The first preliminary results of the astrophysical experiment NUCLEON

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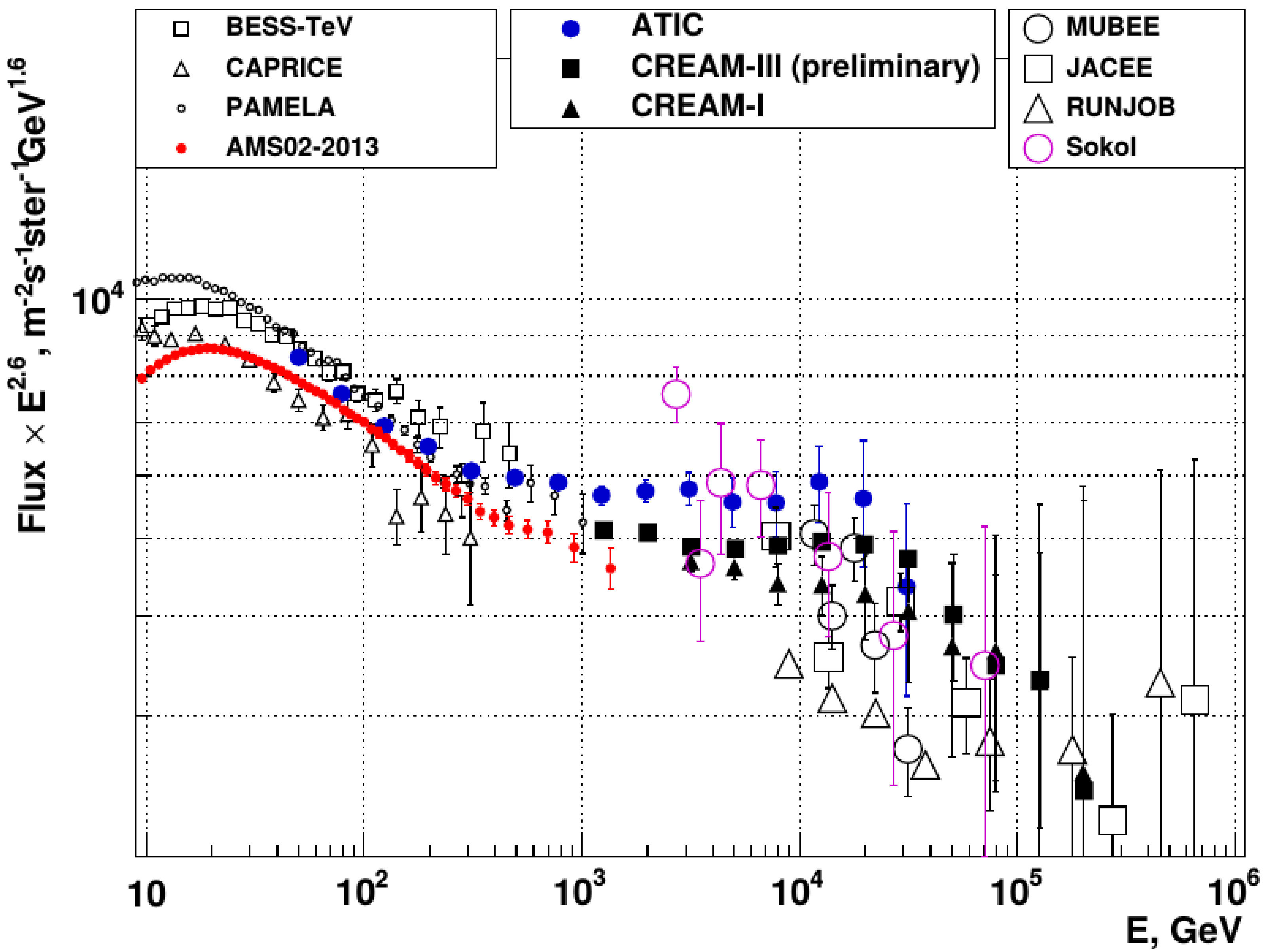
Problems in cosmic-ray spectra at energies 10 TeV - 1PeV per particle
Protons



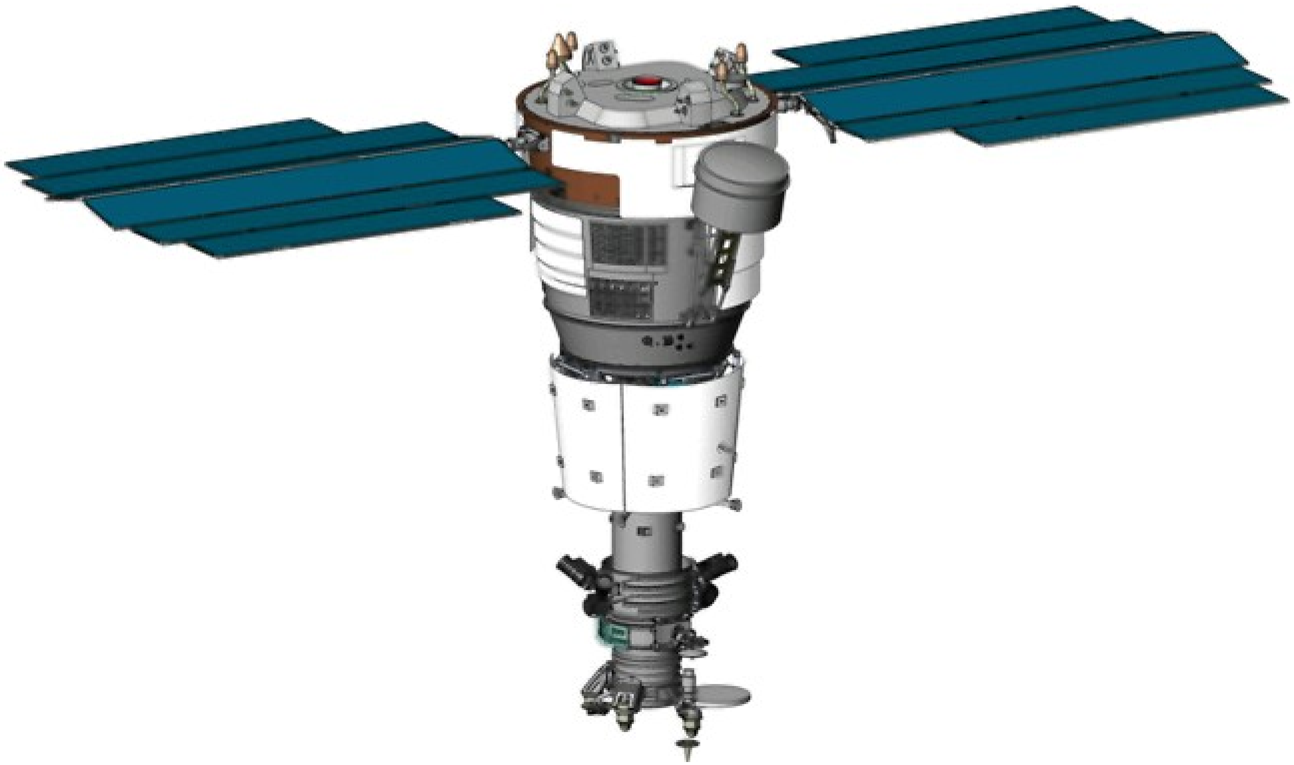
The objectives of NUCLEON space experiment

Main - experimental study of cosmic ray spectra in the energy range 100 GeV-1 PeV per particle, with element by element charge resolution. **Priority: 10 TeV - 1 PeV**

Additional - experimental study of cosmic ray electrons and positrons spectra in the energy range 200-3000 GeV

NUCLEON is a Russian experiment

Nucleon is an additional payload as a part of the spacecraft "Resource-П" No 2



Circular sun-synchronous orbit,
Height ~475 km
Inclination ~97 degrees

Mass ~360 kg
Energy consumption ~160 W
Planned Lifetime more 5 years

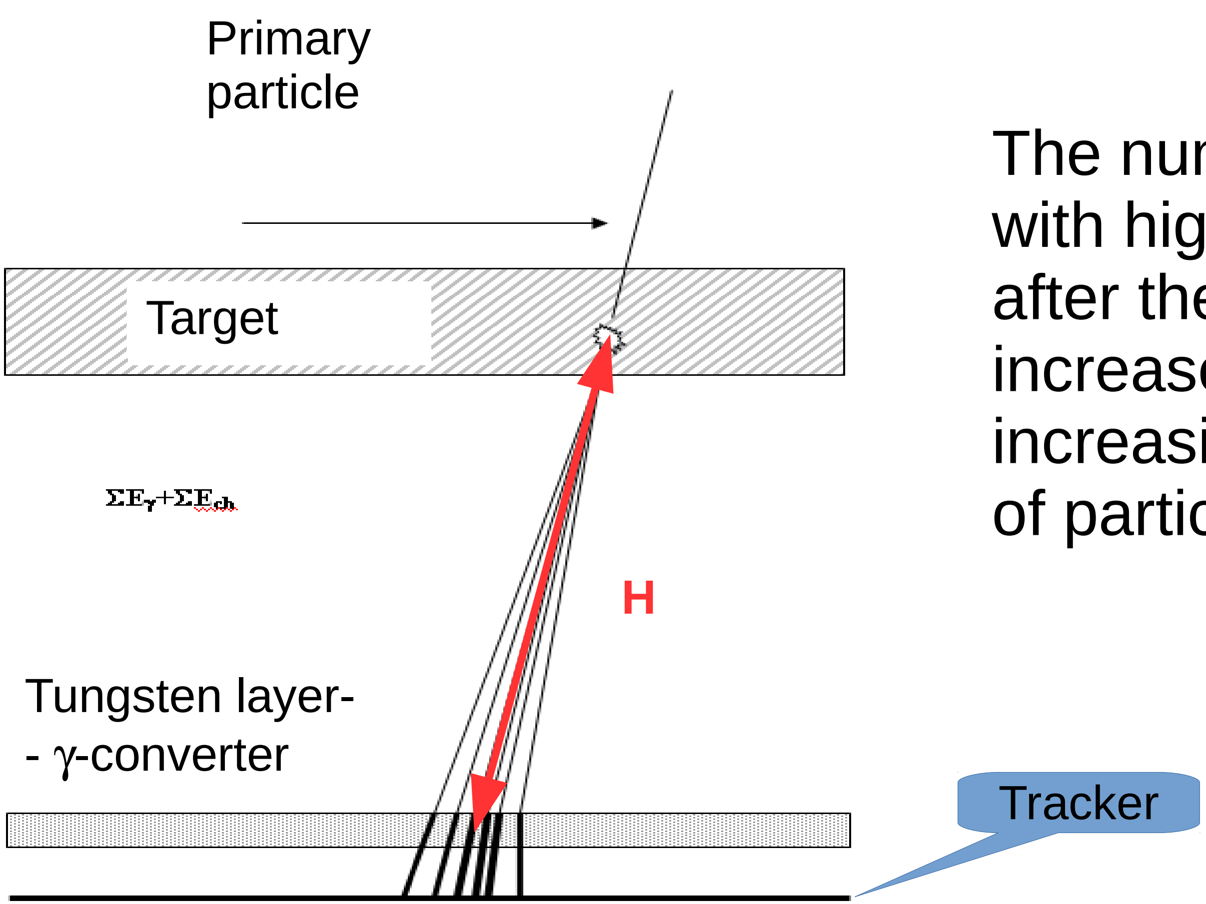
Lanched December 28, 2014.
Switched on January 11, 2015.
From July 2015 up to now - regular measuremetns

IMPORTANT FEATURE OF THE EXPERIMENT:

Two different methods of measuring of the energy of particles are implemented in the NUCLEON experiment:

1. The kinematic method KLEM
   (Kinematic Lightweight Energy Meter)
   -for the first time
2. The calorimatric method
   -usual and well studied

The kinematic method KLEM

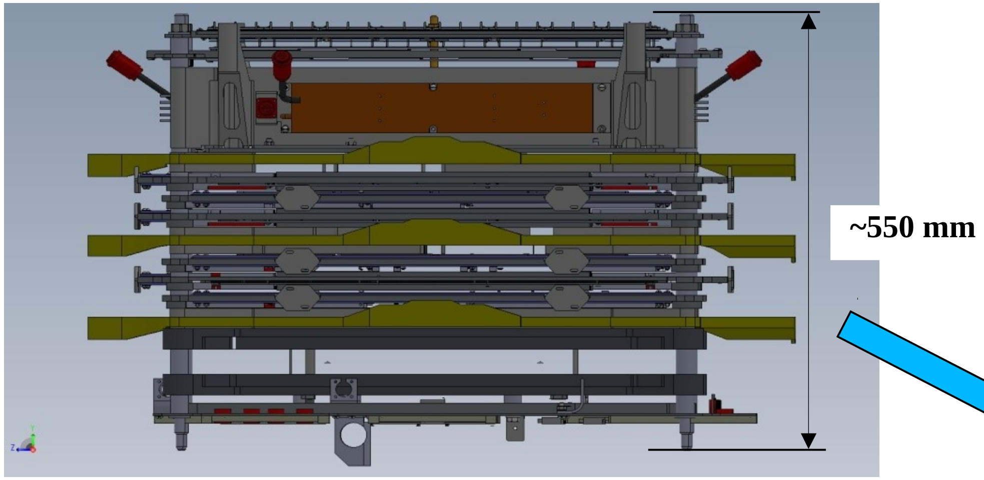


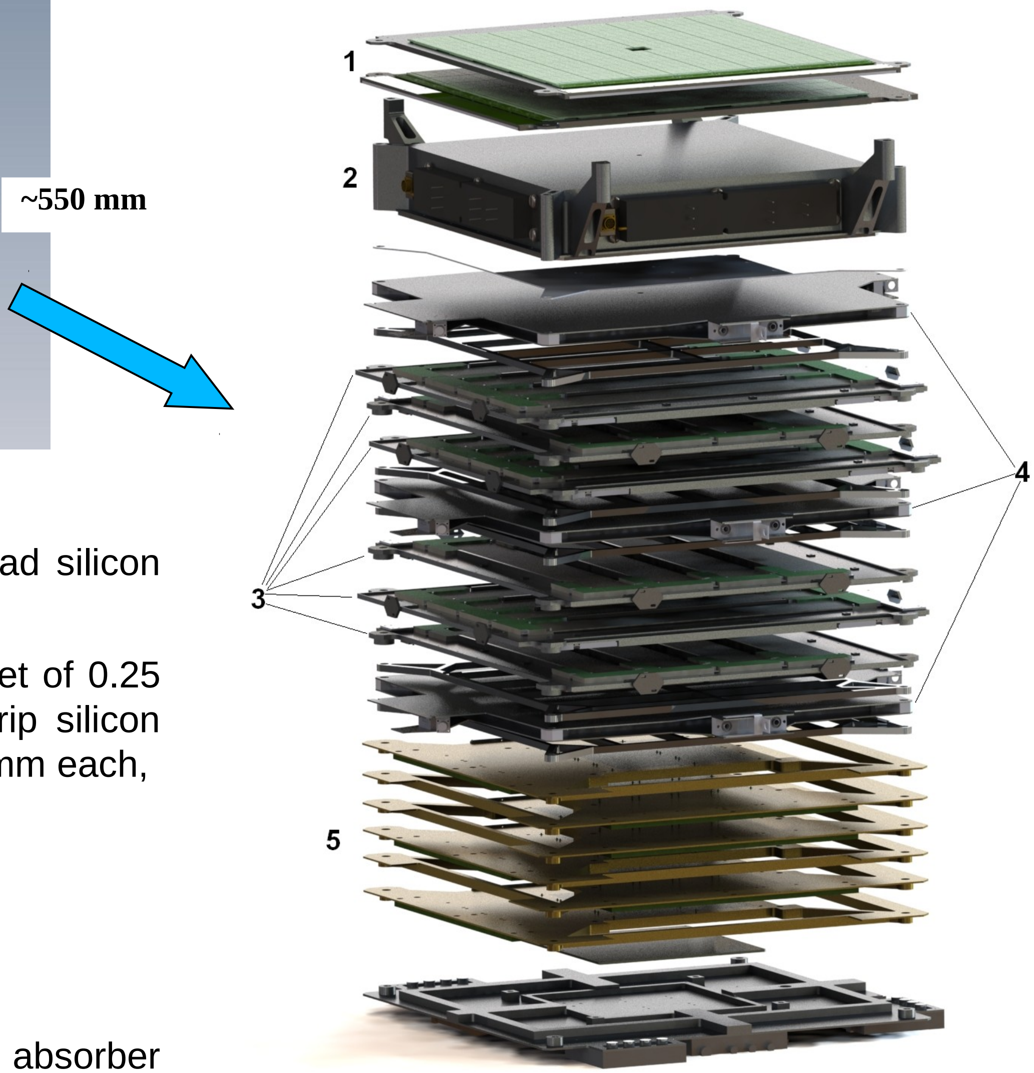
The number of secondary particles with high pseudorapidity after the first interaction increases logarithmically along increasing of the primary energy of particle

The energies are reconstructed trough S-parameter -

$$S=\Sigma(I_i * \ln^2(2H/x_i))$$

The NUCLEON apparatus





- **system of charge measurements** – four planes of pad silicon detectors (1.5×1.5 cm^2) (**1**);
- **tacker for KLEM energy measurement** – carbon target of 0.25 proton iteraction lengths (**2**) and six planes of microstrip silicon detectors (0.4mm step) with tungsten between them (~2mm each, ~3 X-lengths summary) (**3**);
- **trigger sysytem** – tree double sntillator planes (**4**).

Active square 500*500mm².
Geometrical factor 0.24 m²sr.

- Ionizing calorimeter **(IC)** (**5**) – six planes of tungsten absorber (~8mm each, ~12 X-lengths suumary) with silicon strip detectors (1mm step).

Active square 250*250mm².
Geometrical factor (together with charge and KLEM systems) ~0.06м²ср.

10604 independent electronic channels in total

See special poster presentation about the trigger system (No 36):

The trigger system of the NUCLEON space experiment

Torino, Italy
4-9 September 2016

N.Gorbunov[a], V.Grebenyuk[a], D.Karmanov[b], D.Podorozhny[b], M.Lavrova[a], S.Porokhovoy[a], A.Sadovsky[a], A.Tkachenko[a,c], L.Tkachev[a]

[a] *Joint Institute for Nuclear Research, Dubna, 141980, Russia*
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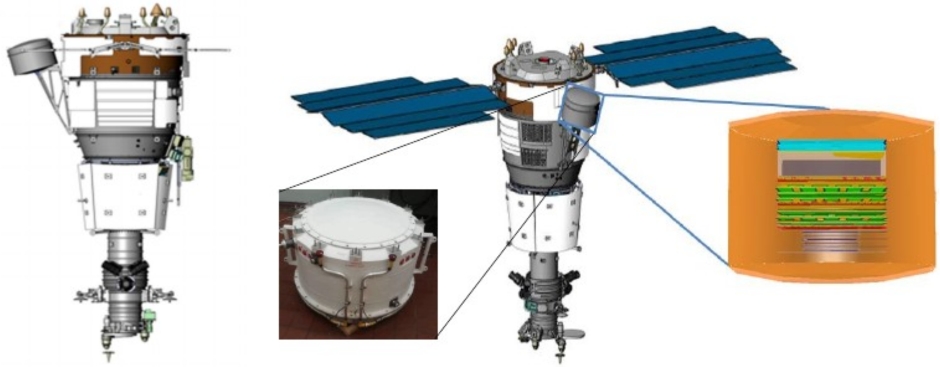
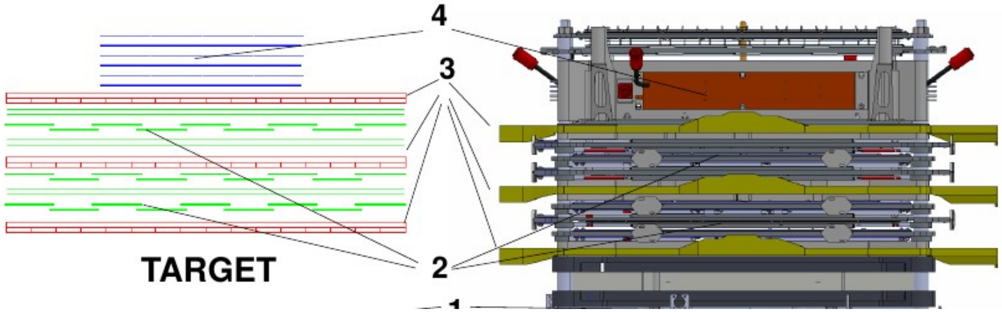
[c] *Bogolyubov Institute for Theoretical Physics, Kiev, 03680, Ukraine*

The NUCLEON detector is in orbit since December 2014 and measuring energy spectrum of Cosmic Ray (CR) and charge composition at 100 GeV – 1000 TeV and Z = 1 - 30 respectively. The NUCLEON apparatus structure and operation, including the scintillator trigger system are described.

ECRS 2016



The NUCLEON detector on board of the satellite RESURS-P N2.



The NUCLEON space mission

The NUCLEON device was designed and produced by a collaboration of SINP, JINR and some other Russian scientific and industrial centers. The detector was launched on board of the RESURS-P N2 satellite in 26 December 2014.
The spacecraft has a Sun-synchronous orbit and a middle altitude of 475 km.
The planned lifetime is more than 5 years.

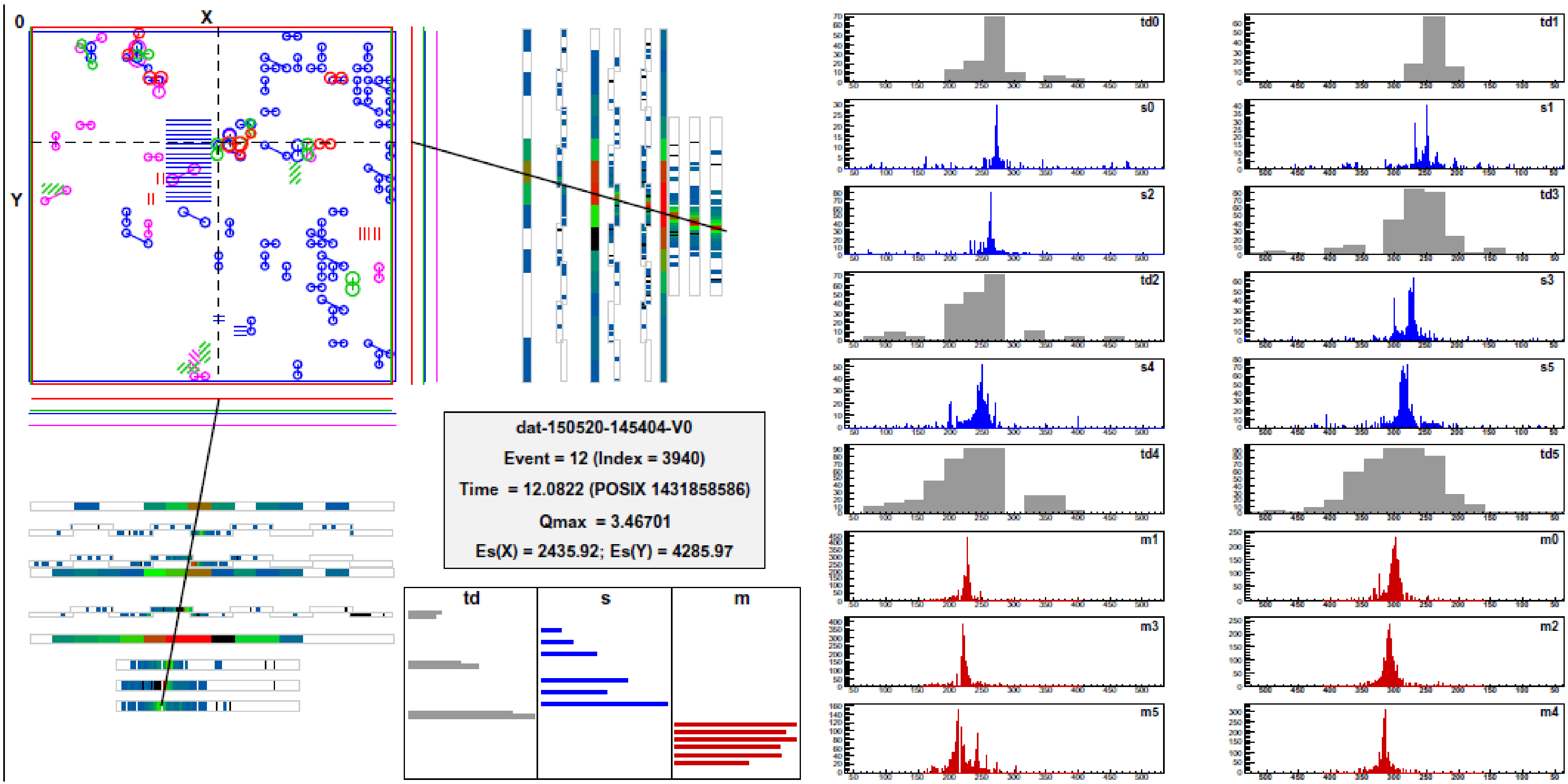
The mission aims to clarify, in the above mentioned energy interval, the details of the origin of cosmic - rays, such as the number and types of sources, identification of actual nearby sources, and the investigation of the mechanisms responsible for the knee.

Specific features of the NUCLEON instrument are a relatively small thickness and a small weight (360 kg). The power consumption is about 160W. The transversal size of the detector was limited to 250 × 250mm.

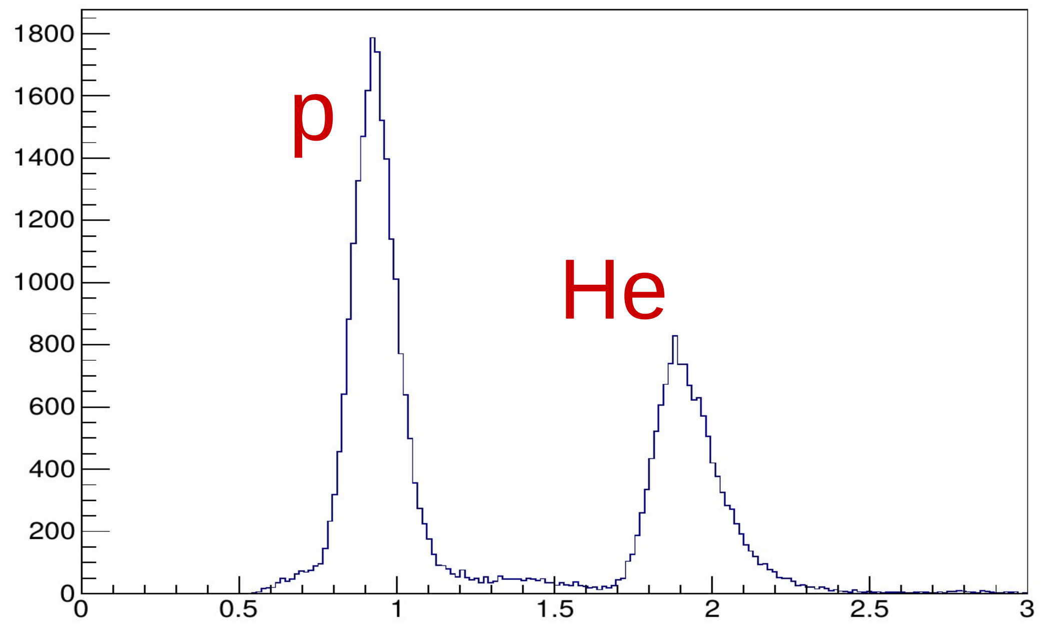
The energy of primary particle is reconstructed by registration of spatial density of the secondary particles. The particles are generated by the first hadronic inelastic interaction in a carbon target. Then additional particles are produced in thin tungsten converter by electromagnetic and hadronic interactions. The technique is based on the generalized Castagnoli kinematical method (KLEM method).

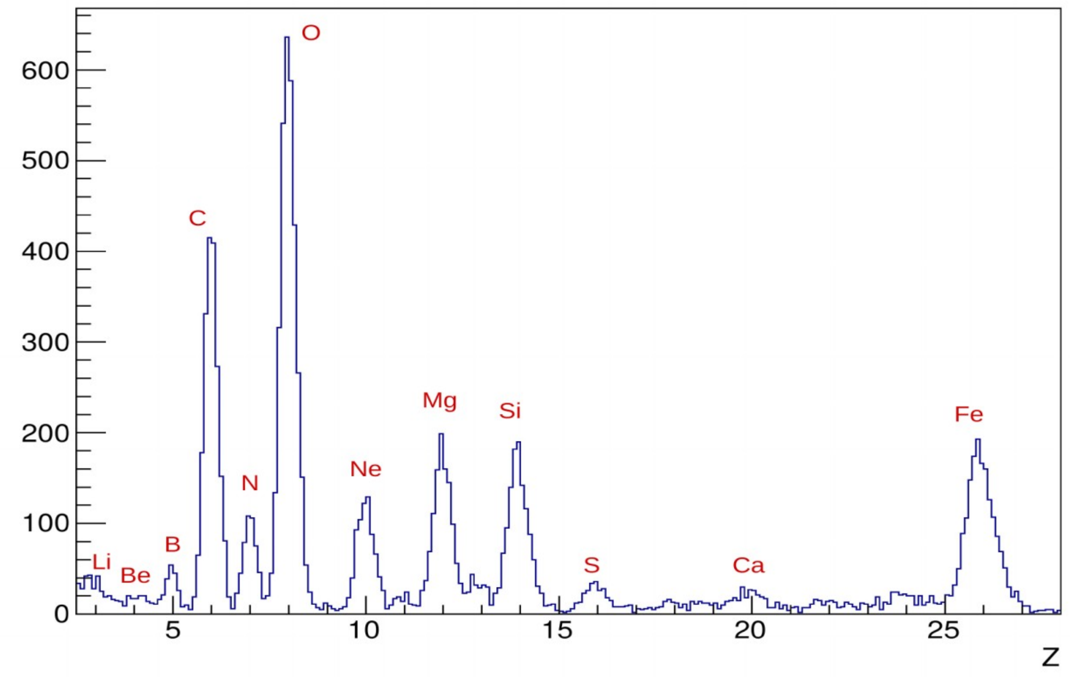
The trigger system: properties and results

An example of an event «portrait»



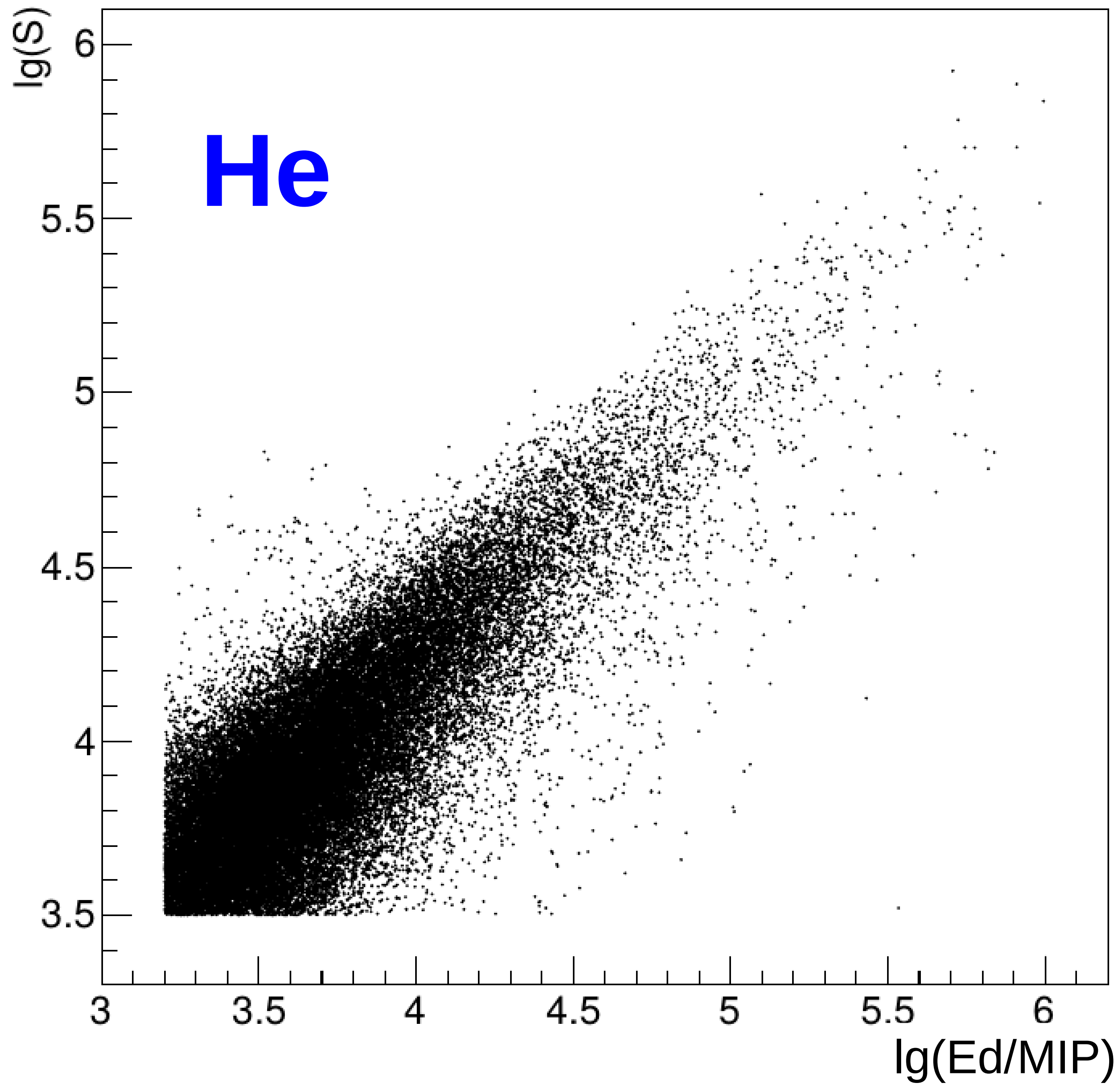
Charge resolution of four silicon planes detector (better than 0.2 charge units for CNO group)



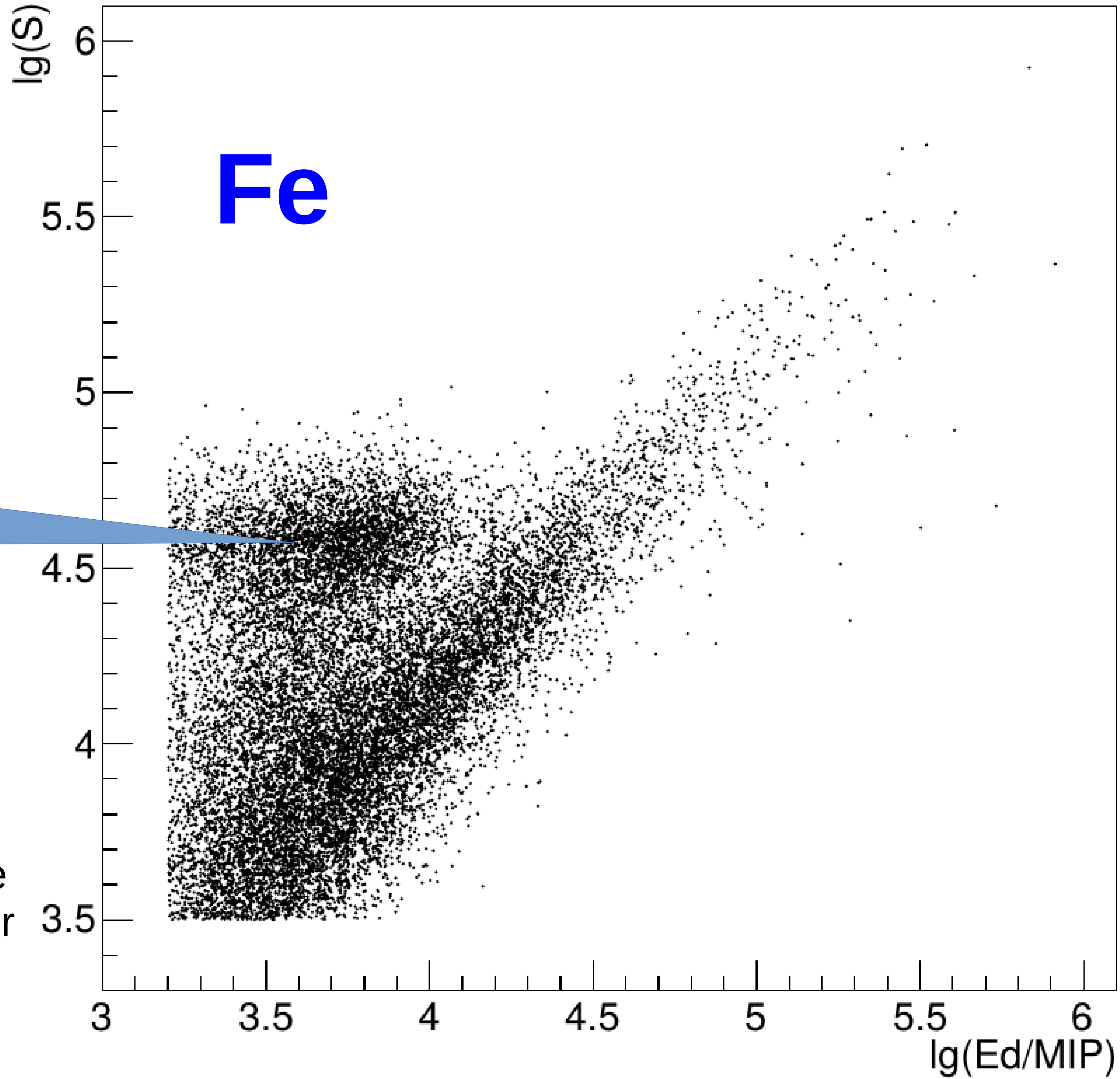


Correlation of the calorimeter energy deposit (Ed) and KLEM parameter (S)

This correlation is a model-independent result



Correlation of the calorimeter energy deposit (Ed) and KLEM parameter (S)



non-interacted nuclei

Heavy nuclei in KLEM method will be presented with higher energy threshold

Reconstruction of primary energy in KLEM and IC methods

Preliminary methods:

Particle-by-particle reconstruction of energy
from Ed (IC) or S (KLEM) by appropriate coefficients
obtained by simulation (GEANT-3, GEANT-4, FLUKA)
and confirmed by beam tests.

No deconvolution procedure.

High energy thresholds (1-8 TeV) -
will be improved

Preliminary results[1]

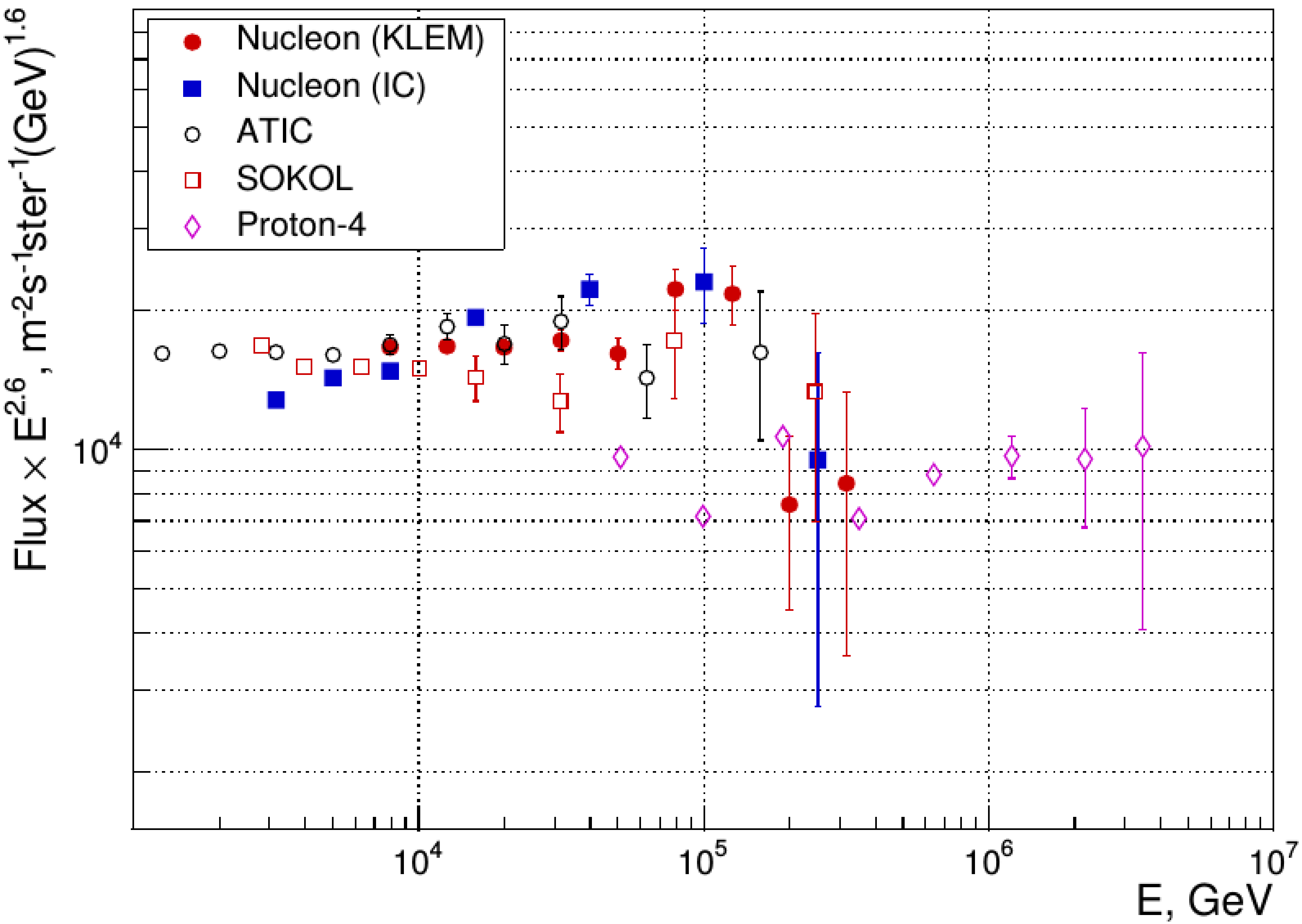
July 2015 -June 2016

AstroTime(days) = 247 LiveTime(days) = 160

Less than 1/5 expected statistics

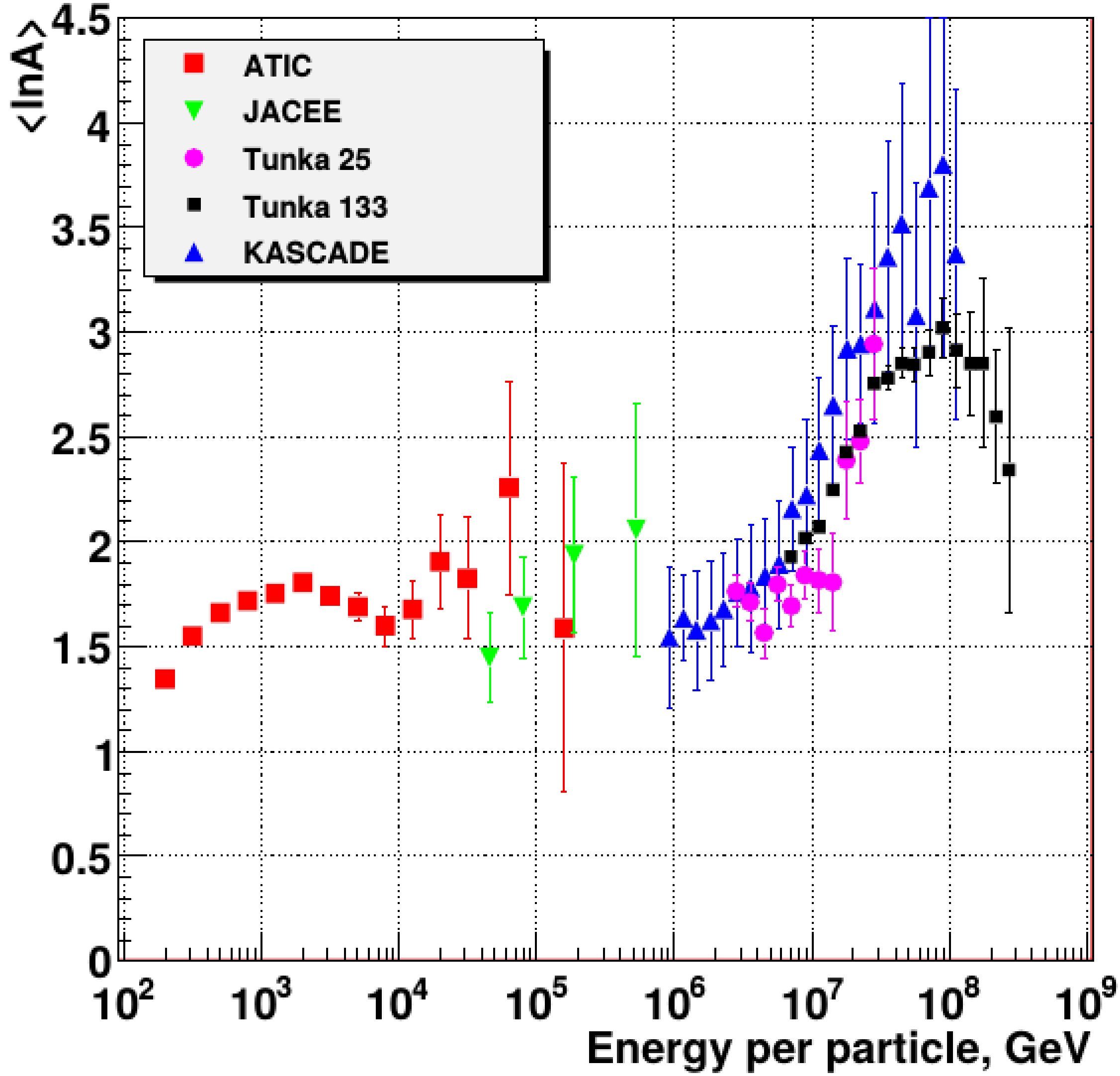
[1]The results are very preliminary

All particle spectrum

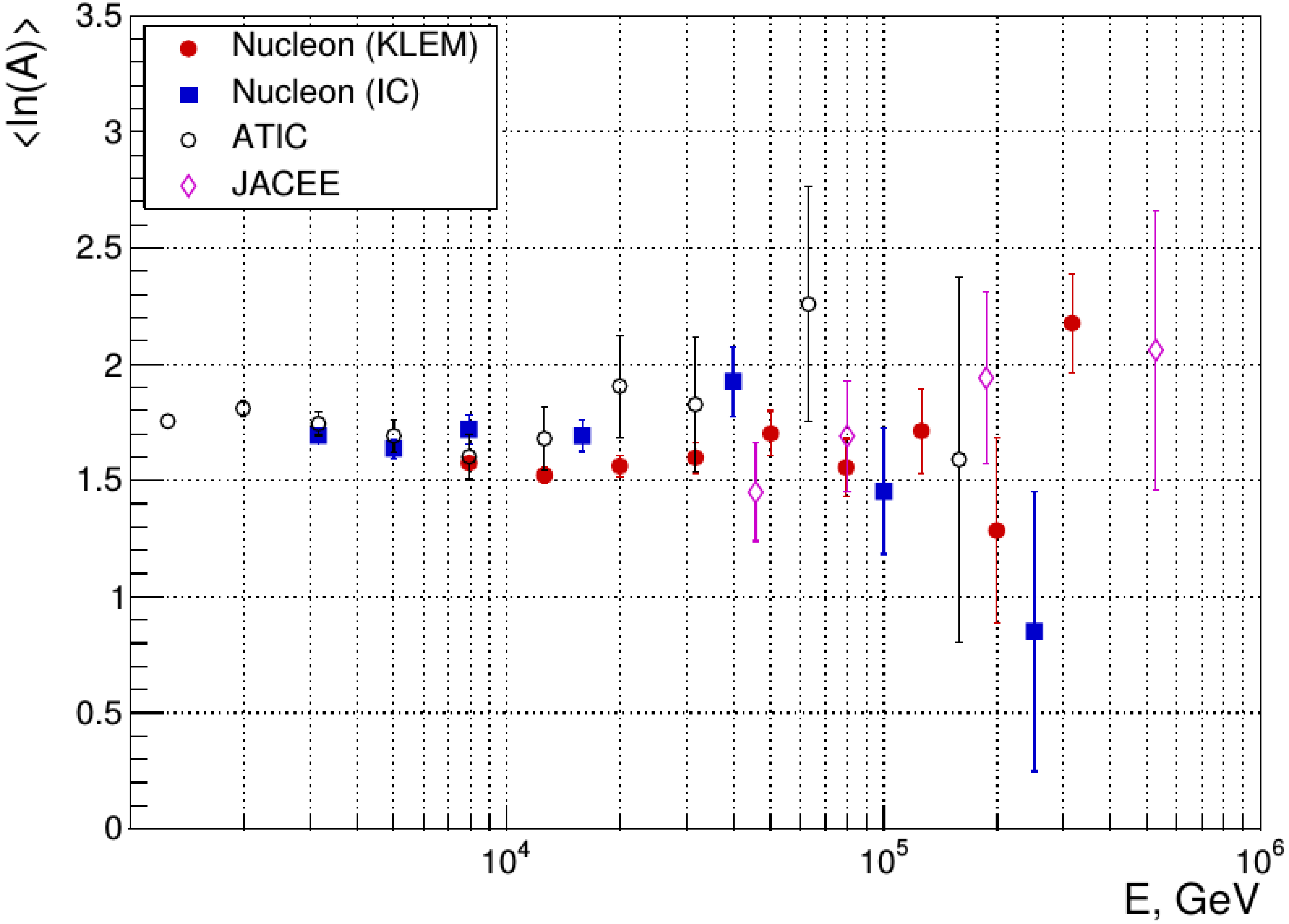


Above 100 TeV: KLEM - 31 (expected > 150-300)
IC - 9 (expected > 70-150)

ATIC (etc.) - ⟨ln A⟩, a "wave-like structure"

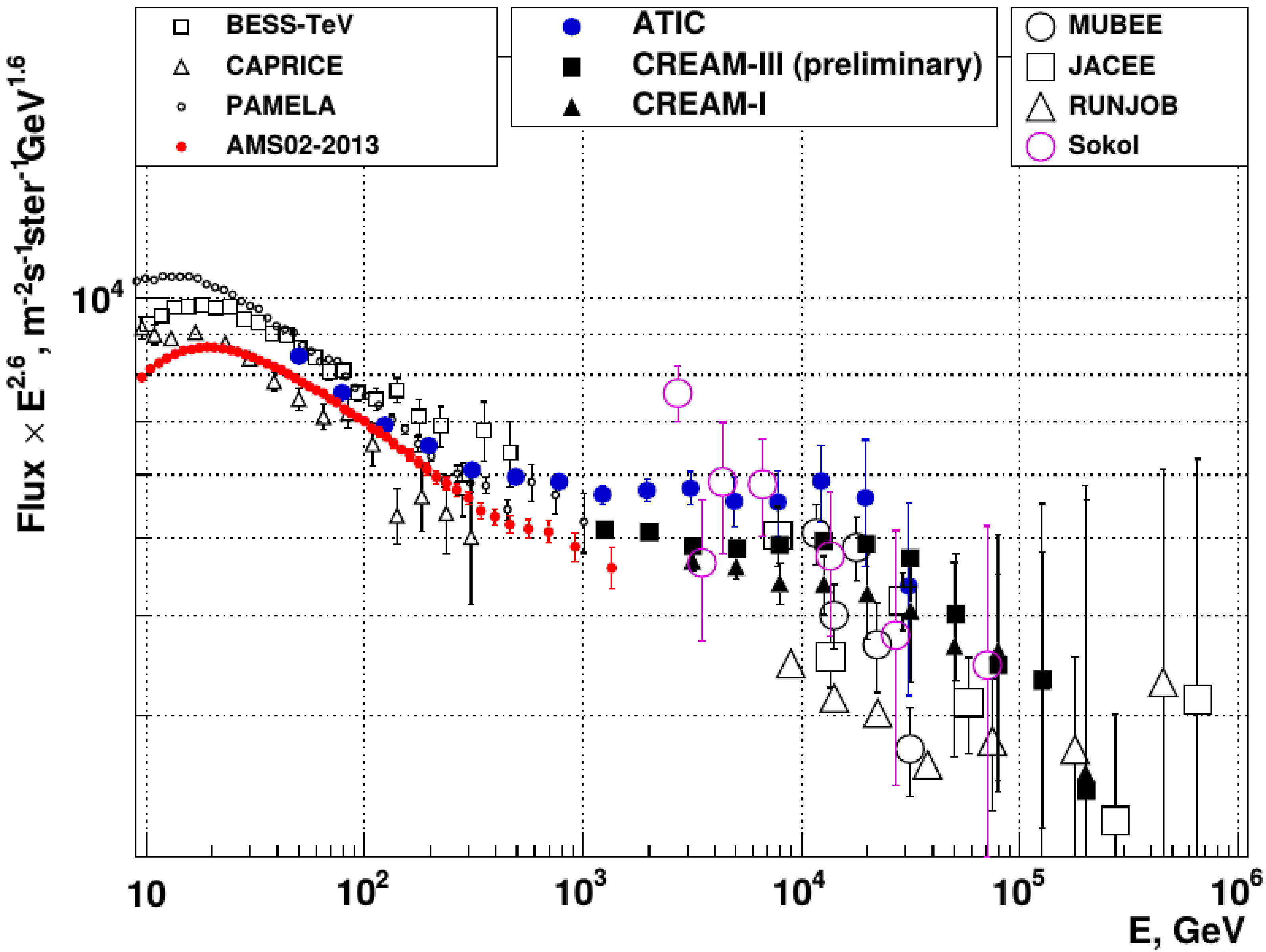


NUCLEON - ⟨ln A⟩

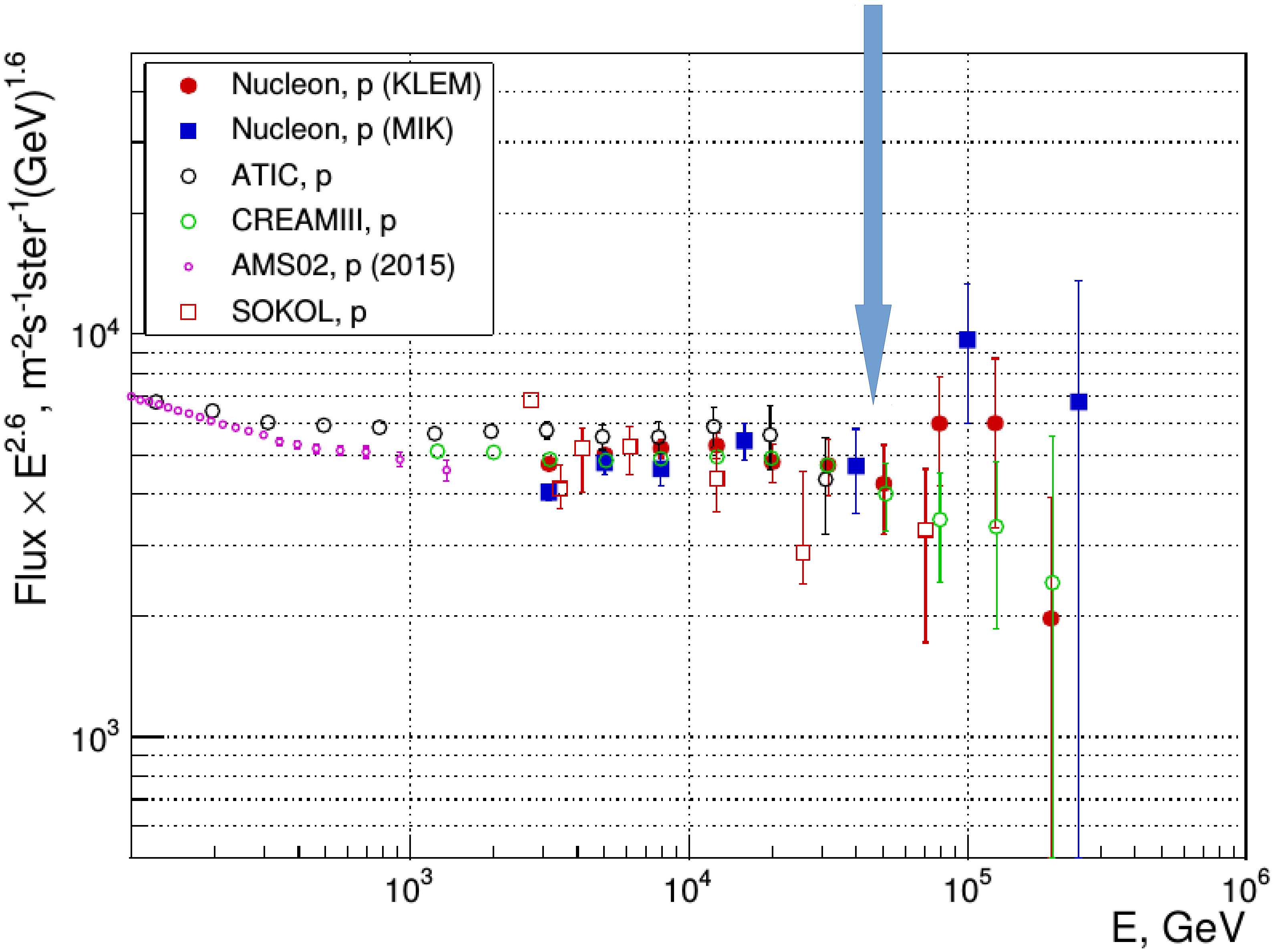


⟨ln(A)⟩
3.5
3
2.5
2
1.5
1
0.5
0
Nucleon (KLEM)
Nucleon (IC)
ATIC
JACEE
10^4
10^5
10^6
E, GeV

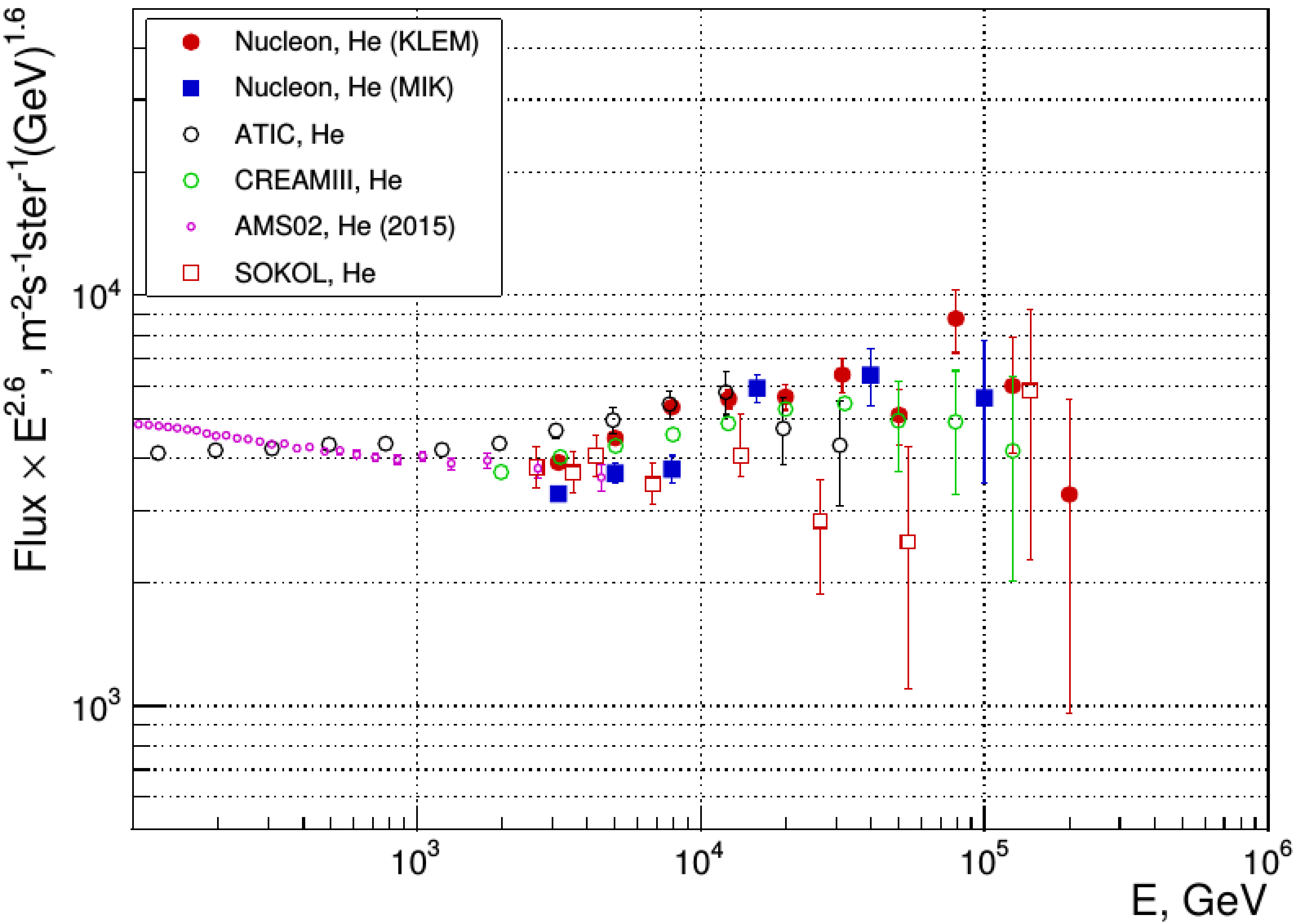
Protons - previous data



Protons - NUCLEON. A 'birdie' feature.

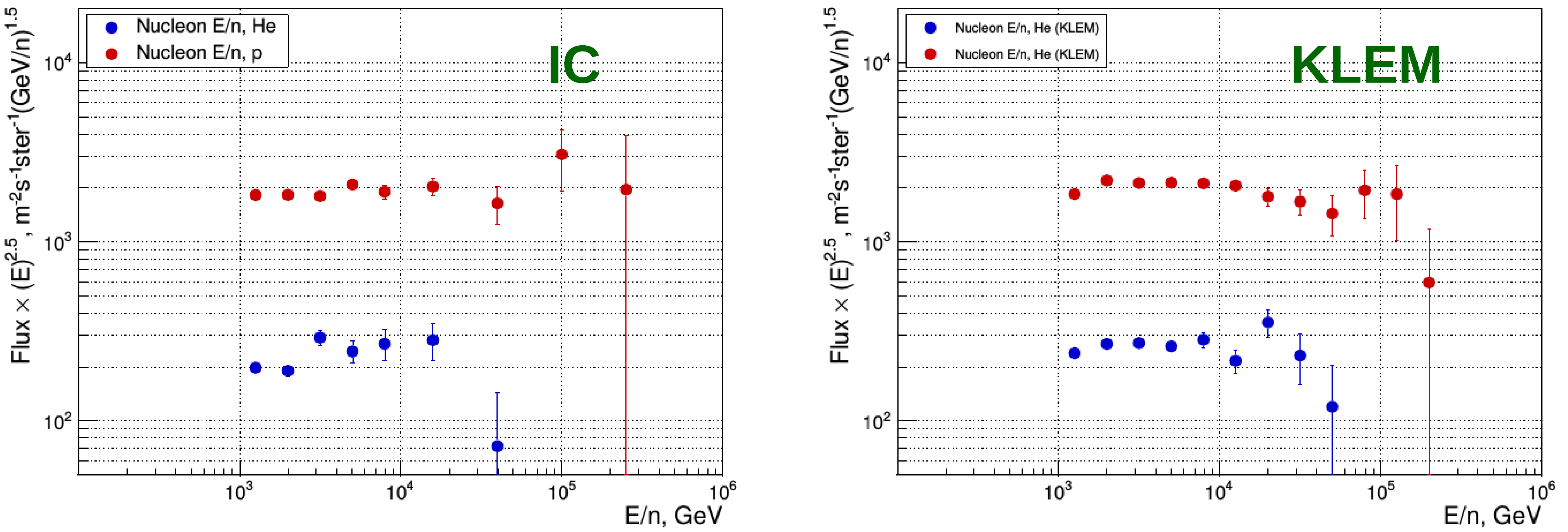


Helium

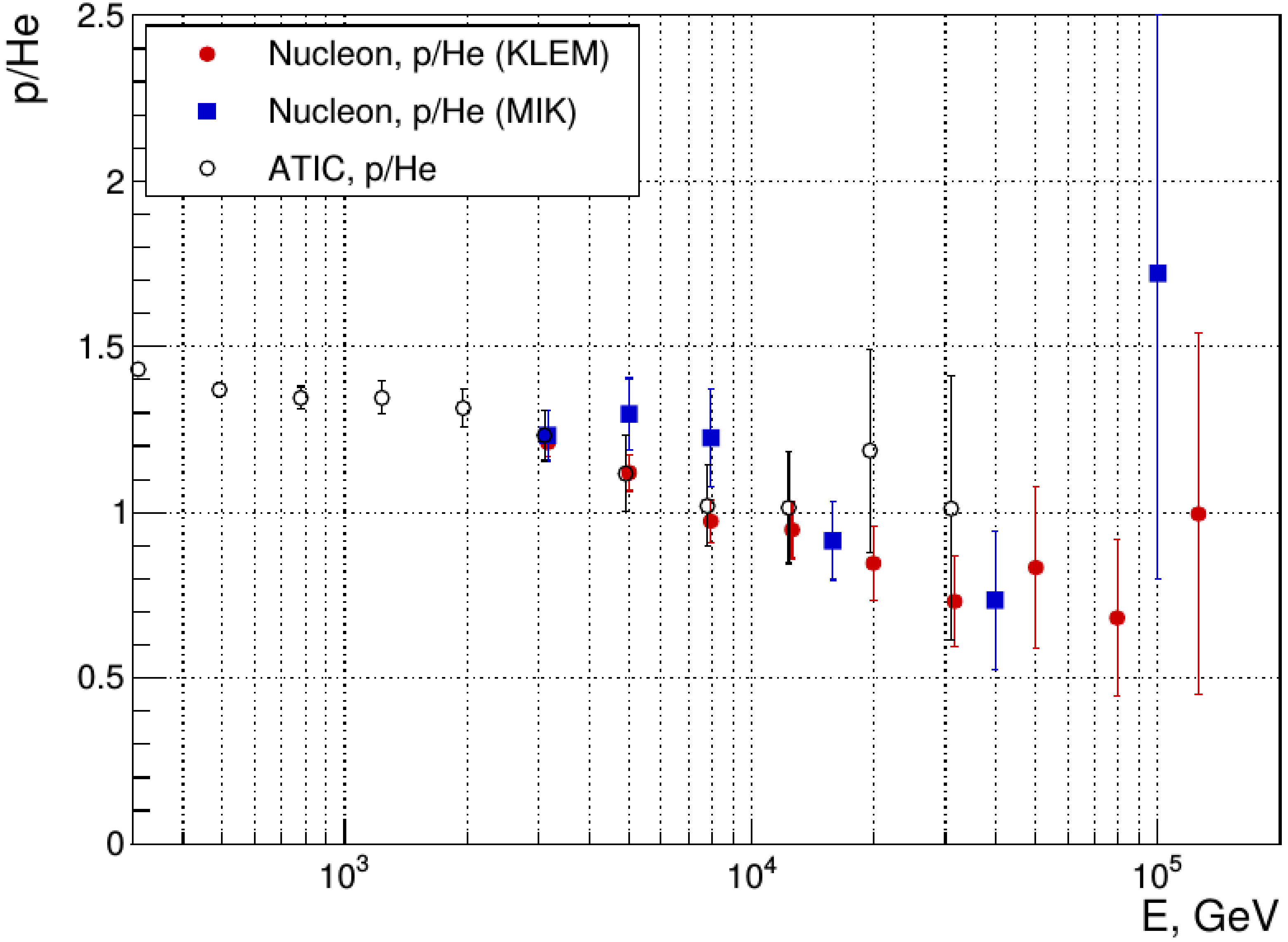


Nucleon, He (KLEM)
Nucleon, He (MIK)
ATIC, He
CREAMIII, He
AMS02, He (2015)
SOKOL, He
$Flux \times E^{2.6}$, $m^{-2}s^{-1}ster^{-1}(GeV)^{1.6}$
10^4
10^3
10^3
10^4
10^5
10^6
E, GeV

Protons and helium spectra in terms of energy per nucleon

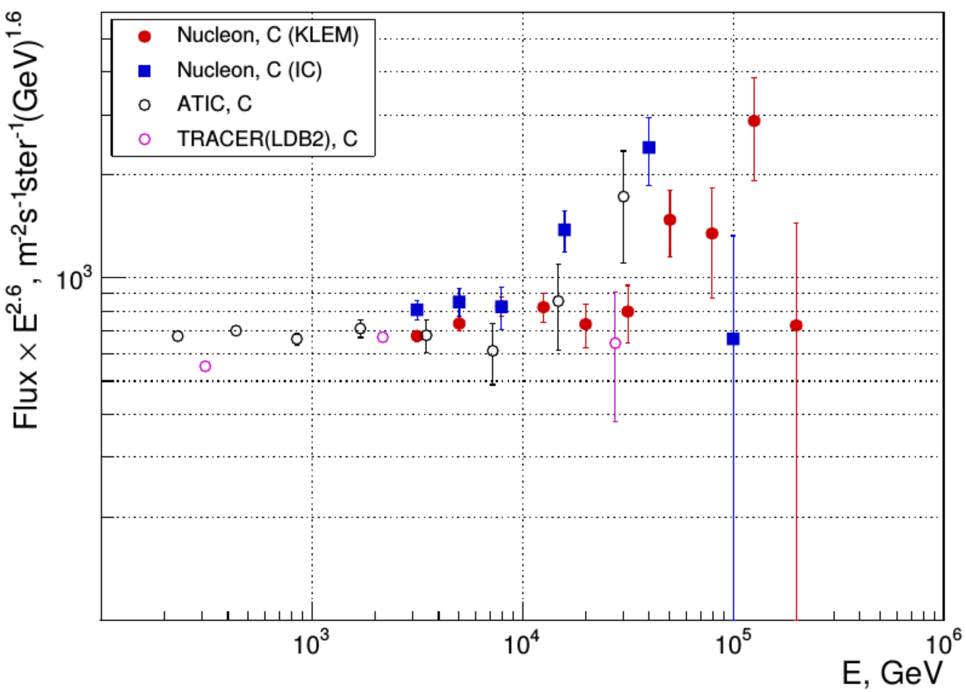


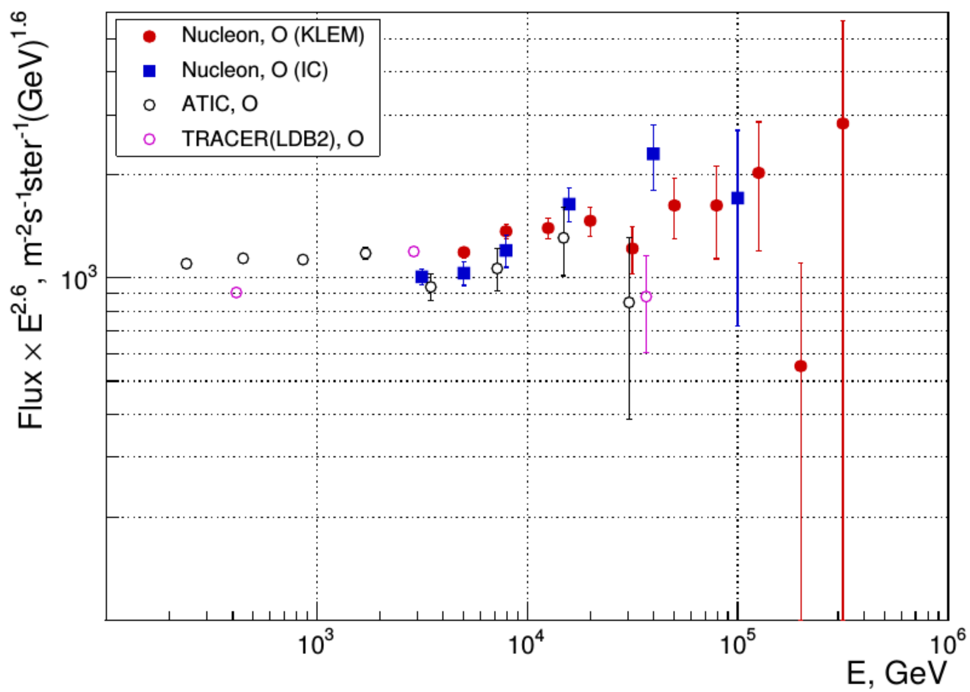
Ratio p/He



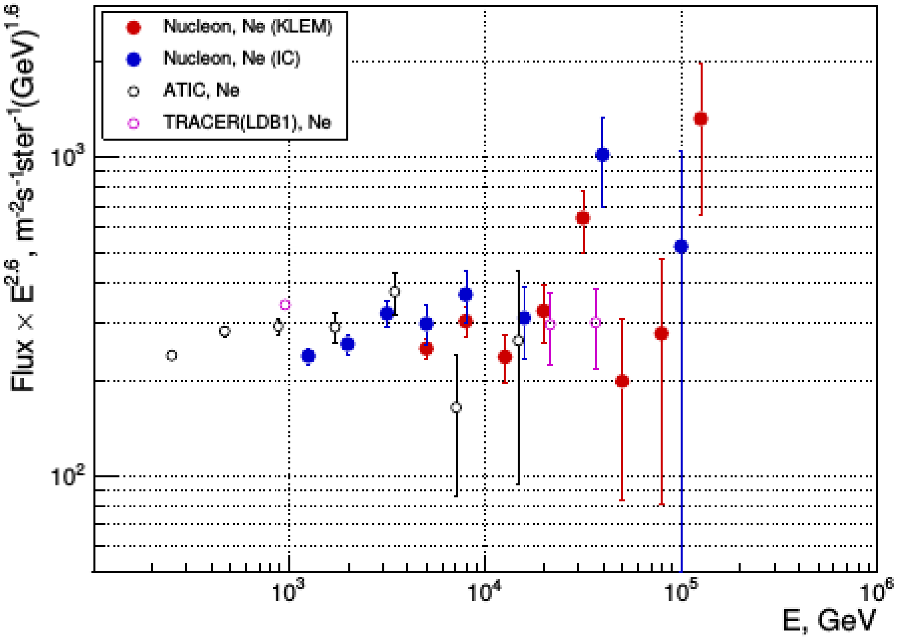
p/He
2.5
2
1.5
1
0.5
0
Nucleon, p/He (KLEM)
Nucleon, p/He (MIK)
ATIC, p/He
10^3
10^4
10^5
E, GeV

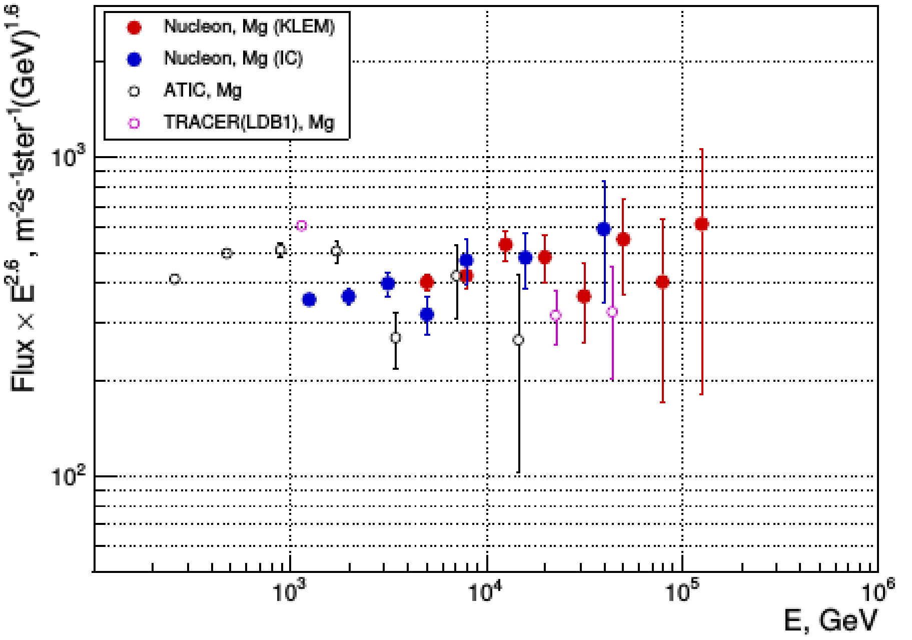
Carbon and oxygen

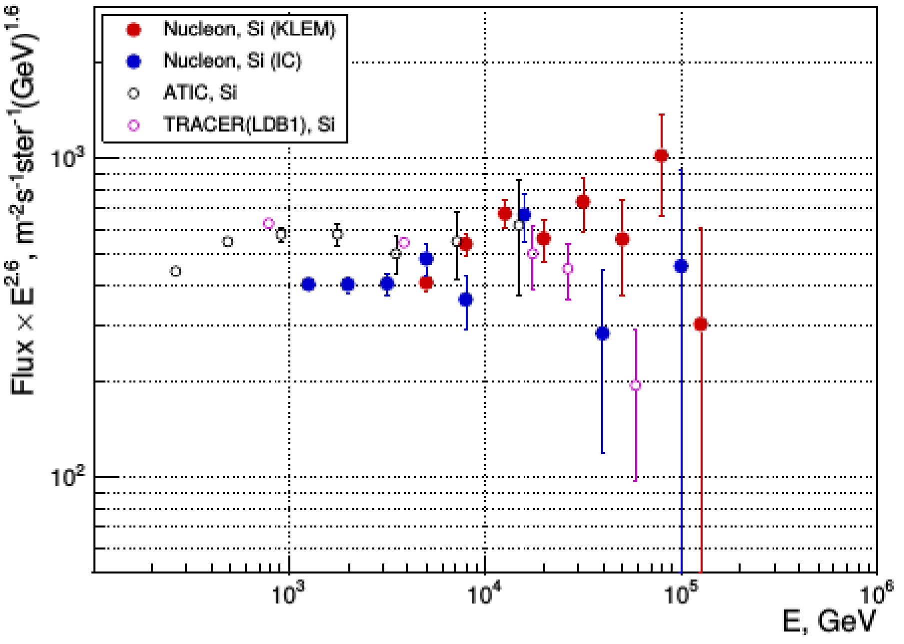




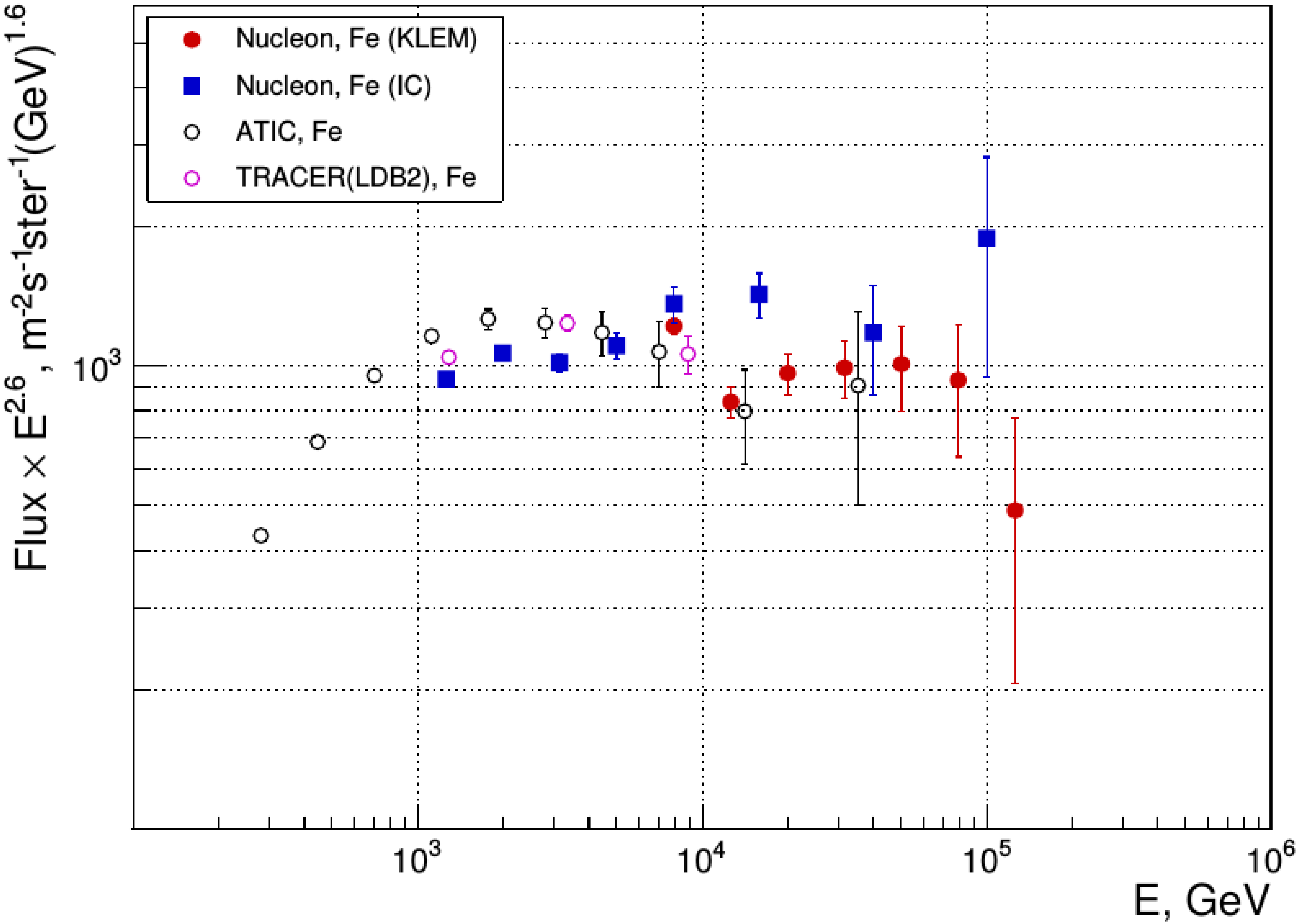
Neon, magnesium, silicon







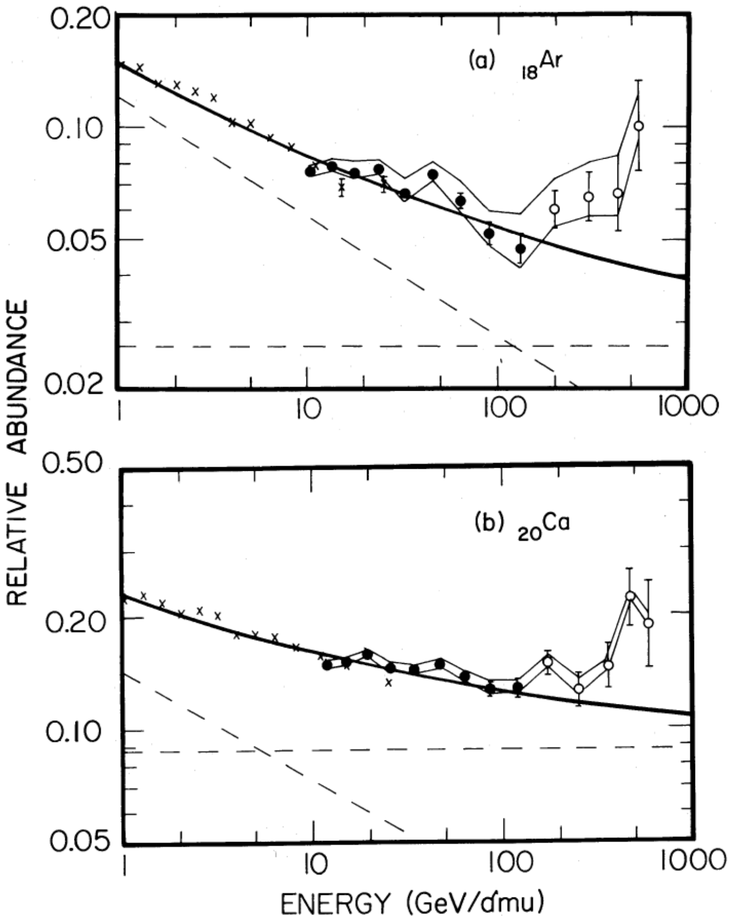
Iron



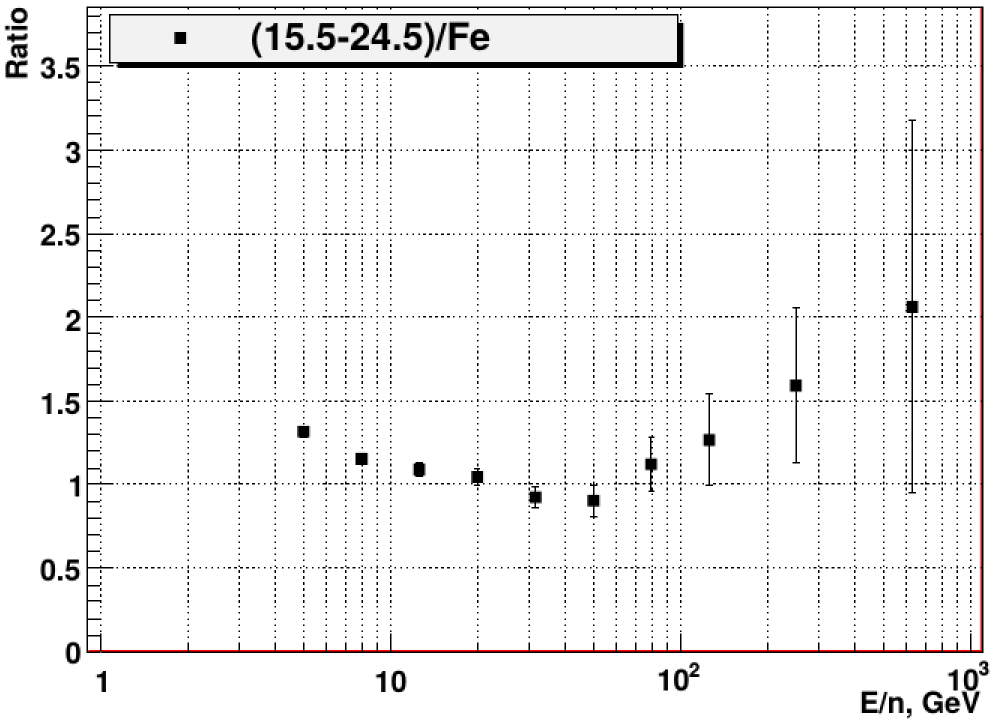
Nucleon, Fe (KLEM)
Nucleon, Fe (IC)
ATIC, Fe
TRACER(LDB2), Fe
Flux × $E^{2.6}$, $m^{-2}s^{-1}ster^{-1}(GeV)^{1.6}$
10^3
10^3
10^4
10^5
10^6
E, GeV

'Subiron' to iron ratio

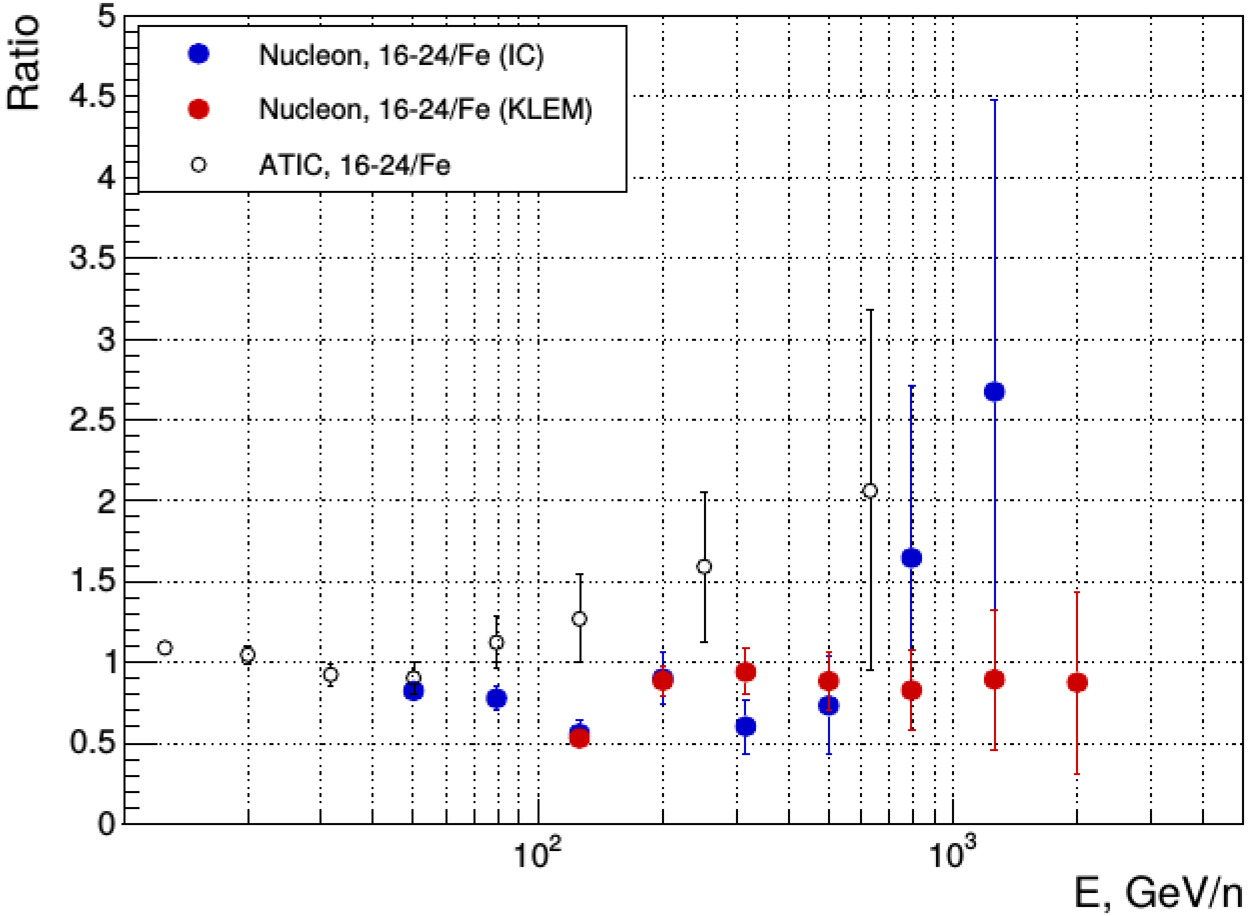
HEAO-3-C3



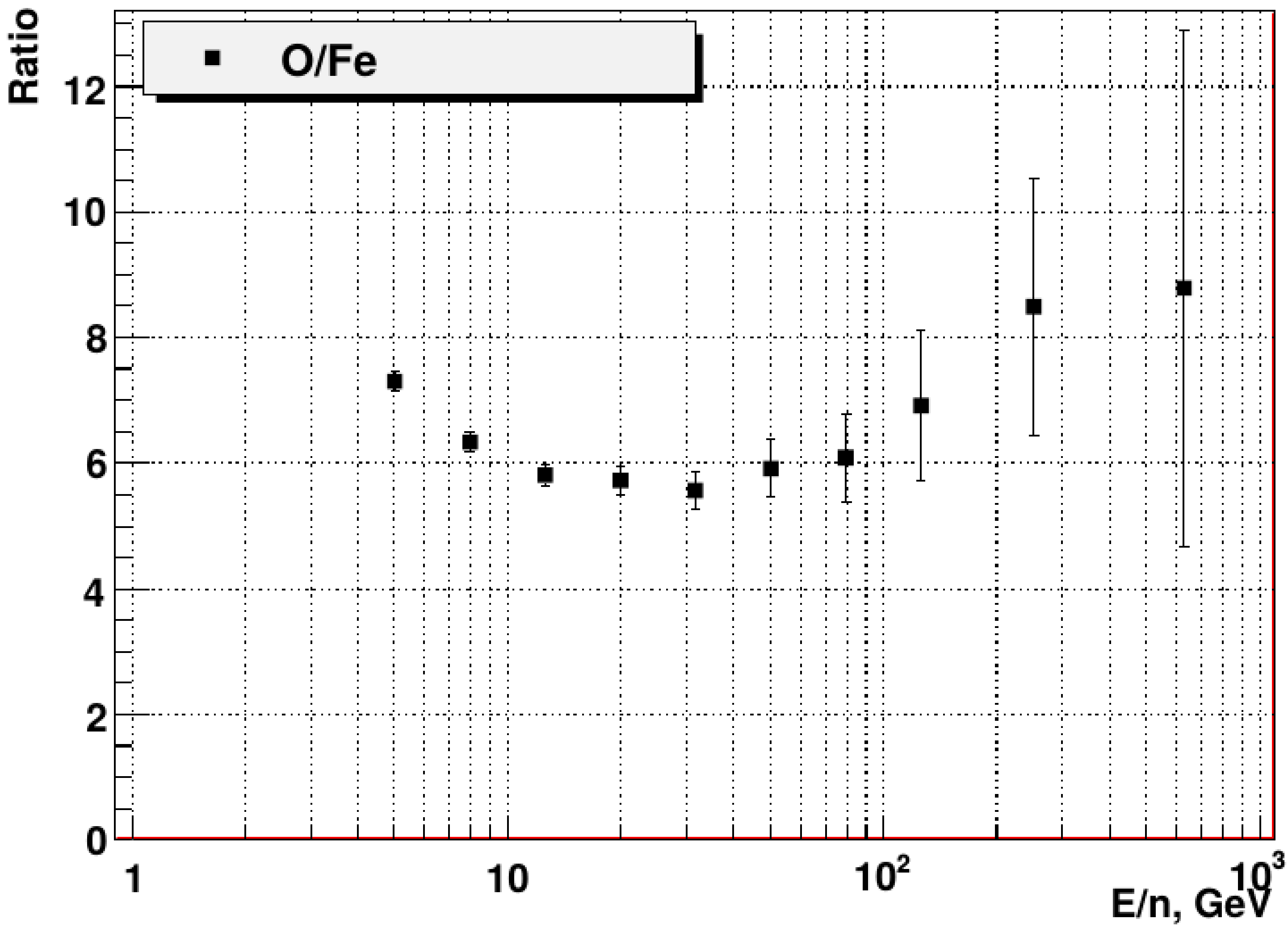
ATIC

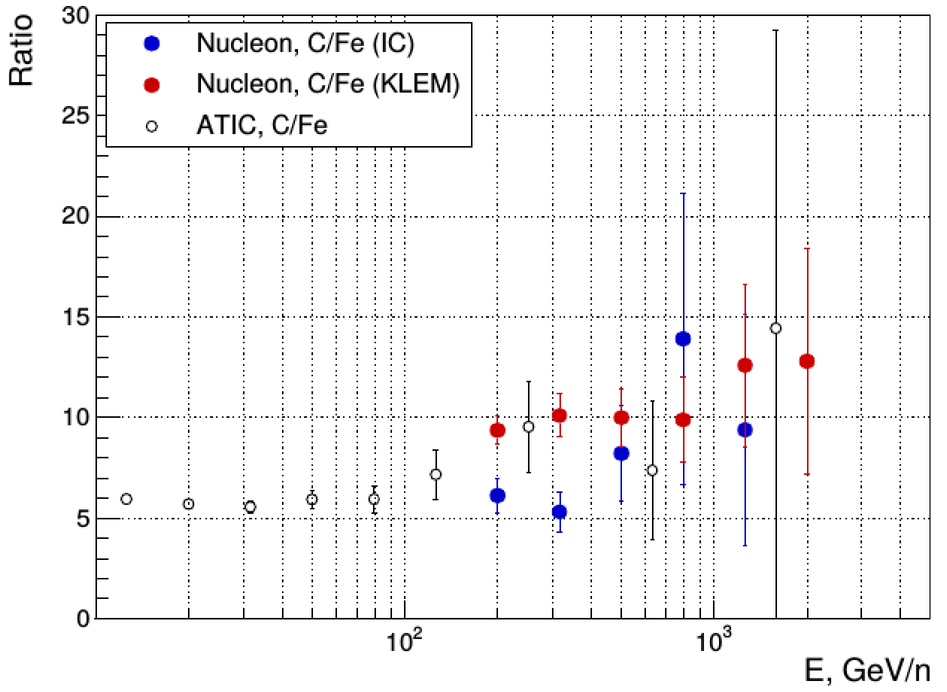


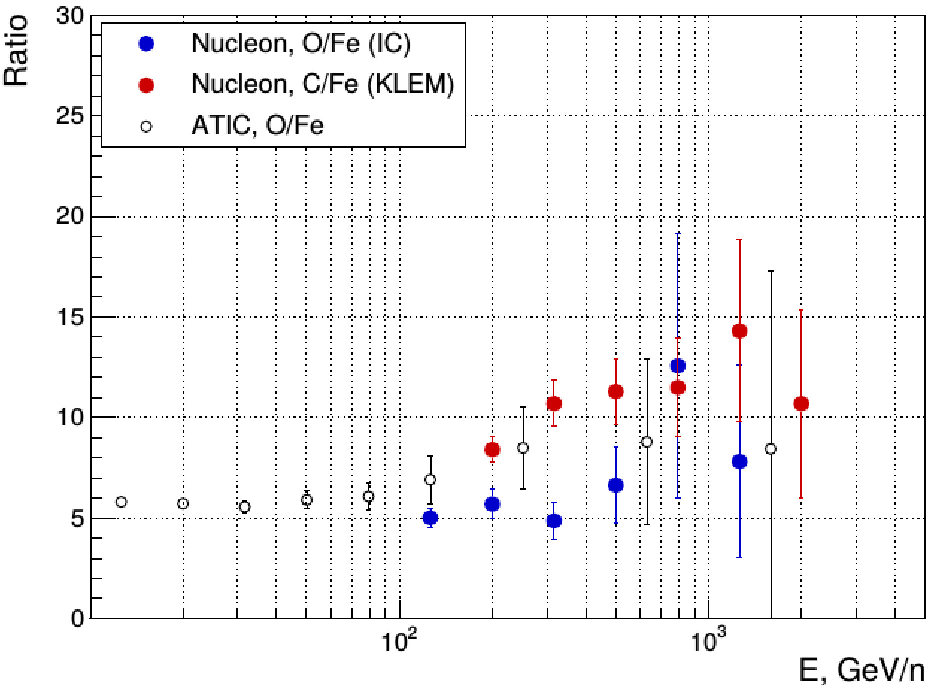
Heavy nuclei to iron ratio - NUCLEON

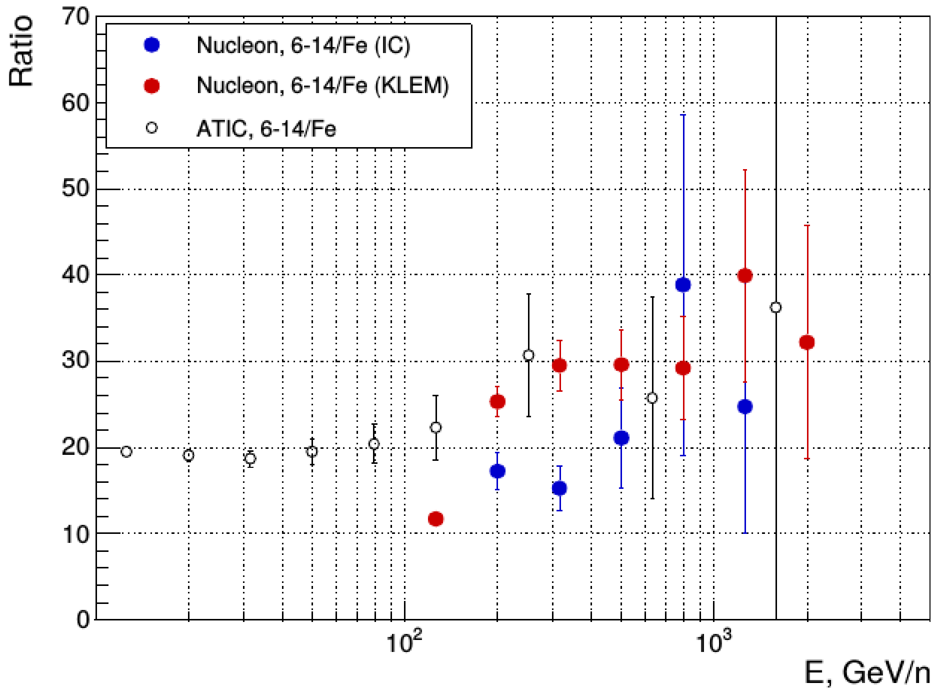


Abundant nuclei to iron ratio: ATIC



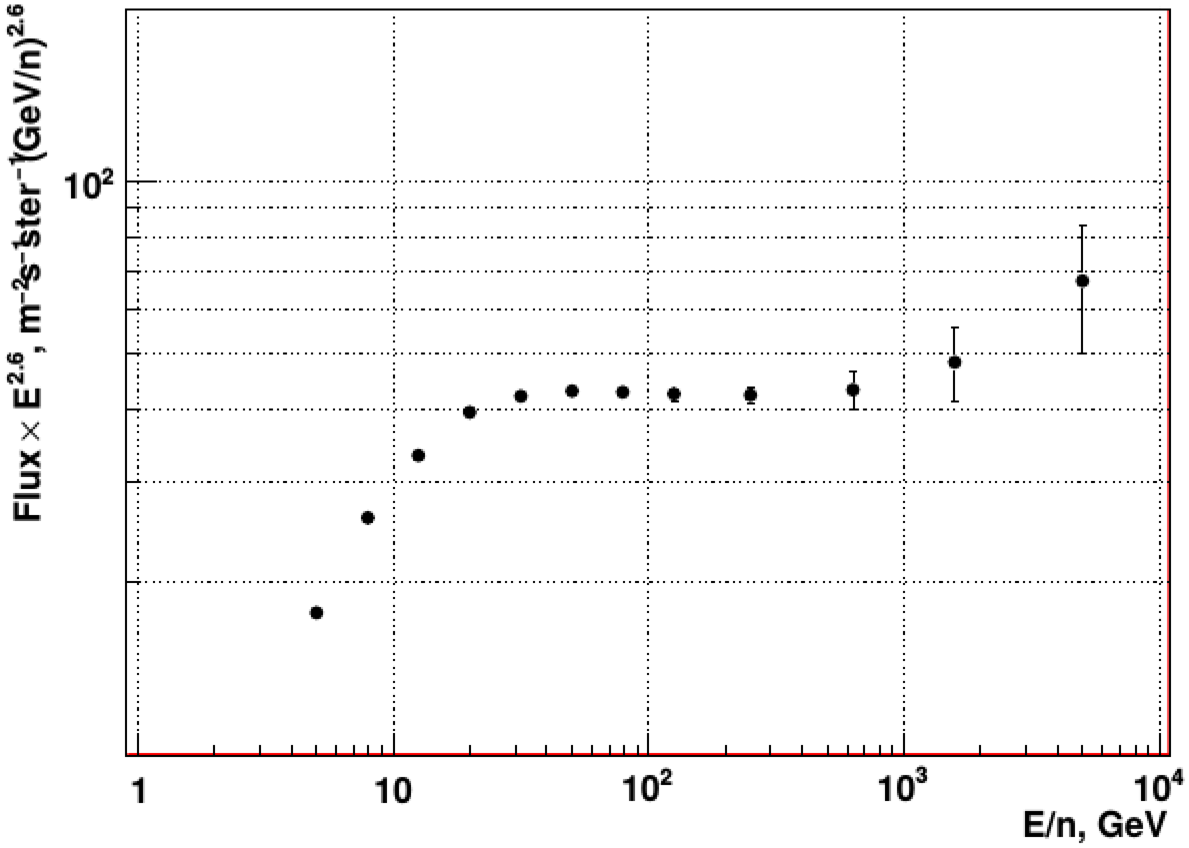






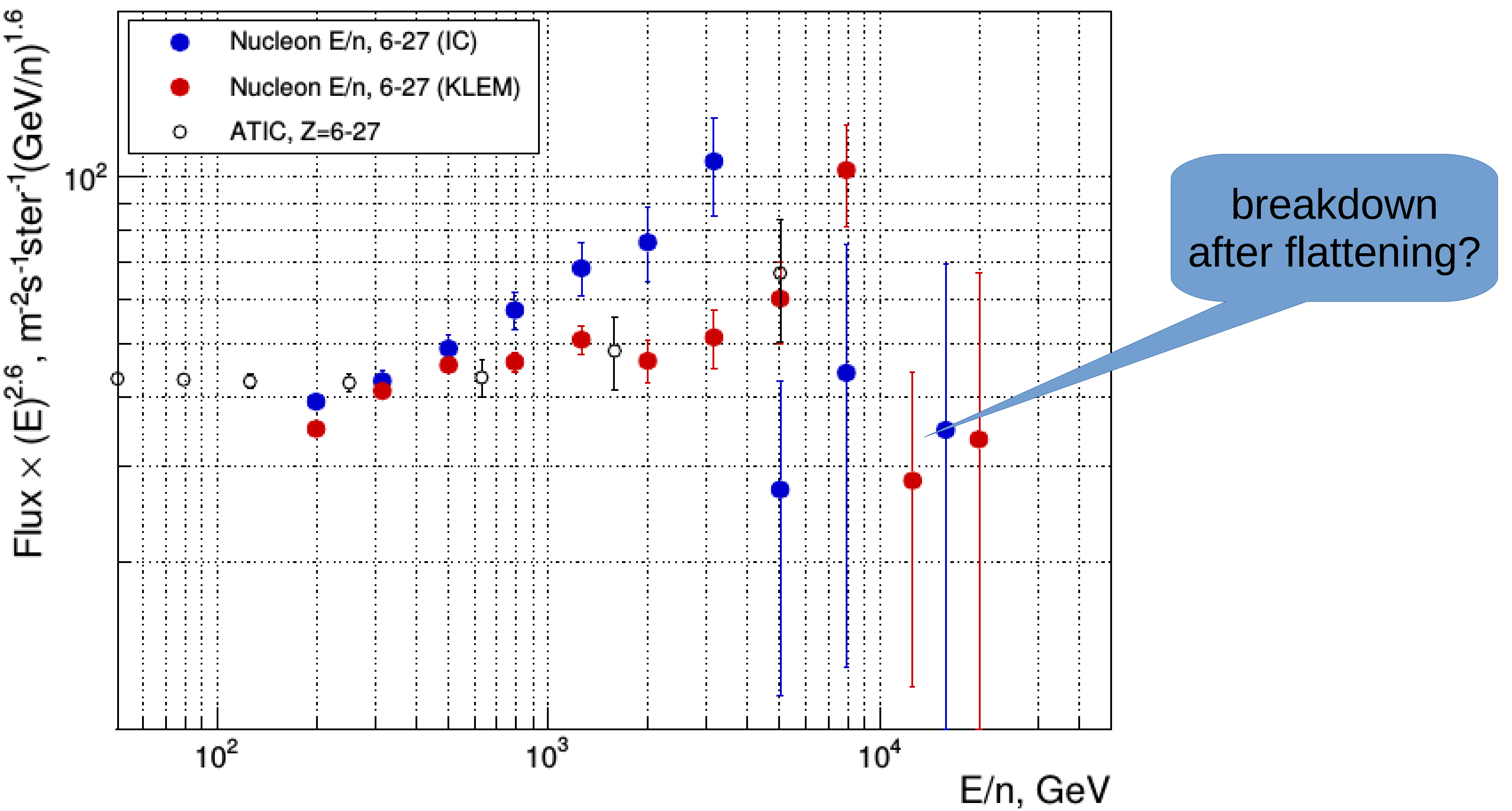
Abundant nuclei to iron ratio - NUCLEON

Heavy nuclei upturn at high energy: ATIC



All nuclei: carbon and more heavy

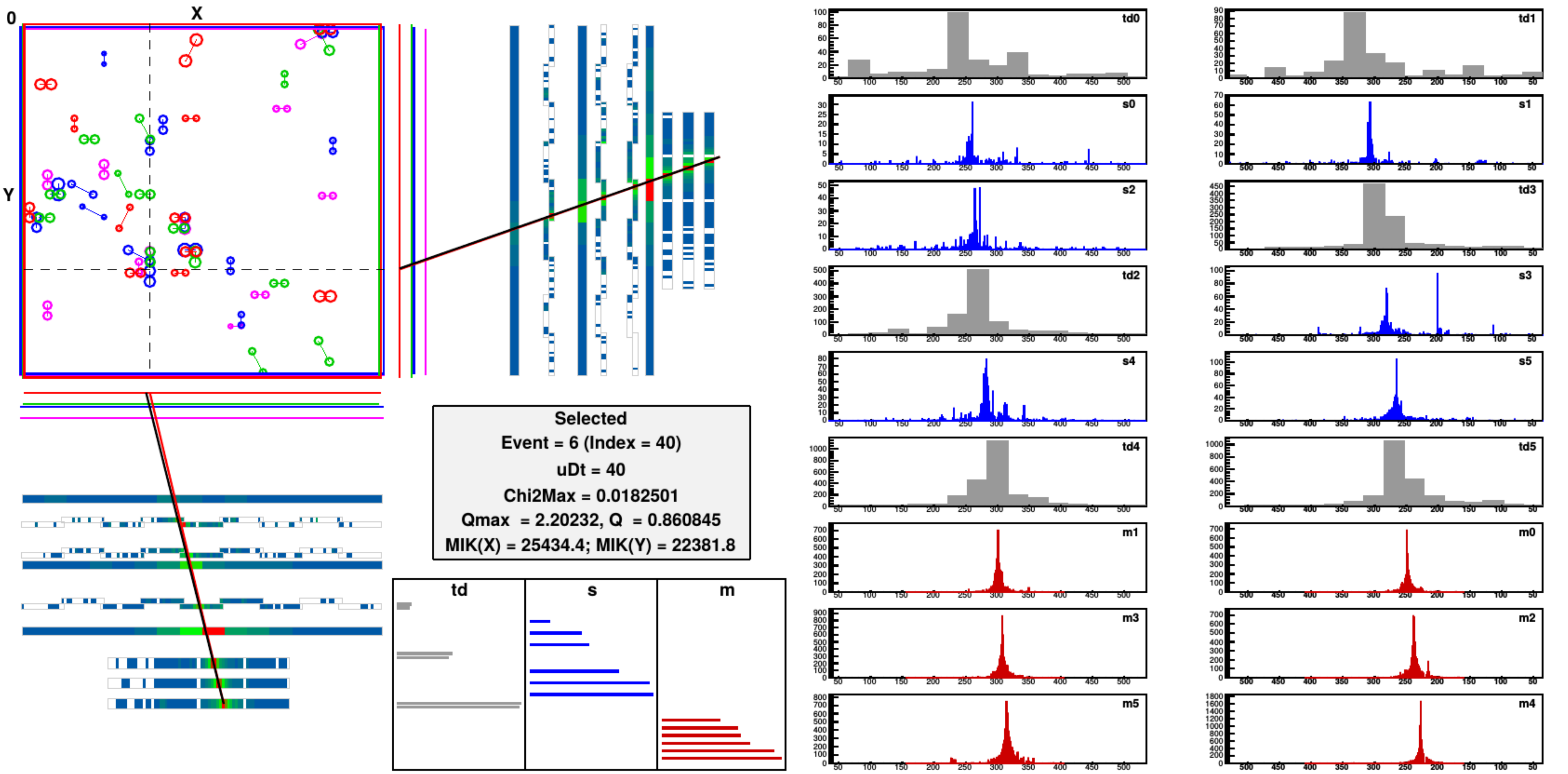
Heavy nuclei upturn at high energy: NUCLEON

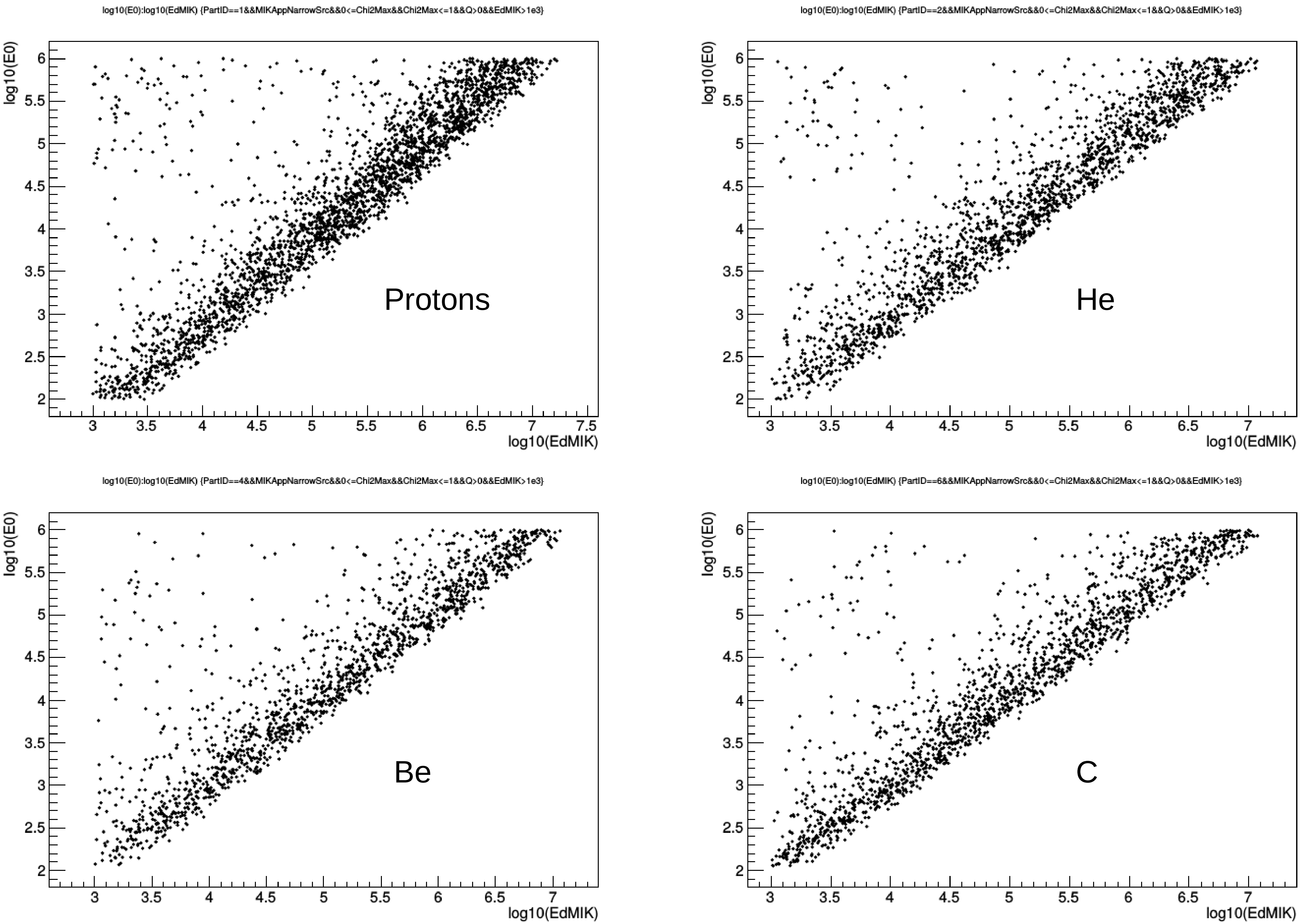


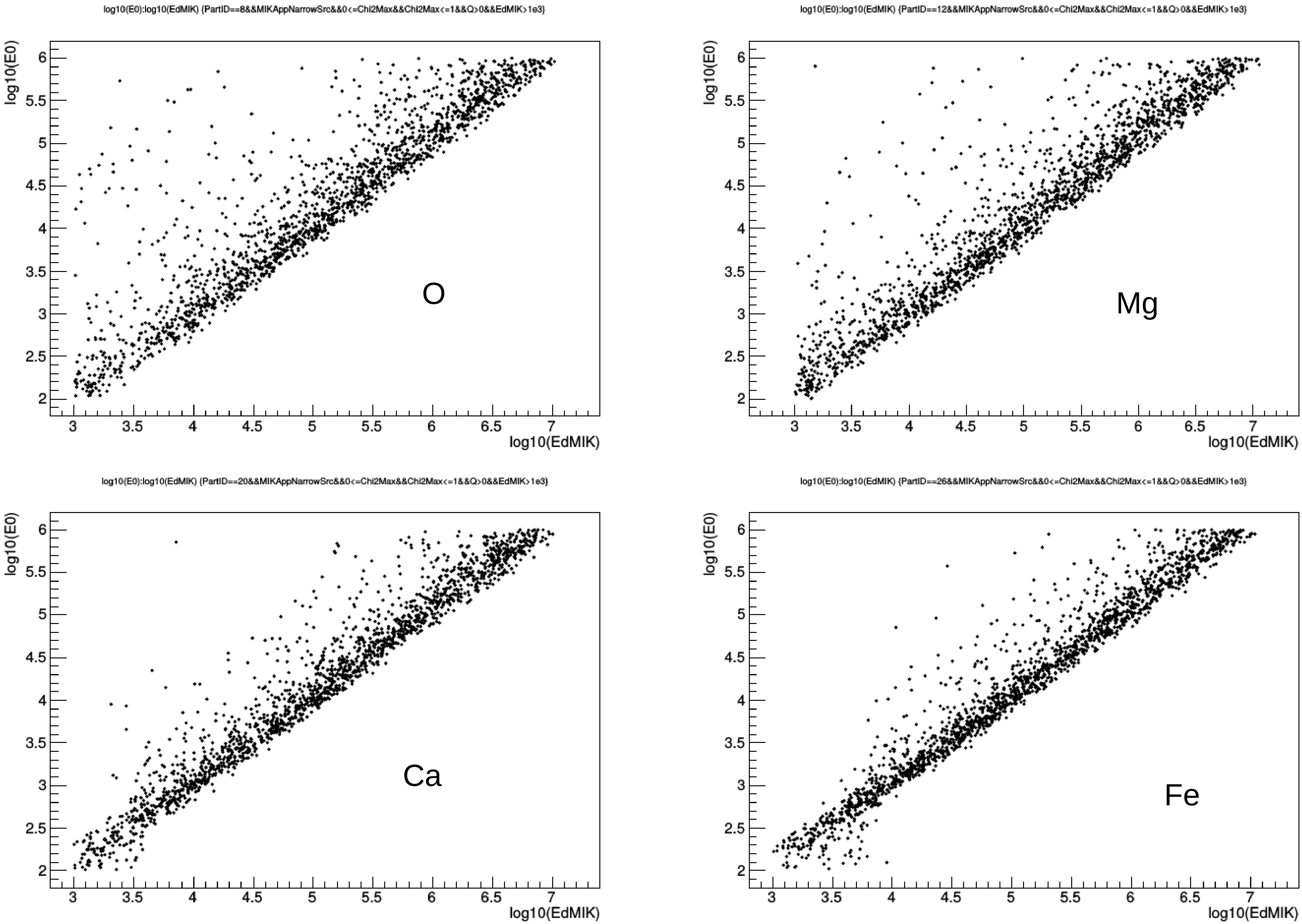
Conclusions

- **Preliminary analysis of the NUCLEON space experiment data gives multiple indications of the existence of a number of features in the energy spectra of cosmic ray nuclei at energies from few TeV to ~100 TeV (per particle).**
- **It is expected that statistical and methodological reliability of the data will be essentially improved in the further course of the NUCLEON experiment**

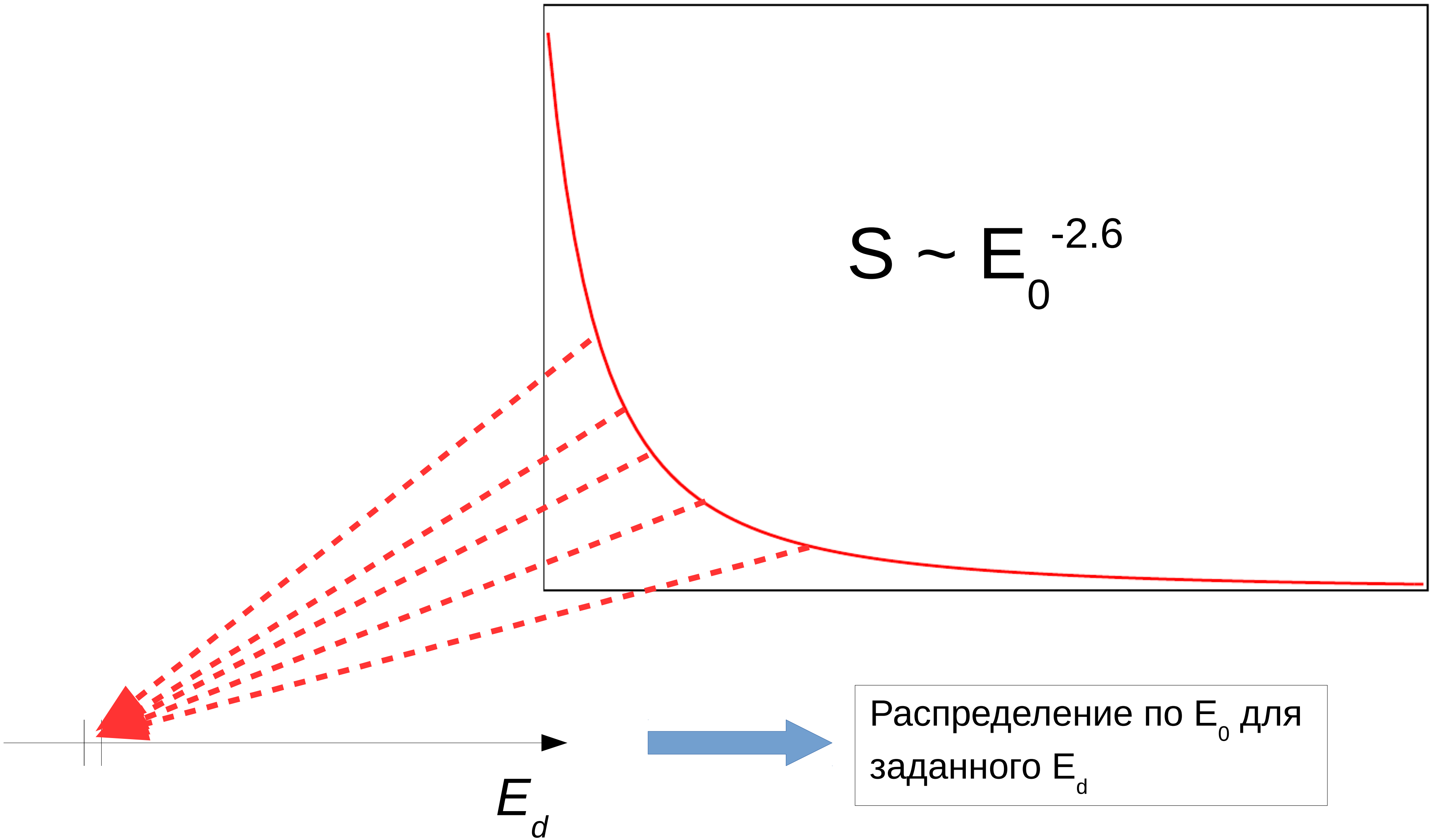
Simulated event




log10(E0):log10(EdMIK) {PartID==1&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
Protons
log10(E0)
log10(EdMIK)
log10(E0):log10(EdMIK) {PartID==2&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
He
log10(E0):log10(EdMIK) {PartID==4&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
Be
log10(E0):log10(EdMIK) {PartID==6&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
C


log10(E0):log10(EdMIK) {PartID==8&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
log10(E0)
log10(EdMIK)
O
log10(E0):log10(EdMIK) {PartID==12&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
log10(E0)
log10(EdMIK)
Mg
log10(E0):log10(EdMIK) {PartID==20&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
log10(E0)
log10(EdMIK)
Ca
log10(E0):log10(EdMIK) {PartID==26&&MIKAppNarrowSrc&&0<=Chi2Max&&Chi2Max<=1&&Q>0&&EdMIK>1e3}
log10(E0)
log10(EdMIK)
Fe

$$\frac{1}{K(E_d)} = \frac{E_0}{E_d} \quad \rightarrow \quad E_0 \approx \frac{E_d}{K(E_d)}$$



Распределение по E_0 для заданного E_d

KLEM: $E_{rec}=aS^b$