CEPC Preliminary Detector Design and Physics Simulation

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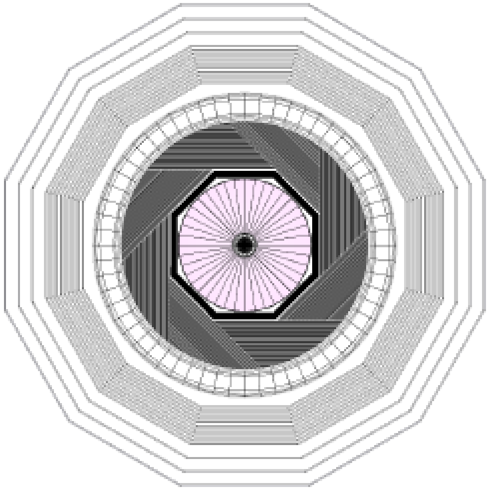
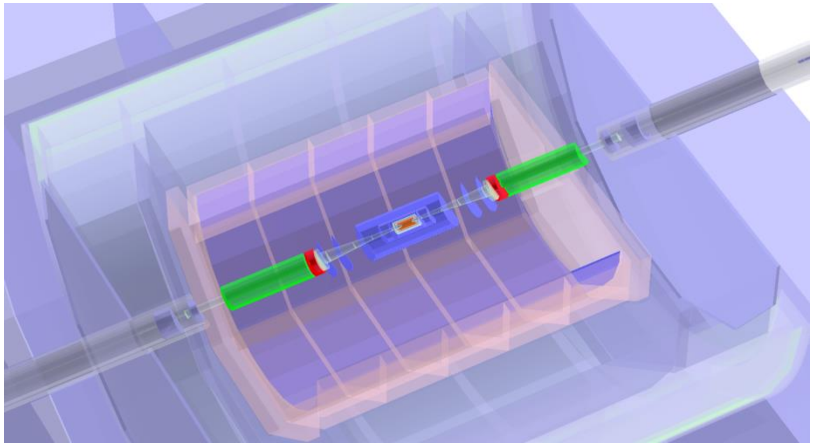
Outline

- ❑ Motivation
- ❑ CEPC preliminary Conceptual Detector Design
  - ❑ MDI
  - ❑ Vertex
  - ❑ Tracker
  - ❑ ECAL
  - ❑ HCAL
  - ❑ Muon
  - ❑ Magnet

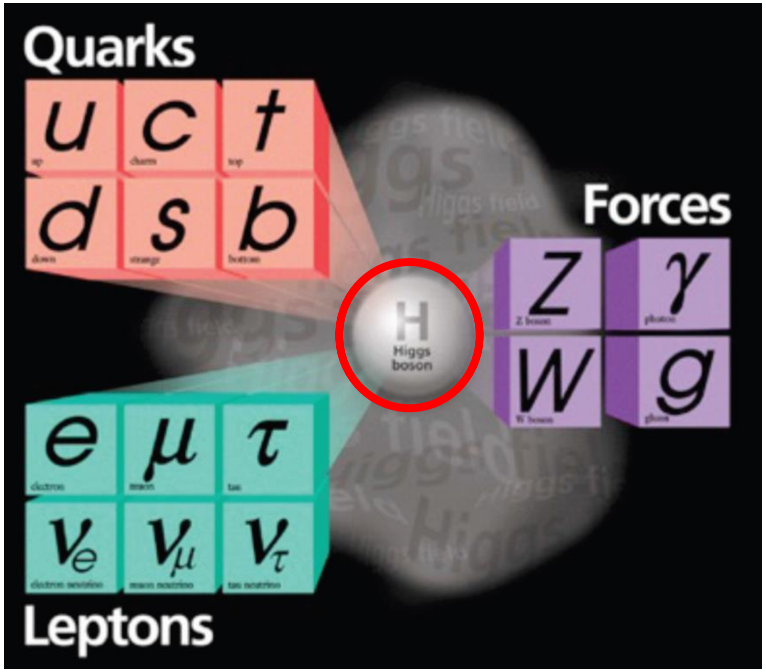


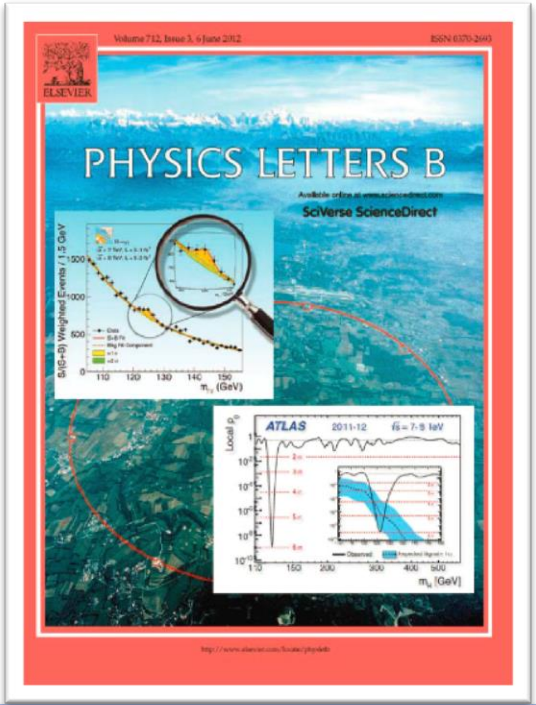


- ❑ Detector Simulation and Physics Analysis
- ❑ Summary and Future Plans

Circular Electron Positron Collider - CEPC

Discovery of low mass Higgs boson at the LHC (July 4, 2012) brings up an opportunity to investigate circular e^+e^- collider as a viable option for the "Higgs Factory" which is dedicated for precision measurement of the Higgs properties with clean collision environment.

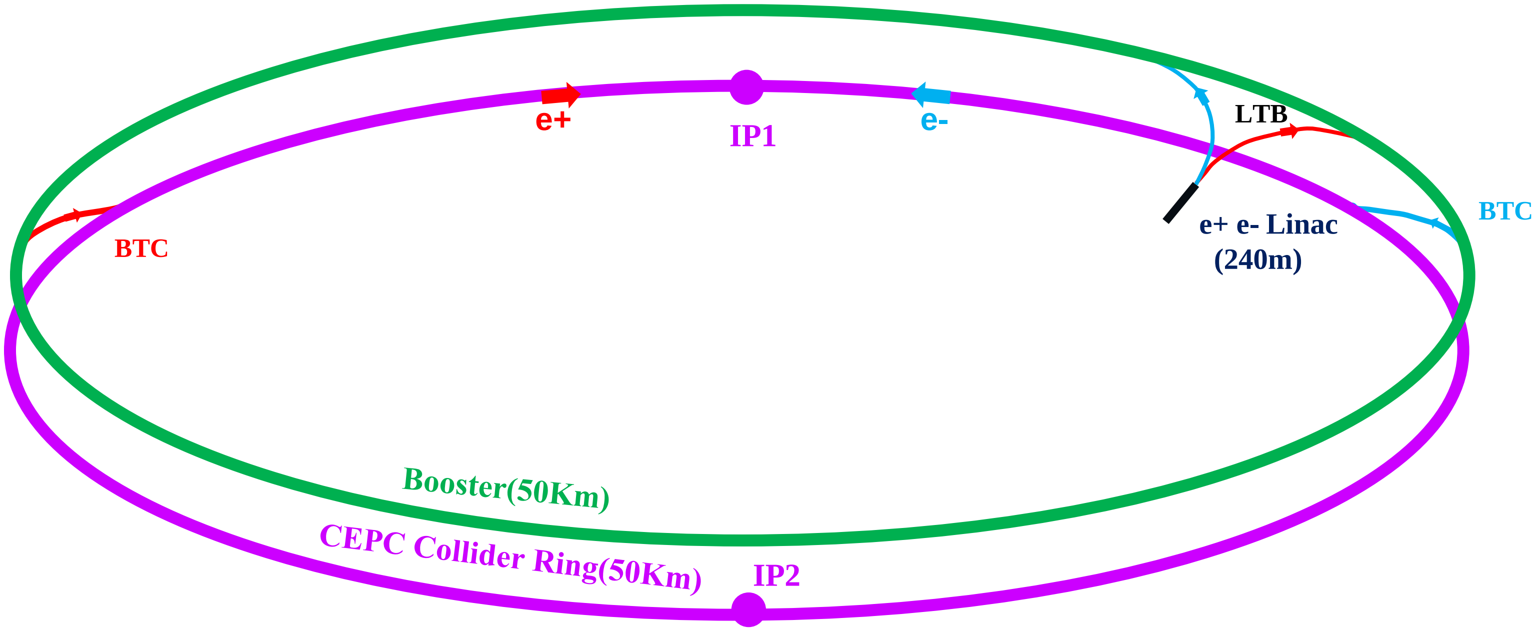




Circular Electron Positron Collider - CEPC

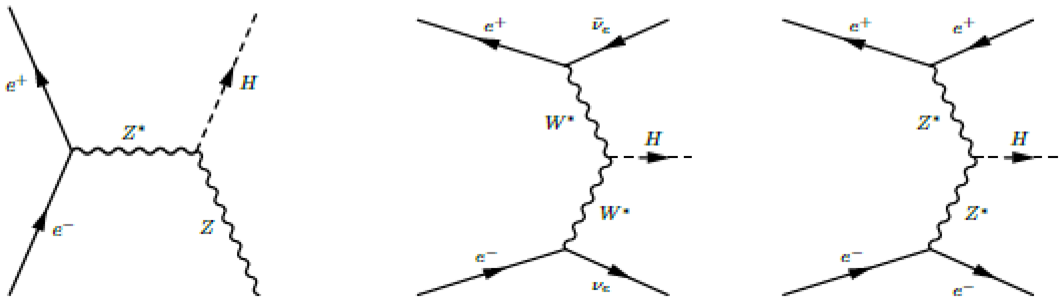
[See Weiren Chou's talk]

LINAC	to generate and accelerate electrons to 6 GeV
Booster	to accelerate electrons to 120 GeV
Main Ring	~54km, to accumulate electrons to 16.9 mA, FODO lattice, single ring with the Pretzel scheme …

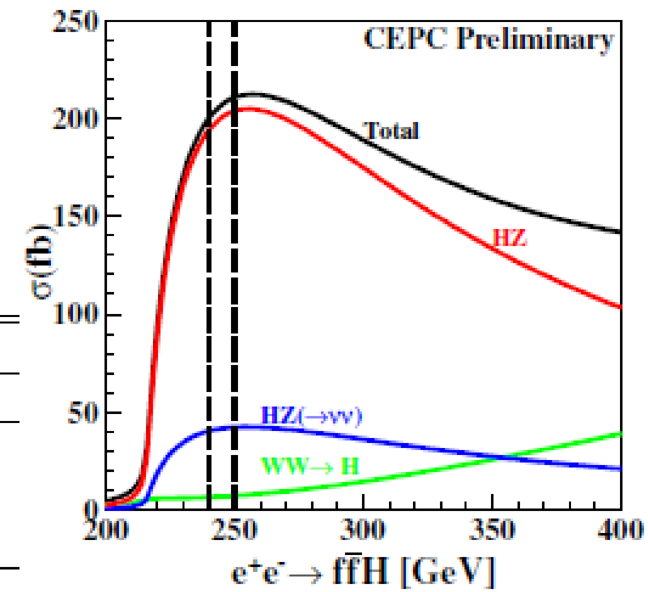


Circular Electron Positron Collider - CEPC

- Precise measurements of the Higgs properties as a Higgs Factory (similar to ILC@250 GeV) **[See Jianming Qian's talk]**
  - Mass, cross section, BR, J^{PC}, couplings, etc. → reach percentage accuracy



Process	Cross section (fb)	Nevents in 5 ab^{-1}
Higgs boson production		
$e^+e^- \to ZH$	209	1×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.9	3.5×10^4
$e^+e^- \to e^+e^-H$	0.6	3.0×10^3



- Precise measurements of Electroweak Symmetry-Breaking parameters at Z-pole and WW threshold
  - $m_Z, m_W, \Gamma_Z, \sin^2\theta_W^{\text{eff}}, \alpha_S$, *etc. + searches for rare decays*

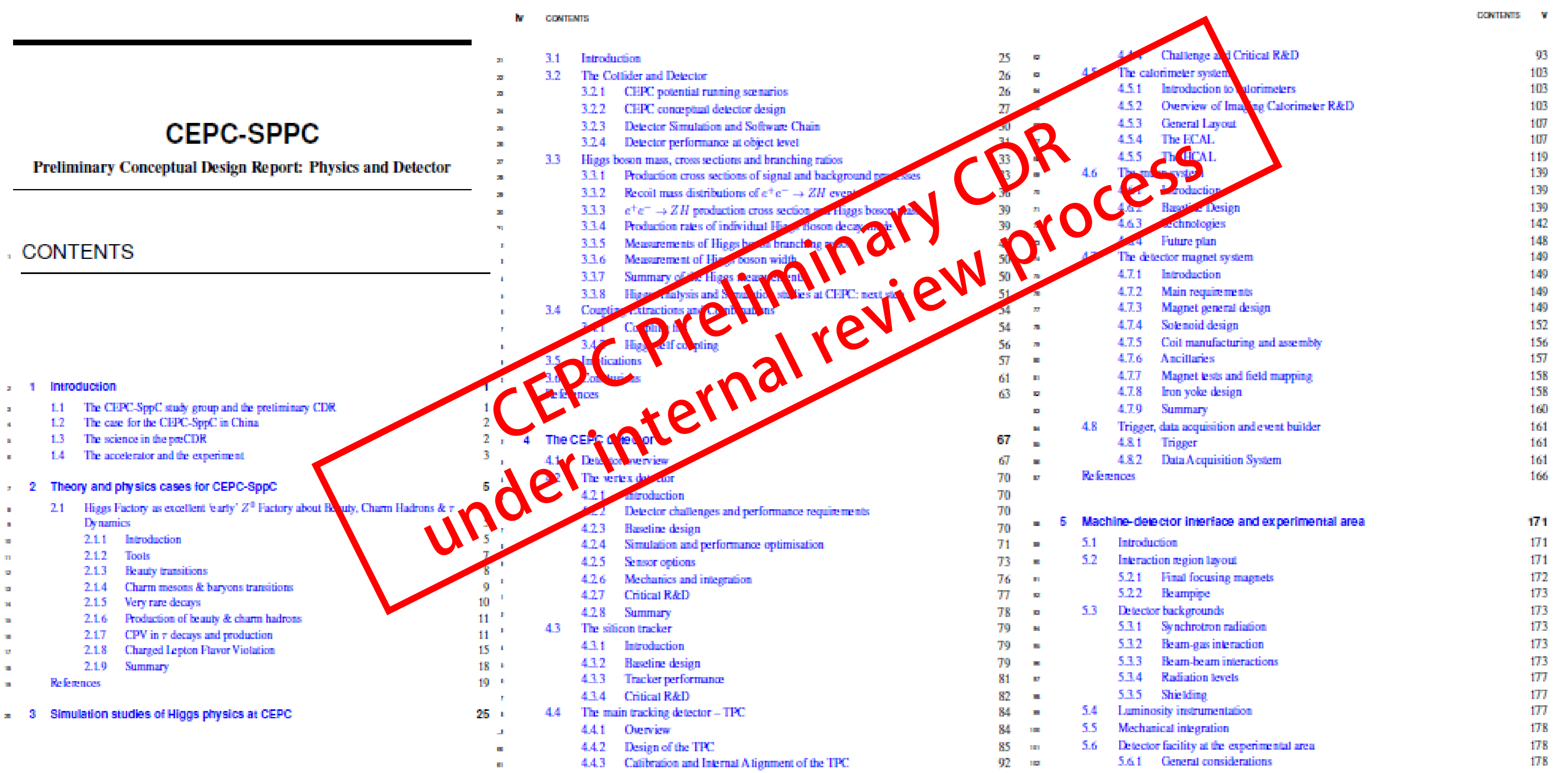
CEPC Physics and Detector Working Group

- **CEPC Project managers: Xinchou Lou, Qing Qin (IHEP)**
- **Physics and Detector Group Co-conveners**

  Yuanning Gao (THU), Shan Jin (IHEP)
- **Sub-groups and co-conveners**
  - Physics simulation and analysis:
    Gang Li, Manqi Ruan (IHEP), Dayong Wang (PKU)
  - MDI: Hongbo Zhu (IHEP), Yiwei Wang (IHEP)
  - Vertex: Qun Ouyang (IHEP), Meng Wang (SDU)
  - TPC tracker: Yulan Li (THU), Huirong Qi (IHEP)
  - Calorimetry and muon:
    Tao Hu (IHEP), Haijun Yang (SJTU)

CEPC PreCDR: Physics and Detector

preCDR author registration is OPEN, http://cepc.ihep.ac.cn/



CEPC-SPPC

Preliminary Conceptual Design Report: Physics and Detector

CONTENTS

CEPC Preliminary CDR
under internal review process

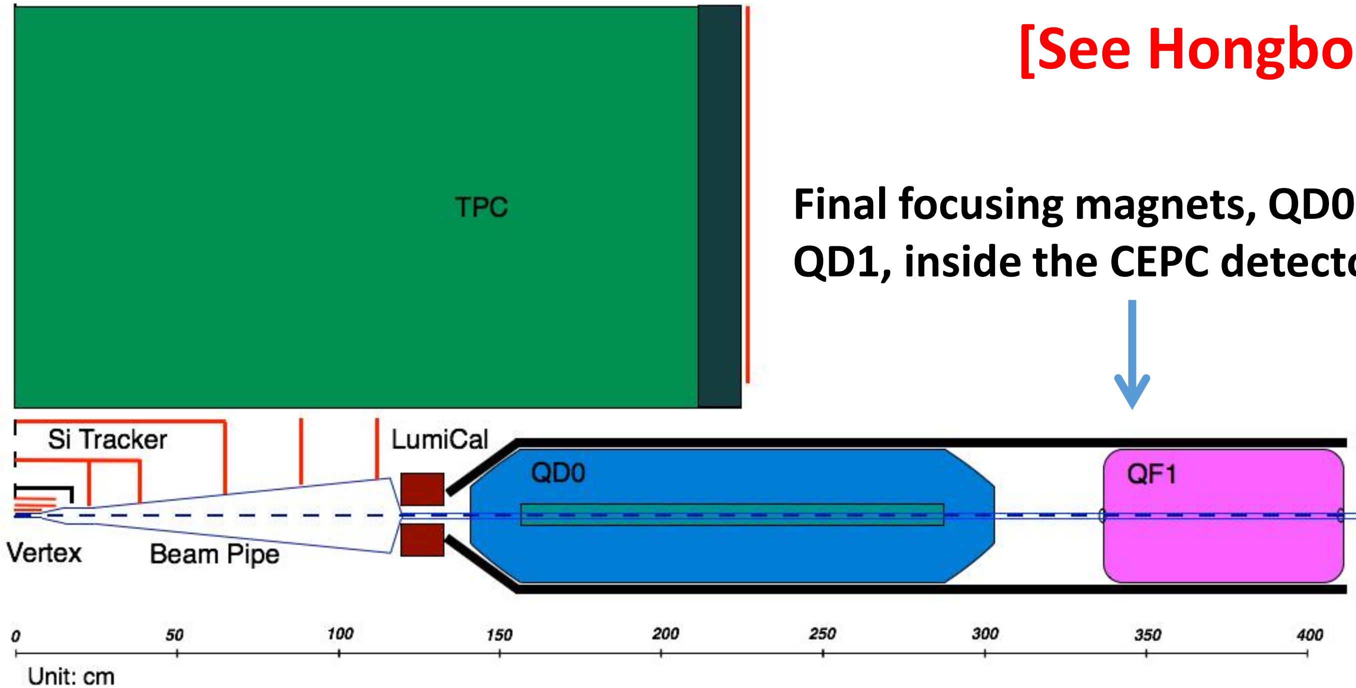
Requirements for CEPC Detector Design

Critical Physics Benchmarks for CEPC Detectors design.

- **ZH → $\ell\ell$X recoil and H→μμ require high δp/p² resolution of charged tracks**
- **H→bb,cc,gg require excellent vertex IP resolution for flavor-tagging**
- **H→qq, WW, PFA require high spatial and energy resolution of Calorimeters**
- **H→γγ requires excellent energy resolution of ECAL**

Physics Process	Measured Quantity	Critical System	Critical Detector Characterstic	Required Performance
ZHH $HZ \to q\bar{q}b\bar{b}$ $ZH \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass $\mathrm{B}(H \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution, $\Delta E/E$	3to4%
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-(\gamma)$ $ZH + H\nu\nu \to \mu^+\mu^- X$	Higgs Recoil Mass Luminosity Weighted $\mathrm{E_{cm}}$ $\mathrm{B}(H \to \mu^+\mu^-)$	Tracker	Charged Particle Momentum Res., $\Delta p_t/p_t^2$	2×10^{-5}
$HZ, H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs Branching Fractions b quark charge asymmetry	Vertex Detector	Impact Parameter, δ_b	$5\mu\mathrm{m} \oplus 10\mu\mathrm{m}/p(\mathrm{GeV/c})\sin^{3/2}\theta$

CEPC Machine Detector Interface (MDI)



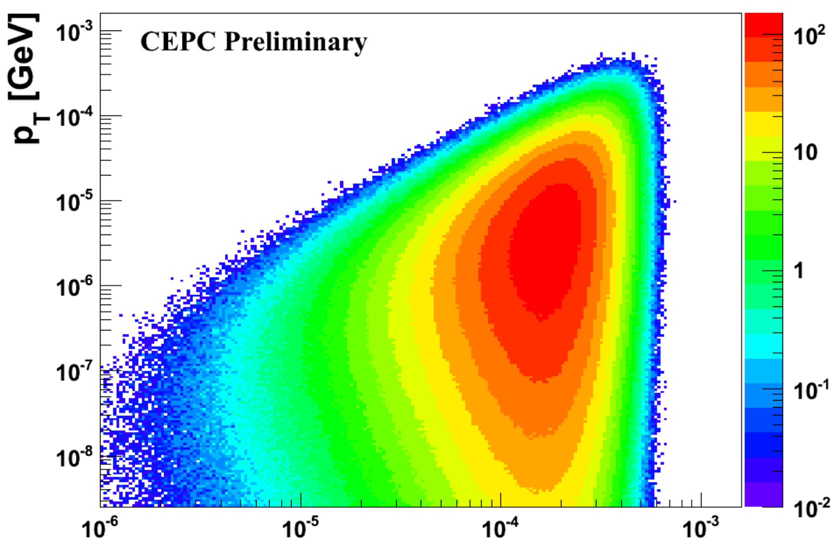
[See Hongbo Zhu's talk]

Final focusing magnets, QD0 and QD1, inside the CEPC detector

- Focal length (L*), the distance between QD0 and the interaction point, shortened to 1.5 m to allow realization of high luminosity without large chromaticity corrections
- Comprehensive understanding and optimization of both detector and collider performance are needed in future studies

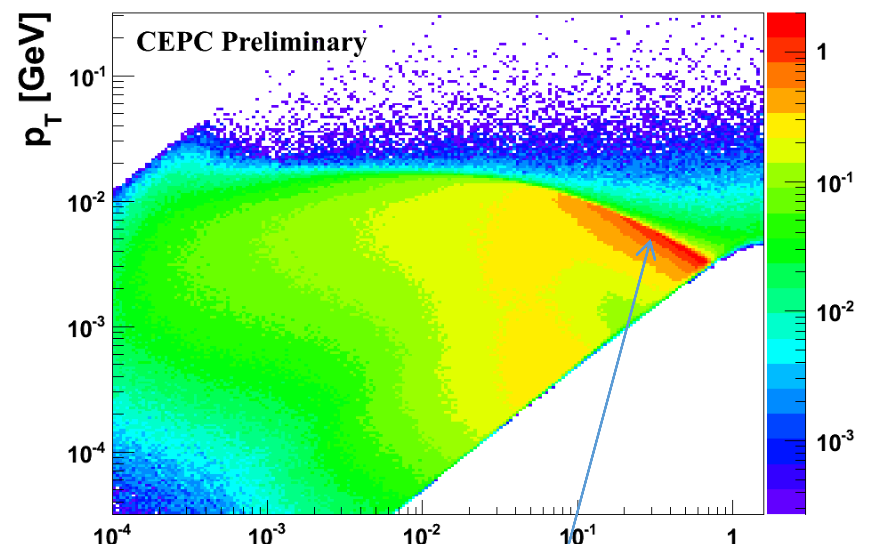
CEPC MDI: Beam-induced Backgrounds

- Beam induced backgrounds (beam-gas, beam-beam, synchrotron radiation) imposes large impact on detector design (eg, occupancies, radiation damage)
- Beam-beam interactions simulated with Guinea-Pig, including Beamstrahlung, e+e- pair production, hadronic backgrounds etc.



Beamstrahlung photons

Low momentum and small polar angle → negligible, but should avoid directing any detector component



e+e- Pair production

Dominant detector background with sharp kinematic edge

CEPC MDI: Luminosity Measurement

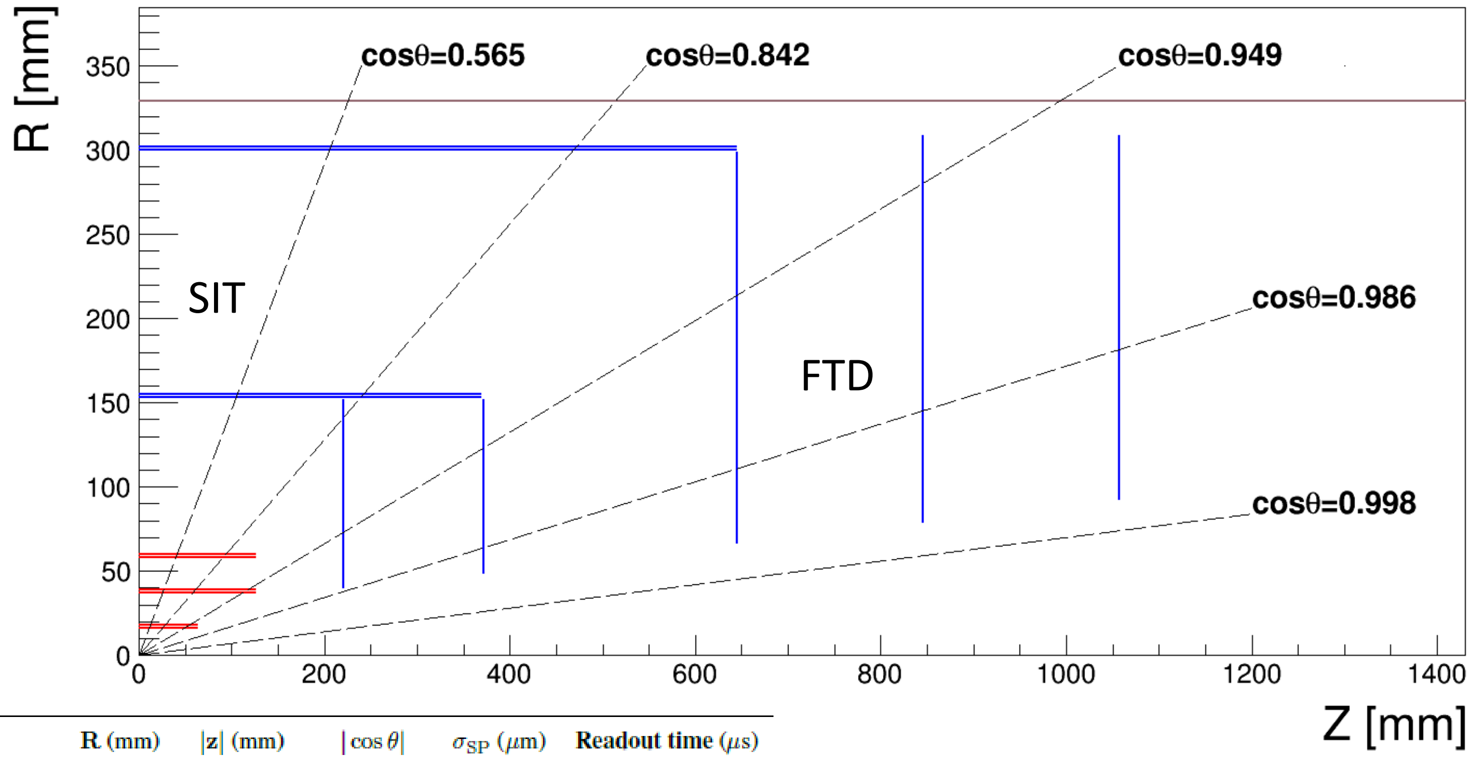
- Luminosity measurement with the dedicated device, LumiCal, with a target uncertainty of 10^{-3}, as required by precision measurements of the Higgs and Z physics.
  - Electromagnetic calorimeter with silicon-tungsten sandwich structure, to measure radiative Bhabha events
  - $\Delta L/L \sim 2\Delta\theta/\theta_{min}$ → necessary to achieve precise polar angle measurement better than $\Delta\theta < 0.015$ mrad

- Online beam luminosity monitor allowing fast beam tuning
  - radiation hard sensor technologies (e.g. CVD diamond), to measure radiative Bhabha events at zero photon scattering angle ← similar design as for the SuperKEKB design

CEPC Vertex and Silicon Tracker

ILD-like but with reduced number of FTD

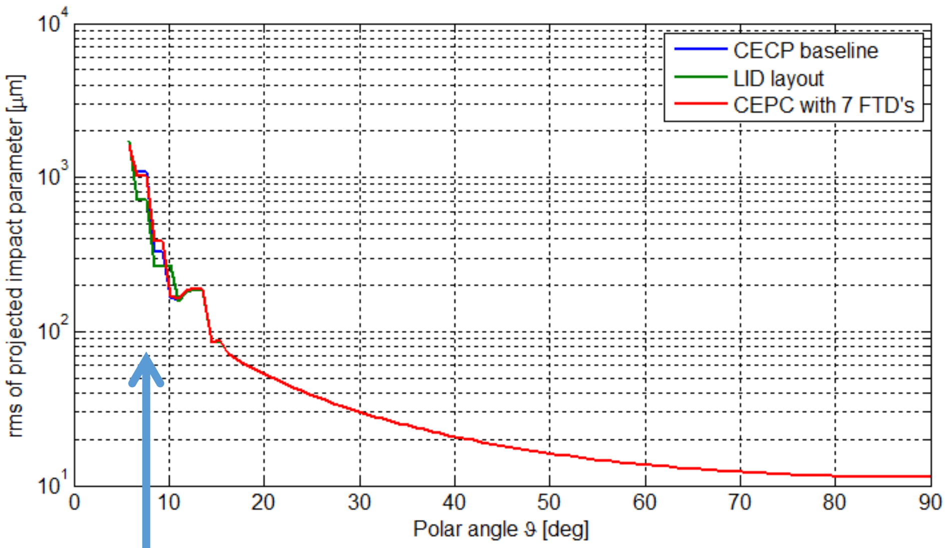
Qun Ouyang @ IHEP



	R (mm)	|z| (mm)	|cos θ|	σ_{SP} (μm)	Readout time (μs)
Layer 1	16	62.5	0.97	2.8	20
Layer 2	18	62.5	0.96	2.8	20
Layer 3	37	125.0	0.96	4	20
Layer 4	39	125.0	0.95	4	20
Layer 5	58	125.0	0.91	4	20
Layer 6	60	125.0	0.90	4	20

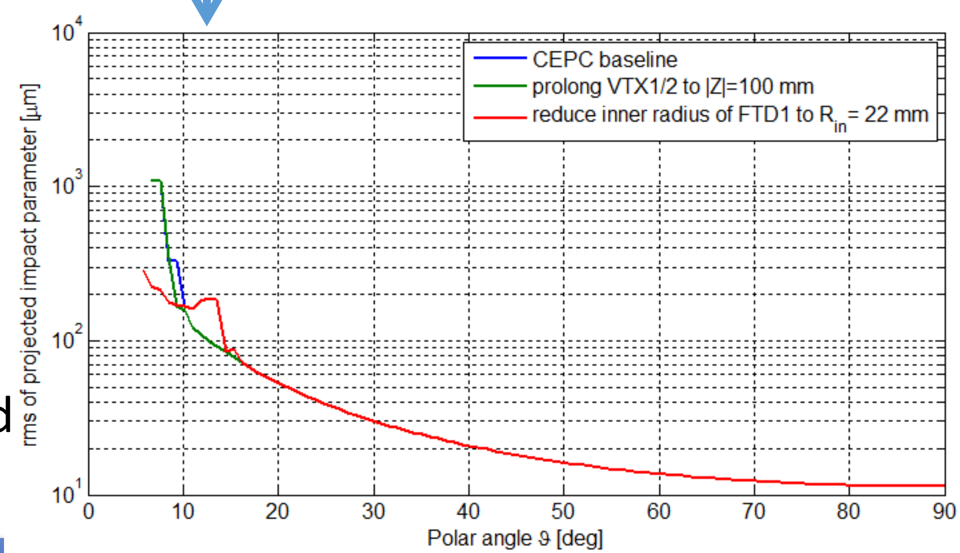
Vertex : **3** layers of double-sided pixels (**in Red**)
Si-tracker: **2** Silicon Internal Tracker, **5** Forward Tracking Disks
Silicon External Tracker (SET) – 1 outer layer Si strip detector
End-cap Tracking Detector (ETD) – 1 end-cap Si strip / side

CEPC Vertex and Si Tracker: Layout Optimization



3. The performance loss can be recovered with extended coverage of the pixel detector layers, either by prolonging first two VTX barrel layers or extending the first FTD disk down to r=22mm

1. Performance loss in the low polar angle region (**impact parameter** resolution of tracks) with reduced number of FTD disks
2. Such loss cannot be recovered with another two disks within the limited space between QD0 and the IP.



CEPC Vertex and Silicon Tracker

B = 3.5T

Performance requirements

- momentum resolution $\sigma_{1/p_T} = 2\times10^{-5} \oplus 1\times10^{-3}/(p_T \sin\theta)$
- impact parameter resolution $\sigma_{r\phi} = 5\mu m \oplus \frac{10}{p(GeV)\sin^{3/2}\theta}\mu m$

Vertex detector specifications:

- spatial resolution near the IP: *≤ 3 μm*
- material budget: *≤ 0.15%X_0/layer*
- pixel occupancy: *≤ 0.5 %*
- radiation tolerance: Ionising dose: *100 krad/ year*
  Non-ionising fluences : *≤ $10^{11} n_{eq}$/ (cm^2 year)*
- first layer located at a radius: *~1.6 cm*

Silicon tracker specifications:

- σ_{SP} : *≤ 7 μm* → small pitch (50 μm)
- material budget: *≤ 0.65%X_0/layer*

CEPC Vertex and Silicon Tracker

Many technologies from ILC/CLIC R&D could be referred.

BUT, unlike the ILD, the CEPC detector will operate in continuous mode.

Pixel sensor: power consumption < 50mW/cm^2 with air cooling, readout < 20μs

- HR-CMOS sensor with a novel readout structure —ALPIDE for ALICE ITS Upgrade
  - In-pixel discriminator and digital memory based on a current comparator
  - In-column address encoder
  - <50mW/cm^2 expected
  - Capable of readout every ~4μs
- SOI sensor with similar readout structure
  - Fully depleted HR substrate, potential of 15μm pixel size design
  - Full CMOS circuit
- DEPFET: possible application for inner most vertex layer
  - small material budget, low power consumption in sensitive area

Silicon microstrip sensor: p^+-on-n technology

pixelated strip sensors based on CMOS technologies

CEPC Vertex and Si Tracker: Critical R&D plan

- Pixel sensors with low power consumption and high readout speed
  - In-pixel discriminator
  - In-matrix sparsification

  Similar to ALPIDE sensor for ALICE ITS Upgrade

  Starting design with HR-CMOS process

  Exploring possibility with SOI process, especially for smaller pixel size
- Light weight mechanical design and cooling
  - 0.05%(0.1%) material budget without(with) cabling
  - Air cooling technology with acceptable vibration due to air flow
- Pixel sensor thinning to 50μm
- Slim edge silicon microstrip sensor
- Low noise, low power consumption FEE for silicon microstrip

CEPC TPC Tracker: Design Goals

Huirong Qi @ IHEP

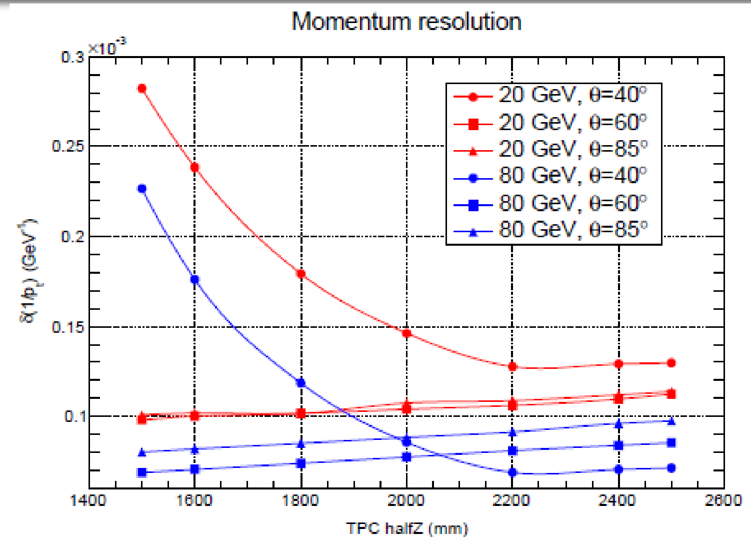
Performance/Design Goals	
Momentum resolution[a] at B=3.5T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c TPC only
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\,X_0$ including the outer field cage in r $< 0.25\,X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2$\times 10^6$/1000 per endcap
Pad pitch/no.padrows	$\simeq 1\,\text{mm} \times 4\text{-}10\,\text{mm}/\simeq 200$
σ_{point} in $r\phi$	$< 100\mu$m (avg for straight-radial tracks)
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq 2$ mm (for straight-radial tracks)
2-hit resolution in rz	$\simeq 6$ mm (for straight-radial tracks)
dE/dx resolution	$\simeq 5$ %
Performance	> 97% efficiency for TPC only (p_t > 1GeV/c) > 99% all tracking (p_t > 1GeV/c)
Background robustness	Full efficiency with 1% occupancy,
Background safety factor	Chamber prepared for 10–20% occupancy (at the linear collider start-up, for example)

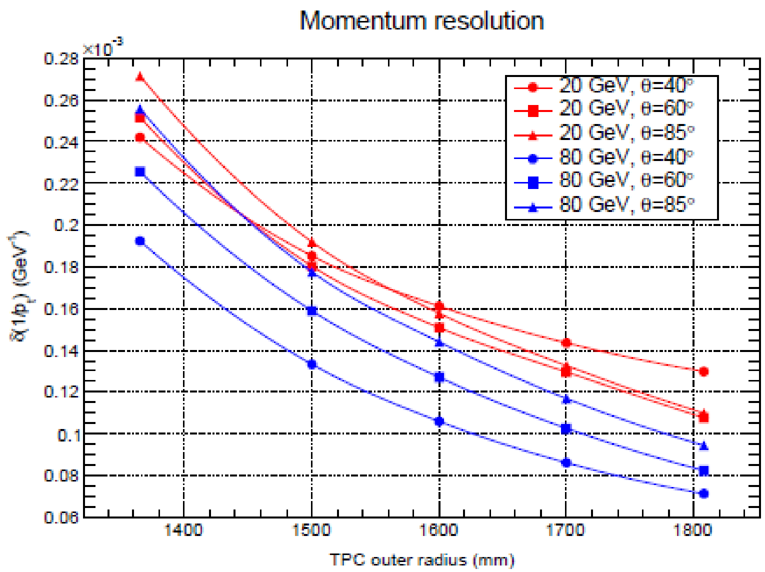
Same as Main performance/ Design goals of ILD-TPC

[a] The momentum resolution for the combined central tracker is $\delta(1/p_t) \simeq 2 \times 10^{-5}$/GeV/c

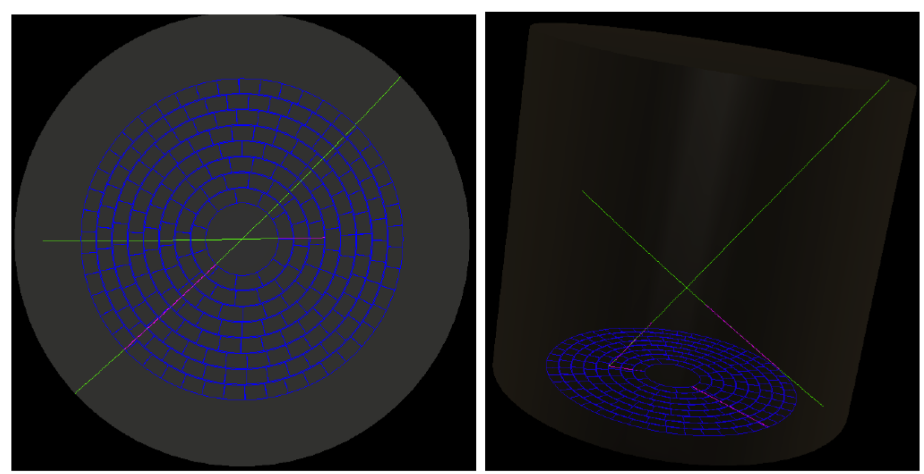
CEPC TPC Conceptual Design

- **Parameter of Simulation**
  - **TPC, Half Z=2.0m**
  - **r_in = 329 mm; r_out = 1808 mm**
  - **Cos(theta) = ~ 0.95**
  - **pad size: 1mm × 6mm**
  - **Number of hits per track: ~200**
  - **B = 3.5 Tesla, with L* = 1.5m**





$e^+e^- \rightarrow \mu^+\mu^-\nu_e\bar{\nu}_e$



Test of a TPC Prototype at THU

- TPC cylinder length: 50 cm
- TPC Diameter = 32 cm
- Readout GEM: 100x100mm^2
- 10x32 pads, staggered
  - Pad size: 9.5x1.5mm^2
  - Pitch: 10 x 1.6 mm^2
- Spatial resolution as a function of drift distance (B=1T)
- Best performance:

  σ_x = 100μm @Z~100mm

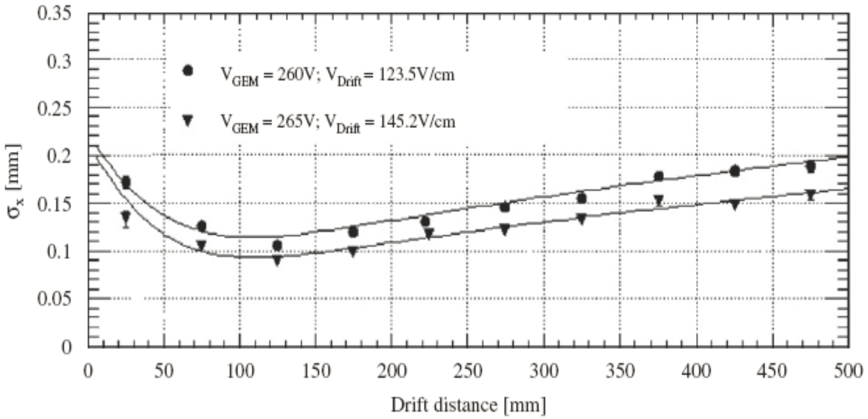


Fig. 6. x-Resolution for Ar–Iso–CF4 = 96.3–3.1–0.6 gas with $B = 1$ T under two different test conditions ($\varphi < 2°$, $\theta < 10°$).

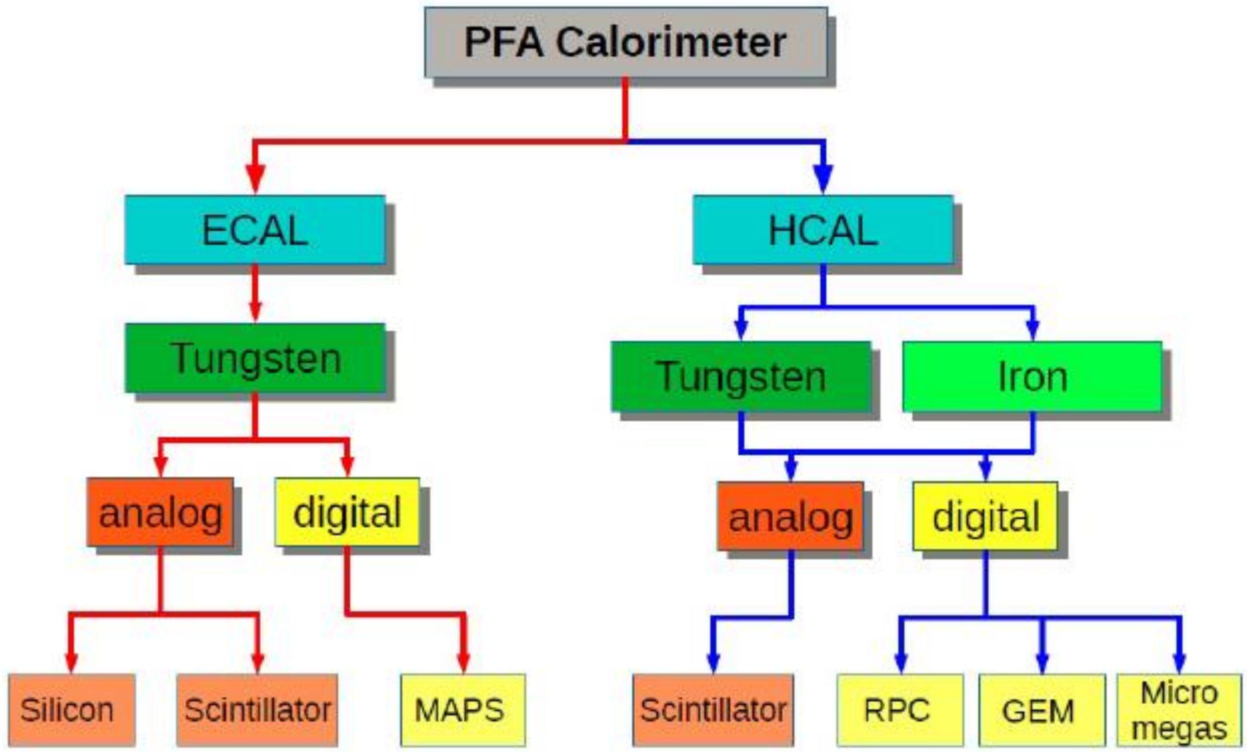
CEPC TPC: Critical R&D plan

- Physical design and optimization of the TPC
  - Length, inner/outer radius, pad size
  - E/B fields and uniformity requirements
  - Working gas, counting rate, ion backflow suppression
  - The time structure of the beam
  - Sensors: GEM and Micromegas detectors ?

- Critical R&D
  - Large prototype design, construction and assembly
  - Laser calibration and alignment device design, assembly
  - Detector readout options (GEM+Pad, Micromegas+Resistive Pad, ThickGEM+Pad ?)
  - Front-end readout electronics and DAQ
  - Cooling system (eg. two-phase CO_2 cooling, micro-channel CO_2)

Global R&D of Imaging Calorimeters

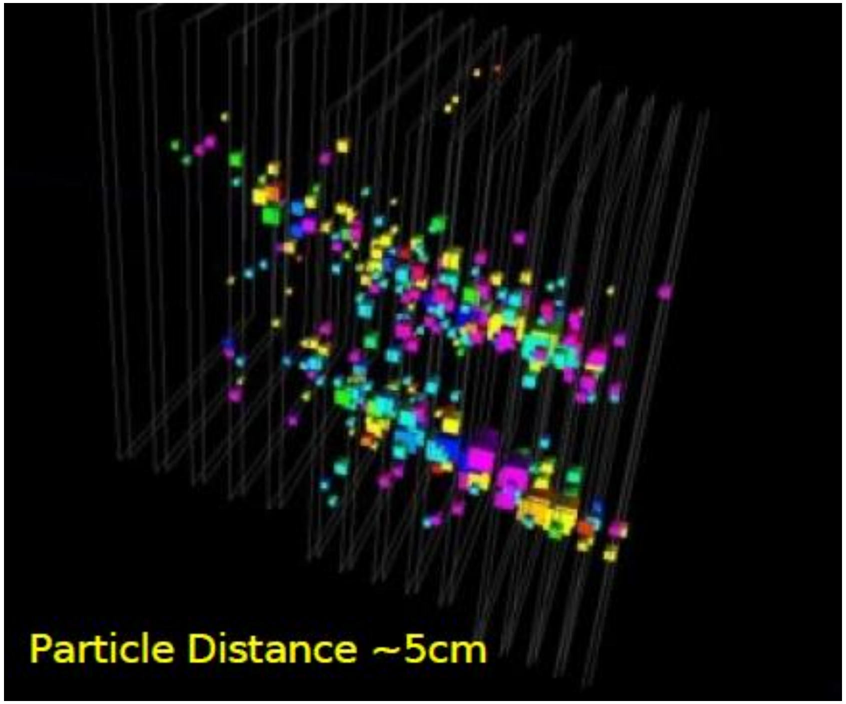
https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers

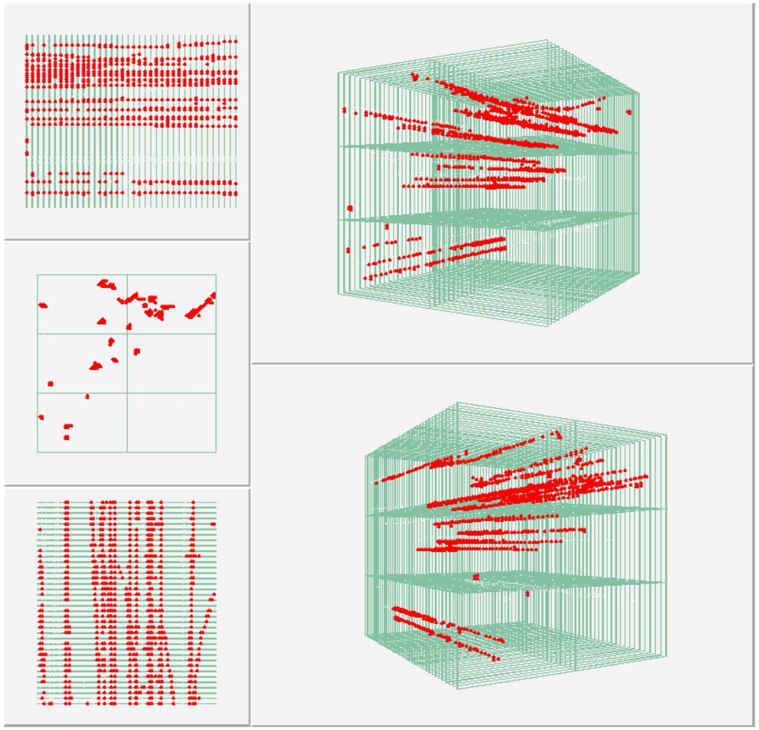


Readout cell size:	144 - 9 cm^2 →	4.5 cm^2 →	1 cm^2 →	0.25 cm^2 →	0.13 cm^2 →	2.5×10^{-5} cm^2
Technology:	Scintillator + SiPM/MPPC	Scintillator + SiPM/MPPC	Gas detectors Silicon	Silicon	Silicon	Silicon (MAPS)

Imaging Calorimeters

L. Xia @ ANL





Two electrons ~5cm apart
CALICE SiW ECAL

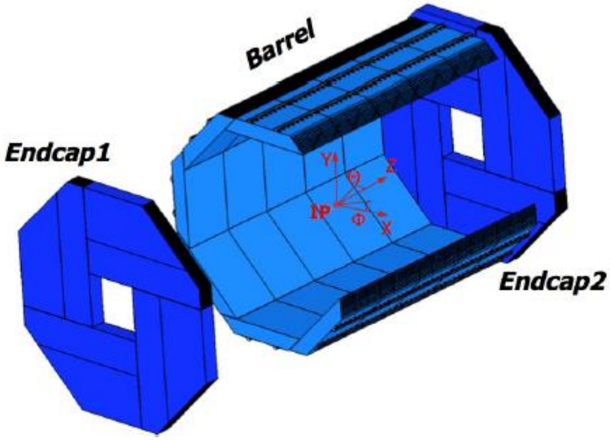
~20 muons in 1m² area
CALICE RPC DHCAL

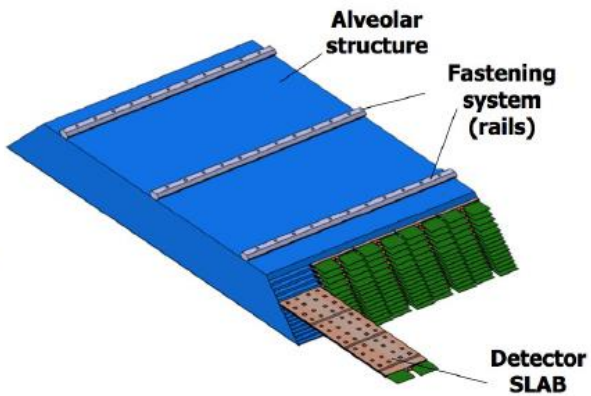
This is exactly what PFA needs: distinguishing individual showers within jet environment, in order to get excellent jet energy/mass resolution

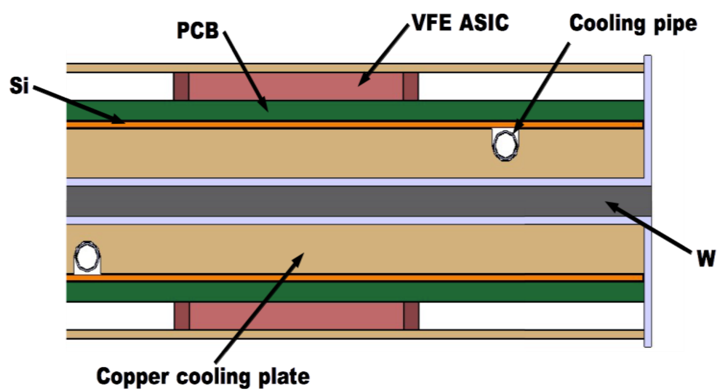
CEPC ECAL: Silicon-W

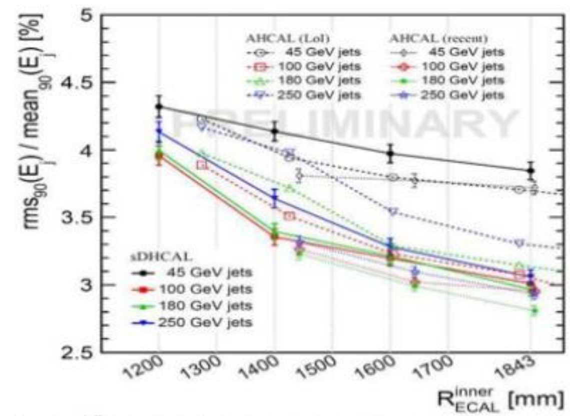
V. Boudry @ IN2P3

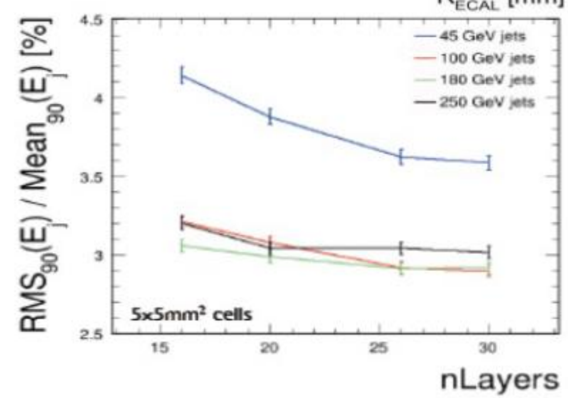
- The ECAL consists of a cylindrical barrel system and two large end caps.
- Two detector active sensors interleaved with tungsten absorber
  - silicon pixel 5 x 5 mm^2; PCB with VFE ASIC









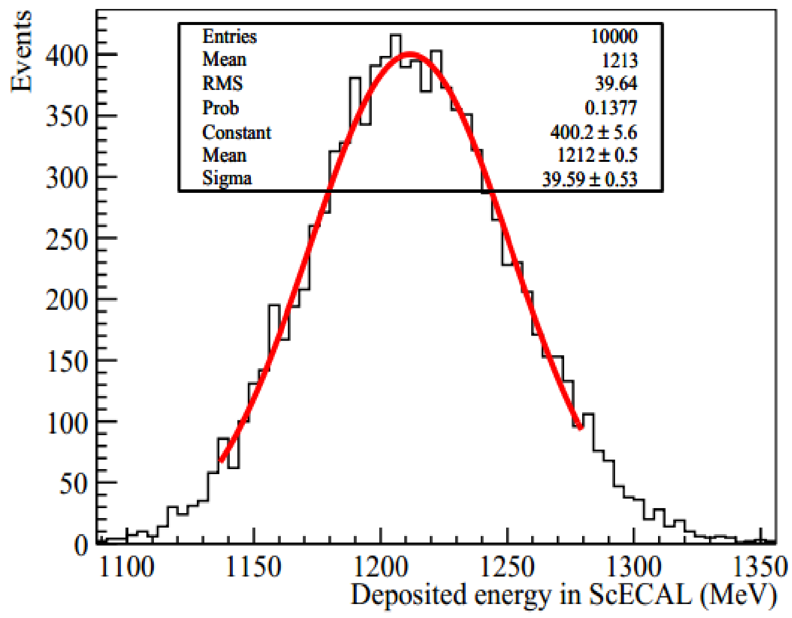


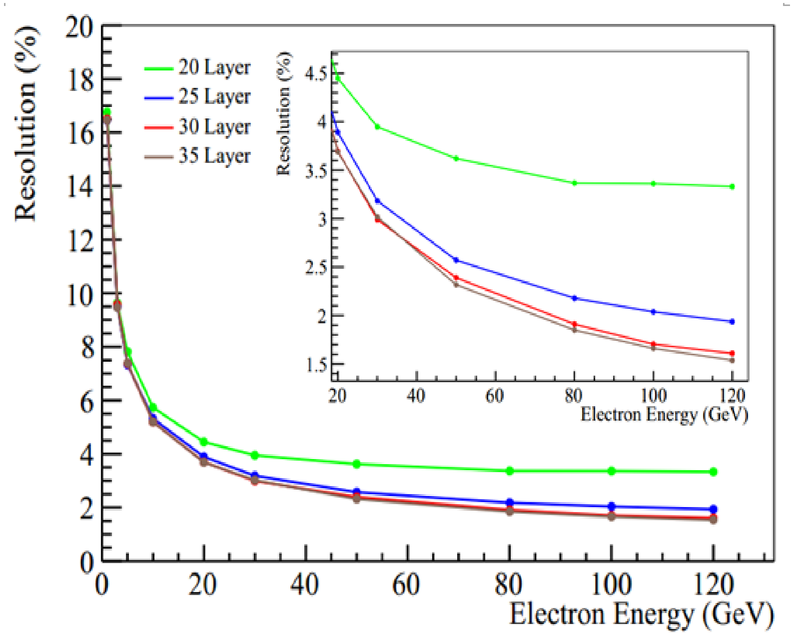
CEPC ECAL: ScW Simulation

Z.G. Wang @ IHEP

Standalone Simulation of ScW ECAL with Geant4 package.

- **Plastic scintillator (2mm)**
- **Tungsten plate (3mm), no readout layer included**

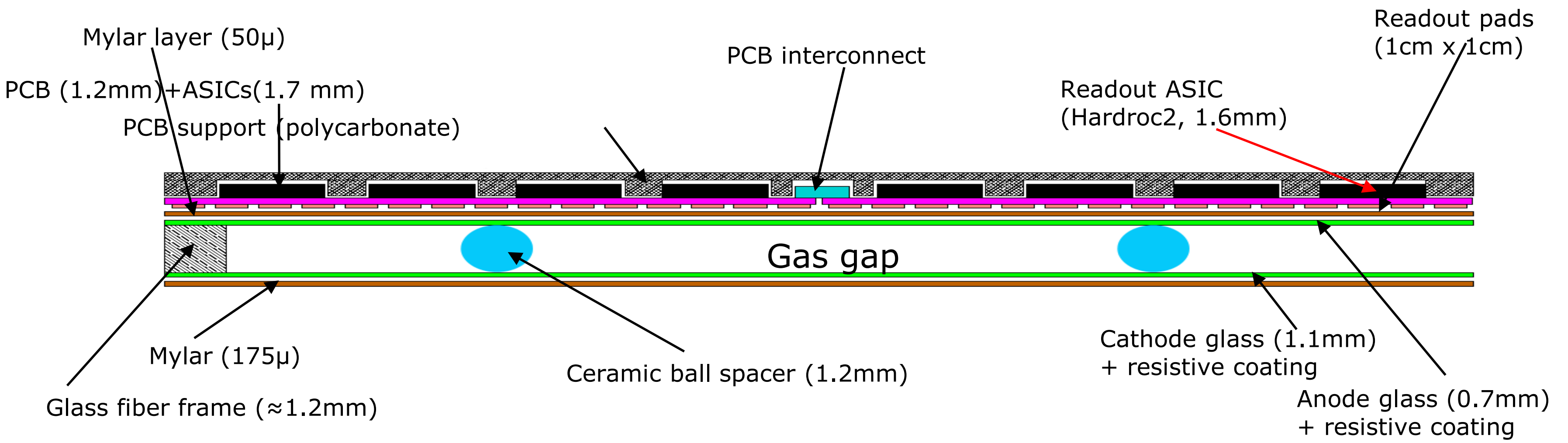




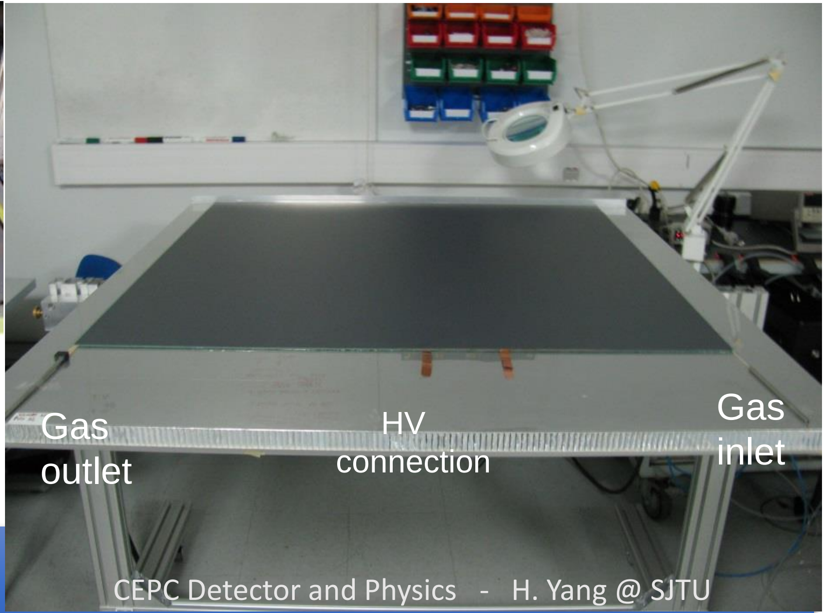
- **The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**

DHCAL with RPC

Imad Laktineh @ IPNL



Large GRPC R&D

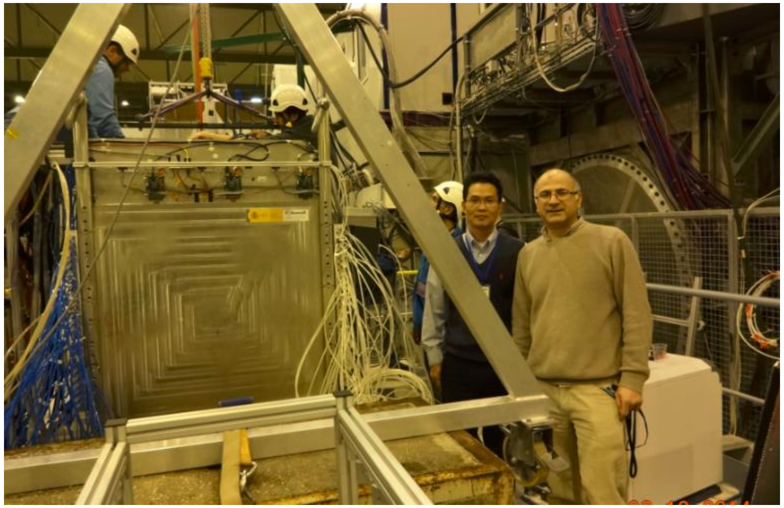


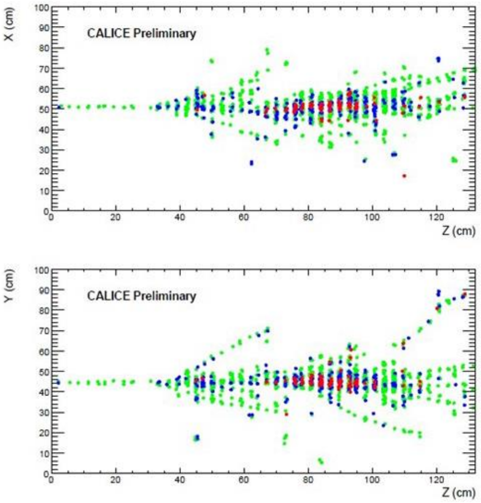
- ✓ Negligible dead zone (tiny ceramic spacers)
- ✓ Large size: 1 x 1 m^2
- ✓ Cost effective
- ✓ Efficient gas distribution system
- ✓ Homogenous resistive coating

Prototypes of DHCAL with RPC

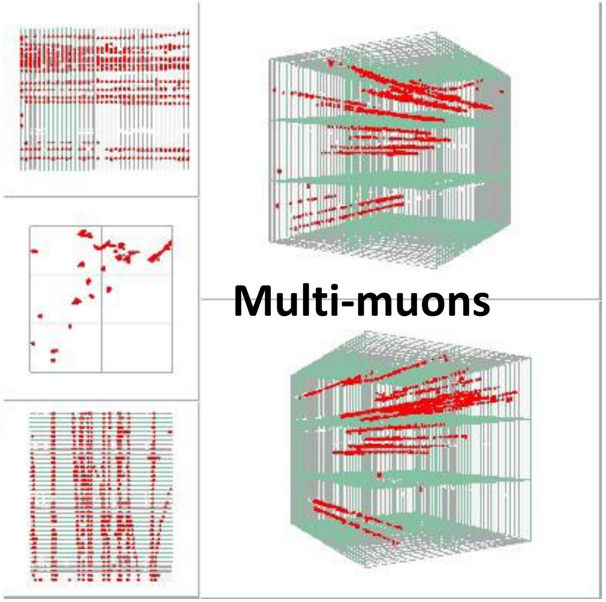
Prototypes of DHCAL based on RPC

- **ANL (J. Repond, L. Xia et.al.)**
  1m^3, 1 threshold, TB at CERN/Fermilab
- **IPNL (I. Laktineh, R. Han et.al.)**
  1m^3, 3 thresholds, TB at CERN in 2014.12





80 GeV Pion

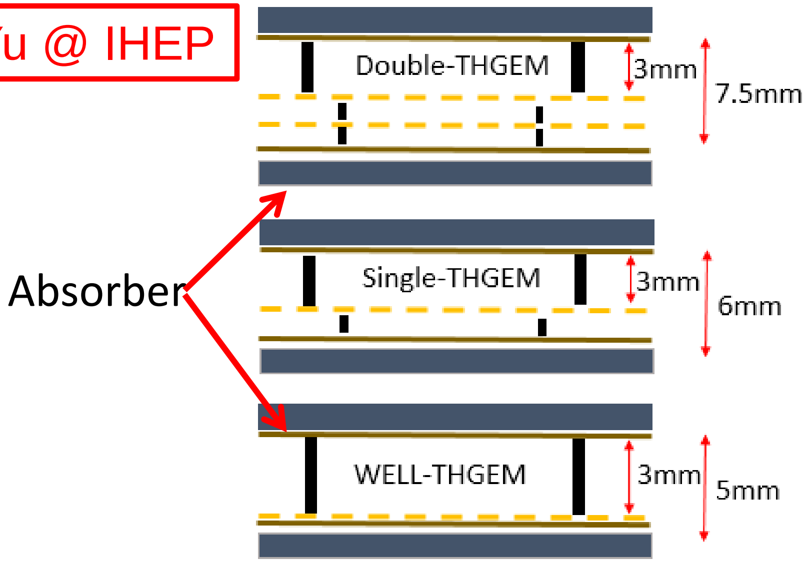


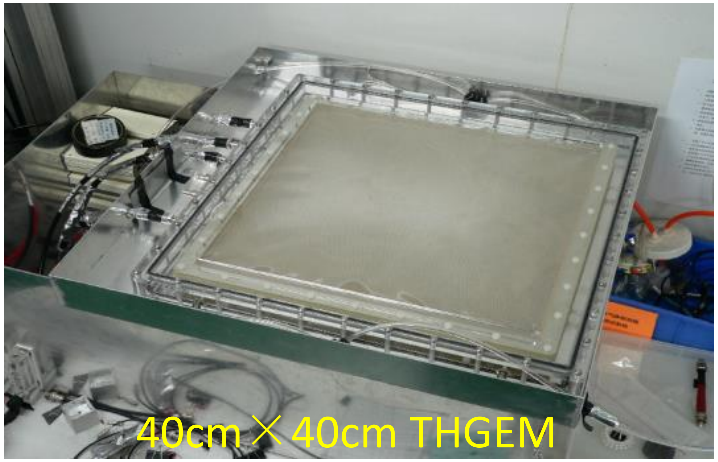
Multi-muons

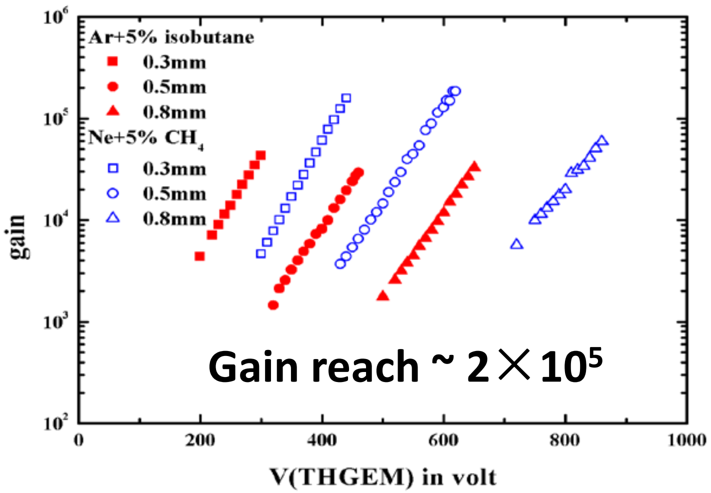
DHCAL based on THGEM

- Three THGEM structures:
  - Double - THGEM
  - Single - THGEM
  - WELL - THGEM
- WELL-THGEM is optimal choice
- thinner, lower discharge
- 40×40 cm^2 of THGEM produced by IHEP, UCAS, GXU

Boxiang Yu @ IHEP



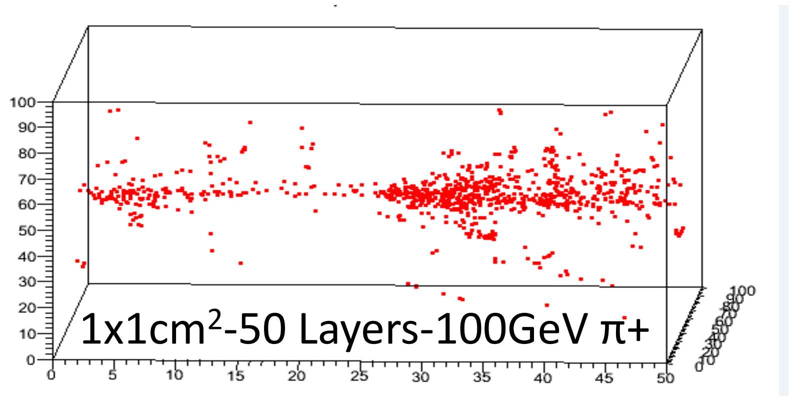


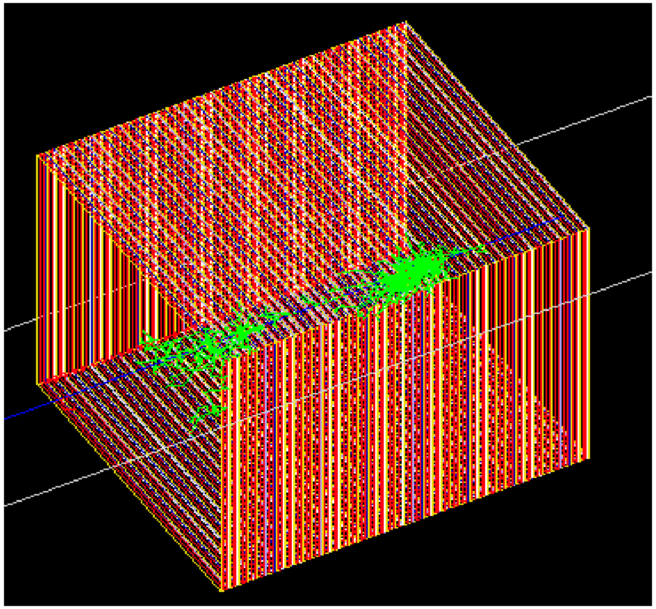


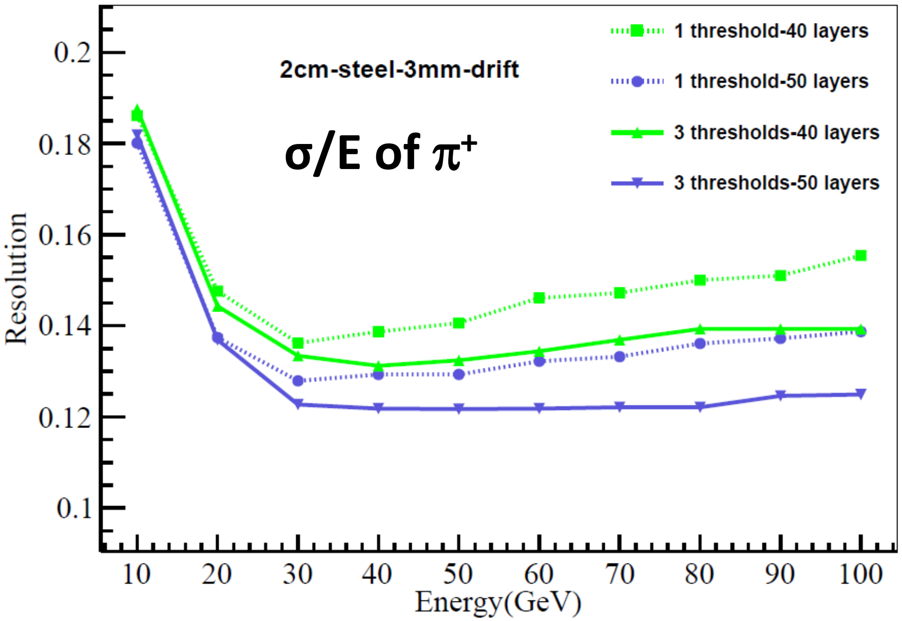
Simulation of DHCAL

Boxiang Yu @ IHEP

- Absorber: 2cm stainless steel
- Drift gap: 3mm
- No. of layers: 40, 50
- Ecell = 1, 5 and 10MIP if the charge is above the thresholds typically placed at 0.1, 1.5 and 2.5 MIPs

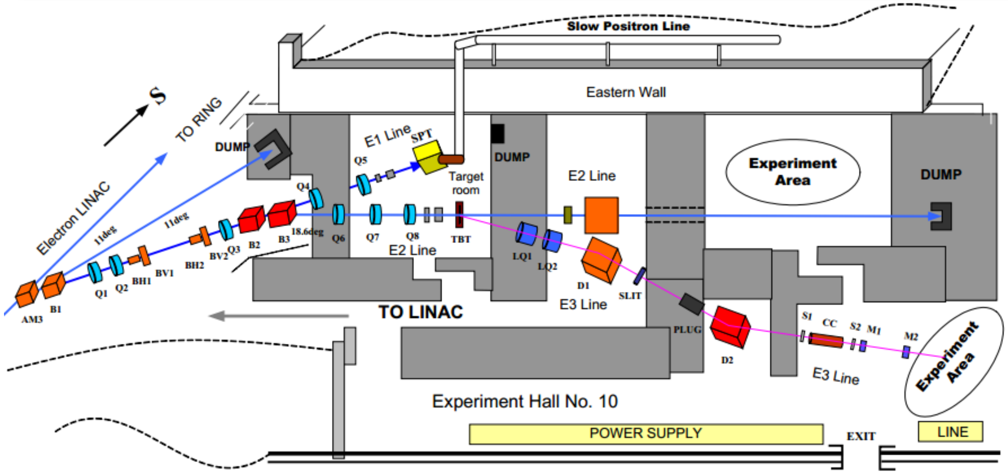






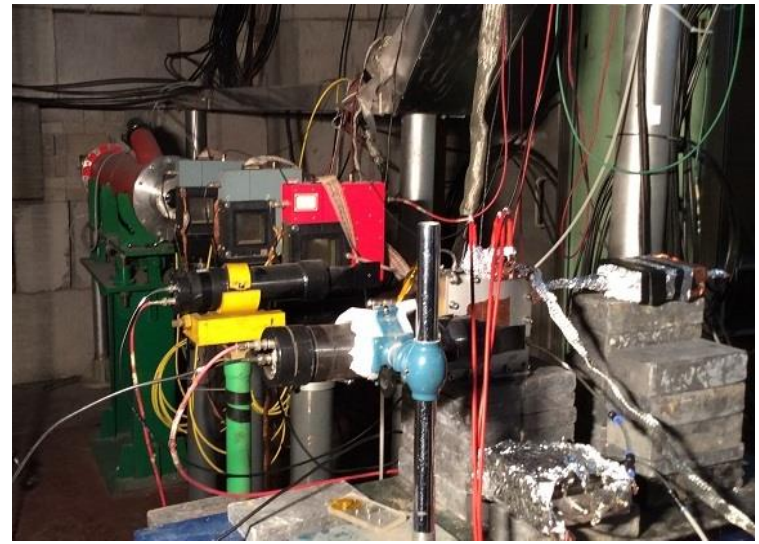
WELL-THGEM Test Beam at IHEP

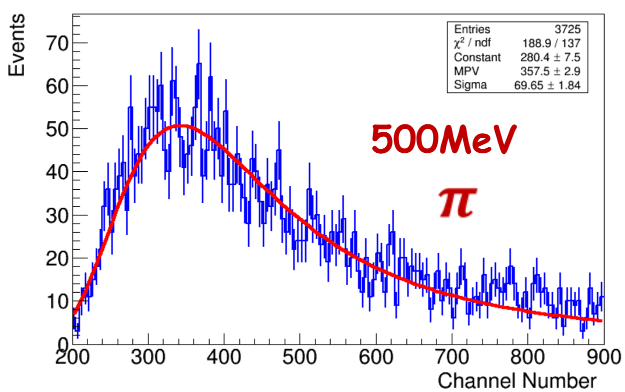
Hongbang Liu @ GXU

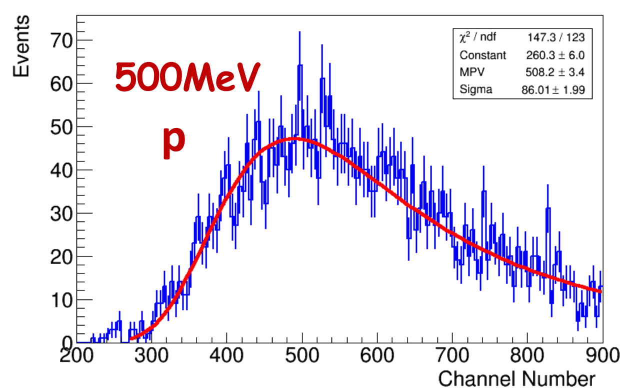


AM3、B1、B2、B3 Bending Magnets,
BH1、BH2、BV1、BV2 Dipole Corrector
Q1、Q2、Q3、Q4、Q5、Q6、Q7、Q8、LQ1、LQ2 Quadrupole
SPT: SLOW POSITRON TARGET; TBT: TEST BEAM TARGET; S1、S2、Scintillator, M1、M2 Multi-wire Proportional Chanber
CC : Cherenkov

IHEP BEPC-LINAC
THE CONFIGURATION OF TEST BEAM







Well-THGEM, Ar/3%iC_4H_{10};

Imaging calorimeter: Critical R&D

- **Detector optimization**
  - Optimize of the pad size of calorimeter
  - Optimize the number of layers of calorimeters, help to reduce the size of magnets and cost
  - Gas recirculation system, HV distribution system
- **Readout Electronics (PCB, low power ASIC FEE)**
- **Cooling**
  - Power pulsing will NOT work at the CEPC, effective cooling and power saving strategy need to be developed and tested
- **Calibration**
  - Energy, position and density calibration etc.
  - Detailed shower measurement gives possibility to use track segments (from data itself) to calibrate calorimeter
- **Mechanical: self-support and compact module**

CEPC Muon System

Yuguang Xie @ IHEP

Functions of muon system

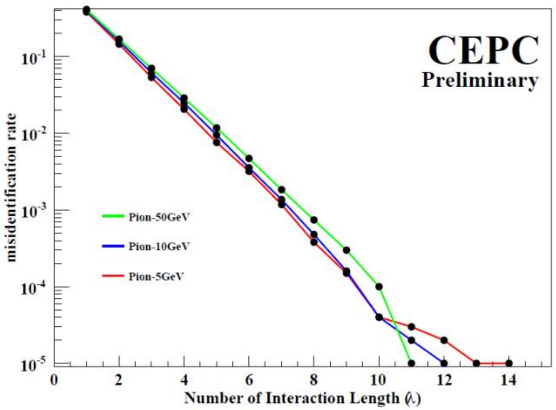
- To separate muons from hadrons
- A tail catcher of HCAL
- Solenoid return roke & support structure

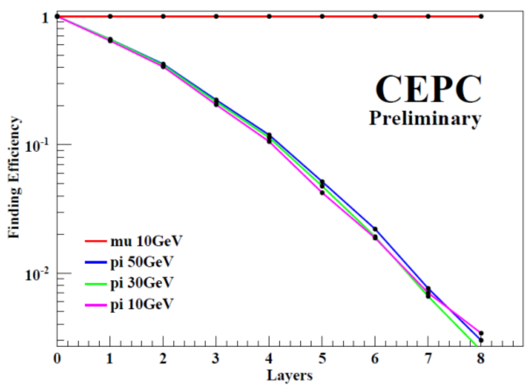
Performance requirements

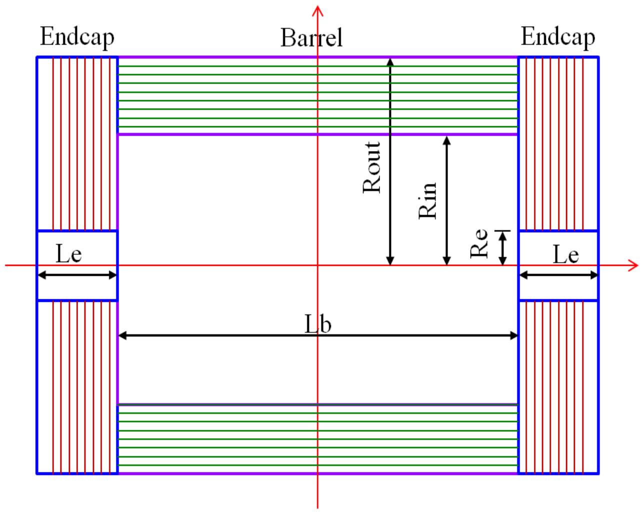
- nLayer >=8, iron thickness >= 6λ
- Eff >=95%, resolution<=2cm
- Misidentification rate (pi->mu)@40GeV <1%

Item	Option	Baseline
Lb	3.6~5.6m	~4.6
Rin	2.5~3.5m	~3.0
Rout	4.5~5.5m	~5.0
Le	1.6~2.4m	~2.0
Re	0.6~1.0m	~0.8
Segmentation	8/10/12	10
Number of layers	6~10	8(~3cm per layer)
Total thickness of iron	6~10λ (λ=16.77cm)	8 (8/8/12/12/16/16/20/20/24cm, Sum=136cm)
Solid angle coverage	0.92~0.96×4	0.94
Position resolution	1.5~2.5cm	2
	: 1~2cm	1.5
Average strip width	Wstrip: 2~4cm	3
Detection efficiency	92%~98%	95%
Reconstruction efficiency	92%~96%	94%

The standalone simulation results show the number of layers and the thickness of iron are reasonable.

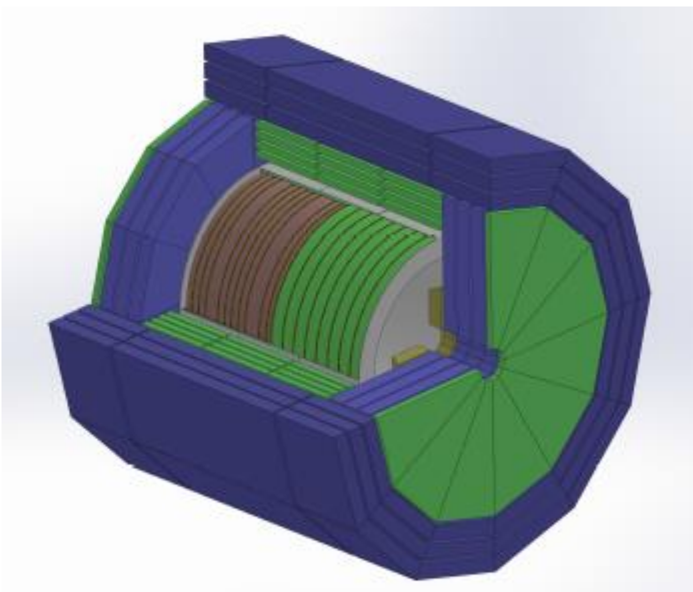


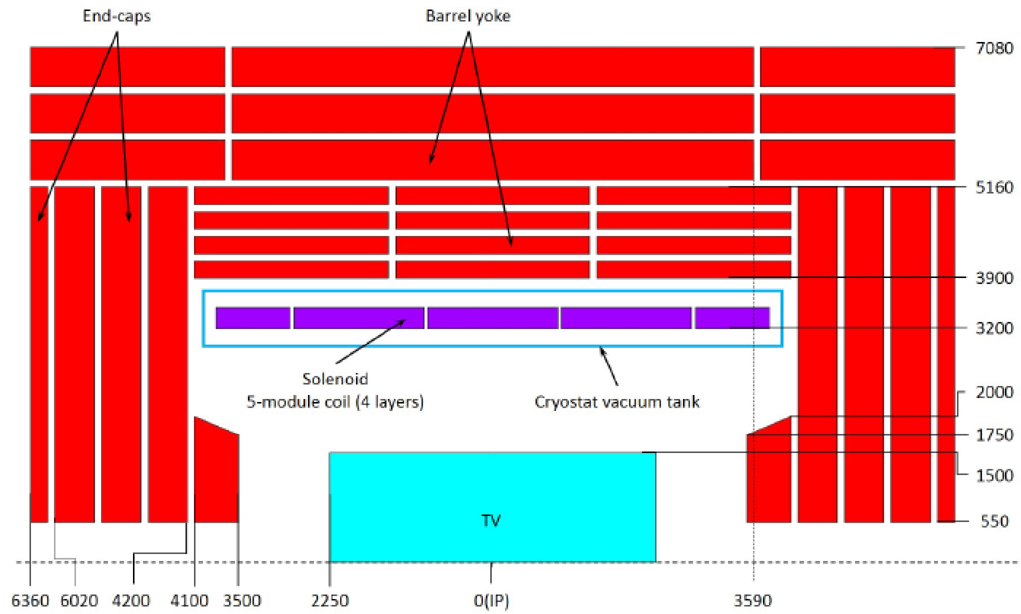




CEPC Magnet Design

Based on CEPC detector, a **3.5T** central field of superconducting solenoid (similar to CMS design) is required in a warm aperture diameter of 6m and length of 8.05m.





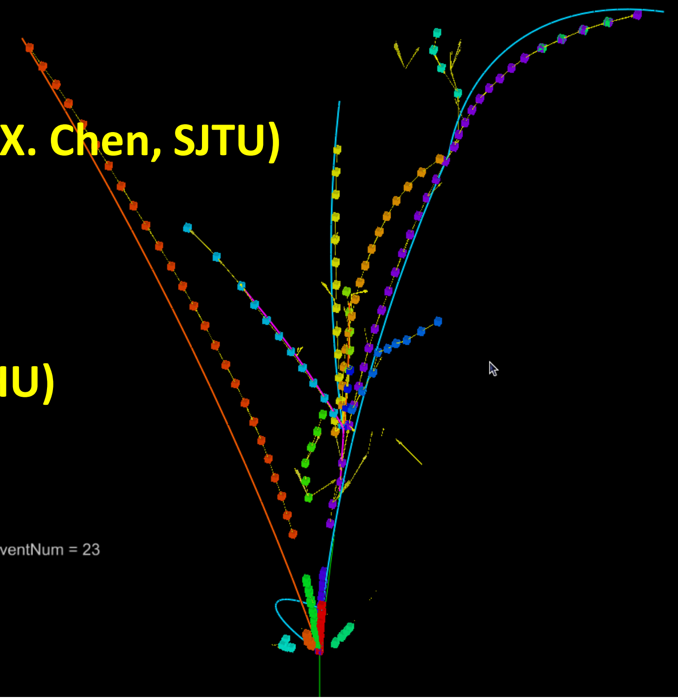
Schematic view of the CEPC detector magnet cross section (Half of the magnet section)

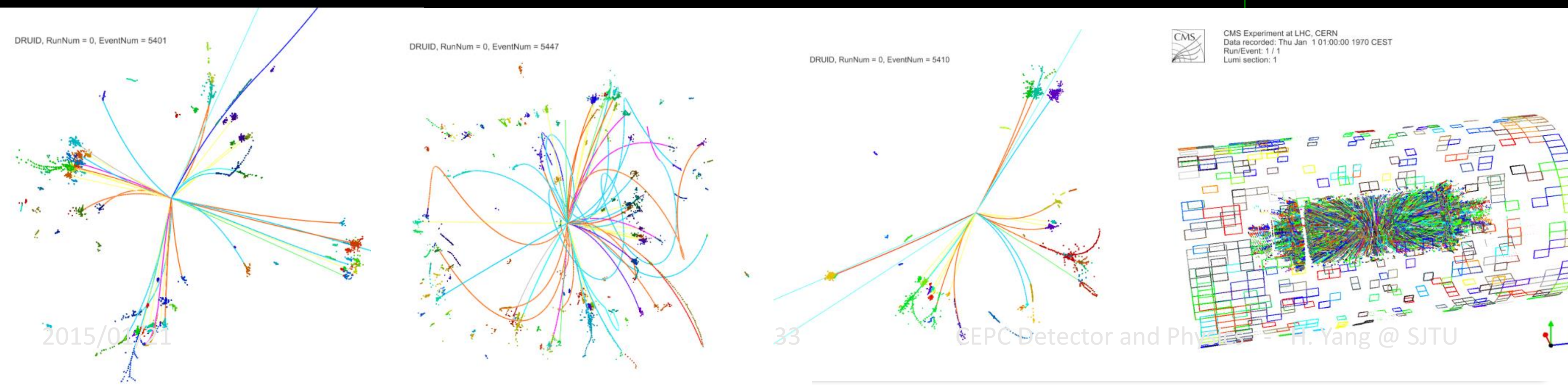
Table 4.20 The main parameters of solenoid coil.

The solenoid central field [T]	3.5	Nominal current [kA]	17.87
Maximum field on conductor [T]	3.75	Total ampere-turns of solenoid [MAt]	22.31
Coil inner radius [mm]	3200	Inductance [H]	8.65
Coil outer radius [mm]	3500	Stored energy [GJ]	1.38
Coil length [mm]	7400	Stored energy per unit of cold mass [KJ/kg]	9.52

Simulation & Reconstruction Software

- Geant 4 Full Detector Simulation:
  - Geometry can be edited freely (Y. Xu, NKU & X. Chen, SJTU)
  - A set of geometries has been generated
- Reconstruction Chain
  - Tracking: Clupatra & ILD tracking (B. Li, etc THU)
  - PFA: Arbor (M. Ruan, etc, IHEP)
  - Flavor Tagging: LFCIPlus (G. Li, etc, IHEP)



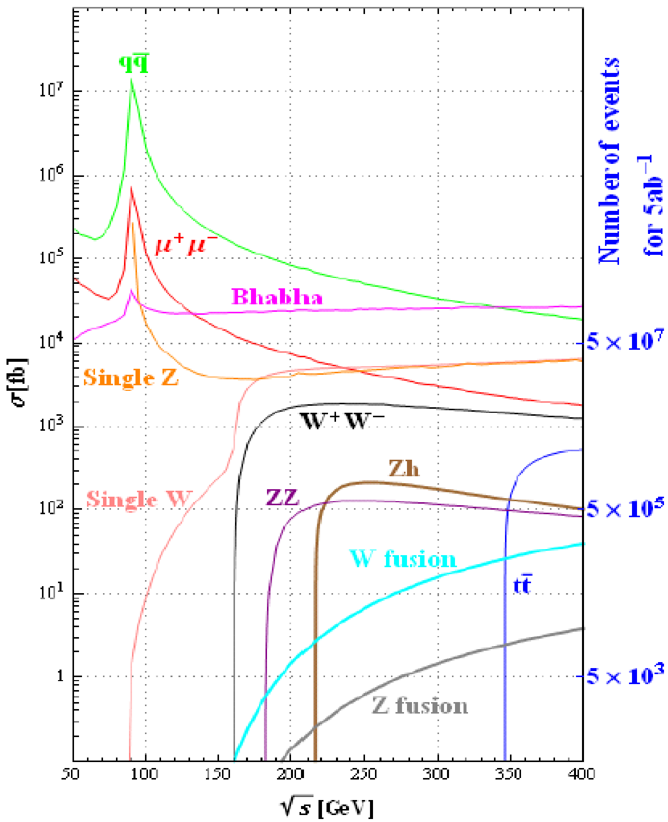


MC Samples & Computing Resources

Using WHIZARD to generate Higgs signal and SM background samples (Gang Li, Xin Mo)

- Computing: ~780 CPU cores
- Storage: 2 – 3 PB storage
- Distributed computing needed

T. Yan @ IHEP

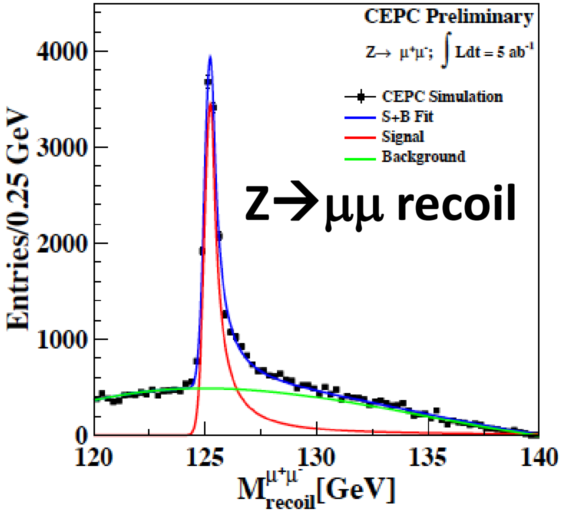


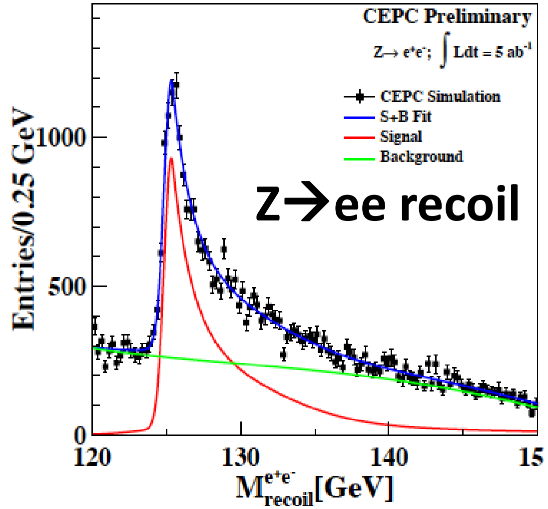
BhaBha
$e^+e^- \to qq$
$e^+e^- \to \mu\mu, \tau\tau$
$e^+e^- \to WW$
$e^+e^- \to ZZ$
$e^+e^- \to ZZ or WW$
Single Z
Single W
Single Z or W

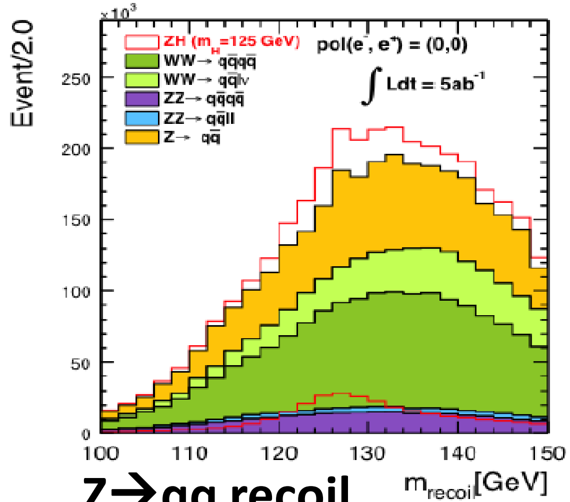
Resources Status

#	Site Name	CPU Cores	OS	Status	Shared by VO
1	CLOUD.IHEP-OPENSTACK.cn	144	SL 6.5	Active	bes,cepc,juno
2	CLOUD.IHEP-OPENNEBULA.cn	120	SL 6.5	Active	bes,cepc,juno
3	CLUSTER.WHU.cn	100	SL 6.4	Active	cepc,bes,juno
4	CLUSTER.SJTU.cn	100	SL 6.5	Active	cepc,bes
5	CLUSTER.GXU.cn	50	CentOS 5.10	Active	cepc
6	CLUSTER.BUAA.cn	50	SL 5.8	Testing	bes,cepc
7	CLUSTER.PKU.cn	64	SL 5.10	Testing	bes,cepc
8	CLUSTER.SDU-MLL.cn	150	SL 6.6	Testing	bes,cepc
9	CLUSTER.SDU-HXT.cn	100		Preparing	bes,cepc
10	CLOUD.WHU.cn	120	SL 6.6	Preparing	cepc,bes,juno
11	CLOUD.IHEP-PUBLIC.cn	10+	SL 6.6	Preparing	cepc,bes,juno
	Total (Active + Testing)	778			

Z recoil mass method: M_H & σ(ZH)







Z→qq recoil

$$m^2_{\rm recoil} = (\sqrt{s} - E_{ff})^2 - p^2_{ff}$$

Z.X Chen (PKU & IHEP)
L.Yuan (Kobe Univ., Japan)
Y. Haddad (LLR, France & Imperial College, UK)

Z decay mode	Δm_h (MeV)	$\Delta\sigma(ZH)/\sigma(ZH)$	$\Delta g(HZZ)/g(HZZ)$
ee	13	1.3%	
$\mu\mu$	6	1.0%	
$ee+\mu\mu$	5.5	0.8%	0.4%
qq		0.65%	
$ee+\mu\mu+qq$		0.5%	0.25%

0.5% accuracy on σ(ZH), the anchor of absolute Higgs measurements
0.25% accuracy on g(HZZ), an extremely sensitive probe to new physics

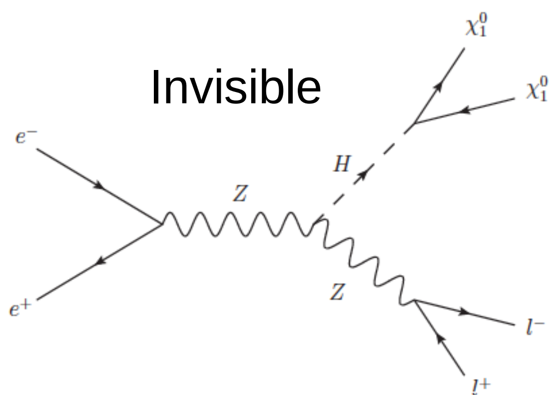
Higgs→ Exotics

- **Model independent tagging of Higgs boson (via Z recoil mass)**
- **Make CEPC extremely sensitive to BSM Higgs decay**

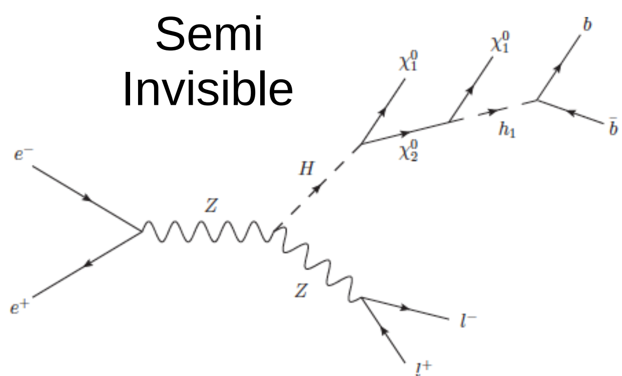
Channel	Accuracy	Methods
$Z \to \mu\mu, H \to invisible$	0.8%	CEPC Full Simulation
$Z \to ee, H \to invisible$	1.1%	Estimation
$Z \to qq, H \to invisible$	0.14%	Extrapolated from ILC result
Combined	0.14%	

- Br(H→inv): **0.14%** accuracy with Br = 100%
- Br(H→bb + MET): 9.4σ sensitivity with Br = 0.2%
- Br(H→bbbb): 8.4σ sensitivity with Br = 0.04%

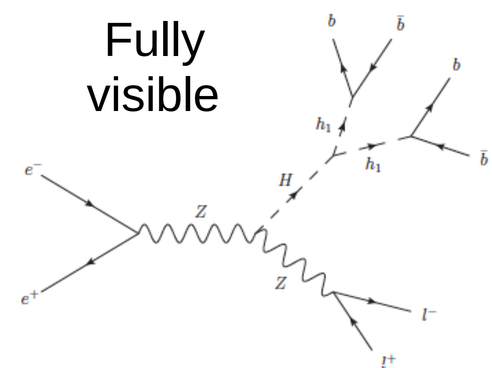
Invisible



Semi Invisible

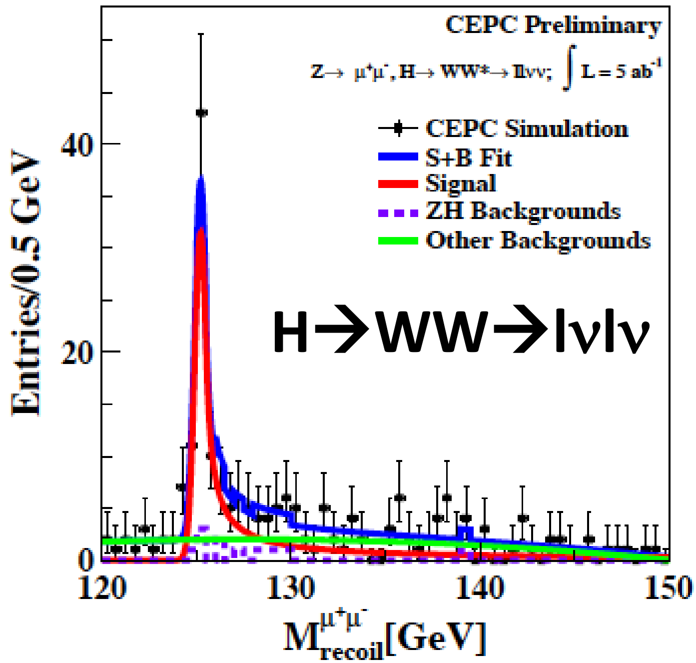


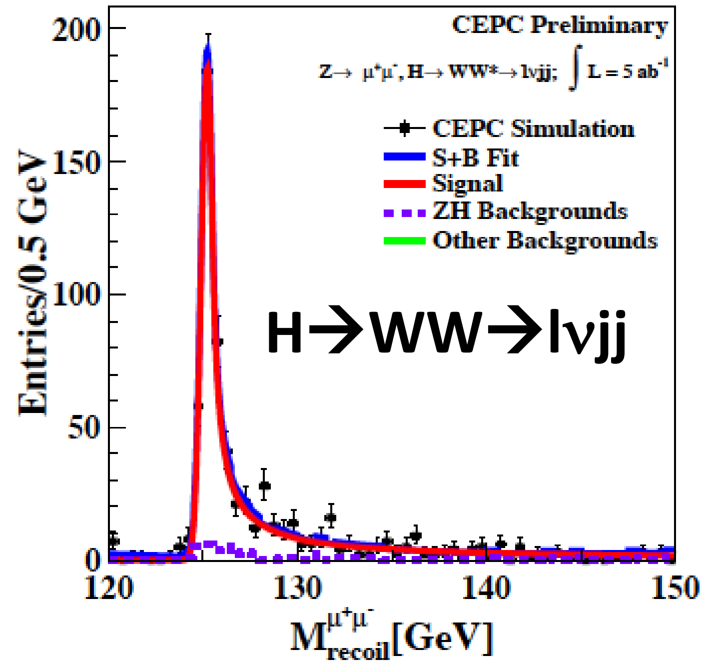
Fully visible



Branching Ratio of H→WW*

Z. Chen @ PKU

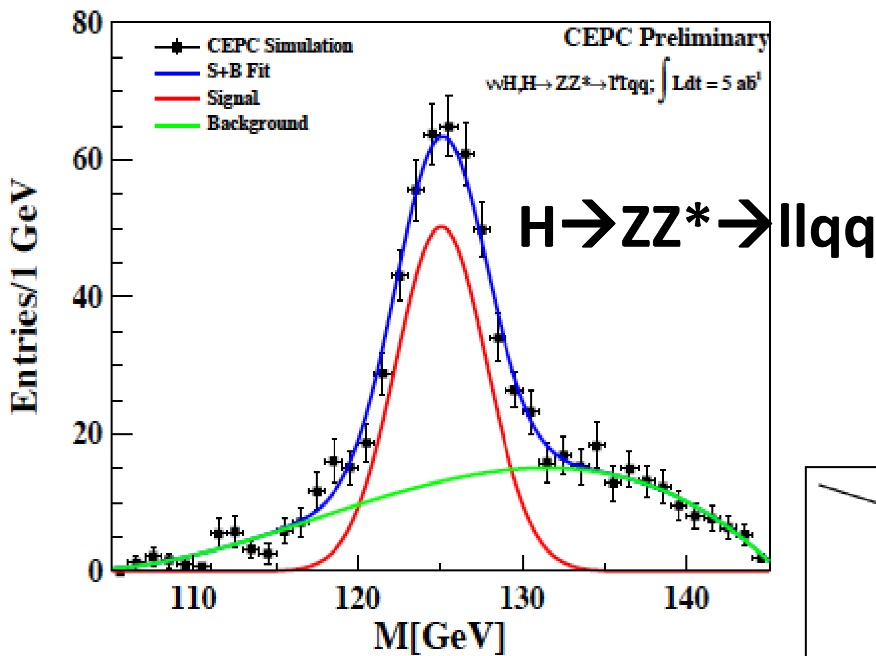




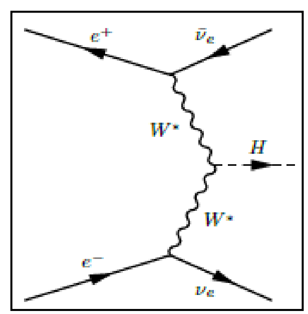
Expected accuracy for the $\sigma(ee \to ZH) \times \mathrm{BR}(H \to WW^*)$ measurement, normalized to 5 ab^{-1}

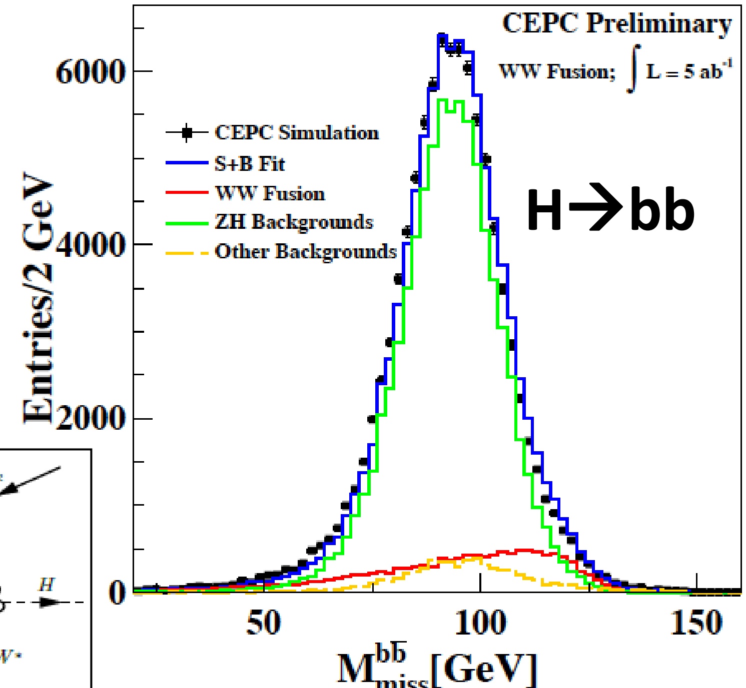
Channel	Accuracy	Methods
$Z \to \mu\mu, H \to WW^* \to l\nu qq, ll\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to l\nu qq, ll\nu\nu$	7.0%	Estimated
$Z \to \nu\nu, H \to WW^* \to 4q$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to l\nu qq$	2.2%	Extrapolated from ILC result
Combined	1.5%	

WW Fusion ee→ννH: Br(H→ZZ*, bb)



X. Yang @ SDU





Z. Chen @ PKU

Table 3.9 Expected accuracy for the BR($H \to ZZ^*$) measurement, normalized to 5 ab^{-1}.

Channel	Accuracy	Methods
$\nu\nu H, H \to ZZ^* \to llqq$	6.9%	CEPC Fast Simulation

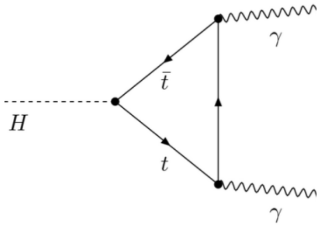
Γ(H→bb) can be independently extracted from WW fusion ee→ννH→ννbb.

Higgs boson total width

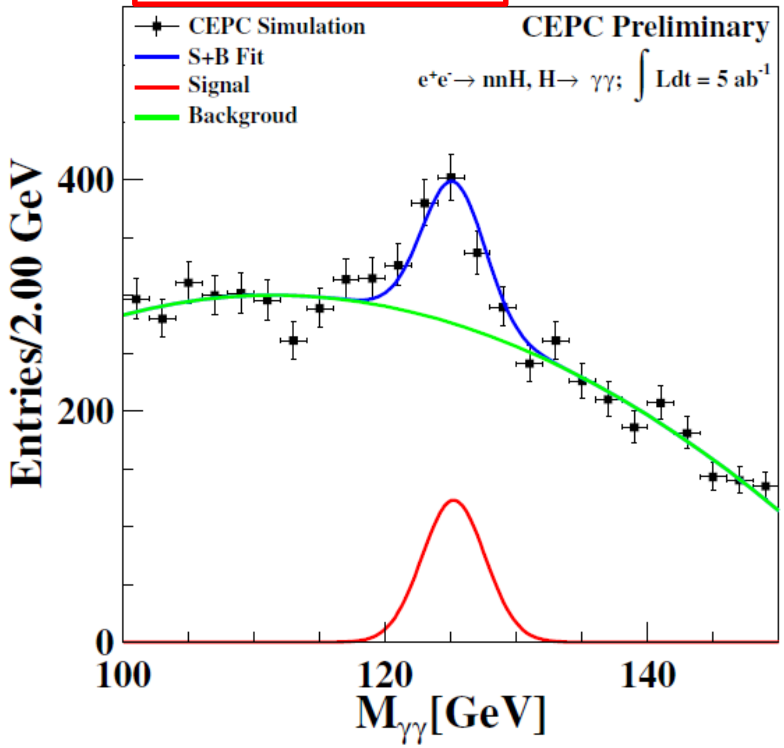
$$\Gamma_H \propto \frac{\Gamma(H \to bb)}{\mathrm{BR}(H \to bb)} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

Higgs Rare Decays

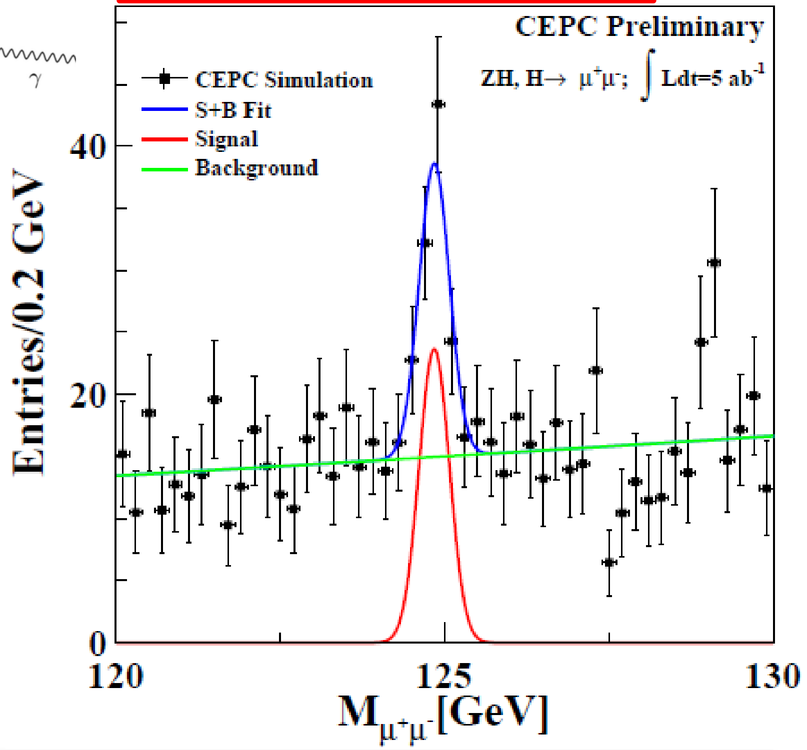
- Higgs → γγ (0.23%) & μμ (0.02%)
  - sensitive probe to heavy charged particle & lepton universality
  - stringent requirements on the ECAL and Tracker performance



F. Wang (WHU)



B.L. Wang, G. Li (IHEP)



CEPC Higgs Simulation & Measurements

Table 3.13 Status of Higgs measurements at the CEPC

Observable	sub-channel	Status
m_H	$Z \to ee$	Fast Simulation
	$Z \to \mu\mu$	Full Simulation
$\sigma(ZH)$	$Z \to ee, qq$	Fast Simulation
	$Z \to \mu\mu$	Full Simulation
$\sigma(ZH) \times Br(H \to bb, cc, gg)$	$Z \to ee, \mu\mu, qq$	Fast Simulation
	$Z \to \nu\nu$	Not covered
$\sigma(ZH) \times Br(H \to WW^*)$	$Z \to \mu\mu$	Full Simulation on $H \to WW^* \to lvqq, llvv$ sub channel
	$Z \to ee$	Scaled from $Z \to \mu\mu$ result
	$Z \to \nu\nu$	Scaled from ILC study on $H \to WW^* \to qqqq$ sub channel
	$Z \to qq$	Scaled from ILC study on $H \to WW^* \to lvqq$ sub channel
$\sigma(ZH) \times Br(H \to ZZ^*)$	$Z \to ee, \mu\mu$	Full Simulation on $H \to ZZ^* \to llqqllvv$ sub channels
	$Z \to \nu\nu$	Fast Simulation on $H \to ZZ^* \to llqq$ sub channel
	$Z \to qq$	Not covered
$\sigma(ZH) \times Br(H \to \tau\tau)$	$Z \to ee, \mu\mu, qq$	Scaled from ILC study
$\sigma(ZH) \times Br(H \to \gamma\gamma)$	$Z \to ee, \mu\mu, qq$	Fast Simulation with Kinematic fit
	$Z \to \nu\nu$	Fast Simulation
$\sigma(ZH) \times Br(H \to \mu\mu)$	$Z \to everything$	Full Simulation
$\sigma(\nu\nu H) \times Br(H \to bb)$		Fast Simulation
$\sigma(ZH) \times Br(H \to invisible)$	$Z \to \mu\mu$	Full Simulation
	$Z \to ee$	Scaled from $Z \to \mu\mu$ result
	$Z \to qq$	Scaled from ILC study
$\sigma(ZH) \times Br(H \to exotic)$	$Z \to ll$	Fast Simulation on several target case

From measurements to couplings

Δm_H	Γ_H	$\sigma(ZH)$	$\sigma(\nu\nu H) \times BR(h \to bb)$
5.5 MeV	2.9%	0.5%	2.6%

Decay mode	$\sigma(ZH) \times BR$	Branching Ratio $BR(h \to XX)$
$h \to bb$	0.25%	0.56%
$h \to cc$	3.2%	3.2%
$h \to gg$	1.3%	1.4%
$h \to \tau\tau$	1.2%	1.3%
$h \to WW$	1.5%	1.6%
$h \to ZZ$	4.3%	4.3%
$h \to \gamma\gamma$	8.2%	8.2%
$h \to \mu\mu$	16%	16%
$h \to inv$	0.14%	0.5%

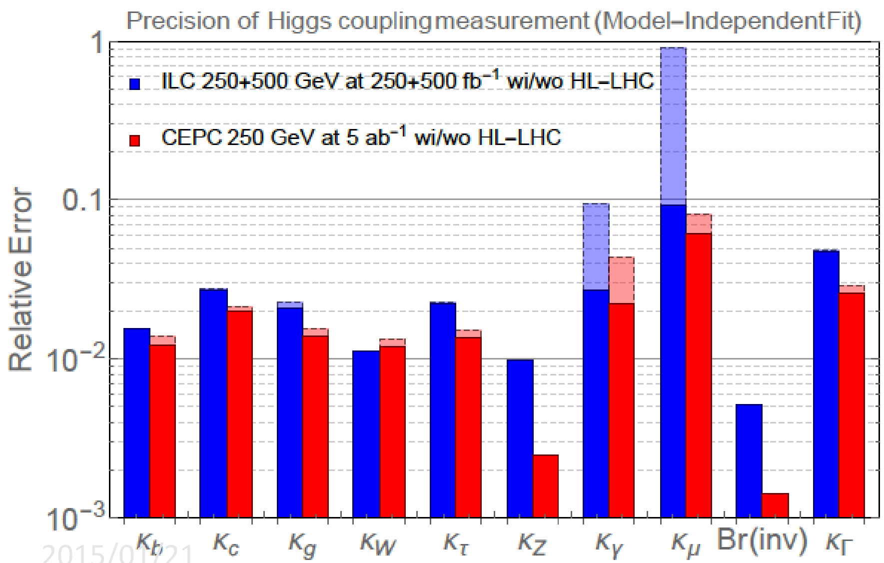
Combination group: Y. Fang, Z. Liu, etc

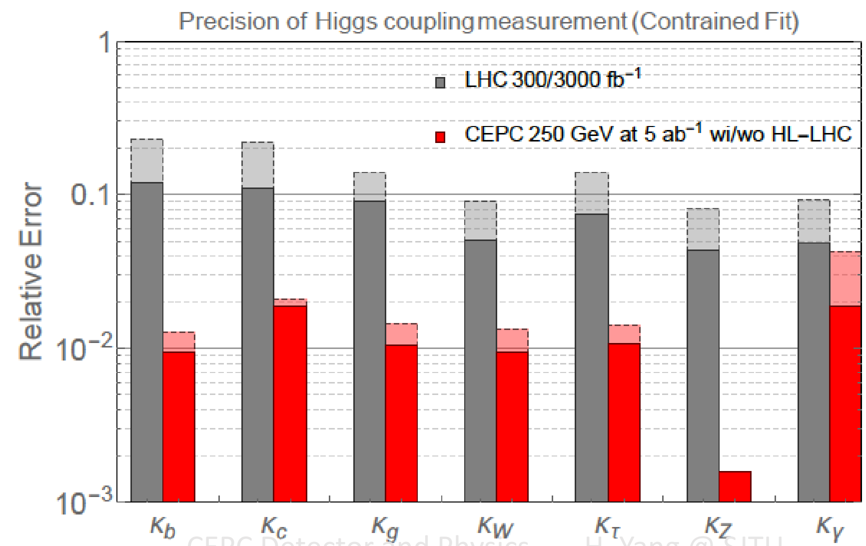
Model independent results compare to ILC

Model dependent results compare to LHC, an order of magnitude improvement of expected coupling measurements over LHC.

7-parameter model:

$\kappa_c, \kappa_b, \kappa_\ell, \kappa_W, \kappa_Z, \kappa_g, \kappa_\gamma$





Team Building & Trainings

Training

Go t

August 2014

11 Aug - 15 Aug Detector Simulation and Geometry editing

October 2013

19 Oct - 20 Oct CEPC Training: Physics Analysis, Detector Optimization and Software tools

International Summer school on TeV Experimental Physics (iSTEP)

20-29 August 2014
IHEP
Asia/Shanghai timezone

Overview

Continuous efforts + dedicated training

We have a group of faculty + students...

Summary and Future Plans

- In the past year, tremendous efforts have been made to prepare the CEPC preliminary Conceptual Design Report for Physics and Detector. It is under internal review.

Future plans include

- Detector optimization, R&D of critical detector technologies, feasibility studies of detector prototypes
- MDI: work with accelerator group to optimize design
- Development of reconstruction and analysis softwares
- Comprehensive studies of benchmark physics processes based on full detector simulations etc.

Many thanks to all members of CEPC Physics and Detector working group who made significant efforts to prepare the CEPC preCDR ！

Backup Slides

Total Decay Width

The SM predicted value of $\Gamma_H \sim 4$ MeV is much smaller than the experimental resolution $(\sim \text{GeV})$ of the recoil mass $\Rightarrow$ cannot measured directly with a reasonable precision.

The Higgs total width can be inferred from the cross section and branching ratio measurements in a model-independent way. Two independent measurements:

$$\sigma(ee \to ZH): \quad \Gamma_H = \frac{\Gamma(H \to ZZ^*)}{BR(H \to ZZ^*)} \propto \frac{\sigma(ee \to ZH)}{BR(H \to ZZ^*)}$$

(Limited by the $H \to ZZ^*$ statistics)

$$\sigma(ee \to \nu\nu H \to \nu\nu bb): \quad \Gamma_H = \frac{\Gamma(H \to bb)}{BR(H \to bb)} \propto \frac{\sigma(ee \to \nu\nu H \to \nu\nu bb)}{BR(H \to bb) \bullet BR(H \to WW^*)}$$

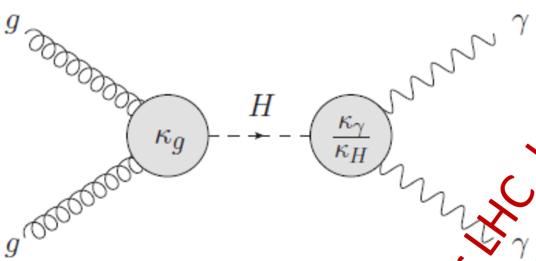
(Limited by the $ee \to \nu\nu H \to \nu\nu bb$ statistics)

Coupling Scale Parameters

Parametrizing deviations from SM using scale parameters: κ (SM: $\kappa = 1$)

$$g_{Hff} = \frac{m_f}{\upsilon}, \quad g_{HVV} = \frac{2m_V^2}{\upsilon} \quad \Rightarrow$$

$$g_{Hff} = \boxed{\kappa_f} \cdot \frac{m_f}{\upsilon}, \quad g_{HVV} = \boxed{\kappa_V} \cdot \frac{2m_V^2}{\upsilon}$$



For LHC, but same idea for Higgs factories

For example: $(\sigma \cdot BR)(gg \to H \to \gamma\gamma) = \left[\sigma(gg \to H) \cdot BR(H \to \gamma\gamma)\right]_{SM} \times \boxed{\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}}$

κ_H^2 is the scale factor to the total Higgs decay width

$$\kappa_H^2 = \sum_x \kappa_x^2 \cdot BR(H \to xx) \xrightarrow{\text{No non-SM decays}} \kappa_H^2 = \sum_x \kappa_x^2 \cdot BR_{SM}(H \to xx)$$

$$\xrightarrow{\text{With non-SM decays}} \kappa_H^2 = \sum \kappa_x^2 \cdot \frac{BR_{SM}(H \to xx)}{1 - BR_{non-SM}}$$

Benchmark models with different assumptions. Most models at LHC assume no non-SM decays $(BR_{non-SM} = 0)$. More generally: $BR_{non-SM} = BR_{inv} + BR_{exotic}$

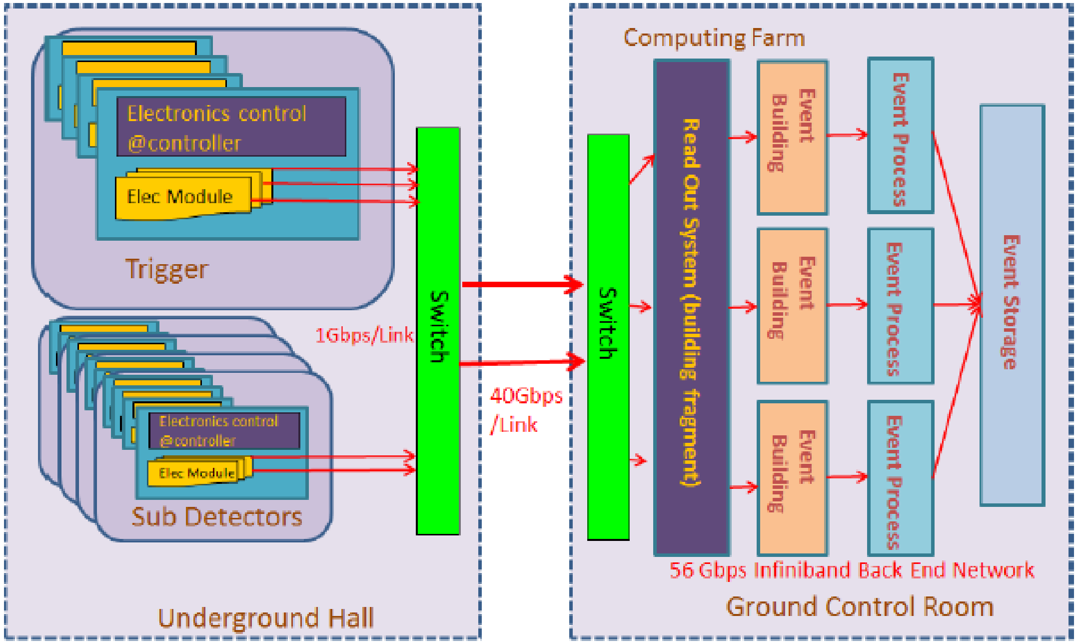
CEPC DAQ Conceptual Design

- CEPC DAQ design based on experiences gained from BESIII and DayaBay experiments.

Table 4.22 CEPC DAQ Data Rate Estimation

	Channels	Occupancy	Hits	B/hit	Volume
VTX	300M	0.2%	600K	4	720GB/s
TPC	1M	0.1%	1K	8	2.4GB/s
ECAL	33M	0.1%	33K	8	80GB/s
HCAL	33M	0.1%	33K	4	40GB/s
Sum					850GB/s

- Data rate is 850GB/s, with level-1 trigger, the DAQ data rate can be reduced to 150GB/s with 5MB/event and 30 kHz trigger rate.



CEPC Silicon Tracker: Geometry

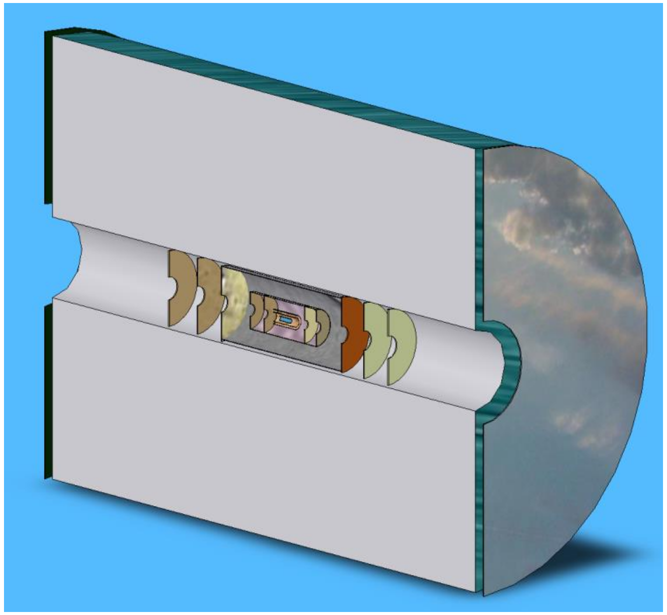


Table 1. Main parameters of the CEPC silicon tracker.

Detector		Geometric dimensions			Material budget $[X/X_0]$
SIT	Layer 1:	$r = 153$ mm,		$z = 664$ mm	0.65%
	Layer 2:	$r = 300$ mm,		$z = 664$ mm	0.65%
SET	Layer 3:	$r = 1811$ mm,		$z = 2350$ mm	0.65%
FTD	Disk 1:	$r_{in} = 39$ mm,	$r_{out} = 151.9$ mm,	$z = 220$ mm	0.50%
	Disk 2:	$r_{in} = 49.6$ mm,	$r_{out} = 151.9$ mm,	$z = 371.3$ mm	0.50%
	Disk 3:	$r_{in} = 70.1$ mm,	$r_{out} = 298.9$ mm,	$z = 644.9$ mm	0.65%
	Disk 4:	$r_{in} = 79.3$ mm,	$r_{out} = 309$ mm,	$z = 846$ mm	0.65%
	Disk 5:	$r_{in} = 92.7$ mm,	$r_{out} = 309$ mm,	$z = 1057.5$ mm	0.65%
ETD	Disk:	$r_{in} = 419.3$ mm,	$r_{out} = 1822.7$ mm,	$z = 2420$ mm	0.65%

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, comparing 7 disks on ILD, due to smaller L*

Silicon External Tracker (SET) – 1 outer layer Si strip detector

End-cap Tracking Detector (ETD) – 1 end-cap Si strip detector on each side

Full Simulation MC Samples

FullSimulation Background

2Fermions	
uu	
dd	58%
ss	
bb	44%
cc	59%
qq	
nn	
n2n2	
n3n3	
e2e2	
e3e3	75%
bhabha	

4Fermions	
sw_l	
sw_sl	
sze_l	finished
szeorsw_l	
sze_sl	finished
sznu_l	
sznu_sl	
wwbosons	
ww_h	running
ww_l	
ww_sl	
zzbosons	
zz_h	
zz_l	finished
zzorww_h	
zzorww_l	
zz_sl	

Toward the CDR: CEPC

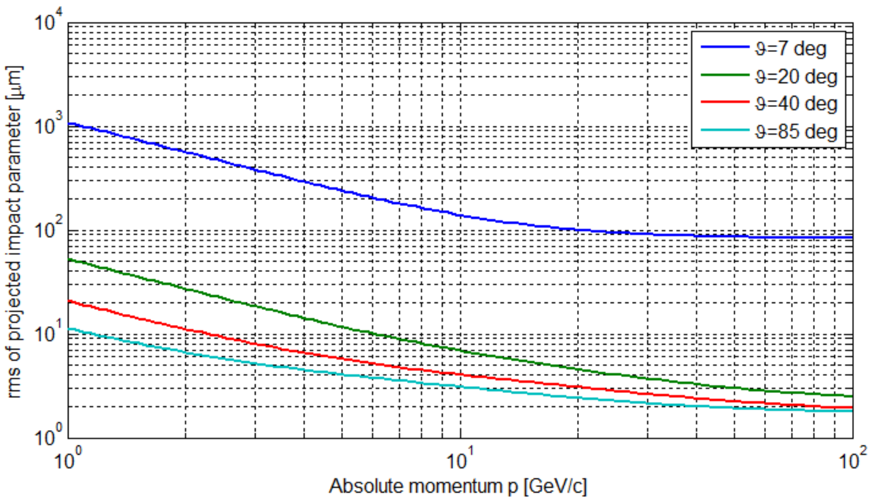
- Physics @ CEPC
  - Higgs measurement simulated (Fast/Full)
    - SM
    - BSM
  - Z pole
    - Flavor physics
    - EW measurements
- ILD based, Conceptual detector model(s) realized at Full Simulation level
- Workable software chain, optimization stage
- MDI: preliminary design

1 – 2 years →

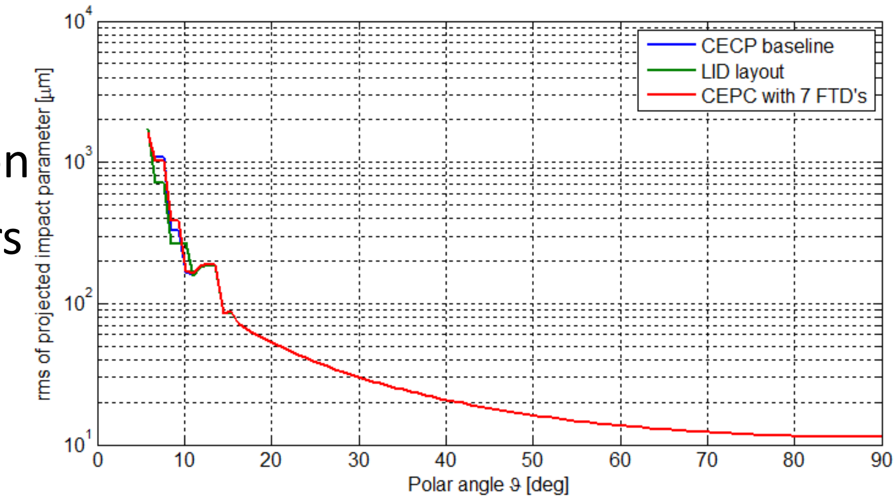
- Physics @ CEPC
  - Higgs
    - Analysis converged to Full simulation level
  - Z pole
    - EW (& flavor?): dedicated Fast simulation tool to be developed
- Iterate with sub-detector studies, and converged to 1 - 2 benchmark detectors
- Develop/Optimize reconstruction algorithm/software by iteration with physics analysis
- MDI: iterate with acc. Group to fix the design...

CEPC Vertex and Silicon Tracker

- LiC Detector Toy simu & reco. (LDT): fast simulation using **Kalman filter**
- **Performance Studies:**
  - Dependence on material budget
  - Dependence on single point resolution
  - Dependence on arrangement of layers
    - Eg. R_beampipe=10 mm



Resolutions of the transverse IP for single muon



Impact parameter resolutions for muon tracks with momentum of p = 1 GeV as a function of polar angle, obtained for the baseline CEPC silicon tracker layout (in blue), the original ILD layout (in green) and the CEPC layout with seven FTD disks (in red).

CEPC VTX and Tracker: Critical R&D

- **Silicon microstrip sensors**:
  - edgeless (< 100 µm), thin (< 200 µm), pitch adapter (connection to readout chip),
  - large wafer size (4' available from domestic vendor but 8' preferred ← cost effective),
  - or with CMOS sensors as pursued by ATLAS
- **Front-end electronics**: low power consumption, low noise, 65nm CMOS technology, potential unified application with calorimeter readout
- **Power and cooling**: DC-DC powering, air cooling (or more aggressive cooling, eg. silicon micro-channel cooling)
- **Mechanics**: low mass supporting structure but with sufficient stiffness and stability, easy integration and replacement etc.

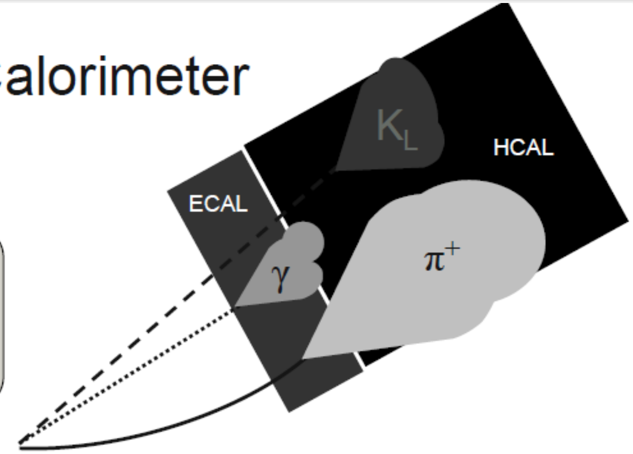
Main Tracker: Two options

Performance comparison between Silicon Tracker and TPC Trackers from ILC Detectors R&D

	TPC in ILD	Silicon in SiD
Material	0.05 X0 (vertical) 0.25 X0 (forward)	0.10-15 X0 (vertical) 0.2-0.25 X0 (forward)
Magnet filed	3.5T	5T
dE/dx	5%	no
r_in	329mm	220mm
r_out	1808mm	1220 mm
Z	± 2350 mm	±1520
Cost (no contingency)	$ 35.9M (Jan 2012 US$)	$ 95.7M

PFA and Imaging Calorimeter

Particle Flow Algorithms and Imaging Calorimeter



The idea…

Charged particles } measured with the { **Tracker**

Neutral particles } measured with the { **Calorimeter**

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/$\sqrt{E}$	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/$\sqrt{E}$	$0.16^2\ E_{jet}$
Confusion	Required for 30%/$\sqrt{E}$		$\leq 0.24^2\ E_{jet}$

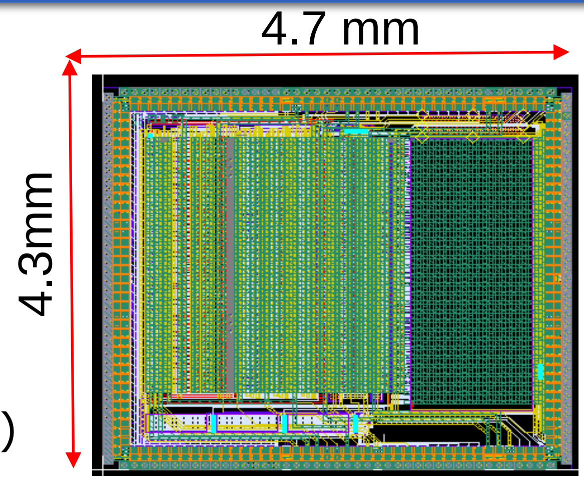
} 18%/$\sqrt{E}$

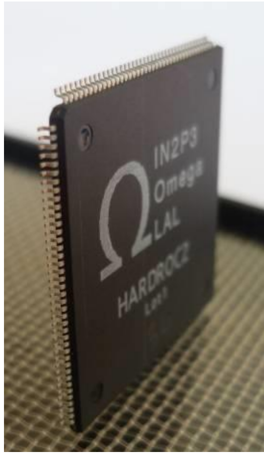
Requirements for detector system

→ Need excellent tracker and high B – field
→ Large R_I of calorimeter
→ Calorimeter inside coil
→ Calorimeter as dense as possible (short X_0, λ_I)
} **thin active medium**
→ Calorimeter with **extremely fine segmentation**

Electronics readout system R&D

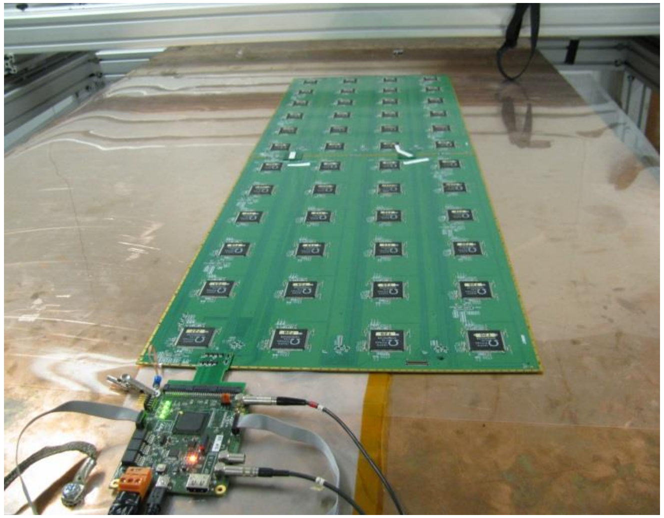
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity
Power-Pulsed (7.5 μW in case of ILC duty cycle)





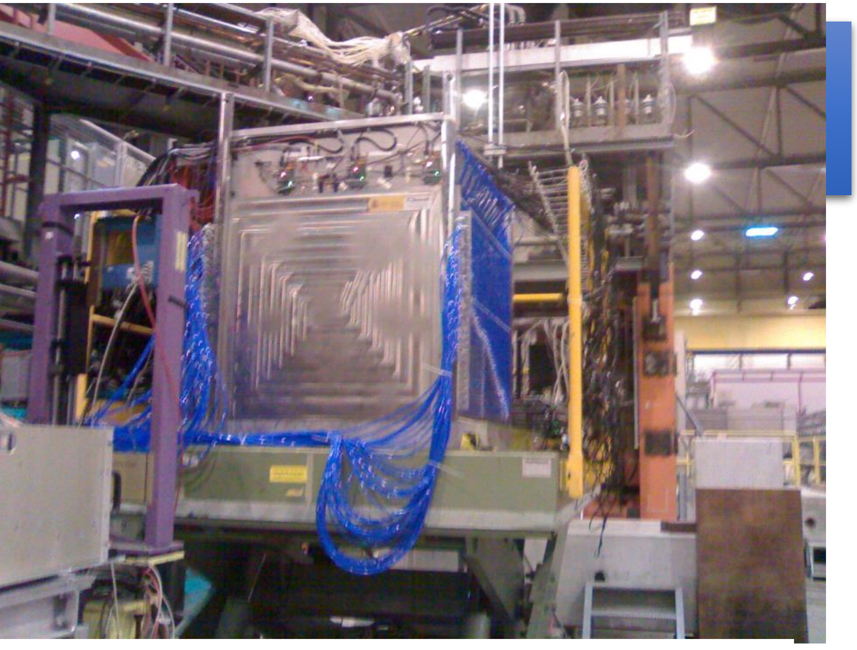
Printed Circuit Boards (PCB) were designed to reduce the x-talk with 8-layer structure and buried vias.

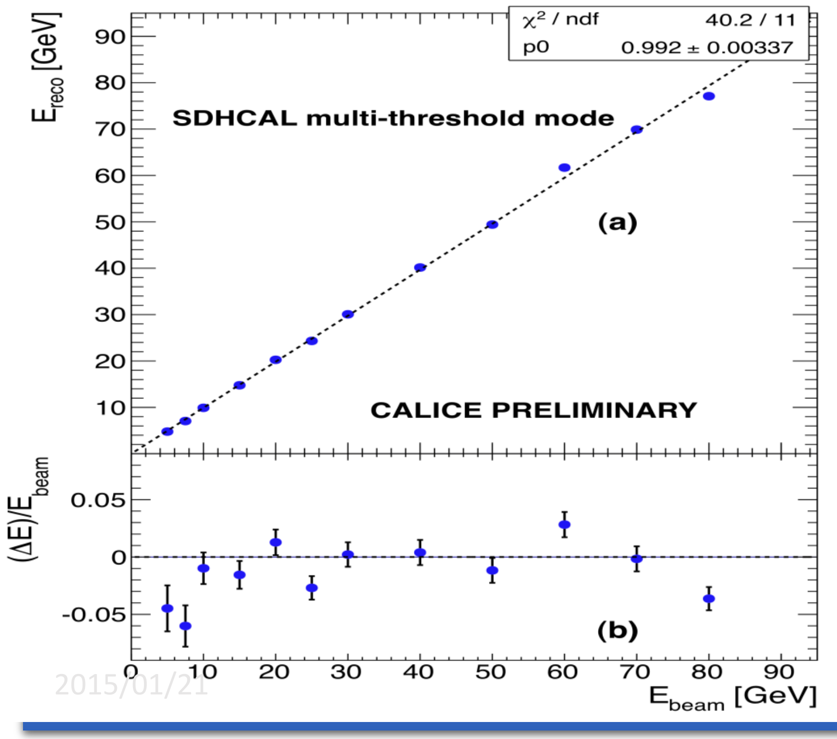
Tiny connectors were used to connect the PCB two by two so the 24X2 ASIC are daisy-chained. Power-Pulsed,70million

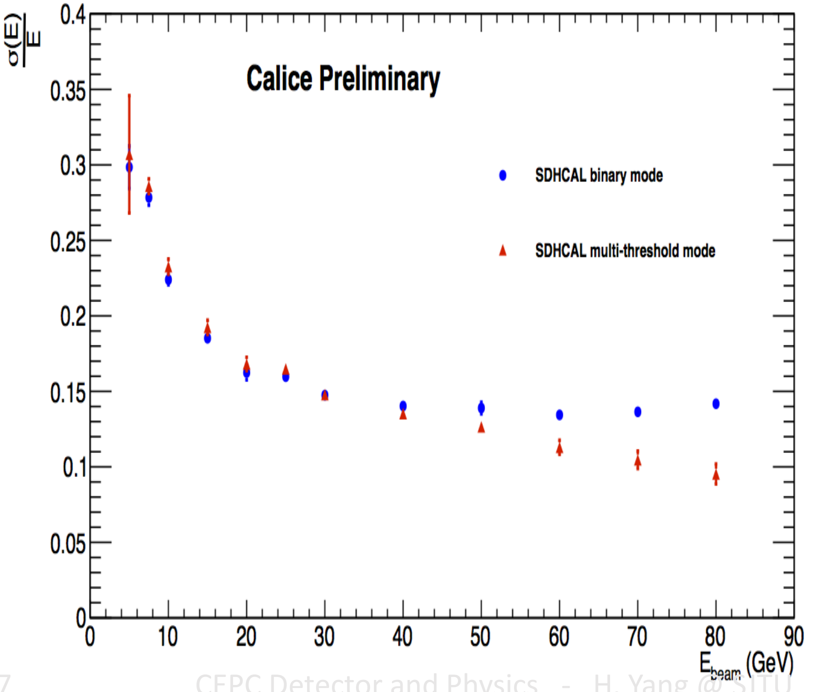


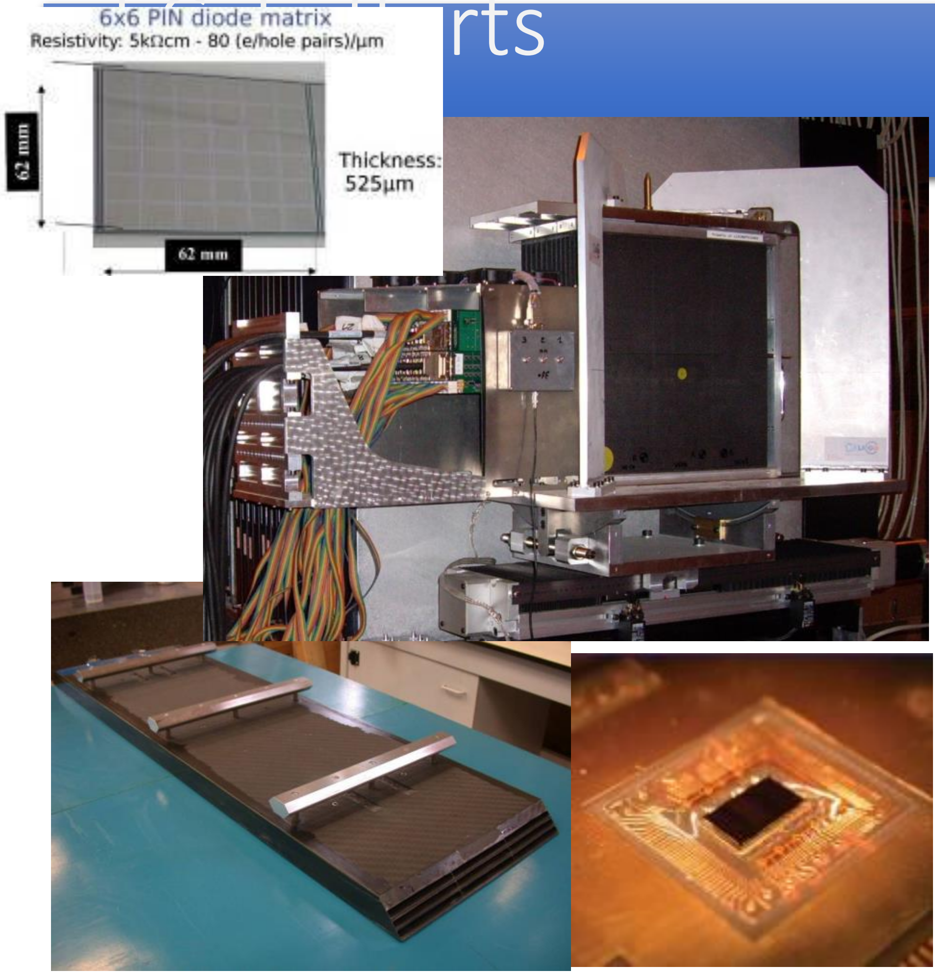
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

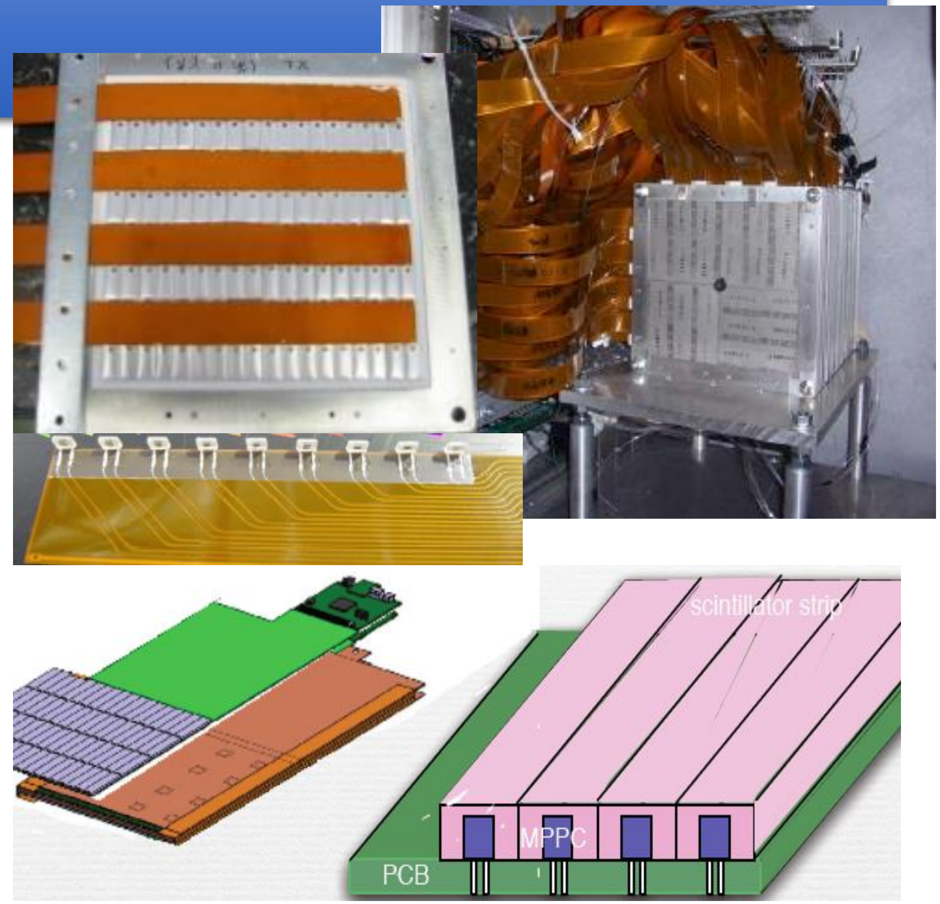
Beam test results









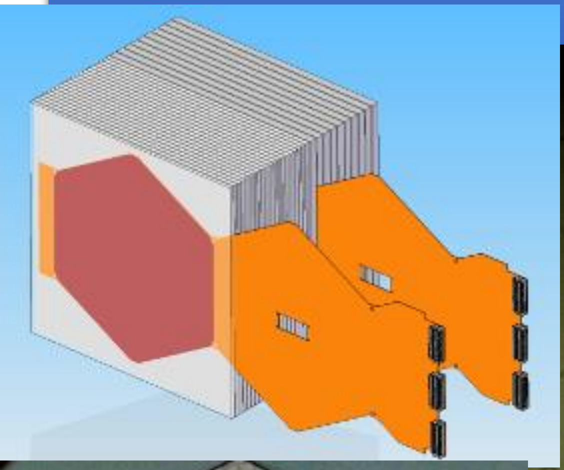


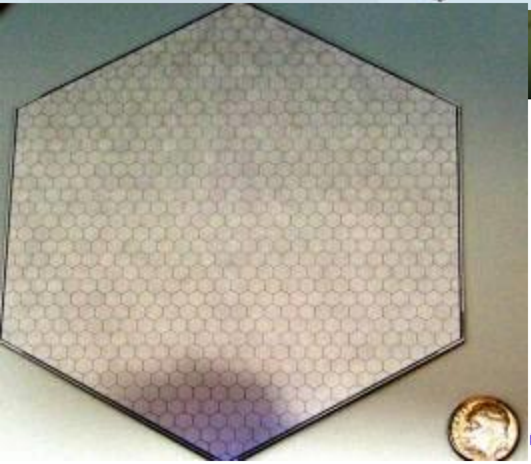
CALICE Si/W ECal:
- Physics prototype* tested in beam (1x1cm^2)
- R&D/construction for Technical prototype**
- Readout cell reduced to 0.25cm^2 for 2nd prototype
- First test beams of new prototype soon

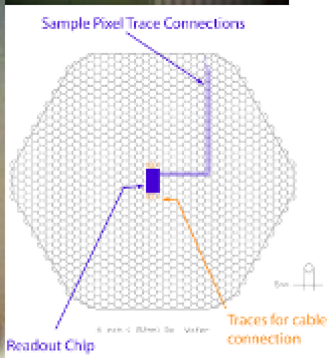
CALICE Sci/W ECal:
- Physics prototype tested in beam (1x4.5cm^2)
- Technical prototype R&D/construction
- Started first beam tests

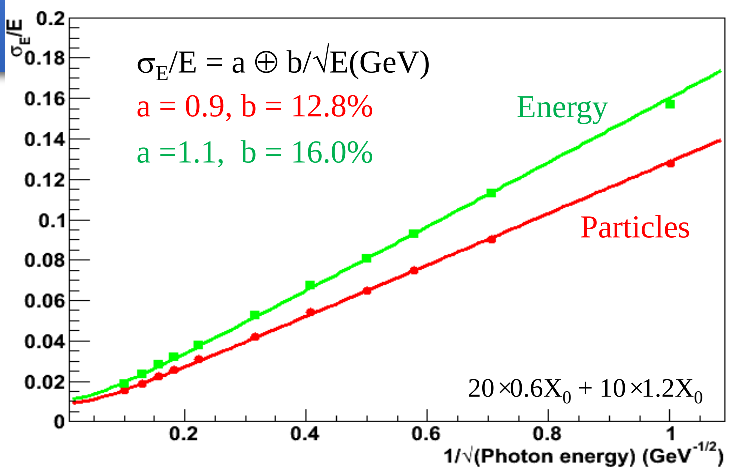
*** Physics prototype: proof of principle device***
***** Technical prototype: prototype close to a real detector***

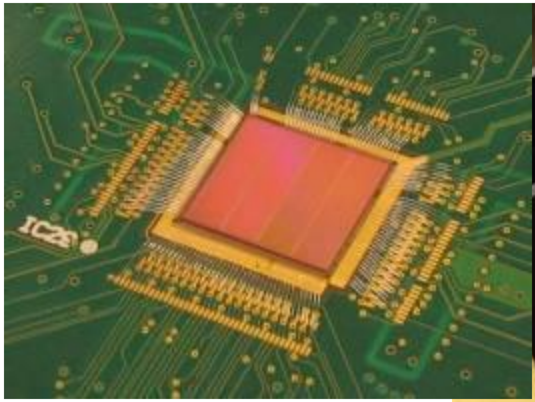
ECal efforts

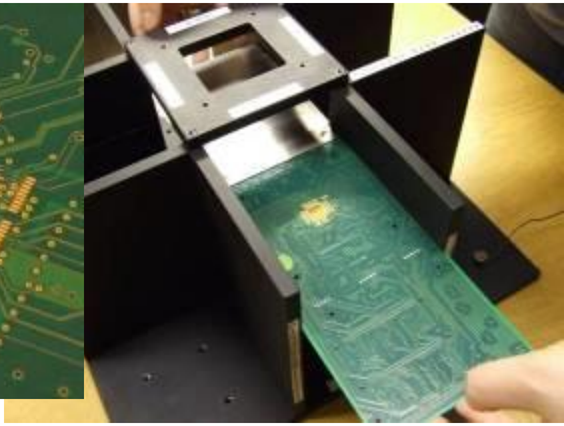












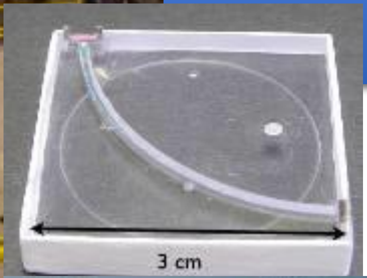
SiD Si/W ECal:

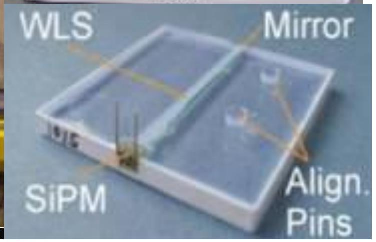
- Target at very compact readout and small cell (~0.13cm^2)
- Address all technical issues from the beginning
- Push technical limits in many aspects
- Total active medium thickness targets at ~1mm
- Test beam module being assembled
- First beam exposures in particle beams

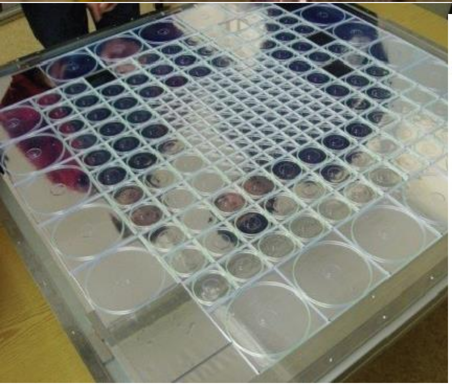
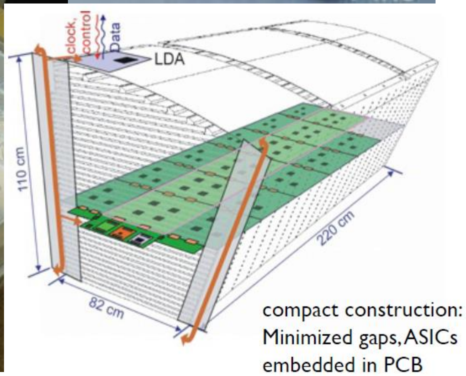
CALICE MEPS Digital ECal:

- Extremely small cell size (0.005x0.005cm^2)
- Working on sensor R&D
- Did sensor test beam

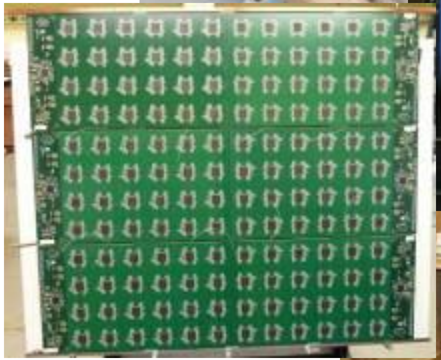
HCal Efforts





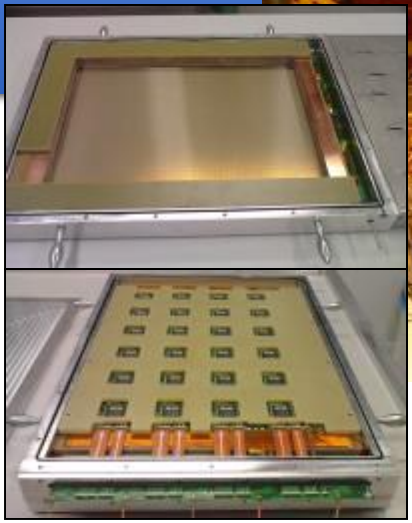
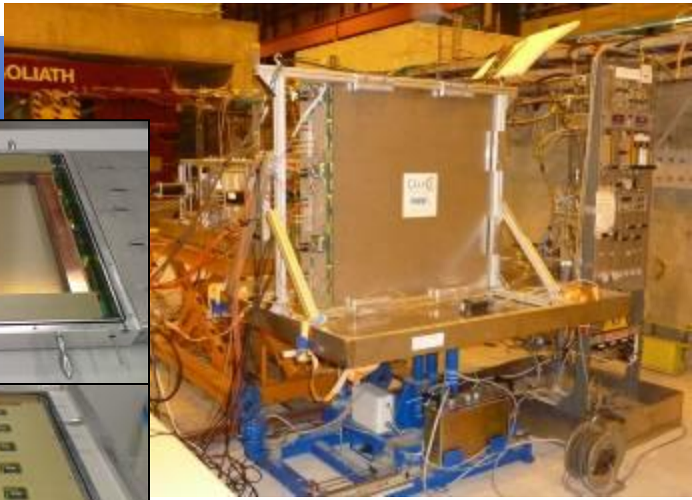


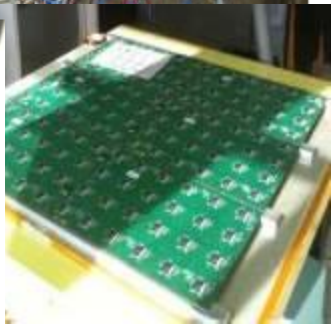
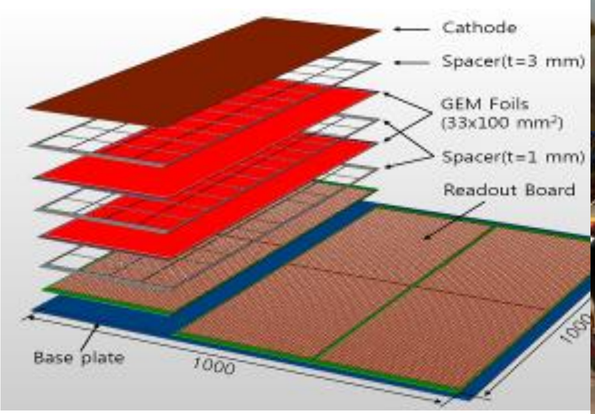

CALICE Sci/SiPM Analog HCal (AHCal):
- Physics prototype (Fe/W) tested in beam
- R&D/construction for Technical prototype
- First test beam of components

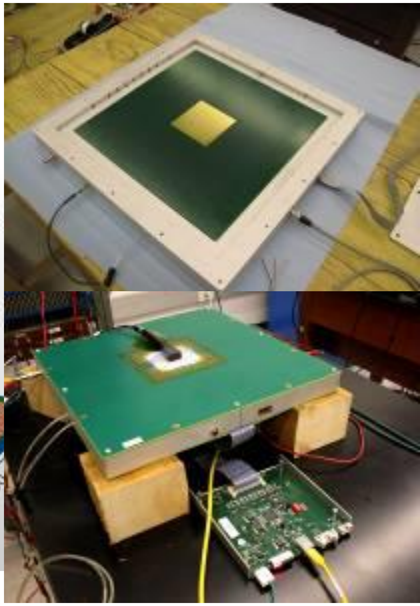
CALICE RPC Digital HCal (DHCal):
- Physics prototype (Fe/W) tested in beam (1cm^{2}pad size)
- Embedded Front End readout, 480K (!) readout channels
- Data analysis on-going
- R&D for Technical prototype started

HCal Efforts



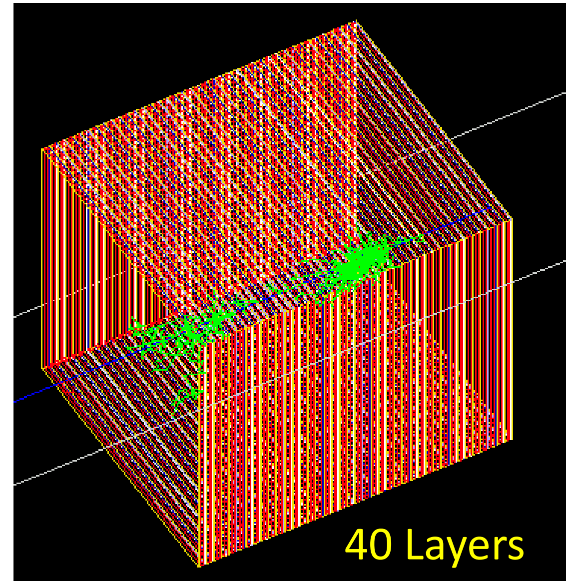


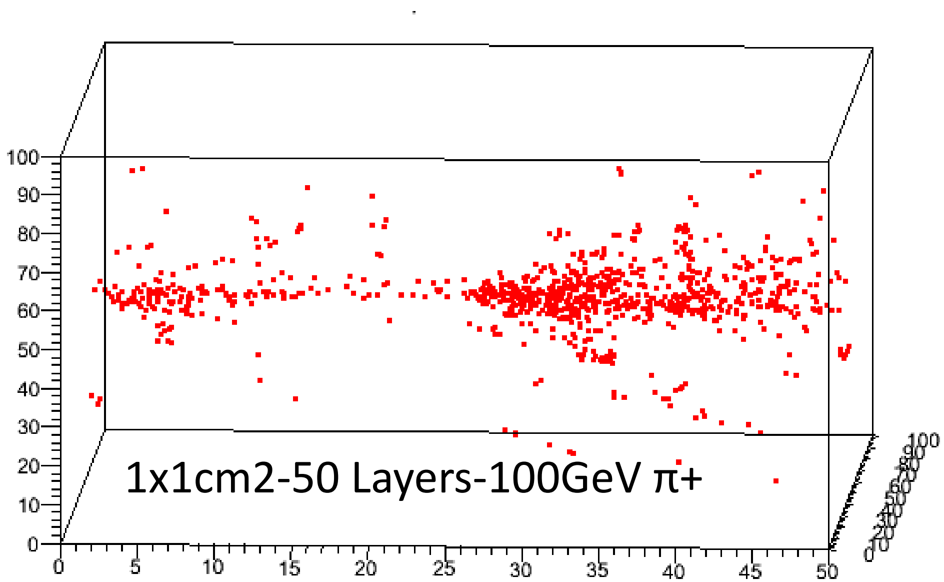
CALICE RPC semi-Digital HCal (sDHCal):
- Large prototype ($1m^3$) constructioned ($1cm^2$pad)
- Beam test at CERN with Fe absorbers
- Addressed several technical issues for real detector
- Explore 3-threshold readout
- R&D towards real detector

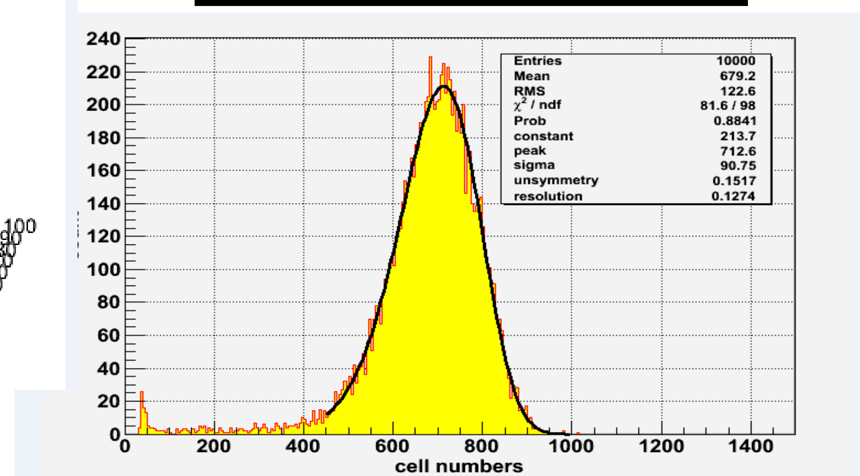
CALICE Micromegas/GEM Digital HCal:
- Prototype layer constructed/expected ($1x1cm^2$)
- Prototype layer beam test done/expected
- Both technologies can handle very high rates

CEPC DHCAL based on THGEM

- ➢ QGSP_BERT physics list was used;
- ➢ 3 kind layer numbers (30, 40, 50)
- ➢ Standalone fast simulation

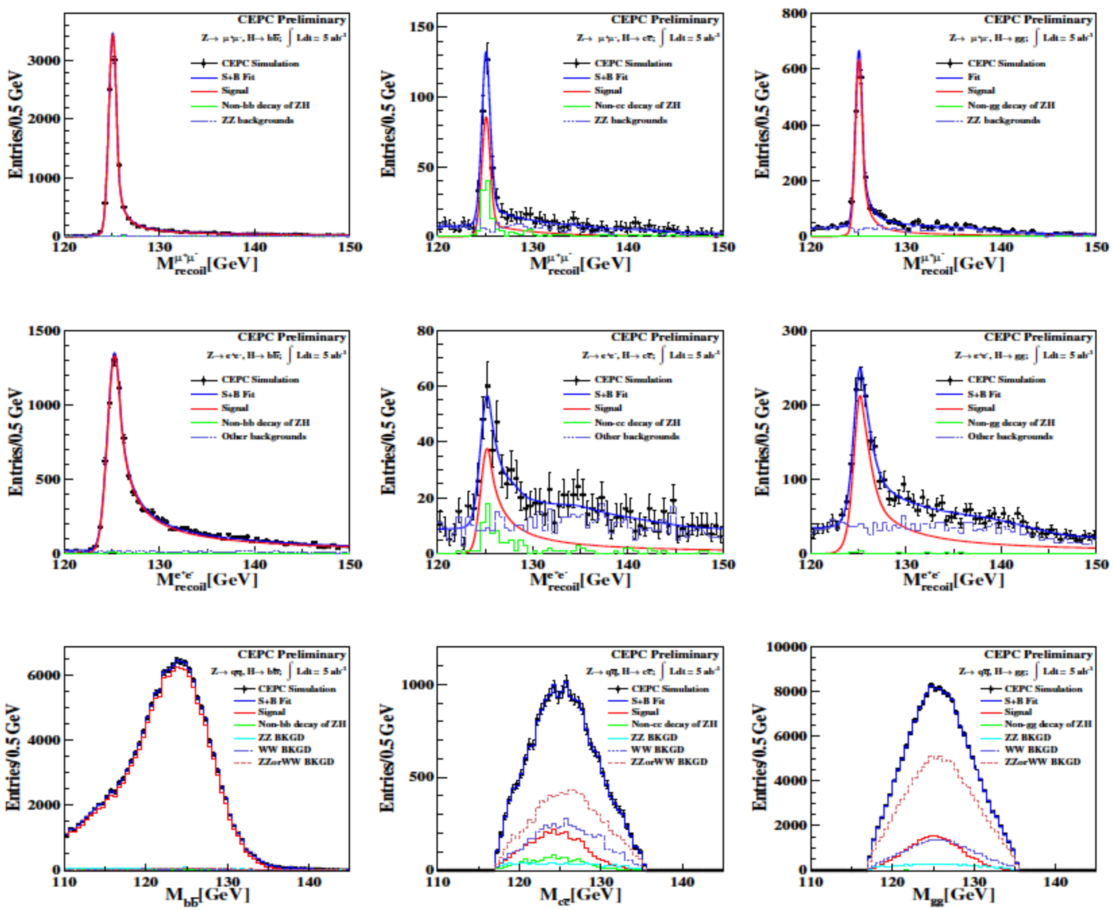




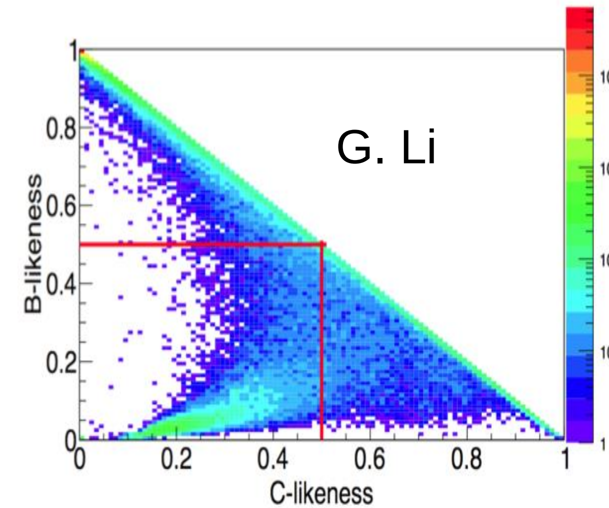


Higgs Analysis: Br(H→bb, cc, gg)

Figure 3.11 Measurements of Br($H \to bb, cc, gg$) from ZH events with $Z \to \mu^+\mu^-, ee, qq$ at CEPC with 5 ab^{-1} of integrated luminosity.



J. Dai (SJTU)& M. Ruan (IHEP)

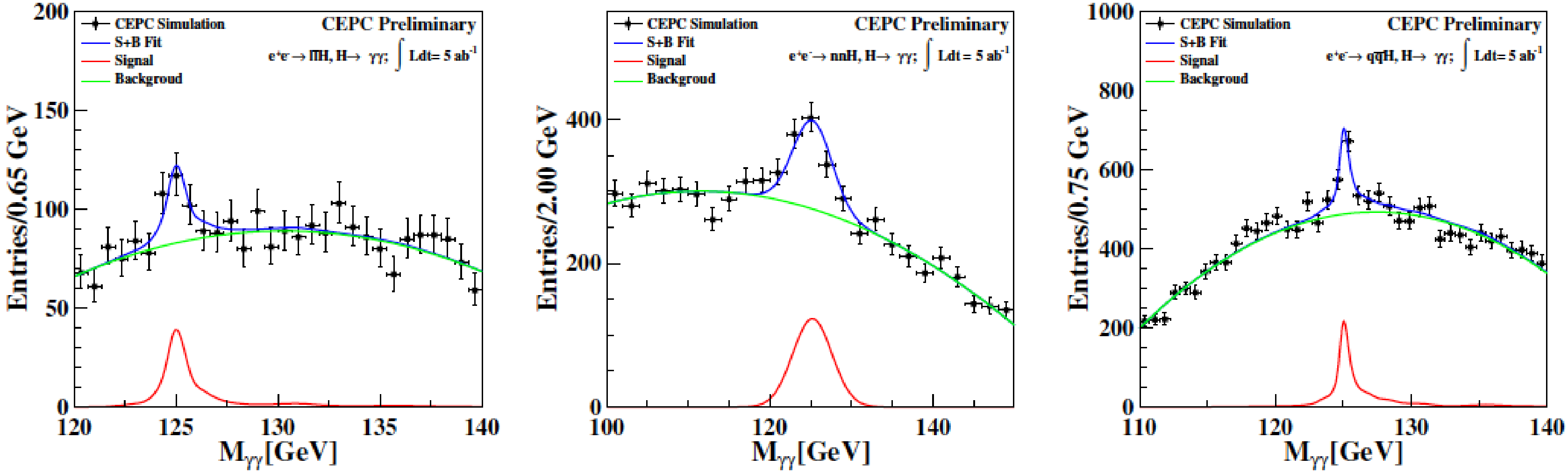



```
migrate matrix w/o eff.
 83.65%, 10.36%,  5.99%
  9.48%, 61.19%, 29.33%
  3.50%,  9.01%, 87.49%
```

Test bed for Vertex design/ Flavor tagging performance...

Higgs Rare Decays

Figure 3.14 $\sigma(ZH, \nu\nu H) \times Br(H \to \gamma\gamma)$ measured from $llH, \nu\nu H$ and qqH channels with different modelling of ECAL energy resolutions.



Z pole

07/05/14 9

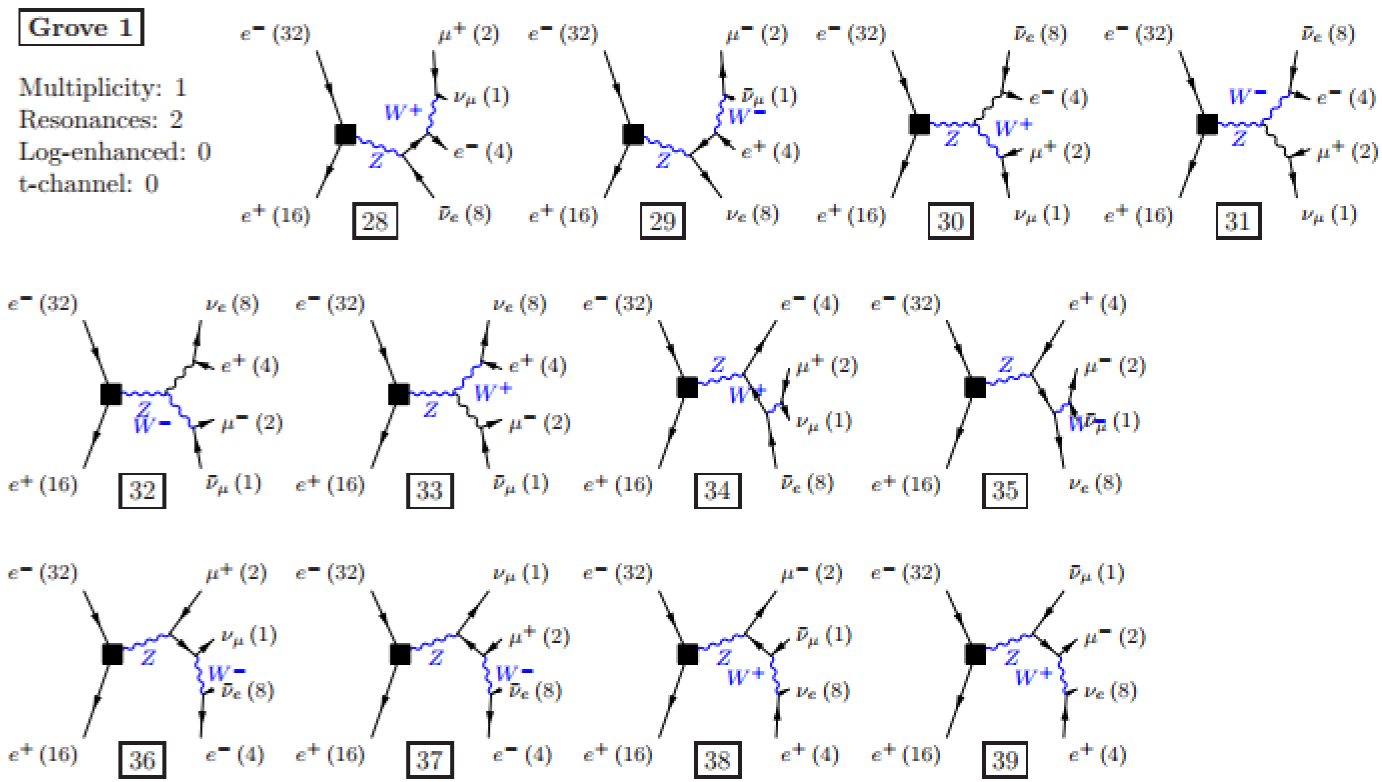
Summary

- Writing a note on CEPC Z-pole physics
  - 30% written
  - More measurements to be covered
    - Z mass/width measurement
    - QCD alpha_S measurement
    - ……

Z. Liang at USCD

Observable	LEP precision	CEPC precision
$A_{FB\ (b)}$	1.7%	0.15%
$Sin^2\theta_W$	0.1%	0.01%
R^b	~0.3%	0.08%
N_ν (direct measurement)	1.7%	0.18%
R^{mu}	0.2%	0.05%
R^{tau}	0.2%	0.05%

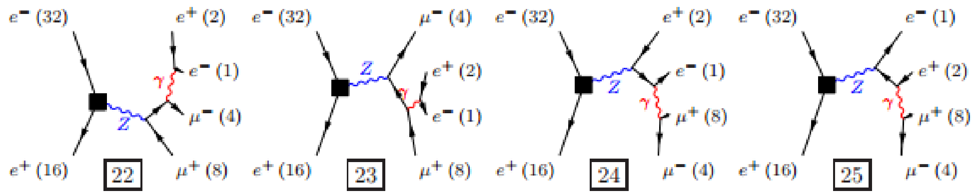
Background: Single W



Background: Single Z

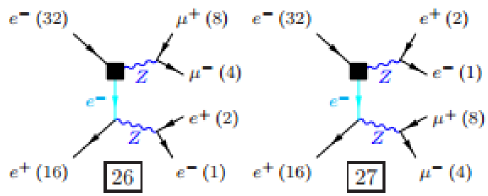
Grove 1

Multiplicity: 1
Resonances: 1
Log-enhanced: 1
t-channel: 0



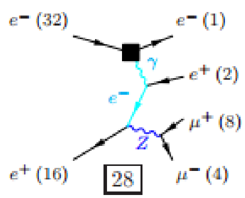
Grove 2

Multiplicity: 2
Resonances: 2
Log-enhanced: 1
t-channel: 1



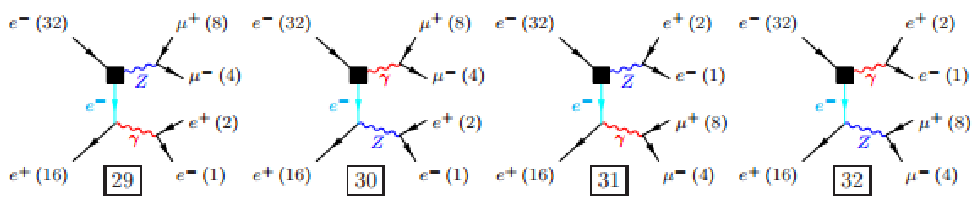
Grove 3

Multiplicity: 3
Resonances: 1
Log-enhanced: 2
t-channel: 2



Grove 4

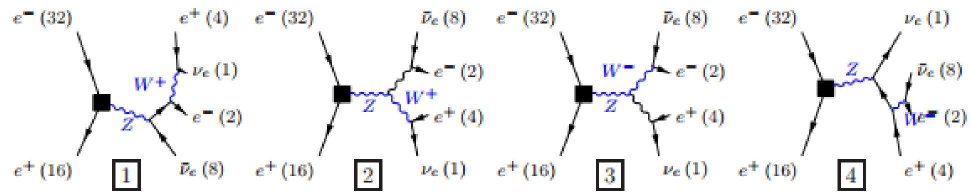
Multiplicity: 3
Resonances: 1
Log-enhanced: 2
t-channel: 1

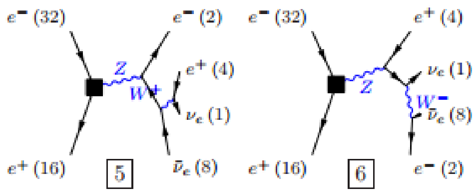


Background: ZorW

Grove 1

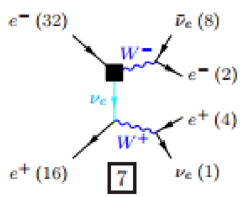
Multiplicity: 1
Resonances: 2
Log-enhanced: 0
t-channel: 0





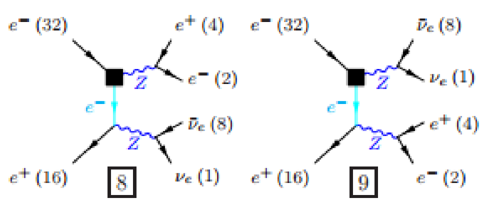
Grove 2

Multiplicity: 2
Resonances: 2
Log-enhanced: 1
t-channel: 1



Grove 3

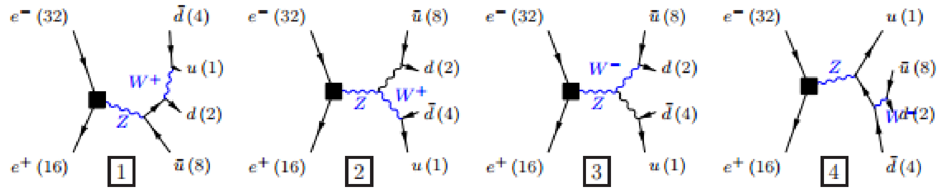
Multiplicity: 2
Resonances: 2
Log-enhanced: 1
t-channel: 1

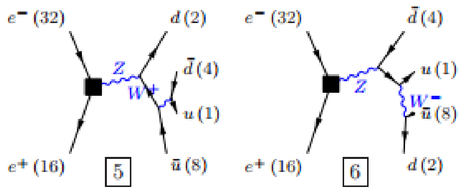


Background: ZZorWW

Grove 1

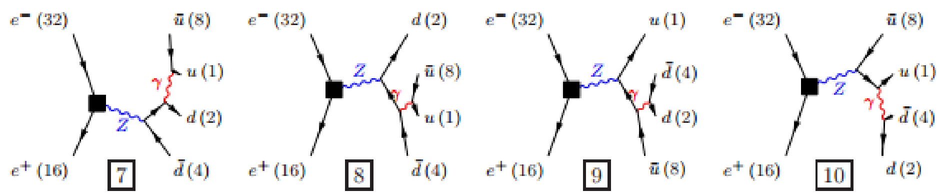
Multiplicity: 1
Resonances: 2
Log-enhanced: 0
t-channel: 0





Grove 2

Multiplicity: 1
Resonances: 1
Log-enhanced: 1
t-channel: 0



Grove 3

Multiplicity: 2
Resonances: 2
Log-enhanced: 1
t-channel: 1