Measurement of the Proton-Air Cross Section at $\sqrt{s} = 57$ TeV with the Pierre Auger Observatory

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Air showers

- Cosmic particle enters atmosphere (source: AGN, supernova, ...)
- Cascade of reactions
- Shower profile
- Distribution of shower maximum (tail is sensitive to proton-air cross section [source])
Proton-air cross section

- Tail: \[ \frac{dN}{dX_{max}} \propto \exp\left(-\frac{X_{max}}{\Lambda_\eta}\right) \]
- \(\Lambda_\eta\) is sensitive to \(\sigma_{p\text{-air}}\)

- Strategy:
  1. Determine \(X_{max}\) distribution
  2. Determine \(\Lambda_\eta\)
  3. Determine \(\sigma_{p\text{-air}}\)
Measurements of Air Showers

- Pierre Auger Observatory

Surface detector

Fluorescence telescope

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Measurements of Air Showers

- Pierre Auger Observatory
Determining $\Lambda_\eta$

- Selection: unbiased $X_{\text{max}}$
- Determine depth corr. to $\eta = 0.2$
- Selection: unbiased $X_{\text{max}}$ in this range
Determining $\Lambda_\eta$

$\Lambda_\eta = 55.8 \pm 2.3 \text{ (stat)} \pm 1.6 \text{ (sys)} \text{ g/cm}^2$

$E = 57 \pm 0.3 \text{ (stat)} \pm 6 \text{ (sys)} \text{ TeV}$
Determining $\sigma_{p\text{-air}}$

- Monte Carlo simulations: 4 models
  QGSJet01, QGSJetII.3, SIBYLL 2.1, EPOS1.99
- Logarithmic extrapolation of $\sigma_{p\text{-air}}$
Determining $\sigma_{p\text{-}air}$

- Monte Carlo simulations: 4 models
  QGSJet01, QGSJetII.3, SIBYLL 2.1, EPOS1.99
- Logarithmic extrapolation of $\sigma_{p\text{-}air}$

- Result: $\sigma_{p\text{-}air} = 505 \pm 22 \text{ (stat)}^{+19}_{-8} \text{ (sys)} \text{ mb}$
## Systematic uncertainties

**TABLE I.** Summary of the systematic uncertainties.

<table>
<thead>
<tr>
<th>Description</th>
<th>Impact on $\sigma_{p\text{-air}}^{\text{prod}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda_\eta$ systematics</td>
<td>$\pm 15$ mb</td>
</tr>
<tr>
<td>Hadronic interaction models</td>
<td>$-8 + 19$ mb</td>
</tr>
<tr>
<td>Energy scale</td>
<td>$\pm 7$ mb</td>
</tr>
<tr>
<td>Conversion of $\Lambda_\eta$ to $\sigma_{p\text{-air}}^{\text{prod}}$</td>
<td>$\pm 7$ mb</td>
</tr>
<tr>
<td>Photons, $&lt;0.5%$</td>
<td>$&lt; + 10$ mb</td>
</tr>
<tr>
<td>Helium, $10%$</td>
<td>$-12$ mb</td>
</tr>
<tr>
<td>Helium, $25%$</td>
<td>$-30$ mb</td>
</tr>
<tr>
<td>Helium, $50%$</td>
<td>$-80$ mb</td>
</tr>
<tr>
<td>Total (25% helium)</td>
<td>$-36$ mb, $+28$ mb</td>
</tr>
</tbody>
</table>
Final result

$$\sigma_{p\text{-air}} = 505 \pm 22 \text{ (stat)}^{+28}_{-36} \text{ (sys)} \text{ mb}$$

at $$\sqrt{s_{pp}} = 57 \pm 0.3 \text{ (stat)} \pm 6 \text{ (sys)} \text{ TeV}$$
Comparison
Comparison
Summary

- Air shower measurements from PAO
- Determine $X_{\text{max}}$ distribution and fit exponential
- Use 4 models to obtain $\sigma_{\text{p-air}}$ from fit
  - $\sigma_{\text{p-air}} = 505 \pm 22 \text{ (stat)}^{+28}_{-36} \text{ (sys) mb}$
- Agrees with some models
- Agrees with LHC extrapolation
- Largest uncertainty: mass composition