Measurement of the Proton-Air Cross Section with Telescope Arrays Black Rock, Long Ridge, and Surface Array in Hybrid Mode.

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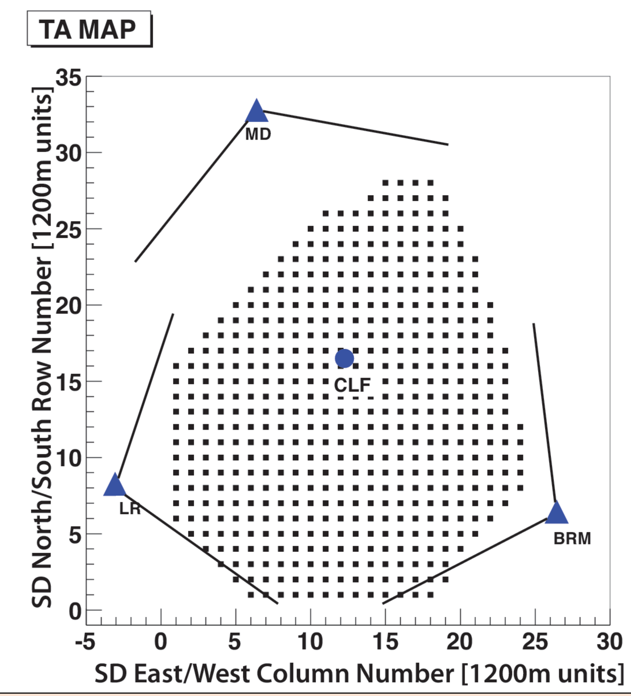
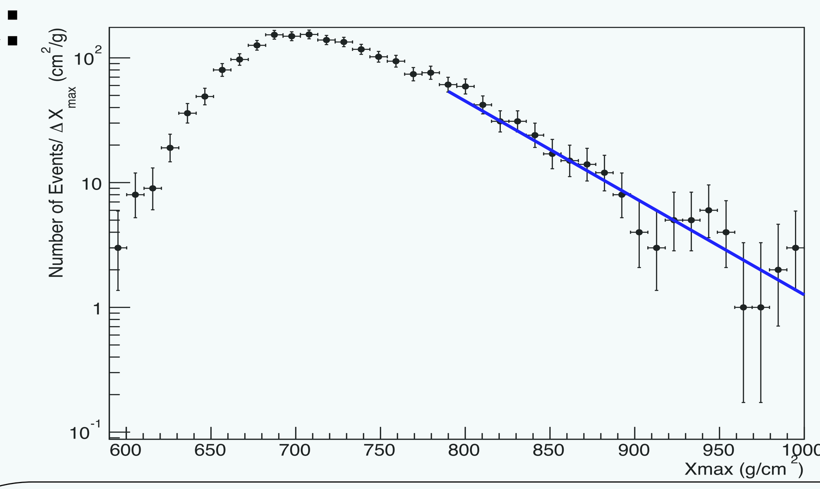
ABSTRACT:

Ultra High Energy Cosmic Ray (UHECR) detectors have been reporting on the proton-air cross section measurement beyond the capability of particle accelerators since 1984. The knowledge of this fundamental particle property is vital for our understanding of high energy particle interactions and could possibly hold the key to new physics. The data used in this work was collected over eight years using the hybrid events of Black Rock (BR) and Long Ridge (LR) fluorescence detectors as well as the Telescope Array Surface array Detector (TASD). The proton-air cross section is determined at $\sqrt{s} = 73$ TeV by fitting the exponential tail of the $Xmax$ distribution of these events. The proton-air cross section is then inferred from the exponential tail fit and from the most updated high energy interaction models. σinel p-air is observed to be 520.1 ± 35.8 [Stat.] +25.3 −42.9 [Sys.] mb.



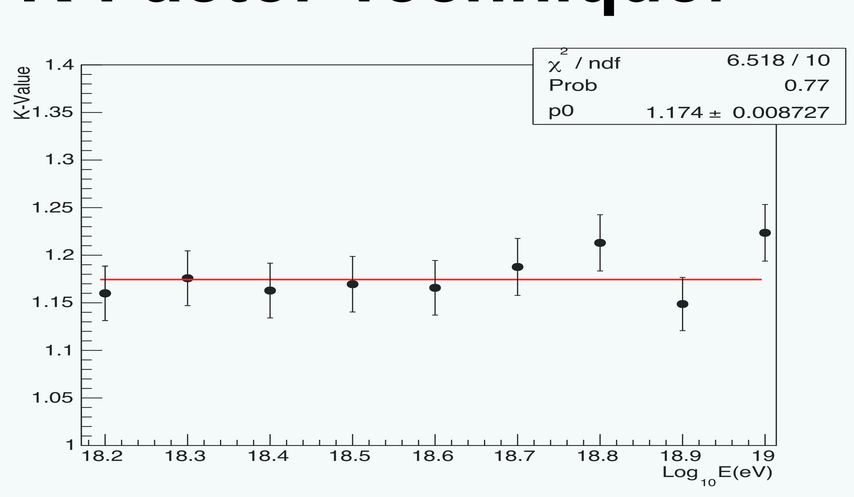
The Telescope Array detector configuration. The filled squares are the 507 SD scintillators on a 1.2 km grid. The SD scintillators are enclosed by three fluorescent detectors shown in filled triangles together with their field of view in solid lines. The northernmost fluorescence detector is called Middle Drum while the southern fluorescence detectors are referred to as Black Rock Mesa and Long Ridge. The filled circle in the middle equally spaced from the three fluorescence detectors is the Central Laser Facility used for atmospheric monitoring and detector calibration.

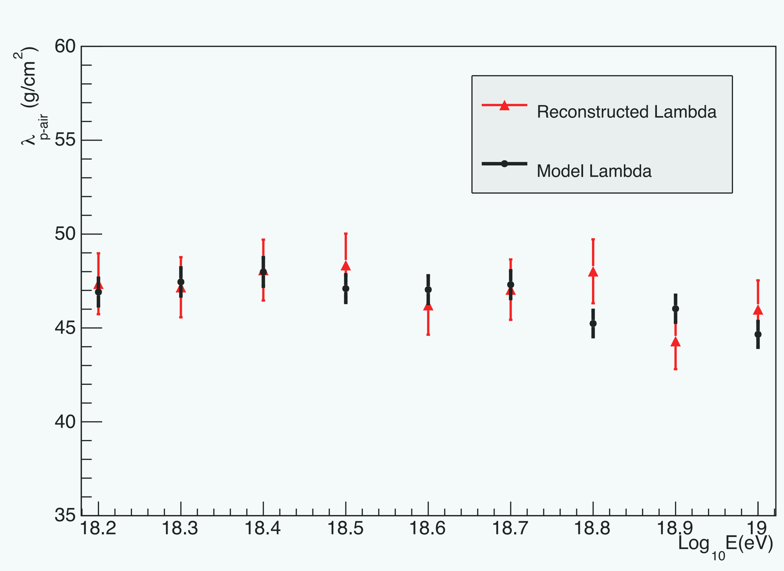
Measuring the Attenuation Length Λm:



The number of events per Xmax bin (ΔXmax) vs. Xmax (g/cm^2) for BRM and LR fluorescence detectors and the Telescope Array surface detector in hybrid mode. The line is the exponential fit to the slope using the unbinned likelihood method between 790-1000 g/cm^2. The final Λm reported by the TA detector at an average energy of $10^{18.45}$ eV is found to be Λm = 55.9 ± 3.8 [Stat.]. Note that Λm is directly derived from the data and is model independent. Therefore, it can be used at a later time to calculate the inelastic proton-air cross section independent of the method or the UHECR models used here.

K-Factor Technique:



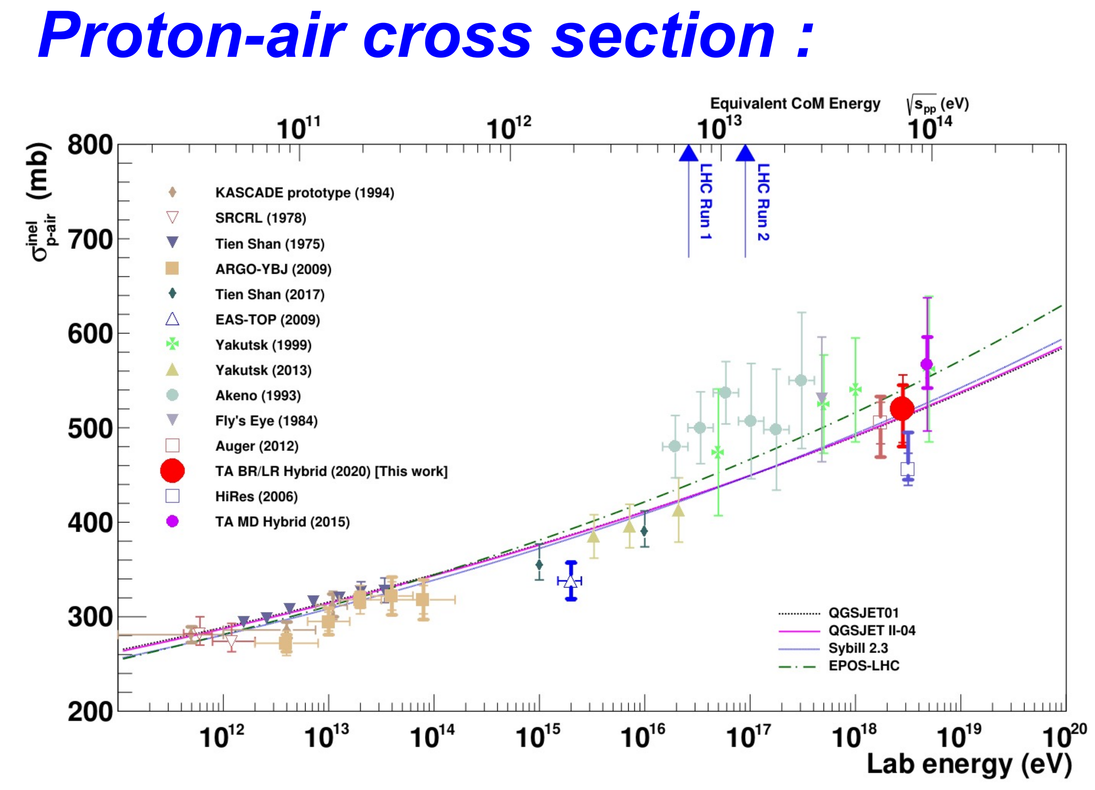


The value of K obtained vs. energy in Log10(eV) for simulated data sets using CONEX 6.4 with the high energy model QGSJET II.4, for the energy range of the data, between $10^{18.2}$ and $10^{19.0}$ eV.

Model	K	σinel (mb) p−air
QGSJET II.4	1.17 ± 0.01	505.4 ± 34.8
QGSJET01	1.19 ± 0.01	514.1 ± 35.4
SIBYLL2.3	1.24 ± 0.01	535.6 ± 36.9
EPOS-LHC	1.22 ± 0.01	527.0 ± 36.3

To confirm the validity of the obtained K values, for each of the generated data sets, for each of the high energy models, λp−air is reconstructed using the K-Factor method and compared to the λp−air provided by the corresponding high energy model.

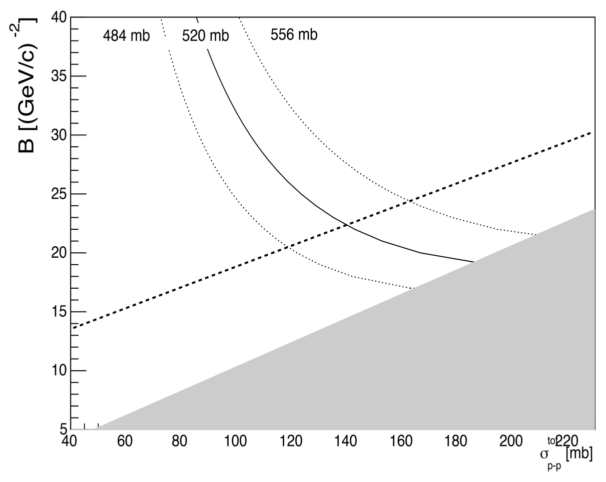
Proton-air cross section :

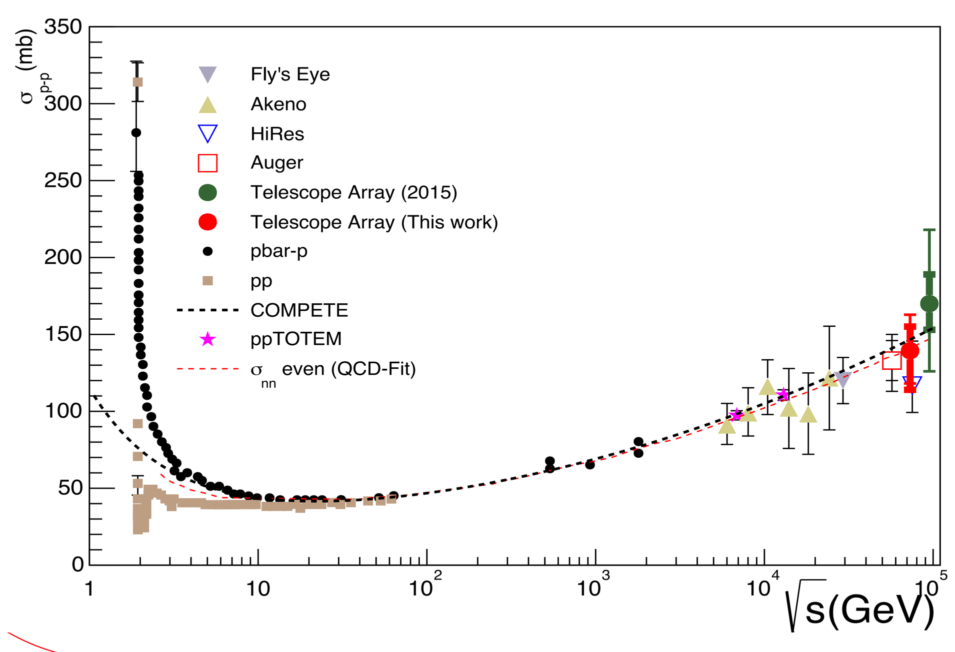


$$\Lambda_m = K\frac{24160}{\sigma_{p-air}} = K\frac{14.45 m_p}{\sigma_{p-air}}$$

The proton-air cross section result of this work, including the statistical (thin) and systematics (thick) error bars, in comparison to previous experimental results. In addition, the high energy models (QGSJET II.4, QGSJET01, SIBYLL 2.3, EPOS-LHC) cross section predictions are shown.

Proton-Proton cross section:





The elastic slope B in ((GeV/c)$^{-2}$) vs. σ_{p-p} total in mb. The solid line is the allowed σ_{pp}total values from the σ_{ip-air} inelastic. Its statistical errors reported in this work. The dashed line is the BHS fit prediction. While the gray shaded area is the unitarity constraint.

A compilation of the proton-proton cross section vs. the center of mass energy result of this work, including the statistical (thin) and systematics (thick) error bars, in addition to previous work by cosmic rays detectors in addition to, the recent result from LHC by TOTEM at curve is the BHS fit and the dashed black curve is the fit by the COMPETE collaboration.

Future outlook:

Future cross section results, using TA × 4 will allow us to report on the proton air cross section with greater statistical power. Moreover, including data from the Telescope Array Lower Extension would allow the measurement from 10^{17}−10^{19} eV with high statistical power and at several energy intervals. This would allow us to make a statement on the functional form of the cross-section energy dependence.

Acknowledgments:

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