



# **Completion of CEPC Accelerator CDR and R&D towards TDR**

**J. Gao**

**On behalf of CEPC Accelerator Team**

**Institute of High Energy Physics**

**XXXIX International Conference on High Energy Physics**

**July 04-11, 2018, COEX, Seoul, Korea**



# Contents

- **CEPC CDR physics and accelerator design goals**
- **CEPC CDR completion status**
- **CEPC site selection and civil engineering implementation**
- **CEPC industrial participation and international collaboration**
- **Conclusions**

# CEPC-SppC Physics Goals in CDR (remind)

- **Electron-positron collider (90, 160, 250 GeV)**
  - **Higgs Factory ( $10^6$  Higgs) :**
    - Precision study of Higgs( $m_H$ ,  $J^{PC}$ , couplings), Similar & complementary to ILC
    - Looking for hints of new physics
  - **Z & W factory ( $10^{10}$   $Z^0$ ) :**
    - precision test of SM
    - Rare decays ?
  - **Flavor factory: b, c,  $\tau$  and QCD studies**
- **Proton-proton collider( $\sim 100$  TeV)**
  - **Directly search for new physics beyond SM**
  - **Precision test of SM**
    - e.g.,  $h^3$  &  $h^4$  couplings

## CEPC Design –Higgs Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*120 GeV
Luminosity (peak)	$>2*10^{34}/\text{cm}^2\text{s}$
No. of IPs	2

## CEPC Design – Z-pole Parameters

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	2*45.5 GeV
Integrated luminosity (peak)	$>10^{34}/\text{cm}^2\text{s}$
No. of IPs	2
Polarization	to be considered in the second round of design

**\*Be noted that here the luminosities are the lowest requirement to accomodate different collider schemes**

# CEPC-SPPC Timeline (preliminary and ideal)

## CEPC

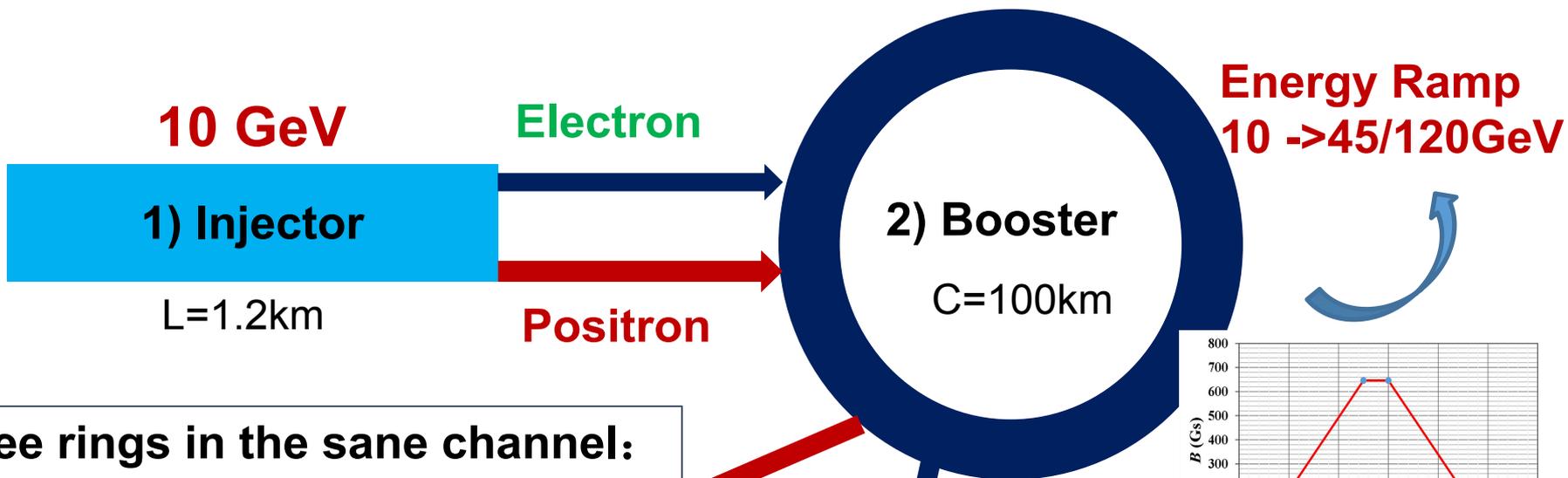


**1<sup>st</sup> Milestone:** Pre-CDR (by the end of 2014); **2<sup>nd</sup> Milestone:** R&D funding from MOST (in Mid 2016); **3<sup>rd</sup> Milestone:** CEPC CDR Status Report (by the end of 2016); **4<sup>th</sup> Milestone:** CEPC CDR Report (by the end of 2017); **5<sup>th</sup> Milestone:** CEPC TDR Report and Proto R&D (by the end of 2020); **6<sup>th</sup> Milestone:** CEPC construction start (2022);

## SPPC



# CEPC CDR Accelerator Chain and Systems

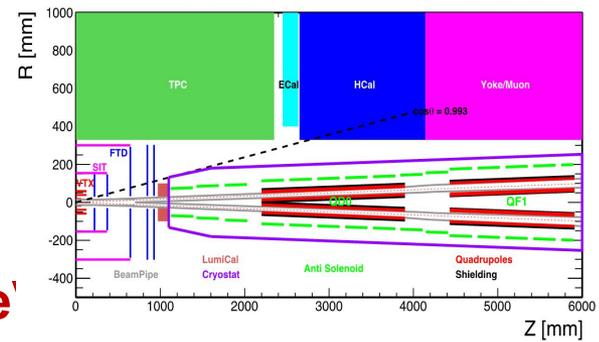
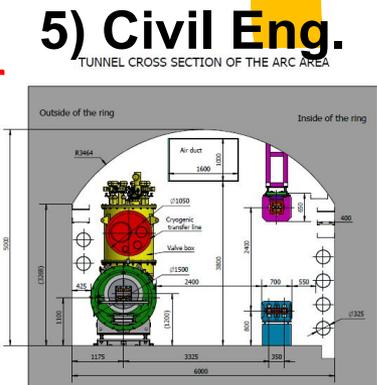


Three rings in the same channel:

- CEPC & booster
- SppC

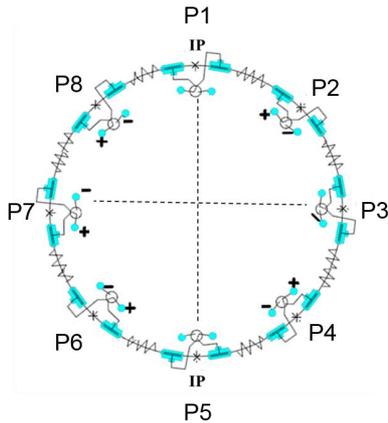
The key systems of CEPC:

- 1) Linac Injector
- 2) Booster
- 3) Collider ring
- 4) MDI
- 5) Civil Eng.



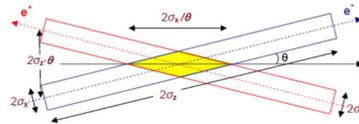
# CEPC Four Options Evolving towards CDR

CEPC Pre-CDR Scheme (head-on collision)

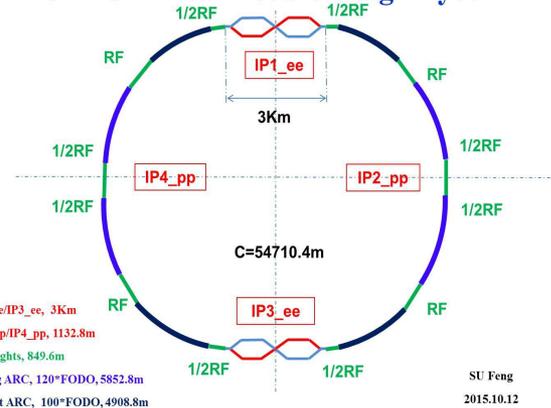


Since Oct 2012

Crab-waist collision  
in CEPC CDR

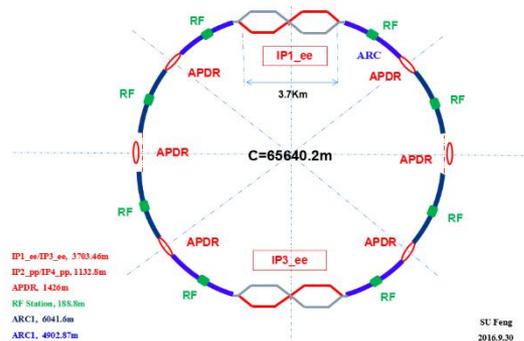


CEPC Partial Double Ring Layout



Since May 2015

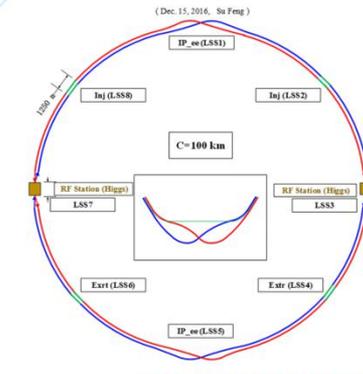
CEPC Advanced Partial Double Ring Option II



Since May 2016

CEPC Alternative Design

Lower cost and reaching the fundamental requirement for Higgs and Z luminosities, under the condition that sawtooth and beam loading effects be solved



Since Nov 2016

CEPC Baseline Design

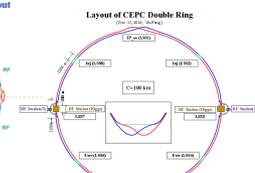
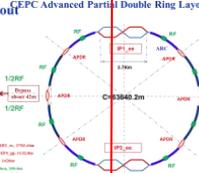
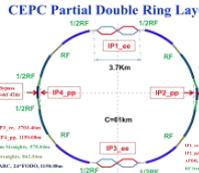
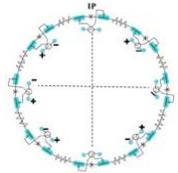
Better performance for Higgs and Z compared with alternative scheme, without bottle neck problems, but with higher cost 30MW synchrotron radiation power/beam

- CEPC 100km circumference was decided by CEPC SC based on the recommendation from IAC in Nov. 2016
- CEPC baseline and alternative options have been decided on Jan. 14, 2017

# Collider Schemes vs Luminosity Potentials

Machine

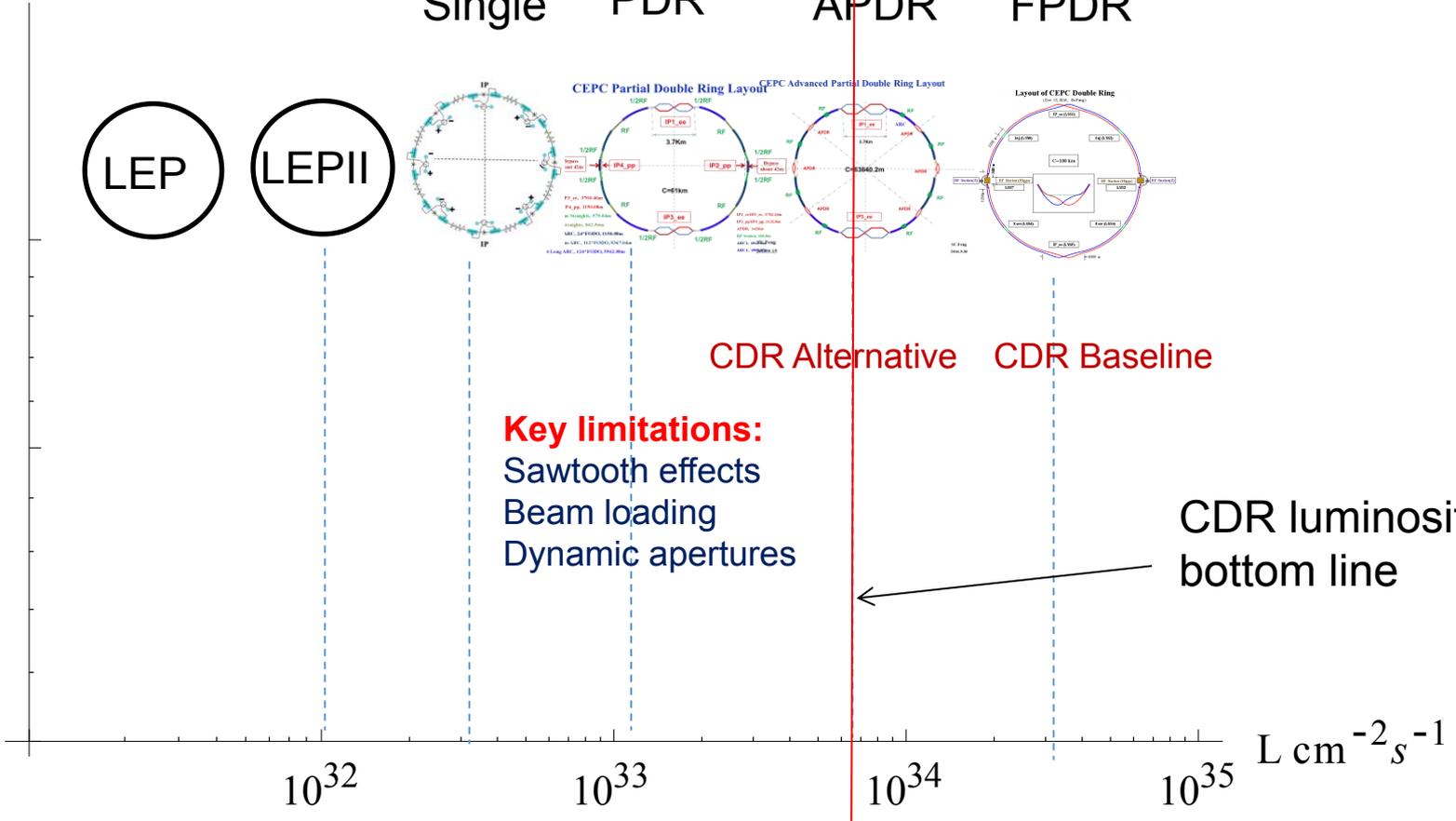
CEPC Single  
CEPC PDR  
CEPC APDR  
CEPC FPDR



CDR Alternative CDR Baseline

**Key limitations:**  
Sawtooth effects  
Beam loading  
Dynamic apertures

CDR luminosity bottom line



Luminosity H

$10^{32}$  (102GeV)

$< \sim 2 \cdot 10^{34}$

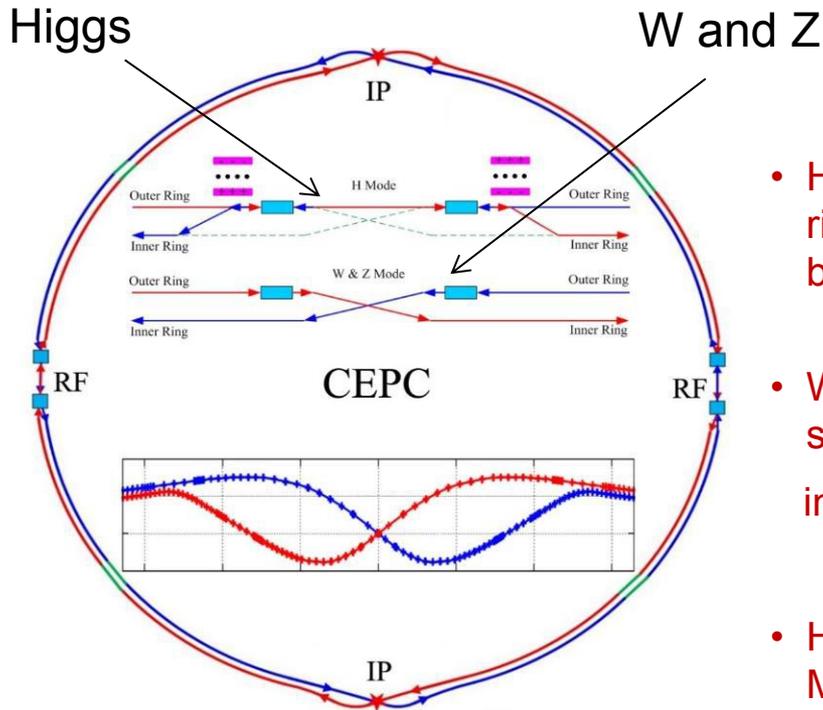
$> 2 \sim 5 \cdot 10^{34}$  ( $\text{cm}^{-2}\text{s}^{-1}$ )

Luminosity Z  $10^{32}$

$< \sim 1 \cdot 10^{34}$

$> 10 \cdot 10^{34}$  ( $\text{cm}^{-2}\text{s}^{-1}$ )

# CEPC SRF Design for H,W, and Z



- Higgs factory as first priority (fully partial double ring, with common SRF system for e+ and e- beams)
- W and Z factories are incorporated by beam switchyard (W and Z factories are double ring, with independent SRF system for e+ and e- beams)
- Higgs factory baseline SR per beam 30 MW to Minimize AC power

## Economic CEPC baseline design as Higgs factory (Design principles):

- W, Z factories incorporated with the same SRF system hardware by using beam switchyard to change from Higgs factory and W, Z factories
- Synchrotron radiation power per beam at Higgs energy is set to 30MW to minimize AC power consumption

# CEPC Accelerator from Pre-CDR to CDR

CEPC accelerator CDR completed in June 2018 (to be printed in July 2018)

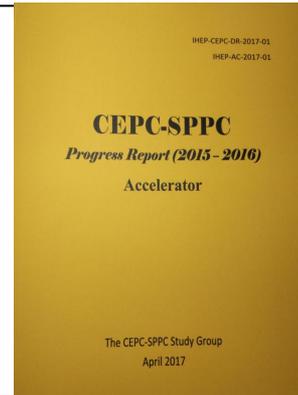
- **Executive Summary**

1. Introduction
2. Machine Layout and Performance
3. Operation Scenarios
4. CEPC Collider
5. CEPC Booster
6. CEPC Linac
7. Systems Common to the CEPC Linac, Booster and Collider
8. Super Proton Proton Collider
9. Conventional Facilities
10. Environment, Health and Safety
11. R&D Program
12. Project Plan, Cost and Schedule

- Appendix 1: CEPC Parameter List
- Appendix 2: CEPC Technical Component List
- Appendix 3: CEPC Electric Power Requirement
- Appendix 4: Advanced Partial Double Ring
- Appendix 5: CEPC Injector Based on Plasma Wakefield Accelerator
- Appendix 6: Operation as a High Intensity  $\gamma$ -ray Source
- Appendix 7: Operation for e-p, e-A and Heavy Ion Collision
- Appendix 8: Opportunities for Polarization in the CEPC
- Appendix 9: International Review Report



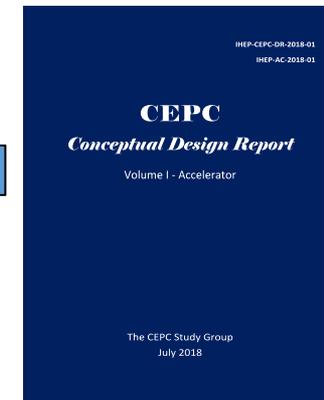
March 2015



April 2017



Draft CDR for  
Mini International  
Review in Nov. 2017



CDR Version for International  
Review from June 28-30 2018

# Mini-Review Workshop of CEPC-SPPC CDR (Nov. 4-5, 2017, IHEP)

CEPC-SPPC CDR Mini-review members

Name (alphabetical order)

Anton Bogomyakov	BINP	Russia
Brian Foster	Oxford U.	U.K.
Eugene Levichev	BINP	Russia
Kexin Liu (刘克新)	Peking U.	China
Ernie Malamud	Fermilab	USA
Kazuhito Ohmi	KEK	Japan
Katsunobu Oide	CERN / KEK	Switzerland
Carlo Pagani	U. of Milan / INFN	Italy
John Seeman	SLAC	USA
Sergey Sinyatkin	BINP	Russia
Mike Sullivan	SLAC	USA
Chuanxiang Tang (唐传祥)	Tsinghua U.	China
Lin Wang (王林)	USTC	China
Xiangqi Wang (王相綦)	USTC	China
Akira Yamamoto	KEK	Japan



Sunday, November 5		
08:30 – 09:00	SRF	Jiyuan Zhai Zusheng Zhou Shaopeng Li Fusan Chen
09:00 – 09:30	RF power source	
09:30 – 10:00	Cryogenic system	
10:00 – 10:30	Magnet	
10:30 – 11:00	Coffee (30')	

## Informal Mini-Review of CEPC-SPPC CDR

November 4 – 5, 2017, IHEP, Main Building, Room A415

Agenda (draft v2. 09/14/2017)

Saturday, November 4		
08:30 – 08:35	Welcome	Yifang Wang Chenghui Yu Dou Wang Yiwei Wang Yuan Zhang
08:35 – 09:10	Overview of beam dynamics	
09:10 – 09:40	Parameters	
09:40 – 10:10	Optics	
10:10 – 10:40	Dynamic aperture	
10:40 – 11:10	Coffee (30')	
11:10 – 11:40	Beam-beam	Yuan Zhang Na Wang Sha Bai
11:40 – 12:10	Instabilities	
12:10 – 12:40	Machine-detector interface	
12:40 – 14:00	Lunch	
14:00 – 14:30	Injection and extraction	Xiaohao Cui Tianjian Bian Cai Meng
14:30 – 15:00	Booster	
15:00 – 15:30	Linac and sources	
15:30 – 16:00	Coffee (30')	
16:00 – 16:30	Synchrotron radiation	Yadong Ding Jingyu Tang Qingjin Xu All
16:30 – 17:00	Overview of SPPC	
17:00 – 17:30	SC magnet for SPPC	
17:30 – 18:30	Discussion	
19:00	Dinner	

# International Review of CEPC CDR (June 28-30, 2018, IHEP)

## International Review of CEPC CDR

June 28 – 30, 2018, IHEP, Main Building, Room A415

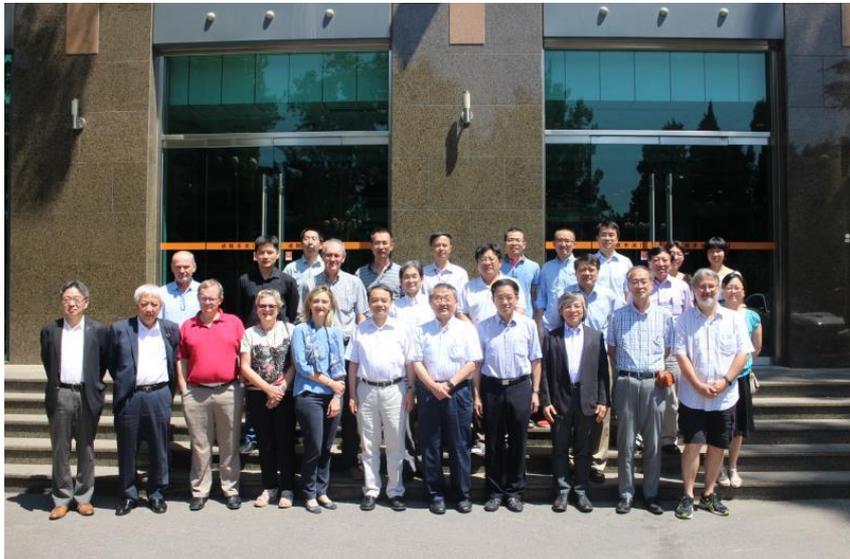
### Agenda

Thursday, June 28		
8:30-9:00	Chair: K. Oide <b>Committee Executive Session</b>	
9:00-9:05 9:05-9:20 9:20-9:35 9:35-10:05 10:05-10:35	Chair: Qing Qin Welcome Overview of CEPC Overview of beam dynamics CEPC collider lattice design CEPC beam-beam and DA	Yifang Wang Jie Gao Chenghui Yu Yiwei Wang Yuan Zhang
11:05-11:35 11:35-12:05	Coffee break(30') Chair: K. Oide Instabilities Machine-detector interface	Na Wang Sha Bai
12:05 – 14:00	Lunch break	
14:00-14:30 14:30-15:00 15:30-16:00	Chair: K. Oide Booster Injection and extraction Linac injector  Coffee break(30')	Dou Wang Xiaohao Cui Cai Meng
16:30-18:30	<b>Committee Executive Session</b>	
19:00	Dinner of Committee	

Friday, June 29		
8:30-9:00 9:00-9:30 9:30-10:00 10:00-10:20 10:20-10:40	Chair: K. Oide SRF system RF power source Cryogenic system CEPC collider ring Magnet CEPC booster ring magnet  Coffee break(30')	
11:10-11:30 11:30-12:00 12:00-12:30	SC magnet for CEPC IR Power supplies Vacuum	
12:30 – 14:00	Lunch break	
14:00-14:30 14:30-15:00 15:00-15:30 15:30-16:00	Chair: K. Oide Instrumentation Control Synchrotron radiation Radiation shielding  Coffee break(30')	
16:30-18:30	<b>Committee Executive Session</b>	
	Dinner	

Saturday, June 30		
8:30-9:00 9:00-9:30 9:30-10:00 10:00-10:30	Chair: K. Oide Survey and alignment Mechanics Conventional facilities Site investigation  Coffee break (30')	Xiaolong Wang Haijing Wang Guoping Lin Yu Xiao
11:00-12:00	Discussion with CEPC team	
12:00 – 14:00	Lunch break	
14:00-16:00	<b>Committee Executive Session</b>  Coffee break (30')	
16:30-17:30	Close out	
	Banquet	



### Review Committee Members:

Brian Foster	Oxford U./DESY
Eugene Levichev	BINP
Katsunobu Oide (chair)	CERN/KEK
Kazuro Furukawa	KEK
Manuela Boscolo	INFN
Marica Biagini	INFN
Masakazu Yoshioka	KEK/Tohoko University
Norihito Ohuchi	KEK
Paolo Pierini	ESS
Steinar Stapnes	CERN
Yoshihiro Funakoshi	KEK
Zhengtang Zhao (absent)	SINAP

# International Review Report (draft) of CEPC CDR (June 28-30, 2018, IHEP)

International Review of CEPC Conceptual Design Report  
- Accelerator Design -

June 28 – 30, 2018  
IHEP, Beijing

DRAFT

This is the review report of the accelerator part of the CEPC CDR. The review is done for the presentations based on the draft version of the CDR. Extensive discussions have been held between the review committee members and the CEPC team during the review meeting.

## General remarks

The Circular Electron-Positron Collider (CEPC) is a very ambitious and important project aimed at various physics at ZH (Ebeam = 120 GeV),  $W^\pm$  (80 GeV), and Z (46 GeV) production which would produce the highest luminosity ever achieved by a collider in the world. The Superconducting Proton-Proton Collider (SppC) is planned as the second stage of the project using the same collider tunnel to explore the energy frontier of elementary particle physics.

The Review Committee unanimously congratulates the CEPC team on the completion of the CDR, with remarkable successes in various aspects of the design. The progress since the pre-CDR has been a major step in the project, especially the full double-ring scheme, lattice design, and various beam dynamics with beam-beam effects and collective phenomena. The design work on each system has verified the basic feasibility of the project, including the superconducting RF, normal and superconducting magnets, vacuum system, injectors with a booster synchrotron and a linac, instrumentation, control, safety, civil engineering, etc.

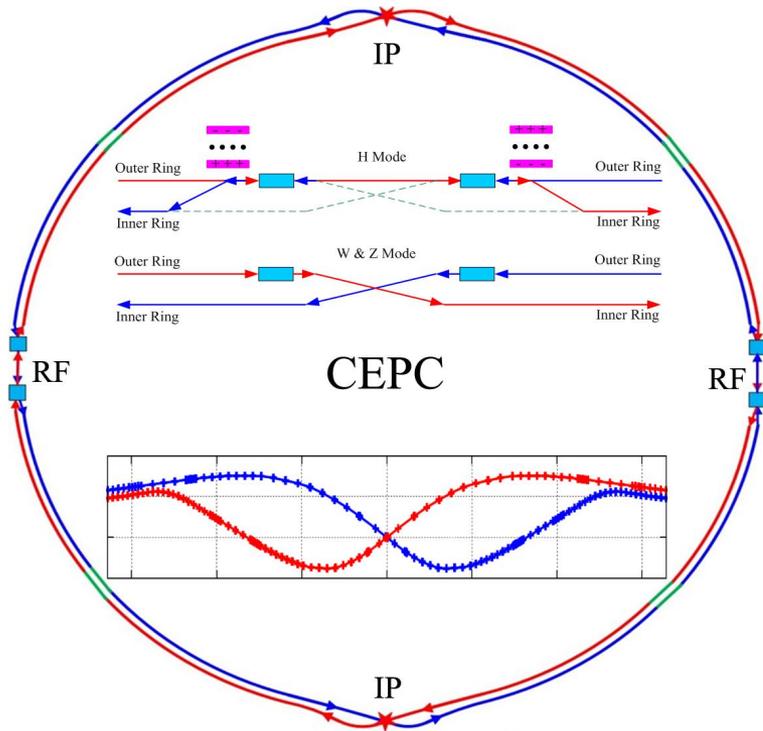
# International Review Report (draft) of CEPC CDR (June 28-30, 2018, IHEP)

The Committee believes that the CDR has already reached a sufficient level of maturity to allow approval to proceed to a Technical Design Report. On the other hand, we think that this machine has more potential for further extensions, including:

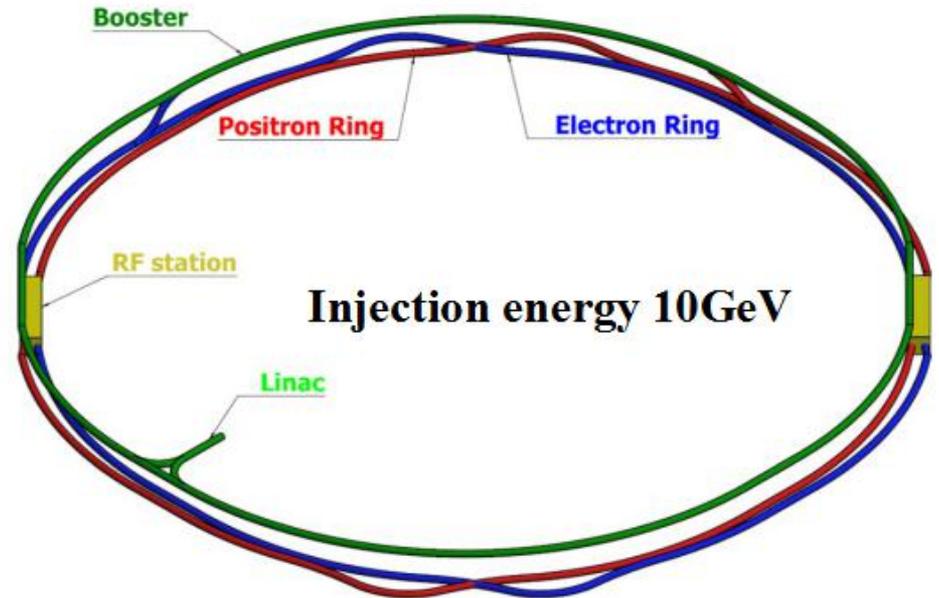
- (1) Experiments for  $t\bar{t}$  production ( $E_{\text{beam}} \approx 180$  GeV);
- (2) Even higher luminosity ( $\sim \times 10$ ) at Z and  $W_{\pm}$ ;
- (3) Higher beam current, up to 50 MW/beam synchrotron radiation loss;
- (4) More interaction points;
- (5) Polarised beams.

These extensions will be achievable if the machine preserves the possibility to implement these possibilities by relatively small investments, such as longer quadrupole magnets, a less compressed layout around the interaction point (IP) with shallower bends, and sufficient length for the RF section. Actually, such improvements may even reduce the operation costs. The committee encourages the CEPC team to explore and preserve these possibilities, since once CEPC is built, no second machine with the same scale is likely to be built in the world.

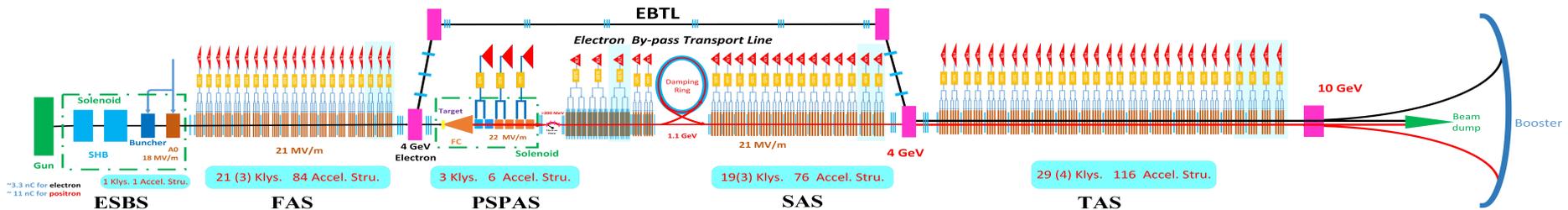
# CEPC CDR Layout



CEPC collider ring (100km)

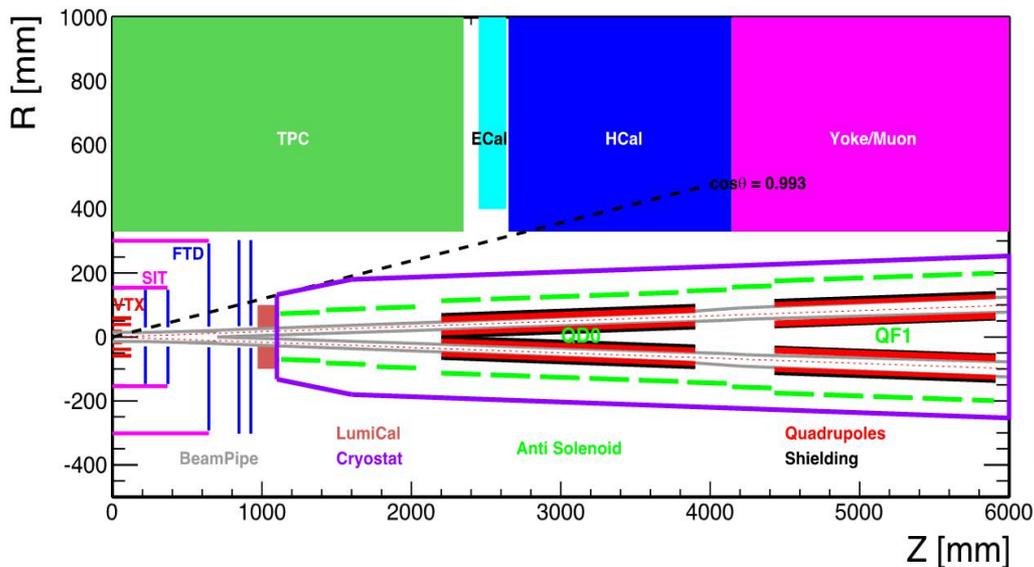


CEPC booster ring (100km)



CEPC Linac injector (1.2km, 10GeV)

# CEPC MDI Layout and Parameters



MDI parameters	Values
$L^*$ (m)	<b>2.2</b>
Crossing angle (mrad)	<b>33</b>
Strength of QD0 (T/m)	<b>150</b>
Strength of detector solenoid (T)	<b>3.0</b>
Strength of anti-solenoid (T)	<b>7.0</b>

- The Machine Detector Interface of CEPC double ring scheme is about  $\pm 7\text{m}$  long from the IP.
- The CEPC detector superconducting solenoid with 3 T magnetic field and the length of 7.6m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of  $\cos\theta=0.993$ .
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

# CEPC CDR Parameters

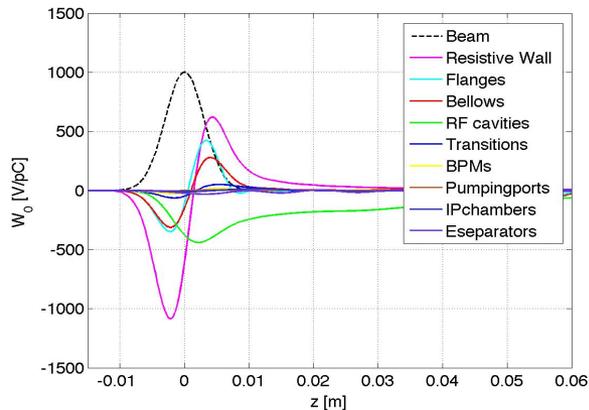
	<i>Higgs</i>	<i>W</i>	<i>Z (3T)</i>	<i>Z (2T)</i>
Number of IPs	2			
Beam energy (GeV)	<b>120</b>	<b>80</b>	<b>45.5</b>	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch $N_e$ ( $10^{10}$ )	15.0	12.0	8.0	
<b>Bunch number (bunch spacing)</b>	<b>242 (0.68μs)</b>	<b>1524 (0.21μs)</b>	<b>12000 (25ns+10%gap)</b>	
Beam current (mA)	17.4	87.9	461.0	
<b>Synchrotron radiation power /beam (MW)</b>	<b>30</b>	<b>30</b>	<b>16.5</b>	
Bending radius (km)	10.7			
Momentum compact ( $10^{-5}$ )	1.11			
<b><math>\beta</math> function at IP <math>\beta_x^* / \beta_y^*</math> (m)</b>	<b>0.36/0.0015</b>	<b>0.36/0.0015</b>	<b>0.2/0.0015</b>	<b>0.2/0.001</b>
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP $\sigma_x/\sigma_y$ (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters $\xi_x/\xi_y$	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage $V_{RF}$ (GV)	2.17	0.47	0.10	
RF frequency $f_{RF}$ (MHz) (harmonic)	650 (216816)			
Natural bunch length $\sigma_z$ (mm)	2.72	2.98	2.42	
Bunch length $\sigma_z$ (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	<b>1.94</b>	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	<b>1.35</b>	<b>0.4</b>	<b>0.23</b>	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	<b>0.67</b>	<b>1.4</b>	<b>4.0</b>	<b>2.1</b>
$F$ (hour glass)	0.89	0.94	0.99	
<b>Luminosity/IP <math>L</math> (<math>10^{34}\text{cm}^{-2}\text{s}^{-1}</math>)</b>	<b>2.93</b>	<b>10.1</b>	<b>16.6</b>	<b>32.1</b>

# CEPC Collider Ring SRF Parameters

Collider parameters: 20180222	H	W	Z
SR power / beam [MW]	30	30	16.5
RF voltage [GV]	2.17	0.47	0.1
Beam current / beam [mA]	17.4	87.9	461
Bunch charge [nC]	24	24	12.8
Bunch number / beam	242	1220	12000
Bunch length [mm]	3.26	6.53	8.5
Cavity number (650 MHz 2-cell)	240	2 x 108	2 x 60
Cavity gradient [MV/m]	19.7	9.5	3.6
Input power / cavity [kW]	250	278	276
Klystron power [kW] (2 cavities / klystron)	800	800	800
HOM power / cavity [kW]	0.54	0.86	1.94
Optimal $Q_L$	1.5E6	3.2E5	4.7E4
Optimal detuning [kHz]	0.17	1.0	18.3
Total cavity wall loss @ 2 K [kW]	6.6	1.9	0.2

# CEPC Collider Ring Impedance Budget

Components	Number	$Z_{  }/n$ , m $\Omega$	$k_{\text{loss}}$ , V/pC	$\kappa_y$ , kV/pC/m
Resistive wall	-	6.2	363.7	11.3
RF cavities	336	-1.4	315.3	0.41
Flanges	20000	2.8	19.8	2.8
BPMs	1450	0.12	13.1	0.3
Bellows	12000	2.2	65.8	2.9
Pumping ports	5000	0.02	0.4	0.6
IP chambers	2	0.02	6.7	1.3
Electro-separators	22	0.2	41.2	0.2
Taper transitions	164	0.8	50.9	0.5
<b>Total</b>		<b>10.5</b>	<b>876.8</b>	<b>20.4</b>



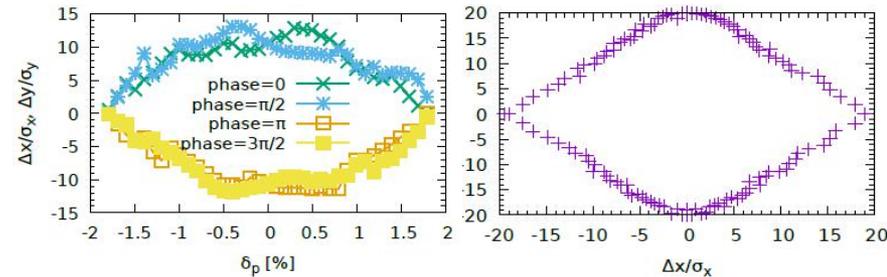
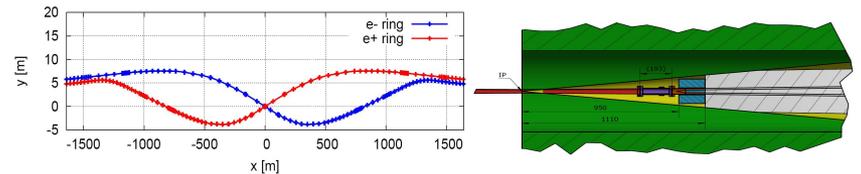
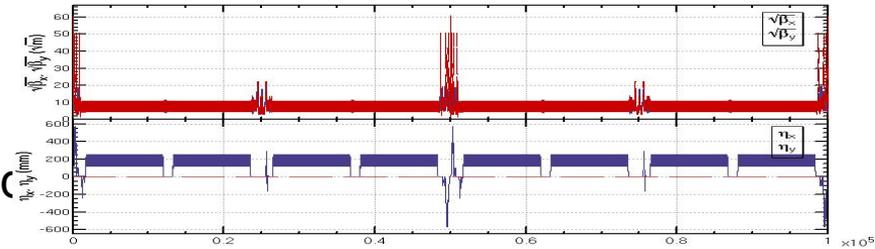
Broadband impedance threshold:

Threshold	ttbar	Higgs	W	Z
$ Z_{  }/n _{\text{eff}}$ , m $\Omega$	13.6	9.0	8.0	2.1
$\kappa_y$ , kV/pC/m	81.2	61.6	69.0	38.7

Longitudinal wake at the nominal  $\sigma_z = 3\text{mm}$

# The Key Beam Dynamic Issues Solved

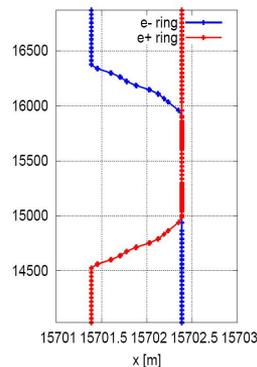
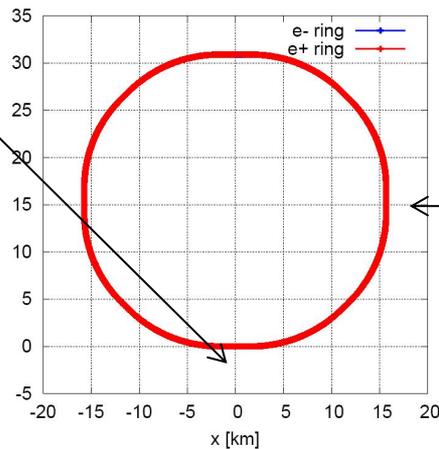
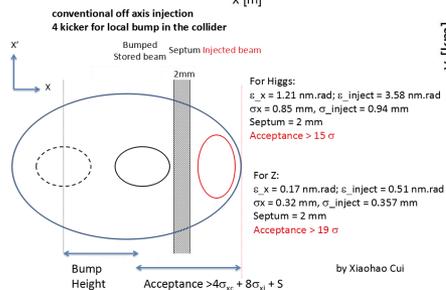
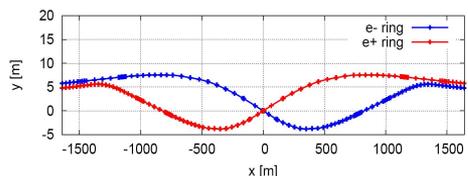
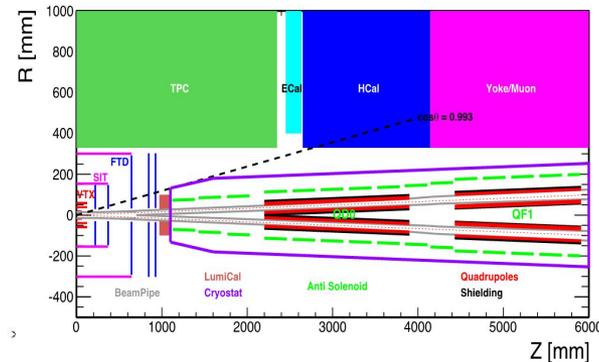
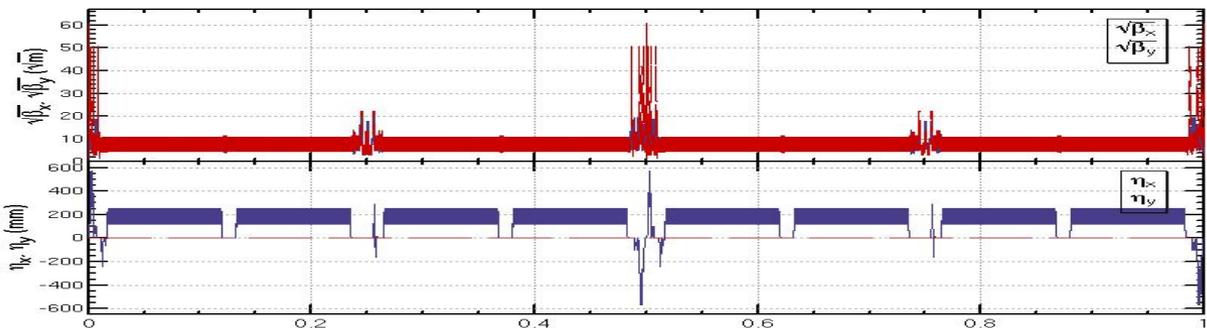
- ✓ The collider ring lattice design
- ✓ The collider SCRF system
- ✓ The MDI and control of detector background
- ✓ The beam-beam effect
- ✓ The optimization of dynamic aperture
- ✓ The on-axis injection scheme
- ✓ The impedance and instabilities
- ✓ Booster design
- ✓ Injection linac design
- ✓ Booster Injection and extraction



# Lattice of the CEPC Collider Ring and MDI

An optics fulfilling requirements of the parameters list, geometry, MDI, background and key hardware

## CEPC MDI



MDI parameters	Values
$L^*$ (m)	<b>2.2</b>
Crossing angle (mrad)	<b>33</b>
Strength of QDO (T/m)	<b>150</b>
Strength of detector solenoid (T)	<b>3.0</b>
Strength of anti-solenoid (T)	<b>7.0</b>

# CEPC Booster parameters @ injection (10GeV)

D. Wang

		<i>H</i>	<i>W</i>	<i>Z</i>
Beam energy	GeV	10		
Bunch number		242	1524	6000
Threshold of single bunch current	$\mu\text{A}$	25.7		
Threshold of beam current (limited by coupled bunch instability)	mA	127.5		
Bunch charge	nC	0.78	0.63	0.45
Single bunch current	$\mu\text{A}$	2.3	1.8	1.3
Beam current	mA	0.57	2.86	7.51
Energy spread	%	0.0078		
Synchrotron radiation loss/turn	keV	73.5		
Momentum compaction factor	$10^{-5}$	2.44		
Emittance	nm	0.025		
Natural chromaticity	H/V	-336/-333		
RF voltage	MV	62.7		
Betatron tune $\nu_x/\nu_y/\nu_s$		263.2/261.2/0.1		
RF energy acceptance	%	1.9		
Damping time	s	90.7		
Bunch length of linac beam	mm	1.0		
Energy spread of linac beam	%	0.16		
Emittance of linac beam	nm	40~120		

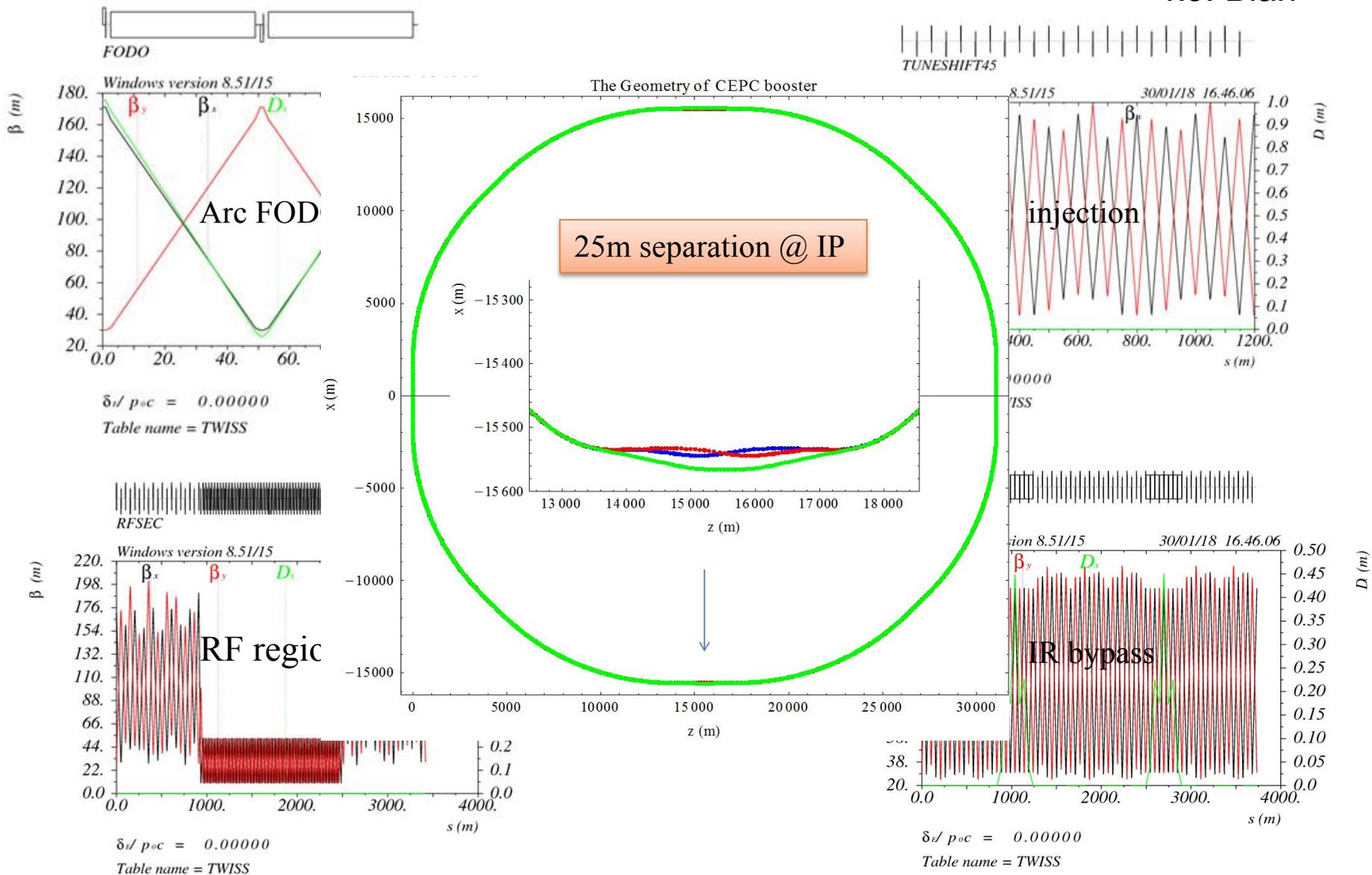
# CEPC Booster parameters @ extraction

D. Wang  
T.J. Bian

		<i>H</i>		<i>W</i>	<i>Z</i>
		Off axis injection	On axis injection	Off axis injection	Off axis injection
Beam energy	GeV	120		80	45.5
Bunch number		242	235+7	1524	6000
Maximum bunch charge	nC	0.72	24.0	0.58	0.41
Maximum single bunch current	$\mu\text{A}$	2.1	70	1.7	1.2
Threshold of single bunch current	$\mu\text{A}$	300			
Threshold of beam current (limited by RF power)	mA	1.0		4.0	10.0
Beam current	mA	0.52	1.0	2.63	6.91
Injection duration for top-up (Both beams)	s	25.8	35.4	45.8	275.2
Injection interval for top-up	s	73.1		153.0	438.0
Current decay during injection interval		3%			
Energy spread	%	0.094		0.062	0.036
Synchrotron radiation loss/turn	GeV	1.52		0.3	0.032
Momentum compaction factor	$10^{-5}$	2.44			
Emittance	nm	3.57		1.59	0.51
Natural chromaticity	H/V	-336/-333			
Betatron tune $\nu_x/\nu_y$		263.2/261.2			
RF voltage	GV	1.97		0.585	0.287
Longitudinal tune		0.13		0.10	0.10
RF energy acceptance	%	1.0		1.2	1.8
Damping time	ms	52		177	963
Natural bunch length	mm	2.8		2.4	1.3
Injection duration from empty ring	h	0.17		0.25	2.2

# CEPC Booster Optics & Geometry

D. Wang  
T.J. Bian



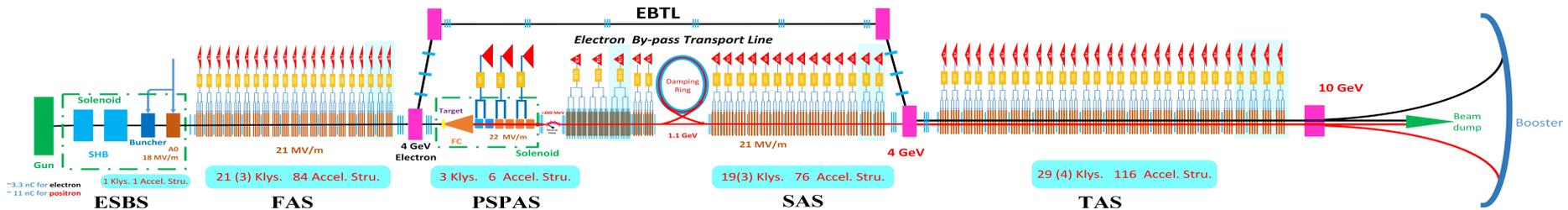
# CEPC Booster SRF Parameters

10 GeV injection	H	W	Z
Extraction beam energy [GeV]	120	80	45.5
Bunch number	242	1524	6000
Bunch charge [nC]	0.72	0.576	0.384
Beam current [mA]	0.52	<b>2.63</b>	<b>6.91</b>
Extraction RF voltage [GV]	1.97	0.585	0.287
Extraction bunch length [mm]	2.7	2.4	1.3
Cavity number in use (1.3 GHz TESLA 9-cell)	96	64	32
Gradient [MV/m]	19.8	8.8	8.6
$Q_L$	1E7	6.5E6	1E7
Cavity bandwidth [Hz]	130	200	130
Beam peak power / cavity [kW]	8.3	12.3	6.9
Input peak power per cavity [kW] (with detuning)	18.2	12.4	7.1
Input average power per cavity [kW] (with detuning)	0.7	0.3	0.5
SSA peak power [kW] (one cavity per SSA)	25	<b>25</b>	<b>25</b>
HOM average power per cavity [W]	0.2	0.7	<b>4.1</b>
$Q_0$ @ 2 K at operating gradient (long term)	1E10	1E10	1E10
Total average cavity wall loss @ 2 K eq. [kW]	0.2	0.01	0.02

# Main Parameters of Injector Linac

Parameter	Symbol	Unit	Designed
e <sup>-</sup> /e <sup>+</sup> beam energy	$E_{e^-}/E_{e^+}$	GeV	<b>10</b>
Repetition rate	$f_{rep}$	Hz	<b>100</b>
e <sup>-</sup> /e <sup>+</sup> bunch population	$N_{e^-}/N_{e^+}$		<b>&gt; 9.4 × 10<sup>9</sup> / &gt; 9.4 × 10<sup>9</sup></b>
		nC	<b>&gt; 1.5</b>
Energy spread (e <sup>-</sup> /e <sup>+</sup> )	$\sigma_e$		<b>&lt; 2 × 10<sup>-3</sup> / &lt; 2 × 10<sup>-3</sup></b>
Emittance (e <sup>-</sup> /e <sup>+</sup> )	$\epsilon_r$	nm·rad	<b>&lt; 120</b>
Bunch length (e <sup>-</sup> /e <sup>+</sup> )	$\sigma_l$	mm	<b>1 / 1</b>
e <sup>-</sup> beam energy on Target		GeV	<b>4</b>
e <sup>-</sup> bunch charge on Target		nC	<b>10</b>

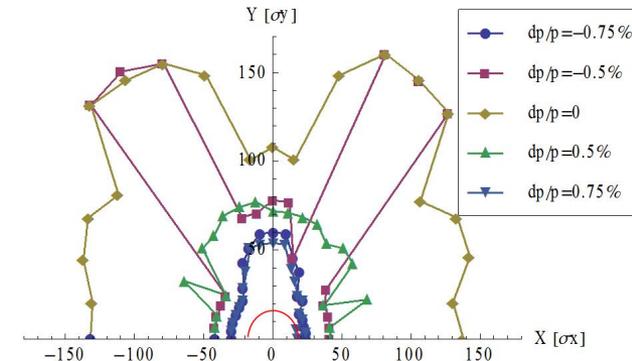
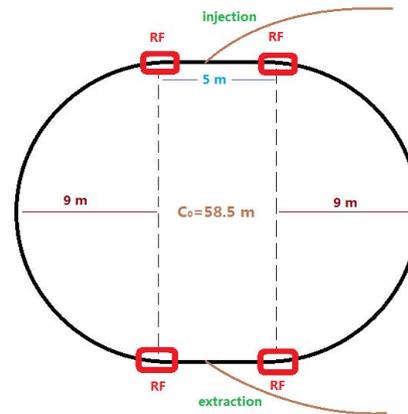
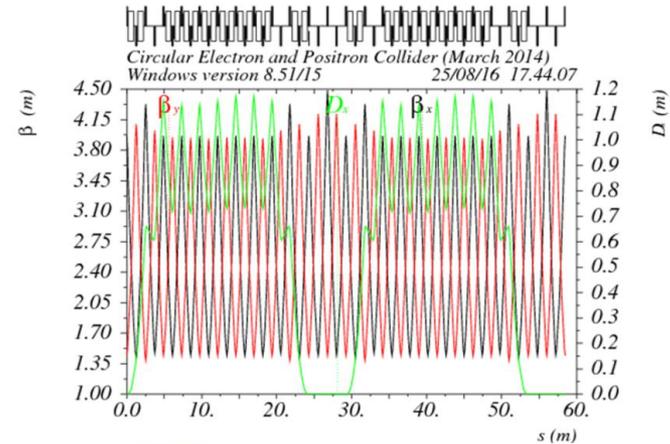
- The total beam transfer efficiency from transfer line to the injection point of collider ring is higher than 90%.
- The transfer efficiency can be much higher with the application of damping ring which the beam energy is 1.1 GeV.



# CEPC Linac Injector Damping Ring

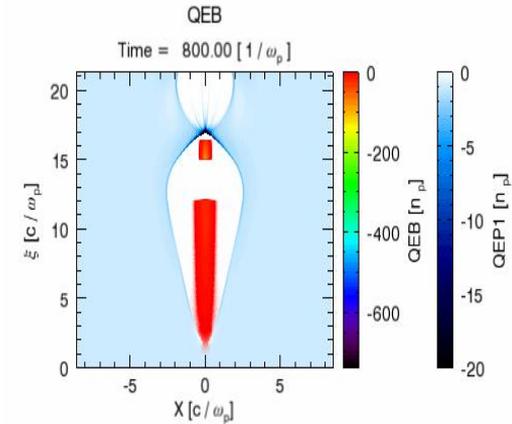
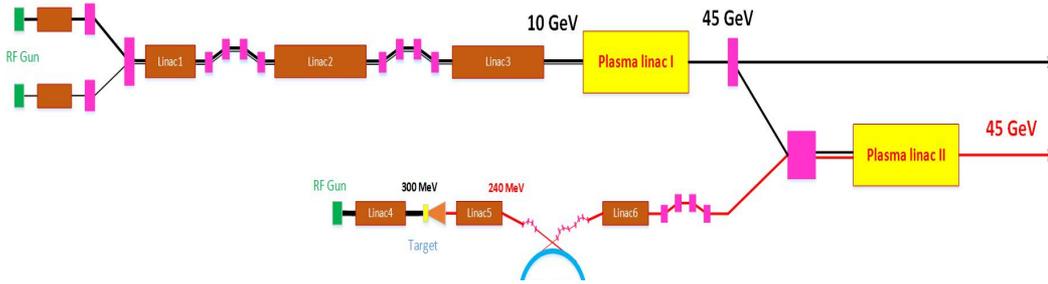
and layout

DR V1.0	Unit	Value
Energy	GeV	1.1
Circumference	M	58.5
Repetition frequency	Hz	100
Bending radius	M	3.6
Dipole strength $B_0$	T	1.01
$U_0$	keV	35.8
Damping time x/y/z	Ms	12/12/6
$\delta_0$	%	0.049
$\varepsilon_0$	mm.mrad	302
Nature $\sigma_z$	mm	7 (23ps)
Extract $\sigma_z$	mm	7 (23ps)
$\varepsilon_{inj}$	mm.mrad	2500
$\varepsilon_{ext\ x/y}$	mm.mrad	716/471
$\delta_{inj}/\delta_{ext}$	%	0.6/0.07
Energy acceptance by RF	%	1.0
$f_{RF}$	MHz	650
$V_{RF}$	MV	1.8



# A High Energy CEPC Injector Based on Plasma Wakefield Accelerator

- HTR PWFA with good stability (single stage TR=3-4, high efficiency)
- Positron generation and acceleration in an electron beam driven PWFA using hollow plasma channel (TR=1)



<b>Plasma density</b> $n_0(cm^{-3})$	$5.15 \times 10^{16}$
Driver charge $Q_d(nC)$	6.47
Driver energy $E_d(GeV)$	10
Driver length $L_d(\mu m)$	285
Driver RMS size $\sigma_d(\mu m)$	10
Driver normalized emittance	10
$\epsilon_{nd}(mm\ mrad)$	10
Trailer charge $Q_t(nC)$	1.25
Trailer energy $E_t(GeV)$	10
Trailer length $L_t(\mu m)$	35
Trailer RMS size $\sigma_t(\mu m)$	5
Trailer normalized emittance	100
$\epsilon_{nt}(mm\ mrad)$	100

<b>Trailer energy</b> $E_t(GeV)$	45.5
Trailer normalized emittance	98.9
$\epsilon_{nt}(mm\ mrad)$	98.9
TR	3.55
Energy spread $\delta_E(\%)$	0.7
Efficiency (driver $\rightarrow$ trailer)	68.6%

@45GeV the plasma accelerated electron and positron beams satisfy the CEPC booster injection requirements

# CEPC CDR Design Status

## CEPC Collider Ring

Parameter	Symbol	Unit	Goal	Status
Beam Energy	$E$	GeV	120	<b>120</b>
Circumference	$C$	km	100	<b>100.006</b>
Emittance	$\varepsilon_x/\varepsilon_y$	nm·rad	1.21 / 0.0036	<b>1.208 / -</b>
Beta functions at IP	$\beta_x/\beta_y$	m	0.36 / 0.002	<b>0.36 / 0.002</b>
Energy acceptance	$\Delta P/P$	%	1.35	<b>1.8</b>
DA requirement	$DA_x/DA_y$	$\sigma$	13 / 12	<b>20 / 20 (w/o errors)</b>

\* Z and W satisfies CDR requirement as well

**CDR goal reached**

# CEPC Booster Design Status

Parameters	Design goals	Design results
Beam current (mA)	<0.8	0.54
Emittance in x (nm rad)	<3.6	3.1
Dynamic aperture for 0.5% off-momentum particles	>3 $\sigma$	8.5 $\sigma$
Energy acceptance	>1%	2.5%
Timing	Meet the top-up injection requirements	✓

**CDR goal reached**

# CEPC Linac Injector CDR Status

Parameter	Symbol	Unit	Goal	Status
e <sup>-</sup> /e <sup>+</sup> beam energy	$E_{e^-}/E_{e^+}$	GeV	10	10/10
Repetition rate	$f_{rep}$	Hz	100	100
e <sup>-</sup> /e <sup>+</sup> bunch population	$N_{e^-}/N_{e^+}$		$>6.25 \times 10^9$	$\sim 1.875 \times 10^{10}$ $\sim 1.875 \times 10^{10}$
	$N_{e^-}/N_{e^+}$	nC	>1.0	1.0/3.0*
Energy spread (e <sup>-</sup> /e <sup>+</sup> )	$\sigma_E$		$<2 \times 10^{-3}$	$1.5 \times 10^{-3}$ $1.4 \times 10^{-3}$
Emittance (e <sup>-</sup> /e <sup>+</sup> )		mm·mrad	<0.3	0.005/0.12**
e <sup>-</sup> beam energy on Target		GeV	4	4
e <sup>-</sup> bunch charge on Target		nC	10	10

# CEPC Power for Higgs and Z

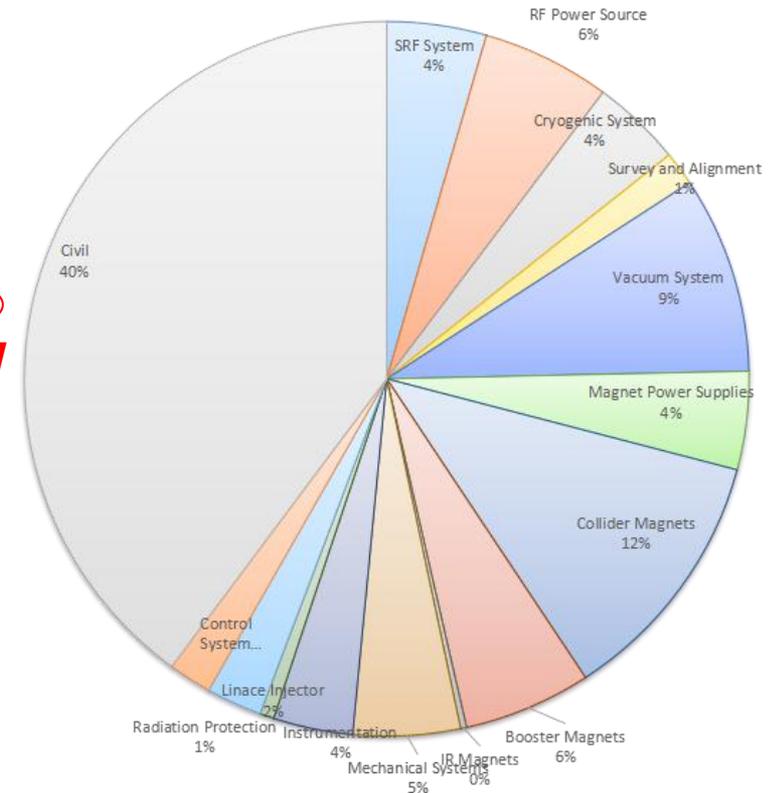
	System for Higgs (30MW)	Location and electrical demand(MW)					Total (MW)	
		Ring	Booster	LINAC	BTL	IR		Surface building
1	RF Power Source	103.8	0.15	5.8				109.75
2	Cryogenic System	11.62	0.68			1.72		14.02
3	Vacuum System	9.784	3.792	0.646				14.222
4	Magnet Power Supplies	47.21	11.62	1.75	1.06	0.26		61.9
5	Instrumentation	0.9	0.6	0.2				1.7
6	Radiation Protection	0.25		0.1				0.35
7	Control System	1	0.6	0.2	0.005	0.005		1.81
8	Experimental devices					4		4
9	Utilities	31.79	3.53	1.38	0.63	1.2		38.53
10	General services	7.2		0.2	0.15	0.2	12	19.75
	<b>Total</b>	<b>213.554</b>	<b>20.972</b>	<b>10.276</b>	<b>1.845</b>	<b>7.385</b>	<b>12</b>	<b>266.032</b>

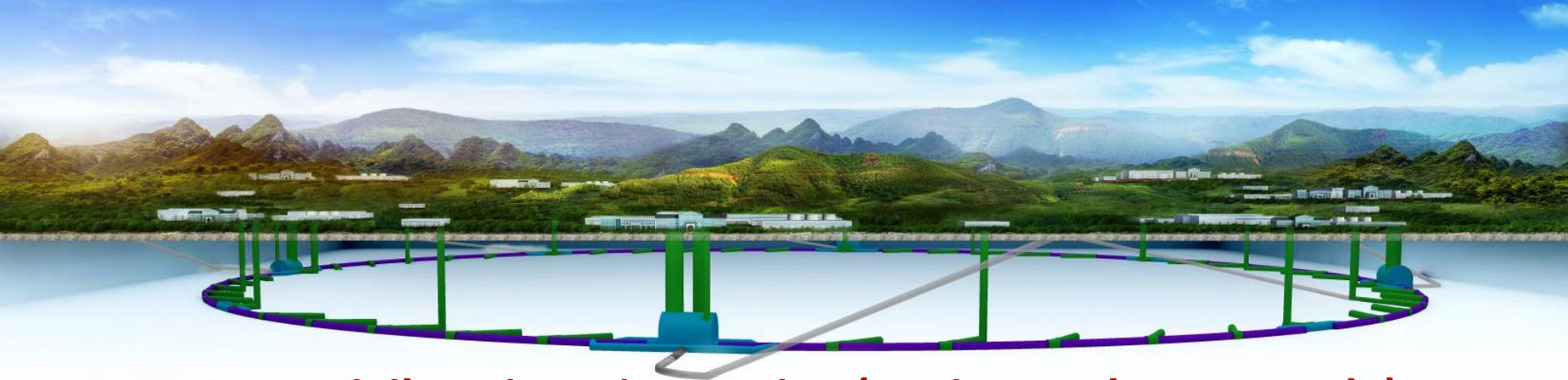
**266MW**

	System for Z	Location and electrical demand(MW)					Total (MW)	
		Ring	Booster	LINAC	BTL	IR		Surface building
1	RF Power Source	57.1	0.15	5.8				63.05
2	Cryogenic System	2.91	0.31			1.72		4.94
3	Vacuum System	9.784	3.792	0.646				14.222
4	Magnet Power Supplies	9.52	2.14	1.75	0.19	0.05		13.65
5	Instrumentation	0.9	0.6	0.2				1.7
6	Radiation Protection	0.25		0.1				0.35
7	Control System	1	0.6	0.2	0.005	0.005		1.81
8	Experimental devices					4		4
9	Utilities	19.95	2.22	1.38	0.55	1.2		25.3
10	General services	7.2		0.2	0.15	0.2	12	19.75
	<b>Total</b>	<b>108.614</b>	<b>9.812</b>	<b>10.276</b>	<b>0.895</b>	<b>7.175</b>	<b>12</b>	<b>148.772</b>

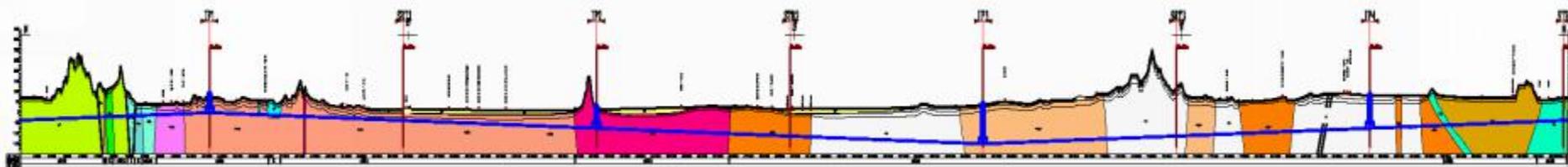
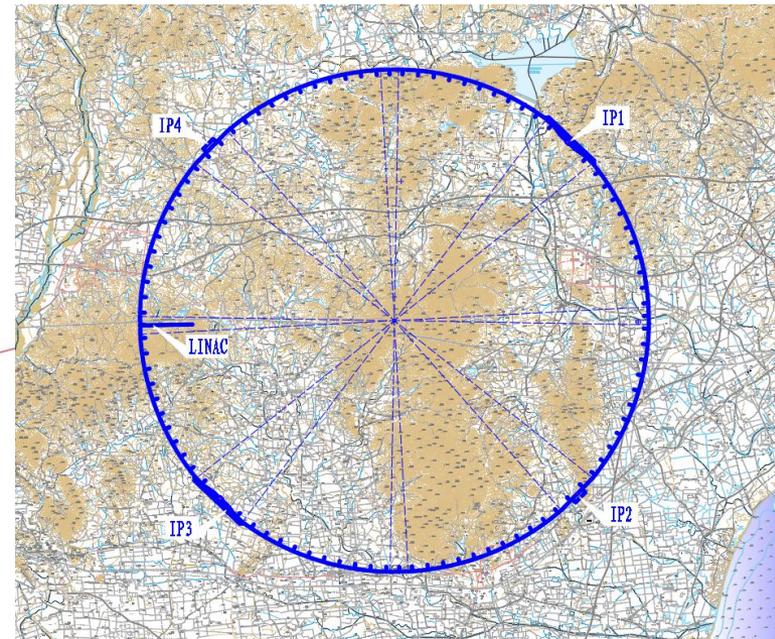
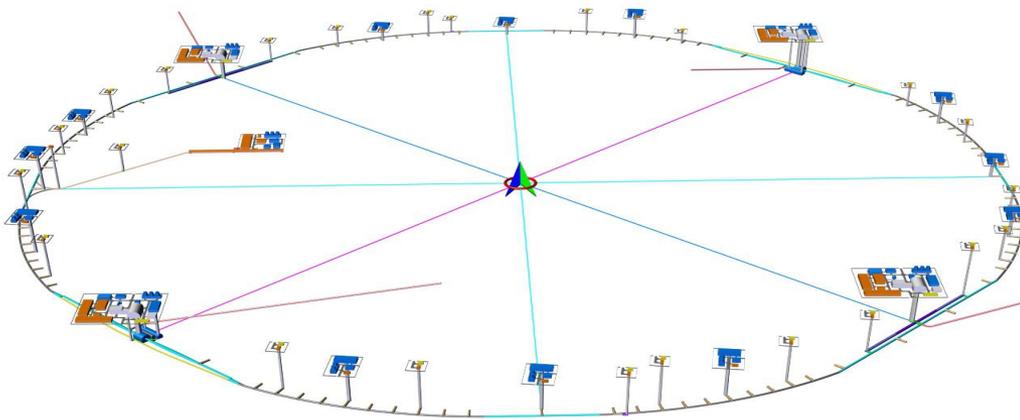
**149MW**

# CEPC Cost Breakdown (no detector)





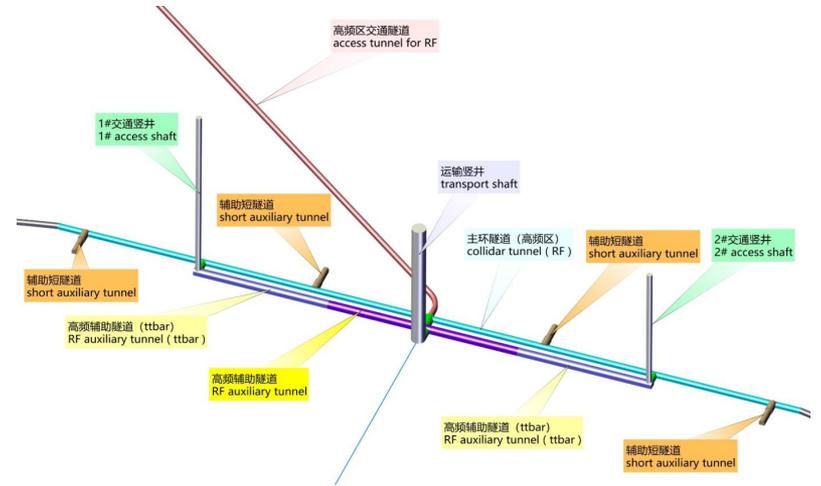
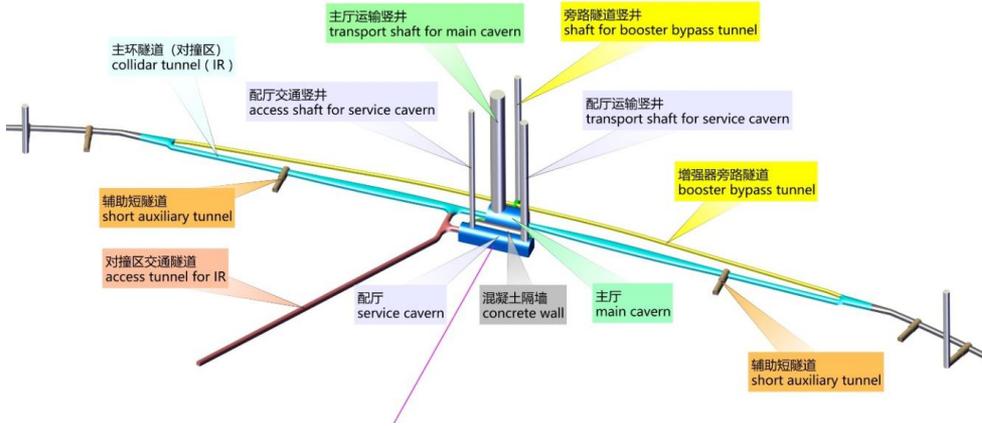
## CEPC Civil Engineering Design (Funing 100km, example)



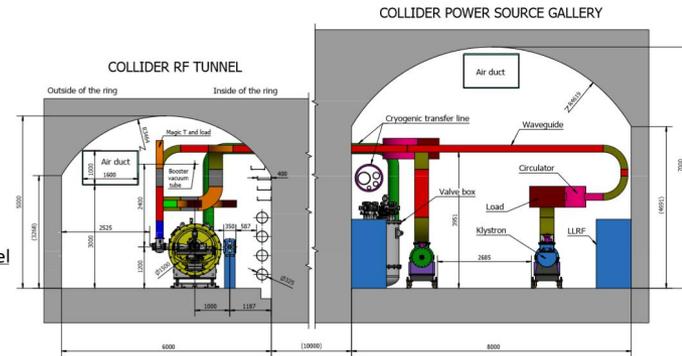
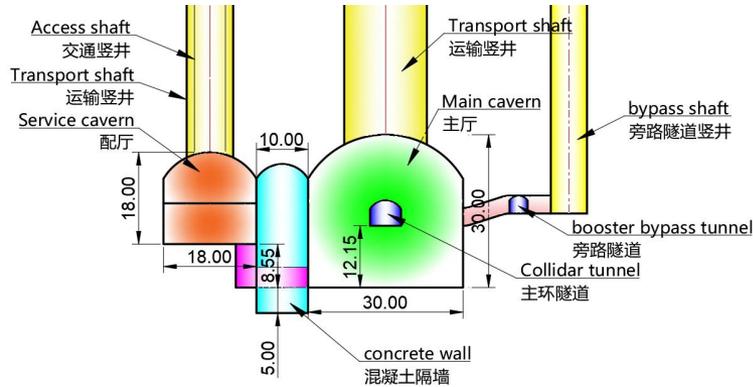
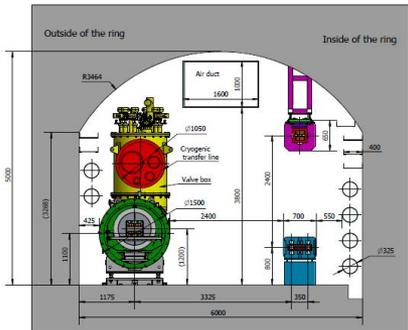
# CEPC Tunnel Cross Sections, Detector and SCRF Regions

## IP1 / IP3

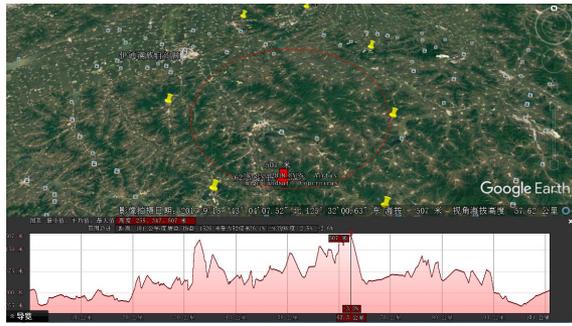
## IP2 / IP4--SCRF region



TUNNEL CROSS SECTION OF THE ARC AREA



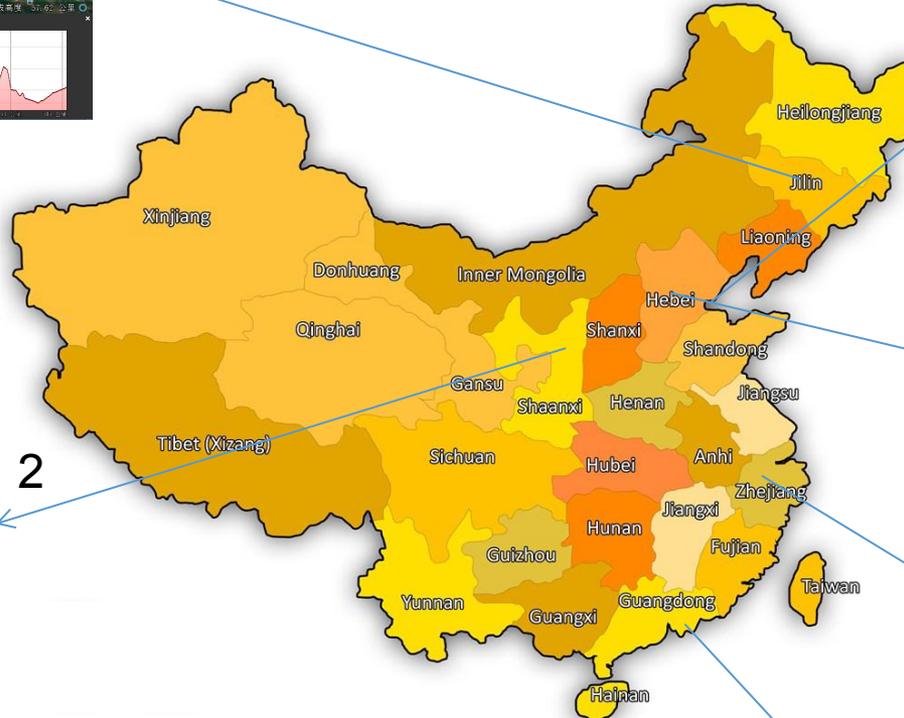
# CEPC Site Selections



6



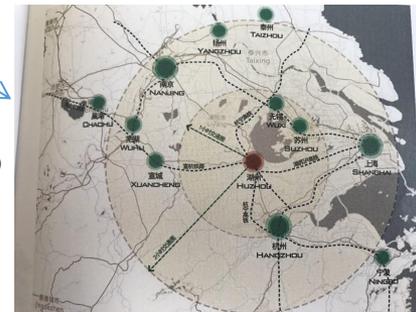
1



4



2



5

- 1) Qinhuangdao, Hebei Province (Completed in 2014)
- 2) Huangling, Shanxi Province (Completed in 2017)
- 3) Shenshan, Guangdong Province (Completed in 2016)
- 4) Baoding (Xiongan), Hebei Province (Started in August 2017)
- 5) Huzhou, Zhejiang Province (Started in March 2018)
- 6) Chuangchun, Jilin Province (Started in May 2018)



3

# **CEPC R&D towards TDR**

# CEPC Accelerator Key Component Designs and Technologies R&D

The CEPC keycomponents hardware have been designed and R&Ds have been planed and execuед on the way

- **Polarized electron gun**

- Super-lalce GaAs photocathode DC-Gun

- **High current positron source**

- bunch charge of  $\sim 3\text{nC}$ ,
- 6Tesla Flux Concentrator peak magnetic field

- **SCRF system**

- High Q cavity - Max operation  $Q_0 = 2\text{E}10 @ 2\text{K}$
- High power coupler - 300kW (Variable)

- **High efficiency CW klystron**

- Efficiency goal  $> 80\%$

- **Low field dipole magnet (booster)**

- $L_{\text{mag}}=5\text{m}$ ,  $B_{\text{min}}=30\text{Gs}$ , Errors  $<5\text{E}-4$

- ◆ **Vacuum system**

- ⇒ 6m long cooper chamber
- ⇒ RF shielding bellows

- ◆ **Electro-static separator**

- ⇒ Maximum operating field strength: 20kV/cm
- ⇒ Maximum deflection: 145 urad

- ◆ **Large scale cryogenics**

- ⇒ 12 kW @4.5K refrigerator, Oversized,
- ⇒ Custom-made, Site integration

- ◆ **HTS magnet**

- ⇒ Advanced HTS Cable R&D:  $> 10\text{kA}$
- ⇒ Advanced High Field HTS Magnet R&D: main field 12~12T

# CEPC Funding

## IHEP seed money

11 M CNY/3 years (2015-2017)

国家重点研发计划  
项目预申报书

FY 2016

Ministry of Science and Technology  
Requested 45M RMB; 36M RMB approved

### R&D Funding - NSFC

Increasing support for CEPC D+RD by NSFC  
5 projects (2015); 7 projects (2016)

CEPC相关基金名称 (2015-2016)	基金类型	负责人	承担单位
高精度气体径迹探测器及激光校正的研究 (2015)	重点基金	李玉兰/ 陈元柏	清华大学/ 高能物理研究所 IHEP Tsinghua
成像型电磁量能器关键技术研究(2016)	重点基金	刘树彬	中国科技大学 USTC
CEPC局部双环对撞区挡板系统设计及螺线管场补偿 (2016)	面上基金	白莎	高能物理研究所
用于顶点探测器的高分辨、低功耗SOI像素芯片的若干关键问题的研究(2015)	面上基金	卢云鹏	高能物理研究所
基于粒子流算法的电磁量能器性能研究 (2016)	面上基金	王志刚	高能物理研究所
基于THGEM探测器的数字量能器的研究(2015)	面上基金	俞伯祥	高能物理研究所
高粒度量能器上的通用粒子流算法开发(2016)	面上基金	阮曼奇	高能物理研究所
正离子反馈连续抑制型气体探测器的实验研究 (2016)	面上基金	祁辉荣	高能物理研究所
CEPC对撞区最终聚焦系统的设计研究(2015)	青年基金	王逗	高能物理研究所
利用耗尽型CPS提高顶点探测器空间分辨精度的研究 (2016)	青年基金	周扬	高能物理研究所
关于CEPC动力学孔径研究(2016)	青年基金	王毅伟	高能物理研究所

项目名称:

高能环形正负电子对撞机相关的物理和关键技术预研究

所属专项:

大科学装置前沿研究

指南方向:

新一代粒子加速器和探测器关键技术和方法的预先研究

推荐单位:

教育部

申报单位: (公章)

清华大学

项目负责人:

白莎

~60M CNY CAS-Beijing fund, talent program

year 2017 funding request (32M) to MOST approved

Basic funding needs for carrying out the CEPC design and the R&D should be met by end of 2018

# **CEPC CIPC and International Collaborations**

# CEPC Industrial Promotion Consortium (CIPC)-1



- 1) Superconducting materials (for cavity and for magnets)
- 2) Superconducting cavities
- 3) Cryomodules
- 4) Cryogenics
- 5) Klystrons
- 6) Vacuum technologies
- 7) Electronics
- 8) SRF
- 9) Power sources
- 10) Civil engineering
- 11) Precise machinery.....

**Established in Nov. 7 , 2017**



More than 50 companies joined in first phase of CIPC, and more will join later....

# CEPC International Collaboration Status-1

## International collaboration experts in the CEPC study team:

- ✓ All accelerator subsystem working groups have established data base of potential international collaboration experts
- ✓ All accelerator subsystems have at least one international collaboration expert in the subsystem working groups

## International collaboration with major international labs:

- ✓ IHEP-BINP (Russia) MoU (Jan 2016) (on CEPC collider lattice design, Z-pole polariztion)
- ✓ IHEP-KEK (Japan) MoU (Sept 2017) (on all systems of Super KEK B accelerators, good reference)
- ✓ IHEP-MEPHI (Russia) (Nov 2017) (CEPC SCRF)
- ✓ IHEP-IEF (University of Rostock, Rostock, Germany) (Jan 2018) (CEPC SCRF)
- ✓ IHEP-Jlab (USA) MoU update is considered (CEPC-SppC-ep)
- ✓ With CERN and Dubna high level collaboration will progress

**More than 20 MoU in general**

# CEPC International Collaboration Status-2



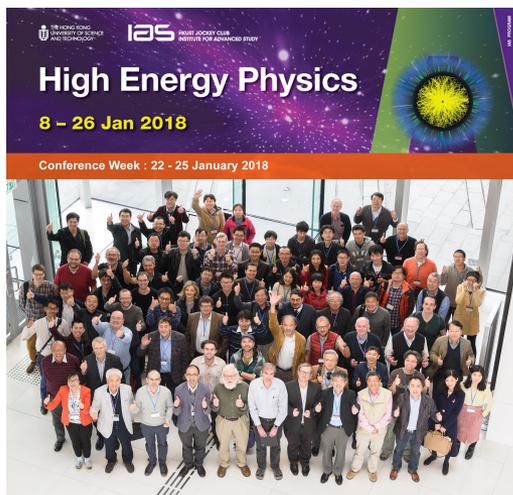
The first CEPC-SppC international Collaboration Workshop  
Nov 6-8, 2017, IHEP, Beijing

<http://indico.ihep.ac.cn/event/6618>



Workshop on the Circular Electron Positron Collider-EU edition  
May 24-26, 2018, Università degli Studi Roma Tre, Rome, Italy

<https://agenda.infn.it/conferenceDisplay.py?ovw=True&confid=14816>



IAS High Energy Physics Workshop  
(Since 2015)

<http://iasprogram.ust.hk/hep/2018>

The second CEPC-SppC international Collaboration Workshop  
Nov 12-14, 2018, IHEP, Beijing

<https://indico.ihep.ac.cn/event/7389/>

# Conclusions

- The study path from CEPC Pre-CDE to CEPC CDR baseline and alternative choice has been overviewed
- CEPC Accelerator CDR has been completed with all systems reaching the CDR design goals with new ideas beyond CDR
- Industry participation in CEPC R&D in key technologies and industrialization and international collaboration progress well

**Thanks go to**

CEPC accelerator team and international collaborators

**Thank you for your attention**