

Vacuum Systems for Storage Rings with High Current

2017.04.27

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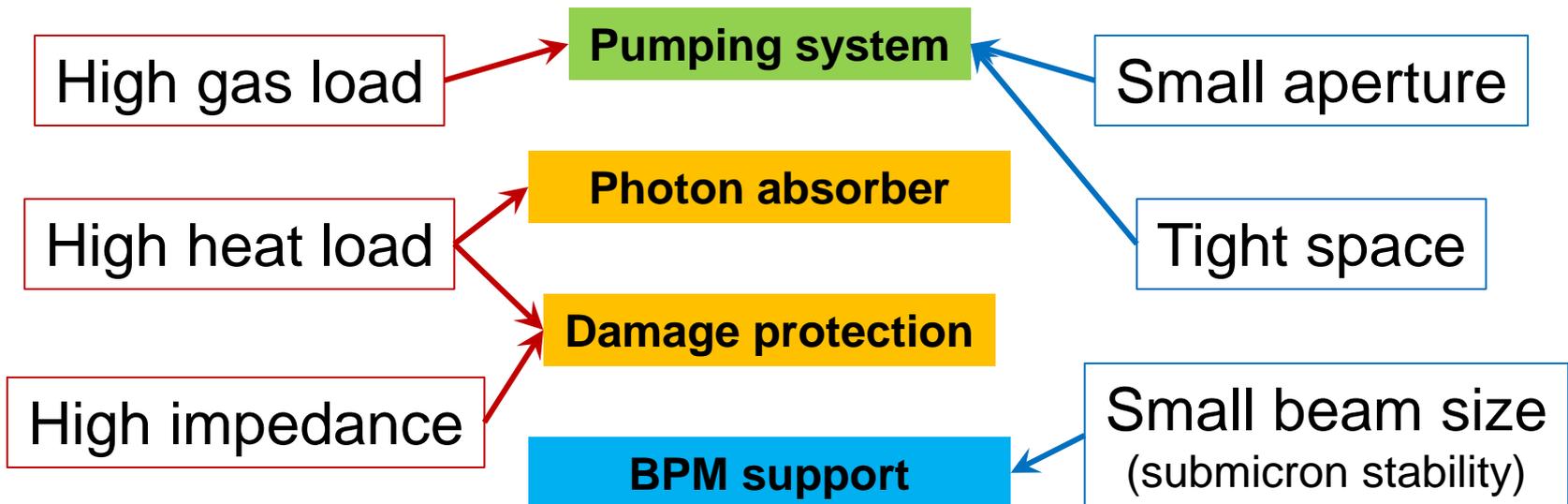
Pohang Accelerator Laboratory

- [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”



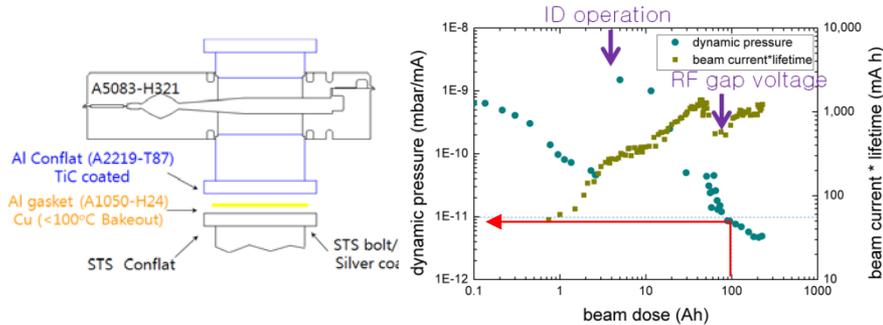
Vacuum system should accommodate:



1. Pumping system

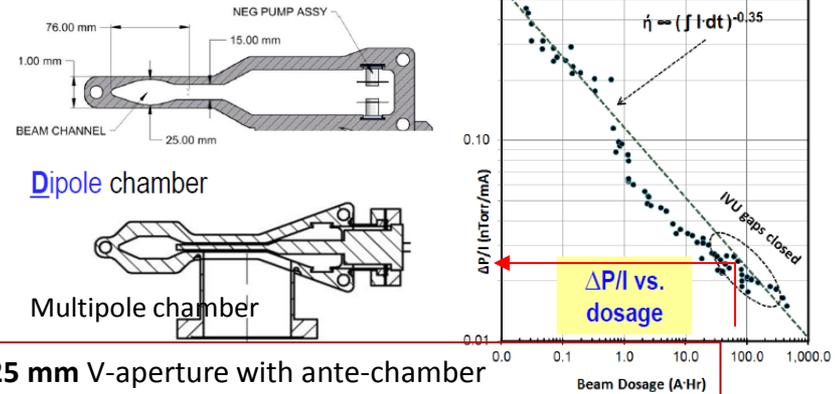
❖ Conventional pumping with ante-chamber

PLS-II[1]



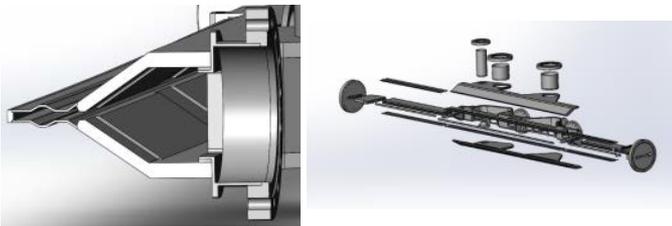
- ✓ 22 mm V-aperture with ante-chamber
- ✓ Machined & welded Al chamber (or SST chamber)
- ✓ NEG strip/cartridge + SIP

NLS-II[2]



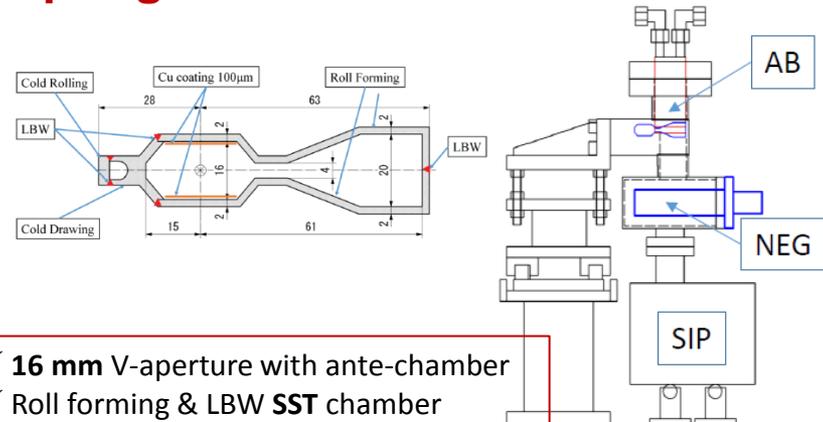
- ✓ 25 mm V-aperture with ante-chamber
- ✓ Extruded & bent Al chamber (or SST chamber)
- ✓ NEG strip/cartridge + SIP + TSP + NEG coated chamber

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 µm copper coated on inner surface
- ✓ NEG cartridge + SIP

1. Pumping system

❖ NEG coated chamber

SOLEIL^[5]

✓ 56% of the ring is NEG coated

SOLEIL Thickness distribution of NEG coating: 0.5 to 1,5µm

Where image current is maximum
→ thickness of NEG is the lower to reduce the « resistive wall effect » impedance
→ Resistivity similar to stainless steel

The roughness depends on the one of the substrate:
Ra=0,3 µm RMS

Where the primary photon density is maximum
→ Thickness is the larger

Compromise between low roughness and pumping speed

C. Herbeaux 80th IUVSTA Workshop : Ultra Low Emittance Light Source Vacuum Systems Oct. 24 - 28, 2016, NSRRG, Hsinchu, Taiwan

SOLEIL NEG activation with a stored e⁻ beam

Start heating Activation starts 100% activation Cooling down

Beam loss monitor signal

Decision has been taken to re-activate the NEG with a small current beam during a shift for users (10 mA)

Before reactivation of the NEG : high signal on the beam loss monitor indicating the presence of a pressure bump in the straight section

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SOLEIL Number of activations

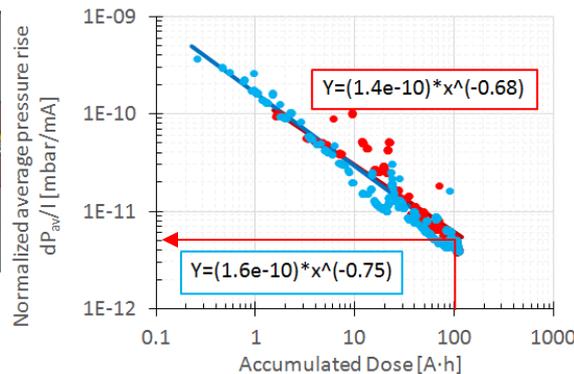
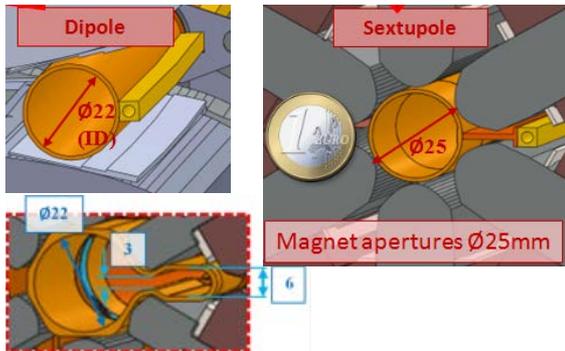
After 10 years of operation :

- The maximum of venting and reactivation of NEG coating : 6 times including the first test in lab
- Quantities of reactivation after partial saturation : 10 (due periodical warm-up of a cryogenic in-vacuum undulator closed to a NEG coated vacuum chamber)
- 7 sections of the ring with NEG coated vacuum chamber have never been reactivated since the first installation : no difference with an equivalent section which have been reactivated several times (not better, not worst)

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MAX-IV^[6]

✓ 100% of the ring is NEG coated



Coating non-conformities

All the chambers were inspected at site before installation.

Observed peeling-off:
At RF fingers Cu-Be insert and Cu end piece, RF fingers and Cu end were not shielded properly during coating.
Solution: new pieces ordered and replaced (without coating).



Peeling-off at the edge of stainless VC. Chamber not approved for installation.



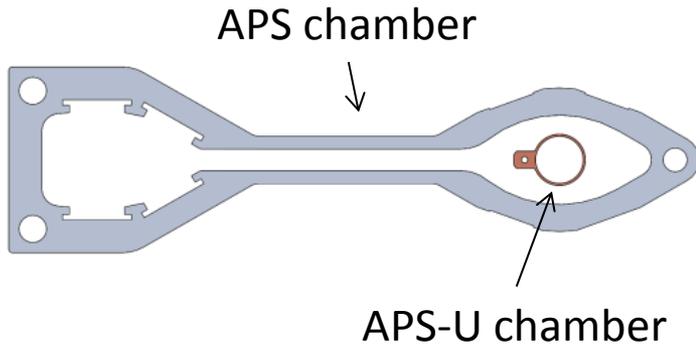
Uncoated areas:
Few cm² uncoated, in complex chambers.



1. Pumping system

❖ Conventional pumping + NEG coated chamber

APS-U^[7]



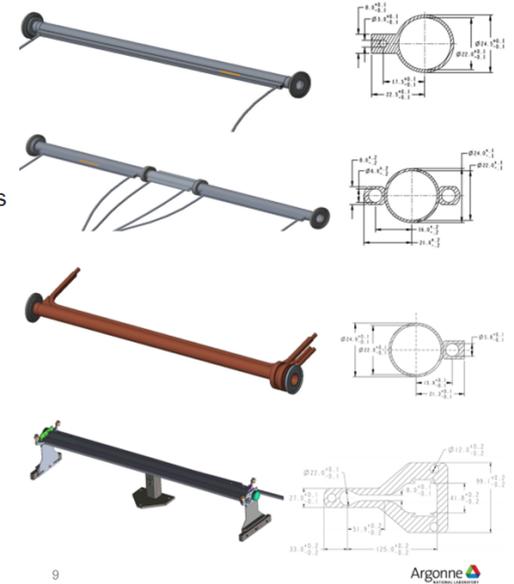
Vacuum chambers

Aluminum at mutiplets and quad doublets
22 mm ID, ~0.3 to 0.8 m lengths

Aluminum bonded to Inconel segment for fast corrector magnets
22 mm ID, ~0.5 m lengths

NEG-coated OFE copper at FODO section
22 mm ID, ~0.8 to 1.6 m lengths

Extruded aluminum with antechamber at L-bends,
22 mm I.D. beam aperture
2.1 m length



1. Pumping system

❖ NEG coated chamber (new technique)

ALS-U^[8]

NEG Coatings in Very Narrow Chambers

1.2 meters long
6 mm ID

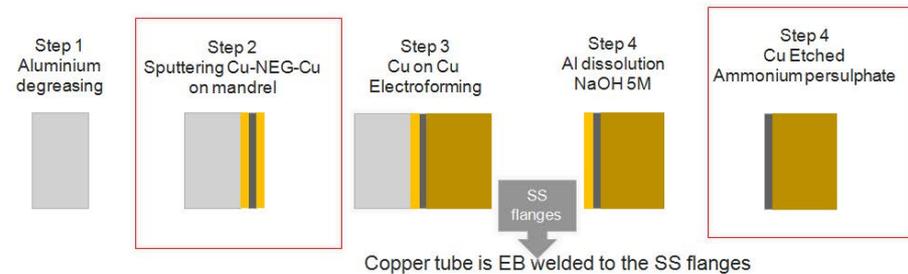
- Use twisted wires
- coating ~ 1 μm thick
- no adhesion issues on Al and Cu chambers
- we find some local composition variations

Optimal parameter set:

- 1000 V, 50 mA
- pulsed (10 μs on/ 50 μs off)
- mag. coil current 20 A dc
- original base pressure in low 10⁻⁸ Torr range
- 0.54 Torr (72 Pa) pure Ar, no flow to get uniformity

CERN^[9]

Procedure: Cu/NEG/Cu/Al sequence



1. Pumping system

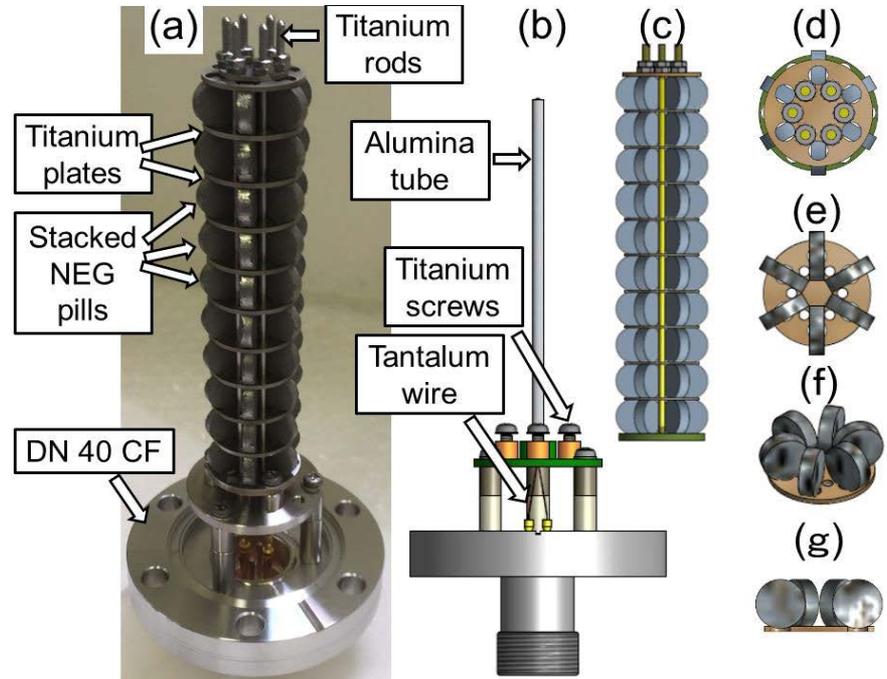
❖ Pill type NEG (low-cost option)

PLS-II^[10]



Type	NEG Film (~ 1 μm)	Pill NEG
Activation	200°C, 1 d	180°C, 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

KEK^[11]



Gasses	H ₂	CO	CO ₂	N ₂
Pumping speed (L/s)	140-130	200-140	190-130	35-17

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

2. Photon absorber

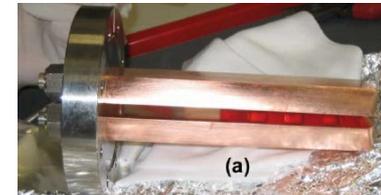
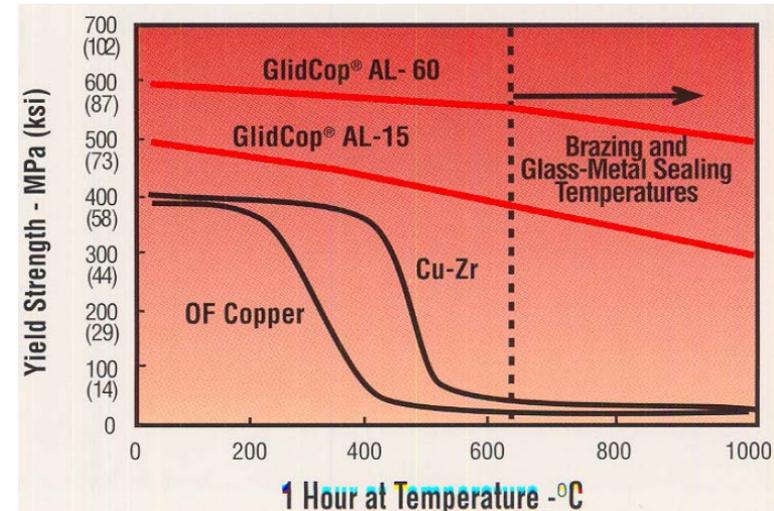
❖ Materials for high-heat-load photon absorber

❑ OFHC Copper

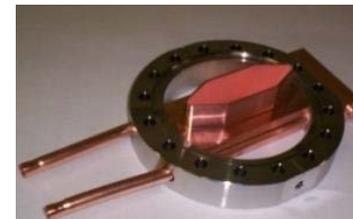
- ✓ Commonly used for photon absorption (easily available)
- ✓ Excellent thermal conductivity
- ✓ Very low outgassing rate
- ✓ Need bi-metal joint with stainless steel flange (brazing, EBW, ...)
- ✓ Softened after exposure to high temperature for brazing

❑ 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

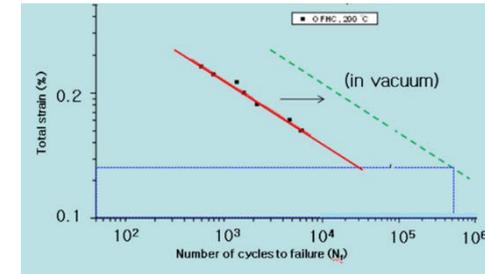
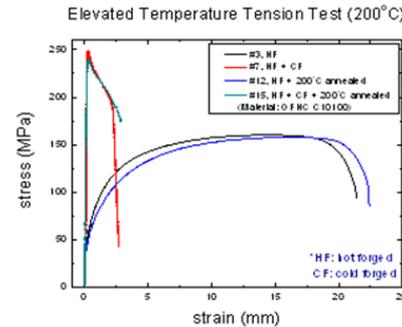
❖ Materials for high-heat-load photon absorber

❑ Cold forged OFHC Copper

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

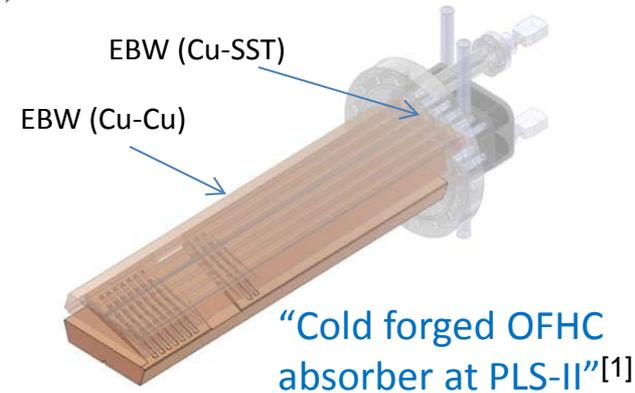
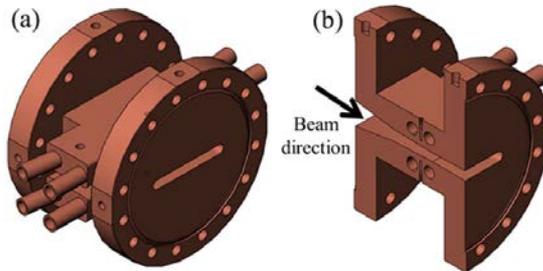
• Elevated temperature (200°C) tension test

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°C Annealed	48.9	157.7	43.9
HF + CF + 200°C Annealed	240.0	240.3	5.8



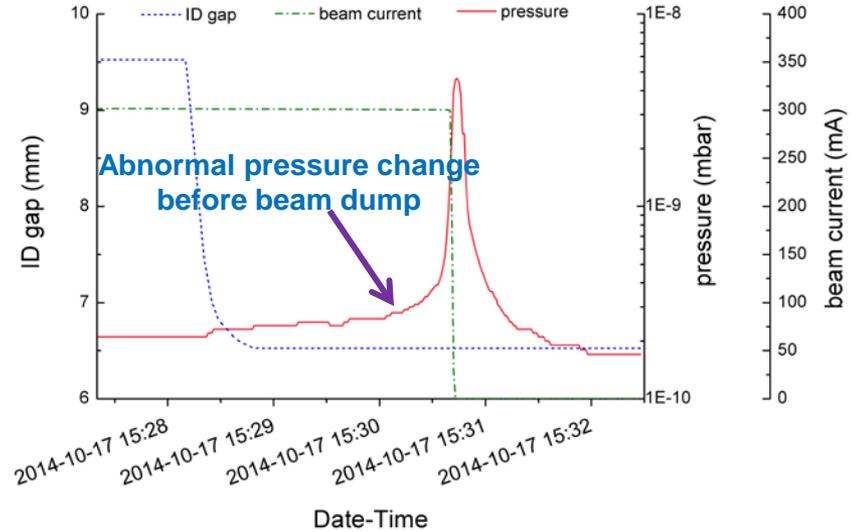
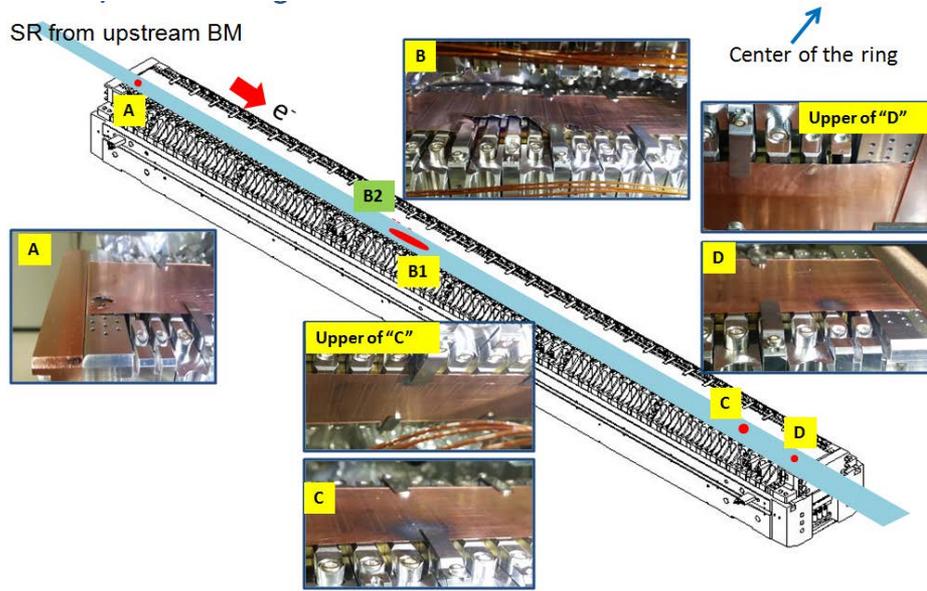
❑ CuCrZr

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



3. Damage protection

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



❖ Possible causes of damage

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

SR from bending magnet

Poor thermal contact

Avalanche meltdown

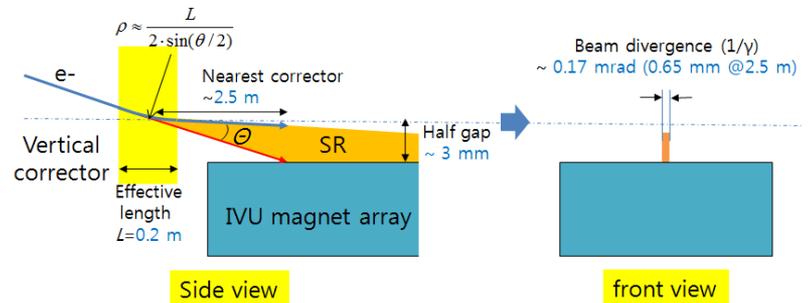
Image current + SR (BM)

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 $\theta = 1.2$ mrad ($=3/2.5$)

- $\rho = 166.6$ 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

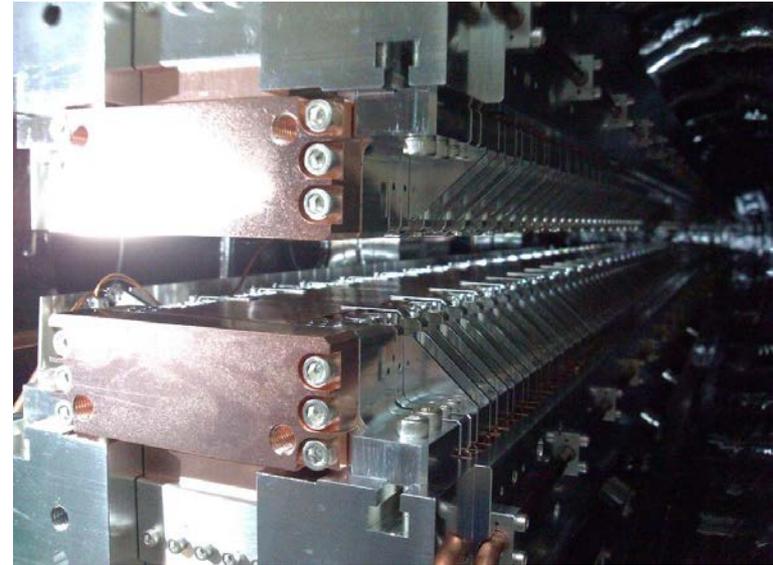
- Removed all side clamps
- Increased the thickness of the Cu/Ni foil from 50/20 μm to 50/50 μm

2. Orbit control

- Apply a fast beam orbit interlock
 - ✓ 200 ms (already implemented)
 - ✓ \rightarrow 10 ms (goal)

3. Heat load reduction (to be done)

- Bunch length \uparrow
 - ✓ RF gap voltage \downarrow by Ext. Q adjustment
 - ✓ 3rd harmonic cavity
- Bunch current \downarrow : 400 \rightarrow 430 bunch (10% \downarrow)



3. Damage protection

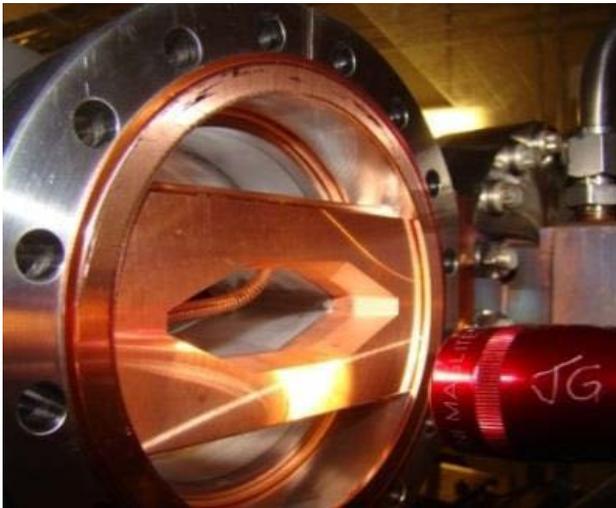
3.2 RF-shielding failures



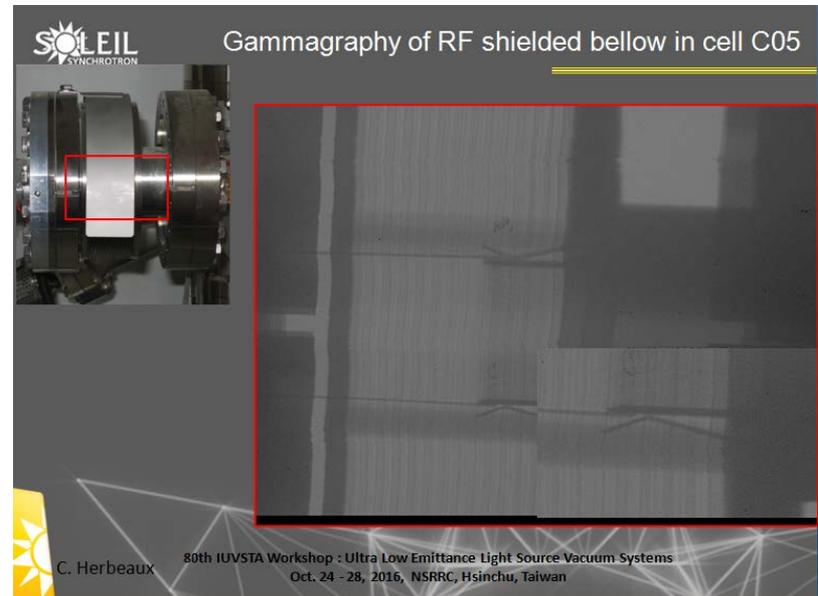
PLS-II



PEP-II



NSLS-II[2]

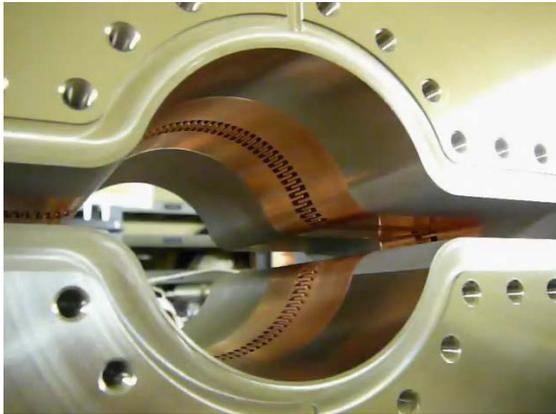


SOLEIL[5]

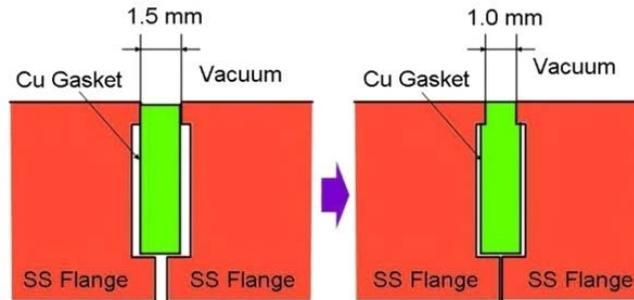
3. Damage protection

3.2 Designs for robust RF-shielding

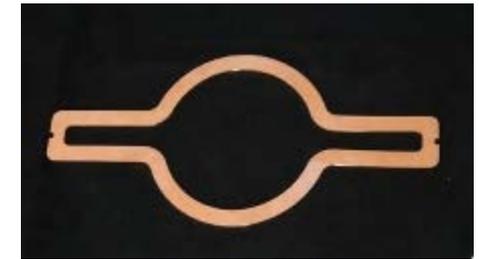
SuperKEK^[15]



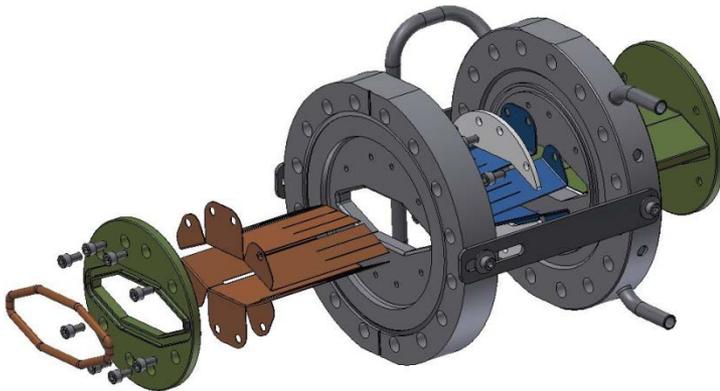
Comb type
RF-shielding



Mo-type flange

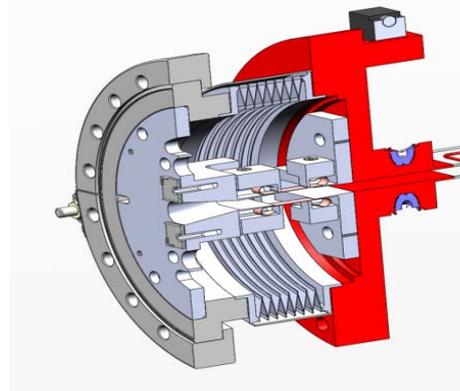


NSLS-II^[2]

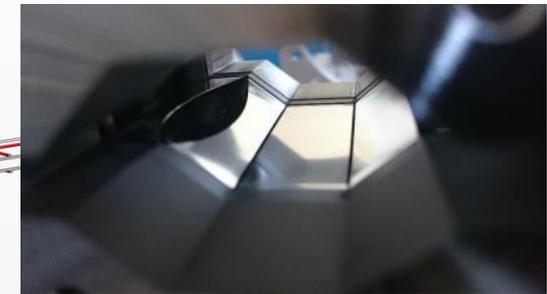


Wide thick fingers

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)

$$: P_{\text{PSD}} = \eta \times I$$

☐ TD (Thermal Desorption)

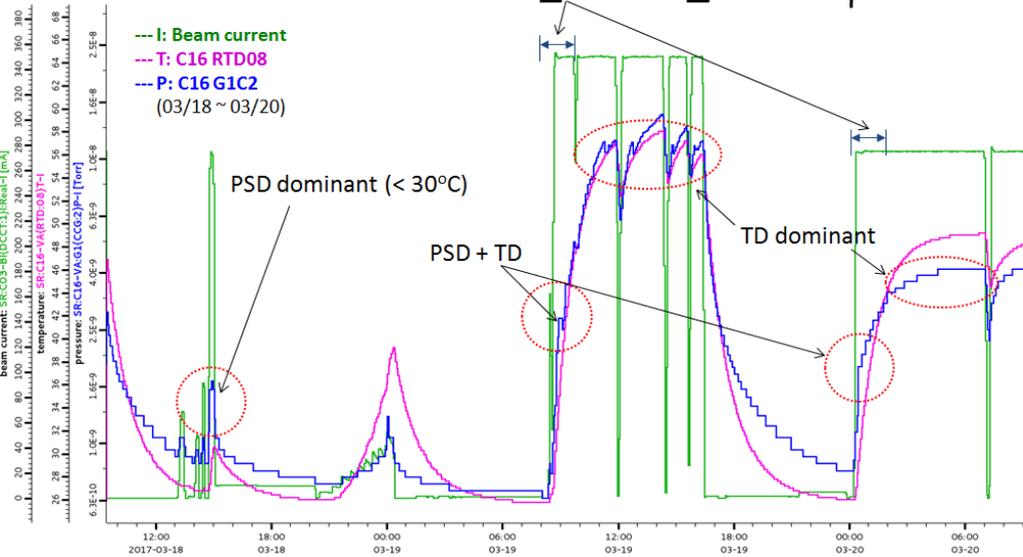
$$: P_{\text{TD}} = P_0 \exp(-E_d/kT)$$

❖ Transient pressure after beam storage

$$: P_{\text{tot}} = \eta \times I + P_0 \exp(-E_d/kT)$$



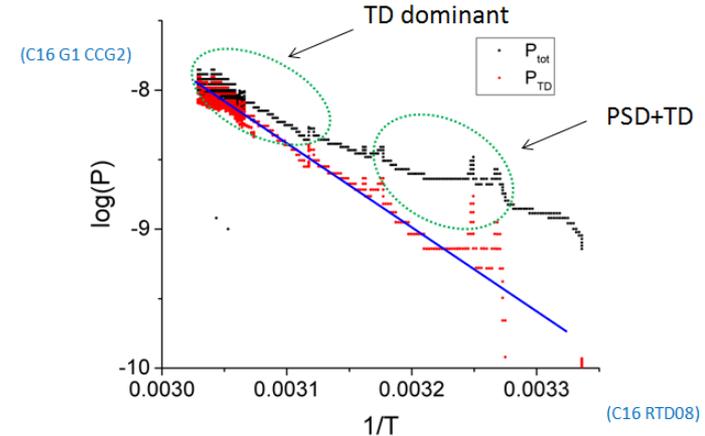
$$= \text{[Step Function]} + \text{[Exponential Decay Curve]}$$



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

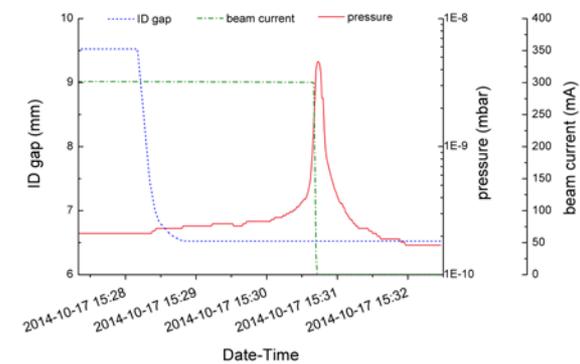


$$\ln(P_{\text{TD}}) = A + B(E_d) * 1/T$$



❖ 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]

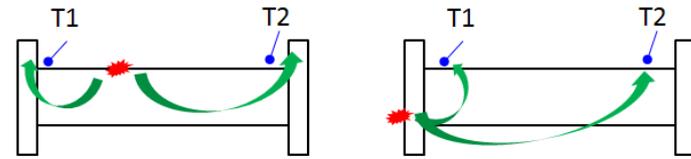
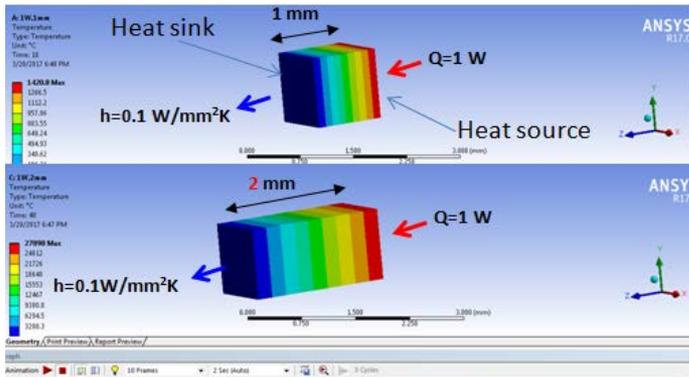


3. Damage protection

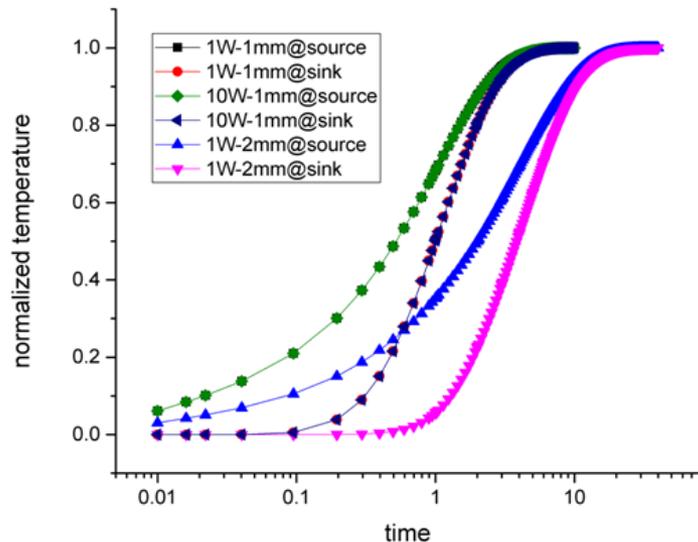
3.3 Analyze of failures

❖ Vacuum chamber heating in NSLS-II

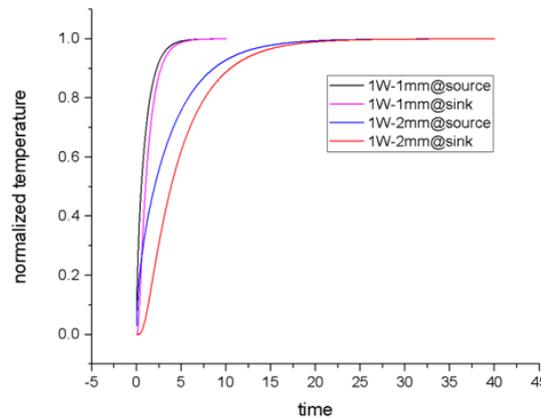
Transition behavior of temperature



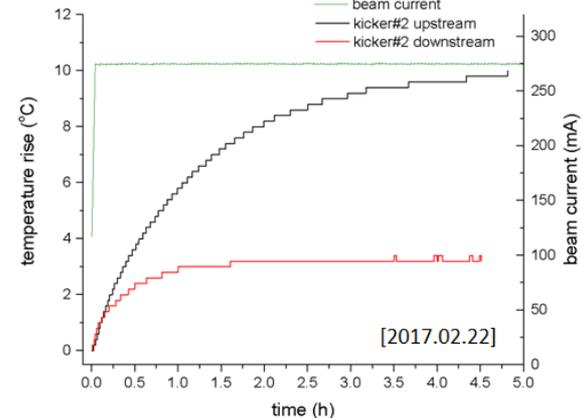
Different transient behavior between T1 & T2? → Case study is needed



Simulation



measurement



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

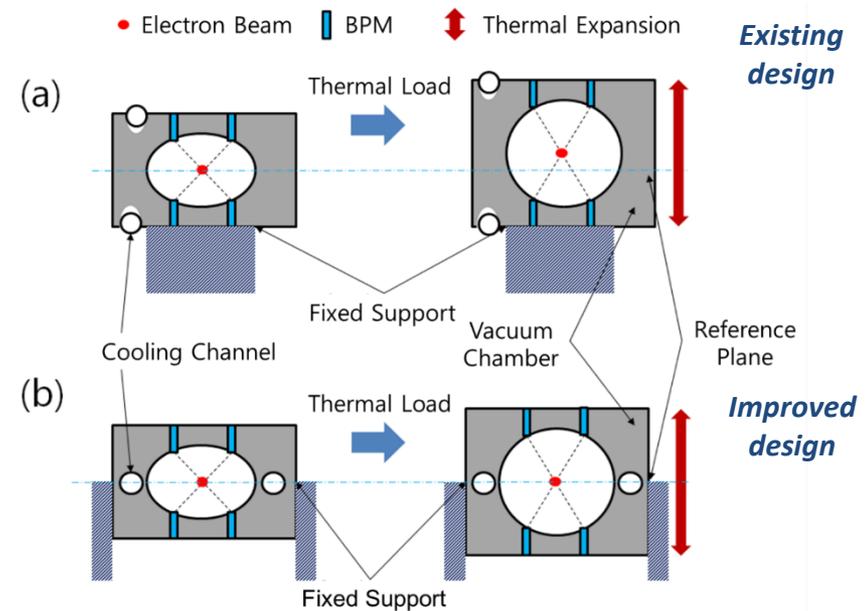
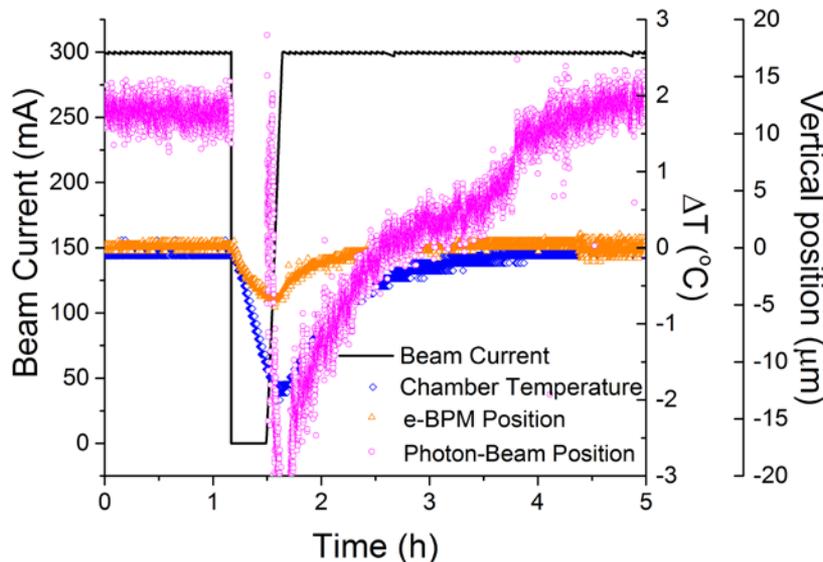
4. BPM support

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 \rightarrow Δ temperature \rightarrow Δ e-BPM position \rightarrow Δ photon beam position

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

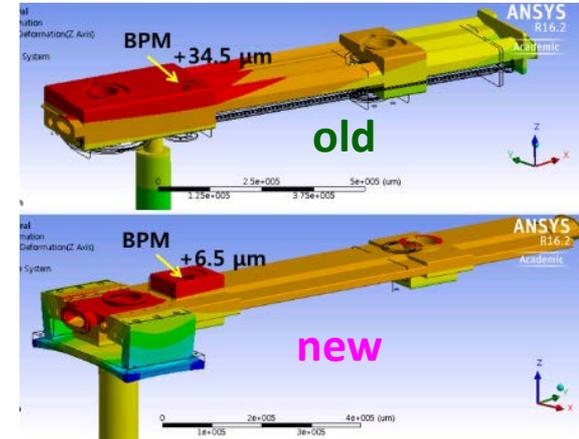


4. BPM support

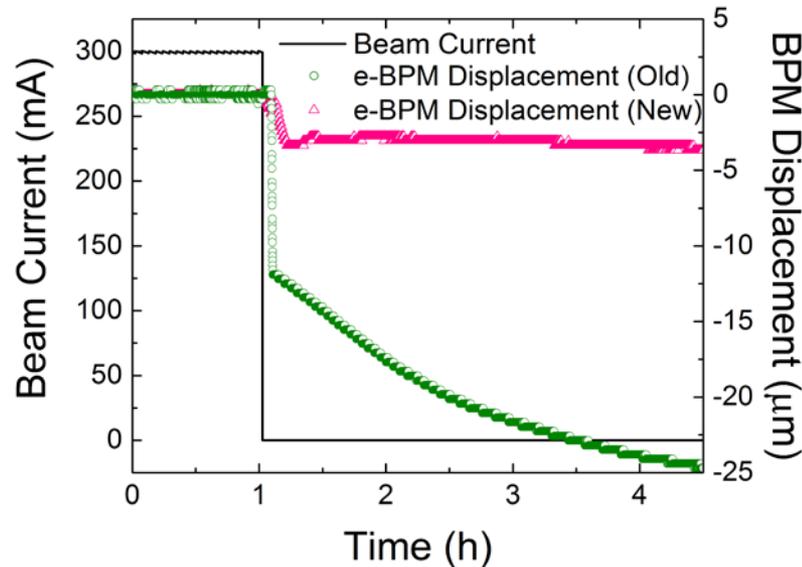
4.1 Improvement in BPM position stability in PLS-II

❖ Improvement of new BPM chamber & support

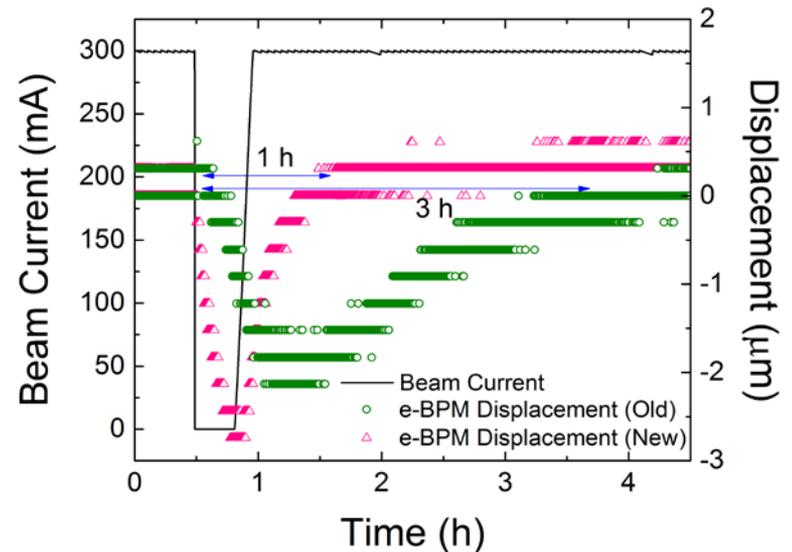
- (a) Reduction of BPM displacement
 - 25 μm \rightarrow 5 μm .
- (b) Fast recovery after beam abort & restoration
 - 3 h \rightarrow 1 h



(a)



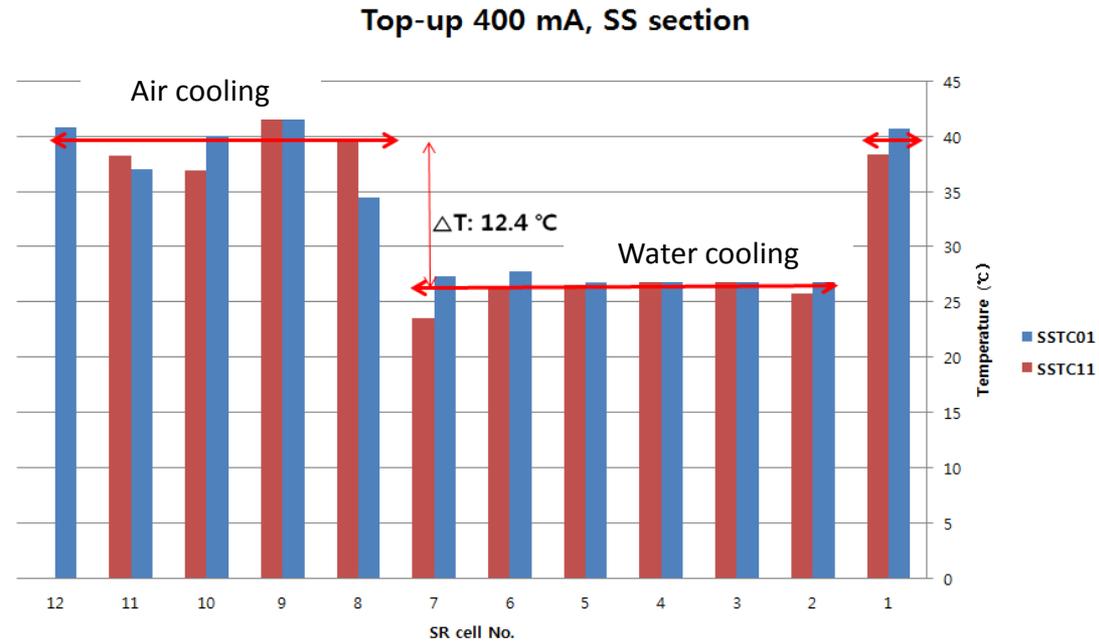
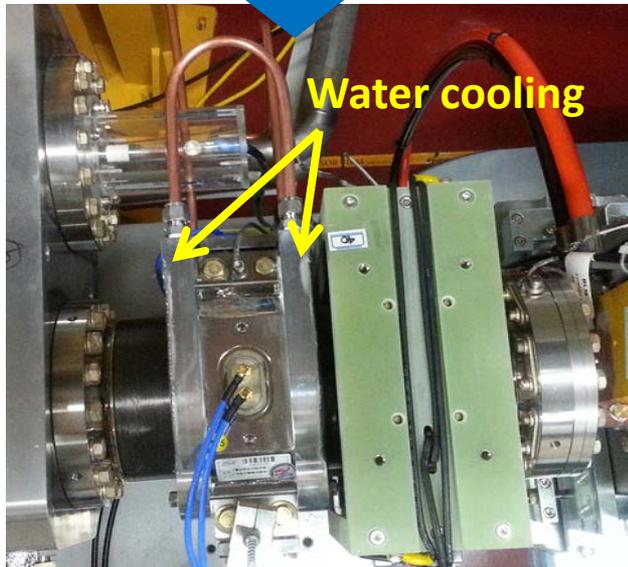
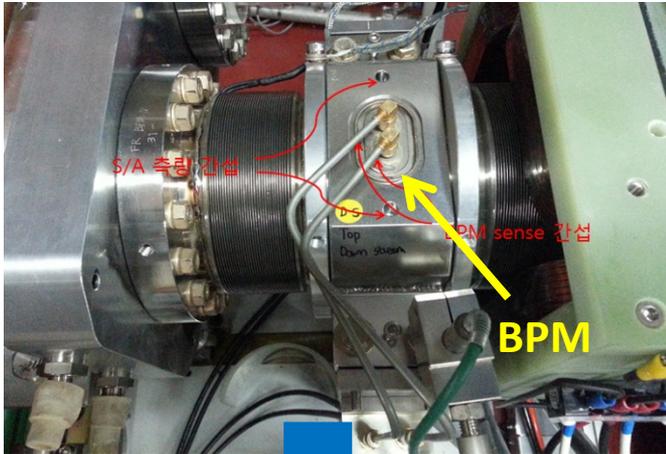
(b)



4. BPM support

4.2 Improvement in BPM position stability in PLS-II

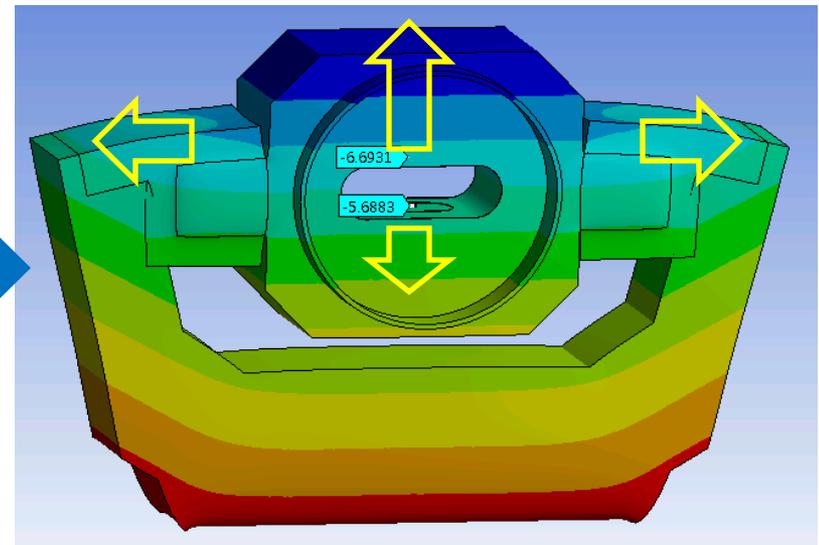
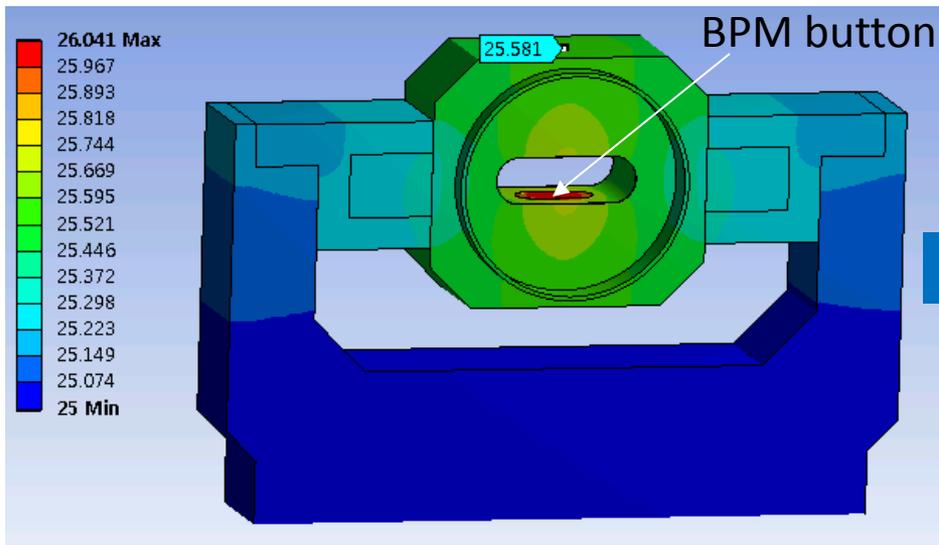
- ❖ Water cooling jacket for BPM chambers



4. BPM support

4.2 Improvement in BPM position stability in PLS-II

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

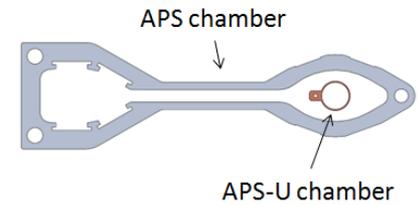


Center of the BPMs moves vertically

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 ($< 10 \text{ } \mu\text{m}$) to prevent damage in IVU
 - ✓ Various shielding mechanisms are studied
- Need high mechanical stability ($< 1 \text{ } \mu\text{m}$)
 - ✓ 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!