Knee Workshop June 2000.

Interpreting the Data from BLANCA

Talk outline:

- BLANCA/CASA hardware and event parameterization.
- CORSIKA shower library and thinning.
- Energy transfer function and E spectrum.
- X_{max} transfer function and $\overline{X_{max}}$ vs. E.
- ln(A) transfer function and $\overline{\ln(A)}$ vs. E.
- Multicomponent composition analysis.

Clem Pryke - University of Chicago

CASA-MIA

Existing large air shower experiment at Dugway, Utah:

- Electron array CASA.
  $\sim$ 1000 units of $\sim$ 2 m^2 in a 500 m $\times$ 500 m grid.

- Muon array MIA.
  16 patches of buried muon detectors, total $\sim$ 2500 m^2.

Chicago/Michigan collaboration

Built to detect 10^{15} eV Gamma Rays... except there weren't any...

Borione *et al* NIMA **346** (1994) 329

BLANCA

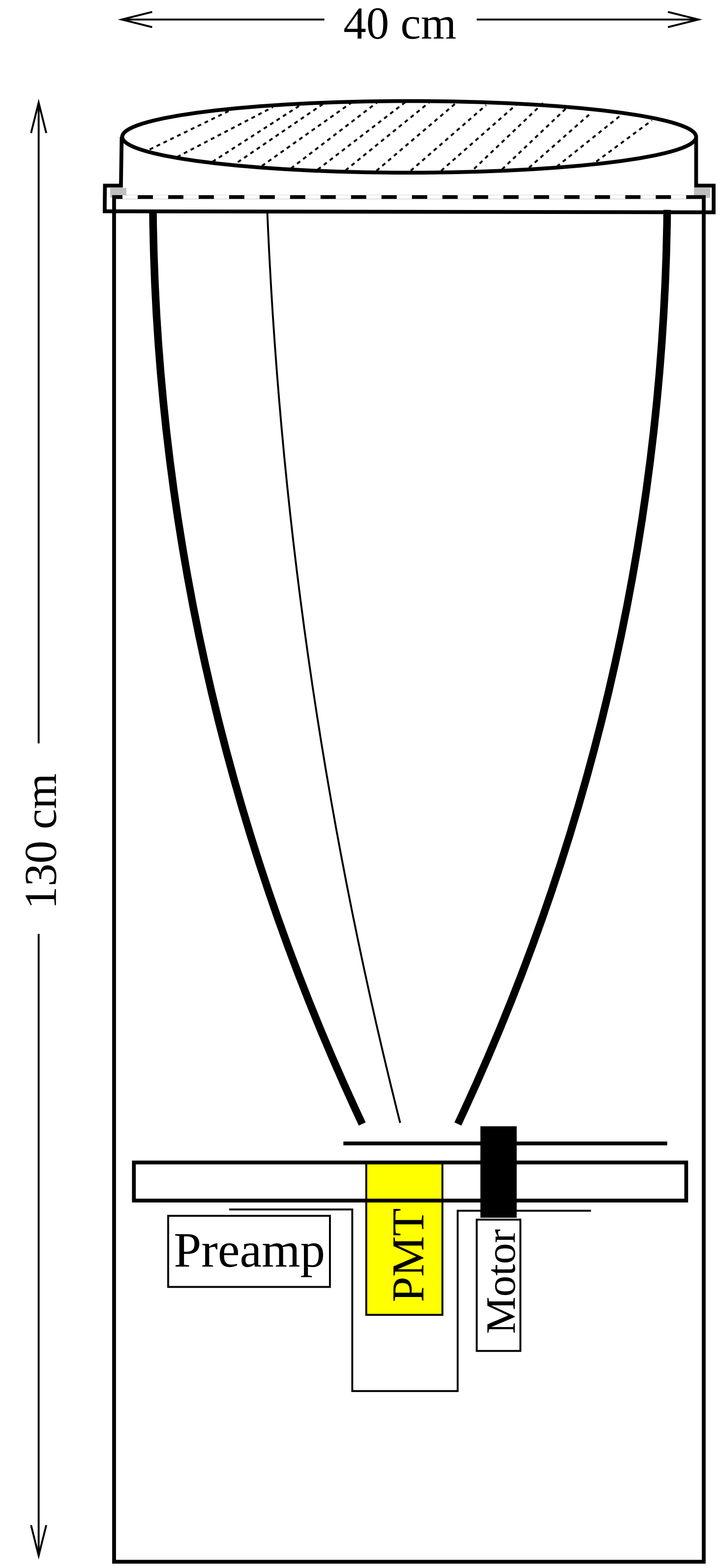
New 144 element angle integrating Čerenkov array.

- Exploit existing equipment and infrastructure.
- Make precision lateral distribution measurements.
- Determine composition at the Knee.

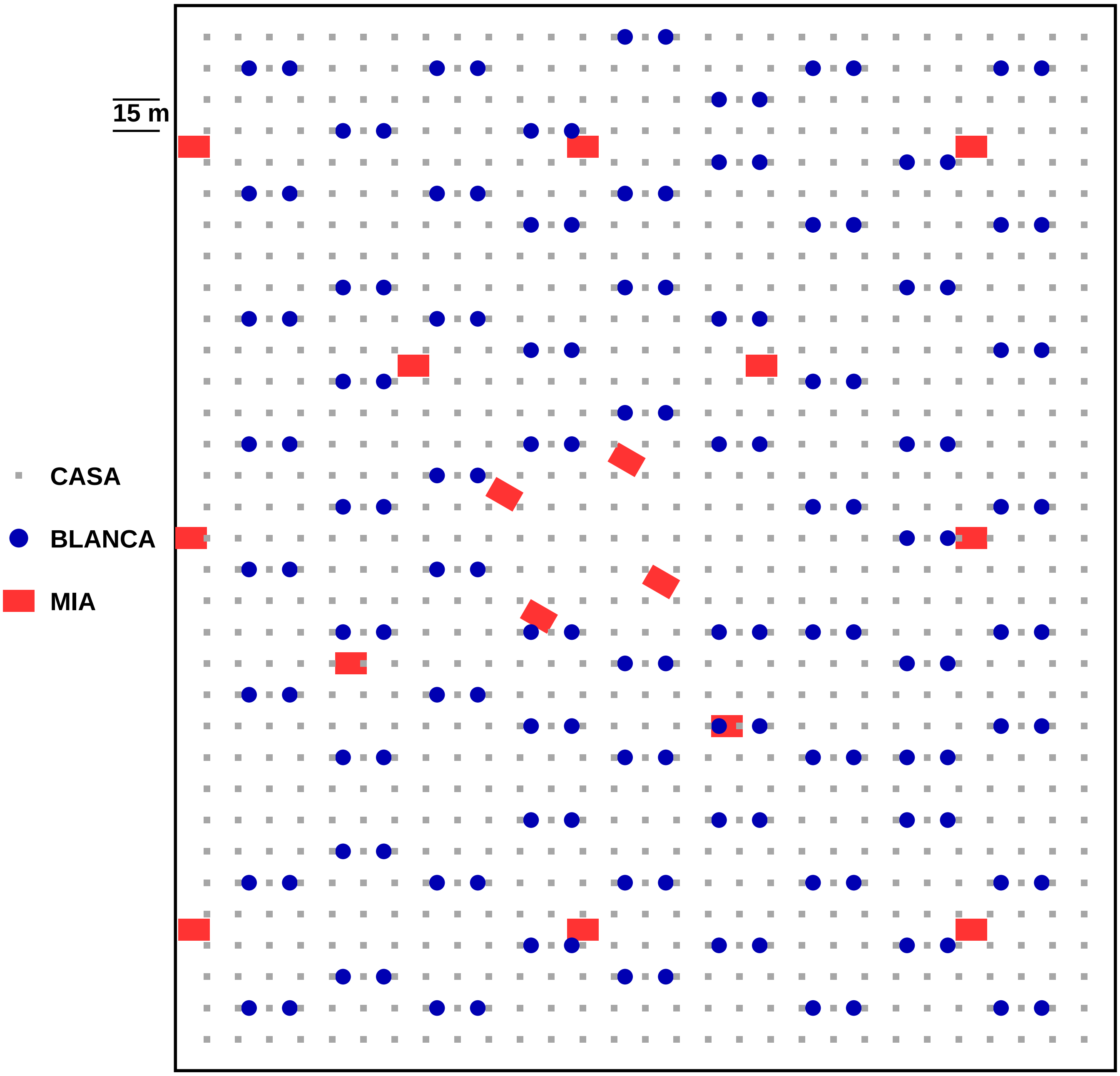
Chicago/Utah collaboration:

- Chicago: J. Fowler, L. Fortson, R. Ong, C. Pryke.
- Utah: C. Jui, D. Kieda, P. Sommers.
- Plus 5 undergrads, 6 volunteers, technician...

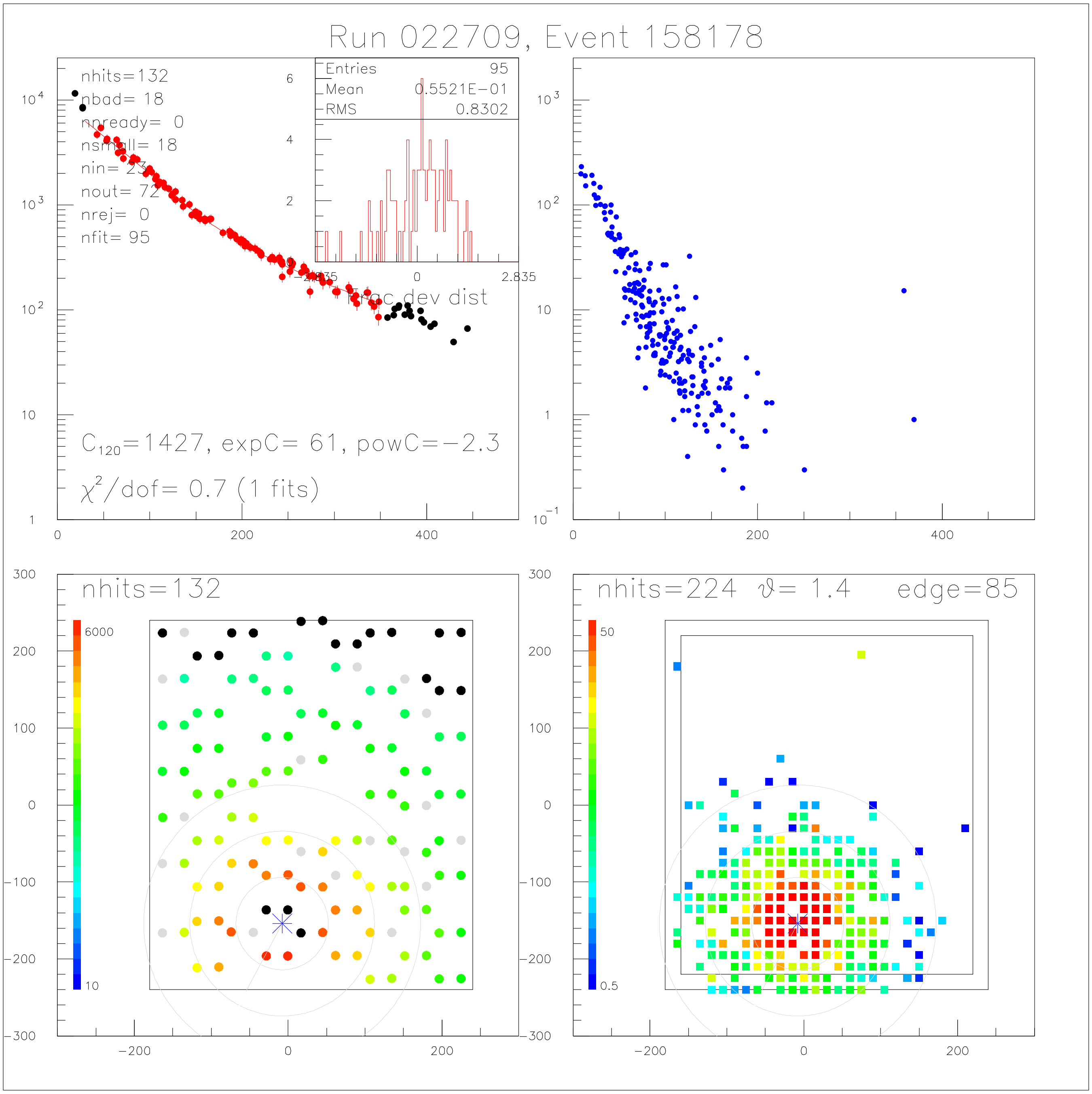
A BLANCA Unit



Array Layout



An Example Event

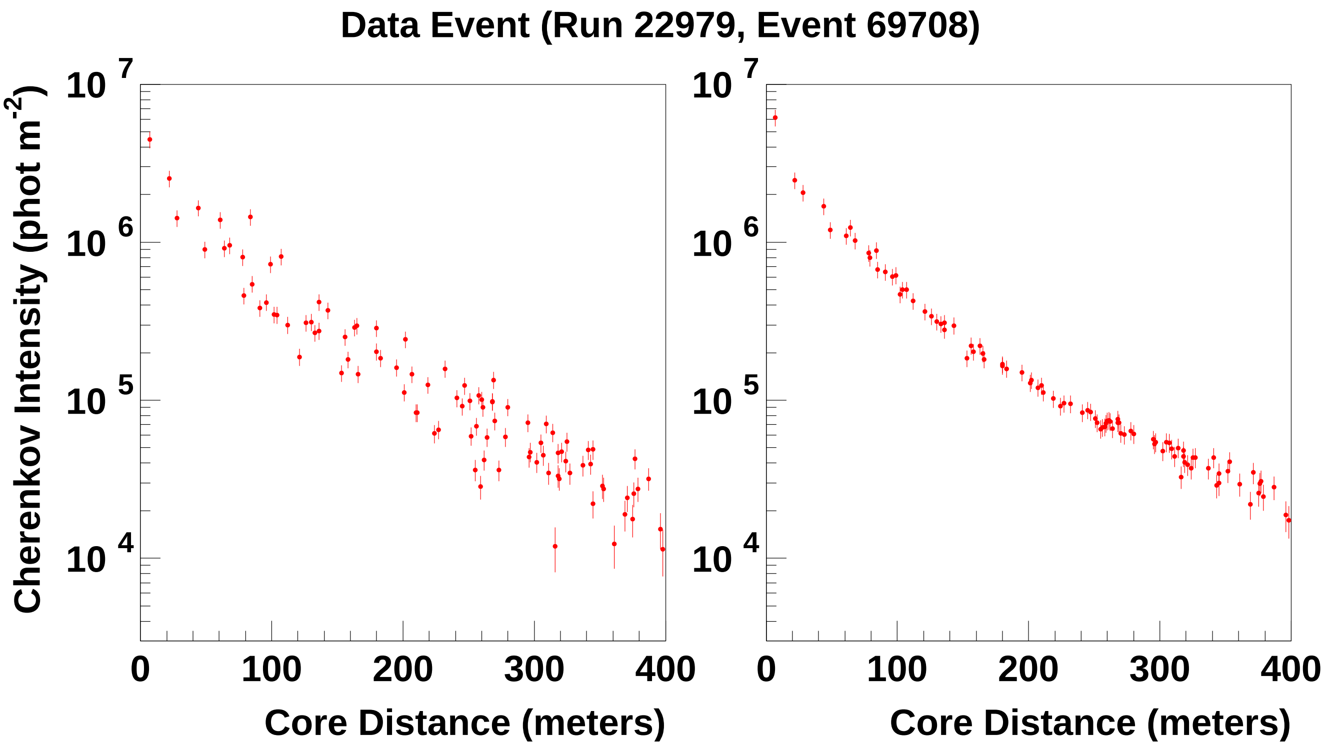


CASA/BLANCA

⇒ Measures both Particles and Čerenkov light.

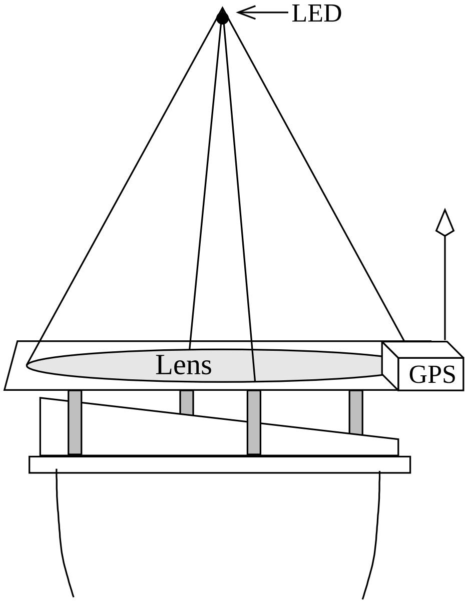
Relative Calibration

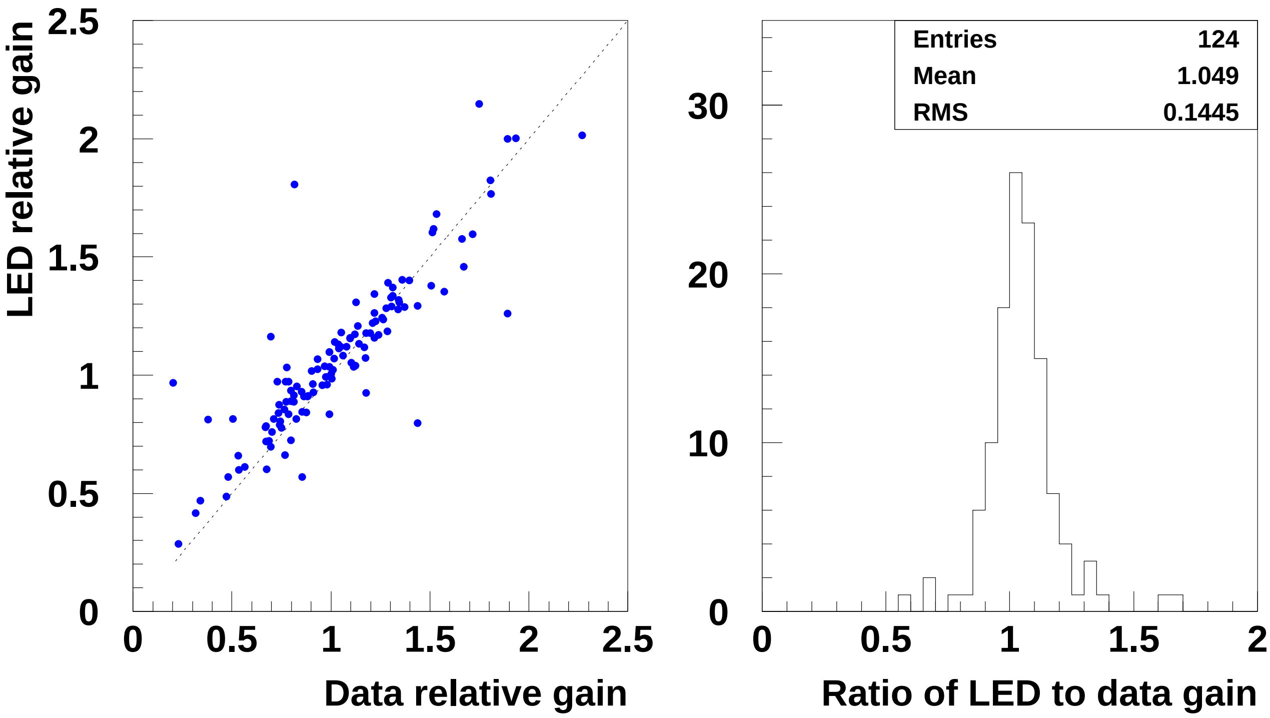
Assume showers are radially symmetric ⇒ relative gains can be extracted from the data.



Before and after on a single event demonstrates that the process works!

Relative Gains Confirmed



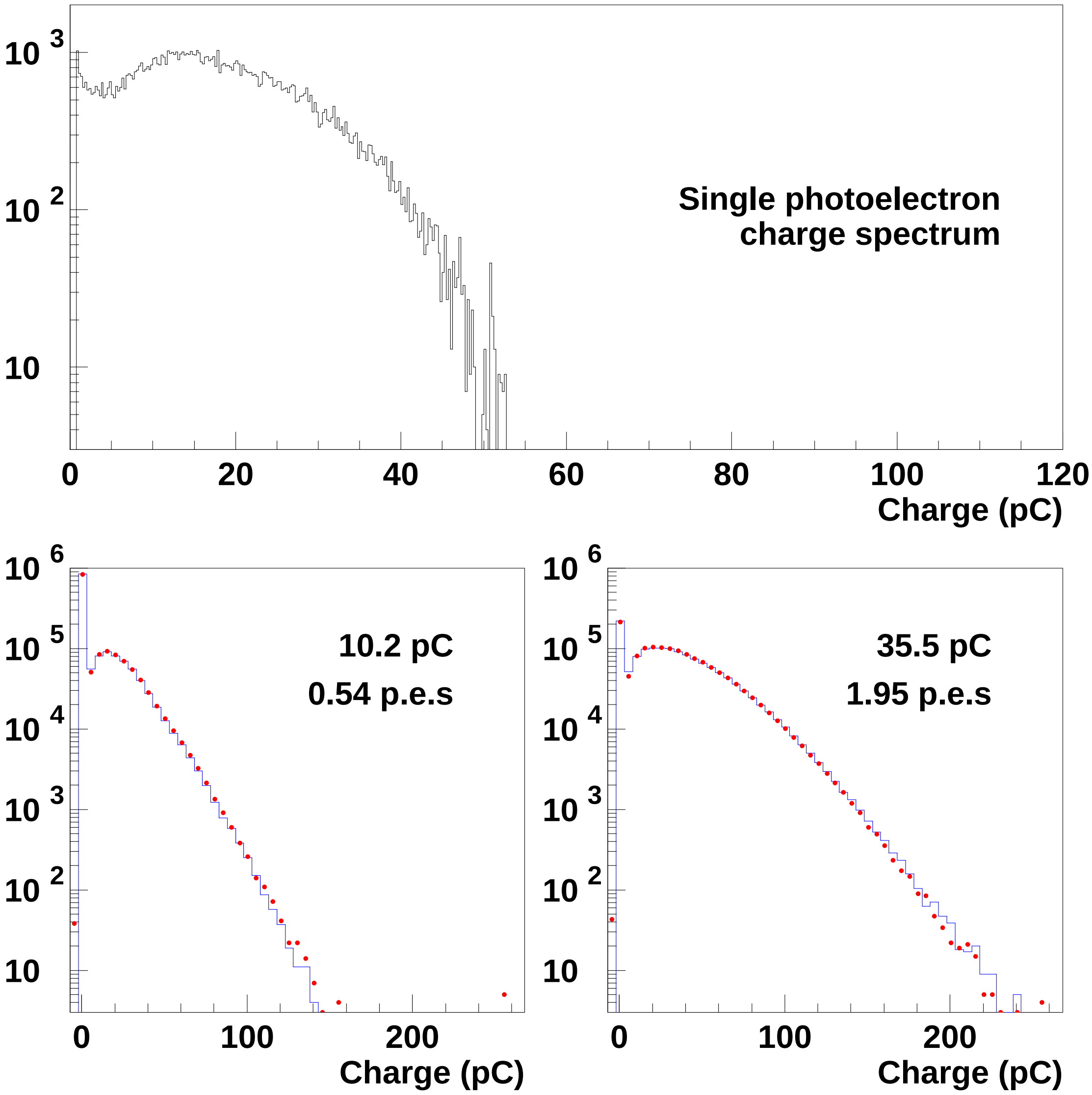


Portable blue LED pulser placed on each detector in turn.

Absolute Calibration

Using 14 complete units in a large light box.

Pulse light source calibrated using a high quality PMT.



Estimate overall systematic error of 20%

Other Calibrations/Corrections

- ADC Pedestals and High/Low channel gain ratios ⇒ extracted from the data for each run
- PMT nonlinearity ⇒ *carefully* measured for a sample of units
- Weather cuts ⇒ assuming CR rate should be constant over a run
- Gain degradation over expt. lifetime ⇒ assuming CR rate constant over all runs
- Detector de-pointing from vertical ⇒ shown from the data to be small

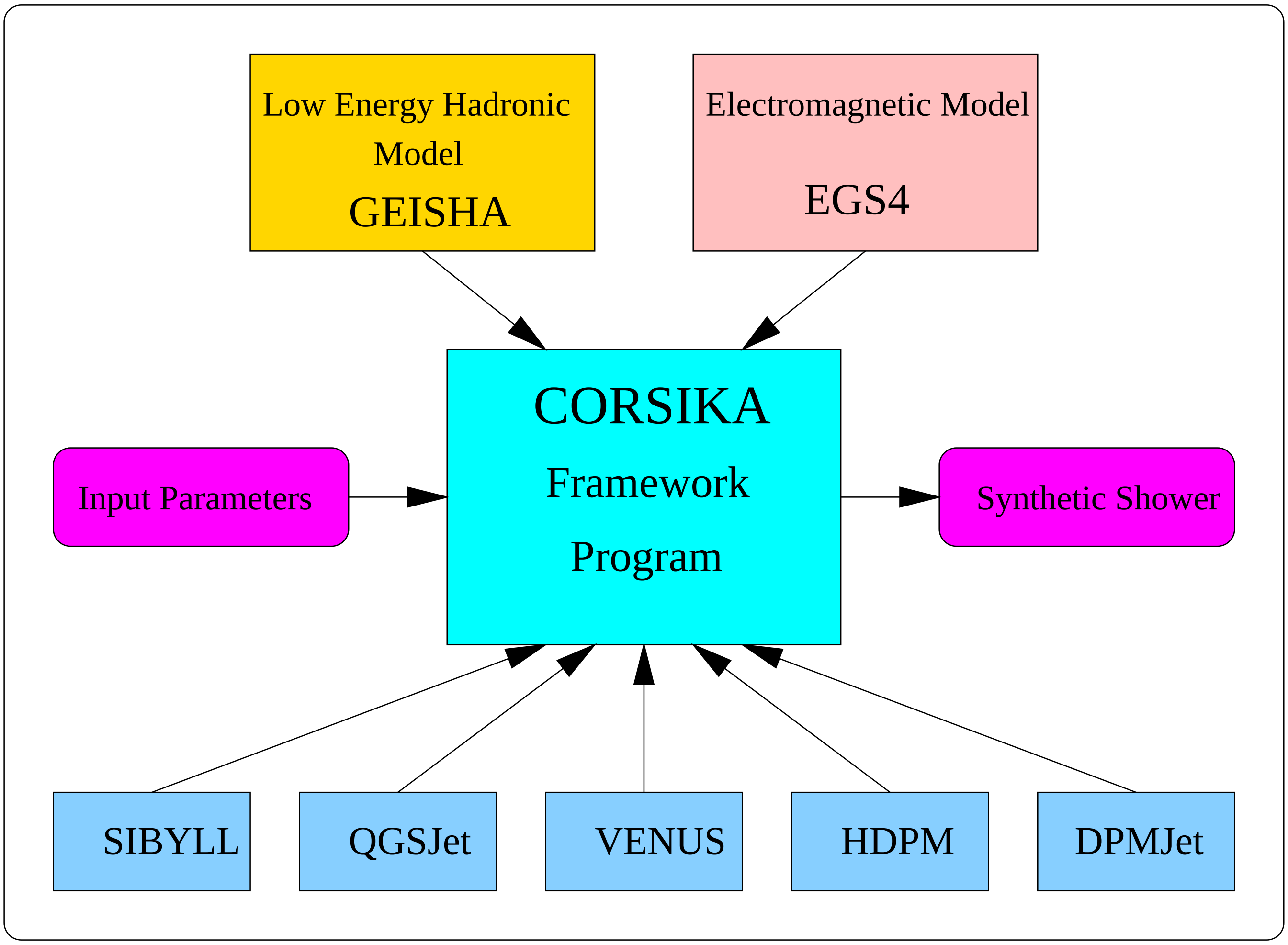
Parameterizing the Events

- Čerenkov lateral distribution fit to exponential in range 30–120 m $\Rightarrow$ Get normalization at 120 m (C_{120}), and Slope (S).

- Standard CASA analysis provides integral under Electron lateral distribution (N_e).

- Standard MIA analysis provides integral under Muon lateral distribution (N_μ).

CORSIKA Air Shower Simulation Program



- Uses highly respected HEP simulation codes for the low energy modeling — GEISHA and EGS4
- Pluggable high energy hadronic models (uncertain).
- Prepared in support of the KASCADE experiment but freely available.
- Philosophy - don't try and reinvent the wheel...

Shower Libraries

- Simulated 4 primary species — Proton, Helium, Nitrogen, Iron — 10,000 of each type with flat spectrum $14.0 < \log(E) < 16.5$

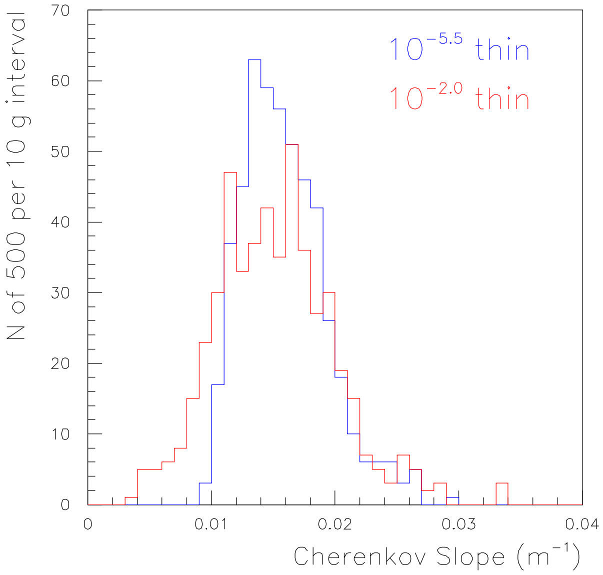
- High energy hadronic models: QGSjet, VENUS, SIBYLL and HDPM.

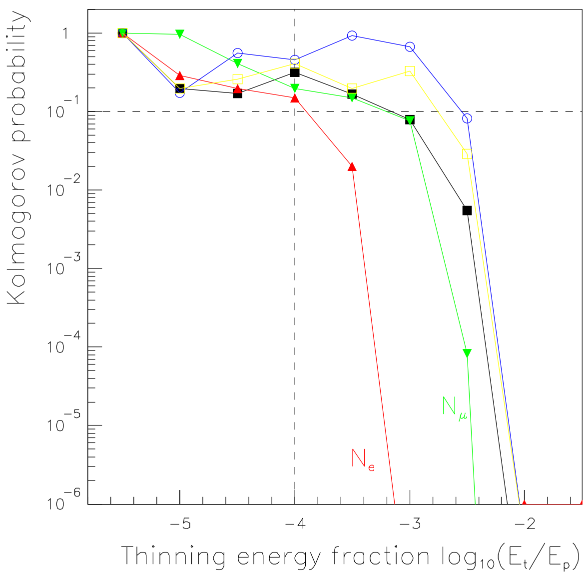
That's $4 \times 10,000 \times 4 = 160,000$ showers.

Need big libraries to characterize Fluctuations...

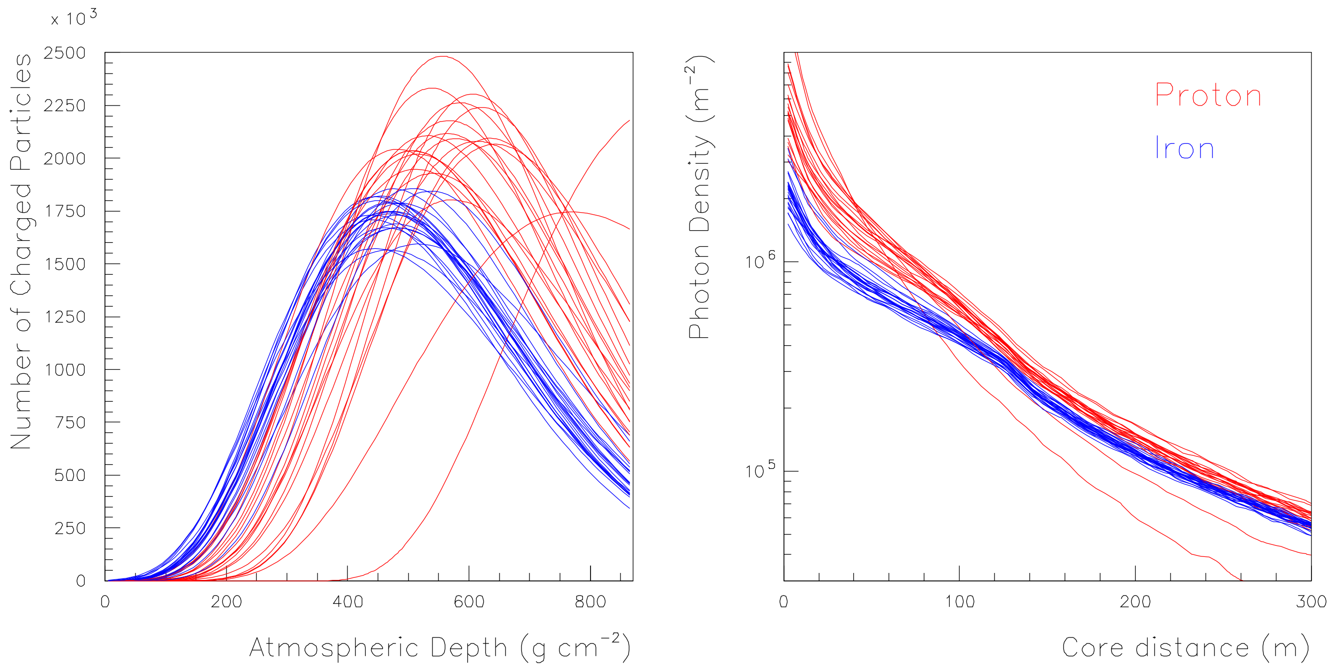
Aside: Thinning

- Necessary to use computational tricks to accelerate shower simulations.
- "Thinning" a popular technique ⇒ Below Threshold Energy only a sample of particles are tracked.
- Threshold normally specified as a fraction of the Primary Energy.
- There is a lot of folklore about what is an appropriate level....





Fluctuations are Severe



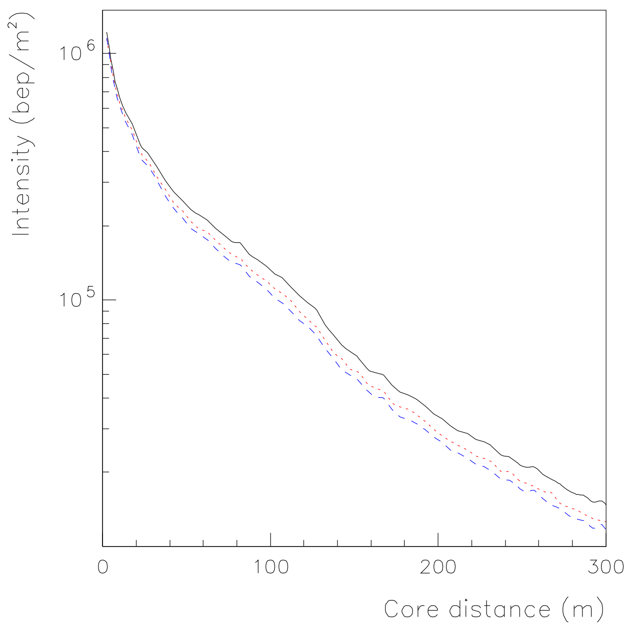
Caused by fluctuations in:

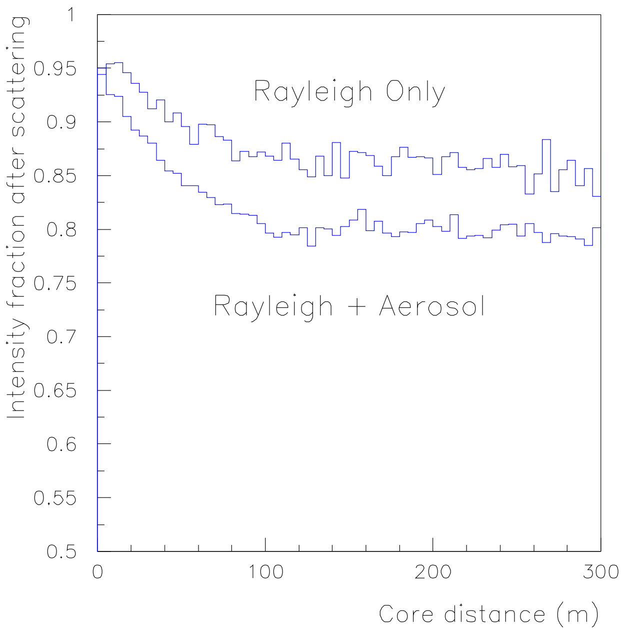
- Depth of first interaction point.
- Elasticity of first interaction.

Nature is very unkind...

Modifications to CORSIKA

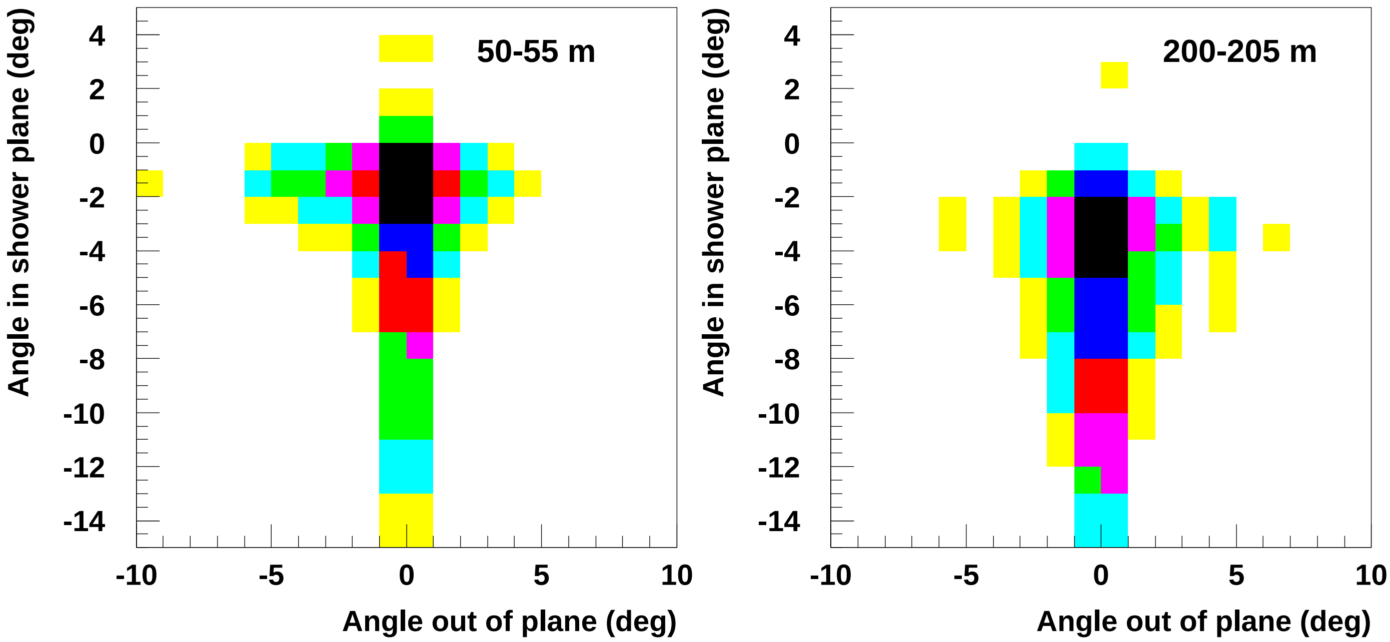
- Give each photon an explicit λ
- Include atmospheric scattering (not in 5.62)





Modifications to CORSIKA cont.

- Convolve detector λ response
- Output a table containing arrival direction information



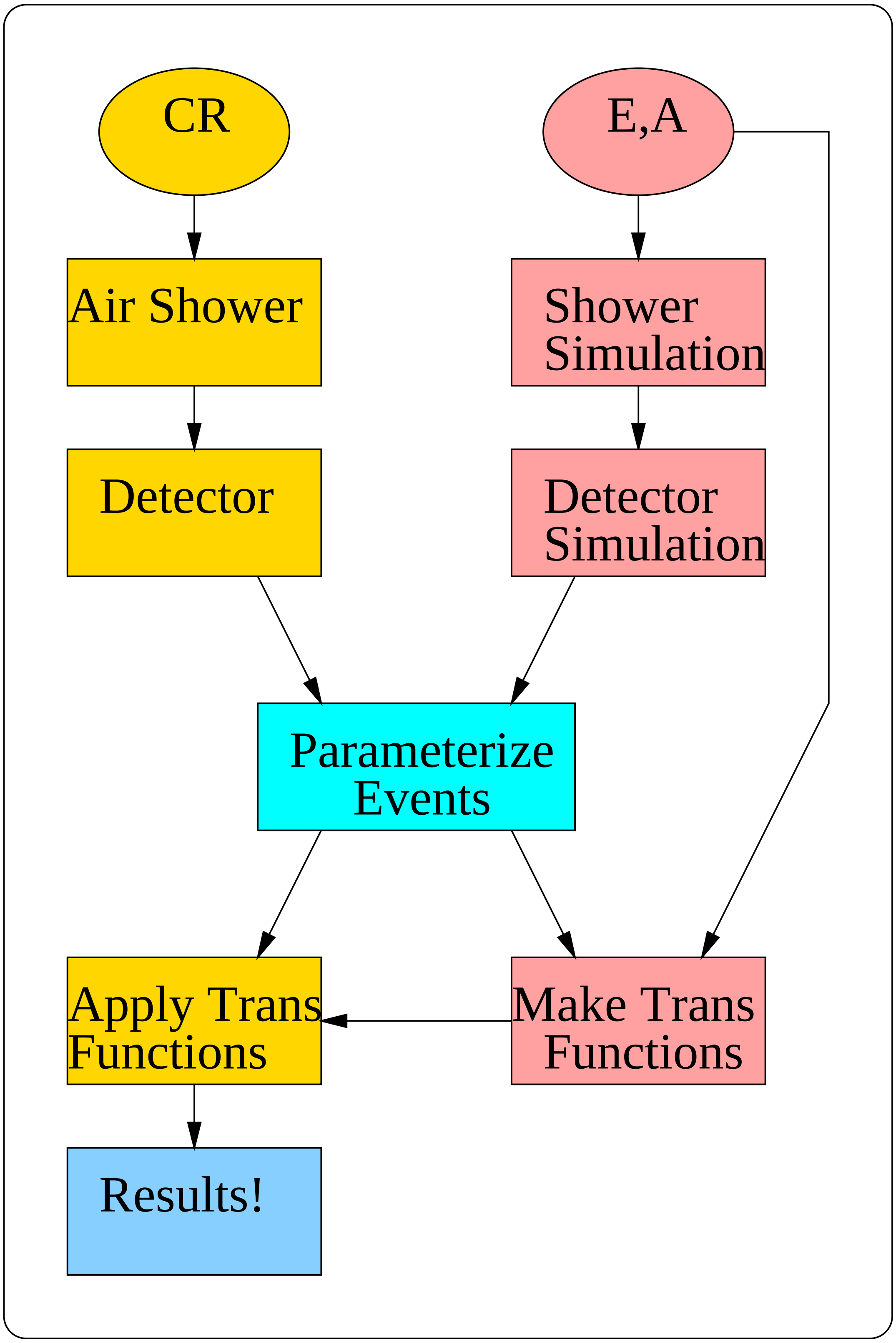
Detector Simulation

Includes the following:

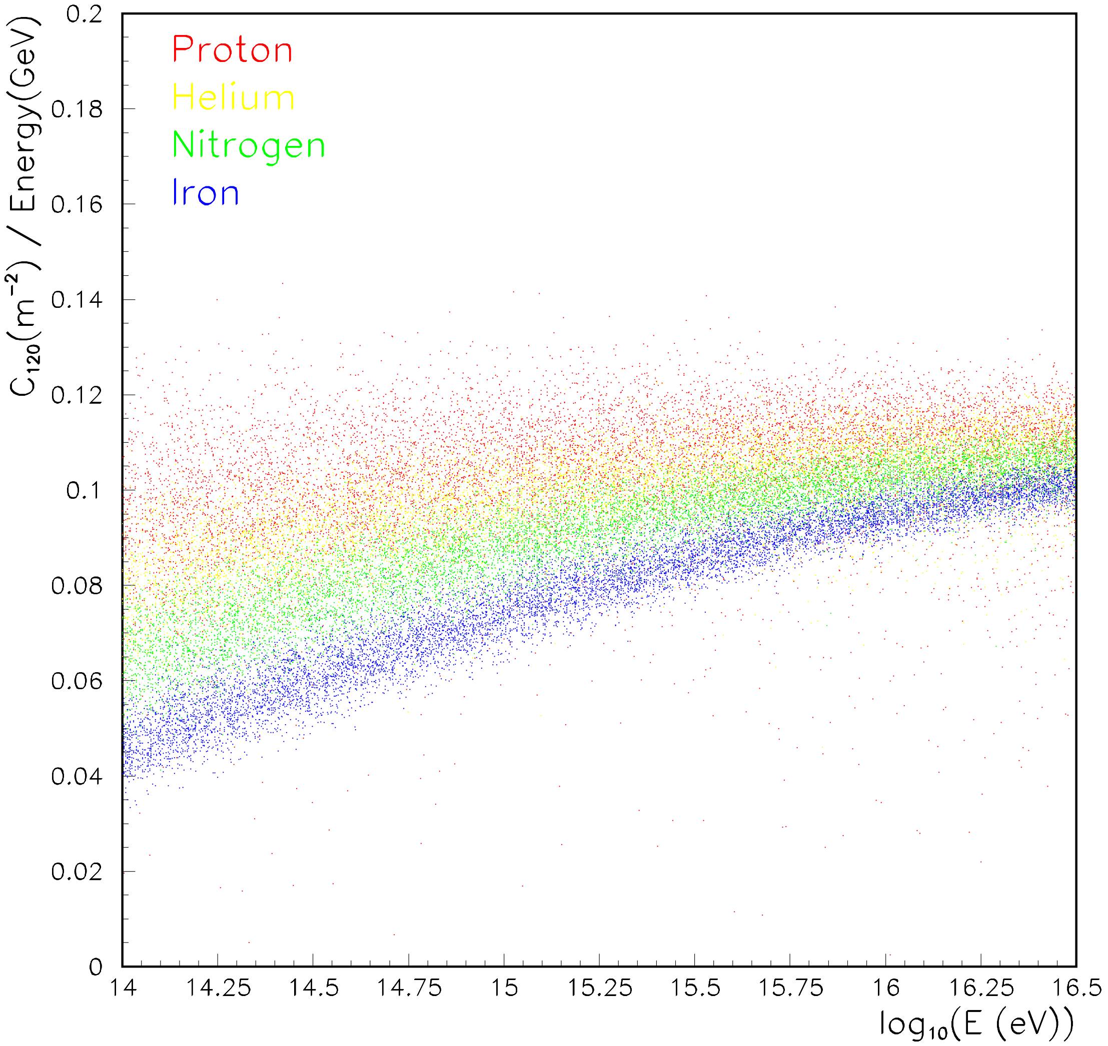
- Imperfect detector alignment towards zenith (1°RMS in both directions).
- The measured Winston cone transmission as a function of incidence angle.
- Fluctuations due to the night sky background light.
- Shot noise in the Cherenkov signal.
- Wide single photoelectron charge spectrum of the photomultipliers.
- Random detector pedestals and gains.
- Variation in detector non-linearity values.
- CASA core location and direction errors.

$\Rightarrow$ Make fake data...

Using Transfer Functions



Energy Transfer Function

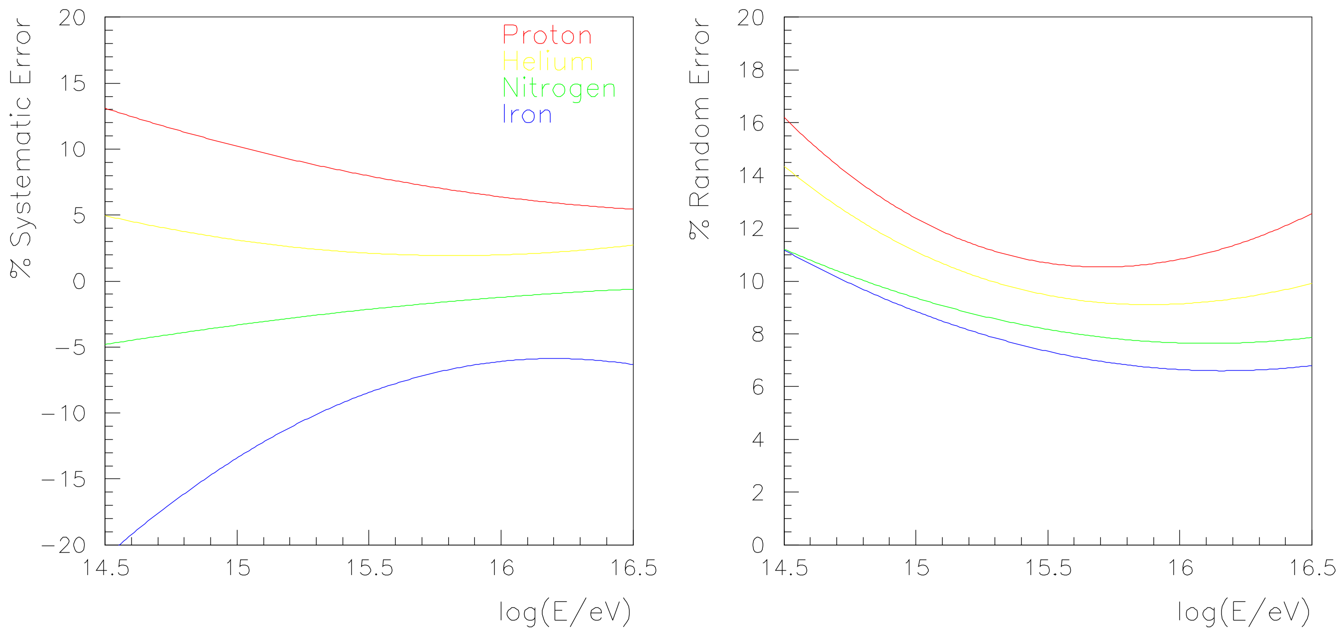


- Primary Energy is close to linearly related to C_{120}.

- In fact make small corrections for Primary Mass (using Č Slope), and Zenith Angle. $E = f(C_{120}, S, \theta)$

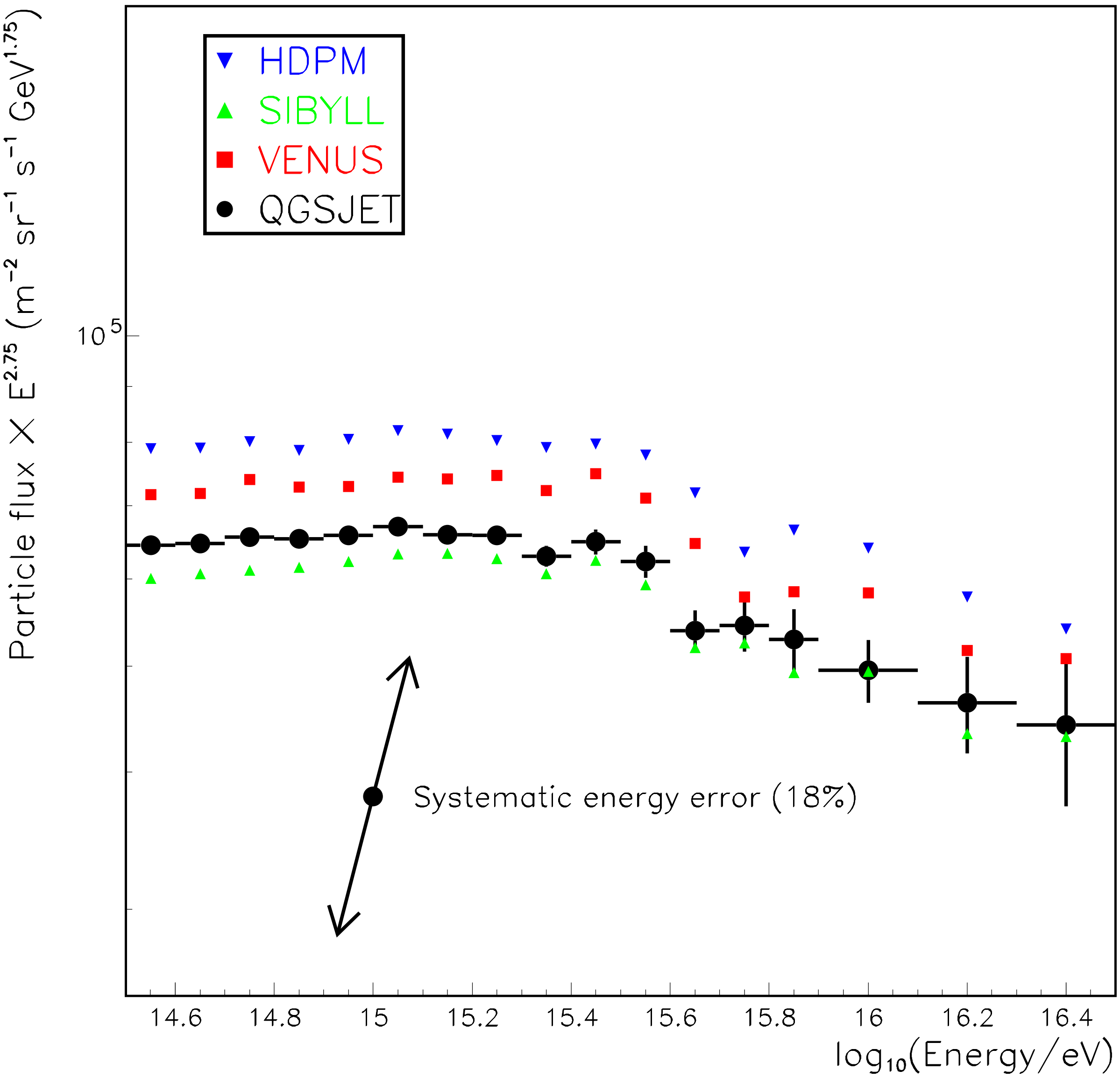
Composition Dependence

- Derive the Transfer Function using an equal composition mix.
- Apply it to each Primary Type in turn:



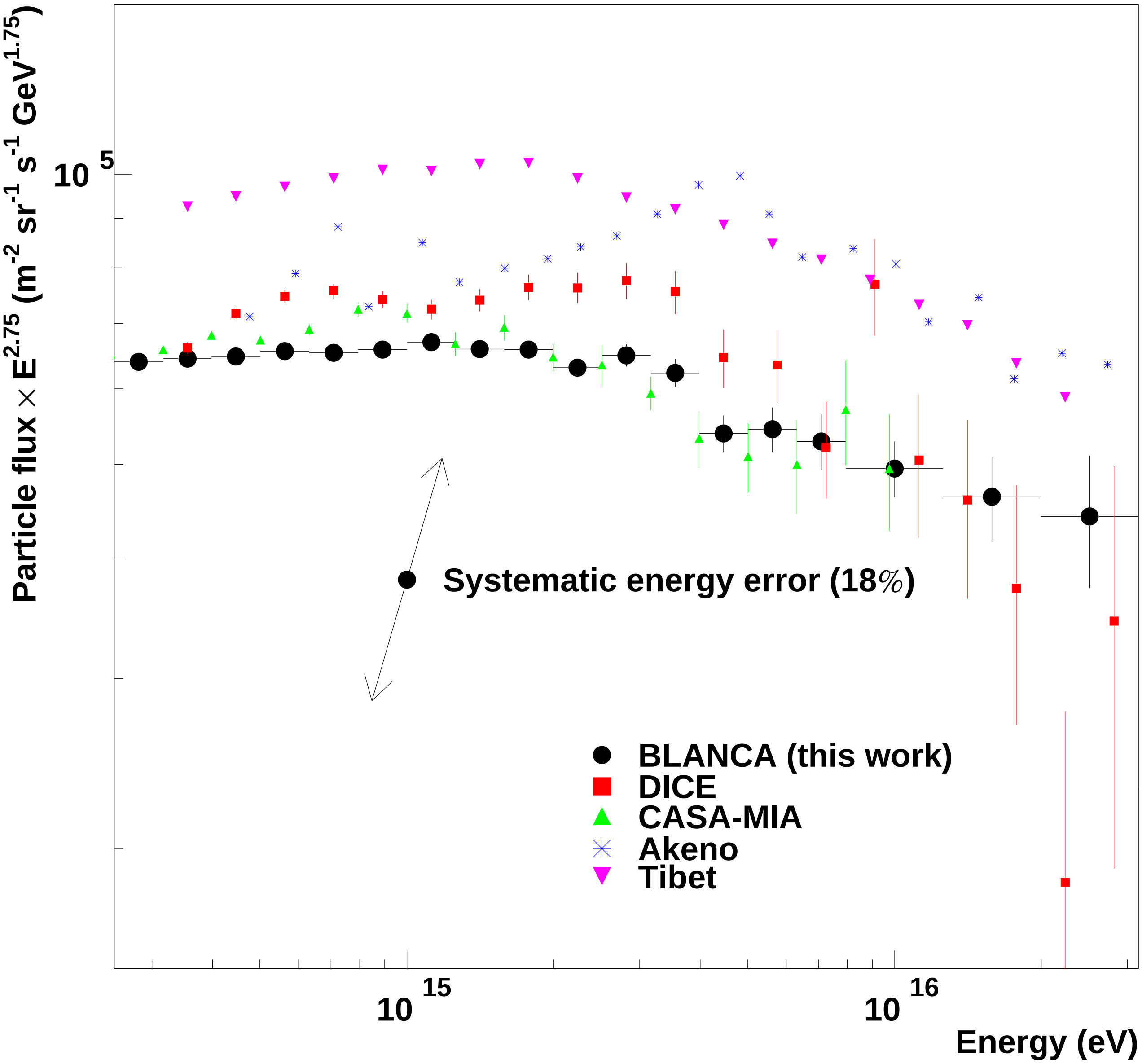
Model Dependence

Make Energy Transfer Function for each of the Four Models...



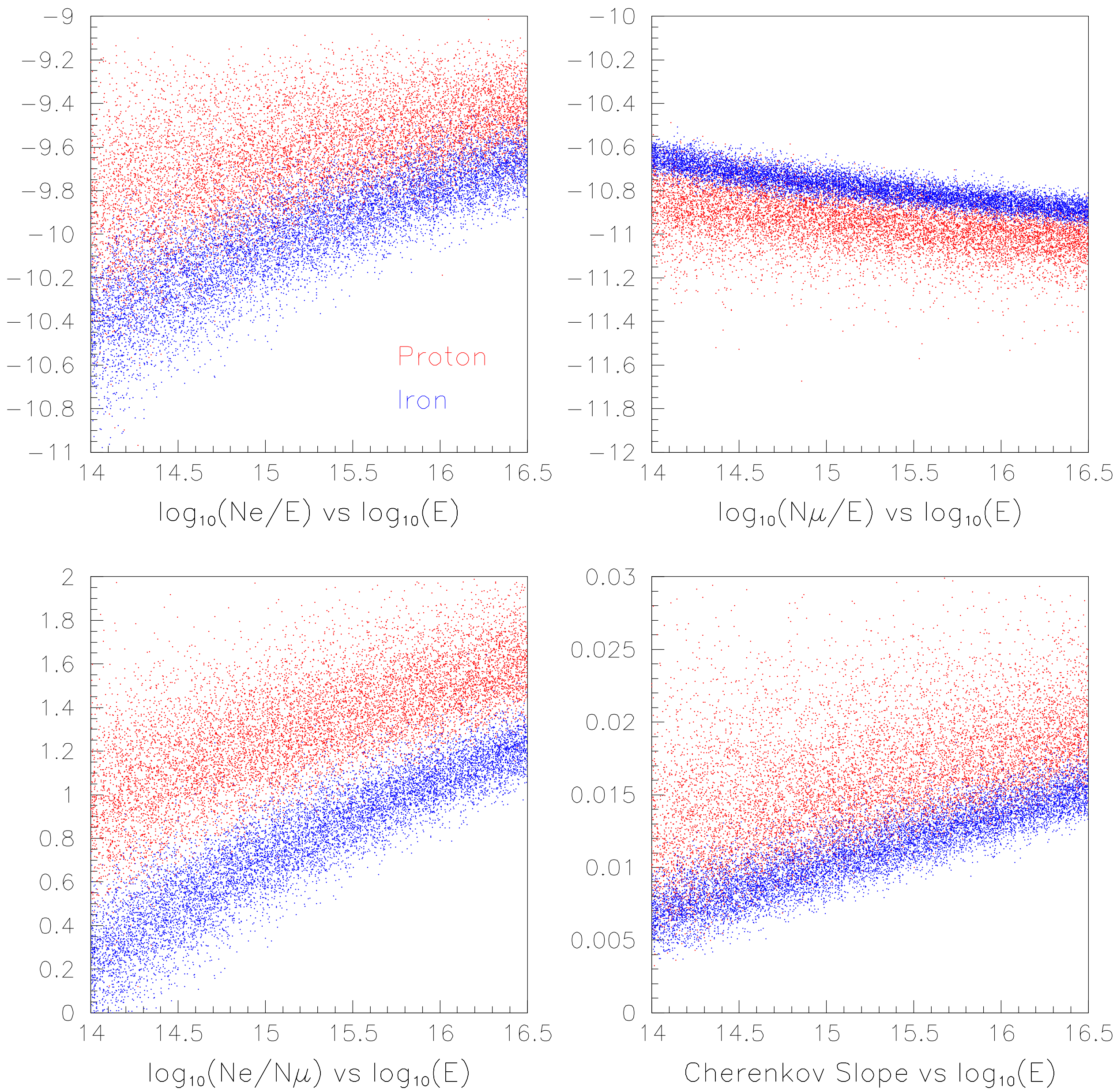
Model Systematic smaller than absolute calibration uncertainty.

BLANCA Energy Spectrum



- Consistent with previous experiments.
- Smooth Knee 0.5 decades wide.

Composition Parameters

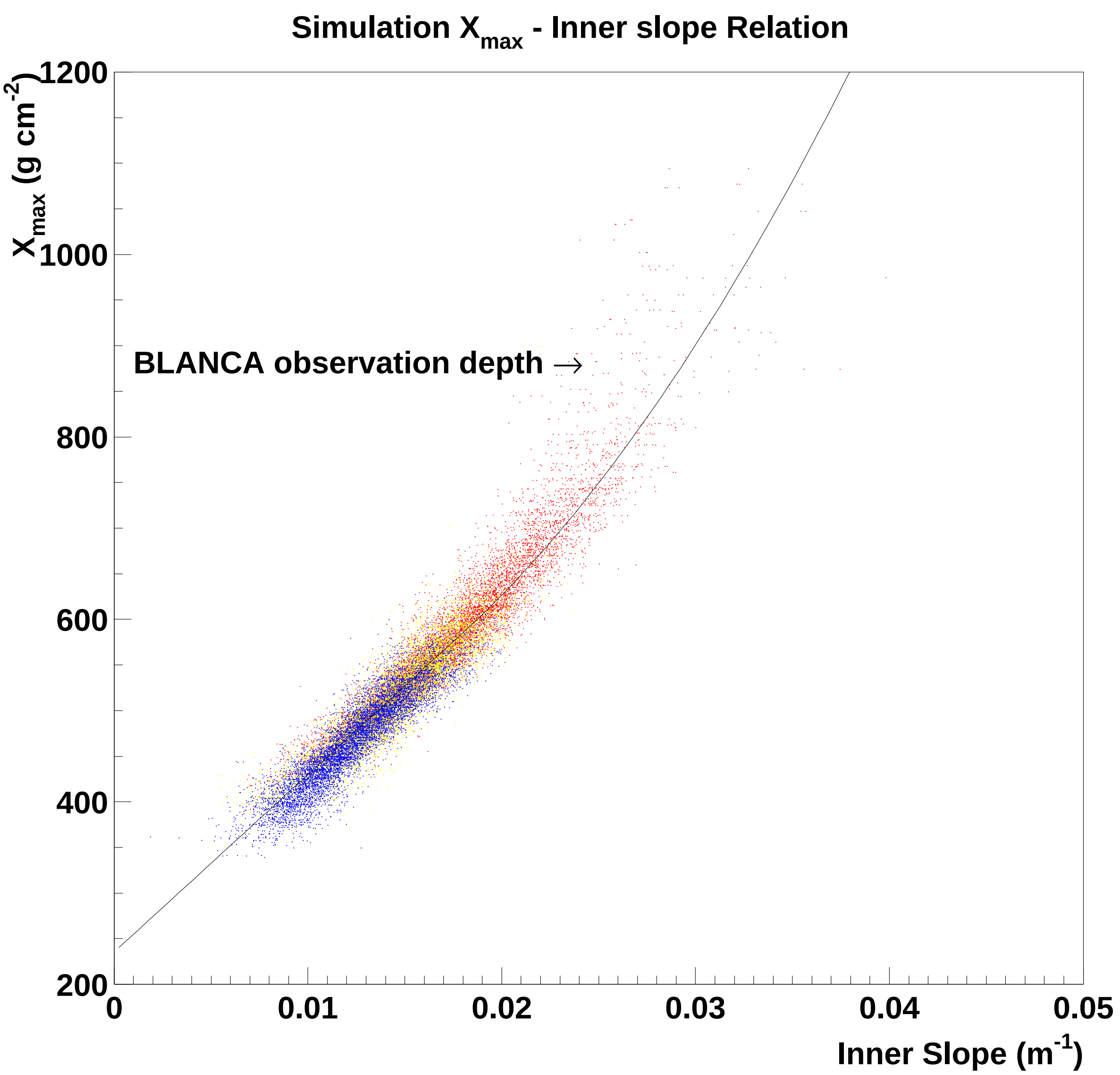


- All are functions of primary Energy as well as Mass.
- In principle N_e/N_μ is better than Čerenkov Slope.

Electron vs. Čerenkov Array?

- In principle Electron and Čerenkov lateral distributions carry similar information.
- The Normalization and Slope are related to primary Energy and Mass.
- However Čerenkov light is much easier to measure with high precision:
  - Photons very numerous $\Rightarrow$ Moderate area detector required.
  - Lateral distribution flatter $\Rightarrow$ Moderate dynamic range required.
  - Downside: Background light means run only on moonless (and cloudless) nights.

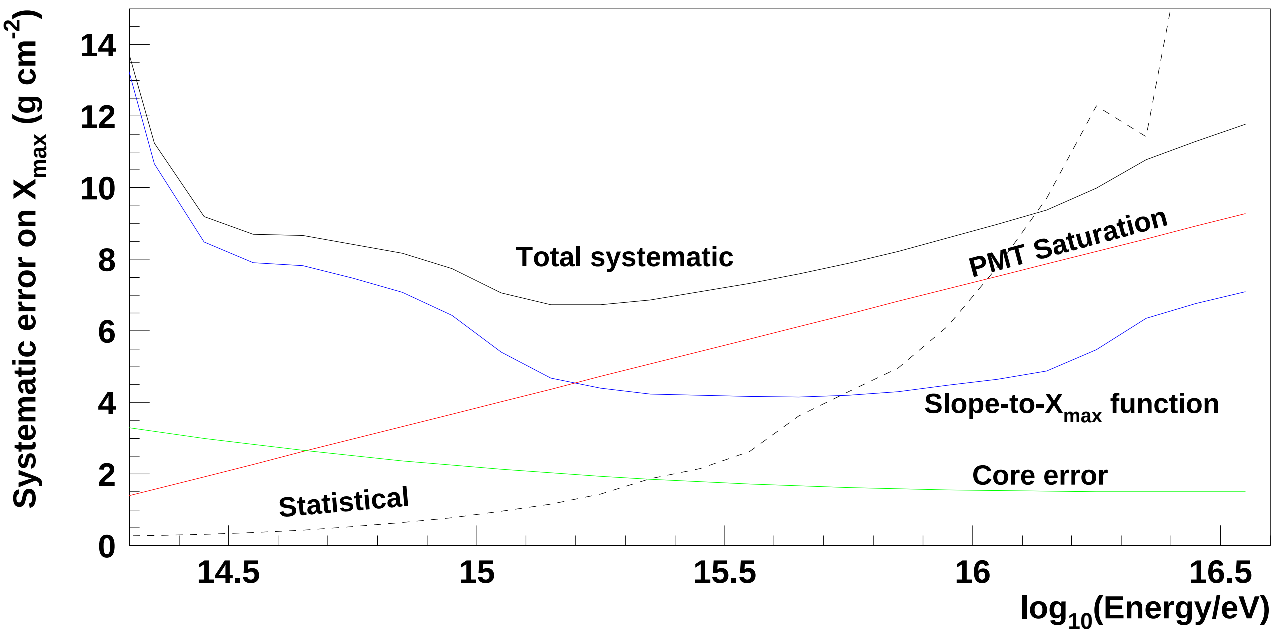
X_{max} Transfer Function



- Simple relationship between Čerenkov Slope and X_{max}
  $X_{max} = f(S)$

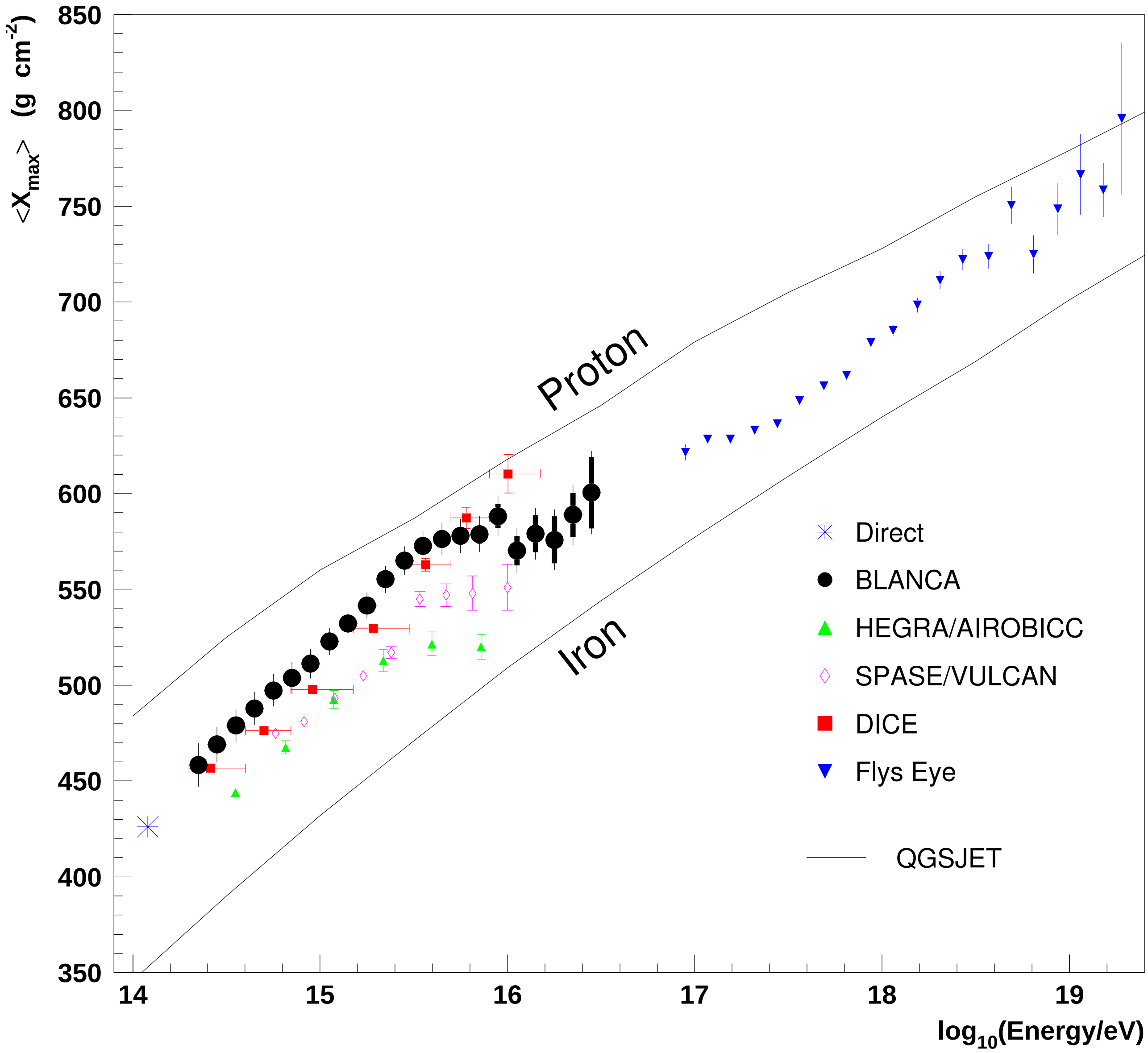
- Remarkably independent of Primary Mass and Interaction Model $\Rightarrow$ a useful middle ground for experimental comparison

X_{max} Systematics



- At low E transfer function dominates
- At high E PMT linearity becomes important, but statistics are more so...

X_{max} Results

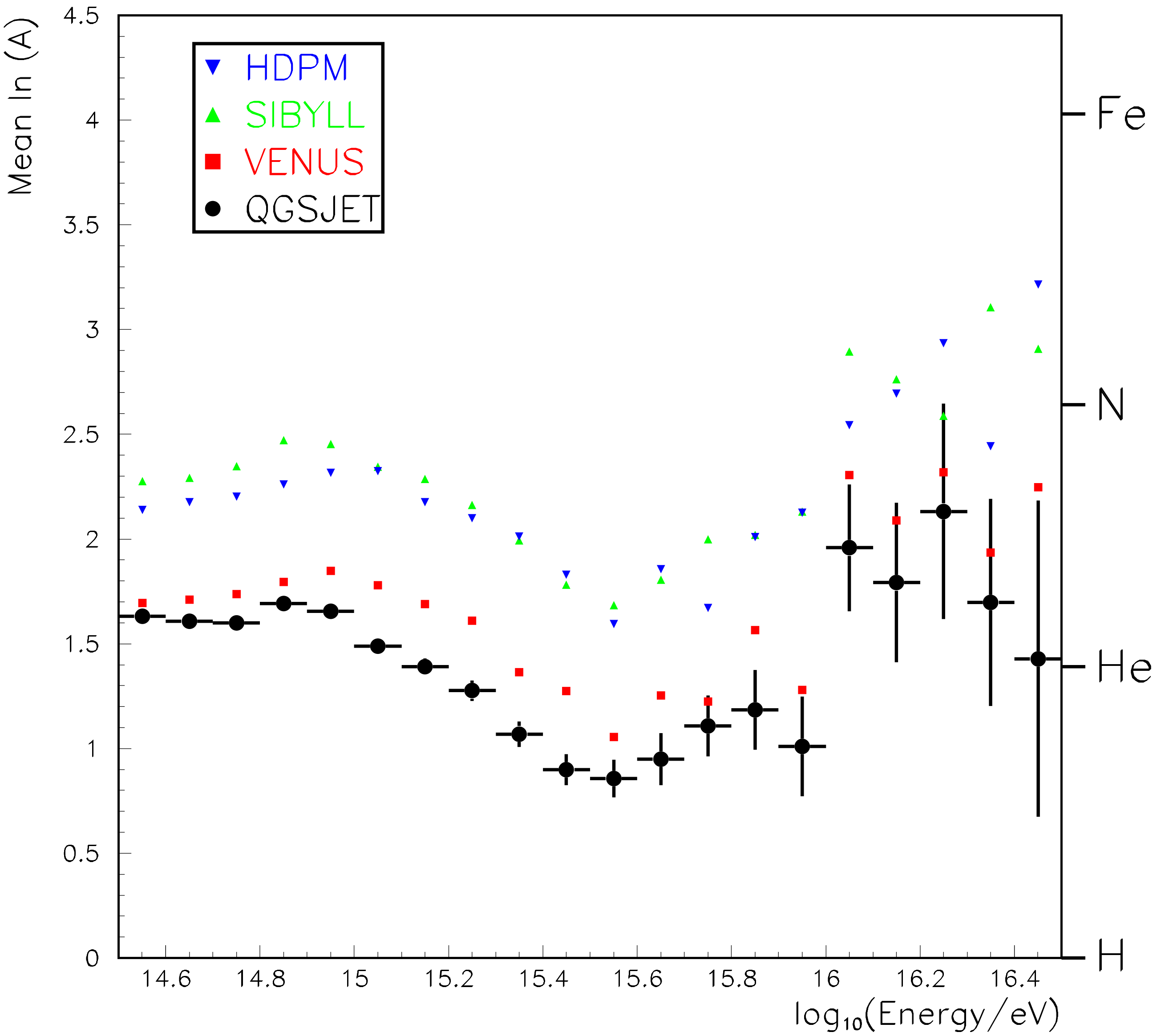


- Better statistics than previous experiments in Knee region.
- Connects well with Fly's Eye at higher energy.
- BLANCA error bars stat+systematic

Mass Estimation using Č Slope

Make a transfer function analogous to X_{max}

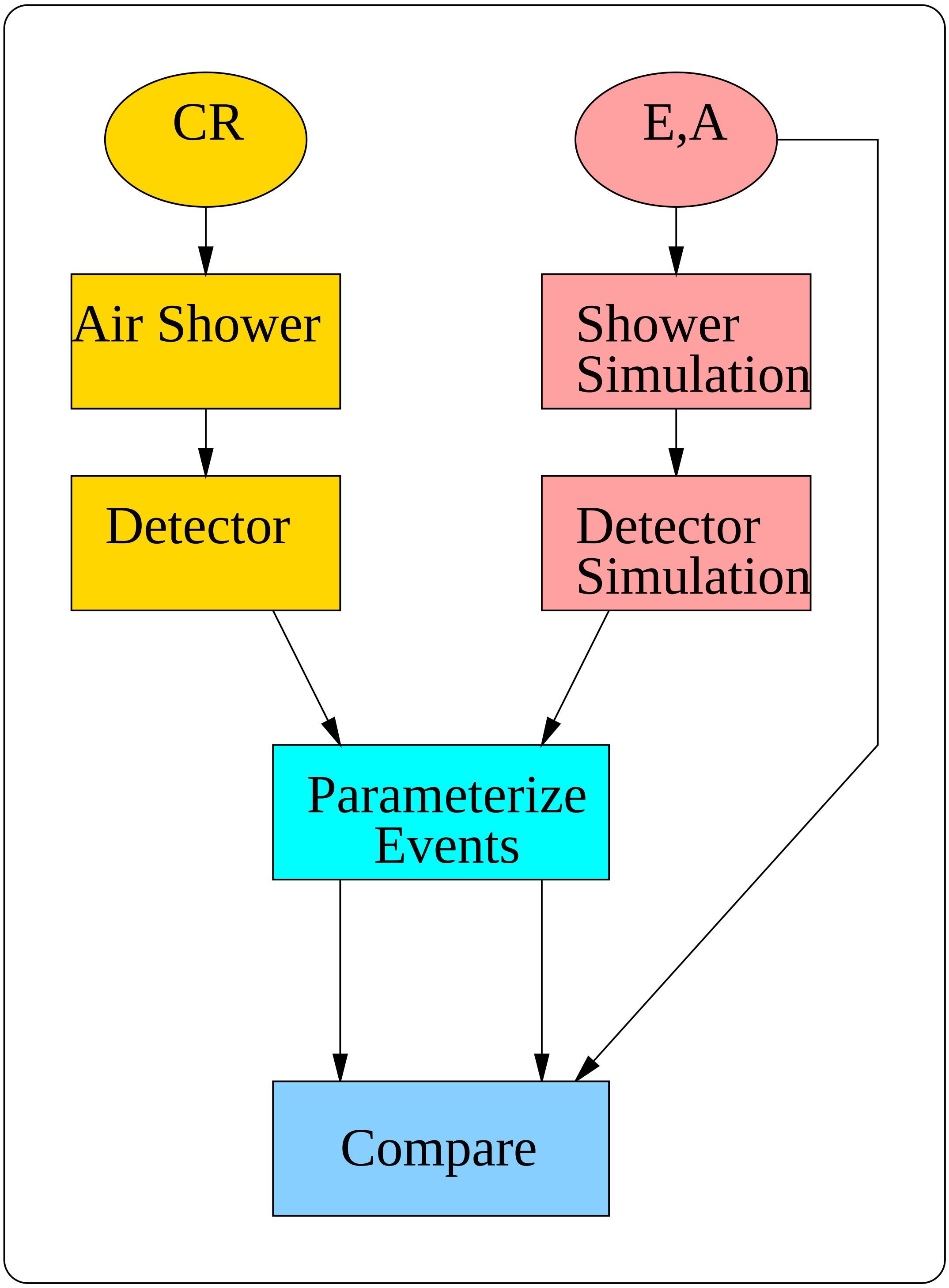
$\ln(A) = f(S, C_{120})$



- Shows heavy $\Rightarrow$ light $\Rightarrow$ heavy trend for all models.

- Absolute normalization model dependent.

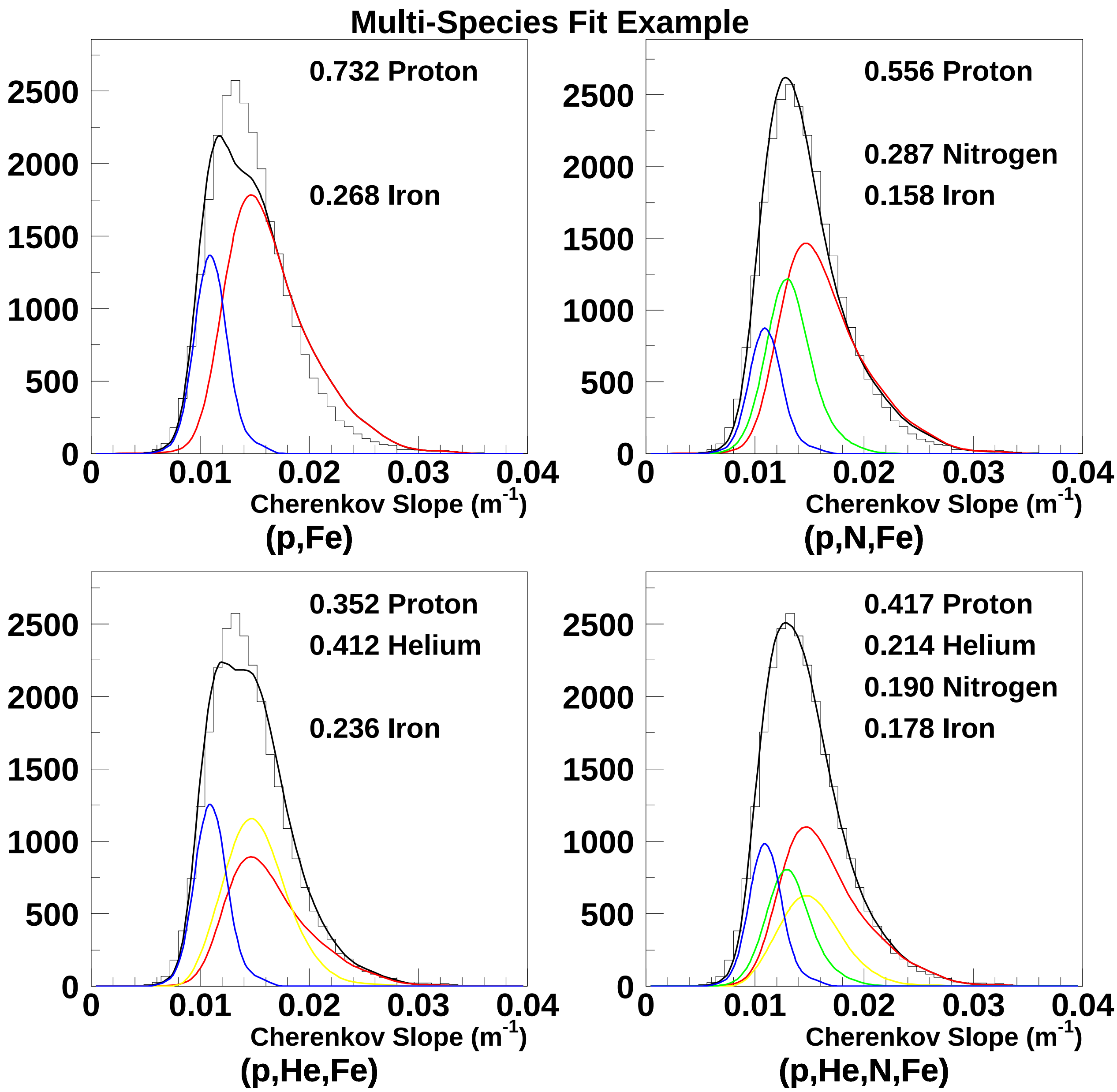
Direct Parameter Comparison



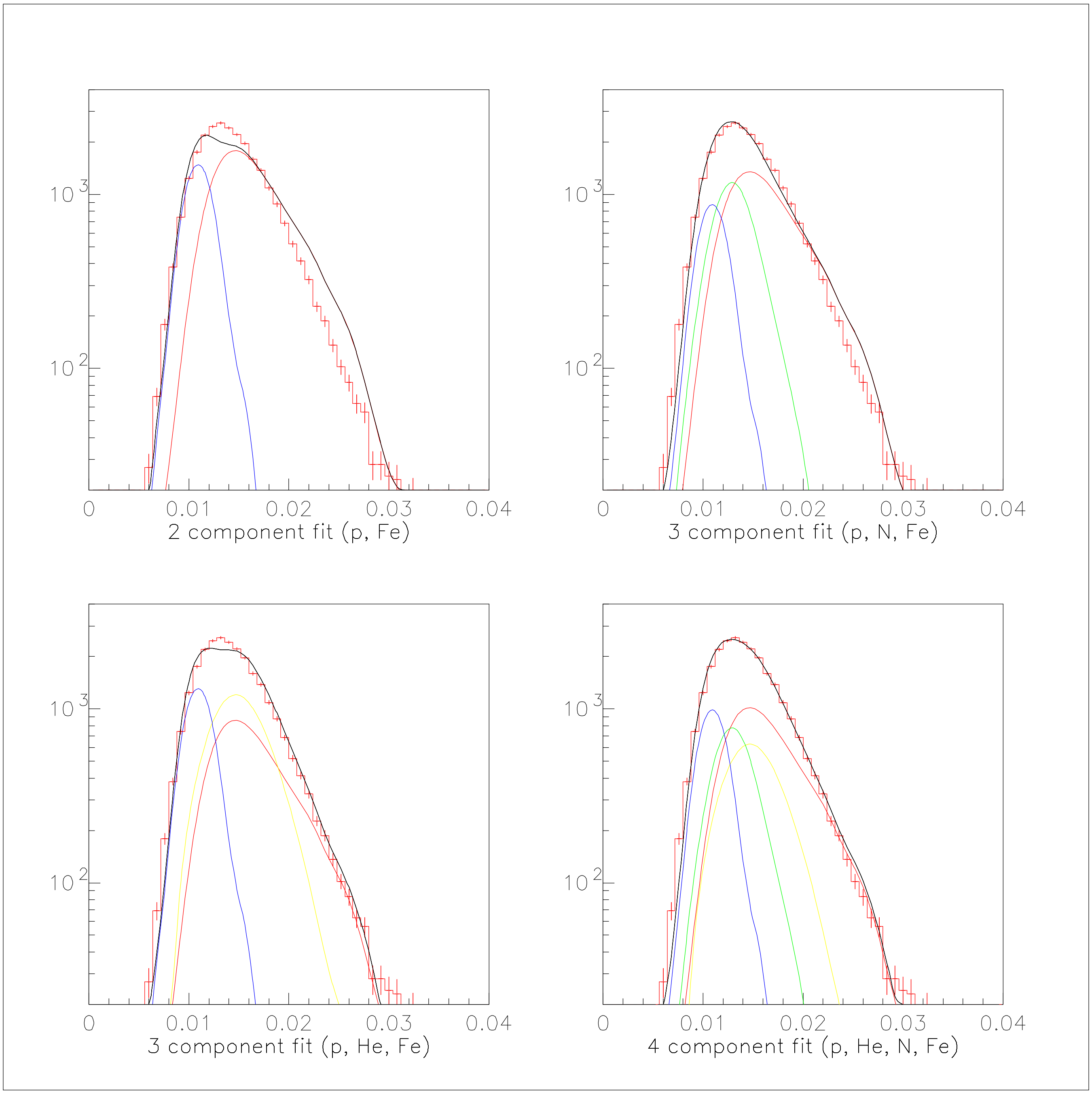
Multicomponent Model

- Mean quantities discard the additional information in the shape of the composition parameter distributions.
- If the detector simulation works there is no need to do this.
- Try to fit the Čerenkov Slope distribution using combination of simulated distributions.

Multicomponent Example (linear scale)

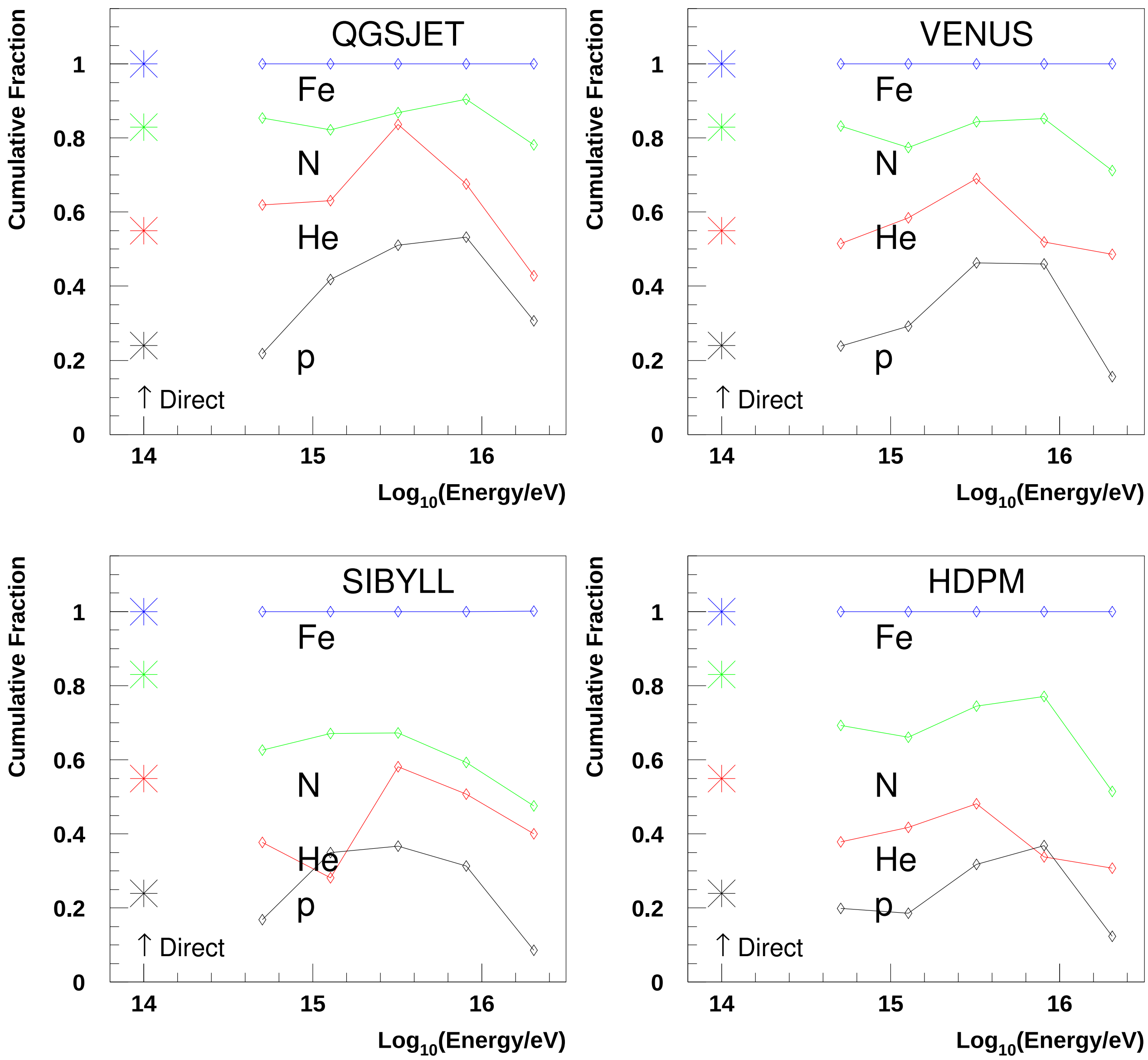


Multicomponent Example (log scale)



Multicomponent Results

- Fractions are not constrained to be 0-1.
- Negative numbers indicate inadequate model.



A dream coming true?...

Mass Estimation using N_e/N_μ

Also have *independent* CASA-MIA data.

Heavy primary showers:

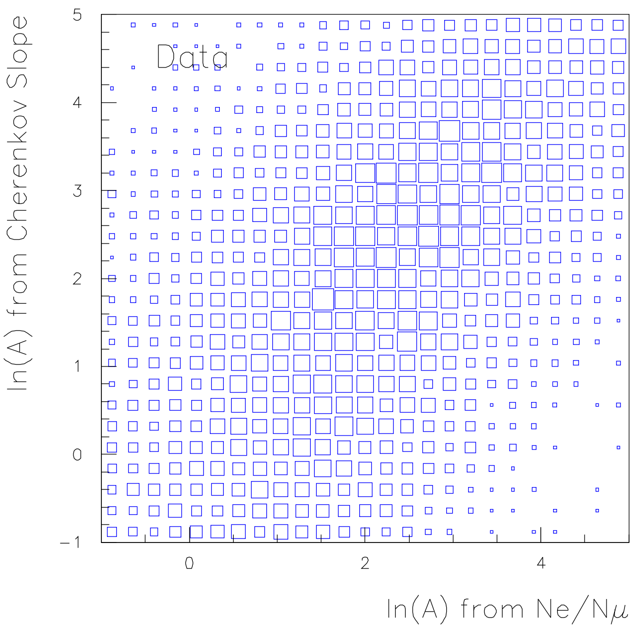
- Are further past max at gnd level
  $\Rightarrow$ Smaller Electron Size

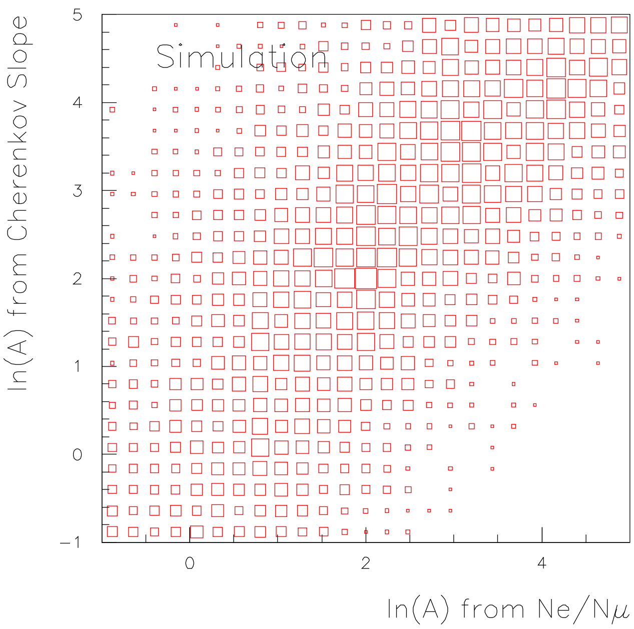
- Reach Pion decay threshold quicker
  $\Rightarrow$ Larger Muon Size

Therefore ratio N_e/N_μ is good estimator of Primary Mass

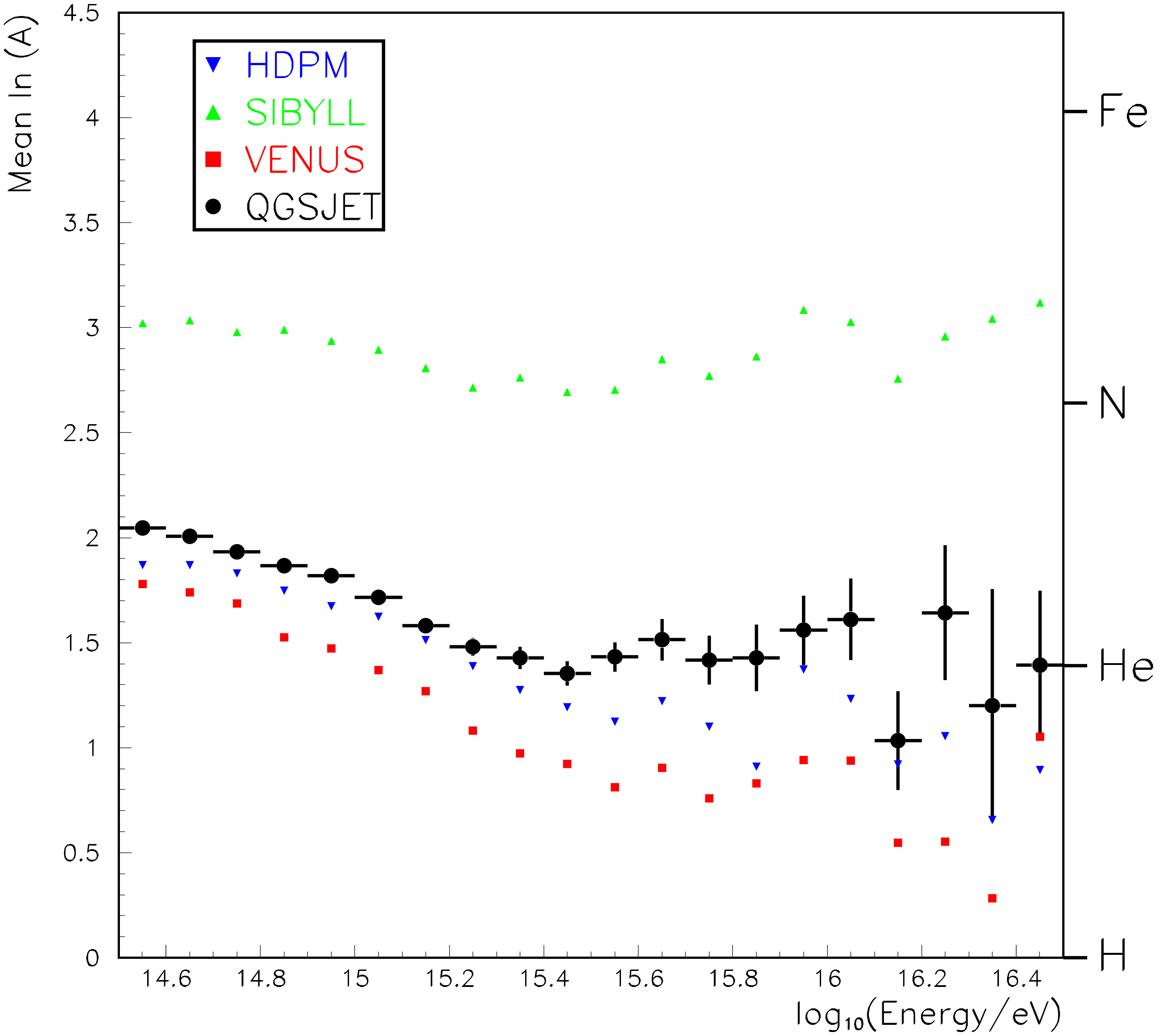
$\ln(A) = f(N_e/N_\mu, C_{120})$

Check event-by-event correlation:





Mean Mass using N_e/N_μ



- Shows similar trend to Čerenkov Slope analysis.
- Interesting but suspect due to incomplete simulation...

Conclusions

The BLANCA results are not consistent with the canonical supernova model:

- Knee is too narrow: 0.5 decades vs. 1.5
- Mass getting lighter towards knee: not heavier!

These results:

- Seem to be model independent (for the models considered anyway).
- Have some internal consistency.

However, determining the Mass of the Primary Cosmic Rays through the Air Showers they produce is a *very hard problem*.

`BLANCA results: astro-ph/0003190,`
`http://cygnus.uchicago.edu/~blanca/`