Composition and Muon Counters

TA Collaboration Meeting

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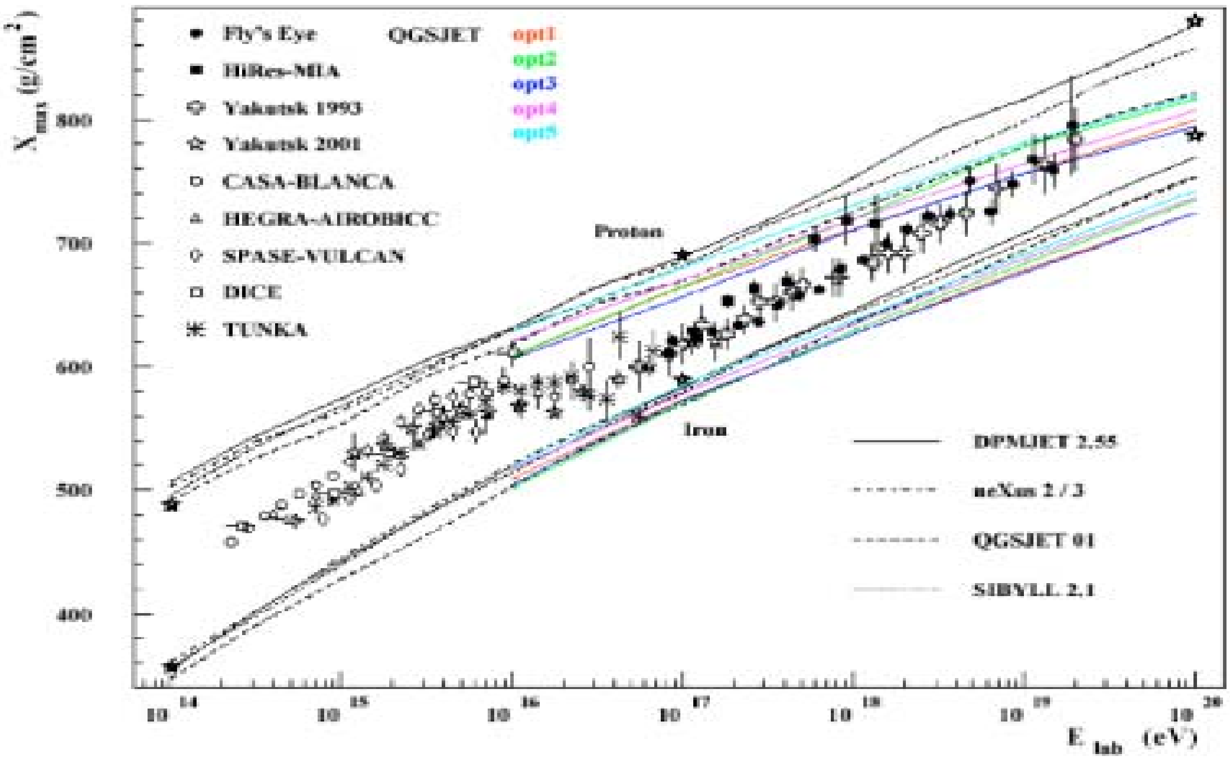
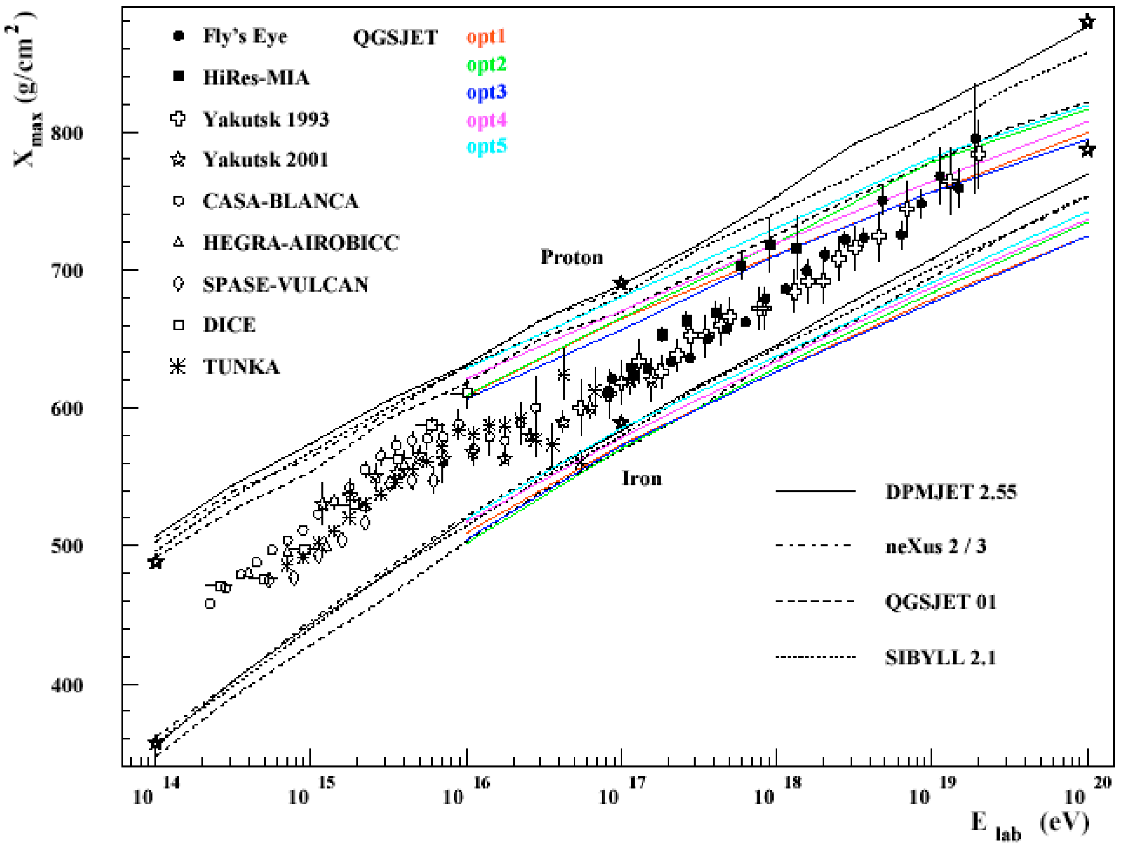
1. Composition ... it is more than $< X_{max} >$
2. SD and FD notes ... so we understand one another
3. *Hybrid* ... a new way of thinking
4. Implications for TA
5. Who is going to do it!

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 straight forward 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!



Fly's Eye
HiRes-MIA
Yakutsk 1993
Yakutsk 2001
CASA-BLANCA
HEGRA-AIROBICC
SPASE-VULCAN
DICE
TUNKA
QGSJET
opt1
opt2
opt3
opt4
opt5
Proton
Iron
DPMJET 2.55
neXus 2 / 3
QGSJET 01
SIBYLL 2.1
X max (g/cm 2)
400
500
600
700
800
10 14
10 15
10 16
10 17
10 18
10 19
10 20
E lab (eV)

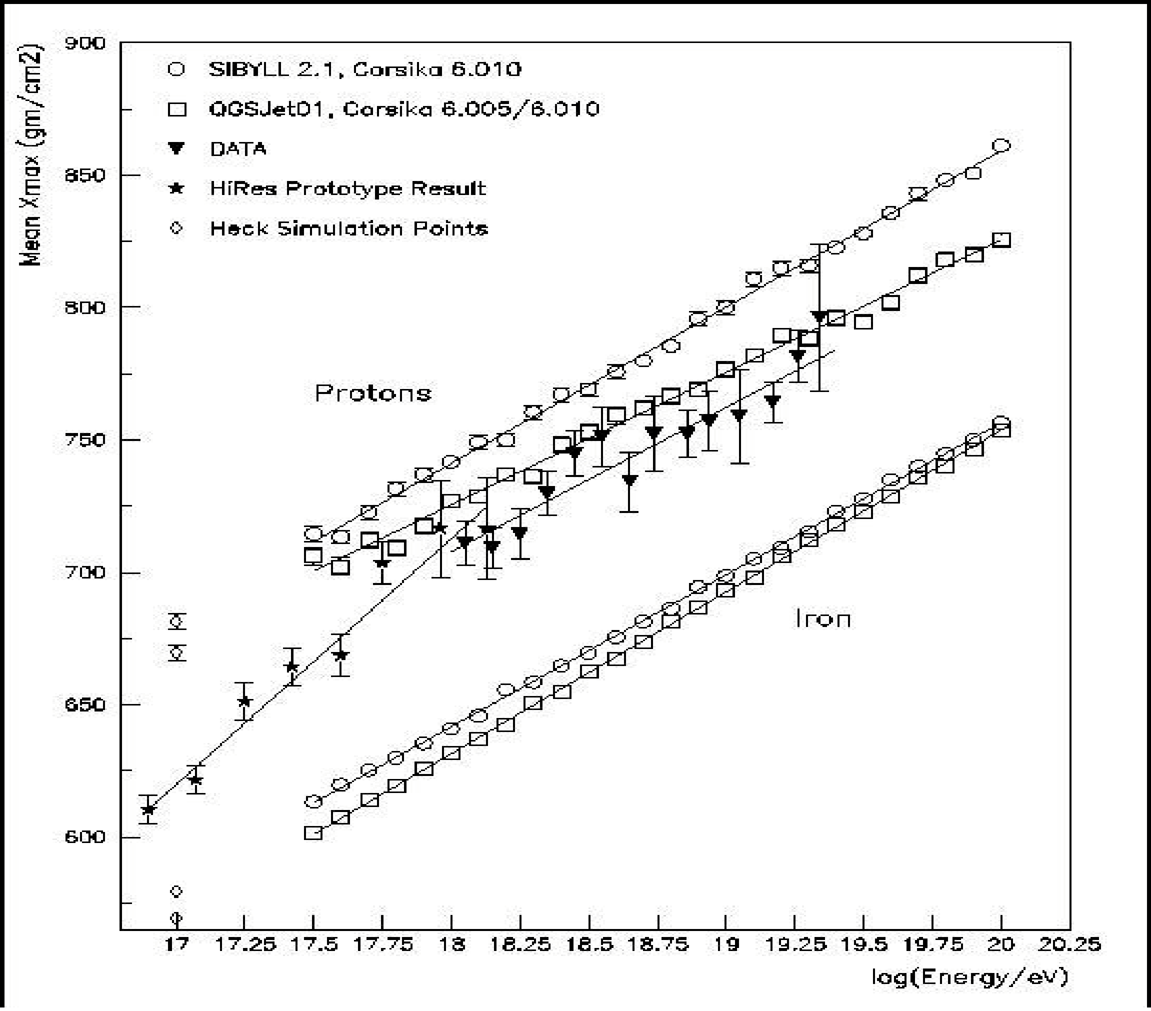
HiRes

Composition: J. Mathews et al. ICRC03

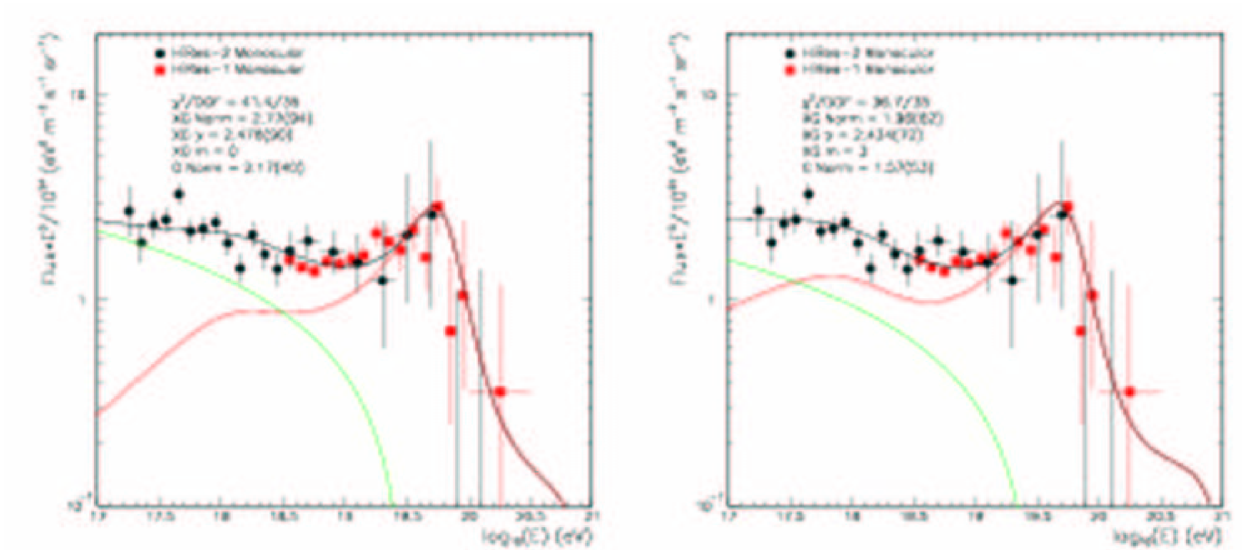
HiRes Stereo: unchanging, light composition above 10^{18} eV
Stereo HiRes and HiRes Prototype-MIA consistent in overlap region

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

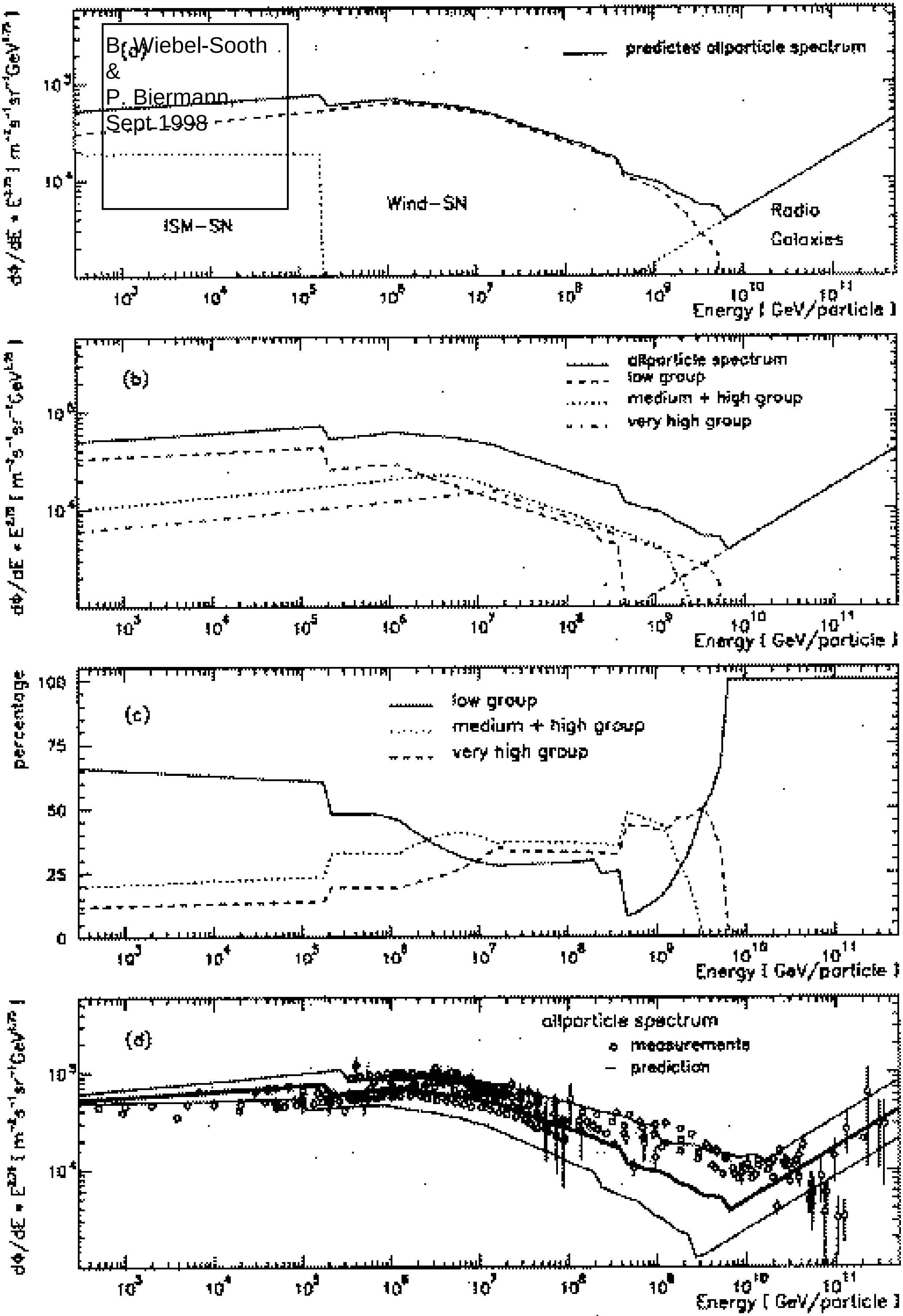


1: Composition ... it is more than $< X_{max} >$ (con't)



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 $(1+z)^3$.

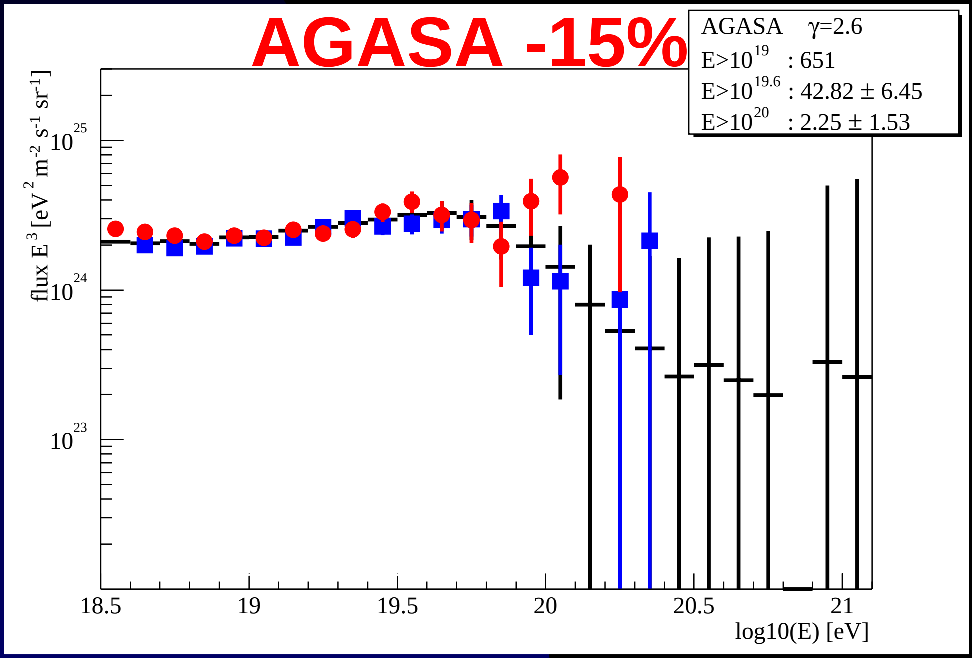
- The *heavy* to *light* transition (above $\sim 4 \times 10^{16}$eV) is believed to be the transition from galactic dominant to extra-galactic dominant CRs. **Is this transition essentially complete by 5×10^{17}eV, or by 10^{18}eV, or not until $> 10^{19}$eV?**
- *GZK-modelers* predict the proton flux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

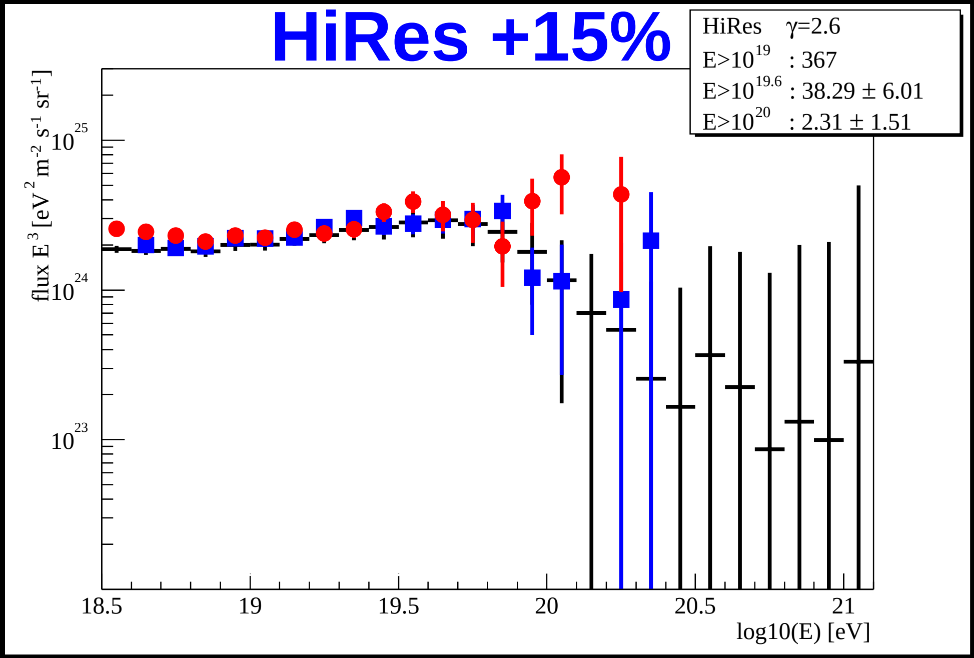


B. Wiebel-Sooth
&
P. Biermann,
Sept 1998
(a)
predicted allparticle spectrum
ISM−SN
Wind−SN
Radio
Galaxies
dΦ/dE * E^2.75 [m^-2 s^-1 sr^-1 GeV^1.75]
Energy [GeV/particle]
(b)
allparticle spectrum
low group
medium + high group
very high group
(c)
percentage
low group
medium + high group
very high group
(d)
allparticle spectrum
measurements
prediction

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





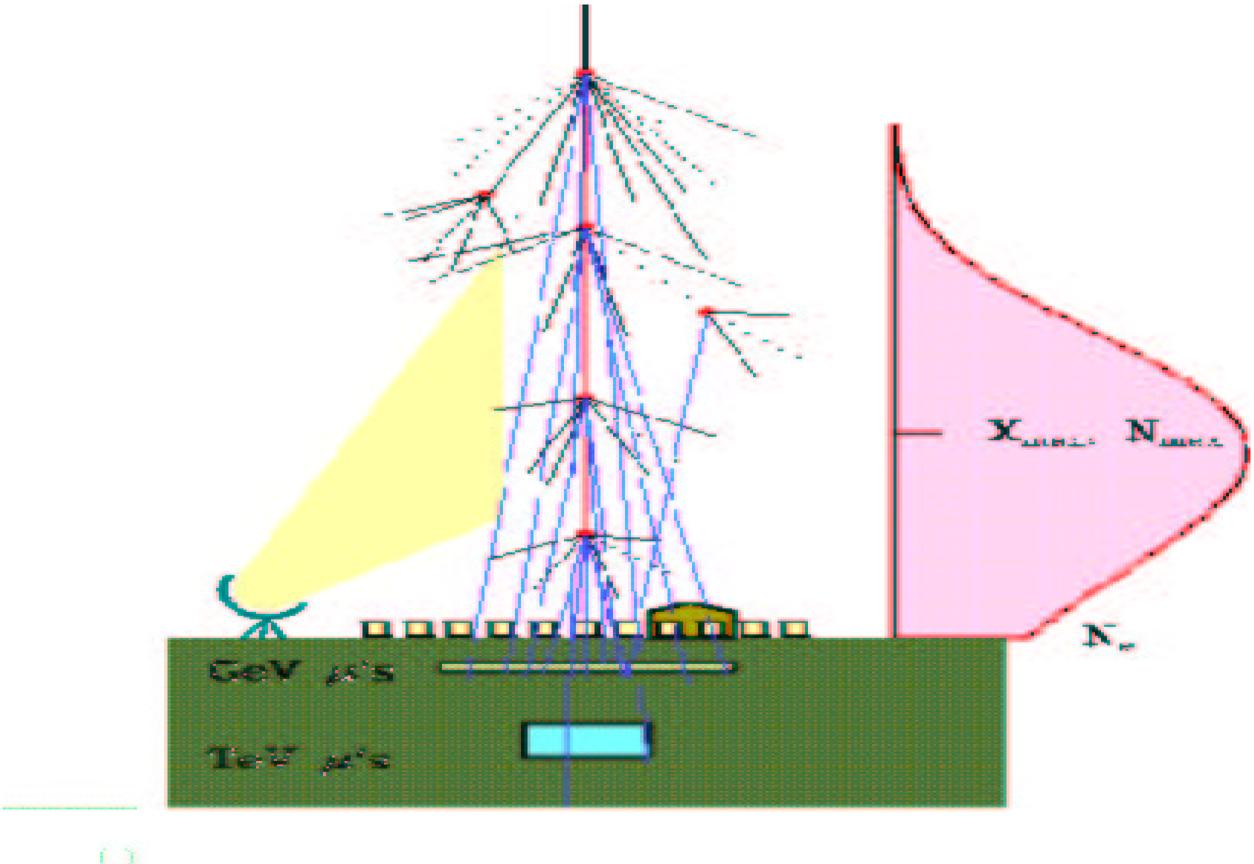
best fit slope: **2.6**

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

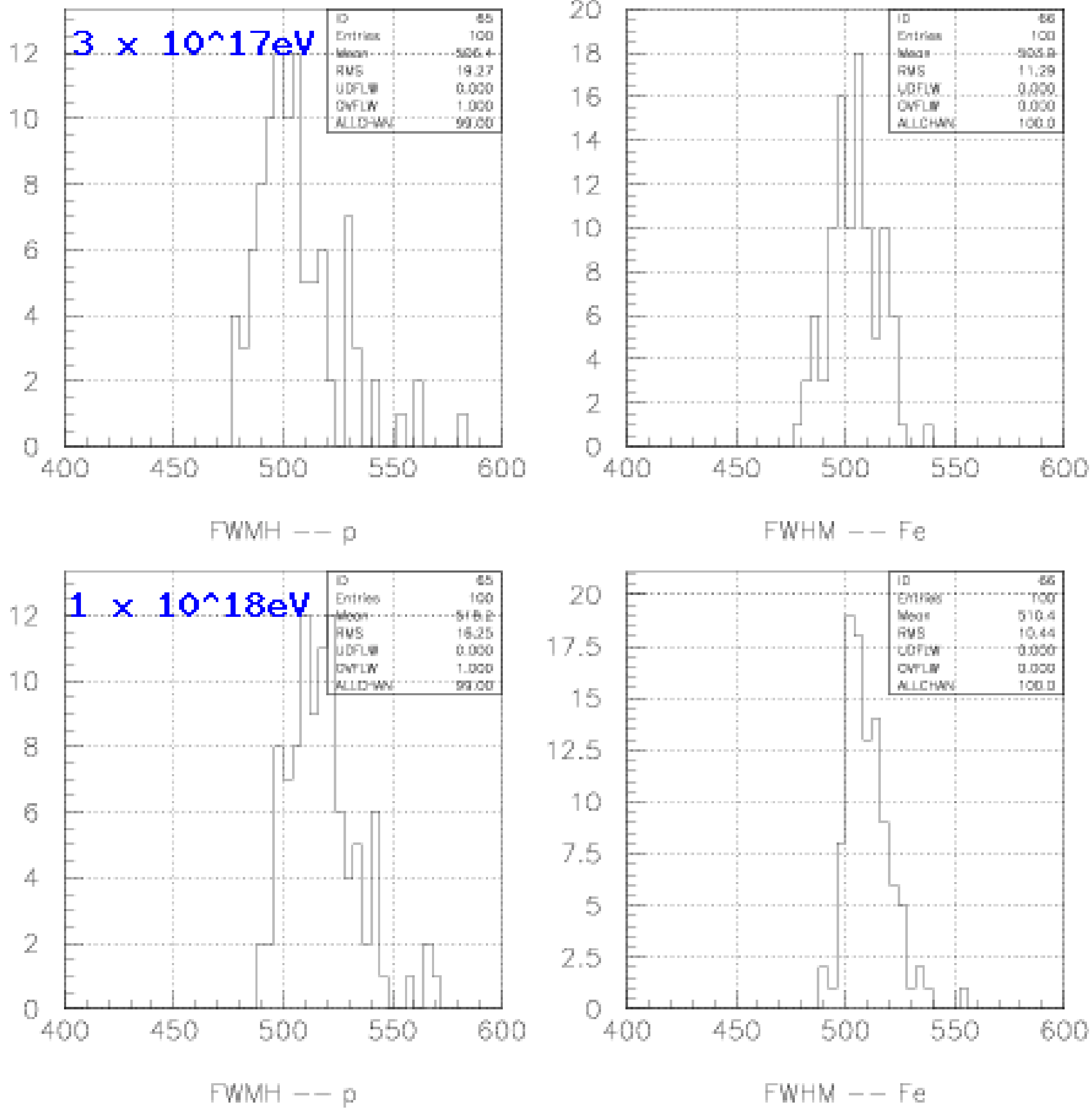


Schematic of extensive air shower ***detection*****.**

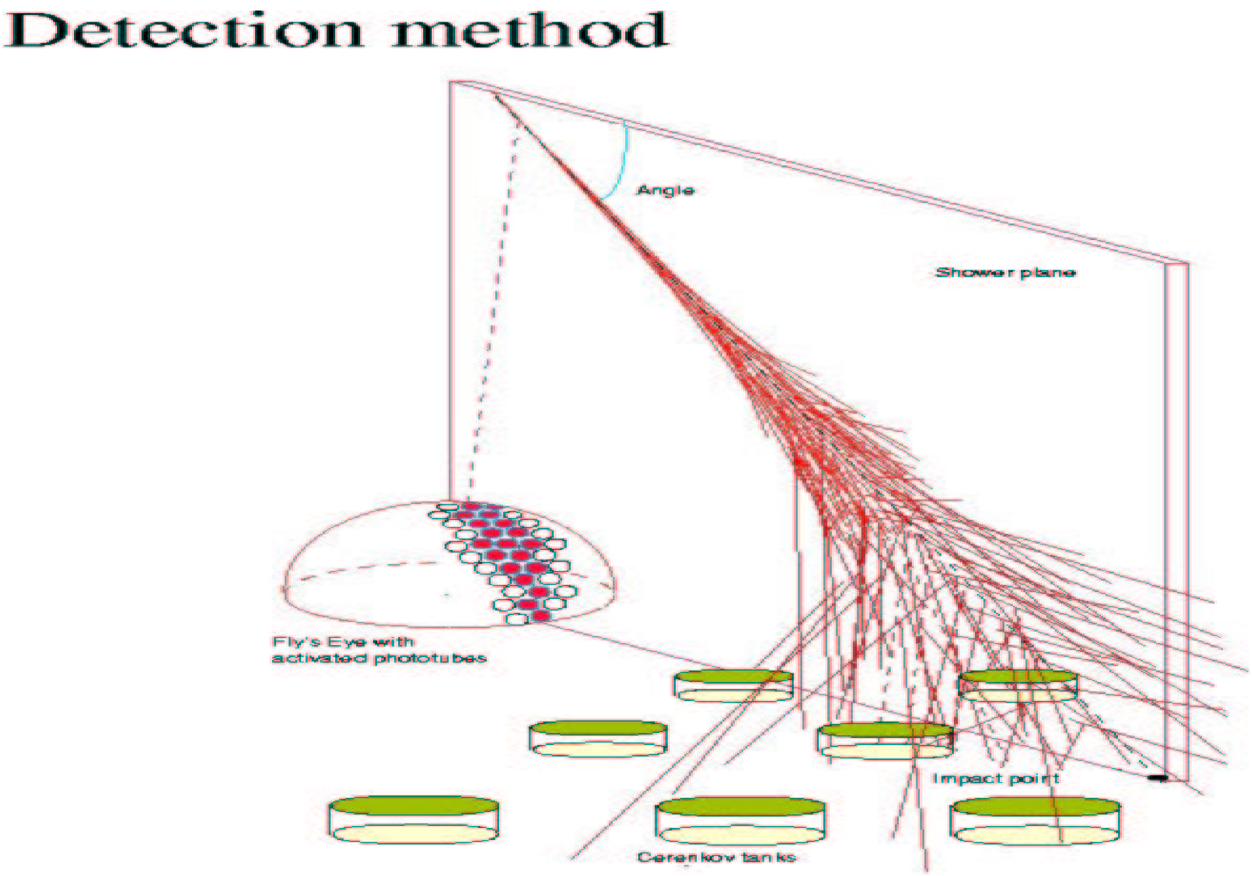
- $\mathbf{E}_{primary}$ measurement:
    1. SD: based on S_{600} or ρ_{1000}, chosen to minimize shower to shower fluctuations (in this measurement).
    2. FD: $\frac{dE}{dx}|_{1.4MeVe} \int N^{fit}_{1.4MeVe}(x)dx$, based on the "1.4 MeV electron" air fluorescence-yield calibration.
- **Composition** measurement:
    1. SD: based on number of muons at ground level
    2. FD: based on X_{max} ... **that is all there is!**

p and Fe showers have essentially the same FWHM ...

thus Xmax is the "only" composition information!



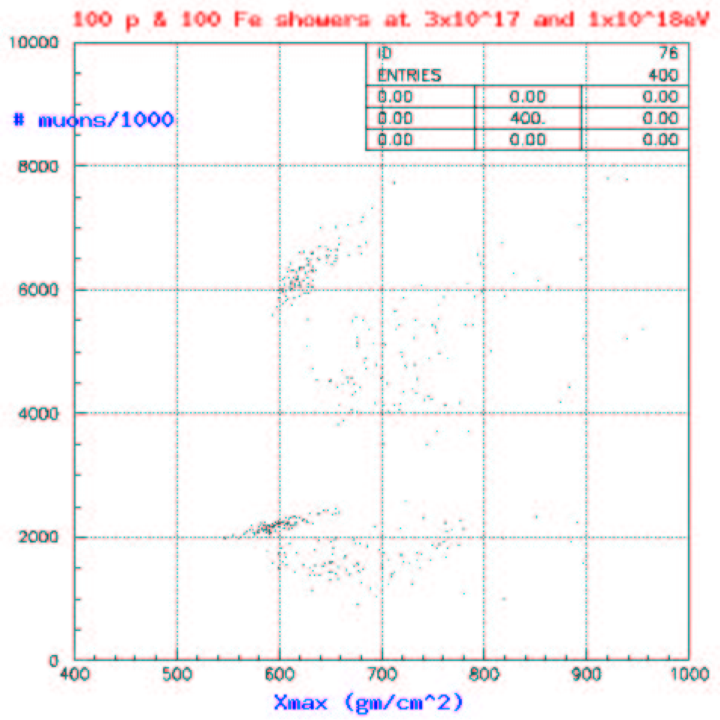
3: *Hybrid* ... a new way of thinking



Sketch of hybrid detection concept.

- *Hybrid* experiments can measure $\mathbf{E}_{primary}$ 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* $\mathbf{E}_{primary}$ measurement
- A possibly growing interest in Auger for the *hybrid* measurement of **composition** ... **what about in TA?**

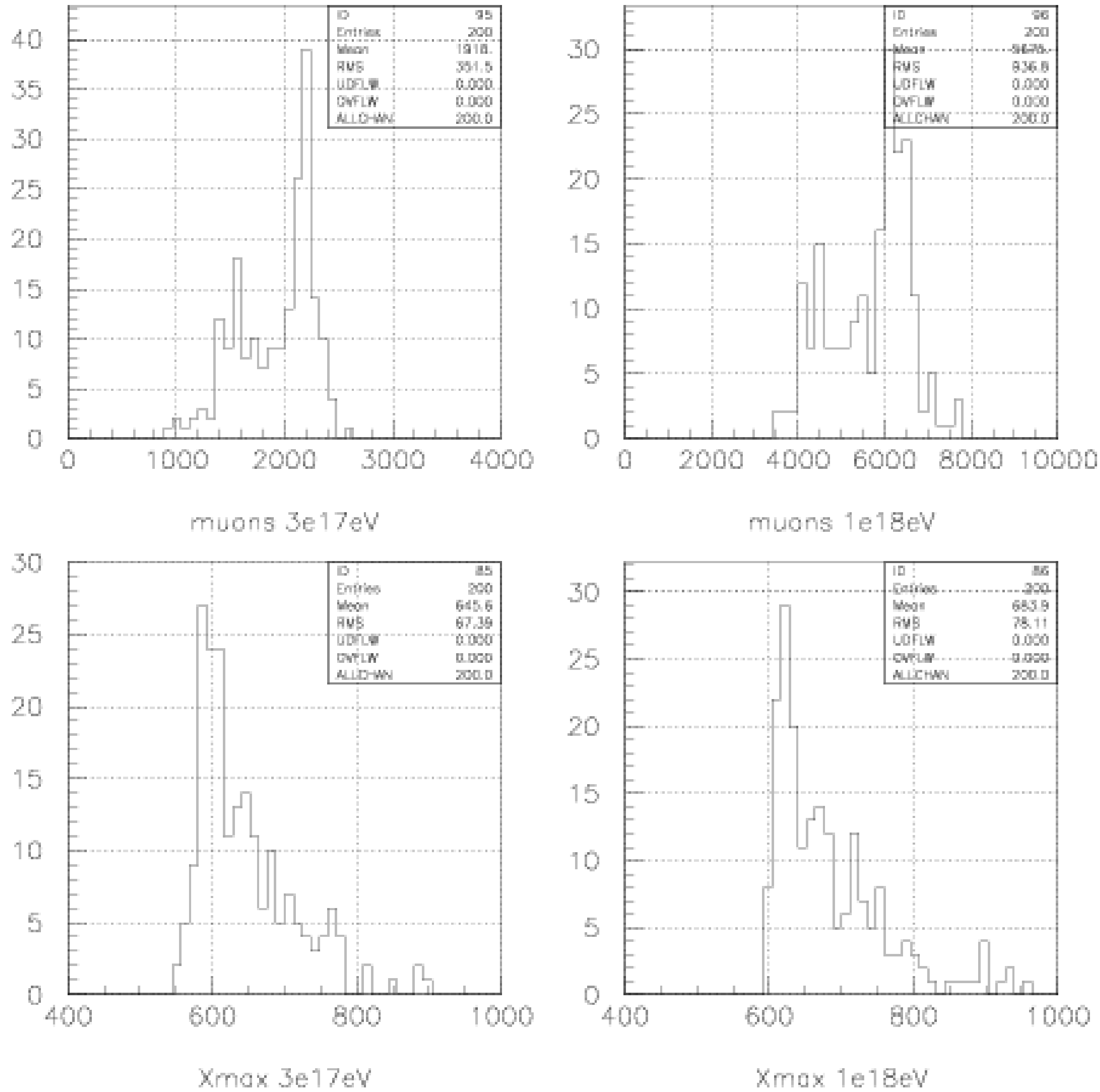
3: *Hybrid* ... a new way of thinking (con't)

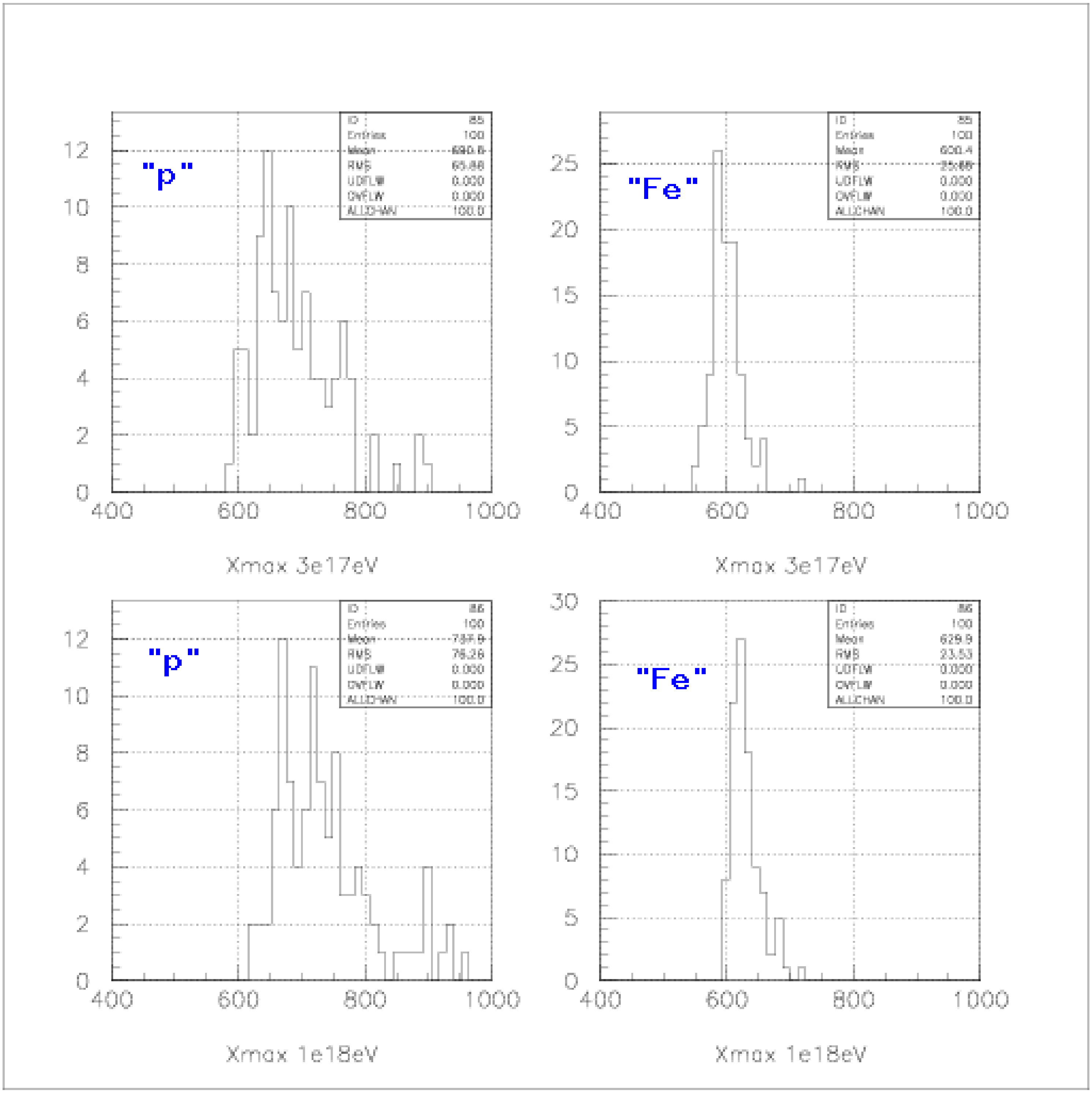


CORSIKA shower simulation of p and Fe showers.

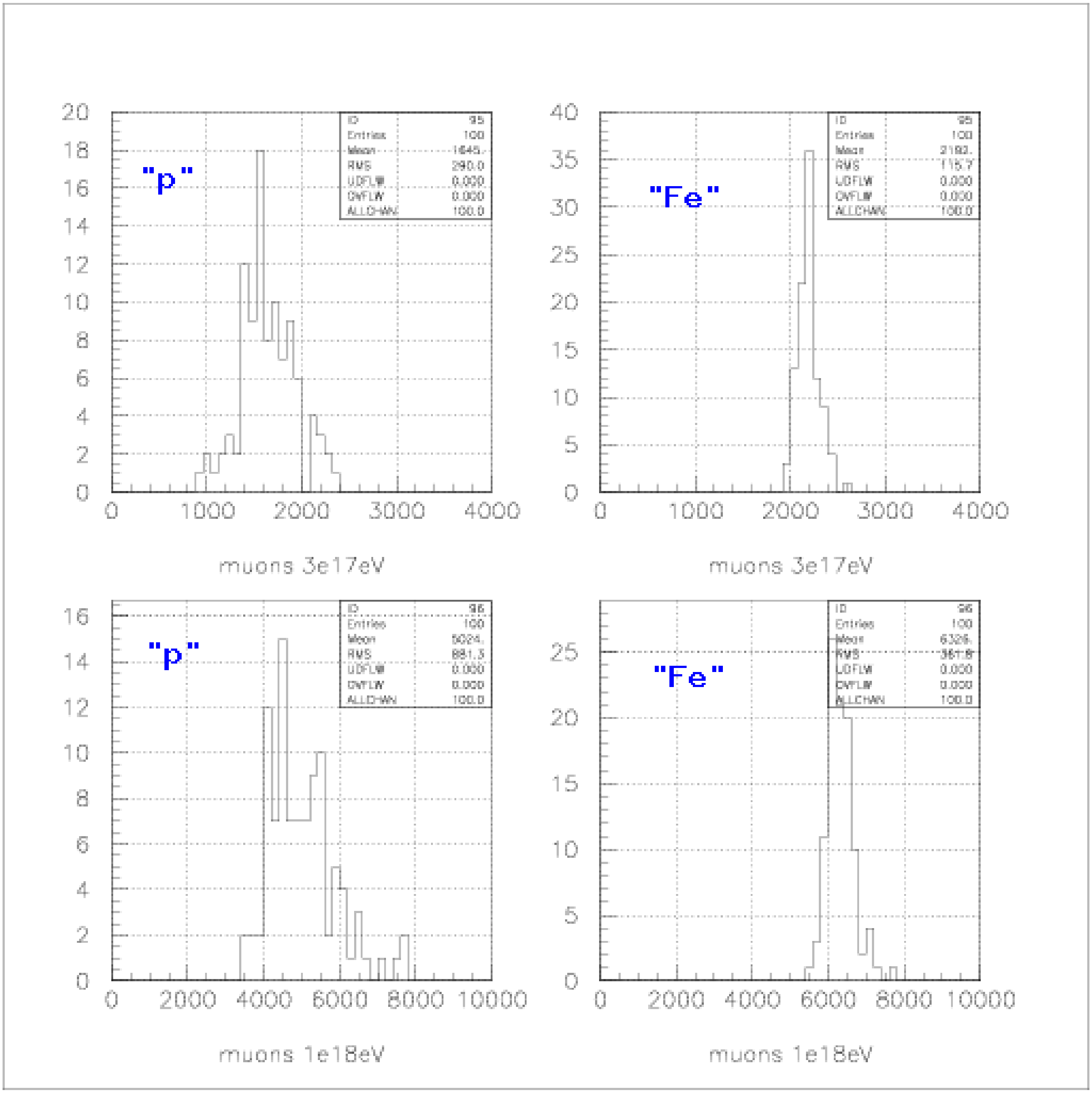
- To 0^{th} order the number of muons (at ground level) and shower X_{max} are uncorrelated
- The number of muons (at ground level) and shower X_{max} depend on the primary cosmic ray composition: p or Fe or ...
- The width and separations of the muon and X_{max} distributions for p and Fe are rather 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 Xmax do not cleanly resolve into "p" and "Fe" ...

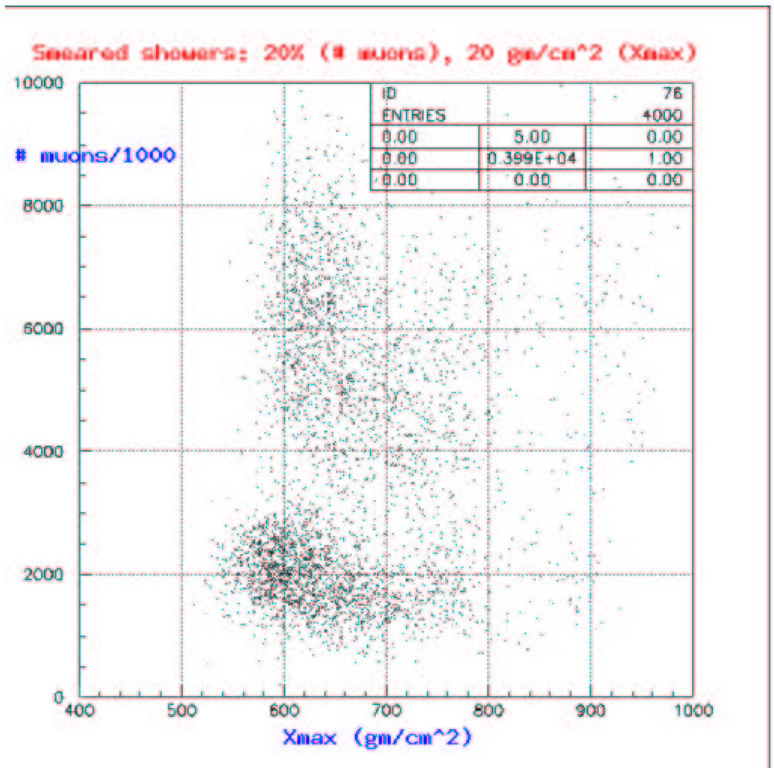




"p"
"Fe"
"p"
"Fe"
ID
Entries
Mean
RMS
UDFLW
OVFLW
ALLCHAN
0
2
4
6
8
10
12
5
15
20
25
30
400
600
800
1000
Xmax 3e17eV
Xmax 3e17eV
Xmax 1e18eV
Xmax 1e18eV

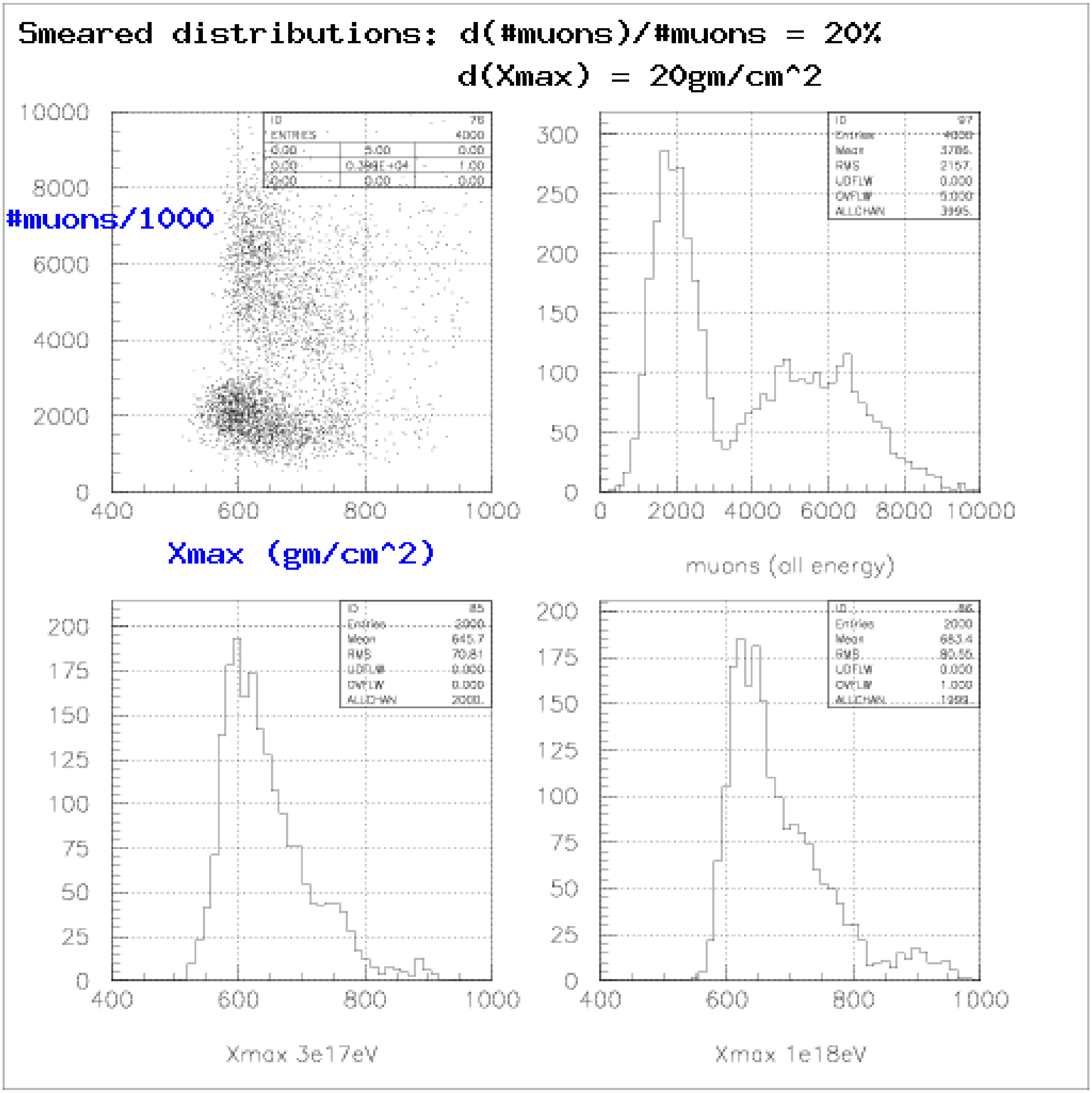

"p"
"Fe"
"p"
"Fe"
muons 3e17eV
muons 3e17eV
muons 1e18eV
muons 1e18eV
ID 95
Entries 100
Mean 1645.
RMS 290.0
UDFLW 0.000
OVFLW 0.000
ALLCHAN 100.0
ID 95
Entries 100
Mean 2193.
RMS 115.7
UDFLW 0.000
OVFLW 0.000
ALLCHAN 100.0
ID 96
Entries 100
Mean 5024.
RMS 881.3
UDFLW 0.000
OVFLW 0.000
ALLCHAN 100.0
ID 96
Entries 100
Mean 6326.
RMS 361.8
UDFLW 0.000
OVFLW 0.000
ALLCHAN 100.0

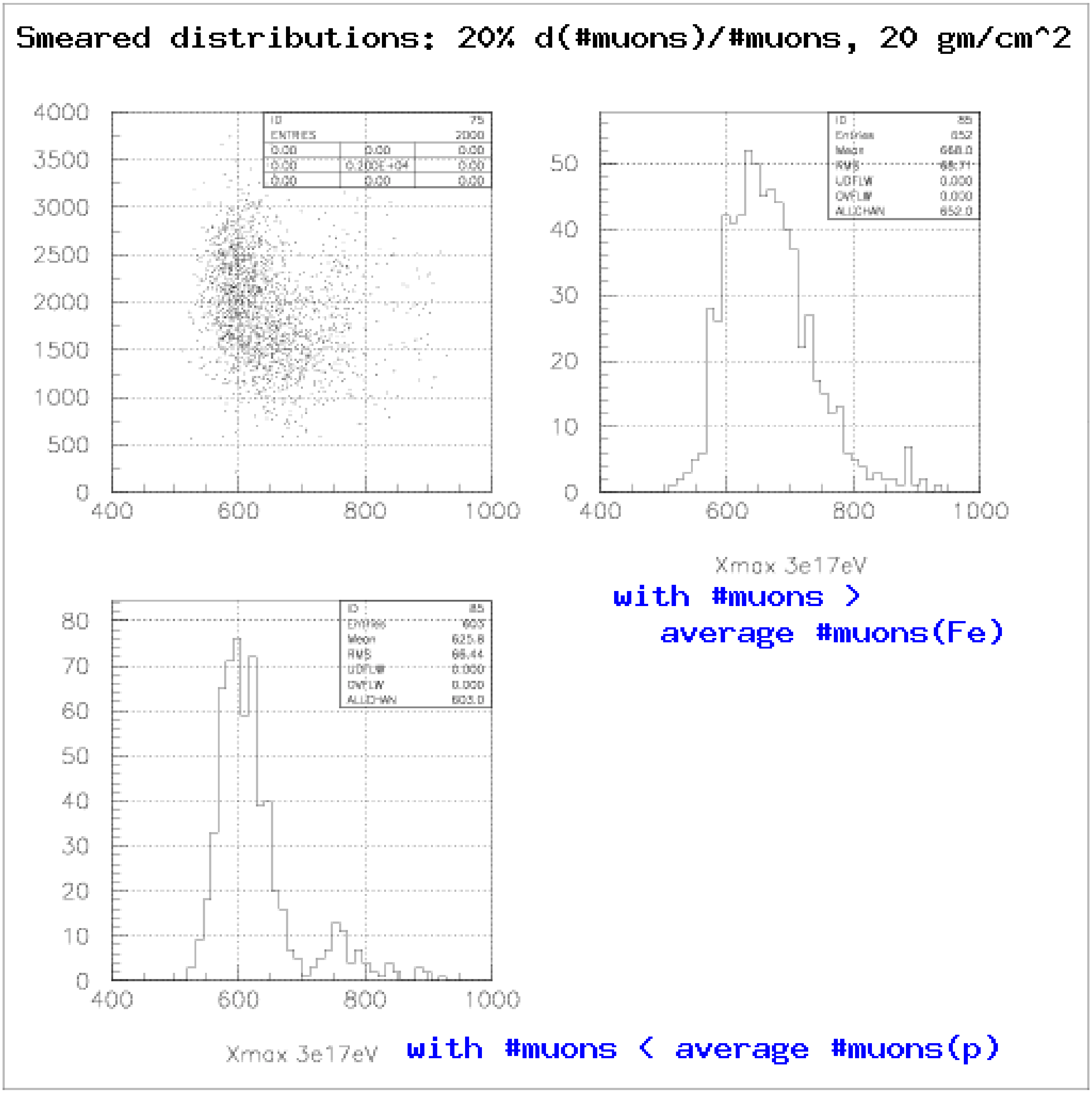
3: *Hybrid* ... a new way of thinking (con't)



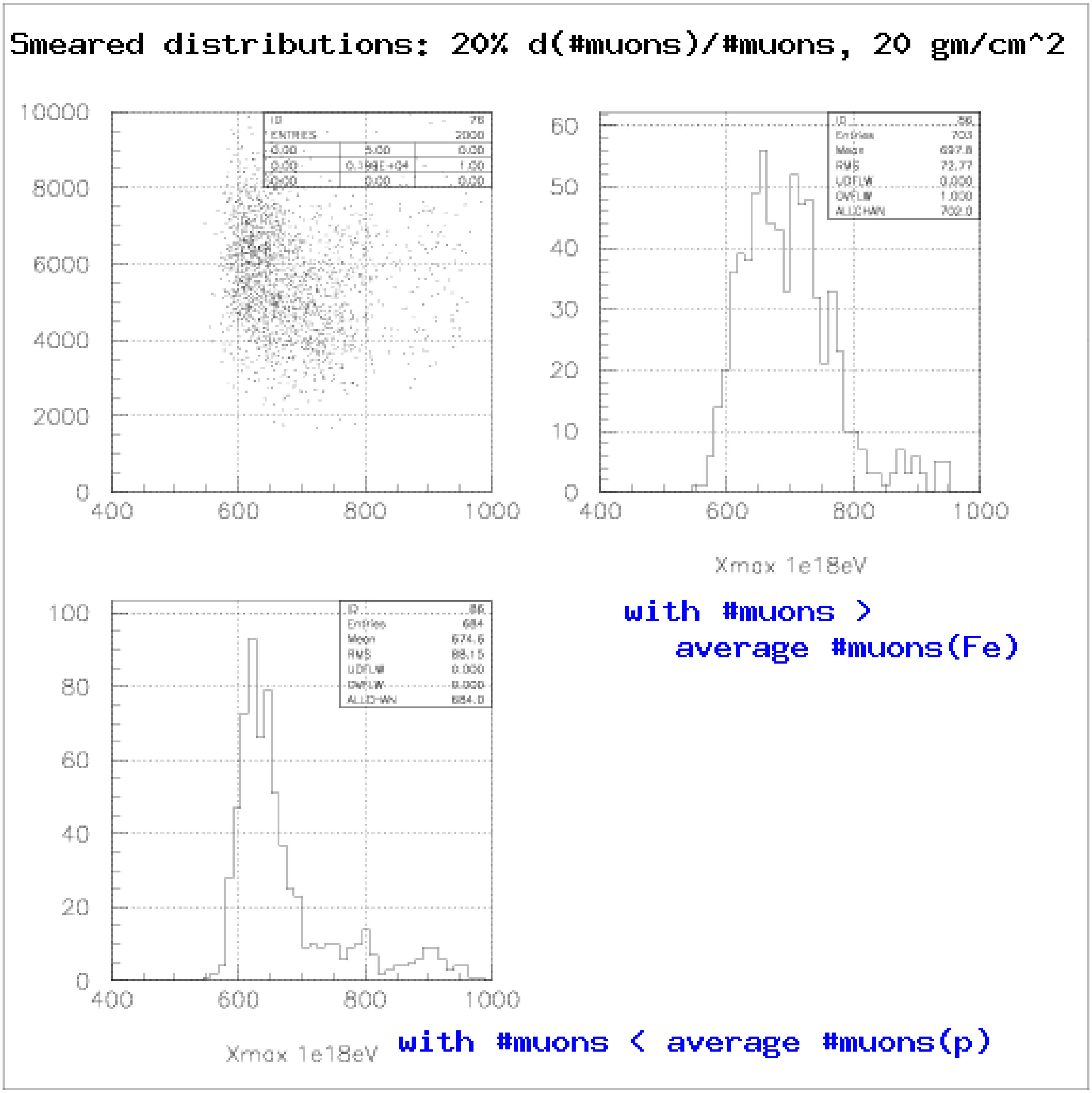
CORSIKA showers *smeared* by detector resolution.

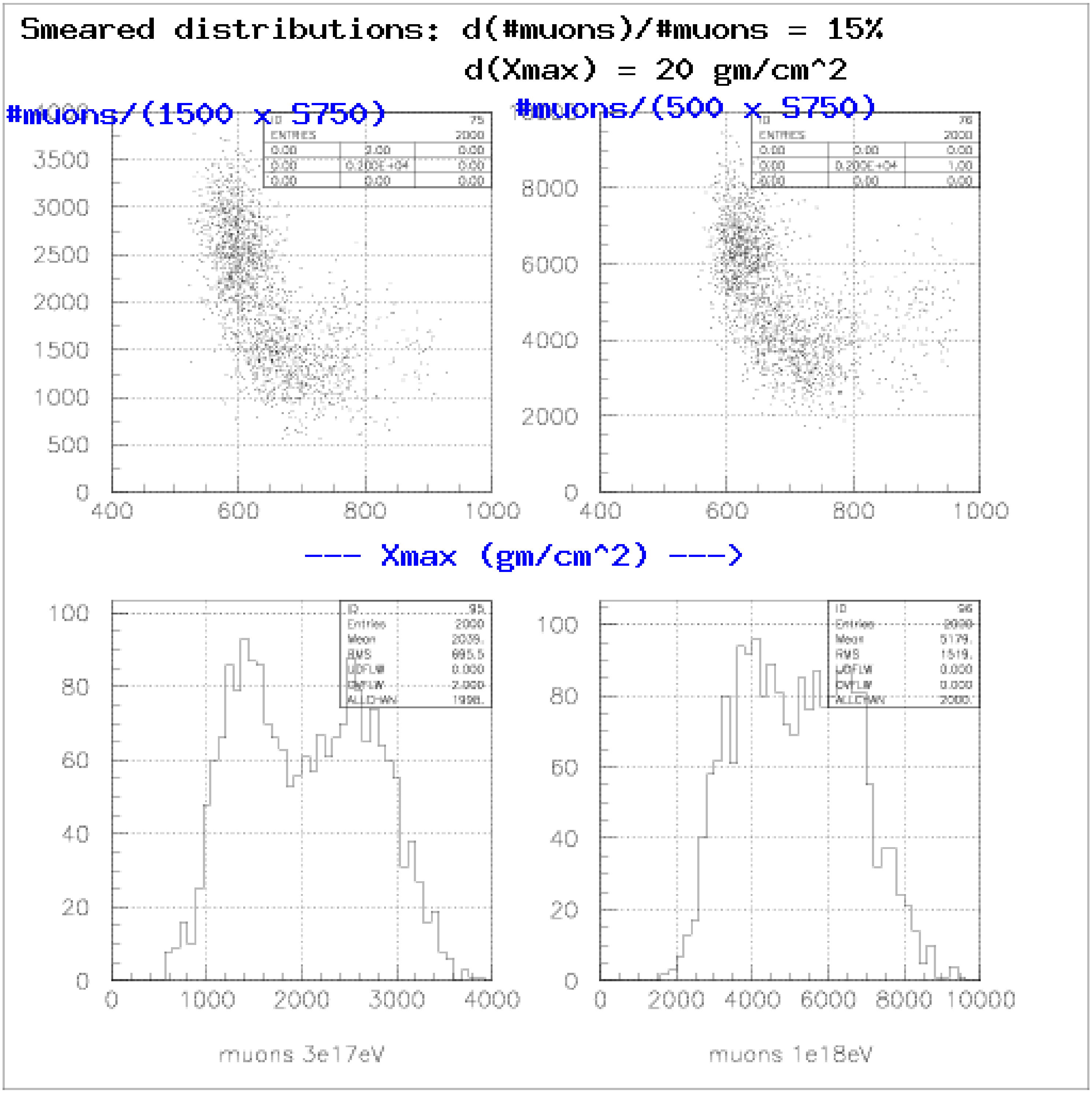
- With detector resolution the p:Fe separation is less clear.
- Two (possibly naive) approaches:
  1. Look at X_{max} projection requiring **#muons** either $\geq \; < \#muons >_{Fe}$ (more pure iron sample), or $\leq \; < \#muons >_{p}$ (more pure proton sample).
  2. Analyze scatter plot of **#muons/S**$_{750}$ *versus* X_{max} as we might expect a more precise measurement of **#muons/S**$_{750}$ than of **#muons**.
  3. **To me it looks promising ...**


Smeared distributions: d(#muons)/#muons = 20%
d(Xmax) = 20gm/cm^2
#muons/1000
Xmax (gm/cm^2)
ID 78
ENTRIES 4000
ID 97
Entries 4000
Mean 3786.
RMS 2157.
UDFLW 0.000
OVFLW 5.000
ALLCHAN 3995.
muons (all energy)
ID 85
Entries 2000
Mean 645.7
RMS 70.81
UDFLW 0.000
OVFLW 0.000
ALLCHAN 2000.
Xmax 3e17eV
ID 86
Entries 2000
Mean 683.4
RMS 80.55
UDFLW 0.000
OVFLW 1.000
ALLCHAN 1999.
Xmax 1e18eV



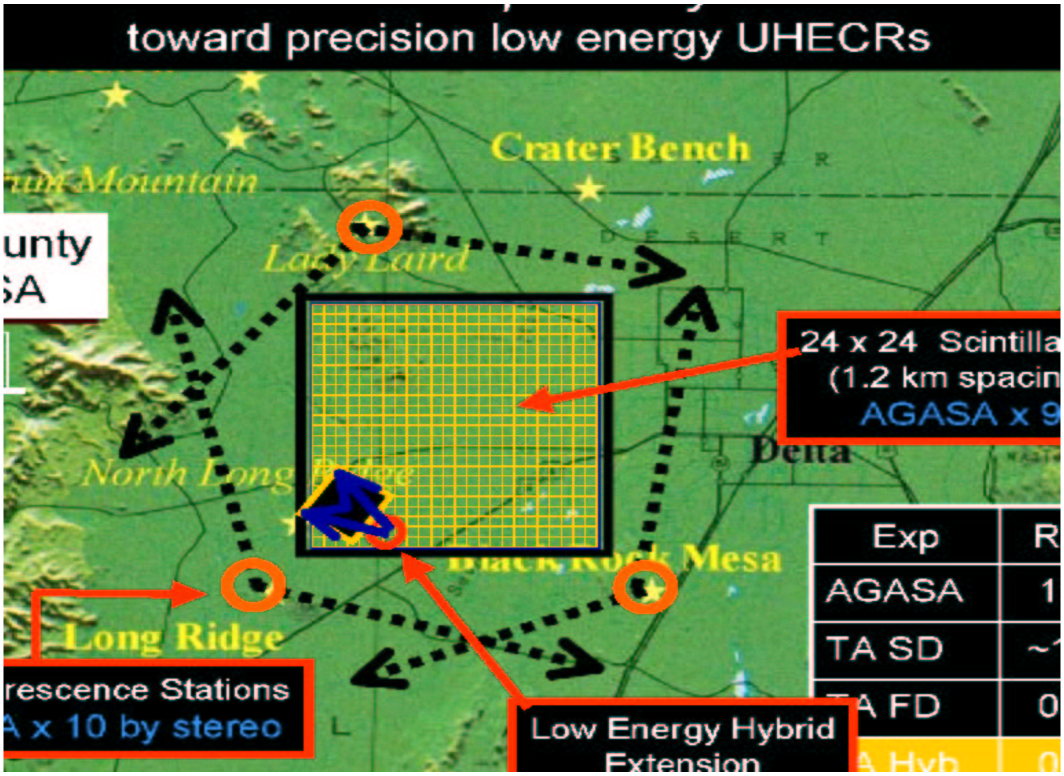
Smeared distributions: 20% d(#muons)/#muons, 20 gm/cm^2
Xmax 3e17eV
with #muons > average #muons(Fe)
Xmax 3e17eV
with #muons < average #muons(p)


Smeared distributions: 20% d(#muons)/#muons, 20 gm/cm^2
10000
8000
6000
4000
2000
0
400
600
800
1000
60
50
40
30
20
10
Xmax 1e18eV
with #muons >
average #muons(Fe)
100
80
Xmax 1e18eV
with #muons < average #muons(p)



#muon projections show 2-component "peaks" ...

4: Implications for TA



- **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) within
  2. effectively 8×8 array on 600m separation (17.6 km^2 area)
- **ADD FD detection up to viewing angles** $\sim 60°$ **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 $\sim 10^{17}$eV would benefit from simultaneous **muon** and X_{max} measurements.

- The measurements must be of sufficient precision ... which may be a challenge for the **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?

- **IF TA wants to do this then there is much work to be done ...**