CR Primary Mass Identification with Lateral Muon Profile of EAS

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Goal

- Identifying primary particle shower–by–shower using muons
- The information on the muons in a simulated EAS, combined with X_{max} and energy of the primary E_p, are used for a log likelihood analysis to distinguish primaries
- Future prospect for detectors: Low-cost Large Area Detector Arrays can be employed to detect muon tracks
- We perform an operational research on feasibility of such detectors

Current limitations

- EM component:
  - Gives E_P, X_{max}, direction, timing
  - However washes out the hadronic history
  - No way to resolve the stochastic 1^{st} interaction jitter
- Muon measurements: current limits
  - Measurements on only muon component: done for numbers and spectrum
  - Limited to a single position, making results meaningful only when integrated over many events (except IceCube+IceTop)

Simulation details

EAS:

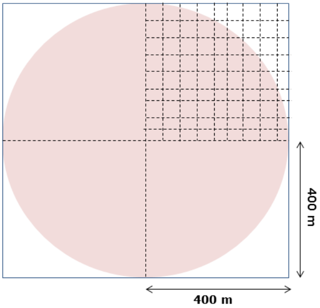
- CORSIKA v7.4002
- Primaries: Proton, Iron
- Energy: 10^{16} eV - 10^{19} eV
- Zenith Angle: 0°
- Hadron Model:QGSJET-II
- 110m above sea level

Detector:

- 2m X 2m stations
- Stations apart by:

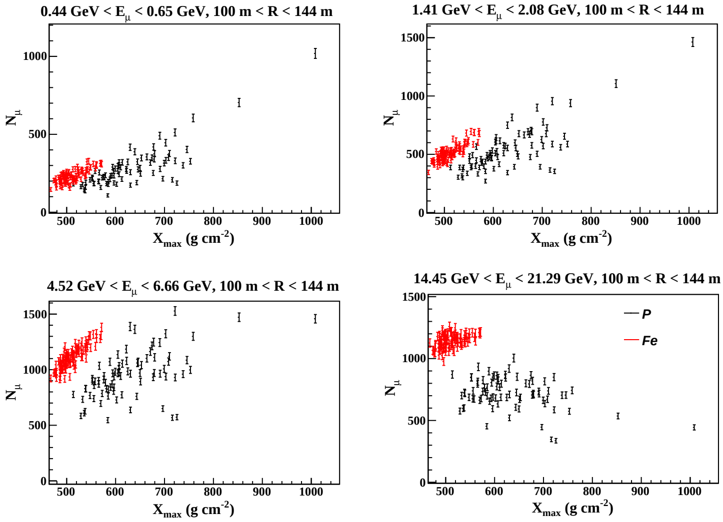
  0m, 20m, 50m, 200m

  (Collection: 100%, 1%, 0.16%, 0.01%)
- $E_{\mu} = 0.5$ - 50 GeV
- E_{μ} resolution: 0, 50%



The number of muons and X_{max}

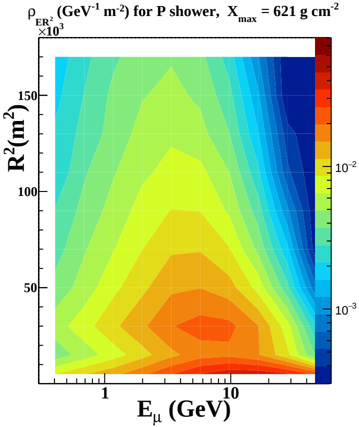
- $E_p = 10^{16} eV$

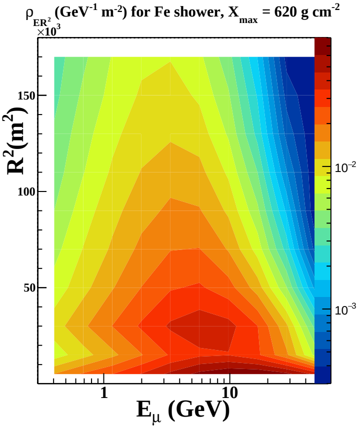


Structure of muon component

- We try to map the possibilities of using the spectral+radial shape of the muon component
- We build a 'map' in $(E_\mu$, R) for each primary and use X_{max} from an external measurement to account for its specific value
- We use a likelihood test for differentiating between hypotheses, taking into account each individually measured muon

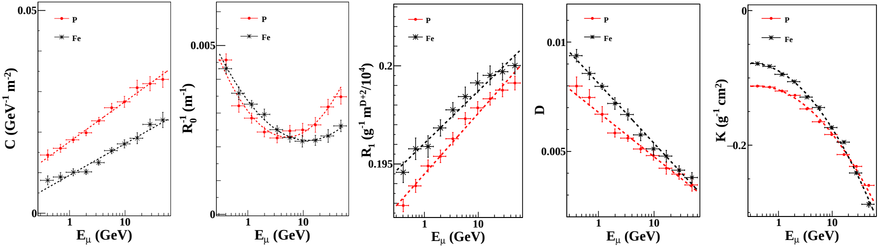
The Lateral Spread





The Mapping

- $\rho_{ER^2} = \frac{dN_\mu}{dE_\mu dR^2}[X_{max}, E_\mu, R] = Ce^{-\frac{R}{R_0}+(R_1 R^{-D}+K)X_{max}}$



- The formulation gives stable fit results (should be redone for changing E, primary, models, angle...)
- Makes calculations efficient compared to e.g. binned data

Statistical Method: With Two Components

- Construction of a likelihood function:
  $\ln L = \ln L_{shape} + \ln L_n$

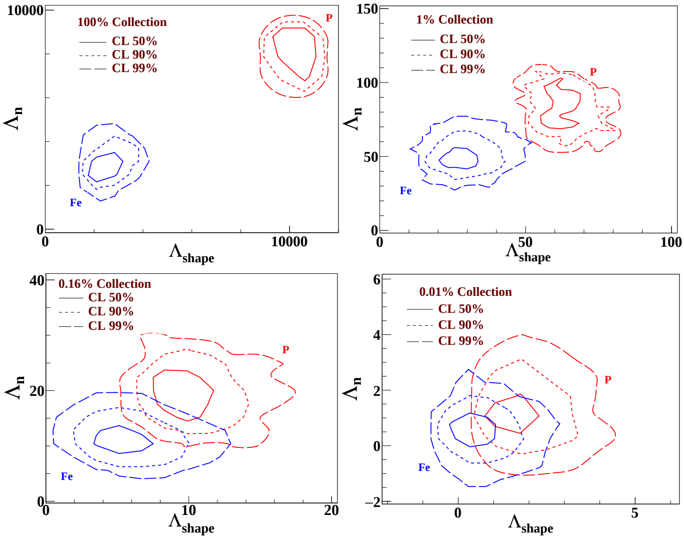
- $L_{shape} = \prod_{i=1}^{N_\mu^{obs}} \rho^i_{ER^2}(E^i_\mu, R^i)$
  Takes into account the normalized expected shape of the muonic shower in (E_μ,R) plane

- $L_{number} = Poisson(N_\mu^{obs} | N_\mu^{exp})$
  Takes into account the total number of muons

- $\Lambda = \ln L(\mathrm{data}) - \ln L(\mathrm{model}) = \Lambda_{shape} + \Lambda_n$

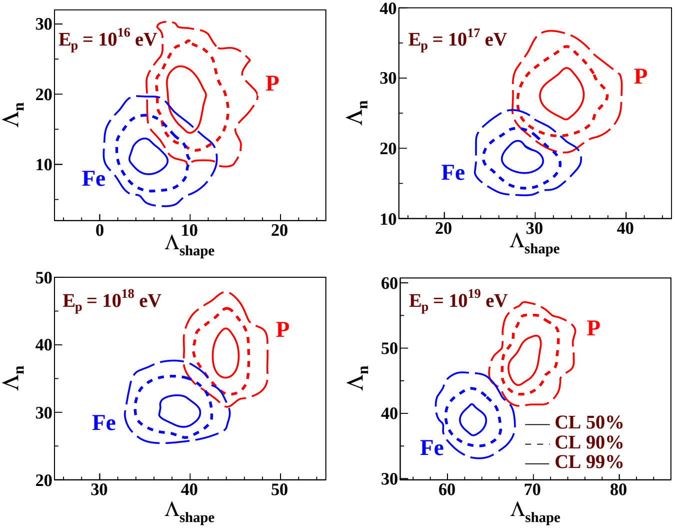
Results: At Different Collection Efficiencies

- $E_p = 10^{16}$ eV, ideal muon detectors



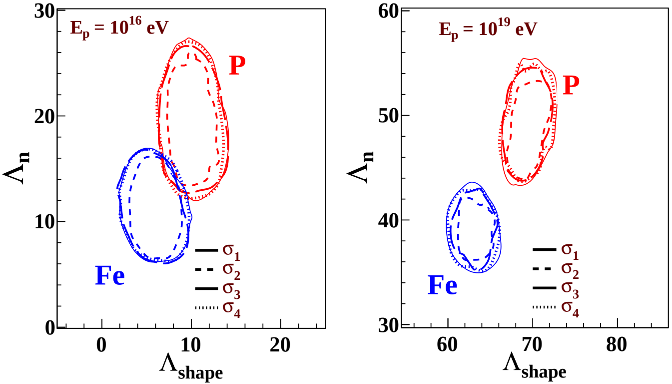
Results: At Different E_p

- Ideal muon detectors, 0.16% Collection



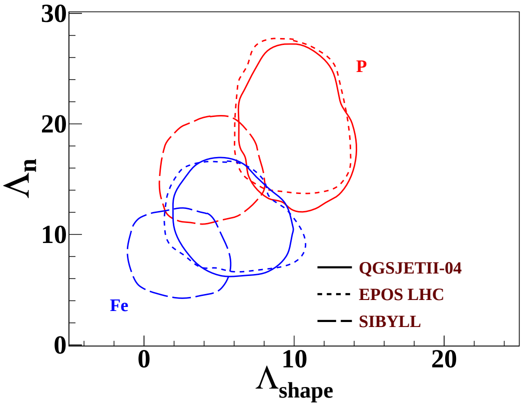
Results: With Detector Resolution

- σ_1 50%
- σ_2: 20% ($E_\mu \leq$ 10 GeV) & 50% (rest)
- σ_3: 20% (10 Gev$\leq E_\mu \leq$ 20 GeV) & 50% (rest)
- σ_4: 20% ($E_\mu \geq$20 GeV) & 50% (rest)



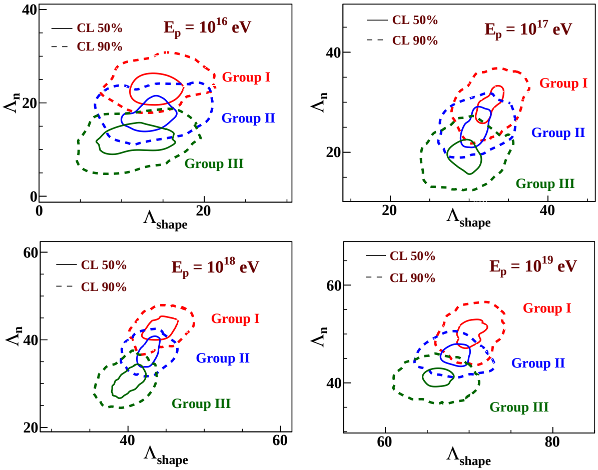
Results: With Hadron Models

- $E_p = 10^{16}$ eV, 0.16% collection, σ_2



Results: for more primaries

- 0.16% Collection
- GroupI (A $\leq$ 4), GroupII (4<A$\leq$25), GroupIII (25<A$\leq$56)



Prospects of upgrading existing surface arrays

- Introduction of muon tracker arrays would provide us the necessary information on muons
- 2m X 2m detectors 50 m apart provides significant identification between P and Fe primaries
- Arrays of large area low cost detectors are suitable for the primary identification
- Reasonable options: Gaseous large area detectors with suitable pickup strip pixels, e.g, THGEM, RPWELL

Concluding Remarks

- The shape of the muon shower component in an EAS has been parametrized.
- Information on the shape and flux are used to identify primaries.
- Identification of primaries with muons collected is possible with a realistic surface array
- Separation of primaries improves with increase in primary energy. At higher energies the flux is much lower, but more precise information on the primaries are obtainable.
- Muon spectrometry has the potential to become a reasonable option for ground arrays

Thank you!