CERN Beamtest of CEPC Calorimeter Prototypes

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for the CALICE and CEPC Calorimeter teams

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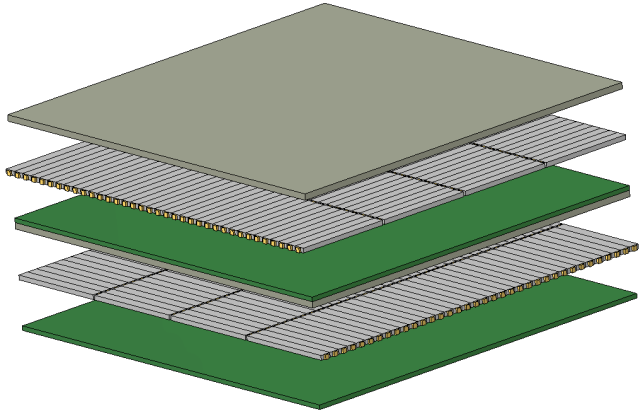
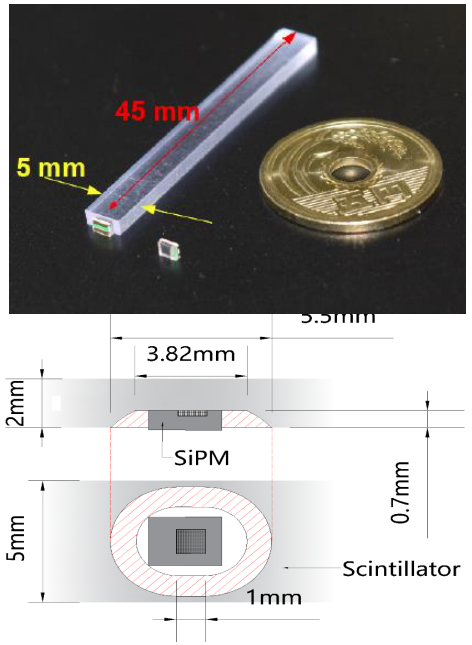
Recap: scintillator-tungsten ECAL prototype

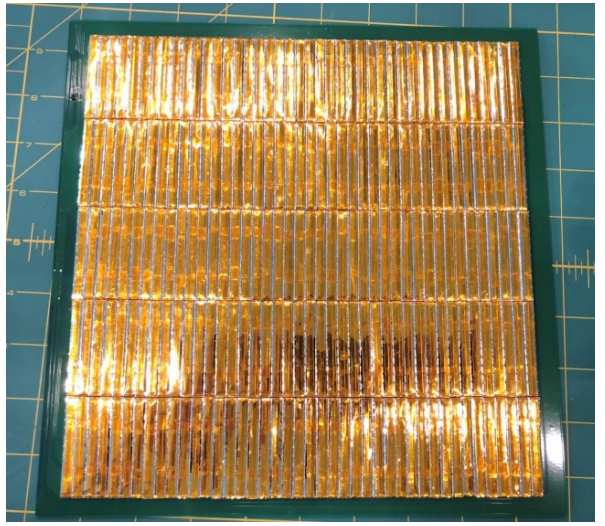
Sampling structure: scintillator strips + tungsten-copper plates



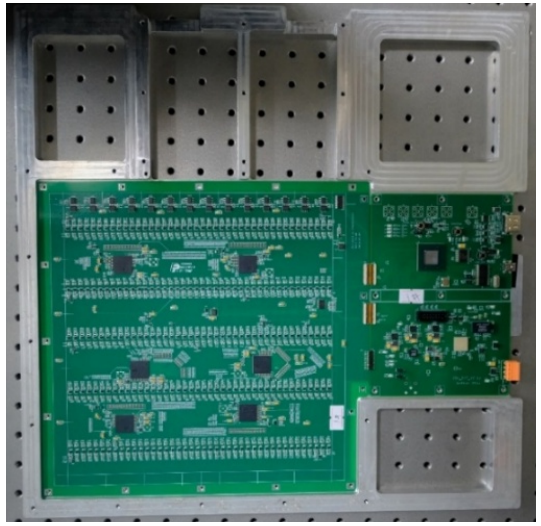
Detector unit: scintillator + SiPM



One sensitive layer (EBU)



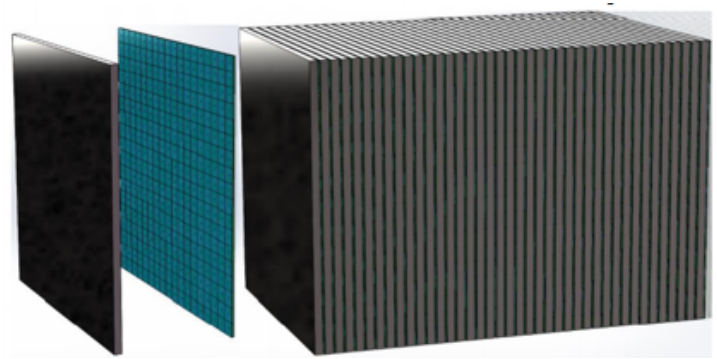
Two EBUs + absorber: integrated with mechanics

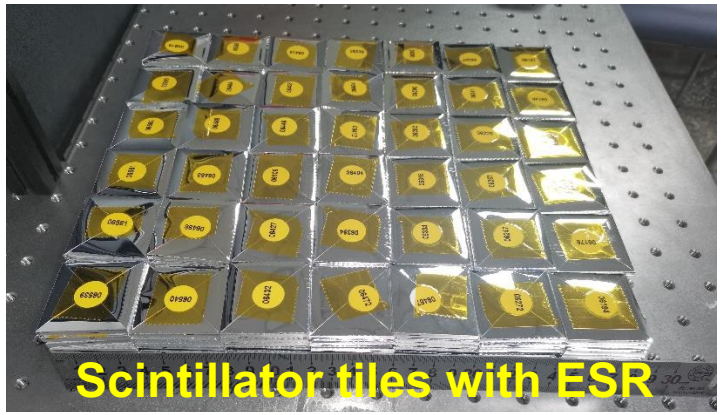


ScW-ECAL prototype

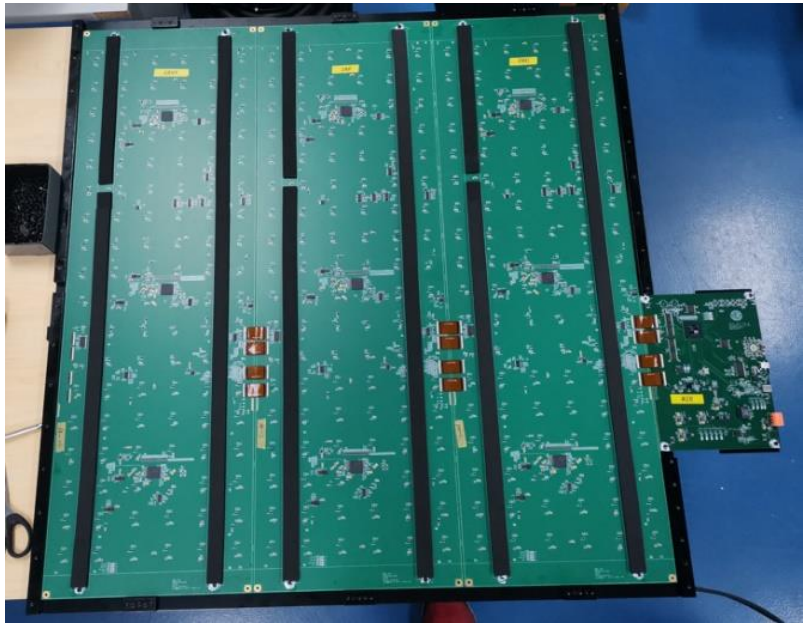
- ScW-ECAL prototype
  - Transverse size ~22×22 cm^2, 32 longitudinal layers (~$25X_0$)
  - 6700 readout channels, ~300 kg in weight
  - Developed during 2016 – 2020
  - Tested with beams at BEPCII-TBF (IHEP) and cosmics at USTC

Recap: scintillator-iron HCAL prototype





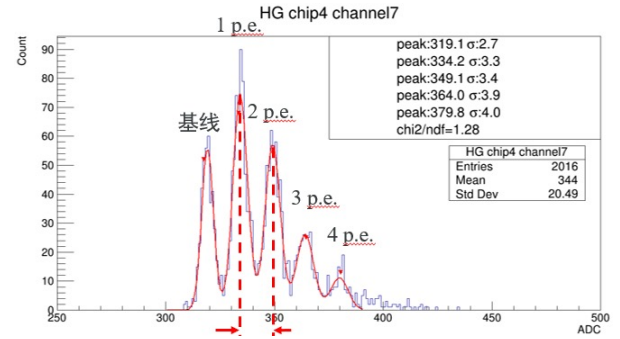
1 full layer: 3 HBUs + cassette

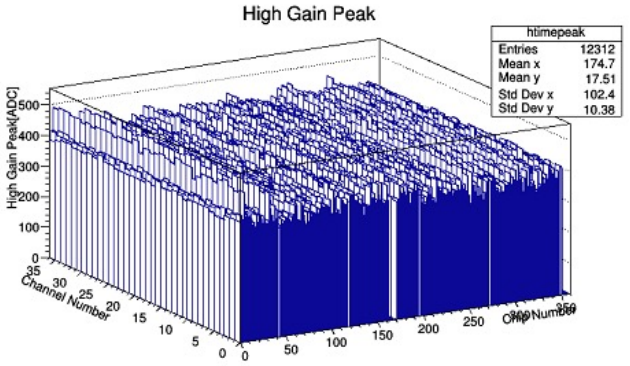


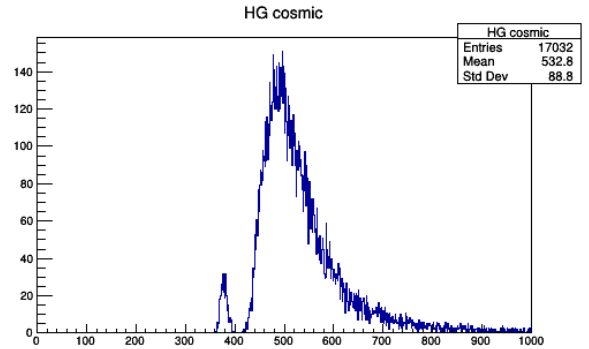
Mechanics Integration

- AHCAL prototype: with "SiPM-on-Tile" design
  - Transverse size $72\times72\ \mathrm{cm}^2$, 40 longitudinal layers ($\sim4.6\lambda_I$)
  - 12960 readout channels, ~5 ton in weight
  - Developed during 2018 – 2022
  - HBU assembly and commissioning (w/ cosmic muons) at USTC

AHCAL: assembly and commissioning (August 2022)



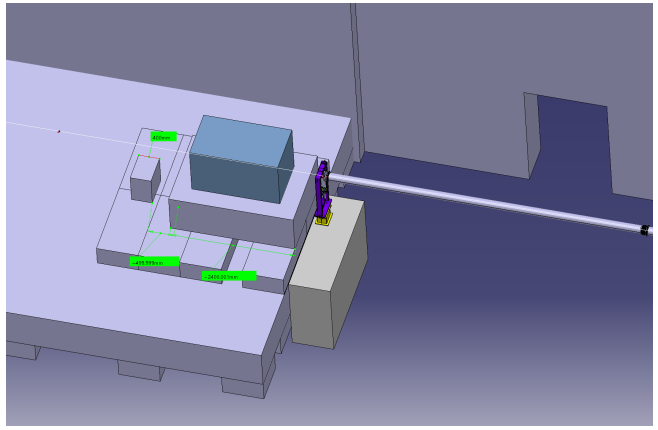


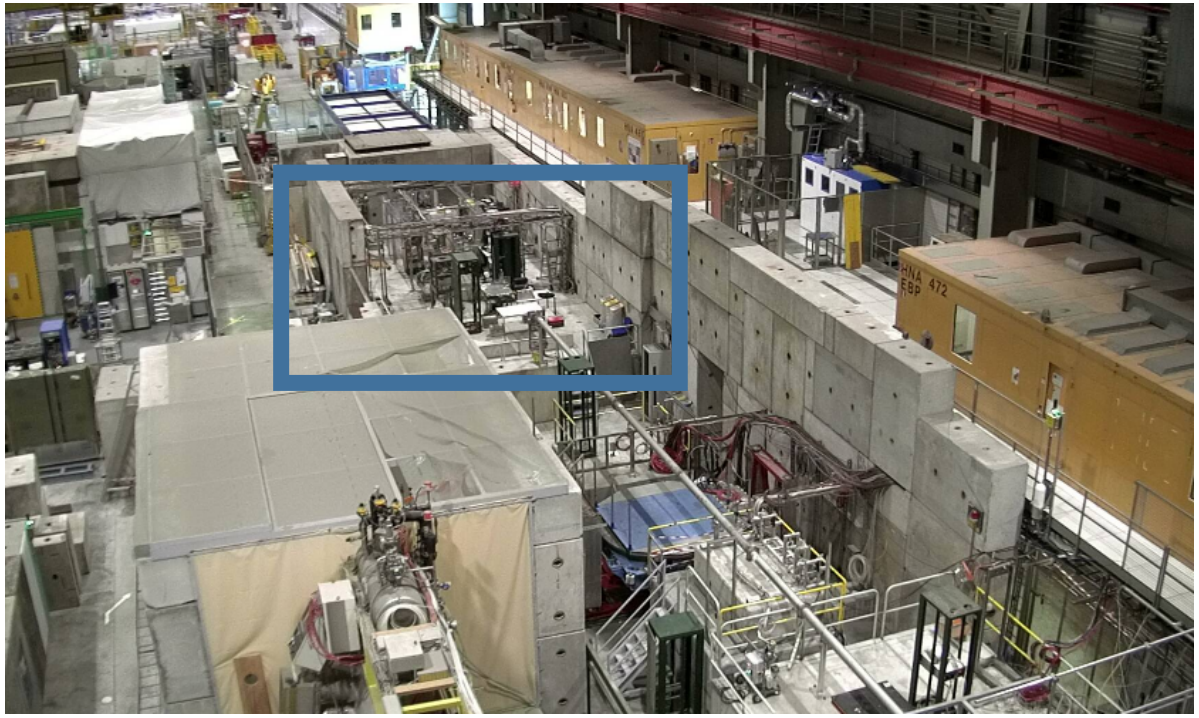


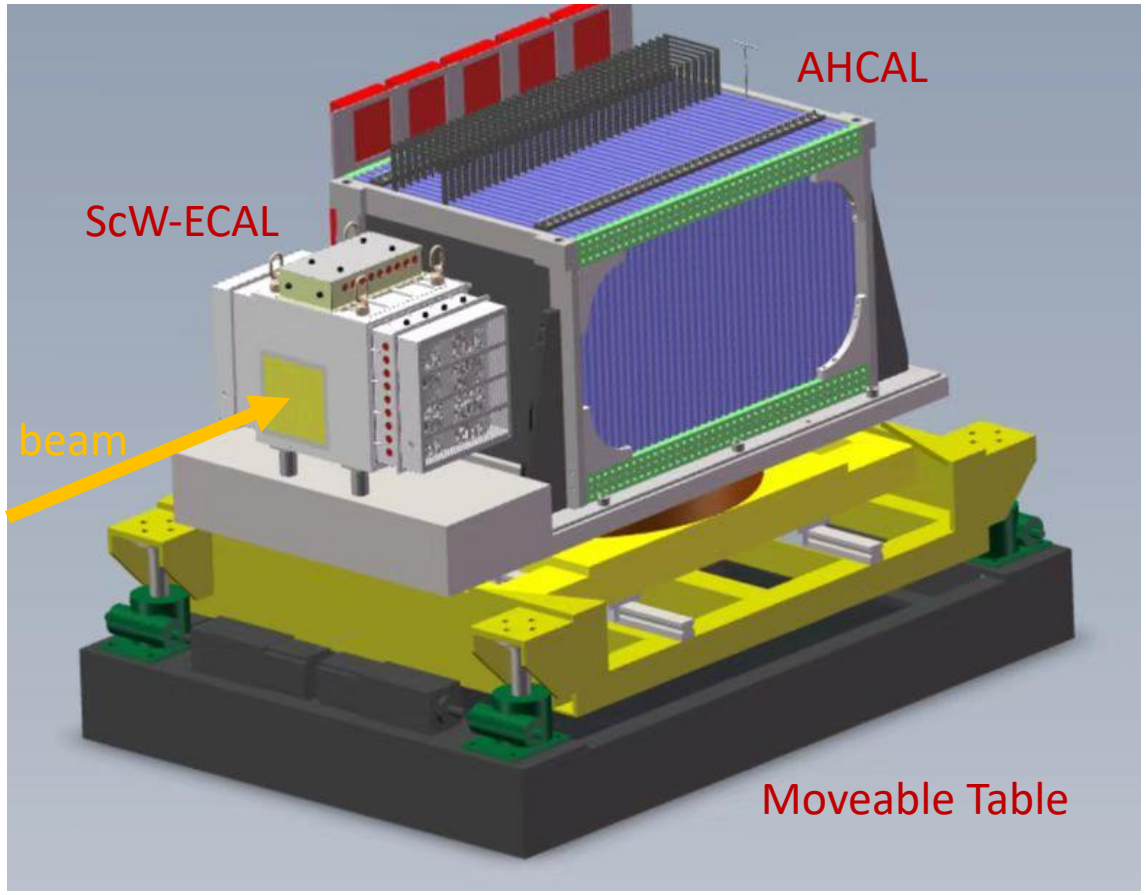
- HBU assembly and commissioning with DAQ at USTC
  - Pedestal runs and calibration
  - LED data for SiPM gain calibration
  - ASIC inter-calibration: High Gain vs. Low Gain
- Cosmic-ray tests: MIP peaks can be seen for most layers
- Joint efforts of USTC, IHEP and SJTU: “rehearsals” for the beamtest

H8 beam area arrangement

Technical discussions with Michael Lazzaroni (CERN)

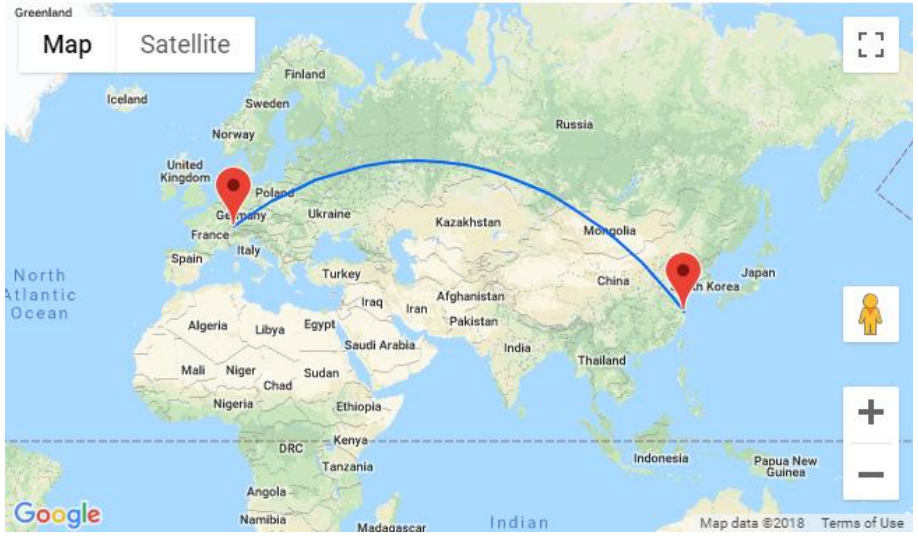






Transport and preparations at CERN SPS

Calorimeters in flight

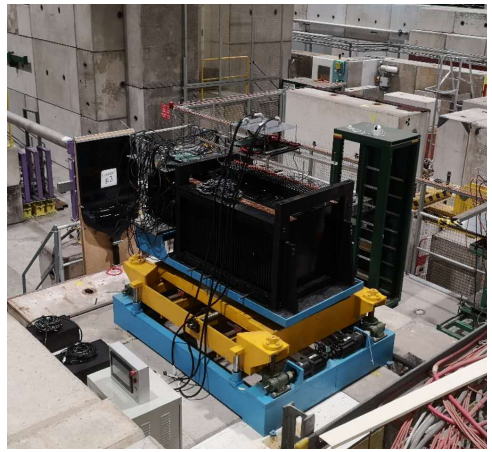


Flying AHCAL

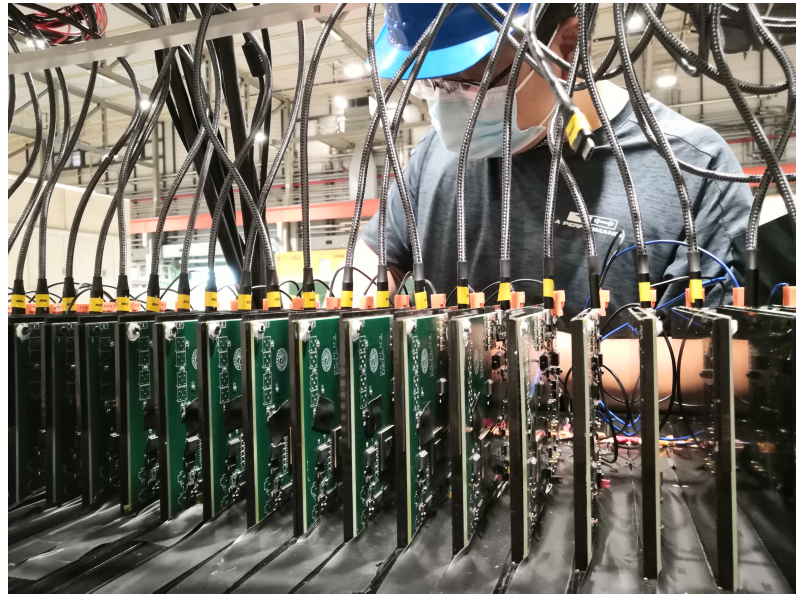
Before cabling

- Successful transportation from China to CERN
  - Transport started from Sep. 15: twists and turns
  - Issues finally solved thanks to the efforts led by Jianbei
- Oct. 14: delivered to the beam area H8C (PPE168)
  - ScW-ECAL and AHCAL prototypes + 1 supporting table
  - Impressions: a few cubic meters and ~10 tons

After cabling: parasitic runs

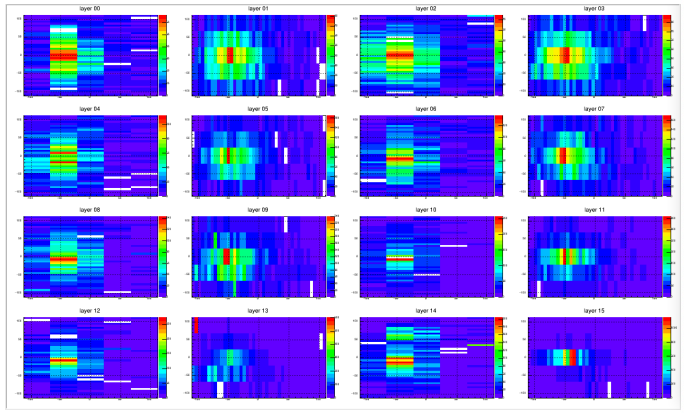


Unpacking and installations

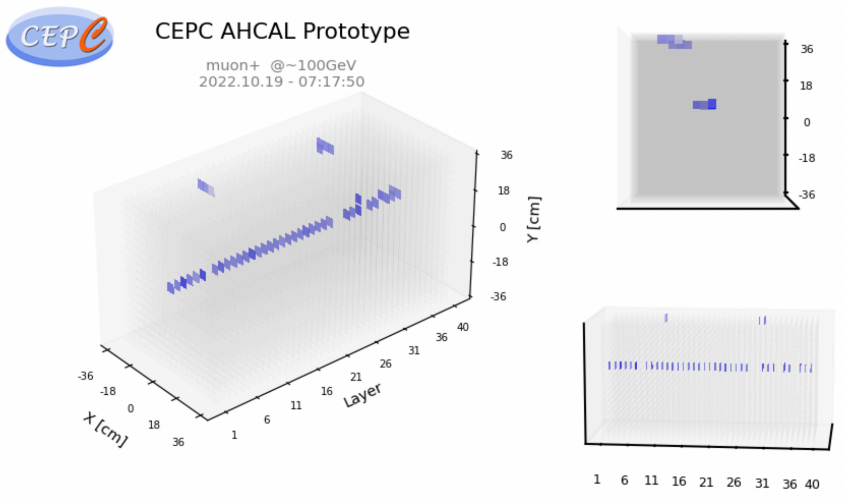


Parasitic beam test: ScW-ECAL + AHCAL

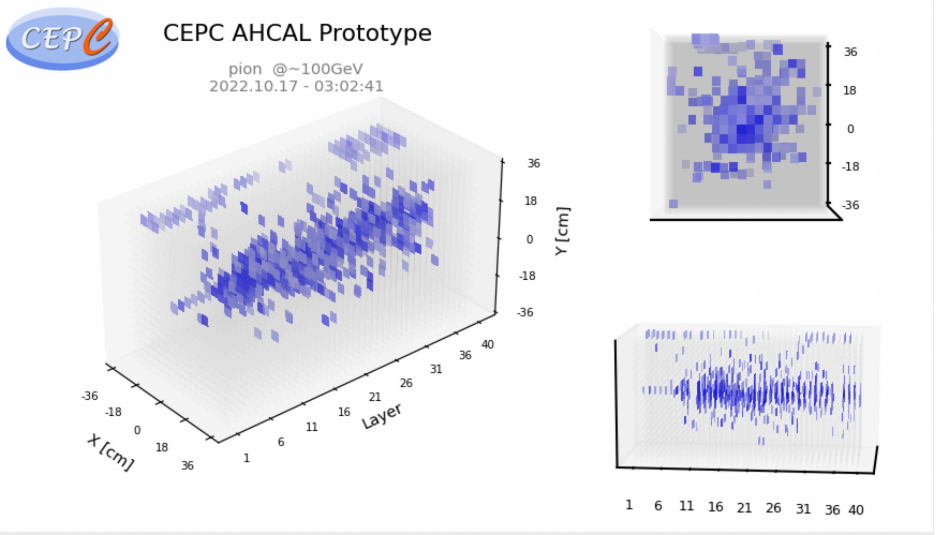
Muons in ECAL: Hit Maps



Muon MIP track in HCAL

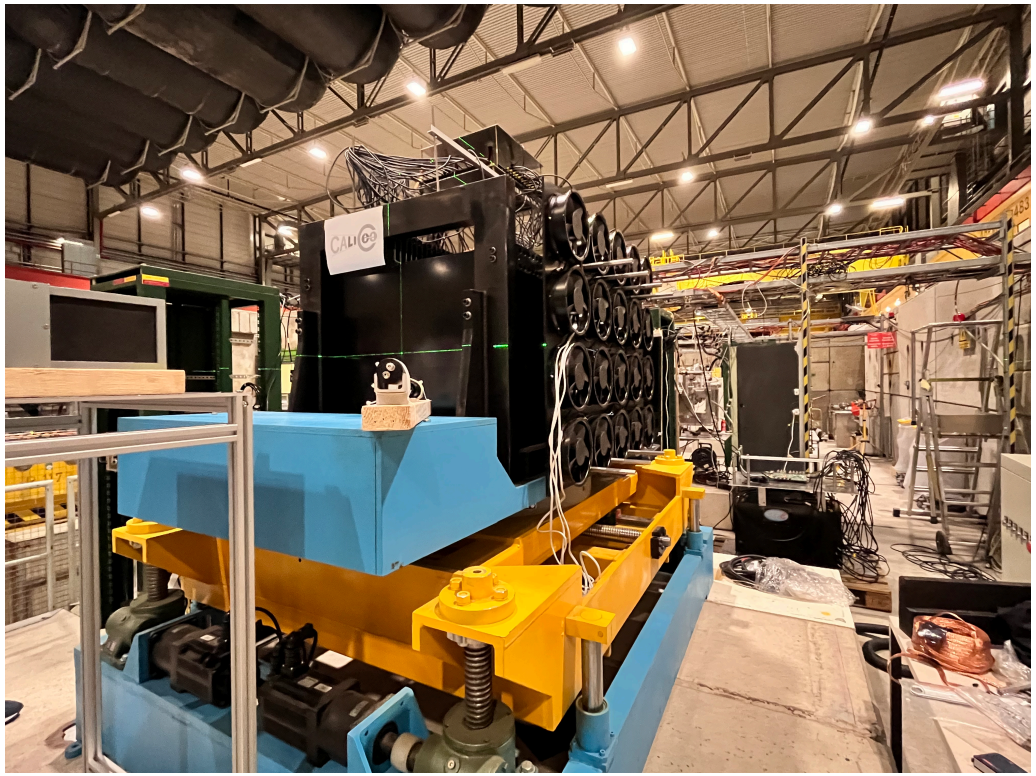


Pion hadronic shower in HCAL



- Motivations: full system commissioning; muons for ECAL and HCAL calibration
- Successful data taking with parasitic beams (Oct. 14-19)
  - Setup: combined ECAL and HCAL, in downstream of LHCb detectors
  - Beams: 160-180 GeV muon+ or pion+
    - MIP tracks and hadronic showers in highly granular calorimeters
  - Thanks to the LHCb team (with muon detectors)

Beam test: motivations and plans



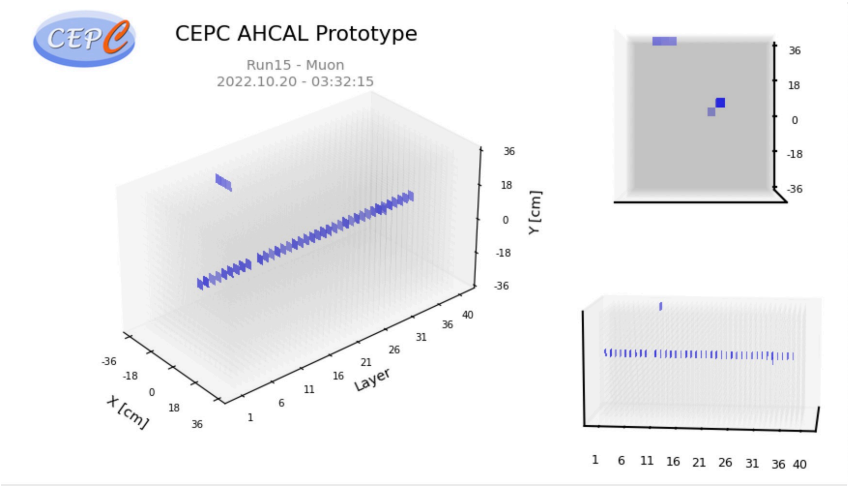
The 1st week as main user (Oct. 19-26): AHCAL prototype alone in H8 beam line

- Muon beam: 160 GeV (1st week); 108 GeV (2nd week)
  - MIP calibration → energy reconstruction
- Positron beam: 10 - 120 GeV
  - Compact EM showers → high energy density → SiPM saturation corrections (essential)
  - EM performance
  - Validation of simulation and digitisers
- Pion beam: 10 - 120 GeV
  - Major goal: hadronic performance (10-80 GeV), e.g. energy linearity and resolution
  - Shower profiles in 3D and time domain
  - Geant4 simulation validation ("Physics Lists")
  - Particle-flow studies: e.g. ArborPFA

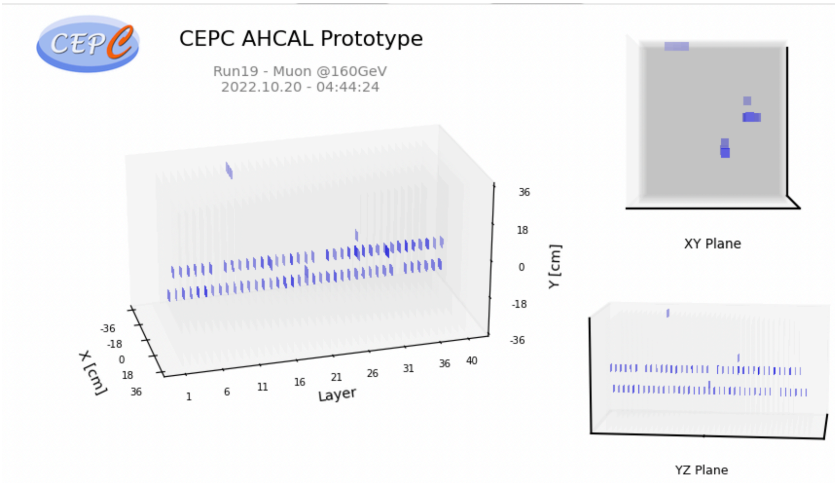
AHCAL beam test with muons

- Muon beam (~160 GeV)
  - Wide beam profile: covers AHCAL lateral area ($72\times72\ \mathrm{cm}^2$)
  - ASIC configuration: threshold scans (all layers)
  - SiPM bias voltage tuning (all layers)
  - Data sets for MIP calibration

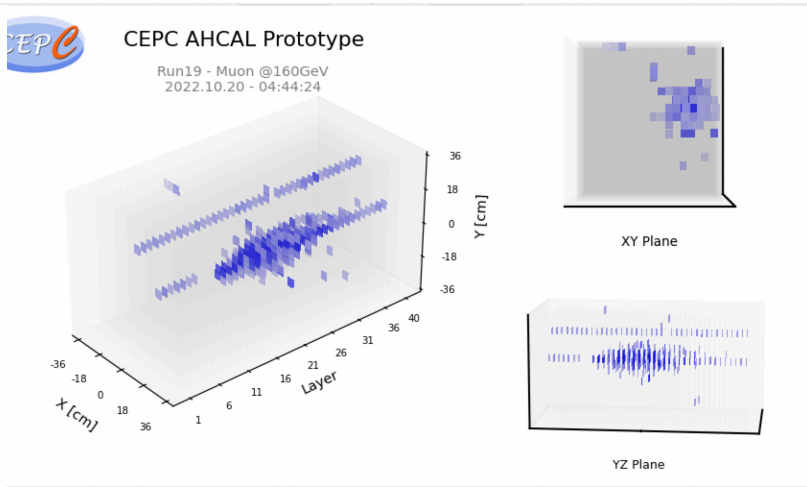
Impressions of high granularity



1 muon track



2 muon tracks



1 muon + 1 pion

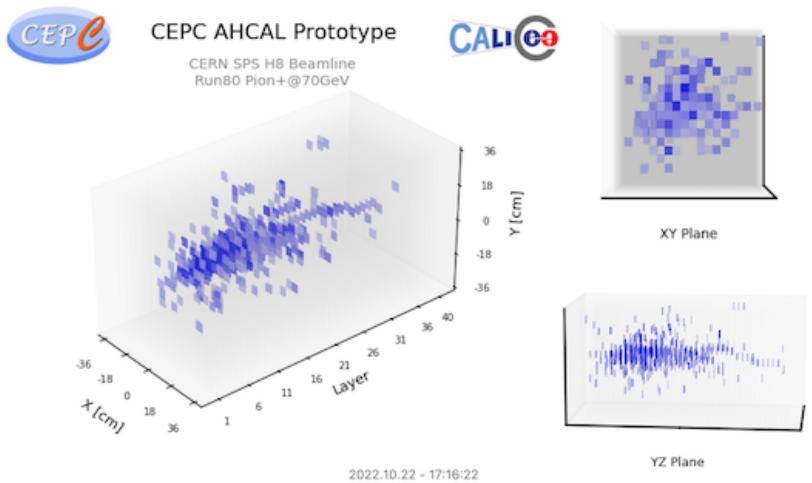
AHCAL pion beam data

- Plans for AHCAL (alone) with pion+ beam
  - 1M events per energy point
  - Accumulate more statistics at one or two low energy point
- Data taking
  - Successfully completed plans
  - SPS running very smoothly and with high beam intensity during Oct. 20 – 26
- Beam purity: issue and solution
  - Contaminations of pion+ beam with protons (energy dependent)
  - 2 Cherenkov counters implemented in DAQ: recorded in data, not part of hardware trigger

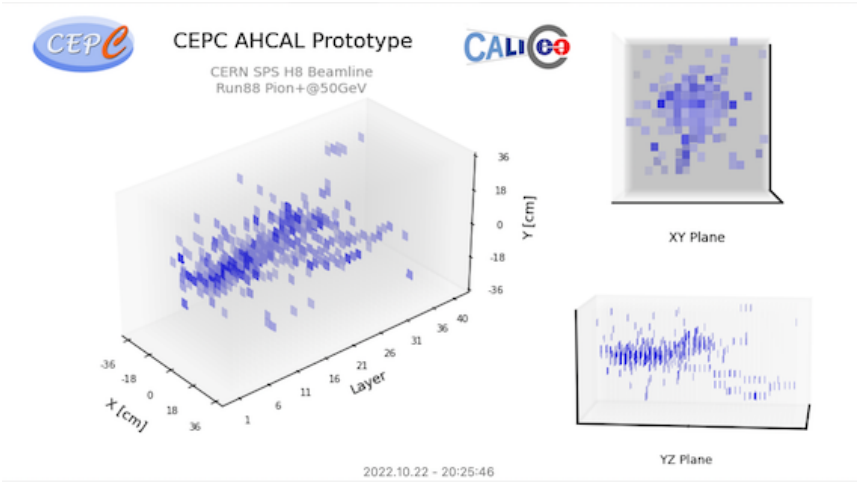
AHCAL data list (pion+)

Momentum (GeV)	Number of Events	Total Runs
120	1086169	8
100	1392510	8
90	1118714	8
80	1040225	8
70	1038162	7
60	1074803	9
50	1066431	6
40	1339732	8
30	2108208	10
20	2059772	14
10	675699	5

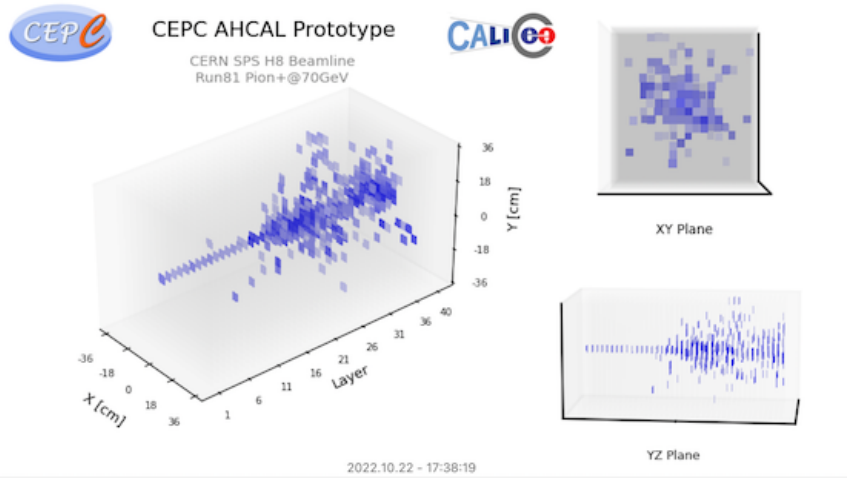
AHCAL with pion+ beam: event display



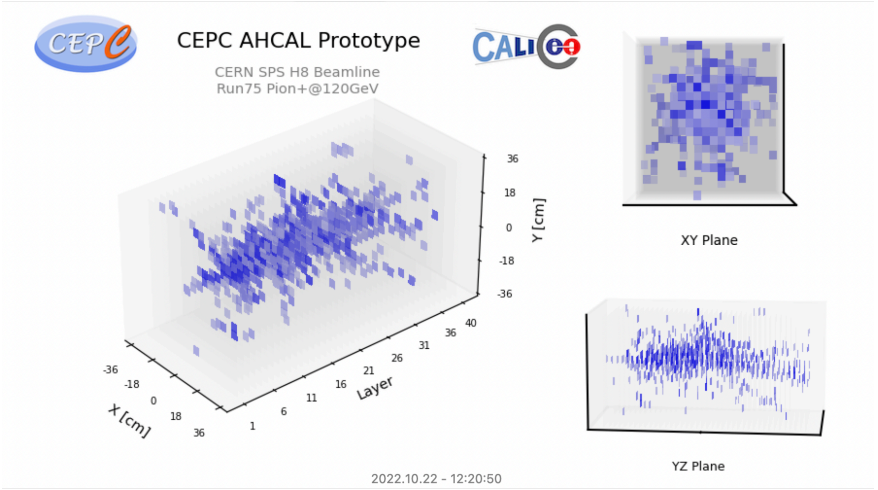
70 GeV pion+ (early showers)



50 GeV pion+



70 GeV pion+ (late showers)



120 GeV pion+

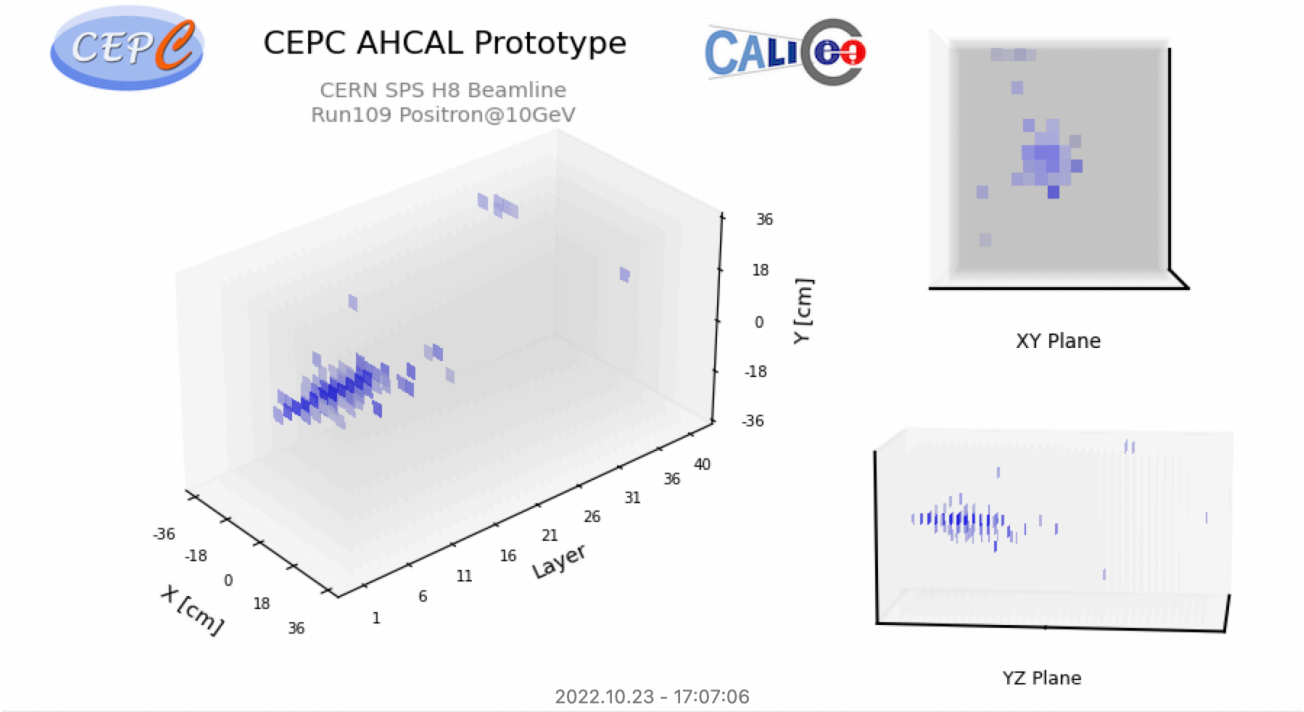
AHCAL positron beam data

- Plan for AHCAL (alone) with e+ beam
  - ~200k events per energy point
- Data taking
  - Successfully completed the plan within half a day (Oct. 24)
  - Thanks to SPS smooth running
- Beam purity: issue and solutions
  - Contaminations of e+ beam with hadrons (energy dependent)
  - 2 Cherenkov counters implemented in DAQ: recorded in data, not part of hardware trigger
  - Shower profiles: EM vs hadronic

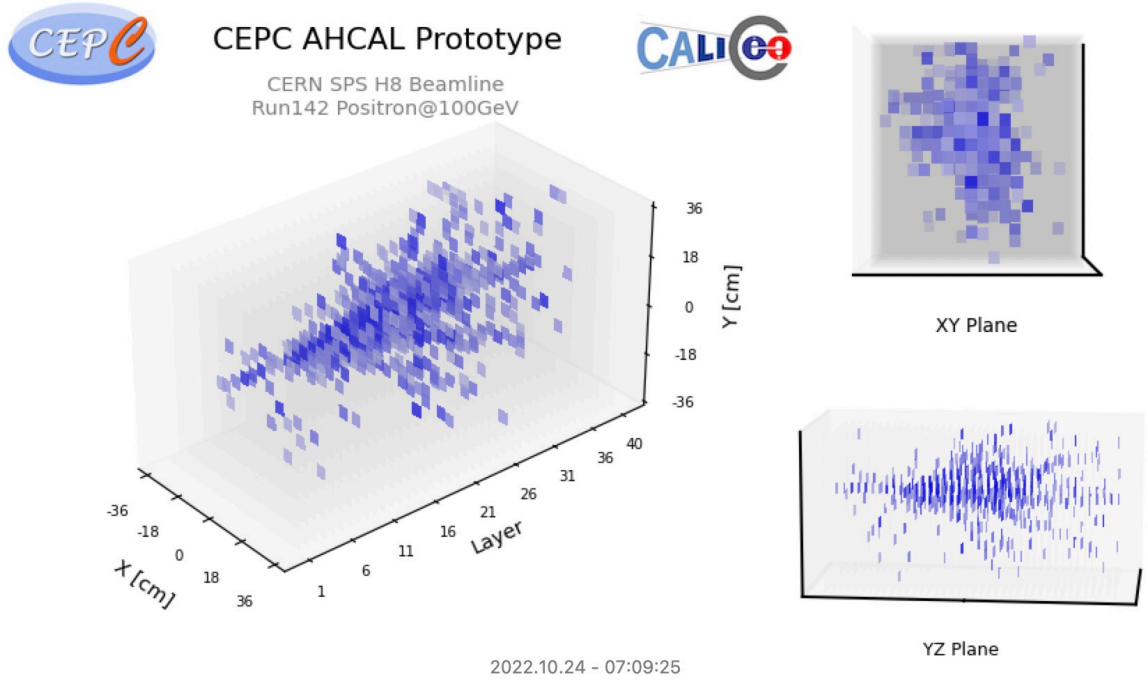
AHCAL data list (e+)

Momentum (GeV)	Number of Events	Total Runs
20	337956	2
30	193054	2
40	159087	2
50	220352	2
60	253464	2
70	189186	2
80	429414	3
100	196267	2
120	286107	2

AHCAL with e+ beam: event display



10 GeV positron beam: EM showers

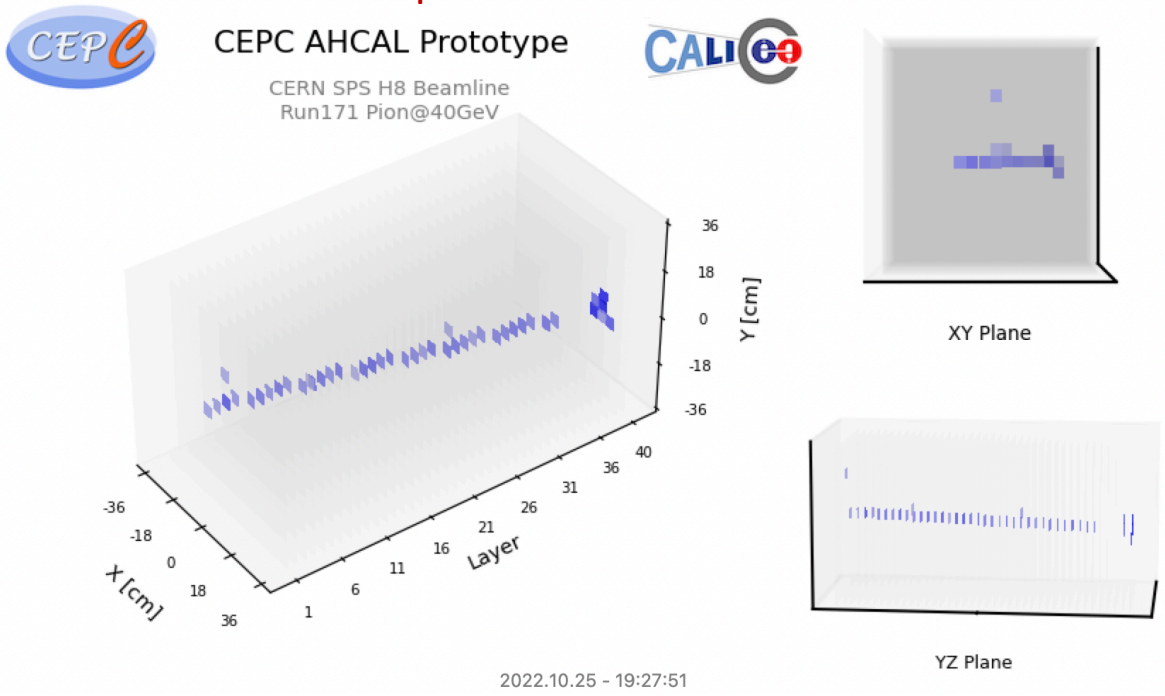


Hadronic showers in 120 GeV positron beam

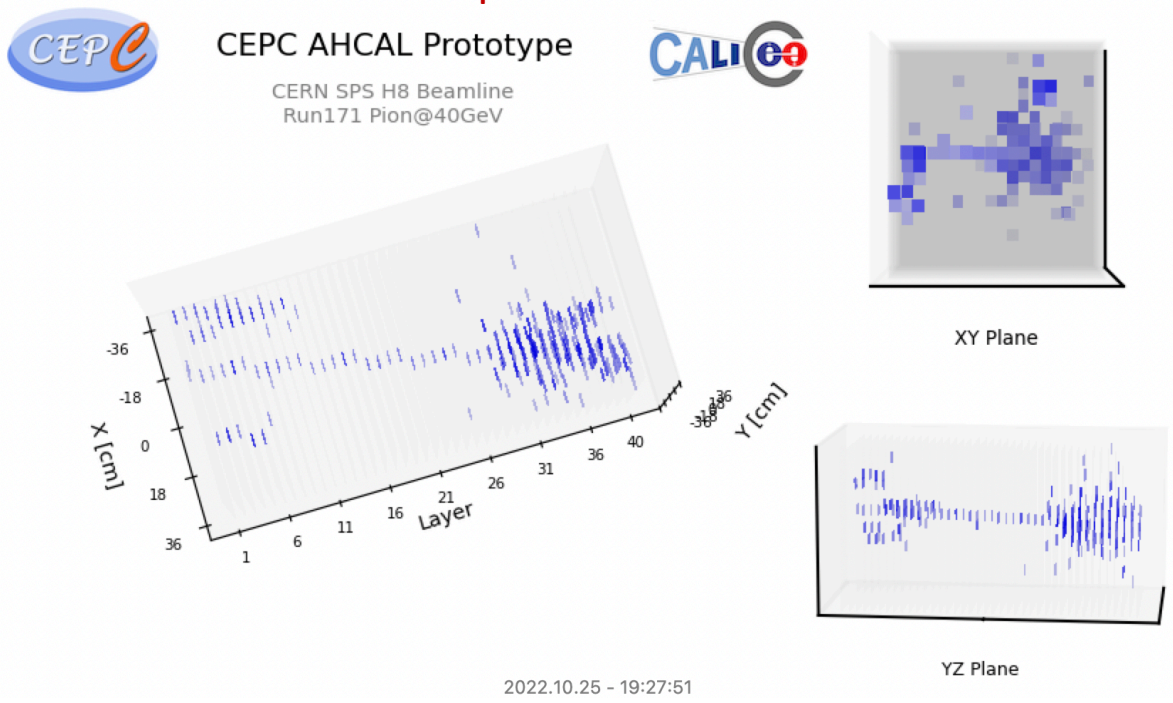
AHCAL prototype rotated

- AHCAL was rotated at 15° w.r.t the beam incidence
  - To study angular dependences: shower energy and profiles
  - Pi+ beams: 20GeV (273k events), 30GeV (1.11M events), 40 GeV (134k events)

40 GeV pion beam: muon track

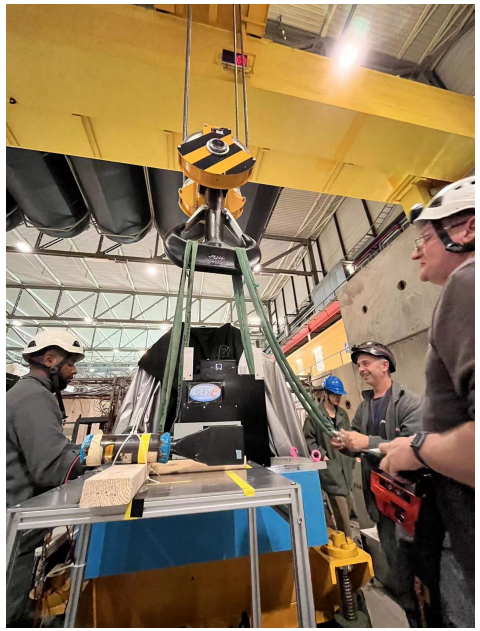


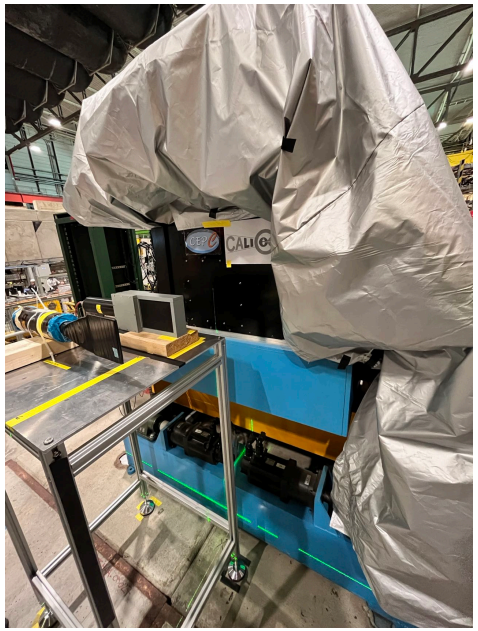
40 GeV pion beam: hadronic showers



ScW-ECAL and AHCAL: combined beam test

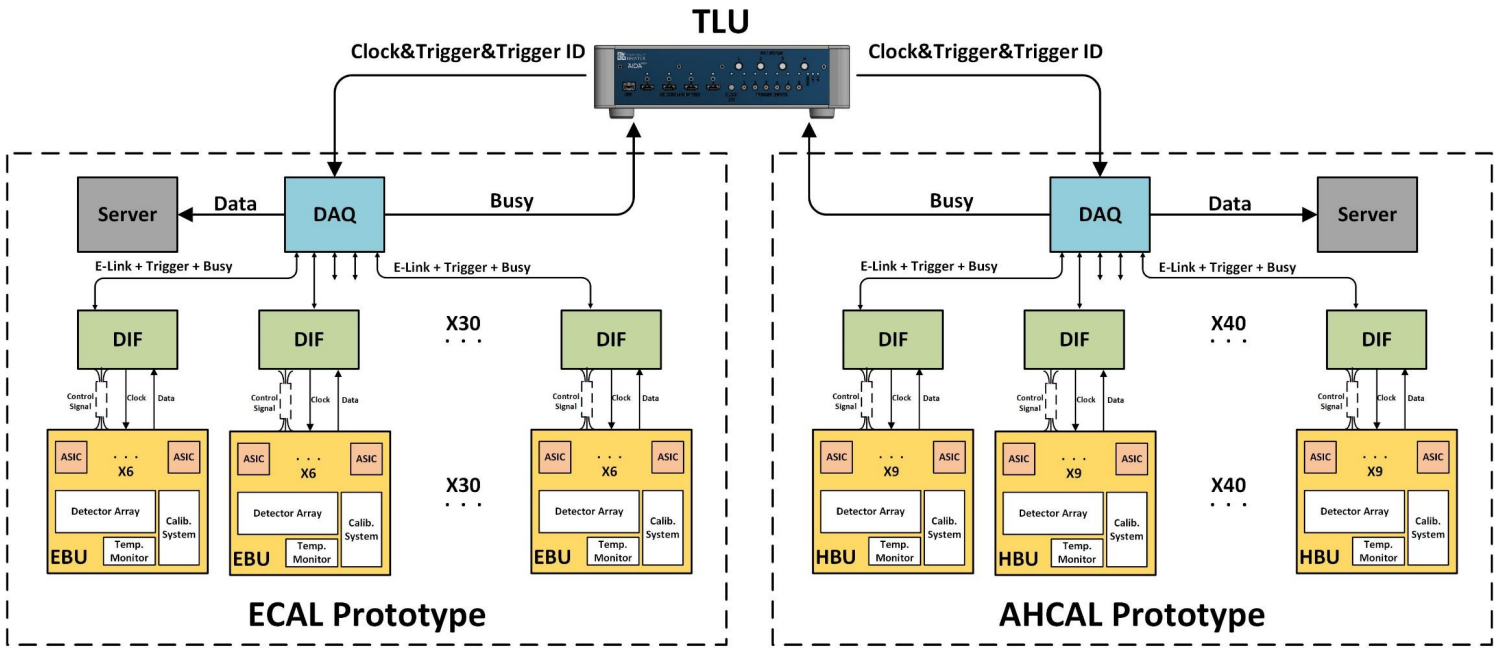
- 120 GeV secondary hadron beam used (180 GeV in the first week)
  - Trying to improve the beam intensity
- Muon beam: wide profiles for MIP calibration
- Positron and pion beams: energy scans

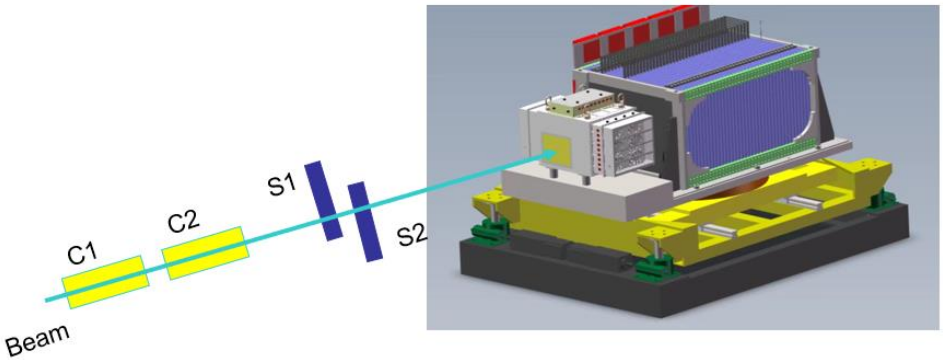




ScW-ECAL and AHCAL: integrated DAQ system

- Integration of 2 DAQ systems
  - ECAL DAQ: 30 DIFs and 1 data aggregator board
  - HCAL DAQ: 40 DIFs and 1 data aggregator board
  - Synchronise via TLU (Trigger Logic Unit) using Trigger ID

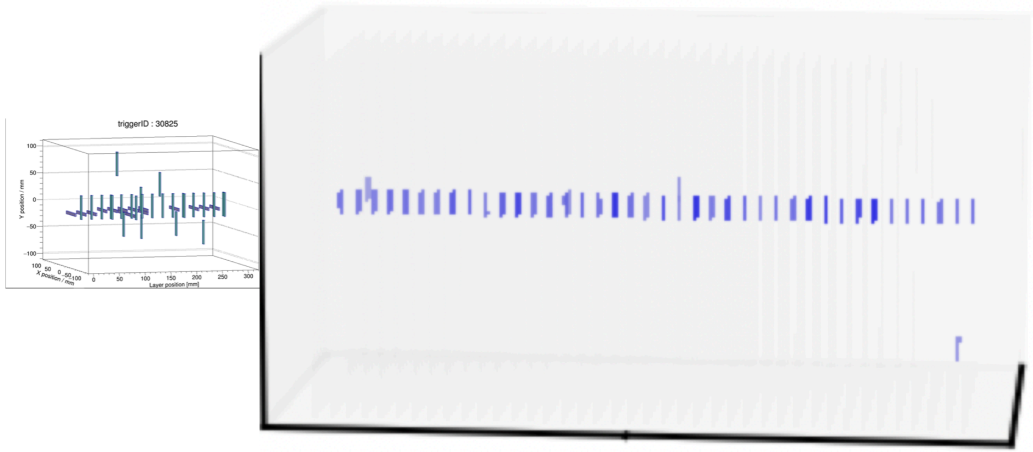




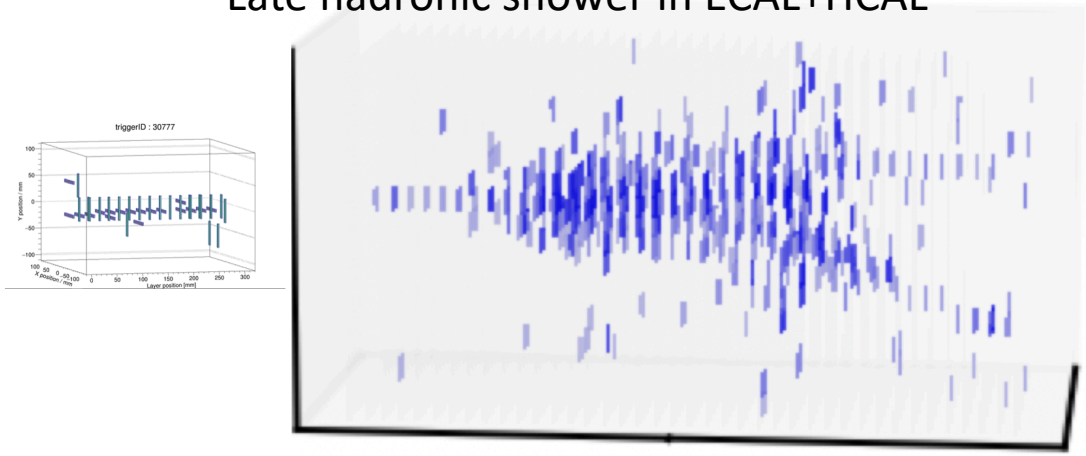
Beam test of combined ECAL+HCAL

- Obtained all data sets as planned for the combined ECAL+HCAL
  - 2nd main user week: Oct. 27 – Nov. 2
  - Muon beam: ~108 GeV
  - Positron beam: 10 – 120 GeV
  - Pion beam: 10 – 120 GeV
- Event-level synchronisation is the key: ongoing efforts

Muon track in ECAL+HCAL

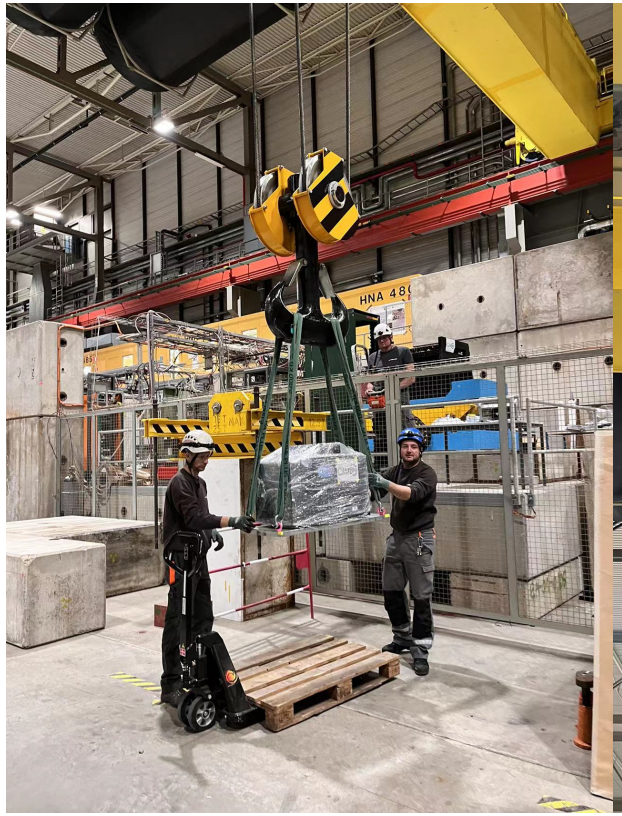
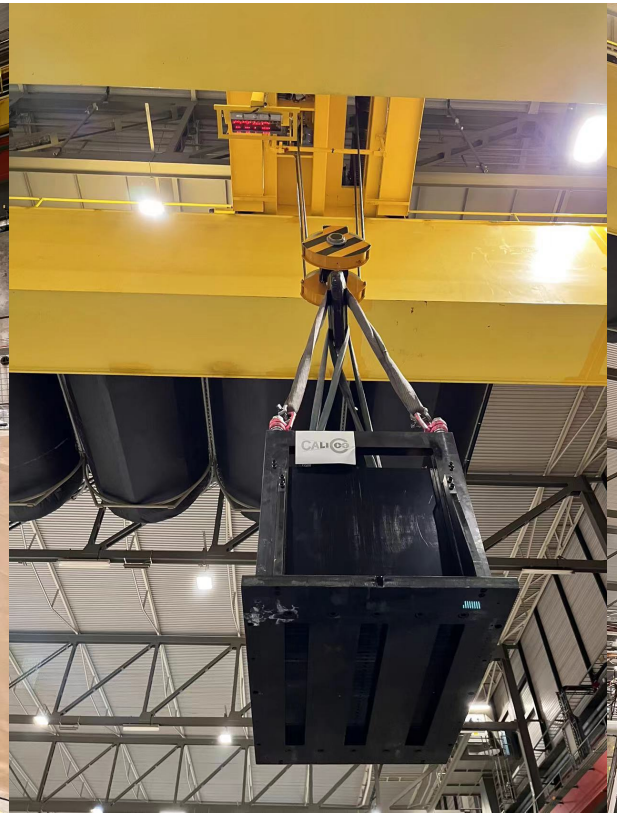
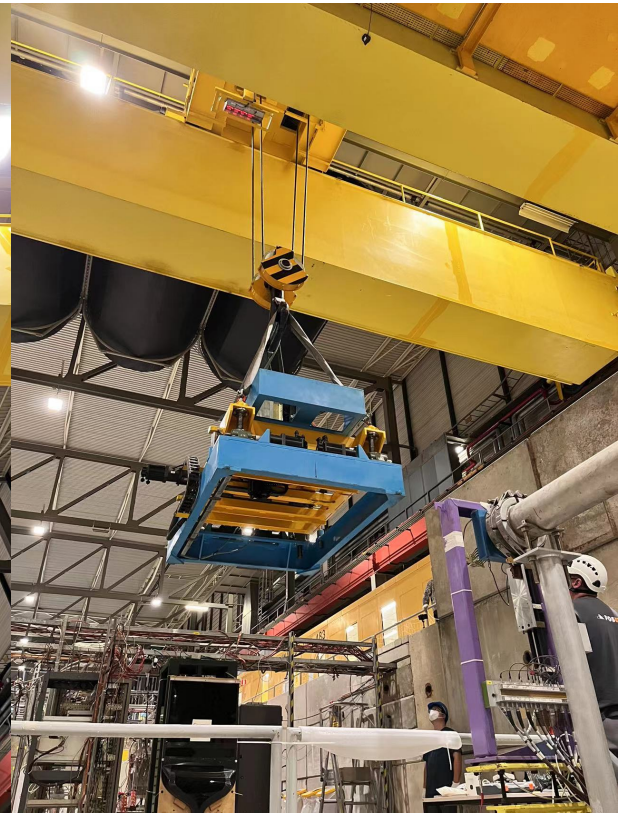


Late hadronic shower in ECAL+HCAL



Event display software under development for ECAL and HCAL

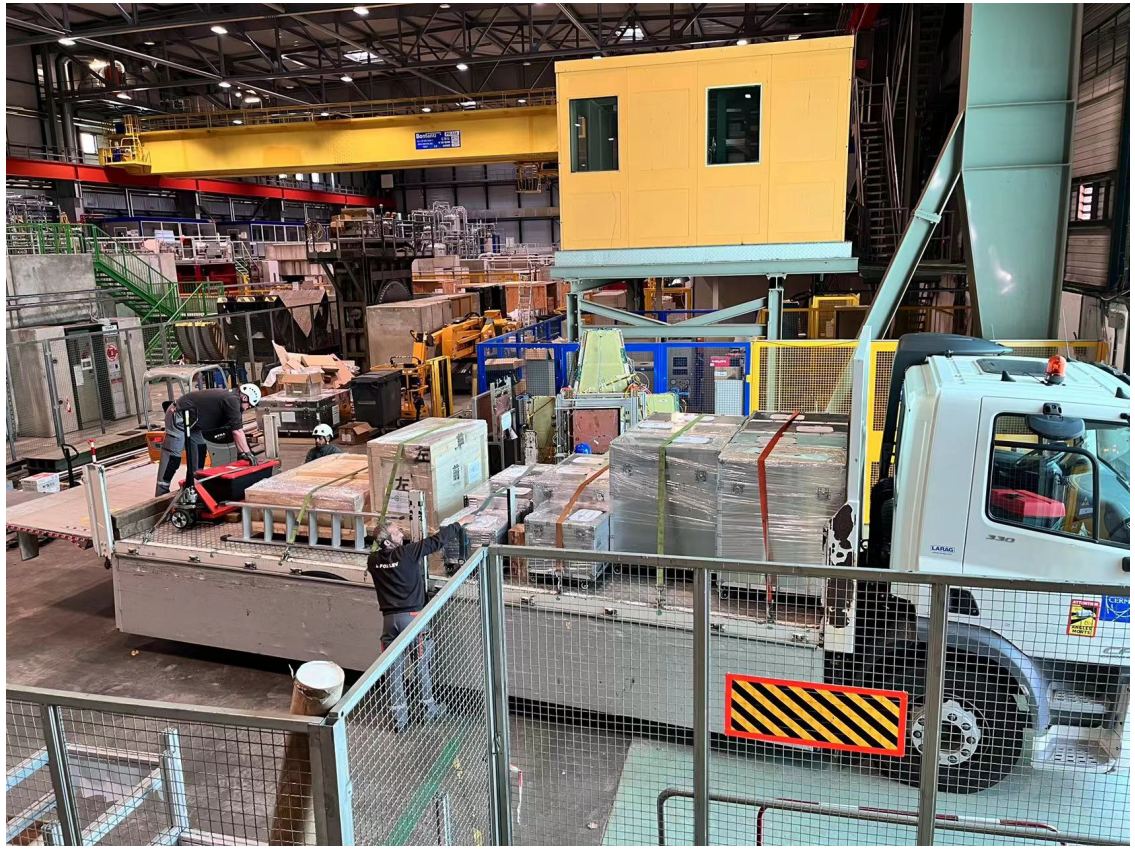
Decommissioning and transport


- Successfully moved out of the beam area (Nov. 2)
  - ECAL + HCAL prototypes, support table

Transport and storage at CERN

- Internal transportation and storage at Building 190: completed in Nov. 9
  - Thanks to the CERN EP support and coordinating efforts of CALICE management



Brief summary of CERN beam test

- First experiences with the complicated system of 2 PFA calorimeters
- Successfully completed all the plans, thanks to
  - Strong teamwork, robust detector system and stable SPS beam running
  - Great substantial support from CALICE and CERN
- Full data sets collected for
  - Highly granular calorimeter performance studies
  - Detailed shower studies in 3D space and time domain
  - Validation of Geant4 simulation
  - Particle-flow studies: e.g. ArborPFA

Acknowledgements

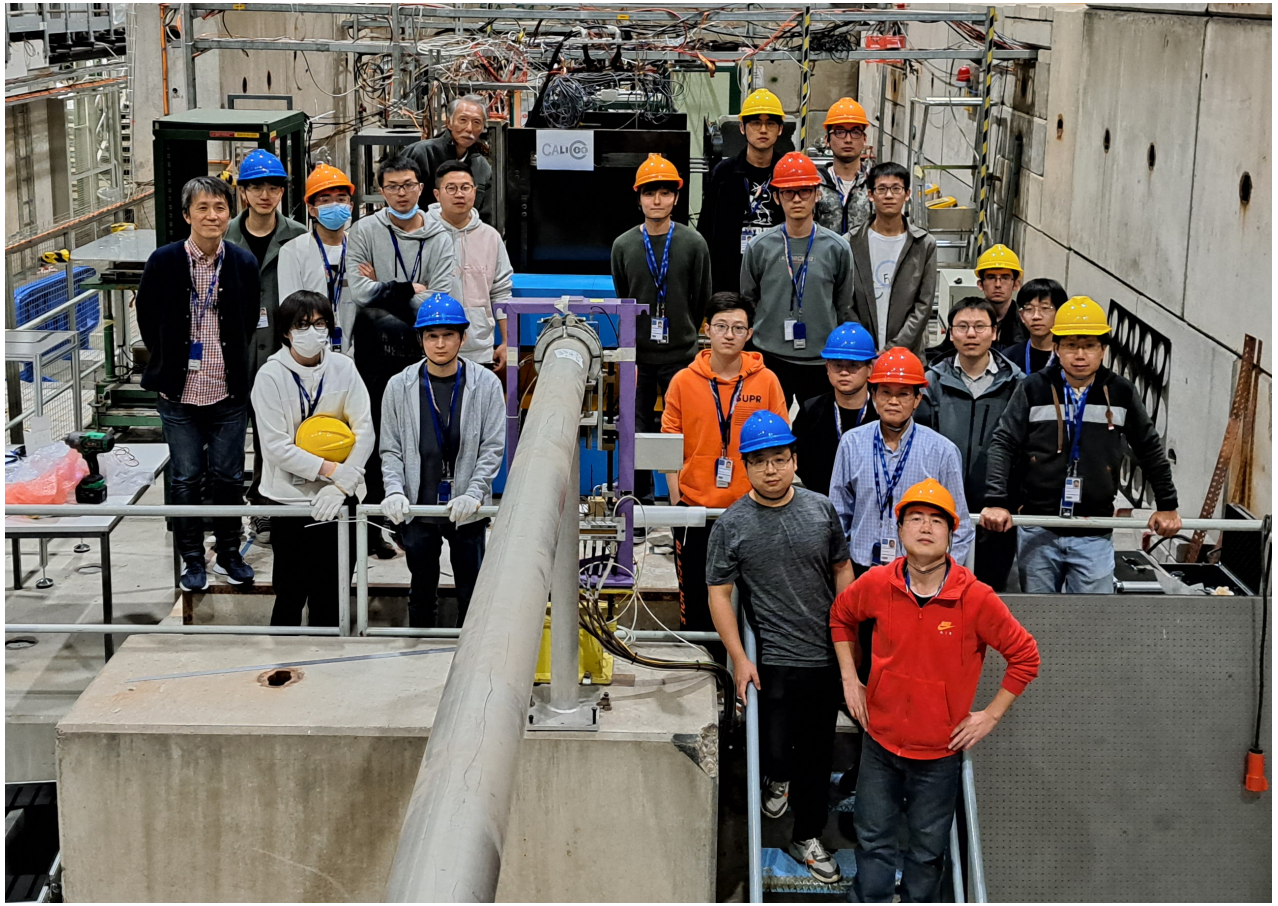
- CALICE and CEPC calorimeter teams: strong team work
  - IHEP, SJTU, USTC; U. Shinshu, U. Tokyo; Weizmann
  - With funding support from MOST, NSFC, CAS, etc.

- CALICE collaboration
  - Management (Roman and Lucia) : coordination with CERN EP for the storage
  - Colleagues at other beamlines for sharing experiences and information

- CERN
  - Experimental Areas group: transport, installation, beam tuning
  - HSE Unit: radiation protection support, safety training
  - PS/SPS coordinators: information exchange at weekly users meeting
  - EP department: coordination of platform certificate issue, prototype storage

Group photos

IHEP, SJTU, USTC; U. Shinshu, U. Tokyo



IHEP, SJTU, USTC; Weizmann; U. Shinshu, U. Tokyo

Thank you!

Lessons from this round of beam test

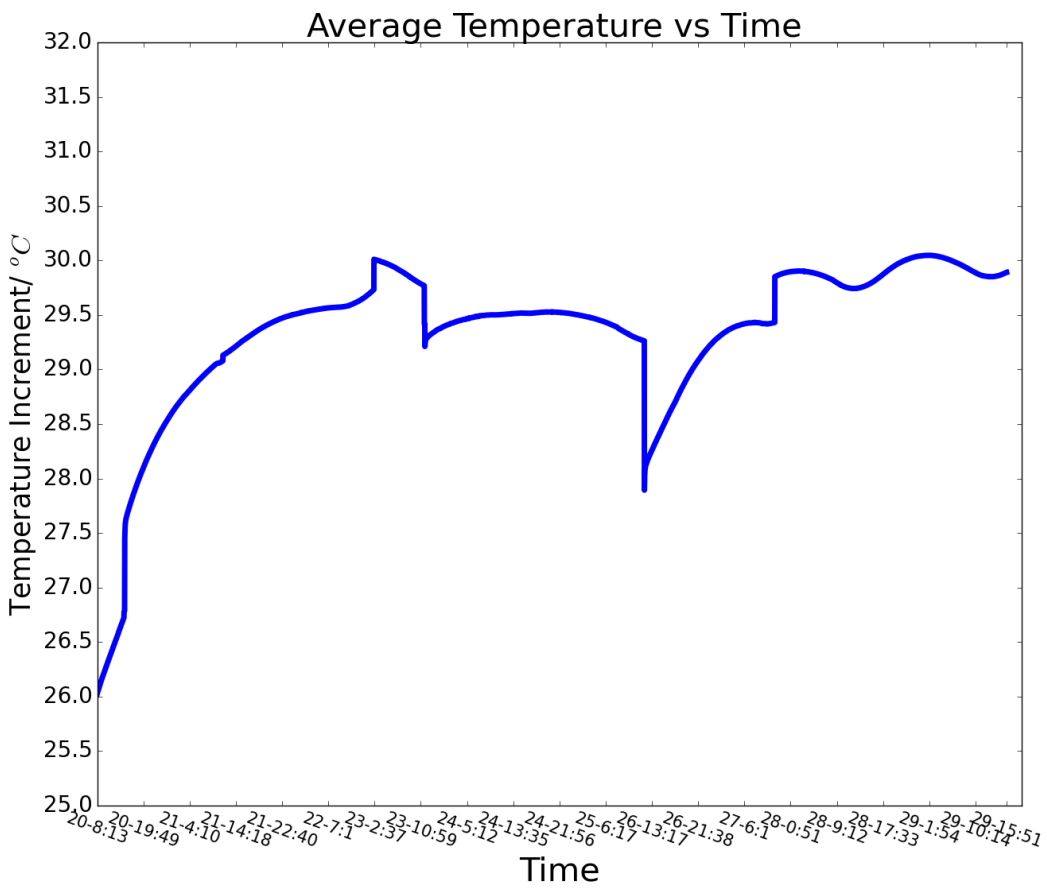
- About the SPS beamlines
  - (Based on discussions with the beam expert)
  - H8 provides abundant positive beam particles: mu+, e+, pi+ and p, but in mixture
    - Contaminations: hadrons in e+ beam, and protons in pi+ beam
    - H8 can provide negative beams, but the intensity is significantly lower
  - H2/H4 are better options with negative beams
    - Much better beam purity
    - More user-friendly beam instrumentation

Past experiences from CALICE:

- Almost all SPS beamtest campaigns happened at H2 or H4
- Only once at H8 in 2011: AHCAL prototype with tungsten absorber

Other information

- AHCAL temperature



- SPS: 3 spills per super cycle