Composition and Muon Counters

-and your point is-

Are we serious about Cosmic Ray Composition?

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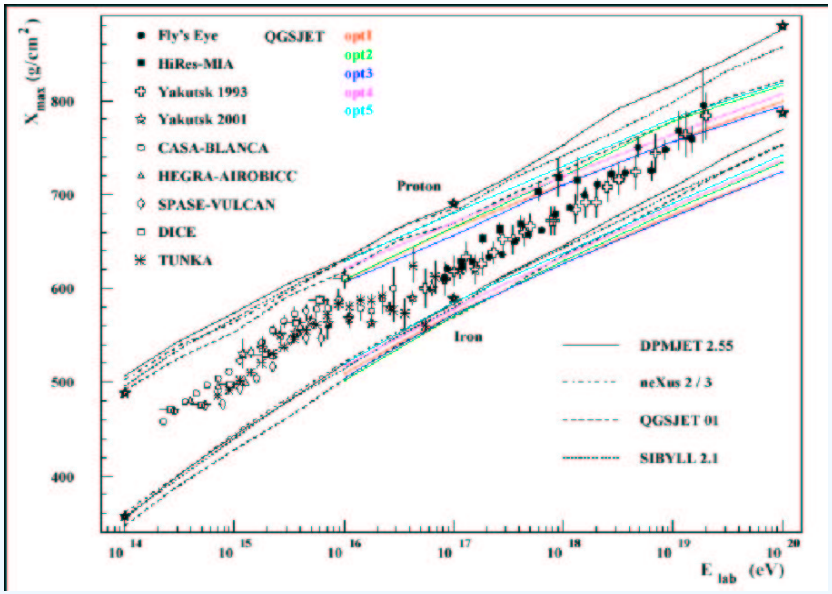
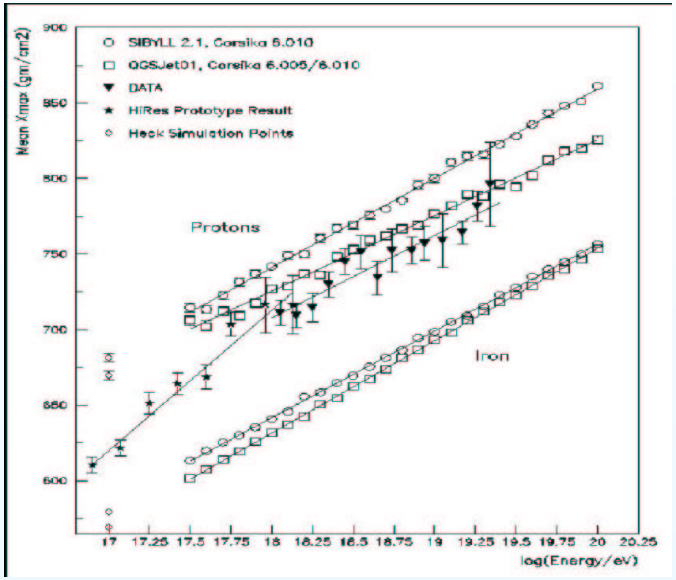
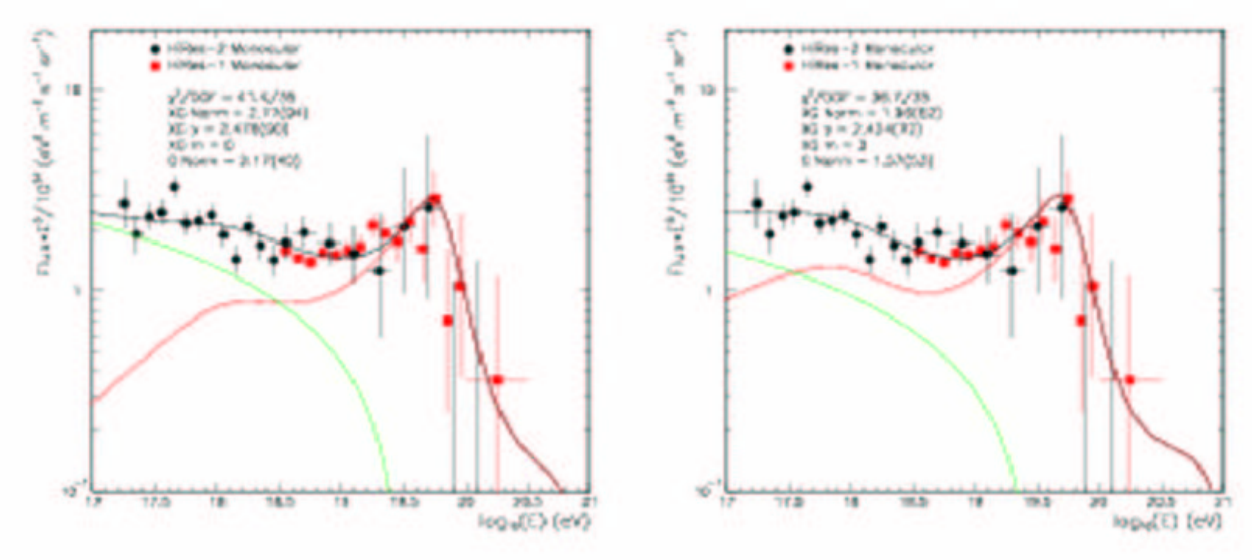
Composition ... it is more than $< X_{max} >$





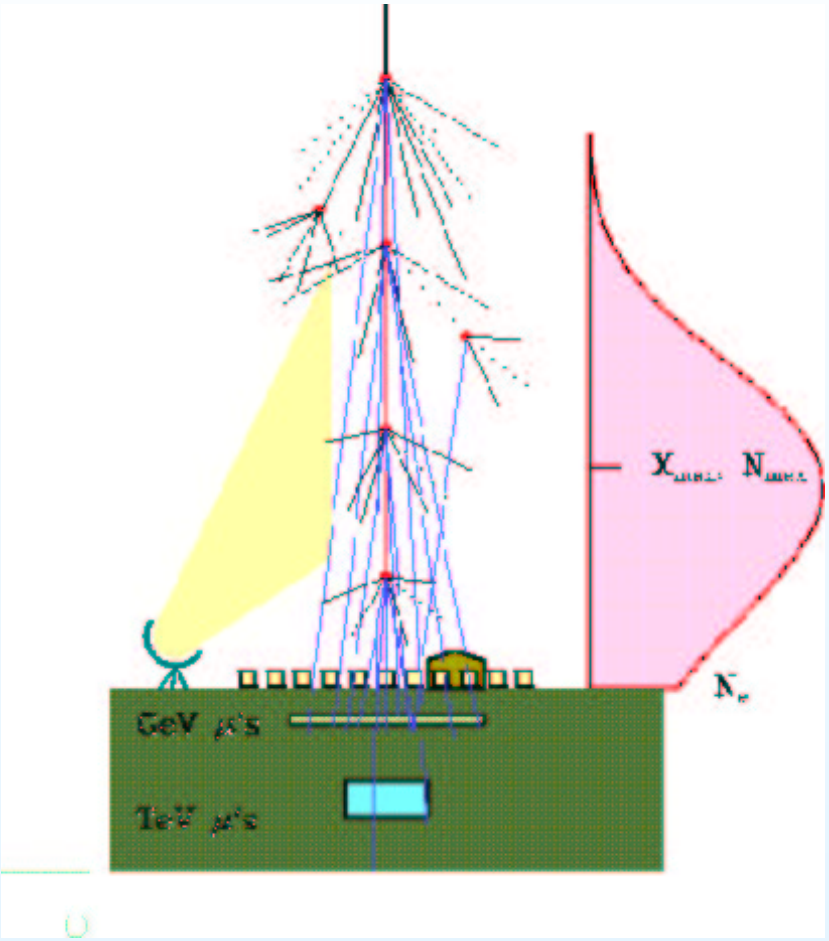
- Clear *trends* but are they correct?
- How do we interpret $< X_{max} >$ (above $\sim 4 \times 10^{16}$eV)?
  1. IF 2 components (p and Fe), then potentially straight forward except for the shower simulation uncertainties.
  2. IF *more than* p and Fe, how meaningful is $< X_{max} >$?
  3. And is the composition *pure*-p by 10^{20}eV?

Composition ... the galactic to extra-galactic transition



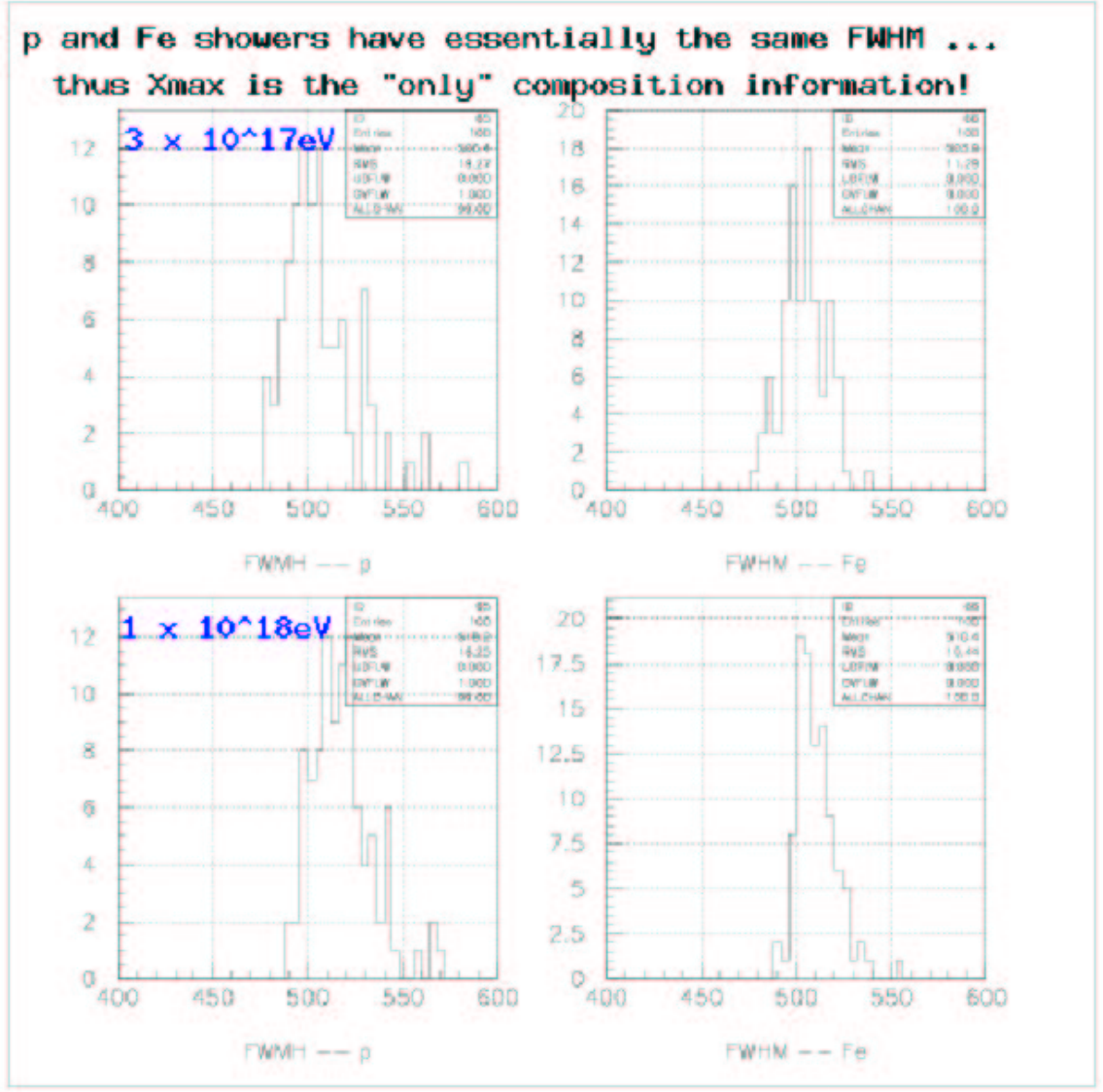
- The *heavy* to *light* transition (above $\sim 4 \times 10^{16}$eV) is believed to be the transition from galactic dominant to extra-galactic dominant CRs.
- **How would we know?** And is **the transition essentially complete by 5×10^{17}eV, or by 10^{18}eV, or not until $> 10^{19}$eV?**
- *GZK-modelers*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



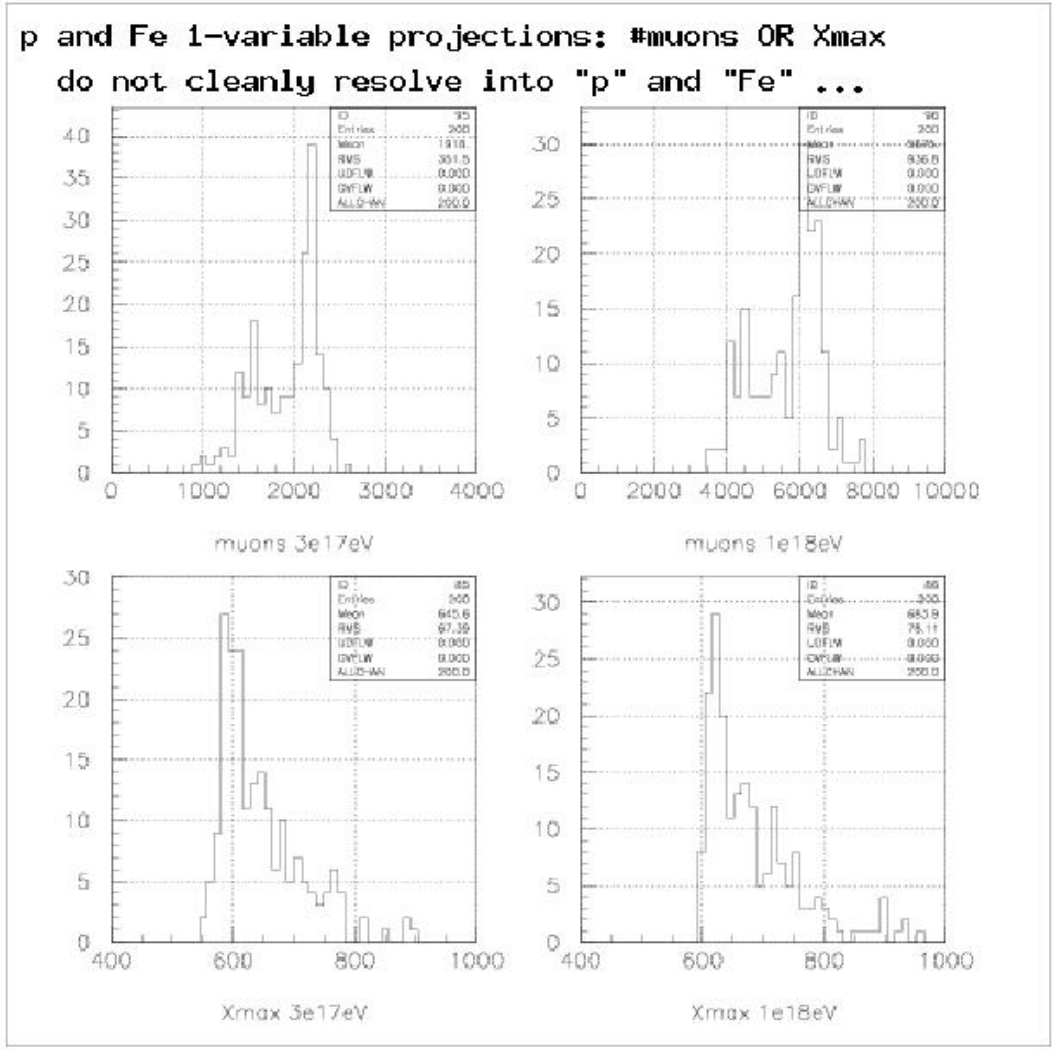
- **E**$_{primary}$ measurement:
  1. SD: based on ρ_{1000}, chosen to minimize shower to shower fluctuations (in this measurement) ... **but with some muon cross-talk!**
  2. FD: $\frac{dE}{dx}|_{1.4MeVe} \int N^{fit}_{1.4MeVe}(x)dx$, based on the "1.4 MeV electron" air fluorescence-yield calibration.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



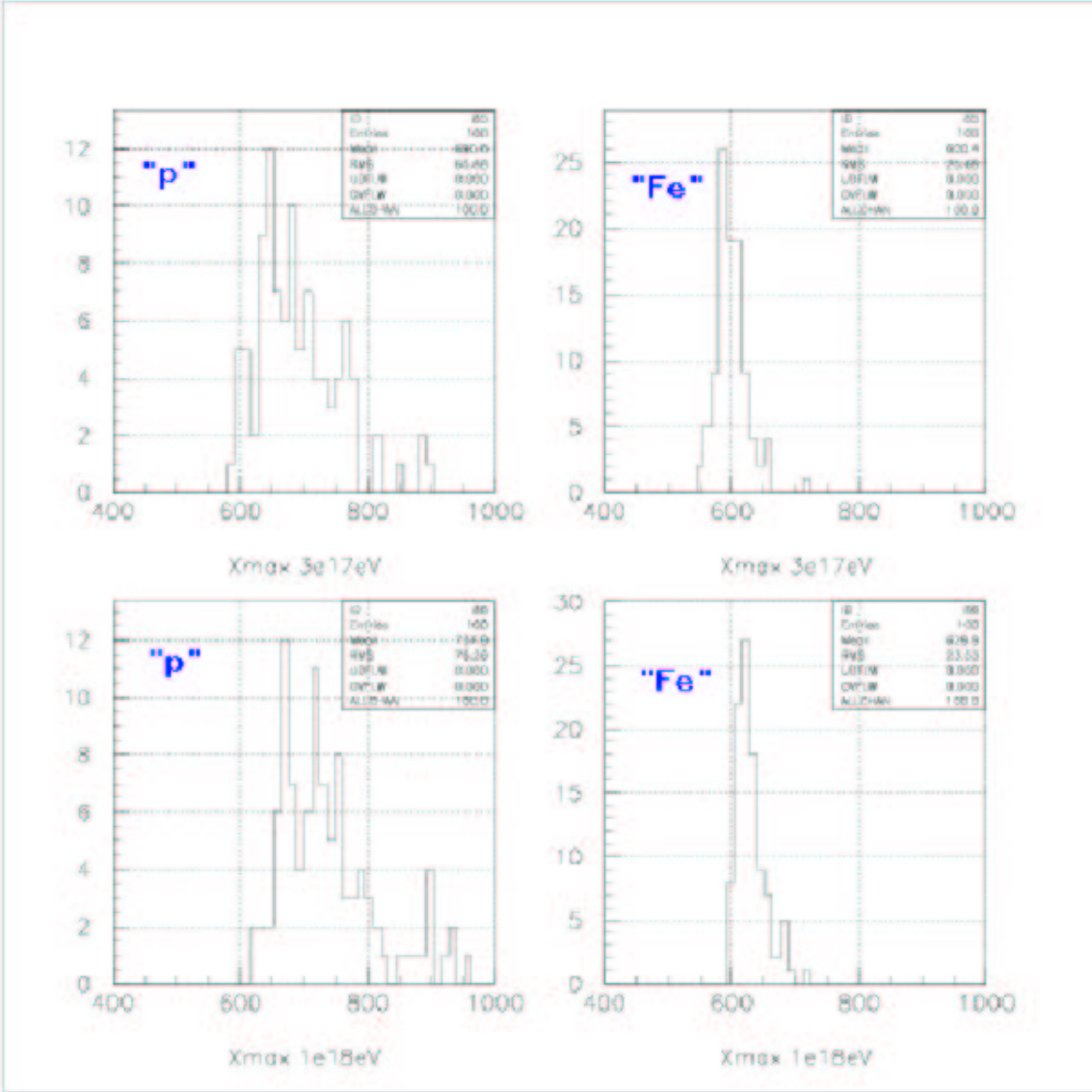
- Unfortunately shower simulations predict similar FWHM for p- and Fe-showers

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



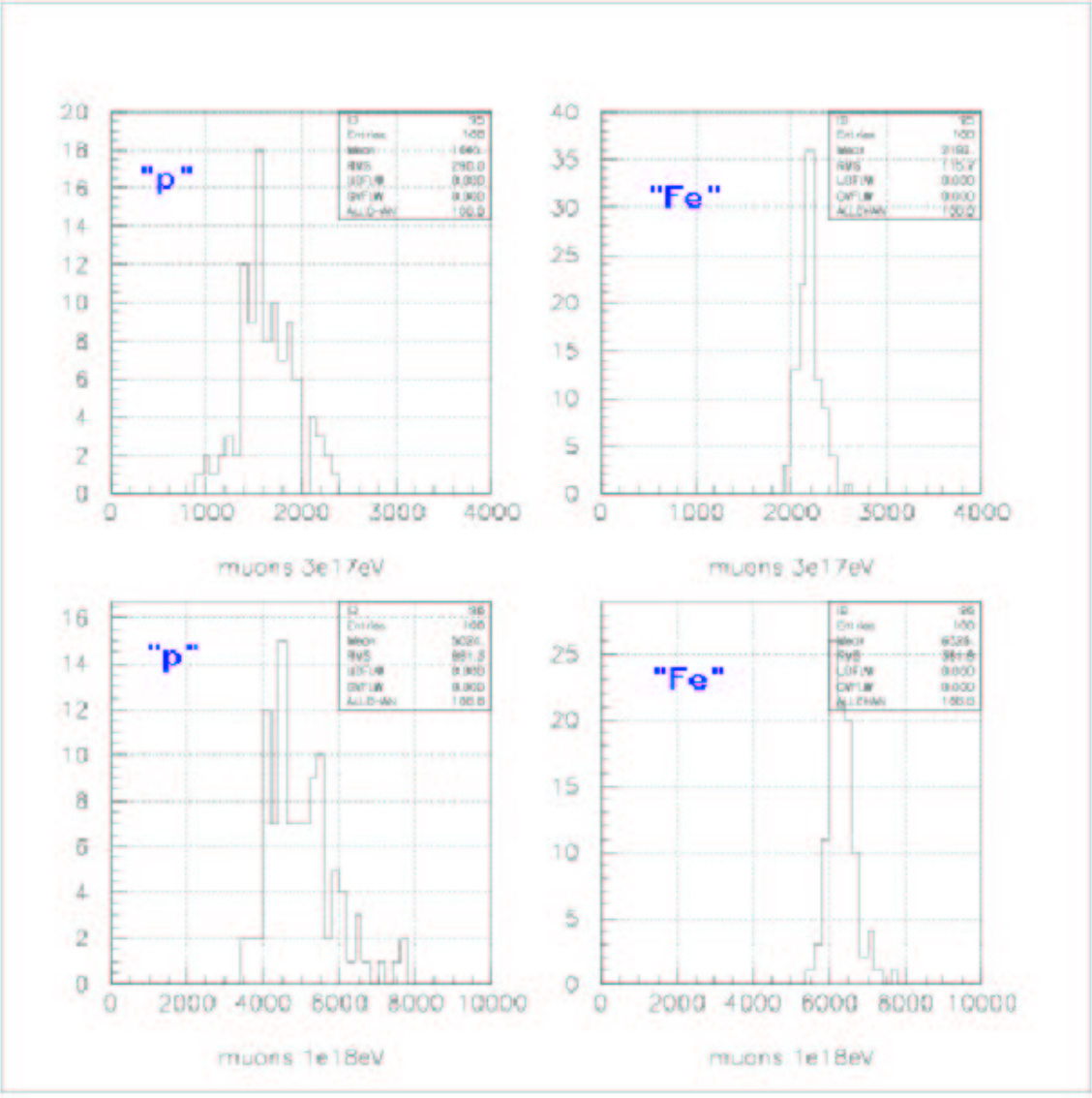
- Plots show combined predictions from 100-p and 100-Fe simulations
- (Ideal) "**#muons**"-only and/or "X_{max}"-only measurements do not show separated "p" and "Fe" components

FD "X_{max}" composition ...



- Simulations show some "p" and "Fe" differences
- But **p** and **Fe** signals are not cleanly separated.

SD “**#muons**” composition ...



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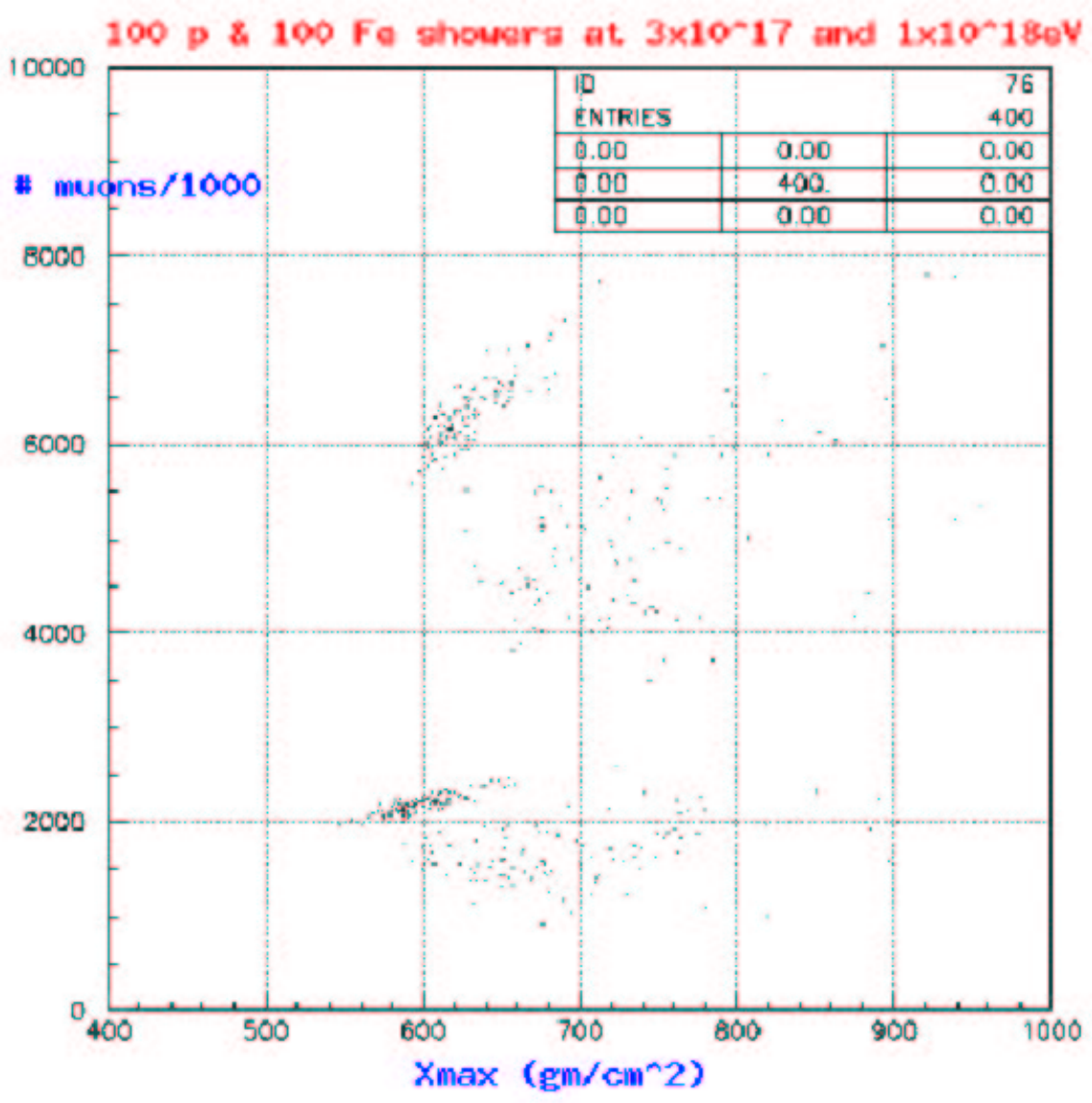
Hybrid composition ... a new way of thinking



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

Hybrid composition ... a new way of thinking

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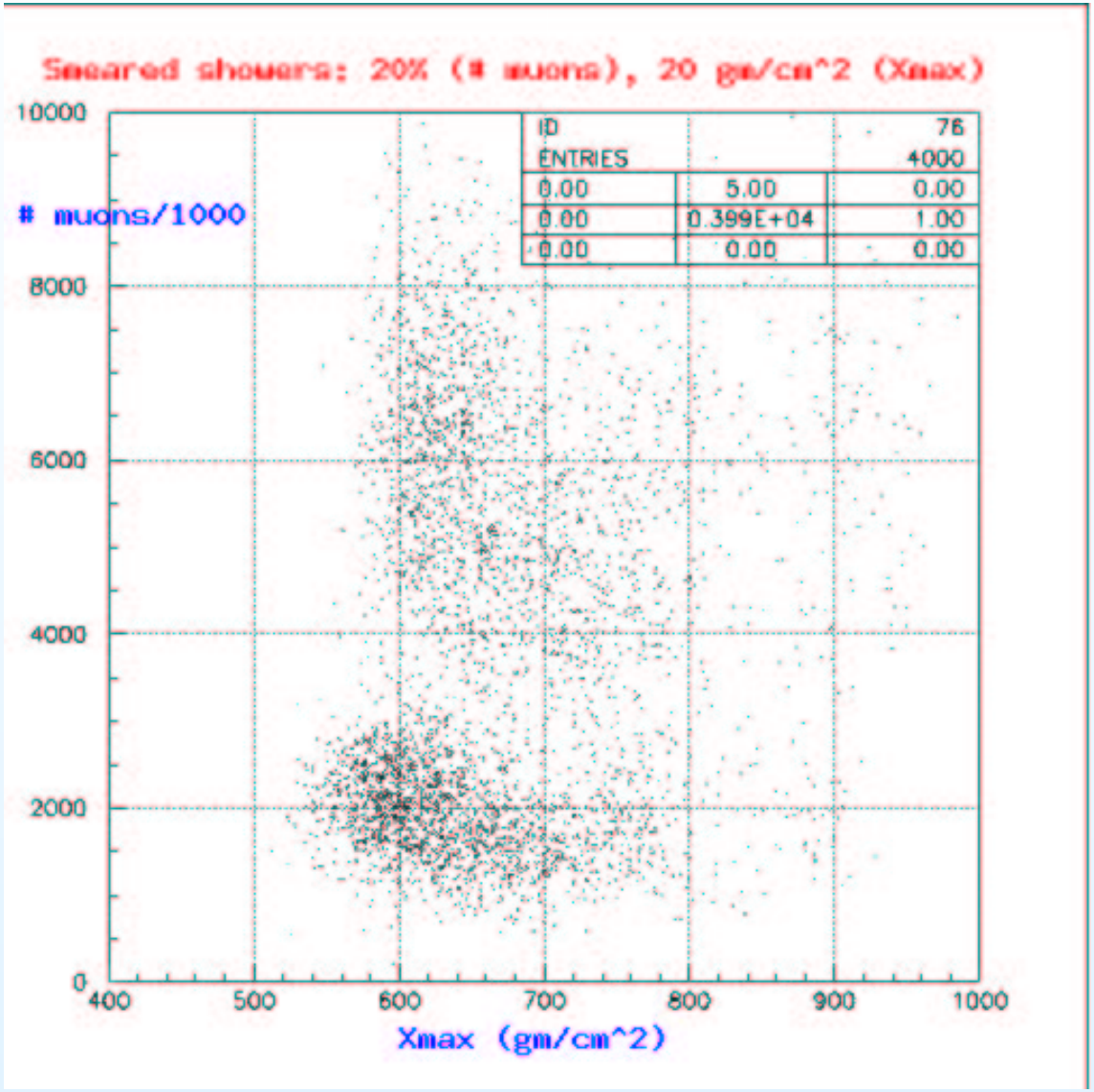
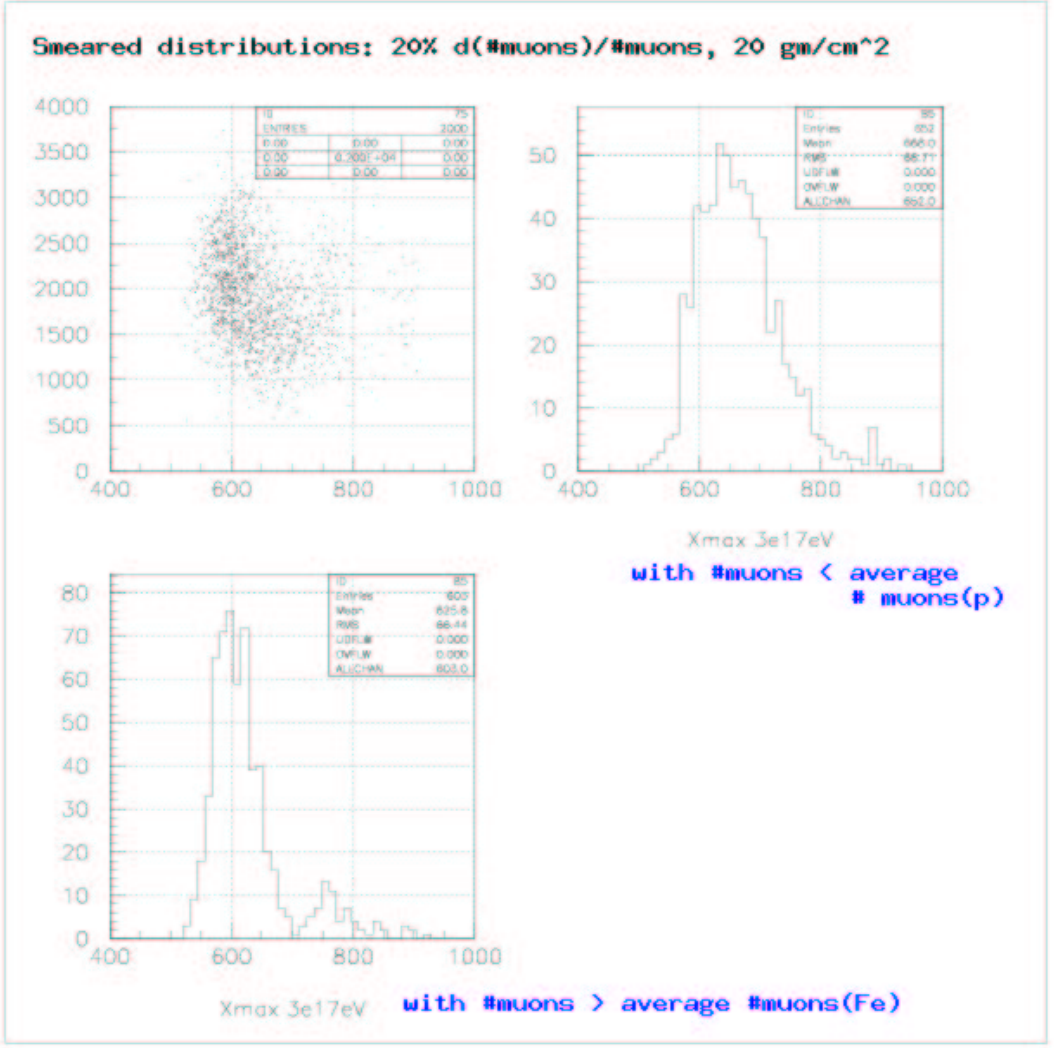
- The **#muons** (at ground level) and shower X_{max} depend on the primary cosmic ray composition: p or Fe or ...
- The width and separations of the **#muons** and X_{max} distributions for p and Fe are rather similar
- **Event by event measurement of shower #muons and X_{max} can (potentially) distinguish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

Hybrid composition ... with detector resolution!



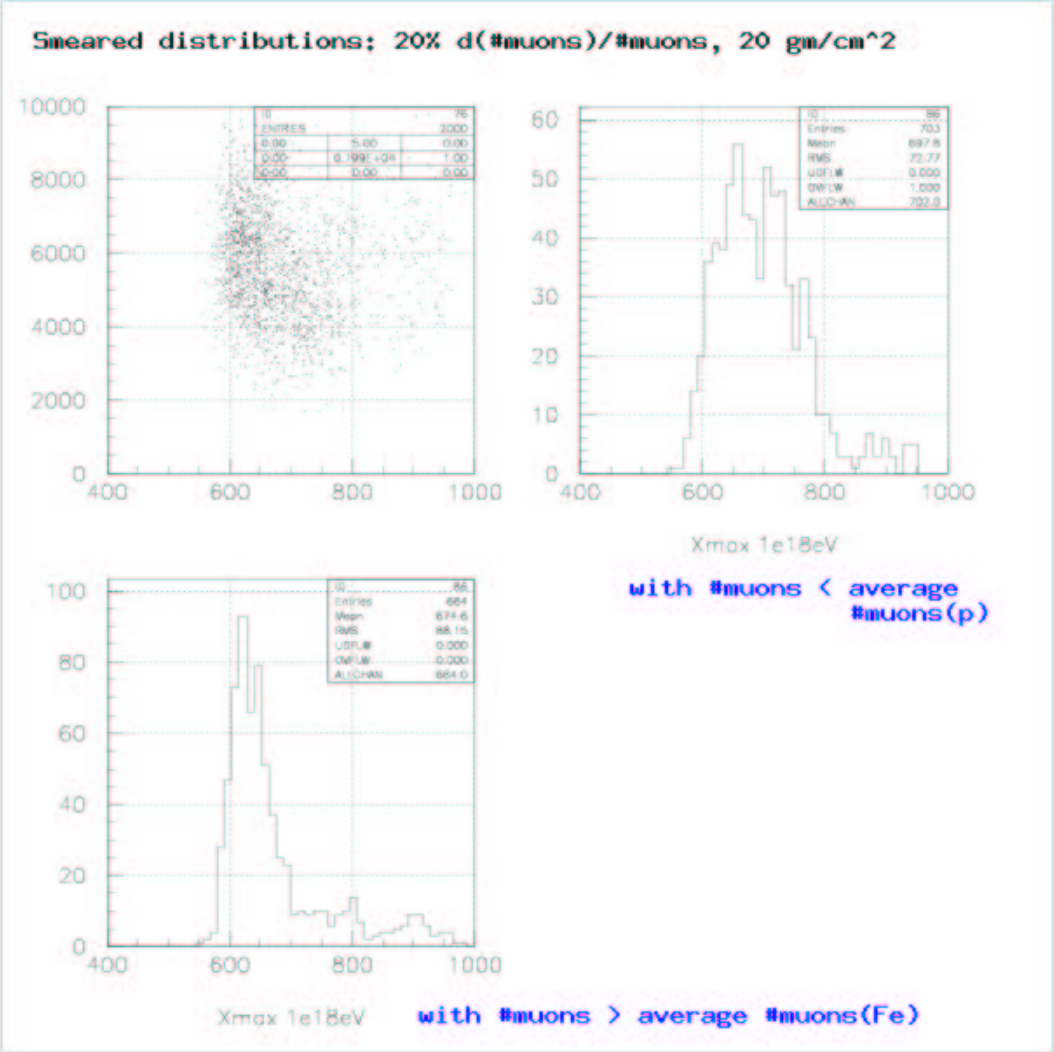
- With detector resolution the p:Fe separation is much less clear
- ... and 20% **#muons** resolution may be difficult to achieve!
- **So for** *hybrid composition* **the #muons and** X_{max} **resolutions are critical!**

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 $\geq \ < \#muons >_{Fe}$ (more pure iron sample), or $\leq \ < \#muons >_{p}$ (more pure proton sample).

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



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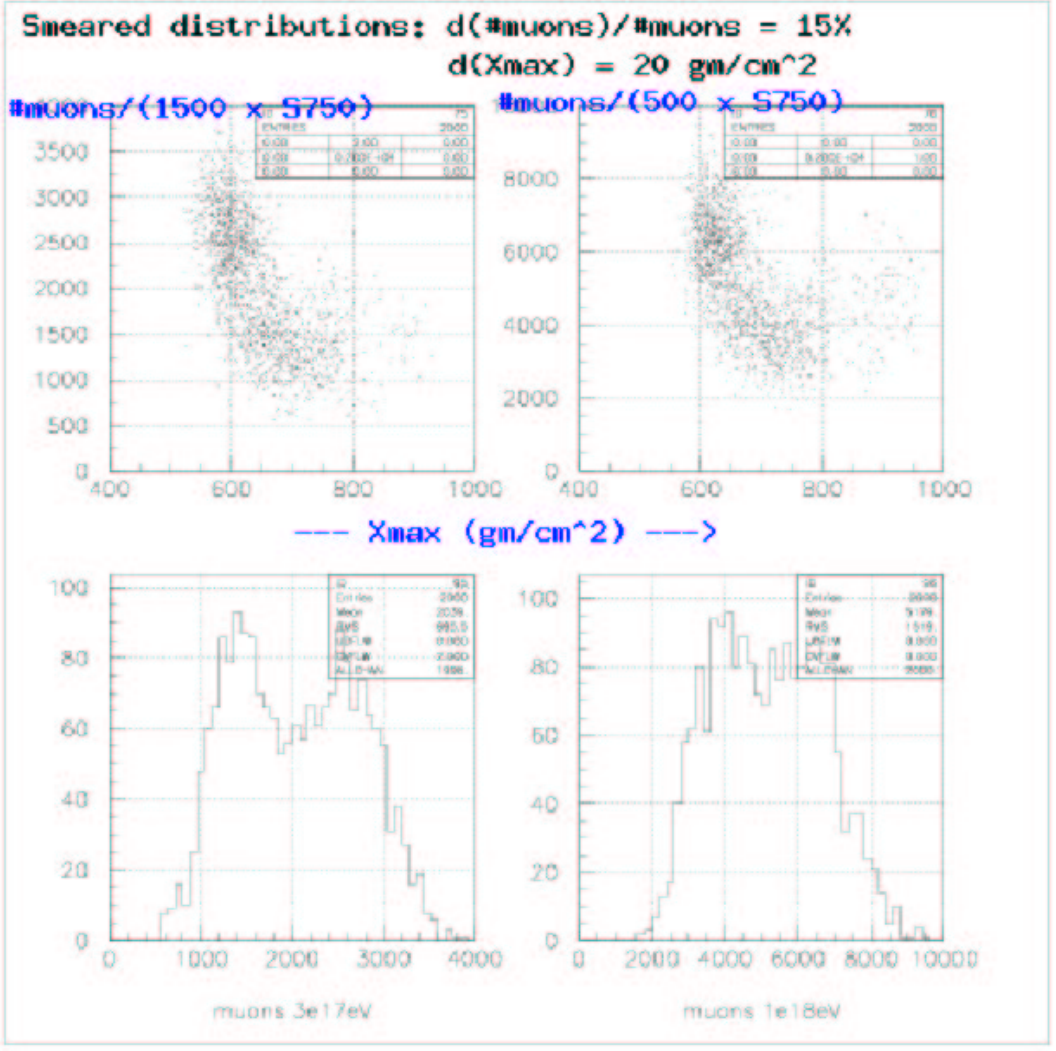
Hybrid composition ... could scintillators help?



- 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!

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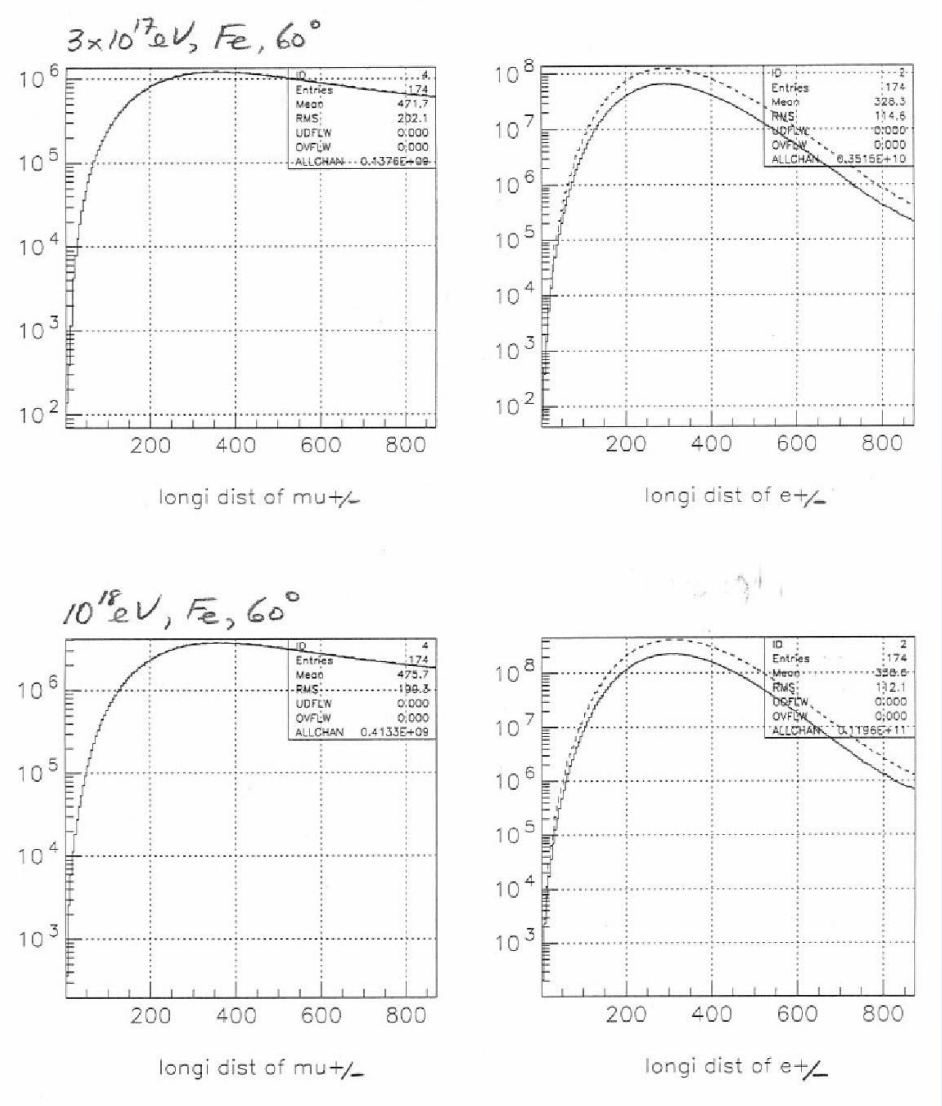
- **Goal**: true *hybrid* composition measurement starting at $\sim 10^{17}$eV

- **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 $\sim$ 50m^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!

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- 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 ...