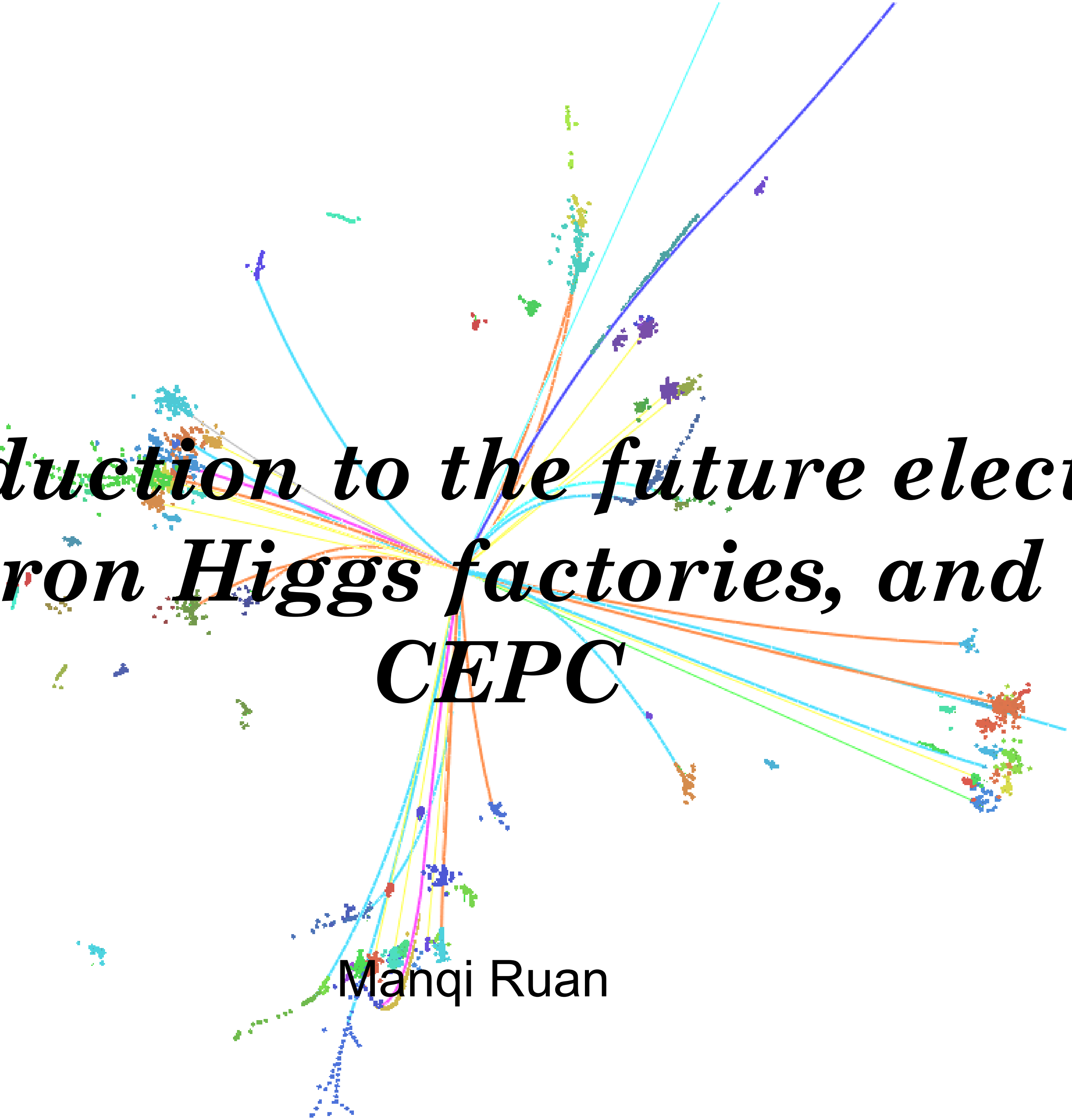
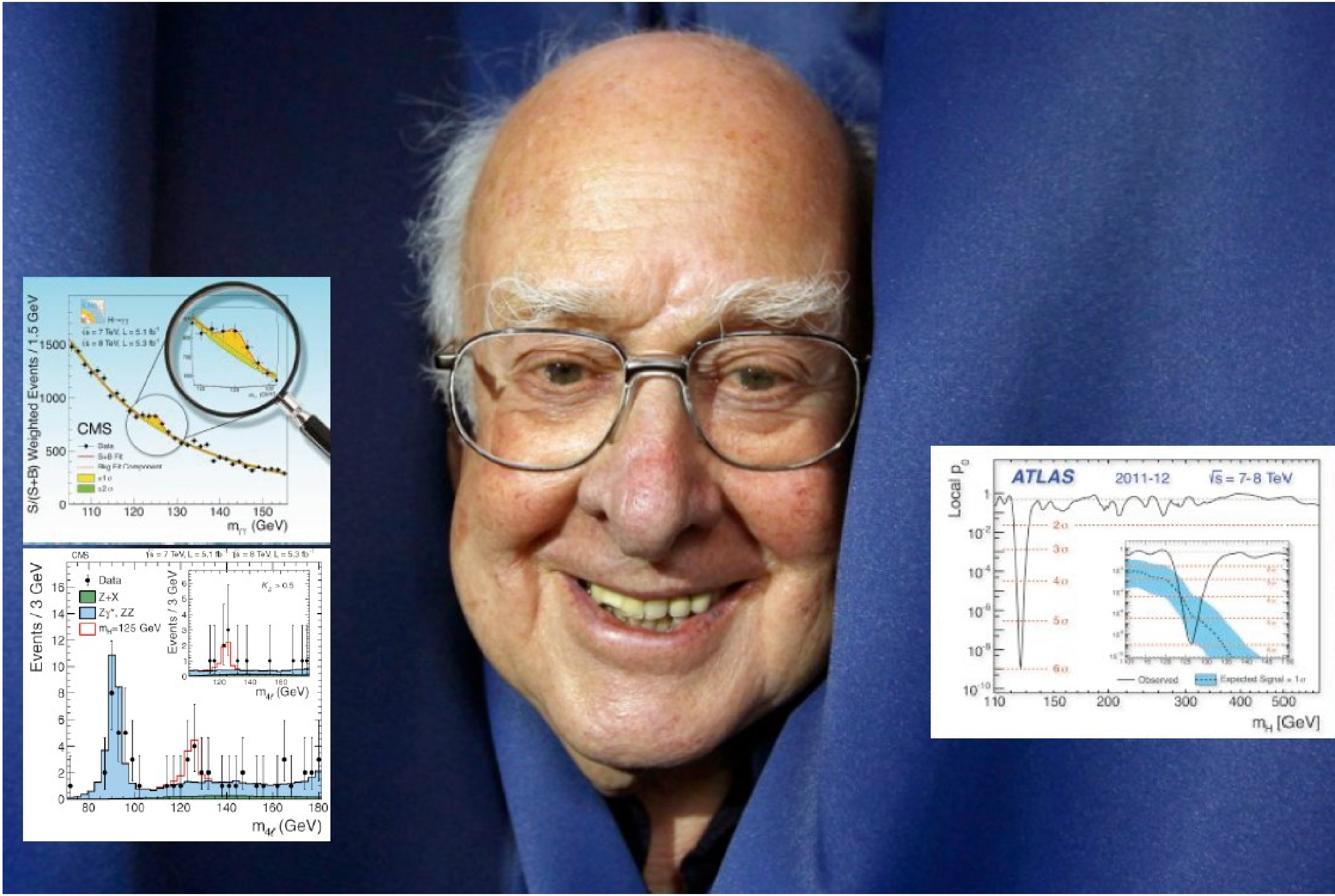


Introduction to the future electron positron Higgs factories, and the CEPC

Manqi Ruan


S/(S+B) Weighted Events / 1.5 GeV
CMS
Data
S+B Fit
Bkg Fit Component
±1σ
±2σ
$m_{\gamma\gamma}$ (GeV)
CMS
Events / 3 GeV
Data
Z+X
Zγ*, ZZ
m_H=125 GeV
$m_{4\ell}$ (GeV)
ATLAS
2011-12
$\sqrt{s}$ = 7-8 TeV
Local p_0
2σ
3σ
4σ
5σ
6σ
Observed
Expected Signal ± 1σ
m_H [GeV]

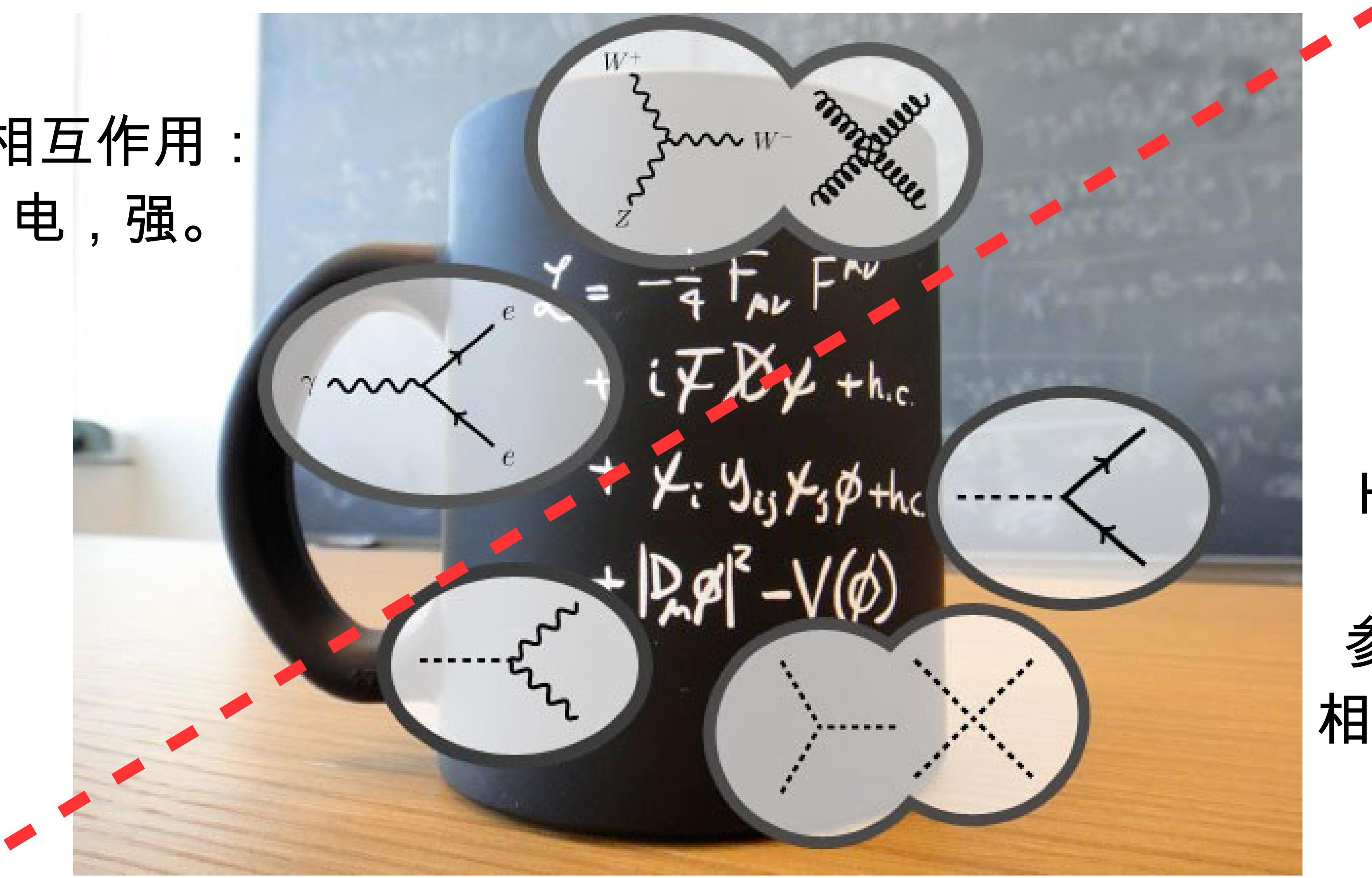
标准模型无法解释的谜团

- 质量等级
- 中微子质量
- 宇宙稳定性：取决于粒子质量
- 暗物质、暗能量：其本质及其质量来源
- 物质-反物质不对称
- 暴涨

  …
- 归根到底：人类对标准模型知其然不知其所以然

Higgs 场：质量之源，标准模型的核心

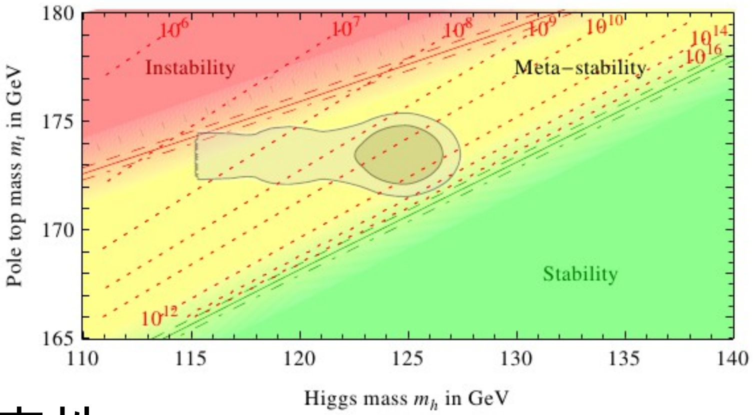
规范相互作用：
弱，电，强。



Higgs
粒子
参与的
相互作用

Higgs 场

- 决定了电子的质量和原子的大小
- 决定了真空是否稳定
  - 决定了顶夸克的质量
  - 决定了 Higgs 粒子本身的质量



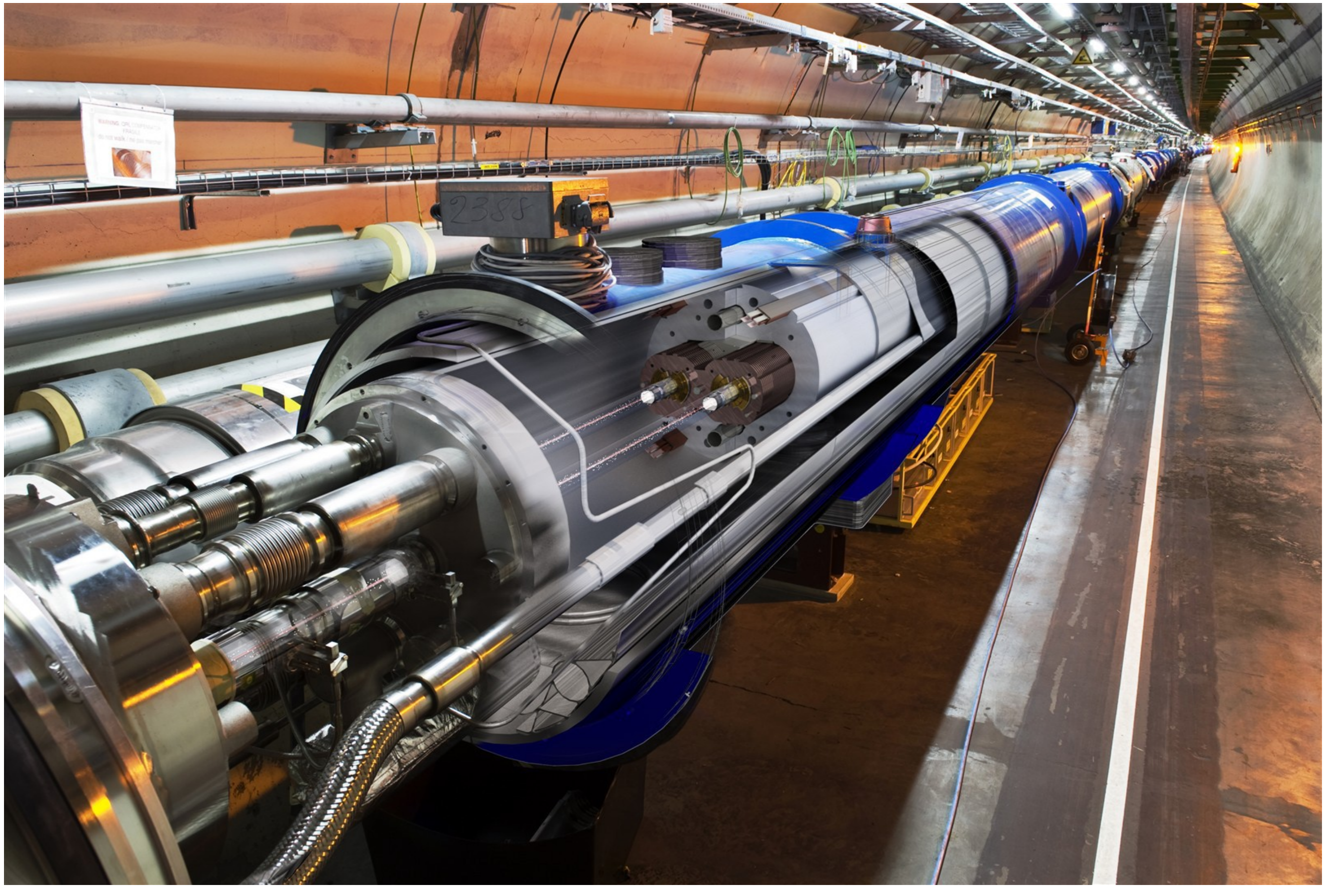
- 参决定了质子和中子的质量差，保证质子稳定性
- 决定了 W, Z 粒子的质量，决定了弱相互作用的力程并影响了其强度
- 通过和物质 / 反物质的不同耦合：物质产生的前提条件

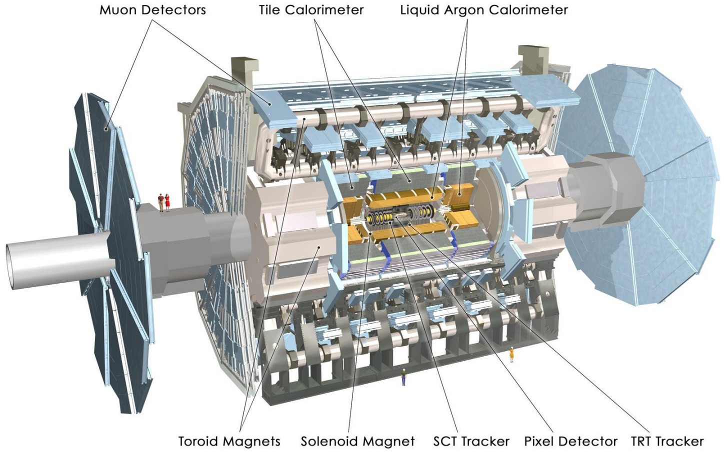
…

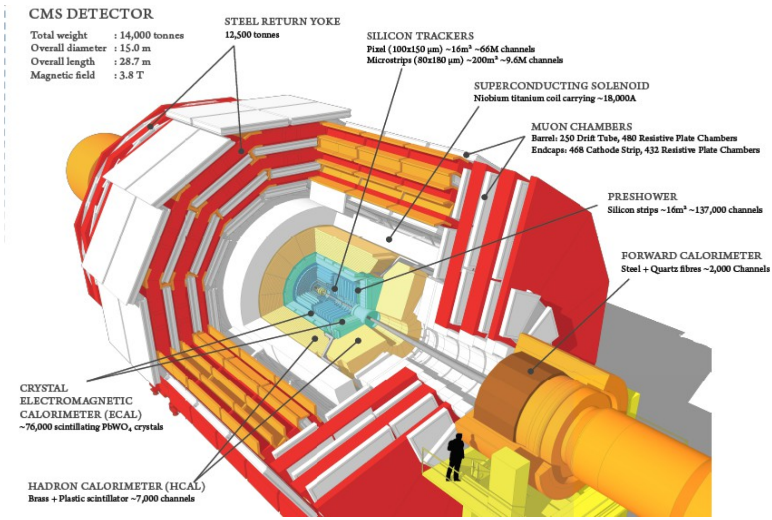
- *是否是暗物质的质量之源？*
- *是否和暗能量、暴涨有深刻的关联？*


Higgs boson precision measurement: a sensitive probe to the unknown!

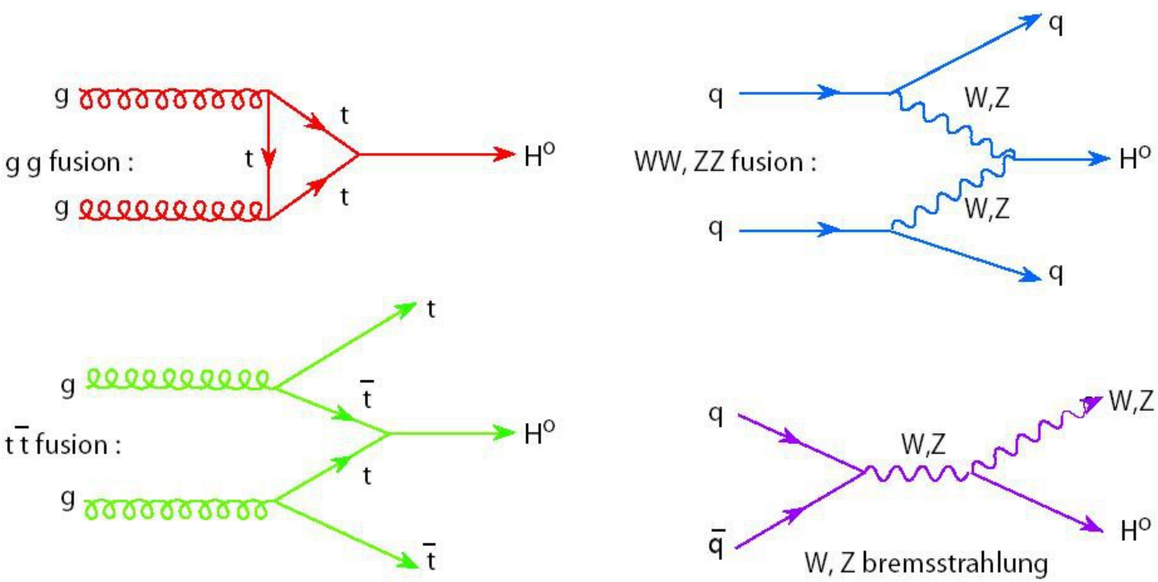
Higgs 工厂：LHC

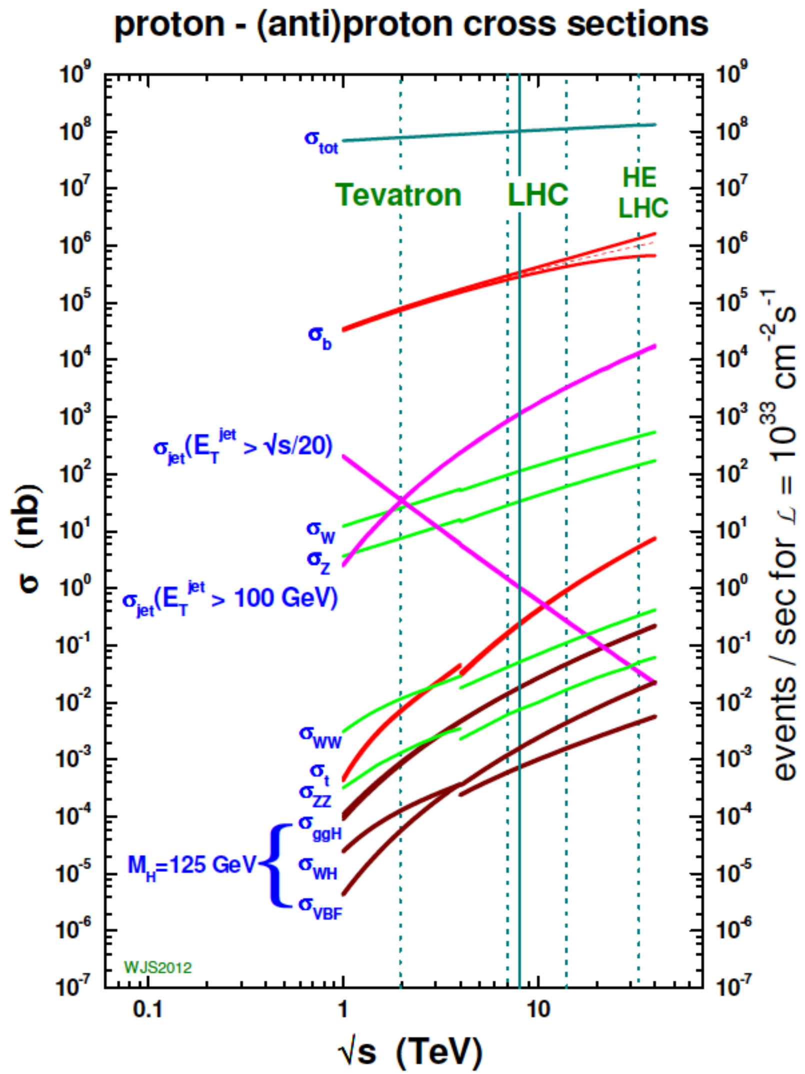



Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker


CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL
ELECTROMAGNETIC
CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

Higgs @ LHC

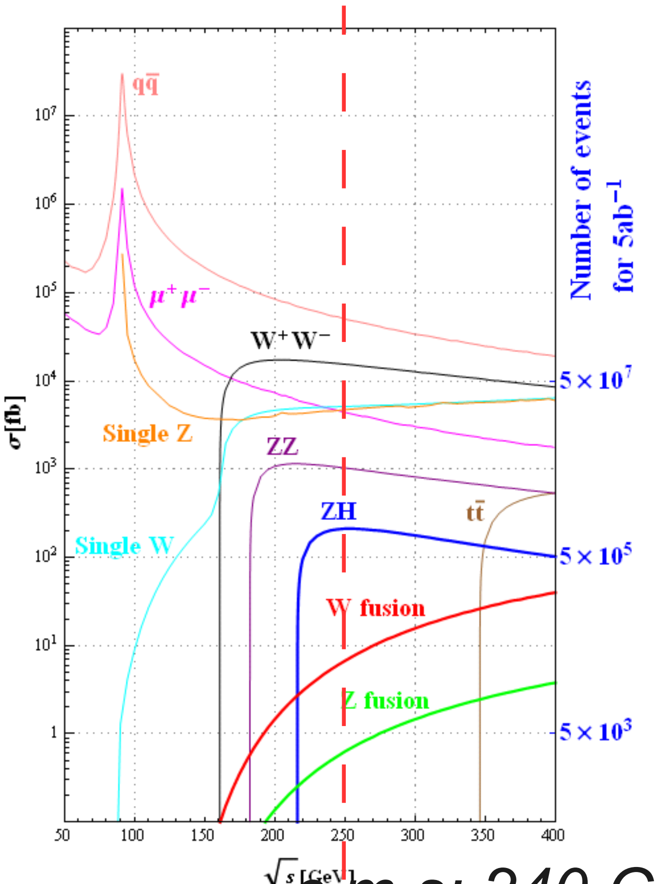


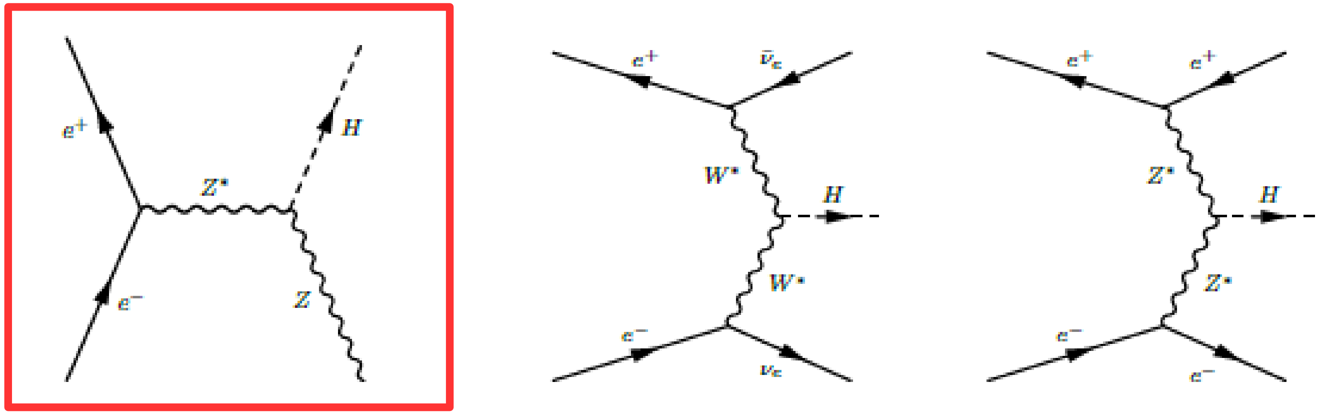


S/B ~ 1:1E10 !!!

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

Higgs @ Electron Positron Higgs Factories





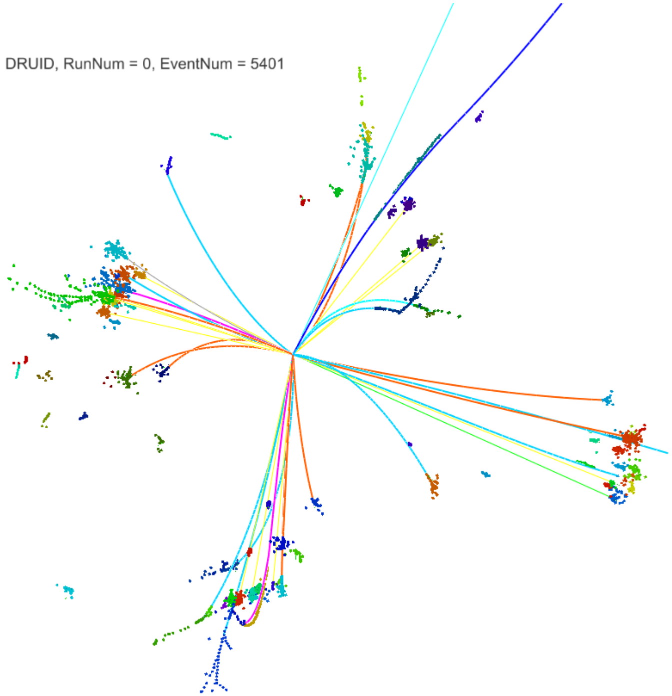
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6

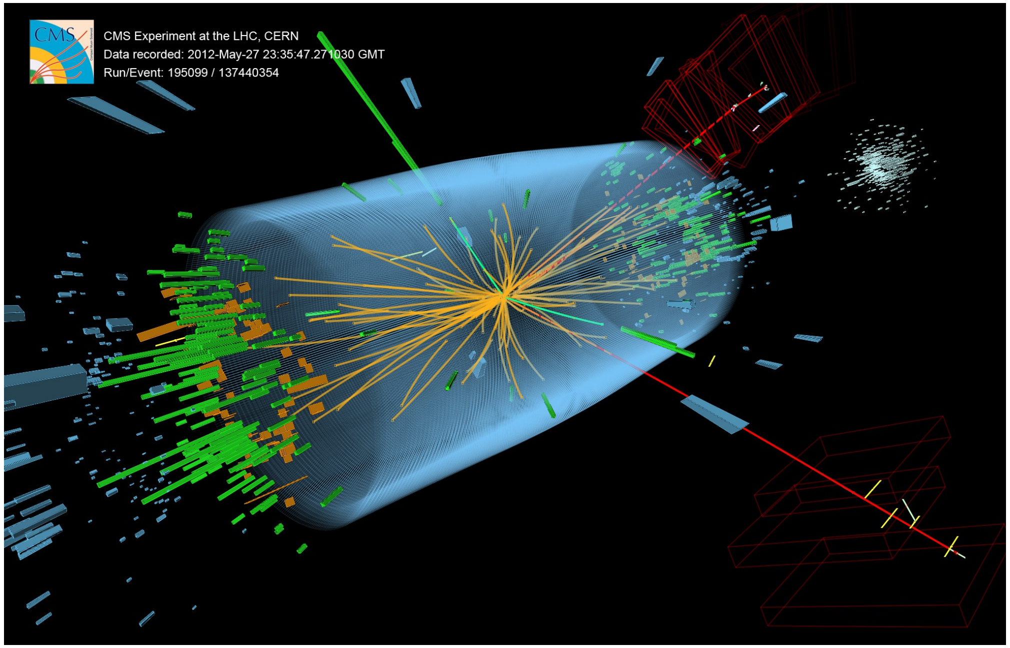
c.m.s: 240 GeV or higher, S/B ~ 1:100 - 1000

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

Derive: Absolute Higgs width, branching ratios, couplings

Higgs measurement at e+e- & pp

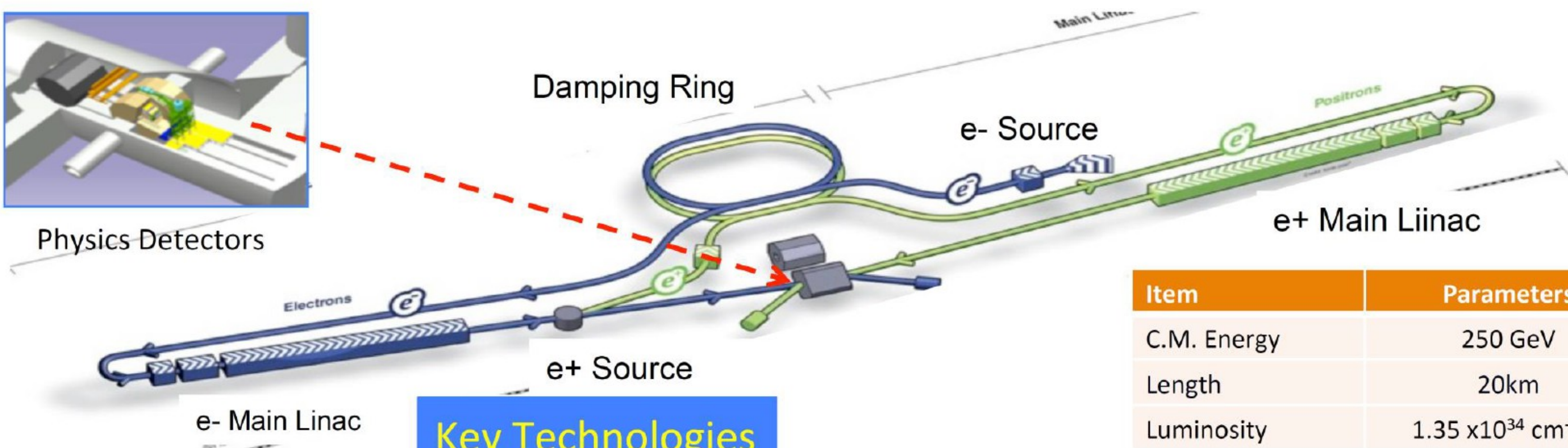


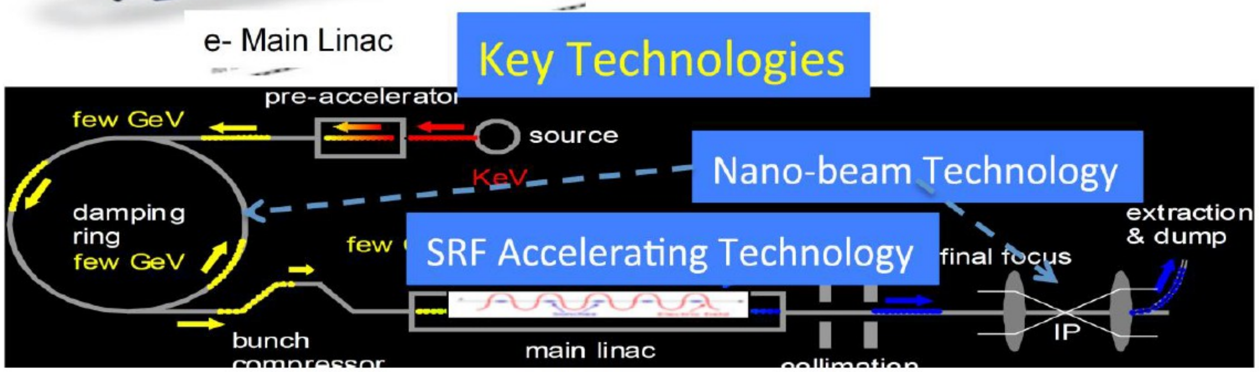


	Yield	efficiency	Comments
LHC	Run 1: 10^6 Run 2/HL: $10^{7\text{-}8}$	~o(10^{-3})	High Productivity & High background, Relative Measurements, Limited access to width, exotic ratio, etc, Direct access to g(ttH), and even g(HHH)
CEPC	10^6	~o(1)	Clean environment & Absolute measurement, Percentage level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

Complementary

e+e- Higgs factories – I: ILC





Item	Parameters
C.M. Energy	250 GeV
Length	20km
Luminosity	1.35 x10^{34} cm^{-2}s^{-1}
Repetition	5 Hz
Beam Pulse	0.73 ms
Beam Current	5.8 mA (in pulse)
Beam size (y) at FF	**7.7** nm@250GeV
SRF Cavity G.	**31.5** MV/m

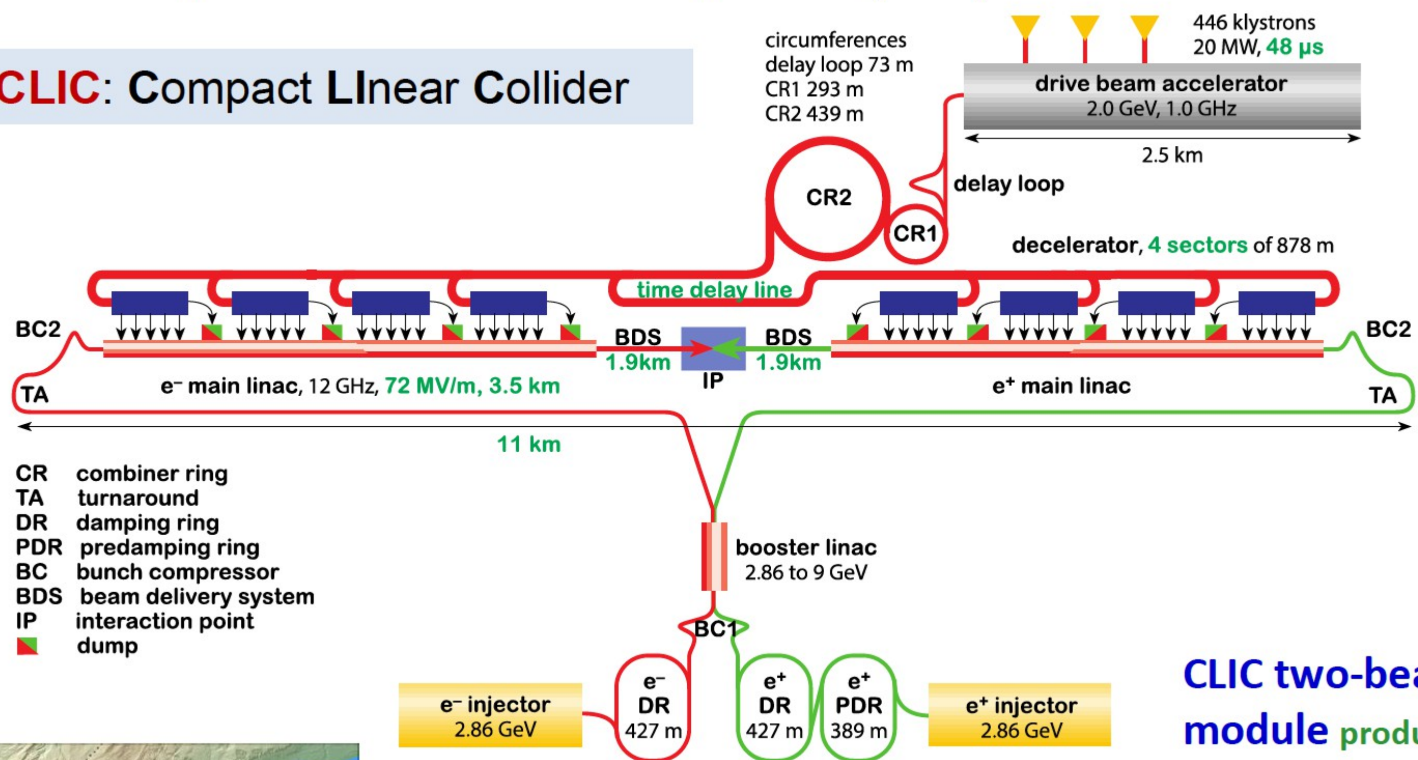
ILC250 - Recent re-scope to start with an initial energy of 250 GeV, key issues:

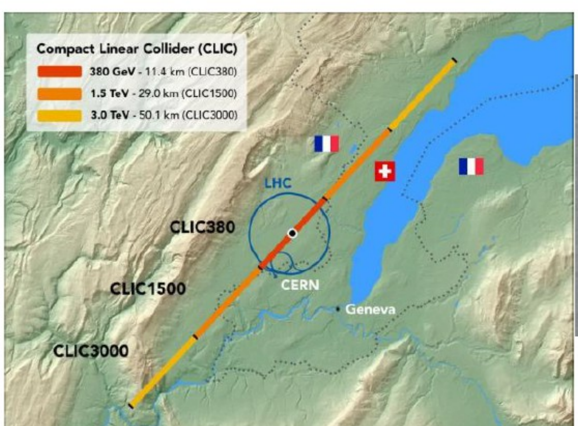
- Precision on H depends on integrated Lumi
- no tt~ at this stage
- reduced ability for BSM search

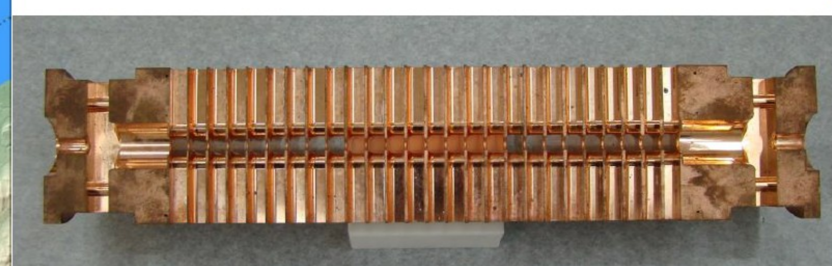
ILC250 does provide impressive precision, and Is upgradable in energy.

e+e- Higgs factories – II: CLIC

CLIC: Compact LInear Collider

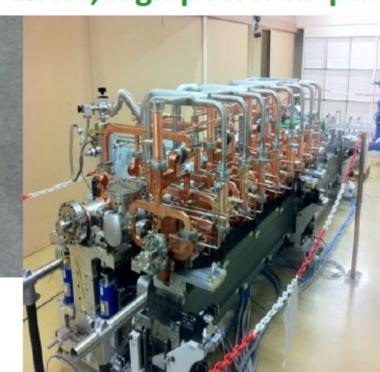




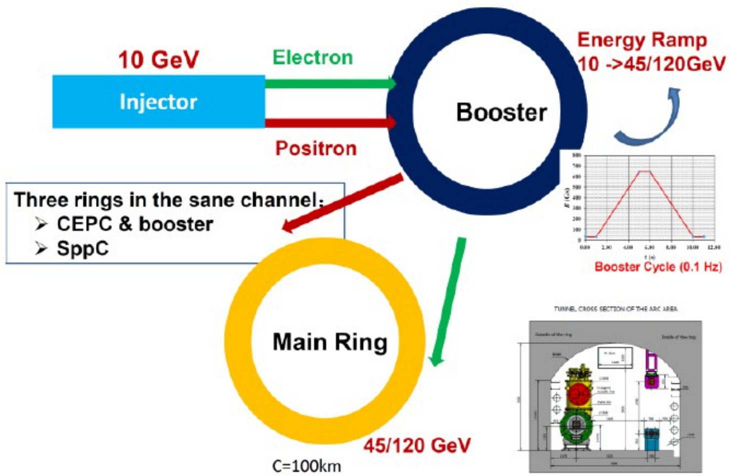


accelerating structure
high gradient makes machine cheap

CLIC two-beam module produces short, high power RF pulse

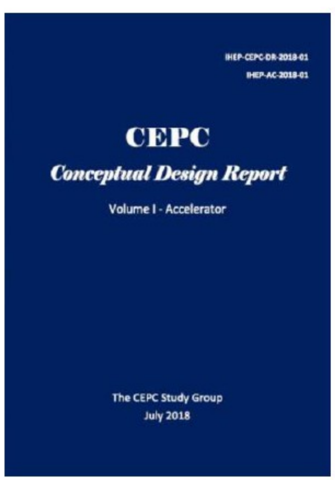


e+e- Higgs factories – III: CEPC

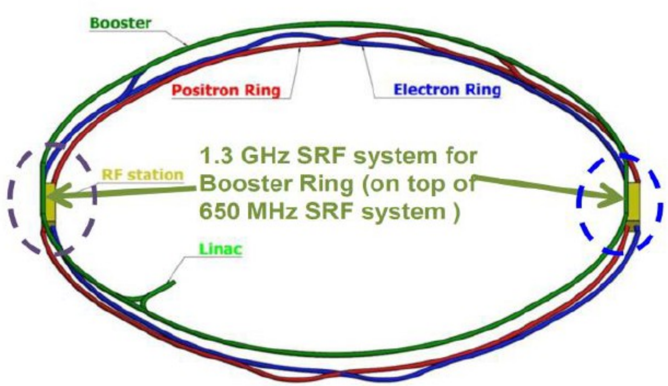


Lumi.	Higgs	W	Z	Z(2T)
$\times 10^{34}$	2.93	11.5	16.6	32.1

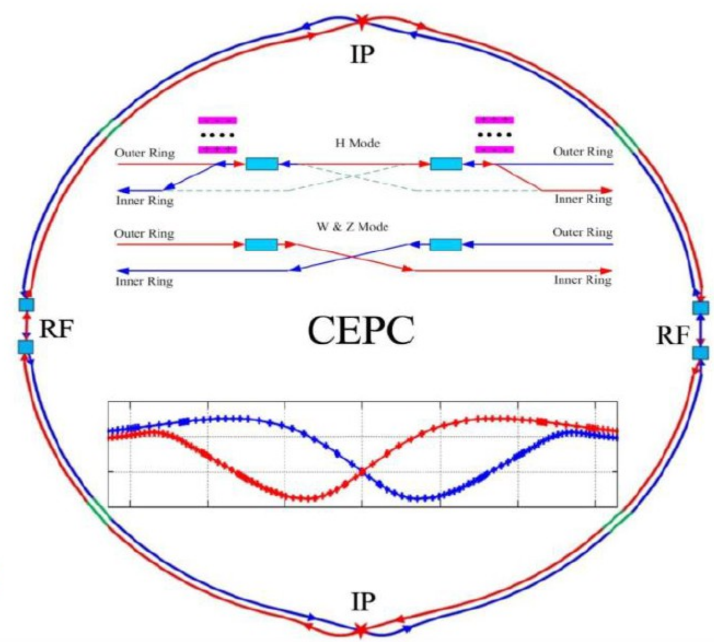
- double ring baseline design (30MW/beam)
- switchable between H and Z/W w/o
- hardware change (magnet switch)
- use half SRF for Z and W
- can be optimized for Z with 2T detector



reviewed by intl. committee, to be finalized soon.

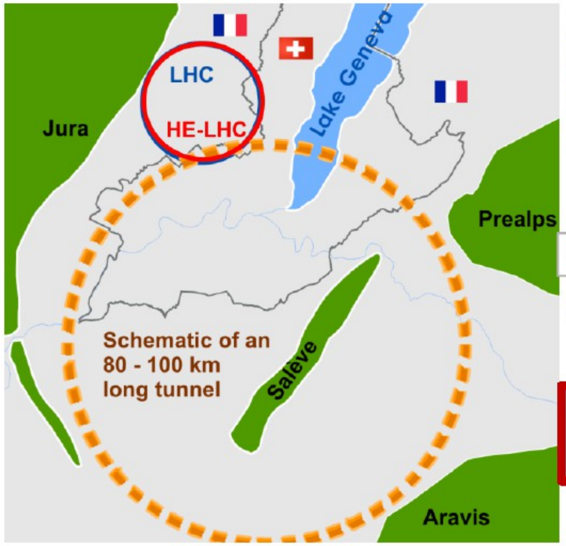


SRF system location of CEPC (two RF stations)



Layout of 650 MHz SRF system for Collider Ring

e+e- Higgs factories – IV: FCC(ee)



International FCC collaboration (CERN as host lab) to study:

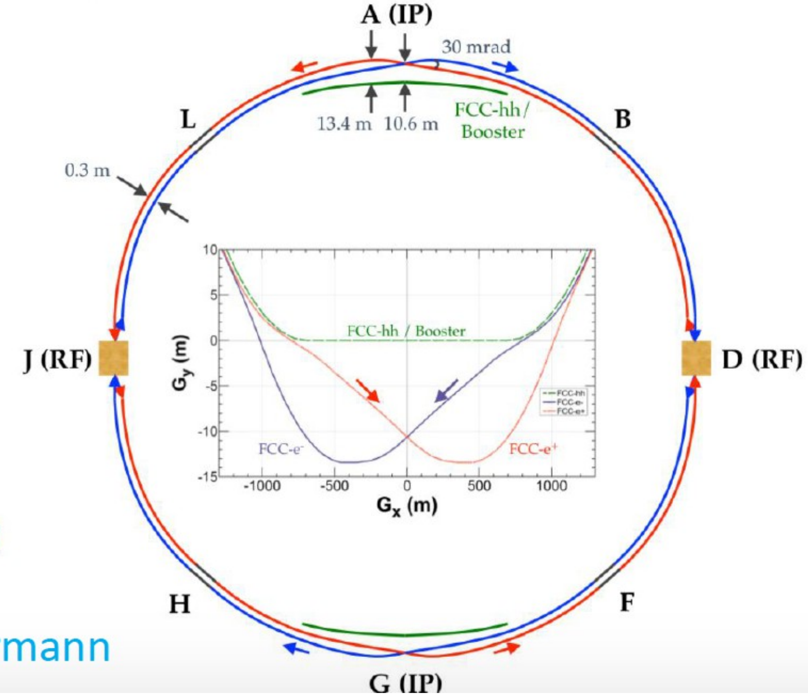
- ***pp*-collider (*FCC-hh*)**
  → long-term goal, defining infrastructure requirements

~16 T ⇒ 100 TeV *pp* in 100 km

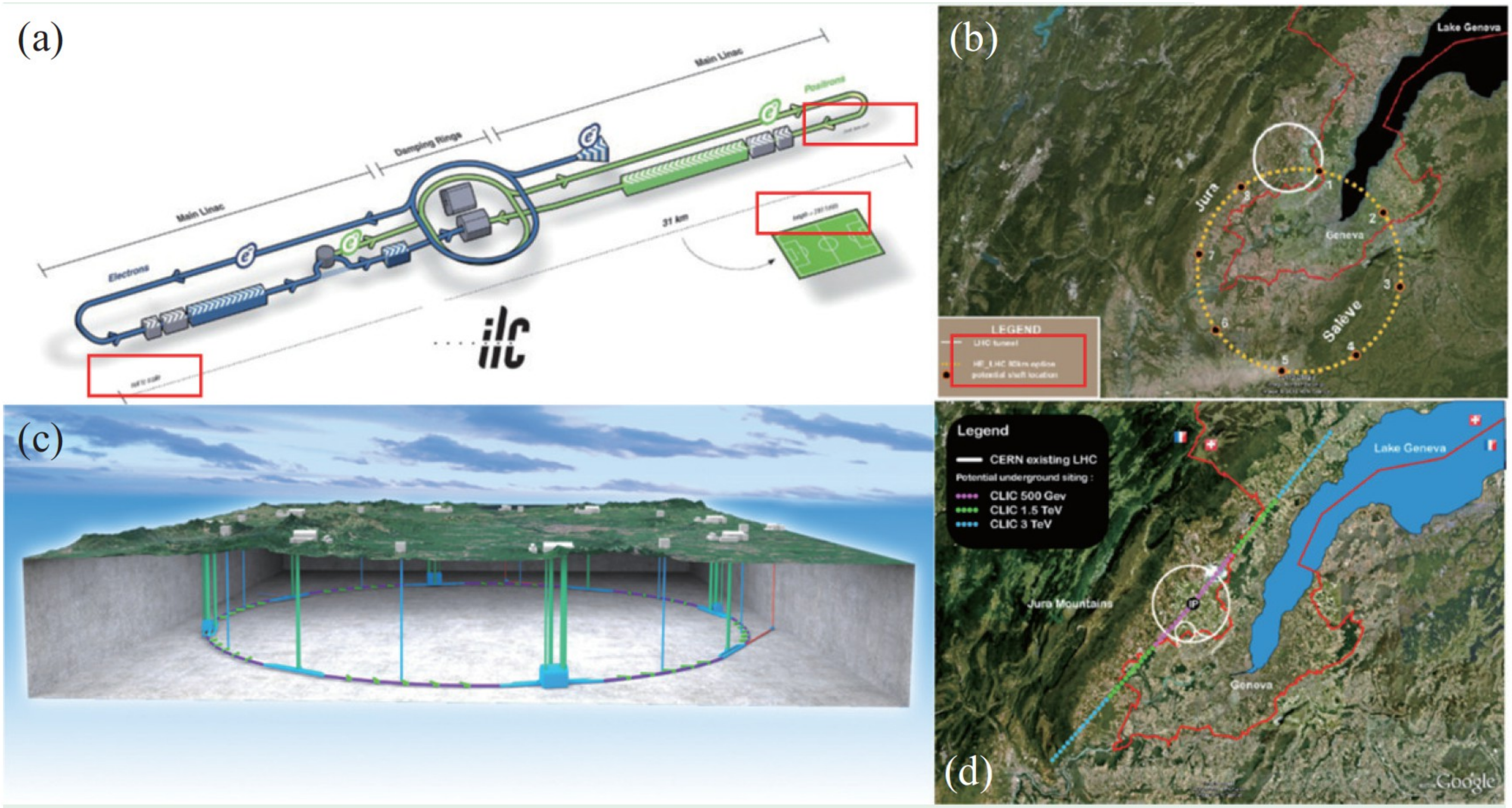
- **~100 km tunnel infrastructure** in Geneva area, site specific
- ***e⁺e⁻* collider (*FCC-ee*),** as potential first step
- **HE-LHC** with *FCC-hh* technology

- **Injection of 20 GeV beams to Booster;**
- **Interleaved filling of e+/e- ;**
- **Continuous top-up**

- **Double ring** e+ e- collider ~100 km
- **Follows footprint of FCC-hh**, except around IPs
- **Asymmetric IR layout and optics** to limit synchrotron radiation towards the detector
- **2 IPs, large** horizontal crossing angle **30 mrad, crab-waist optics**
- **Synchrotron radiation power 50 MW/beam** at all beam energies
- **Top-up injection** scheme for high luminosity
- Requires **booster synchrotron in collider tunnel**

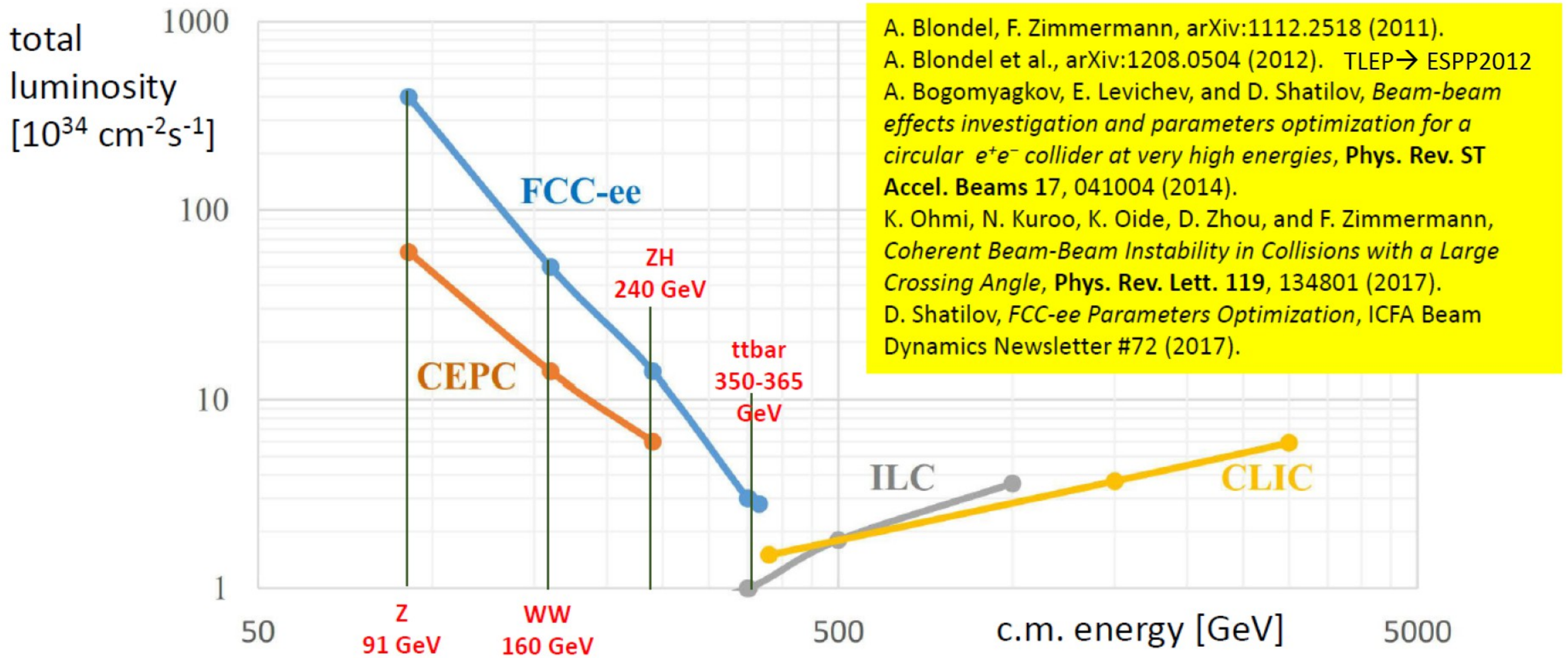


Multiple e+e- Higgs factories are proposed



ILC (a): TDR released in 2013
FCC (b): CDR released in 2019
CEPC (c): CDR released in 2018
CLIC (d): CDR released in 2013

Comparison: Linear & Circular



From A. Blondel's presentation at CEPC Oxford WS

summary of national priorities and interests for large future HEP projects :

country	item #	e+e- e-w,H,.. (ILC, ...)	e+e- incl. ttbar (FCC-ee)	e+e- incl. HH (ILC+,CLIC)	hh beyond LHC	hh he-LHC	hh FCC	eh	accel. R&D	R&D magnets FCC,he-LHC	R&D novel PWA,μ+μ-	non-accelerator (DM,ndbd)	neutrino physics	intensity frontier	nuclear (FAIR,EIC...)	astro-particle
A	108	1			3				2			√			√	√
B	122	1														
CH	142	1	1		3		3		2	2	3		√	√	√	√
CZ	88	3		3	2	2	2		1	1	1		√		4	
D	33	1		1	3	3	3		2	2	2	4	√	√	√	√
DK	61	3	3		3		3		2	2	2	1	√	√	√	√
E	31	1	3	1	3	3	3		2	2	4		√		√	√
F	15,116,155	1	√	√	3		3	√	2	2	√	√	√	√	√	√
FIN	55	1		1									√		√	√
I	26,138	1	1		3		3		2	2	2	√	√	√		√
IL	34	√			√							√	√	√		
N	43	1		1					3		3	√			√	√
NL	166	1	3	2	3		3		2	2	3	√	√	√		√
PL	125	1	√	√					2							
RO	73												√	√		
S	127	1		1					2	2	√	√	√	3		√
SLO	78															
UK	134,144	1		1	2		2	2	3	3	√	√	√		√	
total score:		13,67	3	6,83	3,67	1,17	3,33	0,5	6,67	5,33	3,75					

1...4: priority 1 to priority 4;
√: mentioned without (clear) assignment of priority
total score: =Σ(1/priority) where given; √ not counted

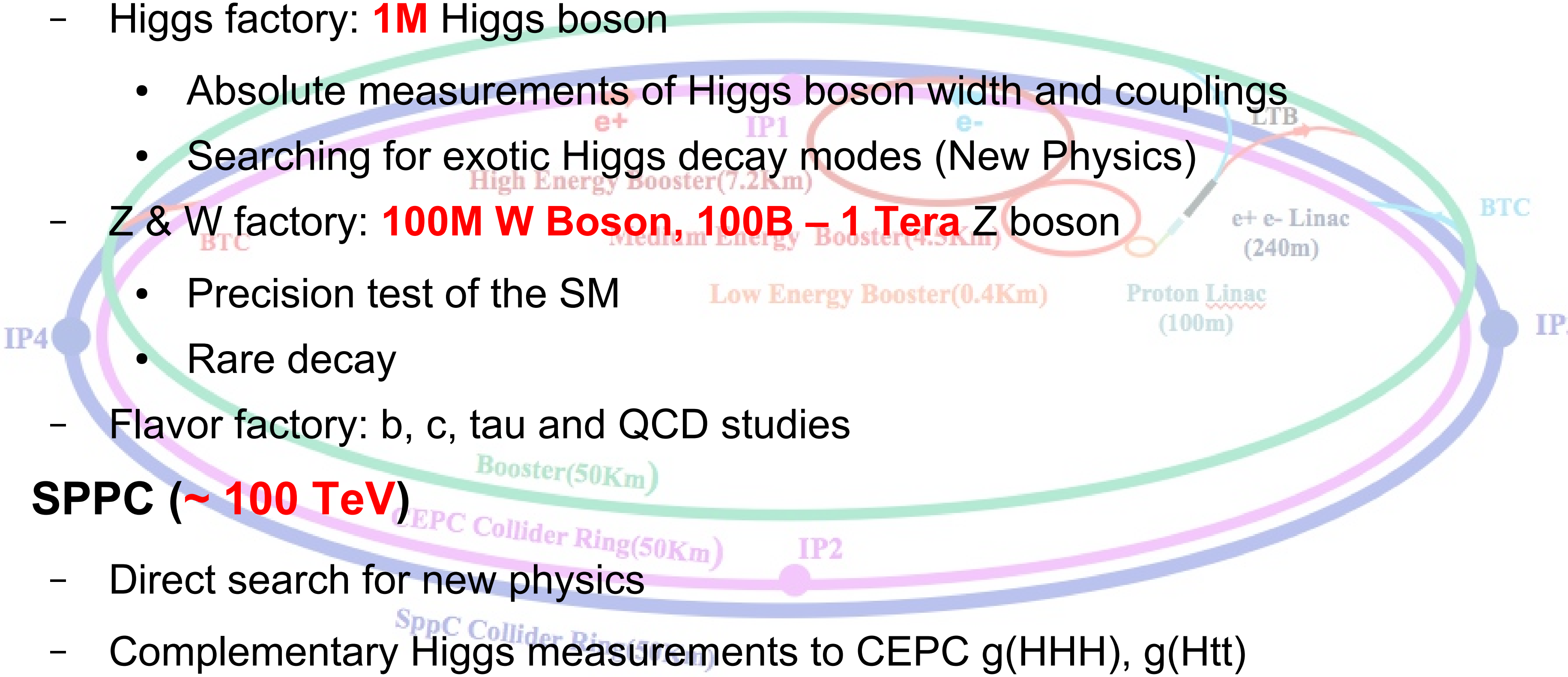
Notes:
– table reflects status of inputs submitted by Dec. 2018
– intended for overview of physics or projects priorities
– see disclaimers on previous and following pages!

Summary of National Inputs | S. Bethke (MPP Munich) | ESPP Symposium, Granada, 15 May 2019 | 5

- clear preference for an e^+e^- collider as the next h.e. collider:
  – as H-factory and for precision e.w. measurements (ILC, CEPC, FCC-ee, CLIC)
  – significant demands for upgradeability to access $t\bar{t}$ (ILC, CEPC, FCC-ee, CLIC) and also HH and ttH final states (ILC+; CLIC)

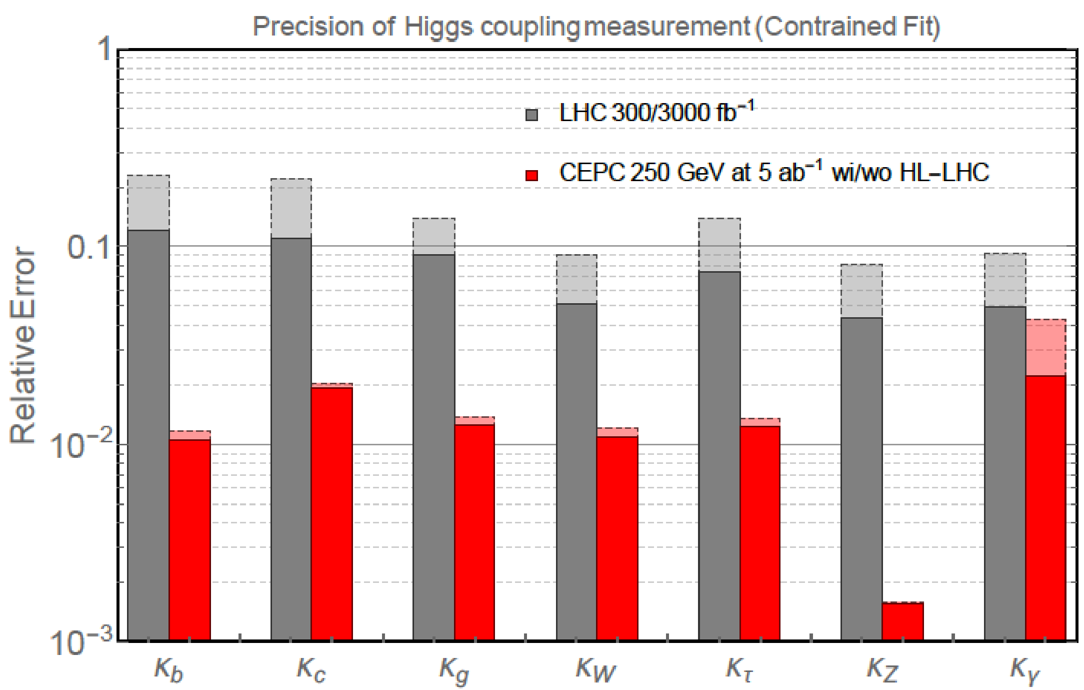
Science at CEPC-SPPC

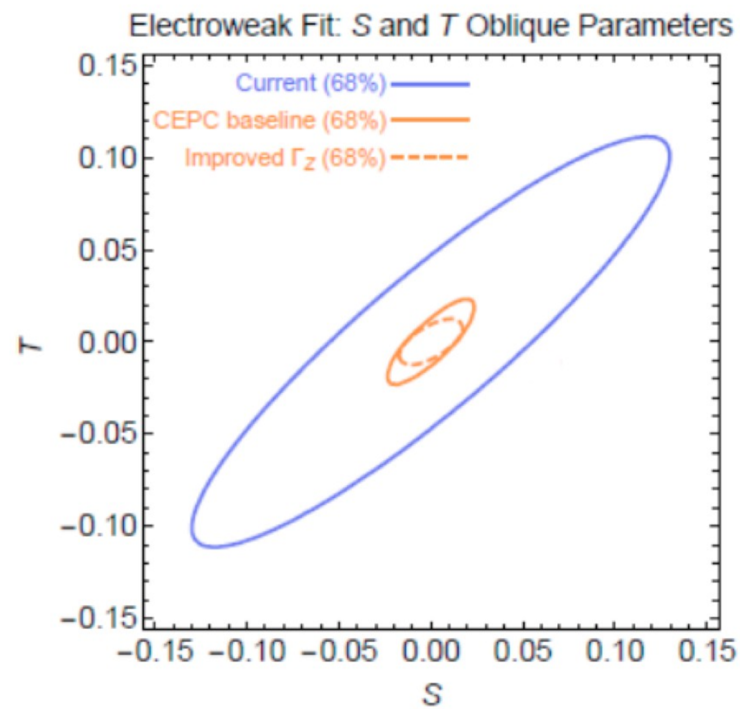
- **Tunnel ~ 100 km**
- **CEPC (90 – 250 GeV)**
  - Higgs factory: **1M** Higgs boson
    - Absolute measurements of Higgs boson width and couplings
    - Searching for exotic Higgs decay modes (New Physics)
  - Z & W factory: **100M W Boson, 100B – 1 Tera** Z boson
    - Precision test of the SM
    - 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

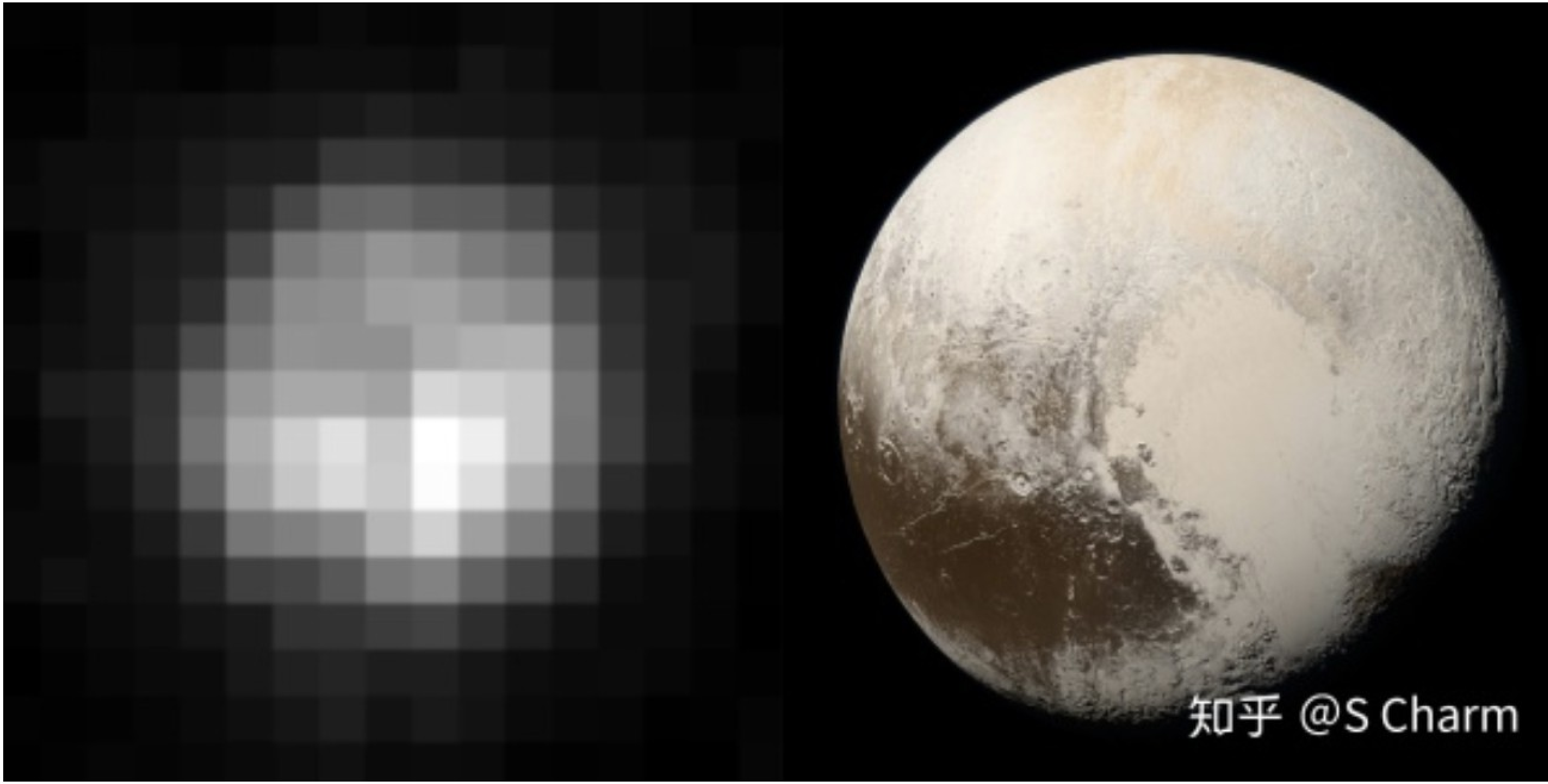
Physics Potential





- 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

看得更清晰意味着什么？



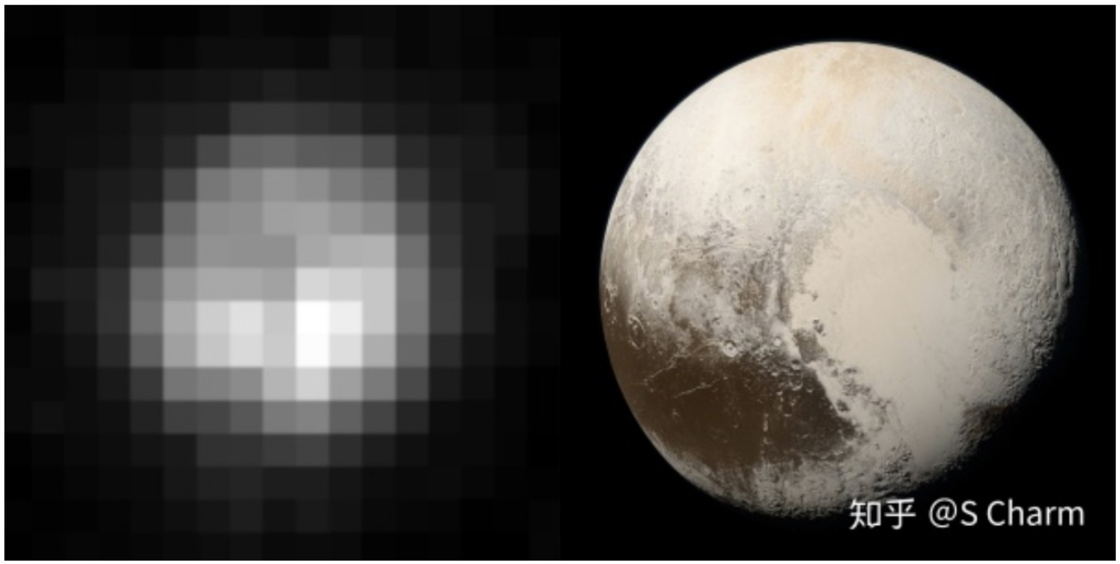
1994年和2018年人类所认知的冥王星的对比图。左图来自哈勃空间望远镜，右图来自新视野号航天器。
（图片来源：NASA）

Higgs 粒子和暗物质

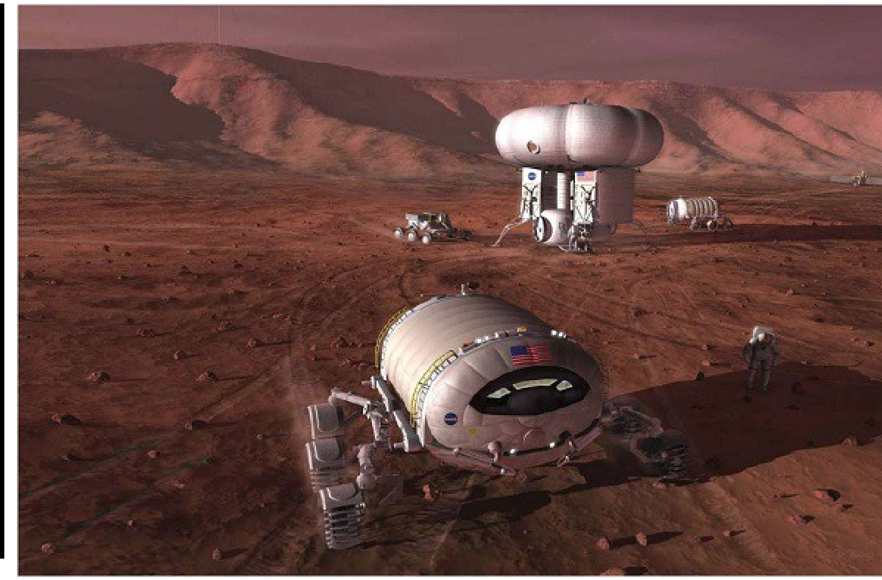
只要有大于千分之一的 Higgs 粒子衰变为不可见粒子 – 暗物质粒子，CEPC 将能够确认这一信号

任意导致 Higgs 粒子衰变行为发生变化的新物理信号→ Higgs 粒子的宽度可被测至 3% 的相对精度

CEPC 的可能升级计划



1994年和2018年人类所认知的冥王星的对比图。左图来自哈勃空间望远镜，右图来自新视野号航天器。
（图片来源：NASA）

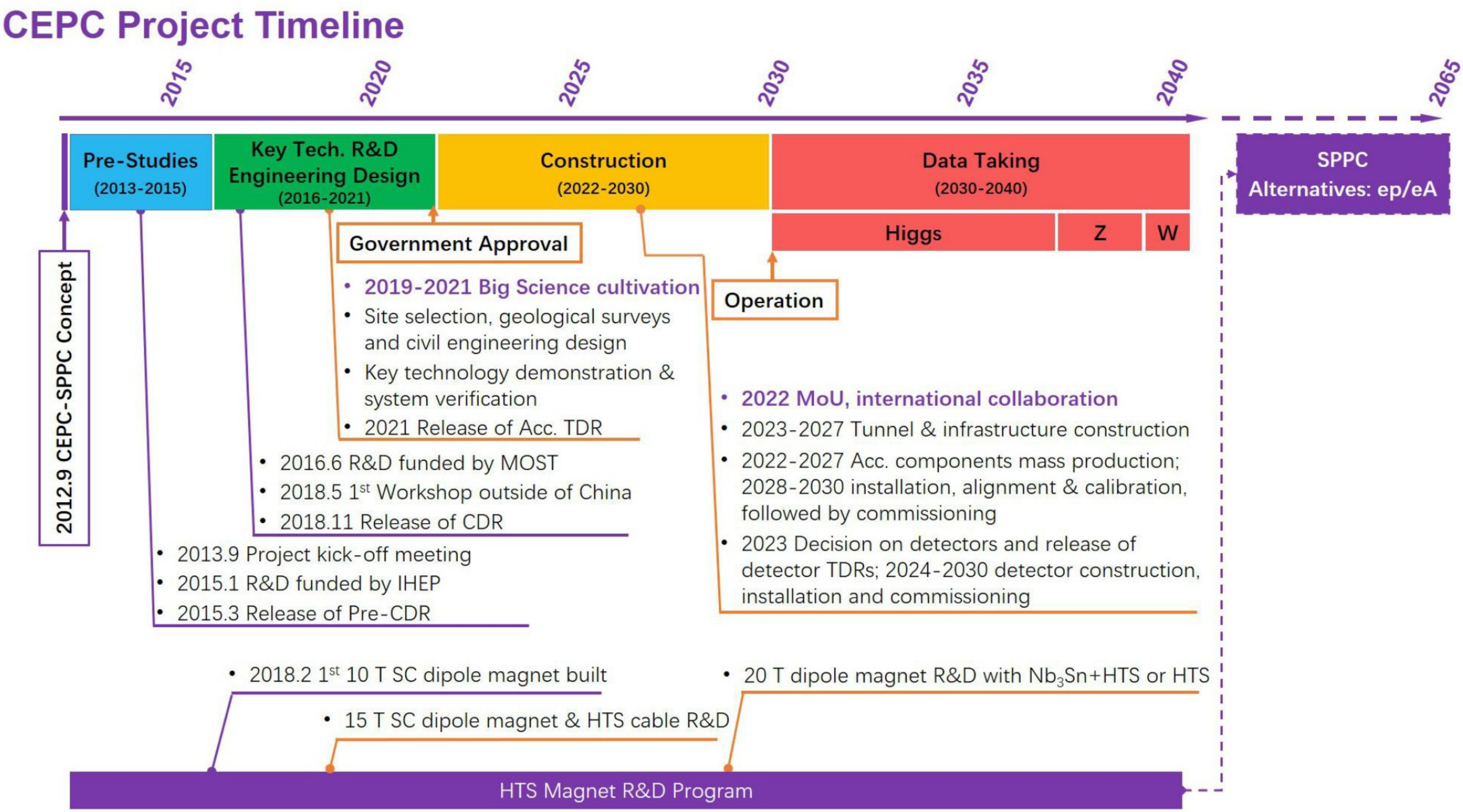


- 高能量
- 高亮度
- SPPC ：质子对撞，质心能量 100TeV ，超过 LHC 近一个量级
- 具体升级高度依赖于 **CEPC 的观测结果**，以及相关技术的研发准备

CEPC ：望远镜，揭示全新的海图 - 是否在我们能力范围内，有新大陆？

SPPC ：驶向未知海域的航船 - 新大陆是怎样的？

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)
SPPC
Alternatives: ep/eA
Higgs
Z
W
Government Approval
Operation
2012.9 CEPC-SPPC Concept
• 2019-2021 Big Science cultivation
• Site selection, geological surveys and civil engineering design
• Key technology demonstration & system verification
• 2021 Release of Acc. TDR
• 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

CEPC Cost and Powert

- 360 亿
  - 北京地铁 16 号线（ 49 公里总长，每公里造价 12 亿）的 60%
- 能耗： 300MW
  - 典型热电厂功率的 15%

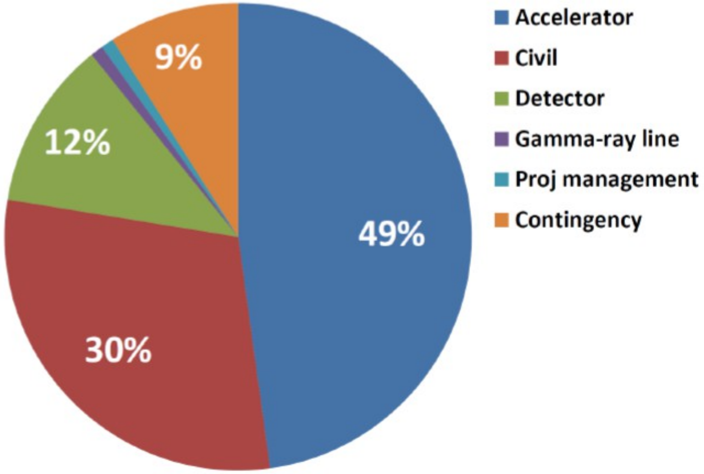


Figure 12.1: Relative cost of the CEPC project constituents.

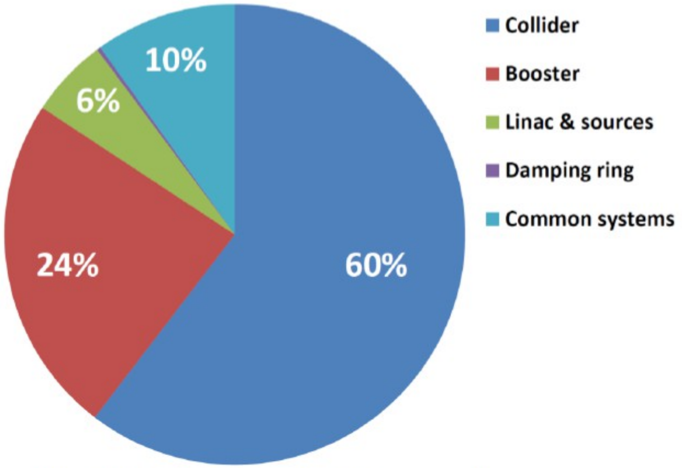
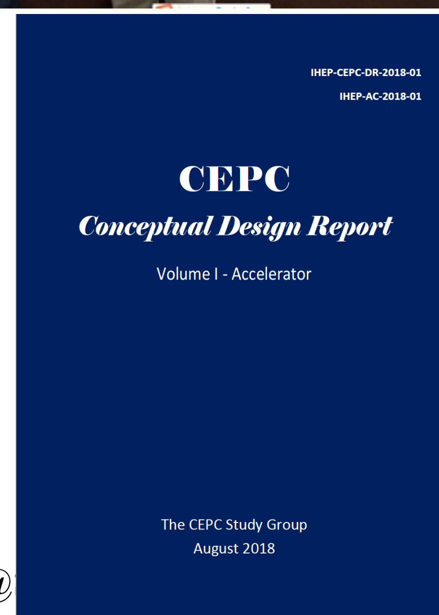
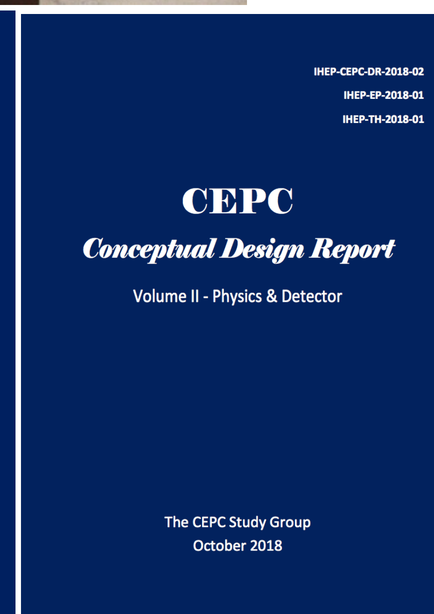


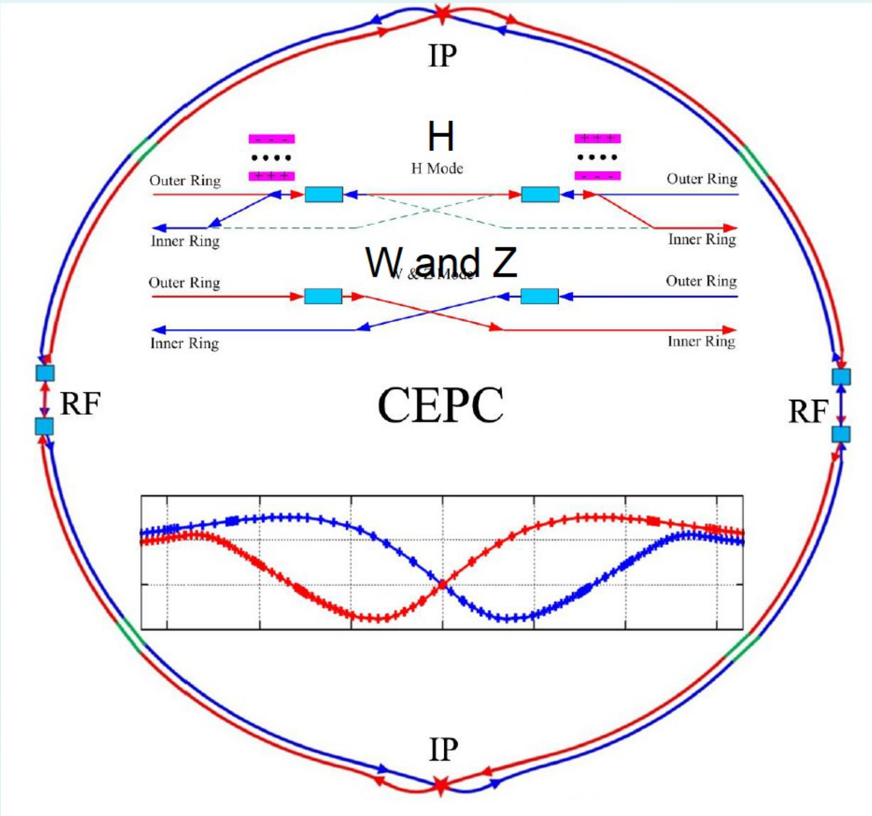
Figure 12.2: Cost breakdown of the CEPC major accelerator components.

CDR released in Nov. 2018

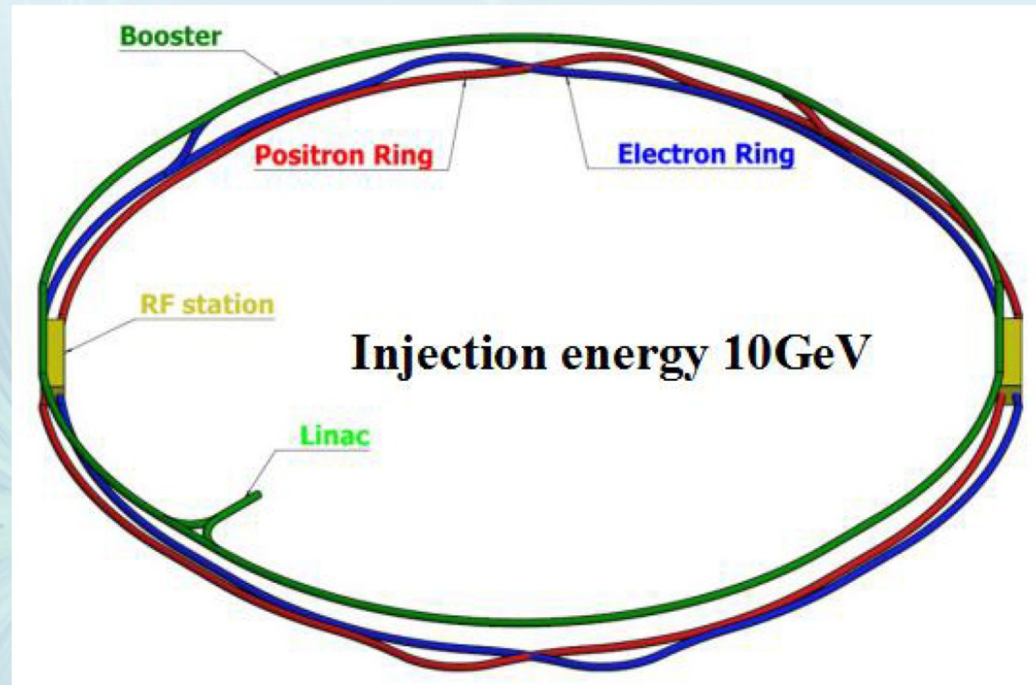




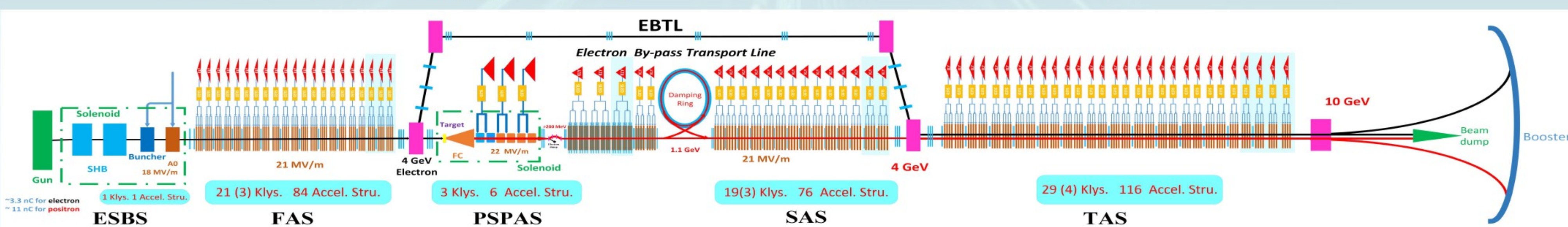
CEPC Accelerator Baseline Layout



CEPC collider ring (100km)



CEPC booster ring (100km)

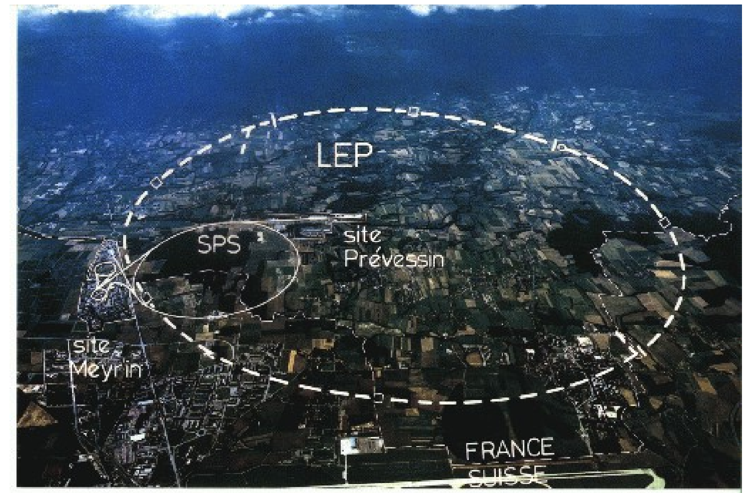


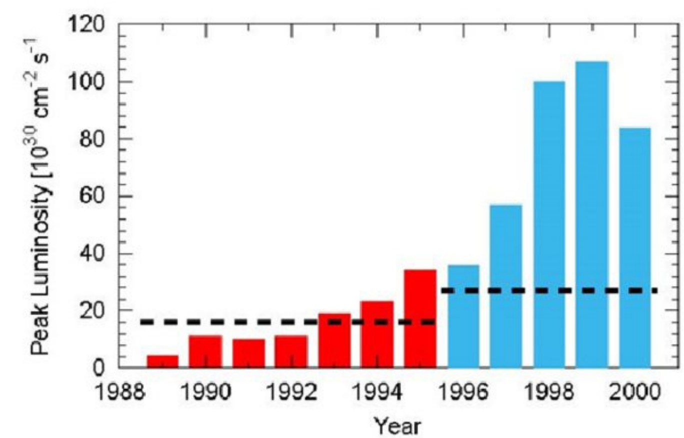
CEPC Collider baseline

CEPC CDR Parameters

D. Wang

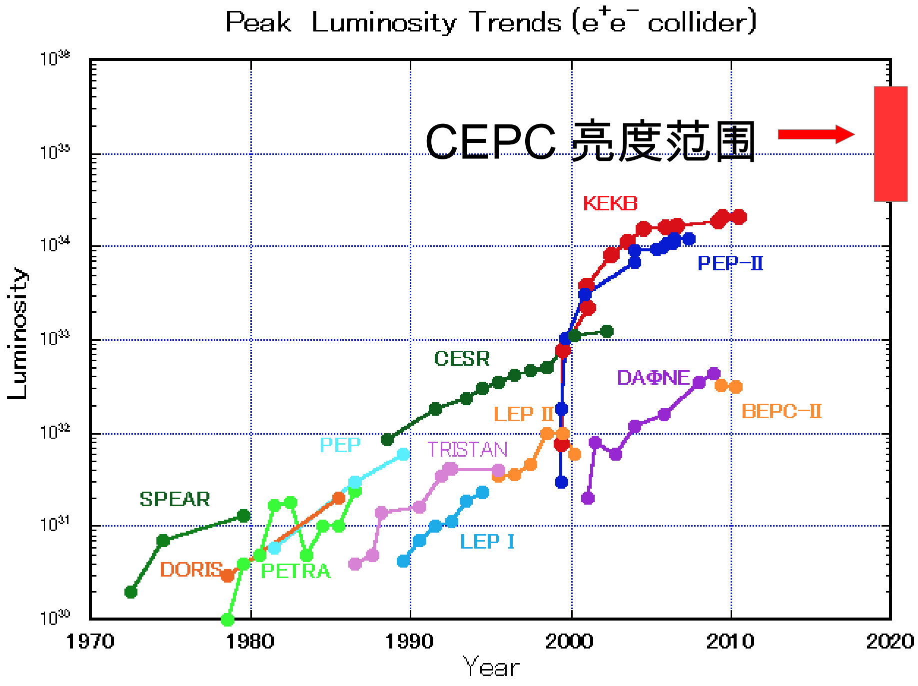
	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (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**

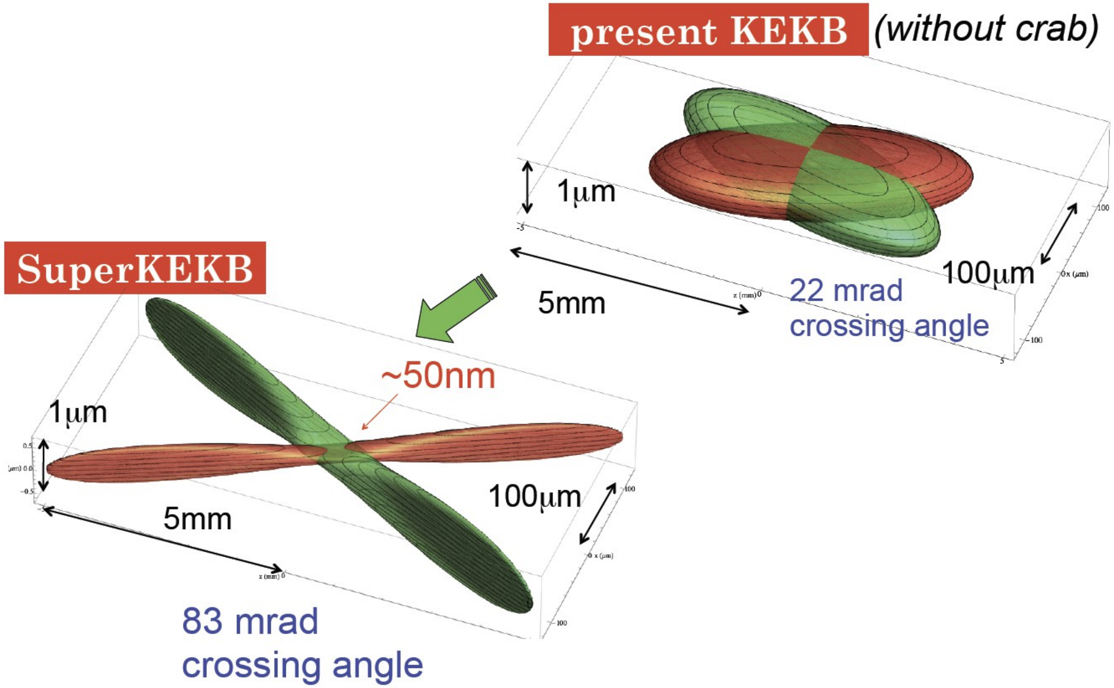




Increased by 3 orders of magnitude w.r.t LEP

Through more powerful, more precise final focusing





Nano Beam technology: The Key

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:

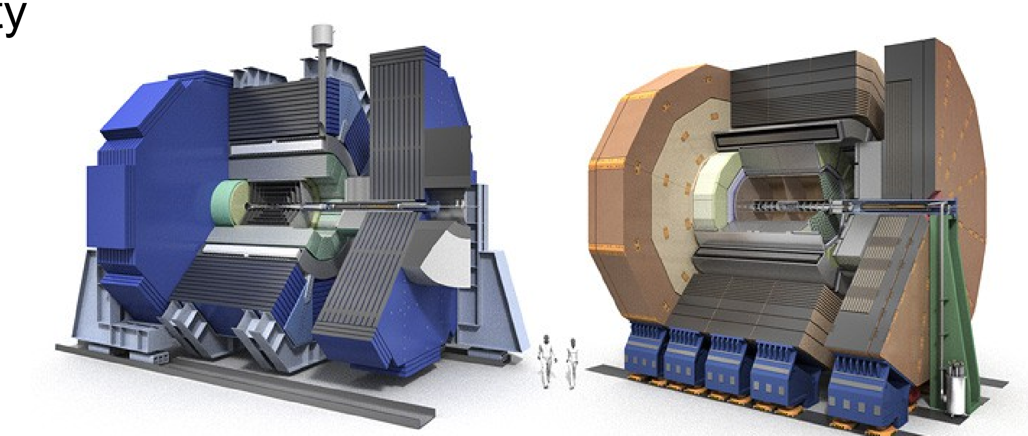
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

HL-Higgs operation Parameters:

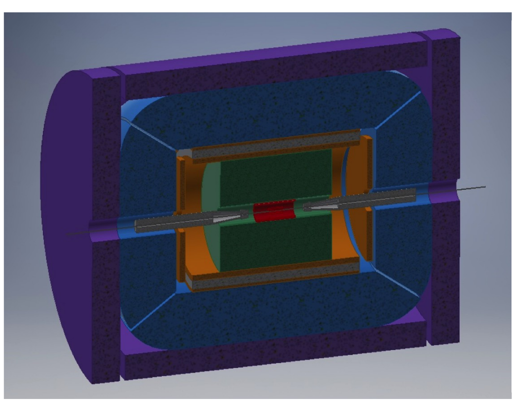
Lifetime (hour)	**0.22**	**1.2**	**3.2**	**2.0**
F (hour glass)	0.85	0.92	0.98	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**5.2**	**14.5**	**23.6**	**37.7**

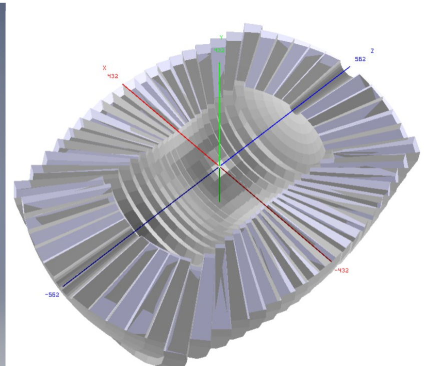
Two classes of Concepts

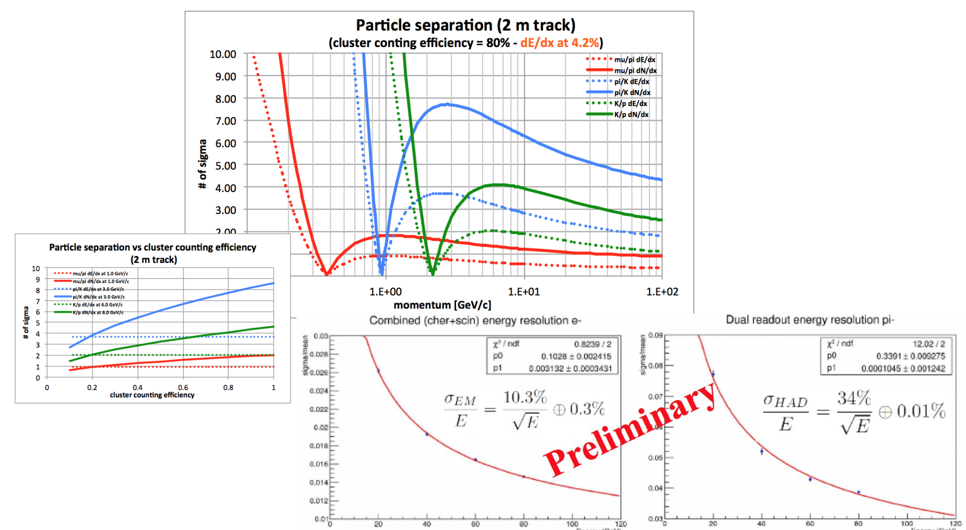
- PFA Oriented concept using High Granularity Calorimeter
  - + TPC (ILD-like, **Baseline**)
  - + Silicon tracking (SiD-like)



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



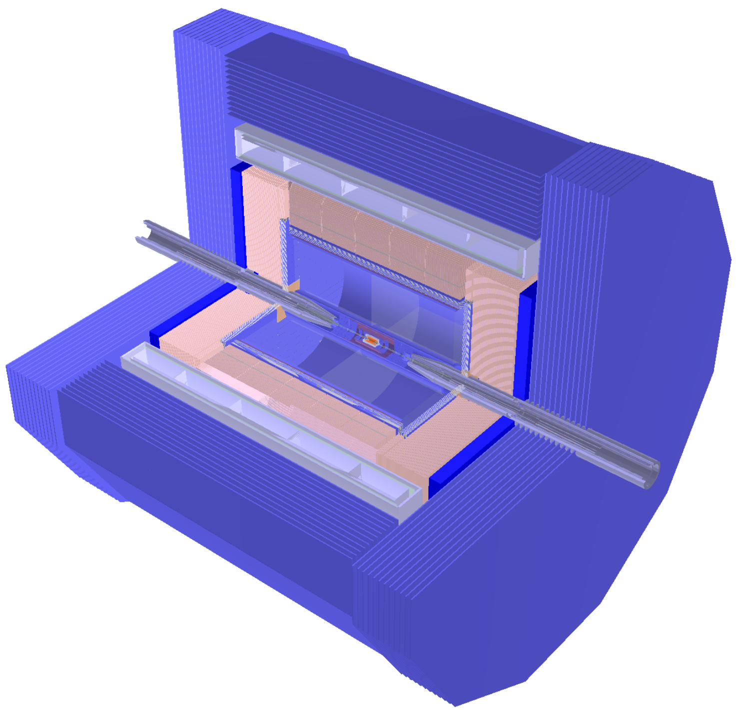


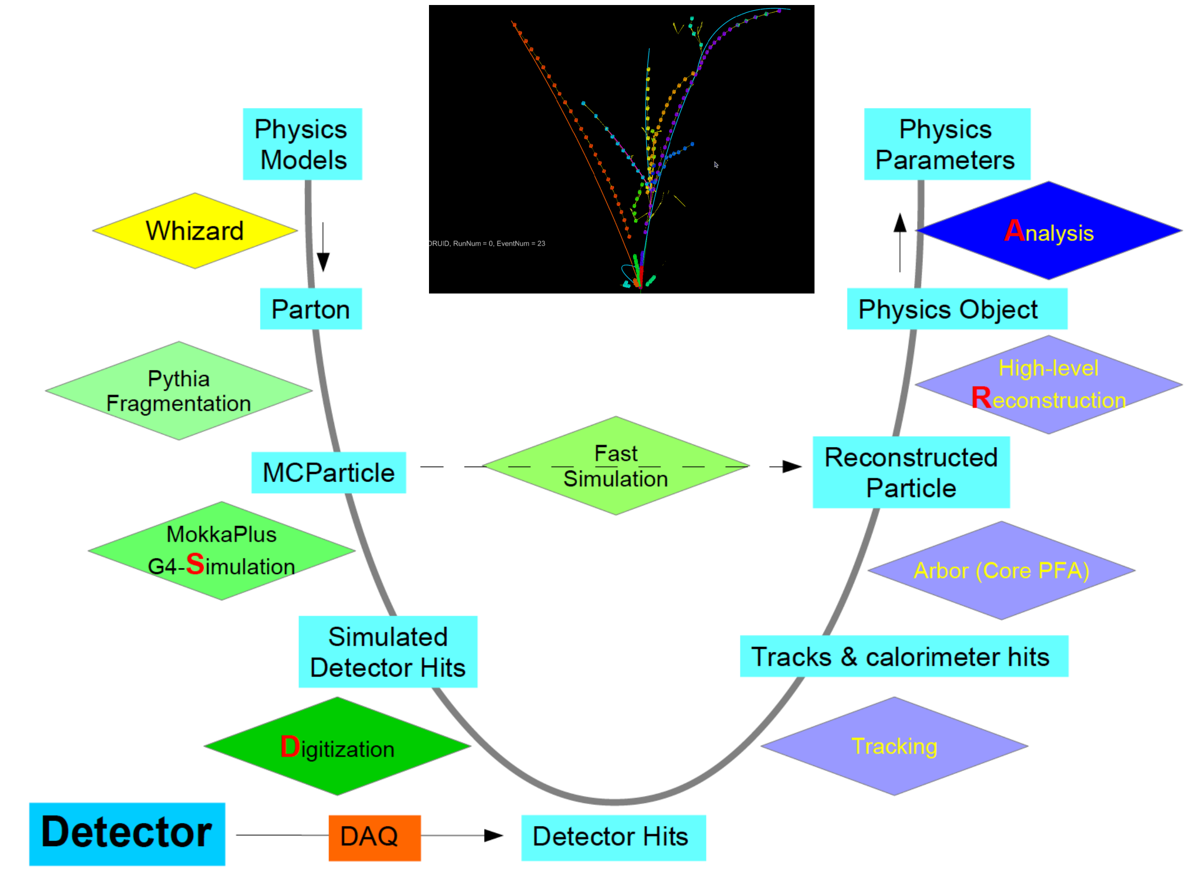


https://indico.ihep.ac.cn/event/6618/

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

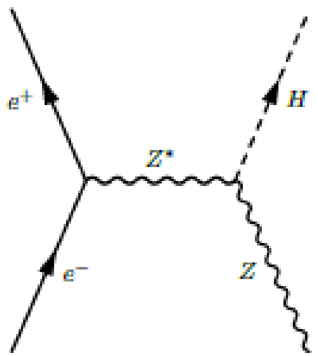
Software & Reconstruction

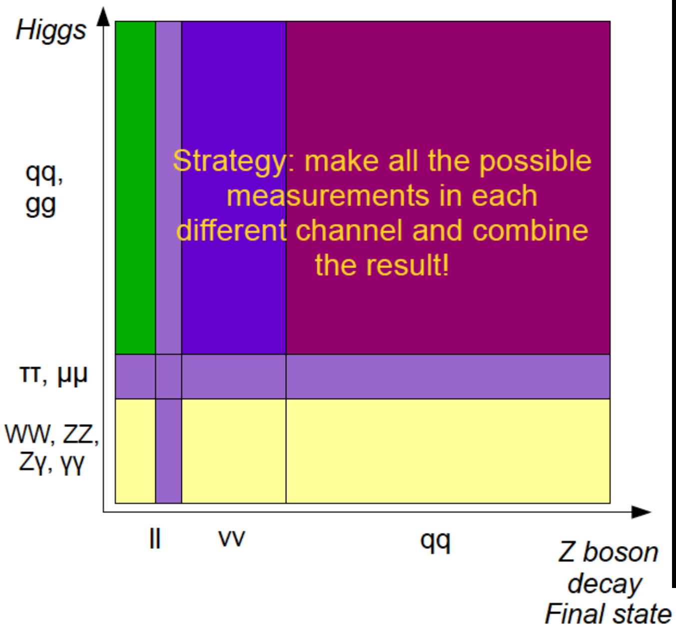


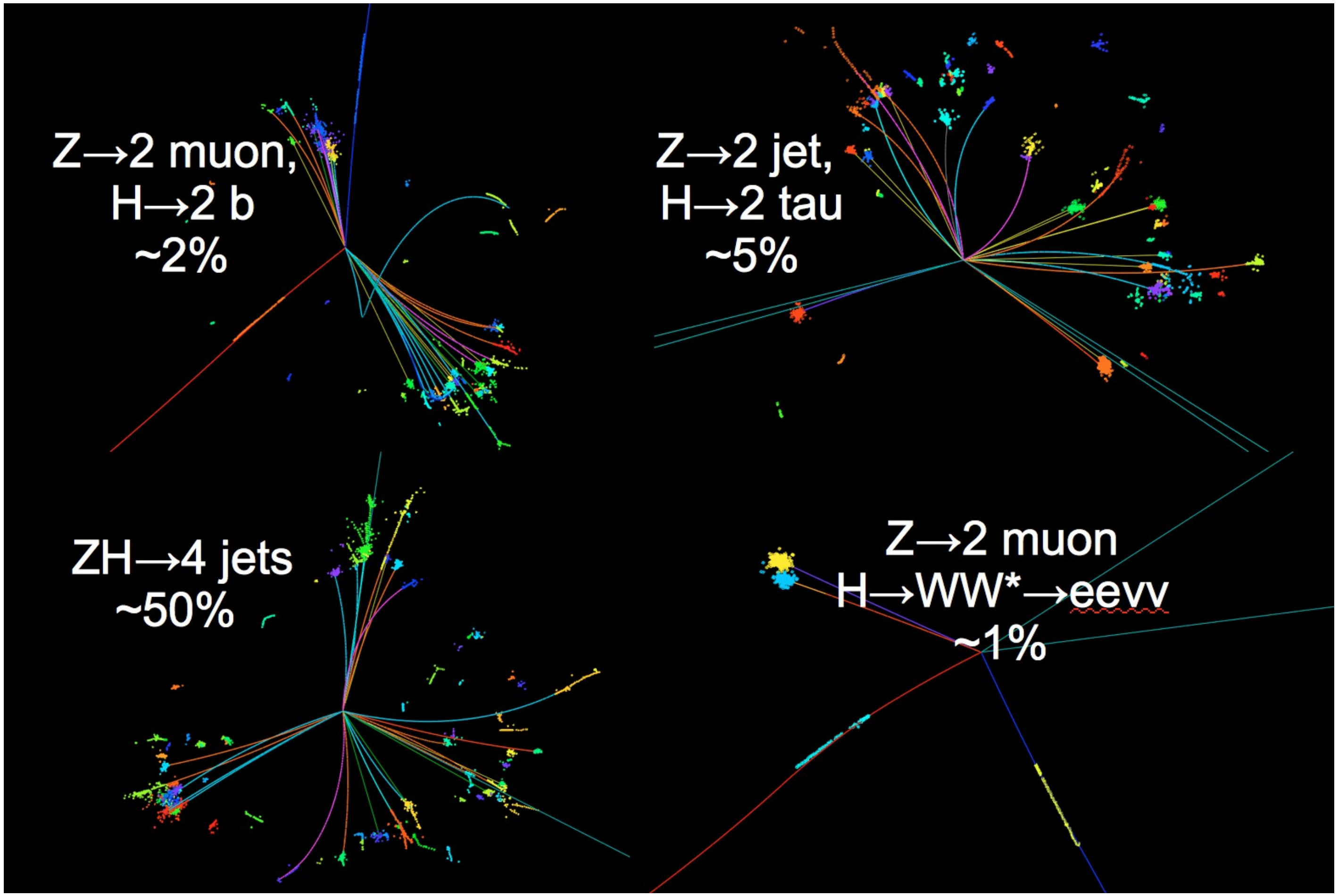


Starting from the ilcsoft & rewriting all the PFA/high-level reconstruction algorithms.

Signal events and detector requirements





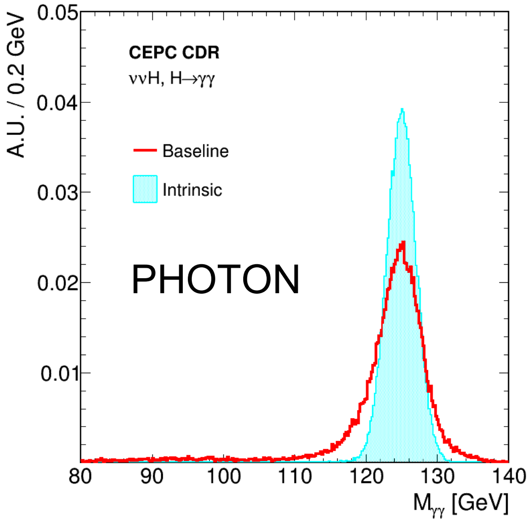


Detector:

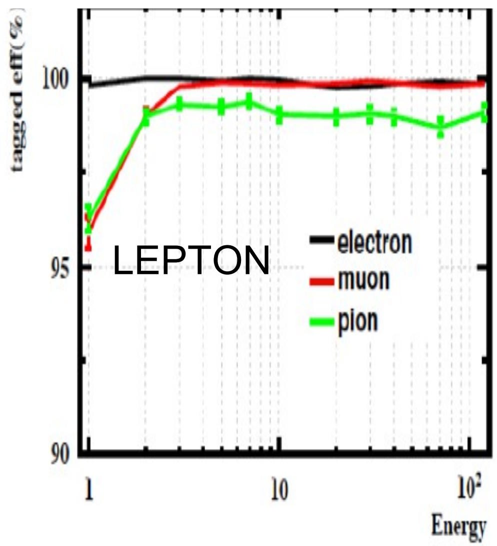
To reconstruct all the physics objects with high efficiency, purity & resolution

Homogenous & Stable enough to control the systematic

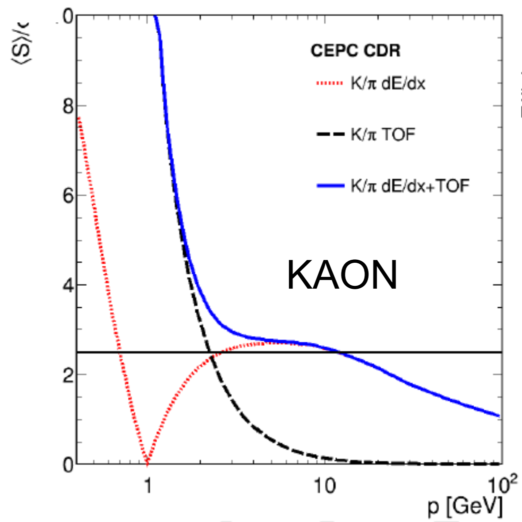
Physics Objects

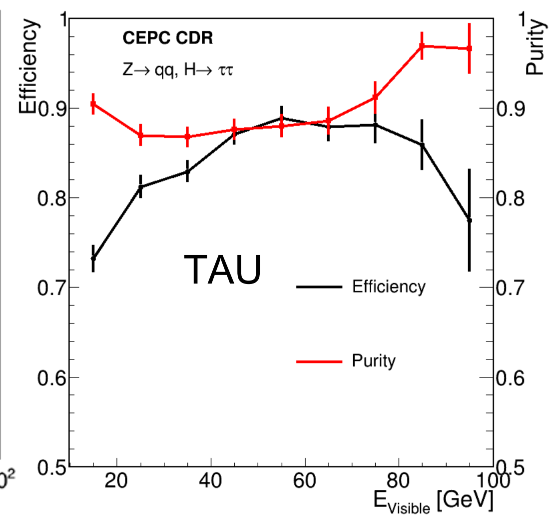


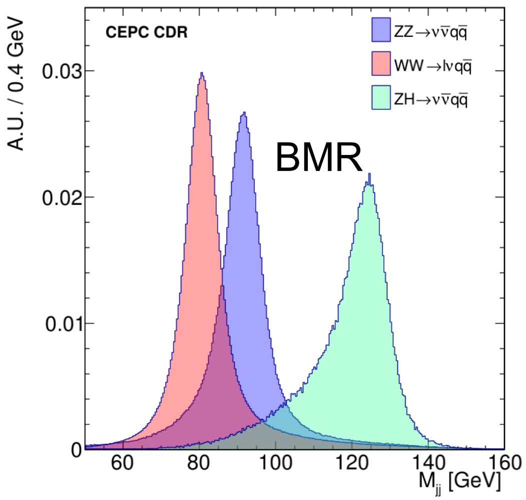
Eur. Phys. J. C (2017) 77: 591

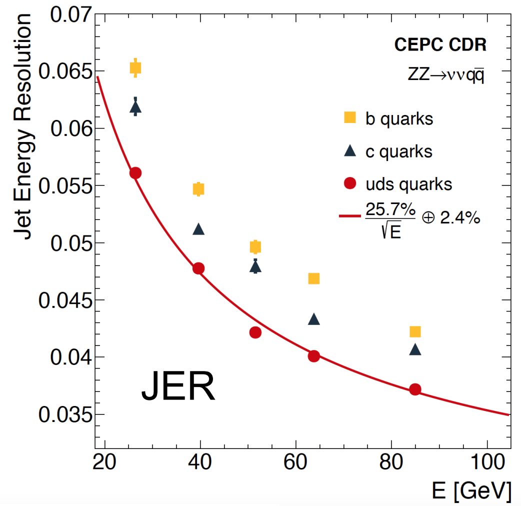


Eur. Phys. J. C (2018) 78:464

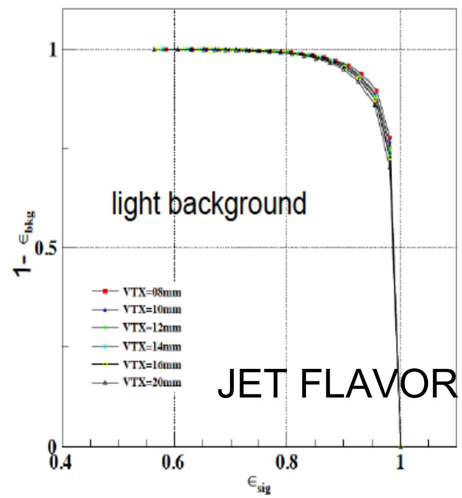


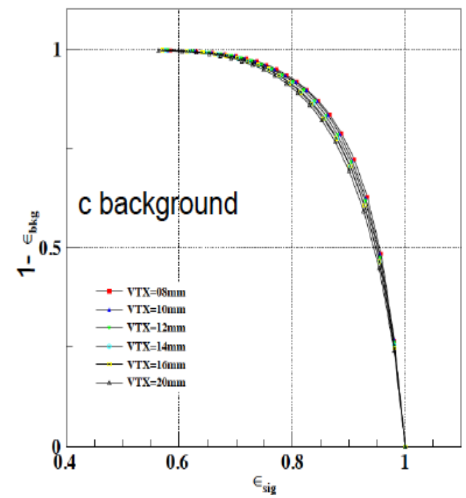




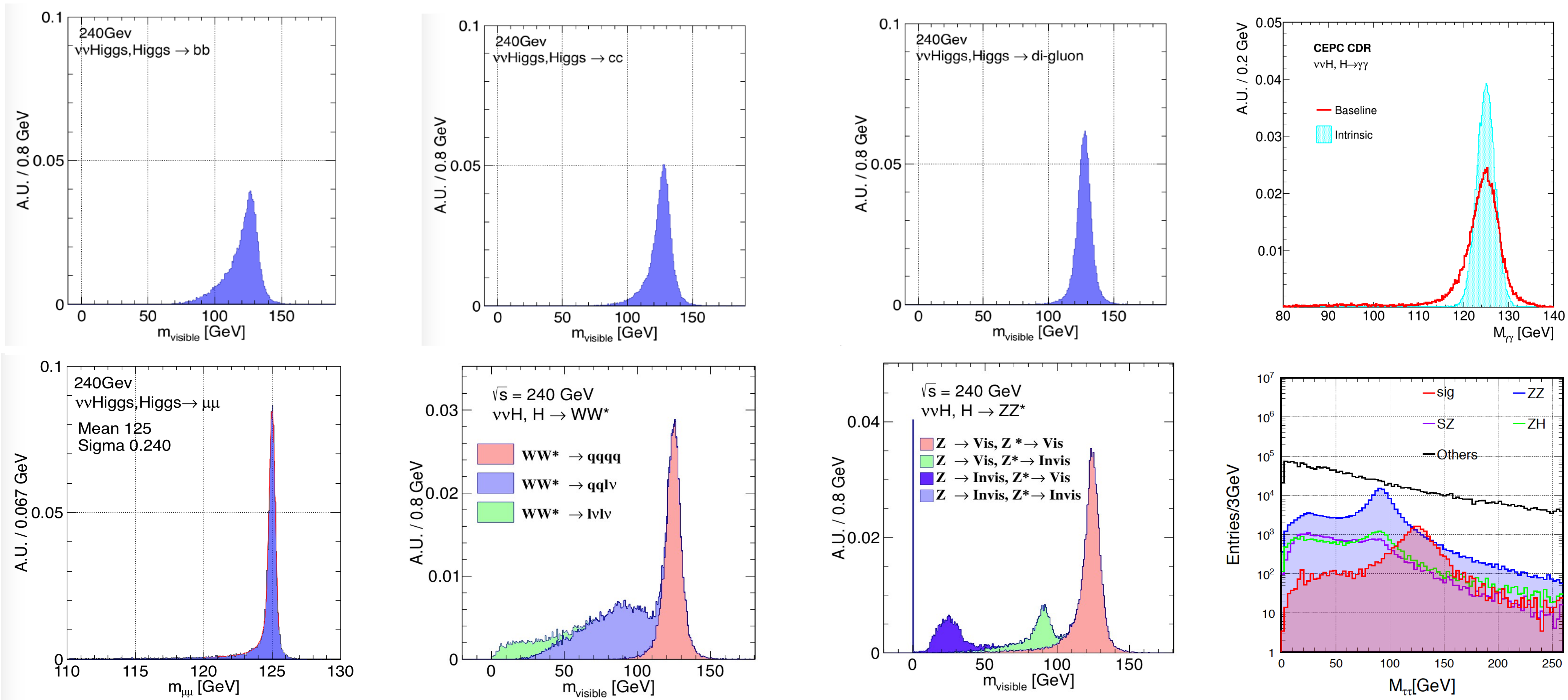


Eur. Phys. J. C (2018) 78: 426





Reconstructed Higgs Signatures

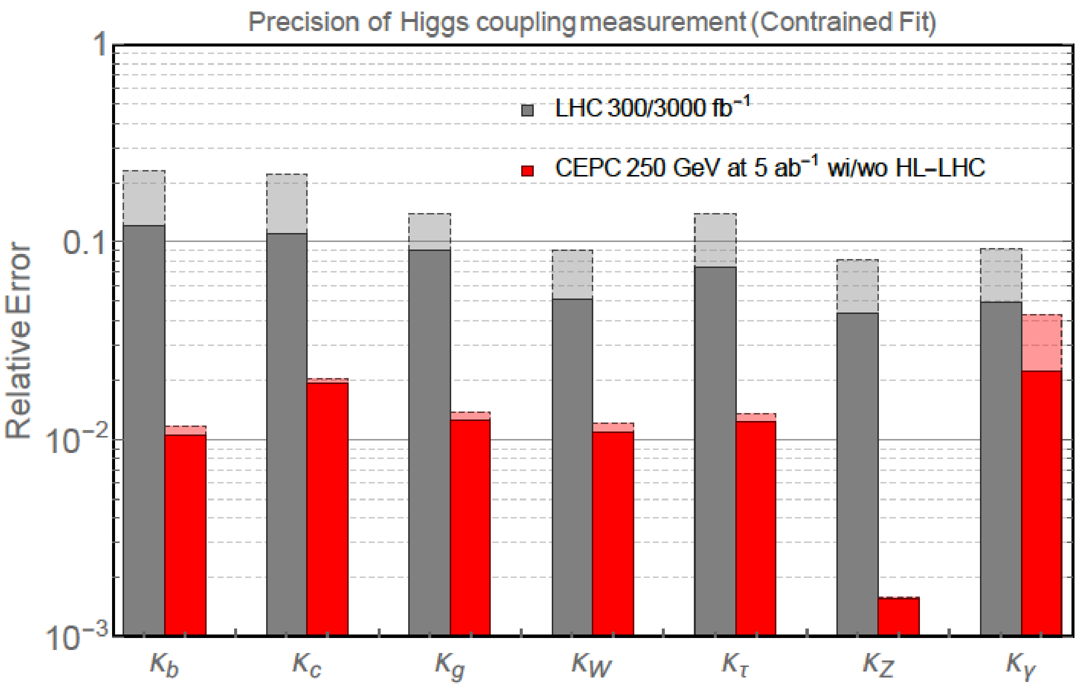


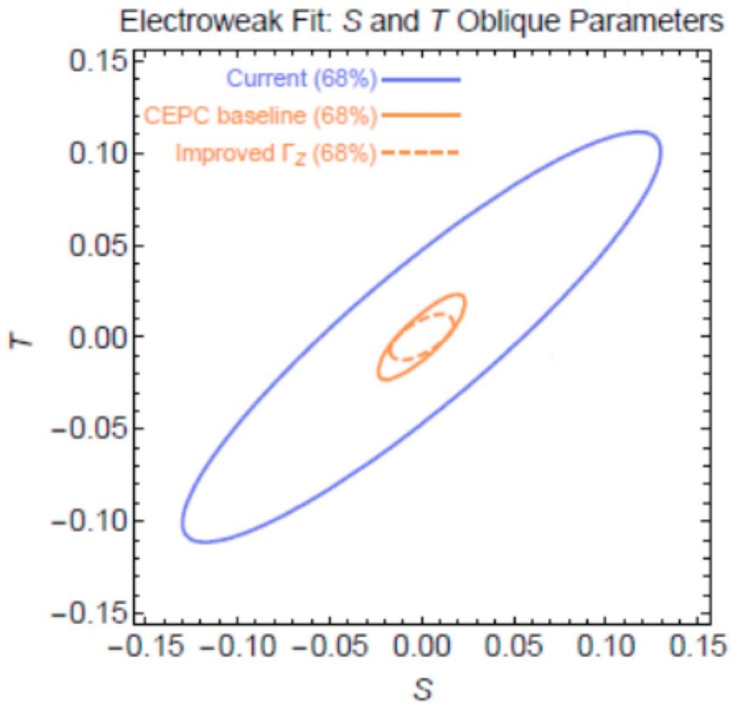
Clear Higgs Signature in all SM decay modes

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

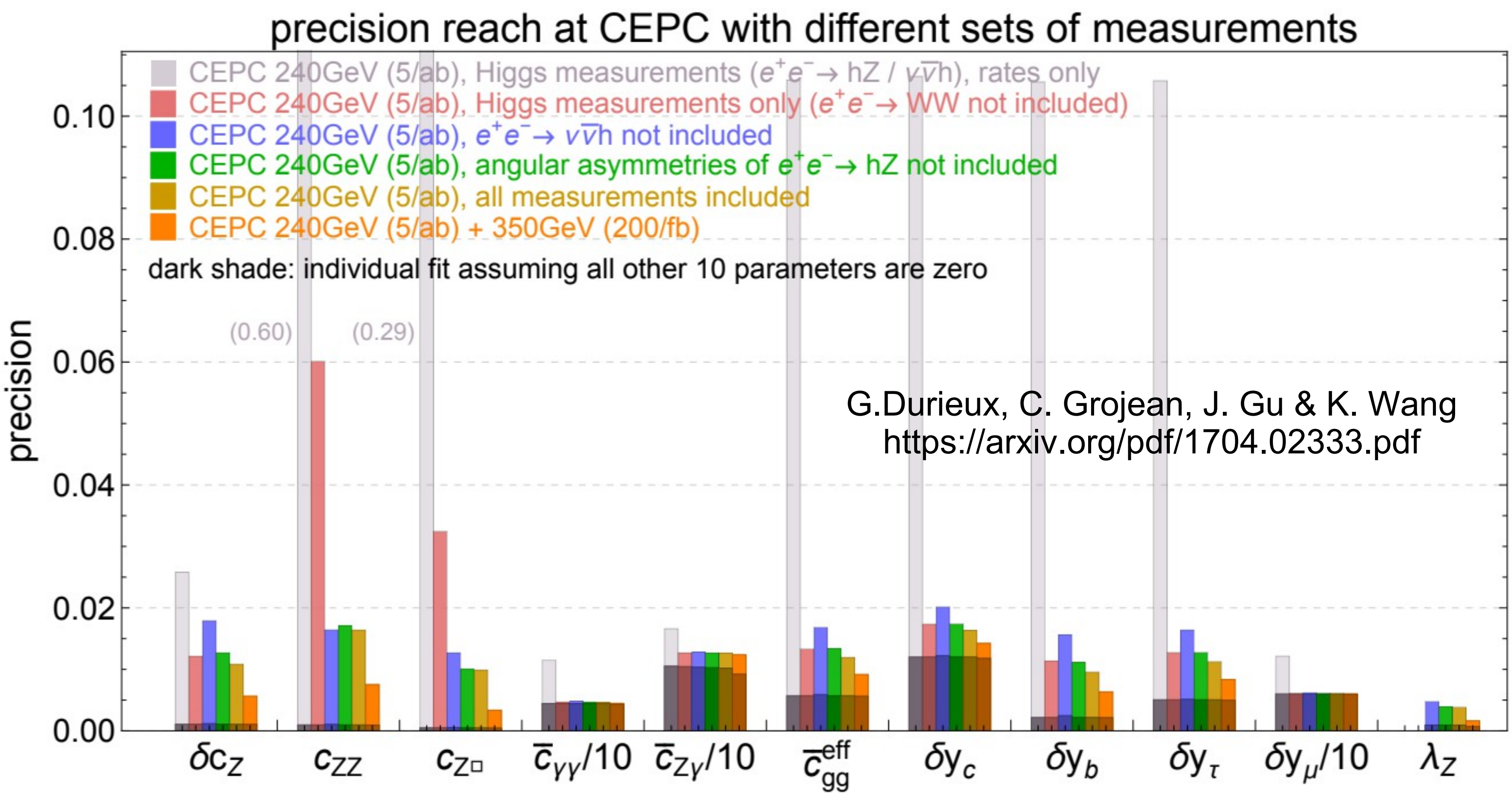
Physics Potential





- 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)

Key technologies in the CEPC

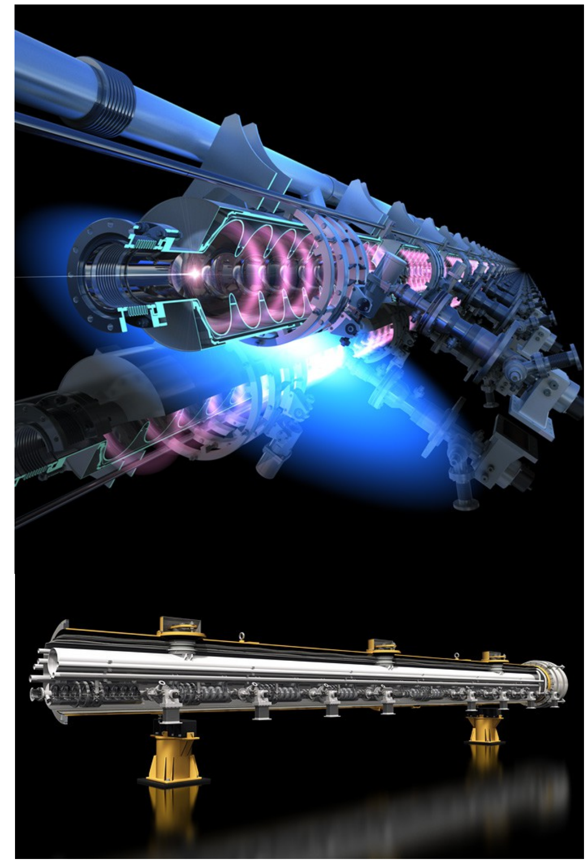
电能

废热

微波

加速器速调管（图片，美国 ORNL 散裂中子源的速调管阵列）

高能粒子束，及同步辐射光



废热

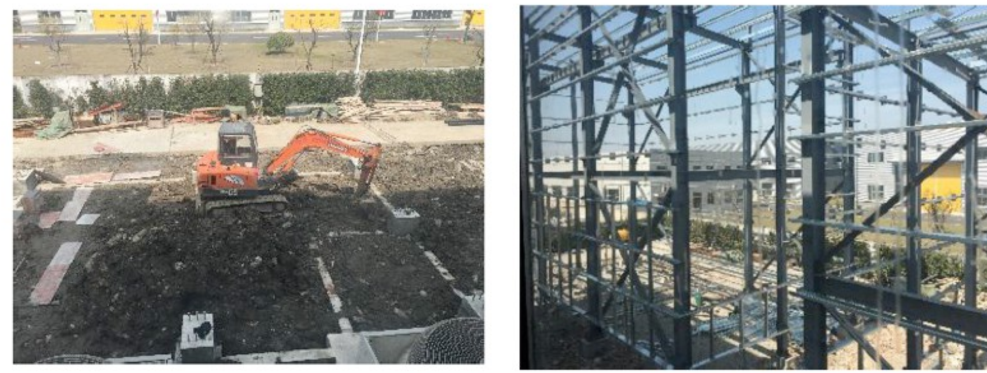
低温组件及其中的超导高频腔（图片， ILC 设计）

High Efficiency Klystron

Modulator anode components

Cavities components

Klystron output window

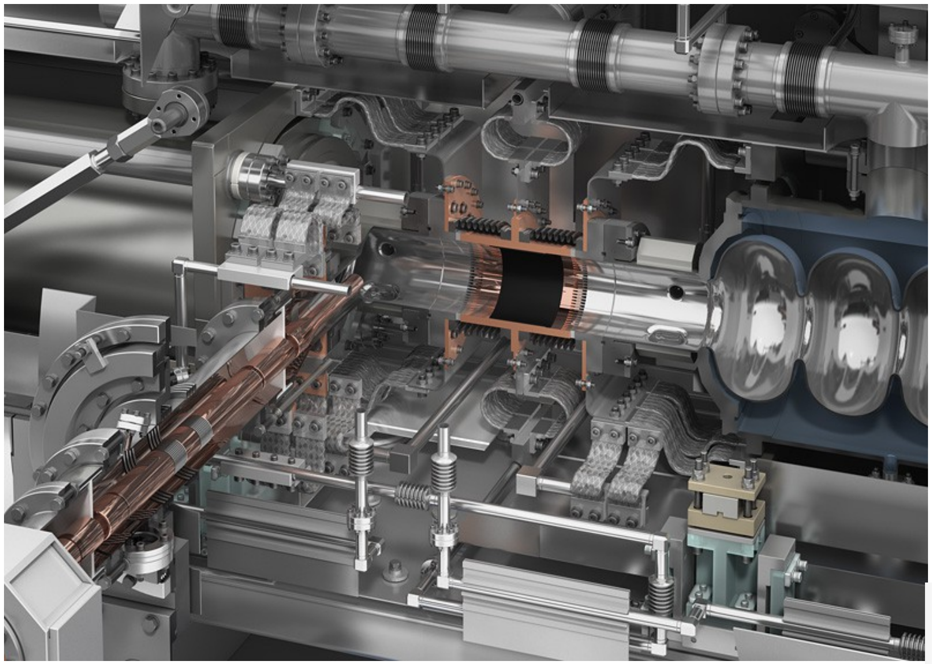


Assembly plant construction

Large size baking furnace commissioning

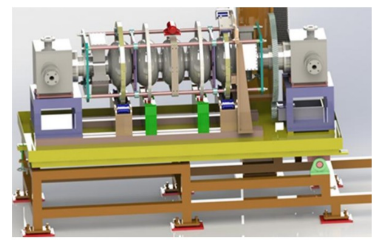
- 目标：将效率从 65% 提升到 80% (同昆山国力合作)
- 首支样管近期将展开测试

Super Conducting RF Cavity



650 MHz 2-cell cavity

650 MHz 5-cell cavity with waveguide HOM coupler



EP facility in construction
(in collaboration with KEK)

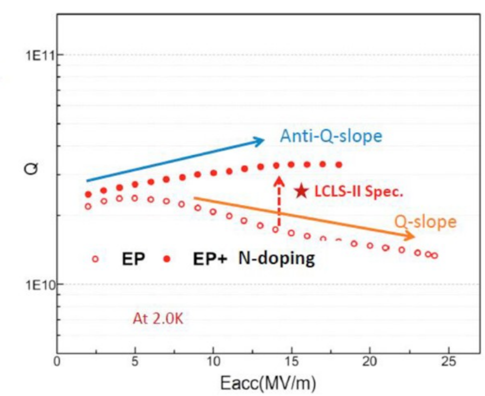
New furnaces for
N-doping and infusion study

Helmholtz coil & flux gate
for high Q research

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.

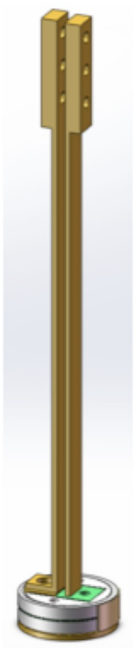
This work is collaborated with KEK colleagues.

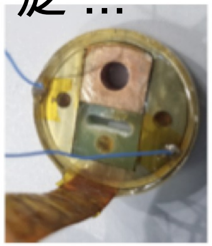


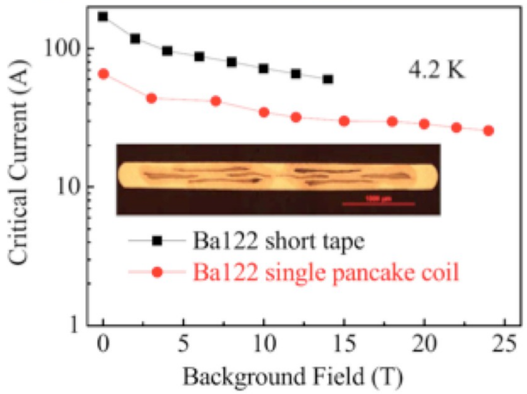
- 提升品质因子（Q值～腔体能量半衰期），控制造价及功耗
  - 电抛光
  - 氮掺杂
  - 大晶粒

Iron-based High Temperature Super Conducting Magnet

- 目标：实用化铁基高温技术
  - 在约为 10 年的时间内
  - 将性能提高 10 倍
  - 将造价降低 10 倍
  - 应用极为广泛 ...







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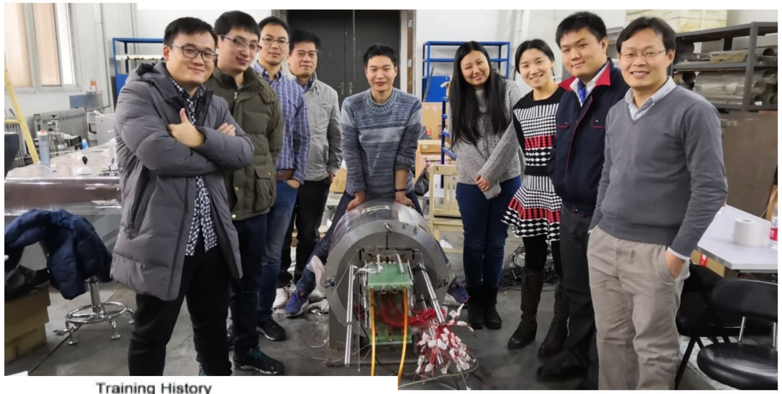
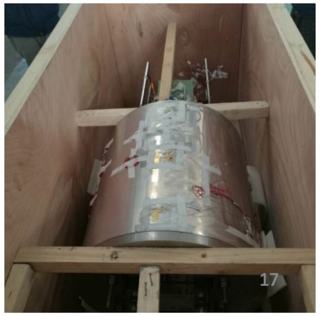
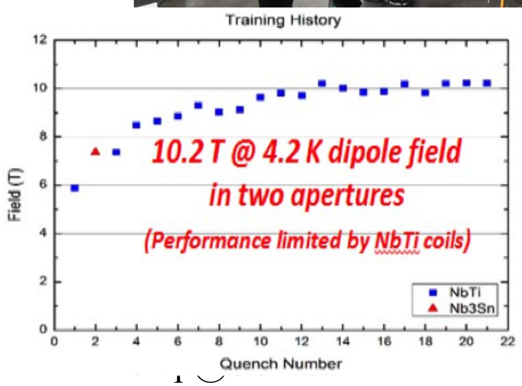


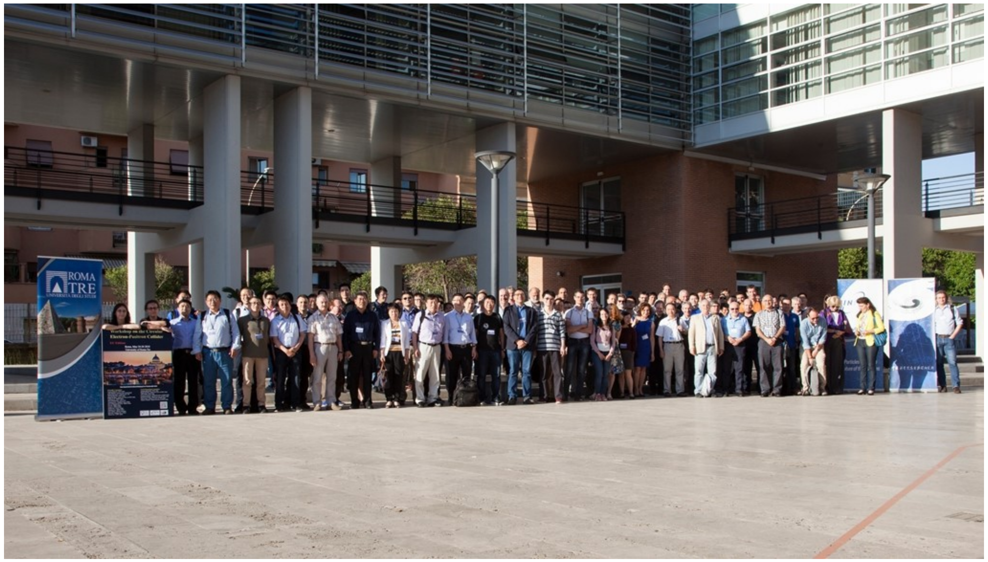




CEPC 工业联盟

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.

国际合作



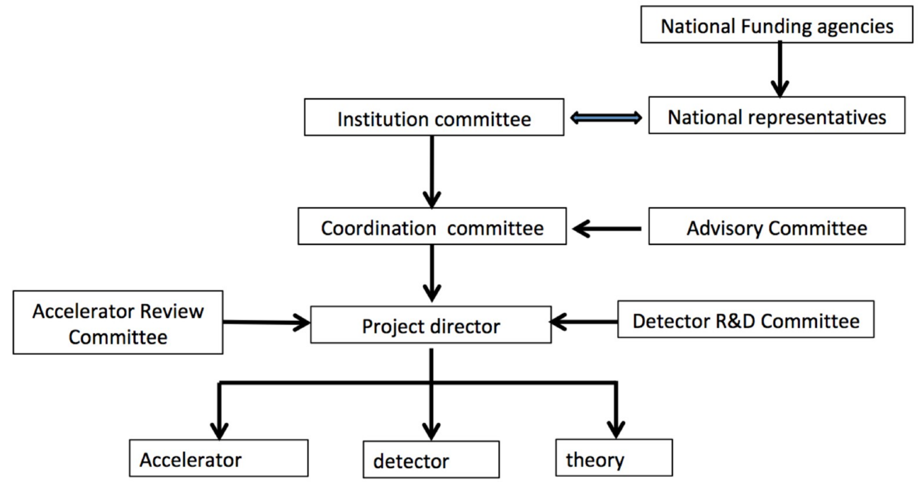


Figure 9, The planned international organization from 2019 till the construction

- CEPC 引起了国际同行的广泛关注和积极支持。目前：
  - 同国际上近 20 个著名研究机构签署了合作协议（ MoU ）；
  - 建立了由国际顶级科学家组成的国际顾问委员会、为项目提供咨询意见；
  - 在 CEPC 的合作国进行工作会议（ 2018- 罗马、 2019- 牛津、 2020- 马赛。。。 ）
  - 在概念设计报告中，作者有 1/3 来自国际合作。

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
  - 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: physics objects + Higgs signal
  - Alternative designs, New ideas are always welcome
- Key technology – civil development:
  - Towards the TDR & significant progresses & link to industrial
- CEPC, a dream worth chasing!

Backup

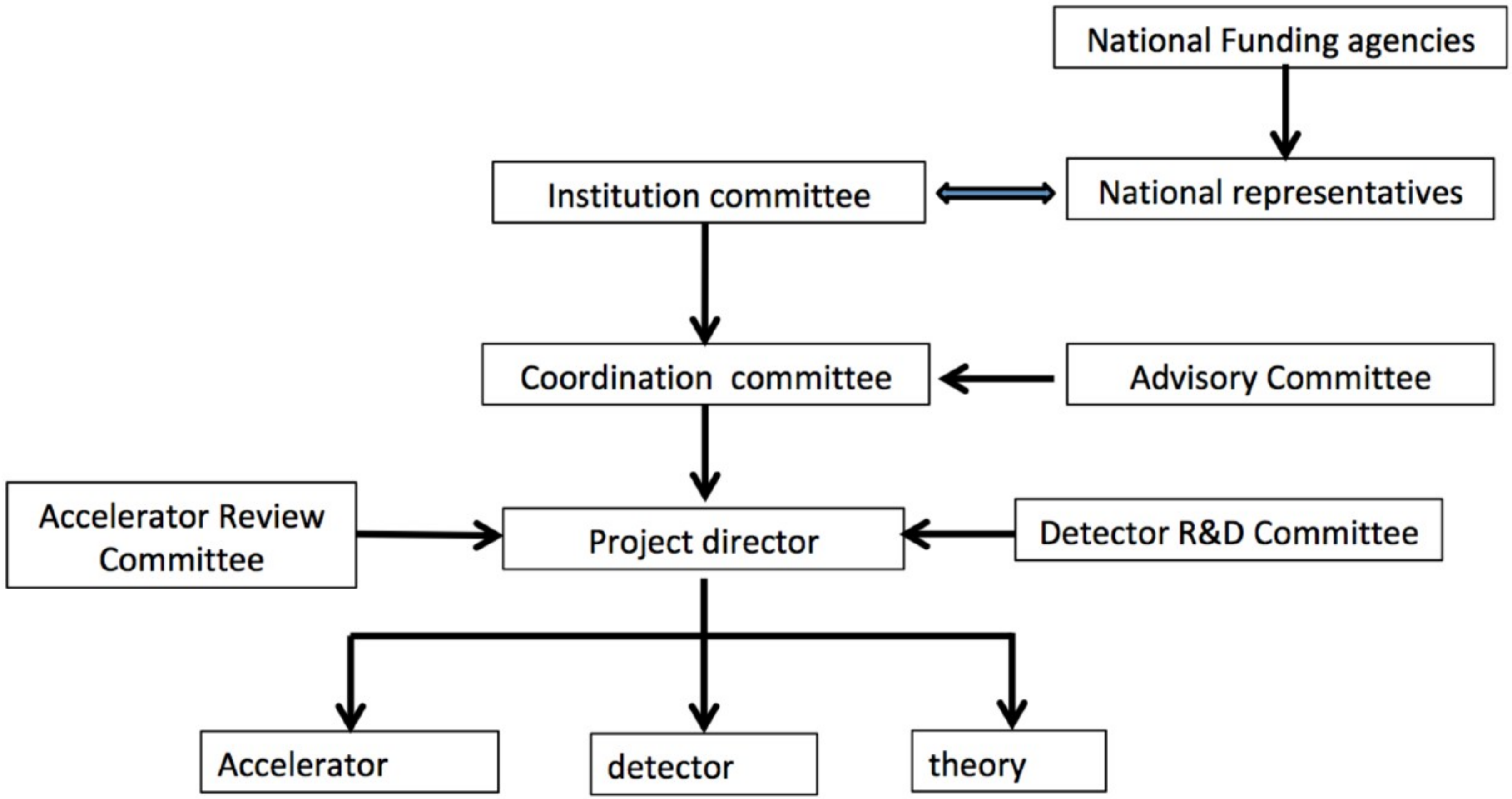
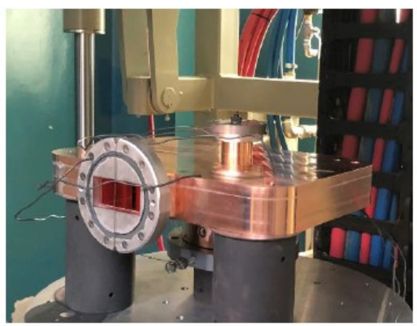


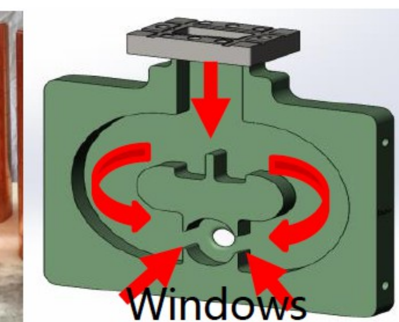
Figure 9, The planned international organization from 2019 till the construction

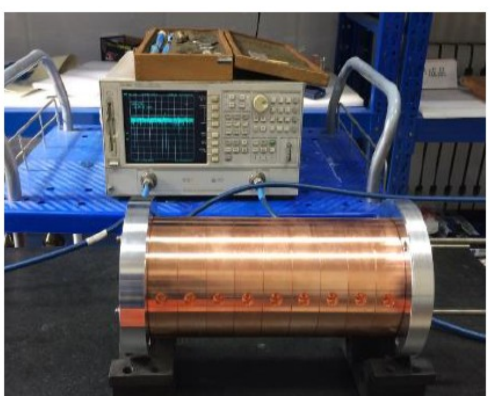
In this structure, all the building blocks will integrate the international participation. The Institution Committee writes the bylaws and makes major decisions on organizational issues. The national representatives interface with the National Funding Agencies and the corresponding institutions are represented 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.

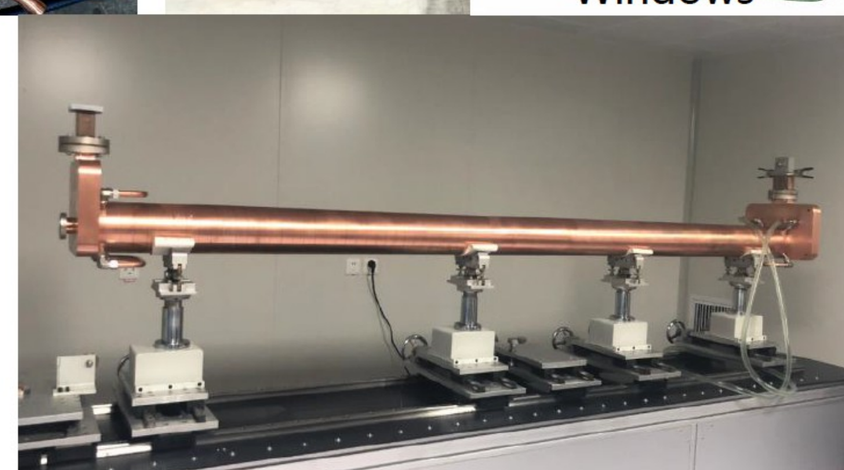
R&D activities on Linac

- 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.



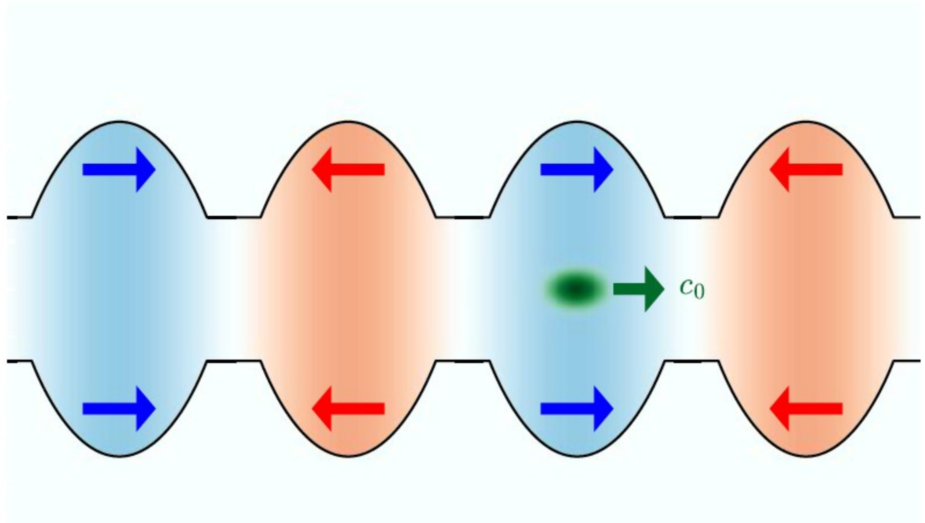


R&D activities on Linac

- 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

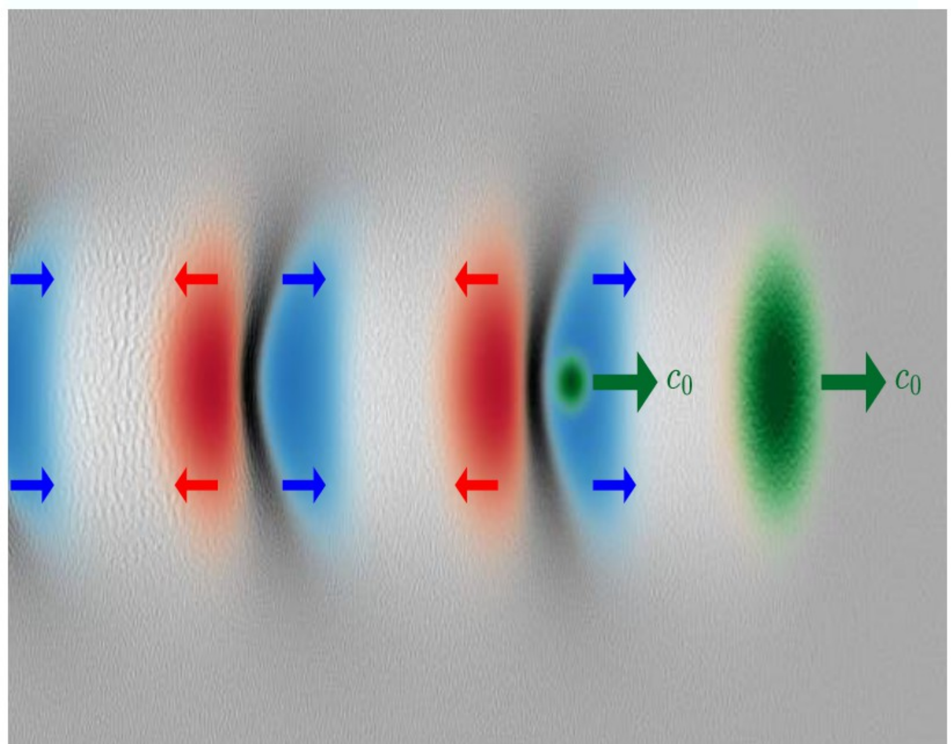
PWFA Linac replacement

RF Cavity



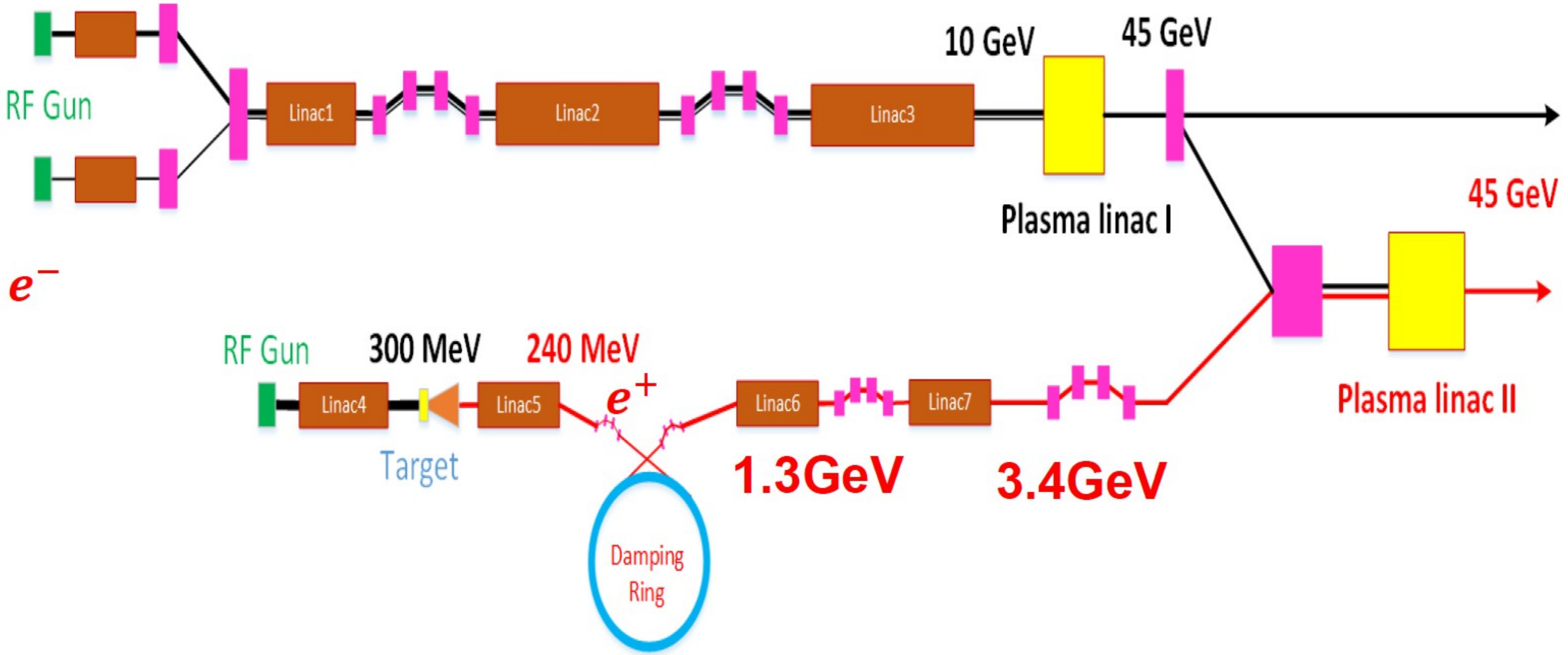
20 – 40 MV/m

Plasma wakefield



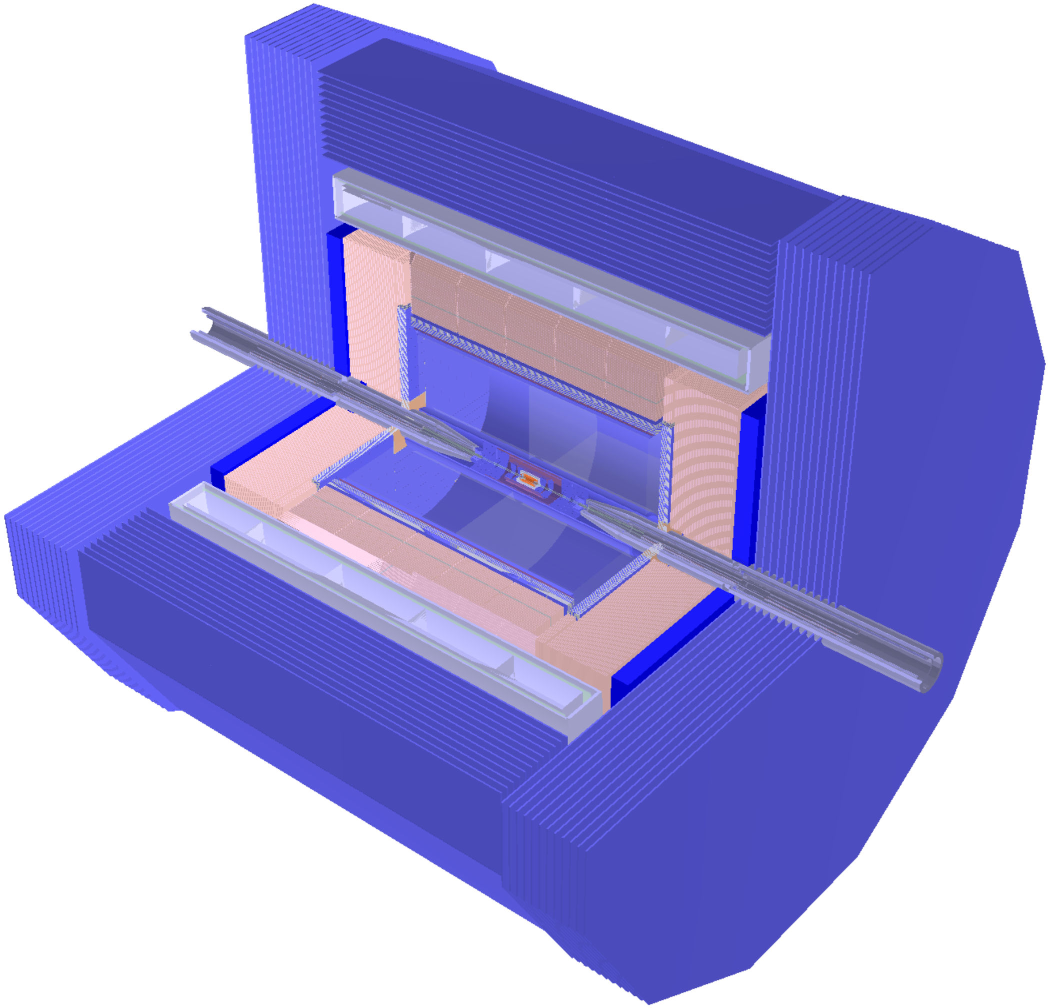
10 – 1000 GV/m

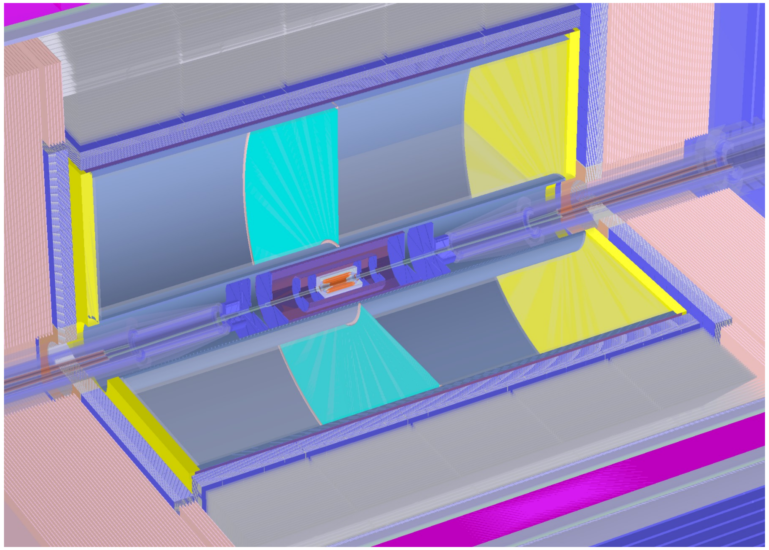
CEPC PWFA Linac

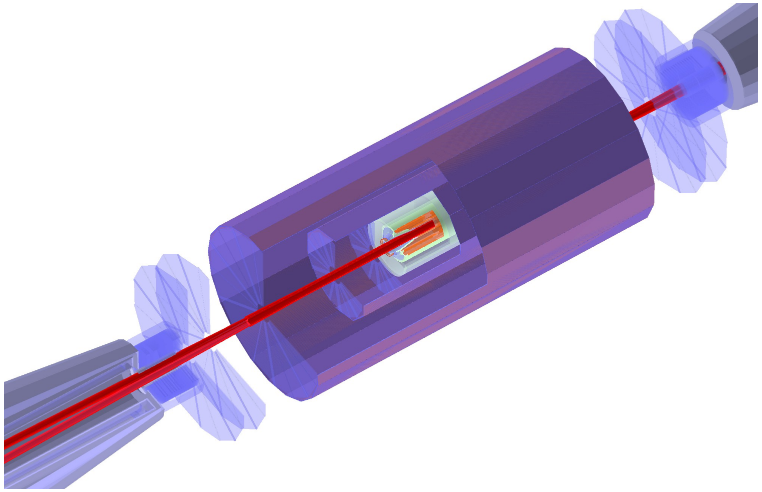


- Driver/trailer beam generation through Photo-injector
- HTR PWFA with good stability (single stage TR=3-4, Cascaded stage 6-12, high efficiency)
- Positron generation and acceleration in an electron beam driven PWFA using hollow plasma channel (TR=1)

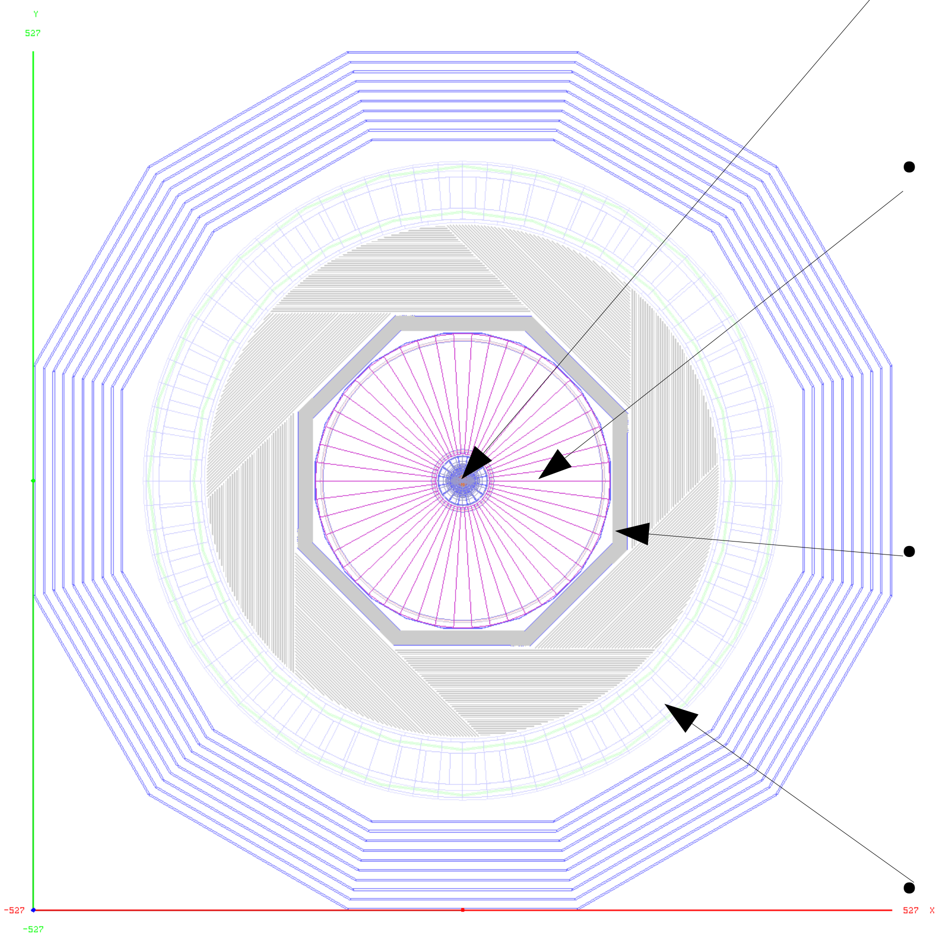
CEPC Baseline Detector





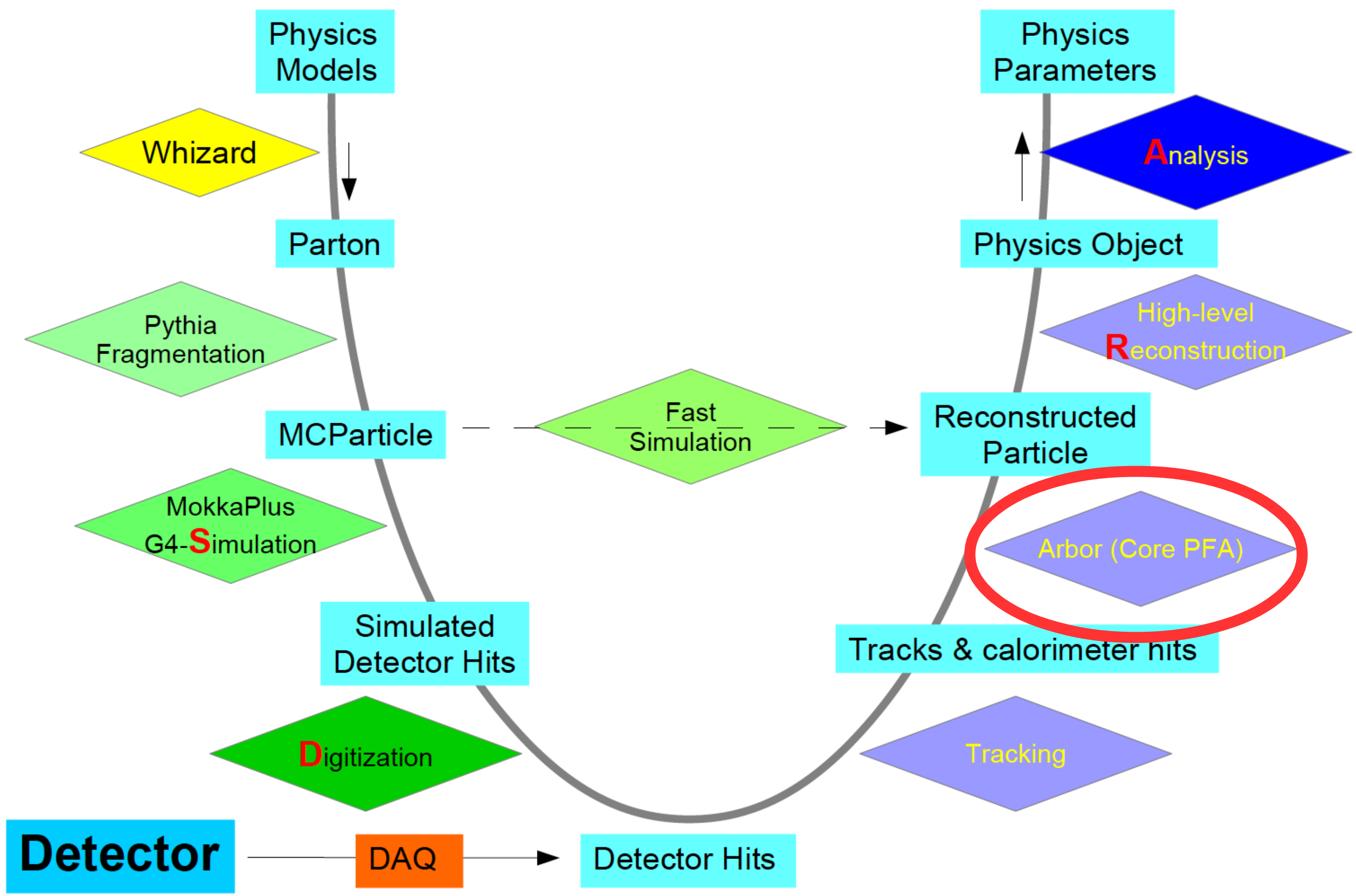


An ILD-like detector at the CEPC



- Different collision environments/rates :
  - MDI design & Implementation: CEPC-SIMU-2017-001
- The CEPC Event rate is significantly higher than linear colliders, charged kaon id can strongly enhance the CEPC flavor physics program
  - TPC Feasibility: JINST-12-P07005 (2017)
  - Pid using TPC dEdx and ToF: Eur. Phys. J. C (2018) 78:464
- No power pulsing at CEPC detector
  - A significant reduction of the readout channel, especially the Calorimeter Granularity: JINST-13-P03010 (2018)
  - HCAL Optimization
- 3 Tesla Solenoid: requested by the Accelerator/MDI

CEPC Baseline Software

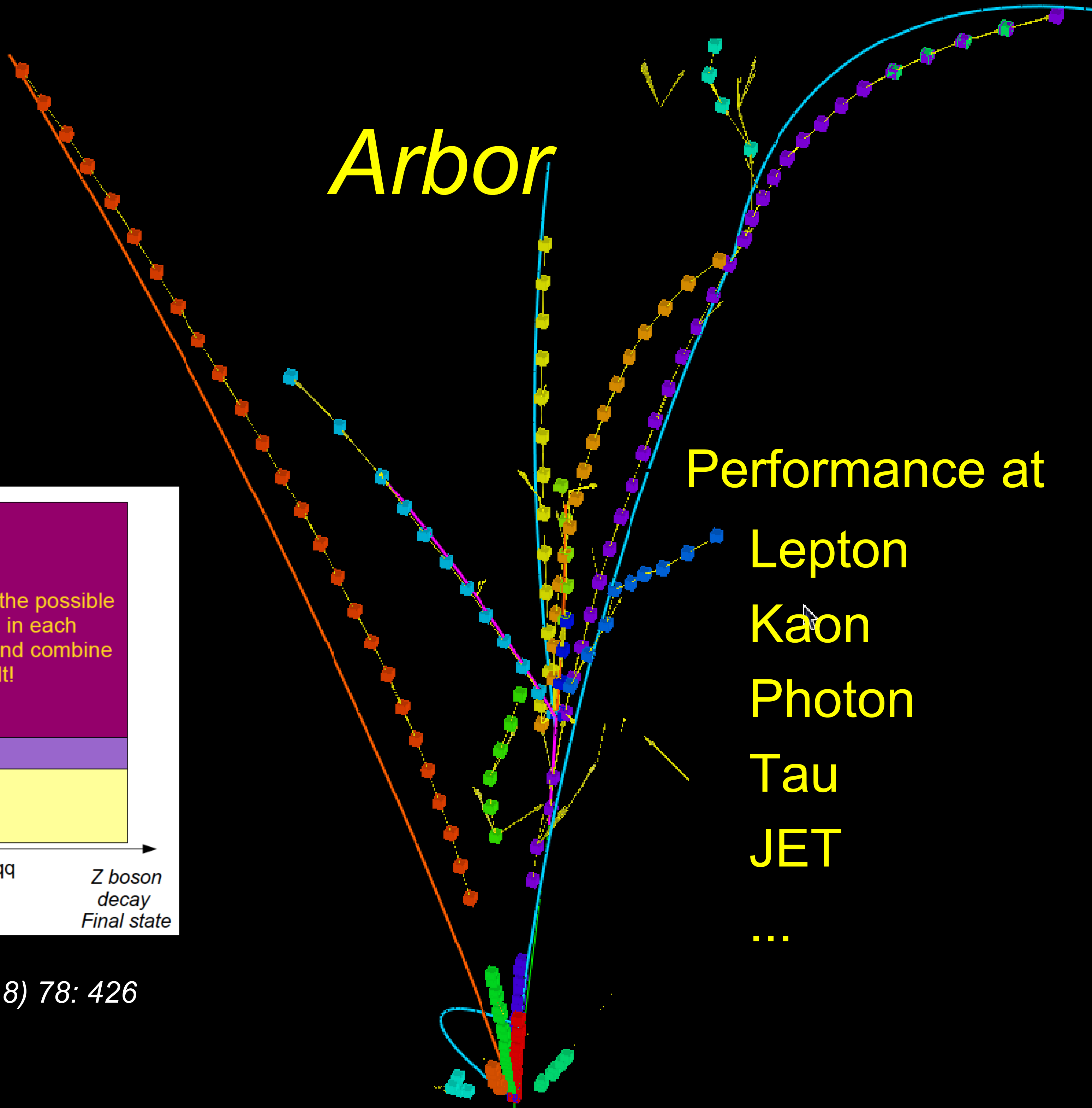


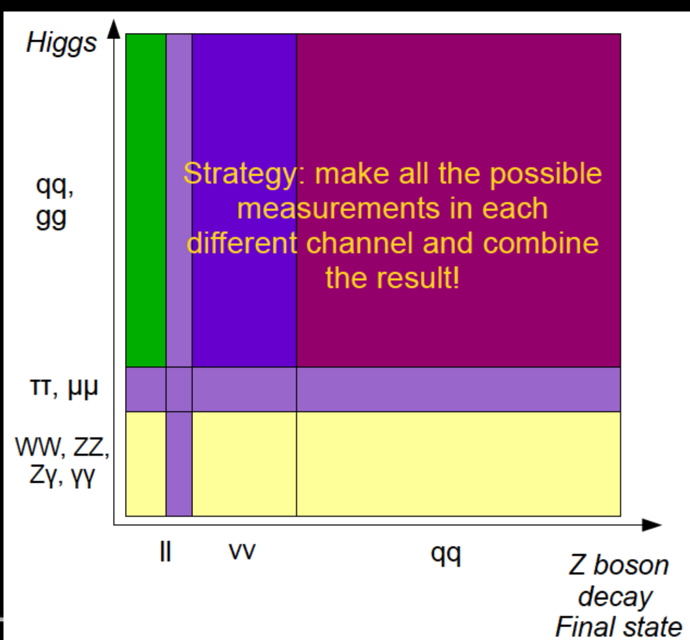
Generators (Whizard & Pythia)
Data format & management (LCIO & Marlin)
Simulation (MokkaC)
Digitizations
Tracking
PFA (Arbor)
Single Particle Physics Objects Finder (LICH)
Composed object finder (Coral)
Tau finder
Jet Clustering (FastJet)
Jet Flavor Tagging (LCFIPLus)
Event Display (Druid)
General Analysis Framework (FSClasser)
Fast Simulation (Delphes + FSClasser)

CEPC-SIMU-2017-001,
CEPC-SIMU-2017-002,
(DocDB id-167, 168, 173)

General Software | ILCSoft | ILCSoft + Development | Developments

Arbor



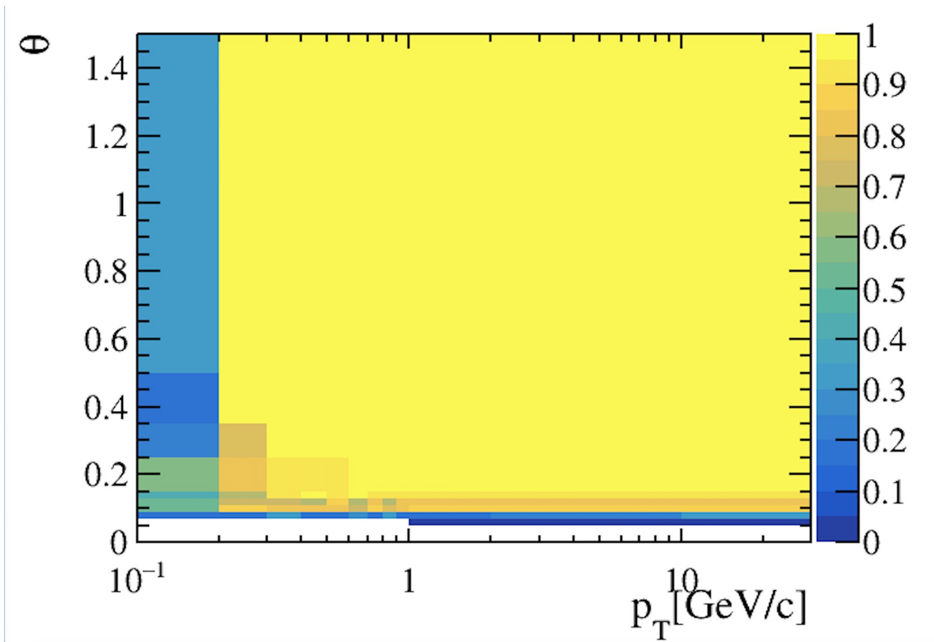


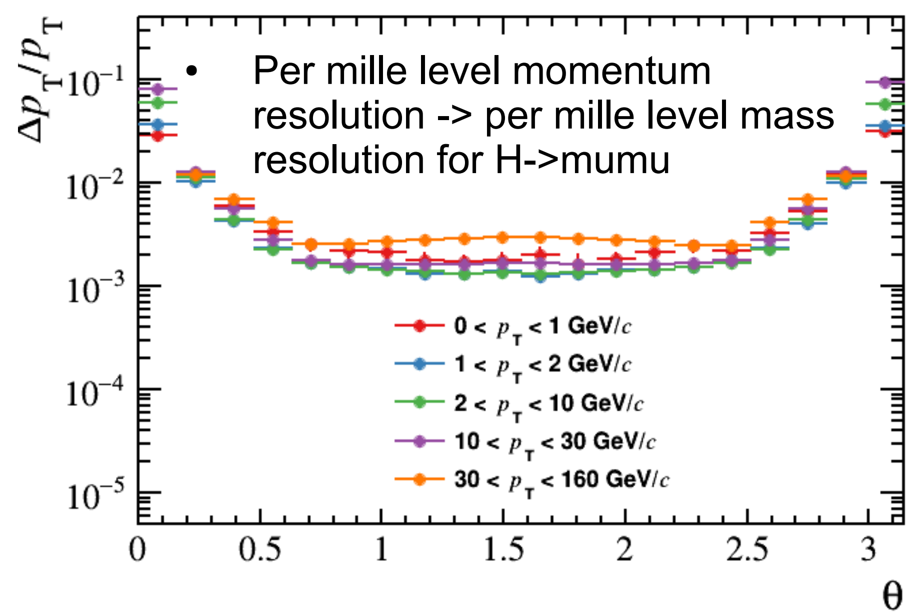
Performance at

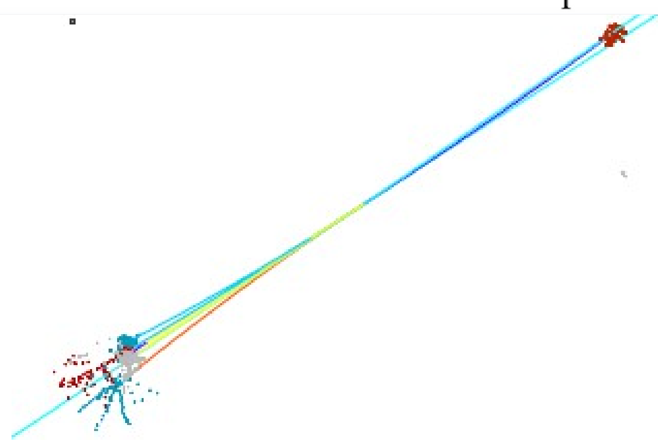
- Lepton
- Kaon
- Photon
- Tau
- JET
- ...

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

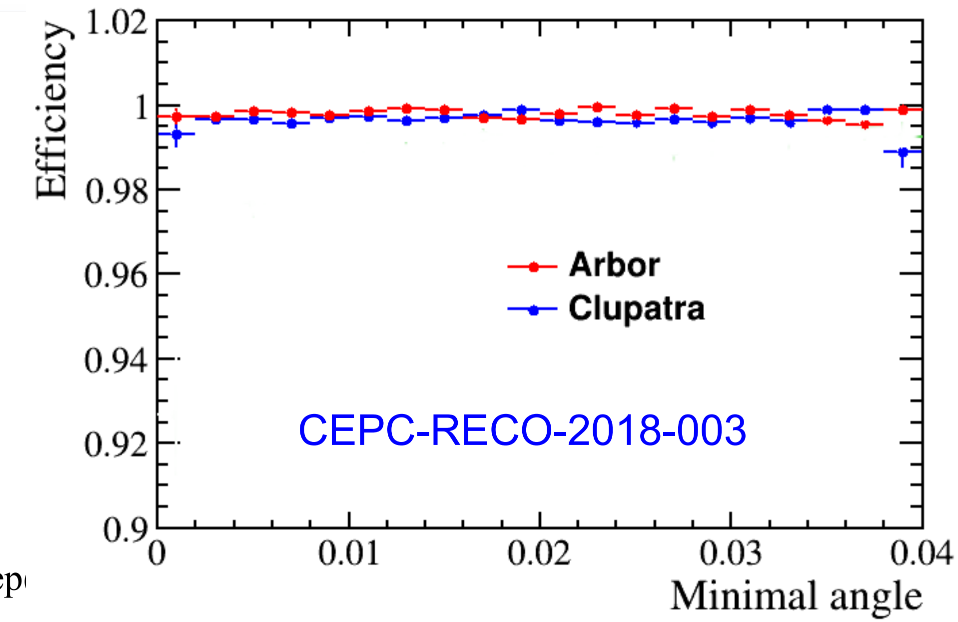
Tracking: via high precision, low mass tracker



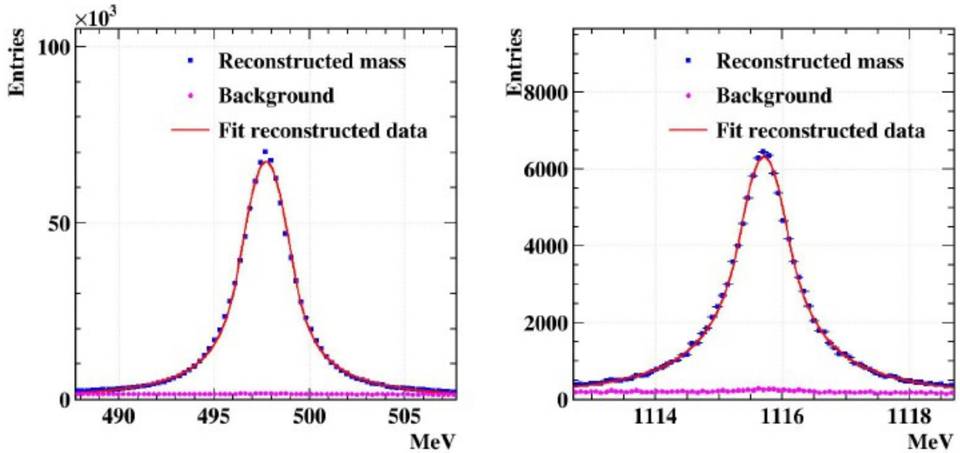




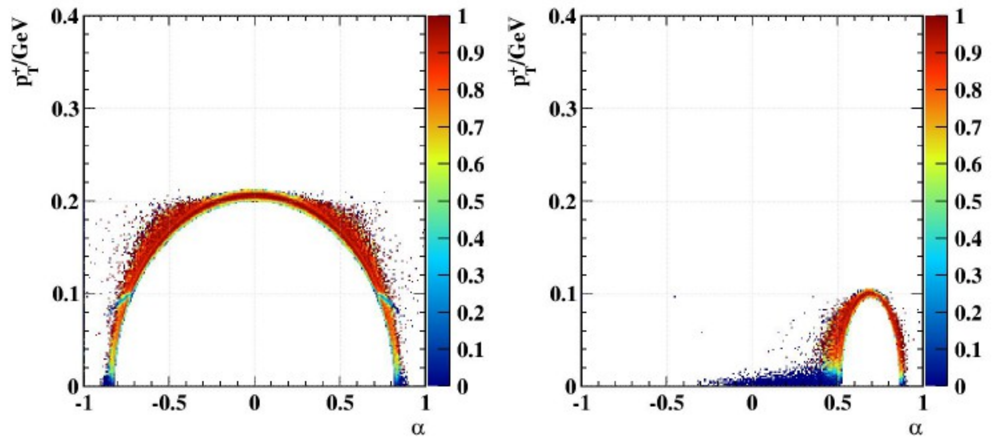
Mingrui Zhao. CEPC CDR



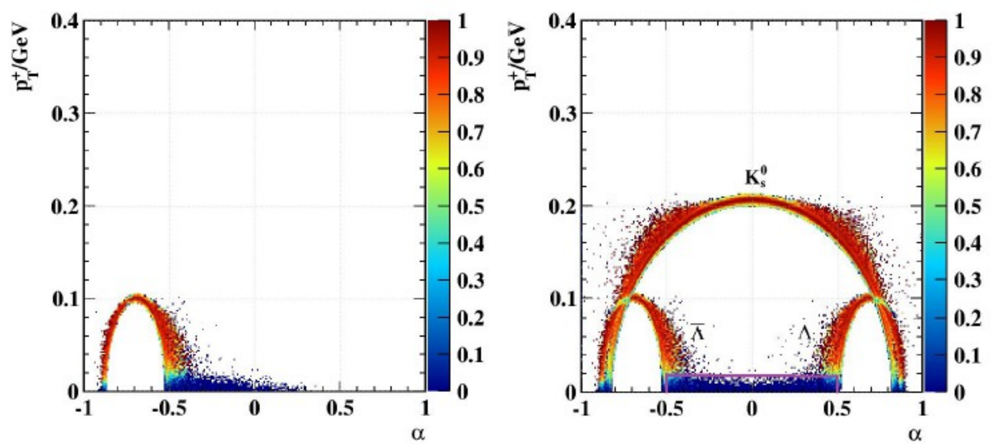
Reconstruction of Ks(Λ) at Z pole (Preliminary)



(a) K_S^0. (b) Λ.



(a) K_S^0 (b) Λ



(c) $\bar{\Lambda}$ (d) All 3 particles

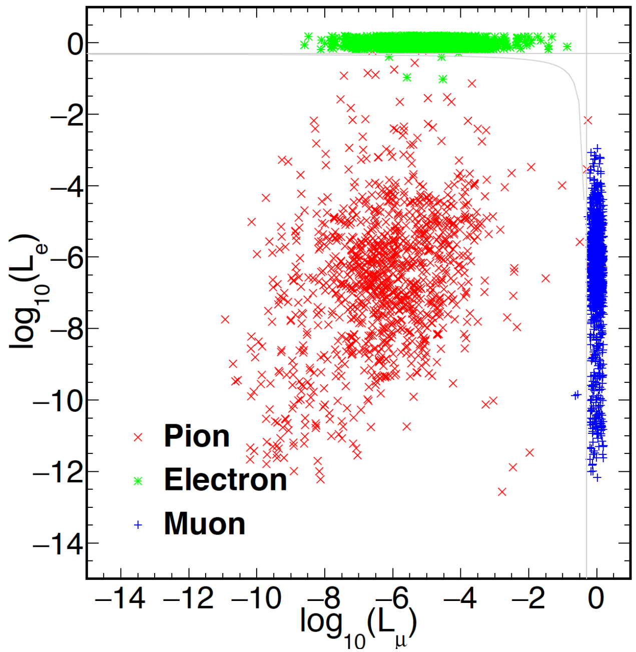
Table 3: K_S^0 and Λ reconstruction performance.

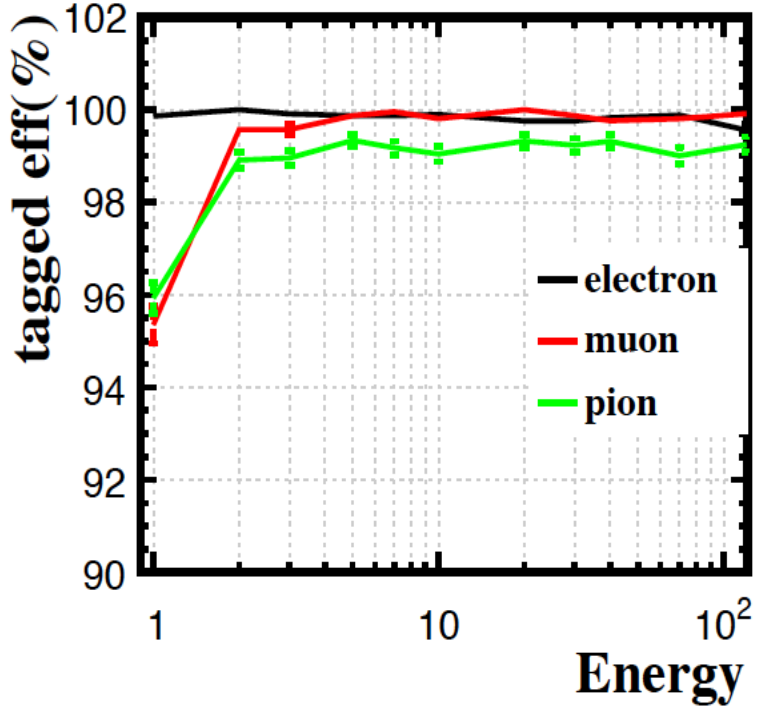
Particle	K_S^0	Λ
ε_R	79.7%	65.1%
ε_T	39.8%	25.5%
P	89.7%	87.9%
$\varepsilon_R \cdot P$	0.715	0.572
$\varepsilon_T \cdot P$	0.357	0.224

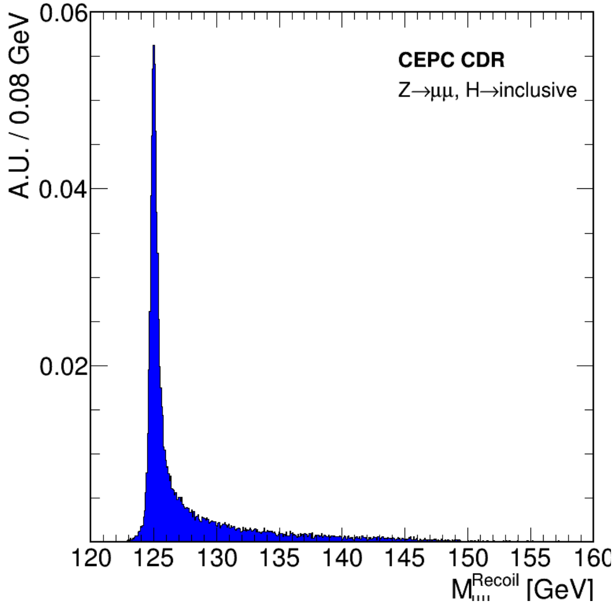
Taifan Zhen

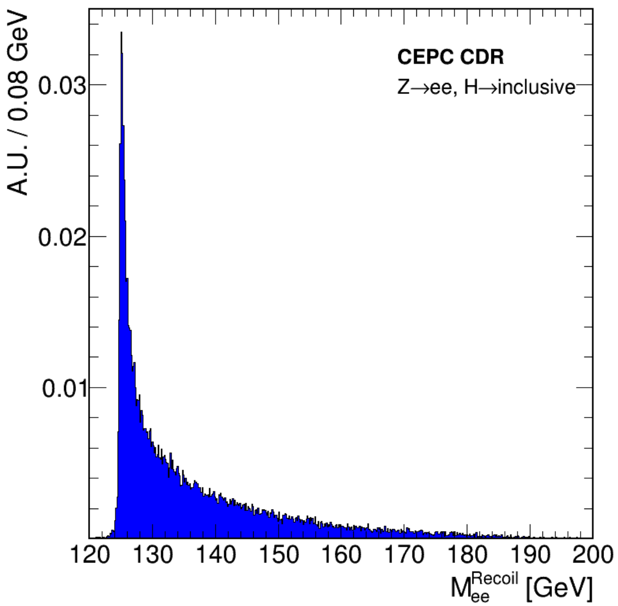
Statistic uncertainty of the mass/life time ~ 1 keV/0.3 ps

Leptons: every subsystem







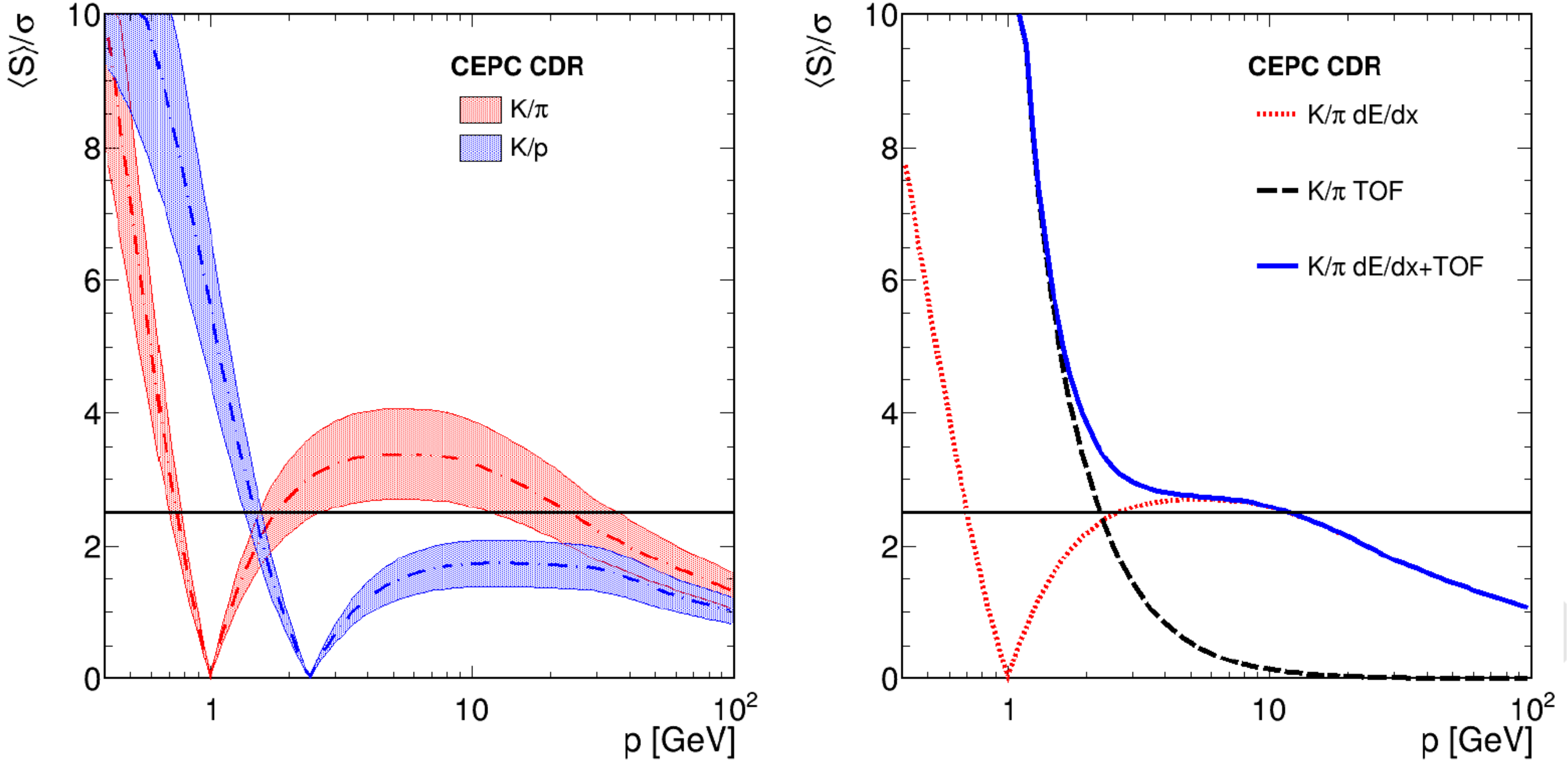


BDT method using 4 classes of 24 input discrimination variables.

Test performance at: Electron = E_likeness > 0.5 ;
Muon = Mu_likeness > 0.5
Single charged reconstructed particle, for E > 2 GeV:
lepton efficiency > 99.5% && Pion mis id rate ~ 1%

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

Kaon: tracker dEdx, + timing (via calo)



Highly appreciated in flavor physics @ CEPC Z pole

TPC dEdx + ToF of 50 ps

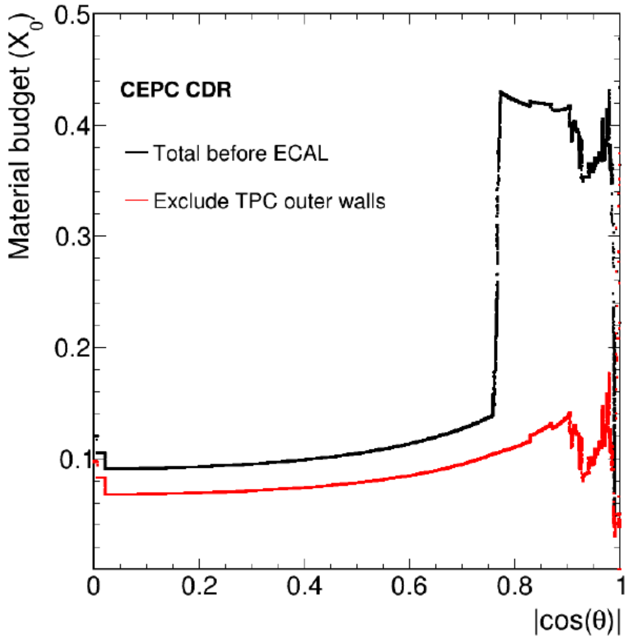
Eur. Phys. J. C (2018) 78:464

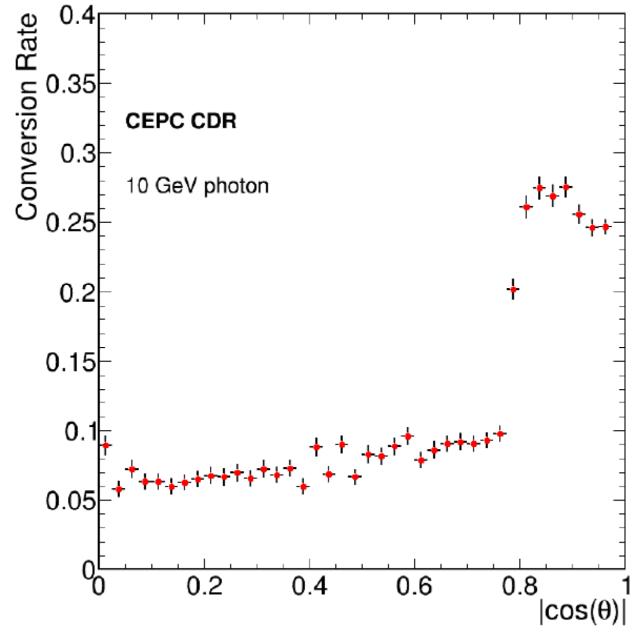
At inclusive Z pole sample:

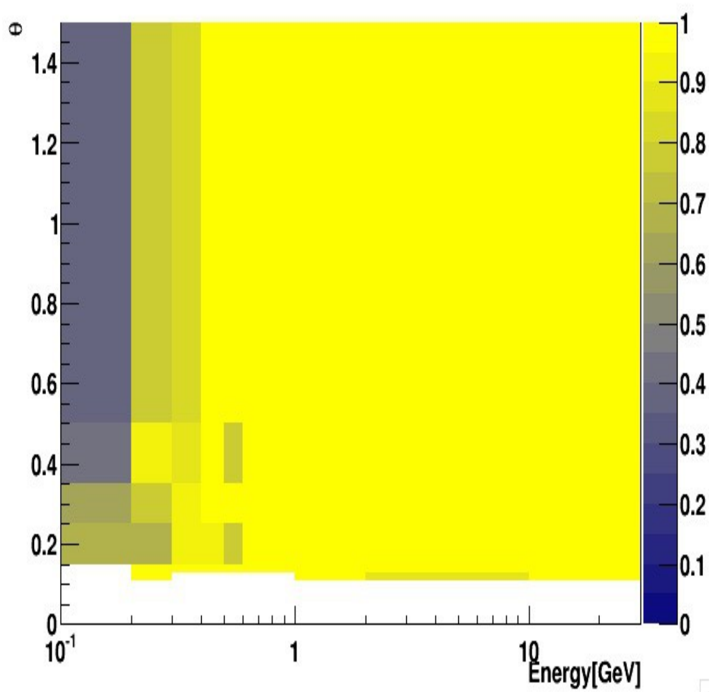
Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)

Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

Photons: ECAL, but appreciate low-mass tracker



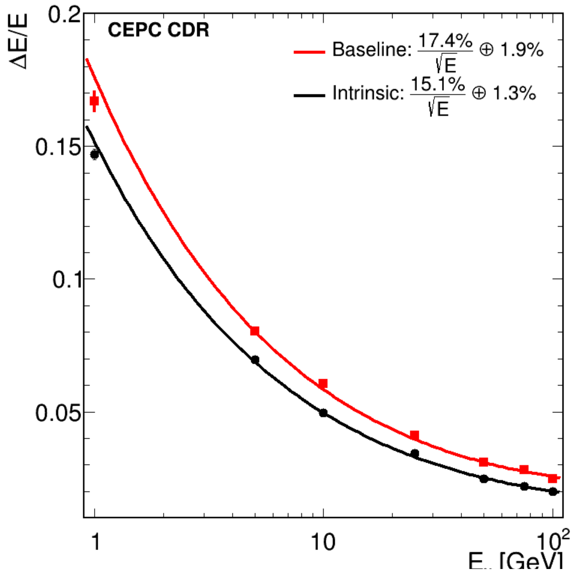


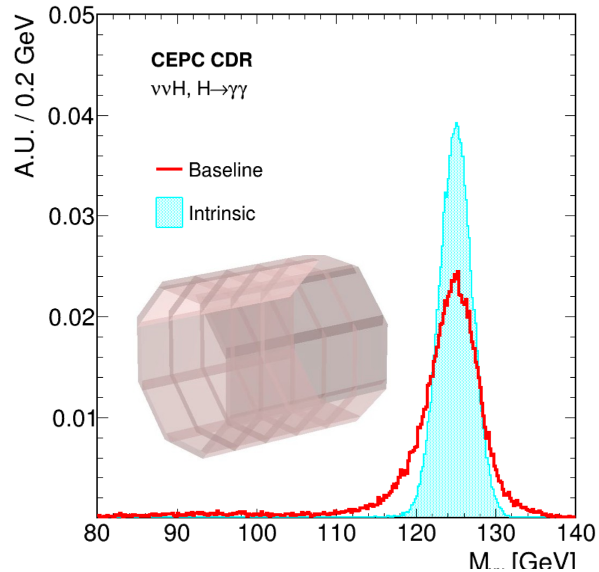


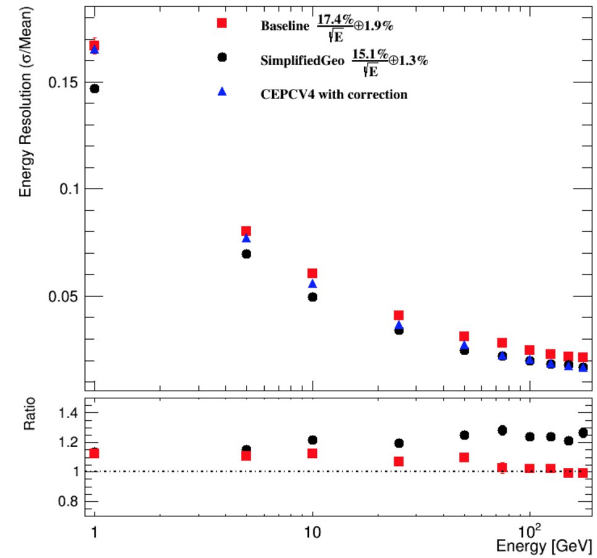
In the barrel region: Roughly 6-10% of the photons converts before reaching the Calorimeter.

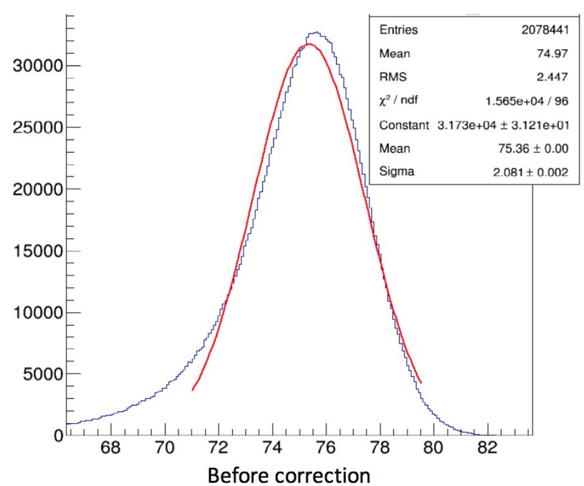
For the unconverted photon: A critical energy of 200 MeV is observed.

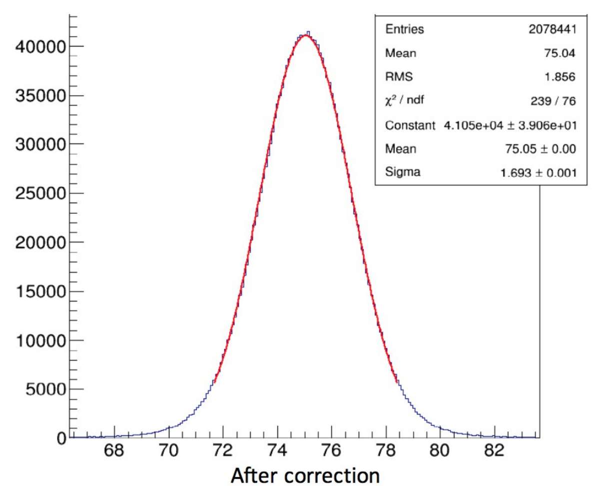
Photon: resolution - ECAL







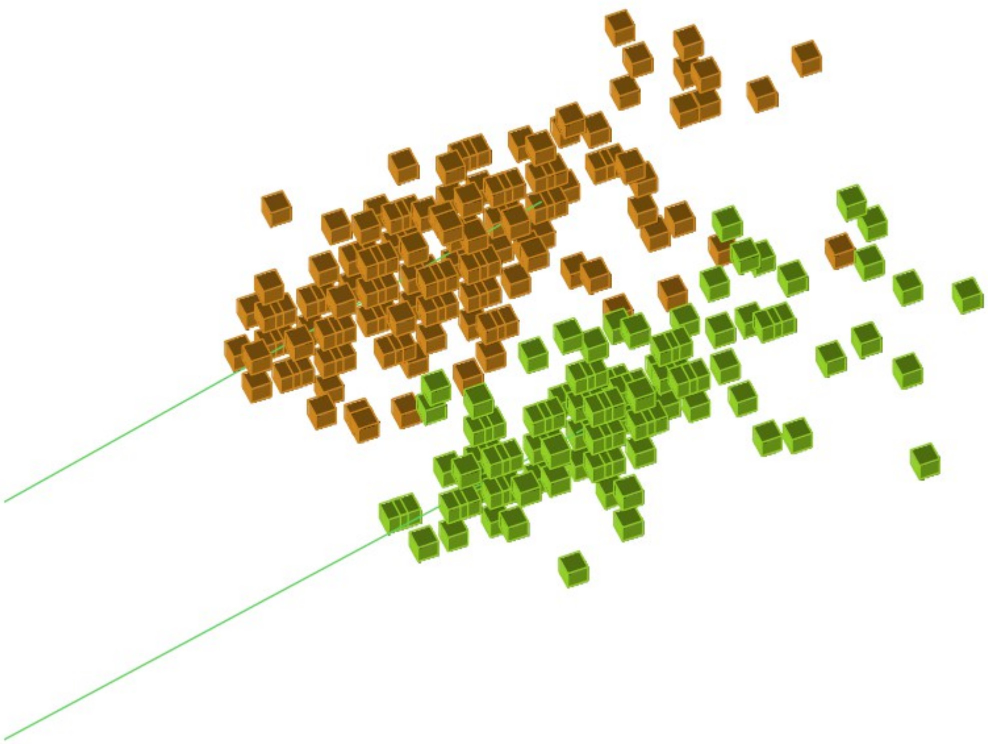


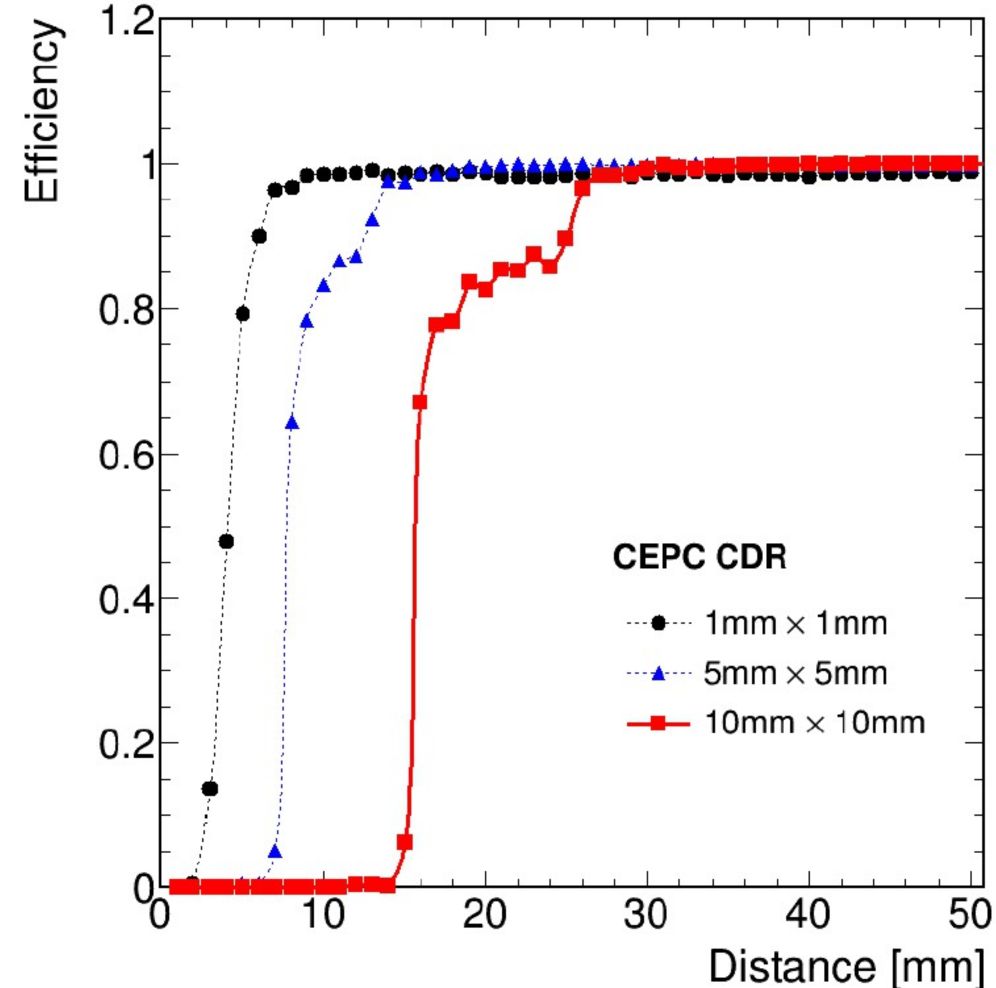


Yuqiao Shen & CEPC CDR

- A Higgs mass resolution of 1.7/2.5% is achieved in the Higgs to di-photon final states with simplified/baseline geometry
- The geometry defects correction could be efficiently corrected (Preliminary)

Clustering – Separation - ECAL

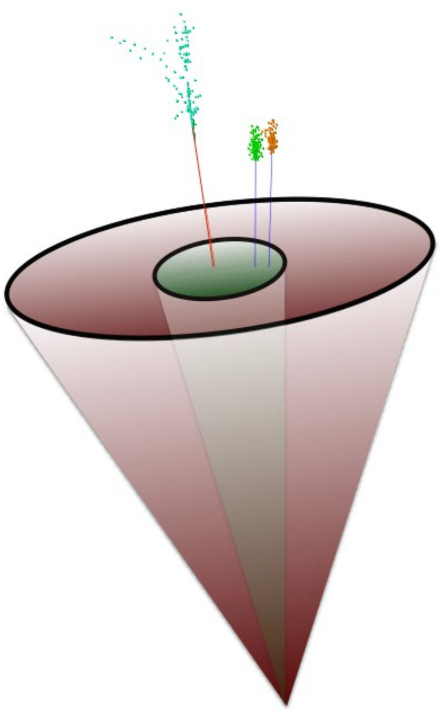


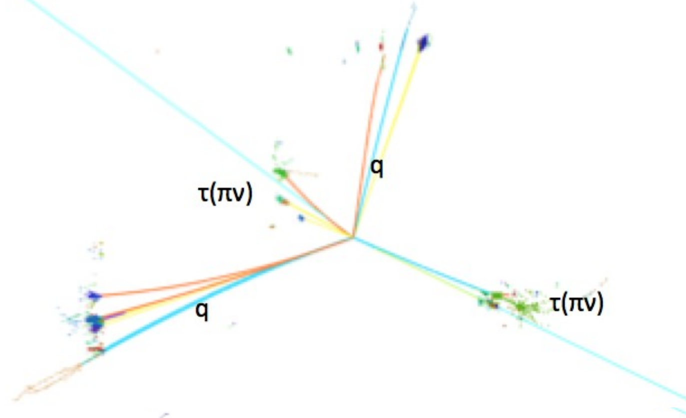


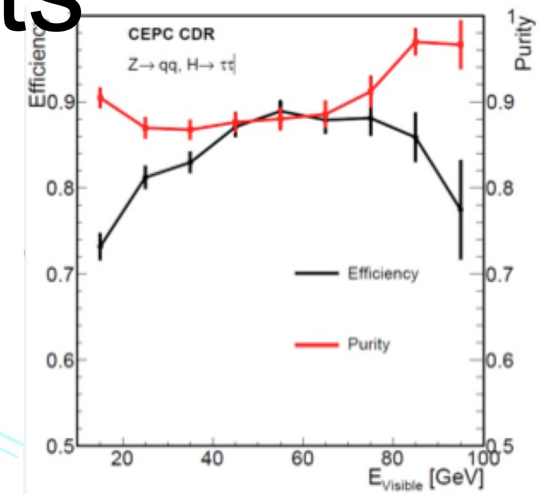
Critical energy to separate an evenly decay π_0: 30 GeV

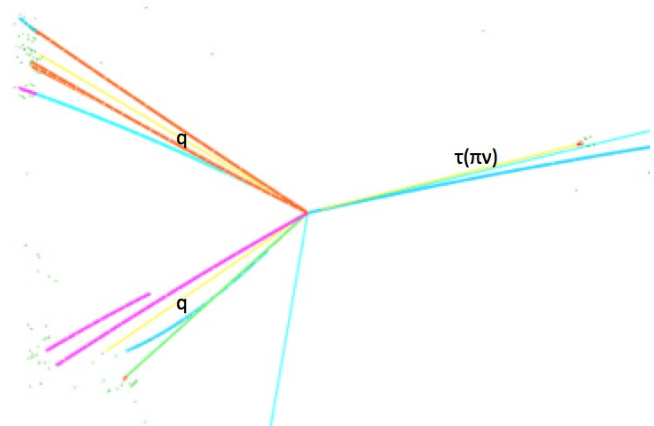
Hang Zhao. CEPC CDR

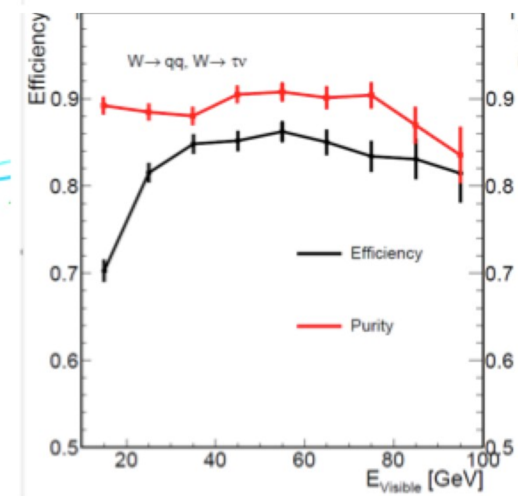
Tau finding: Tracker & ECAL at hadronic events







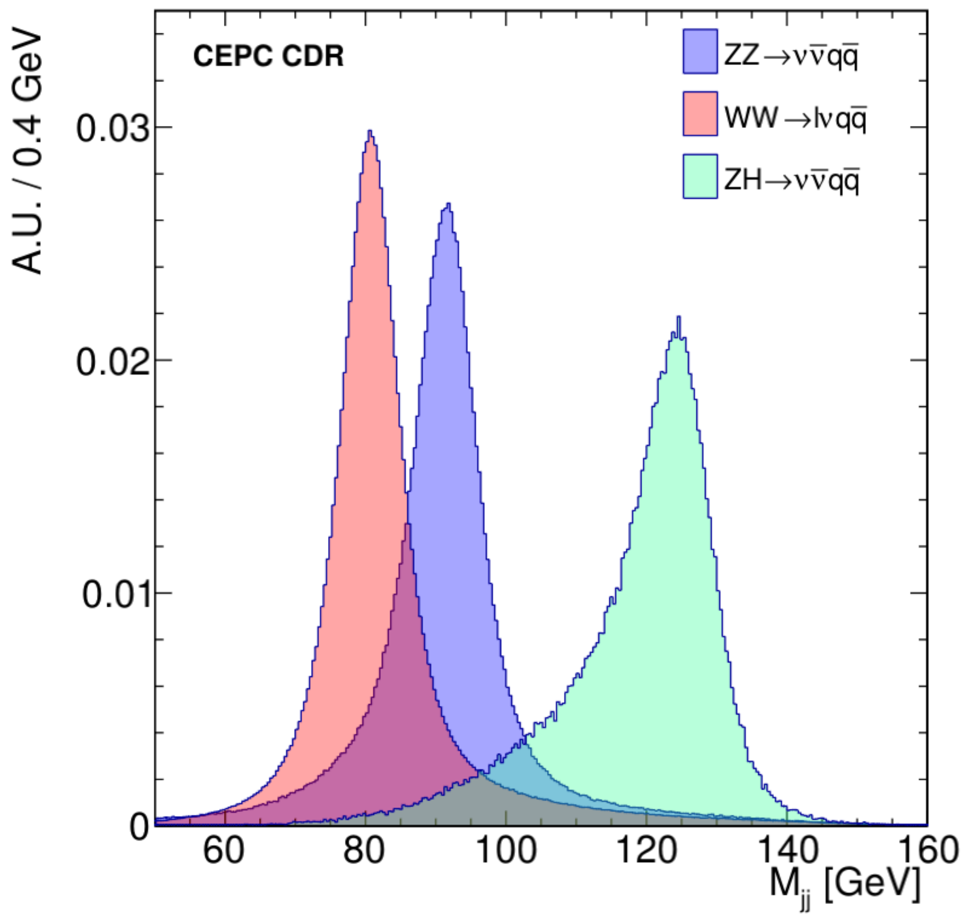


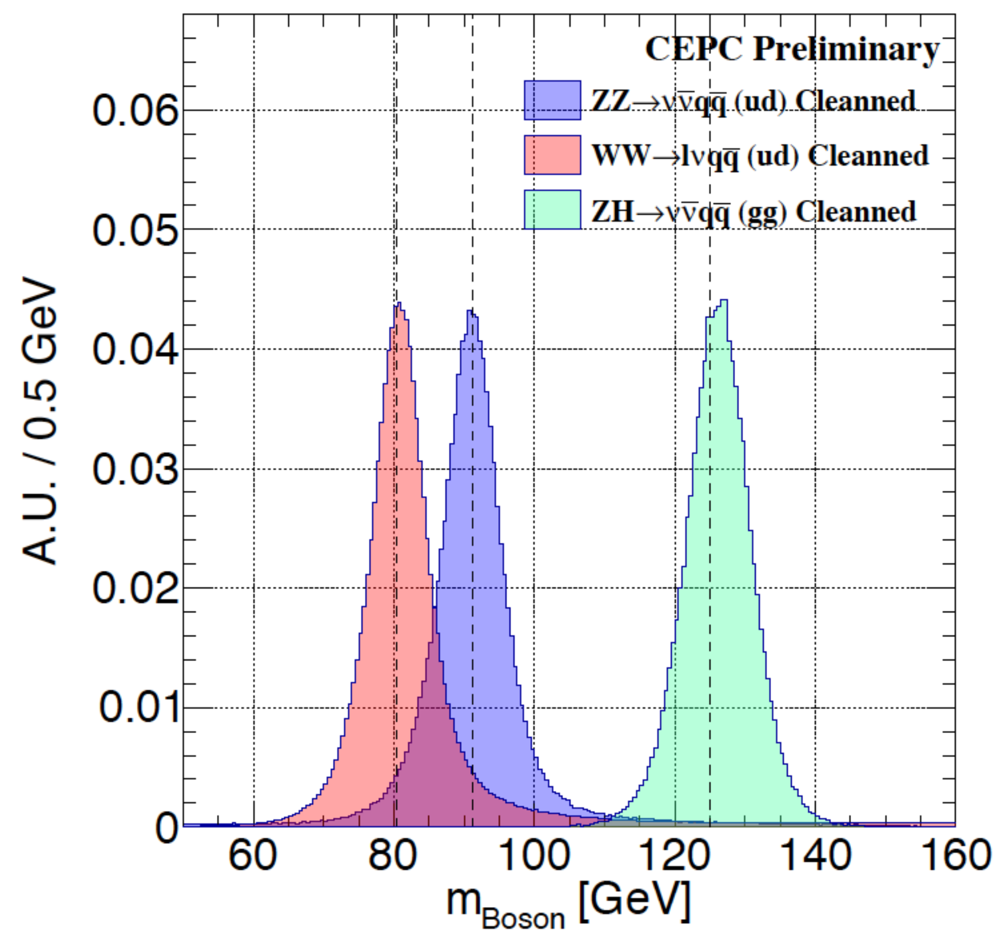


TAURUS (Tau ReconstrUction toolS):
an overall efficiency*purity higher than 70% is achieved for qqττ, and qqτν events

Zhigang Wu, CEPC CDR

JETS: Tracker + Calorimeter - BMS of 3.8% reached, massive bosons separated





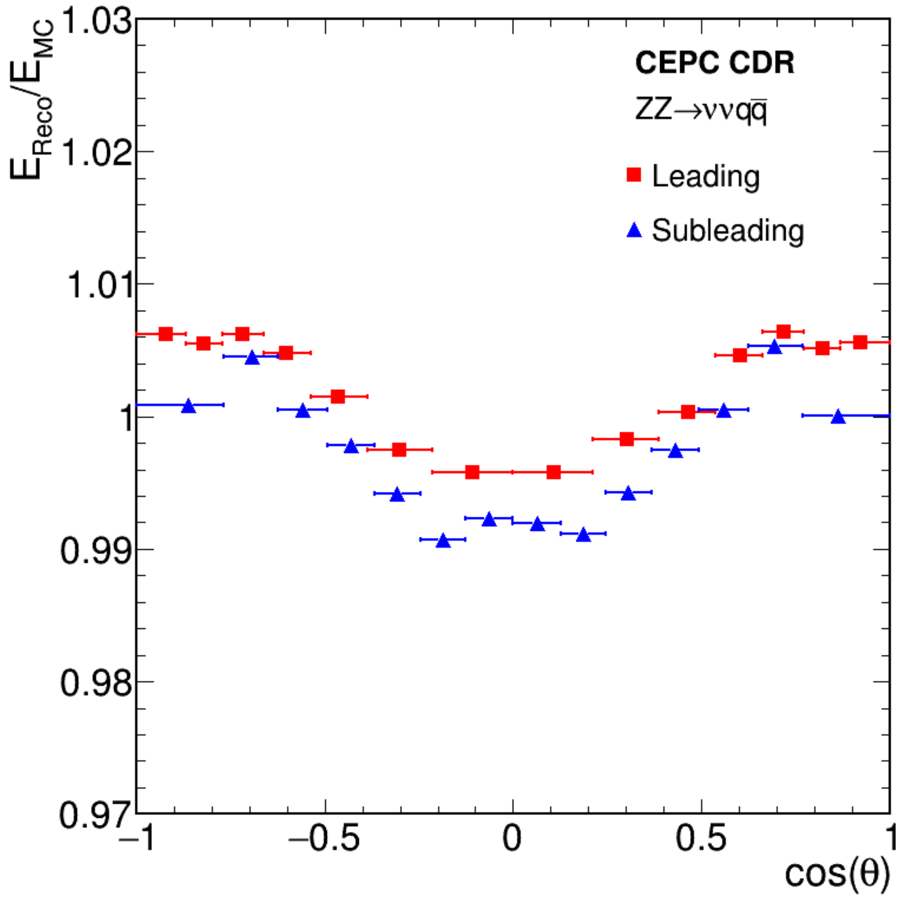
Peizhu Lai & CEPC CDR

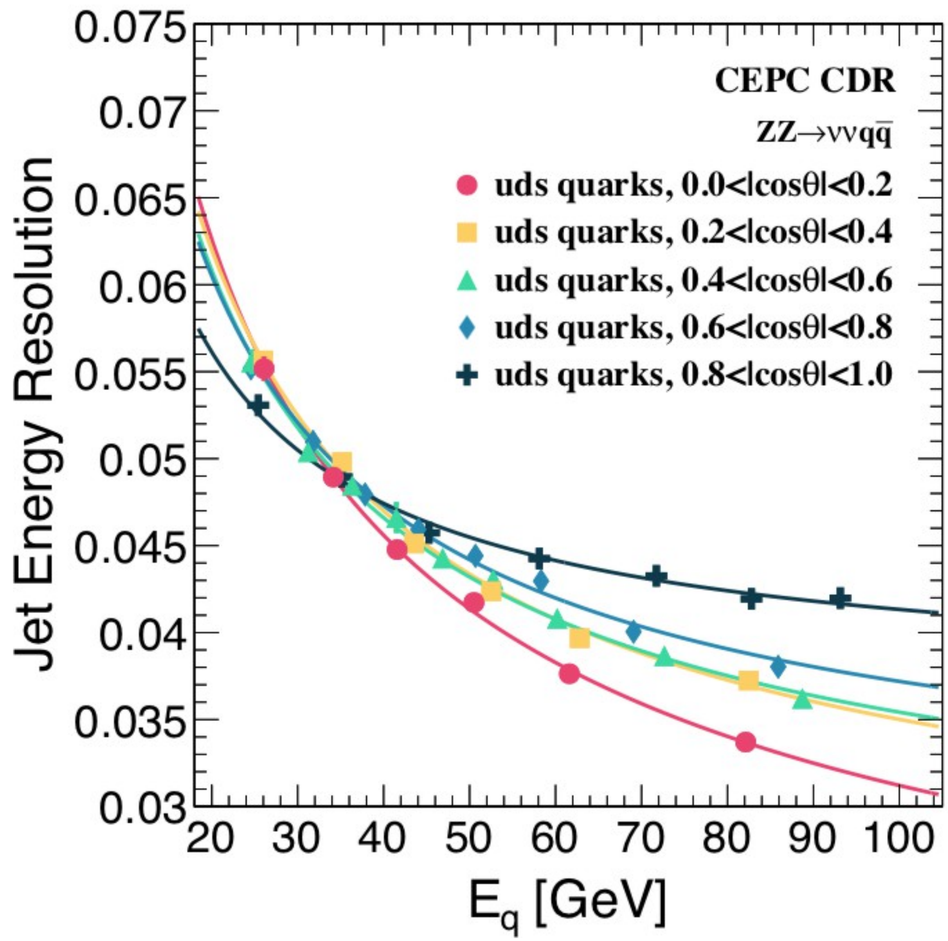
WW sample: using μνqq sample,
Plot: the visible mass without the muon

CEPC-RECO-2017-002 (DocDB id-164),
CEPC-RECO-2018-002 (DocDB id-171),

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

Jet Energy Scale & Resolution

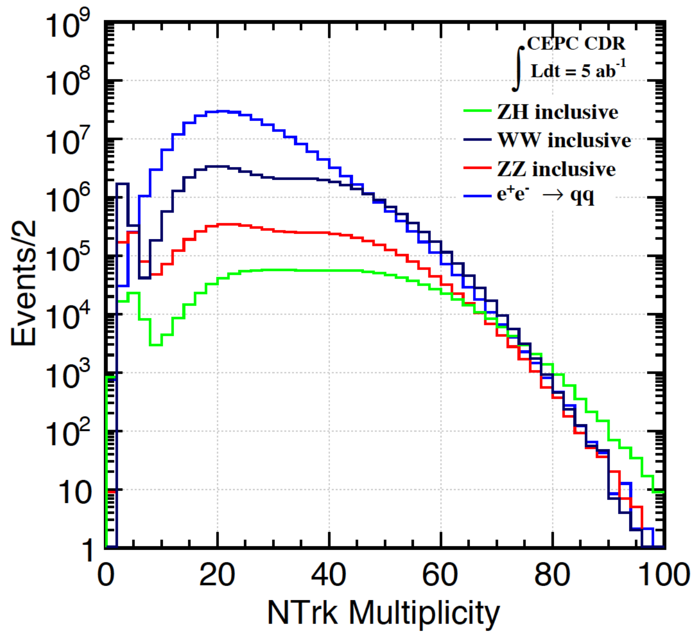


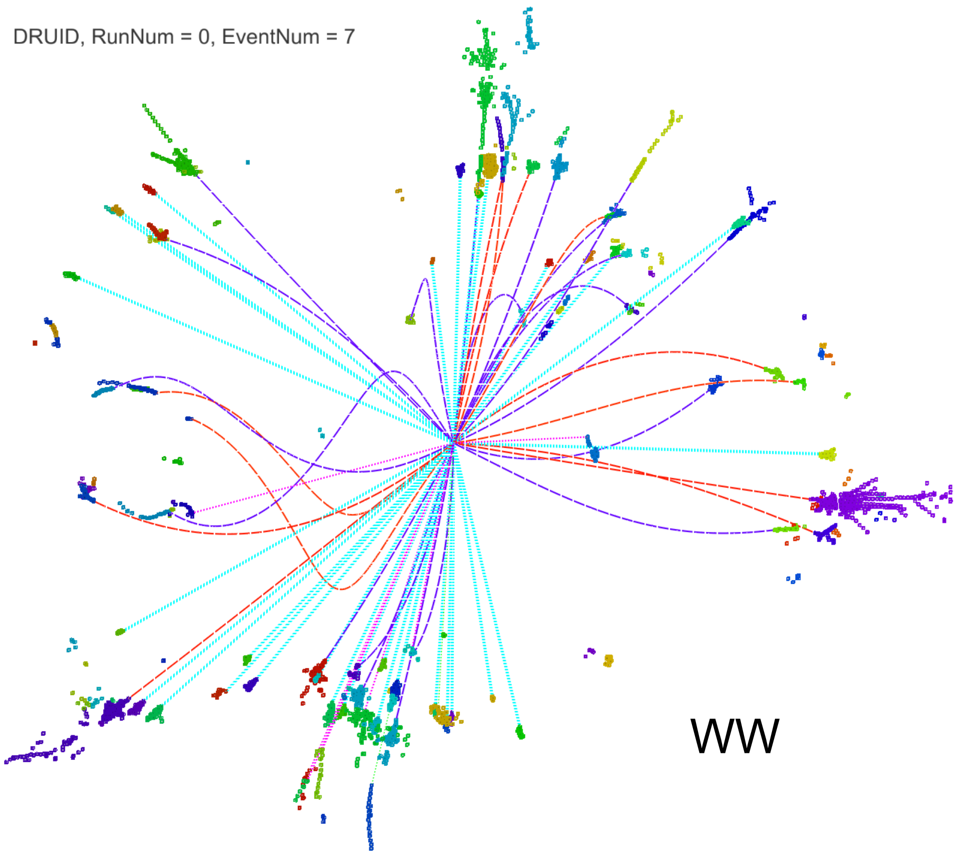


- JES ~ with 1% of the unity (without correction)
- JER ~ 3.5% - 5.5% for E ~ 20 – 100 GeV Jets
- **Both Superior to LHC experiments by 3-4 times**

Peizhu LAI

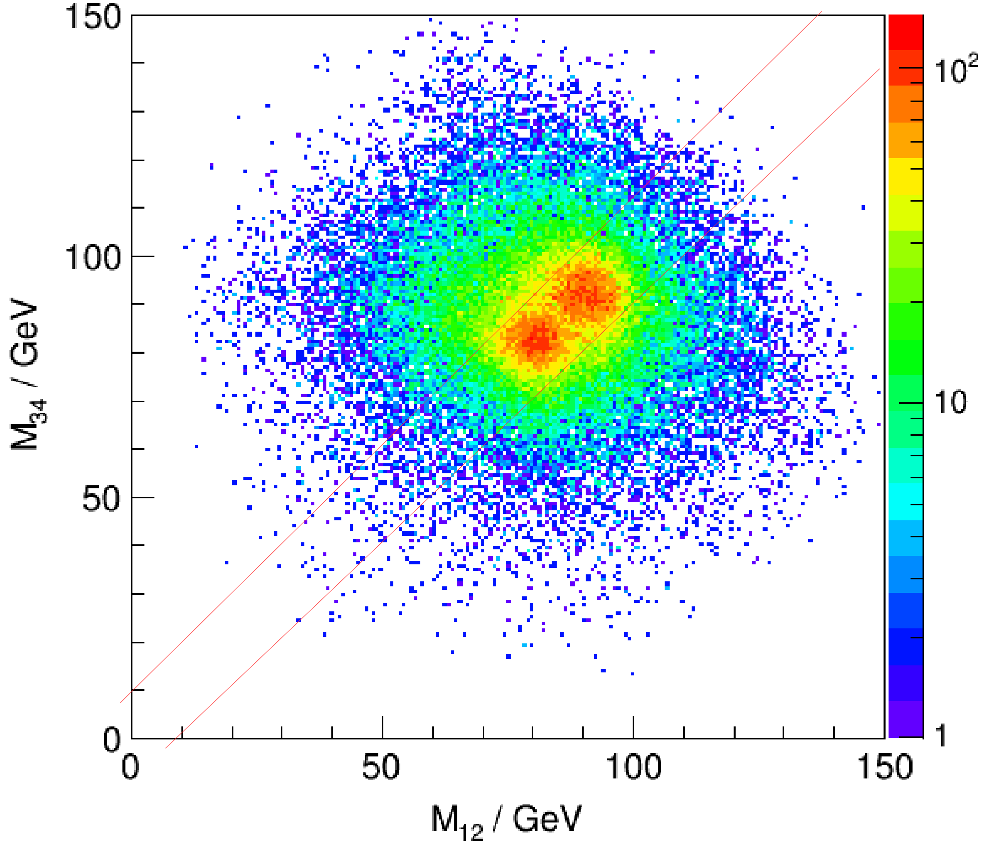
Separation of full hadronic WW-ZZ event

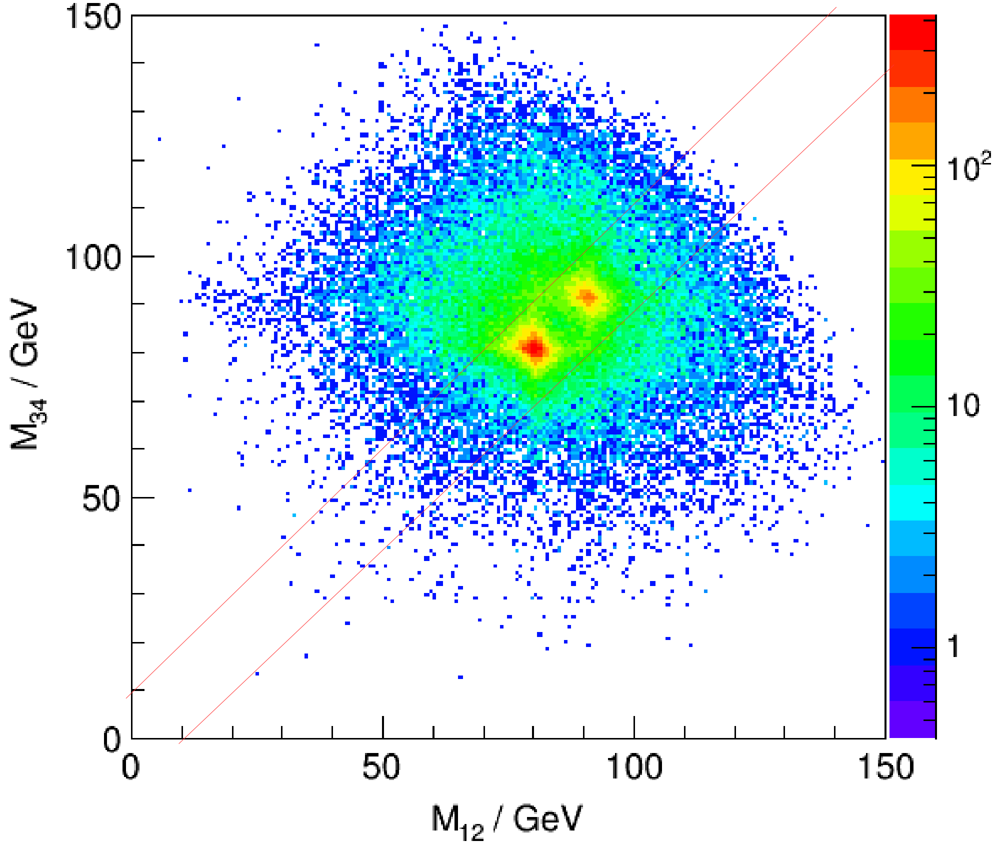




- Low energy jets! (20 – 120 GeV)
- Typical multiplicity ~ o(100)
- WW-ZZ Separation: determined by
  - Intrinsic boson mass/width
  - Jet confusion from color single reconstruction – jet clustering & pairing
  - Detector response

Hadronic WW/ZZ separation: need not only good detector, but also good color singlet identification algorithms...

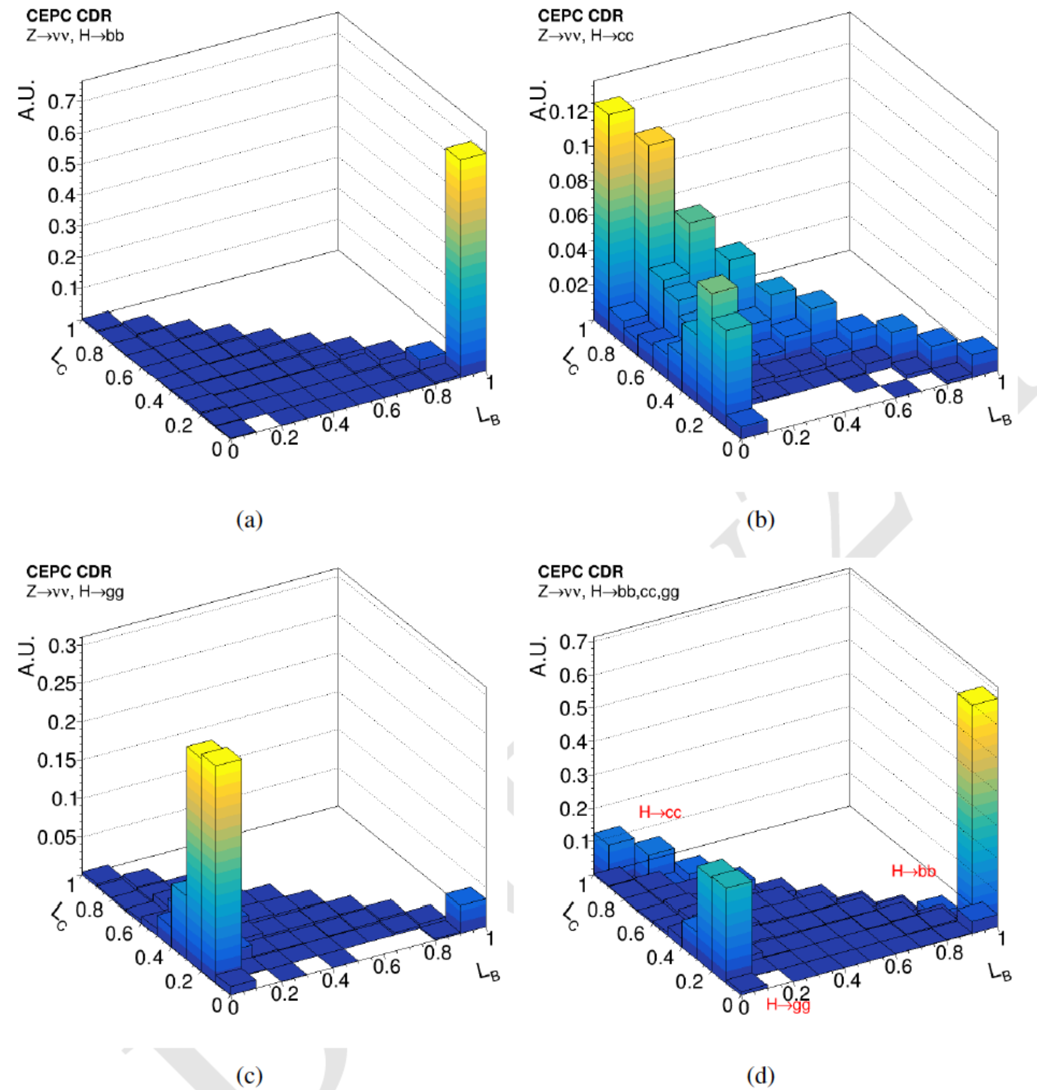




Equal mass condition |M12 – M34| < 10 GeV: At the cost of half the statistic, the overlapping ratio can be reduced from 58%/53% to 40%/27% for the Reco/Genjet

Flavor Tagging: every subsystem, but essentially relies on vertex detector

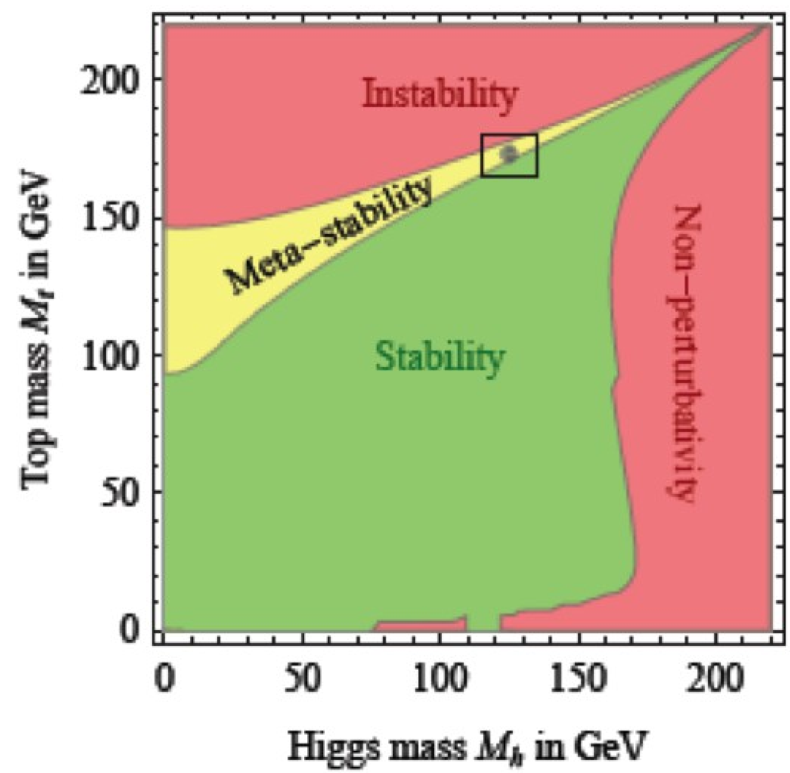
- Using LCFIPlus Package from ilcsoft
- At Higgs->2 jet samples:
  - *Clear separation between different decay modes*
- Typical Performance at Z pole sample:
  - *B-tagging: eff/purity = 80%/90%*
  - *C-tagging: eff/purity = 60%/60%*



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**