CEPC Calorimeter Beamtest: updates and news

Yong Liu (IHEP),

for the CALICE and CEPC Calorimeter teams

Jan. 18, 2023

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

University of Science and Technology of China

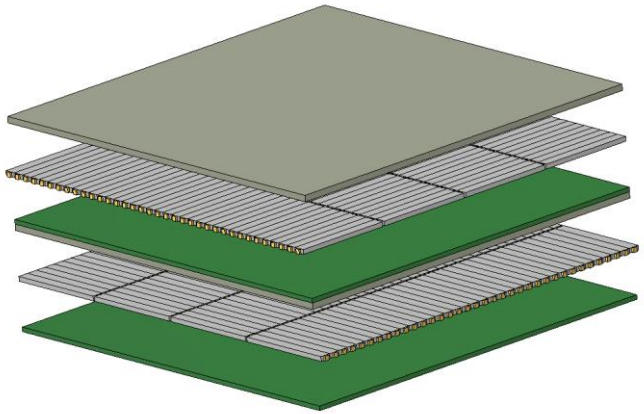
SHANGHAI JIAO TONG UNIVERSITY

信州大学
SHINSHU UNIVERSITY

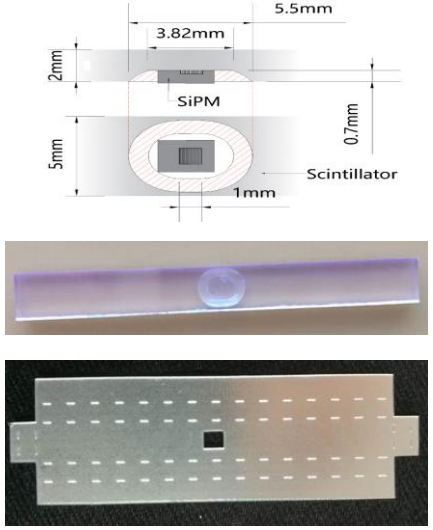
東京大学
THE UNIVERSITY OF TOKYO

Recap: scintillator-tungsten ECAL prototype

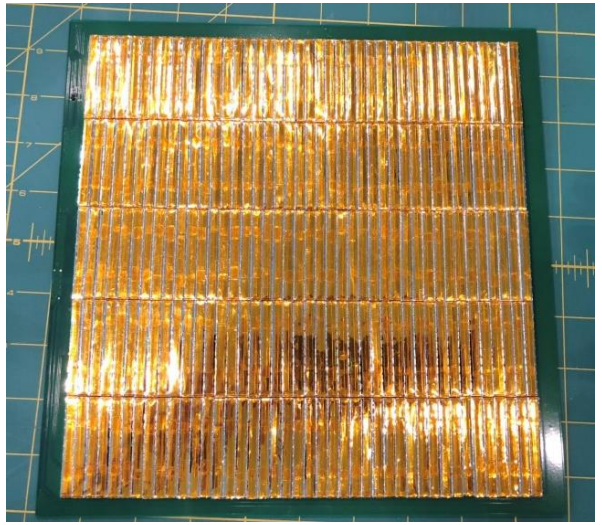
Sampling structure: scintillator strips + tungsten-copper plates



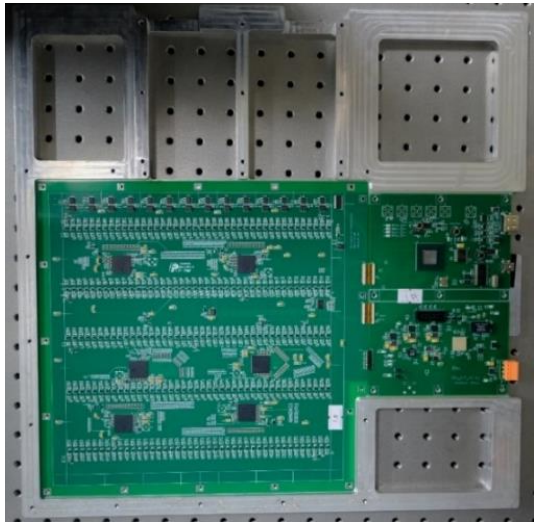
Detector unit: scintillator + SiPM



One sensitive layer (EBU): fully integrated with ASICs



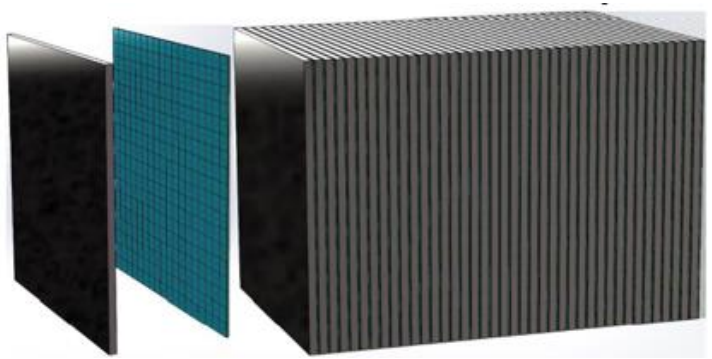
Two EBUs + absorber: integrated with mechanics

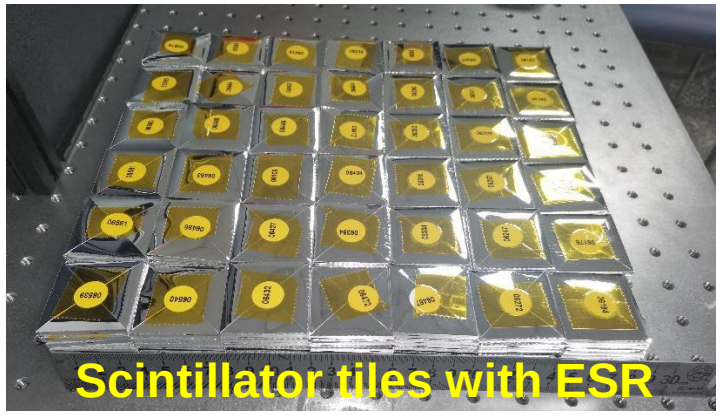


ScW-ECAL prototype

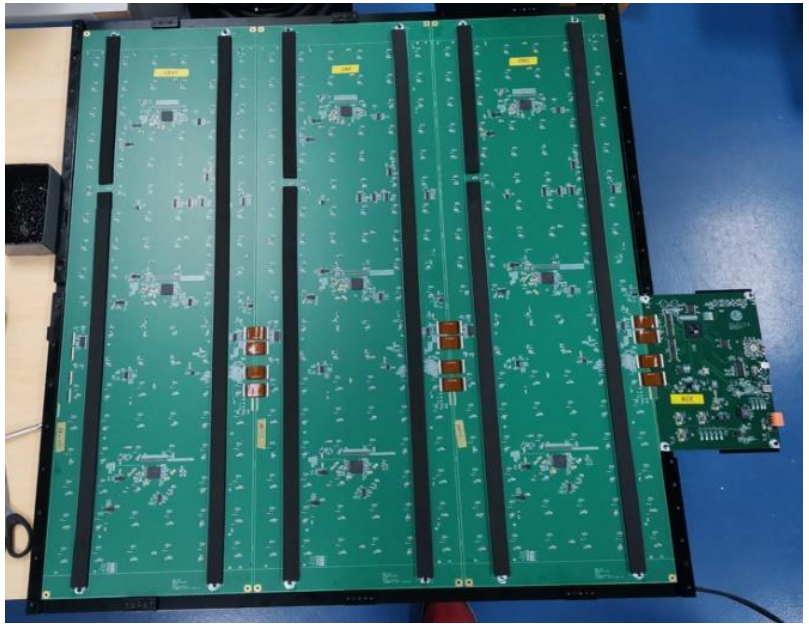
- ScW-ECAL prototype
  - Transverse size ~$22 \times 22\ \mathrm{cm}^2$, 32 longitudinal layers (~$25X_0$)
  - 6700 readout channels, ~300 kg in weight
  - Developed during 2016 – 2020

Recap: scintillator-iron HCAL prototype





1 full layer: 3 HBUs + cassette

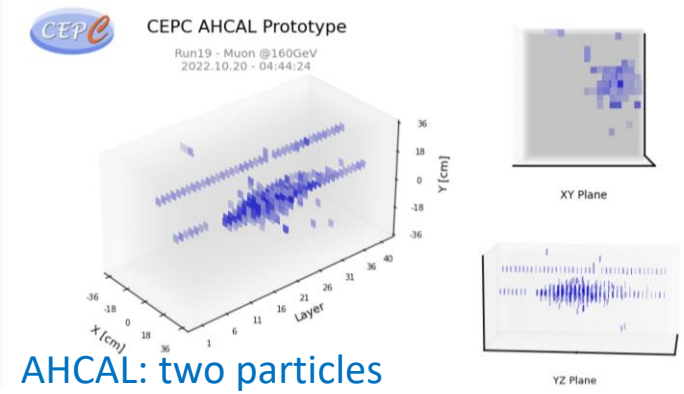


Mechanics Integration

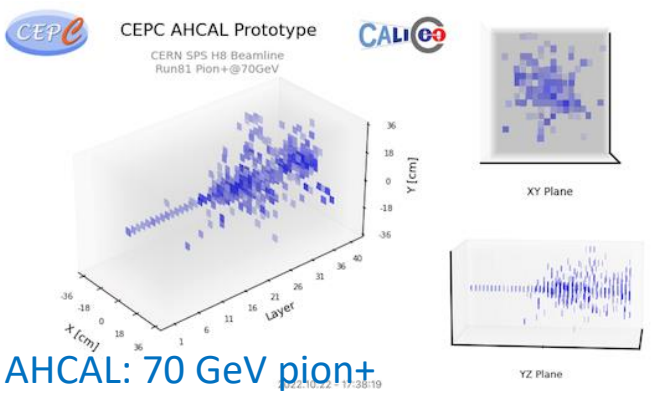
- AHCAL prototype: with “SiPM-on-Tile” design
  - Transverse size $72 \times 72\ \mathrm{cm}^2$, 40 longitudinal layers ($\sim 4.6\lambda_I$)
  - 12960 readout channels, ~5 ton in weight
  - Developed during 2018 – 2022

Brief summary of CERN beamtest

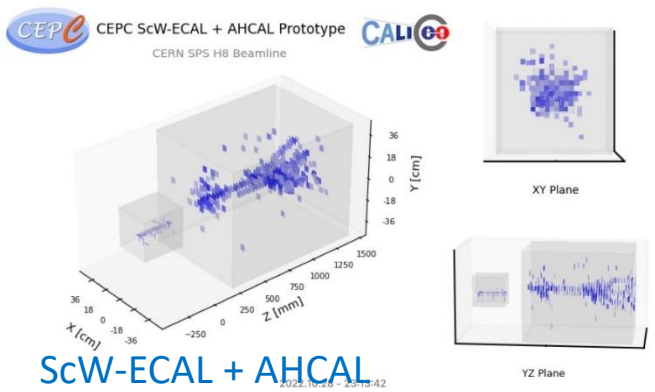
- CERN SPS H8: Oct – Nov, 2022
  - 160/108 GeV muons; 10-120 GeV positrons and hadrons
- Successful experiences
  - with two PFA calorimeter prototypes
- Decent statistics of data sets collected for
  - Highly granular calorimeter performance
  - In-depth shower studies: 3D space, time
  - Validation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



AHCAL: two particles



AHCAL: 70 GeV pion+



ScW-ECAL + AHCAL

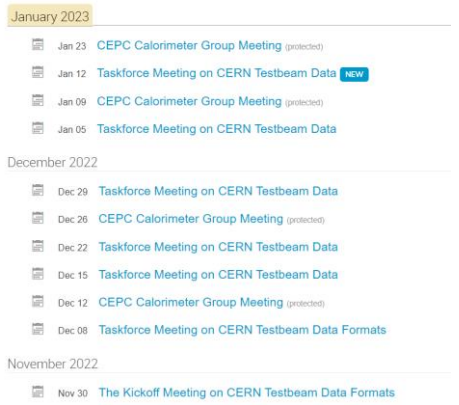
Taskforce on CERN testbeam data

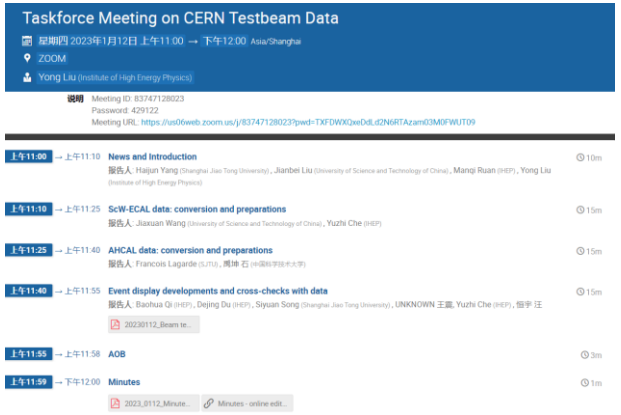
- Taskforce on data conversion and analysis (same groups that participated the CERN beamtest)
  - Data conversion and cross checks (4): Jiaxuan Wang, Yukun Shi; Yuzhi Che; Francois Lagarde
  - Event display (5): Siyuan Song, Zhen Wang; Yuzhi Che, Baohua Qi, Hengyu Wang
  - Data analysis and software 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

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
- Weekly meetings: updates, questions and discussions
  - https://indico.ihep.ac.cn/category/322/
- Welcome new members to join
  - A full task list (evolving) prepared for data analysis





Outline for preliminary results

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

Pedestal calibration

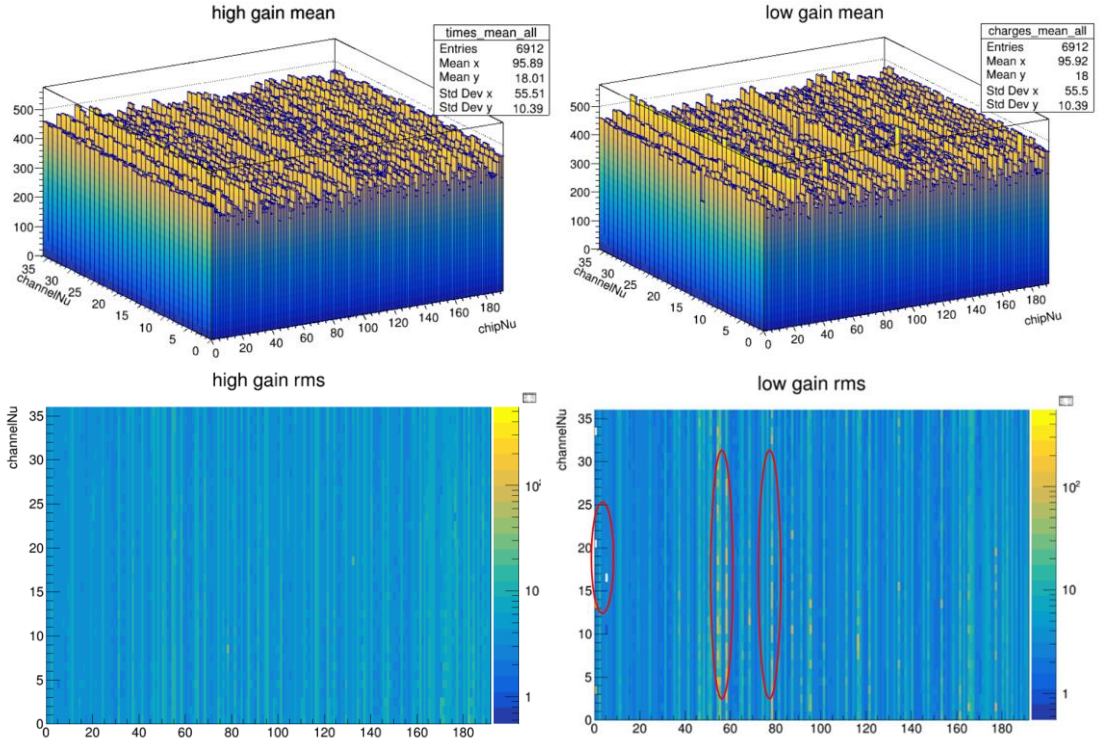
References: Talk 1, Talk 2 (Dec. 12, 2022)

Hongbin Diao, Jiaxuan Wang (USTC)

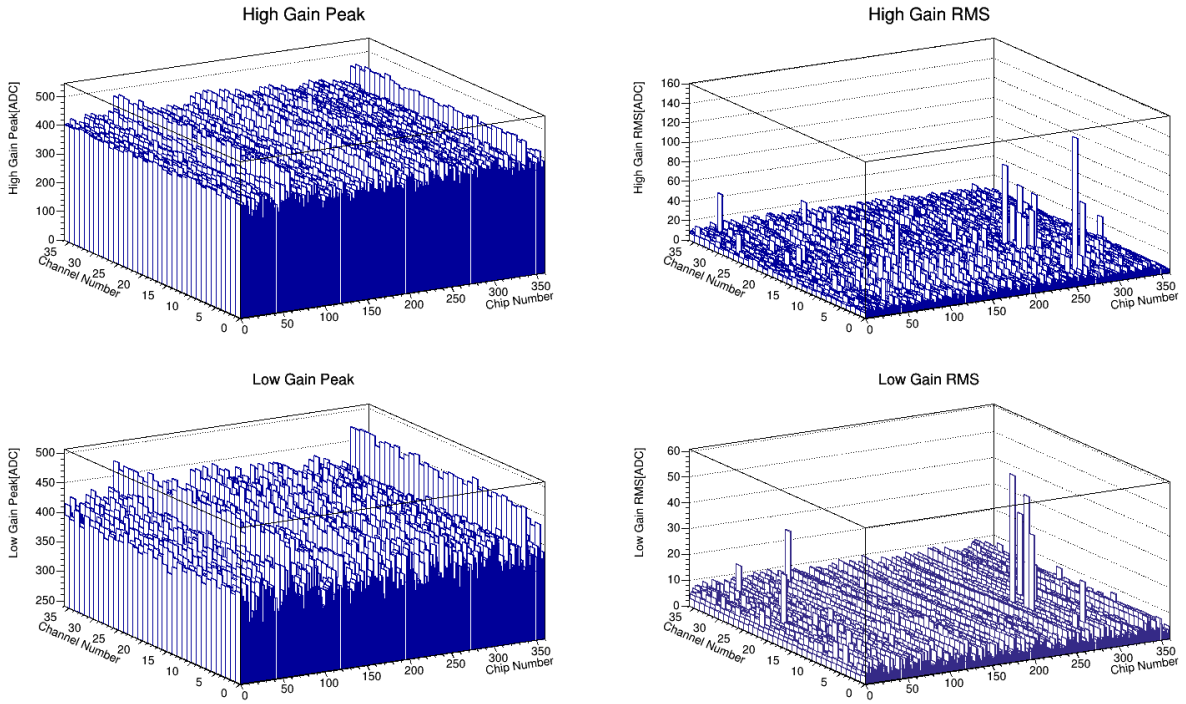
- Extracted for pedestal calibration per channel
  - Basis for MIP calibration and all other analyses

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

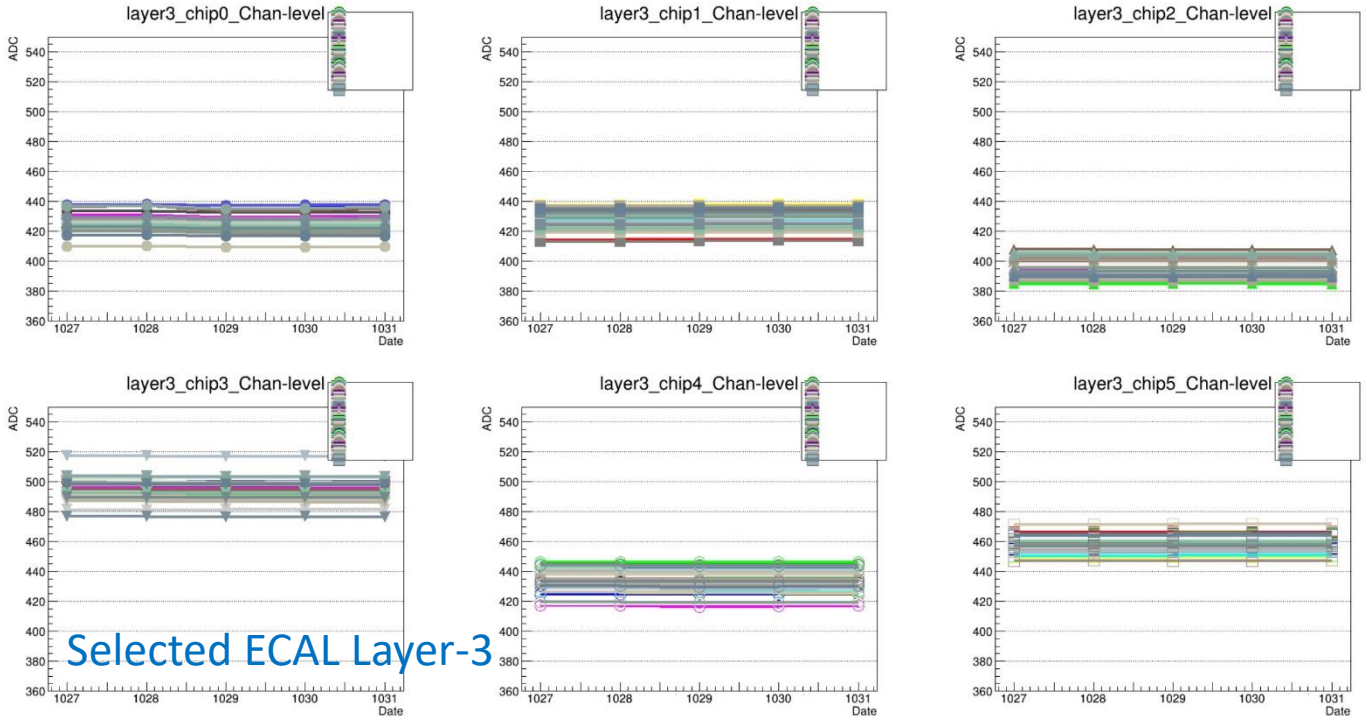
Pedestal calibration

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

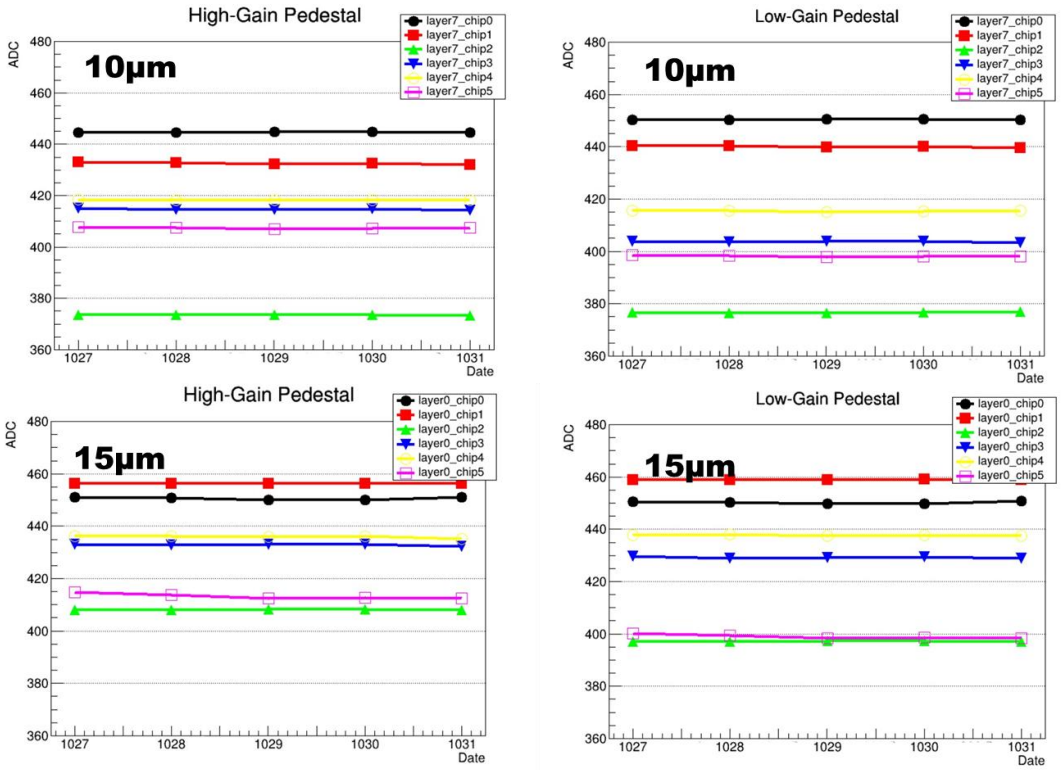
Hongbin Diao, Jiaxuan Wang (USTC)

- Generally pedestals show good stability along with time

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



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.

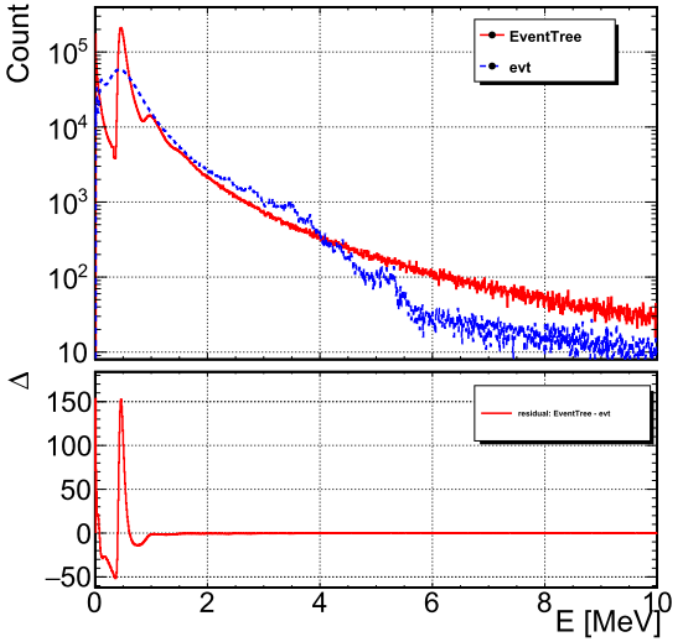
Simulation and validation

Yuzhi Che, Baohua Qi (IHEP)

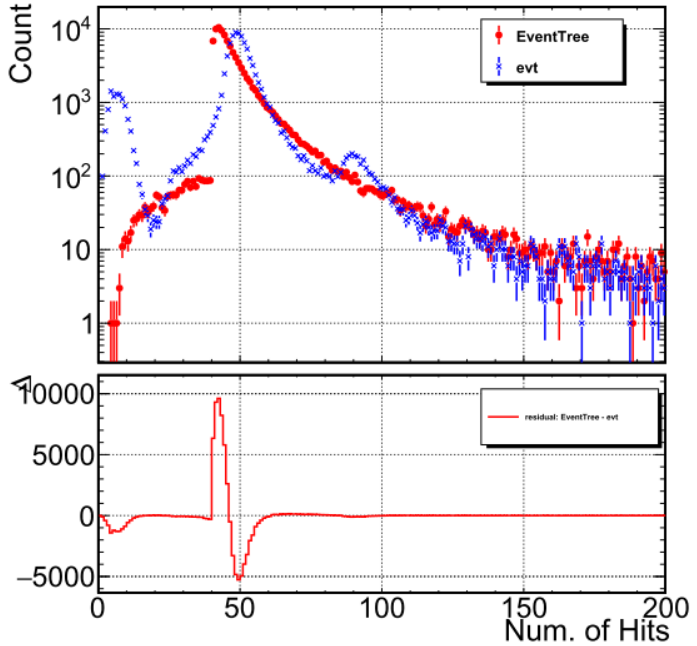
Beam test simulation (Jan. 12, 2023)

- 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 → most likely due to non-uniformity per channel
  - More #hits in data → significant noises, likely with a second muon (2-MIP peak)

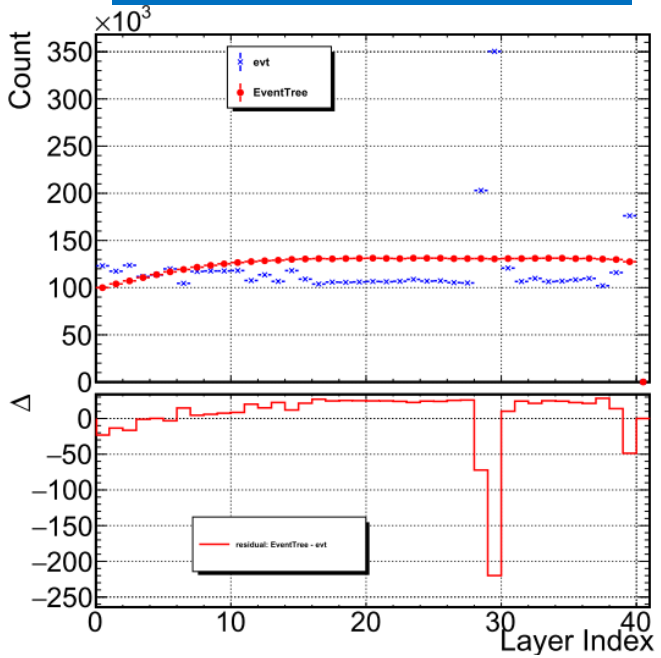
Hit-level: energy spectrum



Total number of hits per event



Number of hits per layer



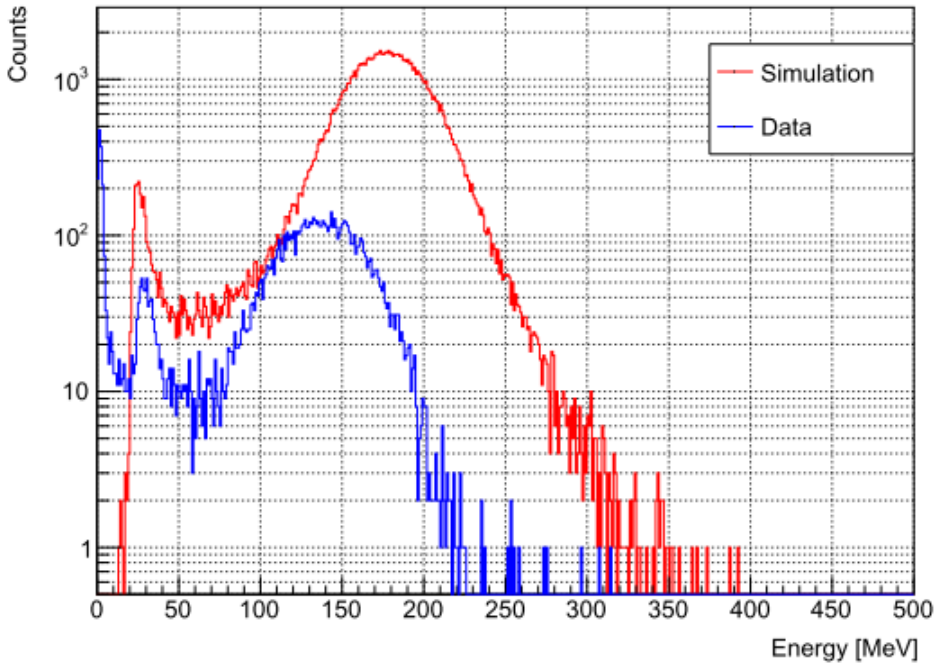
Simulation and validation

Yuzhi Che, Baohua Qi (IHEP)

Beam test simulation (Jan. 12, 2023)

- First comparisons of data vs MC for AHCAL prototype
  - 10 GeV pi+ 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

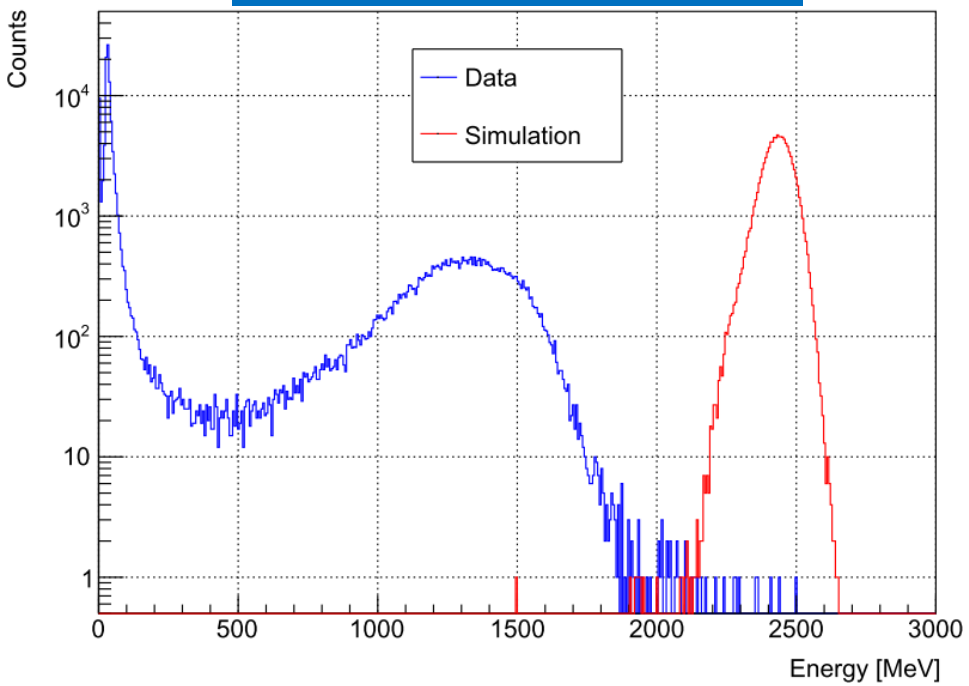
Simulation and validation

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)

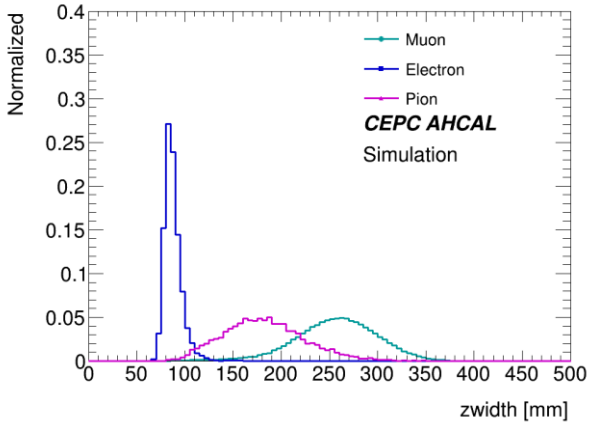
PID studies with simulation samples

Zhen Wang (SJTU)

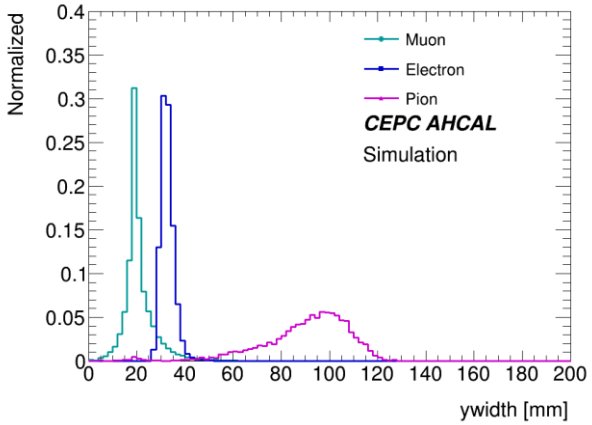
Talk in the Weekly Meeting (Jan. 5, 2023)

- 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

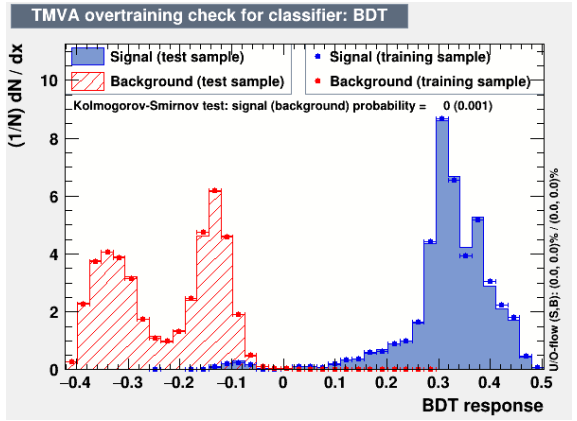
Longitudinal Center of Gravity

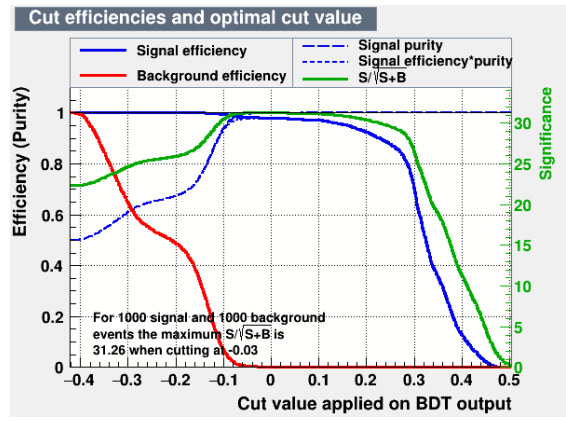


Transverse Center of Gravity



pi+ as signals; e+ and mu+ as backgrounds





No signs for overtraining

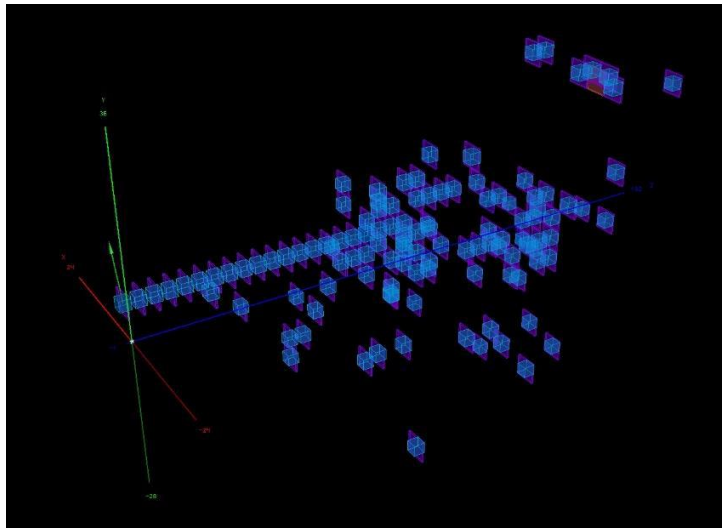
Arbor clustering studies with data

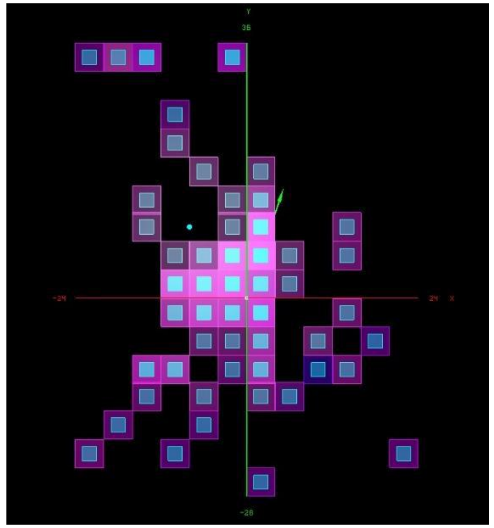
Yuzhi Che, Hengyu Wang, Xin Xia (IHEP)

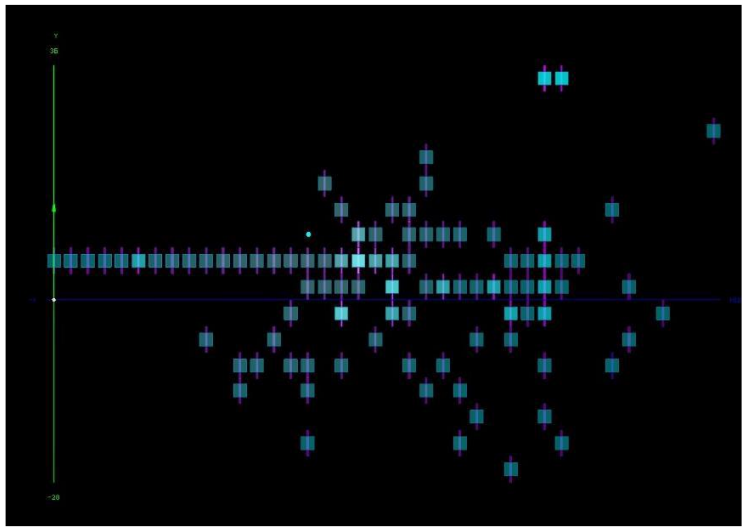
- Qualitative studies with Druid event display

Talk in the Weekly Meeting (Jan. 5, 2023)

  - 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





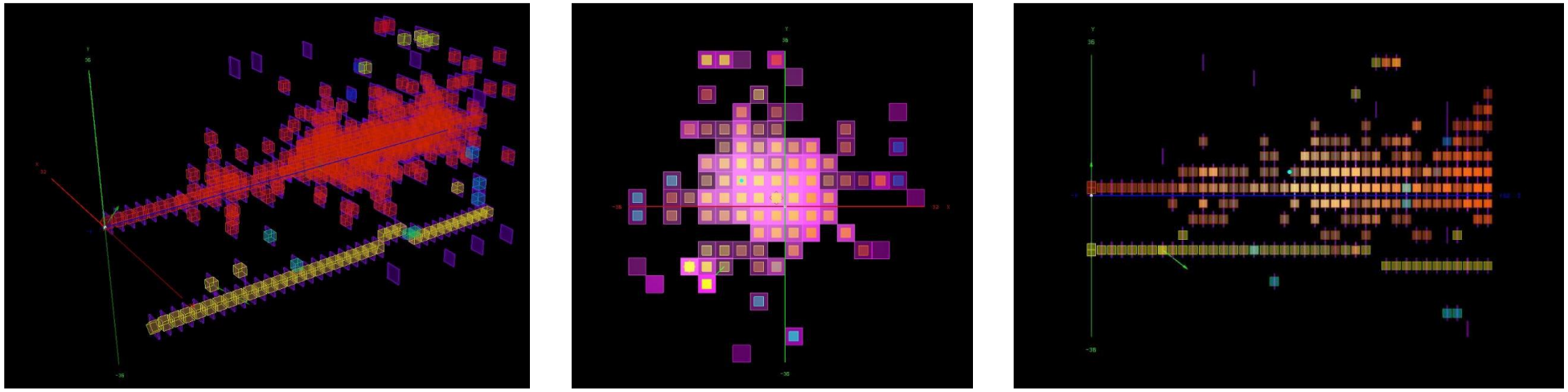


Data Sample: AHCAL_Run156_20221024_231347 (10GeV pi+)

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)

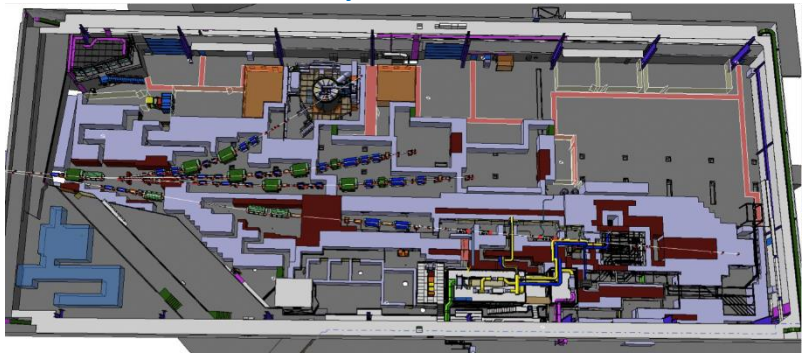
- Calorimeter prototype status: stored at CERN
- CERN testbeam application
  - Proposal submitted (Jan. 6), coordination within CALICE Technical Board
  - Beam time: 2 weeks at PS (T9) and 2 weeks at SPS (H2/H4)
    - Target period: May 30 - Aug. 30, 2023
  - SPS-Committee reviews for proposals: scheduled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


Storage at CERN B.190


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

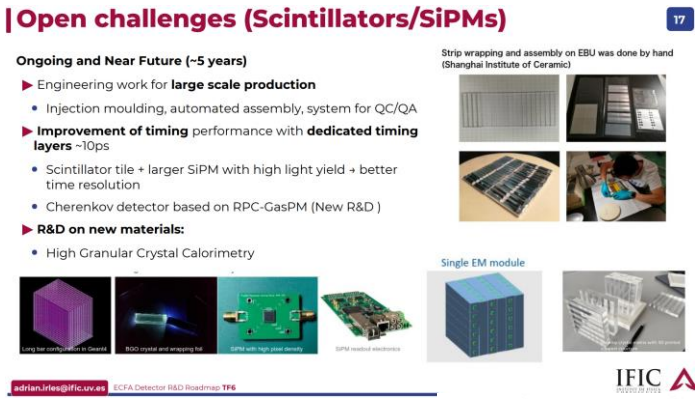
- PS (T9): 1-15 GeV beam
- SPS (H2/H4): 10-120 GeV beam (high purity)

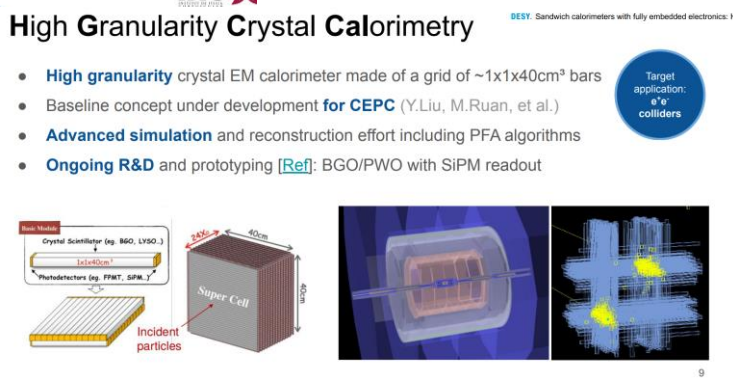
PS beamlines: layout after renovations

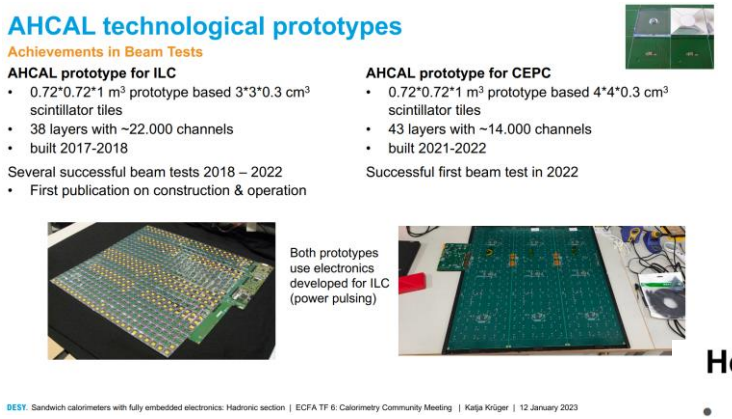


News: ECFA DRD preparations

- 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







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!