International Symposium on Higgs Boson and Beyond Standard Model Physics

CEPC Preliminary Detector Design

Haijun Yang (Shanghai Jiao Tong University)

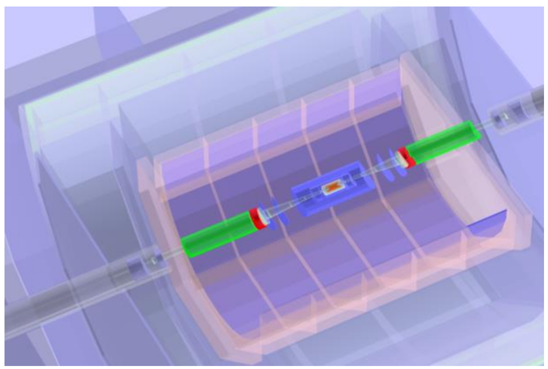
(for CEPC Physics and Detector Working Group)

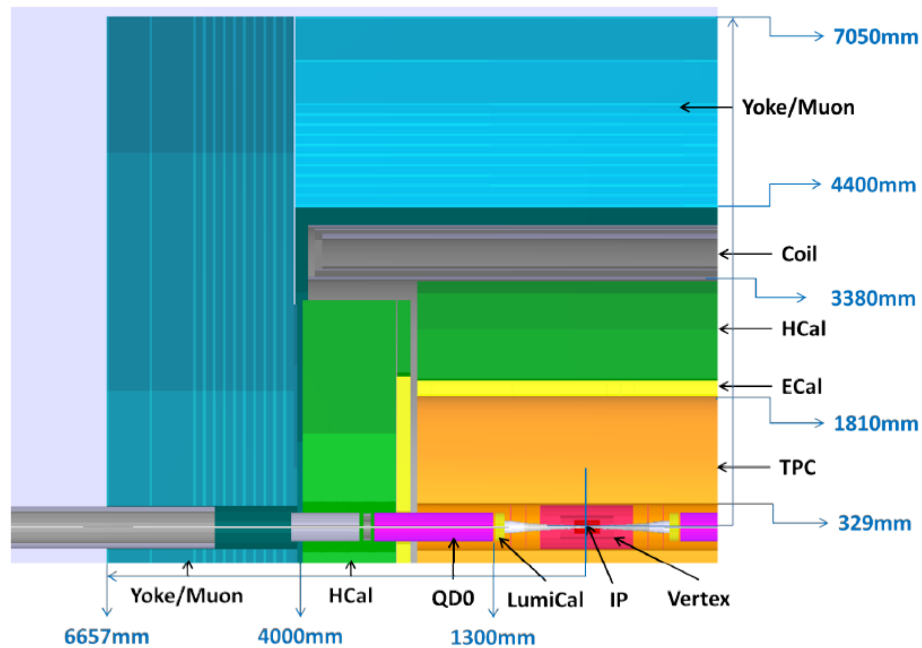
Shandong University, Weihai

August 15-19, 2016

Outline

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

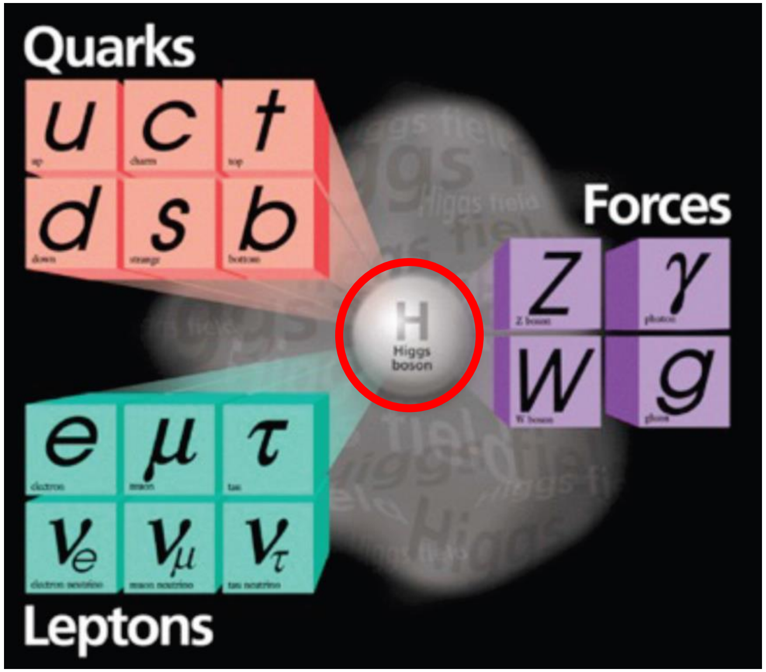


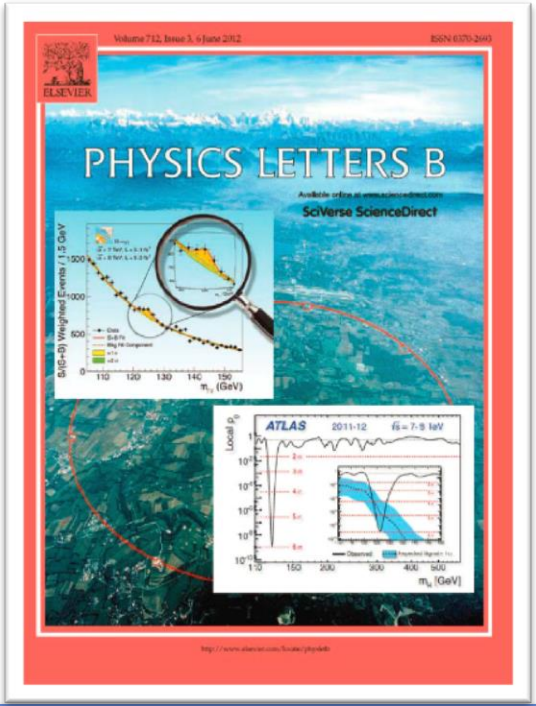


- Summary and Future Plans

Circular Electron Positron Collider - CEPC

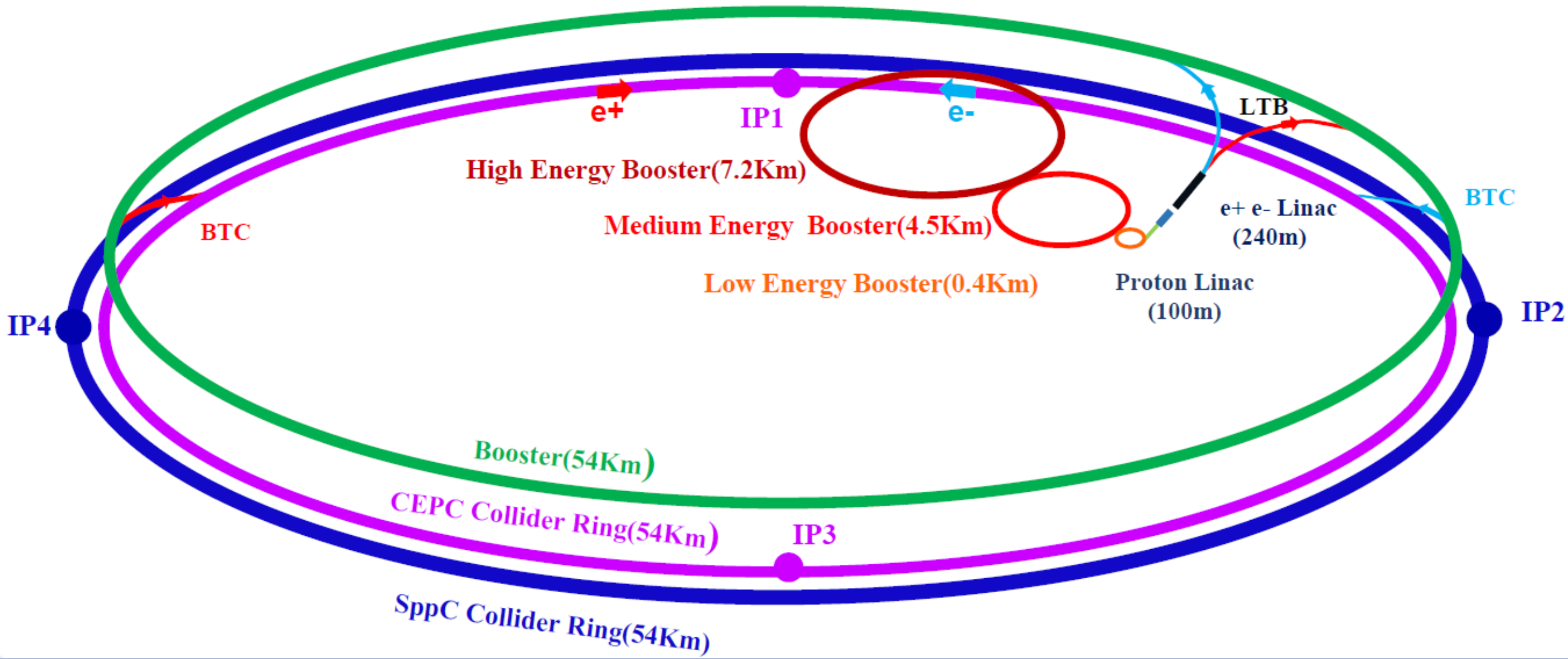
Discovery of low mass Higgs boson at the LHC (July 4, 2012) brings up an opportunity to investigate circular e^+e^- collider as a viable option for the "Higgs Factory" which is dedicated for precision measurement of the Higgs properties with clean collision environment.





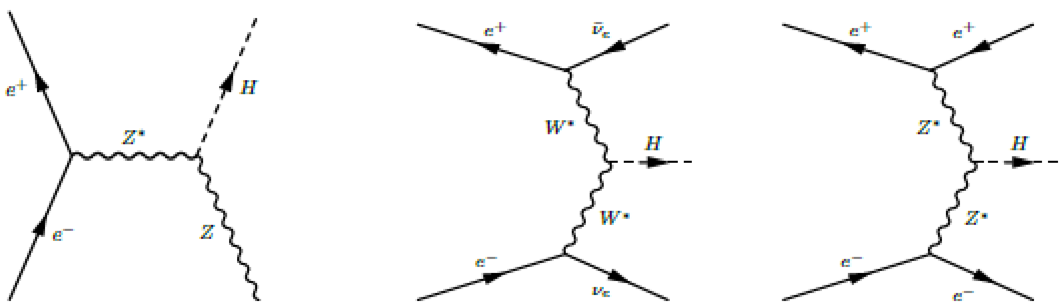
Circular Electron Positron Collider - CEPC

Parameter	Design Goal
Particles	e+, e-
Center of mass energy	240 GeV
Luminosity (peak)	2*10^34/cm^2s
No. of IPs	2

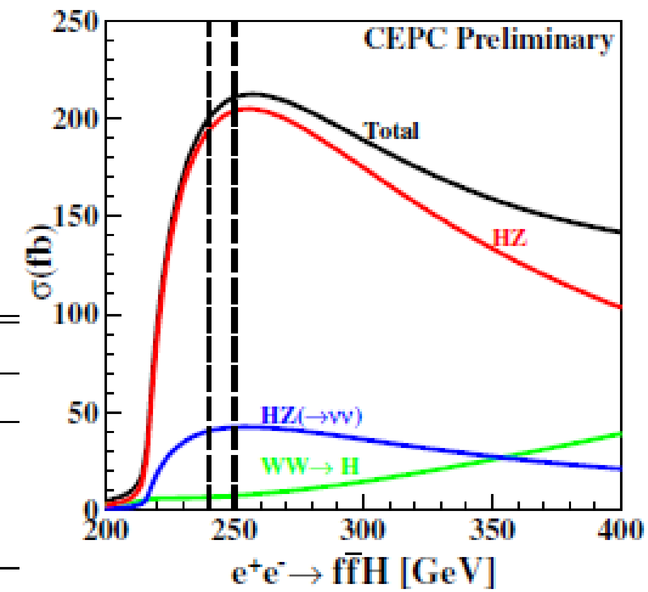


Circular Electron Positron Collider - CEPC

- Precise measurements of the Higgs properties as a Higgs Factory (similar to ILC@250 GeV)
  - 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*

Requirements for CEPC Detector Design

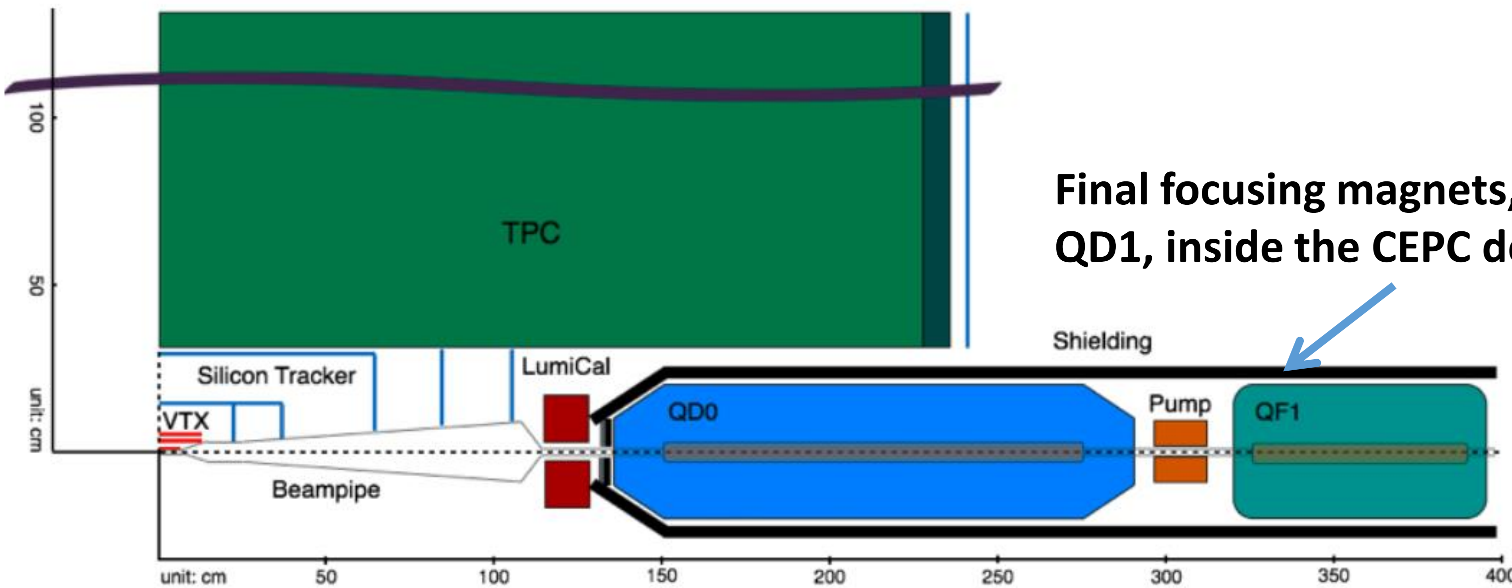
Critical Physics Benchmarks for Detectors design.

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

Physics Process	Measured Quantity	Critical Detector	Required Performance
$ZH \to \ell^+\ell^- X$	Higgs mass, cross section	Tracker	$\Delta(1/p_{\mathrm{T}}) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$\mathrm{BR}(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_{\mathrm{T}} \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$\mathrm{BR}(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu\mathrm{m}$
$H \to q\bar{q},\ V^+V^-$	$\mathrm{BR}(H \to q\bar{q},\ V^+V^-)$	ECAL, HCAL	$\sigma_E^{\mathrm{jet}}/E \sim 3-4\%$
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%\ (\mathrm{GeV})$

- ILD-like, with modifications/considerations
  - No push-and-pull → Less Yoke
  - Shorter L*=1.5m → Challenges for MDI
  - Power pulsing not possible → less power consumption + active cooling

CEPC Machine Detector Interface (MDI)

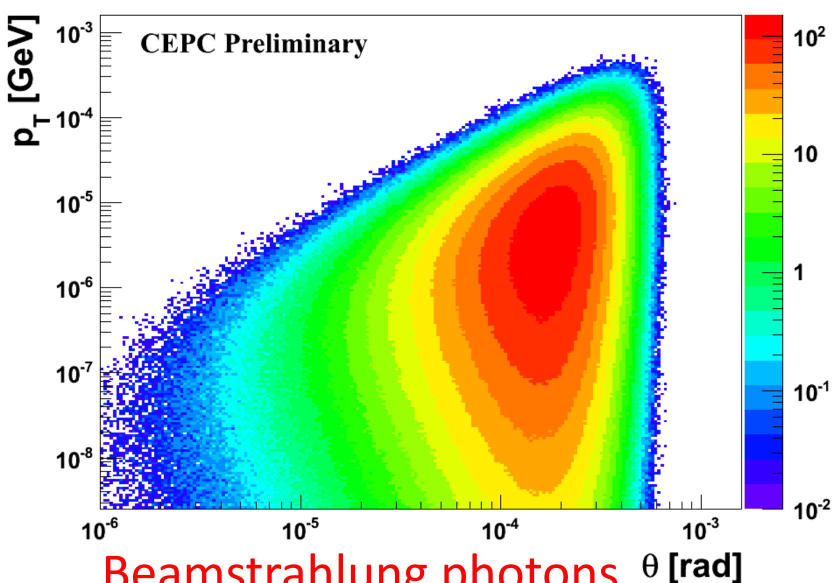


Final focusing magnets, QD0 and QD1, inside the CEPC detector

- Short focal length (L*=1.5m, cf. ~3.5m at ILC), to allow realization of high luminosity.
- Final focusing magnets inside the detector → constraint on the detector design and QD0/QF1 + LumiCal designs
- Comprehensive understanding and optimization of both detector and collider performance are needed in future studies

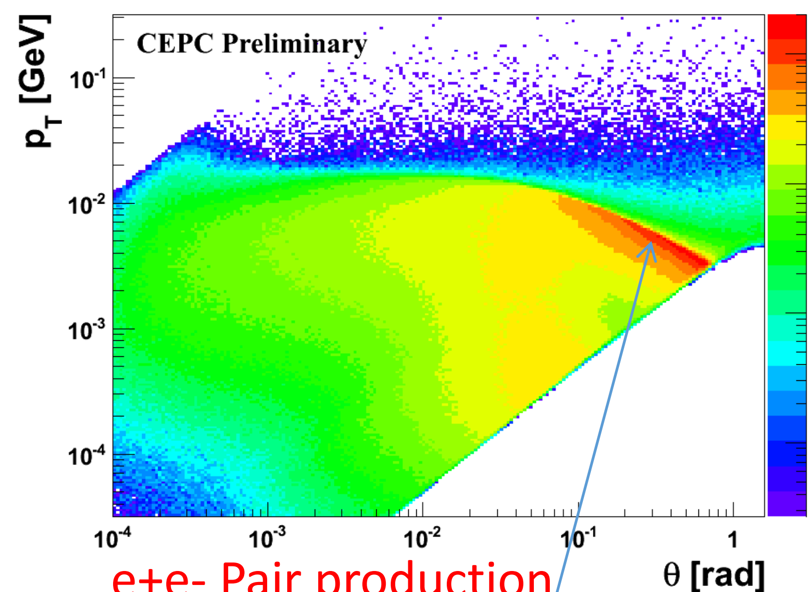
CEPC MDI: Beam-induced Backgrounds

- 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

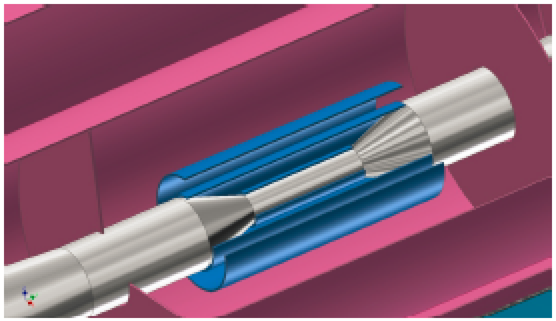
Low momentum and small polar angle → negligible, but should avoid directing any detector component

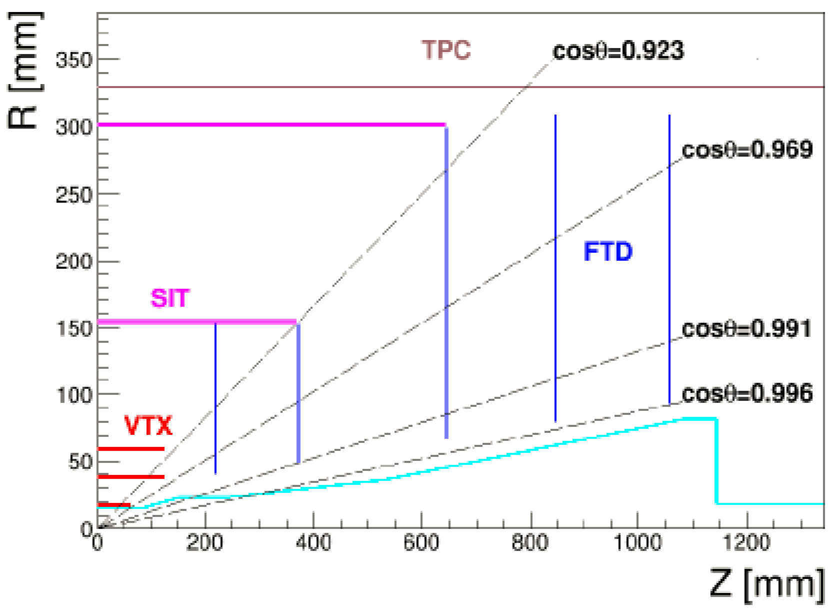


e+e- Pair production

Dominant detector background with sharp kinematic edge

CEPC Vertex and Silicon Tracker





Vertex detector:

- 3 cylindrical and concentric double-layers of pixels

Silicon Internal Tracker (SIT)

- 2 inner layers Si strip detectors

Forward Tracking Detector (FTD)

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

Silicon External Tracker (SET)

- 1 outer layer Si strip detector

End-cap Tracking Detector (ETD)

- 1 end-cap Si strip detector on each side

CEPC Vertex and Silicon Tracker

Ouyang Qun @ IHEP

B = 3.5T

Performance requirements

- momentum resolution

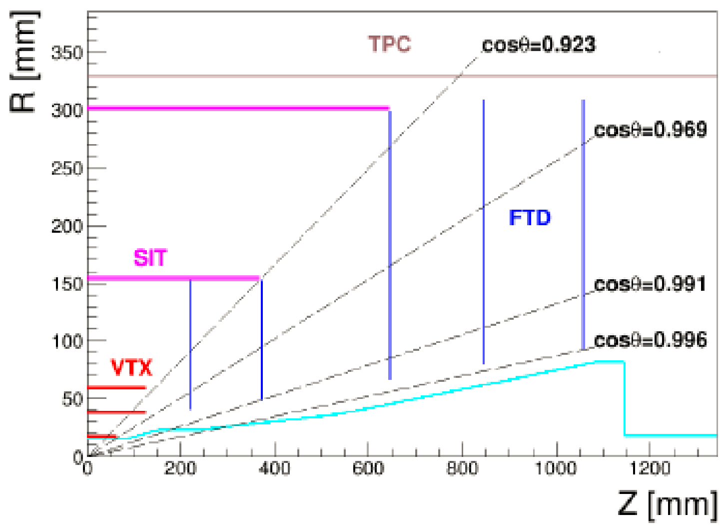
$$\sigma_{1/p_T} = 2\times10^{-5} \oplus 1\times10^{-3}/(p_T \sin\theta)$$

- 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: *≤ 1 %*
- Total ionising dose: *≤ 100 krad/ year*
  Non-ionising fluences : *≤$3x10^{11} n_{eq}/(cm^2\, yr)$*
- first layer located at a radius: *~1.6 cm*

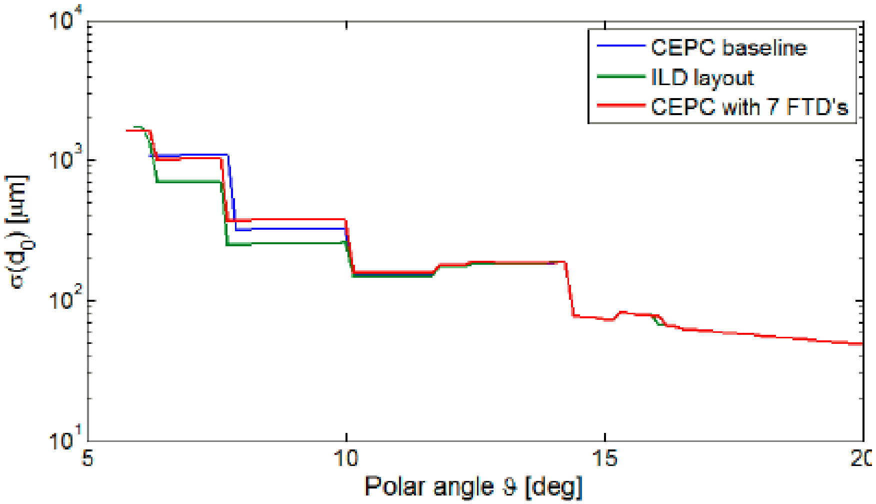


Silicon tracker specifications:

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

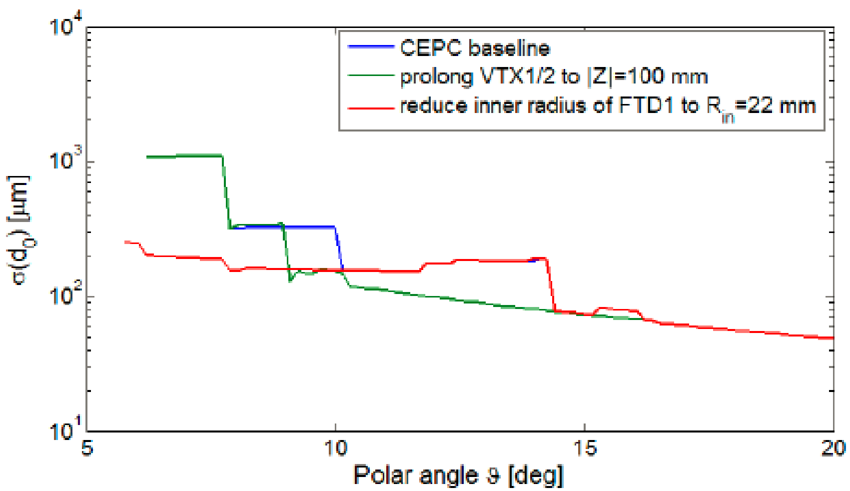
Forward region with L* = 1.5m

- Impact parameter resolution studied with LDT - fast simulation using Kalman filter



Performance loss in the low polar angle region (< 10°) with reduced number of FTD disks

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



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

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 mm$\times$4-10 mm/$\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)

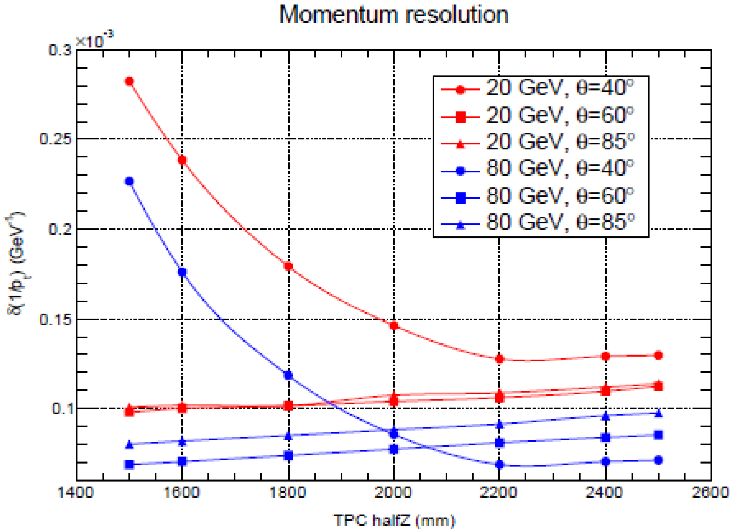
Same as Main performance/ Design goals of ILD-TPC

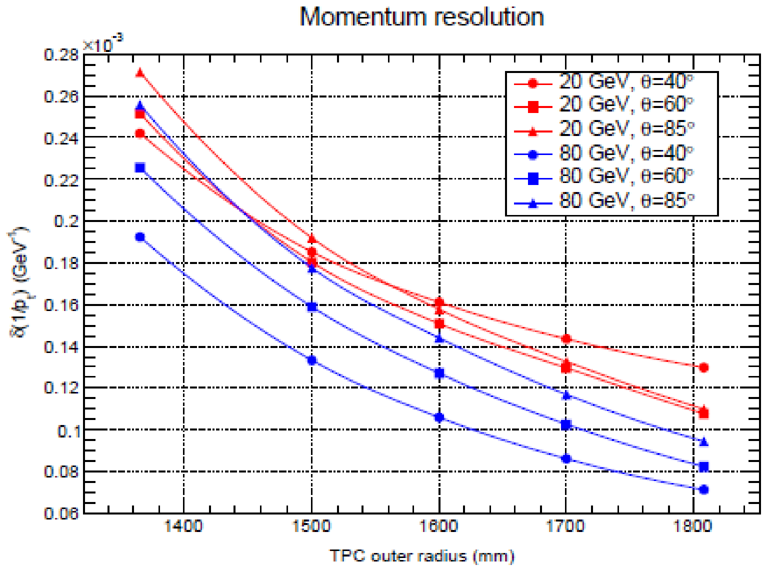
[a]The momentum resolution for the combined central tracker is $\delta(1/p_t) \simeq 2 \times 10^{-5}$/GeV/c

CEPC TPC Conceptual Design

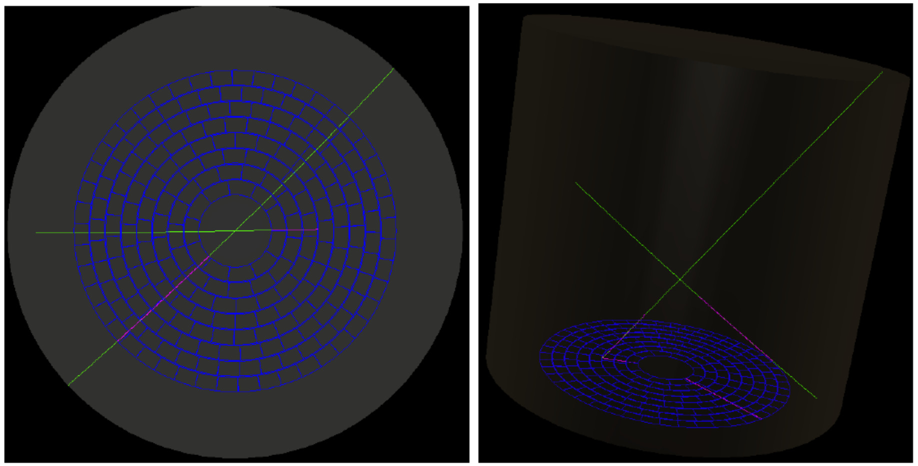
Huirong Qi @ IHEP

- **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**





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



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

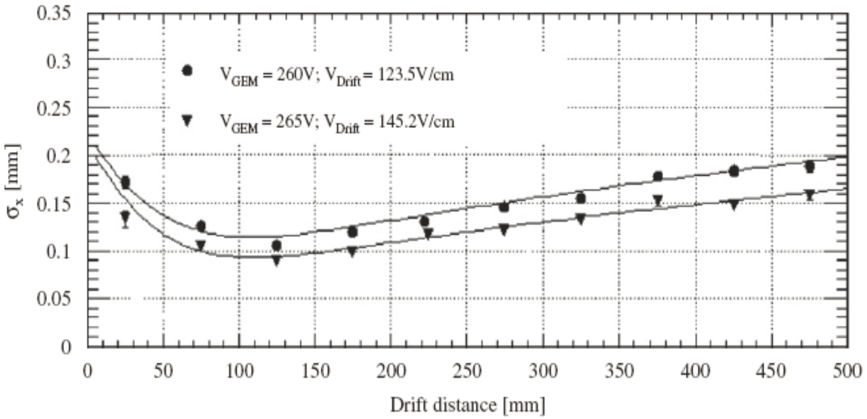
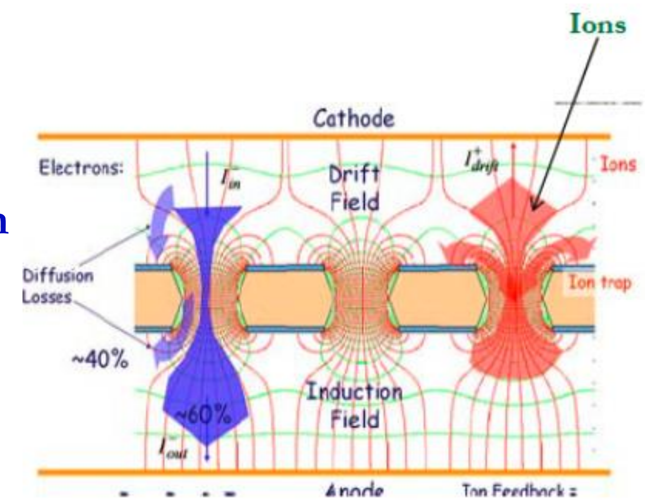


Fig. 6. x-Resolution for Ar–Iso–CF4 = 96.3–3.1–0.6 gas with $B = 1$ T under two different test conditions ($\varphi < 2°$, $\theta < 10°$).

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 ?

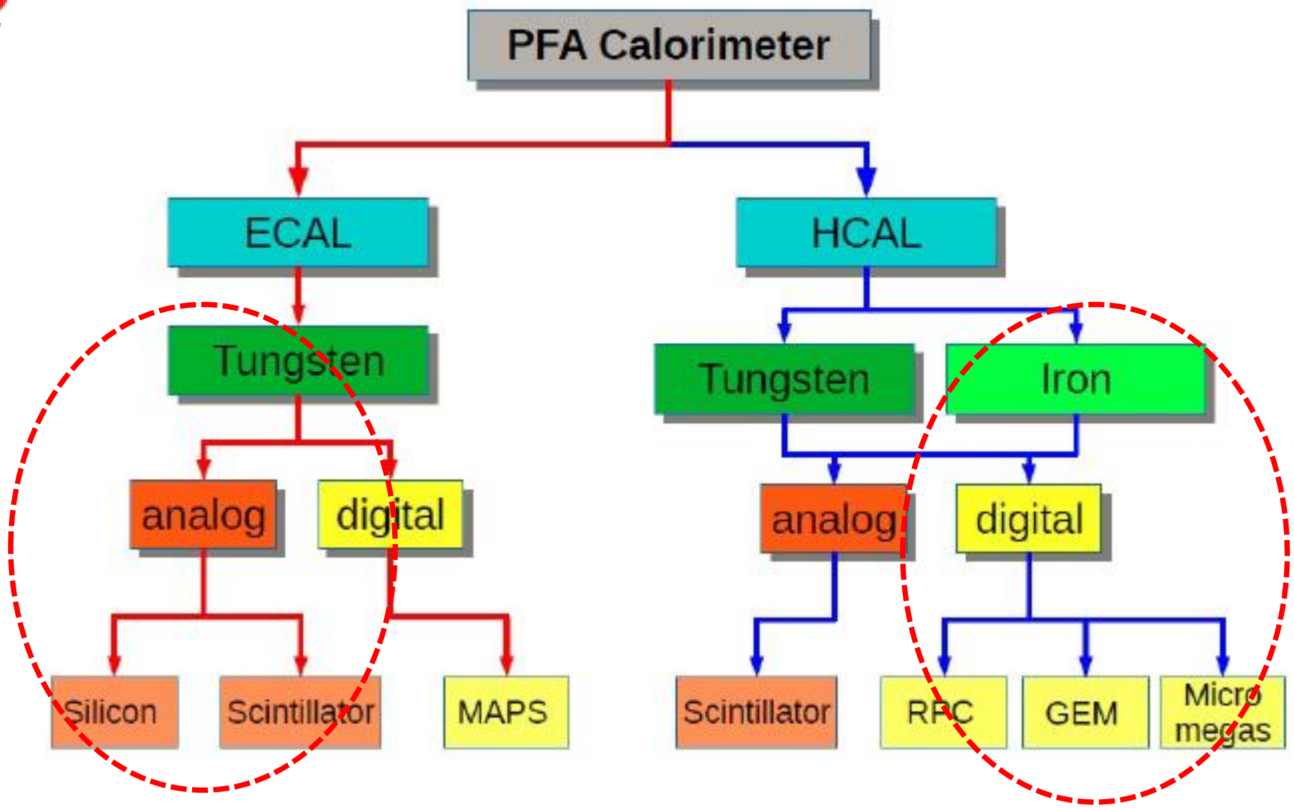


IBF of GEM

- 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

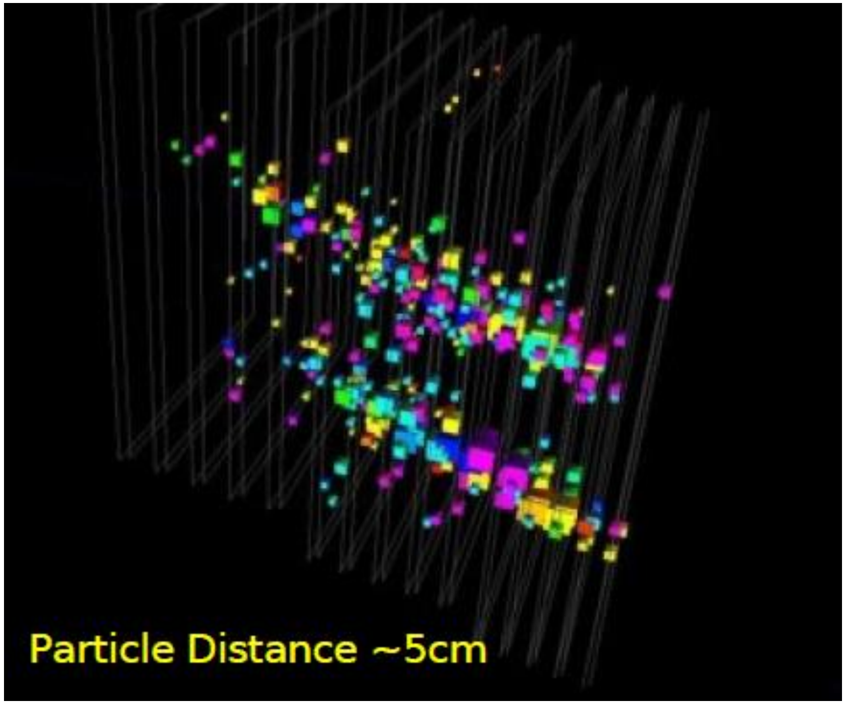


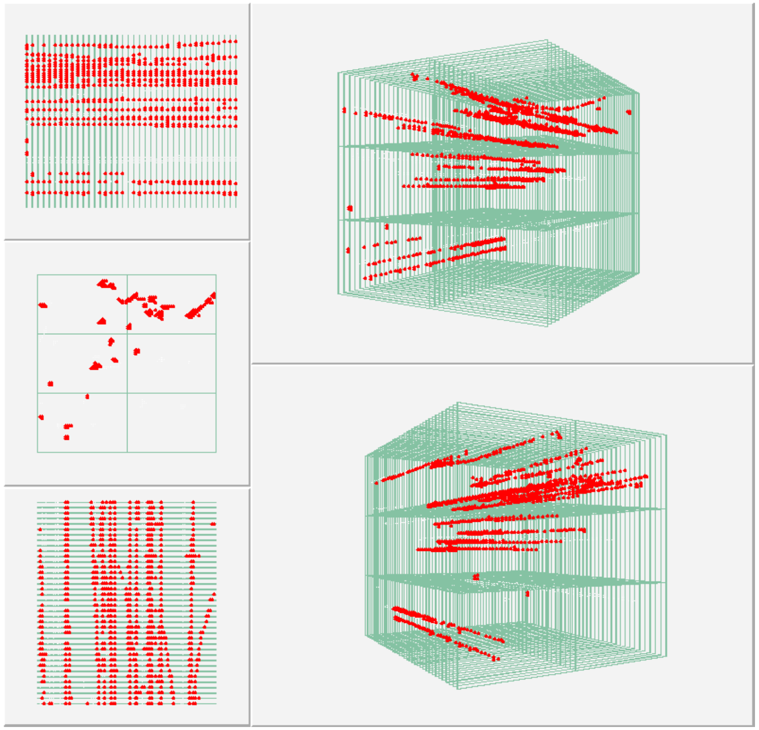
Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 0.13 cm^2 → 2.5x10^{-5} cm^2

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

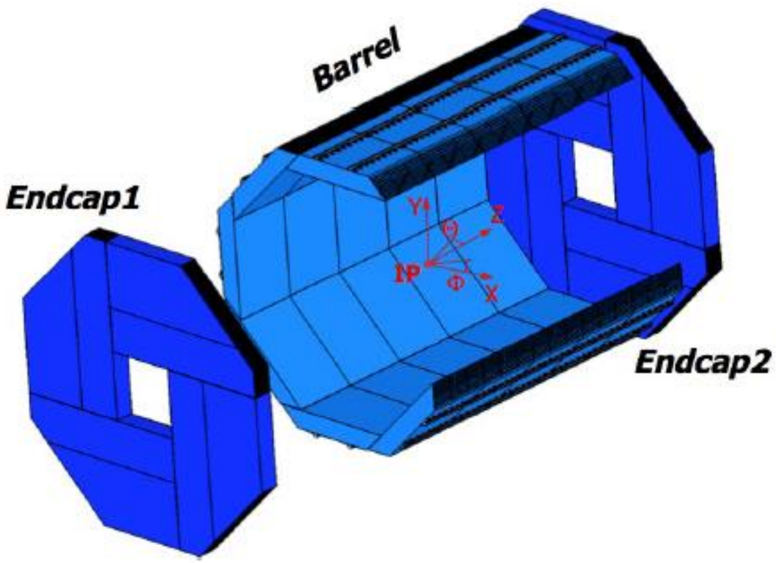
~20 muons in 1m^2 area
CALICE RPC DHCAL

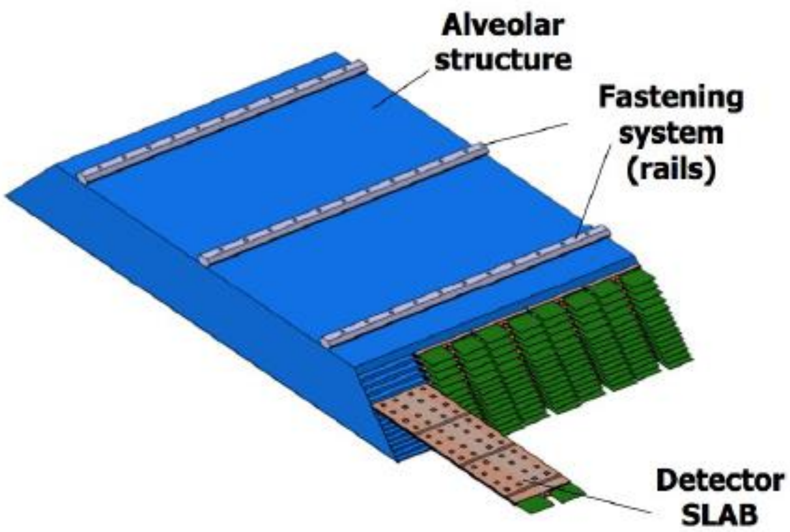
This is exactly what PFA needs: distinguishing individual showers within jet environment, in order to get excellent jet energy/mass resolution

CEPC ECAL: Silicon-W

V. Boudry @ IN2P3

- The ECAL consists of a cylindrical barrel system and two large end caps.
  - One Barrel: 5 octagonal wheels
  - Two Endcaps: 4 quarters each
- Two detector active sensors interleaved with tungsten absorber
  - silicon pixel 5 x 5 mm^2 with 725 μm in thickness
  - PCB with VFE ASIC



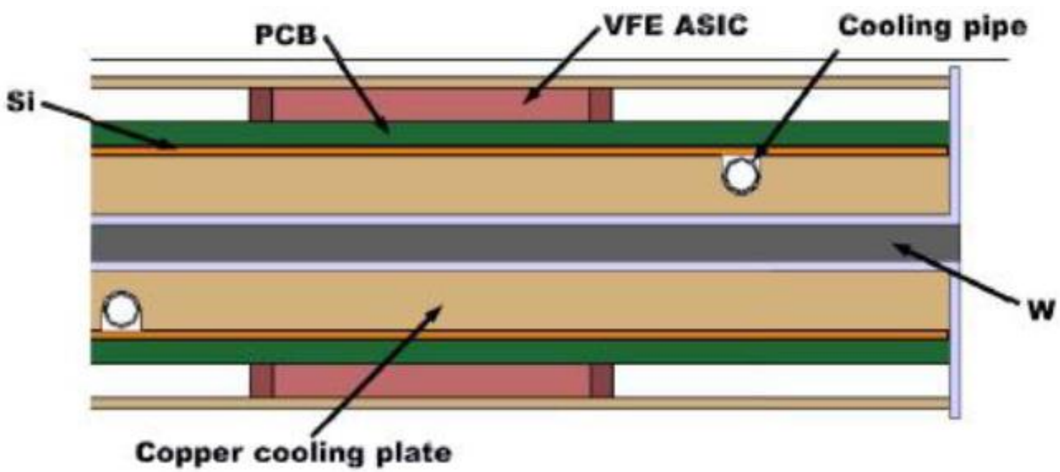


Active Cooling System

- CEPC is designed to operate at continuous mode with beam crossing rate: 2.8×10^5 Hz. Power pulsing will not work at CEPC.
- Compare to ILD, the power consumption of VFE readout electronics at CEPC is about two orders of magnitude higher, hence it requires an active cooling
  - Evaporative CO_2 cooling in thin pipes embedded in Copper exchange plate.
  - For CMS-HGCAL design: heat extraction of 33 mW/cm^2, allows operation with 6×6 mm^2 pixels with a safety margin of 2

➔ Transverse view of the slab with one absorber and two active layers.

➔ The silicon sensors are glued to PCB with VFE chips, cooled by the copper plates with CO_2 cooling pipes.

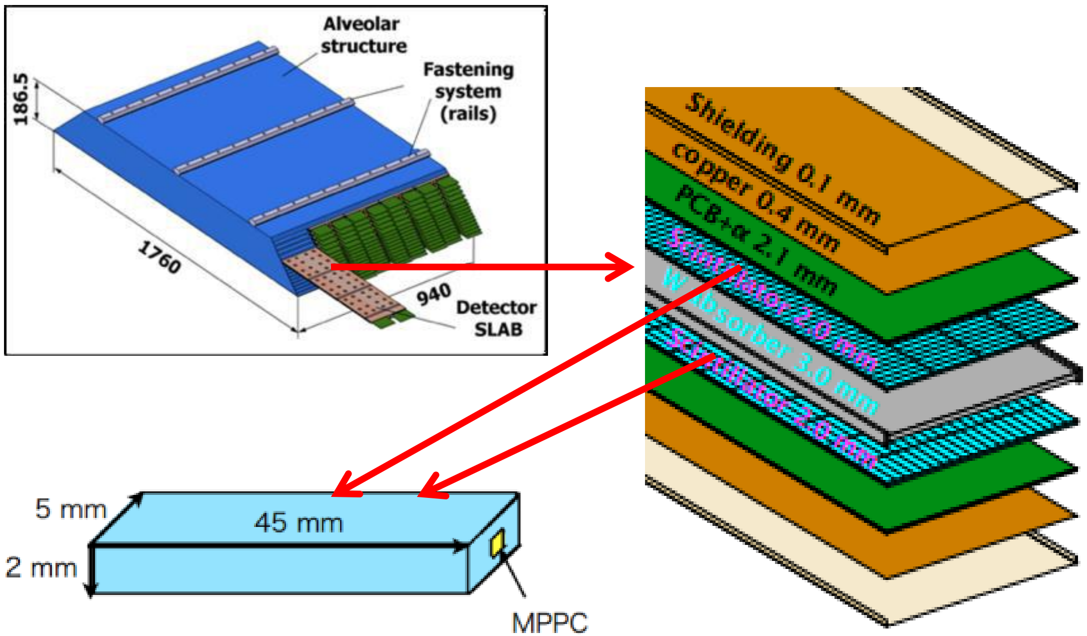


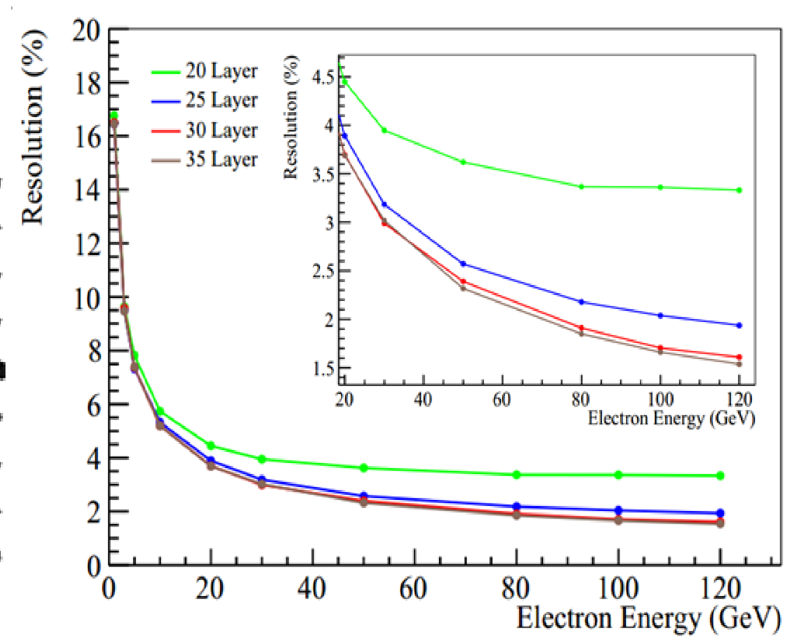
CEPC ECAL: Scintillator-W

Z.G. Wang @ IHEP

A super-layer (7mm) is made of:

- Plastic scintillator (2mm) + Tungsten plate as absorber (3mm thick)
- A readout/service layer (2mm thick)





Scintillator + W + Scintillator

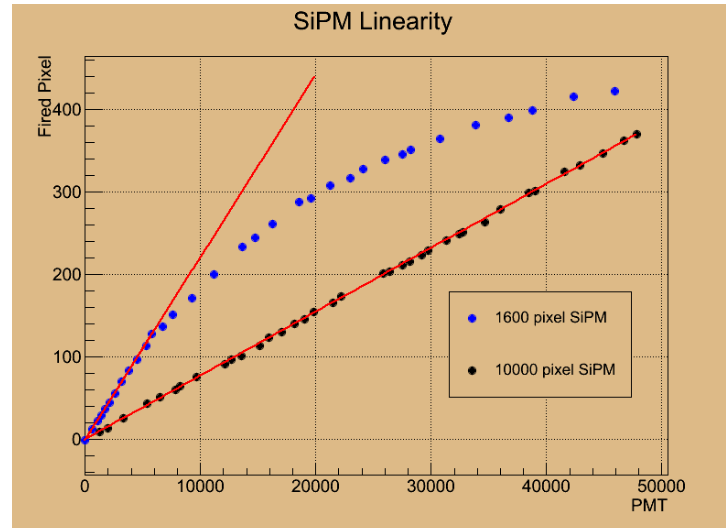
- **The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**

Tests of SiPM at IHEP

The SiPM dynamic range is determined by the number of pixels.

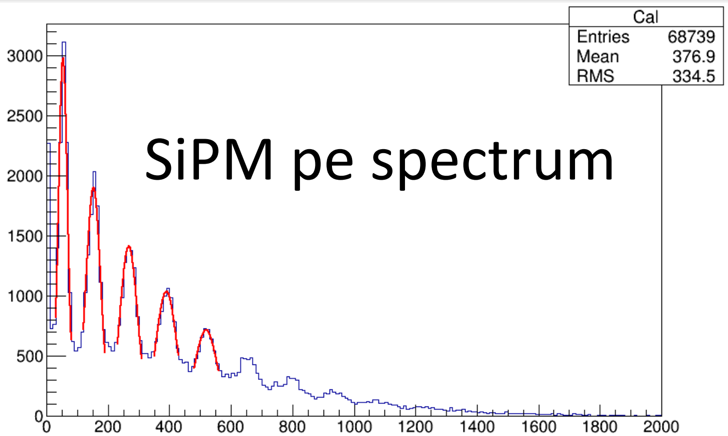
The manufactures have developed the SiPM with 10um pixel which extends the SiPM dynamic range.

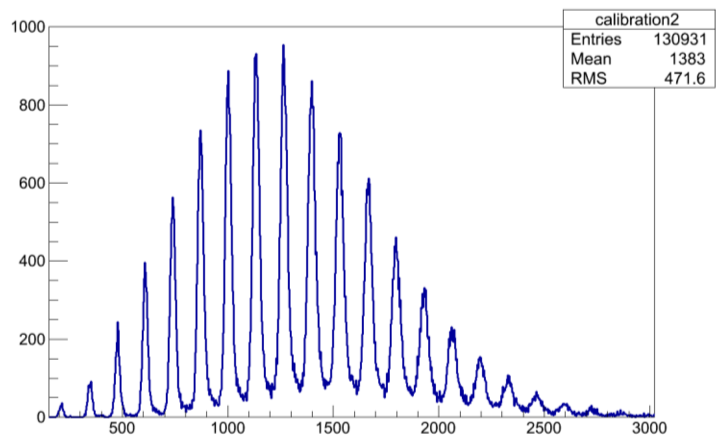
But, the photon detection efficiency of 10um SiPM is only 1/3 of 25um SiPM.



Scintillator strip irradiated with β collimated (1mm) from Sr-90

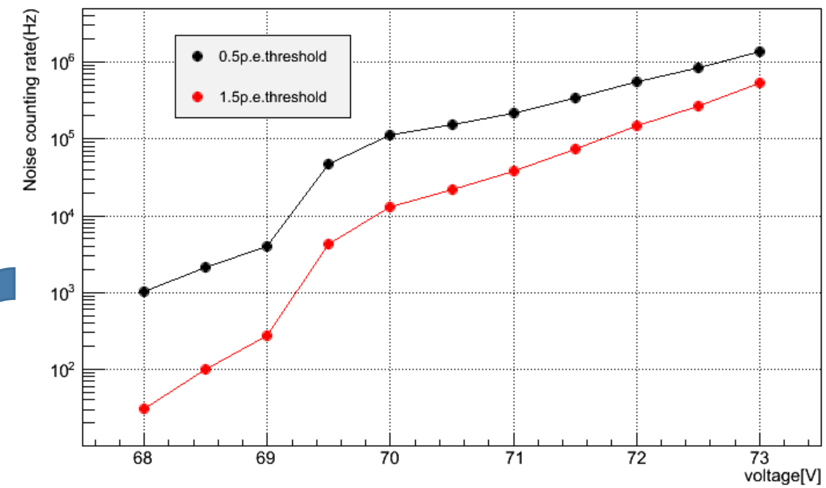
Tests of SiPM at IHEP



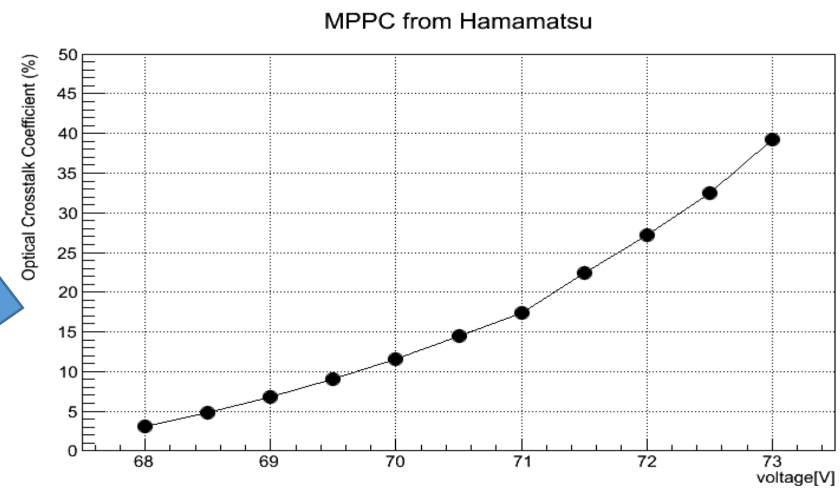


pulse height spectrum.

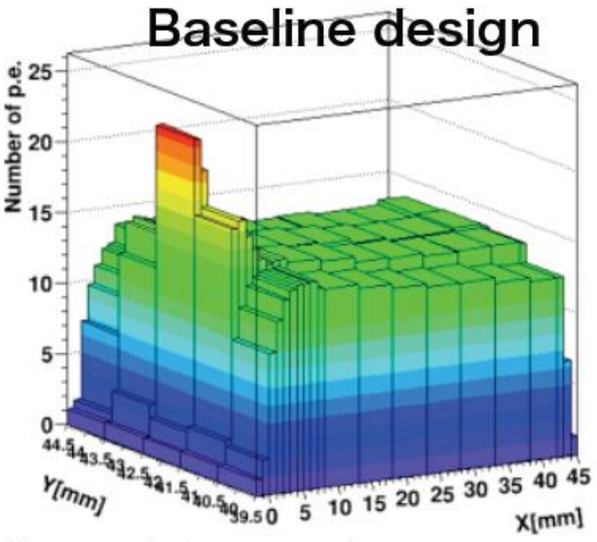
Excellent photon counting

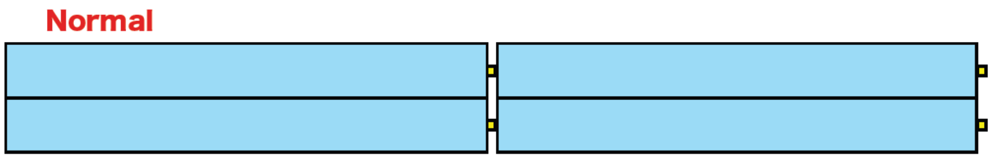


Crosstalk rate = Events (> 1.5p.e)/Events (>0.5p.e)

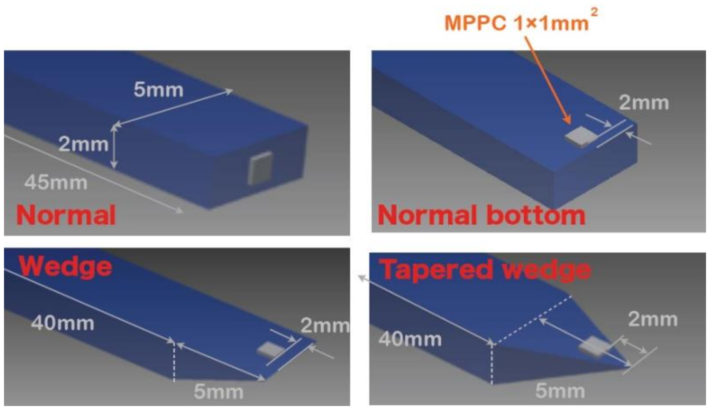


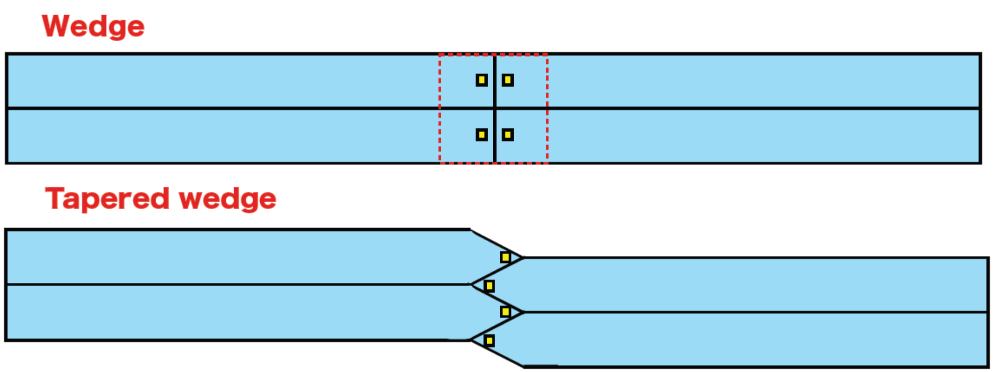
Scintillator Strip Structure Optimization





With normal design, the signal is not uniform with peak response for hits near SiPM. What's more, the dead gap between strips is large due to SiPM installation.



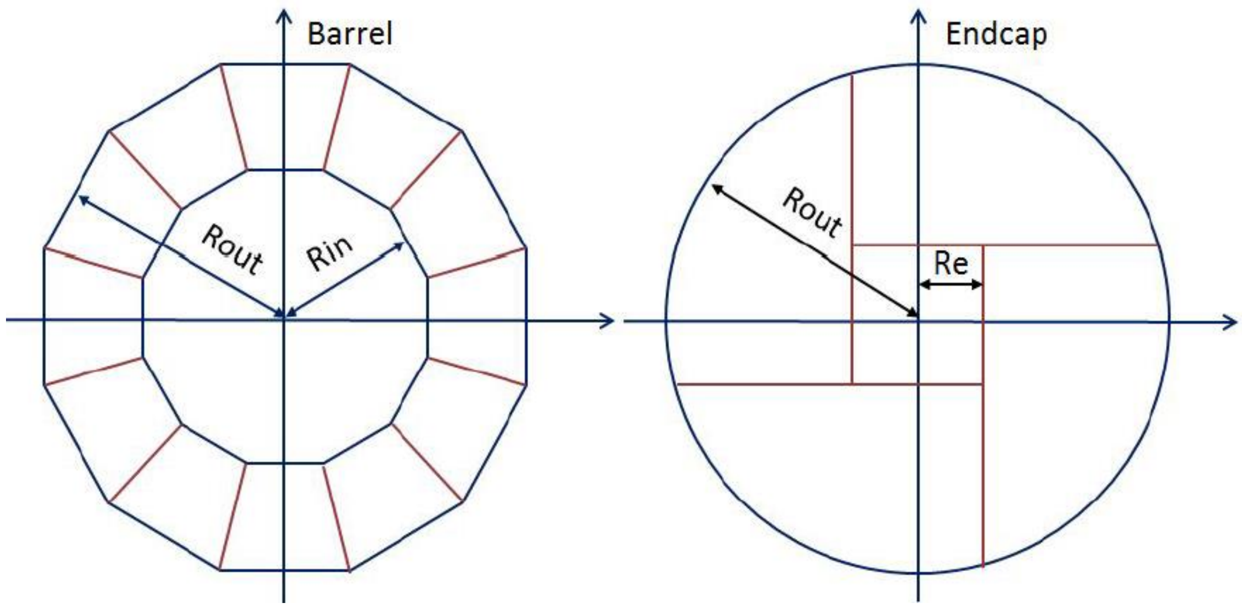


Need MC simulation and experimental tests to optimize the strip structure design.

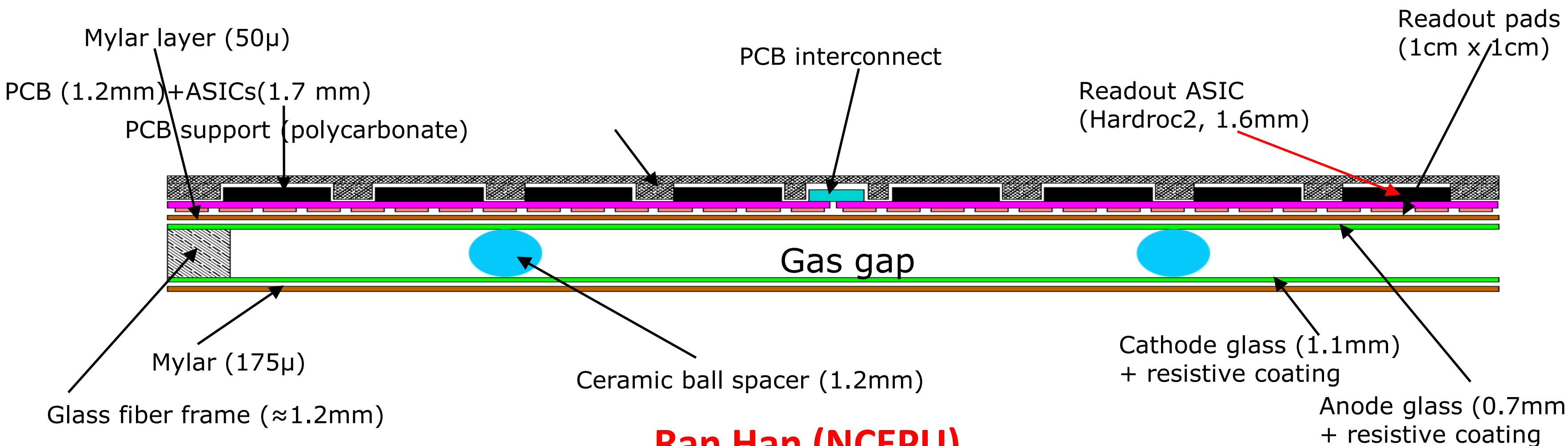
Hadron Calorimeter

- The HCAL consists of
  - a cylindrical barrel system: 12 modules
  - two endcaps: 4 quarters
- Absorber: Stainless steel

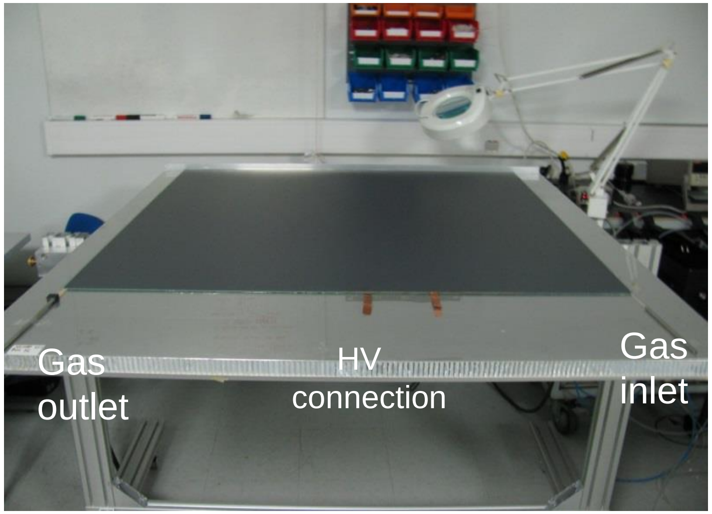
- **Active sensor**
  - Glass RPC
  - Thick GEM or GEM
- **Readout (1×1 cm^2)**
  - Digital (1 threshold)
  - Semi-digital (3 thresholds)



RPC Construction & Performance Study



Ran Han (NCEPU)



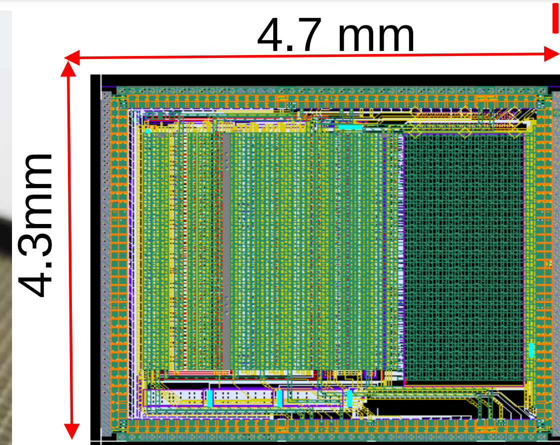
Large GRPC R&D

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

Electronics Readout System R&D

Imad Laktineh (IPNL)

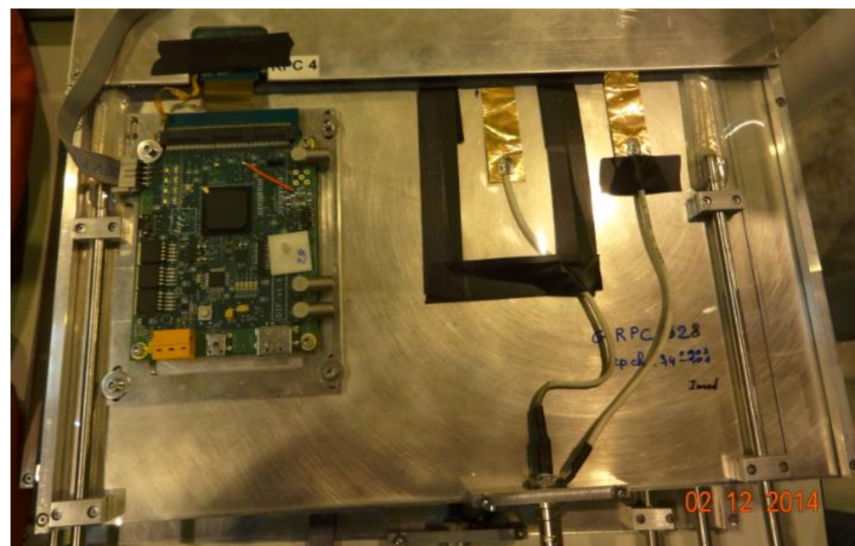
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity



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

Tiny connectors were used to connect the PCB two by two so the 24X2 ASICs are daisy-chained. $1 \times 1 m^2$ has 6 PCBs and 9216 pads.

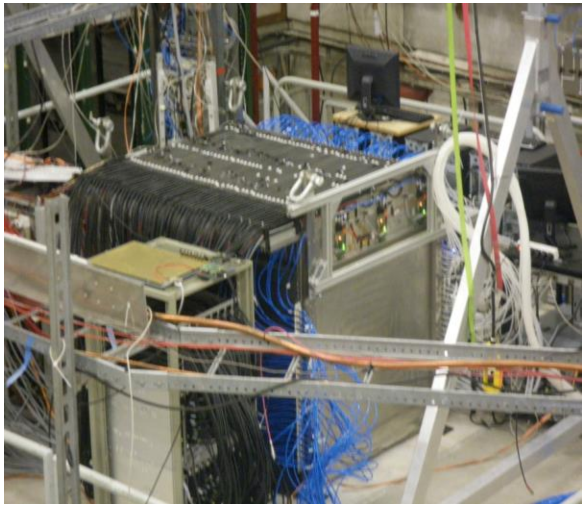
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.

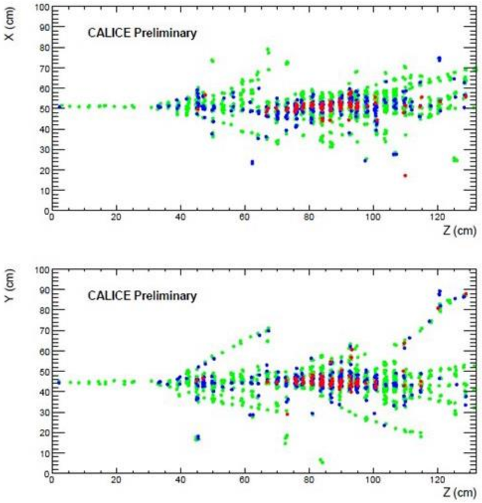


Prototypes of DHCAL with RPC

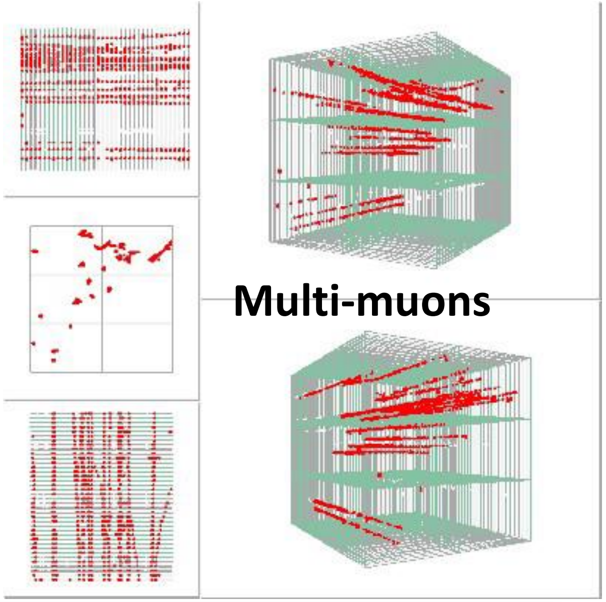
Prototypes of DHCAL based on RPC

- **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





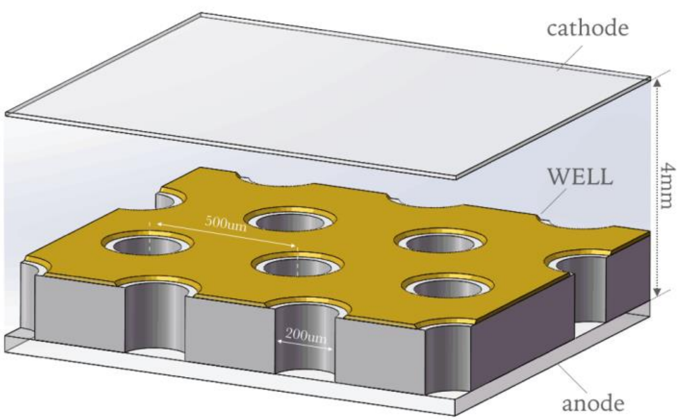
80 GeV Pion

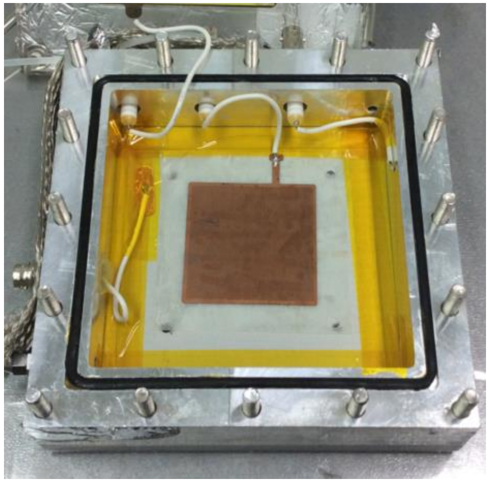


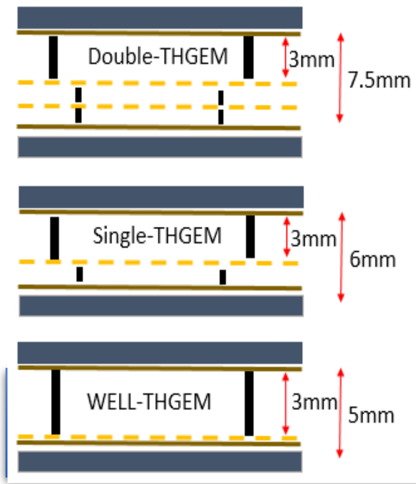
Multi-muons

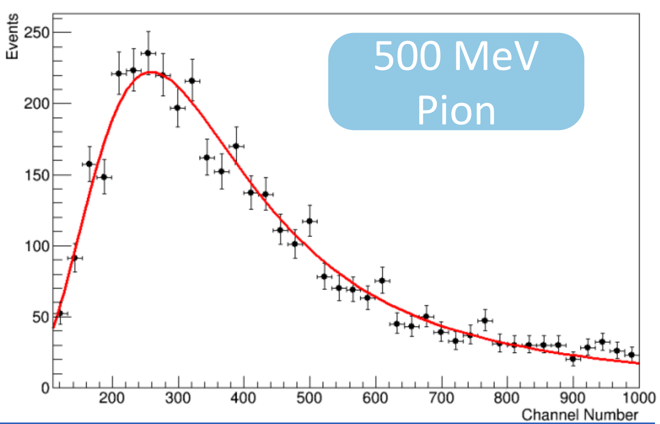
WELL-THGEM Beam Test at IHEP

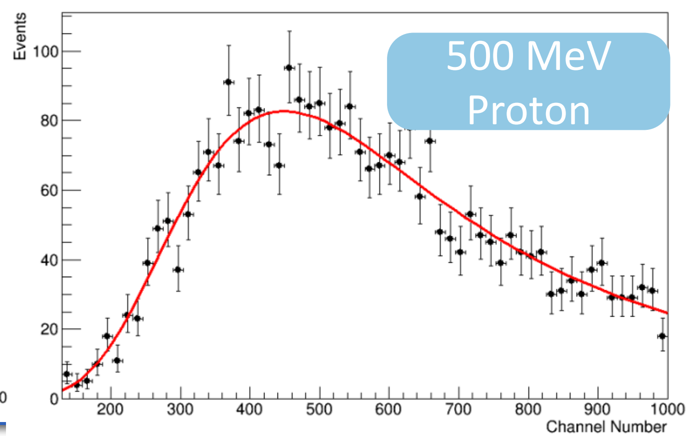
- **Detection efficiency of well-THGEM was measured with BEPC pion / proton beams.**
- **Efficiency:**
  - Ar/iso (97/3) ,Gain ~ 2000; Eff (proton) > 93%; Eff(Pion) > 82%
  - Ne/CH_4 (95/5) ,Gain ~ 9000; Eff (proton) > 99%; Eff(Pion) > 94%







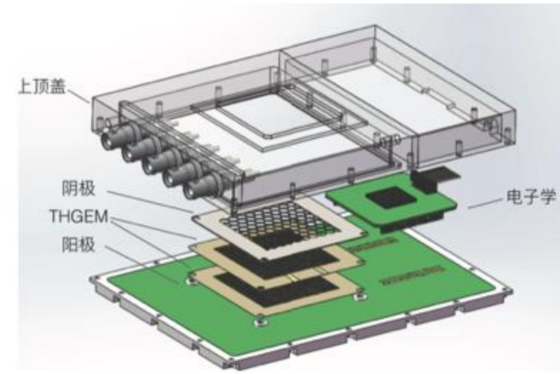


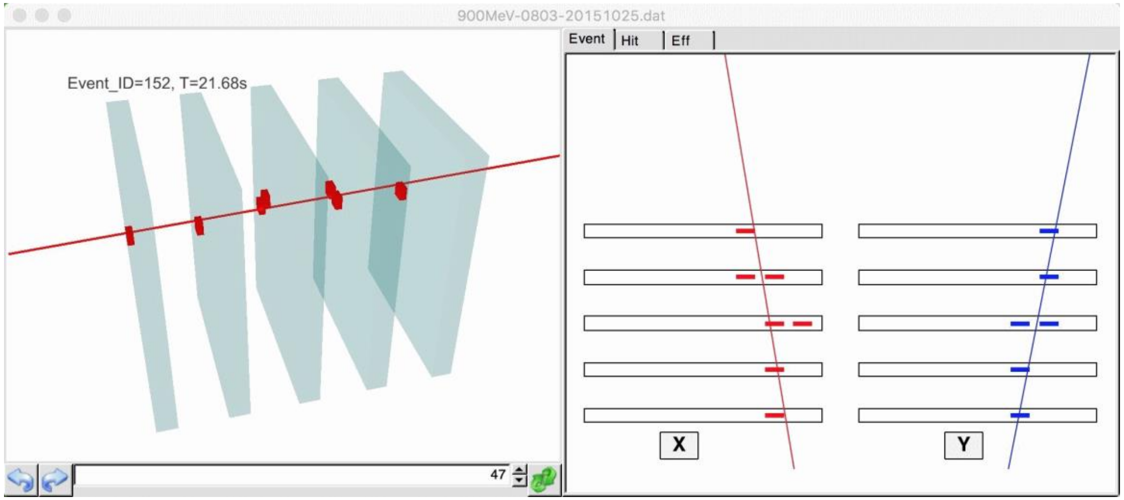


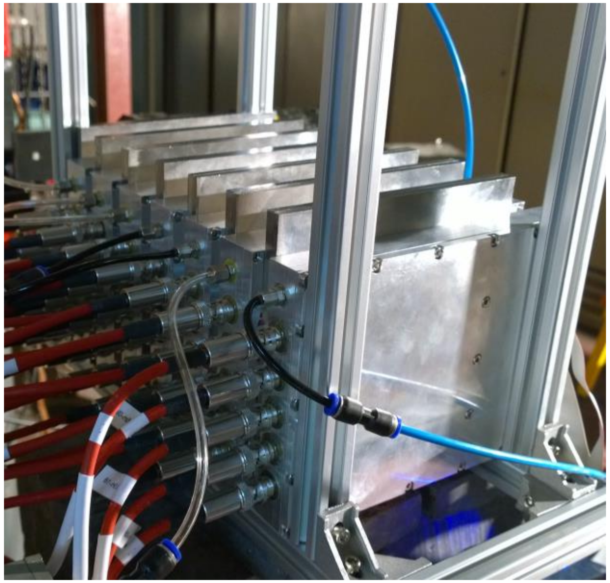
WELL-THGEM Beam Test in Oct., 2015

Hongbang Liu, Qian Liu (UCAS)

- 7 THGEMs are installed, and 5 of them are used, and flushed with Ar/iso-butane = 97:3.
- 1 threshold, binary readout
- 900 MeV proton beam was used
- 5cm x 5cm sensitive region



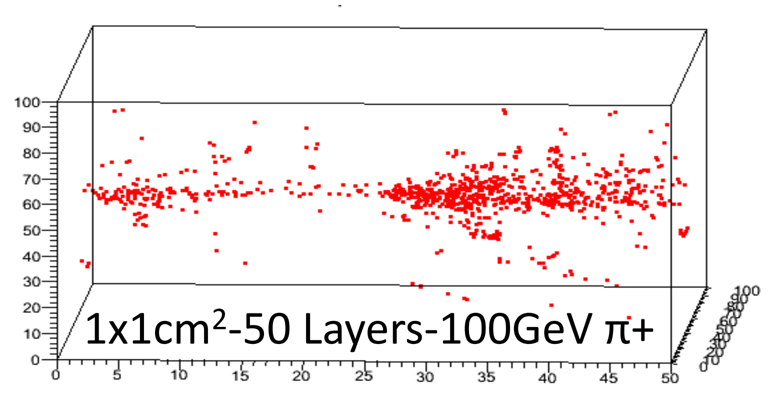


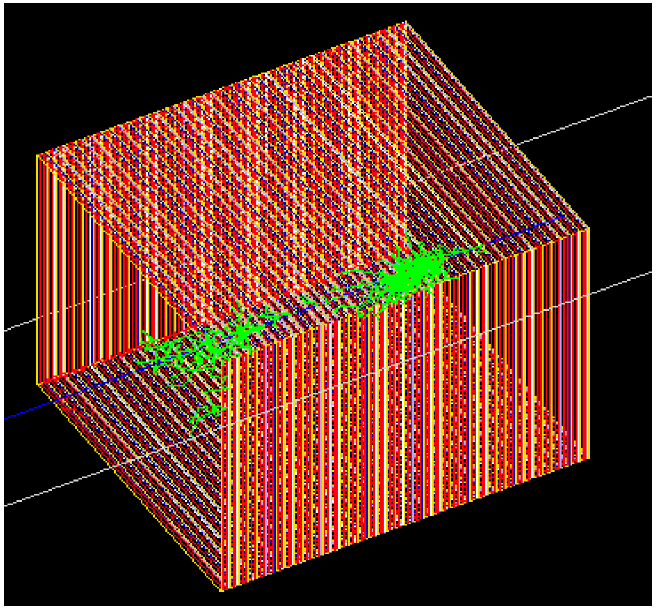


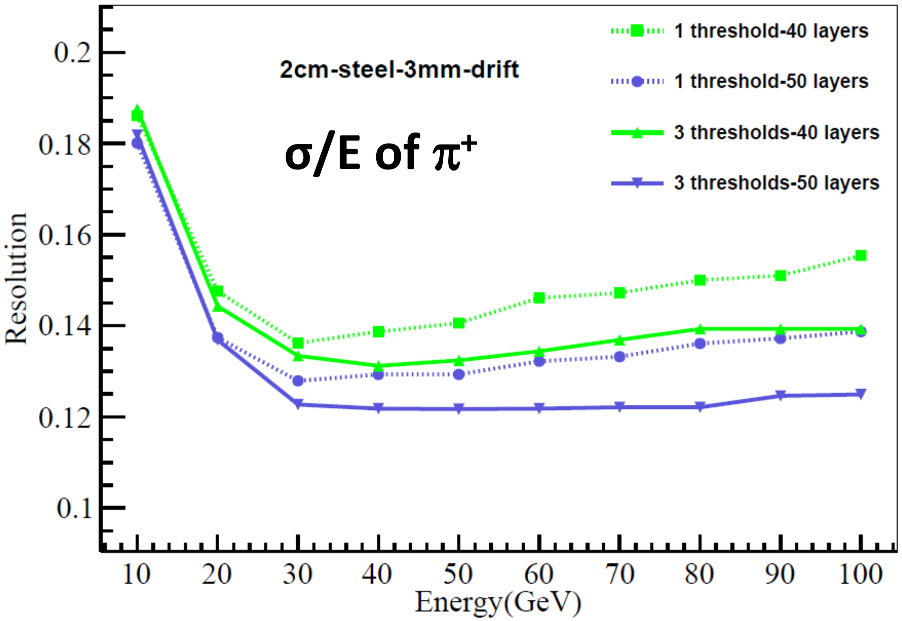
Simulation of DHCAL

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







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

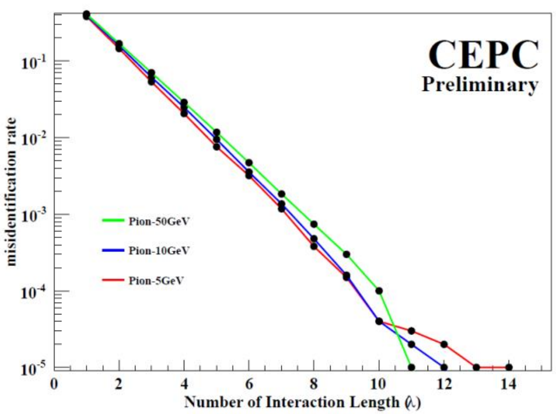
- To separate muons from hadrons
- A tail catcher of HCAL
- Solenoid return roke & support structure

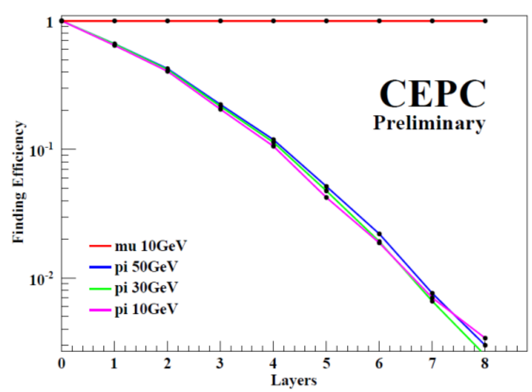
Performance requirements

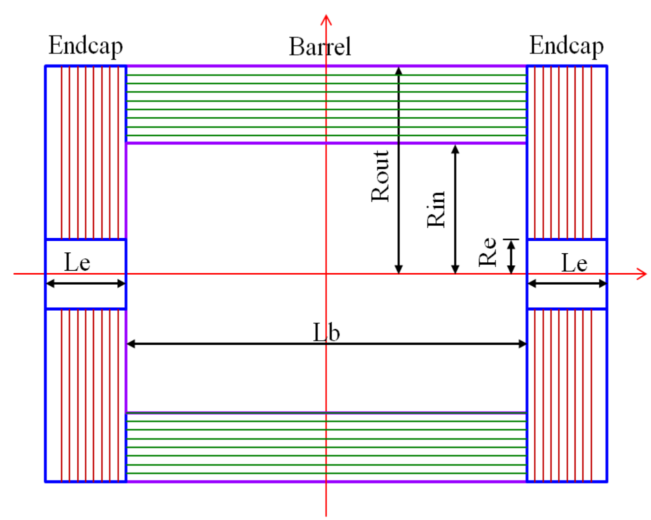
- nLayer >=8, iron thickness >= 6λ
- Eff >=95%, resolution<=2cm
- Misidentification rate (pi->mu)@40GeV <1%

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.

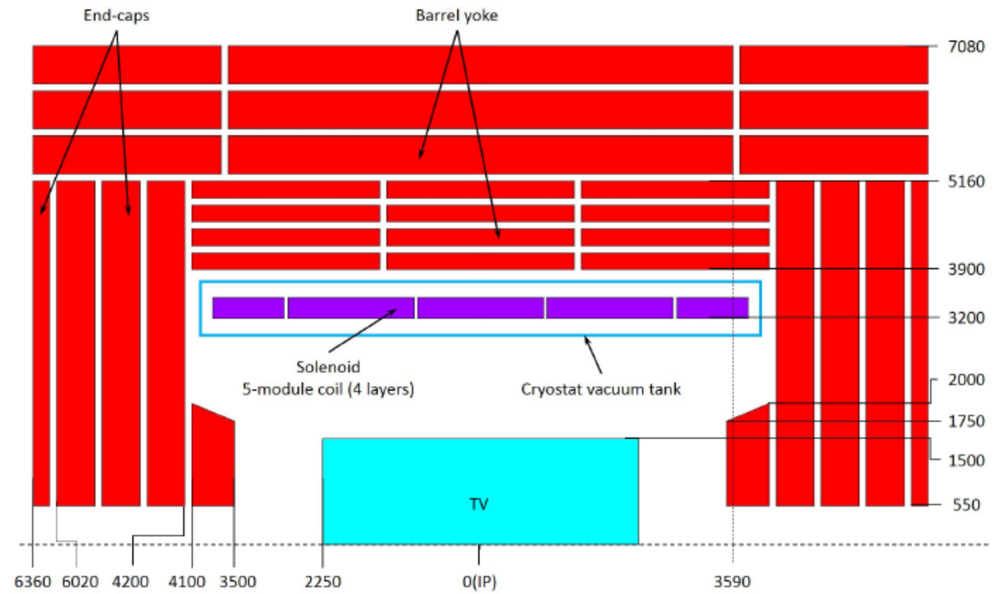




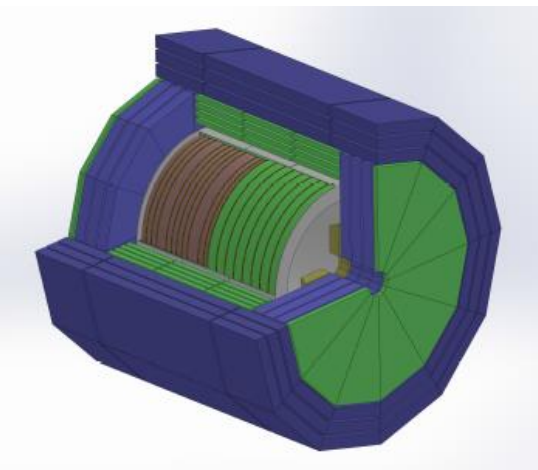


CEPC Magnet Design

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)



Cryostat inner radius(mm)	3400	Barrel yoke outer radius(mm)	7240
Cryostat outer radius(mm)	4250	Yoke overall length(mm)	13966
Cryostat length(mm)	8050	Barrel weight(t)	5775
Cold mass weight(t)	165	End cap weight(t)	6425
Barrel yoke inner radius(mm)	4400	Total yoke weight(t)	12200

The solenoid central field(T)	3.5	Nominal current(KA)	18.575
Maximum field on conductor(T)	3.85	Total ampere-turns of solenoid(MAt)	23.925
Coil inner radius(mm)	3600	Inductance(H)	10.4
Coil outer radius(mm)	3900	Stored energy(GJ)	1.8
Coil length(mm)	7600	Stored energy per unit of cold mass(KJ/kg)	10.91

Summary and Future Plans

- In the past 2-3 years, tremendous efforts have been made to prepare the CEPC preliminary Conceptual Design Report for Physics and Detector.

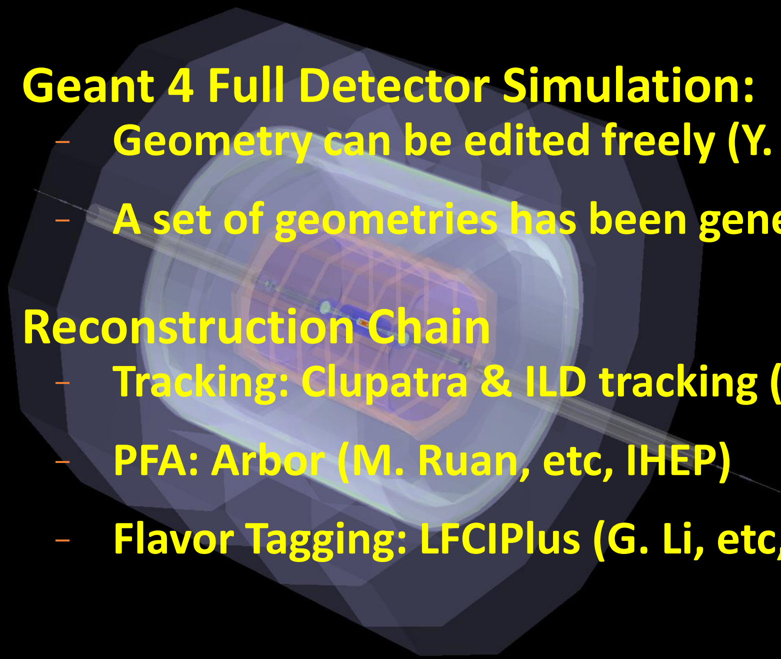
Future plans include

- With MOST funding support (RMB 36M), speeding up R&D of critical detector technologies and optimization
- MDI: work with accelerator group to optimize design
- Feasibility studies of detector prototypes
- Aiming for CEPC CDR and TDR in next 5 years

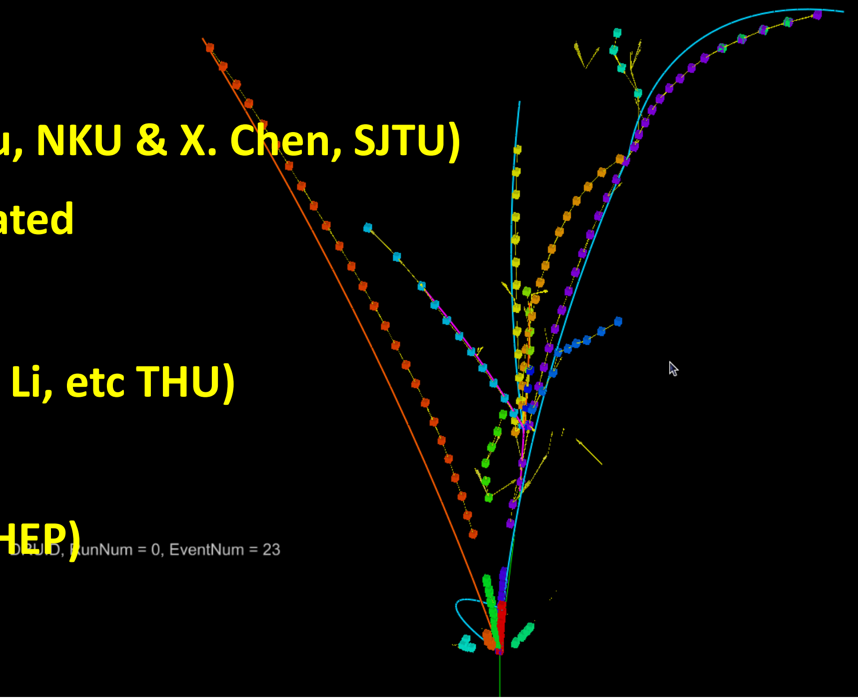
Many thanks to all members of CEPC Physics and Detector working group who made significant efforts for the CEPC detector R&D !

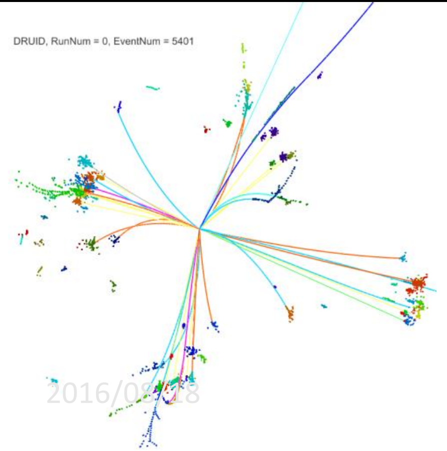
Backup Slides

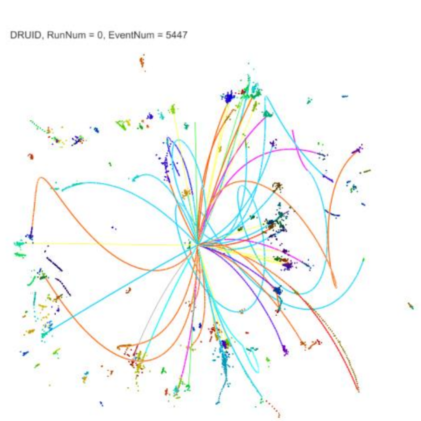
Simulation & Reconstruction Software

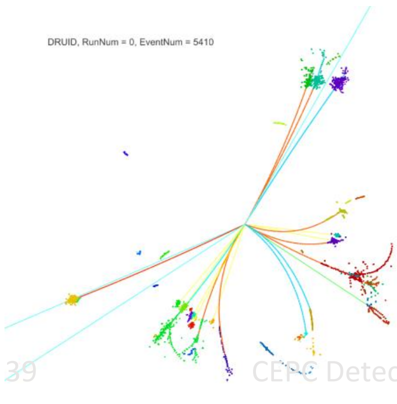


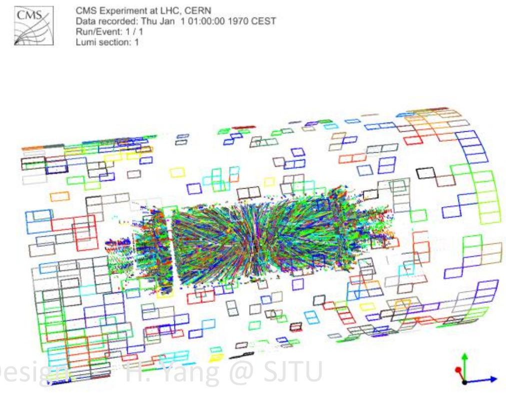
- **Geant 4 Full Detector Simulation:**
  - Geometry can be edited freely (Y. Xu, NKU & X. Chen, SJTU)
  - A set of geometries has been generated
- **Reconstruction Chain**
  - Tracking: Clupatra & ILD tracking (B. Li, etc THU)
  - PFA: Arbor (M. Ruan, etc, IHEP)
  - Flavor Tagging: LFCIPlus (G. Li,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









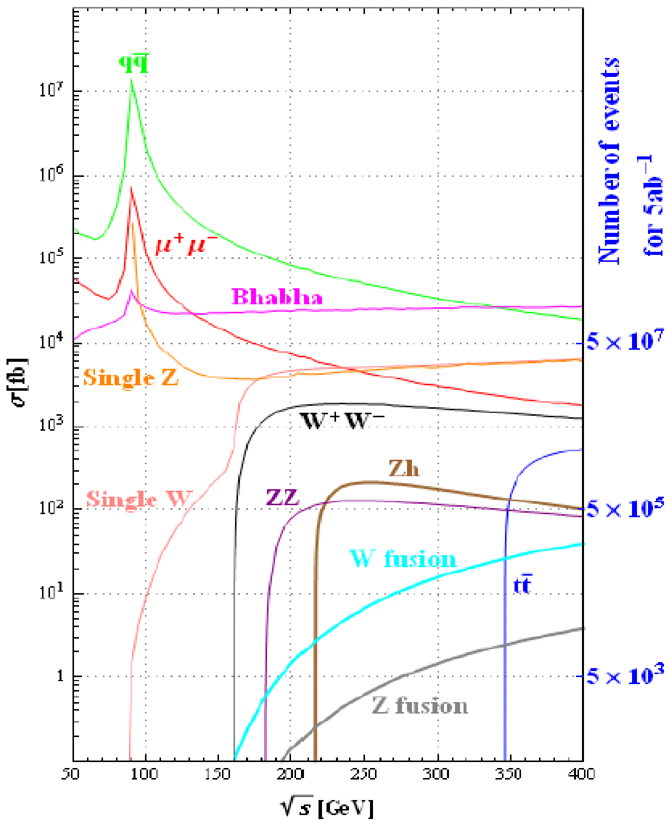


MC Samples & Computing Resources

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			

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...

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)

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

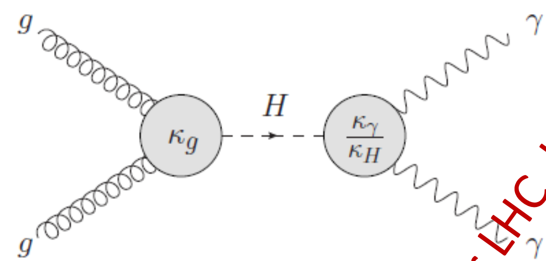
(Limited by the $ee \to \nu\nu H \to \nu\nu bb$ statistics)

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

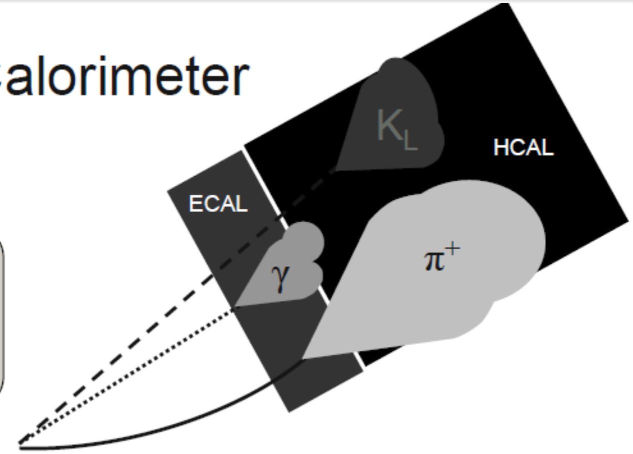
$$\kappa_H^2 = \sum_x \kappa_x^2 \cdot BR(H \to xx) \xrightarrow{\text{No non-SM decays}} \kappa_H^2 = \sum_x \kappa_x^2 \cdot BR_{SM}(H \to xx)$$

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

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

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_l of calorimeter

→ Calorimeter inside coil

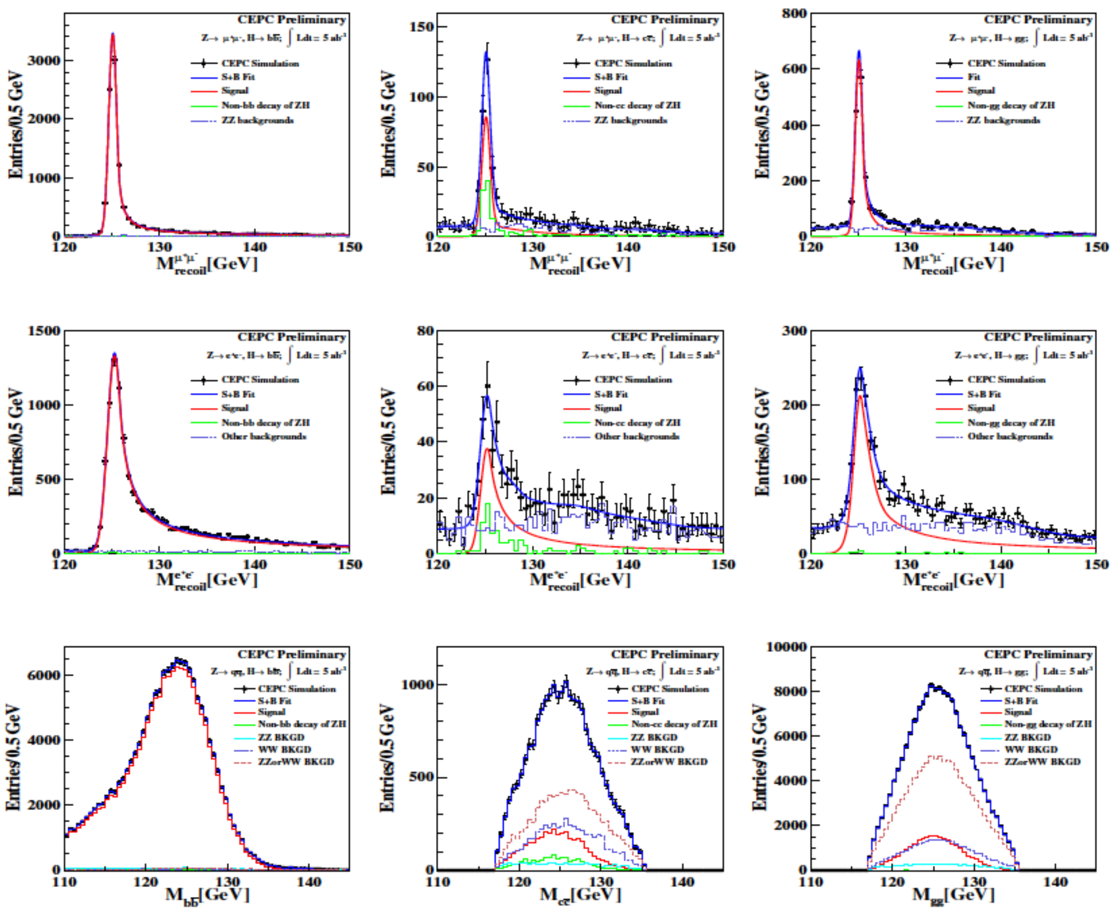
→ Calorimeter as dense as possible (short X_0, λ_I)

} **thin active medium**

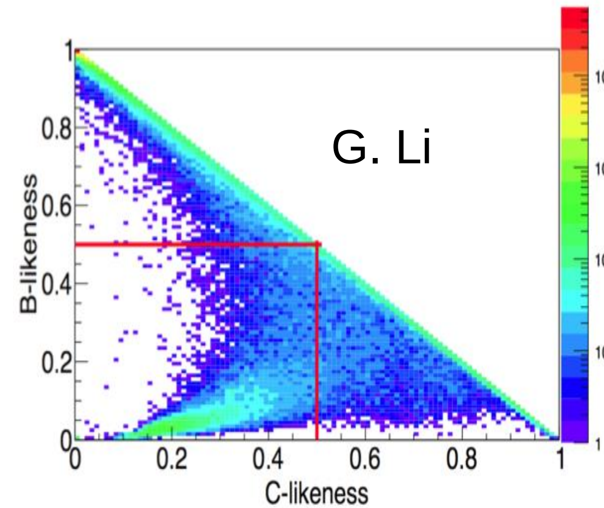
→ Calorimeter with **extremely fine segmentation**

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)

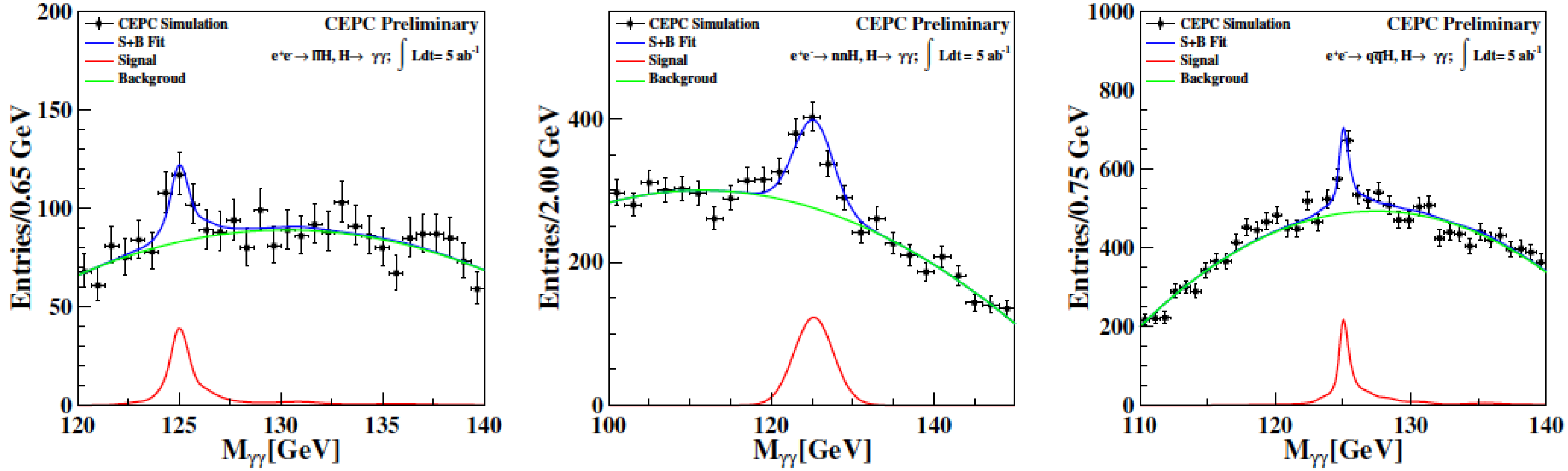



```
migrate matrix w/o eff.
 83.65%, 10.36%,  5.99%
  9.48%, 61.19%, 29.33%
  3.50%,  9.01%, 87.49%
```

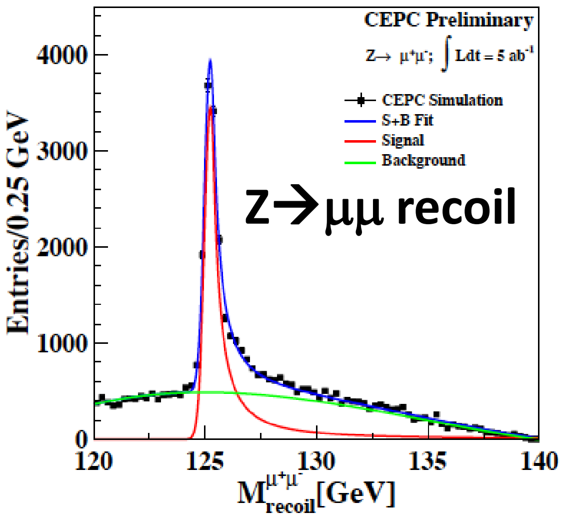
Test bed for Vertex design/ Flavor tagging performance...

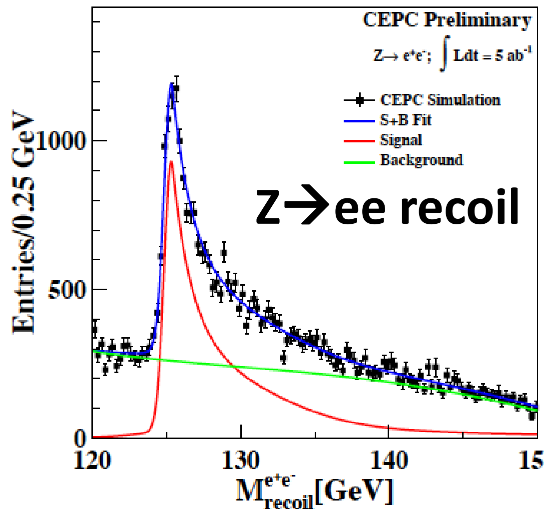
Higgs Rare Decays

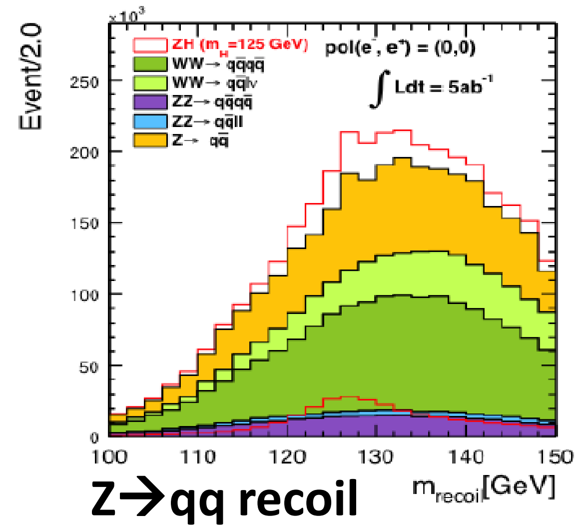
Figure 3.14 $\sigma(ZH, \nu\nu H) \times Br(H \to \gamma\gamma)$ measured from $llH, \nu\nu H$ and qqH channels with different modelling of ECAL energy resolutions.



Z recoil mass method: M_H & σ(ZH)







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

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

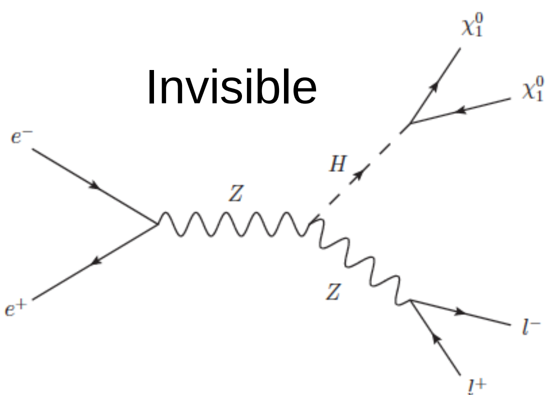
Higgs→ Exotics

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

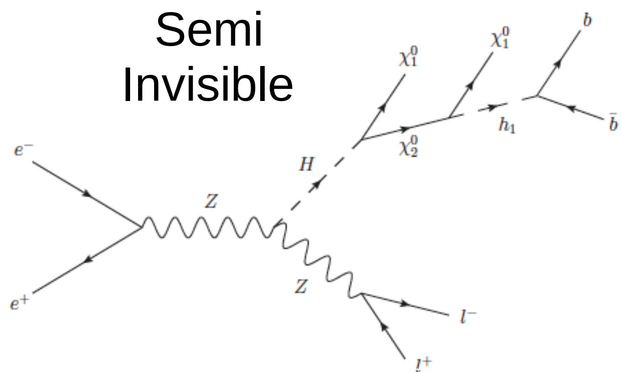
Channel	Accuracy	Methods
$Z \to \mu\mu, H \to invisible$	0.8%	CEPC Full Simulation
$Z \to ee, H \to invisible$	1.1%	Estimation
$Z \to qq, H \to invisible$	0.14%	Extrapolated from ILC result
Combined	0.14%	

- 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%

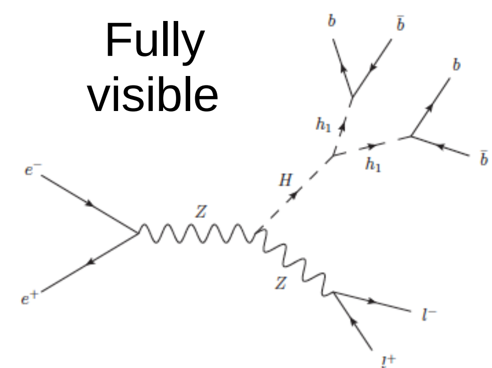
Invisible



Semi Invisible

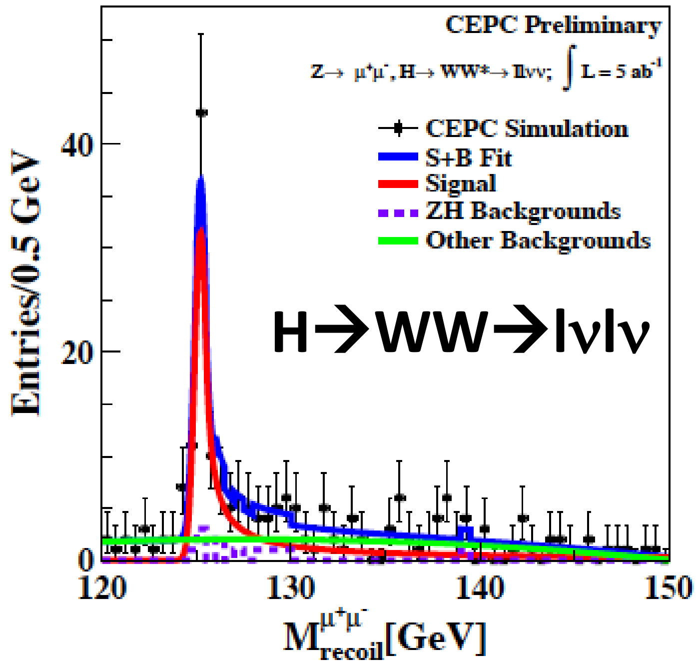


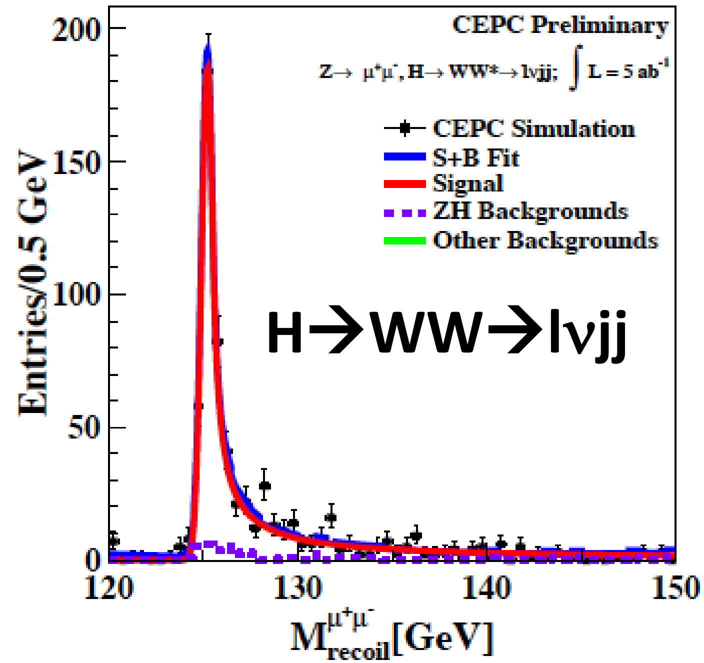
Fully visible



Branching Ratio of H→WW*

Z. Chen @ PKU

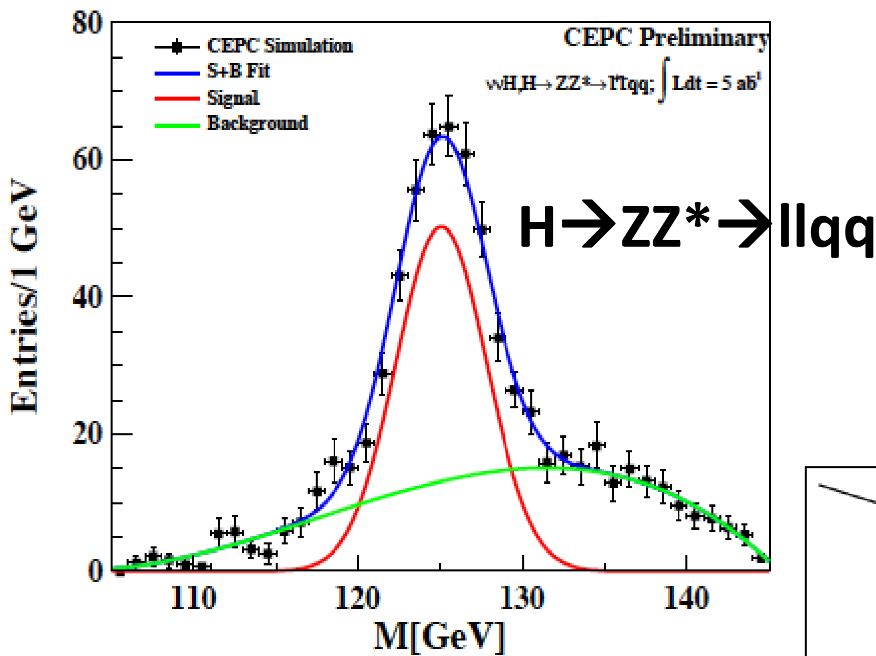




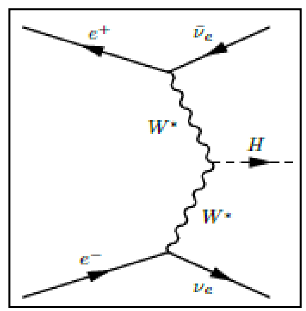
Expected accuracy for the $\sigma(ee \to ZH) \times \mathrm{BR}(H \to WW^*)$ measurement, normalized to 5 ab^{-1}

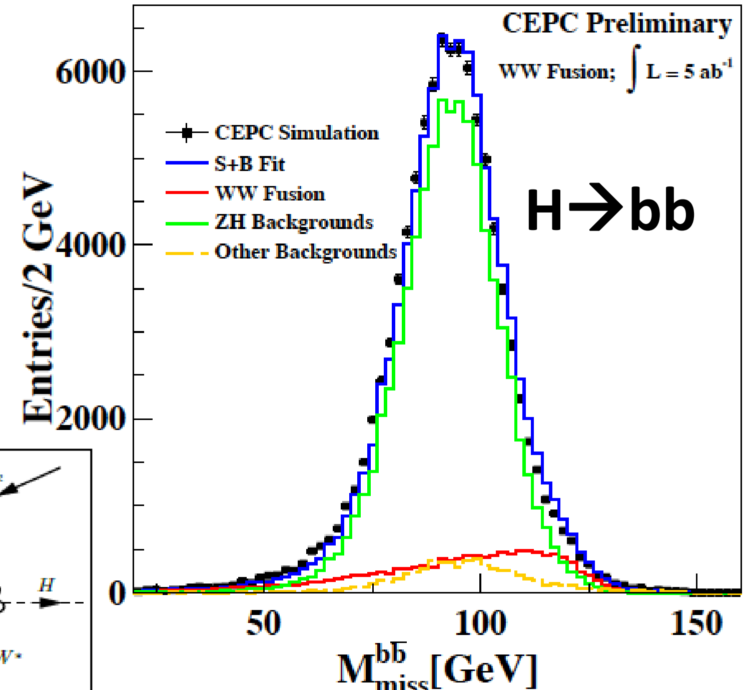
Channel	Accuracy	Methods
$Z \to \mu\mu, H \to WW^* \to l\nu qq, ll\nu\nu$	4.9%	CEPC Full Simulation
$Z \to ee, H \to WW^* \to l\nu qq, ll\nu\nu$	7.0%	Estimated
$Z \to \nu\nu, H \to WW^* \to 4q$	2.3%	Extrapolated from ILC result
$Z \to qq, H \to WW^* \to l\nu qq$	2.2%	Extrapolated from ILC result
Combined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

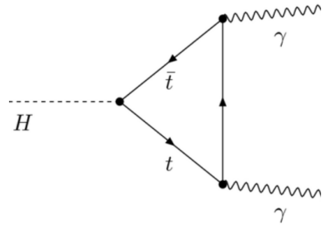
Γ(H→bb) can be independently extracted from WW fusion ee→ννH→ννbb.

Higgs boson total width

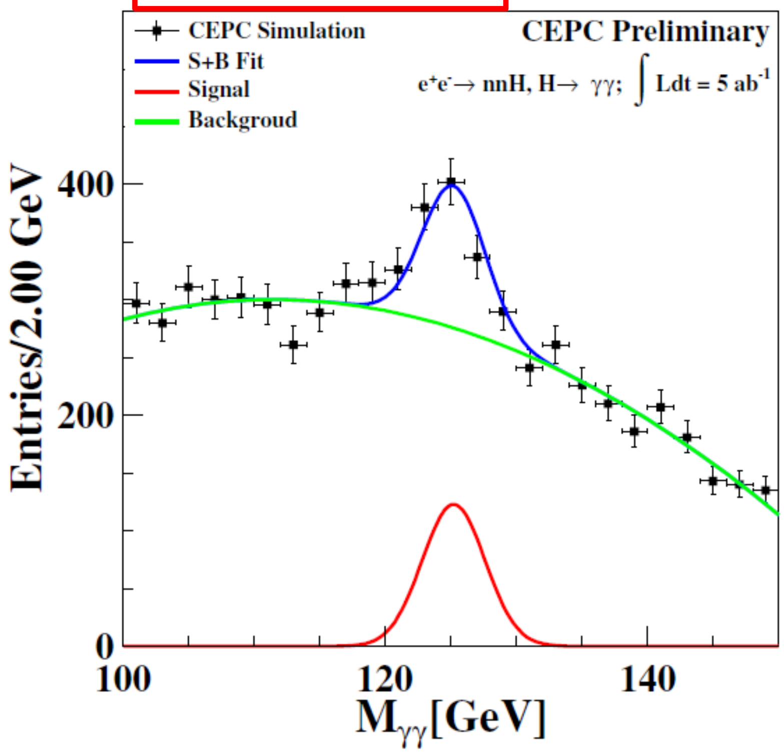
$$\Gamma_H \propto \frac{\Gamma(H \to b\bar{b})}{\mathrm{BR}(H \to b\bar{b})} \propto \frac{\sigma(\nu\bar{\nu}H \to \nu\bar{\nu}b\bar{b})}{\mathrm{BR}(H \to b\bar{b}) \cdot \mathrm{BR}(H \to WW^*)}$$

Higgs Rare Decays

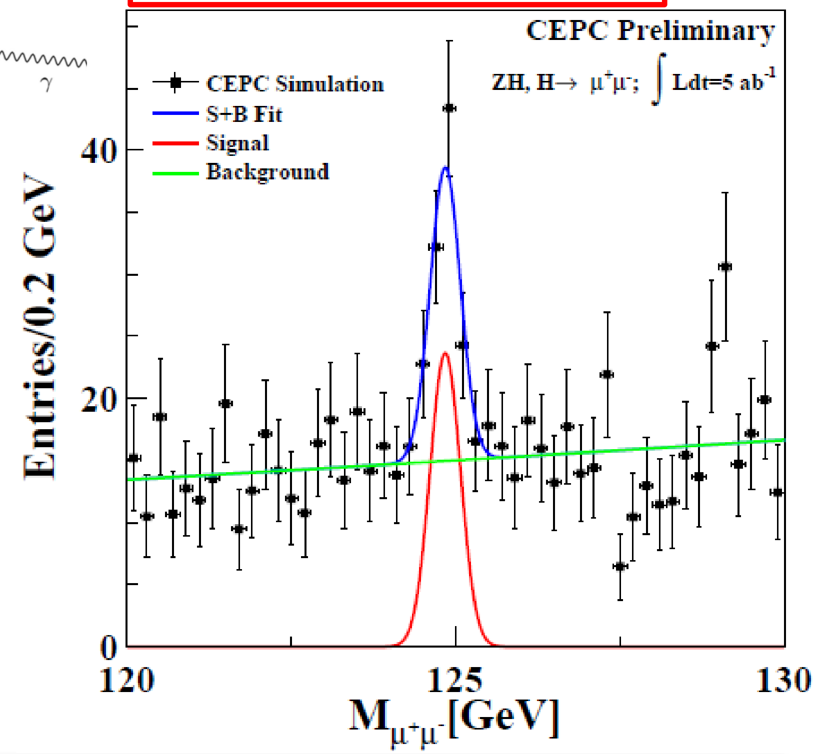
- **Higgs → γγ (0.23%) & μμ (0.02%)**
  - sensitive probe to heavy charged particle & lepton universality
  - stringent requirements on the ECAL and Tracker performance



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 $H \to WW^* \to l\nu qq, ll\nu\nu$ 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 $H \to WW^* \to l\nu qq$ sub channel
$\sigma(ZH) \times Br(H \to ZZ^*)$	$Z \to ee, \mu\mu$	Full Simulation on $H \to ZZ^* \to llqqll\nu\nu$ 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%

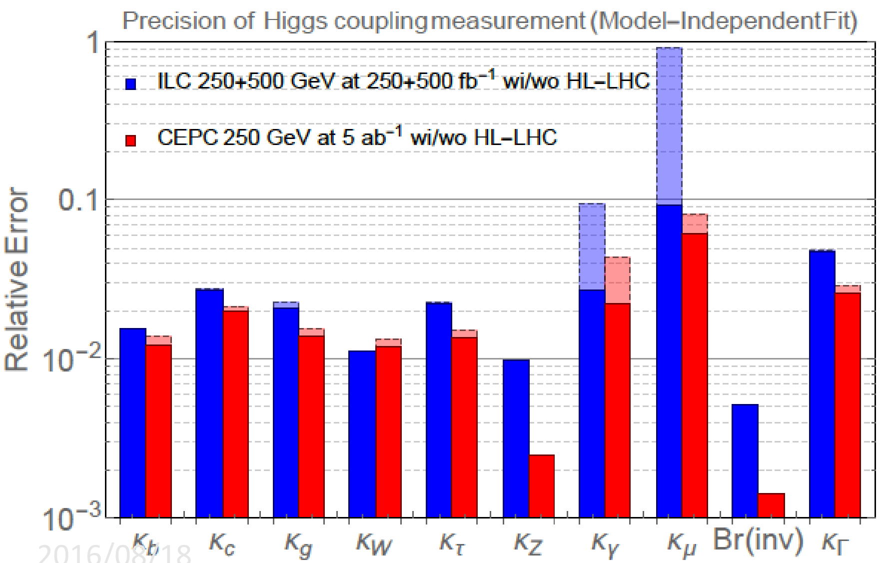
Combination group: Y. Fang, Z. Liu, etc

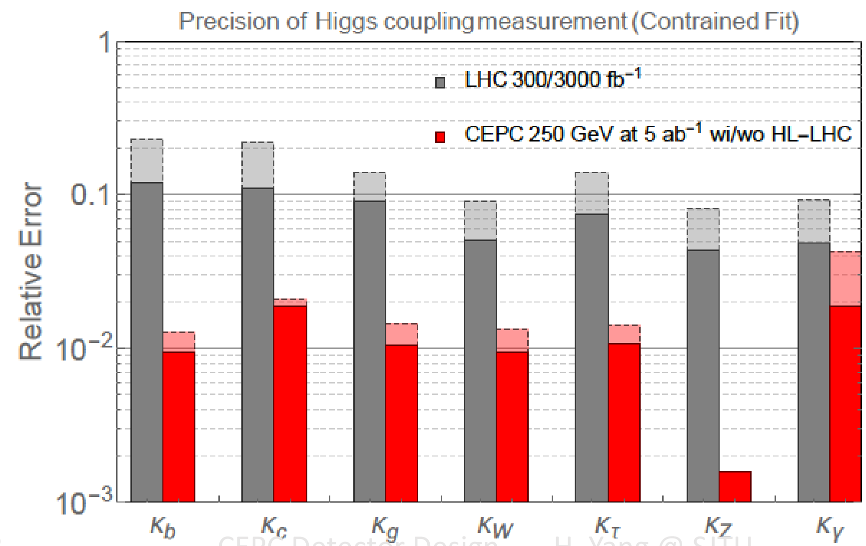
Model independent results compare to ILC

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

7-parameter model:

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



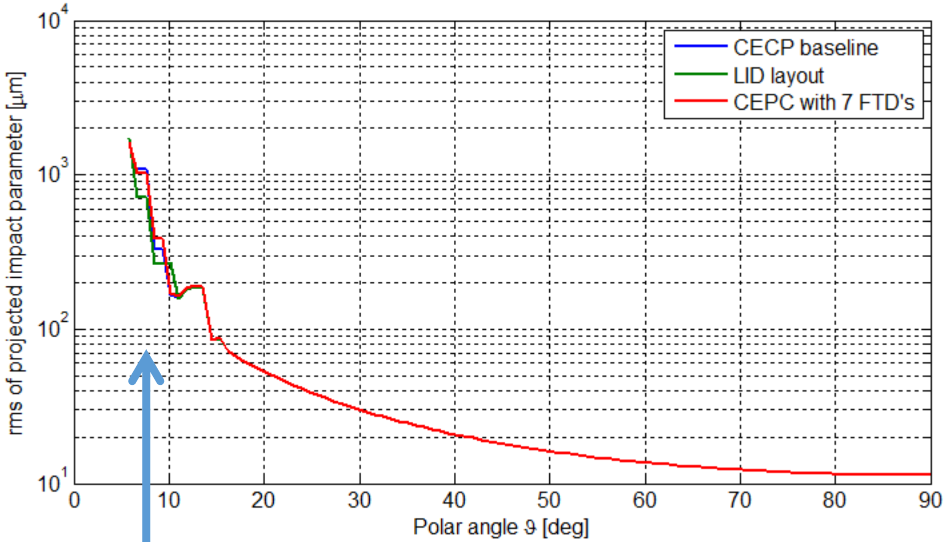


CEPC Physics and Detector Working Group

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

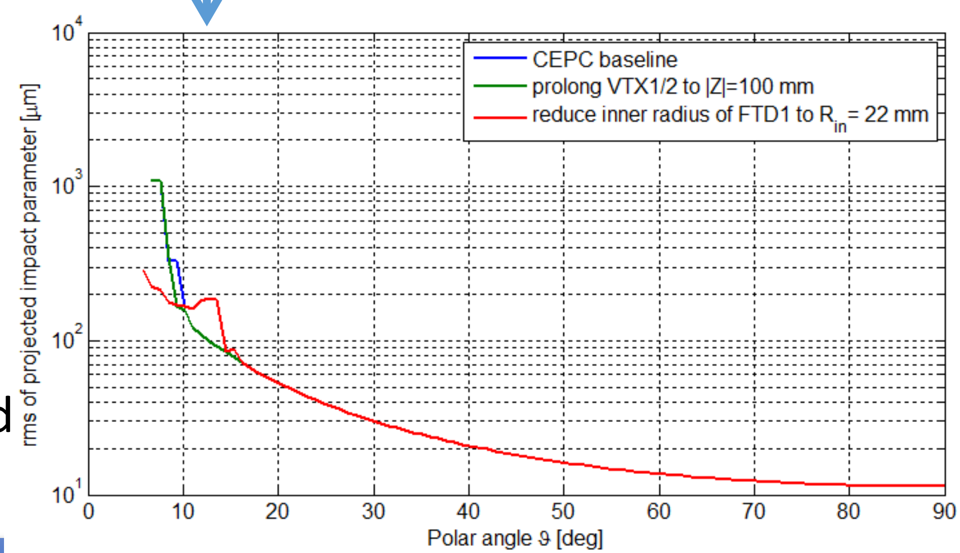
  Yuanning Gao (THU), Shan Jin (IHEP), Nu Xu (CCNU)
- **Sub-groups and co-conveners**
  - Physics simulation and analysis:
    Gang Li, Manqi Ruan, Yaquan Fang (IHEP), Qiang Li (PKU)
  - MDI: Hongbo Zhu (IHEP), Yiwei Wang (IHEP)
  - Vertex: Qun Ouyang (IHEP), Meng Wang (SDU)
  - TPC tracker: Yulan Li (THU),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

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 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

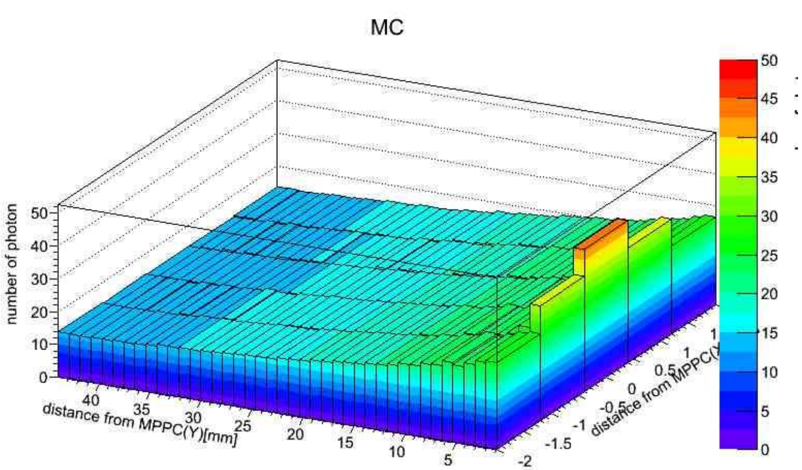
- Online beam luminosity monitor allowing fast beam tuning
  - radiation hard sensor technologies (e.g. CVD diamond), to measure radiative Bhabha events at zero photon scattering angle ← similar design as for the SuperKEKB design

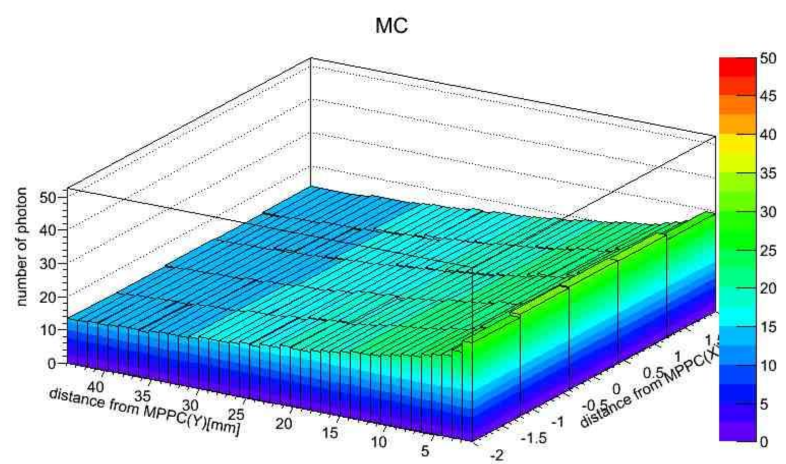
Scintillator Strip Shape Optimization

SiPM sensor area 1×1 mm² ➔ 0.25×4 mm²:

➔ to increase photon acceptance

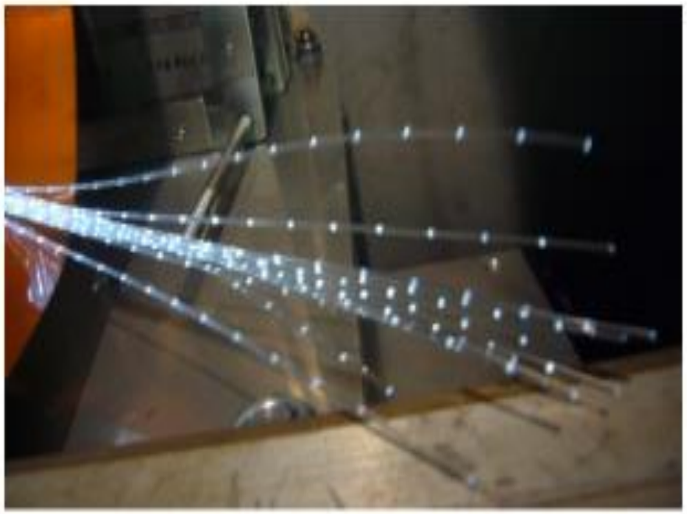
➔ It is easy to make this shape of MPPC with current technology

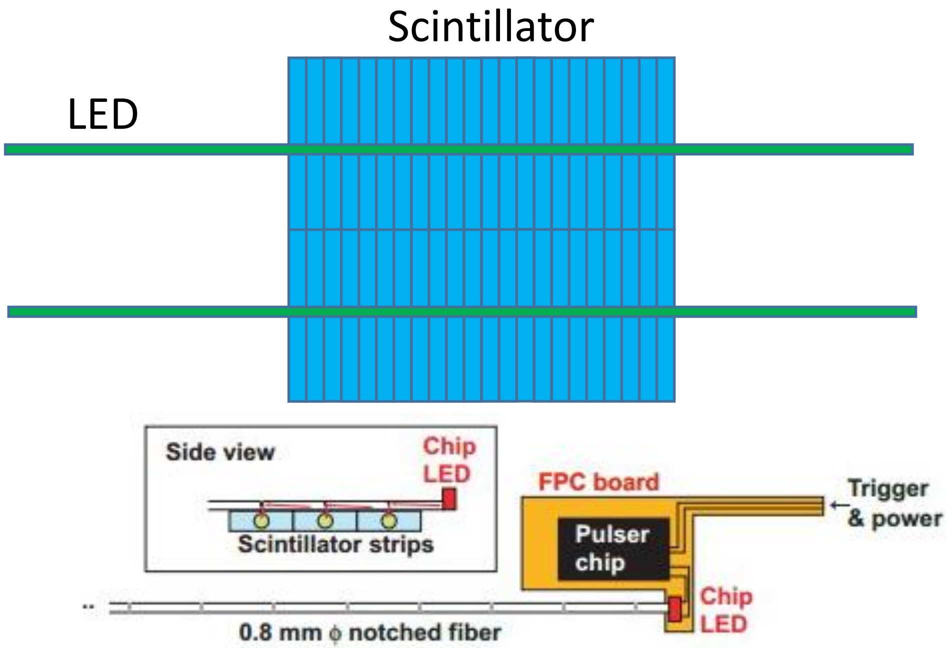




Calibration for Scintillator and SiPM

The ScW ECAL consists of ~8 million channels of scintillator strip units. The stability of the light output has to be monitored. A light distribution system is under study to monitor possible gain drifts of the SiPMs by monitoring photoelectron peaks.



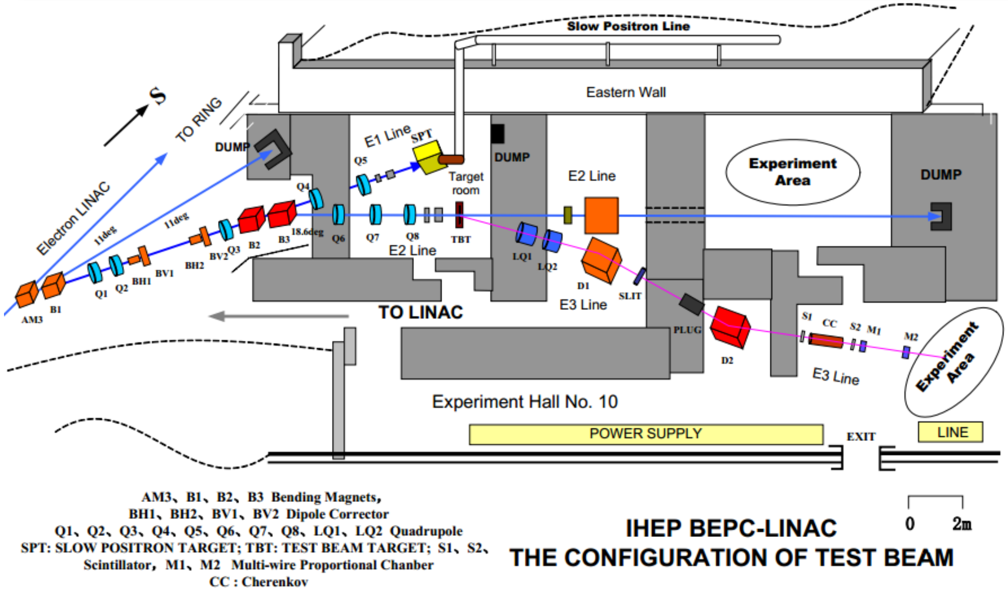


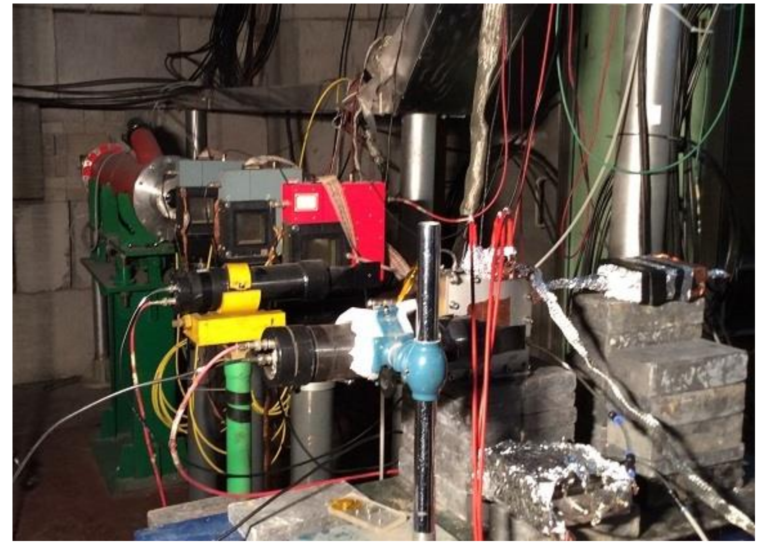
LED – Fiber calibration system:

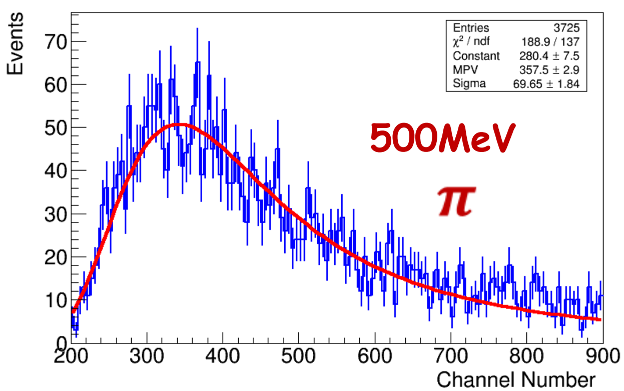
- A pulse generator, a chip LED connect to notched fibers
- Notched Fiber distribute lights to ~ 80 scintillator strips

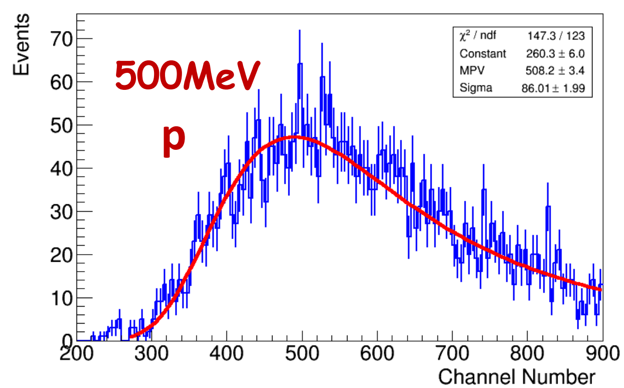
WELL-THGEM Test Beam at IHEP

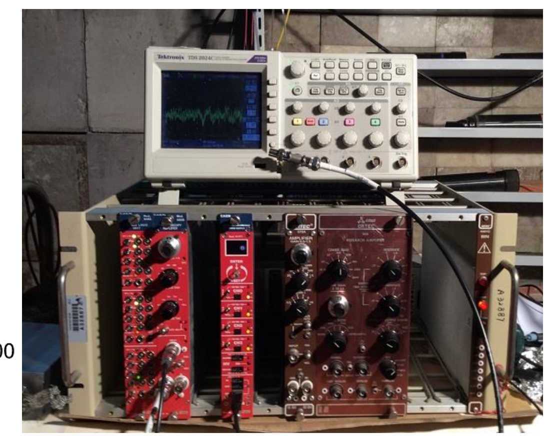
Hongbang Liu @ GXU









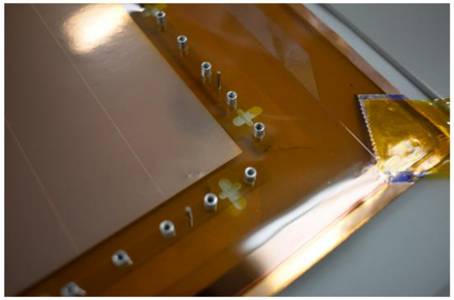


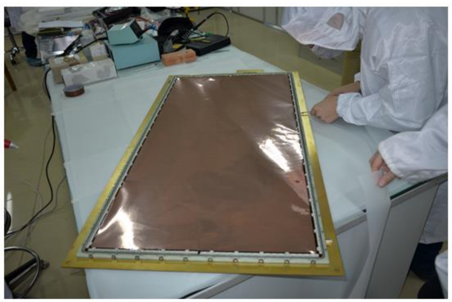
Well-THGEM, $Ar/3\%iC_4H_{10}$;

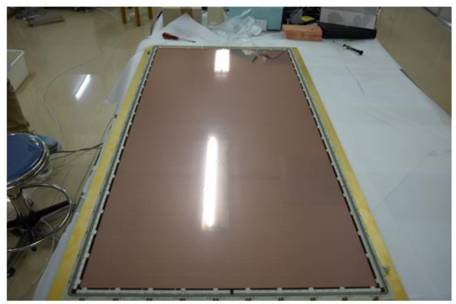
Large-area GEM @ USTC

Jianbei Liu (USTC)

GEM assembly using a novel self-stretching technique



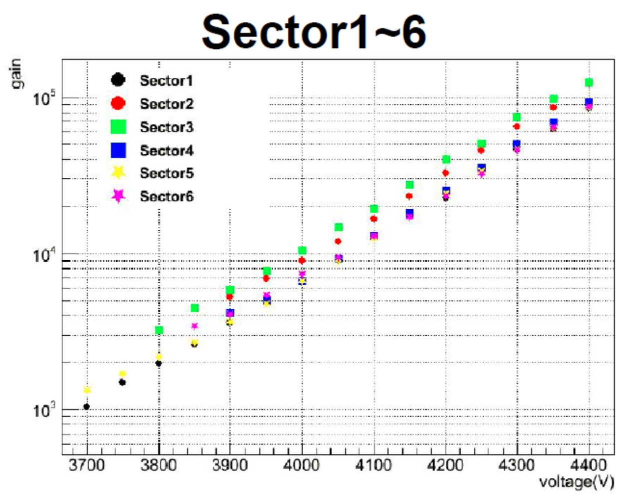




- Large-area GEM (0.5x1m^2) is one of main detector R&D focuses at USTC recently.
- Technology has been developed and matured to produce high-quality GEM detectors as large as ~1m^2 that are also applicable to CEPC DHCAL.

APV25 GEM readout

INFN APV25 chip



- ➔ **Resolution uniformity ~11%**
- ➔ **Gain uniformity ~16%**
- ➔ **Can reach gain of 10^4 at 4000V**