MUON DEFICIT IN SIMULATIONS OF AIR SHOWERS INFERRED FROM AGASA DATA

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Abstract: Multiple experiments reported evidence of a muon deficit in air shower simulations with respect to data [1, 2]. We study this deficit using measurements of the muon density ρ_μ at 1000 m from the shower axis obtained by the Akeno Giant Air Shower Array (AGASA). We compare them against simulations of the hadronic interaction models EPOS-LHC, QGSJetII-04, and Sibyll2.3c.

Analysis

Data

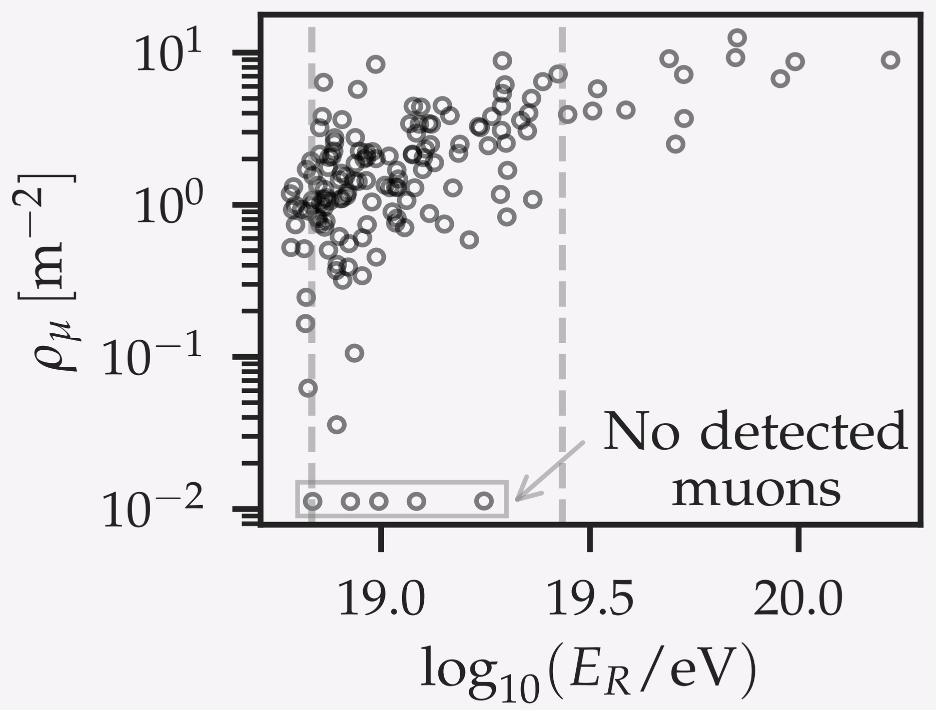

Fig. 1: Data set extracted from Ref. [3]. The reconstructed energy E_R is in the reference scale [4], a factor 0.68 smaller than the original [5]. $\theta \leq 36°$.

Simulations

A		Model
p He N Fe	+	EPOS-LHC QGSJetII-04 Sibyll2.3c

Library described in Ref. [5]. Sim. muon densities $\langle\tilde{\rho}_{\mu,\mathrm{A}}\rangle$ are fitted with a power law.

Mixed composition

The mix. muon densities are

$$\langle\tilde{\rho}_{\mu,\mathrm{mix}}\rangle(E) = \sum_{\mathrm{A}} f_{\mathrm{A}}(E) \cdot \langle\tilde{\rho}_{\mu,\mathrm{A}}\rangle(E),$$

where $f_{\mathrm{A}}(E)$ are the mass fractions from the Pierre Auger fits to $X_{\max}$ [6].

Analytical computation of reconstruction and binning effects

We compute the convolution with the energy resolution kernel and the average on the i-th reconstructed energy bin E_{Ri}:

$$\left\langle\frac{\rho_\mu}{E_R}\right\rangle(E_{Ri}) = \frac{\int_{E_{Ri}^-}^{E_{Ri}^+} dE_R \int_0^\infty dE\, \underbrace{\langle\tilde{\rho}_\mu\rangle(E)}_{\text{sim/mix muon density}} \cdot \underbrace{E_R^{-1}}_{\text{MC energy}} \cdot \underbrace{J(E)}_{\text{CR flux}} \cdot \underbrace{G(E_R|E)}_{\text{energy resolution kernel}}}{\int_{E_{Ri}^-}^{E_{Ri}^+} dE_R \int_0^\infty dE\, J(E) \cdot G(E_R|E)}.$$

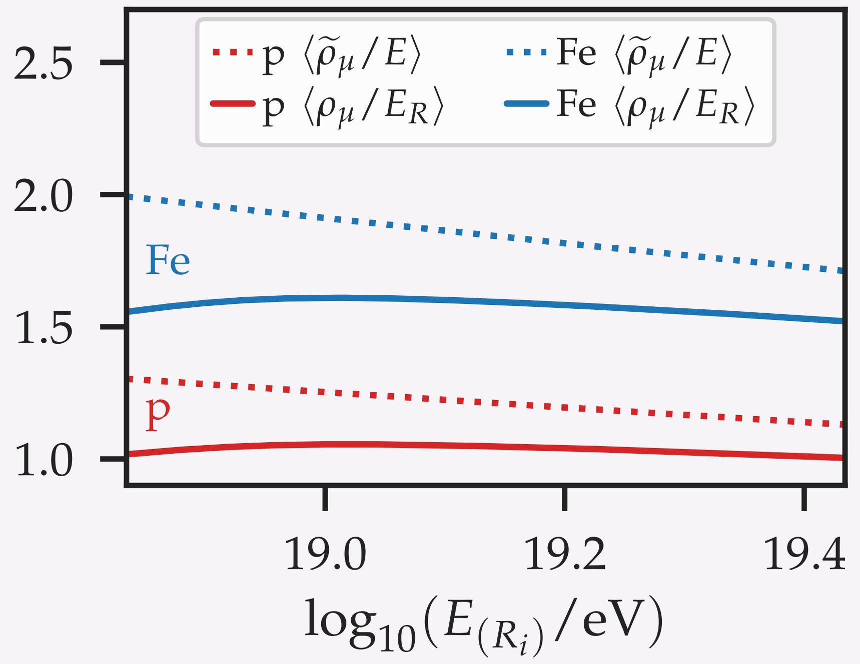

Fig. 2: The energy reconstruction and binning effects in EPOS-LHC simulations. $\langle\rho_\mu/E_R\rangle$ and $\langle\tilde{\rho}_\mu/E\rangle$ are in m^{-2}/10^{19} eV.

The resulting $\langle\rho_\mu/E_R\rangle(E_{Ri})$ is 11 % to 22 % smaller.

Results

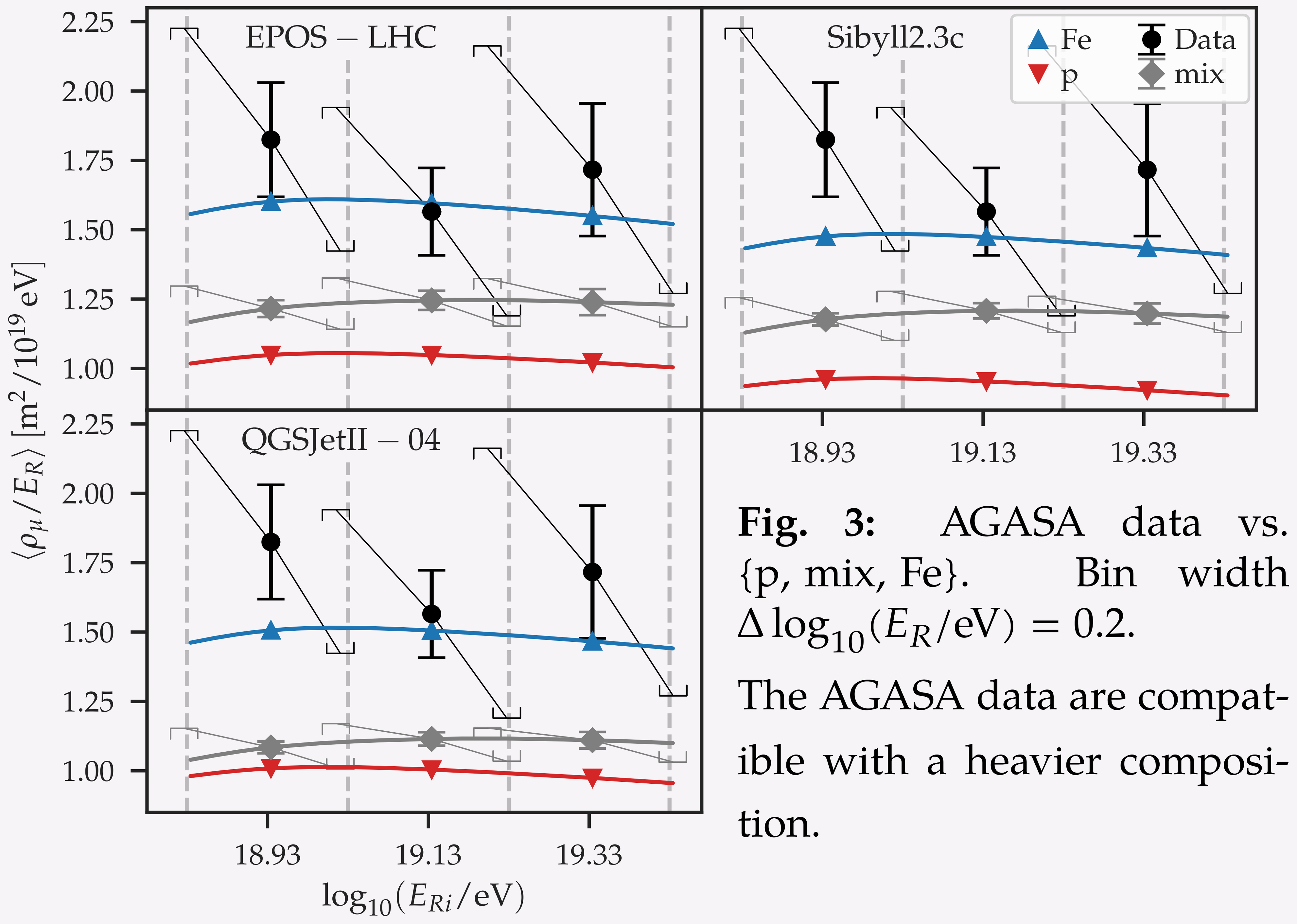

Fig. 3: AGASA data vs. {p, mix, Fe}. Bin width $\Delta\log_{10}(E_R/\mathrm{eV}) = 0.2$.

The AGASA data are compatible with a heavier composition.

Model		$F \pm (\mathrm{stat}) \pm (\mathrm{syst})$
Sibyll2.3c	Fe	$1.24 \pm 0.09^{0.40}_{0.24}$
	Mixed	$1.54 \pm 0.12^{0.50}_{0.31}$
	p	$1.91 \pm 0.14^{0.61}_{0.37}$
EPOS - LHC	Fe	$1.14 \pm 0.08^{0.37}_{0.22}$
	Mixed	$1.49 \pm 0.12^{0.49}_{0.30}$
	p	$1.74 \pm 0.13^{0.56}_{0.33}$
QGSJetII - 04	Fe	$1.21 \pm 0.09^{0.39}_{0.23}$
	Mixed	$1.66 \pm 0.13^{0.54}_{0.34}$
	p	$1.82 \pm 0.13^{0.58}_{0.35}$

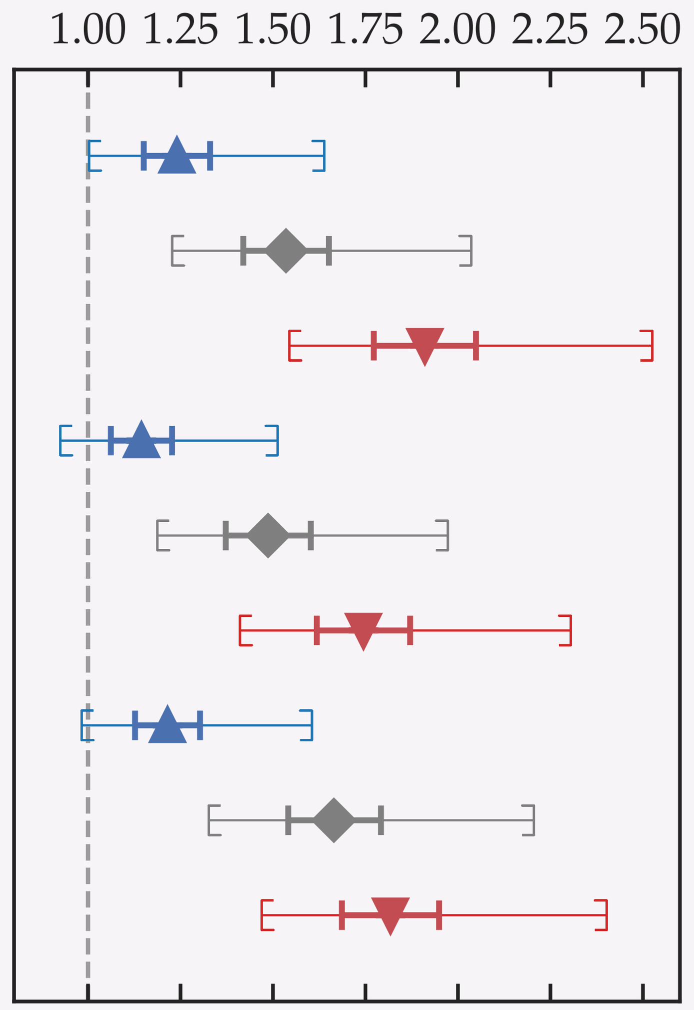

Fig. 4: Correction factors $F_{\{\mathrm{p,\,mix,\,Fe}\}} = \frac{\langle\rho_{\mu,\mathrm{data}}/E_R\rangle}{\langle\rho_{\mu,\{\mathrm{p,\,mix,\,Fe}\}}/E_R\rangle}$ for the three models, where $18.83 \leq \log_{10}(E_R/\mathrm{eV}) \leq 19.46$.

For the three models, F_{mix} does not overlap with 1.

Conclusions

The AGASA data are compatible with a heavier composition, lying above the predictions of the mixed composition scenarios. We interpret this as **further evidence of a muon deficit in air shower simulations at the highest energies**.

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References

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