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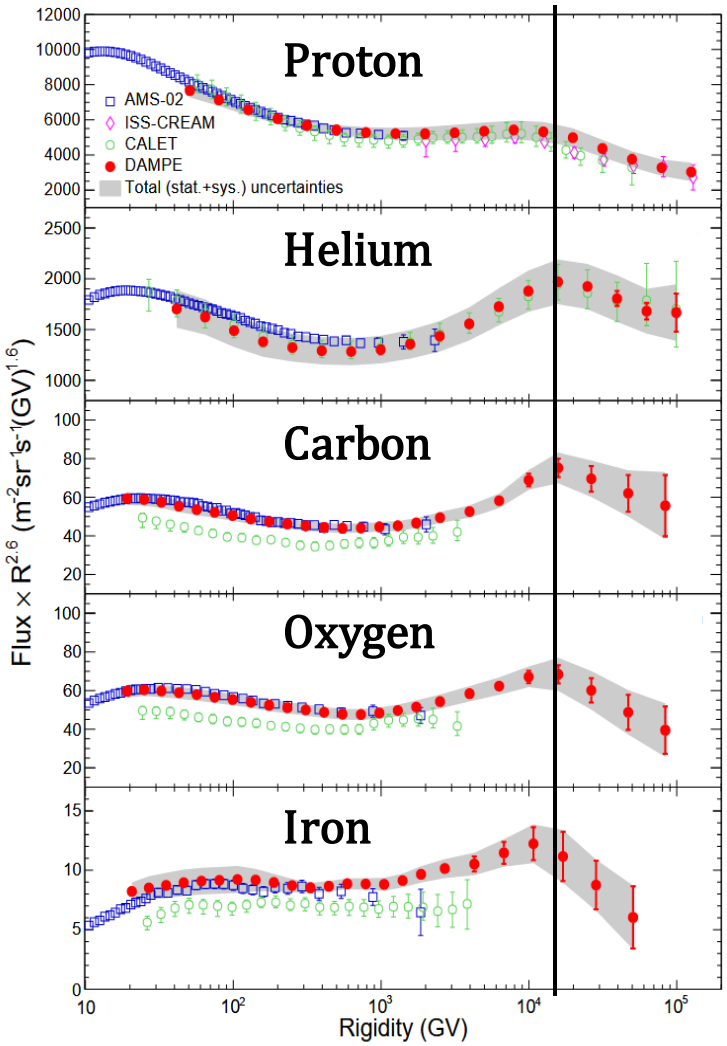
Progress in iron energy spectrum measurement from 100 TeV to PeV

Zhiyong You*, Shoushan Zhang, Suhong Chen, Liqiao Yin, Junxian Yang

Institute of High Energy Physics, Chinese Academy of Sciences

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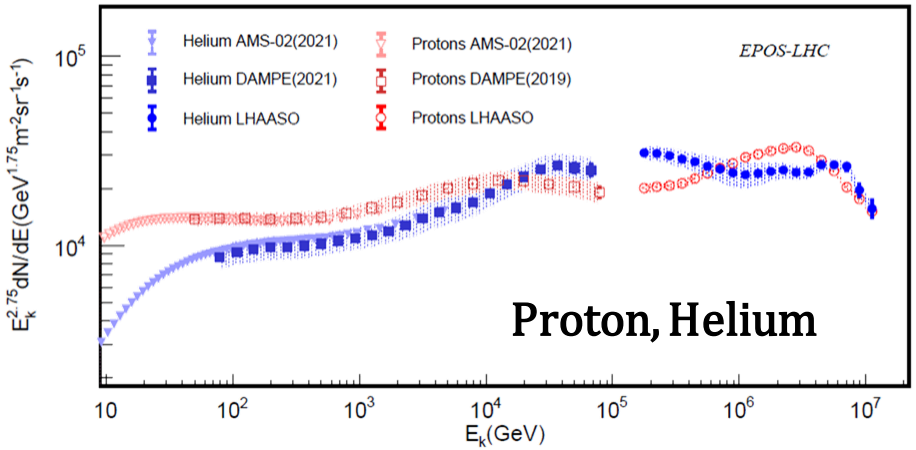
Introduction

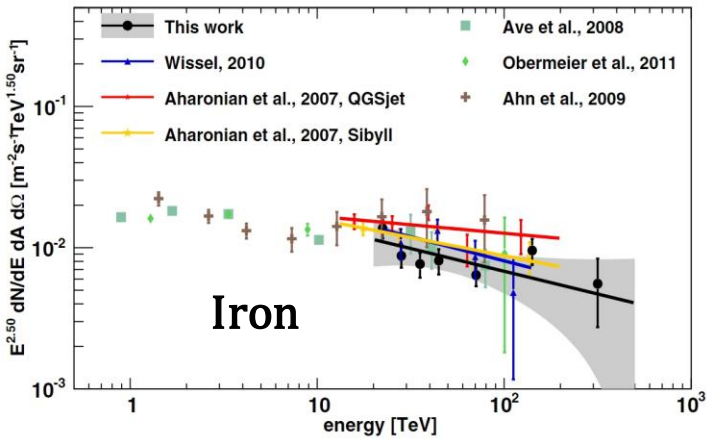


Composition evolution is key to understanding cosmic-ray origin

Background & Motivation

- DAMPE observed a softening structure around 15 TV in several cosmic-ray spectra
- LHAASO has measured the spectra of the two lightest nuclei (Proton, Helium)
- Precise measurements of the iron spectrum above 100 TeV are still lacking





Experimental Setup & Simulation

➢ Key Requirements for the Measurement

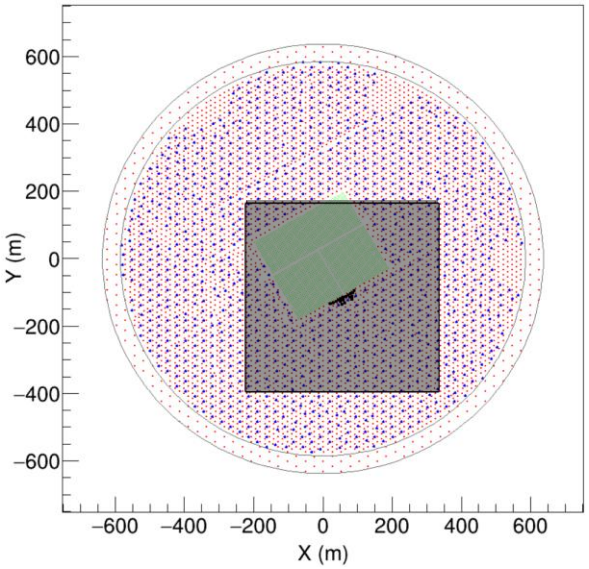
- High-quality event selection
- Reliable energy reconstruction
- Accurate iron-event identification with reliable purity estimation

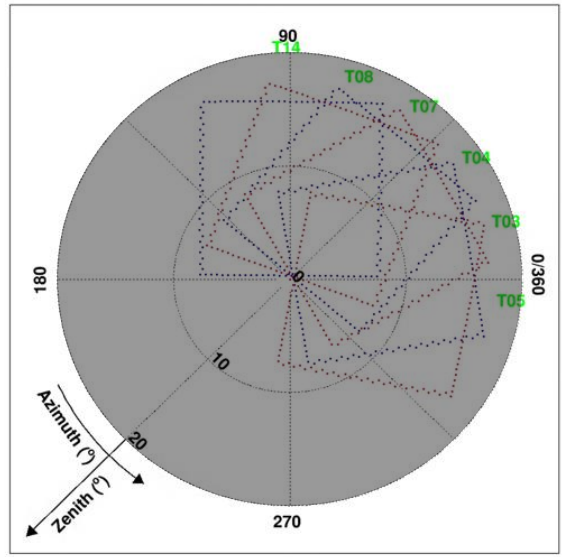
➢ Hybrid observation WFCTA+KM2A

- Near-vertical events are measured for low energy threshold
- WFCTA and KM2A jointly reconstruct energy
- Multi-parameter to select iron events

➢ Simulation

- Hadronic models: EPOS-LHC, QGSJET-II-04, and SIBYLL 2.3d
- Particle types: Proton, He, CNO, MgAlSi, Iron from 10 TeV to 10 PeV
- Zenith angle 0°–20°, full azimuth
- Core location： ±280 m

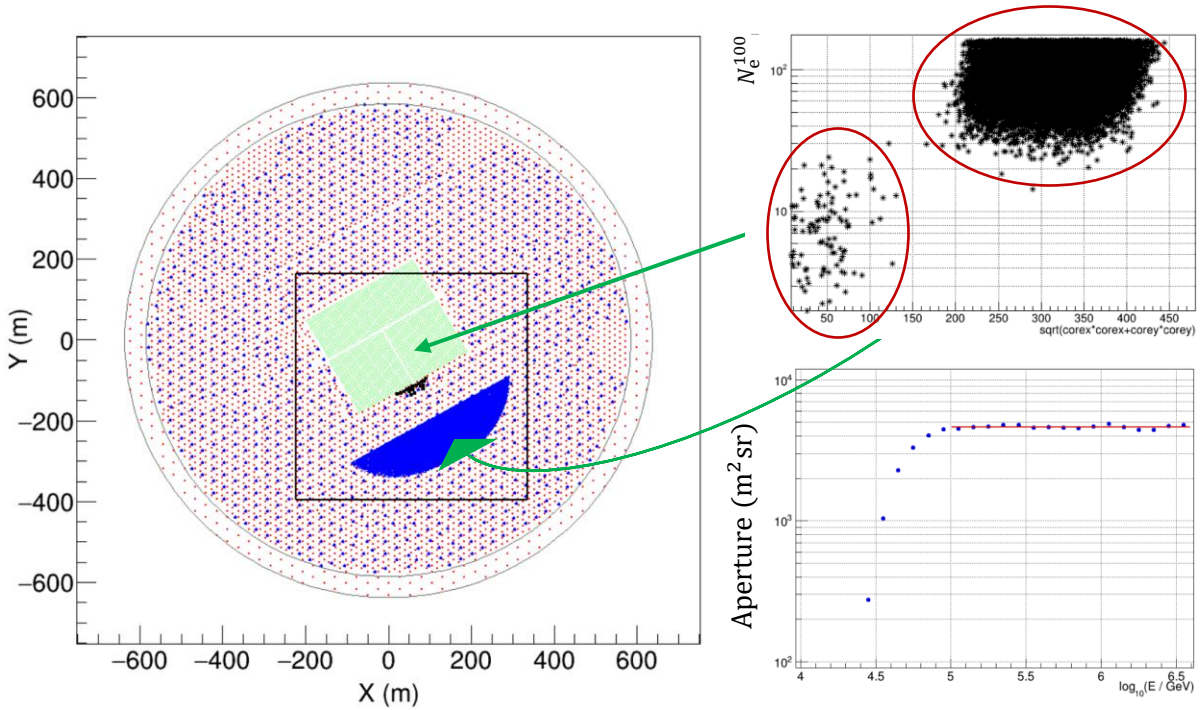




Selection & Energy Reconstruction

➢ Event selection

- Impact parameter: 90 m $< R_{\mathrm{p}} <$ 200 m (full trigger at 100 TeV)
- N_{e}^{100} (measured by EDs) > 20 (reject external events)
- Effective aperture: ~4600 $\mathrm{m^2 sr}$
- Angular resolution $< 0.5°$; core resolution < 14 m



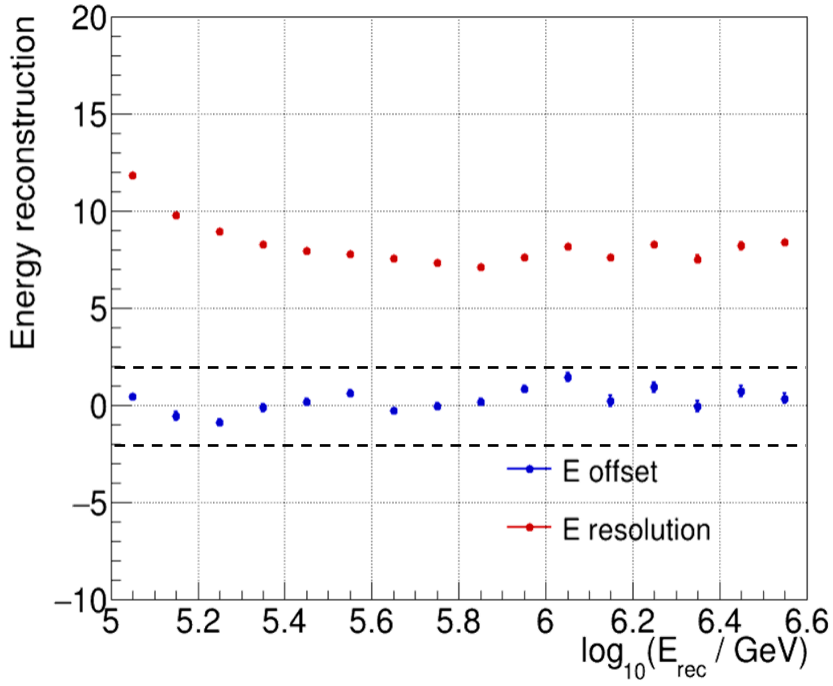
➢ Energy reconstruction

- Hybrid energy estimator:

$$N_{c\mu} = N_{\mathrm{ph}}^{160} + N_{\mu}$$

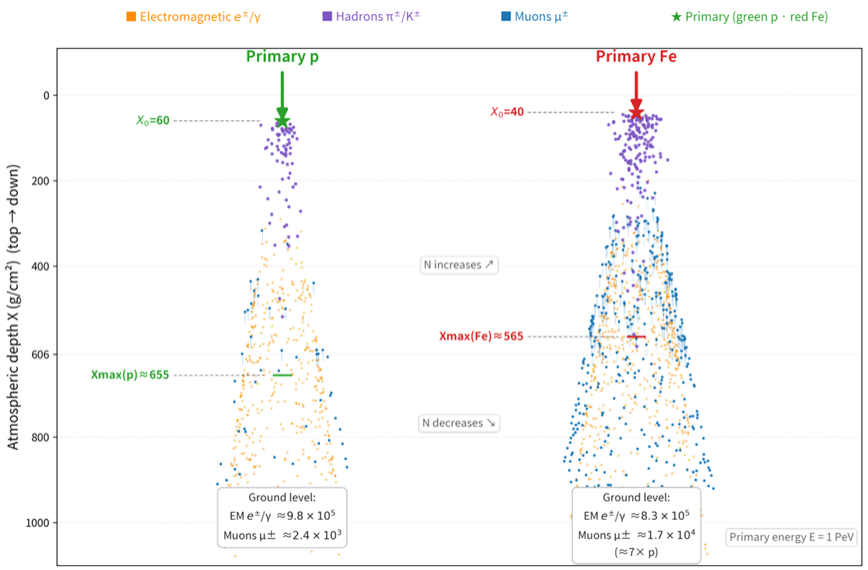
$$\log_{10}(E/\mathrm{PeV}) = p_0 + p_1 \log_{10} N_{c\mu} + p_2 \log_{10}^2 N_{c\mu}$$

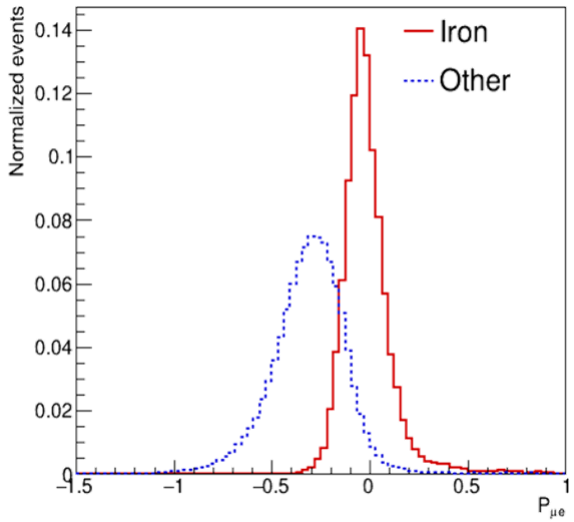
- Weakly dependent on hadronic interaction models
- For iron: bias $< 2\%$
- Energy resolution $< 15\%$, reaching 8% at 1 PeV

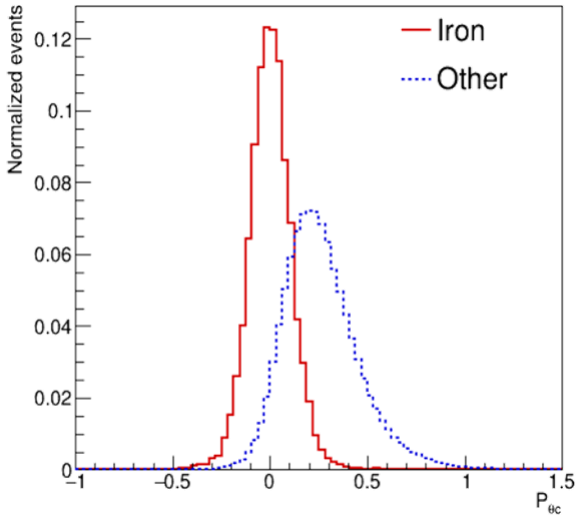


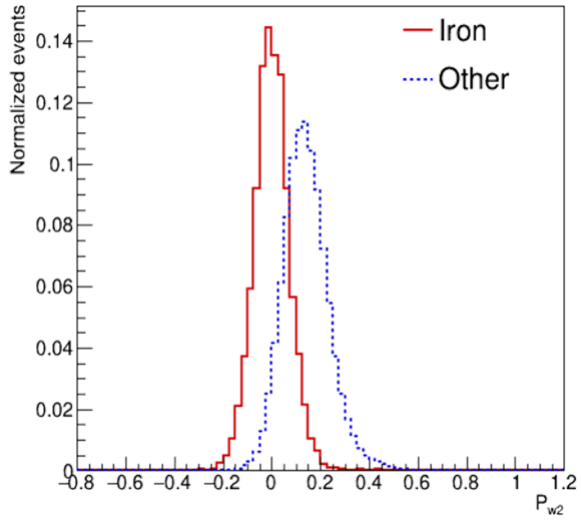
Composition discrimination

- $P_{\mu e} = \log_{10} \frac{N_\mu}{N_e^{0.7}}$ (muons in showers)
  - N_μ: number of muons from MDs
  - N_e: number of EM-particles from EDs
- $P_{\theta c} = \frac{\theta_c^{160} - \langle \theta_c^{160} \rangle}{\langle \theta_c^{160} \rangle|_{\log_{10} E = 5.5}}$ (shower-maximum related parameter)
  - Geometry dependence: $\theta_c^{160} = \theta_c + p_1 \cdot (160 - R_p) + p_2 \cdot (160^2 - R_p^2)$
  - Energy dependence : $\langle \theta_c^{160} \rangle = q_0 + q_1 \cdot \log_{10} E + q_2 \cdot \log_{10}^2 E$
- P_{w2}
  - Transverse uniformity of secondary particles measured by EDs







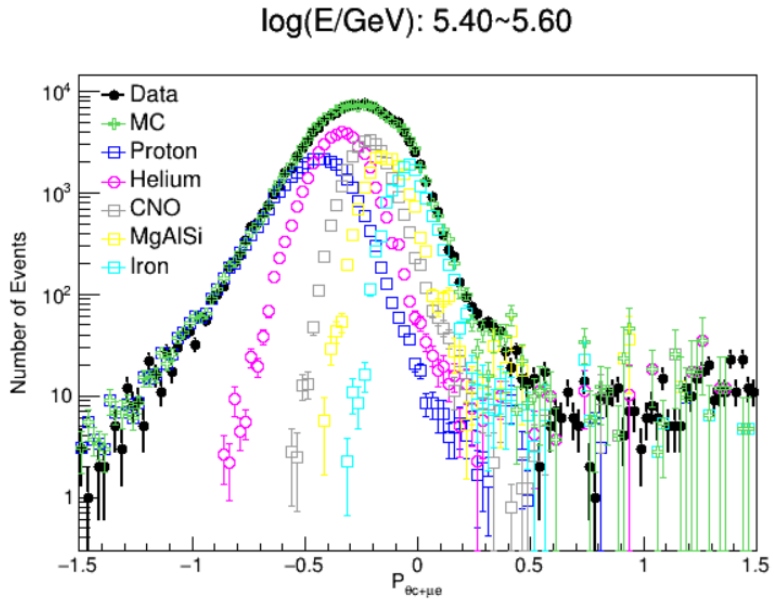


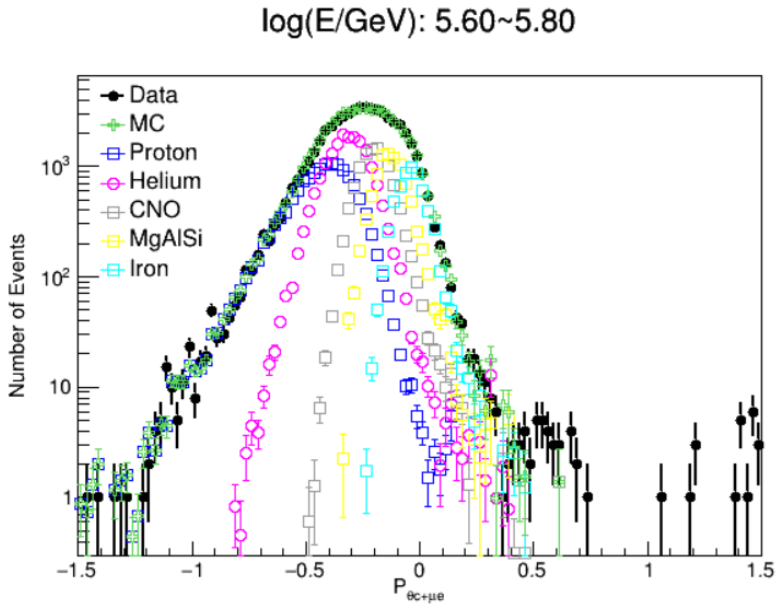
Data-driven Heavy Fractions

Using the recently measured LHAASO proton and helium spectra, we perform a template fit to the experimental distribution of the composition-sensitive parameter:

$$N_i^{\mathrm{fit}} = AT\Delta P_i \left[\overbrace{\Phi_{\mathrm{p}} f_{\mathrm{p}}^i + \Phi_{\mathrm{He}} f_{\mathrm{He}}^i}^{\text{From LHAASO}} + \sum_j \Phi_j f_j^i \right], (j = \mathrm{CNO, MgAlSi, Iron}).$$

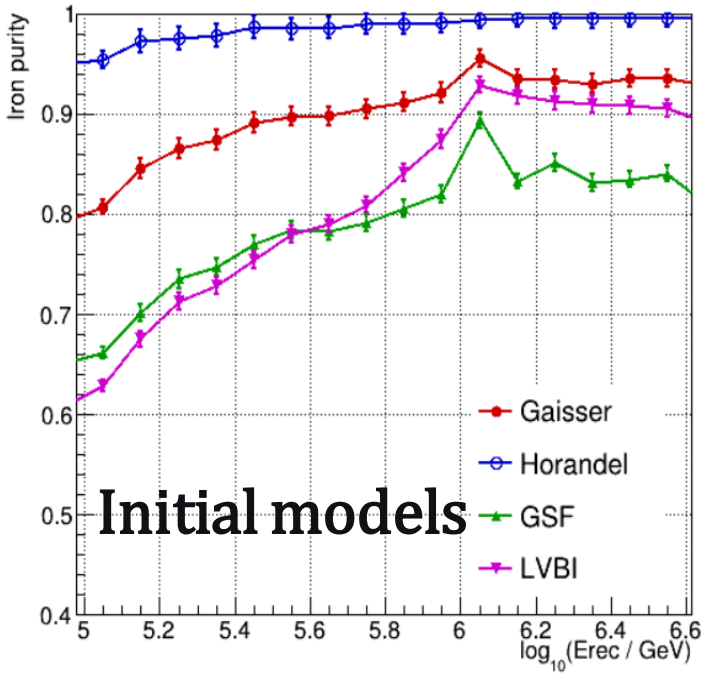
- The shapes f^i of all five components are from simulations
- Fluxes of p and He are from the LHAASO measurements
- The fitting yields the relative fractions of CNO, MgAlSi, and Iron in the experimental data

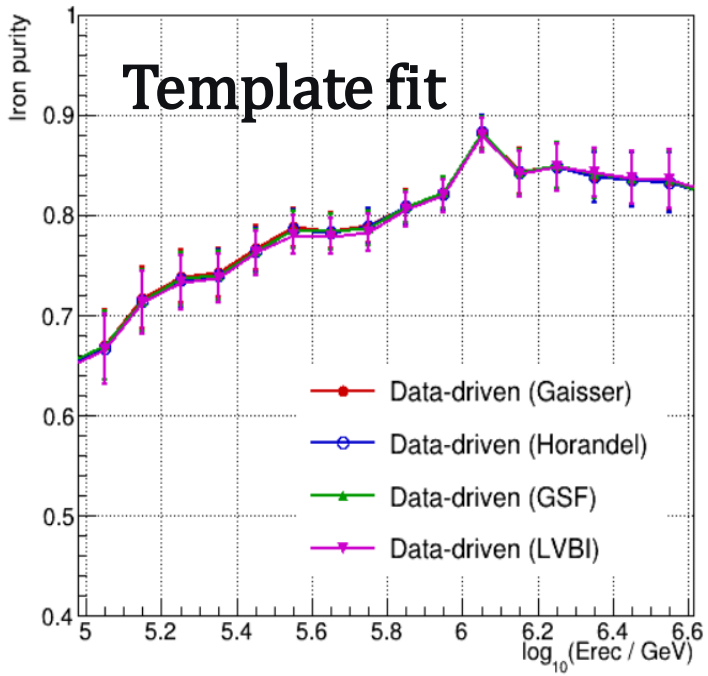




Results: Iron Purity

- Using the fitted heavy-component fractions, we estimate the iron purity
- The iron purities derived from different initial composition models (Gaisser, Horandel, GSF, LVBI) converge to a consistent curve
- Significantly suppressing the previous model-induced discrepancy.





Future Plans

- **Variable dependence**: Investigate the differences in iron purity using different composition-sensitive parameters (e.g., $P_{\mu e}$, $P_{\theta c}$, P_{w2}) for template fitting

- **Hadronic model dependence**: Evaluate the iron purity by performing template fits under different high-energy hadronic interaction models (EPOS-LHC, QGSJET-II-04, SIBYLL 2.3d)

- **Iron spectrum**: Apply this data-driven purity to derive the iron energy spectrum (100 TeV–several PeV) and connect it with higher-energy measurements