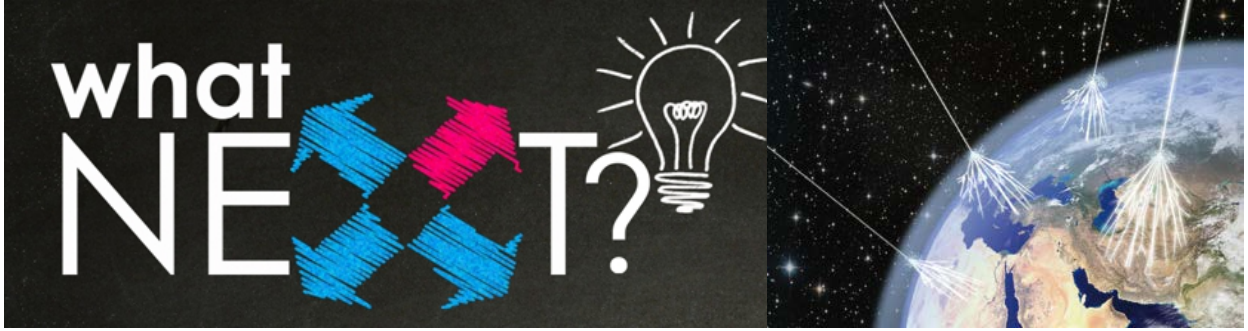

(Some) Open Issues on Galactic Cosmic Rays

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and INFN Sezione di Lecce

INFN workshop on
Cosmic Rays: What next ?
Padova, December 2-4, 2014

Outline and disclaimer

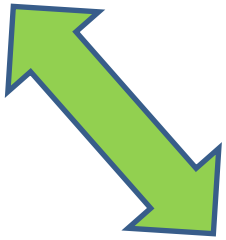
Given the context, this will not be a standard review talk,
but a tool to focus the attention and trigger the discussion
on some general important points.

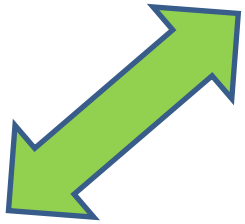
I will concentrate on Cosmic rays as they are “usually” defined,
i.e. on primary protons and heavier nuclei.

I will not cover electrons/positrons, photons and neutrinos, nor UHECR (see elsewhere in the agenda).

What are CR accelerators ?
How do they work ?

High(est) Energy
Particle Physics





Mass composition
Energy spectra
Arrival directions

protons only

all-particle

electrons

positrons

antiprotons

$E^2 dN/dE$ (GeV cm^{-2} sr^{-1} s^{-1})

10^{0} 10^{-2} 10^{-4} 10^{-6} 10^{-8} 10^{-10}

10^{0} 10^{2} 10^{4} 10^{6} 10^{8} 10^{10} 10^{12}

E_{kin} (GeV / particle)

Unbiased study of galactic CR

What we have

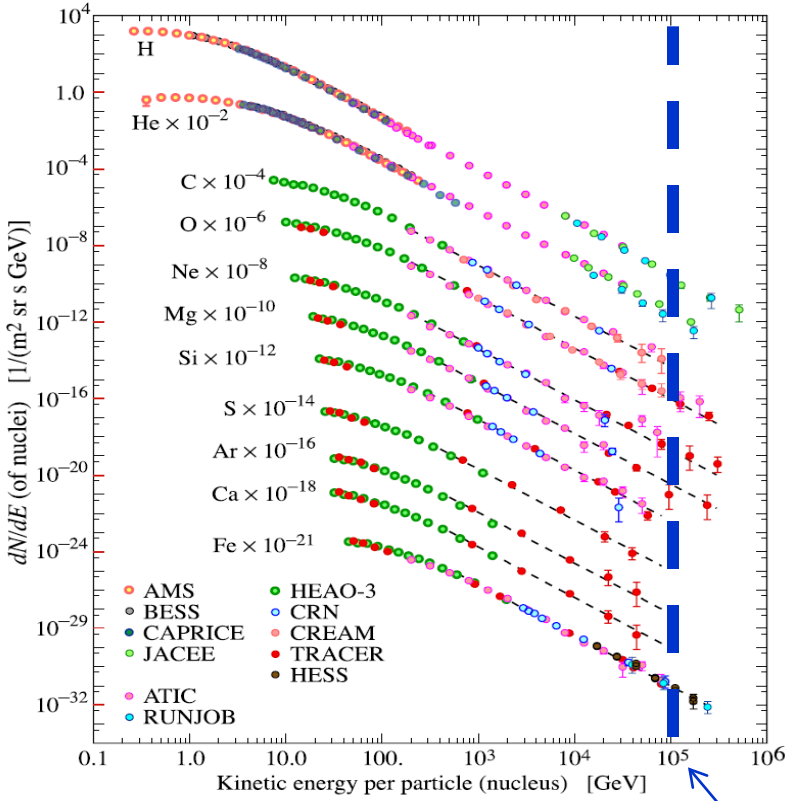
(from PDG)

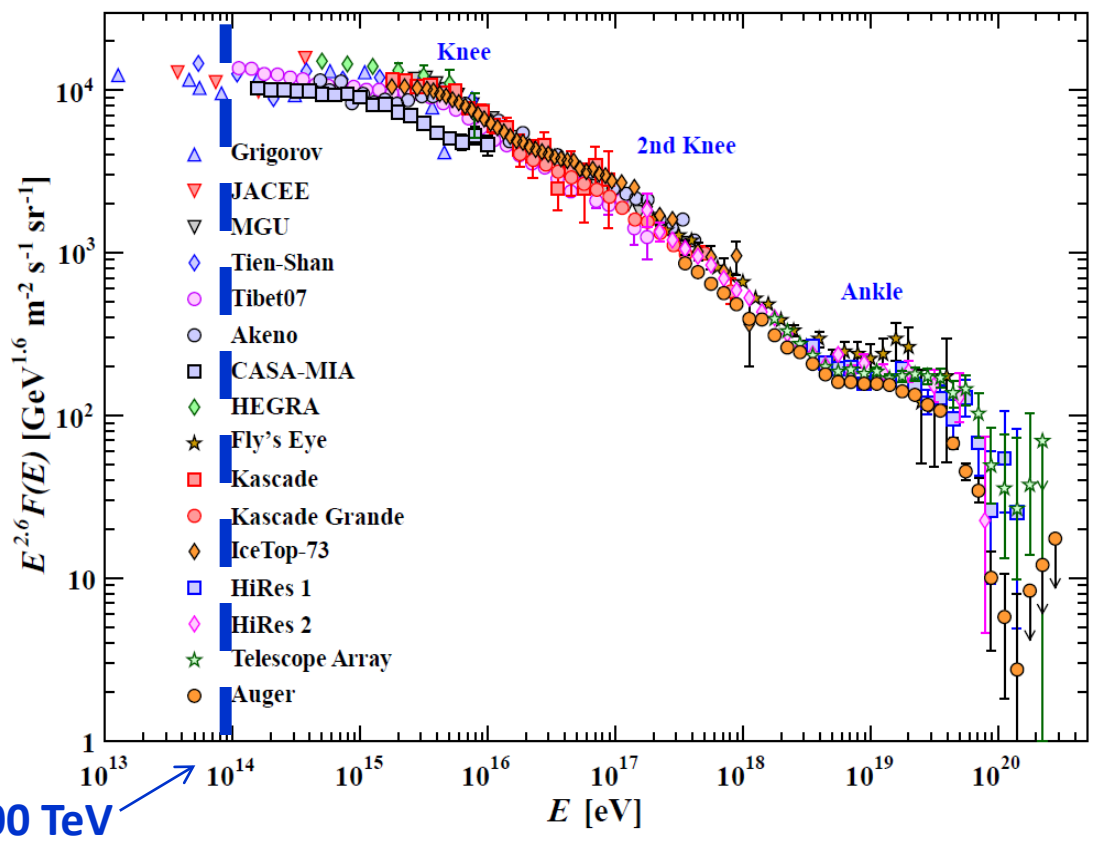
Direct measurements

- High precision
- fluxes of single components
- (acceptance) limited in energy

Indirect measurements

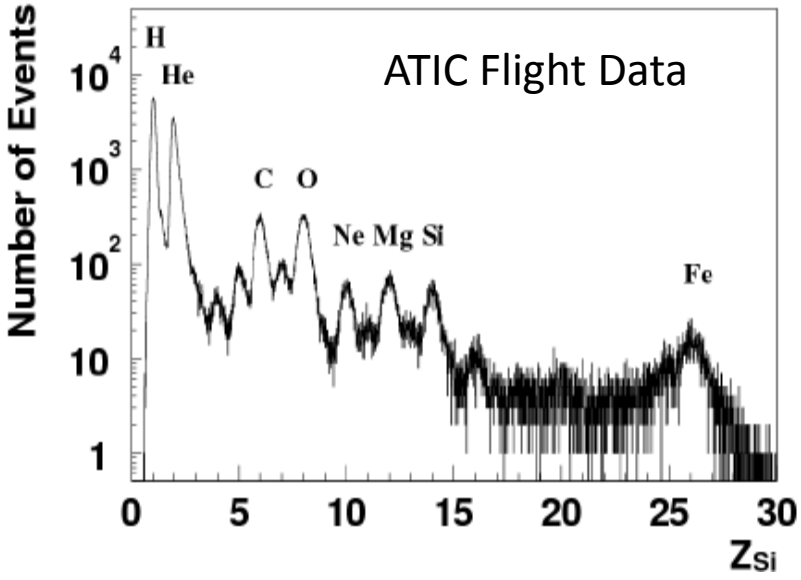
- Larger systematics
- Difficult composition measurements
- Can go to the highest energies

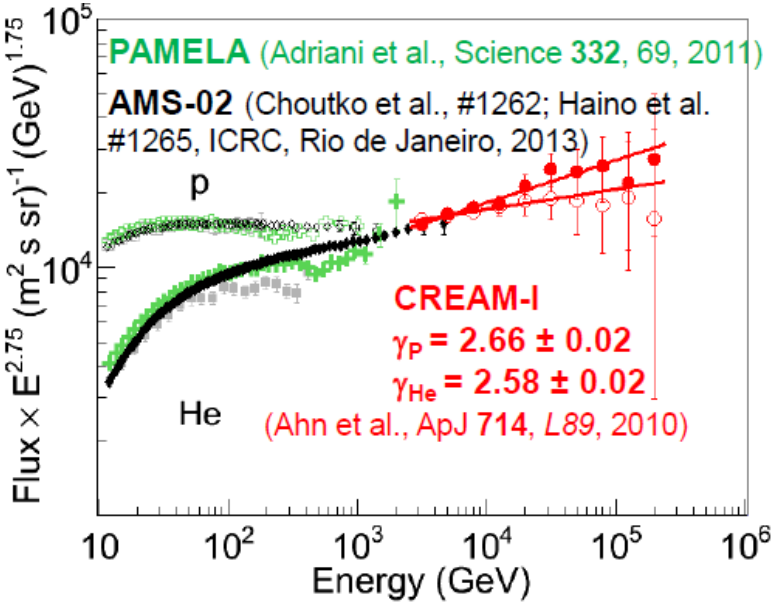


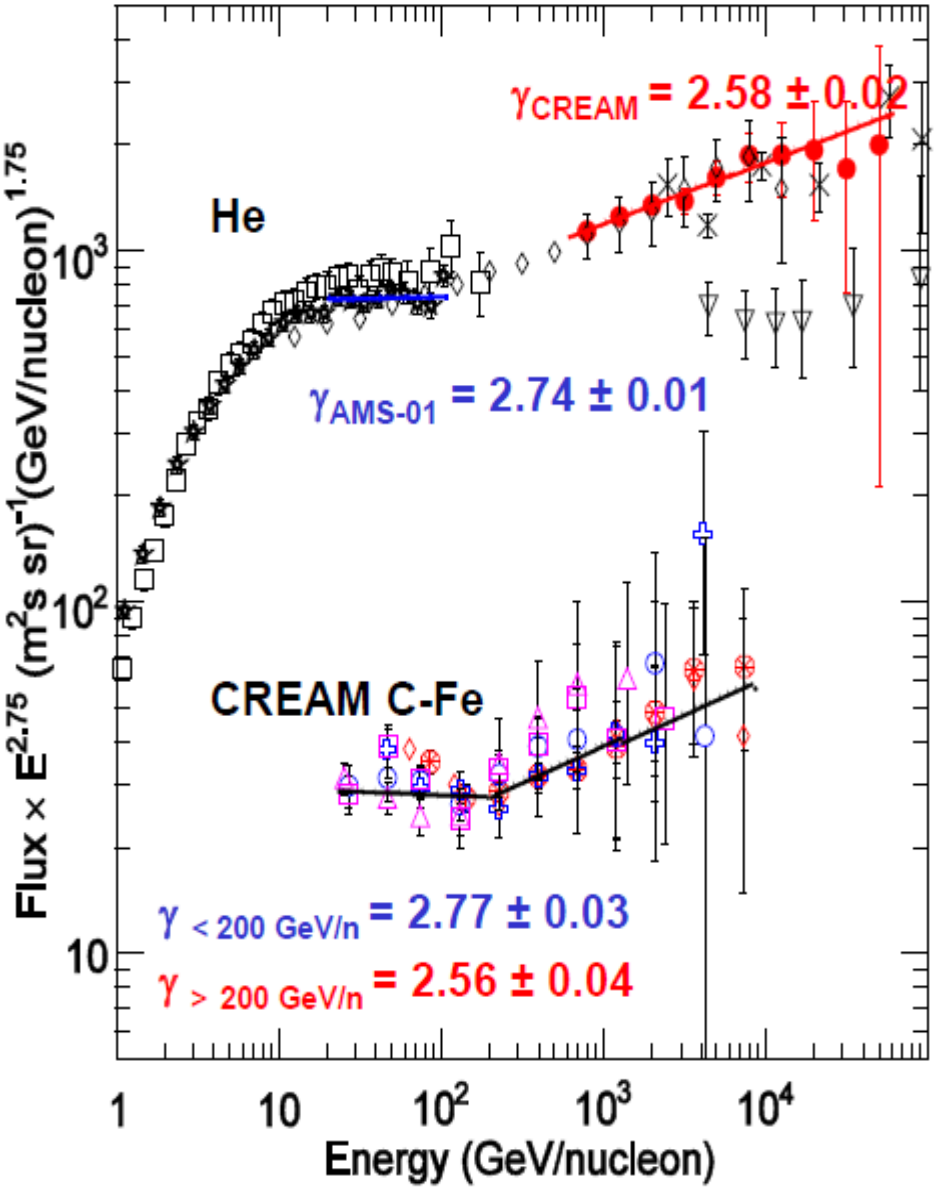


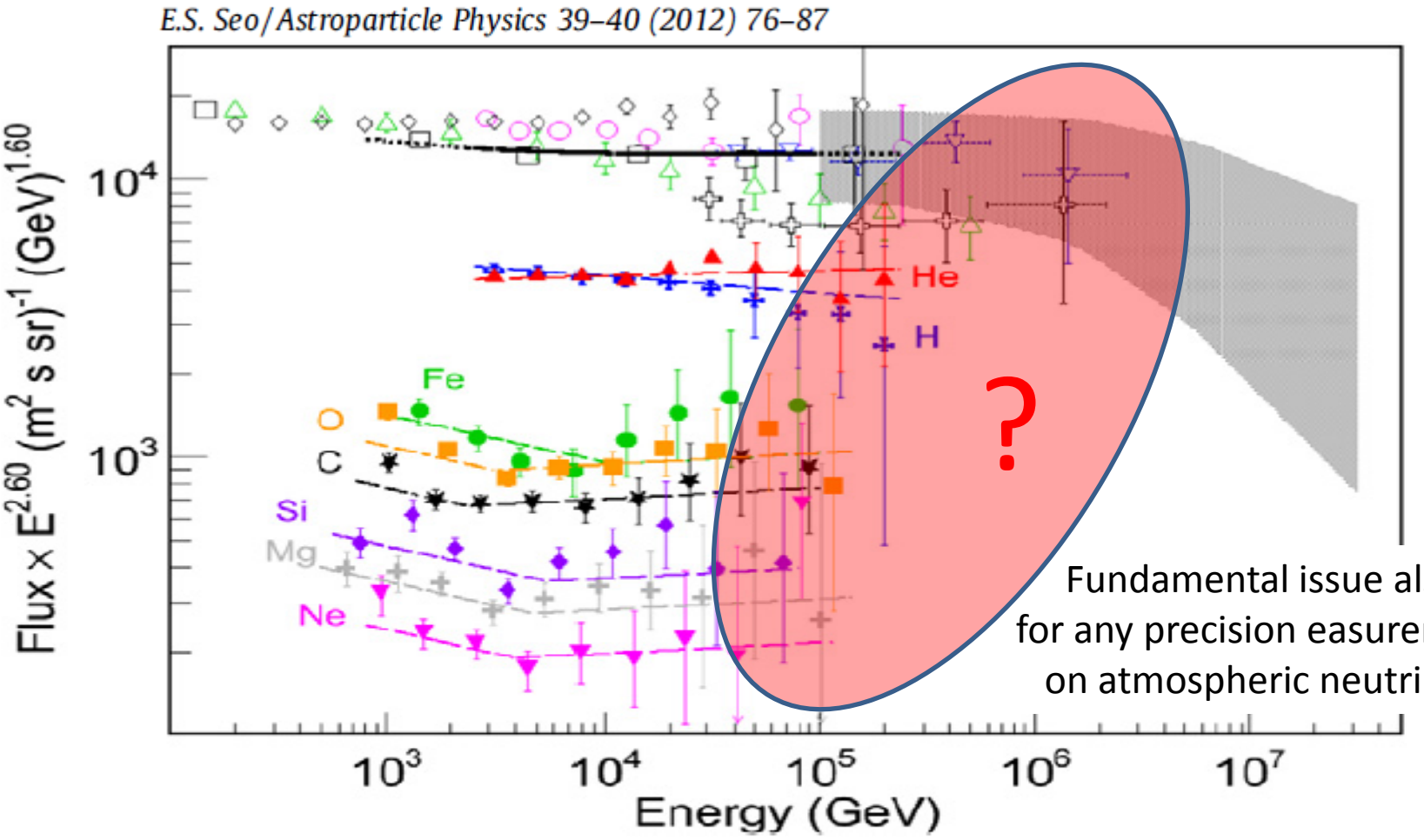
100 TeV

From ballons/satellites…









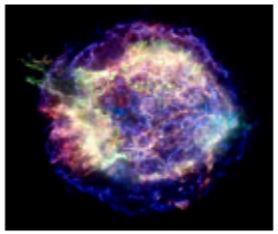
Fundamental issue also for any precision easurement on atmospheric neutrinos

Fig. 11. The all-particle spectrum (black solid curve) obtained by summing up CREAM elemental spectra from p to Fe (filled symbols) is compared with previous measurements (open symbols): ATIC-1 [35], black squares; JACEE, blue downward triangles; RUNJOB, black crosses; Ichimura et al. [71], green upward triangles; SOKOL [72], pink circles. The gray shaded area indicates ground based indirect measurements. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(SNR) Maximum CR energy (for protons)

$$\varepsilon \approx 230\, n_e^{1/2}\, u_7^2\, R_{\rm pc}\ {\rm TeV}$$

Cas A



$\varepsilon \approx 160\ {\rm TeV}$ shock vel ~ 5,000 km s^{-1}

T. Bell
GSSI workshop
Sep. 2014

Sedov phase

$$\varepsilon \approx 20\, E_{44}^{1/3}\, n_e^{1/6}\, u_6^{4/3}\ {\rm TeV}$$

shock vel in 1,000 km s^{-1}

Blast wave energy in 10^{44}J

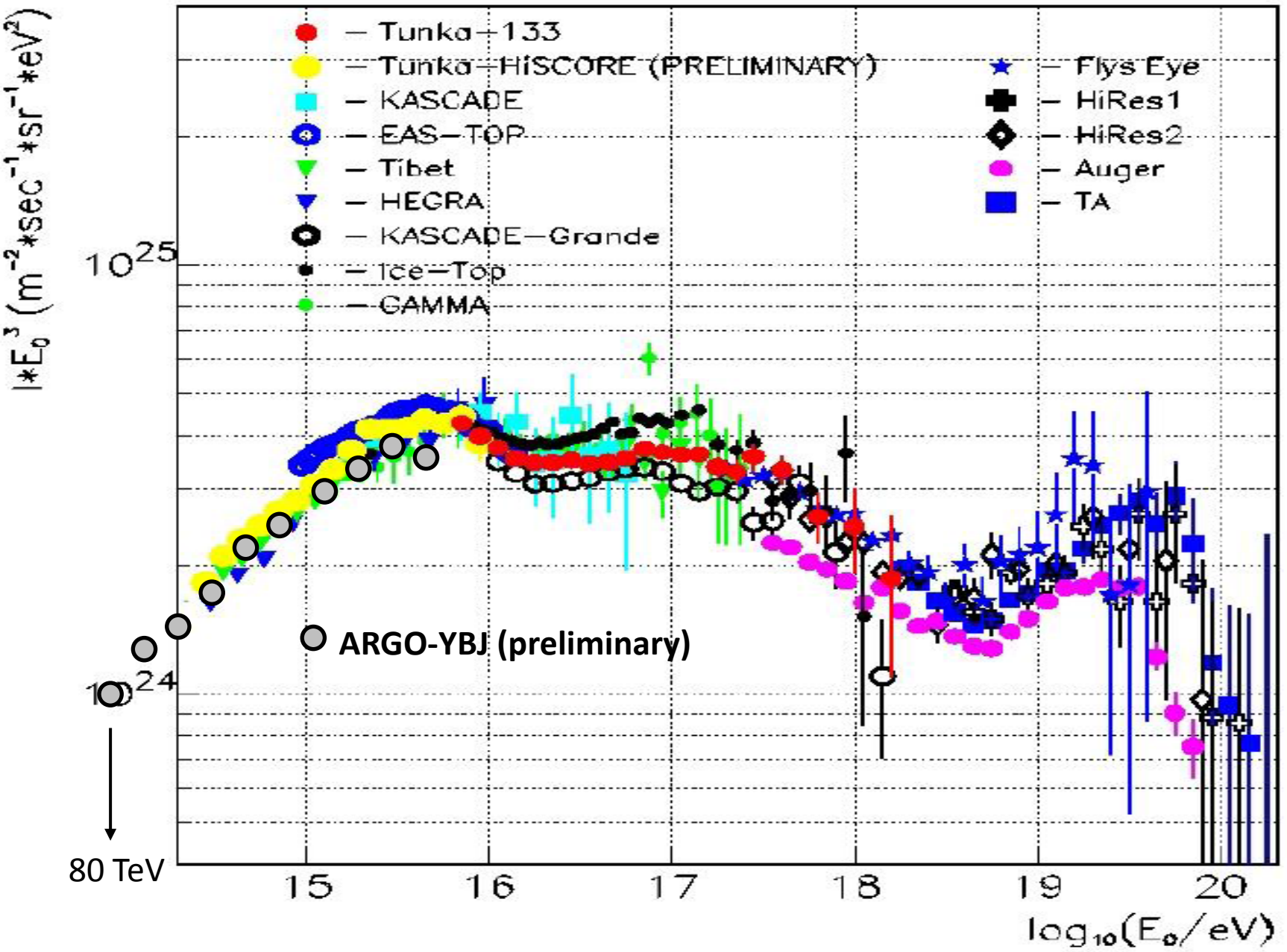
SN expansion into circumstellar wind

wind mass loss in 10^{-5} solar masses yr^{-1}

$$\varepsilon = 800 u_7^2 \sqrt{\frac{\dot{M}_5}{u_4}}\ {\rm TeV}$$

Difficult to get far beyond PeV
(Schure & Bell 2013)

wind vel in 10 km s^{-1}

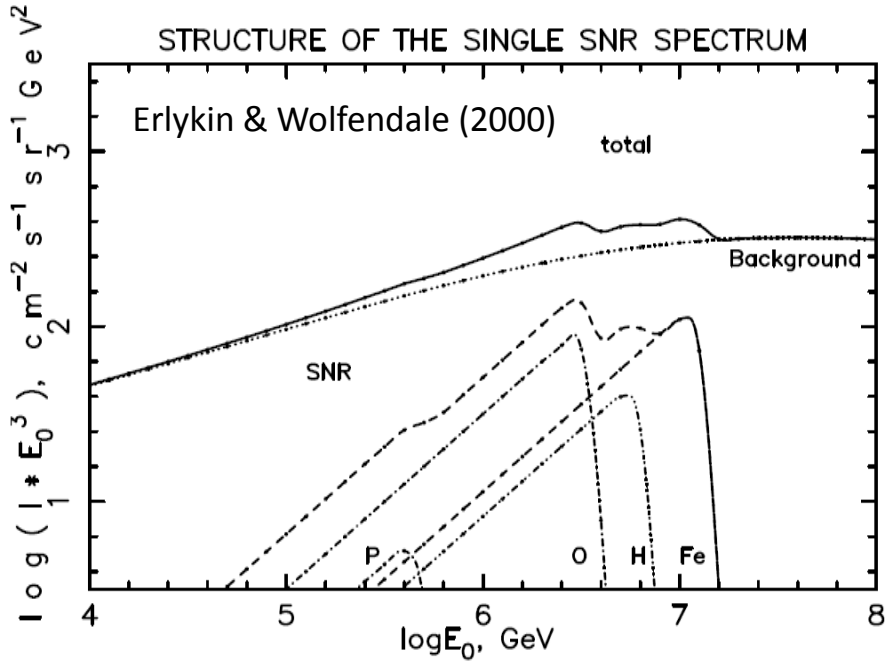

— Tunka-133
— Tunka-HiSCORE (PRELIMINARY)
— KASCADE
— EAS-TOP
— Tibet
— HEGRA
— KASCADE-Grande
— Ice-Top
— CAMMA
— Fly's Eye
— HiRes1
— HiRes2
— Auger
— TA
ARGO-YBJ (preliminary)
80 TeV
$I*E_0^3$ $(m^{-2}*sec^{-1}*sr^{-1}*eV^2)$
10^{25}
10^{24}
15
16
17
18
19
20
$\log_{10}(E_0/eV)$

Structures in the all-particle spectrum

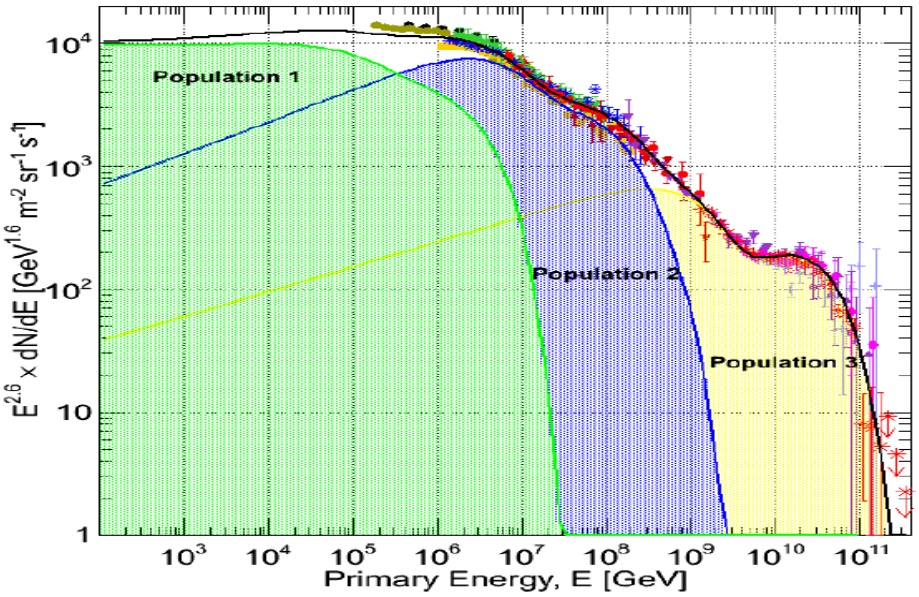
- Acceleration ? Diffusion ?
- Multiple populations ? Nearby sources ?

- Many possible answers…. (**just two examples below**)

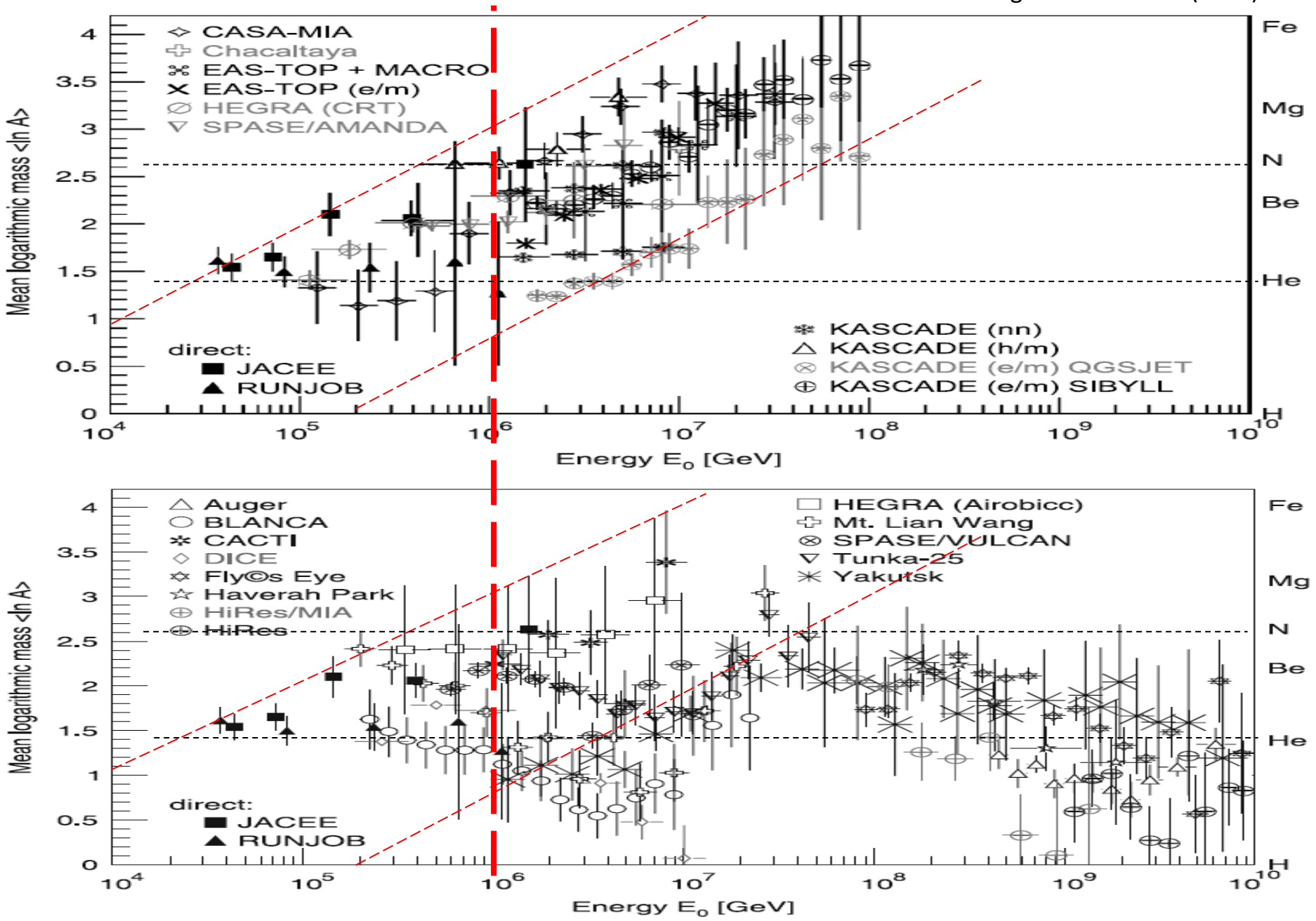
- **We need to understand the mass composition across the kneee**



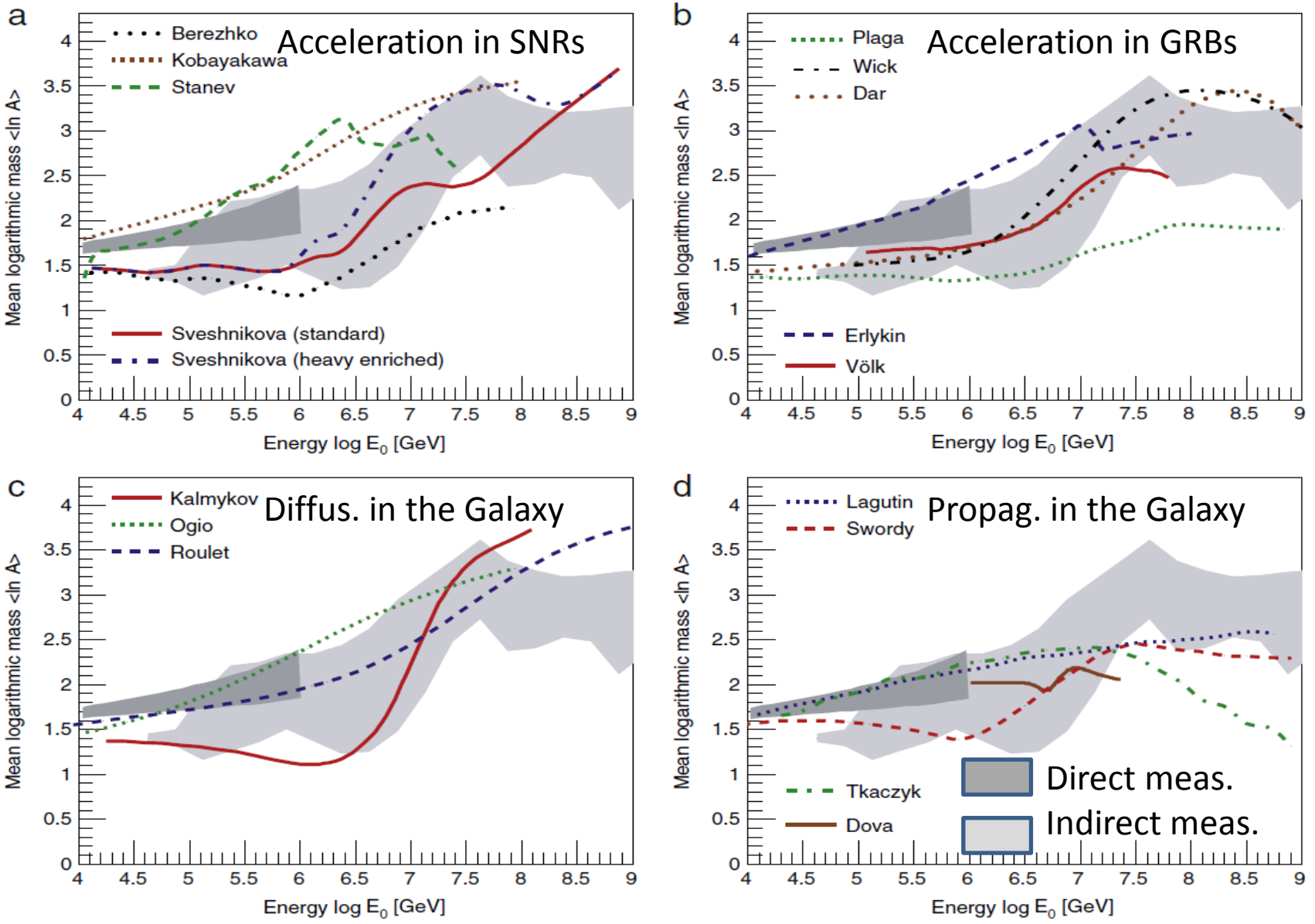
Gaisser Stanev Tilav (2013)



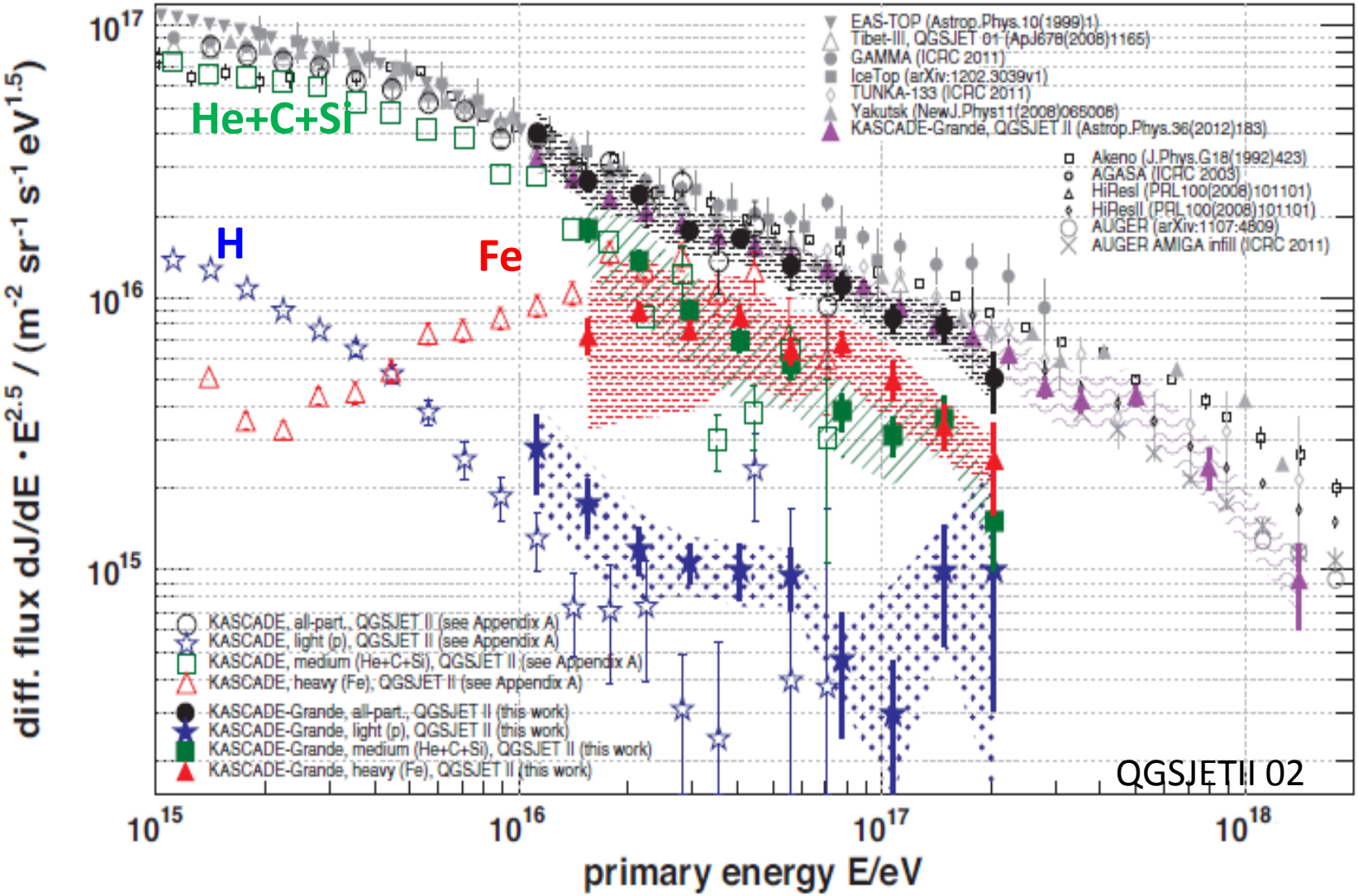
Bluemer - Engel - Hoerandel (2009)



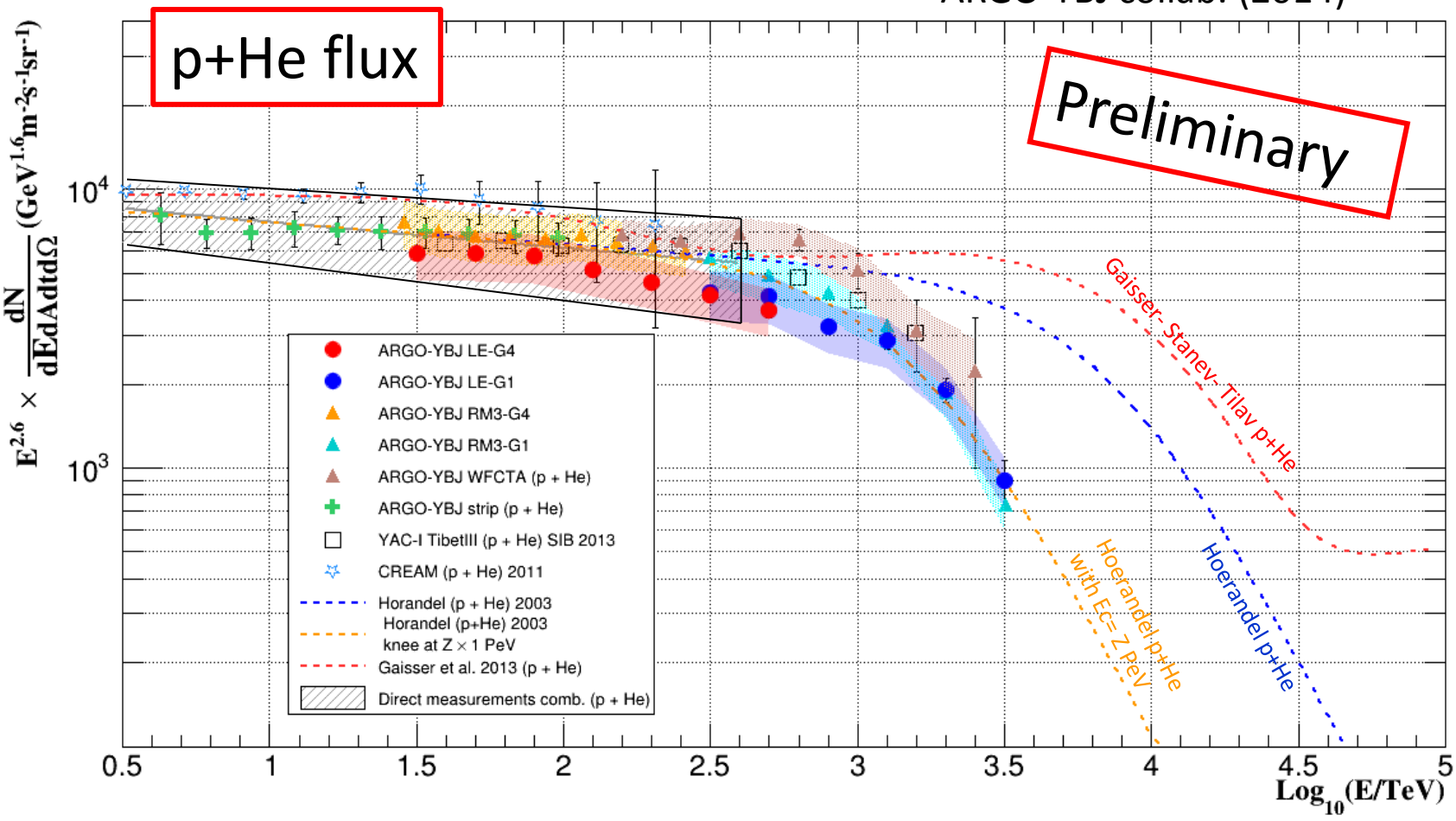
Bluemer - Engel - Hoerandel (2009)



KASCADE-Grande Coll., Astropart. Phys. 47 (2013)



ARGO-YBJ collab. (2014)

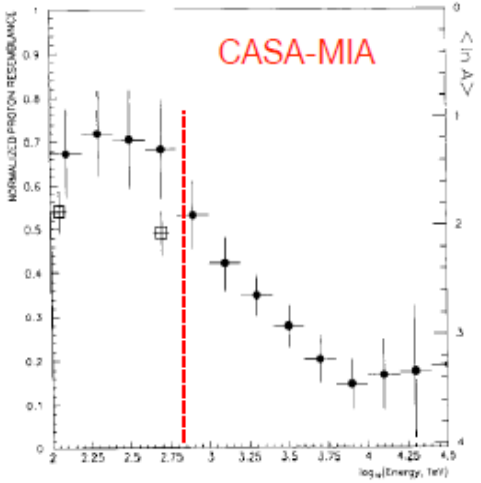


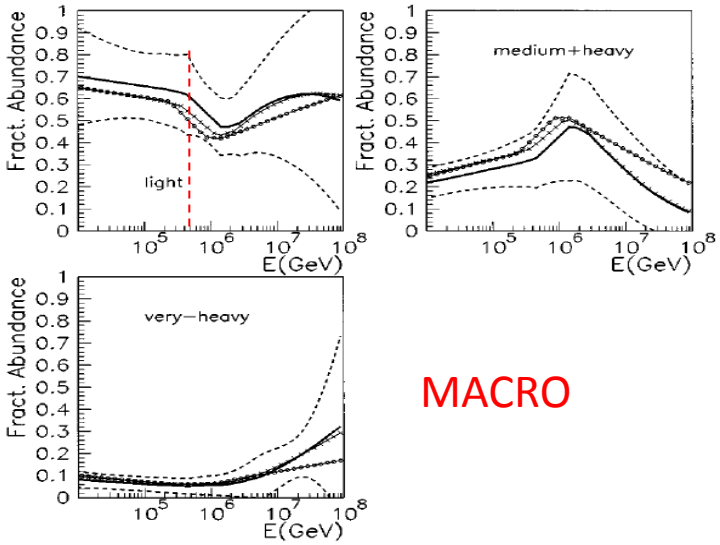
ARGO-YBJ (preliminarY):

Evidence for a bending of the flux of the light component (p+He) below 1 PeV.

Previous hints from Tibet-ASγ and many others (see next slide)

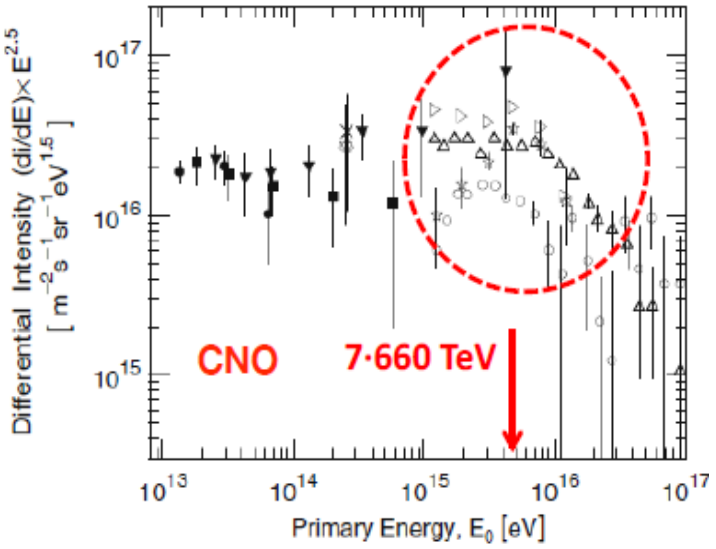
(Some of the) previous hints for a light component bending below 1 PeV

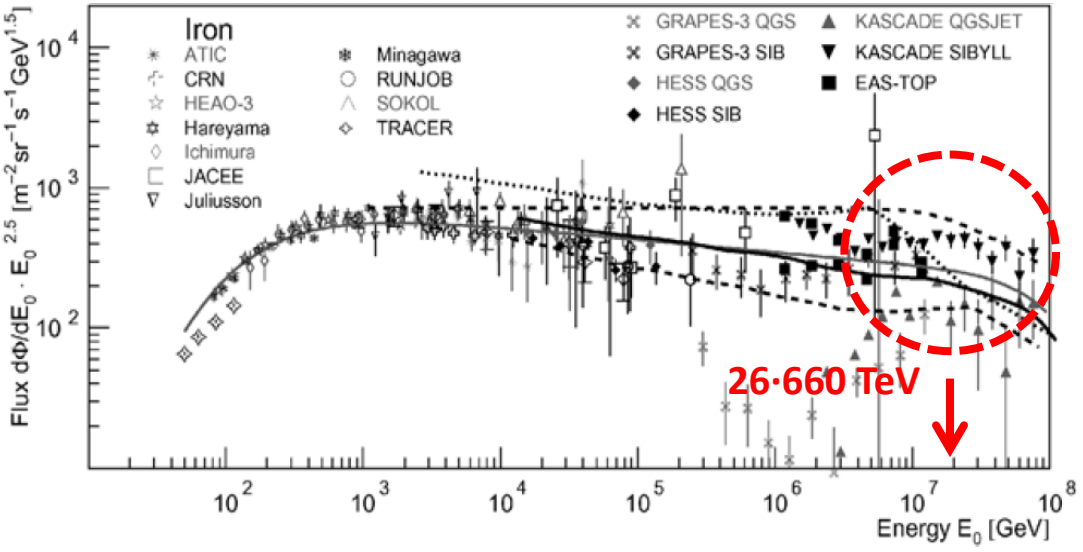




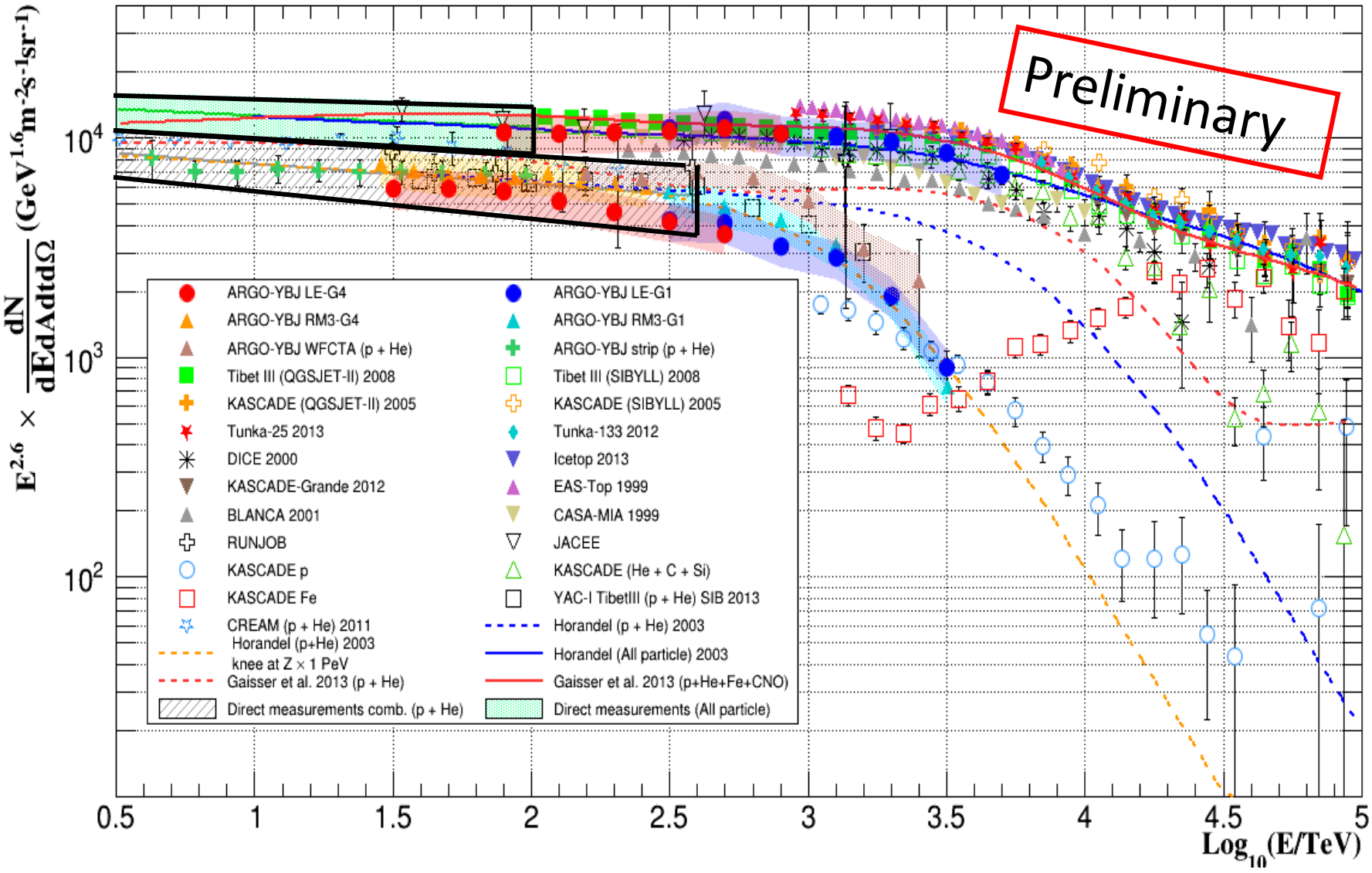
MACRO

- TIBET-ASγ
- CASA-MIA
- CHACALTAYA
- MACRO
- EAS-TOP + MACRO
- Delayed hadrons
- …….





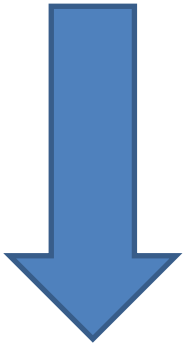
ARGO-YBJ collab. (2014)



What 's … ~~next~~ … needed

- Focus on the 100TeV-10 PeV energy region
- Measure the "knees" of each species

HECR spectroscopy

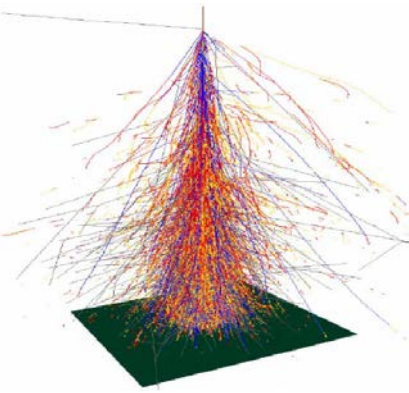


Together with high energy gamma and neutrinos astronomies

- Indentify galactic sources
- Understand acceleration and diffusion mechanisms
- Better understand the transition to extragalactic

How to get it ?

Athens , first What Next workshop, ~360 a.C. (about 50 participants..)

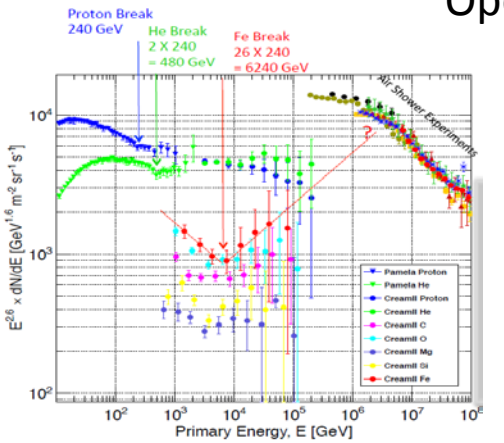


Direct measurements

Requirements:
Calorimetry vs Spectrometry
Large acceptances
<20% resolutions

Output:
Fully explore the sub-PeV region

Limitations:
Surface/weight limited
Hard to reach the all-particle knee
Need high technology



Indirect measurements

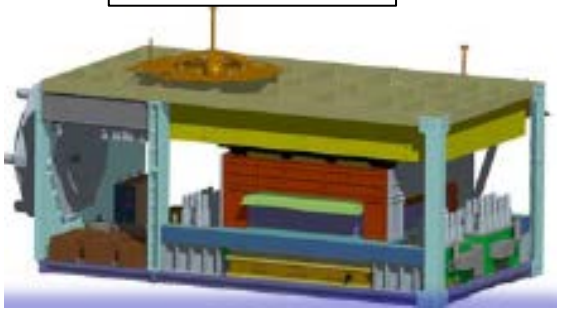
Requirements:
Multi-Hybrid approach
Operate at (not too) high altitude
Large surfaces / samplings

Output:
Reach the highest energies

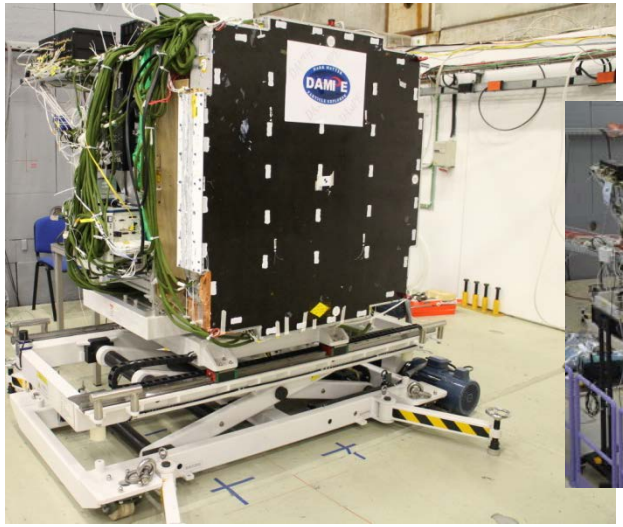
Limitations:
Very poor mass resolution
Intrinsically limited by systematics
Give many hints but few answers

Current and Future projects (space)

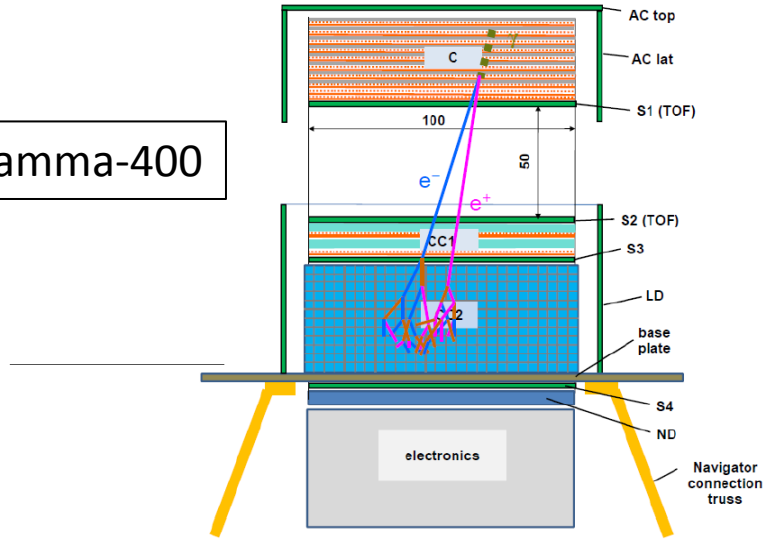
ISS_CREAM



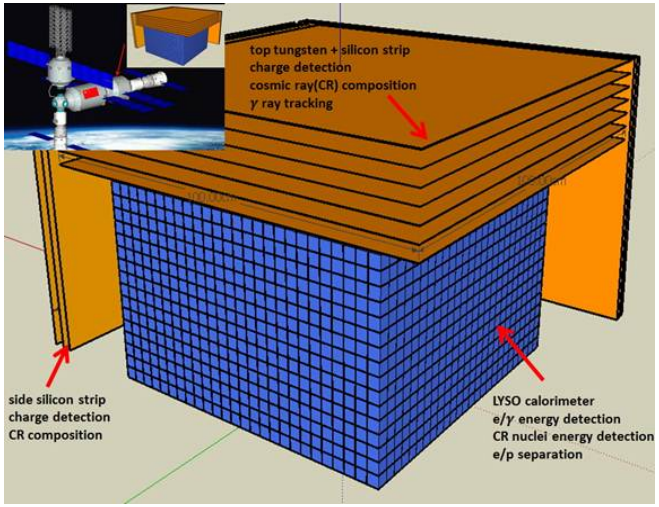
DAMPE



Gamma-400

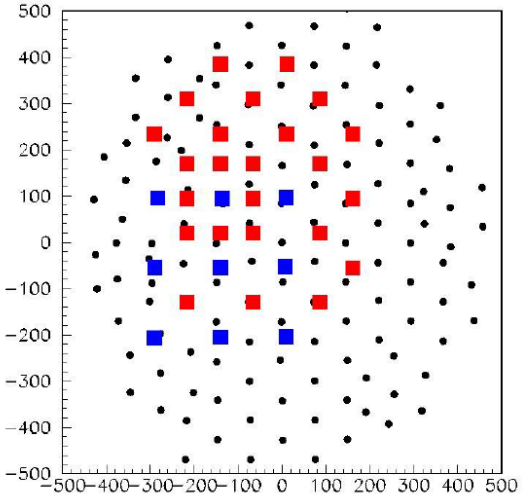


HERD

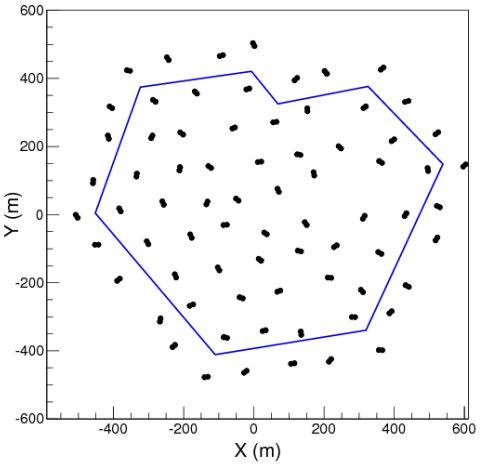


Current and Future projects (ground)

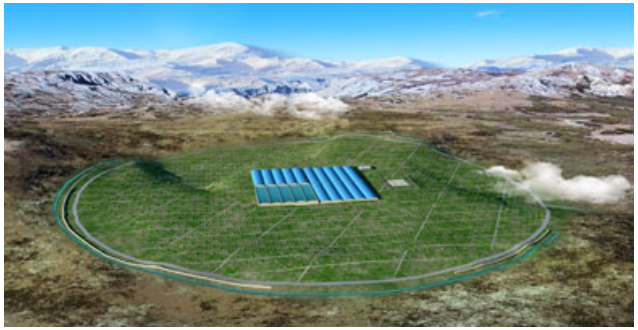
TUNKA-HighSCORE

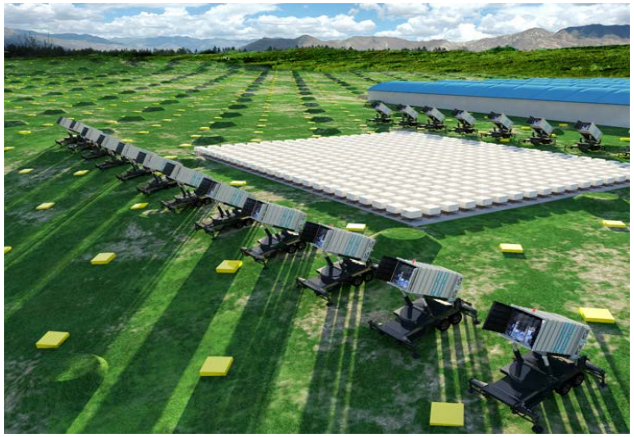


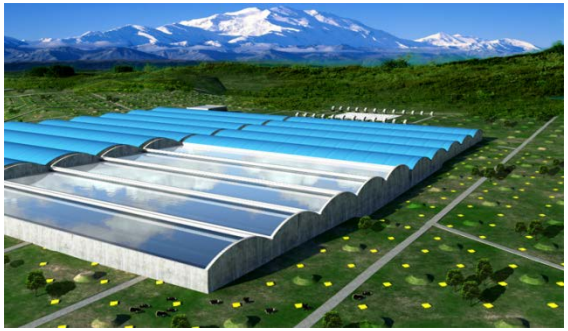
Ice-Top



LHAASO







Summary (1)

✓ We need “Cosmic Ray spectroscopy” across the knee in order to answer the main questions

- Sources and their distributions
- Acceleration processes
- Propagation
- Transition to extragalactic flux
- (building blocks for UHECR physics)

Summary (2)

✓What kind of experiment ?

- Extend direct measurements at the largest possible energies
- Use hybrid approaches in order to limit the systematics of indirect measurements

Summary (3)

- Multimessanger information is more than welcome, but cannot give the answers without the above.

- Precision physics on atmospheric neutrinos possible only if CRs in the sub-PeV region (mainly p and He) are sufficiently well know,

More stuff

Bluemer - Engel - Hoerandel (2009)