Summary of the CEPC Physics and Detector

Haijun Yang (Shanghai Jiao Tong University)
(for CEPC Physics and Detector Working Group)

CEPC-SPPC Study Group, Beihang
September 3, 2016

CEPC Physics & Detector Sessions

- **Three parallel sessions: 16 talks**
- **Two joint sessions:**
  - **Theory + Simulation**
  - **Detector + Accelerator**

Parallel Session I: Physics&detector
Convener: Prof. Shan Jin (IHEP)
Location: Conference Room 8

11:00 **Full silicon tracking studies for CEPC** *20'*
Speaker: Dr. Weiming Yao (LBNL)
Material: Slides

11:20 **Vertex Status** *20'*
Speaker: Prof. Qun OUYANG (IHEP)

11:40 **TPC Status** *20'*
Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)

Parallel Session II: Physics&Detecor
Convener: Prof. Nu Xu (CCNU)
Location: Conference Room 8

14:00 **PID Status** *15'*
Speaker: Dr. Zhiyong Zhang (USTC)

14:15 **ECAL Status** *15'*
Speaker: Dr. Yunlong Zhang (USTC)

14:30 **HCAL Status** *15'*
Speaker: Dr. Qian Liu (UCAS)

14:45 **High rate high granuarity GRPC SDHCAL** *15'*
Speaker: Prof. Yi Wang (Tsinghua University)

15:00 **questions+discussions for CEPC HCAL** *5'*

15:05 **Magnet Status** *15'*
Speaker: Dr. Ling Zhao (IHEP)

15:20 **Understanding the performance of a highly granular Si Pad ECAL for CEPC** *20'*
Speaker: Prof. Stathes Paganis (National Taiwan University)

15:40 **Research and Development on Signal Detection and Data Readout LSI** *20'*
Speaker: Prof. Lianming Li

Parallel Session III: Physics&Detecor
Convener: Prof. Haijun Yang (SJTU)
Location: Conference Room 8

16:20 **Physics simulations and SW tools** *20'*
Speaker: Prof. Patrizia AZZI (INFN/CERN)

16:40 **Pixels and short strips** *20'*
Speaker: Dr. Massimo Caccia (INFN)

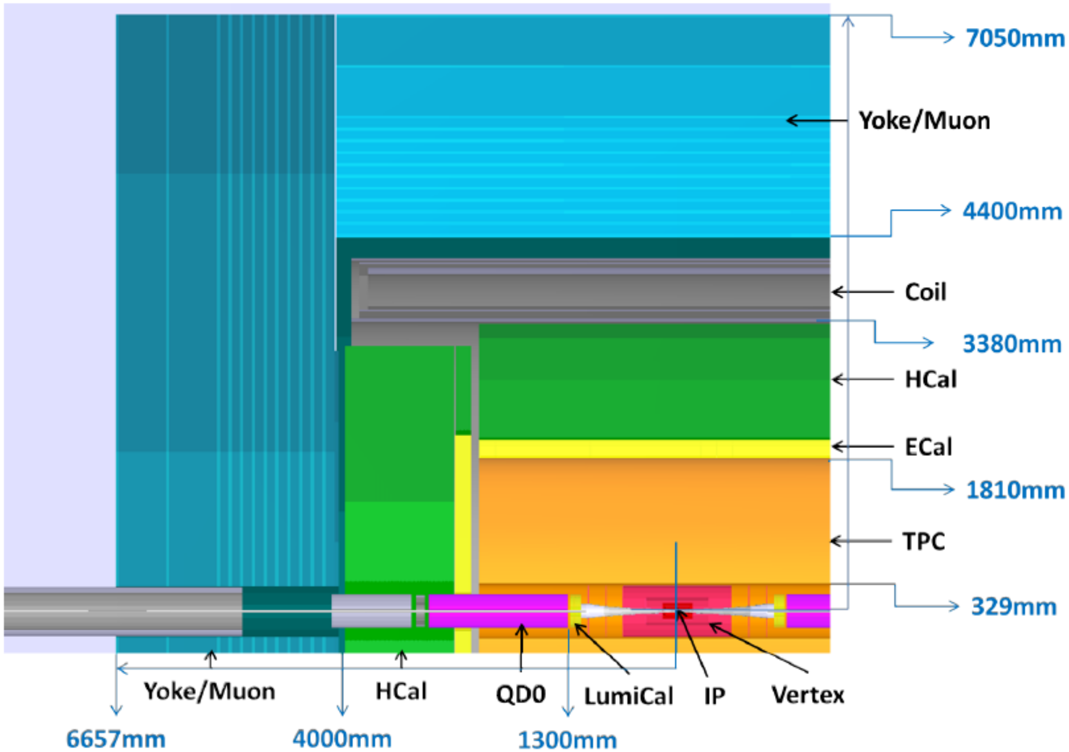
17:00 **Muon systems with MPGD** *20'*
Speaker: Dr. Paolo Giacomelli (INFN Bologna)

17:20 **Next u-strip tracking systems** *20'*
Speaker: Prof. Livio Fano' (Università degli Studi di Perugia and INFN)

17:40 **An ultra-light drift chamber with particle identification capabilities** *20'*
Speaker: Prof. Franco Grancagnolo (Università del Salento and INFN)

Outline

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



CEPC-SPPC

Phase 1: **e^+e^- Higgs (Z) factory** **two detectors, 1M ZH events in ~10yrs**

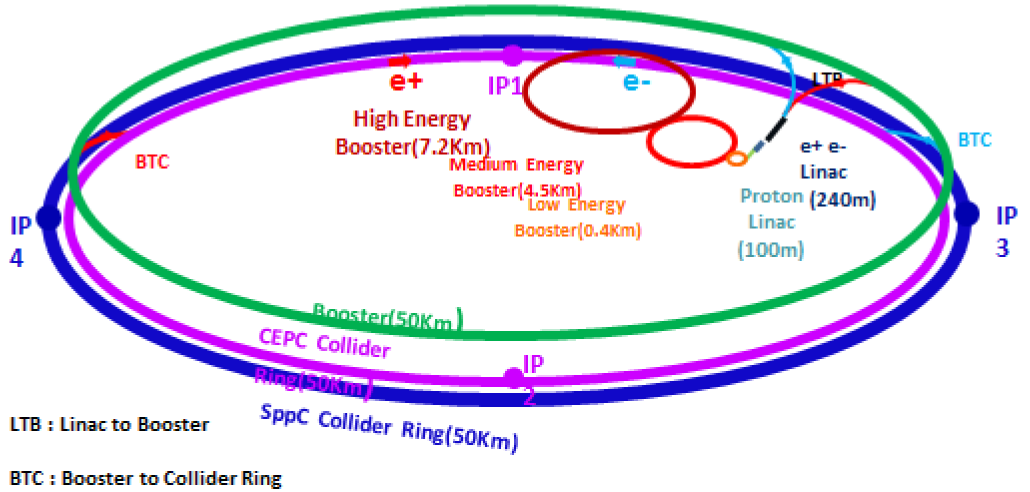
Circular Electron Positron Collider (CEPC)

E_{cm}≈240GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$ can also rum at the Z-pole

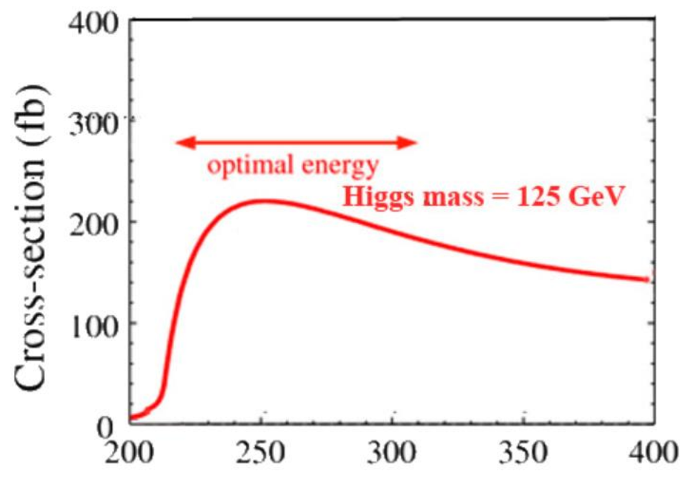
Precision measurement of the Higgs boson (and the Z boson)

Phase 2: **a discovery machine**; pp collision with E_{cm} ≈ 50-100 TeV; ep, HI options

Super proton-proton Collider (SppC)

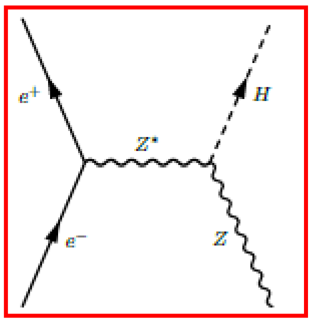


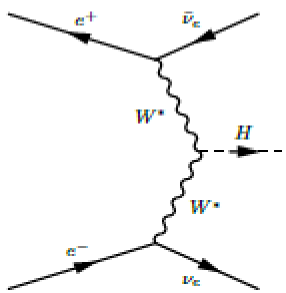
$e^+e^- \to ZH$

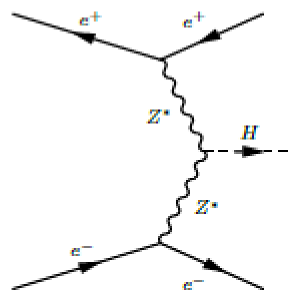


Higgs @ CEPC

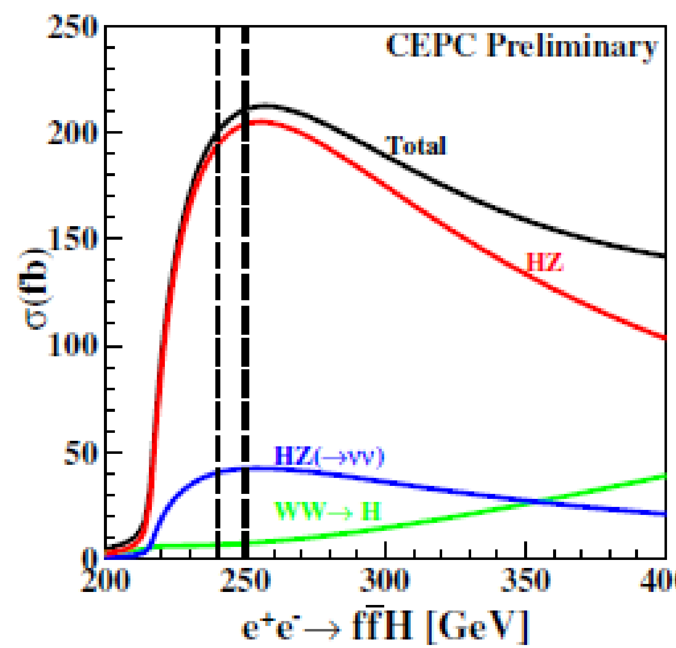
- Precise measurements of the Higgs properties as a Higgs Factory (similar to ILC@250 GeV)
  - Mass, CP, cross section, BR, width, couplings, etc. → percentage accuracy







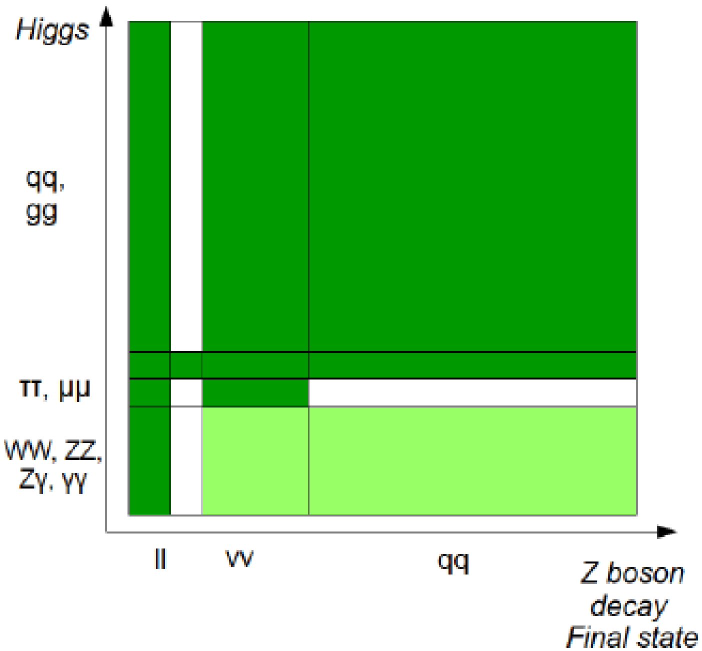
Process	Cross section	Events in 5 ab^{-1}
Higgs boson production, cross section in fb		
$e^+e^- \to ZH$	212	1.06×10^6
$e^+e^- \to \nu\bar{\nu}H$	6.72	3.36×10^4
$e^+e^- \to e^+e^-H$	0.63	3.15×10^3
Total	219	1.10×10^6



Status of Higgs Analysis

M.Q. Ruan, G. Li, Y.Q. Fang et.al.

- **Precision measurements at full simulation level.**



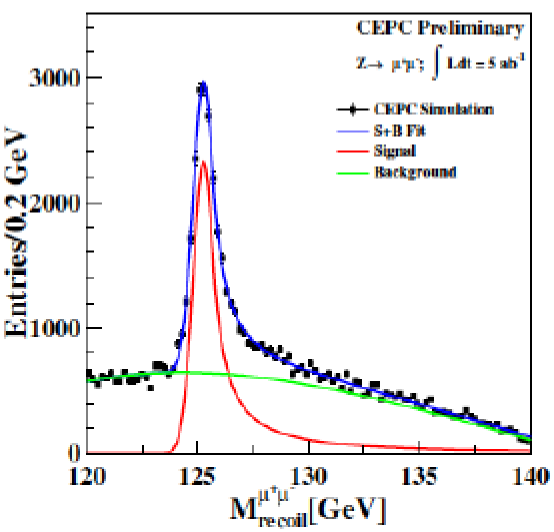
~o(50) independent analyses, mostly studied Full Simulation level

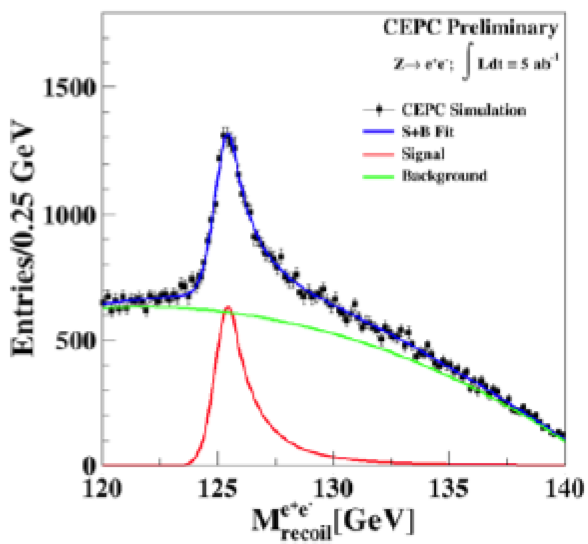
	PreCDR (Jan 2015)	Now (Aug 2016)
σ(ZH)	0.51%	0.50%
σ(ZH)*Br(H→bb)	0.28%	0.21%
σ(ZH)*Br(H→cc)	2.1%	2.5%
σ(ZH)*Br(H→gg)	1.6%	1.3%
σ(ZH)*Br(H→WW)	1.5%	1.0%
σ(ZH)*Br(H→ZZ)	4.3%	4.3%
σ(ZH)*Br(H→ττ)	1.2%	1.0%
σ(ZH)*Br(H→γγ)	9.0%	9.0%
σ(ZH)*Br(H→Zγ)	-	~4 σ
σ(ZH)*Br(H→μμ)	17%	17%
σ(ννH)*Br(H→bb)	2.8%	2.8%
Higgs Mass/MeV	5.9	5.0
σ(ZH)*Br(H→inv)	95%. CL = 1.4e-3	1.4e-3
Br(H→ee/emu)	-	1.7e-4/1.2e-4
Br(H→bbχχ)	$<10^{-3}$	3.0e-4

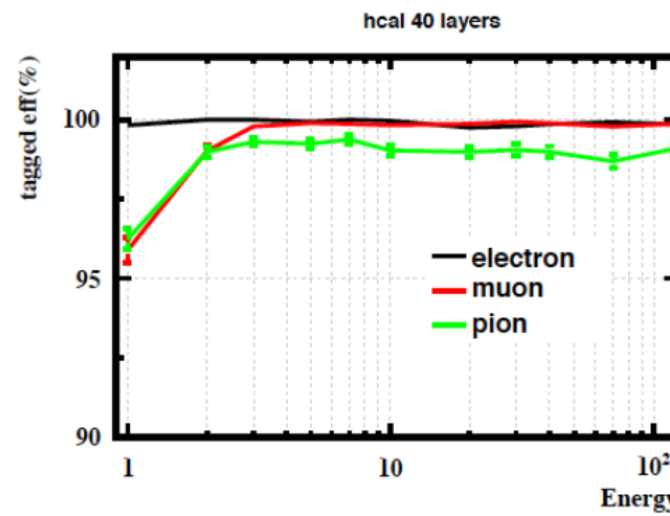
Detector Simulation & Optimization

		CEPC_v1, ILD	Test Geo 1	TG 2	TG 3
ECAL	Cell Size/mm	5	10	20	20
	# Layers	30	30	30	20
HCAL	Cell Size/mm	10	10	20	20
	# Layers	48	48	48	20
Ratio of Channels (X/ILD)	ECAL	1	1/4	1/16	1/24
	HCAL	1	1	1/4	1/10
Event Recon. Efficiency	$\mu\mu$H	95.7%*	98.0%	96.5%	95.2%
	eeH	91.1%*	89.6%	89.1%	74.5%(???)

- **To develop general lepton ID for calorimeter with high granularity (LICH) – Dan Yu et.al**







Model Independent Meas. of Br(H→BSM)

Tim Barklow (SLAC)

$$\left(\frac{\Delta\sigma(ZH)_{hadronic}}{\sigma(ZH)_{hadronic}}\right)^2 = \frac{S+B}{B}\left\{1+\frac{(L\sigma_{ZH})^2}{S+B}\sum_i BR_i^2\left[\left(\frac{\Delta\sigma\bullet BR_i}{\sigma\bullet BR_i}\right)^2(\xi_i-<\xi>)^2+\Delta\xi_i^2\right]\right\}$$

Penalty for non-uniform efficiency → $(\xi_i-<\xi>)^2$; MC calculation → $\Delta\xi_i^2$

ξ_i = efficiency for events from H decay i to pass $\sigma(ZH)_{hadronic}$ analysis

S = Number of signal events in $\sigma(ZH)_{hadronic}$ analysis

B = Number of background events in $\sigma(ZH)_{hadronic}$ analysis

Further improvement in the Higgs coupling measurements can be obtained using the constraint $\sum_i BR_i = 1$ as first noted by Michael Peskin.

This constraint is model independent so long as the error in $BR(H\to BSM)$ is included in the fit. What error in $BR(H\to BSM)$ is required to produce an improvement in Higgs coupling measurements ?

Perform coupling fit with $\sum_i BR_i = 1$ including $\Delta BR(H\to BSM)$

(the constraint $\sum_i BR_i = 1$ is model independent if $\Delta BR(H\to BSM)$ is included in the fit)

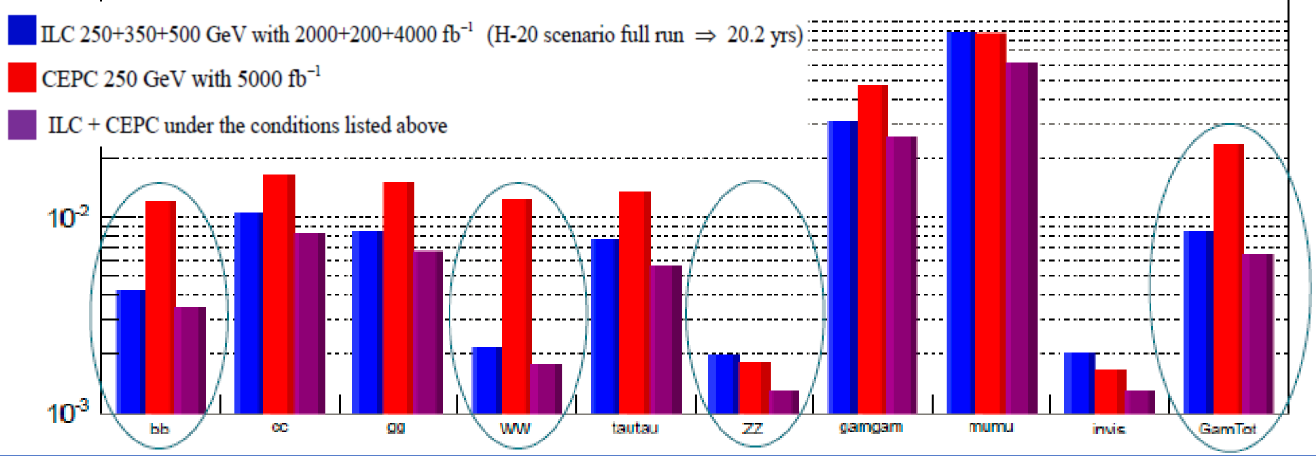
CEPC Higgs Coupling Precision assuming 5 ab^{-1}

$\frac{\Delta BR(H\to BSM)}{\Delta BR(H\to Invis)_0}$	∞	8	4	2	1	0.1
ZZ	0.26%	0.24%	0.22%	0.19%	0.18%	0.17%
WW	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
bb	1.3%	1.3%	1.2%	1.2%	1.2%	1.2%
$\tau^+\tau^-$	1.4%	1.4%	1.4%	1.4%	1.3%	1.3%
gg	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
cc	1.7%	1.7%	1.7%	1.6%	1.6%	1.6%
$\gamma\gamma$	4.7%	4.7%	4.7%	4.7%	4.7%	4.7%
Γ_{tot}	2.8%	2.7%	2.5%	2.4%	2.3%	2.3%

$\Delta BR(H\to Invis)_0$ corresponds to the 5 ab^{-1} CEPC 95% CL limit of 0.28%

40% improvement in Δg_Z if $\Delta BR(H\to BSM)\approx\Delta BR(H\to Invis)$

$$\frac{\Delta BR(H\to BSM)}{\Delta BR(H\to Invis)_0}=1$$



Physics Interest of Italy Group for FC

Patrizia Azzi (INFN, Padova)

« FC » Italy

New INFN Budget Line for « Future Collider » grouping together people interested in future machines to profit of the synergies: ILC,CLIC,FCC,CepC,SppC,MuColl

Bari
M. Abbrescia, N. De Filippis,

Bologna
L. Bellagamba, D. Boscherini, S. Braibant, P. Giacomelli, P. Alessandro

Ferrara
R. Camattari, G. Cibinetto, V. Guidi, A. Mazzolari

Lecce
C. Esposito, F. Grancagnolo, A. Maffezzoli, M. Panareo, G.F. Tassielli, G. Zavarise

Laboratori Nazionali di Frascati
M. Antonelli, M.E. Biagini, G. O. Blanco, M. Boscolo, F. Collamati, S. Dabagoy, S. Guiducci, M. Rotondo, M. Testa

Milano
A. Andreazza, M. Caccia, C. Curatolo, S. Romualdo, L. Serafini

Padova
P. Azzi, N. Bacchetta, A. Bertolin, P. Checchia, D. Lucchesi, A. Lupato, M. Morandin, R. Rossin, L. Sestini, M. Zanetti

Perugia
G. Mario Bilei, C. Cecchi, L. Fano', F. Moscatelli, D. Passeri, A. Rossi

Pisa
F. Bedeschi, V. Cavasinni, C. Roda, R. Tenchini, G.E. Tonelli

Pavia
G. Introzzi, G. Polesello, P. Salvini

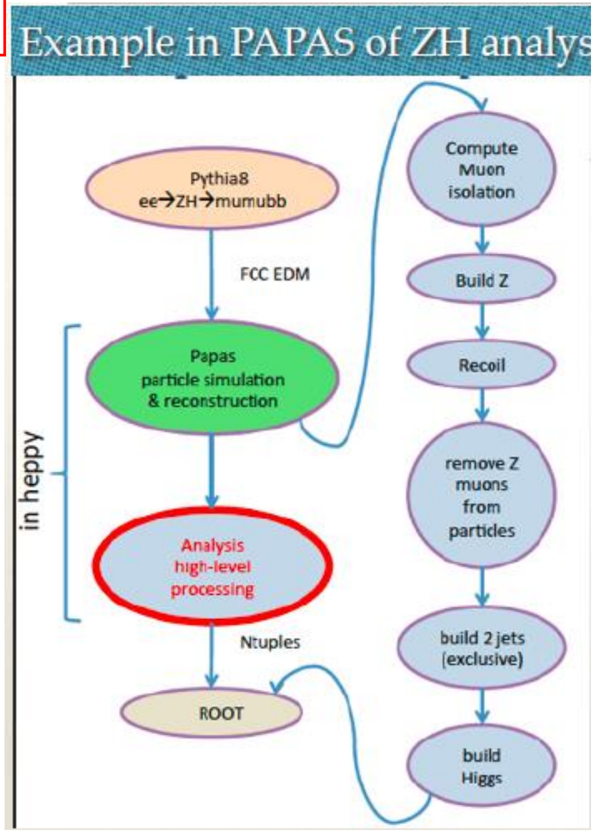
Roma1
F. Anulli, G. Campogiani, M. Marongiu, L. Palumbo

Roma3
M. Biglietti, B. Di Micco,A. Farilla

Trieste
A. Bressan, M. Cobal, S. Dalla Torre, S. Dasgupta, S. Levorato, A. Martin, F. Tessarotto

In this list are not included the theory colleagues, nor the students / postdocs without a permanent contract.

P. Azzi - Cepc/SppS Workshop, Bejing, 2016 3



- Strong collaboration across sevearl experiments ATLAS/CMS/LHCb/CLIC!

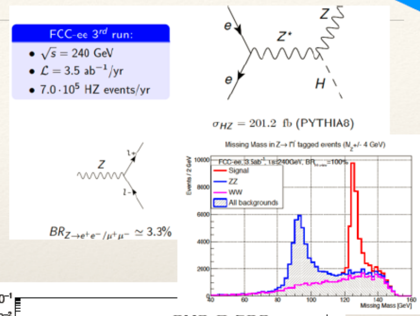
http://fccsw.web.cern.ch/fccsw/

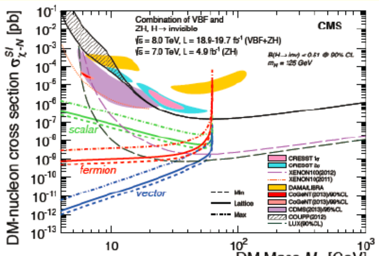
http://github.com/HEP-FCC: open source code on GitHub

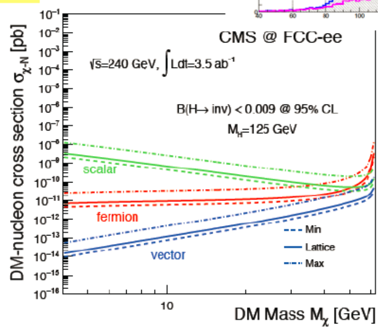
Higgs studies & invisible width

FCC-ee

- **The first studies on the Higgs concerning a circular e+e- machine were documented in the « First look at the physics case of TLEP » (arXiv: 1308.6176).** This type of document ages quickly.
  - the CMS full Geant based detector simulation was used
- in 2015 a new study of the Higgs invisible width was performed using Delphes for the detector simulation.
  - comparing also the CMS and ILD detector







O. Cerri, A. Podo, L. Rolandi (SNS), M. De Gruttola, M. Pierini (CERN)

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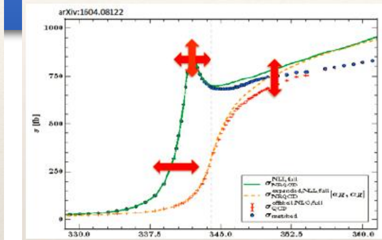
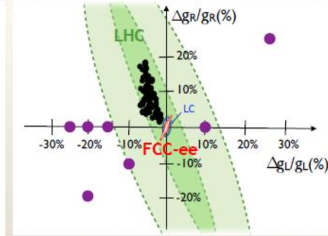
Expertise on top physics at lepton collider

FCC-ee

- At the $\sqrt{s}$=of 350-365 GeV could measure top mass, top width, EWK couplings and estimate of top Yukawa





Probing Composite Higgs models at higher scales

S. De Curtis (Roma1), S Moretti (UK)

	Lumi / 5 years	# top pairs	Δm_{top}	$\Delta\Gamma_{top}$	$\Delta\lambda_{top}/\lambda_{top}$
FCC-ee TLEP	4 × 650 fb^{-1}	1,000,000	10 MeV	12 MeV *	13%

* using α_s from Tera-Z

λtop ~13% with indirect extraction from threshold scan. To improve need higher energy or FCC-hh.

- New analysis with FCC-ee framework and fast simulation (PAPAS) in progress.

P. Azzi (INFN Padova) , N. Foppiani, G. Rolandi (INFN Pisa & SNS)

N. Foppiani, T. Pajero, G. Rolandi (INFN Pisa & SNS)

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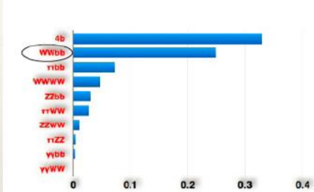
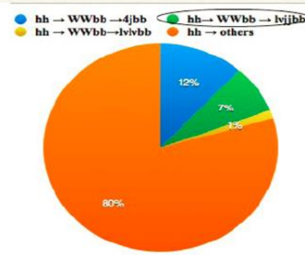
HH->WWbb->lvjjbb

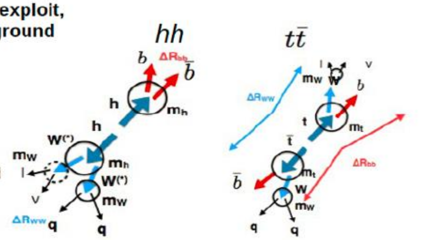
FCC-hh

B. Di Micco (Roma3), M. Testa (LNF)





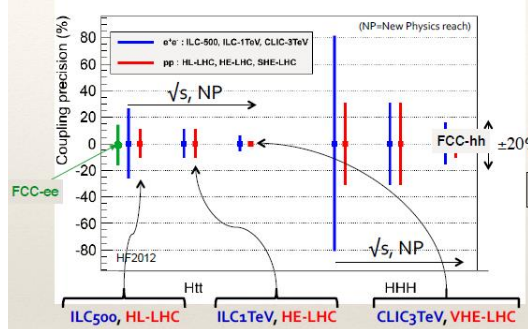
- BR lvjj bb ~ 7% of the total
- 4j channel also interesting to exploit, but overwhelming QCD background
  - Main background: $t\bar{t}$ with same final state
  - Main discriminant variables: M_{bb}, ΔR_{bb}, ΔR_{WW}
  - Kinematics can be closed
  - Crucial to have good, E_T^{miss} and jet, p_T and angular resolution
  - Challenging in high pile-up environments.

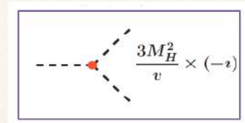


σ(100 TeV) / σ(14 TeV)~ × 40(32) for HH (tt)

Higgs Self-Coupling @100TeV

FCC-hh





~ × 40 at 100 TeV wrt to 14 TeV

$\sqrt{s}$ [TeV]	σ^{NLO} [fb]
8	8.2
14	33.9
33	207.3
100	1417.8

	HL-LHC	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC1400	CLIC3000	HE-LHC	VLHC
$\sqrt{s}$ (GeV)	14000	500	500	500/1000	500/1000	1400	3000	33,000	100,000
$\int\mathcal{L}dt$ (fb^{-1})	3000	500	1600‡	500/1000	1600/2500‡	1500	+2000	3000	3000
λ	50%	83%	46%	21%	13%	21%	10%	20%	8%
λ_t	4%	14%		4%	2%	4%	<4%	3%	1%

Requirements for CEPC Detector Design

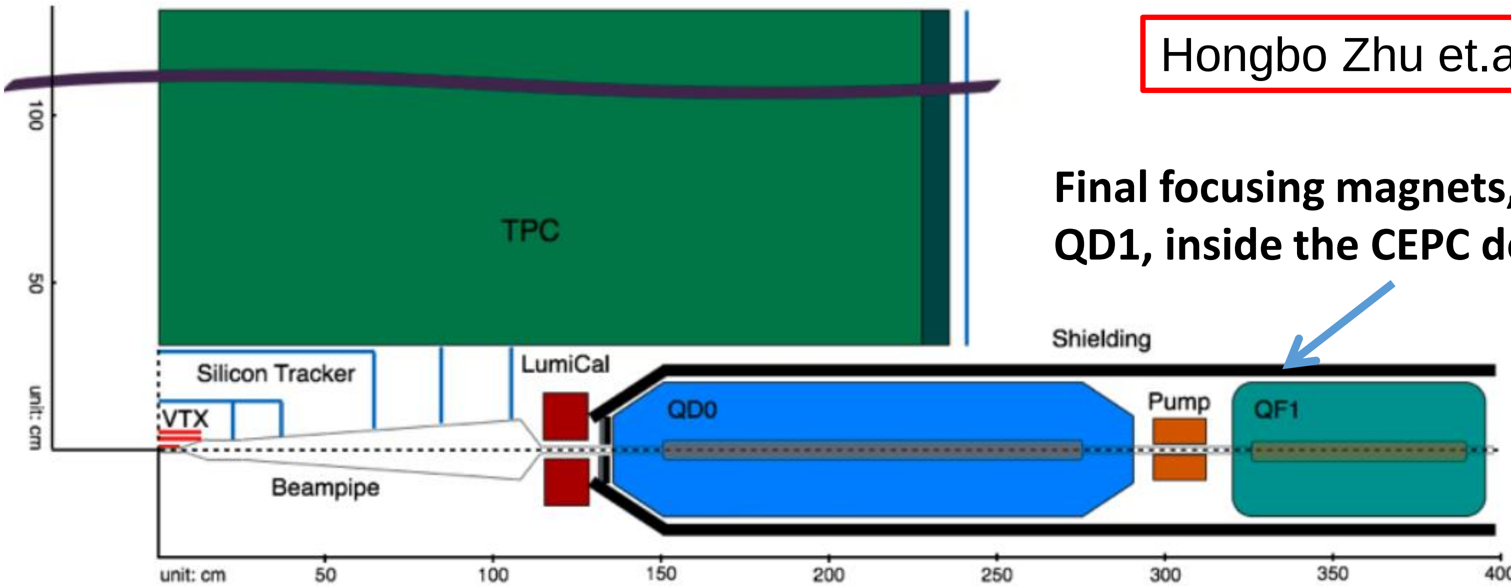
Critical Physics Benchmarks for Detectors design.

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	$\Delta(1/p_T) \sim 2 \times 10^{-5}$
$H \to \mu^+\mu^-$	$BR(H \to \mu^+\mu^-)$		$\oplus 1 \times 10^{-3}/(p_T \sin\theta)$
$H \to b\bar{b},\ c\bar{c},\ gg$	$BR(H \to b\bar{b},\ c\bar{c},\ gg)$	Vertex	$\sigma_{r\phi} \sim 5 \oplus 10/(p \sin^{3/2}\theta)\ \mu m$
$H \to q\bar{q},\ V^+V^-$	$BR(H \to q\bar{q},\ V^+V^-)$	ECAL, HCAL	$\sigma_E^{jet}/E \sim 3-4\%$
$H \to \gamma\gamma$	$BR(H \to \gamma\gamma)$	ECAL	$\sigma_E \sim 16\%/\sqrt{E} \oplus 1\%$ (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)



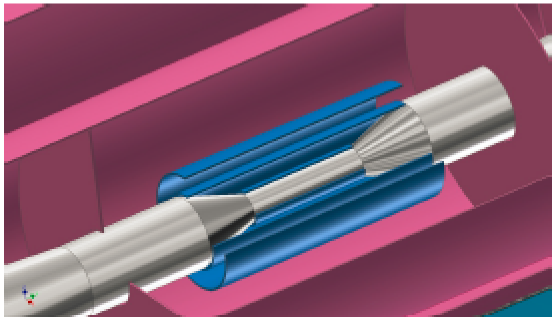
Hongbo Zhu et.al. @ IHEP

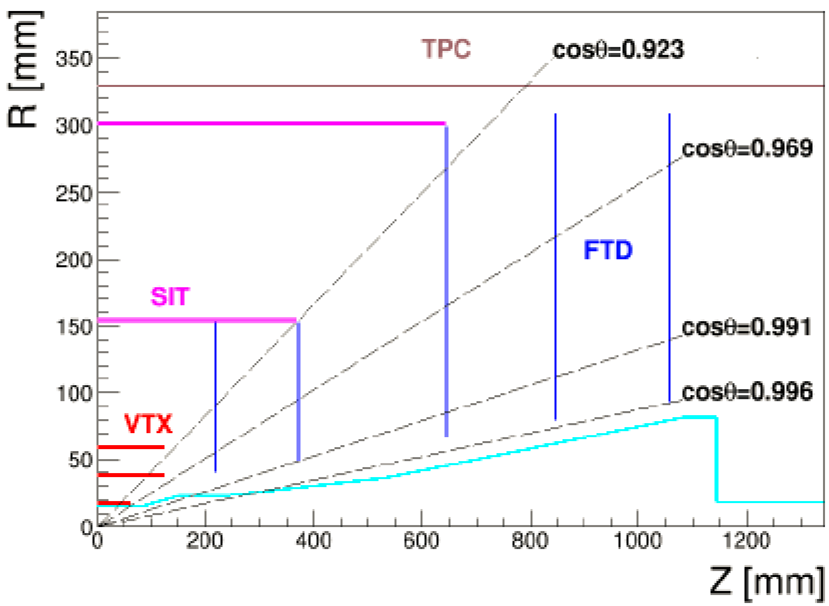
Final focusing magnets, QD0 and QD1, inside the CEPC detector

- 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 Vertex and Silicon Tracker

Ouyang Qun, M. Wang et.al.





Vertex detector:

- 3 cylindrical and concentric double-layers of pixels

Performance requirements with 3.5 T field

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

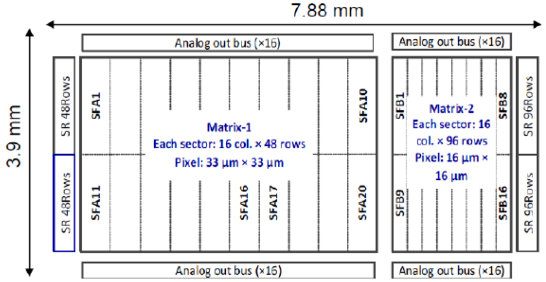
$$\sigma_{r\phi} = 5\mu m \oplus \frac{10}{p(GeV)\sin^{3/2}\theta}\mu m$$

Goal: to develop fine pitch, Low power, fast pixel sensor + light structure

CEPC Vertex and Silicon Tracker R&D

First CPS prototype design

- Goals: sensor optimization and in-pixel pre-amplifier study
- Floorplan overview:
  - Two independent matrices: Matrix-1 with 33 × 33 μm² pixels (except one sector SFA20 with 16 × 16 μm² pixels), Matrix-2 with 16 × 16 μm² pixels.
  - Matrix-1 includes 3 blocks with in-pixel pre-amplifier
  - SFA20 in Matrix-1 contains pixel with AC-coupled pixels

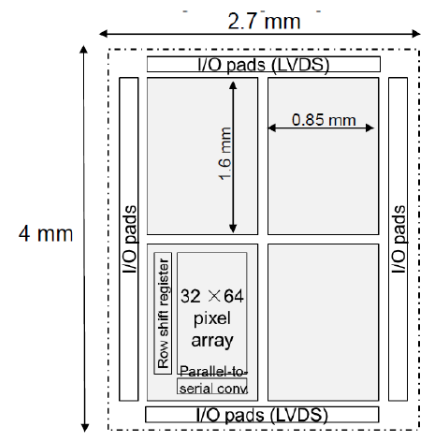


- Tower Jazz CIS 0.18 μm, November 2015 submission
- Two types of wafer:
  - 18 μm HRES epi wafer
  - 700Ω Czochralski wafer

Second CPS prototype - pixel design

Y. Zhang, Y. Yang (IHEP)

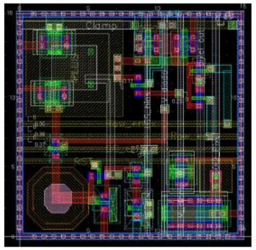
- Purpose: small-size digital pixel design verification
- Proposed floor plan:
  - 4 sub-matrices with different pixel structures, each matrix with 32 columns by 64 rows pixels
  - Pixel size: less than 22 × 22 μm²
  - Each pixel contains a sensing diode, a pre-amplifier and a discriminator

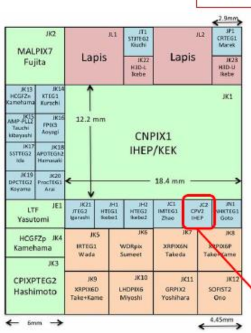


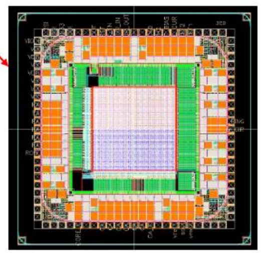
Second SOI pixel prototype design

Y. Lu, Y. Yang (IHEP)

CPV2
- In-pixel CDS stage inserted
- To improve RTC and FPN noise
- To replace the charge injection threshold
- Submitted June, 2016







Pixel Layout: *16 × 16 μm²*

Summary and outlook

- R&D started along the baseline design specifications
- Pixel sensors design submitted
  - CPS diode optimization
  - SOI sensors with small pixel size
- 2nd CPS prototype design in progress
  - More in-pixel electronics
  - New readout architecture

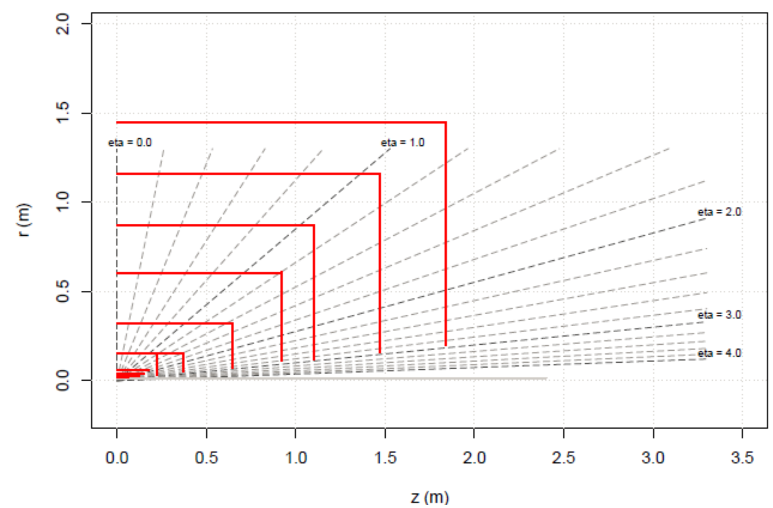
- Test system in preparation and sensor characterization will start soon
- Overall sensor architecture in consideration
- Optimization study of vertex system needed
- Double-sided and light supporting structure, cooling,…
- Possible change of sensor design
  - Beam related background level
  - Impact of partial-double ring scheme, with time-stamp of microsecond
  - Impact of Z^0 pole running

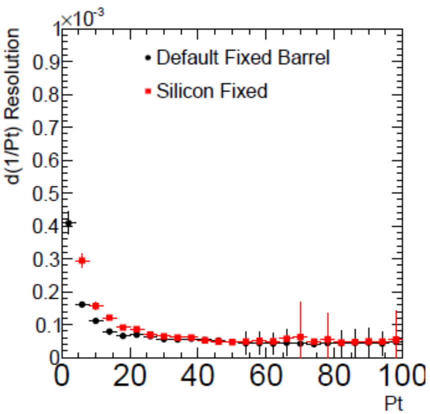
Full Silicon Tracker Concept for CEPC

Weiming Yao (IHEP/LBNL)
for Silicon Tracking Study Group*

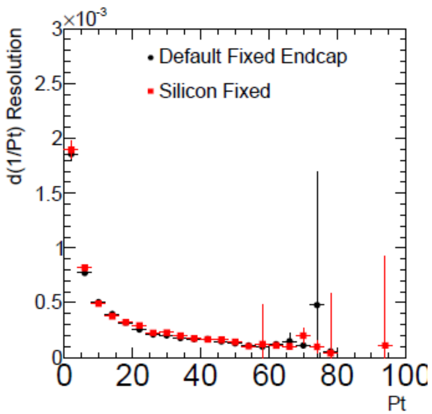
- Based on CEPC V1 silicon elements, we replace TPC with additional SIT layers and FTD endcaps.
- Generated single muon in CEPC full silicon.
- Reconstructed using Marlin Silicon only.
- Modifying pattern recognition to use more silicon layers.

* http://cepc.ihep.ac.cn/ cepc/cepc_twiki/index.php/Pure_Silicon_Detector





(a) Barrel



(b) Endcap

Conclusion

- The concept of full silicon tracker has been implemented and seems working.
- Its single particle performance is comparable to CEPC V1, meeting the physics requirements.
- There are rooms for improvement, especially for improving silicon clustering and fitting.
- Allow us to start reoptimizing its design and improving silicon tracking for CDR.

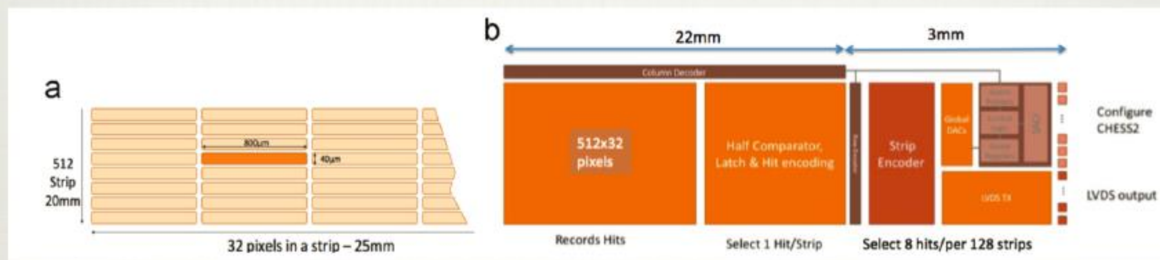
Pixels and Short Strips

Massimo Caccia
Università dell'Insubria @Como & INFN

$$\sigma_{ip} = a \oplus \frac{b}{p \cdot \sin^{3/2}\theta}$$

Accelerator	a [μm]	b [μm·GeV/c]
LEP	25	70
SLC	8	33
LHC	12	70
RHIC-II	13	19
ILC	< 5	< 10

c. possibility to design pixels with unusual aspect ratio ⇢ SHORT STRIPS



Z. Liang et al., NIM A (2016) http://dx.doi.org/10.1016/j. nima.2016.05.007

Technology

TOWERJAZZ

▶ **High Resistivity epitaxial layer, 4 wells (e.g. Tower Jazz 180 nm)**

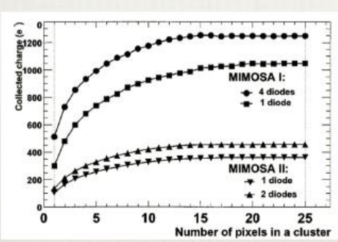
Some of the advantages of this technology:

- 6 metal layers for dense interconnections
- quadruple well
- 18 μm thick epitaxial layer of 1-5 kΩ cm resistivity ⇢ collection by drift

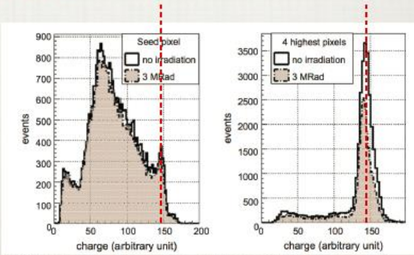
3 good reasons for having high resistivity substrates:

a. smaller charge spread & clustering size

G. Deptuch at al. IEEE-TNS 49 (2002) 601



AMS 0.6 μm technology - 14 μm epitaxial layer - 20 μm pixel pitch



TJ 0.18 μm technology - 18 μm epitaxial layer - 20 μm pixel pitch, illuminated by an 55fe source (5.9 keV X ray, 1640 eh pairs

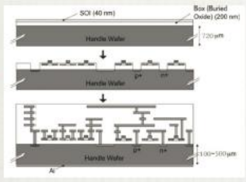
G. Baudot at al. NIM A732 (2013) 480

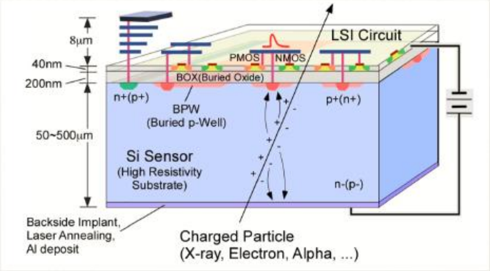
Technology

▶ SOI on High resistivity Substrate (LAPIS, formerly OKI bu TJ seems to be on the track!)

- H. Lan et al. IEEE sensors journals 15 (2015) 2732 a Review!
- J. Marczewski, M. Caccia et al., IEEE *Trans. Nucl. Sci.*, 51 (2004)1025
- M. Jastrzab, M. Caccia et al, NIM A560 (2006) 31

simplified process flow





▶ main advantages:

- a genuine monolithic approach
- more flexible wrt CMOS maps (nmos & pmos naturally integrated in the SOI layer)
- electronics "isolated" from the bulk (fast switching, reduced single event upset) [the motivation for the industrial development of SOI - partially true here]
- the active layer is a very standard and comfortable high resistivity, fully depleted detector

▶ main disadvantages:

- not easy to get SOI wafers on a high resistivity substrate
- mind the effect of the depletion voltage (back-gate effect)
- custom process

Next Si-tracking systems

Livio Fanò
Università degli Studi di Perugia e INFN

Physics requests and detector constraints

Cutting edge technology and ongoing R&D

- Radiation Tolerance
- pT Track and L1-Trigger

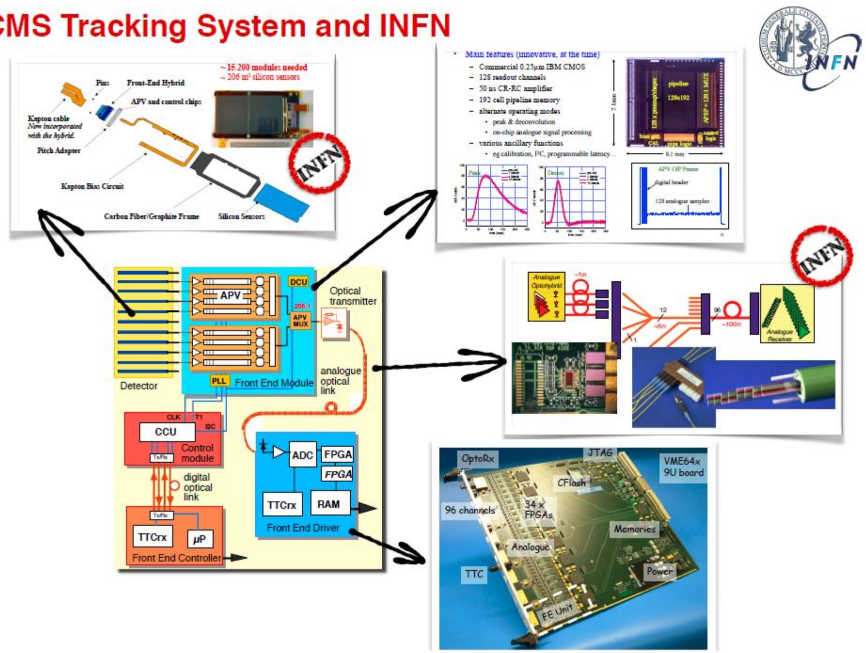
INFN - local expertise in

- Detector development
- Ongoing China/Italy partnership in particle detectors and industrial liaison

CMS Tracking System and INFN

~ Jan 1990	R&D projects
Apr 1992	**CMS Letter of Intent**
Dec 1994	Technical Proposal
Apr 1998	Tracker Technical Design Report
Oct 1999	Front End Readout ASIC in 0.25μm CMOS
Dec 1999	Decision to construct all Silicon Tracker
Feb 2000	**Tracker Technical Design Report Addendum**
Apr 2006	Module production completed
Nov 2006	Tracker integration complete
Dec 2007	Tracker inserted in CMS
Mar 2008	Tracker connections completed
Nov 2009	**Tracker ON with LHC beam**

CMS Tracking System and INFN



INFN has a large and diversified experience in detector construction: sensors, electronics, mechanics and operations. Its participation to the HL-LHC is in both pixel and outer-tracker CMS detectors, an optimal starting point to future colliders

Any collaboration for future preparation to CEPC-SppC will benefit from present institutional collaborations (i.e. IHEP/INFN-Perugia is a very fruitful experience) and from the high quality potential of the ongoing industrial partnership

-from CMS tracker Phase2 to future detectors

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$\times10^6$/1000 per endcap
Pad pitch/no.padrows	$\simeq$ 1 mm$\times$4-10 mm/$\simeq$200
$\sigma_{\rm point}$ in $r\phi$	$< 100\mu$m (avg for straight-radial tracks)
$\sigma_{\rm point}$ 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 $\delta(1/p_t) \simeq 2\times10^{-5}$/GeV/c

CEPC-TPC R&D

Huirong Qi et.al.

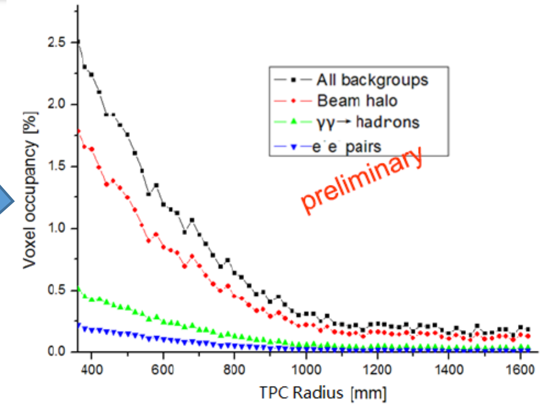
Critical challenges of CEPC-TPC

- Occupancy: at inner diameter
  - Occupancy should be very smaller
  - Overlapping tracks
  - Background at IP
- Ion Back Flow
  - Continuous beam structure
  - Long working time with low discharge possibility
  - Necessary to fully suppress the space charge produced by ion back flow from the amplification gap
- Calibration and alignment
  - Laser calibration system

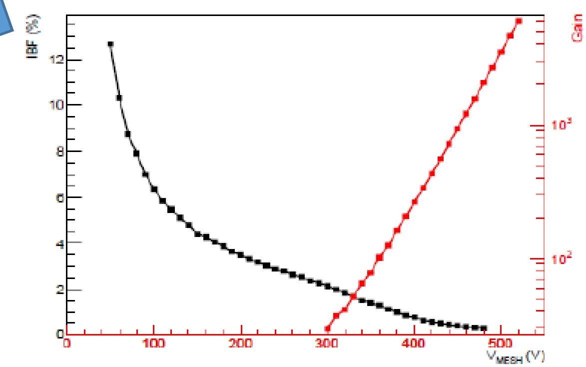
TPC as one option for CPEC-TPC YES or NO

To reduce IONS
To reduce distortion

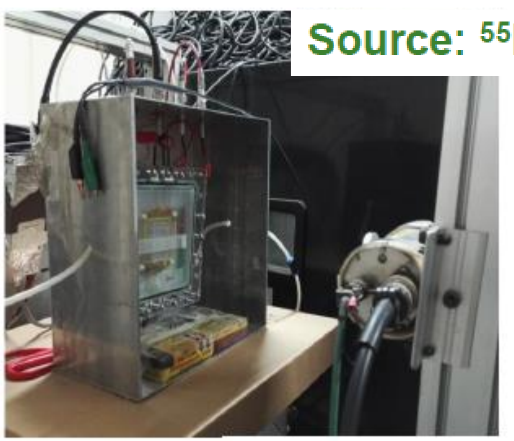
~100um positron resolution with calibration



TPC voxel occupancy simulated in TPC radius



Source: ^{55}Fe, Gas mix: Ar(97) + iC_4H_{10}(3)



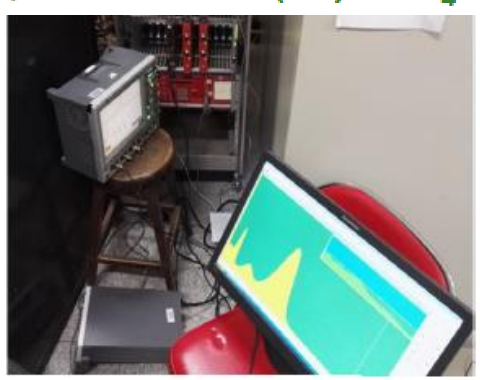
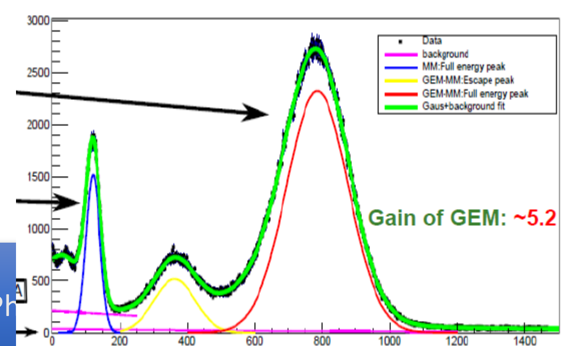


Photo of the GEM+Micromegas Module with X-ray



TPC Performance Comparison

Huirong Qi @ IHEP

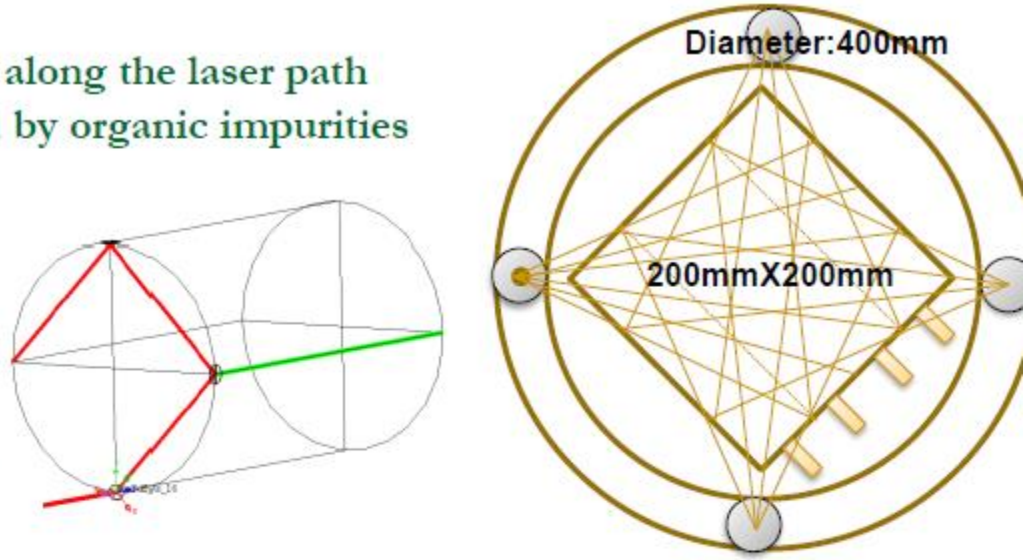
	GEM+MMG 420LPI (IHEP)	2GEMs + MMG 450 LPI (Yale University)	Micromegas only 450 LPI (Yale University)
Ion Back Flow	~0.1% Edrift = 0.25 kV/cm	(0.3 –0.4)% Edrift = 0.4 kV/cm	(0.4 –1.5)% Edrift= (0.1-0.4) kV/cm
<GA>	4000~5000	2000	2000
ϵ-parameter(=IBF*GA)	4~5	6~8	8~30
E –resolution	~16%	<12%	<= 8%
Gas Mixture (2-3 components)	Ar + iC4H10	Ne+CO2+N2, Ne+CO2,Ne+CF4, Ne+CO2+CH4	X + iC4H10 (Ar+CF4+iC4H10)
Sparking (^{241}Am)	$<10^{-8}$	$< 3.*10^{-7}$(Ne+CO2) (N.Smirnov report)	$\sim 10^{-7}$ (S. Procureur report)
Possible main problem	Thin frame	More FEE channel	#
Goals	CEPC TPC	ALICE upgrade	#

- 16 -

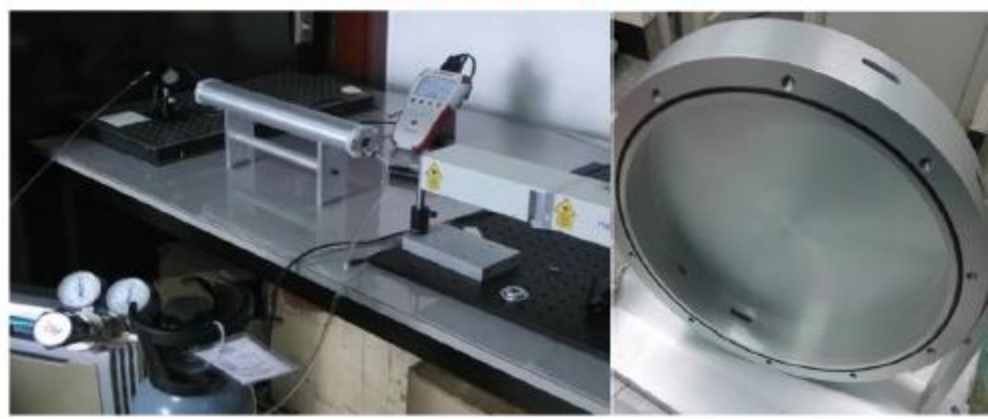
Laser calibration for TPC prototype

Supported by 国家基金委重点基金

- Goals of laser for TPC detector
  - The ionization in the gas volume along the laser path occurs via two photon absorption by organic impurities
  - Drift velocity, gain uniformity
- To reduce the distortion effect
  - E×B effect study
  - Drift Velocity measurement
  - Good resolution in space and tin
    - No production of σ-rays
    - No multiple scattering
- Baseline design **(DONE)**
  - Nd:YAG laser device
  - λ = 266 nm or E = hν = 4.66 eV
  - Energy: ~100 uJ/pulse
  - Duration of pulse: 5 ns
  - Active area:200mm×200mm
  - Drift length: 500mm
  - Outer diameter:~400mm
  - GEM readout



Laser calibration baseline design



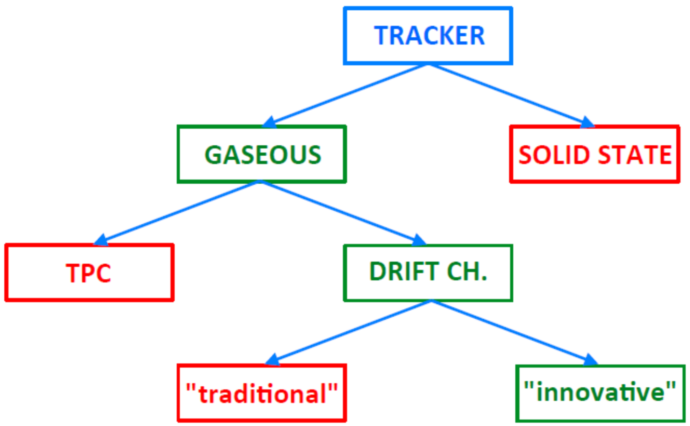
The assembled module test with 266nm laser

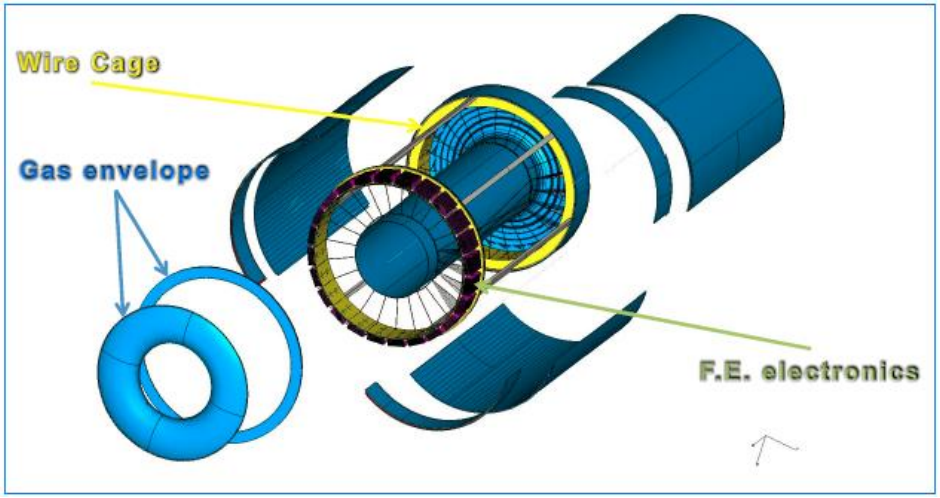
Tsinghua and IHEP Cooperation

Drift Chamber with PID capability

F. Grancagnolo
INFN – Lecce, ITALY

Tracker alternatives





A proposal for CepC (1)

- **24 super-layers**, each one made of **8 para-axial layers (192 total)** at …
  stereo angles, arranged in **16 equal azimuthal sectors**;
- **18 square, single sense wire, drift cells** per sector … 3
  cells increment per sector on each succe…
  function of super-layer radius;
- **Cell sizes** ranging from …
- **Alternating** …
  (cons…

… X_0) at **Radius = 320 mm**;
… of 250 µm) - 2.5 mm Rohacell30 -
… (must support **15 Tons** - check for buckling

… analogy to Mu2e I-Tracker):
… g/cm² - **2×10^{-2} X_0** (incl. power distr., decoupling C's, term. resistors and signal and HV cables).
  - **Gas envelope** made of 6 ply (quasi-isotropic, 6×38 µm = 228 µm) C-fiber plus 0.3 µm Au, for a total of 0.060 g/cm² – **2.1×10^{-3} X_0**;
- **Gas: 90% He - 10% iC4H10** ($\delta = 4\times10^{-4}$ g/cm³, X_0 = 1410 m), - 12.5 p.i./cm, gas gain: 4×10^5 at V ≈ 1400 V on 20 µm wire, v_{drift} ~ 2.5 cm/µs - **4.7×10^{-4} X_0/1m track**
- **Wires**: - **161,280 sense** (20µm Sn coated Ti); **648,480 field** (40µm Sn coated C); **164,640 guard** (50µm Sn coated Al) for a total equivalent thickness of **9.8×10^{-4} X_0/1m track**

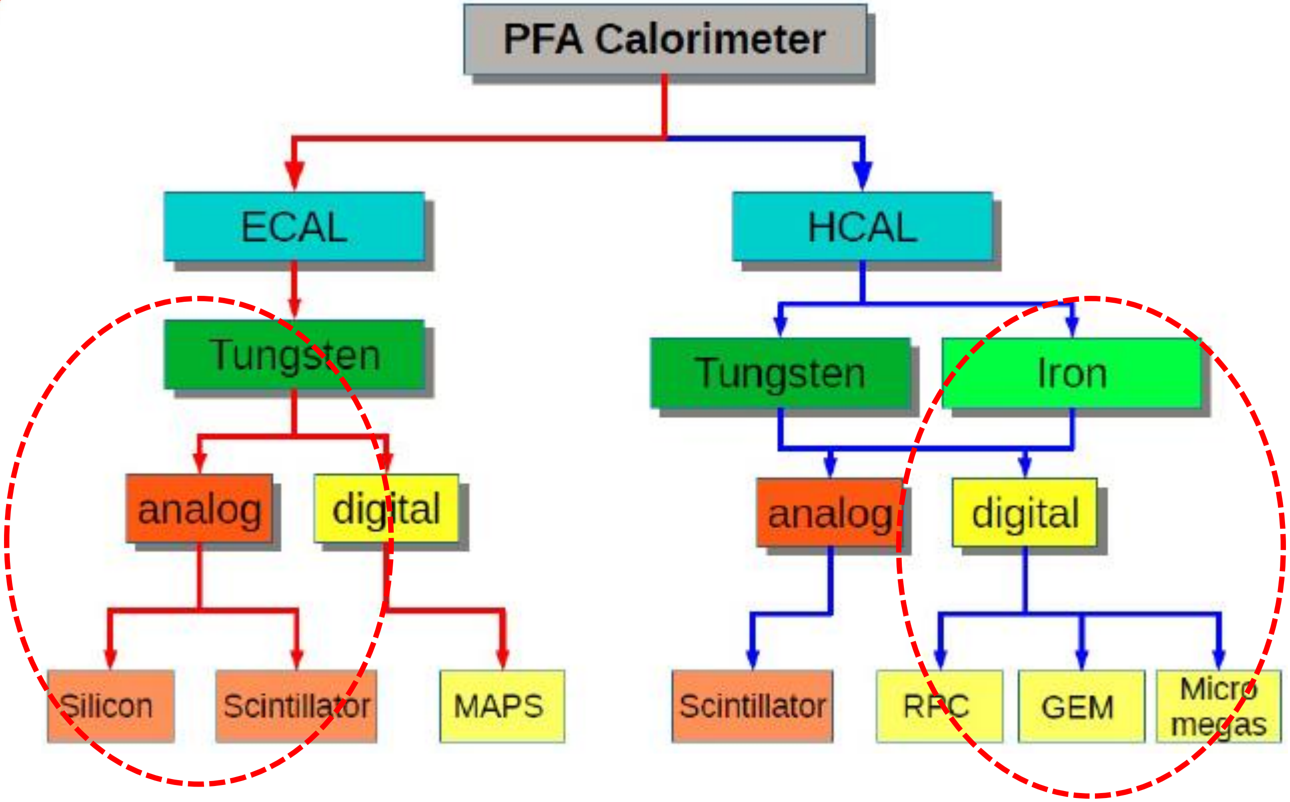
Drift Chamber "Innovations"

1. Separating **gas containment** from **wire support** functions
2. Using **a larger number** of **thinner** (and **lighter** wires)
3. No **feed-through** wiring
4. Using **cluster timing** for im… resolution
5. Using **cluster counting** for pa… identification

Expected spatial resolutions: $\sigma_{r\varphi} < 100$ µm, $\sigma_z < 1$ mm
Expected momentum resolution: $\Delta p_t/p_t = 2.2\times10^{-4}$, $\Delta p/p = 4.0\times10^{-4}$ for p=10GeV/c and ϑ=45°
Expected p. id.: π/κ separation > 3σ for p < 820 MeV/c and p > 1100 MeV/c

Global R&D of Imaging Calorimeters

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



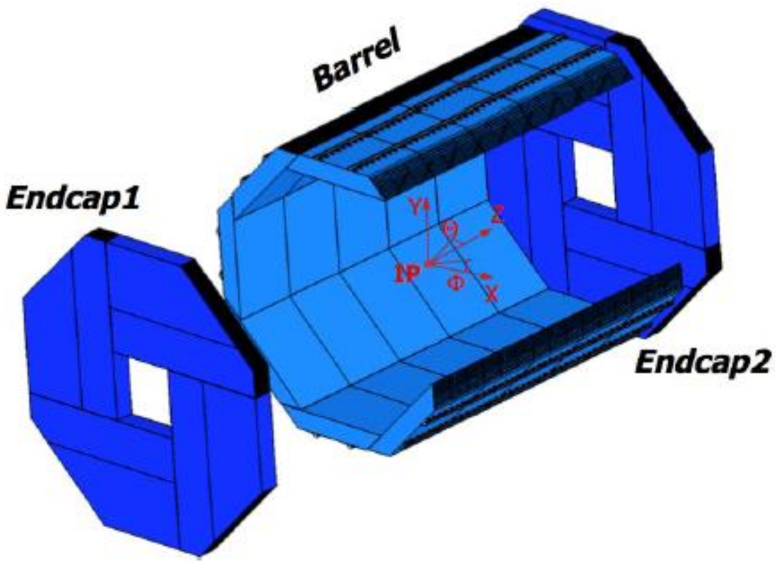
Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 0.13 cm^2 → 2.5×10^{-5} cm^2

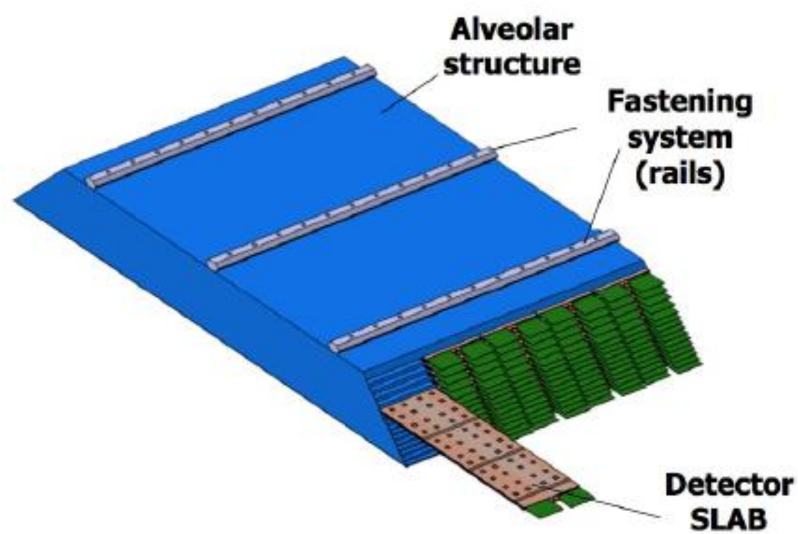
Technology: Scintillator + SiPM/MPPC; Scintillator + SiPM/MPPC; Gas detectors Silicon; Silicon; Silicon; Silicon (MAPS)

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



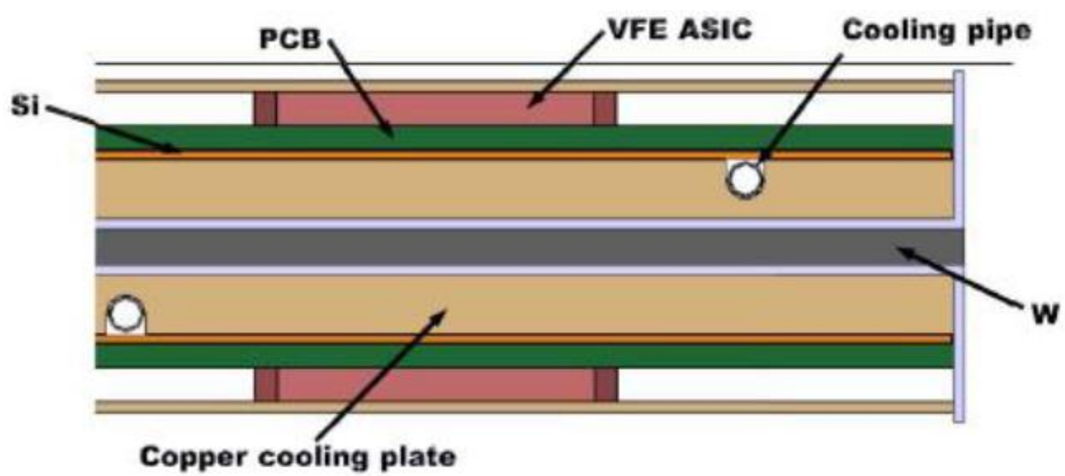


Active Cooling System

- 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.

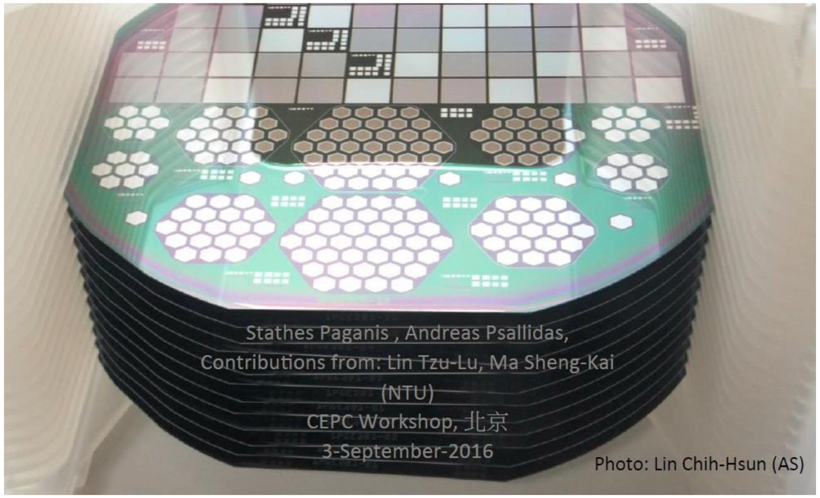
→ The silicon sensors are glued to PCB with VFE chips, cooled by the copper plates with CO_2 cooling pipes.



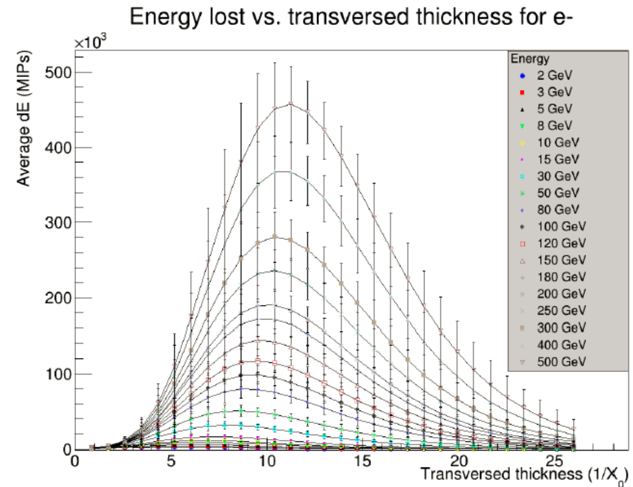
High Granularity ECAL Calibration

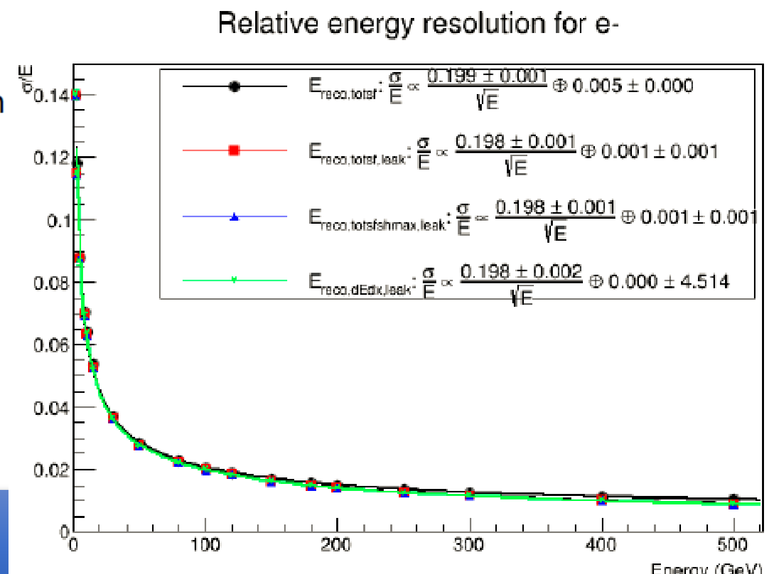
Stathes Paganis @ NTU

High Granularity ECAL Calibration



Longitudinal Energy deposition





- Understand some basic questions:
  - Origin of a ~1% constant term observed in an example of such calorimeter with increasing passive material thickness.
  - How to correct for upstream material losses (presampling).
  - How to correct for leaking EM energy.

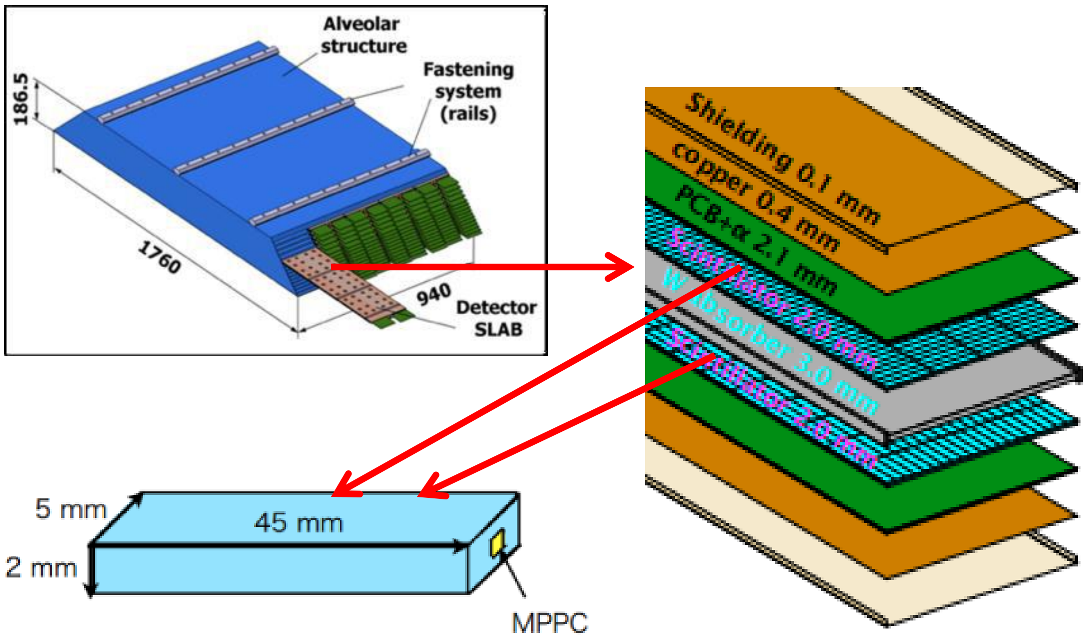
- **Various methods give similar resolution and good linearity.**

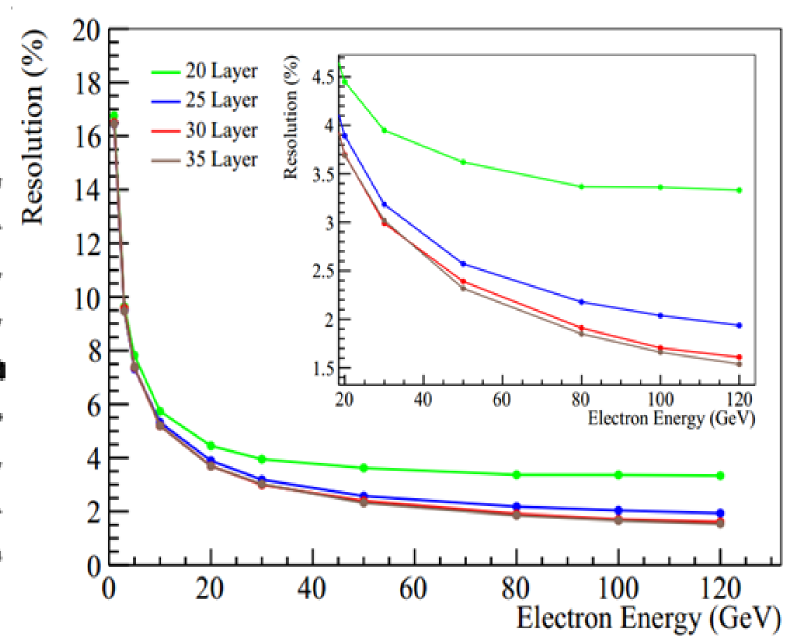
CEPC ECAL: Scintillator-W

Y.L. Zhang, Z.G. Wang et.al.

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

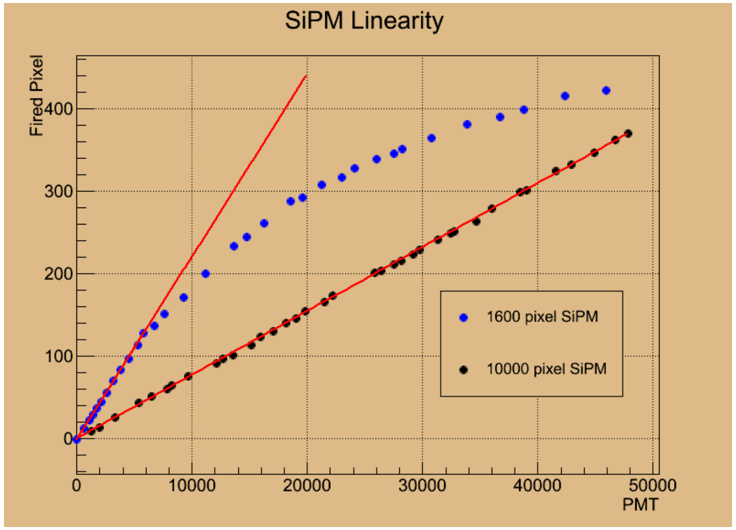
- **The energy resolution of 25GeV electron is about 3.3% (cf. CALICE TB results)**
- **To achieve required energy resolution, the number of layers should be ~ 25.**

Tests of SiPM at IHEP

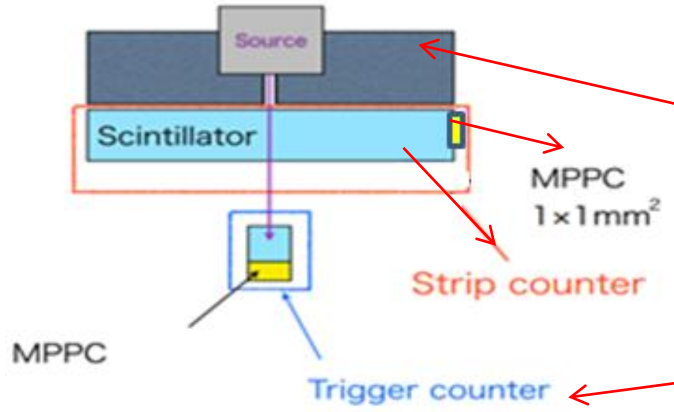
The SiPM dynamic range is determined by the number of pixels.

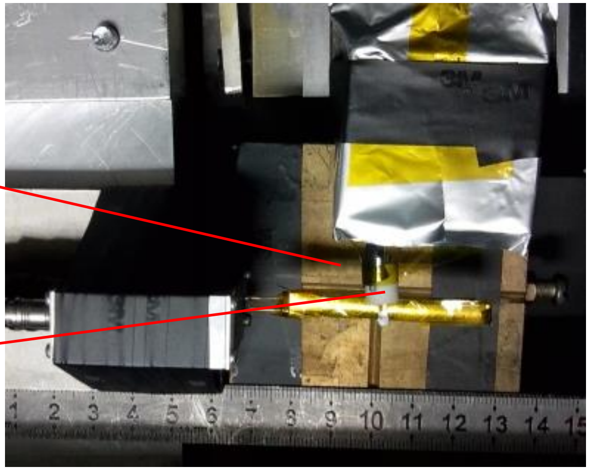
The manufactures have developed the SiPM with 10um pixel which extends the SiPM dynamic range.

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

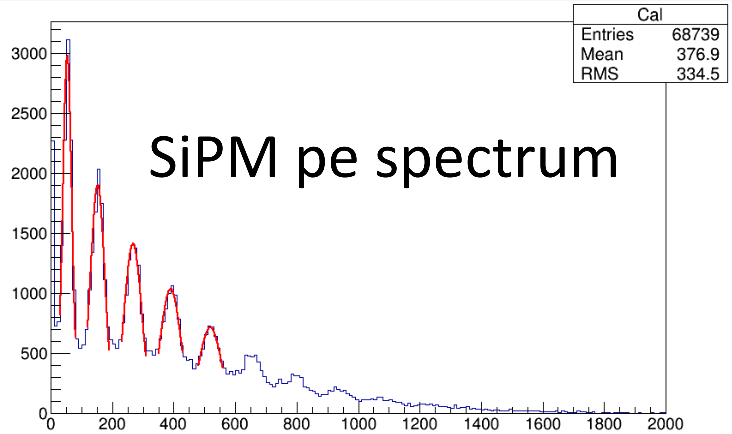


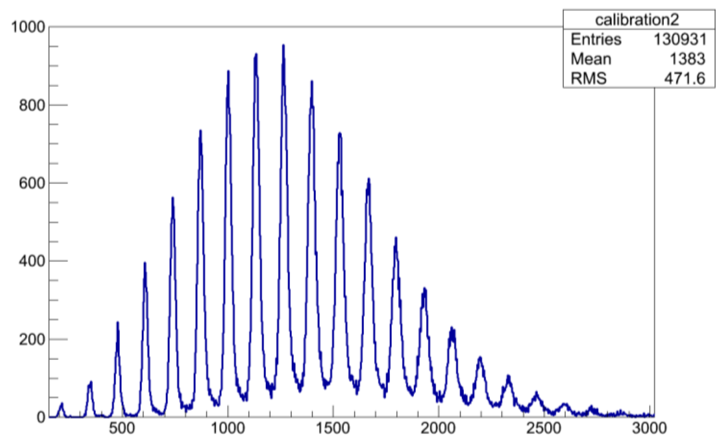
Scintillator strip irradiated with β collimated (1mm) from Sr-90





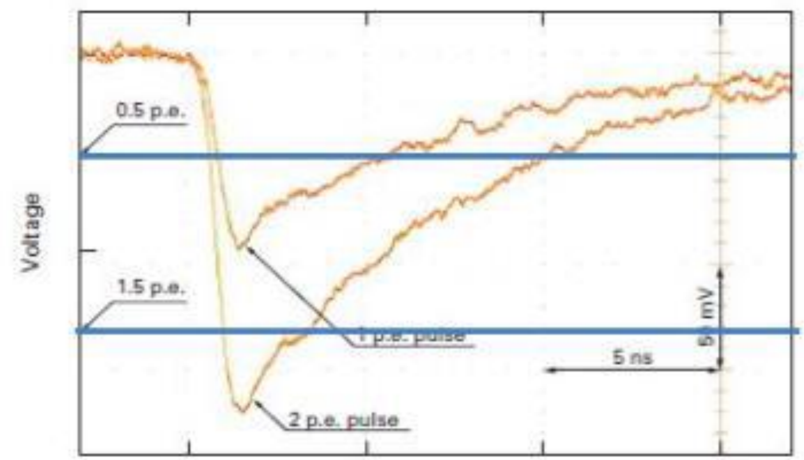
Tests of SiPM (IHEP, USTC)



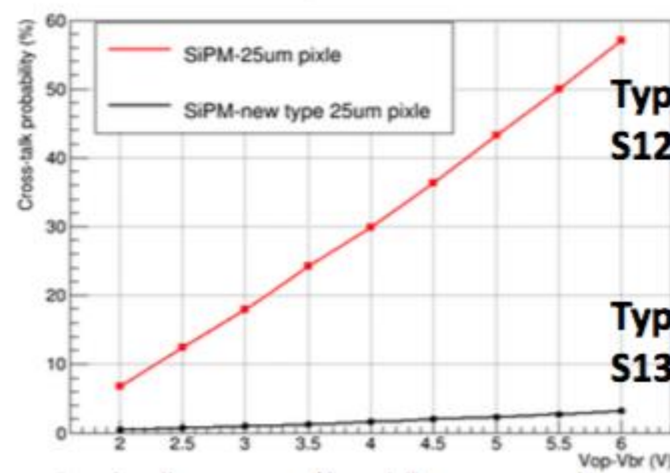


pulse height spectrum.

Excellent photon counting



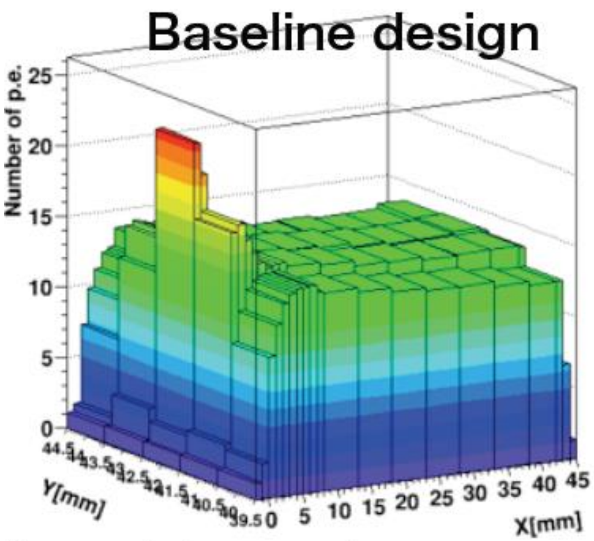
Cross talk rate = Events (> 1.5p.e)/Events (>0.5p.e)



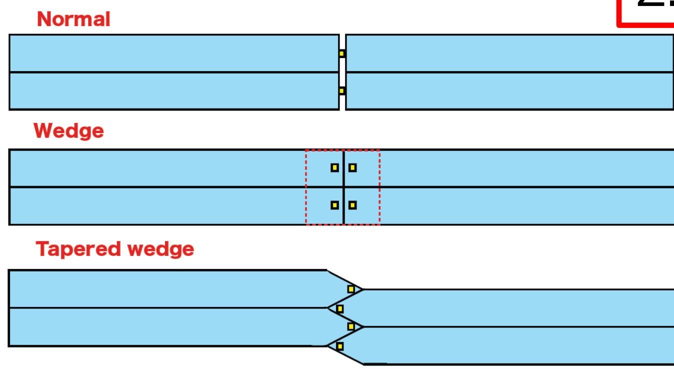
Type No.: S12571-025P

Type No.: S13360-1325PE

Sci-Strip Optimization and LED Calib.

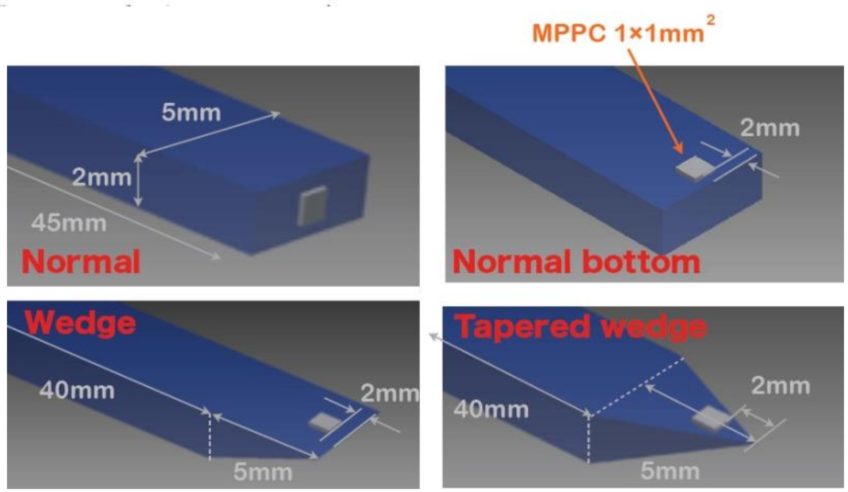


Z.G. Wang, Y.L. Zhang et.al.



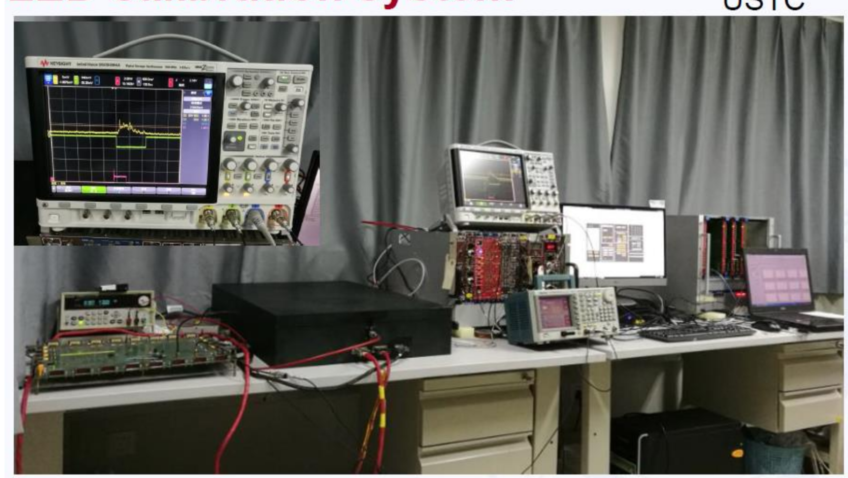
With normal design, the signal is not uniform with peak response for hits near SiPM. What's more, the dead gap between strips is large due to SiPM installation.

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



LED calibration system

USTC



CEPC HCAL R&D

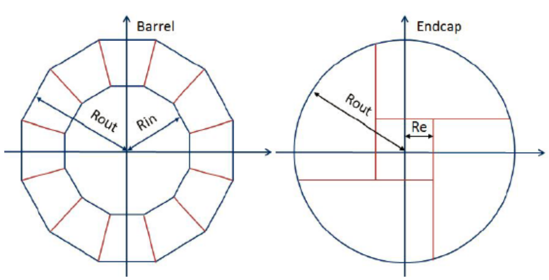
- The HCAL consists of
  - a cylindrical barrel system: 12 modules
  - two endcaps: 4 quarters
- Absorber: Stainless steel

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

CEPC DHCAL OPTIMIZATION

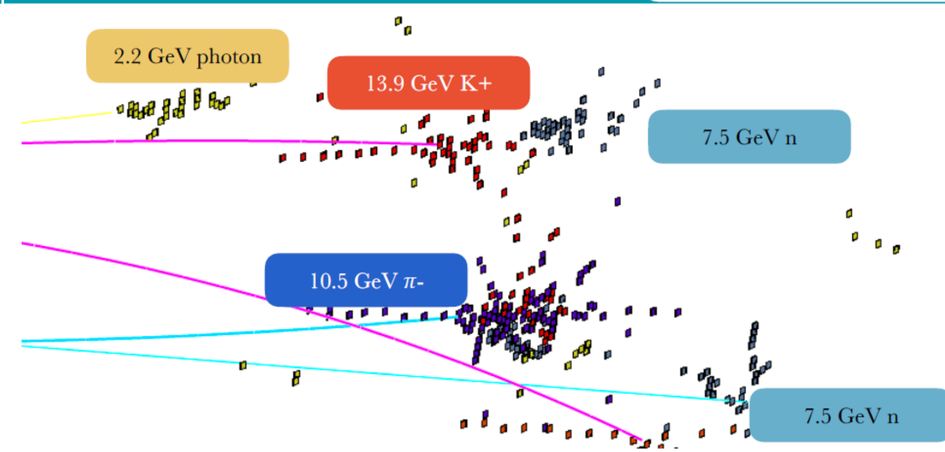
- To full fill the requirements of CEPC PFA, the DHCal is optimized by the following:
  - layers of DHCal, scanned from 20 layers to 48 layers.
  - size of each cell, scanned from 10 mm to 80 mm.
  - digitization (Q spectrum, spatial resolution, semi-Digi, etc..)

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



SIMULATION - PRELIMINARY

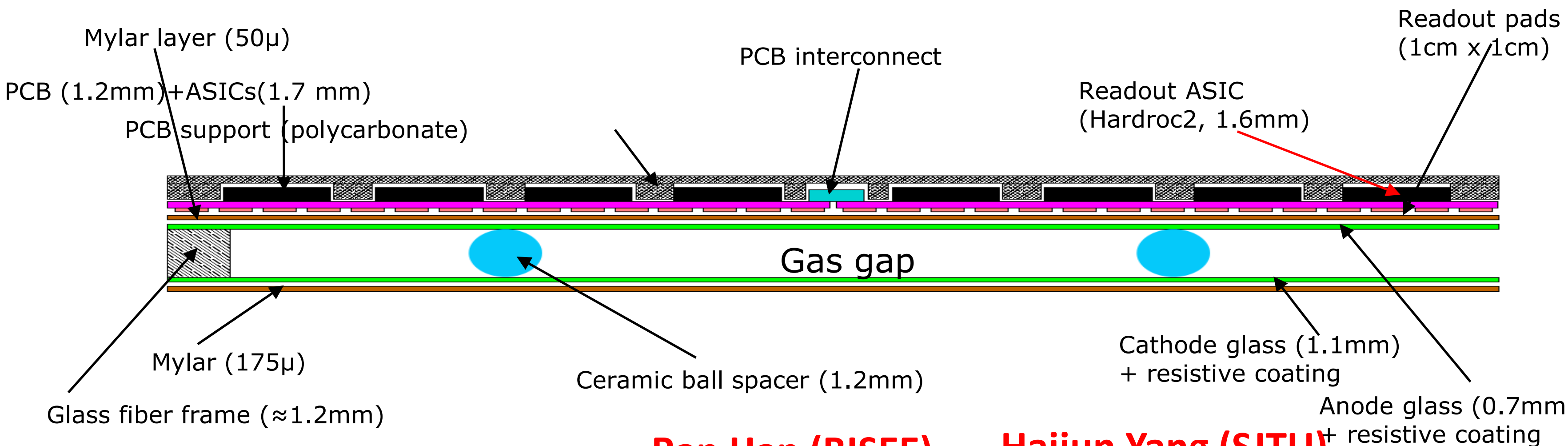
By Shi CHEN (UCAS)



„typical" jet:

		$(\sigma_{jet})^2$
~ 60% charged particles	tracking	$= (\sigma_{tracks})^2$
~ 30% photons	EM calorimeter	$+ (\sigma_{EMCalo})^2$
~ 10% neutral hadrons	HAD calorimeter	$+ (\sigma_{HADCalo})^2$
~~ 1% neutrinos~~		$+ (\sigma_{loss})^2 + (\sigma_{confusion})^2$

RPC Construction & Performance Study



Ran Han (BISEE) **Haijun Yang (SJTU)**

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

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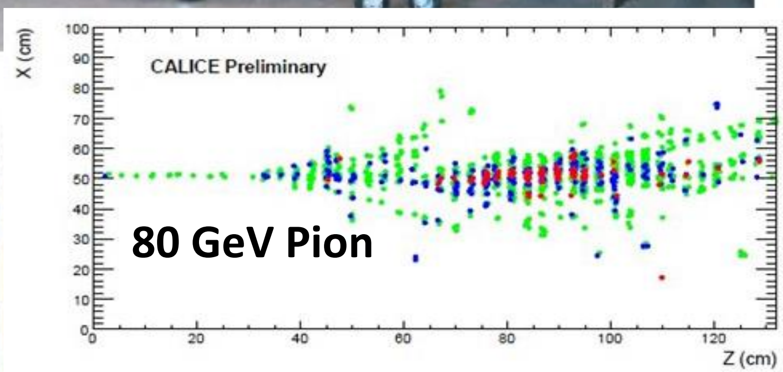
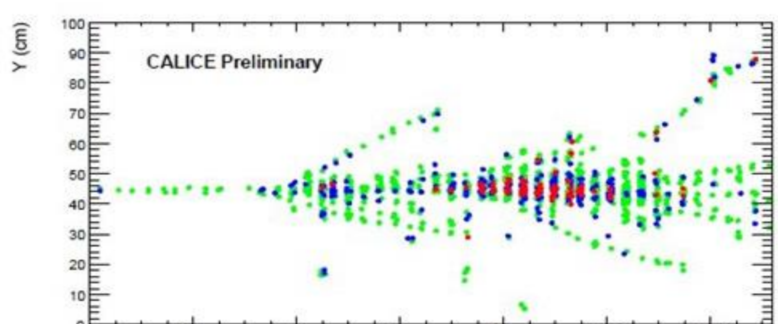
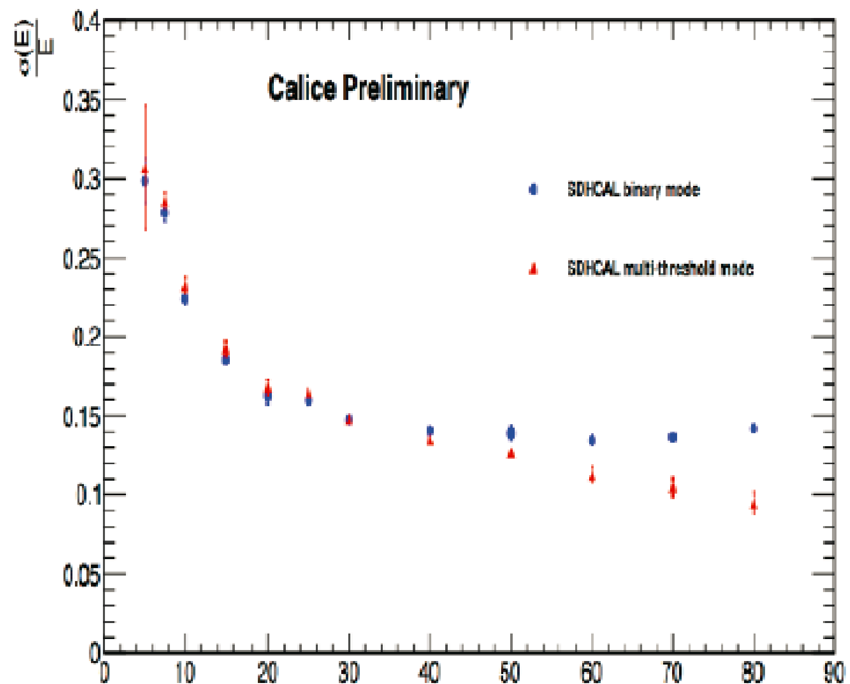
Prototype integration and test

Yi Wang (THU)
Imad Laktineh (IPNL)



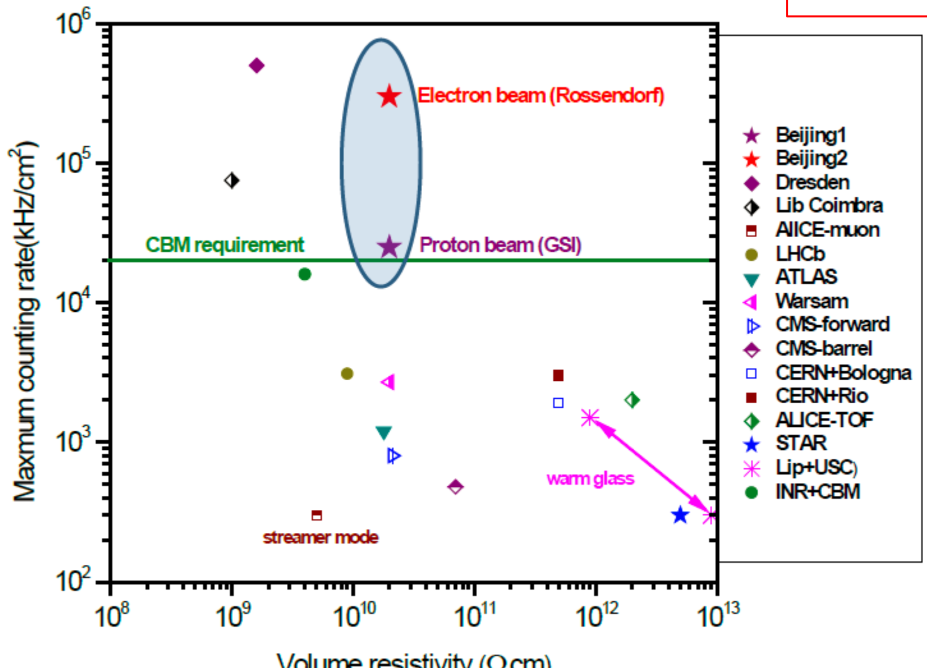




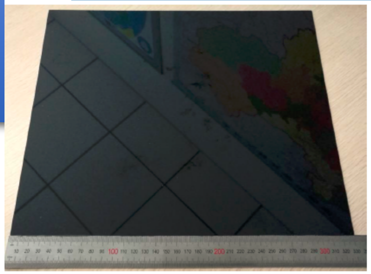
High-Rate GRPC

High-Rate GRPC may be needed in the very forward region

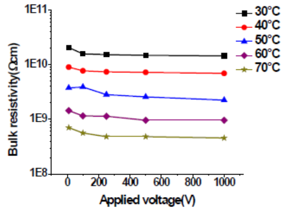
- ✓Low resistive glass ($10^{10}\Omega$.cm) developed by Tsinghua was used to build few chambers .
- ✓4 chambers were tested at DESY as well as standard GRPC(float glass)



Low resistive glass

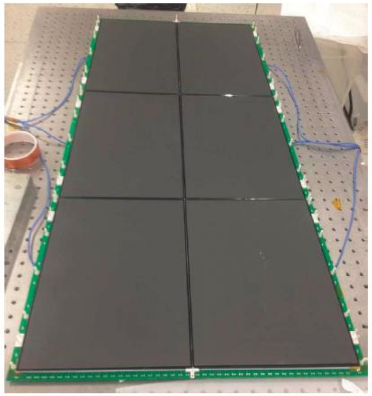


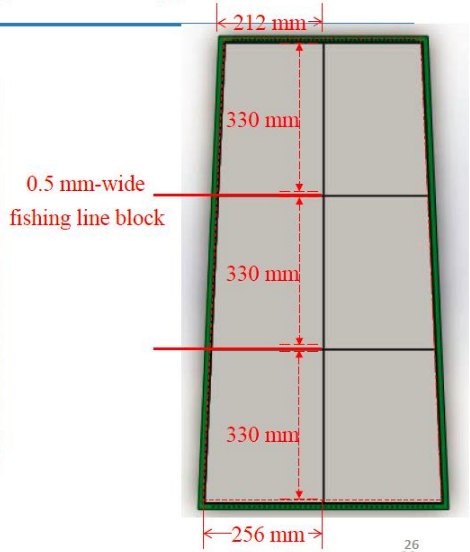
Dimension	33 x27.6cm²
Bulk resistivity	~$10^{10}\Omega$cm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20µm
Surface roughness	<10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic behavior stable up to 1C/cm²



Yi Wang (THU)
Imad Laktineh (IPNL)

Development of high rate big module





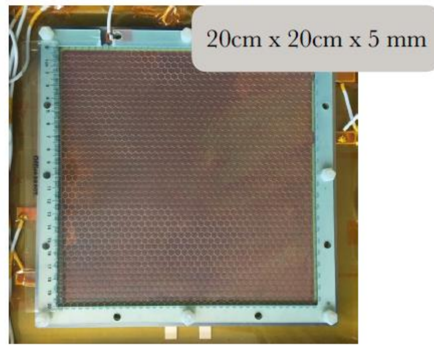
WELL-THGEM BEAM TEST

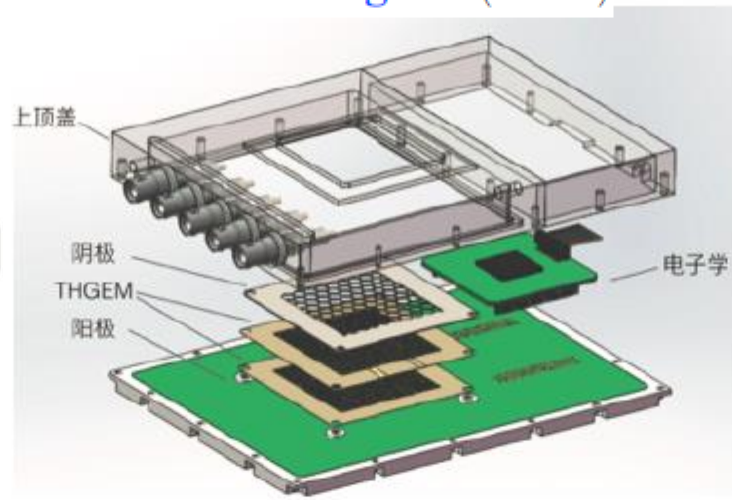
From Qian LIU/Hongbang LIU (UCAS / GXU)

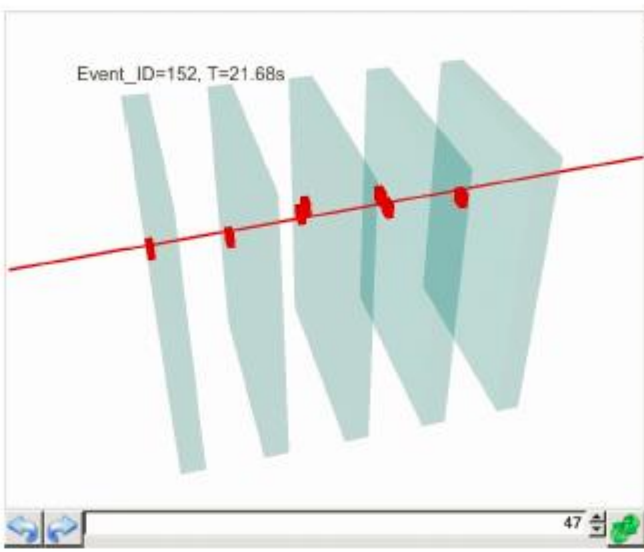
From Boxiang YU (IHEP)

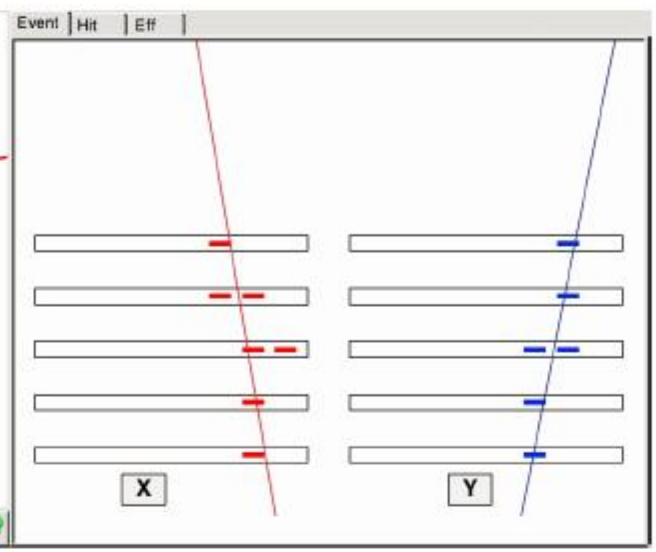
- 7 THGEMs ware installed, and 5 of them were used, and flushed with Ar/iso-butane = 97:3.
- 1 threshold, binary readout
- 900 MeV proton beam was us
- 5cm x 5cm sensitive region
- ASIC: Gastone (From INFN)

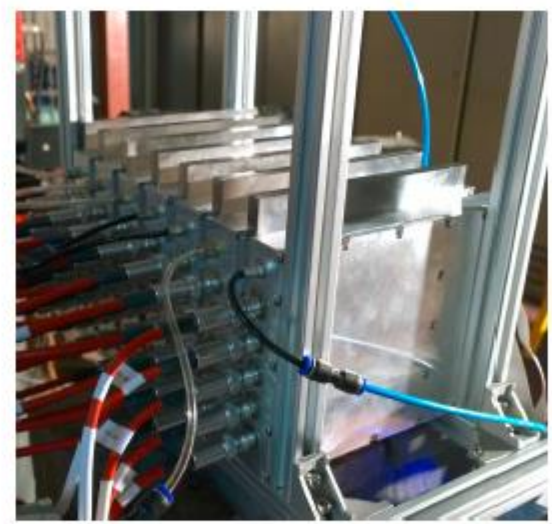
- Double layer of THGEM
- Gas: Ar/isobutane (97:3)







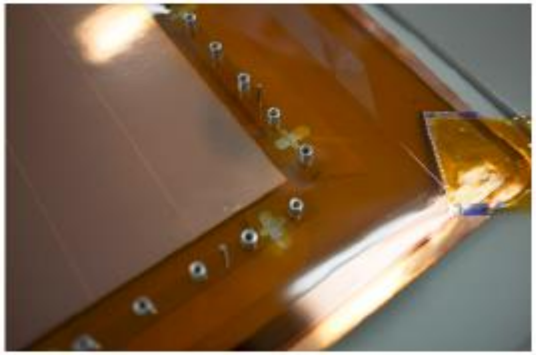


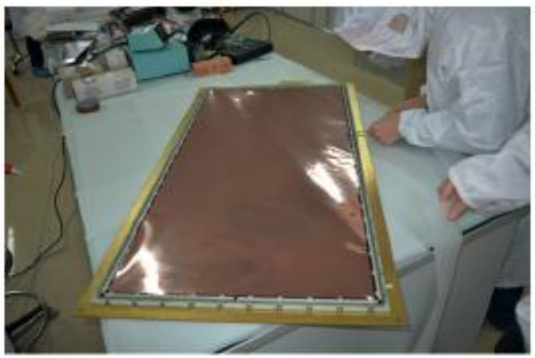
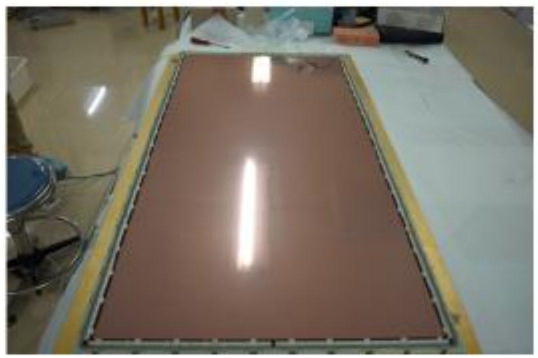


GEM R&D

From **Jianbei LIU** (USTC)

GEM assembly using a novel self-stretching technique

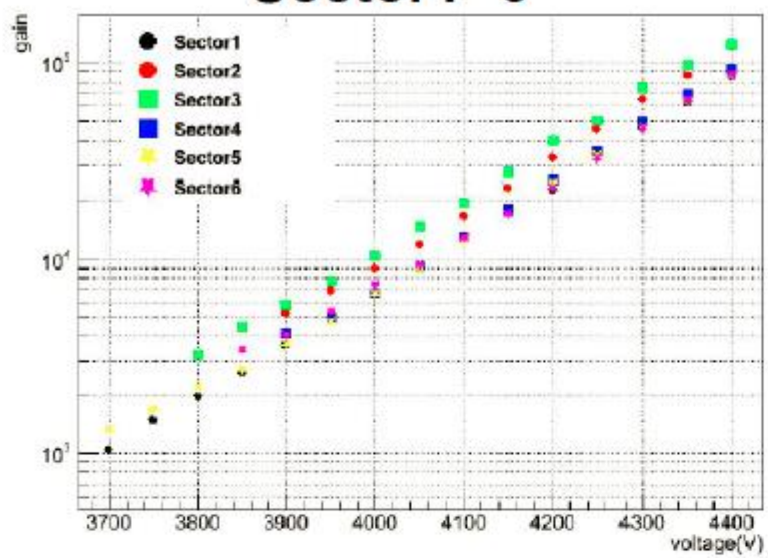


- Large-area GEM (0.5x1m^2) is one of main detector R&D focuses at USTC recently.

APV25 GEM readout **INFN APV25 chip**


Sector1~6



➔ **Resolution uniformity ~11%**

➔ **Gain uniformity ~16%**

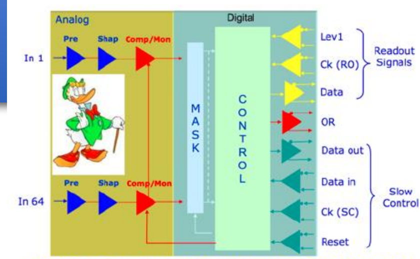
➔ **Can reach gain of 10^4 at 4000V**

CONCLUSION

- Detector simulation:
  - Granularity of calorimeters optimization
  - Number of layers of calorimeters optimization
  - Digitization (RPC/GEM/THGEM)
- Detector R&D
  - RPC (Glass RPC, Polyamide RPC)
  - GEM (double GEM structure, self-stretching)
  - THGEM (Well-THGEM, double THGEM structure)

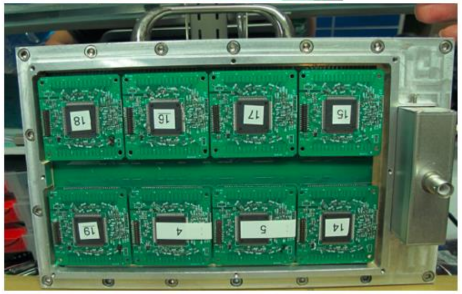
DAQ SYSTEM: GASTONE

From Qian LIU/Hongbang LIU (UCAS / GXU)



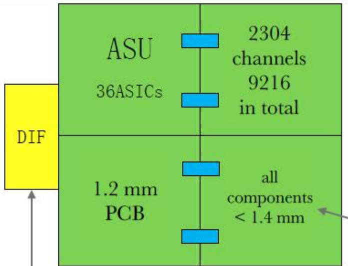
GASTONE (Gem Amplifier Shaper Tracking ON Events)

N channels	64
Chip dimensions	4.5×4.5 mm^2
Input impedance	120 Ω
Charge sensitivity	16 mV/fC (C_{det} = 100 pF)
Peaking time	90 ns (C_{det} = 100 pF)
Crosstalk	< 3%
ENC	800 e$^-$+40 e$^-$/pF
Power consumption	~6 mW/ch
Readout	Serial LVDS (100 Mbps)



HARDROC/MICROROC

From Jianbei LIU (USTC)

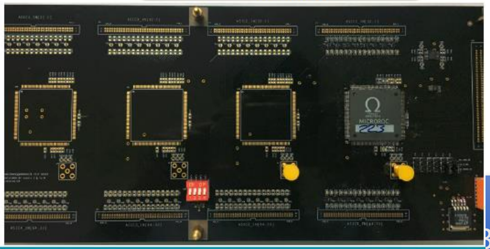


Detector InterFace (**DIF**)

Active Sensor Unit (**ASU**) Test boards

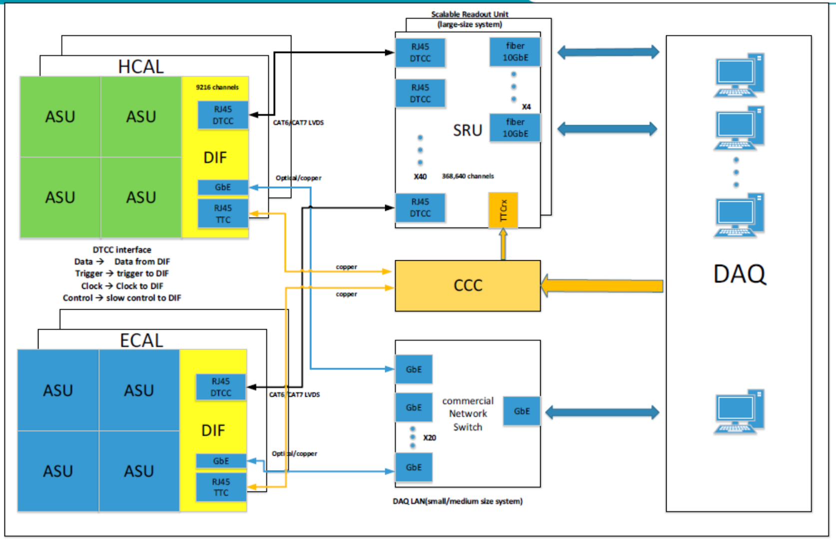
Multi-thresholds	channels	Dynamic range
Hardroc2	64	10fC~10pC
Hardroc3	64	10fC~50pC
Microroc	64	1fC~500fC

MICROROC is dedicated chip for GEM/MICROMEGAS. MICROROC (pin pin compatible with HR2b) is based on HR2b same back-end, same readout format, same pinout, only the preamplifier is changing.



DAQ SYSTEM DESIGN

From Jianbei LIU (USTC)



Muon System with MPGD

Paolo Giacomelli (INFN, Bologna)

Detectors for CEPC and SppC

- Detectors for CEPC could be built right now. They can be thought as developments of the LEP detectors, like the ILD and SID detectors for ILC
- Detectors for SppC are much more challenging and will require extensive R&D before being realised.
  - R&D for HL-LHC is a good starting point, but technologies will have to be pushed even further for SppC (and FCC-hh)
- In both cases muon detectors will be extremely large and will cover ~10000 m^2 in the barrel and 3-5000 m^2 in the forward region
- Micro Pattern Gas Detectors (MPGD) could be used now to build a muon system for CEPC, and, with a significant R&D, should be able to cope with the harsher conditions of SppC.

- Many technologies
  - GEMs
  - THGEMs
  - MicroMegas
  - μRwell

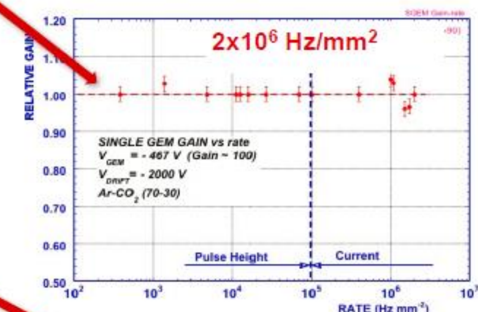
Muon systems for CEPC-SppC will be very large:

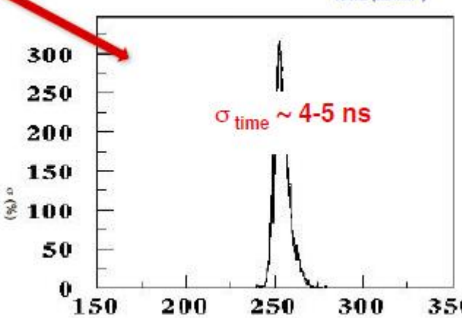
Considering a large solenoid (similar order of magnitudes in other cases as well)

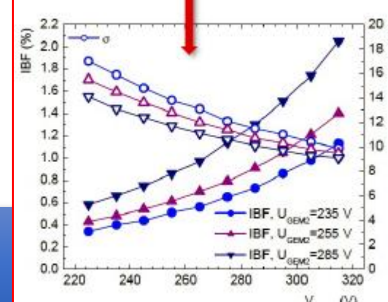
✓ o(10000) m^2 in the barrel
✓ ~ 3000 m^2 in the endcap
✓ ~ 300 m^2 in the very forward

MPGD

✓ High rate capability
✓ Excellent radiation hardness
✓ Large active areas / industrial production
✓ Good timing resolution
✓ Ion backflow/photon feedback reduction







Consideration of RICH Det. for CEPC

Zhiyong Zhang, Jianbei Liu

Motivation

Z pole measurement is one of the goals of CEPC !
The CEPC is expected to collect 10^{10-12} Zs (in CEPC's pre-CDR).

Benefits from high-stat z pole data:

- Precision test of SM & new physics searches
- Fragmentation functions & QCD
- Heavy flavor physics, spectroscopy & new hadrons
- τ-lepton physics $e^-e^+ \to Z^0 \to l^- l^+$
- others $e^-e^+ \to Z^0 \to q^- q^+$

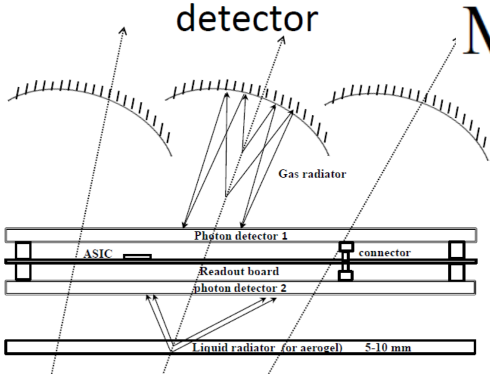
Hadron identification is crucial!
And a dynamic range of GeV to 40 GeV for κ,π is required.

Comparison of RICHs using C4F10 gas radiator.

	Forward RICH of DELPHI	RICH-1 of LHCb	CEPC RICH prototype
Goals	2.5 to 25 GeV/c	10 to 65 GeV/c	20-40GeV κ,π
Active area:	Two end caps	Two end caps	15cm *15 cm
Granularity	Depend on the time resolution (~8ns) and (~5cm/μs) etc.	2.5*2.5 mm2	If 2.5*2.5mm2
Angle resolution	2.8 mrad	1.6mrad	2 mrad
Channels	26880	~200k	3600
Sensitive detector	MWPC (fast electrons signal rise time ~ns)	Silicon detector (rise time ~ 5ns)	Hybrid (THGEM+Mmegas, rise time: ~100ns)
Charge	3fC(or 30) (single photoelectron) to 1000fC (ionization)	5000e- = 8fC	$2*10^5$ e- = 30fC to ~900fC (ionization)
Event rate:	<25 KHz ?	40MHz	?
measurements	Digital time	Charge	Digital(Analog)

Design considerations for the RICH detector

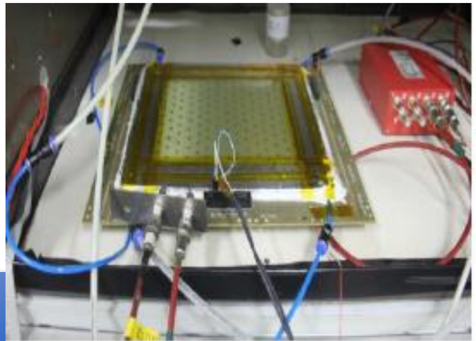
Structure:



- Gas radiator (C4F10 or C5F12): several GeV to 40 GeV
- Liquid Radiator (C6F14) or Silica aerogel : sub-GeV to 10 GeV

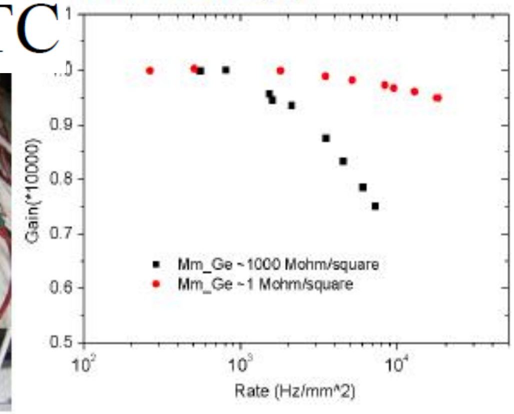
Micromegas R&D at USTC

A 200×200 mm² prototype under testing



A typical ^{55}Fe x-ray spectrum

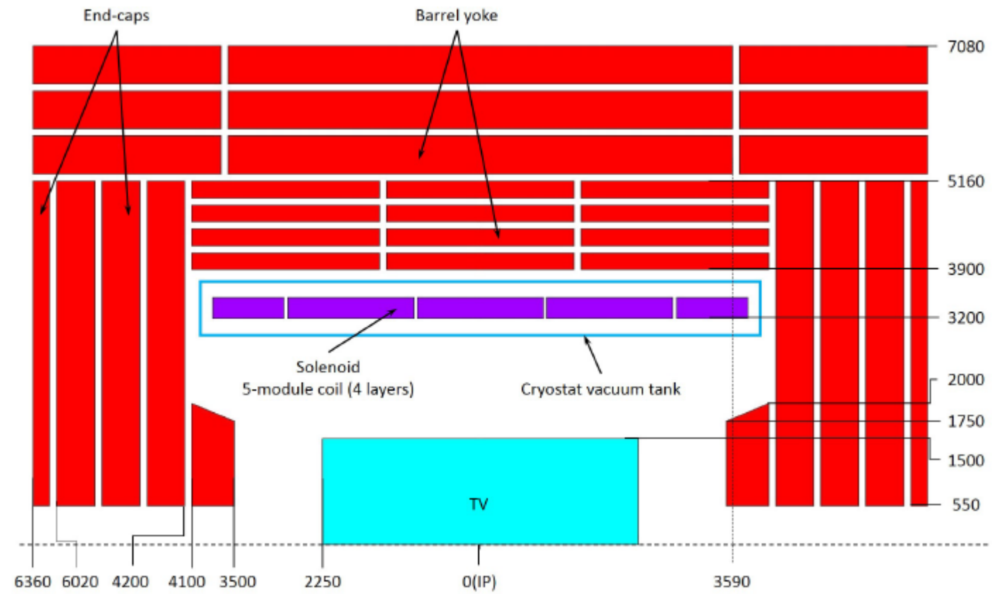
Gain vs the particle rate (8 keV Cu x-rays)



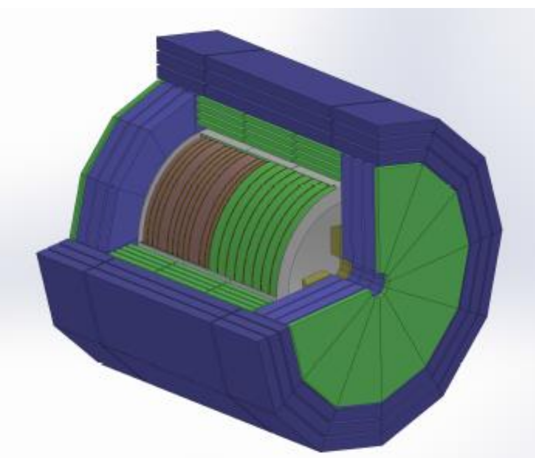
Gas gain versus mesh

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

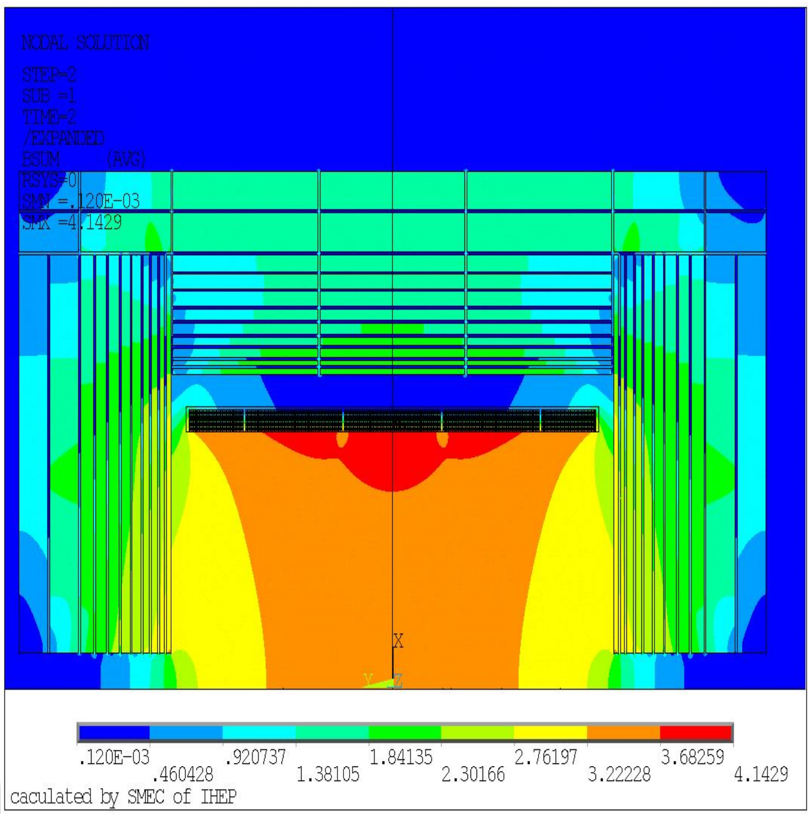
The solenoid central field(T)	3.5	Nominal current(KA)	18.575
Maximum field on conductor(T)	3.85	Total ampere-turns of solenoid(MAt)	23.925
Coil inner radius(mm)	3600	Inductance(H)	10.4
Coil outer radius(mm)	3900	Stored energy(GJ)	1.8
Coil length(mm)	7600	Stored energy per unit of cold mass(KJ/kg)	10.91

Progress of field design

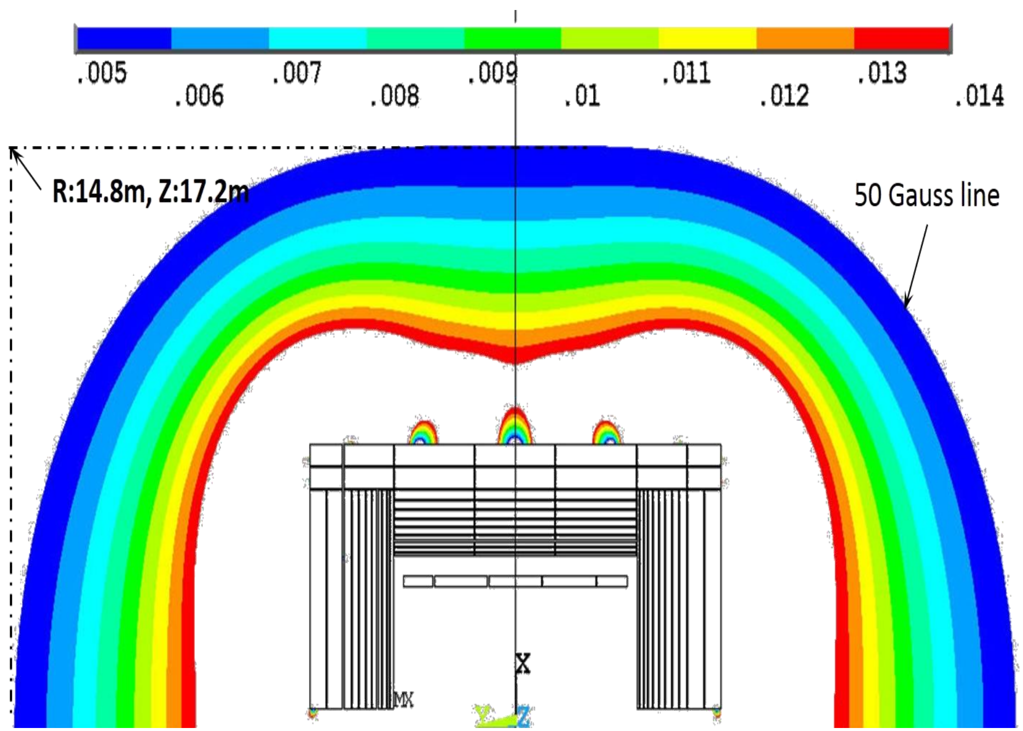
Feipeng Ning

Magnetic field distribution：central filed 3.5T， the Peak-peak field percent deviation of TV is 10.1%

The 50 G line is at 14.8 m radial distance and 17.2 m axial distance with a total thickness of iron of 2.44 m both in the barrel and the two end-caps with the 3.5 T central field.



Magnetic field distribution(unit： T)

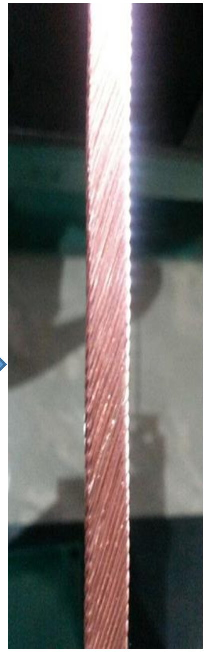


Stray field distribution outside the magnet (the field is given in T)

Progress of the Rutherford cable

Ling Zhao

No. of strands： 20
Strand R.： 1.0mm
Materiel: Copper
Complete:2015.5



No of strands： 17
Strand R: 0.727mm
Materiel :Nb/Ti
Complete:2015.7

No of strands： 24
Strand R： 0.727mm
Materiel :Nb/Ti
Complete:2015.8

Number of strands： 18
Strand diameter： 1.2mm
Materiel :Nb/Ti
Complete time:2016.2

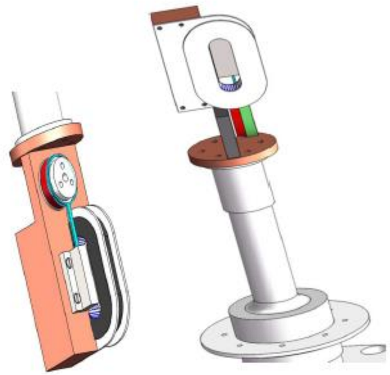
Number of strands： 32
Strand diameter： 1.2mm
Materiel :Nb/Ti
Tangle： 17.32
Length： 》100m
RRR： 》100
Complete time:2016.5

Number of strands： 32
Strand diameter： 1.2mm
Materiel :COPPER+Al
Length： 1m
Complete time:2016.8
Shear strength（copper &Al）： 8.85MPa

Cable research has made great progress!

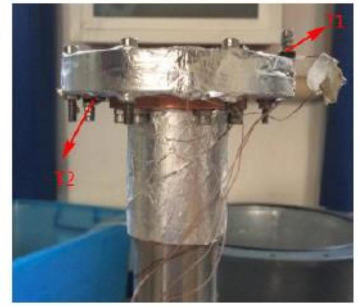
Ling Zhao

Development of testing device



Ic test by induction method

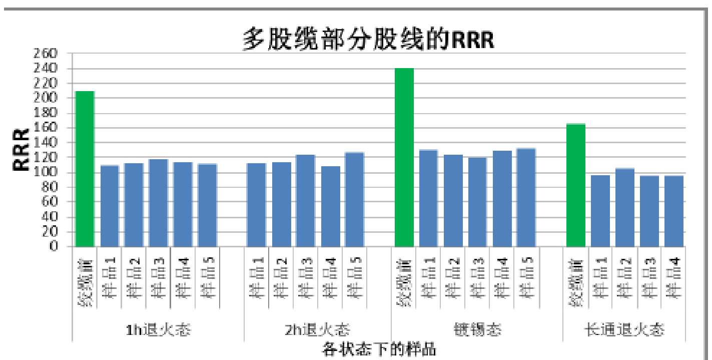
Testing device is based on a small refrigerator.



RRR value test

Testing device based on small refrigerator for Ic and RRR value have put into use.

Cable test results



Test by WTS

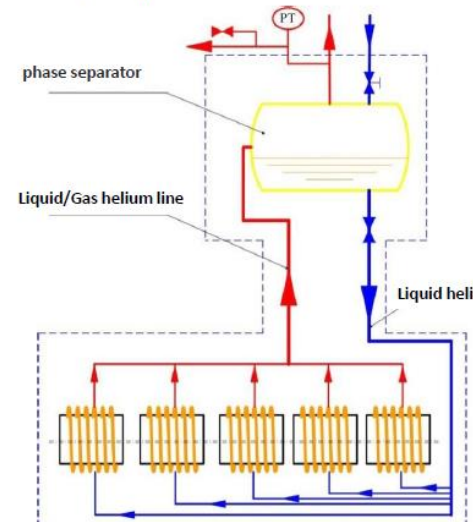
1. RRR value declined by about 1/3 after the stranding process

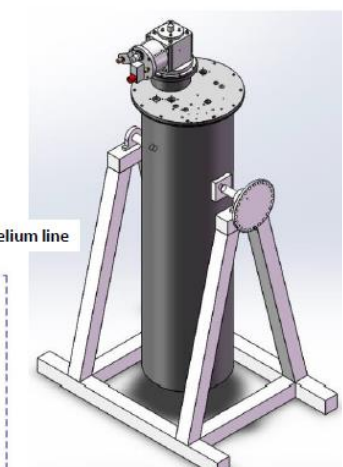
2.Less affected by larger twist pitch of strands.

Meifen Wang

Progress of cooling system

- The coils are cooled by conductive method.
- A thermal siphon principle experiment platform was built based on liquid nitrogen. The next plan is based on liquid helium.





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) and NSFC support, we are speeding up R&D of critical detector technologies and optimization.
- MDI: work with accelerator group to optimize design
- Feasibility studies of detector prototypes.
- International collaboration are needed
- Aiming for CEPC CDR and TDR in next 5 years.

Many thanks to all members of CEPC Physics and Detector working group

- **Physics and Detector Group Co-conveners**

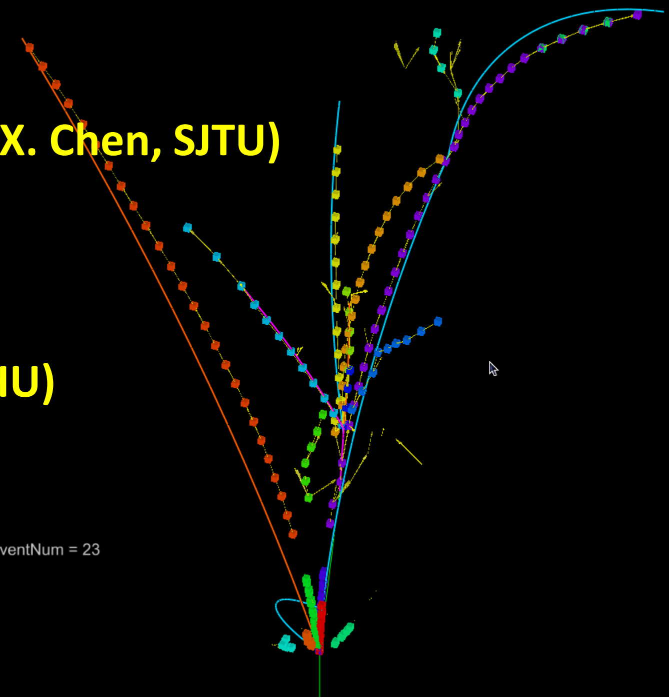
  Yuanning Gao (THU), Shan Jin (IHEP), Nu Xu (CCNU)

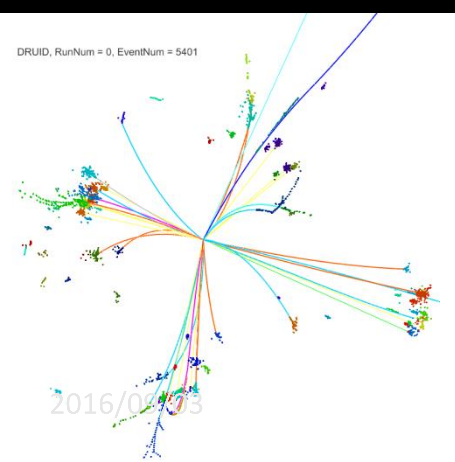
- **Sub-groups and co-conveners**
  - Physics simulation and analysis:
    Gang Li, Manqi Ruan, Yaquan Fang (IHEP)
  - MDI: Hongbo Zhu (IHEP), Yiwei Wang (IHEP)
  - Vertex: Qun Ouyang (IHEP), Meng Wang (SDU)
  - TPC tracker: Yulan Li (THU), Huirong Qi (IHEP)
  - ECAL and HCAL :
    Tao Hu (IHEP), Jianbei Liu (USTC), Haijun Yang (SJTU)
  - Muon: Boxiang Yu (IHEP), Liang Li (SJTU)
  - Magnet: Ling Zhao (IHEP)

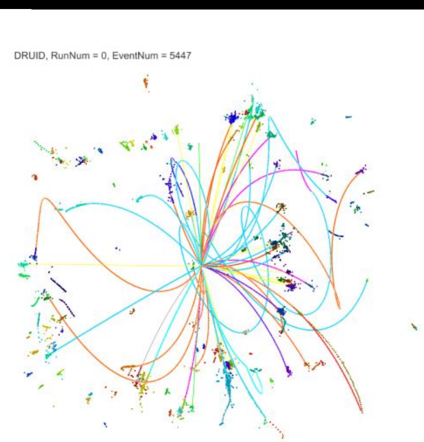
Backup Slides

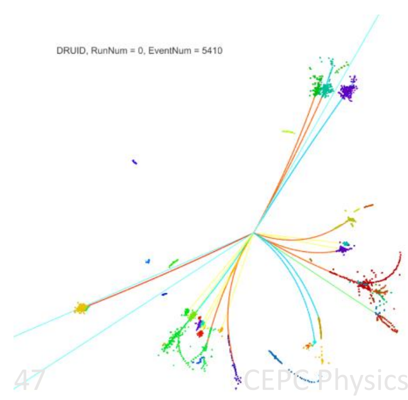
Simulation & Reconstruction Software

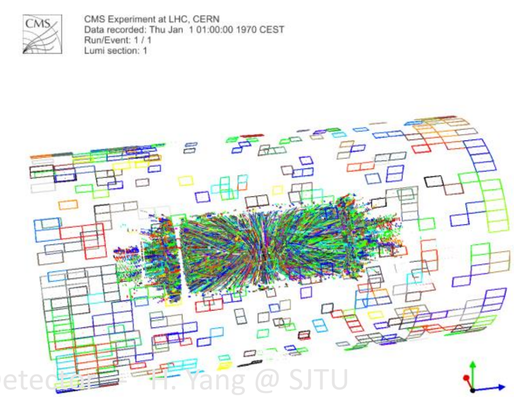
- **Geant 4 Full Detector Simulation:**
  - Geometry can be edited freely (Y. Xu, NKU & X. Chen, SJTU)
  - A set of geometries has been generated
- **Reconstruction Chain**
  - Tracking: Clupatra & ILD tracking (B. Li, etc THU)
  - PFA: Arbor (M. Ruan, etc, IHEP)
  - Flavor Tagging: LFCIPlus (G. Li,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









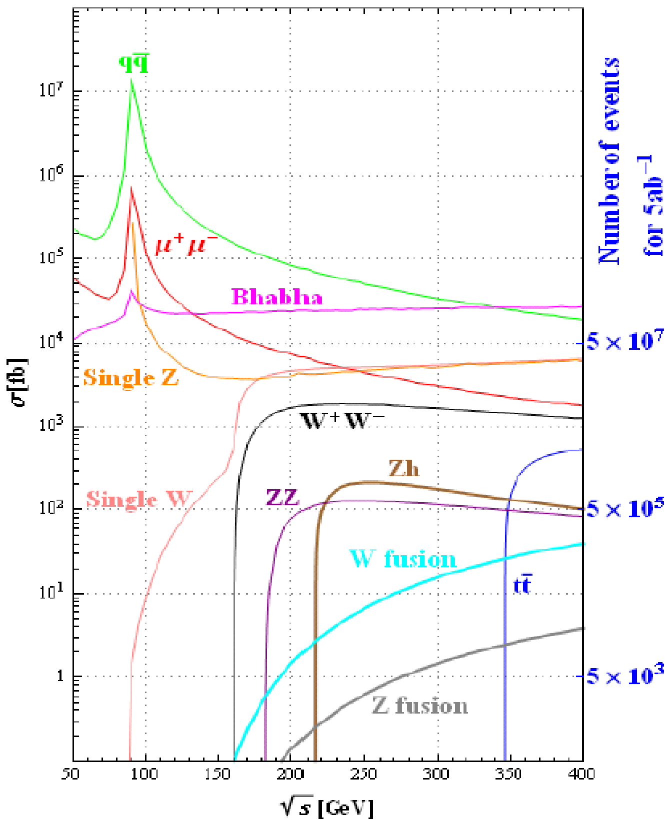


MC Samples & Computing Resources

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
$e^+e^- \to qq$
$e^+e^- \to \mu\mu, \tau\tau$
$e^+e^- \to WW$
$e^+e^- \to ZZ$
$e^+e^- \to ZZorWW$
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

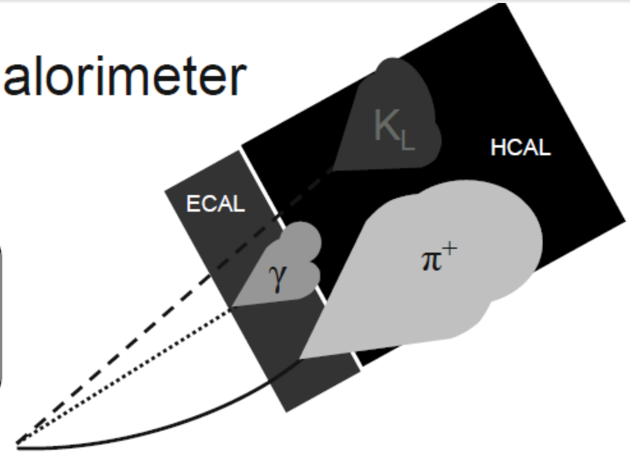
Overview

Continuous efforts + dedicated training

We have a group of faculty + students...

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**

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

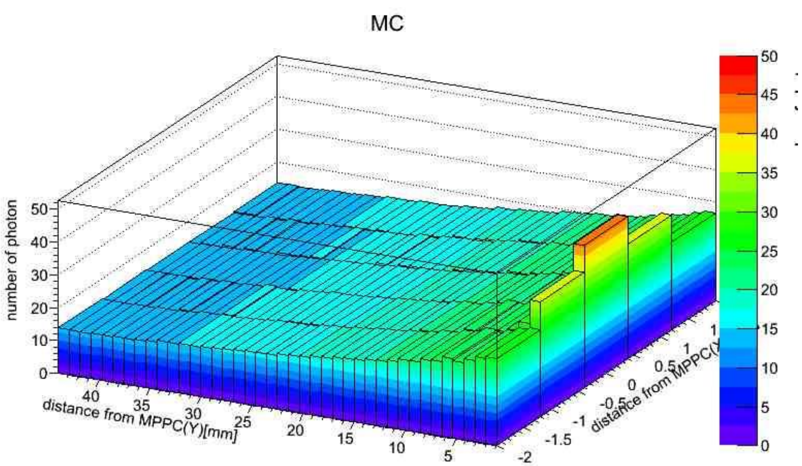
- Online beam luminosity monitor allowing fast beam tuning
  - radiation hard sensor technologies (e.g. CVD diamond), to measure radiative Bhabha events at zero photon scattering angle ← similar design as for the SuperKEKB design

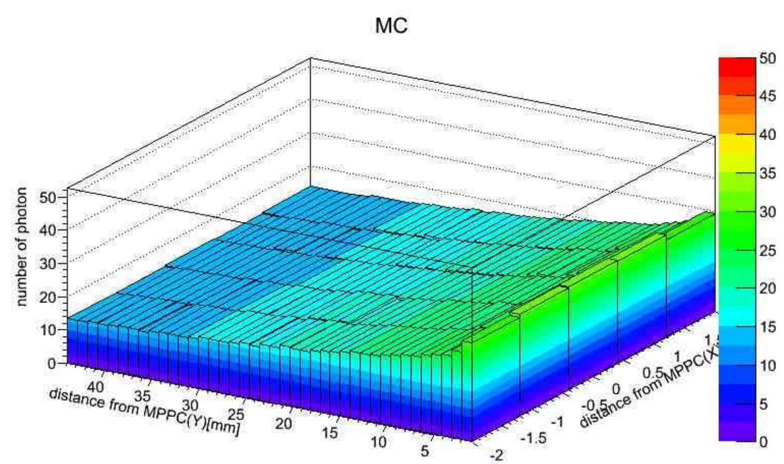
Scintillator Strip Shape Optimization

SiPM sensor area 1×1 mm^2 ➔ 0.25×4 mm^2:

➔ to increase photon acceptance

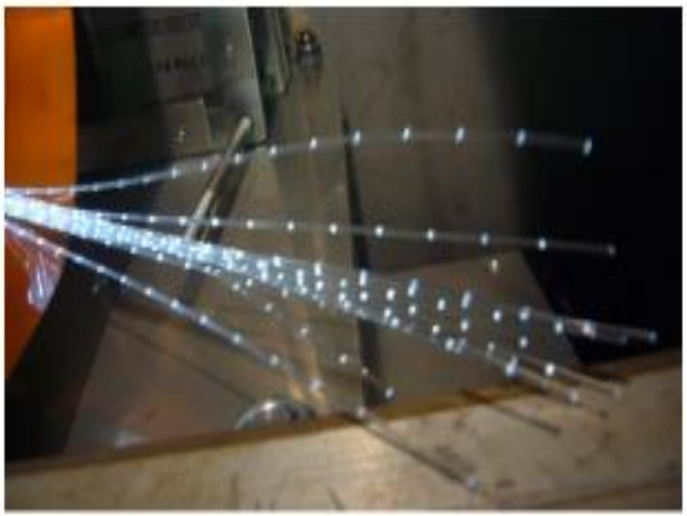
➔ It is easy to make this shape of MPPC with current technology

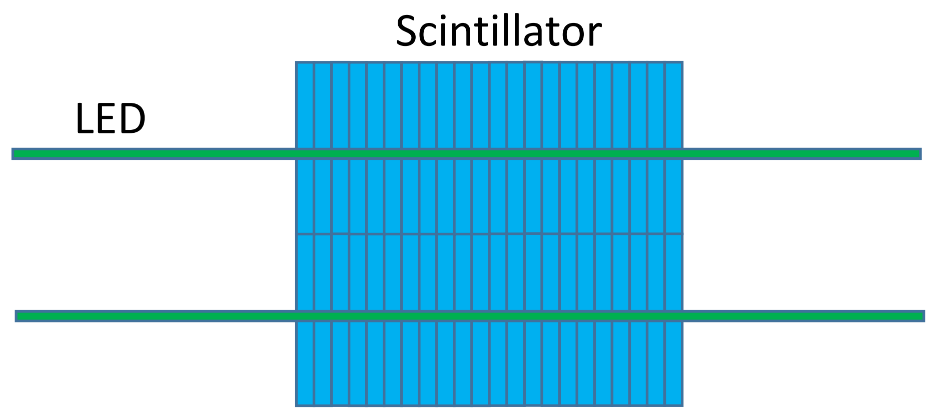


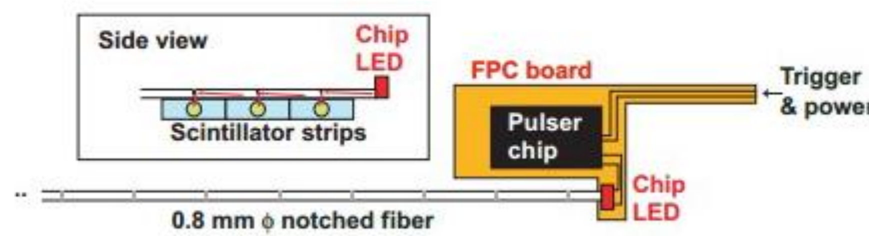


Calibration for Scintillator and SiPM

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.





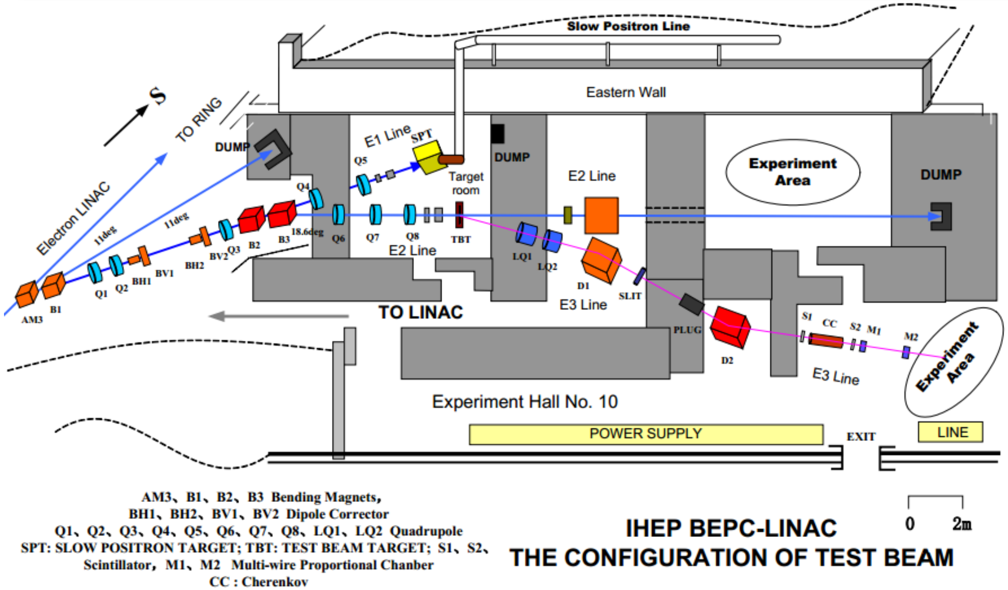


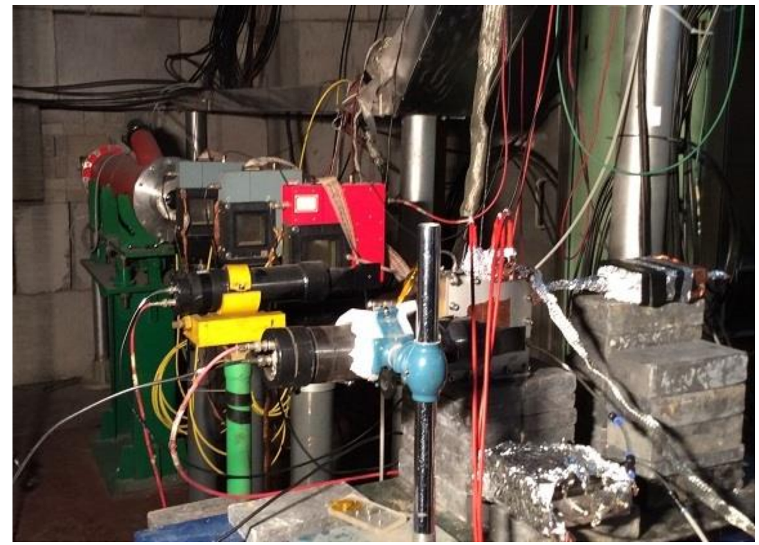
LED – Fiber calibration system:

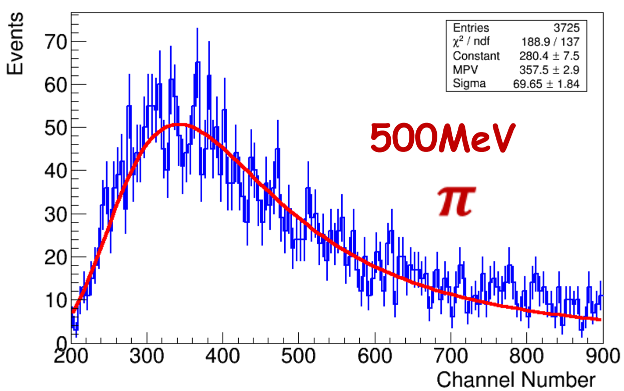
- A pulse generator, a chip LED connect to notched fibers
- Notched Fiber distribute lights to ~ 80 scintillator strips

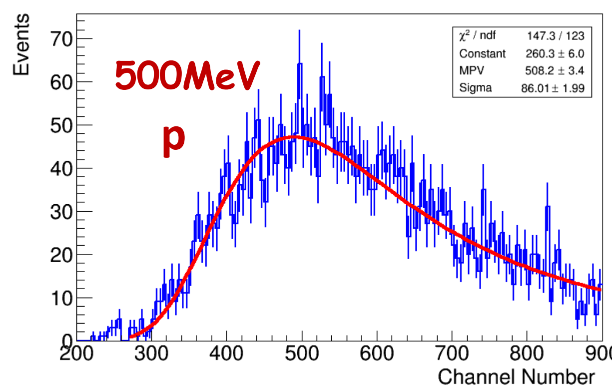
WELL-THGEM Test Beam at IHEP

Hongbang Liu @ GXU







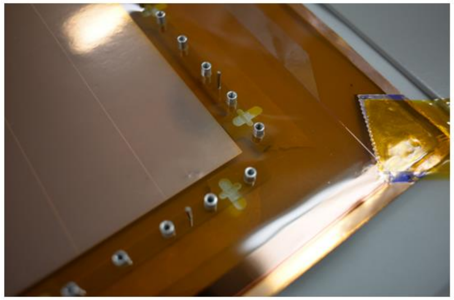


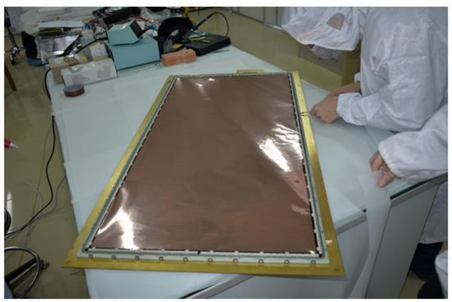
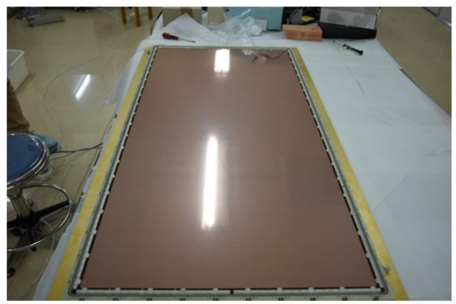
Well-THGEM, Ar/3%iC_4H_{10};

Large-area GEM @ USTC

Jianbei Liu (USTC)

GEM assembly using a novel self-stretching technique

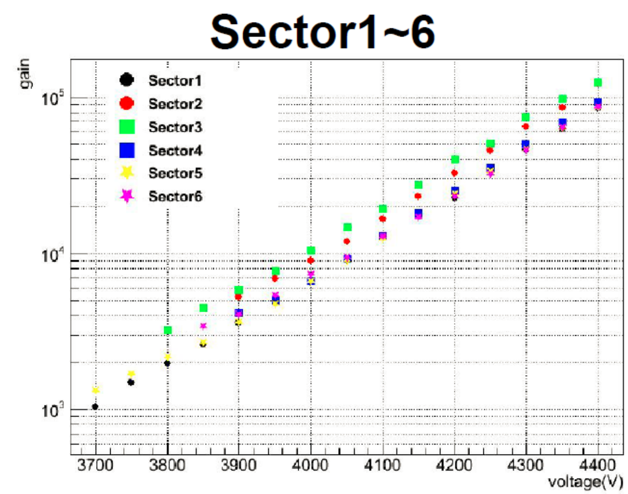


- Large-area GEM (0.5x1m^2) is one of main detector R&D focuses at USTC recently.
- Technology has been developed and matured to produce high-quality GEM detectors as large as ~1m^2 that are also applicable to CEPC DHCAL.

APV25 GEM readout

INFN APV25 chip



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

CEPC Vertex and Silicon Tracker

Ouyang Qun @ IHEP

B = 3.5T

Performance requirements

- momentum resolution

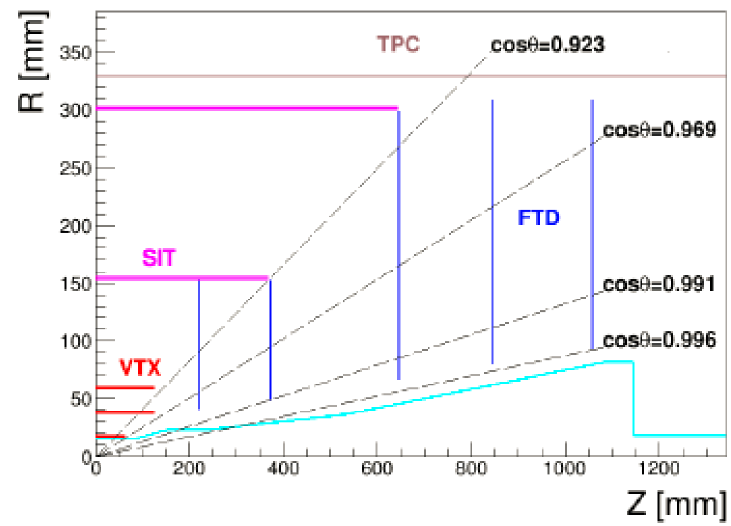
$$\sigma_{1/p_T} = 2\times10^{-5} \oplus 1\times10^{-3}/(p_T \sin\theta)$$

- 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 : *≤$3\times10^{11} n_{eq}/(cm^2\, yr)$*
- first layer located at a radius: *~1.6 cm*

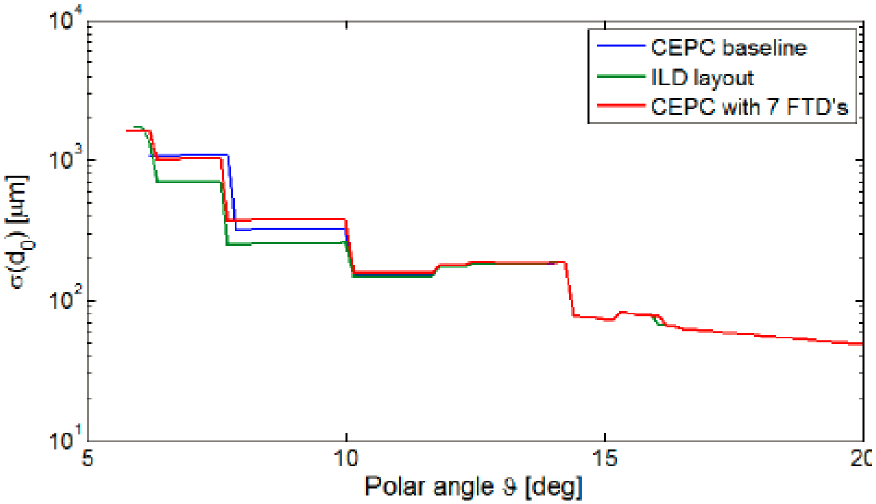


Silicon tracker specifications:

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

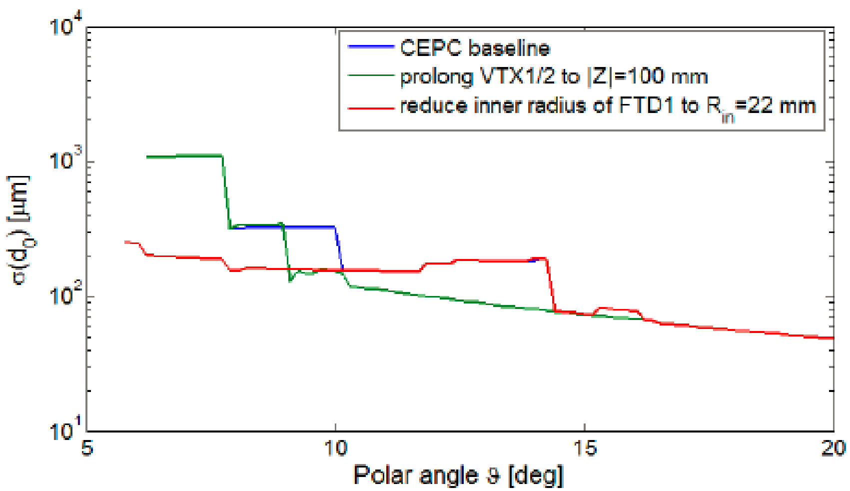
Forward region with L* = 1.5m

- 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

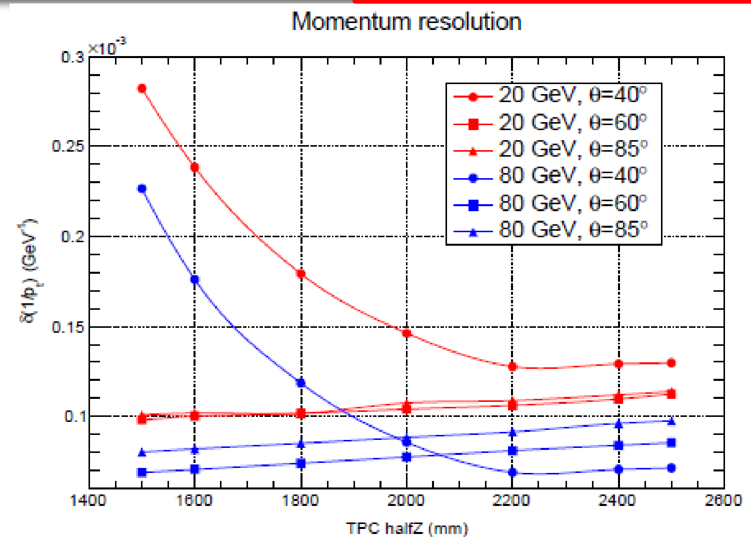
  Starting design with HR-CMOS process

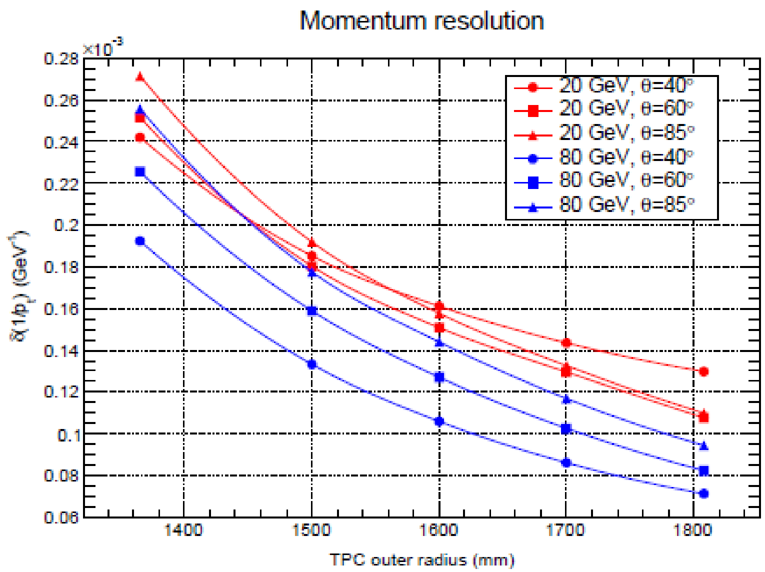
  Exploring possibility with SOI process, especially for smaller pixel size
- Light weight mechanical design and cooling
  - 0.05%(0.1%) material budget without(with) cabling
  - Air cooling technology with acceptable vibration due to air flow
- Pixel sensor thinning to 50μm
- Slim edge silicon microstrip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

CEPC TPC Conceptual Design

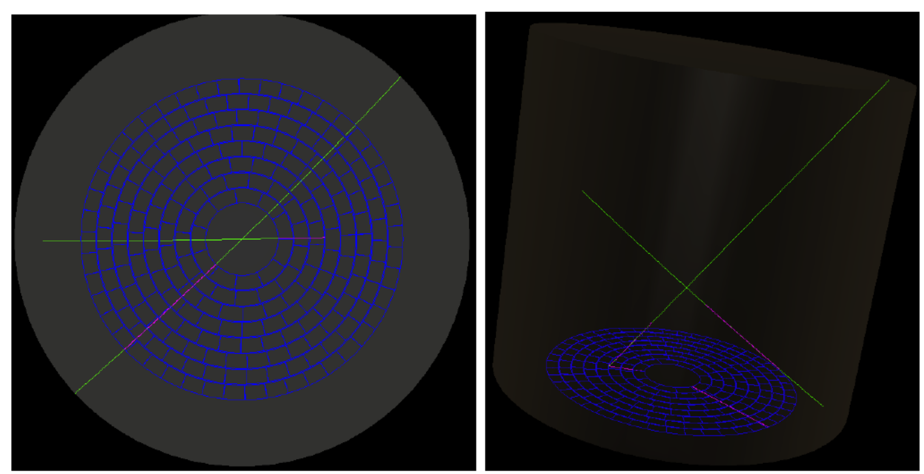
Huirong Qi @ IHEP

- **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: $10 \times 1.6\ mm^2$
- Spatial resolution as a function of drift distance (B=1T)
- Best performance:

  $\sigma_x = 100\mu m$ @Z~100mm

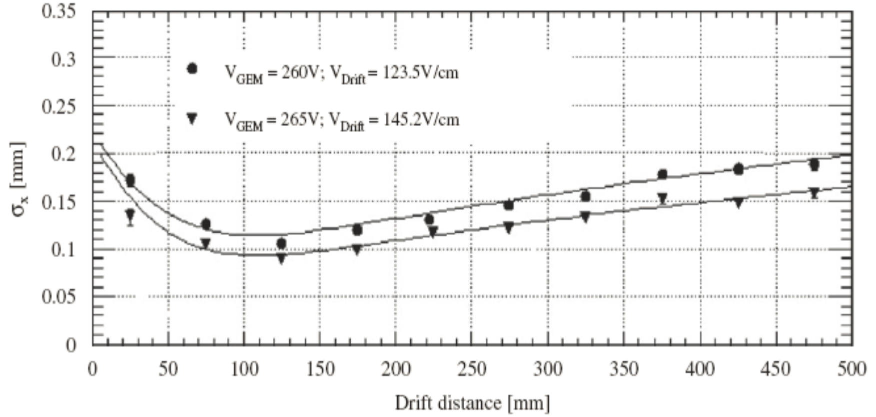
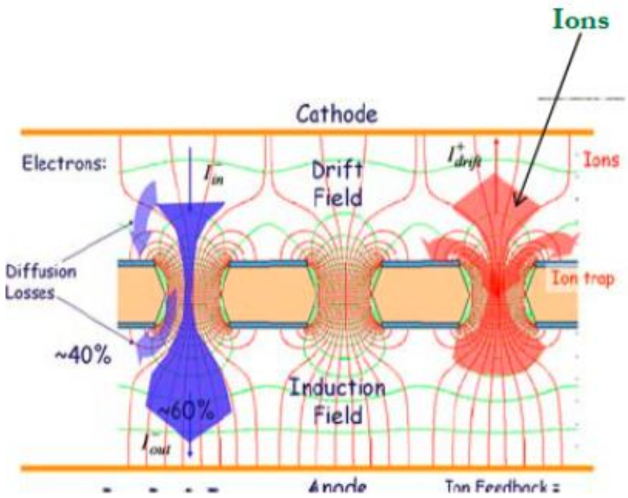


Fig. 6. *x*-Resolution for Ar–Iso–CF4 = 96.3–3.1–0.6 gas with $B = 1$ T under two different test conditions ($\varphi < 2°$, $\theta < 10°$).

CEPC TPC: Critical R&D plan

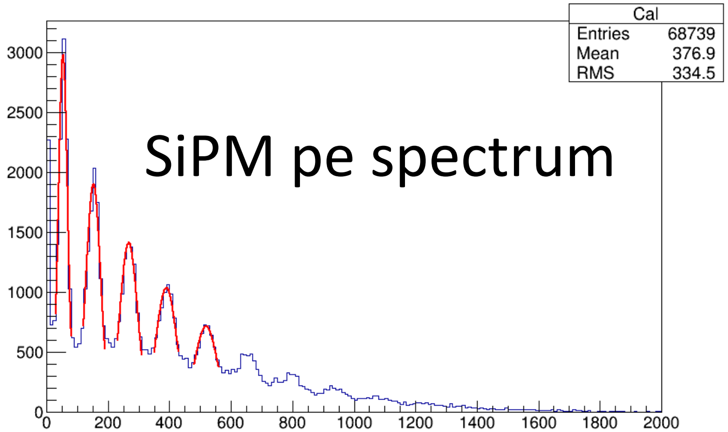
- Physical design and optimization of the TPC
  - Length, inner/outer radius, pad size
  - E/B fields and uniformity requirements
  - Working gas, counting rate, ion backflow suppression
  - The time structure of the beam
  - Sensors: GEM and Micromegas detectors ?

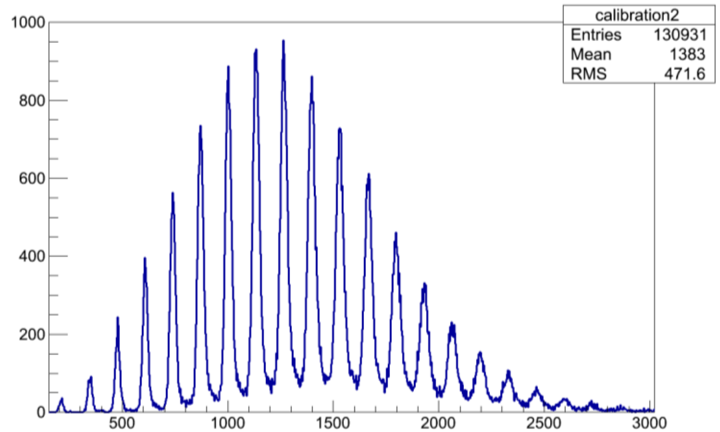


IBF of GEM

- 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)

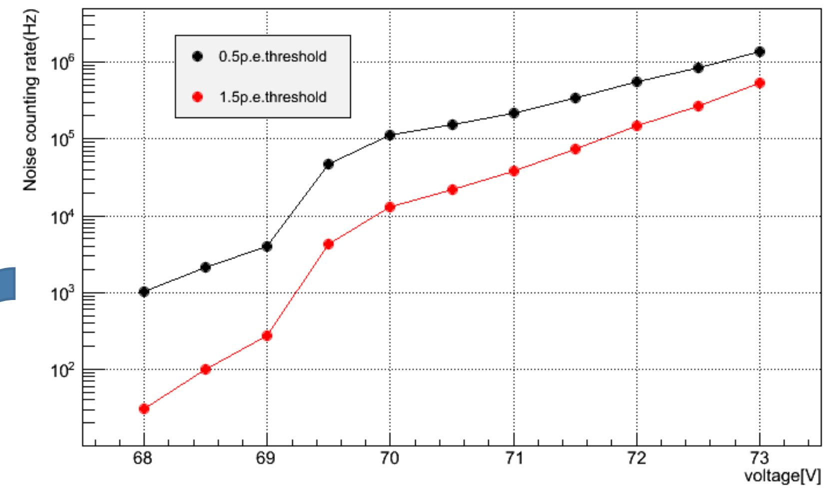
Tests of SiPM and Strip Optimization



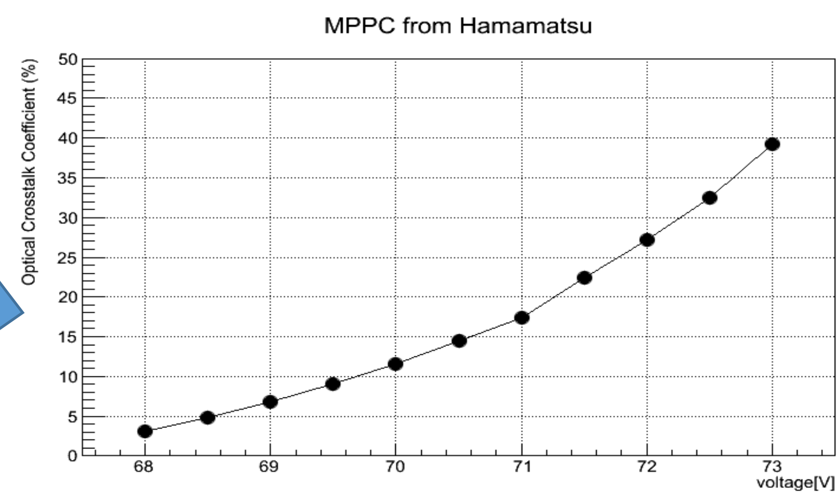


pulse height spectrum.

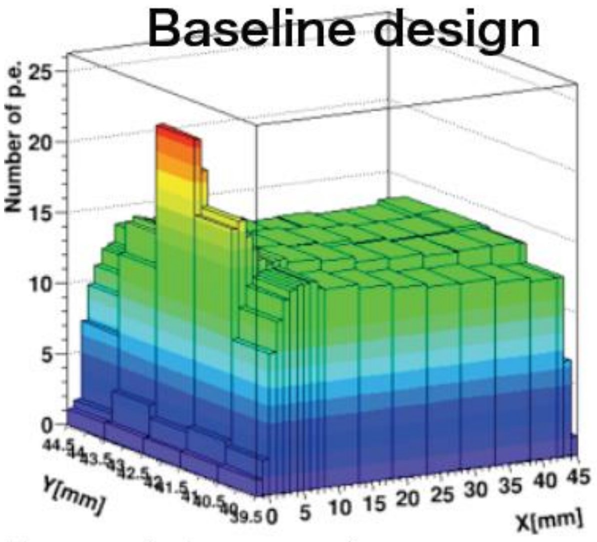
Excellent photon counting

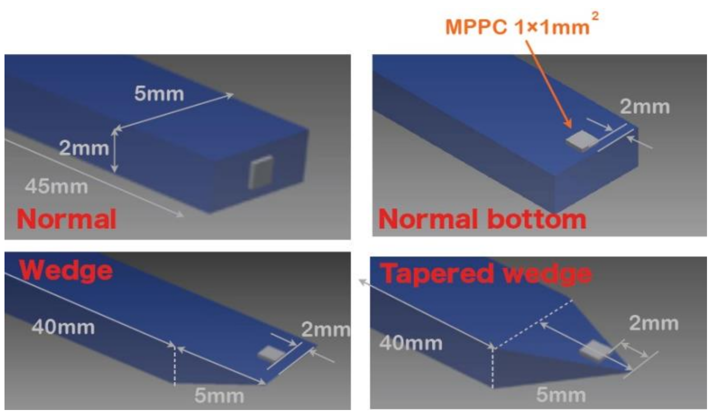


Crosstalk rate = Events (> 1.5p.e)/Events (>0.5p.e)

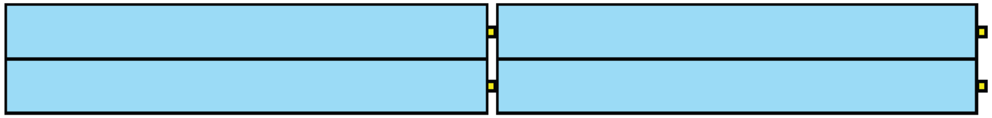


Scintillator Strip Structure Optimization



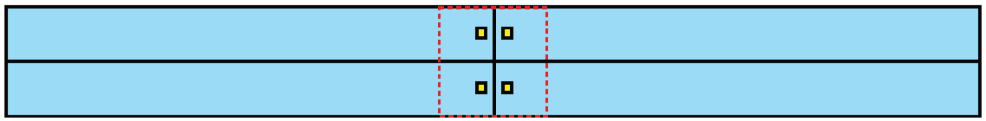


Normal

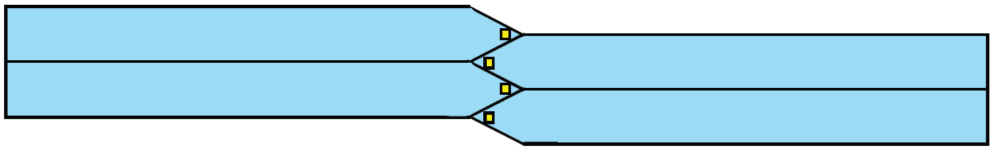


With normal design, the signal is not uniform with peak response for hits near SiPM. What's more, the dead gap between strips is large due to SiPM installation.

Wedge



Tapered wedge

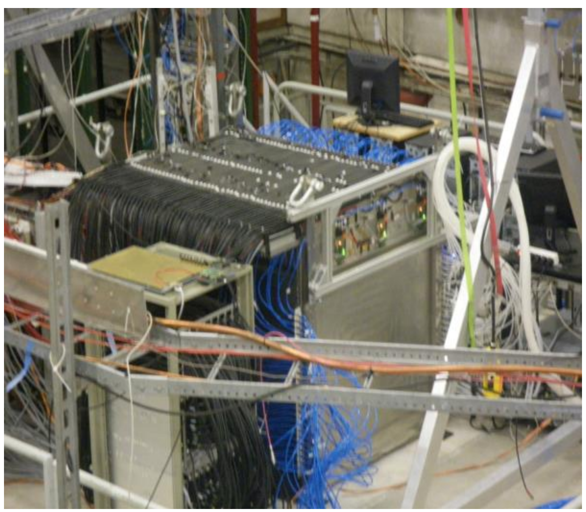


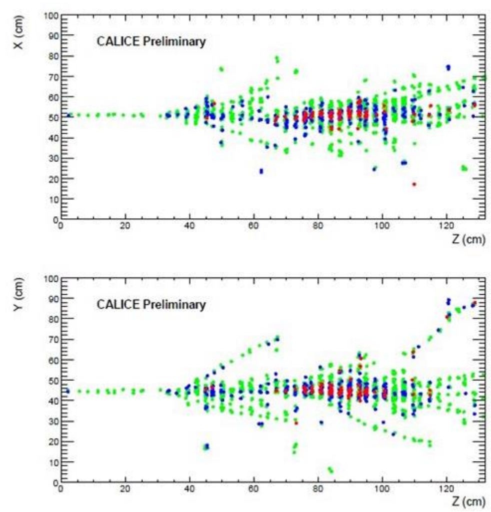
Need MC simulation and experimental tests to optimize the strip structure design.

Prototypes of DHCAL with RPC

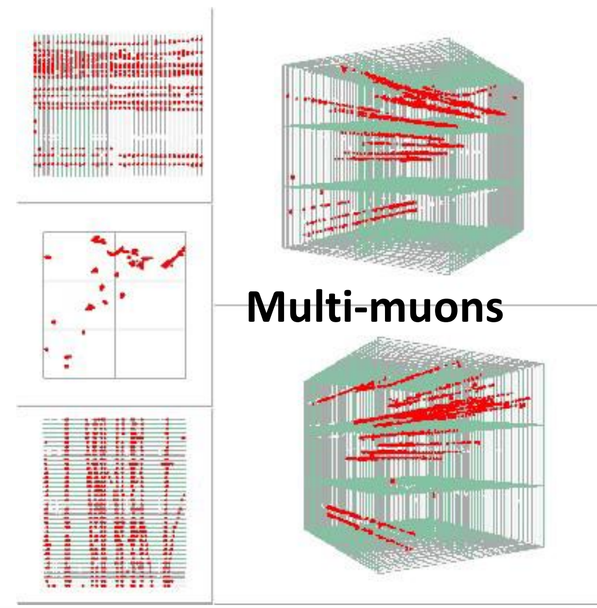
Prototypes of DHCAL based on RPC

- **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





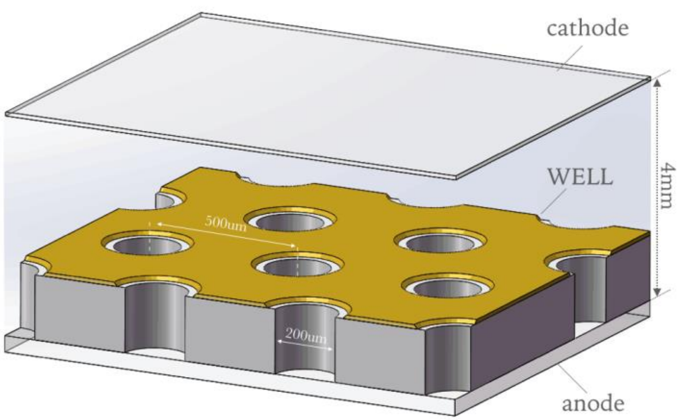
80 GeV Pion

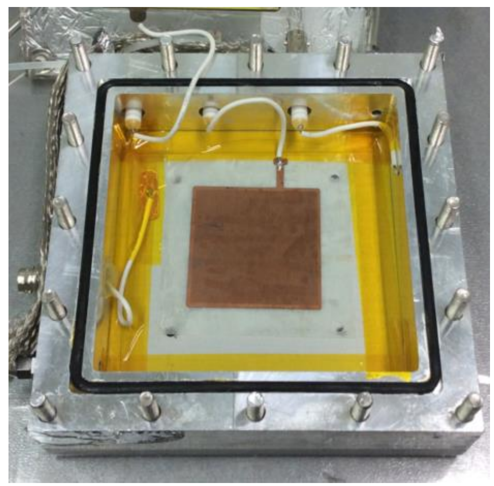


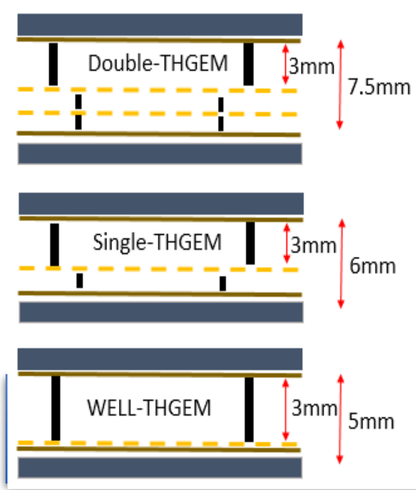
Multi-muons

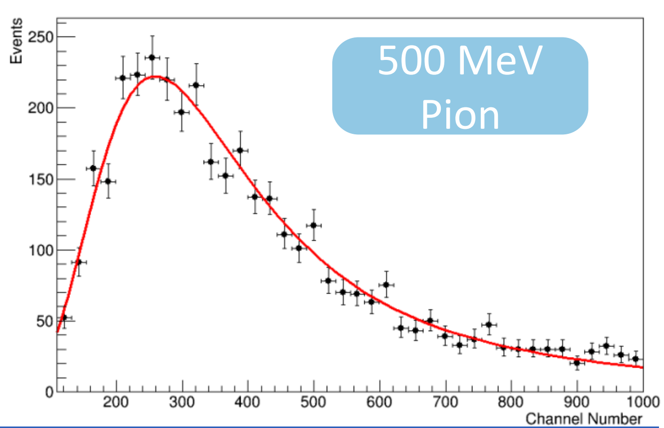
WELL-THGEM Beam Test at IHEP

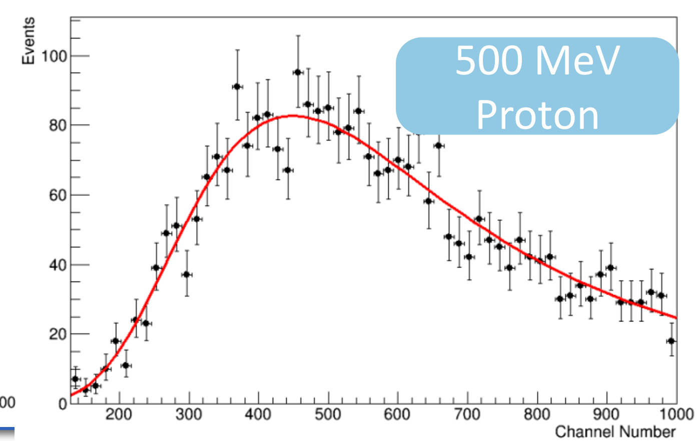
- **Detection efficiency of well-THGEM was measured with BEPC pion / proton beams.**
- **Efficiency:**
  - Ar/iso (97/3) ,Gain ~ 2000; Eff (proton) > 93%; Eff(Pion) > 82%
  - Ne/CH4 (95/5) ,Gain ~ 9000; Eff (proton) > 99%; Eff(Pion) > 94%







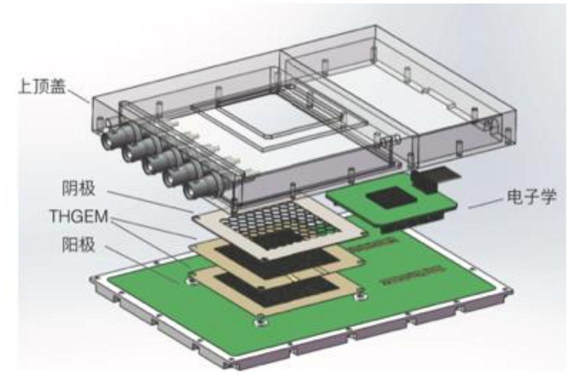


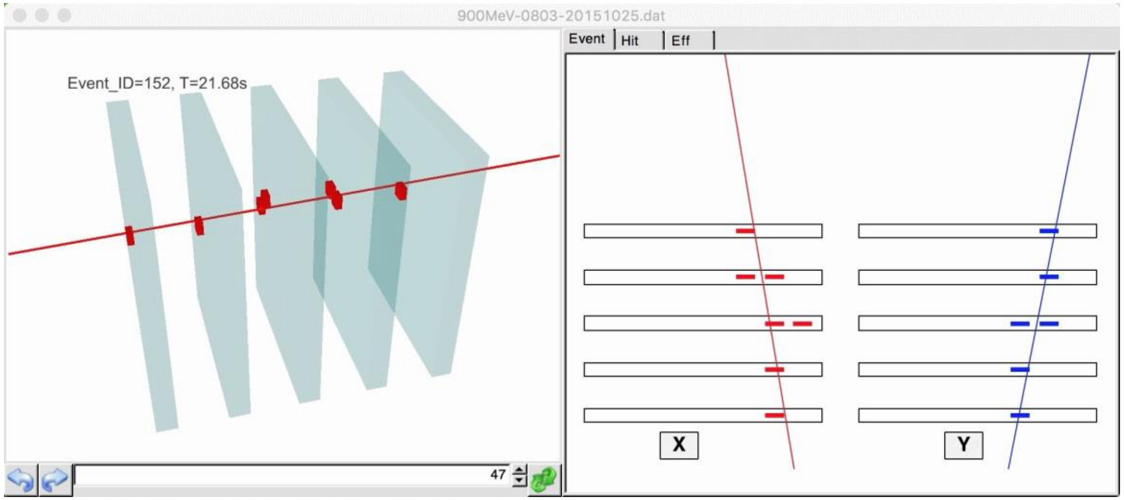


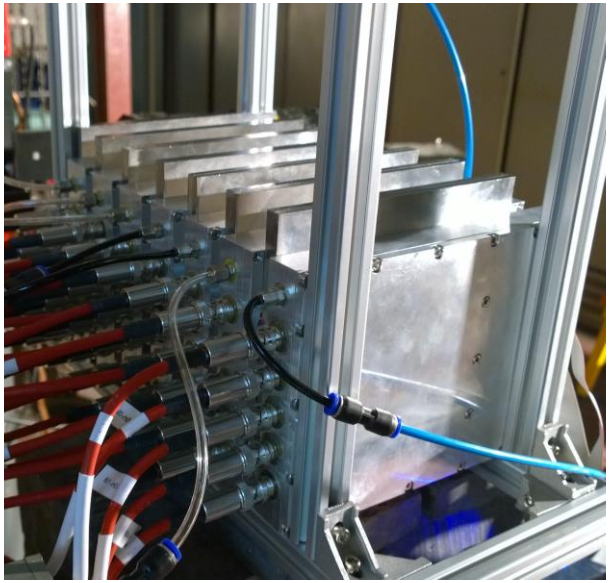
WELL-THGEM Beam Test in Oct., 2015

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



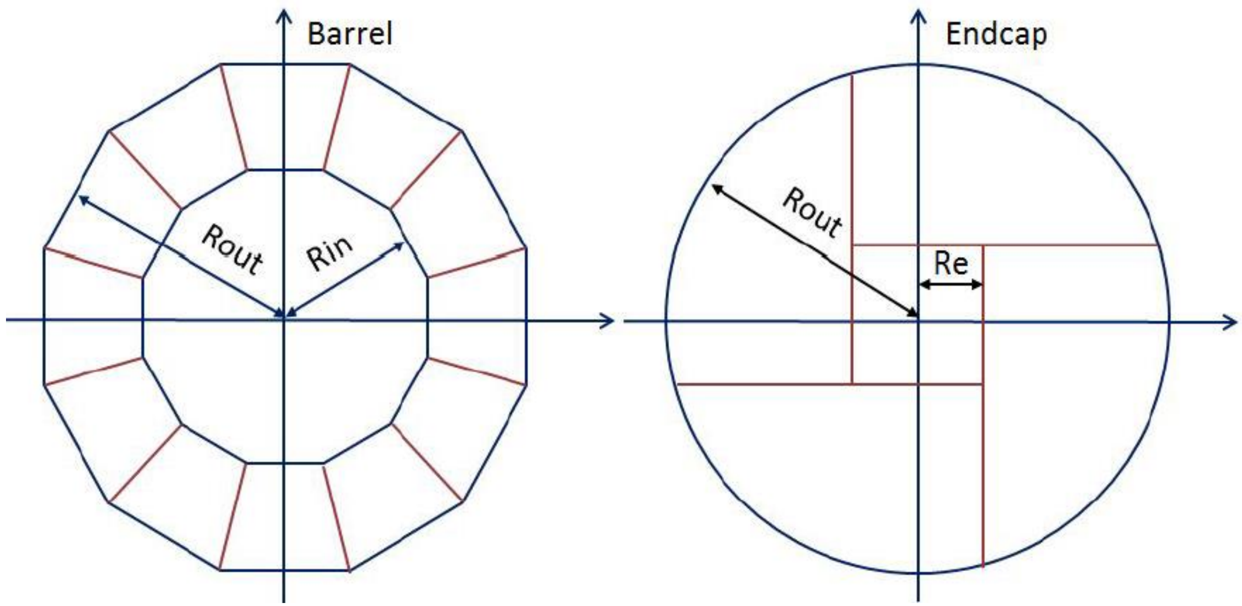




Hadron Calorimeter

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

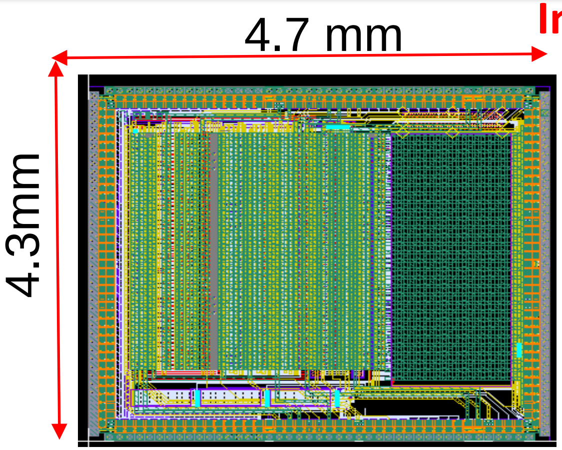
- **Active sensor**
  - Glass RPC
  - Thick GEM or GEM
- **Readout (1×1 cm^2)**
  - Digital (1 threshold)
  - Semi-digital (3 thresholds)



Electronics Readout System R&D

Imad Laktineh (IPNL)

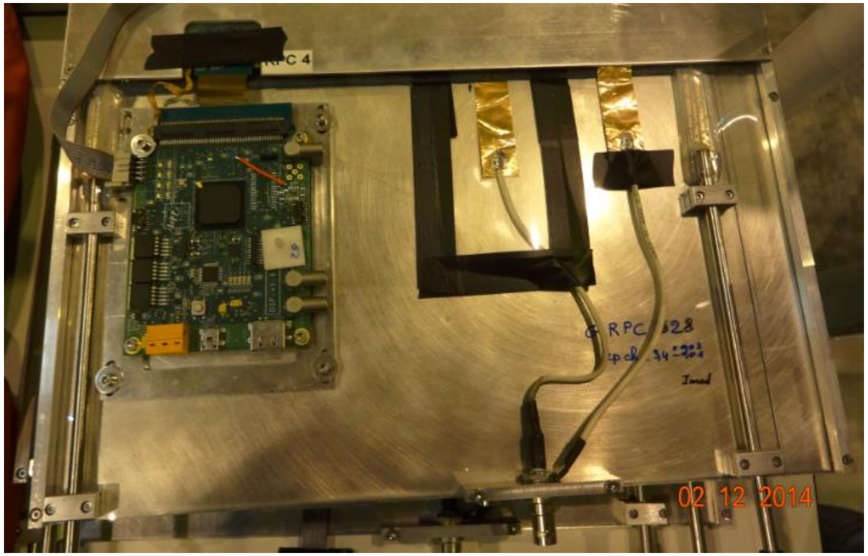
ASICs : HARDROC2
64 channels
Trigger less mode
Memory depth : 127 events
3 thresholds
Range: 10 fC-15 pC
Gain correction → uniformity



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

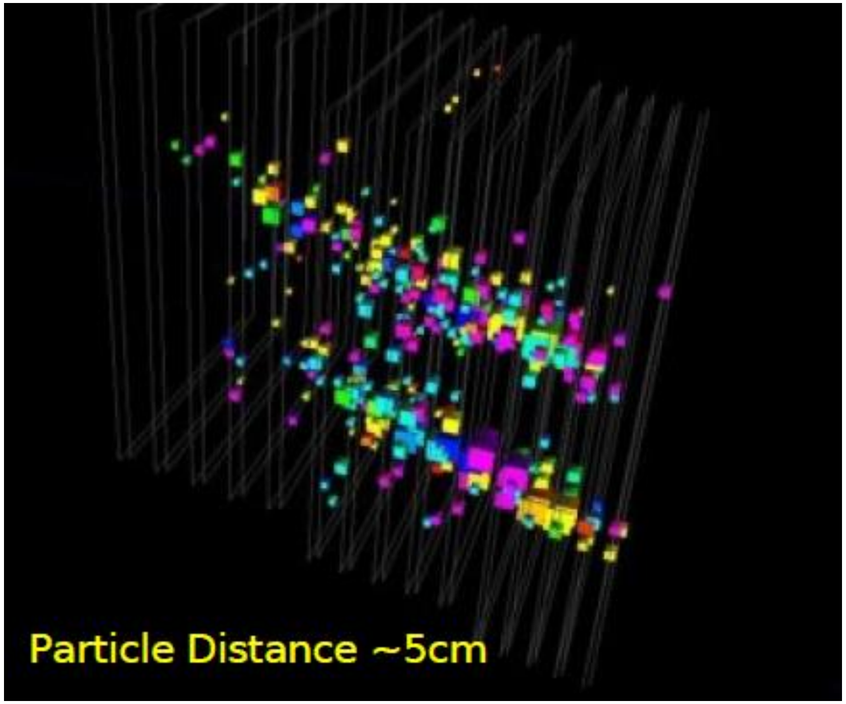
Tiny connectors were used to connect the PCB two by two so the 24X2 ASICs are daisy-chained. 1×1m^2 has 6 PCBs and 9216 pads.

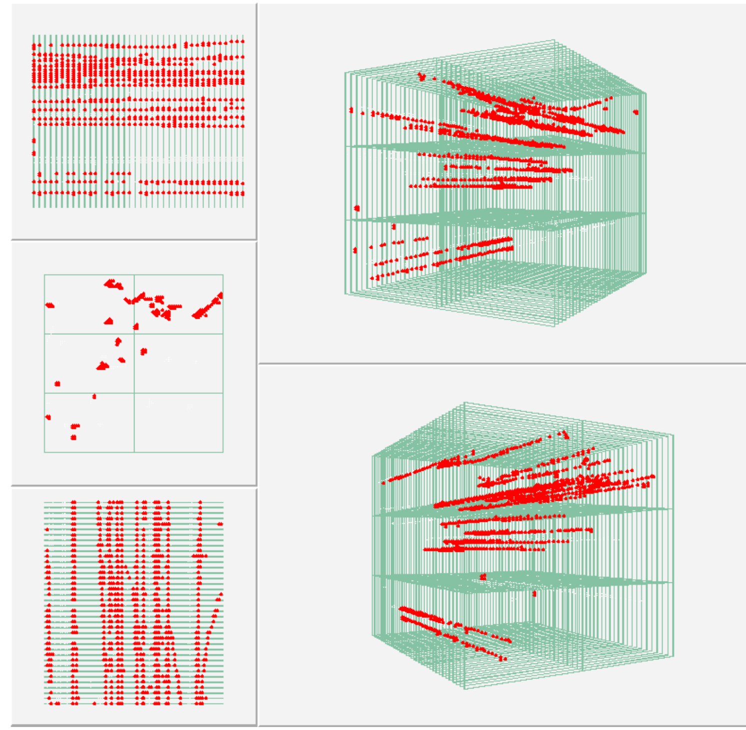
DAQ board (DIF) was developed to transmit fast commands and data to/from ASICs.



Imaging Calorimeters

L. Xia @ ANL





Two electrons ~5cm apart
CALICE SiW ECAL

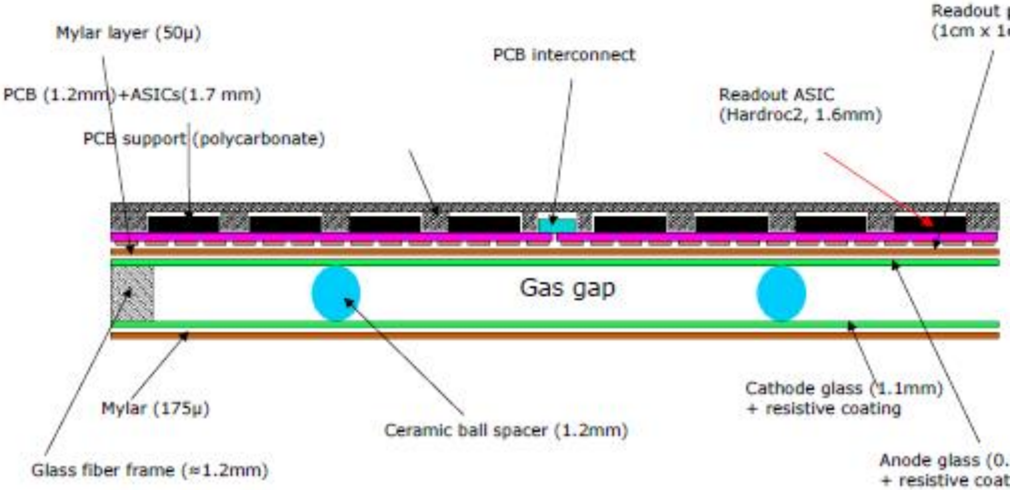
~20 muons in $1m^2$ area
CALICE RPC DHCAL

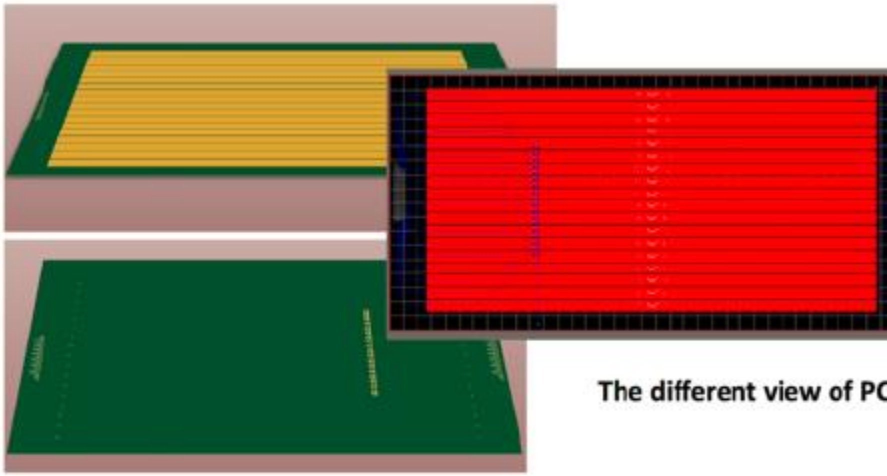
This is exactly what PFA needs: distinguishing individual showers within jet environment, in order to get excellent jet energy/mass resolution

RPC R&D

From **Haijun Yang** (SJTU)

- Large Glass RPC R&D
  - Negligible dead zone
  - Large size: 1x1 m^2
  - Cost effective
  - Efficient gas distribution system
  - Homogenous resistive coating



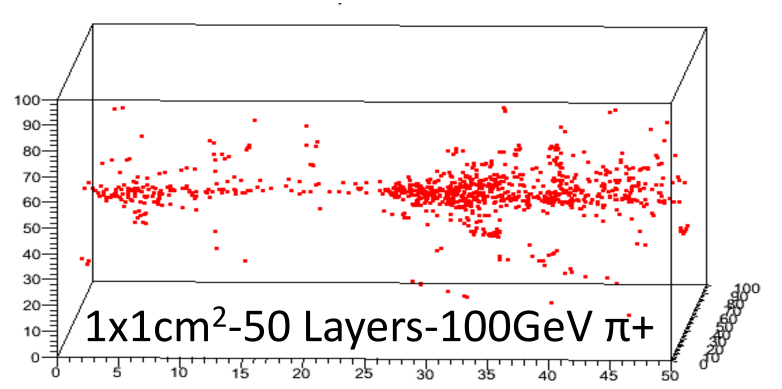


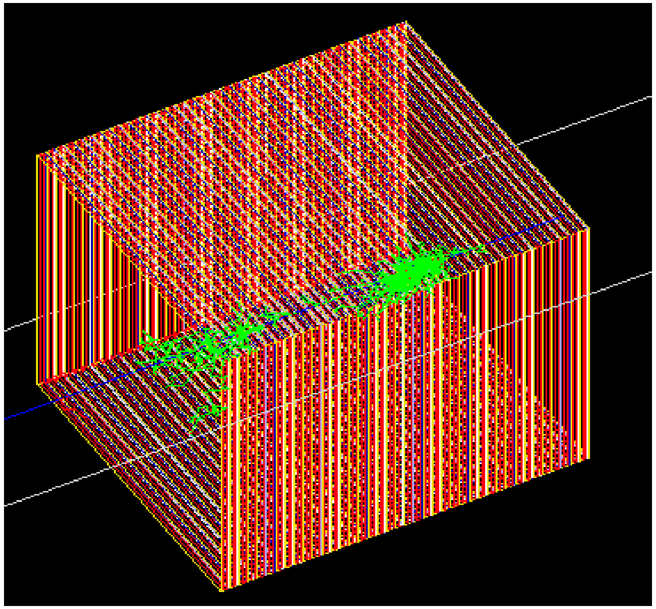
The different view of PC

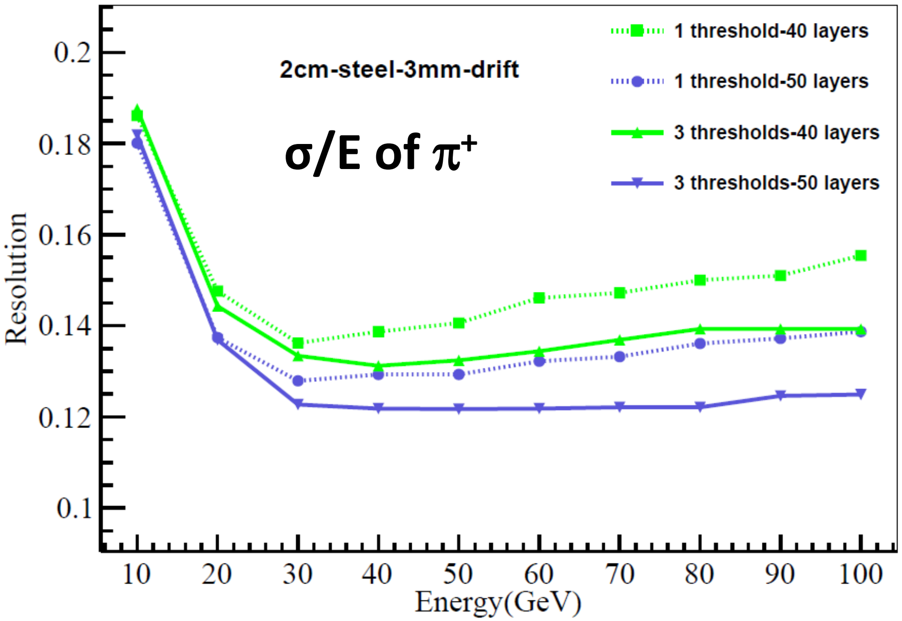
Simulation of DHCAL

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





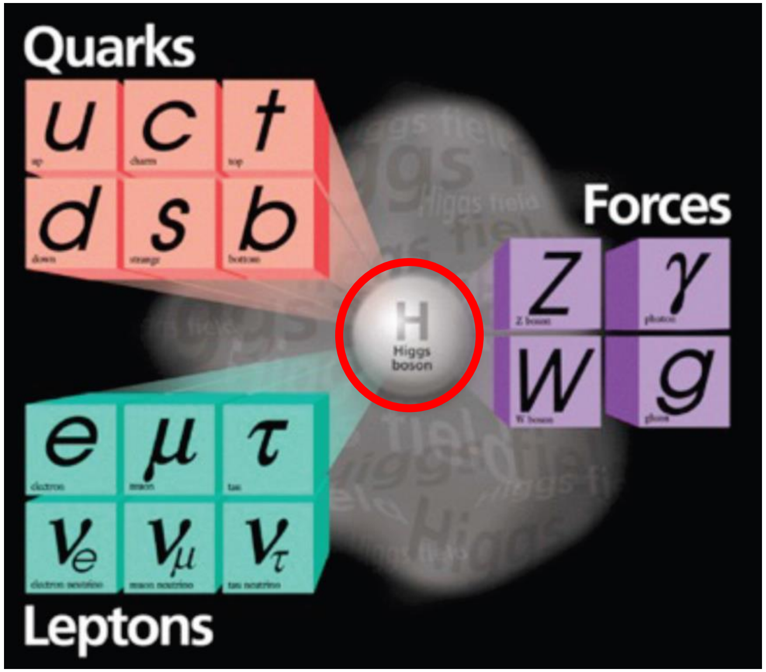


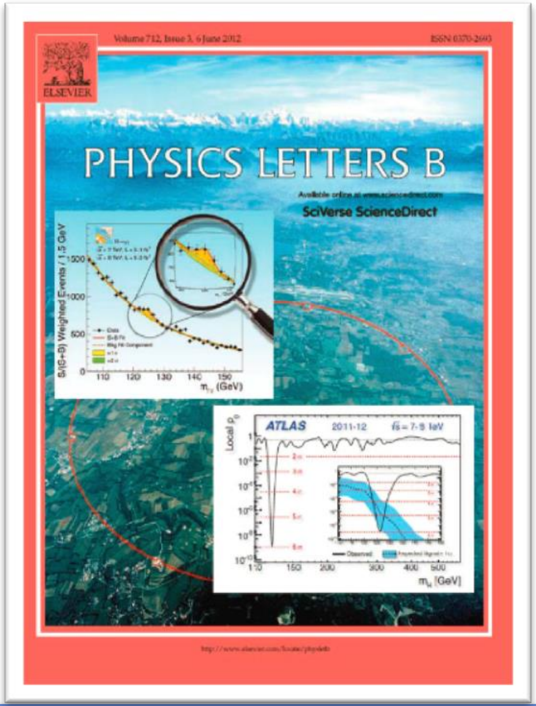
Imaging calorimeter: Critical R&D

- **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**

Circular Electron Positron Collider - CEPC

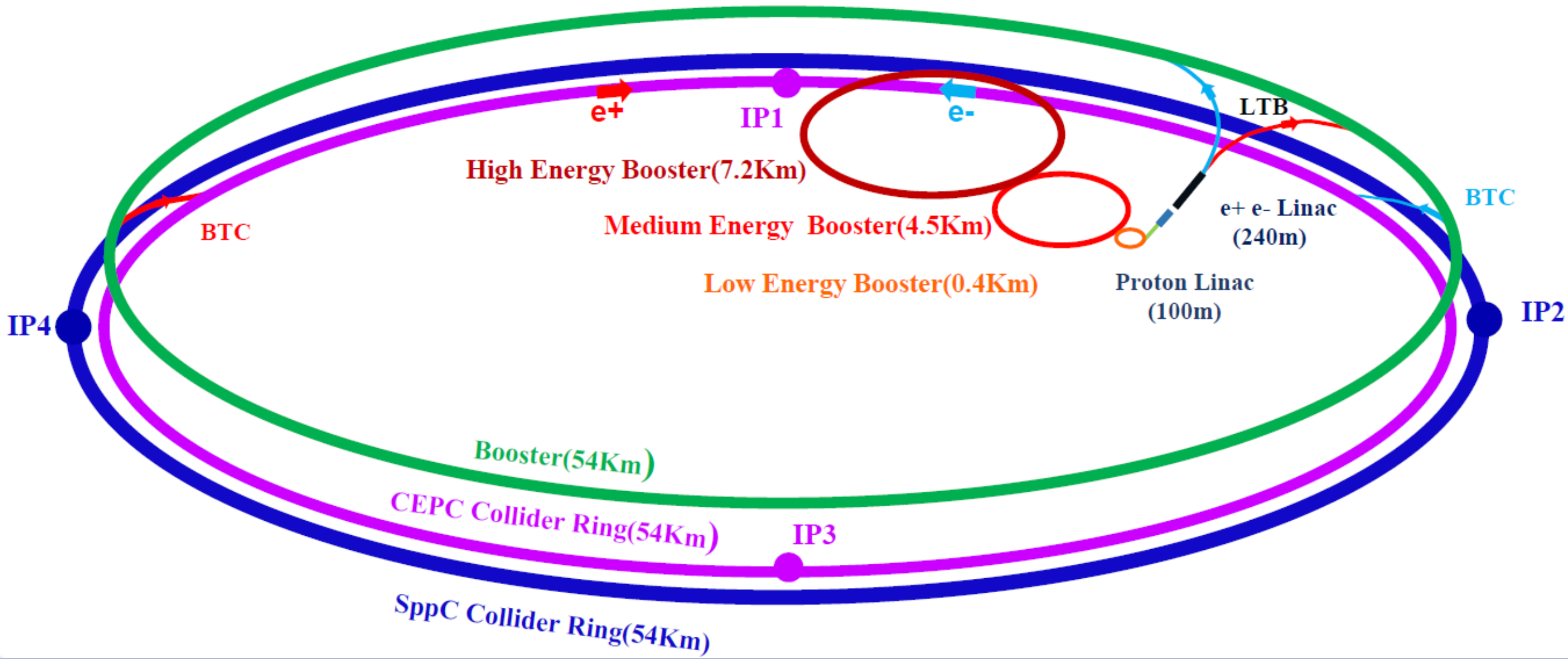
Discovery of low mass Higgs boson at the LHC (July 4, 2012) brings up an opportunity to investigate circular e^+e^- collider as a viable option for the "Higgs Factory" which is dedicated for precision measurement of the Higgs properties with clean collision environment.





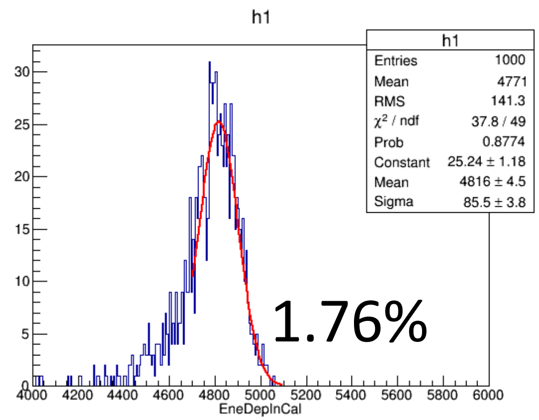
Circular Electron Positron Collider - CEPC

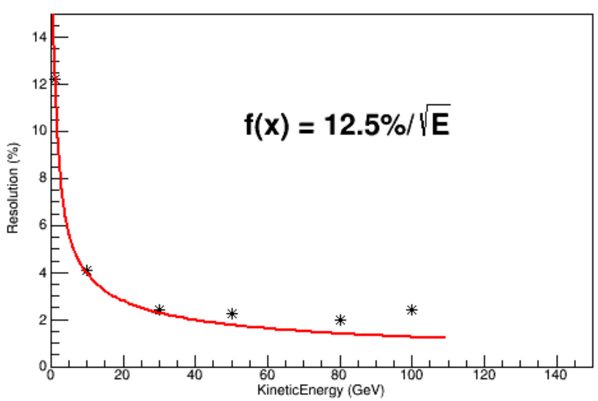
Parameter	Design Goal
Particles	e+, e-
Center of mass energy	240 GeV
Luminosity (peak)	2*10^34/cm^2s
No. of IPs	2



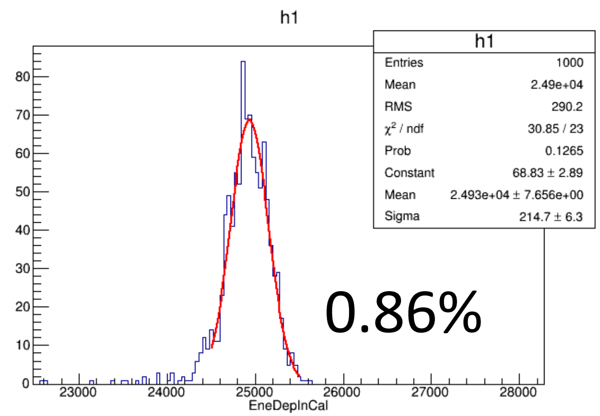
The performance of ECAL

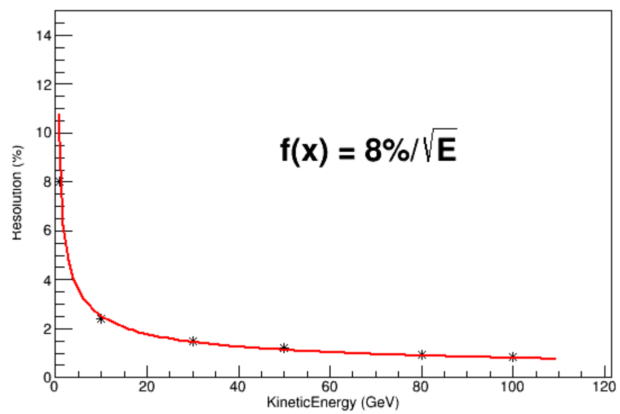
PSD:2mm



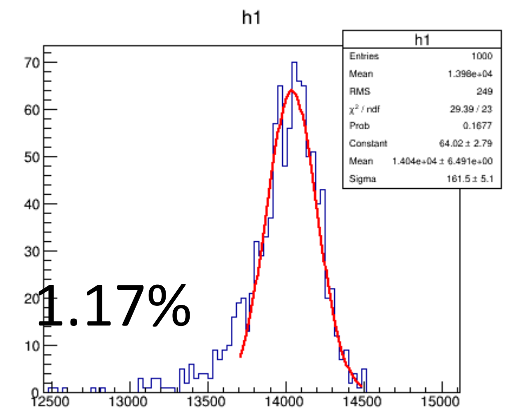


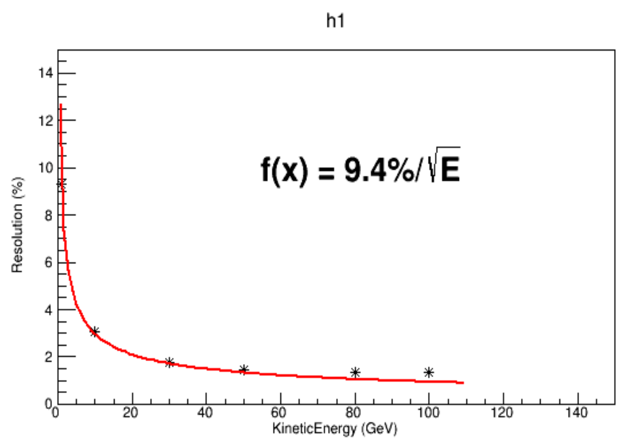
LSO:2mm





LSO:1mm





CEPC Muon System

Yuguang Xie @ IHEP

Functions of muon system

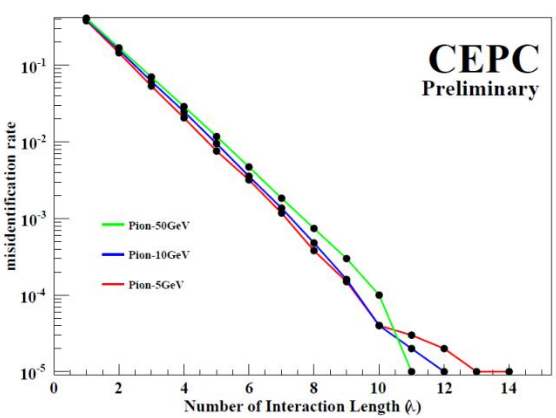
- To separate muons from hadrons
- A tail catcher of HCAL
- Solenoid return roke & support structure

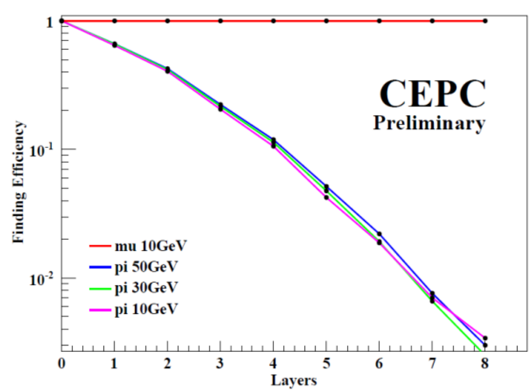
Performance requirements

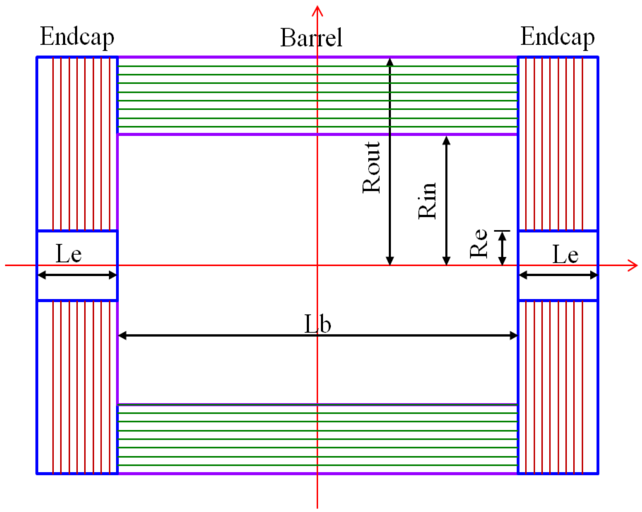
- nLayer >=8, iron thickness >= 6λ
- Eff >=95%, resolution<=2cm
- Misidentification rate (pi->mu)@40GeV <1%

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.







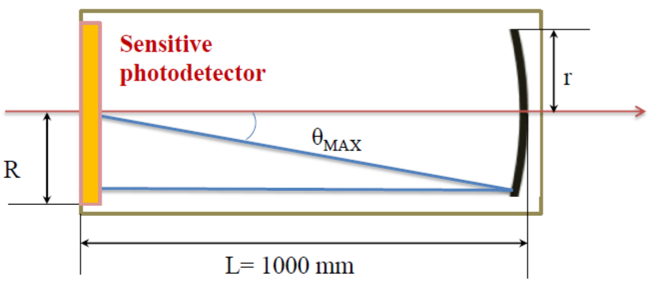
PID

Considerations for a prototype

A prototype is needed to validate the basic performances of designe RICH;

Requirements for 40 GeV κ,π, (C4F10 radiator):

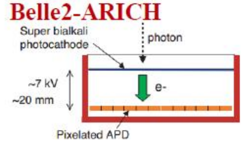
- $\theta_{MAX} = 0.053$
- r (mirror) > $L*\theta_{MAX}$=60 mm, R (sensitive area) = 75 mm
- Angle resolution: 2mrad



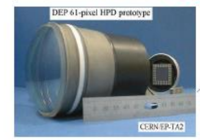
The photon detector is obviously the key challenge.

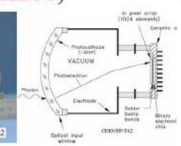
Some classical Photon detector

Hamamatsu Hybrid Avalanche PhotoDetector (HAPD) at **Belle2-ARICH**

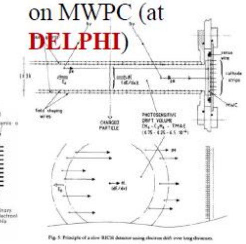


Hybrid photon detectors (HPD at **LHCb**)



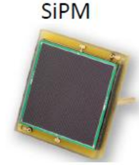


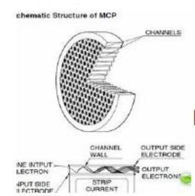
Drift Chamber based on MWPC (at **DELPHI**)



Some new type of Photon detectors

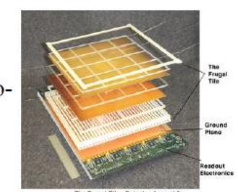
SiPM





MCP

LAPPD: Large Area micro-channel plate photodetector



And also, MPGD (GEM, Micromegas) based Photon detector !