Learning the composition of Ultra High Energy Cosmic Rays

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Ongoing work with B. Bortolato, V. Homsak, J.F. Kamenik and A. Matevc

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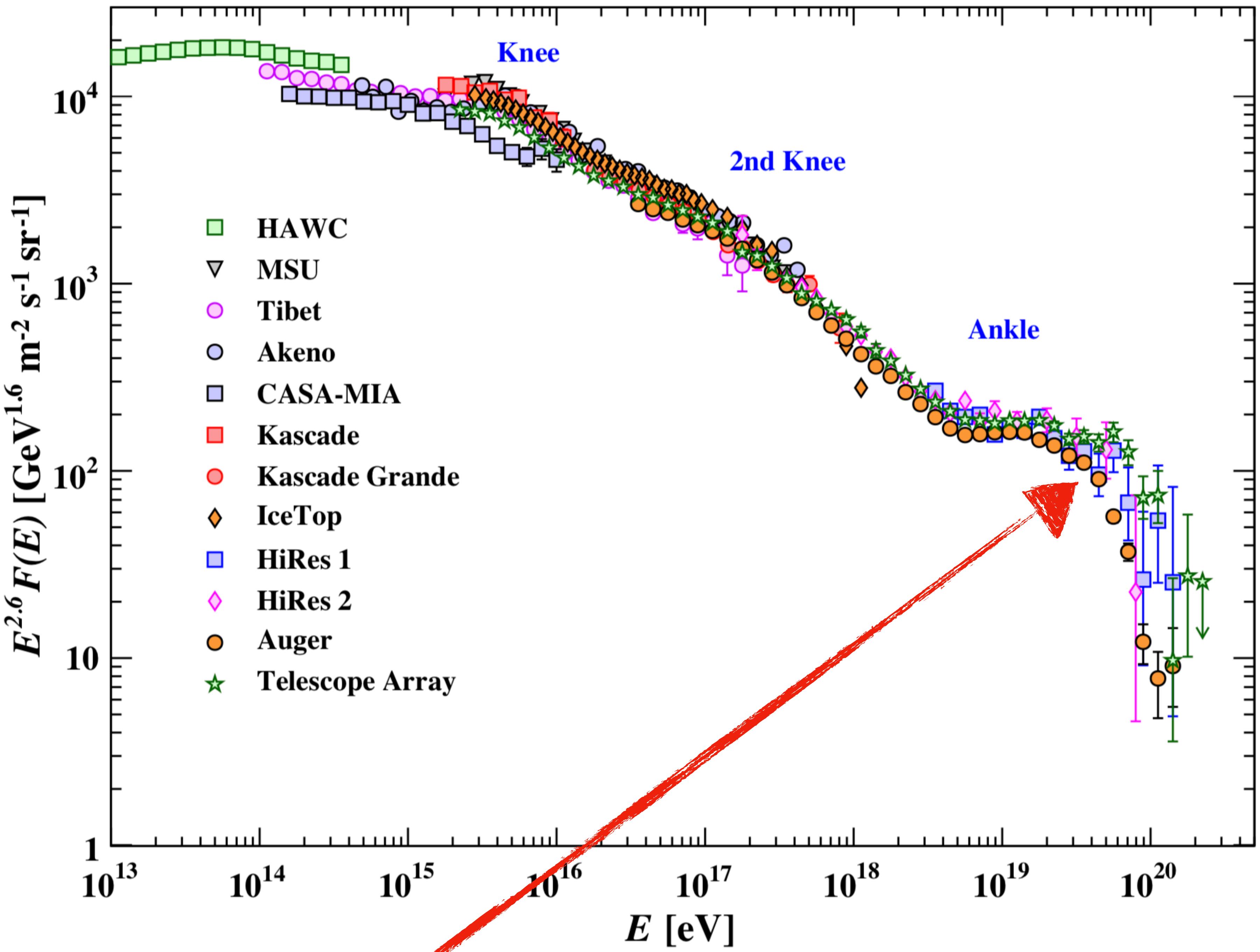
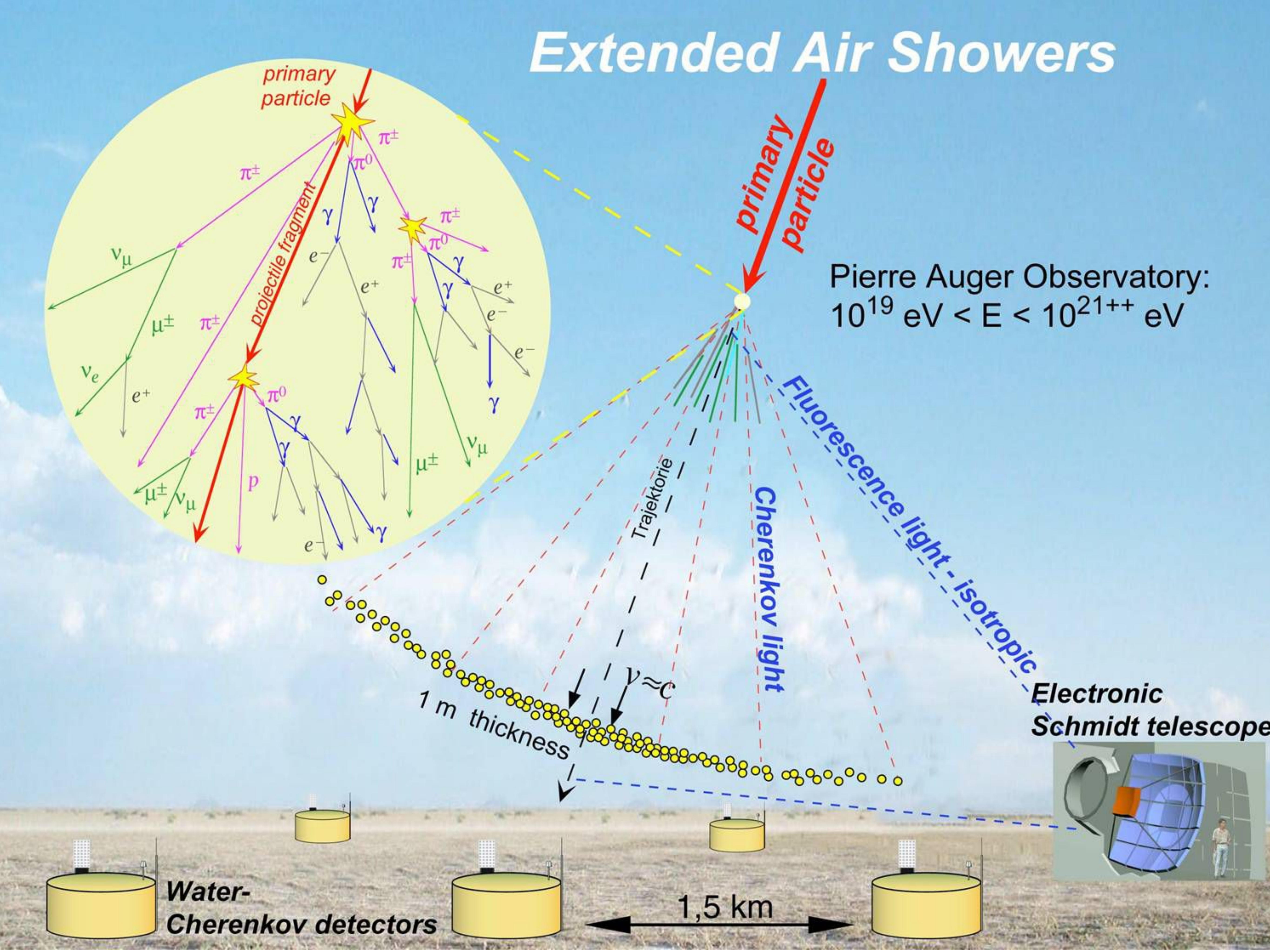
Cosmic Ray Energy Spectrum



$$10^{-2}\ \mathrm{km}^{-2}\ \mathrm{yr}^{-1}$$

Open questions

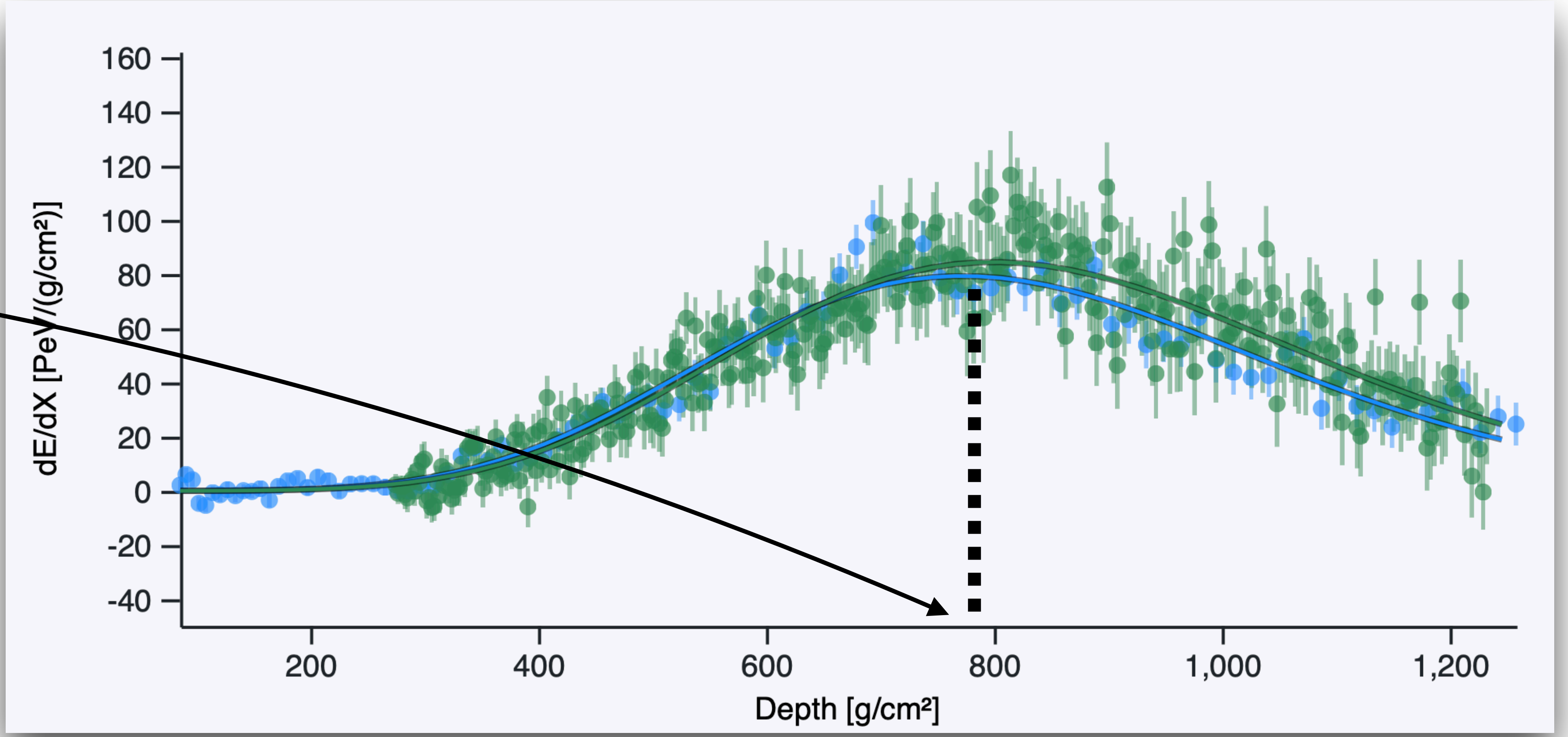
- Original source
- Acceleration
- Mass composition



Extended Air Showers
primary particle
primary particle
Pierre Auger Observatory:
10^{19} eV < E < 10^{21++} eV
projectile fragment
π±
π0
γ
e−
e+
νμ
νe
μ±
p
Trajektorie
Cherenkov light
Fluorescence light - isotropic
$v \approx c$
1 m thickness
Electronic Schmidt telescope
Water-Cherenkov detectors
1,5 km

X_{max}

Can indicates the primary



Elongation rate

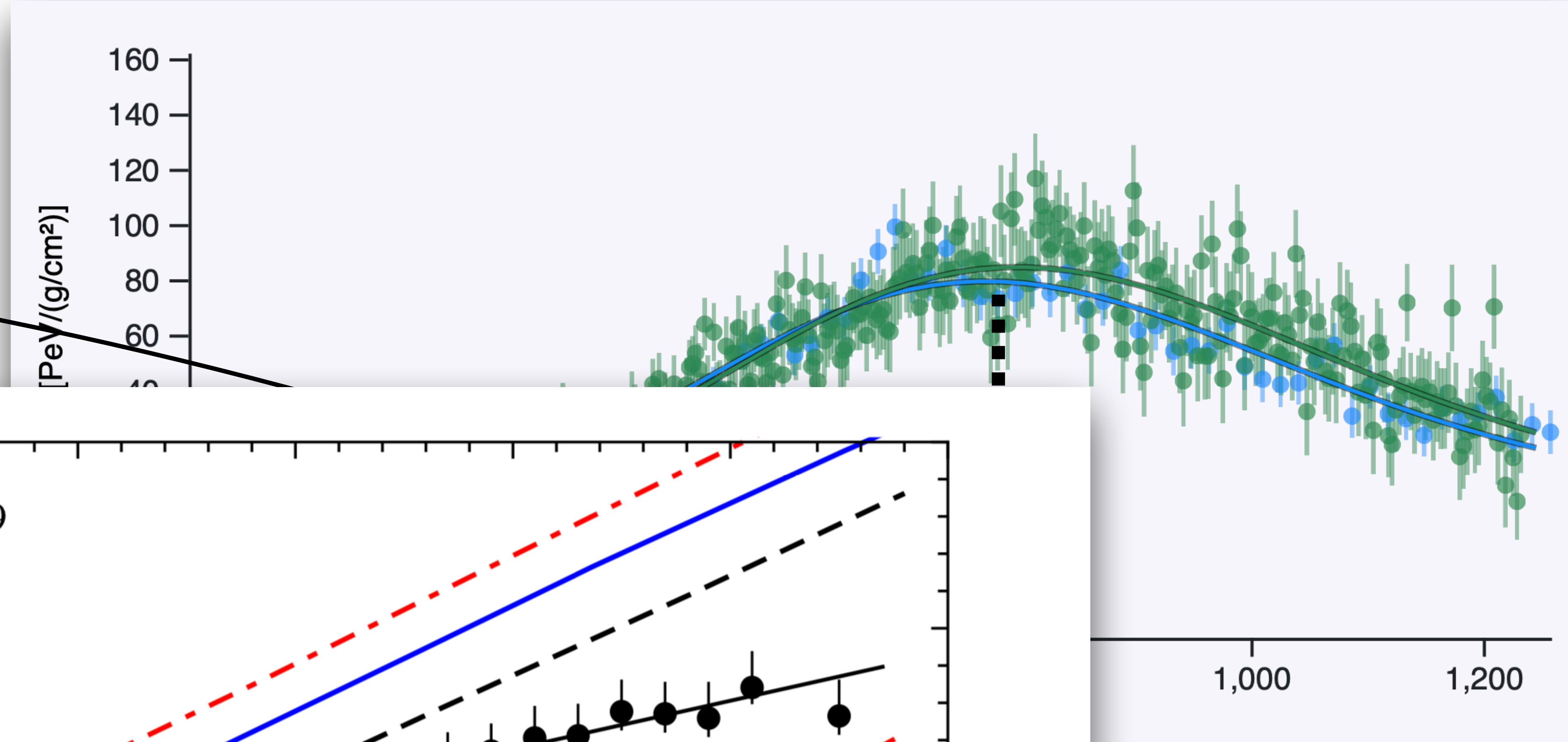
$$D \equiv \frac{\mathrm{d}\langle X_{max}\rangle}{\mathrm{d}\,\ln E}$$

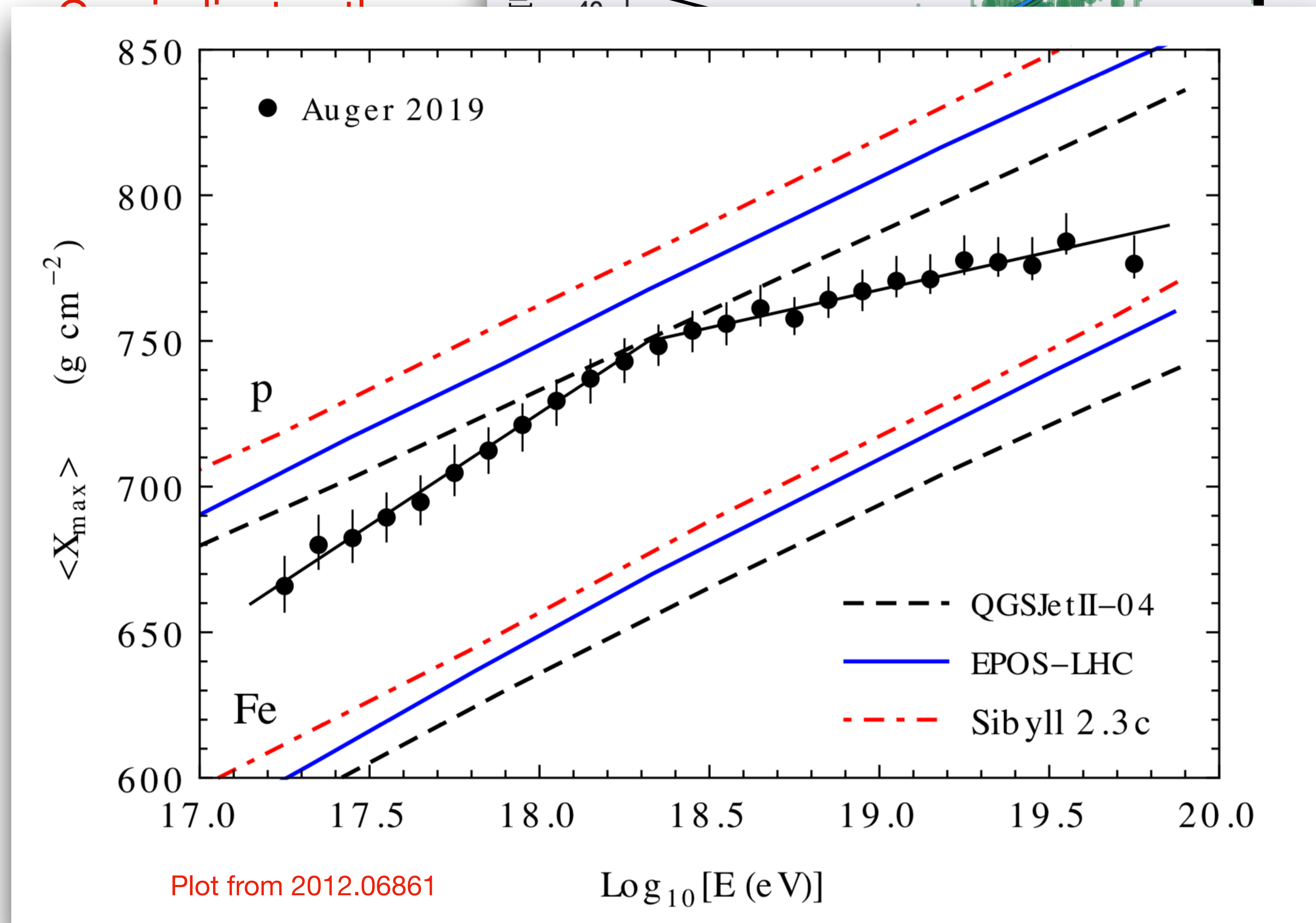
Superposition model

$$\langle X^A_{max}(E)\rangle \simeq \langle X^p_{max}(E/A)\rangle$$

$$\langle X^A_{max}\rangle = X^p_1 + D(\ln E - \ln A)$$

X_{max}





Plot from 2012.06861

model

$_{ax}(E/A)\rangle$

Simulating UHECR

CORSIKA
www.iap.kit.edu/corsika/

3 energy bins

4 hadronic models

26 primaries (from p to Fe)

2k showers/element/model/bin simulated

Then get complaints from both IJS and CERN clusters

Auger Open Data
opendata.auger.org

~10% of total data

~23k Non-Hybrid data

~3k Hybrid data

of which ~1.6k "golden"-hybrid

$$x = (f_p, f_{He}, \ldots, f_{Fe})$$

Composition

From a fixed x

$$\mathcal{D}\Big(\{X_m\}^{sim}\Big) \longrightarrow \{\vec{z}_{sim}\} = \Big(\{\langle X_m \rangle\}, \{\sigma\}, \{\gamma_1\}\Big)_{sim}$$

Dim reduction

z_i Normally distributed

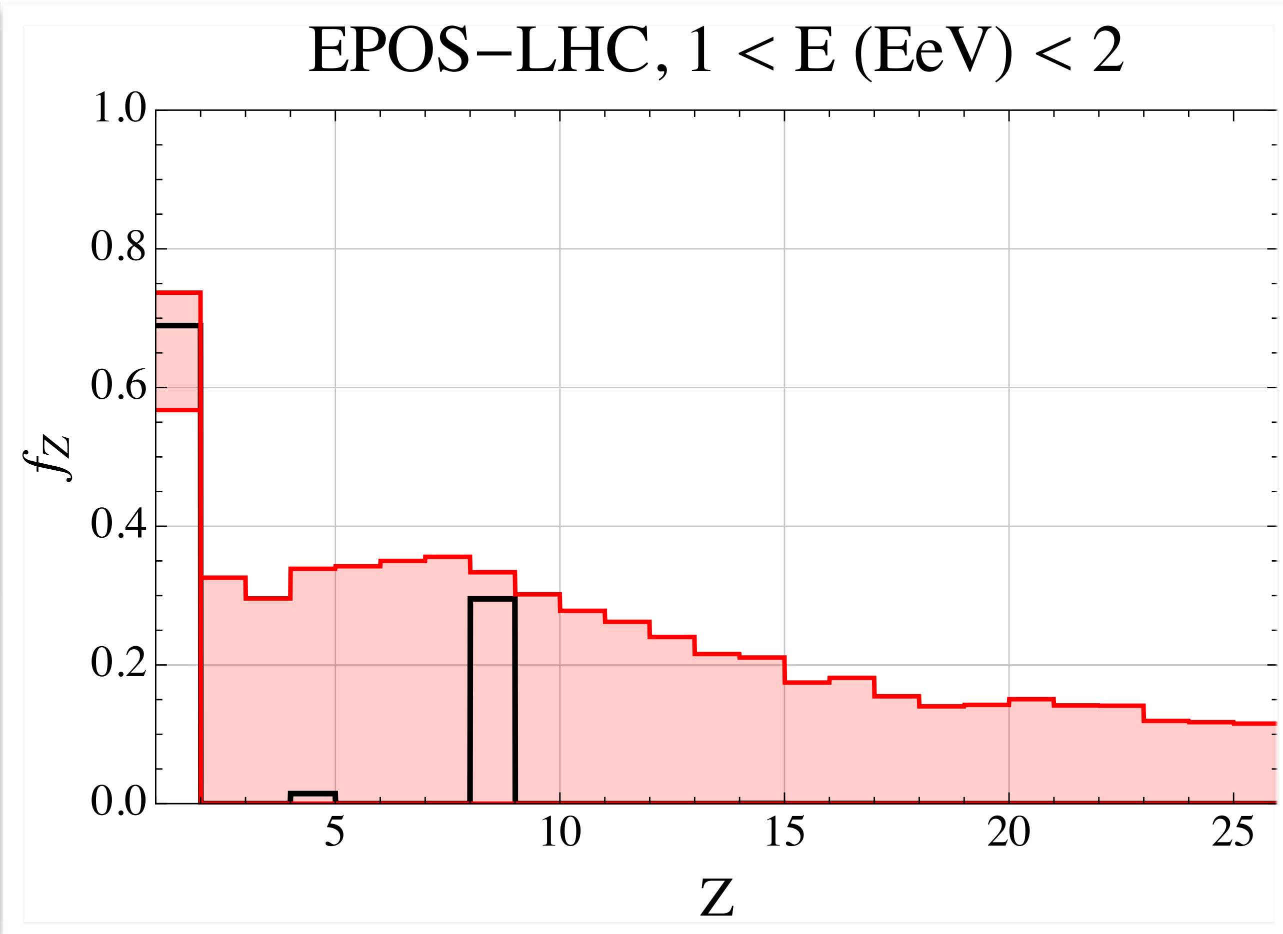
$$\mathcal{D}\Big(\{X_m\}^{Aug}\Big) \longrightarrow \{\vec{z}_{Aug}\}$$

Family of dists from bootstrapping

$$\ln(L) = \int \mathrm{d}^n z \ln\left[\mathcal{N}(z|\mu_{sim}(x), \Sigma_{sim}(x))\right] \mathcal{N}(z|\mu_{Aug}, \Sigma_{Aug})$$

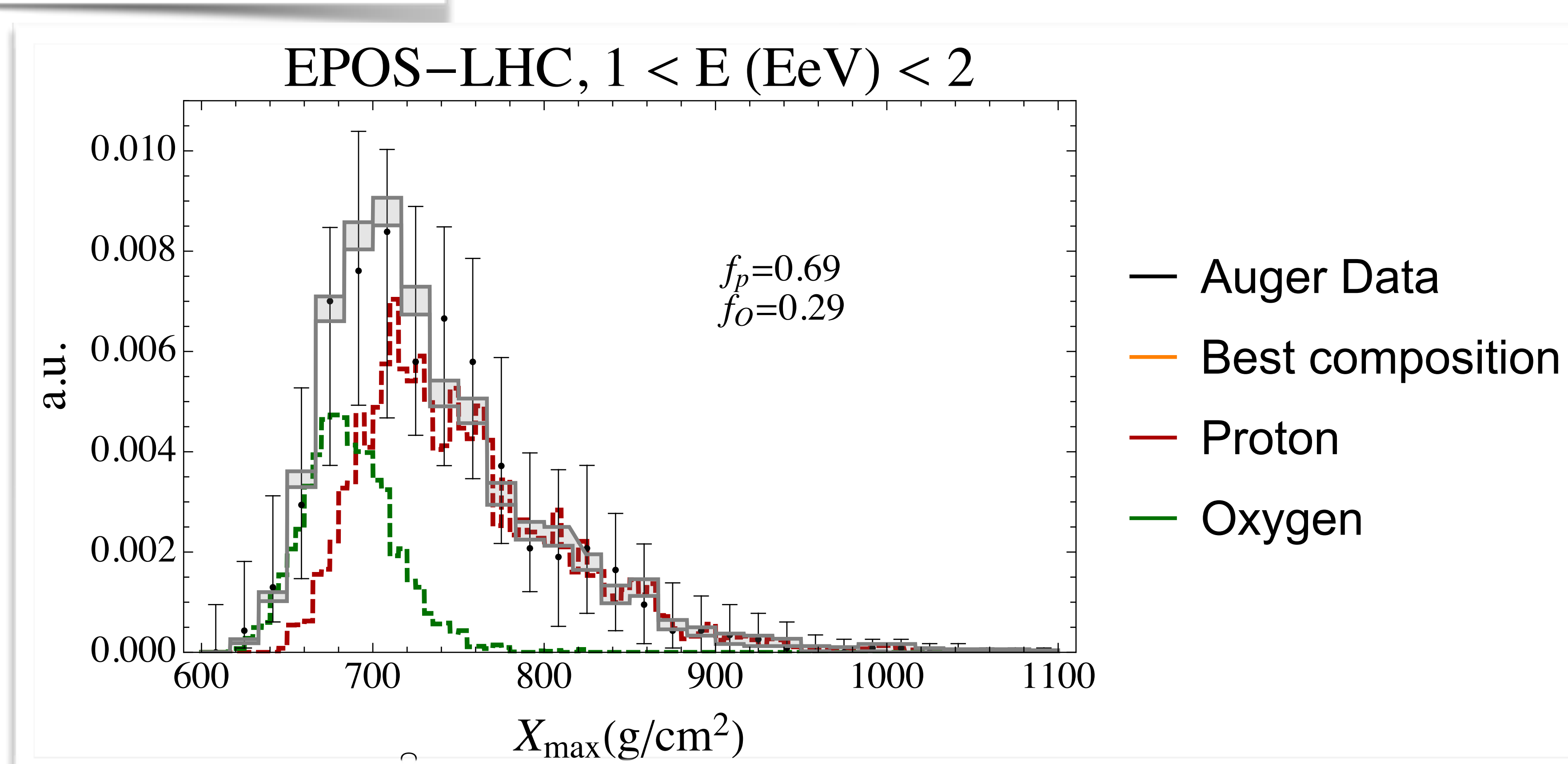
Similar to relative entropy

Preliminary results

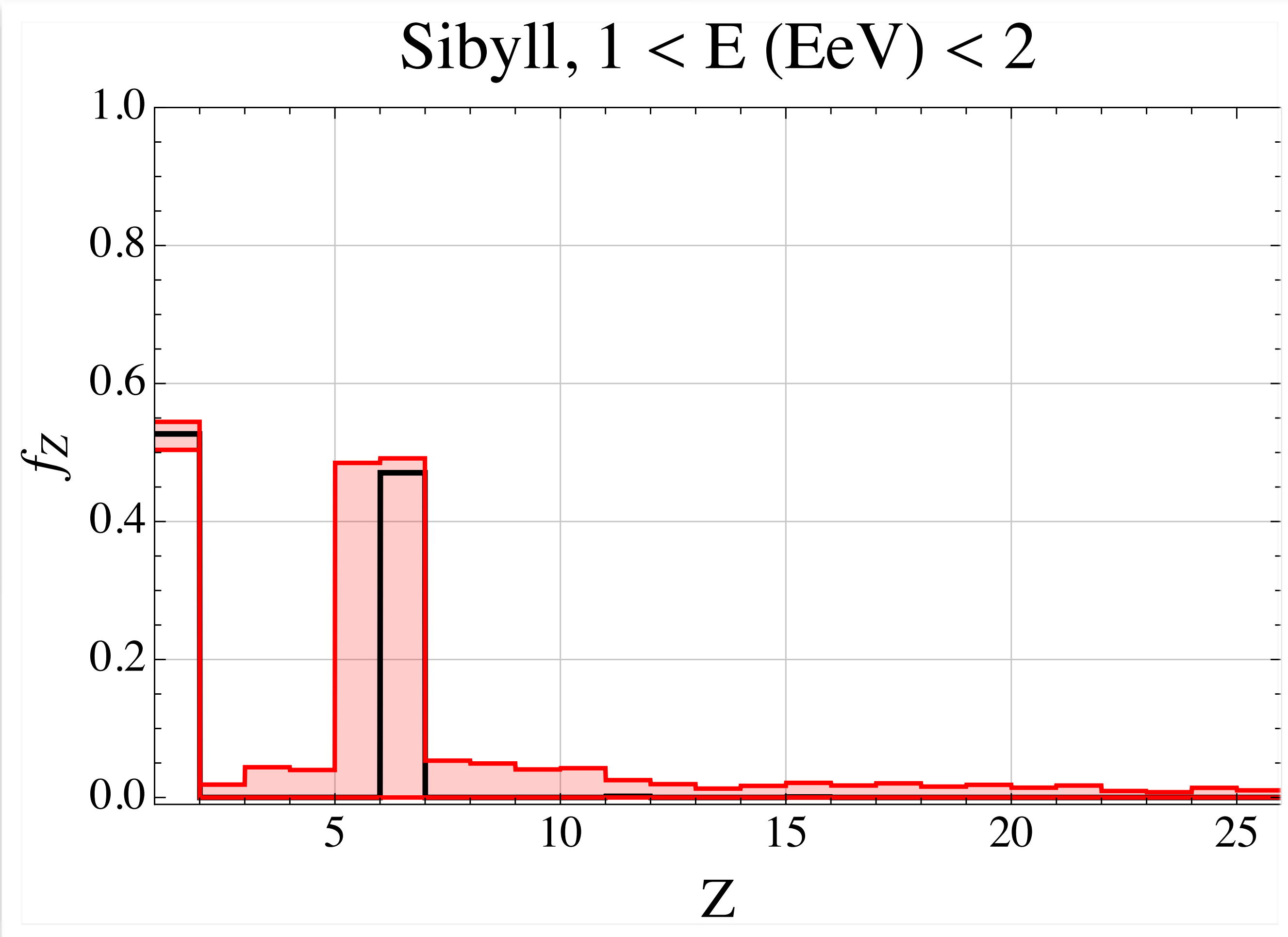


Best composition
with 2sigma CL

Most probable fractions



Preliminary results



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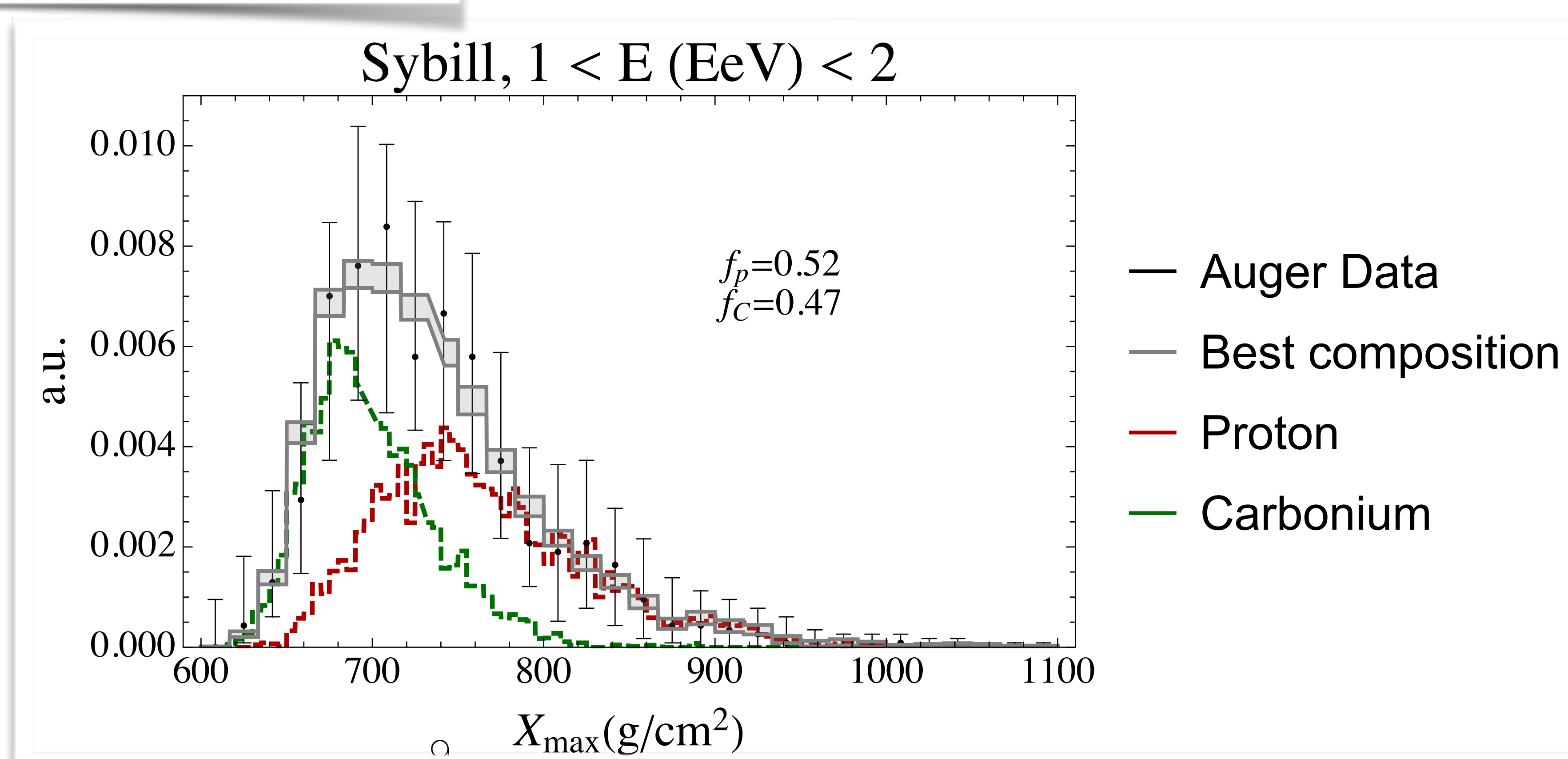

Summary

- Relatively simple (though optimisable) inference of CR composition

- 100% proton composition is excluded

- Working on reducing CL