

Composition and Muon Counters

-and your point is-

Are we serious about Cosmic Ray Composition?

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4C+ group

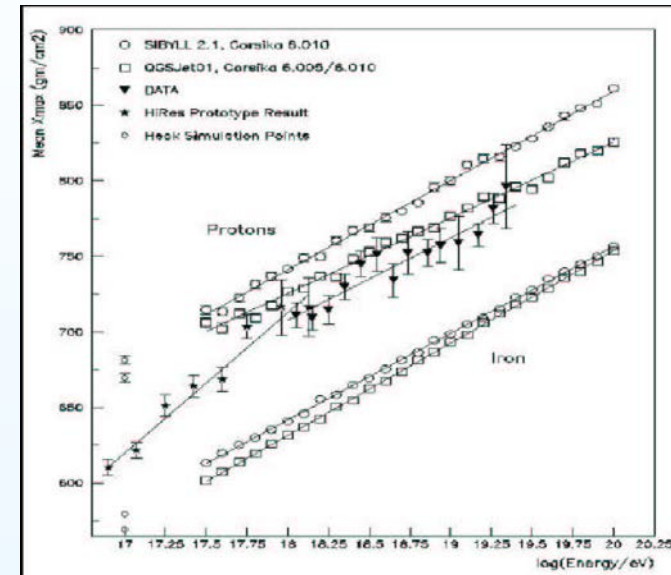
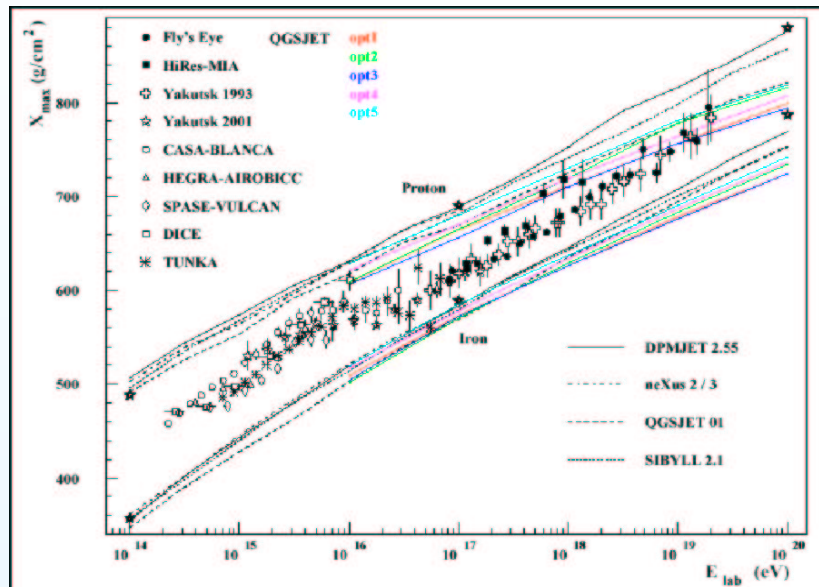
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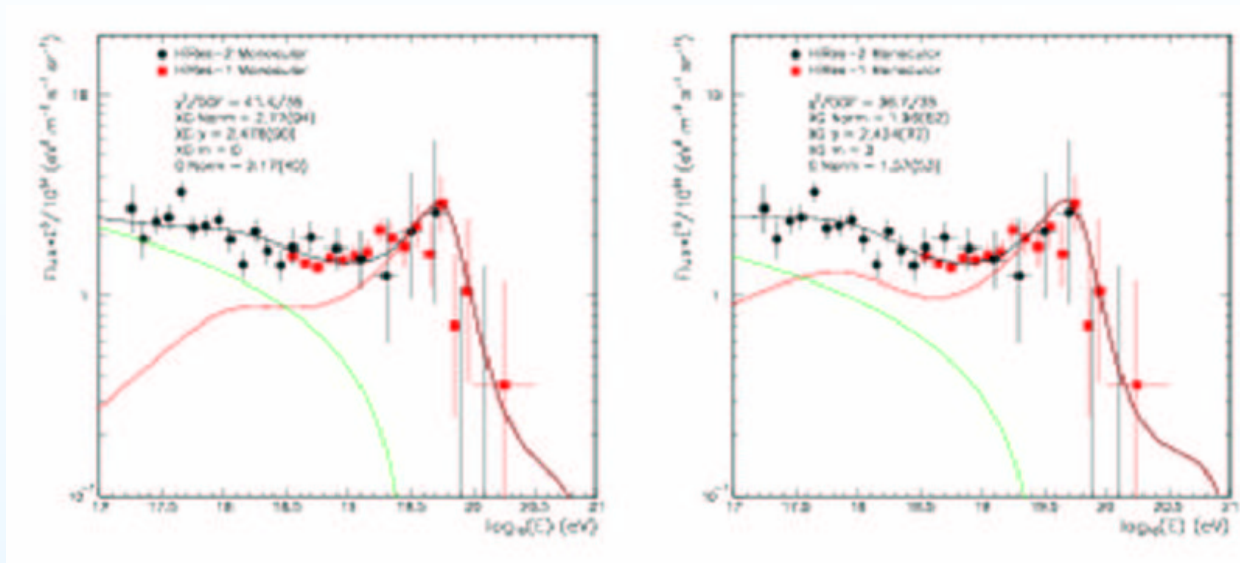
(Originally presented to TA Collaboration, October 25-27, 2003)

Composition ... it is more than $\langle X_{max} \rangle$



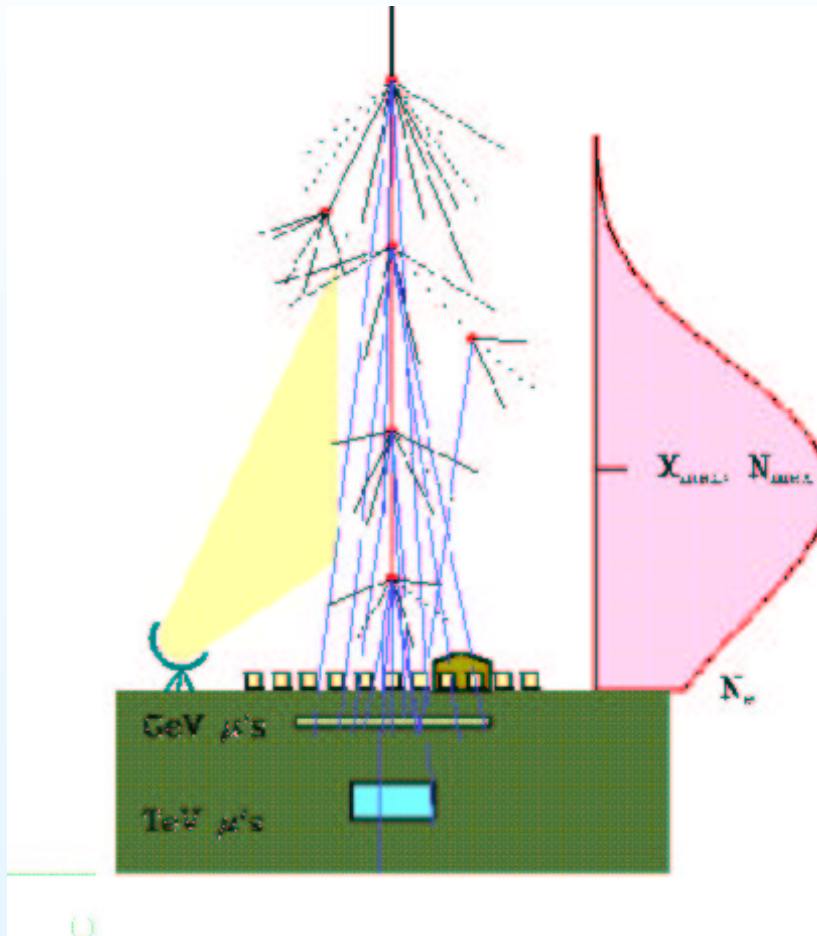
- Clear *trends* but are they correct?
- How do we interpret $\langle X_{max} \rangle$ (above $\sim 4 \times 10^{16}$ eV)?
 1. IF 2 components (p and Fe), then potentially straight forward except for the shower simulation uncertainties.
 2. IF *more than* p and Fe, how meaningful is $\langle X_{max} \rangle$?
 3. And is the composition *pure-p* by 10²⁰ eV?

Composition ... the galactic to extra-galactic transition



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

To first order ... so we understand one another



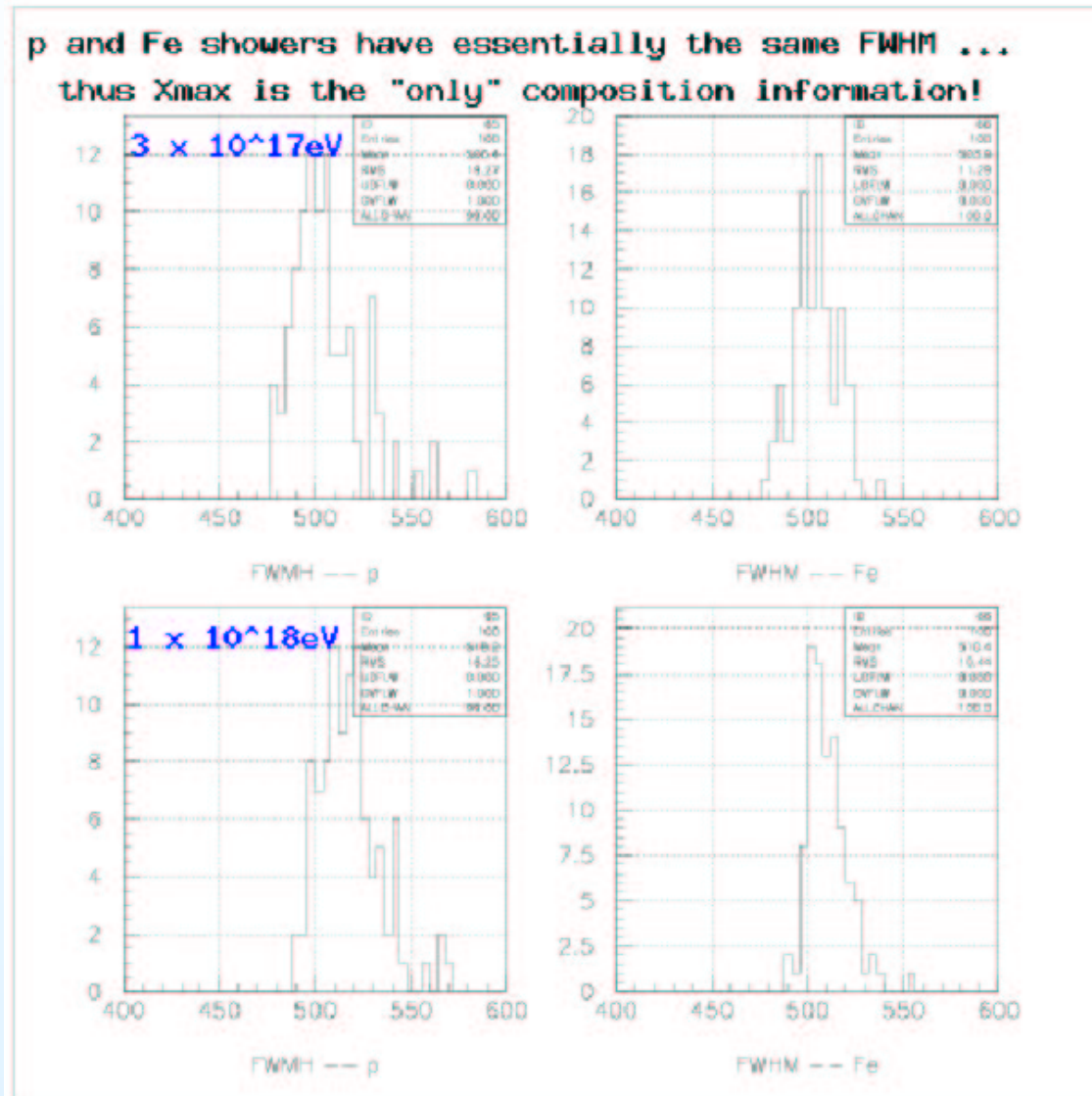
- **$E_{primary}$ measurement:**

1. SD: based on ρ_{1000} , chosen to minimize shower to shower fluctuations (in this measurement) ... **but with some muon cross-talk!**
2. FD:
$$\frac{dE}{dx} \Big|_{1.4 MeV_e} \int N_{1.4 MeV_e}^{fit}(x) dx,$$
 based on the “1.4 MeV electron” air fluorescence-yield calibration.

- **Composition measurement:**

1. SD: based on number of muons (#muons) at ground level
2. FD: based on X_{max} ... **that is all there is!**

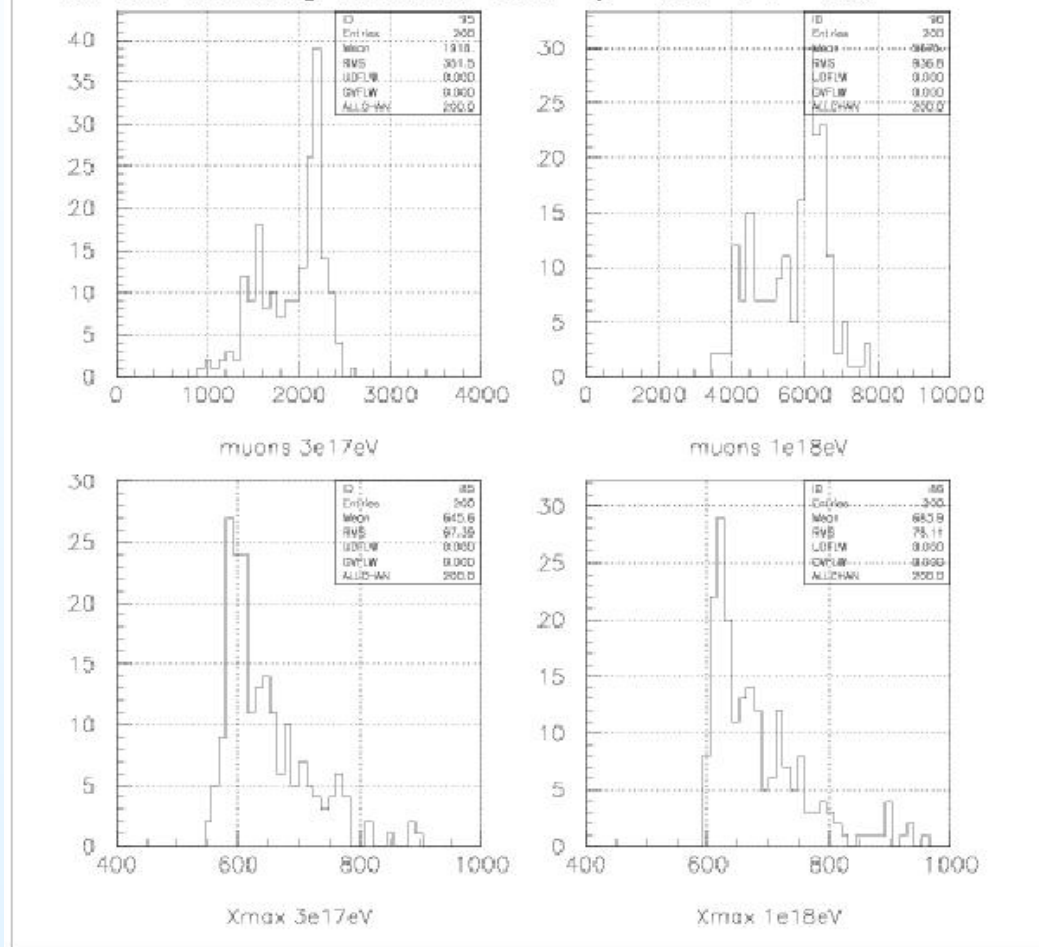
For FD: X_{max} is all there is ... shower profile FWHM



- Unfortunately shower simulations predict similar FWHM for p- and Fe-showers

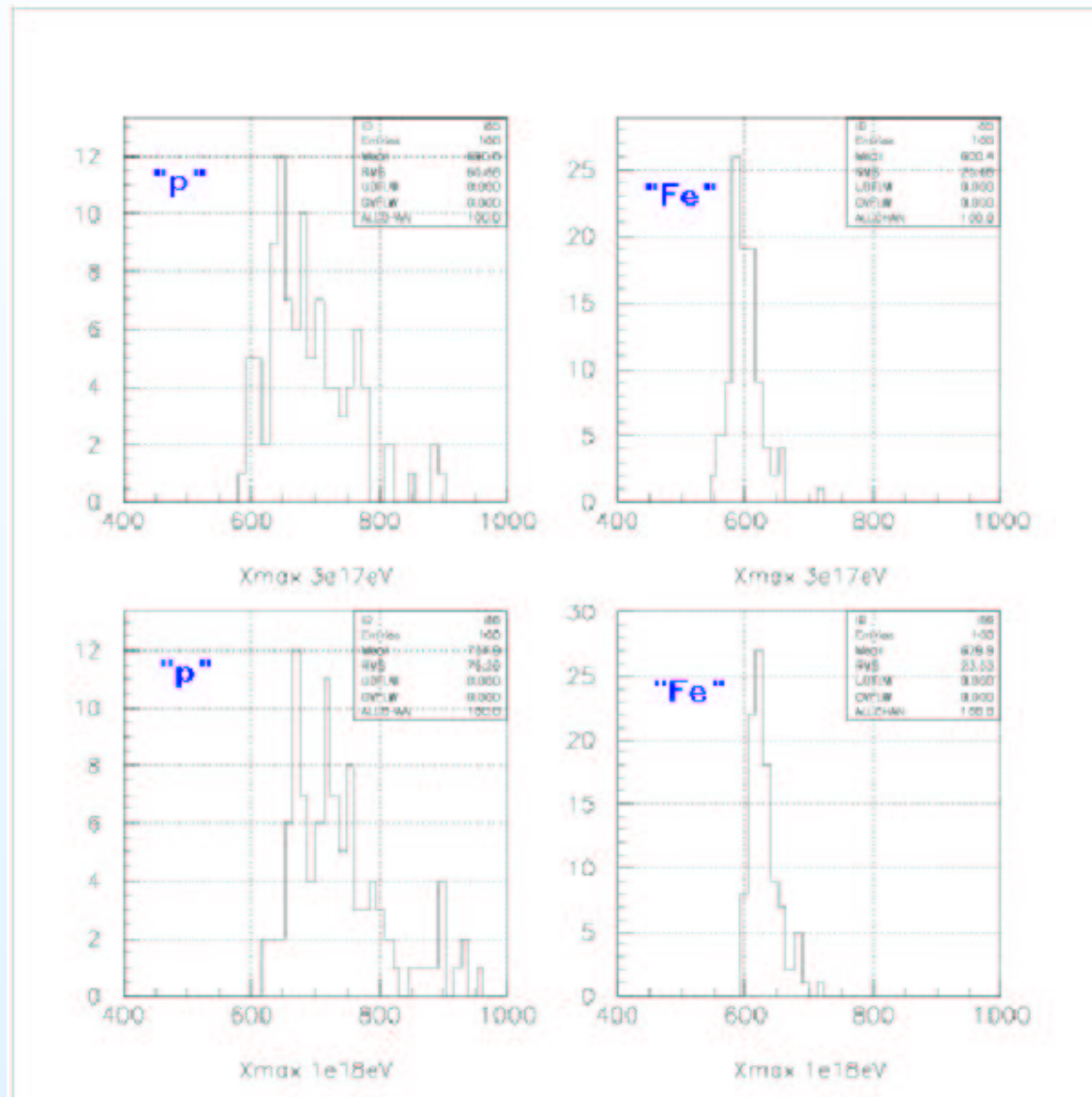
SD or FD composition ... no p-Fe separation

p and Fe 1-variable projections: #muons OR X_{max}
do not cleanly resolve into "p" and "Fe" ...



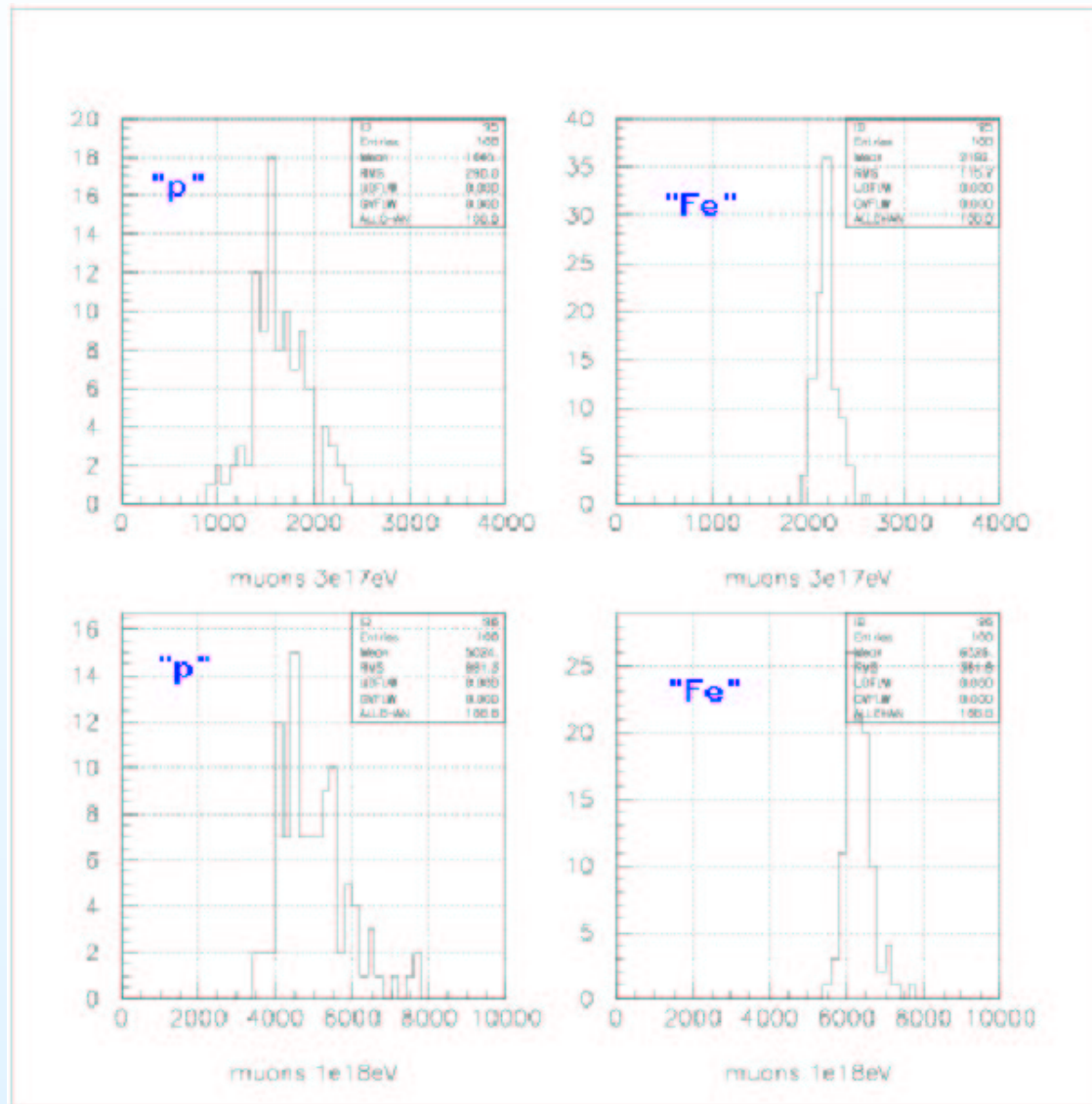
- Plots show combined predictions from 100-p and 100-Fe simulations
- (Ideal) “#muons”-only and/or “ X_{max} ”-only measurements do not show separated “p” and “Fe” components

FD “ X_{max} ” composition ...



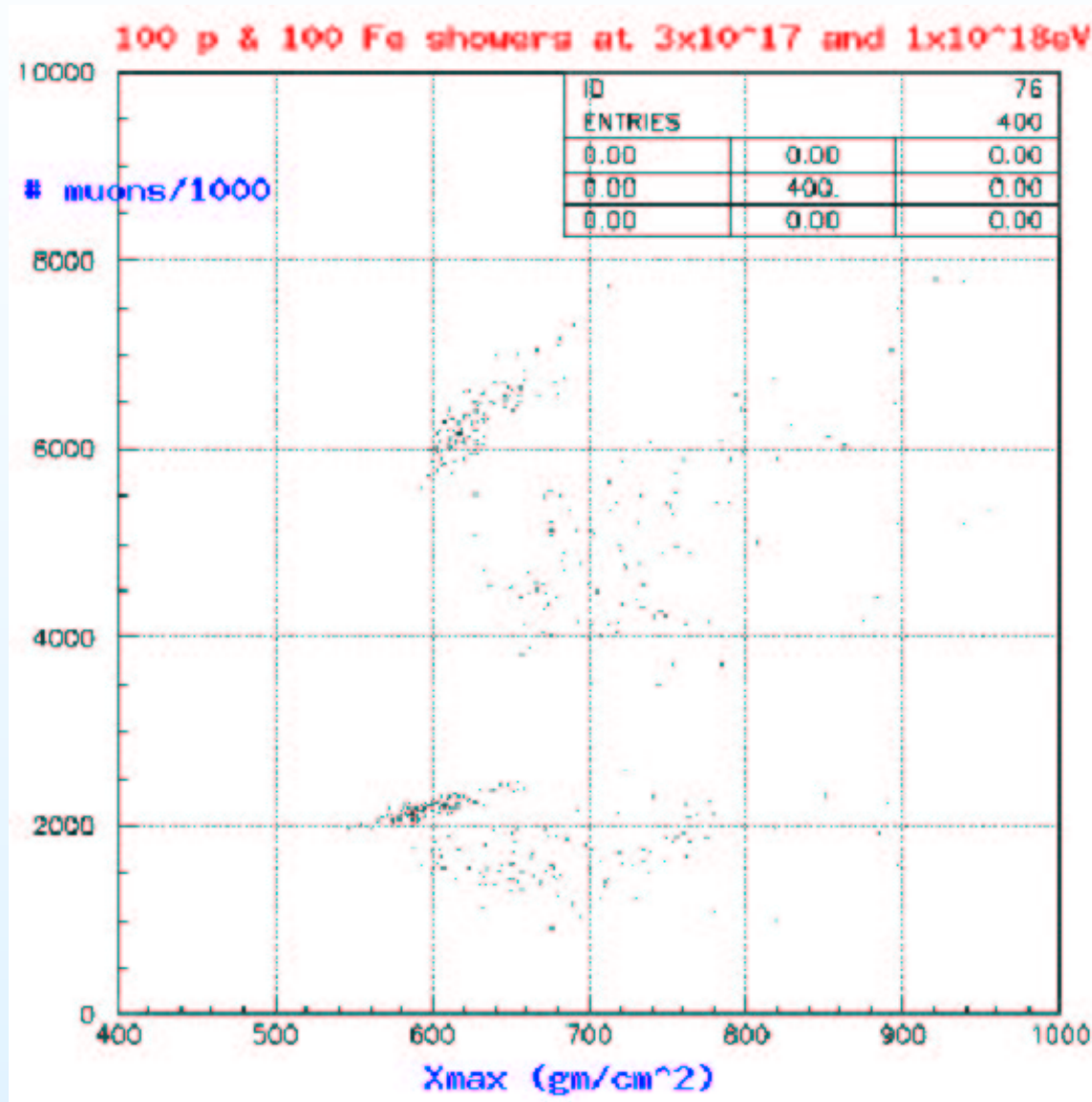
- Simulations show some “p” and “Fe” differences
- But p and Fe signals are not cleanly separated.

SD “#muons” composition ...



- Simulations show some “p” and “Fe” differences
- But p and Fe signals are not cleanly separated.

Hybrid composition ... a new way of thinking

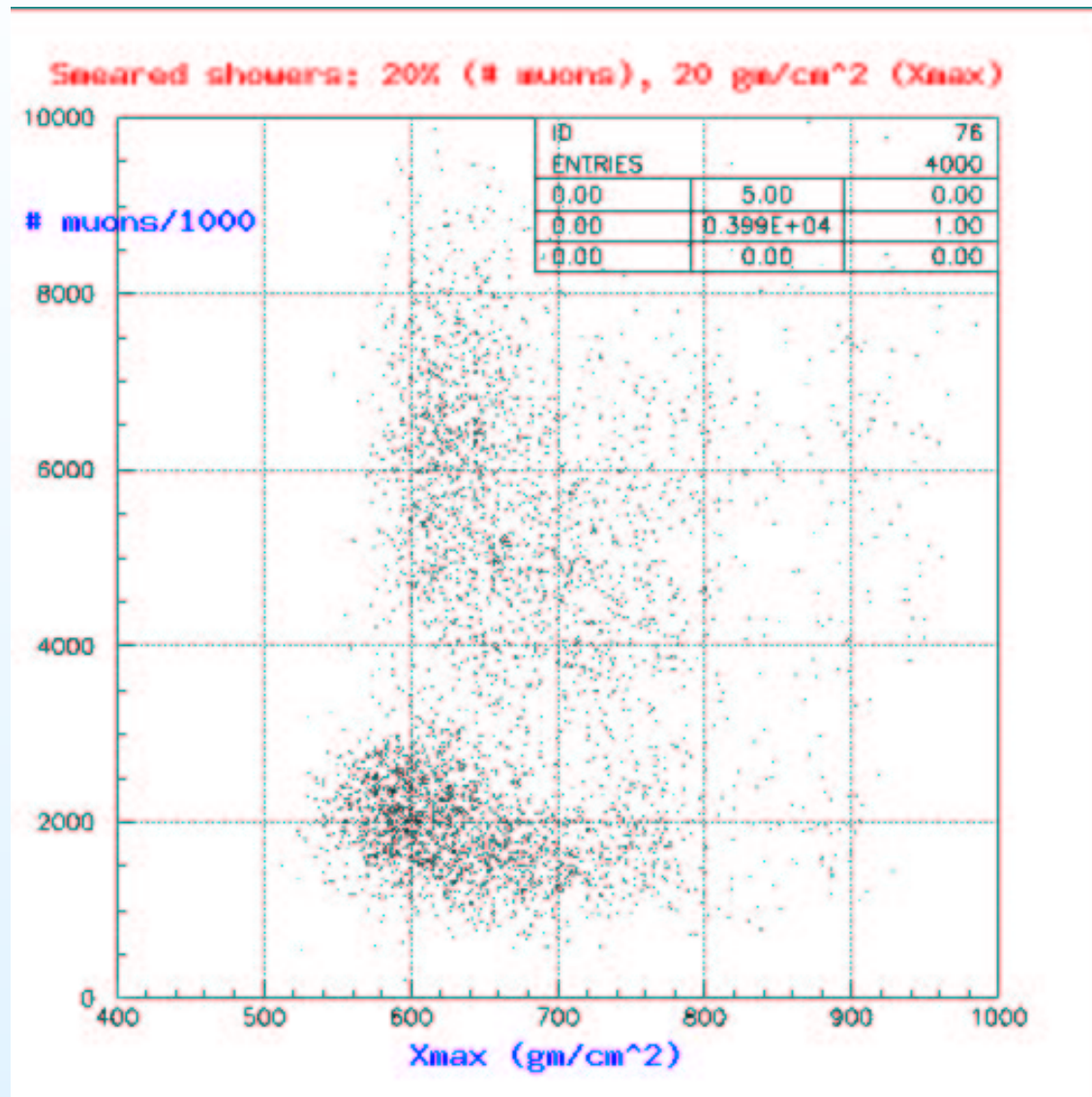


- To 0th order
#muons (at
ground level)
and shower
 X_{max} are un-
correlated

Hybrid composition ... a new way of thinking

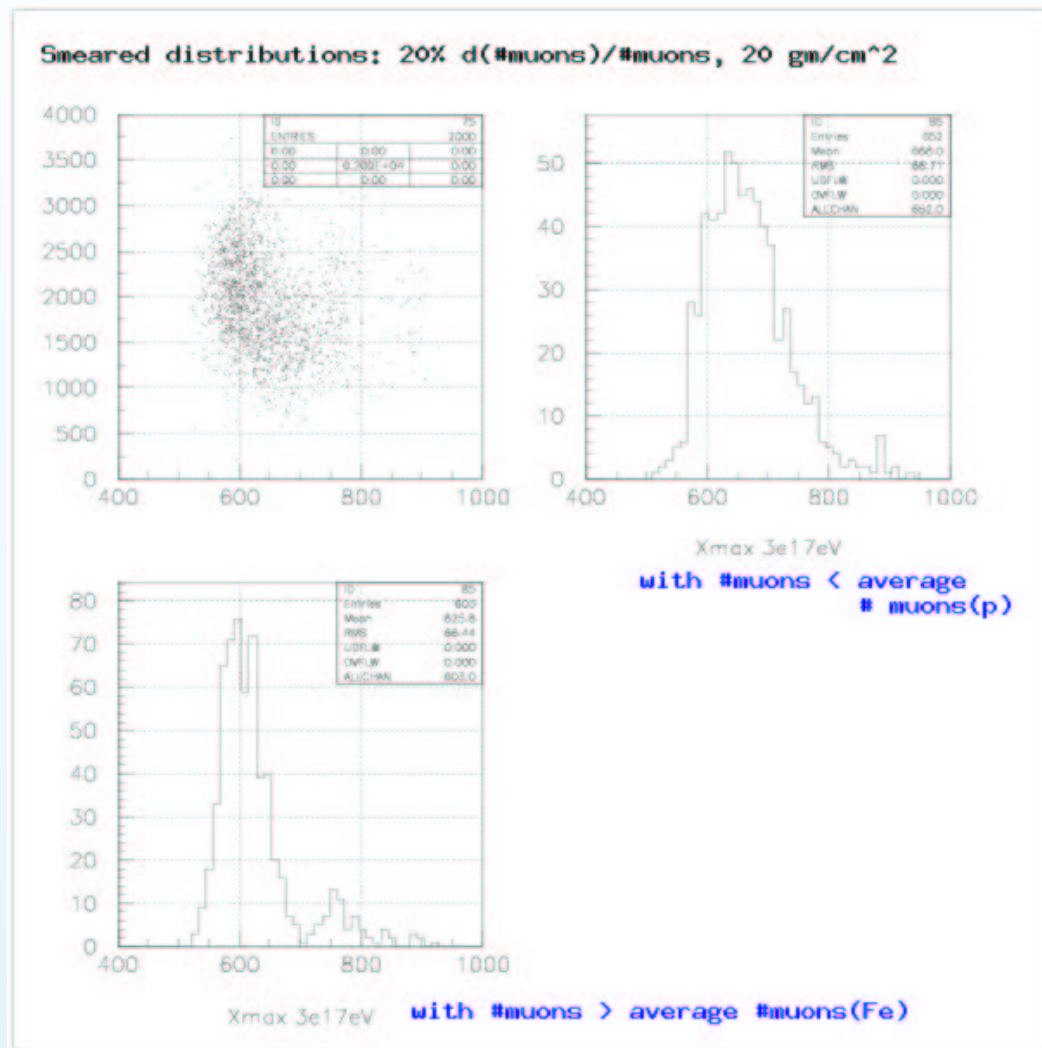
- The #muons (at ground level) and shower X_{max} depend on the primary cosmic ray composition: p or Fe or ...
- The width and separations of the #muons and X_{max} distributions for p and Fe are rather similar
- **Event by event measurement of shower #muons and X_{max} can (potentially) distinguish proton from iron showers.**

Hybrid composition ... with detector resolution!



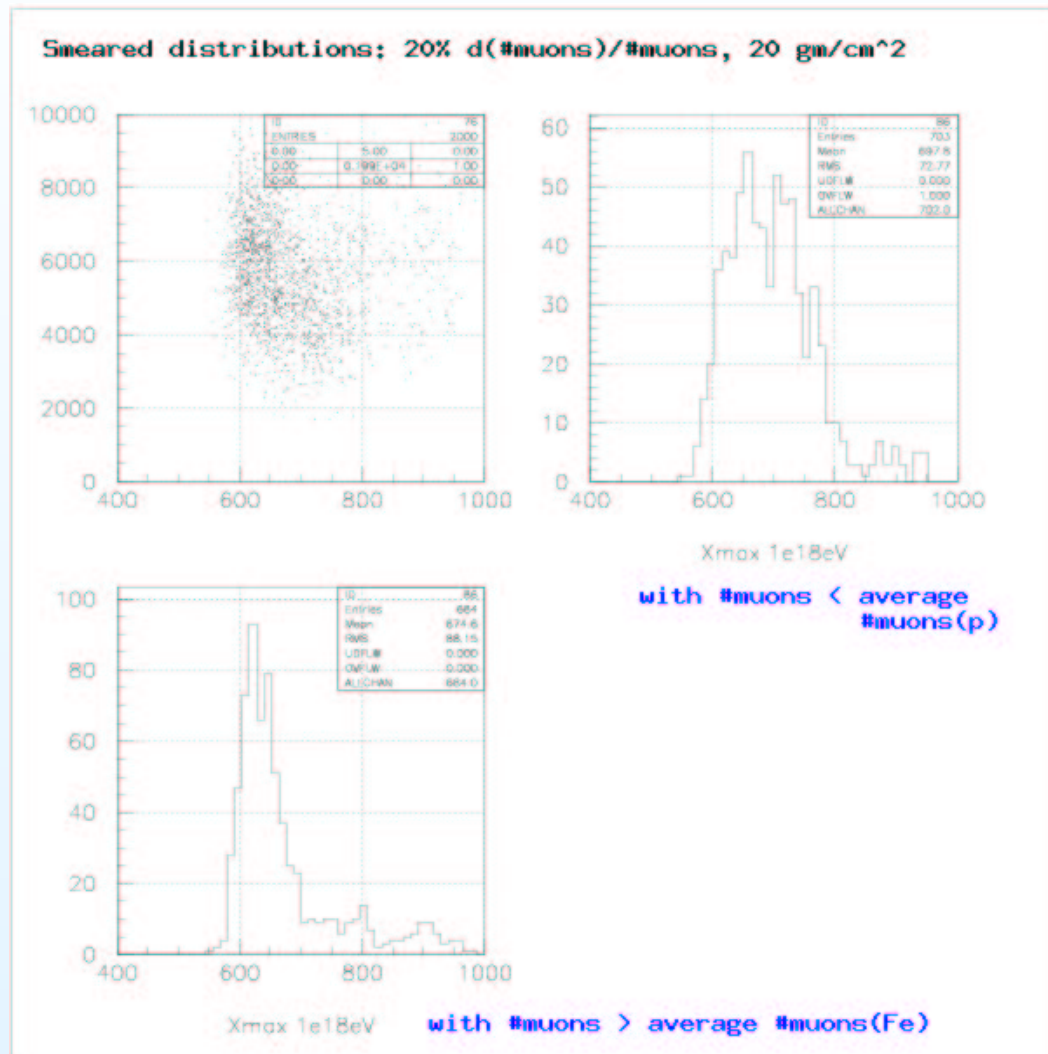
- With detector resolution the $p:Fe$ separation is much less clear
- ... and 20% #muons resolution may be difficult to achieve!
- So for hybrid composition the #muons and X_{max} resolutions are critical!

Hybrid composition ... toy analysis at 3×10^{17} eV!



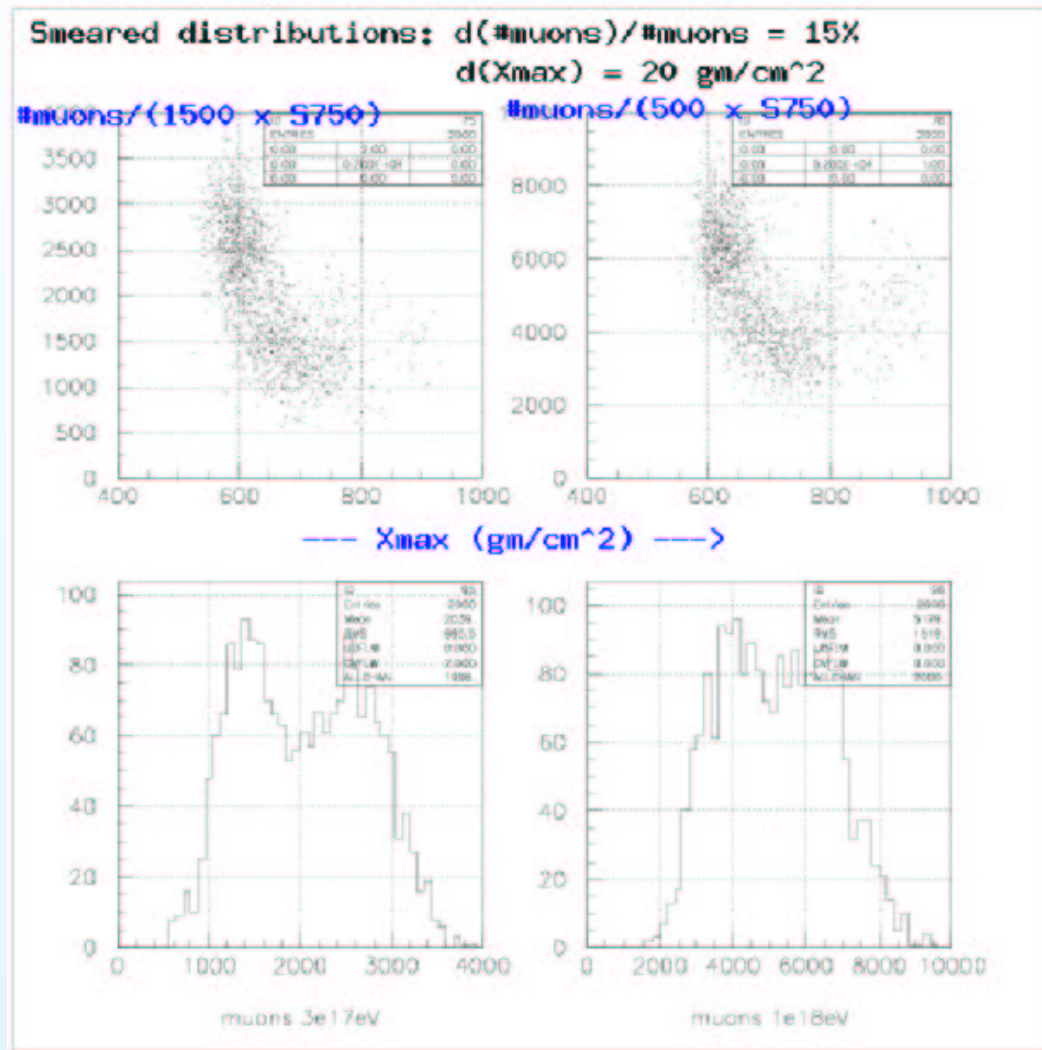
- Use e.g. #muons signal to enhance X_{max} measurement
- Look at X_{max} projection requiring #muons either $\geq \langle \#muons \rangle_{Fe}$ (more pure iron sample), or $\leq \langle \#muons \rangle_p$ (more pure proton sample).

Hybrid composition ... toy analysis at 10^{18} eV!



- Use e.g. $\#muons$ signal to enhance X_{max} measurement
- Look at X_{max} projection requiring $\#muons$ either $\geq < \#muons >_{Fe}$ (more pure iron sample), or $\leq < \#muons >_p$ (more pure proton sample).

Hybrid composition ... could scintillators help?

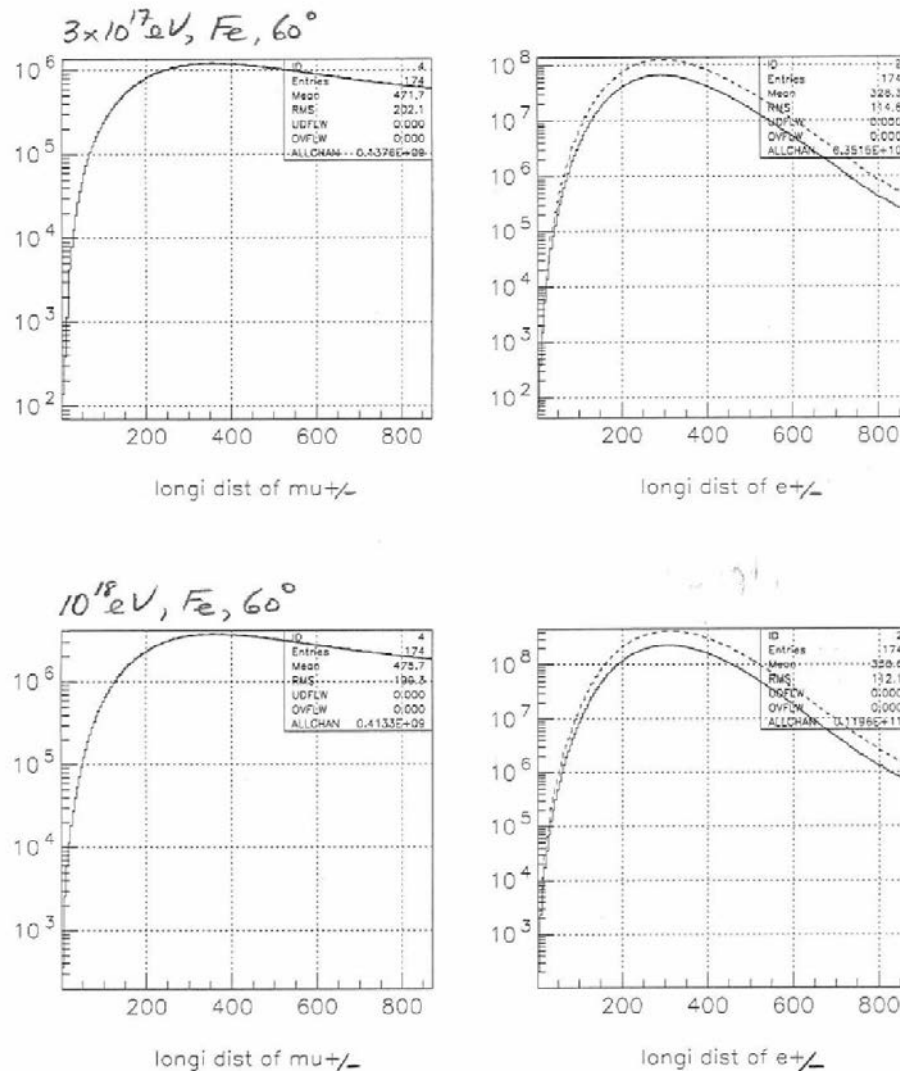


- What if Auger includes scintillators (sensitive to $e^\pm$)?
- Then analyze scatter plot of $\#muons/S_{750}$ versus X_{max} (... because we might expect a more precise measurement of $\#muons/S_{750}$ than of $\#muons$).

Hybrid composition ... for Auger South Upgrade!

- **Goal:** true *hybrid* composition measurement starting at $\sim 10^{17}$ eV
- **ADD** e.g. ~ 100 **muon-detectors** ...
 1. 7×7 array on 300m separation (3.2 km^2 area) [targeting $\geq 10^{17}$ eV showers] within
 2. effectively 8×8 array on 600m separation (17.6 km^2 area) [targeting $\geq 10^{18}$ eV showers]
- **ADD FD detection up to viewing angles $\sim 60^\circ$ to the horizontal.**
- How best to do *muon detectors* is not clear ... but the area of each should be quite large (maybe $25 \sim 50 \text{ m}^2$ from Corsika simulations)!

#muons measurement ... maybe use the atmosphere?



- For highly inclined showers the muons are the signal at the SDs ... although the muon flux is reduced vs more vertical showers!
- What is the *hybrid* acceptance for these showers?

Hybrid composition ... for Auger South Upgrade!

- Composition analyses above $\sim 10^{17}$ eV would benefit from simultaneous (per event) **#muons** and X_{max} measurements ... this is what we call *hybrid*!
- A *hybrid* composition measurement is not the most important Auger measurement ... but it is not the least important either!
- We should be sure that our measurements are of sufficient precision ... this may be a challenge for both the **#muons** and X_{max} measurements ... **but that is why they are candidate Auger South Upgrades!**
- This is technically possible ... **but what is the cost and human effort required?**

Hybrid composition ... other considerations (**Auger North**)

- Auger South Upgrades should help, not hurt, progress to Auger North!
- Is Auger South the only, and/or best, place to do *hybrid composition*?
- IF #muons detectors are a good idea, then is siting at a scintillator SD-array (e.g Telescope Array) preferable?
- And are more groups interested than just current Auger groups? Is this a way to bring together all UHECR groups into a common quest?
- Thus: can this also be the beginnings of Auger North?
- Something to think about ...