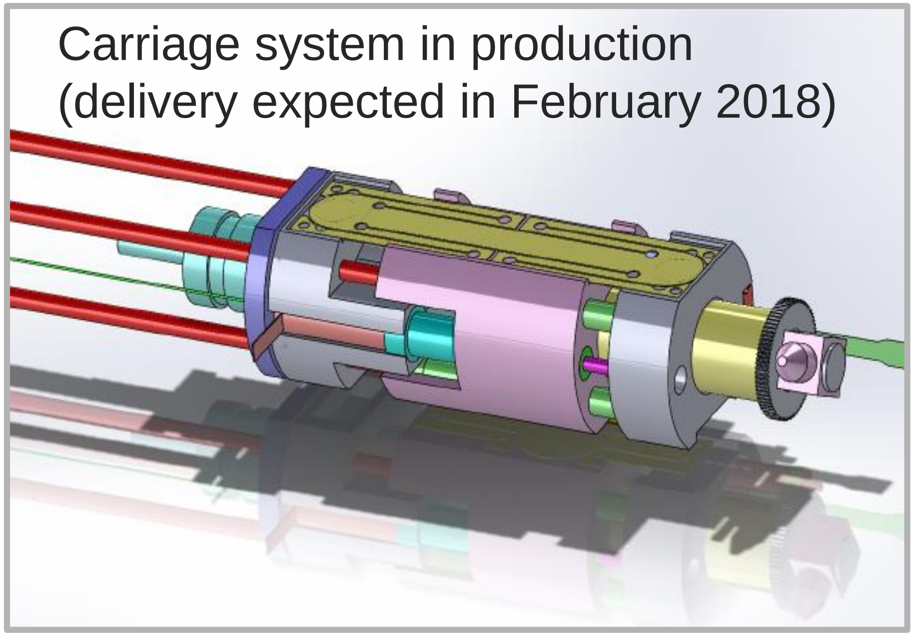

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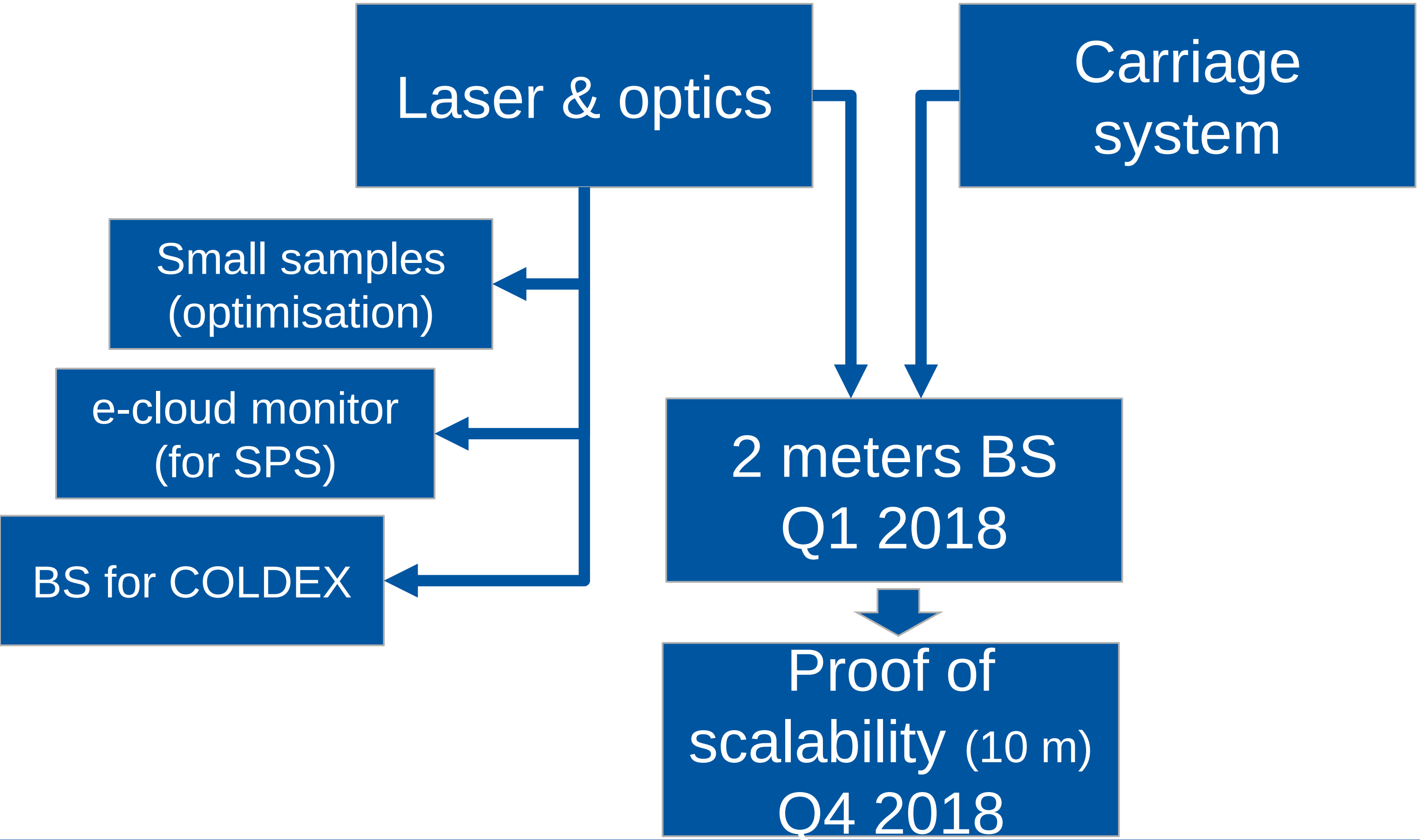


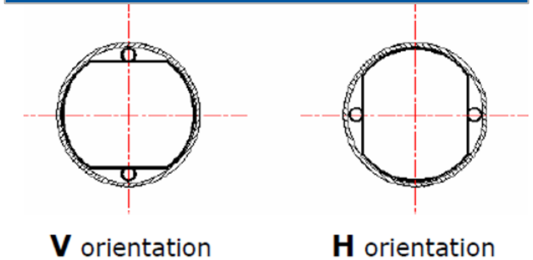
3 – Status of LESS

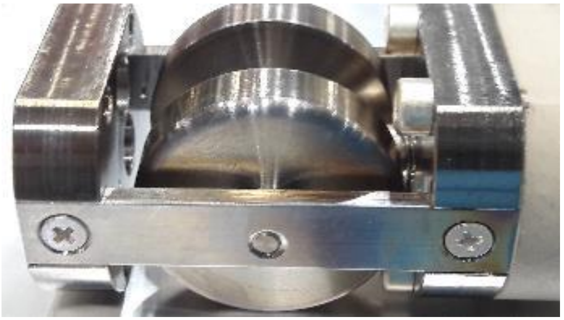
Performance:

- ❑ SEY along 10 metres
- ☑ Tests in accelerators (SPS: e-Cloud detectors + COLDEX)
- ☑ Control of particulates **Measurements ongoing (Q4 2017)**
- ☑ Vacuum: pump down, Isotherms, Photo desorption yield.
  Pumpdown ok. Isotherms & Photodesorption yield to be measured. (2018?)
- ☑ Impedance: measurement.
  Measurements in <u>non optimised LESS</u> shows an increase of the impedance that can lead to a heat load up to 0.8 W/m.
  New measurement to be done in optimised LESS (2018)

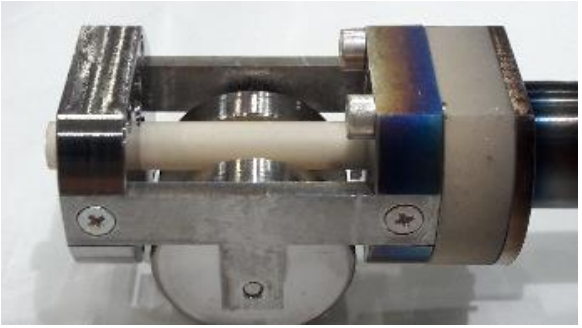
4 – Status of tunnel implementation

Sputtering sources for all configurations





For type 50 “V”



For type 74 “V”

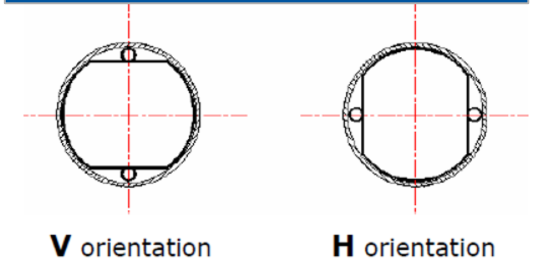
Magnet	BS type	IR2	IR8
Q1	53(50)	H	V
Q2	63	H	V
Q3	63	H	V
DFBX	74	H	V
D1	74	V	V

Q1–Q3: In 10 meters setup

DFBX–D1: In 2 meters setup

4 – Status of tunnel implementation

Sputtering sources for all configurations



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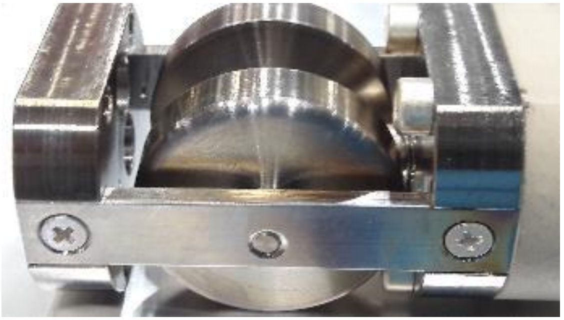
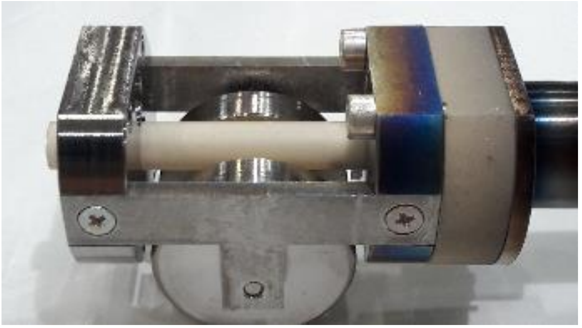


For type 50 “V”



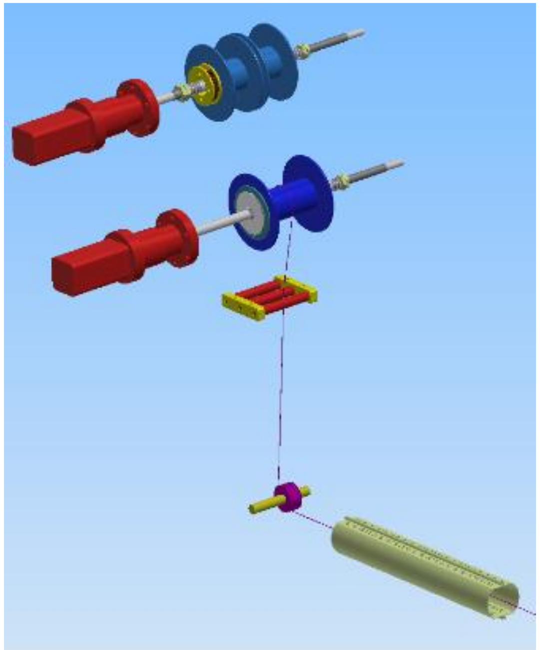
For type 74 “V”

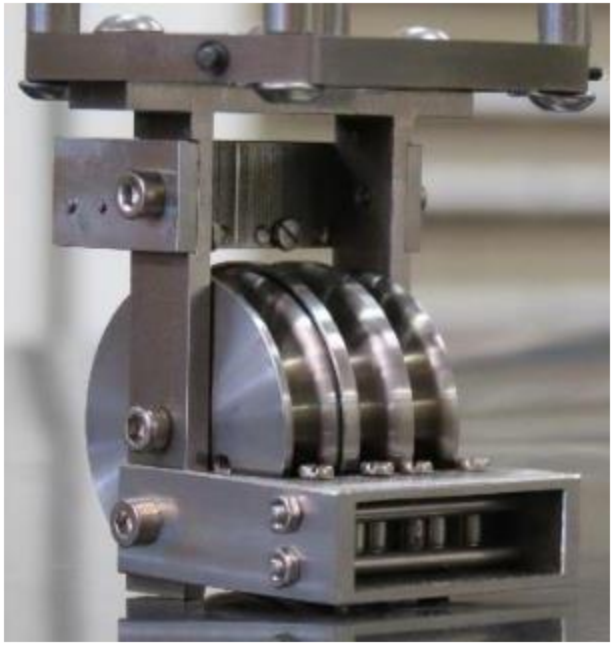
For type 63 “H”

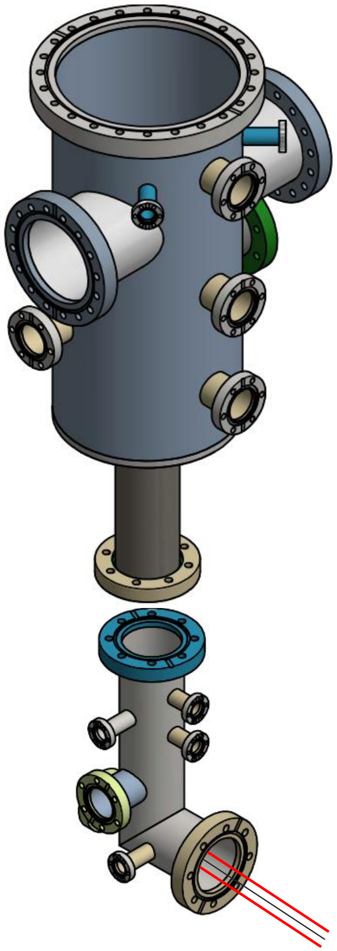
4 – Status of tunnel implementation

Sputtering sources for all configurations

Interfaces for all configurations





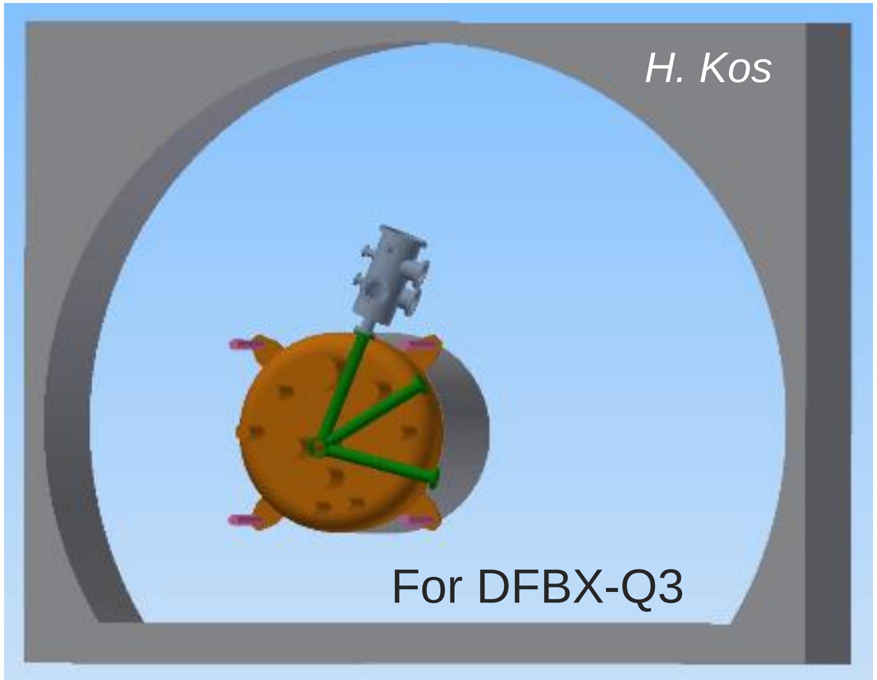


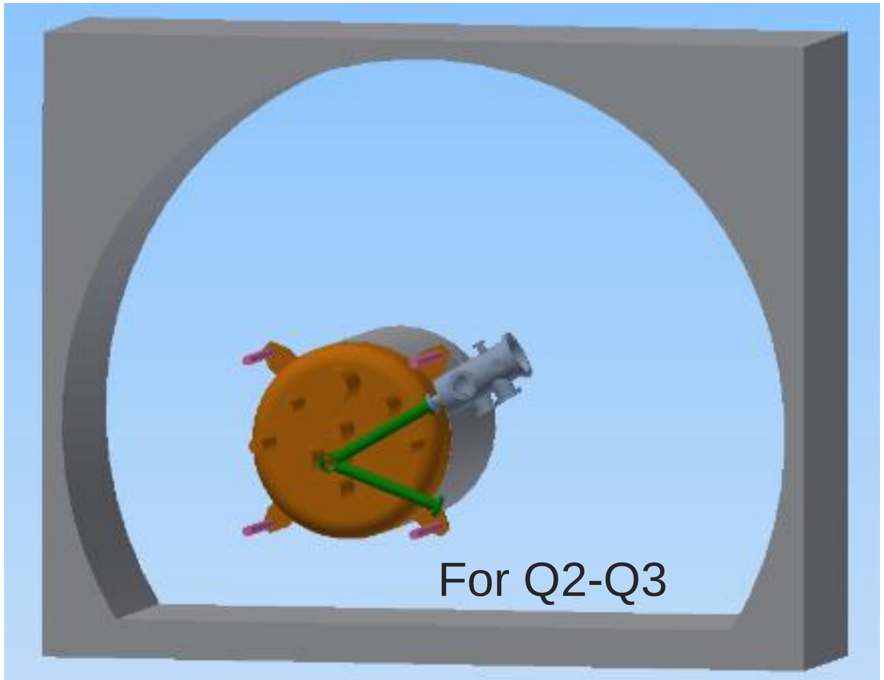
4 – Status of tunnel implementation

Sputtering sources for all configurations

Interfaces for all configurations

Integration in the tunnel





4 – Status of tunnel implementation

Sputtering sources for all configurations

Interfaces for all configurations

Integration in the tunnel

Planning
&
Dose prediction

Training

4 – Status of tunnel implementation

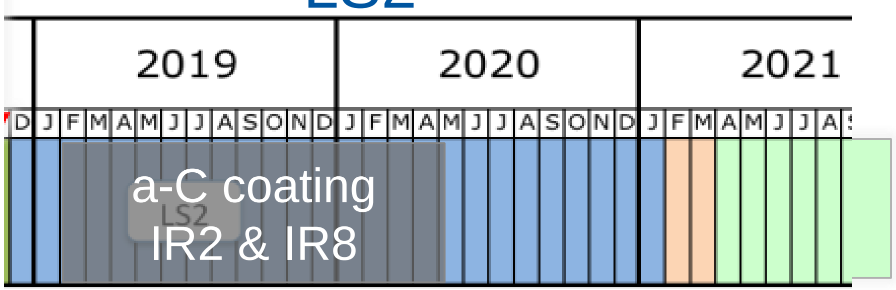
Planning & dose prediction

1 Coating team = 1 physicist + 1 technician

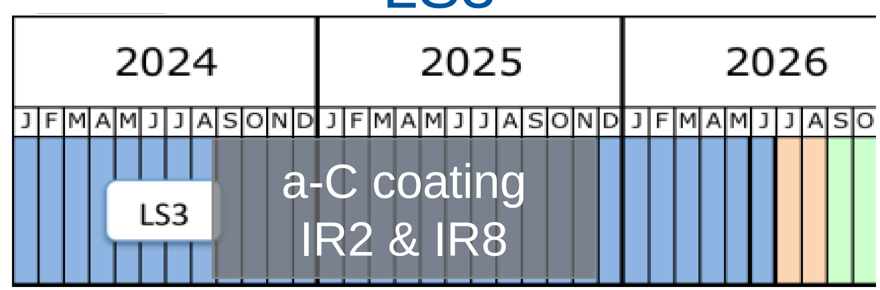
12.5 weeks / string (Q1 + Q2 + Q3 + DFBX + D1)

50 weeks to coat IR2 & IR8

LS2



LS3



4 – Status of tunnel implementation

Planning & dose prediction

LS2 *vs* LS3

Based on dose rate measurements in IR8

By C. Adorisio

Based on dose rate estimations for IR8

LS2 - 1 month cooling time	
Q1	**97**
Q2	**28**
Q3	**22**
DFBX	**20**
D1	**38**
string (Q1-Q2-Q3-DFBX-D1)	**206**
IR8	**411**

[μSv]

LS3 - 4 months cooling time	
Q1	**136**
Q2	**32**
Q3	**30**
DFBX	**20**
D1	**22**
string (Q1-Q2-Q3-DFBX-D1)	**198**
full LSS	**395**

[μSv]

Residual dose in IR2 is negligible

5 – Summary

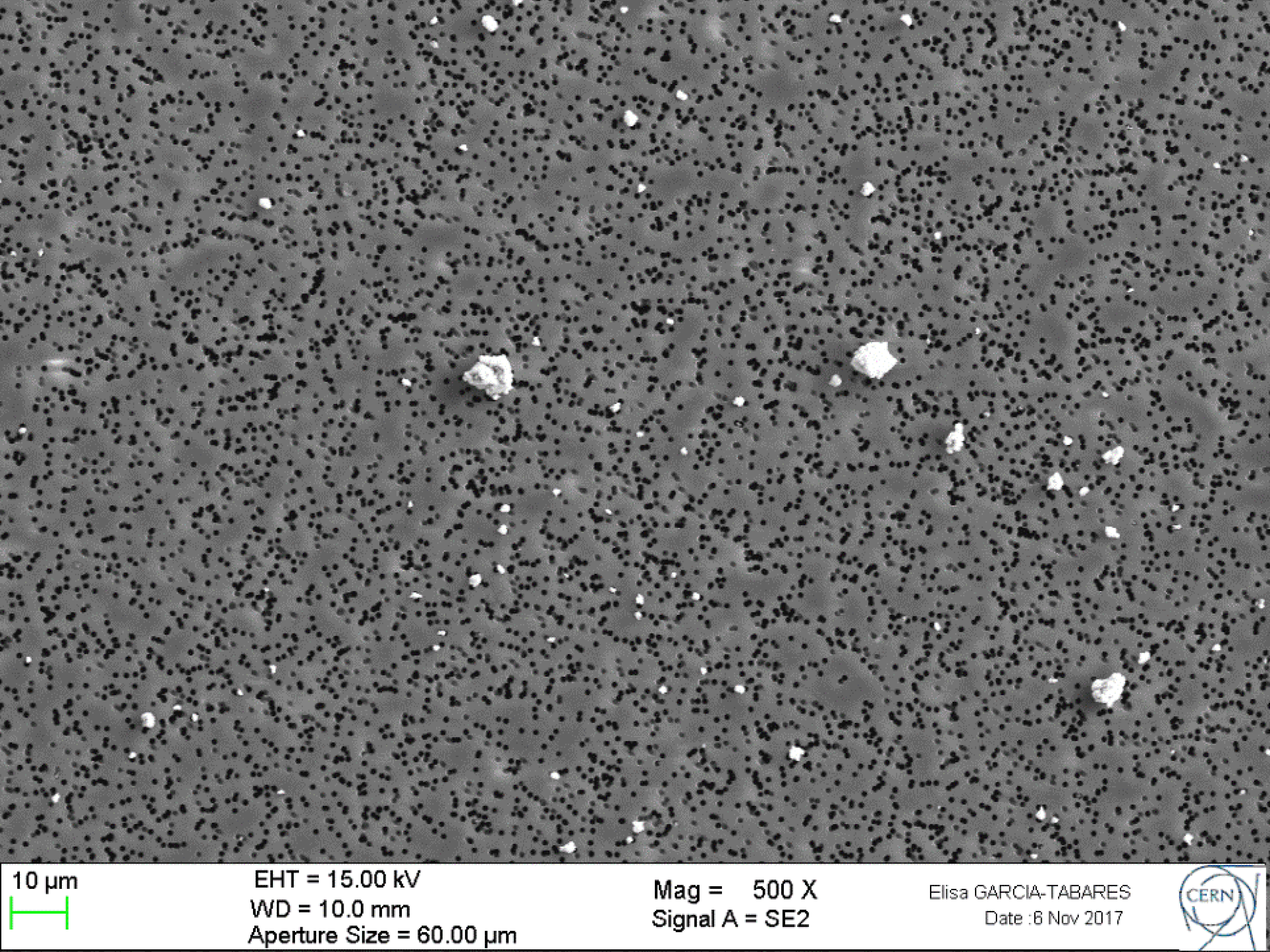
Up to now no show stoppers have been found for either of the technologies.

The a-C coating is ready to be applied in real magnets. In 2018 enters the phase towards tunnel implementation.

By the end of 2018 the LESS is expected to reach the maturity to be applied to real size magnets.

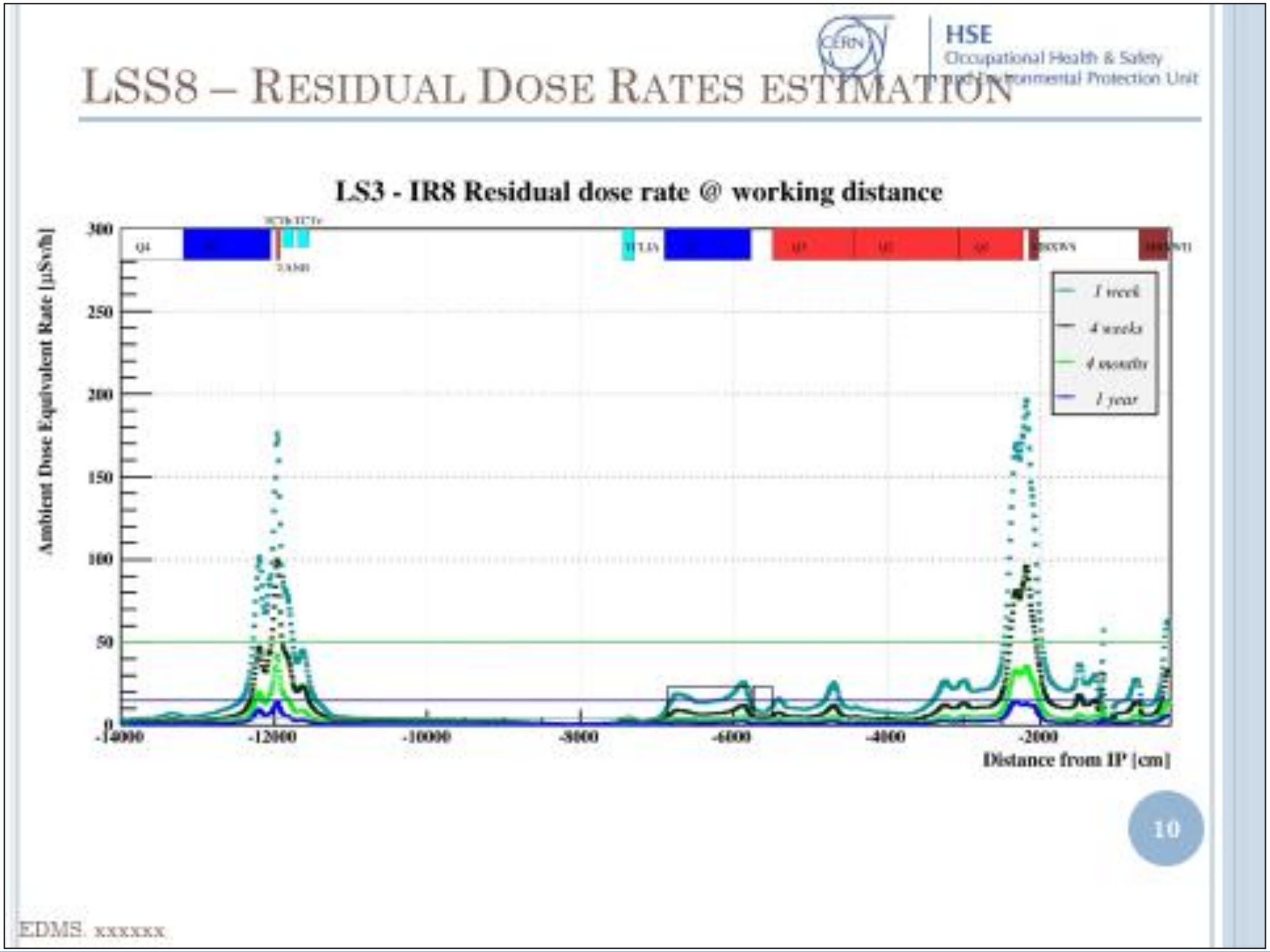
Dose prediction allows choice for deployment in LS2 or LS3.

International review to assess mitigation technology and implementation planned for March 2018


10 µm
EHT = 15.00 kV
WD = 10.0 mm
Aperture Size = 60.00 µm
Mag = 500 X
Signal A = SE2
Elisa GARCIA-TABARES
Date :6 Nov 2017
CERN

4 – Status of tunnel implementation

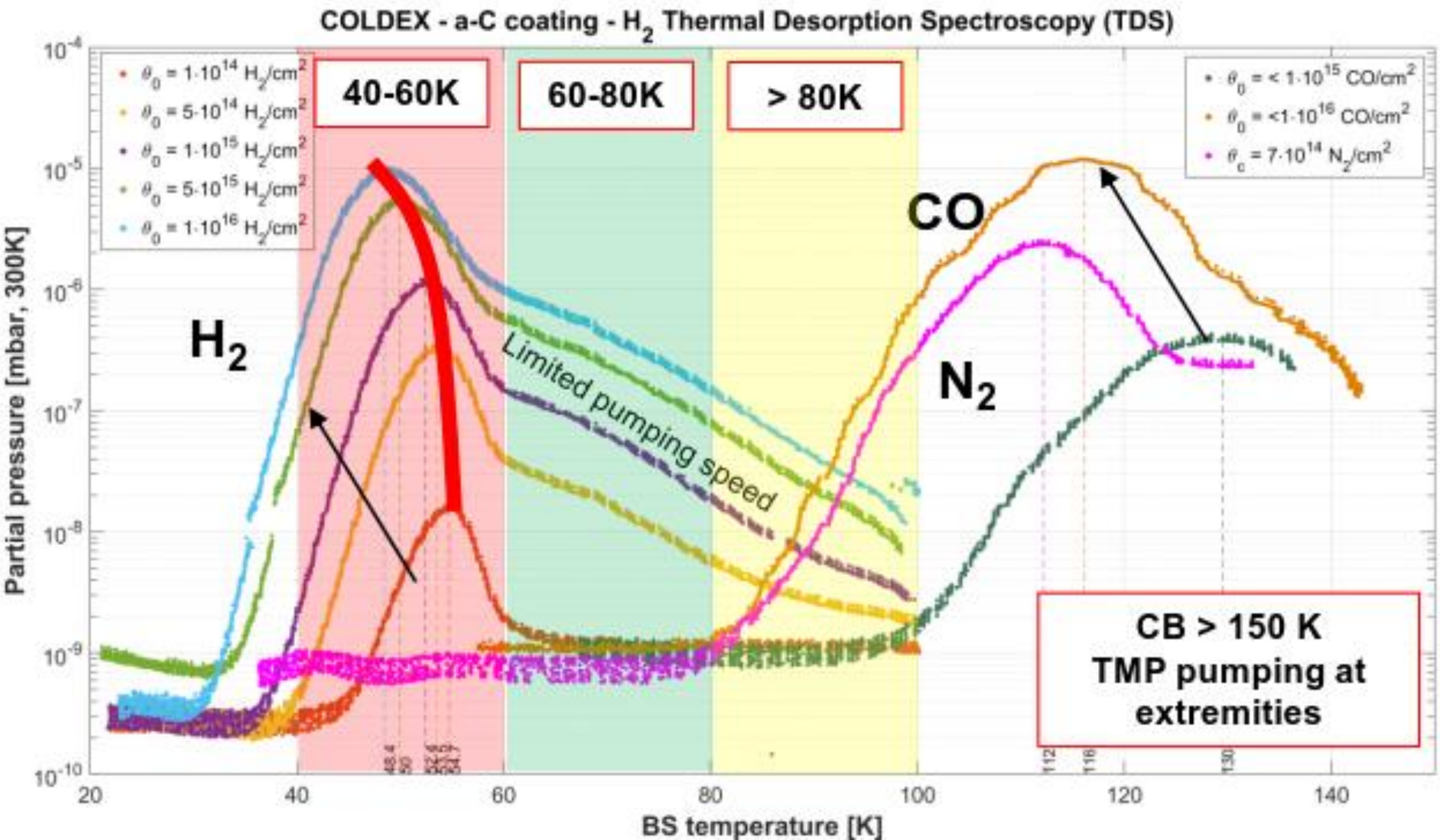
Planning & dose prediction



Performance: Vacuum at low temperatures

Surface capacity of a-C ~100x that of metallic surfaces

New proposal for operation temperature: 60K -> 80K

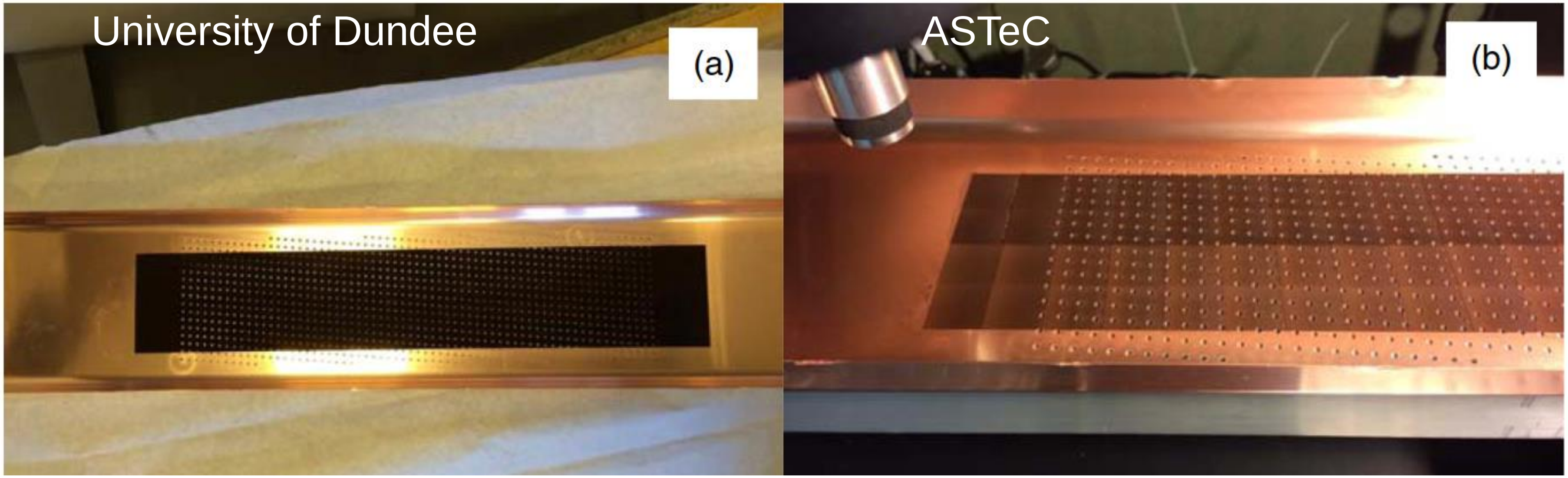


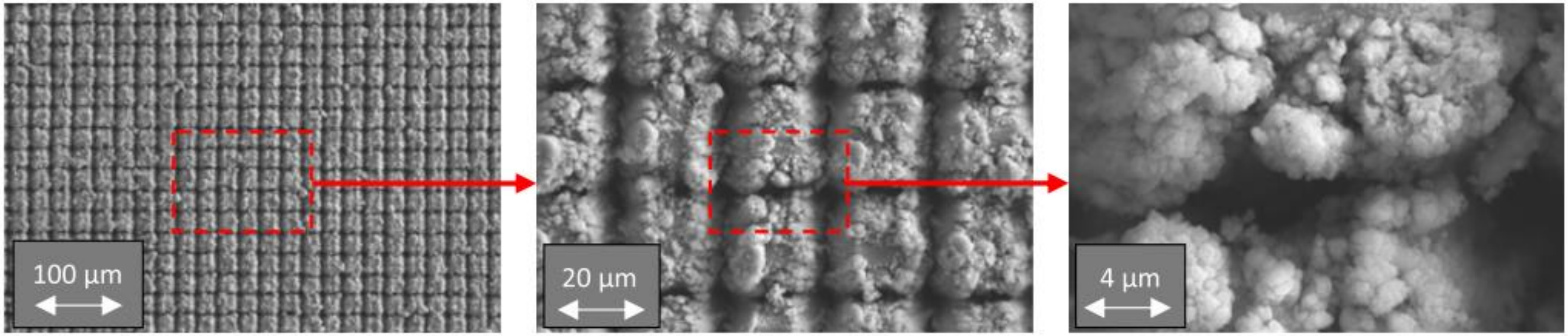
LESS

performances

3 – Status of LESS

Performances: SPS e-cloud detectors

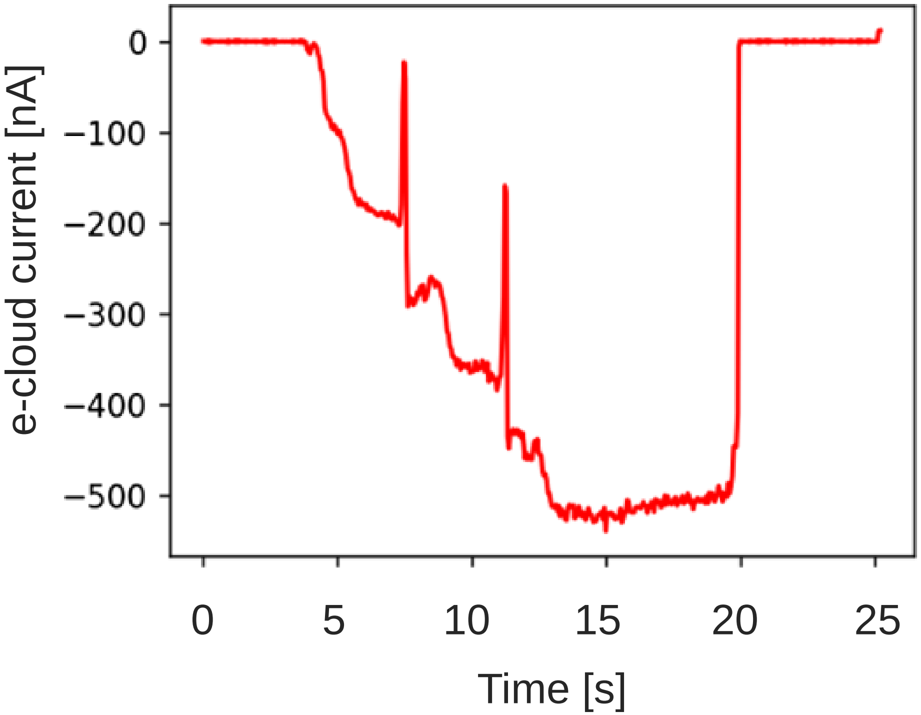




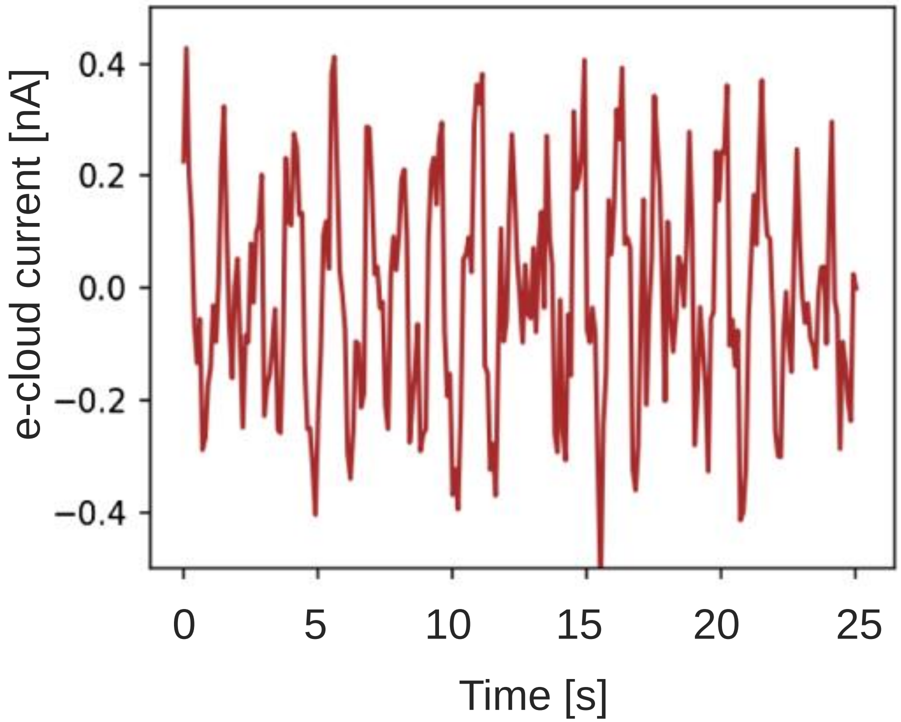
Performances: SPS e-cloud detectors

MD run in SPS (4 batches with72 bunches, 25 ns, $1x10^{11}$ ppb)

UHV cleaned Copper



LESS treated copper



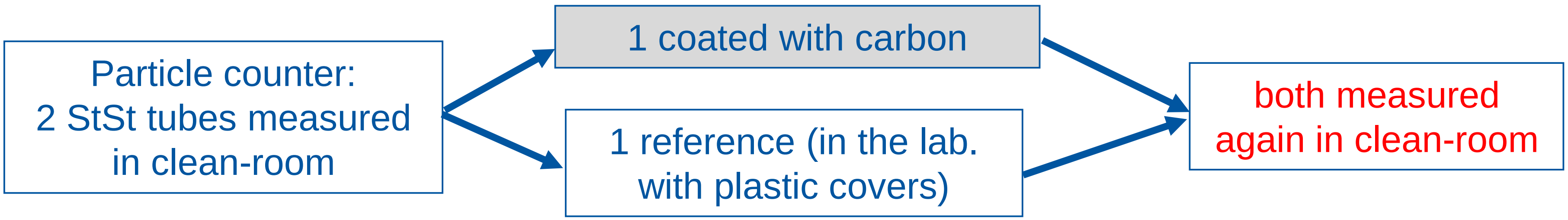
a-C

performances

Performances: control of particulates

No difference between coated and uncoated chambers

On SPS type coating (400 nm on stainless steel)



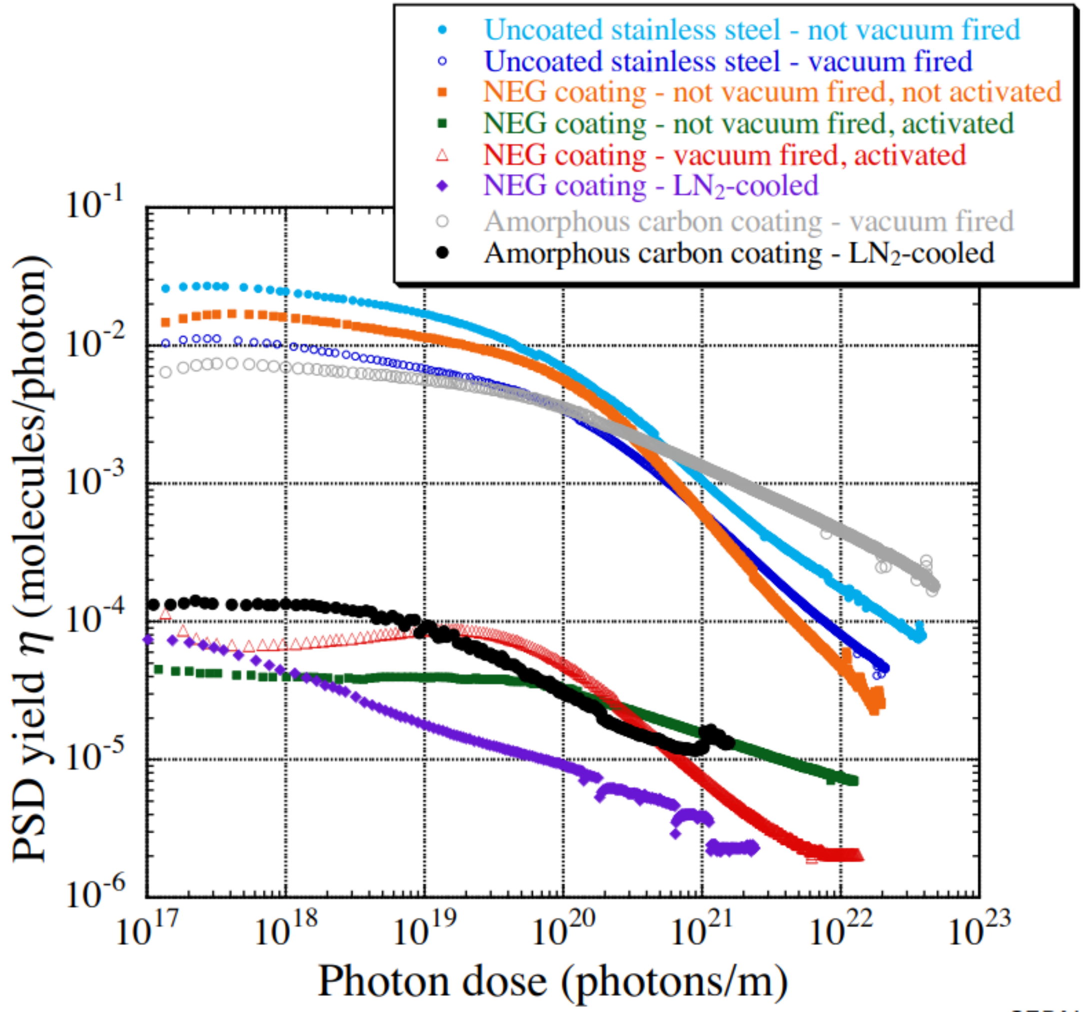
No increase after shaking and gentle hammering of the chamber.

No increase for a chamber left in air for months

To be repeated with final recipe for LHC type coating (2018)

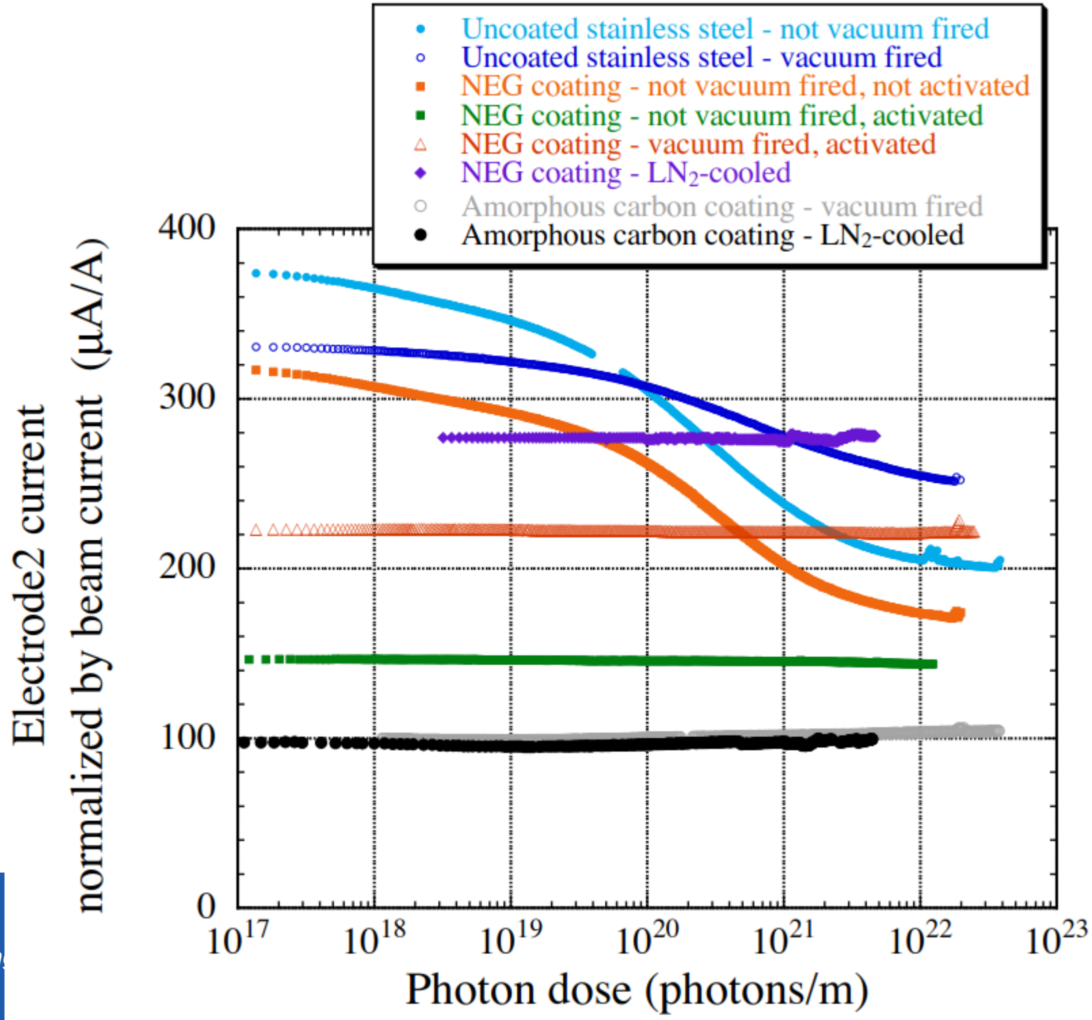
Performances: Vacuum PSD (Photon Stimulated Desorption)

Measured at KEK by Y. Tanimoto & M. Ady (CERN)



Performances: Photon Electron Yield

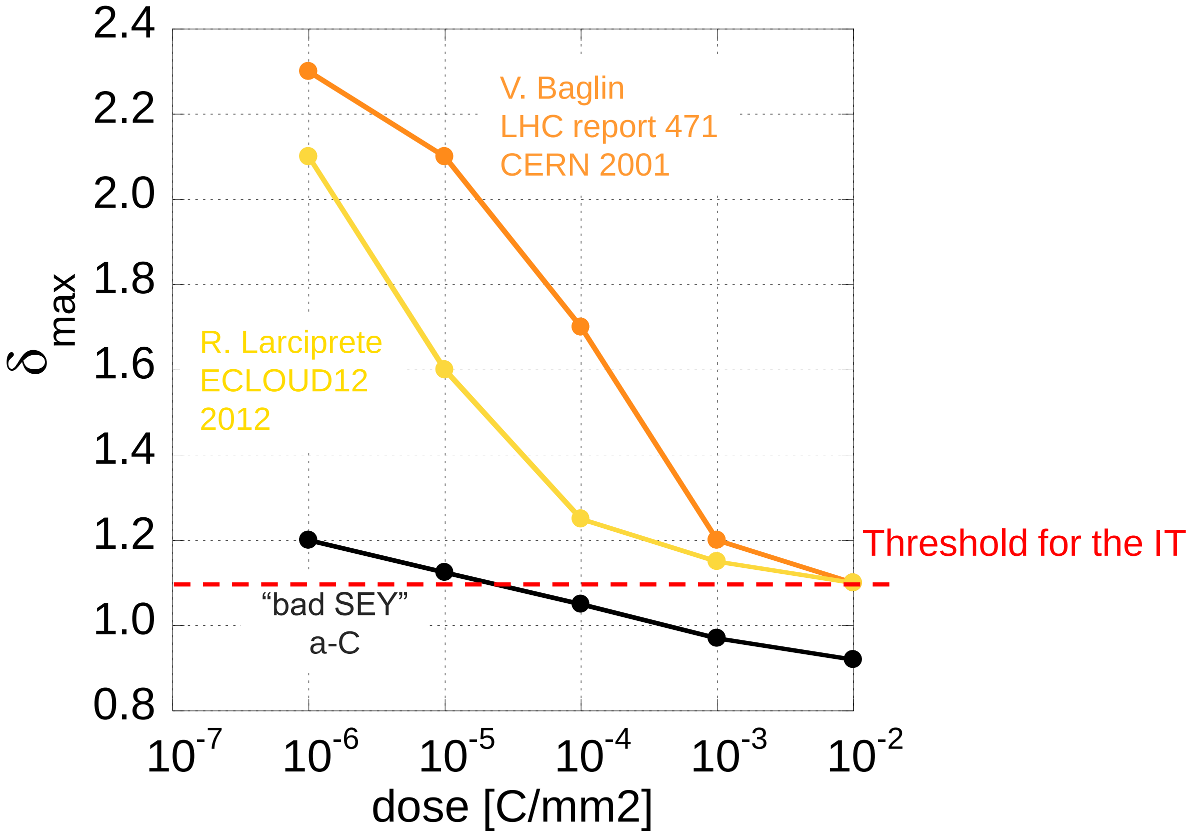
Measured at KEK by Y. Tanimoto & M. Ady (CERN)



Performances

Conditioning of a “bad coating” SEY = 1.2

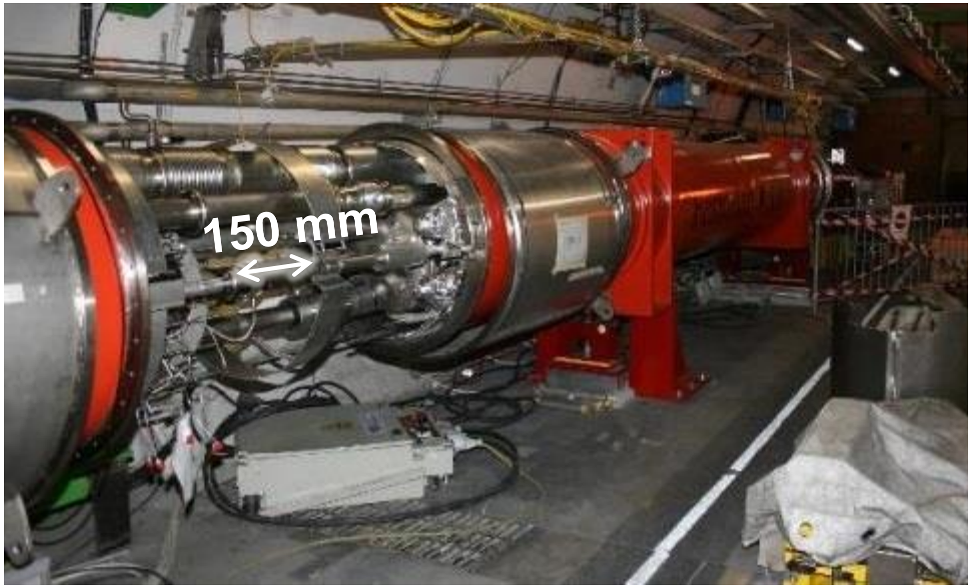
Check conditioning of SEY 1.5 (done by Danilo)



Concept

Coat the beam screens with **low Secondary Electron Yield (SEY) carbon** thin film. ***In-situ for IR2 & IR8*** ***IR1 & IR5 conventional coating***

Modular sputtering source to be inserted in a 150 mm slot and pulled by cables all along a magnet.



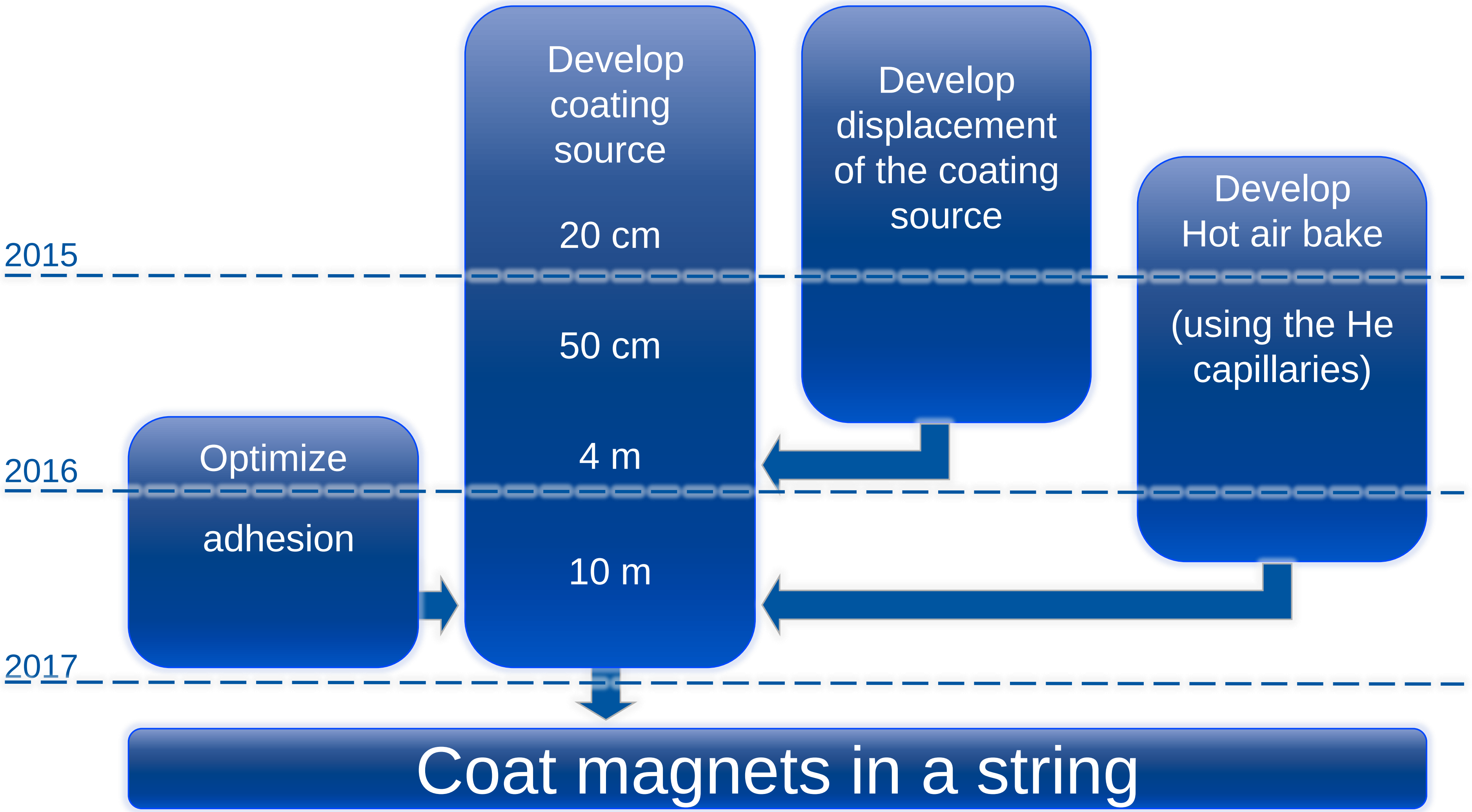
Concept

Coat the beam screens with **low Secondary Electron Yield (SEY) carbon** thin film. ***In-situ for IR2 & IR8***

Modular sputtering source to be inserted in a 150 mm slot and pulled by cables all along a magnet.

Current baseline: **coat magnets separately** to avoid damaging the RF fingers (to be reviewed)

Strategy


Develop coating source
20 cm
50 cm
4 m
10 m
Develop displacement of the coating source
Develop Hot air bake
(using the He capillaries)
Optimize
adhesion
2015
2016
2017
Coat magnets in a string

Adhesion strength measured by “Pull-test” method

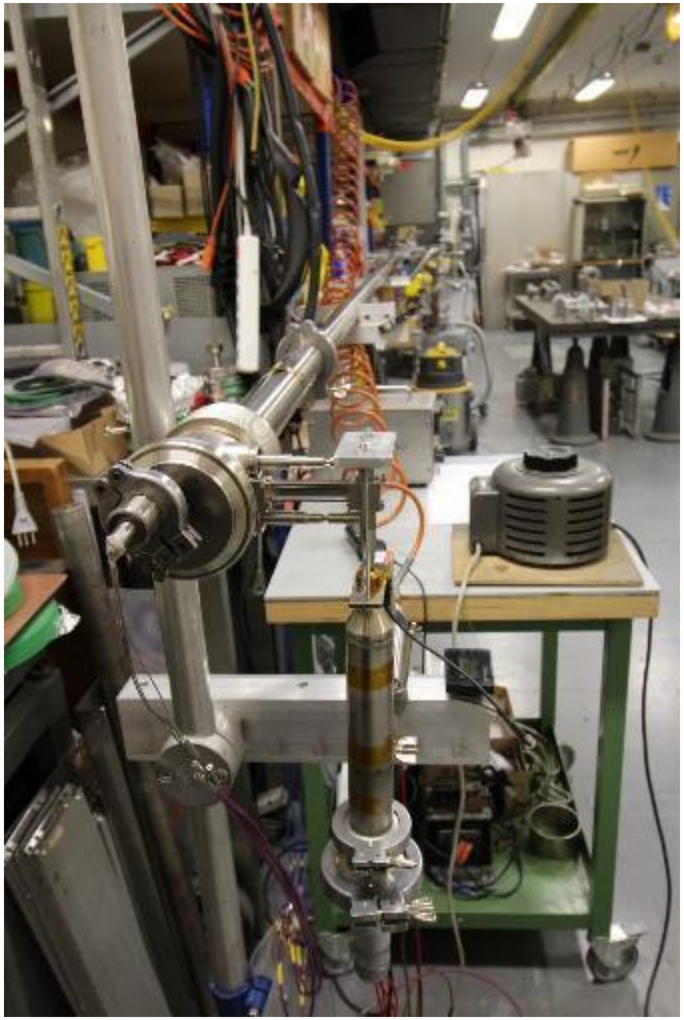
Dolly

up to 40 MPa

4 – Hot air bakeout

Implement hot air bakeout in 10 m coating system (M. Sitko & H. Kos):

Goal: **Improve adhesion & SEY**



4 – Hot air bakeout

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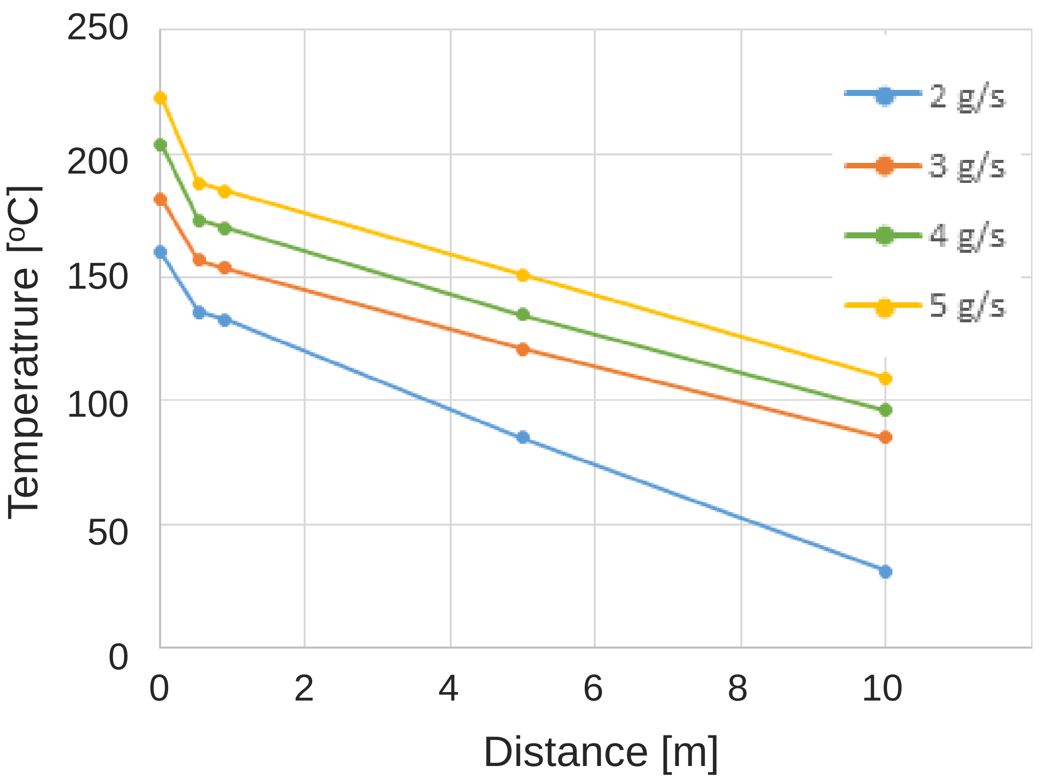
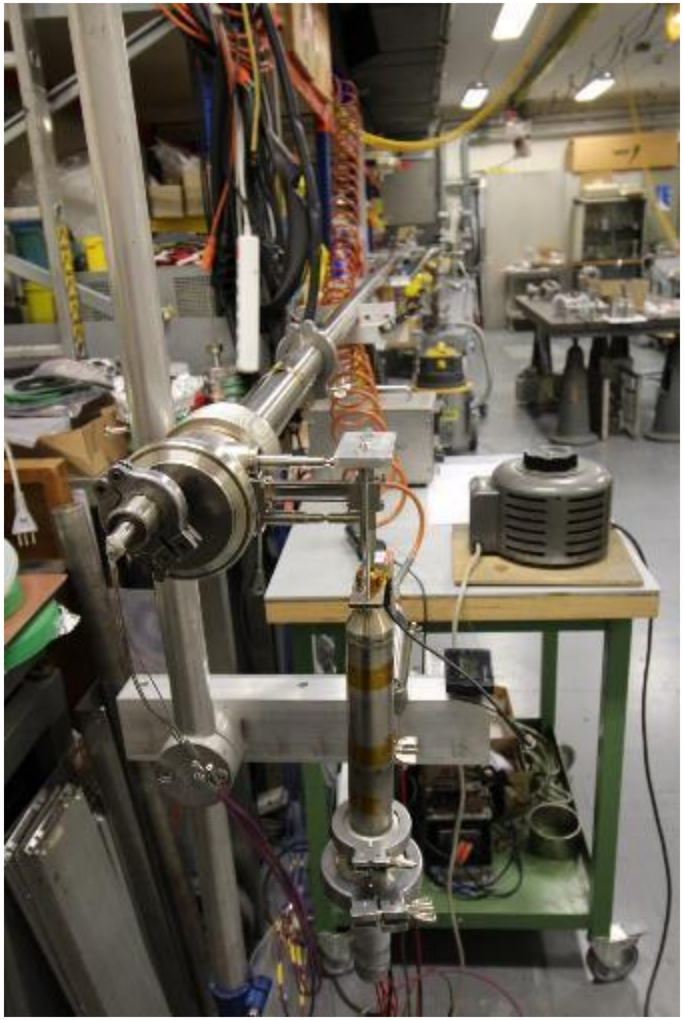
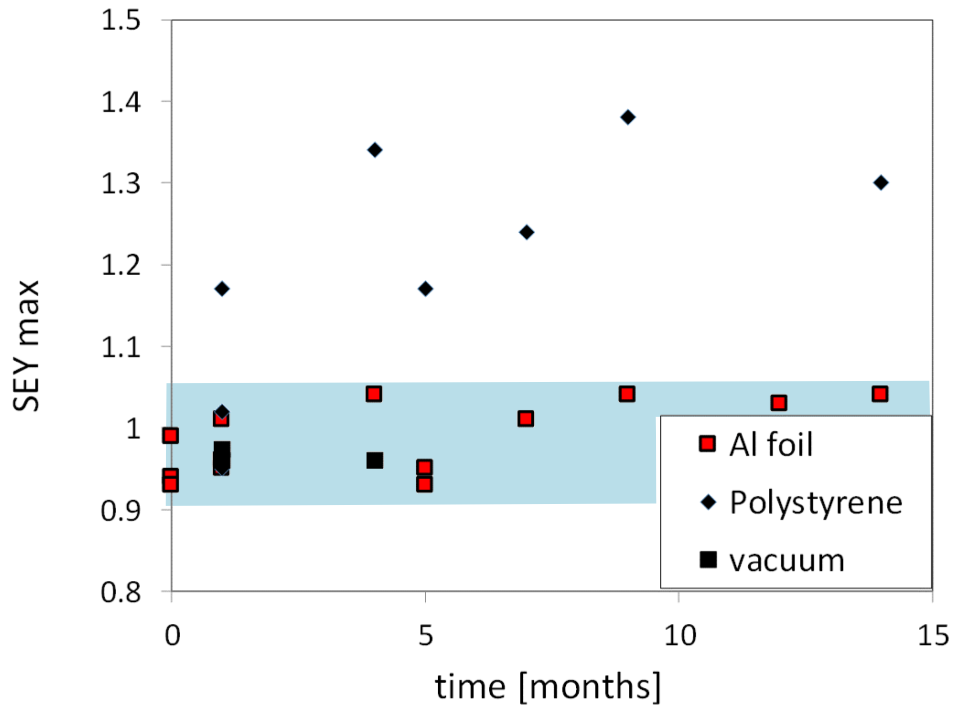
Goal: **Improve adhesion & SEY**





What we learned from the SPS (since 2008)

Robustness: after more than one year in air, just with aluminum foil protection, the SEY_{max} is still below 1.06

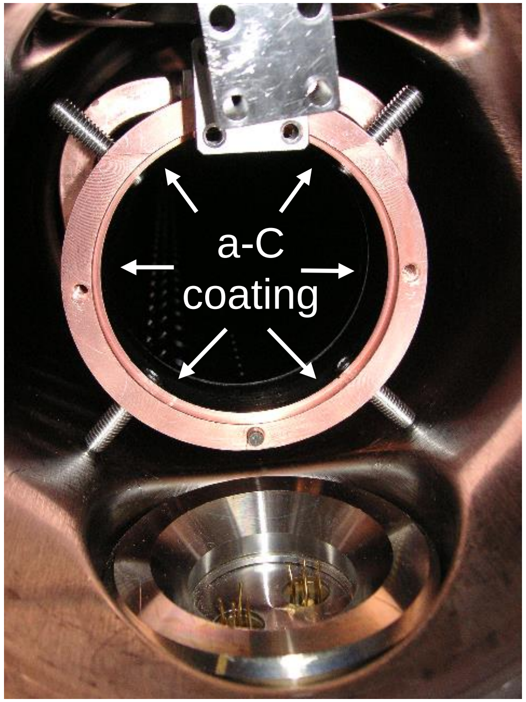


The liner installed in the e-cloud monitors of the SPS **since 2008 keeps its performance** (no measurable e-cloud) in spite of several air venting periods.

2 – a-C coatings

What we learned from the SPS (since 2008)

Extensively tested: e-cloud monitors, microwave transmission, vacuum, multipactor up to 2 Tesla, *in-situ* e-cloud and SEY in CesrTA, more than 100 meters of SPS coated with carbon during LS1, **including COLDEX**.



Roberto Salemme,
Build-up simulations for COLDEX and comparison with experimental data,
Electron Cloud Meeting #20, CERN, March 13th 2015

No e-cloud activity registered on the pickup electrode **I_e< 5 10^{-9} A**

- Electronic noise I_e~5 10^{-9} A
- If SEY ~ 1.10 => 2 10^{-10} A
- If SEY ~ 1.25 => 2 10^{-6} A

(benchmarking with pyECLOUD)

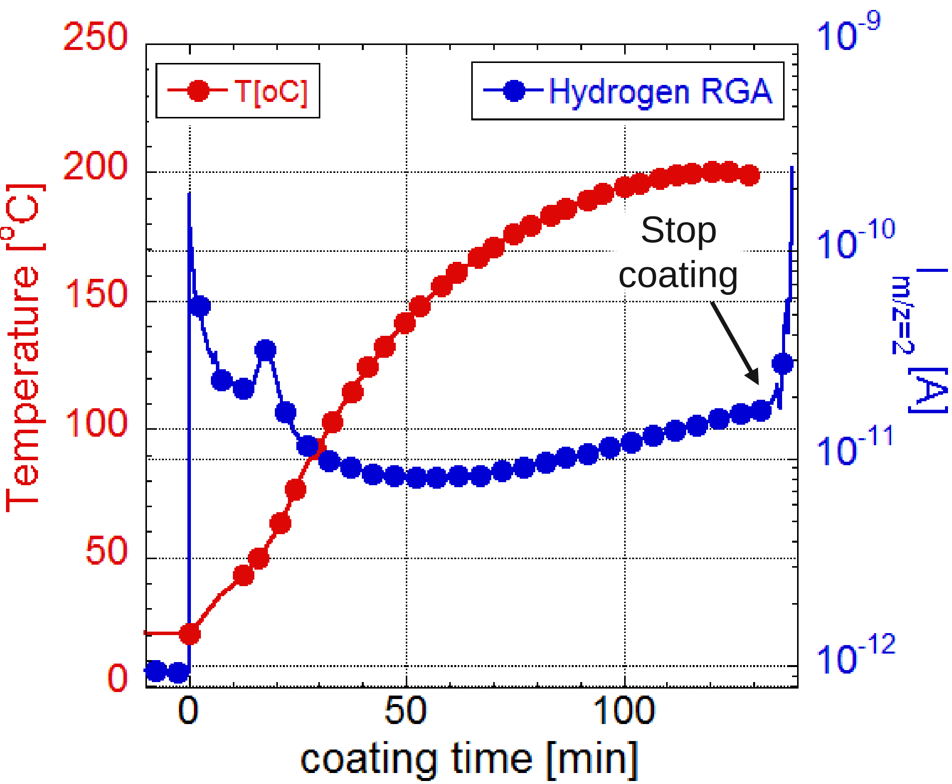
Measured heat load **< 0.2 W/m**

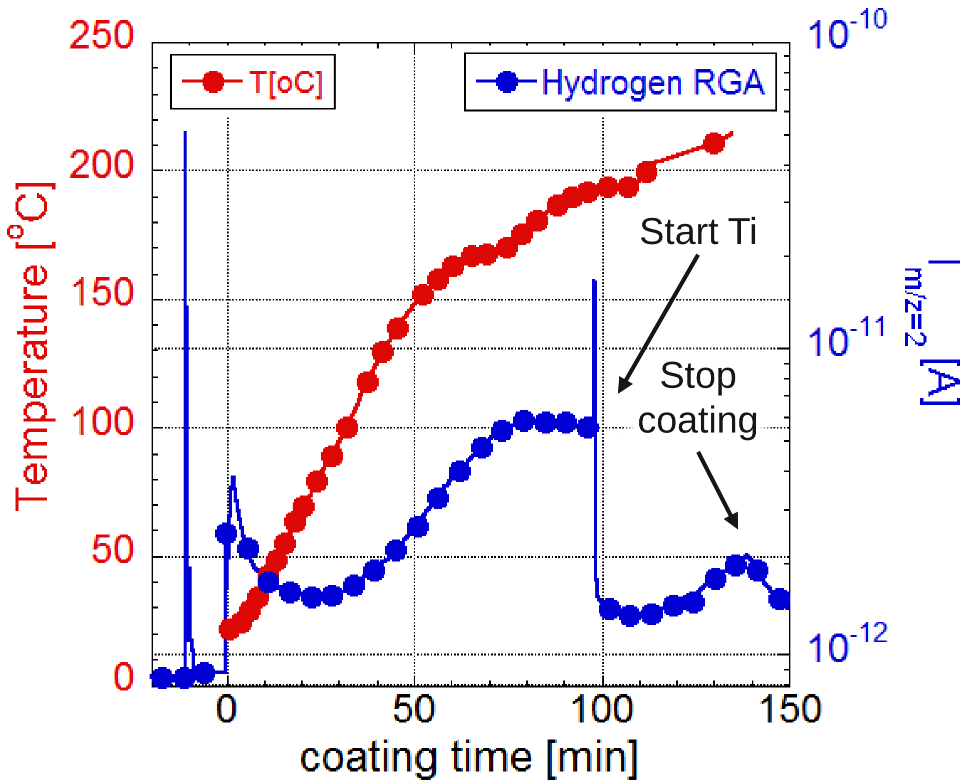
- Sensitivity 0.1 W/m
- In the past, scrubbed Copper gave 1.4 W/m

Ti gettering

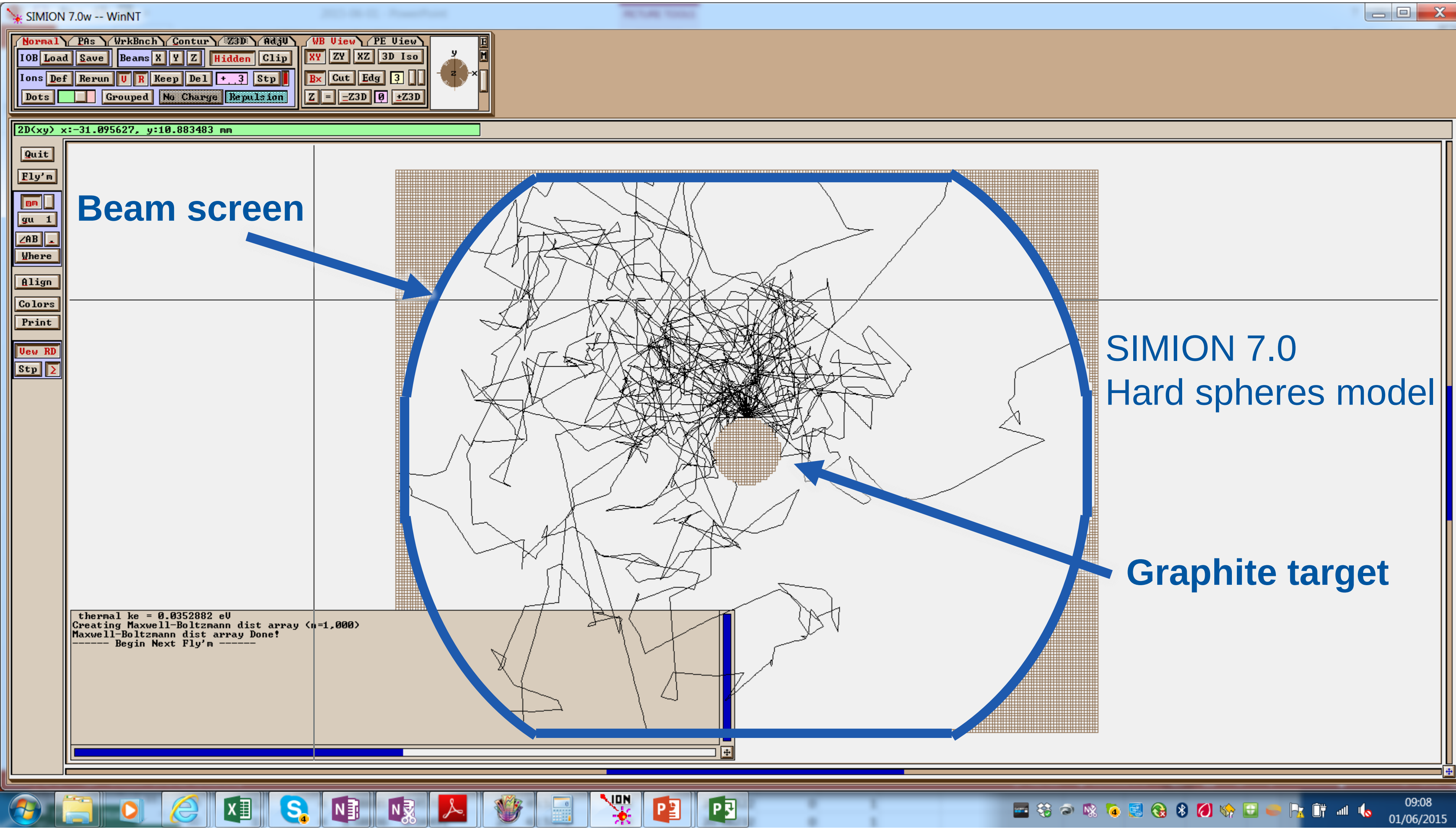
The key parameter for low SEY is the **hydrogen** present in the plasma during the deposition.

Use **Ti gettering** to reduce the hydrogen partial pressure

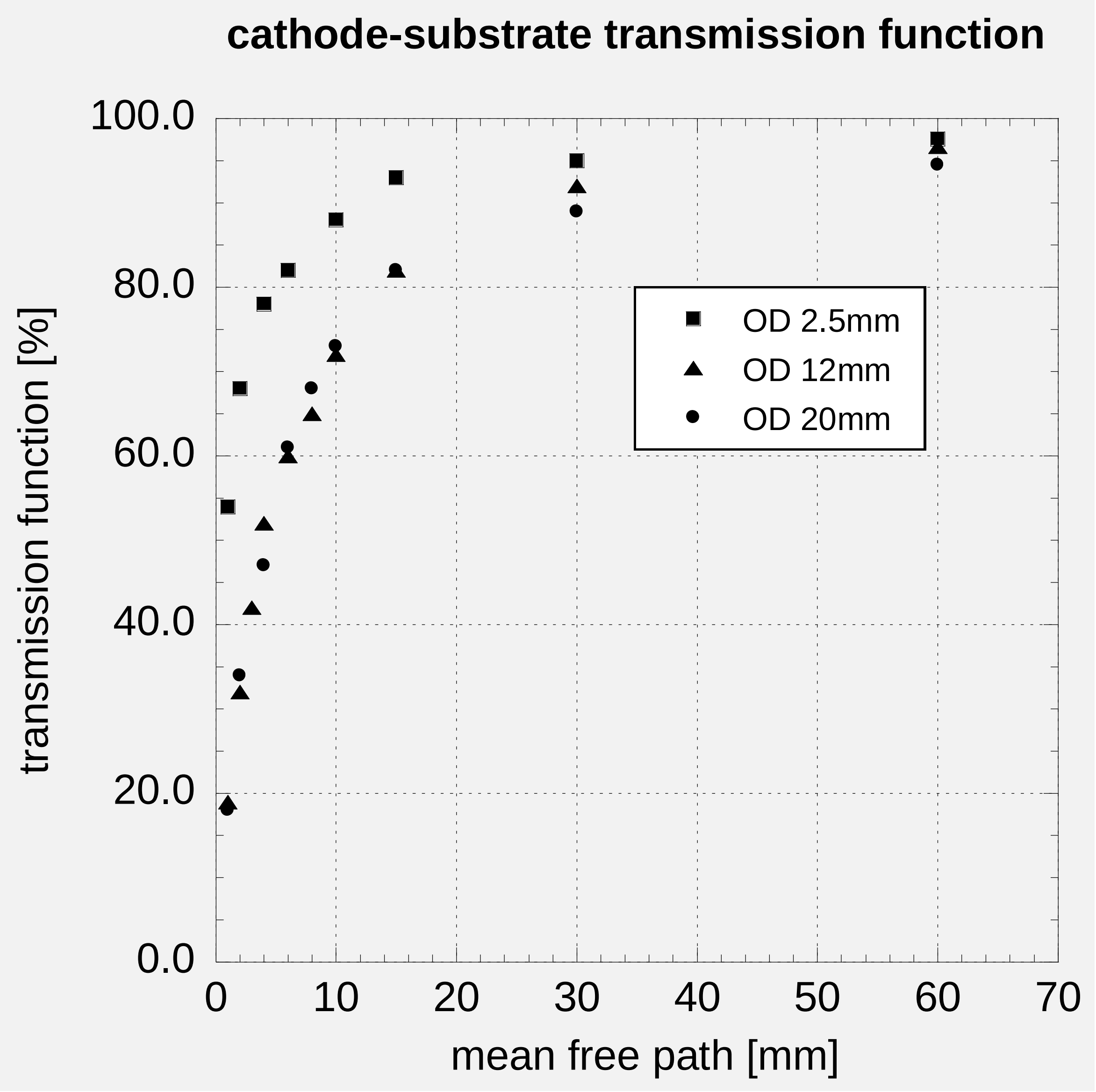




Simulation of target to substrate transmission

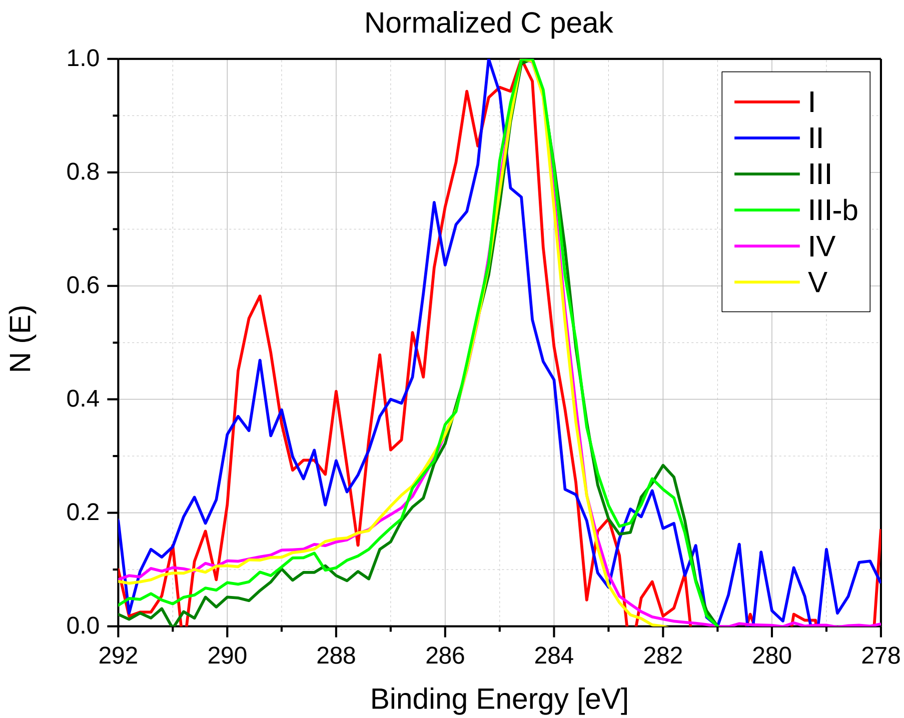


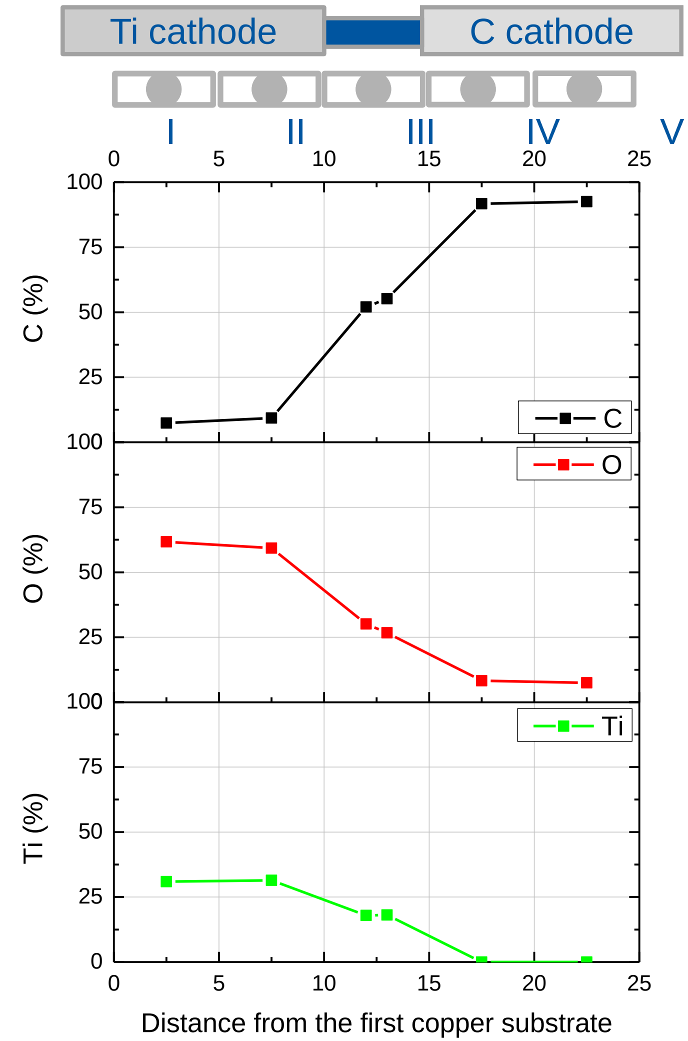
Simulation of target to substrate transmission



XPS results

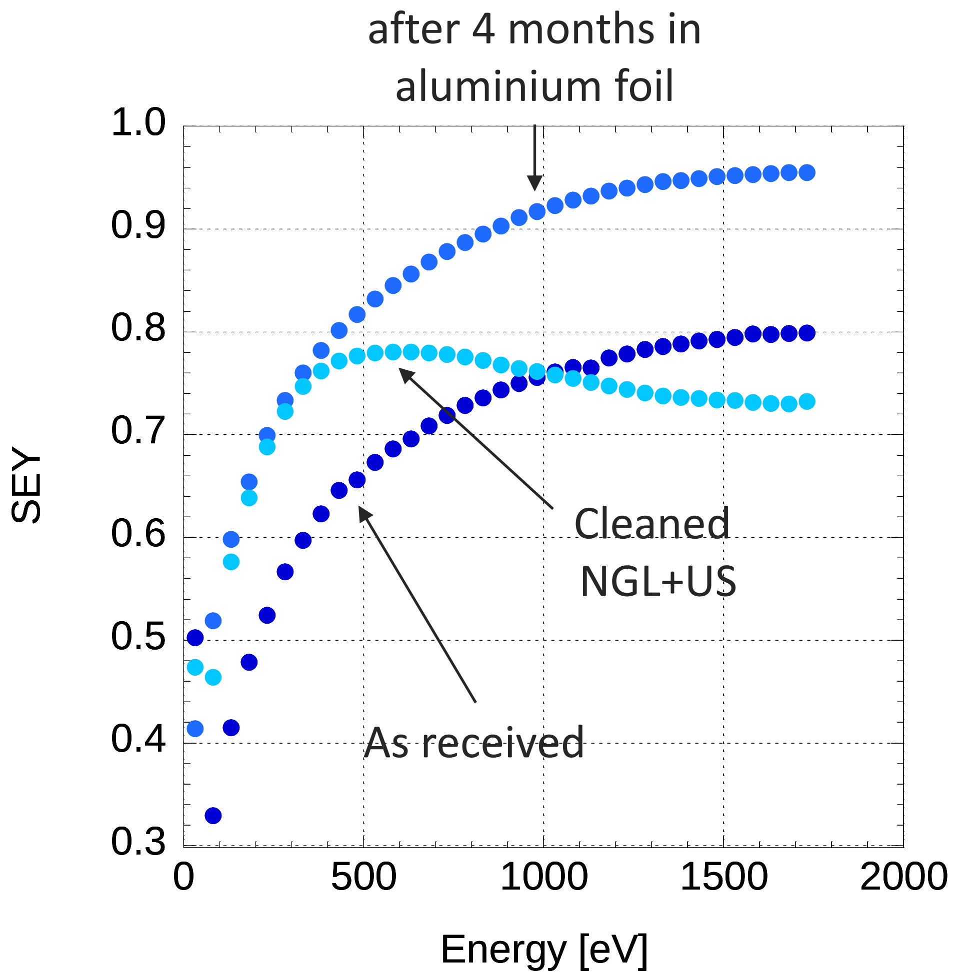
1h30 between the venting of the chamber and the measurements

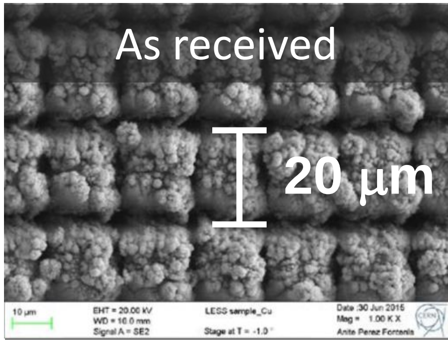


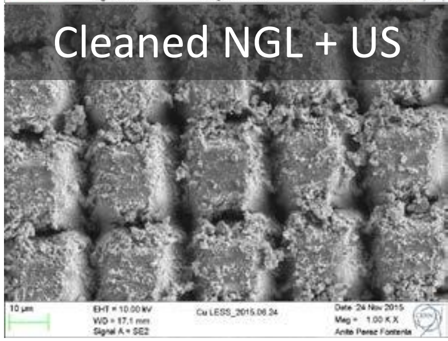


Cleaning LESS

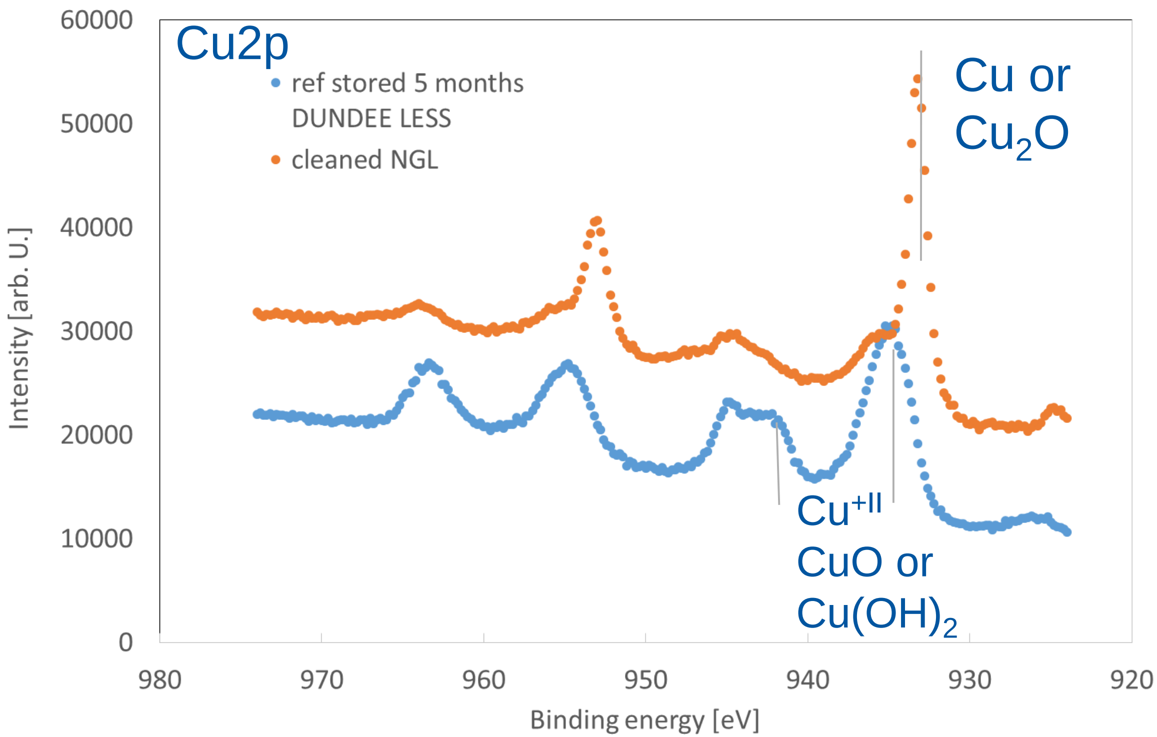
Dust issues after UHV cleaning + Ultra Sounds

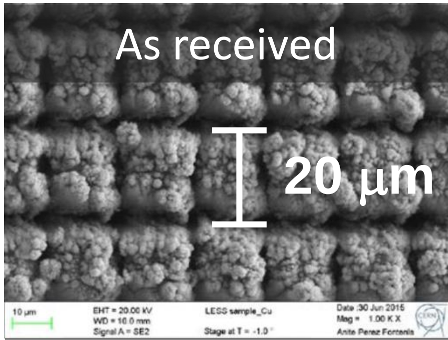


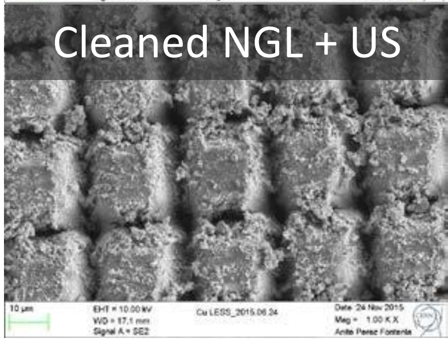




Dust issues after UHV cleaning + Ultra Sounds



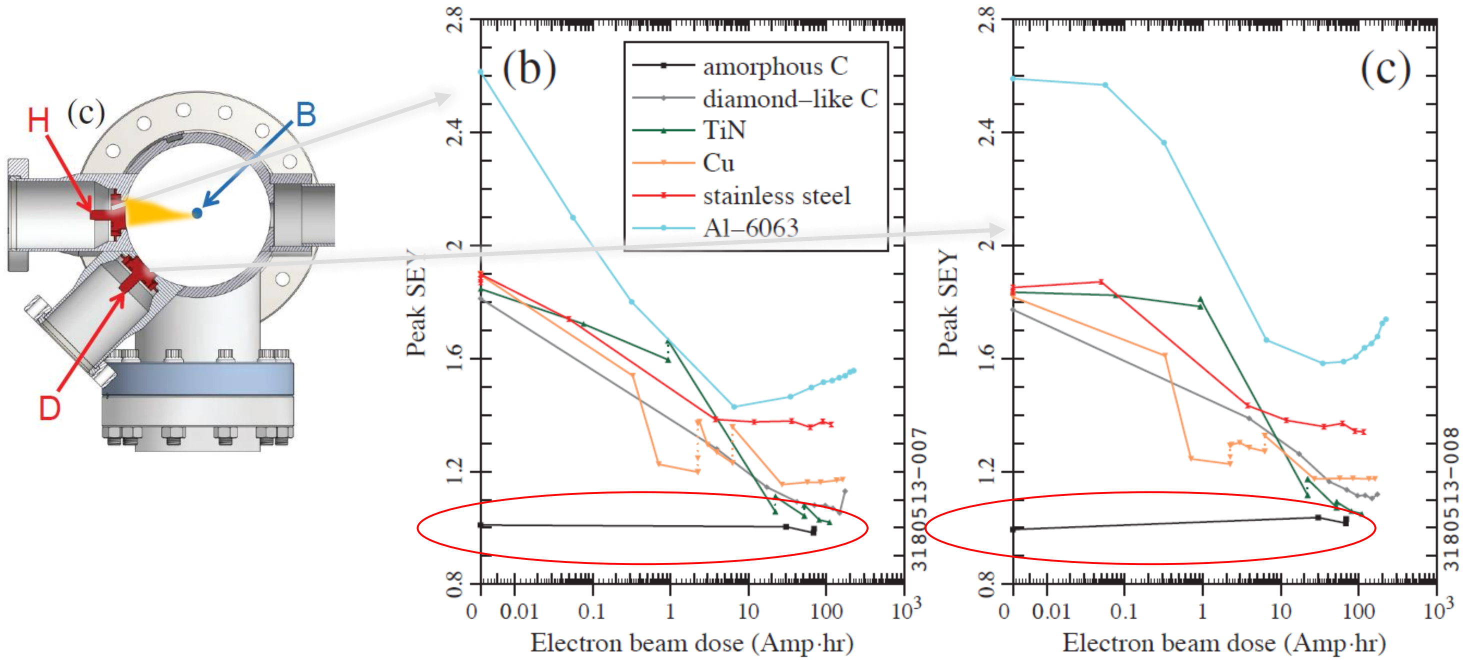




CesrTA

a-C @ CesrTA

SEY of samples measured in situ before and after conditioning



IPAC2013
W.Hartung,
J.Conway,
C.Dennett,
S.Greenwald,
J.-S.Kim,
Y.Li,
T.Moore,
V.Omanovic

- The SEY of the carbon films (from CERN) remains low during the all test.
- It does not show conditioning (even with synchrotron radiation) since it has already an SEY of 1.

UFOS

Preliminary estimates of the minimum UFO size in order to quench triplet magnets (7 TeV)

A. Lechner, B. Auchmann

Round-table discussion

June 18^{th}, 2015

UFOs

Estimated minimum UFO size for quenching a triplet magnet (7 TeV)

- Peak energy density in coils:
  - $\epsilon_{max} = 10^{-8}\,\mathrm{mJ/cm^3}$/collision (MQXA/MQXB)
- Quench level for 0.1-2 msec loss durations (no ad-hoc correction):
  - $QL = 6 - 9\,\mathrm{mJ/cm^3}$ (MQXB)
  - $QL = 9 - 15\,\mathrm{mJ/cm^3}$ (MQXA)
- Number of inelastic collisions to induce a quench:
  - $NmbColl = 6 \times 10^8 - 9 \times 10^8$ (MQXB)
  - $NmbColl = 9 \times 10^8 - 1.5 \times 10^9$ (MQXA)
  - Remark: we neglect any additional steady-state heat deposition due to the collision debris from the IP

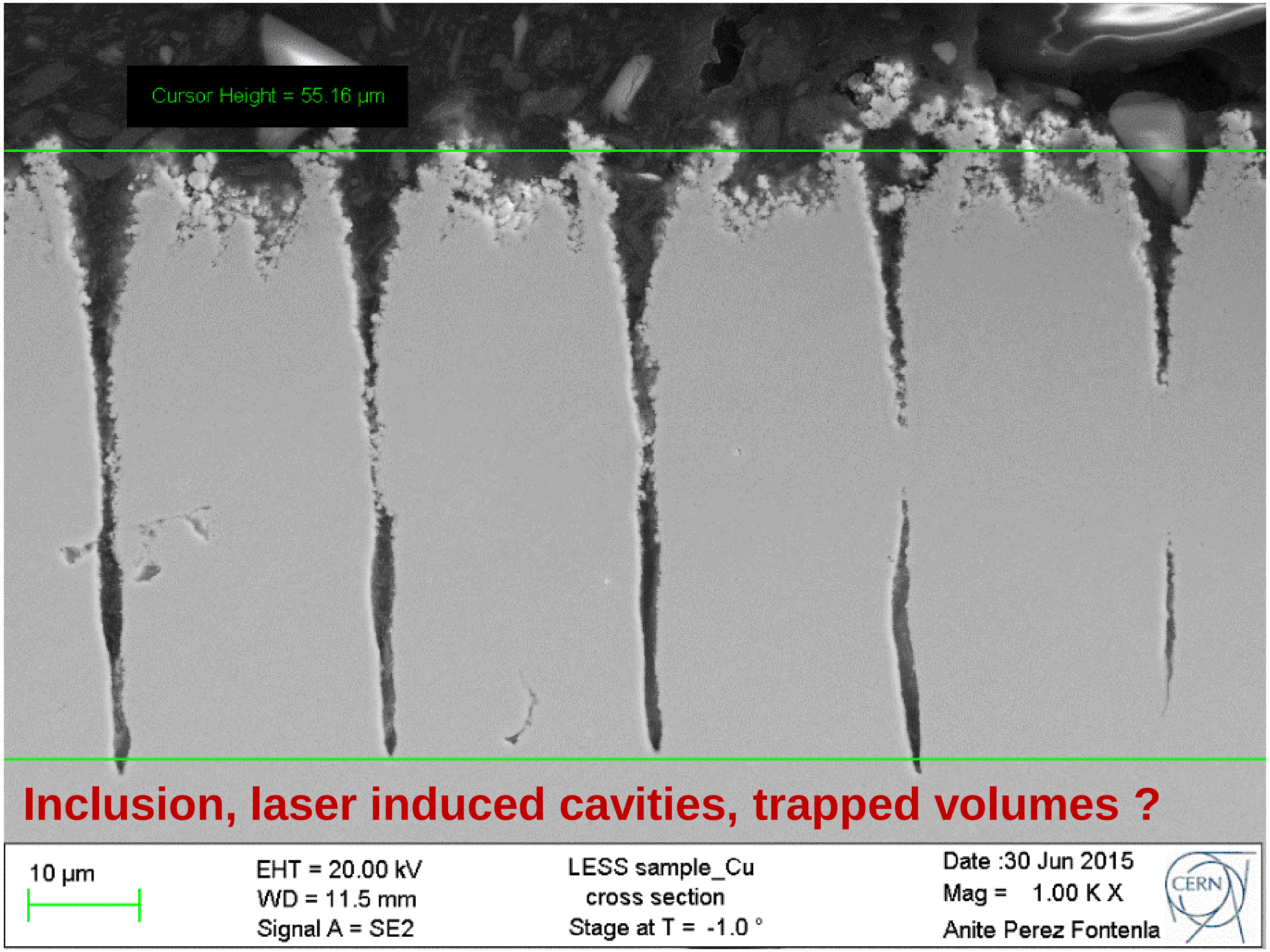
→ Estimated minimum UFO size/mass for inducing a quench:

- $Radius > 100\,\mu$m or $Mass > 5\,\mu$g (carbon with ρ=1.7 g/cm^3)

A. Lechner, B. Auchmann

porosity LESS

DOUBLE PASSING OF LASER

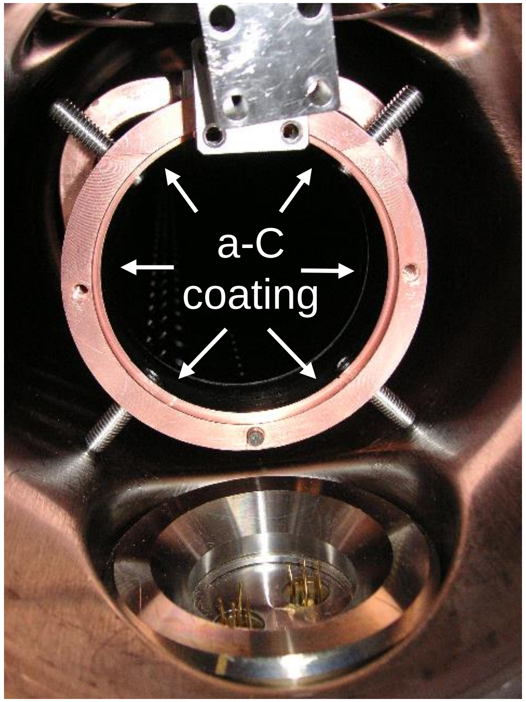


SEM images by A. Perez Fontenia (EN-MME-MM) – courtesy of S. Calatroni and I. Wevers

COLDEX

Performance: Tests in accelerators COLDEX

No e-cloud detected: threshold $1.10 < SEY_{max} < 1.25$



Roberto Salemme,
Build-up simulations for COLDEX and comparison with experimental data, Electron Cloud Meeting #20, CERN, March 13th 2015

No e-cloud activity registered on the pickup electrode **$I_e \sim 10^{-10}$ A**

- If $SEY_{max} \sim 1.10 \Rightarrow 2\ 10^{-10}$ A
- If $SEY_{max} \sim 1.25 \Rightarrow 2\ 10^{-6}$ A

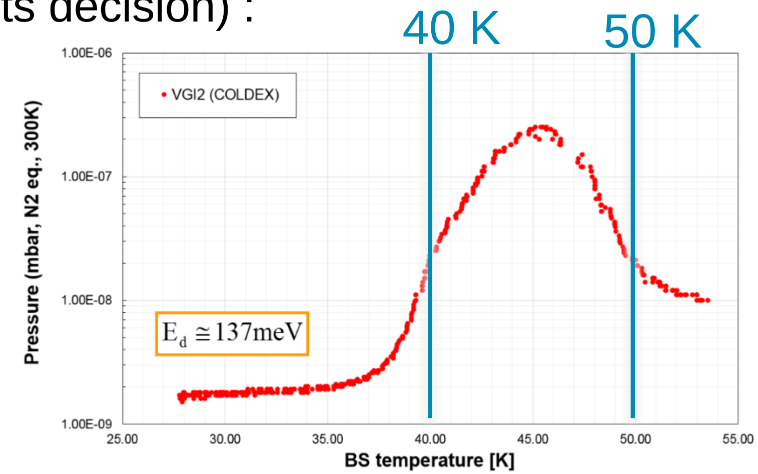
(benchmarking with pyECLOUD)

Measured heat load **< 0.2 W/m**

- Sensitivity 0.1 W/m
- In the past, scrubbed Copper gave 1.4 W/m

COLDEX (from V. Baglin @5th Joint HiLumi LHC-LARP Annual Meeting)

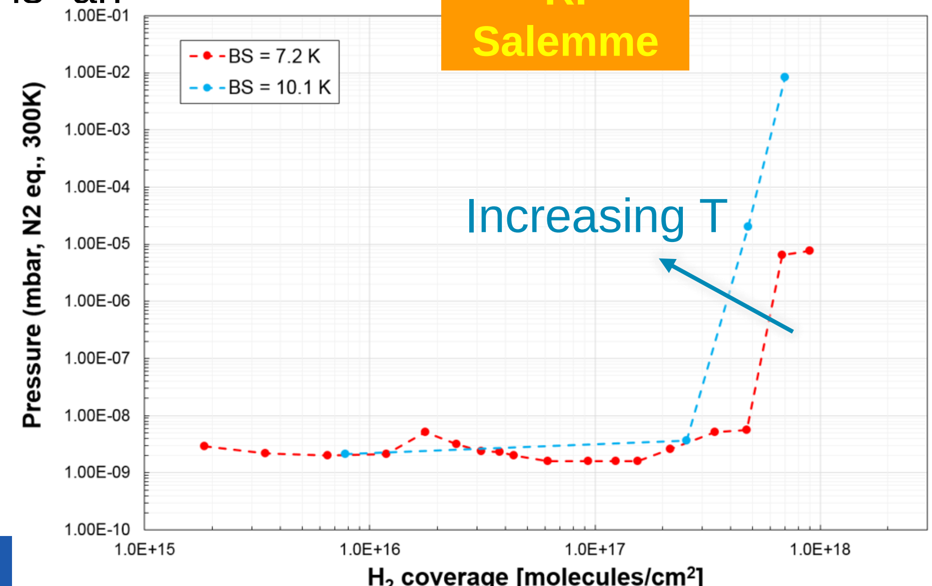
- The COLDEX program (LSS4 of SPS) is in progress, and will continue in LSS4 after EYETS (thanks to HL-LHC and CERN managements decision) :



- Thermal desorption spectroscopy
- Physisorbed / condensed H_2 is released from 400 nm thick a-C coating in the 40-50 K temperature range !

➔ The temperature window 40-60 K is not appropriated
➔ TBC in the coming year(s) if 50–70 K is an alternative

R. Salemme

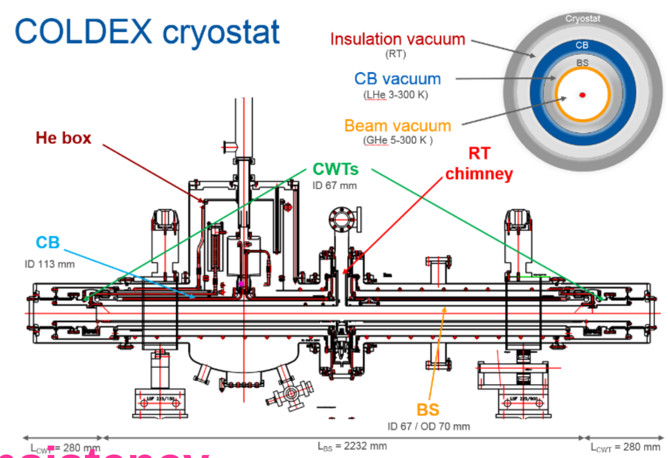


- H_2 adsorption isotherm
- a-C coating is a cryosorber !
- At 10 K:
  - capacity ~ 100 Cu
  - but 1/10 of LHC cryosorber

Characterisation with different gases and temperatures to be continued in 2016

COLDEX (from V. Baglin @5th Joint HiLumi LHC-LARP Annual Meeting)

- COLDEX Studies with SPS beams:
  - A 2 m long LHC type cryogenic beam vacuum system
  - A beam screen temperature from 10 to 80 K and a cold bore temperature from 3 to 4.5 K



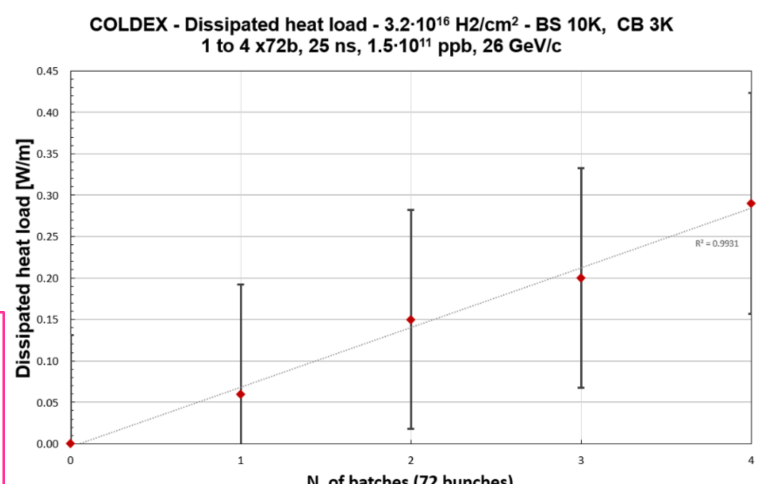
- In the 10 – 80 K range:
  - Pressure rise < 10^{-9} mbar, dominated by H_2
  - Heat load < 0.4 W/m
  - Electron cloud activity < 2 10^{-9} A/cm^2

} **Inconsistency**

R. Salemme

- H_2 condensation up to 3 10^{16} H_2/cm^2 do not strongly modify the behaviour

- Commissioning of COLDEX is not finished:
  - Difficulties to keep the cryogenic settings
  - Helium leak in the insulation vacuum
  - Instruments to be repaired / calibrated / upgraded



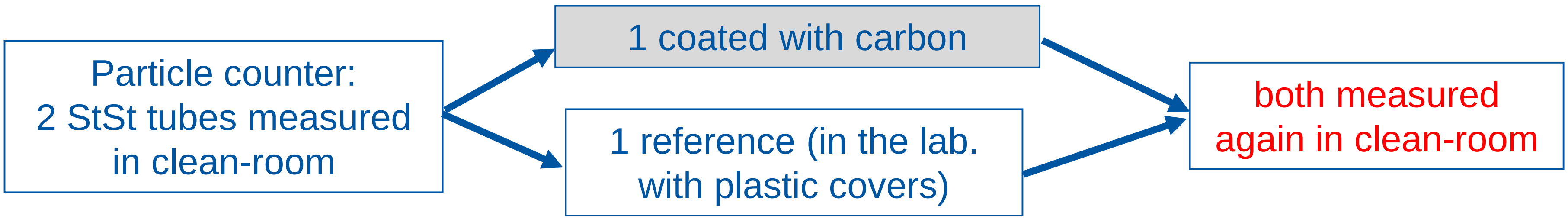
Many activities are planned during this YETS
Several MDs are needed to **consolidate** the results and to continue the **study**

Measure DUST a-C

2 – a-C coatings

What we learned from the SPS (since 2008)

Dust: no difference between coated and uncoated beam pipe.



No increase after shaking and gentle hammering of the chamber.

No increase for a chamber left in air for months

Pull test of adhesion (a-C on copper) shows an adhesion strength of 20-28 MPa even after 1GGy irradiation

2 – a-C coatings

What we learned from the SPS (since 2008)

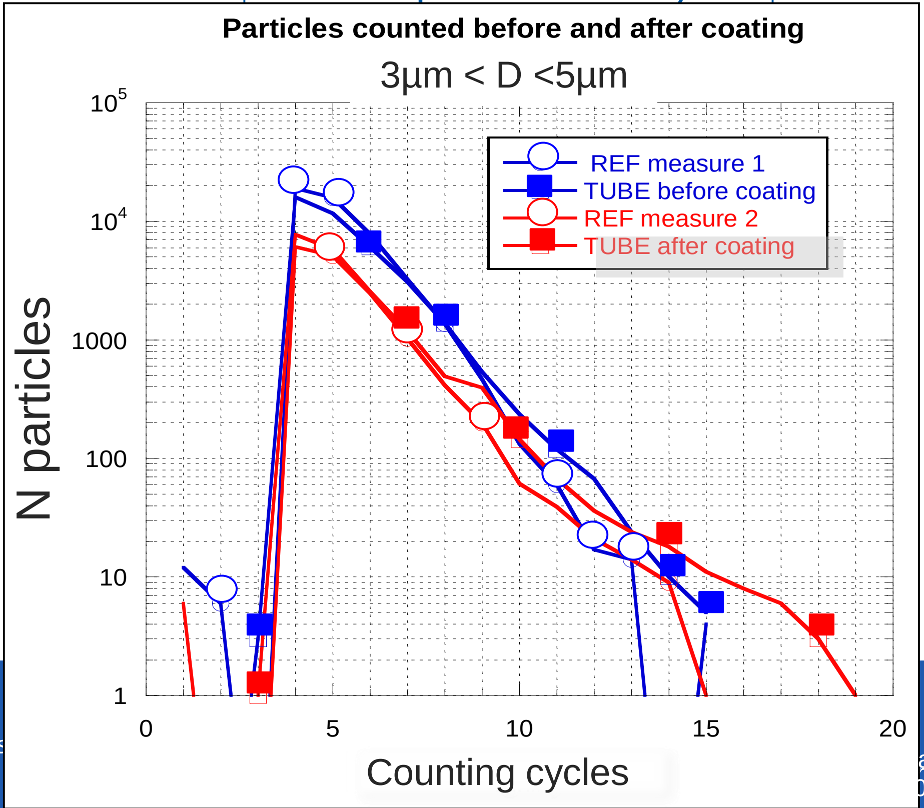
Dust: no difference between coated and uncoated beam pipe.

Particle counter:
2 StSt tubes measured
in clean-room

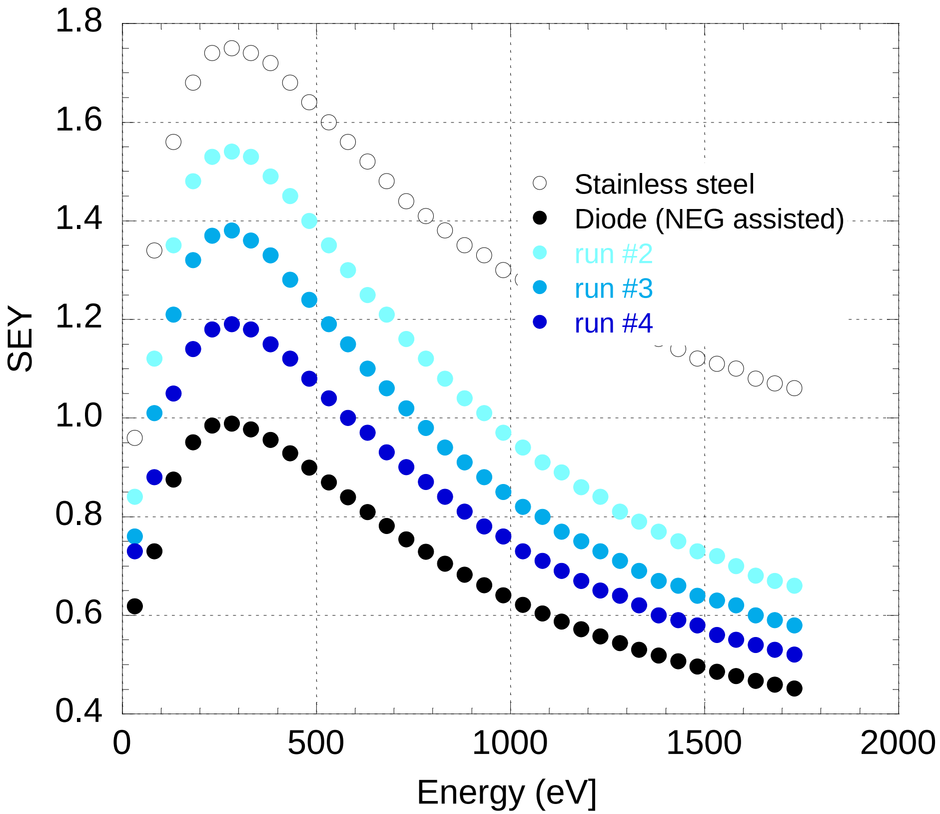
→ 1 coated with carbon

→ 1 reference (in the lab. with plastic covers)

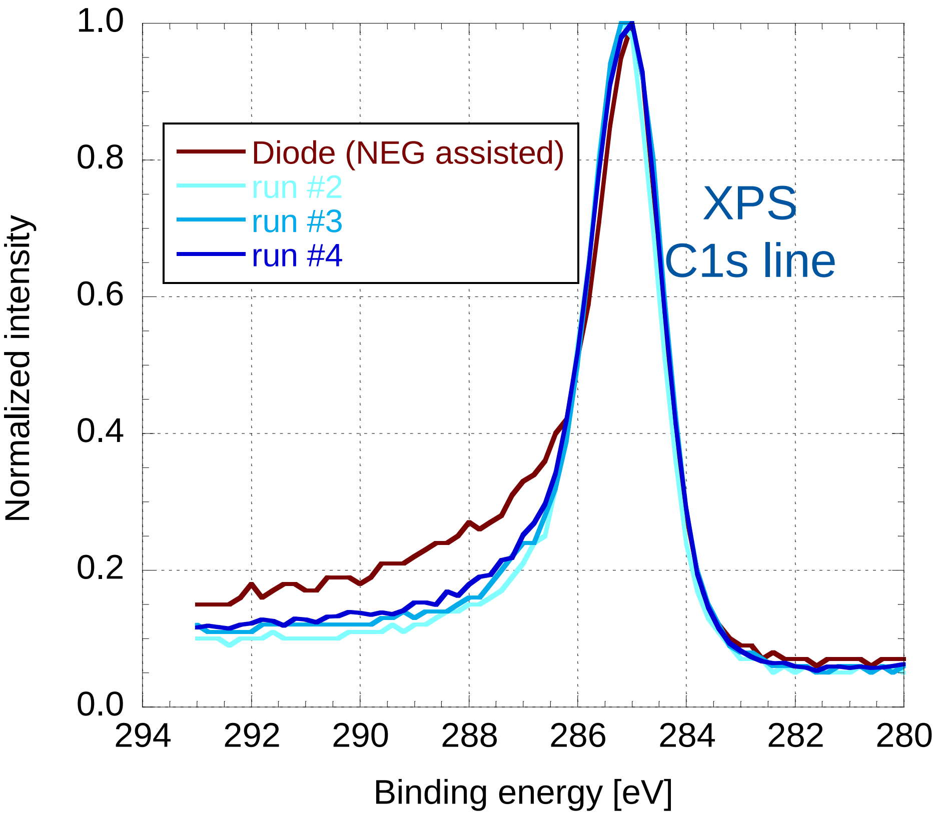
→ both measured again in clean-room



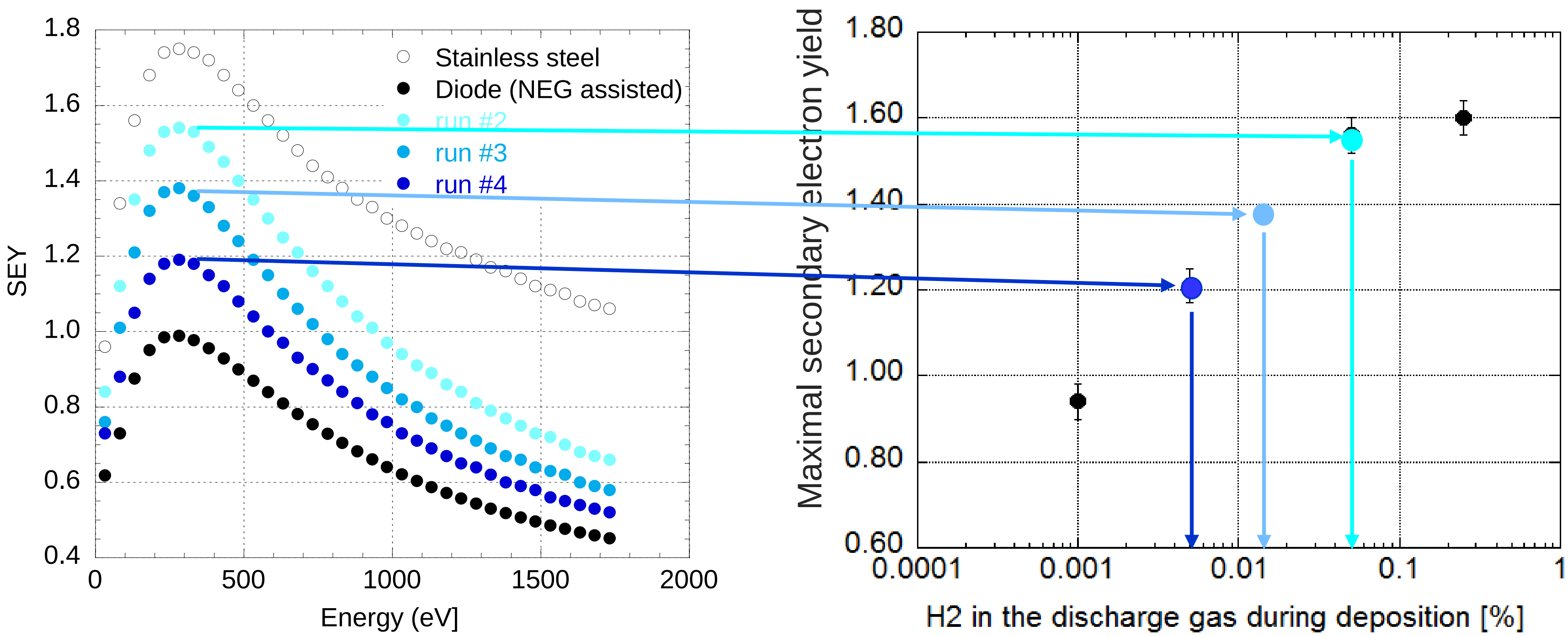
XPS
C1s



1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0
500
1000
1500
2000
SEY
Energy (eV)
Stainless steel
Diode (NEG assisted)
run #2
run #3
run #4



1.0
0.8
0.6
0.4
0.2
0.0
294
292
290
288
286
284
282
280
Normalized intensity
Binding energy [eV]
Diode (NEG assisted)
run #2
run #3
run #4
XPS
C1s line

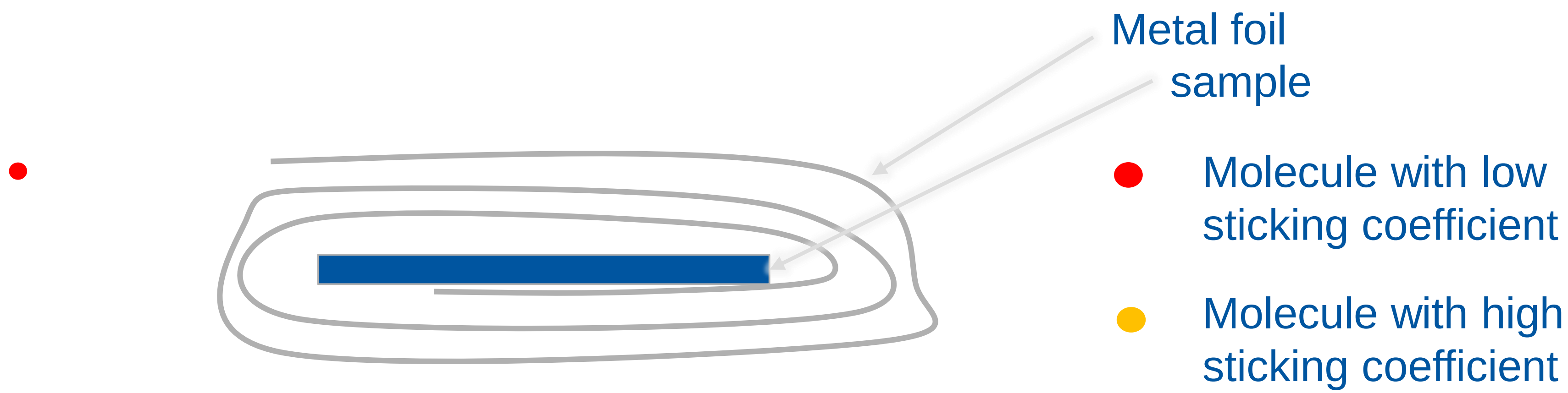


SEY
Energy (eV)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0
500
1000
1500
2000
Stainless steel
Diode (NEG assisted)
run #2
run #3
run #4
Maximal secondary electron yield
H2 in the discharge gas during deposition [%]
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.0001
0.001
0.01
0.1
1

Al foil

Why aging is retarded by wrapping in a metal foil?

Aging is strongly retarded by packaging in metal foil (aluminium or stainless steel), which is not tight to gas



A molecule with low sticking coefficient can go very far in a small conductance. A molecule with high sticking coefficient will adsorb immediately and never reach the sample surface.

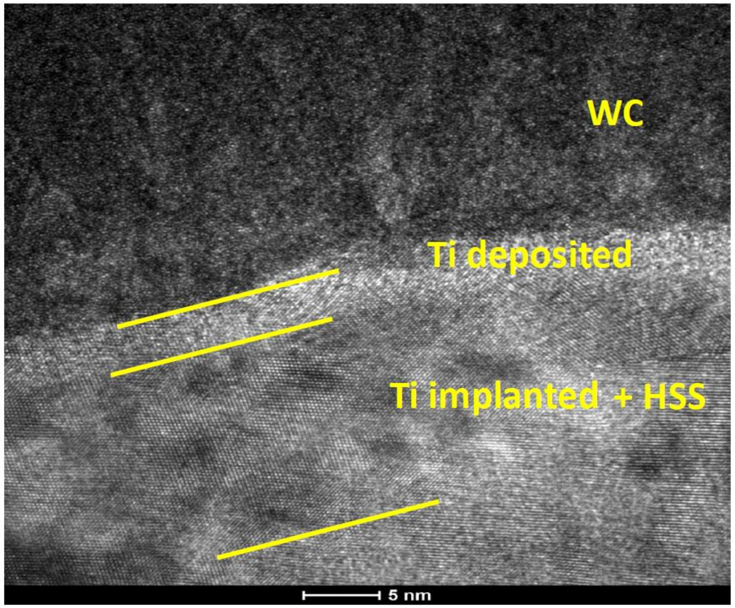
The metal foil protects from molecules with high sticking coefficient, like heavy hydrocarbons.

NB: This is strictly valid only in molecular regime, but also in viscous flow in the absence of drag (if the collisions with the gas can be "mimicked" by a reduced sticking coefficient)

3 – Adhesion studies

Next steps for adhesion studies:

- Investigate impact of the curing step (150^{o}C in air; oxidizing interface?)
- Sputter the copper oxide layer (using the Ti target as anode)
- Use HIgh Power Impulse Magnetron Sputtering (HIPIMS) to implant Ti



Titanium

- **Gradual interface** coating-substrate
- **Epitaxial growth**
- **Alligment** from **steel** substrate to **WC**
- **Ti** implanted into the substrate **lattice**
- No **bubbles**, **voids** or droplets

www.fabricatingandmetalworking.com

DLC coatings deposited by magnetron sputtering : high hardness and enhanced adhesion properties
Ambiorn WENNBERG , Ivan FERNANDEZ , Jose Antonio SANTIAGO , R. GONZÁLEZ-ARRABAL , A. RIVERA , M. CASTILLO , J. MOLINA , M. MONCLÚS
NANO4ENERGY SLNE, Universidad Politécnica de Madrid,, Universidad Politécnica de Madrid, Imdea Materiales