IRKUTSK STATE UNIVERSITY

TAIGA

Mass Composition of Primary Cosmic Rays by the Latest TAIGA-HiSCORE Data

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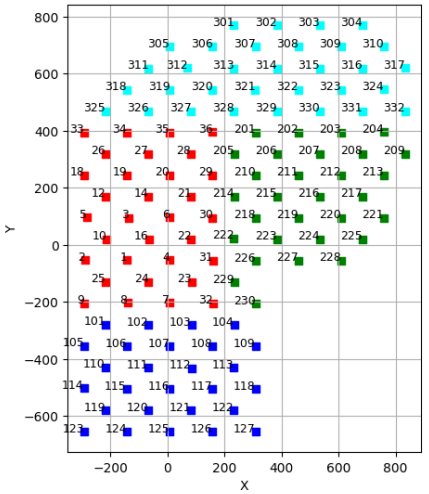
The latest modification of the TAIGA-HiSCORE array

- Expanded TAIGA-HiSCORE array to 1 km² with 114 **zenith-oriented** stations (2022-2023 season, Autumn 2024);
- Each station is equipped with a set of four large photomultiplier tubes (PMTs);

- Air shower energy determined by Cherenkov light flux at 200 m from the axis for >1 PeV, and 100 m for lower energies;

- Results of this work based on 282 hours of data collected from Oct 2022–Apr 2023, and Sept–Oct 2024.



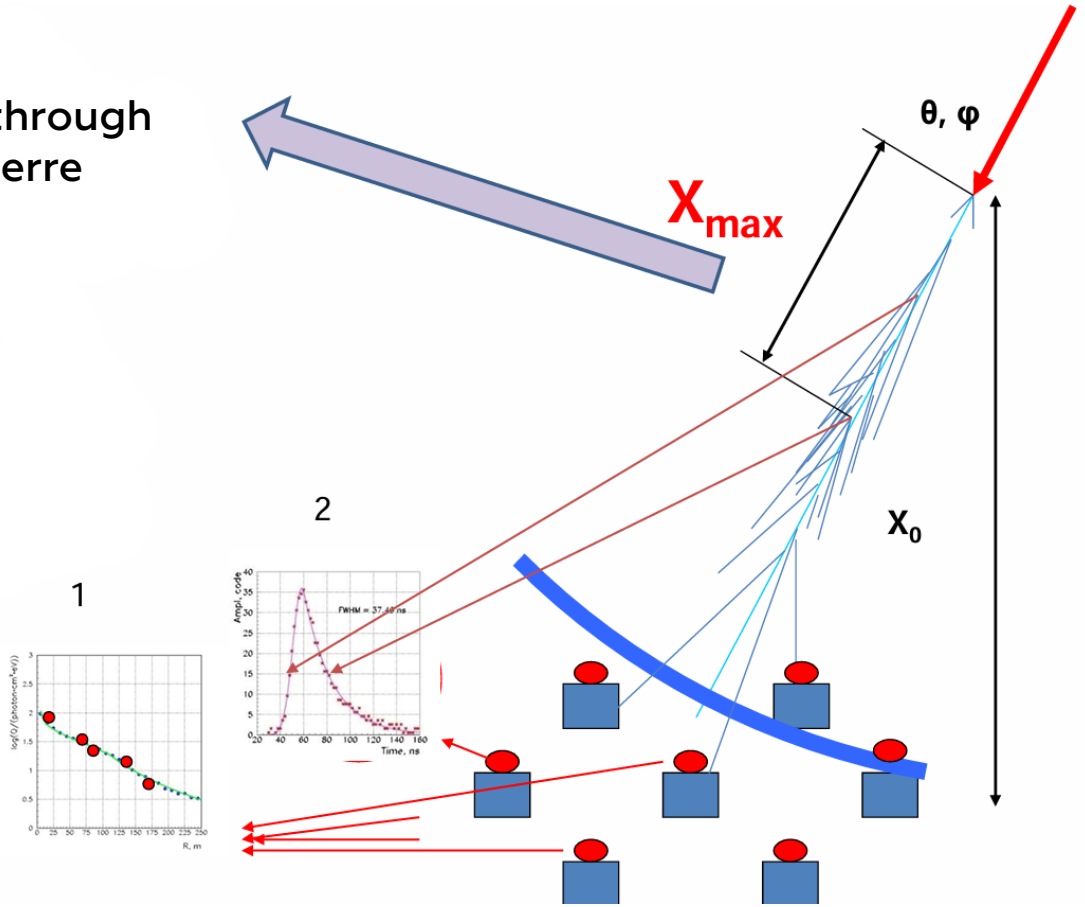
How is the depth of the air shower maximum measured?

10^{18} – 10^{20} eV:

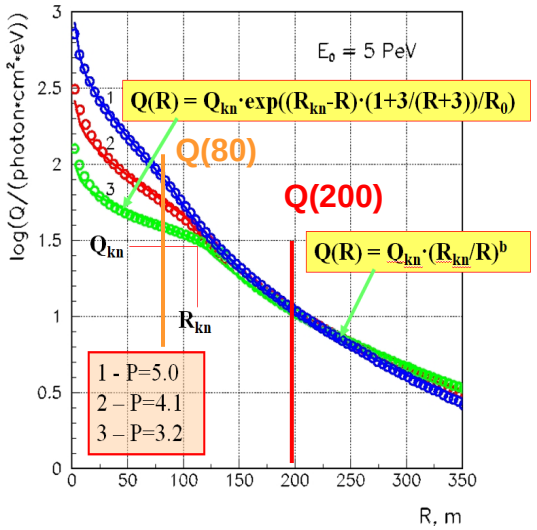
- Direct observation of X_{max} through ionization light, as in the Pierre Auger and Telescope Array experiments.

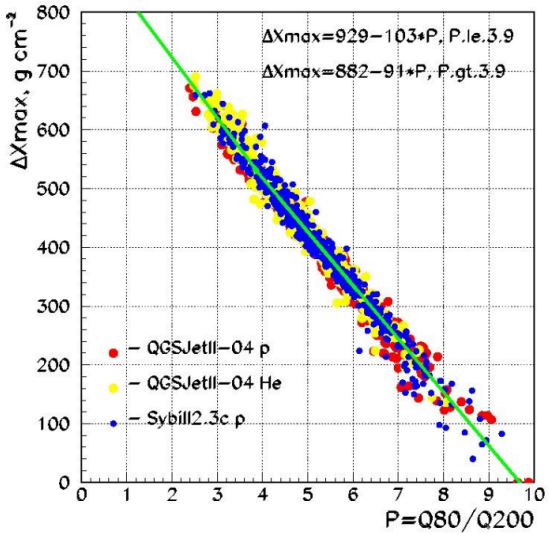
10^{15} – 10^{18} eV:

- Two methods for estimating X_{max}:
  1. Slope of the Light Distribution Function (LDF), **Q(R)**;
  2. Pulse duration, τ_R.



Correlation of the relative position of the X_{max} and the steepness of the LDF



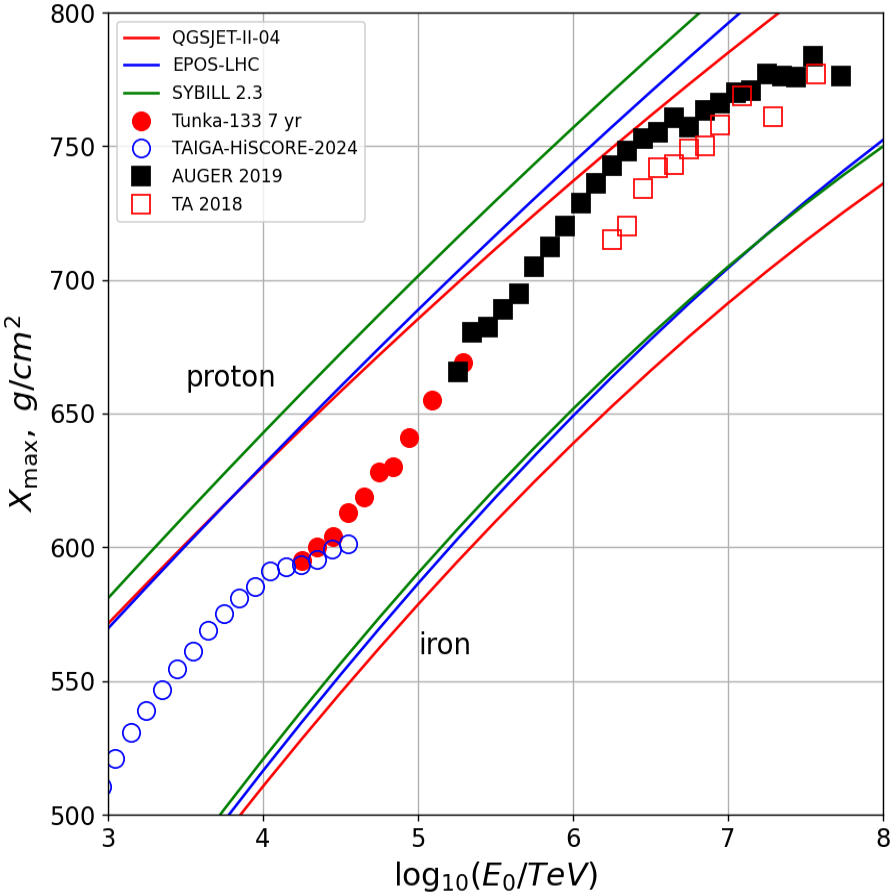


- **Steepness:** $P = Q(80)/Q(200)$
  (parameter introduced in 2021)
- **Relative position of the maximum:**
  $\Delta X_{max} = X_0/\cos\theta - X_{max}$
- (relative to the observation setup)
- Air shower maximum depth determined using the light flux ratio at 80 and 200 m from the axis.

- The experimental distribution of steepness lies within the sensitivity of P to ΔX_{max} under the specified constraints on the zenith angle and energy.
- The conversion from parameter P to ΔX_{max} is independent of:
  - Energy (10^{15} – 10^{18} eV),
  - Zenith angle of the shower (0° - 30°),
  - Model of interaction of the primary particle.

Experimental dependence of X_{max} on the primary particle energy

- **Tunka-133:**
  - 7 years, from 2010 to 2017,
  - Zenith angles $\theta \leq 30°$,
  - Effective area 0.64 km²,
  - Primary particle energies $\geq 10^{16}$ eV – 69,000 events.
- **TAIGA-HiSCORE:**
  - 70 clear, moonless nights,
  - 4 clusters (114 stations),
  - Zenith angles $\theta \leq 30°$,
  - Effective area 1 km²,
  - Primary particle energies $\geq 10^{15}$ eV – 1,980,000 events,
  - Instrumental limitation at energies above $3 \cdot 10^{16}$ eV.

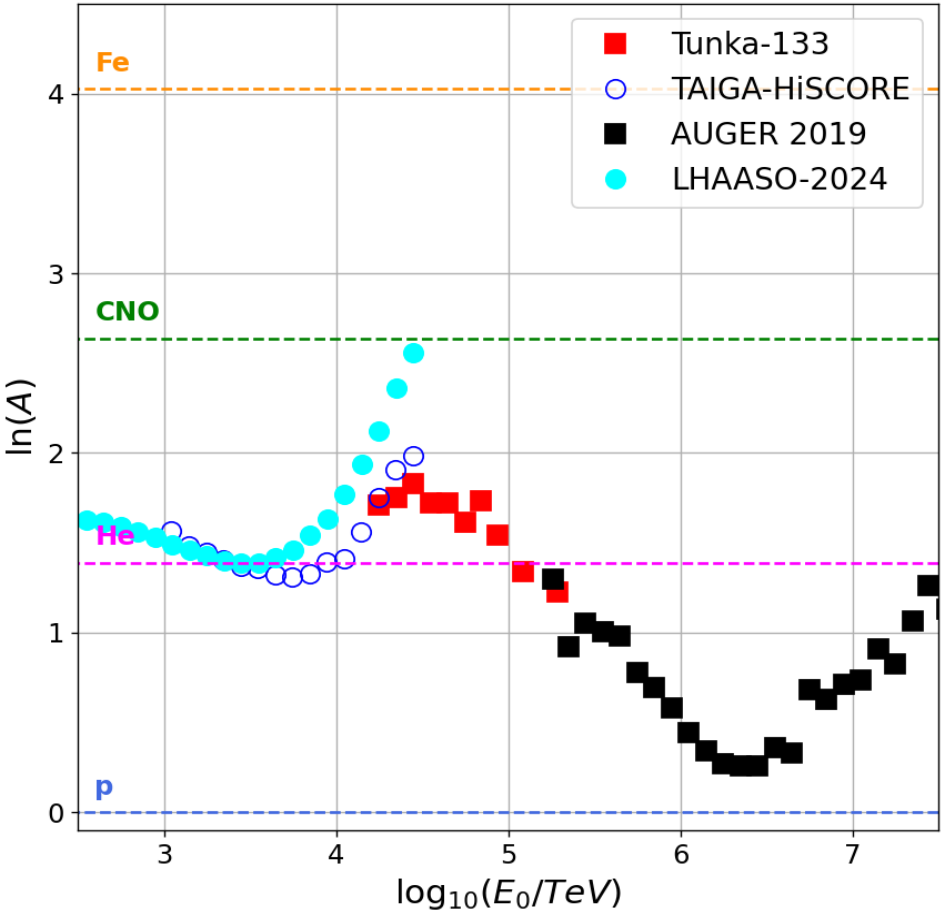


Mean mass composition <lnA> in relation to the primary energy

- There is a dicrect relation <lnA> ~ <X_{max}> (by linear interpolation):

$$\langle lnA \rangle = \ln 56 \frac{(X_{max,p} - X_{max,data})}{(X_{max,p} - X_{max,Fe})}$$

- QGSJet-II-04 was used in the calculation <lnA>.
- Slightly lighter composition (p + He) across the entire energy range.
- The behavior near the "knee" has coincides with the results from the LHAASO experiment, despite the difference in methodology (Cherenkov vs. charged particles).



Conclusions so far and what's next

- The new data from TAIGA-HiSCORE allowed for more accurate information about the average mass composition of cosmic rays in the energy range from 1 to 30 PeV;
- Using a simpler parameter from the LDF has resulted in good agreement between our results, including those from Tunka-133, and direct measurements from the Pierre Auger Observatory (PAO);
- Our data also aligns with LHAASO results.

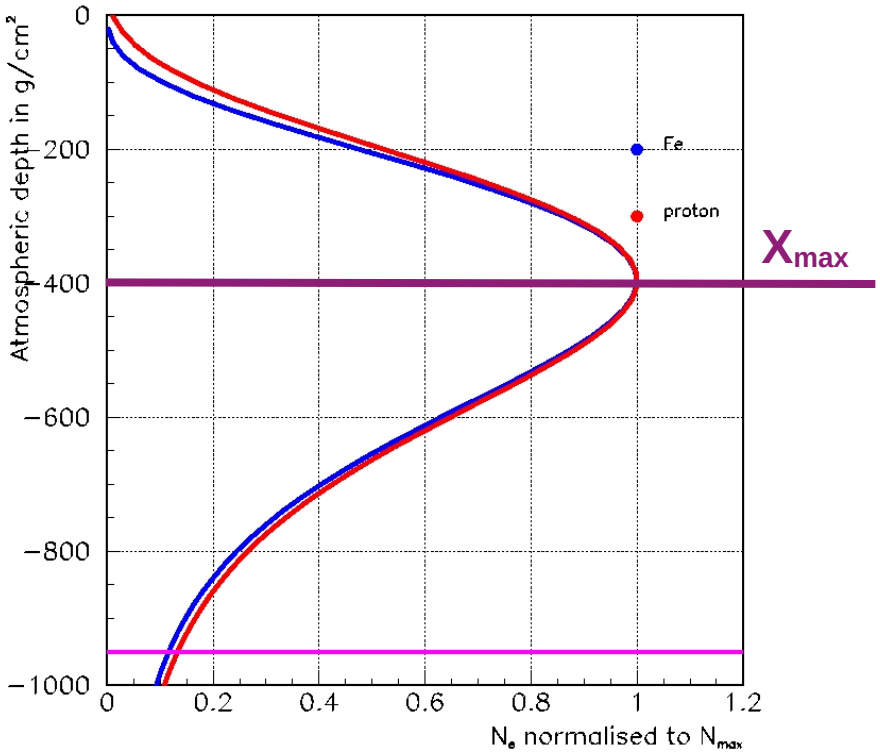
- A detailed examination of the τ-method is in process. The required CORSIKA simulation of air showers, including the Cherenkov process, is currently underway;
- The idea of component-wise separation of mass composition based on the depth of the shower maximum is also under study and implementation.

Backup

Cascade curves similarity

- An important point is the fact that the shapes of the cascade curves, which determine the electron density of the shower with atmospheric depth, are nearly identical for different types of primary particles.
- CORSIKA simulations can prove it.

- Therefore, we can consider the depth of the shower maximum as the main characteristic for assessing the mass composition.



Additional <lnA> with TA and TALE data