FCC hh ee he

EuroCirCol
A key to New Physics
WP4

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

ALBA

Ciemat

ANKA

KIT Karlsruhe Institute of Technology

CERN

STFC ASTeC

Ciemat

Science & Technology Facilities Council

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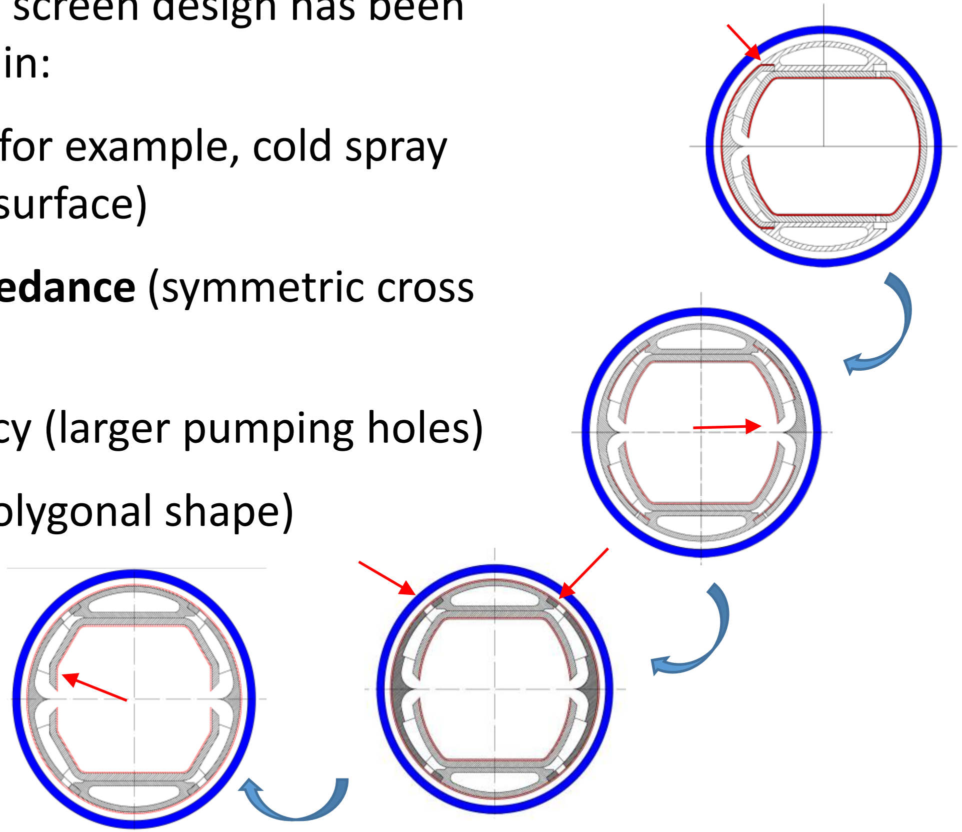
Progress with the cryogenic vacuum system of FCC-hh

Francis Perez (ALBA) and Paolo Chiggiato (CERN)
on behalf of **EuroCirCol WP4**

Progress with the FCC-hh beam screen design

- In the last two year, the beam screen design has been modified several times to attain:
  - Improved **heat transfer** (for example, cold spray copper ring in the outer surface)
  - **Reduced transverse impedance** (symmetric cross section)
  - **Higher pumping** efficiency (larger pumping holes)
  - **Easier manufacturing** (polygonal shape)



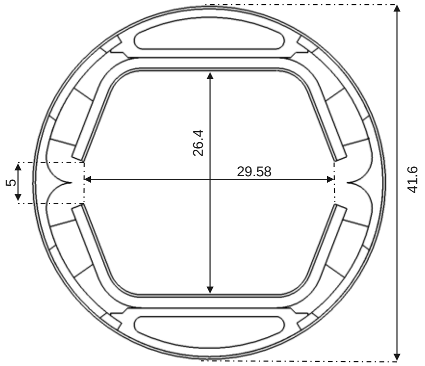
Progress with the FCC-hh beam screen design

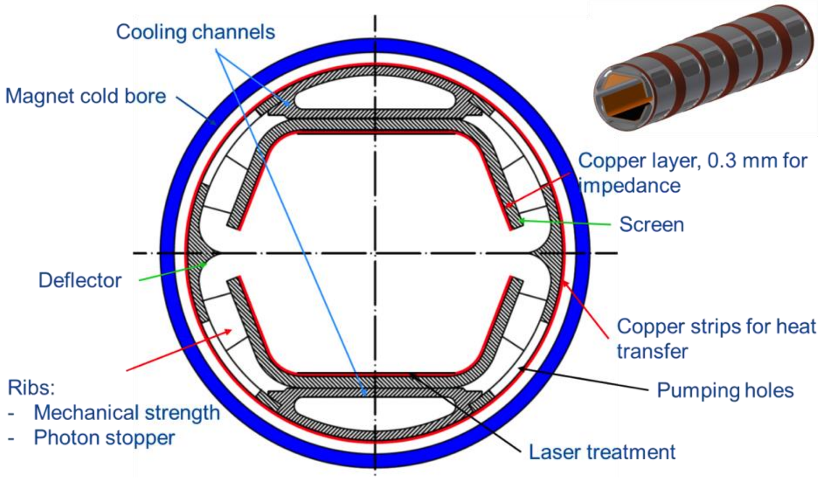
Orsay 09/2015
3th WP4 meeting

Geneva 06/2016
4th WP4 meeting

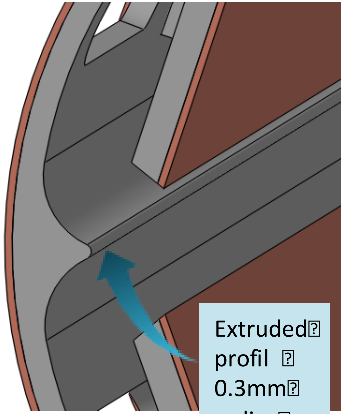
Barcelona 11/2016
5th WP4 meeting

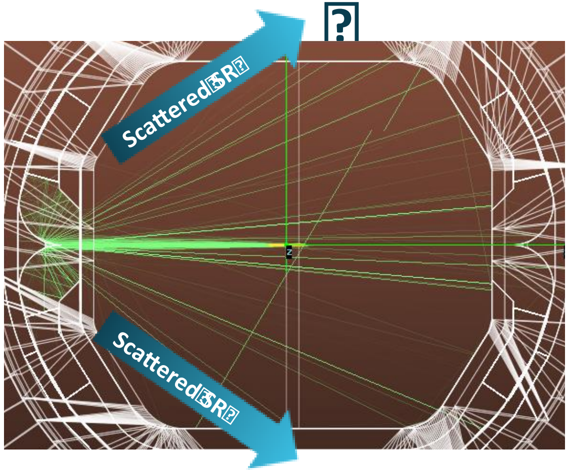
Karlsruhe 04/2017
6th WP4 meeting

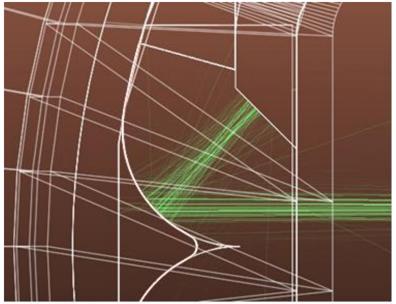




SR POWER REDIRECTION







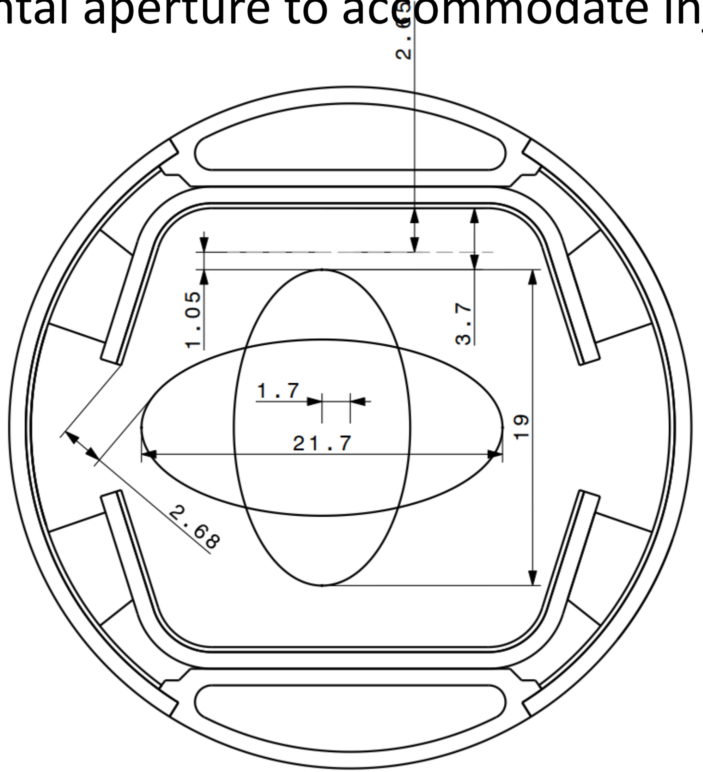
SR ray tracing simulation

- The reflector, with a **V shape**, was **aimed to redirect the radiation** towards the **ribs**, in order to avoid scattering photons back to the main chamber and to improve the conductance of molecules towards the cold bore
- Nevertheless, the chosen manufacturing methodology (**extrusion**) would always leave a **rounded edge** instead of a perfectly sharp one. Even being as small as 0.3mm (best found supplier), if the beam is centered, and without machining it afterwards, makes a **huge amount of SR go back to the main chamber** where it was originated
- Besides, to work properly even being perfectly sharp, the beam **can´t be misaligned more than 1mm**, otherwise the beam sees a flat surface. And, as previously studied it **has to be very polished** to work efficiently, **rising the costs**

BEAM DYNAMICS REQUIRED LARGE APERTURES

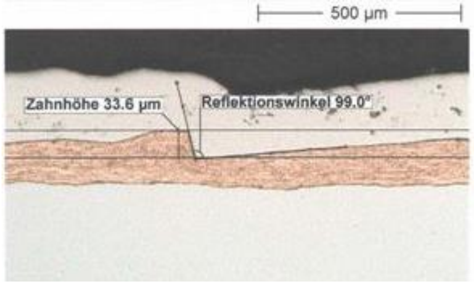
Large acceptance to accommodate vertical orbit error

Larger horizontal aperture to accommodate injection (15.5 sigma)

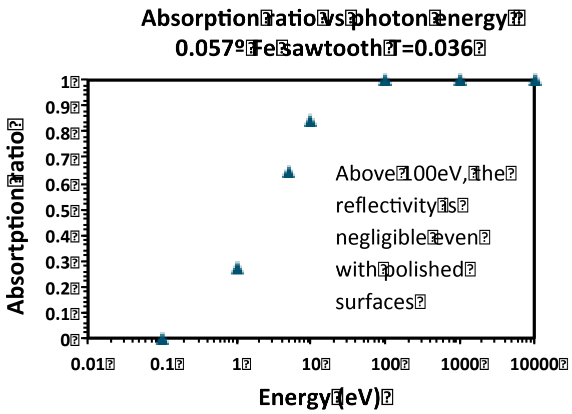


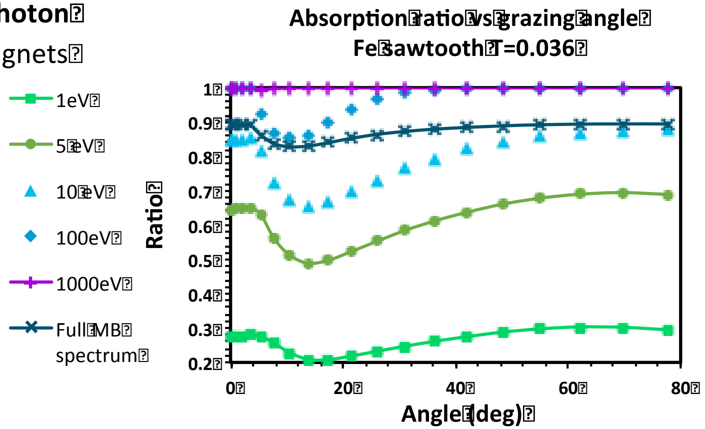
SAWTOOTH SURFACE PROPERTIES

- Owing to the difficulties of **effectively reflect** the synchrotron radiation with the reflector and within an **affordable complexity**, the **approach has been changed to maximize the absorption** on the first impact area, along the beam screen walls
- For this, a **sawtooth profile has been proposed**, because of its proved efficacy in absorbing X rays with a relatively low manufacturing cost whilst besides **decreasing** the photoelectron yield (PEY) and **light scattering**
- According to the carried out simulations, even with a polished copper surface, **it can absorb more than the 90%** of the **photon flux** and **99.5% of the power** coming from the bending magnets



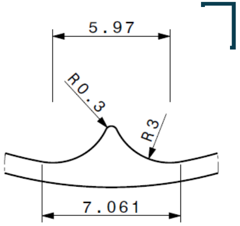
Sawtooth profile of the LHC's BS

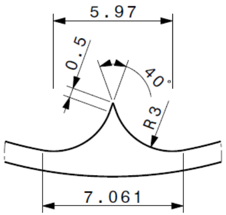


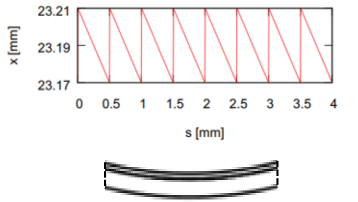


REFLECTOR PROFILE COMPARISON

- With the former beam screen dimensions, a **comparison of three possible reflector profiles** has been performed, with polished surface and the beam aligned, for **50 TeV, 500 mA,** SR > 4eV



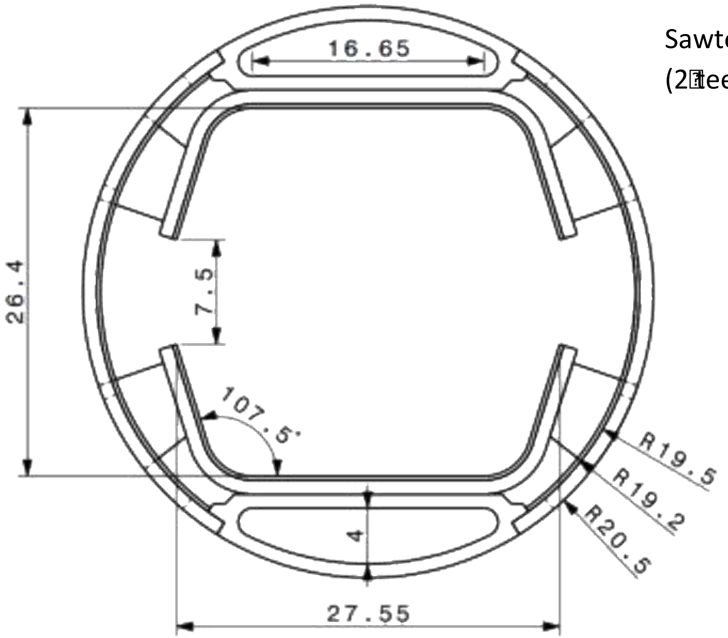


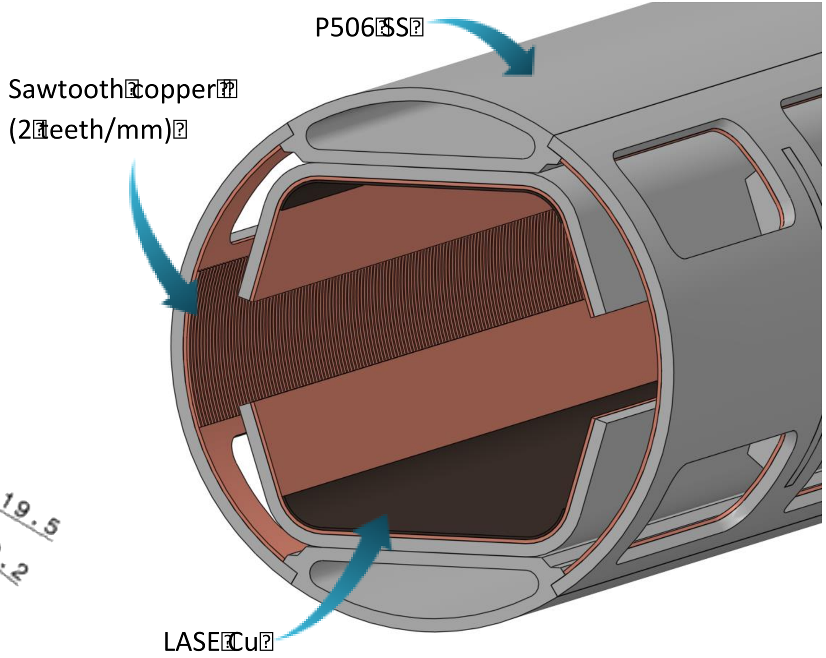


	Extruded profile	Extr.+ machined profile	Cu sawtooth
Leaked SR power to cold mass (σ=1)	0.035 W	0.045 W	0.002 W
Inner beam Cu chamber SR power	80.1W (16% of MB)	3.6 W (0.8% of MB)	0.18 W (0.04% of MB)
Power on flat area of the inner Cu	13.2 W (2.7% of MB)	0.3W (0.06% of MB)	0.006W (0.0013% MB)
Leaked % SR power through main slot	20%	1%	0.01%
Ribs SR absorbed power	25 W	91.2 W	0.0025 W
% Power absorption on the reflector	49%	49%	99.5%
H_2 molecular density PSD 36 A·h	$1.7 \cdot 10^{14}$ H_2/m^3	$1.2 \cdot 10^{14}$ H_2/m^3	$4.8 \cdot 10^{13}$ H_2/m^3
Manufacturing complexity	Low	Medium	High

- **Best numbers are given by the sawtooth profile in all critical fields**, redirecting **400 times less power** to the inner Cu chamber, also **lowering** the total PSD generated **outgassing.** Shown numbers are per MB, for the previous design

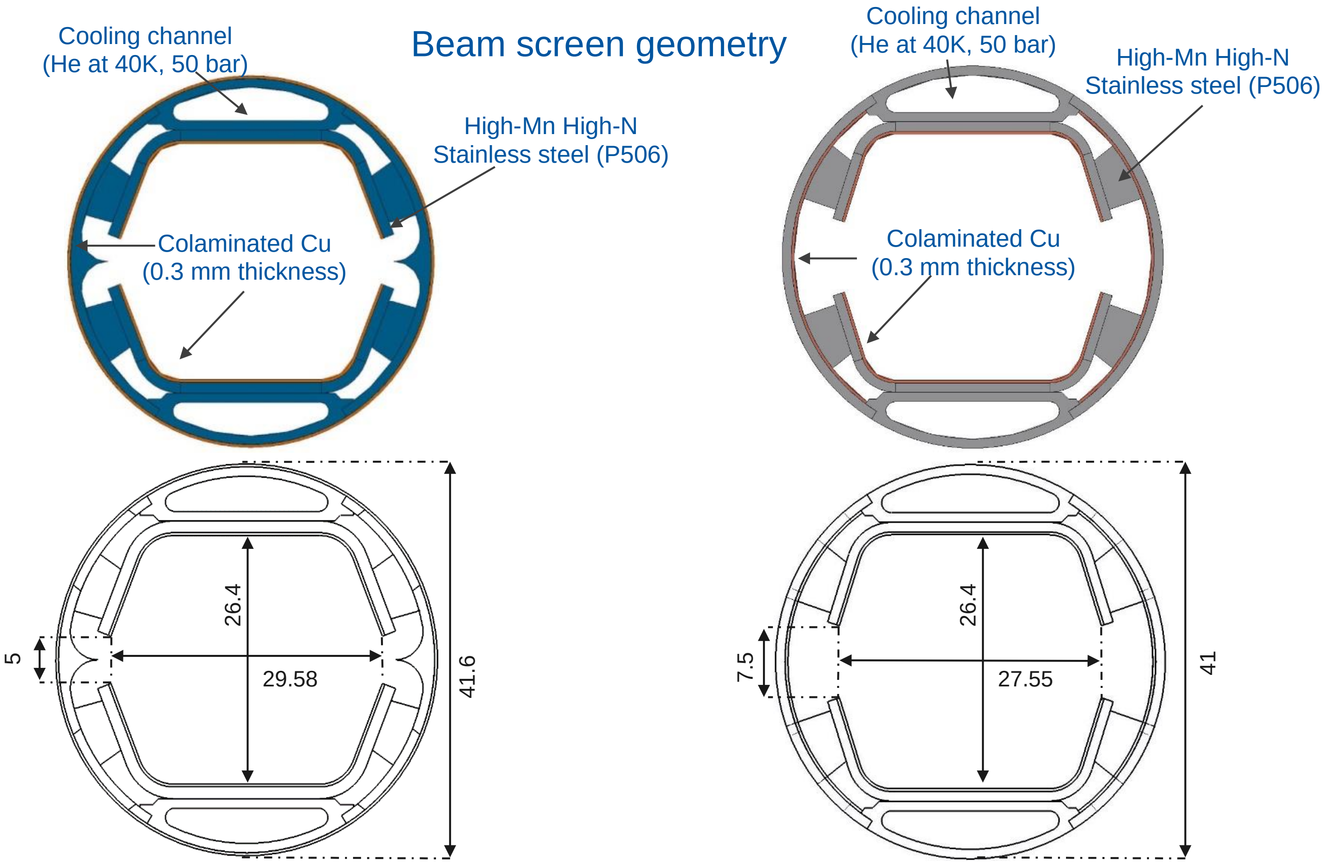
NEW BEAM SCREEN PROPOSAL





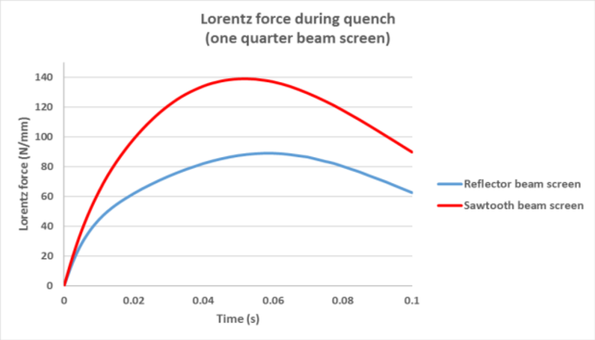
Beam Screen Design

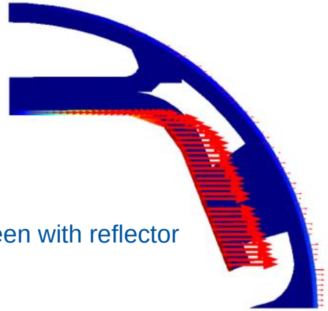
Beam screen geometry



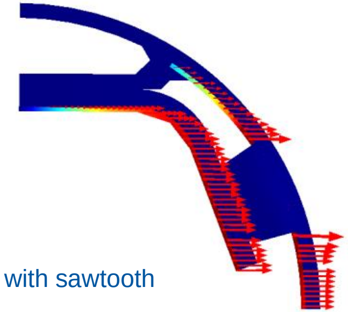
Mechanical Design

Lorentz forces



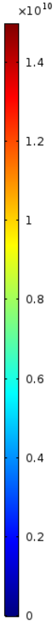


Beam screen with reflector



Beam screen with sawtooth

1.5E10



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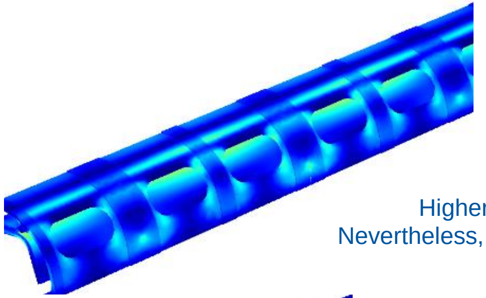
Lorentz force (N/m^3)

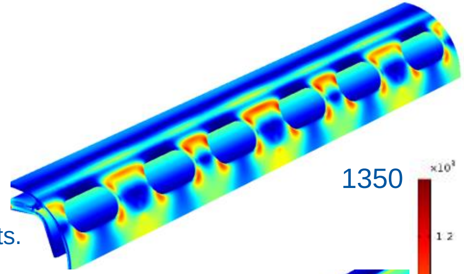
New copper part increases 57% Lorentz force.

High copper electrical conductivity produces more induced currents, thus, more Lorentz force during quench.

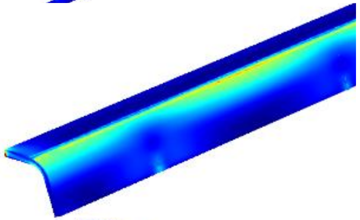
Mechanical Design

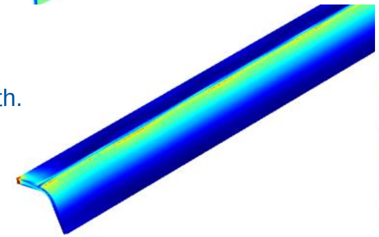
Stress analysis



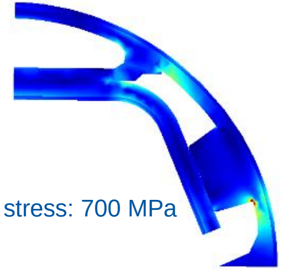


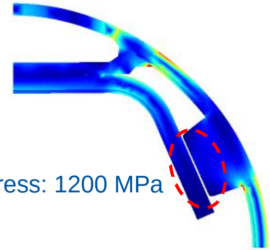
Higher stress with new co-laminated copper.
Nevertheless, plasticity was not reached in any of its points.





Welding lines must be studied in detail to ensure its strength.





Bigger displacements provoke eventual separation between stiffeners and inner chamber.

Max stress: 700 MPa

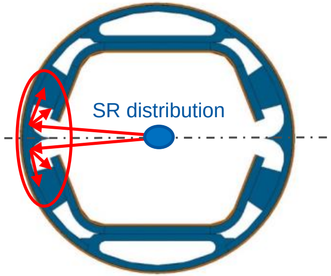
Max stress: 1200 MPa

Max displacement exterior beam screen: 0.35 mm

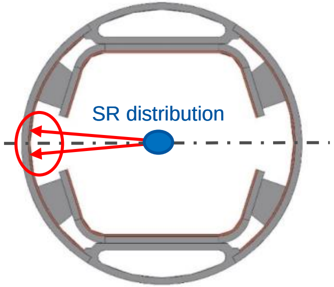
Max displacement exterior beam screen: 0.6 mm

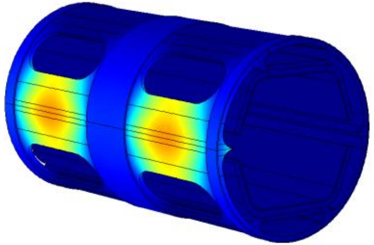
Thermal analysis

Synchrotron radiation impact

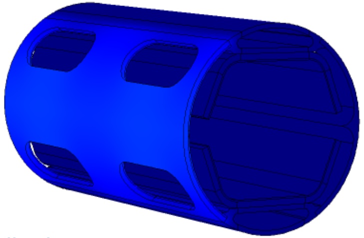


SR distribution changes with sawtooth.
Different heat load.

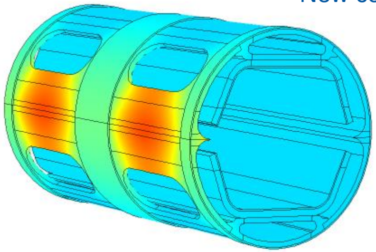




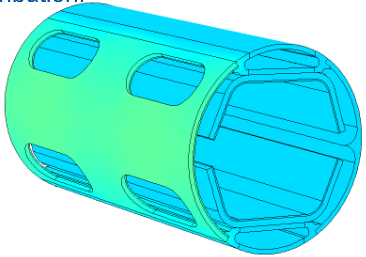
Helium inlet conditions
40 K, 5000 W/m^{2}K, 50 bar



New copper layer produces different temperature distribution.

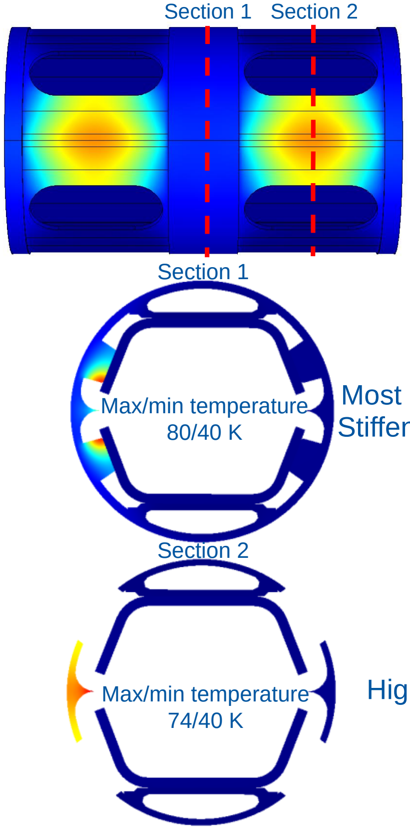


Helium outlet conditions
57 K, 5000 W/m^{2}K, 50 bar



Thermal analysis

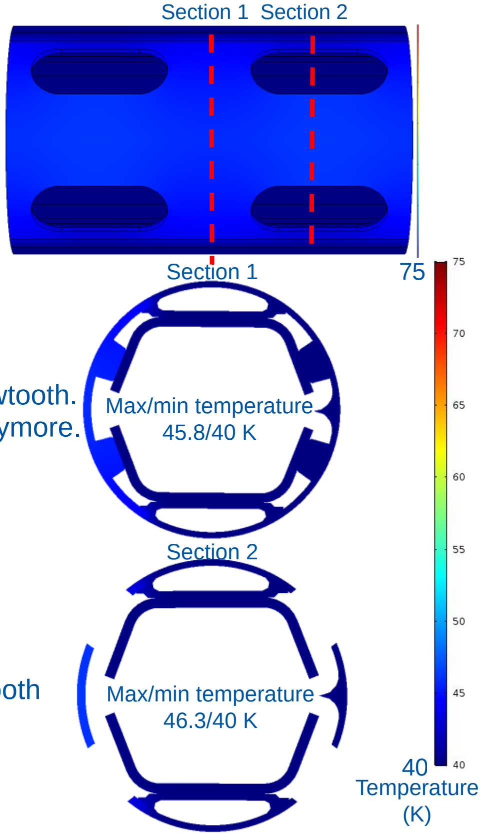
Synchrotron radiation impact



Helium inlet conditions
40 K, 5000 W/m^{2}K, 50 bar

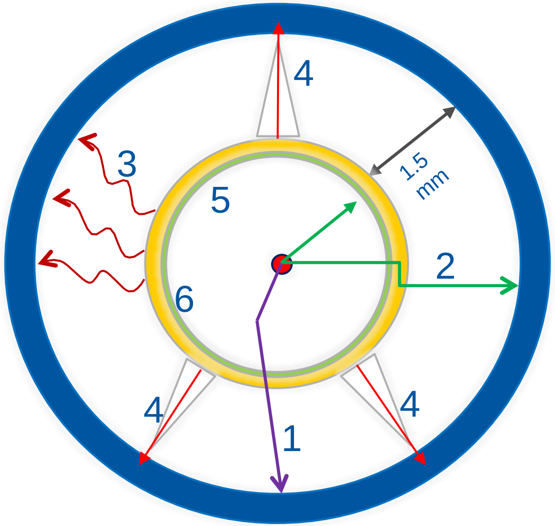
Most of the radiation is absorbed by the sawtooth.
Stiffeners don't act as a photon stoppers anymore.

High thermal conductivity in copper sawtooth layer helps to reduce temperatures



Thermal analysis

Heat transferred to cold bore



			Reflector	Sawtooth
1	•	Nuclear scattering:	191 mW/m	191 mW/m
2	•	Synchrotron radiation:	2.4 mW/m	0.5 mW/m
3	•	Thermal radiation:	1 mW/m	0.6 mW/m
4	•	Beam screen supports:	100 mW/m	75 mW/m
5	•	~~Image currents~~		
6	•	~~Electron cloud~~ effect		

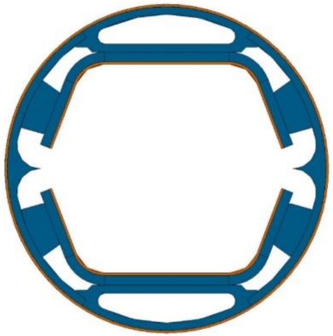
Max power allowed: 300 mW/m

Total thermal load transferred to cold bore with sawtooth: 267.1 mW/m

Beam Screen Design

Beam screen evolution

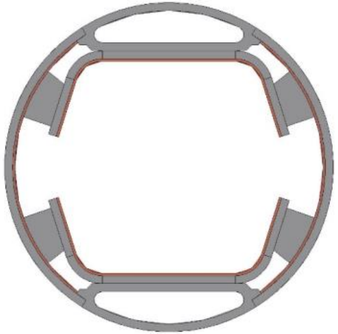
Berlin 05/2017
FCC week

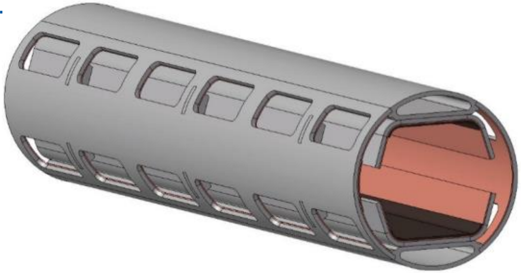


1. Reflectors have been changed by an co-laminated copper coating and sawtooth synchrotron radiation absorber.

2. Copper strips have been eliminated since copper coating increases thermal efficiency.

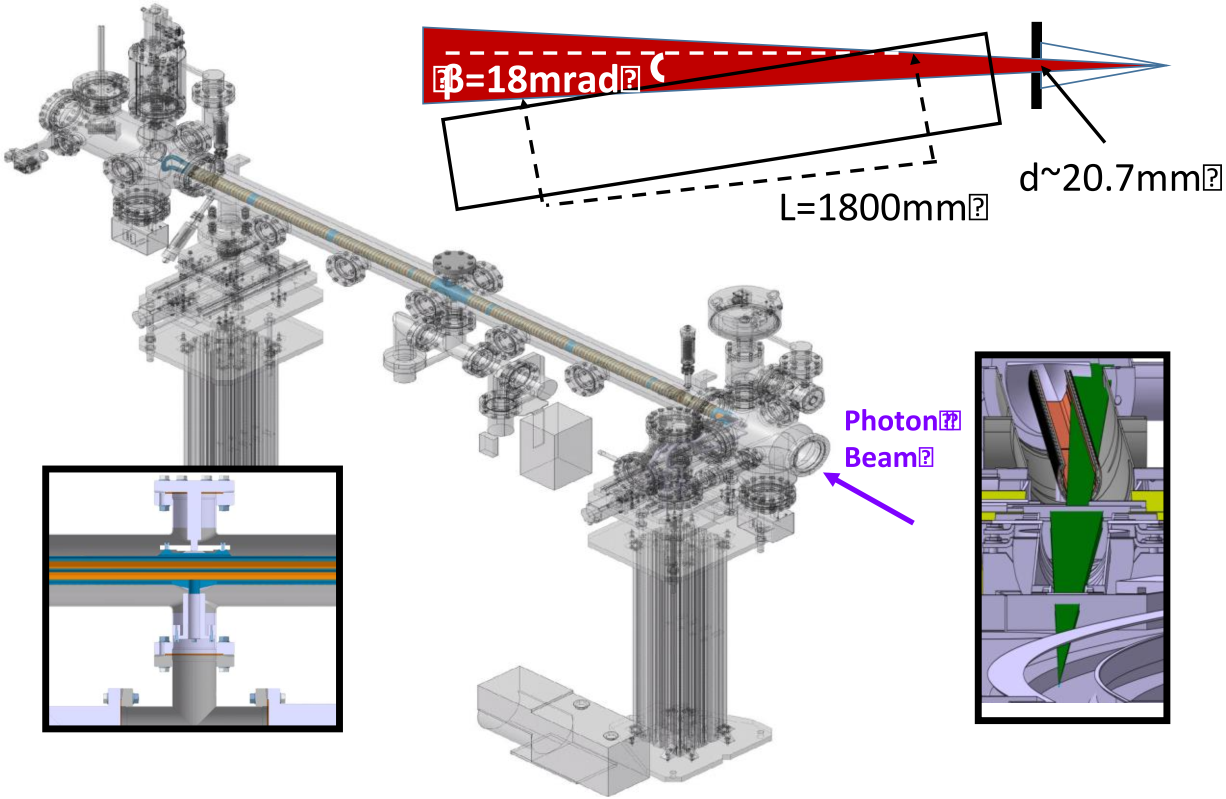
Geneva 10/2017
WP4 meeting





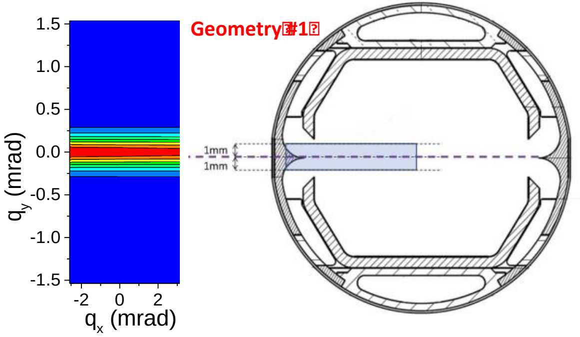
KARA (Karlsruhe Research Accelerator - Ex-ANKA)

BESTEX (**BE**am **S**creen **T**estbench **EX**periment)

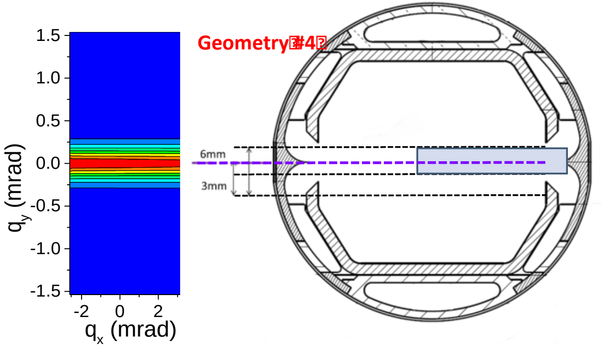


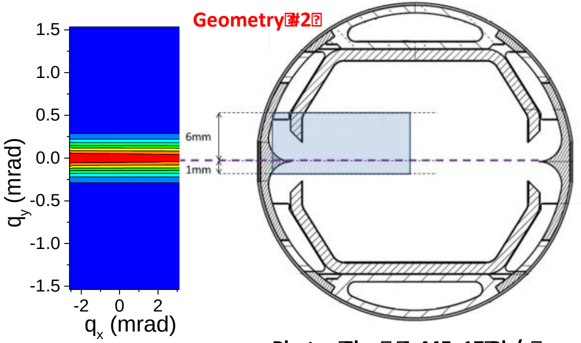
1st Prototype Measurements: Experimental Configurations

Photon Flux = 8.73E+16 Ph/s

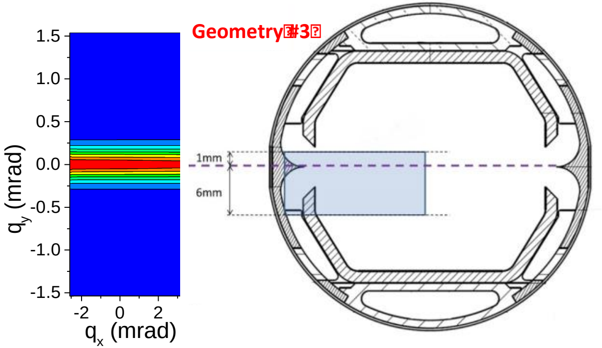


Photon Flux = 8.73E+16 Ph/s





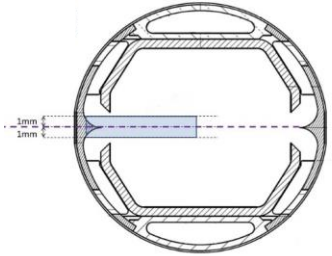
Photon Flux = 1.44E+17 Ph/s



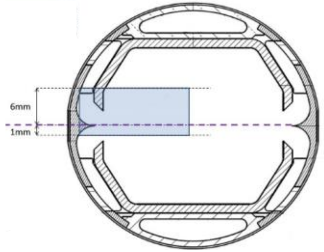
Photon Flux = 1.44E+17 Ph/s

1st Prototype Measurements: Pressure Evolution Results

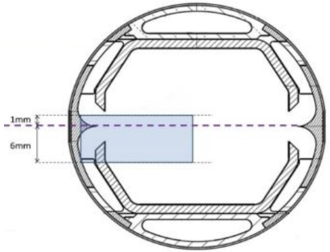
Geometry #1

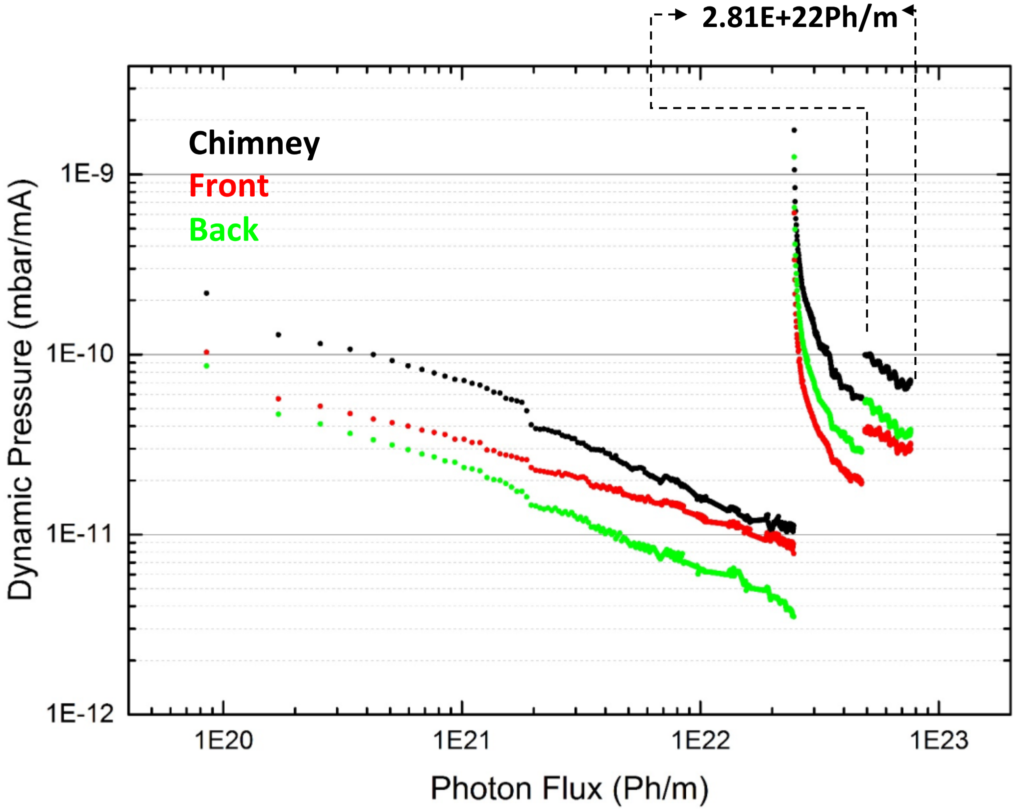


Geometry #2



Geometry #3





1st Prototype Measurements: Comparison with Simulations

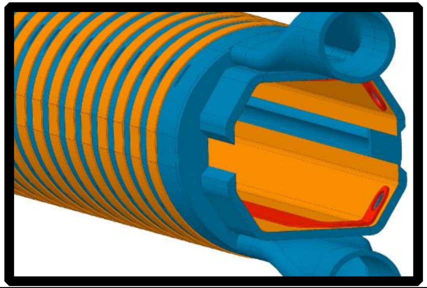
Pressures (mbar)

	2.5GeV/130mA					
	3Ah			9.5Ah		
	Experiment	Simulations	Rel Discrepancy %	Experiment	Simulations	Rel Discrepancy %
Middle	7.25E-09	2.30E-08	68.5%	3.71E-09	1.20E-08	69.0%
Front	3.87E-09	4.70E-09	17.7%	2.44E-09	2.80E-09	12.9%
Back	2.42E-09	3.80E-09	36.4%	1.39E-09	2.00E-09	30.3%

RGA masses

	3Ah		9Ah	
	Experiment	Simulations	Experiment	Simulations
H2	72.0%	29.8%	71.6%	36.4%
CO	24.5%	28.9%	24.5%	27.1%
CO2	1.9%	33.6%	2.4%	28.8%
CH4	1.6%	7.7%	1.5%	7.7%

2^{st} Prototype Installation: Planning



#2:#1 + electrodes for **photoelectron current measurements**

Irradiation 4^{th} config

Disasemble SetUp and transport outside the ring

Assembly and comitioning Outside the ring

Transport inside the ring Commissioning

Bake out Conditioning

Irradiation 2^{nd} Prototype

October

Day	Week		Shift 9-18	19-8
1				
2	40		NO	NO
3		Tag d. deutsch	NO	NO
4			NO	NO
5			NO	NO
6			NO	NO
7				
8				
9	41		NO	St
10			UO	UO
11			UO	UO
12			UO	UO
13			UO	UO
14				
15				
16	42		NO	MP
17			MP	MP
18			SUO	SUO
19			SUO	SUO
20			MP	MP
21				
22				
23	43		NO	St
24			UO	UO
25			UO	UO
26			UO	UO
27			UO	UO
28				
29				
30	44		NO	NO
31		Reformationsta	NO	NO

November

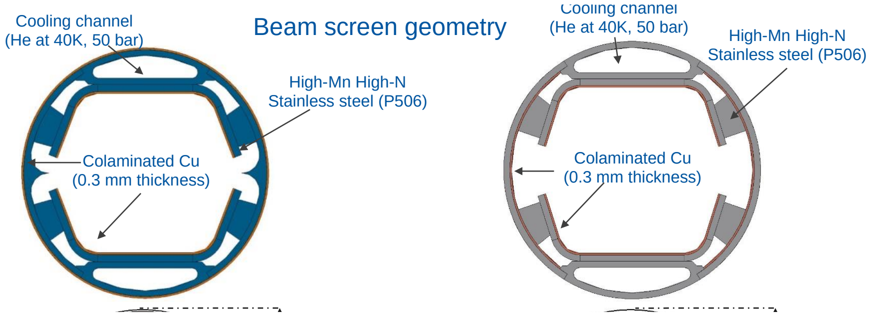
Day	Week		Shift 9-18	19-8
	44			
1		Allerheiligen	NO	NO
2			NO	NO
3			NO	NO
4				
5				
6	45		NO	St
7			UO	UO
8			UO	UO
9			UO	UO
10			UO	UO
11				
12				
13	46		NO	MP
14			MP	MP
15			SUO	SUO
16			SUO	SUO
17			MP	MP
18				
19				
20	47		NO	St
21			UO	UO
22			UO	UO
23			UO	UO
24			UO	UO
25				
26				
27	48		NO	St
28			UO	UO
29			UO	UO
30			UO	UO

Next prototypes:

Considering several options:

Work in parallel with LASE, deflector &/or sawtooth

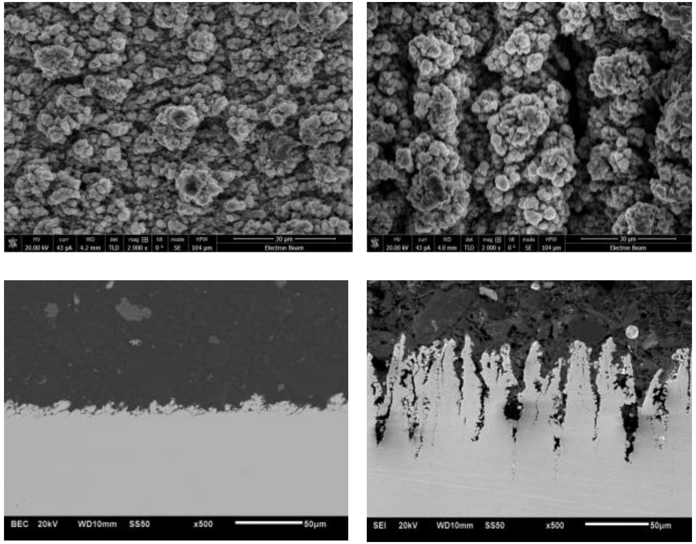
Final decision before welding (April 18 – July 18)



4th prototype: Sawtooth (& electrode) ??

Laser Treated Copper

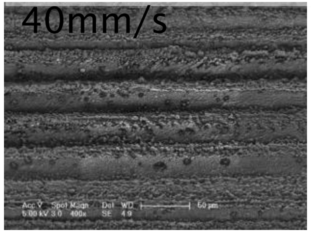
- Surfaces have a micro and nanostructure
- Optically black
- Various laser parameters can be varied to change the topology
- Images (left) are of different scan speeds, 180 mm/s and 30 mm/s shown



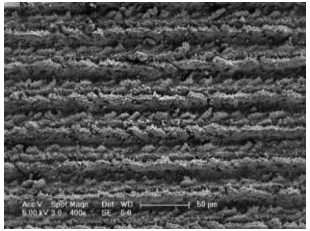
Varying power and scan speed at 1064 nm

λ=1064 nm
P=20 and 10.5 W
τ=2 ns
F=40 kHz
H=0.02 μm
v=80 and 40mm/s

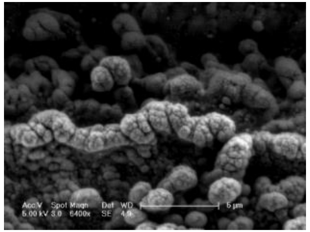
Produced With Micronanics



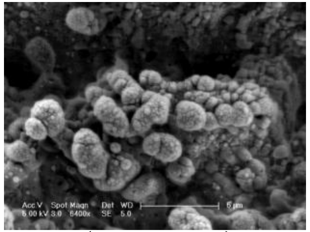
100μm



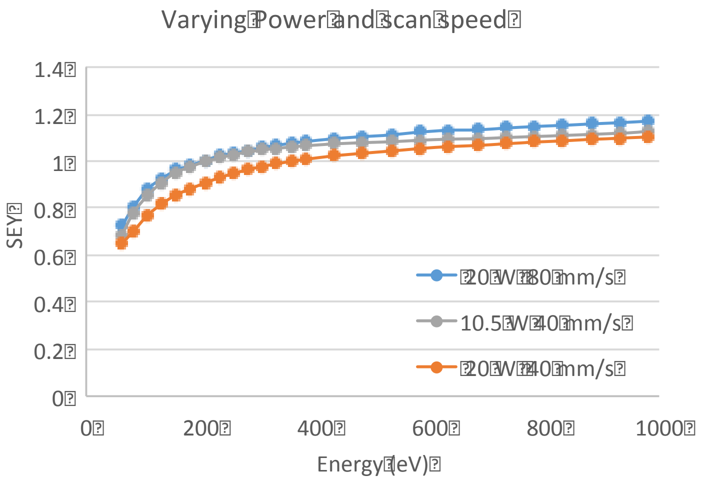
100μm



10μm
20 W 80 mm/s



10μm
10.5 W 40 mm/s

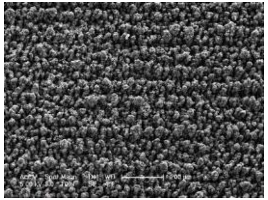


- Power normalised by scan speed give similar results within parameters explored

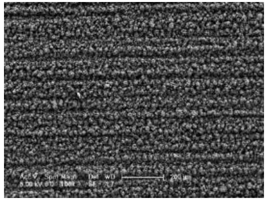
Varying speed and pitch

λ=1064 nm
P=5 W
τ=70 ns
F=100 kHz
H=5 and 10 μm
v=100 and 200 mm/s

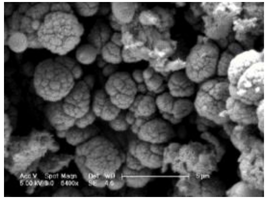
Produced with Micronanics



400μm

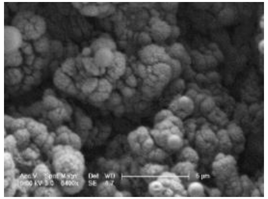


400μm



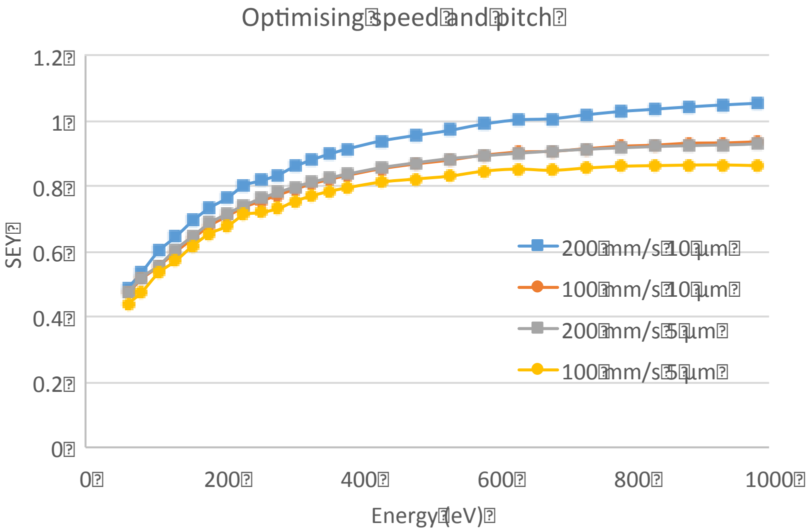
5μm

100 mm/s 5 μm



5μm

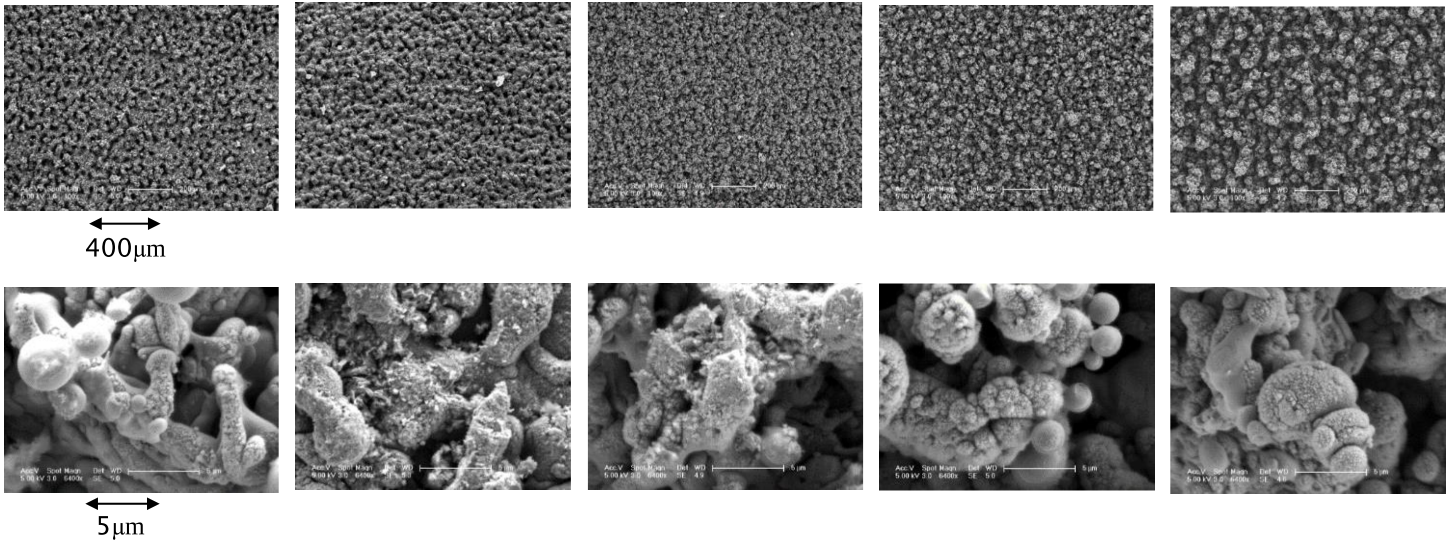
100 mm/s 10 μm



- Same SEY observed for faster scan speed when matched with a smaller pitch

SEM

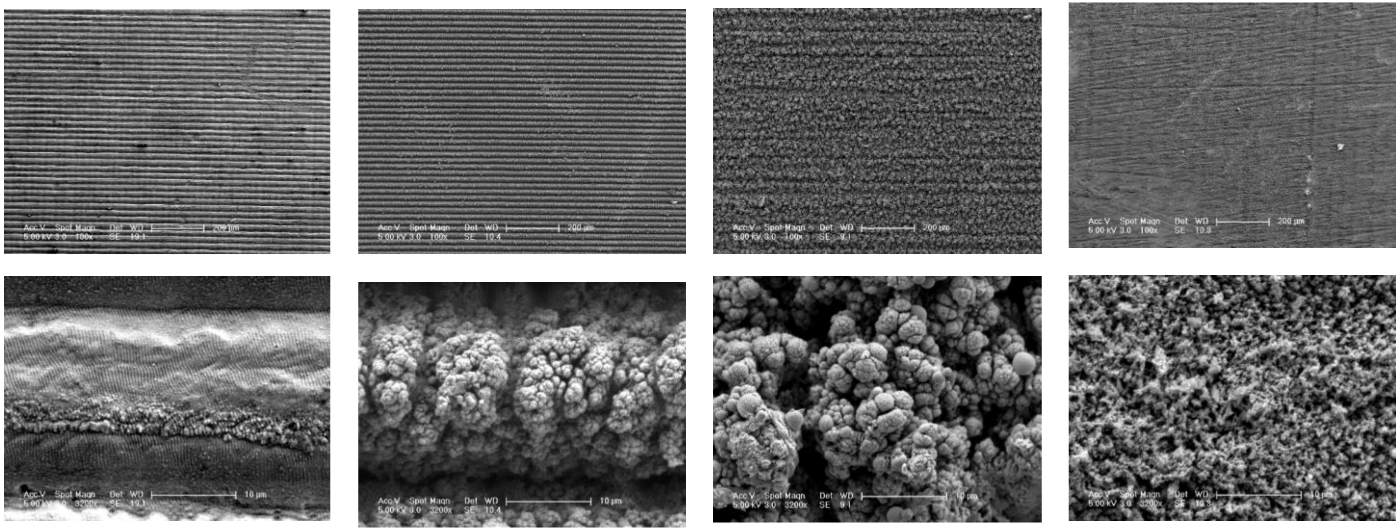
Highest SEY→Lowest SEY



Compressed air with glass | Pumped flow with glass | Air, no glass | Compressed air, no glass | Pumped flow, no glass

Various structures

- Can make various shapes with different structures all with different properties and SEY



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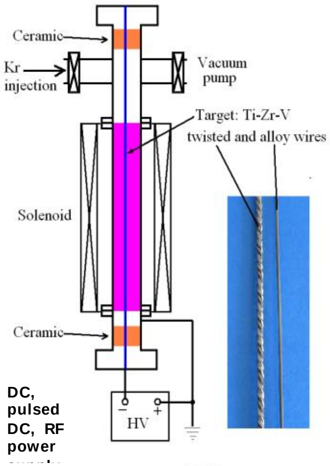
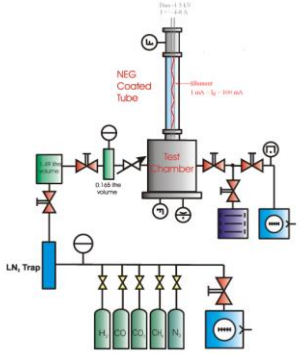
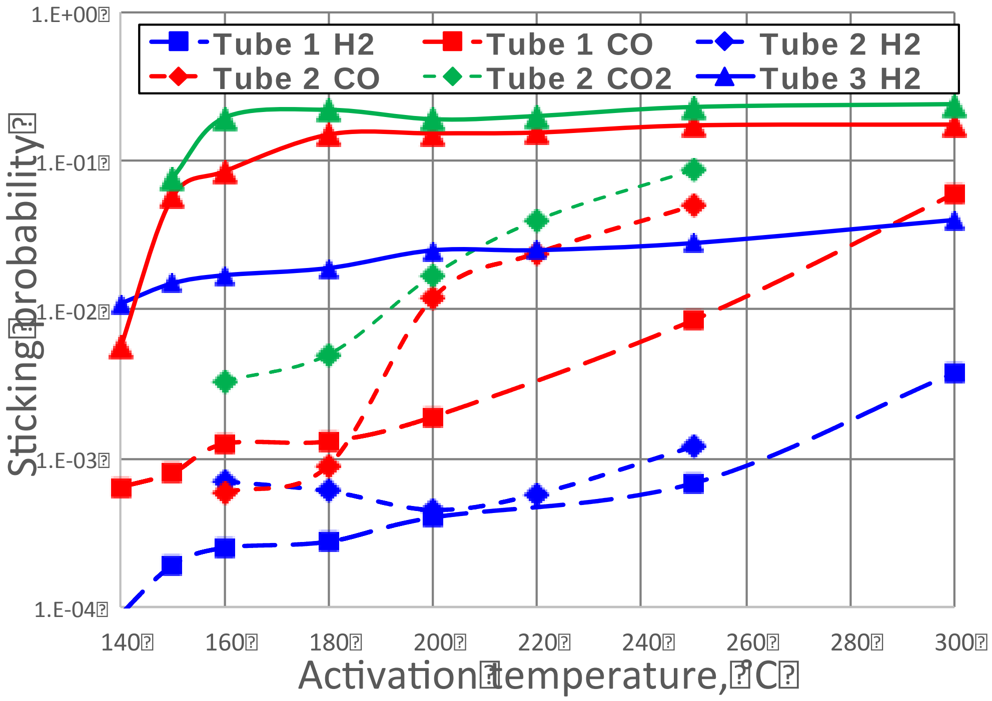
NEG coating studies





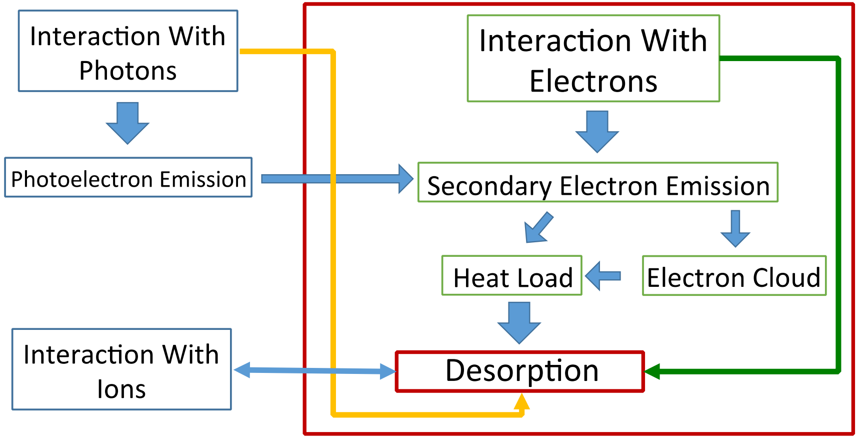
- Current work:
  - MOLFLOW modelling of the test facility - completed
  - Deposition of Zr on a sample tube, ESD and pumping measurements
    - Sample 1 (dense film) – measurements are completed, data analysis in progress
    - Sample 2 (dense film) – measurements are completed, data analysis in progress
    - Sample 3 (columnar film) – pumping property measurements are completed, ESD measurements have started
- Next Steps:
  - Modifying a facility for measurements with LN_2
  - Ti-Zr-Hf-V film to be deposited and measured at temperatures between room temperature and LN_2
  - Design of a facility for cryogenic (dry system 4 K < T < 80 K) measurements
  - Analysis of the experimental results
- Showstoppers
  - None at this stage

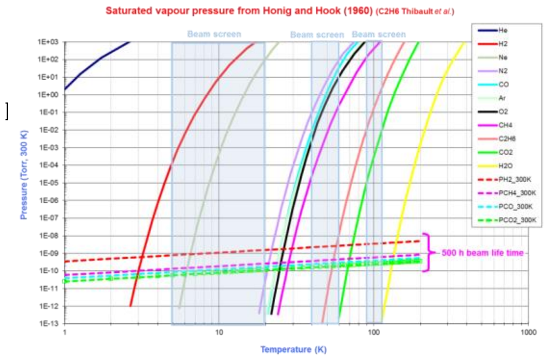
Samples 1&2 - dense Zr, sample 3 - columnar Zr



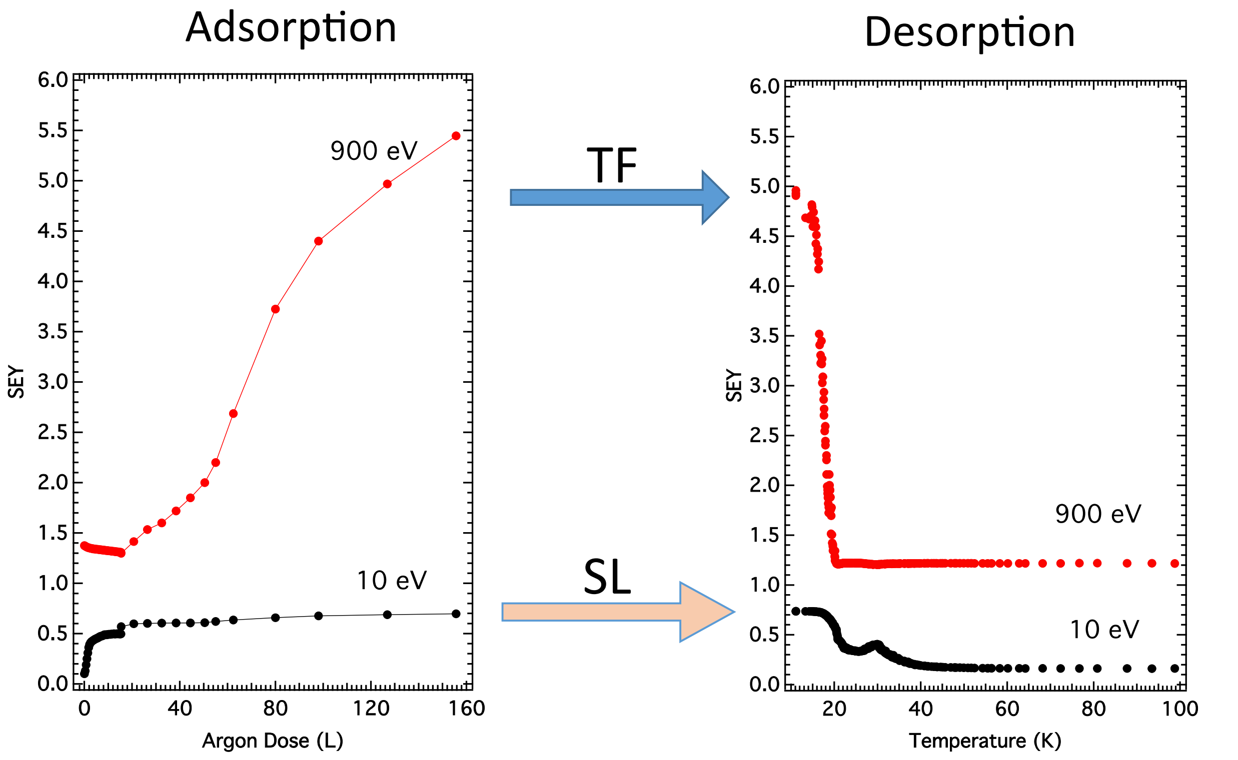
- Pure Zr coated tube with a columnar structure demonstrated good pumping properties after activation to 150°C.
- ESD - to be analysed

Gas adsorption/desorption dynamics and SEY



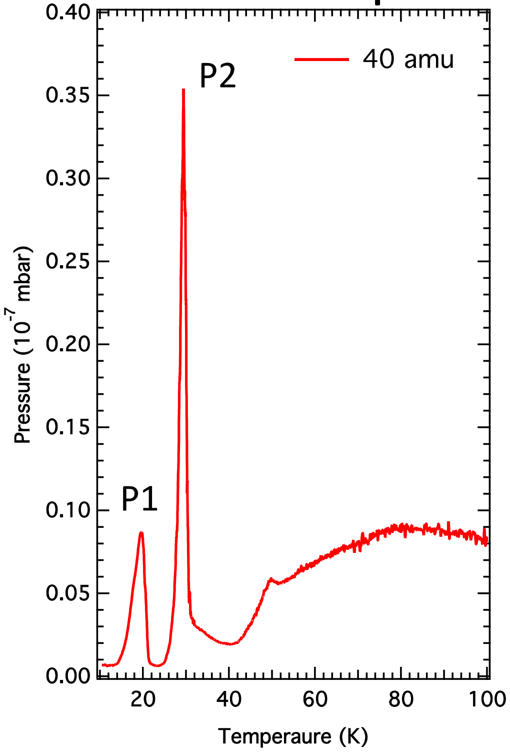


Argon Desorption (SEY)



Argon Desorption (TPD)

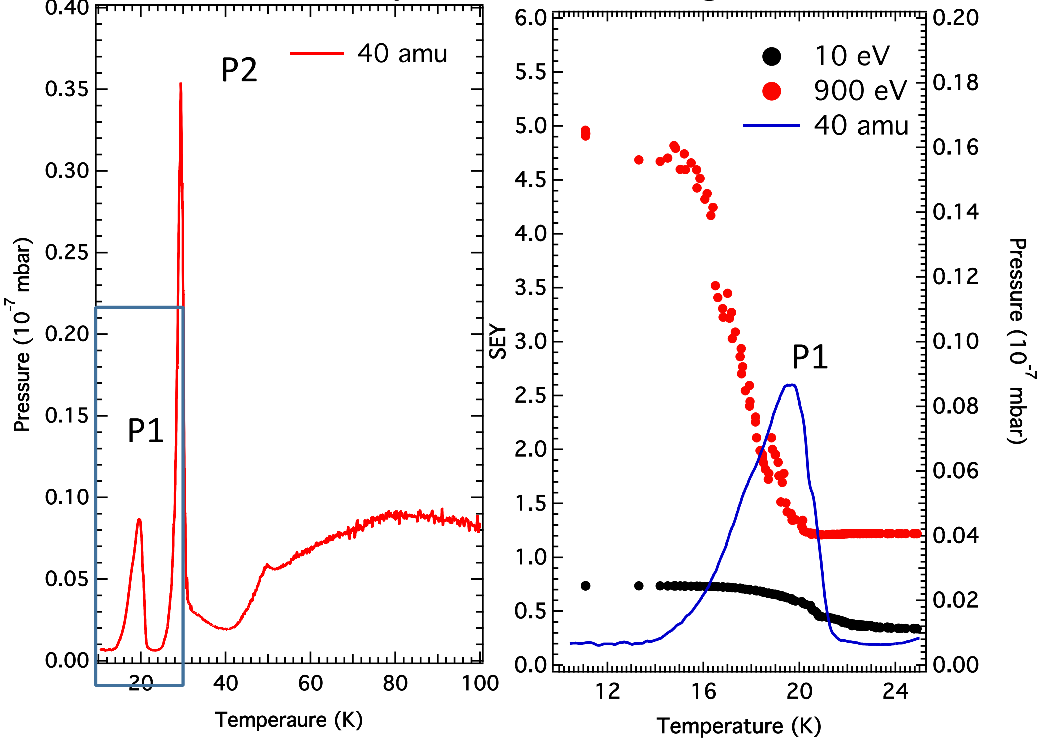
Temperature Programmed Desorption (TPD)



- Characteristic desorption behaviour
- First desorption process around 20 K (P1)
- Second desorption process @ 30 K (P2)
- Other desorption after 50 K

Argon Desorption (TPD)

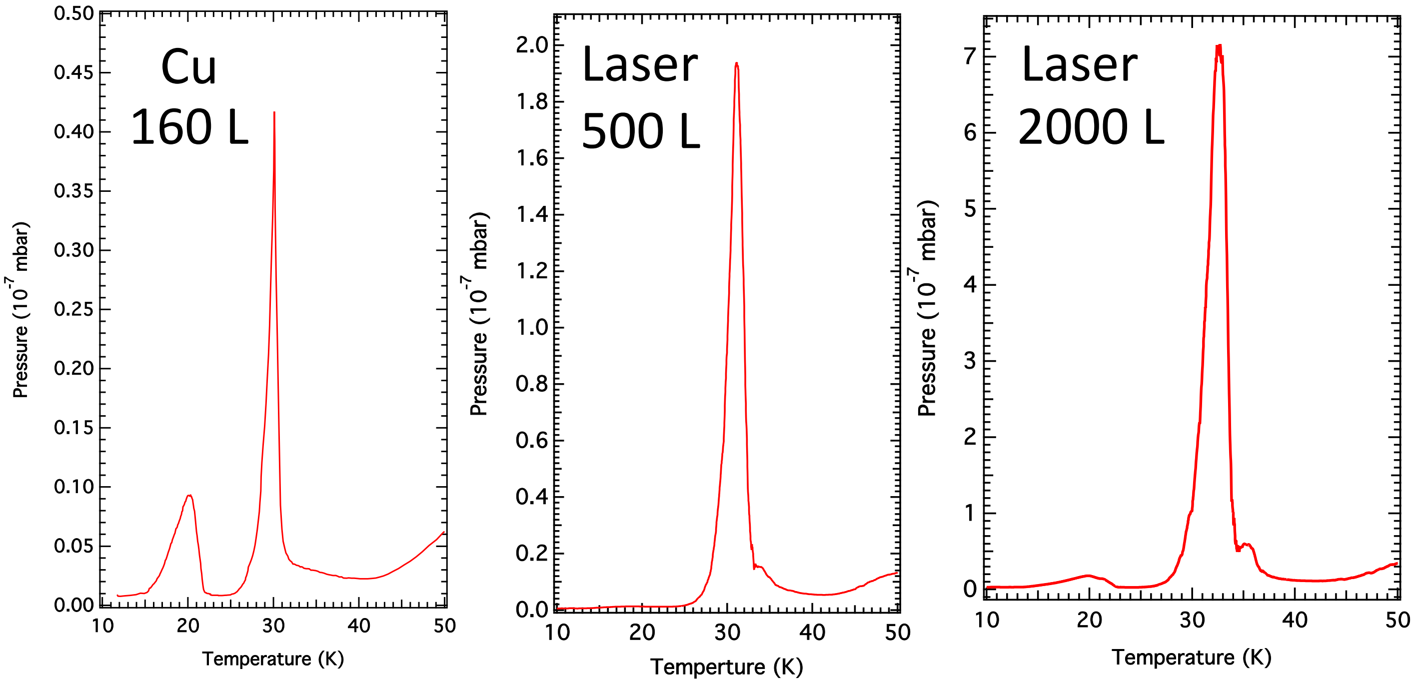
Temperature Programmed Desorption (TPD)



Correlation between P1 and SEY signals

Laser Treated Sample

Temperature Programmed Desorption (TPD)



Conclusion

Impresive work by the team

Thanks