# What do FD events with *well measured* Profiles say about $X_{max}$ and $X_{max}$ $RMS$?

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**FOR**

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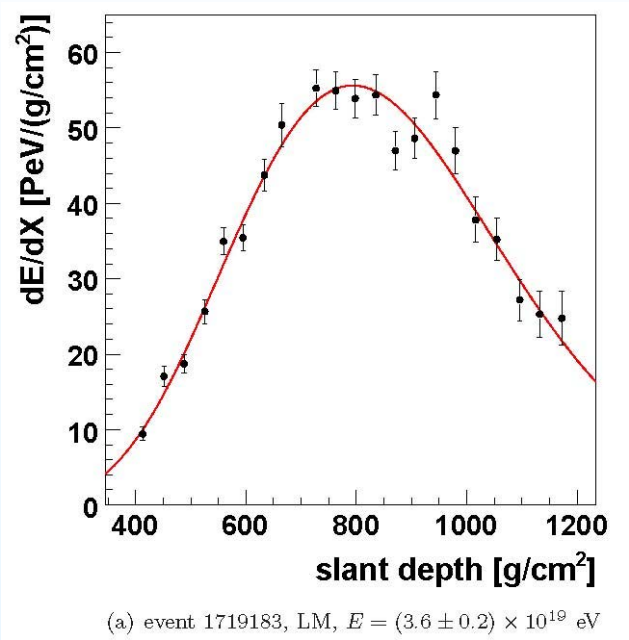
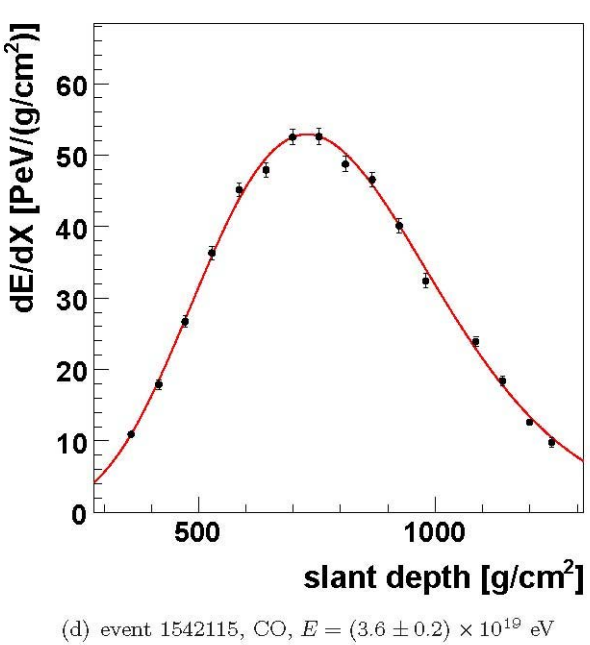
# While studying shower profiles ...



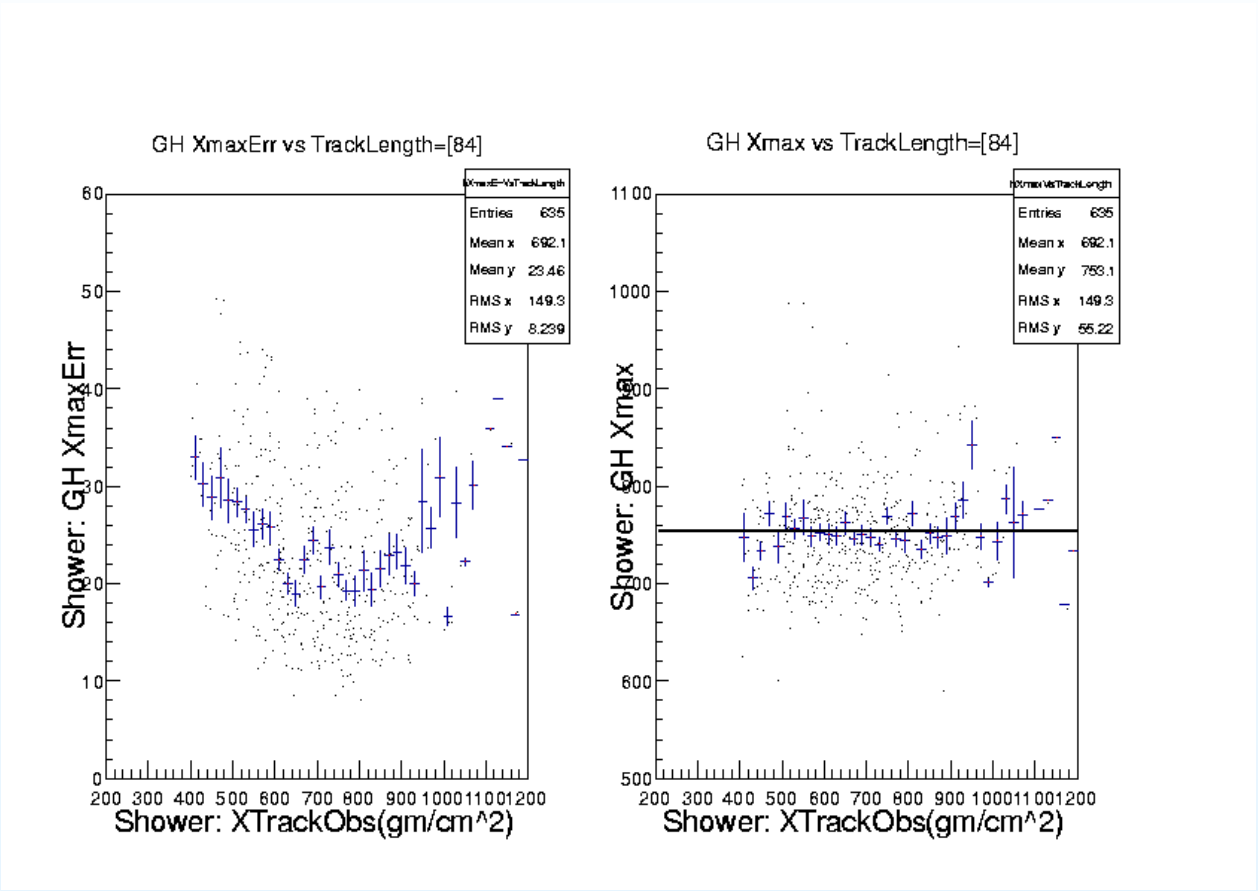

(a) event 1719183, LM, $E = (3.6 \pm 0.2) \times 10^{19}$ eV




(d) event 1542115, CO, $E = (3.6 \pm 0.2) \times 10^{19}$ eV

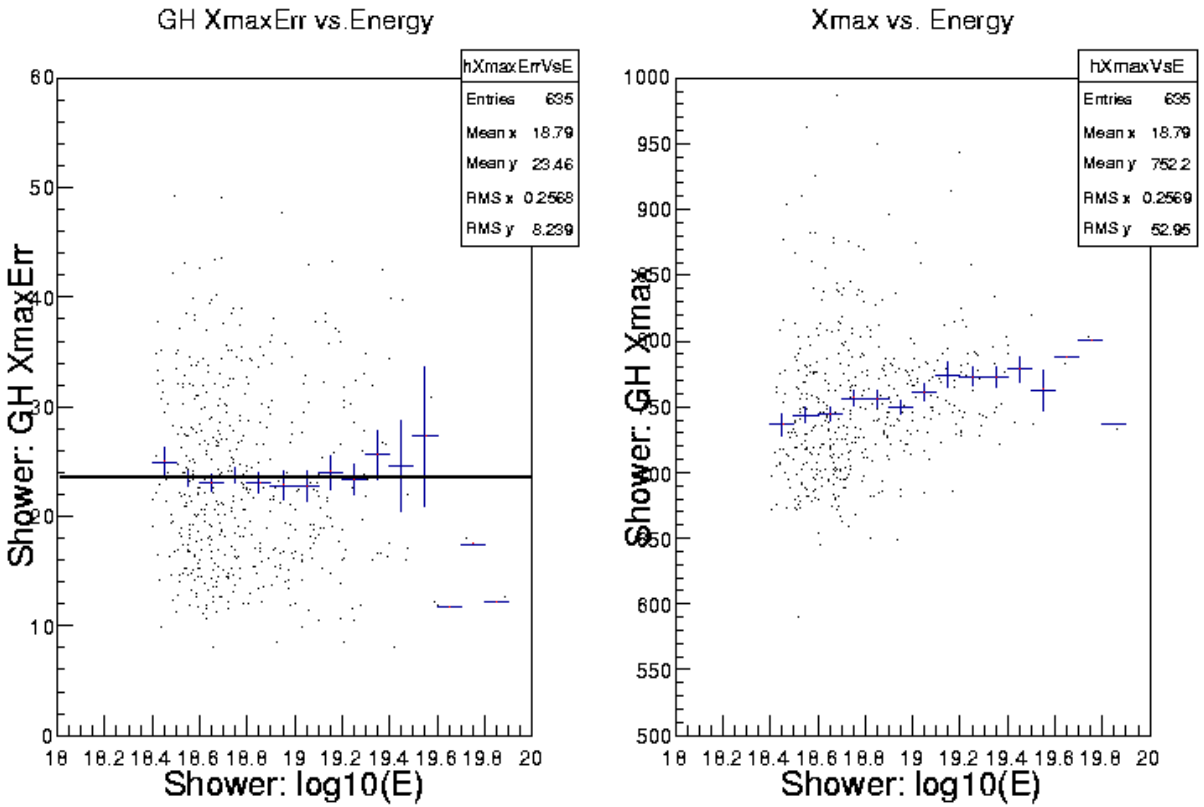
- A subset of FD showers show classic shower profiles with shower maximum, $X_{max}$, clearly within the field of view (FOV) and with an observed track length $\gtrsim 600 gm/cm^2$. (The typical shower FWHM $\sim 525 gm/cm^2$.)
- While our initial interest was that these events should allow a measurement of the Gaisser Hillas, $X_0$ and $\lambda$ parameters, these events should also provide unbiased measurements of $X_{max}$.

# Now accept *shorter* showers ...



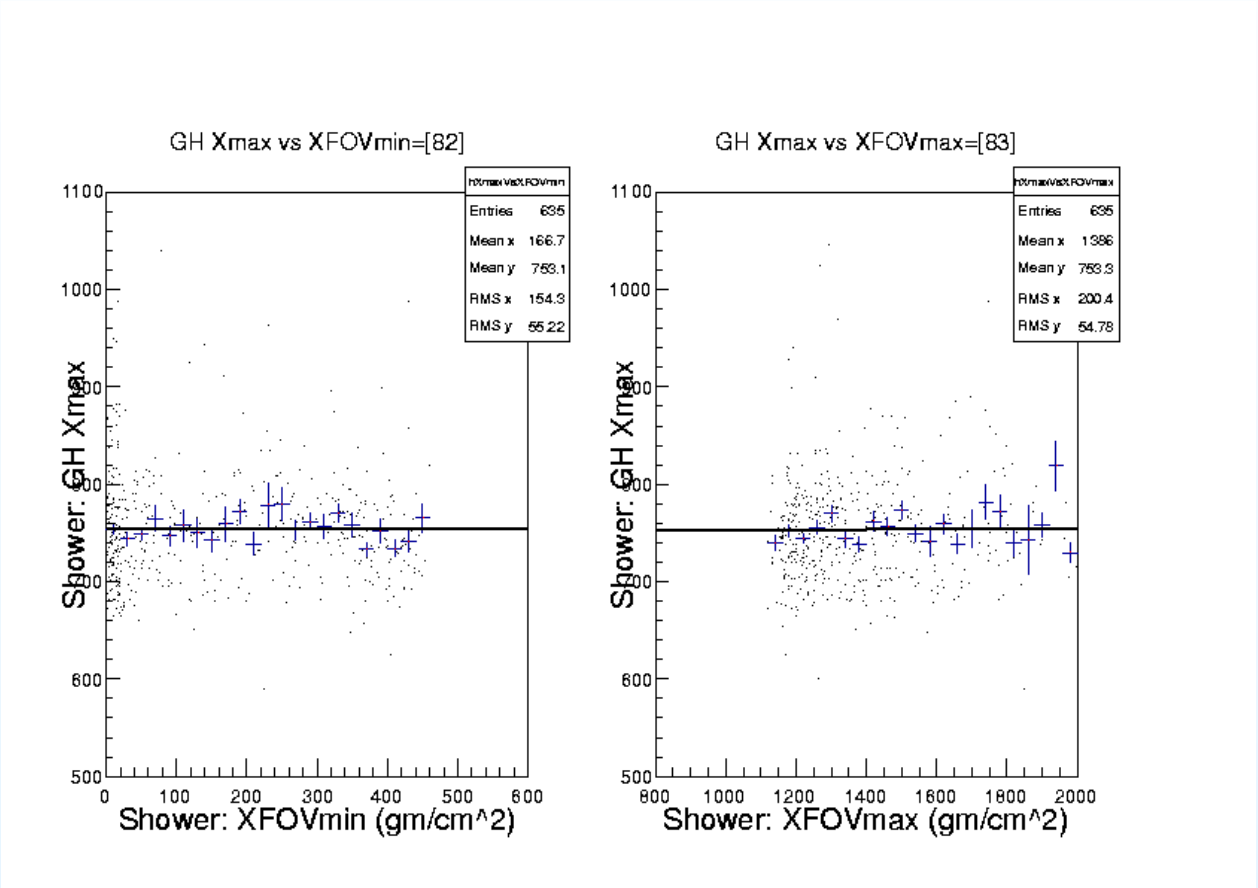

- Long (XtrackObs $> 600$ gm/cm$^2$), unbiased (XFOVmin $< 450$ gm/cm$^2$, XFOVmax $> 1150$ gm/cm$^2$, Xmax - XTrackMin $> 100$ gm/cm$^2$ and XTrackMax - Xmax $> 150$ gm/cm$^2$) ADST events selected with shower zenith $\leq 60^\circ$ and $E_{shower} \geq 3$ EeV.
- Change to: XtrackObs $> 400$ gm/cm$^2$ and zenith $\leq 70^\circ$ ... otherwise the same.

# Variations with shower energy ...



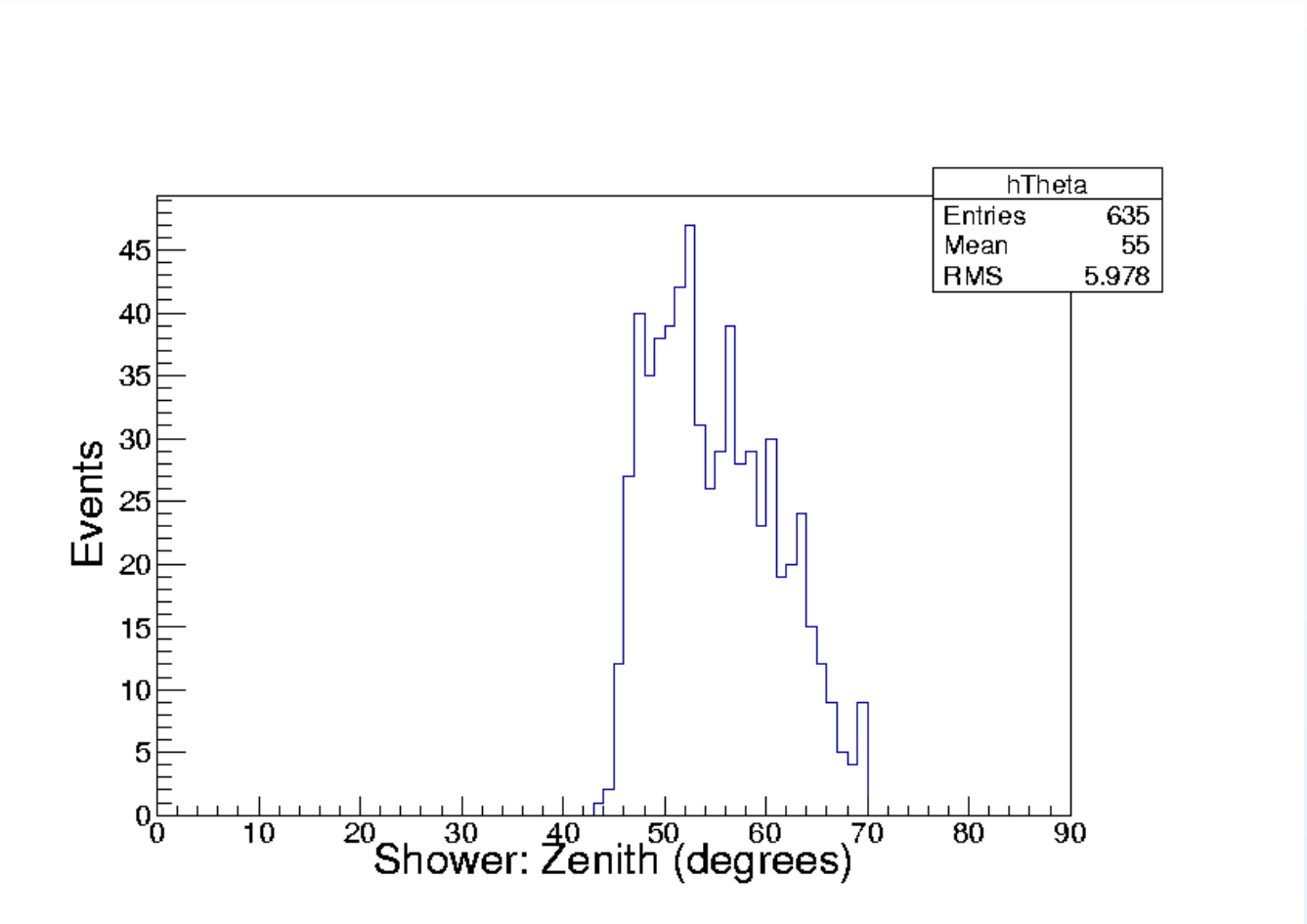

- No variation in $X_{max}$ measurement error, $\delta X_{max}$.
- Known $X_{max}$ elongation rate ...

# Check for $X_{max}$ biases ...



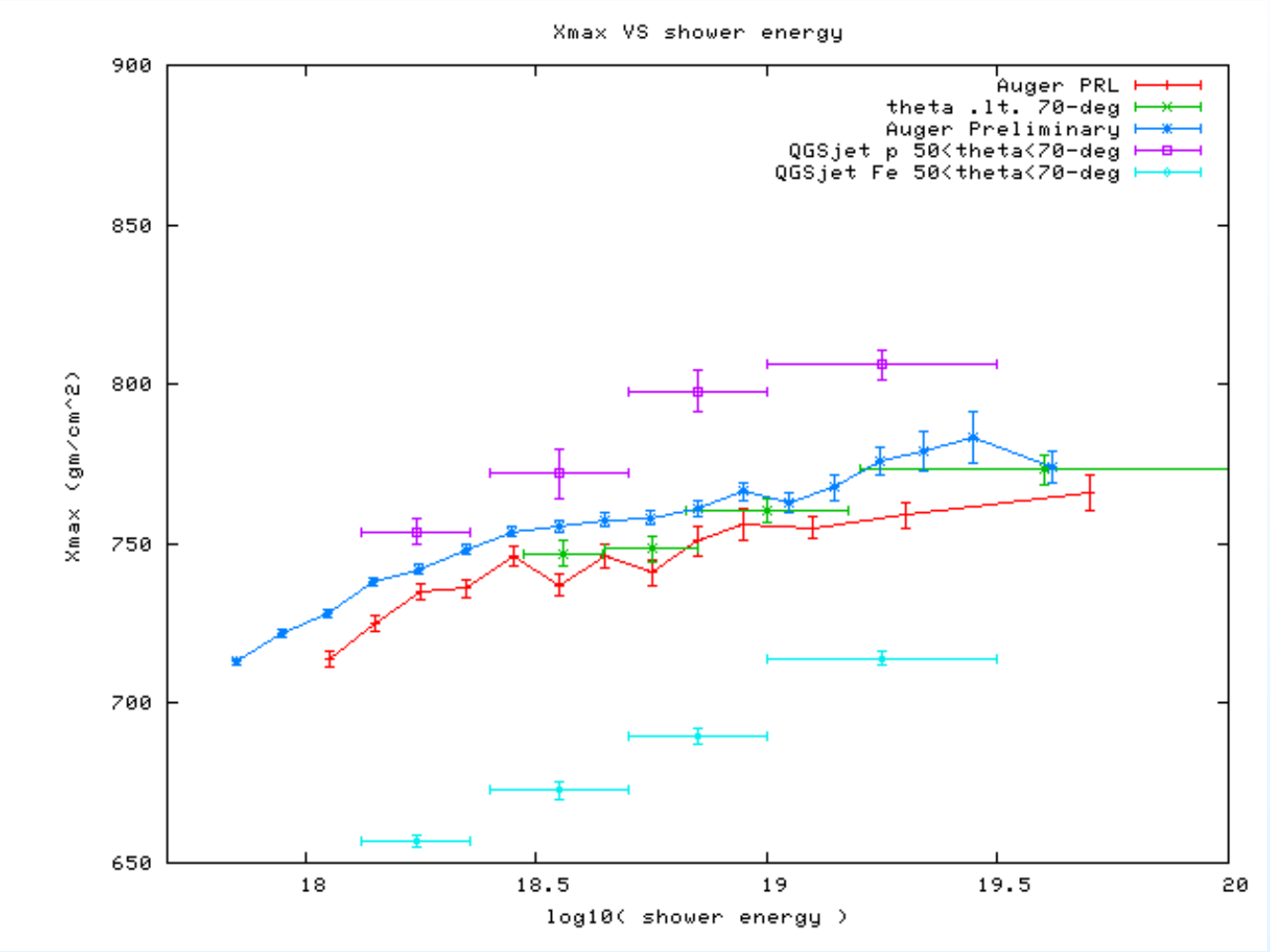

- Set maximum XFOVmin $= 450$ gm/cm$^2$ so that XFOVmin + (Xmax - XTrackMin$\geq 100$ gm/cm$^2$) = 550 gm/cm$^2$ was less than any observed $X_{max}$.
- Set minimum XFOVmax $= 1150$ gm/cm$^2$ so that XFOVmax - (XTrackMax - Xmax$\geq 150$ gm/cm$^2$) = 1000 gm/cm$^2$ was greater than almost all observed $X_{max}$.

# Cuts limit event zenith angles ...



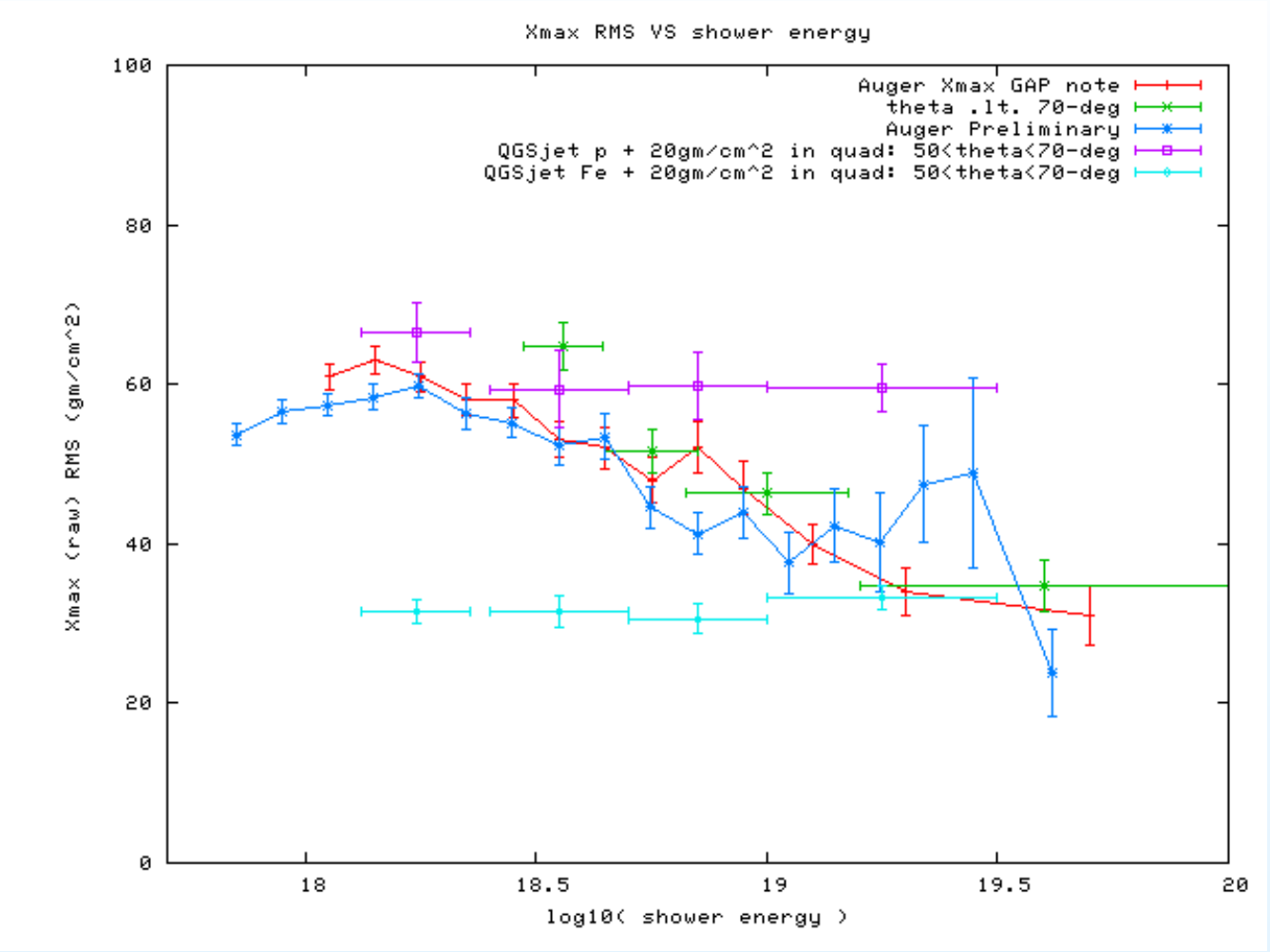

- The selection cuts, to avoid biases in reconstructed values of $X_{max}$, restrict the range of zenith angles, $\theta$, of the accepted events.
- The minimum XFOVmax $= 1150$ gm/cm$^2$ selection restricts $45^\circ \lesssim \theta$.

# $X_{max}$ VS Energy ...



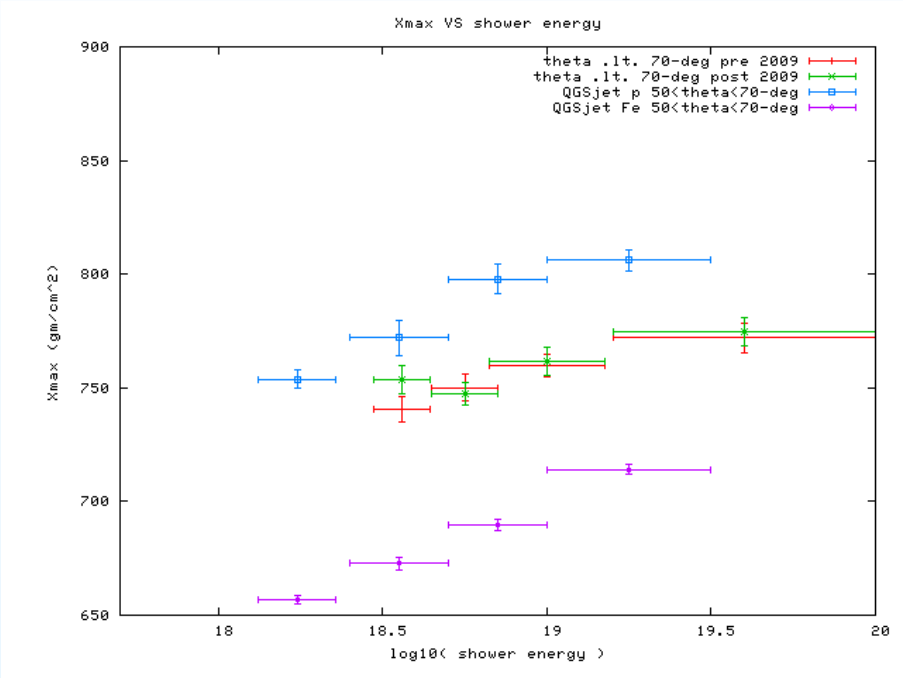

- Four bins in energy; ADST result in green.
- Good agreement with Auger results ...

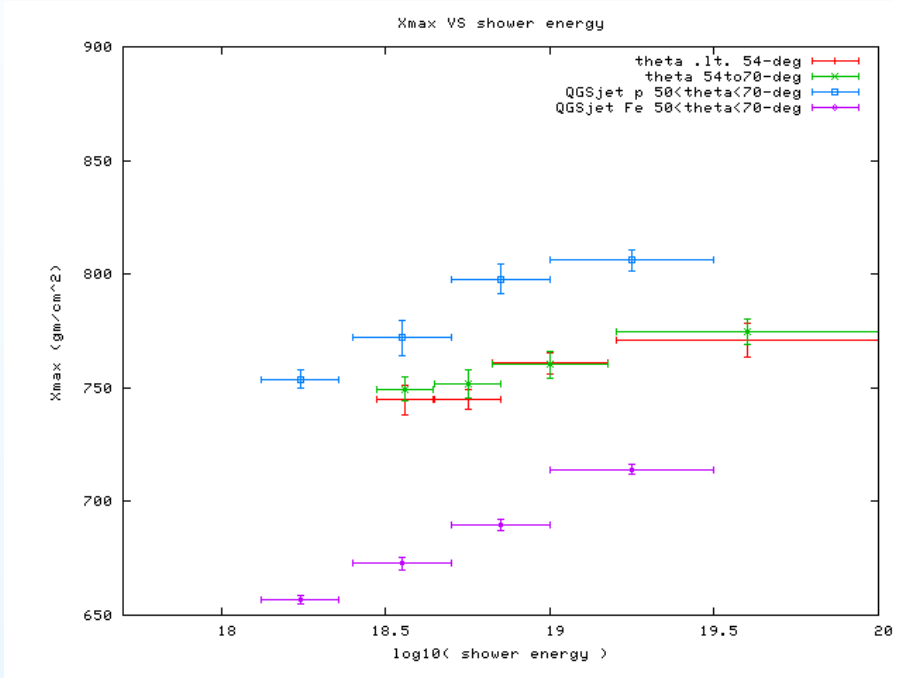
# $X_{max}RMS$ VS Energy ...




- Four bins in energy; ADST result in green.
- First energy bin, $3.0 < E < 4.47$ EeV, somewhat higher than Auger results ...

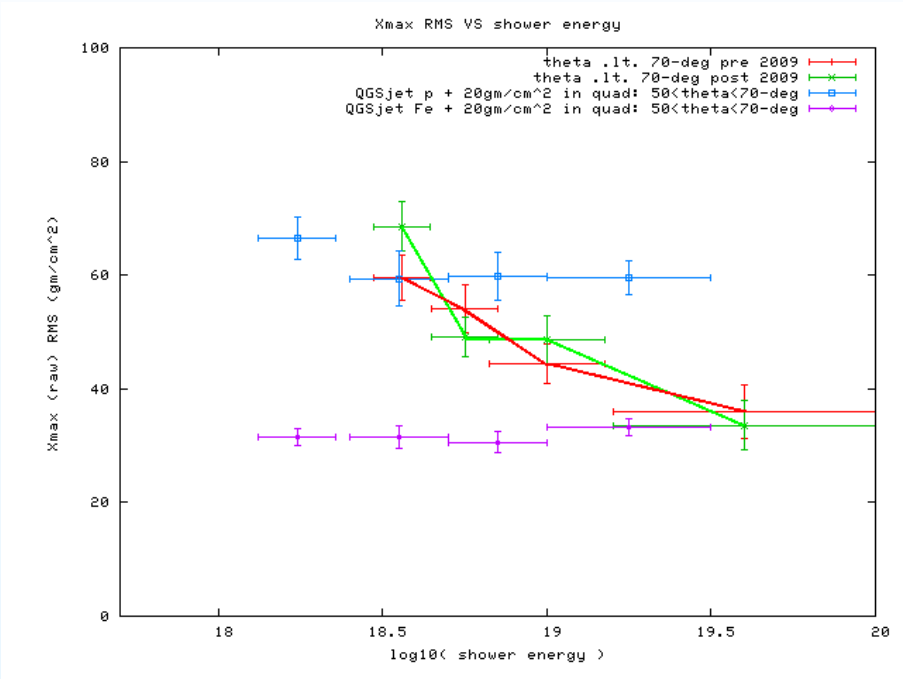
# Split $X_{max}$ data into 2 halves ...

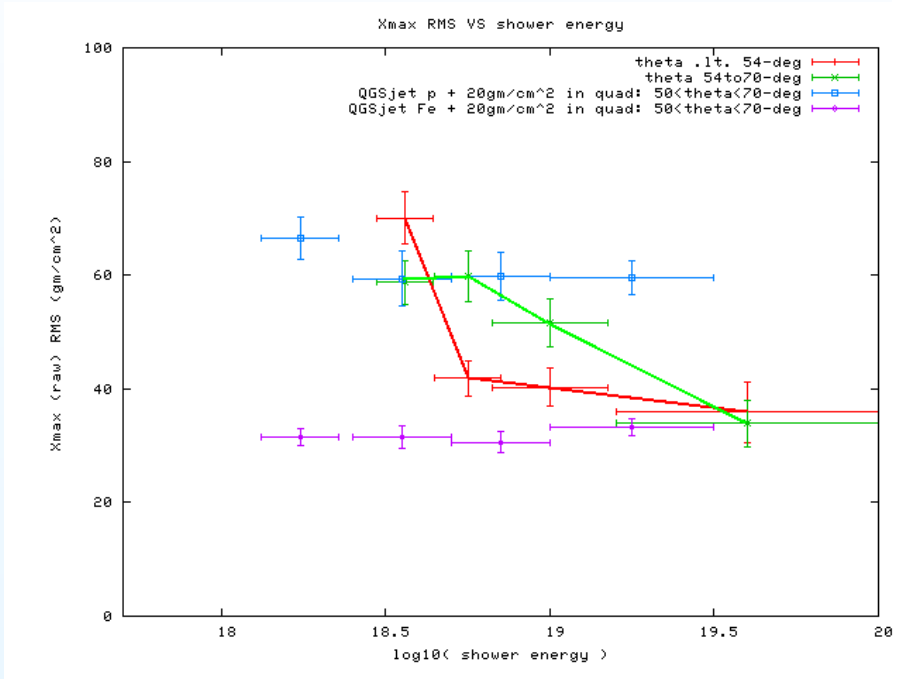



- Left: Data split in time: midpoint January 1, 2009
- Right: Data split in zenith angle: midpoint $\theta = 54°$
- Agreement between the two “half” data-sets is almost too good ...

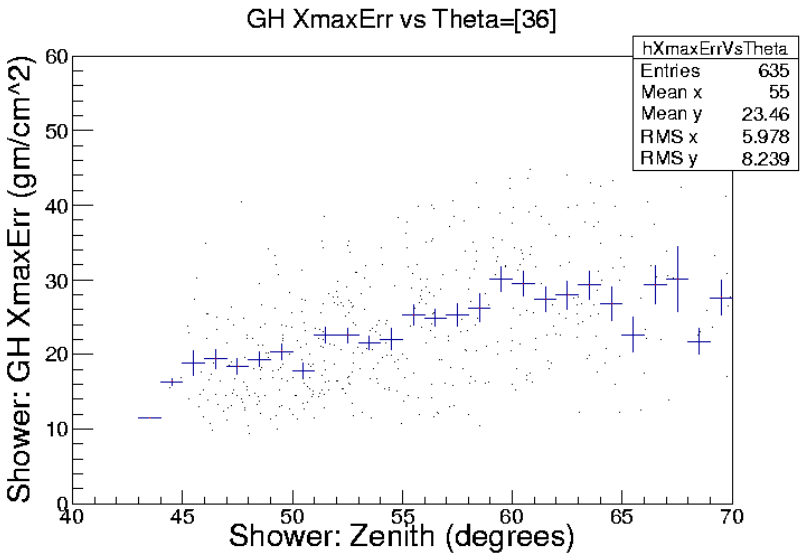
# Split $X_{max}$ $RMS$ data into 2 halves ...

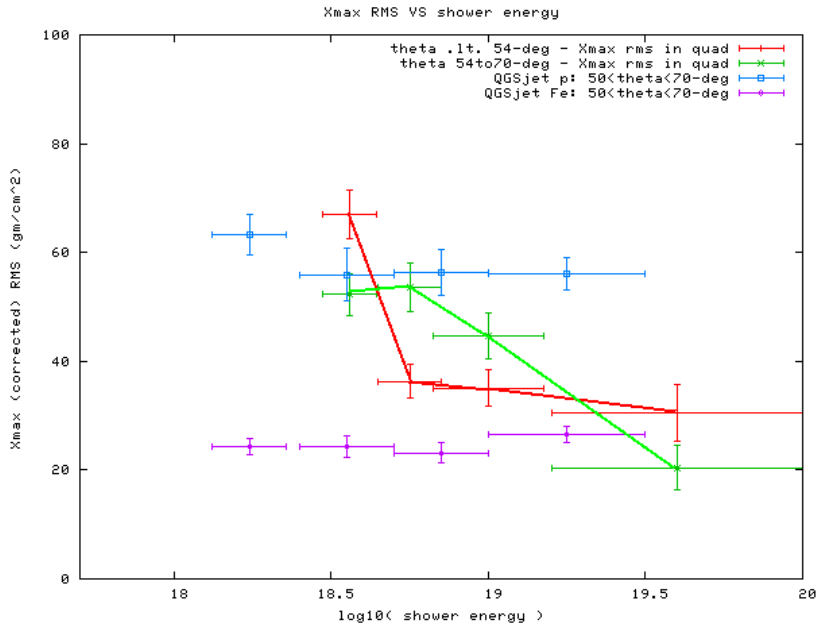



- Left: Data split in time: midpoint January 1, 2009
- Right: Data split in zenith angle: midpoint $\theta = 54°$
- While the trend with energy is qualitatively the same between the two “half” data-sets, the details are noisy. Is this “just” statistics? What is this saying?
- Does the variation with zenith angle suggest some systematic (analysis) bias?

# Split $X_{max}$ $RMS$ data into 2 halves ... (con't)




- Left: The measurement error in $X_{max}$ increases with zenith angle ...
- Right: $X_{max}$ $RMS$ data split in zenith angle: red points $\theta < 54°$, green points $\theta > 54°$. The plotted points are now corrected for $X_{max}$ measurement error (subtracted in quadrature).
- The two zenith angle bins again give rather different results ...

## Summary ...

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- Our study for: Can shower profiles measure more than Xmax and E? (reported at the Lisbon collaboration meeting) allowed for a simple study of the variation of shower $X_{max}$ and $X_{max}$ $RMS$ with energy.
- And independent analyses are always a good idea ...
- The comparison of our ADST-based measurement of $X_{max}$ VS energy is in good agreement with official Auger results.
- The comparison of the ADST-based measurement of $X_{max}$ $RMS$ VS energy is in qualitative agreement with official Auger results.
- The inconsistency of results from two zenith angle "half-data" sets, suggests that large variations are possible in $X_{max}$ $RMS$ measurements. Baring an analysis mistake, what is this saying about the size of (systematic) uncertainties in $X_{max}$ $RMS$?

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# Additional slides