Snapshot of the 2020 online mini-workshop on a CEPC detector concept with a crystal ECAL

Jianming Qian
University of Michigan

Disclaimer: mostly cut-and-paste, no time to prepare a real summary,
Apology for missing or misrepresenting information.

2020 Workshop

Online mini-workshop on a detector concept with a crystal ECAL

22-23 July 2020
Zoom
Asia/Shanghai timezone

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In this online mini-workshop during July 22-23, 2020, we will discuss a CEPC detector con crystal electromagnetic calorimeter, which goes in parallel with the current baseline concep the IDEA concept in the CEPC CDR.

To accommodate participants in different time zones, we come up with the schedule as follc Beijing Time (GMT+8) applies,

July 22 (Wednesday): 8:30-11:00 AM, 8:30-11:00 PM

July 23 (Thursday): 8:30-11:00 AM, 8:30-11:00 PM.

Here is the link to connect to the Zoom meeting room,

https://weidijia.zoom.com.cn/j/63645143402?pwd=ZnNZV1hob2VyQUdMR1dBUFB1VjFl

Meeting ID: 636 4514 3402

Organizing Committee

Sarah Eno (Unviersity of Maryland)

Jianbei Liu (University of Science and Technology of China)

Yong Liu (Institute of High Energy Physics, CAS), **workshop secretariat**

Xinchou Lou (Institute of High Energy Physics, CAS)

Jianming Qian (Unviersity of Michigan), **committee chair**

Manqi Ruan (Institute of High Energy Physics, CAS)

Christopher Tully (Princeton University)

Jianchun Wang (Institute of High Energy Physics, CAS)

Haijun Yang (Shanghai Jiao Tong University)

Originally planned in person,
Changed to two-day online

Participant List

Number of participants: 43

Thanks to Yong, Jianchun and others for the logistics!

Unusual Schedule

Designed for people in Beijing and US Eastern time zones

Wednesday, 22 July 2020

08:30 - 11:00 Session 1: Latest development in crystals and calorimeters

8:30-11:00AM, Wednesday Beijing Time
2:30-5:00AM, Wednesday, Central European Time
8:30-11:00PM, Tuesday, US Eastern Daylight Time

Convener: Dr. Jianchun WANG (IHEP)

- 08:30 **Introduction** *10'*
  Speaker: Prof. Xinchou LOU (高能所)
- 08:40 **Latest development in crystals and readout** *40'*
  Speaker: Dr. Ren-Yuan Zhu (Caltech)
  Material: Slides
- 09:20 **Status of crystal ECAL studies at IHEP** *30'*
  Speaker: Dr. Yong Liu (Institute of High Energy Physics)
  Material: Slides
- 09:50 **Crystal ECAL Optimization studies: transverse granularity and longitudinal**
  Speaker: Liu ChunXiu (高能所)
  Material: Slides
- 10:10 **Crystal ECAL design and optimization** *20'*
  Speaker: Yuezin (悦心) Wang (王)
  Material: Slides

20:30 - 23:00 Session 2: Crystal ECAL development

8:30-11:00PM, Wednesday Beijing Time
2:30-5:00PM, Wednesday European Central Time
8:30-11:00AM, Wednesday US Eastern Daylight Time

Convener: Prof. Christopher Tully (Princeton University)

- 20:30 **Review of past DREAM work on dual-readout crystals** *40'*
  Speaker: Dr. Gabriella Gaudio (INFN-PV)
  Material: Slides
- 21:10 **Segmented crystal electromagnetic precision calorimeter (SCEPCAL)** *40'*
  Speaker: Dr. Marco Lucchini (Princeton University)
  Material: Slides
- 21:50 **New ideas on the readout schemes of crystal calorimetry** *25'*
  Speakers: Dr. Zhigang WANG (IHEP), Prof. Junguang LV Junguang (IHEP)
  Material: Slides
- 22:15 **Stand-alone pion resolutions with the IDEA concept** *25'*
  Speaker: Iacopo Vivarelli (University of Sussex)
  Material: Slides

Thursday, 23 July 2020

08:30 - 11:00 Session 3: Tracking, solenoid and simulation

8:30-11:00AM, Thursday Beijing Time
2:30-5:00AM, Thursday, Central European Time
8:30-11:00PM, Wednesday, US Eastern Daylight Time

Convener: Prof. Sarah Eno (University of Maryland)

- 08:30 **Simulation of dual readout crystals** *15'*
  Speaker: Mr. Yihui Lai (University of Maryland)
  Material: Slides
- 08:45 **Detector optimization w.r.t. the BMR** *15'*
  Speaker: Yunkun Shi (USTC)
  Material: Slides
- 09:00 **Tracking options** *30'*
  Speaker: Xin Shi (IHEP)
  Material: Slides
- 09:30 **Solenoid R&D** *30'*
  Speaker: Dr. Feipeng NING (IHEP)
  Material: Slides
- 10:00 **Discussion** *1h0'*

20:30 - 23:00 Session 4: Simulation and performance studies

8:30-11:00PM, Thursday Beijing Time
2:30-5:00PM, Thursday Central European Time
8:30-11:00AM, Thursday US Eastern Daylight Time

Convener: Dr. Manqi Ruan (IHEP)

- 20:30 **Latest development of the PFA calorimeter** *30'*
  Speaker: Mr. Roman Pöschl (Laboratoire de l'accélérateur Linéaire)
  Material: Slides
- 21:00 **Introduction to Key4HEP, the common software framework** *10'*
  Speaker: Paolo Giacomelli (INFN-Bo)
  Material: Slides
- 21:10 **Development efforts of software framework to simulate DR calorimeter** *20'*
  Speaker: Sanghyun Ko (Seoul National University)
  Material: Slides
- 21:30 **Identification performance of leptons in jets** *15'*
  Speaker: Dan YU (IHEP)
  Material: Slides
- 21:45 **Differential jet performance** *15'*
  Speaker: [illegible] (國立中央大學)
  Material: Slides
- 22:00 **Discussion and Wrap up** *1h0'*

2019 Workshop

Topical Workshop on the CEPC Calorimetry

11-14 March 2019
Institute of High Energy Physics, Beijing
Asia/Shanghai timezone

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The Topical Workshop on the CEPC Calorimetry will take place during March 11-14, 2019 at the Institute of High Energy Physics (IHEP) in Beijing. It will be semi-informal with presentations interleaved with plenty of time for discussions.

This workshop intends to bring together experts on calorimetry to have informal and in-depth discussions on the technical options for the calorimeter system at the proposed circular electron positron collider (CEPC), including both the options presented in the Conceptual Design Report and possible new options.

Topics to be discussed include physics drivers, expected performance, channel count and data rate, power consumption, cost estimation as well as potential interested groups.

Meeting Room: **A415**, Main Building in IHEP

WIFI: CEPC201903

Vidyo link: http://vidyo.ihep.ac.cn/flex.html?roomdirect.html&key=sBdUsAF95e0X2wOF7BNL7KD9GGw

Participant List

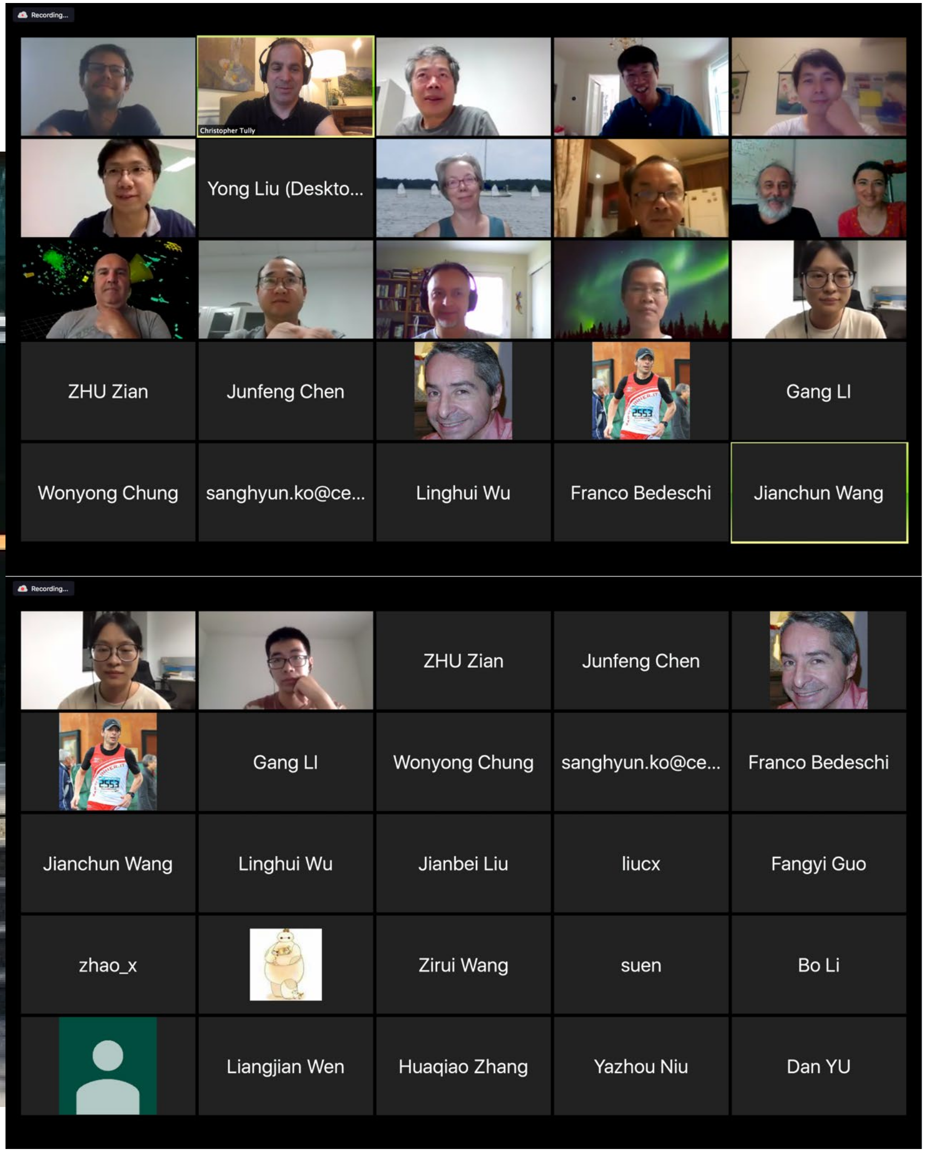
Number of participants: 45

In person for 4 days at IHEP, lots of discussion

Workshop photos

What a difference one year makes…

2019



2020

About 55 people are connected to the 1st session at the peak

Latest Development in Inorganic Scintillators and Readout for Future Crystal Calorimeters

Ren-Yuan Zhu

California Institute of Technology

July 22, 2020

Presentation in the Online Mini-Workshop on a Crystal ECAL

Fast and Ultrafast Inorganic Scintillators

	BaF_2	BaF_2:Y	ZnO:Ga	YAP:Yb	YAG:Yb	β-Ga_2O_3	LYSO:Ce	LuAG:Ce	YAP:Ce	GAGG:Ce	LuYAP:Ce	YSO:Ce
Density (g/cm^3)	4.89	4.89	5.67	5.35	4.56	5.94[1]	7.4	6.76	5.35	6.5	7.2[f]	4.44
Melting points (°C)	1280	1280	1975	1870	1940	1725	2050	2060	1870	1850	1930	2070
X_0 (cm)	2.03	2.03	2.51	2.77	3.53	2.51	1.14	1.45	2.77	1.63	1.37	3.10
R_M (cm)	3.1	3.1	2.28	2.4	2.76	2.20	2.07	2.15	2.4	2.20	2.01	2.93
λ_I (cm)	30.7	30.7	22.2	22.4	25.2	20.9	20.9	20.6	22.4	21.5	19.5	27.8
Z_{eff}	51.6	51.6	27.7	31.9	30	28.1	64.8	60.3	31.9	51.8	58.6	33.3
dE/dX (MeV/cm)	6.52	6.52	8.42	8.05	7.01	8.82	9.55	9.22	8.05	8.96	9.82	6.57
λ_{peak}[a] (nm)	300 220	300 220	380	350	350	380	420	520	370	540	385	420
Refractive Index[b]	1.50	1.50	2.1	1.96	1.87	1.97	1.82	1.84	1.96	1.92	1.94	1.78
Normalized Light Yield[a,c]	42 4.8	1.7 4.8	6.6[d]	0.19[d]	0.36[d]	6.5 0.5	100	35[e] 48[e]	9 32	115	16 15	80
Total Light yield (ph/MeV)	13,000	2,000	2,000[d]	57[d]	110[d]	2,100	30,000	25,000[e]	12,000	34,400	10,000	24,000
Decay time[a] (ns)	600 0.5	600 0.5	<1	1.5	4	148 6	40	820 50	191 25	800 80	1485 36	75
LY in 1st ns (photons/MeV)	1200	1200	610[d]	28[d]	24[d]	43	740	240	391	640	125	318
40 keV Att. Leng. (1/e, mm)	0.106	0.106	0.407	0.314	0.439	0.394	0.185	0.251	0.314	0.319	0.214	0.334

Existing Crystal Calorimeters in HEP

Date	75-85	80-00	80-00	80-00	90-10	94-10	94-10	95-Now	10-Now
Experiment	C. Ball	L3	CLEO II	C. Barrel	KTeV	BaBar	BELLE	CMS	BES III
Accelerator	SPEAR	LEP	CESR	LEAR	Tevatron	PEP	KEKB	LHC	BEPC
Laboratory	SLAC	CERN	Cornell	CERN	FNAL	SLAC	KEK	CERN	IHEP
Crystal Type	NaI:Tl	BGO	CsI:Tl	CsI:Tl	CsI	CsI:Tl	CsI:Tl	PWO	CsI:Tl
B-Field（T）	-	0.5	1.5	1.5	-	1.5	1.0	4.0	1.0
r_{inner} (m)	0.254	0.55	1.0	0.27	-	1.0	1.25	1.29	0.94
Crystal number	672	11,400	7,800	1,400	3,300	6,580	8,800	75,848	6,240
Crystal Depth（X_0）	16	22	16	16	27	16 to 17.5	16.2	25	15
Crystal Volume（m^3）	1	1.5	7	1	2	5.9	9.5	11	5.3
Light Output（p.e./MeV）	350	1,400	5,000	2,000	40	5,000	5,000	2	5,000
Photo-detector	PMT	Si PD	Si PD	WS+Si PD	PMT	Si PD	Si PD	Si APD	Si PD
Gain of Photo-detector	Large	1	1	1	4,000	1	1	50	1
σ_N/Channel（MeV）	0.05	0.8	0.5	0.2	Small	0.15	0.2	40	0.2
Dynamic Range	10^4	10^5	10^4	10^4	10^4	10^4	10^4	10^5	10^4

Summary

- LYSO crystals are radiation hard for HL-LHC applications, such as CMS BTL. BaF_2 shows a radiation hardness similar to LYSO at high radiation level. LuAG:Ce ceramics appears promising for FCC-hh, provided that its slow component is eliminated.
- Undoped BaF_2 crystals provide ultrafast light with sub-ns decay time. Yttrium doping enhances its F/S ratio while maintaining its sub-ns fast component not changed. 20 cm long BaF_2:Y crystals with LO_F>100 p.e./MeV, F/S>2, 10% LRU and $|\delta_F|<3\%/X_0$ are developed. R&D continues to optimize yttrium doping in large size BaF_2:Y crystals for Mu2e-II. SB photo-detectors are also under development for BaF_2:Y readout.
- Mass-produced Sapphire crystals costs less than $1/cc. Sapphire:Ti crystals show a weak/strong fast/slow scintillation at 325/755 nm with LO of 1.3k/6.6k photons/MeV and 151 ns/3 μs decay. With a cut-off of 280 nm and LO similar to BGO it may be used for an HHCAL with dual readout of both scintillation and Cerenkov light.
- Additional ultrafast scintillators under development, such as ZnO:Ga films, quantum confinement based all inorganic Cs Pb halide perovskite quantum dots etc.

Acknowledgements: DOE HEP Award DE-SC0011925

中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

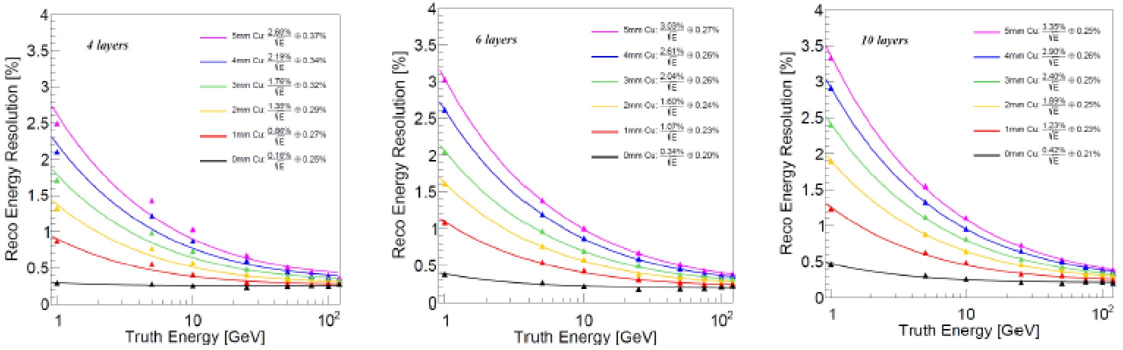
High-granularity Crystal Calorimeter: R&D status

Yong Liu (Institute of High Energy Physics, CAS),
on behalf of the CEPC Calorimetry Working Group

Mini-workshop on a detector concept with a crystal calorimeter
July 22-23, 2020

Longitudinal segmentation: impact from services

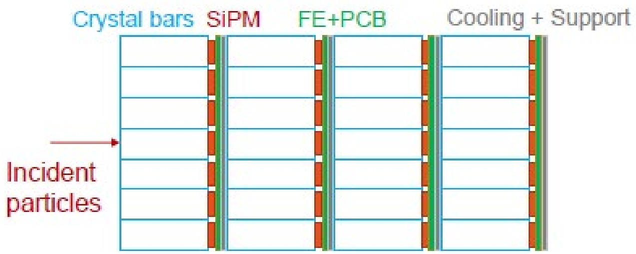
- Energy resolution with different numbers of sampling layers
  - 24X0 total depth for crystals (fixed) in all scenarios
  - Used copper to model the inter-layer services (e.g. cooling)
    - Light materials will be considered for realistic cooling designs: Al, carbon-fibre…



Note: digitization not implemented yet; so energy fluctuations and leakages dominate

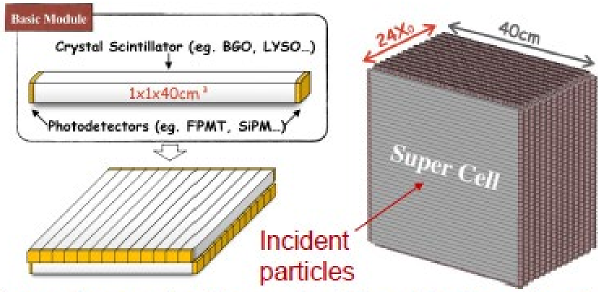
High-granularity crystal ECAL: 2 major designs in pursuit

Design 1



- Longitudinal segmentation
- Fine transverse segmentation
  - 1×1cm or 2×2cm cells
- Single-ended readout with SiPM
- Potentials with PFA

Design 2

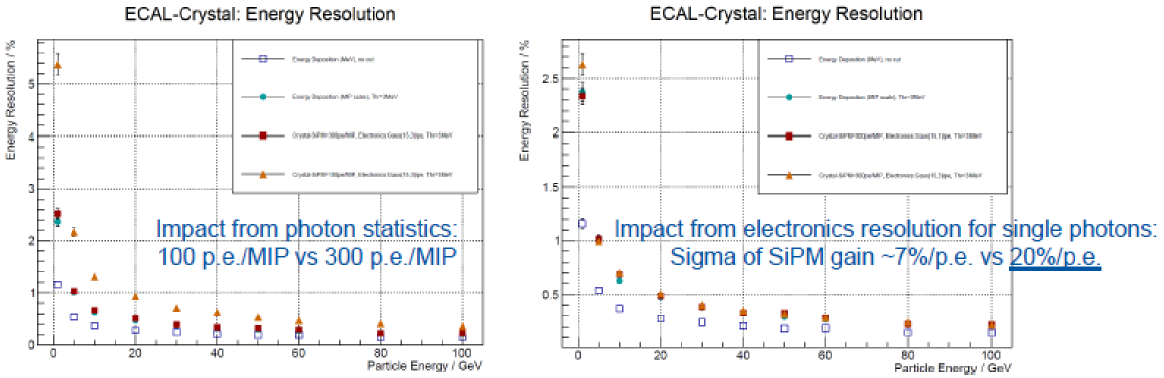


- Long bars: 1×40cm, double-sided readout
  - Super cell: 40×40cm cube
- Crossed arrangement in adjacent layers
- Significant reduction of #channels
- Timing at two sides: positioning along bar

Digitizer in simulation for crystal ECAL

Geant4 version 10.5.0

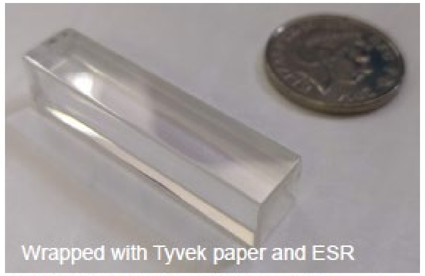
MC samples: electrons



- Quantitative studies for the impacts of photostatistics and electronics
  - Stochastic terms: ~5% for lower light yield (e.g. PWO), ~2% for higher light yield (e.g. BGO)
  - Negligible impact from single photon resolution at energy regions > 5GeV

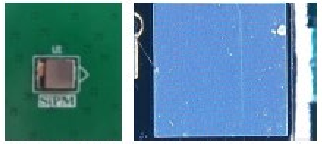
Studies with PWO crystal bar and NDL-SiPM

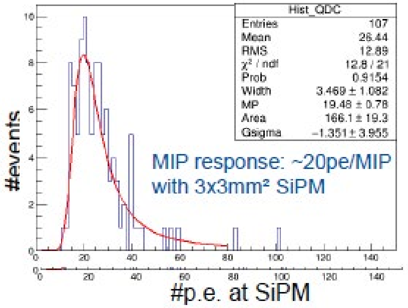
- Cosmic ray tests with a PWO crystal
  - Read out with a 3x3mm² SiPM (90k pixels)
  - SiPM designed by Novel Device Lab (NDL) in Bejiing Normal University



PbWO crystal (produced by SIC), 10x10x45 mm³


Example of pre-cut Tyvek paper

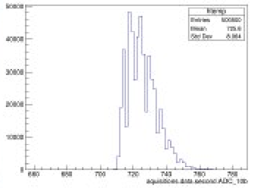

NDL-SiPM 3x3mm² with 10um pixels



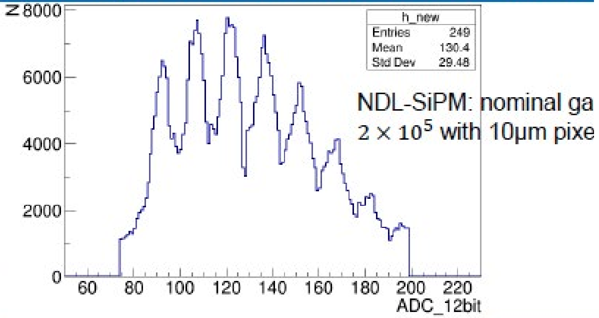
Note: a larger SiPM (e.g. 6x6mm²) can be used for better light collection efficiency

Klaus5 tests with NDL-SiPM

- NDL-SiPM features: small pixel pitch (10μm or smaller), high PDE
  - Requires high S/N ratio in electronics to resolve single photons (small gain)
- Klaus5 proved to be able to resolve the single photons (32fC/p.e.)
  - Benefits from its high S/N ratio and high resolution


Single photon spectrum in 10-bit ADC mode: can not be resolved

Single photon spectrum in 12-bit ADC mode: after corrections



Summary

- High-granularity crystal ECAL
  - Aim to keep optimal energy resolution and PFA capability
  - Key issues for optimization and technical challenges (partially) identified
    - Needs further discussions and iterations
  - Steady R&D progress
    - Optimisation studies: longitudinal depth and segmentation, transverse
    - Technical developments:
      - SiPMs and crystals
      - Characterisations of SiPM-dedicated low-power readout ASIC (within CALICE)
      - Dynamic range: TOT technique
- Welcome broader collaborations
  - Early R&D stage, many open issues

Thank you!

Ghost ambiguities need to be understood.

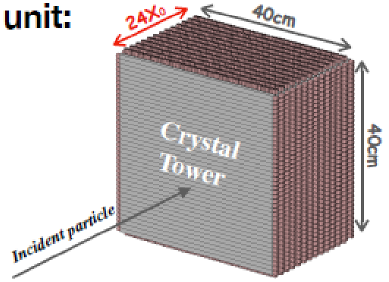
Crystal ECAL design for CEPC

Speaker: Yuexin Wang (IHEP)
Manqi Ruan, Yong Liu, Chengdong Fu

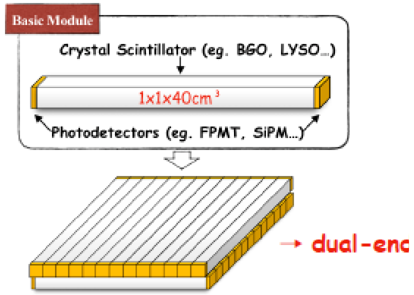
Overview

Ideas on homogeneous crystal ECAL design

Basic unit:



Geometry Structure:



Advantages:

- *Longitudinal granularity guaranteed*
- *Timing measurement for hit positions to get transverse granularity*
  - *ghost ambiguity largely removed*
- *De facto 3D calorimeter by 2D detector components*
  - *#channels, ~15 times less*
  - *Easy for cables*

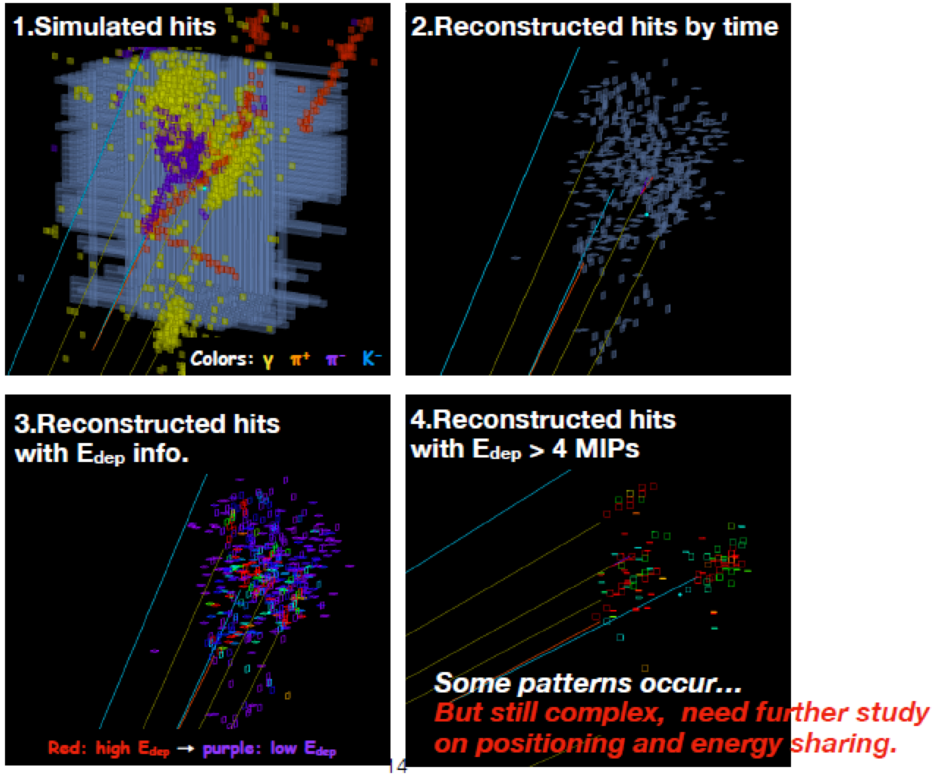
Key issues:

- *Remaining ambiguity: multiple hits in one crystal bar*
- *Separation of nearby showers*
- *Impact on the Jet Energy Resolution (JER)*

3

Pattern study using Event Display

Jet event, with increasing multiplicity and combinations



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Crystal ECAL Optimization studies: transverse granularity and longitudinal depth

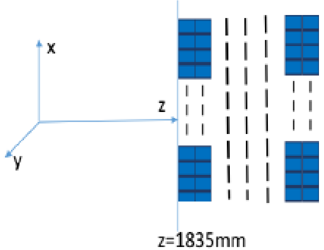
Chunxiu Liu Yong Liu Junguang Lv
Institute of High Energy Physics, CAS

July 22, 2020
Online mini-workshop on a detector concept with a crystal ECAL

Optimization with a fixed ECAL length, e.g. 24X0?

Simulation in Geant4 and Cluster reconstruction

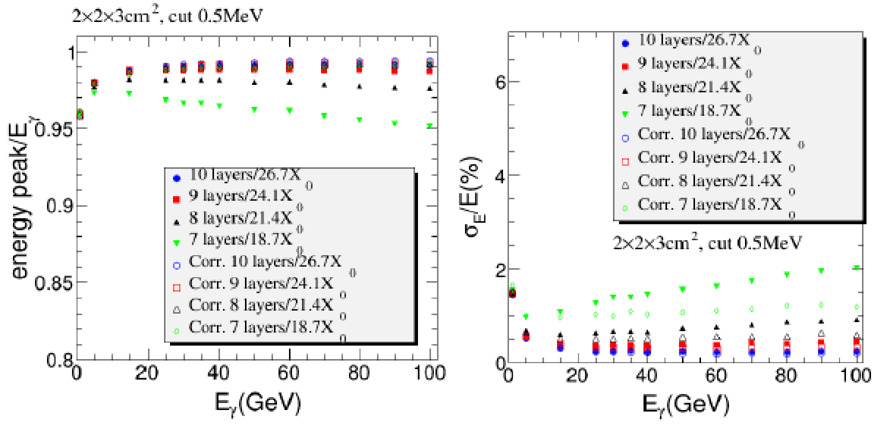
- Construct a 3D BGO Matrix module with 60 ×60 ×60 cells/ cell size 1×1×1cm^3
  - Easily merge cells / layers
  - The front face of the array is 1835mm from zero (origin of coordinates), the inner radius of CEPC baseline ECAL Barrel.
- Without any photodetector materials and wrappers
- Without any materials in front of BGO Matrix module
- Geant4 simulates the energy deposited in crystal cell
- Cluster reconstruction of each layer is based on the method of the traditional crystal ECAL without longitudinal layer.



BGO crystal material properti
Crystal radiation length: ~1.
Moliere radius R_M: 2.23cm;

Impact of the crystal ECAL longitudinal depth

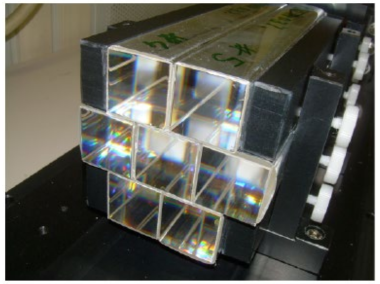
- Energy peak and resolution have been a big improvement after longitudinal energy leakage correction
- For 7 layers/18.7X_0
  - The effect of the energy leakage is very large.
  - The constant term of the energy resolution is larger than 1%



Online mini-workshop on a detector concept with a crystal ECAL

Review of past DREAM work on dual-readout crystals

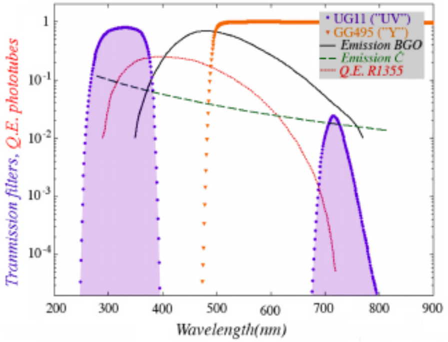
Gabriella Gaudio
INFN-Pavia

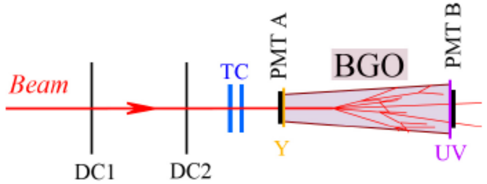


C to S separation: optical spectra

Properties	Čerenkov	Scintillation
Optical spectra	$\frac{dN_C}{d\lambda} = \frac{k}{\lambda^2}$	Strongly dependent on the crystal type, usually concentrated in a (narrow) wavelength range

Nucl. Instr. and Meth. A 595 (2008) 359





Use optical filters to separate lights

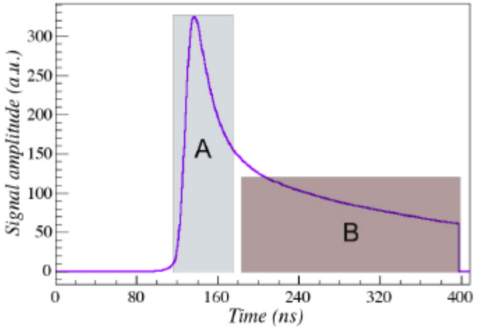
Cherenkov to scintillation separation

Properties	Čerenkov	Scintillation
Angular distribution	Light emitted at a characteristic angle by the shower particles that generate it $\cos\theta = 1/(n\beta)$	Light emission is isotropic: excited molecules have no memory of the direction of the particle that excited them
Time structure	Instantaneous, short signal duration	Light emission is characterized by one (or several) time constant(s). Long tails are not unusual (slow component)
Optical spectra	$\frac{dN_C}{d\lambda} = \frac{k}{\lambda^2}$	Strongly dependent on the crystal type, usually concentrated in a (narrow) wavelength range
Polarization	polarized	not polarized

Combination of these two techniques were applied to crystal matrix readout together with DREAM fiber calorimeter

C to S separation: time structure

Properties	Čerenkov	Scintillation
Time structure	Instantaneous, short signal duration	Light emission is characterized by one (or several) time constant(s). Long tails are not unusual (slow component)



PMT signal (inverted) containing both Cherenkov and scintillation.

- From pure scintillation channel determine S content
- Integration over to gates gives

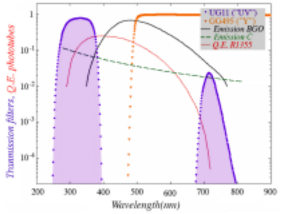
$$S = (1 + f_S) * Q_B$$

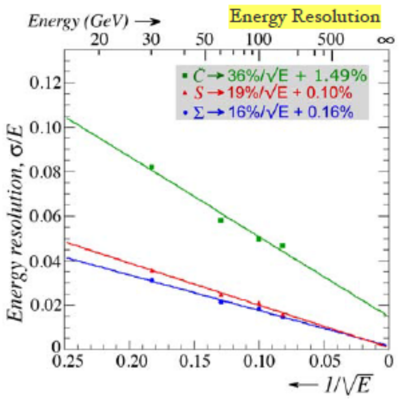
$$C = Q_A - f_S * Q_B$$

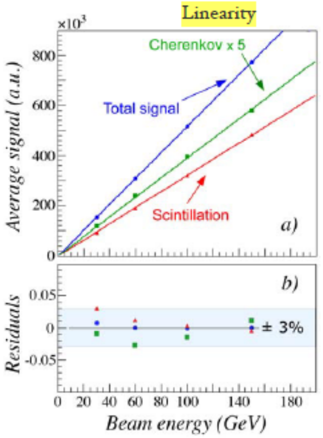
BGO matrix results: EM performance

Results:

- Čerenkov energy resolution shows a constant term of about 1.5%
- good linearity (within ± 3%)
- Čerenkov light yield about 6 p.e./GeV







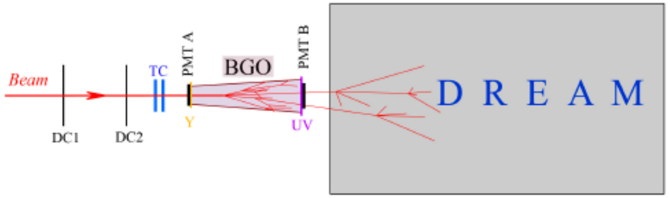
Nucl. Instr. and Meth. A 686 (2012) 125

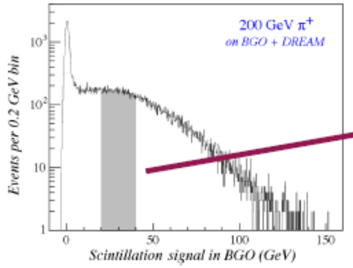
EM resolution is not as good due to the losses of photons from filters or time windows.

New developments in readout may overcome these issues.

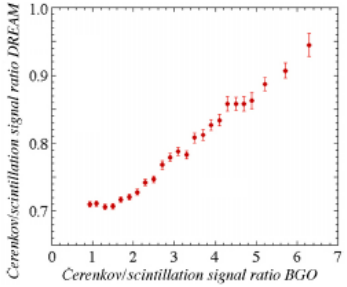
Dual-readout hybrid calorimeter

Nucl. Instr. and Meth. A 598 (2009) 710



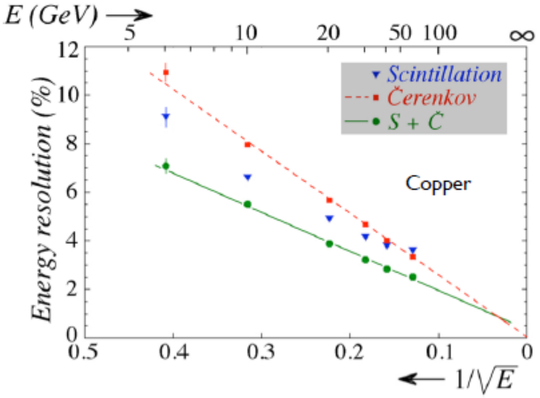


Pions depositing energy in the xtals
Mainly energetic π0 produced in early stage of the shower



Conclusions and Outlook

- DREAM/RD52 collaboration didn't proceed in the DR crystals calo studies due to new results obtained with an optimized layout with DR fiber calorimeter (13%/sqrt(E) with a costant term smaller than 1%.)
- A proof of principle that DR xtal ECAL combined with DR fiber HCAL can hold both good EM and HAD resolutions was made
- Advancements/improvements in RO techniques could overcome limitation on DR crystals found (~ 10 y ago)



Segmented Crystal Electromagnetic Precision Calorimeter (SCEPCal)

Online mini-workshop on a detector concept with a crystal ECAL

29/05/20

S.Eno[2], Y.Lai[2], M.Lucchini[1], M.Nguyen[1], C.Tully[1]

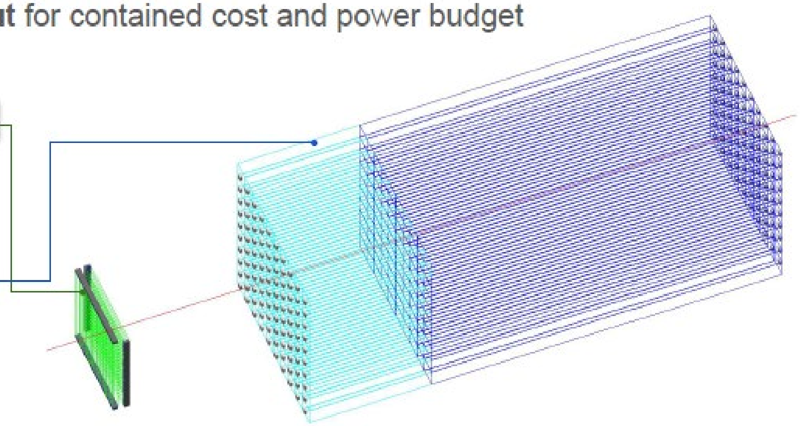
[1]Princeton University, [2]University of Maryland

PRINCETON UNIVERSITY

Overview of a SCEPCal module

- ***SCEPCAL:*** a **S**egmented **C**rystal **E**lectromagnetic **P**recision **C**alorimeter
- **Transverse and longitudinal segmentations** optimized for particle identification, shower separation and performance/cost
- Exploiting **SiPM readout** for contained cost and power budget

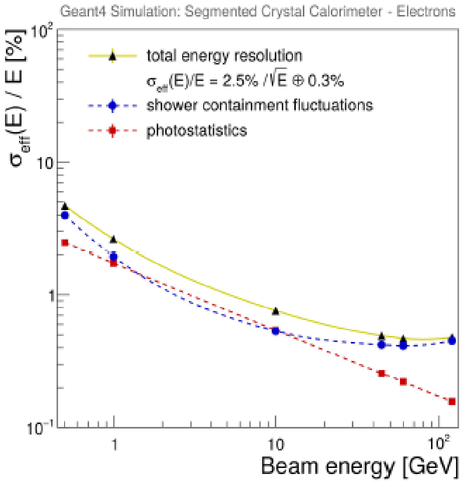
- **Timing layer** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x54 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layer** — $\sigma_E/E \sim 3\%/\sqrt{E}$
  - PbWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)



SCEPCAL e.m. resolution

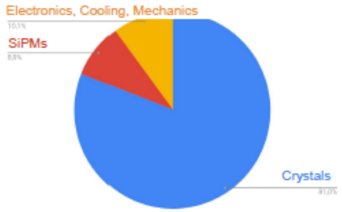
- Contributions to energy resolution:
  - Shower containment fluctuations
    - Longitudinal leakage
    - Tracker material budget
    - Services for front layer readout
  - Photostatistics
    - Tunable parameter depending on:
      - SiPM choice
      - Crystal choice
  - Noise
    - Negligible with SiPMs
      - low dark counts, high gain
  - Channels intercalibration
    - ~0.5% constant term (not in the plot)

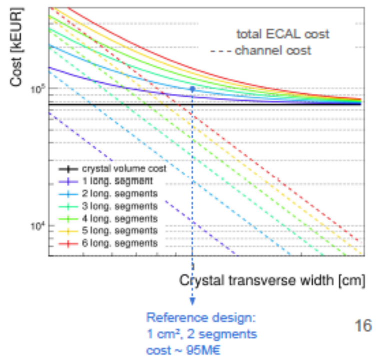
$\sigma_E/E \sim 3\%/\sqrt{E} \oplus 0.5\%$



Cost-power drivers and optimization

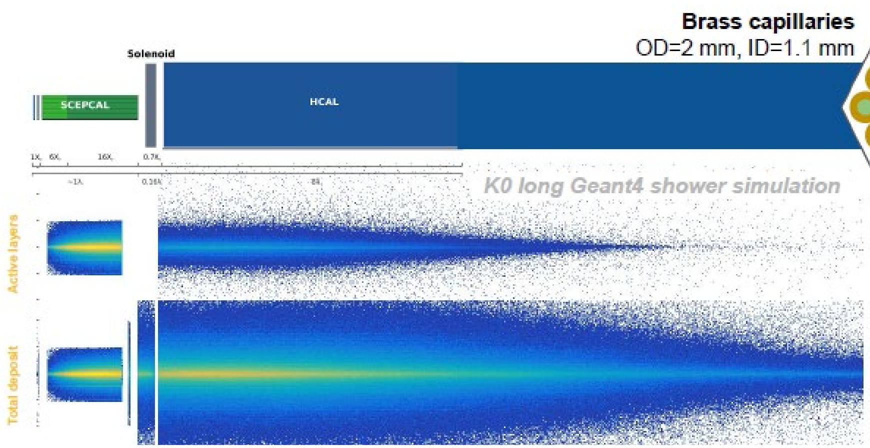
- **Channel count** in **SCEPCal** is limited to **~2.5M**
  - 625k channels/layer (2 "timing layers" + "ECAL layers")
- Cost drivers in **ECAL** layers (tot ~95M€):
  - **~81% crystals**, **9%** SiPMs, **10%** (electronics+cooling+mechanics)
  - **~19% of cost scales with channel count**
- Power budget driven by electronics: ~74 kW
  - 18.5 kW/layer
- Room for fine tuning of the segmentation and of the detector performance/cost optimization (see backup)

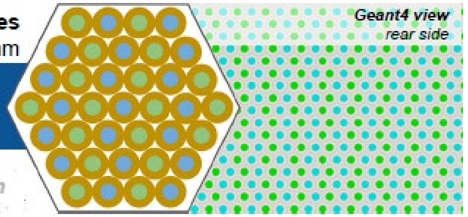




Integrating excellent ECAL with excellent HCAL

- Ultra-thin solenoid (~$0.6X_0$) between ECAL and HCAL
- Ease the HCAL design (cost/performance) from the ‘burden’ of e.m. resolution





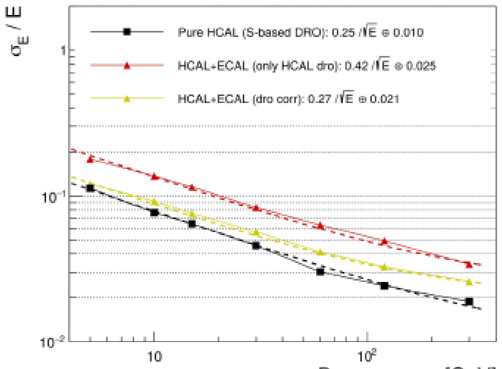
Geometry inspired by the presentation of V.Chmill at FCC-ee workshop

17

More studies to confirm jet resolution, use iron instead of brass for B field return yoke?

Combining ECAL&HCAL dual readout

1. Correct the energy deposit in the HCAL with DRO
2. Correct the energy deposit in the ECAL with DRO
3. Calibrated sum of ECAL+HCAL

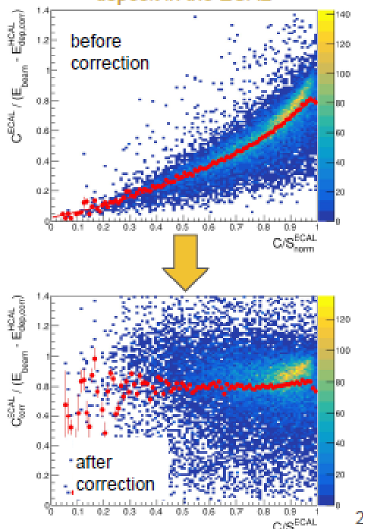


~27%/√E ⊕ 2%

Good stochastic term recovered with ECAL Dual Readout!

← adding raw ECAL energy
← adding DRO corr ECAL
← pure HCAL

DRO correction for the energy deposit in the ECAL



2

Summary

- **Highlights of a segmented crystal ECAL (SCEPCal):**
  - **Excellent DRO hadron calorimetry** with ~27%/√(E) is achieved with a segmented crystal EM calorimeter in front of the thin solenoid in the IDEA detector
  - **Addition of ~3%/√(E) EM resolution** for photons and brem recovery for electrons
  - Enables **efficient pre-clustering of pizero photons**, shown to reduced photon misassignment in the 4th jet by a factor of 4.5 and the 6th jet by a factor of 8 - impacting 2/3 of all HZ events.
- **Optimization of DRO capabilities**:
  - Methods to extract C from rear crystals significantly improved with SiPMs and shorter crystals, relative to previous tests
  - Option for interleaved pure-C radiating crystals with PWO also being studied.
- Combination of DRO ECAL and DRO HCAL allows for **separate optimizations of channel count, readout and cost**

Validation of MC predictions for Cherenkov yields of dual readout crystal calorimeters

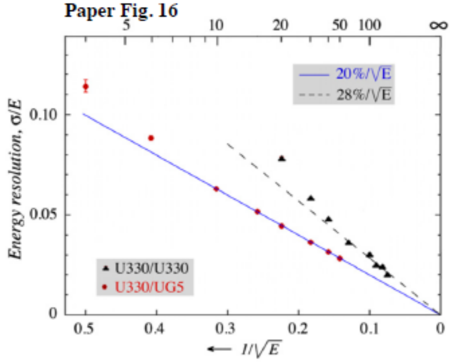
Sarah Eno, **Yihui Lai**
University of Maryland
July 22, 2020

Tune simulation to reproduce the RD52 test beam results.

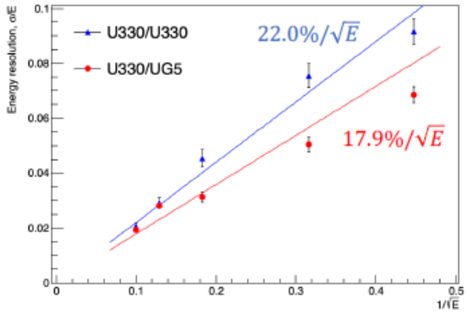
Simulation/data comparison

- In experiment: The energy resolution plot is well described by a straight line. The stochastic fluctuations dominate the energy resolution.
- Assuming these fluctuations are entirely determined by photoelectron statistics, $N = \frac{1}{a^2_{stoch.\ term}}$. The light yield is **13/GeV** for U330/U330 and **25/GeV** for U330/UG5
- In simulation: following the same method, the light yield is **21/GeV** for U330/U330 and **31/GeV** for U330/UG5

Paper Fig. 16

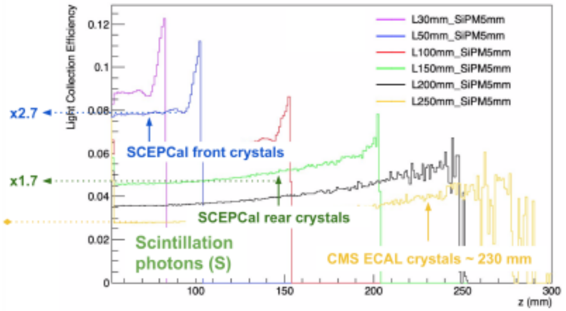


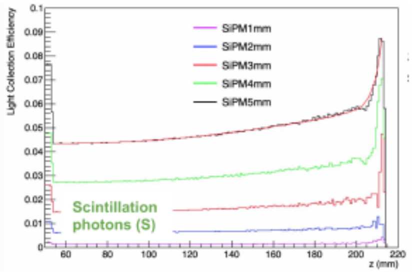
Simu

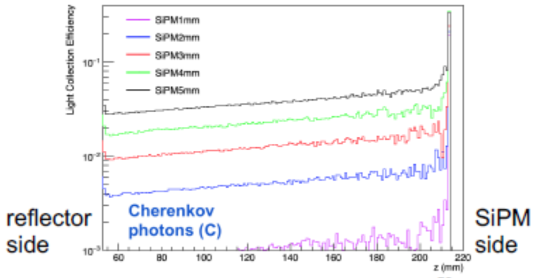


The optimization of SCEPCal

- LCE for rear SCEPCal crystal
  - LCE grows linearly with SiPM active area
  - LCE grows with shorter crystals







CEPC Silicon Drift Chamber Tracker

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Xin Shi

Gang Li, Ryuta Kiuchi, Mingyi Dong, Jianchun Wang

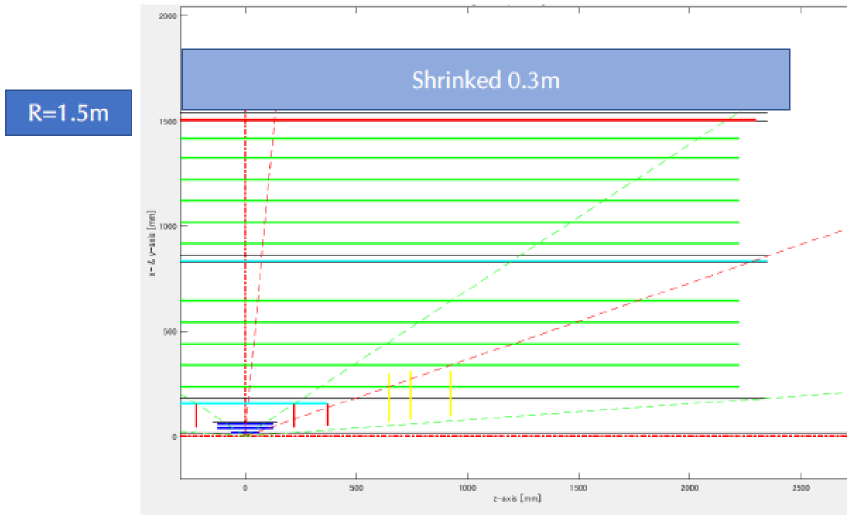
Mini-workshop on crystal ECAL - 2020.07.23

The role of drift chambers?

One chamber? Material?

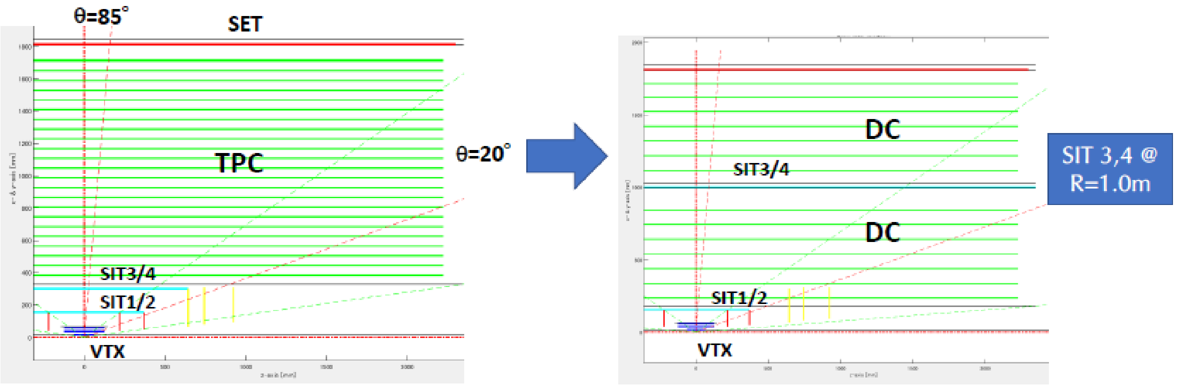
Silicon + Drift Chamber Tracker: v1.1

- Smaller radius : R = 1.5 m (reduced size for crystal ECAL)



CEPC Silicon + Drift Chamber Tracker: v1.0

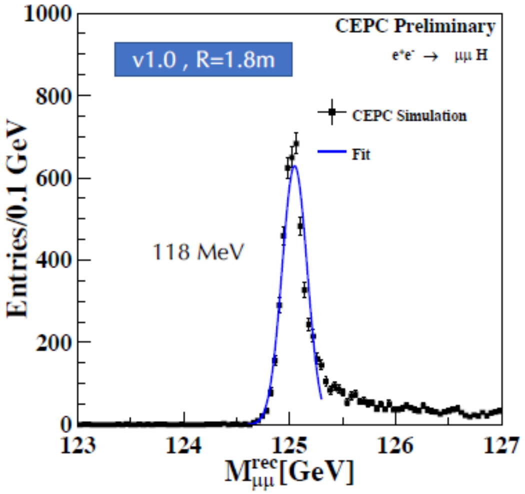
- Based on the baseline Silicon + TPC
- Replace TPC layers with two drift chamber layers
  - SIT 3&4 set at R=1.0m / larger cell size of DC than TPC

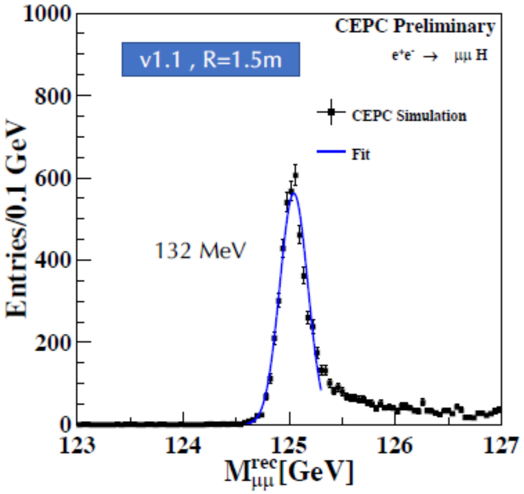


baseline

Recoil mass resolution v1.0 and v1.1

- ~12% increase





Key4HEP, the common software framework for future experiments

P. Giacomelli
INFN Bologna

(Don't shoot me I'm only the piano player...)

Need to implement the detector concept into the framework to facilitate design studies.

Additional people are urgently needed.

Short Key4HEP history

- Proposed a common software framework for all future HEP experiments at a workshop in Bologna on June 2019
  - Software experts from ILC, CLIC, FCC, CEPC, LHC, SCTF, HSF and more were present
  - Decided to use a common EDM for all experiments
    - Flexibility to add special sections tailored to specific needs of an experiment
  - Then decided to adopt a common software framework encompassing all the typical needs of HEP experiments
  - Key4HEP was chosen as name
  - A second workshop was organised in Hong Kong on January 2020
    - The decision to move to Key4HEP was confirmed and strengthened
    - CEPC confirmed the willingness to act as "beta testers"

Conclusions

- Key4HEP is the best example of collaboration between different future projects! People from ILC, CLIC, FCC, CEPC, SCTF, etc., work together.
- Key4HEP accommodates both full and fast simulation
  - Delphes being ported to Key4HEP these days
- IHEP and CepC will be the first testers of Key4HEP
  - First implementation already available
  - Should have have a full implementation before the end of 2020
- IDEA simulation will use the same implementation for FCC-ee and CepC
- Event data model is ready to accept modifications and additions needed for the Dual Readout calorimeter
  - Key4HEP developers expressed their interest in helping to implement the DR needs
  - Implementing a crystal ECAL option will certainly be possible as well
- Key4HEP is part of the new CERN R&D program
- Key4HEP is the main task of the software WP of the AIDAinnova project

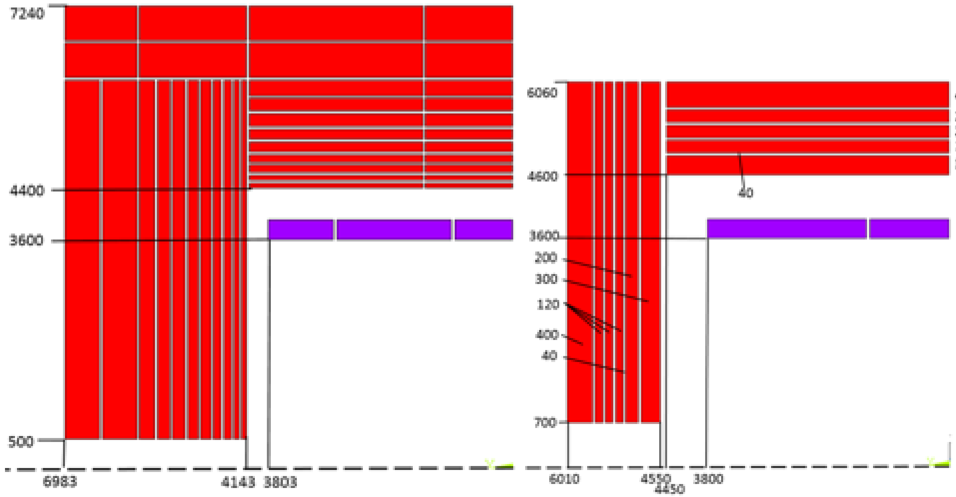
CEPC detector solenoid magnet

Ning Feipeng

For the CEPC Detector Magnet Team

2020-07-23

The Solenoid for a detector concept with a crystal ECAL will be between that for the baseline and IDEA concept

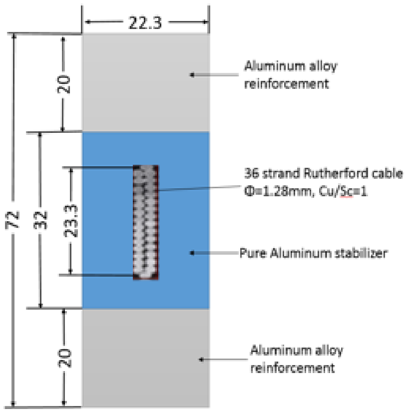


CDR version

New version

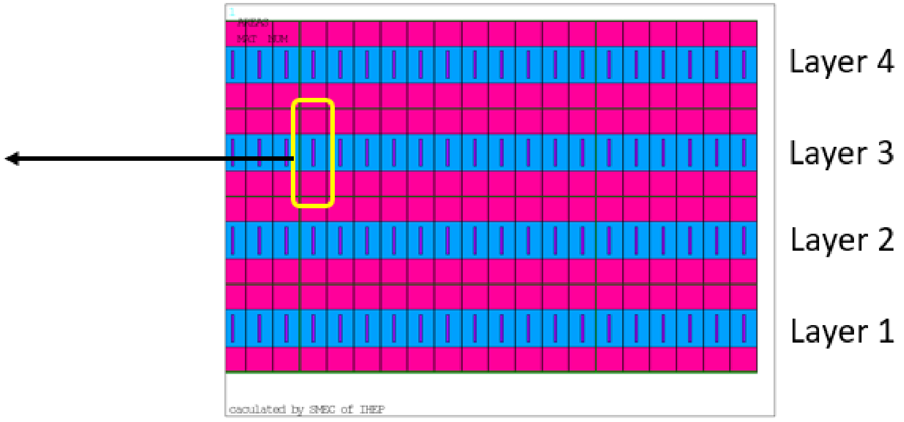
CEPC detector magnet baseline

- Cable:
  - Al stabilized NbTi Rutherford cable



Cable configuration, unit, mm

- Coil
  - Divide into 3 coils in axial direction， 4 layers in radial direction



Latest development of the PFA Calorimeter

With focus on CALICE achievements

Roman Pöschl

On behalf of the CALICE Collaboration

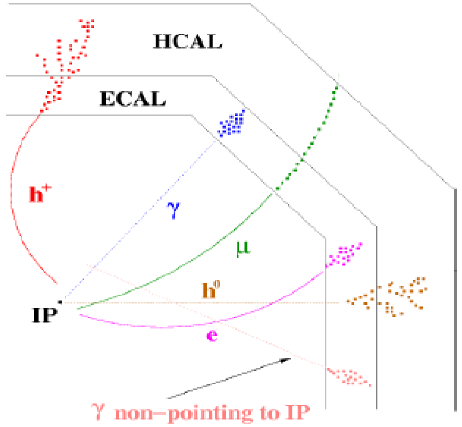
Thanks to Frank for sharing his material with me

CEPC Xtal Calorimeter Workshop July 2020

Particle Flow Detector

Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

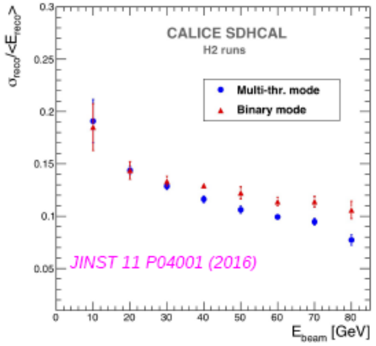
- large radius and length
  - to separate the particles
- large magnetic field
  - to sweep out charged tracks
- "no" material in front of calorimeters
  - stay inside coil
- small Molière radius of calorimeters
  - to minimize shower overlap
- **high granularity of calorimeters**
  - to separate overlapping showers



Particle flow as privileged solution for experimental challenges
=> Highly granular calorimeters!!!
Emphasis on tracking capabilities of calorimeters

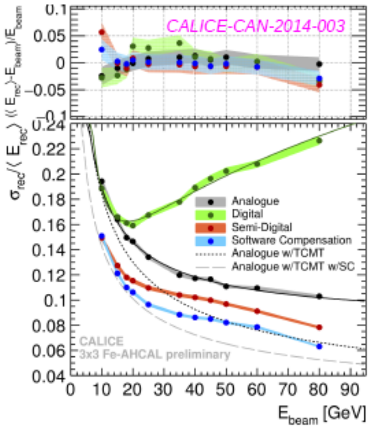
Different schemes of hadronic energy reconstruction

SDHCAL – Semi-digital vs. binary readout



- Semi-digital mode shows improved resolution towards higher energies
- Resolution curves deviate above 30 GeV

Systematic study with scintillating tiles



- Control of shower fluctuations improve resolution
  - Semi-digital or analogue with s/w compensation

Summary and conclusion

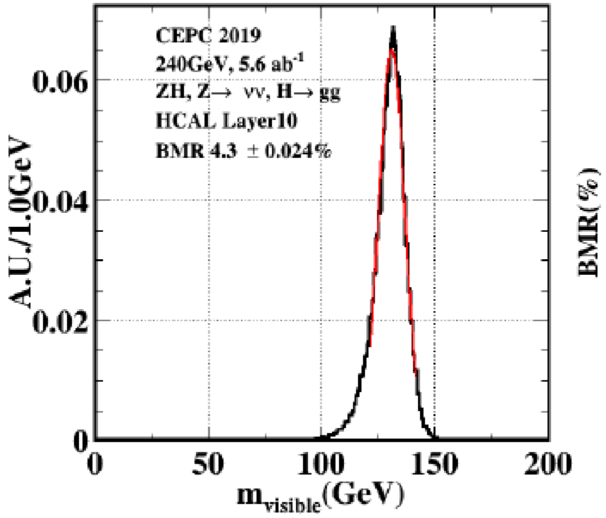
- CALICE pioneered R&D on highly granular calorimeters
  - Main target Linear Collider Detectors
  - R&D since 2002 starting with "physics prototype" phase
  - Large scale prototypes with rich set of results obtained in combined beam tests
  - Successful R&D inspired CMS to opt for a highly granular calorimeter for the LHC Phase 2 Upgrade
  - Further Spin-offs ALICE FOCAL, DUNE ND, Belle II CLAWS
- Technological prototypes address technological challenges of highly granular calorimeters
  - High level integration => dense detector layers
  - Proven stable operation of prototypes
  - Power pulsing is established but may need further scrutiny
  - Versatile mechanics to avoid inactive detector zones (sorry for having been short on this)
  - Timing capabilities studied and will be exploited further
- Ways forward (not mutually exclusive)
  - Finalising R&D and accompany Linear Collider experiments during technology selection
  - Common beam tests
  - Addressing new challenges at Circular Colliders
- Precious feedback from LHC Upgrades
  - System integration, timing, active cooling
- CALICE federates many different proposals under one roof which facilitates comparison and technology evaluation
  - It is this sense (nearly) unique in worldwide detector R&D

Detector optimization w.r.t. the BMR

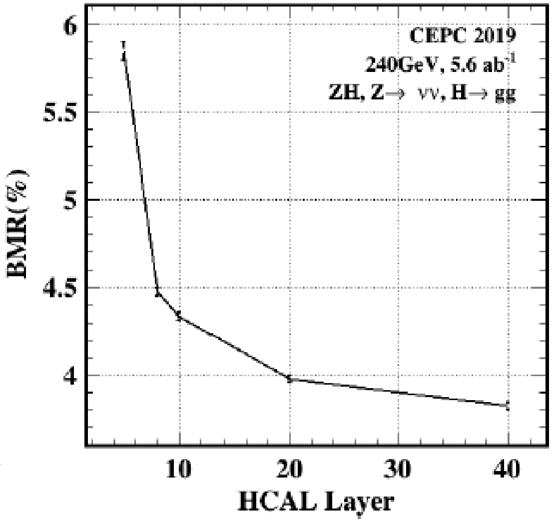
Yukun Shi, Hanhua Cui, Jiechen Jiang,

HCAL Layer

- The number of sampling layers has a strong impact on energy resolution
- The number of sampling layer is fixed, the number of readout layer is changed by merging cell from adjacent layers
- So in this simulation, the energy resolution for HCAL is fixed, but the longitudinal position resolution is changed



BMR at 10 HCAL readout layer



HCAL readout layer- BMR

Identification Performance of Leptons in Jets

Online mini-workshop on a detector concept with a crystal ECAL

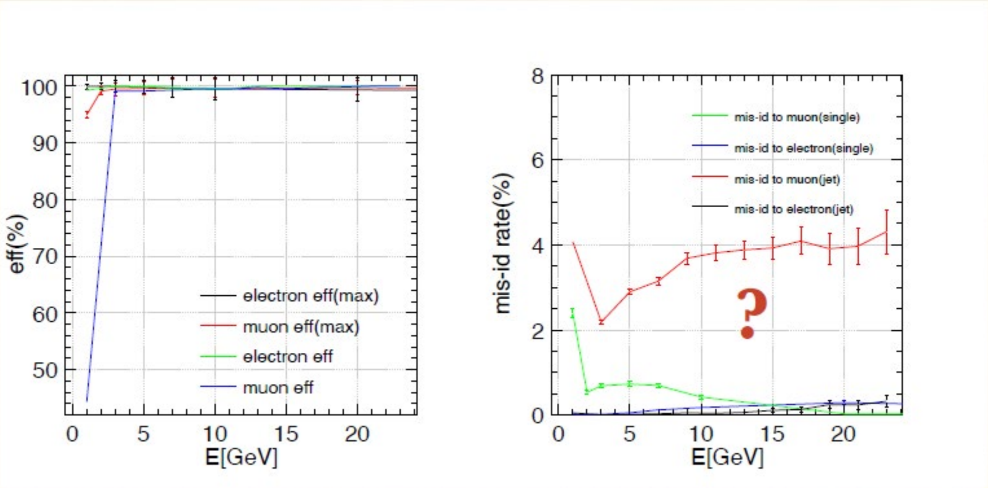
Dan YU, Manqi RUAN

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

CEPC

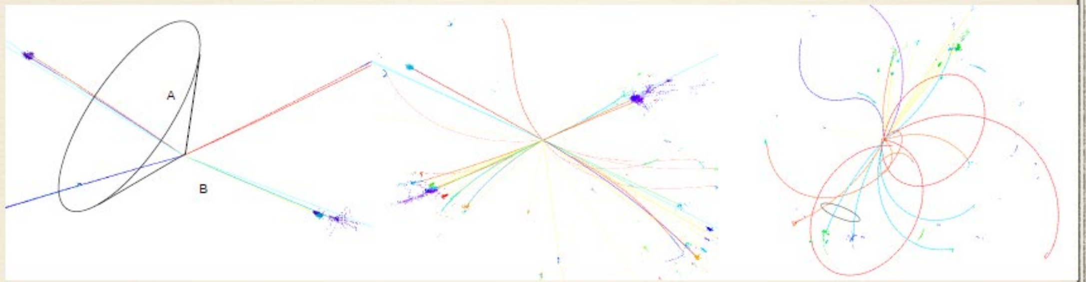
Comparison

- Comparison of lepton identification performance for perfect clusters and the performance of single particle
- Pion in jets more likely to be mu-like

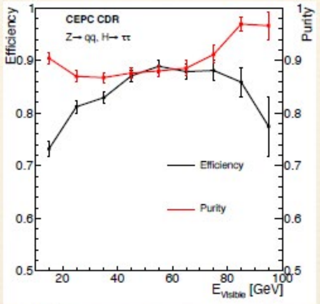


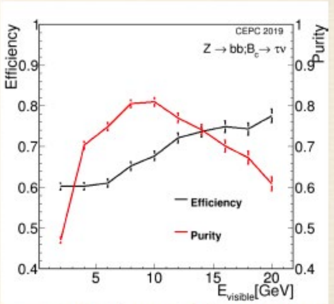
Event topology

- llH channel / $Z \to \tau\tau$
- qqH (isolate τ with jets)
- τ inside jets



- (Veto the two isolate lepton)
- Divide the whole space into 2 part
- Multiplicity & Impact parameter
- Efficiency > 90%





Differential Jet Performance

Pei-Zhu Lai

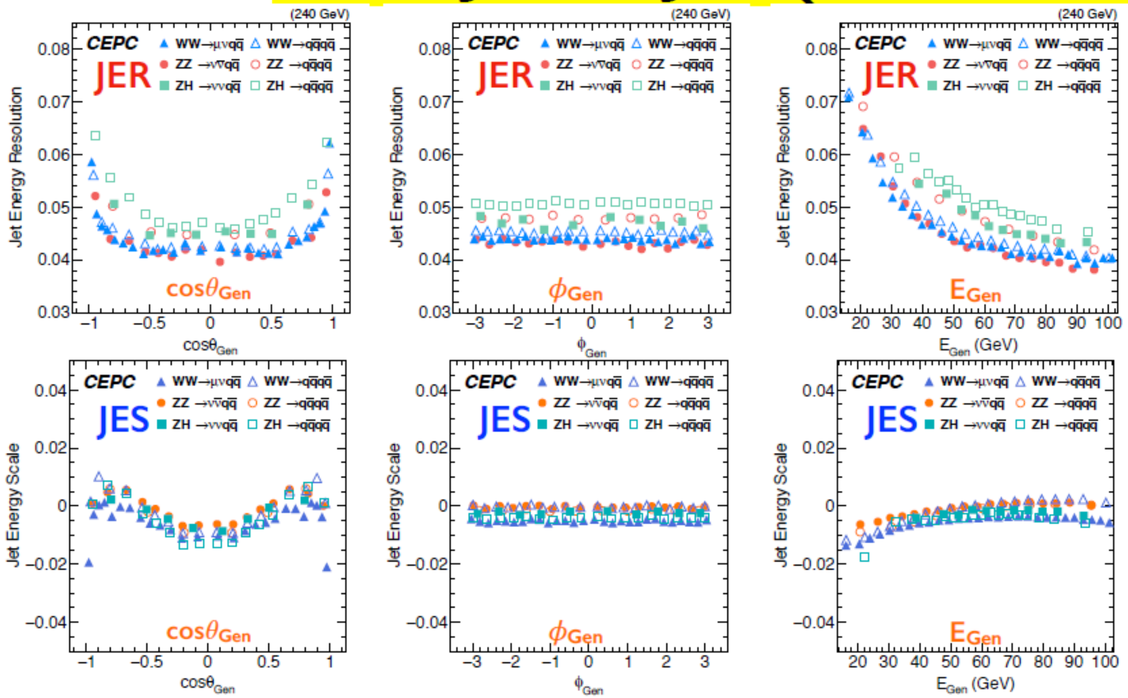
NCU (Taiwan)

On the behalf of the CEPC Collaboration

Online mini-workshop, National Central University (NCU), Chung-li Taiwan

July 23, 2020

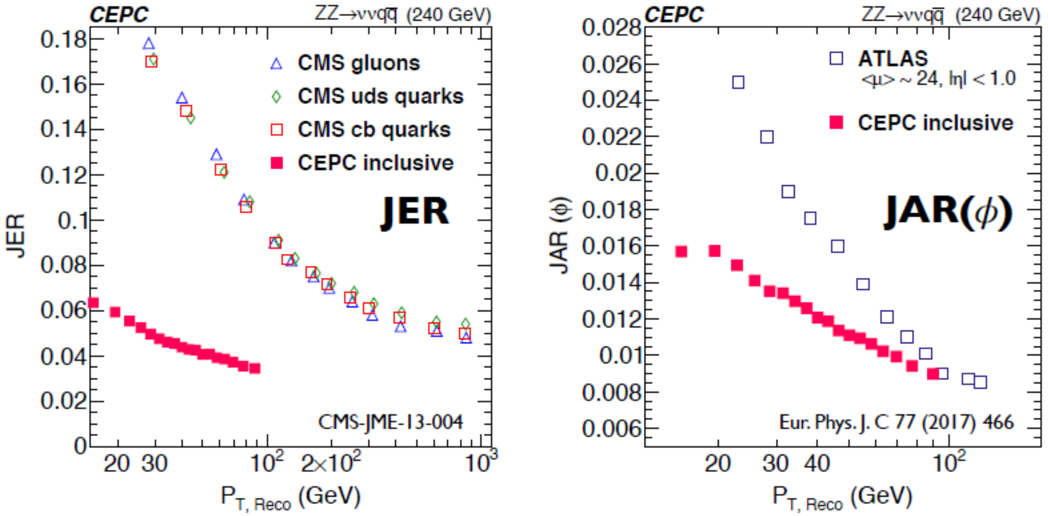
BM3: JER & JES (Reco-Gen)



■ JER is around **4.5%** in barrel region; JES is around **1%**.

■ The difference between 2 and 4 jets final-state is controlled within **1%** level.

Compare to CMS & ATLAS at LHC



■ **JER** at CEPC is better than **CMS** as it should be; **3-4 times** better in the same pT region.

■ **JAR(ϕ)** at CEPC is better than **ATLAS** as it should be; **1.0-1.6 times** better in the same pT region.

■ Free from: QCD Background, Underlying Event, Pile Up. ■ Benefit from: PFA (Arbor), Fine-segments of Calorimeter

Summary

A very productive workshop: interesting presentations and fruitful discussions
A lot of progress has been made since the workshop in March 2019

Several promising options for a crystal ECAL, interesting ideas to read out both scintillator and Cherenkov light to improve jet resolutions. Need more studies.

A detector concept with a crystal ECAL is taking shape:
- Silicon tracker w/o drift chamber
- A crystal ECAL: transverse/longitudinal segmentations, C-light readout?
- A solenoid operating at 2-3T
- HCAL: explore duel readout option, understand the cost
- Muon detector, not discussed, probably a relative cheap option

Next step: meet online in 6 months, in-person workshop in a year?