

Can shower profiles measure more than X_{\max} and E ?

John A.J. Matthews

johnm@phys.unm.edu

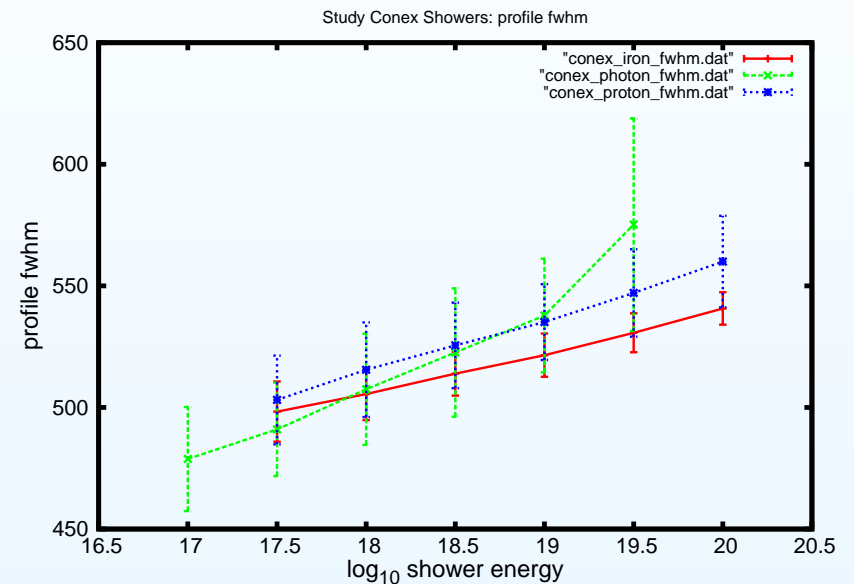
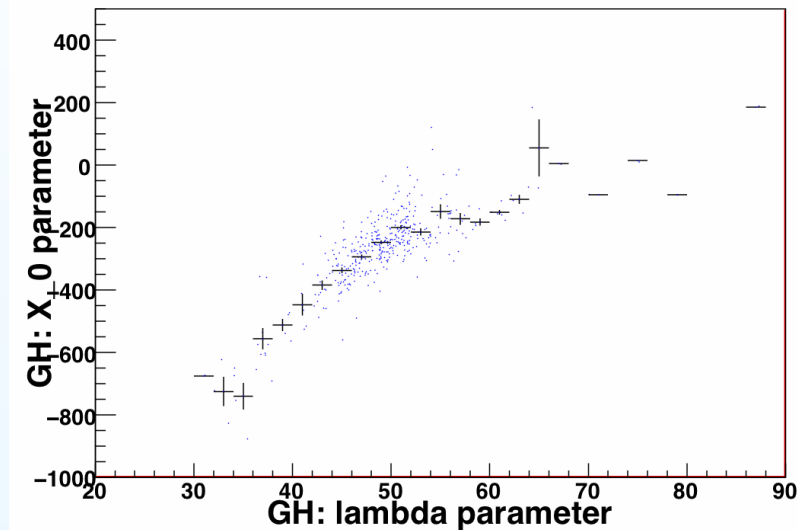
University of New Mexico

Albuquerque, NM 87131

FOR

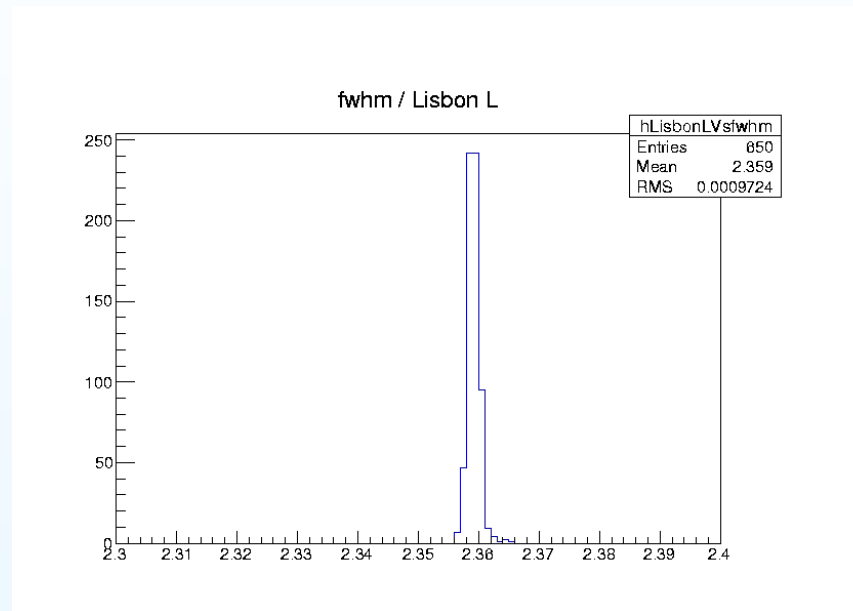
Robert Lauer (UNM), Miguel Mostafa (CSU) and Patrick Younk (LANL)

Gaisser Hillas Shower Profiles



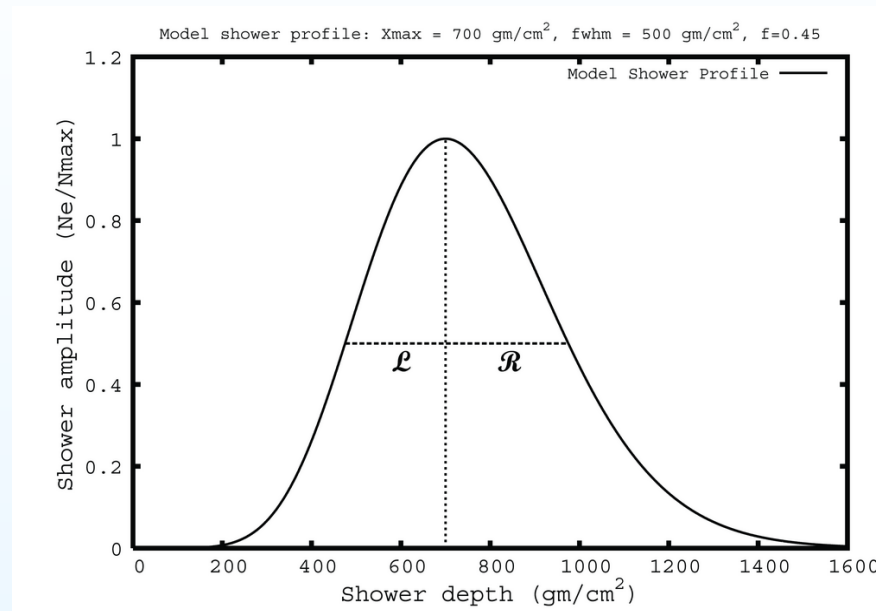
- Shower profiles are typically reconstructed using the Gaisser Hillas (GH) form with 4 parameters: N_{max} , X_{max} , X_0 and λ .
- **Left:** Conex shower simulations suggest that parameters X_0 and λ are correlated. Are there alternatives to X_0 and λ ?
- **Right:** Conex simulations show near equality of the profile width at half-maximum, $fwhm$, for **proton**, **iron** and **photon** showers. Is shower $fwhm$ a possible alternative GH parameter?

In 2009/10 Shower Profiles *re-evaluated* ...



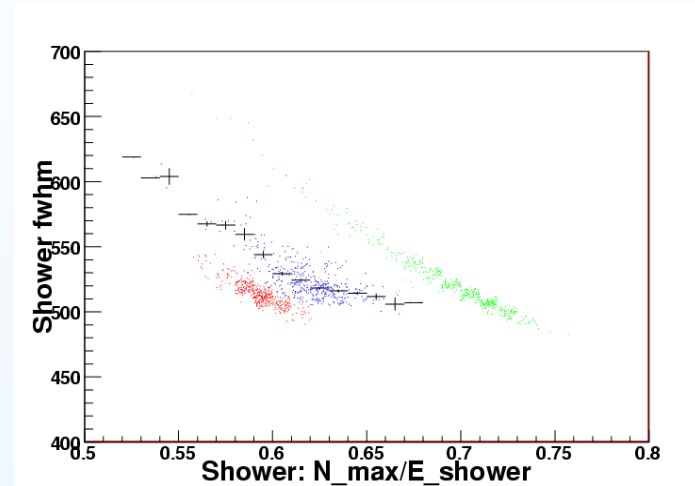
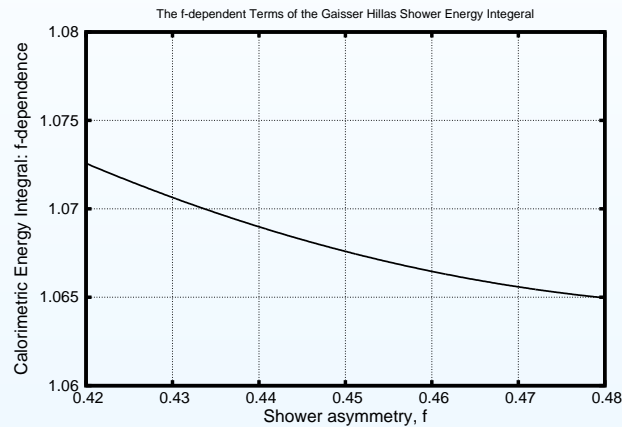
- For a variety of reasons, independently, and at about the same time UNM: J. Phys G37, 25202 (2010) and LIP: AstroPart. Phys. 34 360 (2011) groups proposed alternatives to the Gaisser Hillas (GH) X_0 and λ parameters.
- In these parameterizations: X_0, λ are replaced by: $fwhm, f$ (UNM) or by: L, R (LIP). (UNM and LIP parameterizations retain the physically motivated GH parameters: N_{max}, X_{max} .)
- In detail $fwhm/L \approx 2.36$ (see plot) and R depends on f . Thus these two parameterizations are essentially identical.

fwhm, f explained ...



- The $fwhm \equiv \mathcal{L} + \mathcal{R}$ is the shower width at half-maximum (see figure above)
- The $f \equiv \mathcal{L}/(\mathcal{L} + \mathcal{R})$ parameter characterizes the shower asymmetry.
- A simple 1:1 mapping relates $(fwhm, f)$ to (X_0, λ) .
- Briefly the GH profile then depends on **two dimensionless ratios**: $\epsilon \equiv \frac{\Delta}{W}$ where $\Delta = X - X_{max}$, X_0 is replaced by $W \equiv X_{max} - X_0 = \frac{fwhm}{R(f)}$, $R(f)$ is a known function of f , **and** $\xi \equiv \frac{W}{\lambda}$ which depends only on the asymmetry f . (Note: LIP parameter $R^2 = 1/\xi$.)

The shower $fwhm$ is sensitive to ...

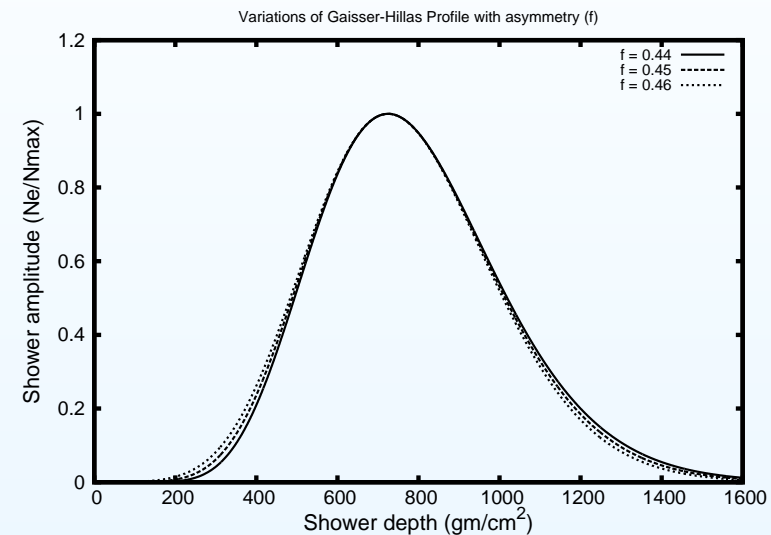
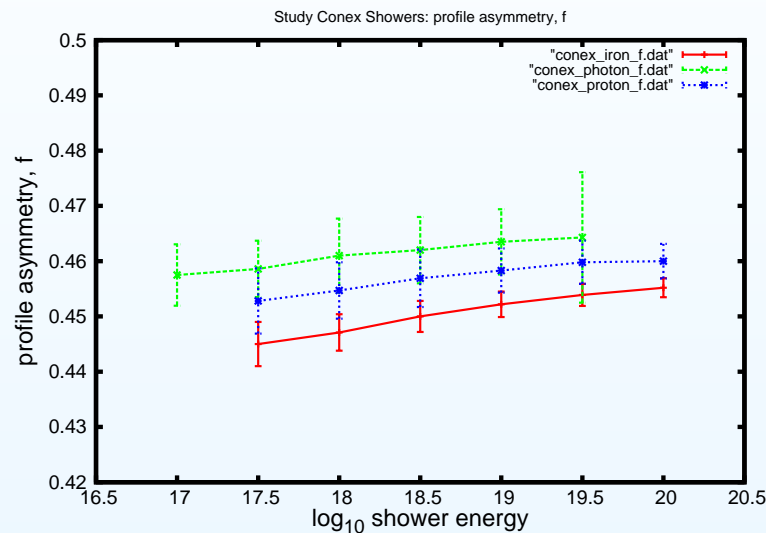


- The GH calorimetric shower energy is to a good approximation:

$$E_{shower}^{calor} = \langle dE/dx \rangle N_{max} fwhm \left(\frac{\xi^{-(\xi+1)} e^{\xi} \Gamma(\xi + 1)}{R(f)} \right)$$

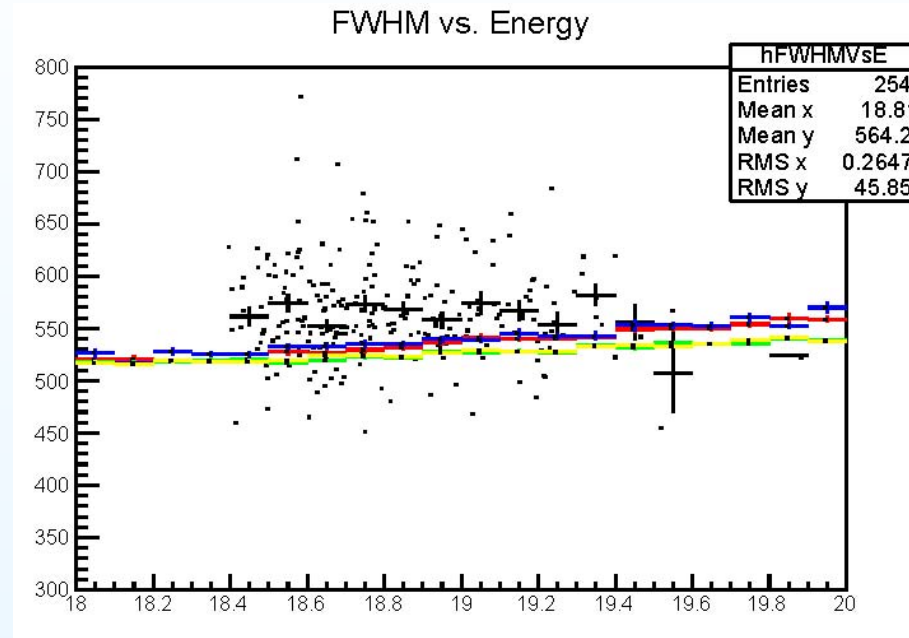
- Left plot: Nasty term in () depends on f but is almost constant!
- Right plot: Thus $E_{shower}^{calor} \propto N_{max} fwhm$
(Conex predictions color coded for proton, iron and photon showers at $10^{18.5}$ eV)
- Do Auger measurements for $fwhm$ match with Conex predictions?

The shower asymmetry f is sensitive to ...



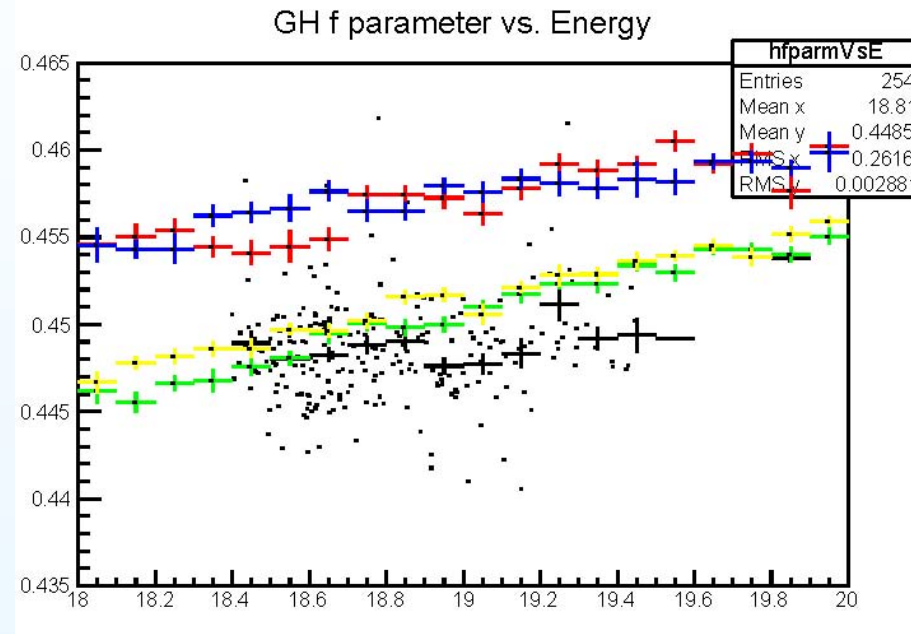
- **Left plot:** Conex simulations suggested that the asymmetry parameter f may provide some discrimination in primary composition
- This has been emphasized by the LIP group (see reference above)
- **Right plot:** But the effect is subtle. The GH shower profiles have $X_{max} = 725 \text{ gm/cm}^2$, $fwhm = 525 \text{ gm/cm}^2$ and asymmetry: $f = 0.44, 0.45$ and 0.46 .
- Is the f -parameter sufficiently well determined by Auger data to provide any primary particle discrimination?

Auger $fwhm$ from ADST showers ...



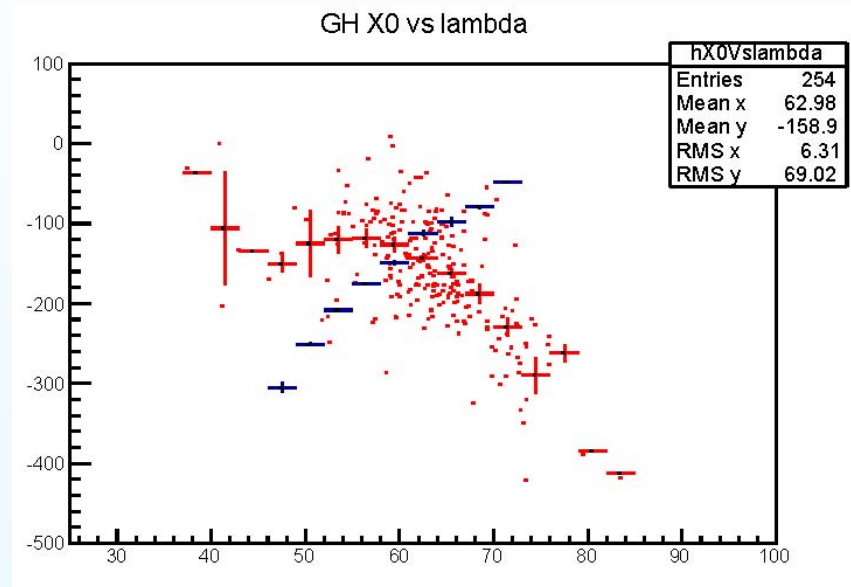
- Long ($X_{\text{trackObs}} > 600 \text{ gm/cm}^2$), unbiased ($X_{\text{FOVmin}} < 450 \text{ gm/cm}^2$, $X_{\text{FOVmax}} > 1150 \text{ gm/cm}^2$, $X_{\text{max}} - X_{\text{TrackMin}} > 100 \text{ gm/cm}^2$ and $X_{\text{TrackMax}} - X_{\text{max}} > 150 \text{ gm/cm}^2$) ADST events selected with shower zenith $\leq 60^\circ$ and $E_{\text{shower}} \geq 3 \text{ EeV}$.
- Map from GH shower parameters (X_0, λ) to ($fwhm, f$)
- **plot:** shows $fwhm$ vs shower energy.
- Colored points show Conex QGSjet II.04 (p,Fe) and EPOS LHC (p,Fe) predictions.
- Auger points are systematically above the simulations with *no* energy dependence.

Auger shower asymmetry f from ADST showers ...



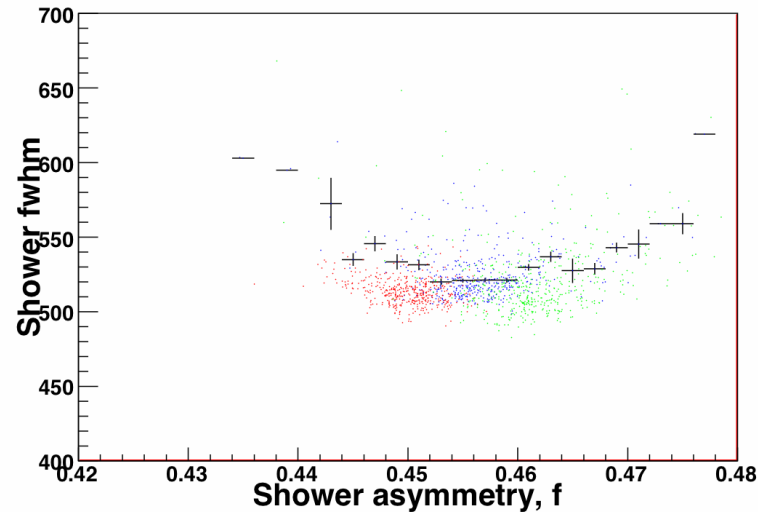
- Long, unbiased, ADST events selected with shower zenith $\leq 60^\circ$.
- Map from GH shower parameters (X_0, λ) to $(fwhm, f)$
- **plot:** shows f vs shower energy.
- Colored points show Conex QGSjet (p,Fe) and EPOS (p,Fe) predictions.
- Auger points inconsistent with proton (blue, red) predictions!
- Auger points consistent with iron (green, yellow) predictions below about 10^{19} eV, then systematically below all Conex predictions!

Are ADST showers measuring $fwhm, f$?



- There is more to a shower than N_{max} and X_{max} .
- These quantities: (X_0, λ) or $(fwhm, f)$ are, at a minimum, a diagnostic tool and are possibly a source of physics.
- plot of Auger ADST (X_0, λ) correlations (in red) is *opposite* to all Conex simulations (blue points are for EPOS iron); Is this known? Should we be concerned? Can we trust the resulting $fwhm, f$?
- Earlier plot of shower $fwhm$ was systematically $\sim 5\%$ above Conex predictions. Given that $E_{shower} \propto fwhm$ might we have an energy systematic?

Summary ...



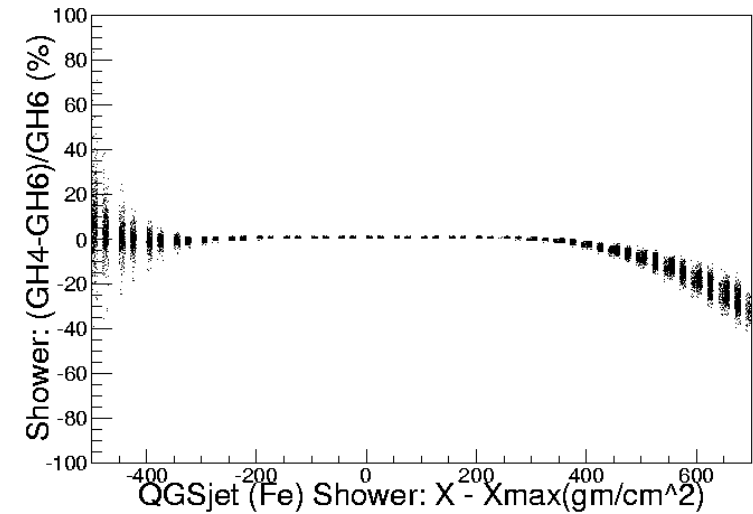
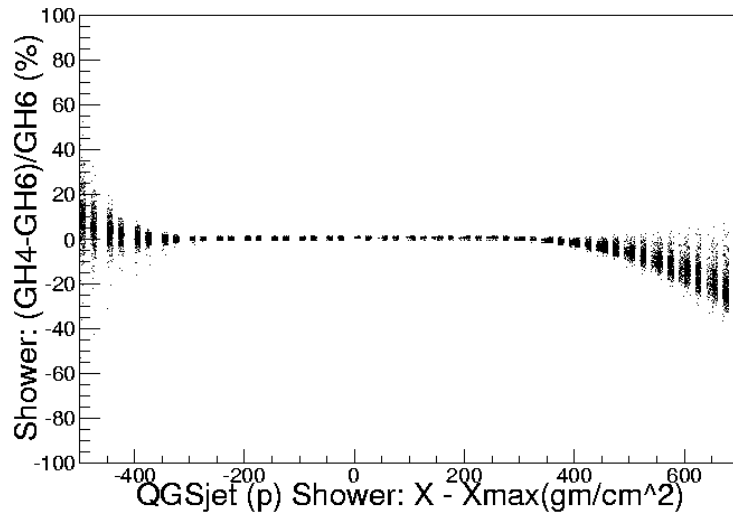
- The point of the talk is to ask some questions ...
- The data and simulations are probably primitive ... but they suggest some topics for further study.
- If no one has looked at these issues and/or if there is even a shred of reality to what may be systematic effects, then we need to see if these effects have an impact on the more important X_{max} and E_{shower} measurements.
- If collaborators have working FD reconstructions, please let us know as we would like to work together to e.g. replace X_0 and λ constraints with a GH profile fit with possible $fwhm$ and/or f constraints. ($fwhm$, f largely uncorrelated: see plot)

Additional/backup slides



Additional slides

Comparison of GH 4 and 6-parameter profiles ...



- For Conex simulations, GH $fwhm$, f parameters are simply evaluated using $1/2$ -maximum points of the Conex 6-parameter GH profile.
- **Left plot:** Comparison of GH 4- and 6-parameter profiles: QGSjet proton showers
- **Right plot:** Comparison of GH 4- and 6-parameter profiles: QGSjet iron showers
- A simple 1:1 mapping relates $(fwhm, f)$ to GH (X_0, λ) .