Power absorption consideration for HEPS Storage Ring Vacuum System

Ping He
On Behalf of HEPS Vacuum System

Outline

- ☐ **1. Introduction: HEPS storage ring parameters**
- ☐ **2. Vacuum chamber design**
- ☐ **3. Special consideration for the power absorption and hardware components Development**
- ☐ **4. Conclusions**

Introduction

Goals and the target performance of LS (Light Source) storage rings:

Constant delivery of a high quality, intense and stable photon beam to a large number of beamlines

High quality and intense photon beams: Often characterized in terms of

$$Brilliance = \frac{Photons}{Second \cdot mrad^2 \cdot mm^2 \cdot 0.1\% BW} \propto \frac{I}{\varepsilon_x \varepsilon_y}$$

I : Beam current, ε_u : Transverse emittance

Presently a big global wave for 3GLS → DLSR (Diffraction Limited Storage Rings or 4GLS)

Lowering of transverse beam emittance

Optimal ring structure from DBA, TBA lattice → MBA lattice

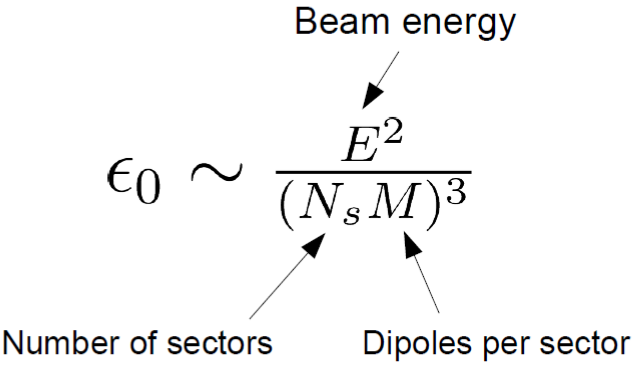
Ring-Based LS Future Trends

- A global wave today to construct (or *re-construct*) ring-based LSs having the horizontal emittance ε_H by **tens of factors** below the “nm·rad” range

<u>Basic principle used:</u>

$$\boxed{(\varepsilon_H)^{Theoretical}_{Minimum} \propto E^2 \cdot \theta^3}$$

E: Beam energy, *θ*: Bending angle

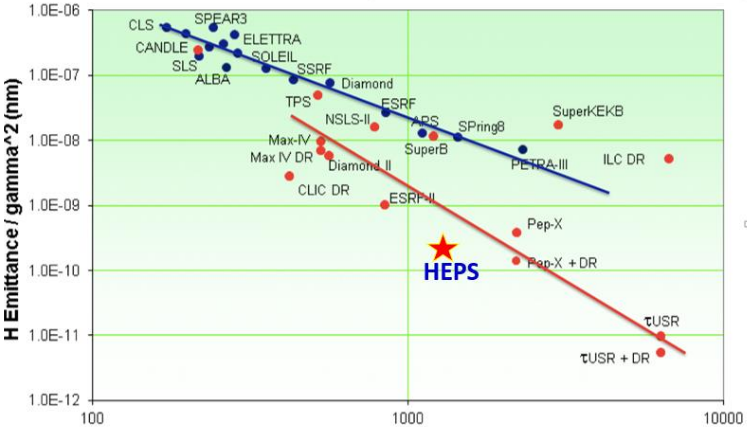


Beam energy

$$\epsilon_0 \sim \frac{E^2}{(N_s M)^3}$$

Number of sectors

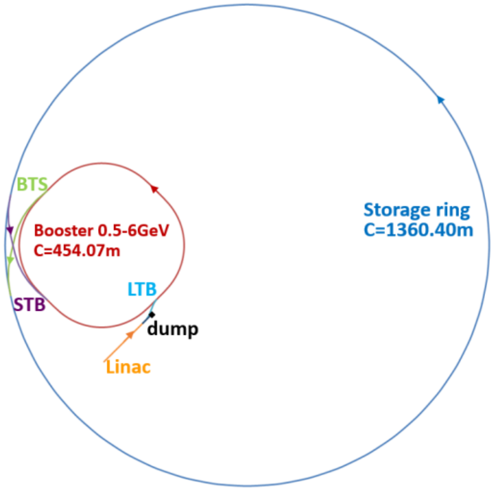
Dipoles per sector



Courtesy R. Bartolini

HEPS Storage Ring Parameters

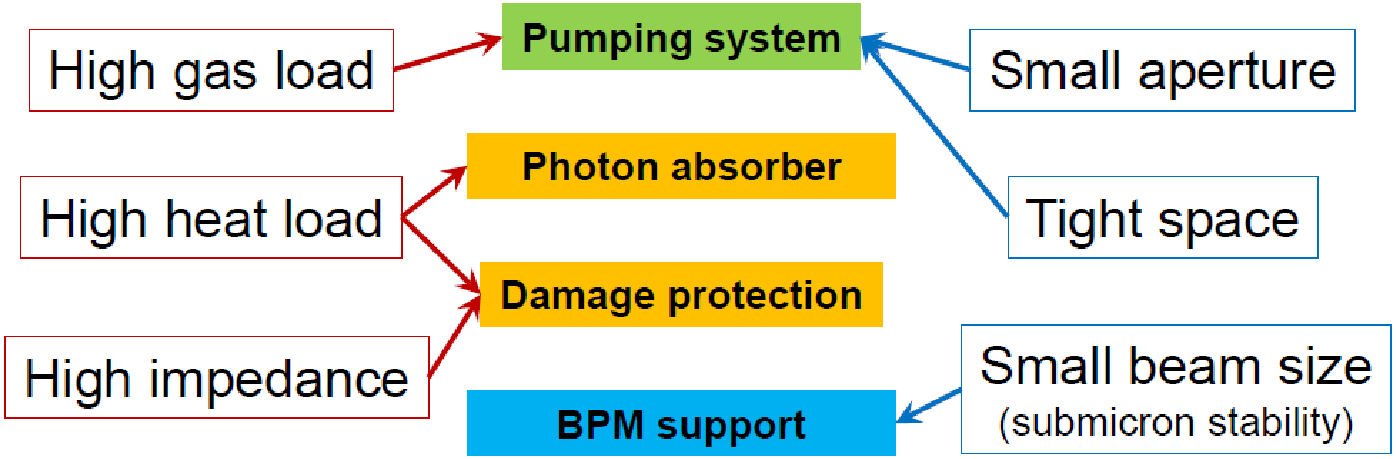
Beam Energy（GeV）	6
Current（mA）	200
Storage Ring（m）	1360.4
Booster（m）	453.5
Emittance（nm·rad）	<0.06
Lattice	7BA
Straight Section Length（m）	6
Cell Number	48



New Generation Low Emittance Ring

“High current & low emittance”

Vacuum system should accommodate:



High gas load

High heat load

High impedance

Pumping system

Photon absorber

Damage protection

BPM support

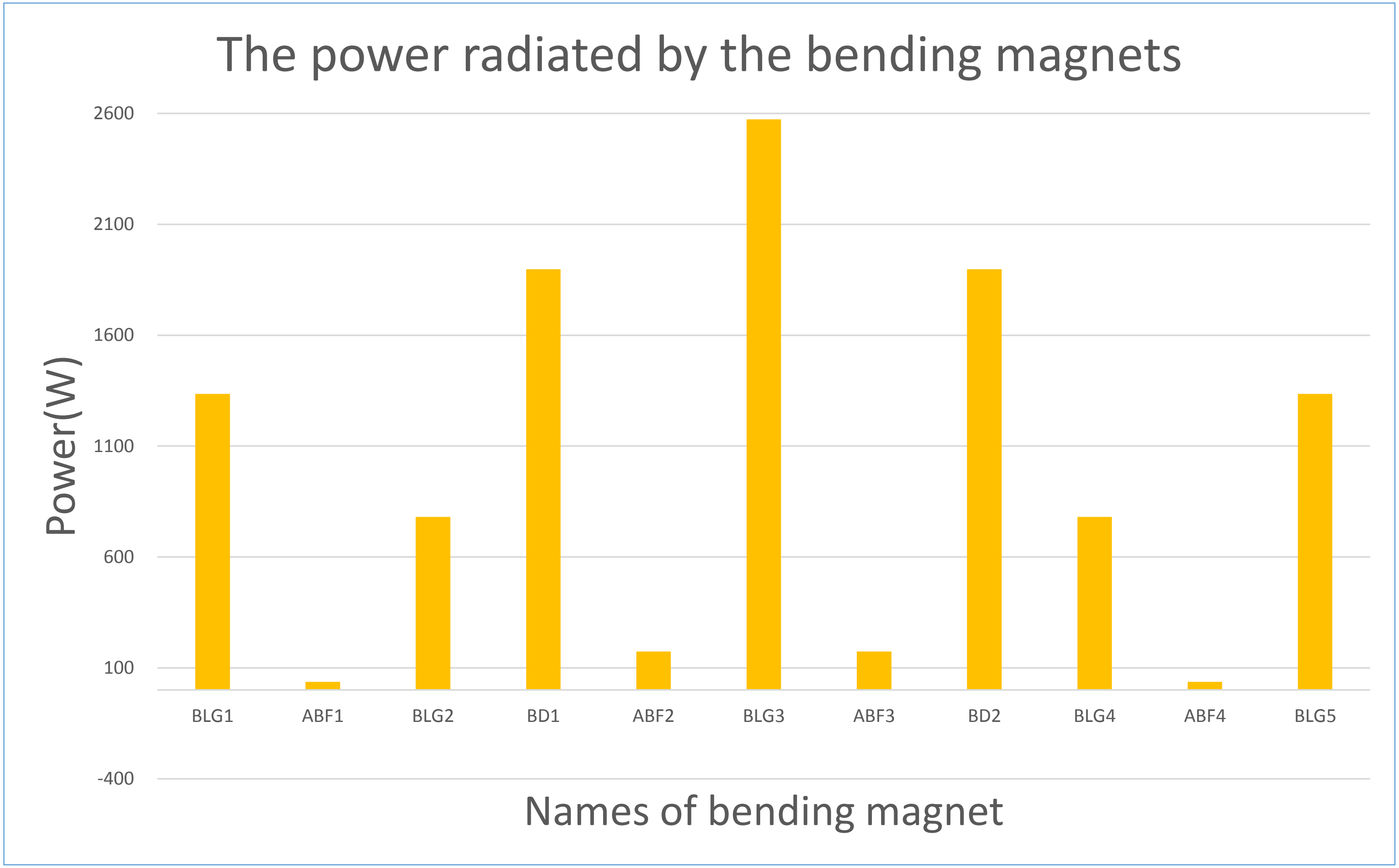
Small aperture

Tight space

Small beam size
(submicron stability)

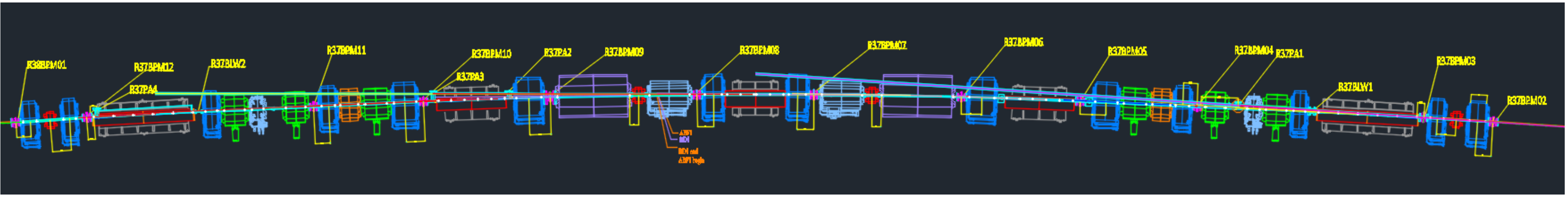
Main Purpose of LESRs_Vacuum System Design:
Have low dynamic pressure which gives good beam lifetime, and to handle the power deposited by SR.

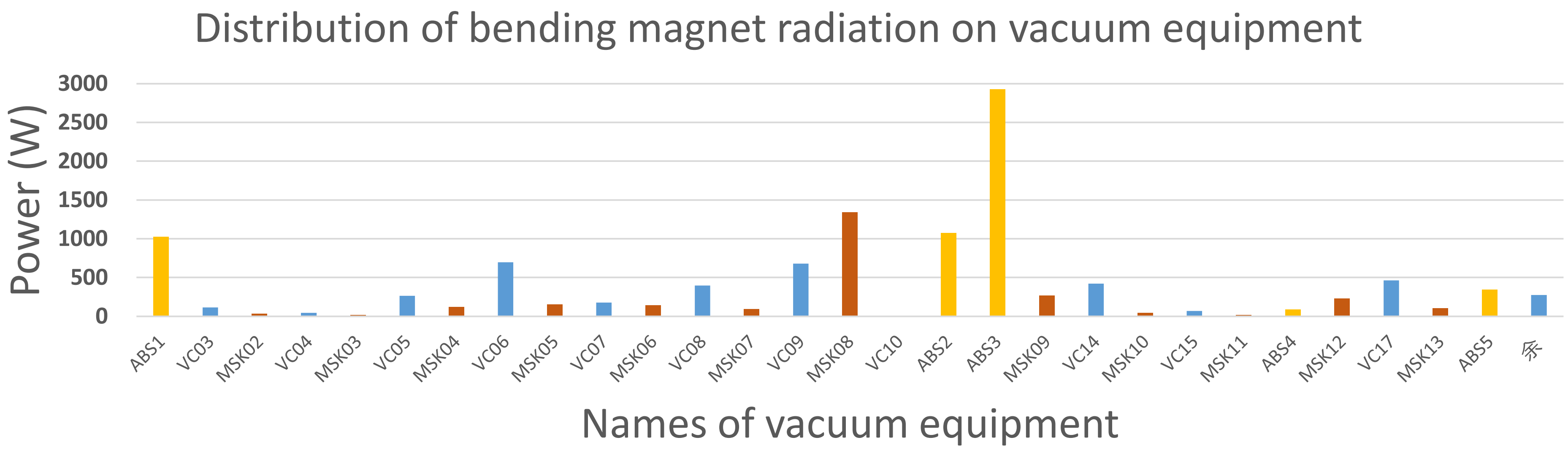
Distribution of SR power for bending magnets



The power of each cell is 11.02kW, the total power of 48 cells is 529 kW.

Distribution of SR power on the vacuum components



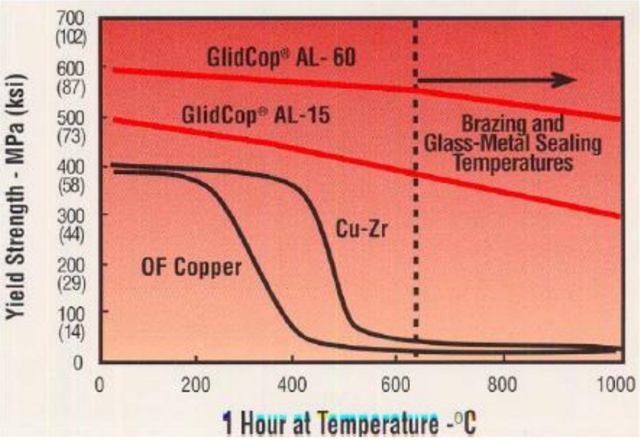


ABS:	Photon Absorber	**Yellow**
MSK:	Mask	**Brown**
VC:	Vacuum Chamber	**Blue**

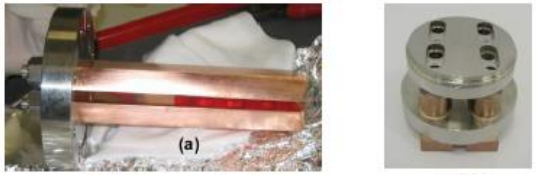
Handle higher SR Power(1)

❖ 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]

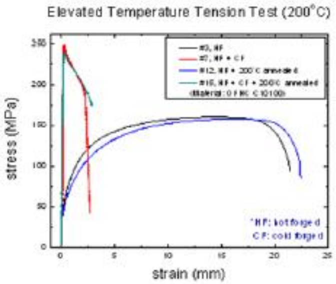
Handle higher SR Power(2)

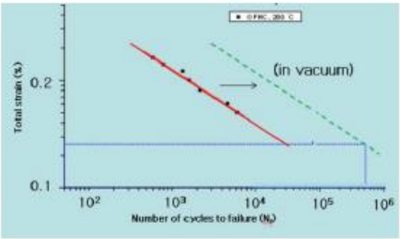
❖ Materials for high-heat-load photon absorber

- ☐ **Cold forged OFHC Copper**
  - ✓ Excellent thermal conductivity
  - ✓ Easily available
  - ✓ E-beam weld to prevent softening from brazing (shorter exposure to high temperature than brazing)

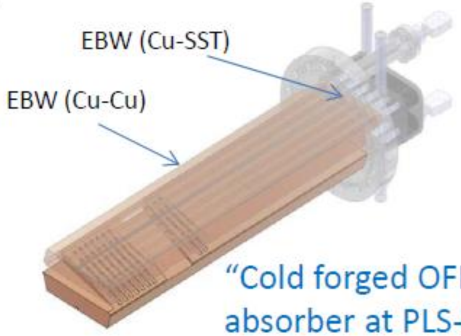
- Elevated temperature (200℃) tension test

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**



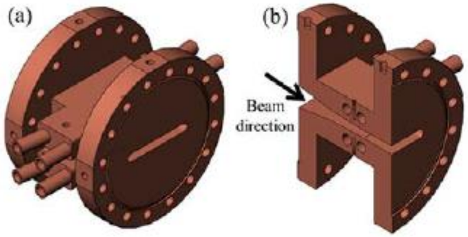


- ☐ **CuCrZr**
  - ✓ Good thermal conductivity
  - ✓ UHV compatible
  - ✓ Conflat flange integrated to absorber
  - ✓ Widely available



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

“CuCrZr flange at NSLS-II”[13]



“CuCrZr absorber at TPS”[14]

Handle higher SR Power(3)

Material Selection “Glidcop AL-15 Vs Copper Chromium Zirconium (C18150)”

Material Properties

○ *Thermal Conductivity (RT):*
Glidcop Al25, Al15: 344 - 365 W/(m.K)
Cu-Cr-Zr: 314 - 335 W/(m.K)

○ *Elastic Modulus:*
Glidcop Al15, Al25: 130 GPa
Cu-Cr-Zr: 123 GPa

○ *0.2 % Yield Strength, (RT, Cold Worked):*
Glidcop Al15, Al25: 470 - 580 MPa
Cu-Cr-Zr: 350 - 550 Mpa

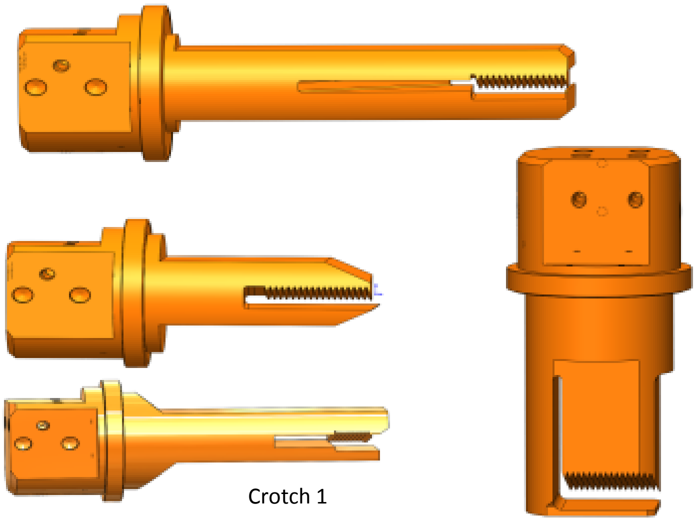
○ *Coefficient of Thermal Expansion:*
Glidcop Al15, Al25: 16.6 µm/K
Cu-Cr-Zr: 17.0 µm/K

- *Cu-Cr-Zr (C18150) is 1/4th the price of Glidcop AL-15.*
- *Cu-Cr-Zr is readily available in different forms and sizes from many suppliers.*
- *Cu-Cr-Zr loses its strength rapidly if exposed to sustained temperatures > 500°C*
- *Glidcop is the choice if brazing is required.*

Ref: Li M. and Zinkle S. J. (2012) Physical and Mechanical Properties of Copper and Copper alloys, Comprehensive Nuclear Materials, Vol. 4, pp 667-690

Lumped Photon Absorbers

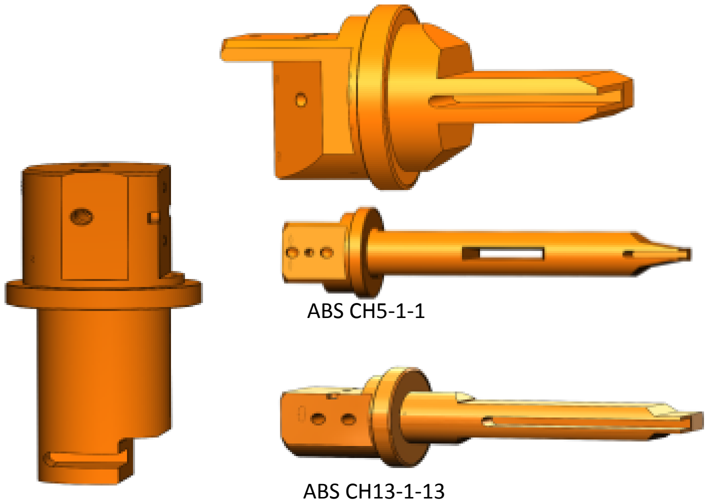
Family Toothed (up to 110 W/mm^2)



Crotch 1

ABS CH9-1-29

Family Frontal (up to 50 W/mm^2)



ABS CH4-1-1

ABS CH5-1-1

ABS CH13-1-13

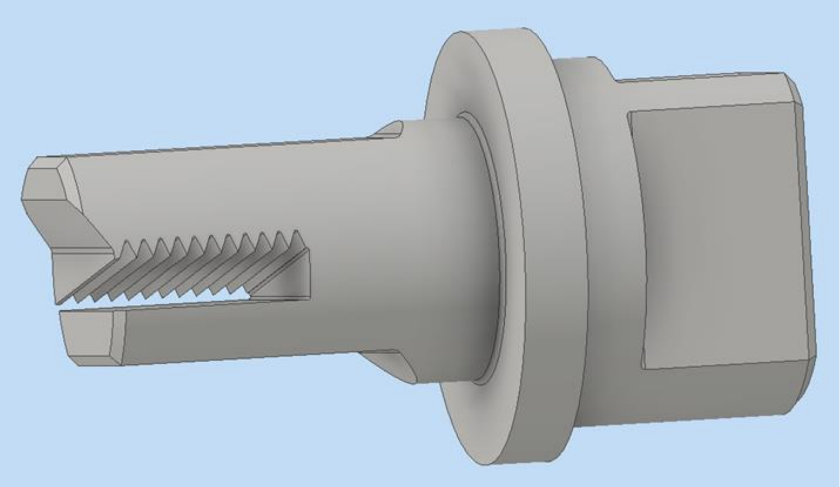
EBS

- 12 lumped removable photon absorbers (on flanges) per cell
- These absorbers will be machined from a block CuCrZr, including the CF knife edge

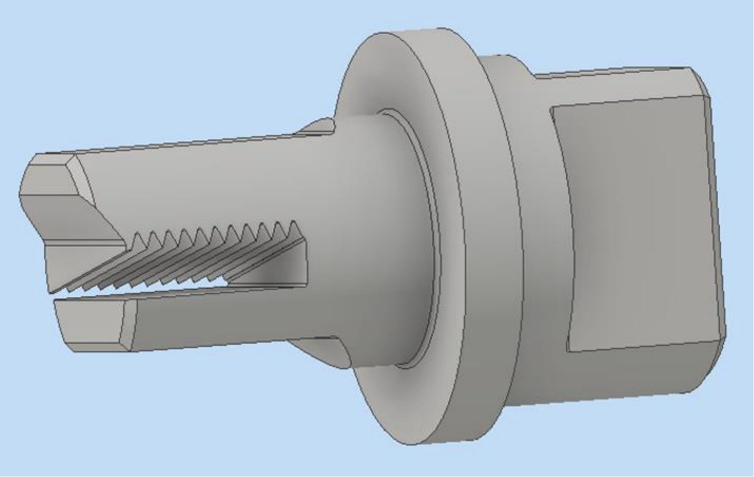
Single piece construction without brazing or welding.

The shapes of HEPS photon absorbers

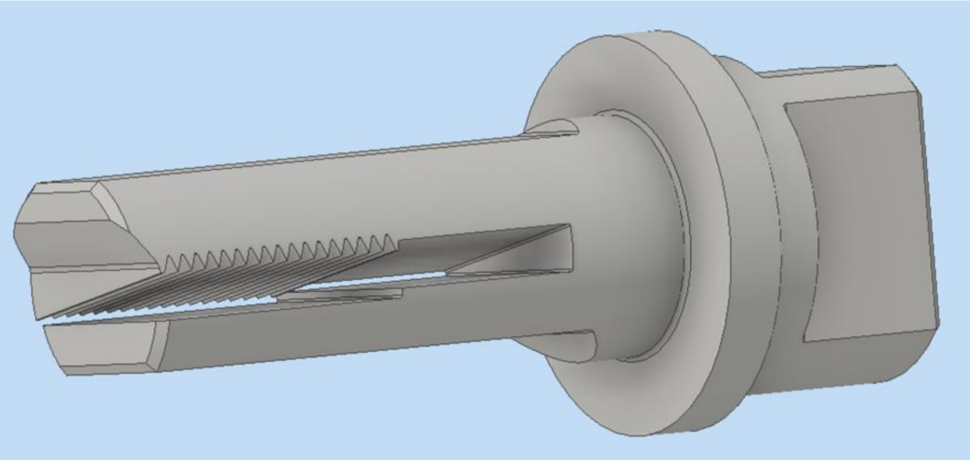
ABS1



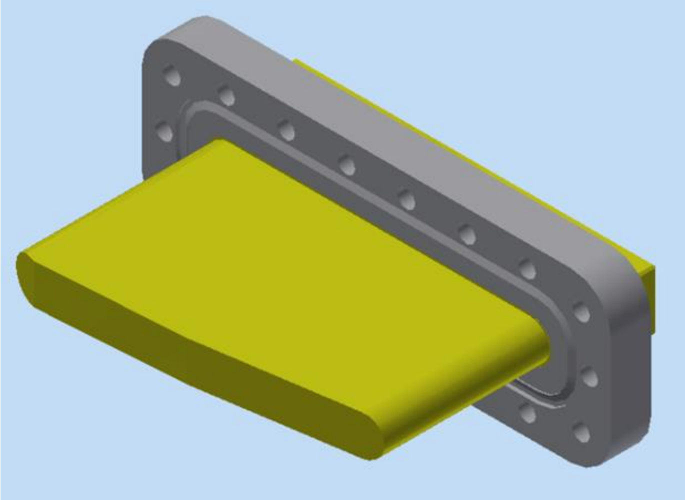
ABS2



ABS3



ABS4

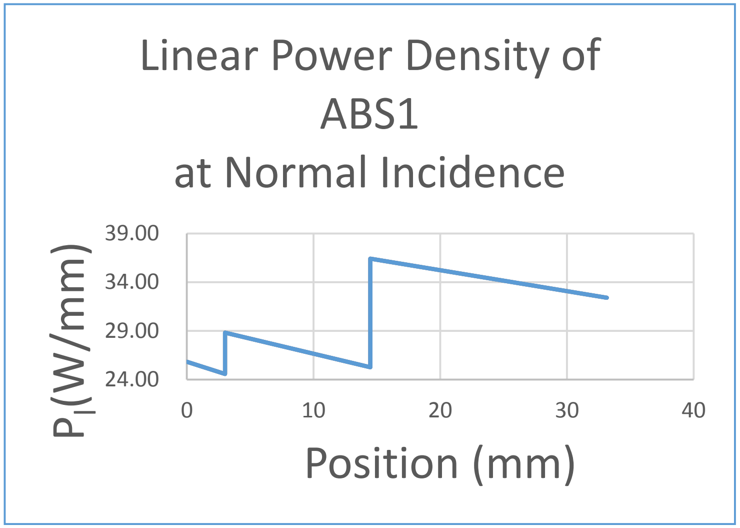


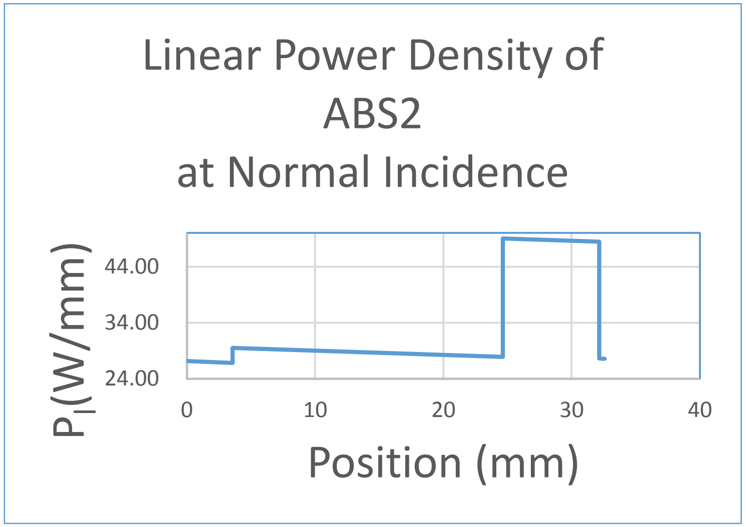
FEA Results of HEPS ABS1~4

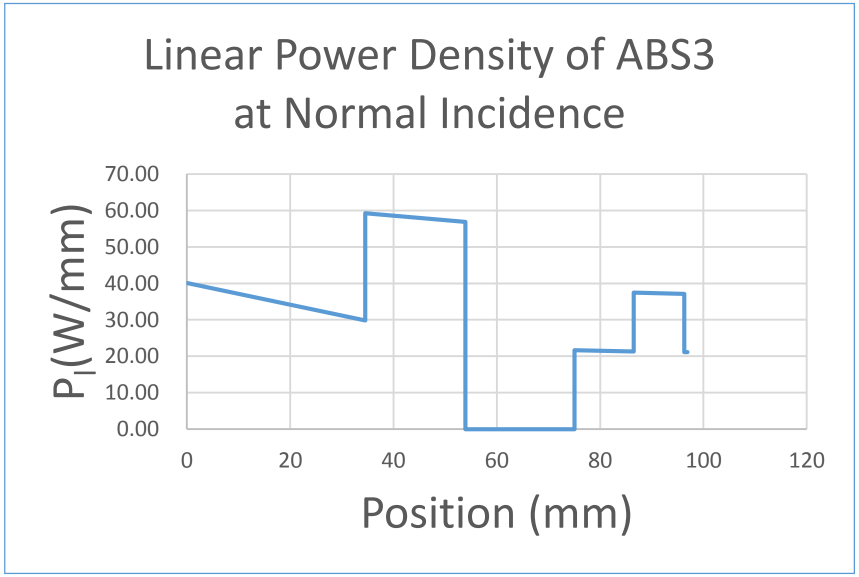
Type	Material	Total Power [W]	Tmax [°C]	Tboundary [°C]	Stress [MPa]	Strain [mm/mm]	Deformation [mm]
ABS1	CuCrZr	1129	166	79	138	0.0011	0.06
ABS2	CuCrZr	1135	158	77	146	0.0012	0.06
ABS3	CuCrZr	3358	258	118	199	0.0016	0.21
ABS4	OFHC	425	64.4	47	40.6	0.00035	0.03

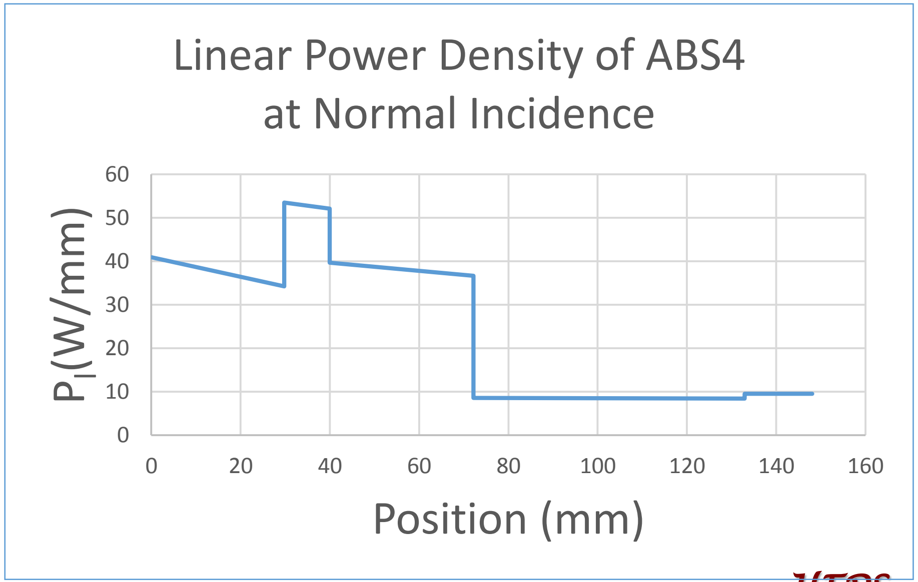
Hcv=0.01 W/mm^2/°C, Twater=22°C

Linear Power Density of ABS1~4 at Normal Incidence

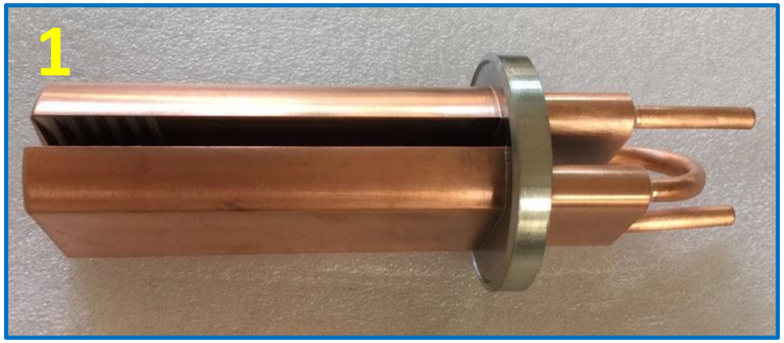


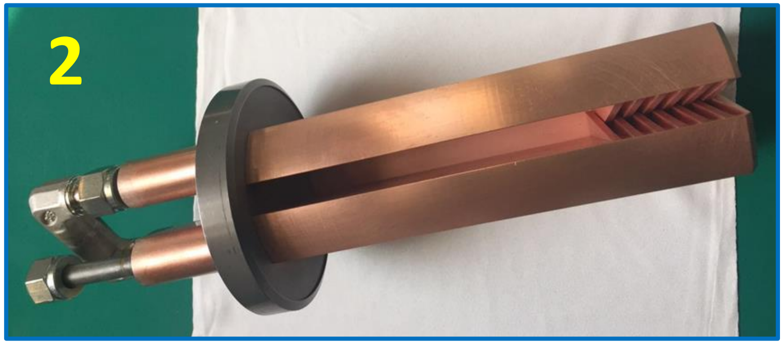


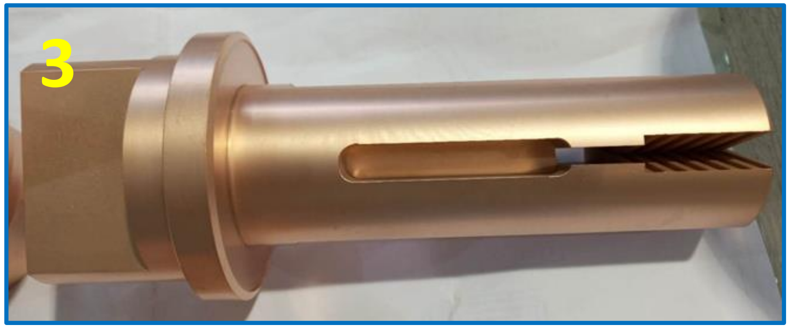


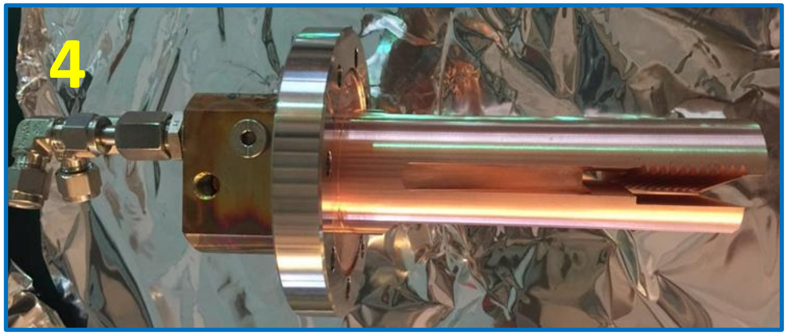


HEPS Photon absorber prototypes









1 **GlidCop-AL15** and SS316L flange brazing in a vacuum furnace.

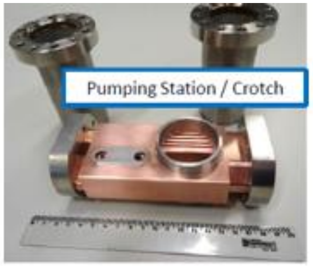
2 **GlidCop-AL15** and SS316L flange brazing in a hydrogen furnace.

3 and 4 **CuCrZr copper** Integrating flange (no brazing).

Mask or in-line absorbers

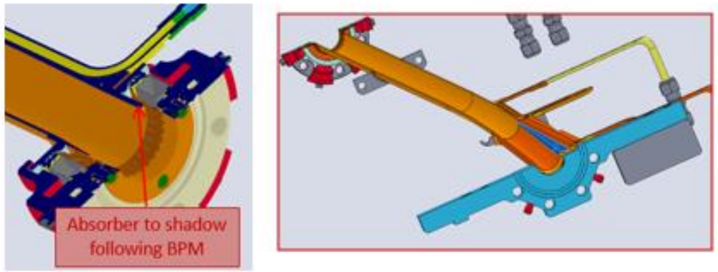
Integration of pumping port and photon absorber

Compact geometry with adequate cooling and minimized radiation scattering

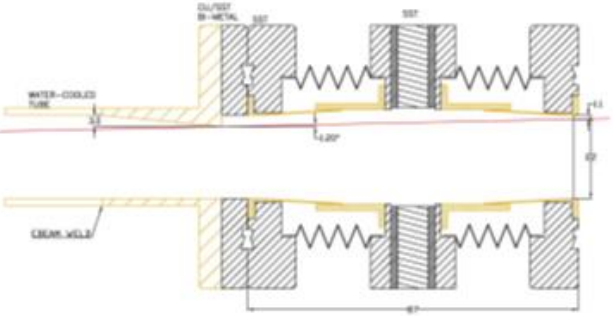


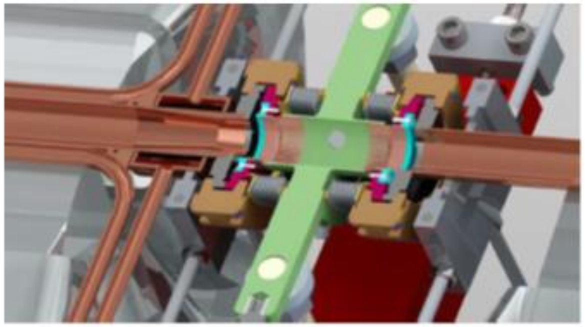
SIRIUS

In-line absorber was used for shadow following BPM



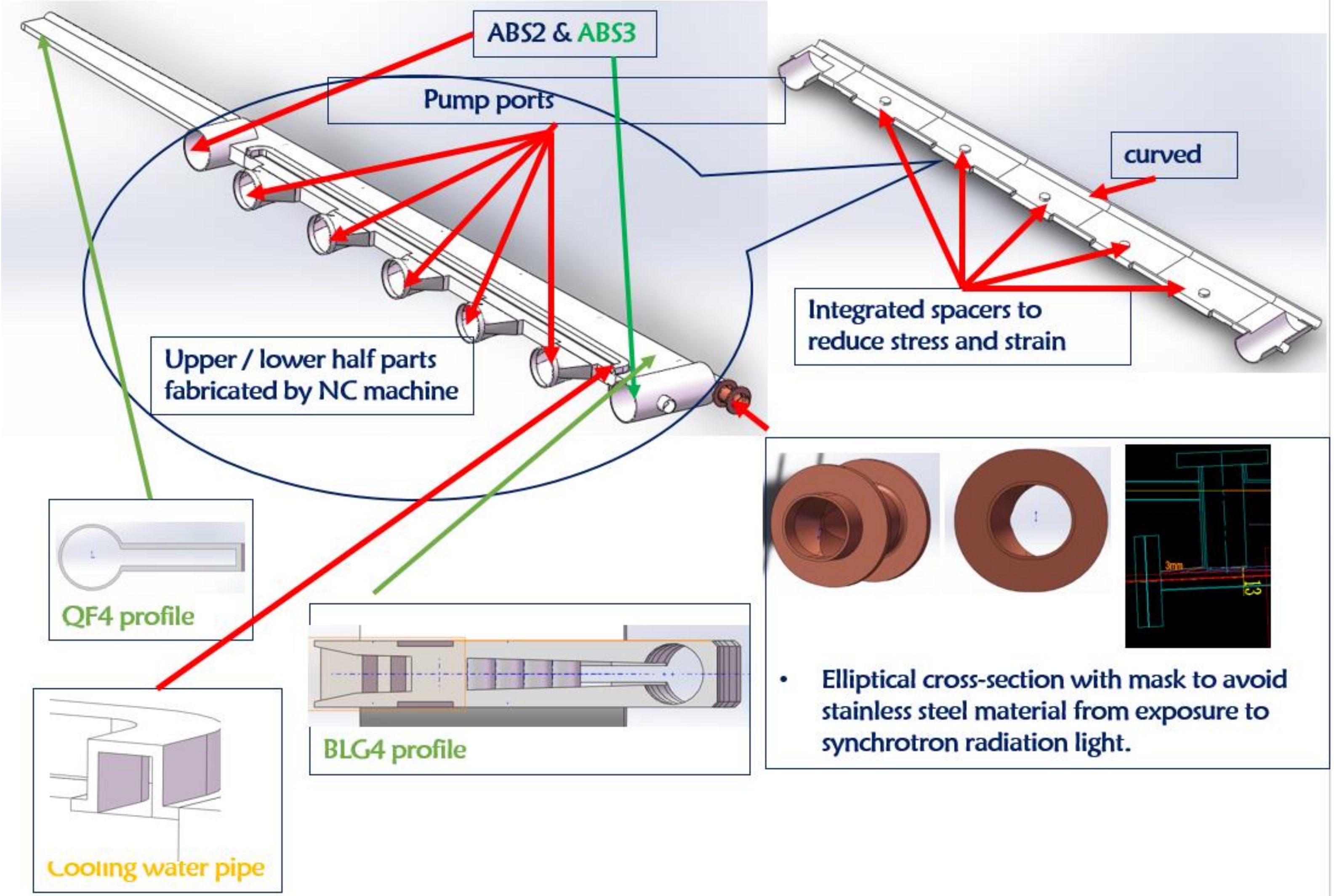
MAX-IV





APS-U

Vacuum chamber designs (BLG4+QF4)



ABS2 & ABS3

Pump ports

curved

Integrated spacers to reduce stress and strain

Upper / lower half parts fabricated by NC machine

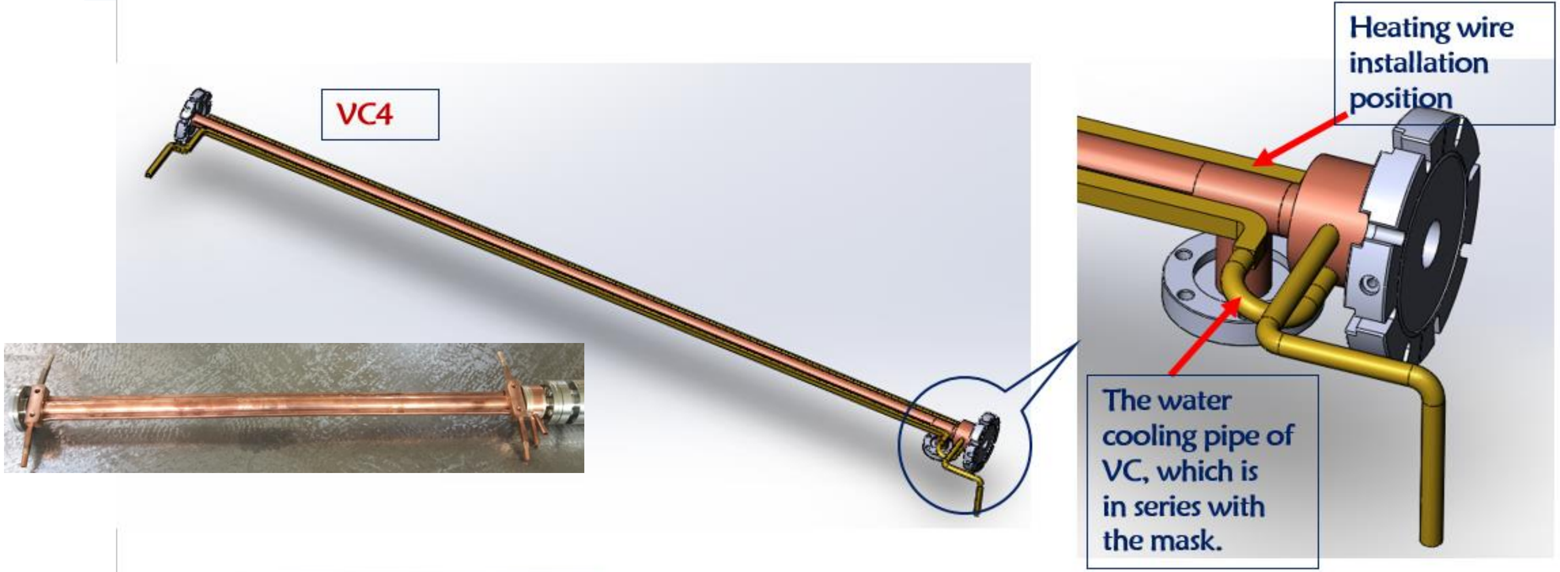
QF4 profile

BLG4 profile

Cooling water pipe

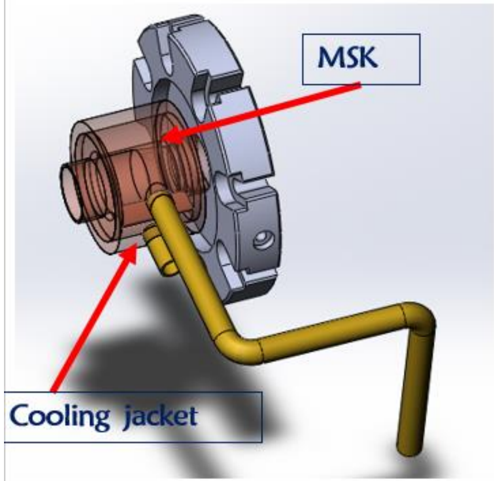
- Elliptical cross-section with mask to avoid stainless steel material from exposure to synchrotron radiation light.

Vacuum chamber designs (VC3+VC4)

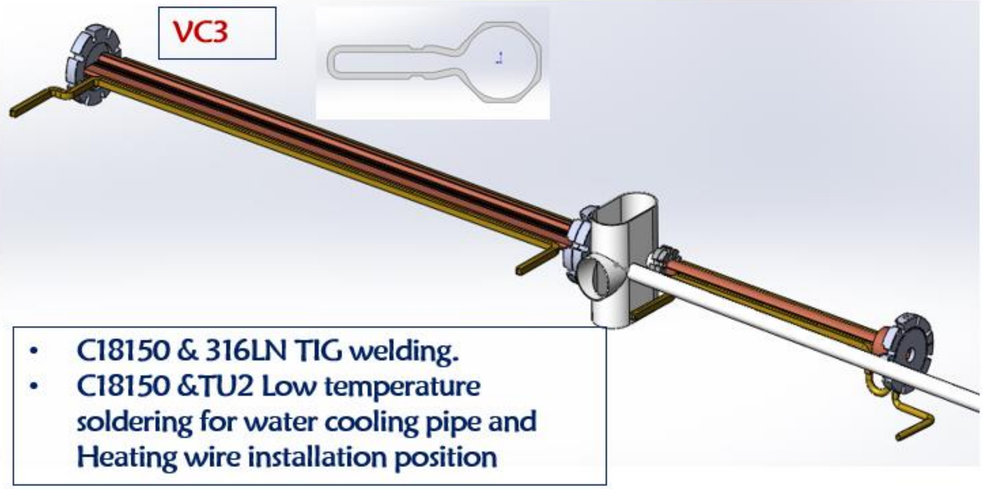


Heating wire installation position

The water cooling pipe of VC, which is in series with the mask.

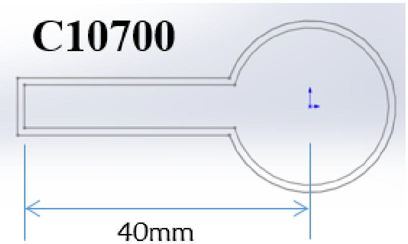


Cooling jacket

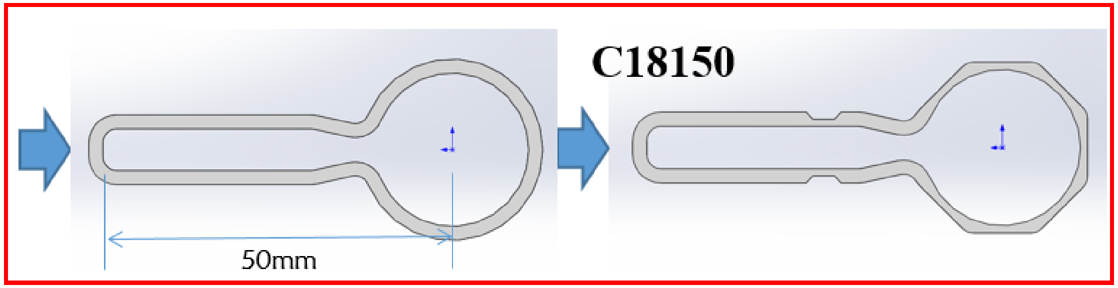


- C18150 & 316LN TIG welding.
- C18150 &TU2 Low temperature soldering for water cooling pipe and Heating wire installation position

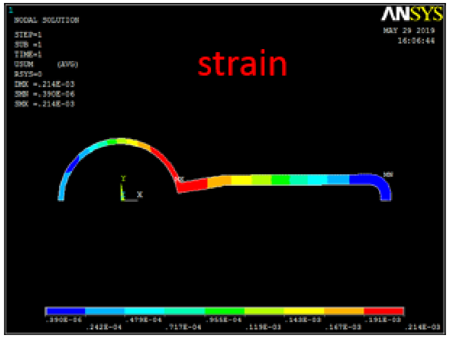
Finite Element Analysis for cross section of different material and shape

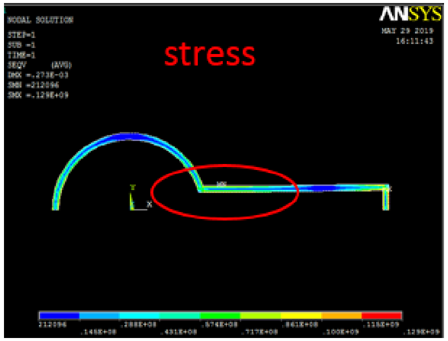


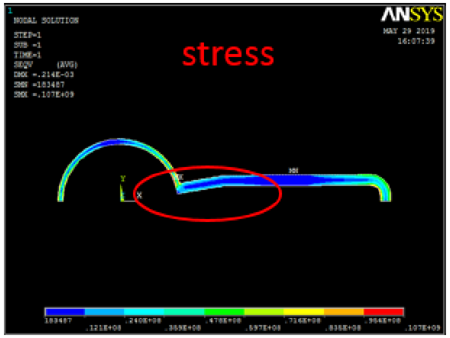
Thickness is 1 mm



Thickness is 2mm
Extrusion pipe & After machining







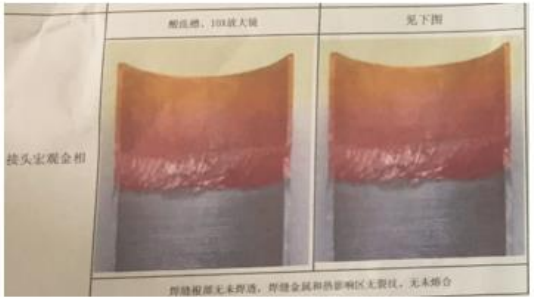
	cross-section 1mm	cross-section 2mm
Max. strain （MPa）	0.273	0.214
Max. stress （mm）	129	107

- The stress in the red circle was improved from 80~90Mpa to 20~30Mpa.

CrZrCu（C18150）& Stainless Steel（316LN） TIG welding experiments

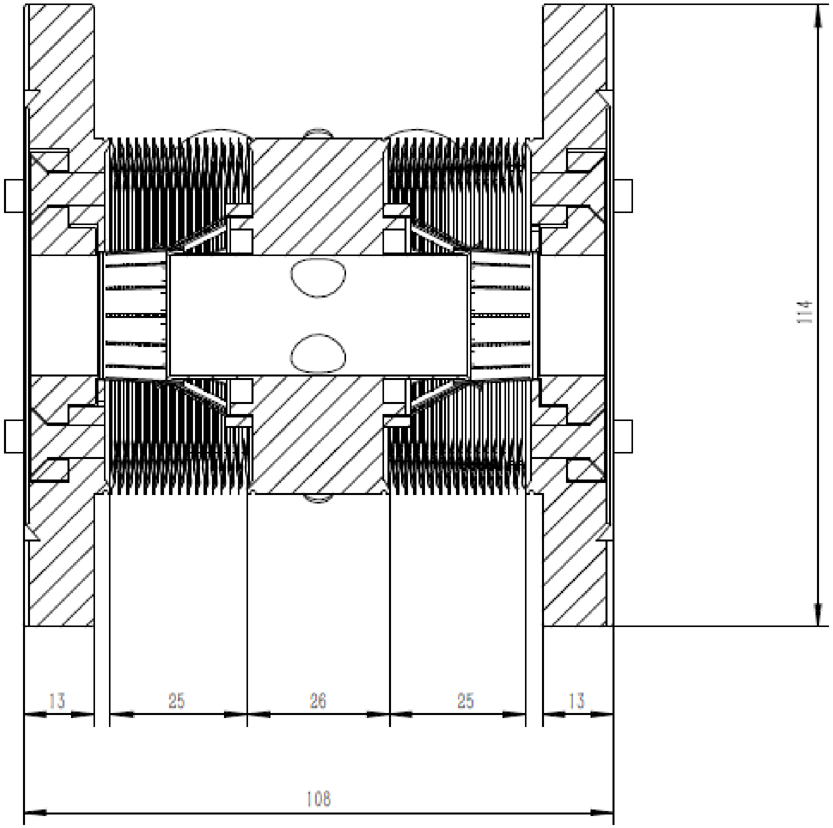
CrZrCu（φ24*1）pipe welding test

CrZrCu（φ24*1）pipe and Stainless Steel flange welding test



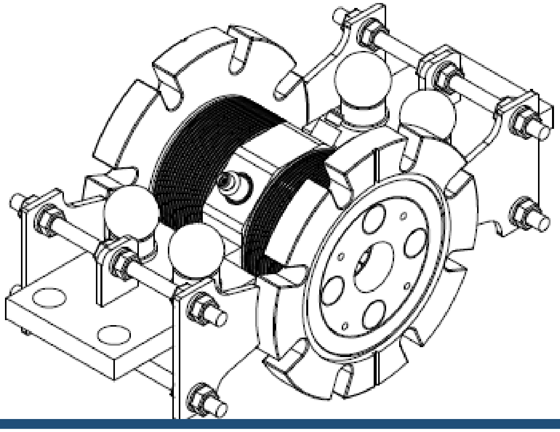
- The fracture of the two samples were at one end of the base material of chrome-zirconium copper, about 2mm away from the center of welding seam.
- The measured tensile strength of the base material were 282 MPa and 297 MPa respectively, and the tensile strength of welding seams should be higher than that of the base material.

Design of BPM & double-sided RF shielding bellows



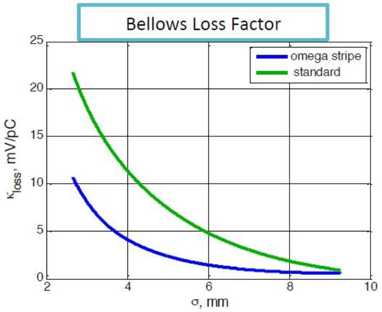
Technical Parameters

Total length/mm	108
Axial Stroke	-16~+4
Radial Offset/mm	±2
Bend angle/°	±1
Be-Cu strip thickness/mm	0.2
Contact pressure/g	125±15
Permeability of stainless steel	<1.02

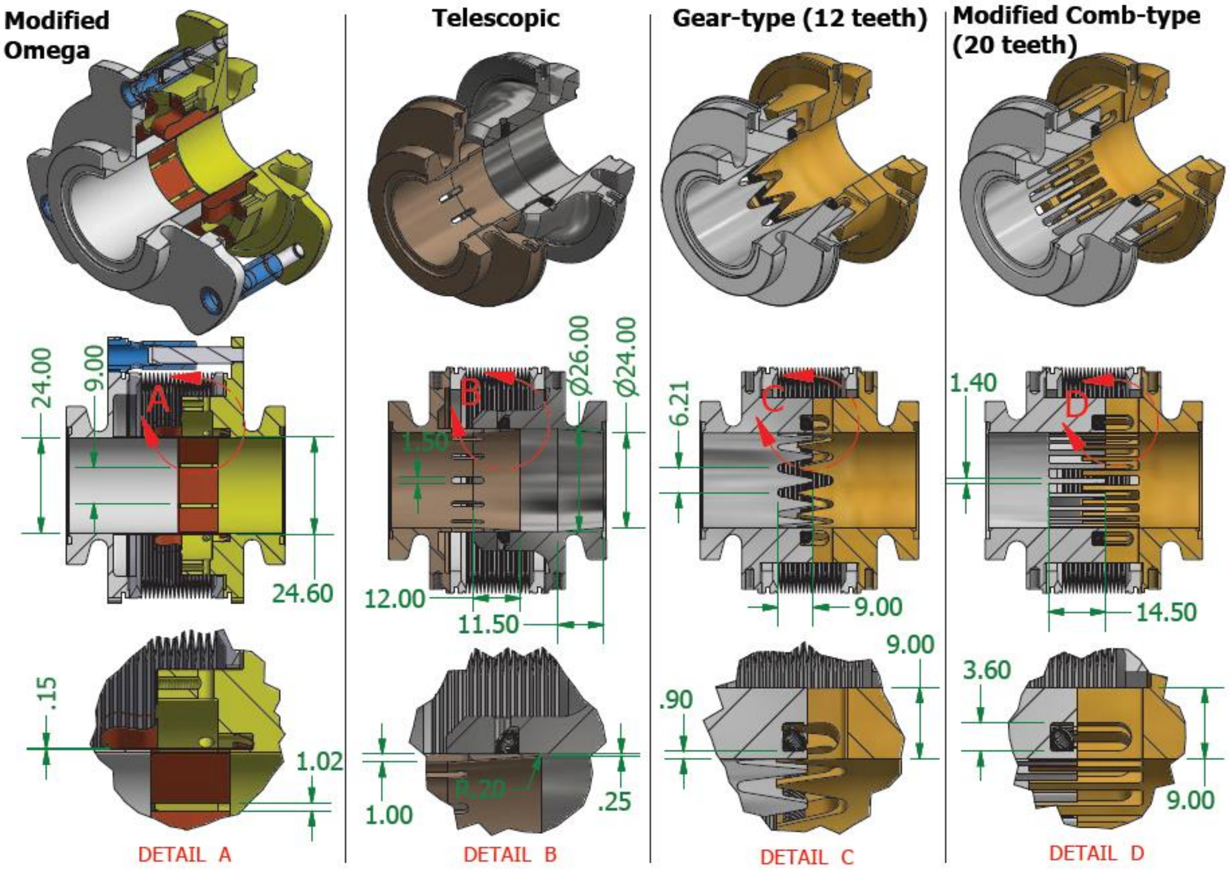


A Few More Options

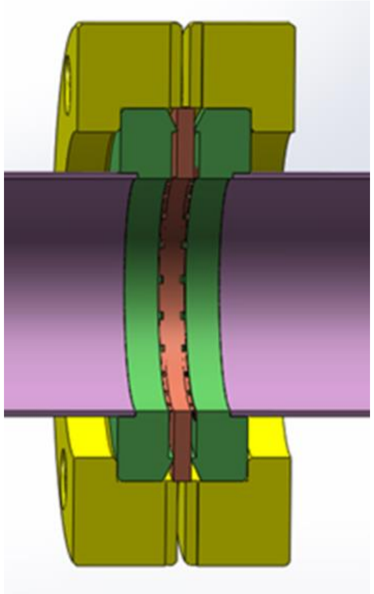
H.O.C. Duarte, IPAC’2019, MOPGW001

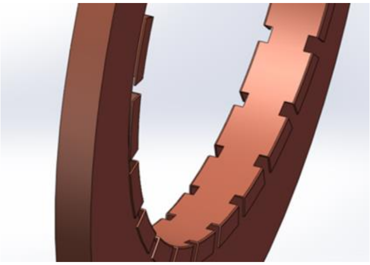


Bellows Loss Factor

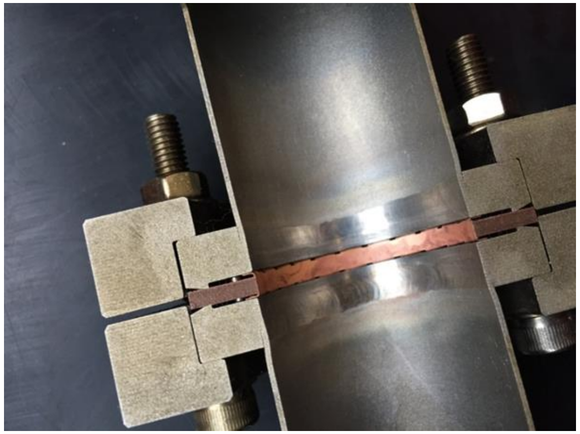


Tests of low impedance gaskets

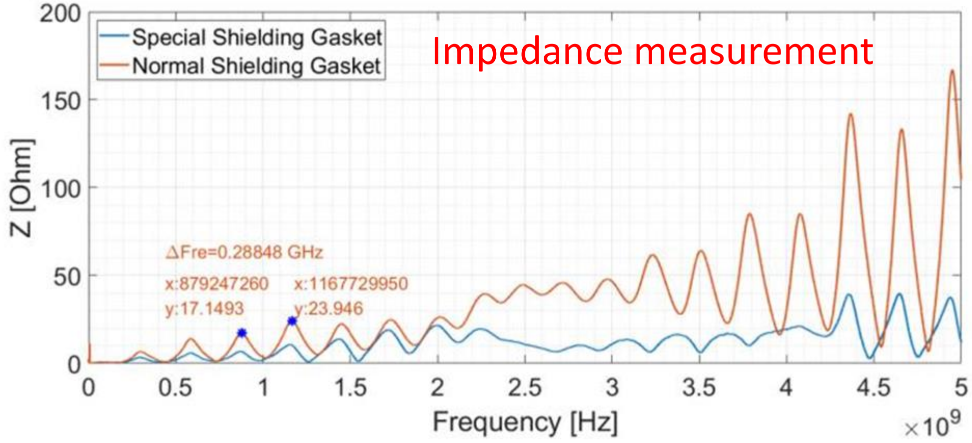




Copper gasket with contact fingers



Preload force /N	4
Leakage rate/mbar.L/s	＜1E-10
Baking temperature/°C	250
Baking time/h	24
Repeated Baking times	6
Repeat installation times	4



Impedance measurement

Several experiments indicate the contact fingers have a good contact with flange surface.

Summary

Handle higher SR power is very important during the low emittance ring vacuum system design:

☐Need more Iterative Design Process for vacuum components (impendence, HOM heating, etc..).

☐High heat load photon absorber:

Lumped &in-line absorbers: More options in material choice

rather than Glidcop

☐Damage protection need to be studied(Various shielding mechanisms, etc...)

☐Need high mechanical stability for vacuum components: Water cooling is very effective, Need careful design for the support

☐Need fast orbit interlock(FOFB) system to keep the e-beam stable and prevent the damage of the vacuum components.

☐The detailed engineering designs for HEPC storage ring vacuum system are being under the way, many issues such as very tight space, strong SR power density, need to be find the solution.

Thanks!