Diffraction Limited Storage Ring
Overview of Vacuum Design Issues

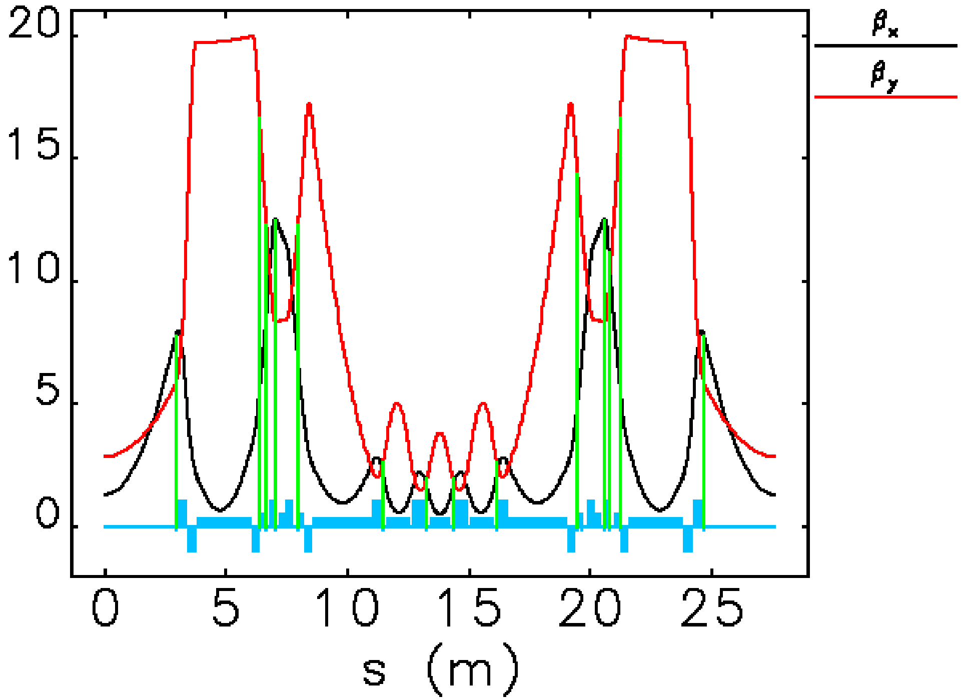
H. Cease,
APS Upgrade
Dec. 10, 2013

Overview:

- DLSR Lattice
  - Vacuum System Design Goals
- Vacuum Systems
  - Distributed pumping
  - Discrete pumping
- Vacuum Components
  - Flanges, Bellows, BPMs, Absorbers
  - Chamber materials
- Bakeout / activation methods
- Vacuum Simulations
- Summary

DLSR Lattice:

Reference: M. Borland, APS



Vacuum System Design in a Compact Lattice Space:

- Increase from 2 to between 5 and 7 bending magnets, multiple radiation fans.
- Less space for BPMs, bellows, isolation valves.
- Stronger magnetic fields, smaller magnet bores, typically 26mm, low conductance vacuum chamber.
- Stringent alignment stability for BPMs, absorbers, chambers.
- Vacuum requirement is 1e-9 Torr average pressure with beam.

DLSR Vacuum System Design Goals:

Design Goals:

- Provide long beam lifetime environment:
  - Vacuum pressure requirement 1 e-9 Torr.

- Minimize impedance impact:
  - Large diameter vacuum chambers.
  - High electrical conductivity chamber materials.
  - Smooth surfaces and chamber transitions.

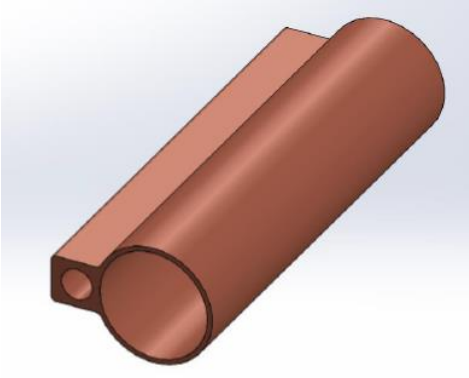
- Alignment requires precise stable chambers and instrumentation.

- Minimized installation time:
  - In-situ bakeout / activation is preferred.

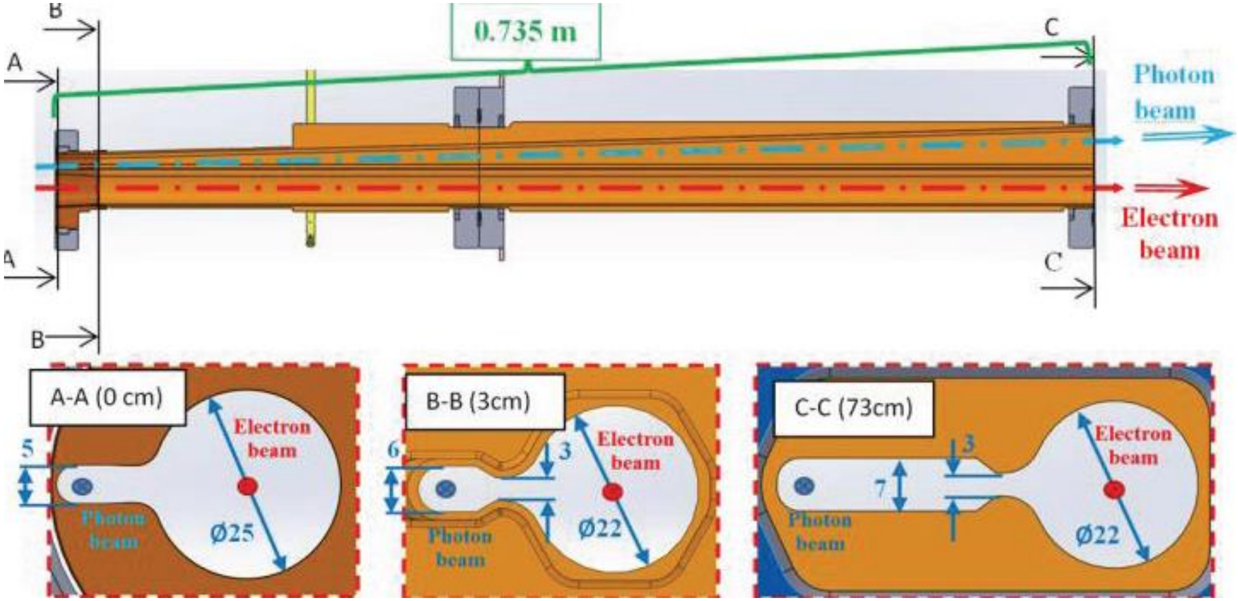
Sector Chamber Design: Distributed pumping

100% Distributed absorbers, distributed pumping: MAX-IV, SIRIUS

- NEG coated water cooled copper chamber, distributed absorber and pumping.
- Photon extraction ports: keyhole geometry



Standard chamber



Photon Extraction chamber

Reference: NEG Thin Film Coating Development for the MAX-IV Vacuum System. Proc. IPAC2013.

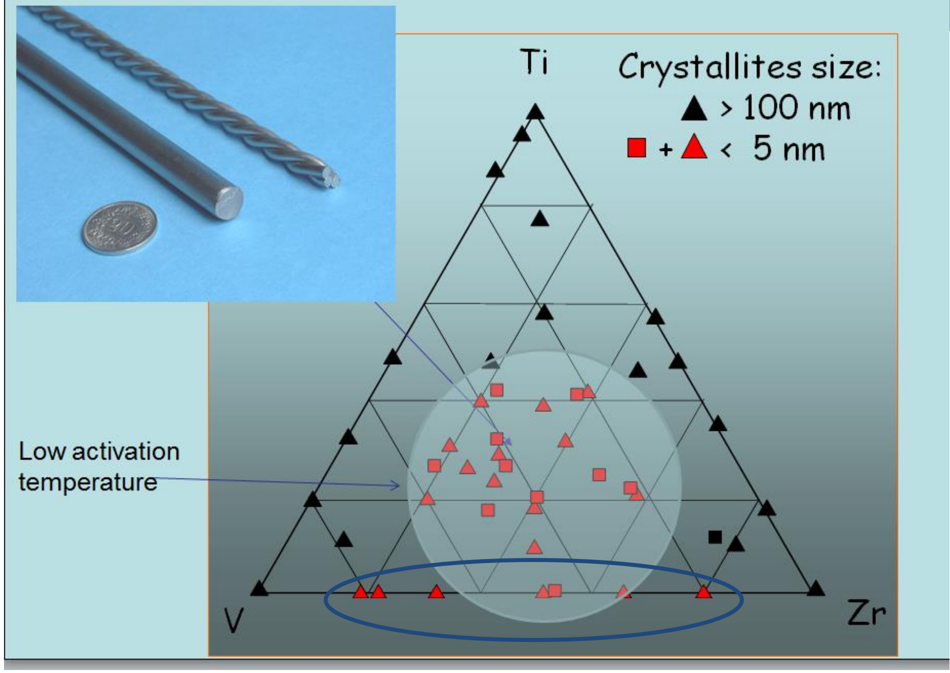
Distributed pumping:

NEG coatings:

Compostition: 31.5% Ti: 26% Zr : 42.5%V

Activation: begins 180°C, improves above 250°C

Applied: Uniformly to the inside of the chamber



Reference: CERN, P. Chiggiato

Challenges:

- Coating all surfaces in a region.
  - Bare surfaces locally outgass and contaminate coated surfaces during activation.
- In-Situ chamber bakeout and activation.
  - Elevated temperatures and small clearance to magnets often force ex-situ activation.
- Fabrication techniques compatible
  - with coating process

Regeneration:

- Getter can be repeatedly regenerated
  - activation above 250°C improves pumping speed and capacity.

Reference: Vacuum properties of TiZrV non-evaporable getter Vacuum 60 (2001) 57-65, CERN

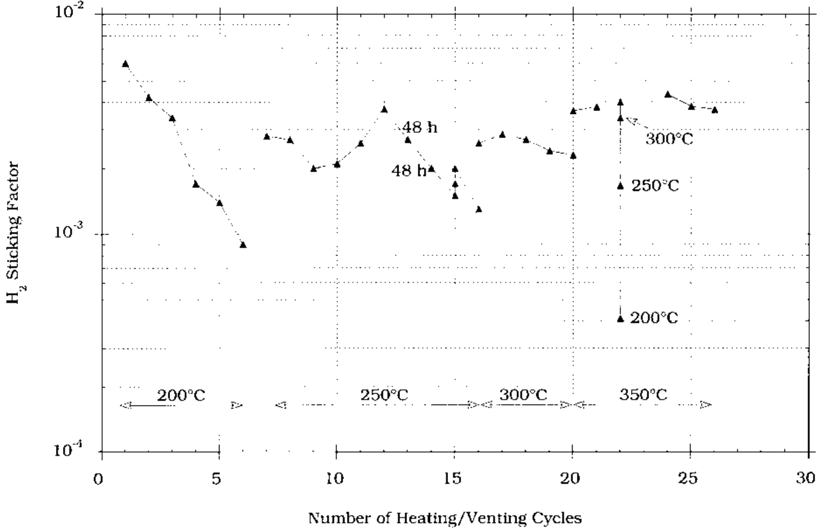


Fig. 6. Variation of the H_2 sticking factor for a 5 μm thick TiZrV film as a function of the number of activation–air-venting cycles. The activation temperature applied during 24 h is progressively increased to compensate for the decrease of sticking factor. The figure shows that 26 cycles may be carried out with a 30% decrease of the H_2 sticking factor provided that the heating temperature is raised to 350°C.

Distributed pumping:

NEG Coatings:

Chamber fabrication considerations:

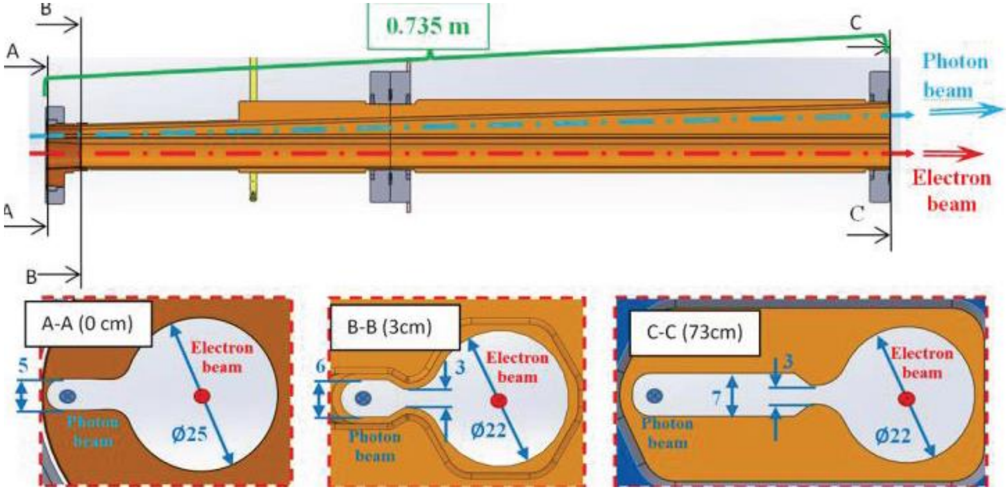
- **Distributed absorbing:**
  - Requires high Z and high thermal conductivity substrate: OFS Copper
- **Aspect ratio:**
  - Coating thickness goes as R^2
  - Distance from the cathode to the wall, R does not vary more than factor 2
- **Surface validation: Brazing and Wire Erosion fabrication processes**
  - Verify chamber cleaning procedure will not attack the braze material
  - Verify NEG coating meets adhesion requirements
- **Thin wall materials:**
  - Thin wall materials are difficult to reprocess,
  - Processing further reduces the wall thickness.
  - Chambers with bellows may not be able to reprocess.
- **Post fabrication processing:**
  - Best if coating is the last procedure,
    - reduces chance of coating contamination.
  - Chambers have been formed and welded after coating
    - using careful purging procedures.
    - Neon gas does not contaminate the NEG coating.

Distributed pumping:

NEG Coatings:

Coating special chambers: Photon Extraction Ports

Keyhole geometry: interface with magnet poles



Reference: NEG Thin Film Coating Development for the MAX-IV Vacuum System. Proc. IPAC2013.

Reference: Vacuum System of the MAX IV 3 GeV ring
Low emittance ring 2013 workshop. M. Grabski

Photon extraction port interface with sextupole magnet

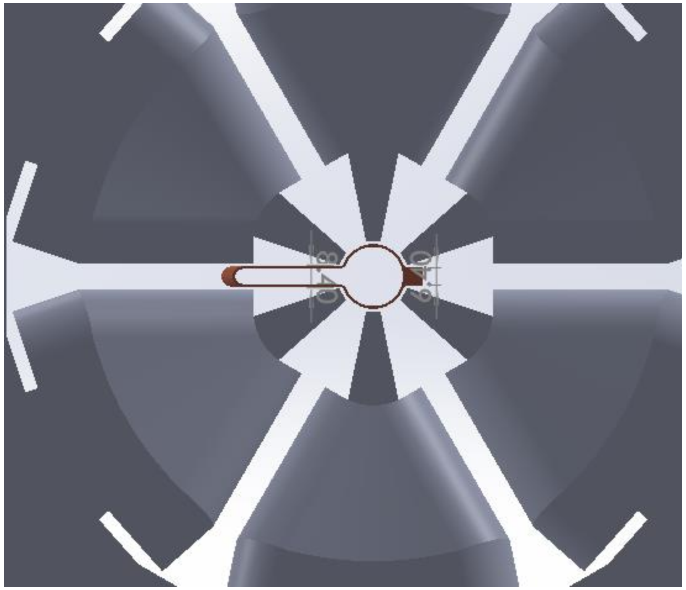
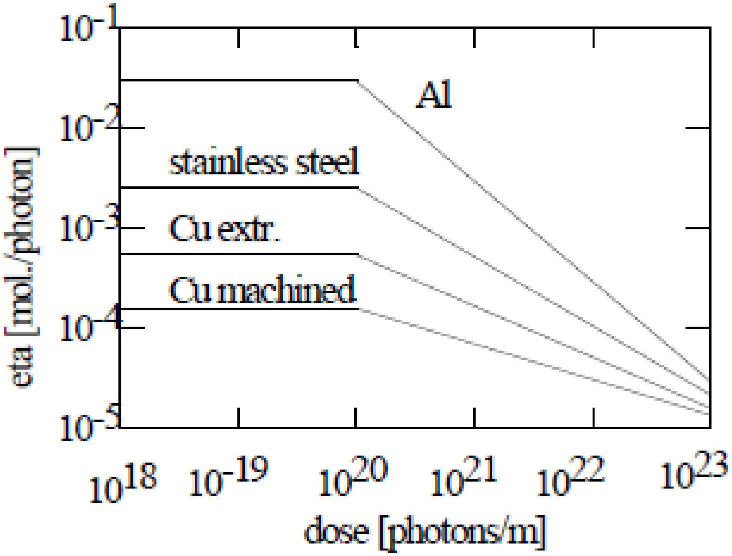


Image Courtesy: B. Brajuskovic APS

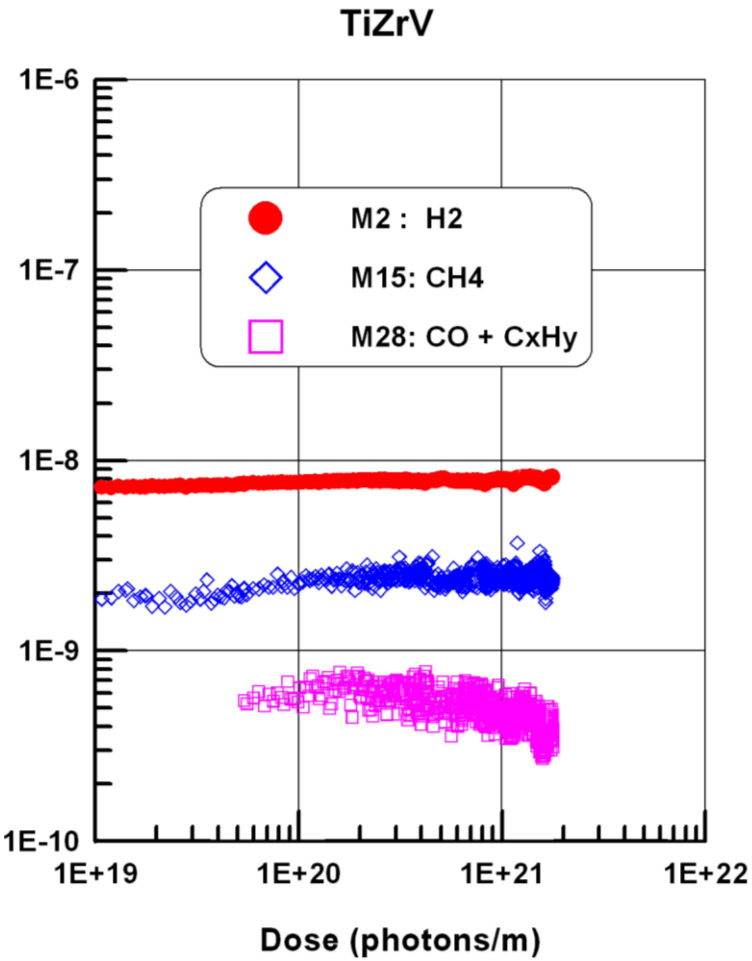
Distributed pumping:

Photon Stimulated Desorption:

NEG Compostition: 31.5% Ti: 26% Zr : 42.5%V



Reference: Materials for Accelerator Vacuum Systems. E. Huttel, ANKA



Reference: V.V. Anashin Vacuum 75, 2004

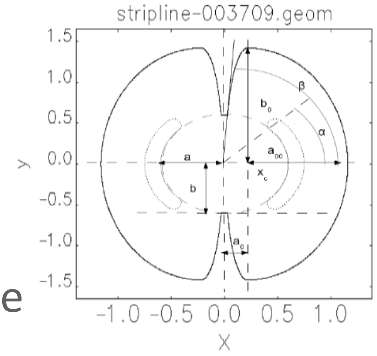
NEG Coatings provide distributed pumping, and less gas load than uncoated chambers

Coatings:

Coatings with low Secondary Electron Yield:

SEY is minimized with α-C coatings.

Kicker geometry:
α-C at high field
NEG coating elsewhere



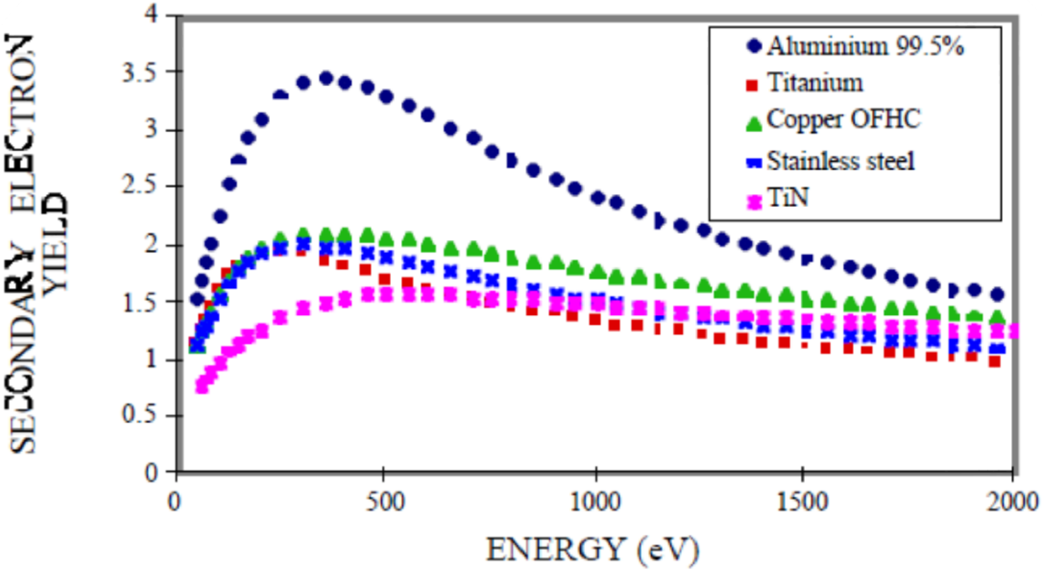


Figure 3: S.E.Y. of various as received technical materials

THE SECONDARY ELECTRON YIELD OF TECHNICAL MATERIALS AND ITS VARIATION WITH SURFACE TREATMENTS

V. Baglin, J. Bojko[1], O. Gröbner, B. Henrist,
N. Hilleret, C. Scheuerlein, M. Taborelli CERN, Geneva, Switzerland

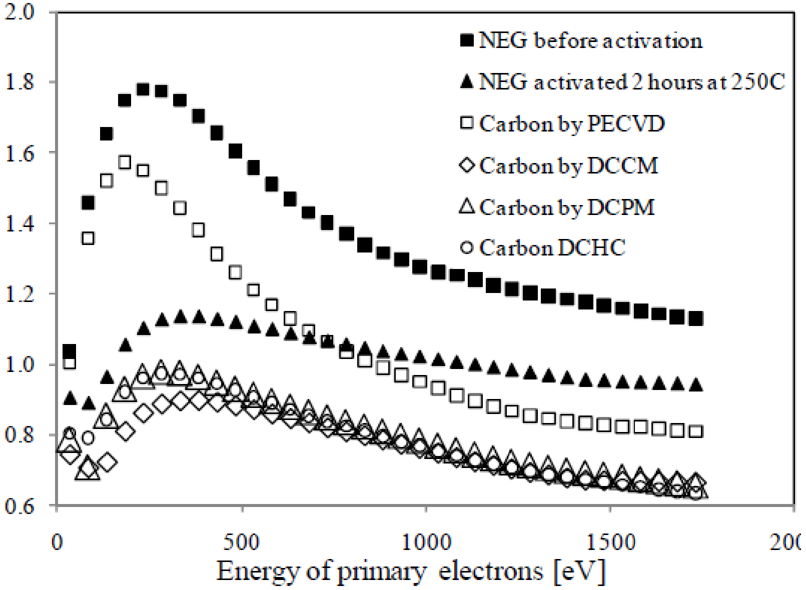


Figure 1: SEY as a function of the energy of the primary electrons for NEG, (before and after activation), and for carbon coated by different techniques.

THIN FILM COATINGS FOR SUPPRESSING ELECTRON MULTIPACTING IN PARTICLE ACCELERATORS

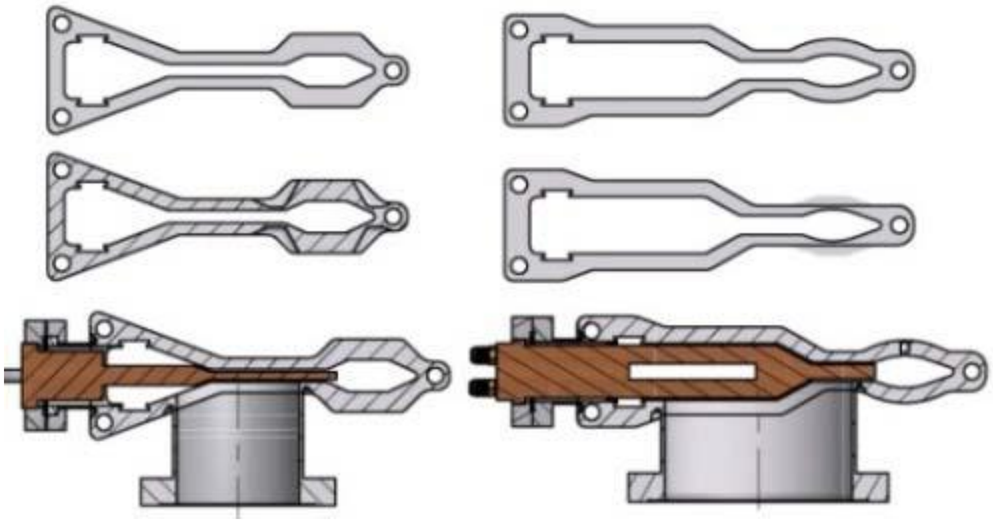
P. Costa Pinto, S. Calatroni, P. Chiggiato, H. Neupert, W. Vollenberg, E. Shaposhnikova, M. Taborelli, C. Yin Vallgren, CERN, Geneva, Switzerland.

Sector Chamber Design: Ante-Chambers

Ante-chambers

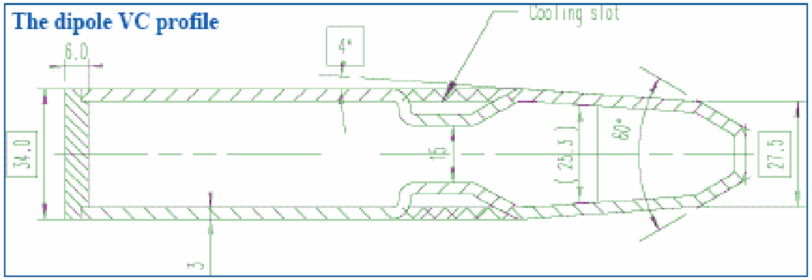
- Strip getters in the ante-chamber
- Discrete absorbers
  - Thermal loading on absorbers, less on chambers
- Stiff structure, BPMs can be integrated with the chamber
- Photon extraction ports: with ante-chamber profile or oval tube profile.
- Bakeout at 130-150°C, activation of strip getters in vacuum

Aluminum Extrusion



Reference: Status of NSLS-II Storage Ring Vacuum Systems, H.C. Hseuh

Stainless Steel formed and welded

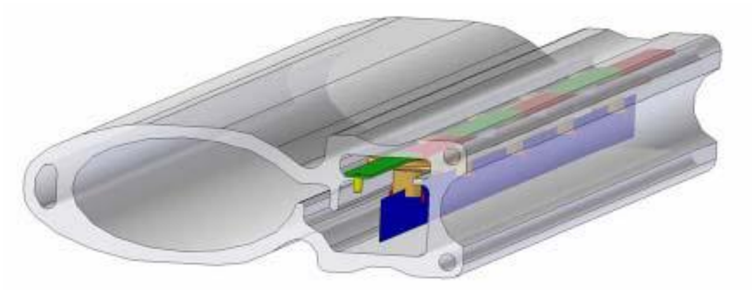


Reference: The Vacuum System for the Spanish Synchrotron Light Source (ALBA). E. Al-Dmour. EPAC2006

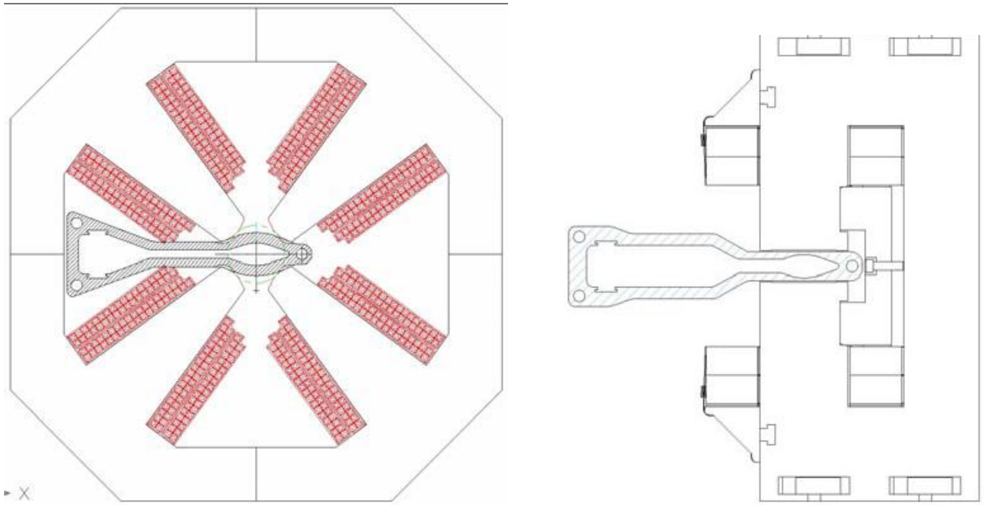
Ante-Chambers:

Aluminum Extrusions: APS, NSLS-II, Spring-8, PETRA-III

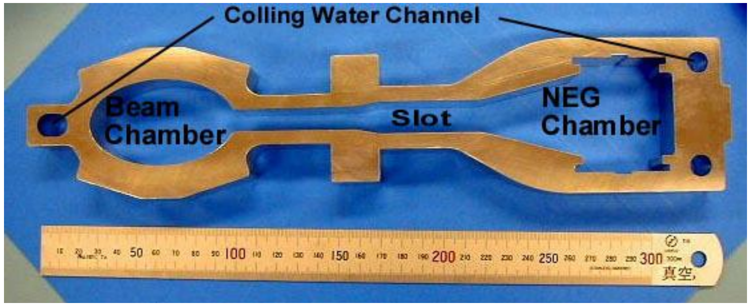
- TIG welding flanges, ports
- Strip getters in ante-chamber
- Candidate locations: dipoles
- Quadrupoles and Sextupoles
  require careful integration



Reference: Vacuum System Design of the Third Generation Synchrotron Radiation Source PETRA III, B. Nagorny, JoP, 2012



Reference: NSLS-II Vacuum Systems, H.C. Hseuh, ASAC Review 2007

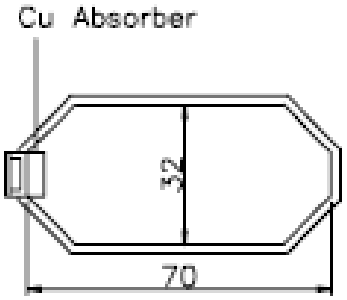


Reference: SPring-8 Vacuum Sysem. T. Yorita, 2005

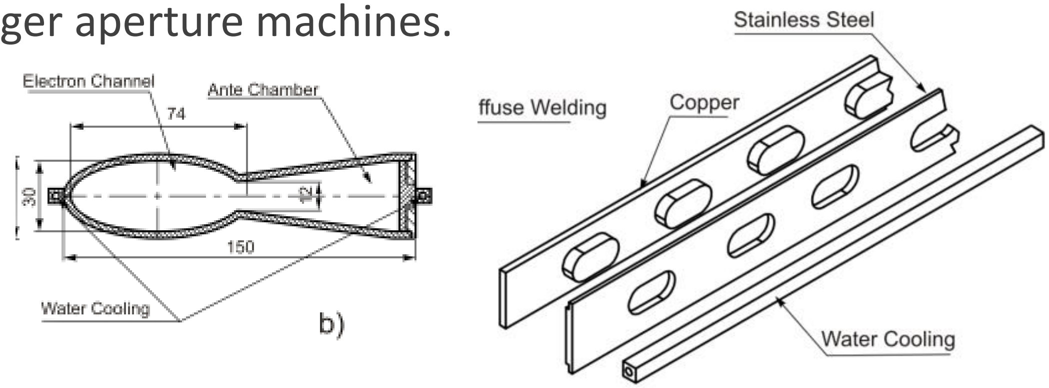
Ante-Chambers:

Stainless steel chambers: ALBA, ANKA, CANDLE, ESRF

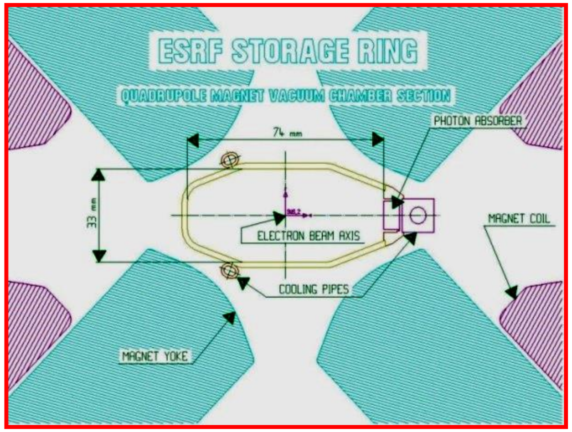
- Formed and TIG welded
- Copper distributed absorbers can be integrated with the chamber
- Impedance an issue, better suited for larger aperture machines.



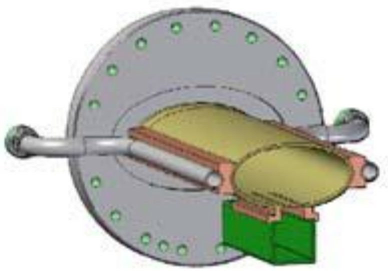
Reference: The Vacuum System for the Synchrotron Radiation Source ANKA. E. Huttel, IEEE 1998



Reference: CANDLE Design Report, July 2012



Reference: ESRF, R. Kersevan, JUAS 2012

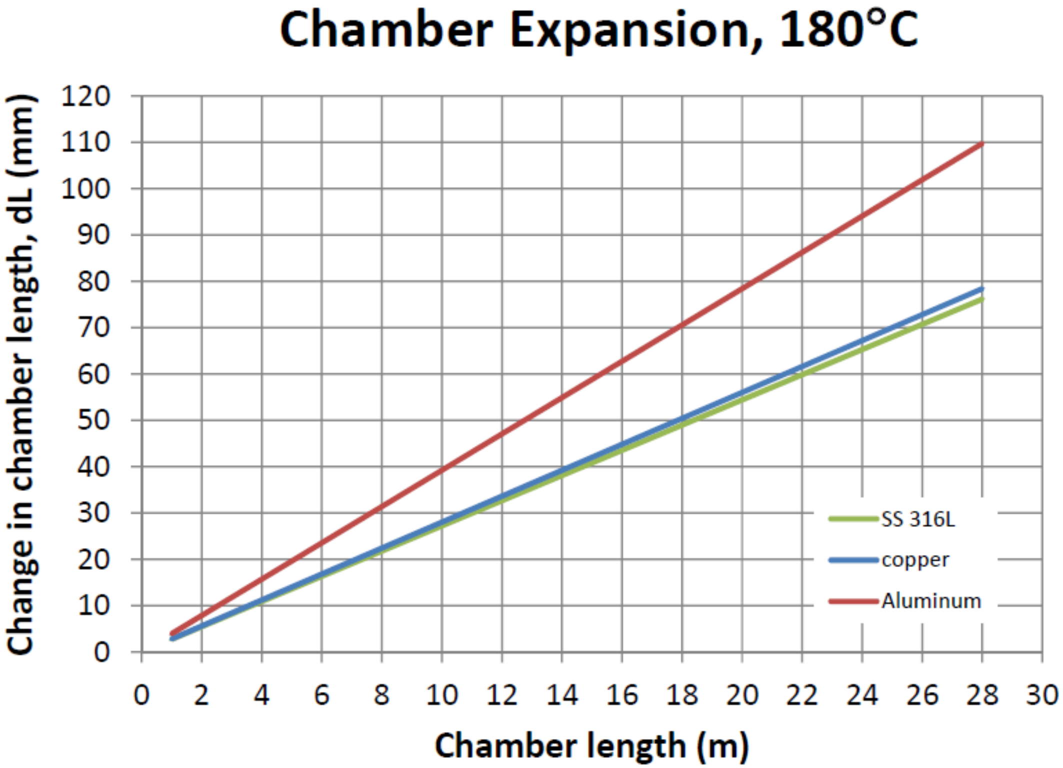


Reference: Vacuum System Design of the Third Generation Synchrotron Radiation Source PETRA III, B. Nagorny, JoP, 2012

Bellows:

Expansion needs:

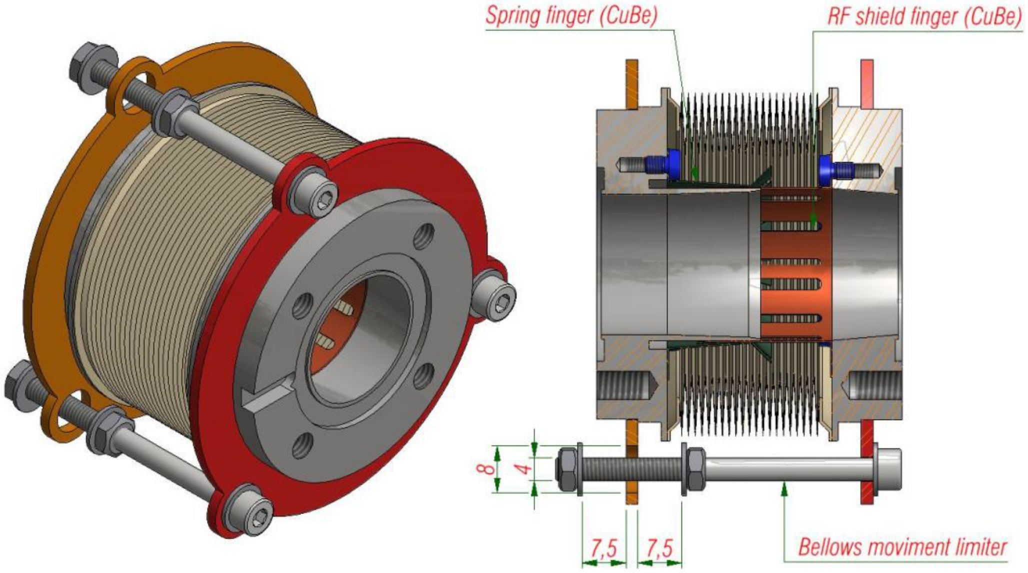
Bellows expansion needed
- installation, access to joints
- Chambers with distributed absorbers
  - Chamber expansion.
  - Isolating BPM motion from the chamber
- In-situ chamber bakeout



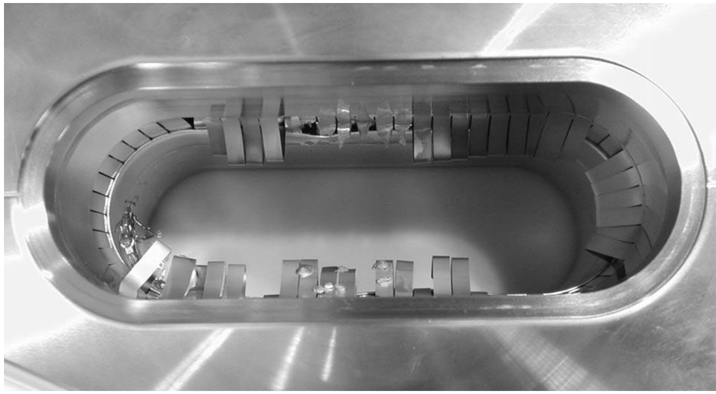
Bellows:

RF-Shielded Bellows:

- Edge welded bellows proved a wider range of motion than formed bellows especially in a compact lattice.
- Bellows need external protection against mechanical damage during handling.
- Shielding needs to allow axial and transverse motions
- Provides the amount of expansion needed per sector.
- Optimization with impedance is needed.
- Need to evaluate for cleaning procedures and virtual leaks issues.
- Evaluate adequate radiation shielding, wakefield heating.



Reference: SIRIUS Design Report, 2/2013



Reference: Possibility of a comb-type rf shield structure for high-current accelerators. KEK, 2003

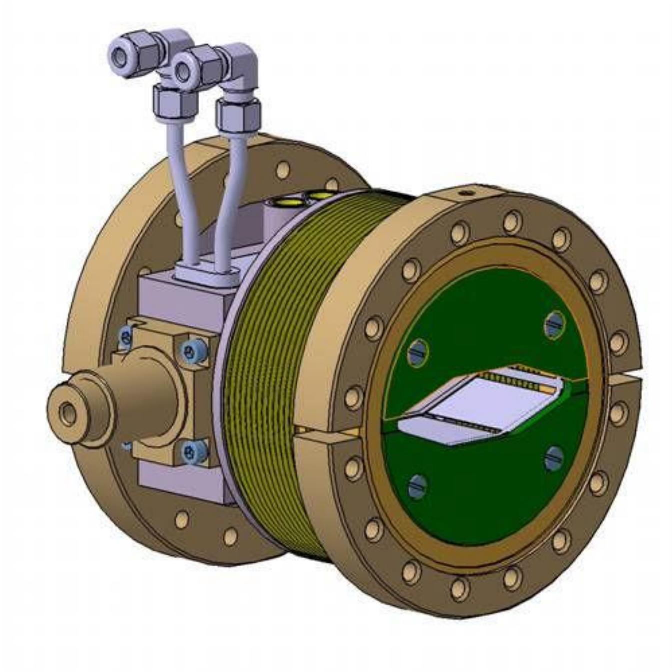
BPMs and Bellows:

Integrated assemblies:

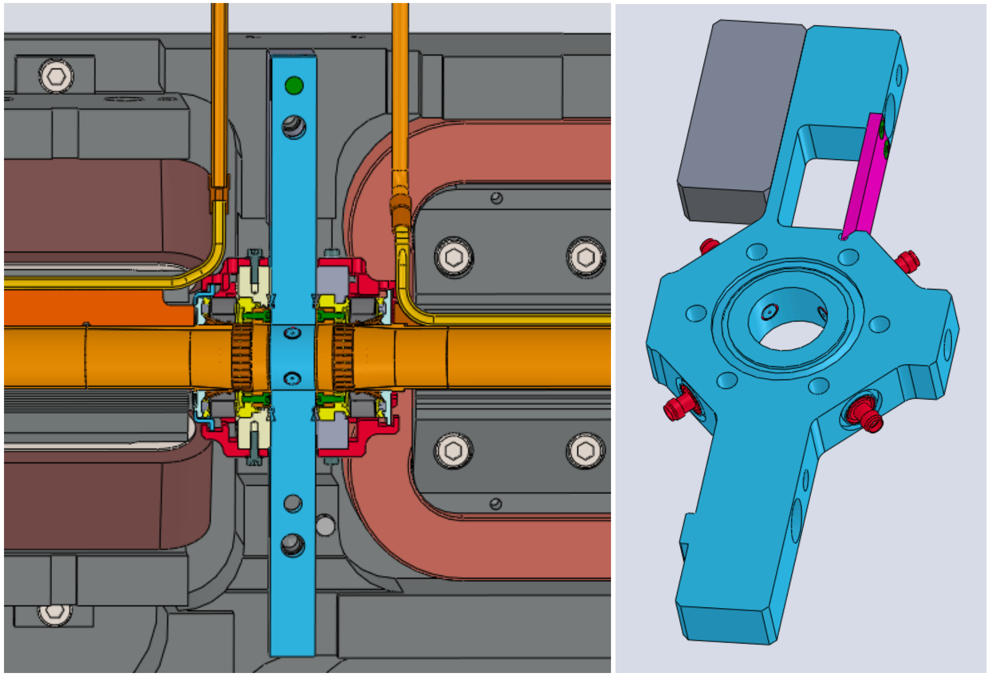
BPM stability requirements are tight.

BPMs with fixed supports, isolated from chamber motions by bellows.

Assembly shielding by upstream absorber



Reference: Storage Ring Vacuum System,
C. Herbeaux, SOLEIL, LER2010



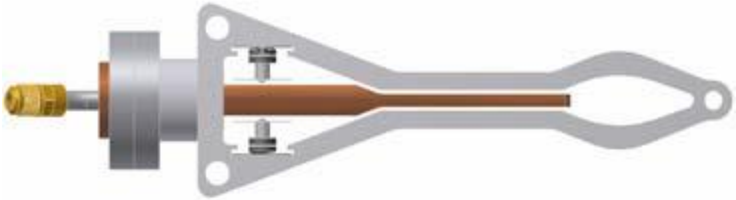
Reference: Vacuum System of the MAX IV 3 GeV ring
Low emittance ring 2013 workshop. M. Grabski

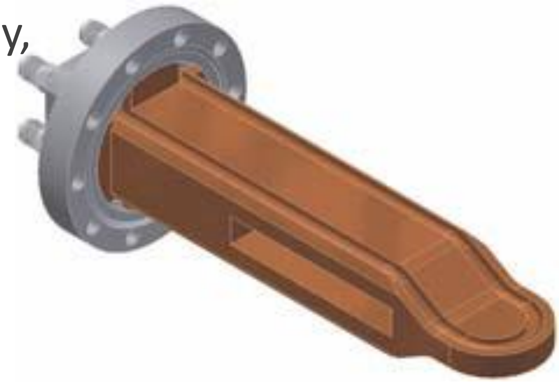
Discrete Absorbers:

Discrete absorber:

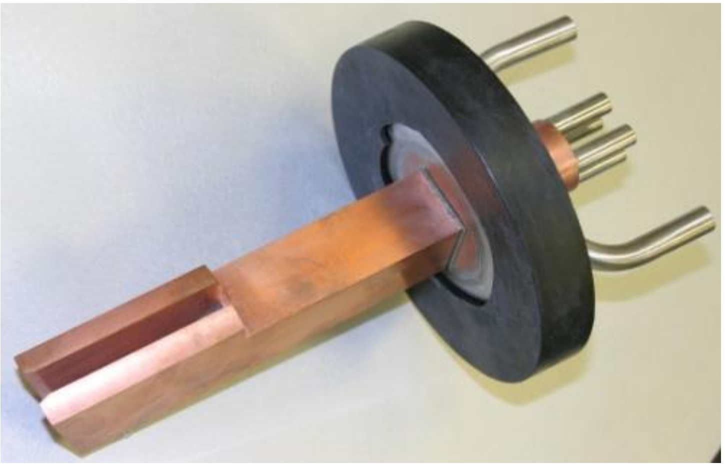
Crotch absorber needed at each photon extraction port

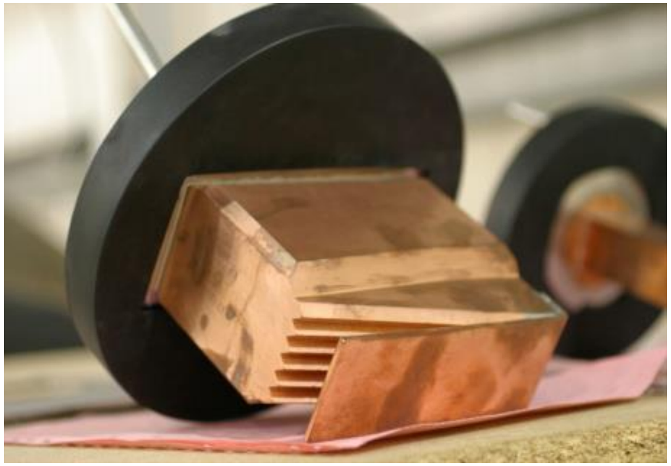
Surfaces and incident angles optimized to reduce reflectivity, minimizes heat loading on neighboring chambers .





Reference: NSLS-II Vacuum Systems, H.C. Hseuh, ASAC Review 2007





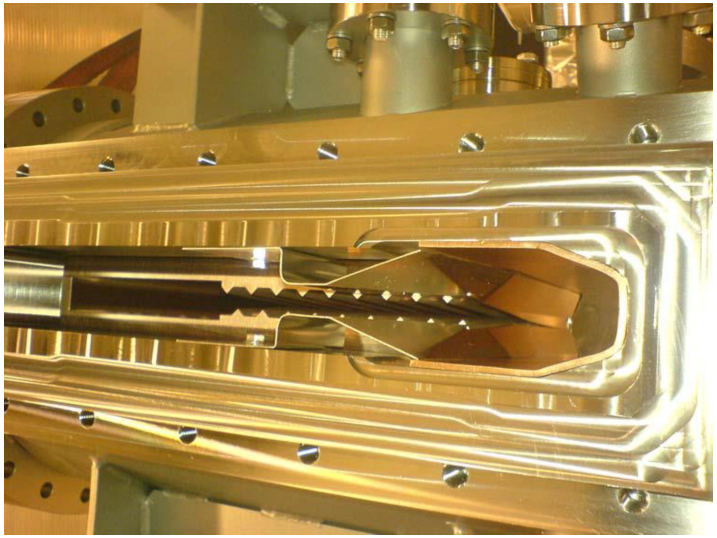
Reference: Achieving Ultra-high vacuum without (in-situ) bakeout:
M. Cox, Diamond. WS-63 Avila 2010

Absorbers:

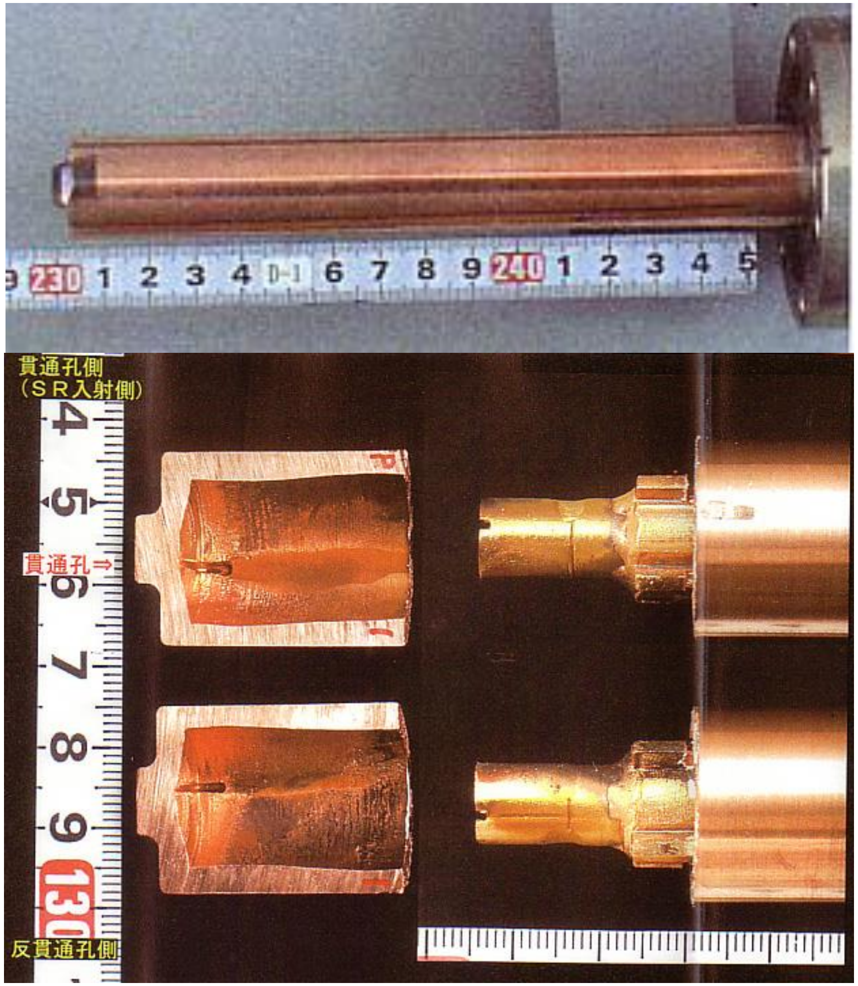
Corrosion:

Water to vacuum channels can corrode through.
Careful absorber design, and water system design is needed.

There is a possibility that SR, water and dissolved oxygen corroded Cu.



Reference: Troubleshooting, maintenance and upgrade program preparation for the ESRF Accelerator vacuum systems, M. Hahn, ESRF



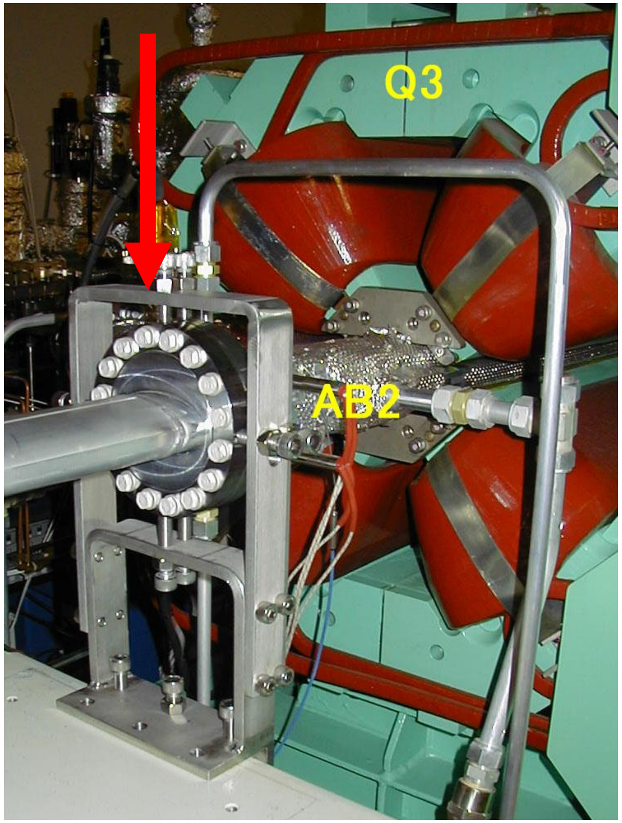
Reference: SPring-8 Vacuum Sysem. T. Yorita, 2005

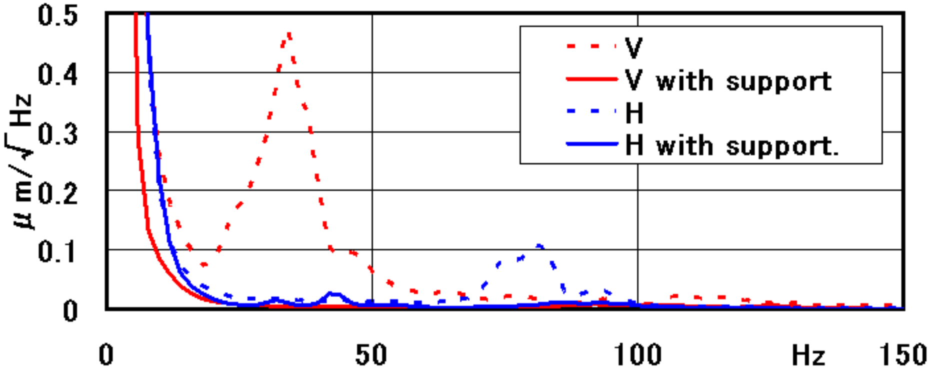
Vibrations:

Supports:

Water flow can induce vibration, especially in low mass, small cross section chambers.

Reduction with additional supports





Reference: SPring-8 Vacuum Sysem. T. Yorita, 2005

Vacuum chamber material:

Chamber Materials:

Aluminum: PETRA III, ALS, APS, NSLS-II, Spring- 8, PF, TLS, TPS

Material: Al 6063-T5.
½ year to develop extrusion parameters.
Chambers with bends require roll bending.
Machining in narrow gaps.
TIG welding flanges, exit ports, side ports.

Stainless Steel: DIAMOND, ELLETRA, ESRF, SLS, SOLEIL, CANDLE, ALBA, ASP

Material: SS304L or 316L.
Formed and welded chambers.
Explosion bonded copper absorbers, cooling channels.

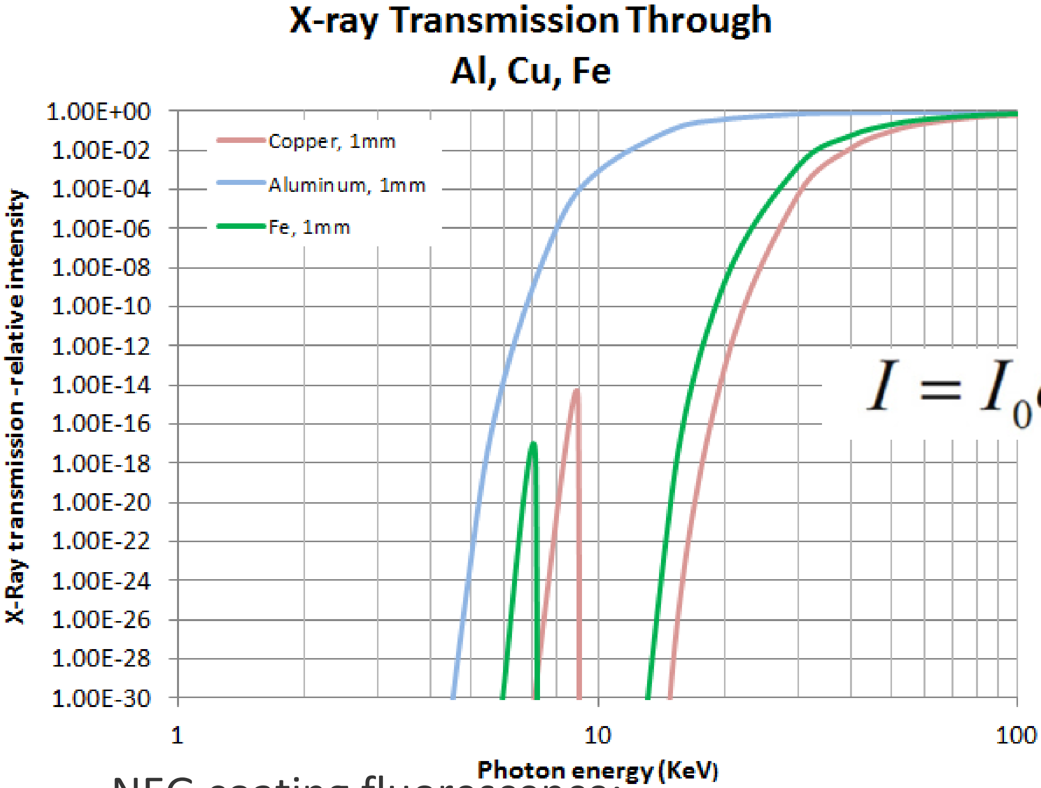
Copper: SPEAR-III, MAX-IV, SIRIUS

Material OFS copper, C10700. Allows higher strength at elevated temperatures.
Ebeam welding.
Brazing anneals the material, lower strength.

Vacuum chamber material:

Aluminum chambers:

- Shielding is needed around absorbers.
- Shield NEG coated surfaces from incident photons.
- Investigate coatings without Zr

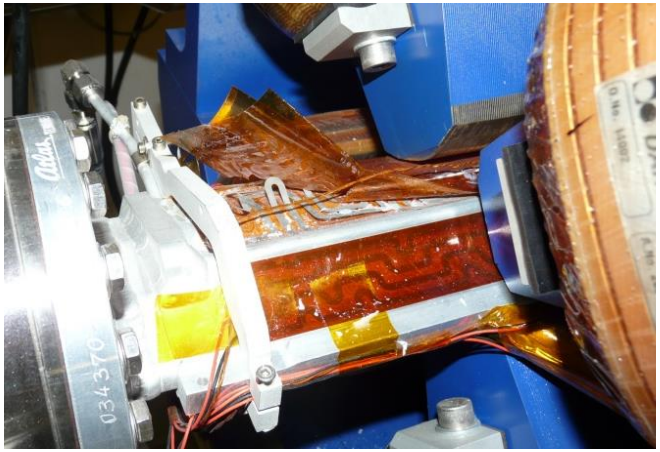


X-ray Transmission Through Al, Cu, Fe

$$I = I_0 e^{-\mu x}$$

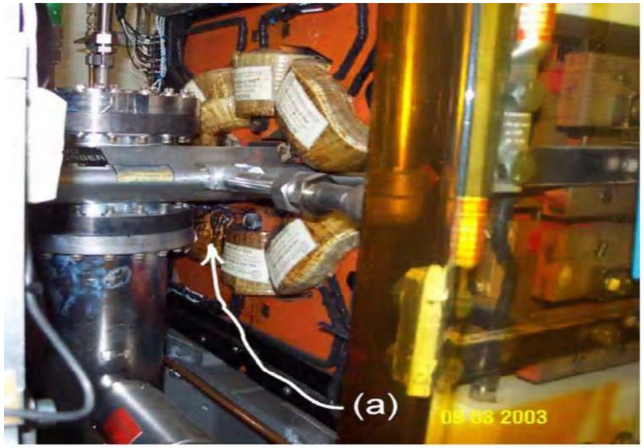
NEG coating fluorescence:

30% Titanium (Ti)	Kα: 4.51 keV	Kβ: 4.93 keV
40% Vanadium (V)	Kα: 4.95 keV	Kβ: 5.43 keV
30% Zirconium(Zr)	Kα: 15.78 keV	Kβ: 17.67 keV



Radiation damage to film adhesive

Reference: Radiation Damage and Characterization in the SOLEIL Storage Ring. N. Hubert. IBIC 2013



Reference: Aging of accelerator components at the APS. J. Quintana, 2003.

Bakeout / Activation:

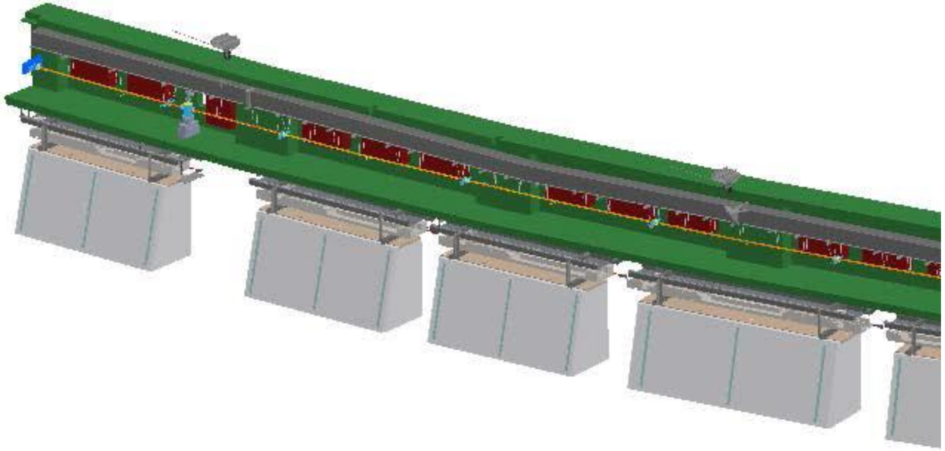
Activation of NEG Coatings:

- 180°C to 250°C is needed
- Limited radial gap to magnets forces ex-situ bakeout and activation.
- Investigating activation methods and minimum gap needed.

Ex-Situ Activation

- ANKA, ALBA, ELETTRA, MAX-IV
- Requires: ovens, fixtures, advantage if tunnel roof is removable.

Reference: The ALBA Vacuum System: Installation and Commissioning, E. Al-Dmour, IPAC2010



Reference: Vacuum System of the MAX-IV 3 GeV ring, E. Al-Dmour , Dec. 2013

Bakeout:

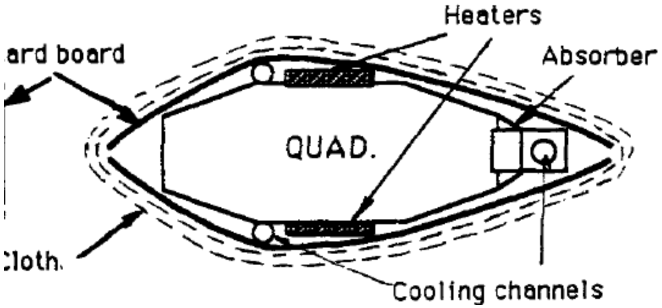
In-Situ Bakeout

- APS, NSLS-II, ESRF, Spring-8
- Bakeout methods: hot water 130 to 150°C, electric film heaters, rod heaters inserted into an unused cooling channel.
- Typically 3mm gap to magnets, investigating minimum gap required.

Reference: CERN

Heater films with reflective barrier
Adhesive tapes degrade with radiation damage

Consider high temperature
radiation hard
adhesive or shrink tubing



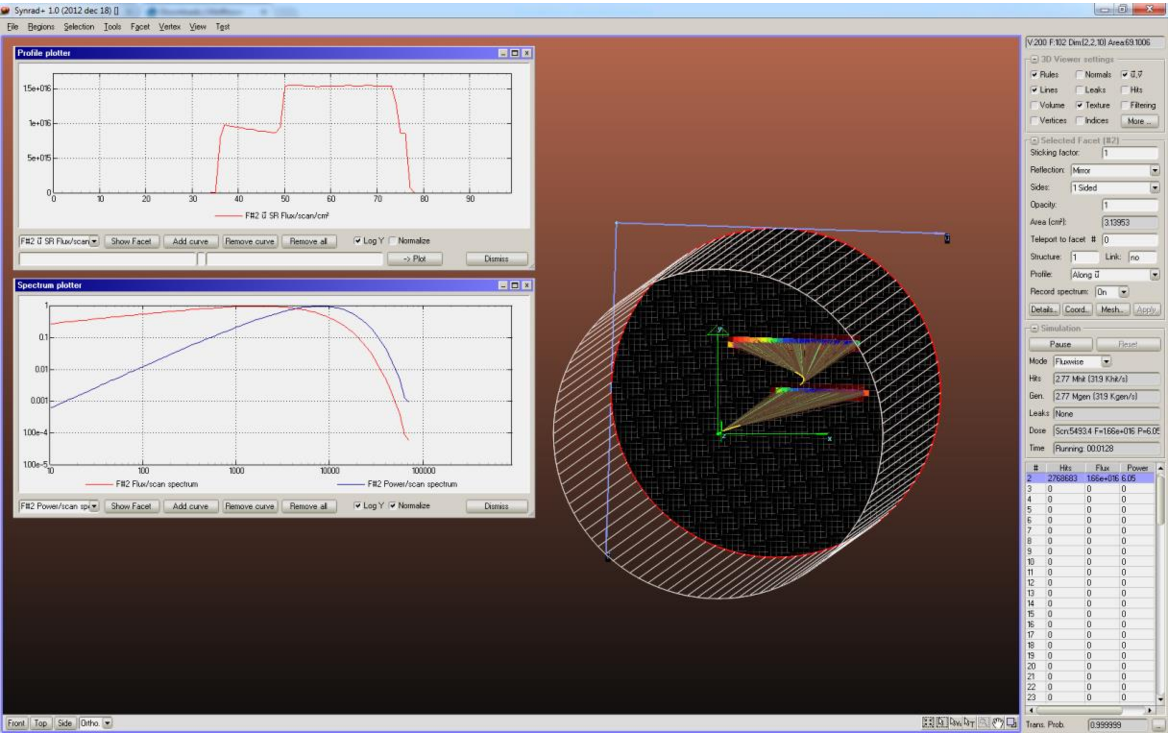
Heat film surrounded by blanket
3 mm gap to magnets

Reference: Development of the ESRF Vacuum System. M. Renier, AIP 1991

Vacuum Simulations:

Analysis:

- Analytical Calculations
    - OK for preliminary analysis to determine sense of scale
- Simulation packages are available: COMSOL, VASCO…..
- Integrated photon distribution calculation and vacuum pressure using SynRad and MolFlow+



Profile plotter: F#2 ū SR Flux/scan ☑ Log Y ☐ Normalize

Spectrum plotter: F#2 Power/scan sp… ☑ Log Y ☑ Normalize

V:200 F:102 Dim:(2,2,10) Area:69.1006

☑ Rules ☐ Normals ☑ ū,v̄
☑ Lines ☐ Leaks ☐ Hits
☐ Volume ☑ Texture ☐ Filtering
☐ Vertices ☐ Indices More ...

Sticking factor: 1
Reflection: Mirror
Sides: 1 Sided
Opacity: 1
Area (cm²): 3.13953
Teleport to facet #: 0
Structure: 1 Link: no
Profile: Along ū
Record spectrum: On

Mode: Fluxwise
Hits: 2.77 Mhit (31.9 Khit/s)
Gen.: 2.77 Mgen (31.9 Kgen/s)
Leaks: None
Dose: Scn:5493.4 F=1.66e+016 P=6.05
Time: Running: 00:01:28

#	Hits	Flux	Power
2	2768683	1.66e+016	6.05
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	0	0	0
11	0	0	0
12	0	0	0
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
22	0	0	0
23	0	0	0

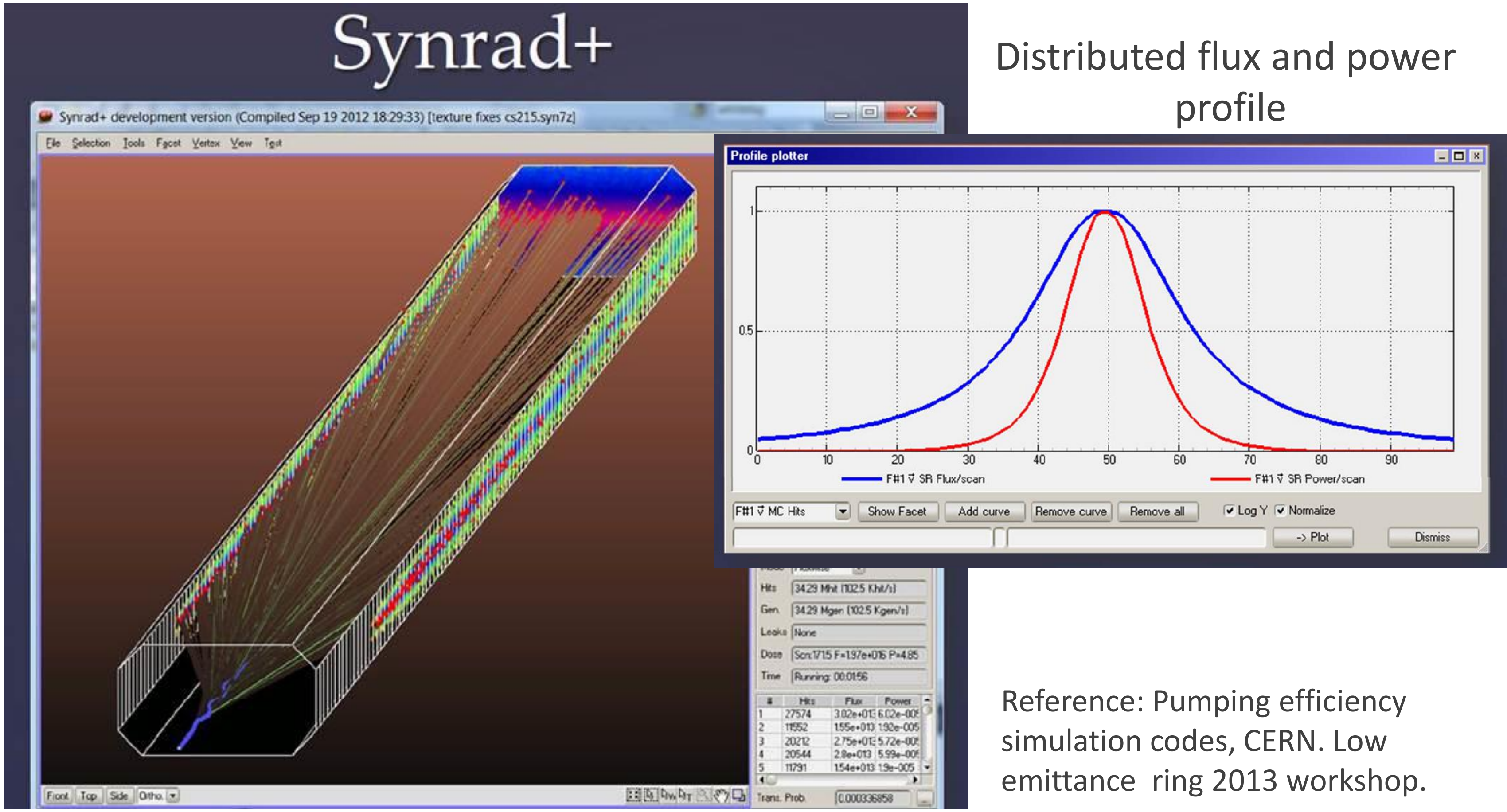
Trans. Prob.: 0.999999

Import:
    Vacuum surfaces from CAD
Apply:
    Dipole, quadrupole regions
    Beam emittance
Calculate:
    Electron trajectory
    Primary flux distribution on walls
    Secondary flux distribution
    Energy profile of the photons
    Power distribution
Export to MolFlow:
    Calculates pressure profile
    Includes
        Photon stimulated desorption

Ray Tracing:

DLSR lattice :

- CAD ray tracing ok for nominal case
- Ray tracing simulations to investigate all miss steering cases
- Power distribution and energy spectrum on absorbers
- Integrated flux and power distribution simulations using SynRad and MolFlow+



Hits: 34.29 Mhit (102.5 Khit/s)
Gen.: 34.29 Mgen (102.5 Kgen/s)
Leaks: None
Dose: Scn:1715 F=1.97e+016 P=4.85
Time: Running: 00:01:56

#	Hits	Flux	Power
1	27574	3.02e+01	6.02e-00
2	11952	1.55e+013	1.92e-005
3	20212	2.75e+01	5.72e-00
4	20544	2.8e+013	5.99e-00
5	11791	1.54e+013	1.9e-005

Trans. Prob.: 0.000336858

Distributed flux and power profile

Reference: Pumping efficiency simulation codes, CERN. Low emittance ring 2013 workshop.

Summary I:

DLSR Vacuum designers use different approaches, each designed carefully.

- Integration: Early in the design process consider interfaces with magnet and supports.
  - Negotiate space for bellows, BPMs, absorbers, cooling channels, chamber profile…..
- Stability
  - BPMs isolated by bellows and anchored to stiff supports.
  - Investigating vibration isolation of water cooling on small cross section chambers.
- Minimize installation time, time to recover from an “event”
  - In-situ bakeout / activation methods,
  - Investigating minimum gap to magnet pole required .
  - Investigating methods to attach heat films.

- All NEG coated: MAX-IV, SIRIUS
  - Advantage for low conductance, and narrow gap chambers.
  - Requires ex-situ activation in compact lattices.
  - Challenge to coat all surfaces, photon extraction ports.
  - Shield coating from radiation when used with aluminum chambers due to Zr fluorescence.
- Ante-Chambers: NSLS-II, APS, ESRF
  - Aluminum extrusions: advantage with large bending radii, narrow radiation fans, small gap chambers.
  - Stainless steel: advantages with large apertures.
  - Discrete absorbers, distributed absorbers can be integrated with the chamber.
  - Strip getters in the ante-chamber

Summary II:

Chamber Aperture ↓

Circumference <250 m	Circumference 0-300 m	Circumference 300-750 m	Circumference 750-1000m	Circumference 1000-1500m	Circumference >1500m
		MAX-IV, 22mm 100% NEG Coated OFS Copper	ESRF-Upgrade ~26mm magnet bore	APS-Upgrade ~26mm magnet bore	
		SIRIUS, 26 mm 100% NEG Coated OFS Copper		SPring-8 Upgrade ~26mm magnet bore	
ASP 32x70mm Stainless Steel, keyhole Antechambers	ALBA 28x72 mm Stainless steel - antechambers	SOLEIL 25x70mm NEG coated Aluminum SS antechambers at dipoles	NSLS-II Aluminum ante-chamber 25x76 mm		
SPEAR III 34x84 mm OFE Copper Clamshell		DIAMOND 38x80 mm Stainless Steel, Antechambers at dipoles	ESRF 33 x74mm Stainless Steel	SPring-8 40 x70 mm Aluminum ante-chamber	PETRA III 40x80 mm At Dipoles Aluminum Ante-chamber Stainless elliptical
ALS 42mm Vertical Aluminum Clam shell	ELETTRA 60x88 mm Stainless Steel 316LN rhomboidal shape			APS 42x85 mm Aluminum ante-chamber	

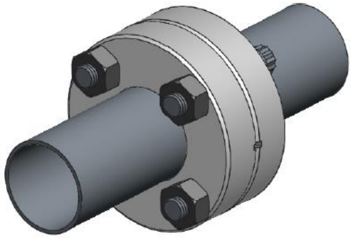
Thank You!

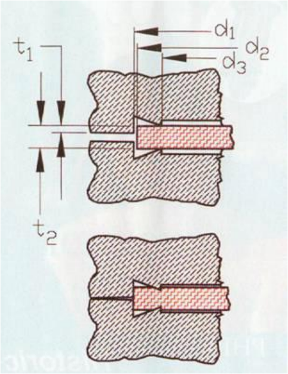
APS: B. Stillwell, B. Brajuskovic,
J. Carter, D. Fallin, J. Noonan,
M. O’Neill, E. Trakhtenberg
CERN, ESRF, MAX-IV colleagues

Backup Slides:

Flanges:

Components:





Reference: B. Stillwell,
E. Trakhtenberg APS

Flange styles:

Conflat: knife edge

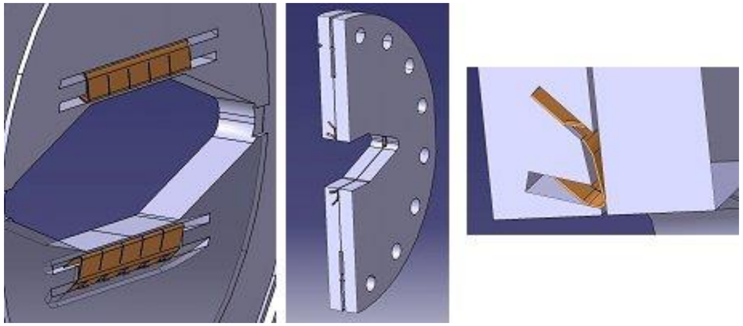
Zero Gap:

modified Conflat

Spigot type

VATseal

Flange with RF shield



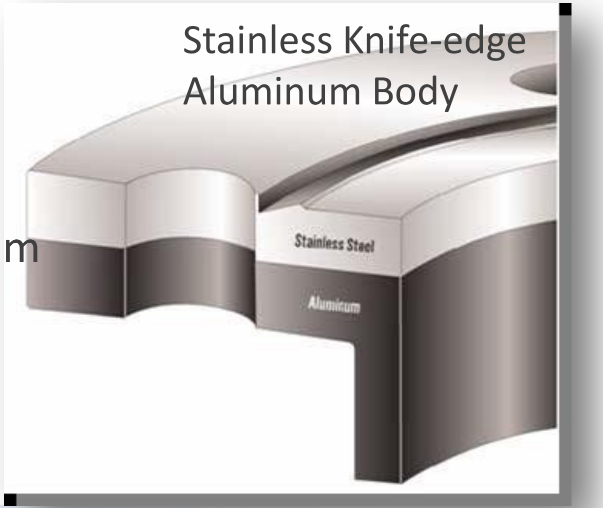
Reference: SOLEIL

Joining techniques:

Explosion bonding Stainless to Aluminum

Stainless to copper

Brazing Stainless to Copper



Stainless Knife-edge
Aluminum Body

Reference: ATLAS