



U.S. DEPARTMENT OF
ENERGY

Office of Science



Recent Achievements in the NEG Technology in Application to Coating Vacuum Chambers of Constrained Geometries

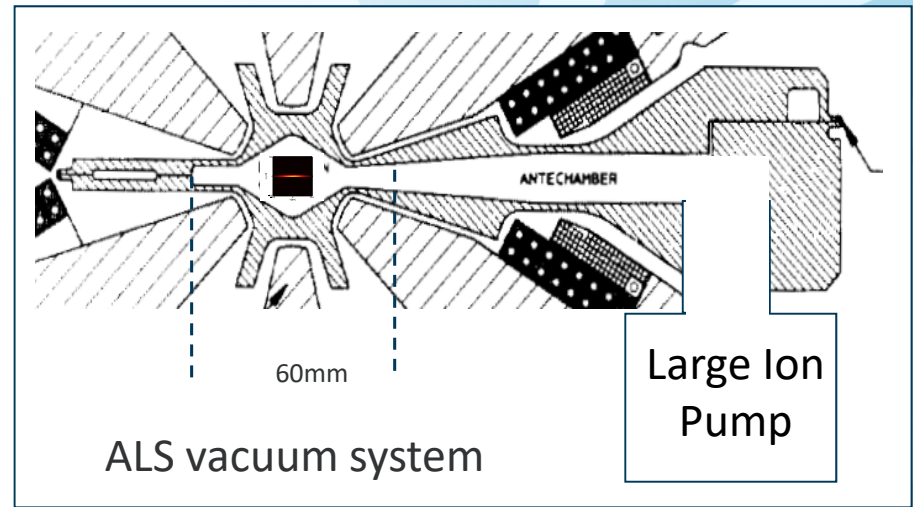
Sol Omolayo

ALS-U Project Lead Vacuum Engineer

Contributors: Ken Tokunaga, Guobin Wang, Jim Curtis

Outline

- Motivation
 - The ALS-U project
- Overview of NEG coating R&D
 - Samples
 - NEG coating tools
 - Pumping measurement
- Result
 - Pumping
 - PSD
 - SEM

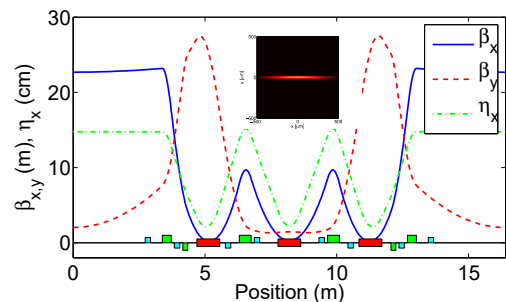
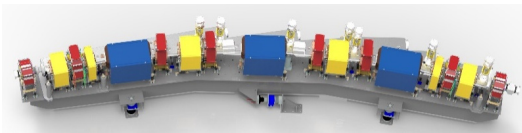


3rd DLSR Workshop SLAC 2013: Accelerator Session Close-Out Report: Vacuum

- In-situ bake out / activation procedures:
 - Minimum gap needed between chamber and magnet poles.
 - Chamber heating methods, how to apply thin radiation resistant heat films.
- NEG Coatings:
 - Coating very narrow gap and small <10 mm chambers.
 - Surface roughness
 - Photon extraction ports:
 - Coating key hole geometry is challenging.
 - Fabrication methods compatibility with coating processes.
 - Coating development in industry. Very limited industrial capability – a possible risk.
 - NEG impedance might become a problem for very short bunches.

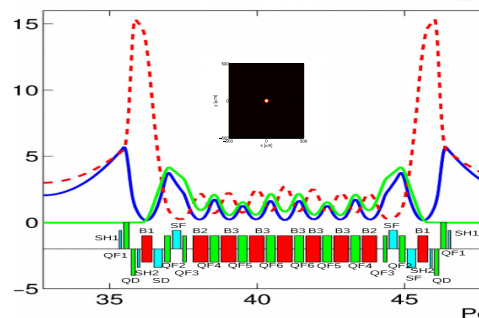
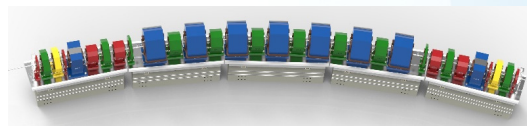
ALS-U Project: Motivation – Lower Emittance & Higher Brightness

ALS today : triple-bend achromat



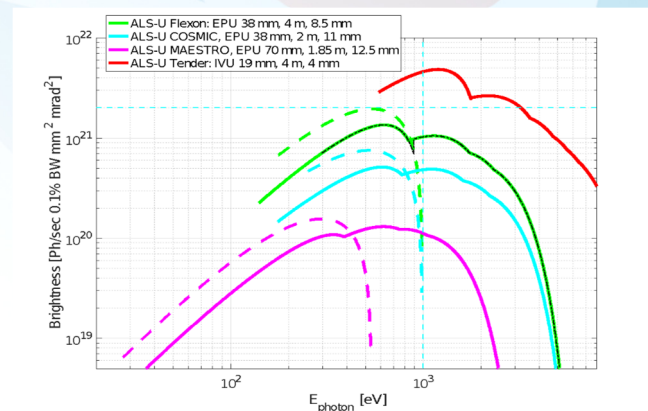
$\epsilon_x \approx 2000 \text{ pm rad at } 1.9 \text{ GeV}$

ALS-U: nine-bend achromat with reverse bends



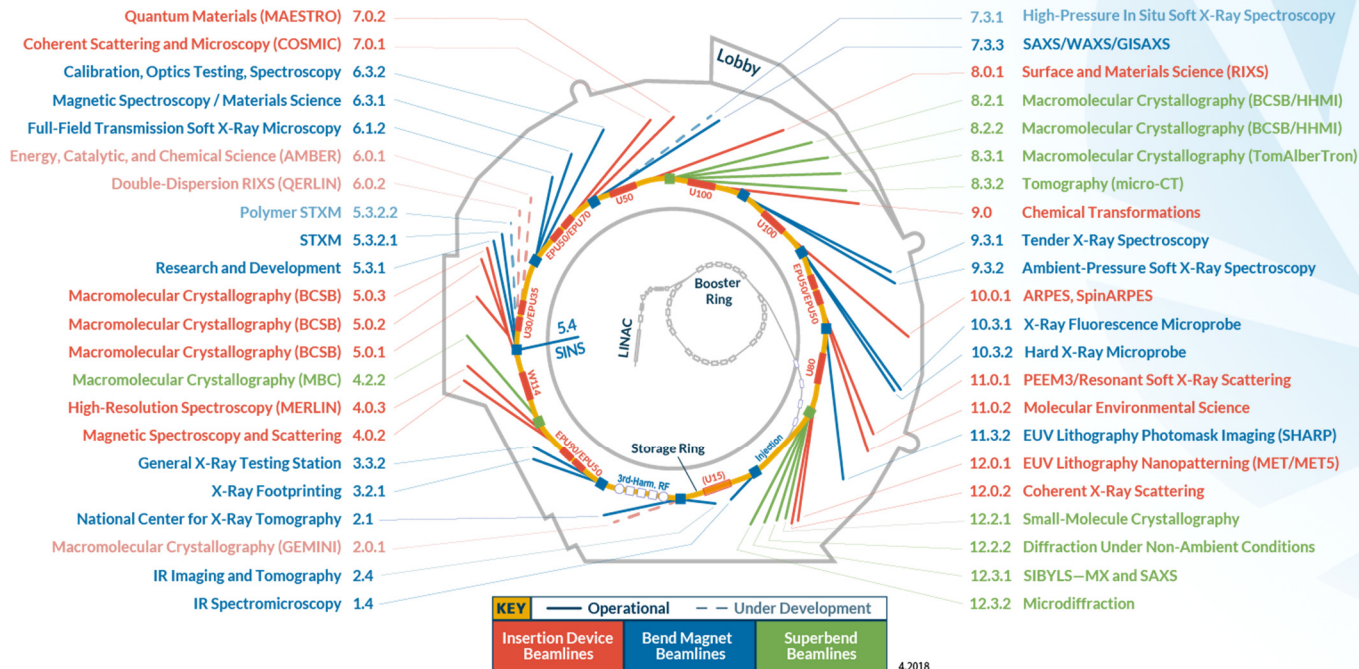
$\epsilon_x < 71 \text{ pm-rad at } 2.0 \text{ GeV}$

Storage Ring Parameters	Value
Electron energy	2.0 GeV
Average current	500mA
Bunch Length (FWHM)	110 ps
Total lifetime	>0.5h
Circumference	196.510 m



Large increase in coherent fraction due to lower emittance and smaller β -functions

Enabling new science frontiers



Quantum Materials
Research & Discovery

Multiscale Structure &
Dynamics

Chemical
Transformations

Earth, Environment &
Biological Systems

Instrumentation
Science

- 40 beamlines
- 2,100+ users/year
- 950+ pubs/year
- 20% in high-impact journals

Infrared

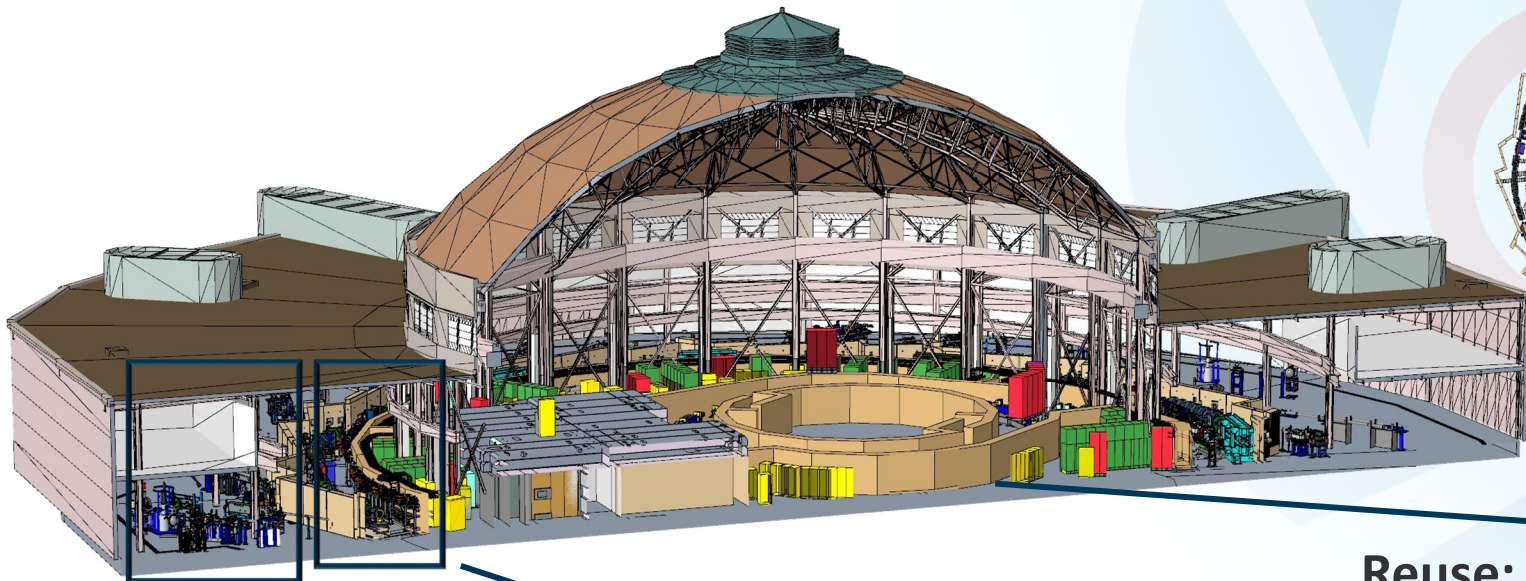
VUV

Soft

Tender

Hard

ALS-U Accelerator Systems Complex



Reuse: Existing ~40 photon beamlines

Add: 3 New flagship beamlines

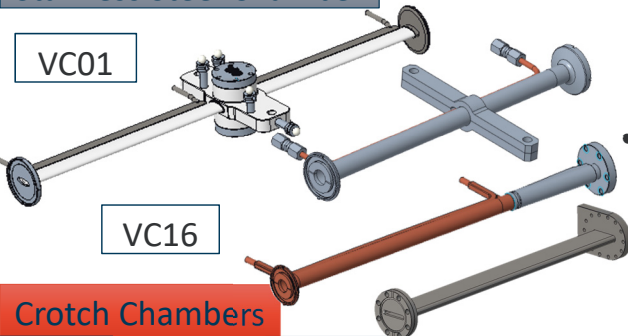
Replace: 3 bend storage ring with a 9 bend storage ring

Add: New accumulator ring + Transfer line

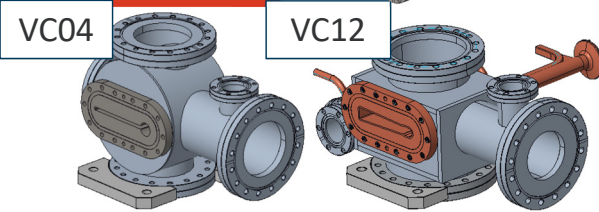
Reuse: Existing LINAC, Booster & Conventional facilities

Vacuum Chamber Designs

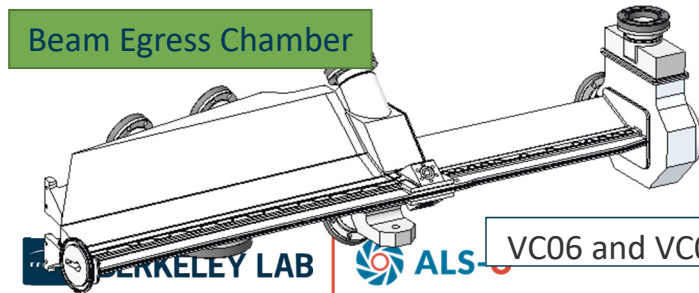
Stainless Steel Chamber



Crotch Chambers

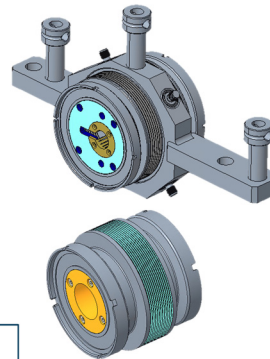


Beam Egress Chamber

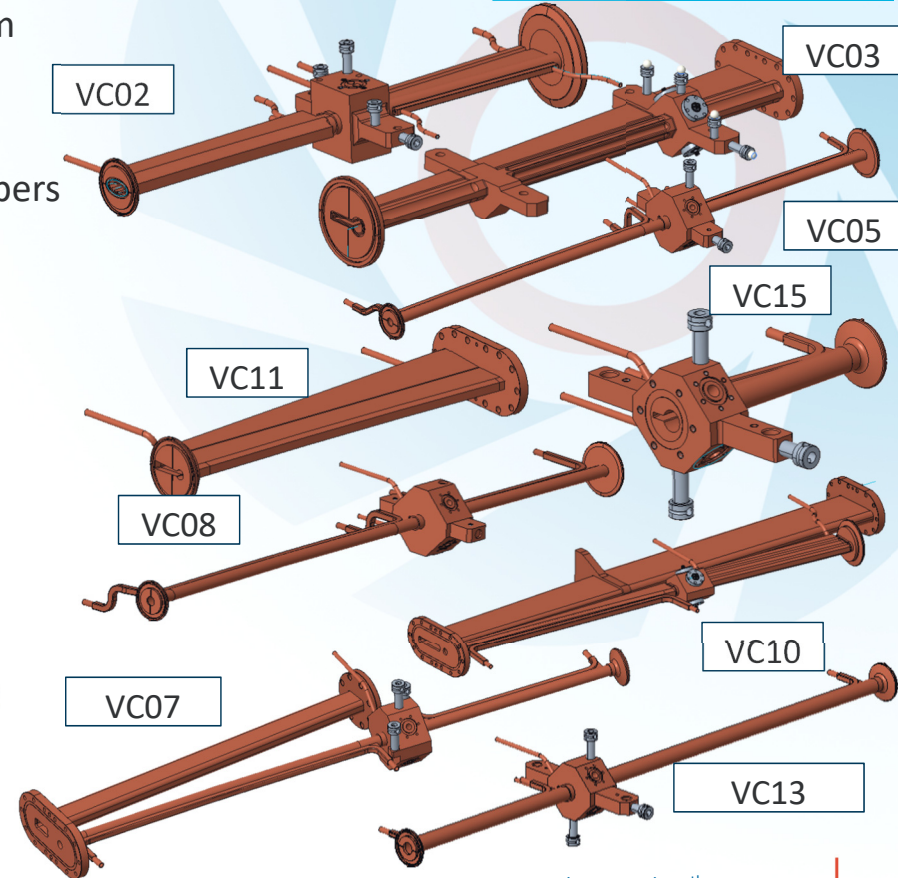


- Broad array of vacuum chambers and components
- Majority of the chambers are NEG coated

RF Bellows

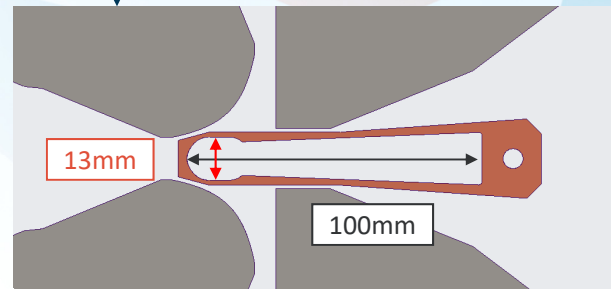
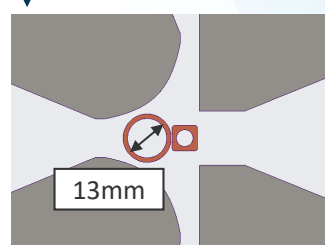
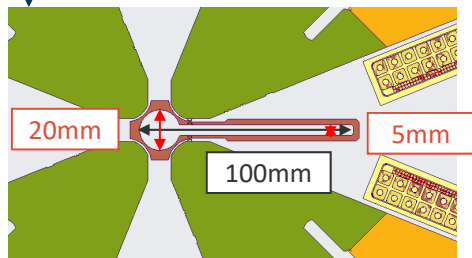
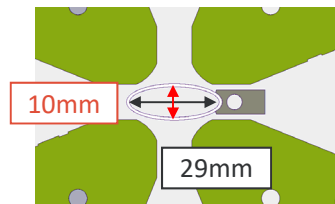
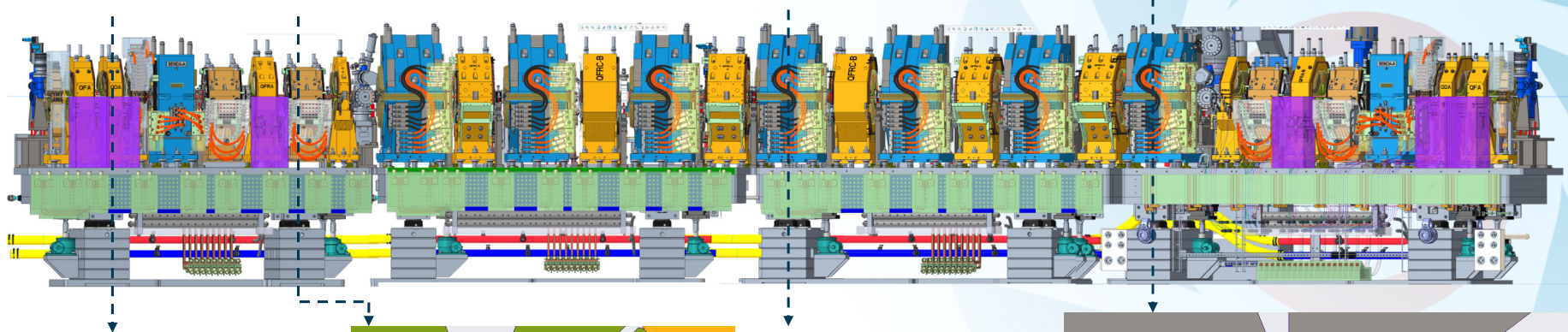


Keyhole & HHL Chamber

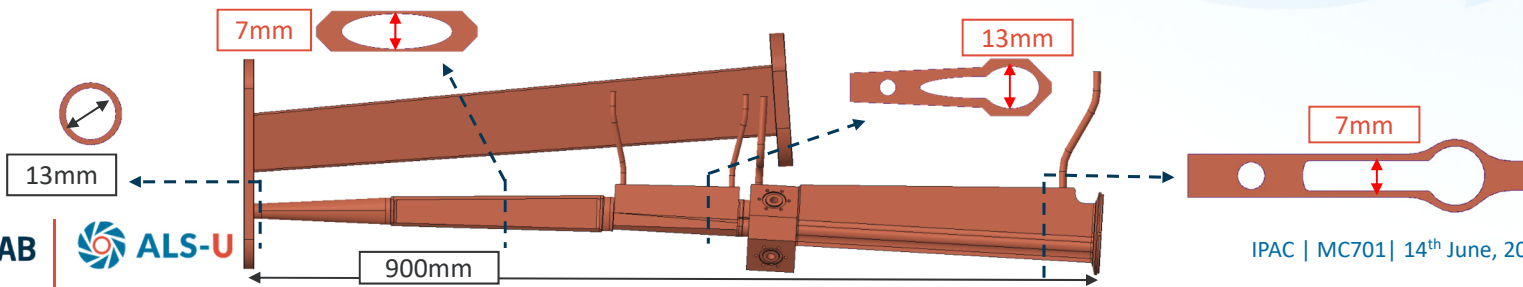


Vacuum chamber apertures

1 Arc Sector

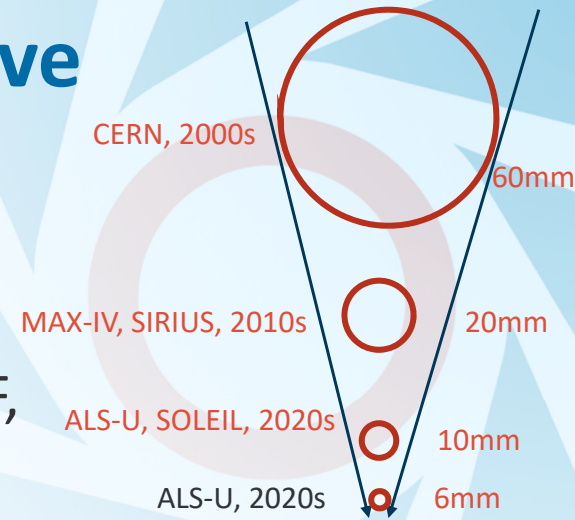


High Field
Magnet
Chamber

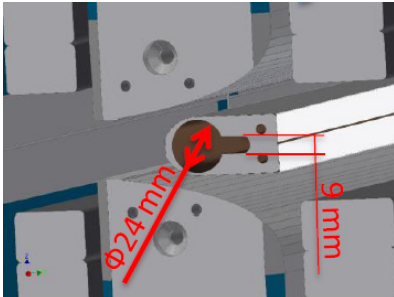


NEG Coating Development Objective

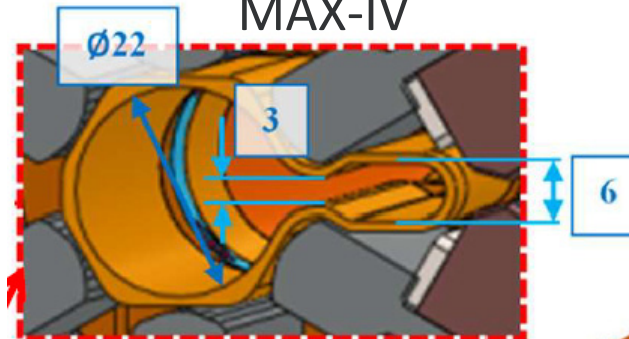
- Demonstrate current NEG coating technology is applicable to ALS-U relevant chambers
- Explore/develop industry and research capability and partnerships – SOLEIL, STFC, ESRF, SAES, FMB
- Develop in-house NEG coating capability



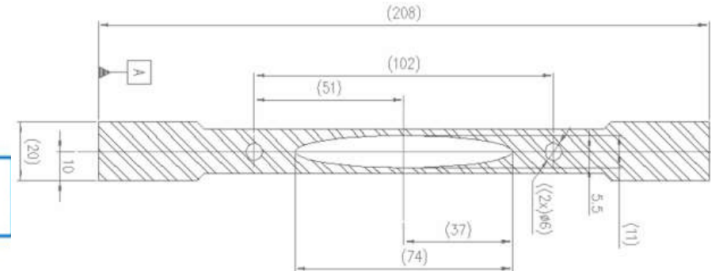
SIRIUS



MAX-IV



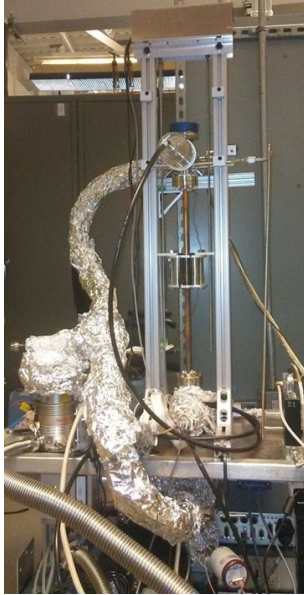
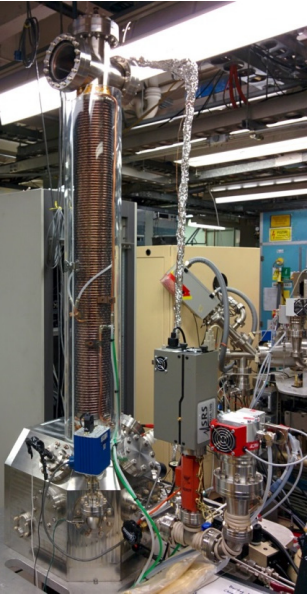
ESRF chamber CV5073 (L=5073 mm, 11 mm x 74 mm)



R. Kersevan, Proc. EPAC-2000 Conference, Vienna, June 2000, page 2289-2291, available at <http://accelconf.web.cern.ch/accelconf/e00/PAPERS/THP5B11.pdf>.

NEG Coating Systems

Lab size systems: 2016 to 2018

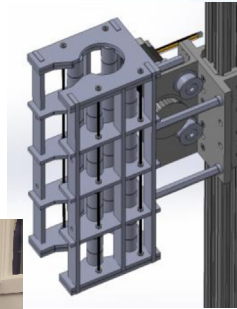
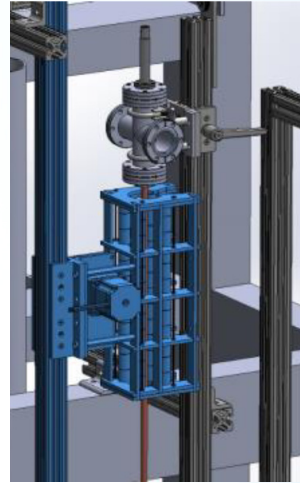


- Ultra pure Ar gas
- Permanent magnet and electromagnet solenoids
- Ti,Z,V twisted wire (0.2 -2mm thick)
- Coating at 100°C
- Base pressure 5e-10 Torr
- Continuous gas flow
- Typically 12hr for coating 1 micron
- Silicon sample
- Standard UHV cleaning

Samples: 0.5m long, 6mm & 9mm ID
Cu tubes



Production size systems: 2019 to now



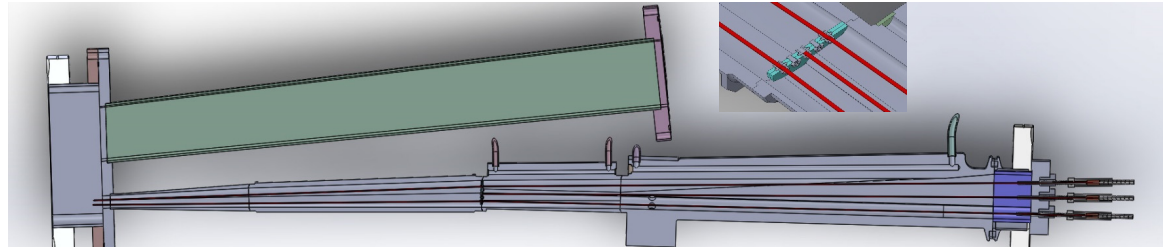
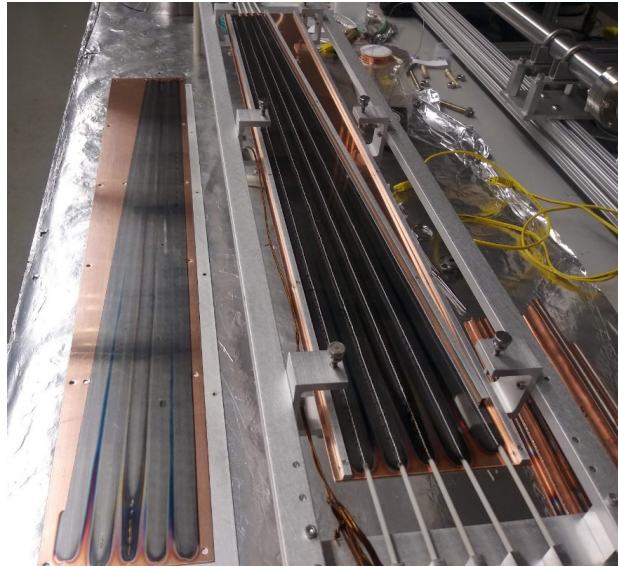
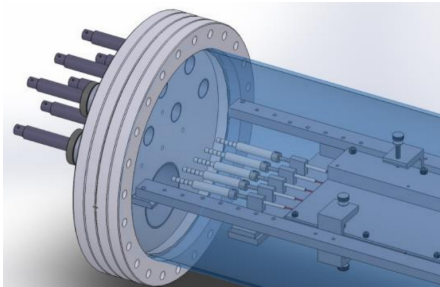
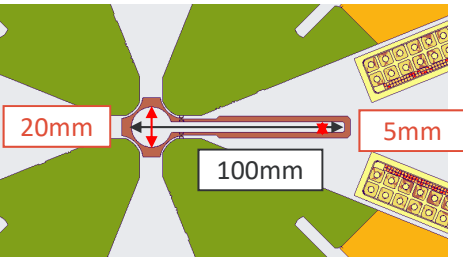
4m long narrow NEG
coating rig



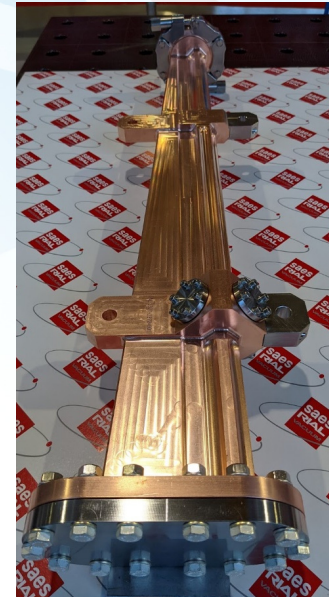
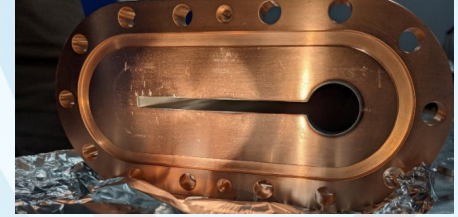
2m long X 300mm wide
NEG coating rig

Complex Shape Chamber NEG coating Trials

Keyhole chamber NEG coating setup



Keyhole chamber NEG coated in industry



Pumping test system

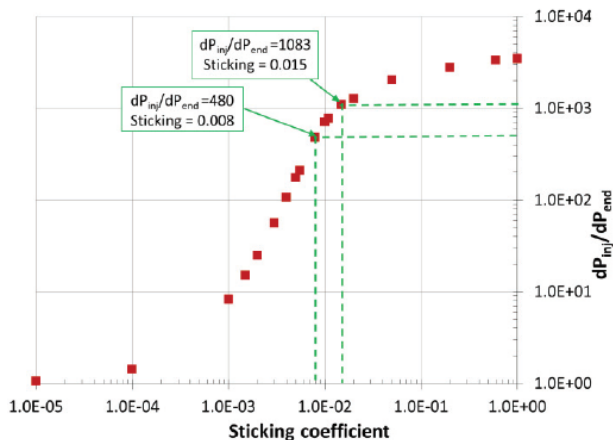
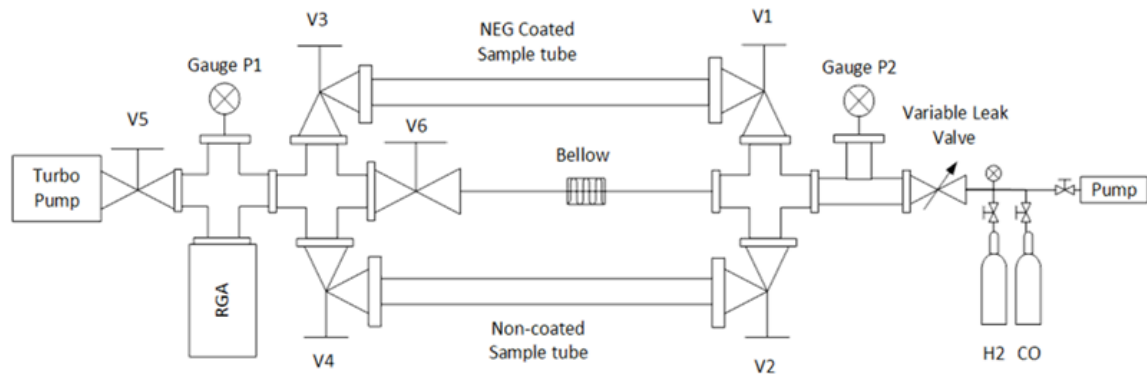


Figure 2: Monte Carlo simulations results for a 1 m long NEG-coated tube of 21 mm inside diameter.

NEG THIN FILM COATING DEVELOPMENT FOR THE MAX IV VACUUM SYSTEM

S. Calatroni, P. Chiggiato, P. Costa Pinto, M. Taborelli, CERN, Geneva, Switzerland
M. Grabski[†], J. Ahlback, E. Al-Dmour, P. Fernandes Tavares, MAX IV Laboratory, Lund University, 22100 Lund, Sweden



CERN Data based on 60mm ID tubes,

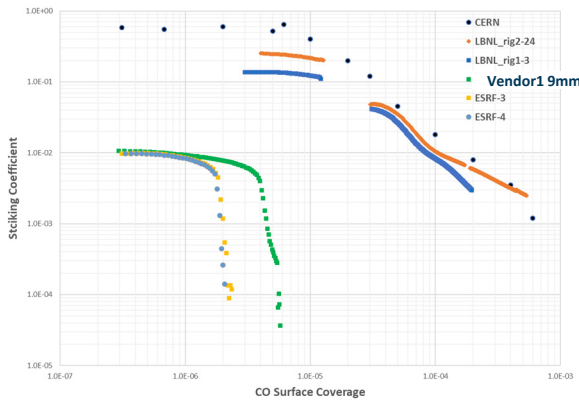
		H ₂	CO	N ₂	CH ₄
Maximum sticking probability	smooth	8x10 ⁻³	0.7	1.5x10 ⁻³	
	rough	3x10 ⁻³	0.9	3.0x10 ⁻³	
Surface capacity [molecules cm ⁻²]	smooth		8x10 ⁻¹⁴	1.5x10 ⁻¹⁴	
	rough		8x10 ⁻¹⁵	1.5x10 ⁻¹⁵	
Electron stimulated desorption yields [molecules per impinging electron]	electron energy = 500 eV negligible dose	2x10 ⁻⁴	1x10 ⁻⁴		5x10 ⁻⁶
Photon stimulated desorption yields [molecules per impinging photon]	Ec=194 eV [51] negligible dose, normal incidence	3x10 ⁻⁶	<2x10 ⁻⁸		<3x10 ⁻⁸
	Ec=4.5 KeV [41, 42] 10 ²¹ ph m ⁻¹ 10 mrad incidence	1.5x10 ⁻⁵	<10 ⁻⁵		2x10 ⁻⁷

Tab.1: Summary of the some functional properties of Ti-Zr-V film coatings. Pumping speed and gas capacity are referred to film coated at 100°C (smooth) and 250°C (rough). Electron and photon desorption yields are reported only for smooth films. Pumping speed and gas capacity can be improved by increasing the substrate roughness.

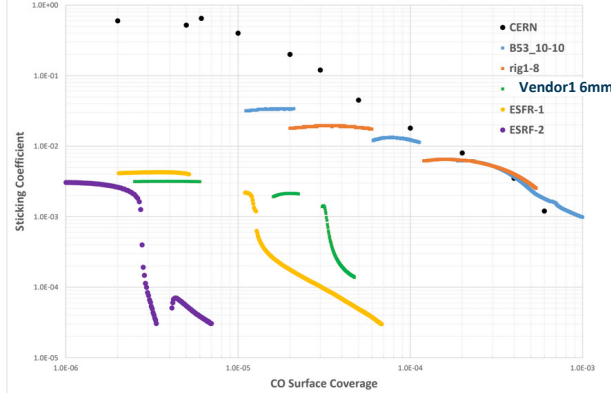
- Activation: 240°C for 12 hrs
- Pumping test: Throughput
- MCTP simulations used to determine corresponding sticking coefficient to measured $P_{\text{INJ}}/P_{\text{INJ}}$
- Test carried out using CO & H₂

Pumping performance

9mm ID and 500mm long NEG Coating CO Pumping Capacity



6.2mm ID and 500mm long NEG coating CO pumping capacity



Sample	H2 Sticking Coeff.	CO Sticking Coeff.	CO Capacity
CERN Benchmark	0.007	0.7	8e-14 [molecules/cm]
LBL 6 mm	0.007	0.03	Comparable to CERN
LBL 9 mm	0.007	0.25	Comparable to CERN
Vendor1 6 mm	0.0025	0.003	low
Vendor1 9 mm	0.0065	0.015	low
ESRF 6 mm	0.003	0.004	low
ESRF 9 mm	0.005	0.01	low
Vendor2 10 mm	0.005	0.0015	poor

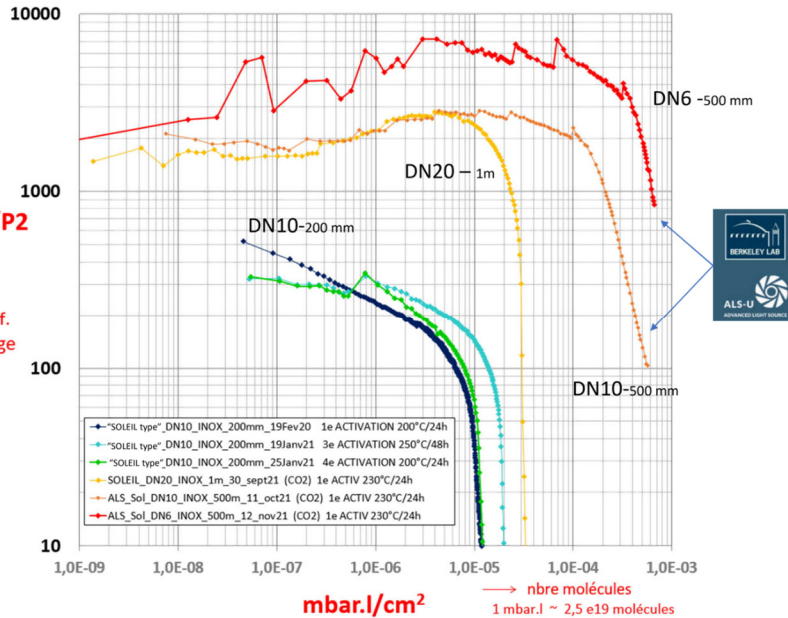
Factor that impact pumping performance

- Substrate temperature
- Cathode voltage
- Plasma power or deposition rate
- Initial base pressure
- Coating pressure
- Tube ID
- NEG wire contamination content
- Moving magnets vs full length solenoid
- Gas purity
- DC power vs pulsed-DC power
- NEG wire degassing
- Substrate roughness

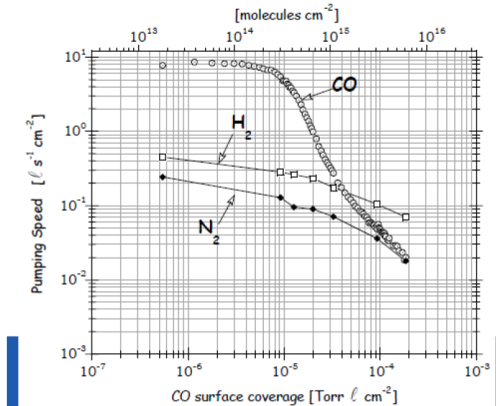
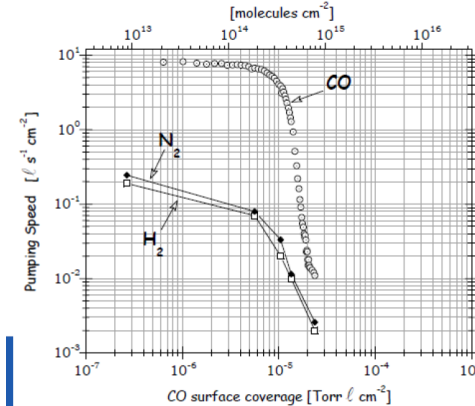
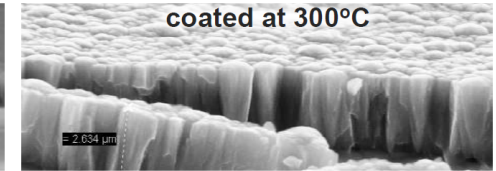
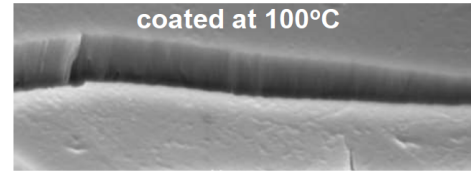
Findings

- 9mm samples consistently performs better than 6mm – aspect ratio rules out
- In-house coated sample out performs those sourced externally
- Vendor and other labs struggle with coating 6mm. Some declined

Pumping comparison at SOLEIL



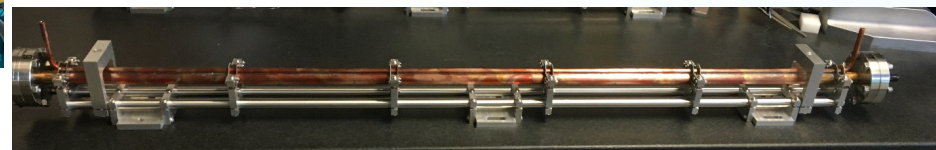
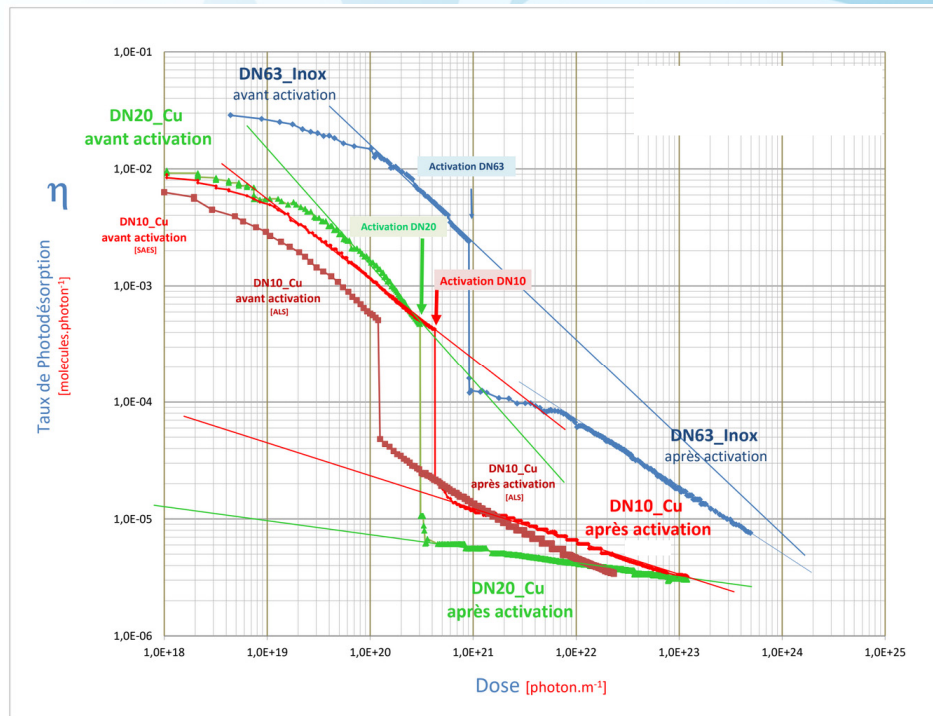
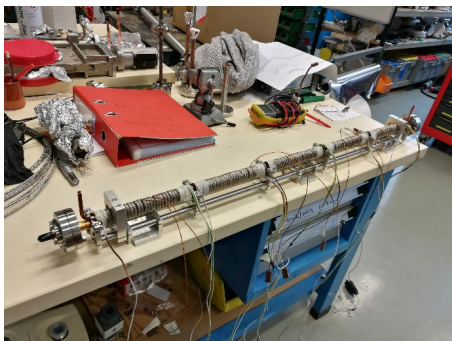
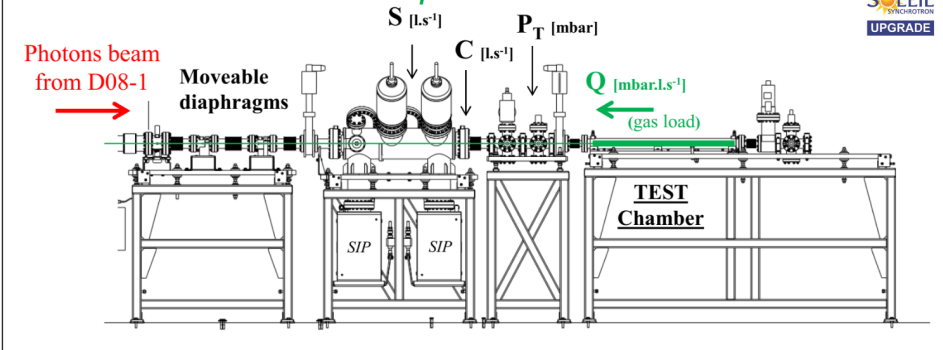
Pumping speed and surface capacity of TiZrV. (activation 24h@230°C)



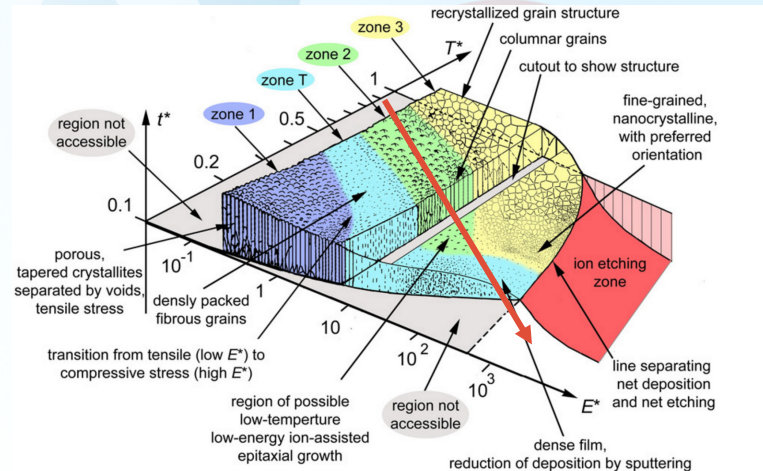
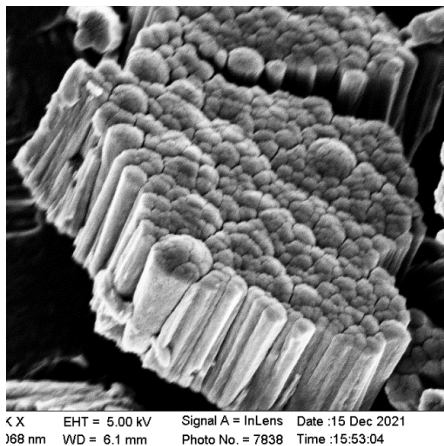
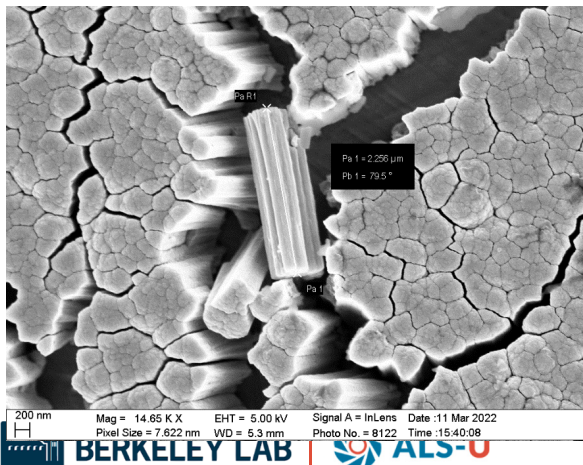
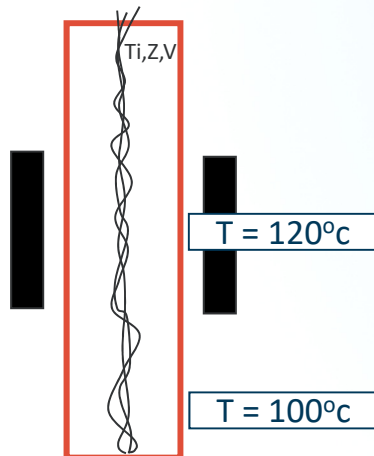
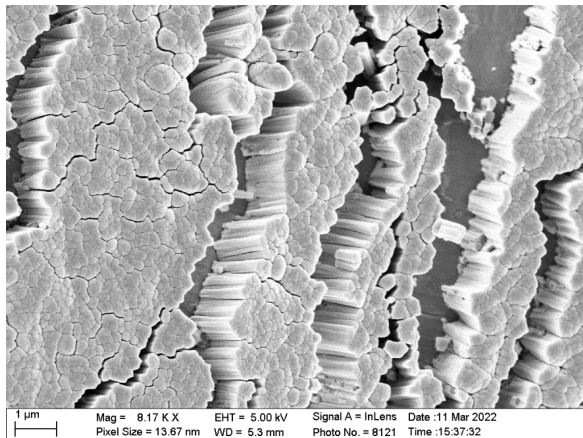
CERN-TS-2006-001(MME); Ti-Zr-V non-evaporable getter films: from development to large scale production for the Large Hadron Collider.

PSD Measurement at SOLEIL

PSD Beamline on D08-1 photon exit

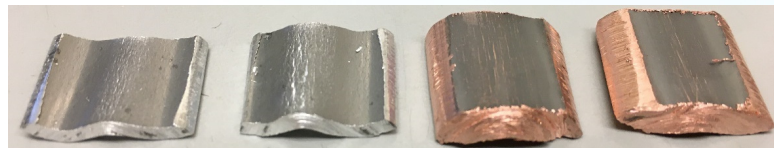


SEM Analysis of NEG film morphology



A.Anders, A structure zone diagram including plasma-based deposition and ion etching, *Thin Solid Films*, 2009

SEM samples



Summary

- NEG coating technology for narrow vacuum chambers demonstrated down to 6mm inner diameter round chambers
- Extensive vacuum testing performed to optimize pumping performance
- NEG coating pumping and PSD performance for narrow aperture chambers are comparable to larger chambers