Determining First Interaction Length and Nuclear Composition

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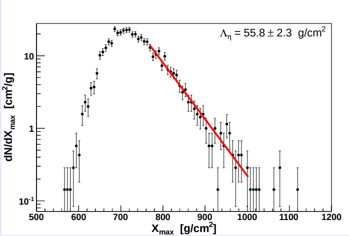
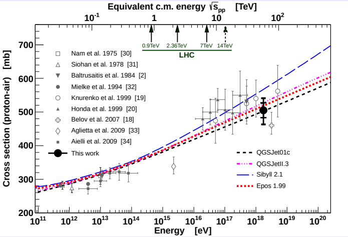
Motivation

- Understand the nuclear composition of cosmic rays at the highest energies,
- Extract information about the hadronic interactions at the highest energies,
- Devise a method to do more particle physics with Pierre Auger Observatory.

Proton Cross-section measurement with the FD telescopes of the Pierre Auger Observatory





Pierre Auger Collaboration, Phys.Rev.Lett. 109 (2012)

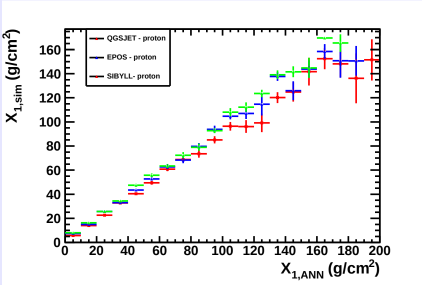
With EM components, because of the limitations, we cannot do more.
We used muon production profile since muons carry more information.

Method

- Dataset: CONEX/CORSIKA extensive air shower simulations
  - lg(E/eV) :18.5, 19.0, 19.5, 20.0; Zenith Angle: 60°
  - Primaries: p, C, N, O, Fe
- Algorithm/Techniques:
  - Artificial Intelligence (Artificial Neural Network)
    - Feed the characteristic inputs to ANN
    - Minimize the number of characteristic inputs and iterate
    - Calculated the first interaction length for a single event
  - Fitting to interaction lengths distributions to compute $\langle X_1 \rangle$ and nuclear composition
  - Detector Simulation (Offline software)
    - Includes "Muon Production Depth Finder" Module (written by Lisbon group) and "Interaction Length Finder" Modules
    - Includes possible detector upgrades, i.e. faster electronics

Presented in

- Lisbon Meeting, 2012
- MTU Meeting, 2011
- ...

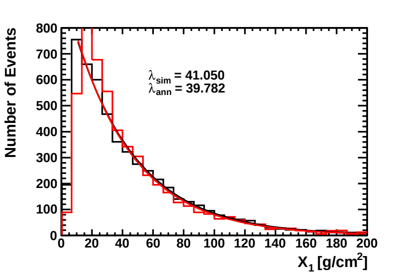


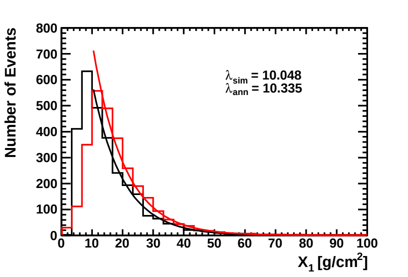
- Model Independence
  - QGSJET, SYBILL, EPOS
- Composition Independence
  - p, CNO, Fe
- Works with changing cross-section
  - increased p cross-section

Results

First interaction length results two different primaries (p, Fe)

log(E/eV)=19.5





proton

$X_{1,sim} = 41.1$ g/cm^2

$X_{1,ANN} = 39.8$ g/cm^2

iron

$X_{1,sim} = 10.1$ g/cm^2

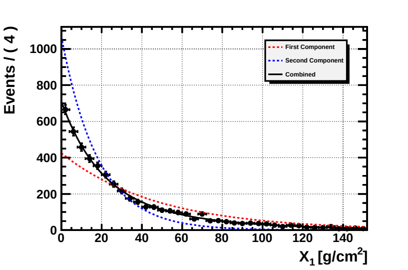
$X_{1,ANN} = 10.3$ g/cm^2

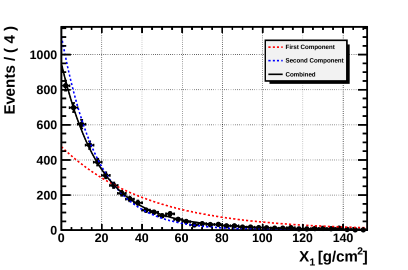
Results [Toy Model]

Sample results for mixed composition

log(E/eV)=18.5,

Input p Int. Len.: 47.6±1.3 g/cm^2, Input CNO Int. Len.: 17.4±0.3 g/cm^2





60% proton + 40% CNO,

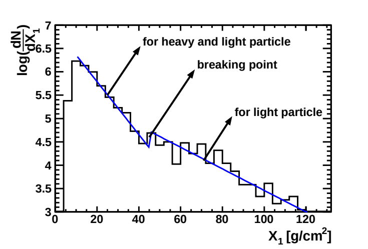
Comp. p Int. Len.: 47.9±0.7 g/cm^2,

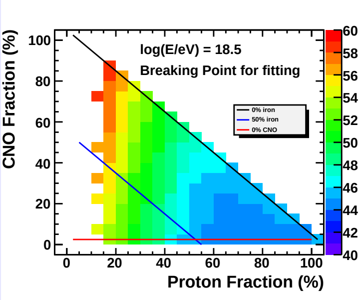
Comp. CNO Int. Len.: 18.3±0.5 g/cm^2

25% proton + 75% CNO,

Comp. p Int. Len.: 42.8±1.7 g/cm^2,

Comp. CNO Int. Len.: 17.9±0.3 g/cm^2

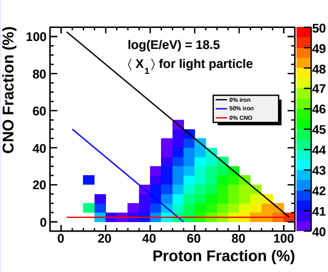


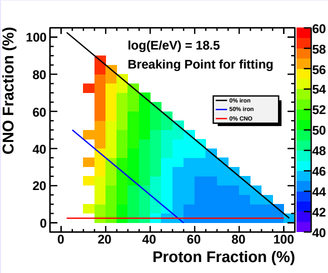


- Step 1: Randomly choose showers
- Step 2: Find breaking point
- Step 3: Find $<X_1>_{light}$
- Step 4: Find $<X_1>_{heavy}$
- Step 5: Record averages and goto step 1

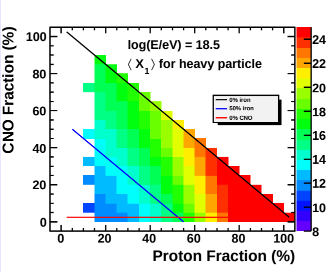
A sample bootstrap result

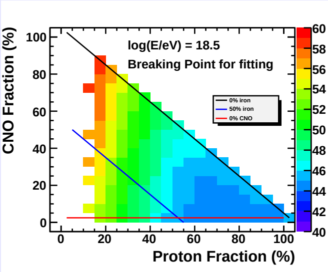
- Each bin is a result of a single bootstrap
- Black line is for p $\rightarrow$ CNO
- Red line is for p $\rightarrow$ Fe
- Anything in between those lines is p, CNO and Fe mixture



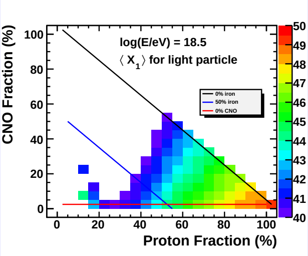


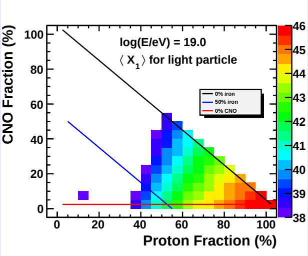
- Till ~60% proton fraction:
  - $<X_1>_p$ can be determined
  - Breaking point assumes single composition
- Below that limit, breaking point tends to move forward. With the addition of low statistics on the tail, determination is not possible.
- A cut on breaking point (~44 gm/cm^2) will help on mixed composition decision.





- Till ~60% proton fraction:
  - $<X_1>_{heavy}$ can not be determined
  - Breaking point assumes single composition
- If iron fraction is greater than 60%:
  $<X_1>_{Fe}$ can be determined
- If CNO fraction is greater than 60%:
  $<X_1>_{CNO}$ can be determined





Summary

- Model and composition independent ANN based prediction model was developed
- Mixed composition studies were done
- If the fraction of a nuclei is greater than 60%, its average interaction length can be determined,
- Detector simulations and their results are being carried out