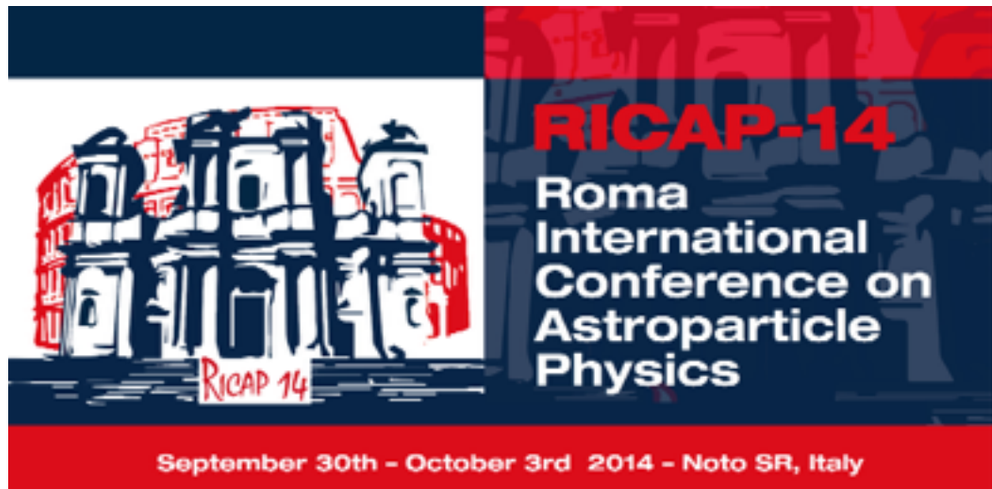
The Cosmic Ray light component spectrum in the 10-1000 TeV energy range measured by the ARGO-YBJ experiment by using a bayesian approach

Paolo MONTINI on behalf of the ARGO-YBJ Collaboration

INFN - Sezione di Roma TRE



RICAP 2014 - Noto

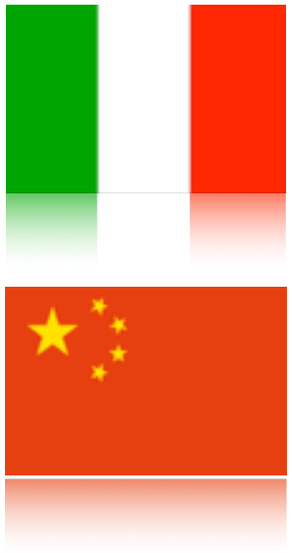
The ARGO-YBJ experiment

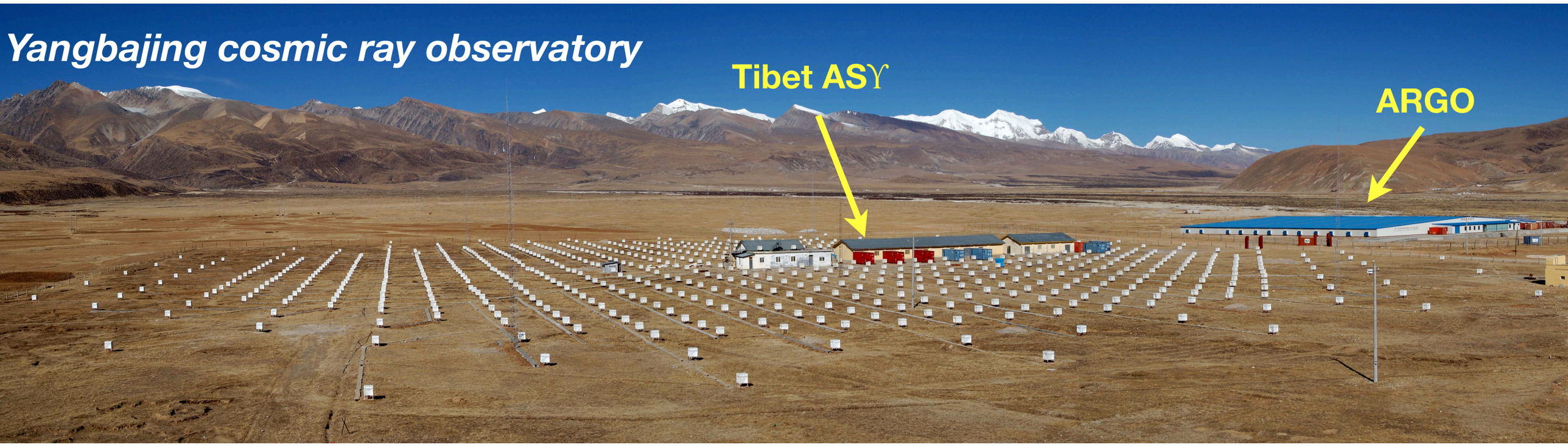
Istituto Nazionale di Fisica Nucleare (INFN) - Chinese Academy of Science (CAS)

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

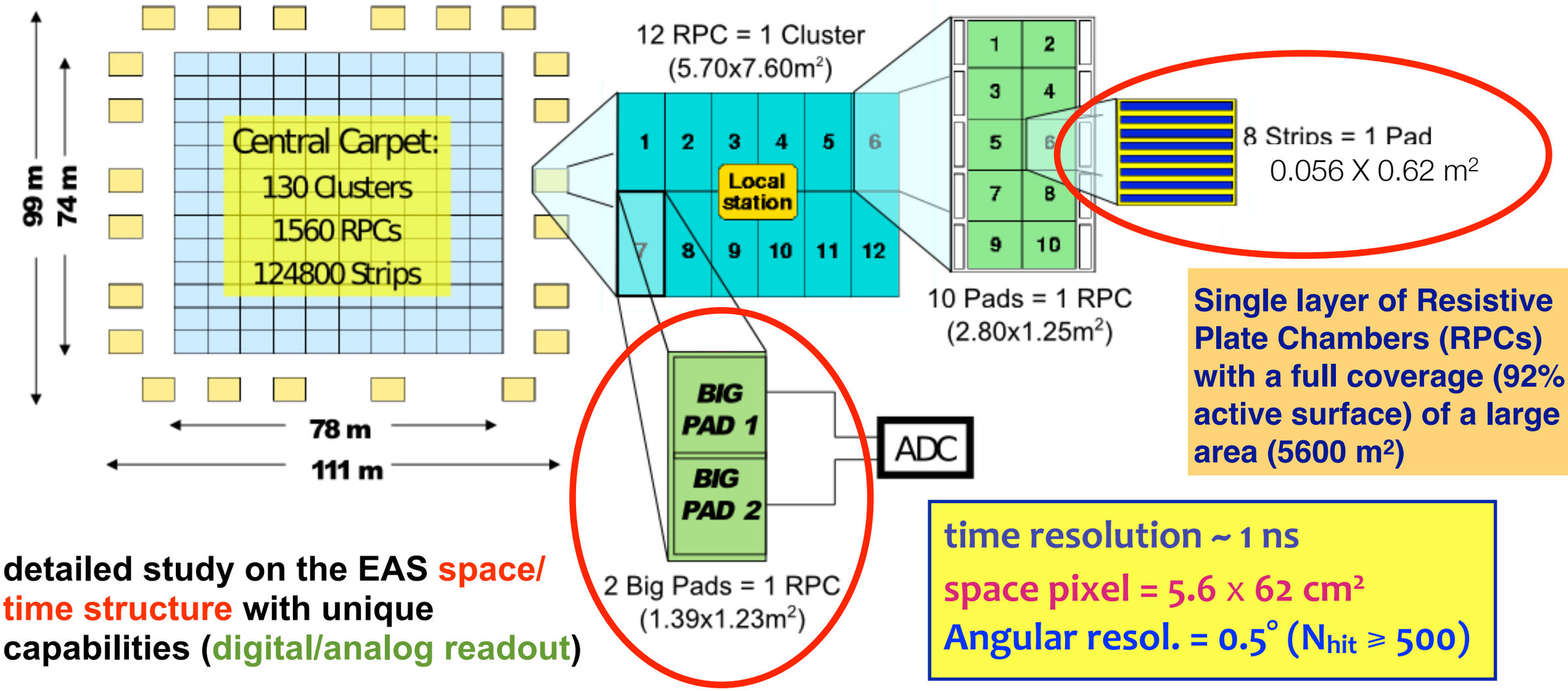
- ***COSMIC RAY PHYSICS***
- ***GAMMA RAY ASTRONOMY***

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





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

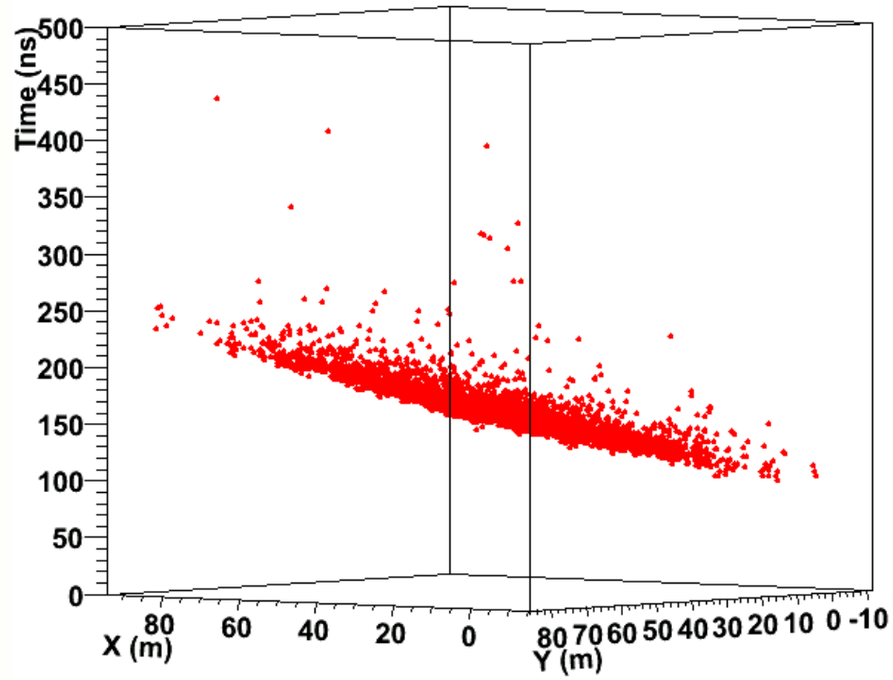
space pixel = 5.6 x 62 cm²

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

The ARGO-YBJ experiment

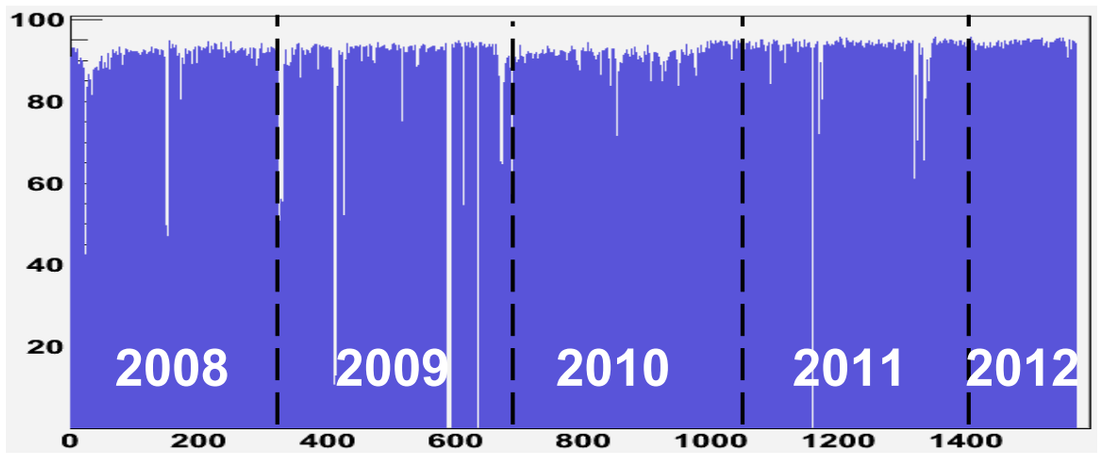
- ✓ **Full coverage and high segmentation**
- ✓ **Digital and analog readout**
- ✓ **Active area:**
  - **Central carpet ~5600 m²**
  - **Sampling guard-ring ~1000 m²**

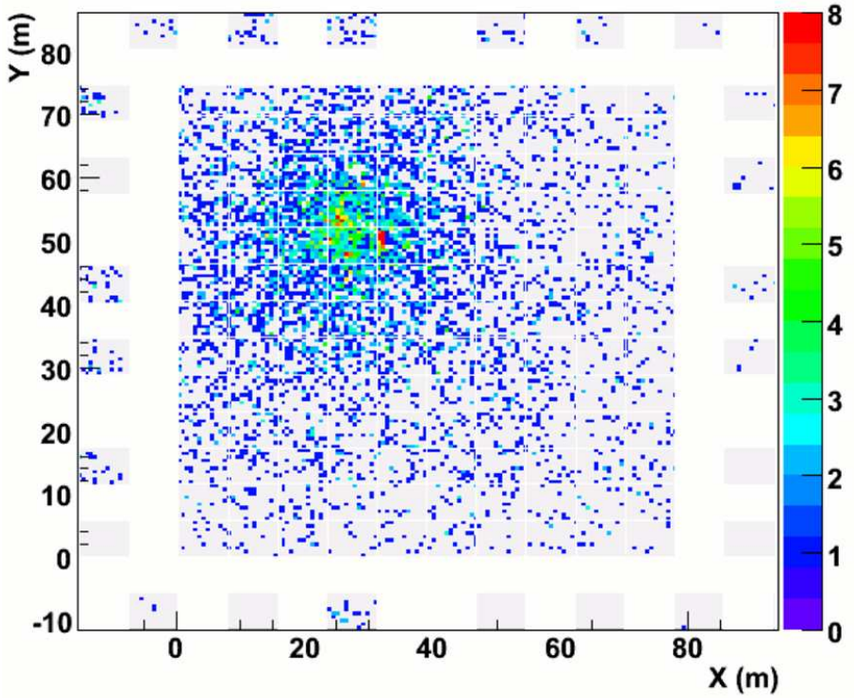
- ✓ *Stable data taking since Nov. 2007 to Feb. 2013 with full detector*
- ✓ *Average duty cycle ~ 90%*
- ✓ *~10^{11} events/year*



High space/time granularity
+ Full coverage
+ High altitude

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





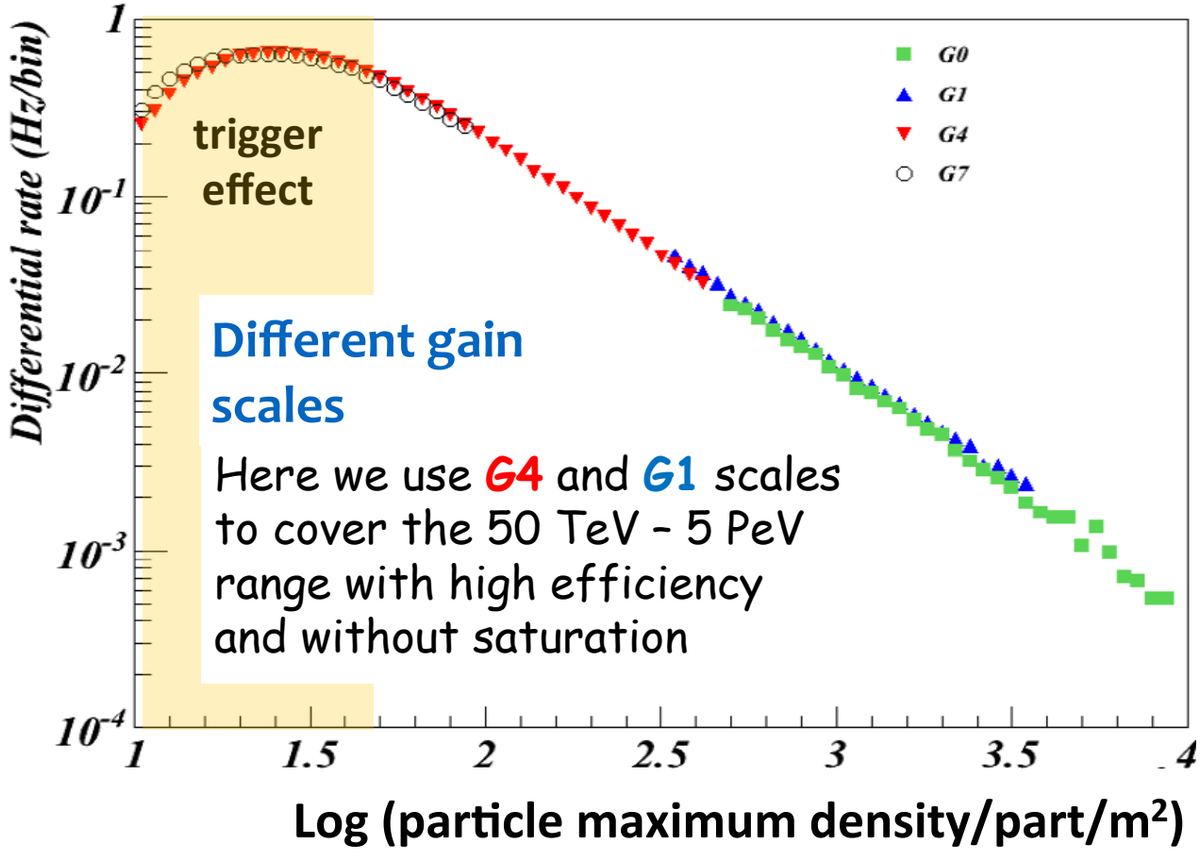
The ARGO-YBJ experiment

Cover a wide range in particle density

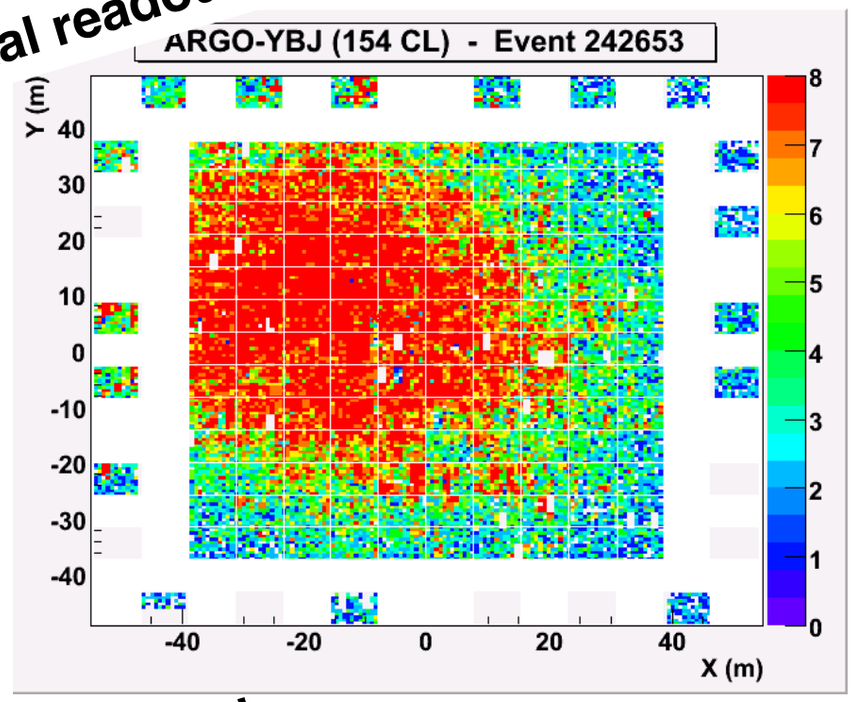
Digital readout:
Showers up to ~23 particles/m²

Analog readout:
Showers up to ~10⁴ particles/m²

Extend the maximum energy range up to the PeV region

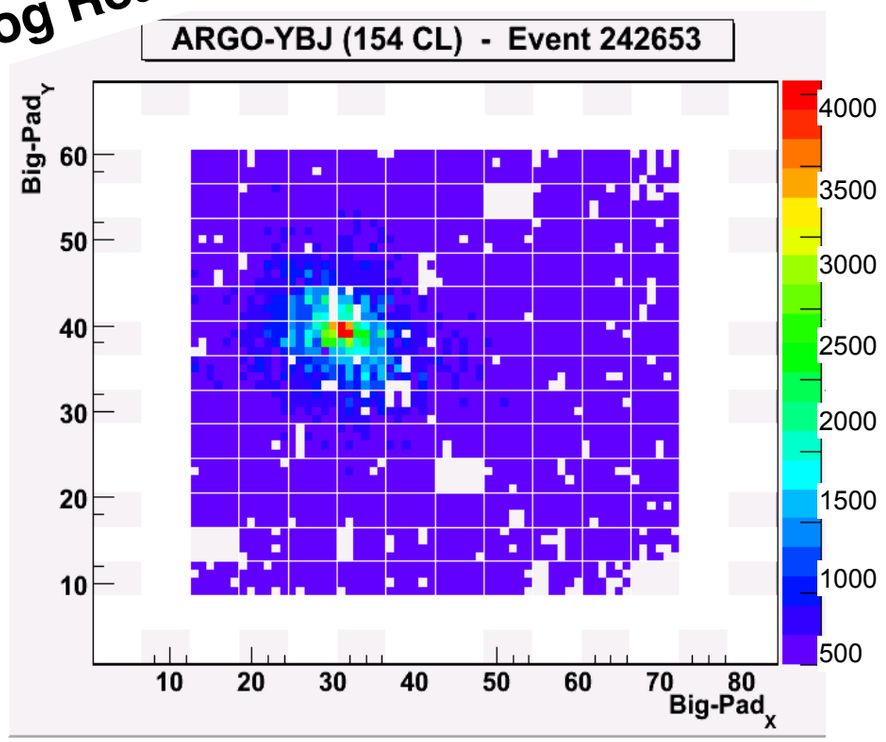


Digital readout



Analog Readout

Same event 😄



The Bayesian Unfolding Method

- ***Learn information about the energy spectrum from the experimental data by using probability theory***

Experimental data → **Probability theory** → **Energy Spectrum Composition**

$$N(E, ID) = P(E, ID|M, D_1, \ldots D_n) \cdot N(M, D_1, \ldots D_n)$$

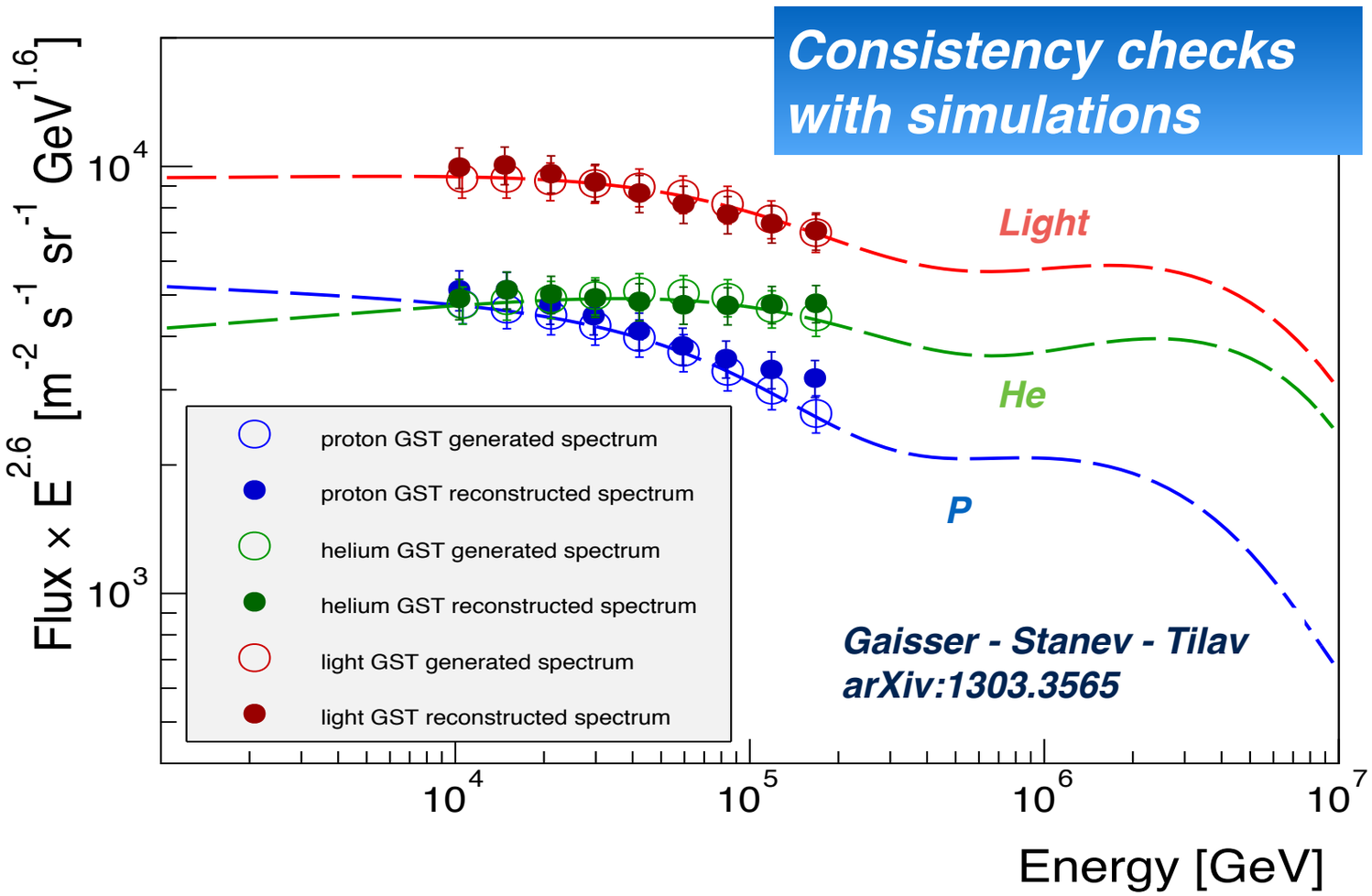
- **Causes: $\{E_i, \ldots E_n; ID_i, \ldots ID_n\}$**
- **Effects: $\{M_i, \ldots, M_n; D_i, \ldots, D_n\}$**

Monte Carlo Simulations

+

Iterative procedure

Consistency checks with simulations



Data analysis

Monte Carlo data sample

- *EAS development: CORSIKA (QGSJETII.03 + FLUKA + EGS4)*
- *Energy range: 0.316 - 31600 TeV*
- *Full detector simulation (GEANT3)*
- *Protons + Helium nuclei + CNO nuclei + Iron nuclei*

Data sample

Three data sets in order to explore the energy range 1 - 1000 TeV

Digital Readout
(1 - 100 TeV)

- *About 9 X 10^{10} events (~ 8000 hours) recorded in the period Jan. 2008 - Dec 2012*

G4 Gain Scale
(10 - 100 TeV)

- 17 days (195-211) 2010
- 461Files

G1 Gain Scale
(100 - 1000) TeV

- 75 days (290-365) 2010
- 830 Files

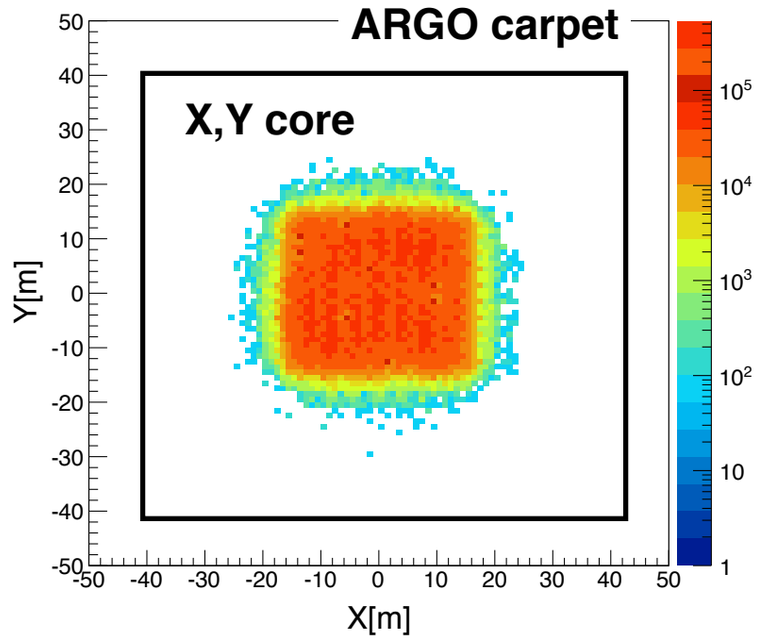
Data Analysis - Digital Readout Data

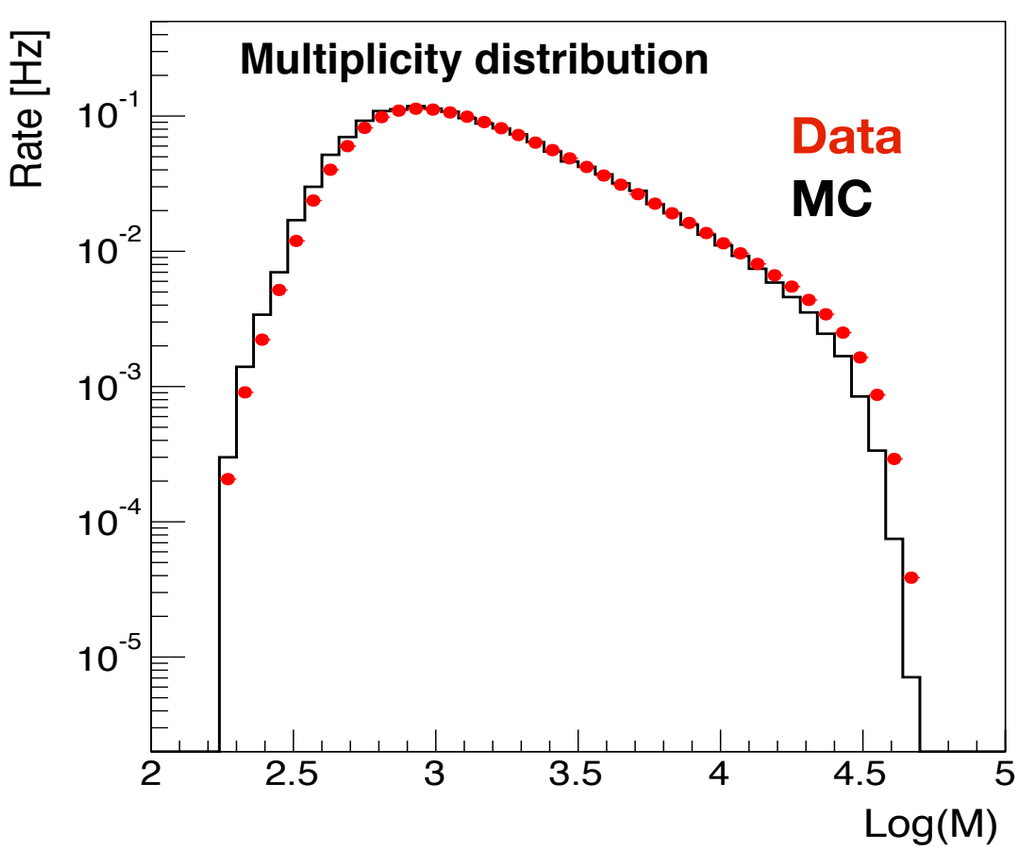
Event selection based on:

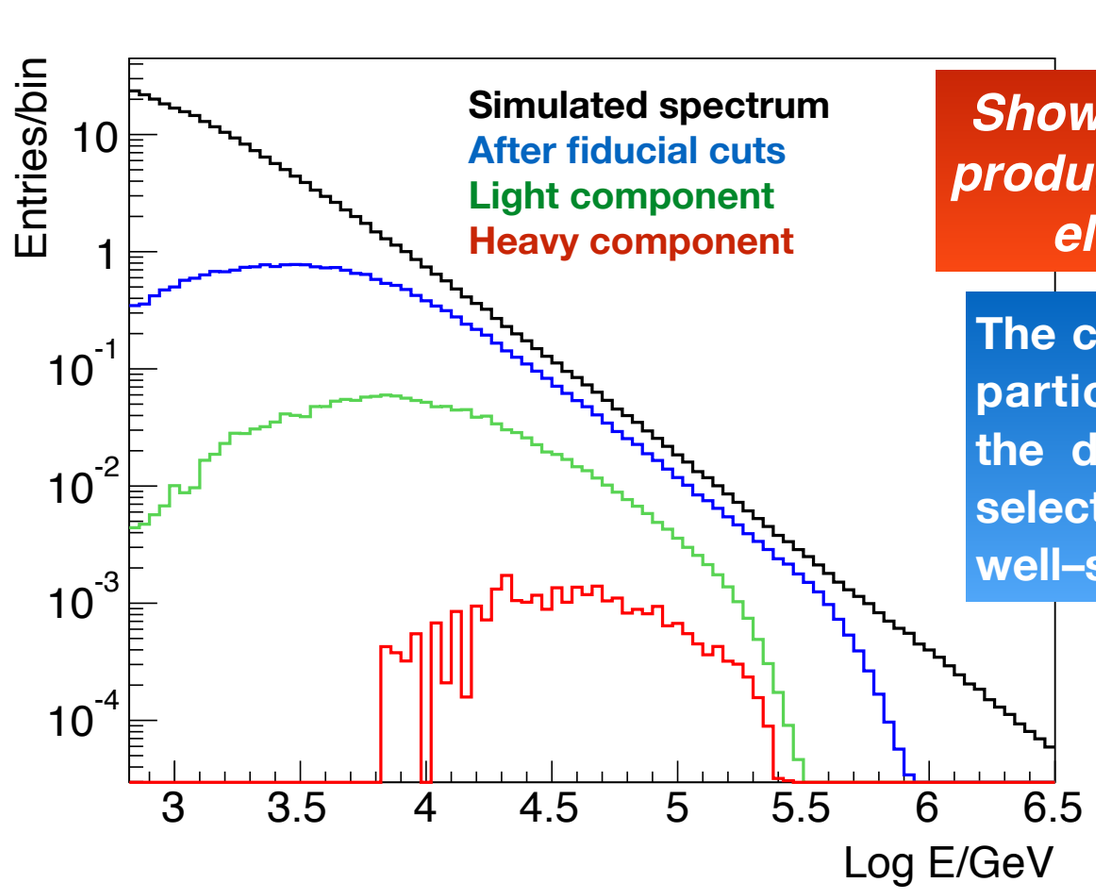
- ➡ Shower size on detector, **M** (strip multiplicity)
- ➡ Reconstructed zenith angle
- ➡ Core Position

Light - Heavy discrimination

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



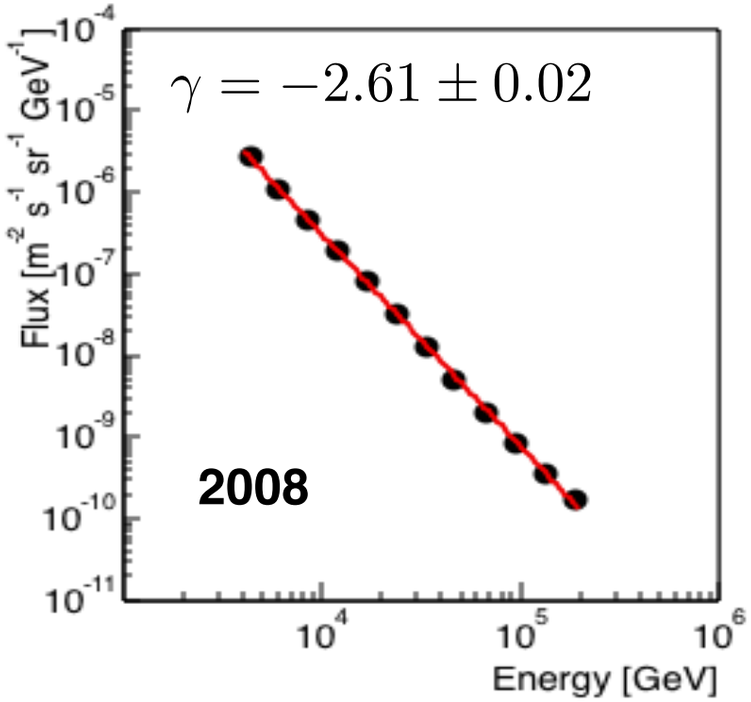


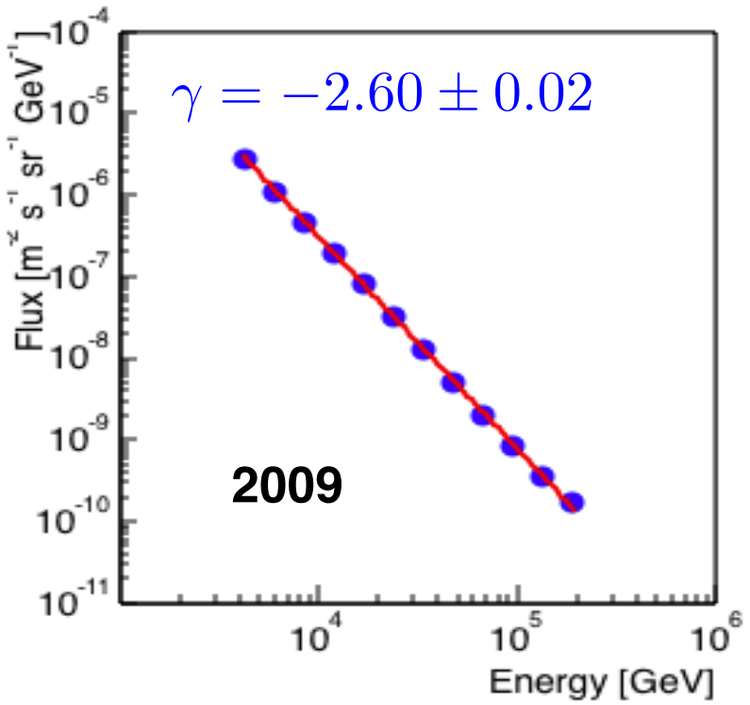


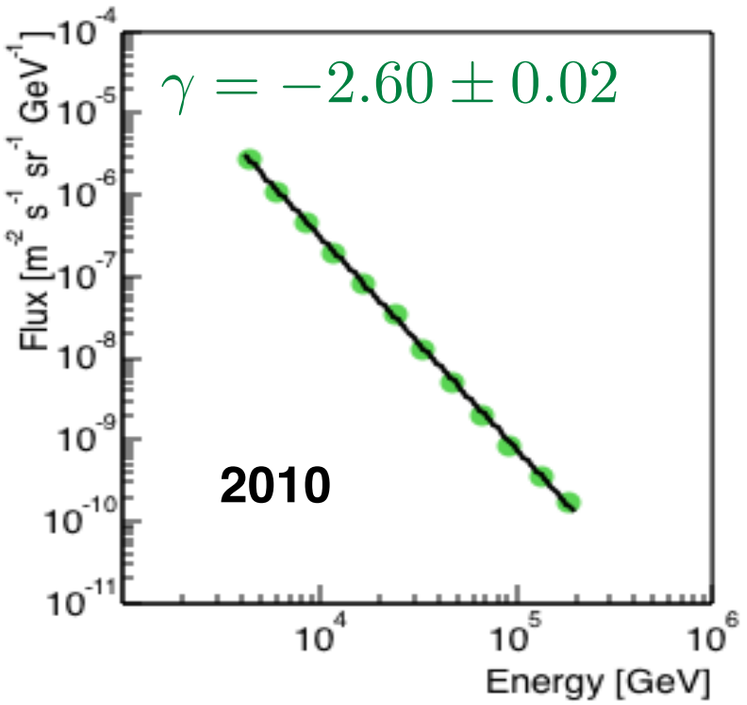
Showers mainly produced by light elements

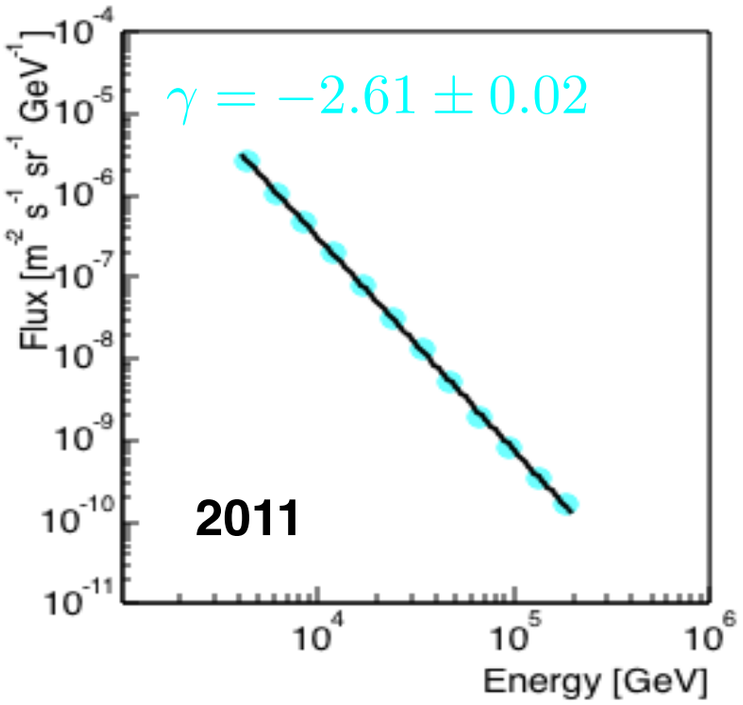
The cut based on the particle density on the detector surface selects showers with well–shaped core

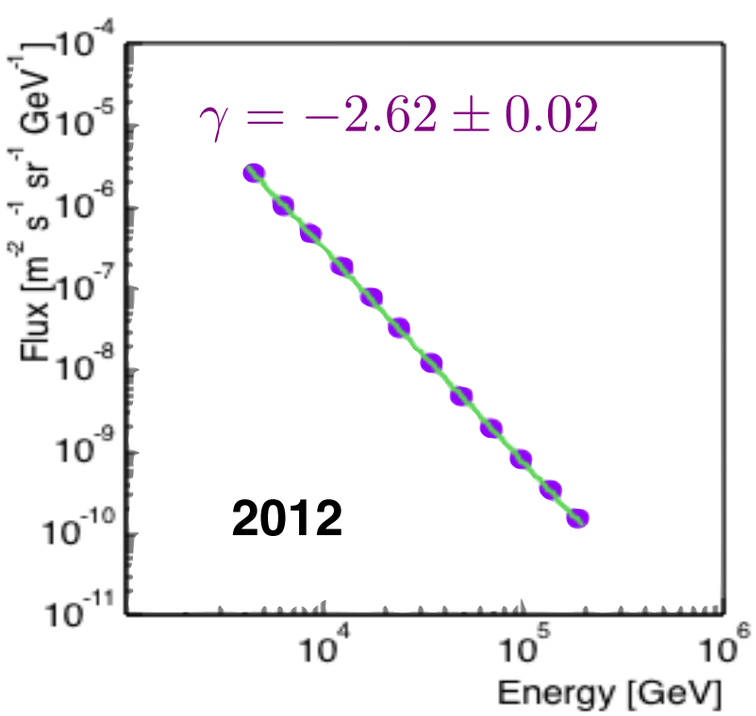
Light Component Spectrum: 1 - 100 TeV

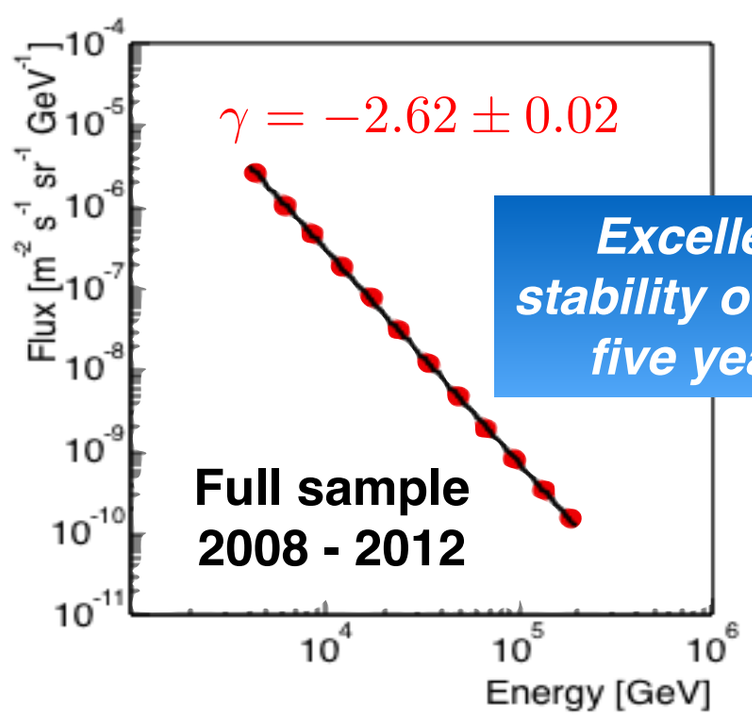








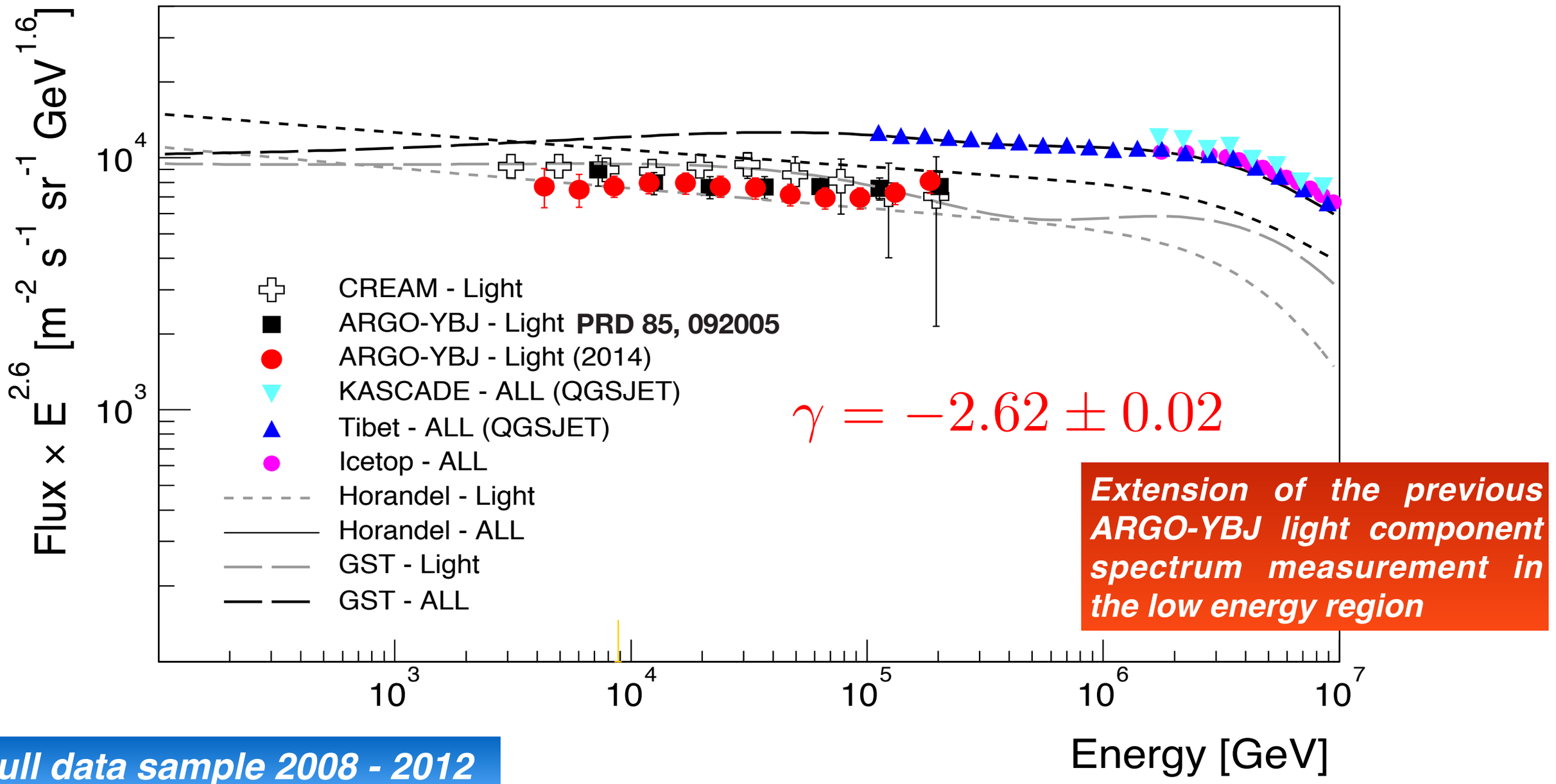




Excellent stability over all five years

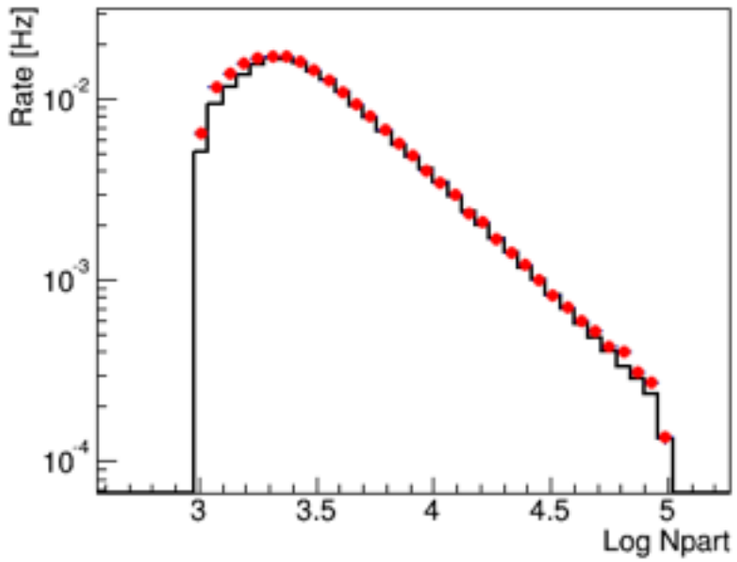
Light Component Spectrum: 1 - 100 TeV

- **Excellent stability over a long period**
- Overlap with direct measurements in a wide energy region
- Total systematic uncertainty ~ 10%



Full data sample 2008 - 2012

Data Analysis - Analog data (G4 scale)



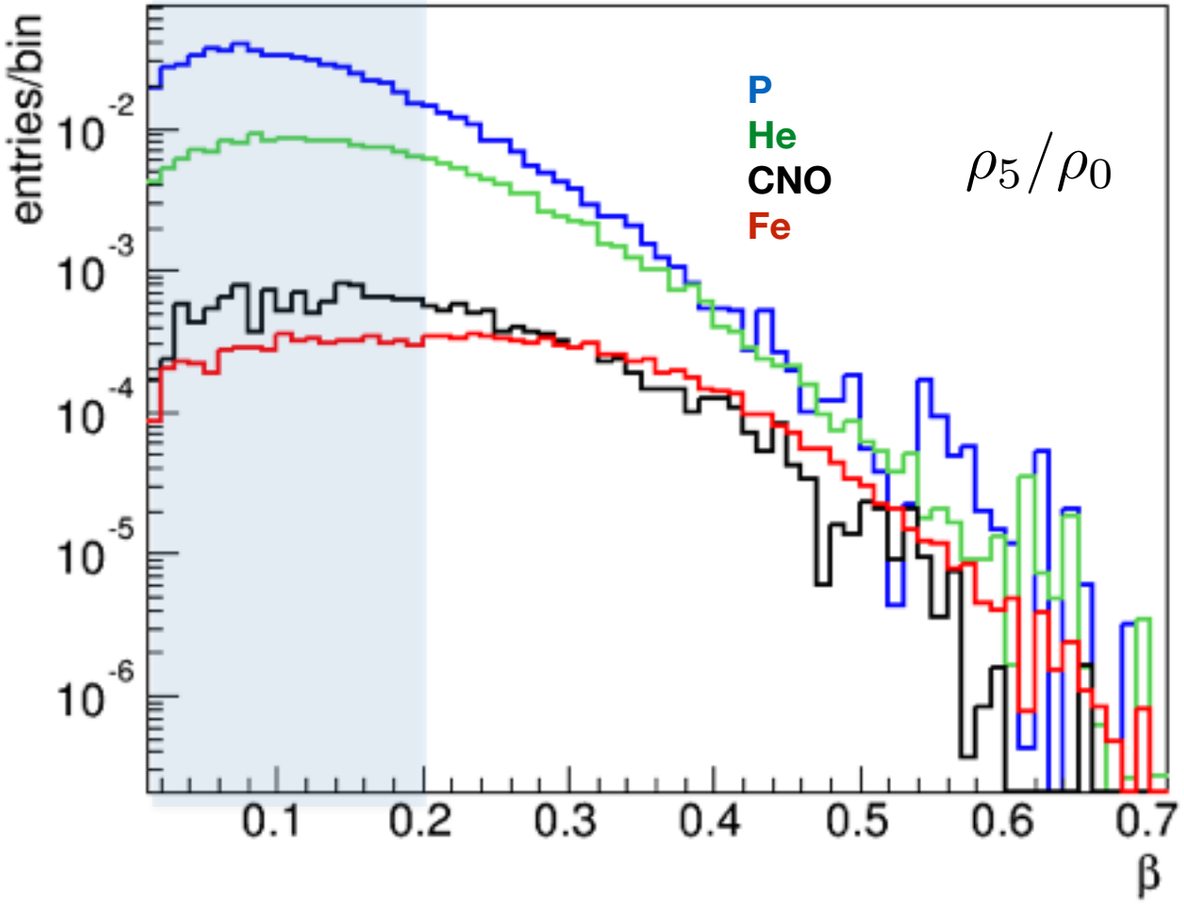
Fiducial cuts

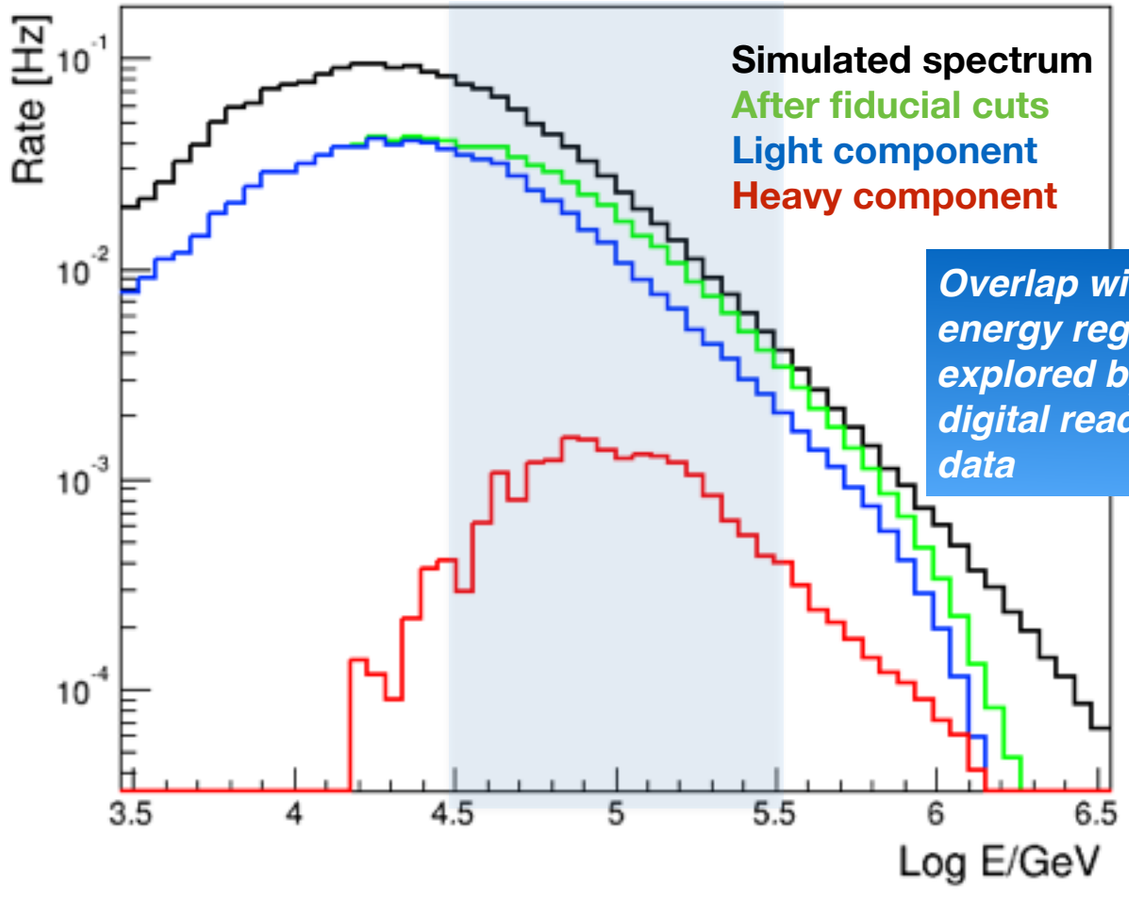
- ➡ Reconstructed zenith angle
- ➡ Core Position
- ➡ # of particles in a radius ~8m from the core

Light - Heavy discrimination

Essentially based on the LDF ρ_5 / ρ_0

Energy range for the Light spectrum measurement with G4





Overlap with the energy region explored by using digital readout data

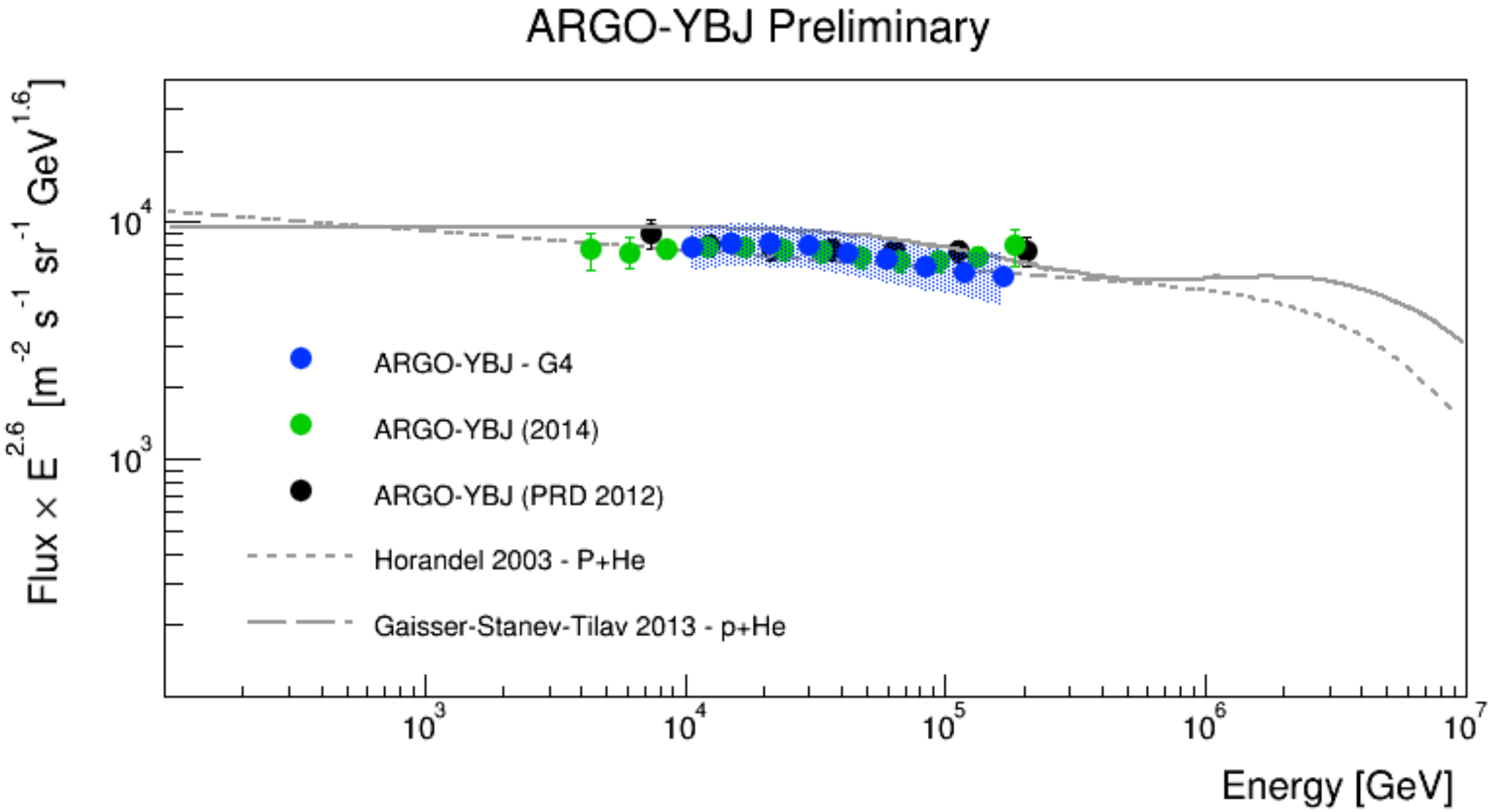
Light Component Spectrum: 10 - 100 TeV

➡ **Good agreement with the Digital Readout data (different data set)**

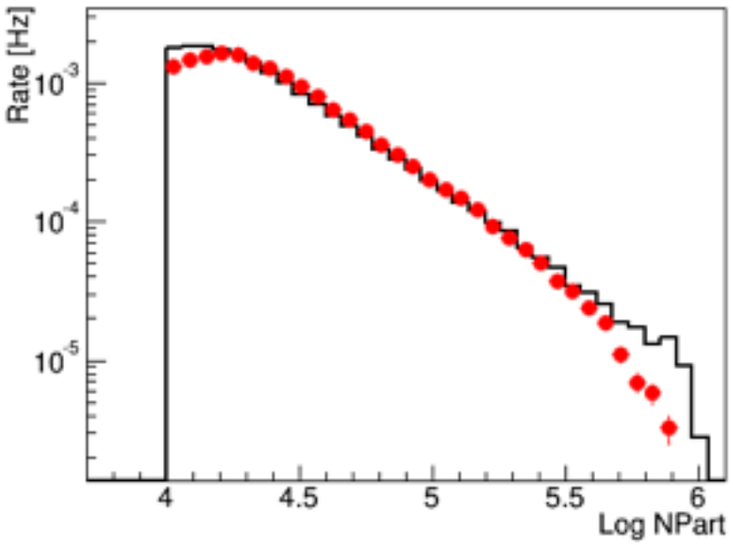
➡ Overlap with direct measurements in a wide energy region

➡ Two independent analyses gave consistent results (more details in next slides)

➡ Systematics ~ 10%



Data Analysis - Analog data (G1 scale)



Fiducial cuts

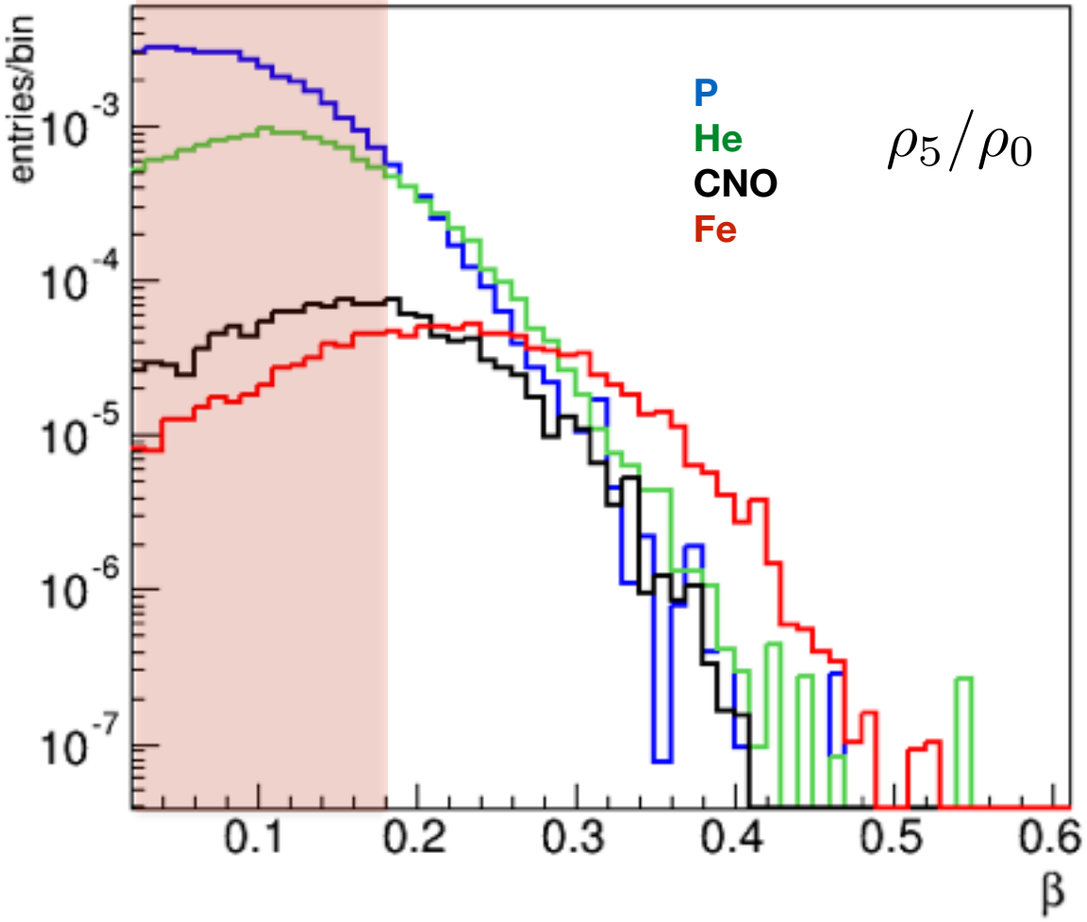
- ➡ Reconstructed zenith angle
- ➡ Core Position
- ➡ # of particles in a radius ~8m from the core

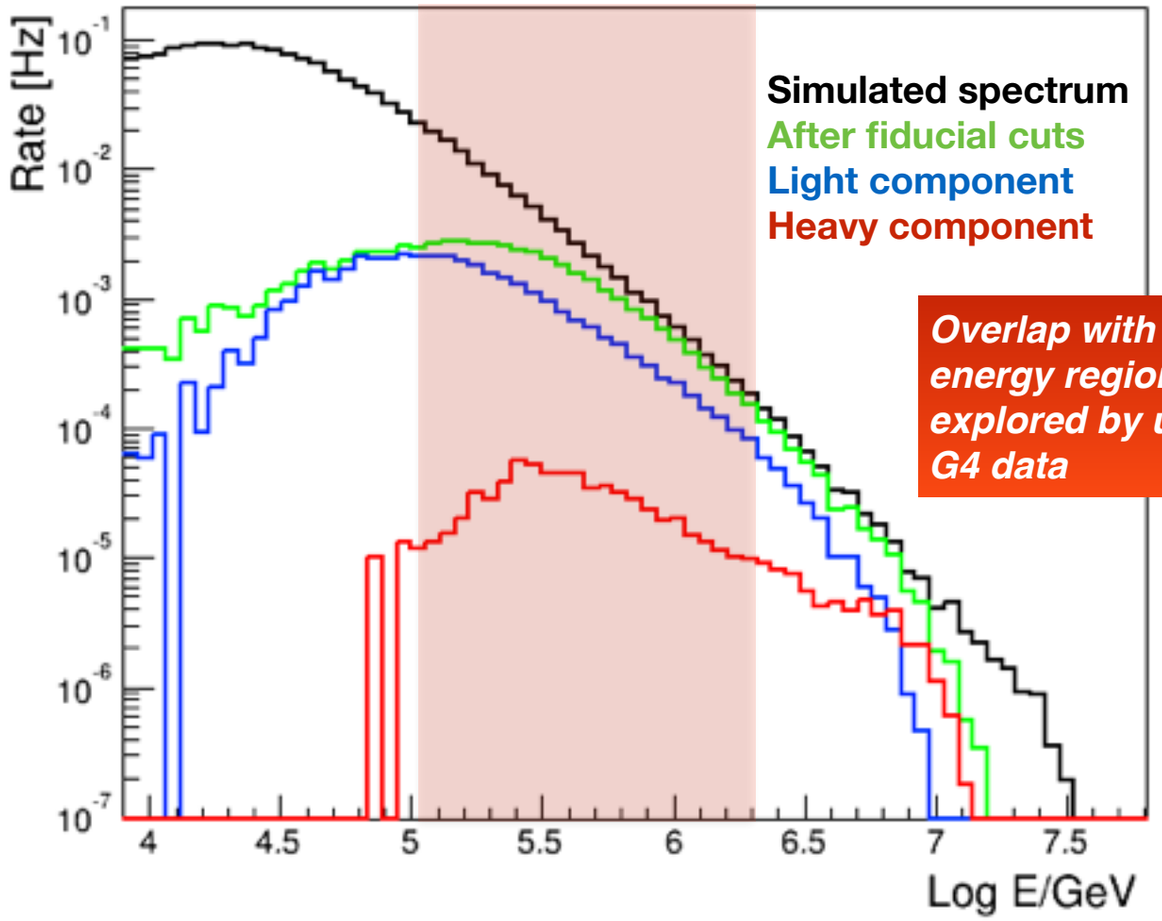
Light - Heavy discrimination

Essentially based on the LDF

$$\rho_5/\rho_0, \quad \rho_{10}/\rho_0$$

Energy range for the Light spectrum measurement with G1

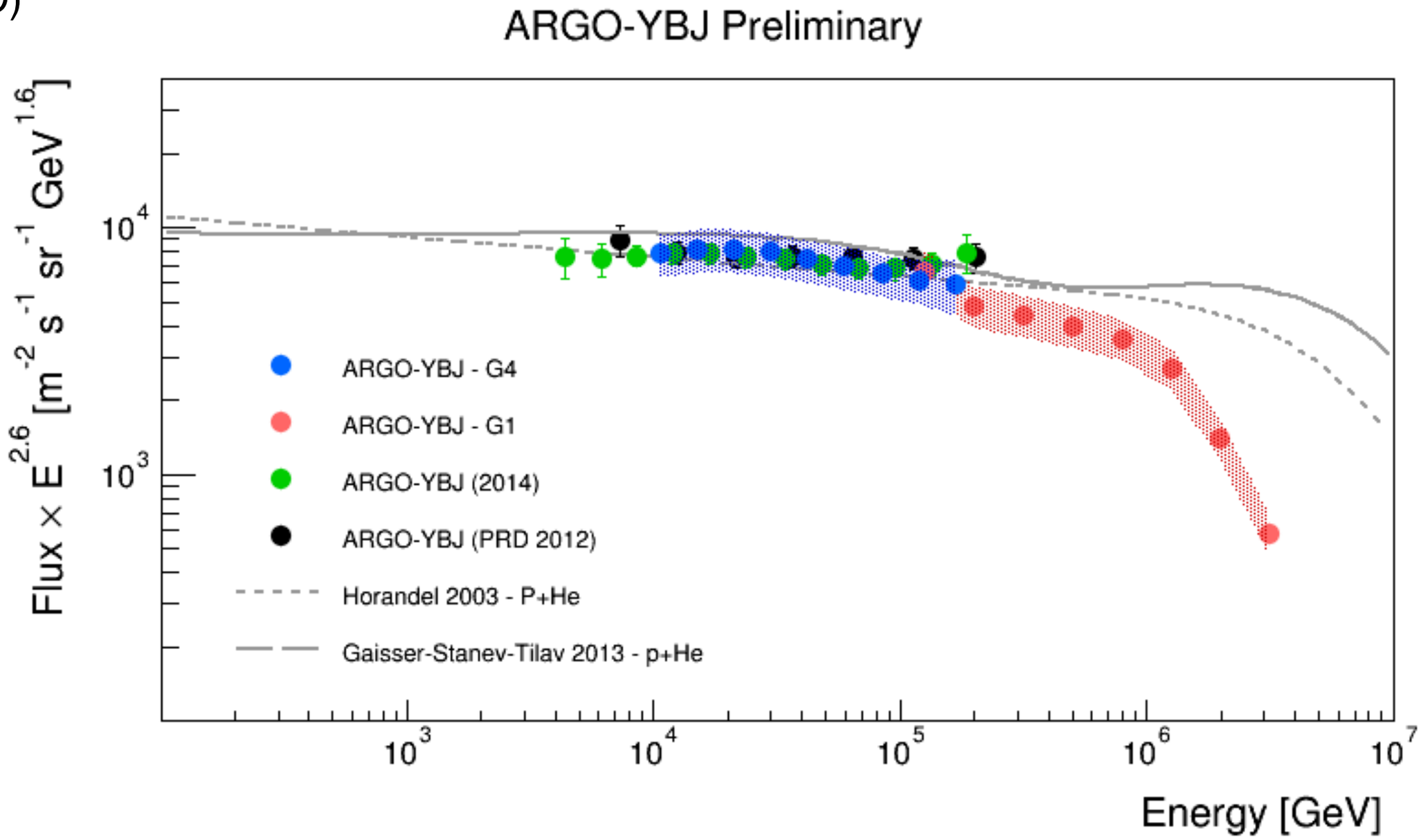




Overlap with the energy region explored by using G4 data

Light component spectrum: 100 - 1000 TeV

- **Gradual change of the spectral index at E ~ 700 TeV**
- Two independent analyses gave consistent results (more details in next slides)
- Systematics as for G4 data analysis + ~10-12% of contamination of heavy elements (mainly CNO)

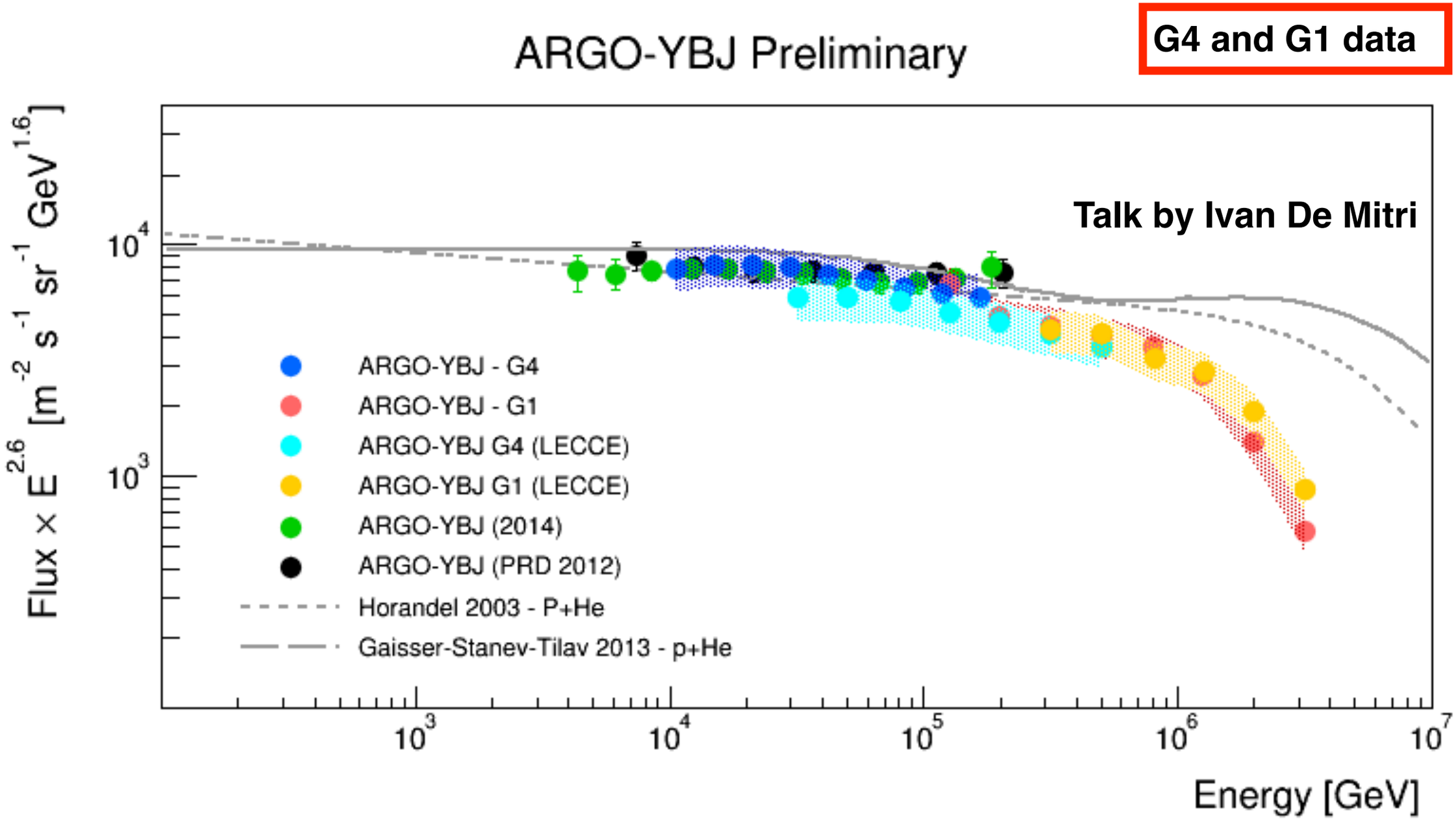


Light component spectrum

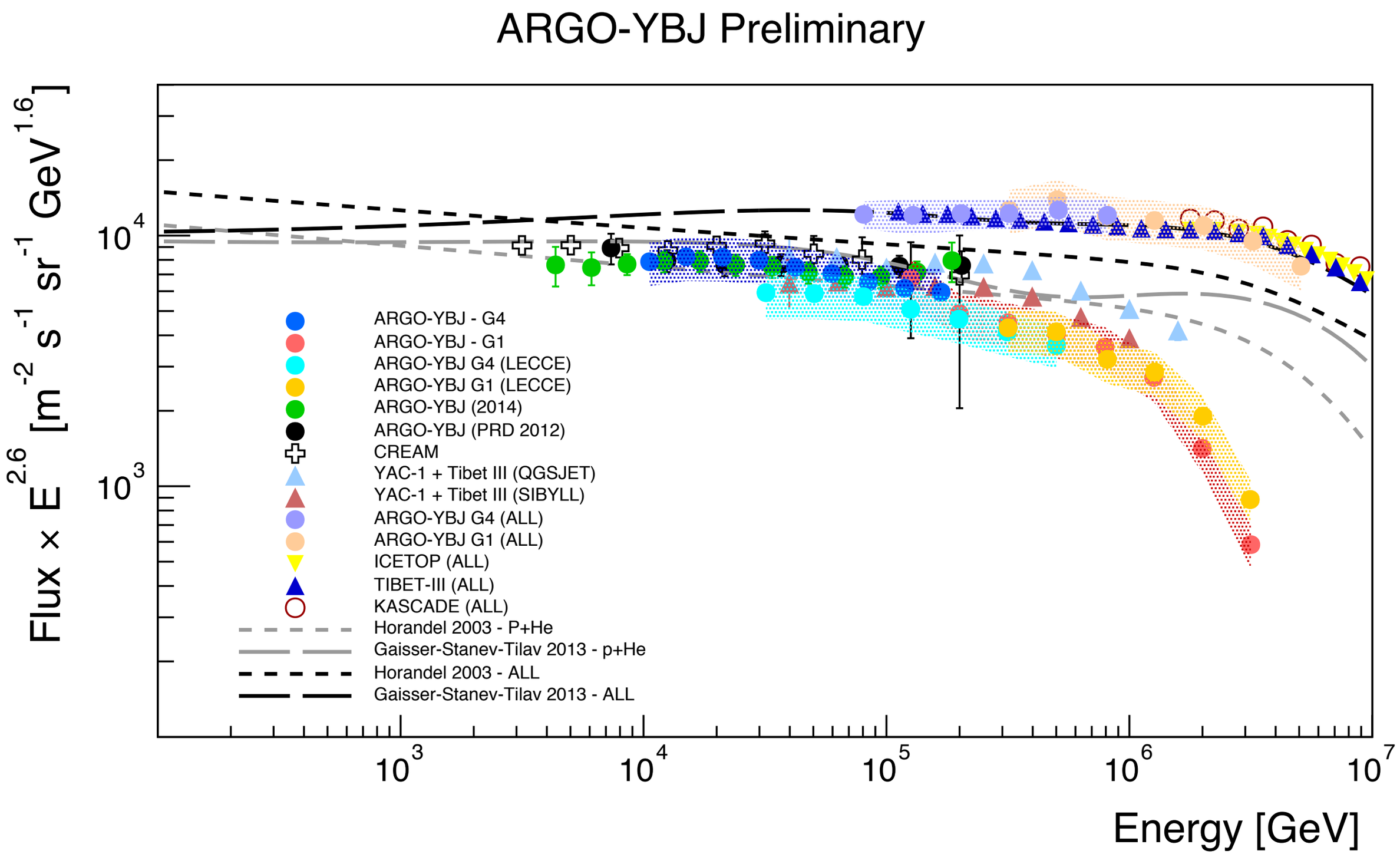
Same data, different fiducial cuts and different approach

Results are consistent with the presented analysis

G4 and G1 data



The Overall Picture



Conclusions and outlook

- *Light component spectrum measured in the energy range by using the full 2008-2012 digital data sample*
- *Very good stability of the detector over a long period*
- *Spectral indexes obtained consistent with very good stability*

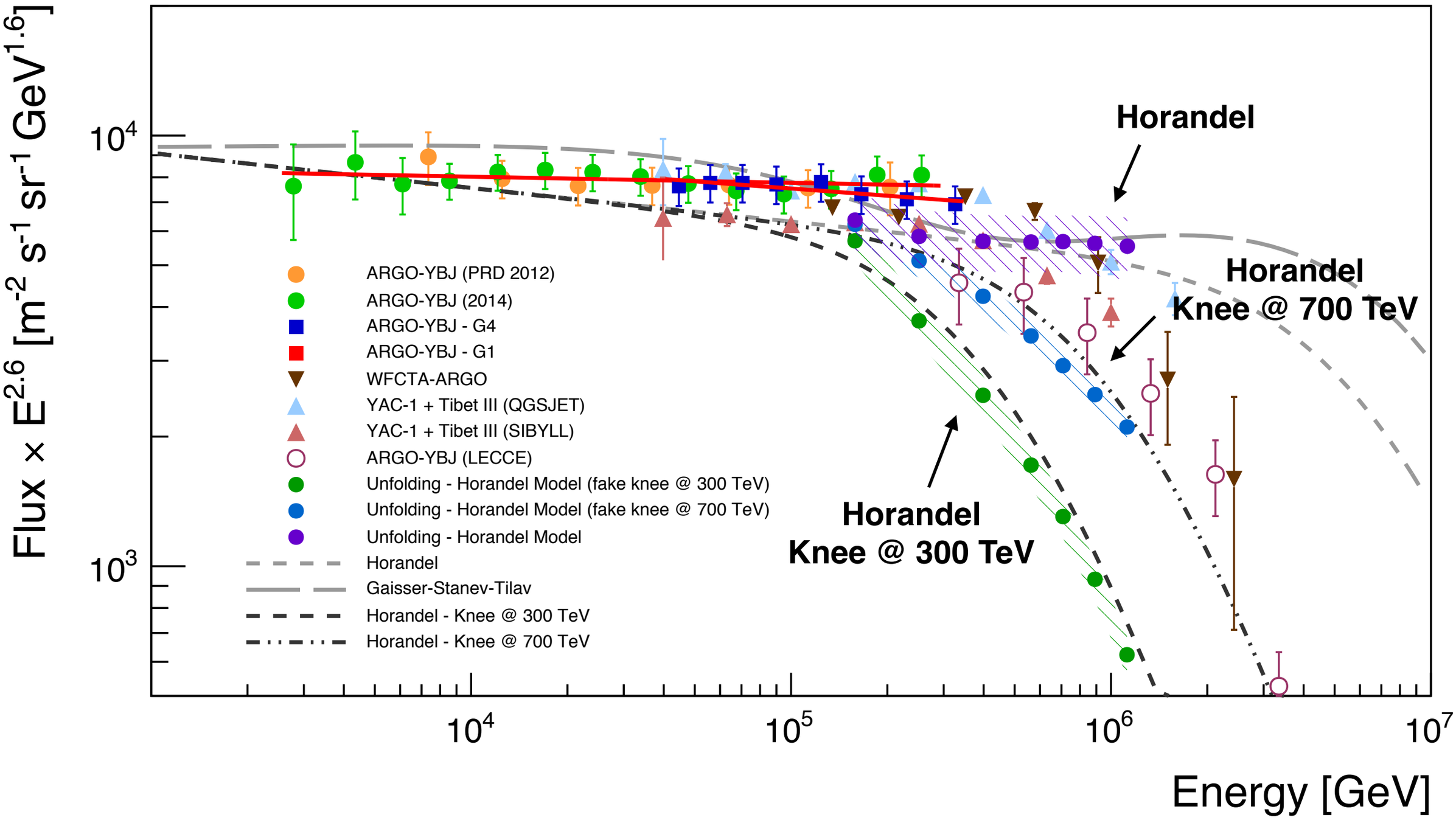
- *G4 data are in good agreement with the measurement obtained by using ~ 5 years of data*
- *Clear evidence of a bending of the light component spectrum at E < 1Pev*
- *Two independent analyses gave consistent results*
- *Analisys of the full analog readout data sample:*
  - *Heavy component spectrum*
  - *All particle spectrum*

BACKUP SLIDES

Consistency Checks

- **Check of the reliability of the method**
- **Two different weights for S2: Horandel model & Horandel model with a "fake knee" @ 300 TeV**

2 MC samples
S1: Bayesian Probabilities
S2: "Data"



- **Analysis of the multiplicity distribution in each energy bin**
- **Relation between primary energy and shower multiplicity**