Data analysis and interpretation of UHECR measurements by the Pierre Auger Observatory

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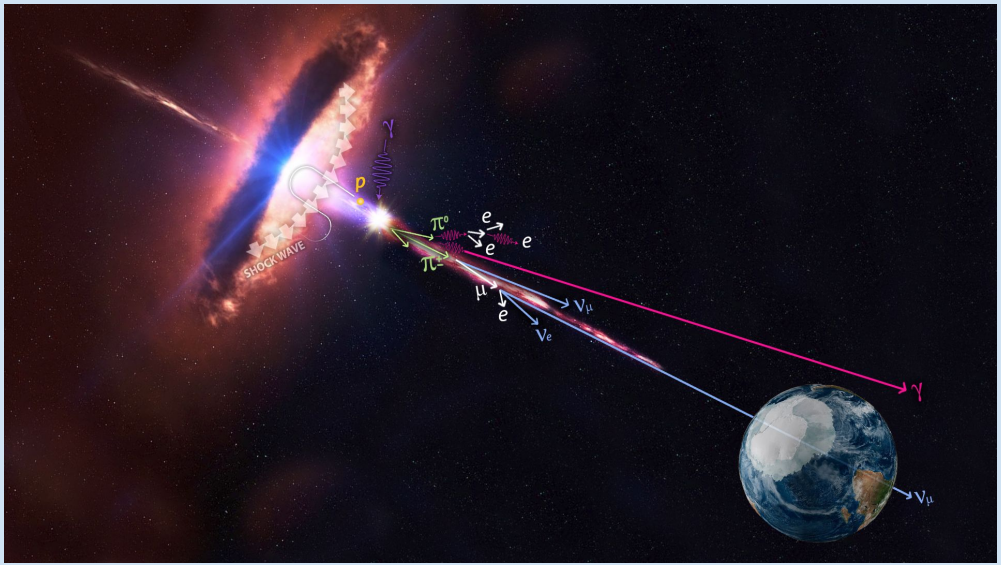
What are UHECRs?

- UHECRs charged particles that exceed energies of 10e17 eV
- They can be protons or heavier nuclei
- Detected by the Pierre Auger Observatory

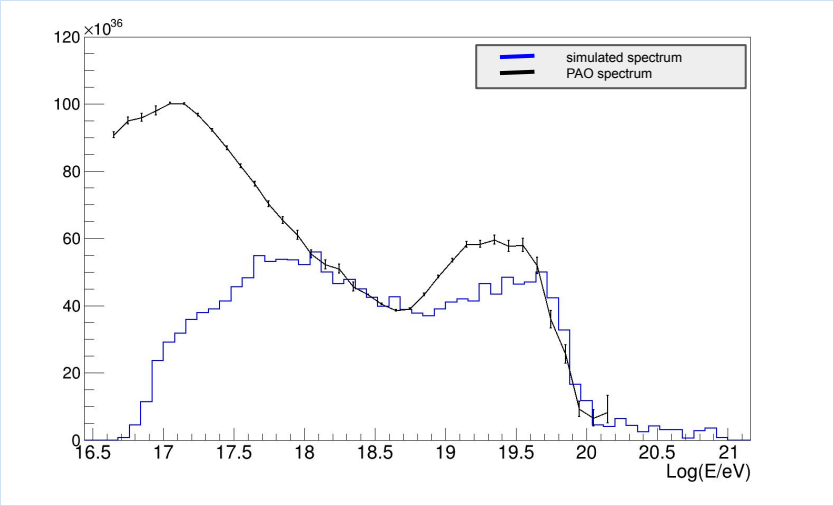


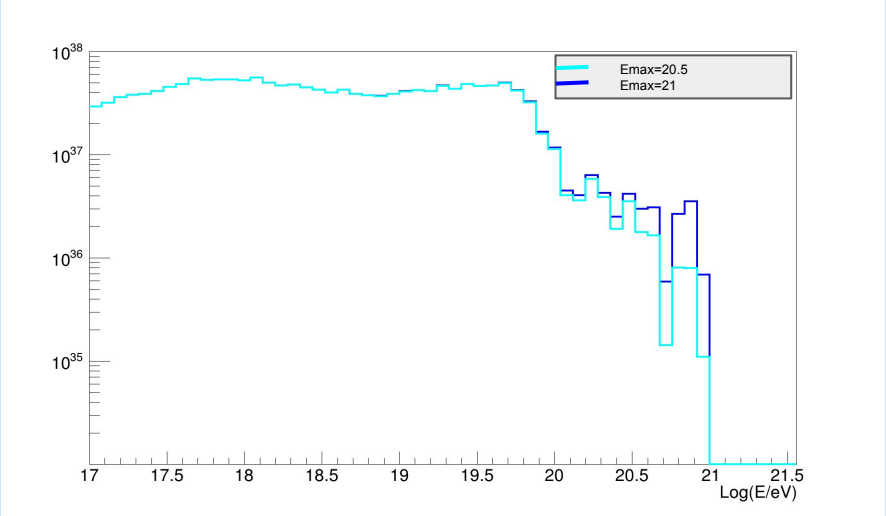
What is SimProp?

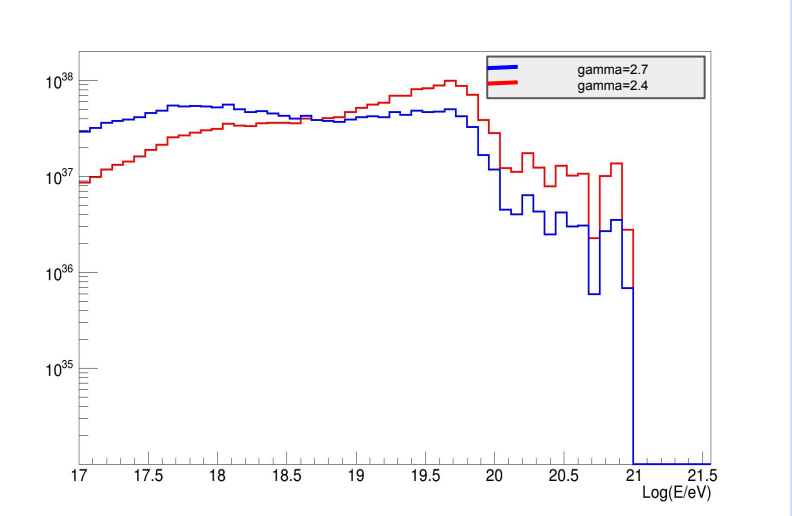
- It is a Monte Carlo code used to simulate the propagation of UHECRs

Protons:

- We assume a pure composition of protons at the source
- We normalise the simulated spectrum using the energy at the ankle
- We plot the spectrum for different values of gamma and Emax

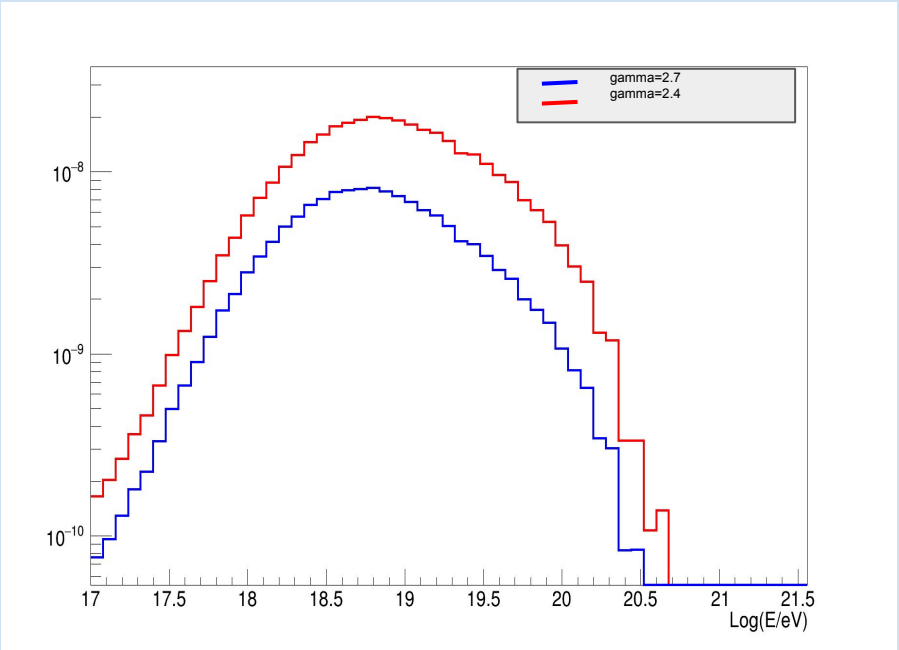


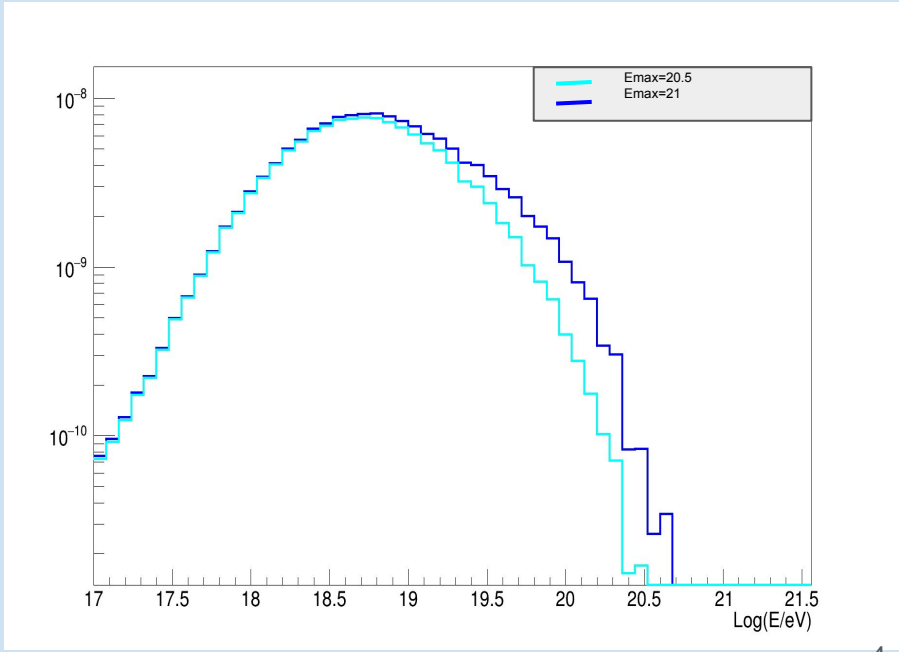




Neutrino Spectra:

- pp and pγ interactions produce pions
- charged pions decay into muons and muon neutrinos

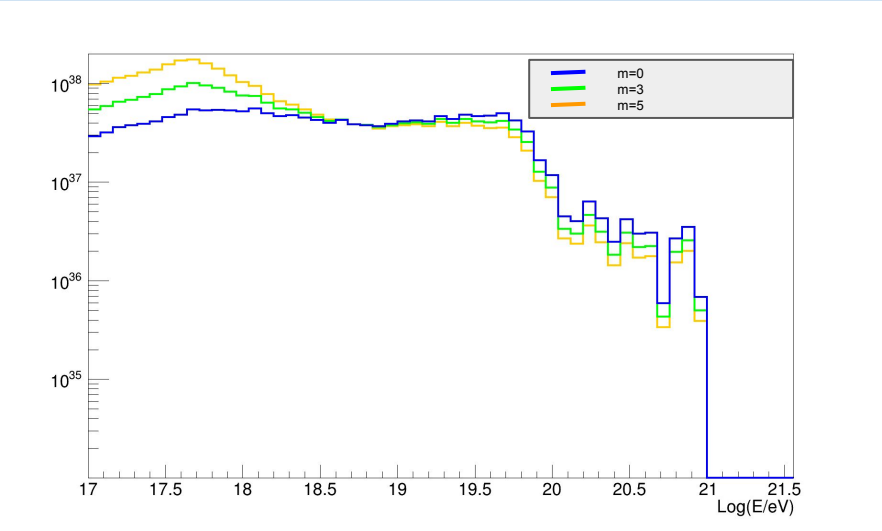


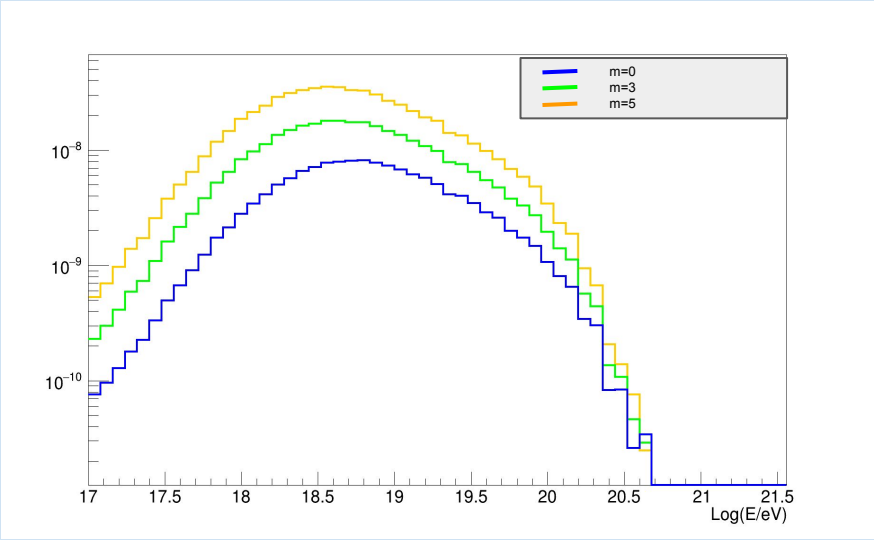


Proton and neutrino spectra for different source evolution models:

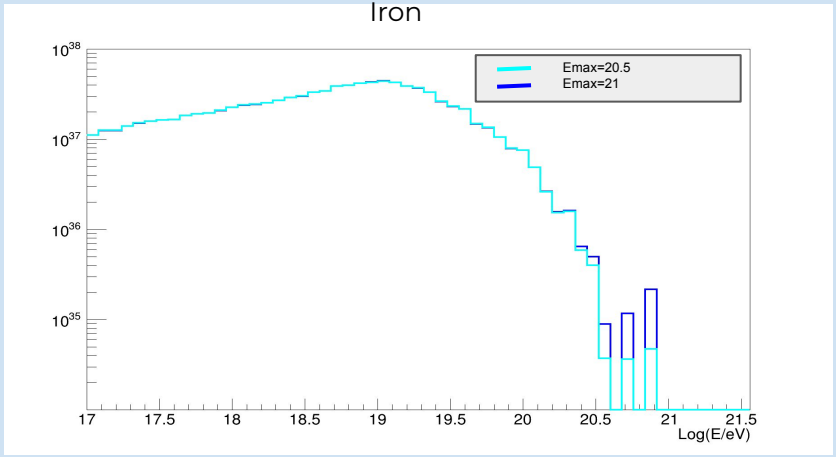
m = 0 no source evolution
m = 3 following star formation rate evolution
m = 5 following AGNs evolution

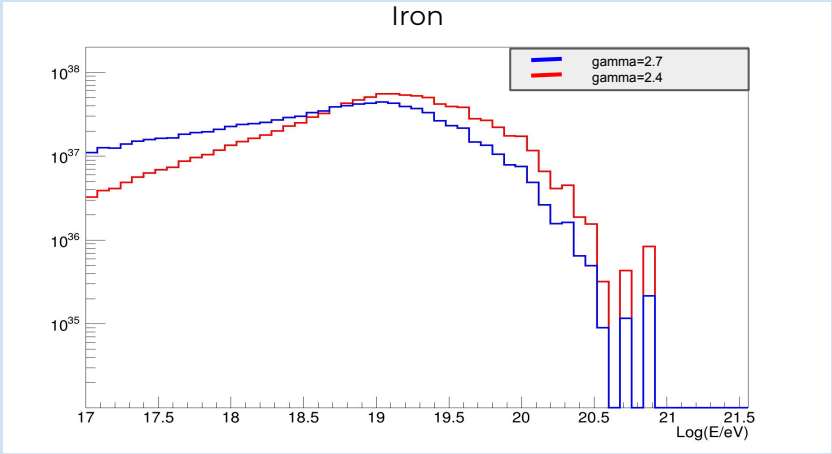
$(1+z)^m$

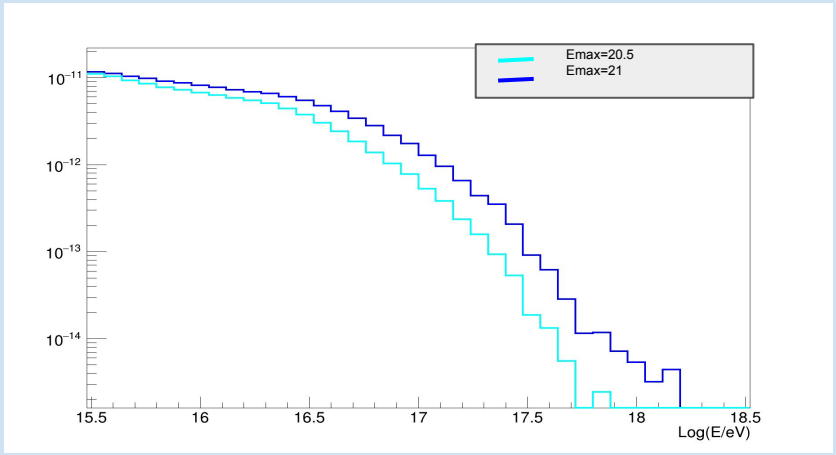




Iron:


Iron
Emax=20.5
Emax=21
Log(E/eV)


Iron
gamma=2.7
gamma=2.4
Log(E/eV)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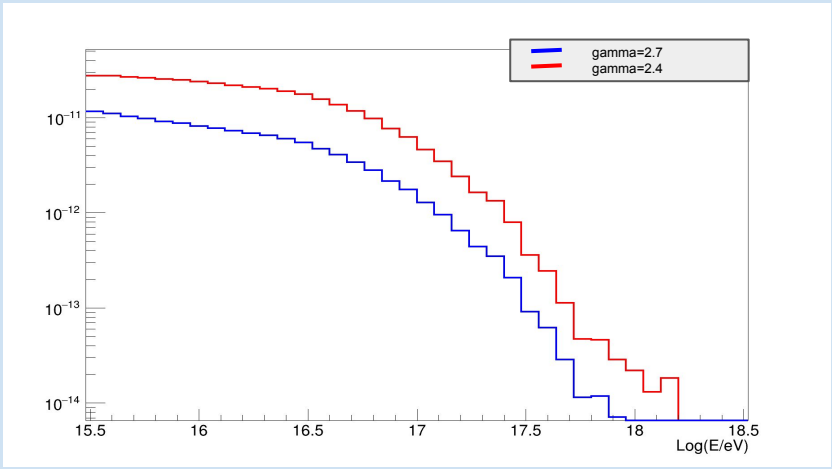
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Iron and neutrino spectra for different source evolution models:

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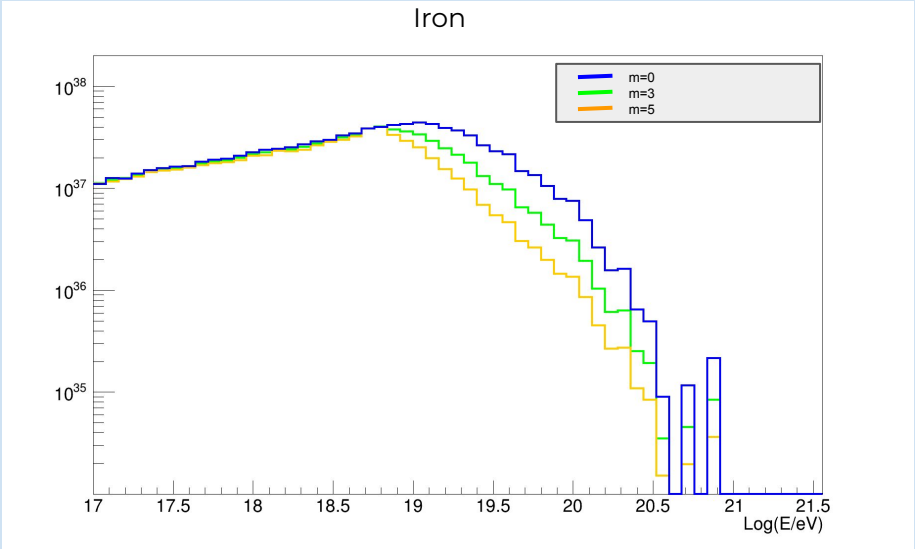
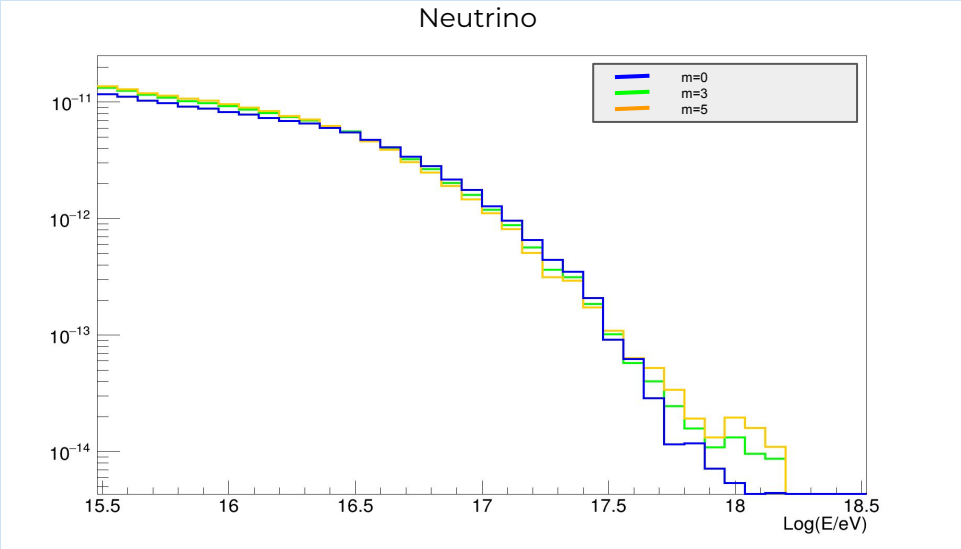
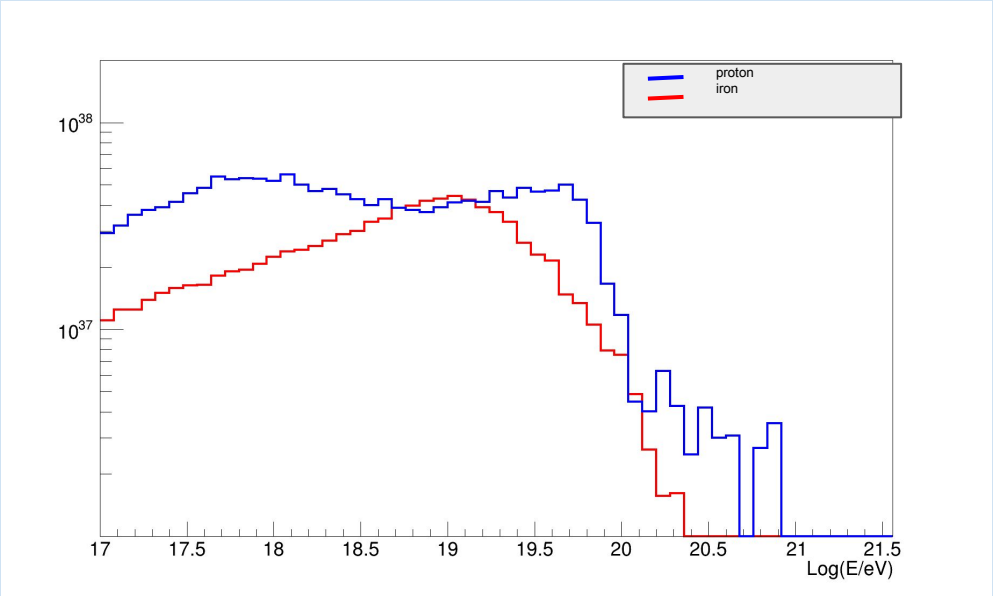
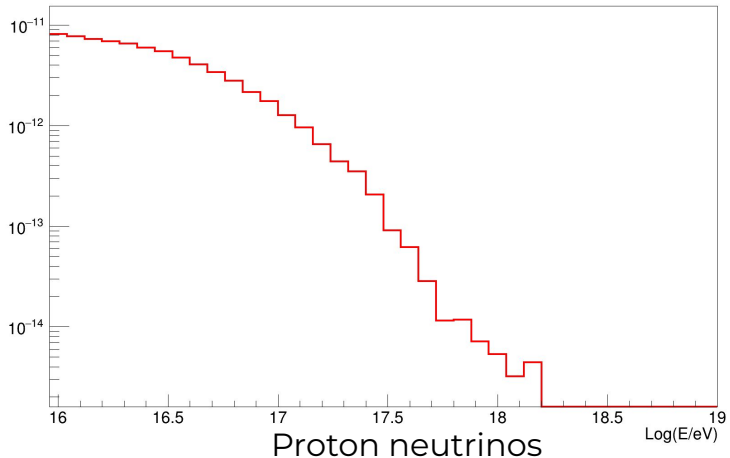




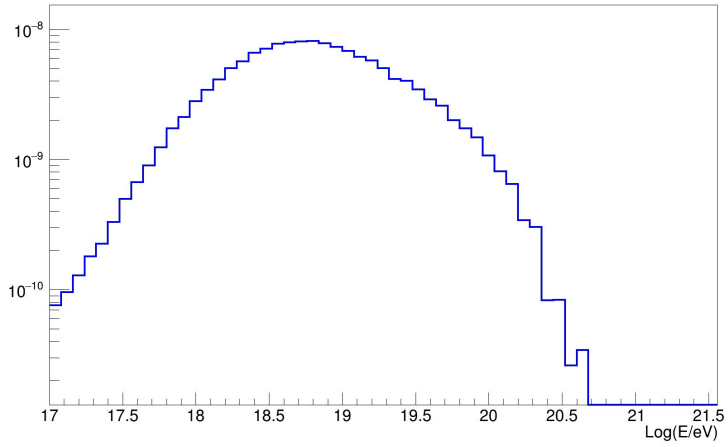
Proton vs Iron



Iron neutrinos



Proton neutrinos



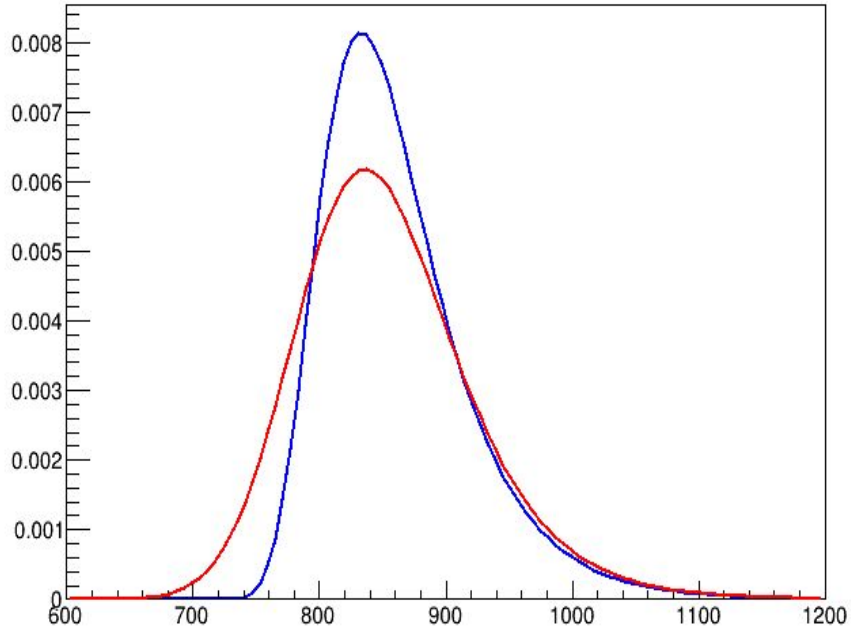
Composition

- The position of the shower maximum Xmax is the most accurate mass estimator
- The generalized Gumbel distribution is used to describe the statistics of the Xmax:

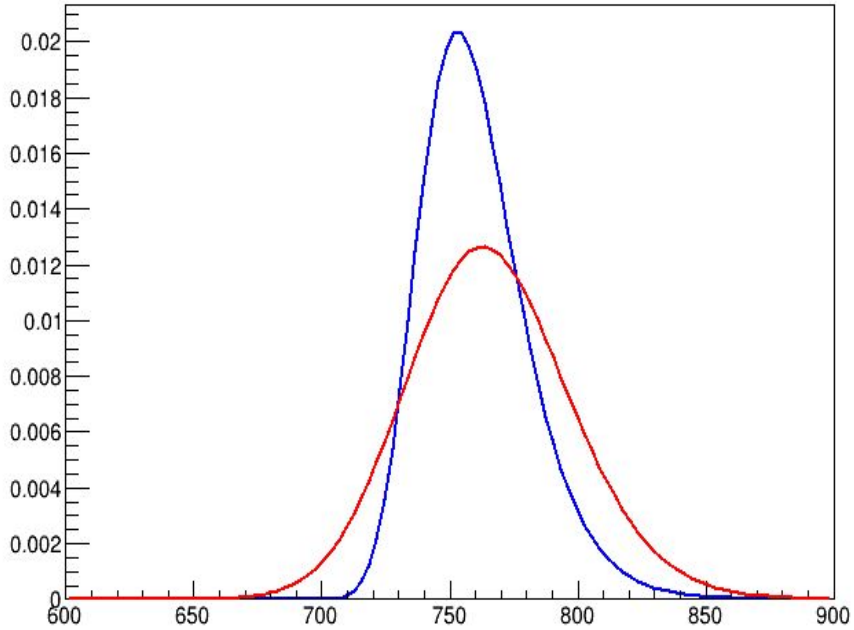
$$\mathcal{G}(z) = \frac{1}{\sigma}\frac{\lambda}{\Gamma(\lambda)}\left(e^{-\lambda z - \lambda e^{-z}}\right); \qquad z = \frac{x-\mu}{\sigma}$$

We used Gumbel ROOT C++ library, which allows also to consider the detector effect

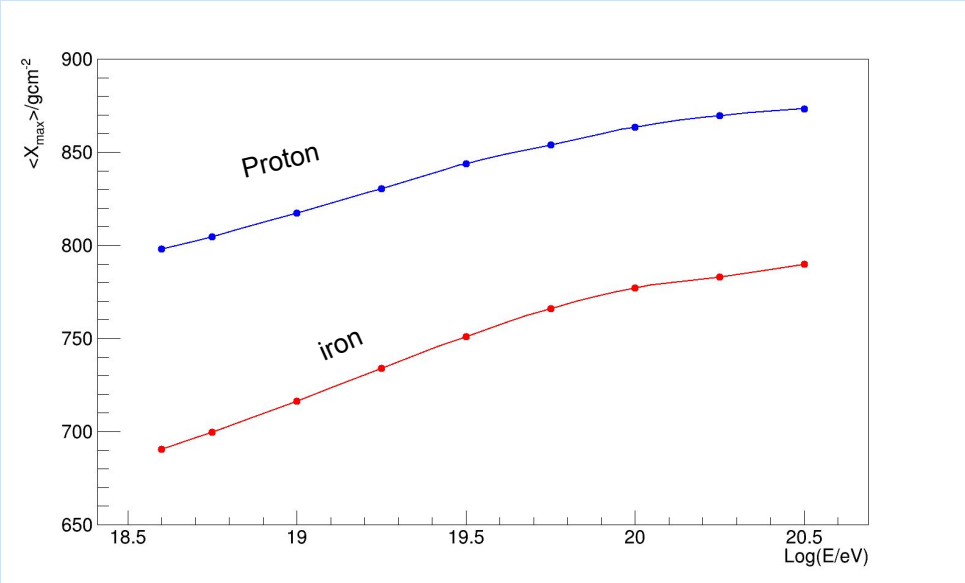
Spectrum of Proton and convoluted spectrum of Proton at 19.75

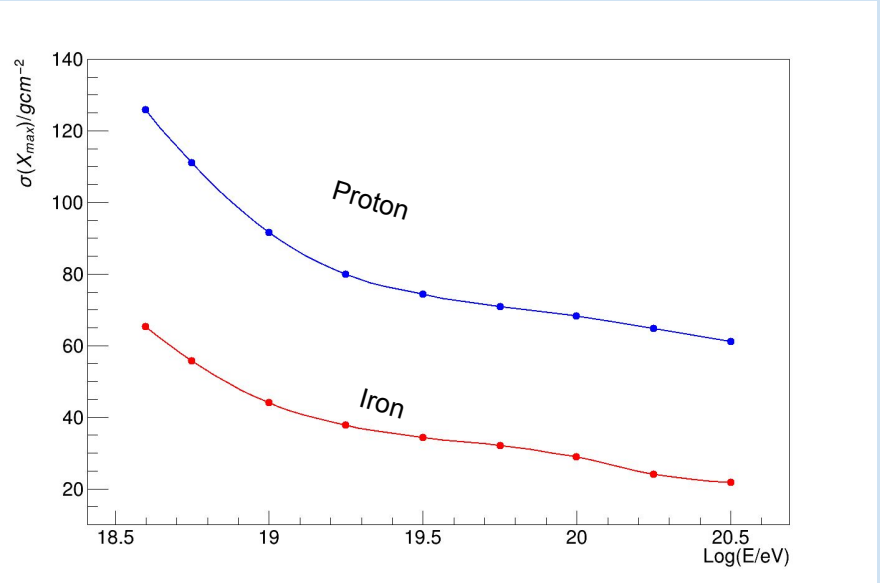


Spectrum of Iron and convoluted spectrum of Iron at 19.75



First two moments of the Xmax distribution for proton and iron as a function of the Log(E/eV)





First moment of the distribution (<Xmax>): Fe interacts higher in the atmosphere (lower Xmax)

Second moment of the distribution (σXmax): Fe Xmax has less shower to shower fluctuations

Outlook:

- Simulations with higher statistics
- Compute source emissivity
- Include mixed composition at injection
- Study <Xmax> and σ Xmax for mixed composition
- Study <Xmax> and σ Xmax for different hadronic models

Thank you!!

Back up slides start here:

Loss lengths for proton and iron: