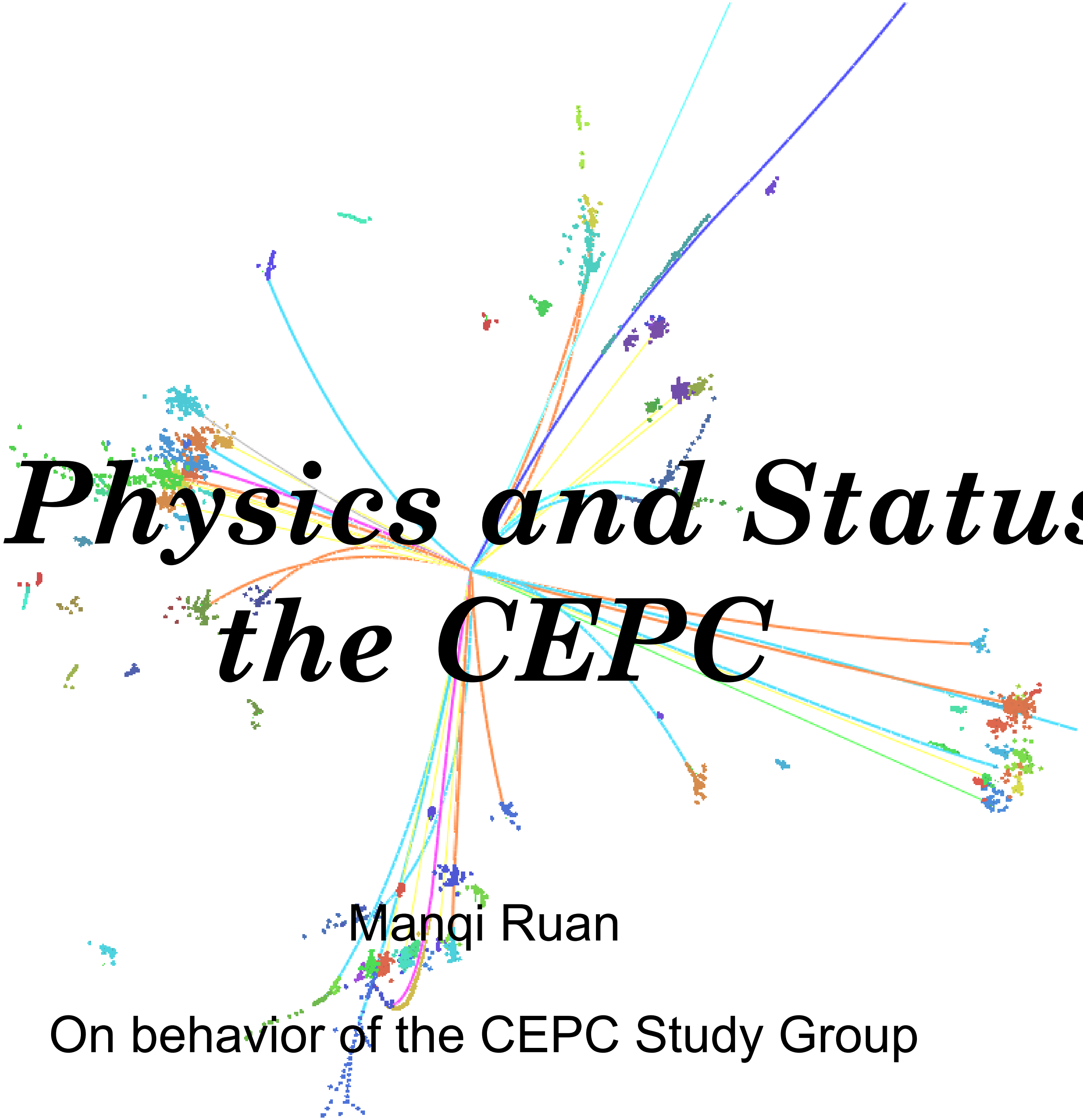
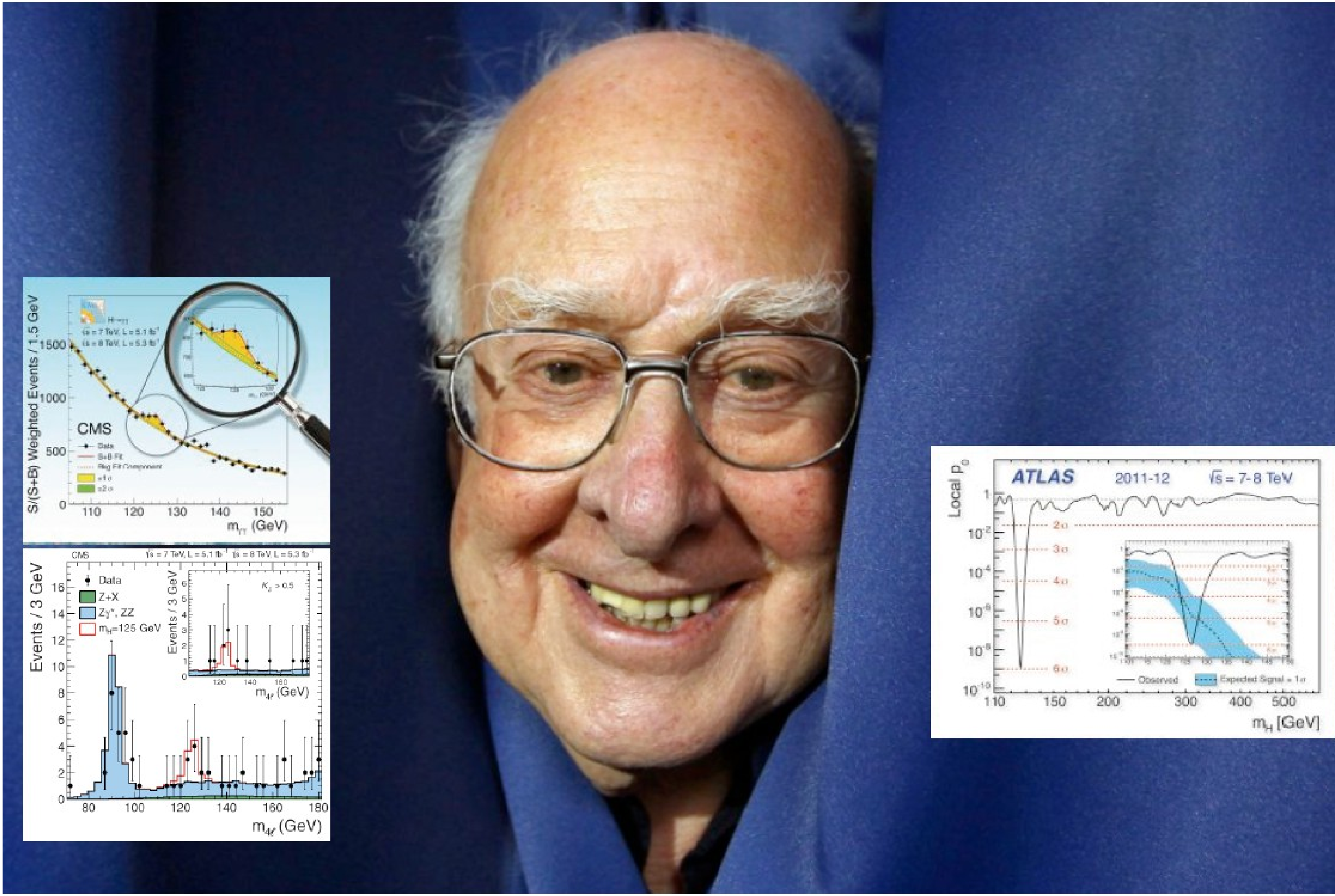


The Physics and Status of the CEPC

Manqi Ruan

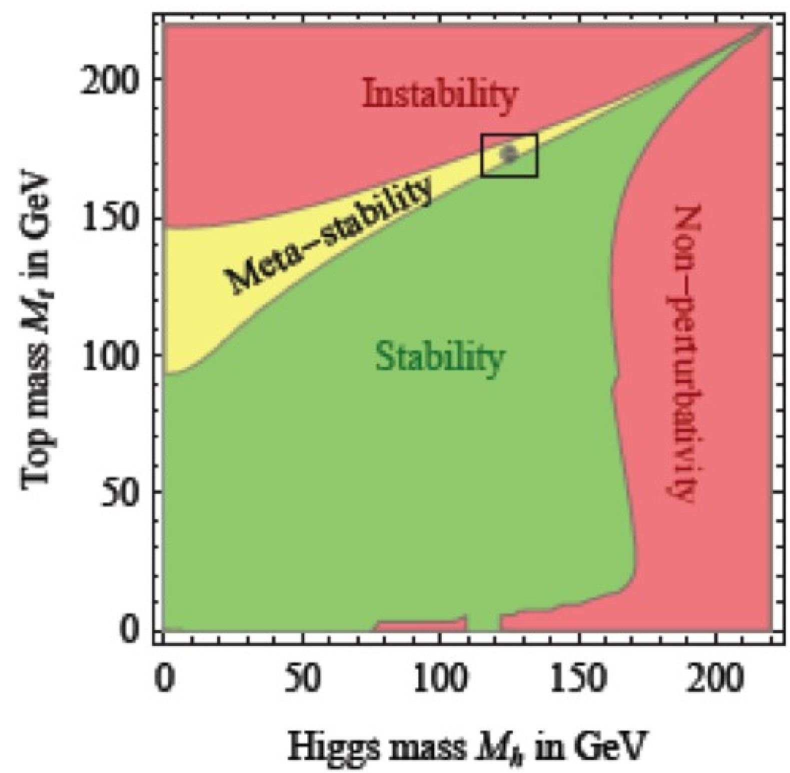
On behalf of the CEPC Study Group


CMS
S/(S+B) Weighted Events / 1.5 GeV
Data
S+B Fit
m_γγ (GeV)
Events / 3 GeV
Data
Z+X
Zγ*, ZZ
m_H=125 GeV
m_4ℓ (GeV)
ATLAS
2011-12
√s = 7-8 TeV
Local p_0
Observed
m_H [GeV]

SM is **NOT** the end of story...

- Hierarchy: From neutrinos to the top mass, masses differs by 13 orders of magnitude
- Naturalness: Fine tuning of the Higgs mass
- Masses of Higgs and top quark: meta-stable of the vacuum
- Unification?
- Dark matter candidate?
- Not sufficient CP Violation for Matter & Antimatter asymmetry

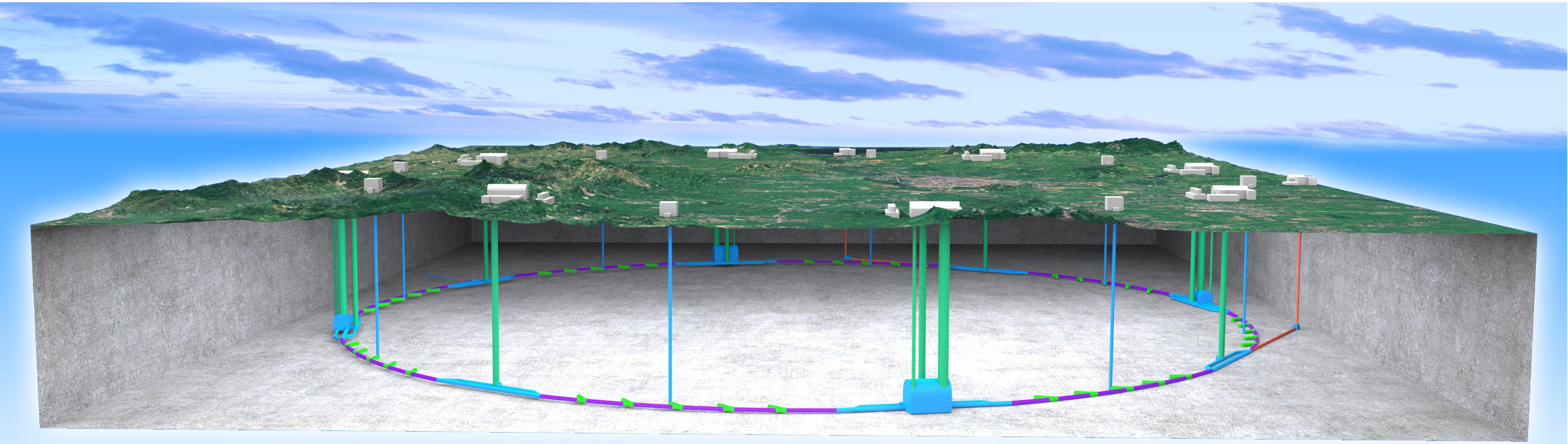
$$m_H^2 = 36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}933{,}023$$
$$-36{,}127{,}890{,}984{,}789{,}307{,}394{,}520{,}932{,}878{,}928{,}917{,}398$$
$$= (125\ \mathrm{GeV})^2\ !\ ?$$



- **Most issues related to Higgs**

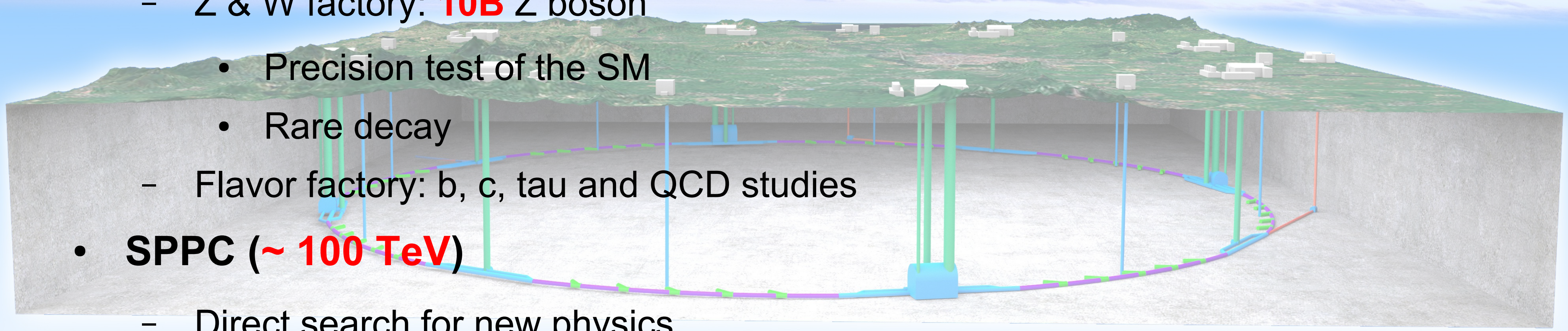
Key: a precise Higgs factory

- Higgs mass ~ 125 GeV, it is possible to build a Circular e+e- Higgs factory (CEPC), followed by a proton collider (SPPC) in the same tunnel
- Looking for Hints (from Higgs) at CEPC → direct search at SPPC



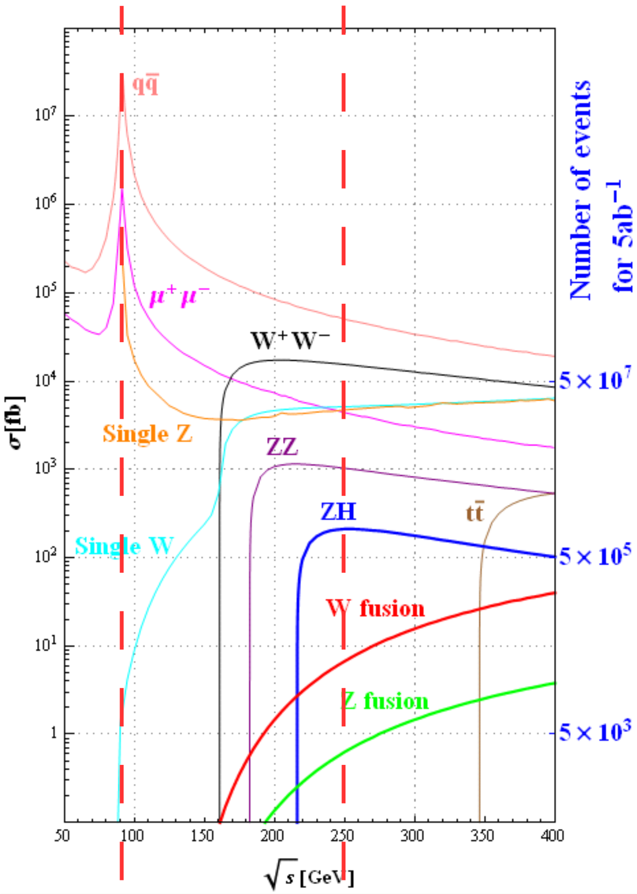
Science at CEPC-SPPC

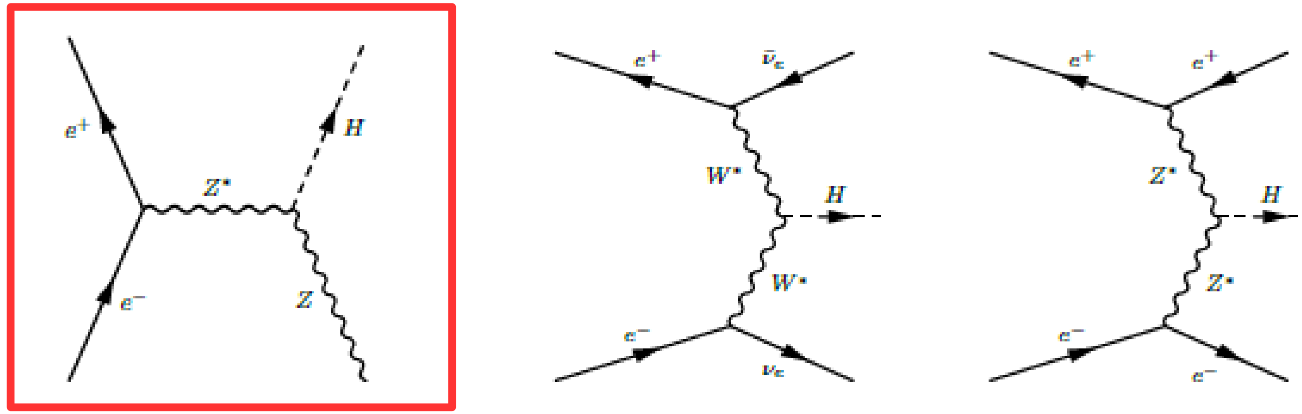
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **10B** Z boson
    - Precision test of the SM
    - Rare decay
  - Flavor factory: b, c, tau and QCD studies
- **SPPC (~ 100 TeV)**
  - Direct search for new physics
  - Complementary Higgs measurements to CEPC g(HHH), g(Htt)
  - ...
- **Heavy ion, e-p collision...**



Complementary

Higgs @ CEPC





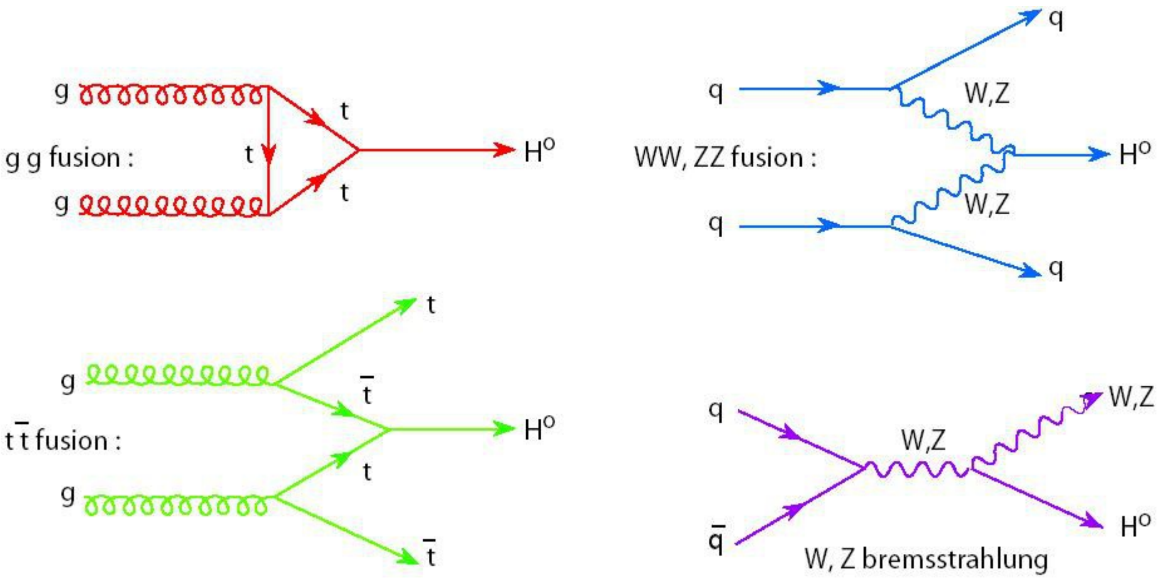
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

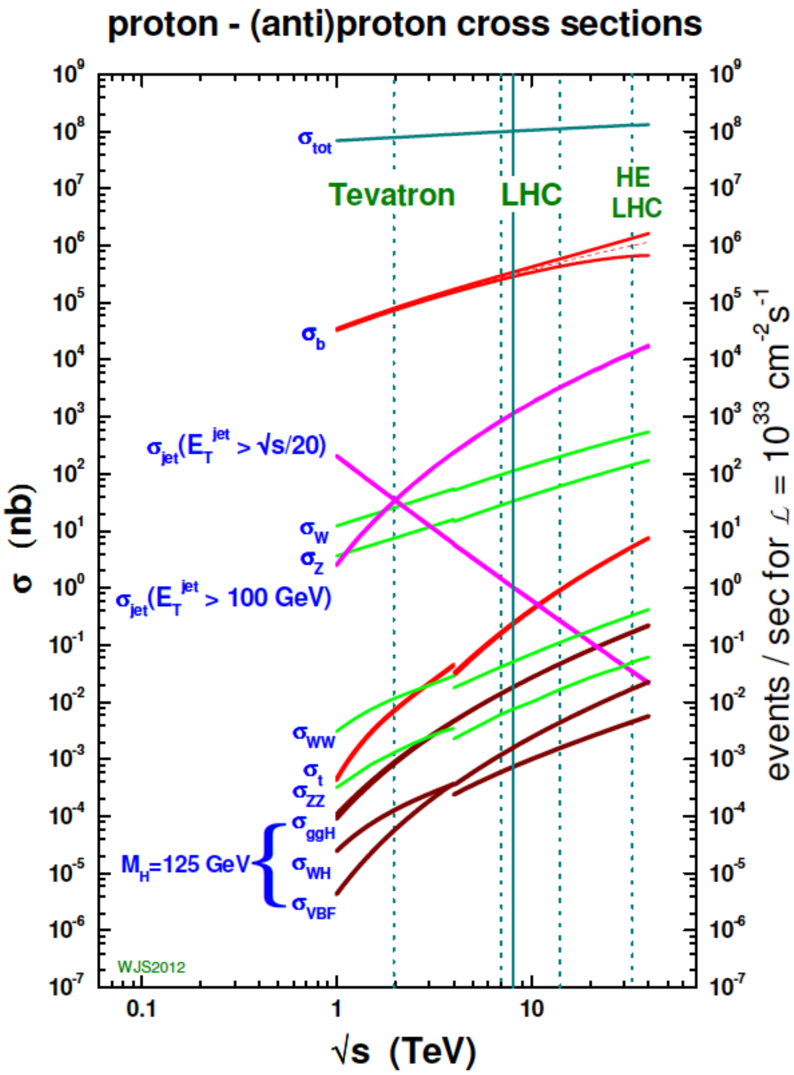
S/B ~ 1:100 - 1000

Observables: Higgs mass, CP, σ(ZH), event rates (σ(ZH, vvH)*Br(H→X)), Diff. distributions

Derive: Absolute Higgs width, branching ratios, couplings

Higgs @ LHC

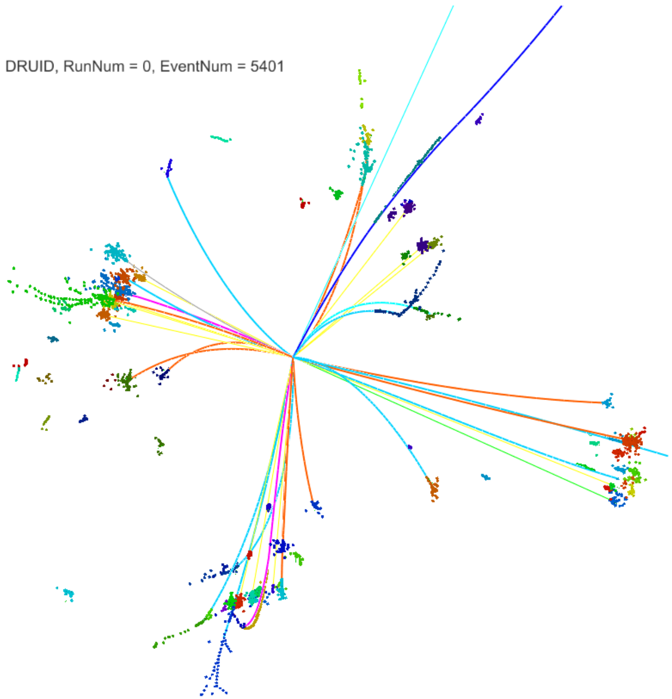


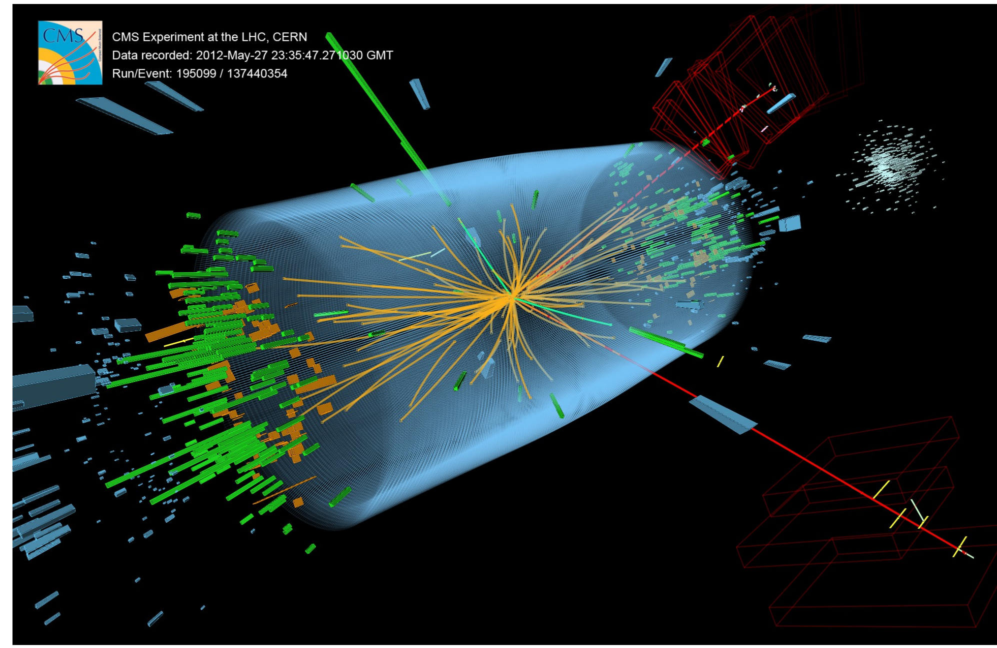


S/B ~ 1:1E10 !!!

$$\sigma(AA \rightarrow H \rightarrow BB) \sim g^2(HAA)g^2(HBB)/\Gamma_{total}$$

Higgs measurement at e+e- & pp





	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: 10^{7-8}	~o(10^{-3})	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	~o(1)	Clean environment & Absolute measurement, Percentage level accuracy of Higgs width & Couplings

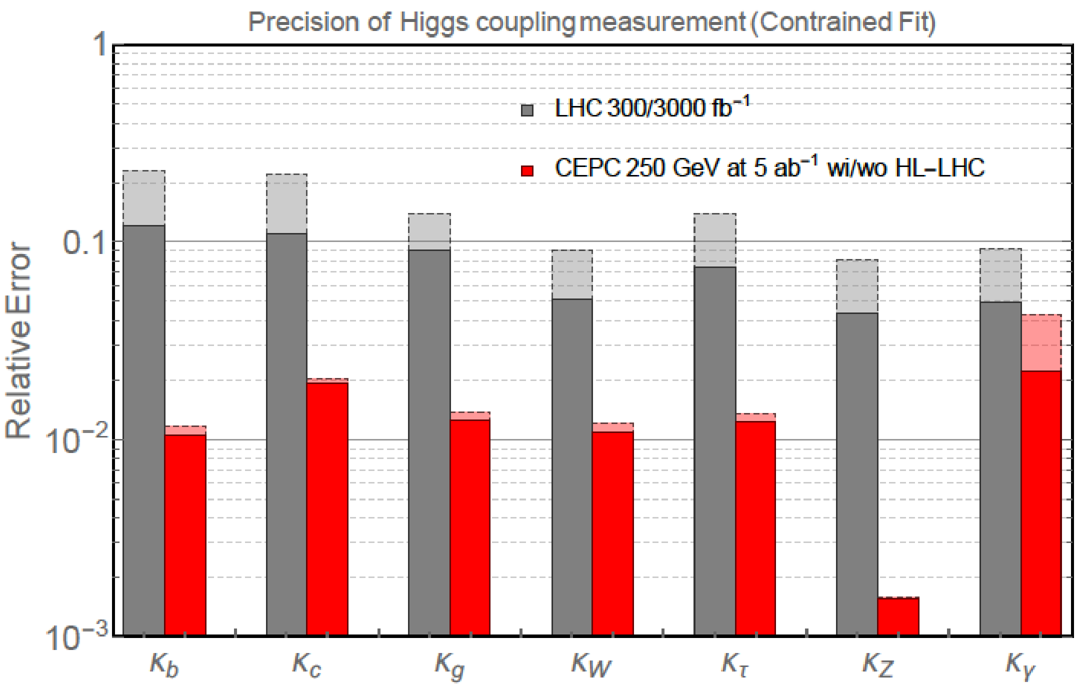
Complementary

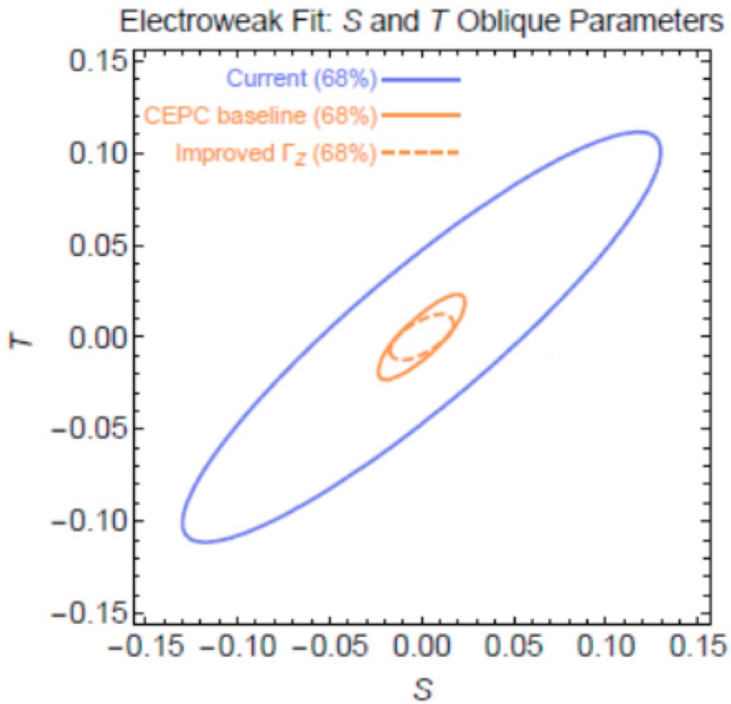
Status of W/Z physics study in CEPC

- The prospect of W/Z physics study in CEPC are under study
- Mainly based on projection from LEP

Observable	LEP precision	CEPC precision	CEPC runs	$\int \mathcal{L}$ needed in CEPC
m_Z	2 MeV	0.5 MeV	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,b}$	1.7%	0.1%	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,\mu}$	7.7%	0.3%	Z threshold scan	3.2ab^{-1}
$A_{FB}^{0,e}$	17%	0.5%	Z threshold scan	3.2ab^{-1}
R_b	0.3%	0.02%	Z pole	3.2ab^{-1}
R_μ	0.2%	0.01%	Z pole	3.2ab^{-1}
N_ν	1.7%	0.05%	ZH runs	5ab^{-1}
m_W	33 MeV	2-3 MeV	ZH runs	5ab^{-1}
m_W	33 MeV	1 MeV	WW threshold	2.5ab^{-1}

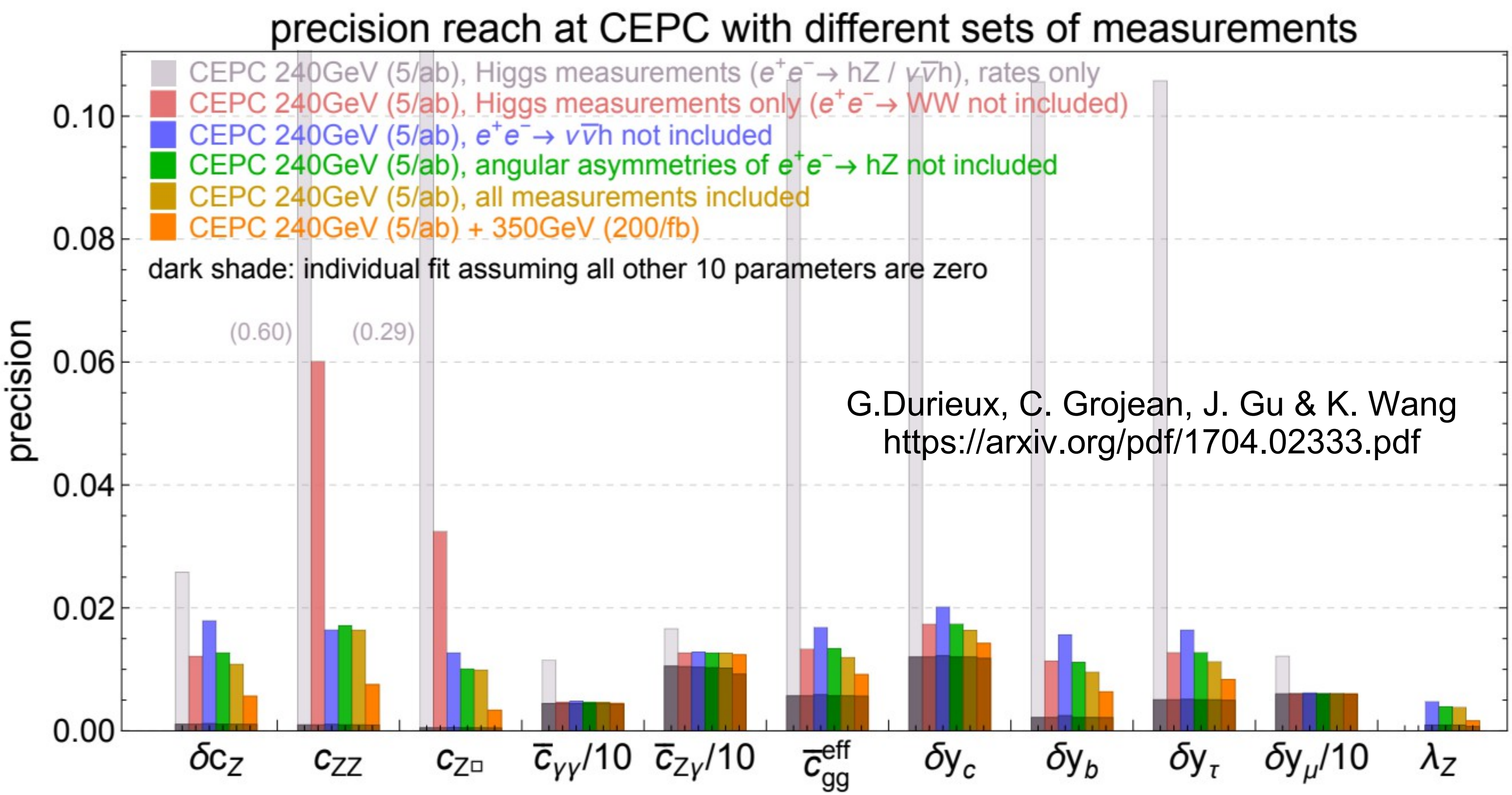
Physics Potential





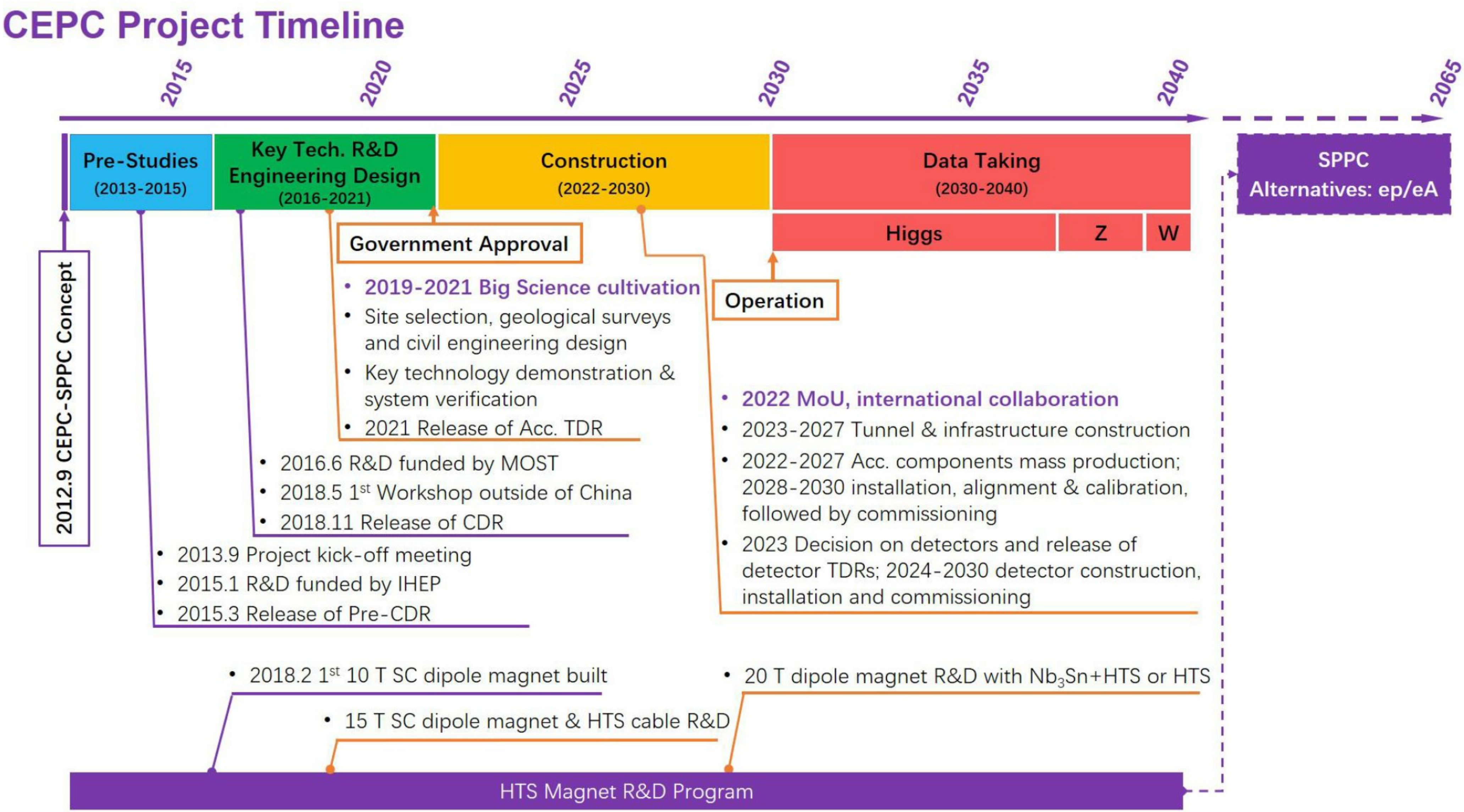
- The nature of Higgs boson & EWSB, + flavor physics...
  - Higgs signal strengths (In kappa framework): expected accuracy roughly 1 order of magnitude better than HL-LHC
  - Absolute measurement to the Higgs boson: 2-3% level accuracy of Higgs boson width, 10^{-3} - 10^{-5} up limit to Higgs invisible/exotic decay modes (improved by at least 2 orders of magnitude comparing to HL-LHC)
  - Improve EW measurement precision by at least 1 order of magnitude

Pheno-studies: EFT & Physics reach

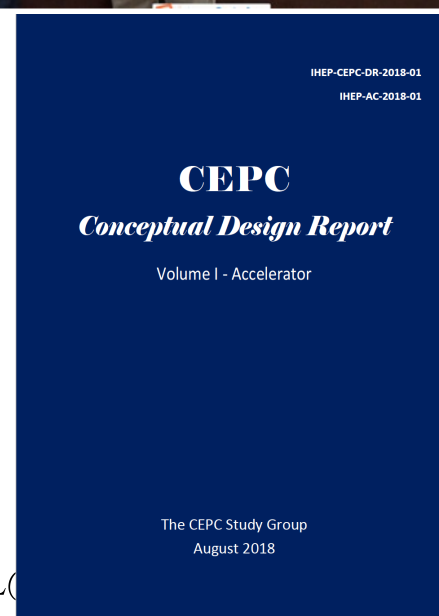


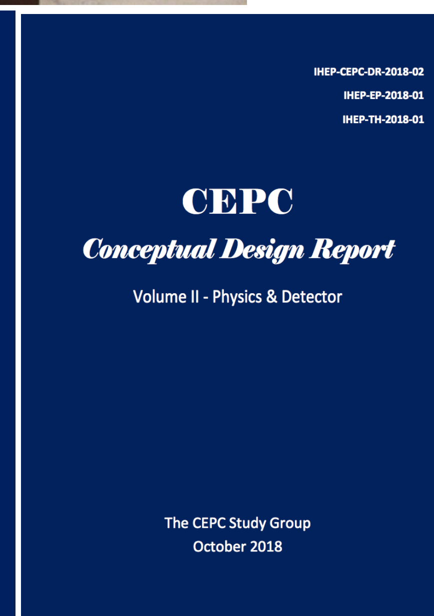
The Physics reach could be largely enhanced if the EW measurements is combined
With the Higgs measurements (in the EFT)

Timeline

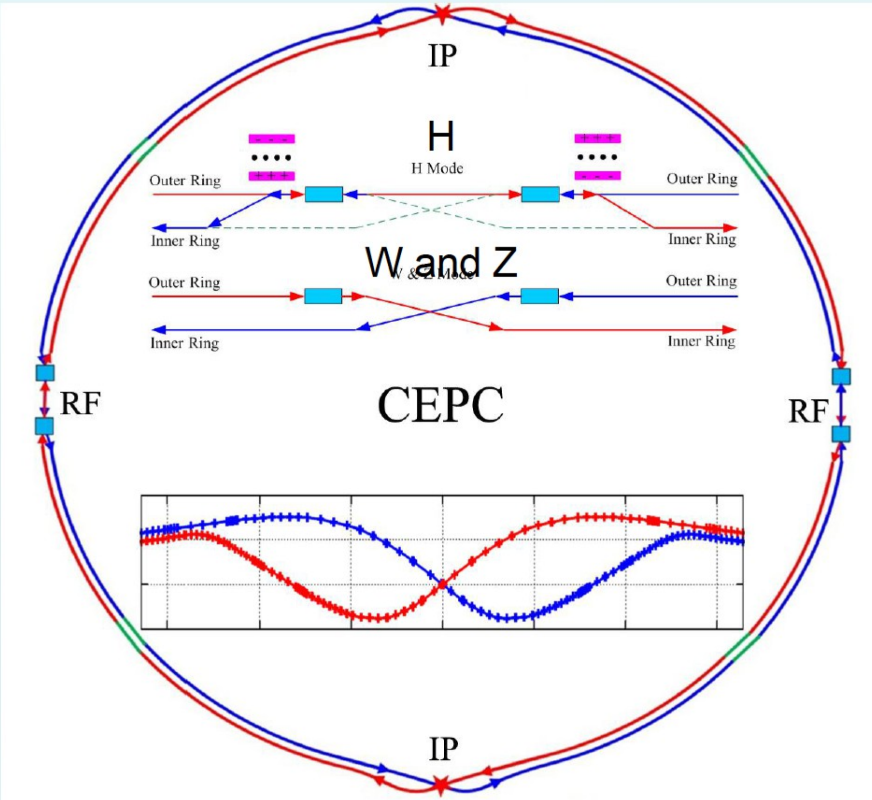

CEPC Project Timeline
2015
2020
2025
2030
2035
2040
2065
Pre-Studies
(2013-2015)
Key Tech. R&D
Engineering Design
(2016-2021)
Construction
(2022-2030)
Data Taking
(2030-2040)
Higgs
Z
W
SPPC
Alternatives: ep/eA
2012.9 CEPC-SPPC Concept
Government Approval
• 2019-2021 Big Science cultivation
• Site selection, geological surveys and civil engineering design
• Key technology demonstration & system verification
• 2021 Release of Acc. TDR
Operation
• 2022 MoU, international collaboration
• 2023-2027 Tunnel & infrastructure construction
• 2022-2027 Acc. components mass production; 2028-2030 installation, alignment & calibration, followed by commissioning
• 2023 Decision on detectors and release of detector TDRs; 2024-2030 detector construction, installation and commissioning
• 2016.6 R&D funded by MOST
• 2018.5 1st Workshop outside of China
• 2018.11 Release of CDR
• 2013.9 Project kick-off meeting
• 2015.1 R&D funded by IHEP
• 2015.3 Release of Pre-CDR
• 2018.2 1st 10 T SC dipole magnet built
• 20 T dipole magnet R&D with Nb3Sn+HTS or HTS
• 15 T SC dipole magnet & HTS cable R&D
HTS Magnet R&D Program

CDR released in Nov. 2018

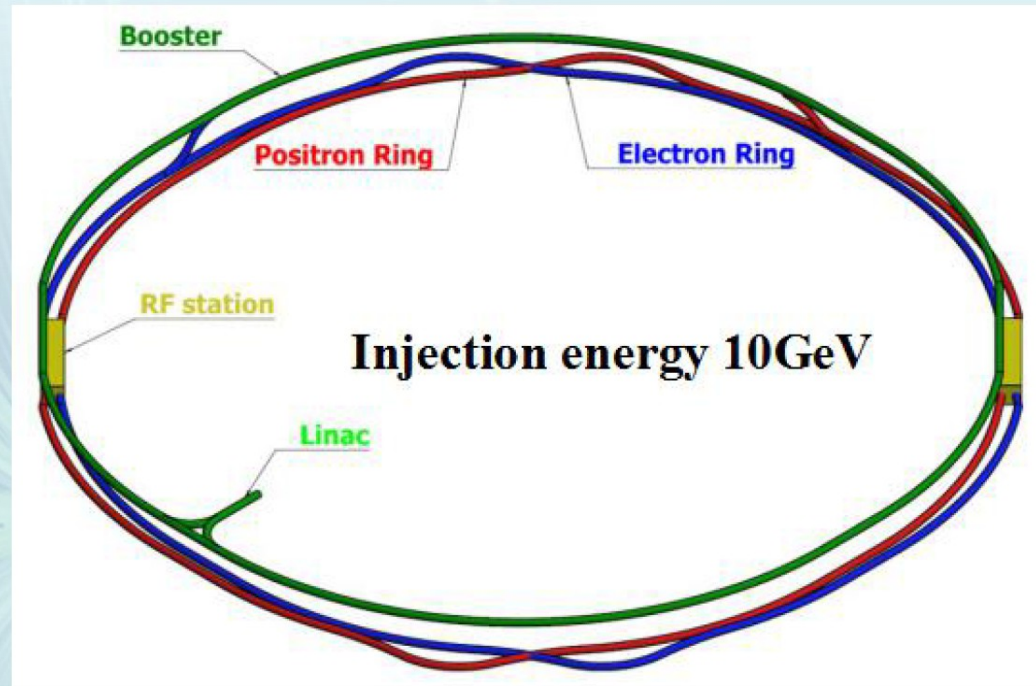




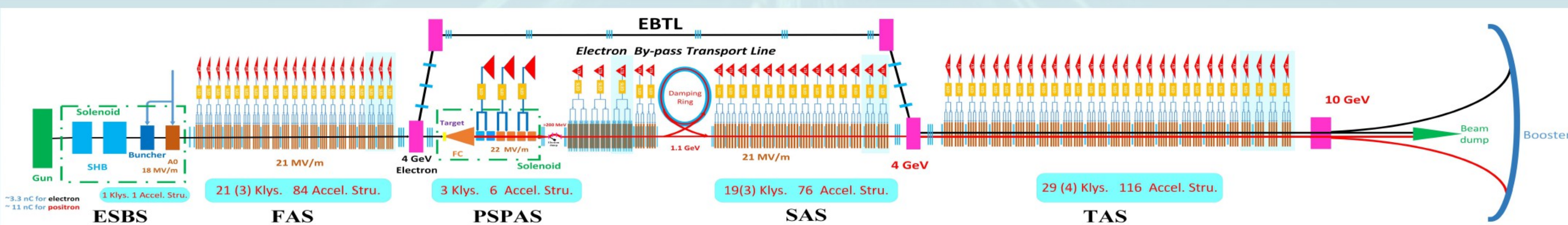
CEPC Accelerator Baseline Layout



CEPC collider ring (100km)



CEPC booster ring (100km)



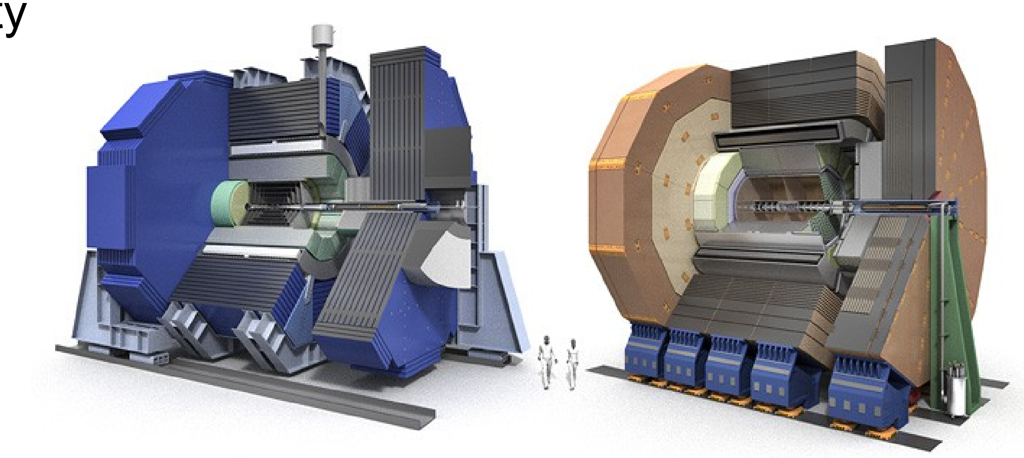
CEPC CDR Parameters

D. Wang

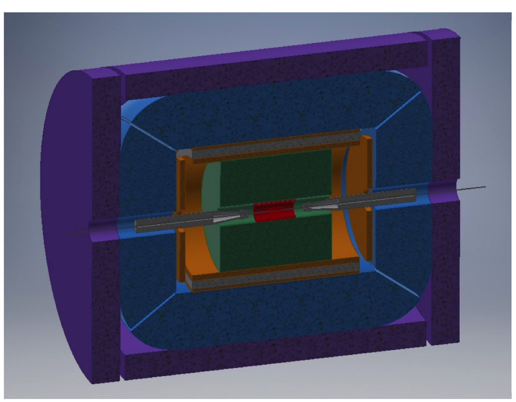
	Higgs	*W*	*Z* （*3T*）	*Z* （*2T*）
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
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 σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_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 σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
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)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP L ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

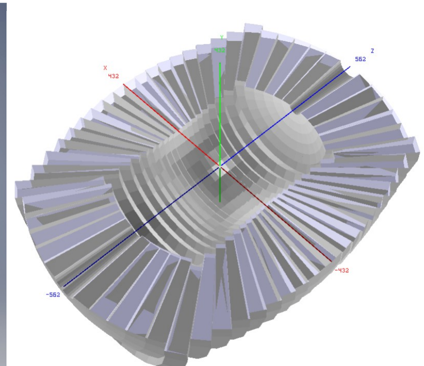
Two classes of Concepts

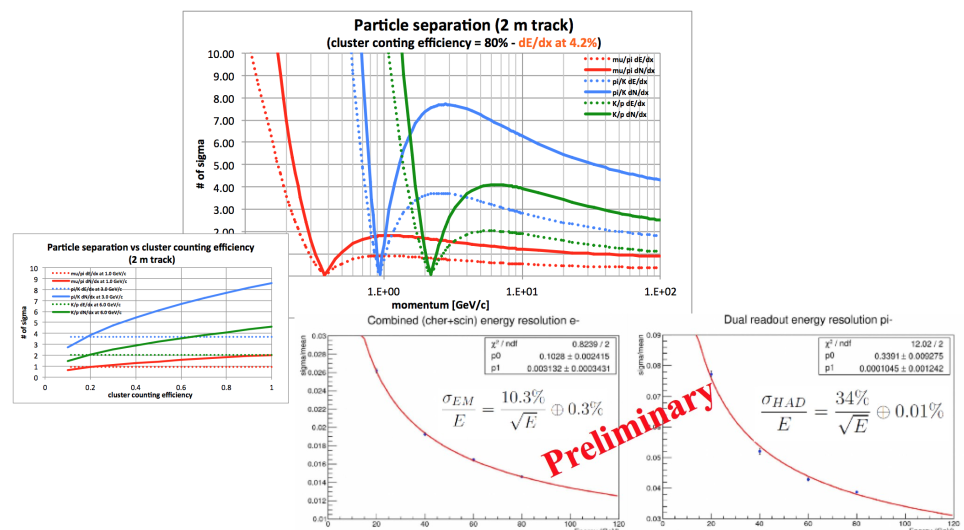
- PFA Oriented concept using High Granularity Calorimeter
  - + TPC (ILD-like, **Baseline**)
  - + Silicon tracking (SiD-like)



- Low Magnet Field Detector Concept (IDEA)
  - Wire Chamber + Dual Readout Calorimeter



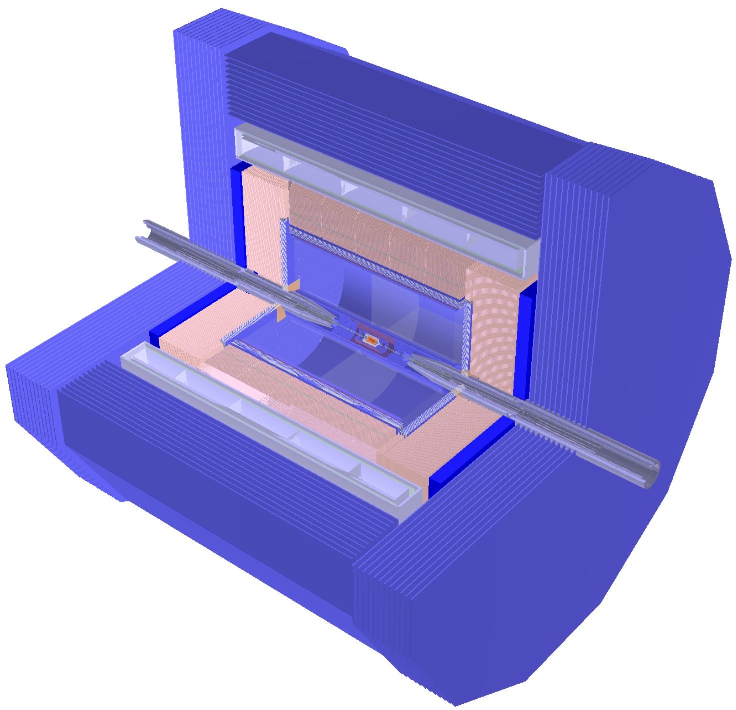


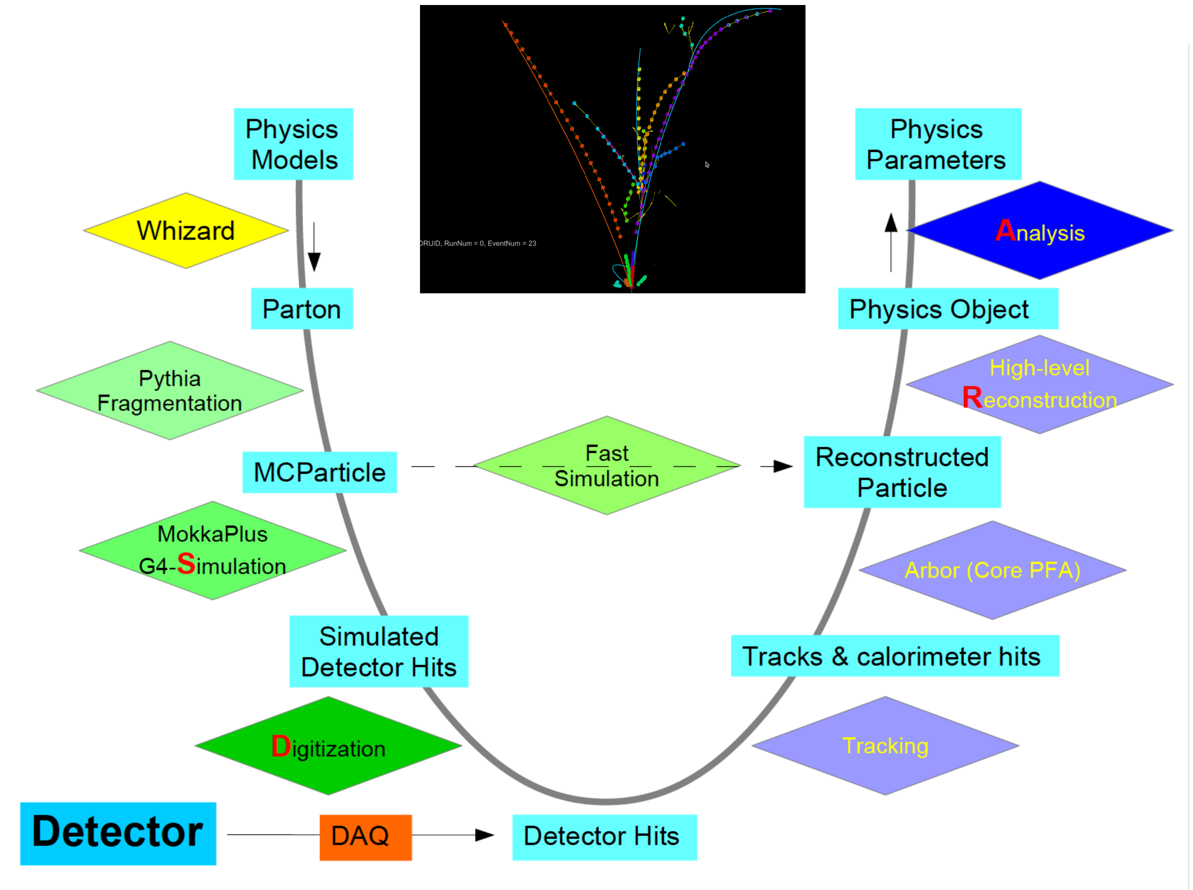


https://indico.ihep.ac.cn/event/6618/

https://agenda.infn.it/conferenceOtherViews.py?view=standard&confId=14816

Software & Reconstruction



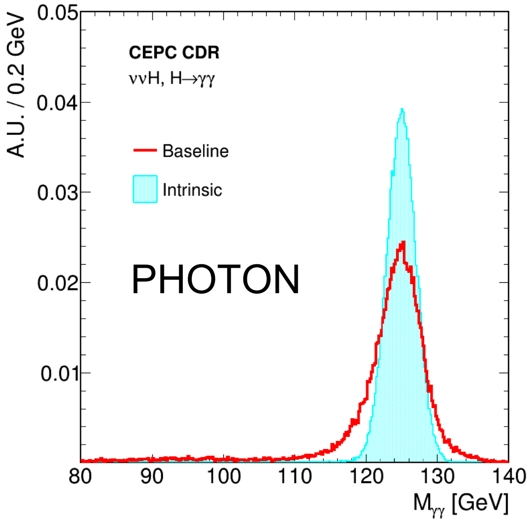


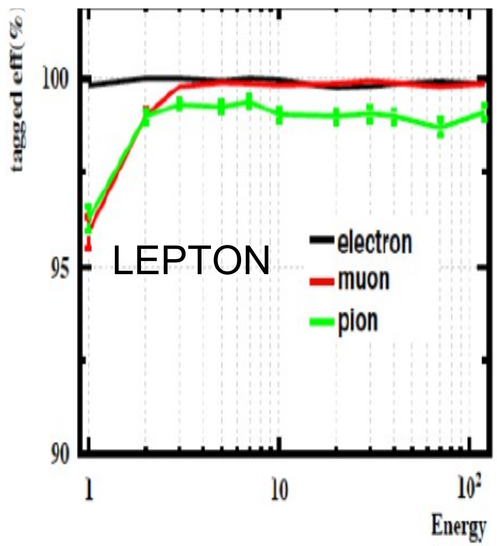
Starting from the ilcsoft & rewriting all the PFA/high-level reconstruction algorithms.

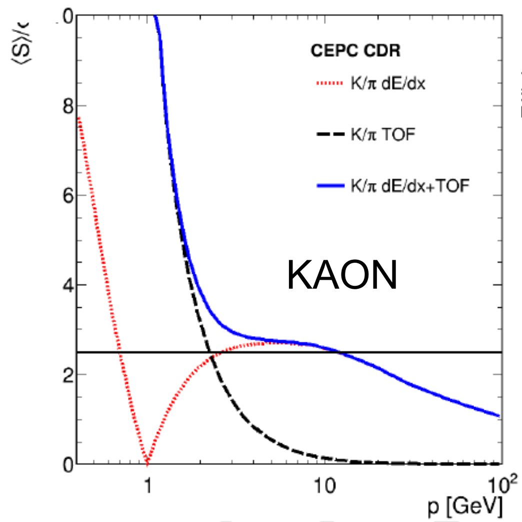
Physics Objects

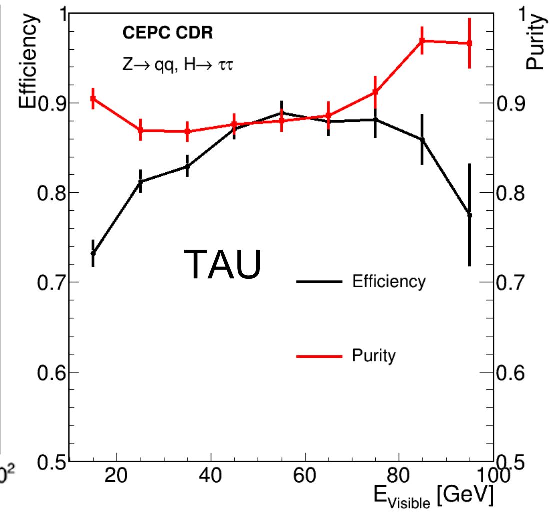
Eur. Phys. J. C (2017) 77: 591

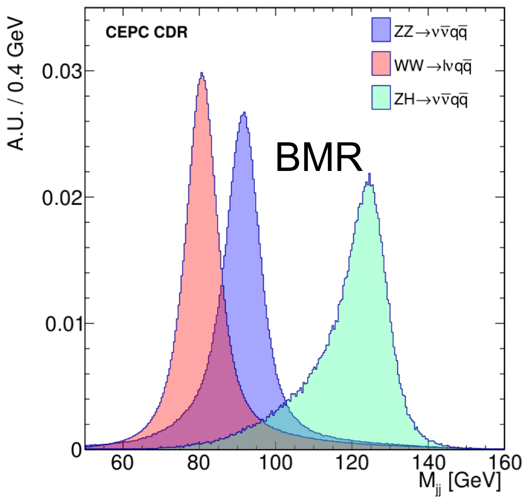
Eur. Phys. J. C (2018) 78:464

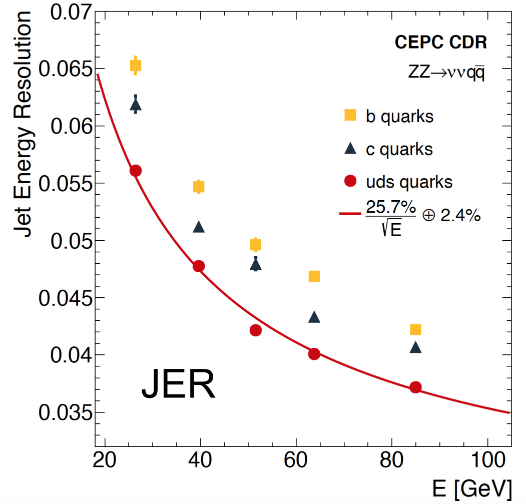


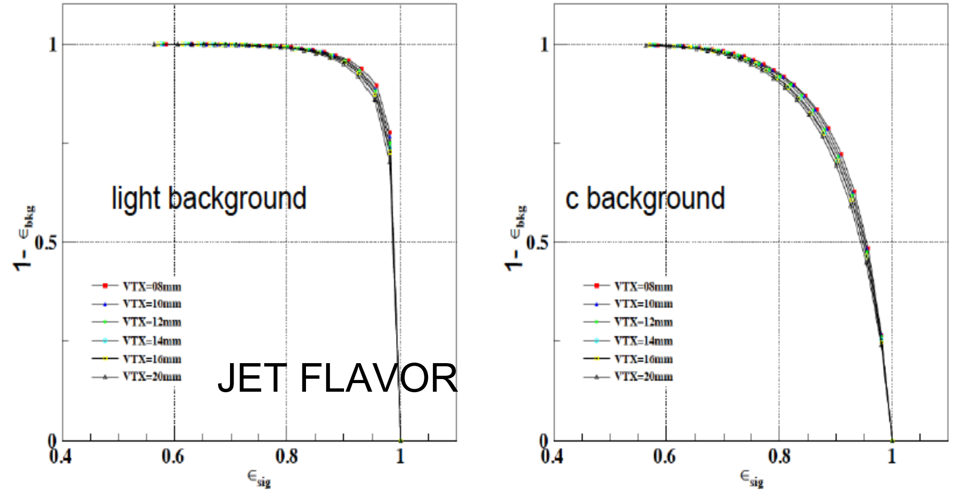






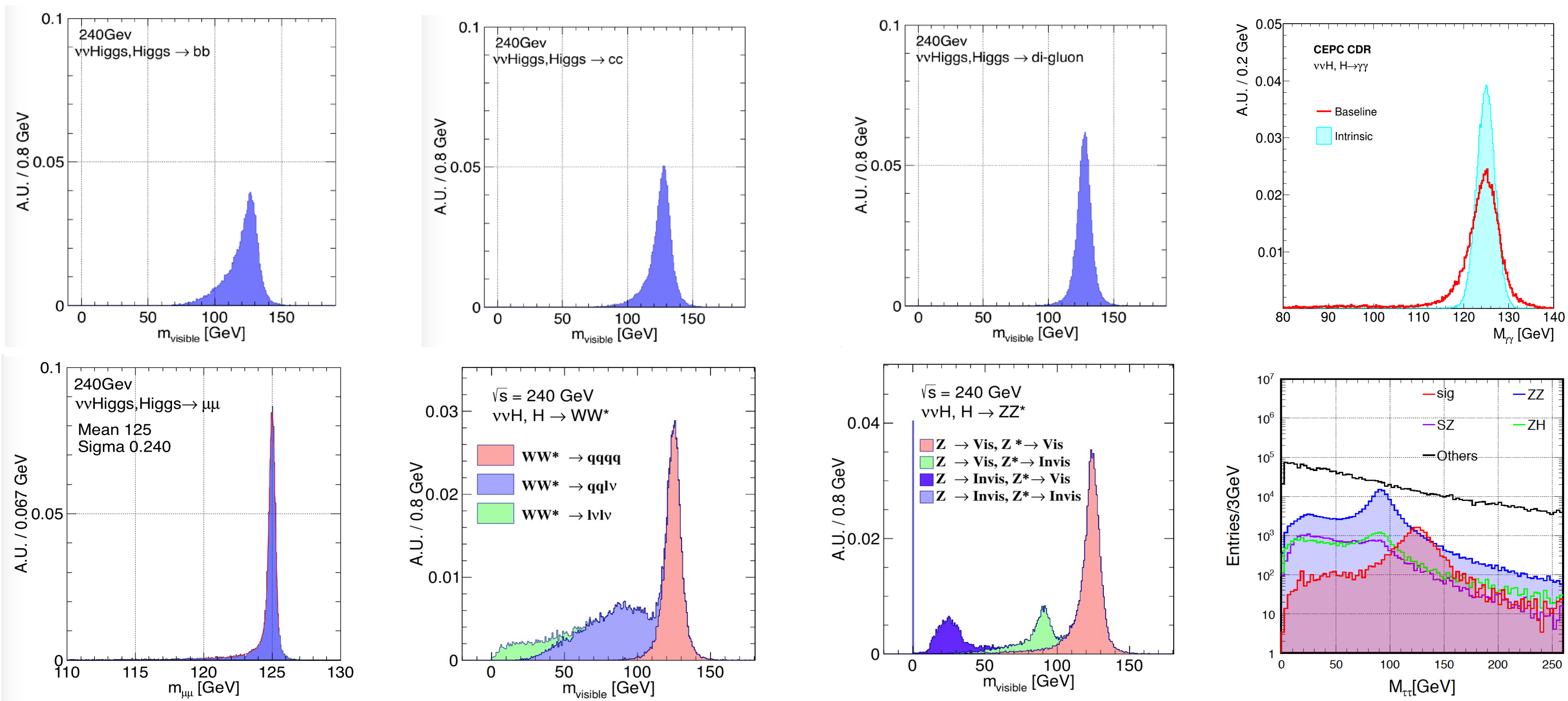






Eur. Phys. J. C (2018) 78: 426

Reconstructed Higgs Signatures

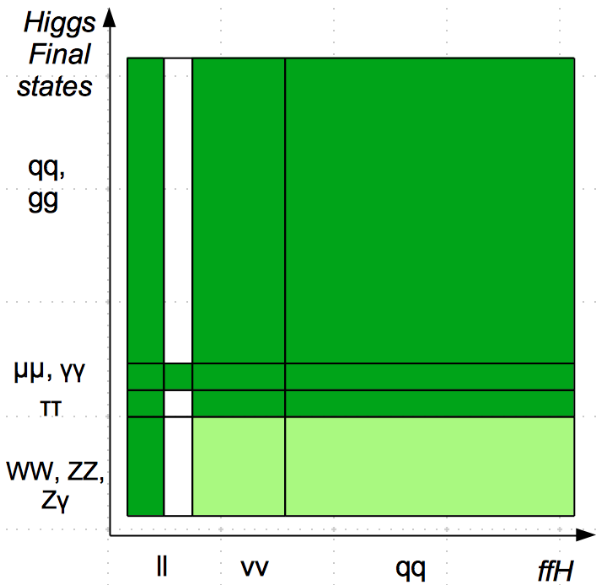


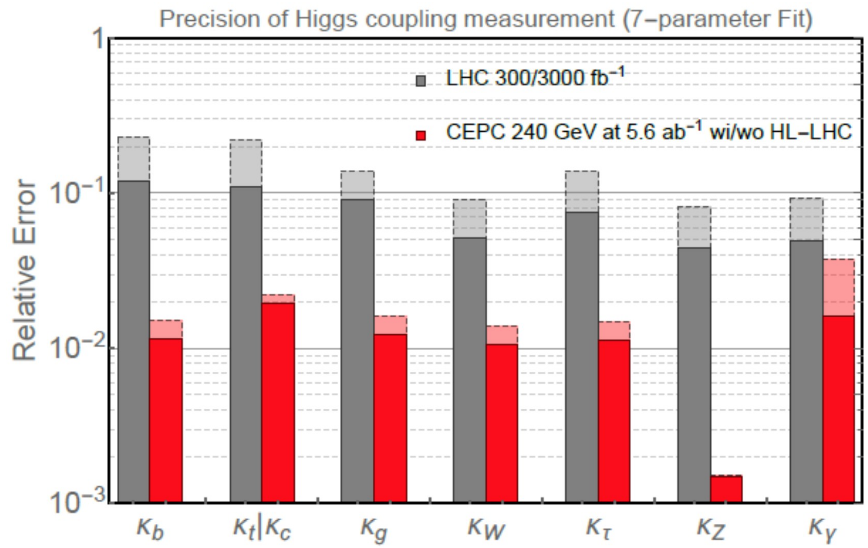
Clear Higgs Signature in all SM decay modes

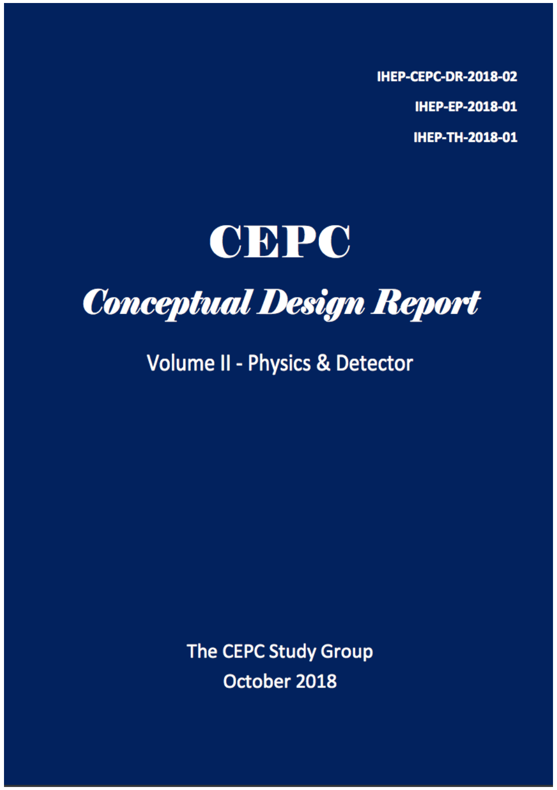
Massive production of the SM background (2 fermion and 4 fermions) at the full Simulation level

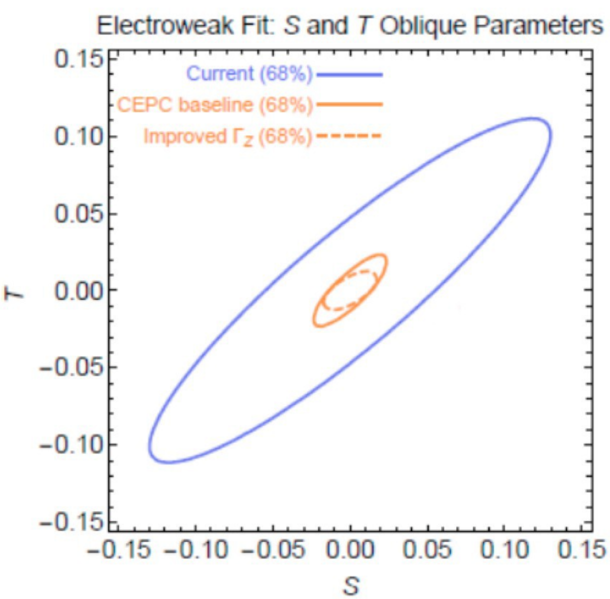
Right corner: di-tau mass distribution at qqH events using collinear approximation

Applied to physics potential study



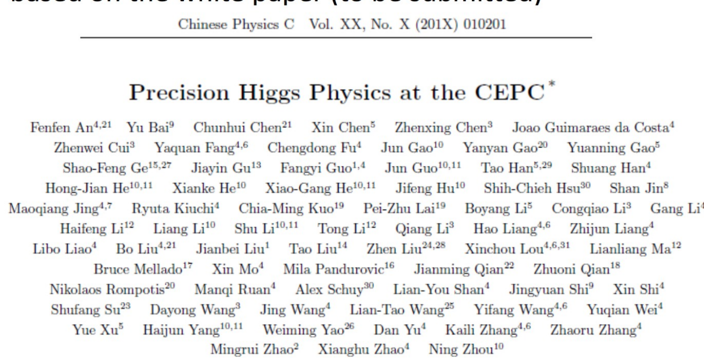






Precision Higgs Physics at CEPC

Initial assessments of Higgs physics potential at the CEPC based on the white paper (to be submitted)


Chinese Physics C Vol. XX, No. X (201X) 010201

Precision Higgs Physics at the CEPC*

Fenfen An[4,21] Yu Bai[9] Chunhui Chen[21] Xin Chen[5] Zhenxing Chen[3] Joao Guimaraes da Costa[4]
Zhenwei Cui[3] Yaquan Fang[4,6] Chengdong Fu[4] Jun Gao[10] Yanyan Gao[20] Yuanning Gao[5]
Shao-Feng Ge[15,27] Jiayin Gu[13] Fangyi Guo[1,4] Jun Guo[10,11] Tao Han[5,29] Shuang Han[4]
Hong-Jian He[10,11] Xianke He[10] Xiao-Gang He[10,11] Jifeng Hu[10] Shih-Chieh Hsu[30] Shan Jin[8]
Maoqiang Jing[4,7] Ryuta Kiuchi[4] Chia-Ming Kuo[19] Pei-Zhu Lai[19] Boyang Li[5] Congqiao Li[3] Gang Li[4]
Haifeng Li[12] Liang Li[10] Shu Li[10,11] Tong Li[12] Qiang Li[3] Hao Liang[4,6] Zhijun Liang[4]
Libo Liao[4] Bo Liu[4,21] Jianbei Liu[1] Tao Liu[14] Zhen Liu[24,28] Xinchou Lou[4,6,31] Lianliang Ma[12]
Bruce Mellado[17] Xin Mo[4] Mila Pandurovic[16] Jianming Qian[22] Zhuoni Qian[18]
Nikolaos Rompotis[20] Manqi Ruan[4] Alex Schuy[30] Lian-You Shan[4] Jingyuan Shi[9] Xin Shi[4]
Shufang Su[23] Dayong Wang[3] Jing Wang[4] Lian-Tao Wang[25] Yifang Wang[4,6] Yuqian Wei[4]
Yue Xu[5] Haijun Yang[10,11] Weiming Yao[26] Dan Yu[4] Kaili Zhang[4,6] Zhaoru Zhang[4]
Mingrui Zhao[2] Xianghu Zhao[4] Ning Zhou[10]

https://arxiv.org/pdf/1810.09037.pdf

Recent Progresses

- New beam parameters
- Accelerator technologies
  - SRF
  - Klystron
- High Temperature Super Conductor
- Link to the industrial
- Civil & Site Study

- *Many slides are taken directly from the Prof. Foster and Prof. Gao's summary talks at the CEPC Oxford Workshop*

Beam parameters: higher Luminosity

	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
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	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	

CDR Parameters:

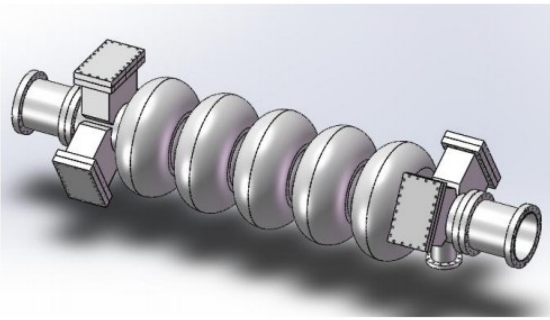
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

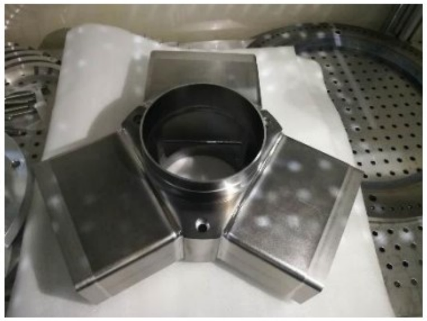
HL-Higgs operation Parameters:

Lifetime (hour)	**0.22**	**1.2**	**3.2**	**2.0**
F (hour glass)	0.85	0.92	0.98	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**5.2**	**14.5**	**23.6**	**37.7**

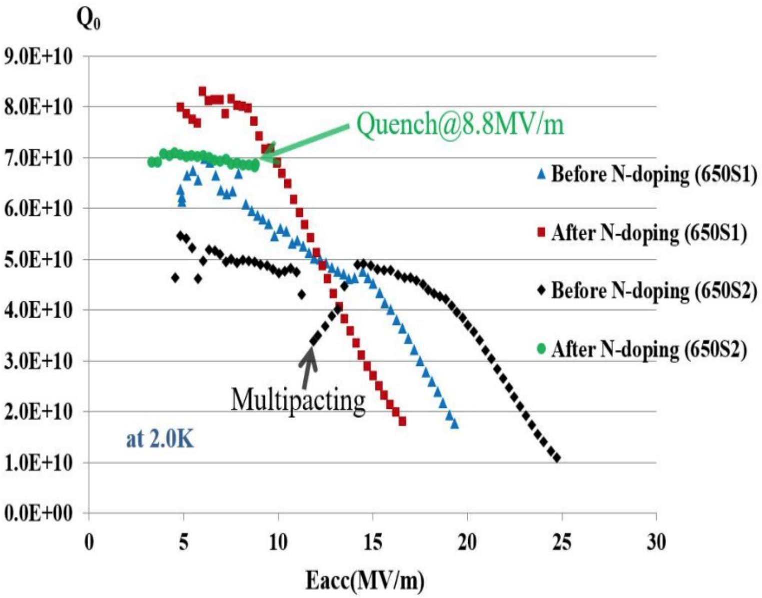
SRF prototyping & tests

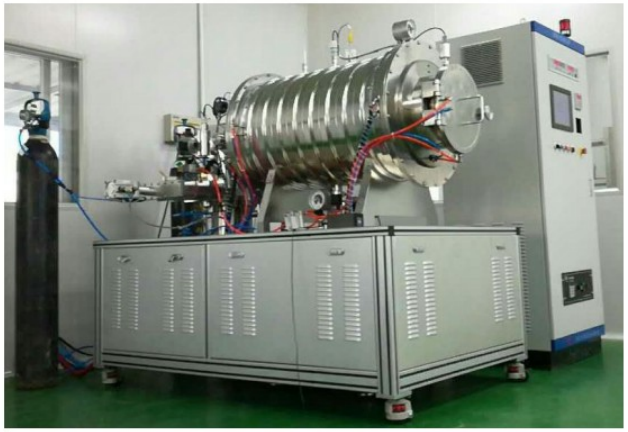
650 MHz 2-cell cavity



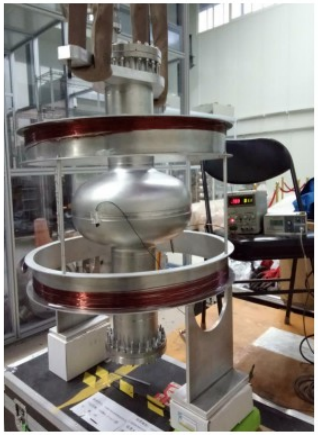


650 MHz 5-cell cavity with waveguide HOM coupler



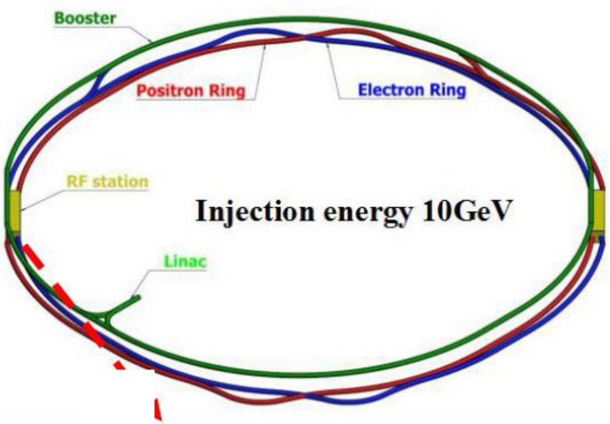


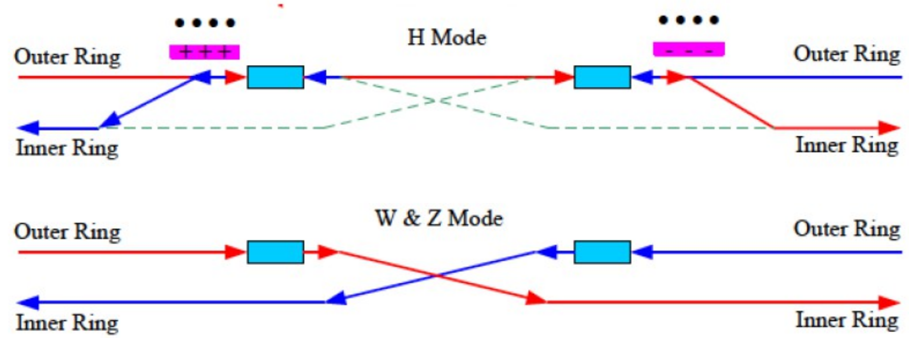
New furnaces for
N-doping and infusion study

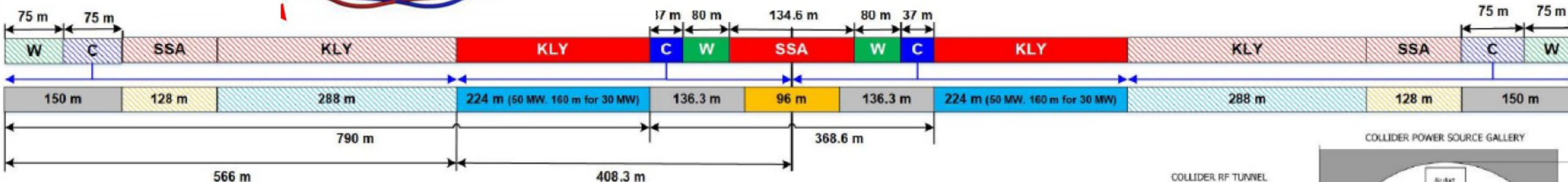


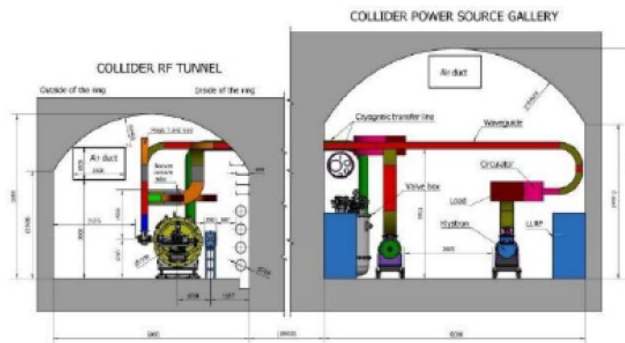
Helmholtz coil & flux gate
for high Q research

CEPC SCRF Cavities





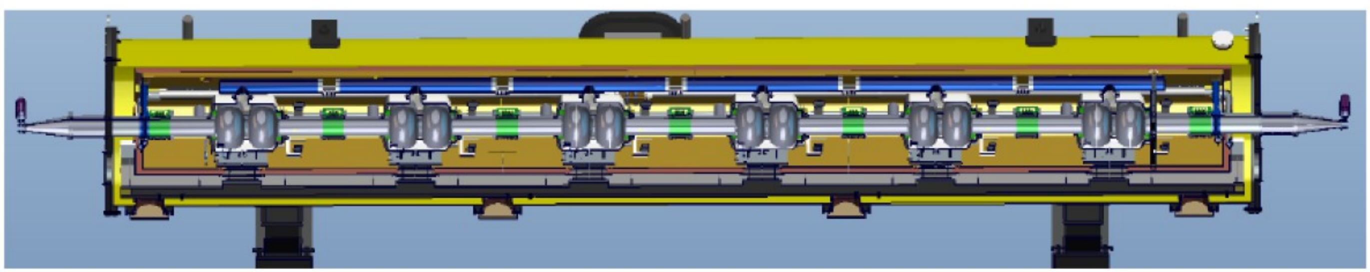


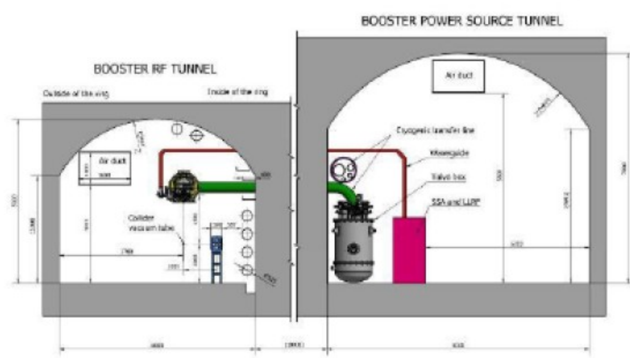


30 MW Higgs:

Collider: 240 650 MHz 2-cell cavities in 40 cryomodules (6 cav./ module).

Booster: 96 1.3 GHz 9-cell cavities in 12 cryomodules (8 cav. / module).





For higher Z lumi, look at 1-cell cavity design.

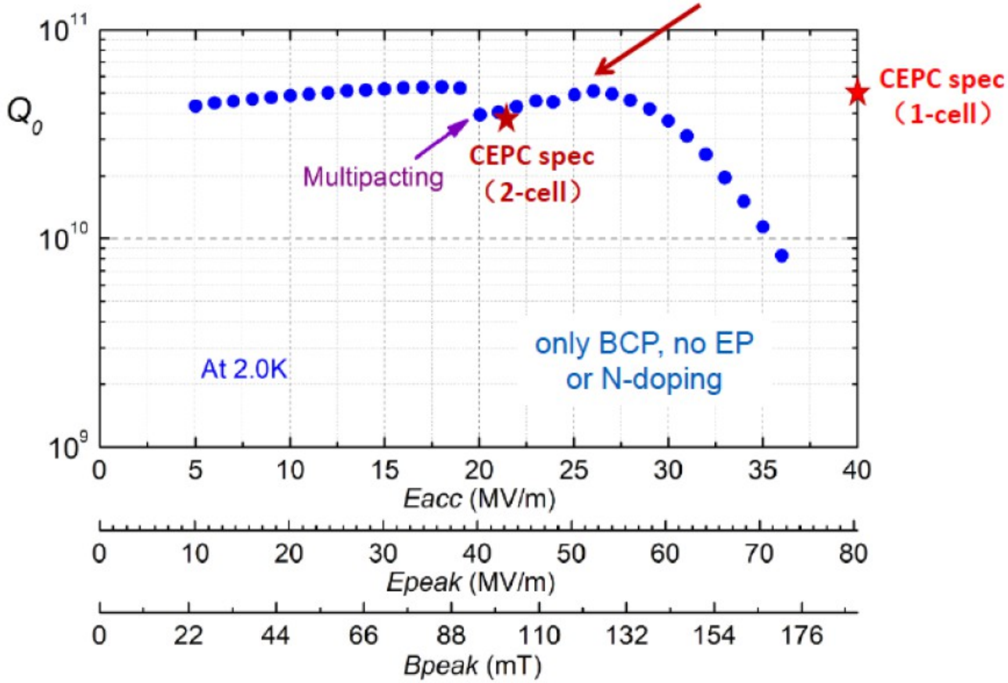
CEPC SCRF Cavities

650 MHz 1-cell cavity

Accelerating gradient (Eacc) reach 36.0 MV/m, **Q = 5.1E10 @ Eacc = 26 MV/m。**

Next, increase the Q and Eacc through N-doping, EP, etc. Target: **5E10@42MV/m** for vertical test.

Record highest Q-factor in China

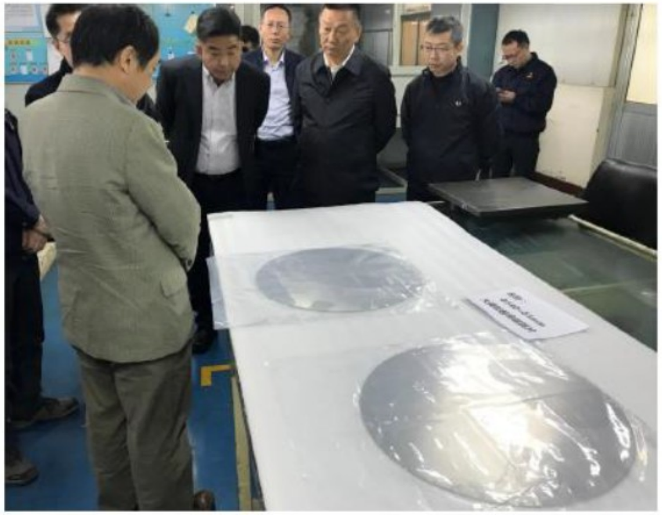


650 MHz 1-cell cavity

CEPC SCRF Cavities

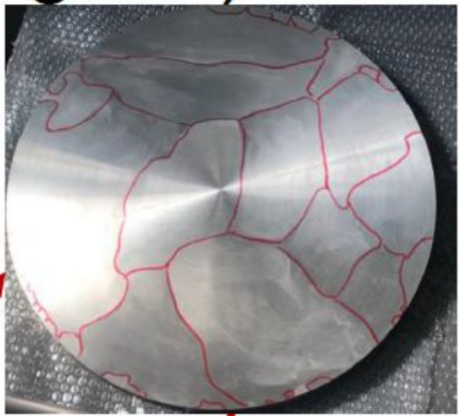
650 MHz 1-cell cavity (large grain)

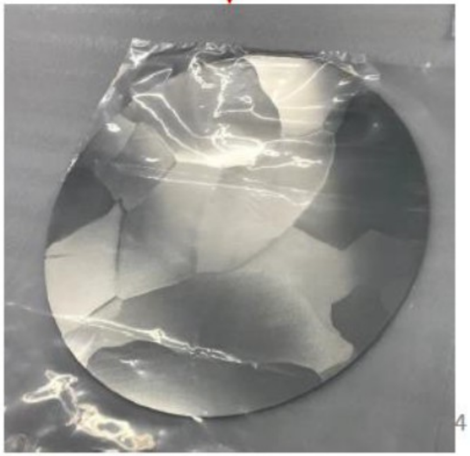
- Then, OTIC made a new Nb ingot (Φ480mm) for us, which was processed to qualified Nb sheet.
- Four cavities are under fabrication now, which will be tested in the middle 2019. Target of Vertical test: **5E10 @ 42MV/m** at 2.0 K.



Large grain Nb sheets made by OTIC

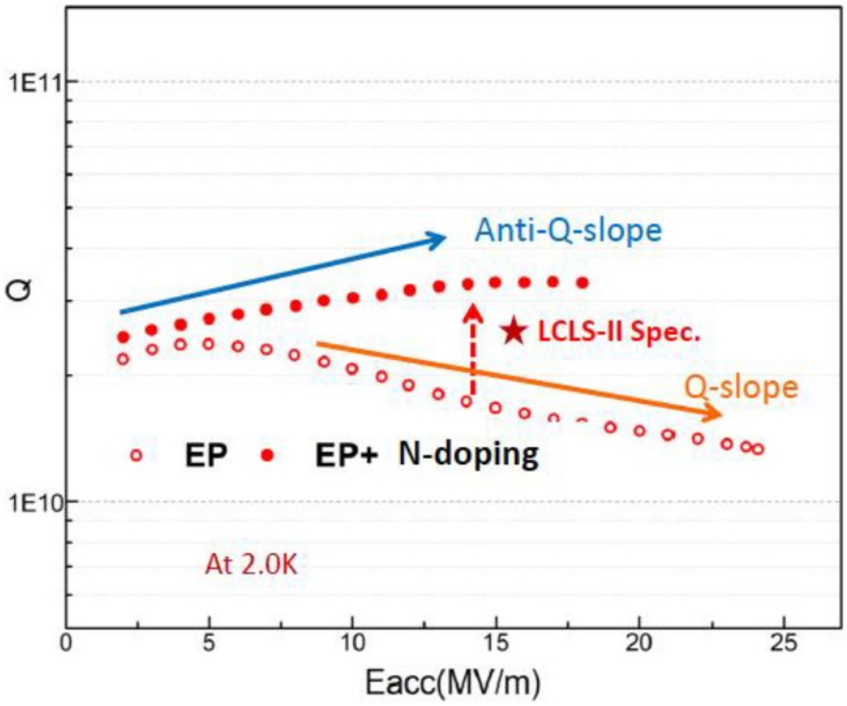
Nb ingot (Φ480mm)





N-doping of 1.3 GHz cavity

- After N-doping, 1.3 GHz 1-cell cavity reached 3.3E10 @ 18MV/m, twice of baseline Q, which exceeded LCLS-II Spec (2.7E10 @ 16MV/m) domestically for the first time. This result is also very exciting for Shanghai hard X-FEL (SHINE), which have a 8-GeV SRF LINAC and adopted N-doping as baseline.
- This work is collaborated with KEK colleagues.



CEPC SCRF Cavities

PAPS-SRF infrastructure

- SRF facility construction
  - Civil construction will be finished by end of April, 2019
  - Clean-room and cryogenic system will be ready by the end of 2019
  - Some components are ready for shipment, e.g. furnace, cryomodule for horizontal test, Nb-Cu sputtering system, etc.

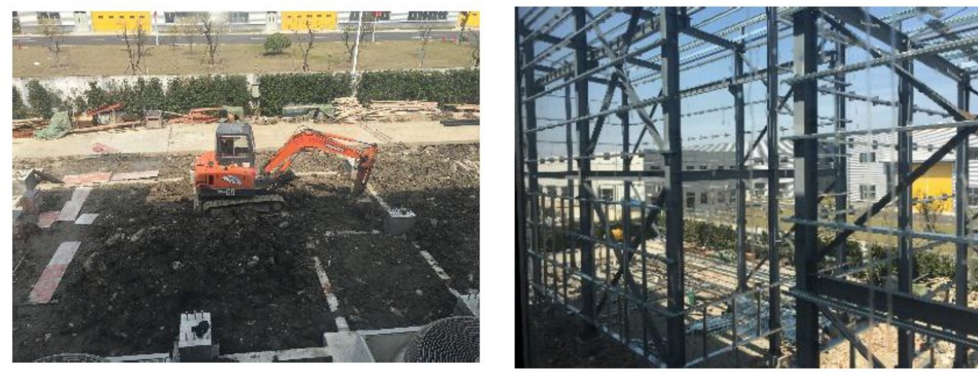
1st 650MHz Klystron Manufacturer and Infrastructure Preparation Progress

Z.S. Zhou

Modulator anode components

Cavities components

Klystron output window



Assembly plant construction

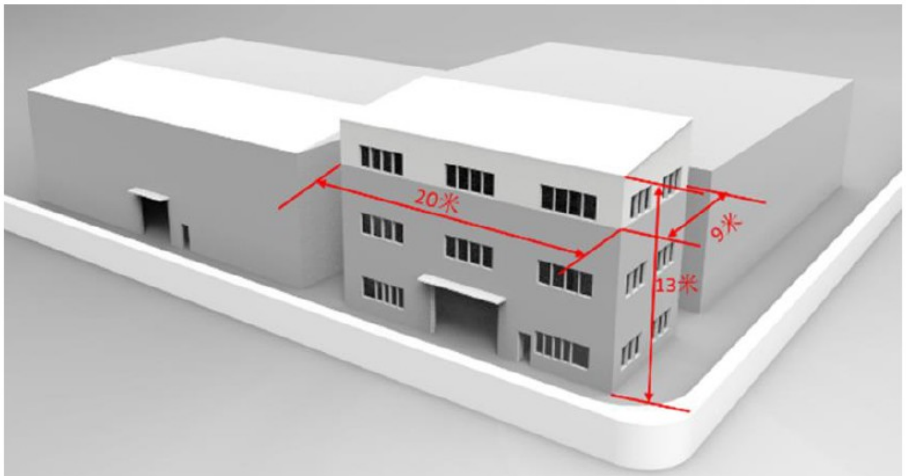
Large size baking furnace commissioning

Klystron R&D

650MHz/800kW meets CEPC project demands
80% efficiency

◆1st prototype tube

Mechanical design and manufacture
Plant and infrastructure preparation



Dimension of new building

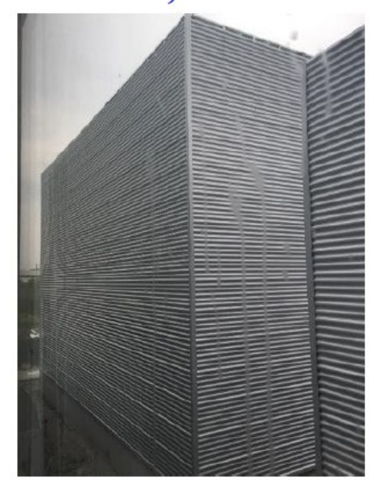
Dec. 29, 2018

Jan. 10, 2019

Jan. 28, 2019

Mar. 3, 2019

Mar. 27, 2019



Apr. 12, 2019

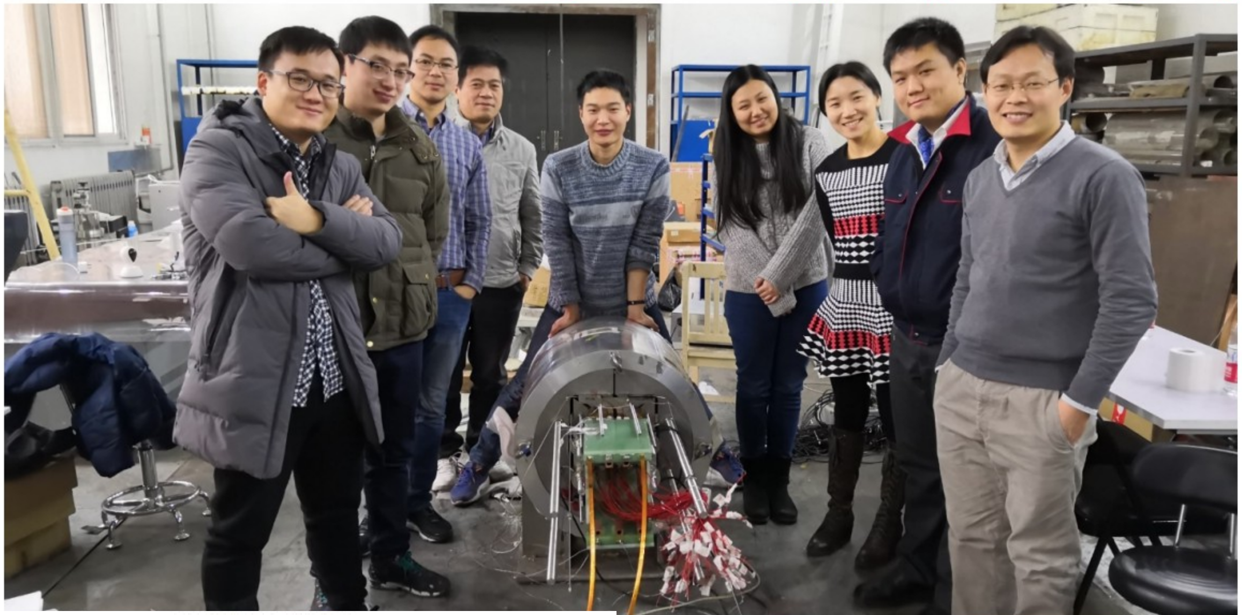
◆High efficiency design

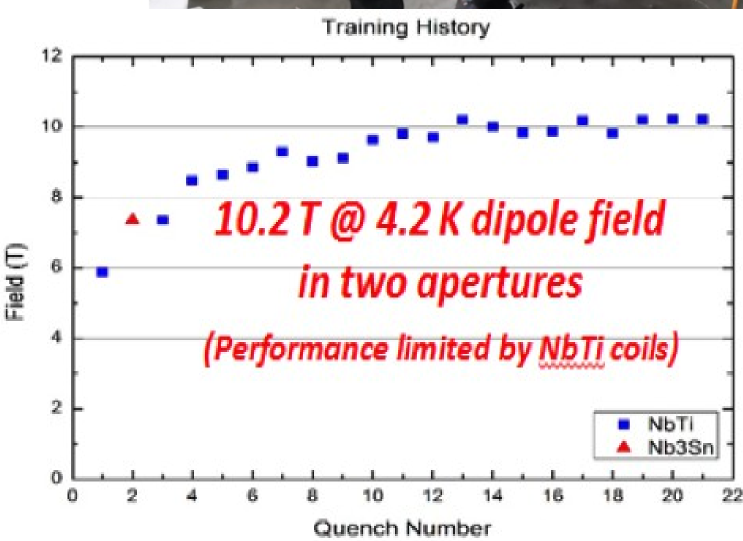
2nd prototype optimization Multi-beam klystron consideration

HTC Superconducting Cables

- Huge impact If magnet can be used at ~ 4.5K - 20 K
- Fe-based HTC cable
  - Metal, easy to process; Isotropic; Cheap in principle
- Background in CAS
  - World highest Tc Fe-based materials
  - World first ~ 115 m Fe-based SC cables: 12000 A/cm^2 @ 10 T
- A collaboration on "HTC SC materials" : Institute of Physics, USTC, Institute of electric engineering, IHEP, 3 SC cable companies in China
  - Iron based HTC cables
  - ReBCO & Bi-2212
  - Goal: ~ 3-5 $ /kA·m
    - Current density: × 10
    - Cost/m: ÷10

Dipole Prototype: B = 10.2T @ 4.2K

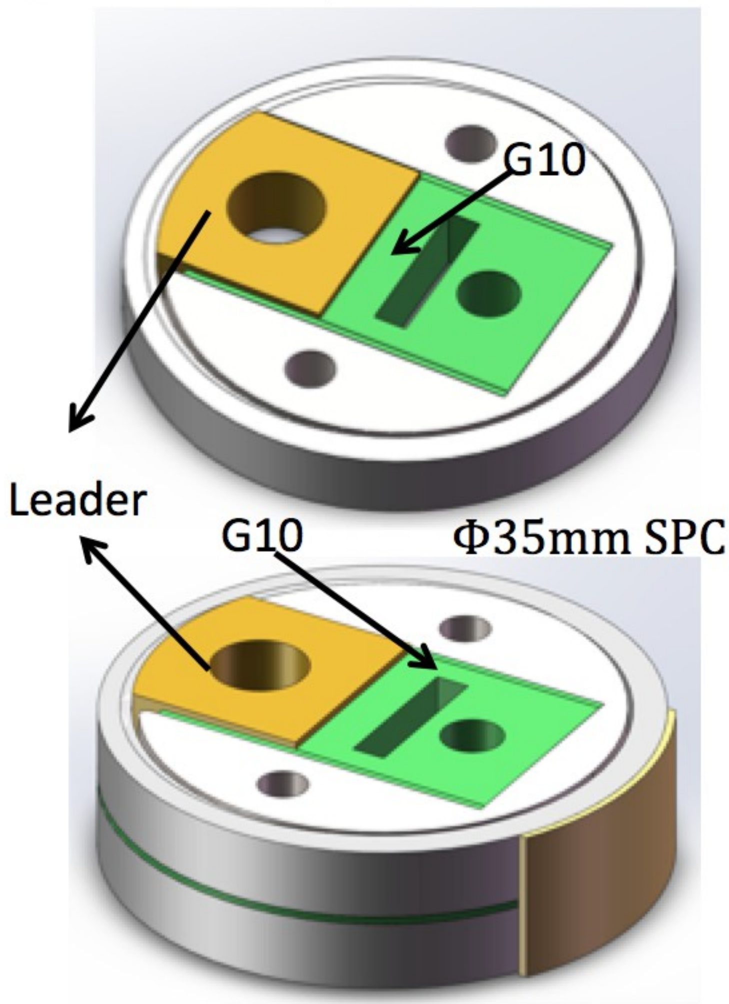




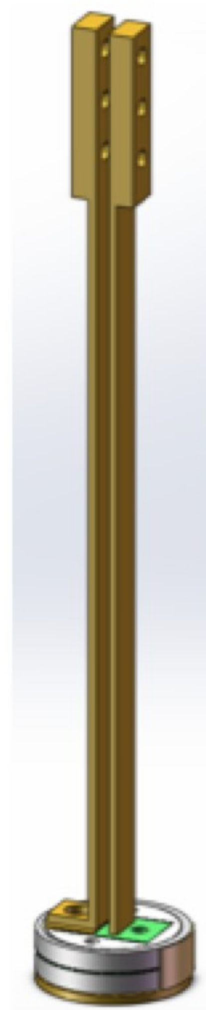
R&D of High Field Dipole Magnets

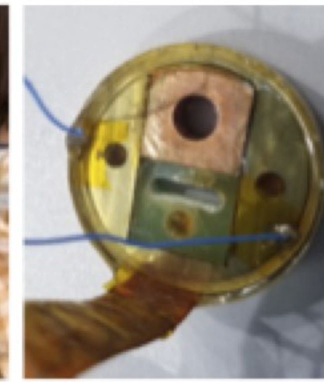
IBS solenoid for testing at 24T

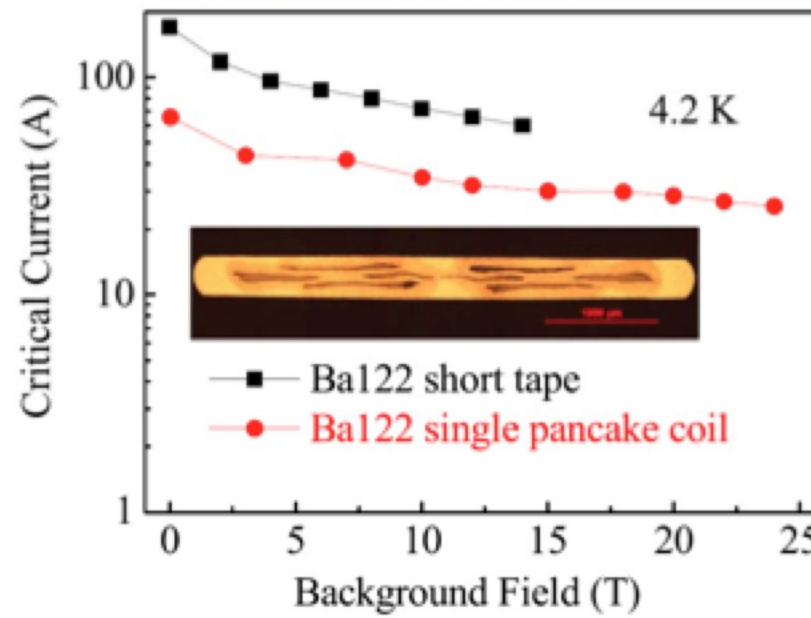
Single and double pancake IBS coils



Φ35mm DPC







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Collaboration with industry

The CEPC Industrial Promotion Consortium (CICP) is established in Nov 2017. More than 50 companies joined CICP, with expertise on superconductor, superconducting cavities, cryogenics, vacuum, klystron, electronics, power supply, civil engineering, precise machinery, etc. The CIPC serves as a communication forum for the industrial and the HEP community.

Civil Engineering & Site Selection

Factors affecting site selection:

1、Social factors:

National planning, Regional economic conditions, Cultural environment, Immigration, Environmental protection.

2、Natural conditions and engineering factors:

Climate, Traffic, Topographical geology, Engineering layout, Construction Conditions, Engineering investment.

3、Operating factor:

Water supply, power supply, operating costs

In China, there are many sites that meet the construction conditions.

International Science City

Overall Scale : 3.3km² of construction area for short-term use & 6.7km² for future use.

Summary

- CEPC, a productive and clean Higgs/W/Z factory,
  - Boost the Higgs/EW precision by ~ 10 times w.r.t HL-LHC/current boundary
  - Huge potential on QCD, Flavor, etc
  - Surprises: seeking for direct evidence of NP & deviations
- CDR released
  - Accelerator baseline secures high productivity for Higgs, Z and W bosons.
  - Detector baseline fulfills the requirements: clear physics objects + Higgs signal
  - Alternative designs, New ideas are always welcome
- Key technology – civil development:
  - Towards the TDR & significant progresses & link to industrial
- Giving the importance of electron positron Higgs factory, we hope at least one of them (ILC, CLIC, CEPC, FCC) can be realized. We fully support the global studies, even if is not build in China

Significant Progress are made – challenges & topics everywhere

Your ideas and participations are more than welcome!

Backup

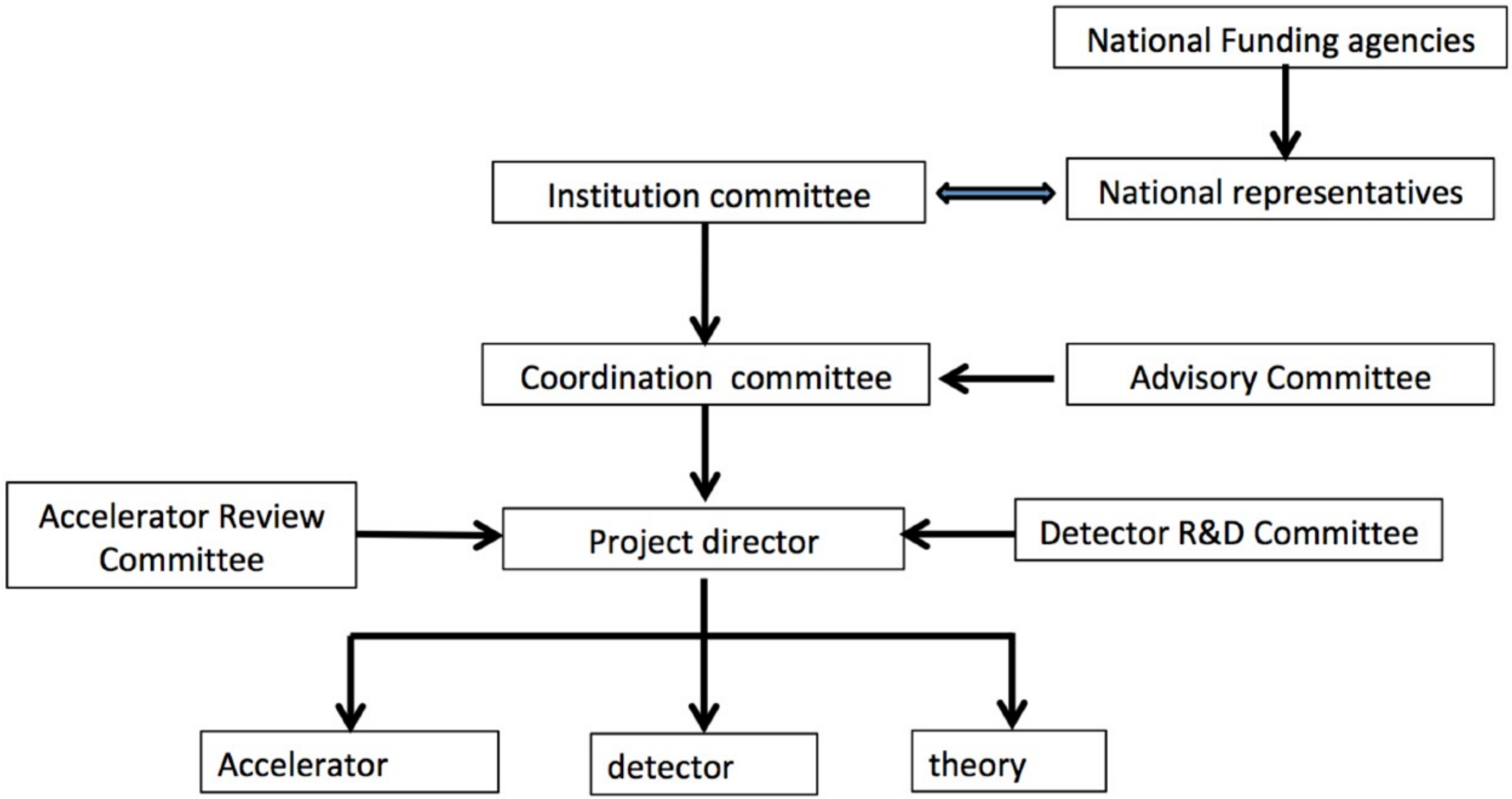
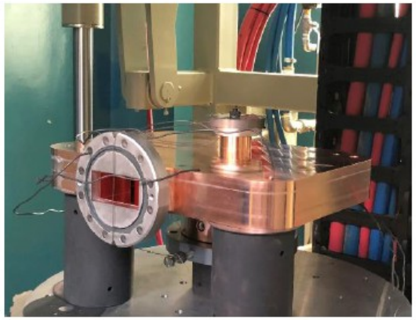


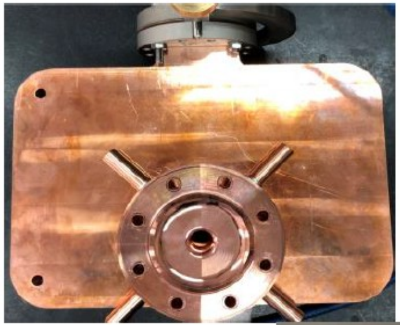
Figure 9, The planned international organization from 2019 till the construction

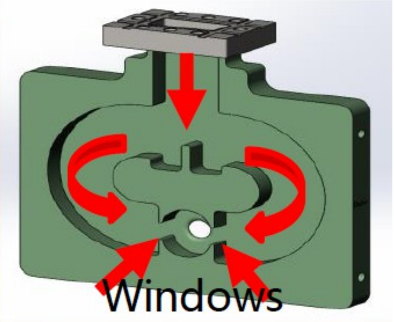
In this structure, all the building blocks will integrate the international participation. The Institution Committee writes the bylaws and makes major decisions on organizational issues. The national representatives interface with the National Funding Agencies and the corresponding institutions are represented in the Institution Committee. Supported by the Accelerator Review Committee and the Detector R&D Committee, the Project director is responsible for the coordination of studies at each group.

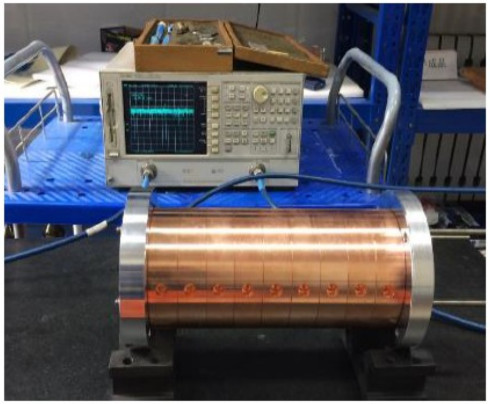
R&D activities on Linac

- S-band accelerating structure design
  - Mechanical design
    - Inner water-cooling has been adopted. 8 pipes are around the cavity.
    - Compact coupler arrangements. The splitter is milling together with the coupling cavity.







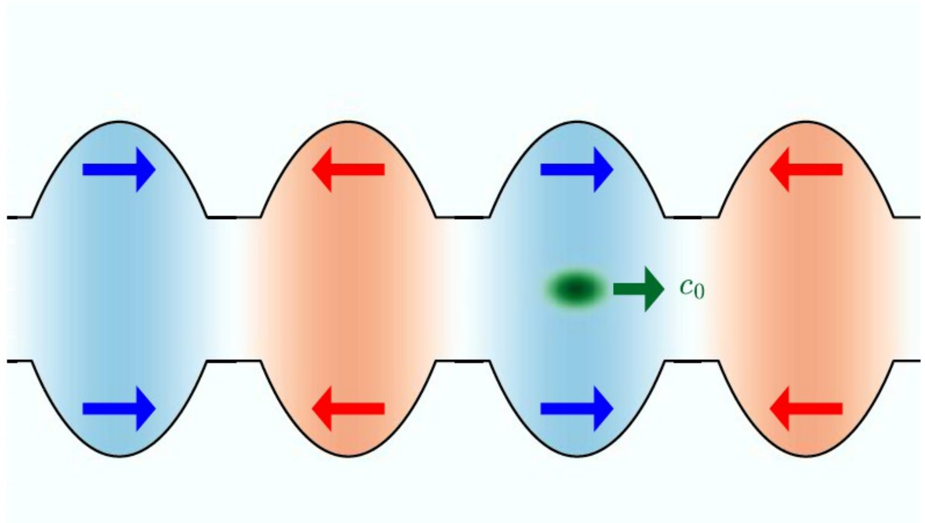


R&D activities on Linac

- High power test bench @ IHEP
  - The accelerating structure have carried from laboratory to test bench and finished assembling
  - Vacuum leak detection is under way
  - Two faraday cups are in upstream and downstream of the structure respectively

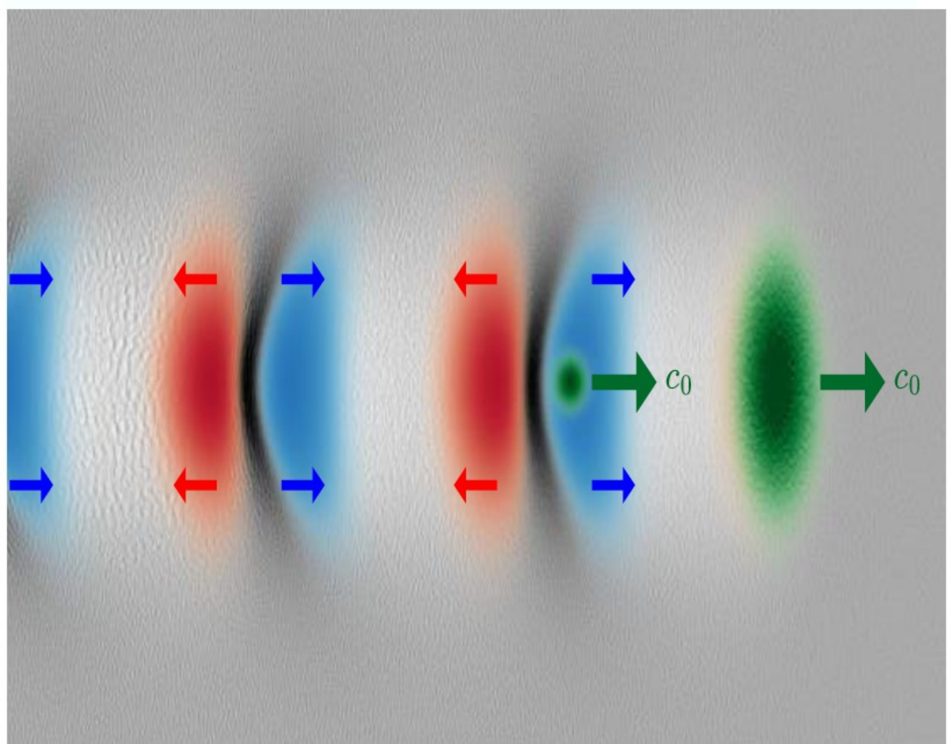
PWFA Linac replacement

RF Cavity



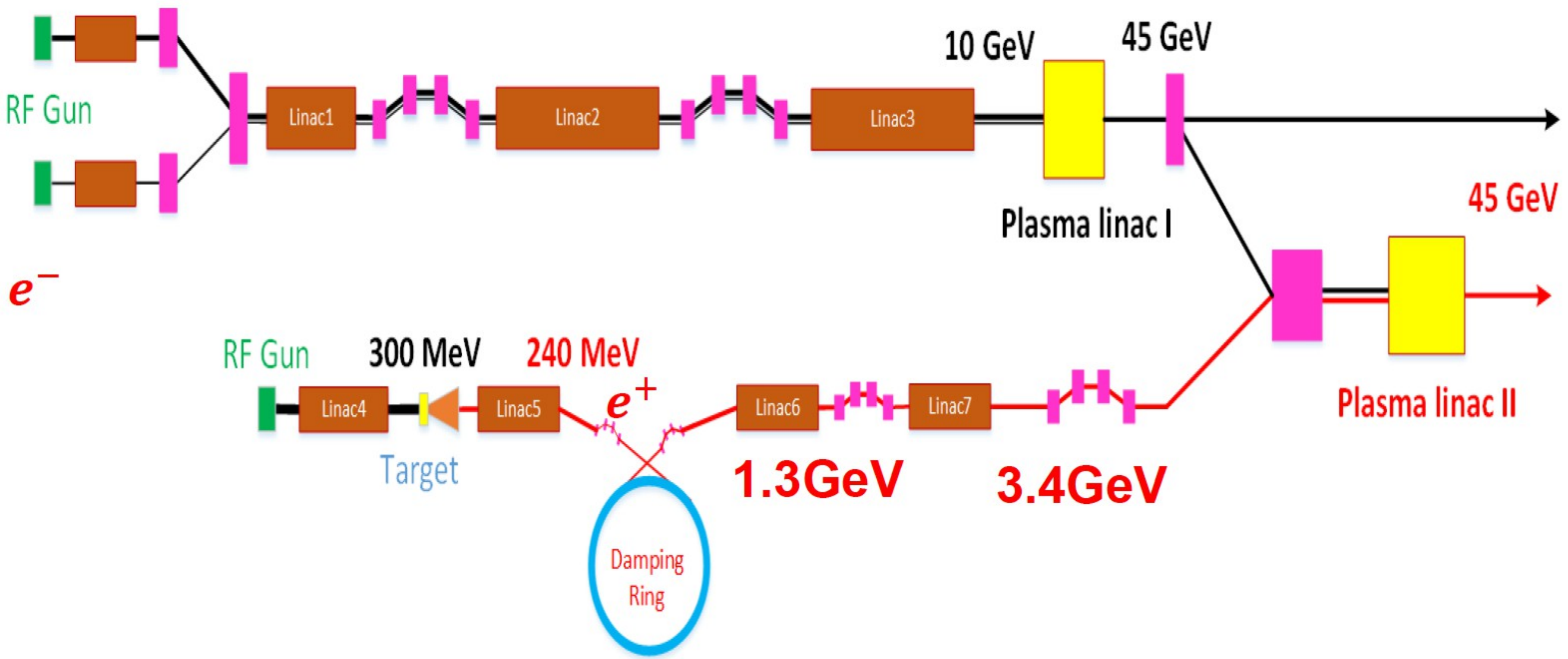
20 – 40
MV/m

Plasma
wakefield



10 – 1000
GV/m

CEPC PWFA Linac



- Driver/trailer beam generation through Photo-injector
- HTR PWFA with good stability (single stage TR=3-4, Cascaded stage 6-12, high efficiency)
- Positron generation and acceleration in an electron beam driven PWFA using hollow plasma channel (TR=1)