SAGENAP presentation Nov 97.

Simulated performance of the Auger Observatory Hybrid Detectors

Talk outline:

- Shower simulation
- Experimental simulation
  - Fluorescence detectors
  - Ground array
- Hybrid reconstruction
- Ground only reconstruction
- Composition Sensitivity
- Conclusions

Clem Pryke - Chicago, USA

Hybrid simulation by Bruce Dawson - Adelaide, Australia

Shower simulation

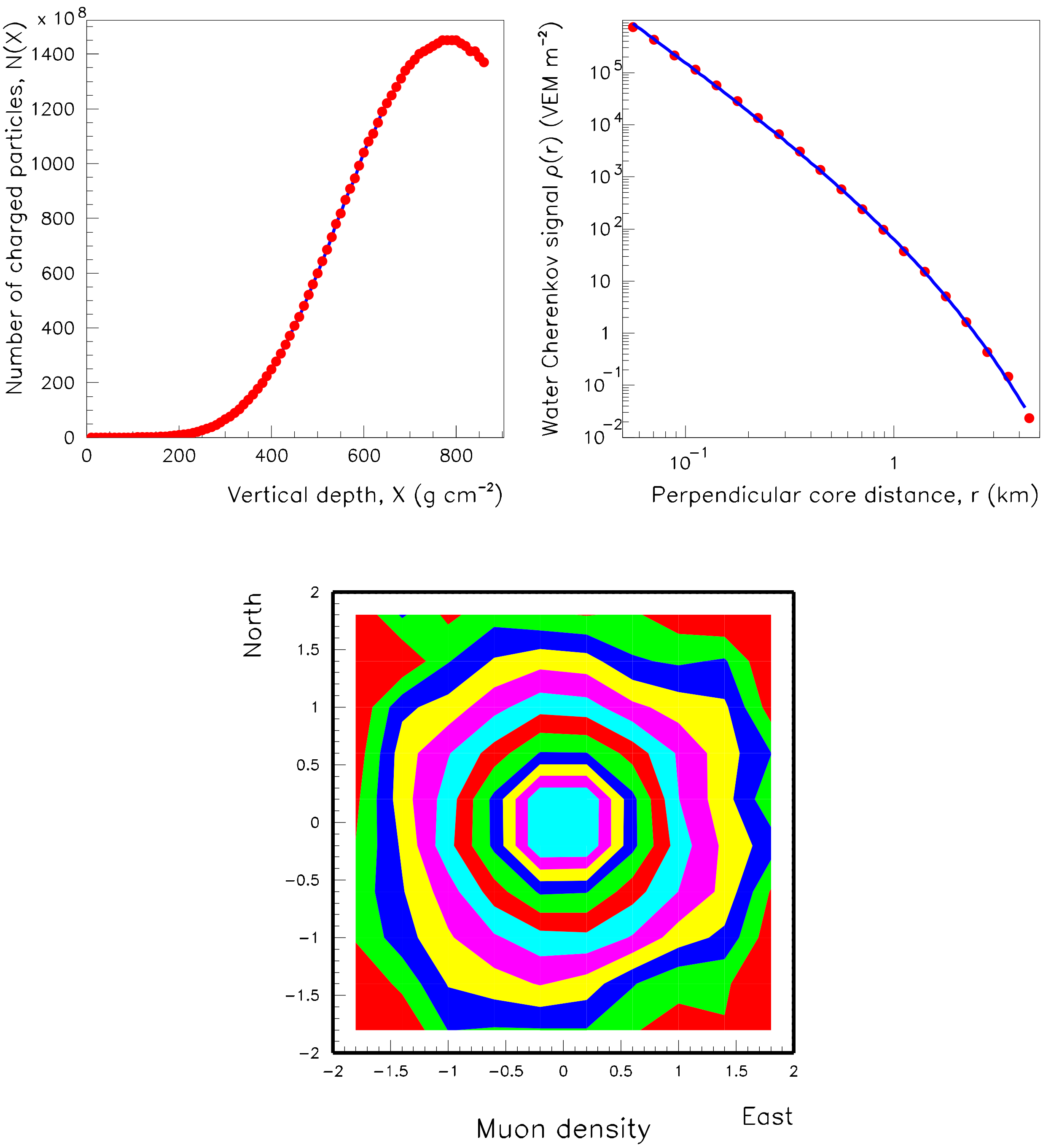
- MOCCA shower simulation used* with Sibyll hadronic interaction model†.
- 1000 events generated at a thinning level of 10^{-7} of the primary energy $\Rightarrow$ 1500 CPU days on R5000!
- Events generated at 13 discrete energy steps; $10^{19.1} < \log E < 10^{20.7}$.
- Continuous zenith angle range; $\theta < 63^\circ$ with appropriate distribution.
- 50:50 proton/iron mix.

*A. Hillas, *Proc. of the ICRC Rome*, **1**, 270 (1995)

†R. Fletcher et al., Phys. Rev. D., 5710, **50** (1994)

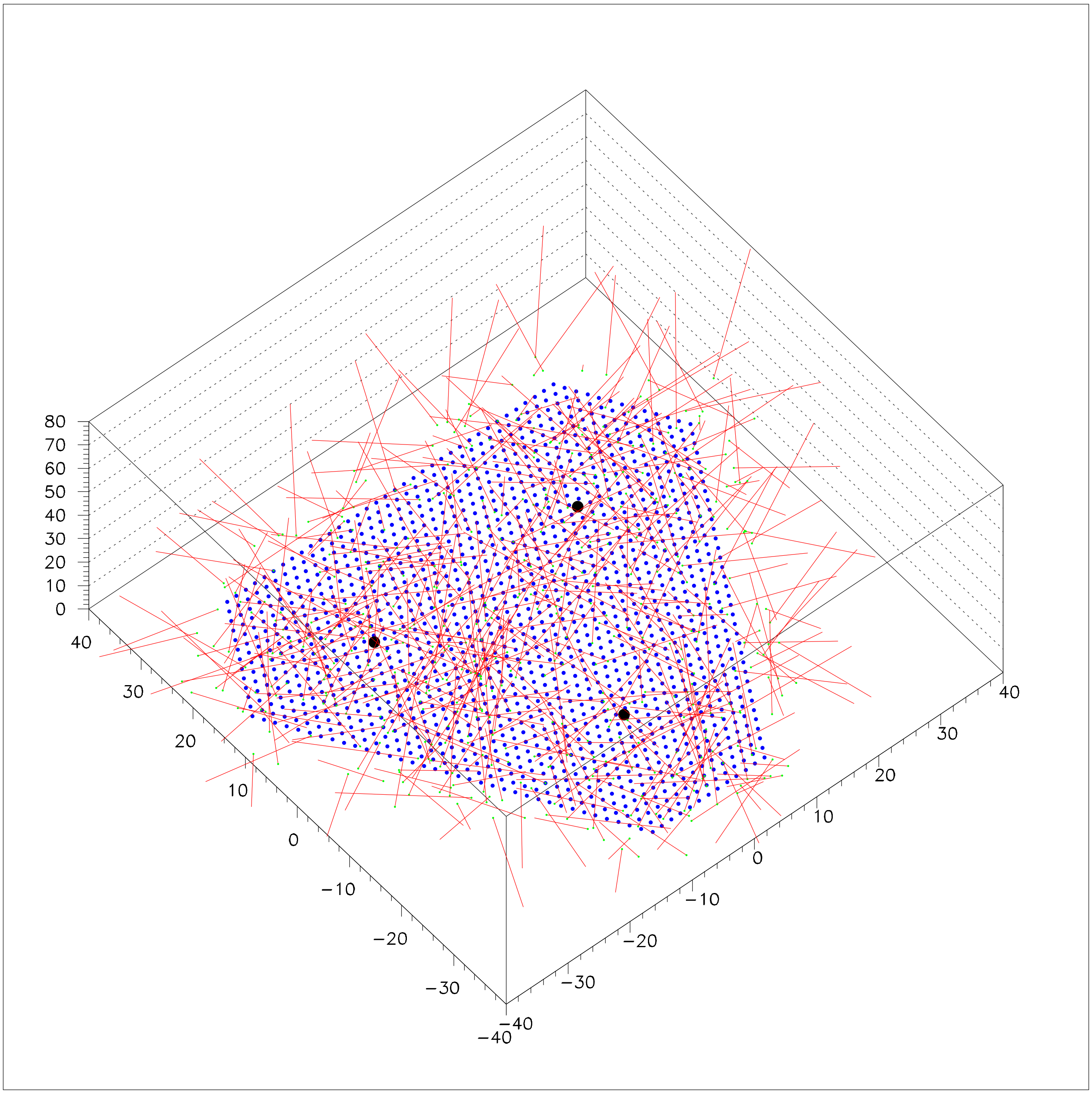
Shower simulation cont...

- High quality of single events



Experimental simulation

- Shower core positions chosen randomly — shower tracks defined.

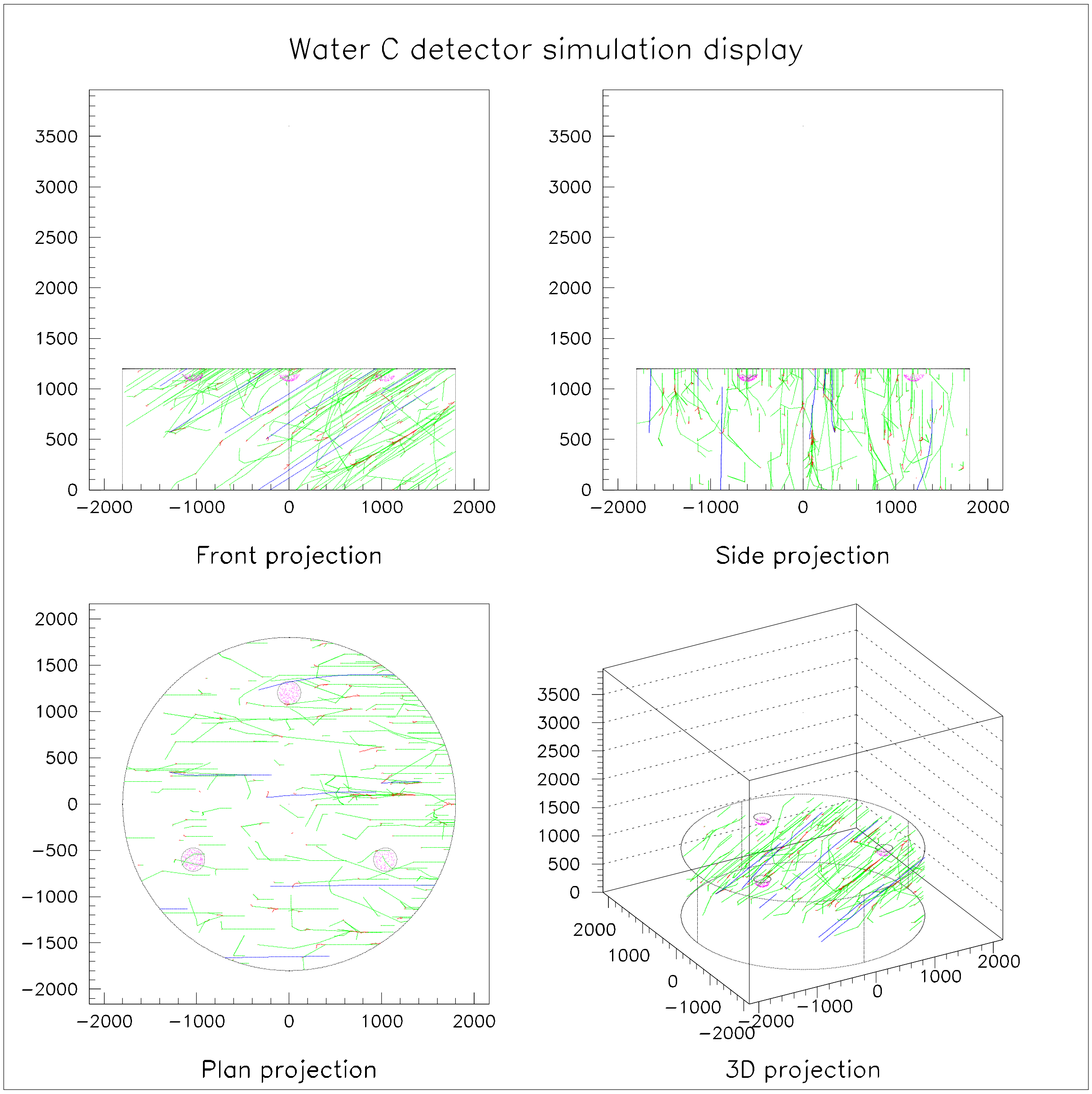


Fluorescence detector simulation

- Well tested HiRes code used.
- For details of fluorescence detector design please see Design Report
- Longitudinal profile of charged particles taken direct from shower simulation output.
- Fluorescence and Čerenkov light generated and propagated.
- Rayleigh and Mie scattering treated.
- Night sky noise, mirror optics, filters, PMTs, electronics etc. included.
- Caveat: Perfectly stable atmosphere assumed...

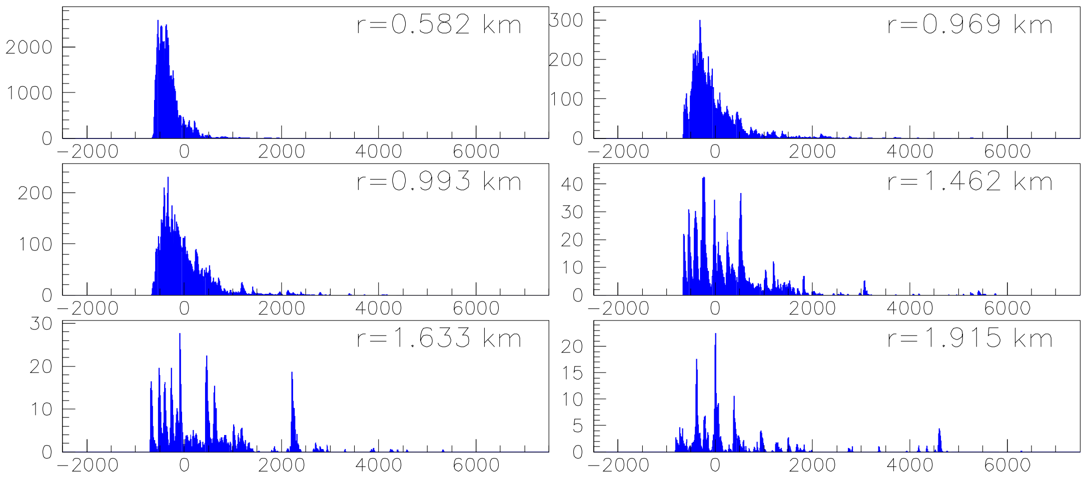
Ground array simulation

- Ground particle list re-sampled to generate list of particles striking each detector.
- Water tanks simulated using purpose designed code (checked against GEANT and EGS4).

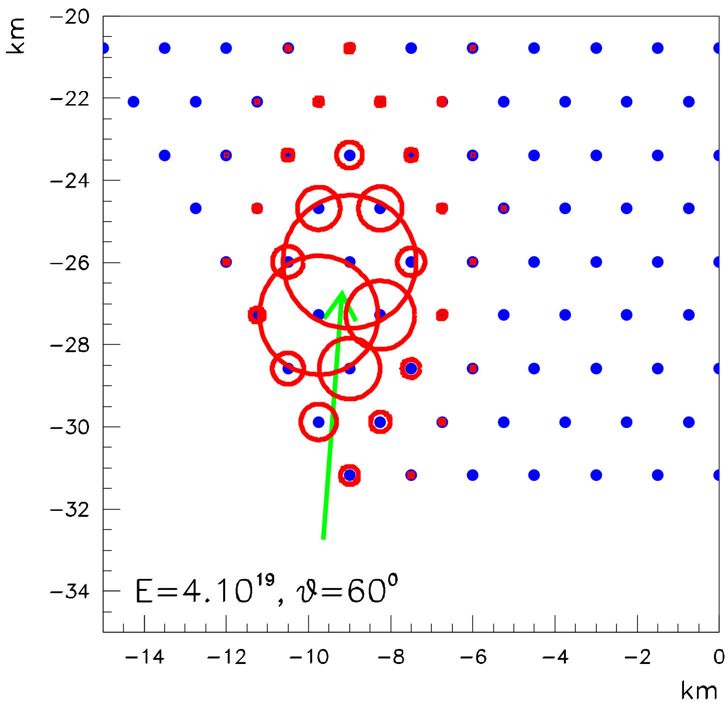


Ground array simulation cont...

- Front end FADC electronics simulated:



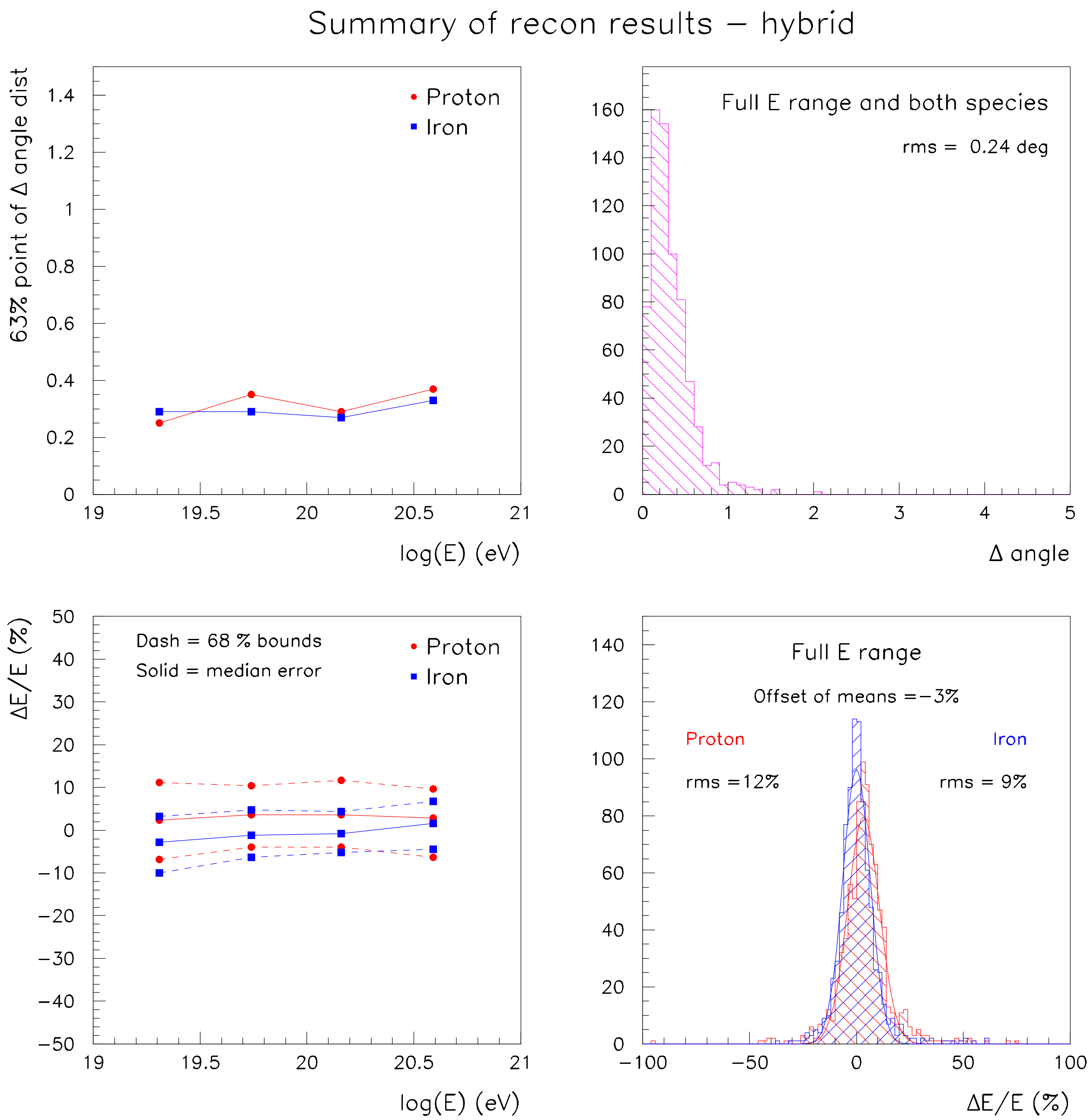
- Shower footprints are end result:



Hybrid reconstruction

- Shower-Detector Plane found using fluorescence tube pointing directions and signal sizes.
- Orientation of track within this plane found using fluorescence timing (a la mono Fly's Eye) in combination with surface array timing.
- Yields excellent measurements of shower Energy and Direction ($< 10\%$ and 0.3° errors at 10^{20} eV).
- Core position is also determined with < 50 m rms error without using surface array density information.

Hybrid reconstruction cont...



Ground array only reconstruction

- Generic empirical ldf has two parameters; normalization (size), and slope (steepness).
- We use $\rho(r) = 10^{c_1} r^{-c_2 r^{-\sqrt{r}}}$, r in km, $c_1 = \log \rho(1km)$, c_2 measures steepness*.
- Ground array must "know" $E = f(c_1, \theta)$ to infer primary energy.
- Conventionally:
  - Form of ldf found using infilled array (at lower E!).
  - θ dependence of $E = f(c_1, \theta)$ found from data (constant intensity method - again at lower E).
  - c_1 dependence of $E = f(c_1, \theta)$ from calculation. This is the energy calibration!

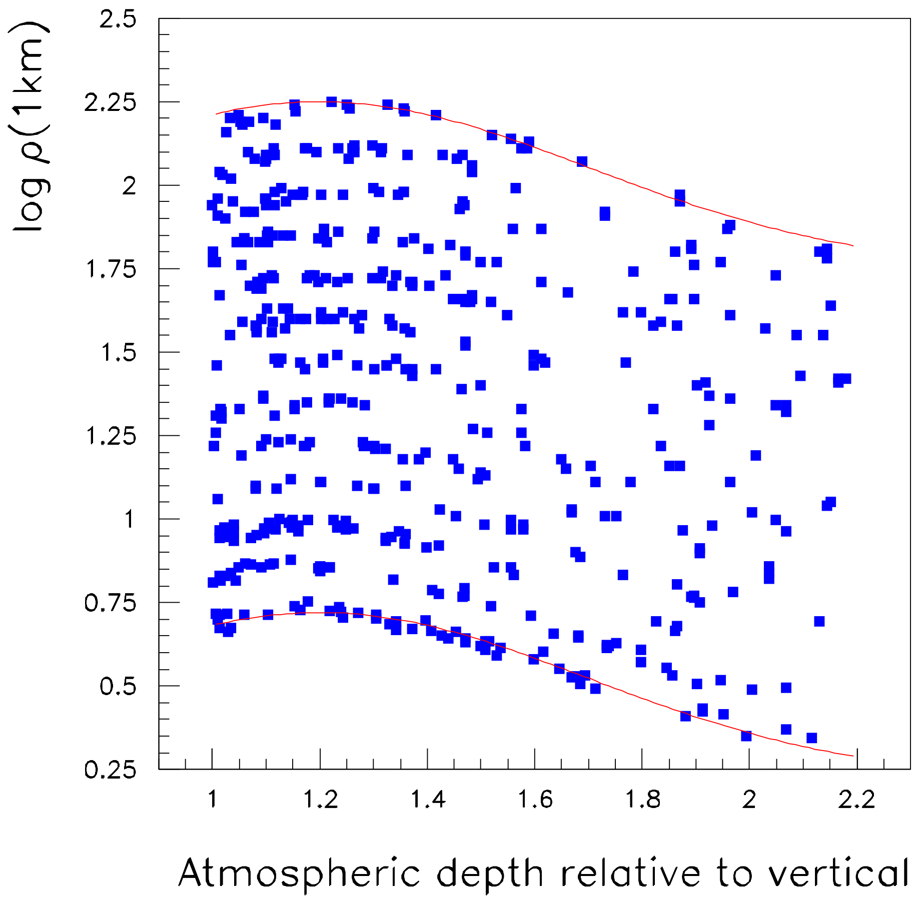
*Works for MOCCA-Sibyll and 1.2 m deep tank — maybe another func for real data....

Ground array only reconstruction cont...

- Hybrid detector has huge advantage! Hybrid reconstruction provides events with known E, θ and core position (*just like Monte Carlo!*).
- $\Rightarrow$ fit independent density data to find $E = f(c_1, \theta)$ relationship.
- $\Rightarrow$ Then use this relationship to reconstruct remaining 90% of ground array only data with essentially no Monte Carlo dependence.

Aside...

- Dependence of $\rho(1km)$ on θ for $E > 10^{19}$ eV is interesting...*



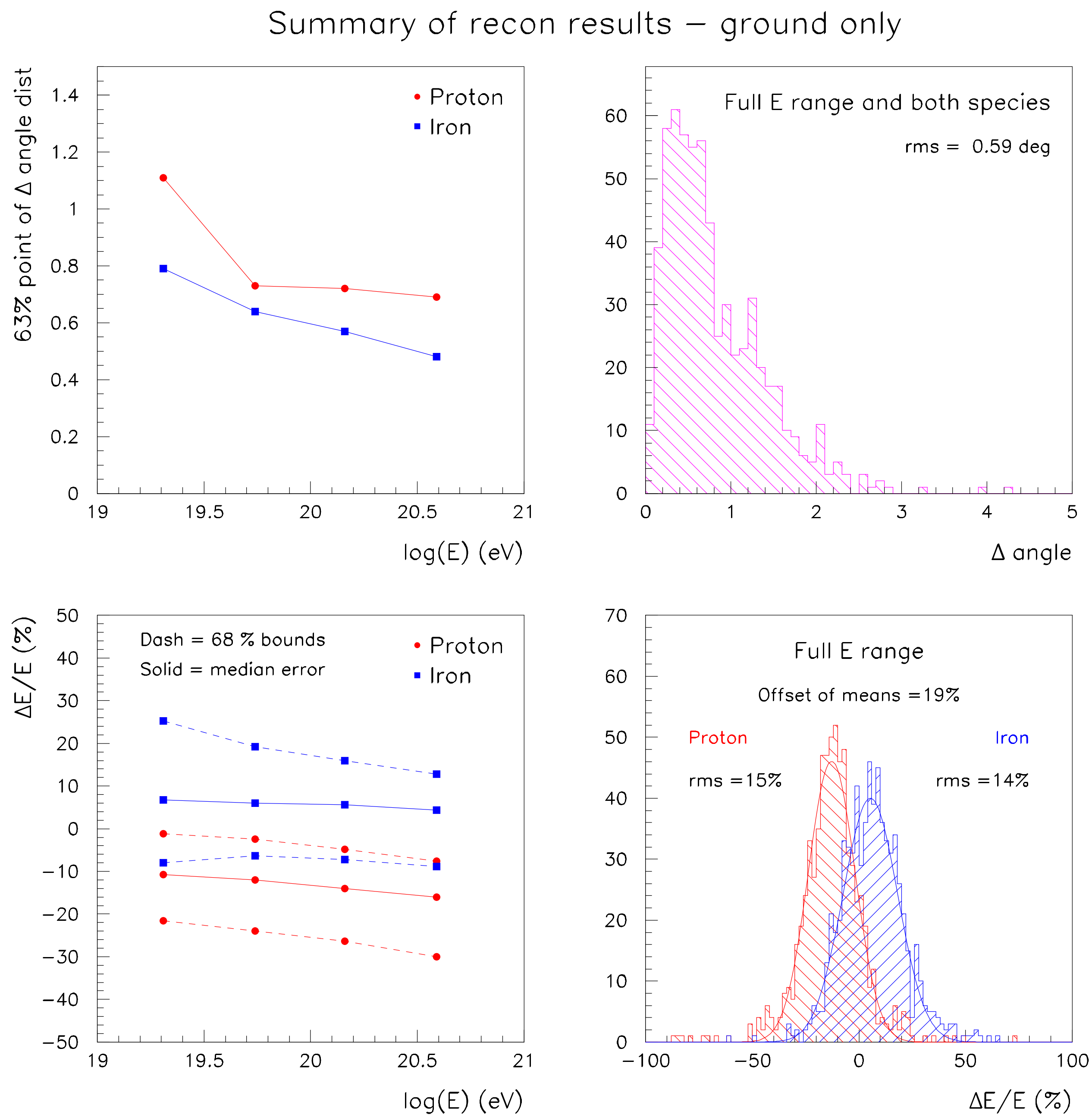
- Vertical showers are passing through a broad maximum at ground level.

*Plot shows iron showers with ground level at 870 g cm^{-2}.

Ground array only reconstruction cont...

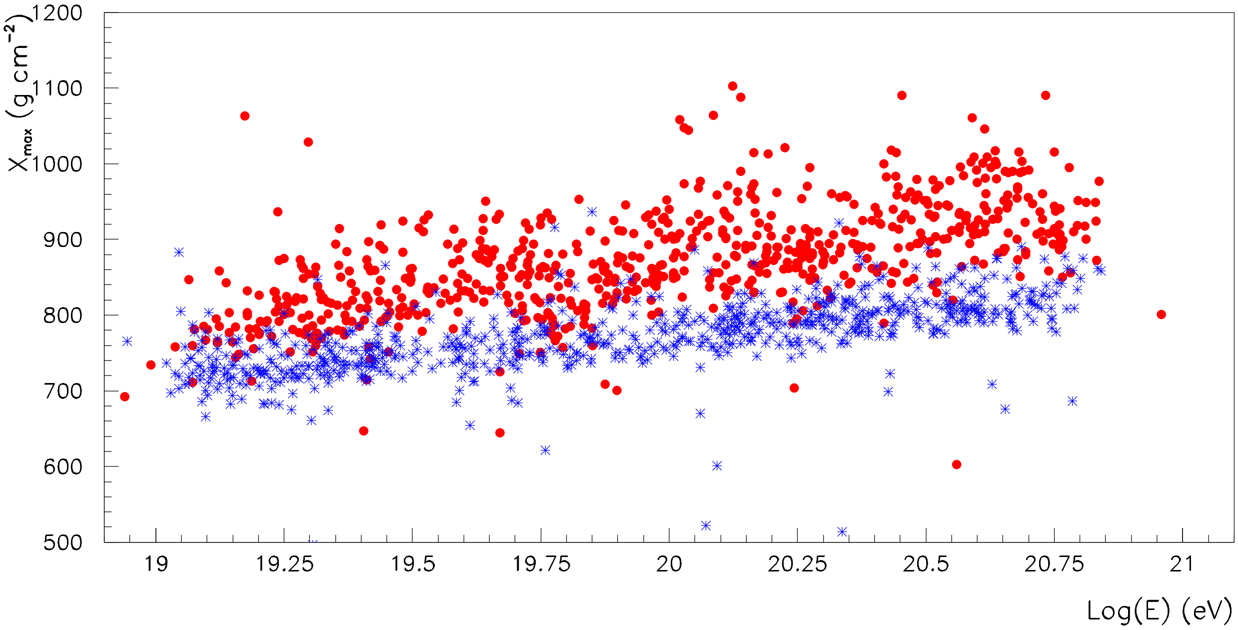
- The "Hybrid trains ground-only" process is now fully simulated.
- The $E = f(c_1, \theta)$ model fit uses only lower half of the energy range to compensate for unrealistically flat spectrum.
- Energy rms error is 15% proton for both proton and iron. $\Rightarrow$ This is the value taken over the complete energy and zenith angle range. ($\theta < 60$ deg.)
- There is a 20% systematic offset between proton and iron. This is only a problem if the primary composition is indeed mixed. Perhaps a correction can be made...
- Angular reconstruction rms error is 0.6° taken for both species and the complete energy range.

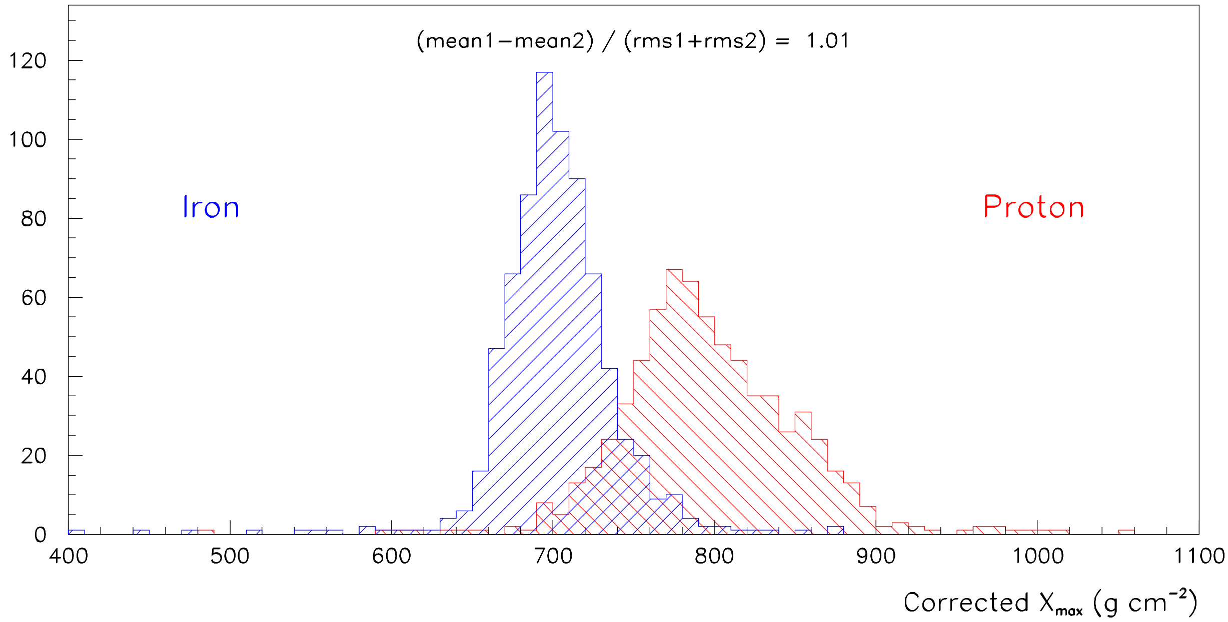
Ground array only reconstruction cont...



Composition Sensitivity

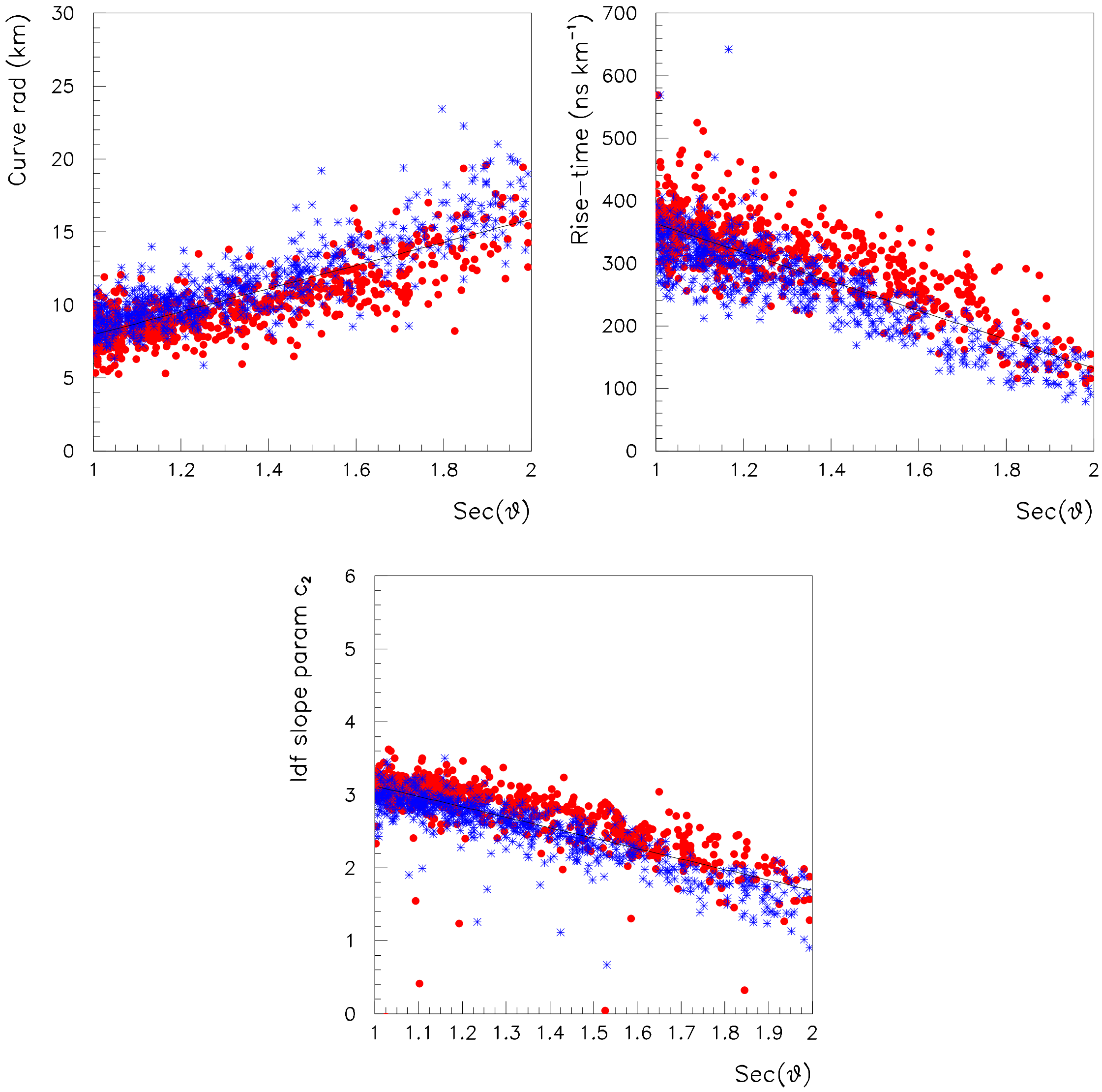
- Hybrid data set $\Rightarrow$ "Classic" X_{max} parameter; rms error < 20 g cm^{-2}.





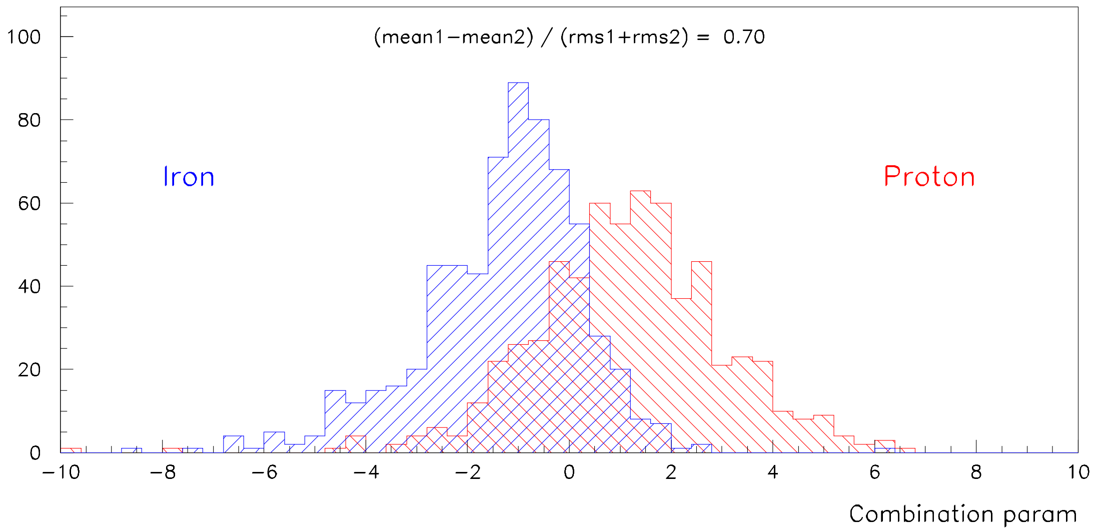
Composition sensitivity cont......

- Ground array has various handles ⇒ Rise-time, shower front curvature, lateral distribution slope etc... Also "FADC trace analysis".

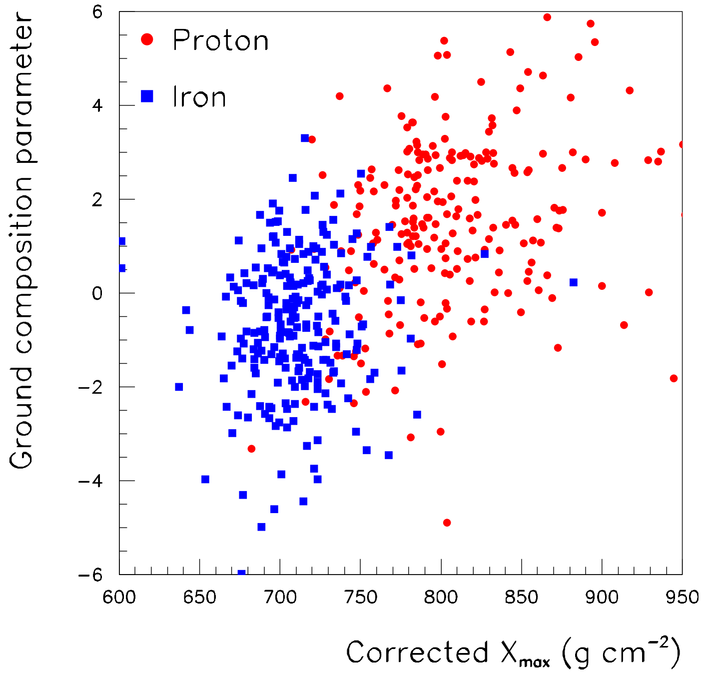


Composition sensitivity cont......

- Crude combination of Curve, Rise-time and ldf slope:



- Correlations will be highly instructive:



Conclusions

- New shower calculations with very low thinning mean that fluctuation effects are included in our simulations much more thoroughly than before.

- We are starting to understand how the hybrid data sub-set will be used to drive the analysis of the much larger ground-only data set, and free it from Monte Carlo dependence.

- Predicted performance of the Auger design remains well within our goals.

- A hybrid observatory of fluorescence "eyes" and surface detectors is an excellent and cost effective way to get the vast aperture demanded by the low flux of cosmic rays above 10^{20} eV.