ポスター番号 : P-003

CALETによる陽子，ヘリウムの エネルギースペクトルの観測の最新結果

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早大理工総研, 東大宇宙線研[A], Siena Univ./INFN Pisa[B]

小林兼好, 鳥居祥二, 浅岡陽一[A], 赤池陽水, Pier S. Marrocchesi[B], Paolo Brogi[B], 他CALETチーム

第２３回宇宙科学シンポジウム

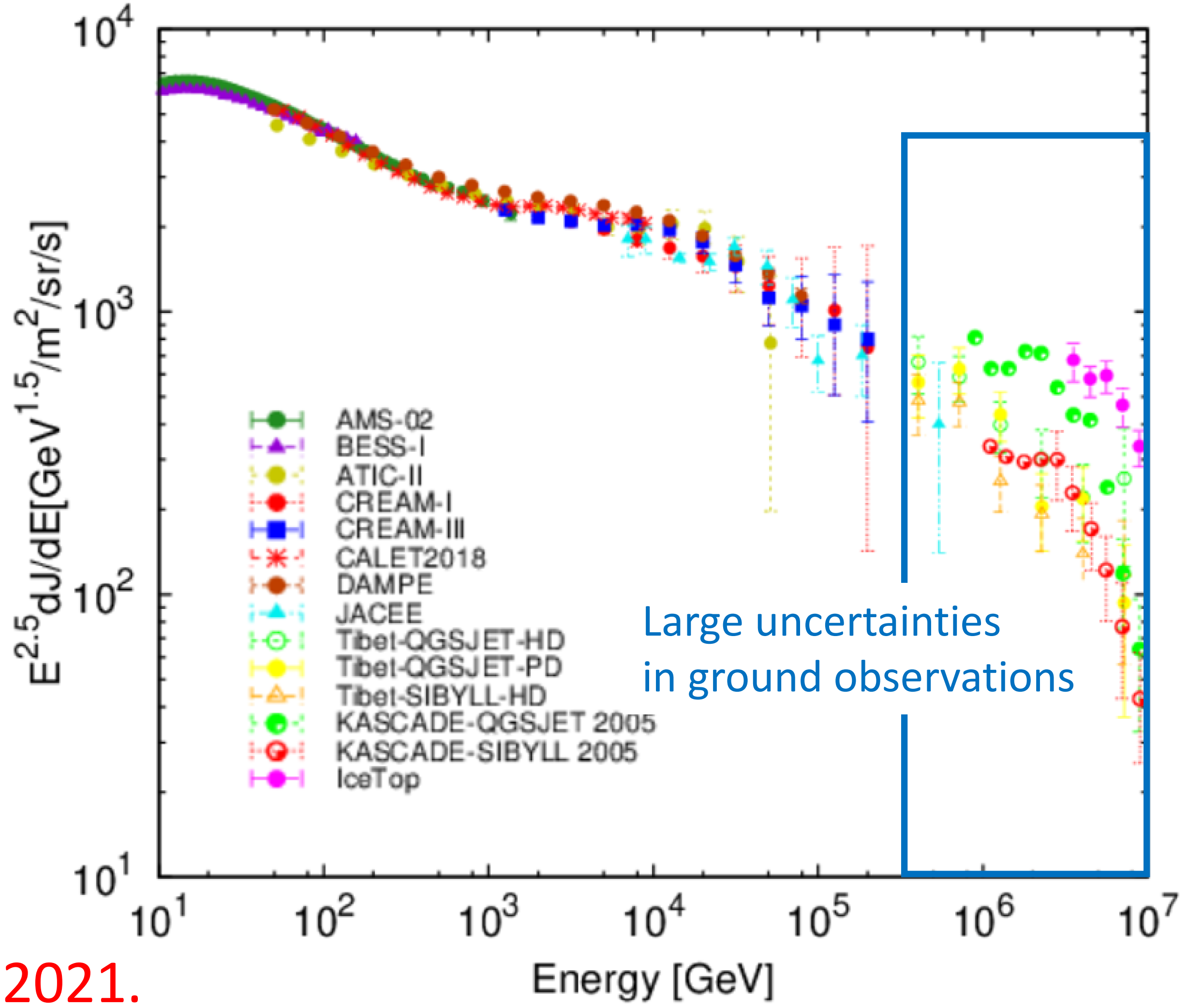
Motivation

- Proton flux hardening has been observed around a few 100GeV region. Also softening was observed by CALET, DAMPE and Balloon Experiments around 10TeV. It is important to determine spectrum hardening and softening parameters in order to understand cosmic ray source, acceleration mechanism, and propagation effects.
- It is also important to determine the flux up to hundreds of TeV by the direct measurements. That would also give a normalization of flux, for ground observations, and help an understanding of the origin of the KNEE in all-particle energy spectrum

-> Compare to the PRL2019, we expanded the energy region up to 60TeV (from 10TeV) and increased statistics by ~2.2 using data until Dec. 2021.

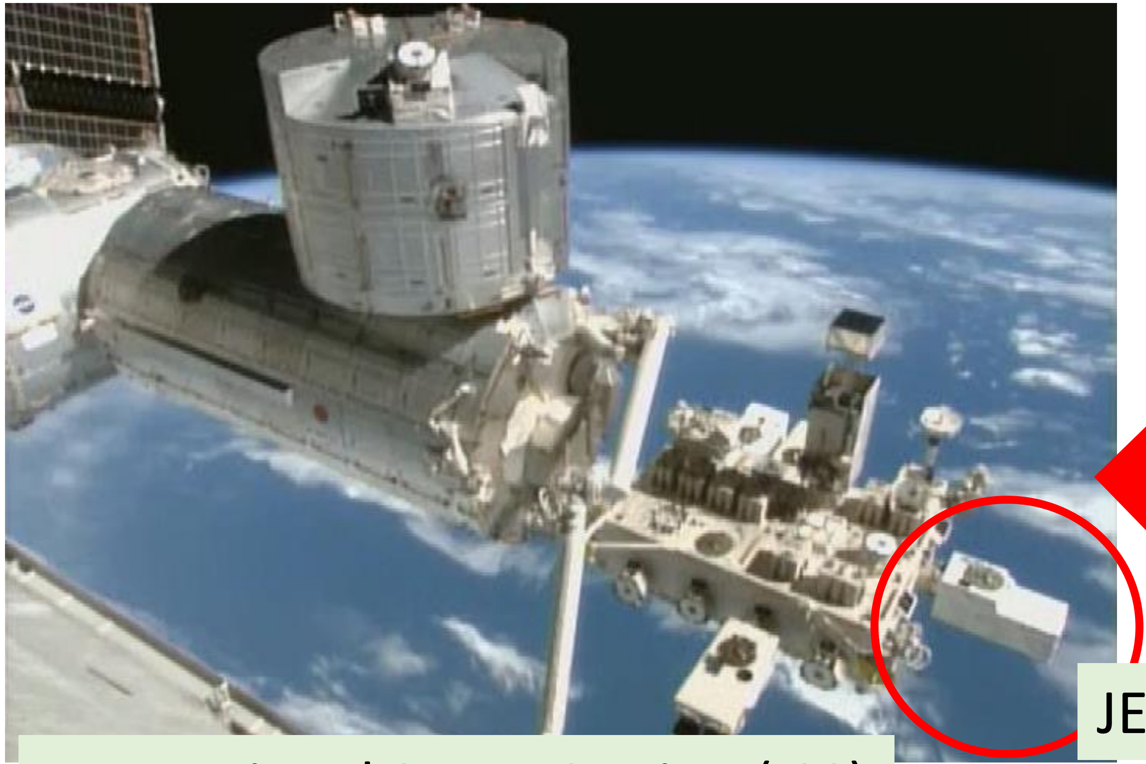
published at PRL 129, 101102 (2022)

Proton flux in PRL2019 compared to other direct and ground measurements

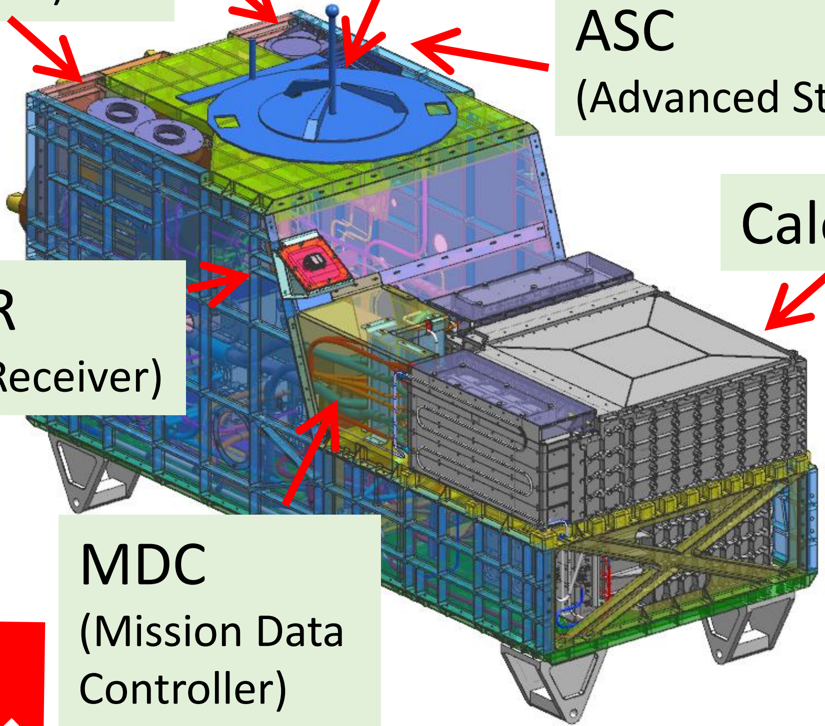


CALET project

Aug. 2015: launched and emplaced on the ISS
Oct. 2015: start data taking
Data taking is stably running up to now.
We plan to take data until 2024 (at least).

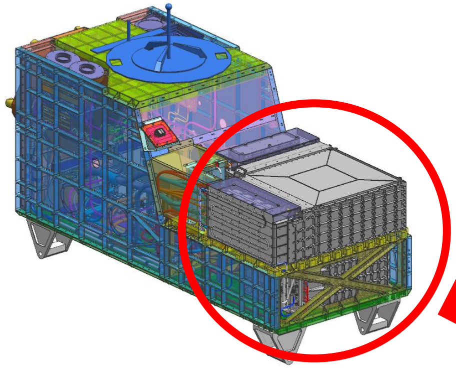


International Space Station (ISS)

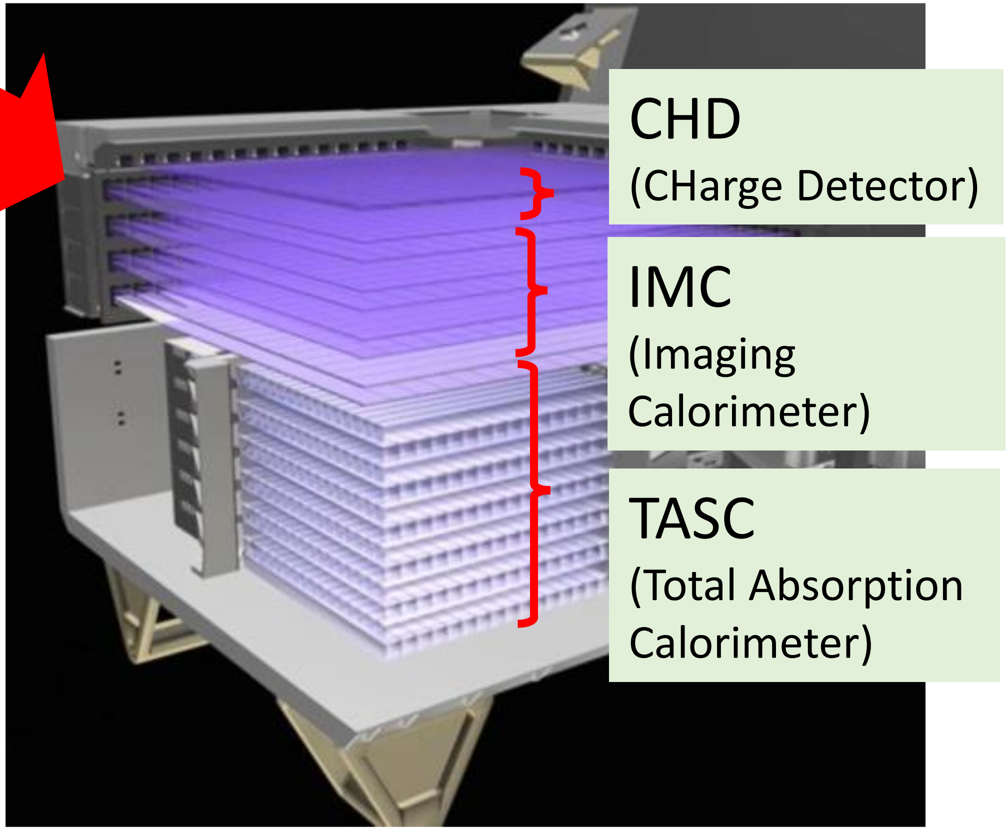


mass	612.8kg
power	507W (max)
telemetry	600kbps (6.5GB/day)

CALET detector

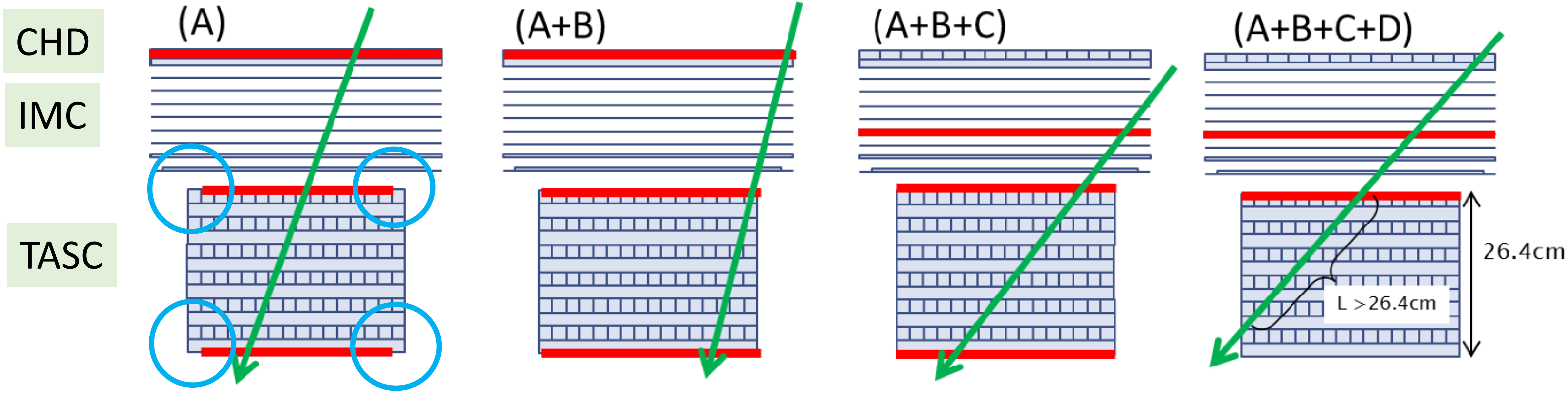


	Material/sensor	Purpose
CHD	Plastic scintillator + PMT 28 paddles (=14x2layers(x,y)) (paddle size: 32x10x450mm)	Charge ID
IMC	Scifi./W + MAPMT (64anode) 7168 Scifi. (=448x16layers(x,y)) +7 W layers (Scifi. size: 1x1x448mm)	Tracking, charge ID
TASC	PWO scintillator + APD/PD or PMT 192 logs (=16x12layers(x,y)) (Log size: 19x20x326mm)	Energy



In total $30X_0$ thickness
(=1.2λ, $27X_0$ in TASC + $3X_0$ in IMC)

Geometrical acceptance



2cm margin in TASC is taken.

- In this proton analysis, we use the events with acceptance A: The reconstructed track is required to cross the CHD and TASC from top to bottom.
- Geometrical factor for acceptance A is ~0.1m^{2}sr.

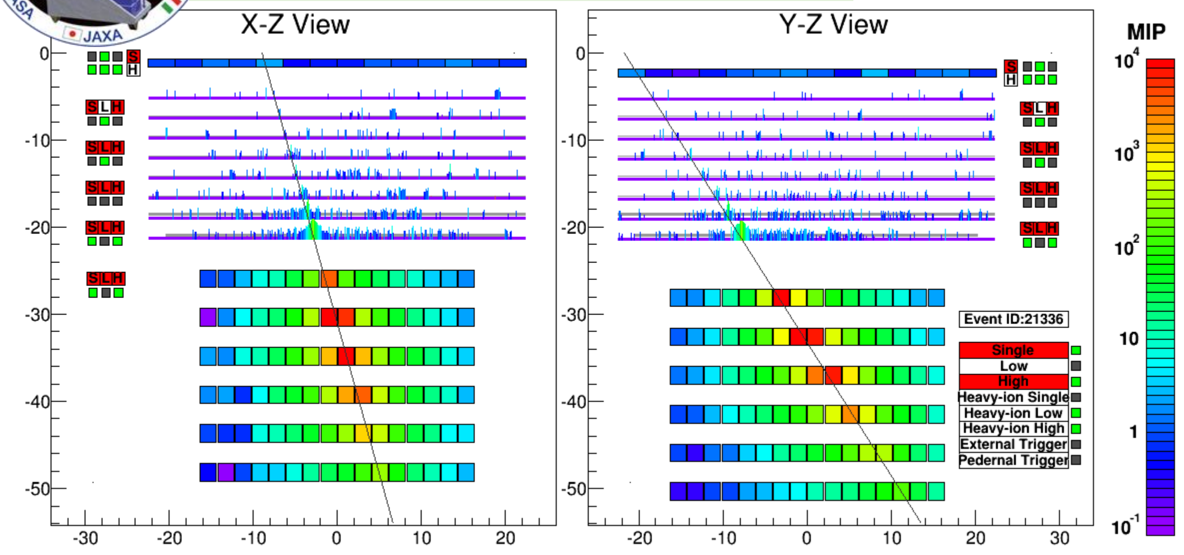
proton

Proton event selection

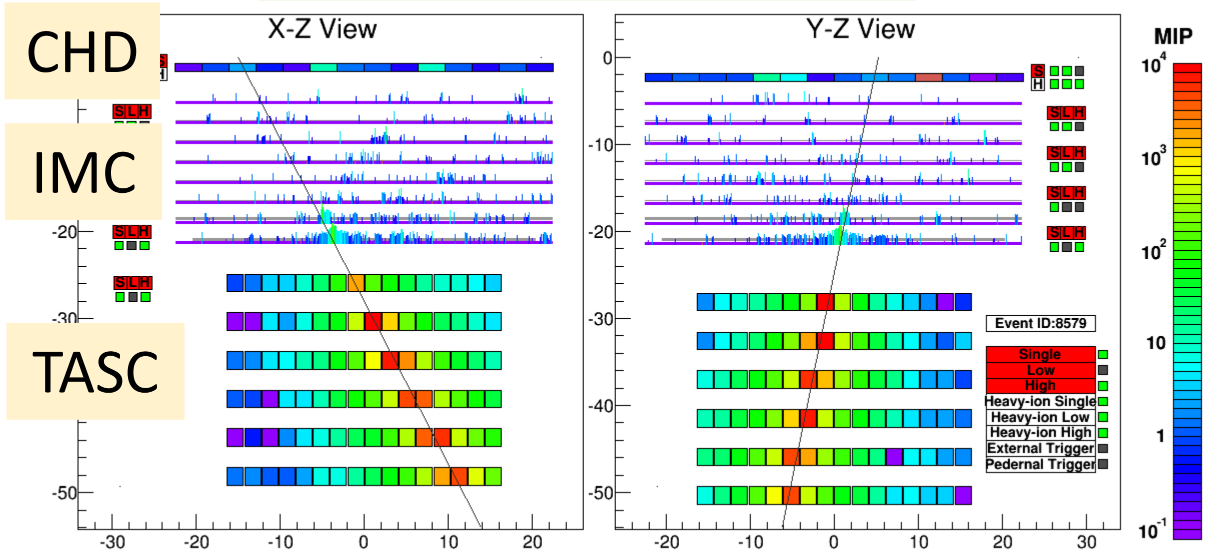
selection	Brief description
1. Event trigger	HE trigger in E>300GeV and LE trigger in E<300GeV.
2. Geometrical acceptance	Track going through the detector from the top to the bottom is selected.
3. Track quality cut	Reliability of Kalman Filter fitting in IMC is checked.
4. Electron rejection	Electron events are rejected using the energy deposit within one Moliere radius along the track.
5. Off-acceptance cut	Residual events crossing the detector from the sides are rejected.
6. TASC hit consistency	In order to reject the events with mis-reconstructed track, we reject the events which doesn’t have consistent energy deposit at the top X/Y layer of TASC where the track is expected to go through from the track reconstruction in IMC.
7. Shower start in IMC	Shower development starting in IMC is required.
8. Charge identification in CHD and IMC	Charge identification using the energy deposit in CHD and IMC (before shower development starts) is performed to reject helium events, mainly.

Event examples

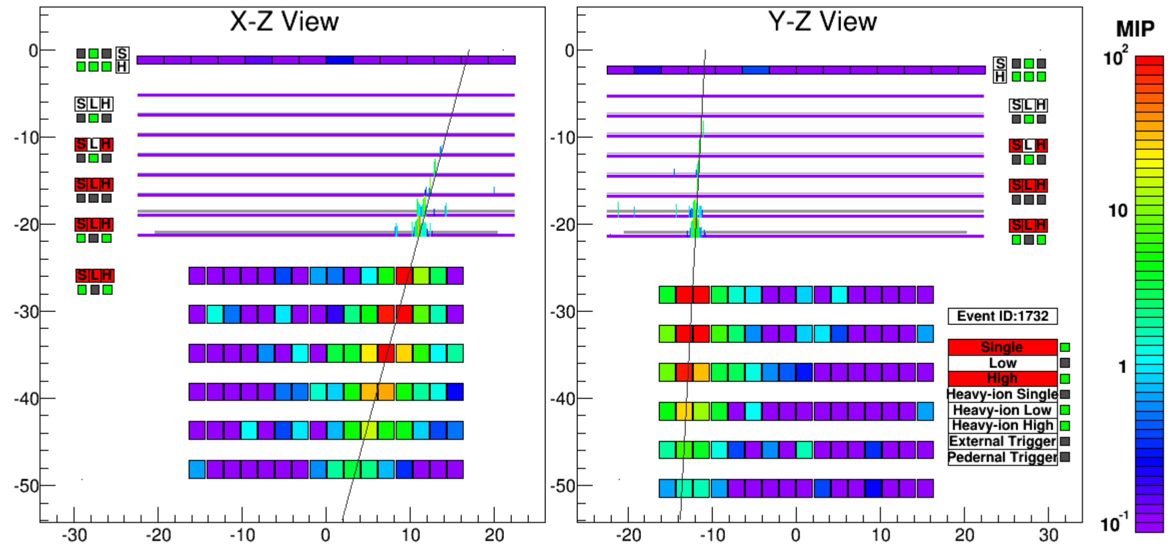
Electron, E=3.05 TeV



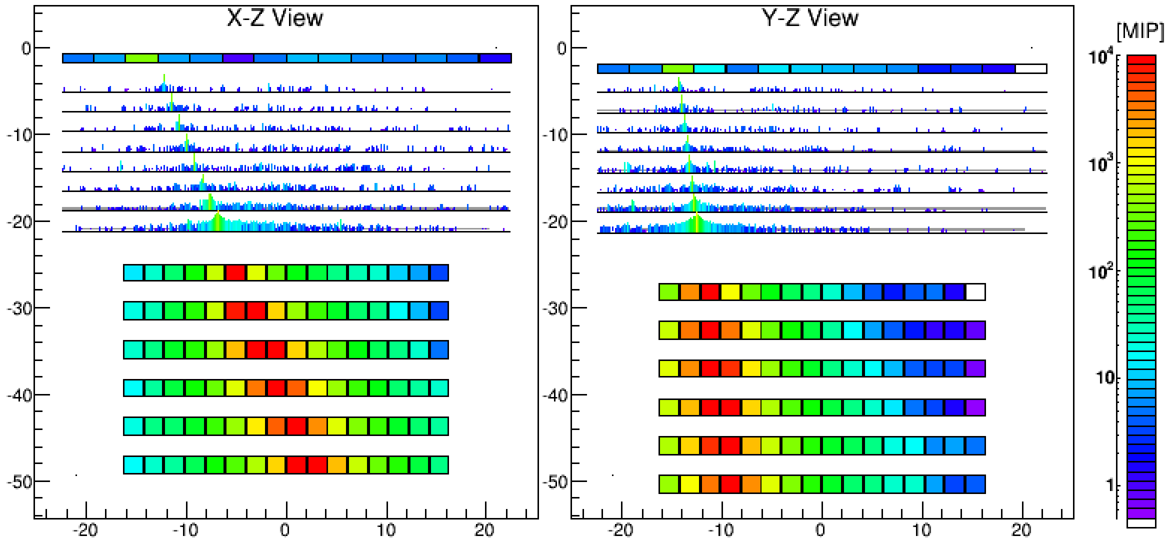
Proton, ΔE=2.89 TeV



Gamma-ray, E=44.3 GeV



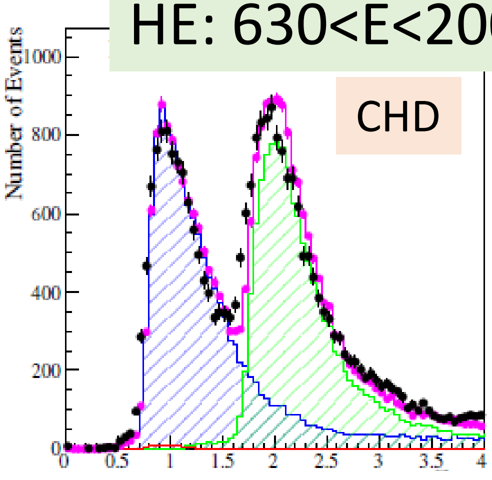
Fe, ΔE=9.3 TeV

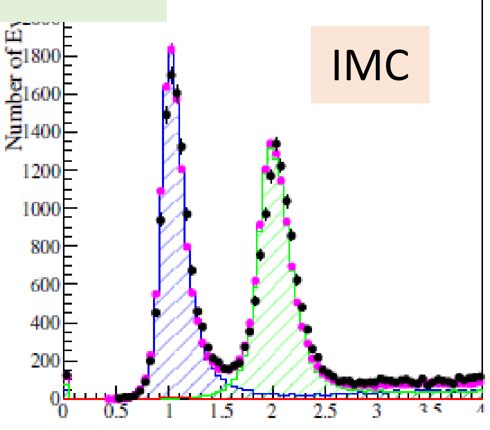


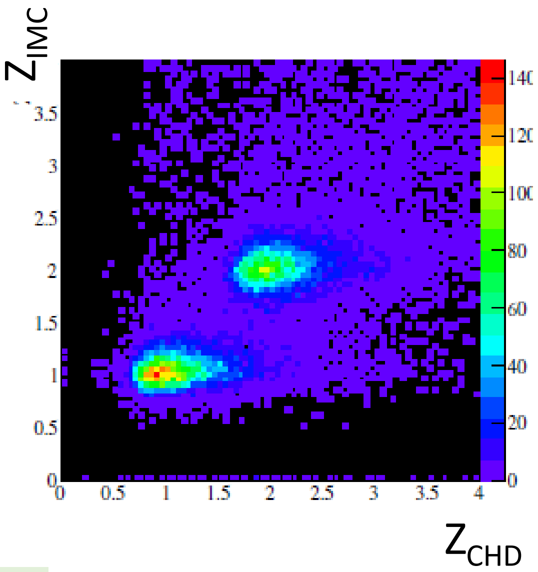
proton

Charge identification (proton) in CHD and IMC

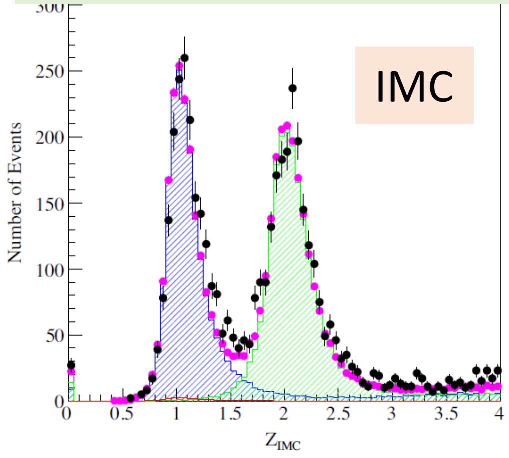
HE: 630<E<2000GeV



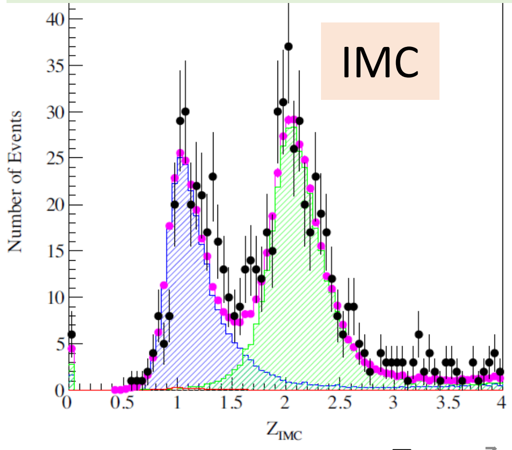




HE: 2<E<6.3TeV



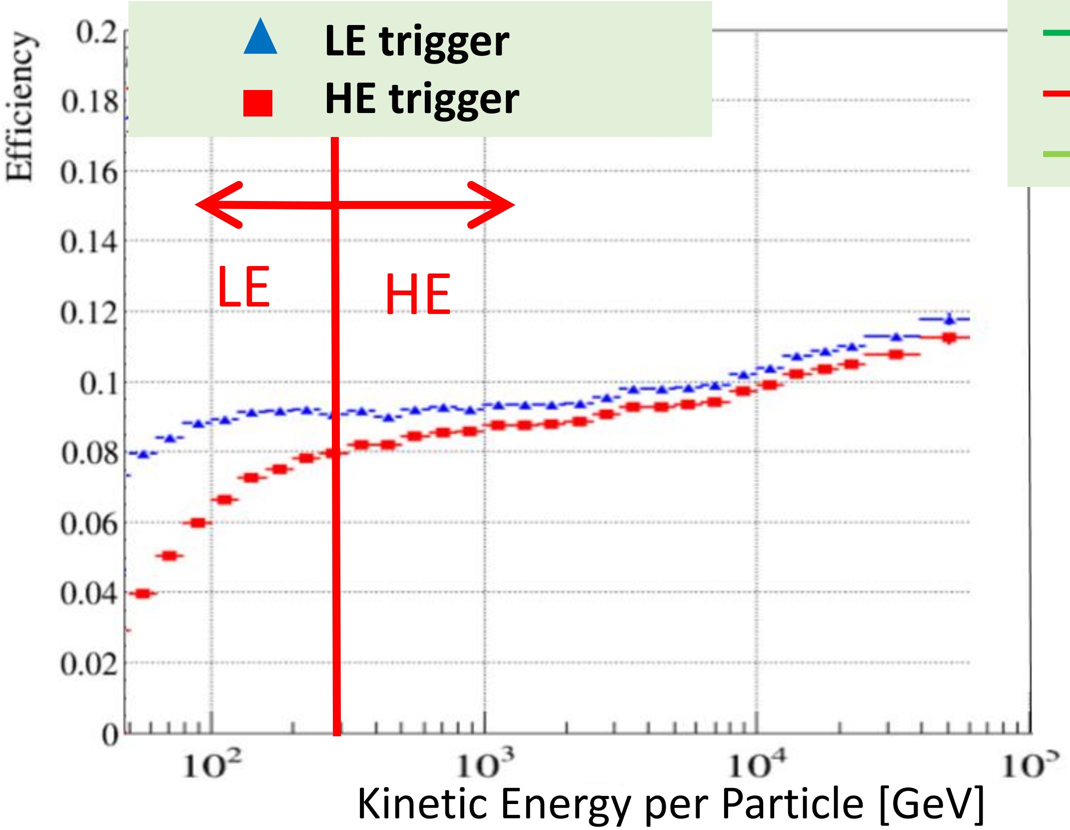
HE: 6.3<E<20TeV

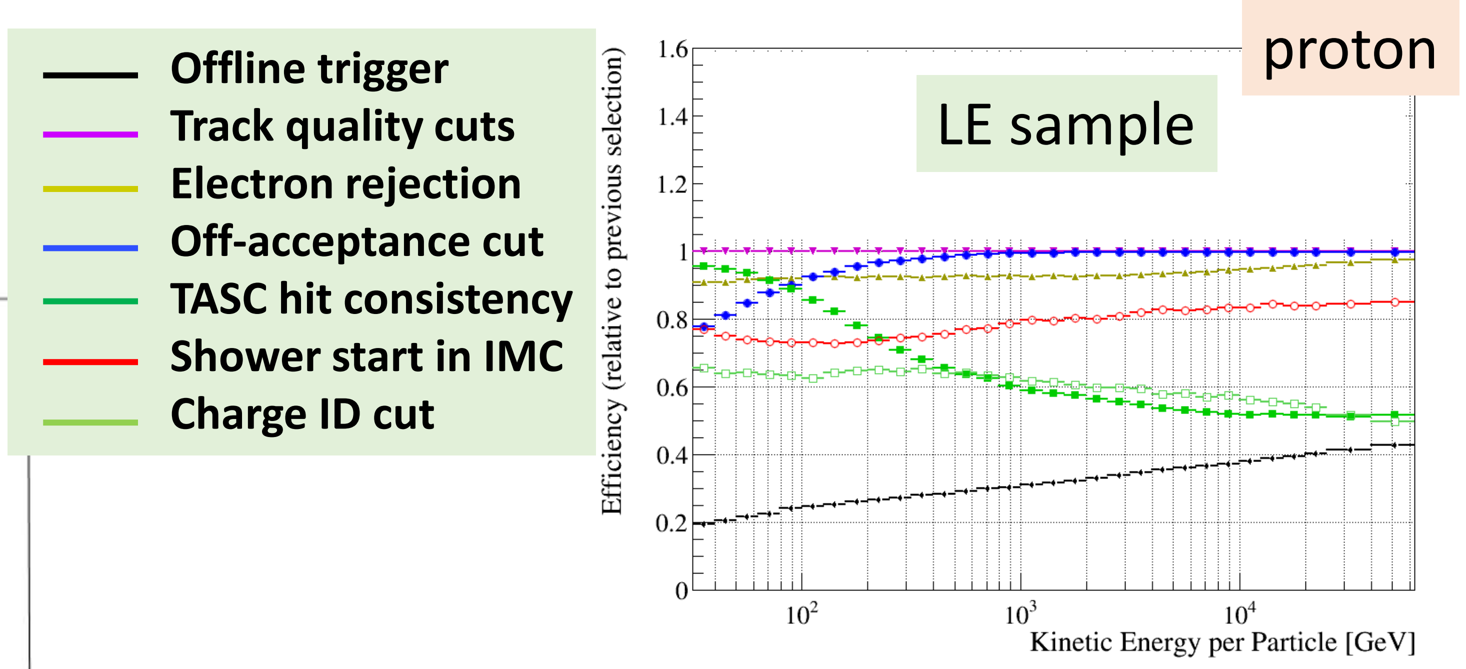


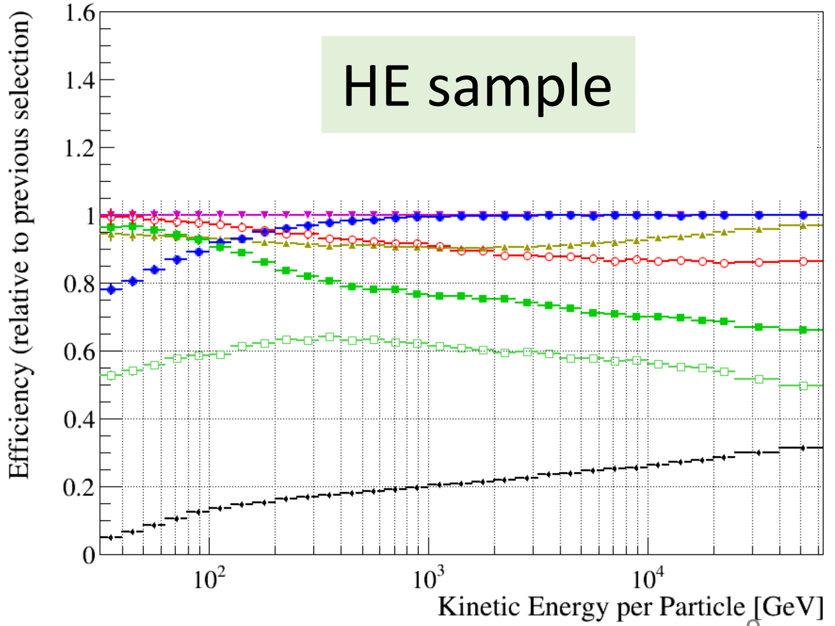
- Data
- MC all (EPICS)
- MC proton (EPICS)
- MC He (EPICS)
- MC electron (EPICS)

- Using the two charge identification parameters (Z_{CHD} and Z_{IMC}), proton and helium can be clearly separated.
- Total background contaminations are less than 13% in HE sample (630<E<2000GeV), respectively.
- Although charge identification using CHD doesn't work in higher energy region, identification using IMC works and p/He are clearly separated

Detection efficiency (proton)





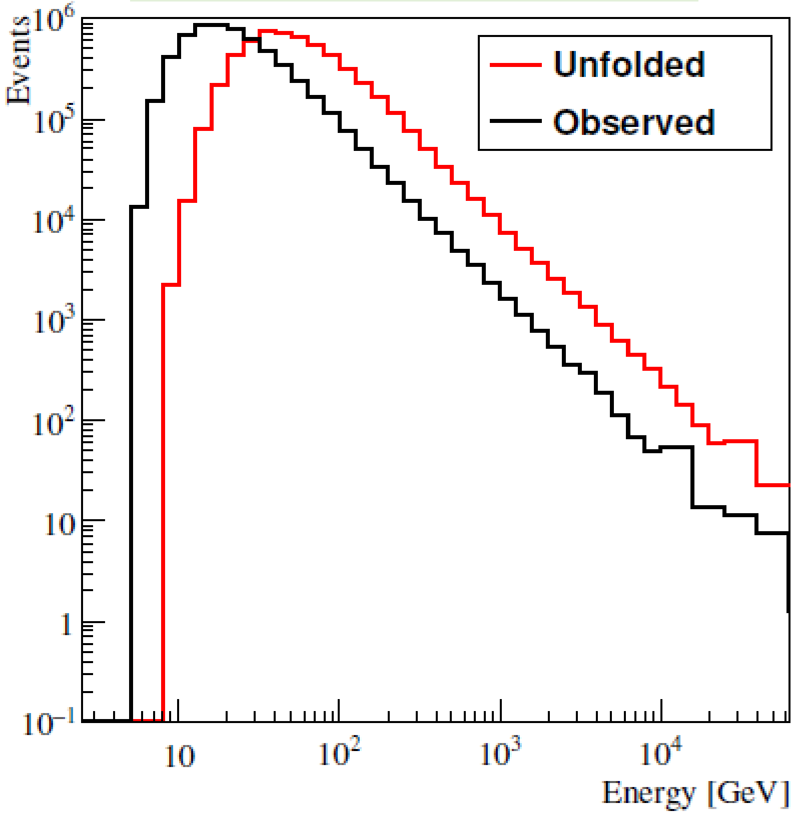


- In E>300GeV (E<300GeV), HE trigger (LE) is used. LE is used due to the high efficiency.
- Detection efficiency is 8-12% in 50GeV<E<60TeV.

proton

Energy unfolding

Observed/Unfolded energy spectrum

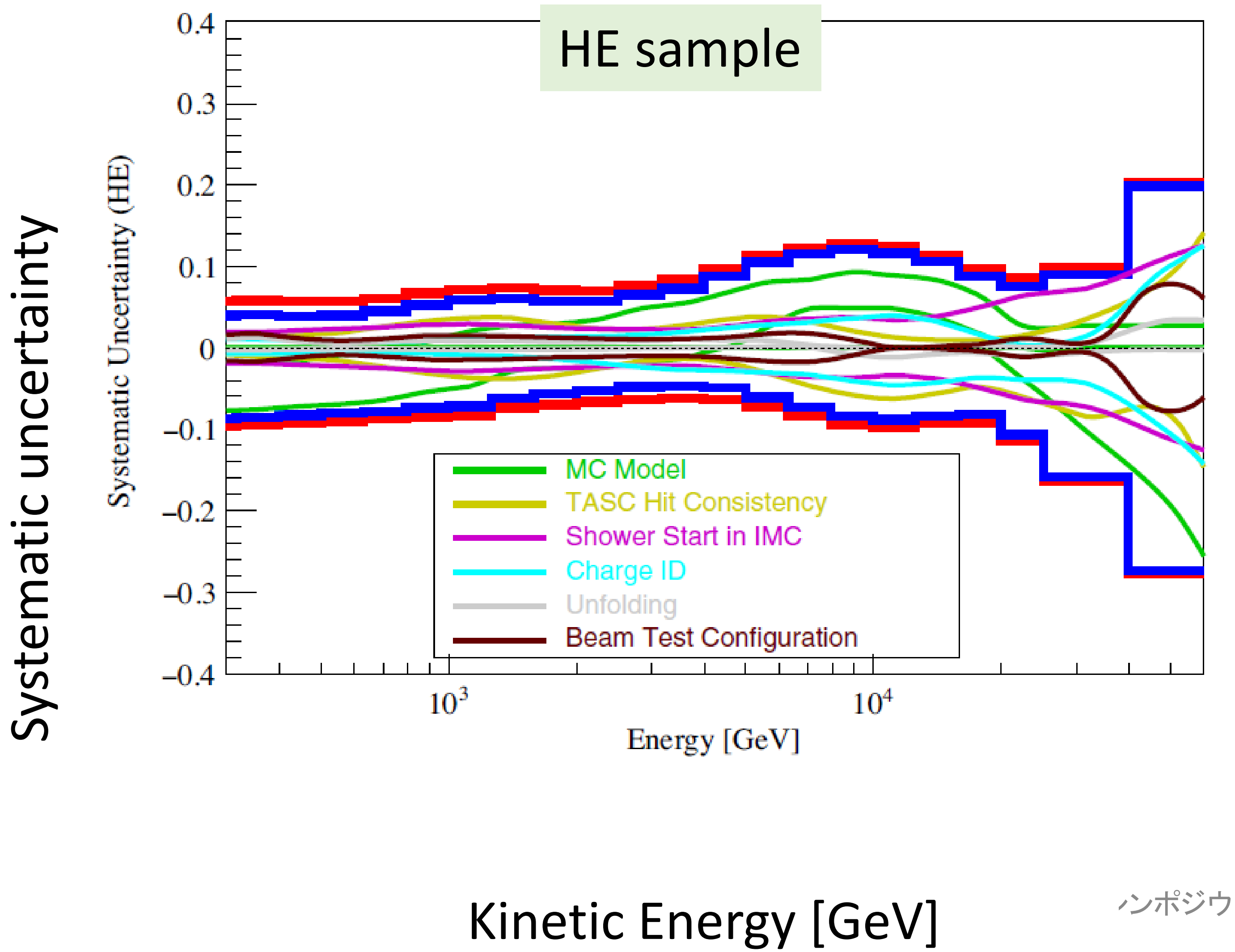


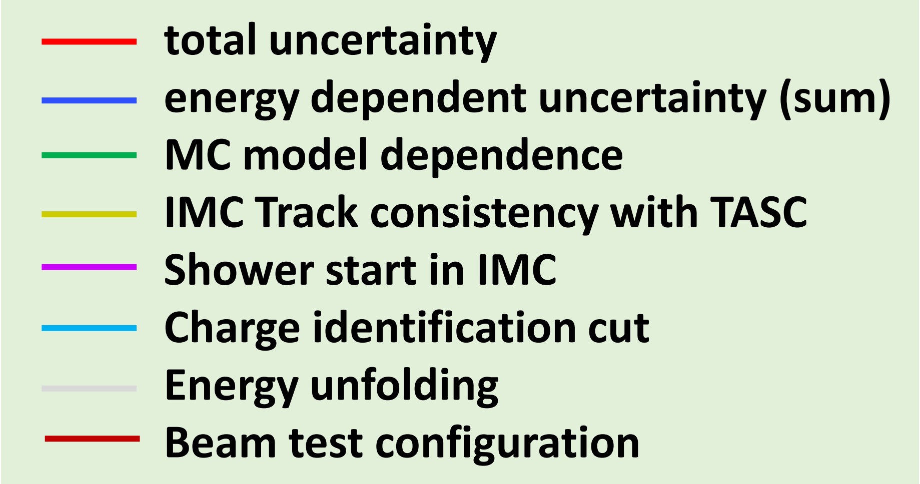
The energy resolution of proton is 30-40%. Therefore, we apply Bayes unfolding to reconstruct energy.

1. We build response matrix between true and observed energy spectrum using MC simulation.
2. We apply unfolding (RooUnfold) iteratively based on Bayes theorem with helium and electron background evaluation.

Systematic uncertainty (proton)

proton





- Systematic uncertainty in E<20TeV is less than 10%.
- The uncertainty in E>20TeV comes from the MC model dependence and charge identification, mainly.

Proton spectrum (50GeV<E<60TeV)

proton

$$\Phi(E) = \frac{N(E)}{S\Omega T \Delta E \varepsilon(E)}$$

$\Phi(E)$: proton flux
$N(E)$: number of events in ΔE bin (after background subtraction)
$S\Omega$: geometrical acceptance ($510 cm^2 sr$)
T: livetime
ΔE: energy bin width
$\varepsilon(E)$: detection efficiency

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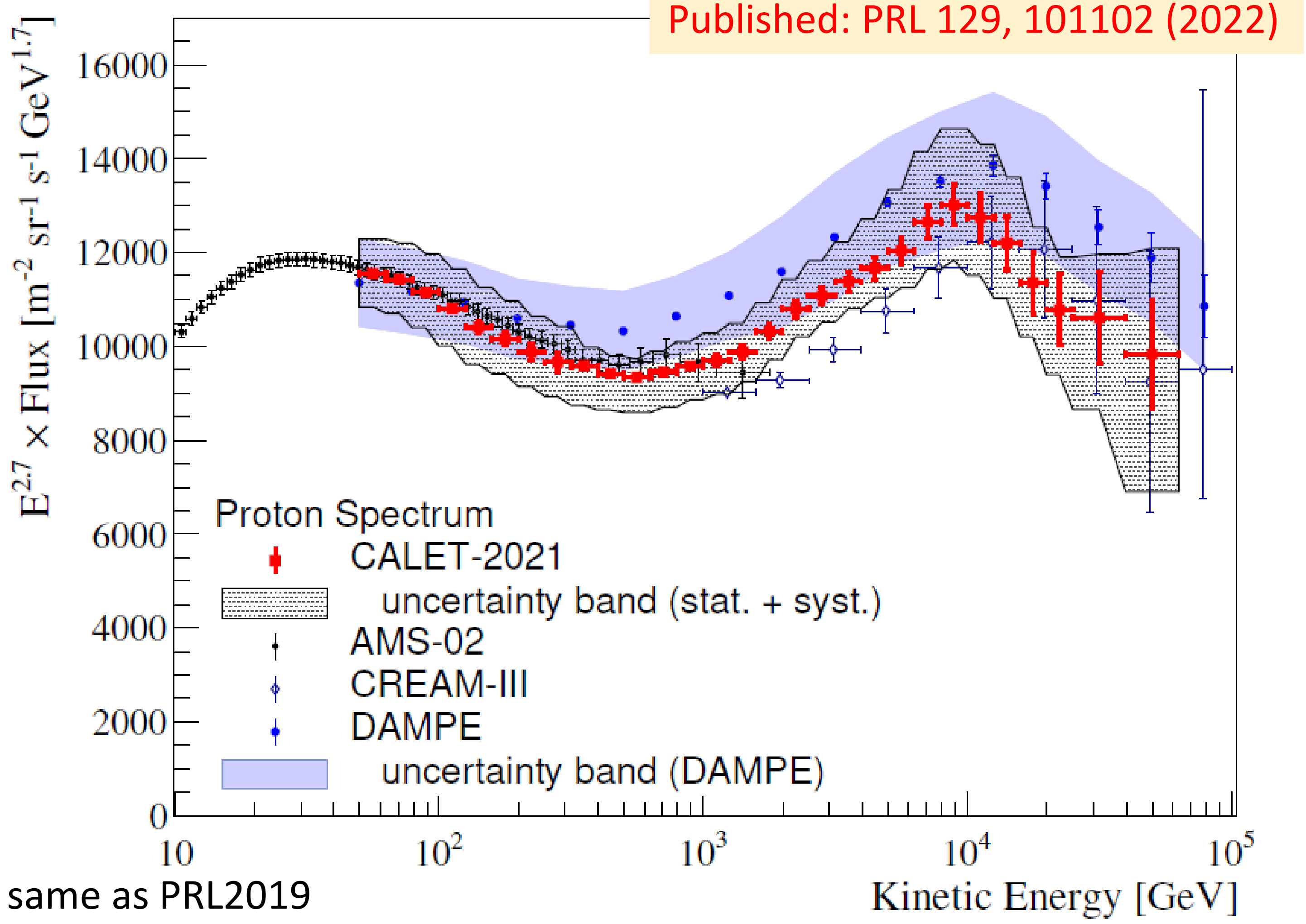
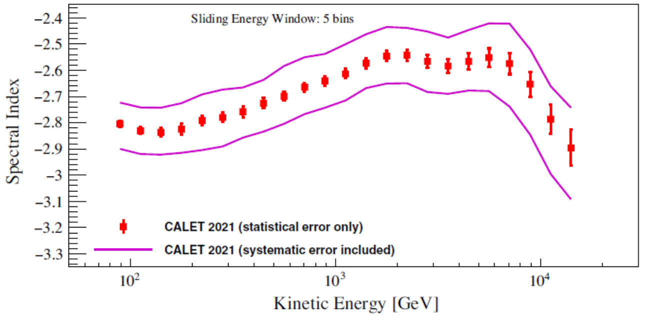
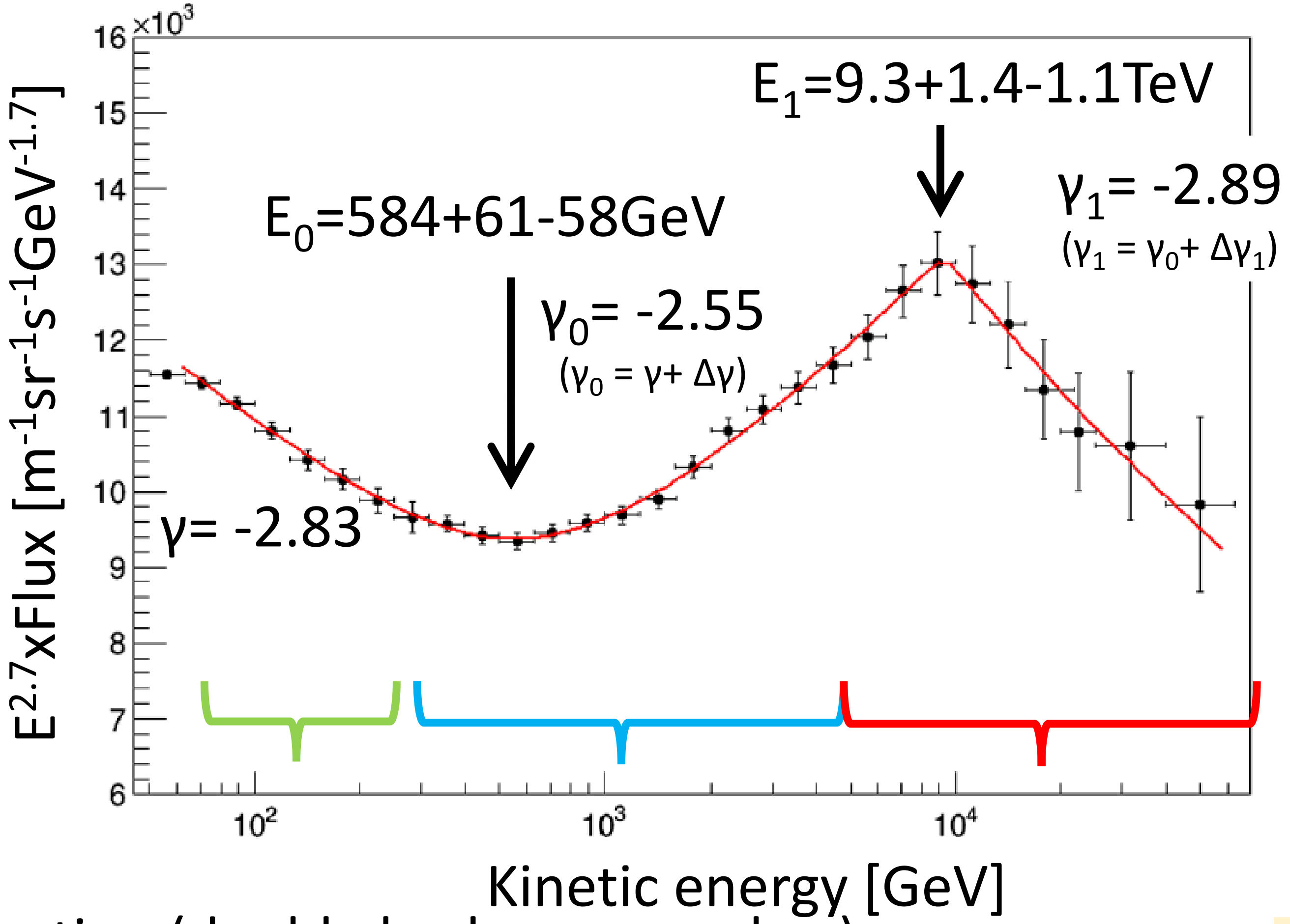


LE: same as PRL2019
HE: 1925 days of live time (Oct. 2015 – Dec. 2021)

- We also observe a spectral softening in E>7TeV.
- Two independent analyses with different efficiencies confirm the same result.



Spectral fit with Double Broken Power Law (statistical error only)



proton

$$\chi^2 = 4.4/20$$

γ	-2.83+0.01-0.02
S	2.4+0.8-0.6
$\Delta\gamma$	(2.8+0.4-0.2)x10^{-1}
E_0	(5.84+0.61-0.58)x10^2
$\Delta\gamma_1$	(-3.4±0.6)x10^{-1}
E_1	(9.3+1.4-1.1)x10^3
s_1	~30

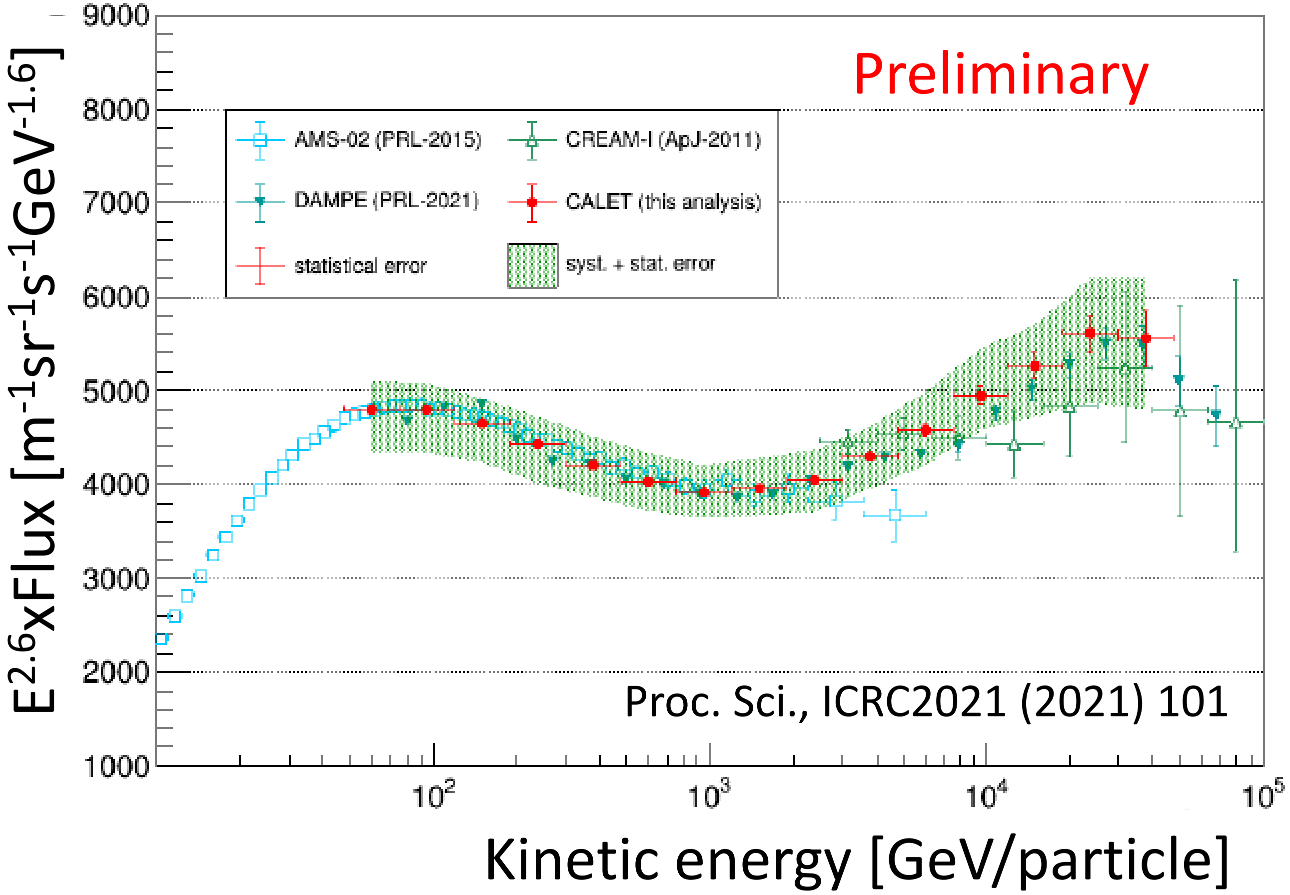
Fitting function (double broken power law):

$$\Phi = E^{2.7} \times C \times \left(\frac{E}{1}\right)^{\gamma} \times \left(1 + \left(\frac{E}{E_0}\right)^{s}\right)^{\frac{\Delta\gamma}{s}} \times \left(1 + \left(\frac{E}{E_1}\right)^{s_1}\right)^{\frac{\Delta\gamma_1}{s_1}}$$

Low energy hardening softening

Softening is much sharper and the s_1 becomes higher with a large uncertainty.

Helium spectrum



- We observe the spectral hardening starting at 1.3±0.3TeV. This is consistent with DAMPE result (PRL 2021).

Summary

- CALET data taking is stably running without any serious problem more than 6 years. We have updated the proton analysis and the helium data. Our proton result have just been published in PRL 129, 101102 (2022) (selected as Editors' Suggestion!).
- Proton
  - We expanded the energy region to 60TeV and observed a clear proton spectrum softening starting at 9.3+1.4-1.1TeV. The spectral index changes from -2.6 to -2.9.
- Helium
  - We also analyzed the helium spectrum and we observed helium spectrum hardening starting at 1.3±0.3TeV (preliminary).