Composition and Muon Counters

TA Collaboration Meeting
University of Utah

John A.J. Matthews
New Mexico Center for Particle Physics
University of New Mexico
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1. Composition ... it is more than $< X_{max} >$

2. SD and FD notes ... so we understand one another

3. Hybrid ... a new way of thinking

4. Implications for TA

5. Who is going to do it!
1: Composition ... it is more than \(< X_{max} >\)

Compilation of composition measurements

• Clear trends but are they correct?

• How do we interpret \(< X_{max} >\) (above \(\sim 4 \times 10^{16}\)eV)?

  1. IF only two components (protons and iron), then potentially straightforward except for the shower simulation uncertainties.

  2. IF anything else, our current measurements are (quantitatively) almost worthless ... until \(< X_{max} >\) hits the proton-rail near \(10^{20}\)eV!
Model Uncertainties

EXPERIMENTS should use the SAME SIMULATION codes!!
There are way too many moving parts… pick ONE (CORSIKA, or…)

Hybrid Codes - H.J. Drescher ICRC03

*FLUKA* - R. Engels ICRC03

best description of Low Energy - important water tanks far from core

An extreme comparison in composition studies with QGSJet...

J. Knapp ICRC03
**Composition:**

HiRes Stereo: unchanging, light composition above $10^{18}$ eV
Stereo HiRes and HiRes Prototype-MIA consistent in overlap region

HiRes Prototype-MIA Hybrid changing composition (Heavy to Light) between $10^{17}$ and $10^{18}$ eV

No significant information near GZK region yet
Come back to 29th ICRC
1: Composition ... it is more than $< X_{max} >$ (con’t)

Two phenomenological fits compared to HiRes data: the left hand figure assumes a uniform distribution of extra-galactic sources, the right hand figure assumes a distribution that increases with red shift, $z$, as $(1 + z)^3$.

- The **heavy to light** transition (above $\sim 4 \times 10^{16}\text{eV}$) is believed to be the transition from galactic dominant to extra-galactic dominant CRs. **Is this transition essentially complete by** $5 \times 10^{17}\text{eV}$, or by $10^{18}\text{eV}$, or not until $> 10^{19}\text{eV}$?

- **GZK-modelers** predict the proton flux well below the GZK peak. **Do they agree with** $f_p(E) \times \Phi(E)$ where $f_p(E)$ is the fraction of protons and $\Phi(E)$ is the total flux VS energy?
systematic errors in by hand...

- 30% in order to reconcile low energy data ($10^{18.5}-10^{19.5}$ eV)
- 15% within limits allowed by both collaborations

**AGASA** -15%  
AGASA \(\gamma = 2.6\)  
\(E > 10^{19}\) : 651  
\(E > 10^{19.6}\) : 42.82 ± 6.45  
\(E > 10^{20}\) : 2.25 ± 1.53

**HiRes** +15%  
HiRes \(\gamma = 2.6\)  
\(E > 10^{19}\) : 367  
\(E > 10^{19.6}\) : 38.29 ± 6.01  
\(E > 10^{20}\) : 2.31 ± 1.51

**best fit slope:** 2.6  

**number of events above** $10^{20}$eV:  
**no GZK @ 1.5 sigma**  

**number of events above** $10^{20}$eV:  
**GZK cutoff**

DeMarco et al (ICRC03)
2: SD and FD notes ... so we understand one another

Schematic of extensive air shower detection.

- **$E_{\text{primary}}$** measurement:
  1. SD: based on $S_{600}$ or $\rho_{1000}$, chosen to minimize shower to shower fluctuations (in this measurement).
  2. FD: $\frac{dE}{dx}|_{1.4\text{MeV}} \int N_{1.4\text{MeV}}^{\text{fit}}(x)dx$, based on the “1.4 MeV electron” air fluorescence-yield calibration.

- **Composition** measurement:
  1. SD: based on number of muons at ground level
  2. FD: based on $X_{\text{max}}$ ... that is all there is!
p and Fe showers have essentially the same FWHM ... thus Xmax is the "only" composition information!

$3 \times 10^{17}$ eV

$1 \times 10^{18}$ eV
3: *Hybrid* ... a new way of thinking

**Detection method**

Sketch of hybrid detection concept.

- *Hybrid* experiments can measure $E_{\text{primary}}$ and **composition** two, independent ways ...

- In practice **without some modification** true *hybrid* is in the middle of the energy acceptance with **only** SD for the highest energy showers and **only** FD for the lowest energy showers!

- Auger and TA emphasize *hybrid* $E_{\text{primary}}$ measurement

- A possibly growing interest in Auger for the *hybrid* measurement of **composition** ... **what about in TA?**
3: *Hybrid* ... a new way of thinking (con’t)

CORSIKA shower simulation of *p* and *Fe* showers.

- To 0th order the number of muons (at ground level) and shower $X_{max}$ are uncorrelated.
- The number of muons (at ground level) and shower $X_{max}$ depend on the primary cosmic ray composition: *p* or *Fe* or ...
- The width and separations of the muon and $X_{max}$ distributions for *p* and *Fe* are rather similar.
- **Event by event measurement of shower muon content** and $X_{max}$ can (potentially) distinguish proton from iron showers.
p and Fe 1-variable projections: \#muons OR X\text{max} do not cleanly resolve into "p" and "Fe" ...
3: *Hybrid* ... a new way of thinking (con’t)

CORSIKA showers *smeared* by detector resolution.

- With detector resolution the $p$:$Fe$ separation is less clear.
- Two (possibly naive) approaches:
  1. Look at $X_{\text{max}}$ projection requiring $\#\text{muons}$ either
     \[ \geq \ < \ #\text{muons} >_F \] (more pure iron sample),
     or \[ \leq \ < \ #\text{muons} >_p \] (more pure proton sample).
  2. Analyze scatter plot of $\#\text{muons} / S_{750}$ *versus* $X_{\text{max}}$ as we might expect a more precise measurement of $\#\text{muons} / S_{750}$ than of $\#\text{muons}$.
  3. To me it looks promising ...
Smeared distributions: \( \frac{d(\# \text{muons})}{\# \text{muons}} = 20\% \)
\( d(X_{\text{max}}) = 20 \text{gm/cm}^2 \)

#muons/1000

\( X_{\text{max}} \text{ (gm/cm}^2 \)
Smeared distributions: 20% d(#muons)/#muons, 20 gm/cm^2

with #muons > average #muons(Fe)

with #muons < average #muons(p)
Smeared distributions: 20% d(#muons)/#muons, 20 gm/cm^2

with #muons >
average #muons(Fe)

with #muons < average #muons(p)
Smeared distributions: d(#muons)/#muons = 15%

\[ d(\text{Xmax}) = 20 \text{ gm/cm}^2 \]

#muons/(1500 \times 5750)  #muons/(500 \times 5750)

--- Xmax (gm/cm^2) --->

#muon projections show 2-component "peaks" ...
4: Implications for TA

- **Goal**: true *hybrid* composition measurement starting at $\sim 10^{17}$ eV
- **ADD e.g.** $\sim 100$ *muon-detectors* ...
  1. $7 \times 7$ array on 300m separation (3.2 km$^2$ area) within
  2. effectively $8 \times 8$ array on 600m separation (17.6 km$^2$ area)
- **ADD FD detection up to viewing angles $\sim 60^\circ$ to the horizontal.**
- How best to do *muon detectors* is not clear ... *maybe a combined “Auger SD + TA scintillator” detector which could be a joint Auger TA R&D project?*
5: Who is going to do it!

- Composition analyses above \( \sim 10^{17}\text{eV} \) would benefit from simultaneous \textbf{muon} and \( X_{\text{max}} \) measurements.

- The measurements must be of sufficient precision ... which may be a challenge for the \textbf{muon} measurement.

- This is not more important than other TA measurements ... but it is not less important either!

- TA or Auger should do this! OR is there a way to collaborate to do it together?

- \textbf{IF TA wants to do this then there is much work to be done ...}