# Proton-Air inelastic cross section measurement with ARGO-YBJ


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On behalf of the ARGO-YBJ Collaboration



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# The ARGO-YBJ experiment


**High Altitude Cosmic Ray Laboratory @ YangBaJing,Tibet, China**

**Site Altitude: 4,300 m a.s.l. , ~ 600 g/cm$^2$**

# ARGO-YBJ physics goals

- **Cosmic ray physics**:
  anti-p / p ratio at TeV energy,
  spectrum and composition ($E_{th}$ few TeV),
  study of the shower space-time structure,
  p-Air cross section, ….

- **VHE $\gamma$-Ray Astronomy**:
  search for point-like (and diffuse) galactic and
  extra-galactic sources at few hundreds GeV energy threshold

- **Search for GRB's** (full GeV / TeV energy range)

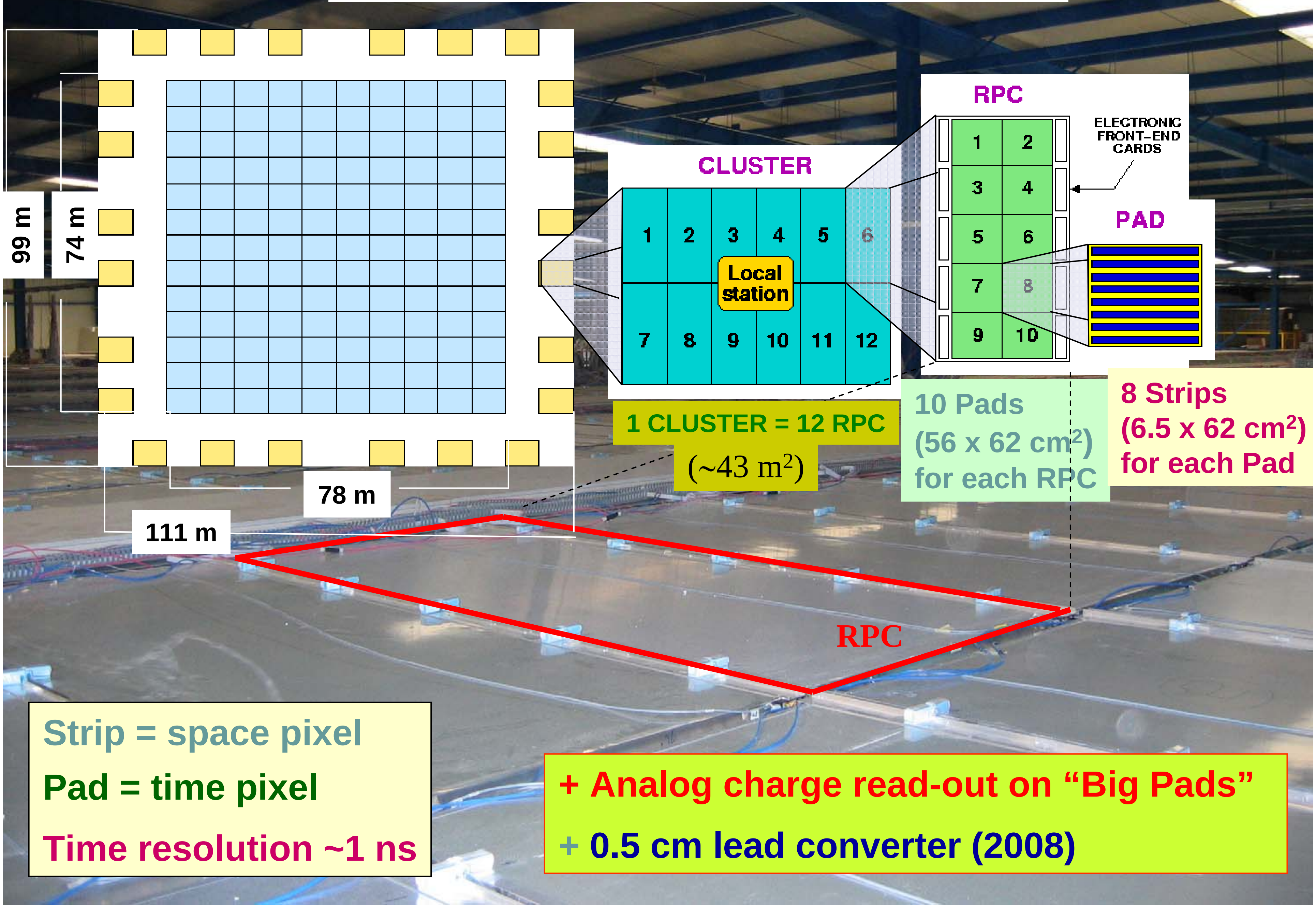
- **Sun and Heliosphere physics** ($E_{th}$ ~ few GeV)

through …

**Observation of *Extensive Air Showers* produced in the atmosphere by primary $\gamma$'s and nuclei**

| See other ARGO-YBJ contributions to this conference |
|---|
| 218 |
| 219 |
| 447 |
| 458 |
| 573 |
| 826 |
| 857 |
| 887 |
| 900 |
| 904 |
| 910 |
| 931 |
| 950 |
| 1029 |
| 1034 |
| 1100 |

# The ARGO-YBJ detector

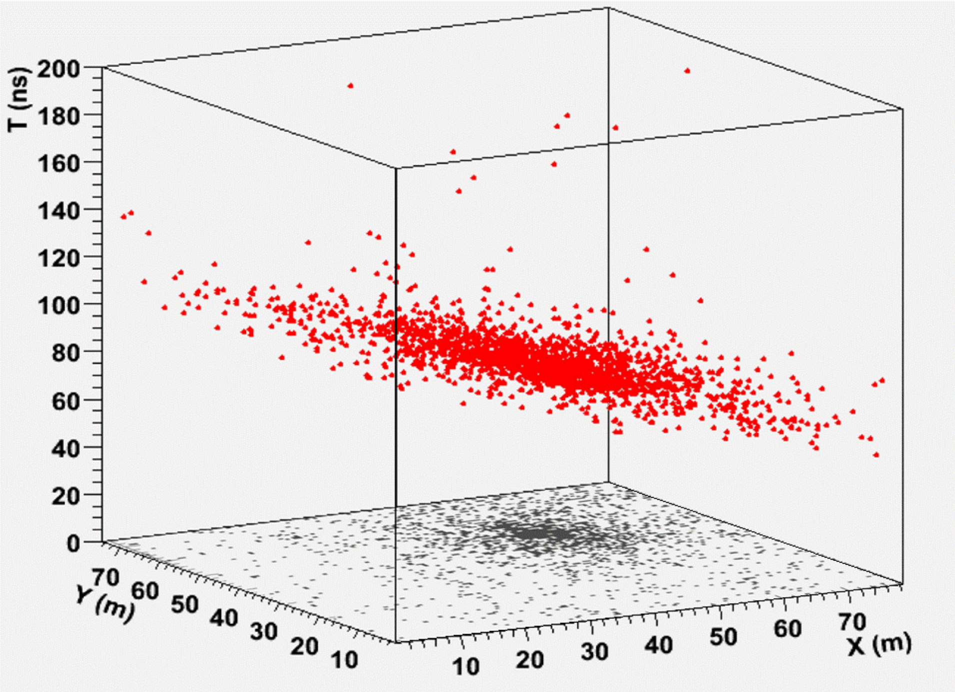


# EAS reconstruction

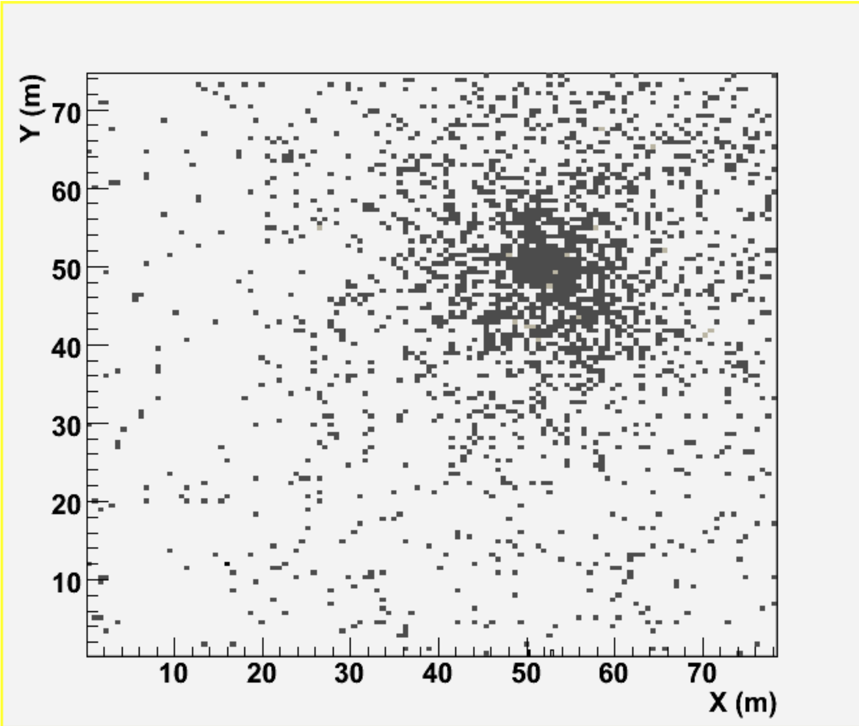
Event Rate ~ 4 kHz for $N_{hit}$ >20

**High space/time granularity**
**+ Full coverage**
**+ High altitude**

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

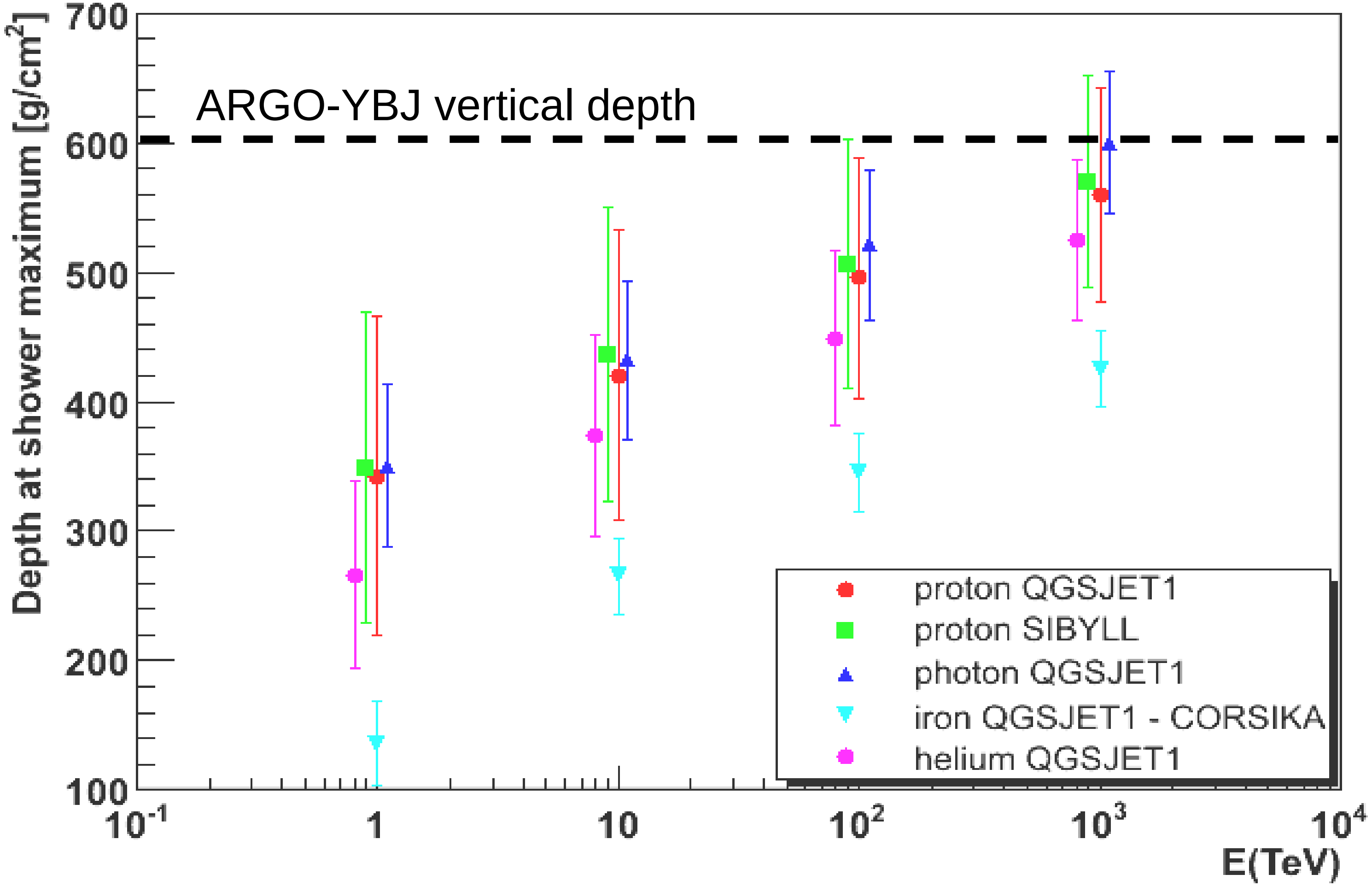



**3-D view of a detected shower**




**Top view of the same shower**

# The position of the shower maximum (and its rms)

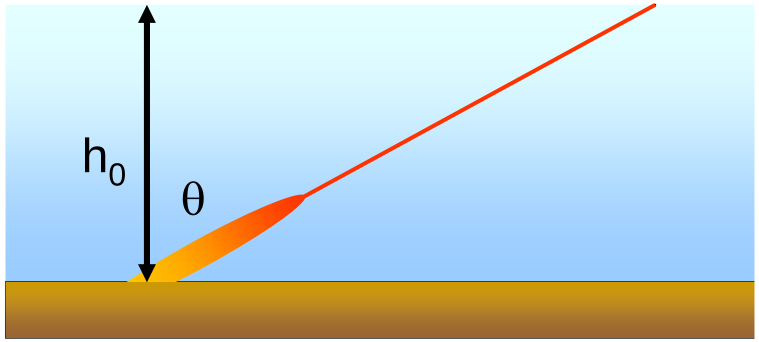


# Measurement of the Flux attenuation

Use the shower frequency vs (sec$\theta$ -1)

$$I(\theta) = I(0) \cdot e^{-\frac{h_o}{\Lambda}(\sec(\theta)-1)}$$

for fixed energy and shower age.




However $\Lambda$ **= k** $\lambda_{int}$ mainly because of shower fluctuations.

It is determined by simulations and depends on:

- interaction model
- actual set of experimental observables
- energy
- ……..

Then: **$\sigma_{p\text{-}Air}$ (mb) = 2.4 10$^4$ / $\lambda_{int}$(g/cm$^2$)**

Warning

Take care of shower fluctuations

- **Constrain** $X_{DO} = X_{det} - X_0$ or better $X_{DM} = X_{det} - X_{max}$
- **Select** deep showers (large $X_{max}$, i.e. small $X_{D0}$ or $X_{DM}$)
- **Exploit** detector features (space-time pattern) and location (depth).

# Data selection

➢ **Event selection based on:**

(a) "shower size" on detector, $N_{hit}$ (pad multiplicity)

(b) core reconstructed in a fiducial area (60 x 60 m$^2$)

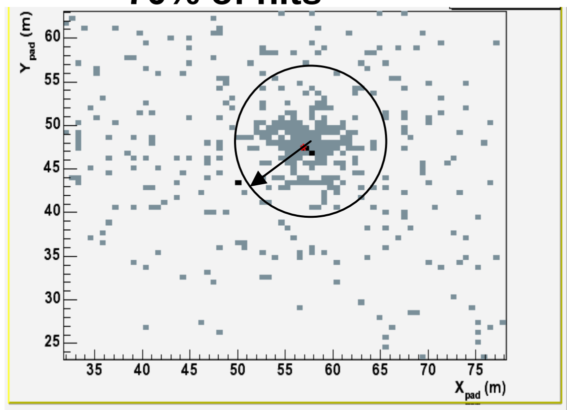
(c) constraints on Strip density (> 0.2/m$^2$ within $R_{70}$ )

and shower extension ($R_{70}$ < 25m)

**$N_{hit}$ is used to get two separated E sub-samples**

**($N_{hit}$= 300÷1000, $N_{hit}$ > 1000)**

$R_{70}$: radius of circle including 70% of hits



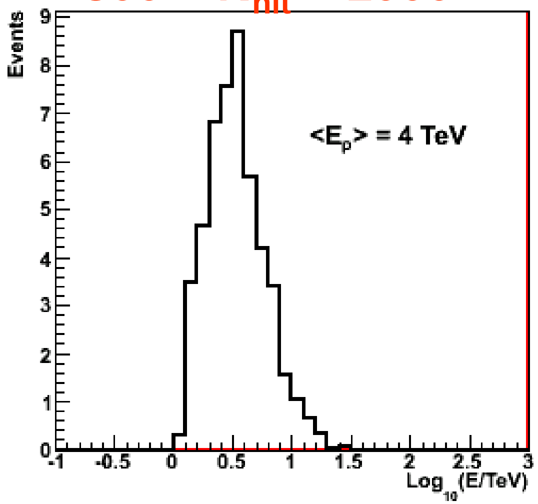

## Full Monte Carlo simulation:

Corsika showers

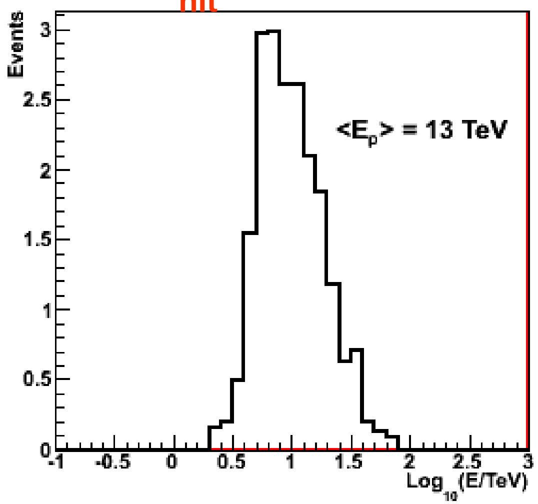
QGSJET int. model

GEANT detector simulation

**300 < $N_{hit}$ < 1000**

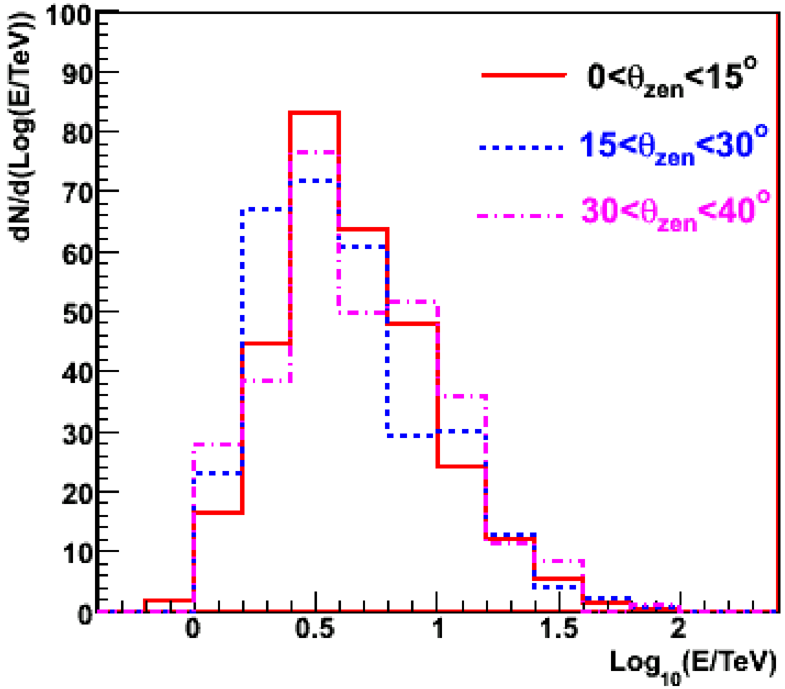



**$N_{hit}$ > 1000**

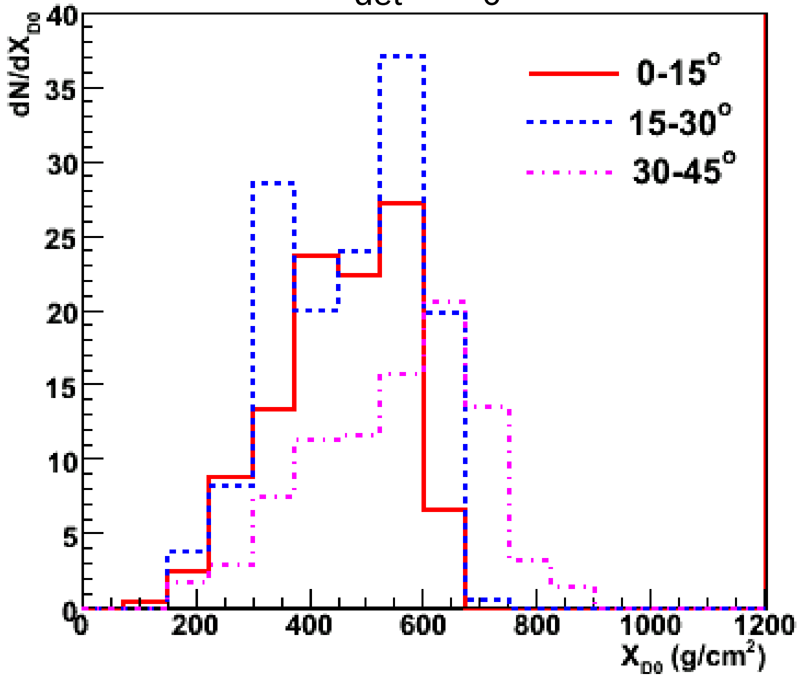


# Cuts in-dependence on the zenith angle

Energy




$X_{det}-X_0$

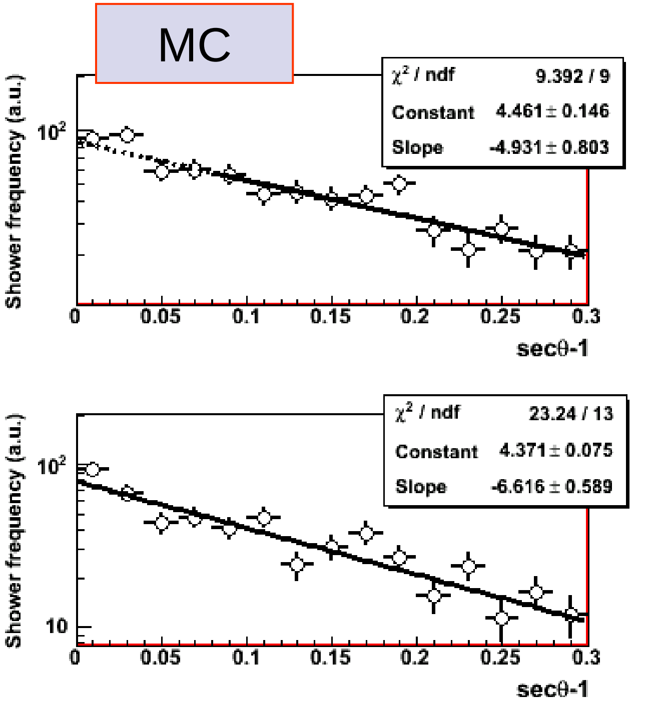


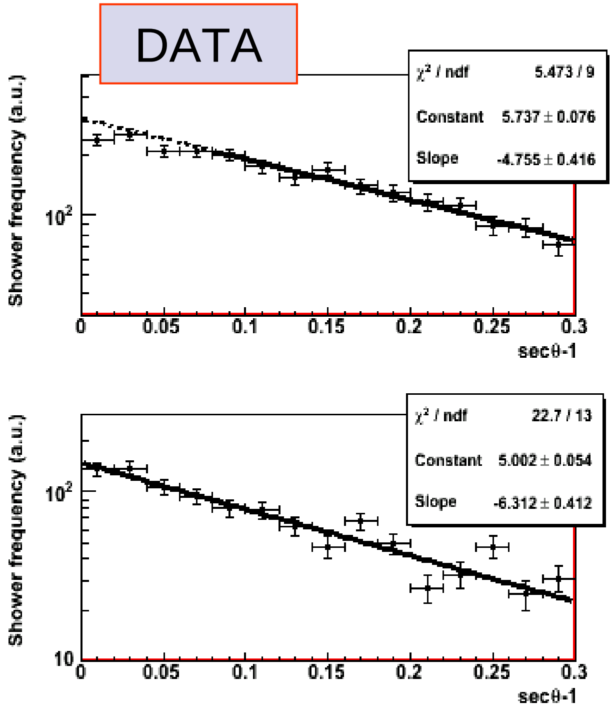

**No significant zenith angle dependence below 30 degrees.**

**A slight shift might be seen above 40 degrees.**

**In this analysis we stop at 40 degrees**

# The sec(θ) distributions



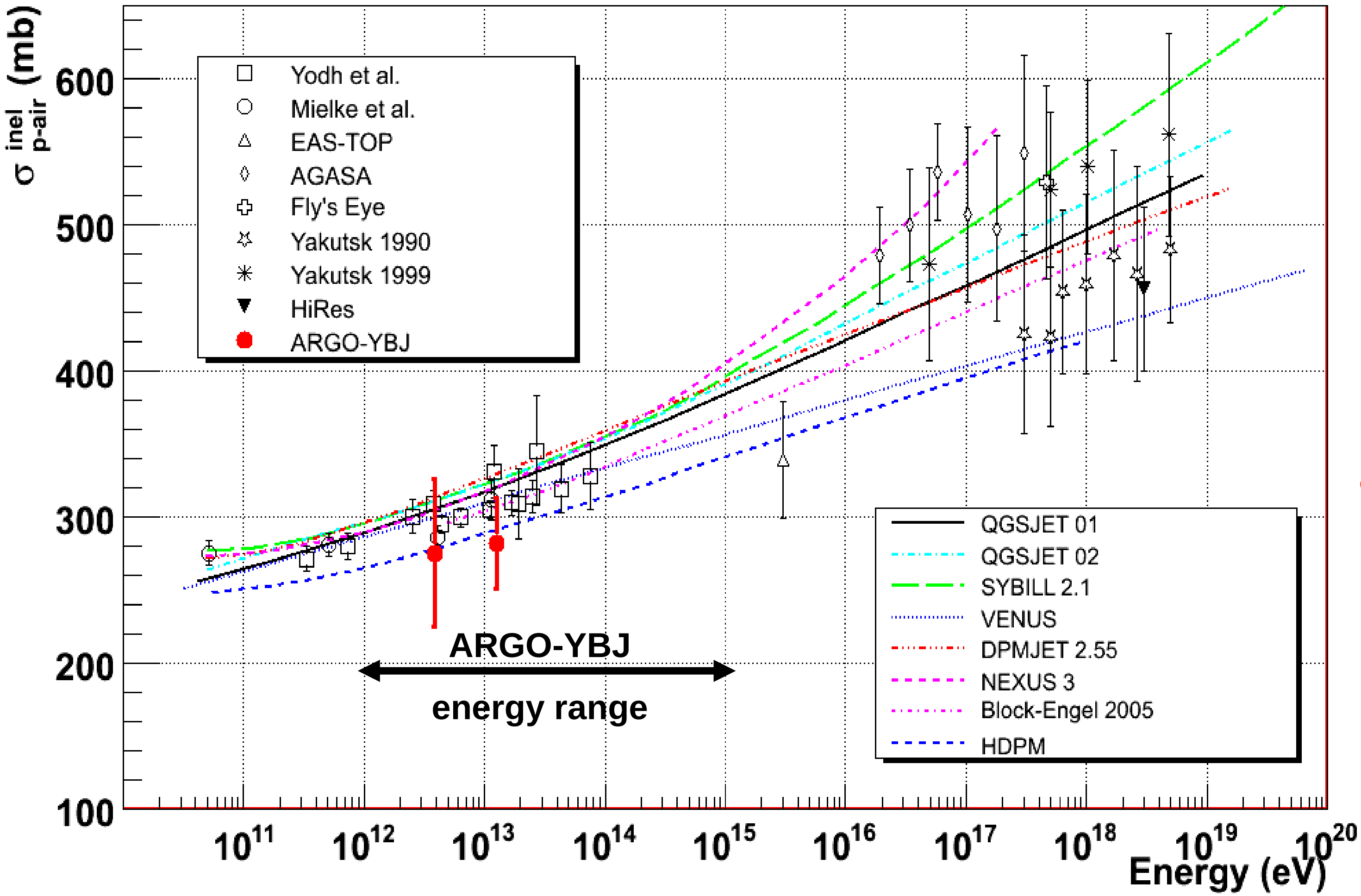

Exponential dependence in both MC and real data.

Larger contamination of "external" showers in the low energy bin

| Nhit | <E> | k | $\sigma_{CR-Air}$ (mb) |
|---|---|---|---|
| 300 ÷ 1000 | 3.9 ± 0.1 TeV | 1.6 ± 0.3 | **299 ± 55** |
| > 1000 | 12.7 ± 0.4 TeV | 1.2 ± 0.1 | **306 ± 34** |

The contribution of **He primaries** has been checked to increase the cross section values by **7-9%** (depending on the assumed primary spectra).

Correction for heavier primaries are expected to be negligible.




**In this plot ARGO-YBJ data points have been already corrected for the effect of primaries heavier than protons.**

| Nhit | <E> | k | $\sigma_{CR\text{-}Air}$ (mb) | $\sigma_{p\text{-}Air}$ (mb) |
|---|---|---|---|---|
| 300 ÷ 1000 | 3.9 ± 0.1 TeV | 1.6 ± 0.3 | **299 ± 55** | **275 ± 51** |
| > 1000 | 12.7 ± 0.4 TeV | 1.2 ± 0.1 | **306 ± 34** | **282 ± 31** |

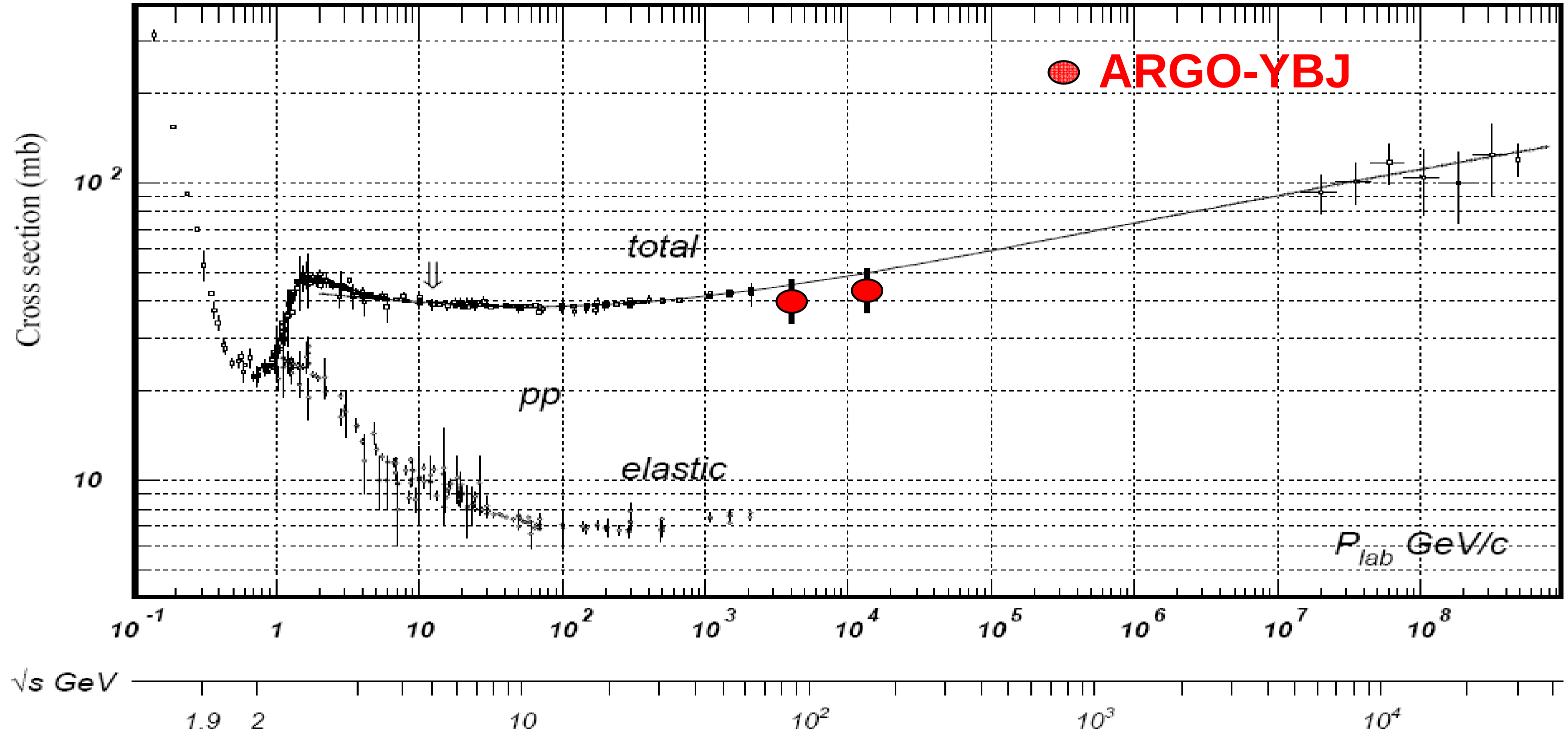
In agreement with a previuos work based on 42 clusters data

(ECRS, Lisbon 2006)

$\sigma^{inel}_{p\text{-}Air} \Rightarrow \sigma^{tot}_{p\text{-}p}$

- Glauber – Matthiae theory
- Durand – Pi
- Wibig – Sobczynska
- ....

**Models agree within few % in our energy range**




| Nhit | <E> | k | $\sigma_{CR\text{-}Air}$ (mb) | $\sigma_{p\text{-}Air}$ (mb) | $\sigma_{p\text{-}p}$ **(mbarn)** |
|---|---|---|---|---|---|
| 300 ÷ 1000 | 3.9 ± 0.1 TeV | 1.6 ± 0.3 | 299 ± 55 | 275 ± 51 | **40 ± 7** |
| > 1000 | 12.7 ± 0.4 TeV | 1.2 ± 0.1 | 306 ± 34 | 282 ± 31 | **43 ± 5** |

# Summary and Outlook

- The **flux attenuation** technique has been shown to give reliable results, by exploiting the **ARGO-YBJ detector features and location**
- The inelastic proton-air (and the total p-p) cross section has been measured, giving results **in agreement with previous works**.
- **The analysis will be extended to larger energies (up to 1 PeV)**, by also using the analog RPC readout, thus covering a region with few experimental information
- **More accurate shower age and energy** determinations by the use of **timing** (rise time, front curvature,..) and **topological** information
- **Further checks on systematics** will be done (shower fluctuations, interaction models, heavy primaries contribution, …)