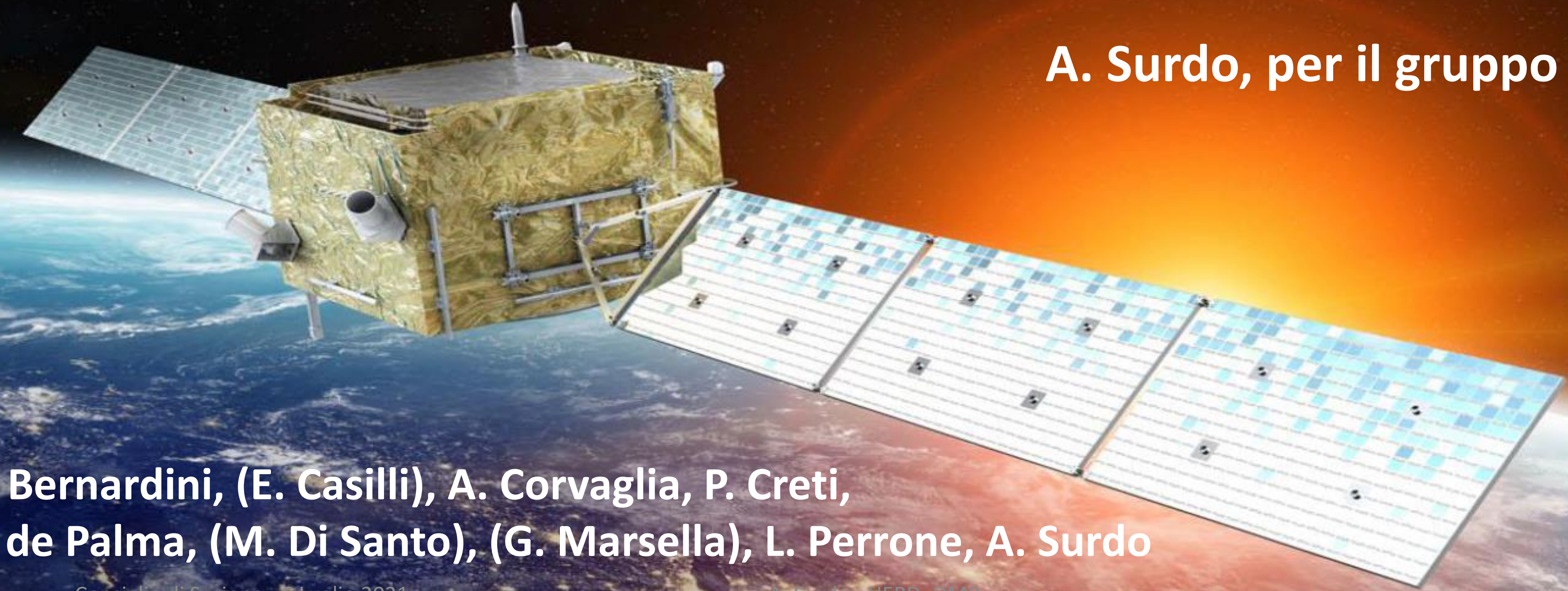
6 Luglio 2021 - Preventivi 2021/22

HERD_DMP

A. Surdo, per il gruppo di Lecce



P. Bernardini, (E. Casilli), A. Corvaglia, P. Creti,
F. de Palma, (M. Di Santo), (G. Marsella), L. Perrone, A. Surdo

DAMPE + HERD R&D

La sigla INFN include 2 missioni spaziali:

- L’esperimento DAMPE *(DArk Matter Particle Explorer)* su satellite
  - in presa-dati da oltre 5 anni (lancio nel Dicembre 2015)
  - range di energia: 10 GeV - 10 TeV e/γ, 50 GeV - 100 TeV CRs
  - complementare a *Fermi*, *AMS-02, CALET, ISS-CREAM, …*

- Il progetto HERD *(High Energy Radiation Detection facility)* *(R&D)* per la Stazione Spaziale Cinese
  - Lancio previsto nel 2026-2027
  - grande accettanza (~3 m^2sr) e profondità del calorimetro (~55X_0)
  - range di energia: 10 GeV-100 TeV e, 0.5 GeV-100 TeV γ, 30 GeV – 3 PeV CRs
  - copertura gap in energia per i CRs tra misure dirette e misure a terra

DAMPE physics goals

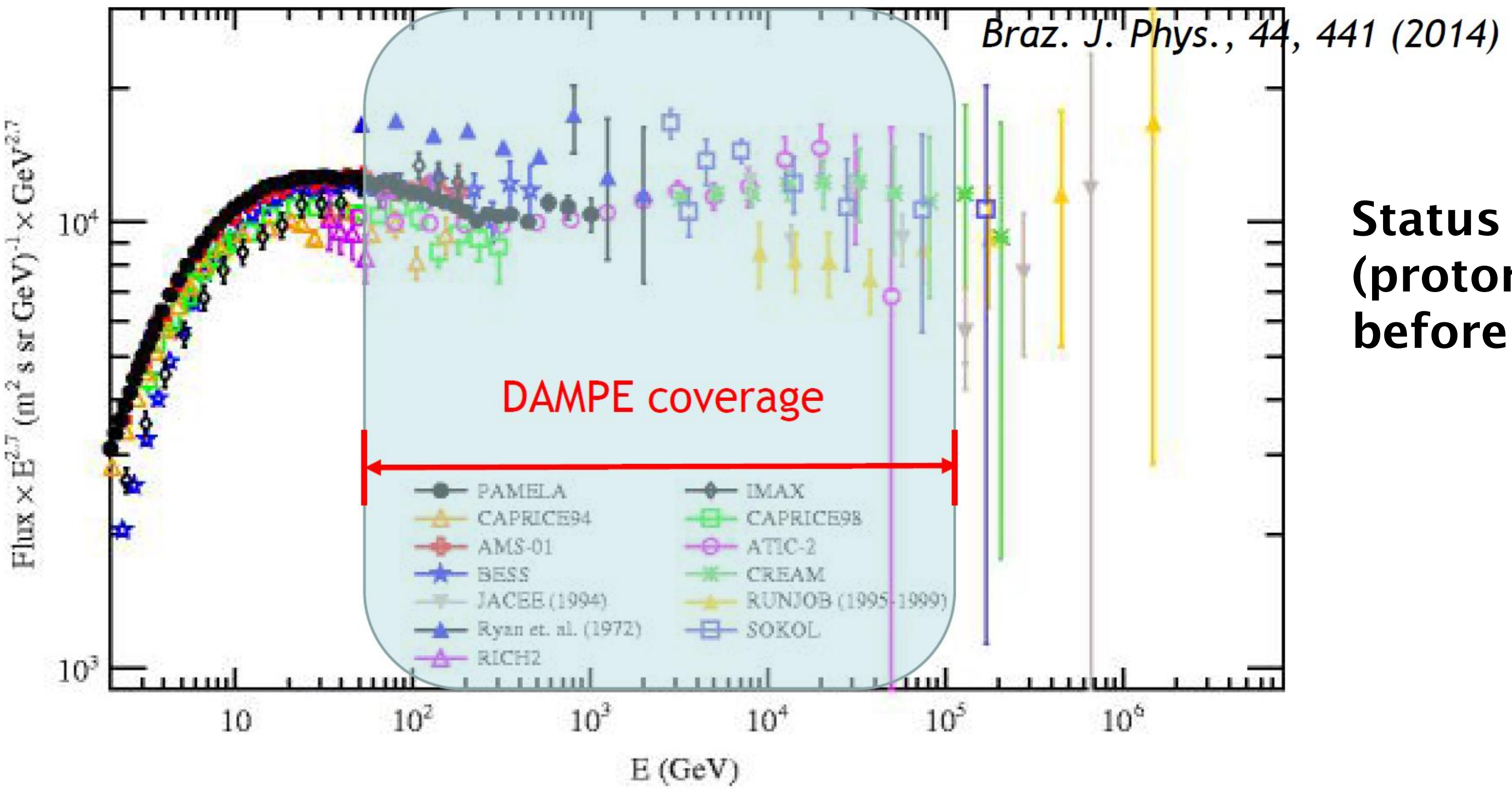
- **High energy particle detection in space**
  - **Measurement of the cosmic e^-+e^+ and γ spectra $\rightarrow$ DM search**
  - **Study of cosmic ray (nuclei) spectrum and composition**
  - **High energy gamma ray astronomy**

Detection of 10 GeV - 10 TeV e/γ, 50 GeV - 100 TeV CRs

Complementary to Fermi, AMS-02, CALET, ISS-CREAM, …

- **Main detector features**
  - **Very good particle identification (e/p separation, charge selection)**
  - **Wide dynamic range (electrons/photons from GeV to 10 TeV)**
  - **High tracking precision**
  - **Excellent energy resolution**

Cosmic ray spectra and composition

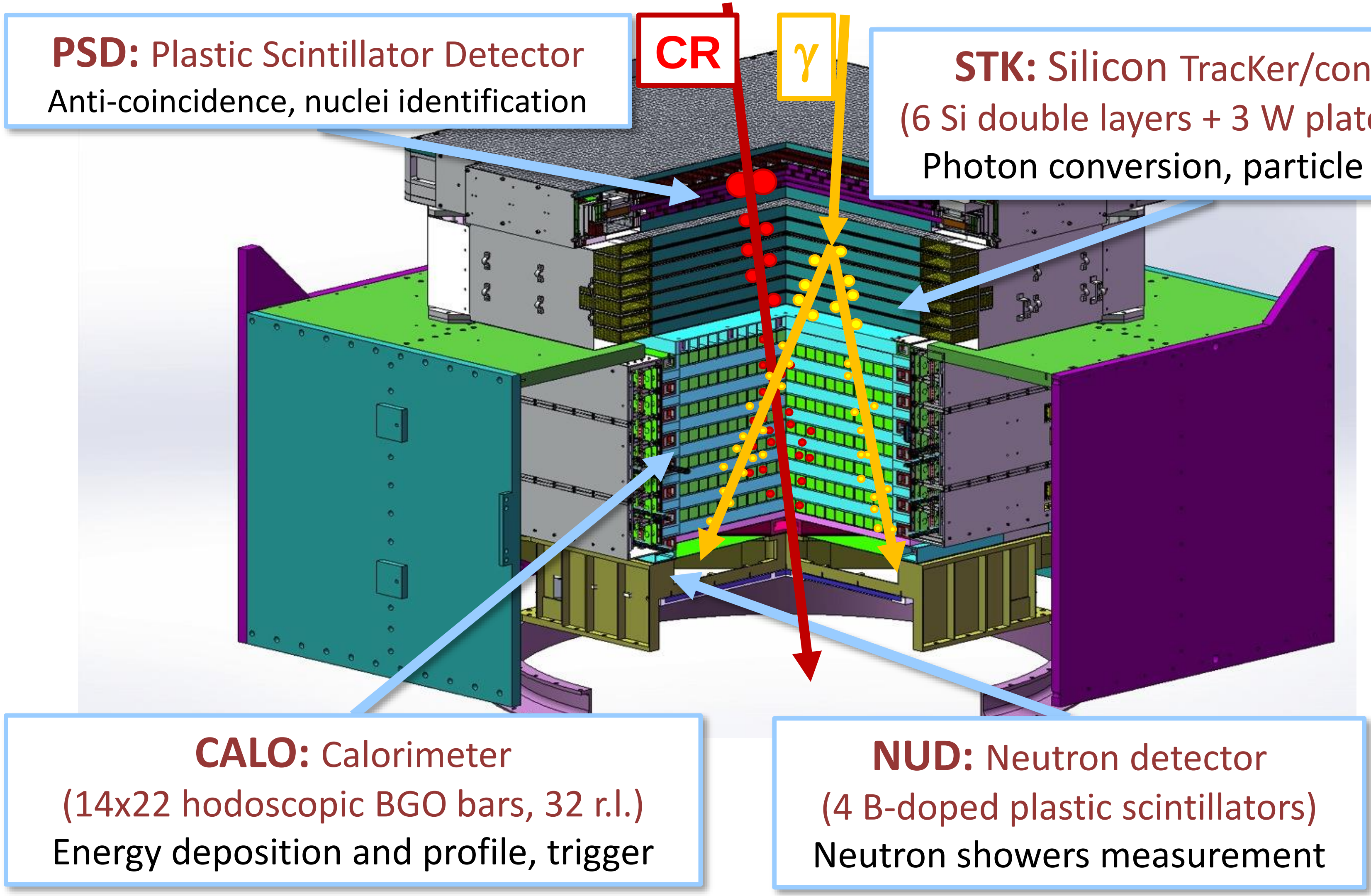


Status of cosmic ray (proton) observations before DAMPE …

- **Precision measurements of cosmic ray nuclei spectra: cosmic ray origin, acceleration and propagation**
- **The spectra at TeV energies not well measured due to limited statistics**

The DAMPE detector

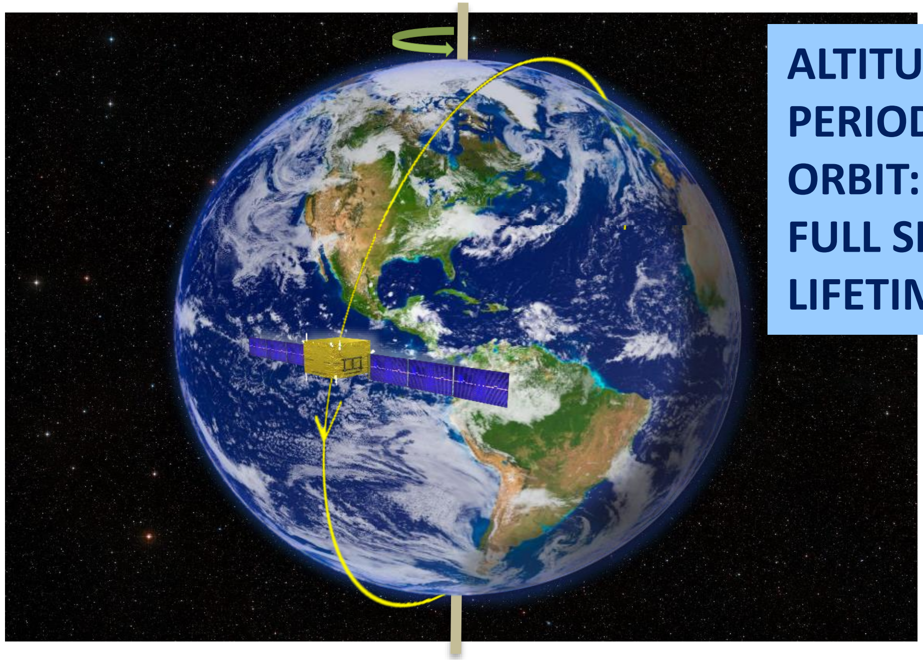
Astrop.Phys. 95 (2017) 6–24



DAMPE features
Mass: 1400 kg
Power consumption: 400 W
Readout channels: > 75k
Data transfer: 16 Gbyte/day
Lifetime: >5 years

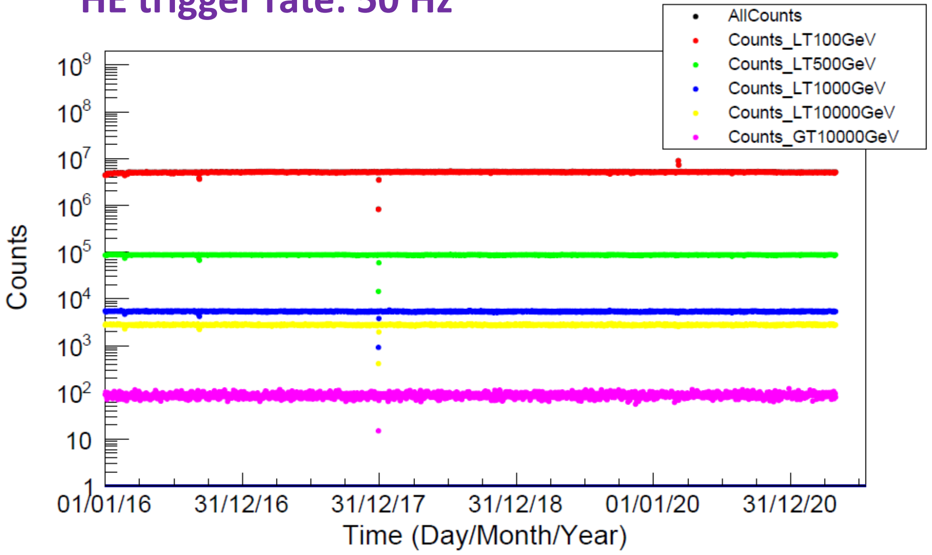
Performance	DAMPE
e/γ Energy resol. @100 GeV (%)	<1.5
e/γ Angular resol. @100 GeV (deg.)	<0.2
e/p discrimination	$>10^5$
Calorimeter thickness (X_0)	32
Geometrical acceptance (m^2sr)	0.3

DAMPE mission

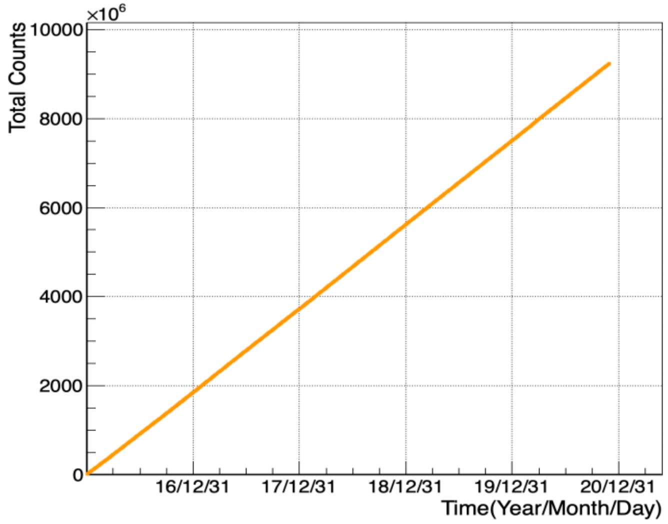


ALTITUDE: 500 km
PERIOD: 95 minutes
ORBIT: Sun-synchronous
FULL SKY SCAN: two/year
LIFETIME > 5 years

Events per day in different energy intervals.
HE trigger rate: 50 Hz

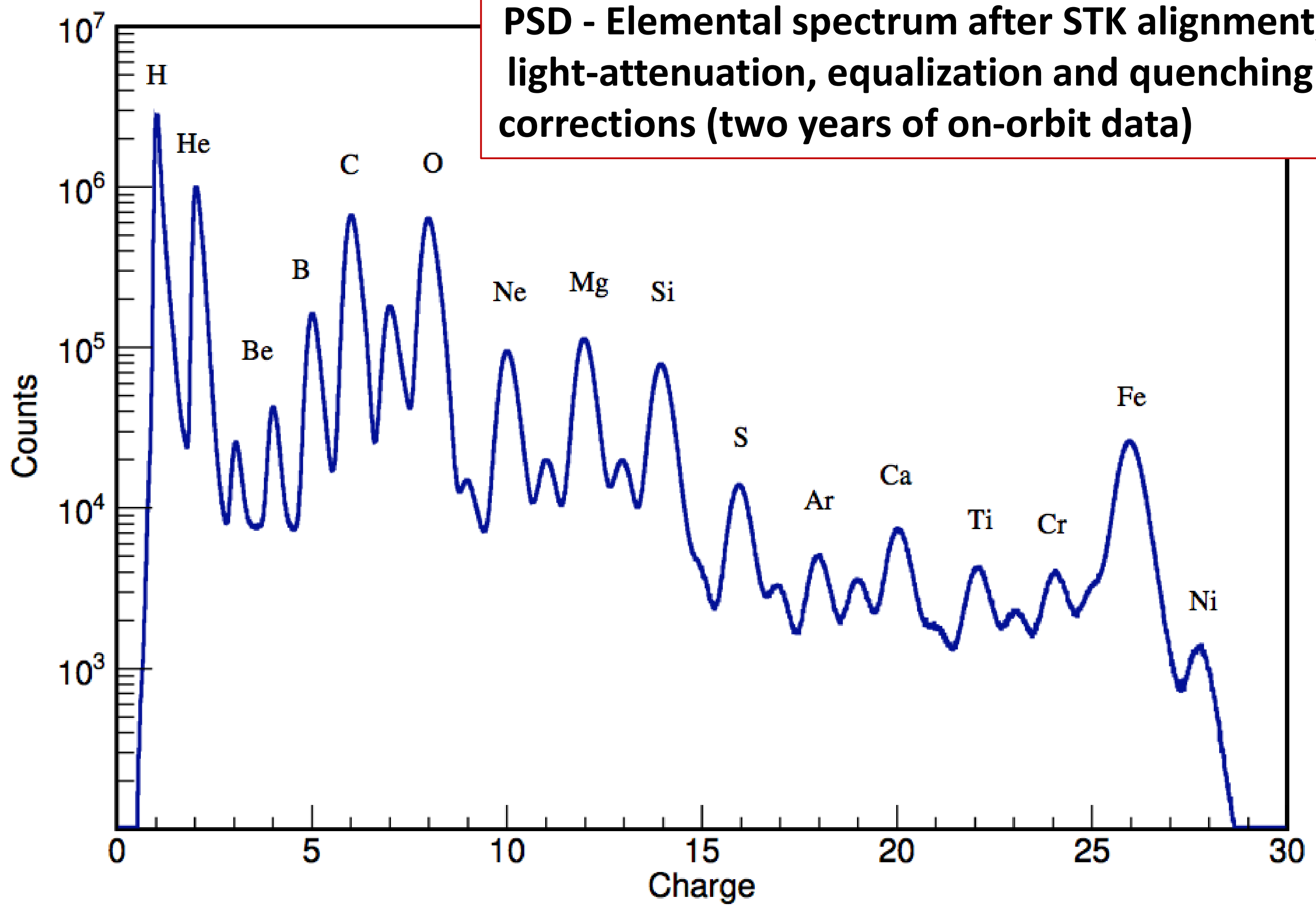


Events collected by DAMPE in 5 years of data-taking



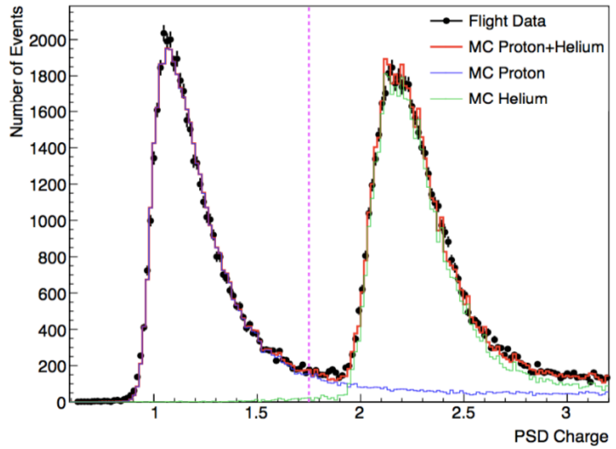
On-orbit performance: PSD charge measurement

PSD - Elemental spectrum after STK alignment, light-attenuation, equalization and quenching corrections (two years of on-orbit data)

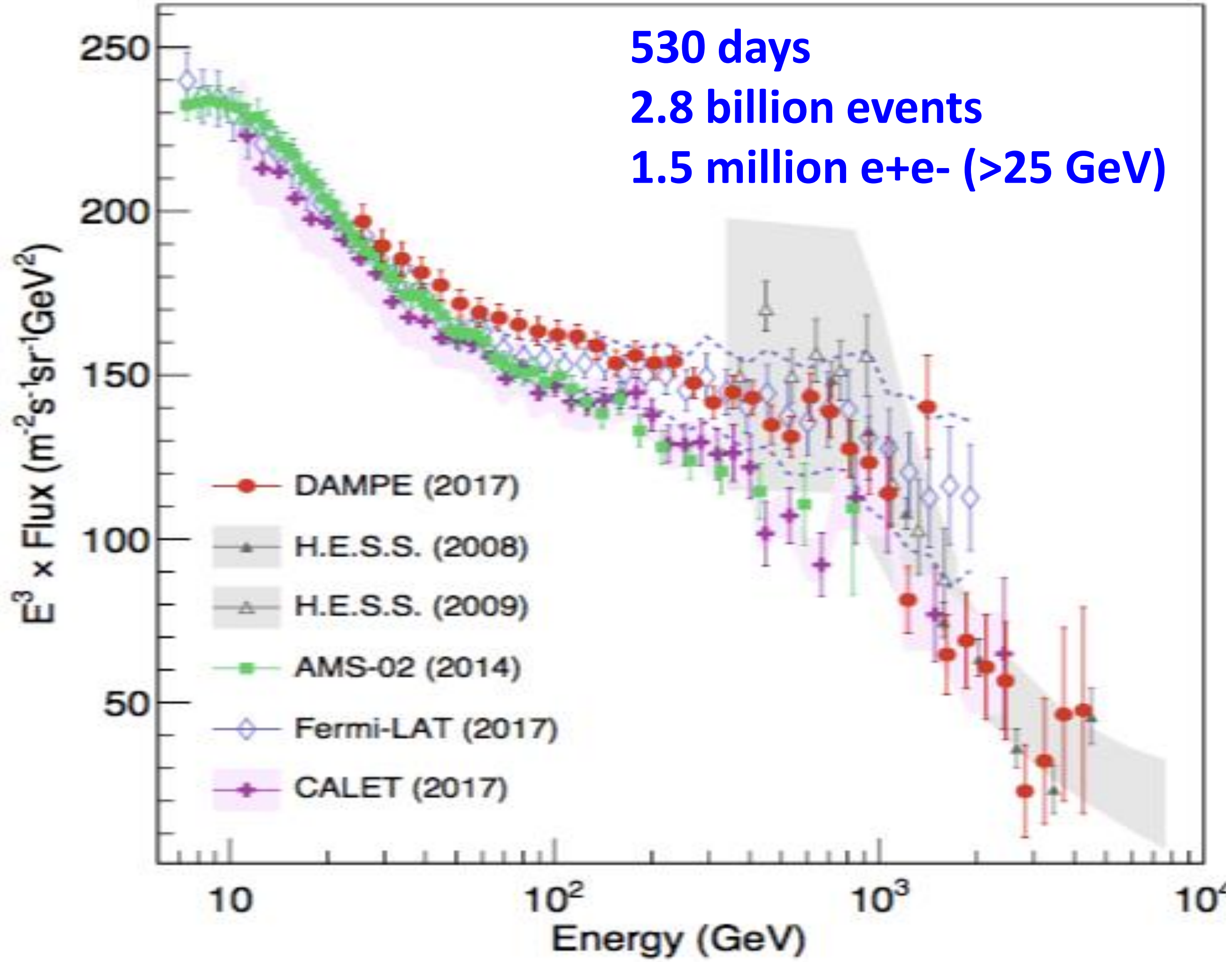


Element	σ_Z
p	0.07
He	0.12
Li	0.14
Be	0.21
B	0.17
C	0.18
N	0.21
O	0.21

Dong et al., Astrop. Phys., 105 (2019) 31



Electron+positron spectrum



- ✓ Analysis of new data ongoing
- ✓ Improved results foreseen from the whole dataset!

nature International journal of science 552 (2017) 63-66

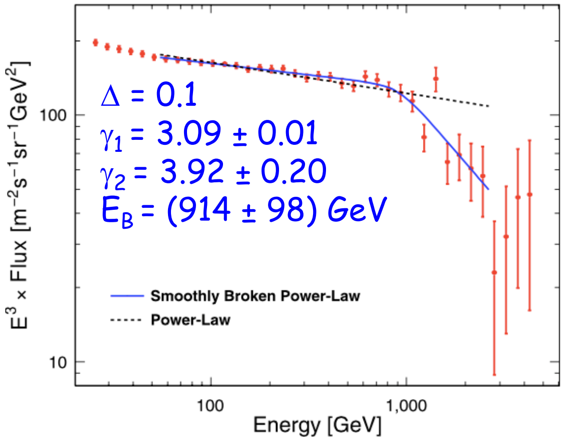
Energy range: 25 GeV – 4.6 TeV

Energy resolution <1.2% @ E>100 GeV

Direct detection of a spectral break at ~1 TeV with 6.6 σ C.L.

Smootly Broken Power-Law fit:

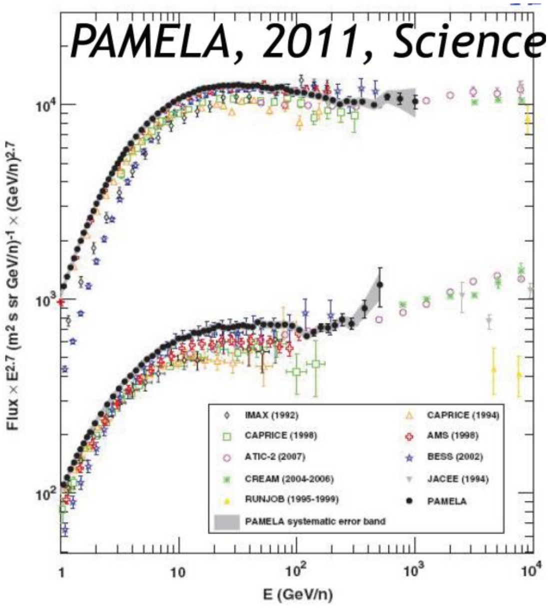
$$F = F_0 (E/100\ GeV)^{-\gamma_1}\left[1+(E/E_B)^{-(\gamma_1-\gamma_2)/\Delta}\right]^{-\Delta}$$

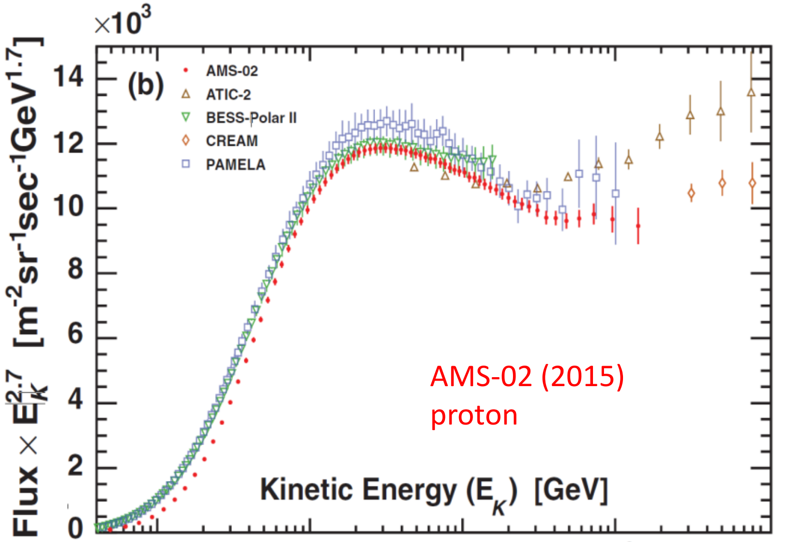


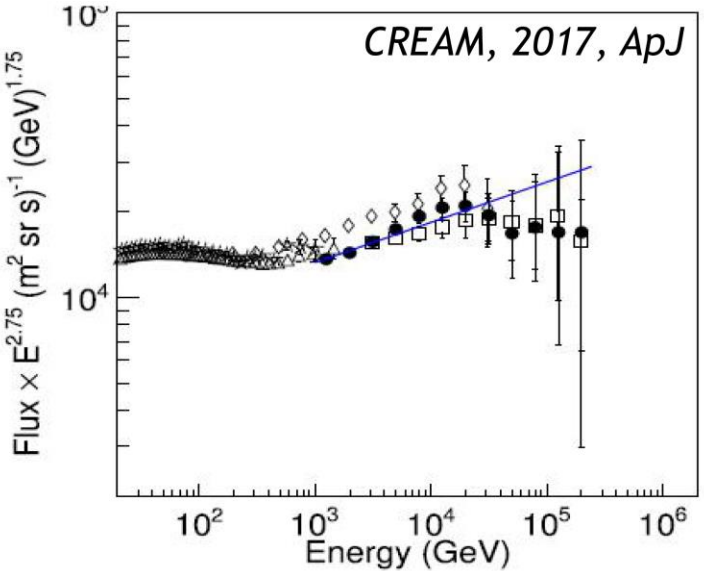
Implications:

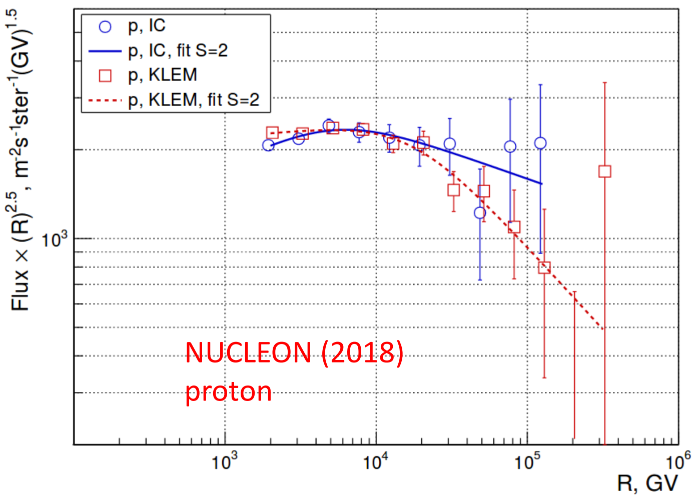
discreteness of source distributions?

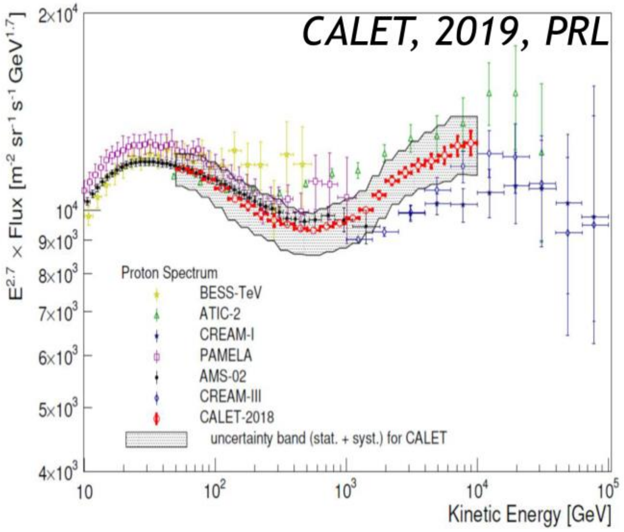
Spectra of Cosmic Ray nuclei: protons







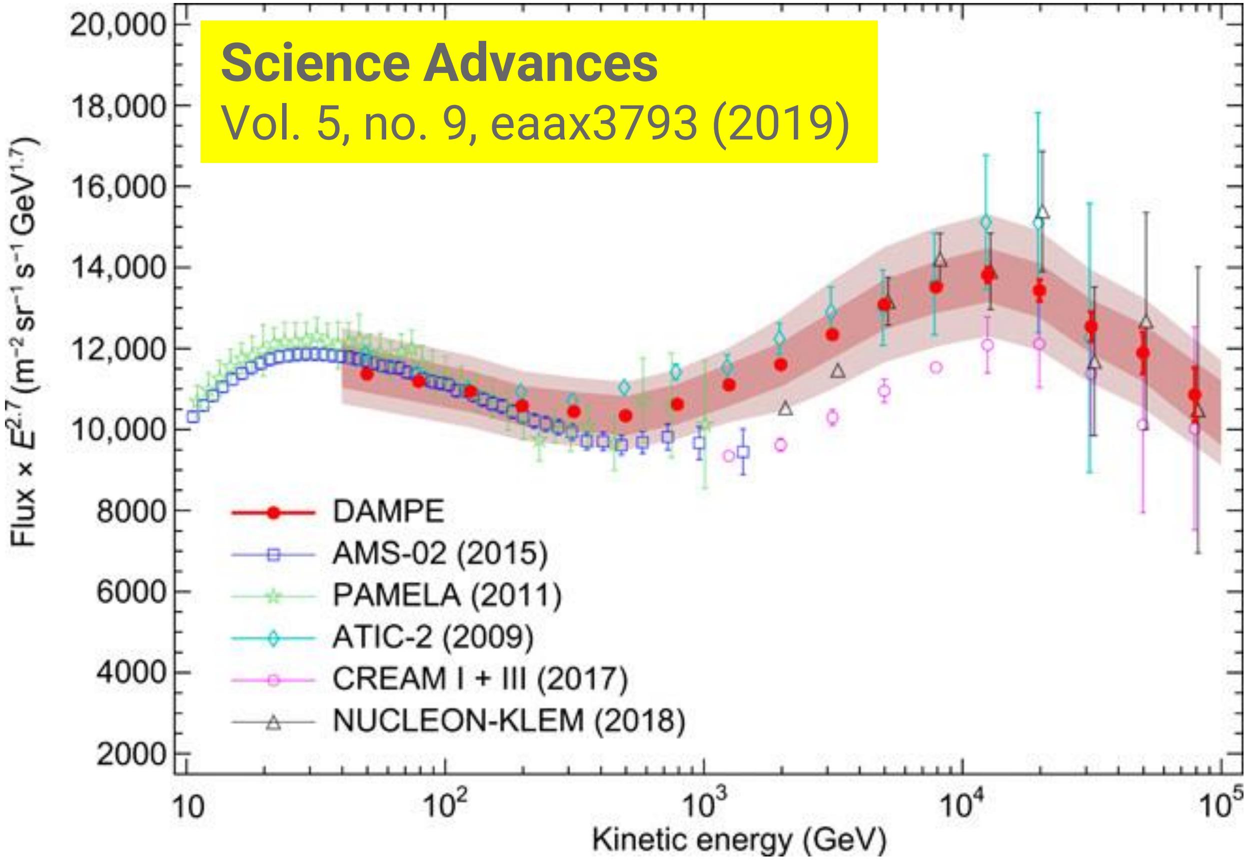




Direct measurements from several experiments before DAMPE:

- spectral hardening at few hundreds GeV
- hints of a softening above ~10TeV ?

CR Proton Spectrum by DAMPE



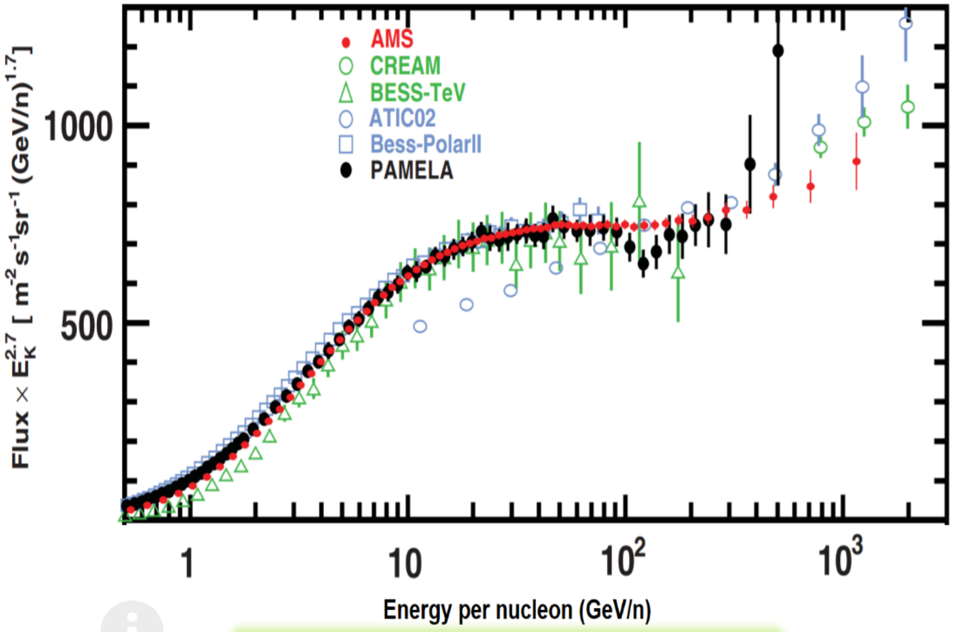
- Spectrum measured from 40 GeV to 100 TeV
- 30 months of data (01/01/2016 – 30/06/2018)
- **spectral hardening confirmed at ~400 GeV**
- **strong evidence of softening around 10 TeV**
- **fitting with a smoothly broken power-law:**
  $\gamma = 2.60 \rightarrow 2.85$ **at** $13.6^{+4.1}_{-4.8}$ **TeV**

The Lecce independent analysis (PhD Thesis by A. De Benedittis) observed the same structures, in agreement with the published result.

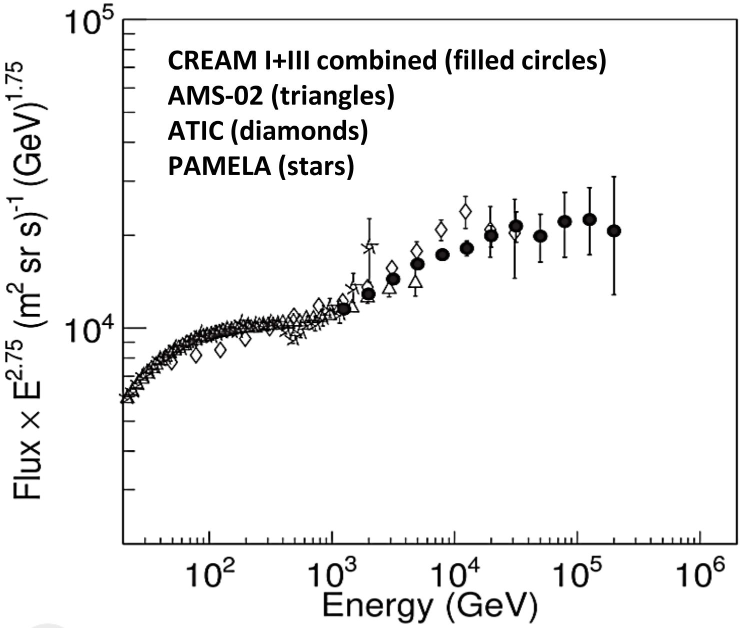
Possible explanations:

- Different classes of accelerators that generate different spectral shapes at the source
- Different acceleration regimes: propagation effects are different and dependent on rigidity
- CR fluxes due to a bck component from the uniformly distributed sources + the contribution of nearby sources (spectral bump at E~ 10 TeV)

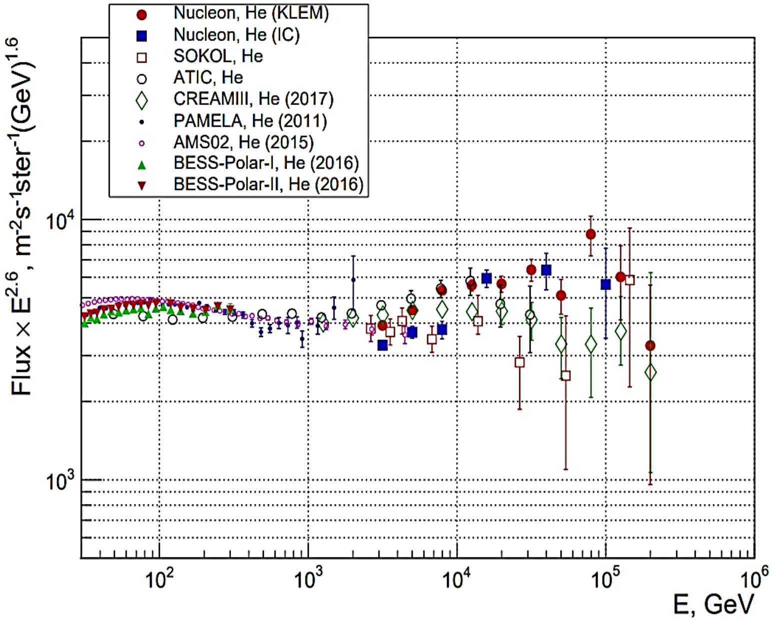
Spectra of Cosmic Ray nuclei: Helium



M. Aguilar *et al.* (AMS-2) PRL 119 (2017)



Y.S. Yoon *et al.* (CREAM) Astrophys. J. 839 (2017)



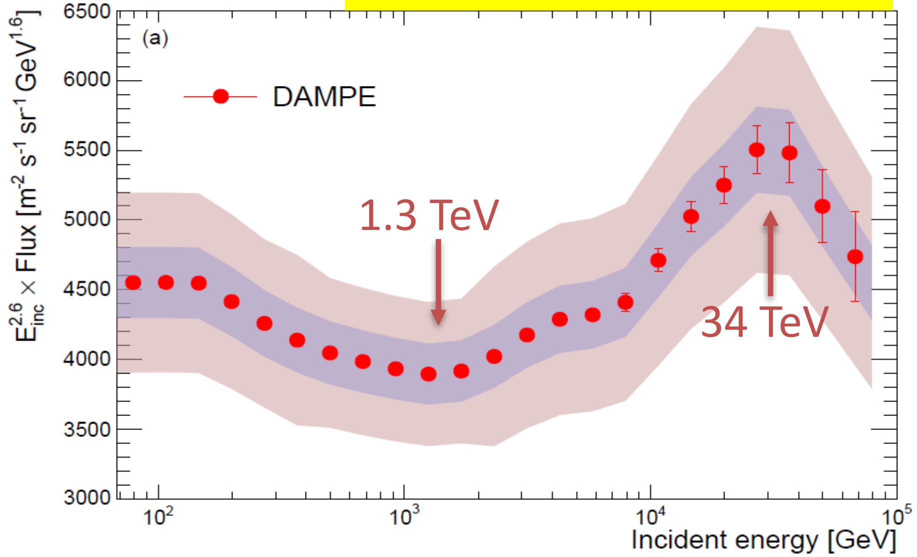
E. Atkin *et al.* (NUCLEON) arXiv:1702.02352 (2018)

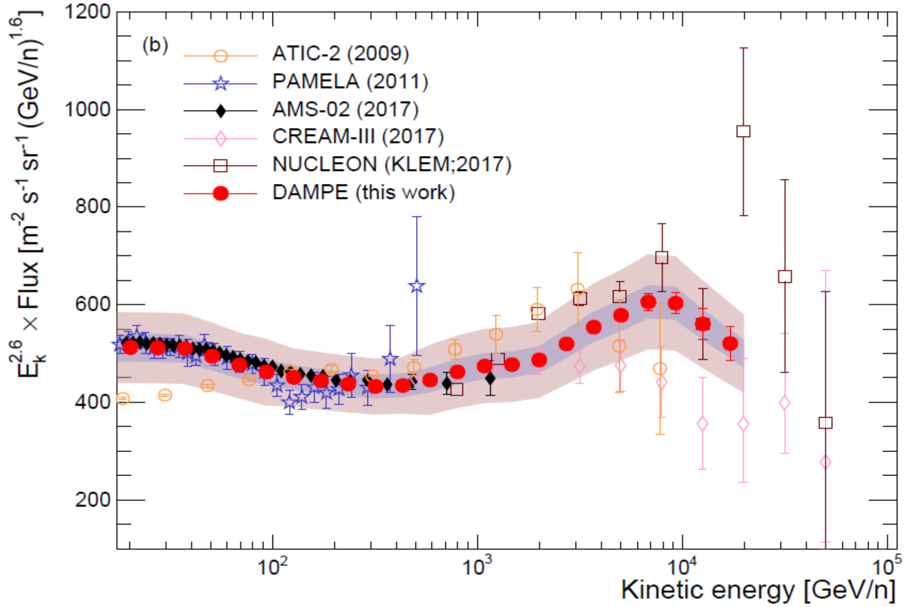
Previous direct measurements:

- spectral hardening at few hundreds GeV
- hints for any other structure at higher energies?

CR Helium spectrum by DAMPE

PRL 126, 201102 (2021)



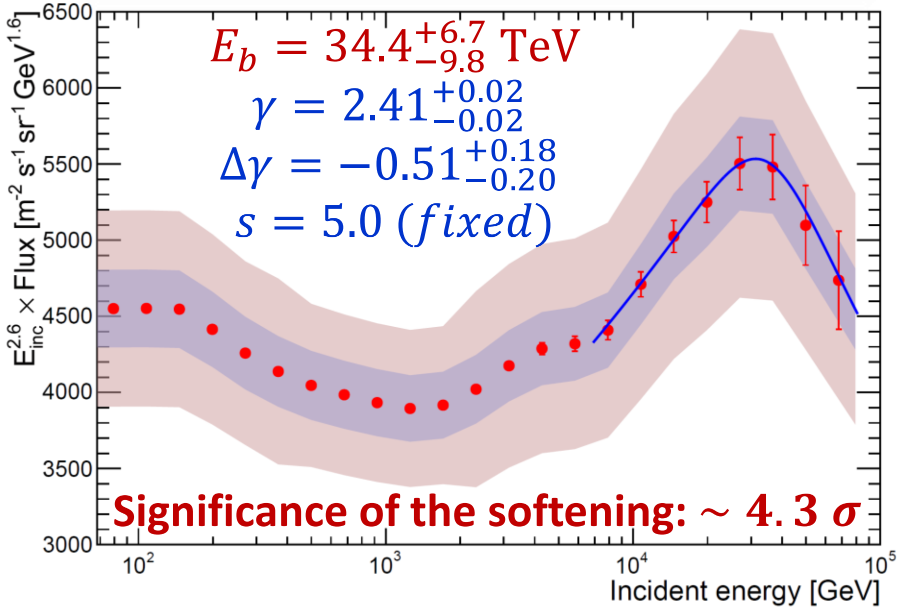


Comparison with the softening observed by DAMPE in the proton energy spectrum, at ~14 TeV, suggests a charge-dependent softening energy.

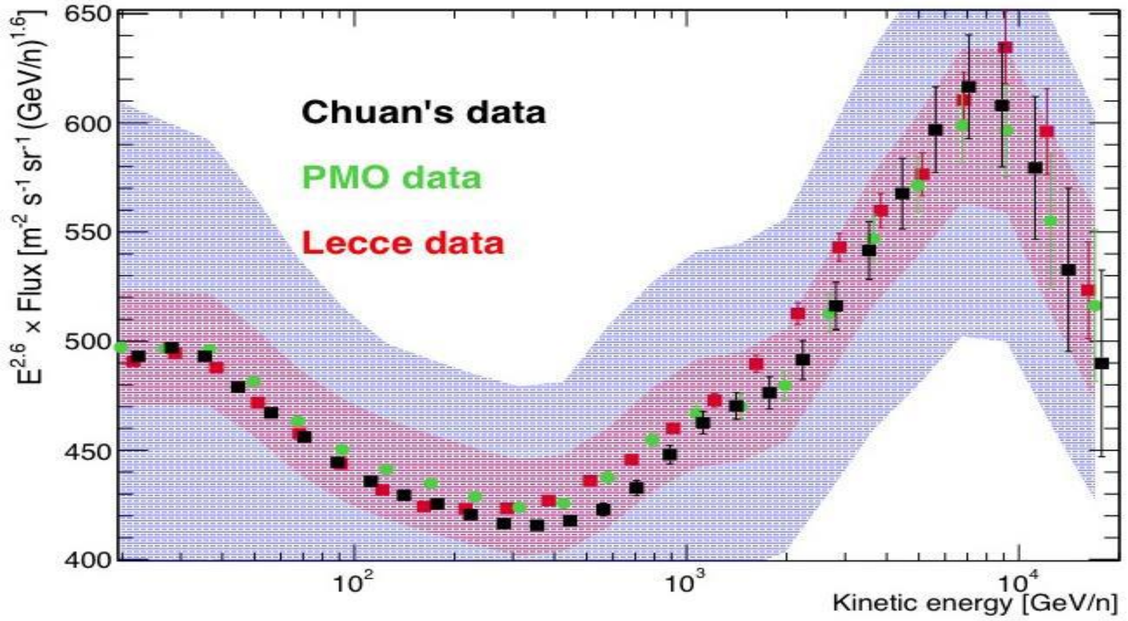
- ✓ Spectrum measured up to 80 TeV (4.5 y of collected data)
- ✓ **Hardening at ~300-400 GeV/n confirmed**
- ✓ **Clear evidence of softening at ~34 TeV**

BPL fit:

$$\Phi(\mathrm{E}) = \Phi_0 \left(\frac{E}{\mathrm{TeV}}\right)^{\gamma} \left[1 + \left(\frac{E}{E_b}\right)^{s}\right]^{\Delta\gamma/\omega}$$



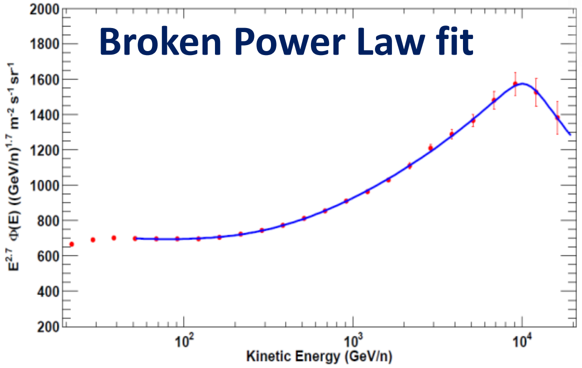
Lecce analysis: spectrum of CR He nuclei



- ✓ Three independent analyses
- ✓ Lecce analysis: PhD Thesis by M. Di Santo
- ✓ The three results in agreement within analysis uncertainty

Lecce analysis flux

Broken Power Law fit



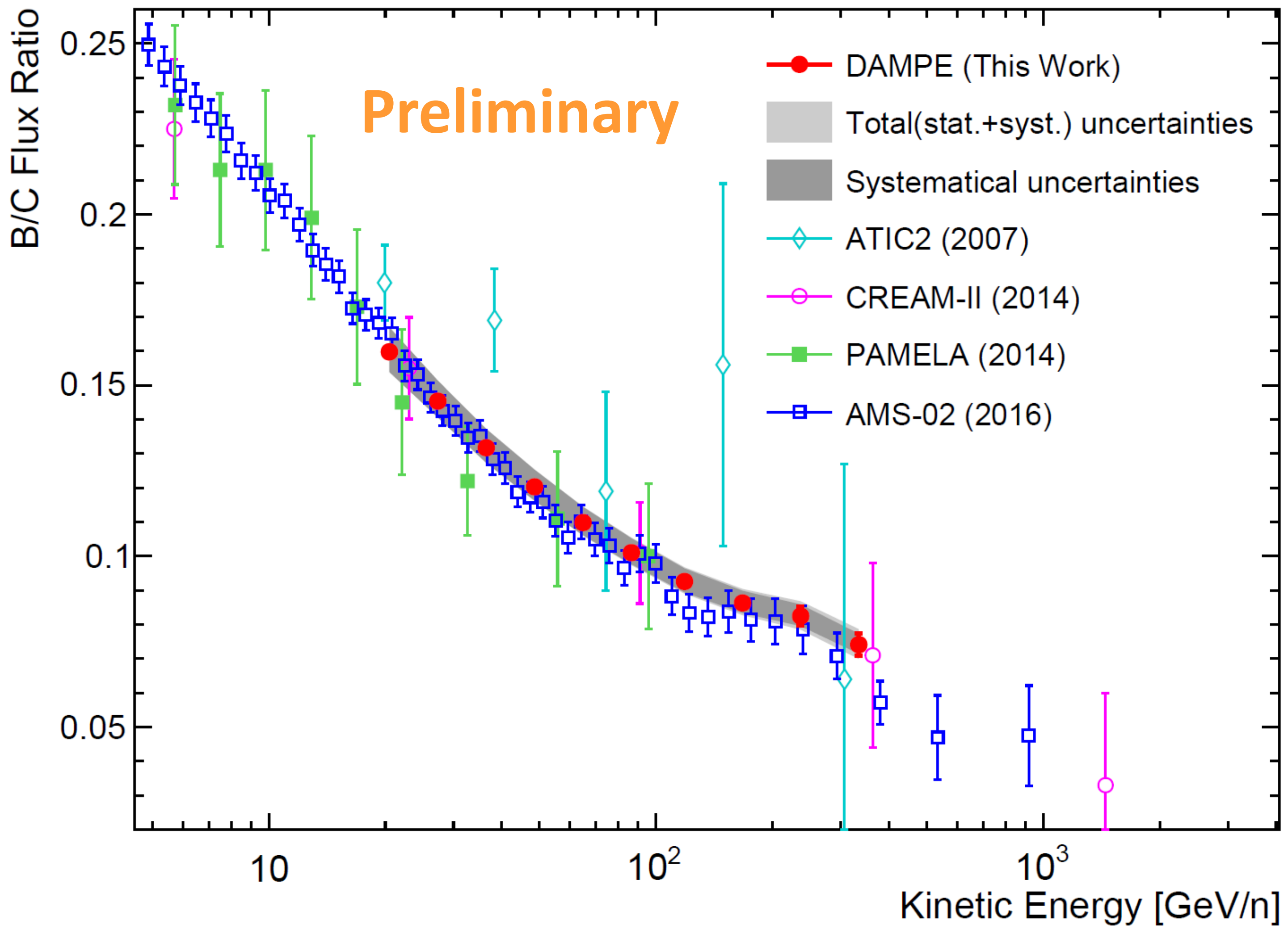
$$\Phi(E) = \Phi_0 \left(\frac{E}{TeV}\right)^{-\gamma} \left[1 + \left(\frac{E}{E_b}\right)^{1/\omega}\right]^{-\Delta\gamma\cdot\omega}$$

- Φ_0: flux value at 1 TeV
- γ : spectral index before break
- $\Delta\gamma$: index variation due to break
- E_b : break energy
- ω : *width* of the break region

Fit range	Hardening [0.05 – 2] TeV/n	Hardening [0.05 – 20] TeV/n
Φ_0 $((GeV/n)^{-1}m^{-2}s^{-1}\ sr^{-1})$	$(0.511 \pm 0.021) \times 10^{-5}$	$(0.488 \pm 0.023) \times 10^{-5}$
γ	2.72 ± 0.01	2.74 ± 0.01
$\Delta\gamma$	-0.242 ± 0.028	-0.289 ± 0.024
E_b (TeV/n)	0.227 ± 0.018	0.255 ± 0.016
ω	0.48 ± 0.10	0.62 ± 0.09

Fit range	Softening [2 – 20] TeV/n	Softening [0.05 – 20] TeV/n
Φ_0 $((GeV/n)^{-1}m^{-2}s^{-1}\ sr^{-1})$	$(0.733 \pm 0.021) \times 10^{-5}$	—
γ	2.45 ± 0.02	2.45 ± 0.01
$\Delta\gamma$	0.64 ± 0.36	0.66 ± 0.37
E_b (TeV/n)	10.4 ± 2.2	10.6 ± 2.0
ω	0.10 ± 0.07	0.10 ± 0.07

Measurement of B/C ratio



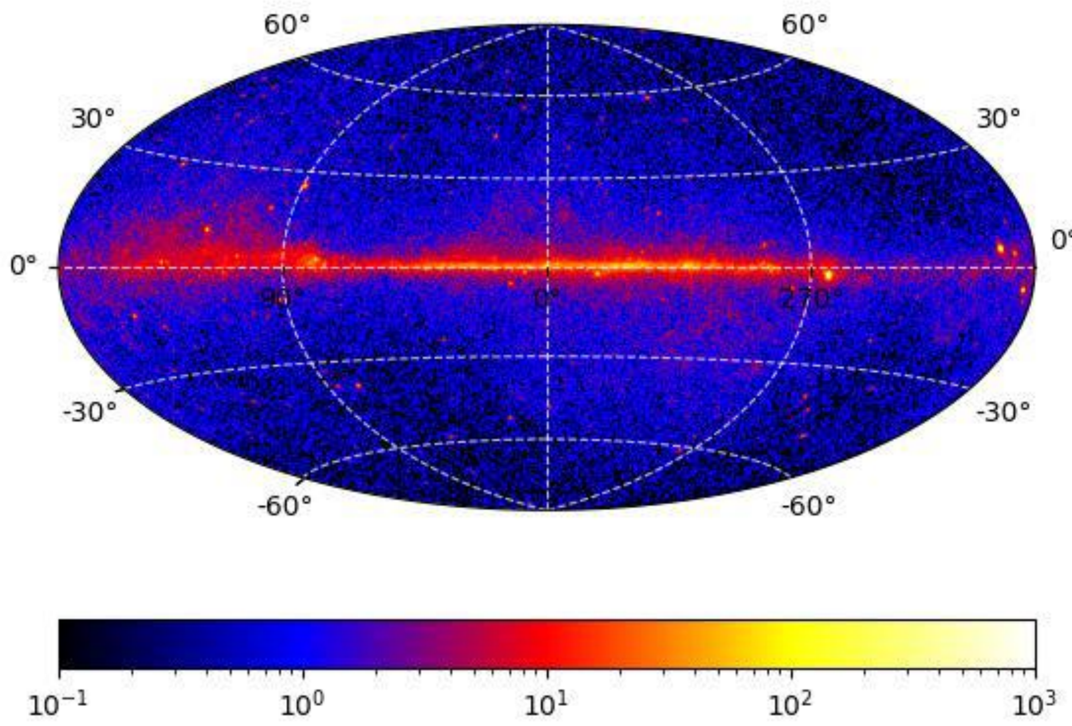
DAMPE result is consistent with PAMELA and AMS-02 below ~400 GeV/n within uncertainties

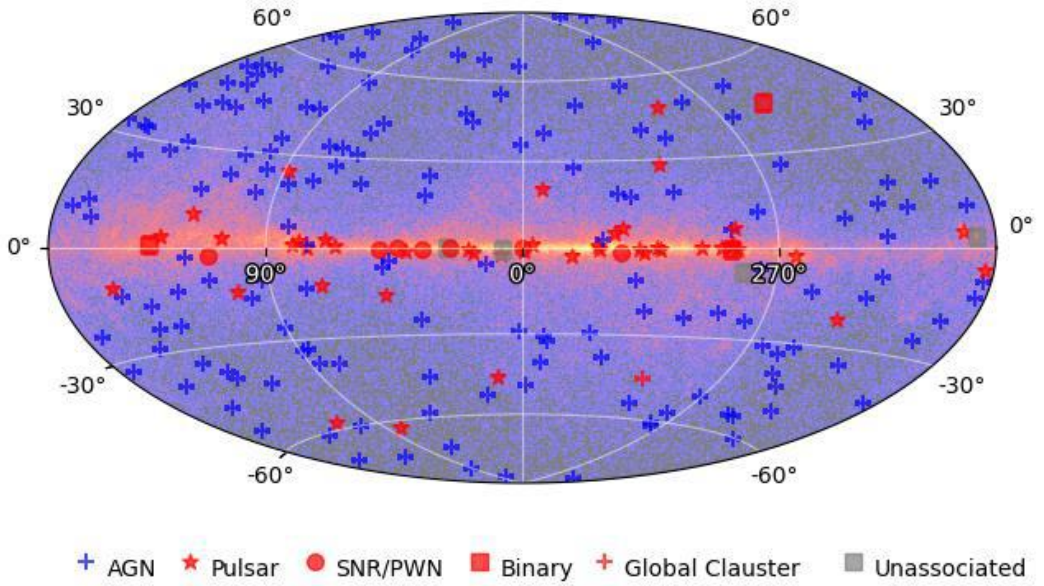
B/C flux ratio maybe cannot be described by a single power law on the whole energy range; measurement at higher energies needed.

Systematic shifts on separate fluxes (which cancel on ratio) to be solved …

Gamma ray sky map

Five years of data in galactic coordinates



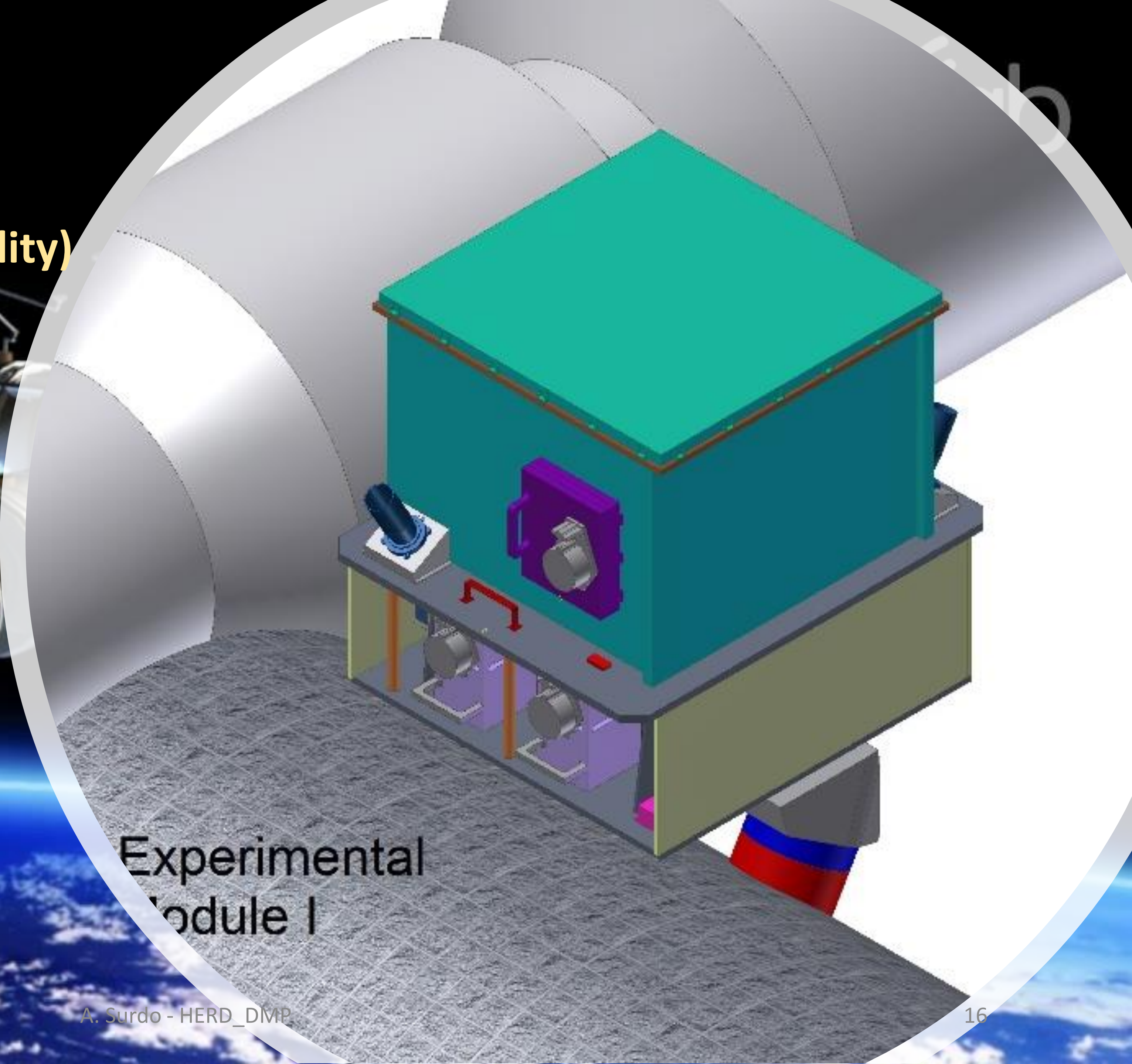


222 gamma-ray sources observed by DAMPE.
Most sources exhibit Power-Law spectrum
3 sources favors curved spectra.

Towards the future…

HERD

(High Energy Radiation Detection facility)

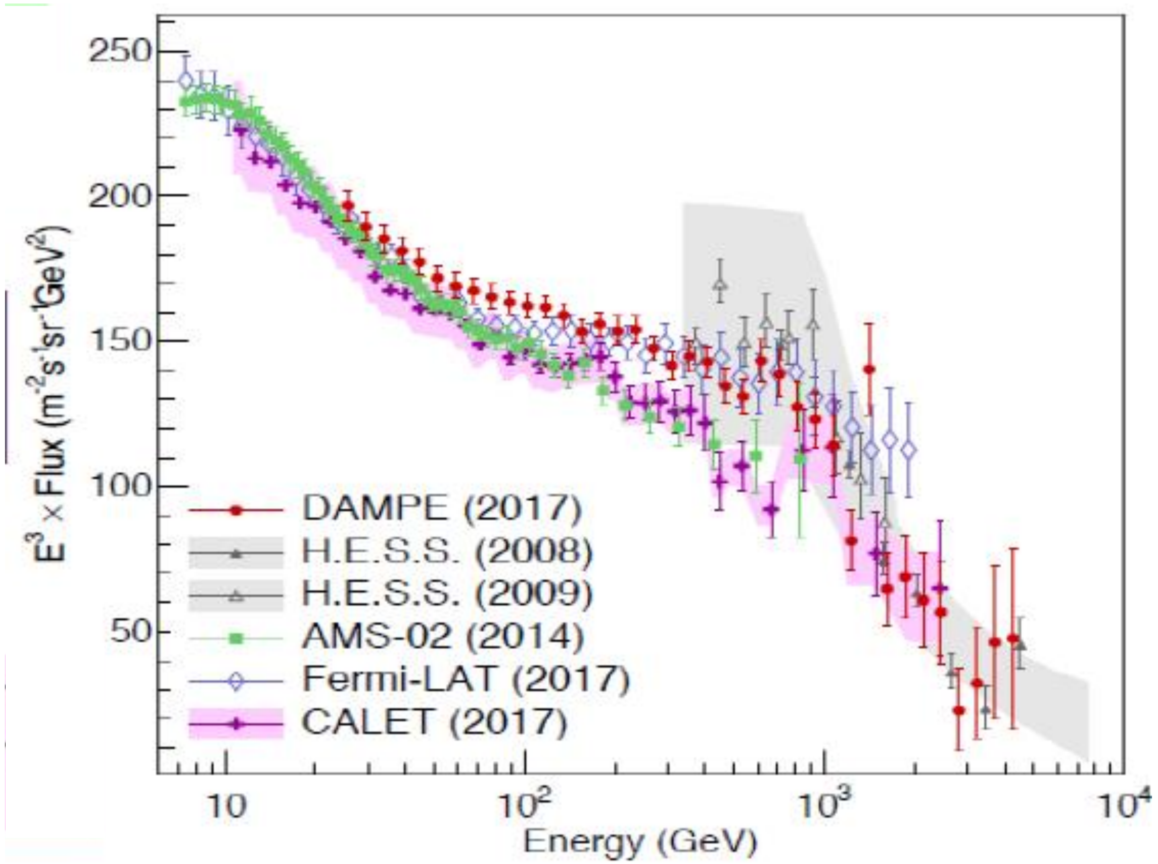


Life time	> 10y
Orbit	Circular LEO
Altitude	340-450 km
Inclination	42°

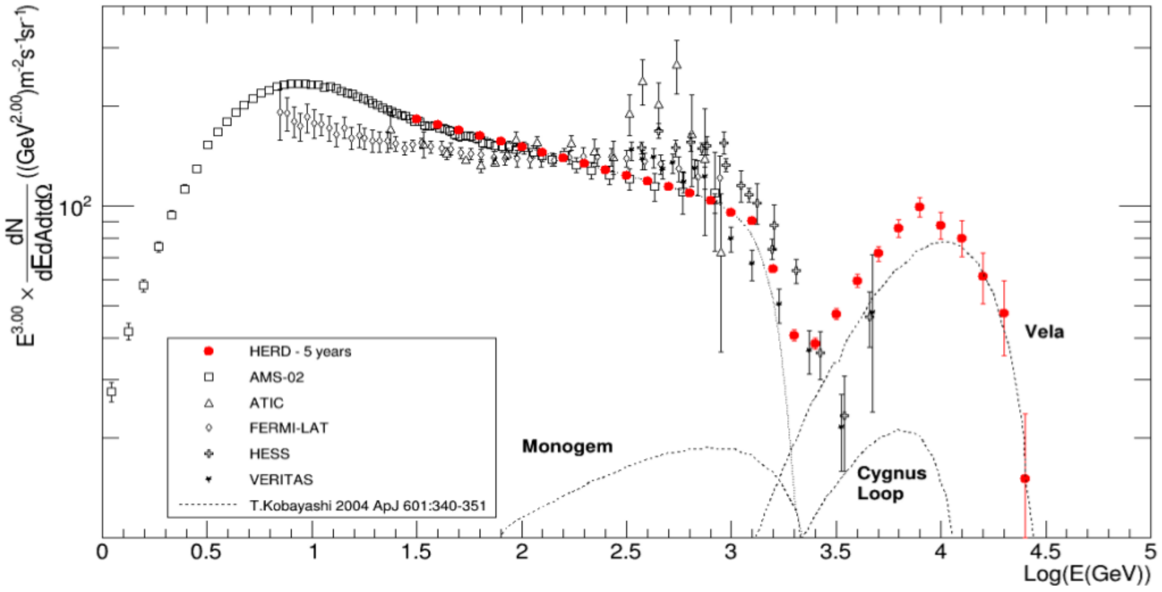
HERD: physics motivations

➢ Electrons/positrons

Recent measurements of the e^++e^- flux (Fermi-LAT, CALET, DAMPE) lead to **very different results** and **no clear conclusion**



Expected e^++e^- flux in 5 years



HERD could help in resolving the "conflict" between different measurements:

(a) improving the measurement precision

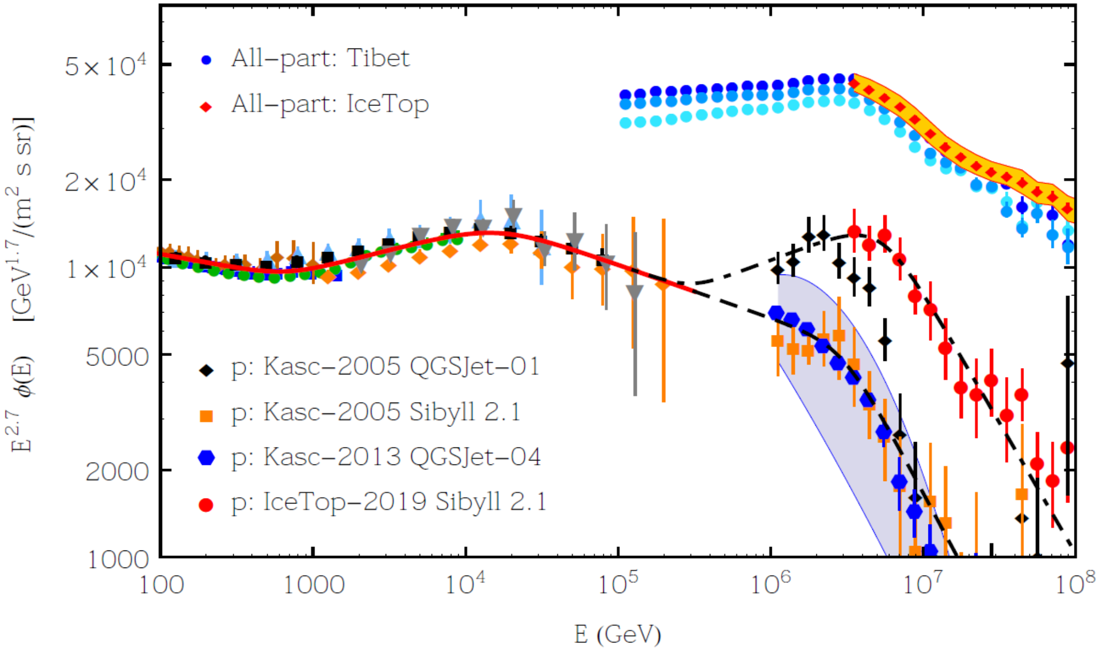
(b) extending the measurement to higher energy

HERD: physics motivations

➢ Cosmic rays

P. Lipari and S. Vernetto, arXiv:1911.01311v1 [astro-ph.HE]

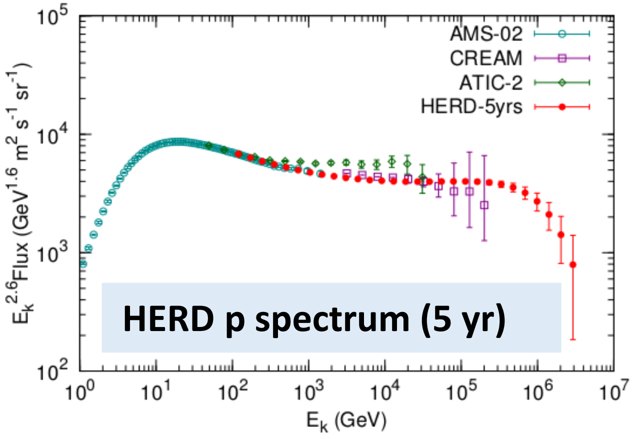
All-particle and proton spectra obtained by direct measurements and EAS observations

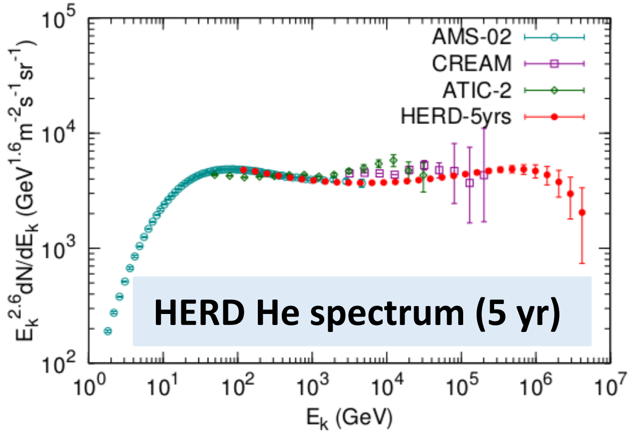


Understanding the origin of these unexpected spectral features is a significant challenge for models of the Galactic cosmic rays.

An important open question is whether additional features are present in the p spectrum between the softening and the "knee".

- Bridging direct to indirect detections
- Extending measure of p and He spectra over PeV energies



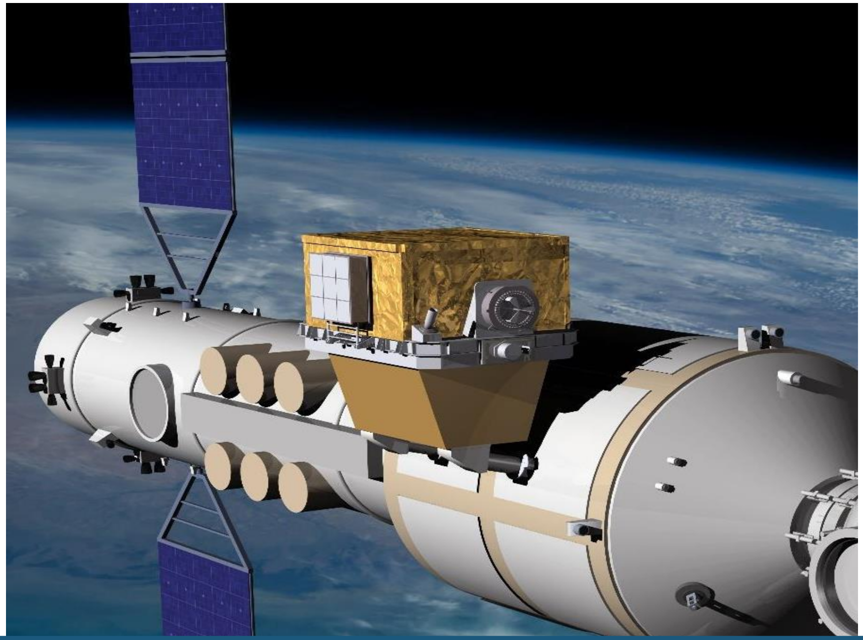


Estimates of the proton flux in the PeV energy range performed by Kascade and IceTop/IceCube for E≈2 PeV differ by a factor > 3

HERD Experiment

The **High Energy cosmic-Radiation Detection** (HERD) facility is a China-led international space mission that will start operation around 2026/27 on the Chinese Space Station (**CSS** expected to be completed in 2023)

The experiment is based on a **3D, homogeneous, isotropic and finely-segmented calorimeter** that fulfills the following requirements and goals



Item	Value
Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV - 100 TeV (γ)
Energy range (CR)	30 GeV - 3 PeV
Angular resolution	0.1 deg.@10 GeV
Charge resolution	0.1-0.15 c.u
Energy resolution (e)	1%@200 GeV
Energy resolution (p)	20%@100 GeV – PeV
e/p separation	~10^{-6}

Main Scientific goals
Direct measurement of cosmic ray flux and composition up to the knee region
Gamma-ray monitoring and full sky survey
Indirect dark matter search (e^++e^-, γ,...)

HERD Collaboration

CHINA

Institute of High Energy Physics, CAS (IHEP)
Xi'an Institute of Optical and Precision Mechanics, CAS (XIOPM)
Guangxi University (GXU)
Shandong University (SDU)
Southwest Jiaotong University (SWJTU)
Purple Mountain Observatory, CAS (PMO)
University of Science and Technology of China (USTC)
Yunnan Observatories (YNAO)
North Night Vision Technology (NVT)
University of Hong Kong (HKU)
Academia Sinica

ITALY

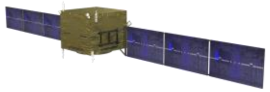
INFN Bari and Bari University
INFN Firenze and Firenze University
INFN Pavia and Pavia University
INFN Perugia and Perugia University
INFN Pisa and Pisa University
INFN Laboratori Nazionali del Gran Sasso and GSSI Gran Sasso Science Institute
INFN Lecce and Napoli University
INFN Napoli and Salento University
INFN Roma2 and Tor Vergata University
INFN Trieste and Trieste University

SPAIN

CIEMAT - Madrid
ICCUB – Barcellona
IFAE – Barcellona

SWITZERLAND

University of Geneva

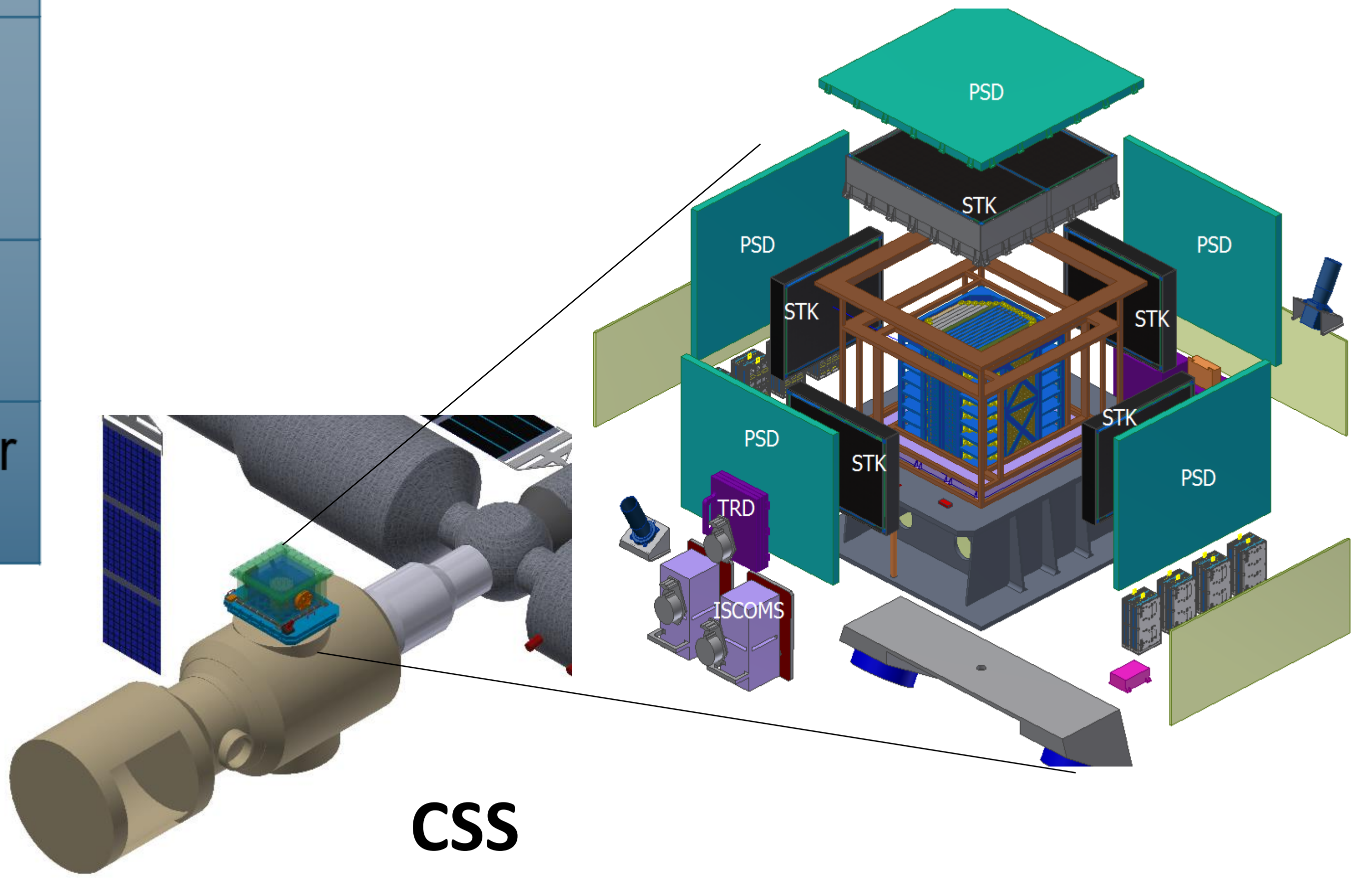



	HERD	DAMPE	CALET	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	<1	<1.5	2	3	10
e/γ Angular res.@100 GeV (deg.)	< 0.1	<0.2	0.2	0.3	0.1
e/p discrimination	$>10^6$	$>10^5$	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	55	32	27	17	8.6
Geometrical accep. ($m^2 sr$)	>3	0.3	0.12	0.09*	1

*After analysis cuts for electrons

HERD: basic layout

CALO	Energy Reconstruction e/p Discrimination
STK	Trajectory Reconstruction Charge Identification
PSD	Charge Reconstruction γ Identification
TRD	Calibration of CALO response for TeV proton



The HERD design

Detector design still in progress …

MC simulations to optimize the geometry

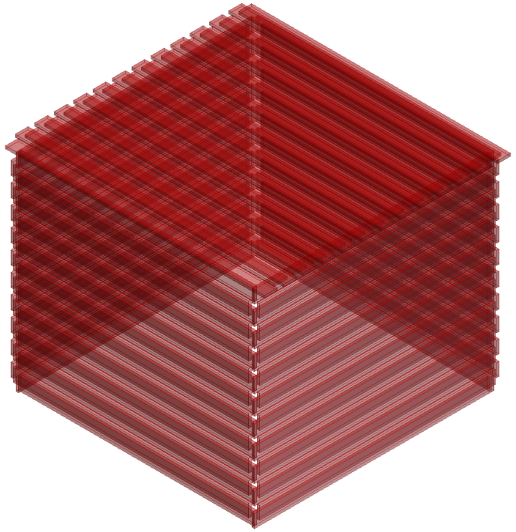
PSD (plastic scintillator detector)

- Low energy gamma identification (veto)
- CR identification by Charge Measurement

- Basic design
  - 1 X/Y layer on top and 4 lateral sides
    for Z measurement and e/gamma discrimination
  - SiPM + IDE3380 ASIC (Low & high range to cover Z=1-26)

- Bars vs Tiles layout resulting from:

- efficiency optimization
- backsplash effects
- mechanics
- no. of Read-out channels



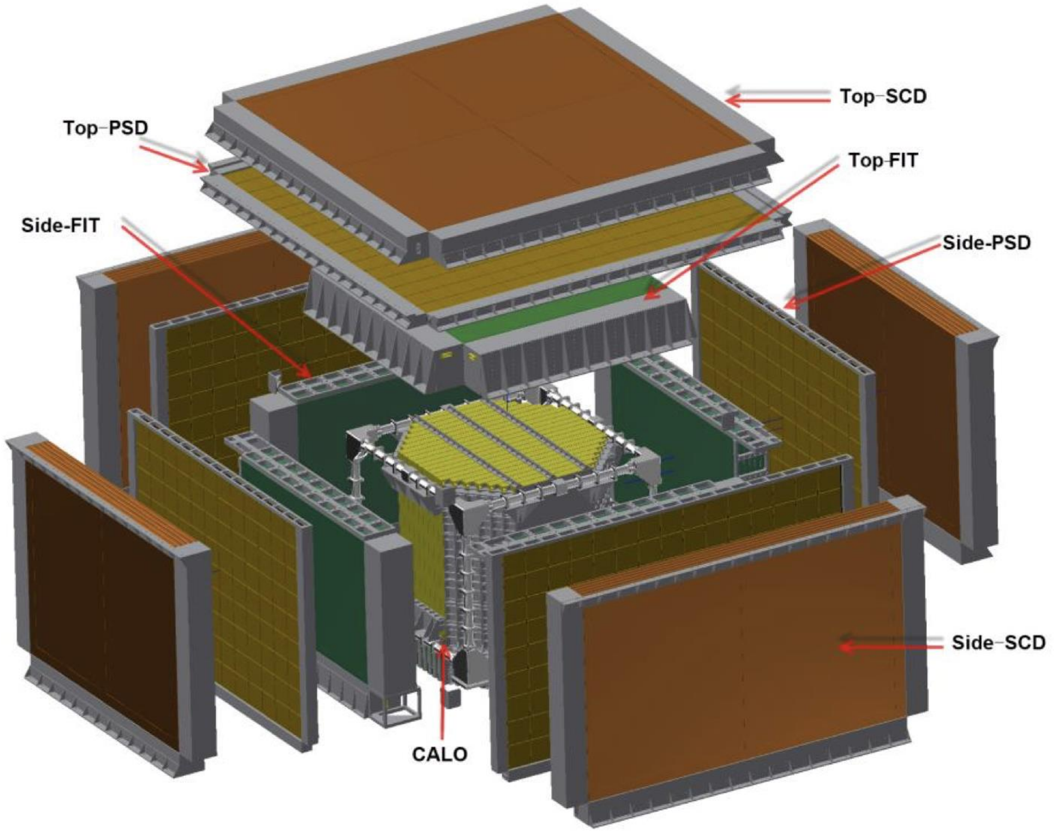
From DAMPE data and MC:

effects of nuclear interactions in PSD critical for identifying charge of heavy nuclei from dE/dx measurement

The HERD design

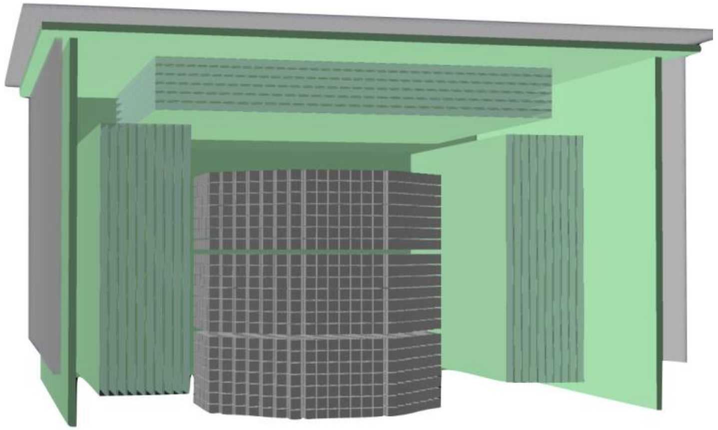
Improved configuration

- Good for nuclei detection
- Performance unchanged for electrons
- SCD: Silicon Charge Detector with silicon microstrips
  - redundant measurement and tracking on all sides
- FIT: Fiber Tracker
  - photon conversion and tracking on all sides
- PSD: Veto for gamma identification
  - charge measurement
  - reduction of backsplash events
- CALO: LYSO Calorimeter



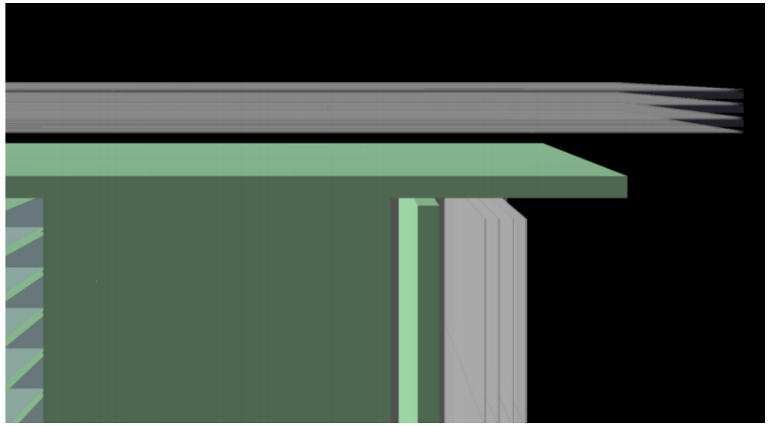
Confirmation and suggestions arriving from MC

HERD Silicon Charge Detector (SCD)

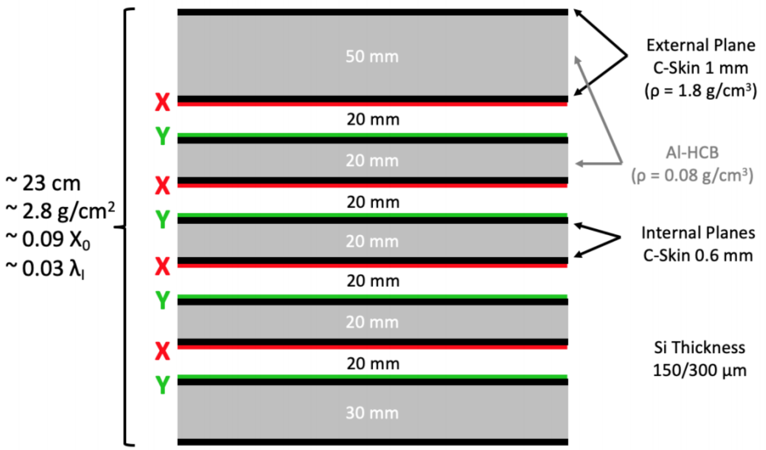


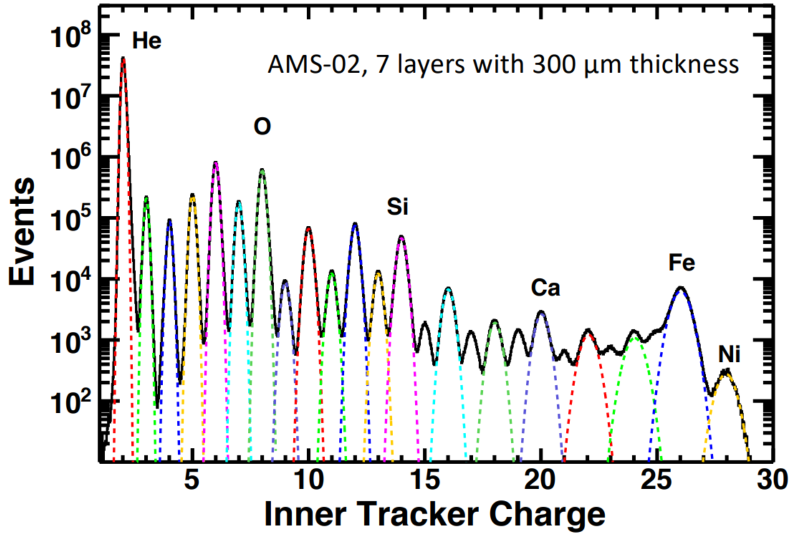
SCD is the outermost detector to identify the ions with high accuracy

9.5cm x 9.5cm x 150um silicon wafers
8 single sided top layers - 1.92m x 1.92m
8 single sided side layers - 1.72m x 0.86m
Carbon fiber support structures



SCD Simple Design (à la DAMPE)

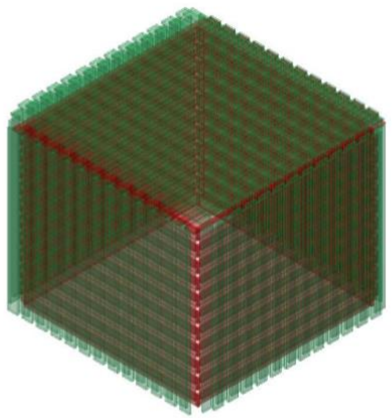


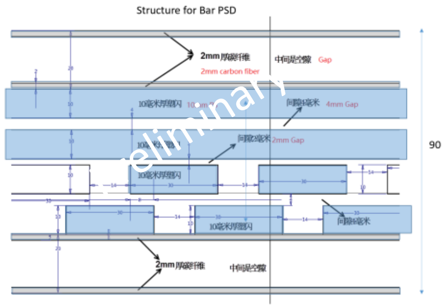


HERD Plastic Scintillator Detector (PSD)

- PSD provide γ **identification** (VETO of charged particles) and **nuclei identification** (energy loss $\propto Z^2$)
- PSD needs to have a very high efficiency in charged particles detection (>99,98%) to be used as veto, but also a very high dynamic range to identify nuclei at least up to iron
- Back-scattering can greatly degrade the PID performances

Two layout configuration are under investigation:



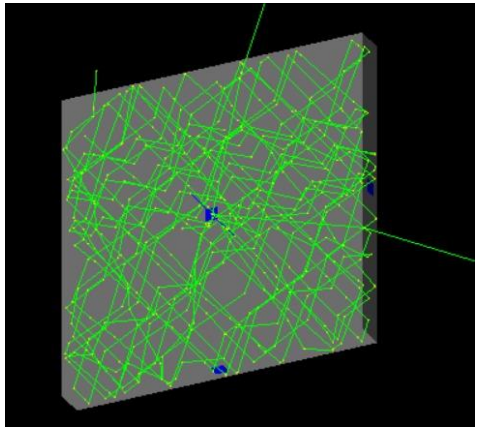


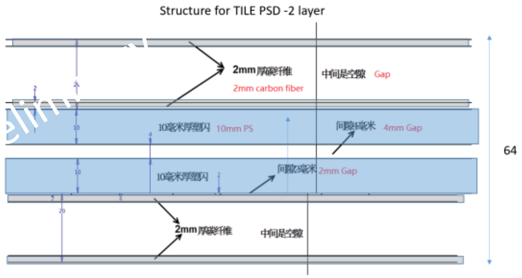
▪ Bar option

- Long bars 160x3x1 cm^3
- Two layers (X and Y)
- Read-out with 4 SiPM (two for each end)
- PRO
  - Less number of readout channel
- CONS
  - Higher Back-scattering problem

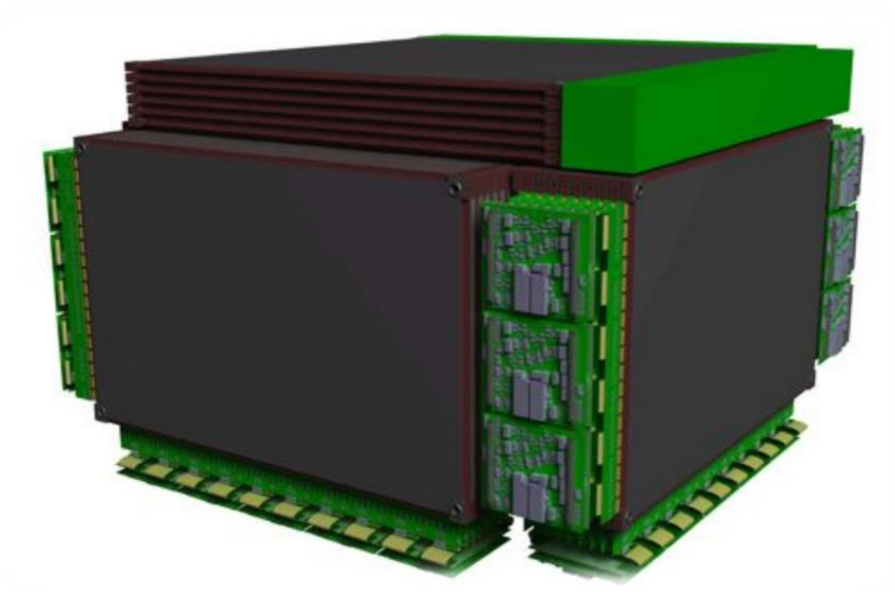
▪ Tile option

- Small square tile 10x10x1 cm^3
- Two layer of tiles to increase nuclei Id
- Each tile is readout by 6 SiPM (three on two sides)
- PRO
  - Reduce back-scattering problem
- CONS
  - Higher number of readout channel



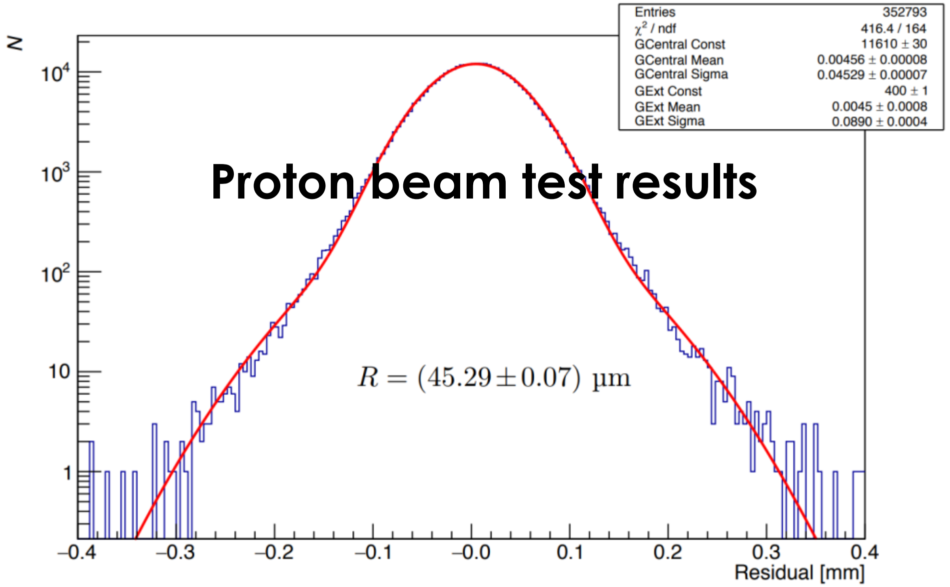


HERD Fiber Tracker (PSD)



- 4 identical side sectors + 1 top sector
- 7 x-y planes in each side and top sector
- 6 x modules (106 cm fiber length) in each x plane
- 10 y modules (77 cm fiber length) in each y plane
- 1 fiber mat + 3 silicon photomultiplier (SiPM) arrays

Residual distribution for the reconstructed tracks



$$\sigma_{FIT} = (45.0 \pm 0.1)\ \mu m$$

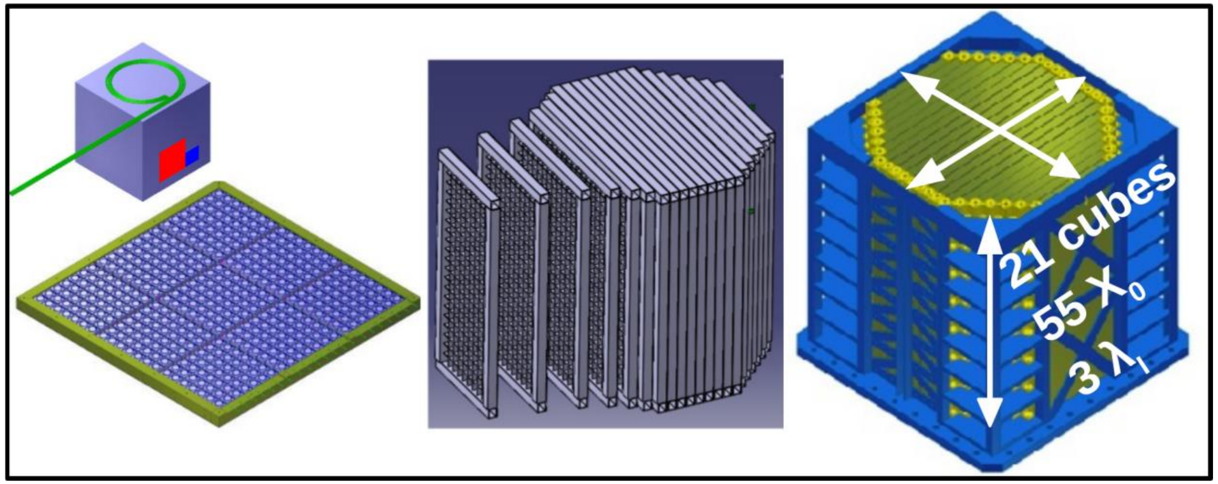
Takes into account the external tracker resolution

Ion identification capability
Very preliminary results

Z	μ_Z	σ_Z	σ_Z/μ_Z
2	1.99	0.31	15 %
3	3.07	0.40	13 %
4	4.01	0.51	12 %

Preliminary

HERD CALOremeter (CALO)



Octagonal homogeneous Prism made of about **7500 LYSO** cubic crystals, each of 3 cm side

Overall dimensions: 80x80x80 cm^3

Depth: 55 X_0

Deep homogeneous calorimeter	Good energy resolution
Isotropic 3D geometry	Large geometric factor (top + lateral faces)
Shower imaging with 3D segmentation	Good e/p discrimination, identification of shower axis and of shower starting point

Read-out by two independent systems:

1. WLS fibers coupled to image Intensified scientific CMOS (IsCMOS) cameras
2. photo-diodes (PD) connected to custom front-end electronics (HIDRA)

The ***double read-out system*** achieves the capability of cross-calibrating the scintillation light measurement and help in **reduce the systematic errors**

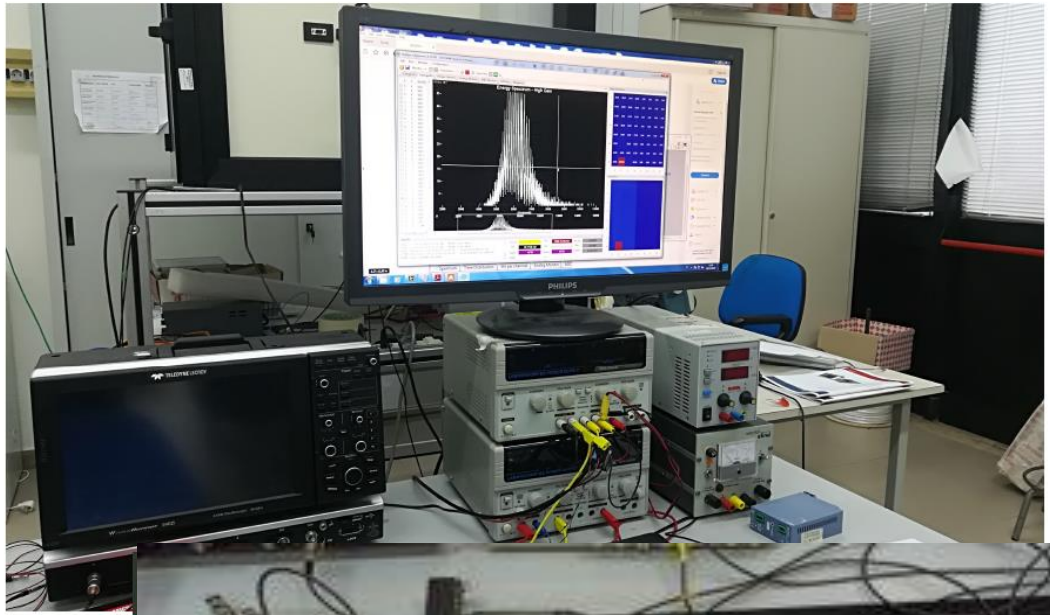
HERD: Attività del Gruppo di Lecce

- Software:
  - simulazione MC per ottimizzazione geometria e struttura del rivelatore
  - simulazione risposta PSD nella cfg a barre e a tile (reiezione back-splash)

- In laboratorio (in collaborazione con BA, GSSI, PV):
  - studio segmentazione PSD (barre o tile) per ottimizzare geometria e meccanica
  - studio read-out in varie configurazioni dei SiPM per ottimizzare efficienza e range dinamico (Z da 1 a 26)
  - uso di diversi tipi di SiPM, con caratteristiche differenti
  - riprogrammazione DAQ-board CAEN per il DAQ dei prototipi nei beam-test

- Beam-test in autunno al CERN (PS ed SPS):
  - risposta (efficienza, uniformità, risoluzione in carica, …) PSD da lettura con SiPM
  - scelta tra barre (vari spessori) e tile PSD
  - risposta e misura di carica di un piano di SCD
  - risposta da prototipo di tracciatore FIT
  - risposta da prototipo di CALO letto con CMOS e FD

HERD: Attività in Lab



CAEN DT5550W
2 citiroc

- Characterization of SiPM with LED
- First tests on bars with SiPMs
- Tuning DAQ System
- CAEN DAQ board firmware re-programming
- …

HERD: stato di approvazione ed avanzamento

- HERD selezionato (in alta priorità) tra i progetti scientifici inclusi nel programma strategico di Scienza nello Spazio per la Chinese Space Station
- Non ancora approvato ufficialmente dai più alti Organi decisionali cinesi
- Re-design tecnico del modulo di lancio per HERD, in seguito al venir meno del «modulo italiano» (cambio della politica in campo spaziale)
- Maggio-2021: incontro formale tra ASI e Agenzia Spaziale Cinese (CMSA)
- ASI: interesse a partecipare (e finanziare) l'impresa scientifica di HERD

  - in attesa dello sblocco dei fondi da parte del COMINT

  - definizione entità e profilo del finanziamento

  - firma del MoU con l'Agenzia Spaziale Cinese

HERD: programma per il 2022

- Definizione entità e profilo di finanziamento ASI in progress …
- Ulteriore anno di R&D dopo il triennio 2019/21
- Realizzazione del prototipo completo di una faccia del rivelatore (scala 1:1)
- Beam-Test sul prototipi (CERN, CNAO)
- Test meccanici, elettrici e vibrazionali
- …

Tesi e Relazioni a Convegni 2020-2021

- ✓ Tesi di Dottorato A. De Benedittis (Apr 2020): “*The protonic component of CRs measured with DAMPE*”
- ✓ Tesi di Dottorato M. Di Santo (Feb 2021): “*Cosmic Ray Helium spectrum measured with the DARK MATTER PARTICLE ESPLORER Experiment*”
- ✓ Tesi di Laurea Magistrale E. Casilli (Dic 2020): “*Studio della Radiazione Cosmica primaria con DAMPE*”
- ✓ M. Di Santo, “ Cosmic Ray Helium spectrum measured by DAMPE“, 106^ SIF (2020)
- ✓ P. Bernardini "Measurements of the cosmic rays fluxes with DAMPE satellite", invited talk a "Les Rencontres de Physique de la Vallee d'Aoste", La Thuile (2020)
- ✓ P. Bernardini «The fluxes of charged cosmic rays as measured by the DAMPE satellite", talk at «Marcel Grossman Meeting», 2021

Ruoli di responsabilità

- ✓ Convenor «Cosmic-Ray Analysis Working Group»

P. Bernardini $\rightarrow$ A.S.

Anagrafica HERD_DMP

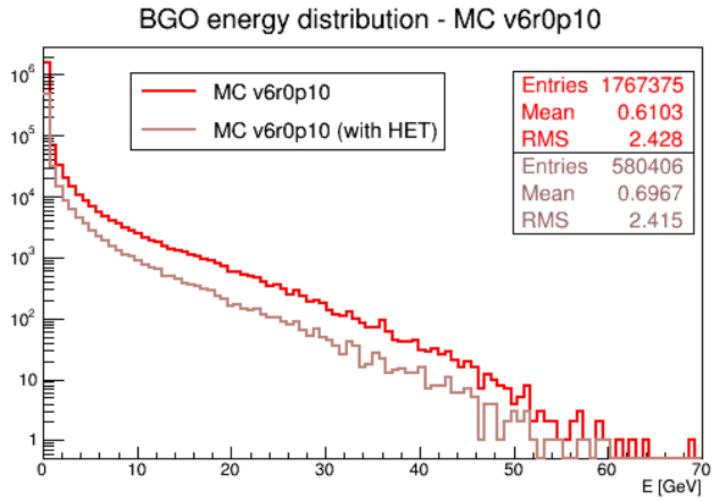
Ricercatori		
Nome	Contratto	%
Bernardini P.	Prof. Associato	50
de Palma F.	Ricercatore Univ.	30
Perrone L.	Prof. Associato	20
Surdo A.	Primo Ricercatore	60
+ Dottorando (?)	Dottorando	100

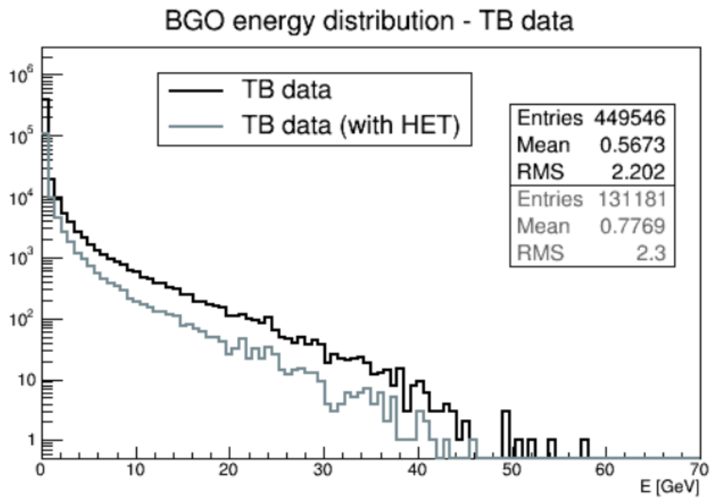
Tecnologi		
Nome	Contratto	%
Creti P.	Primo Tecnologo	30

+ 2 m.u. Servizio Elettronica

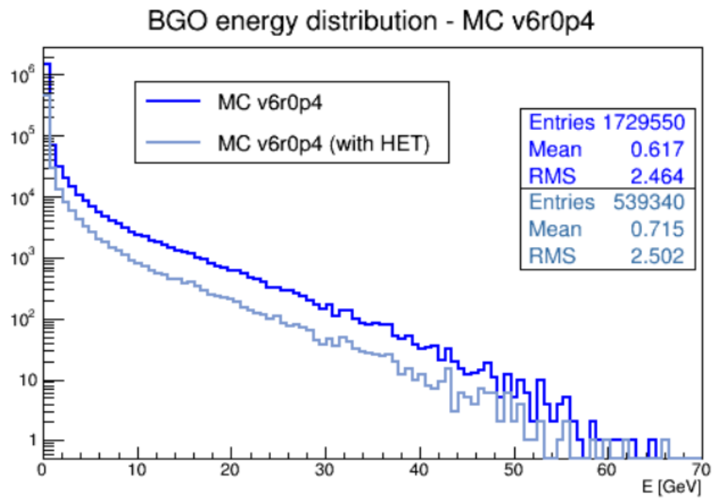
BACKUP

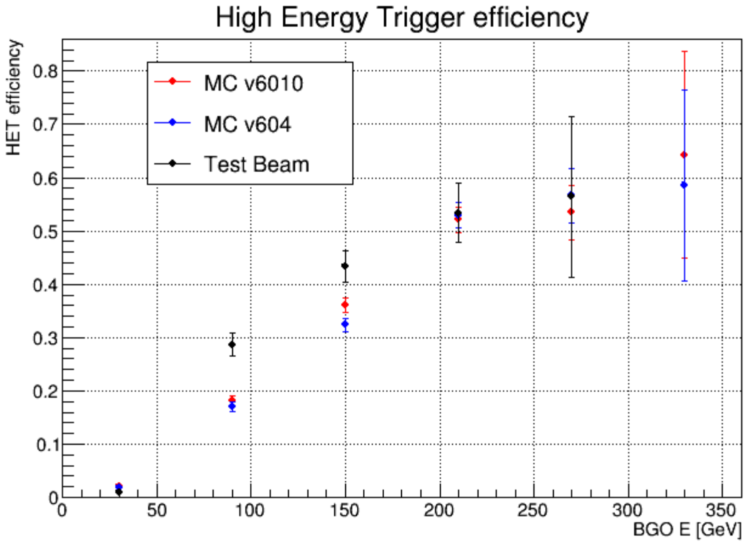
HE Trigger





Validation of new version of MC simulation concerning HE trigger response, on the basis of Test-Beam data (E. Casilli)





HE Trigger efficiency

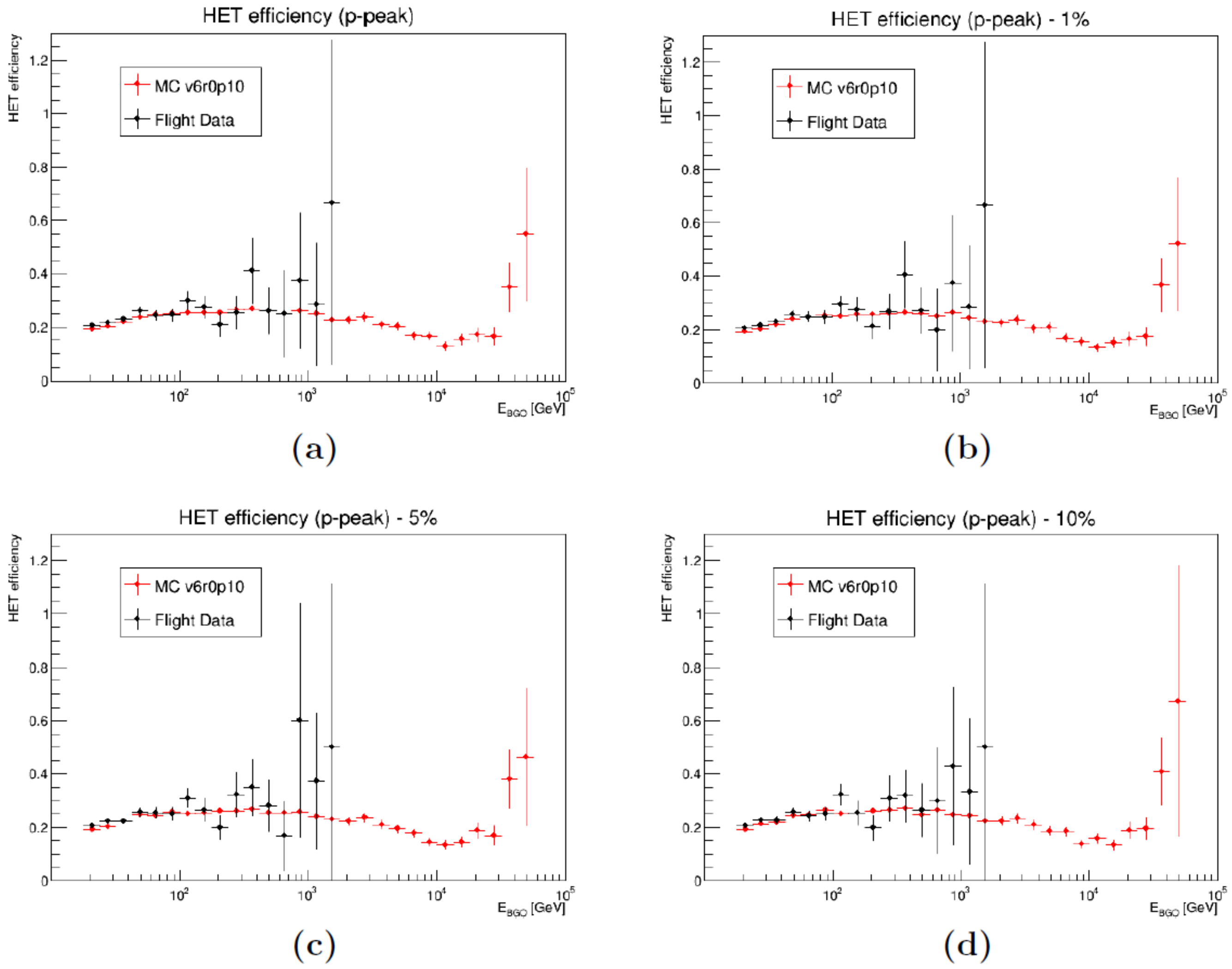
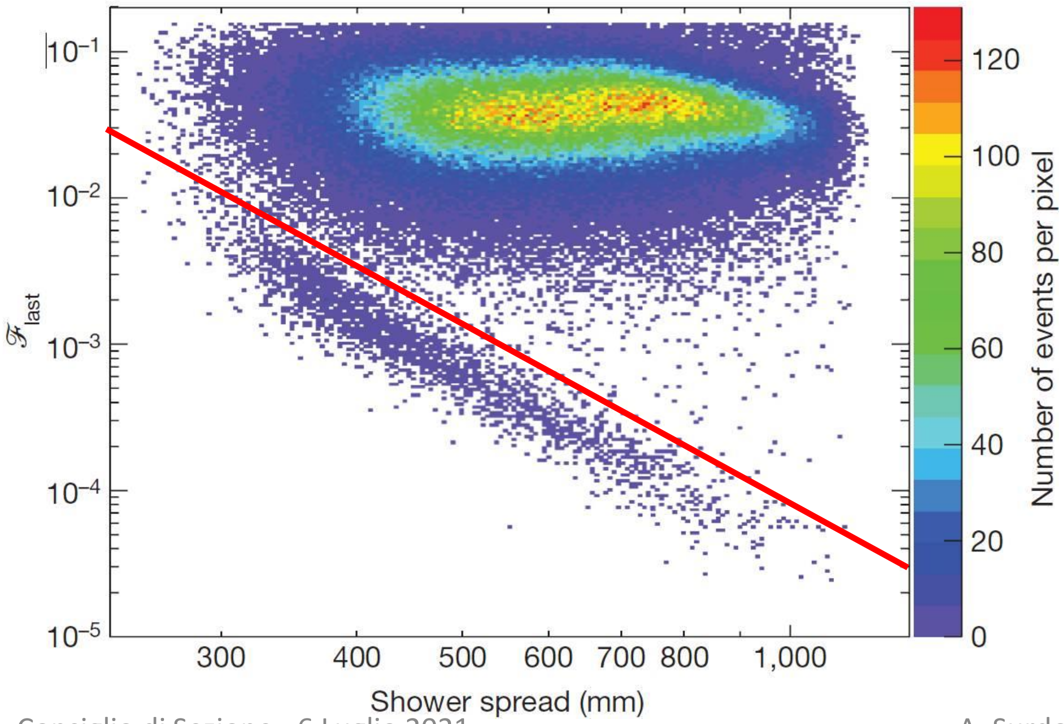
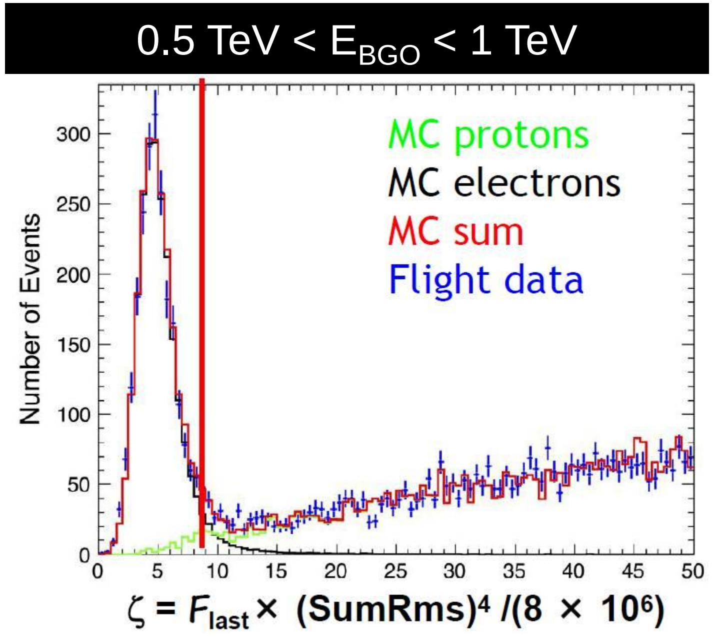


Figura 4.16: *Nel riquadro* **(a)**, *efficienza dell'HET in funzione dell'energia depositata nel BGO, per i campioni relativi ai protoni dei raggi cosmici e MC selezionati. Lo stesso grafico è stato ottenuto a seguito di una correzione che rimuove gli hits contenenti l'1%* **(b)**, *il 5%* **(c)** *e il 10%* **(d)** *dell'energia totale rilasciata all'interno del calorimetro.*

Electron/proton separation

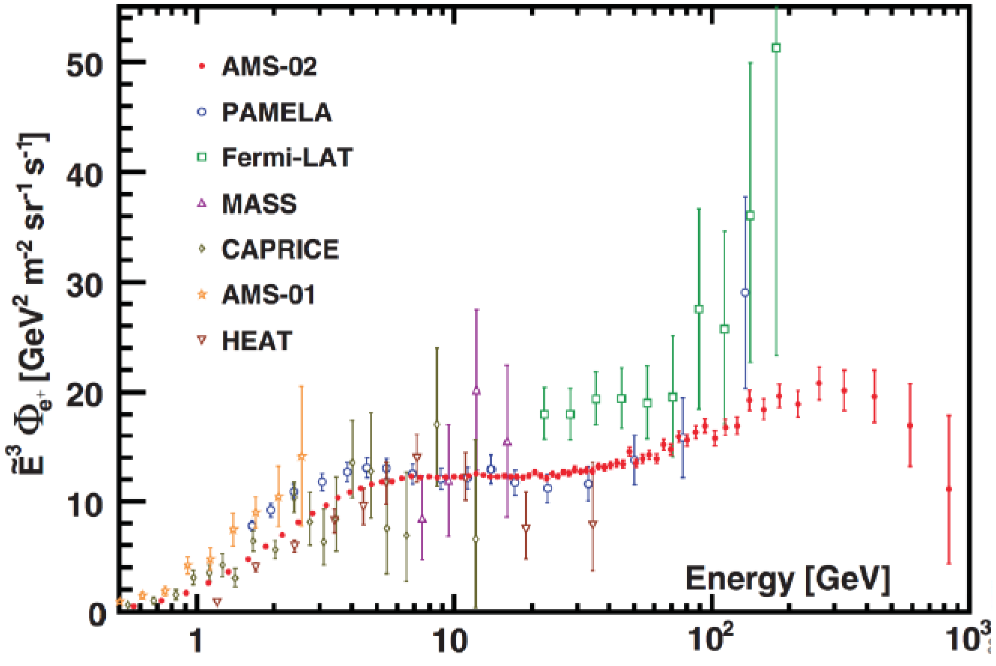
- The "ζ shower parameter" was computed from the lateral shower development in BGO and the energy deposition in the last layer
  - the cut $\zeta > 8.5$ was adopted to discriminate e^- (and e^+) from p
  - for 90% $e^\pm$ efficiency, p background ~2% @ 1 TeV, ~5% @ 2 TeV, ~10% @ 5 TeV

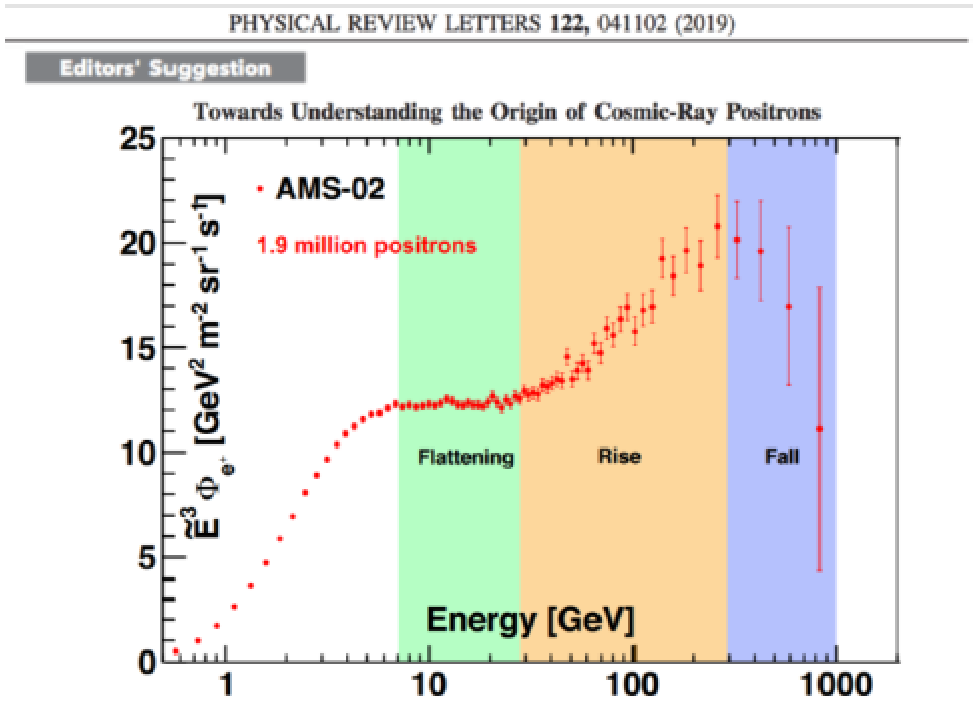




The positron excess (PAMELA and AMS-02)

Precision measurements by AMS of the positron flux to 1 TeV.



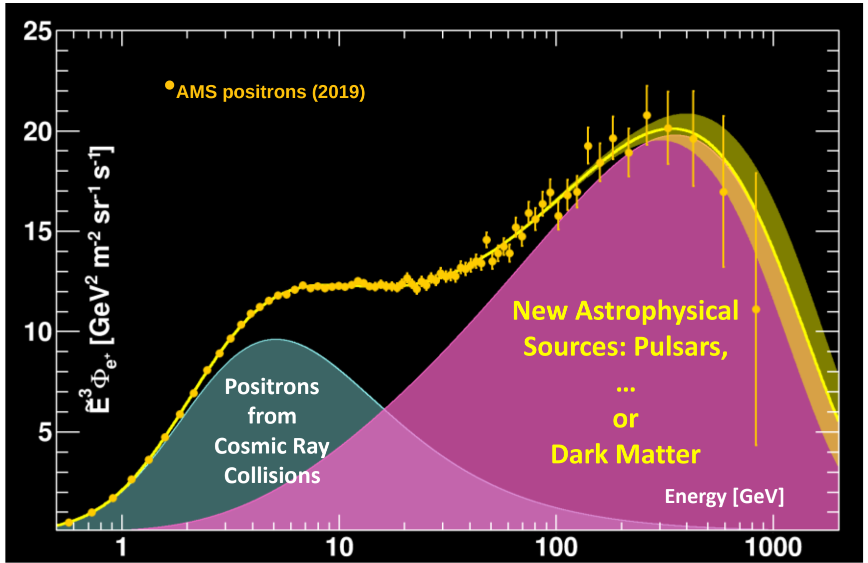


The positron flux shows a well-defined energy dependence:

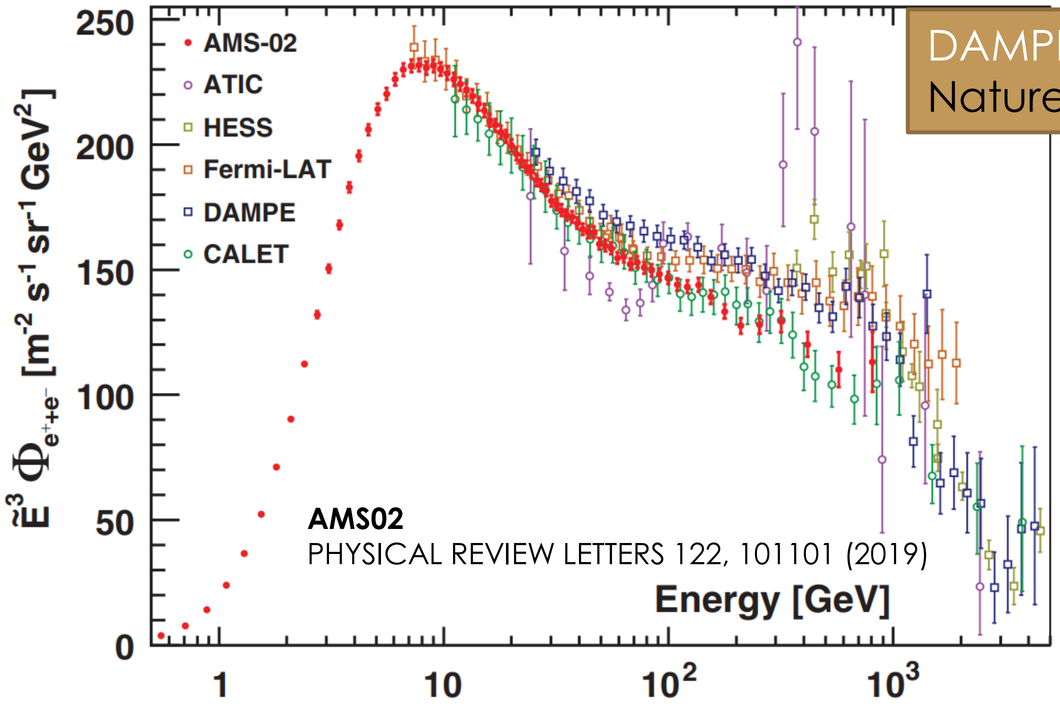
- A rise @ 25.2 GeV
- A fall above 284 GeV

The positron flux could be described by the sum of a diffuse term and a new source term with a finite energy cutoff at almost 800 GeV

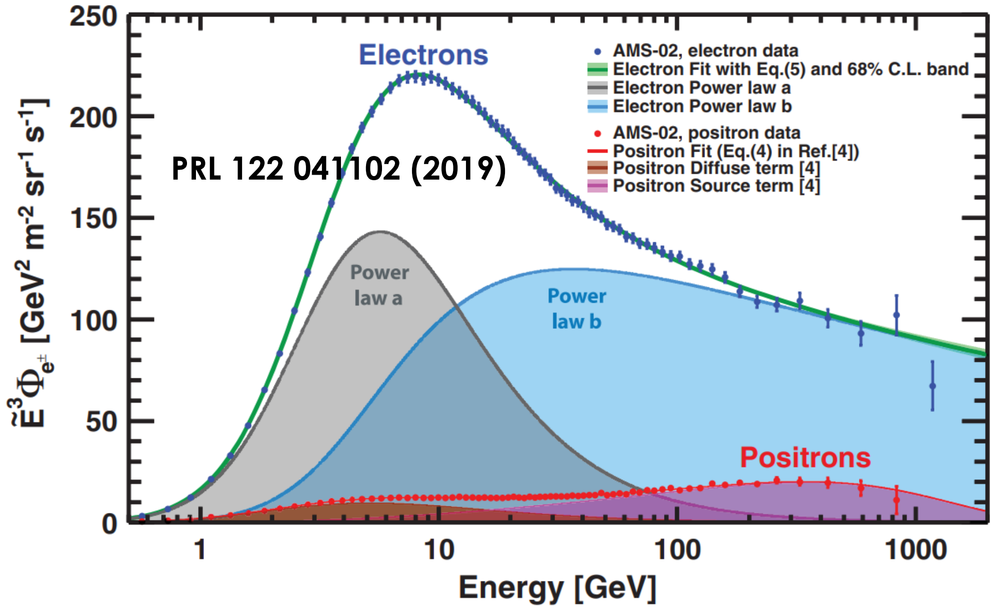
Complementary measurements are still needed to understand the source nature (gamma-ray emission from pulsars, anisotropy studies, antiproton spectrum, …)



All electron spectrum

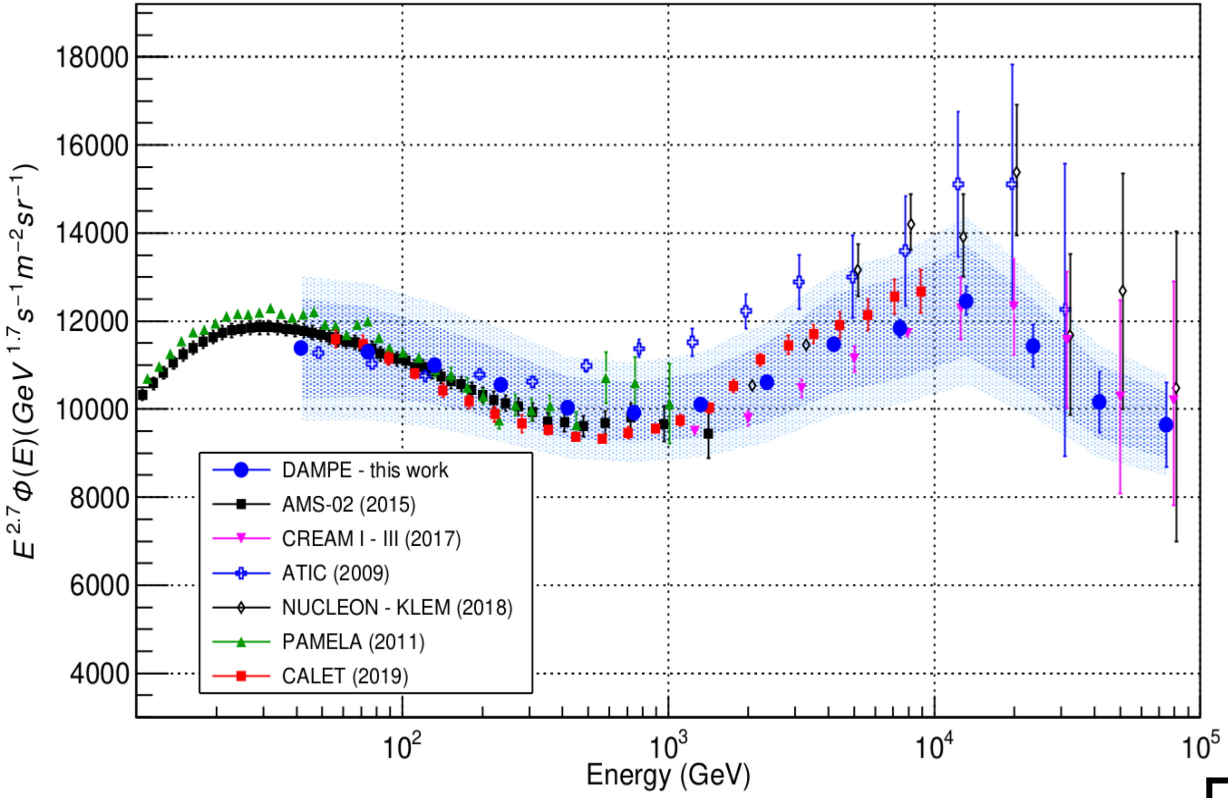


DAMPE 1st direct detection of the break @ 1TeV
Nature volume 552, pages 63–66(2017)



"The different behavior of the cosmic-ray electrons and positrons measured by AMS is clear evidence that most high energy electrons originate from different sources than high energy positrons"
PRL 122 041102 (2019)

Lecce analysis: proton spectrum



Analisi del tutto indipendente (diversi criteri di selezione degli eventi, diversa procedura di unfolding, …)

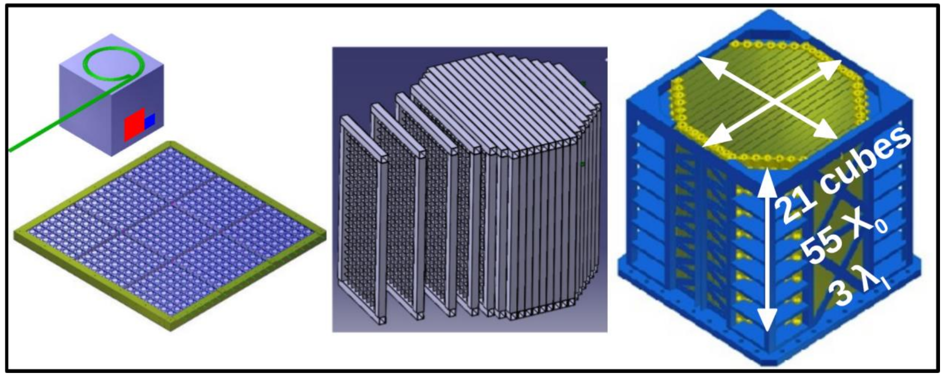
I risultati in accordo con l'analisi oggetto della pubblicazione.

Essi confermano la presenza dell'hardening ed in particolare del softening nell'andamento dello spettro, allo stesso valore di energia.

Tesi di Dottorato di A. De Benedittis,
"The protonic component of cosmic rays measured with DAMPE",
Dottorato di ricerca in Fisica e Nanoscienze - XXXII ciclo.

$\Phi_0(10^{-5}GeV^{-1}s^{-1}m^{-2}sr^{-1})$	7.86 ±0.04
γ	2.777 ± 0.002
E_b(TeV)	0.74 ± 0.04
$\Delta\gamma$	0.168 ± 0.001

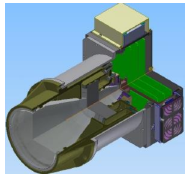
$\Phi_0(10^{-5}GeV^{-1}s^{-1}m^{-2}sr^{-1})$	7.80 ± 0.05
γ	2.60 ± 0.01
E_b(TeV)	13 ± 2
$\Delta\gamma$	0.27 ± 0.01



The design of the CALO consists of about **7500 LYSO cubes** with edge length of 3 cm, corresponding to about 2.6 X0 and 1.4 Molière radius

The scintillation light of each crystal is read-out by two independent systems:

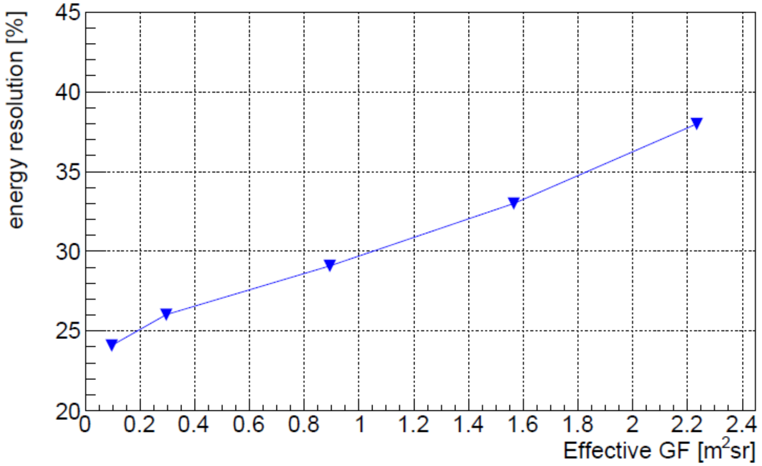
1. WLS fibers coupled to image Intensified scientific CMOS (IsCMOS) cameras
2. photo-diodes (PD) connected to custom front-end electronics (HIDRA)



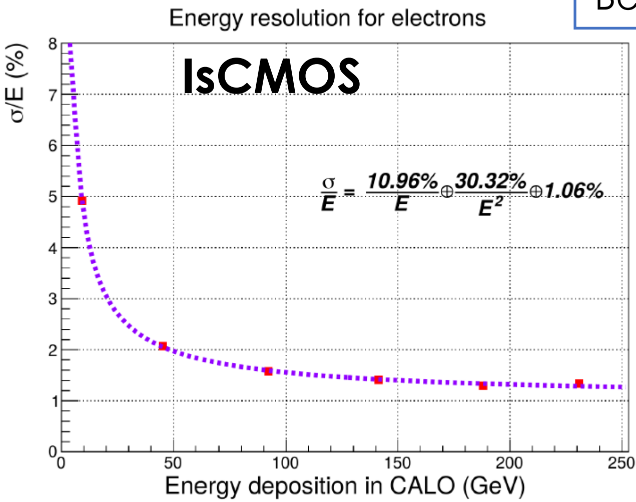
The ***double read-out system*** achieves the capability of cross-calibrating the scintillation light measurement and help in **reduce the systematic errors**

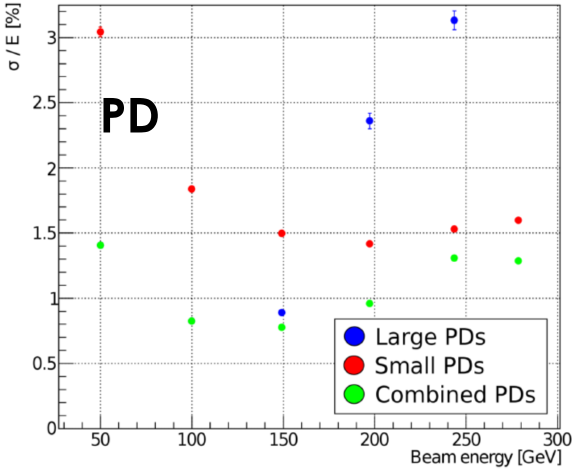
The effective geometrical factor is >2 m^2sr for electrons and > 1 m^2sr protons

Energy resolution
MC **protons**



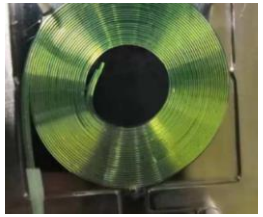
Energy resolution
Beam test **electrons**

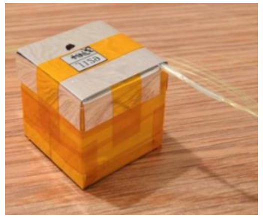




HERD CALO read-out

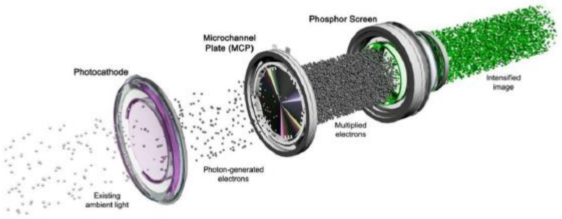
Dynamic range of 10^7 is needed to detect from a MIP (~30 MeV released in a single crystal) to a PeV proton (~20 TeV released in a single crystal)

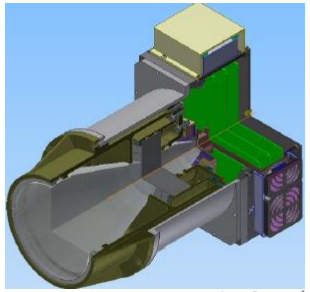




• WLS read-out

- Each cube is read-out by 3 WLS fibers.
- One of the fiber is used for triggering and the light signal is readout by a fast PMT
- The light signal from the other two fibers is amplified by an Image Intensifier (two gains) and read-out by a IsCMOS camera





• PIN-Diode read-out

- Each cube is read-out by 2 PIN-Diode of different area (1:100 ratio)
- Each PIN-Diode is read-out by CASIS chip with two gains and trigger capability