Performance evaluation of LHCf-ATLAS ZDC joint measurement using proton beam

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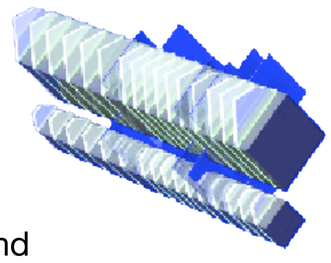
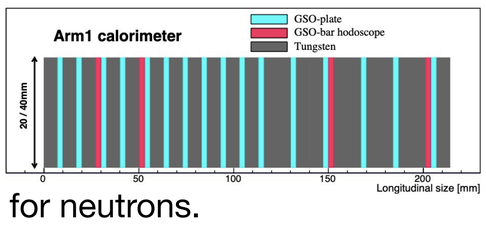
Introduction

The muon excess and model dependency of composition results in ultra-high energy cosmic-ray observations are due primarily to a poor understanding of high-energy hadronic interaction. To study the hadronic interaction and to contribute to improving the models, **LHC-forward (LHCf) experiment** [1] measures neutral particles emitted to the very forward region of pp collision at the Large Hadron Collider (LHC).
The LHCf experiment is expected to make a larger contribution to model improvement due to the improved energy resolution of neutrons. Energy resolution for neutron events will be improved by summing deposited energies of LHCf and ZDC, which is located behind the LHCf detector

LHCf experiment and Arm1 detector

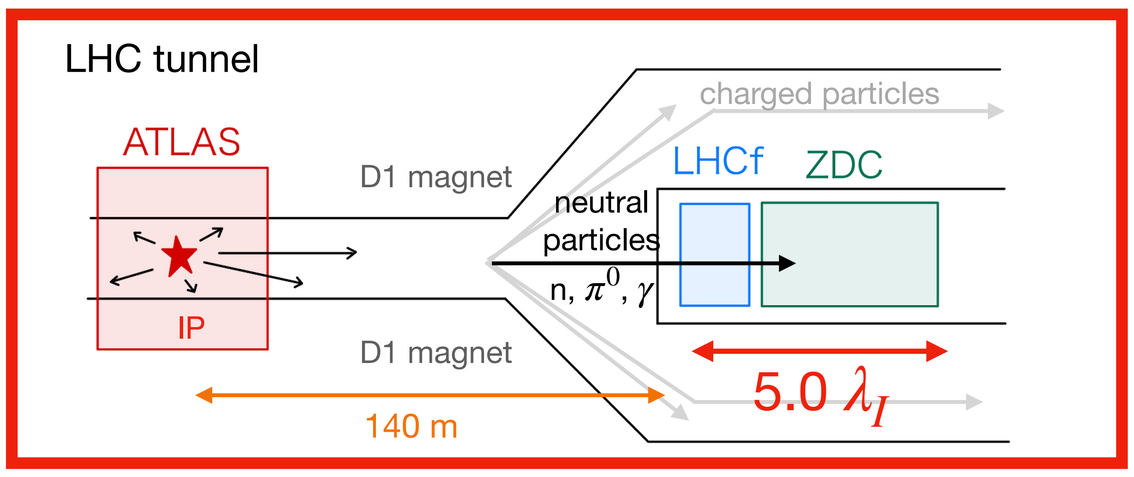
- LHCf detectors are located 140 m apart on either side of the ATLAS Interaction point (IP1). One is called Arm1 and the other Arm2. We measure photons, π^0, and neutrons.
- Arm1 detector consists of two sampling towers, the Large Tower (TL) and the Small Tower (TS).
- Each tower has a sandwich structure of 16 layers of GSO plates, 4 layers of GSO-bar XY hodoscopes, and 16 layers of Tungsten.
- The total length is 44 X_0 and **1.6**λ_I.
- The energy resolution is **~ 40%** for neutrons.
- The position resolution is better than 1 mm for neutrons.





Strategy of the operation in 2022

- To improve the energy resolution for neutrons, we perform a joint operation with ATLAS-Zero Degree Calorimeter (ZDC) detector.
- The hadronic sector of the ZDC detector consists of 3 modules, Tungsten + quart fibers. The total interaction length is 3.4. [2]
- **By placing the ZDC detector behind the LHCf detector, the total length of LHCf and ZDC is 5.0 λ_I.** So, most of the entire hadron shower can be covered and the energy resolution is expected to be improved.

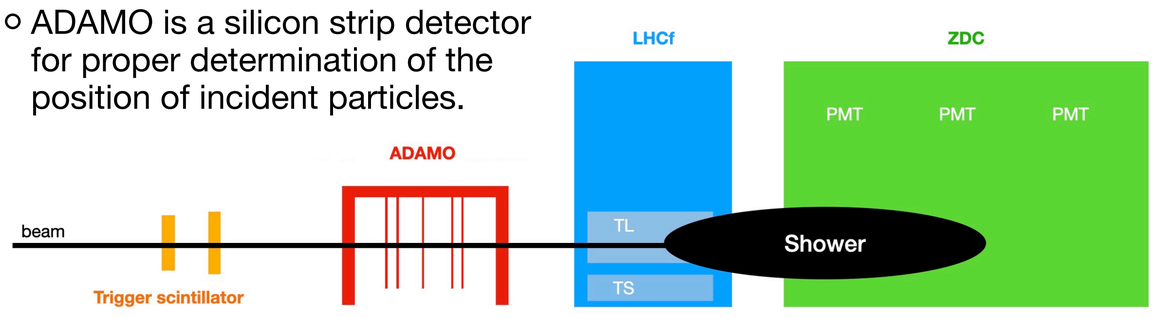


Beam test at SPS in 2021

- We conducted a beam test at the H4 beam line of SPS to verify the performance of the joint measurement and to calibrate the energy.
- The setup is like below. The beam is coming from the left side. Trigger scintillator, ADAMO (silicon tracker), LHCf detector, and ZDC detector were arranged in this order.
- Beam and statistics

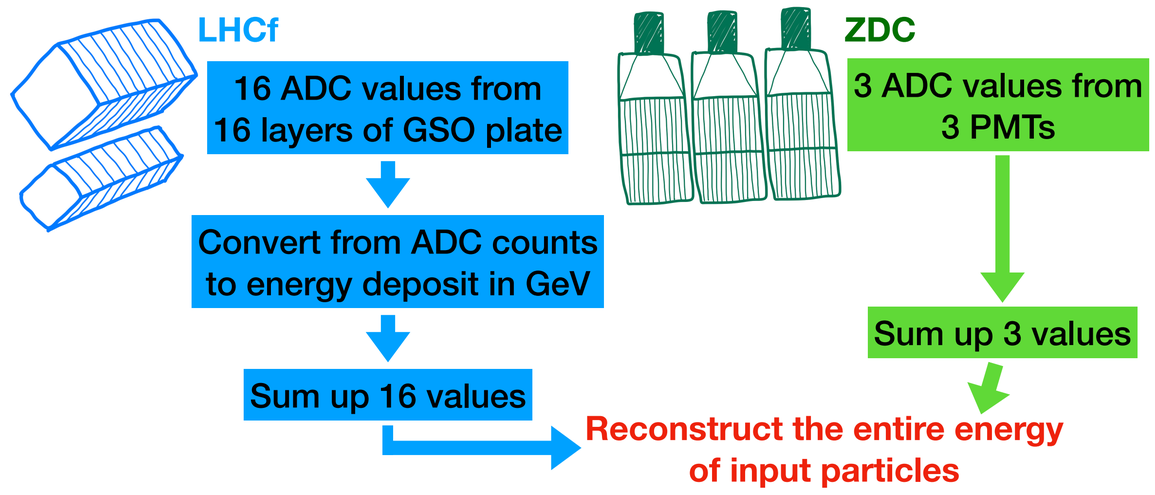
beam	energy	statistics
proton	350 GeV	860,000 events
electron	100 GeV	400,000 events
	200 GeV	820,000 events

- ADAMO is a silicon strip detector for proper determination of the position of incident particles.



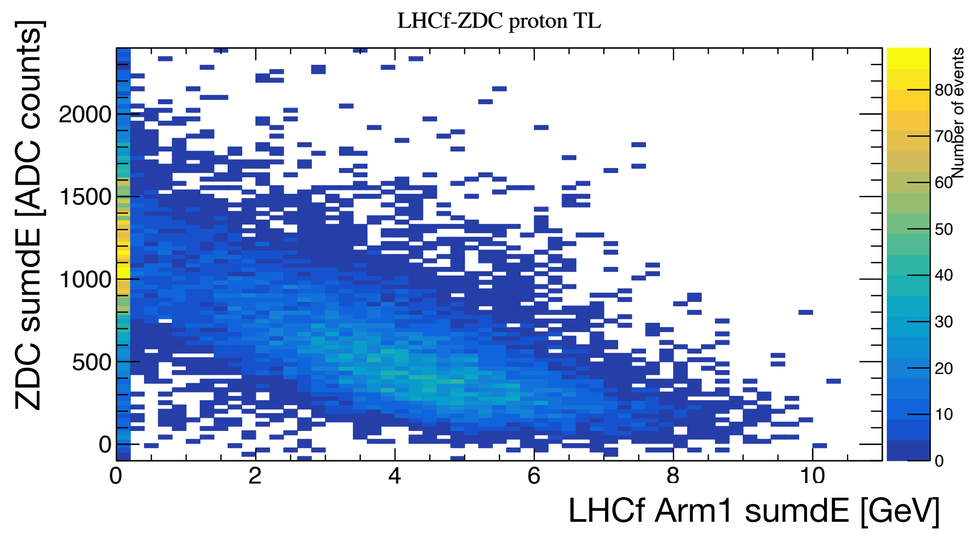
Event quality cut, precise positioning, and calibration

- Event quality cut and precise positioning
  - Select the event in which only one track is observed in ADAMO, a silicon tracker to remove the events with multiple incidents and with showering in materials of the beam line.
  - By projecting the track at ADAMO, determine the position of particles incident on the detector.
  - Select the events with incident positions in 8mm square centered on the center of the TL.
- Energy Reconstruction
  - The ADC value is converted to an energy deposit in GeV and multiplied by correction factors to calibrate the measured energy.
  - Correction factors were revised to account for aging deterioration.
  - Estimate the particle energies from the energy deposit summation measured in the LHCf and ZDC detectors.

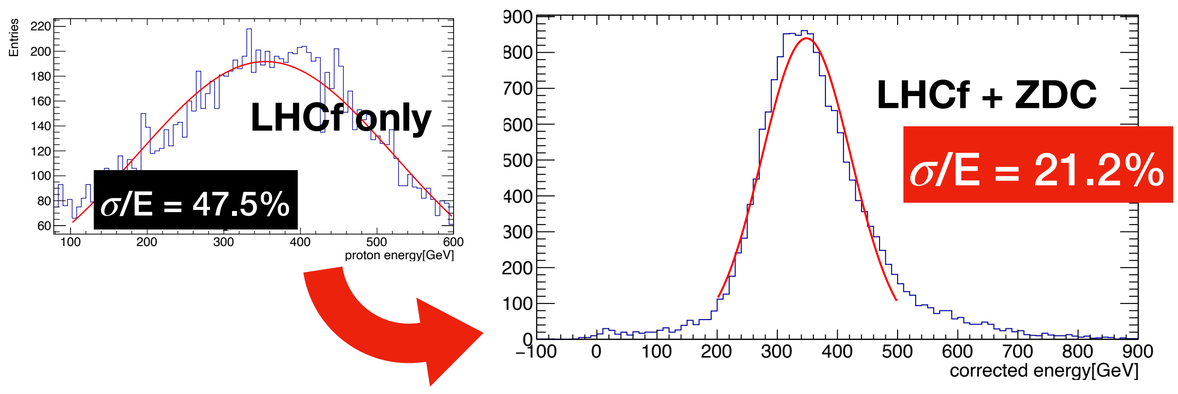


Result

- Data for 350 GeV protons injected at the TL center were used in the following analysis.
- Leaked shower particles from the LHCf detector were measured in the ZDC detector. So, we expect a linear correlation between LHCf and ZDC energy.
- Correlation plot
  - Horizontal axis: sum of LHCf energy deposit, dE [GeV]
  - Vertical axis: sum of three ZDC module's ADC count
  - As expected, we confirmed the energy deposit's anti-correlation between LHCf and ZDC.
  - An energy scale factor between the two detectors was obtained by fitting it with a linear function.



- Energy resolution
  - The energy resolution was measured from the energy distribution obtained from the LHCf + ZDC data.
  - The resolution of LHCf+ZDC was **21%**, which is much better than the LHCf standalone result of 47%.



Summary

- the improvement of energy resolution for hadronic showers from 47% (LHCf alone) to 21% by a joint operation of LHCf and ATLAS ZDC with proton beams at SPS.
- We took data at LHC in September 2022 (Plans as of early September). The combined method will be applied to the obtained data for neutron analyses.

References

[1] O. Adriani et al., JINST 3 (2008) S08006
[2] S. White, Nucl.Instrum.Meth.A 617 (2010) 126-128