Vacuum Systems for Storage Rings with High Current

2017.04.27

Taekyun Ha

Pohang Accelerator Laboratory

References

[1] T. Ha, "*The First 3 Years of Operation of PLS-II Vacuum System*", OLAV IV (2014)

[2] H.C. Hseuh, "*Two-Year Operation Experience of National Synchrotron Light Source II Storage Ring Vacuum Systems*", 80th IUVSTA Workshop (2016)

[3] M. Hahn, "*Vacuum for the ESRF EBS project*", 80th IUVSTA Workshop (2016)

[4] M. Oishi, et al., "*Design for the SPring-8 upgrade storage ring vacuum system*", 80th IUVSTA (2016)

[5] C. Herbeaux, et al., "*10 year experience of operation with NEG coating at the SOLEIL synchrotron light source*", 80th IUVSTA (2016)

[6] M. Grabski, "*MAX IV 3 GeV storage ring vacuum system: from development to operation*", 80th IUVSTA Workshop (2016)

[7] J. Carter, "*APS-Upgrade vacuum system status*", 80th IUVSTA (2016)

[8] A. Anders, et al., "*Non-evaporative getter (NEG) coatings for ultrahigh vacuum in very narrow chambers*", 80th IUVSTA (2016)

[9] L. L. Amador, et al., "*Development of copper electroformed chambers with integrated getter thin film coating*", 80th IUVSTA (2016)

[10] T. Ha, et al., "*Study of Vacuum Chamber Upgrading in PLS-II*", 80th IUVSTA (2016)

[11] H. Kodama, et al., "*Development of Low-Cost, High-Performance Non-Evaporable Getter (NEG) Pumps for Synchrotron Light Facilities* ", 80th IUVSTA (2016)

[12] E. Al-Dmour, "*The status of ALBA vacuum system*", OLAV II (2008)

[13] S. Sharma, "*A Novel Design of High Power Masks and Slits*", MEDSI (2014)

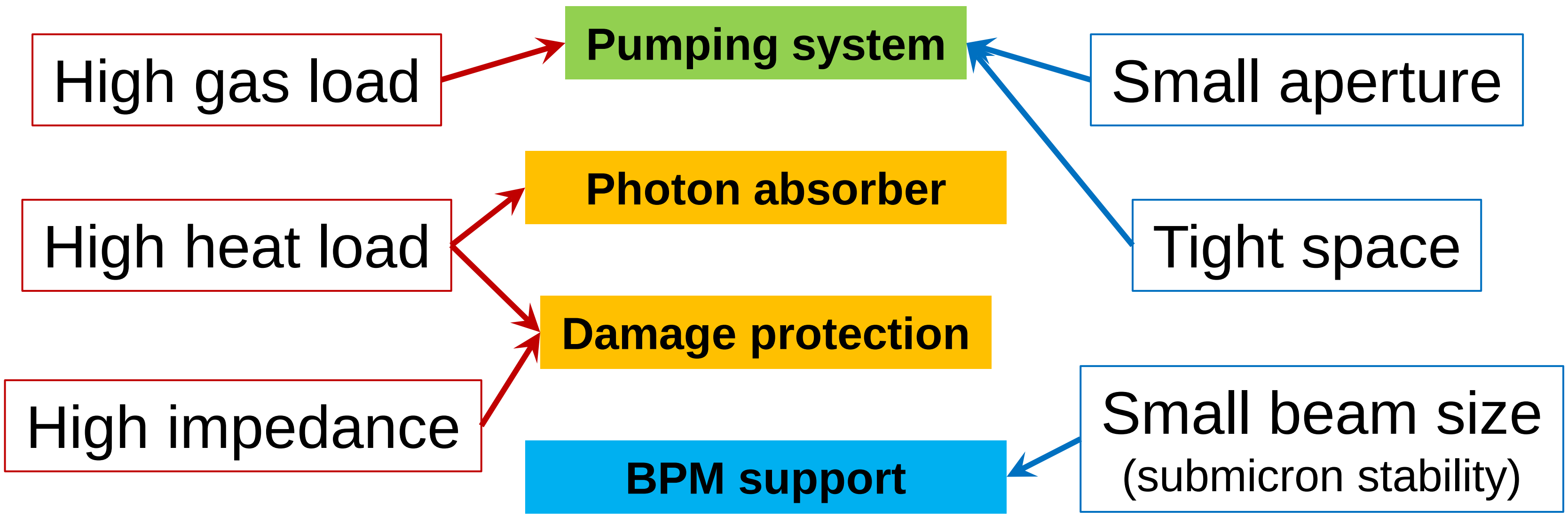
[14] C. Shueh, "*Investigation of vacuum properties of CuCrZr alloy for high-heat-load absorber*", NIMA 841 (2017)

[15] Y. Suetsugu, "*Experiences in Vacuum System of KEKB and SuperKEKB*", 80th IUVSTA (2016)

New generation light source:

"High current & low emittance"

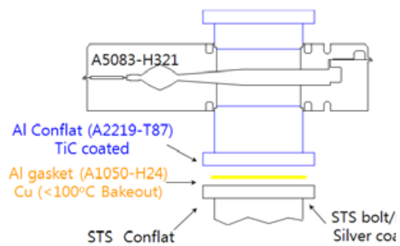
Vacuum system should accommodate:

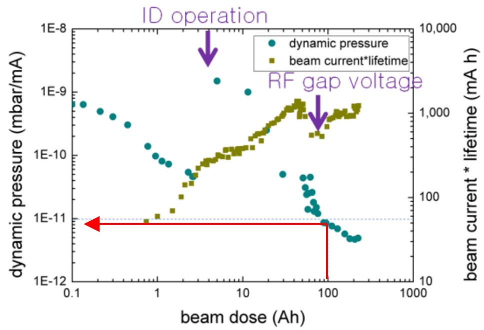


1. Pumping system

❖ Conventional pumping with ante-chamber

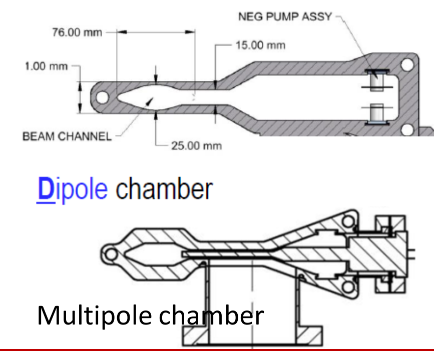
PLS-II[1]

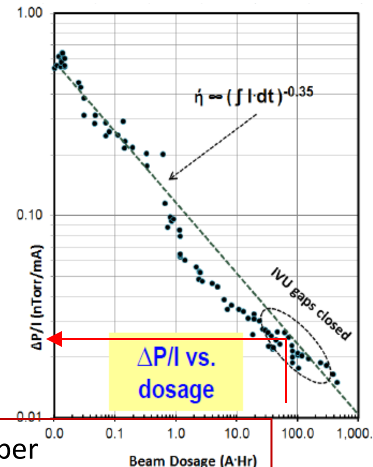




- ✓ **22 mm** V-aperture with **ante-chamber**
- ✓ **Machined** & welded **Al** chamber (or SST chamber)
- ✓ NEG strip/cartridge + SIP

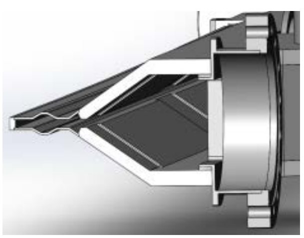
NSLS-II[2]

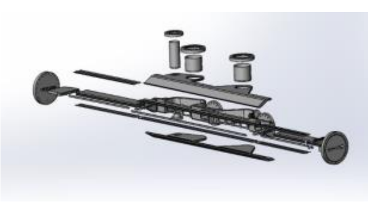




- ✓ **25 mm** V-aperture with ante-chamber
- ✓ **Extruded** & bent **Al** chamber (or SST chamber)
- ✓ NEG strip/cartridge + SIP + TSP + NEG coated chamber

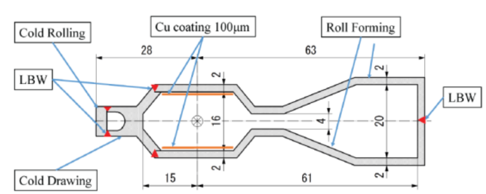
ESRF EBS[3]

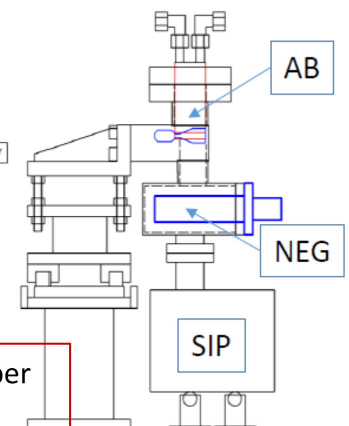




- ✓ **13 mm** V-aperture with **ante-chamber**
- ✓ **Deep drawing** & welded **SST** chamber (or Al chamber)
- ✓ Thick ante-chamber as a stiffener
- ✓ NEG cartridge + SIP

Spring-8-II[4]





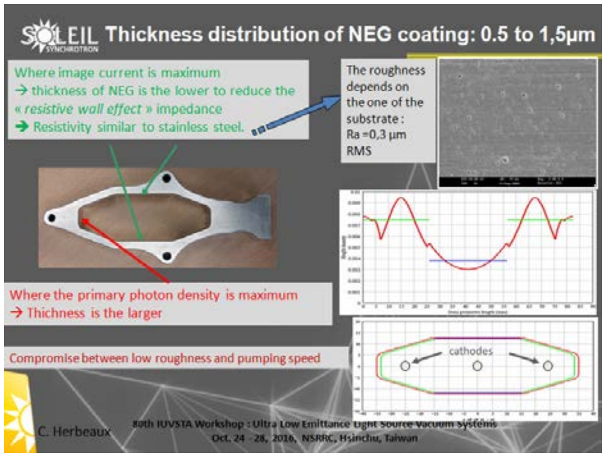
- ✓ **16 mm** V-aperture with ante-chamber
- ✓ Roll forming & LBW **SST** chamber
- ✓ 100 um **copper coated** on inner surface
- ✓ NEG cartridge + SIP

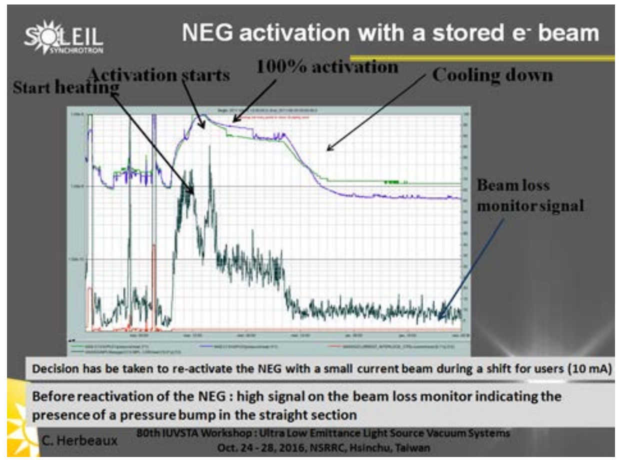
1. Pumping system

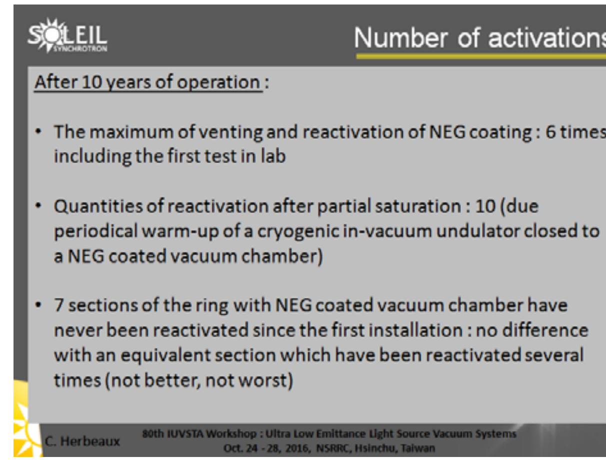
❖ NEG coated chamber

SOLEIL[5]

✓ 56% of the ring is NEG coated

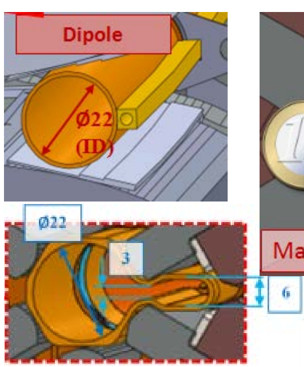


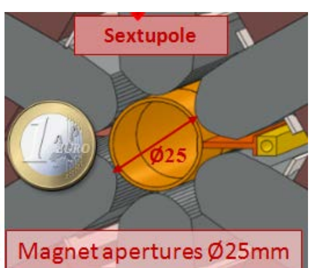


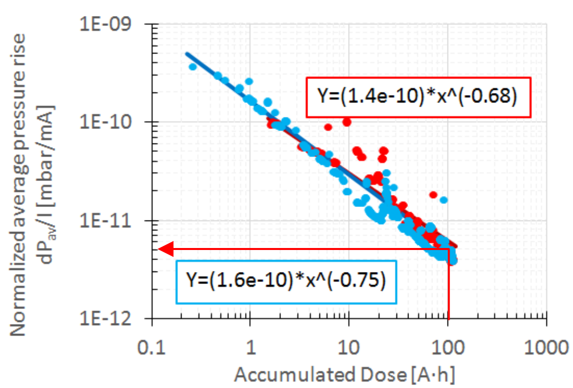


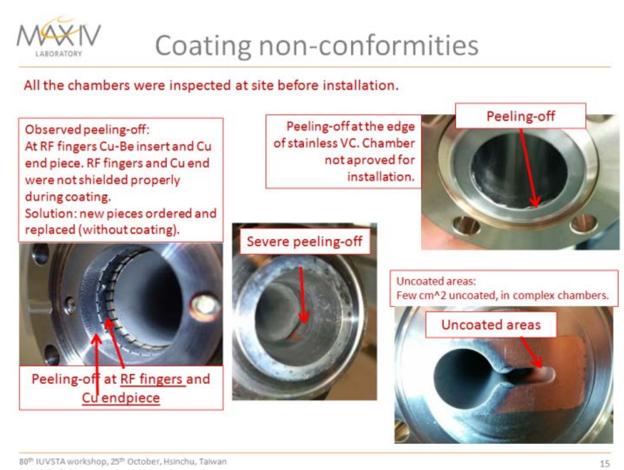
MAX-IV[6]

✓ 100% of the ring is NEG coated





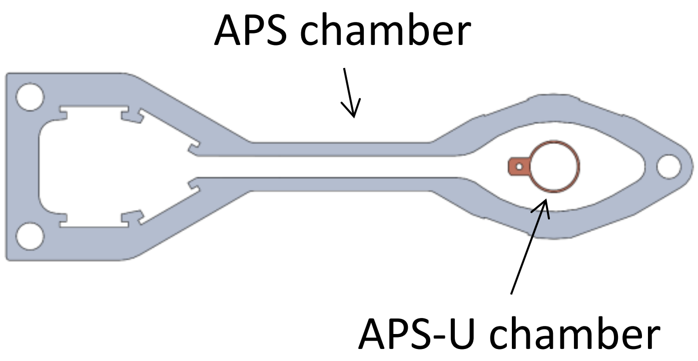


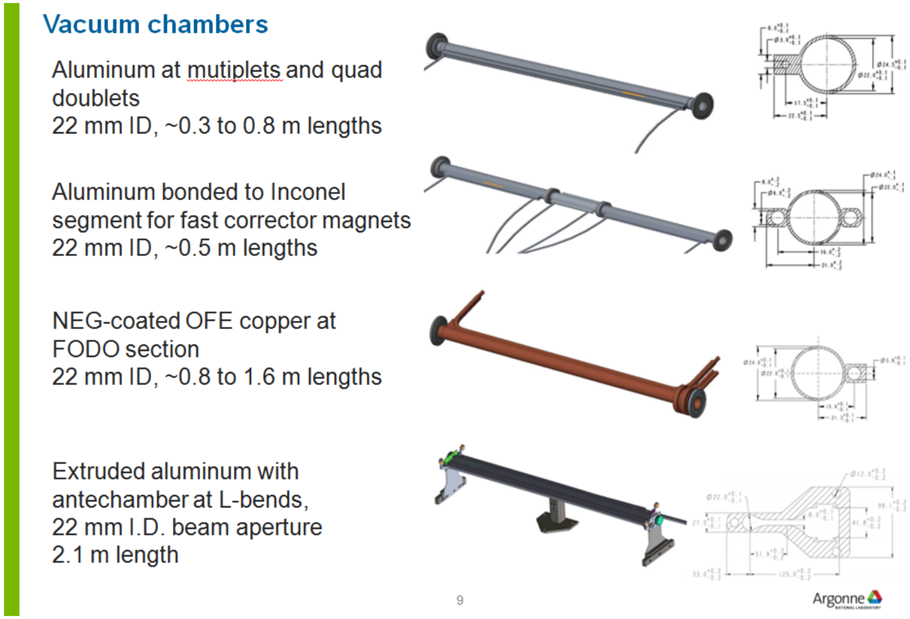


1. Pumping system

❖ Conventional pumping + NEG coated chamber

APS-U[7]

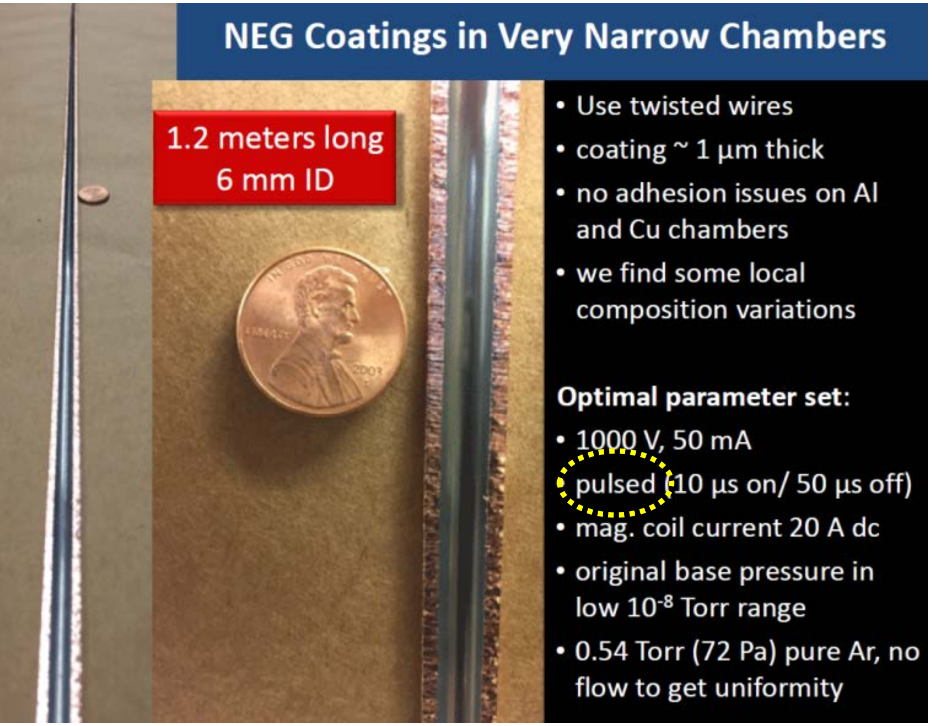




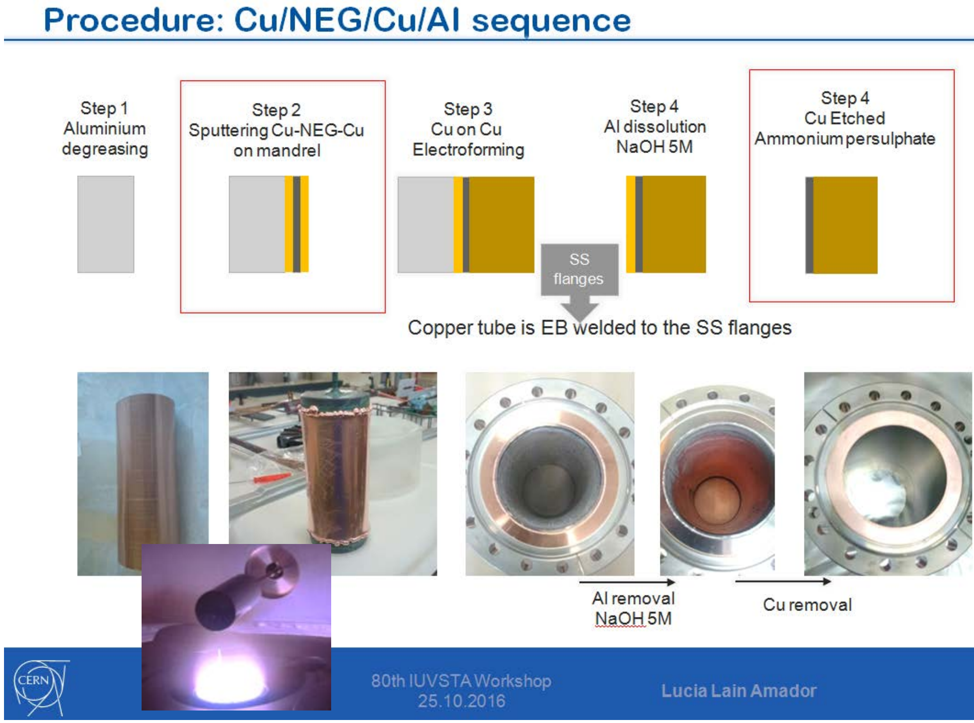
1. Pumping system

❖ NEG coated chamber (new technique)

ALS-U[8]



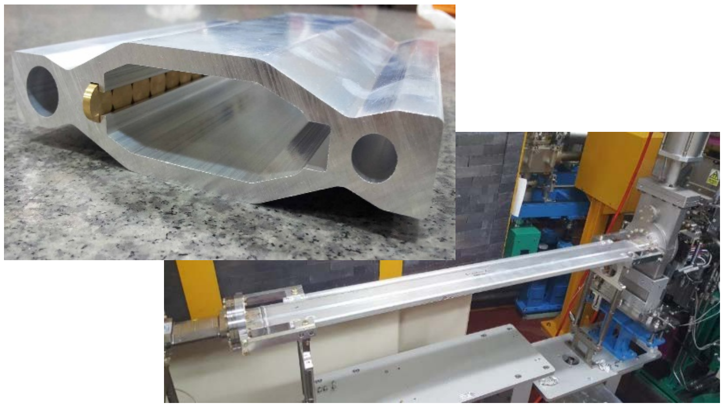
CERN[9]



1. Pumping system

❖ Pill type NEG (low-cost option)

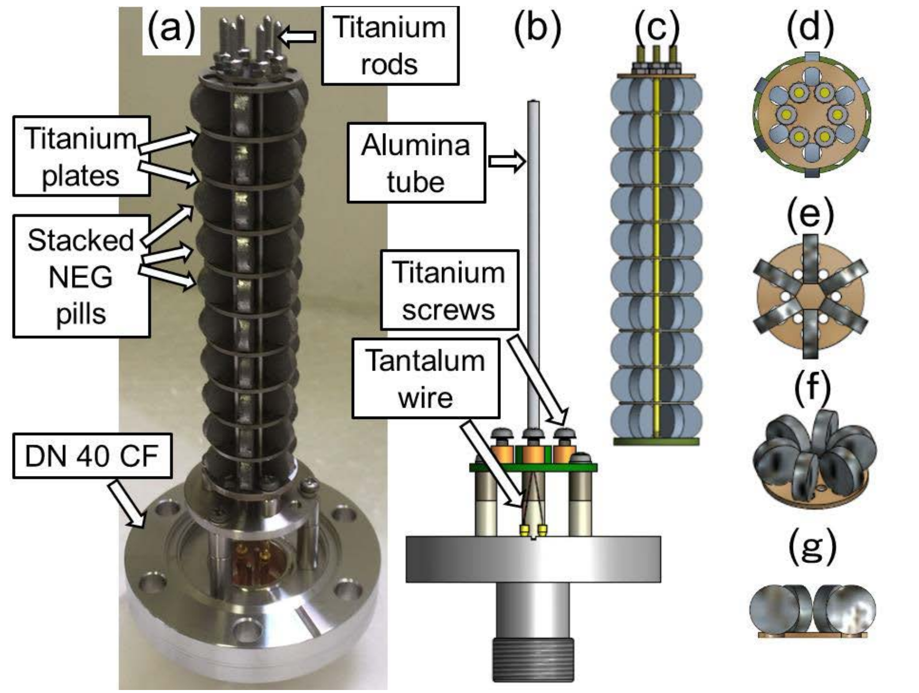
PLS-II[10]



Type	NEG Film (~ 1 μm)	Pill NEG
Activation	200℃, 1 d	180℃, 1 ~ 2 d
Pumping Speed / length	-	Low (< 1/5)
Sticking probability (α)	0.015 (200°C, 24 h)	0.003 ~ 0.0037 (180°C, 48 h)
α (after two additional venting)	0.015 → 0.008	Substantially constant
Capacity(H_2)	-	1000×
Disadvantages	Aging after venting	Particle

- Vacuum chamber with the pill NEG is being used since 2015
- Do not experience particular issue in a storage ring for a year

KEK[11]



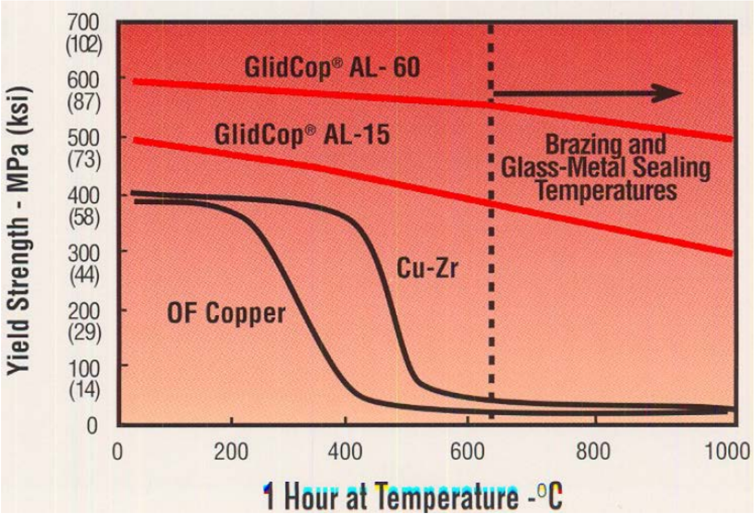
Gasses	H2	CO	CO2	N2
Pumping speed (L/s)	140–130	200–140	190–130	35–17

2. Photon absorber

❖ Materials for high-heat-load photon absorber

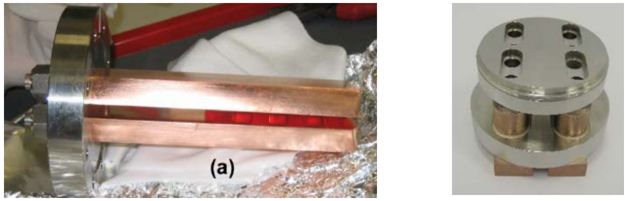
❑ **OFHC Copper**

- ✓ Commonly used for photon absorption (easily available)
- ✓ Excellent thermal conductivity
- ✓ Very low outgassing rate
- ✓ Need bi-metal joint with stainless steel flange (brazing, EBW, …)
- ✓ Softened after exposure to high temperature for brazing



❑ **Glidcop**

- ✓ Good thermal conductivity & high strength
- ✓ Resistance to thermal softening
- ✓ UHV compatible
- ✓ Widely used for high-heat-load vacuum components
- ✓ Difficult to optimize brazing condition
- ✓ Limited supplier (cost, delivery)



"Glidcop absorbers at ALBA" [12]

"Glidcop absorbers at NSLS-II"[2]

2. Photon absorber

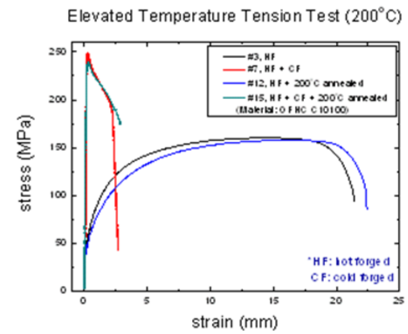
❖ Materials for high-heat-load photon absorber

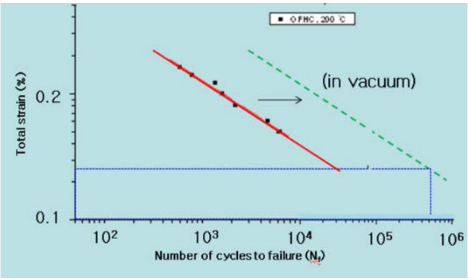
❑ **Cold forged OFHC Copper**

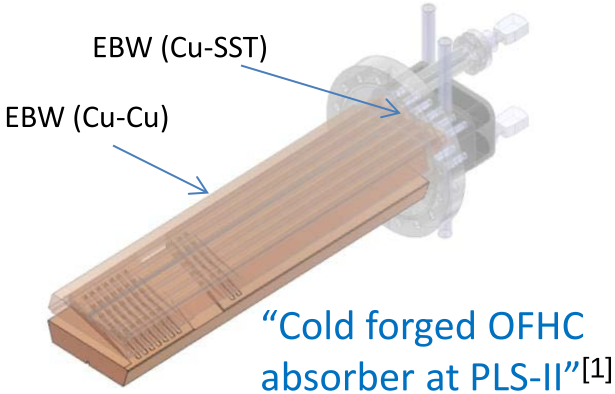
- ✓ Excellent thermal conductivity
- ✓ Easily available
- ✓ E-beam weld to prevent softening from brazing (shorter exposure to high temperature than brazing)

• Elevated temperature (200℃) tension test

Material process	YS(0.2%) / MPa	TS / MPa	EL / %
Hot forged (OFHC)	48.3	160.3	42.4
Hot + Cold forged	244.4	249.1	5.2
HF + 200℃ Annealed	48.9	157.7	43.9
HF + CF + 200℃ Annealed	**240.0**	**240.3**	**5.8**



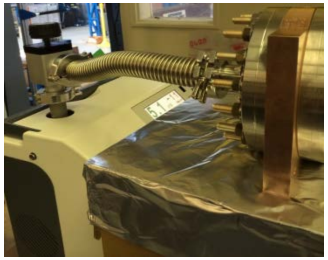




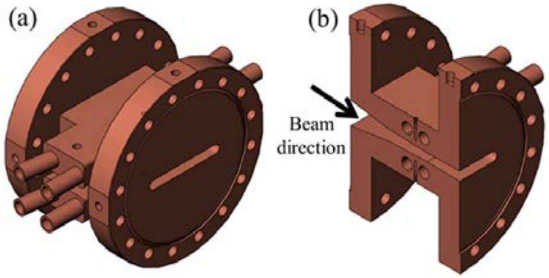
“Cold forged OFHC absorber at PLS-II”[1]

❑ **CuCrZr**

- ✓ Good thermal conductivity
- ✓ UHV compatible
- ✓ Conflat flange integrated to absorber
- ✓ Widely available



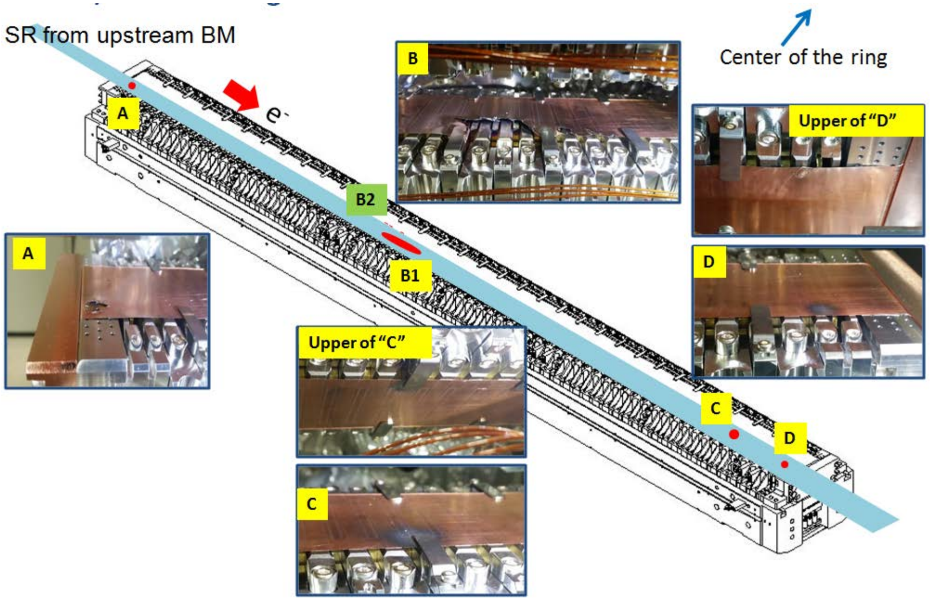
“CuCrZr flange at NSLS-II”[13]

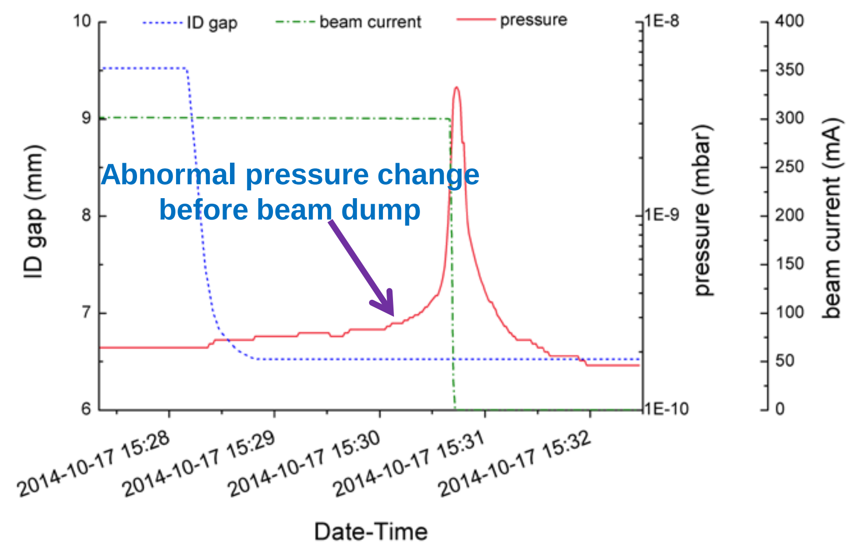


“CuCrZr absorber at TPS”[14]

3. Damage protection

3.1 Cu/Ni foil damage in IVUs at PLS-II





❖ **Possible causes of damage**

SR from bending magnet

- ✓ MPS malfunction
- ✓ Beam miss-steering
  - 28 mW/mm² → surface
  - 28 W/mm² → side clamp
- ✓ Local foil bump
- ✓ Gap btw foil & magnet

Poor thermal contact

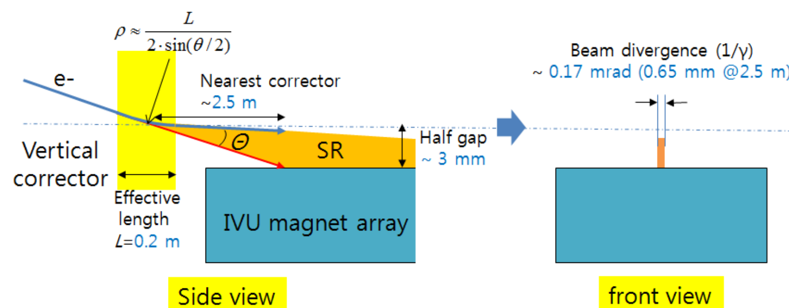
Avalanche meltdown

Image current + SR (BM)

SR from vertical corrector (?)

- ✓ Image current
  → 0.6 mW/mm²
- ✓ SR from vertical corrector
  → 2 mW/mm²

$$P\,[kW] = 88.463 \cdot \frac{E[GeV]^4}{\rho[m]} \cdot I[A]$$



If θ = 1.2 mrad (=3/2.5)

- ρ = 166.6 m, heat flux = **2 mW/mm²**, foot print = 0.65 mm wide
- Foot print is sharper than image current effect
- Heat flux is larger than image current effect
- But the power is too low to fuse the foil

3. Damage protection

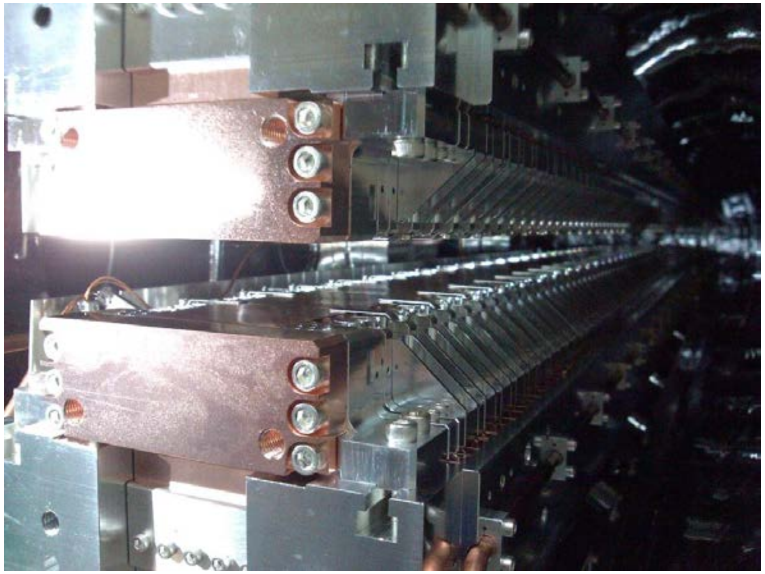
3.1 Cu/Ni foil damage in IVUs at PLS-II

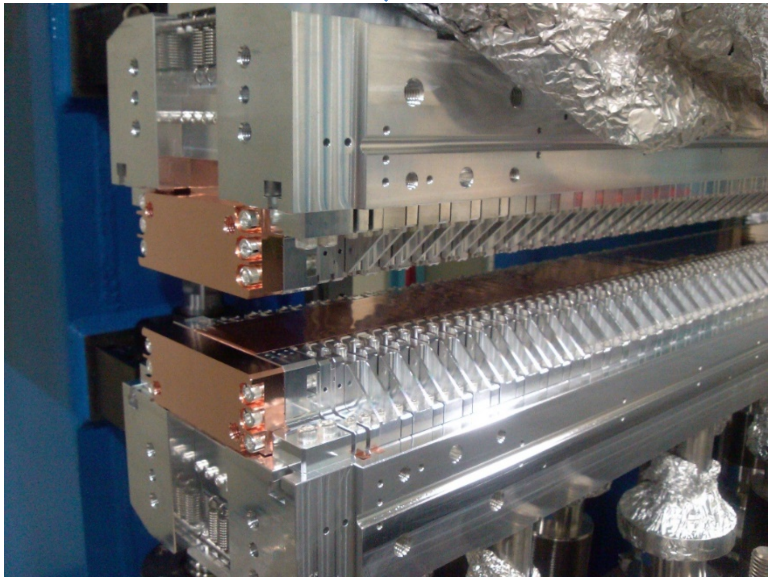
❖ **Improvements**

1. Hardware
   - Removed all side clamps
   - Increased the thickness of the Cu/Ni foil from 50/20 μm to 50/50 μm

2. Orbit control
   - Apply a fast beam orbit interlock
     - ✓ 200 ms (already implemented)
     - ✓ → 10 ms (goal)

3. Heat load reduction (to be done)
   - Bunch length ↑
     - ✓ RF gap voltage ↓ by Ext. Q adjustment
     - ✓ 3rd harmonic cavity
   - Bunch current ↓: 400 → 430 bunch (10% ↓)



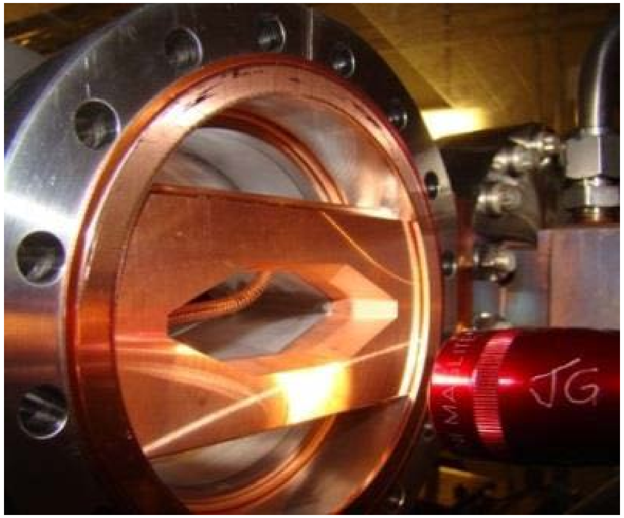


3. Damage protection

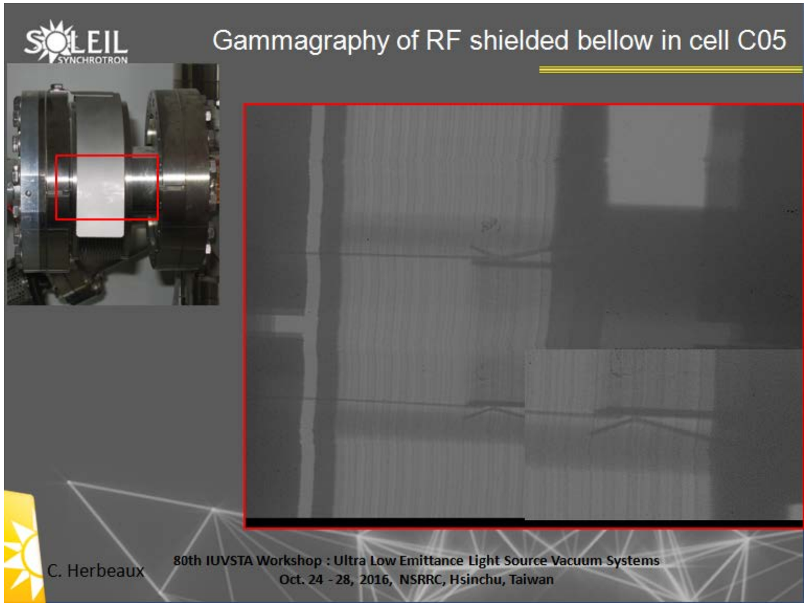
3.2 RF-shielding failures

PLS-II

PEP-II



NSLS-II[2]

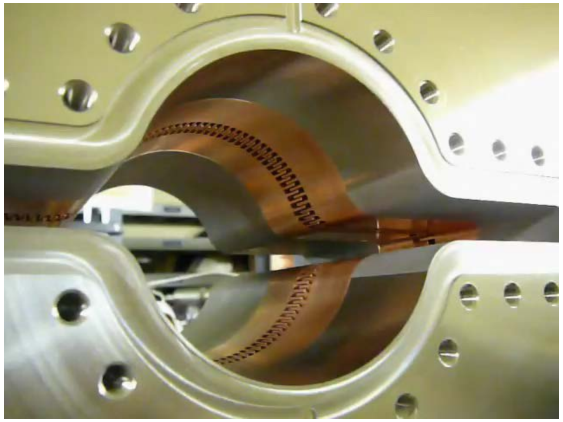


SOLEIL[5]

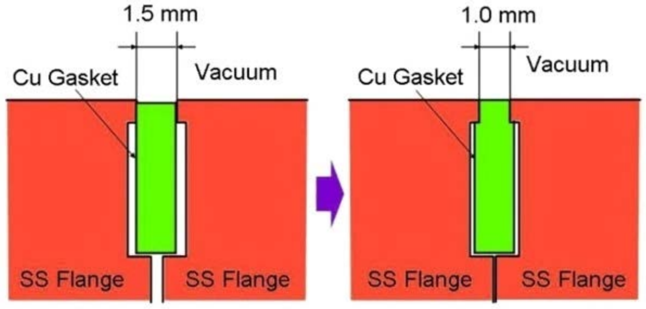
3. Damage protection

3.2 Designs for robust RF-shielding

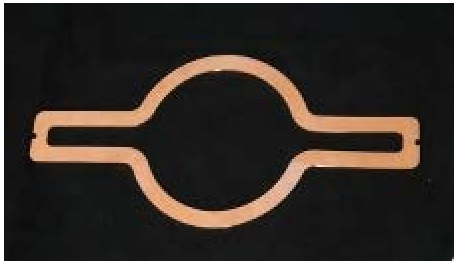
SuperKEK[15]



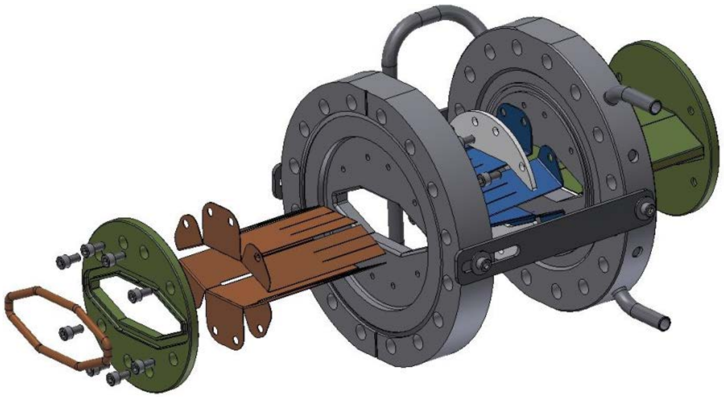
Comb type
RF-shielding



Mo-type flange

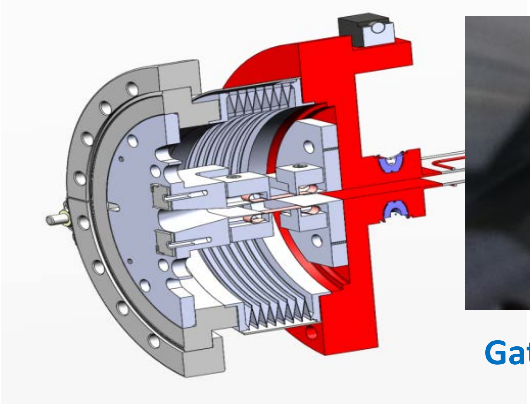


NSLS-II[2]

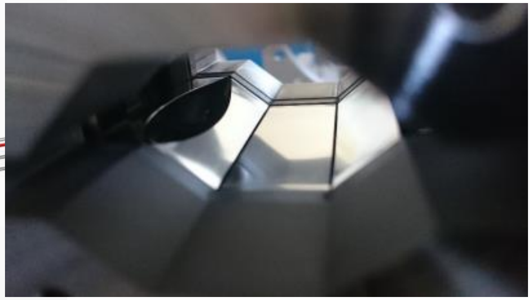


Wide thick fingers

ESRF EBS[3]



Sliding fingers



Gate valve with wide fingers

3. Damage protection

3.3 Analyze of failures

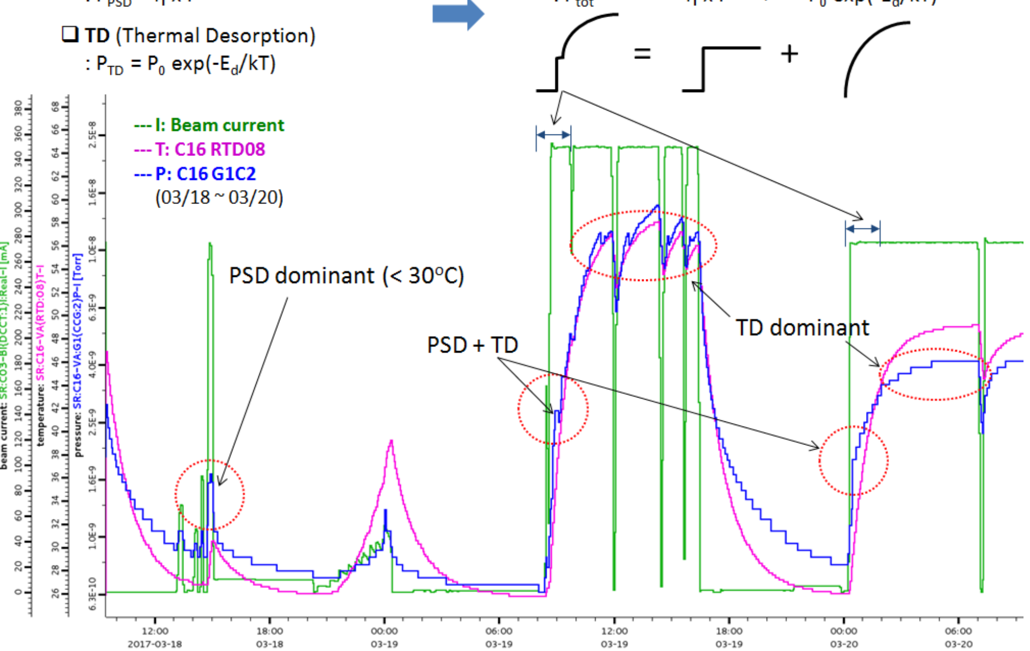
❖ Vacuum chamber heating in NSLS-II

❑ Transition behavior of pressure

❑ **PSD** (Photon Stimulated Desorption)
: $P_{PSD} = \eta \times I$

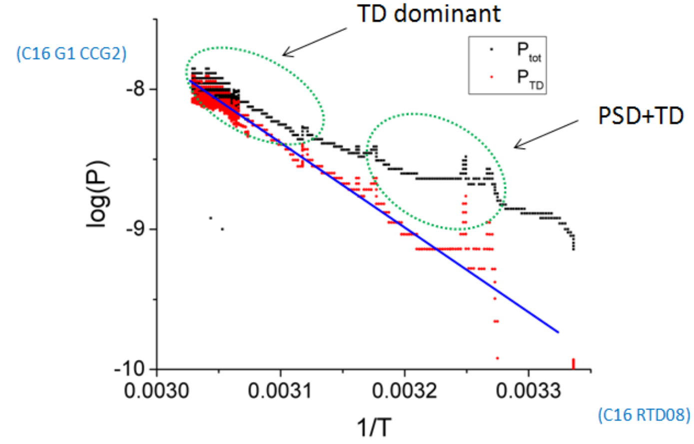
❑ **TD** (Thermal Desorption)
: $P_{TD} = P_0 \exp(-E_d/kT)$

❖ **Transient pressure after beam storage**
: $P_{tot} = \eta \times I + P_0 \exp(-E_d/kT)$



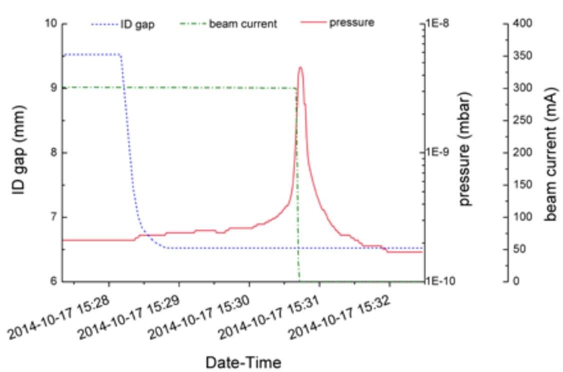
❑ $P_{TD} = P_{tot} - P_{PSD}$
$= P_0 \exp(-E_d/kT)$

➡ $\ln(P_{TD}) = A + B(E_d) * 1/T$



❖ The linear relation between P_{TD} (C16G1C2) and 1/T (C16RTD08) means that the pressure evolution of C16G1C2 is strongly related to the thermal desorption around C16RTD08.

[cf. foil damage in PLS-II]

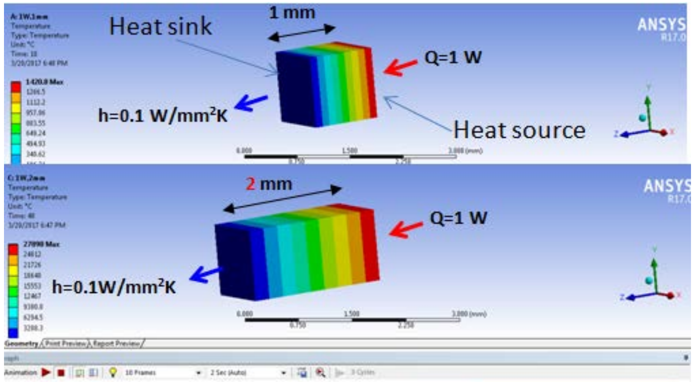


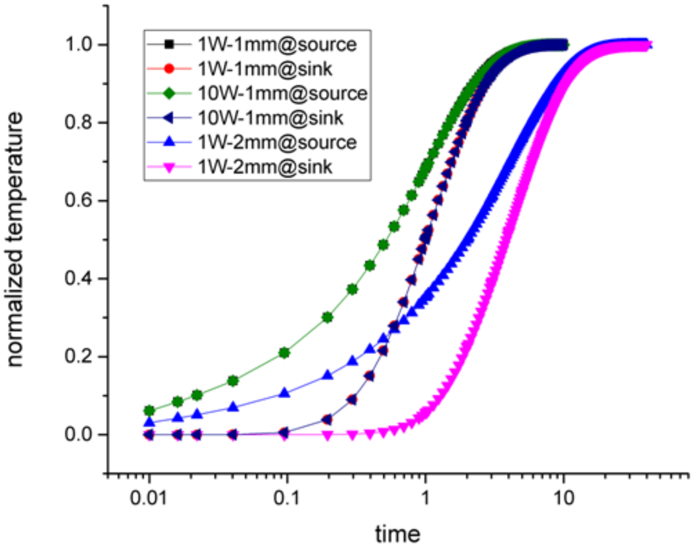
3. Damage protection

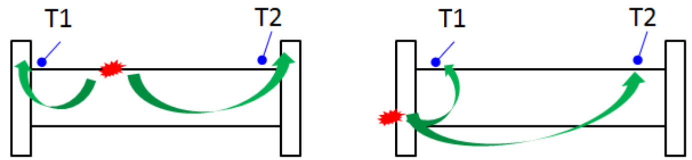
3.3 Analyze of failures

❖ Vacuum chamber heating in NSLS-II

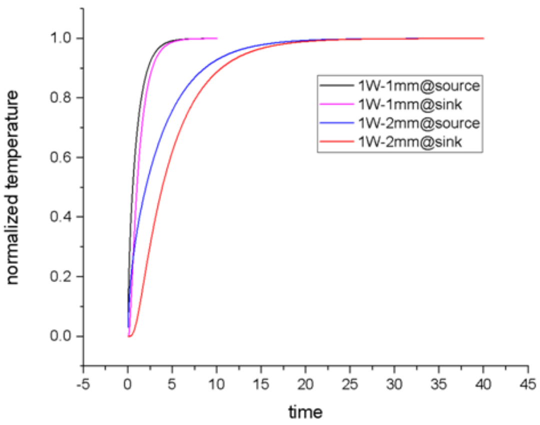
❑ **Transition behavior of temperature**

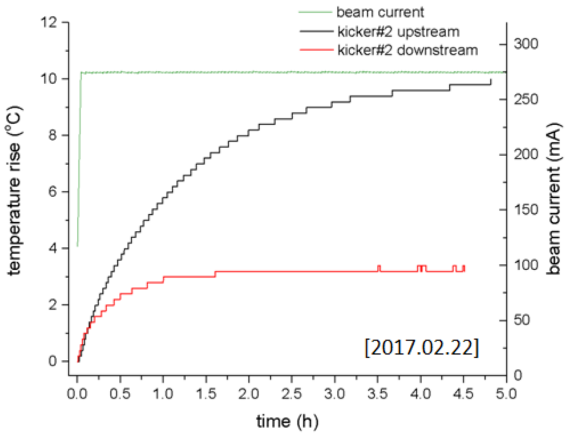






Different transient behavior between T1 & T2? → Case study is needed





❖In principle, it is possible to find heat source with transient data of temperature at several points.

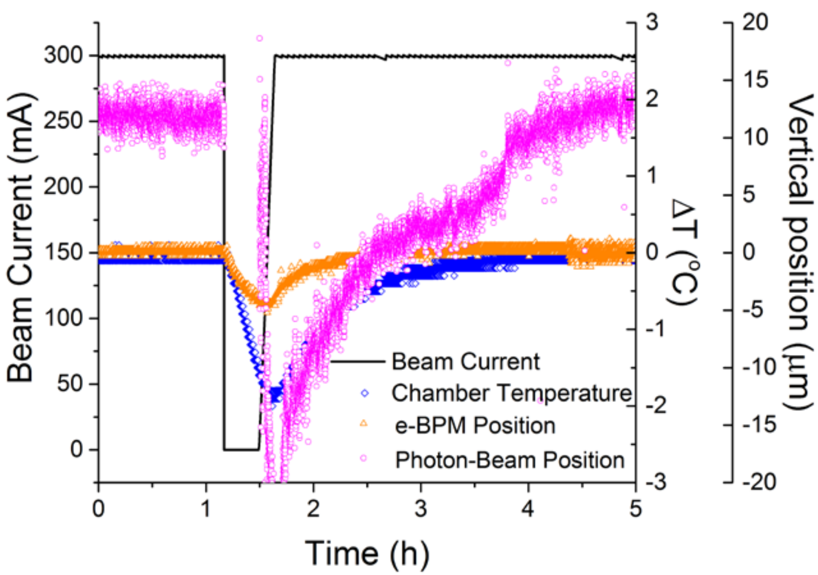
4. BPM support

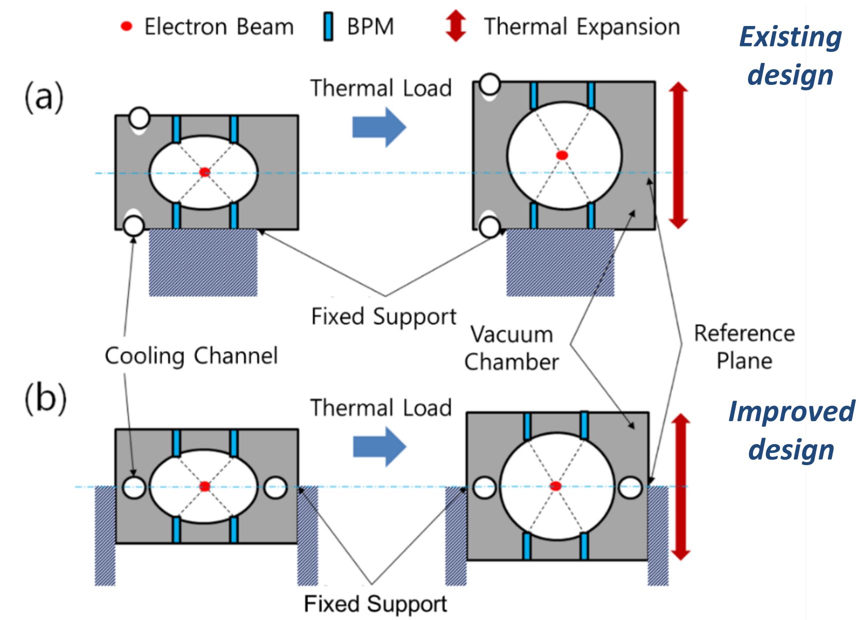
4.1 Improvement in BPM position stability in PLS-II

- Effect of BPM displacement to photon beam stability
  - ✓ Orbit feedback system intends that the electron beam pass through the center of the BPMs
  - ✓ Position of BPM could be changed by ground motion, thermal load change, etc., then the electron beam orbit can be changed

Beam dump → Δtemperature → Δe-BPM position → Δphoton beam position

- New design of BPM chamber & support
  - ✓ Balance in thermal expansion
  - ✓ Enhanced cooling

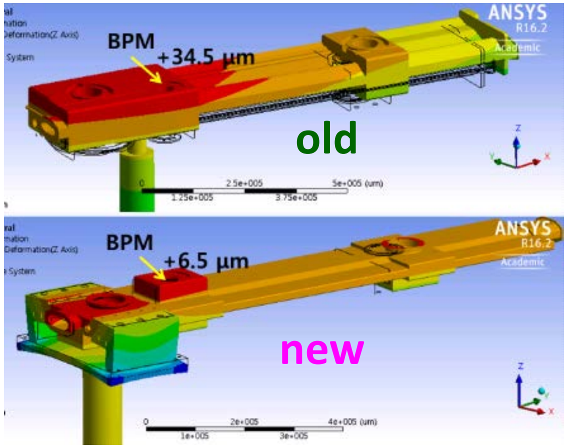




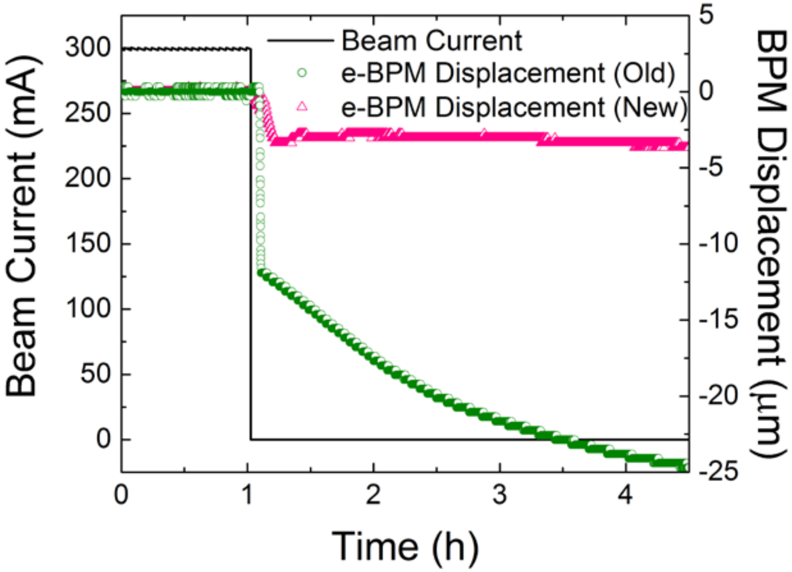
4. BPM support

4.1 Improvement in BPM position stability in PLS-II

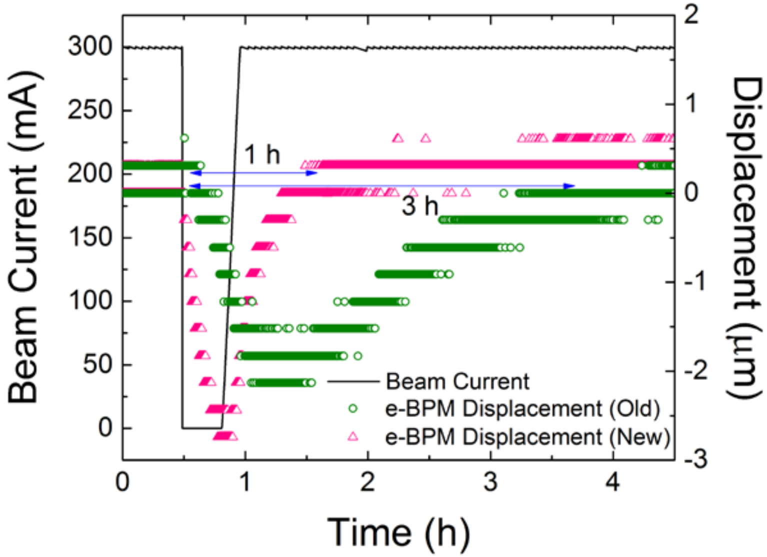
- Improvement of new BPM chamber & support
  - (a) Reduction of BPM displacement
    - 25 um → 5 um.
  - (b) Fast recovery after beam abort & restoration
    - 3 h → 1 h



(a)

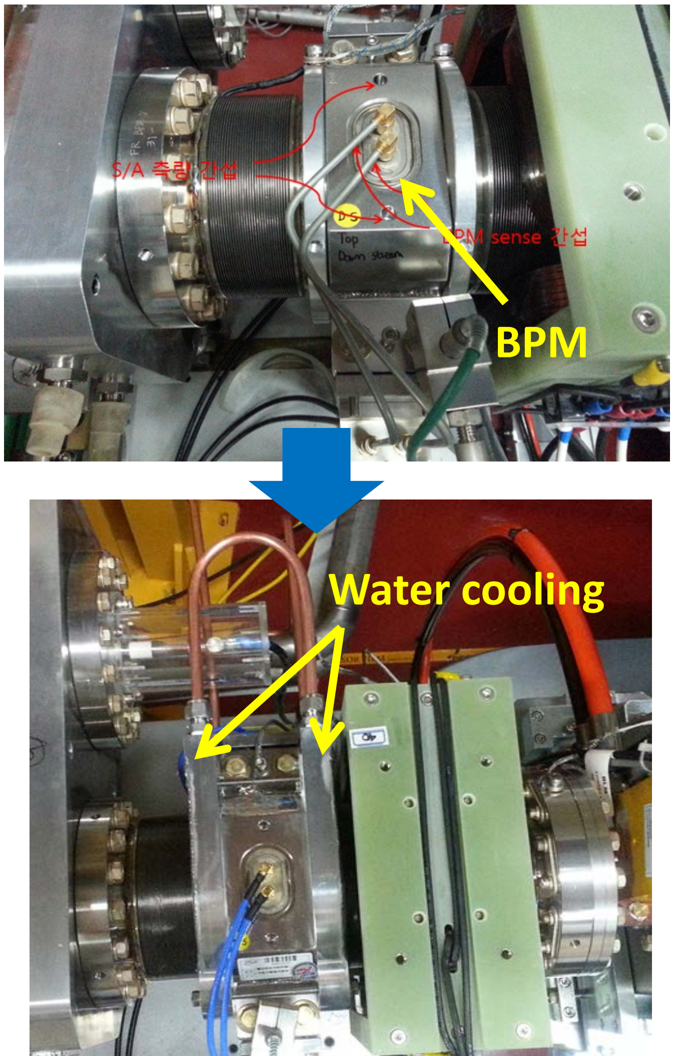


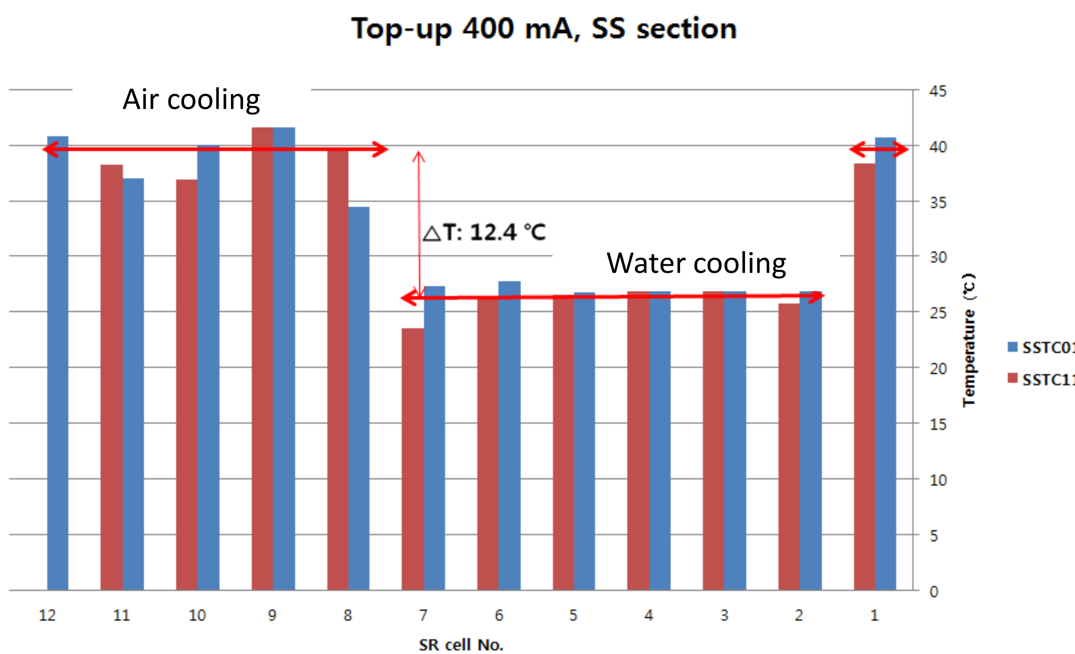
(b)



4.2 Improvement in BPM position stability in PLS-II

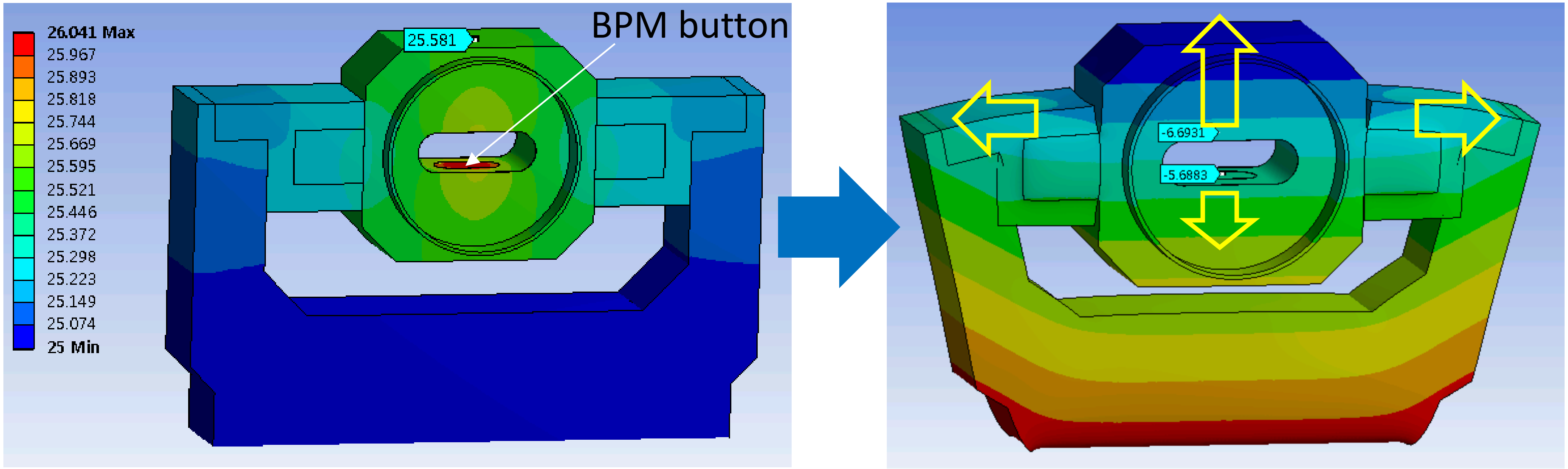
❖ Water cooling jacket for BPM chambers





4.2 Improvement in BPM position stability in PLS-II

- Need more careful design of support to keep the center of the BPMs still

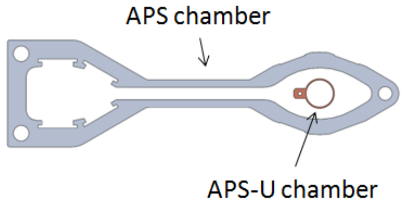


Center of the BPMs moves vertically

Summary

- Pumping system
  - ✓ Conventional pumping
    - Antechamber, NEG strip, NEG cartridge, SIP, TSP, …
  - ✓ NEG coated chamber
  - ✓ Combination of conventional pumping and NEG coated chamber
- High heat load photon absorber
  - ✓ More options in material choice rather than Glidcop
    - Cold forged OFHC copper with EBW or LW
    - CuCrZr absorber integrated with flange (no bi-metal joint)
- Damage protection
  - ✓ Need fast orbit interlock (< 10 um) to prevent damage in IVU
  - ✓ Various shielding mechanisms are studied
- Need high mechanical stability (< 1 um)
  - ✓ Water cooling is very effective
  - ✓ Need careful design of BPM support

I would like to close my talk by introducing a great description by **Ben Stillwell** in vacuum group of APS-U



We need a

Ferrarabu!

High performance modifications to an otherwise conservative design.

Thank you!