BEPCII Vacuum System

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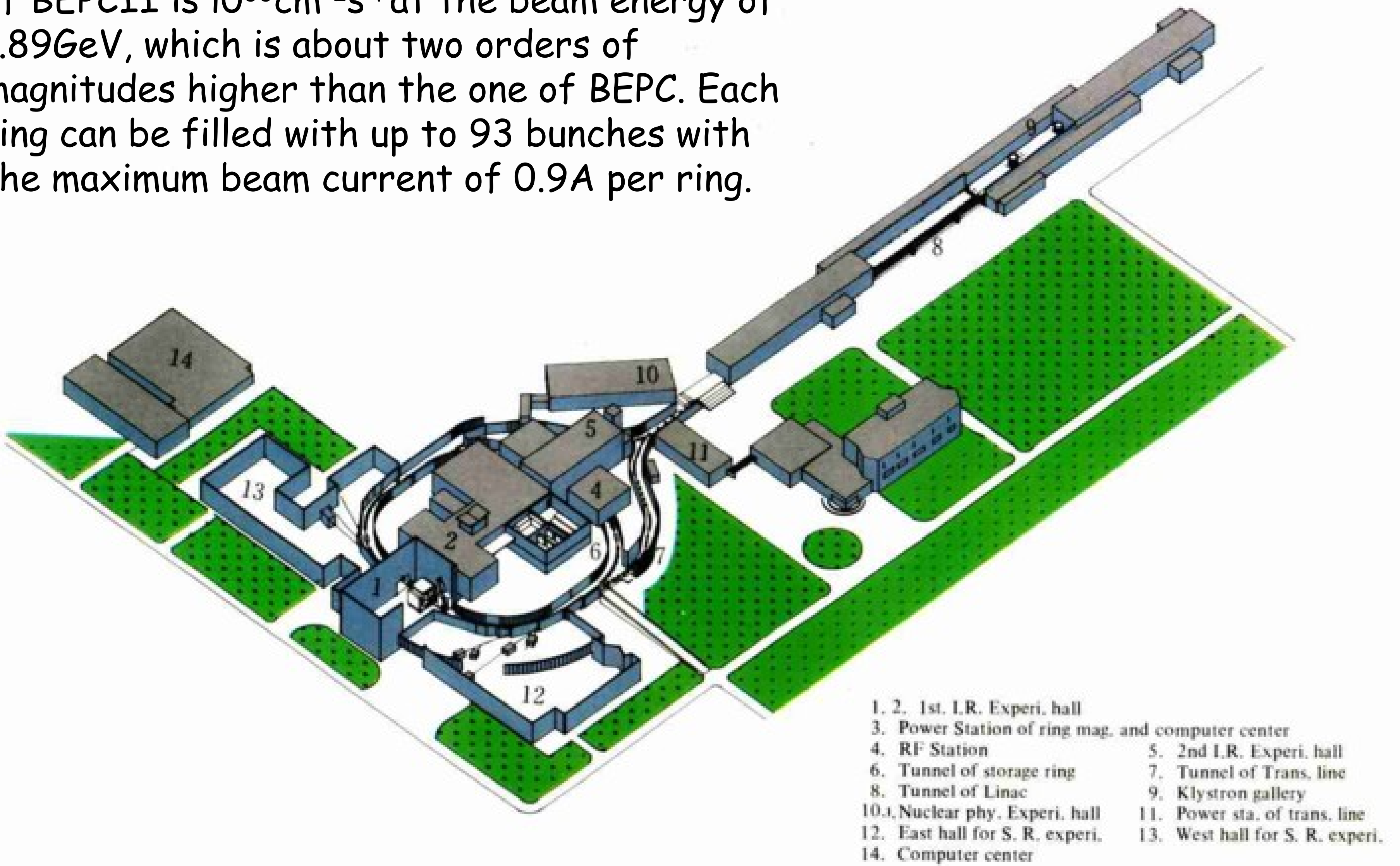
BEPCII is a double-ring collider within the existing BEPC tunnel. The designed luminosity of BEPCII is $10^{33}cm^{-2}s^{-1}$ at the beam energy of 1.89GeV, which is about two orders of magnitudes higher than the one of BEPC. Each ring can be filled with up to 93 bunches with the maximum beam current of 0.9A per ring.



The Layout of BEPCII

The Milestones

January 2004	Construction started
May. 4, 2004	Dismount of 8 linac sections started
Dec. 1, 2004	Linac delivered e^- beams for BEPC
July 4, 2005	BEPC ring dismount started
Mar. 2, 2006	BEPCII ring installation started
Nov. 13, 2006	Phase 1 commissioning started
Aug. 3, 2007	Shutdown for installation of IR-SCQ's
Oct. 24, 2007	Phase 2 commissioning started
Jan. 29, 2008	2×500mA collision, $L > 1\times10^{32}cm^{-2}s^{-1}$

July 2009, $L=3.2x10^{32}cm^{-2}s^{-1}$, National acceptance
April 2016, $L=1x10^{33}cm^{-2}s^{-1}$, Design parameter

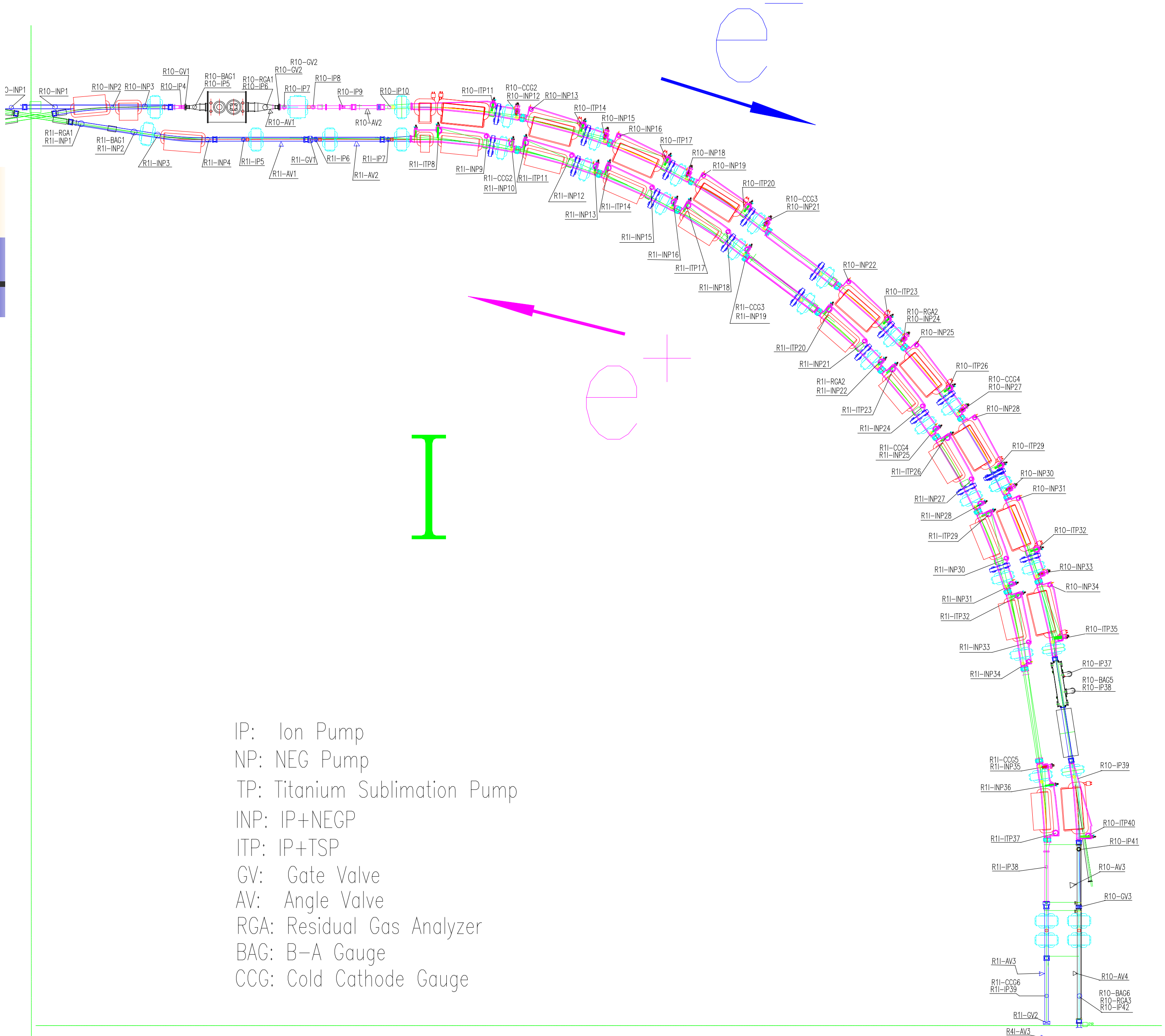
Double Ring, Dual Purposes

The BEPCII serves the purposes of both high energy physics experiments and synchrotron radiation applications.

Beam energy range	1–2 GeV
Optimized beam energy	1.89GeV
Luminosity @ 1.89 GeV	1×10^{33} $cm^{-2}s^{-1}$
Injection from linac	Full energy injection: E_{inj}=1.55–1.89GeV Positron injection rate > 50 mA/min
Dedicated SR operation	250 mA @ 2.5 GeV

The main parameters of vacuum system for BEPCII storage rings

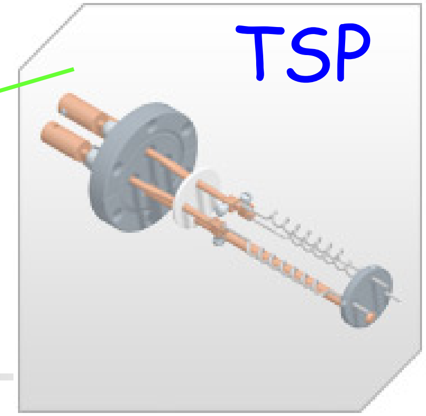
Parameter	BEPC	BEPCII	
		Electron ring	Positron ring
Energy [GeV]	2.8	1.89	
Current [A]	0.132	0.91	
Circumference of ring [m]	240.4	237.5	
Dipole magnet radius [m]	10.35	10.35(O), 9.15(I)	
Bending magnet field [T]	0.9028	0.7293	
SR critical energy [keV]	4.7	1.64	
Total SR power [kW]	69.38	112.31	
SR linear density [kW/m]	1.07	1.73(O), 1.95(I)	
Desorption coefficient	2×10^{-6}	2×10^{-6}	
Total SR gas load [Torr·L/s]	1.79×10^{-5}	8.32×10^{-5}	
Linear SR gas load [Torr·L/s·m]	2.75×10^{-7}	1.45×10^{-6}	
Pumping speed of DIP[L/s·m]	110		
Dynamic pressure [Torr]	3×10^{-9}	5×10^{-9}	
Beam stay clear[mm×mm][H×V]		105×43	
Aperture of arc chamber [mm×mm][H×V]	120×58	108×52	108×52



IP: Ion Pump
NP: NEG Pump
TP: Titanium Sublimation Pump
INP: IP+NEGP
ITP: IP+TSP
GV: Gate Valve
AV: Angle Valve
RGA: Residual Gas Analyzer
BAG: B-A Gauge
CCG: Cold Cathode Gauge

Distribution of the vacuum devices in a quadrant

Ring Vacuum System



TSP

Ion Pump

Photon Absorber

RF Bellows

NEG

Vacuum Chamber

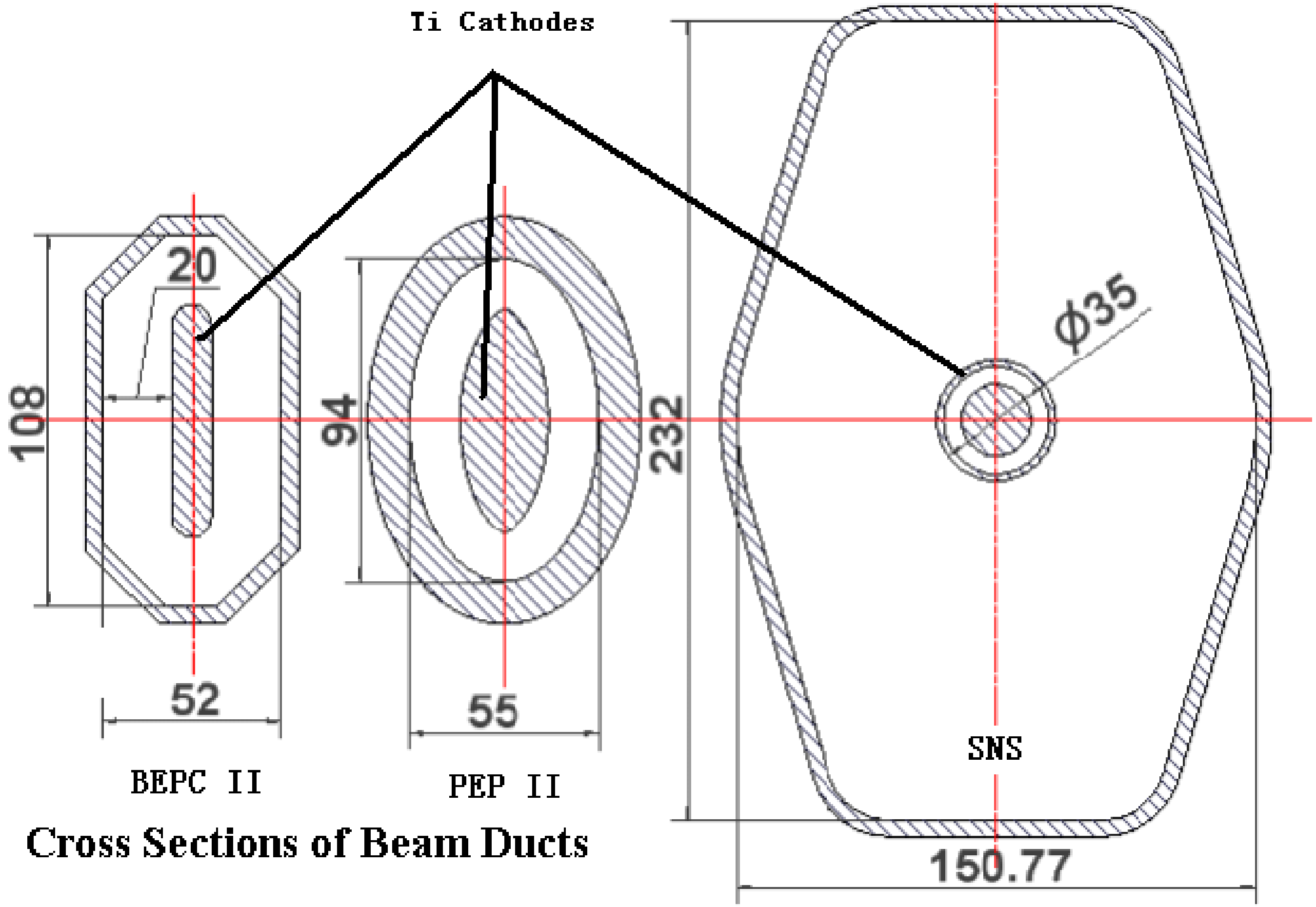
- Aluminum alloy 5083-H321 is chosen as the arc vacuum chamber material.
- In the straight sections, the vacuum chambers are fabricated from 316LN stainless steel, Al-alloy(Al-5083-H321) and Al-alloy(Al-6061).
- Standard stainless-steel conflat flanges with copper gaskets are used due to its reliability.

Half of Arc Chamber

The vacuum chamber consists of the upper and lower pieces. The two pieces made by an oil-less machining process to improve the contour precision and reduce the outgassing rate, are welded together.

TiN Coating of Vacuum Chambers

- The inner surface of the positron ring vacuum chambers have been coated with ~100 nm of Titanium Nitride (TiN) in order to minimize the secondary electron yield (SEY) and thus avoid the so-called electron clouds instability caused by electron multipacting.
- TiN coating of the positron vacuum chambers has been done by using DC sputtering, and the main design parameters have been measured.



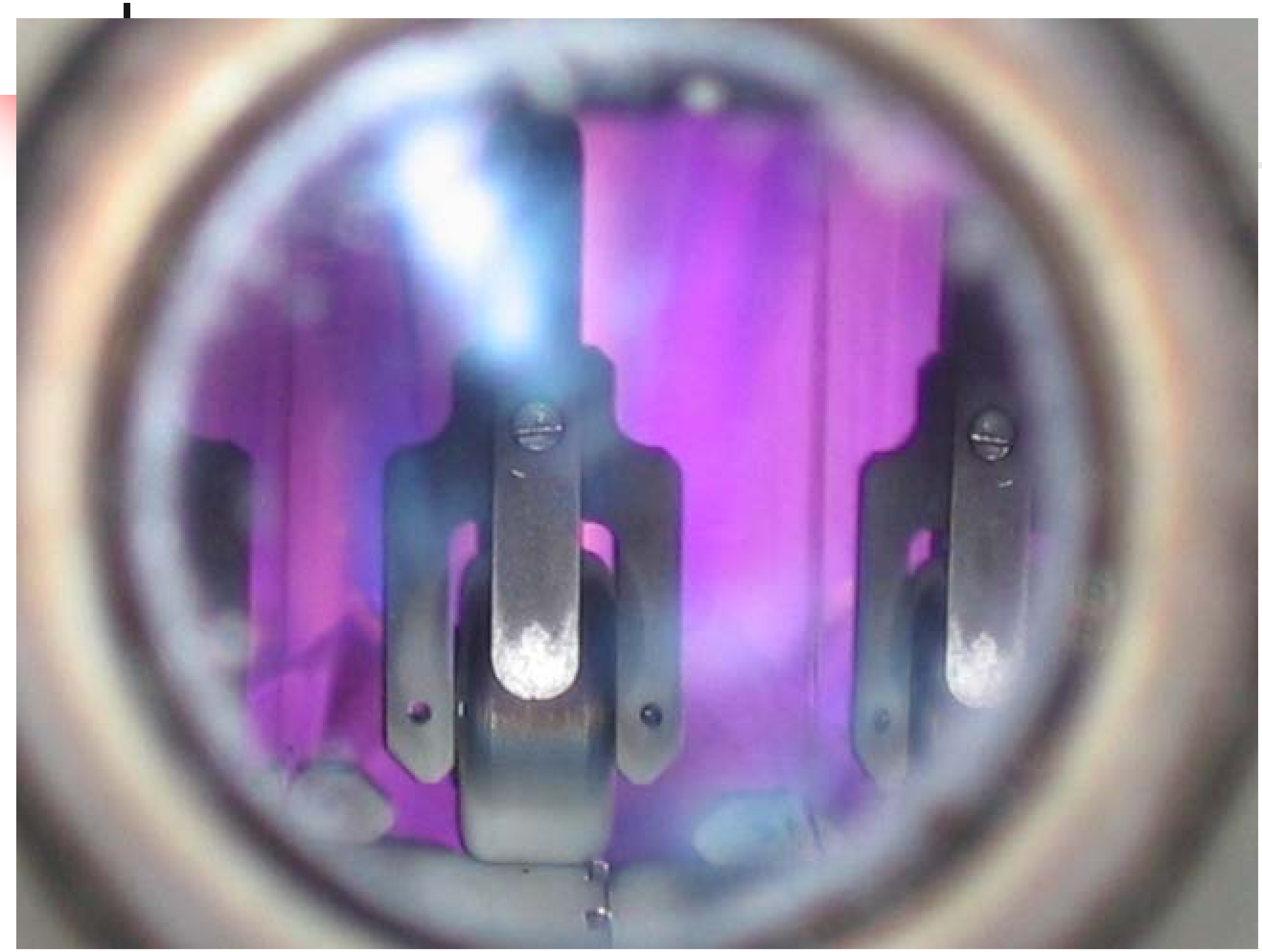
Cross Sections of Beam Ducts

The arc chambers for the BEPCII positron ring are 3 m long with 8.86° bending. We adopt the similar coating construction as PEPII LER. A sputtering cathode is put inside the vacuum chamber, which has to reflect the shape of the chamber and keep a constant gap between the cathode and the inner surface of the beam duct.

The Arc Vacuum Chamber Bakeout Before TiN Coating

TiN Coating Setup for the Cross Vacuum Chamber

Discharge Characteristics of DC sputtering



Cathode Potential:

1250～1300 V

Process Pressure:

1.5～1.7×10^{-1} mbar

Gas Composition:

70% Ar — 30% N_2

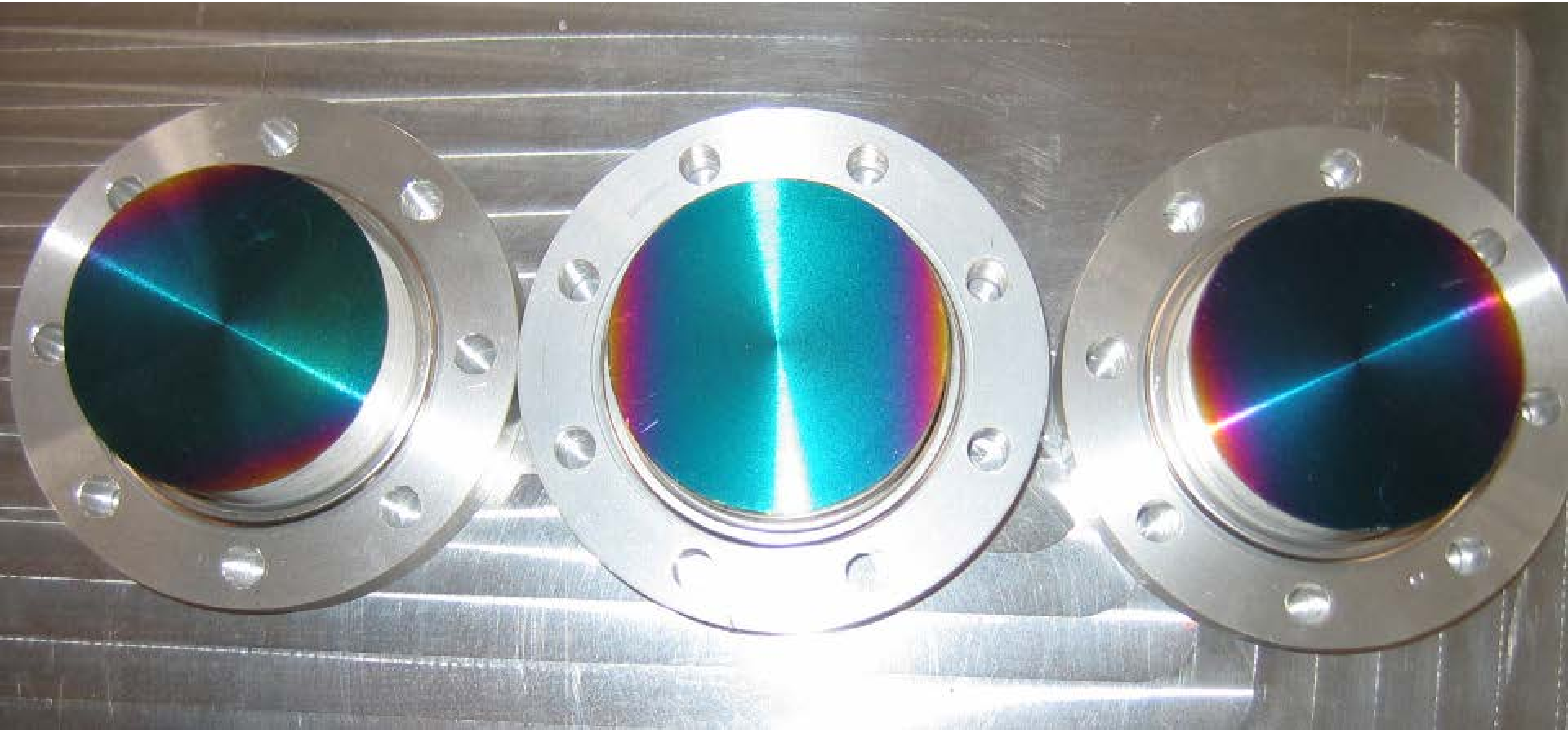
Current Density:

1.0～1.1×10^{-4} A/cm^2

Time to Discharge:

6 ～8 hours

BEPCII TiN-coated Samples



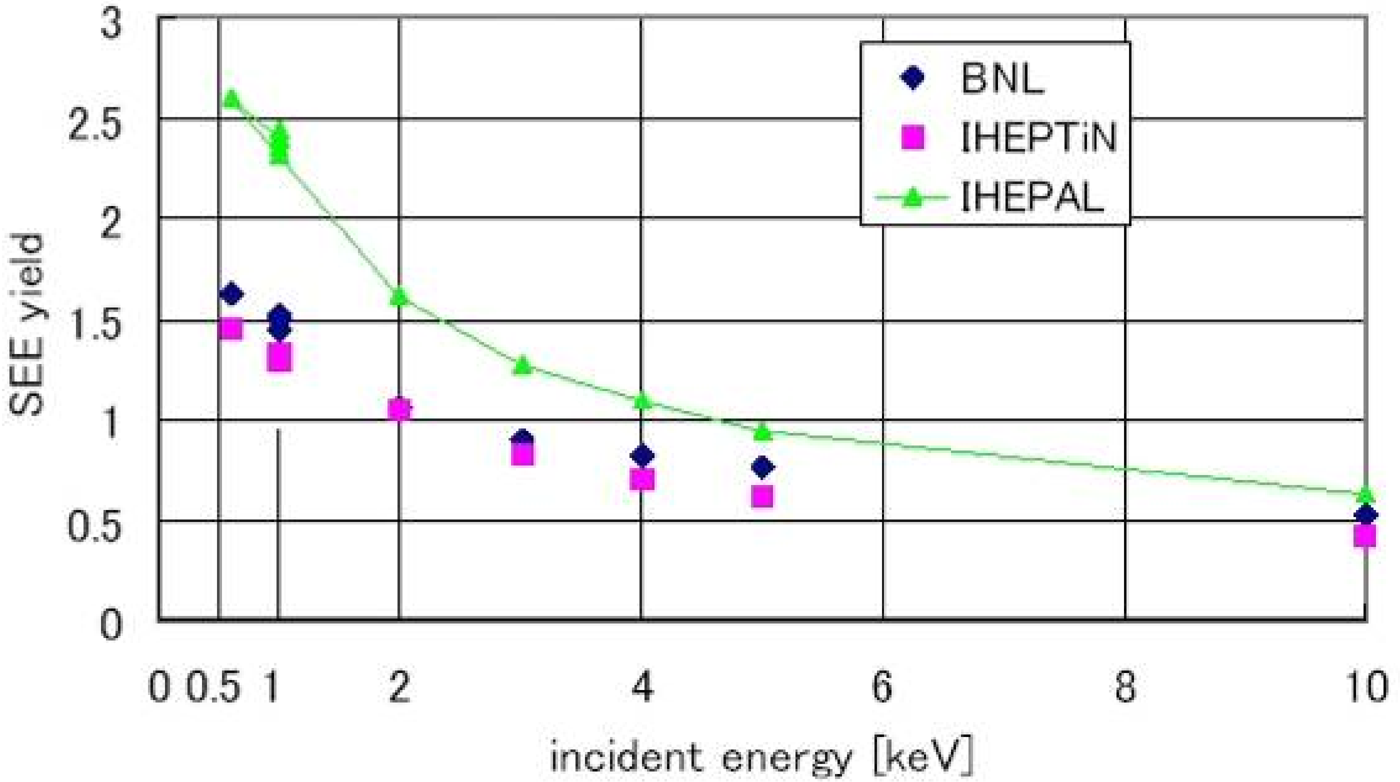
Color is due to three factors: Thickness, stoichiometry, and structure.

Gold color does not guarantee low SEY.

1. Measured SEEY

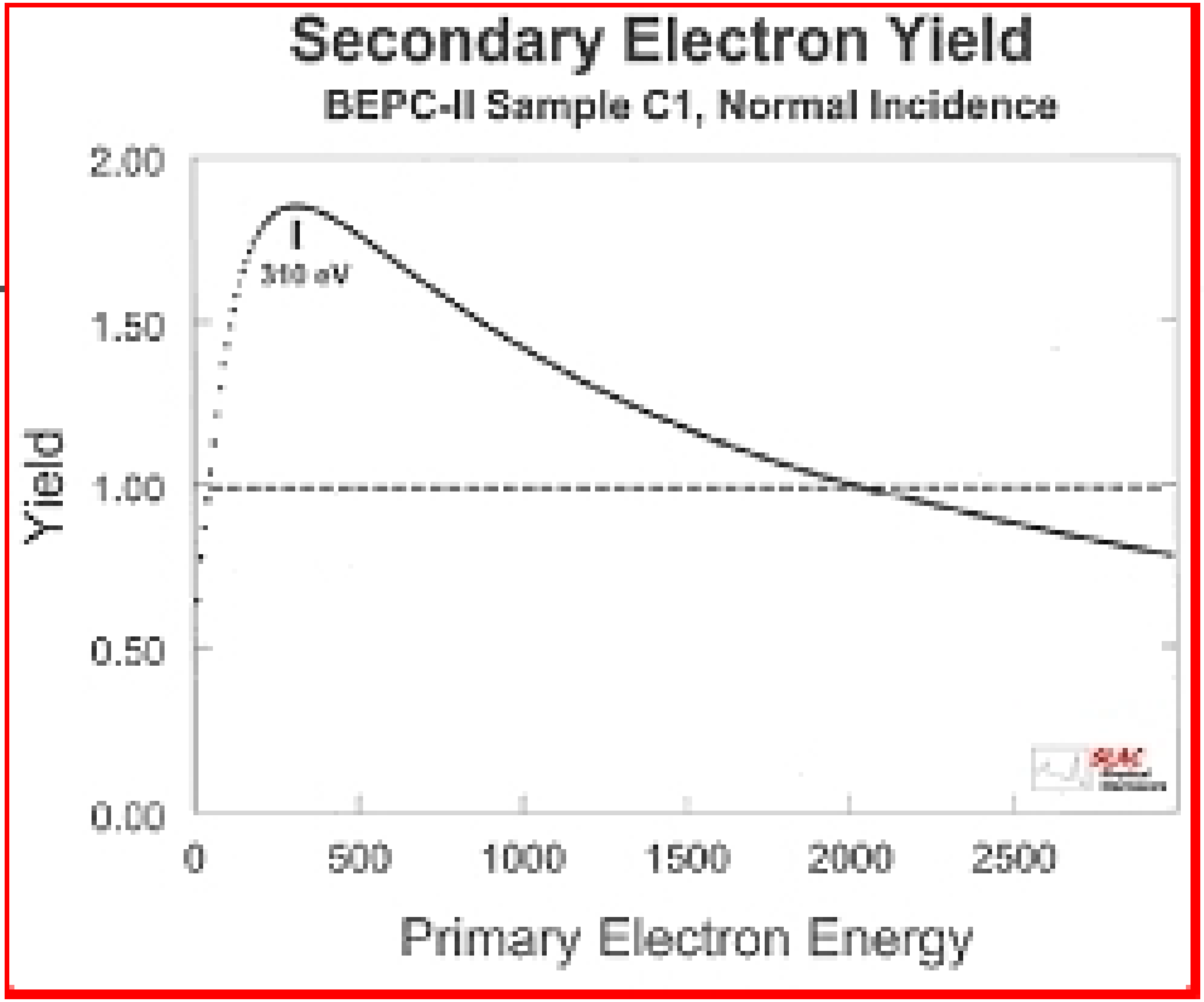
The results are shown in the figure.

SEY measured in KEK



Several points are measured at the incident energy of 1keV. The scatterings are about 2%.

The yields of about 1 at the incident energy of 2keV agree with our prior measurements of TiN films by ion-plating method.



SEY of BEPCII TiN-coated samples measured in SLAC

Analysis of TiN Coating Property

The measurement results of BEPCII TiN-coated samples

Ti/N ratio: 1.10-1.19

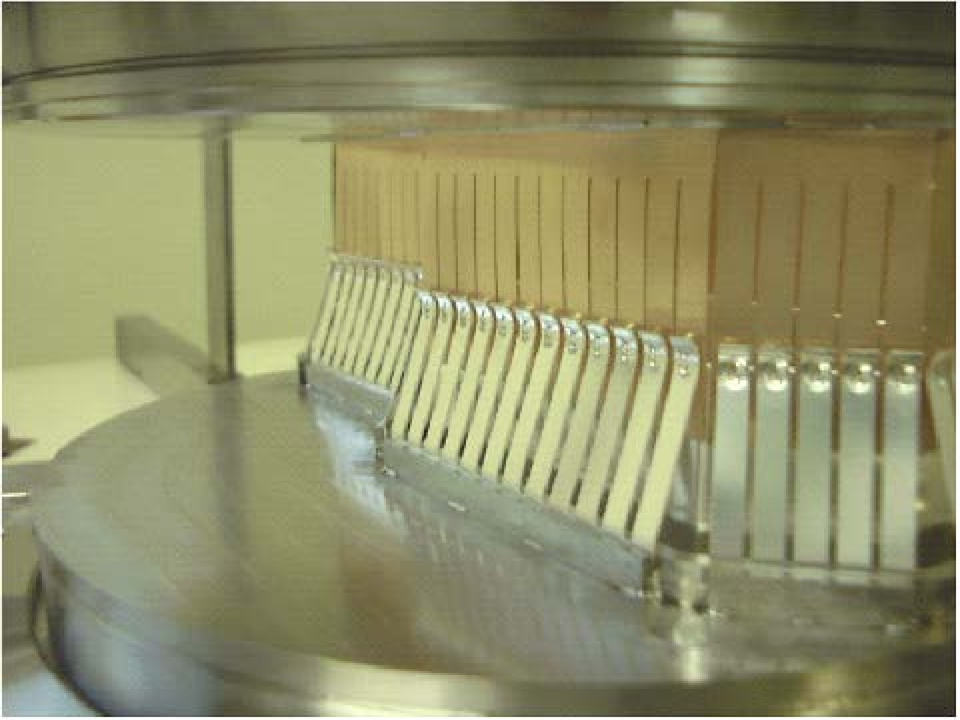
SEY: <1.95

TiN film thickness: 100-200nm

Coating adhesion: good

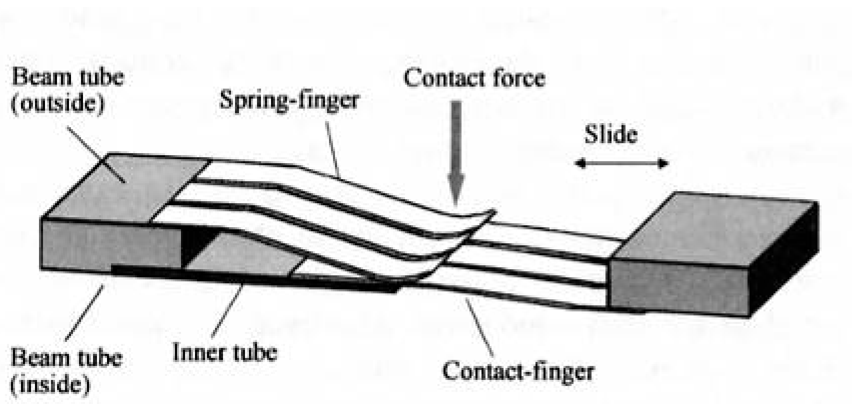
RF Shielding Bellows

The primary function of the bellows module is to allow for thermal expansion of the chambers and for lateral, longitudinal and angular offsets due to tolerances and alignment, while providing a uniform chamber cross section to reduce the impedance seen by beam.



Double-Fingers RF Bellows

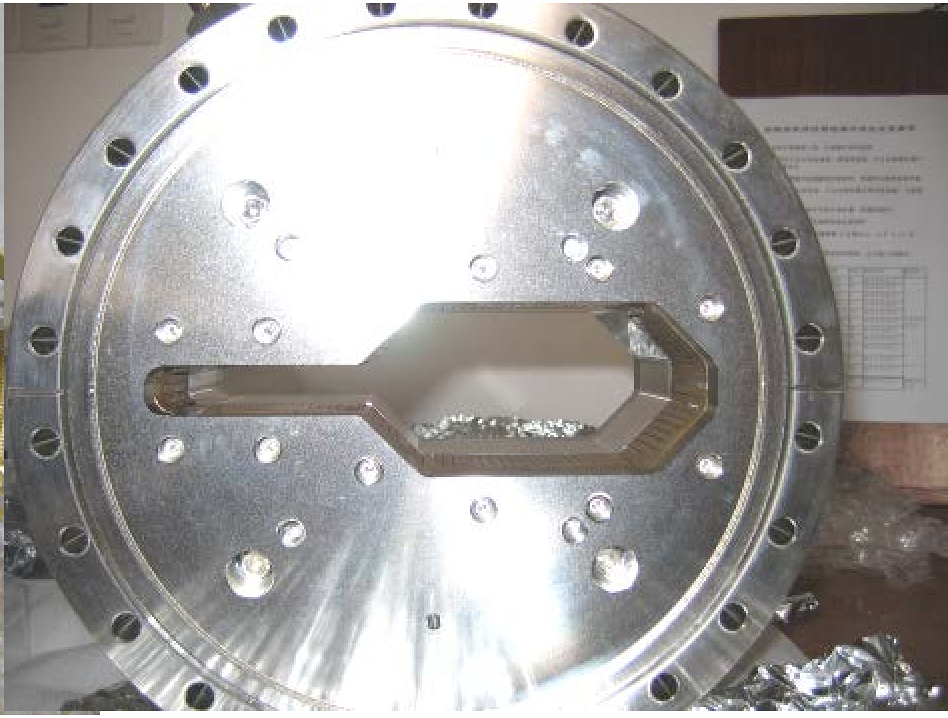
(VALQUA LTD.)



- Fingers: Shield-Finger + Spring-Finger
- Spring-Finger : Inconel alloy
- Contact-Finger: CuBe (C1720)
- Max. Contraction : 16 mm
- Max. Expansion : 8 mm
- Offset : ±2 mm
- Bend: ±50 mrad
- Tilt: 0

"PLS" type RF Bellows

(AnZ Corp.)

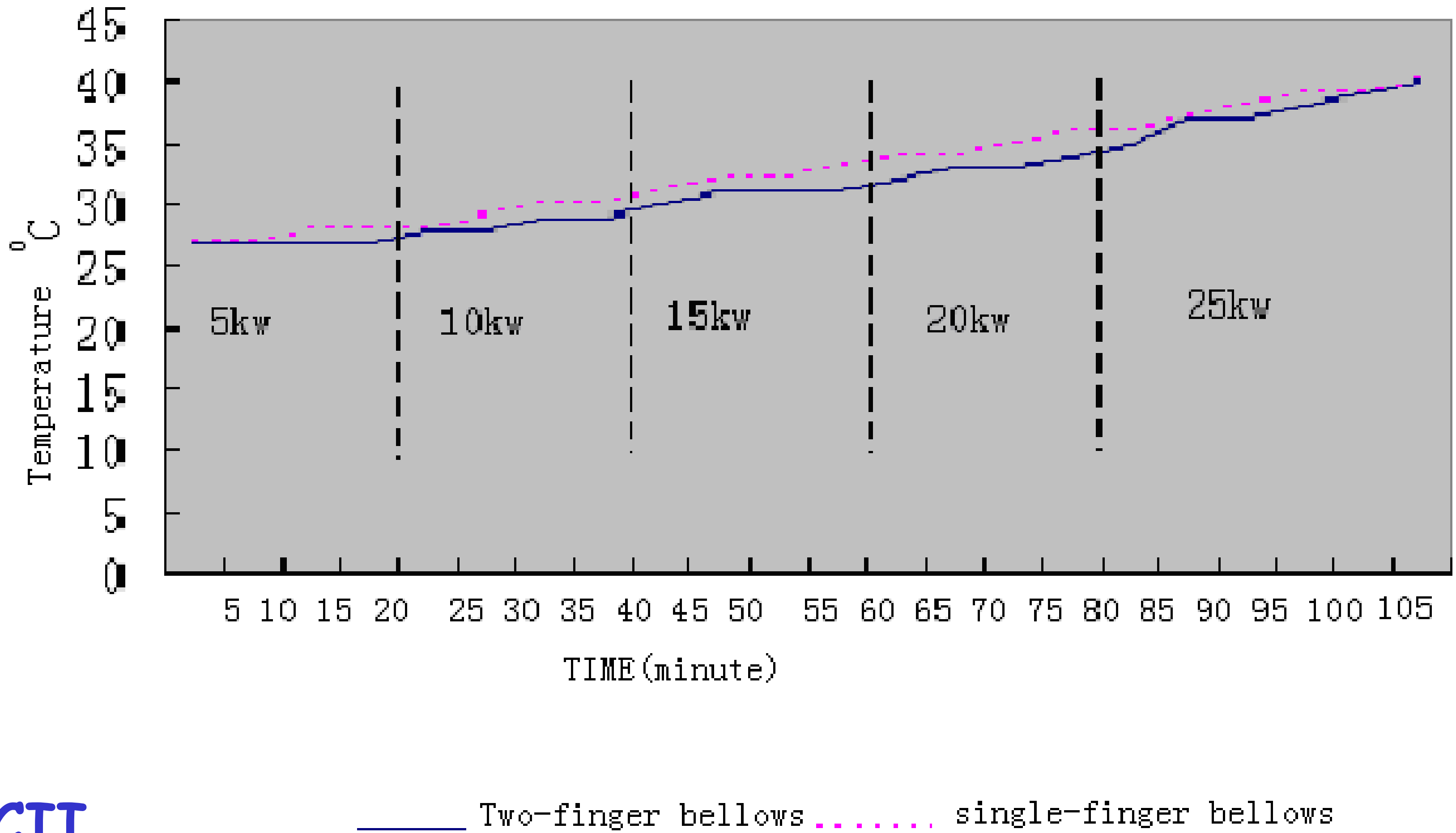


1.Structurally strong and flexible (offset: ±5 mm)

2. Functionally stable and reliable 3. Smooth inner surface

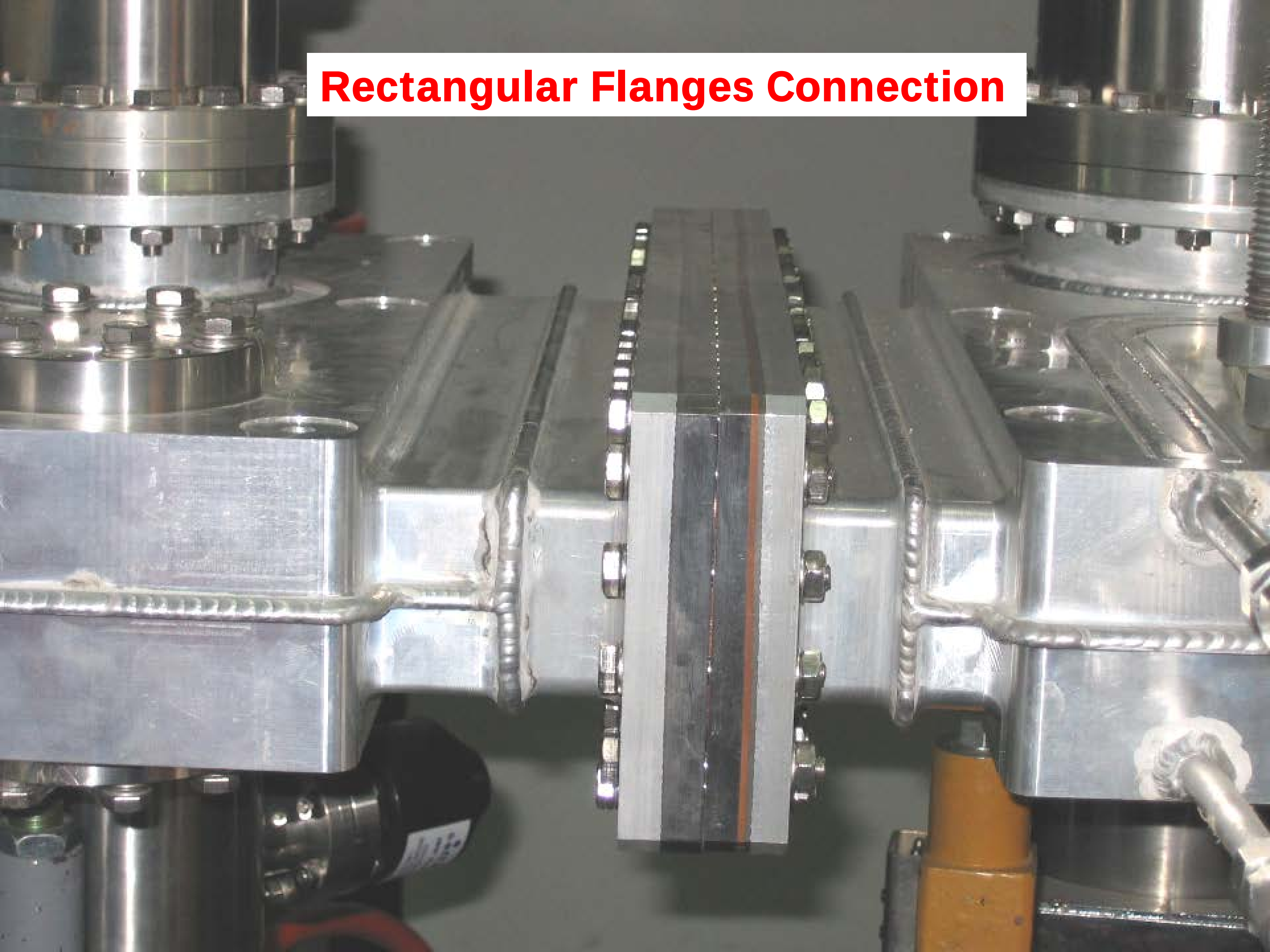
4. Low broad band impedance 5. Long operation

Temperature rise of contact fingers as a function of input powers for two kinds of RF shielding Bellows



BEPCII

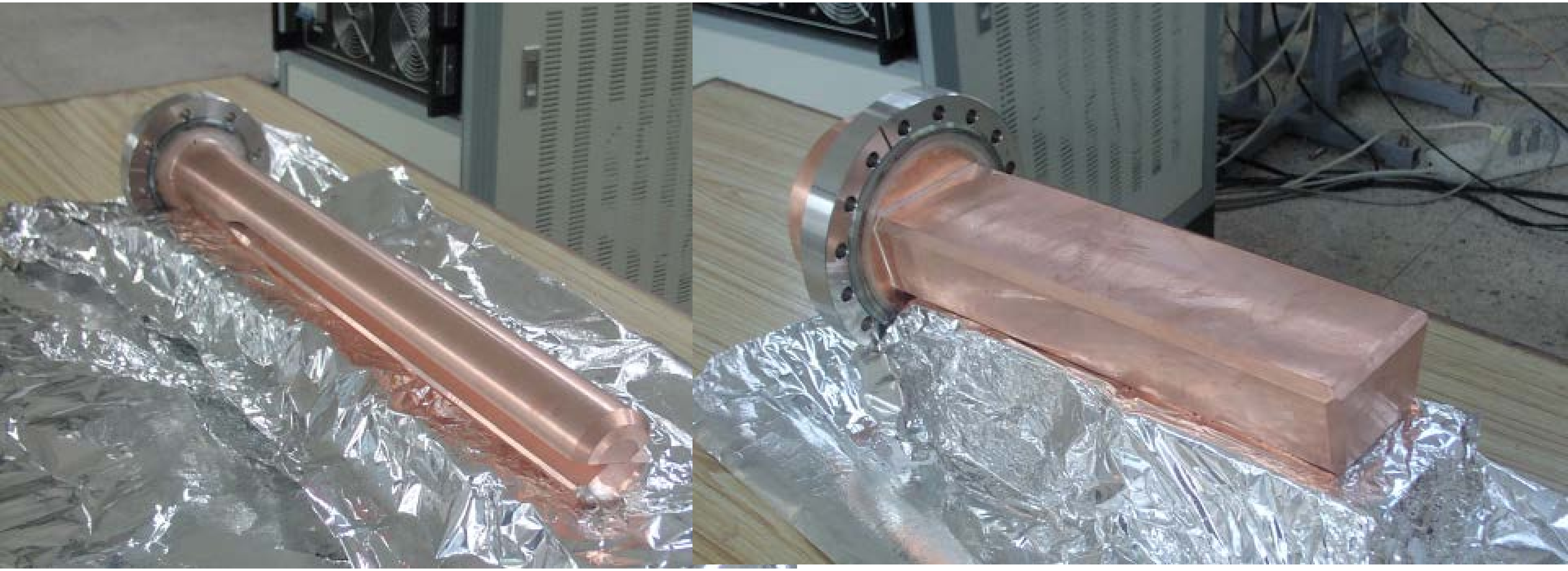
Peak wall current	RMS wall current	Peak wall current density	RMS wall current density	Peak electric field at wall
58.1 A	6.1 A	355.8 A/m	37.4 A/m	1.34×10^5 V/m


Rectangular Flanges Connection

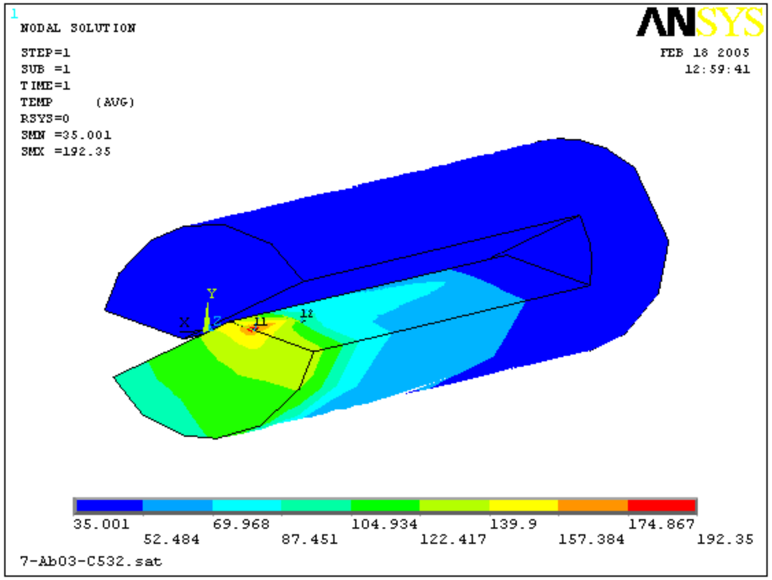
Photon Absorber

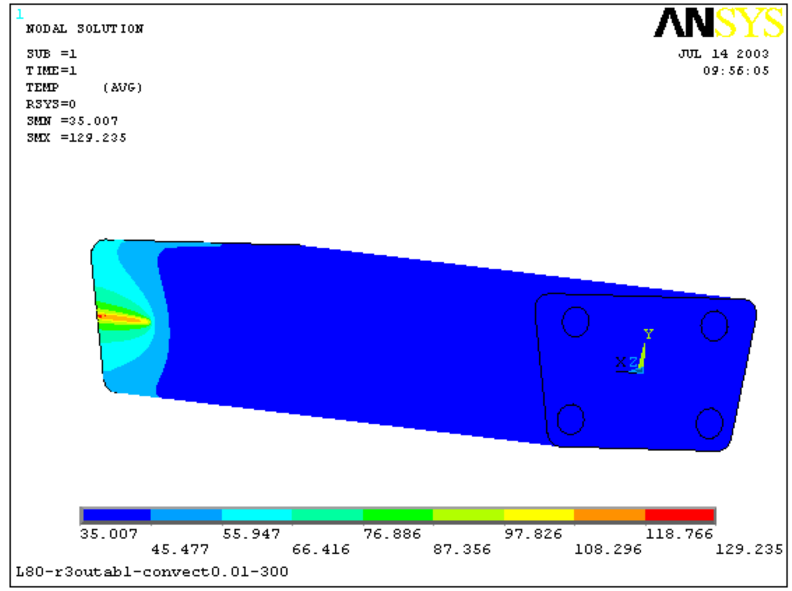
The primary function of the photon absorbers is to intercept the dipole radiation from falling on the bellows and vacuum chambers. The absorbers are made of oxygen free copper and have a direct cooling water system.

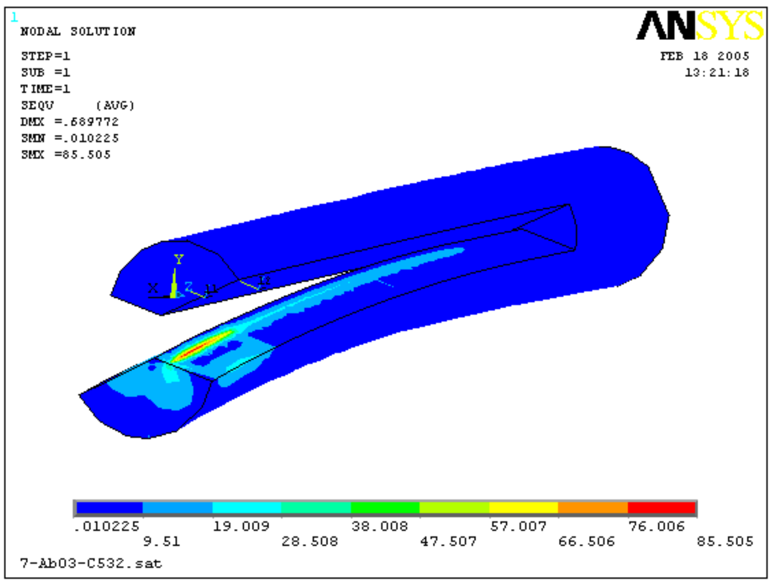
The Prototypes of Photon Absorbers

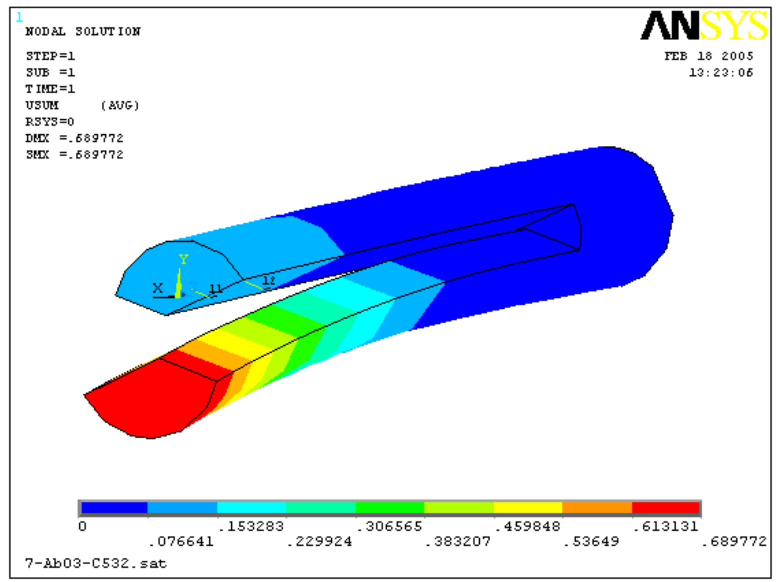


As there are the dedicated SR mode and the colliding mode in double rings, the absorbers were designed with two faces to accept the synchrotron radiation produced by the electron and the positron, respectively. In addition, in order to reduce the synchrotron radiation density of impinging on the face of the absorbers, the face is sloped at 22.5° grazing incidence angle. The rectangular absorber is located near BPM to increase the cutoff frequency.







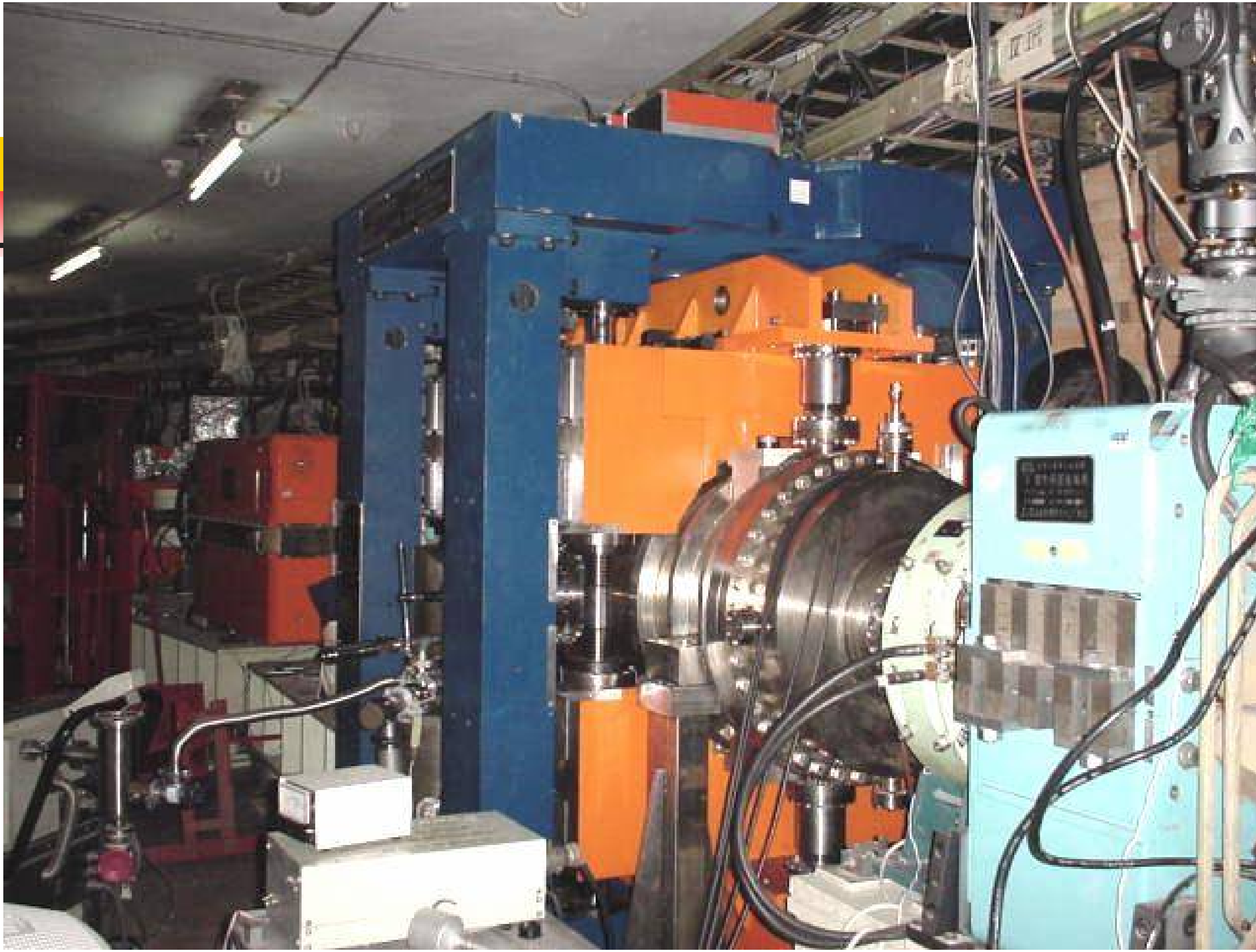


Max. temperature:192°C， Max. temperature on cooled wall:111°C，

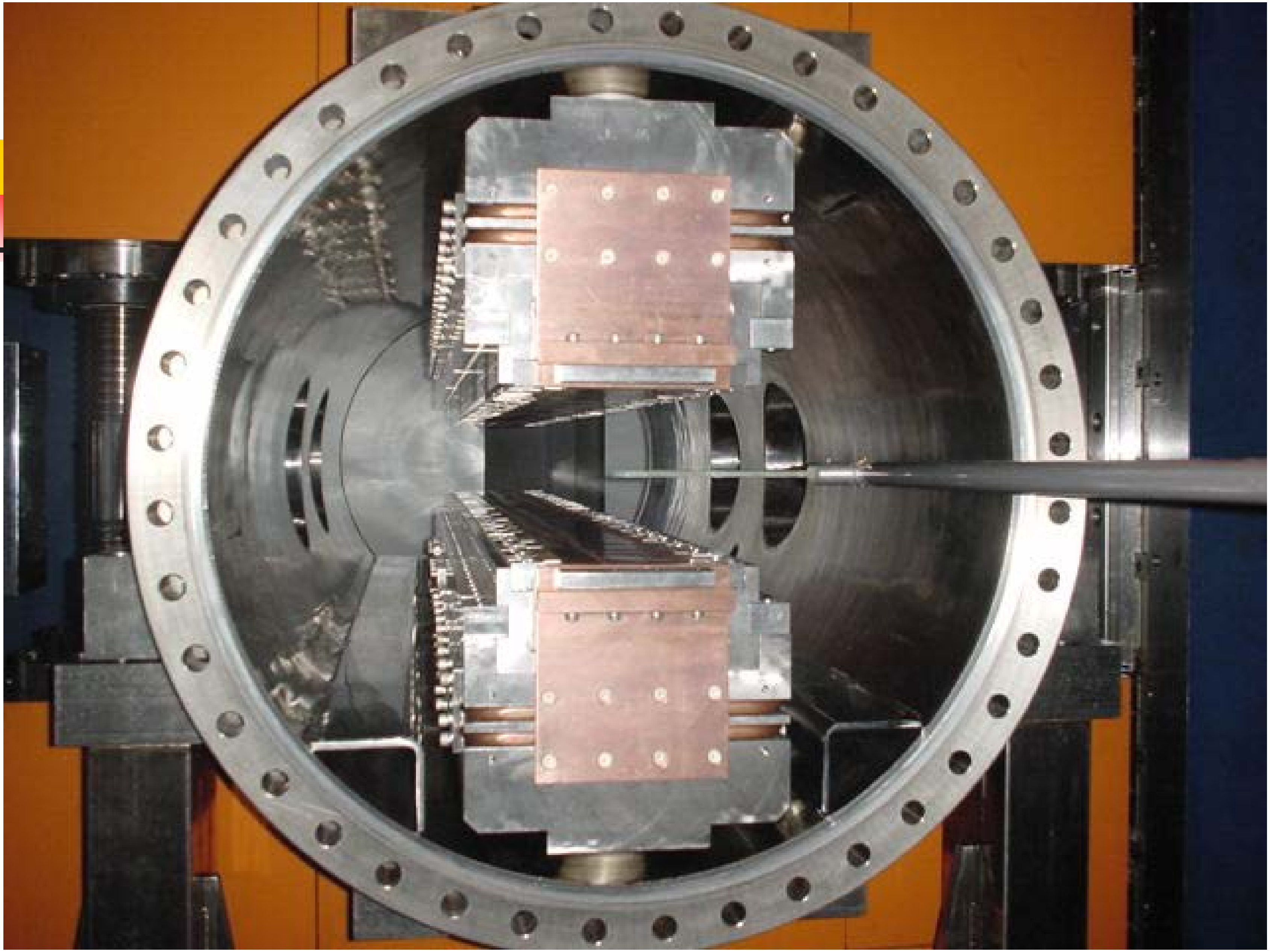
Max. thermal stress: 85Mpa, Max. distortion: 0.69mm.

In-vacuum Wiggler

- One of the main difficulties for fabricating in-vacuum wiggler is how to achieve the ultra-high vacuum in the situation of the large outgassing rates produced by the permanent-magnet blocks.
- The static pressure of 2×10^{-10}Torr has been achieved by coating TiN on the permanent-magnet blocks and the reasonable pumpdown techniques.



In-vacuum Wiggler

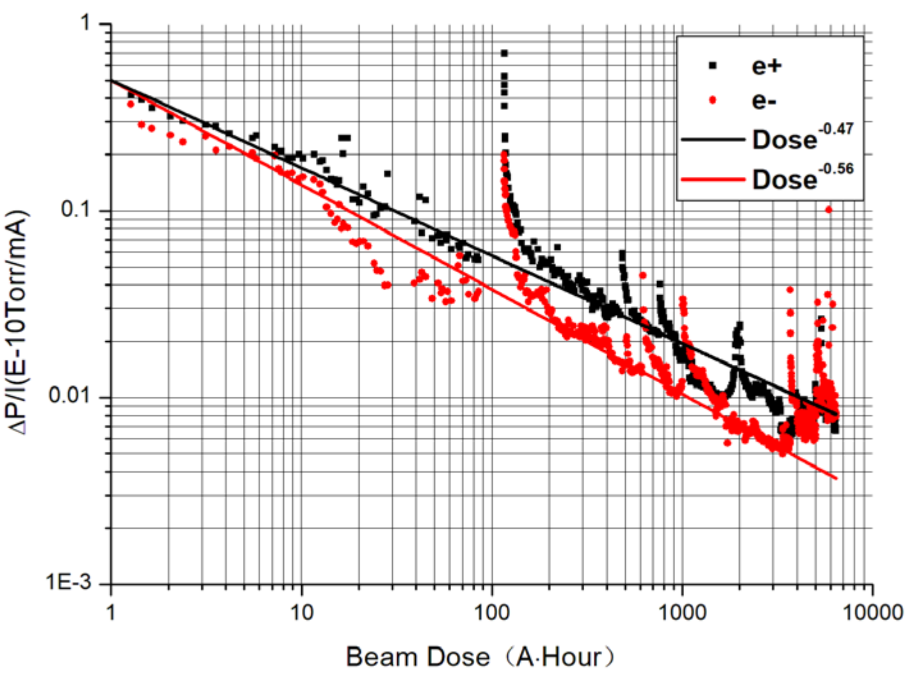


In-vacuum Wiggler Opened

Overall Vacuum Performance

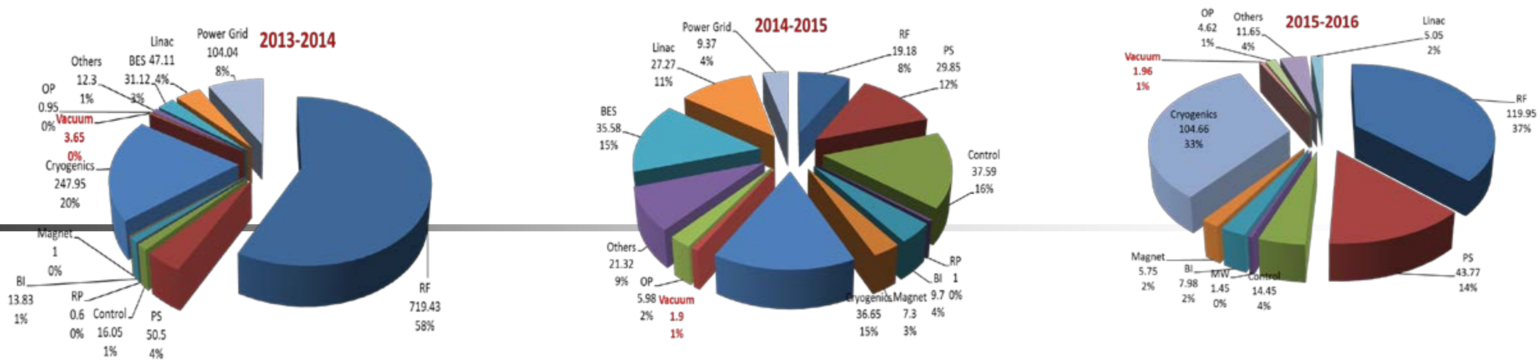
- The vacuum components began to be installed in storage ring tunnel in March, 2006, and all the sectors of double rings reached a static pressure of less than 6.0×10^{-10} Torr by the end of October, 2006.
- The dynamic pressure rise decreased to 2×10^{-7} Pa/A after 1000 Ah of the beam dose.
- Some problems occurred for the vacuum components such as RF bellows, vacuum chambers, photon absorbers etc.
- The vacuum system has performed well during beam run, most of vacuum components were repaired in time of machine shutdown.

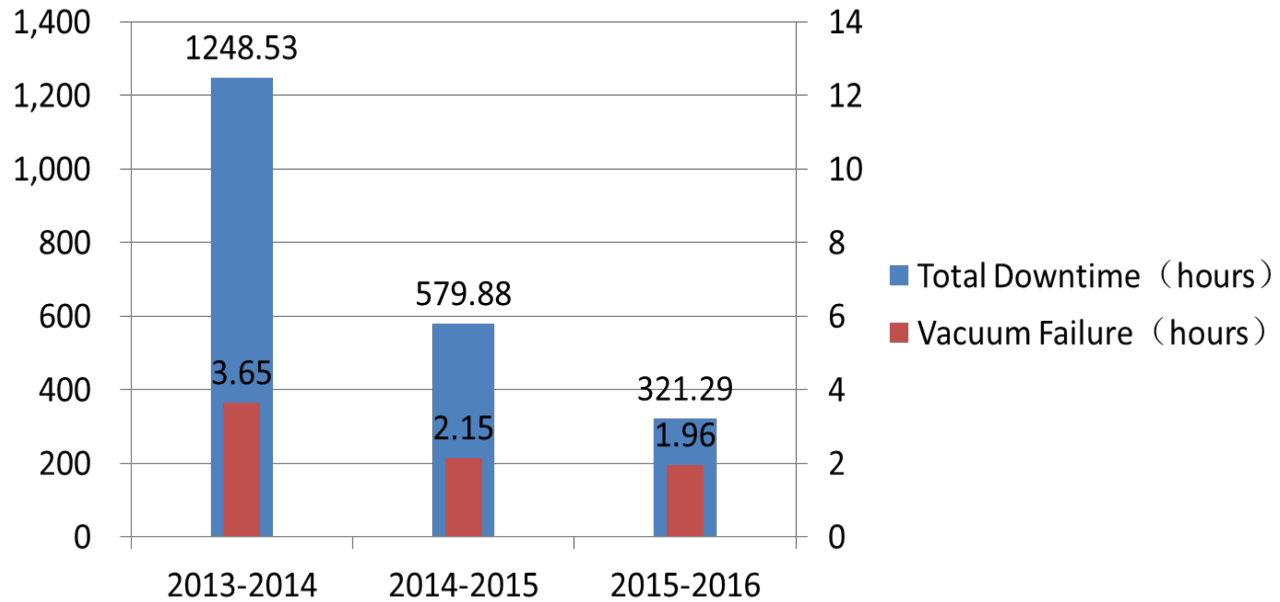
Dynamic pressure rise vs. beam dose

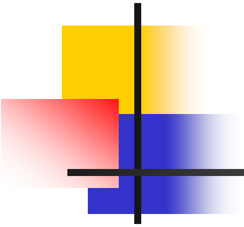


- For electrons down to 10^{-7} Pa/A and for positrons down to 2×10^{-7} Pa/A nearly 1000 Ah of beam dose.
- Each exposure to atmosphere, the dynamic pressure was relatively high when a beam started to run in the storage ring.

Statistics of each hardware system failure time







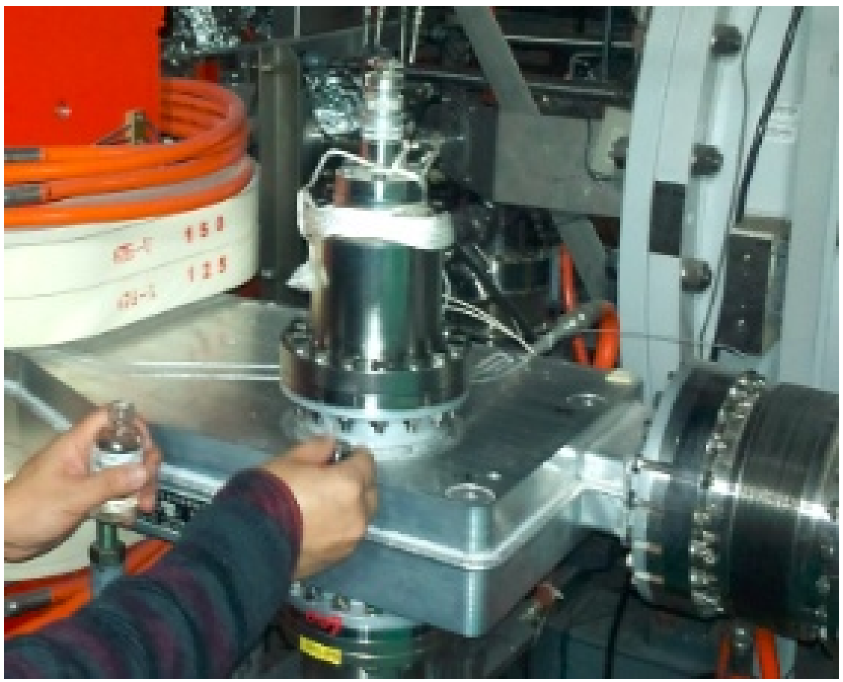
- Since 2013, only a few downtime due to vacuum failure every year.
- Several vacuum systems exposed to the atmosphere are due to RF(coupler ceramic), magnet(kicker), beam measurement(DCCT) system failures.

RF shielding Bellows troubles

SR? Beam? HOM?

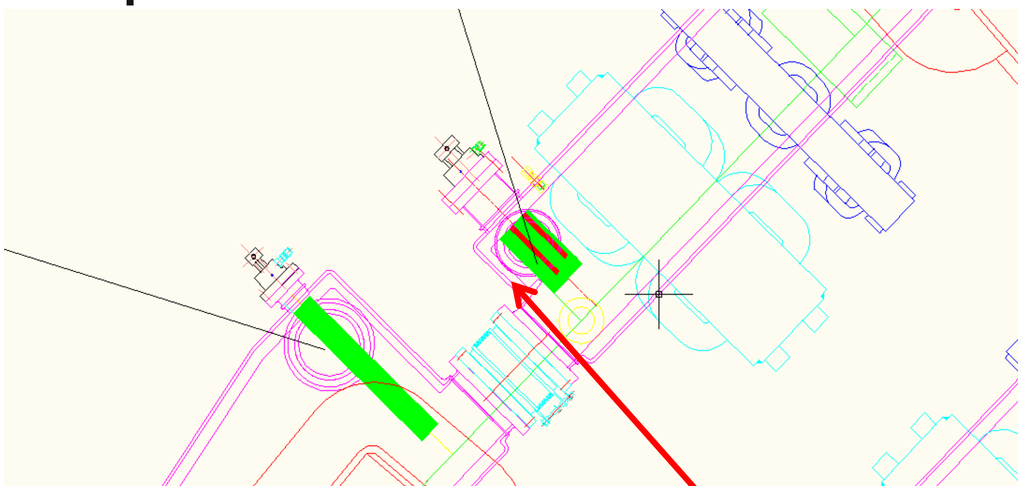
Installation errors

The leak of Al-SST transition flange

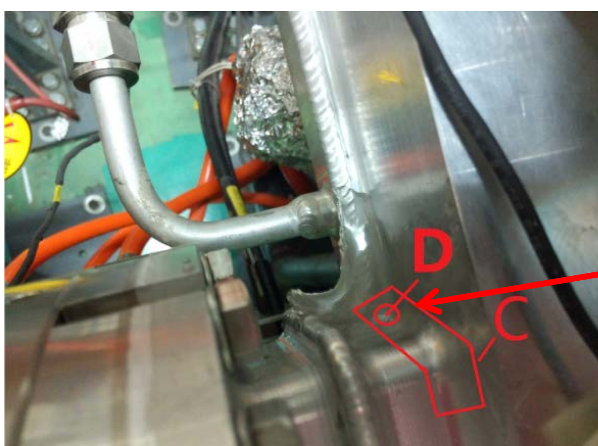


- The nearby pressure increased from 2×10^{-10}Torr to 1.5×10^{-9}Torr, and the current of ion pump risen also.
- The leak was located on the weld of Al-SST transition flange.
- Leak rate: ~ 4.2×10^{-7}Torr ·L/s.
- The leak was cured by vacuum sealant.

The leak of the aluminum vacuum chamber material

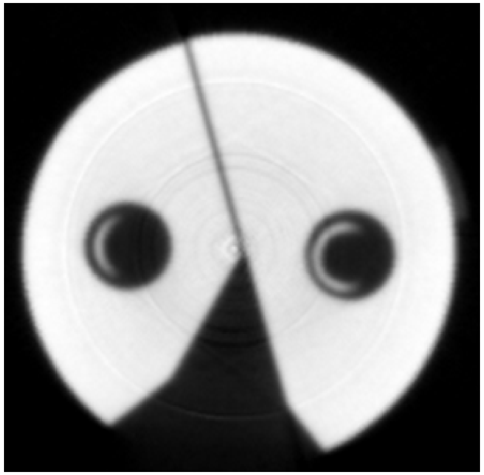


The Location of leak

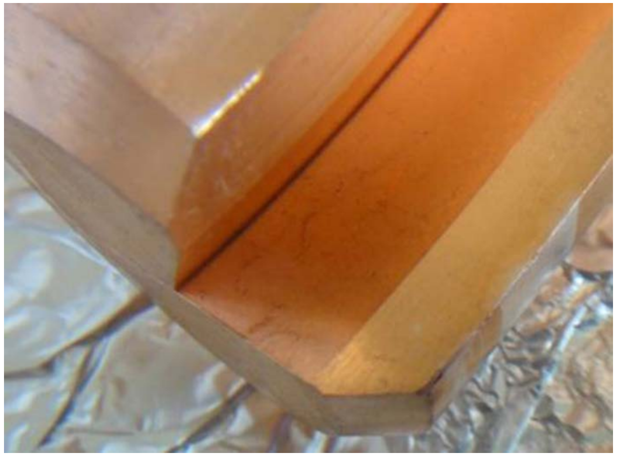


- The nearby pressure increased to 2×10^{-8}Torr.
- Helium and alcohol were used to locate the position of leak.
- The leak was caused by the material defect, not by flanges and welding seams.
- Similar problems have occurred in two vacuum chambers to date.
- The leaks were repaired by vacuum sealant, and the spare chamber have been prepared.

The damage of photon absorber

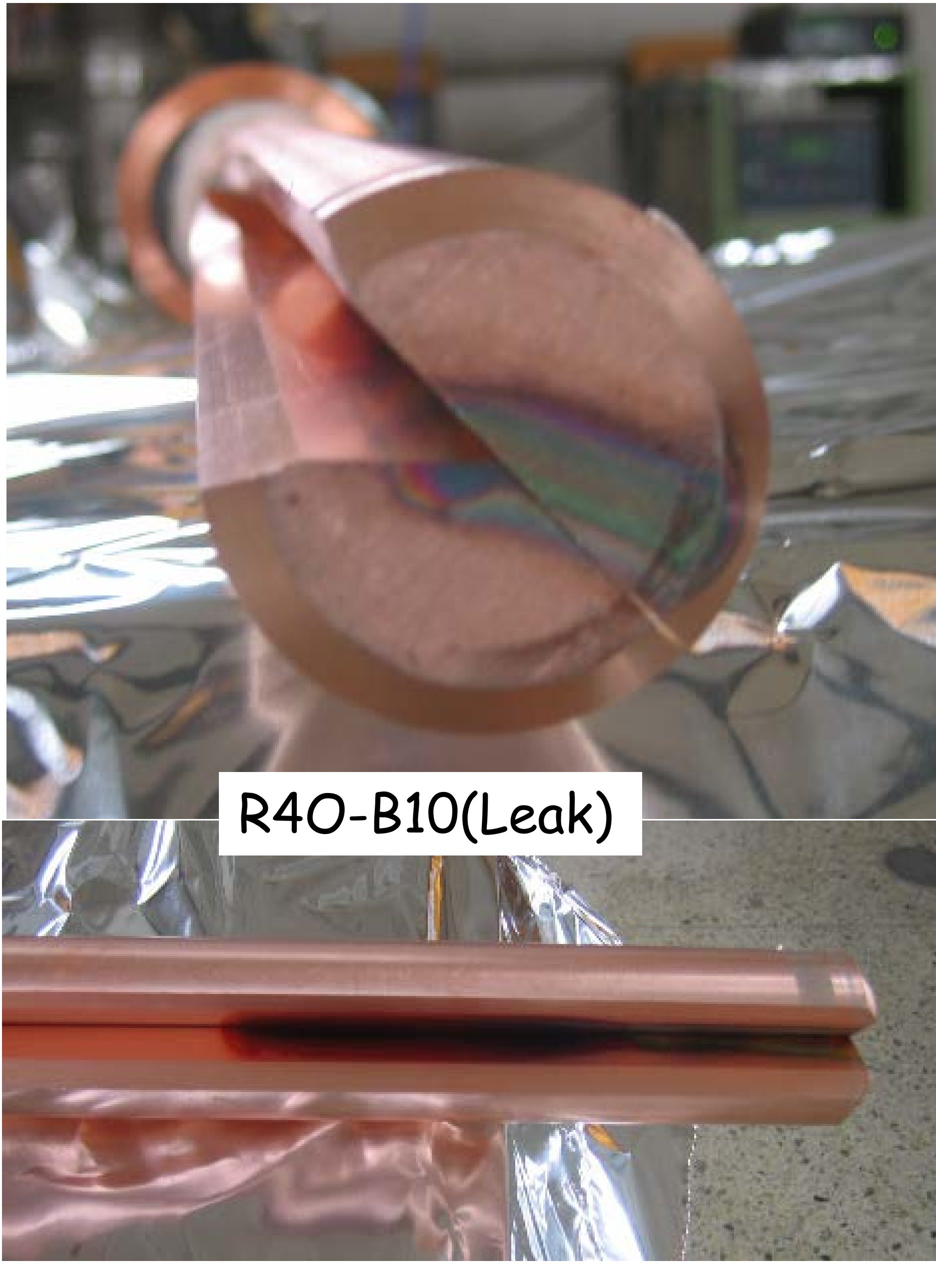


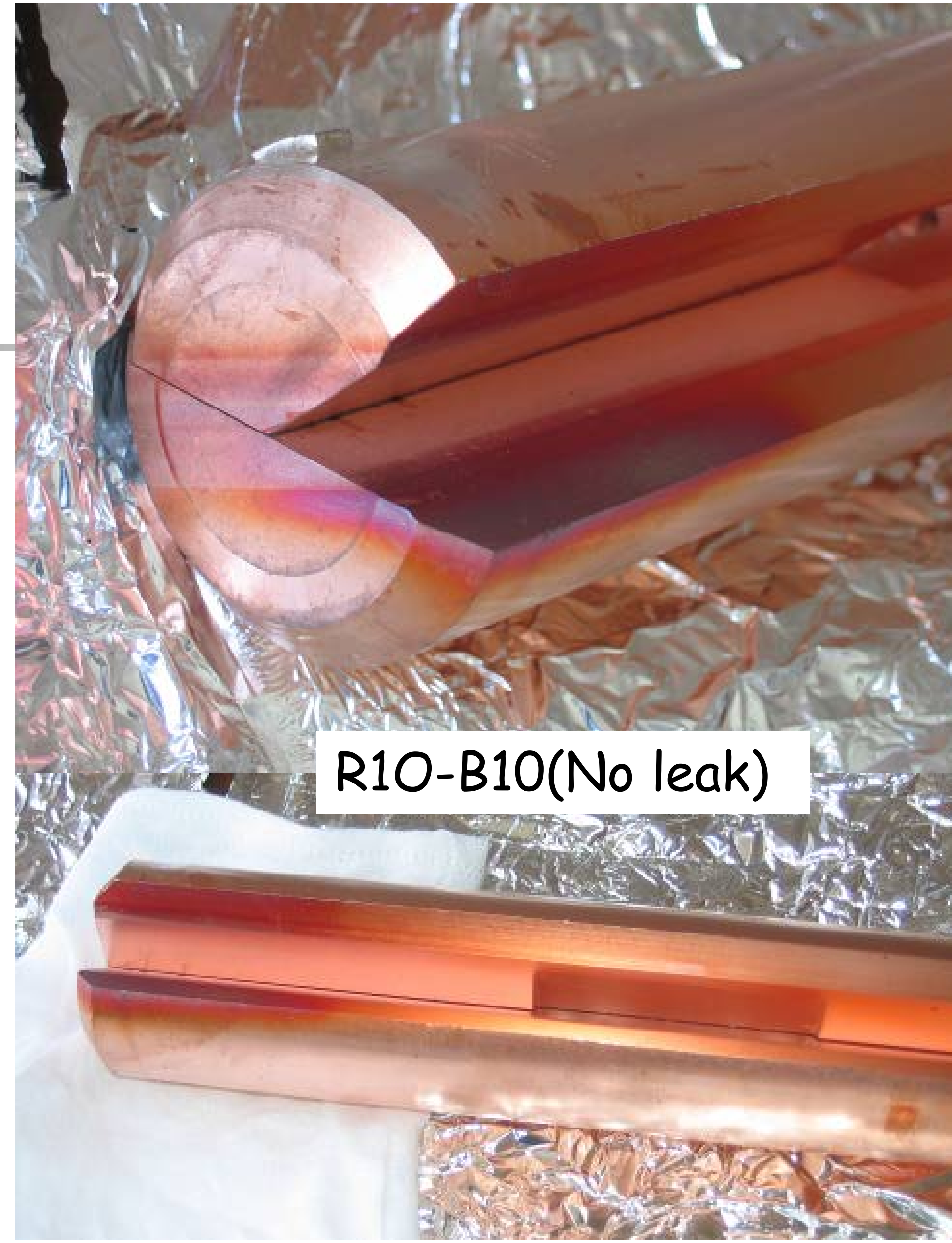
Industrial CT check



H_2 furnace treatment

The surfaces were oxidized seriously.
There were not problems found by CT.
A leak rate of 1.2×10^{-7}Torr·L/s was detected and the thin cracks were seen after Hydrogen furnace treatment at 700°C.
Possible reason: material defect.

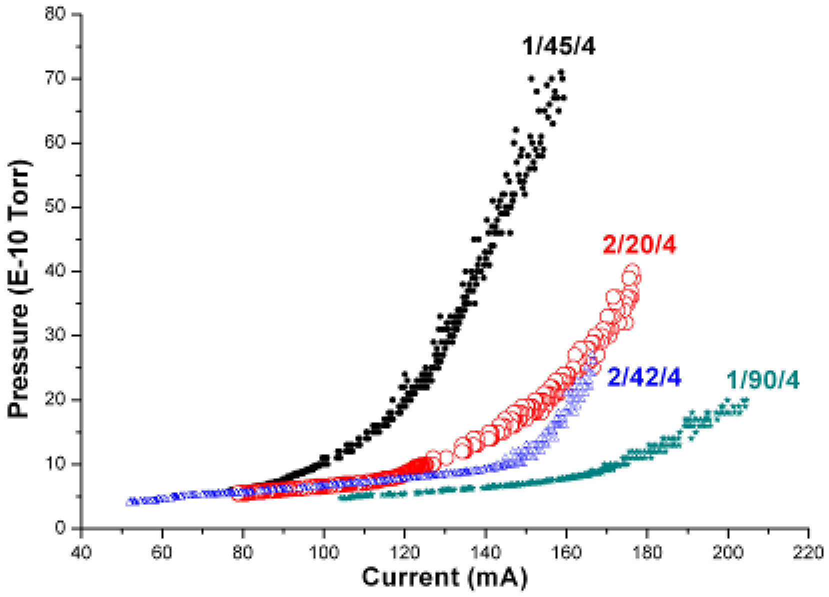




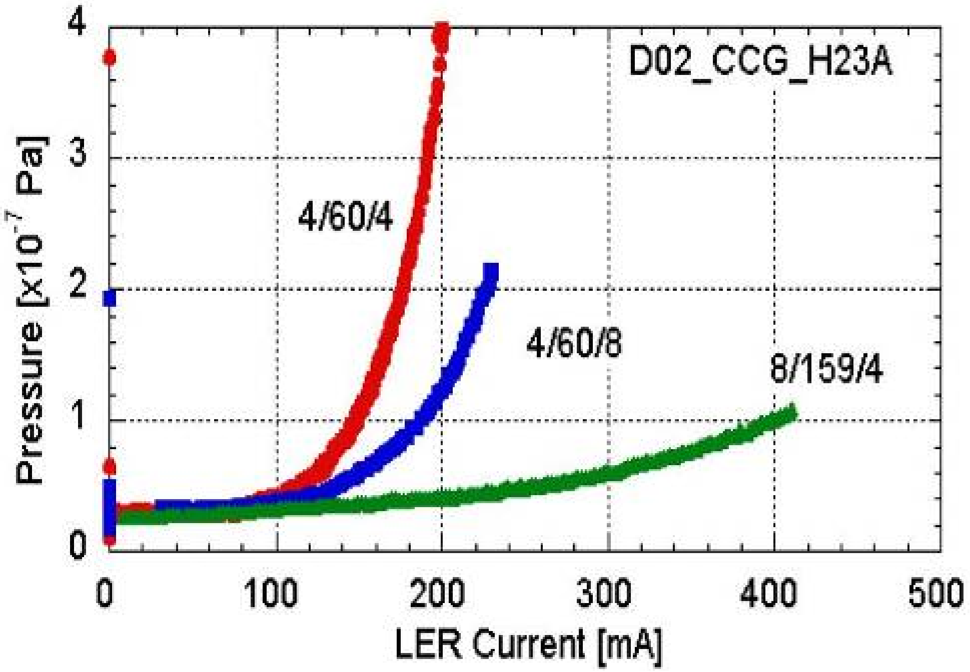
Comparation of a leak and no-leak absorber

P vs I curve for the different pattern of e^+ bunches

BEPCII



KEKB



- **The nonlinear effect of pressure with beam current were observed in the positron ring, which were related to the bunches patterns.**
- **The possible reason was electron multipacting effect.**

Conclusions

- The colliding luminosity of the BEPCII reached the design parameter in April 2016.
- The vacuum system has performed well during beam running, and the dynamic pressure rise as a function of beam dose decreased to 2×10^{-7} Pa/A after 1000 Ah of the beam dose.
- Several vacuum components such as RF bellows, vacuum chambers and photon absorber failed, and were repaired or replaced.

Thank You for your attention !