CEPC vacuum system development and status

Yongsheng Ma

Vacuum group, IHEP,CAS

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中国科学院高能物理研究所

Institute of High Energy Physics

Chinese Academy of Sciences

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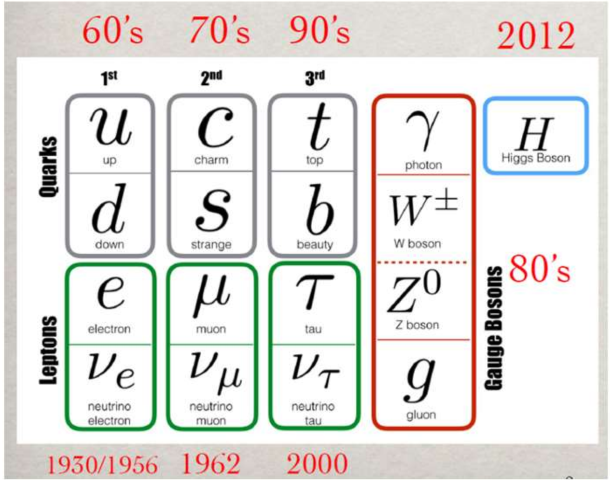
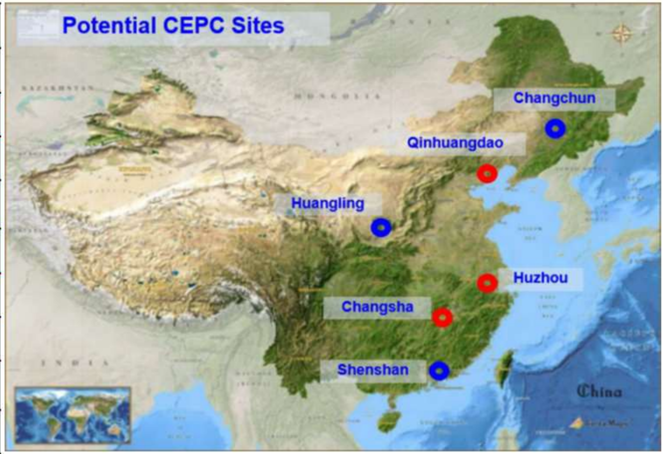
Introduction

- CEPC is an e+e- Higgs factory producing Higgs / W / Z bosons and top quarks, aims at discovering new physics beyond the Standard Model.
- Proposed in 2012 right after the Higgs discovery
- Proposed to commence construction in ~2026 and start operation in 2030s.
- Upgrade: Super pp Collider (SppC) of s ~ 100 TeV in the future.

CEPC Major Milestones



CEPC Operation mode		ZH	Z	W⁺W⁻	ttbar
$\sqrt{s}$ [GeV]		~ 240	~ 91.2	~ 160	~ 360
Run time [years]		7	2	1	-
CDR (30MW)	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	3	32	10	-
	$\int L\, dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
	Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run time [years]		10	2	1	5
Latest TDR (50MW)	L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	8.3	191.7	26.6	0.8
	$\int L\, dt$ [ab^{-1}, 2 IPs]	20	96	7	1
	Event yields [2 IPs]	4×10^6	4×10^{12}	5×10^7	5×10^5



Introduction

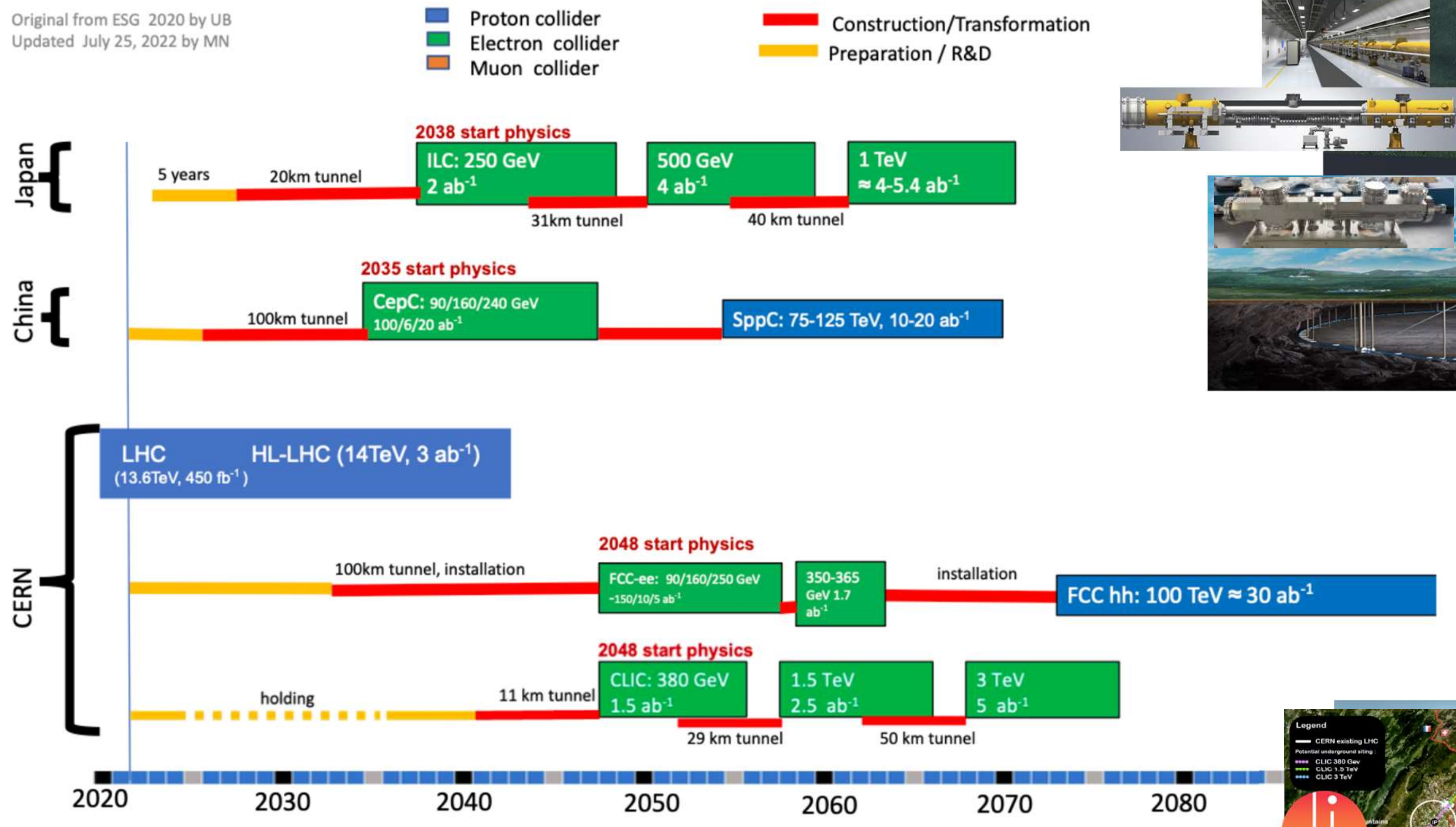
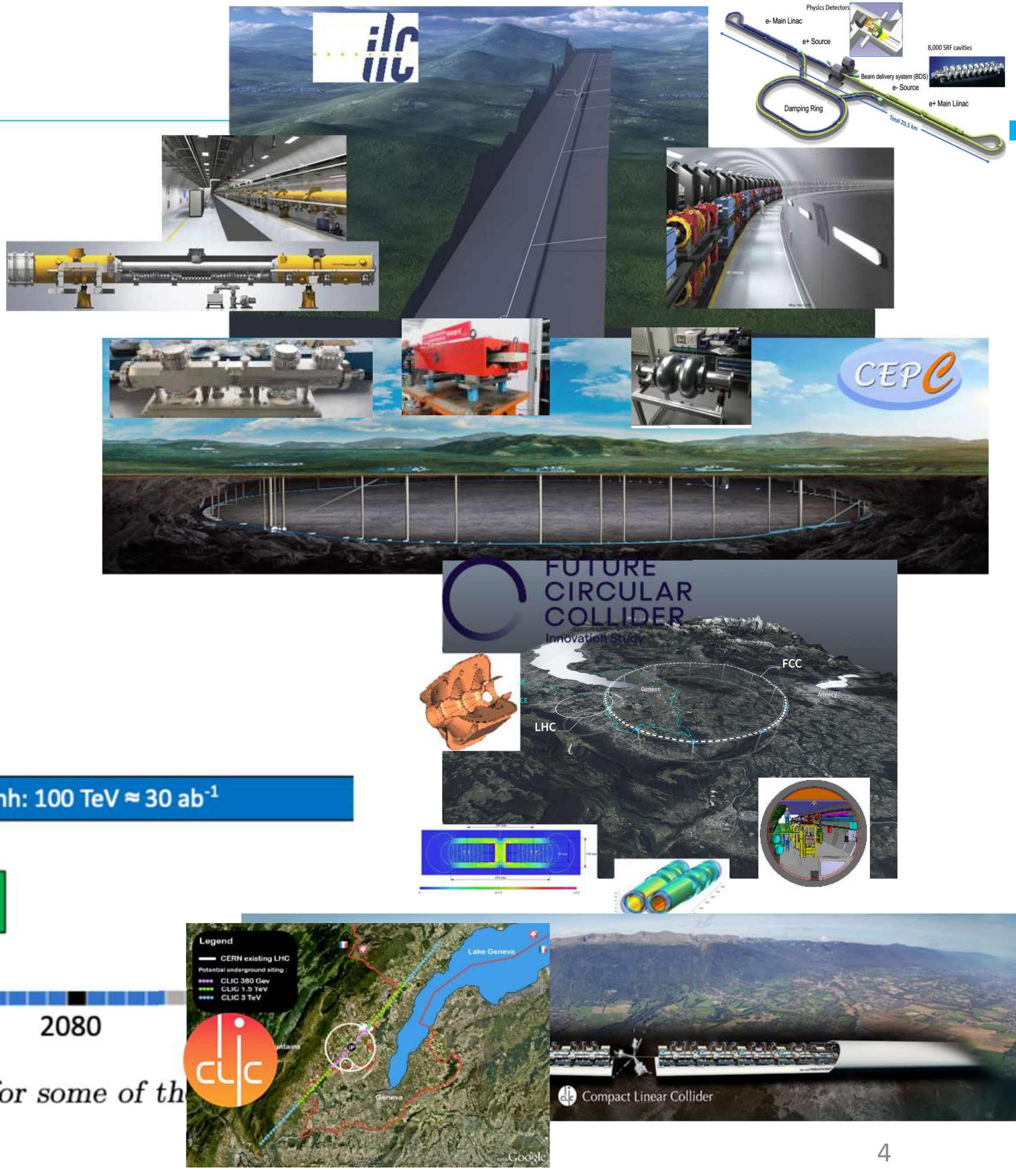


Figure 6-40. *Projected timelines for R&D, construction, and physics operations for some of th[e] proposed future collider options.*



Introduction

The US EF community proposes to develop plans to site an e^+e^- collider in the US. A Muon Collider remains a highly appealing option for the US, and is complementary to a Higgs factory. For example, some options which are considered as attractive opportunities for building a domestic EF collider program are:

- **A US-sited linear e^+e^- (ILC/CCC) Collider**
- **Hosting a 10 TeV range Muon Collider**
- **Exploring other e^+e^- collider options to fully utilize the Fermilab site**

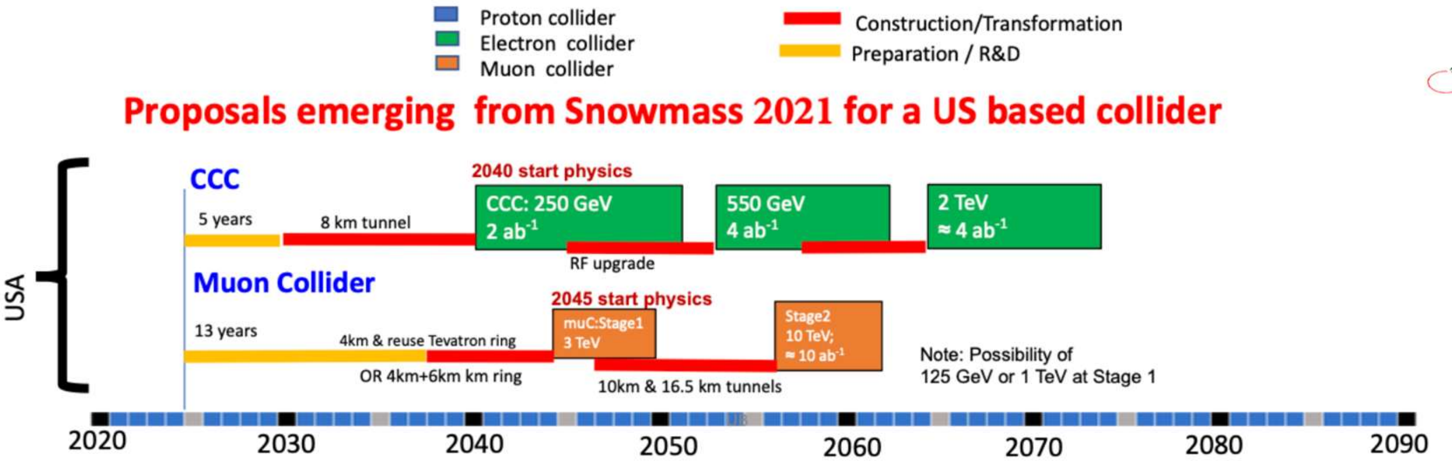
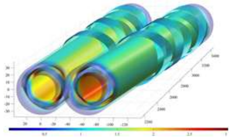
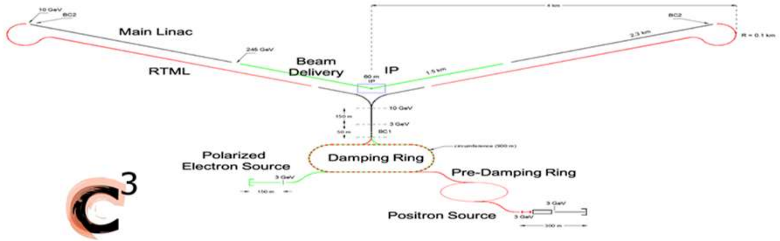


Figure 6-41. *Approximate timelines for proposals for ILC/CCC and Muon Collier emerging from Snowmass 2021 for a US based collider option.*





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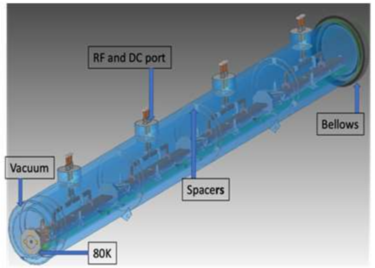
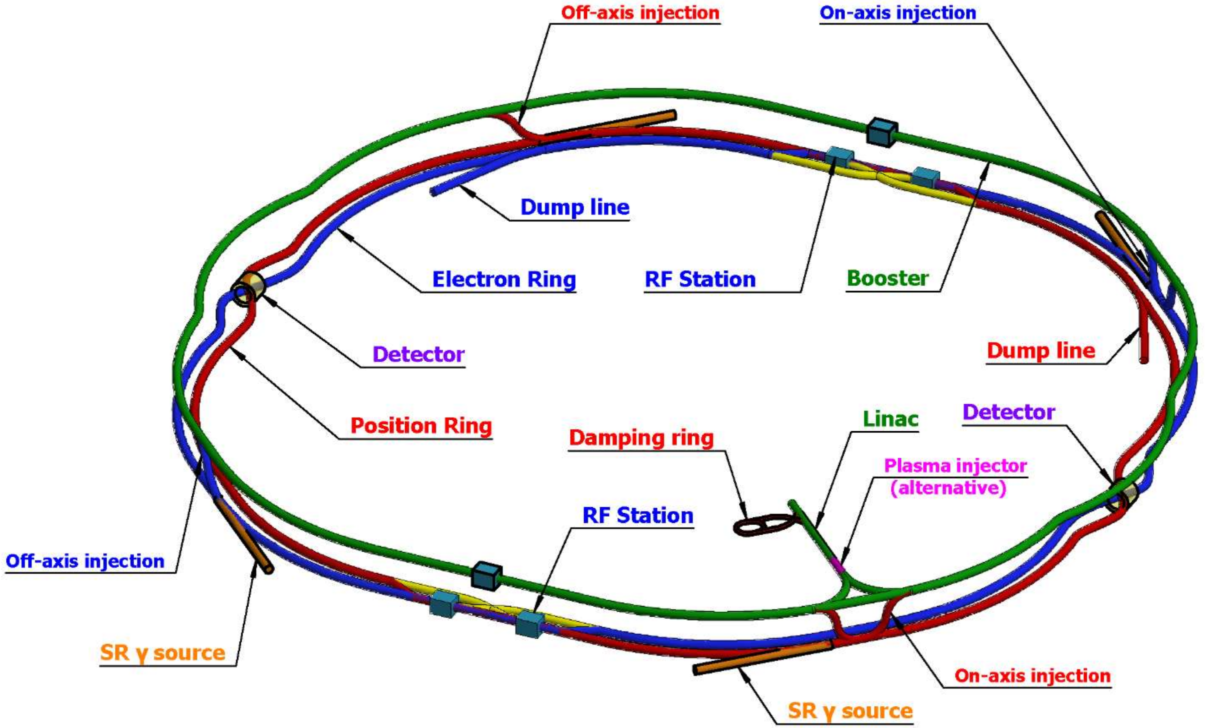


Preview of CEPC vacuum system

Machine and Vacuum Parameters

	E	I	ρ
	Gev	A	m
Higgs	120	0.0167	10700
W	80	0.084	10700
Z	45.5	0.803	10700
tt	180	0.0033	10700

Accelerator	**length/m**
LINAC	1,601+335
Damping ring	147
Booster	100,000
Collider	200,000
Transport line	4,680
Total length/m	*306,763*



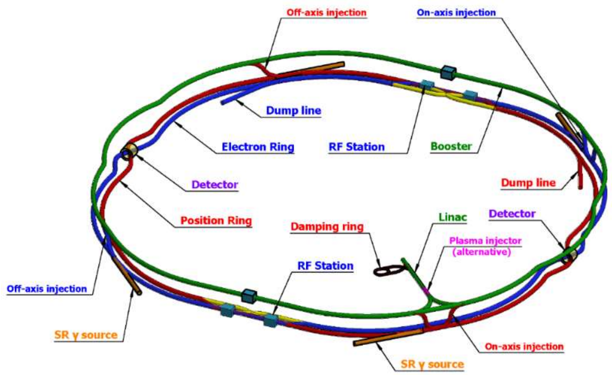
Vacuum requirements and configuration

	Energy	Material	Cross Section/mm	Length/m	Dynamic pressure /Torr
LINAC	30 GeV	Stainless steel, copper	Φ20~30	1,601+ 335 (BTL)	Acc $<2\times10^{-7}$ E-gun$<2\times10^{-8}$
Damping ring	1.1 GeV	Extruded aluminum 6061	Φ30/Al 6061	147	$<2\times10^{-8}$
Booster	30 to 180 GeV	Extruded aluminum 6061	Φ56/thickness of 2mm	100,000	$<3\times10^{-8}$ tt$<4\times10^{-8}$
Collider	45.5~180 GeV	Extruded copper, NEG film SEY<1.2	Φ56/thickness of 2mm	100,000×2	Z$<8\times10^{-10}$ tt$<1\times10^{-8}$
MDI	45.5~180 GeV	Copper/tungsten alloy, NEG film	Φ20	12	$<3\times10^{-9}$
LTB	30 GeV	Stainless steel	Φ56	3,000	$<1\times10^{-7}$
BTC(CTB)	6 GeV	Stainless steel	Φ56	240×6	$<1\times10^{-7}$
DL	1.1 GeV	Stainless steel	Φ30	240	$<1\times10^{-7}$

Layout & configuration of Collider

	Classification	*length/m*
collider	Arc beam pipe	78752
	Straight section beam pipe	**8456**
	RF Substitute pipe	**1192**
	RF system	352
	Insertion and extraction	286
	Manifold for SIP	**1333**
	Bellows	**2082**
	BPM	300
	Manifold for Gauge & RGA	247
	Detector 1	12
	Detector 2	12
	Collider section	7000
	Total length	**100000**

Parameter	e^+ & e^-
Energy [GeV]	45.5~180
Beam current [A]	0.0033~1.39
Circumference [m]	100,000 ×2
Bending radius [m]	10,700
Beam pipe material	Extruded copper (water-cooled) NEG coating
Beam pipe shape (mm)	Φ56/thickness of 2mm
Pump type in arcs	SIP



Modes	E (Gev)	Beam gas scattering lifetime (h)	Vacuum requirement (Torr)
Higgs	**120**	**10**	$\mathbf{2 \times 10^{-9}}$
W	80	5	1.5×10^{-9}
Z	45.5	3	8×10^{-10}
tt	180	15	1×10^{-8}

Collider rings Vacuum requirements

- Basic requirements for the Collider ring vacuum system
  - Good beam lifetime must be achieved soon after the initial startup with a stored beam.
  - The vacuum system must be capable of quick recovery after sections are exposed to air for maintenance or repairs.
  - The chamber wall must be as smooth as possible to minimize electromagnetic fields induced by the beam.
  - Very low pressure must be attained in the interaction regions to minimize detector backgrounds from beam-gas scattering, ideally 3×10^{-9} Torr or lower outside of the Q1 magnet.
  - Sufficient cooling is necessary to safely dissipate the heat load associated with both synchrotron radiation and higher-order-mode (HOM) losses.

Modes	E (Gev)	Beam gas scattering lifetime (hours)	Vacuum requirement (Torr)
Higgs	120	10	2×10^{-9}
W	80	5	1.5×10^{-9}
Z	45.5	3	8×10^{-10}
tt	180	15	1×10^{-8}

SR power and gas load of rings

For the synchrotron radiation power (in kW) emitted by an electron beam in uniform circular motion [1]

$$P_{SR} = \frac{88.5E^4 I}{\rho} \qquad P_L = \frac{P_{SR}}{2\pi\rho} = \frac{88.5E^4 I}{2\pi\rho^2}$$

To estimate the desorption rate, we can use the approach developed by Grobner et al. [1]. The effective gas load due to photodesorption can be calculated as

$$Q_{gas} = 24.2EI\eta \ [\mathrm{Torr{\cdot}L/s}],$$

where E is the beam energy in GeV, I the beam current in A, and η the photodesorption coefficient in molecules/photon.

The photodesorption coefficient η is a property of the chamber and depends on several factors:

- the chamber material
- the fabrication and preparation of the chamber material
- the amount of prior exposure to radiation
- the photon angle of incidence
- the photon energy

[1] "An Asymmetric B Factory (based on PEP) Conceptual Design Report", SLAC, June, 1993.

SR power and gas load of rings

◆ **PSD （photon-stimulated desorption）as a Function of Critical Energy of SR**

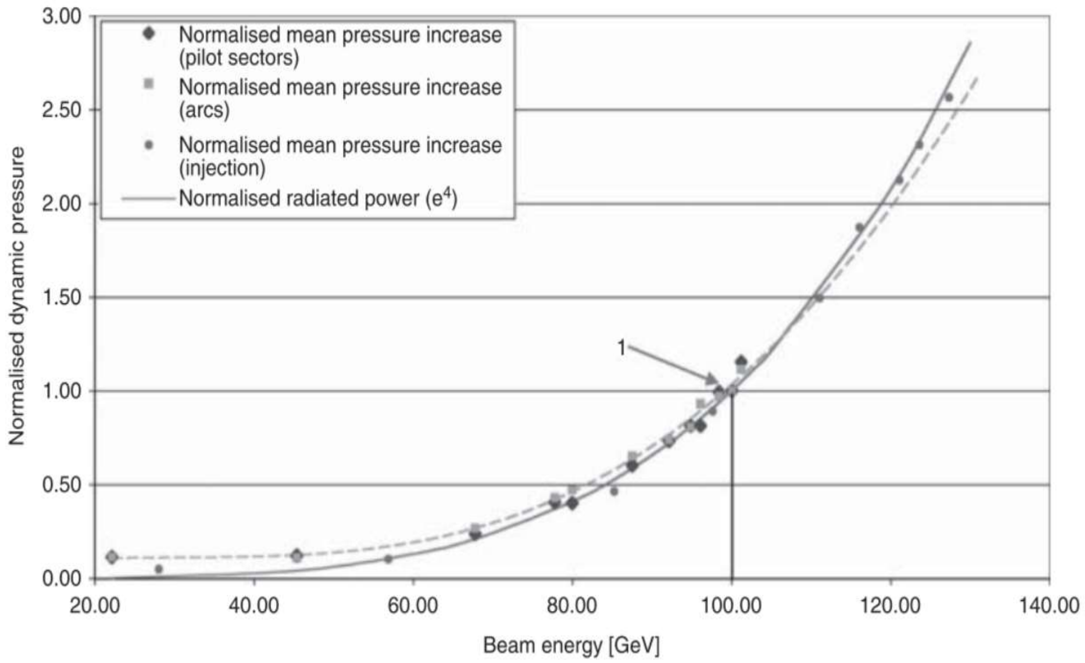


Figure 4.38 Normalised pressure increase in LEP as a function of beam energy. Source: Reprinted with permission from Billy et al. [114], Fig. 4. Copyright 2001, Elsevier.

Modes	**E**	**PSD**
	Gev	*Molecules/photon*
Higgs	120	2.00E-05
W	80	1.00E-05
Z	45.5	2.00E-06
tt	180	1.35E-03

[1] MALYSHEV O B. Vacuum in Particle Accelerators [J]. 2020,

Gas load of collider rings

The gas load under different beam energy and beam density

Mode	E	I	PSD	Q_{gas}	Q_{LSR}
The total synchrotron radiation power P_{SR} = 30 MW					
	Gev	*A*	*Molecules/photon*	*Torr·L/s*	*Torr·L/s·m*
Higgs	120	0.0167	2.00E-05	9.70E-04	1.44E-08
W	80	0.084	1.00E-05	1.63E-03	2.42E-08
Z	45.5	0.803	2.00E-06	1.77E-03	2.63E-08
tt	180	0.0033	1.35E-03	1.94E-02	2.89E-07
The total synchrotron radiation power P_{SR} = 50 MW					
Higgs	120	0.029	2.00E-05	1.68E-03	2.51E-08
W	80	0.147	1.00E-05	2.85E-03	4.24E-08
Z	45.5	1.39	2.00E-06	3.06E-03	4.56E-08
tt	180	0.0054	1.35E-03	3.18E-02	4.73E-07

- The NEG coating is used to suppress the e-cloud of the positron ring. It also provides distributed pumping speed for both the positron and electron rings simultaneously.
- Sputter ion pumps will be employed to maintain pressure and pump off CH_4 and noble gases that cannot be pumped off by the NEG coating. **1% gas load was considered as inert gases** when vacuum pressure calculating.

Vacuum Requirement Vs configuration of Collider

- PSD （photon-stimulated desorption）& TD （thermal desorption）
- Pav-Ar, CH4-partial pressure， calculated as 1% gas load

CEPC 30MW								
	PSD	q_{td}	q_{lsr}	q	P_s	SIP Distance	Pav	Vacuum requirement
	Molecules/photon	*Torr·L/s·cm²*	*Torr·L/s·cm²*	*Torr·L/s·cm²*	*L/s*	*m*	***Torr***	***Torr***
Higgs	2.00E-05	1E-12	8.21E-12	8.21E-12	30	**22**	**5.3×10^{-10}**	**2×10^{-9}**
W	1.00E-05	1E-12	1.38E-11	1.38E-11	30	**22**	**8.6×10^{-10}**	**1.5×10^{-9}**
Z	2.00E-06	1E-12	1.50E-11	1.50E-11	30	**11**	**4.2×10^{-10}**	**8×10^{-10}**
tt	1.35E-03	1E-12	1.64E-10	1.64E-10	30	**11**	**4.3×10^{-9}**	**1×10^{-8}**
CEPC 50MW								
Higgs	2.00E-05	1E-12	1.43E-11	1.43E-11	30	**22**	**8.8×10^{-10}**	**2×10^{-9}**
W	1.00E-05	1E-12	2.41E-11	2.41E-11	30	**22**	**1.5×10^{-9}**	**1.5×10^{-9}**
Z	2.00E-06	1E-12	2.59E-11	2.59E-11	30	**11**	**7.1×10^{-10}**	**8×10^{-10}**
tt	1.35E-03	1E-12	2.69E-10	2.69E-10	30	**11**	**7.0×10^{-9}**	**1×10^{-8}**

- Sputtering ion pumps distributed around the circumference at intervals of about 22 m for Higgs and W modes.
- In Z & tt mode, the number of sputtering ion pumps (SIP) needs to be doubled

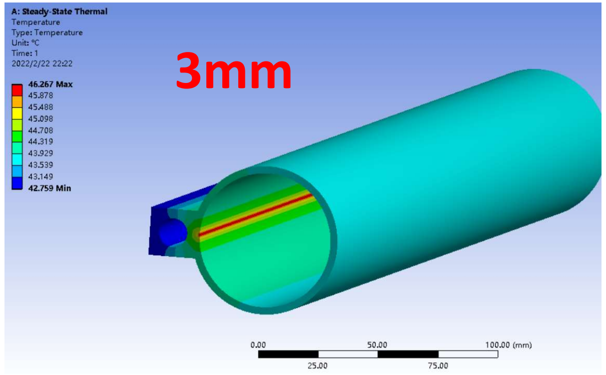
[4] MALYSHEV O B. Vacuum in Particle Accelerators [J]. 2020,

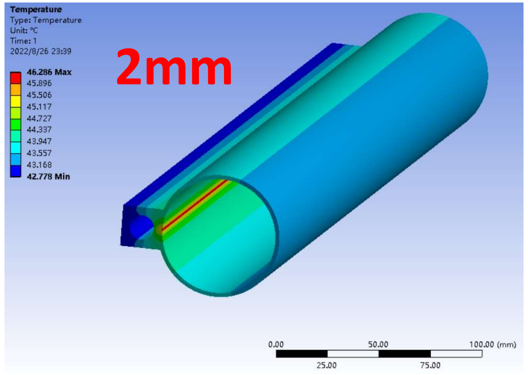
R&D of Vacuum chamber

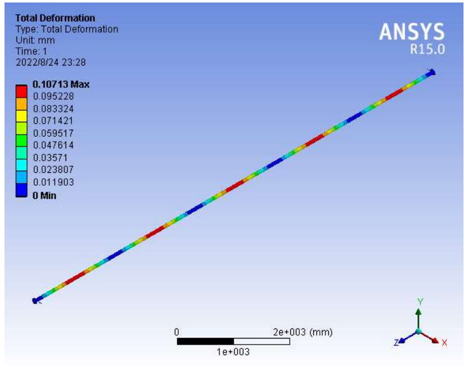
■ Wall thickness optimizing of vacuum chamber

◆ **Boundary conditions:**

- water cooling convection heat transfer coefficient 1000 W/ $m^2 \cdot k$,
- air natural convection heat transfer coefficient W/ $m^2 \cdot k$;
- Photon power density 740W/m (SR 50MW); The width of photon beam is 0.85mm.







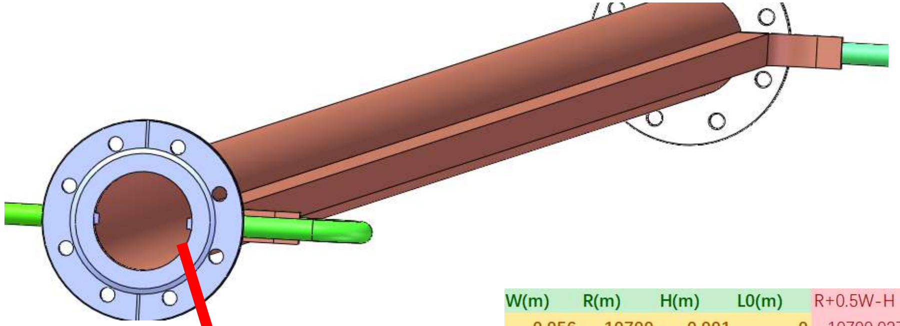
Every 2m is supported, with a maximum deformation of 0.1mm

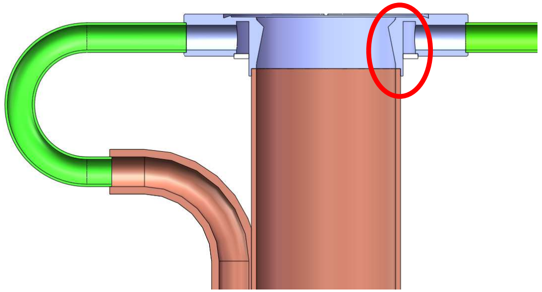
◆ **Conclusion:**

- The water cooling efficiency has a great influence on the temperature
- Vacuum chamber Wall thickness has little effect on temperature
- the thermal deformation caused by synchronous light mainly depends on the water cooling effect
- When the chamber wall is thinner, better support is needed to prevent deformation

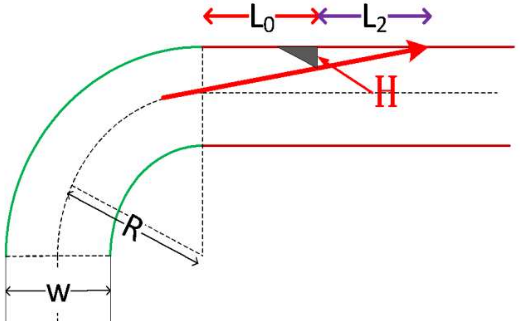
The Mask and water cooling design for collider

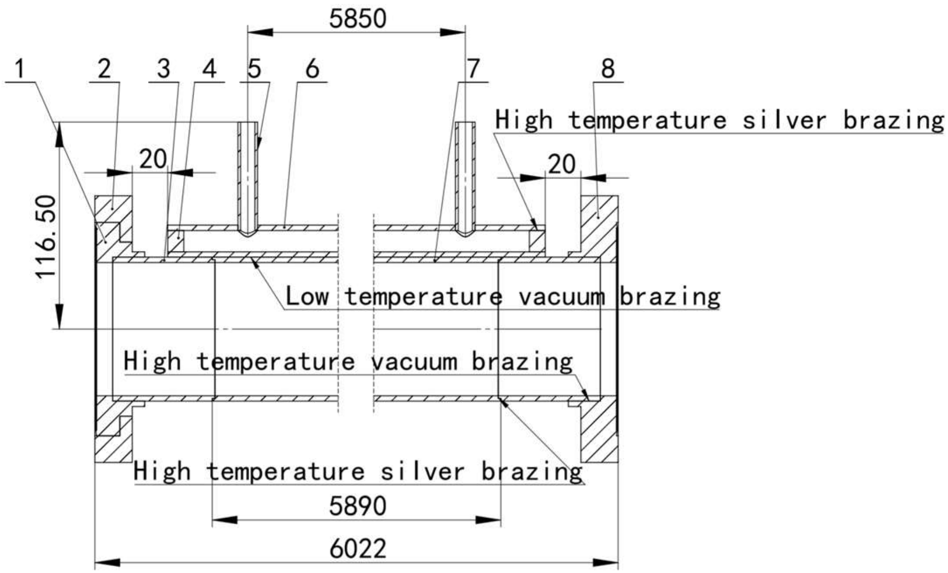
- Due to the large bending radius, a 1mm mask at the dipole iron outlet can block the synchronous light irradiation in the downstream 0.44m area, theoretically.
- The installation accuracy needs to be very high.





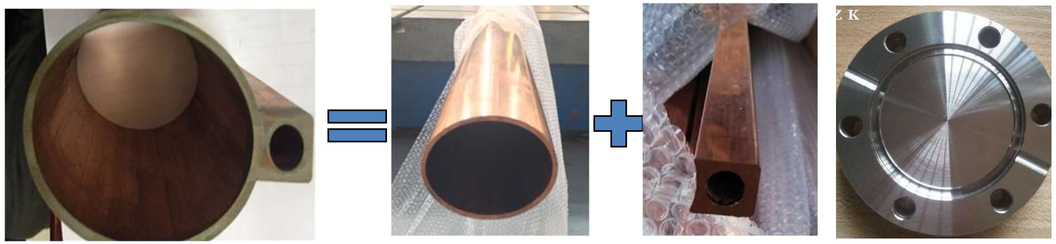
W(m)	R(m)	H(m)	L0(m)	R+0.5W-H	Cos	Thita	L2(m)
0.056	10700	0.001	0	10700.027	0.9999975	0.00225	0.445
0.056	10700	0.0005	0	10700.028	0.9999974	0.00227	0.221



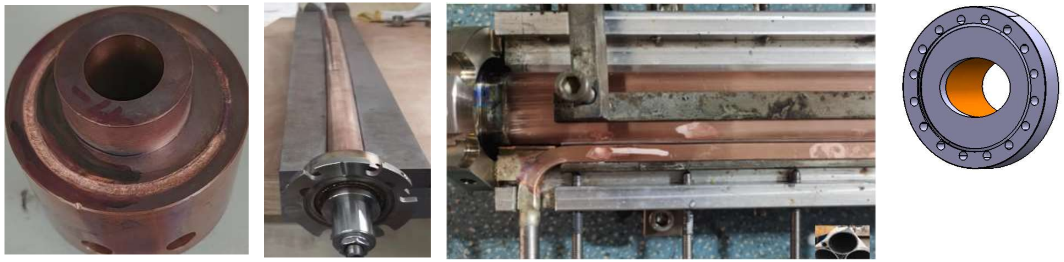


Technique process of Cu vacuum chamber (VC)

- Cu beam pipe and water cooling channel are extruded respectively, and brazed together.
- Stainless steel material is used for flanges, and there is a rotatable flange at an end of vacuum chamber.
- The flanges and beam pipe are welded by high temperature brazing solder, and low temperature brazing solder are used between the beam pipe and water cooling channel.

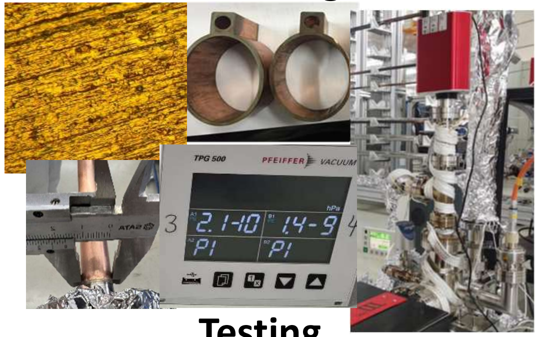


Vacuum chamber = Beam pipe + Cooling channel Conflat Flange



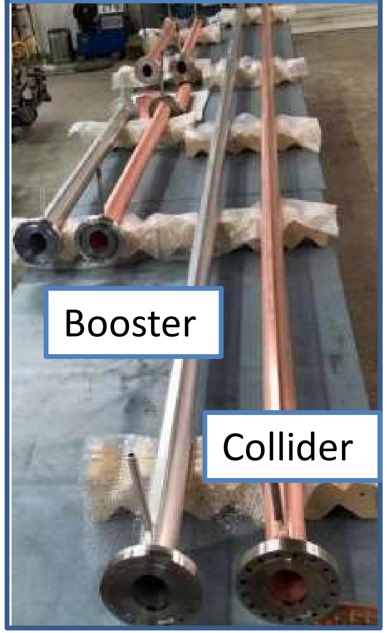
Manufacturing Welding/Brazing

Cleaning



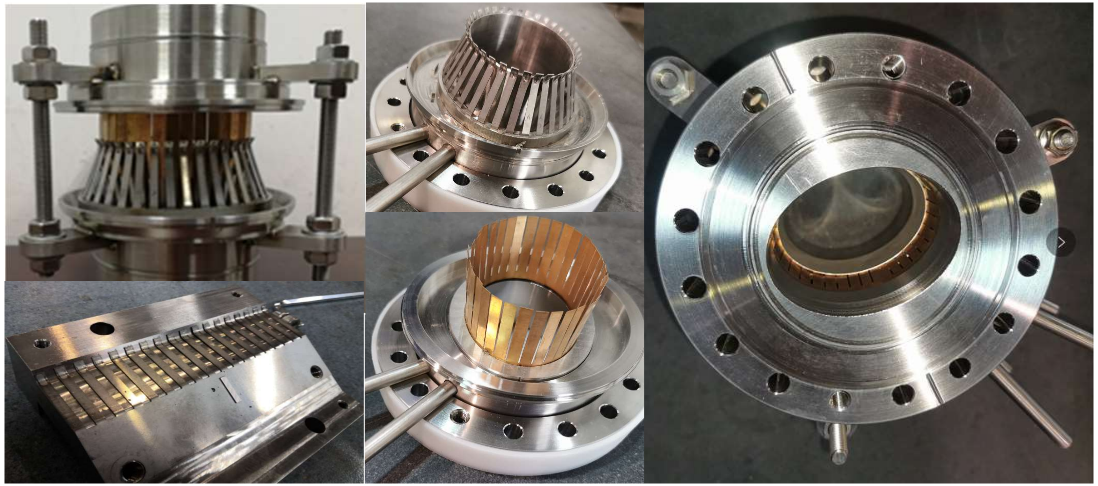
Testing

VC Prototypes with 6m length

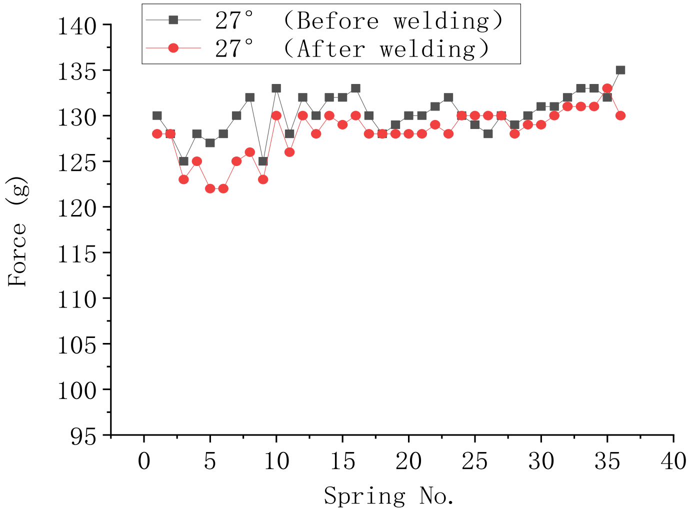


R&D of RF shielding bellows

- Vacuum bellow modules are needed to compensate the mechanical misalignments of the vacuum chambers during installation and to absorb their thermal expansion during the bake-out. In order to reduce the beam impedance during operation with beams these modules are equipped with RF bridges to carry the image current.[1]
- The key components experiments such as spring fingers and contact fingers have been carried out. Contact force is uniformly from different fingers and meets the target of 125±25g. The prototypes of RF shielding bellows have been fabricated in local company.



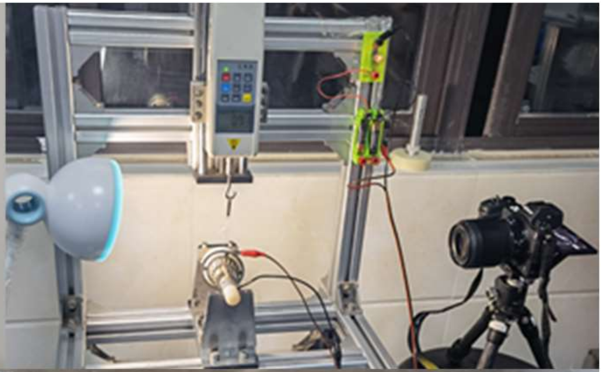
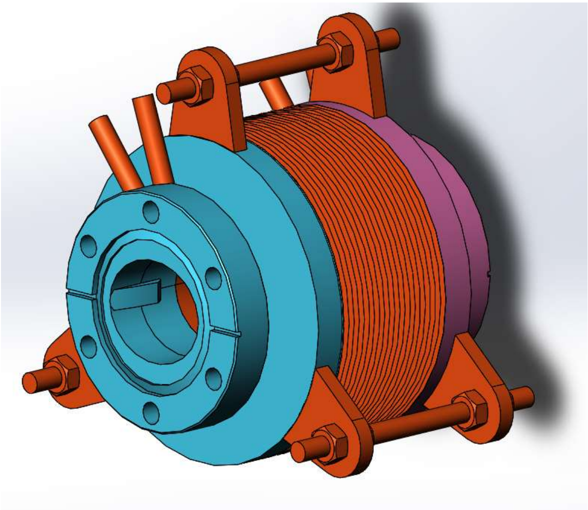
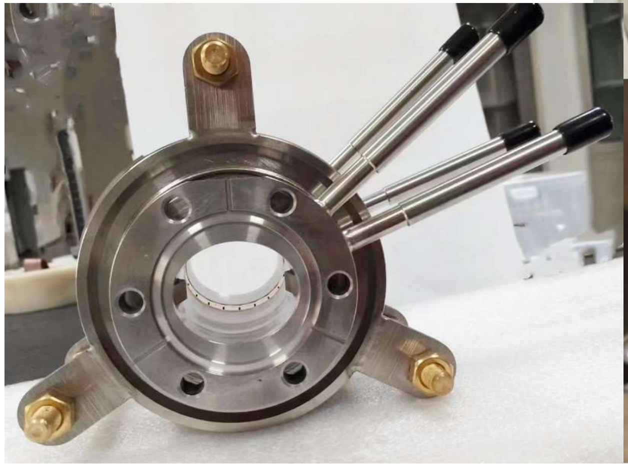
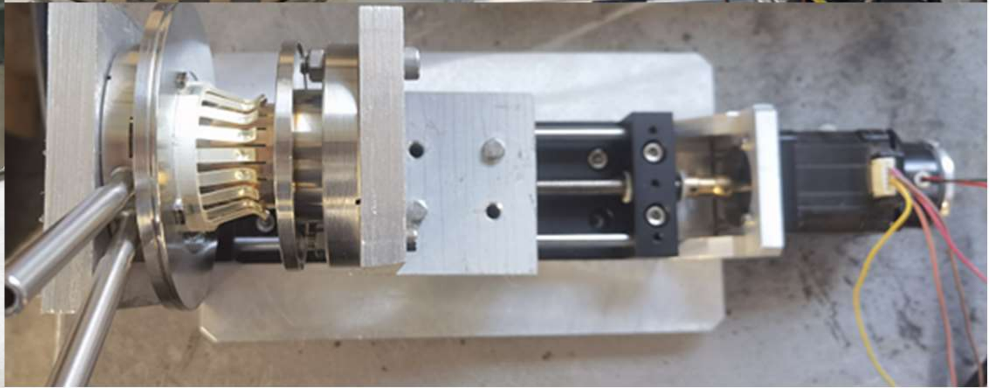
Prototypes R&D



RF shielding bellows for Collider & damping ring

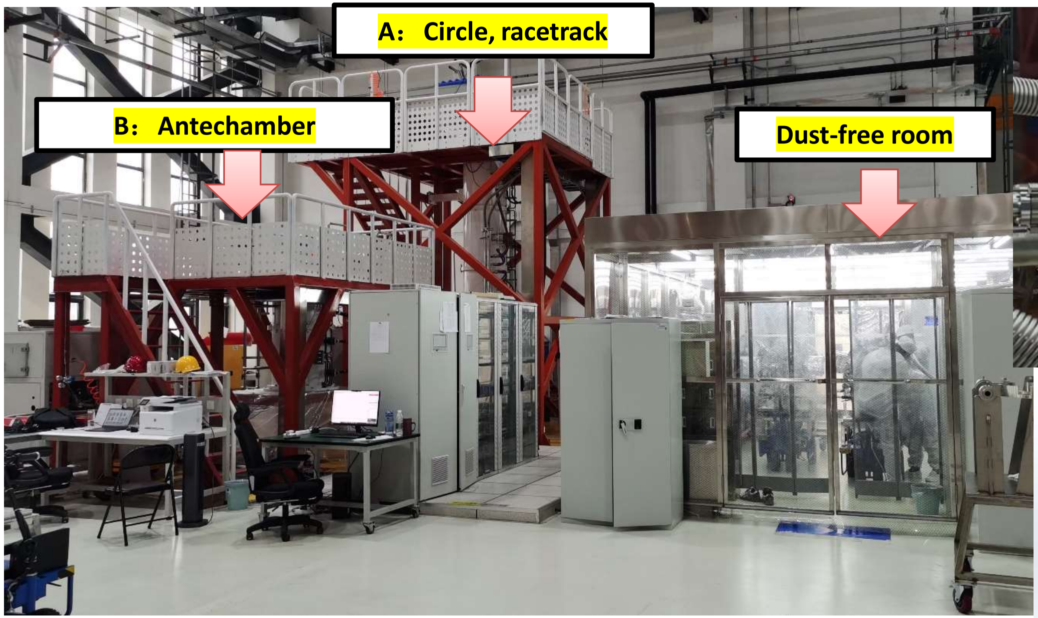
Total length	Expansion	Contraction	Ellipse cross section	Contact pressure	Maximum radial offset
70-180mm	10mm	20mm	56, 30mm	125±25g	2mm

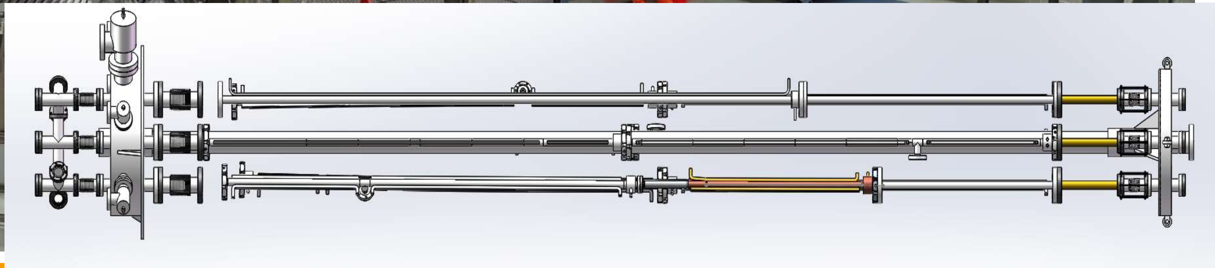
- Mask is designed on the upstream of RF bellows to absorb the SR
- The all RF bellows were produced by local company in China, and massive used in HEPS.

Massive produce of NEG coating synergy of HEPS

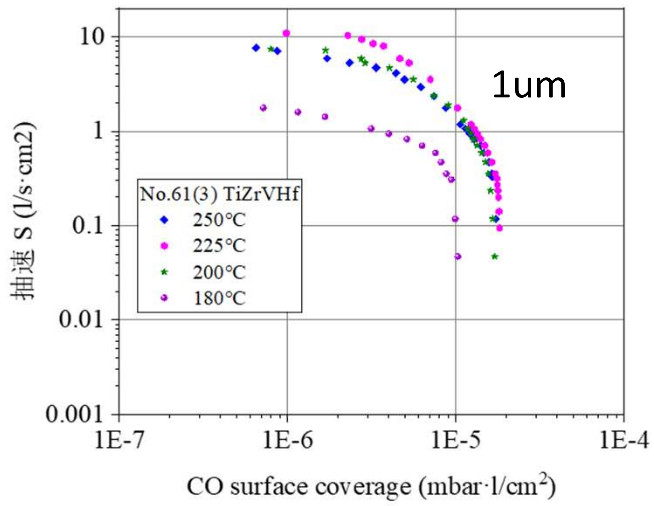
- The coating device A: Vacuum chambers are connected in parallel to 6 groups, each group of vacuum chambers length should be lower than 3.5m, outer diameter is about 0.47m;
- The coating device B: Antechamber are connected in parallel to 4 groups, each group of vacuum chambers length should be lower than 1.5m, due to its discharge difficulty.
- Two setups of NEG coating have been built for vacuum pipes of HEPS at IHEP Lab. And a lot of test vacuum pipes have been coated, which shows that NEG film has good adhesion and thickness distribution.

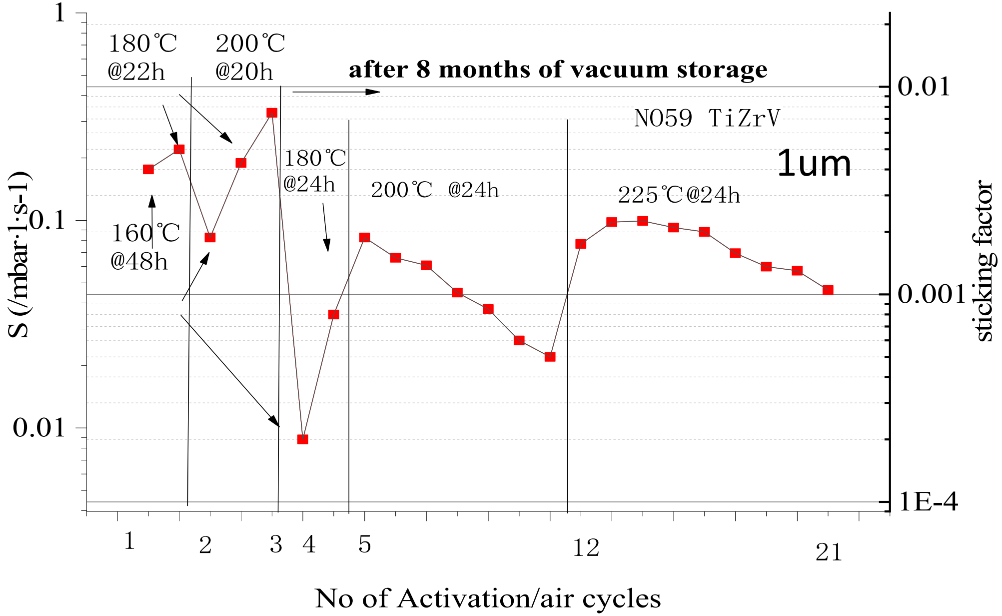


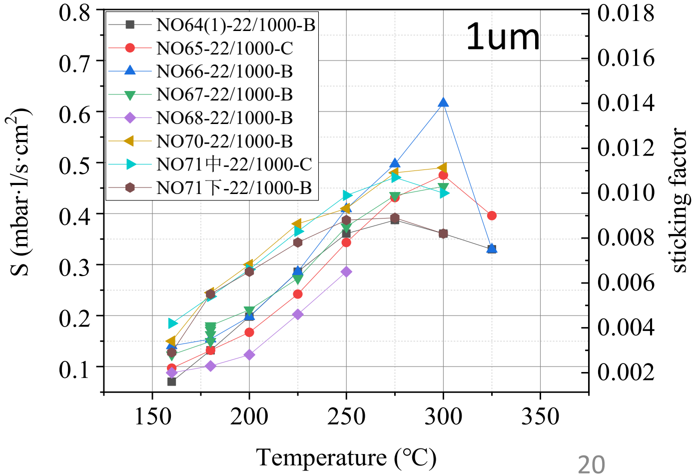


Performance of NEG coating from massive produce

- The discharge of antechamber is very difficult due to its height is only 7mm , the whole antechamber which length is 1200mm has been NEG coated by last year.
- The life times of NEG coating activation exceeded 21@225℃.



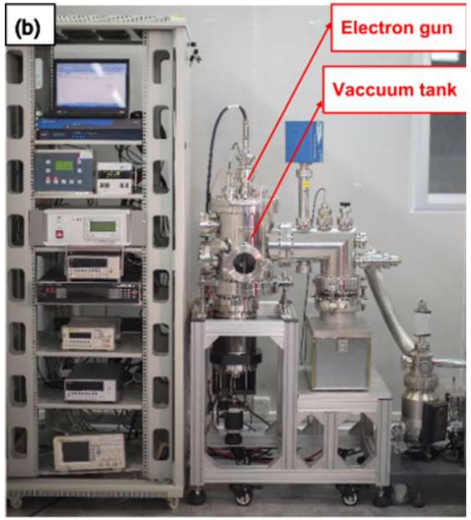




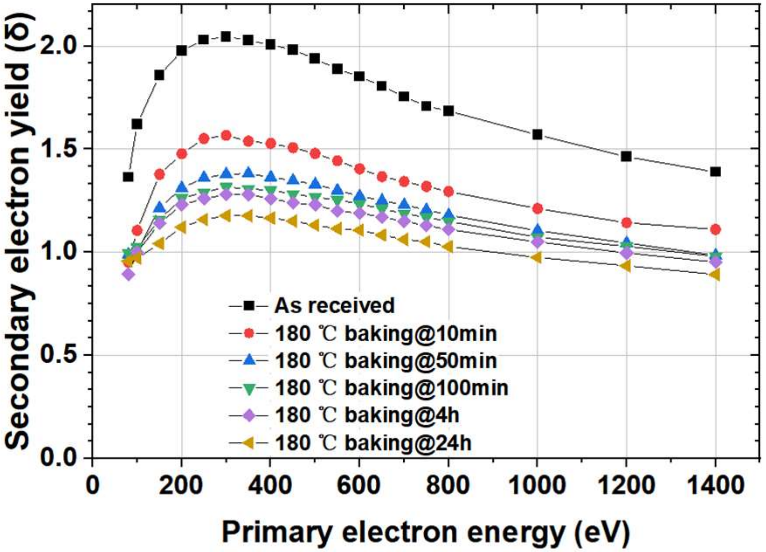
SEY of NEG coating

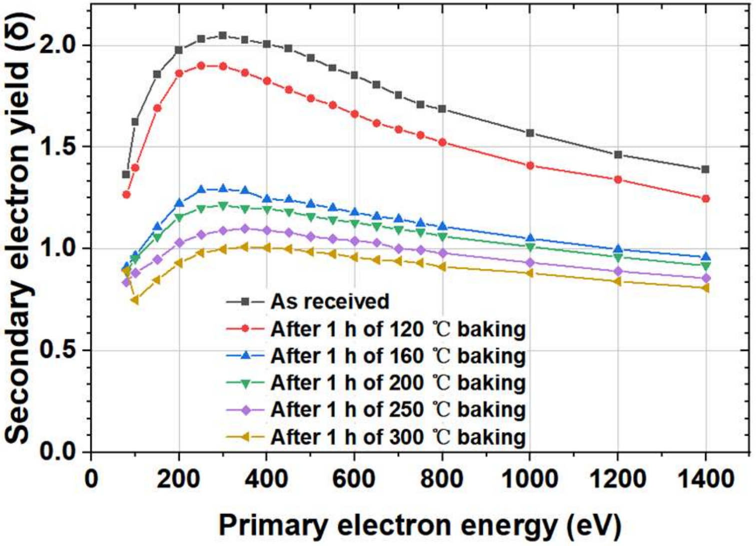
- SEY will decrease to 1.2 after 24h activation of 180℃.
- SEY could even close to 1.0 after 300℃ activation.

Wang Pengcheng



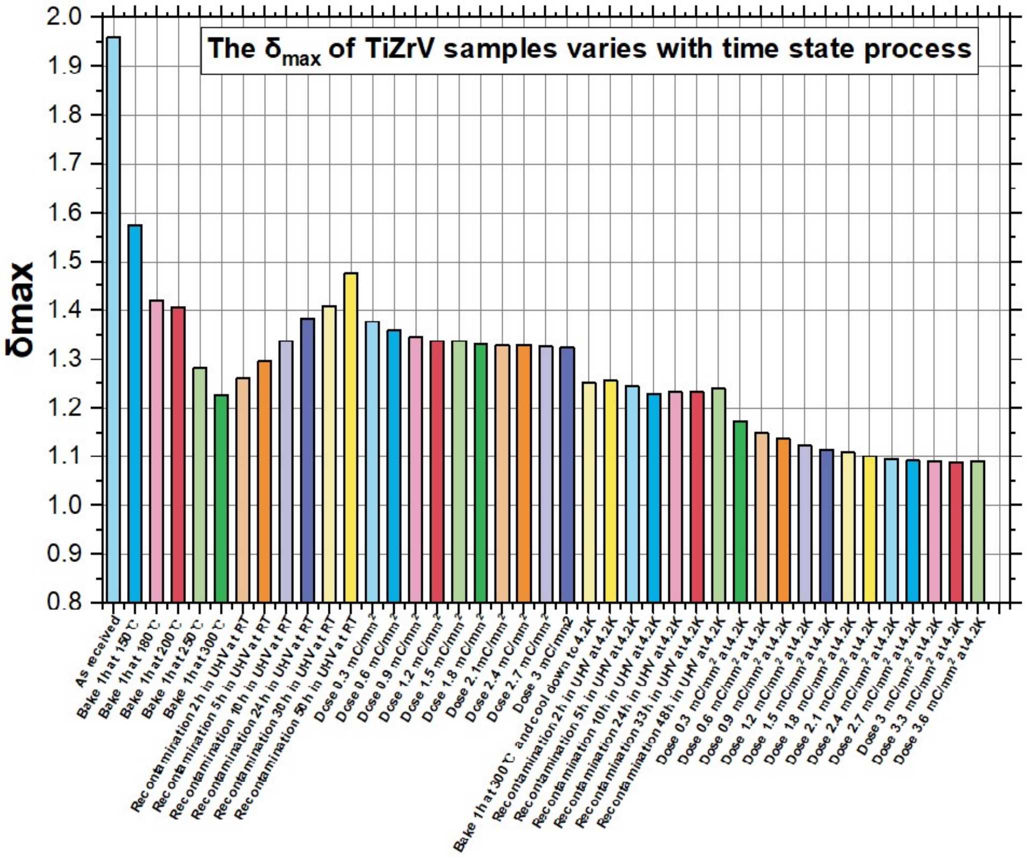
SEY test setup in Dongguan of IHEP

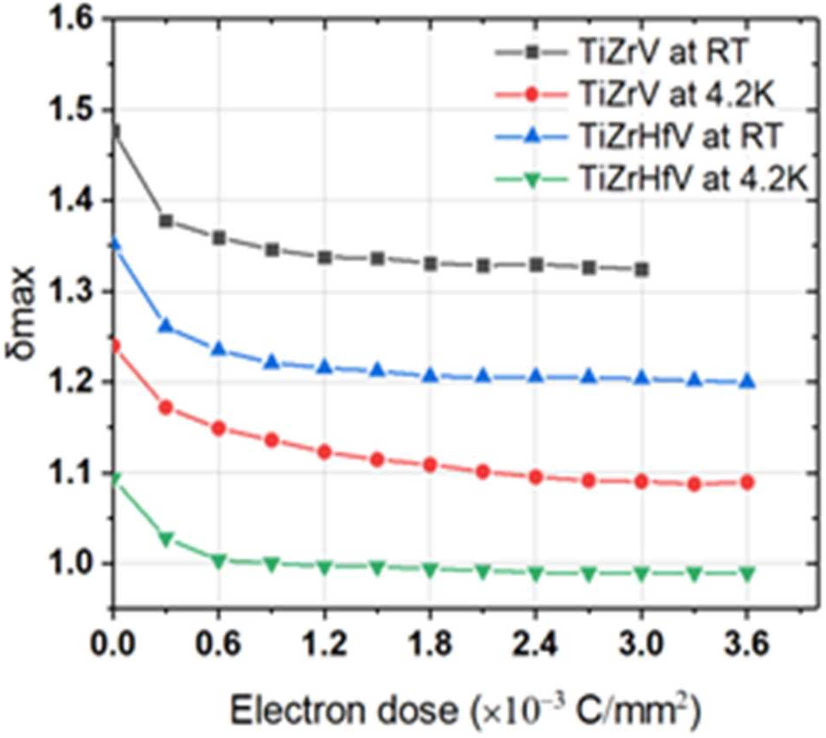




SEY of NEG coating

SEY will decrease after electron bombardment

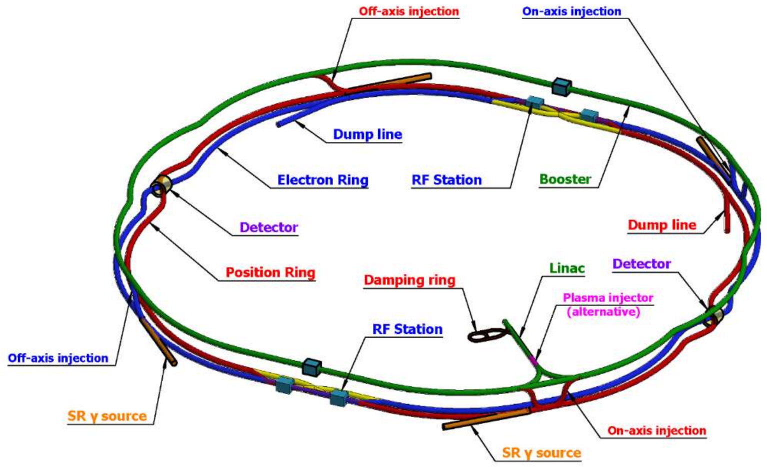




Layout & configuration of Booster

	Classification	length/m
booster	arc beam pipe	78428
	Straight section beam pipe	17010
	RF Substitute pipe	384
	RF system	96
	insertion and extraction	198
	Manifold for SIP	1250
	Bellows	850
	BPM	240
	Manifold for Gauge & RGA	1544
	total length	**100000**

Parameter	e^+ & e^-
Energy [GeV]	30~180
Beam current [A]	$0.11\sim14.4\times10^{-3}$
Circumference [m]	100,000
Bending radius [m]	11,380.8
Beam pipe material	Extruded Al
Beam pipe shape (mm)	Φ56/thickness of 2mm
Pump type in arcs	SIP
Dynamic pressure /Torr	$<3\times10^{-8}$ tt$<4\times10^{-8}$



Booster vacuum system

- Booster will work in four modes of higgs, W, Z, tt under 30MW and 50MW alternatively. 50MW is given to calculate the vacuum parameters as it has the highest energy and gas load.

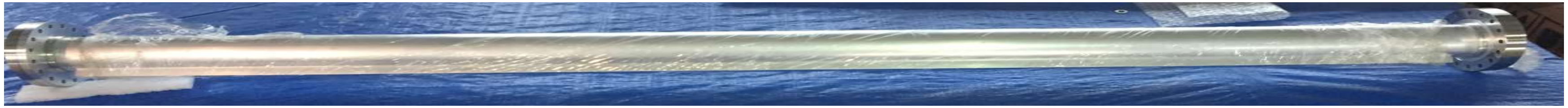
The gas load under different beam energy and beam density

Mode	E	I	PSD	PL	Q_{gas}	Q_{LSR}	P_{ave}
	Gev	*A*	*Molecules/photon*	*W/m*	*Torr·L/s*	*Torr·L/s·m*	*Torr*
Higgs	120	1.03E-03	2.00E-05	23.31	6.00E-05	**8.40E-10**	2.15E-08
W	80	5.17E-03	1.00E-05	23.03	1.00E-04	**1.40E-09**	2.21E-08
Z	45.5	2.67E-02	2.00E-06	12.44	5.87E-04	**8.22E-09**	2.14E-08
tt	180	2.00E-04	1.35E-03	22.84	1.18E-03	**1.65E-08**	3.96E-08

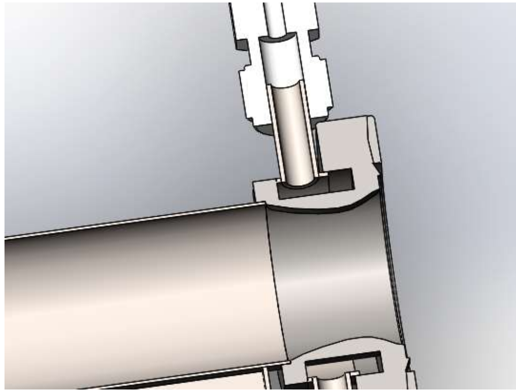
- The finite element analysis conducted on the vacuum chamber indicates that the highest temperature reached is 28.9°C when the ambient temperature is 25°C and a convective heat transfer coefficient of 2×10^{-5} W/mm^2·°C is assumed.
- The main pumping process will then be followed by ion pumps distributed around the circumference at intervals of about 12 m.

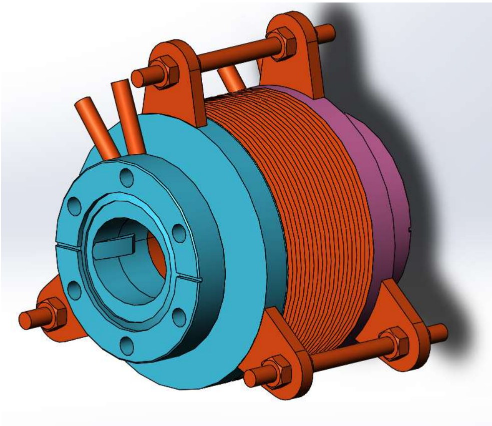
Booster vacuum system

- The dipole vacuum chamber in the Booster has a circular cross-section with a diameter of 56 mm, a length of approximately 11 m, and a wall thickness of 2 mm. These chambers are extruded from Al 6061, and stainless steel conflat flanges are welded onto the ends using transition material.



- The circumference of the Booster will be divided into 520 sectors, each with an all-metal gate valve, allowing for manageable length and volume during pumping down, leak detection, bake-out, and vacuum interlock protection. Bellows made of stainless steel will be employed to absorb the extension and the misalignment of vacuum chambers and other vacuum devices during installation.
- The in-line absorbers are used to prevent SR photons from falling on the bellows, BPM etc.

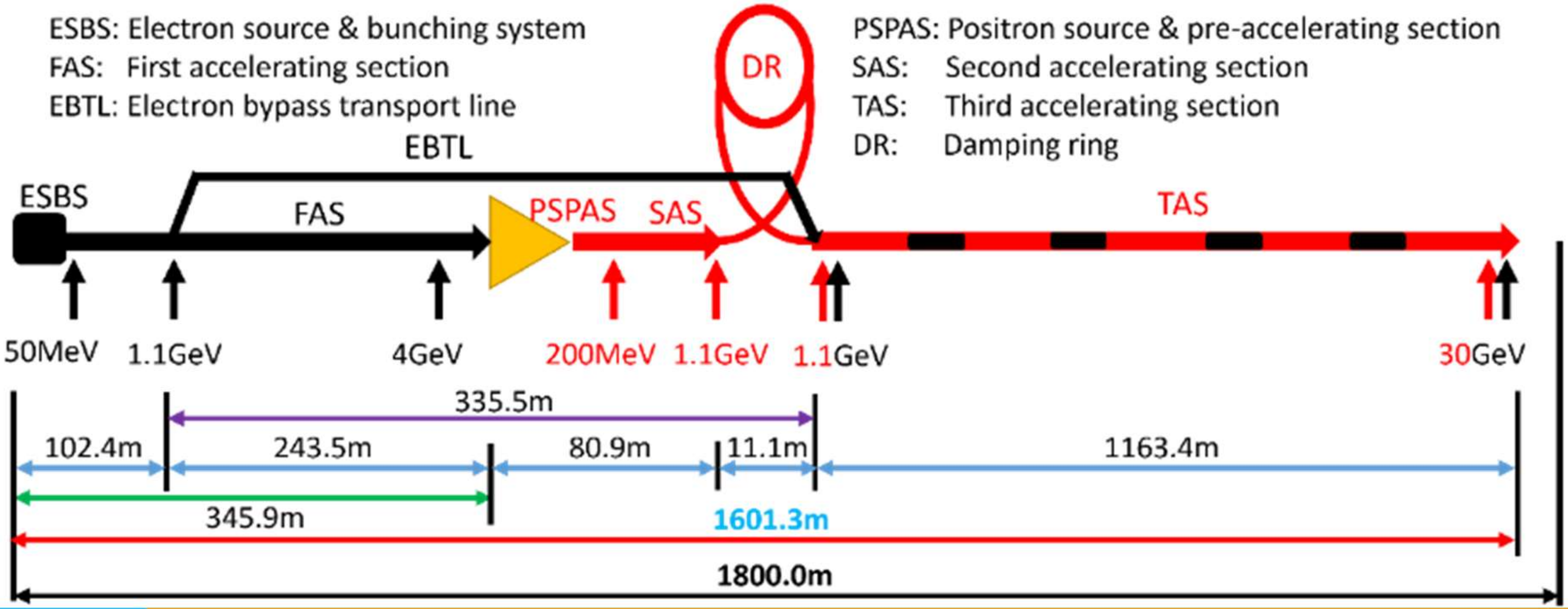




Linac vacuum system

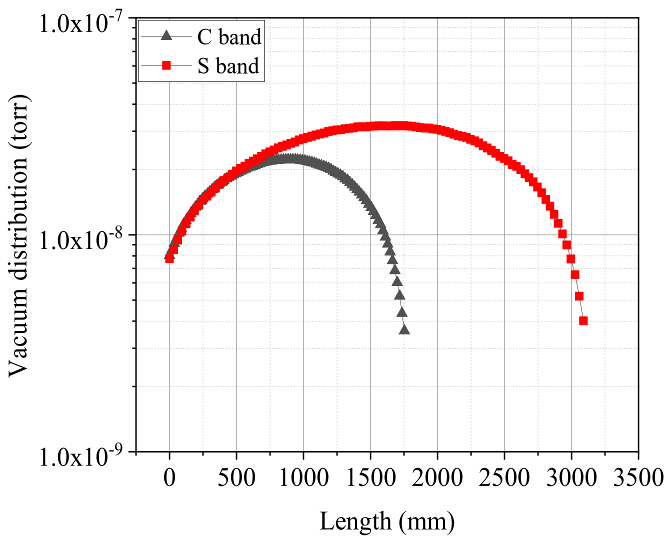
- The Linac vacuum system with a length of 1936m is divided into 59 sections. it consists of electron gun, bunching system, accelerating structures .
- Sputter ion pumps: 3431; Vacuum gauges: 1352; Gate valves: 60

Section	Static pressure /Torr	Dynamic pressure /Torr
E-gun	$<1\times10^{-9}$	$<2\times10^{-8}$
Buncher	$<5\times10^{-8}$	$<2\times10^{-7}$
Accelerating structure	$<5\times10^{-8}$	$<2\times10^{-7}$
Waveguide	$<5\times10^{-8}$	$<5\times10^{-7}$

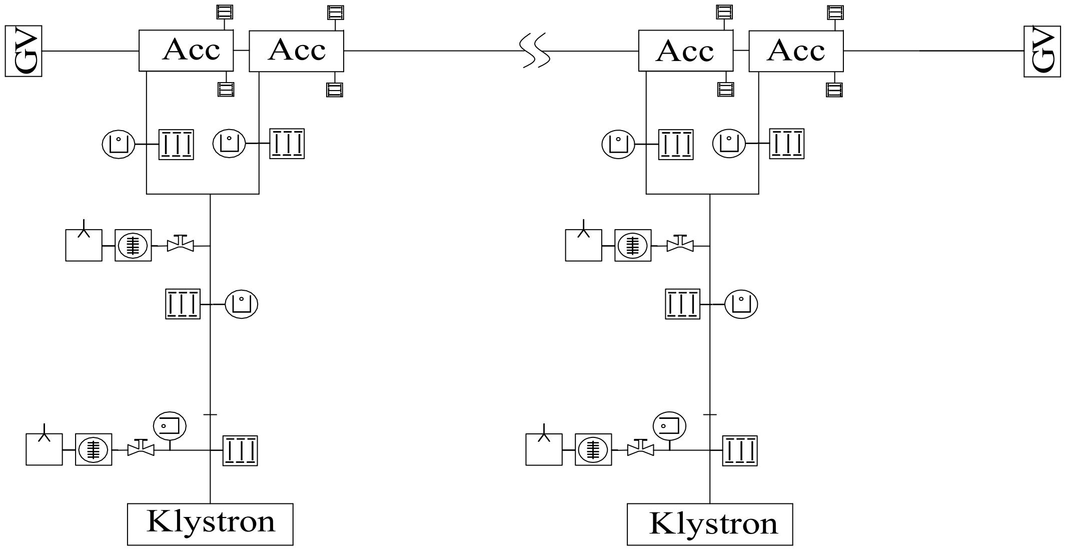


Linac vacuum system

◆ Most of the components are made of oxygen-free copper . The thermal outgassing rate is 1×10^{-11} Torr·l/s·cm^2.



The static pressure distrubition of a accelerator structure

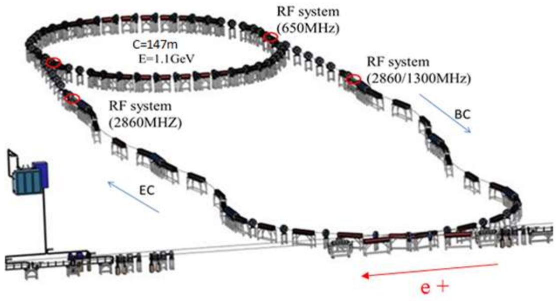


Vacuum diagram of klystron and accelerator structures

Layout of Damping ring, Transport line

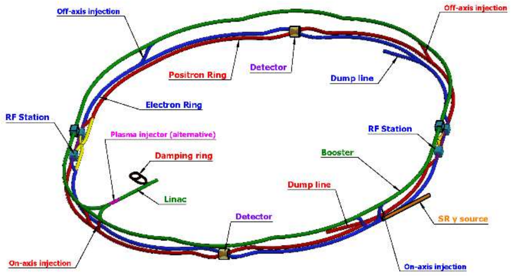
	Classification	length/m
DR	arc beam pipe	119.0
	Straight section beam pipe	14.0
	RF Substitute pipe	0.0
	RF system	3.0
	insertion and extraction	2.8
	Manifold for SIP	1.5
	Bellows	1.5
	BPM	4.0
	Manifold for Gauge & RGA	1.5
	total length	147.3

Parameter	e^+ & e^-
Energy [GeV]	1.1
Beam current [A]	0.012~0.024
Circumference [m]	147
Bending radius [m]	2.87
Beam pipe material	Extruded Al
Beam pipe shape (mm)	Φ30/thickness of 1
Pump type in arcs	SIP
Dynamic pressure /Torr	2×10^{-8}



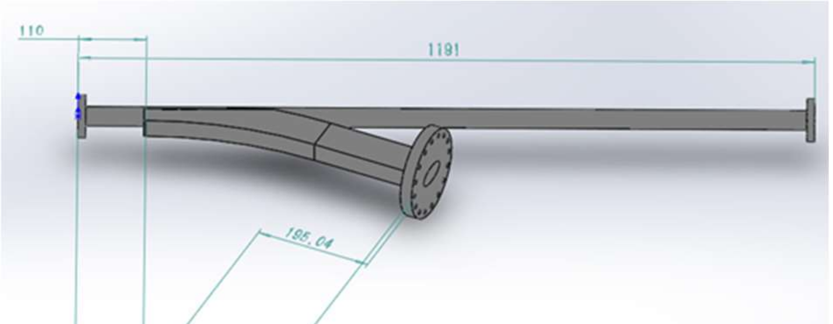
	Classification	length/m	Note
transport line	linac to booster	3000	e- & e+ 1500 m
	booster to colider	960	On axis： e- & e+ 240 m Off axis: e- & e+ 240 m
	colider to booster	480	e- & e+ 240 m
	damping ring	240	In & ex 120 m
	total length	4680	

Parameter	e^+ & e^-
Linac to Damping Ring	
Energy (GeV)	1.1 GeV
Linac to Booster	
Energy (GeV)	30 GeV
Booster to Collider	
Energy (GeV)	45 GeV~180 GeV
Dynamic Pressure (Torr)	2e-8

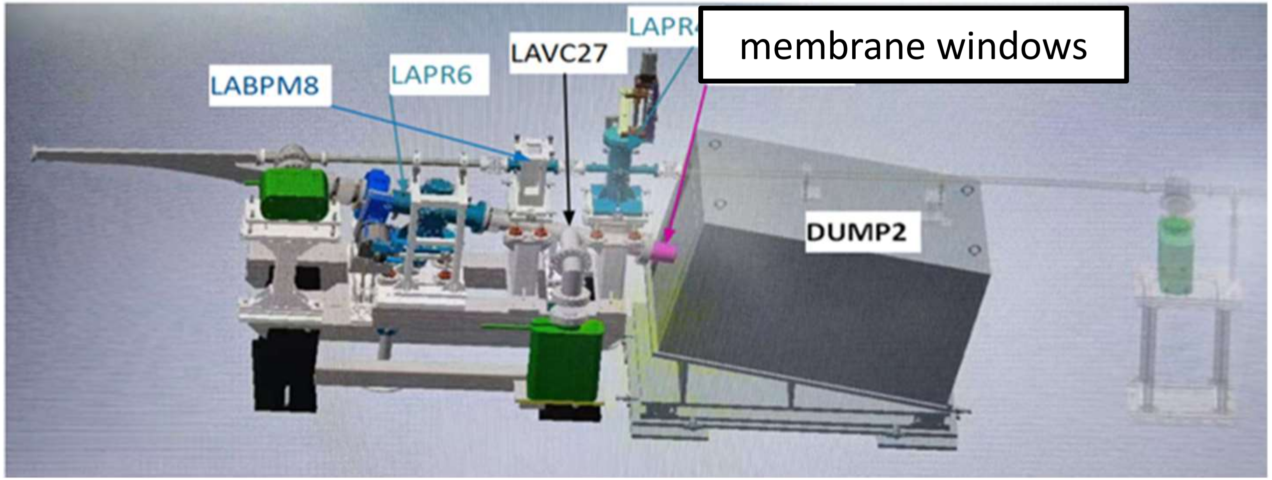


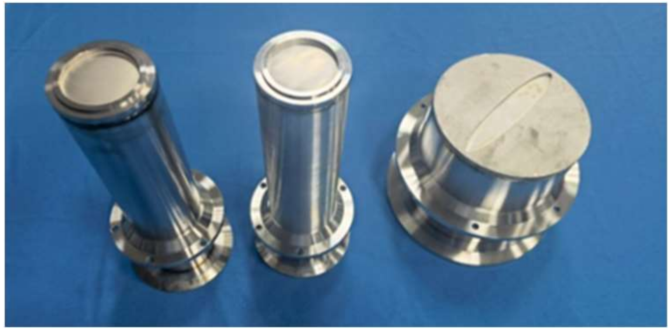
Protypes of Dump chamber and membrane window for Linac

◆ The elliptical Ti thin membrane window of 170×10 mm with a thickness of 0.1 mm was welded on the s. s. plate with a diameter of 183 mm and a thickness of 5mm.



- Inner cross section of ellipse in 60 × 30 mm
- Outer cross section of rectangle in 62 × 32 mm





◆ Membrane windows

- The thickness of Ti window is 0.1mm
- Deformation test under vacuum: elliptical window is 0.4mm, circle window is 2.3mm;
- ultimate vacuum<5 $\times 10^{-8}$Pa。

Damping ring vacuum system

- For the DR, with values of E = 1.1 GeV, I = 0.012~0.024 A, and ρ = 2.87 m, these equations give a total synchrotron radiation power of P_{SR} = 1.08 kW and a linear power density of P_L = 60.1 W/m.

The gas load under different beam energy and beam density

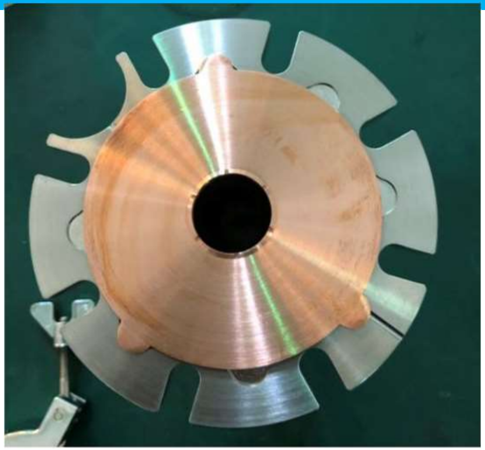
Mode	E	I	PSD	P_L	Q_{gas}	Q_{LSR}	P_{ave}
	Gev	*A*	*Molecules/photon*	*W/m*	*Torr·L/s*	*Torr·L/s·m*	*Torr*
	1.1	0.024	2.00E-06	60.1	1.28E-06	7.09E-8	1.78E-08

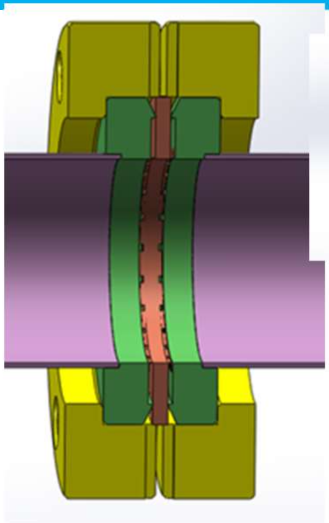
  - With an effective pumping speed of 15 L/s and a distribution of 2 meters sputtering ion pumps, the vacuum value of 1.78×10^{-8} Torr will be reached.

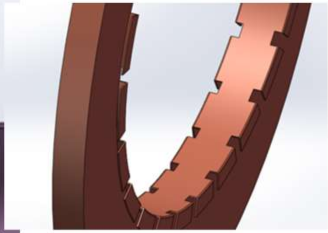
- Due to the beam current of damping ring is low enough, SEY of aluminium vacuum chamber which do not need NEG coating or TiN coating could meet the requirement of physics.

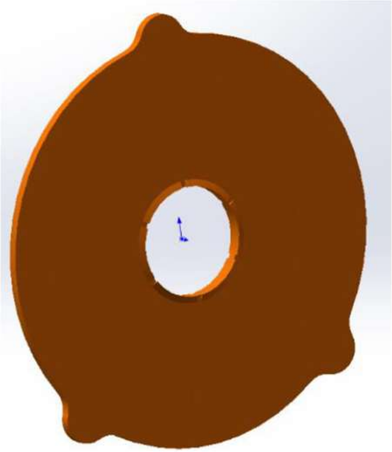
- RF shielding Bellows with spring and contact fingers made of stainless steel will be employed to absorb the extension and the misalignment of vacuum chambers and other vacuum devices during installation.

Tests of low impedance gaskets

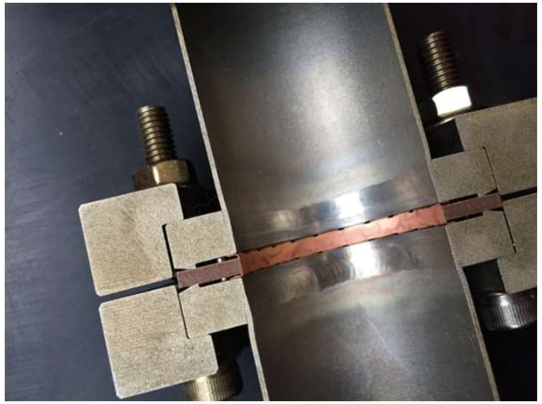




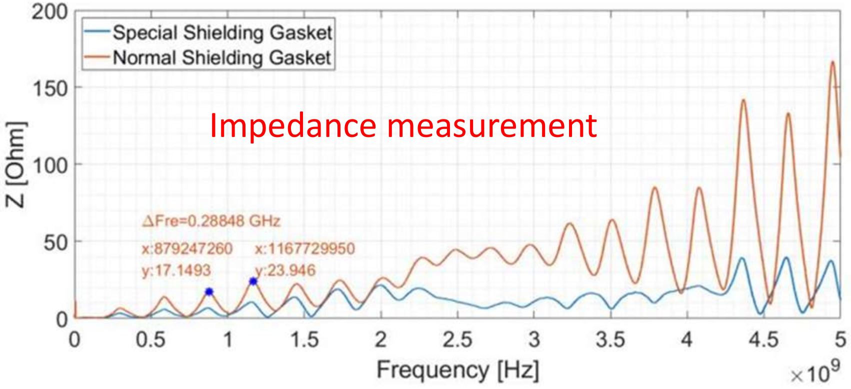




Copper gasket with contact fingers



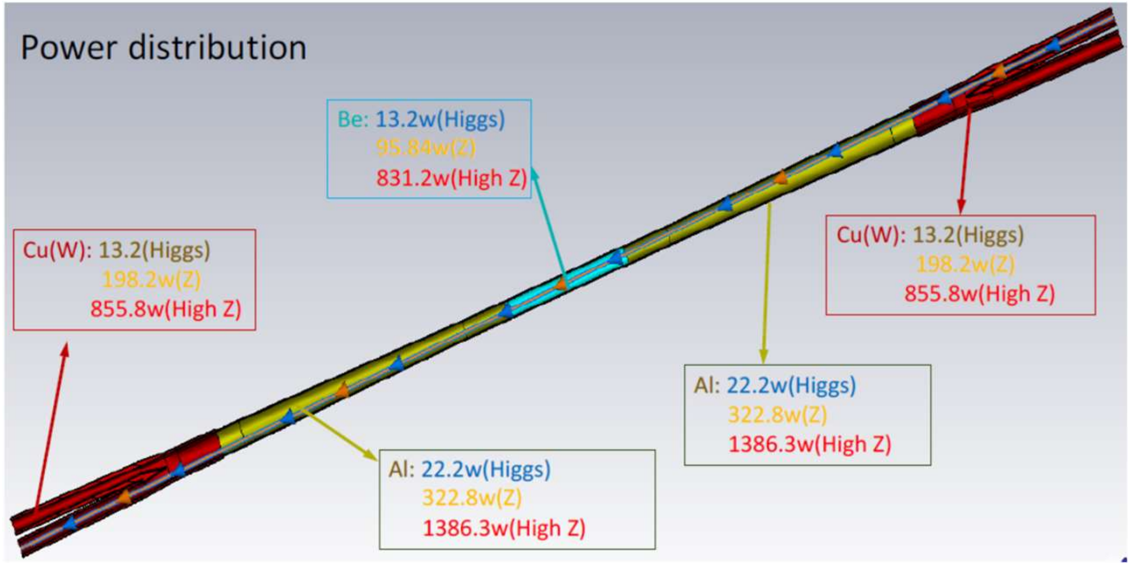
Preload force /N	4
Leakage rate/mbar.L/s	＜1E-10
Baking temperature/°C	250
Baking time/h	24
Repeated Baking times	6
Repeat installation times	4



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

MDI Vacuum

- OFE copper or Tungsten alloy will be used to made the fork vacuum chamber of MDI
- NEG coating is suggested to the fork vacuum chambers
- The vacuum of Be chamber would be lower than 3ntorr, if the thermal degassing of Be vacuum chamber is lower then 1×10^{-12} mbar.L/s, assumption that two ion pumps are set at the two sides MDI, separately.
- Water cooling pipe is designed due to the high thermal load of impedance at high light Z model
- SR absorber will be used on the upstream of MDI to decrease the gas load of Synchrotron radiation.



Summary

	Energy	Material	Dynamic pressure /Torr	Technical
LINAC	30 GeV	Stainless steel, copper	Acc $<2\times10^{-7}$ E-gun$<2\times10^{-8}$	**Conventional**
Damping ring	1.1 GeV	Extruded aluminum 6061	$<2\times10^{-8}$	**Conventional**
Booster	30 to 180 GeV	Extruded aluminum 6061	$<3\times10^{-8}$ tt$<4\times10^{-8}$	**Conventional**
Collider	45.5~180 GeV	Extruded copper, NEG film, SEY<1.2	Z$<8\times10^{-10}$ tt$<1\times10^{-8}$	**Conventional & NEG coating**
MDI	45.5~180 GeV	Copper/tungsten alloy, NEG film	$<3\times10^{-9}$	**NEG coating**
LTB	30 GeV	Stainless steel	$<1\times10^{-7}$	**Conventional**
BTC(CTB)	6 GeV	Stainless steel	$<1\times10^{-7}$	**Conventional**
DL	1.1 GeV	Stainless steel	$<1\times10^{-7}$	**Conventional**

Summary

- **NEG coating of 200nm is employed to suppress e-cloud of positron ring and absorb residual gases simultaneously. SEY will blow 1.2 after 24h activation of 180℃ and could even lower under higher activation temperature.**
- **Similar to positron ring, NEG coating is proposed to vacuum chamber of electron storage ring to absorb extra gas load.**
- **Prototypes of vacuum chambers of Cu, Al, and RF shielding bellows have been developed and manufactured, which meet the requirements of CEPC.**
- **Mask is used to prevent SR photons from falling on the bellows, BPM etc.**
- **OFE copper or tungsten alloy will be used to made the fork vacuum chamber of MDI.**

Thanks for your attention