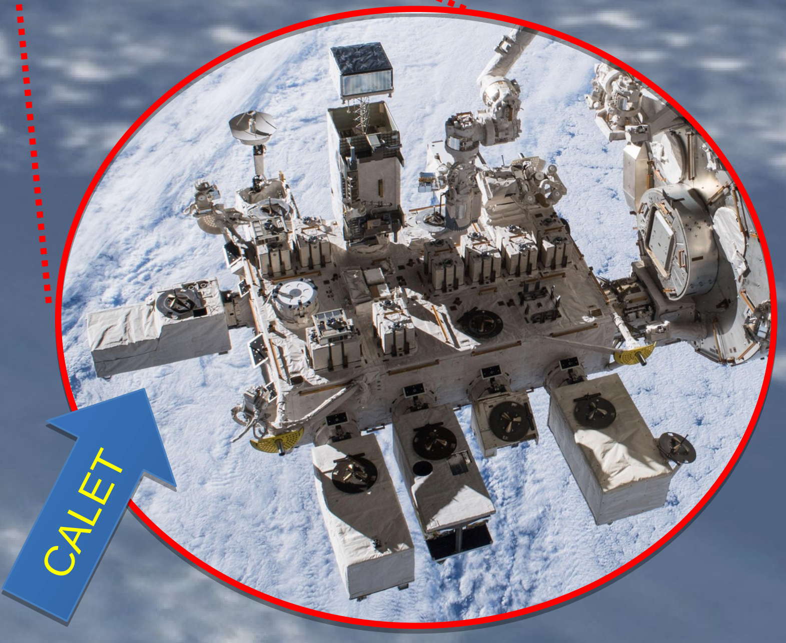
Measurement of the energy spectrum of cosmic-ray helium with CALET on the International Space Station

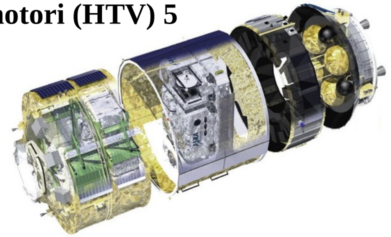


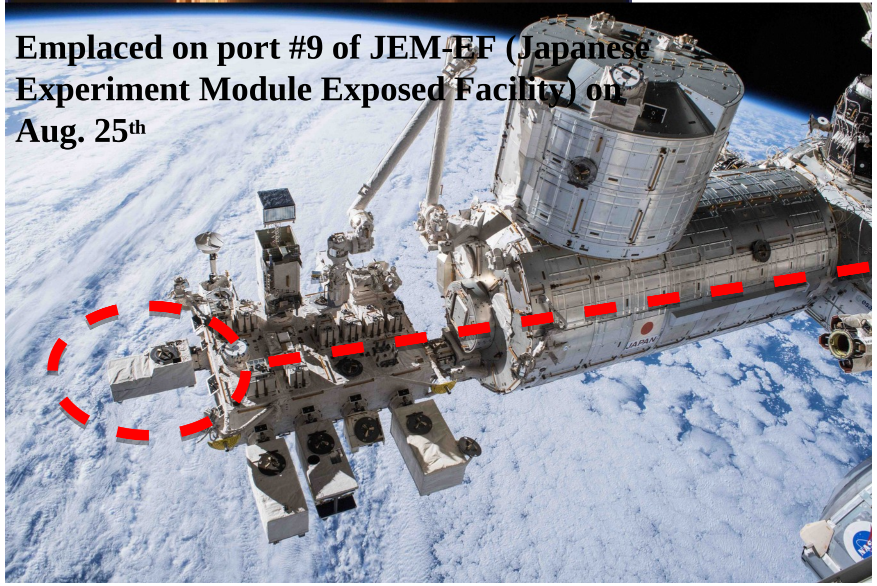
Paolo Brogi
University of Siena
for the CALET collaboration

CALET payload

Launched on Aug. 19th, 2015
by the Japanese H2-B rocket

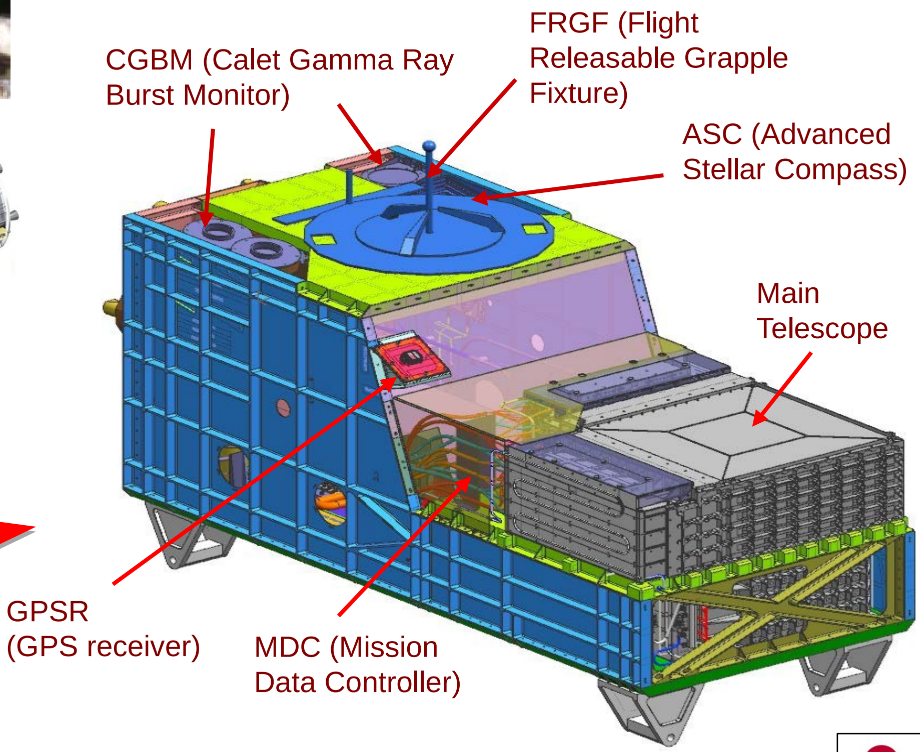
Kounotori (HTV) 5





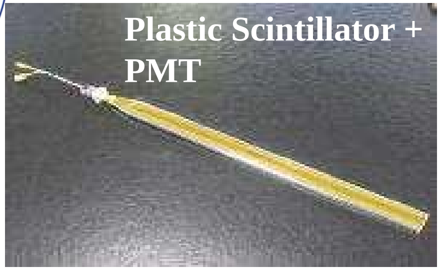
Emplaced on port #9 of JEM-EF (Japanese Experiment Module Exposed Facility) on Aug. 25th

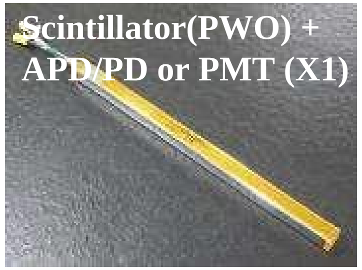
- Mass: 612.8 kg (JEM Standard Payload)
- Size: 1850mm (L) × 800mm (W) × 1000mm (H)
- Power: 507 W (max)
- Telemetry: Medium 600 kbps (6.5GB/day)



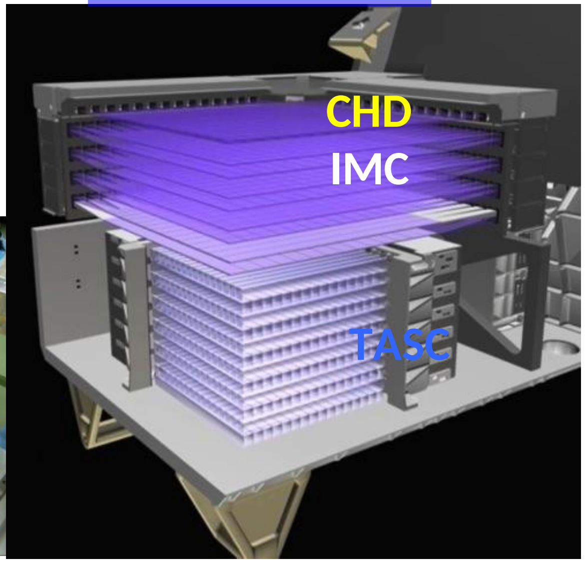
Continues stable observation since Oct. 13, 2015 and collected >2.7 billions events so far.

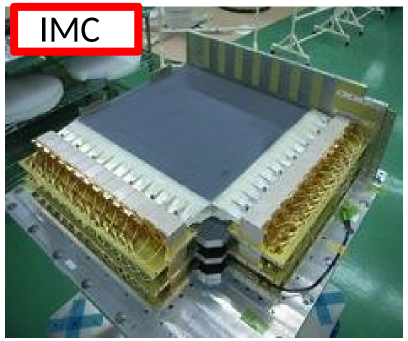
Detector overview





CALORIMETER

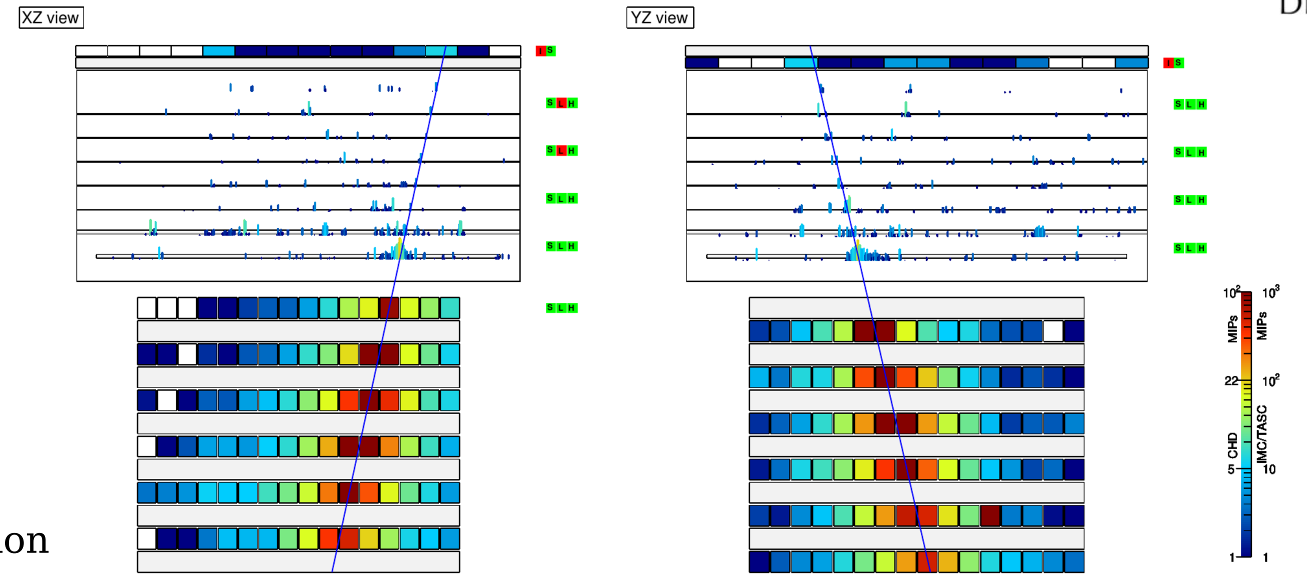




	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Measure	Charge (Z=1-40)	Tracking , Particle ID	Energy, e/p Separation
Geometry (Material)	Plastic Scintillator 14 paddles x 2 layers (X,Y): 28 paddles Paddle Size: 32 x 10 x 450 mm³	448 Scifi x 16 layers (X,Y) : 7168 Scifi 7 W layers ($3X_0$): $0.2X_0$ x 5 + $1X_0$ x2 Scifi size : 1 x 1 x 448 mm³	16 PWO logs x 12 layers (x,y): 192 logs log size: 19 x 20 x 326 mm³ Total Thickness : 27 X_0 , ~1.2 λ_I
Readout	PMT+CSA	64-anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)@top layer

Selection of Helium candidate

Event display of a selected He candidate (~700 GeV TASC dep. en.)



Analysed flight data:

- 1815 days (October 13, 2015 to September 30 2020)
- live time fraction ~85% of the accumulated observation time

Selection criteria:

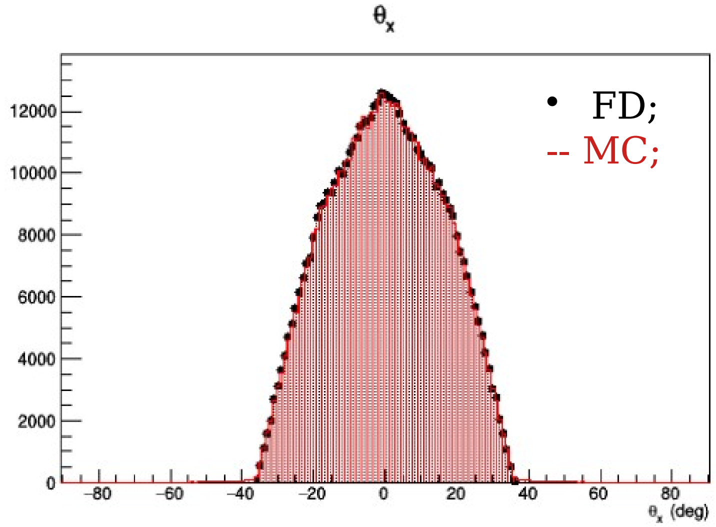
- HE shower trigger + off-line trigger confirmation
- IMC reconstructed track + track quality cut
- acceptance cut (events crossing CHD, TASC top and bottom layers within 2 cm from the edge)
- off-acceptance rejection cuts (additional cuts to remove contamination from mis-reconstructed off-acceptance events)
- charge ID (identification of the primary particle through the dE/dx measurements in CHD and along the IMC track)

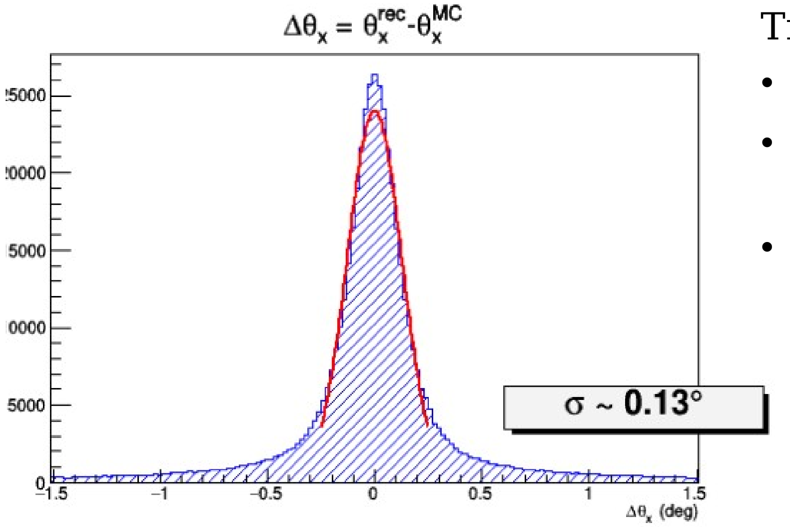
MC simulation:

- Two detailed MC simulations of the instrument were developed based on Fluka and Epics (w/ DPMJET-III).
- Digitization of signals and trigger were modelled accurately in simulation and tuned using beam test results and flight data.
- MC is used to estimate: tracking and selection efficiencies; the energy response ("smearing") matrix.

Tracking performance

Robust track finding, through combinatorial Kalman Filter algorithm, that exploits the IMC fine granularity and imaging capability.



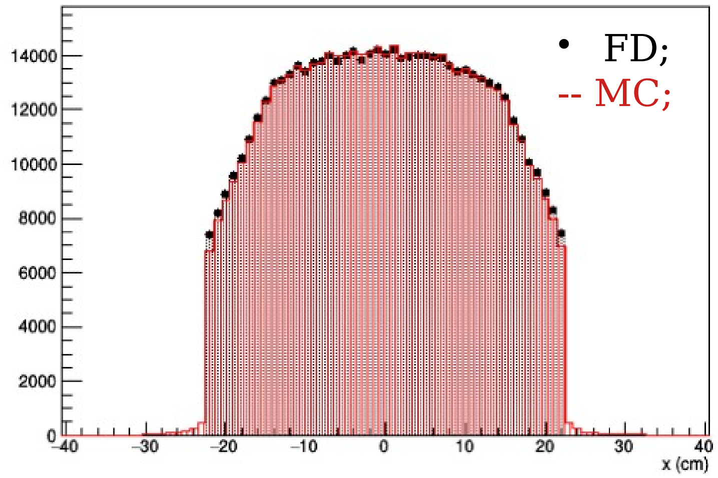


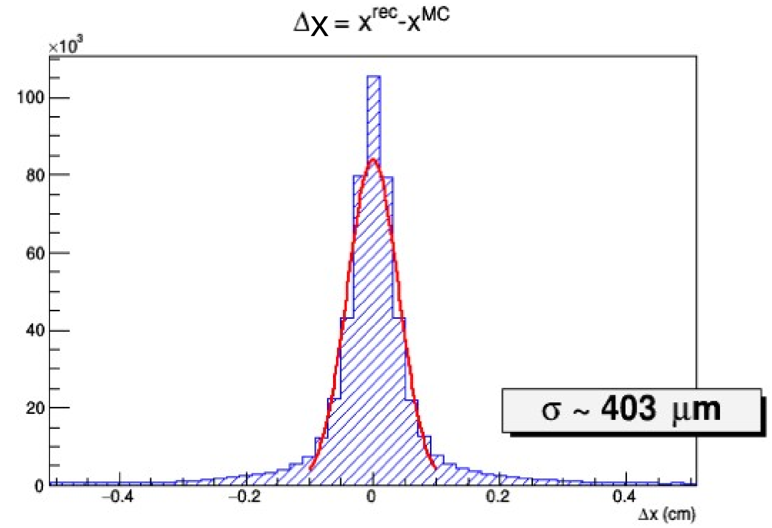
Tracking provides:

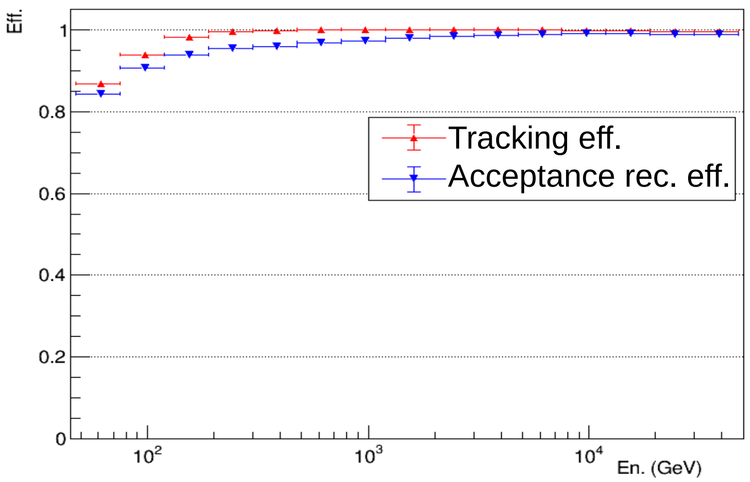
- CR arrival direction
- the geometrical acceptance of reconstructed events
- the CHD paddles and IMC scifi's crossed by CR particle (for particle ID)

- Angular resolution: ~0.13°
- IP resolution on CHD: ~400 μm

Impact Point on CHD x



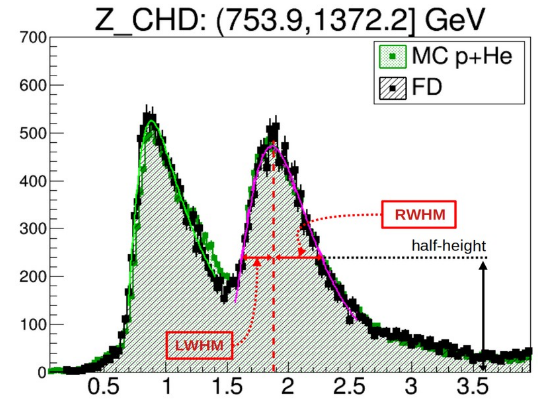


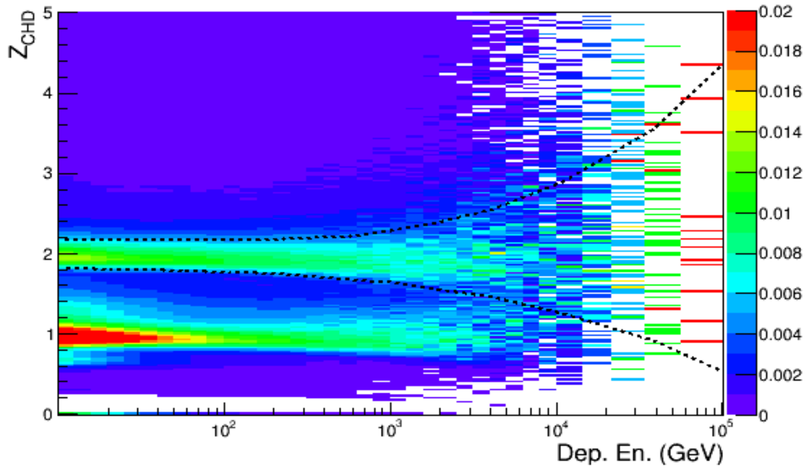


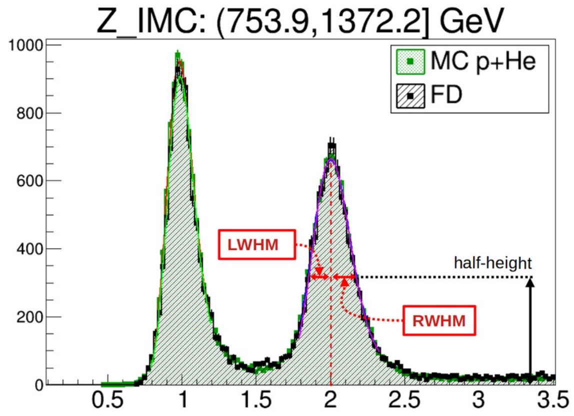
Charge identification of Nuclei

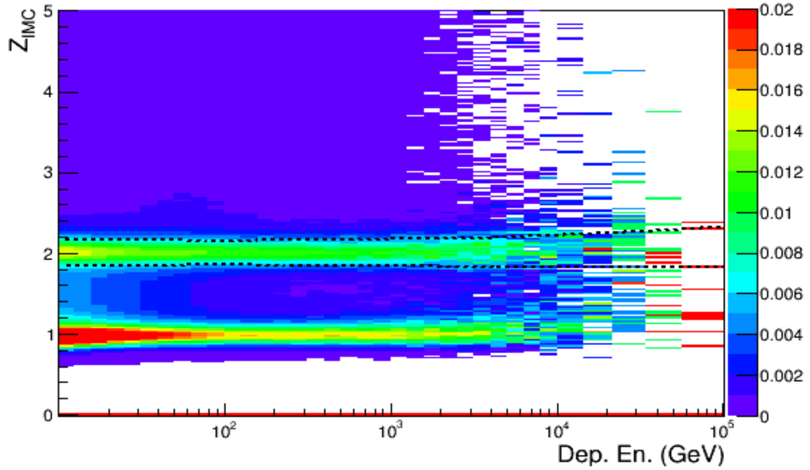
Single element selection for He nuclei is achieved by CHD + IMC charge analysis.

Deviation from Z^2 response is corrected both in CHD and IMC using a “Voltz” ionization model.

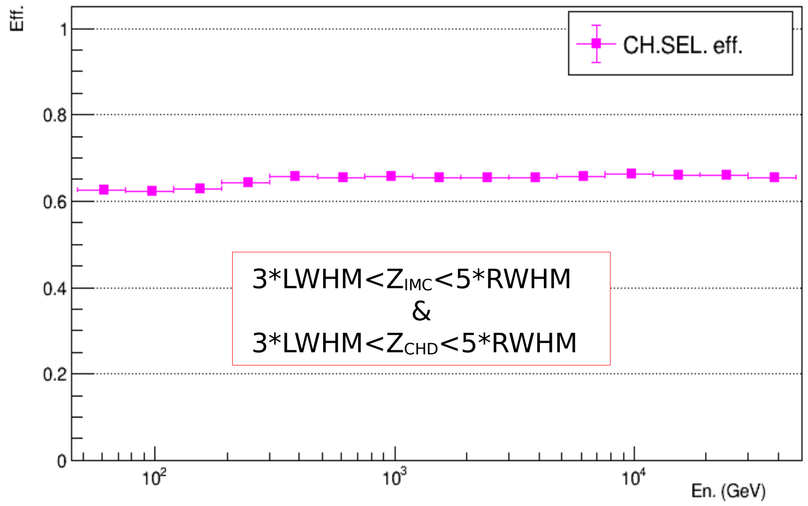








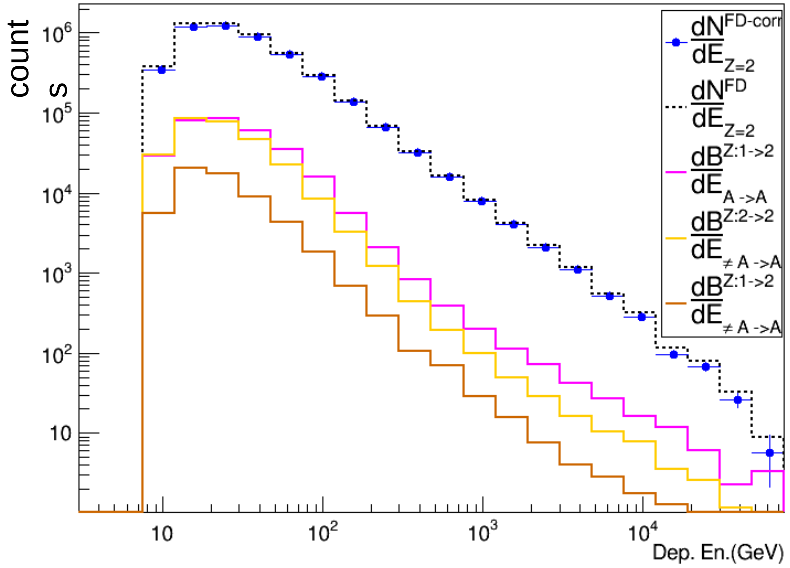
Almost flat helium selection efficiency is achieved via an energy dependent cut, that follows the energy dependence of the peak position and the asymmetric (Left and Right) Width at Half Maximum of the charge distributions.

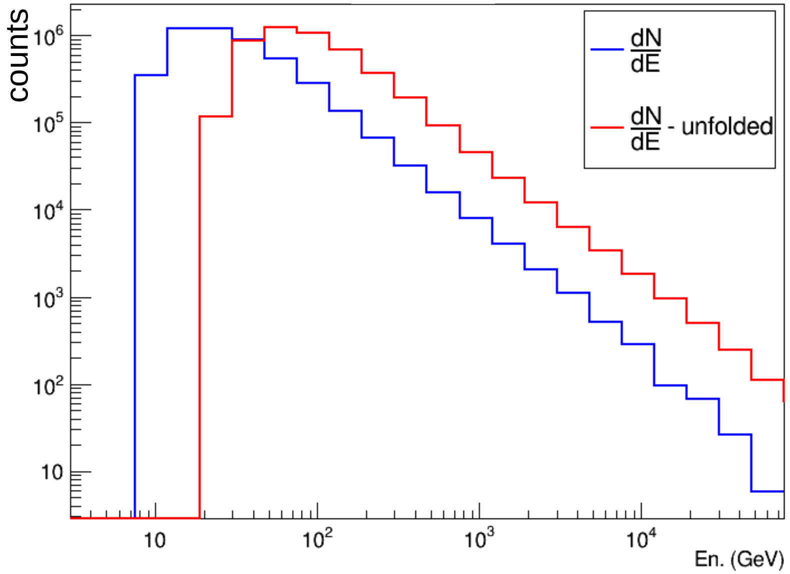


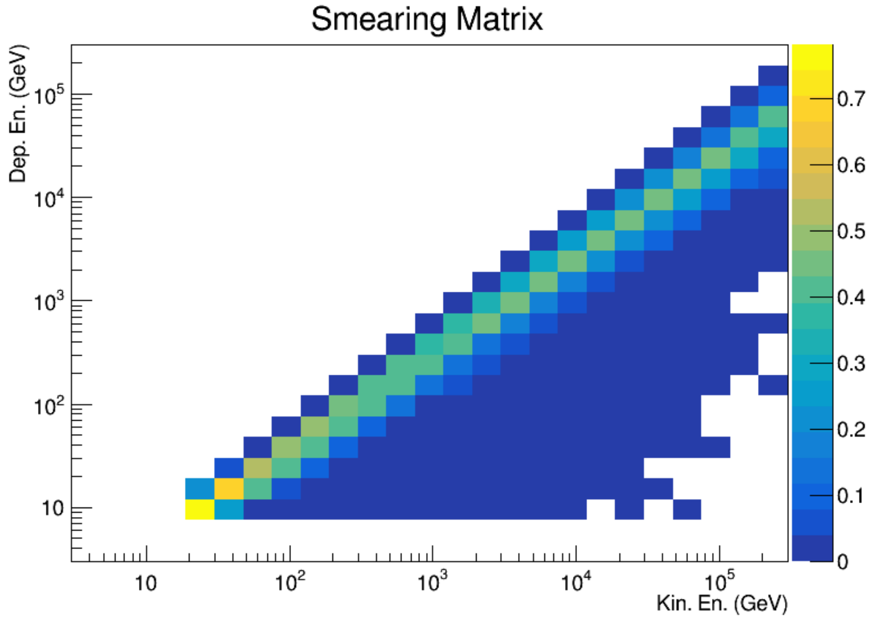
Background Estimation and Unfolding

The main background in the He selected sample (dN/dE) is charge contamination from misidentified protons, followed by off-acceptance contamination from mis-reconstructed protons and helium events.

The number of contaminating events (dB/dE) is estimated using both MC (to evaluate the background ratio) and the FD (to evaluate the helium and proton abundances) and then subtracted.







- The smearing matrix is computed using Epics MC.
- The unfolding is performed by an iterative method based on the Bayes theorem.
- Energy bins are commensurate with RMS resolution of TASC (~30% for nuclei).

Helium Flux Measurement

Preliminary CALET results in the energy range from ~50 GeV to ~50 TeV.

Flux measurement:

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

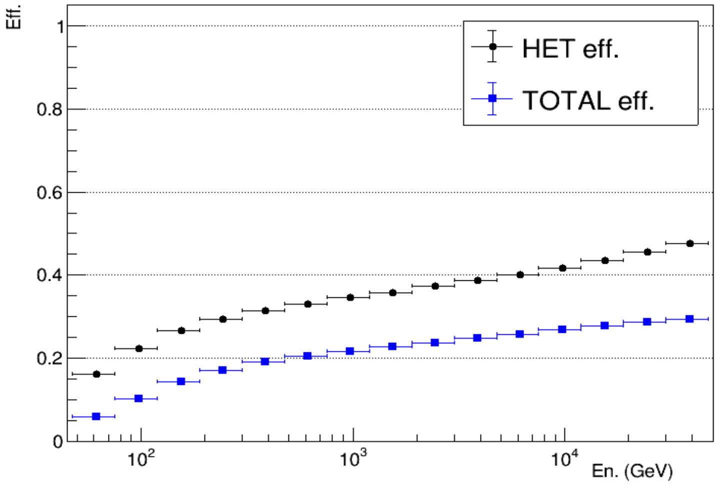
$N(E)$: events in unfolded energy bin

$S\Omega$: geometrical acceptance (510 cm^2sr)

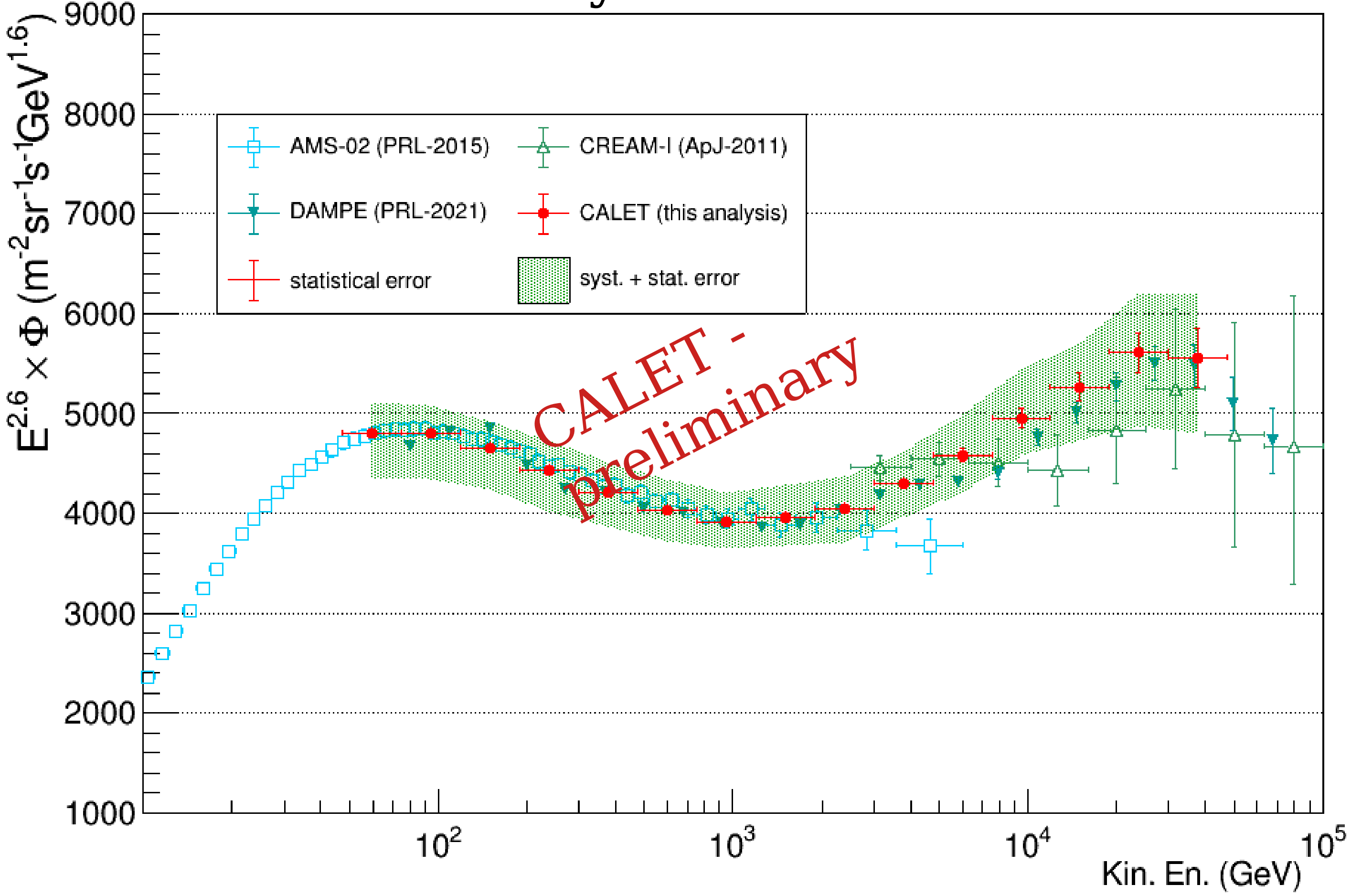
$\varepsilon(E)$: efficiency

T: live Time

ΔE: energy bin width

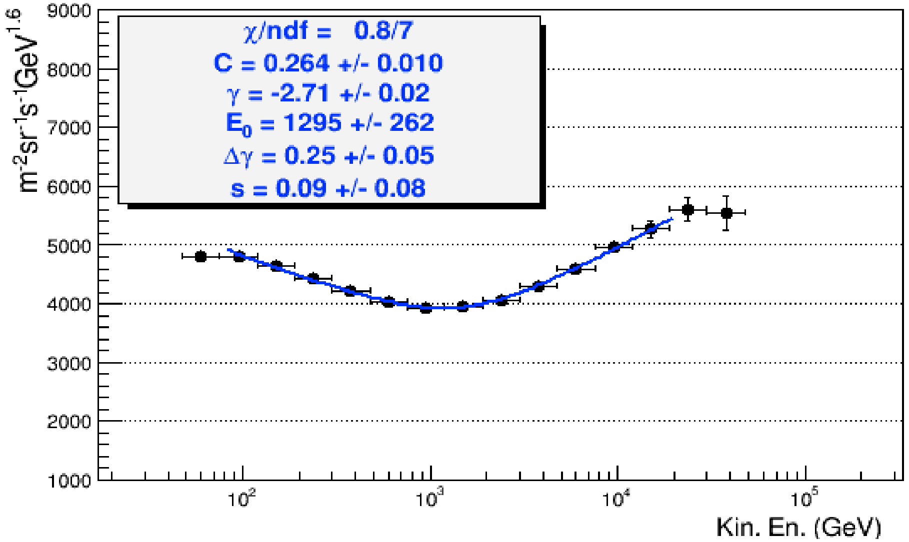


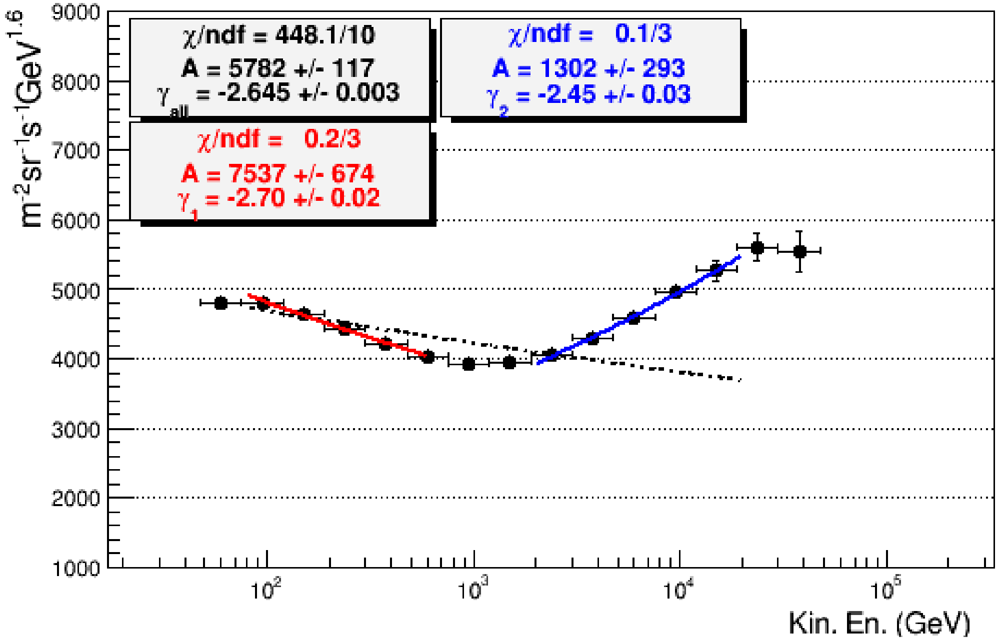
Preliminary Helium Flux x $E^{2.6}$



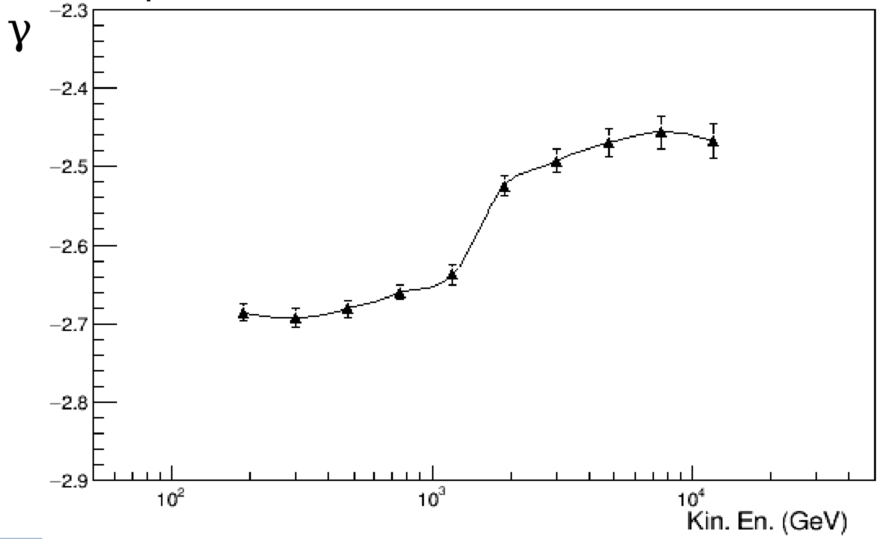
Spectral Behavior of Helium Flux

Preliminary results, only the statistical errors have been taken into account.





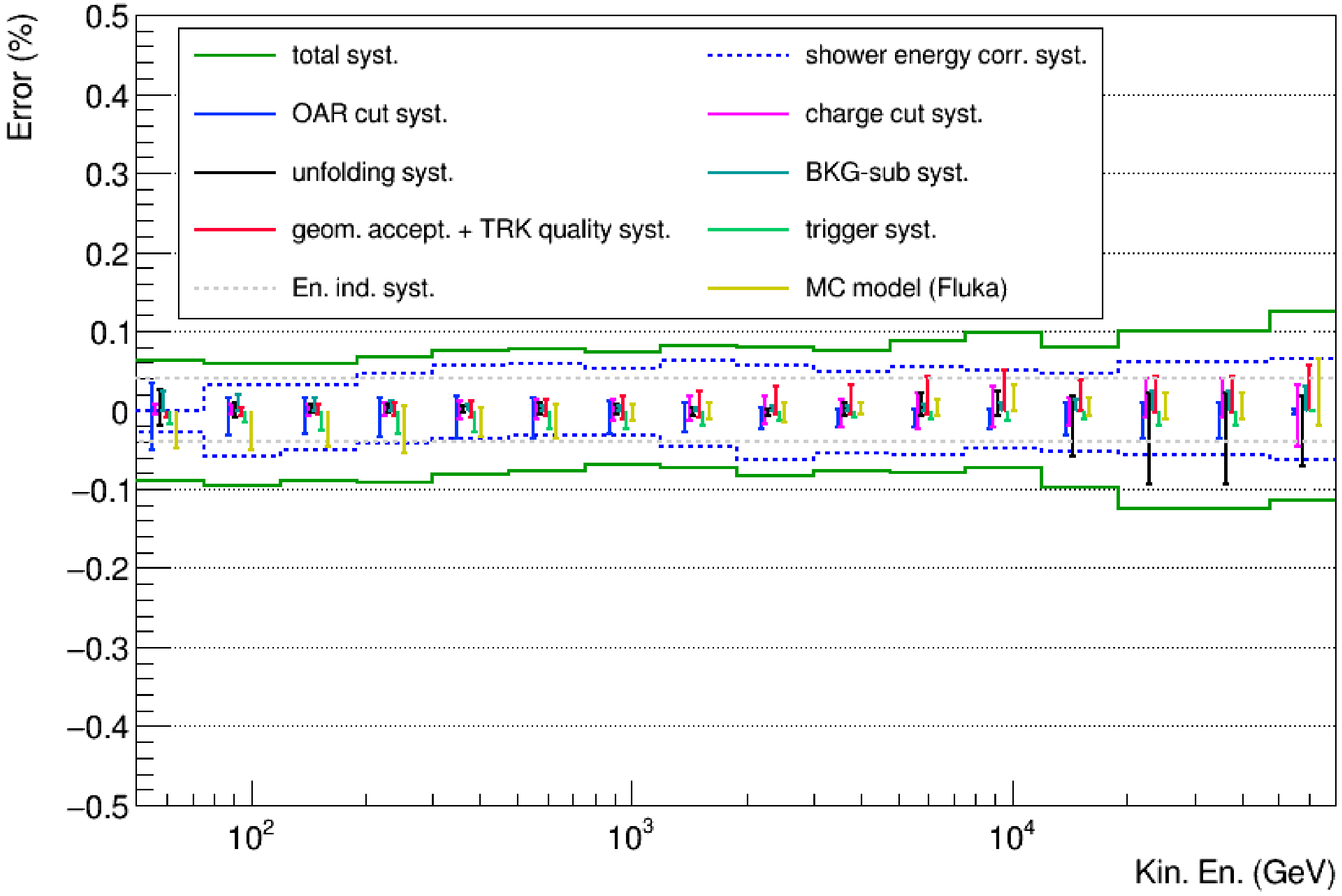
Spectral index (6 bins wide sliding windows)



- Sub-ranges of 80-600GeV, 2-20 TeV can be fitted with single power law function, but not the whole range.
- Progressive hardening up to the multi-TeV region was observed.
- "Smoothly broken power-law fit" gives power law index (γ), Δγ and break energy (E_0) consistent with the recent results from DAMPE.

Preliminary evaluation of systematic

Breakdown of systematic uncertainties (preliminary).



Energy dependent:

- shower energy correction (Beam test calibration)
- off-acceptance rejection cuts
- charge cut
- unfolding
- background subtraction
- tracking
- trigger
- MC model (Fluka)

Energy independent:

- live time
- long term stability
- radiation environment

Energy scale:

- beam test calibration

Conclusions

- CALET measure light nuclei in CRs from few tens of GeV up to tens of TeV.
- Excellent performances and remarkable stability of the instrument have been achieved.
- Preliminary measurement of the He flux has been carried out up to 50 TeV of particle energy with ~60 months of data.
- Preliminary results demonstrate CALET capability to resolve spectral features in the CR spectra.
- Independent analyses were carried out using different event selection and background rejection procedures, preliminary results are consistent within the errors.
- Further study to increase statistics at high energies and to carefully assess the systematic uncertainty are ongoing.
- In this presentation we don’t include ^{3}He contribution.

Thanks for your attention!

The CALET Collaboration Team

O. Adriani[1,2], Y. Akaike[3,4], K. Asano[5], Y. Asaoka[5], E. Berti[1,2], G. Bigongiari[6,7], W.R. Binns[8], M. Bongi[1,2], P. Brogi[6,7], A. Bruno[9.10], J.H. Buckley[8], N. Cannady[11,12,13], G. Castellini[14], C. Checchia[6],M.L. Cherry[15], G. Collazuol[16,17], K. Ebisawa[18], A.W. Ficklin[15], H. Fuke[18], S. Gonzi[1,2], T.G. Guzik[15], T. Hams[11], K. Hibino[19], M. Ichimura[20], K. Ioka[21], W. Ishizaki[5], M.H. Israel[8], K. Kasahara[22], J. Kataoka[23], R. Kataoka[24], Y. Katayose[25], C. Kato[26], N. Kawanaka[27,28], Y. Kawakubo[15], K. Kobayashi[3,4],K. Kohri [29], H.S. Krawczynski[8], J.F. Krizmanic[11,12,13], J. Link[11,12,13], P. Maestro[6,7], P.S. Marrocchesi[6,7], A.M. Messineo[30,7], J.W. Mitchell[31], S. Miyake[32], A.A. Moiseev[33,12,13], M. Mori[34], N. Mori[2], H.M. Motz[35], K. Munakata[26], S. Nakahira[18], J. Nishimura[18], G.A. de Nolfo[9], S. Okuno[19], J.F. Ormes[36], N. Ospina[16,17], S. Ozawa[37], L. Pacini[1,14,2], P. Papini[2], B.F. Rauch[8], S.B. Ricciarini[14,2], K. Sakai[11,12,13], T. Sakamoto[38], M. Sasaki[32,12,13], Y. Shimizu[19], A. Shiomi[39], P. Spillantini[1], F. Stolzi[6,7], S. Sugita[38], A. Sulaj[6,7], M. Takita[5], T. Tamura[19], T. Terasawa[40], S. Torii[3], Y. Tsunesada[41], Y. Uchihori[42], E. Vannuccini[2], J.P. Wefel[15], K. Yamaoka[43], S. Yanagita[44], A. Yoshida[38], K. Yoshida[22], and W.V. Zober[15]

1) *University of Florence, Italy*
2) *INFN Florence, Italy*
3) *RISE, Waseda University, Japan*
4) *JEM Utilization Center, JAXA, Japan*
5) *ICRR, University of Tokyo, Japan*
6) *University of Siena, Italy*
7) *INFN Pisa, Italy*
8) *Washington University, St. Louis, USA*
9) *Heliospheric Physics Lab., NASA/GSFC, USA*
10) *Catholic University of America, Washington DC, USA*
11) *University of Maryland, USA*
12) *Astroparticle Physics Lab., NASA/GSFC, USA*
13) *CRESST, NASA/GSFC, USA*
14) *IFAC, CNR, Fiorentino, Italy*
15) *Louisiana State University, USA*
16) *University of Padova, Italy*
17) *INFN Padova, Italy*
18) *ISAS, JAXA, Japan*
19) *Kanagawa University, Japan*
20) *Hirosaki University, Japan*
21) *YITP, Kyoto University, Japan*
22) *Shibaura Institute of Technology, Japan*
23) *Waseda University, Japan*
24) *National Institute of Polar Research, Japan*
25) *Yokohama National University, Japan*
26) *Shinshu University, Japan*
27) *Hakubi Center, Kyoto University, Japan*
28) *Kyoto University, Japan*
29) *IPNS, KEK, Japan*
30) *University of Pisa, Italy*
31) *National Institute of Technology, Japan*
33) *University of Maryland, USA*
34) *Ritsumeikan University, Japan*
35) *GCSE, Waseda University, Japan*
36) *University of Denver, USA*
37) *National Institute of Information and Communications Technology, Japan*
38) *Aoyama Gakuin University*
39) *Nihon University, Japan*
40) *RIKEN, Japan*
41) *Osaka City University, Japan*
42) *National Institutes for Quantum and Radiation Science and Technology, Japan*
43) *Nagoya University, Japan*
44) *Ibaraki University, Japan*