CEPC: a Great Challenge and Opportunity

Yifang Wang
Institute of High Energy Physics, Beijing

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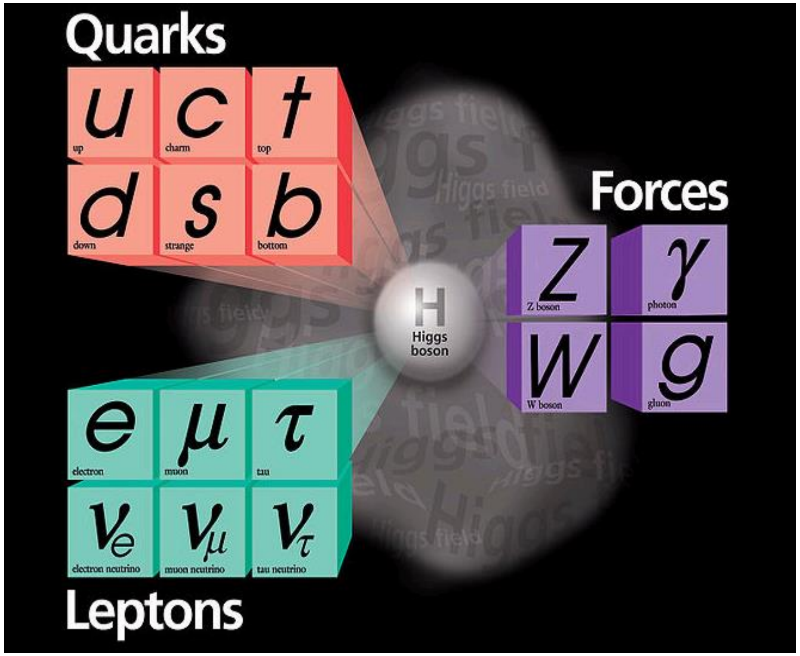
Where Are We Going ?

- After the Higgs, game is over ?
- Shall we wait for results from LHC/HL-LHC ?
- ILC ?
  - If yes, enough？ Next？
  - If no, then ?



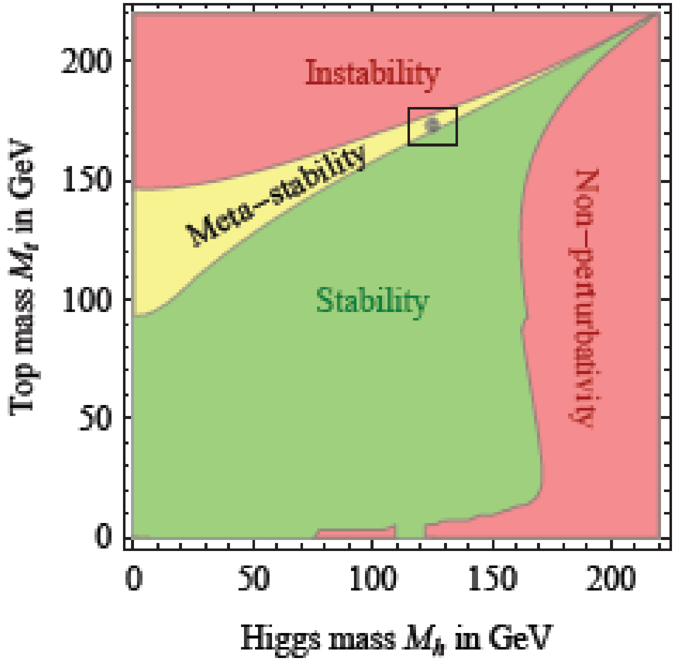
- What is the future of our field ?

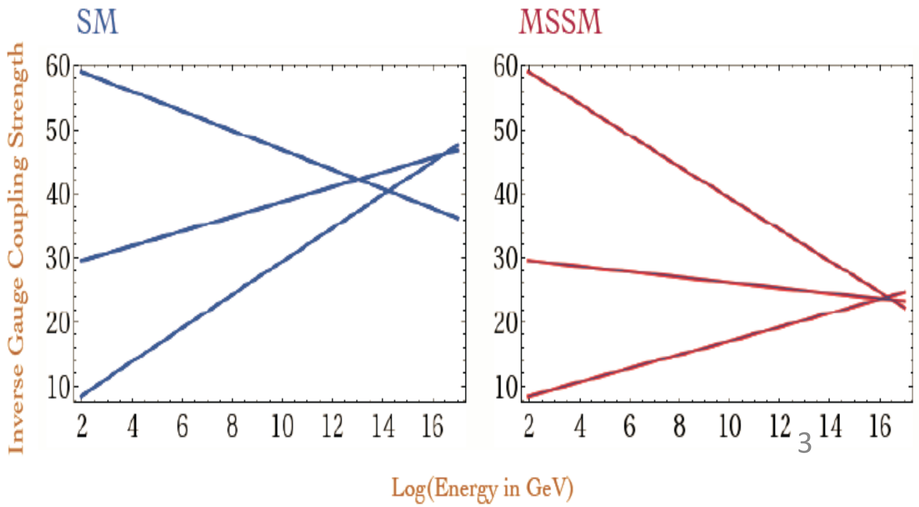
SM is not the End after the Higgs

- From neutrinos to top quark, masses differs by a factor 10^{13} (Hierarchy)
- Fine tuning of Higgs mass(naturalness)

$$m_H^2 = 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023$$
$$-36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398$$
$$= (125\text{ GeV})^2 \text{ ! ?}$$

- Masses of Higgs and top quark are in the meta-stable region
- Dark matter particles ?
- No CP in the SM to explain Matter-antimatter asymmetry
- Neutrinos
- Unification at a high energy ?

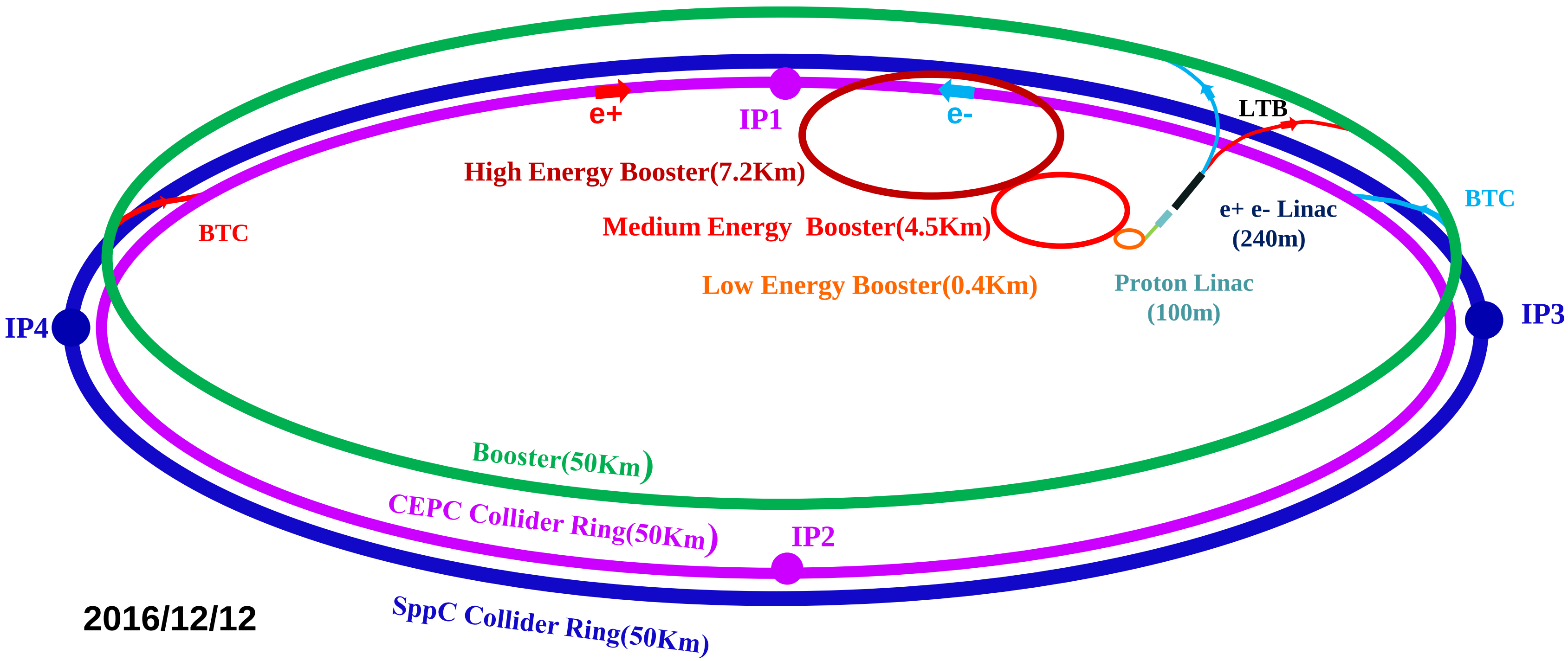




Most of the issues related to Higgs

A Key Step: Higgs Factory

- Thanks to the low mass Higgs, it is possible to build a Circular Higgs Factory(CEPC), followed by a proton collider(SppC) in the same tunnel
- Looking for Hints (from Higgs) ➔ direct searches



Science of CEPC-SPPC

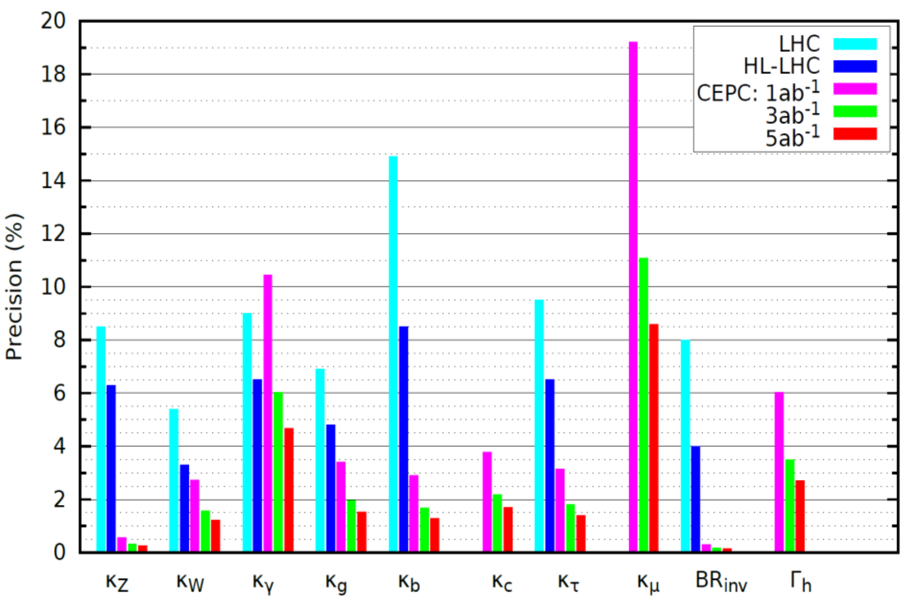
- **Electron-positron collider(90, 250 GeV)**
  - Higgs Factory（10^6 Higgs）：
    - Precision study of Higgs(m_H, J^{PC}, couplings)，Similar & complementary to ILC
    - Looking for hints of new physics
  - Z & W factory（10^{10} Z^0）：
    - precision test of SM
    - Rare decays ?
  - Flavor factory: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

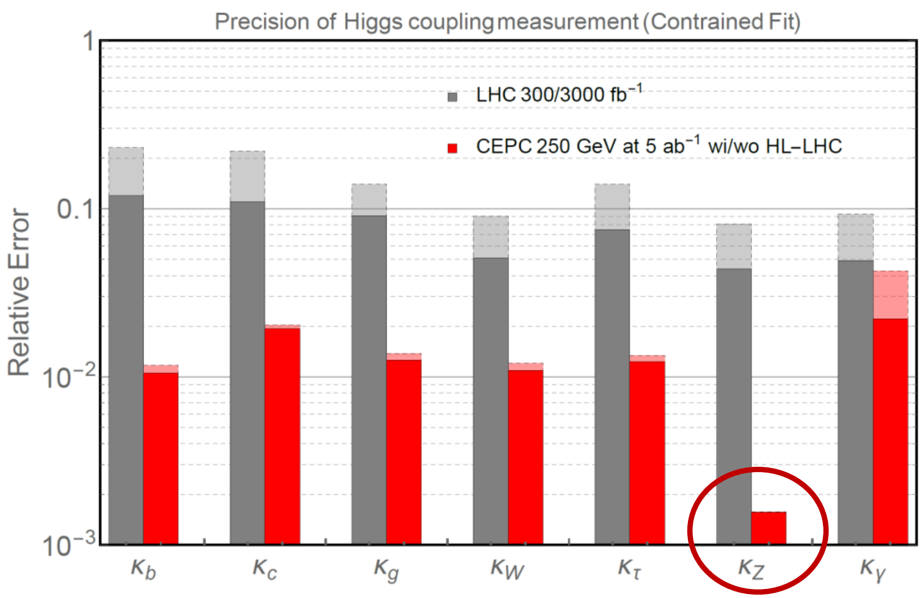
Precision measurement + searches:
Complementary with each other !

Precision Higgs Physics by CEPC

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{M^2} \mathcal{O}_{6,i} \qquad\qquad \delta \sim c_i \frac{v^2}{M^2}$$

% precision → M ~ 1 TeV
to new physics → ~ × 10 over LHC

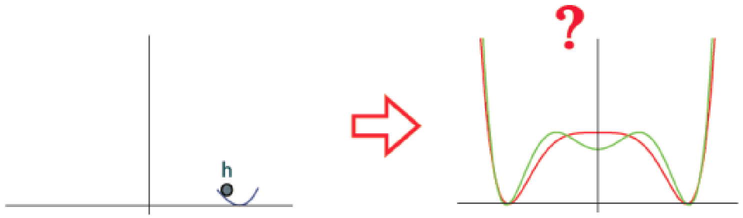


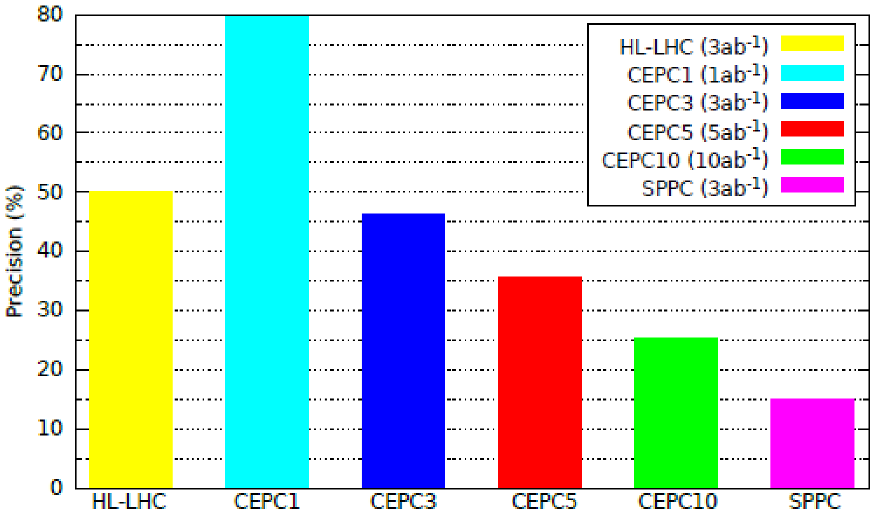


CEPC preCDR Volume 1 (p.9)

Nature of EW Phase Transition ?

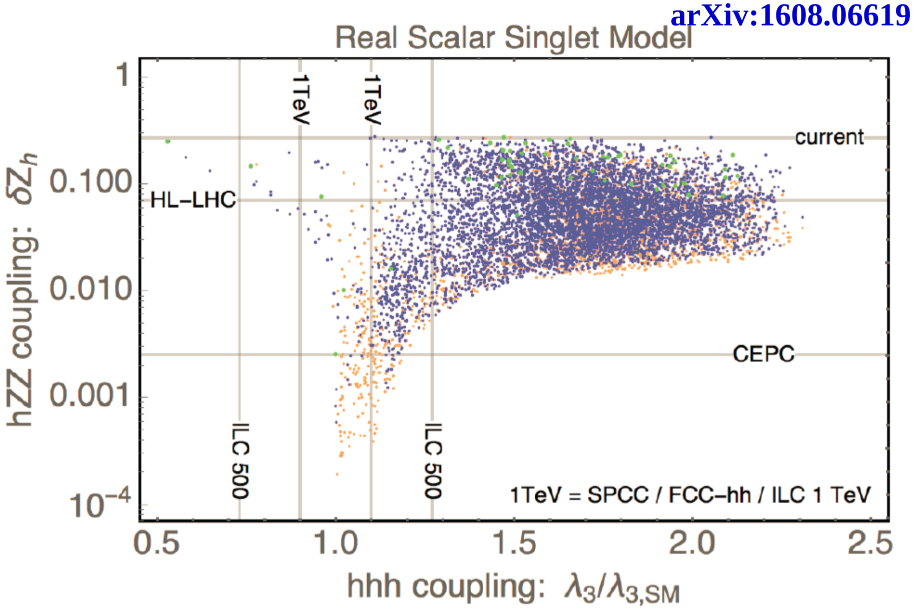
- 1^{st} or 2^{nd} order ➔ Huge implications
  - O(1) deviations in h^3 coupling
  - O(1%) shift in h-Z coupling
- CEPC can determine it:
  - h^3 coupling at CEPC： 20-30%
  - h-Z coupling at CEPC： < 0.2%



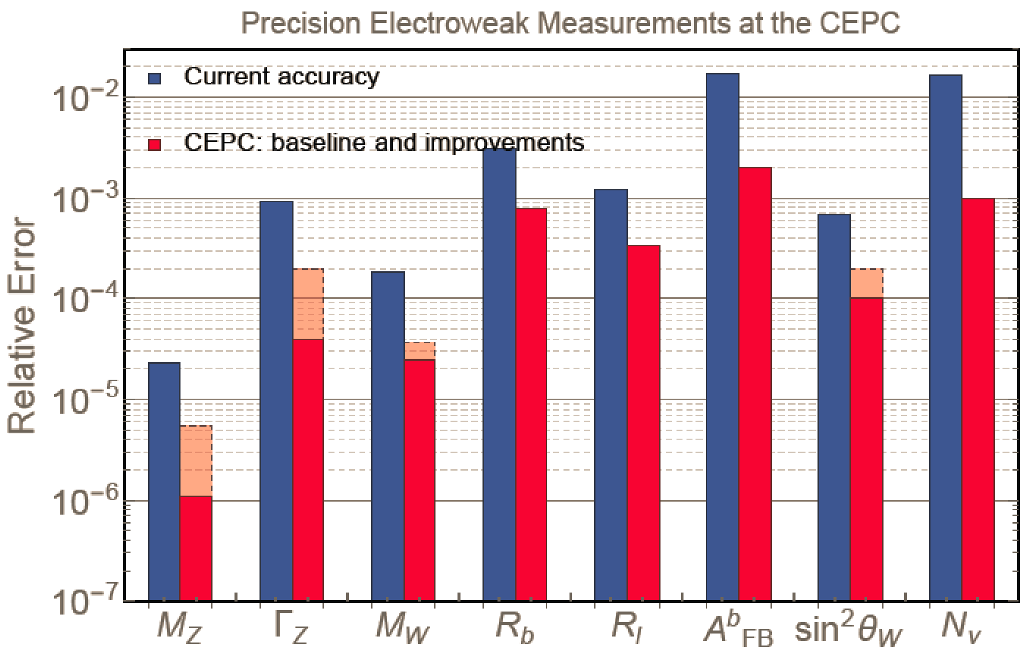


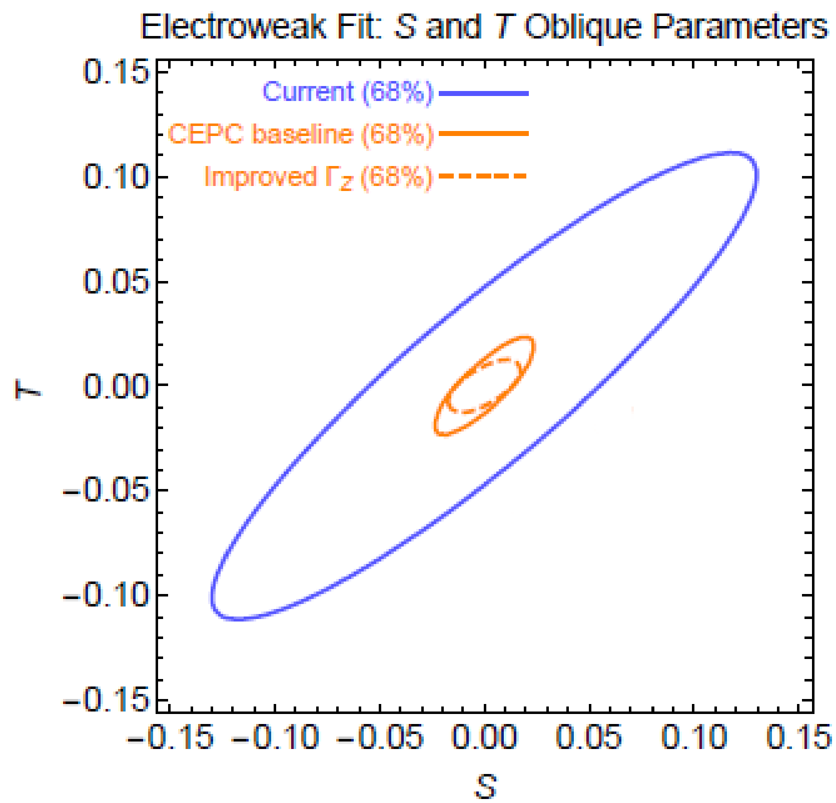
M. McCullough, PRD 90(2014)015001

arXiv:1608.06619



Improvement in Electroweak Precision

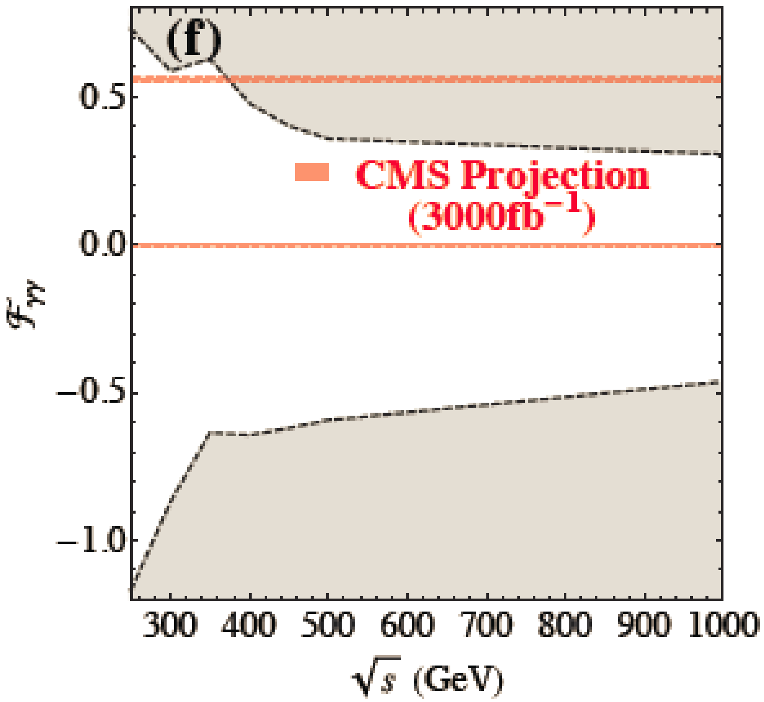




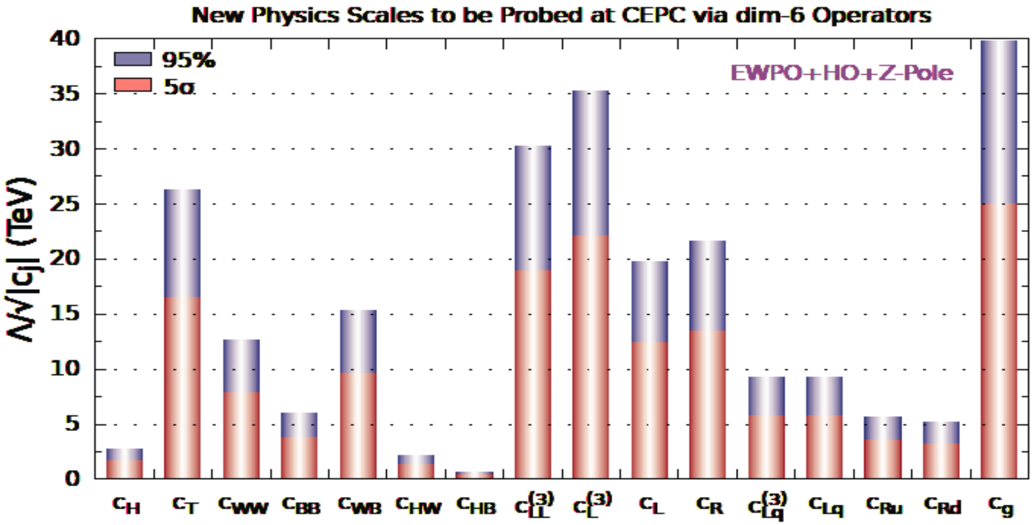
CEPC preCDR Volume 1 (p.10)

Probing New Physics(I)

anomalous Higgs
to gamma and Z coupling



Q. Cao, B.Yan, 1507.06204



S. Ge, H. He, R. Xiao, 1603.03385

Experiment	κ_Z (68%)	f (GeV)	κ_g (68%)	$m_{\tilde{t}_L}$ (GeV)
HL-LHC	3%	1.0 TeV	4%	430 GeV
ILC500	0.3%	3.1 TeV	1.6%	690 GeV
ILC500-up	0.2%	3.9 TeV	0.9%	910 GeV
CEPC	0.2%	3.9 TeV	0.9%	910 GeV
TLEP	0.1%	5.5 TeV	0.6%	1.1 GeV

Experiment	S (68%)	f (GeV)	T (68%)	$m_{\tilde{t}_L}$ (GeV)
ILC	0.012	1.1 TeV	0.015	890 GeV
CEPC (opt.)	0.02	880 GeV	0.016	870 GeV
CEPC (imp.)	0.014	1.0 TeV	0.011	1.1 GeV
TLEP-Z	0.013	1.1 TeV	0.012	1.0 TeV
TLEP-t	0.009	1.3 TeV	0.006	1.5 TeV

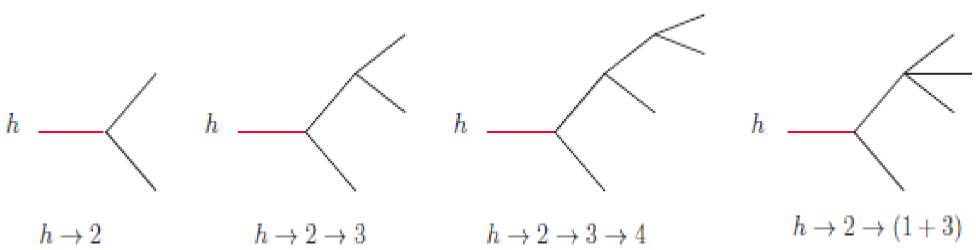
Into the Multi-TeV regime

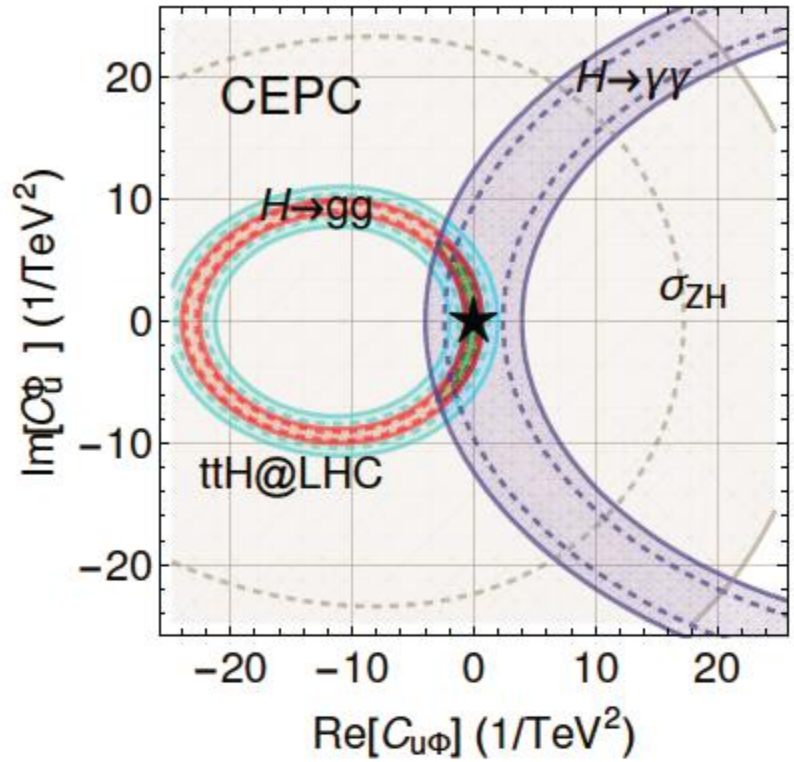
Probing New Physics(II)

A likely window to new physics through top and Higgs

- Both are special
- Important for the vacuum stability & EWSB

- Higgs couplings to the dark sector through BR_{inv}





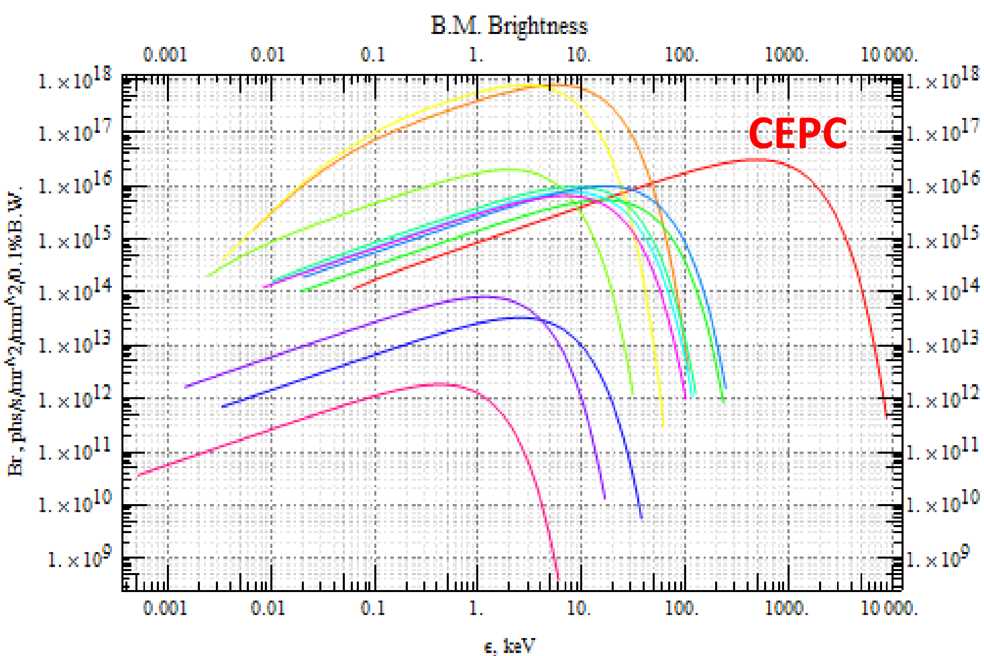
C. Shen, S. Zhu 1504.05626
Z. Liu, I. Low, LTW, in progress

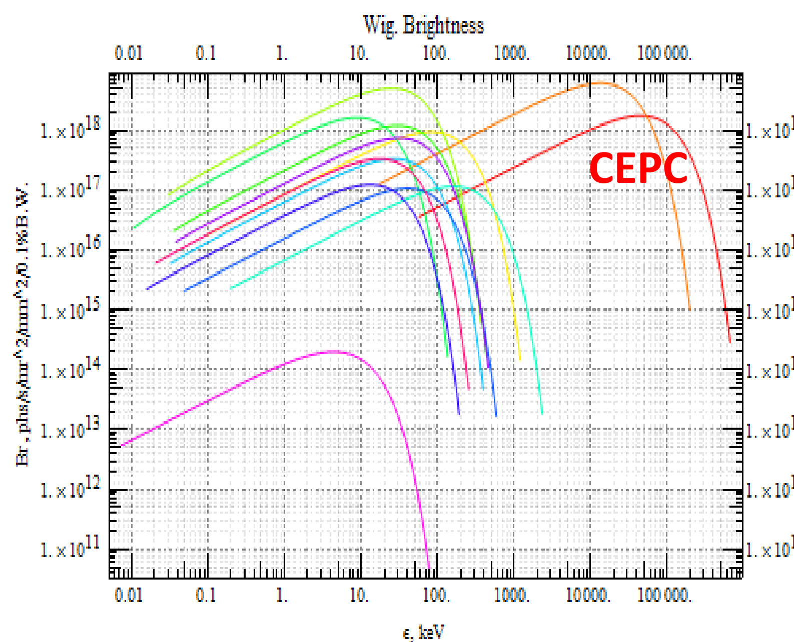
Comparison with Other Machines

	Science	Upgrade	Technology	Cost	Schedule
CEPC	****	****	****	*****	*****
SppC	*****	*	**	***	***
ILC	****	*	***	****	*****
FCC-ee	****	****	****	****	?
FCC-pp	*****	*	**	**	***
CLIC	****	**	***	***	**
VLHC	*****	***	****	**	?
Muon collider	*****	****	*	*	?
New acceleration	*****	?	? ?	?	? ?

CEPC is a Great Light Source

- From dipole magnet, synchrotron radiation can reach energies up to 628keV, with a very high flux
- By using undulators or wigglers, photon energies can reach 100 MeV with a huge flux
- Unprecedential monochromatic gamma sources
  - Nuclear physics , material science, micro-processing, high pressure and extreme conditions, …





CEPC is a Great Opportunity

- There are new physics, and also “standard” physics to be learned
- No need to wait for LHC
  - If LHC finds nothing, a Higgs factory can give us a first indication
  - If LHC finds something, it is a new era
    - Higgs need(s) to be understood anyway
    - new energy scale, new spectrum, LHC can not complete it ➔ A higher energy pp collider is needed
      - An e+e- Higgs factory can give us time to develop technologies for 16-20 T magnet and SC cables
- ILC may not be enough. CEPC is a Complementary:
  - Push-pull option can be given up
  - Luminosity at H, Z, W
- High energy frontier is still the center of particle physics

IHEP-CEPC-DR-2015-01

IHEP-EP-2015-01

IHEP-TH-2015-01

Can be downloaded from

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

CEPC-SPPC

Preliminary Conceptual Design Report

Volume I - Physics & Detector

403 pages, 480 authors

The CEPC-SPPC Study Group

March 2015

IHEP-CEPC-DR-2015-01

IHEP-AC-2015-01

CEPC-SPPC

Preliminary Conceptual Design Report

Volume II - Accelerator

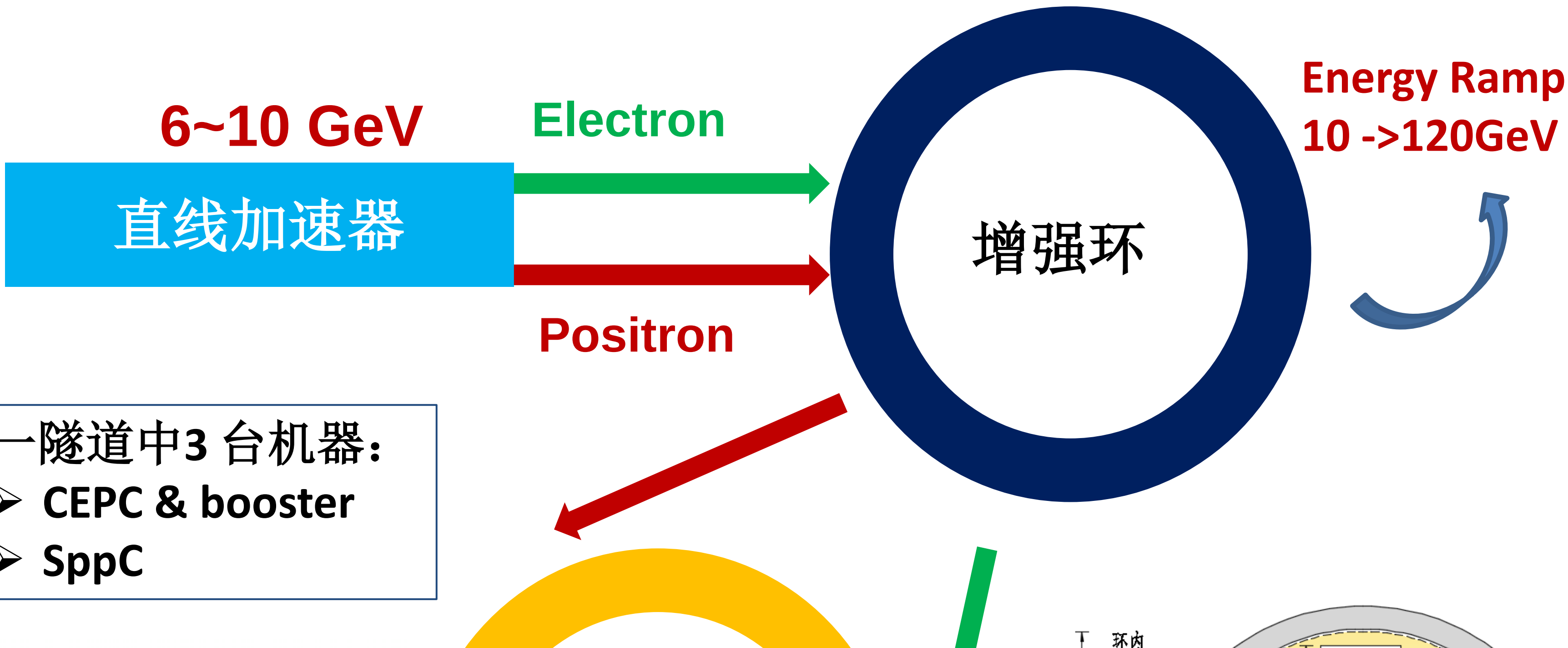
328 pages, 300 authors

The CEPC-SPPC Study Group

March 2015

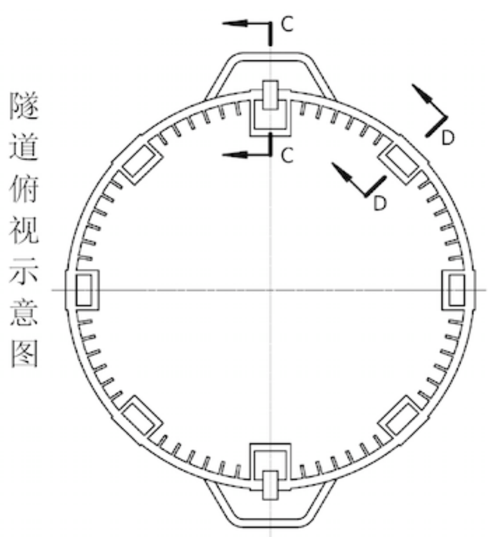
International Review of Pre-CDR

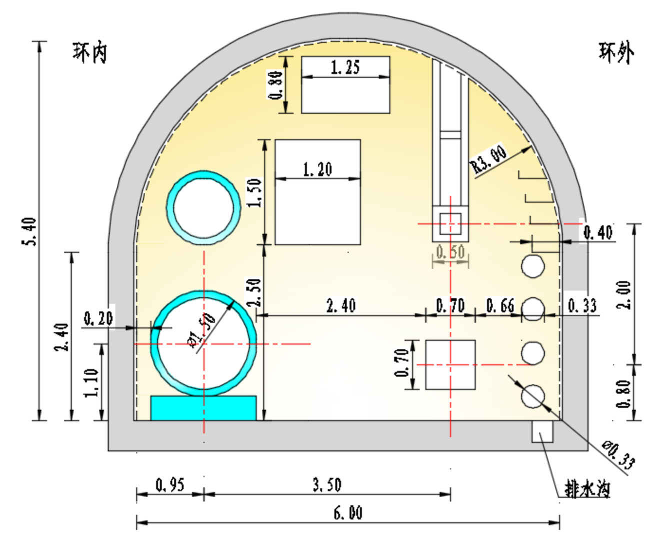
CEPC 加速器设计



同一隧道中3 台机器:

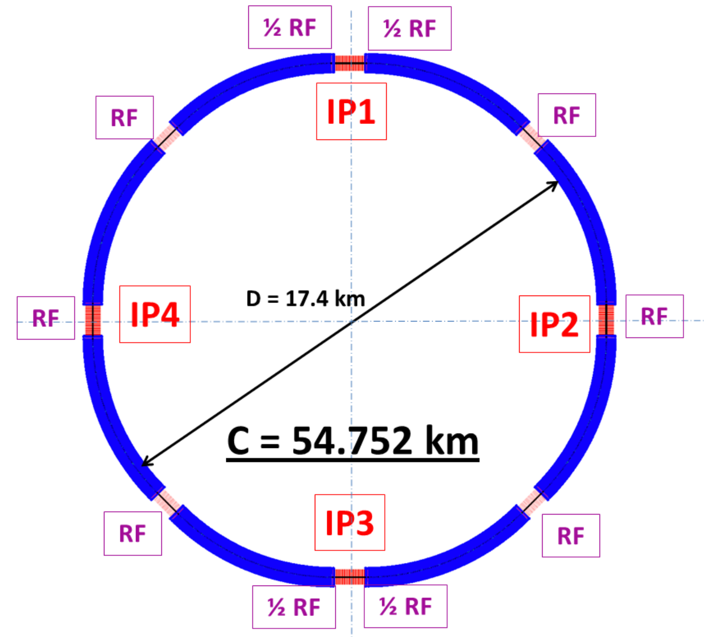
- CEPC & booster
- SppC





CEPC Design

- Critical parameters:
  - SR power: 51.7 MW/beam
  - 8*arcs, 2*IPs
  - 8 RF cavity sections (distributed)
  - RF Frequency: 650 MHz
  - Filling factor of the ring: ~70%



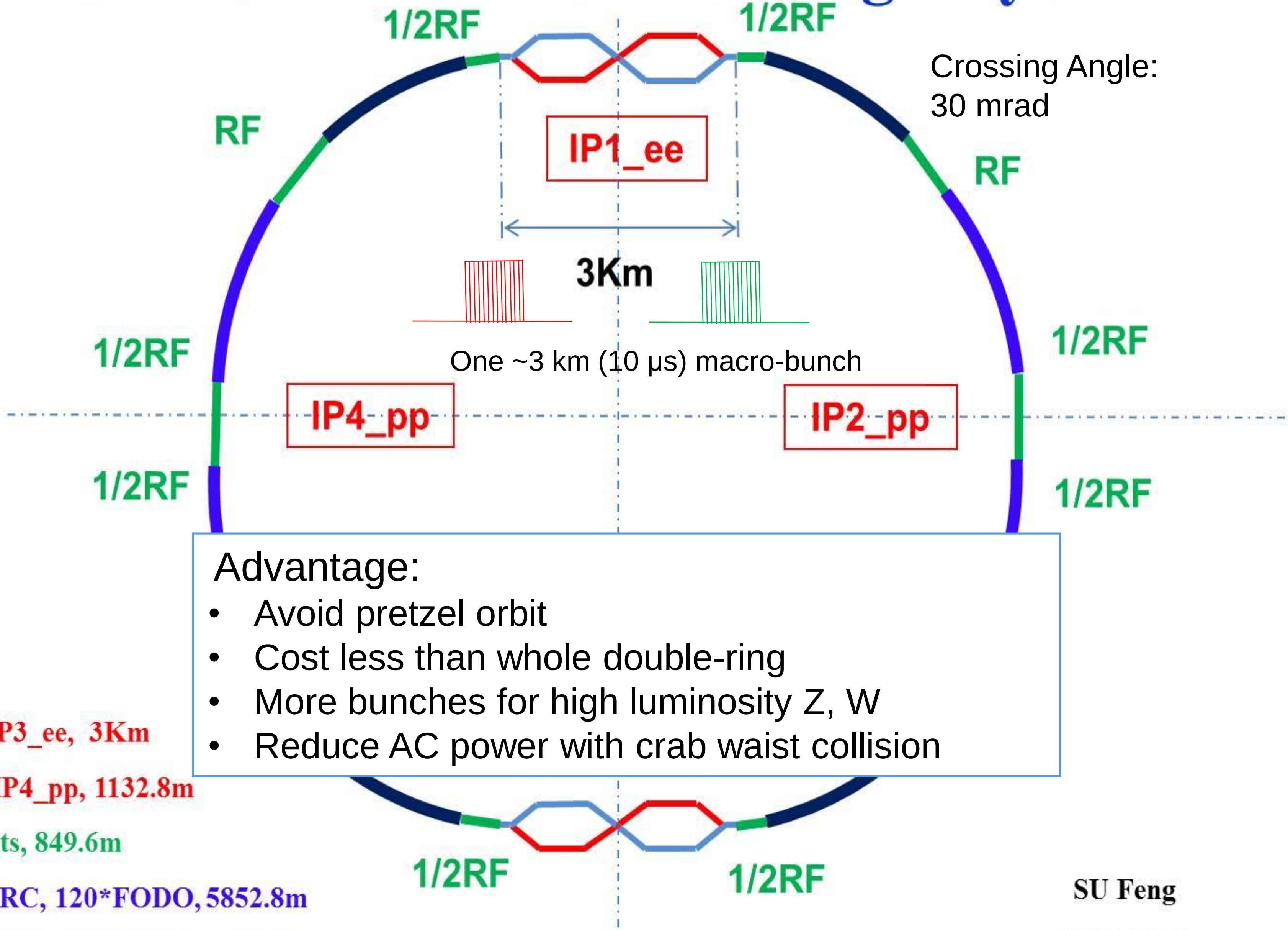
Parameter	Unit	Value	Parameter	Unit	Value
Beam energy [E]	GeV	120	**Circumference [C]**	m	54752
Number of IP[N_{IP}]		2	**SR loss/turn [U_0]**	GeV	3.11
Bunch number/beam[n_B]		50	**Energy acceptance RF [h]**	%	5.99
SR power/beam [P]	MW	51.7	**Beam current [I]**	mA	16.6
emittance (x/y)	nm	6.12/0.018	**β_{IP}(x/y)**	mm	800/1.2
Transverse size (x/y)	μm	69.97/0.15	**Luminosity /IP[L]**	$cm^{-2}s^{-1}$	2.04E+34

Main Problems left in Pre-CDR

1. Pretzel scheme is difficult to design and operate, with little flexibility and stability
2. Too high AC power consumption (~ 500 MW)
3. Very low luminosity for Z
4. Booster with very too low magnetic field (30 Gauss for 6GeV injection in a background field of 3 Gauss, say in the BEPCII tunnel) and too small dynamic aperture
5. Very small Dynamic Aperture at 2% energy spread with beam-beam effects and magnetic errors

- **Goal of CEPC CDR:** a "design" working on paper

CEPC Partial Double Ring Layout



Advantage:
- Avoid pretzel orbit
- Cost less than whole double-ring
- More bunches for high luminosity Z, W
- Reduce AC power with crab waist collision

IP1_ee/IP3_ee, 3Km

IP2_pp/IP4_pp, 1132.8m

4Straights, 849.6m

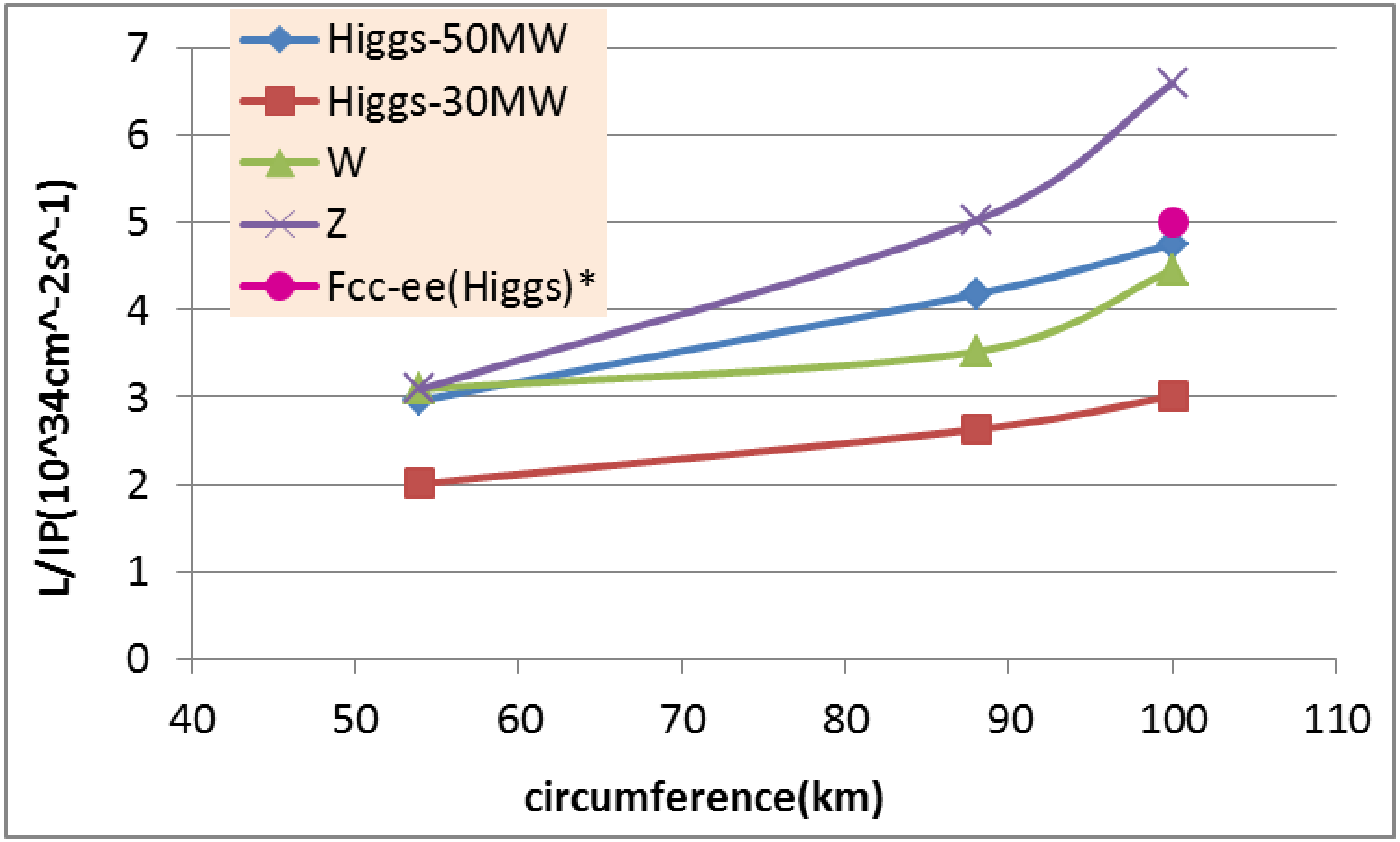
4Long ARC, 120*FODO, 5852.8m

4Short ARC, 100*FODO, 4908.8m

SU Feng

2015.10.12

CEPC PDR Luminosity vs circumference



* Fabiola Gianotti, Future Circular ColliderDesign Study, ICFA meeting, J-PARC, 25-2-2016.

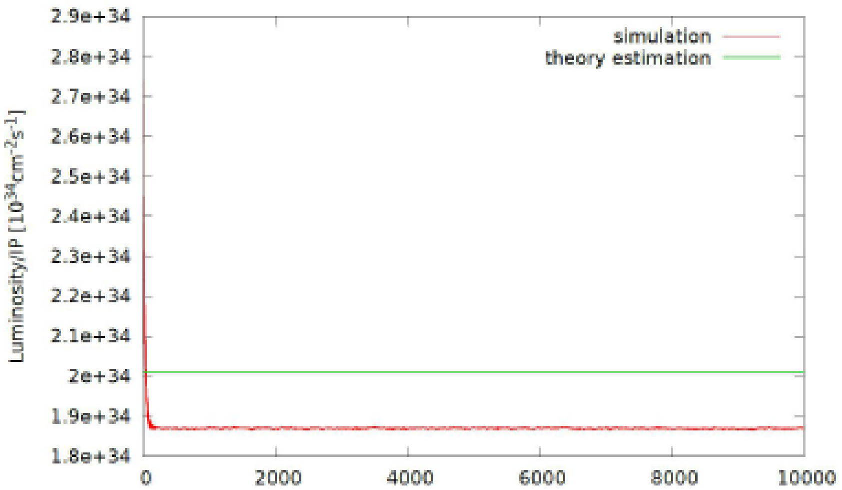
Parameter for CEPC partial double ring

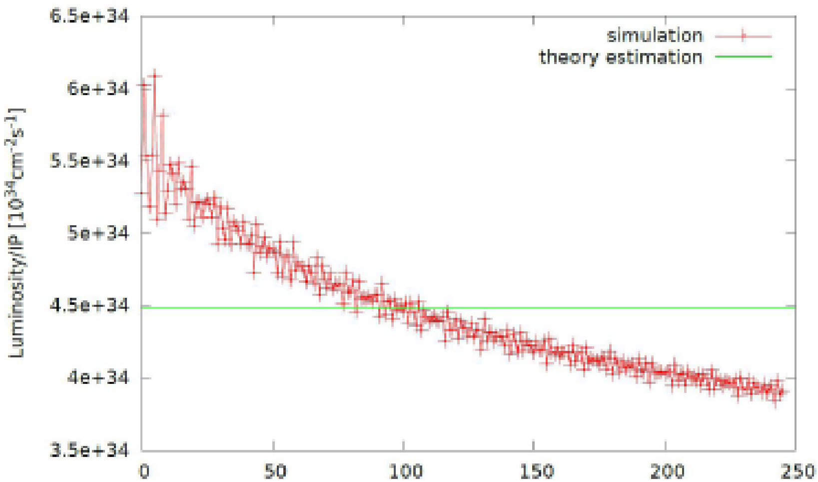
（wangdou20160918）

	Pre-CDR	H-high lumi.	H-low power	W	Z
Number of IPs	2	2	2	2	2
Energy (GeV)	120	120	120	80	45.5
Circumference (km)	54	61	61	61	61
SR loss/turn (GeV)	3.1	2.96	2.96	0.58	0.061
Half crossing angle (mrad)	0	15	15	15	15
Piwinski angle	0	1.88	1.84	5.2	6.4
N_e/bunch (10^{11})	3.79	2.0	1.98	1.16	0.78
Bunch number	50	107	70	400	1100
Beam current (mA)	16.6	16.9	11.0	36.5	67.6
SR power /beam (MW)	51.7	50	32.5	21.3	4.1
Bending radius (km)	6.1	6.2	6.2	6.2	6.2
Momentum compaction (10^{-5})	3.4	1.48	1.48	1.44	2.9
β_{IP} x/y (m)	0.8/0.0012	0.272/0.0013	0.275 /0.0013	0.1/0.001	0.1/0.001
Emittance x/y (nm)	6.12/0.018	2.05/0.0062	2.05 /0.0062	0.93/0.0078	0.88/0.008
Transverse σ_{IP} (um)	69.97/0.15	23.7/0.09	23.7/0.09	9.7/0.088	9.4/0.089
ξ_x/IP	0.118	0.041	0.042	0.013	0.01
ξ_y/IP	0.083	0.11	0.11	0.073	0.072
V_{RF} (GV)	6.87	**3.48**	**3.51**	**0.74**	**0.11**
f_{RF} (MHz)	650	650	650	650	650
Nature σ_z (mm)	2.14	**2.7**	**2.7**	**2.95**	**3.78**
Total σ_z (mm)	2.65	2.95	2.9	3.35	4.0
HOM power/cavity (kw)	3.6	0.74	0.48	0.88	0.99
Energy spread (%)	0.13	0.13	0.13	0.087	0.05
Energy acceptance (%)	2	2	2		
Energy acceptance by RF (%)	6	**2.3**	**2.4**	**1.7**	**1.2**
n_γ	0.23	0.35	0.34	0.49	0.34
Life time due to beamstrahlung_cal (minute)	47	37	37		
F (hour glass)	0.68	0.82	0.82	0.92	0.93
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	3.1	2.01	4.3	4.48

Beam-Beam simulation check of H-low power and Z-pole parameter lists

(Y. Zhang)



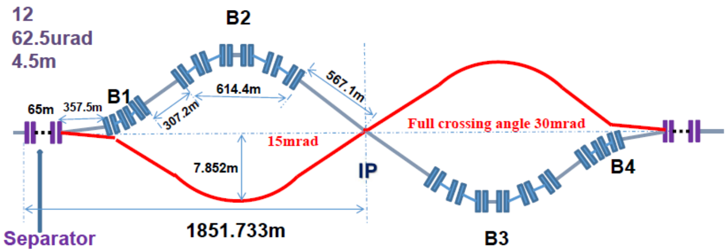


H-low power:
Theory L: 2*10^34/cm^2s
Beam-beam: 1.9*10^34/cm^2s

Z-pole:
Theory L: 4.48*10^34/cm^2s
Beam-beam: 4*10^34/cm^2s

Beam-beam simulation confirmed the H-low power and Z-pole parameter design

CEPC Partial Double Ring Layout

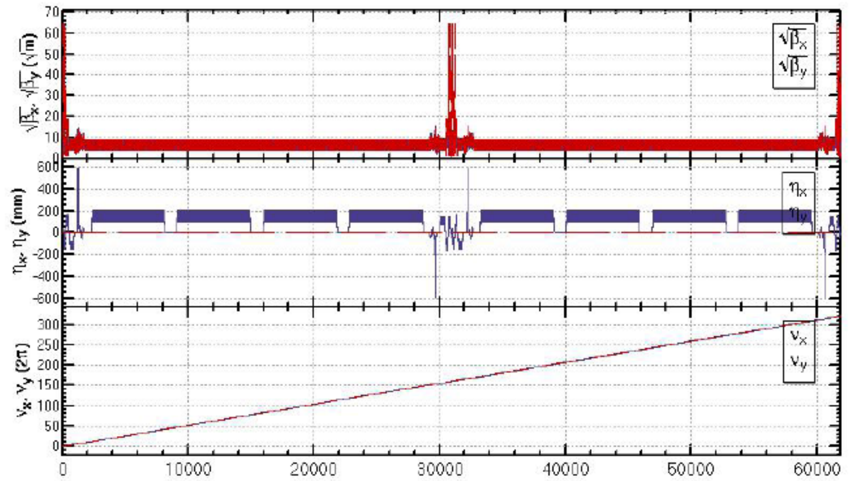


For CEPC 120GeV beam:
➢Max. deflection per separator is 66 μ rad.

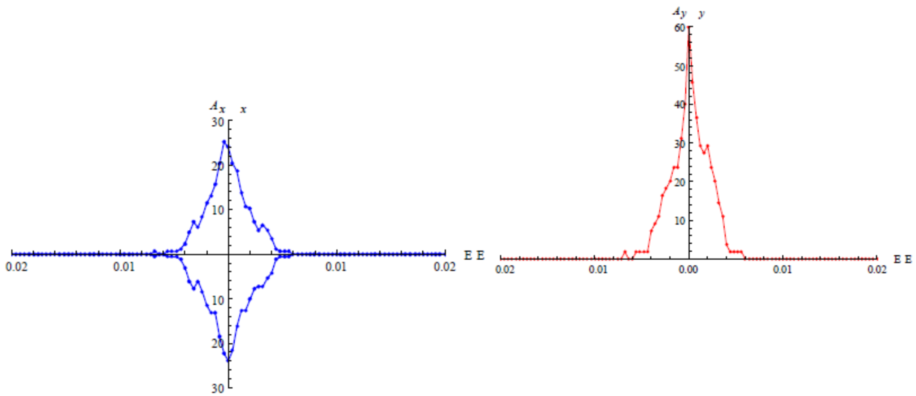
Version 1.0
sufeng
2016.9.15

部分双环方案全环lattice

- A lattice of the whole ring (ARC+PDR+IR) basically fulfilling the design parameters

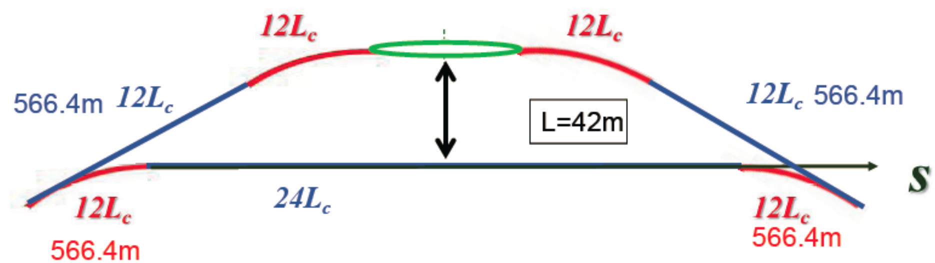


DA of CEPC Advanced Partial Double Ring Optics II



2 Sextupole group results (first try)

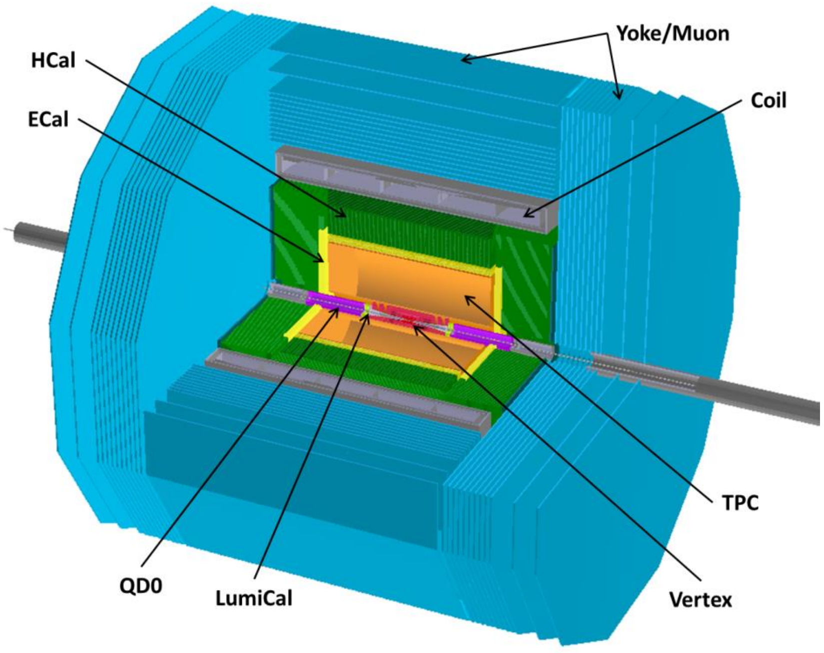
Bypass Part at IP2/4

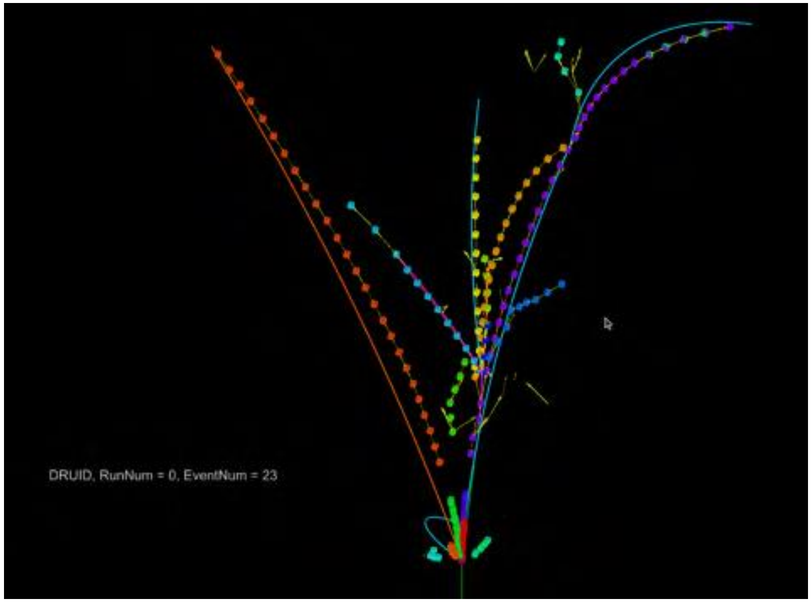


CEPC Detector

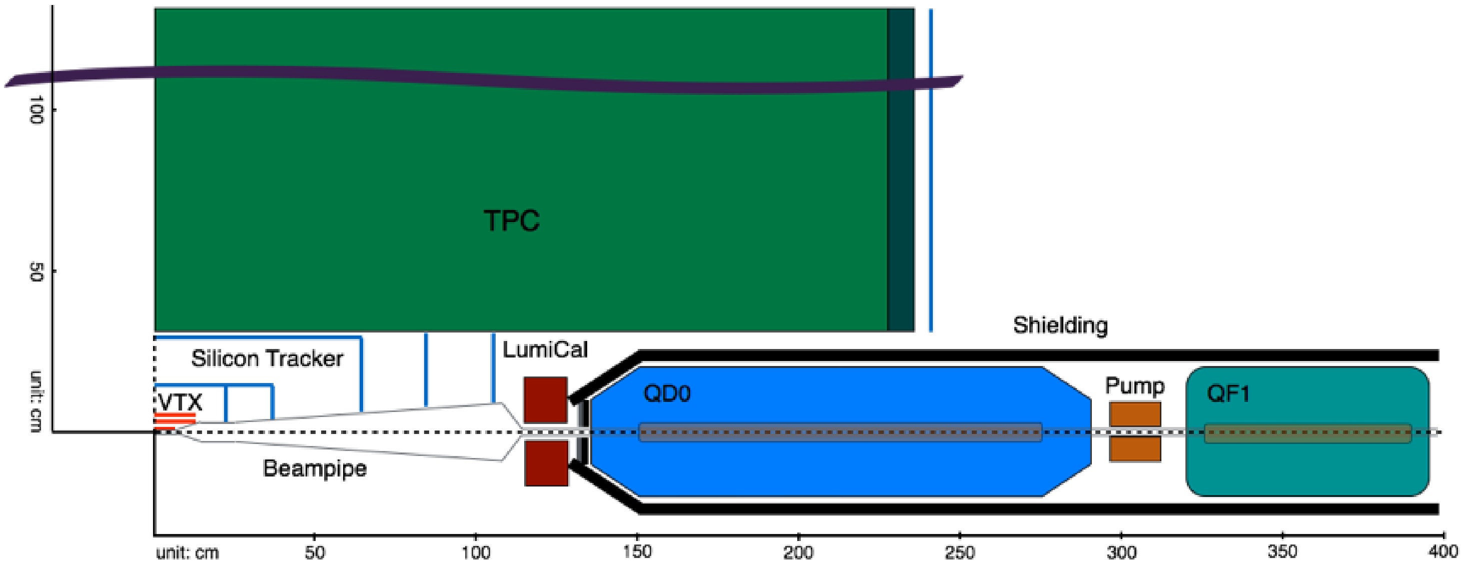
- **Requirements**
  - **Momentum:** $\sigma_{1/p} < 5\times10^{-5}\ \mathrm{GeV^{-1}}$
  - **Vertex:** $\sigma_{r\phi} = 5 \oplus 10/(p\cdot\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$
  - **Energy:** $\frac{\sigma_E}{E} \approx 3-4\%$

- **Key sub-detectors:**
  - **Silicon vertex and tracking**
  - **SC solenoid magnet**
  - **Gaseous tracking**
  - **Calorimeters**
  - **Electronics, trigger & DAQ**



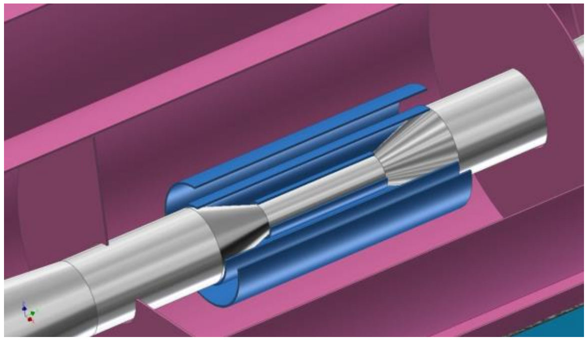


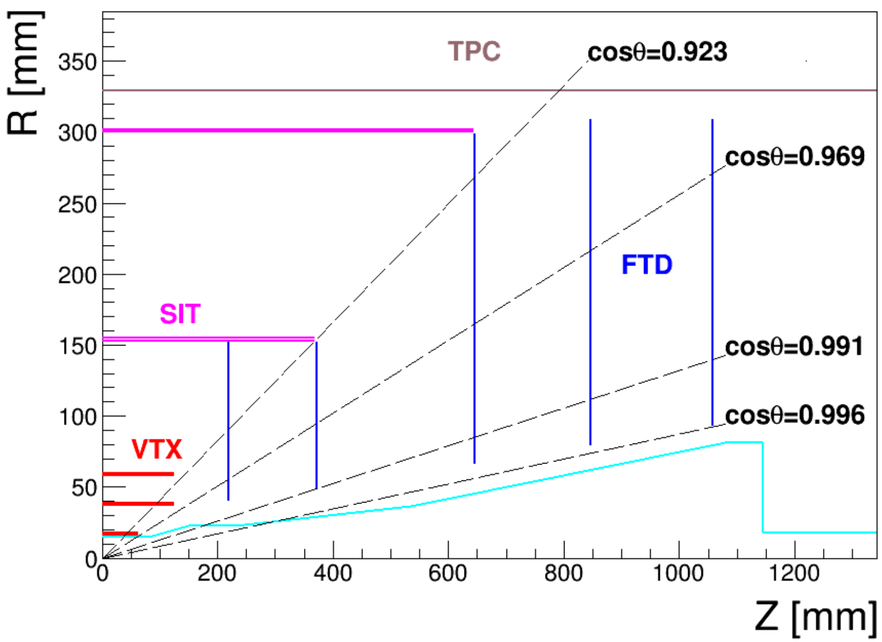
Interaction region layout



- Short focal length of L* = 1.5 m (cf. ~3.5m at ILC)
- Final focusing magnets inside the detector →→ constraints on the detector design + QD0/QF1 design
  - No. of FTD's reduced to 5 (cf. 7 for ILD)
  - redesign of offline/online luminosity instrumentation
  - design of QD0/QF1

Vertex Detector and Silicon Trackers





Vertex detector:

- 3 cylindrical and concentric double-layers of pixels

Silicon Internal Tracker (SIT)

- 2 inner layers Si strip detectors

Forward Tracking Detector (FTD)

- 5 disks (2 with pixels and 3 with Si strip sensor) on each side

Silicon External Tracker (SET)

- 1 outer layer Si strip detector

End-cap Tracking Detector (ETD)

- 1 end-cap Si strip detector on each side

Key Issues and R&D items

- Accelerator & Detector design
  - Beam physics: dynamic aperture, momentum acceptance, electron cloud, …
- Site selection, civil design
- Key technology development
  - High Q_0 SRF cavities and high efficiency thermal power removing SRF accelerating unit
  - High efficiency RF power sources(Klystron, solid state, …)
  - High power Cryogenic system
  - Beam monitor and diagnostics
  - Silicon detectors
  - High field SC magnets

SRF System: three key issues

- Extremely high Q_0 cavities
  - New technology: N-doping to improve Q_0 by a factor ~ 4
- Efficient thermal power extraction
  - SR power
  - HOM power
- Mass production

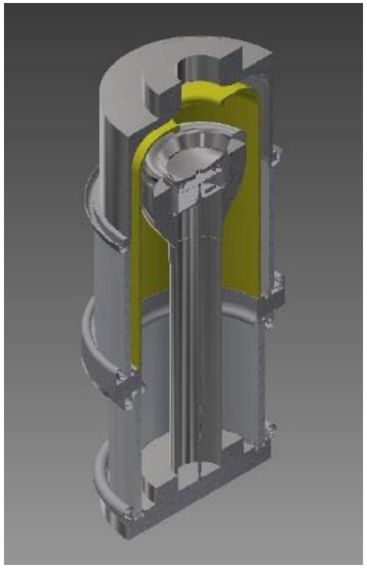
> ➢ **Largest SRF system next to ILC**
> ➢ **Technically challenge**
> ➢ **Useful for all future accelerators**
> ➢ **Key factor for the cost**

RF power source: Efficiency

Key parameters of NEW klystron design

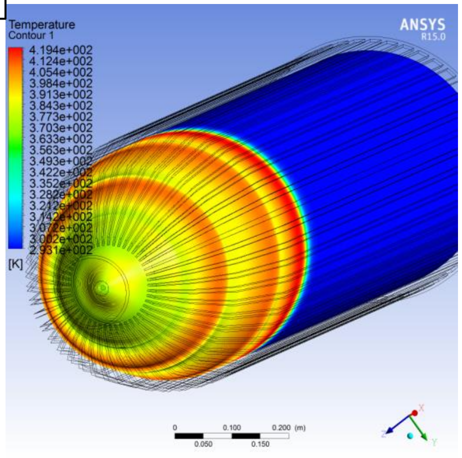
Parameters mode	Now	Future
Centre frequency (MHz)	650+/-0.5	650+/-0.5
Output power (kW)	**800**	**800**
Beam voltage (kV)	80	70
Beam current (A)	16	15
Efficiency (%)	**65**	**80**

- **Key factor for the cost and the power**
- **Useful for radar, communication tech., …**



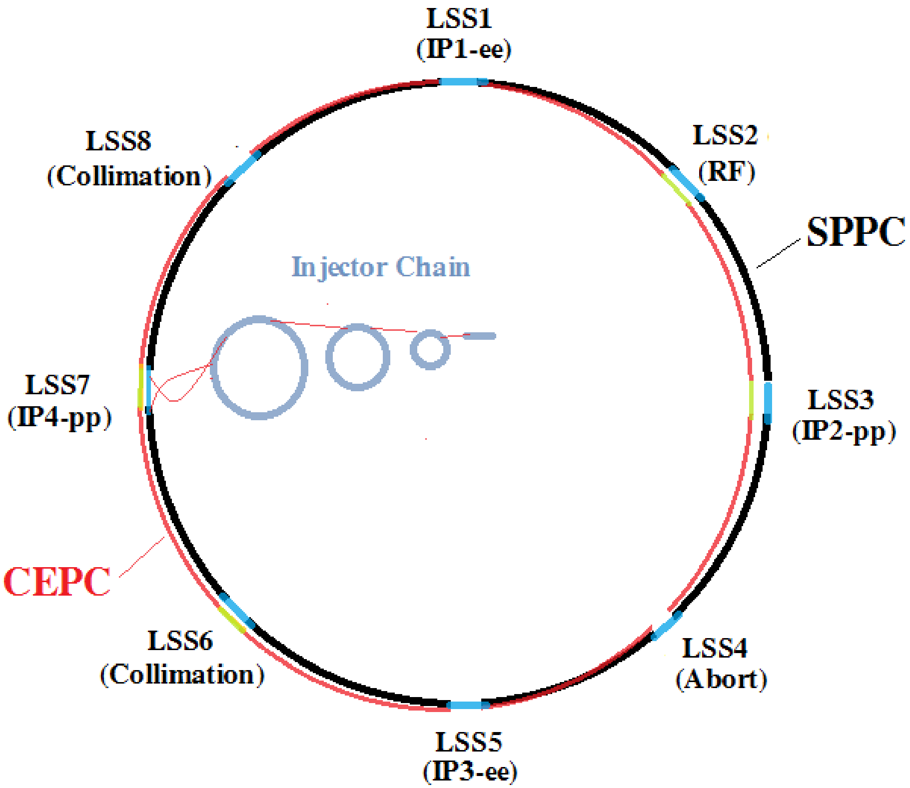
Gun assembly

Collaboration with industries



Collector design

Conceptual Design of SppC



- 8 arcs (5.9 km) and long straight sections (850m*4+1038.4m*4)

Parameter	Value
Circumference	54.36 km
Beam energy	35.3 TeV
Dipole field	20 T
Injection energy	2.1 TeV
Number of IPs	2 (4)
Peak luminosity per IP	**1.2E+35 $cm^{-2}s^{-1}$**
Beta function at collision	0.75 m
Circulating beam current	1.0 A
Max beam-beam tune shift per IP	0.006
Bunch separation	25 ns
Bunch population	2.0E+11
SR heat load @arc dipole (per aperture)	56.9 W/m

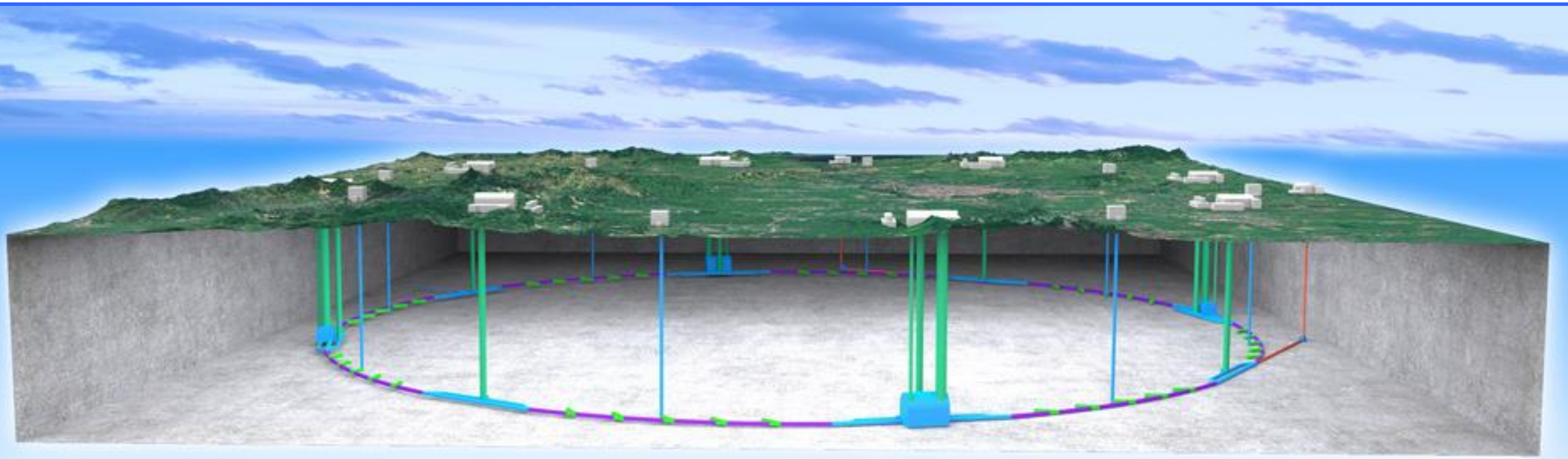
Conditions for SPPC Construction

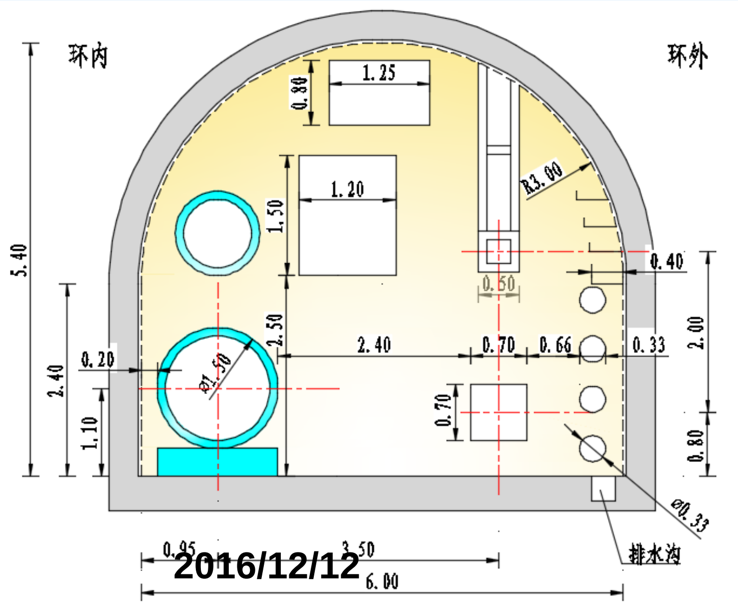
- CEPC results ➔ indication of new physics
- Maturity of superconducting cable technology
  - Current density: $\times$ 10
  - Cost/m: $\div$10

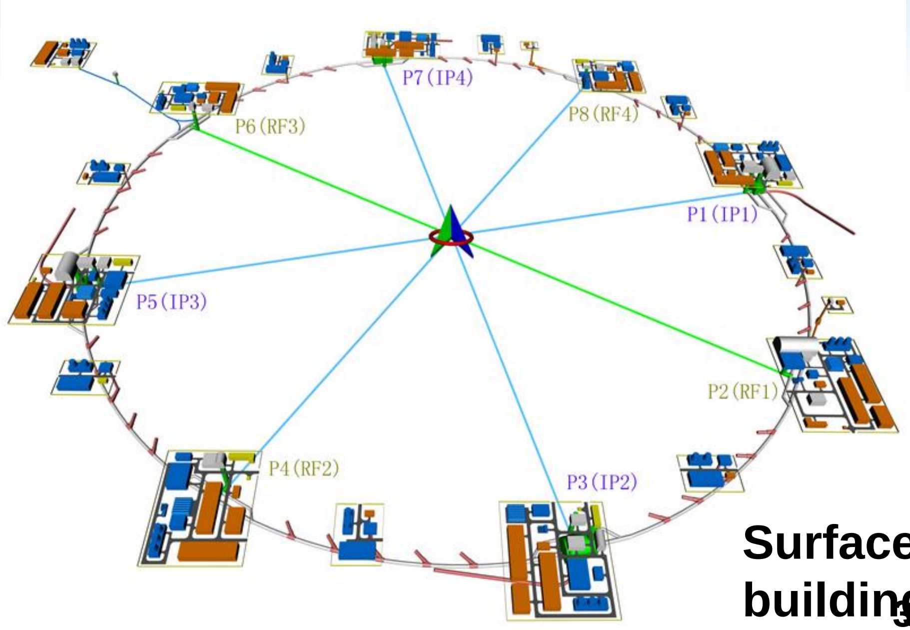
  } ~ 3-5 $ /kA·m

- **A collaboration on "HTC SC materials" : Institute of Physics, USTC, Institute of electric engineering, IHEP, companies**
  - Iron based HTC cables
  - ReBCO & Bi-2212

Civil Construction



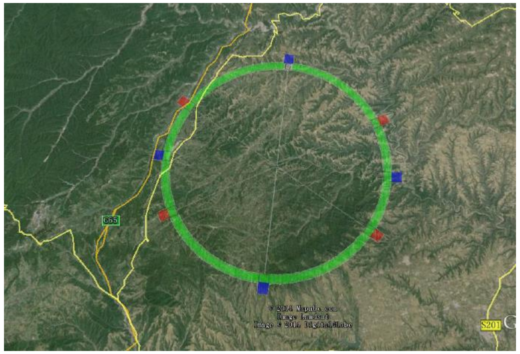




Surface buildings

Site selections (a few main candidates)

1)



2)

3)

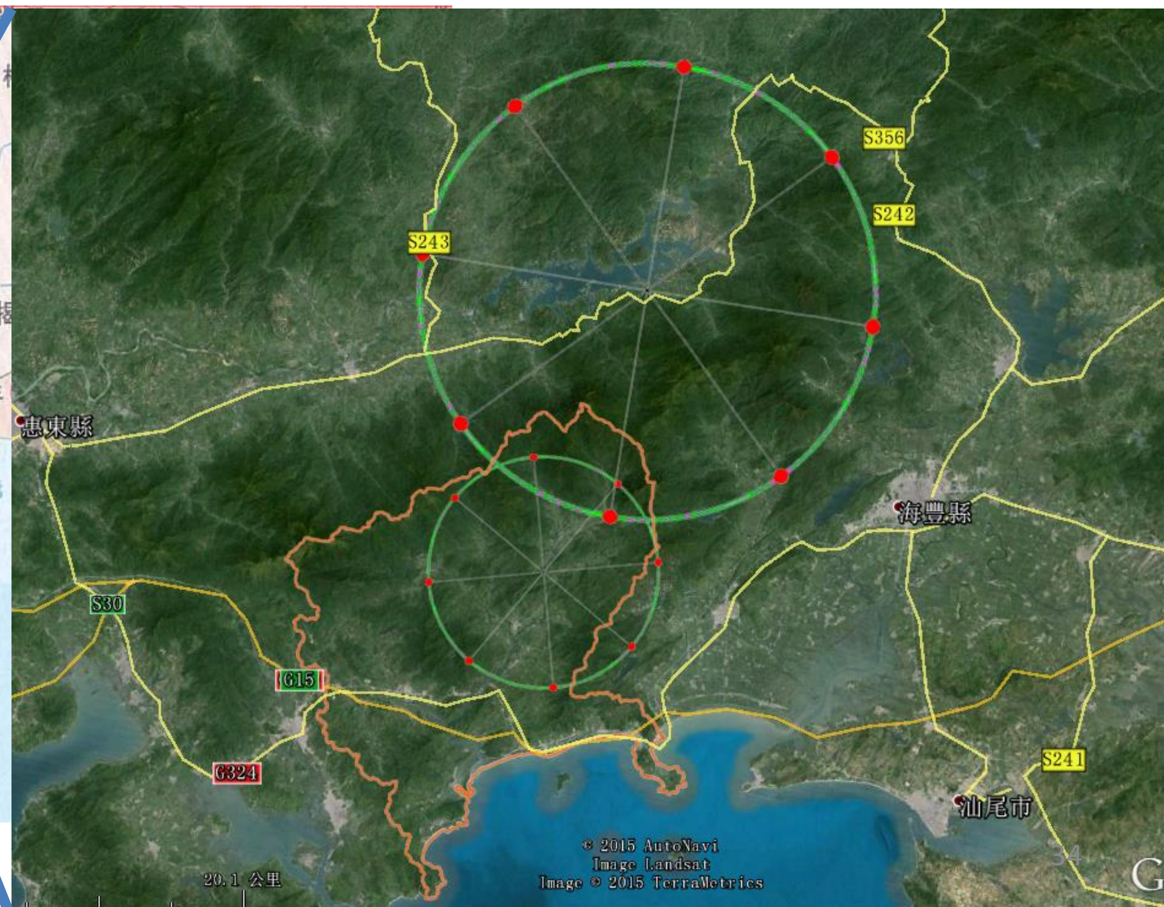
1) Qinhuangdao

2) Shanxi Province

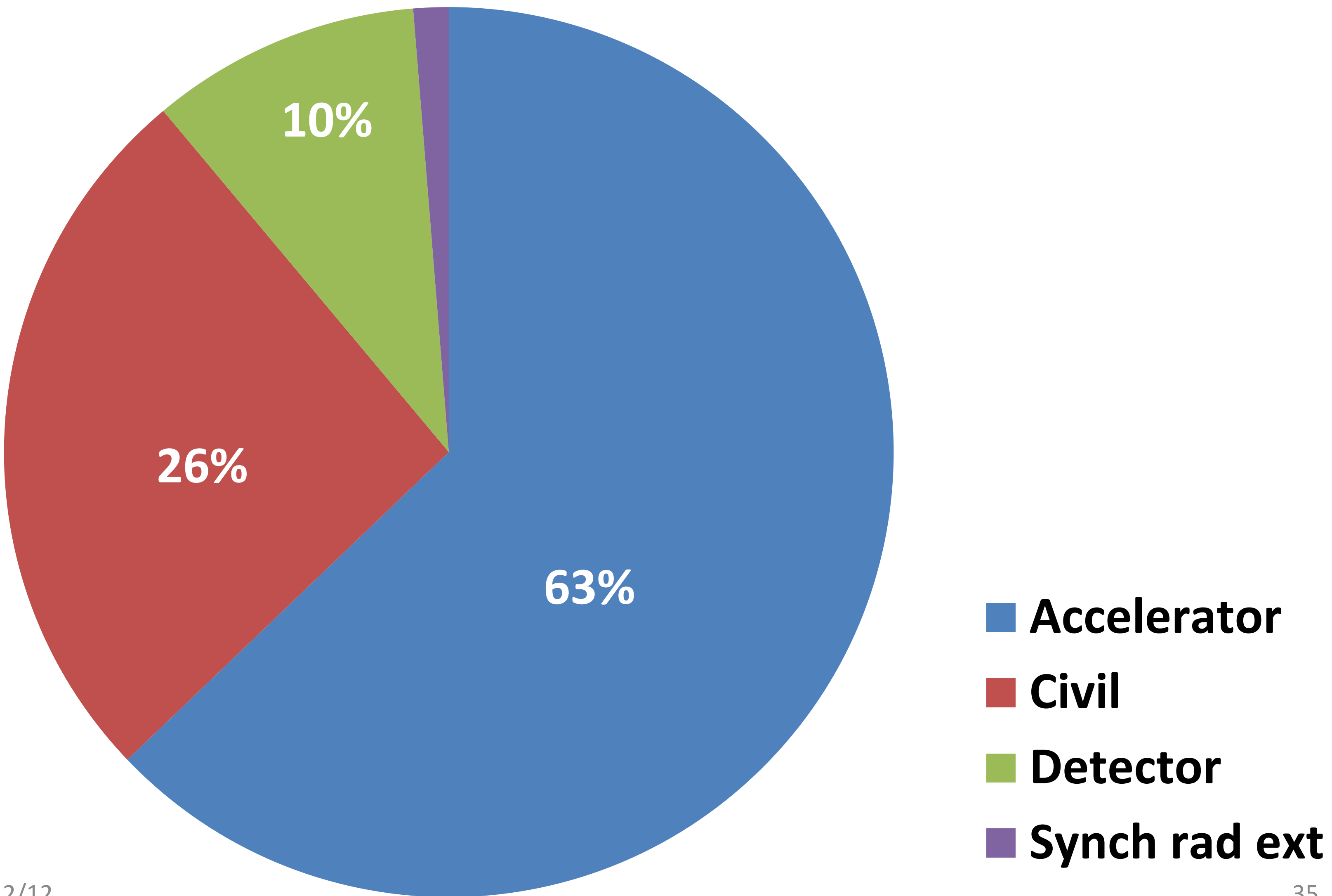
3) Near Shenzhen and Hongkong

Site Selection

- Continue to work on site selection
- Previously investigated: 300 km north-east of Beijing
- A new possibility close to Hong Kong, invited by the local government



Total Cost Breakout



Current Status and the Plan

- **Pre-CDR completed**
  - No show-stoppers
  - Technical challenges identified → R&D issues
  - Preliminary cost estimate
- **Working towards CDR**
  - A working machine on paper
  - Ready to be reviewed by government at any moment
- **R&D issues identified and funding request underway**
  - Seed money from IHEP: 12 M RMB/3 years
  - MOST: 36 M/5 yr approved, ~40 M to be asked next year
  - NCDR: ~0.8 B RMB/5 yr, failed in a voting process
  - CAS & CNSF: under discussion, hopefully ~ 50M/y

Timeline (dream)

- **CPEC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15
      - **Pre-CDR for R&D funding request**
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2028-2035
- **SppC**
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2035-2042
  - Data taking: 2042 -

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 is formed to discuss in particular this issue, together with others**

AsiaHEP/ACFA Statement on ILC + CEPC/SPPC

AsiaHEP and ACFA reassert their strong endorsement of the ILC, which is in a mature state of technical development. The aim of ILC is to explore physics beyond the Standard Model by unprecedented precision measurements of the Higgs boson and top quark, as well as searching for new particles which are difficult to discover at LHC. The Higgs studies at higher energies are especially important for measurement of WW fusion process, to fix the full Higgs decay width, and to measure the Higgs self-coupling. In continuation of decades of world-wide coordination, we encourage redoubled international efforts at this critical time to make the ILC a reality in Japan. 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.

Summary

- CEPC is the first Chinese effort for a Science project at such a scale ➔ Challenges every where.
- Tremendous progresses up to now, but a long way to go
- Given the importance of Higgs, we hope that at least one of them, FCC-ee, ILC, or CEPC, can be realized.

We fully support a global effort, even if it is not built in China