A Parametrization of Cosmic Ray Shower Profiles Based on Shower Width

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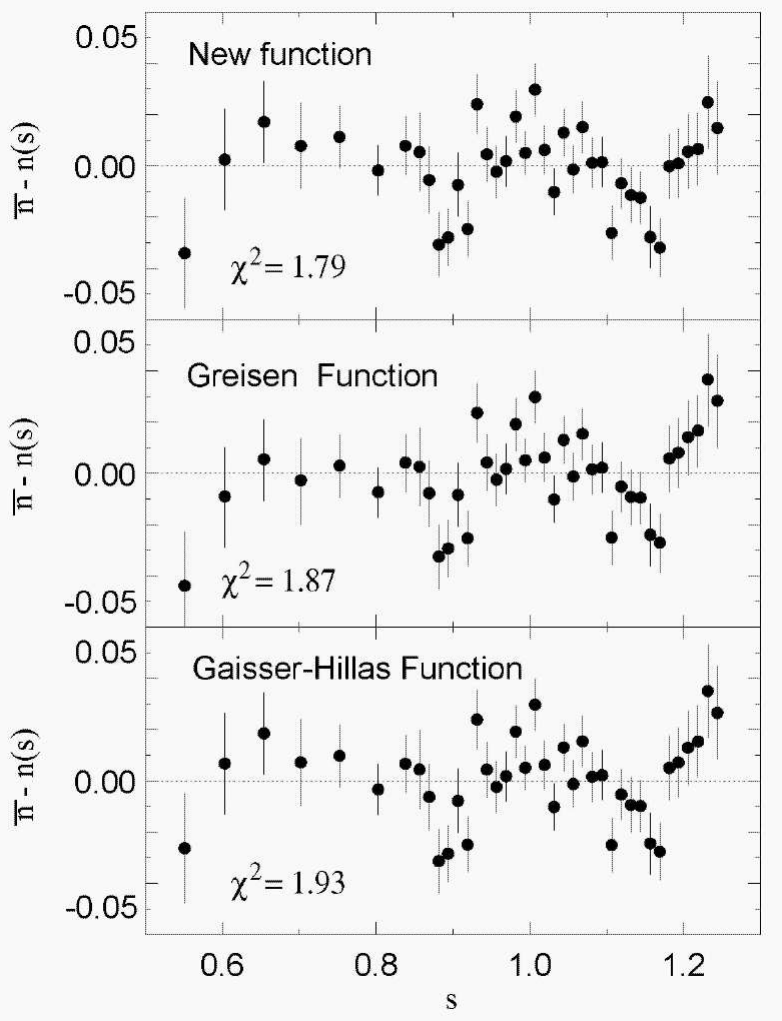
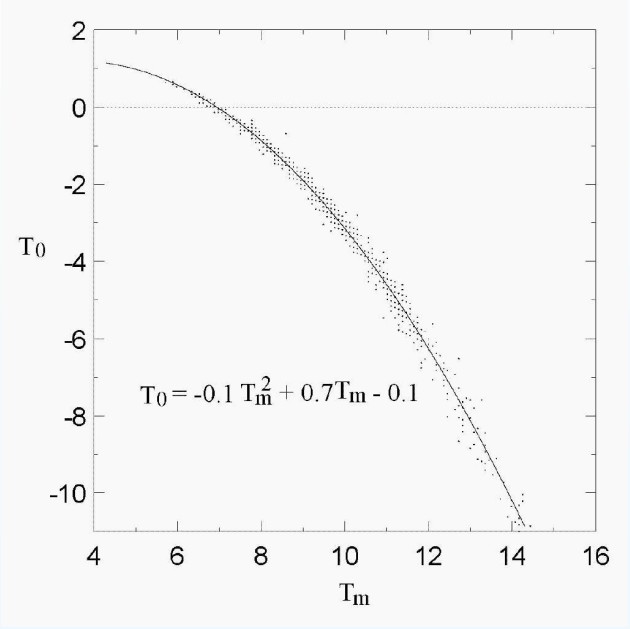
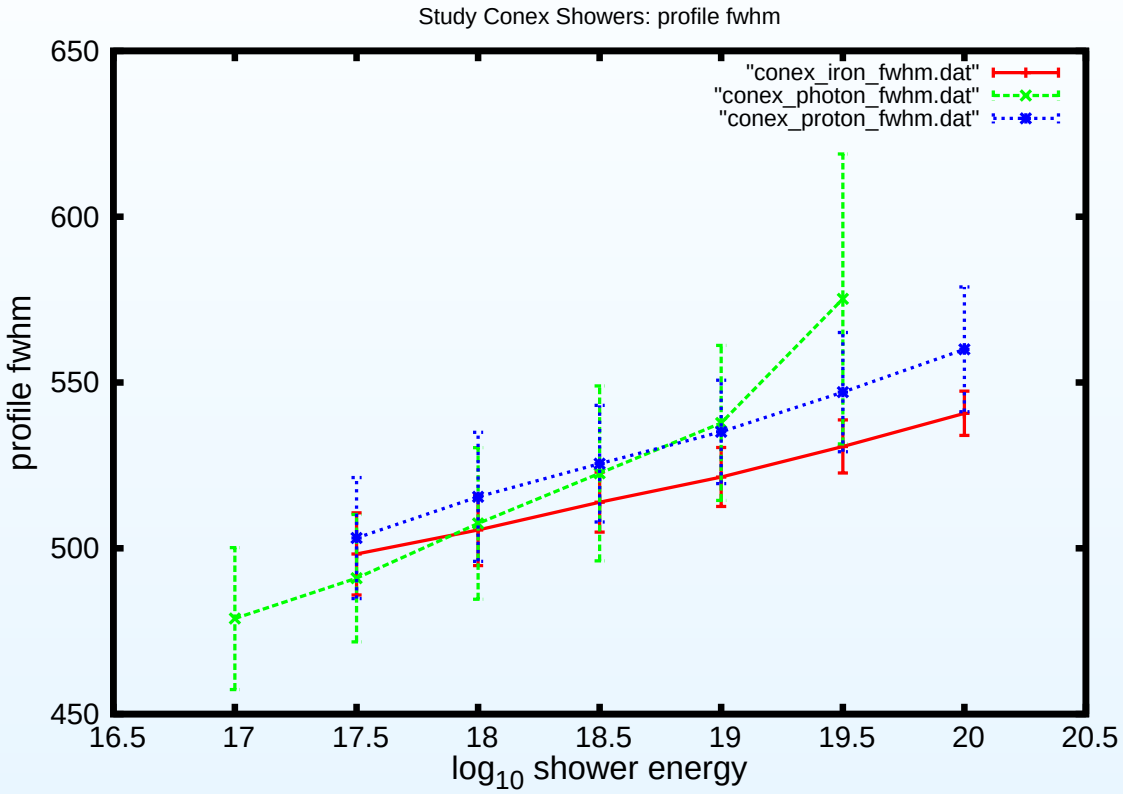
HiRes-Prototype (2001) Study of Shower Profiles





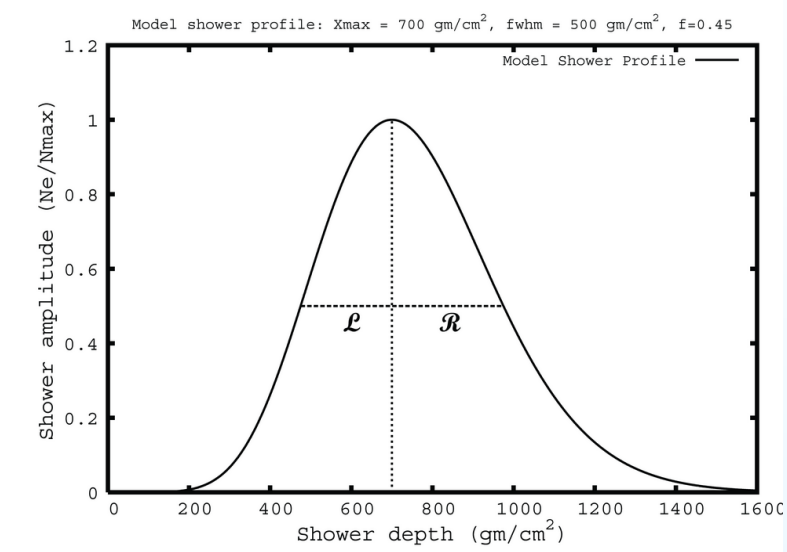
- Left plot: Residuals from comparison of HiRes-Prototype composite shower profile to GIA, Greisen and GH parameterizations. Events have $10^{17} \leq E \leq 10^{18}$eV.
- Top plot: Observed correlation between GH parameters: $T_0 = \frac{X_0}{\lambda}$ and $T_m = \frac{X_{max}}{\lambda}$

HiRes (2001) Corsika Study of Shower Profiles



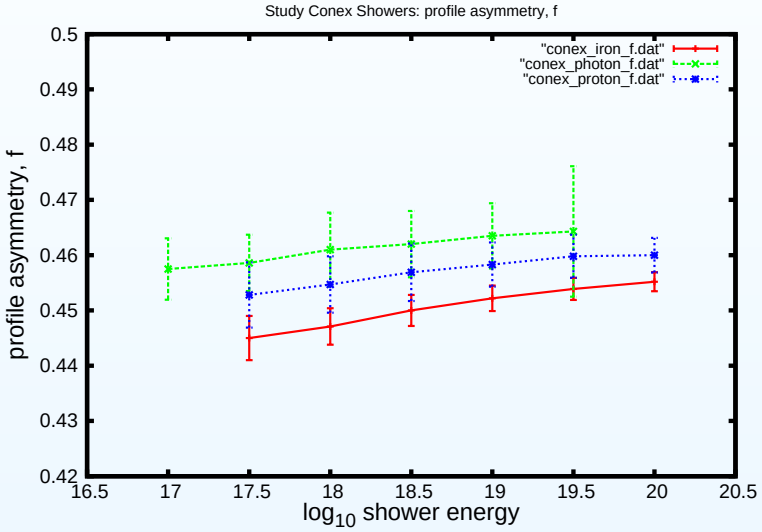
- Conclusion: GH and GIA functions described Corsika showers comparably well
- However GIA was preferable as it required only 3 parameters
- The Monte Carlo study observed the near equality of the width at half-maximum, $fwhm$, of proton, iron and photon showers but did not exploit this fact

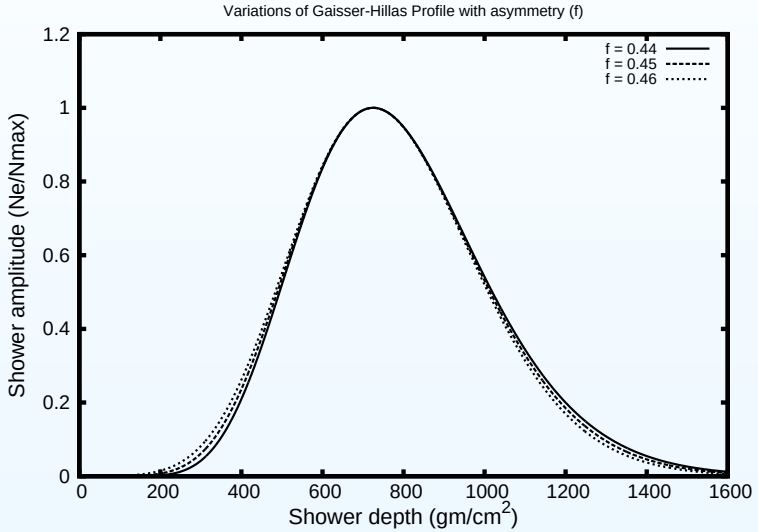
A New Approach to Shower Profiles (I)



- 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 $\xi \equiv \frac{W}{\lambda}$, σ or $\frac{W}{p_{36.7}}$ where ξ depends only on the asymmetry f.

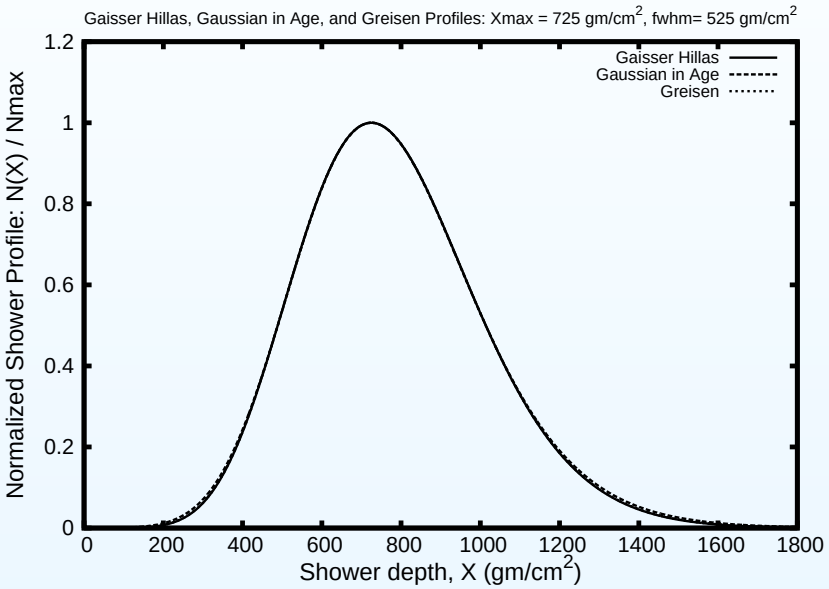
A New Approach to Shower Profiles (II)

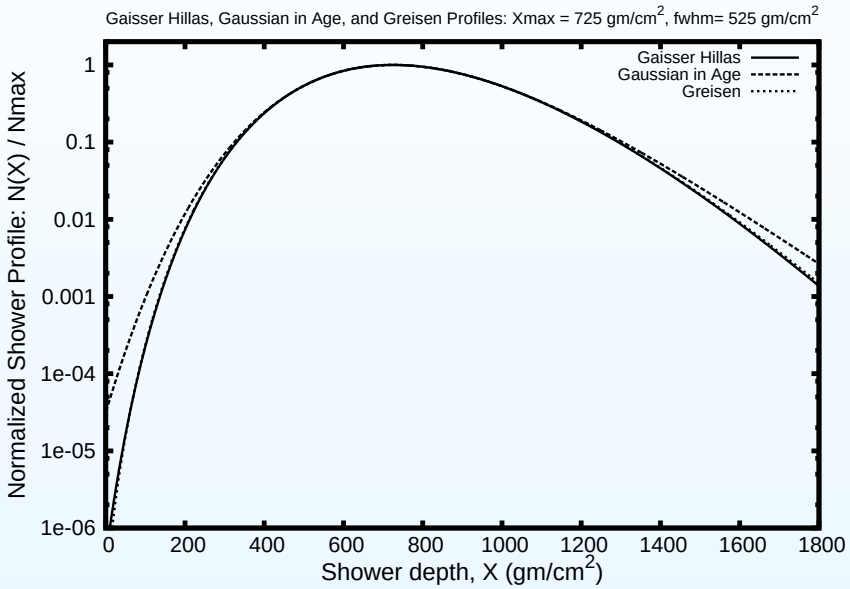




- **Left plot:** CONEX simulations suggest that the asymmetry parameter f may provide some discrimination in primary composition
- **Note:** as the GIA "σ parameter" and the GH "$(Xmax - X_0)/\lambda$ ratio" depend **only** on the asymmetry f, this echos the results of: V. Scherini et al (ICRC 2007)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

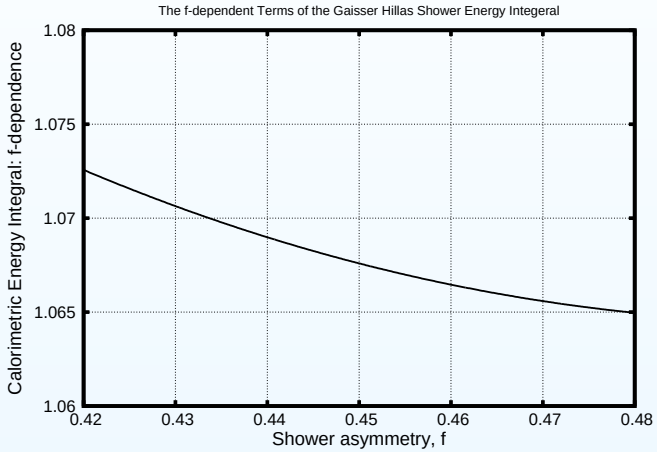
What did we learn? (I)

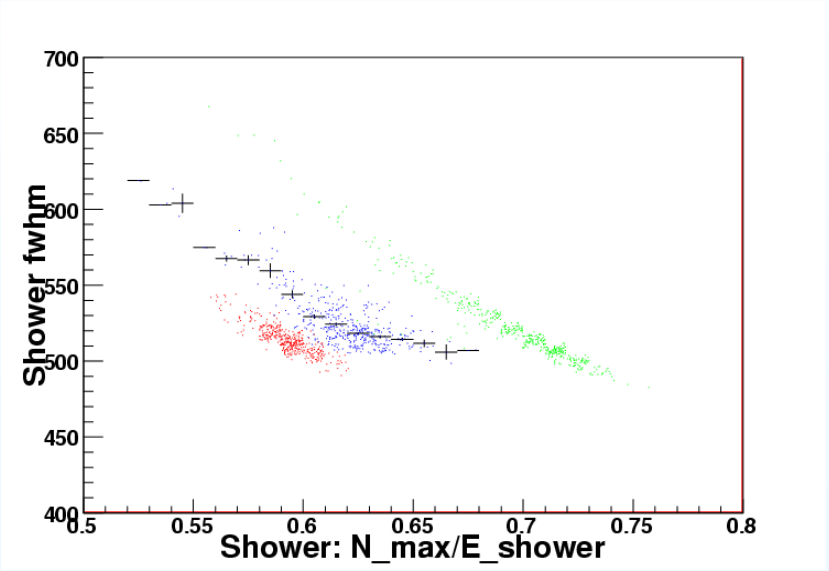




- **Left plot:** Shower profiles with the same $fwhm$ and asymmetry f are almost indistinguishable
- **Right plot:** The GH and Greisen profiles are systematically below the GIA profile for shower depths well away from shower maximum. Thus shower calorimetric energies evaluated using the GIA function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

What did we learn? (II)



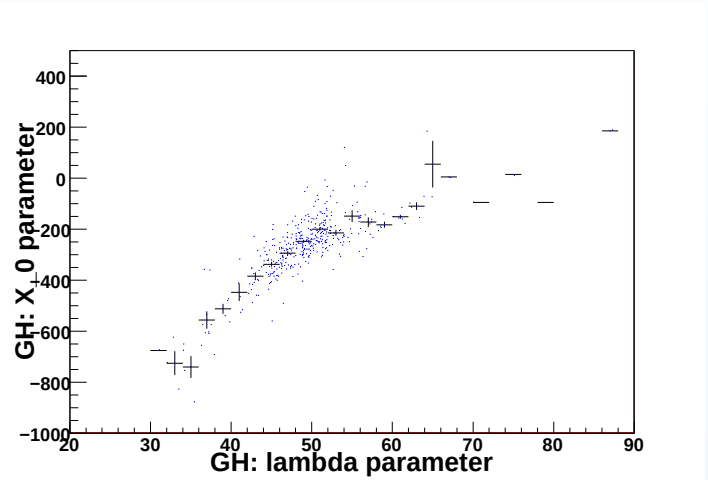


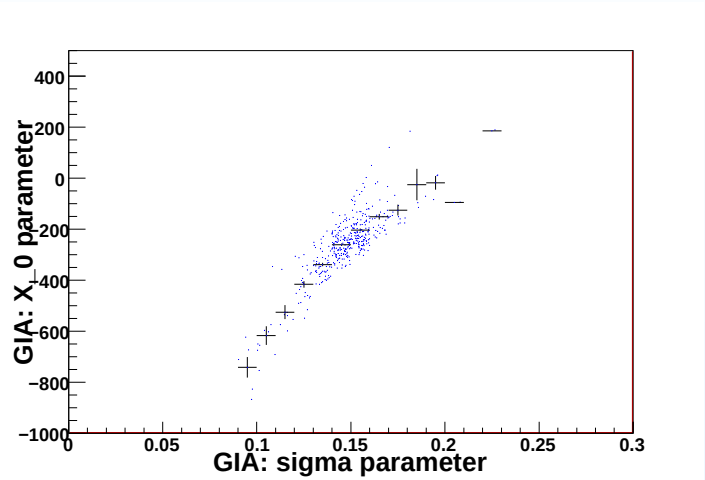
- The GH calorimetric shower energy is to a good approximation:

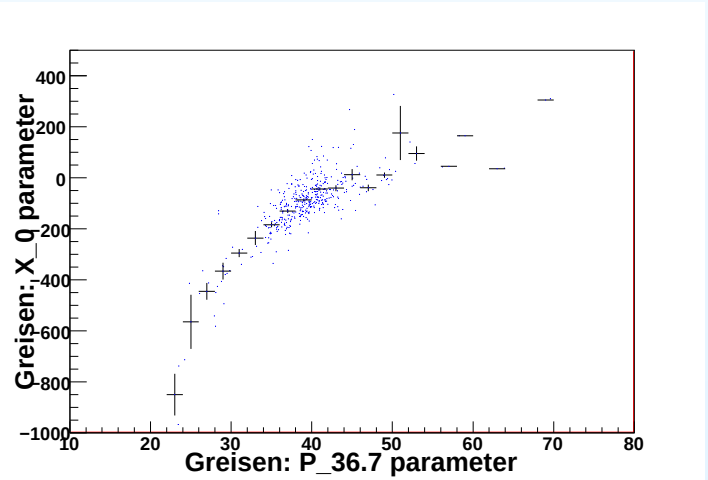
$$E^{calor}_{shower} = < dE/dx > N_{max}\ fwhm\ (\frac{\xi^{-(\xi+1)}\ e^{\xi}\ \Gamma(\xi+1)}{R(f)})$$

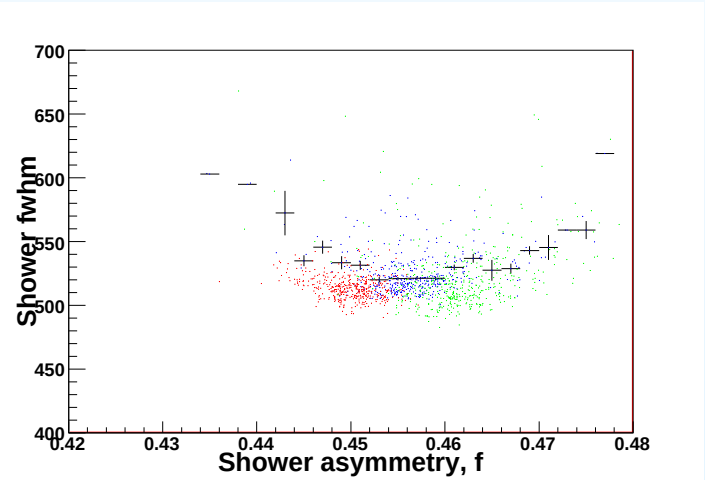
- **Left plot:** The asymmetry parameter f dependence, terms in ( ), is small
- **Right plot:** Thus $E^{calor}_{shower} \propto N_{max}\ fwhm$; CONEX simulations are shown for proton, iron and photon showers at $10^{18.5}$eV

What did we learn? (III)



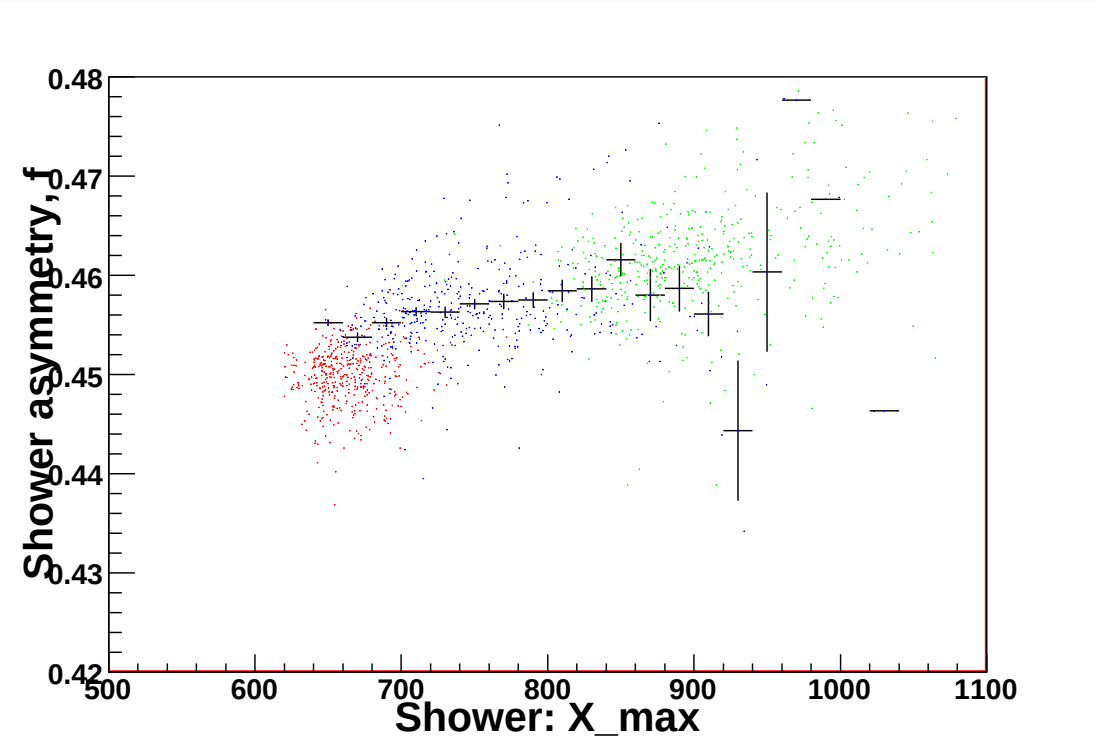






- Shower ($fwhm$, f) parameters are less correlated than conventional parameters
- But correlated doesn't mean that 3 parameters are sufficient ...

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

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- 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, λ).
- 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 γ.
- For all the juicy details see: LANL arXiv:0909.4014