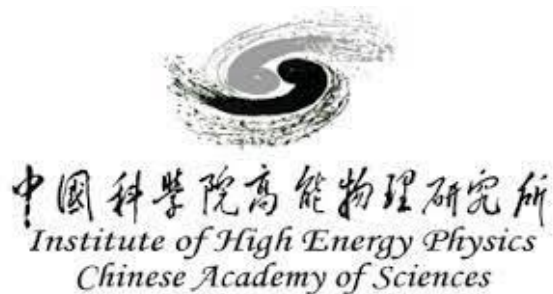
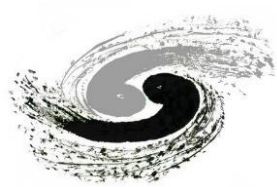


CEPC Calorimeter Beamtest: updates and news

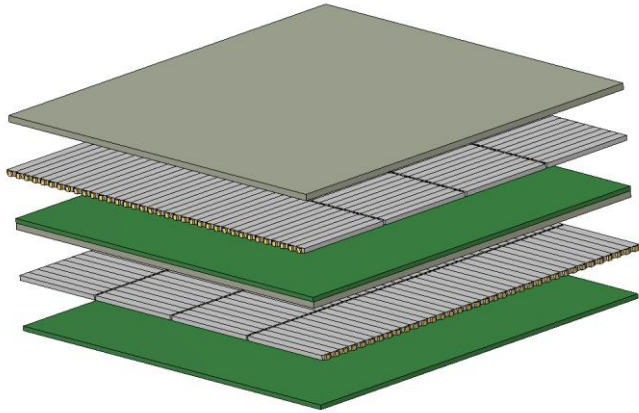
Yong Liu (IHEP),
for the CALICE and CEPC Calorimeter teams
Jan. 18, 2023





Recap: scintillator-tungsten ECAL prototype

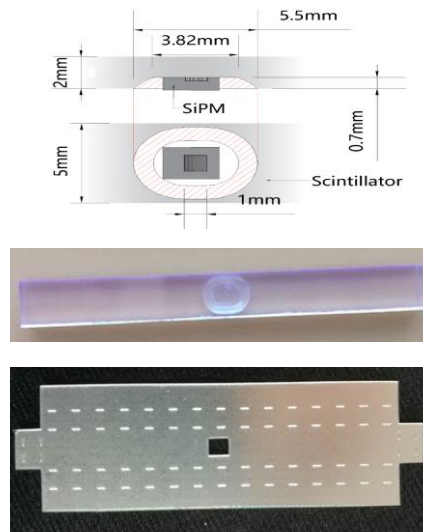
Sampling structure: scintillator strips + tungsten-copper plates



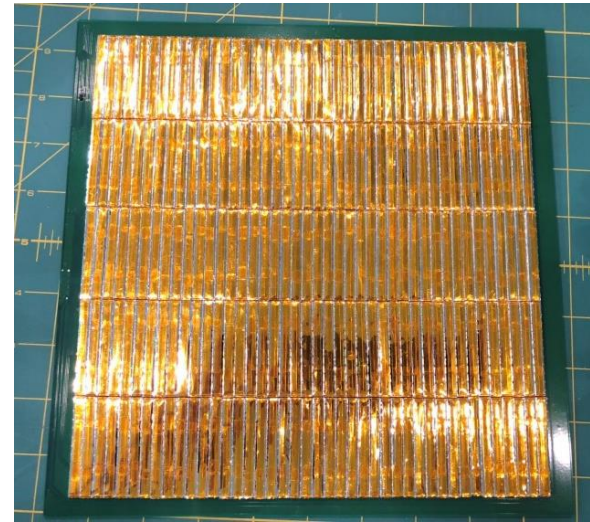
ScW-ECAL prototype



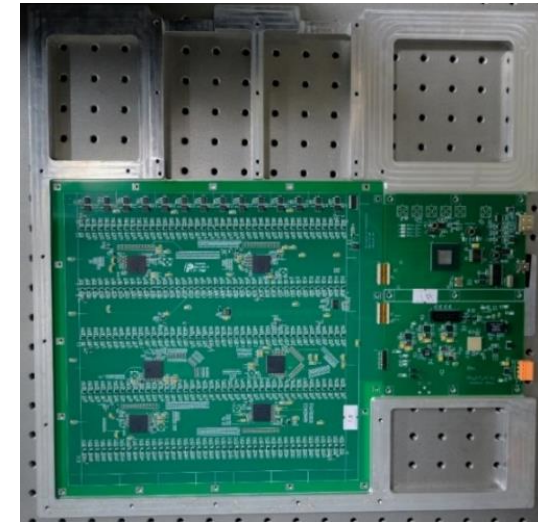
Detector unit:
scintillator + SiPM



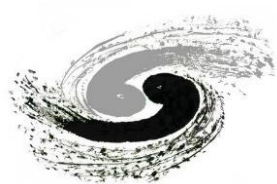
One sensitive layer (EBU):
fully integrated with ASICs



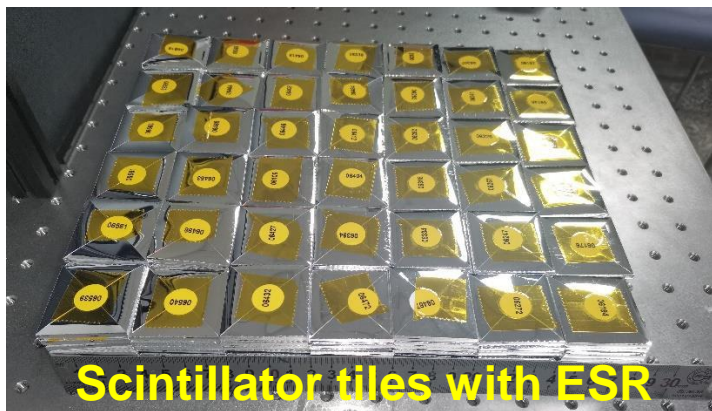
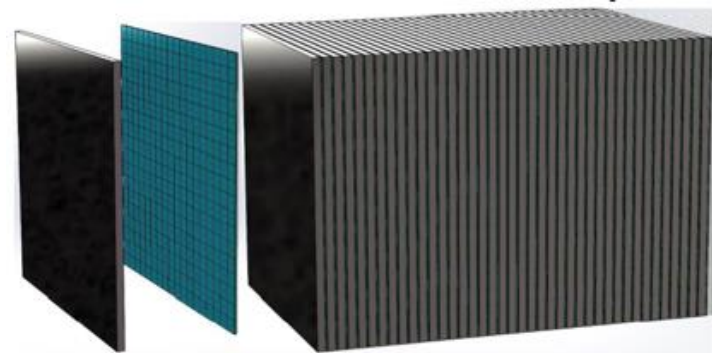
Two EBUs + absorber:
integrated with mechanics



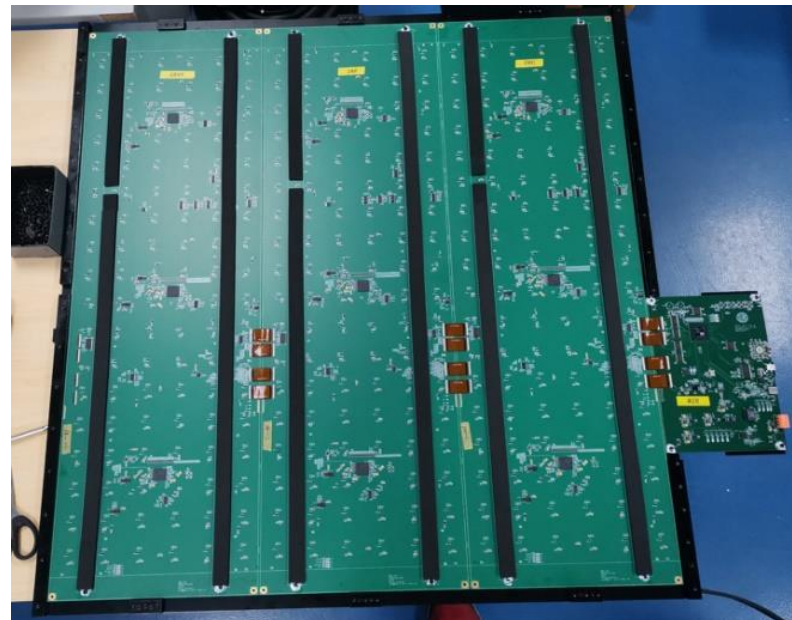
- ScW-ECAL prototype
 - Transverse size $\sim 22 \times 22 \text{ cm}^2$, 32 longitudinal layers ($\sim 25X_0$)
 - 6700 readout channels, $\sim 300 \text{ kg}$ in weight
 - Developed during 2016 – 2020



Recap: scintillator-iron HCAL prototype



1 full layer: 3 HBUs + cassette



Mechanics Integration

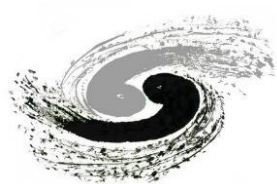


Scintillator tiles with ESR



SiPM on PCB with an LED

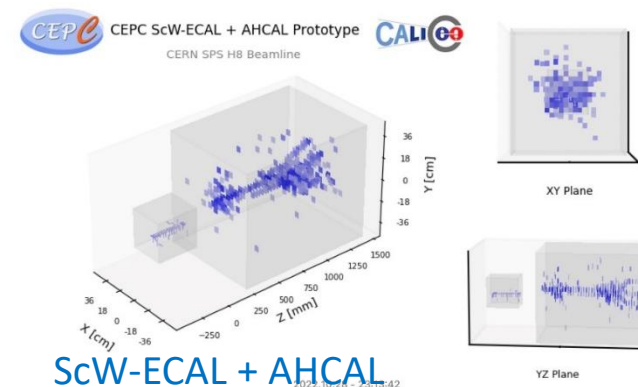
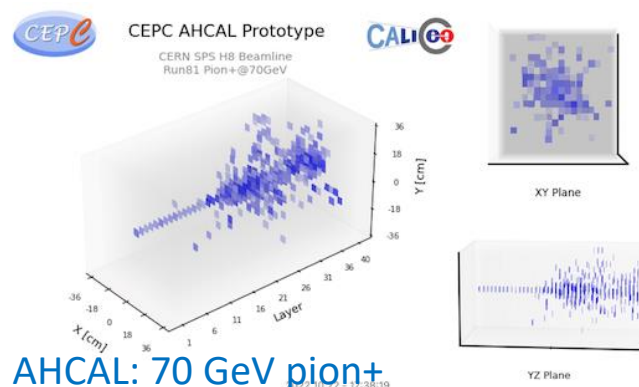
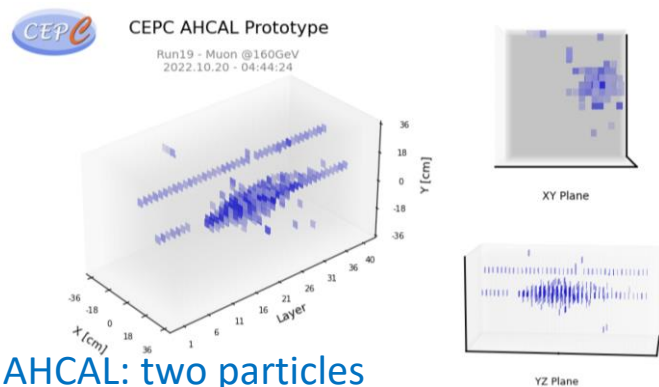
- AHCAL prototype: with “SiPM-on-Tile” design
 - Transverse size $72 \times 72 \text{ cm}^2$, 40 longitudinal layers ($\sim 4.6\lambda_I$)
 - 12960 readout channels, ~ 5 ton in weight
 - Developed during 2018 – 2022

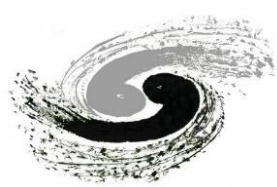


Brief summary of CERN beamtest



- CERN SPS H8: Oct – Nov, 2022
 - 160/108 GeV muons; 10-120 GeV positrons and hadrons
- Successful experiences
 - with two PFA calorimeter prototypes
- Decent statistics of data sets collected for
 - Highly granular calorimeter performance
 - In-depth shower studies: 3D space, time
 - Validation of Geant4 simulation
 - Particle-flow studies: e.g. Arbor





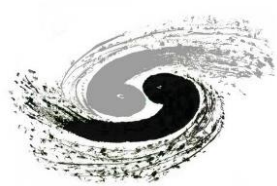
Taskforce on CERN testbeam data

- Taskforce on data conversion and analysis (same groups that participated the CERN beamtest)
 - **Data conversion and cross checks** (4): Jiaxuan Wang, Yukun Shi; Yuzhi Che; Francois Lagarde
 - **Event display** (5): Siyuan Song, Zhen Wang; Yuzhi Che, Baohua Qi, Hengyu Wang
 - **Data analysis and software tooling** (5): Hongbin Diao, Jiaxuan Wang, Yukun Shi; Yuzhi Che; Francois Lagarde
 - **Full simulation and validation** (5): Dejing Du, Baohua Qi; Yukun Shi; Zhen Wang, Zixun Xu
 - **Arbor clustering studies** (3): Yuzhi Che, Hengyu Wang, Xin Xia
 - Japanese groups on **ScW-ECAL performance** (5): Ryunosuke Masuda, Tatsuki Murata, Wataru Ootani, Tohru Takeshita, Yuki Ueda
 - **Coordination**: Yong Liu
- Institutions involved in the taskforce
 - China (14): IHEP, SJTU, USTC
 - Japan (5): U. Shinshu, U. Tokyo



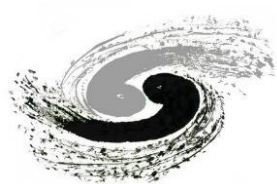


- | | |
|---------------|--|
| January 2023 | |
| Jan 23 | CEPC Calorimeter Group Meeting (protected) |
| Jan 12 | Taskforce Meeting on CERN Testbeam Data NEW |
| Jan 09 | CEPC Calorimeter Group Meeting (protected) |
| Jan 05 | Taskforce Meeting on CERN Testbeam Data |
| December 2022 | |
| Dec 29 | Taskforce Meeting on CERN Testbeam Data |
| Dec 26 | CEPC Calorimeter Group Meeting (protected) |
| Dec 22 | Taskforce Meeting on CERN Testbeam Data |
| Dec 15 | Taskforce Meeting on CERN Testbeam Data |
| Dec 12 | CEPC Calorimeter Group Meeting (protected) |
| Dec 08 | Taskforce Meeting on CERN Testbeam Data Formats |
| November 2022 | |
| Nov 30 | The Kickoff Meeting on CERN Testbeam Data Formats |



Outline for preliminary results

- Pedestal calibration
- Simulation and comparison with data
- Event display with animations and PID studies
- Arbor clustering studies



Pedestal calibration

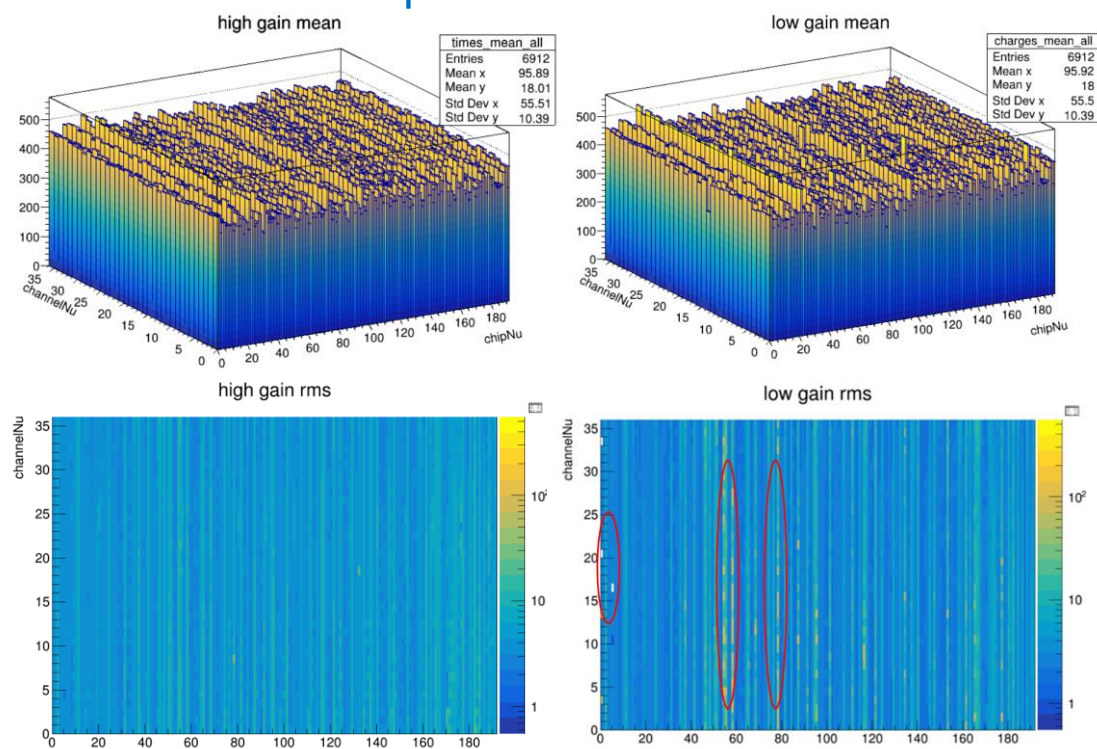
References: [Talk 1](#), [Talk 2](#) (Dec. 12, 2022)

Hongbin Diao, Jiaxuan Wang (USTC)

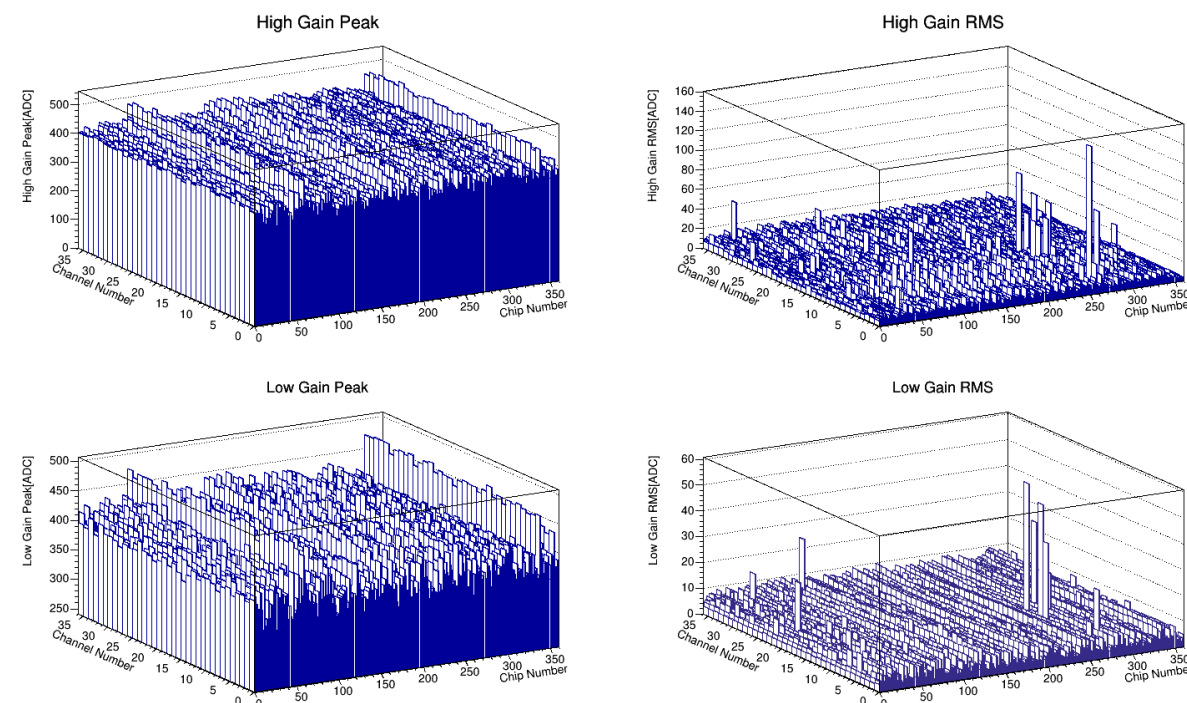
- Extracted for pedestal calibration per channel
 - Basis for MIP calibration and all other analyses

Featuring ASIC-dependent spreads

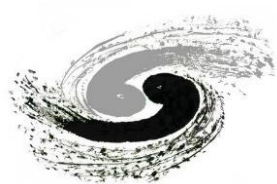
ScW-ECAL data: pedestals for all 6912 channels



AHCAL data: pedestals for all 12960 channels



Only a few channels with large pedestal spreads: under investigation



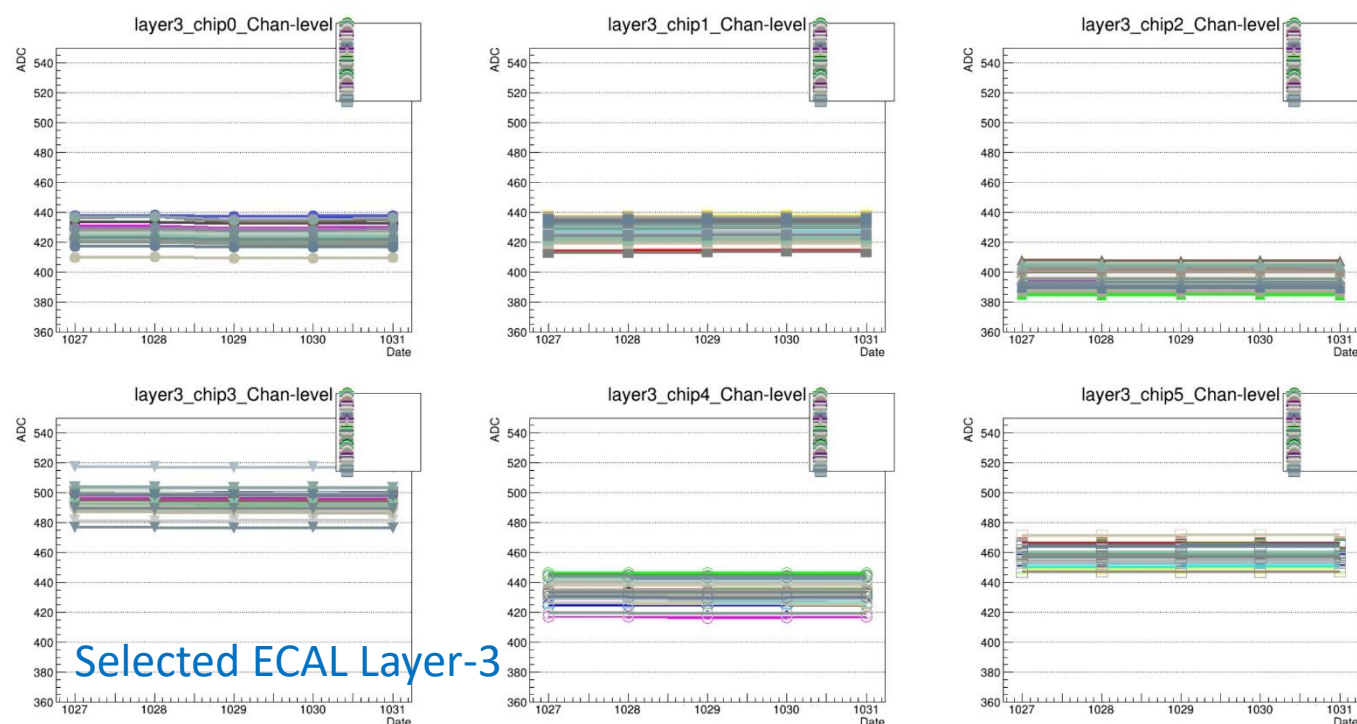
Pedestal calibration

References: [Talk 1](#), [Talk 2](#) (Dec. 12, 2022)

Hongbin Diao, Jiaxuan Wang (USTC)

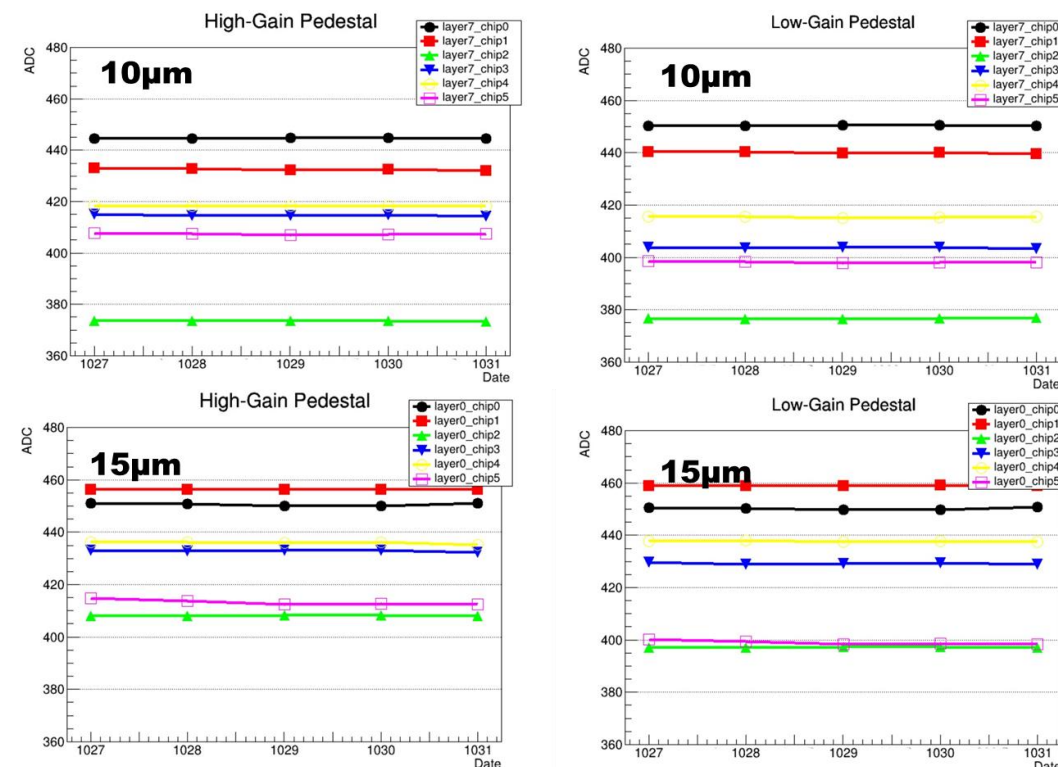
- Generally pedestals show good stability along with time

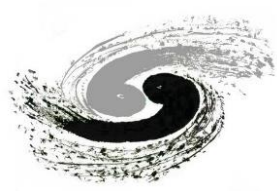
ScW-ECAL data: pedestals in 5 days (layer-level)



Selected ECAL Layer-3

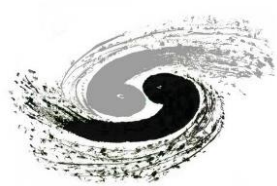
ScW-ECAL data: pedestals in 5 days (chip-level)





Simulation and validation

- Geant4 full simulation established
 - Geometry: for both ScW-ECAL and AHCAL prototypes
 - Scintillation: quenching effect (Birks' law) implemented
 - Assuming perfect response uniformity for each channel
 - Digitisation (scintillator-SiPM and ASIC):
 - Synergy: originally developed for crystal ECAL
 - In the stage of testing, not yet implemented in following results
- First comparisons of data vs MC for AHCAL prototype
 - Muons: noises, channel-wise uniformity, etc.
 - Positrons and hadrons: beam contaminations, SiPM and ASIC saturation effects, etc.

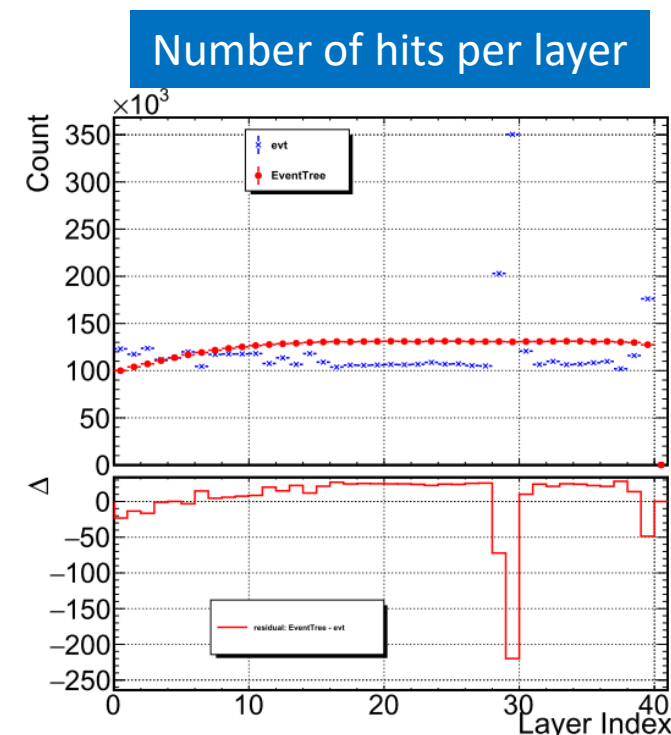
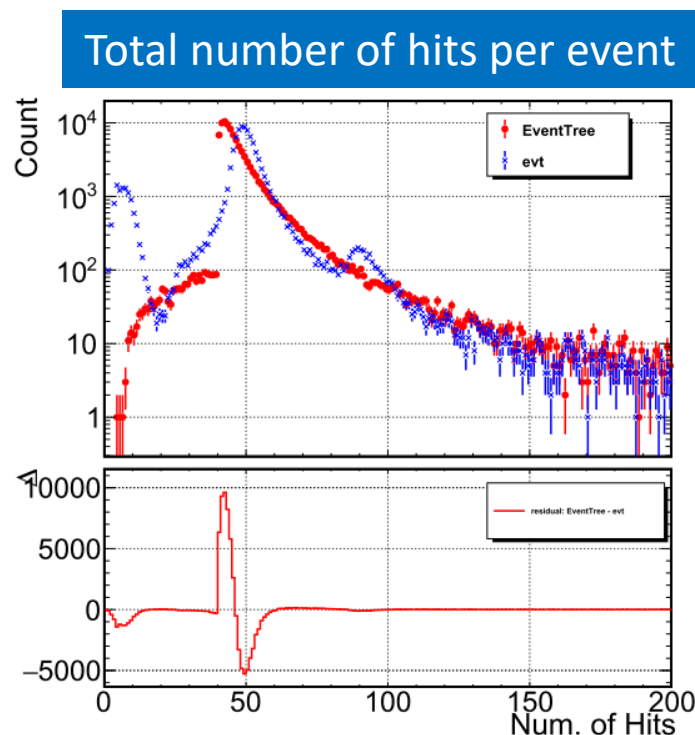
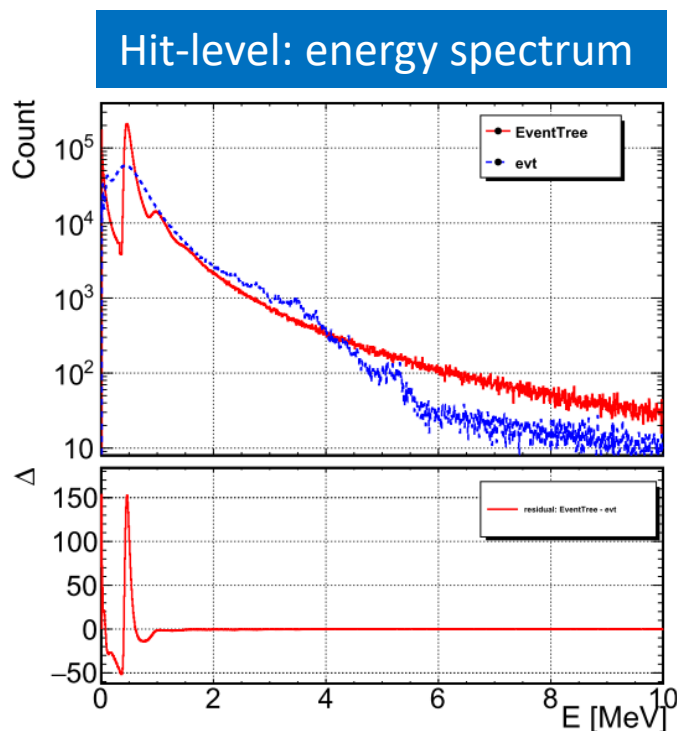


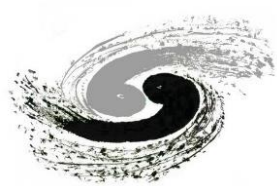
Simulation and validation

Yuzhi Che, Baohua Qi (IHEP)

[Beam test simulation \(Jan. 12, 2023\)](#)

- First comparisons of data vs MC for AHCAL prototype
 - 160 GeV muons: **data in blue**, **simulation in red**
 - MIP peak in data is less significant than MC \rightarrow most likely due to non-uniformity per channel
 - More #hits in data \rightarrow significant noises, likely with a second muon (2-MIP peak)





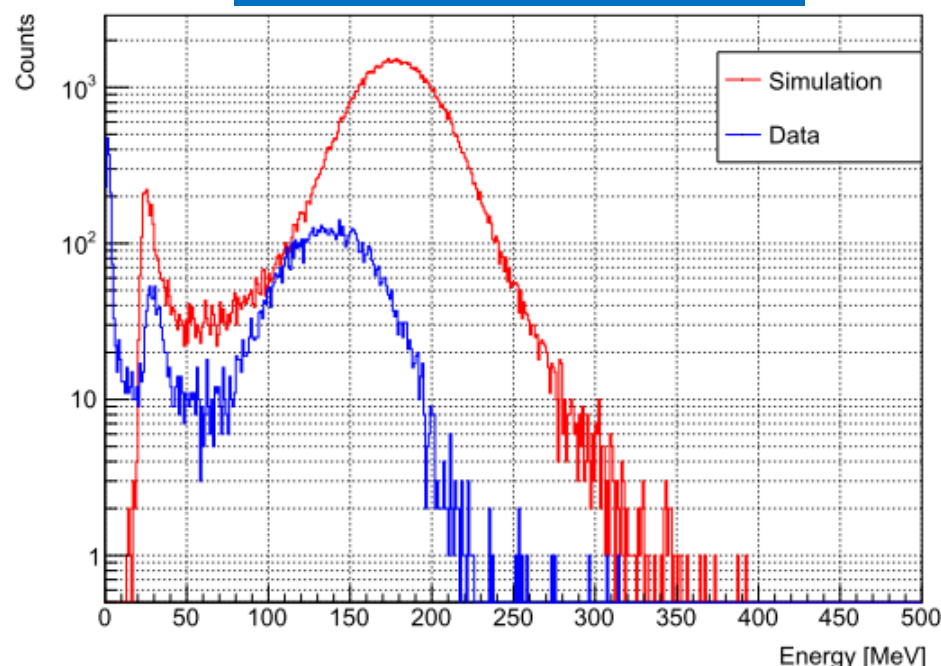
Simulation and validation

Yuzhi Che, Baohua Qi (IHEP)

[Beam test simulation \(Jan. 12, 2023\)](#)

- First comparisons of data vs MC for AHCAL prototype
 - 10 GeV π^+ beam: data in blue, simulation in red
 - Energy sum: clustering of all hits (above trigger threshold)
 - Generally MC can reproduce data at first order, except a few known effects (below)

Hit-level: energy spectrum



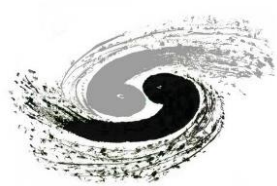
Possible reasons for MC/data discrepancies

- Noises in data (left most peak in blue)
- SiPM and ASIC saturation effects not yet implemented in MC (right most peak in red)

Planning for further comparisons

- Implementation of digitisation in simulation
- More energy points

Note that #events for MC is more than data, which should be the same



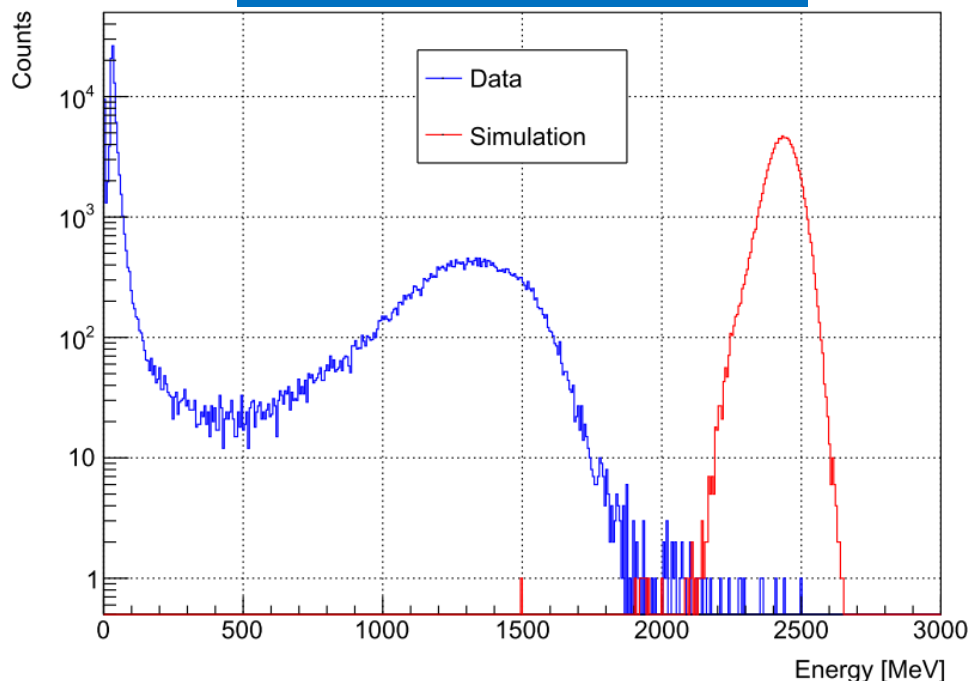
Simulation and validation

Yuzhi Che, Baohua Qi (IHEP)

[Beam test simulation \(Jan. 12, 2023\)](#)

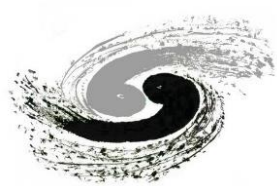
- First comparisons of data vs MC for AHCAL prototype
 - 120 GeV e^+ beam: data in blue, simulation in red
 - Energy sum: clustering of all hits (above trigger threshold)
 - Prominently large MC/data discrepancy: not a big surprise

Hit-level: energy spectrum



Discussions

- We've known contamination issues in positron beams at H8 (beam experts + other H8 users)
- Generally positron purity goes down along with beam energy
- If the simulation is correct (appear so with hadrons), this would indicate positron purity is close to 0 at 120 GeV
- More crosschecks to be done with PID studies (shower profiles, Cherenkov counters)



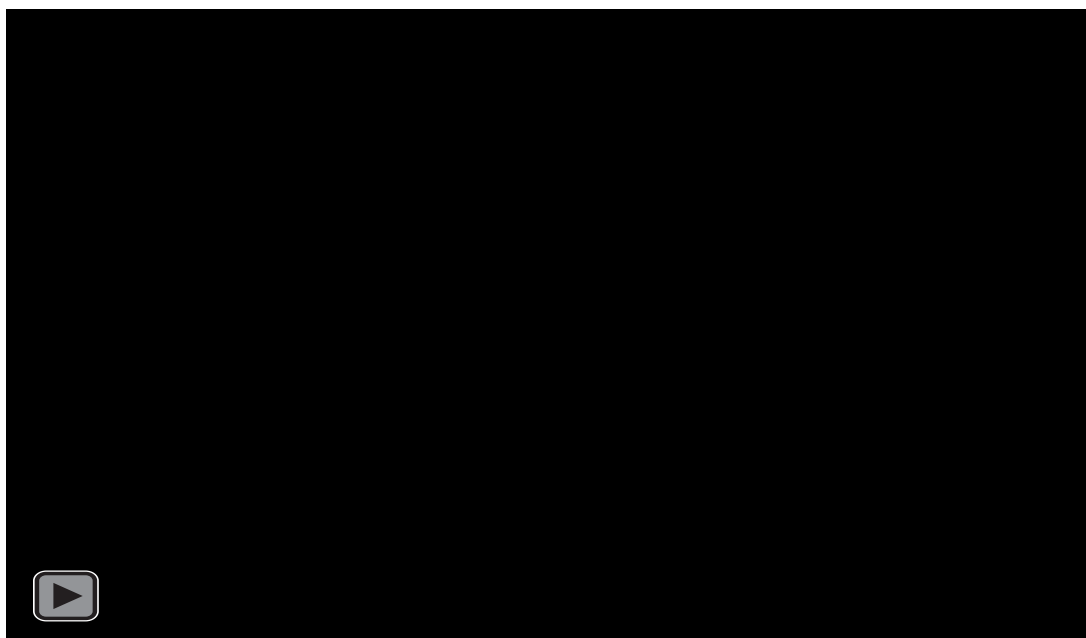
Event display developments

Zhen Wang (SJTU)

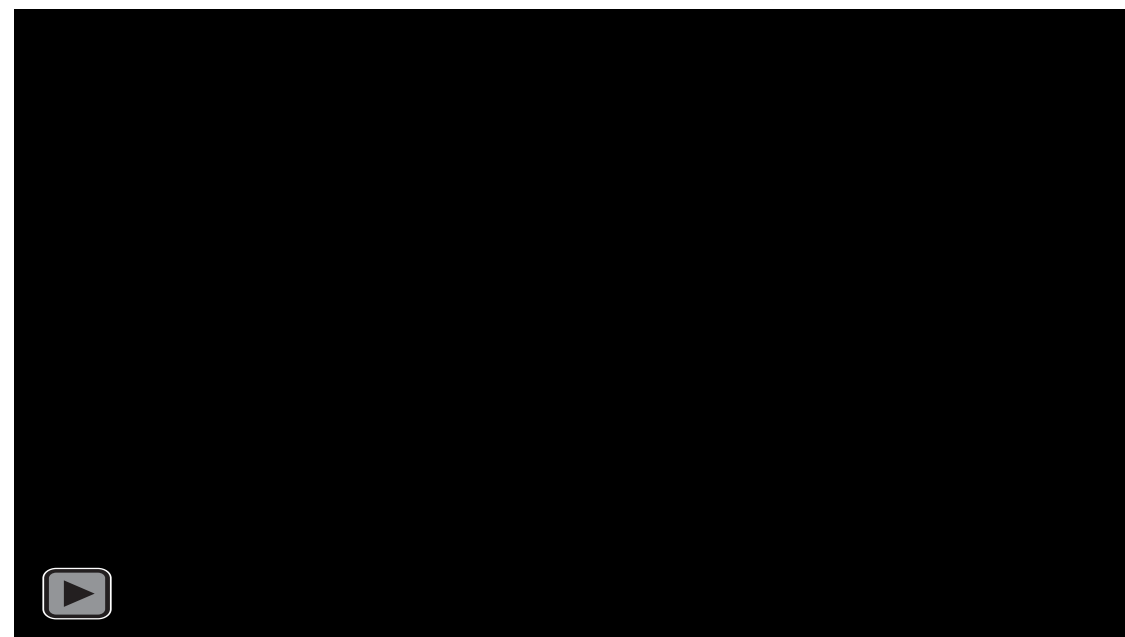
[Talk](#) in the [Weekly Meeting \(Jan. 5, 2023\)](#)

- Event display: animations for EM/hadronic shower evolution

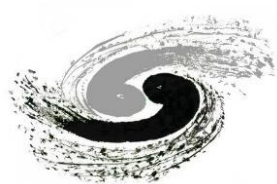
50 GeV Electrons (MC sample)



50 GeV Pions (MC sample)



It would be interesting to apply this tool to testbeam data
(requiring TDC calibration beforehand)

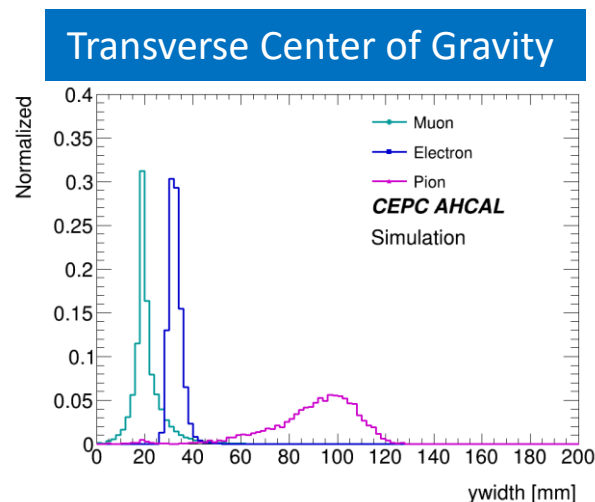
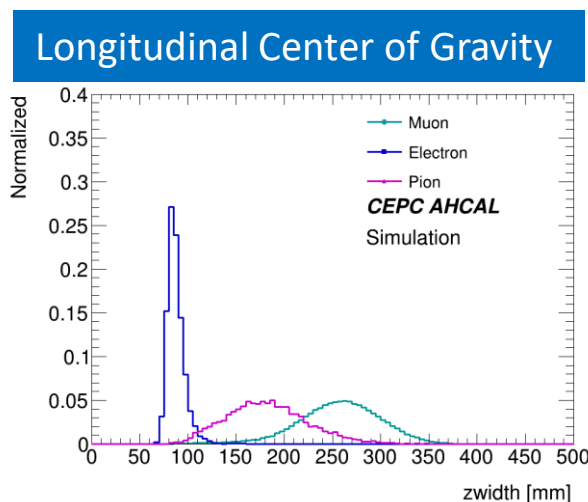


PID studies with simulation samples

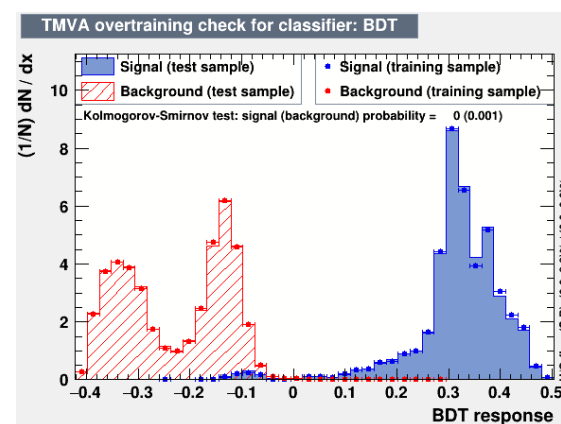
Zhen Wang (SJTU)

[Talk](#) in the [Weekly Meeting \(Jan. 5, 2023\)](#)

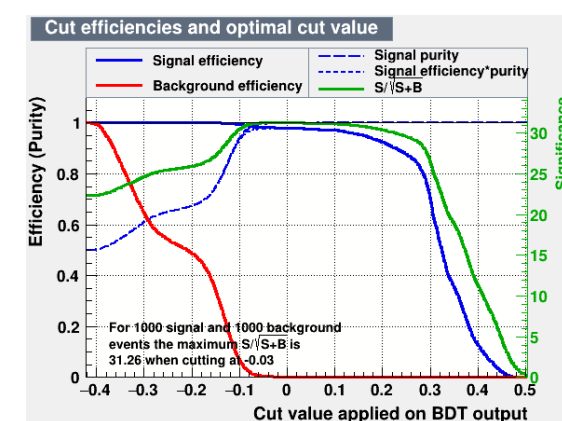
- Motivations
 - To study beam purity and mitigate beam contaminations
- PID techniques
 - Shower profiles to distinguish different incident particles
 - BDT with several input variables: shower profiles, shower start layer, energy
 - Cherenkov counters (as part of CERN beam instrumentation): not presented here

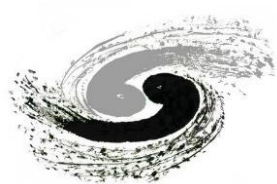


π^+ as signals; e^+ and μ^+ as backgrounds



No signs for overtraining



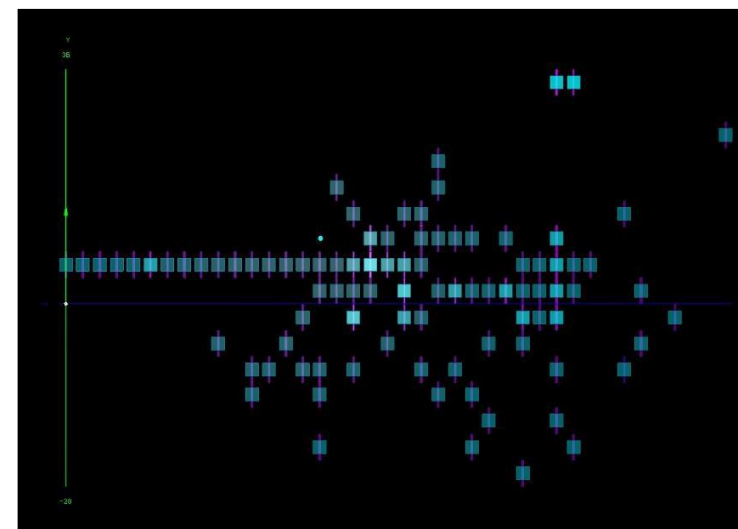
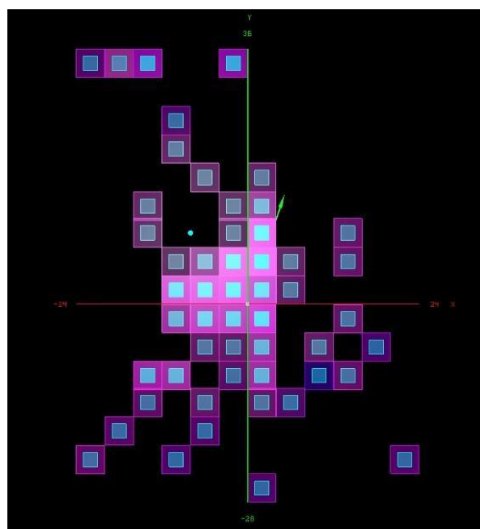
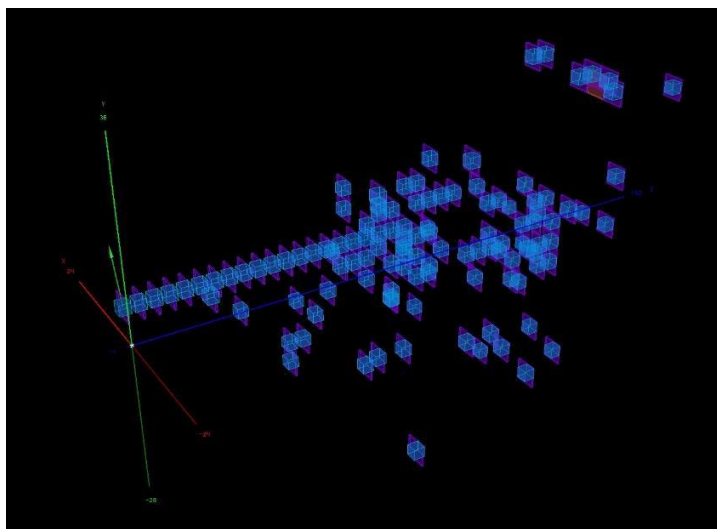


Arbor clustering studies with data

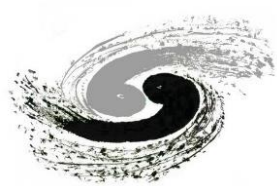
Yuzhi Che, Hengyu Wang, Xin Xia (IHEP)

[Talk](#) in the [Weekly Meeting \(Jan. 5, 2023\)](#)

- Qualitative studies with Druid event display
 - Larger cube: raw hits in data; small cube: reconstructed hits in clusters
 - Color coding for different clusters
 - Most hits are correctly reconstructed as a single cluster (major shower part), with a few noise hits and isolated hits



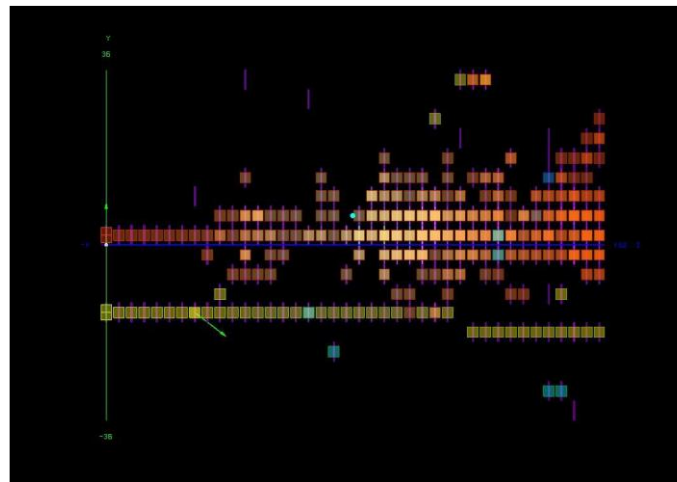
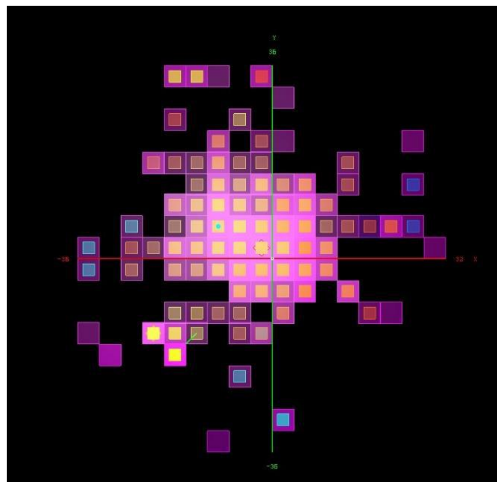
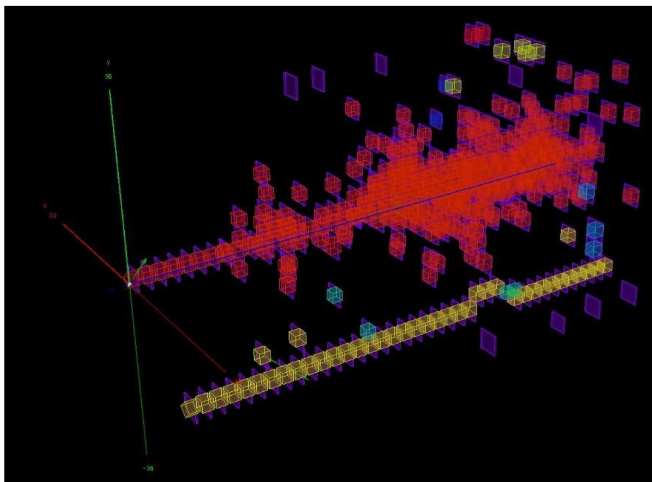
Data Sample: AHCAL_Run156_20221024_231347 (10GeV π^+)



Arbor clustering studies with data

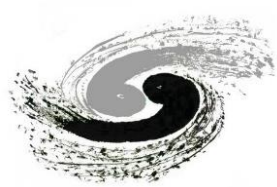
Yuzhi Che, Hengyu Wang, Xin Xia (IHEP)

[Talk](#) in the [Weekly Meeting \(Jan. 5, 2023\)](#)



Data Sample : AHCAL_Run144_20221024_073230 (120GeV e+)

- Qualitative studies with Druid event display
 - Color coding for different clusters
 - Clusters of two incident particles can be successfully reconstructed
- Quantitative studies: in progress
 - Clustering efficiencies: based on energy or #hits, for EM/hadronic showers



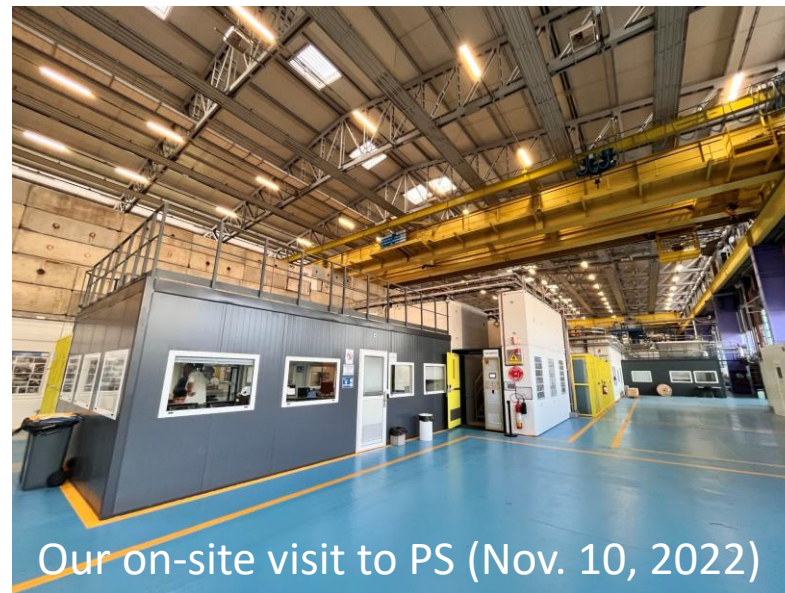
News: beamtest in 2023

[Proposal](#) presented at [CALICE TB Meeting \(Dec. 15, 2022\)](#)

- Calorimeter prototype status: stored at CERN
- CERN testbeam application
 - **Proposal submitted** (Jan. 6), coordination within CALICE Technical Board
 - **Beam time: 2 weeks at PS (T9) and 2 weeks at SPS (H2/H4)**
 - Target period: May 30 - Aug. 30, 2023
 - SPS-Committee reviews for proposals: scheduled in Feb. 7, 2023



Storage at CERN B.190

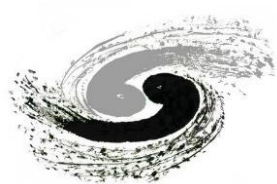


Our on-site visit to PS (Nov. 10, 2022)

- PS (T9): 1-15 GeV beam
- SPS (H2/H4): 10-120 GeV beam (high purity)

PS beamlines: layout after renovations





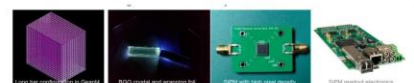
News: ECFA DRD preparations

- ECFA Detector R&D Task Force 6: [Calorimetry Community Meeting](#) (Jan. 12)
- CEPC calorimeter R&D well presented in several overview talks
 - PFA sandwich: ScW-ECAL, AHCAL prototype for CEPC
 - Homogeneous: crystal ECAL, scintillating glass

[Open challenges (Scintillators/SiPMs)]

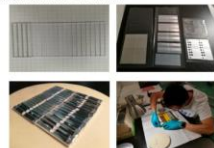
Ongoing and Near Future (~5 years)

- ▶ Engineering work for **large scale production**
 - Injection moulding, automated assembly, system for QC/QA
- ▶ **Improvement of timing** performance with **dedicated timing layers** ~10ps
 - Scintillator tile + larger SiPM with high light yield + better time resolution
 - Cherenkov detector based on RPC-GasPM (New R&D)
- ▶ **R&D on new materials:**
 - High Granular Crystal Calorimetry



edrian.lieu@ific.uva.es ECFA Detector R&D Roadmap TFS

Strip wrapping and assembly on EBU was done by hand (Shanghai Institute of Ceramics)



Single EM module

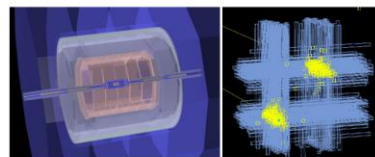
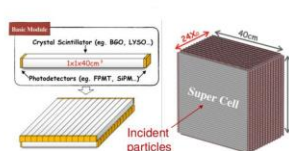


IFIC
FUNDING 2023

High Granularity Crystal Calorimetry

- **High granularity** crystal EM calorimeter made of a grid of $\sim 1 \times 1 \times 40 \text{ cm}^3$ bars
- Baseline concept under development for CEPC (Y.Liu, M.Ruan, et al.)
- **Advanced simulation** and reconstruction effort including PFA algorithms
- **Ongoing R&D** and prototyping [Ref]: BGO/PWO with SiPM readout

Target application:
e⁺e⁻ colliders



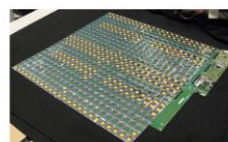
9

AHCAL technological prototypes

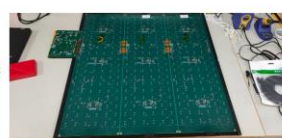
Achievements in Beam Tests

AHCAL prototype for ILC

- $0.72 \times 0.72 \times 1 \text{ m}^3$ prototype based $3 \times 3 \times 0.3 \text{ cm}^3$ scintillator tiles
- 38 layers with $\sim 22,000$ channels
- built 2017-2018
- Several successful beam tests 2018 – 2022
- First publication on construction & operation



Both prototypes use electronics developed for ILC (power pulsing)



AHCAL prototype for CEPC

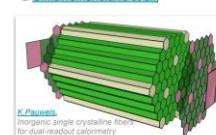
- $0.72 \times 0.72 \times 1 \text{ m}^3$ prototype based $4 \times 4 \times 0.3 \text{ cm}^3$ scintillator tiles
- 43 layers with $\sim 14,000$ channels
- built 2021-2022
- Successful first beam test in 2022



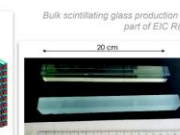
Homogeneous Hadron Calorimeters

- Full absorption dual-readout hadron calorimetry concepts aiming at further boosting the energy resolution for hadronic showers $\rightarrow \sim 15\%/\sqrt{E}$
- **Major challenges: requires breakthrough in mass production** (quality/uniformity) and cost reduction for high density scintillators (crystals/heavy glasses)
 - Various options under investigation by the international community (DSB:Ce, AFO:Ce, ...)
 - Recent R&D collaboration and progress on Gd-rich heavy glasses for a HHCAL for CEPC

Exploiting bundles of meta-crystal fibers
[P.Lecoq, J. Phys. 160 (2008) p12016 & G. Mavromanolakis et al.]



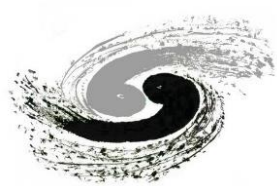
Exploiting bulk cost-effective dense scintillators [CPAD2021, M. Demarteau et al.]



Sen QIAN, R&D for high density, high light yield glass scintillator for CEPC

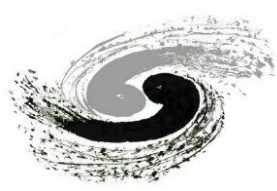


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News: ECFA DRD preparations

- ECFA Detector R&D Task Force 6: [Calorimetry Community Meeting](#) (Jan. 12)
- CEPC calorimeter R&D well presented in several overview talks
 - PFA sandwich: ScW-ECAL and “Asian-AHCAL” prototypes
 - Homogeneous: crystal ECAL, scintillating glass
- General impressions (personal)
 - Friendly atmosphere and open for wide collaborations
 - Unclear: how Asian community can substantially get involved
- Plans: next community meeting in April



Summary

- CERN 2022 beamtest data analysis in progress
 - Will converge for quantitative studies
 - Timelines
 - Short term: target for MOST review
 - Mid/Long term: joint efforts with software teams (framework/tooling)
- CERN 2023 beamtest application submitted, pending for SPSC review
- ECFA DRD-Calorimetry formation and preparations: ongoing

Thank you!