

# A Parametrization of Cosmic Ray Shower Profiles Based on Shower Width

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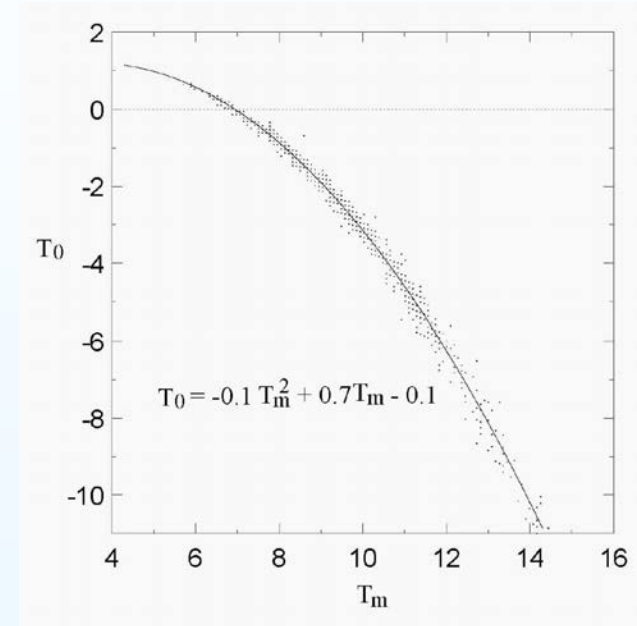
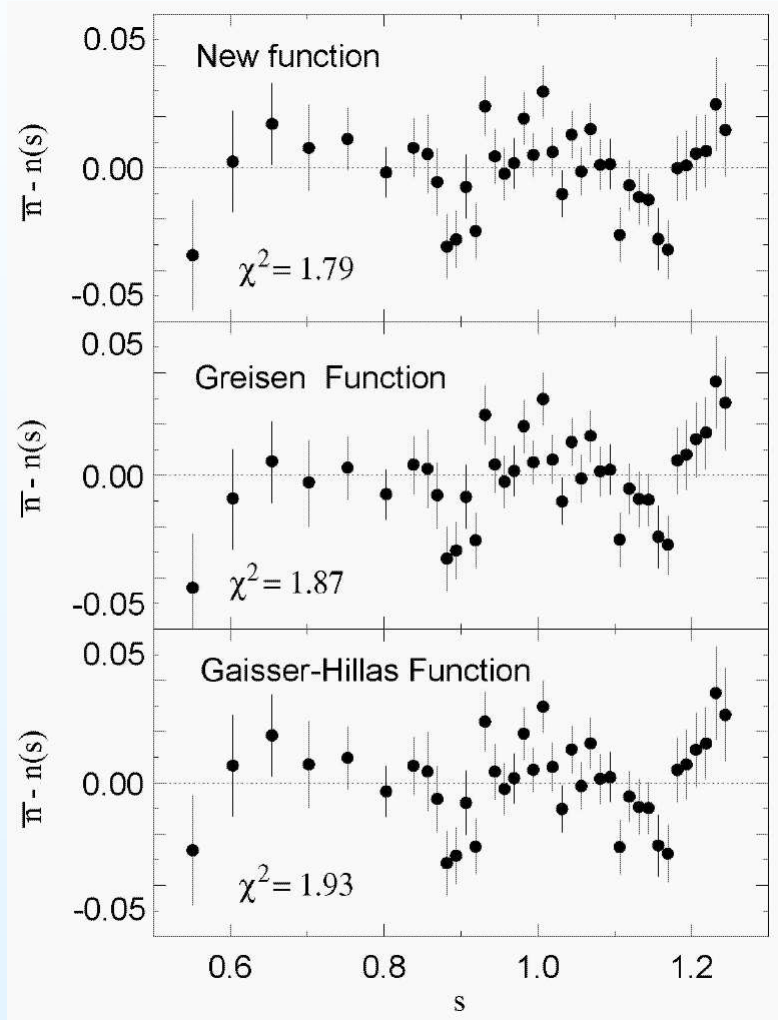
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**FOR**

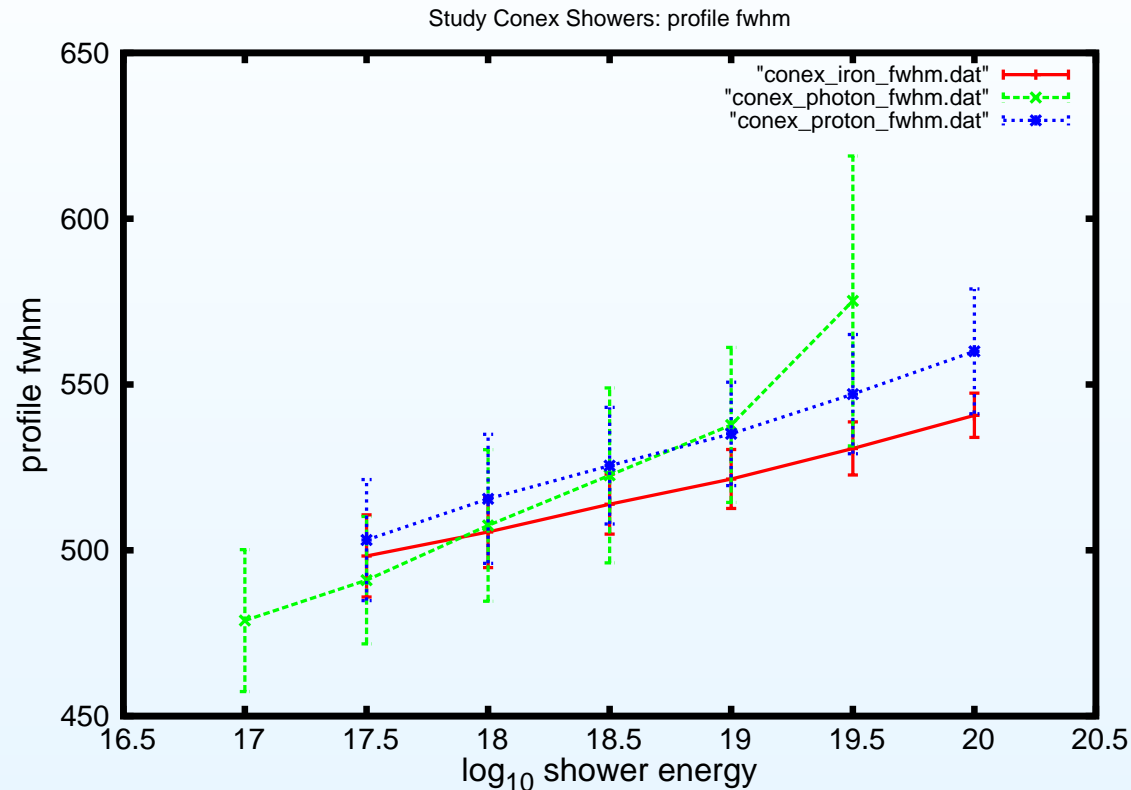
Bernie Becker, Michael Gold, Doug Hague and Bob Mesler

# HiRes-Prototype (2001) Study of Shower Profiles



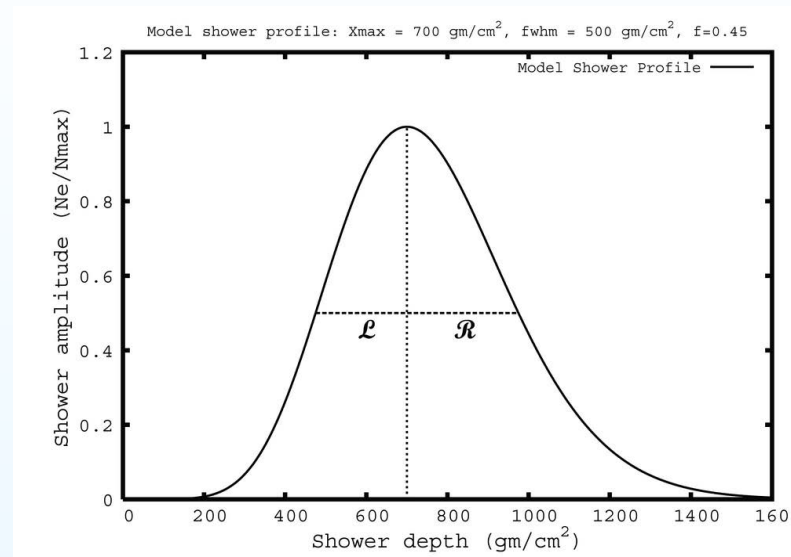
- **Left plot:** Residuals from comparison of HiRes-Prototype composite shower profile to GIA, Greisen and GH parameterizations. Events have  $10^{17} \leq E \leq 10^{18}$  eV.
- **Top plot:** Observed correlation between GH parameters:  $T_0 = \frac{X_0}{\lambda}$  and  $T_m = \frac{X_{max}}{\lambda}$

# HiRes (2001) Corsika Study of Shower Profiles



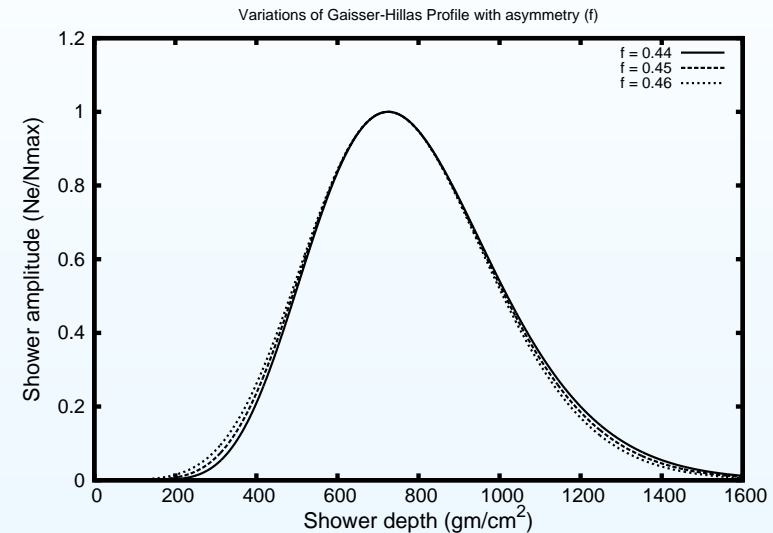
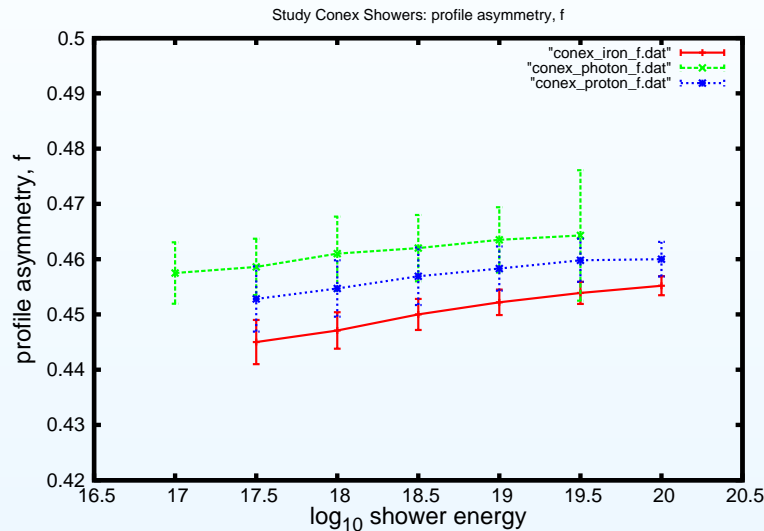
- Conclusion: GH and GIA functions described Corsika showers comparably well
- However GIA was preferable as it required only 3 parameters
- The Monte Carlo study observed the near equality of the width at half-maximum, *fwhm*, of proton, iron and photon showers but did not exploit this fact

# A New Approach to Shower Profiles (I)



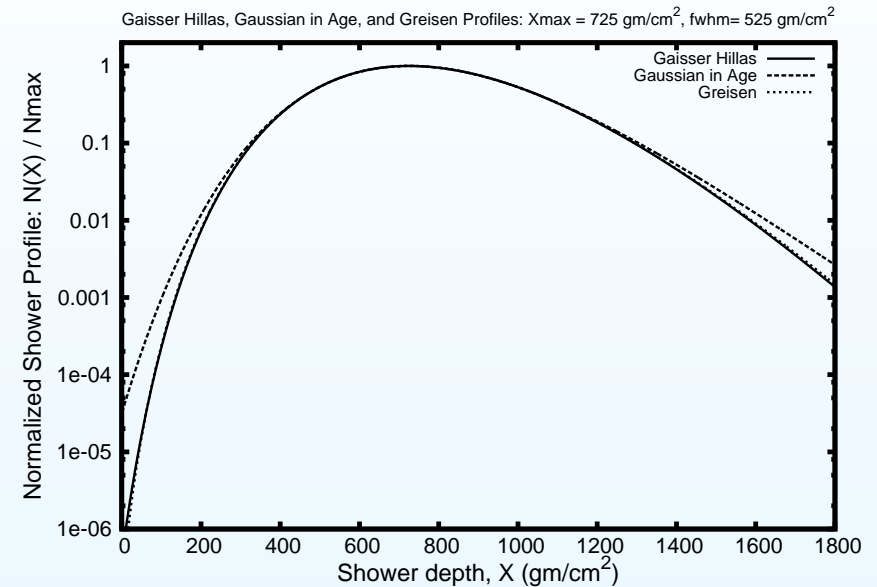
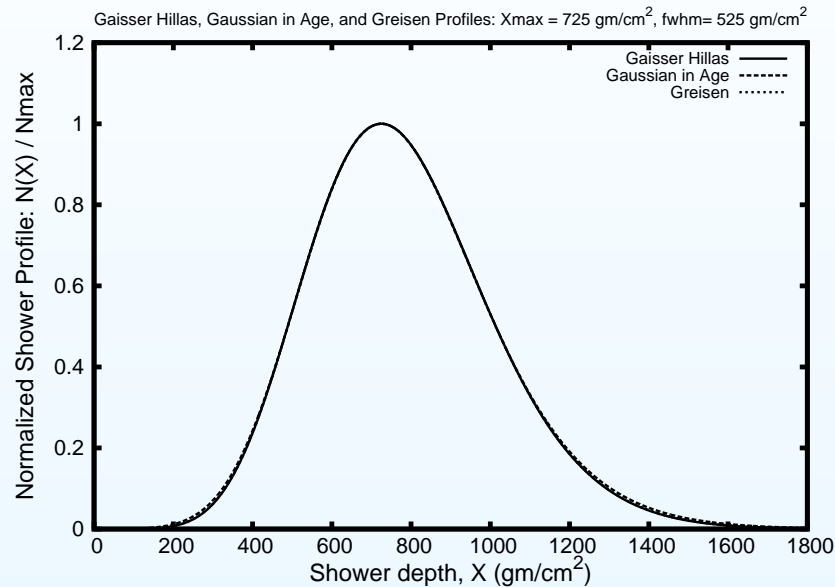
- How different are the different: GH, GIA and Greisen profiles?
- Are 3-parameters indeed sufficient or are 4-parameters needed?
- Can we profit from similarity of shower *fwhm*?
  1. reformulate GH, GIA and Greisen profiles based on:  $N_{max}$ ,  $X_{max}$ ,  $fwhm \equiv \mathcal{L} + \mathcal{R}$  and shower asymmetry  $f \equiv \mathcal{L}/(\mathcal{L} + \mathcal{R})$ .
  2. then **all profiles** depend on **two dimensionless ratios**:  $\epsilon \equiv \frac{\Delta}{W}$  where  $\Delta = X - X_{max}$ ,  $W \equiv X_{max} - X_0 = \frac{fwhm}{R(f)}$ , and  $\xi \equiv \frac{W}{\lambda}$ ,  $\sigma$  or  $\frac{W}{p_{36.7}}$  where  $\xi$  depends only on the asymmetry  $f$ .

# A New Approach to Shower Profiles (II)



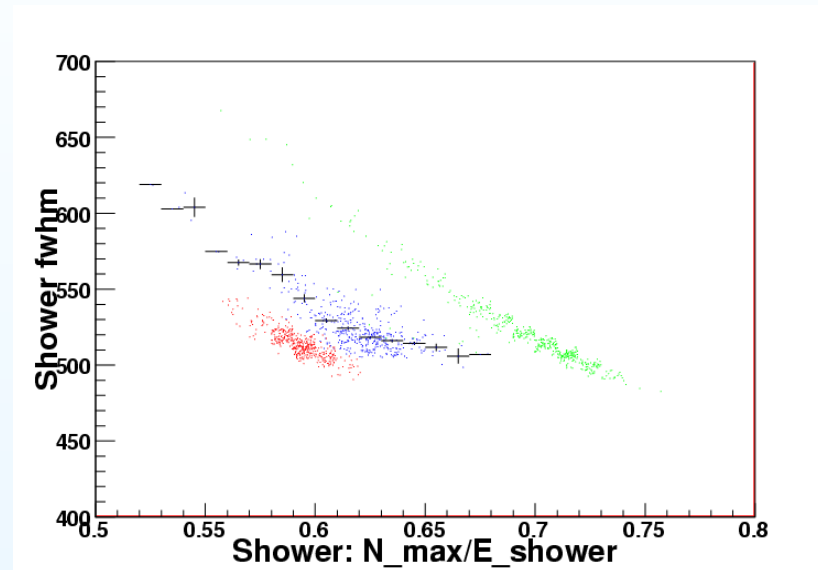
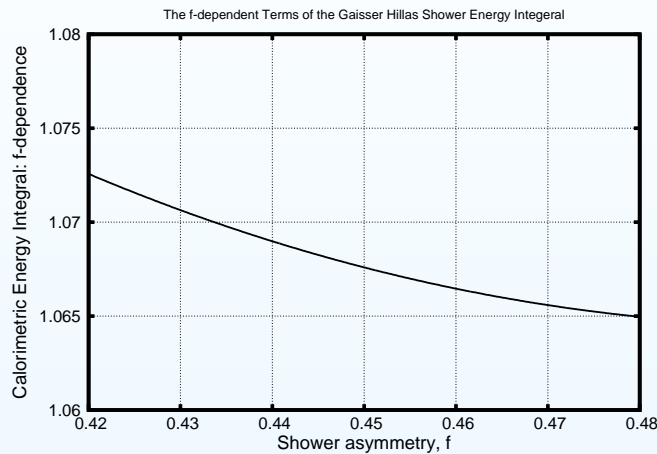
- **Left plot:** CONEX simulations suggest that the asymmetry parameter  $f$  may provide some discrimination in primary composition
- **Note:** as the GIA “ $\sigma$  parameter” and the GH “ $(X_{max} - X_0)/\lambda$  ratio” depend **only** on the asymmetry  $f$ , this echos the results of: V. Scherini et al (ICRC 2007) and S. Andringa et al (ICRC 2009)
- **Right plot:** But the effect is subtle. The GH shower profiles have  $X_{max} = 725$  gm/cm<sup>2</sup>,  $fwhm = 525$  gm/cm<sup>2</sup> and three different values of asymmetry:  $f = 0.44$ , 0.45 and 0.46.

# What did we learn? (I)



- **Left plot:** Shower profiles with the same *fwhm* and asymmetry *f* are almost indistinguishable
- **Right plot:** The GH and Greisen profiles are systematically below the GIA profile for shower depths well away from shower maximum. Thus shower calorimetric energies evaluated using the GIA function are  $\sim 1\%$  larger than those evaluated using GH or Greisen forms.

# What did we learn? (II)

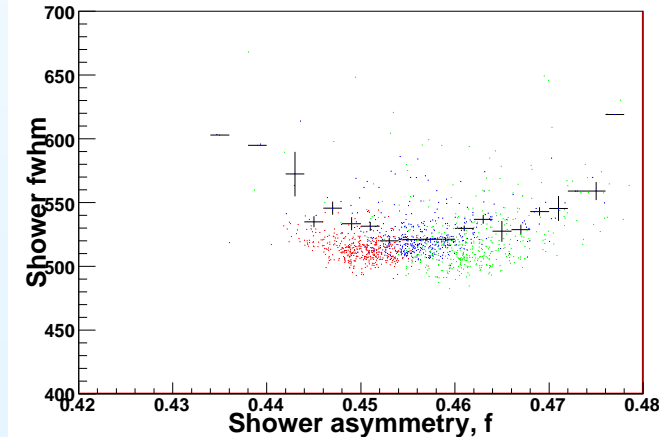
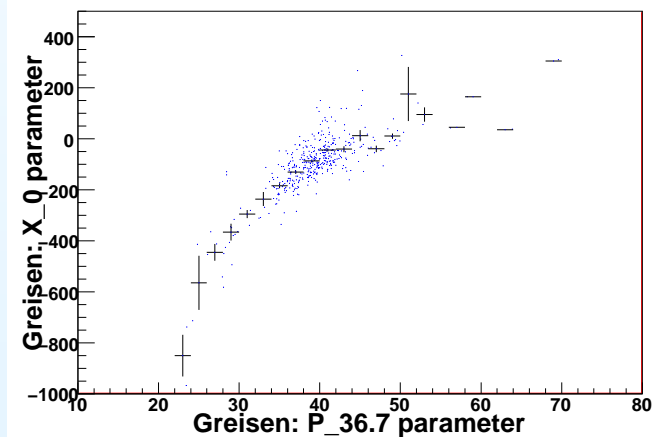
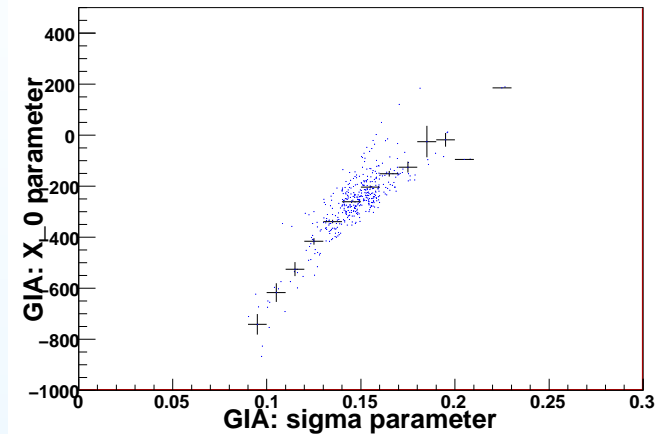
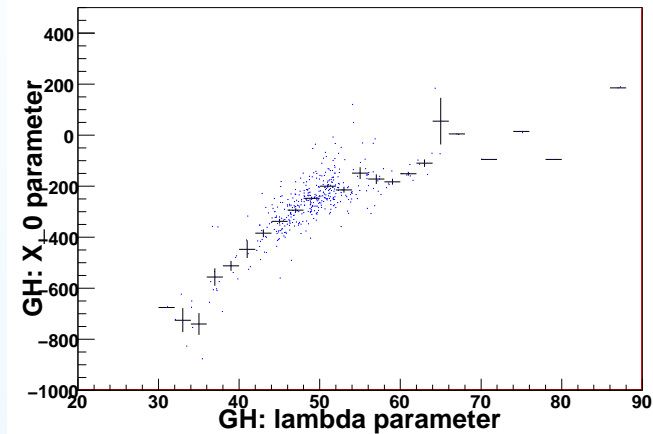


- The GH calorimetric shower energy is to a good approximation:

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

- **Left plot:** The asymmetry parameter  $f$  dependence, terms in ( ), is small
- **Right plot:** Thus  $E_{shower}^{calor} \propto N_{max} fwhm$ ; CONEX simulations are shown for **proton**, **iron** and **photon** showers at  $10^{18.5}$  eV

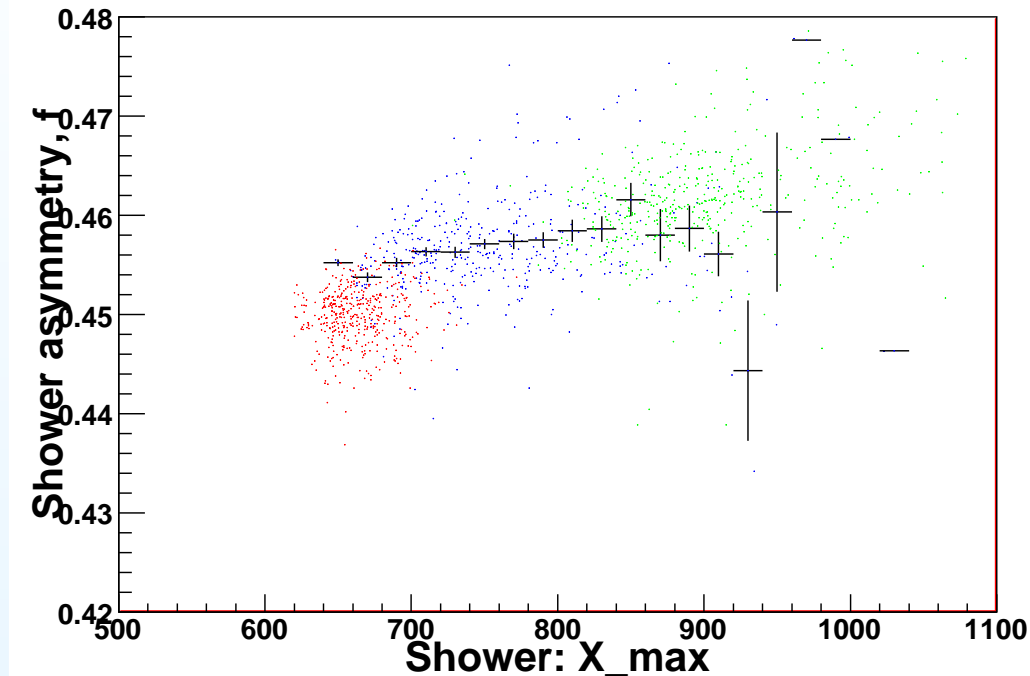
# What did we learn? (III)



- Shower ( $fwhm$ ,  $f$ ) parameters are less correlated than conventional parameters
- But correlated doesn't mean that 3 parameters are sufficient ...



# Composition and Exotics studies



- Plot of shower asymmetry  $f$  VS  $X_{max}$  for CONEX simulations of proton, iron, and photon showers near  $10^{18.5}$  eV
- As conventional showers have tails mostly to larger values of shower asymmetry  $f$ , typically associated with showers with larger values of  $fwhm$ , exotic studies are urged to search for showers with smaller values of shower asymmetry: *i.e.* more asymmetric showers!

## Conclusions: Shower Profile based on $fwhm, f$

- For profiles with the same  $(fwhm, f)$ , the GH and Greisen shower profiles are essentially identical and systemically less than GIA for shower depths away from shower maximum.
- Of the three functions, GH is most convenient as the integral of the GH profile is an analytic function.
- Monte Carlo simulated air showers using CONEX, and parameterized in terms of the new parameters:  $(fwhm, f)$ , have correlations (between those parameters) greatly reduced over the standard parameterizations *e.g.* Gaisser-Hillas parameters:  $(X_0, \lambda)$ .
- This allows shower profile reconstructions to add constraints (if needed) on the mostly uncorrelated parameters  $fwhm, f$ .
- While not a new result, the CONEX shower simulations suggest that the shower asymmetry parameter,  $f$ , may have some sensitivity to the incident cosmic ray particle type: *e.g.*  $p$ ,  $C/N/O$ ,  $Fe$  or  $\gamma$ .
- For all the juicy details see: LANL arXiv:0909.4014