Energy spectrum of Cosmic ray Proton and Helium nuclei measured by the ARGO-YBJ experiment

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The ARGO-YBJ experiment

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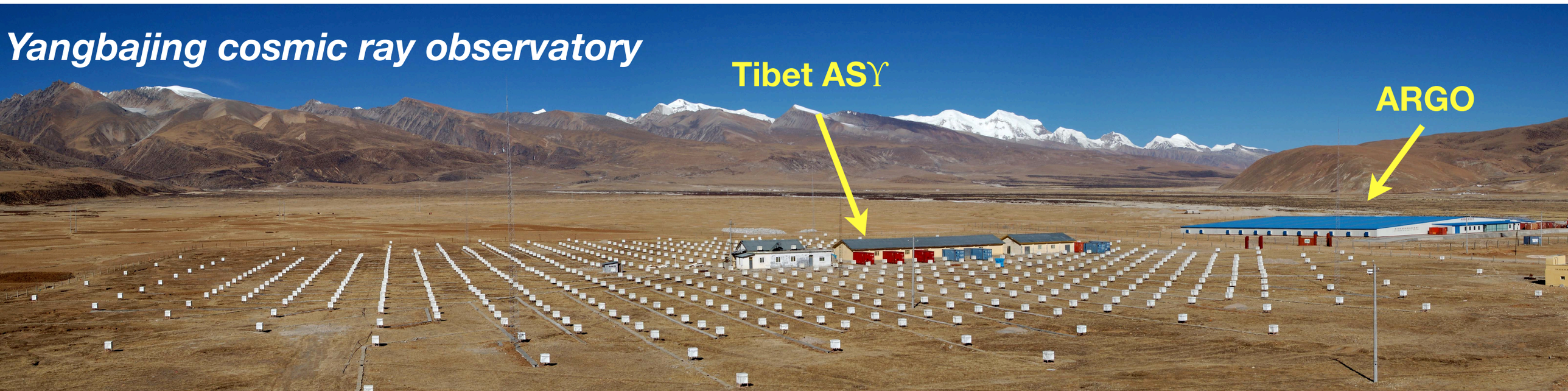
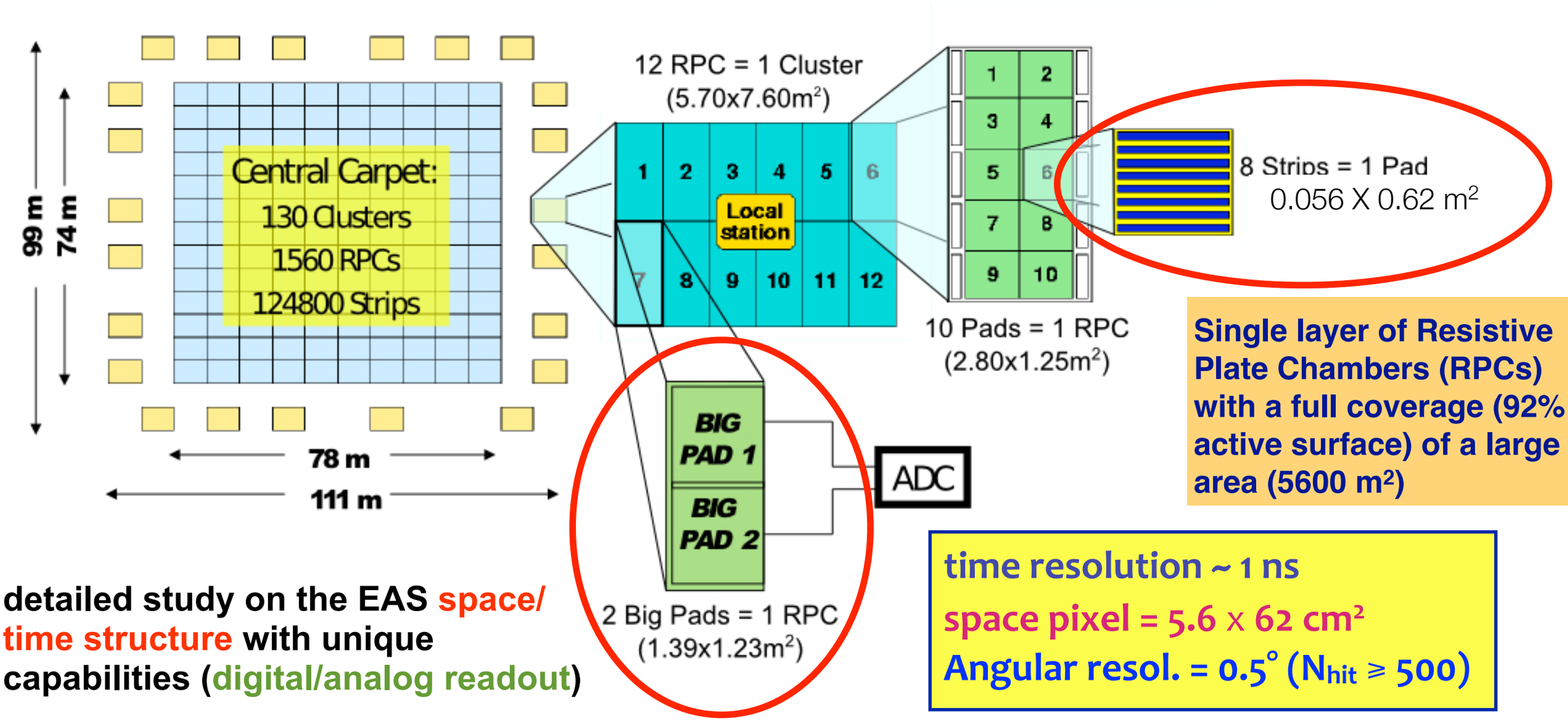
(**A**strophysical **R**adiation with **G**round-based **O**bservatory at **Y**ang **Ba** **J**ing)

Yangbajing International Cosmic-Ray Observatory

- **Longitude 90° 31' 50" East**
- **Latitude 30° 06' 38" North**
- **Altitude 4300 m a.s.l.(approx 600 g/cm²)**
- **~ 90 km far from Lhasa**



The ARGO-YBJ experiment



Single layer of Resistive Plate Chambers (RPCs) with a full coverage (92% active surface) of a large area (5600 m²)

detailed study on the EAS space/ time structure with unique capabilities (digital/analog readout)

time resolution ~ 1 ns

space pixel = 5.6 x 62 cm²

Angular resol. = 0.5° ($N_{hit} \geq 500$)

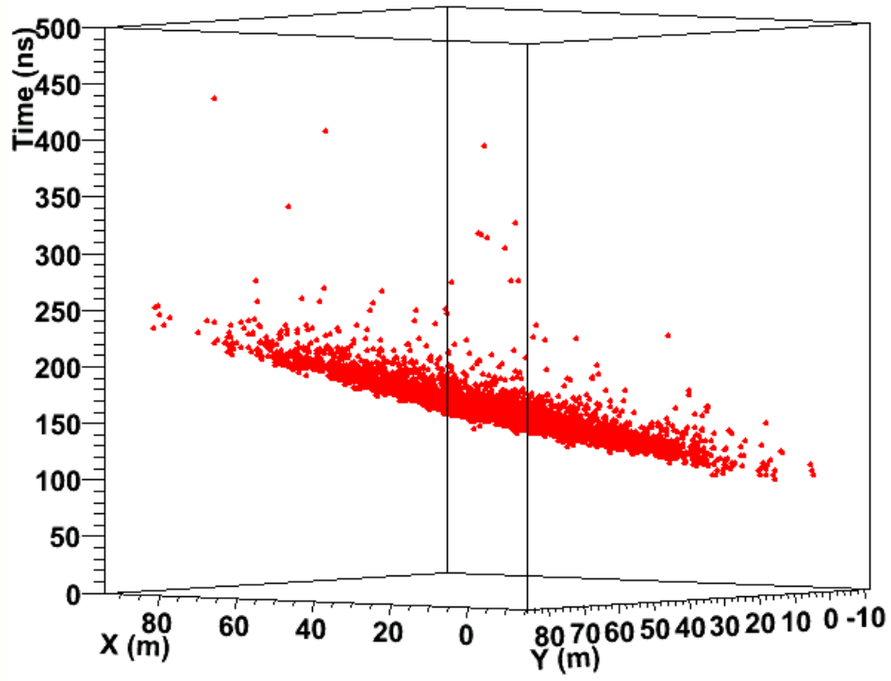
The ARGO-YBJ experiment

- ✓ Stable data taking since Nov. 2007 to Jan. 2013 with full detector
- ✓ Average duty cycle ~ 90%
- ✓ Trigger rate ~3.6 kHz @ 20 pad threshold
- ✓ Dead time 4%
- ✓ ~10^{11} events/year

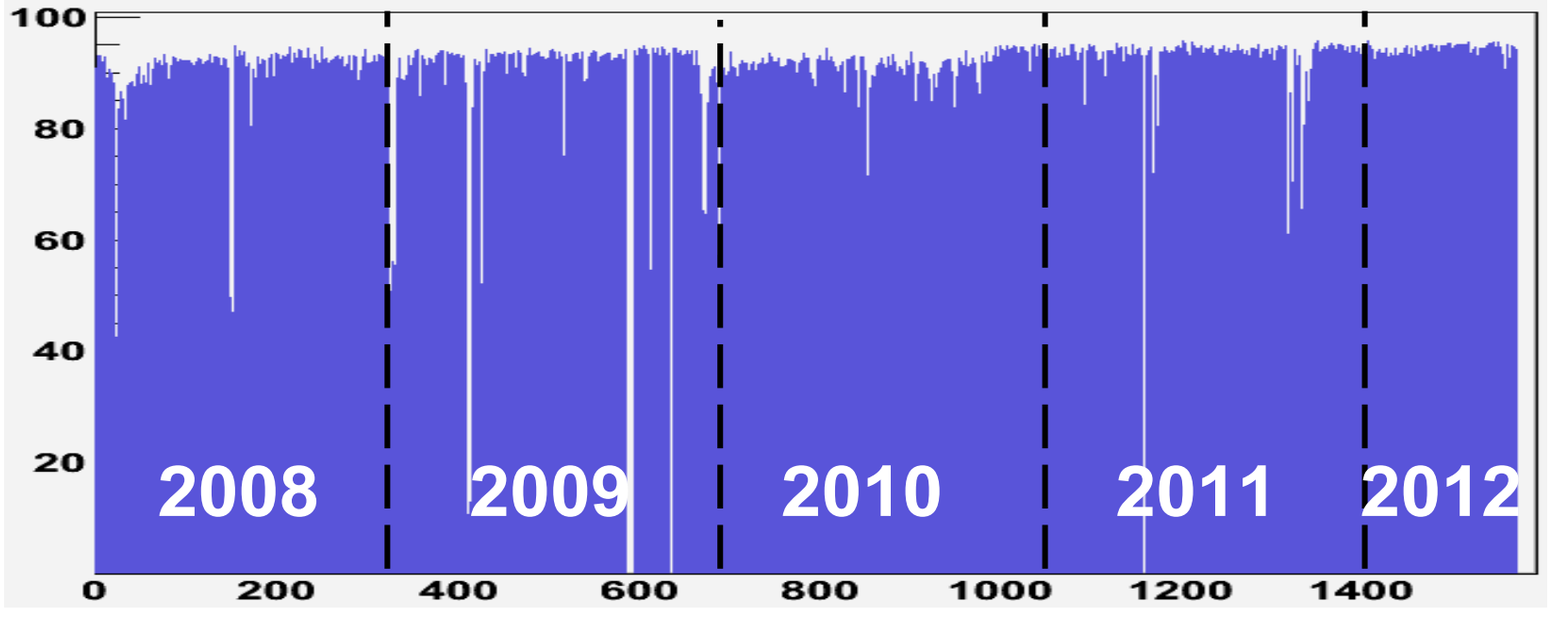
High space/time granularity
+ Full coverage
+ High altitude

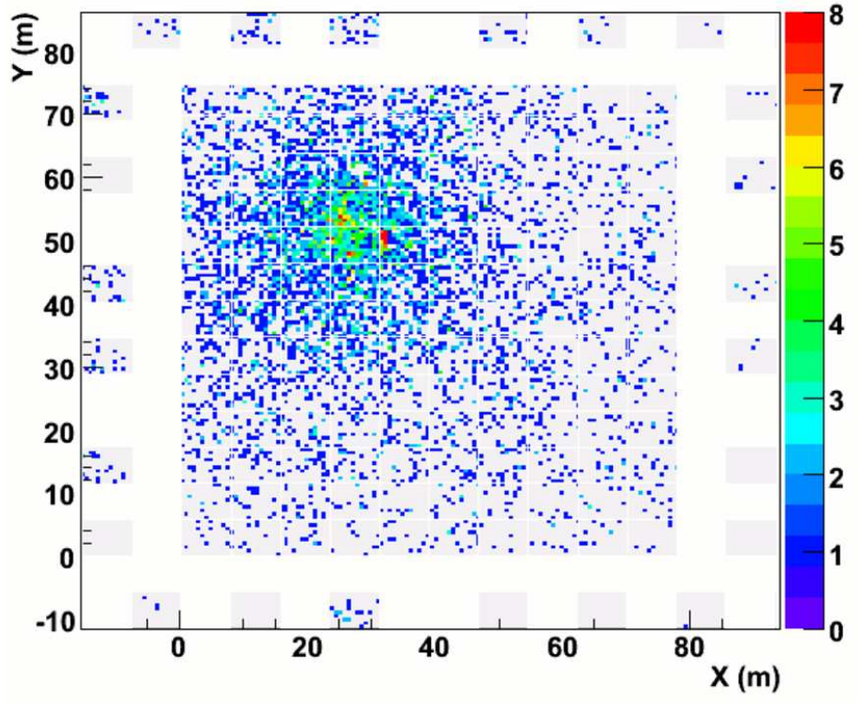
→

detailed study on the EAS space/time structure with unique capabilities



Sampling of showers produced by primaries of ~1 TeV





Data analysis

Data sample

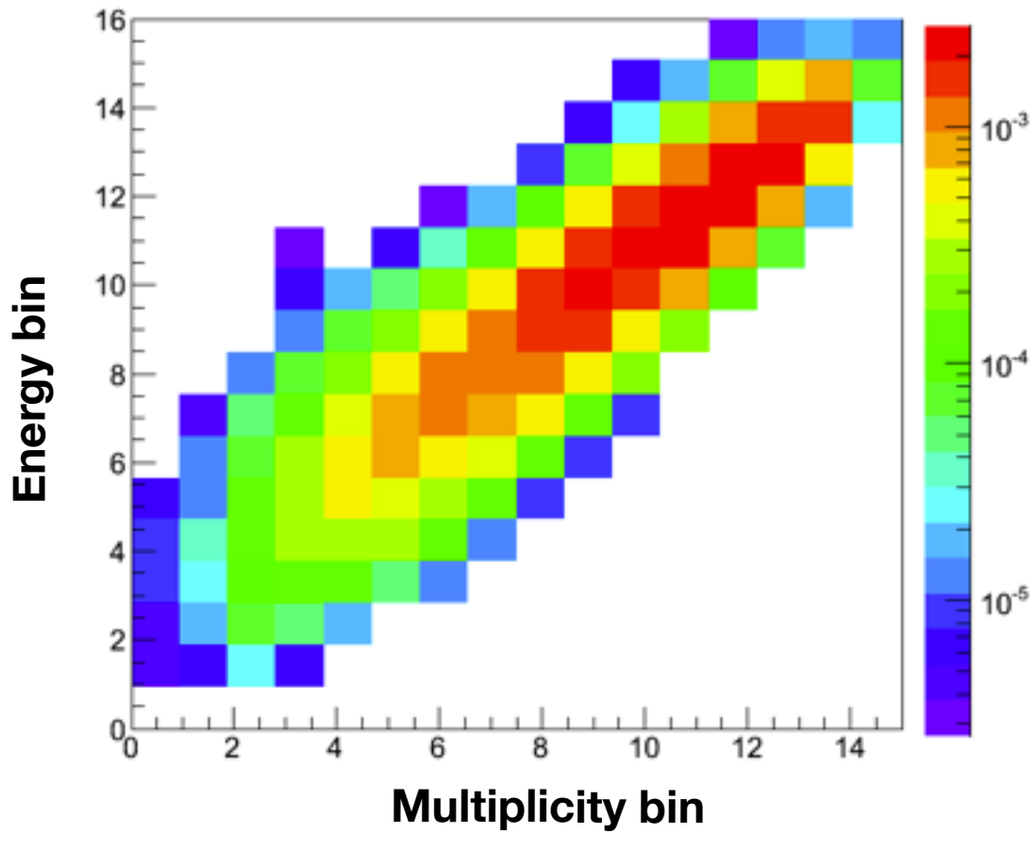
- *Preliminary selection based on the data and reconstruction quality*
- *About 7 X 10^{10} events (~ 5800 hours) recorded in the period Jan. 2008 - Dec 2011*

Monte Carlo data sample

- *EAS development: CORSIKA (QGSJETII.03 + FLUKA + EGS4)*
- *Energy range: 0.3 - 31600 TeV*
- *Full detector simulation (GEANT3)*
- *Protons + Helium nuclei + CNO nuclei + Iron nuclei*

The energy distribution of primary cosmic rays can be extracted from the observed multiplicity distribution by using an iterative procedure based on the Bayes theorem

The conditioned probabilities can be evaluated by using a Monte Carlo simulation



Data analysis

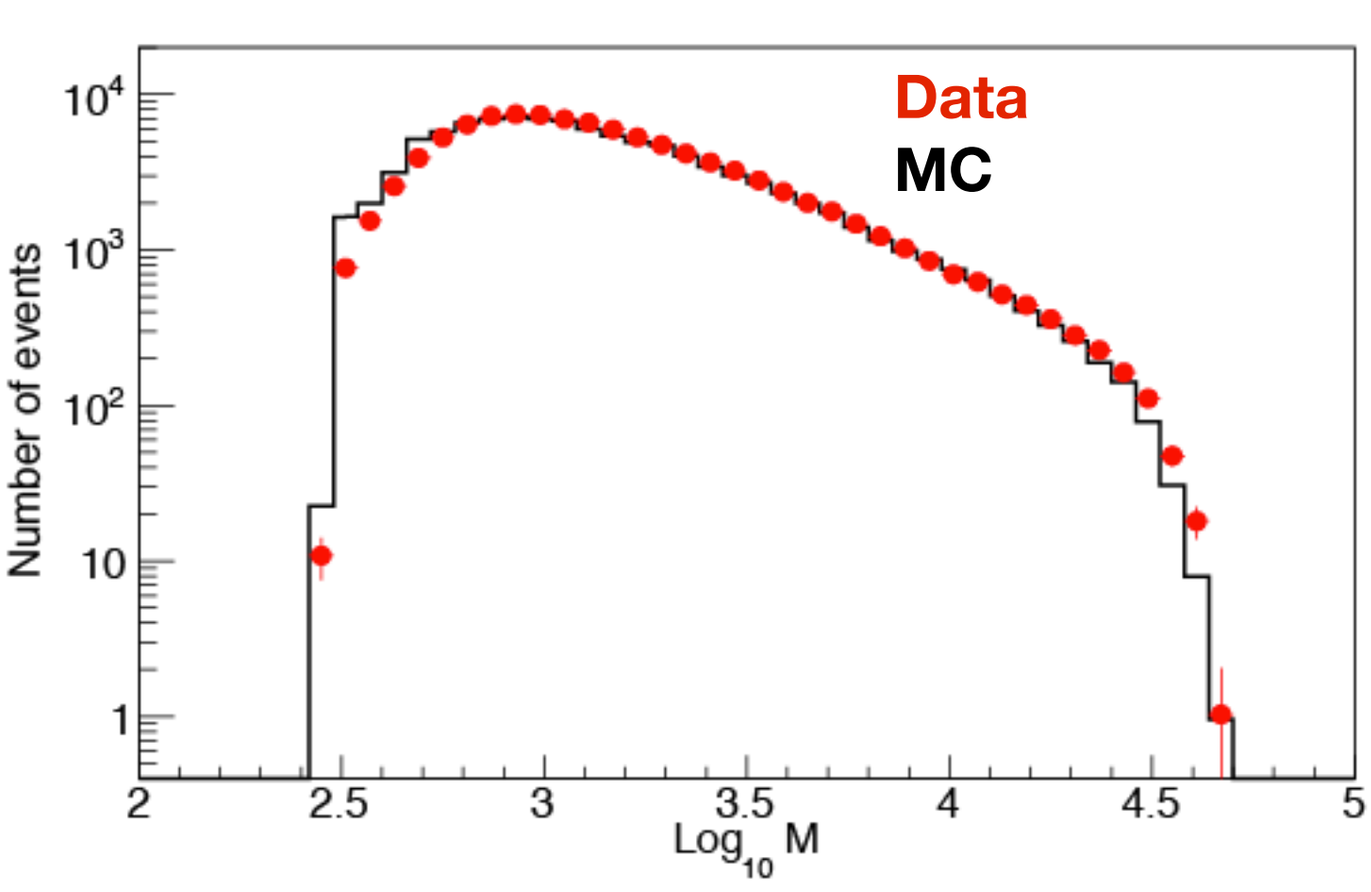
- ***Select "well-reconstructed" events***
- ***Avoid contamination of events coming from non simulated regions***

Event selection based on:

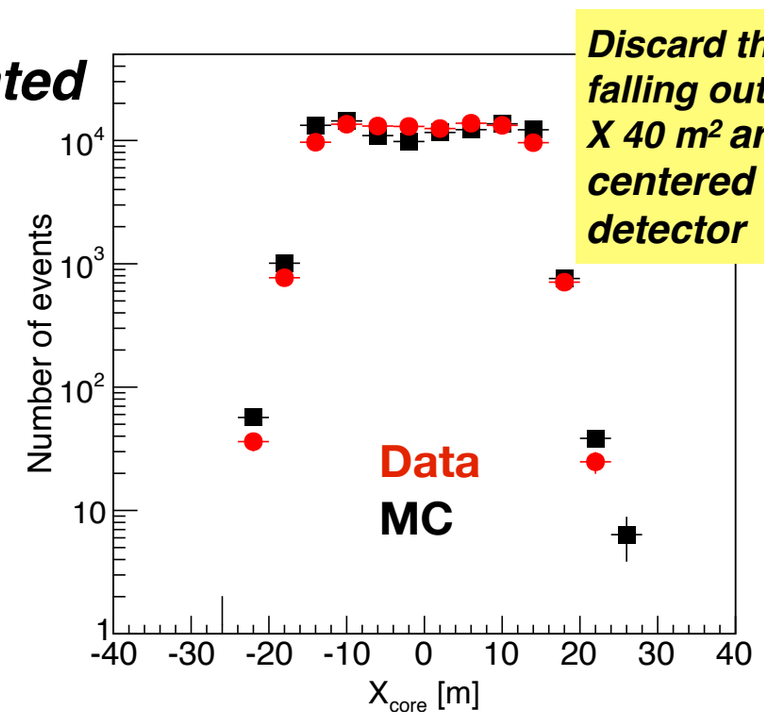
➡ Shower size on detector, **M** (strip multiplicity)

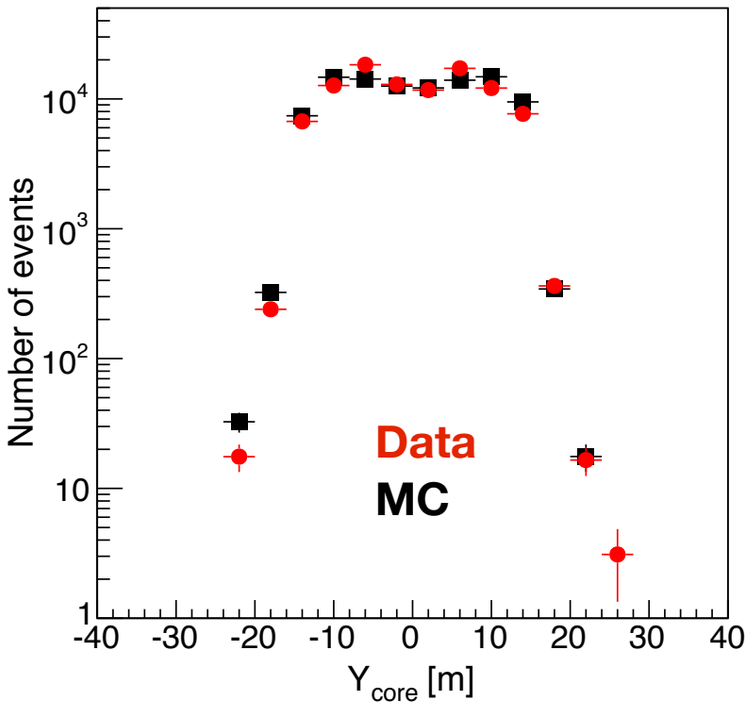
➡ Reconstructed zenith angle

➡ Constraint on strip density (ρ) in the innermost and outermost area of the detector



Discard the events falling outside a 40 X 40 m² area centered on the detector





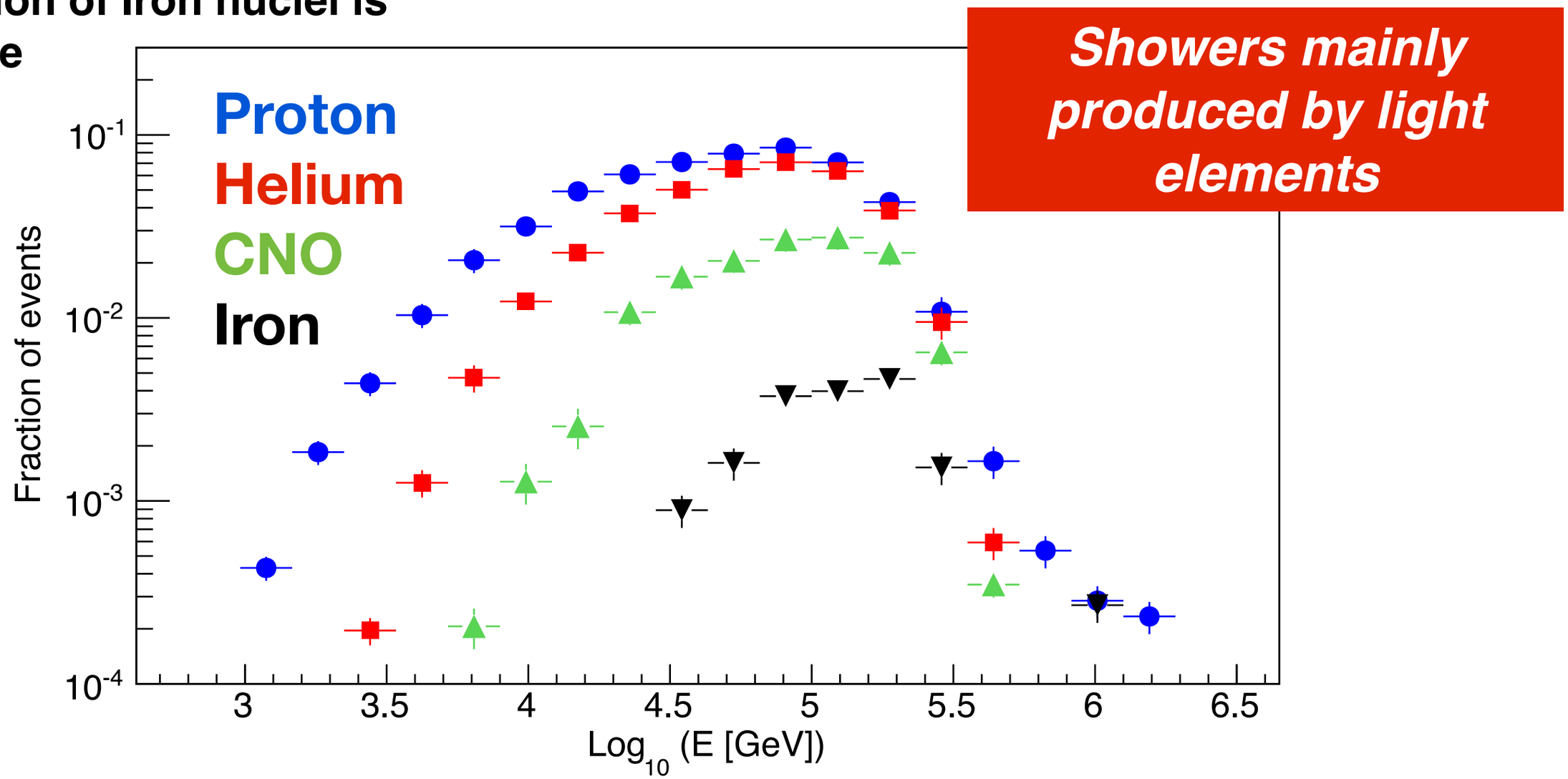
Data analysis

The cut based on the particle density on the detector surface selects showers with well–shaped core, mainly induced by light primaries

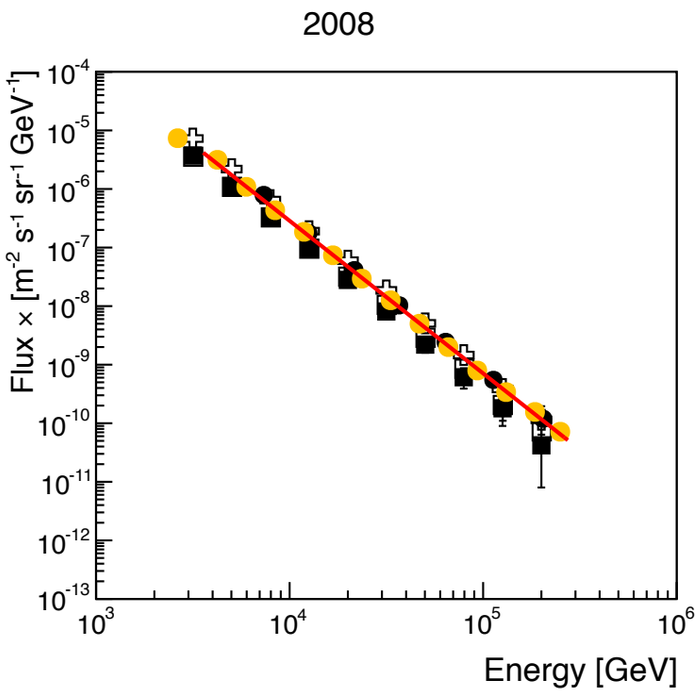
The fraction of selected CNO nuclei is reduced by a factor ~ 5 if compared with the fraction of selected Protons and Helium nuclei.

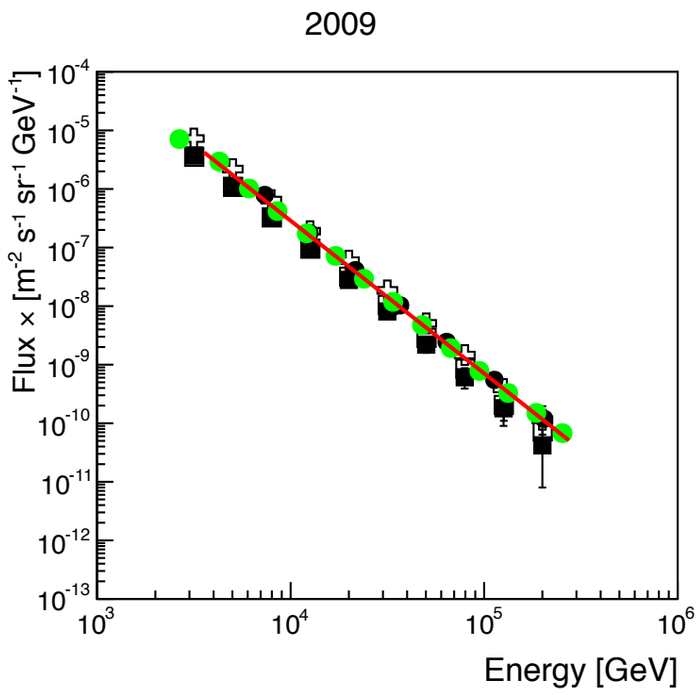
The fraction of Iron nuclei is neglegible

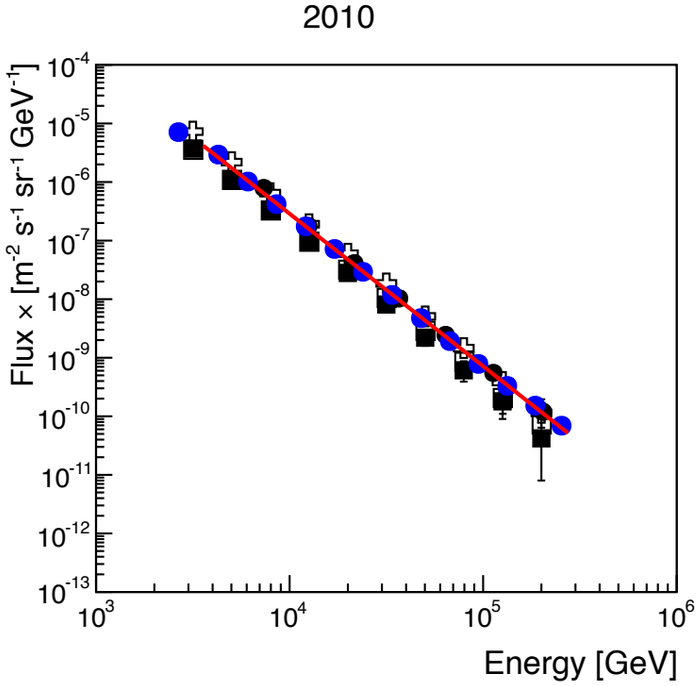
Showers mainly produced by light elements

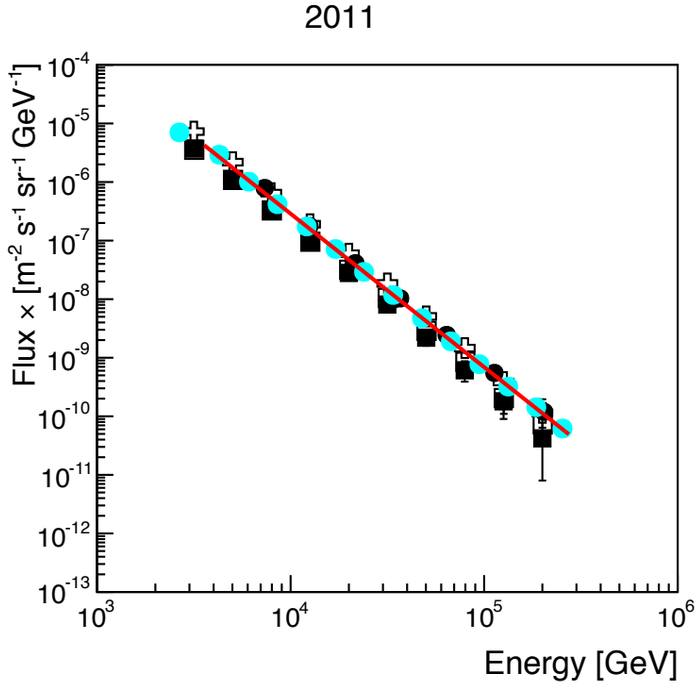


The light component spectrum

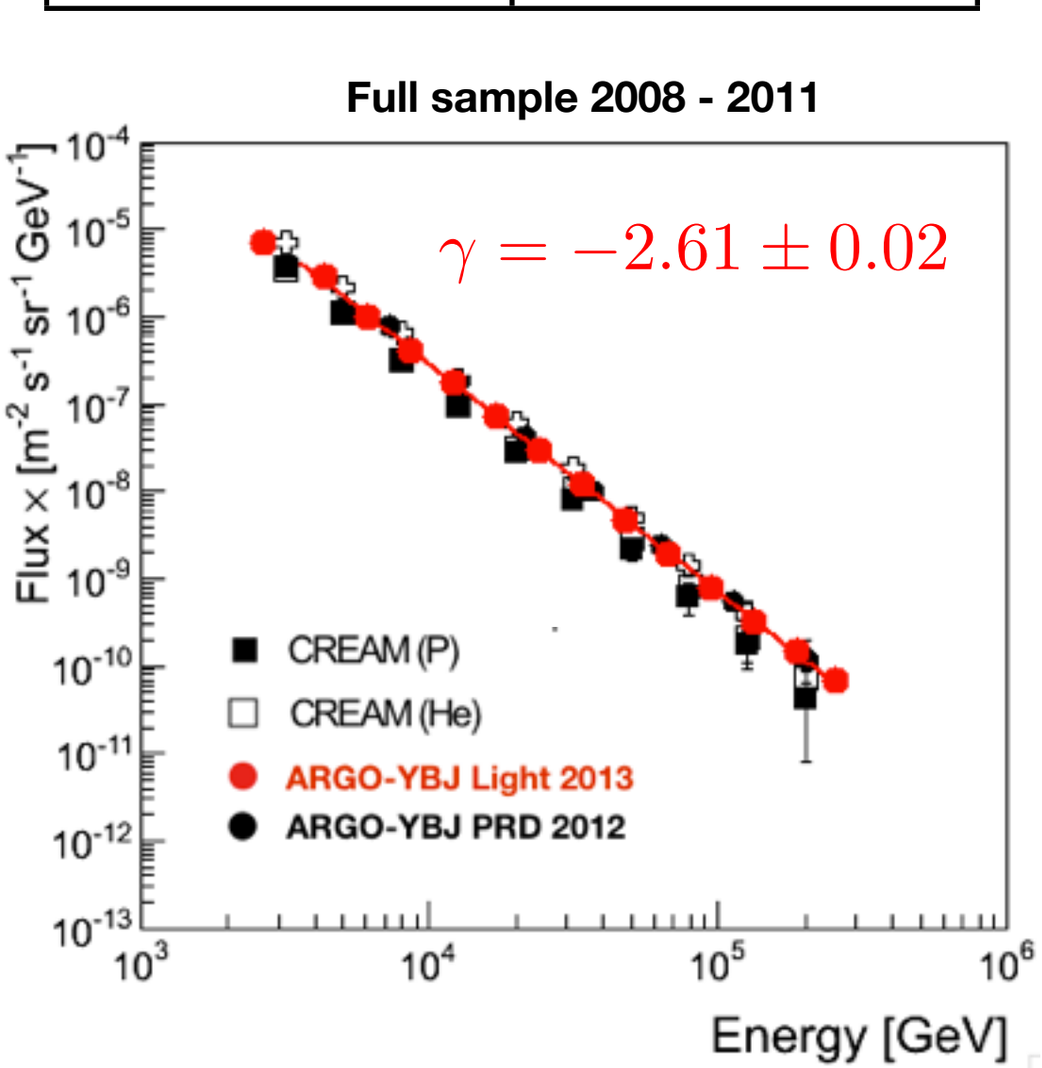








Year	Spectral index
2008	-2.61 ± 0.02
2009	-2.61 ± 0.02
2010	-2.61 ± 0.02
2011	-2.62 ± 0.02



Systematic uncertainties

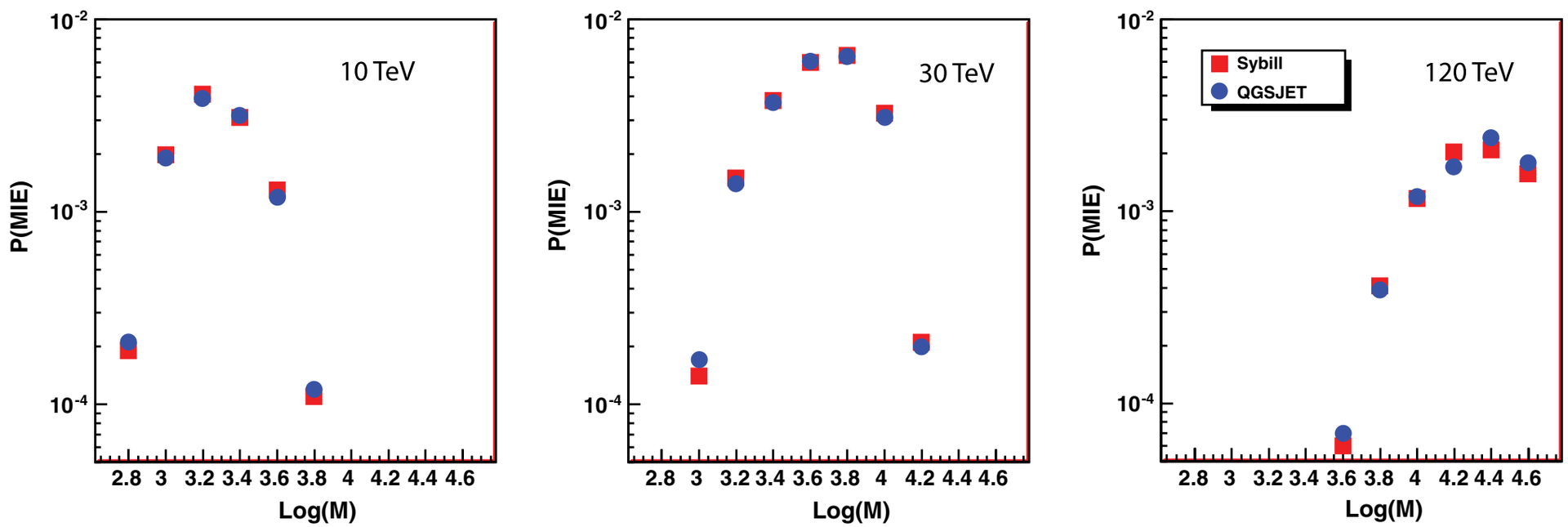
- ***Selection cuts on the measured quantities (M, ρ, ϑ)***
  - *Estimated by applying large variations to the selection cuts*
- ***Reliability of the simulation of detector response***
  - *Comparison between the distributions of several variables obtained by applying the same selection cuts to Data and to MC events*
- ***Effects related to the fraction of helium component***
  - *Variation on the fraction of the helium component in a wide range has been evaluated as negligible.*
- ***Effect related to the different hadronic interaction models implemented in MC***

Total uncertainty not exceeding ± 10 %

Evaluate the bayesian probabilities by using two different high energy interaction models in MC simulations

No significative differences between the two models.

QGSJETII.03 - SYBILL

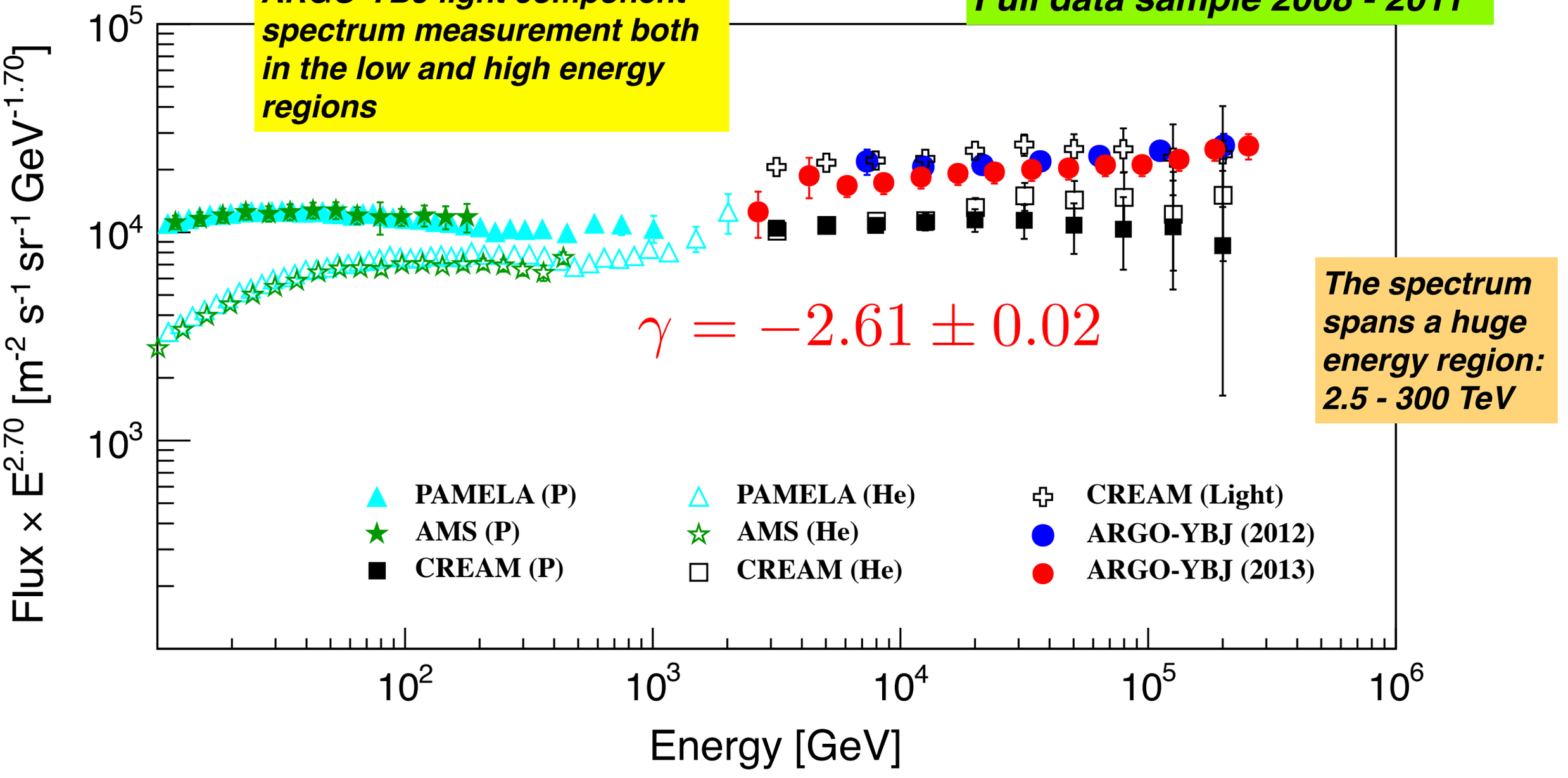


The light component spectrum

Extension of the previous ARGO-YBJ light component spectrum measurement both in the low and high energy regions

Full data sample 2008 - 2011

The spectrum spans a huge energy region: 2.5 - 300 TeV



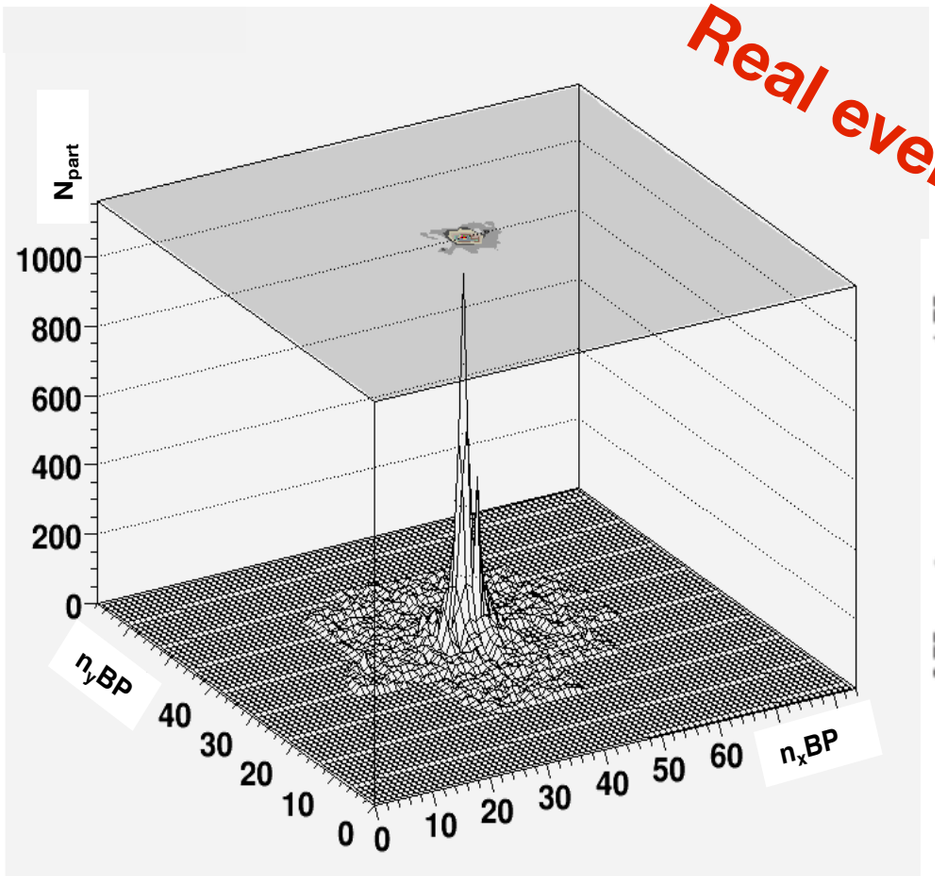
Direct and ground-based measurements overlap for a wide energy range thus making possible the cross-calibration of the experiments.

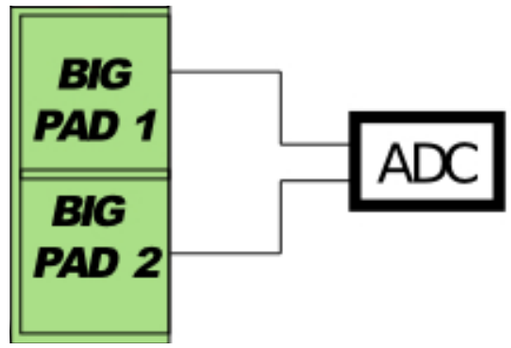
The light component spectrum

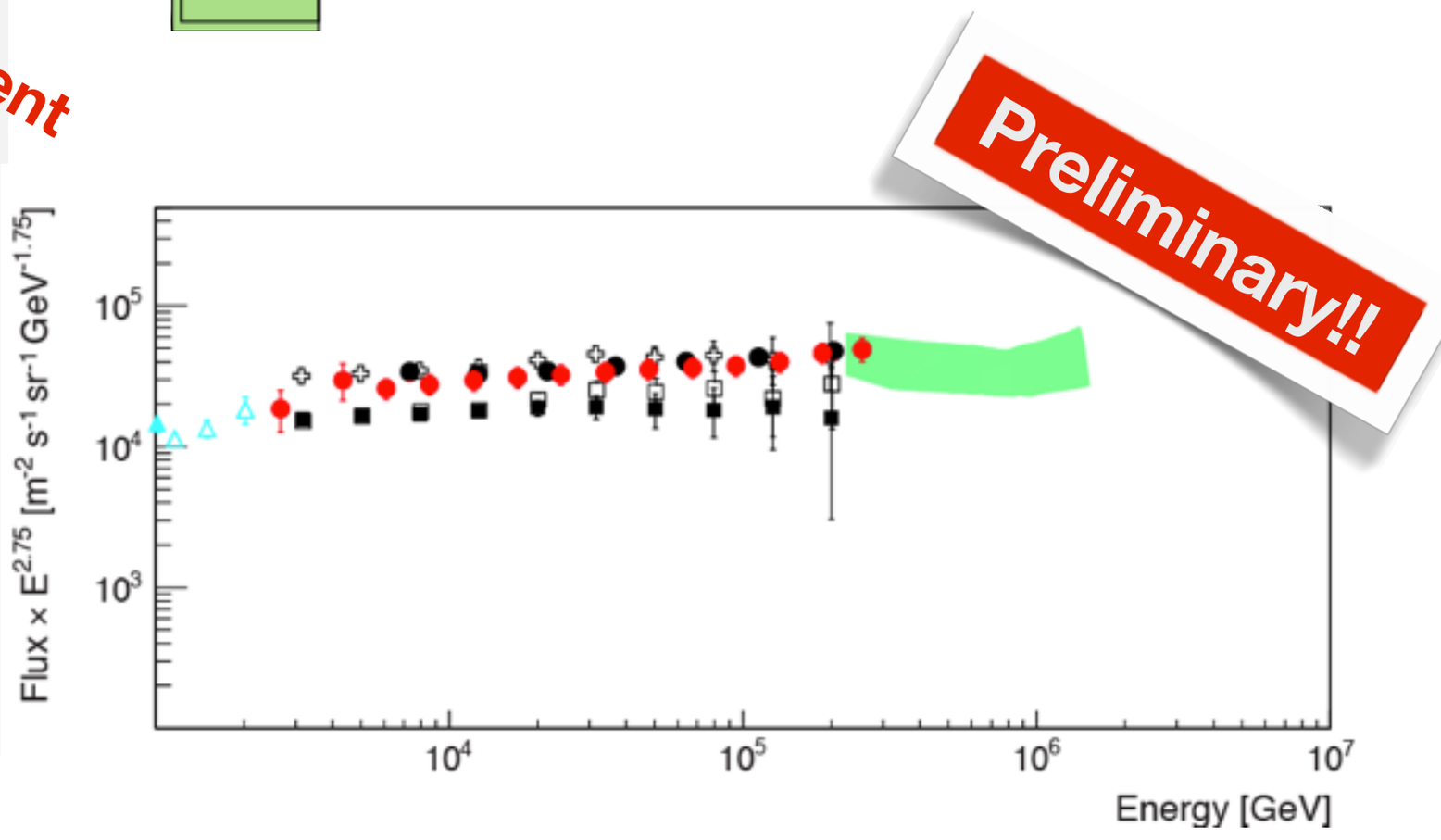
Towards the highest energies and the knee region

Readout of the charge signal by using large electrodes (big pads) - 2 BP/RPC

Sampling of showers with up to 1000 particles/m²







Summary and Conclusions

- ☑ **Light component spectrum measured in the energy range 1-300 TeV with the full data sample 2008 - 2011 (work in progress on 2012 data)**

- ☑ **The data confirmed the first measurement made with a small sample of the first data collected by ARGO in 2008**

- ☑ **First attempt to extend the light component spectrum towards the knee region by using the analog readout**

- ☐ **Analysis of data taken during 2012 is coming soon**

- ☐ **We are working on the extension of the measurement towards the knee**