



CEPC 预研究进展

高原宁（清华大学）
代表CEPC-SPPC工作组

第十二届全国粒子物理学术会议

Introduction

|

发现希格斯粒子后的粒子物理学

- ICHEP2016: “*The Standard Model works very very well*”
- 高能量前沿：寻找新粒子
 - 是哪一个呢？
LHC
- 高精度前沿：寻找对标准模型的（微小）偏离
 - H : “*Higgs is now part of the intensity frontier*”
 - Z
 - $t, b, c, \tau, \mu, \dots$
LHC, SuperKEKB, BEPC, ...

高精度前沿的希格斯物理

- LHC 上的精确测量

$$m_H = 125.09 \pm 0.24 \quad (0.2\% \text{ accuracy!})$$

性质与标准模型一致

ATLAS&CMS, PRL 114, 191803;
arXiv:1606.02266

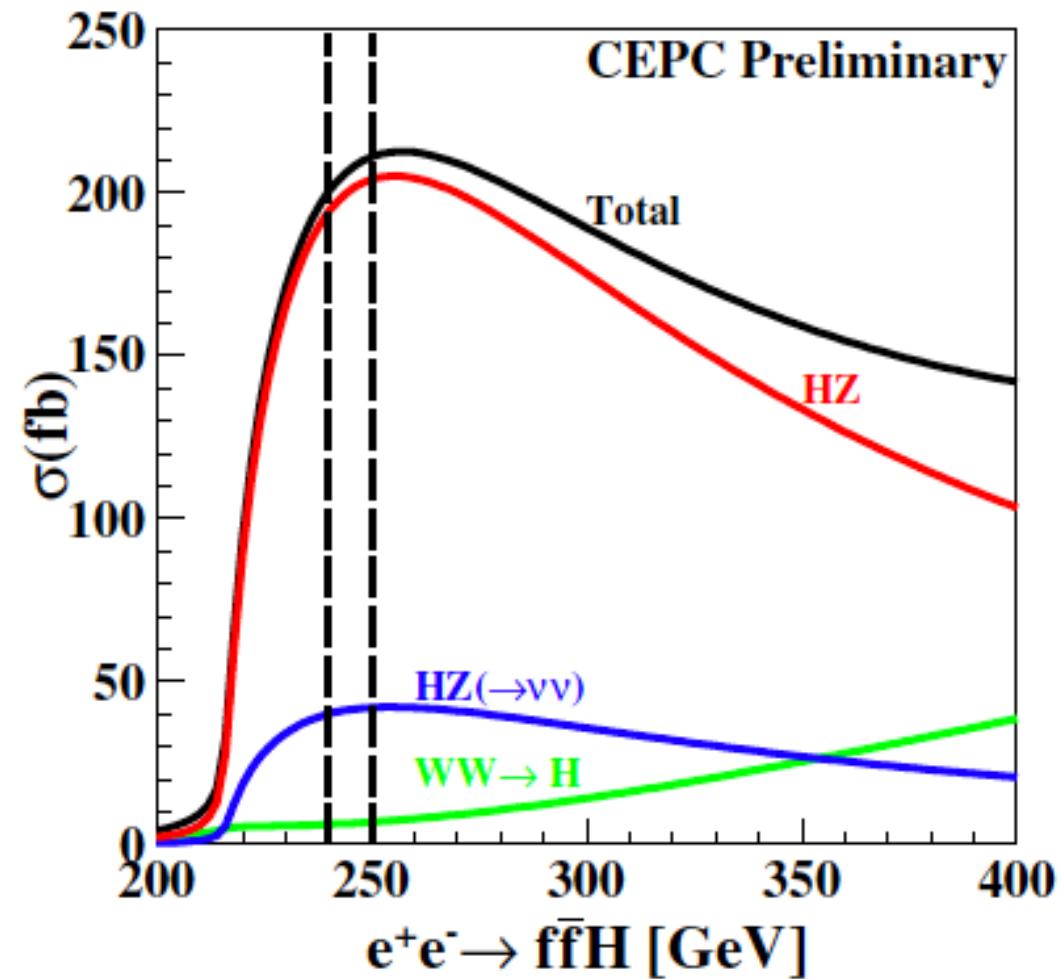
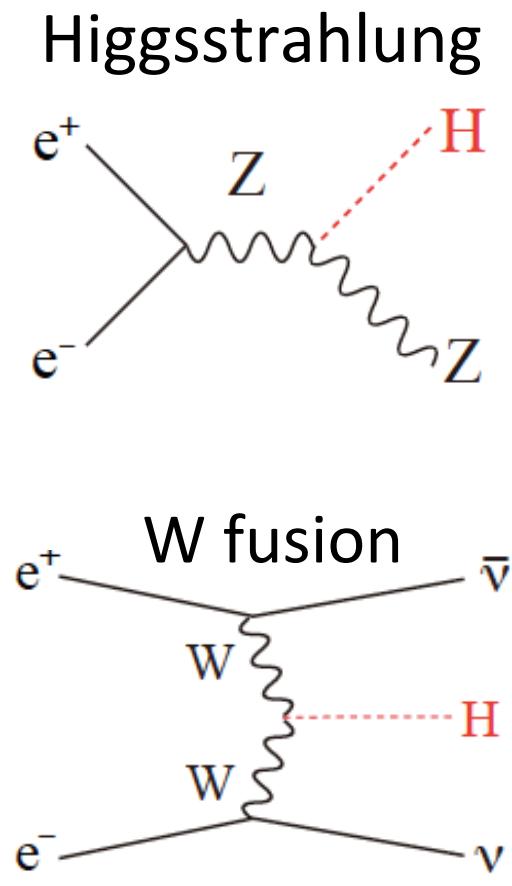
- *The Decoupling Limit*

R.S. Gupta et al., PRD 86 (2012) 095001;
ILC TDR

$$g_{Hxx} = g_{Hxx}^{SM}(1 + \Delta_x), \quad \Delta_x < 1 - 5\%$$

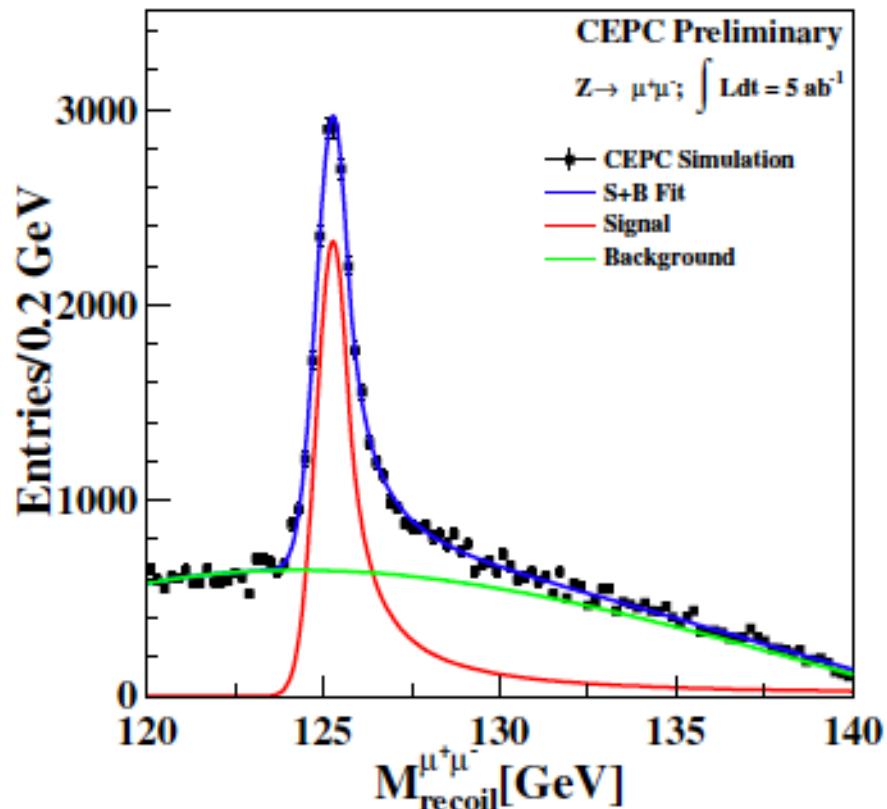
→ 需要正负电子对撞机来达到所需的高精度

CEPC上的希格斯粒子产生



Higgs reconstruction by recoil

- $e^+e^- \rightarrow HZ, Z \rightarrow ll$



2016/8/22

CEPC预研究进展

Observables:

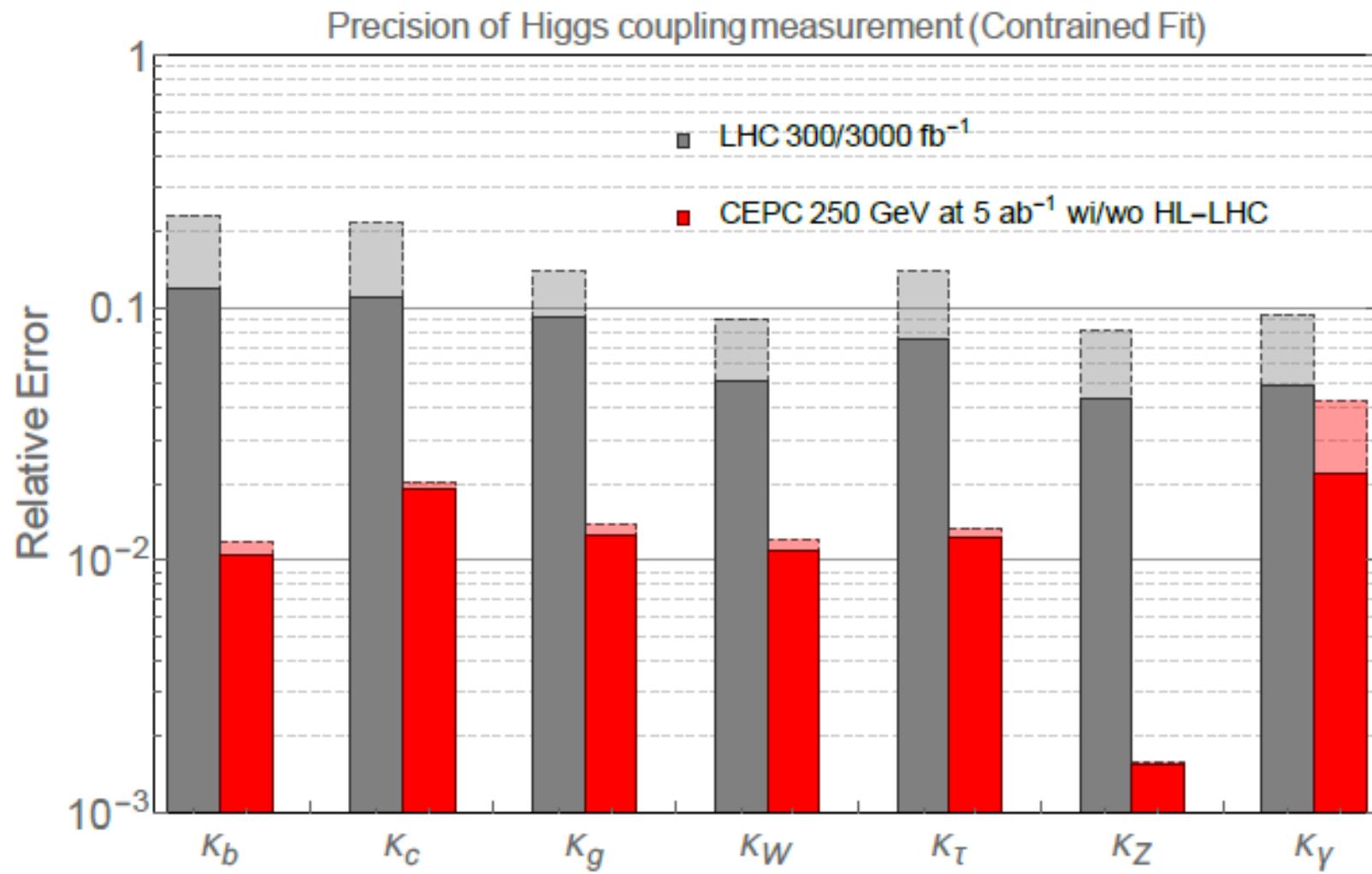
- $\int Ldt$
- m_H
- N_{rec}
- $\mathcal{B}(H \rightarrow X) = \frac{N_X}{N_{\text{rec}}}$
- N_{fusion}

CEPC Baseline Program

- $\sqrt{s} = 240 \text{ GeV}$
 - $L = 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - 2 IP's
 - $\int L dt = 5 \text{ ab}^{-1} : \sim 10^6 e^+e^- \rightarrow ZH$

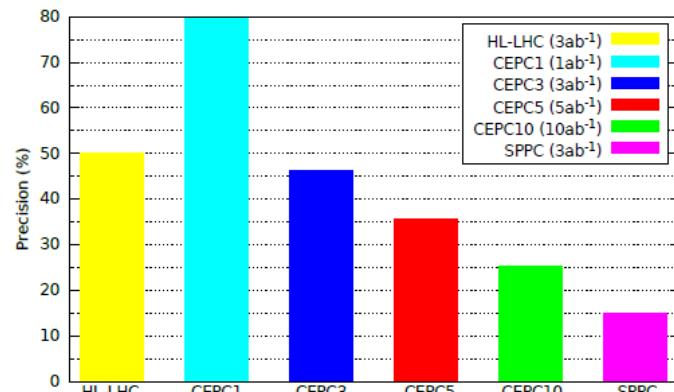
- $\sqrt{s} = 91.2 \text{ GeV}$
 - $L = 1 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - $\sim 10^{10-11} Z\text{-decays}$
 - easy setup for alignment/calibration
 - no beam polarization

Higgs couplings at CEPC



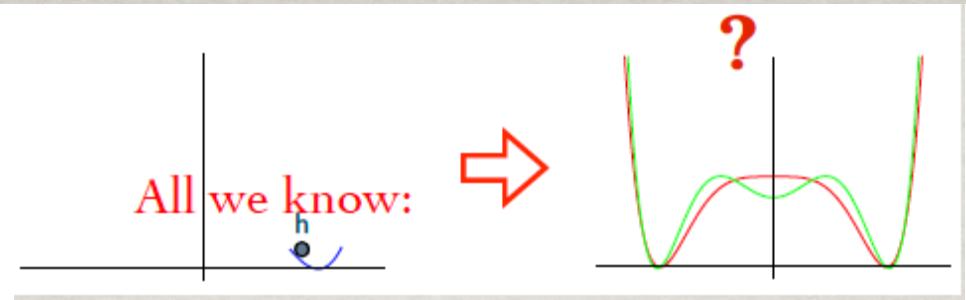
环形正负电子对撞机的局限

- 无法达到更高能量...
 $Ht\bar{t}, HHH, HHHH, \dots$
- Higgs self-couplings at CEPC:
through loop contribution
to HZZ , *model dependent*



$$V(h) \rightarrow m_h^2(h^\dagger h) + \frac{1}{2}\lambda(h^\dagger h)^2 + \frac{1}{3!\Lambda^2}(h^\dagger h)^3, \rightarrow \lambda_{hhh} = (7/3)\lambda_{hhh}^{SM}$$
$$\rightarrow \frac{1}{2}\lambda(h^\dagger h)^2 \log \left[\frac{(h^\dagger h)}{m^2} \right] \rightarrow \lambda_{hhh} = (5/3)\lambda_{hhh}^{SM}$$

EW phase transition strong 1st order!
 $\rightarrow O(1)$ deviation on λ_{hhh}



Complementary to ILC/CLIC

Next pp collider, SPPC

CEPC Baseline Program

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- $\sqrt{s} = 91.2 \text{ GeV}$
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Physics at Z pole

- Precision EW measurements: promising & challenging

Table 13: Exclusive $\mu^+\mu^-$ selection: examples of relative systematic uncertainties (in %) for the 1994 (1995) peak points.

Source	$\Delta\sigma/\sigma$ (%)
Acceptance	0.05
Momentum calibration	0.006 (0.009)
Momentum resolution	0.005
Photon energy	0.05
Radiative events	0.05
Muon identification	$\simeq 0.001$ (0.02)
Monte Carlo statistics	0.06
Total	0.10 (0.11)

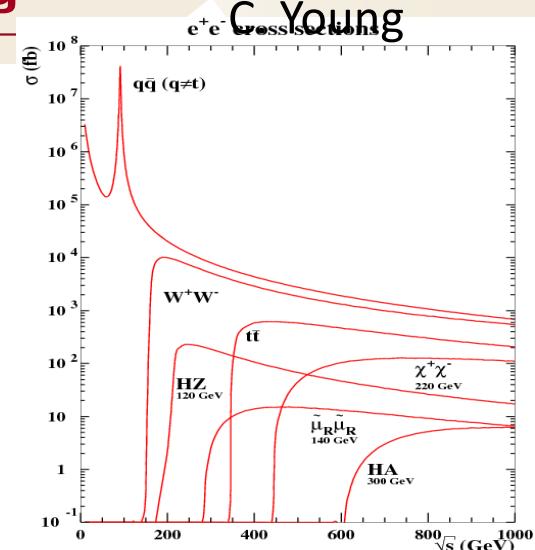
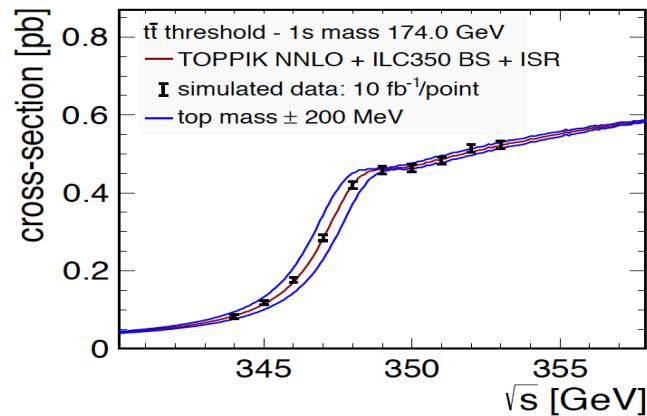
- Potential for flavor physics etc under exploration

Special considerations at $t\bar{t}$?

- Counting or detail studies - accelerator design

Top Mass – Not Part of CEPC Planning

Rate measurement at $t\bar{t}$ threshold



- $\sigma \sim 0.3 \text{ pb}$ (higher than ZH at $\sqrt{s} = 240 \text{ GeV}$)
- $\sqrt{s} = 350 \text{ GeV}$ challenging for a “small” ring like CEPC
 - $1.5 \times \text{beam energy} \rightarrow 1.5^4 = 5 \times \text{SR}$ (per particle)
- $\pm 20 \text{ MeV}$ with 100 fb^{-1}

CEPC-SppC PreCDR

涵盖科学目标、加速器和探测器、初步地质调查、需求分析和隧道及辅助设施、造价估计

IHEP-CEPC-DR-2015-01
IHEP-EP-2015-01
IHEP-TH-2015-01

IHEP-CEPC-DR-2015-01
IHEP-AC-2015-01

<http://cepc.ihep.ac.cn/preCDR/volume.html>

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

**403 pages, 19 个国家/地区
480 authors**

The CEPC-SPPC Study Group

March 2015

2016/8/22

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

**328 pages, 13 个国家/地区
300 authors**

The CEPC-SPPC Study Group

March 2015

CEPC预研究进展

13

国际评审

加速器，理论，实验，土建



对PreCDR评审的主要结论

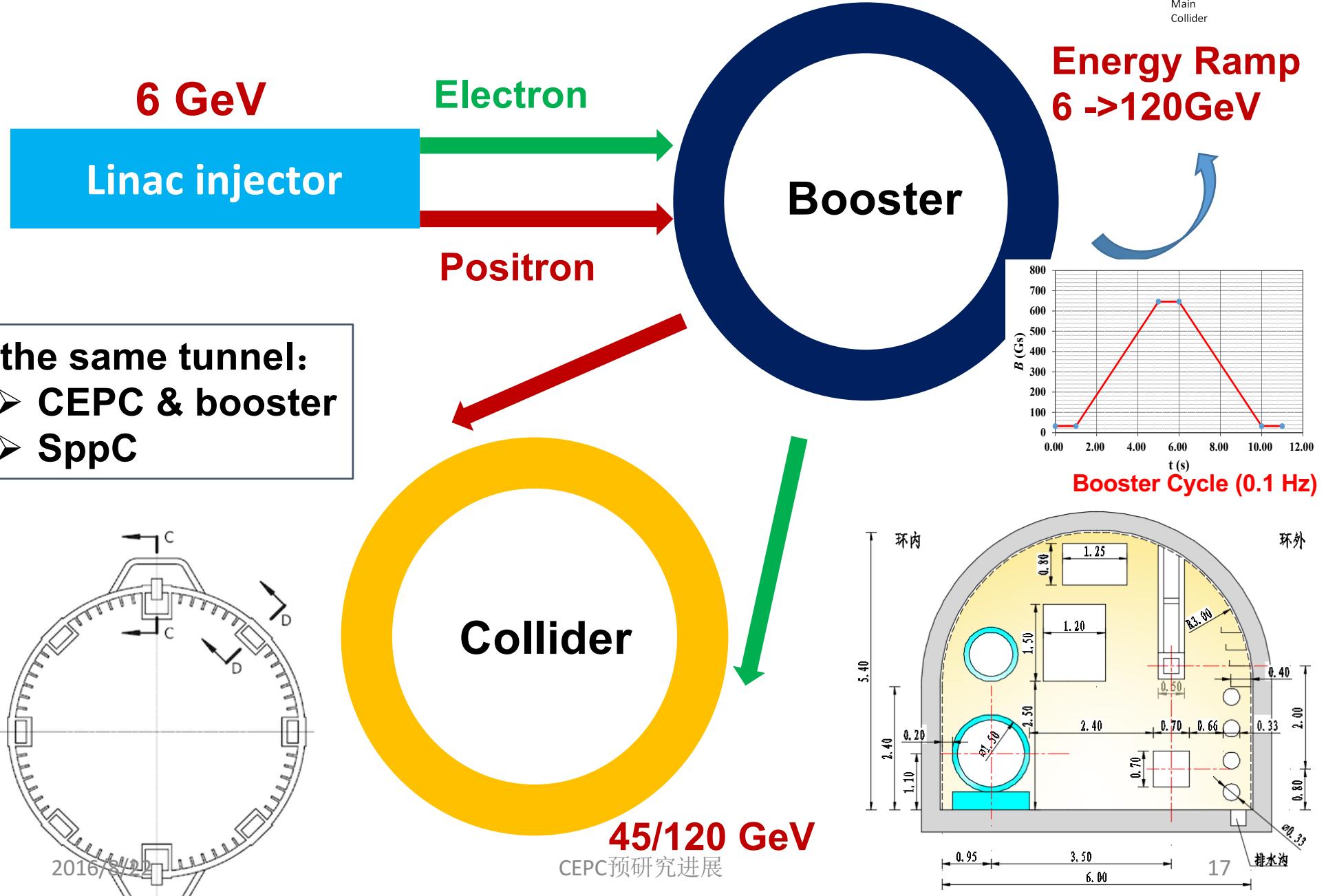
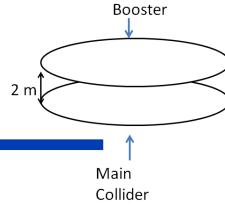
- 科学意义重大
- 加速器、探测器、土建和通用系统设计完整，方案选择合理
- 没有不可克服的技术困难
- 预研项目的选择合适
- 年轻的队伍成长迅速，设计、研究水平令人印象深刻

CEPC-SPPC 其后开展更深入的预研究

Accelerator design

II

CEPC Accelerator



Luminosity vs. power consumption

- SR power : 50MW/beam
 - Limited number of bunches at 240 GeV
 - More bunches at Z pole, ...
- Possible schemes
 - double ring
 - partial doubling ring
 - single ring

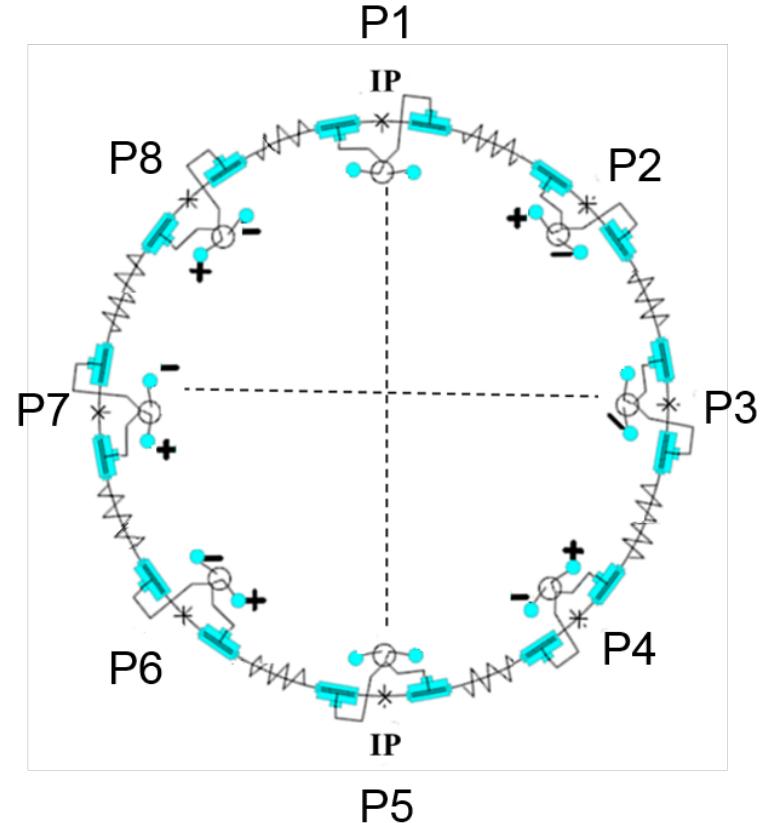
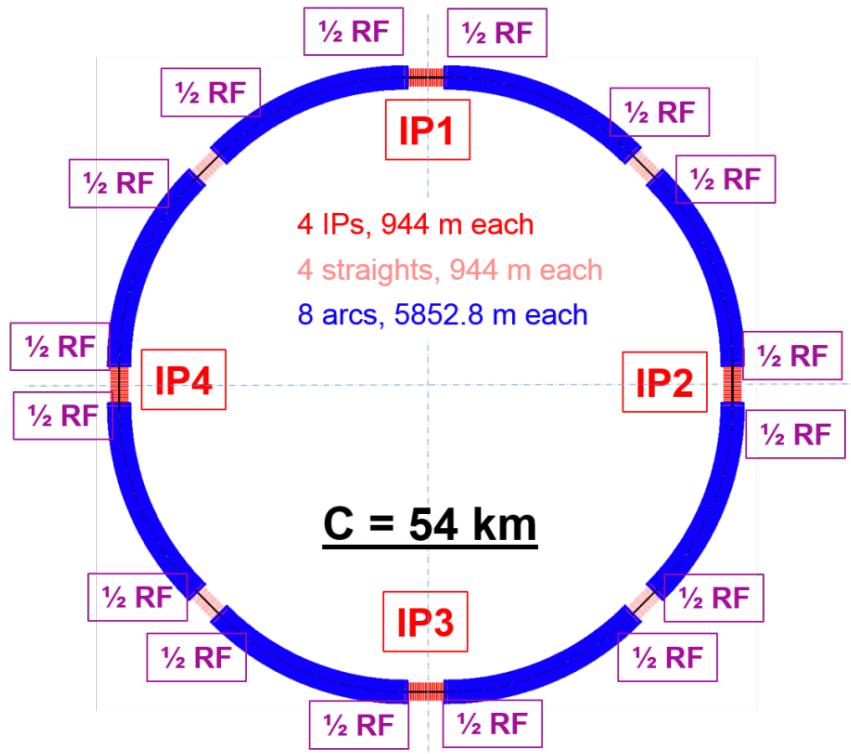
- Pretzel scheme is difficult in design, operation, flexibility and stability
- High AC power
- Booster with very low magnetic field (30 Gauss for 6GeV injection compared with 3 Gauss background magnetic field in BEPCII tunnel) and small dynamic aperture
- Very low luminosity for Z with single ring
- Very small DA at 2% energy spread
- The clear criterion for reaching CDR requirement on DA with beam-beam effects and magnetic errors
- **What is the goal of CEPC CDR?**

In short, Pre-CDR is a "design" even not working on paper

Main parameters for CEPC (Pre-CDR)

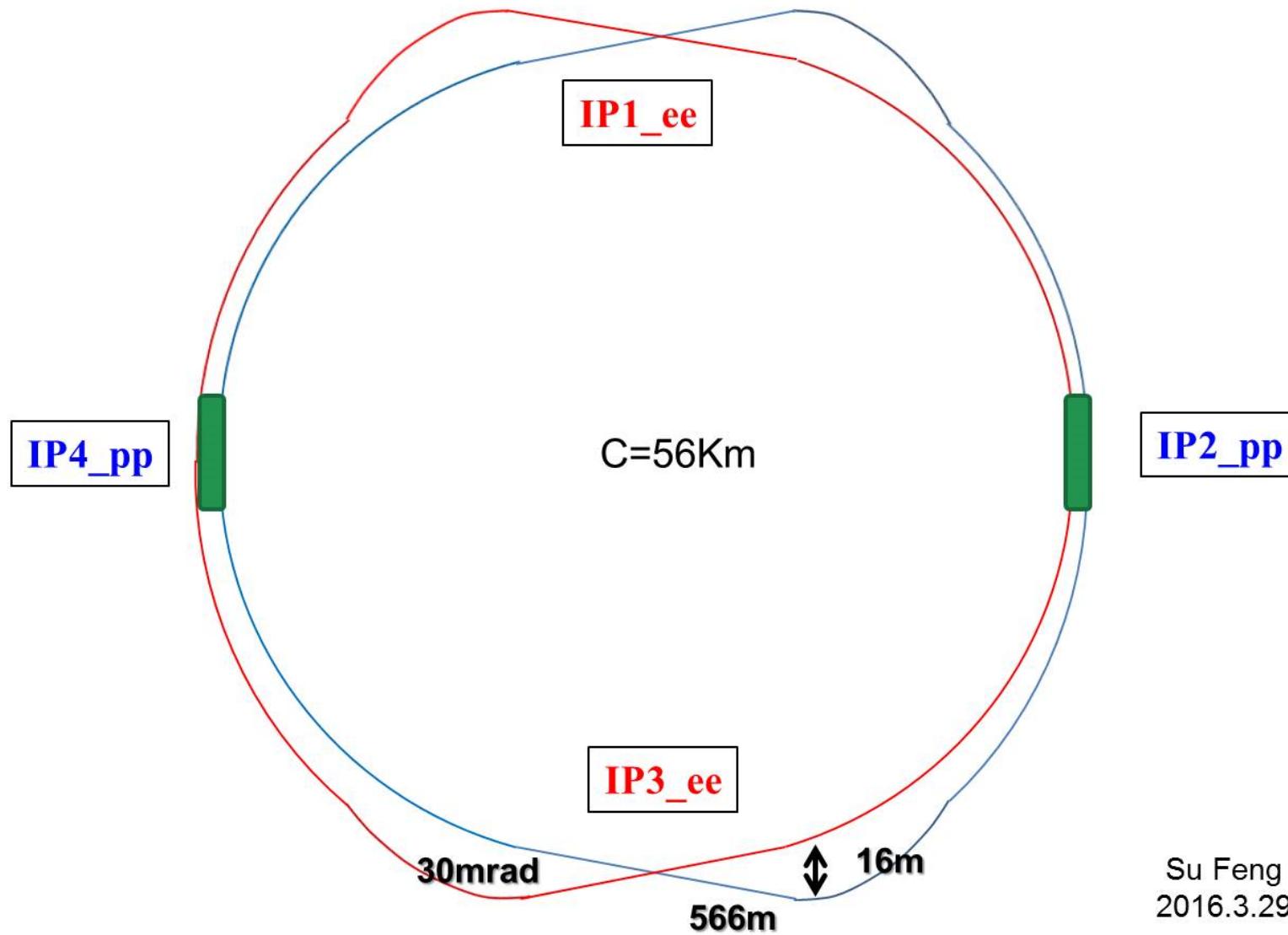
Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	Circumference [C]	m	54420
Number of IP[N _{IP}]		2	SR loss/turn [U ₀]	GeV	3.11
Bunch number/beam[n _B]		50	Bunch population [N _e]		3.71E+11
SR power/beam [P]	MW	51.7	Beam current [I]	mA	16.6
Bending radius [ρ]	m	6094	momentum compaction factor [α _p]		3.39E-05
Revolution period [T ₀]	s	1.82E-04	Revolution frequency [f ₀]	Hz	5508.87
emittance (x/y)	nm	6.12/0.018	β _{IP} (x/y)	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	ξ _{x,y} /IP		0.116/0.082
Beam length SR [σ _{s.SR}]	mm	2.17	Beam length total [σ _{s.tot}]	mm	2.53
Lifetime due to Beamstrahlung	min	80	lifetime due to radiative Bhabha scattering [τ _l]	min	52
RF voltage [V _{rf}]	GV	6.87	RF frequency [f _{rf}]	MHz	650
Harmonic number [h]		117900	Synchrotron oscillation tune [v _s]		0.18
Energy acceptance RF [h]	%	5.98	Damping partition number [J _ε]		2
Energy spread SR [σ _{δ.SR}]	%	0.13	Energy spread BS [σ _{δ.BS}]	%	0.08
Energy spread total [σ _{δ.tot}]	%	0.16	n _γ		0.23
Transverse damping time [n _x]	turns	78	Longitudinal damping time [n _ε]	turns	39
Hourglass factor	Fh	0.692	Luminosity /IP[L]	cm ⁻² s ⁻¹	2.01E+34

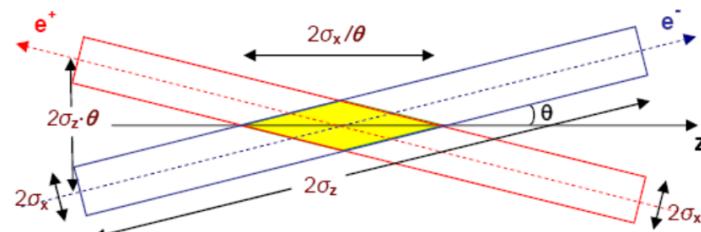
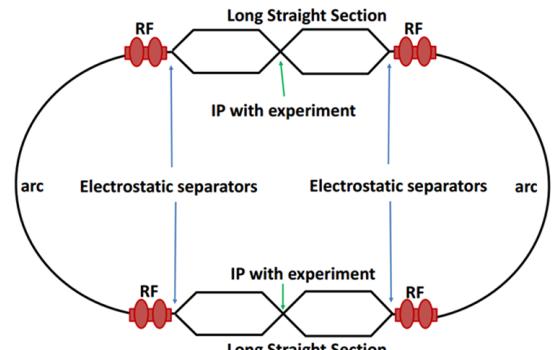
CEPC Pretzel Scheme



- 48 bunches / beam, 96 parasitic collision points ($\sim 500 \text{ m}$ spacing)
- Horizontal separation, no off-center orbit in RF section
- One pair of electrostatic separators for each arc (green)
- One pair of electrostatic separators for P2, P3, P4, P6, P7, P8

CEPC Double Ring Scheme Layout





MITIGATING PERFORMANCE LIMITATIONS OF SINGLE BEAM-PIPE CIRCULAR e^+e^- COLLIDERS

M. Koratzinos, University of Geneva, Switzerland and F. Zimmermann, CERN, Geneva, Switzerland.

Abstract

Renewed interest in circular e^+e^- colliders has spurred designs of single beam-pipe machines, like the CEPC in China, and double beam pipe ones, such as the FCC-ee effort at CERN. Single beam-pipe designs profit from lower costs but are limited by the number of bunches that can be accommodated in the machine. We analyse these performance limitations and propose a solution that can accommodate O(1000) bunches while keeping more than 90% of the ring with a single beam pipe.

SINGLE BEAM-PIPE LIMITATION

The CEPC collider [1] is a single beam-pipe e^+e^- collider with the main emphasis on 120 GeV per beam running with possible running at 45 and 80 GeV. Bunch separation is ensured by a pretzel scheme and the maximum number of bunches is limited to 50. This very small number of bunches for a modern Higgs factory introduces luminosity limitations at 120 GeV, and severe limitations at any eventual 45 GeV running.

A machine of the size of CEPC at 120 GeV ought to be designed to be operating at the beam-beam limit and not reach the beamstrahlung limit first. The best way to reach this goal is by keeping the bunch charge low and emittances as small as possible. A large momentum acceptance also helps. Another way (and the route chosen for the CEPC) is to keep the bunches as long as possible, but this gives rise to lower instability thresholds as well as to geometric luminosity loss. According to our calculations and with reasonable assumptions for the length of the FODO cell and phase advance, we arrive at an optimal number of bunches of around 120 at 120 GeV [2]. The accommodation of this number of bunches with the pretzel scheme would be more demanding.

For an eventual running at 45 GeV the limit of 50 bunches would be inadequate, as hundreds of bunches would be needed to explore the full potential of the machine [2].

THE 'BOWTIE' DESIGN

Without changing the basic design philosophy of the

apart transversely so that separate beam pipes and magnetic elements can be used to manipulate the electron and positron beams individually, and without any parasitic collisions. The length of the electrostatic separator section would be around 100 m on both sides of the straight section. Since now the beams travel in separate beam pipes, great flexibility about the choice of collision angle is ensured. The FCC-ee is pursuing a crab waist approach which gives excellent performance at low energies and where the crossing angle is 30 mrad.

Assuming a total length of the double beam pipe to be 2×2000m, and assuming that bunches within a train can be separated longitudinally by as little as 2 m (7 ns) then 2×1000 bunches for each species can be accommodated in the machine.

The ratio of single to double beam pipe would be ~4/52 or about 8%. Note that the cost increase would be much smaller than the above figure and actually the cost per luminosity unit would be greatly improved.

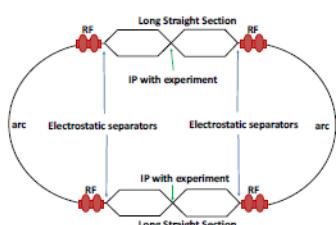


Figure 1: Schematic of the 'bowtie' idea (not to scale)

ELECTROSTATIC SEPARATORS

For illustration purposes we have chosen the LEP electrostatic separators [3]. These were 4 m long, 11 cm wide and the maximum operating voltage was 220 kV. Each separator produced a maximum deflection of 145



IHEP-AC-LC-Note2013-012

ILC-物理-2013-08

June 16th, 2013

关于CEPC采用亚毫米 β_y 带角度对撞以减少辐射功率并保证对撞亮度的Lattice优化设计建议

高杰

ILC Group, Accelerator Center

Institute of High Energy Physics (IHEP), Beijing

关于CEPC采用亚毫米 β_y 带角度对撞
以减少辐射功率并保证对撞亮度
的Lattice优化设计建议

高杰, 2013.6.14

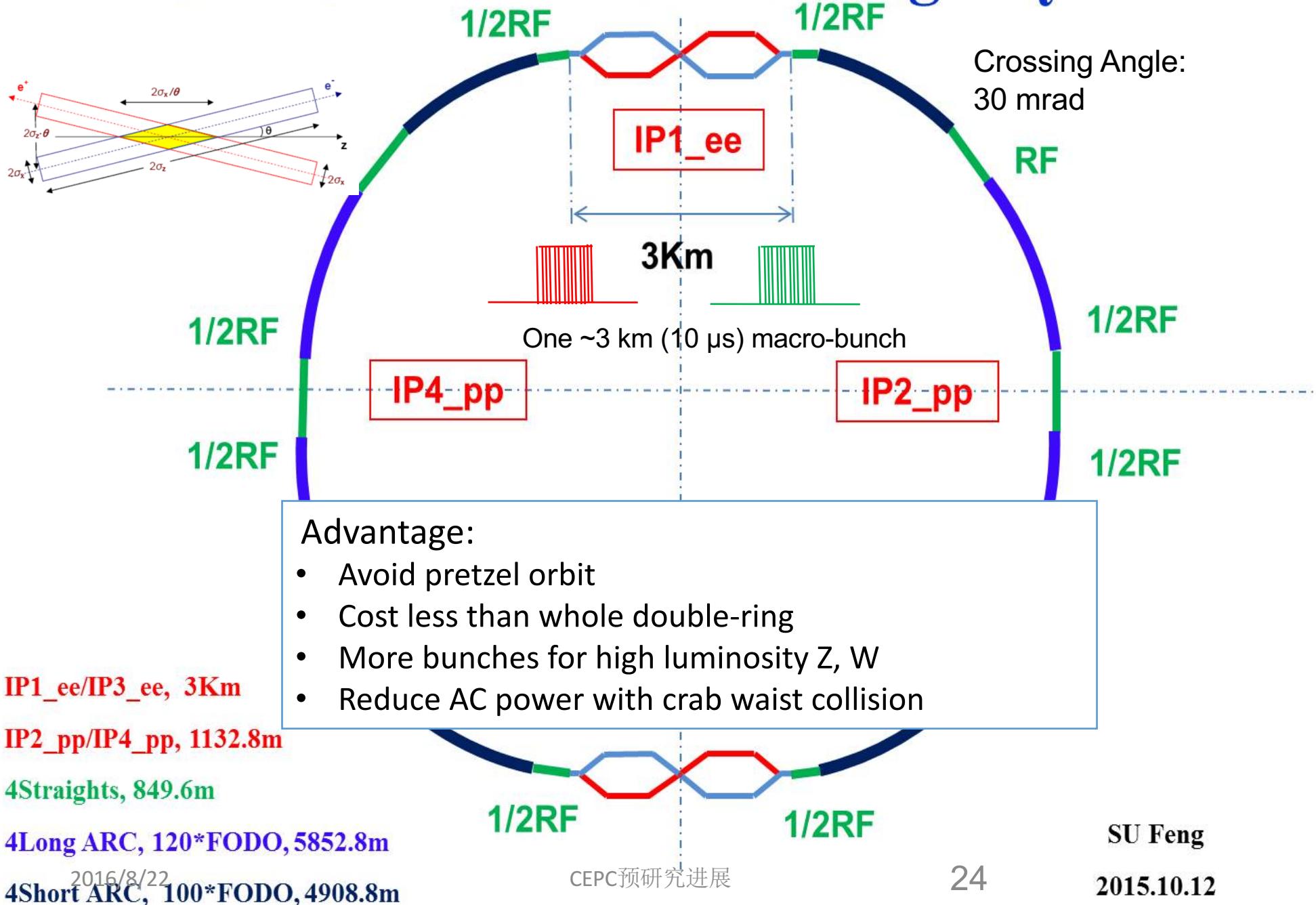
附录三, 高杰, 涉及CEPC(CRF)辐射功率,
从50 MW(单束)减到25 MW(例如), 同
时保证亮度设计亮度($2 \times 10^{34} / \text{cm}^2 \cdot \text{s}$)和满足其
(见高杰 2013.6.13 日常报告要求) 不失。

- 建议如下设计方案:
- 1) 采用带角度对撞, 利用
静电隔板 IP + crab-waist 技术提高亮度
 - 2) 降低束流功率, 从 50 MW → 25~20 MW
 - 3) 保证对撞亮度设计 $2 \times 10^{34} / \text{cm}^2 \cdot \text{s}$
达到 $2 \times 10^{34} / \text{cm}^2 \cdot \text{s}$ 以上。
 - 4) 分离区 l, 同时使分离区
分离区与对撞区长度 L 相等
 $l = 10\% \cdot L \approx 7.5\%$

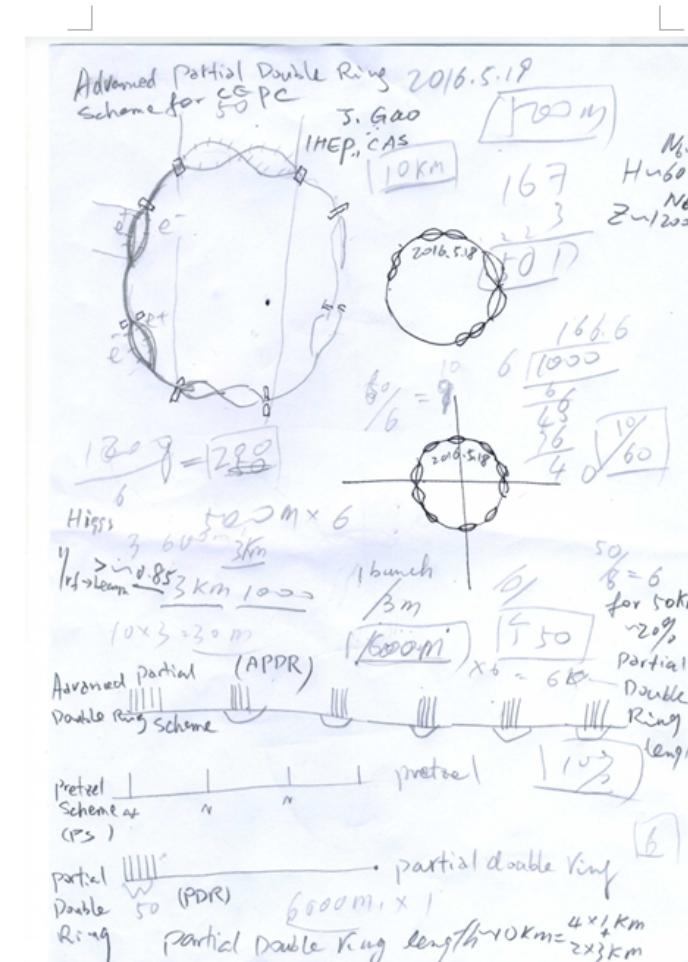
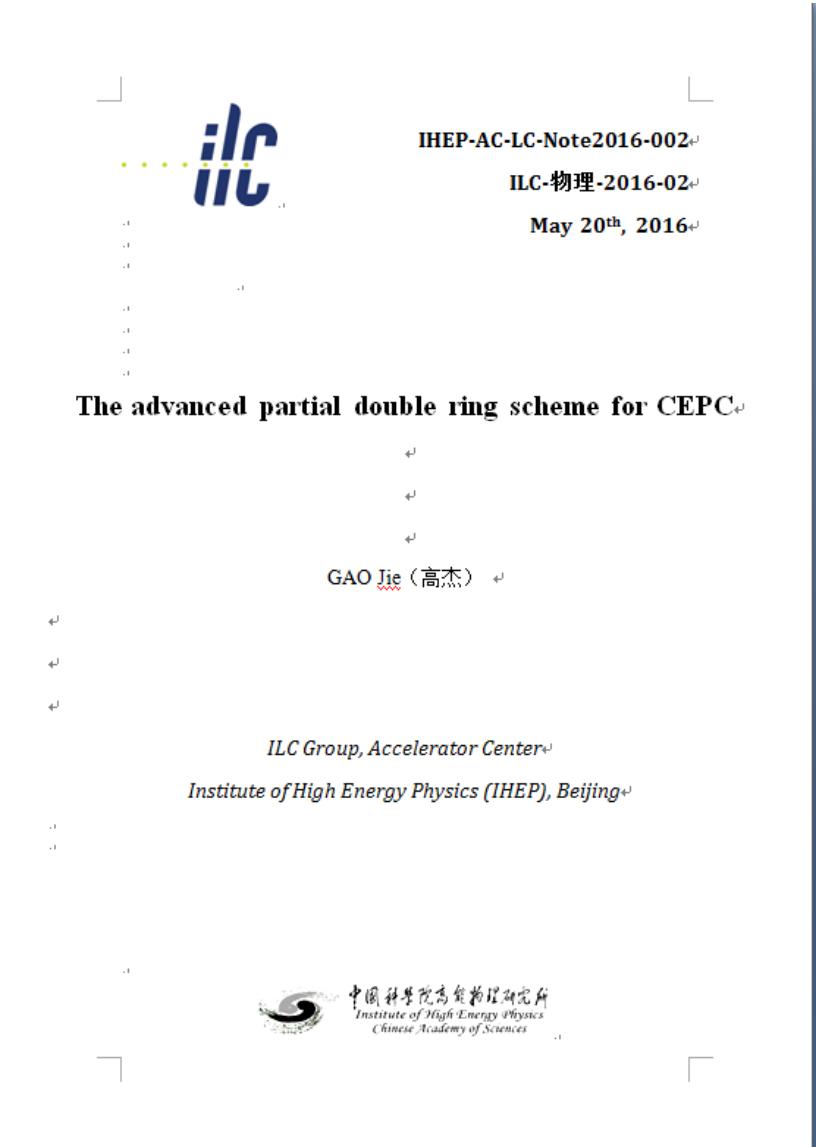
Partial Double Ring (DPR) was proposed independently at IHEP and CERN:

- 1) J. Gao, IHEP-AC-LC-Note 2013-012
- 2) M. Moratzinos and F. Zimmermann, 2015
(IPAC 2015 M. Moratzinos and F. Zimmermann)

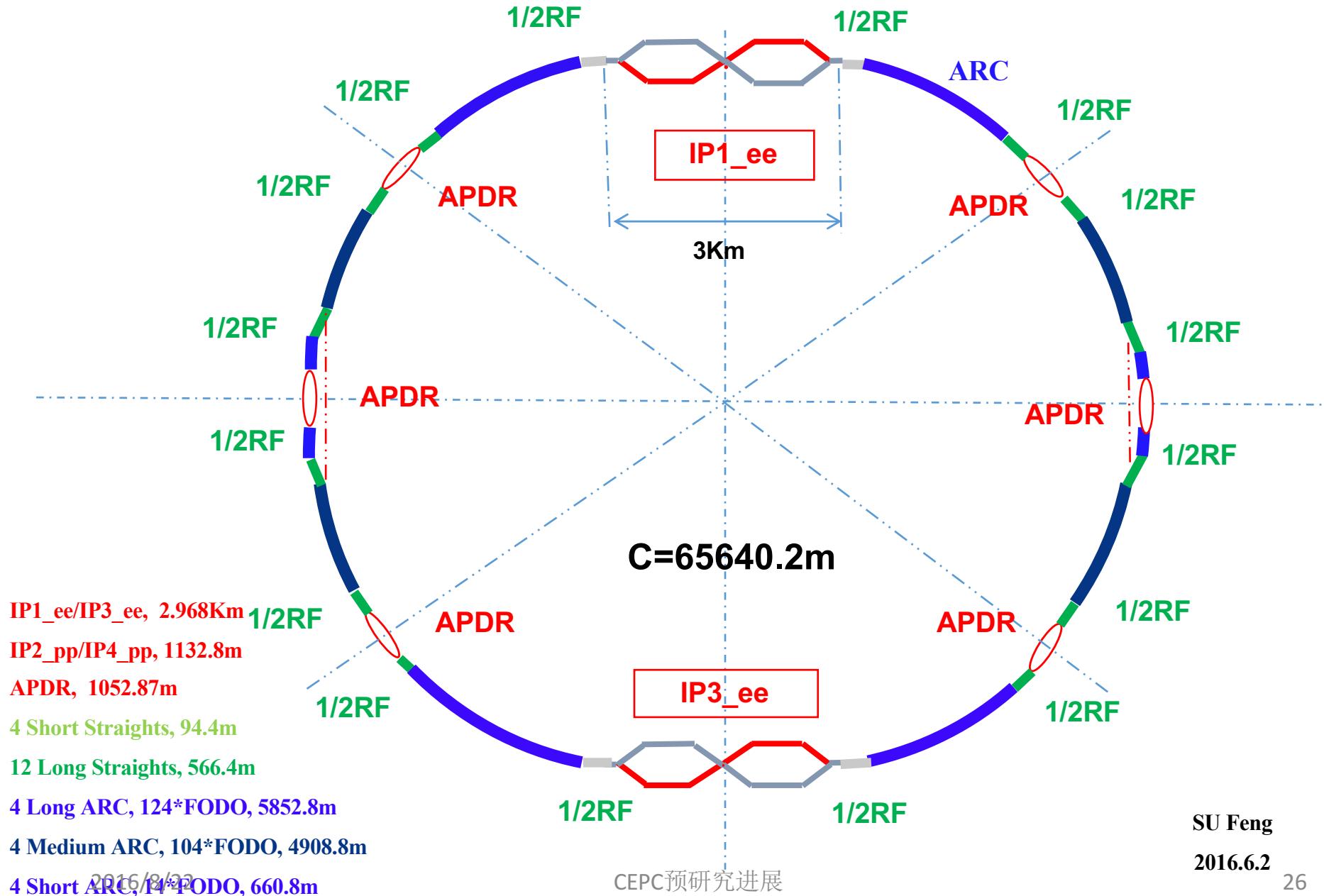
CEPC Partial Double Ring Layout



New idea: APDR



CEPC Advanced Partial Double Ring Layout II



CEPC vs LEP2

Parameter	CEPC			LEP2	
Physics working point	H		Z	Z	
Energy/beam [GeV]	120		45.5	105	45.6
Circumference [km]	54		54	27	
Single ring/double ring	Partial double				Single
Pretzel scheme	No				Yes
Bunches/beam	67	44	1100	4	12
Bunch population [10^{11}]	2.85	2.67	0.46	4.2	1.96
Emittance [nm]	2.45/0.0074	2.06 /0.0062	0.62/0.0028	38	
IP beta [mm]	250/1.36	268 /1.24	100/1	1500/50	2000/50
Beam current [mA]	16.9	10.5	45.4	3	4.2
Luminosity/IP $\times 10^{34} \text{cm}^{-2}\text{s}^{-1}$	2.9	2.0	3.1	0.0012	0.0034
Energy loss/turn [GeV]	2.96		0.062	3.34	0.12
Synchrotron power [MW]	50	31	2.8	22	1.1
RF voltage [GV]	3.6	3.5	0.12	3.5	
f_{RF} [MHz]	650				352

CEPC vs ILC

Parameter	CEPC		ILC	
Physics working point	H	Z	H	
Energy/beam [GeV]	120	45.5	125	250
Linear/circular	circular		linear	
Bunches/beam	67	1100	1312	1312
Bunch population [10^{11}]	2.85	0.46	0.2	0.2
Normalized emittance [nm]	575342/1738	55205/249	10000/35	10000/35
IP beta [mm]	250/1.36	100/1.0	13/0.41	11/0.48
IP RMS vertical beam size [nm]	100	53	7.7	5.9
Beam current [mA]	16.9	45.4	5.8	5.8
Luminosity/IP $\times 10^{34} \text{cm}^{-2}\text{s}^{-1}$	2.9	3.1	0.97	2.05
Energy loss/turn [GeV]	2.96	0.062	No	
f_{RF} [MHz]	650	650	1300	1300
Average number of photons / particle n_γ	0.47	0.24	1.16	1.72

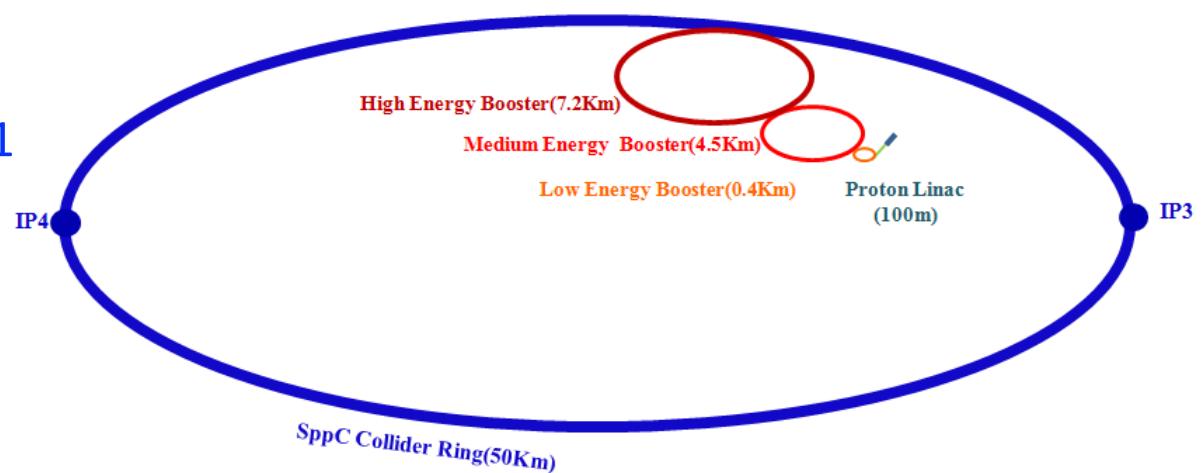
Remarks on SppC Program

- $\sqrt{s} \sim 100 \text{ TeV}$

Main constraint: **high-field superconducting dipole magnets**

- 50 km: $B_{\max} = 12 \text{ T}, E = 50 \text{ TeV}$
- 50 km: $B_{\max} = 20 \text{ T}, E = 70 \text{ TeV}$
- 70 km: $B_{\max} = 20 \text{ T}, E = 90 \text{ TeV}$

- $L \sim 10^{35} \text{ cm}^{-2}\text{s}^{-1}$



开建SPPC应满足的条件

- CEPC的物理成果 → 未来发展的指引
- 超导技术的成熟
 - 电流密度 ↑ 10 倍
 - 超导电缆价格 ↓ 10倍
- SPPC造价低于1000亿
 - 主要由超导磁铁/导线决定

走一条中国自己的路

- 基于国内优势，发展铁基超导，大幅提高超导线材性价比，争取在十年内取得技术及产业化的重大突破，
- 继续发展ReBCO与Bi-2212线材技术，追赶国际水平，争取在性能和价格方面有新的突破

第505次香山会议：超导技术在未来电网中的应用

巨大的应用价值：输电电缆，超导电机...

中国科学院高能物理研究所

中国科学院高能物理研究所关于
第一届“高温与高场超导材料及其应用技术研讨会”
的情况简报

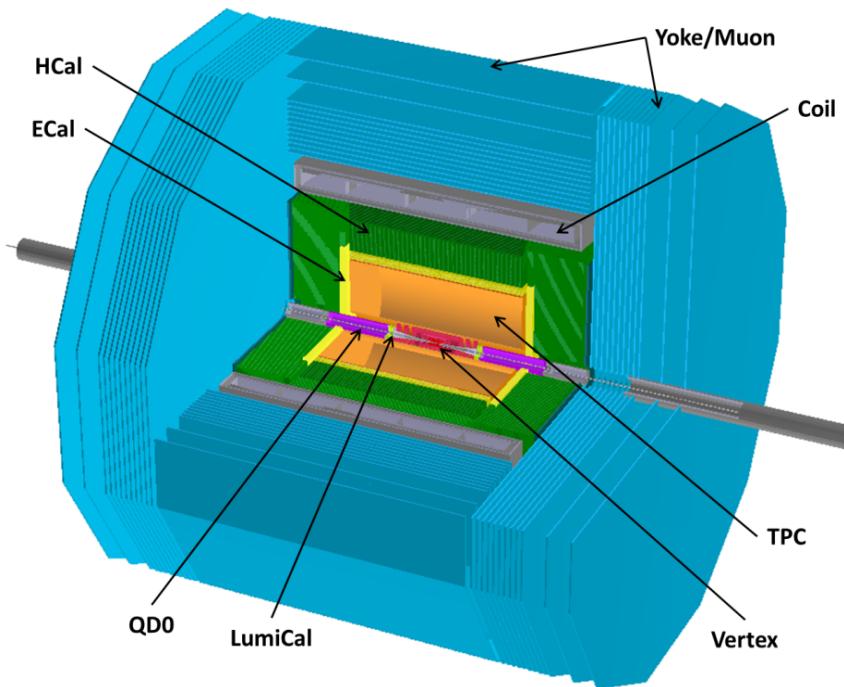
近年来，我国在高温与高场超导材料的机理研究、材料制备及其应用技术方面取得显著进步，特别是铁基超导获得国家自然科学一等奖，表明我国高温超导的研究走到了世界前列。在应用方面，造价低廉、指标优异的超导材料一直是限制超导技术大规模应用的瓶颈。国内的一些大科学工程项目，如未来聚变工程实验堆（CFETR）及环形正负电子对撞机-超级质子对撞机（CEPC-SPPC），也希望采用超导技术，以提高性能、降低造价。

基础研究、应用研究、产业化结合

CEPC Detector Design

III

CEPC Detector (preCDR)



ILD-like detector with additional considerations (*incomplete list*):

- Shorter L^* (1.5/2.5m) → constraints on space for the Si/TPC tracker
- No power-pulsing → lower granularity of vertex detector and calorimeter
- Limited CM (up to 250 GeV) → calorimeters of reduced size
- Lower radiation background → vertex detector closer to IP
- ...

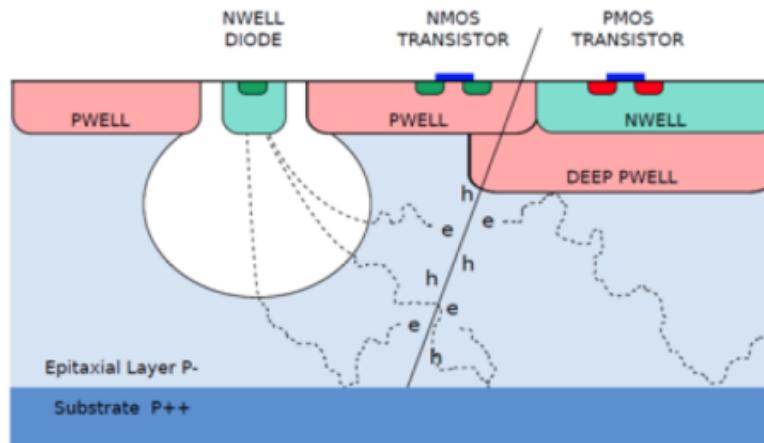
- **Similar performance requirements to ILC detectors**
 - Momentum: $\sigma_{1/p} < 5 \cdot 10^{-5} \text{ GeV}^{-1}$ ← recoiled Higgs mass
 - Impact parameter: $\sigma_{IP} = 5\mu\text{m} + 10\mu\text{m}/p \sin^{3/2}\theta$ ← flavor tagging, BR
 - Jet energy: $\sigma_E/E = 3 - 4\%$ ← W/Z di-jet mass separation

CEPC Detector – Pixel Vertex Detector

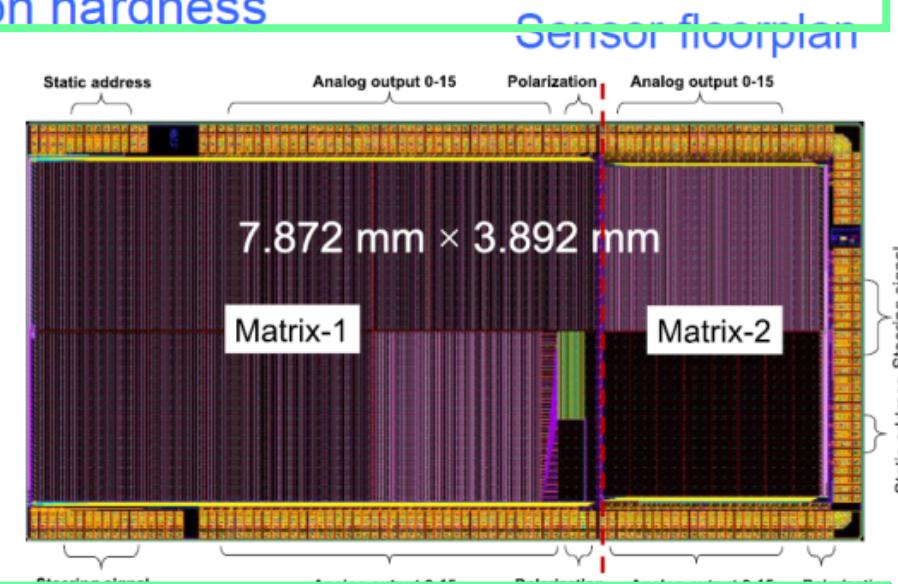
CMOS Sensor design and production

Funding from Key Lab, IHEP

- Initialized CEPC pixel sensor design based **CMOS** technology
- 1st joint MPW submission** with IPHC last November to understand **charge collection** with different **diode geometries**, **epitaxial-layer properties** and possible **radiation hardness**



CMOS sensor working principle

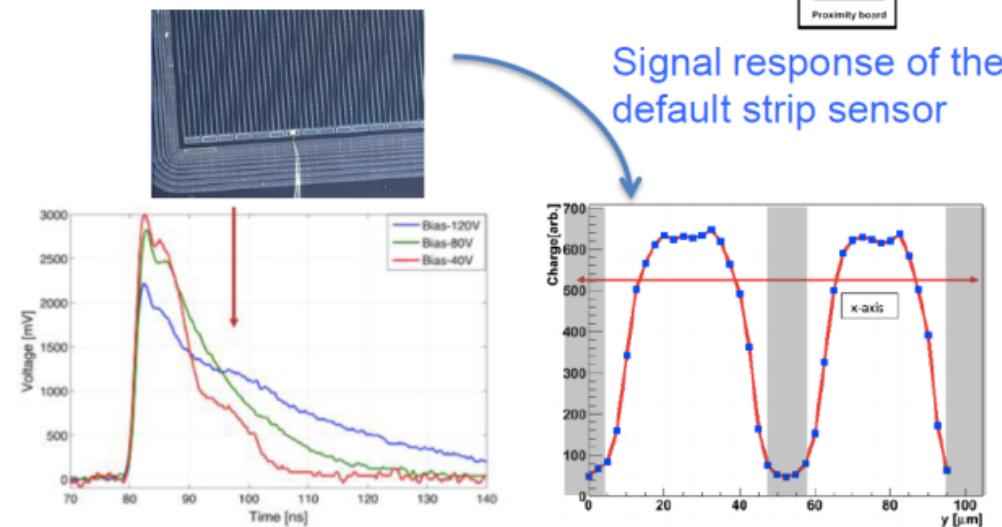
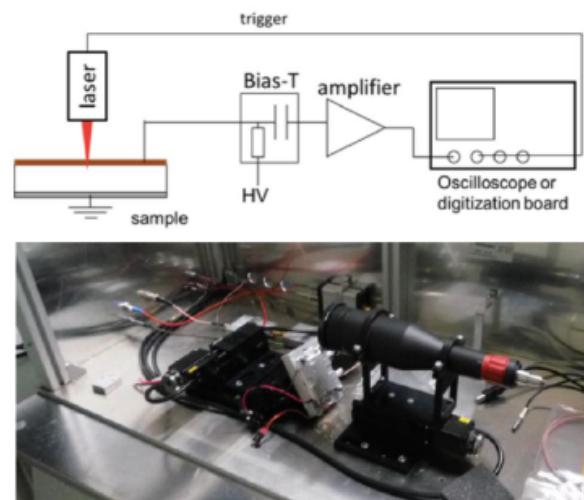


- On-going design effort on **in-pixel electronics** and **readout architecture**; second MPW submission later this year

CEPC Detector – Pixel Vertex Detector

Sensor Characterization (Preparation)

- Prepare test system to characterize charge collection
 - NI crate based or customized DAQ system
- Signal response with the TCT scan system
 - Commissioned to achieve resolution $\sim 30\mu\text{m}$ (target: $10\mu\text{m}$)



- Irradiation facilities @ NINT allowing TID up to 5 MRad (Co-60) and NIEL up to $10^{14} \text{ 1MeV n}_{\text{eq}}/\text{cm}^2$ (pulsed neutron reactor)

CEPC Detector – TPC

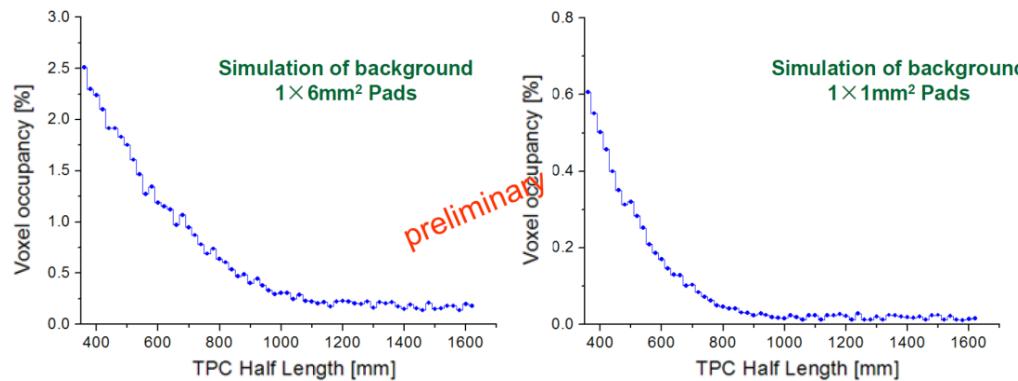
Simulation of occupancy

Supported by 高能所创新基金

Occupancy@250GeV

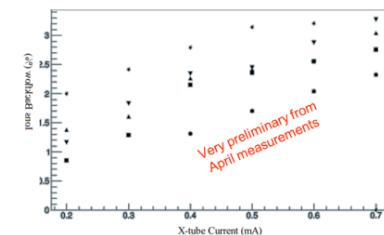
- Very important parameter for TPC
- Detector structure of the ILD-TPC like
- ADC sampling 40MHz readout
- Time structure of beam: 4us/Branch
- Beam Induced Backgrounds at CEPC@250GeV(Beam halo muon/e+e- pairs)+ $\gamma\gamma \rightarrow$ hadrons with safe factors($\times 15$)

CLIC_ILD ~30%@3TeV
1×6mm² Pads
CLIC_ILD ~12%@3TeV
1×1mm² Pads
NO TPC Options!

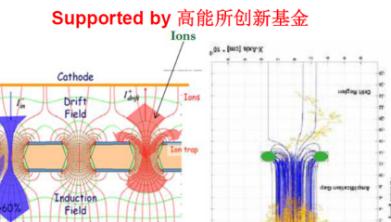


New ideas for the ions

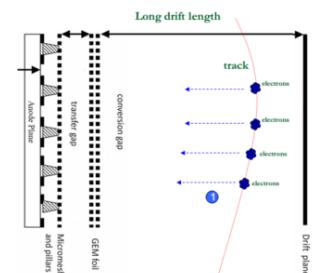
- GEM+Micromegas hybrid module
 - GEM as the preamplifier device
 - GEM as the device to reduce the ion back flow continuously
 - Stable operation in long time
 - Reach to the higher gain than standard Micromegas with the pre-amplification GEM detector
 - Increase the operating voltage of GEM detector to enlarge the whole gain



IBF of the hybrid module



IBF of GEM
IBF of GEM and Micromegas



Particles track in the hybrid module

CEPC Detector – TPC

Common efforts R&D

Collaboration for the IBF R&D:

CEA Scalay (France)

IHEP, Tsinghua Univ. (China)

ALEKSAN Roy (Saclay)
GAO Yuanning (THU)
QI Huirong (IHEP)

Collaboration for the Laser calibration R&D:

Tsinghua University, Beijing

IHEP, Beijing

LI Yulan (THU)
DENG Zhi (THU)
QI Huirong (IHEP)

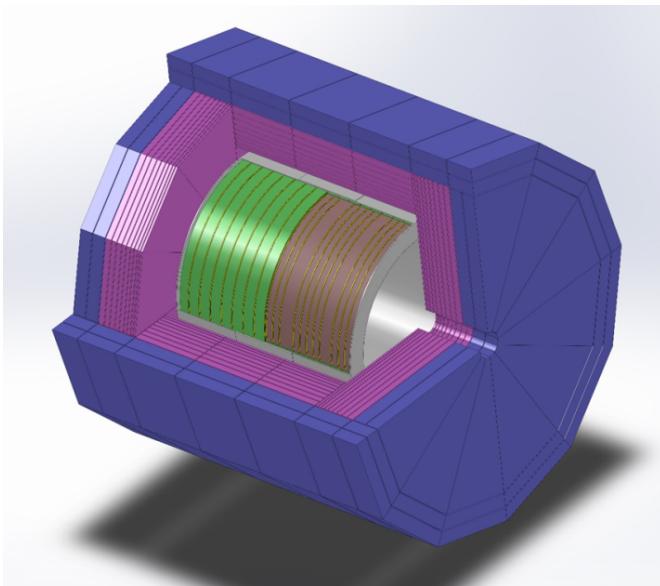
Targets:

- R&D of IBF used UV light
 - Goal: ~0.1% IBF, Resistive Micromegas modules, Hybrid modules
- Laser optical design
- TPC Prototype design with Laser calibration
 - Readout active area: ~200mm², Drift length: ~500mm
- ASIC electronic readout
 - Goal: ~32Chs/CHIP, Channels: ~1K
- Toward CEPC CDR

CEPC Detector – Detector Magnet

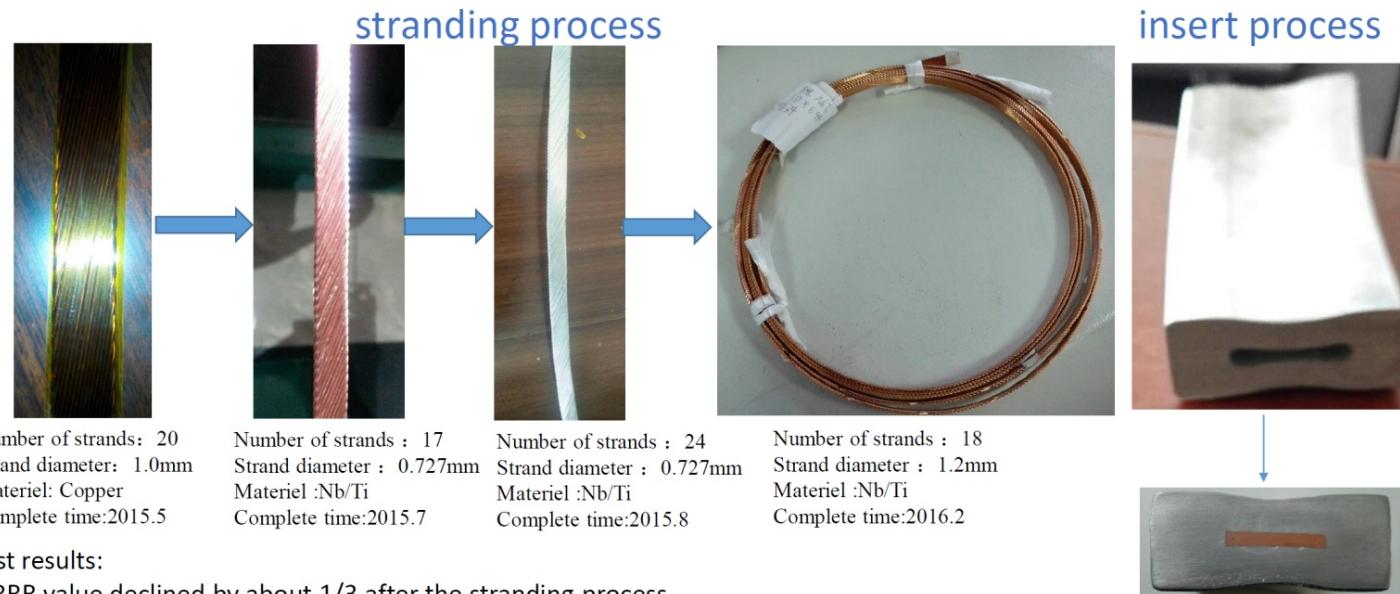
L. Zhao et. al.

Funding: IHEP IF



Key technology:

- Optimization of Magnetic filed
- Superconductor
- Inner winding and impregnating
- Coil cryogenic system
- Power lines with HTS
- Manufacturing and assembling of huge scale yoke



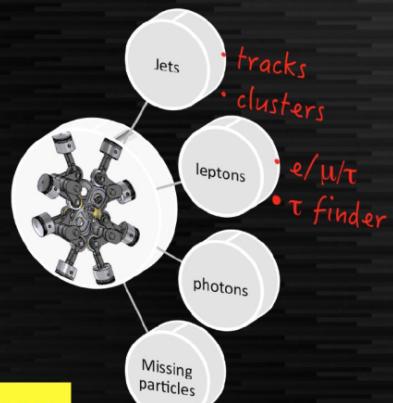
CEPC Detector – Software & Tools

Funding: IHEP IF

A dedicated analysis framework

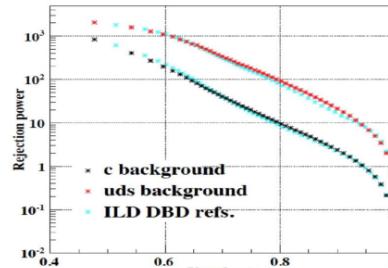
Novices can start from root ...

Feed all types of particle object to the combination engine for further processing

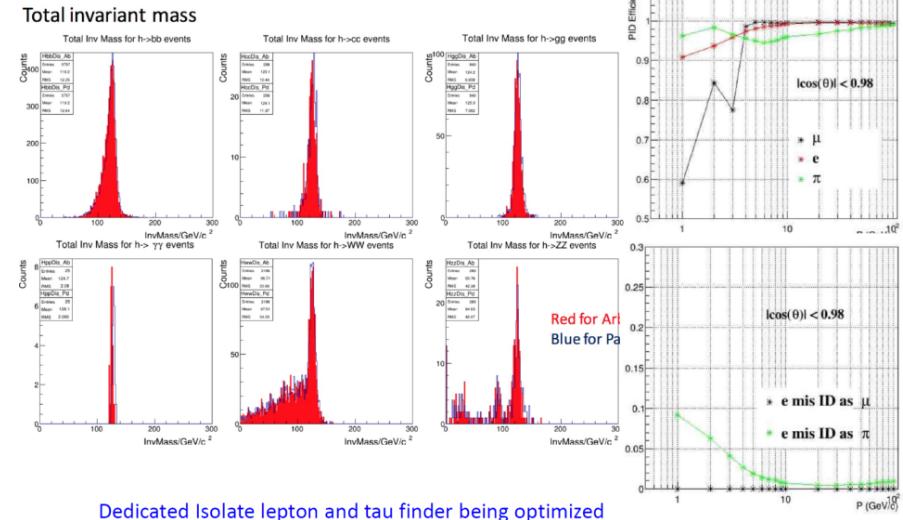
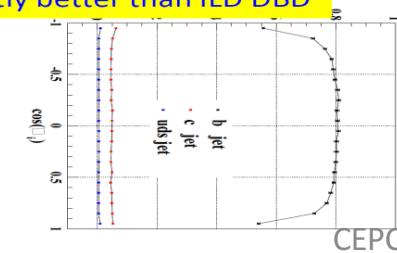
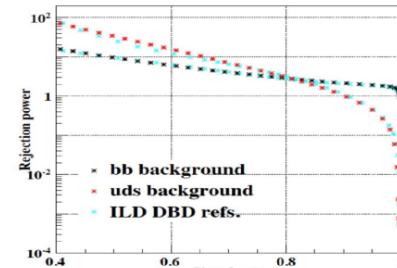
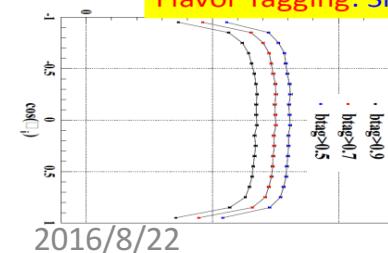


$ee+X, \mu\mu+X, jj+ee, jj+\mu\mu \dots$

Data → ntuples → plots



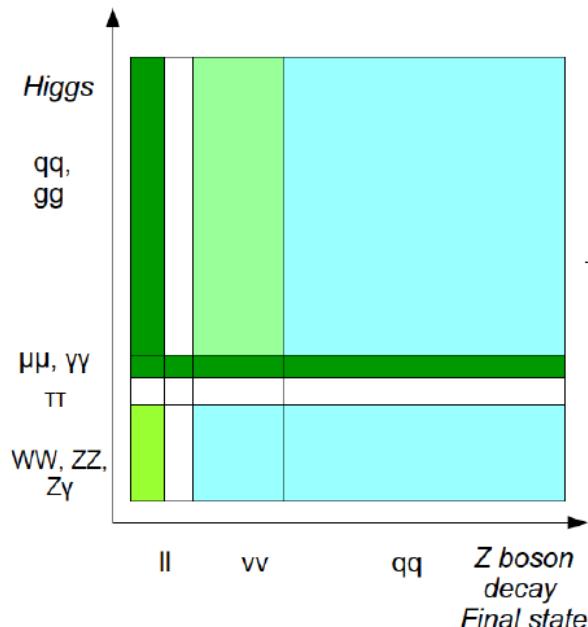
Flavor Tagging: Slightly better than ILD DBD



- 统计工具: **Analysis Tools**
 - 变量的shape information 可用在fit中.
 - 可以同时测量分值比和散射截面.
 - 可以将各个道的migration和相关性引入统计工具之中.
- 多变量分析:
 - 多个道引入多变量分析的方法: $h \rightarrow bb, cc, gg, ll$
- 数据驱动(data-driven)的方法:
 - 产生较完整数据(背景),用来进行data-driven method's练习.
 - 三月份workshop给学生们一次tutorial,介绍ATLAS中各用到的data-driven methods.

CEPC Detector – Software & Tools

Physics analysis, PreCDR->now



Significant progress had been made on
 $\text{Br}(\text{H} \rightarrow \text{bb}, \text{cc}, \text{gg})$
 $\text{Br}(\text{H} \rightarrow \text{WW}, \text{ZZ})$
 $\text{Br}(\text{H} \rightarrow \text{exotic})$

	PreCDR	Now
$\sigma(\text{ZH})$	0.51%	0.50%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{bb})$	0.28%	0.21%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{cc})$	2.1%	2.5%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{gg})$	1.6%	1.7%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{WW})$	1.5%	1.2%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{ZZ})$	4.3%	4%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \pi\pi)$	1.2%	1.0%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \gamma\gamma)$	9.0%	9.0%
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \mu\mu)$	17%	17%
$\sigma(\text{vvH})^* \text{Br}(\text{H} \rightarrow \text{Z}\gamma)$	-	-
$\sigma(\text{vvH})^* \text{Br}(\text{H} \rightarrow \text{bb})$	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
$\sigma(\text{ZH})^* \text{Br}(\text{H} \rightarrow \text{inv})$		
$\text{Br}(\text{H} \rightarrow \text{ee})$		
$\text{Br}(\text{H} \rightarrow \text{bbXX}, 4\text{b})$	$< 10^{-3}$	95%. CL = 3e-4

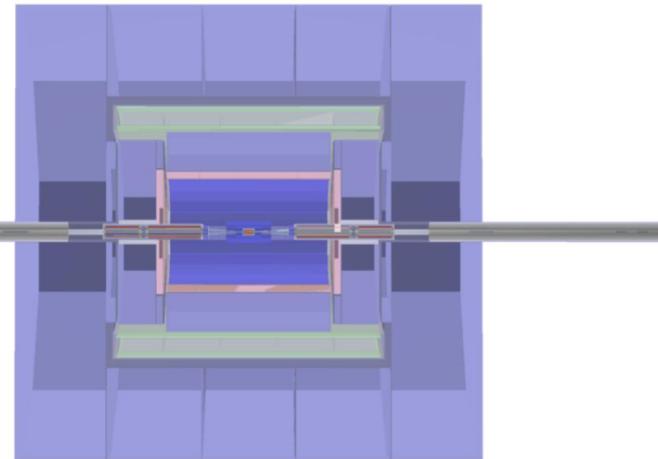
CEPC Detector – Software & Tools

New geometry: CEPC_o_V2

shrink the ILD detector

- New calo, TPC, and MDI
- Smaller TPC& Calo sizes
- More details in MDI
- Detailed B field map

Parameter	CEPC_o_v2	CEPC_v1
LStar_zbegin	1150	1146.9
VXD_inner_radius	12	15
VXD_radius_r1	12	15
VXD_radius_r3	35	37
TPC_outer_radius	1500	1808
Hcal_nlayers	40	48
Ecal_cells_size	10	4.9
Field_nominal_value	3	3.5
Yoke Layers	2	3



an important step towards sizing, design & optimization of the CEPC detector

- Need more validation
- To be released soon ...

Plus:

- full simulation of all analyses
- two papers: one published and other answering the referee's questions

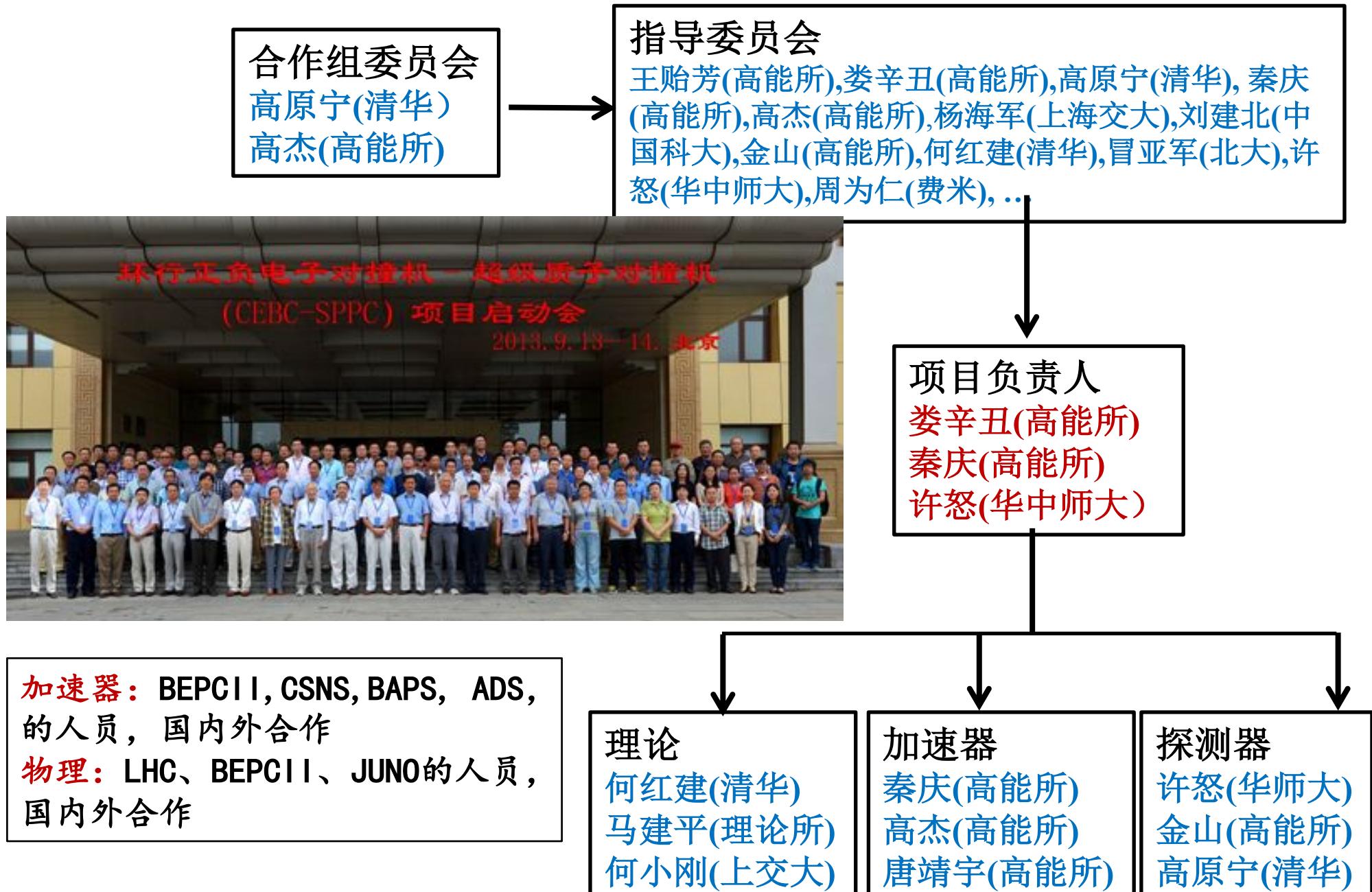
Special considerations at Z-pole

- Can TPC stand for (extremely) high event rate?
- Particle Identification ($\pi/K/p$) for flavor physics?
- Special designs to reduce systematic uncertainties of EW observables ?
 - modified sub-detectors
or a new detector concept?

Organization and activities

IV

CEPC-SPPC 工作组



CEPC – Web :Documentation and Meeting Annoucement

<http://cepc.ihep.ac.cn/>



CEPC-SppC Study Group Meeting in September 2-3, 2016, Beijing

<http://indico.ihep.ac.cn/event/6149/>

Site selections (some main places)

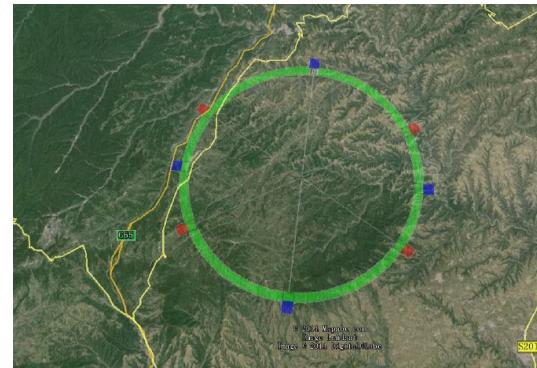


1) Qinhuangdao



1)

2) Shanxi Province



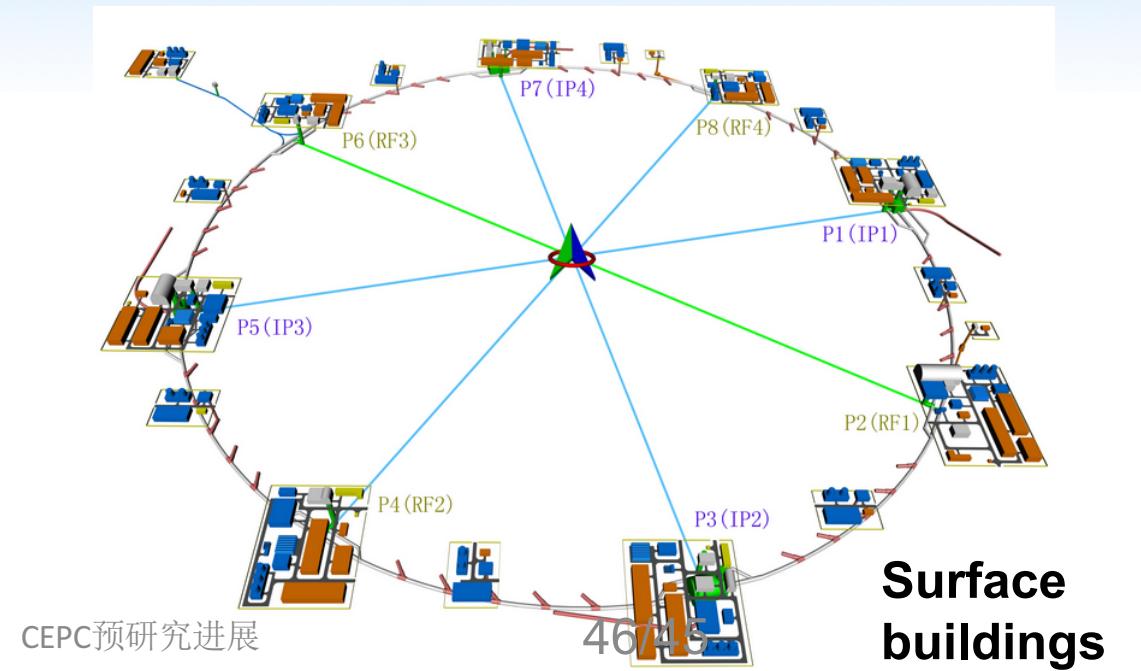
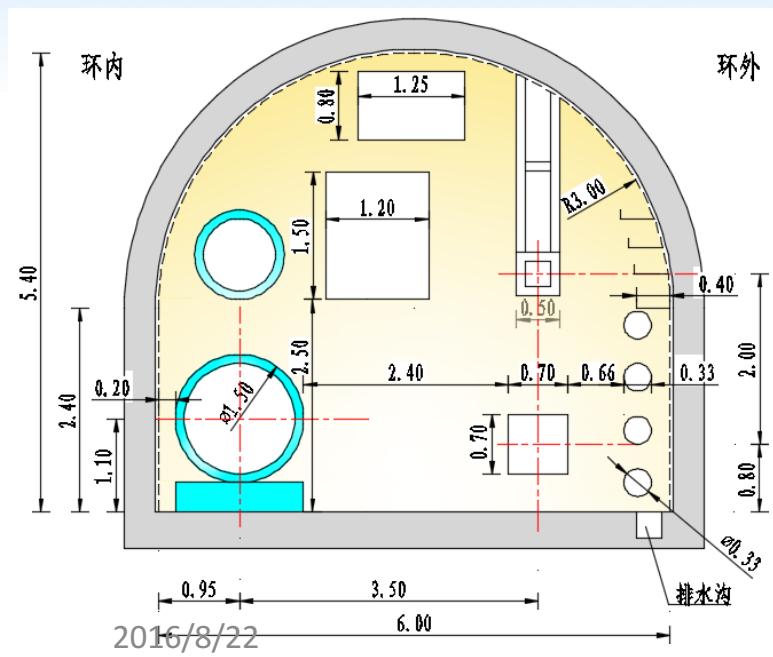
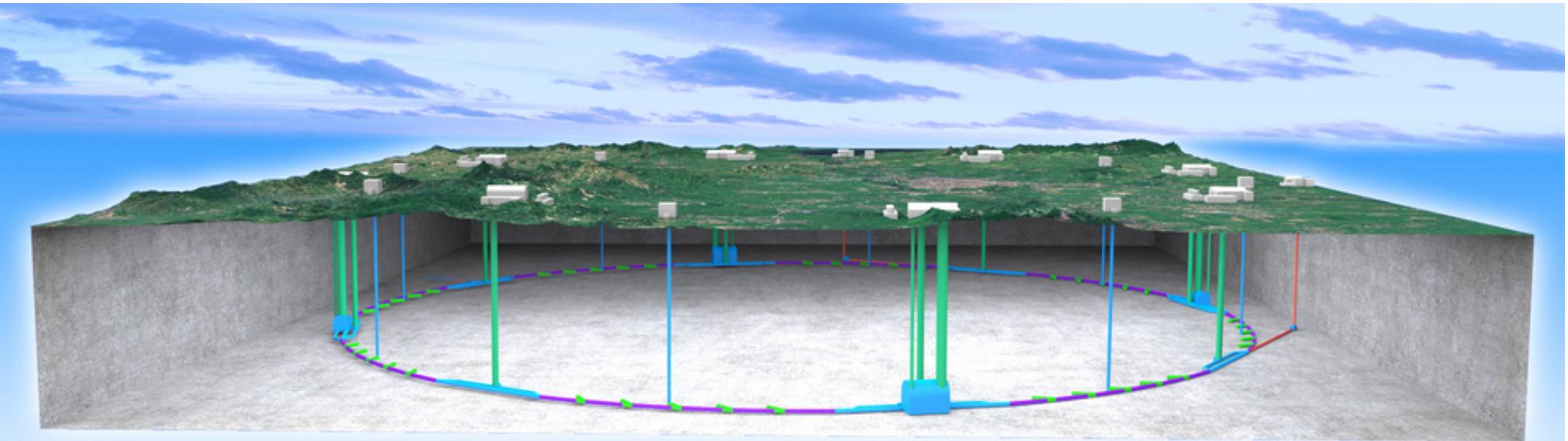
2)

3) Near Shenzhen and Hongkong



3)

Civil Construction



(理想的) 时间进度安排

- **CEPC (建设: 2022-2028)**

- 预先研究及准备工作
 - 2014年底之前完成 pre-CDR, 争取纳入十三五规划
 - 预研: 2016-2020
 - 工程设计: 2016-2020
- 建设: 2022-2028
- 数据获取: 2028-2038 (等SPPC成熟)

- **SppC (建设: 2038-2045)**

- 预先研究及准备工作
 - 预先研究: 2014-2030
 - 工程设计: 2030-2035
- 建造: 2038-2045
- 数据获取: 2045 - 2060

显然具体过程不会如此简单，应该有：
概念设计评审
预研项目申请与审批
项目建议书评审
工程设计评审
国际评审
。 。 。

经费来源：调动各方面的积极性

- 中央政府：科学设施建设（70-80%）与运行费
 - 重大国际合作专项？
- 地方政府：土地与配套设施建设，办公与研究环境建设，科学城规划，研究中心部分运行费
 - 对地方发展推动巨大；推动土地升值
- 国际合作：部分 (~ 20-30%) 科学设施建设与运行费
 - 国际惯例，先进的设施，重大成果的期望
 - 已有经验：北京谱仪(~100万美元)、大亚湾(~1000万美元)、江门 (~2000-3000万欧元)
- 私人与企业赞助：提高设施的性能；科学城建设
 - 生活设施建设，土地开发回报，。。。
- 科学院：研究中心运行费、人员费

International Collaboration

- Limited international participation for the pre-CDR
 - An excise for us
 - Build confidence for the Chinese HEP community
- International collaboration is needed not only because we need technical help
 - A way to integrate China better to the international community
 - A way to modernize China's research system("open door" policy)
- A new scheme of international collaboration to be explored
- An international advisory board has been formed to discuss in particular this issue, together with others
- A number of MoUs have been signed between IHEP and relevant labs, such BINP and VINCA

国际顾问委员会

- 前美国费米国家实验室副主任 Young-Kee Kim 任主席
- 2015年9月16–17日召开了首次会议



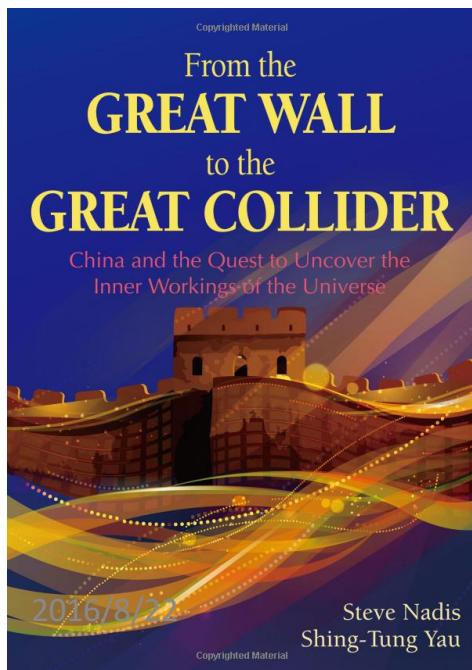
David Gross	诺贝尔奖获得者	Eckhard Elsen	DESY加速器部主任
Luciano Maiani	前CERN总干事	Peter Jenni	前ATLAS发言人
M. Mangano	CERN 理论部主任	Harry Weerts	阿贡实验室副主任
Joe Lykken	Fermilab 副主任	Young-Kee Kim*	前Fermilab副主任
Henry Tye	港科大高研院院长	Ian Shipsey	牛津粒子物理负责人
H.Murayama	东京Kavli所长	Michael Davier	前法LAL实验室主任
R. Godbole		Geoffrey Tayler	澳粒子物理卓越中心主任
Katsunobu Oide	前KEK加速器部主任	George Hou	台大粒子物理负责人
S. Stapnes	CERN CLIC负责人	Lucie Linssen	CERN CLIC 实验负责人
John Seeman	SLAC加速器部主任	Barry Barish	前ILC 全球设计负责人
E. Levichev	俄BINP副所长	Brain Foster	ILC管理设计组组长
Robert Palmer	BNL 加速器专家	Hesheng Chen	前高能所所长

国内外的支持与协调

- 2013年6月12-14日香山会议：“环形正负电子对撞机Higgs工厂(CEPC)+ 超级质子对撞机(SppC)是我国高能物理发展的重要选项和机遇”
- 第三届和第四届“中国高能加速器物理战略发展研讨会”结论：“环形正负电子对撞机Higgs工厂(CEPC) + 超级质子对撞机(SppC)是我国未来高能物理发展的首要选项”
- 2014年2月国际未来加速器委员会(ICFA): “**ICFA supports studies of energy frontier circular colliders and encourages global coordination**”
- 2014年7月的ICFA再次发表声明：“**ICFA continues to encourage international studies of circular colliders, with an ultimate goal of proton-proton collisions at energies much higher than those of the LHC**”
- 2016年2月亚洲未来加速器委员会(ACFA)及亚洲高能物理委员会(AsiaHEP)发表声明：“**The past few years have seen growing interest in a large radius circular collider, first focused as a “Higgs factory”, and ultimately for proton-proton collisions at the high energy frontier. We encourage the effort lead by China in this direction, and look forward to the completion of the technical design in a timely manner**”

国际影响和媒体报道

- Nature、Science等多次报道
- 时任ICFA主席, 美国费米国家实验室主任 Nigel Lockyer 在《自然》(V504, 18 Dec. 2013) 发表文章
- 诺贝尔奖获得者David Gross 和菲尔兹奖获得者Edward Witten在华尔街日报发表文章
- 丘成桐的书成为Amazon原子核物理/高能物理学销售榜首



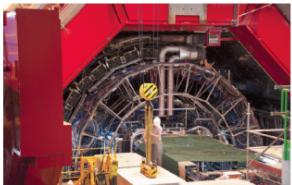
THE WALL STREET JOURNAL
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From the
GREAT WALL
to the
GREAT COLLIDER
China and the Quest to Uncover the
Inner Workings of the Universe

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<http://www.wsj.com/articles/chinas-great-scientific-leap-forward-1443136976>

OPINION | COMMENTARY

China's Great Scientific Leap Forward

Completion of a planned 'Great Collider' would transform particle physics.



Atlas, one of two general-purpose detectors at CERN's Large Hadron Collider below the France-Switzerland border near Geneva. PHOTO: GETTY IMAGES

By DAVID J. GROSS AND EDWARD WITTEN
Sept. 24, 2015 7:22 p.m. ET

Chinese President Xi Jinping's visit to Washington is an excellent opportunity to recognize China's scientific contributions to the global community, and to foster more cooperation between the U.S. and China in many areas of science, especially particle physics.

The discovery of the Higgs particle at Europe's Large Hadron Collider in 2012 began a new era. It confirmed an essential feature of the 40-year-old Standard Model of particle physics, a missing ingredient that was needed to make the whole structure work. But the discovery also left many questions unanswered. These include the mass of the Higgs particle, the unification of all subatomic forces, and the incorporation of quantum gravity—issues that must be addressed if scientists wish to understand the origin of the universe.

CEPC预研院进展



Together to the next frontier

As emerging players jostle old ambitions, Nigel Lockyer calls for the next generation of particle-physics experiments to be based on a global scale.

"If China does jump ahead, it will change the landscape of science."

This year was a watershed year for physics. The detectors to discover the Higgs boson are finally complete. Still, although the Higgs prediction has been confirmed, the particle-physics community is feeling a bit like the early 1990s: we know what we want to do, but where might the origin of their tiny masses come from? In the early Universe, Fermilab is heading a US proposal to build a large neutrino-beam experiment, running 1,300 kilometres from Fermilab to the Homestake mine in South Dakota. An ambitious 35-kilotonne liquid argon detector located nearly 1,500 metres below the surface emerged as the preferred project when the US community met in Minnesota for a ten-day planning symposium in July. It would help us to understand neutrino masses and whether these particles contribute to the matter-antimatter asymmetry of the Universe.

With the total construction budget nearing \$1 billion, the experiment will require international partners — a new approach for US domestic science. The US Department of Energy's Office of Science has indicated that it would support such a major proposal if there was involvement from

China. This machine could start up in the 2030s.

And the United States still has ambitions to host a high-energy frontier machine, after turning off the Fermilab's Tevatron accelerator in 2011 and failing to realize the Superconducting Supercollider in the 1990s. Perhaps the high-energy baton could be passed back to the United States. Fermilab is still a world leader in high-field magnets for proton accelerators, which would be necessary for any 100-TeV proton-proton collider.

To add to the suspense, there is the changing role of China. Historically a small player in particle physics, it last year stepped onto the world stage with

Illinois, I have spent the past six months in discussions about the future of US particle physics. But particle physics is an international pursuit, with projects in and participants from many different countries. The United States is well positioned to take the lead in some areas, such as neutrino physics, but the global landscape is uncertain. Resources need to be pooled, and new players are emerging. China's and India's talent, infrastructure and ambitions must now be factored into the global equation.

We are at a critical moment for the field. Each country and major project

Fermilab and the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan: these are the only places where large particle-physics projects are currently feasible. Demands from emerging economies such as China to host other projects will challenge the long-term plans of the existing leaders. Scientists in the United States and Europe will have to find out how best to use international competition as a spur for advancing projects on their own soil while still being good international partners. This may become tricky.

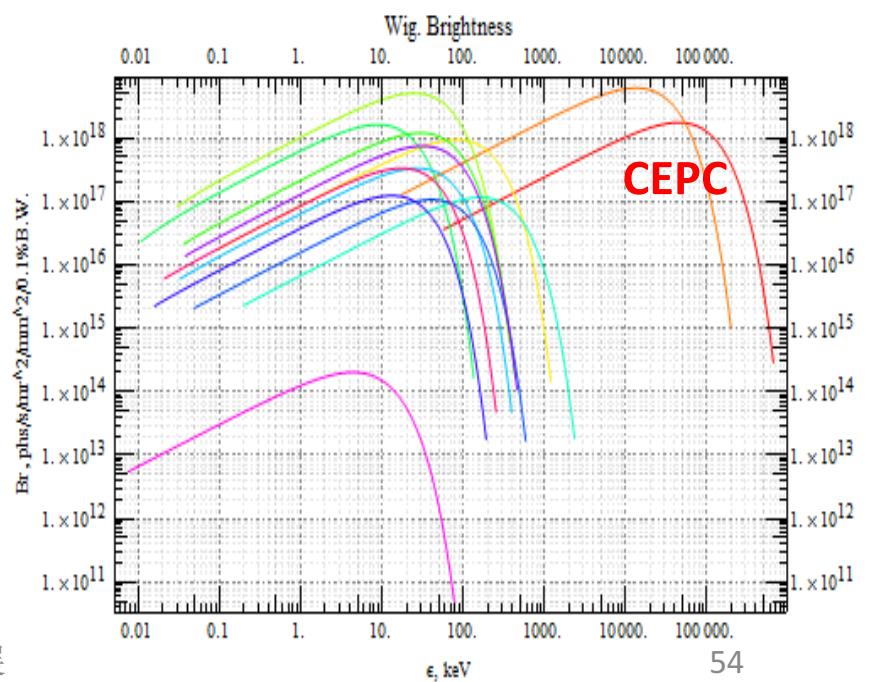
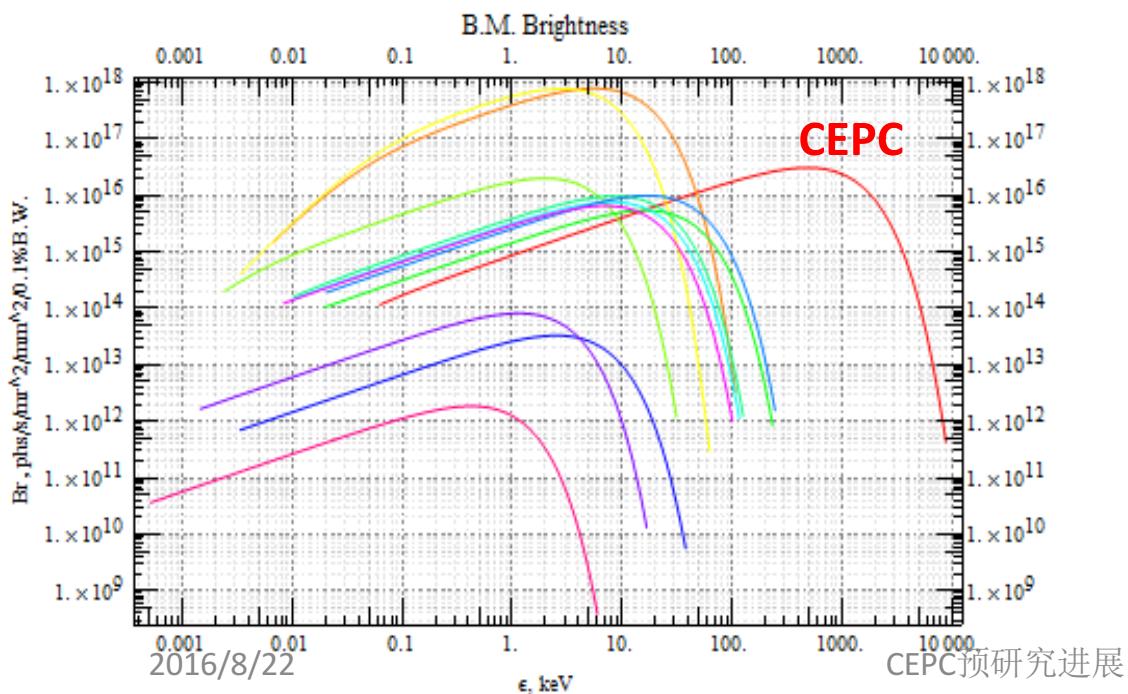
Higgs bosons are not export-controlled, nor are pictures of deep space from advanced telescopes. But the technologies developed, often through international collaborations, may have dual use — for defence applications or for economic gains, for example, as well as for basic science. Countries will have to decide how to oversee and exploit these

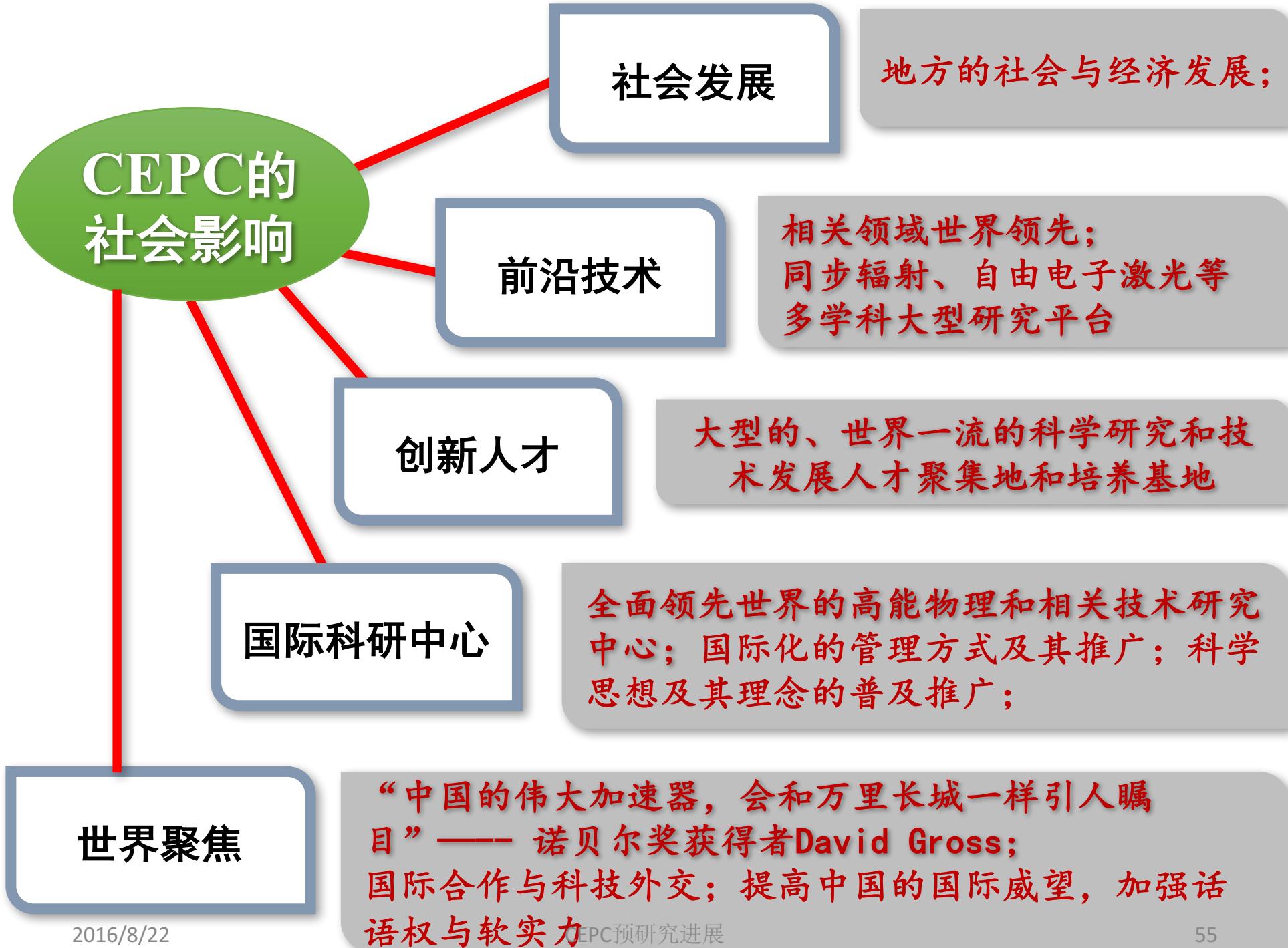
对技术的辐射带动作用

- 粒子物理研究不仅是科学的最前沿，也是技术的最前沿
 - 加速器物理与技术，核探测与核电子学技术，网络与计算技术等
- 典型事例：
 - **CERN**: 互联网、**www**与浏览器的发明与传播
 - 高能所：**email**、互联网的引入；加速器及低温超导技术的应用
- **CEPC**几项关键技术及其转化目标
 - **大型低温制冷机**与理化所合作，实现国产化
 - 广泛应用于加速器、航天航空中的氢液化装置以及天然气液化等
 - **高功率微波功率源**与电子所、**4404厂**、北广等合作，实现国产化
 - 广泛应用于加速器、广播、雷达等领域
 - **超导线实现国产化并引领国际,占领部分超导磁铁市场**
 - 广泛应用于加速器、发电、医疗成像、工业磁分离等领域
 - 高温超导取得突破，未来可以实现超导输电
 - **硅像素探测器**：掌握集成电路芯片、抗辐照技术，实现国产化
 - 广泛应用于同步辐射、加速器物理、军事等领域

CEPC也是高能同步辐射光源

- 从环上的二极铁引出的高能同步辐射光，能量可达**628keV**，超过目前所有正在运行和在建光源光子能量
- 使用扭摆磁铁或波荡器后，光子能量可以超过**20MeV**
- 前所未有的**MeV**级同步辐射光源
 - 核物理、国防、材料结构及缺陷、微加工、极端条件、高压、辐照改性、育种。 . .





CEPC是我国高能物理乃至整个科学发展的一个重大机遇

- Higgs研究的重大科学意义
- Higgs 质量较小（125 GeV），可以建环形 e^+e^- 对撞机
- 国际环境：无暇它顾
 - 欧洲手上有LHC
 - 日本：ILC
 - 美国：中微子
- 我国的优势
 - 隧道建设能力与优势
 - 大型项目建设与管理经验
 - 年轻的队伍，较低的成本。 . .
 - 我们有30年北京 e^+e^- 对撞机设计、建造、科学的研究的基础

中国发起的国际大科学工程
地方的社会与经济发展
国际科学技术研究中心
人才引进和培养基地
国际化的科研体制建设
科技外交与中国软实力

香山科学会议

高能环形正负电子对撞机-中国发起的大型国际科学实验

2016年10月18-19日

王乃彦、张焕乔、赵光达、赵政国、张闯、王贻芳

香山科学会议

高能环形正负电子对撞机-中国发起的大型国际科学实验

会议主题：

高能环形正负电子对撞机-中国发起的大型国际科学实验

中心议题：

CEPC科学意义、物理目标、发展潜力

CEPC预研究，和加速器、探测器、实验室建设

对社会发展的牵引作用和国际合作

CEPC方案，时间表和论证

香山科学会议

高能环形正负电子对撞机-中国发起的大型国际科学实验

申请召开本次会议的目的及预期成果

- 向国内高能物理界通报并讨论LHC Run II实验结果和Higgs发现后高能粒子物理研究的最新进展，讨论CEPC与之相关的重要物理课题和研究方法，进一步明确我国未来高能环形正负电子对撞机项目发展目标和方向。
- 介绍CEPC 概念设计（CDR）进展和预研究项目实施状况，总结国际合作思路和进展，国内论证方案，分析CEPC项目的必要性、紧迫性、优先程度和可行性等，达成学术界内的共识。
- 研讨CEPC的设计、预研、造价估计及下一步工作计划，对CEPC项目进行风险分析，对可能出现的问题和难点做出合理、科学的对应方案。
- 给出我国建造、实施CEPC的路线图建议（如，我国开展CEPC预制研究的计划和前期专项经费投入建议、我国建造CEPC的国际合作模式和运行方式、以CEPC建造为目标的人才培养计划等），为政府的决策和部署提供必要的参考。

香山科学会议

高能环形正负电子对撞机-中国发起的大型国际科学实验 主题评述报告、中心议题评述报告及专题发言题目和报告人

序号	报告类别	报告题目	报告人
1	主题评述报告	高能环形正负对撞机（CEPC）：科学意义、物理目标、实验方法、发展潜力	娄辛丑
2	中心议题1评述报告	CEPC物理目标	韩涛
3	专题报告	CEPC希格斯玻色子物理	何红建
4	专题报告	CEPC非希格斯玻色子物理	何小刚
5	中心议题2评述报告	CEPC加速器概念设计和预研究	高杰
6	专题报告	CEPC加速器关键技术	翟纪元，池云龙
7	专题报告	CEPC 12kW@4K大型制冷机	刘立强
8	中心议题3评述报告	CEPC探测器概念设计和预研究	杨海军
9	专题报告	CEPC硅径迹探测器预制研究	欧阳群
10	专题报告	CEPC TPC探测器研究	李玉兰
11	中心议题4评述报告	CEPC的国际合作、时间表及对社会发展的牵引作用	高原宁
12	专题报告	国际合作对中国建造CEPC的重要性和必要性	许怒
13	专题报告	中国建造CEPC的时间表和实施方案	秦庆

R&D plan

V

未来5年预研计划

- 十三五期间完成CEPC技术设计报告（TDR）
 - 科技部专项（3600万元）作为先导
 - 2017/2018 启动第二个专项项目（4500万）
 - 各种可能的经费来源
 - 国际合作
- 目标：十四五工程预研 + 开始建造

预研计划

- 加速器/探测器的概念设计、工程设计
- 土建方面的选址、规划、地质勘探、设计、评估、评审。。
- 关键技术预研
 - 超导射频加速腔
 - 功率源（大功率速调管、固态功率源）
 - 束流测量与诊断
 - 半导体硅像素探测器
 - 高场超导磁铁及超导线

掌握这些范围极为广泛的关键技术应用，实现国产化，是国家的重大需求

内 容	预研经费 (亿元)	内 容	预研经费 (亿元)
加速器	8.20	探测器	0.80
加速器物理	0.03	径迹探测器 (TPC)	0.10
高频系统	3.10	顶点探测器 (VTX)	0.10
低温系统	2.00	量能器 (电磁+强子)	0.24
磁铁系统	0.09	Muon 探测器	0.02
电源系统	0.05	探测器磁铁	0.10
机械系统	0.01	计算、物理模拟与软件组	0.22
真空系统	0.06	触发与数据获取系统	0.02
束测系统	0.02		
准直	0.20	同步辐射装置	0.30
控制系统	0.07	伽玛射线应用系统-光束线站	0.30
辐射防护	0.03	土建和通用设施	0.70
直线加速器	0.17		
功率源	0.75		
超导加速器磁铁 (SPPC) R&D	1.62		

总结

- CEPC-SPPC 完成PreCDR后，开始深入的预研
 - 以科技部专项项目为先导，近期完成对撞机和探测器的概念设计；开展最关键的技术预研。
 - 在十三五期间完成技术设计报告，争取在十四五开始工程预研和建造。
- 其它各项工作、国际合作有序开展。