Measurement of the all-particle energy spectrum with the DAMPE mission

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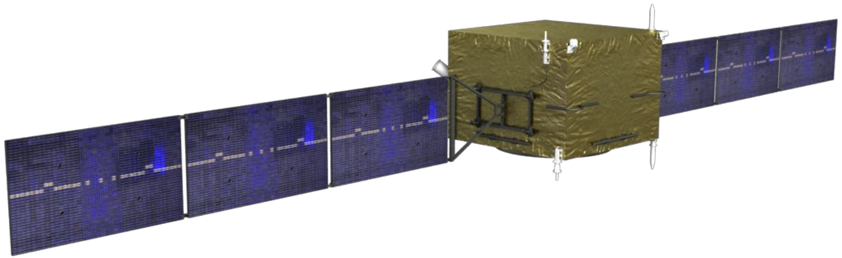

GRAN SASSO SCIENCE INSTITUTE
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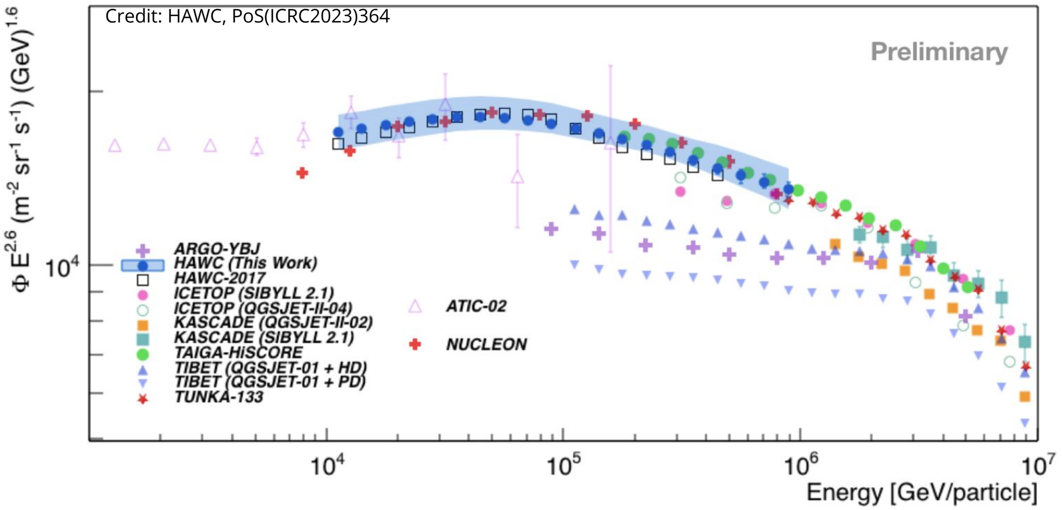
The all-particle spectrum about the knee

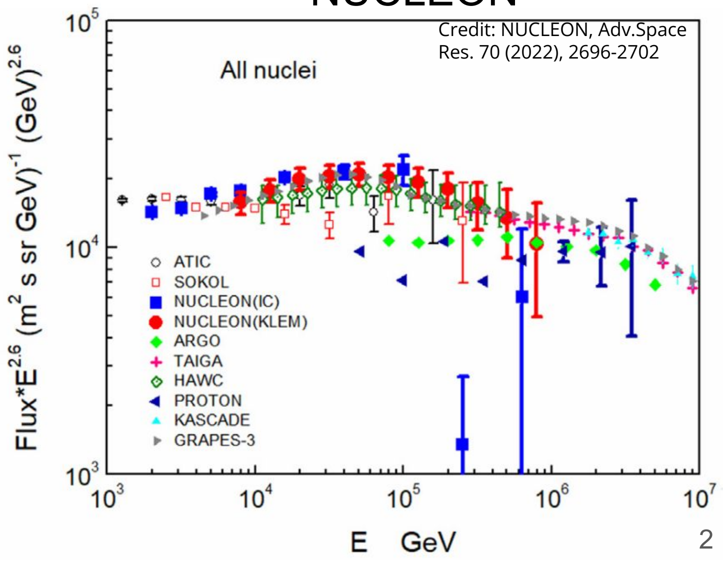
Goal: measurement of the spectrum up to about 1 PeV

- link between direct and indirect CRs detectors
- search for spectral features in the energy spectrum below the knee
- test theoretical models

HAWC



NUCLEON



The DAMPE detector

Plastic Scintillator Detector (PSD)

- **Charge** measurement + **anti-coincidence** for γ ID
- 2 planes (X/Y) of plastic scintillator bars

Silicon TracKer (STK)

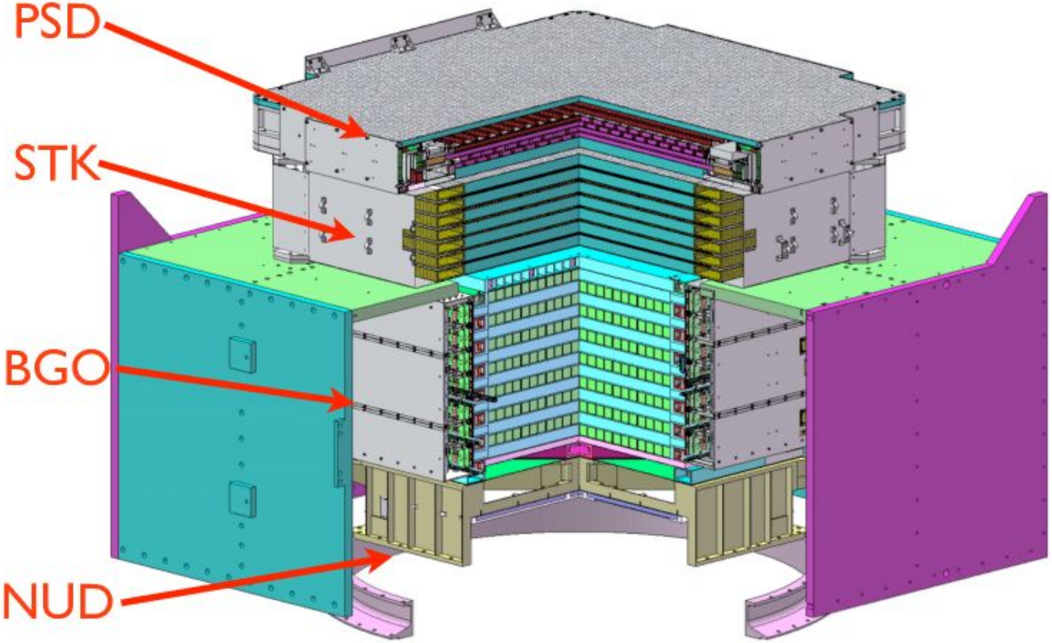
- **Track** reconstruction + additional **charge** measurement
- 6 planes of Si microstrip detectors + 3 W layers

BGO calorimeter (BGO)

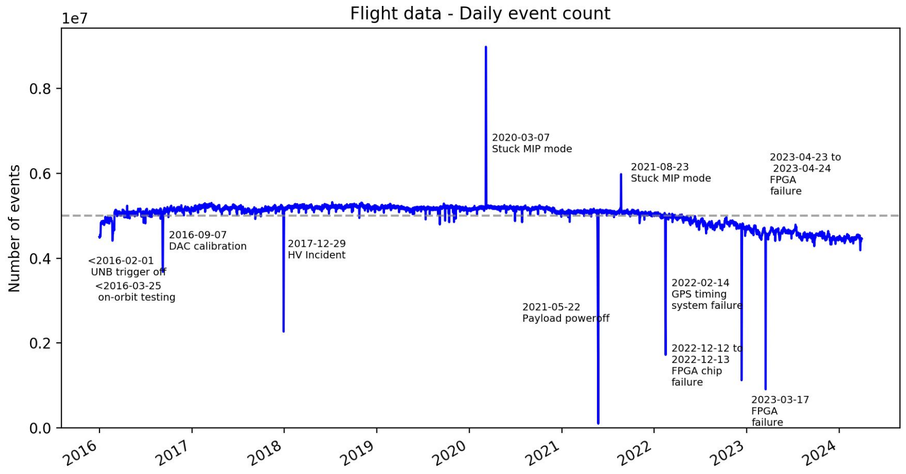
- **Energy** measurement + **em/had showers** discrimination
- 14 layers of BGO crystal bars
- 32 X_0 and 1.6 λ_I

NeUtron Detector (NUD)

- Further em/had showers separation
- 4 boron-doped scintillator tiles



Analysis selection & procedure



Experimental data

- 96 months of flight data (January 2016 - December 2023)
- Total live time ~1.9 10^8 s

Monte-Carlo simulations

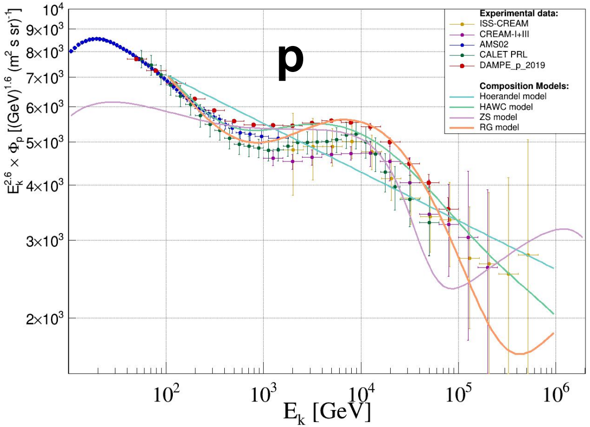
- p, He, C, O, Ne, Mg, Si, Fe
  - [100 GeV - 500 TeV] range
  - GEANT4v4.10.5 with FTFP_BERT and EPOS-LHC
- Assumed a mass composition model
  - To build the weighted mean acceptance and response matrix
  - Different models considered to evaluate the model dependence of the output spectra

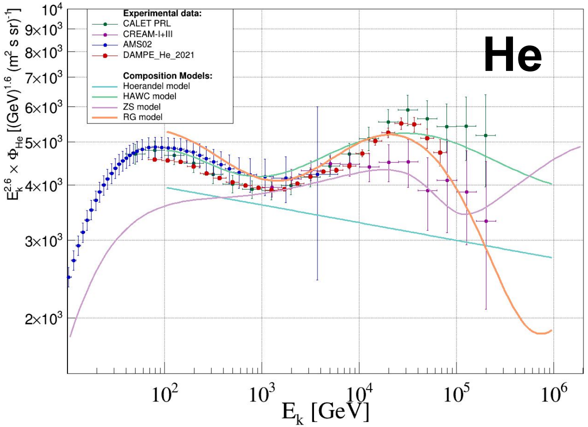
Selection cuts

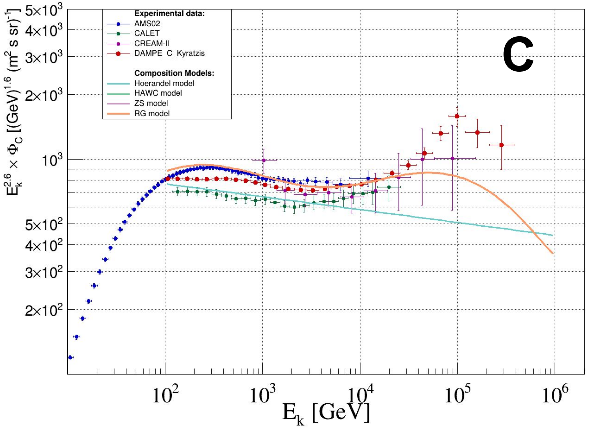
- SAA exclusion
- E_{depo} in each BGO layer < 35% E_{BGO}
- HET trigger ON
- E_{BGO} > 100 GeV
- BGO fiducial cuts
  - Reconstructed shower axis inside the fiducial volume
  - ∀ layer: max E_{depo} inside the fiducial volume
- No charge/track selection cuts

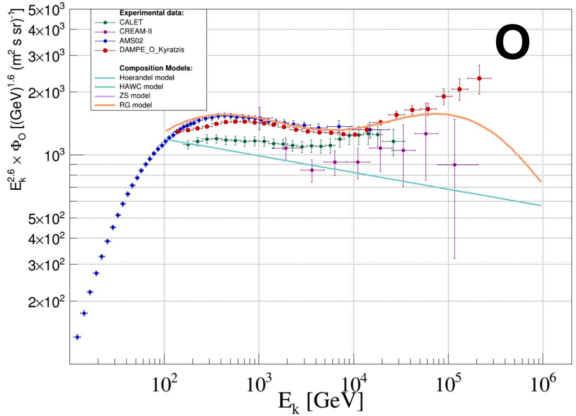
Selection of the composition model

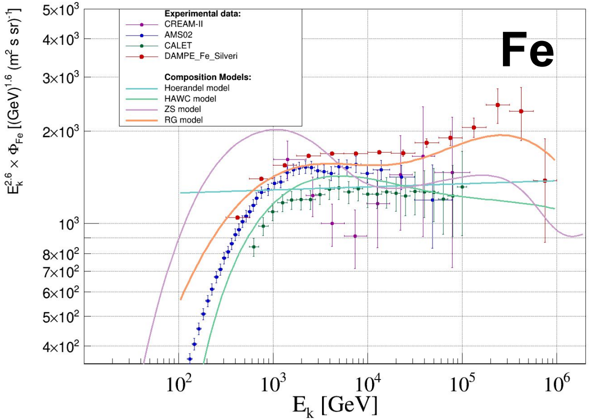
- **Hoerandel (poly-gonato) model** [10 GeV - 10^9 GeV] (J. R. Hörandel, Astropart.Phys. 19 (2003) 193-220)
- **HAWC model** [10^2 GeV - 10^6 GeV] (HAWC, PoS ICRC (2023) 299)
- **Recchia-Gabici (RG) model** [~GeV - multi PeV] (S. Recchia, S. Gabici (2023) arXiv:2312.11397)
- **Zatsepin-Sokolskaya (ZS) model** [10 GeV - 10^8 GeV] (V. I. Zatsepin, N. V. Sokolskaya, A&A 458 (2006) 1)





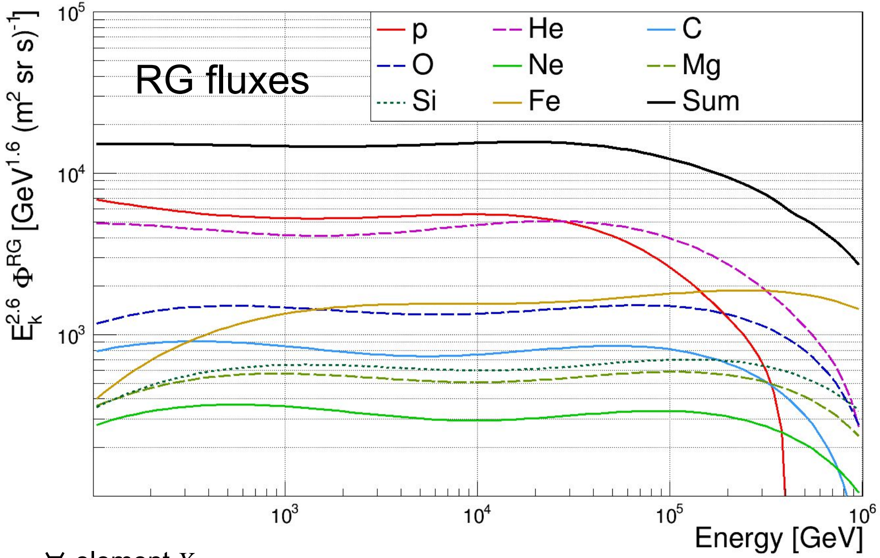


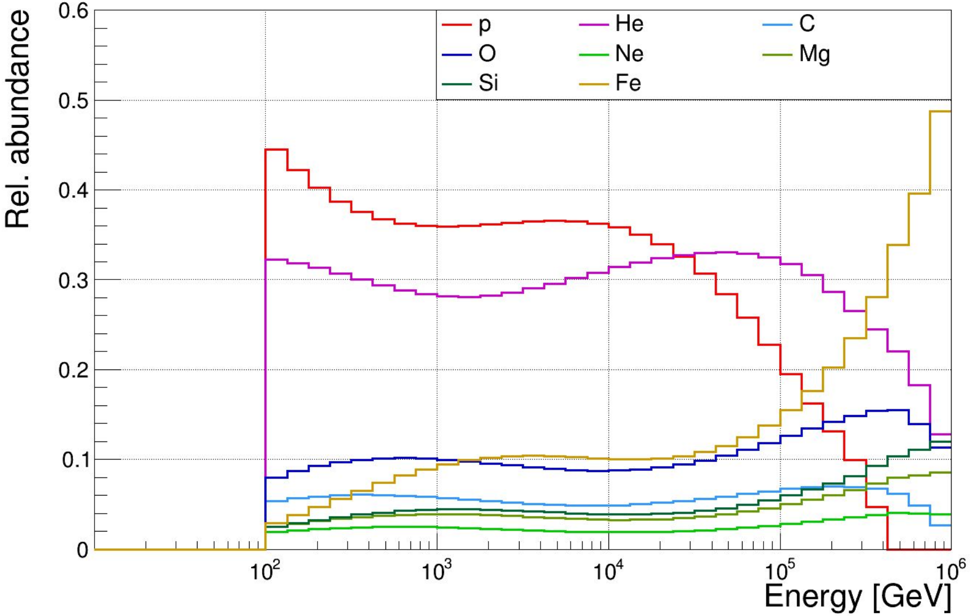




Composition model weights

The **RG model** accurately reproduces the single nuclei spectra: **assumed as the composition model for the analysis**





∀ element X

- its flux is described by the RG model
- its rel. abundance is computed and used as a weight to compute the mean acceptance & response matrix

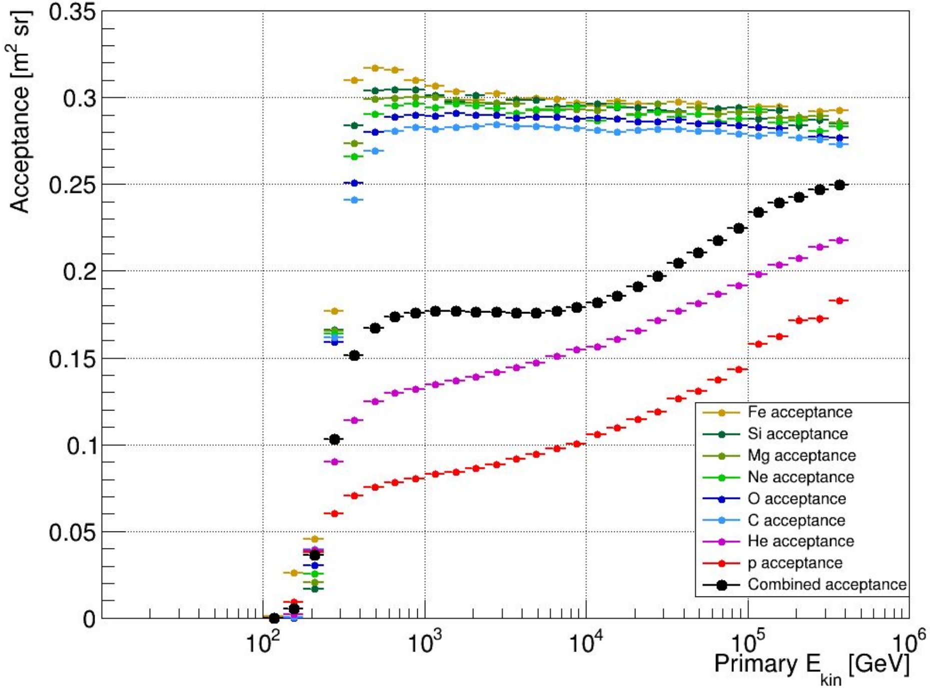
$$w_i^X = \frac{\int_{E_i^{min}}^{E_i^{max}} \Phi_{RG}^X(E)dE}{\sum_{el} \int_{E_i^{min}}^{E_i^{max}} \Phi_{RG}^{el}(E)dE}$$

$el =$ p, He, C, O, Ne, Mg, Si, Fe

Acceptance and unfolding

Weighted mean acceptance

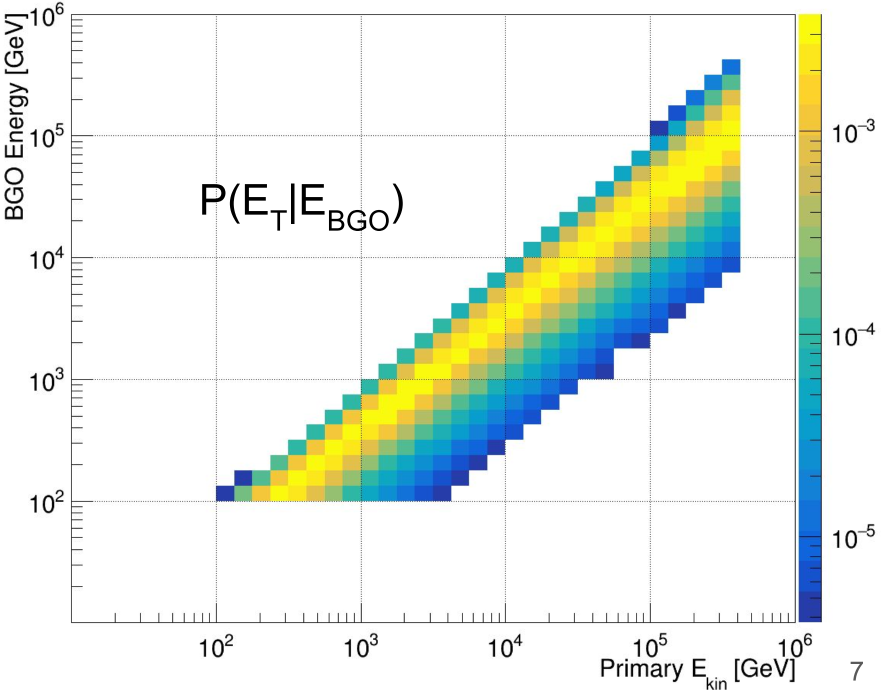
$$A_i = \sum_{el} w^{el} \; G^{el}_{gen} \; \frac{N^{el}_{sel}(E^i_T)}{N^{el}_{gen}(E^i_T)}$$



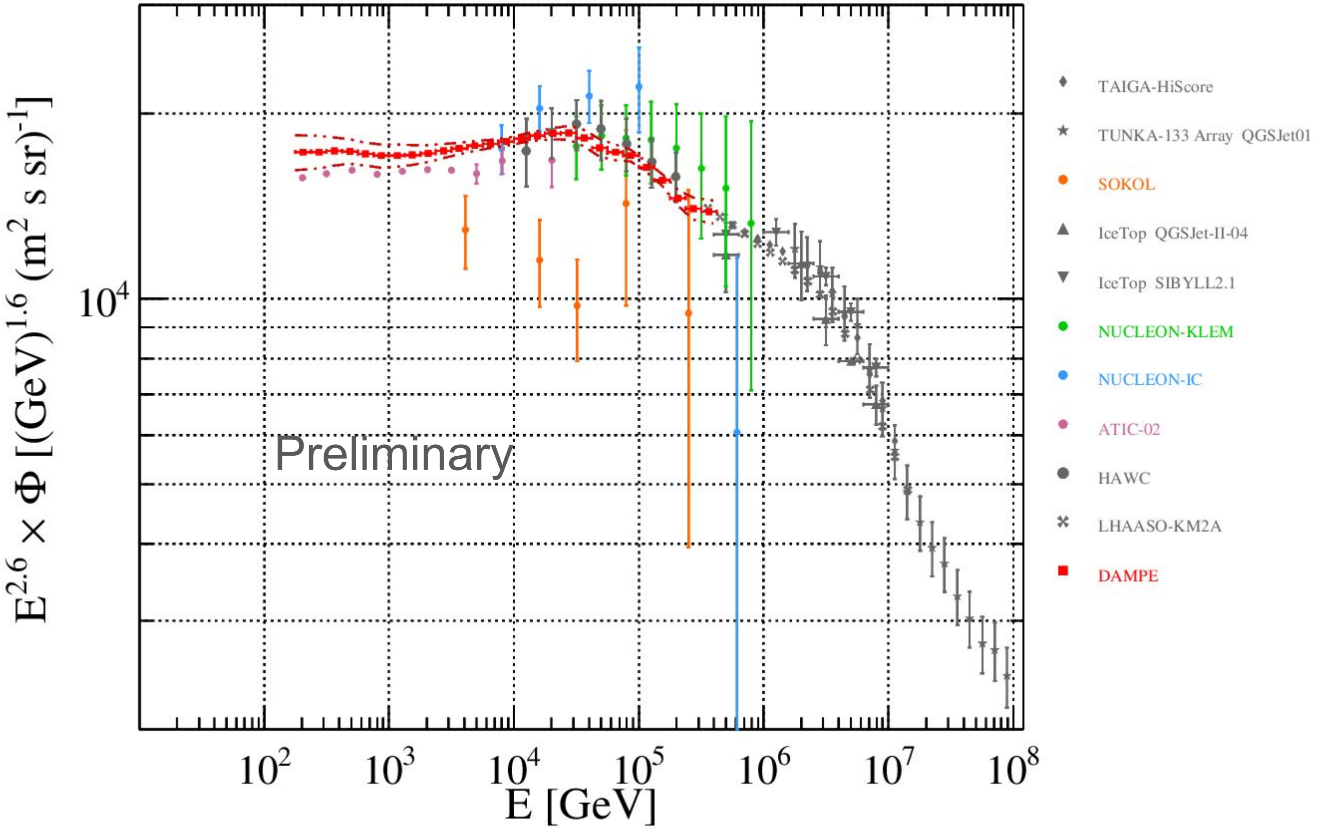
Weighted mean response matrix

for the unfolding: iterative Bayesian procedure is adopted to reconstruct the primary energy of the events

$$N_i = \sum_{el} w^{el} \sum_{j=1}^{n} P^{el}(E^i_T | E^j_{BGO}) \; N^{el}(E^j_{BGO})$$



All-particle flux



Differential flux:

$$\Phi_i = \frac{N_i}{\Delta T \times A_i \times \Delta E_i}$$

Evaluated systematics due to the composition model assumption

Contribution from hadronic model is under evaluation

Conclusions

Preliminary result of the all-particle spectrum in the 200 GeV - 0.4 PeV energy range

- Loose charge cut selection to increase the statistics
- Assumed a composition model: Recchia-Gabici model
- Systematics evaluation ongoing (limited dependence on the composition model)
- In agreement with other experiments data

Backup

G S
S I

The DAMPE space mission

- Collaboration of Chinese, Italian and Swiss scientific institutions
- Launched on 17 December 2015
- The primary **scientific goals**:
  - Study of cosmic (e^- + e^+) spectrum
  - Study of CR protons and nuclei
  - High energy gamma ray astronomy
  - Indirect search for dark matter signatures in lepton spectra
- The main features

Acceptance	~0.3 $m^2 sr$
Energy resolution	1.2% at 100 GeV (e/γ) < 40% at 800 GeV (nuclei)
e/γ angular resolution	0.2° at 100 GeV
Detection	10 GeV - 10 TeV (e/γ) 50 GeV - 200 TeV (nuclei)

Hoerandel model

- Spectra of individual elements obtained from direct observations and extrapolated to high energies

- Direct experiments data fitted with SPL function $\Phi(E) = \Phi^0 \left(\frac{E}{1TeV} \right)^{\gamma}$

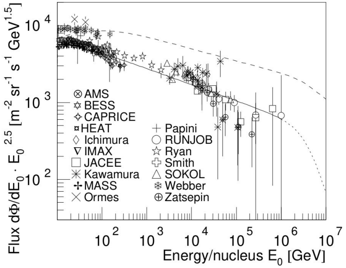
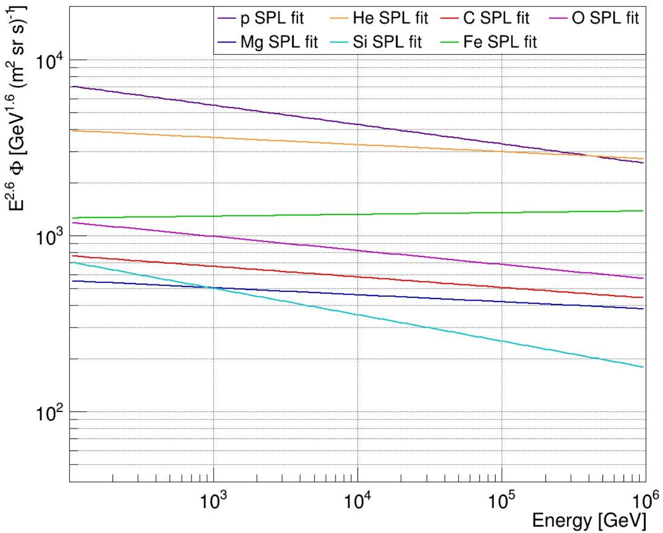
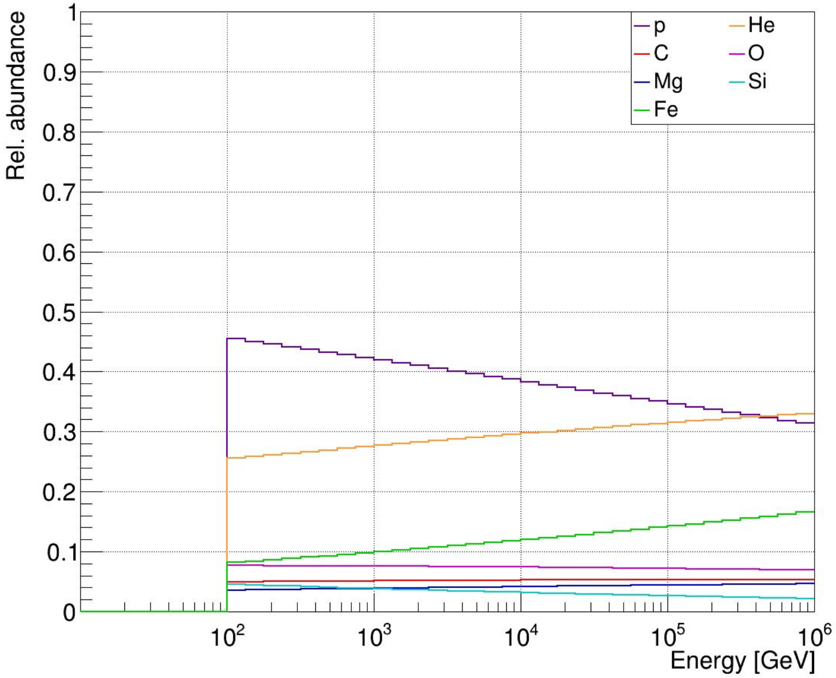


Table 7: Absolute flux Φ_Z^0 [$(m^2$ sr s TeV$)^{-1}$] at E_0 = 1 TeV/nucleus elements.

Z		Φ_Z^0	$-\gamma_Z$	Z		Φ_Z^0	$-\gamma_Z$
1^2	H	$8.73 \cdot 10^{-2}$	2.71	32^4	Ge	$4.02 \cdot 10^{-6}$	2.54
2^2	He	$5.71 \cdot 10^{-2}$	2.64	33^4	As	$9.99 \cdot 10^{-7}$	2.54
3^3	Li	$2.08 \cdot 10^{-3}$	2.54	34^4	Se	$2.11 \cdot 10^{-6}$	2.53
4^3	Be	$4.74 \cdot 10^{-4}$	2.75	35^4	Br	$1.34 \cdot 10^{-6}$	2.52
5^3	B	$8.95 \cdot 10^{-4}$	2.95	36^4	Kr	$1.30 \cdot 10^{-6}$	2.51
6^3	C	$1.06 \cdot 10^{-2}$	2.66	37^4	Rb	$6.93 \cdot 10^{-7}$	2.51
7^3	N	$2.35 \cdot 10^{-3}$	2.72	38^4	Sr	$2.11 \cdot 10^{-6}$	2.50
8^3	O	$1.57 \cdot 10^{-2}$	2.68	39^4	Y	$7.82 \cdot 10^{-7}$	2.49
9^3	F	$3.28 \cdot 10^{-4}$	2.69	40^4	Zr	$8.42 \cdot 10^{-7}$	2.48
10^3	Ne	$4.60 \cdot 10^{-3}$	2.64	41^4	Nb	$5.05 \cdot 10^{-7}$	2.47
11^3	Na	$7.54 \cdot 10^{-4}$	2.66	42^4	Mo	$7.79 \cdot 10^{-7}$	2.46
12^3	Mg	$8.01 \cdot 10^{-3}$	2.64	43^4	Tc	$6.98 \cdot 10^{-8}$	2.46
13^3	Al	$1.15 \cdot 10^{-3}$	2.66	44^4	Ru	$3.01 \cdot 10^{-7}$	2.45
14^3	Si	$7.96 \cdot 10^{-3}$	2.75	45^4	Rh	$3.77 \cdot 10^{-7}$	2.44
15^3	P	$2.70 \cdot 10^{-4}$	2.69	46^4	Pd	$5.10 \cdot 10^{-7}$	2.43
16^3	S	$2.29 \cdot 10^{-3}$	2.55	47^4	Ag	$4.54 \cdot 10^{-7}$	2.42
17^3	Cl	$2.94 \cdot 10^{-4}$	2.68	48^4	Cd	$6.30 \cdot 10^{-7}$	2.41
18^3	Ar	$8.36 \cdot 10^{-4}$	2.64	49^4	In	$1.61 \cdot 10^{-7}$	2.40
19^3	K	$5.36 \cdot 10^{-4}$	2.65	50^4	Sn	$7.15 \cdot 10^{-7}$	2.39
20^3	Ca	$1.47 \cdot 10^{-3}$	2.70	51^4	Sb	$2.03 \cdot 10^{-7}$	2.38
21^3	Sc	$3.04 \cdot 10^{-4}$	2.64	52^4	Te	$9.10 \cdot 10^{-7}$	2.37
22^3	Ti	$1.14 \cdot 10^{-3}$	2.61	53^4	I	$1.34 \cdot 10^{-7}$	2.37
23^3	V	$6.31 \cdot 10^{-4}$	2.63	54^4	Xe	$5.74 \cdot 10^{-7}$	2.36
24^3	Cr	$1.36 \cdot 10^{-3}$	2.67	55^4	Cs	$2.79 \cdot 10^{-7}$	2.35
25^3	Mn	$1.35 \cdot 10^{-3}$	2.46	56^4	Ba	$1.23 \cdot 10^{-6}$	2.34
26^2	Fe	$2.04 \cdot 10^{-2}$	2.59	57^4	La	$1.23 \cdot 10^{-7}$	2.33
27^3	Co	$7.51 \cdot 10^{-5}$	2.72	58^4	Ce	$5.10 \cdot 10^{-7}$	2.32
28^3	Ni	$9.96 \cdot 10^{-4}$	2.51	59^4	Pr	$9.52 \cdot 10^{-8}$	2.31
29^4	Cu	$2.18 \cdot 10^{-5}$	2.57	60^4	Nd	$4.05 \cdot 10^{-7}$	2.30
30^4	Zn	$1.66 \cdot 10^{-5}$	2.56	61^4	Pm	$8.30 \cdot 10^{-8}$	2.29
31^4	Ga	$2.75 \cdot 10^{-6}$	2.55	62^4	Sm	$3.68 \cdot 10^{-7}$	2.28





HAWC composition model

- Derived by fitting BPL functions to data from ATIC-2, CREAM, PAMELA, AMS-2, NUCLEON, CALET, DAMPE, KASCADE