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/cm²
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** (\(E_{th} \sim\) few GeV)
  - through ...

Observation of *Extensive Air Showers* produced in the atmosphere by primary \(\gamma\)’s and nuclei
The ARGO-YBJ detector

- Strip = space pixel
- Pad = time pixel
- Time resolution ~1 ns
- 10 Pads (56 x 62 cm²) for each RPC
- 8 Strips (6.5 x 62 cm²) for each Pad
- 1 CLUSTER = 12 RPC
- (~43 m²)

+ Analog charge read-out on “Big Pads”
+ 0.5 cm lead converter (2008)
EAS reconstruction

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

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)

![Graph showing the depth at shower maximum vs. energy for different particle interactions.](image)
Measurement of the Flux attenuation

Use the shower frequency vs (secθ -1)

\[ I(\theta) = I(0) \cdot e^{-\frac{h_0}{\Lambda}(sec(\theta) - 1)} \]

for fixed energy and shower age.

However \( \Lambda = k \lambda_{\text{int}} \) mainly because of shower fluctuations.

It is determined by simulations and depends on:
- interaction model
- actual set of experimental observables
- energy
- ........

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

Warning

Take care of shower fluctuations

- **Constrain** \( X_{DO} = X_{\text{det}} - X_0 \) or better \( X_{DM} = X_{\text{det}} - X_{\text{max}} \)
- **Select** deep showers (large \( X_{\text{max}} \), 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, $N_{\text{hit}}$ (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 ($R_{70} < 25$m)

$N_{\text{hit}}$ is used to get two separated E sub-samples
($N_{\text{hit}} = 300\div1000$, $N_{\text{hit}} > 1000$)

Full Monte Carlo simulation:
Corsika showers
QGSJET int. model
GEANT detector simulation

$R_{70}$: radius of circle including 70% of hits
Cuts in-dependence on the zenith angle

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**

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.

**Exponential dependence in both MC and real data.**

Larger contamination of “external” showers in the low energy bin

<table>
<thead>
<tr>
<th>Nhit</th>
<th>⟨E⟩</th>
<th>k</th>
<th>σ_{CR-Air} (mb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 ÷ 1000</td>
<td>3.9 ± 0.1 TeV</td>
<td>1.6 ± 0.3</td>
<td>299 ± 55</td>
</tr>
<tr>
<td>&gt; 1000</td>
<td>12.7 ± 0.4 TeV</td>
<td>1.2 ± 0.1</td>
<td>306 ± 34</td>
</tr>
</tbody>
</table>
In this plot, ARGO-YBJ data points have been already corrected for the effect of primaries heavier than protons.

In agreement with a previous work based on 42 clusters data (ECRS, Lisbon 2006)
\begin{itemize}
  \item Glauber – Matthiae theory
  \item Durand – Pi
  \item Wibig – Sobczynska
  \item …. \end{itemize}

Models agree within few % in our energy range.

\[ \sigma_{\text{inel}}^\text{p-Air} \Rightarrow \sigma_{\text{tot}}^\text{p-p} \]

\begin{tabular}{|c|c|c|c|c|}
  \hline
  Nhiten & \(<E>\) & \(k\) & \(\sigma_{\text{CR-Air}}\) (mb) & \(\sigma_{\text{p-Air}}\) (mb) & \(\sigma_{p-p}\) (mbarn) \\
  \hline
  300 ÷ 1000 & 3.9 ± 0.1 TeV & 1.6 ± 0.3 & 299 ± 55 & 275 ± 51 & 40 ± 7 \\
  \hline
  > 1000 & 12.7 ± 0.4 TeV & 1.2 ± 0.1 & 306 ± 34 & 282 ± 31 & 43 ± 5 \\
  \hline
\end{tabular}
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, ..)