Status of CEPC Physics and Detector Studies

Yuanning Gao
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On behalf of the CEPC Physics & Detector Working group

Outline

- Introduction
  - CEPC program, organization and activities
- Physics performance
- Detector studies
  - vertex, tracker, calorimeters, …
- Status of the pre-CDR
- Summary

CEPC Physics Program

- Not extremely ambitious goal for CEPC

  (Yes CEPC+SppC !)

  - 5 ab^{-1} for Higgs studies @240-250 GeV
  - 10^{10-12} Z's @~ 91 GeV
  - 10^{6-8} W's @~160 GeV
  - …

- But rather ambitious timeline!

CEPC-SppC Schedule (Preliminary)

J. Gao, ICHEP2014

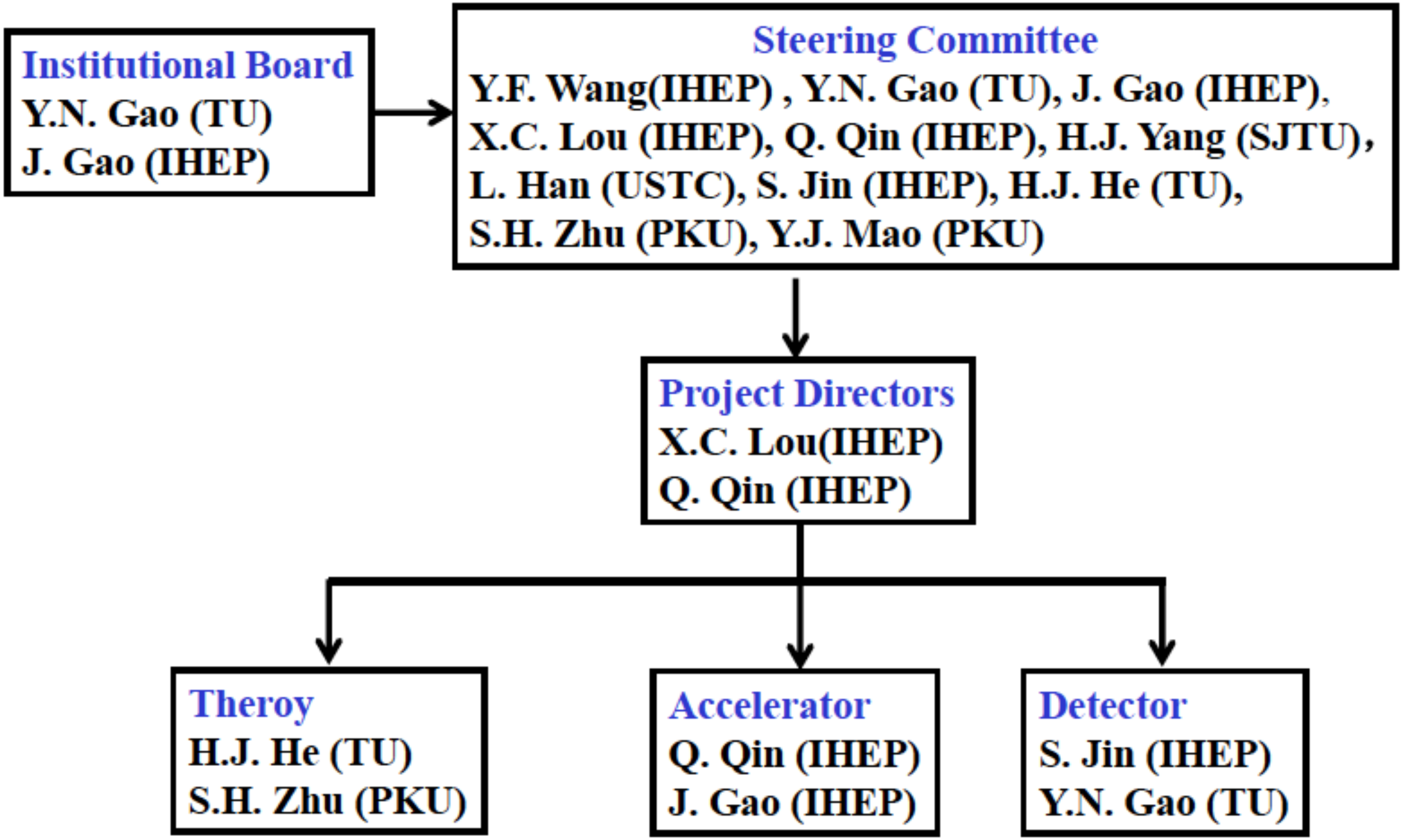
- CPEC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-15 ➔ Pre-CDR by 2014
    - R&D: 2016-2020
    - Engineering Design: 2015-2020
  - Construction: 2021-2027
  - Data taking: 2030-2036

- SPPC
  - Pre-study, R&D and preparation work
    - Pre-study: 2013-2020
    - R&D: 2020-2030
    - Engineering Design: 2030-2035
  - Construction: 2036-2042
  - Data taking: 2042 -

CEPC-SppC Organization

J. Gao, ICHEP2014

(Since 2013-09-13)



X.C. Lou, 20140912

Schedule guideline for CEPC pre-CDR

August – December 2014

August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-31	November 1-15	November 16-30	December 1-15	December 16-31
pre-CDR draft version 0 from each (sub-)group ; (with all required elements, some contents may be missing)									
(1) external reviewers identified and invitations sent out during first period; (2) additions and revisions being worked on; (3) formation of editorial board at SJTU workshop; (4) internal reviews within (sub-)groups.									
(1) revision and finalization of pre-CDR chapters; (2) internal reviews of chapters (**theory, detector-simulation, accelerator, site design and civil engineering**); (3) draft **Introduction** and **Summary** sections available for comments and revision.									
(1) reviews of chapters (**theory, detector-simulation, accelerator, site design and civil engineering**) by external review committees; (2) revisions of and improvements to the pre-CDR chapters .									
(1) final edition (including **Introduction & Summary**) in English; (2) translation of pre-CDR into Chinese completed and reviewed									
(1) proof; (2) print and release to CAS and public									

X.C.Lou

Physics & Detector Working Group

- Conveners: Yuanning Gao(THU), Shan Jin(IHEP)
- sub-groups
  - physics analysis and optimization:
    Gang Li (IHEP),Manqi Ruan (IHEP), Dayong Wang(PKU)
  - vertexing and silicon tracking:
    Qun Ouyang(IHEP), Meng Wang(SDU)
  - main tracking:
    Yulan Li (THU), Huirong Qi (IHEP)
  - calorimetry and muon:
    Tao Hu (IHEP), Haijun Yang (SJTU)

Tasks of the working group for pre-CDR

- Explore the physics potential: thanks to 20+ years' world-wide efforts from ILC community and from Fcc-ee recently.
- Focus on feasibility studies

  - keep in mind the timeline !

  - clarify performance requirements

  - skeletonize a baseline detector design

  - availability of technologies

  - identify items for future R&D

Preliminary results for the expected precision of the measurement

	ILC 250fb-1		CEPC 500 fb-1		CEPC 2000 fb-1		CEPC 5000 fb-1	
	w/o sys (%)	w/ sys (%)	w/o sys (%)	w/ sys (%)	w/o sys (%)	w/ sys (%)	w/o sys (%)	w/ sys (%)
Br : bb	0.82	1.38	0.65	1.29	0.33	1.16	0.21	1.14
cc	10.64	13.84	6.82	6.91	3.41	3.59	2.16	2.43
gg	8.83	10.70	5.62	5.73	2.81	3.03	1.78	2.10
tautau	3.53	3.60	3.76	3.93	1.87	2.18	1.19	1.64
ww	8.05	8.13	4.48	4.61	2.24	2.50	1.42	1.80
gamgam	N/A	N/A	51.97	51.98	26.45	26.48	16.79	16.83
Cross-section	0.79	1.18	0.63	1.07	0.32	0.82	0.20	0.68

✓ The tools are ready for the measurement; those results donot consider shape information.

✓ The systematics incorporating in the fit are 1% for each branching ratio, 0.5% for xsection (theory)

✓ At the level of ~1 ab-1, The improvement of ΔBr/Br is limited by the constraint of the systematic uncertainty.

One caveat: assume ratio of eff. of bb,cc, gg for leptonical Z Decays and hadronic Z decay (will be replaced with new inputs)

Strategy for the detector design

- ILC detectors, especially ILD as a reference
  - state of art detector, maximize the potential of the (rather expensive) machine
  - (hopefully) less technology challenges than ILD
  - take advantages from world-wide studies
  - sharing future critical R&D with ILC community

- "The detector" in pre-CDR has similar performance as ILD, with special considerations

Performance requirements of ILC detectors

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

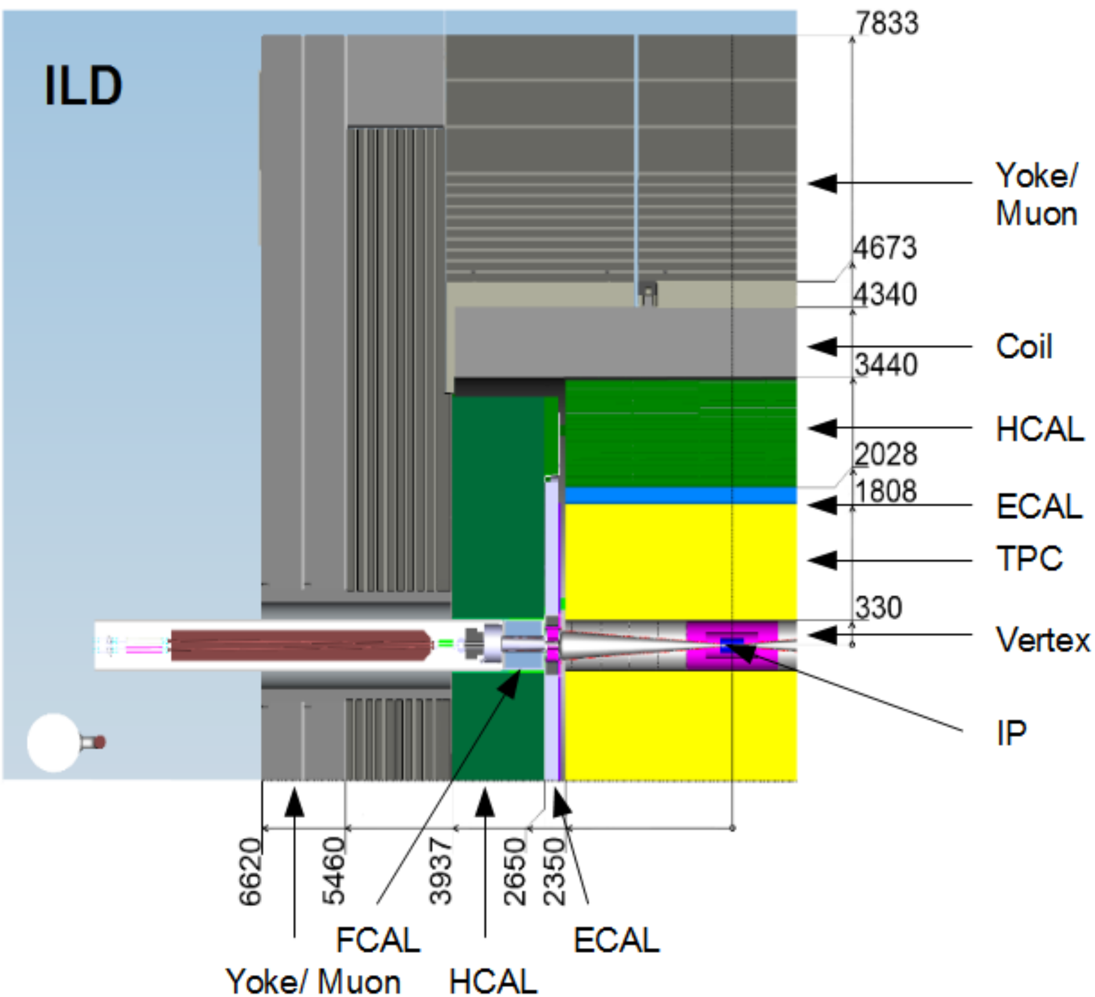
- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\quad \text{incl.}\ h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

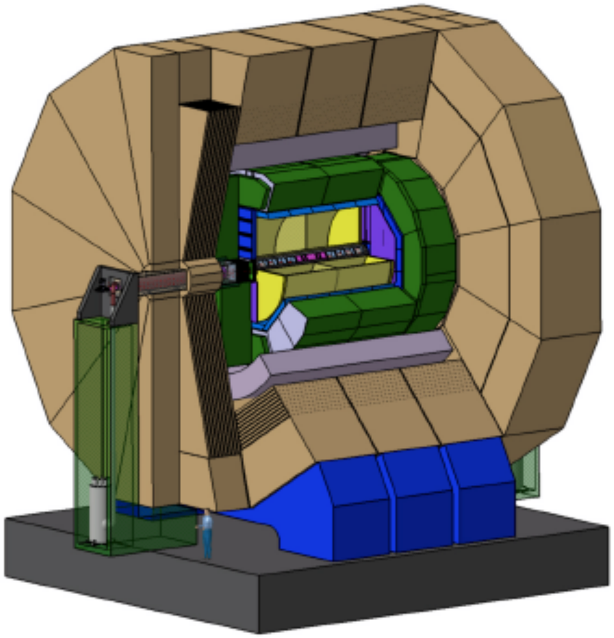
$$\sigma(1/p) = 5\times10^{-5}/GeV \quad \text{or better}$$

- Jet energy (Higgs self-coupling, W/Z seperation)
  - ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3/\sqrt{E(GeV)}$$

ILD Detector Design





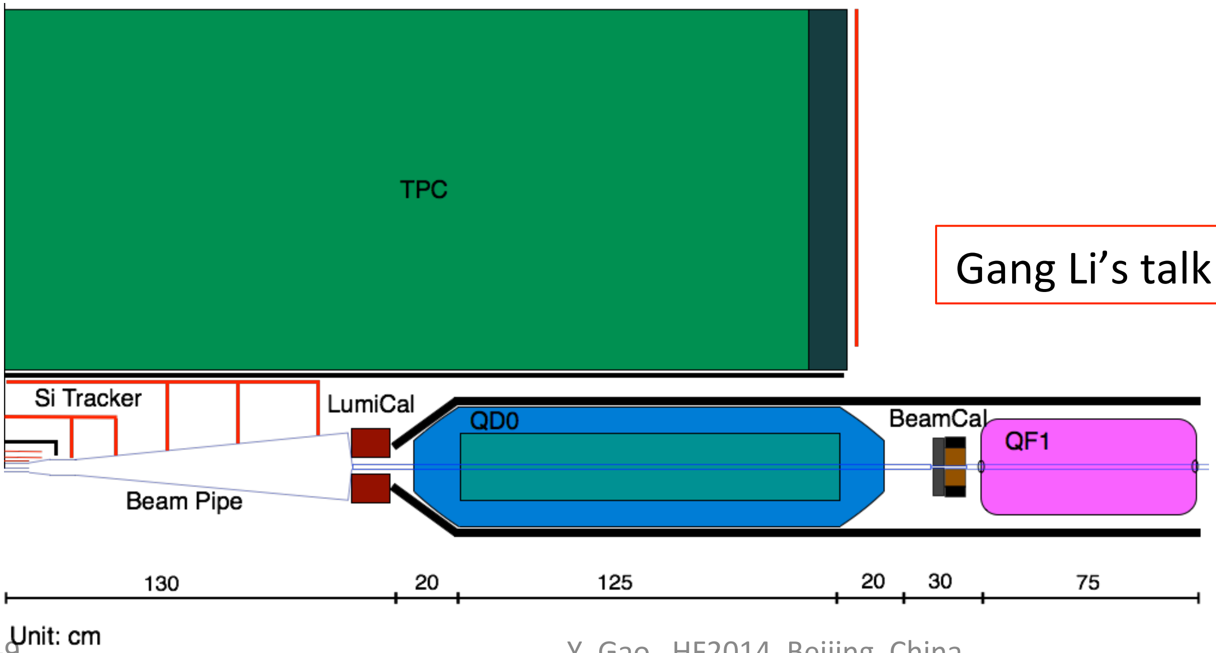
Special considerations

- Power pulsing not possible:

  more cooling and/or less channels?

- L* =1.5m (cf. 3.5m at ILC):

  challenges for the IR design



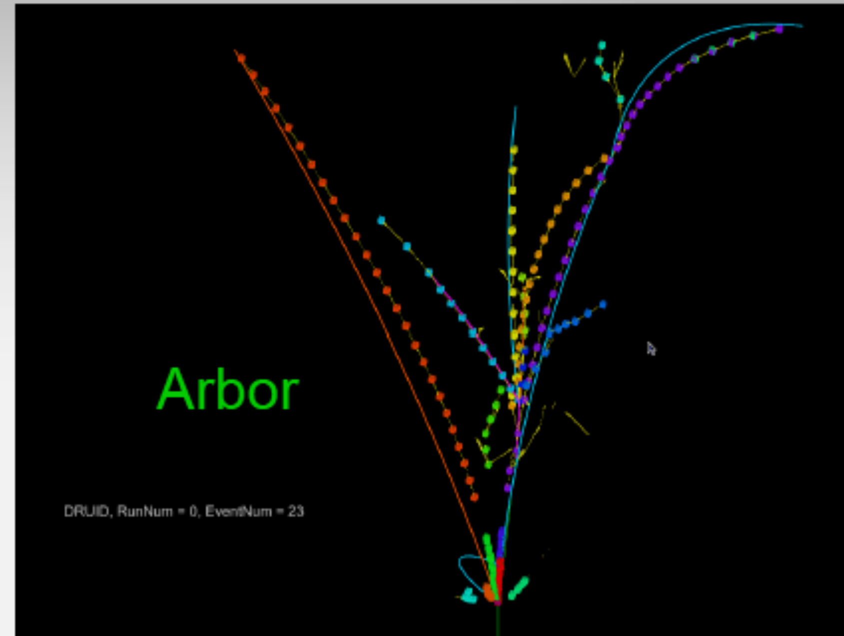
Gang Li's talk at this workshop

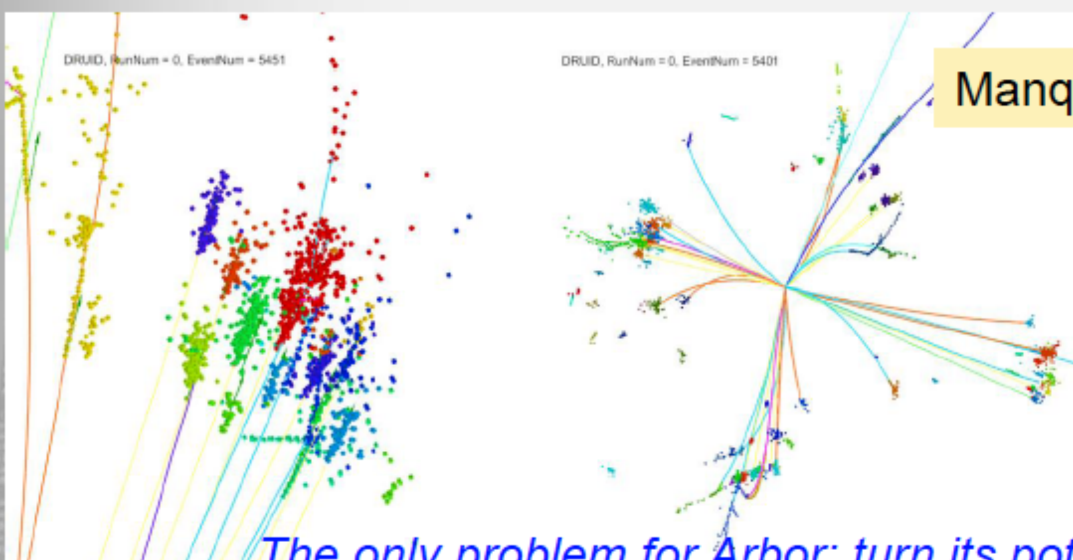
Processing to Full Simulation

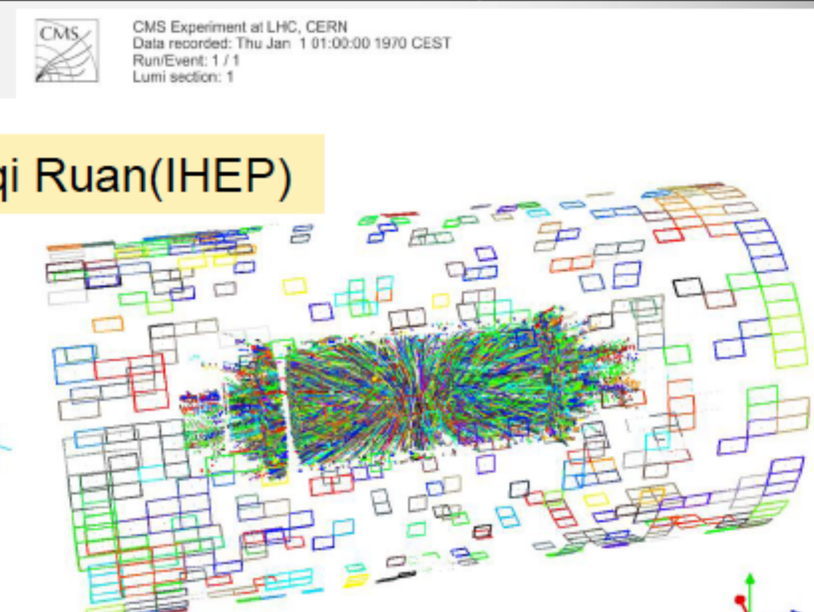
- Geometry: modifying as we want
- Full Reconstruction: adjusting to new geometries
- Sample:
  - Signal (o(100 k)): Full Simulated, reconstructed and Validated
    - ILD, and ILD with Smaller L*: Validated
    - Smaller L* & Smaller TPC: In Validating, minor unexpected pattern emerge
    - ...
  - Background:
    - ILC Reconstructed DST file
    - Fast simulated
- Tactic:
  - Accomplish the analysis at ILD & Smaller L* ILD, then process to further modified version
  - Process background Full Simulation once we got enough computing resource

Reconstruction step
Arbor PFA

- generic PFA to future
  - Excellent separation & sub-shower structure recognition
  - Clear physics interpretation
- breakthrough at speed: < 1min to process an event with ~100k hits (eg, CMS detector with 140 Pile up)
- applying to Full Simulation at CEPC



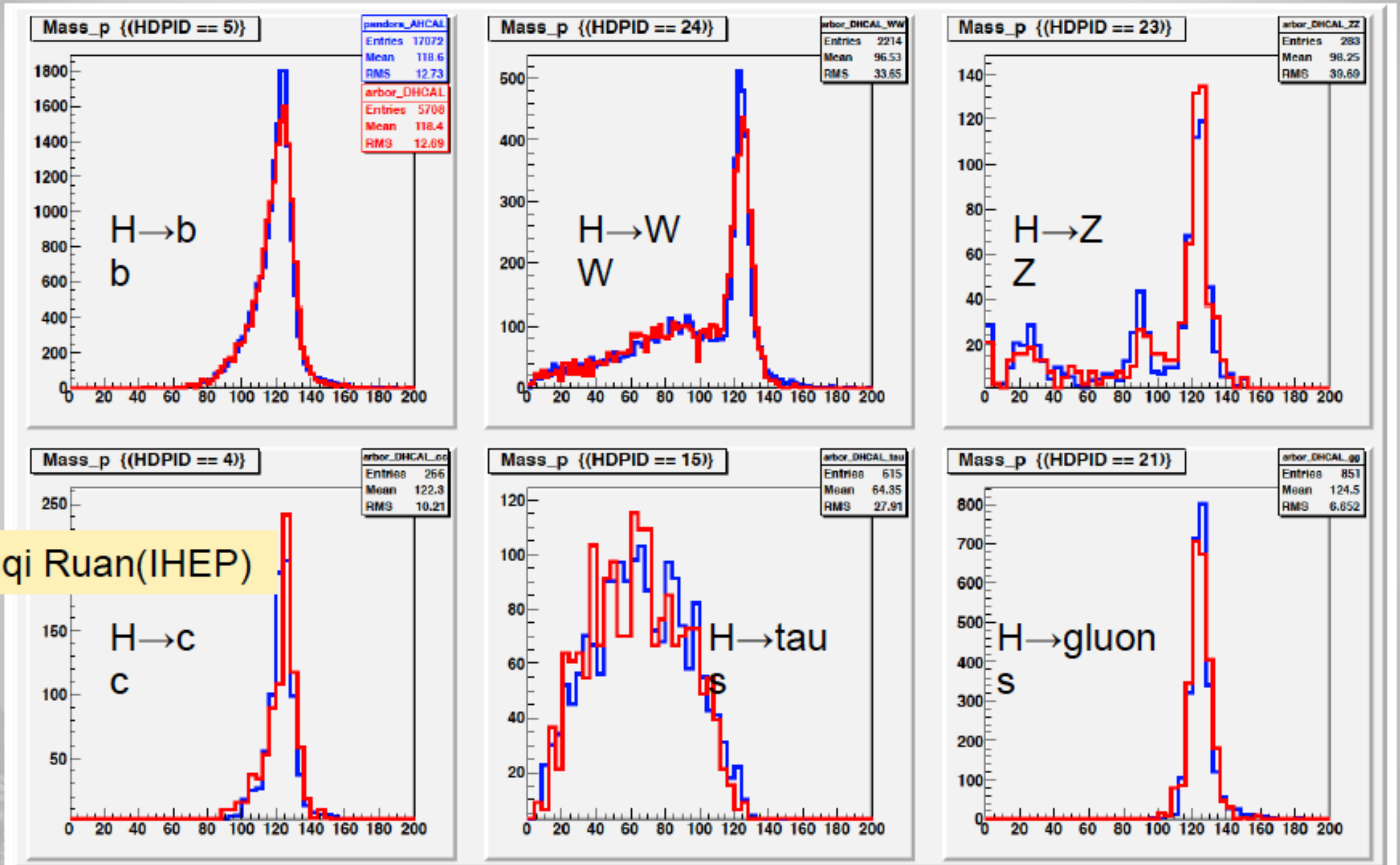




Manqi Ruan(IHEP)

The only problem for Arbor: turn its potential into excellent performance
time, patient & passion...

Arbor vs Pandora



Manqi Ruan(IHEP)

Arbor Uses GRPC Hadron Calorimeter, whose intrinsic resolution – based on current energy estimator is worse than that Pandora Used (Scintillator Tile Analogy HCAL).

Vertexing

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\quad \text{incl.}\ h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

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- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3/\sqrt{E(GeV)}$$

Baseline design

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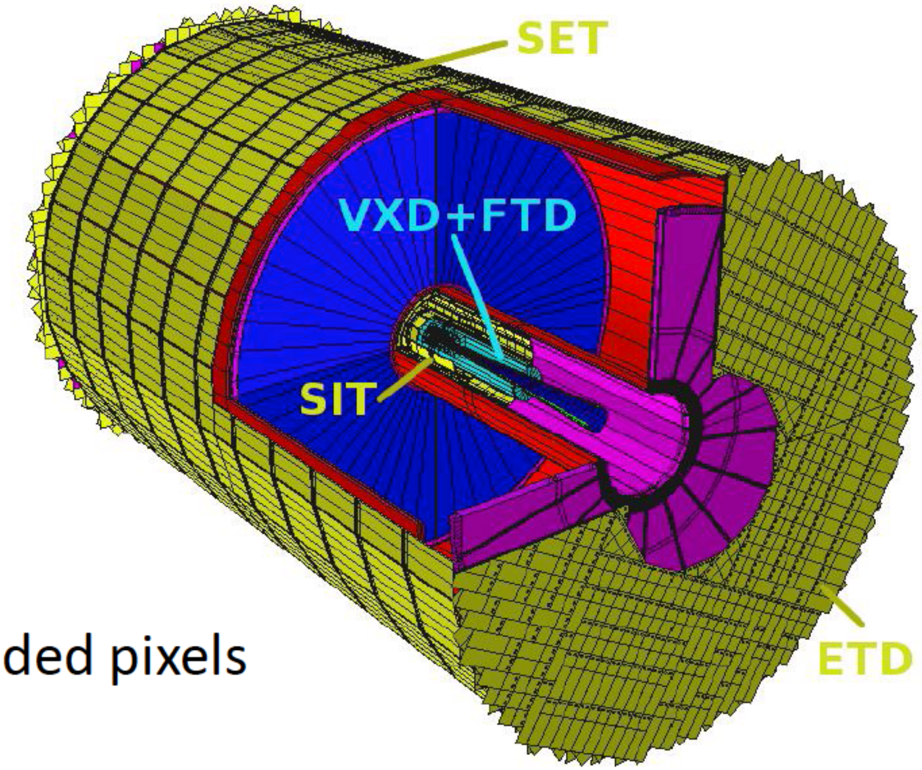
ILD-like design



- VXD： 3 layers double-sided pixels
- Si-tracker：

  FTD — 7 disks (2 disks with pixels and 5 disks with Si strip sensor) on each side

  SIT — 2 inner layers Si strip detectors

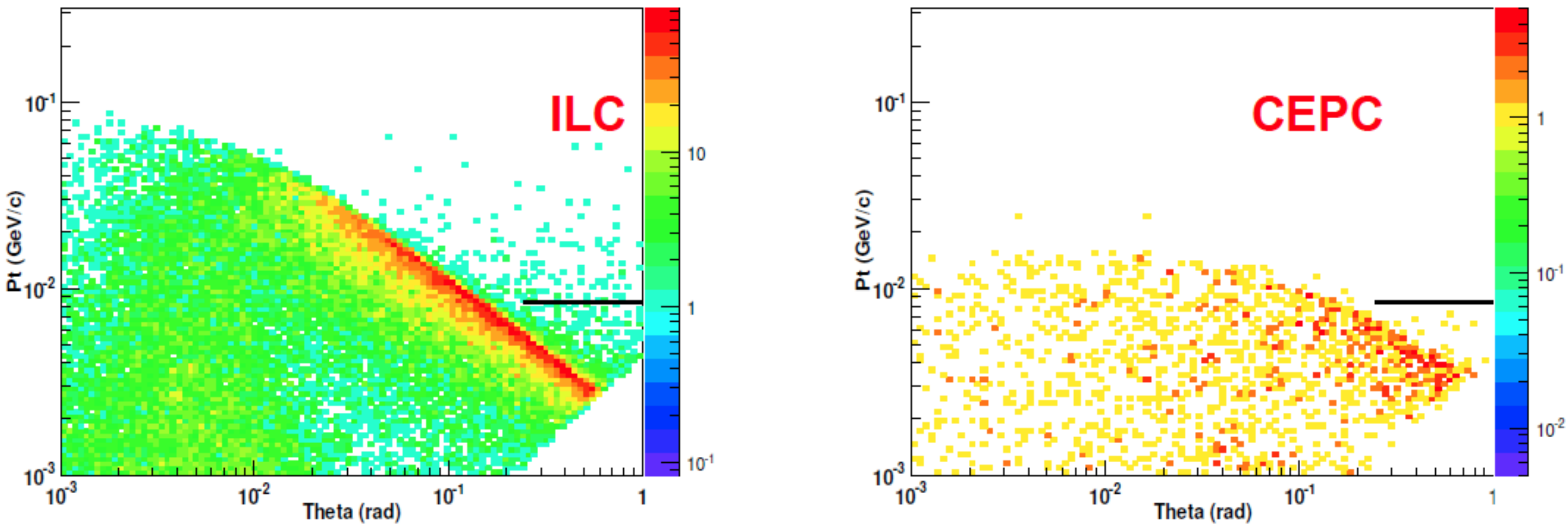
  SET — 1 outer layer Si strip detector

  ETD — 1 end-cap Si strip on each side

Radiation Background

Hongbo Zhu's talk at this workshop

- beam induced background imposes large impacts on detector design (e.g. detector occupancies, radiation damage, etc.)
- may degrade detector performance (additional noise in finding tracks/vertices)
- **Guinea-Pig** (beam-beam interaction simulation) + **Geant4**



two main processes: **beamstrahlung photons + pair production**

The black line indicates the polar angle coverage of the vertex detector

Baseline design: forward region

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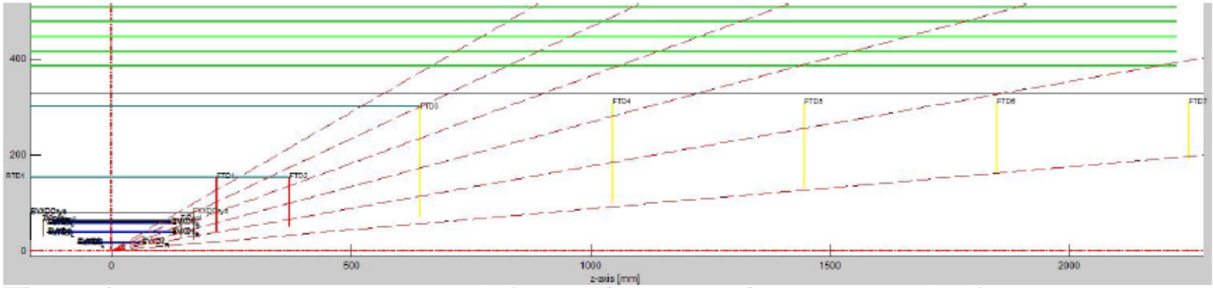
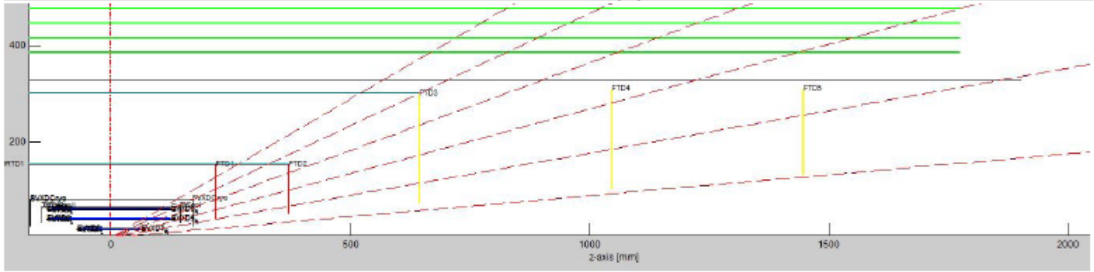
L*=1.5m

An alternative layout is being investigated for the constraints induced by the QD0 at 1.5m



ILC_ILD



Smaller TPC without FTD6, 7

- Remove FTD6 and FTD7 will ruin the IP resolution for tracks <10 degrees (and if smaller TPC, worse momentum resolution)
- One more pixel measurement can save the IP resolution
- further optimization studies needed based on IP design and background

Simulation and performance optimization studies

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- LDT simulation setup

  LDT: Fast simulation using **Kalman filter**

  - A helix track model inclusion **multiple scattering**
  - Simplified **simulation** + track **reconstruction**
  - **"Validated" by CLIC CDR**
- Studies
  - Dependence on material budget
  - Dependence on single point resolution
  - Dependence on arrangement of layers
    - R_beampipe=10 mm
    - L*~=1.5m

- If single point resolution worse by 50%, ip.resol worse by 30%/10% for high/low pt tracks
- If material budget increase by a factor of 2, ip.resol worse by 20% for 90 degrees tracks
- Reduce the radius of beam pipe will gain a little

Forward impact parameter resolution and momentum resolution can be cured by 1 additional pixel measurement

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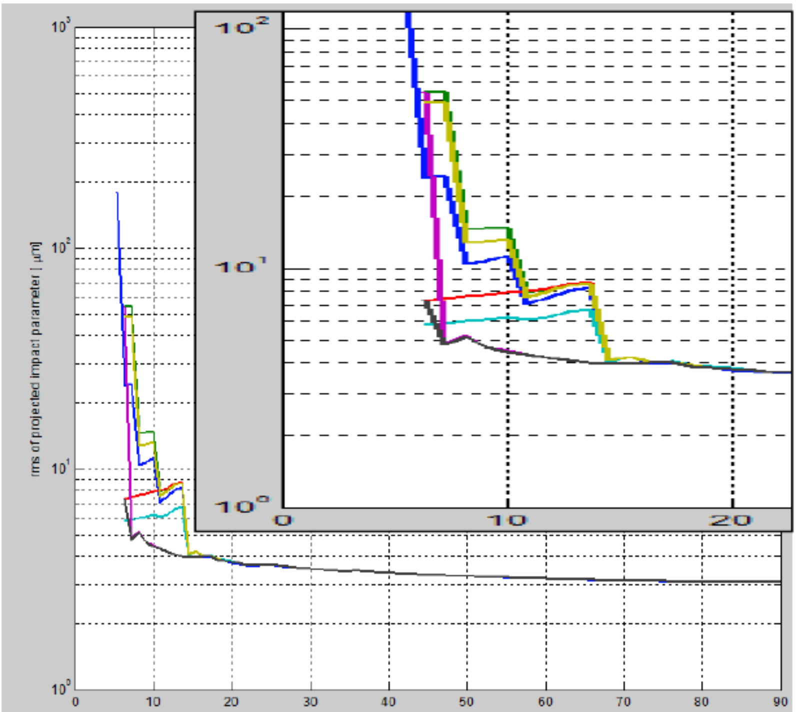
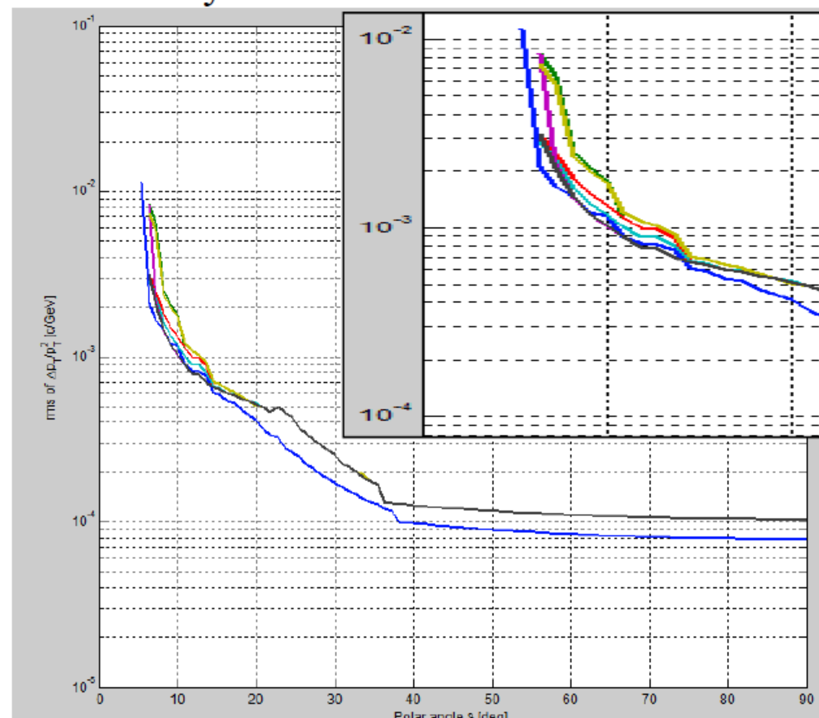
Barrel momentum resolution is dominated by the smaller TPC





1， ILC

2， L*=1.5 remove FTD6/7

~~3， 2 and insert FTD6/7~~

4， 2 and Extend VTX1/2

5， 2 and Reduce FTD1 inner radius

6， 2 and Add FTD0

7， with both 4 and 5. only slightly better than 4

constrained by IP region, background

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Sensor options

Identification of b/c quarks and τ lepton requires:

- Spatial resolution
  - 3um
- Material Budget
  - 0.15% X0/Layer
- Inner-most Layer Radius
  - ~1.6cm
- Occupancy
  - Less than a few %
- Radiation tolerance
  - 1KGy&$10^{11}n_{eq}/cm^2$ per year

→

- Pixel Pitch
  - 20um
- Sensor thinning
  - 50um thick
- Power consumption
  - Less than 50 mW/cm^2 required by air cooling
- Time window
  - 20us (depends on beam induced background)
- Radiation tolerance
  - 1KGy&$10^{11}n_{eq}/cm^2$ per year

- ILC/CLIC Vertex — The same physics, but pulsed colliding mode
- DEPFET for BELLEII
- ALPIDE for ALICE upgrade

(DEPFET for BELLEII and ALPIDE for ALICE upgrade:) Continuous colliding mode

DEPFET for BELLEII

Possible application for CEPC inner most layer:

- 0.15% material budget (0.21% currently)
- 2.5W/ladder in sensitive area
- Time window of 50μs

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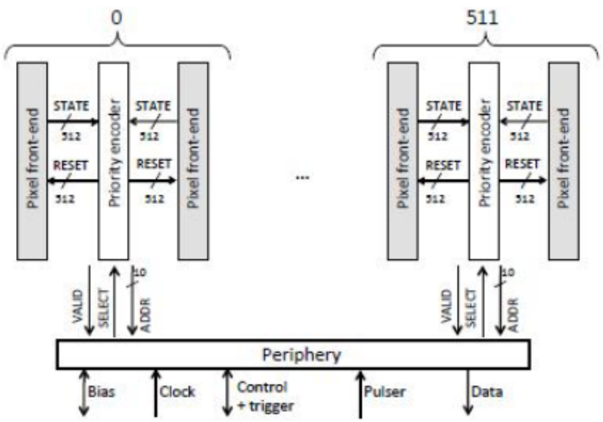
ALPIDE for ALICE Upgrade

- HR-CMOS Sensor with a novel readout structure
  - In-pixel discriminator and digital memory based on a current comparator,
  - In-column address encoder,
  - End-of-column read-out,
  - 22μm*22μm,
  - <50mW/cm^2 expected,
  - Capable of readout every ~4μs.
- The same principle can be applied to SOI
  - Mature process available, 0.2μm KEK-SOI process,
  - Full CMOS circuit,
  - Fully depleted HR substrate,
  - Thinning to 50μm demonstrated.

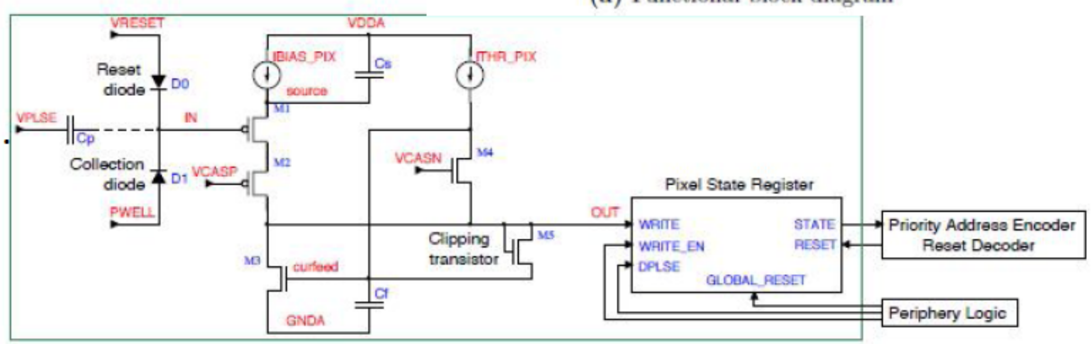
Low power

Read hit pixel only

Data compression



(a) Functional block diagram



(b) In-pixel front-end circuitry of ALPIDE (simplified)

Tracking

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\quad \text{incl. } h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

$$\sigma(1/p) = 5\times10^{-5}/GeV \quad \text{or better}$$

- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

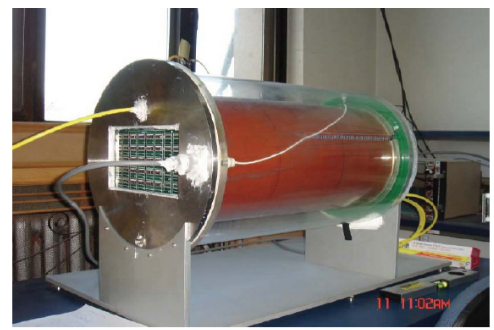
$$\sigma_E / E = 0.3/\sqrt{E(GeV)}$$

Baseline design

- TPC as the main tracker
  - same as ILD
  - a relative earlier involvement in LCPC collaboration

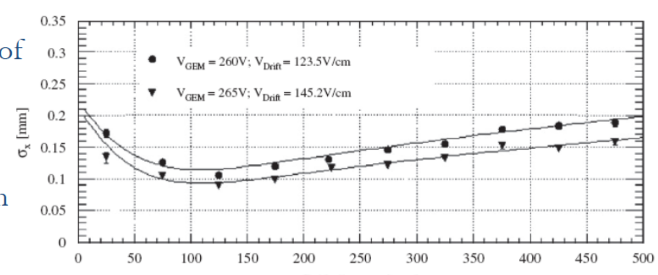
test of a TPC prototype at THU

- cylinder length: 500 mm
- readout GEM: 100 x 100 mm^2
- 10 x 62 pads, staggered placement
  - pad size: 9.5 × 1.5 mm^2
  - pitch: 10 mm × 1.6 mm
- 10 x 32 pads used due to limited number of electronic channels



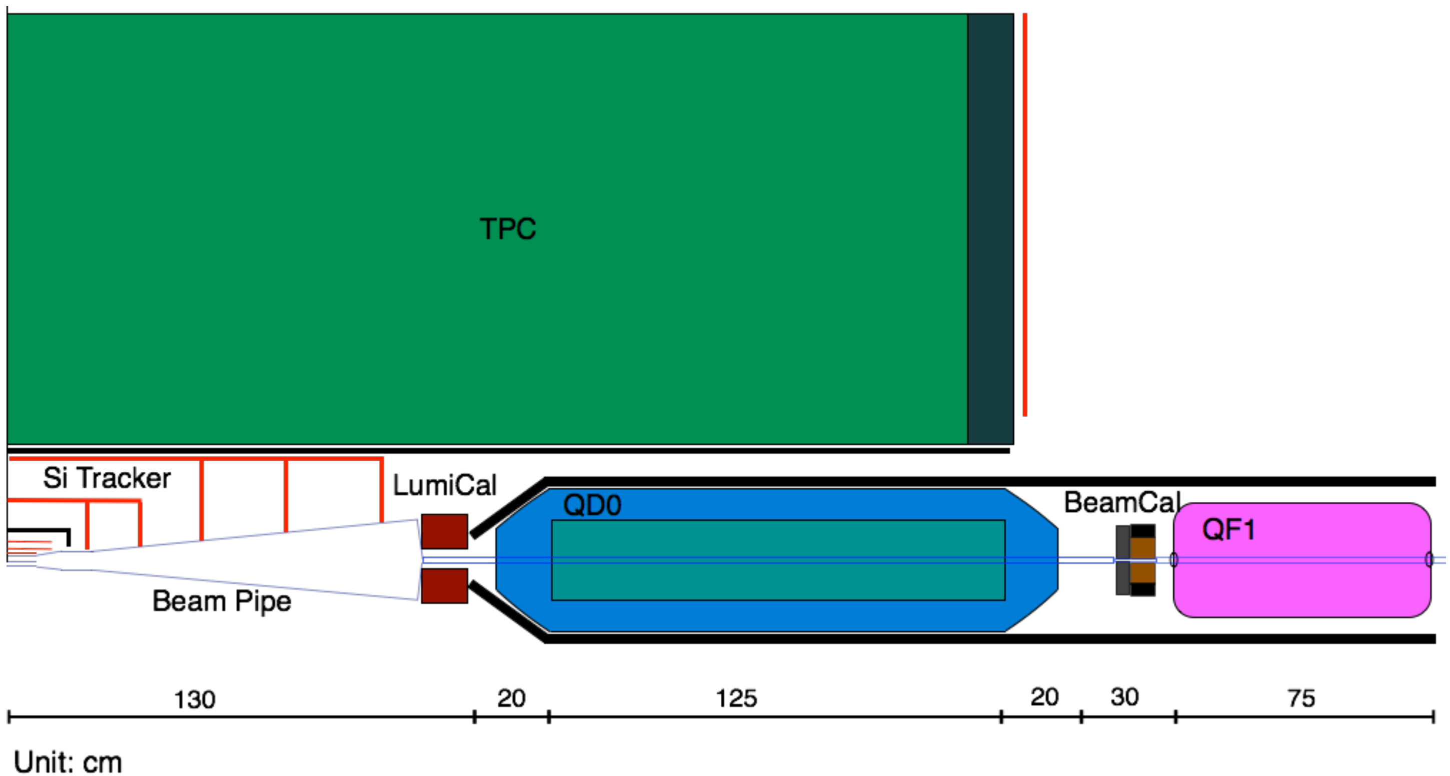
spatial resolution as a function of drift distance (B = 1 T)

best reach:
$\sigma_X = 100\ \mu m\ @\ Z \approx 100\ mm$



Impact of a shorter L*

- a shorter TPC?
- non-uniformity of the B-field due to QD0?



Simulation studies

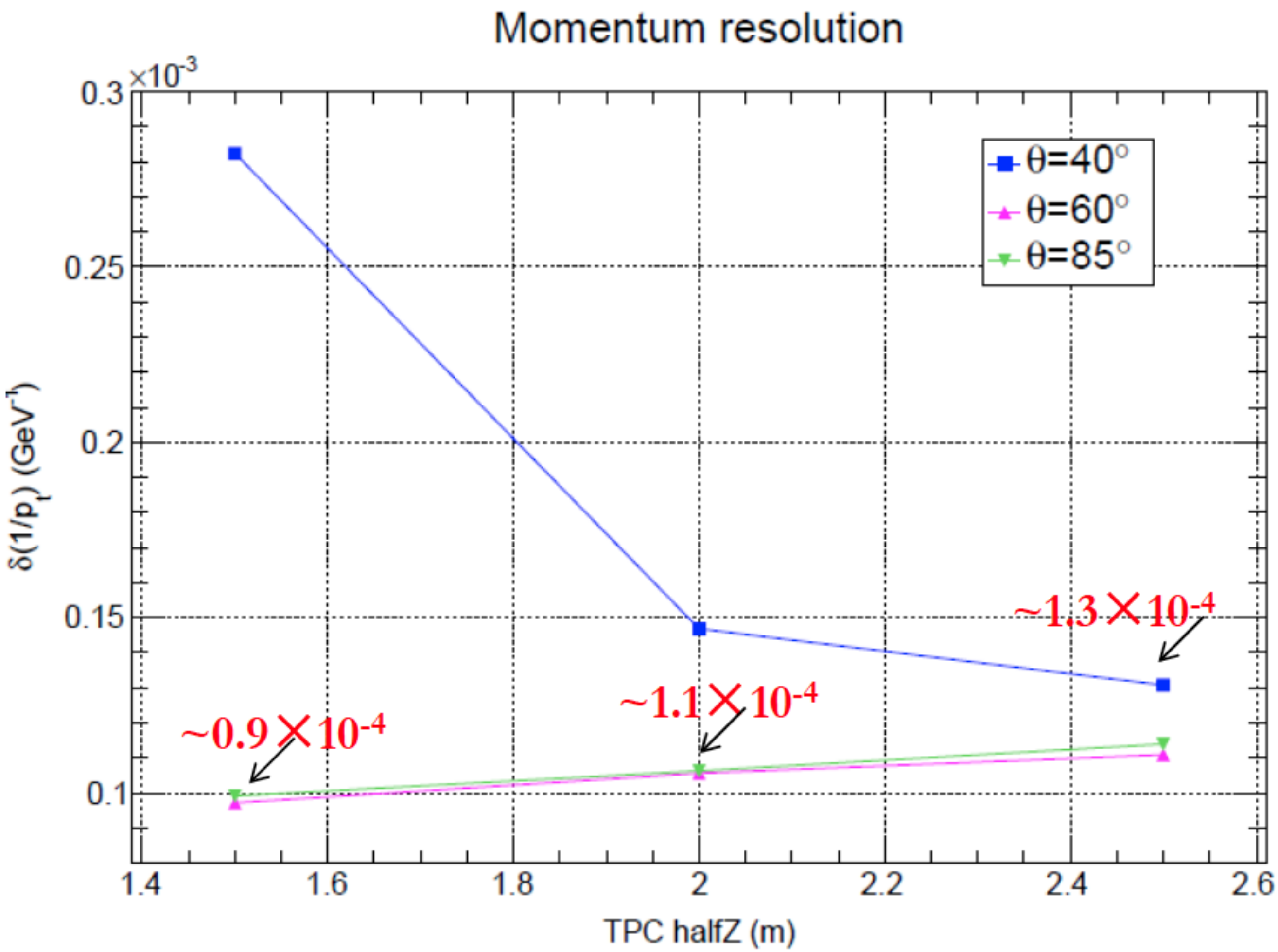
- Mokka for detector simulation: the track of charged particle; energy deposit; particle decay and scattering.
- Digitization by MarlinTPC
  - Available gas: TDR, P10, P5, T2K
  - However, it seems that the progresses of gas amplification and charge distribution are very time-consuming.
- Two options for track reconstruction:
  - Clupatra
  - MarlinTPC: maybe more suitable for detailed TPC research; **need further optimization.**
- Occupancy
  - Input of beam parameters: luminosity, bunch crossing rate ...
  - **The impact of occupancy on tracking and ion back flow.**
- **TPC tracking performance in non-uniform magnetic field.** The effect of electron drifting should be also be considered.

Impact of a short TPC

Parameter of Simu.

- Half Z=1.0m,2.0m,2.5m
- r_in = 329 mm
- r_out = 1808 mm
- pad size: 1mm×6mm
- Number of pads:~200
- B = 3.5 Tesla
- With multiple scattering
- Position resolution based on ILD-TPC with smearing of 100μm

- Momentum:20GeV

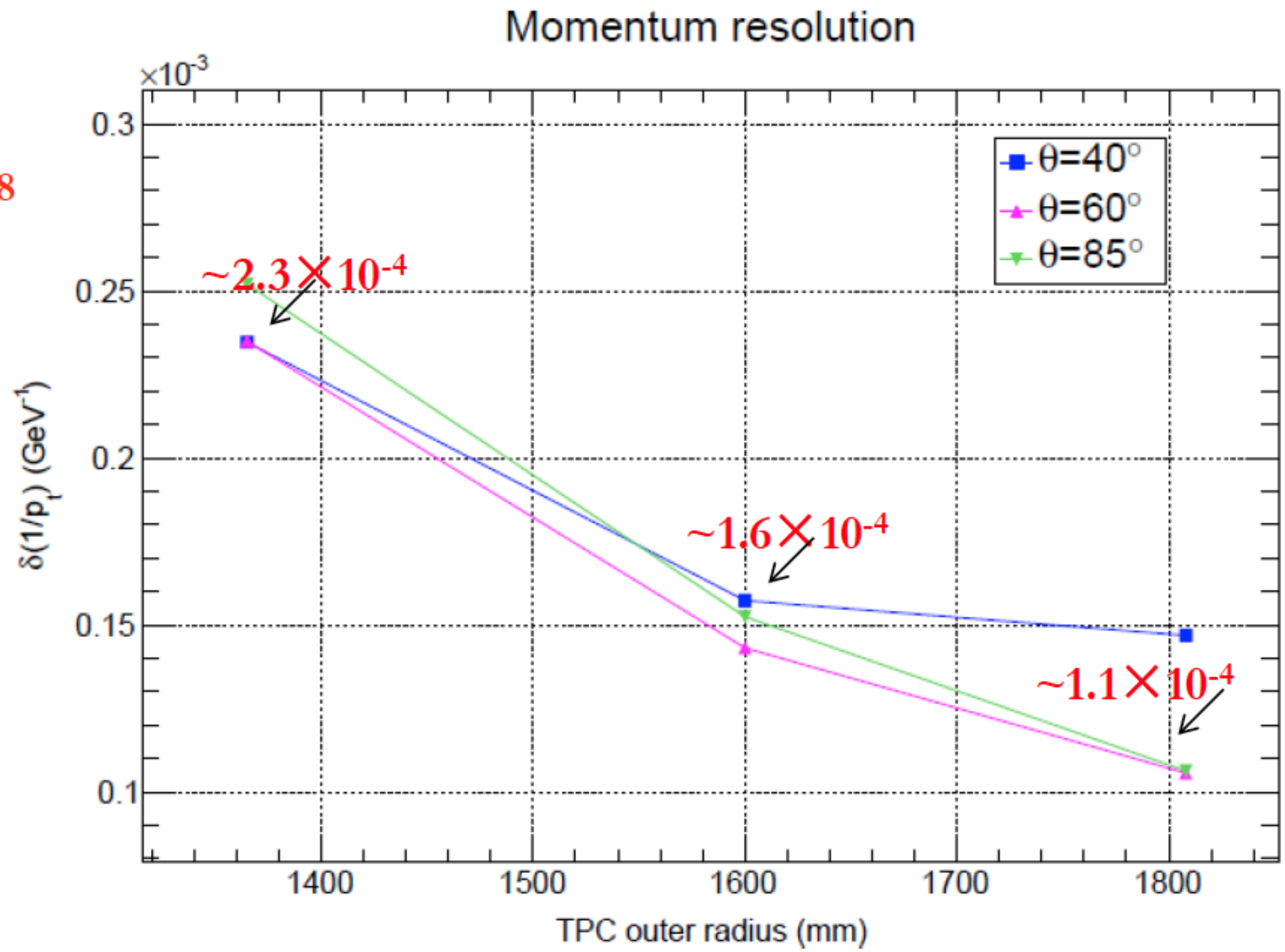


Impact of a thin TPC

Parameter of Simu.

- out_radius=1365,1600,1808
- Half Z=2.0m
- r_in = 329 mm
- pad size: 1mm×6mm
- Number of pads:~200
- B = 3.5 Tesla
- With multiple scattering
- Position resolution based on ILD-TPC with smearing of 100μm

- Momentum:20GeV



Simulation studies - summary

- TPC as the main tracker fulfill the performance requirements

- Challenge due to short L*

  - Half_Z ≥ 2m is necessary => QD0 fully inside TPC

  - B-field non-uniformity not a big issue

    if an accurate B-field map is given $\Delta B(x)/B(x) < 10^{-4}$

- Prepare another option for the main tracker?

Calorimeters

- Vertexing $(h \to b\bar{b}, c\bar{c}, \tau^+\tau^-)$
  - ~1/5 $r_{beampipe}$,~1/30 pixel size (wrt LHC)

$$\sigma_{ip} = 5\mu m \oplus 10\mu m / p\sin^{3/2}\theta$$

- Tracking $(e^+e^- \to Zh \to \ell^+\ell^- X;\quad \text{incl.}\ h \to \text{nothing})$
  - ~1/6 material, ~1/10 resolution (wrt LHC)

$$\sigma(1/p) = 5\times 10^{-5} / GeV \quad \text{or better}$$

- Jet energy (Higgs self-coupling, W/Z separation)
  - ~1/2 resolution (wrt LHC)

$$\sigma_E / E = 0.3/\sqrt{E(GeV)}$$

Challenge: cooling

- ILD has some ~100M channels

  cooling <-> power pulsing

- However for a machine with $E_{\rm cm}^{\rm max} < \mathbf{250GeV}$,

  W/Z separation is not necessary for detectors at CEPC

- Detectors at CEPC

  + active cooling

  - readout channels

  electronics with even lower power consumption

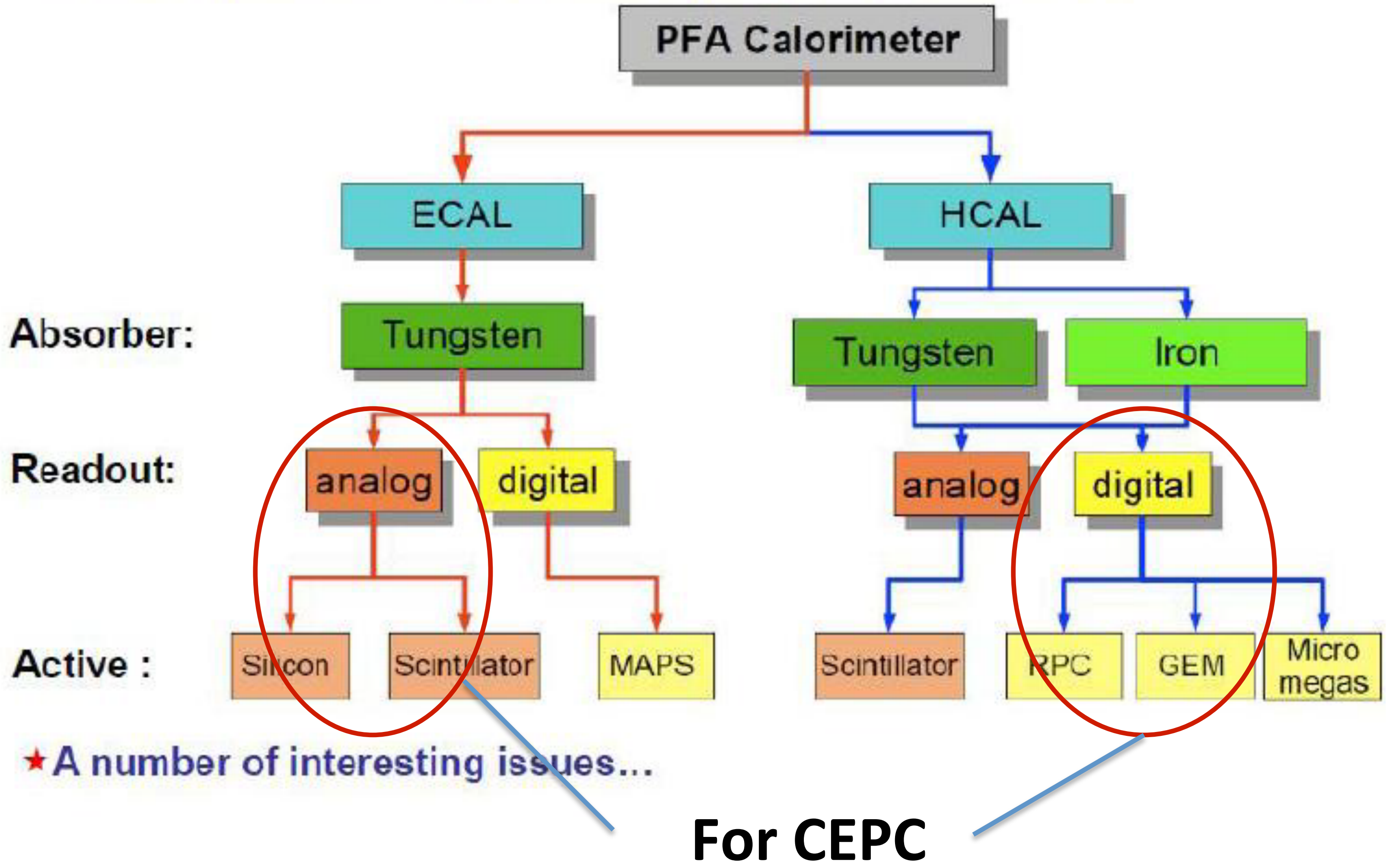
- For pre-CDR

  - ECAL/HCAL same as ILD

  - explore technologies for cooling

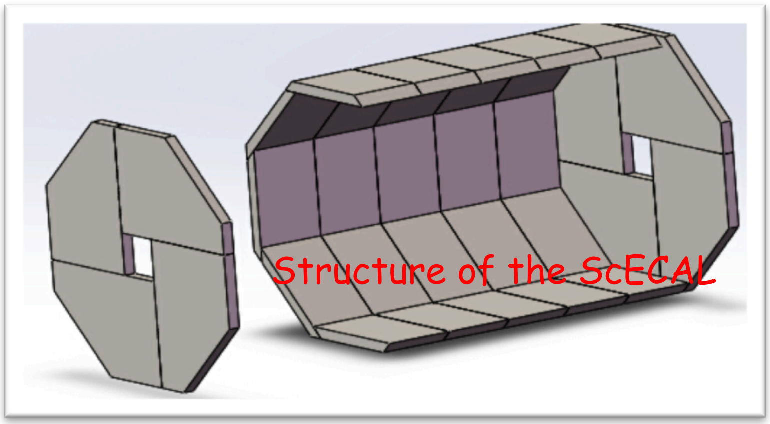
LC PFlow Calorimetry options

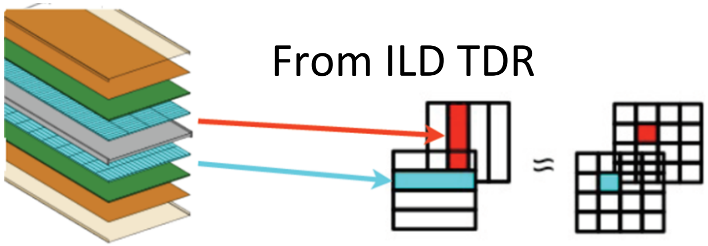
★ Various options for high granularity sampling calorimeters…

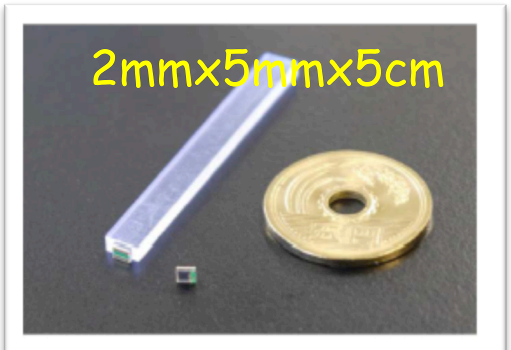


★ A number of interesting issues…

The progress of ScECAL

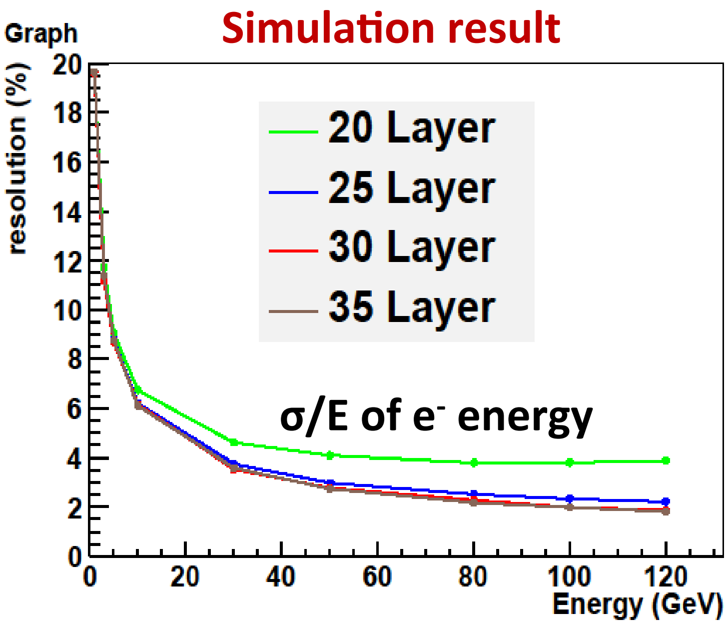






PS and SiPM

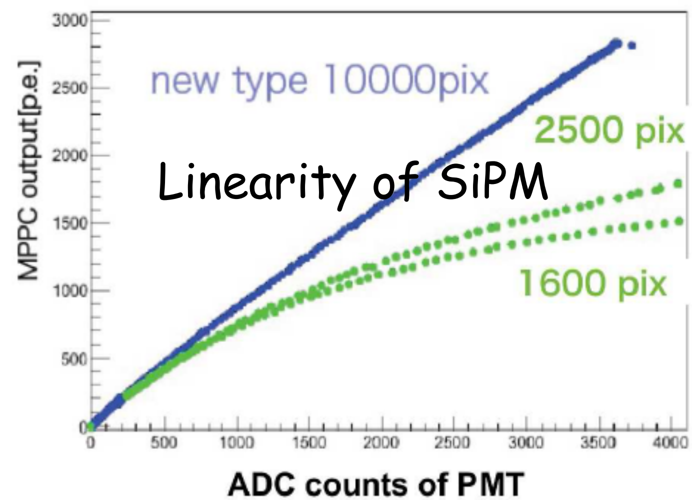
- A scintillator-tungsten sandwich sampling calorimeter (ScECAL) is proposed to build **a fine-segmented calorimeter** in a stable, robust and cost effective way.
- A super-layer is made of a tungsten plate (3 mm thick), scintillator strips (2 mm thick), and a readout/service layer (2 mm thick). The thickness of a super-layer is 7 mm.



Energy resolution Vs thickness

- 25 layers is an optimized option for CEPC energy, it is a balance between performance and cost.

A SiPM has a saturation phenomenon due to its finite number of pixels. According to the ILD estimation considering of e+e- → e+e- events at $\sqrt{s}=500$ GeV , **15000-18000** pixel SiPM is needed. What about CEPC ScEcal? 10000 pixel?



Si-W ECAL for the CEPC

Same mechanical structure as ILD but...

- Rates of machine ≠ ⇒ worst case: ~continuous
- no power-pulsing ⇒ **VFE power ↗↗↗**
  - 27 μW/ch ⟶ **~5mW/ch** (for 25 ns BX)
    - μ-power pulsing for slower modes ?

Adaptations:

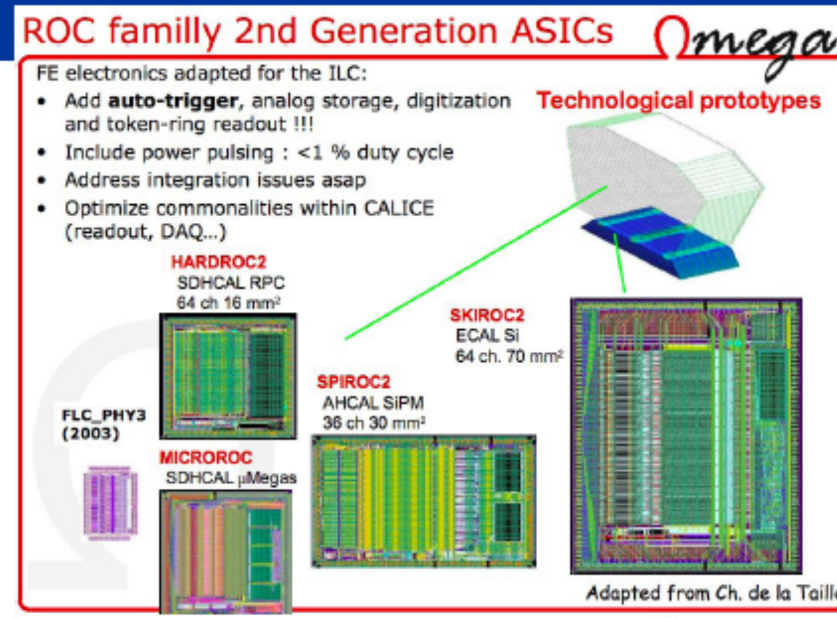
- Reduced number of layers
  - 30 ⟶ 20 ?
- Less electronics channels
  - 0.5×0.5 cm^2 ⟶ 1×1 cm^2 ?

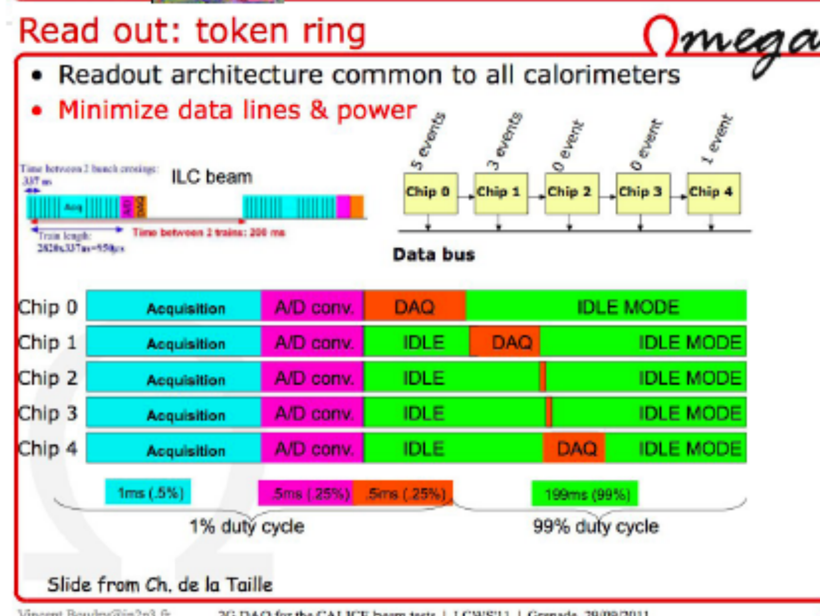
Radiations ? ⟶ leakage current ↗

- cooling at -20°C for CMS-HGCAL ?

Performances to be evaluated

- Occupancy!!! ⟶ power consumption
- (Simulation on Small ILD version).





Exemple of design with cooling

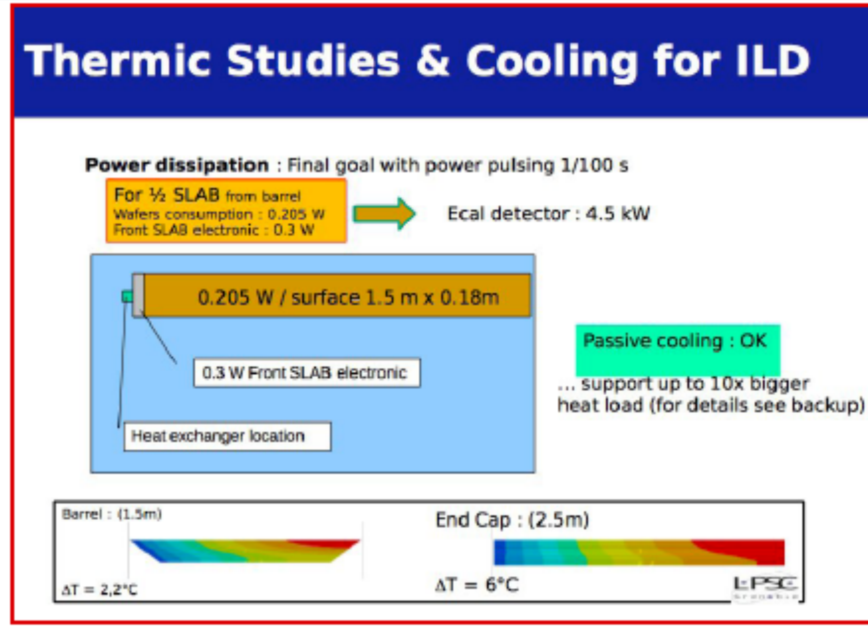
Passive cooling

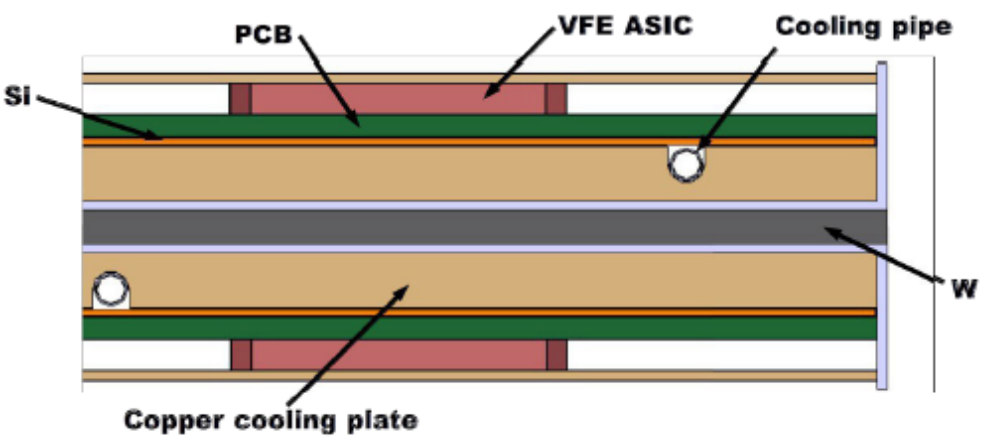
- too much gradient in Si...

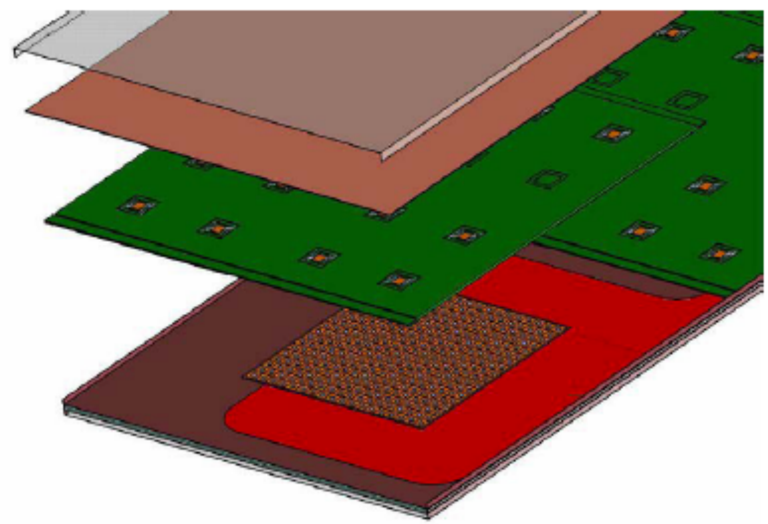
Active cooling

- Evaporative CO_2 cooling in thin pipes embbeded in Copper exchange plate
  - for CMS-HGCAL : 33mW/cm²
    - down to 0.6×0.6cm² OK (safety margin of 2)

→ To be modelled for Mokka simulation







Perspectives

Many years of R&D on ECAL (esp. at LLR) for ILC “easily” adaptable to CEPC case

Work on design modell has started

- benefit from CMS-HGCAL studies
- expertise on cooling and thermal simulation building-up

Most urgent to assess the performances and the needed granularity:

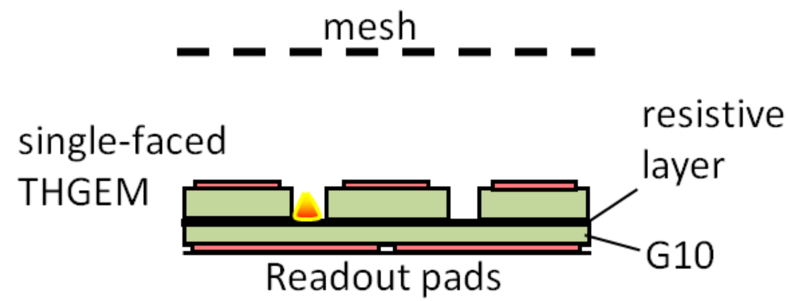
- Bunch structure of the machine will determine the granularity and performance of the ECAL

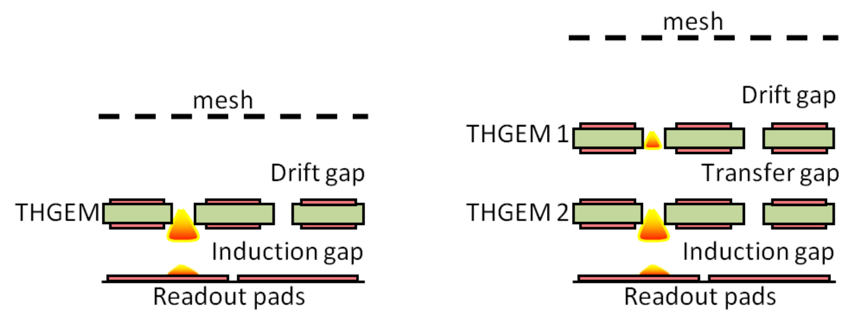
  ⇒ Occupancy studies mandatory to fine tune the electric comsumption

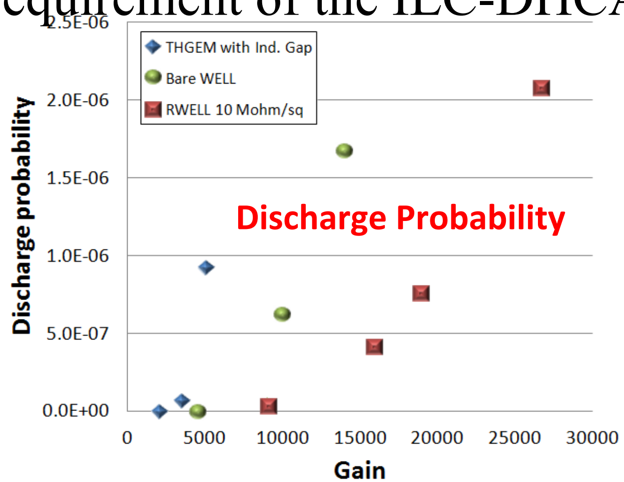
  - Specific R&D needed on VFE ASICs
- Updated GEANT4/Mokka models needed (support from LLR)
- 1 PhD student (Dan Yu) will work both on ILD and CEPC performances

THGEM DHCAL research of RD51

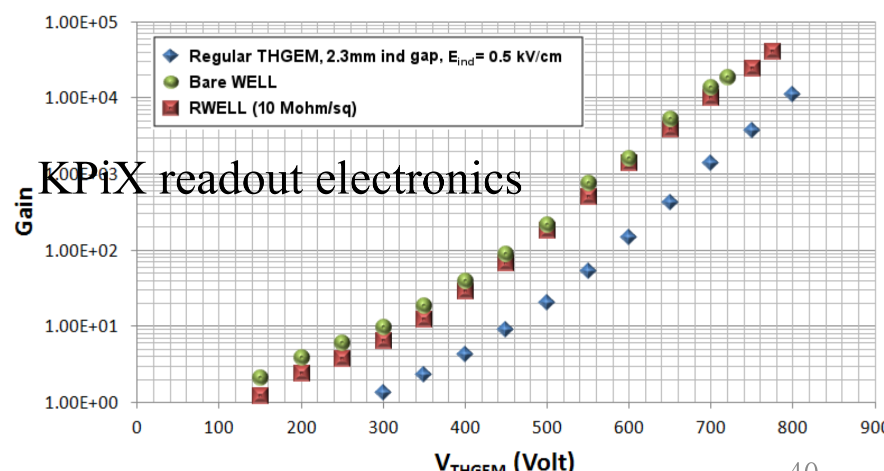
- RD51 research WELL-THGEM DHCAL;
- The beam studies showed a single-THGEM structure operating at a low gain (~1×10^3) can run at 96% efficiency with low discharge probability (10^{-6} or lower).
- The particular configuration tested, which can still be optimized, had a total thickness of 5.5 mm within the requirement of the ILC-DHCAL.





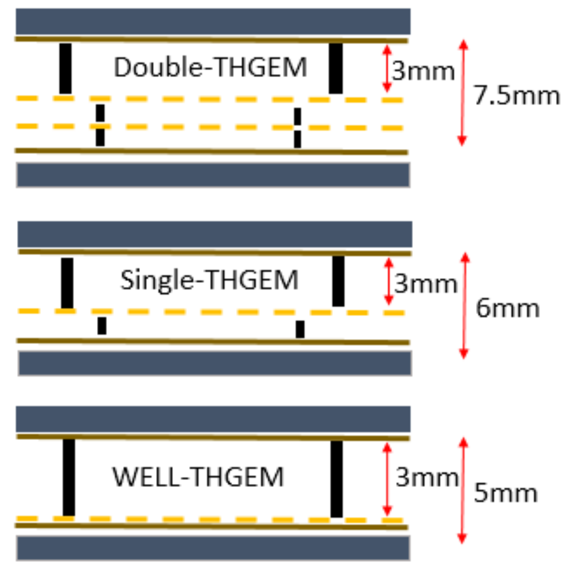


KPiX readout electronics

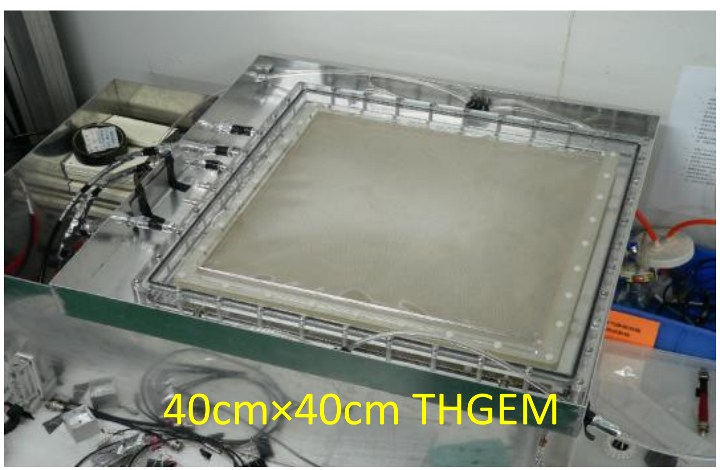


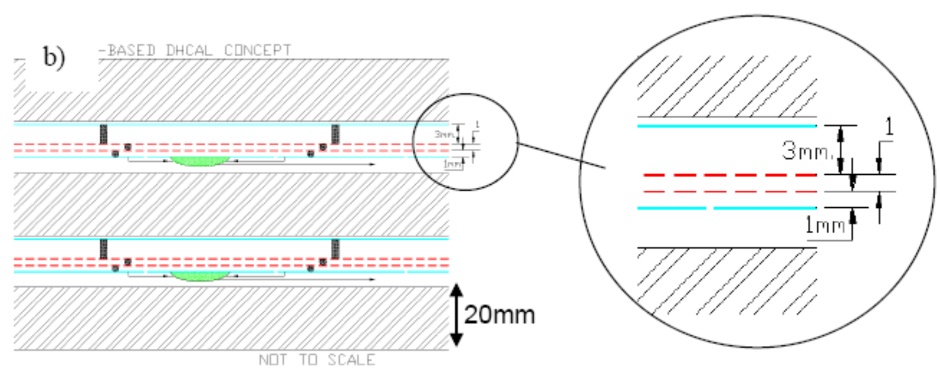
Structure of THGEM-DHCAL

- three structure can be selected;
  - Double THGEM;
  - Single-THGEM;
  - WELL-THGEM;
- WELL-THGEM is the-best selection.
  - thinner, high gain, lower discharge
- Simplicity, Robustness, is similar to glass RPC
- Sub-mm spatial resolution, better than glass RPC
- Few-ns temporal resolution , better than glass RPC
- 1 MHz/mm^2 rate capability . better than glass RPC
- But glass RPC may be cheaper



Including electronics

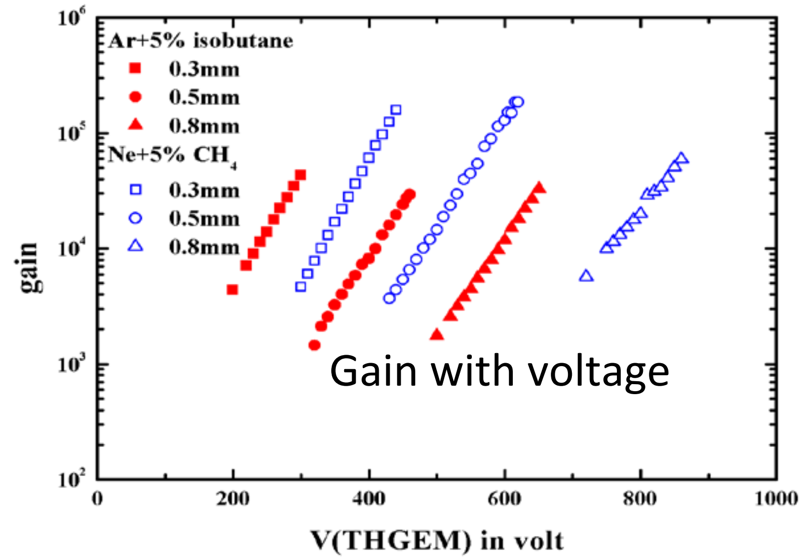


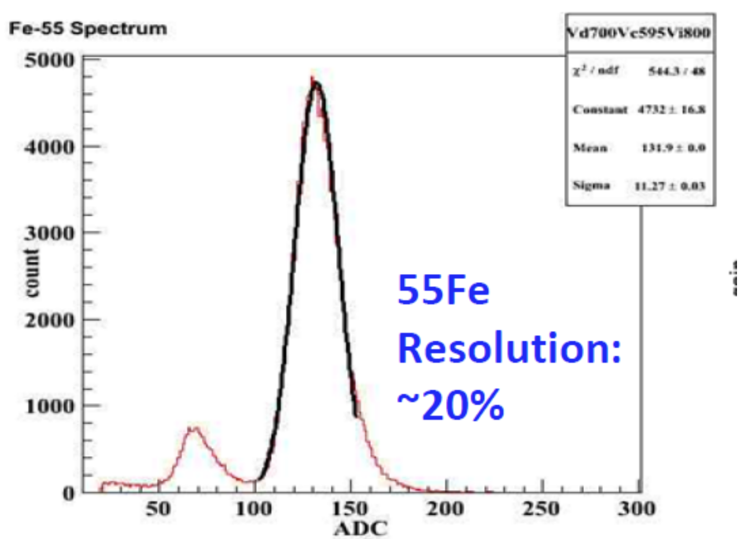


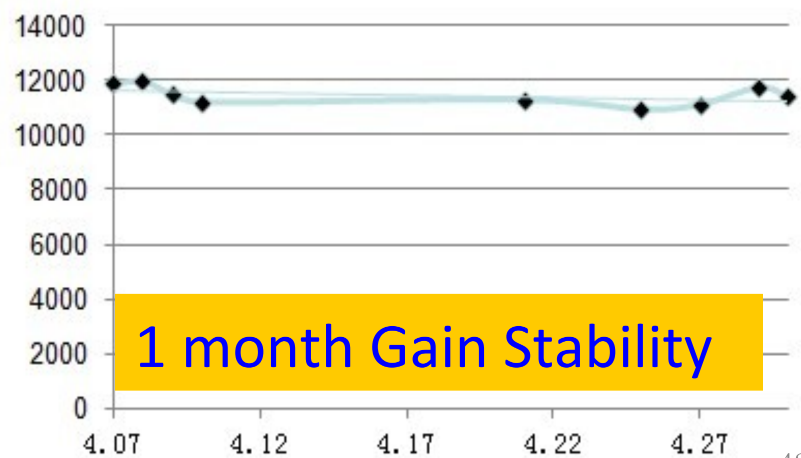
Structure of GEM-DHCAL

IHEP&UCAS THGEM detector performance study

- Maximum gain of double THGEM reach to 2×10^5(using Neon);
- Long time stability;
- High energy resolution;



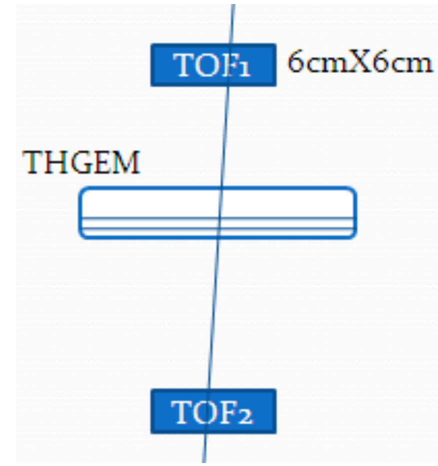


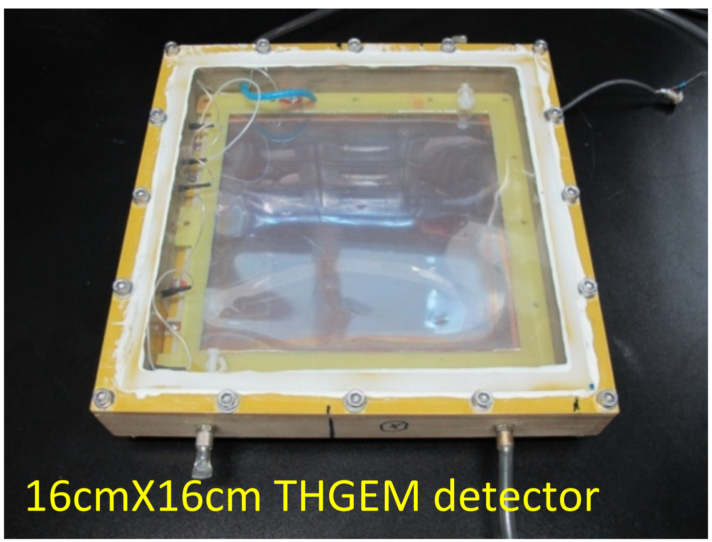


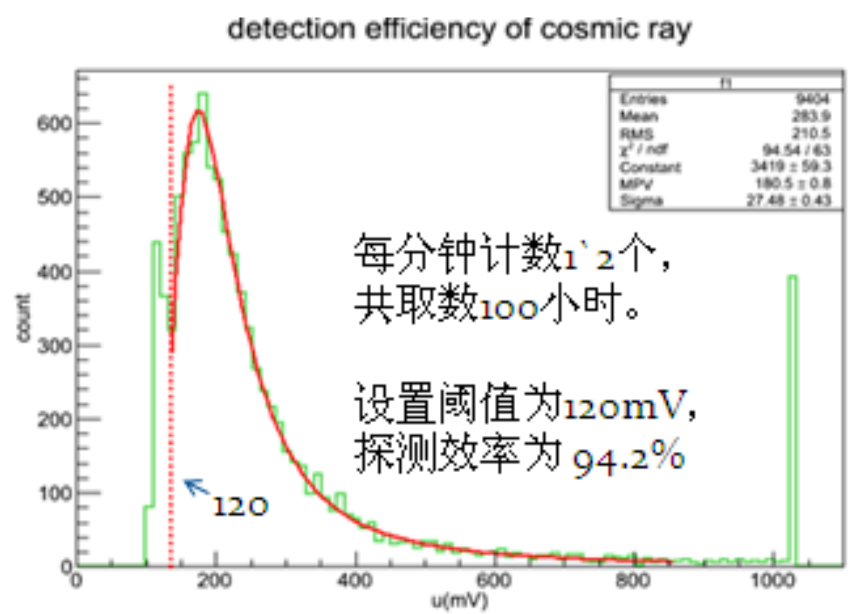
THGEM detector experiment

Double THGEM cosmic ray test

- Cosmic ray test， measure the detection efficiency of 16cmX16cm THGEM detector;
- Detection efficiency reach to 94.2% with 4mm drift gap detector.




16cmX16cm THGEM detector



SDHCAL

I.Laktineh

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OUTLINE

- SDHCAL concept
- SDHCAL-GRPC prototype
- Prototype results
- Present and future development
- Conclusion

Road map in the 2-3 coming years

-Improve on the energy reconstruction using new techniques;

-Improve on simulation (digitizer) and compare hadronic shower models to data;

-Develop PFA techniques to be used to separate close-by hadronic showers;

-Complete TB (ECAL+SDHCAL+…);

- Publish results;

-Build few very large GRPC detectors (2-3 m2) : gas circulation system, thickness…;

-Test the new version of electronics (I2C, roll mode..) ;

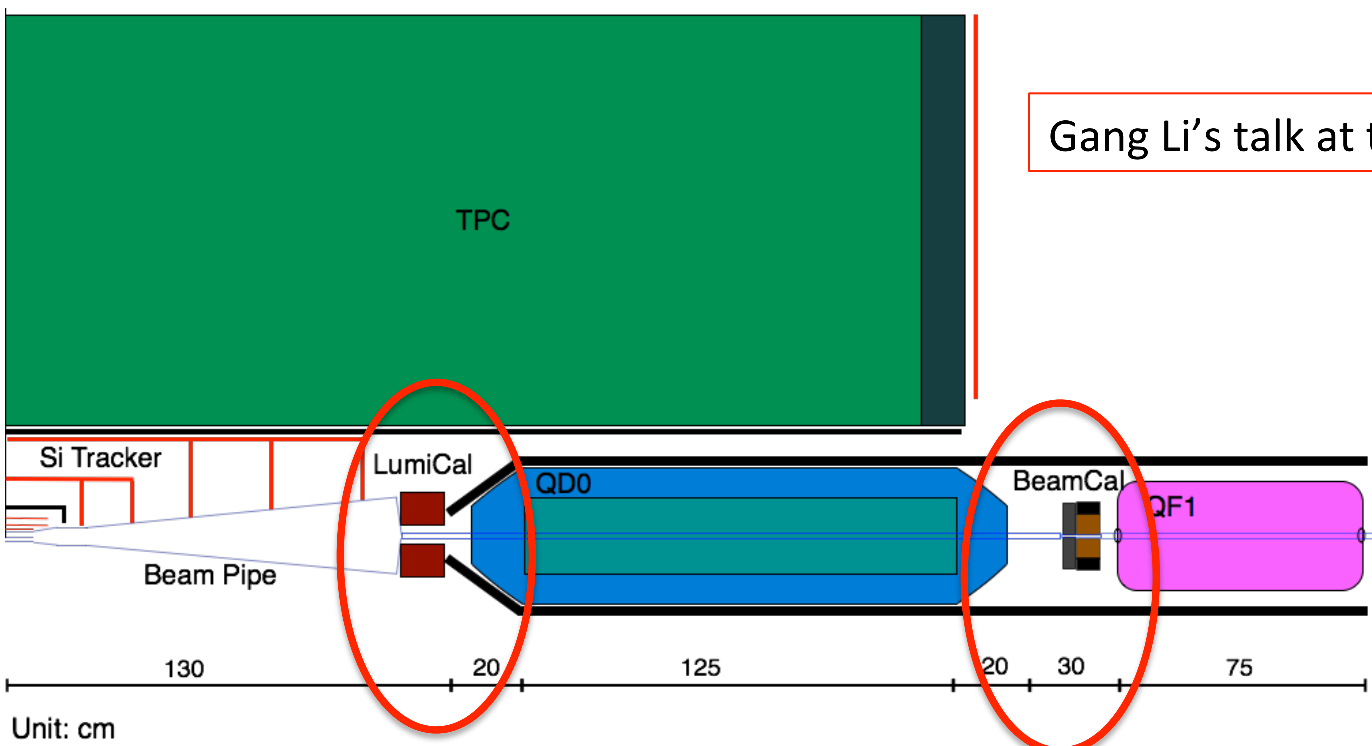
-Design a new ASU capable to read the large GRPC (up to 3 m^2);

-Develop a new DIF (low consumption, reduced size, new functionalities);

-Build a small mechanical prototype to host the few large chambers and test it.

Luminosity measurements

- Requirements:
  - luminosity measurement reaches 0.1%
  - online luminosity monitor



Gang Li's talk at this workshop

Summary

- Benchmark Physics performance of CEPC program has been studied

- Feasibility studies for a detector at CEPC
  - ILD-like design
  - challenging due to short L*, but acceptable
  - cooling is an issue to be studied in future R&D

- Pre-CDR is underway