

# Composition below $10^{19}$ eV

US Auger Collaboration Meeting

Colorado State Univeristy

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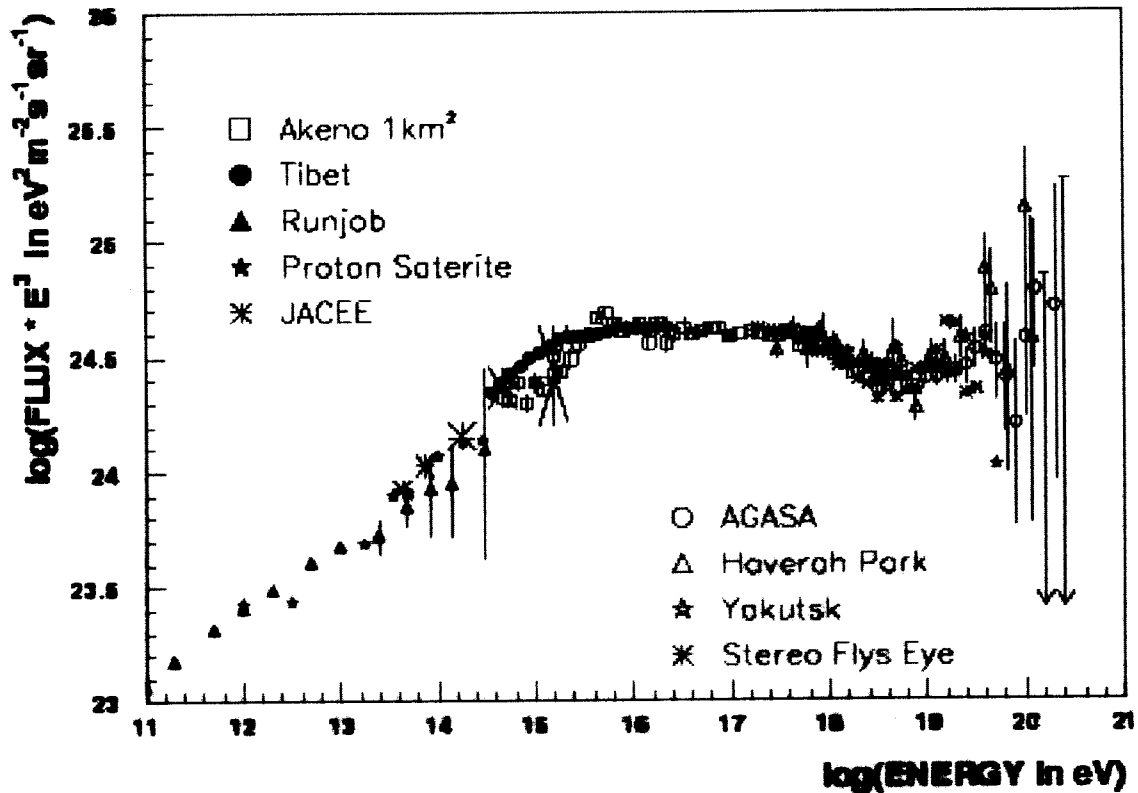
New Mexico Center for Particle Physics

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1. What do we know?
2. We would like to know:  $f_p$  versus  $E$
3. **And** over the largest  $\Delta E$
4. Energies below  $\sim 10^{19}$ eV implies hybrid:
  - (a) ... to maintain experimental resolution
  - (b) **and** below some energy hybrid is 100% of the **data**

# 1. Background (con't) ...

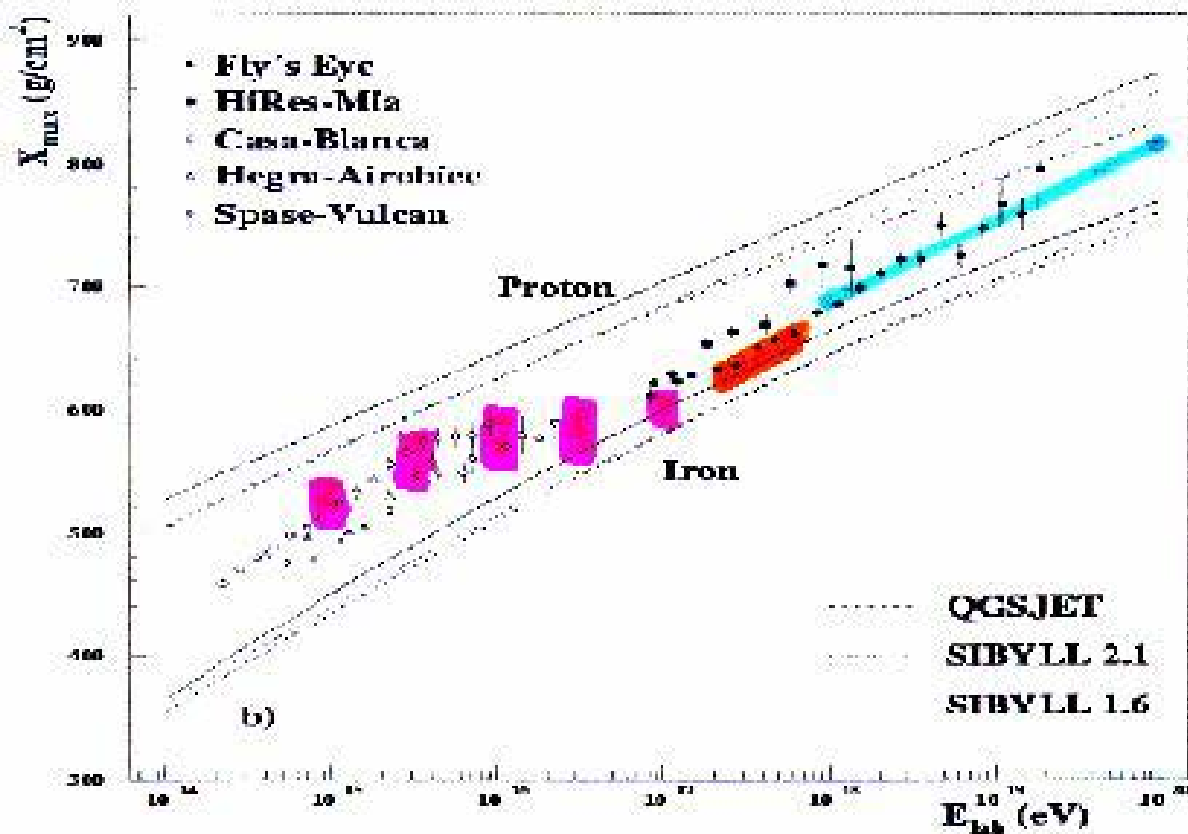


Cosmic ray flux scaled by  $E^3$

- **Structure in a power law spectrum:**

1. *knee* at  $\sim 4 \times 10^{15}$  eV
2. second *knee* at  $\sim 4 \times 10^{17}$  eV
3. *ankle*  $\sim 4 \times 10^{18}$  eV
4. *cutoff* at  $\sim 10^{20}$  eV ... or not!

### 3. New results (con't) ...



#### Cosmic ray *composition* including new results

- Average depth of shower maximum ( $X_{max}$ ) is sensitive to primary cosmic ray *composition*:
  1. *red* - KASCADE (preliminary): astro-ph/0201109
  2. *orange* - Haverah Park (re-analyzed): astro-ph/0203150, consistent with *mixed* composition [34%-light (p), 66%-heavy (Fe)]
  3. *blue* - HiRes (preliminary): K. Reil, Thesis, March 2002

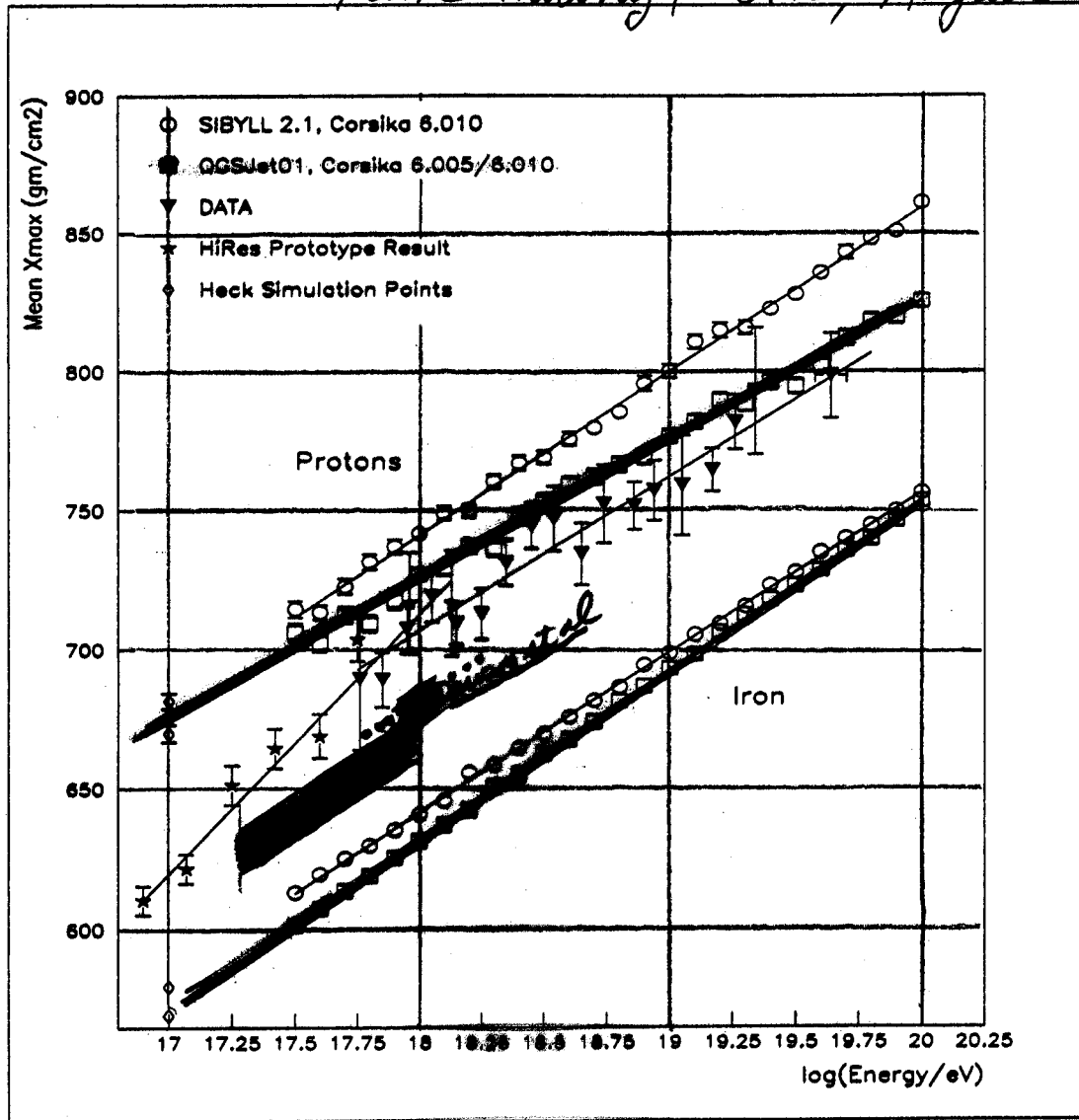


Fig. 9. Elongation Rate of HiRes stereo data set ( triangles ) and HiRes prototype/MIA data (stars). Open symbols show expected elongation rate for pure proton or pure Fe flux for two models of the hadronic interactions as implemented in CORSIKA.

Kevin Reid, Thesis, March 2002

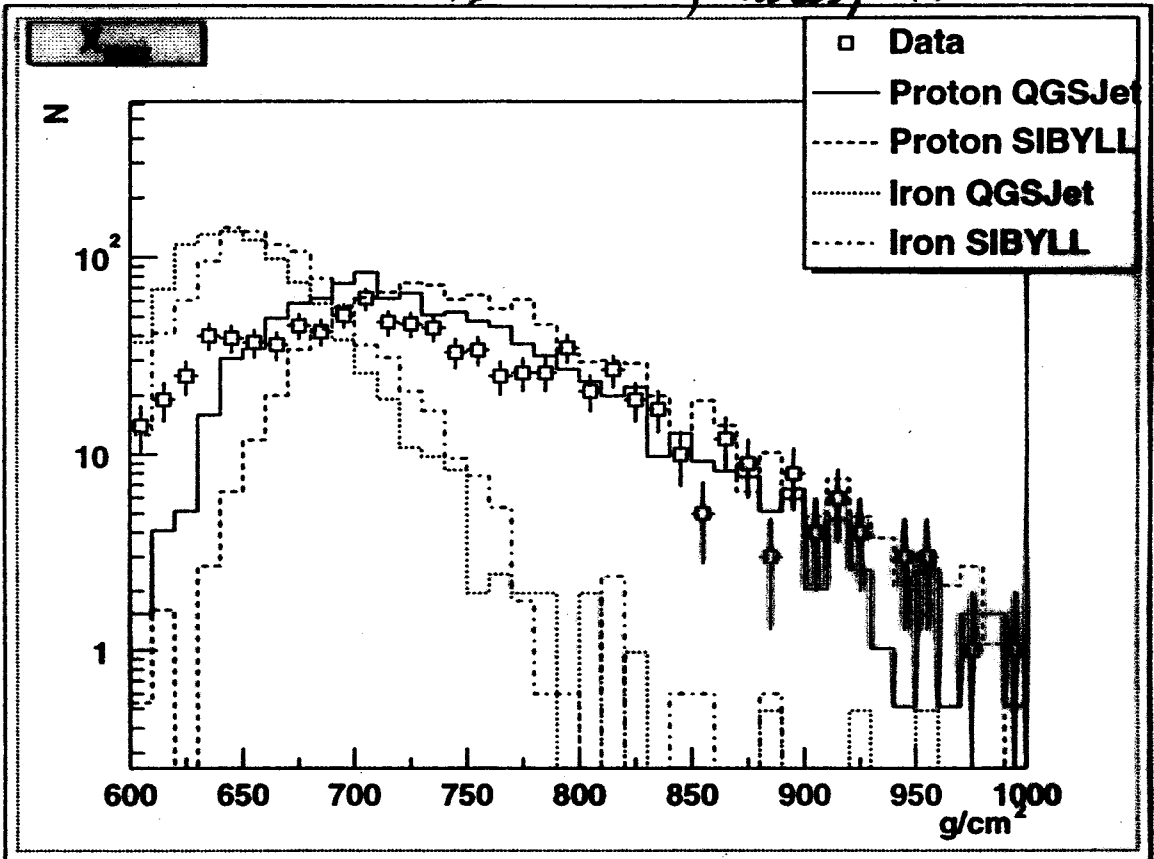
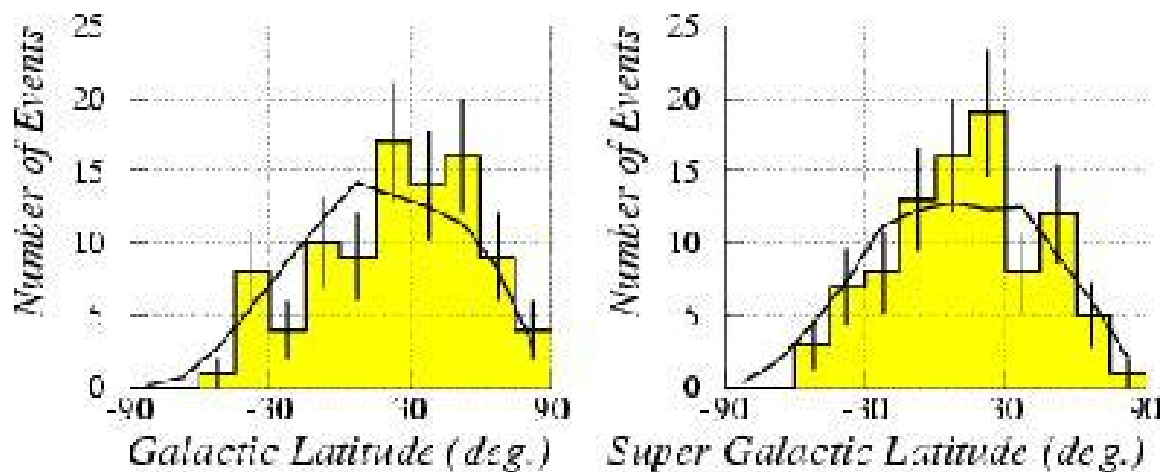


Figure 7.26.  $X_{max}$  Distribution

#### 4. Emerging model (con't) ... *Simple* summary



**Cosmic ray ( $> 4 \times 10^{19}$ eV) arrival directions ...**

1. 1<sup>st</sup> component: broad *composition* light (p,He) to heavy (Si,Fe,...); may extend to energies  $\sim 10^{19}$ eV
2. 2<sup>nd</sup> component: lighter (significant proton) composition; possibly measurable implications to below  $10^{18}$ eV
3. **Primary motivations for the 2<sup>nd</sup> component: flattening** of the flux above the ankle ( $\sim 4 \times 10^{18}$ eV) and a **change to lower mass composition** at the highest cosmic ray energies: above  $\sim 10^{18}$ eV
4. The primary motivation for identifying the 2<sup>nd</sup> component as **extra-galactic** is the **isotropy of the highest energy cosmic rays** (strengthened if *light* (p,He))

D. De Marco, P. Blasi & A. Olinto, Jan 2003.

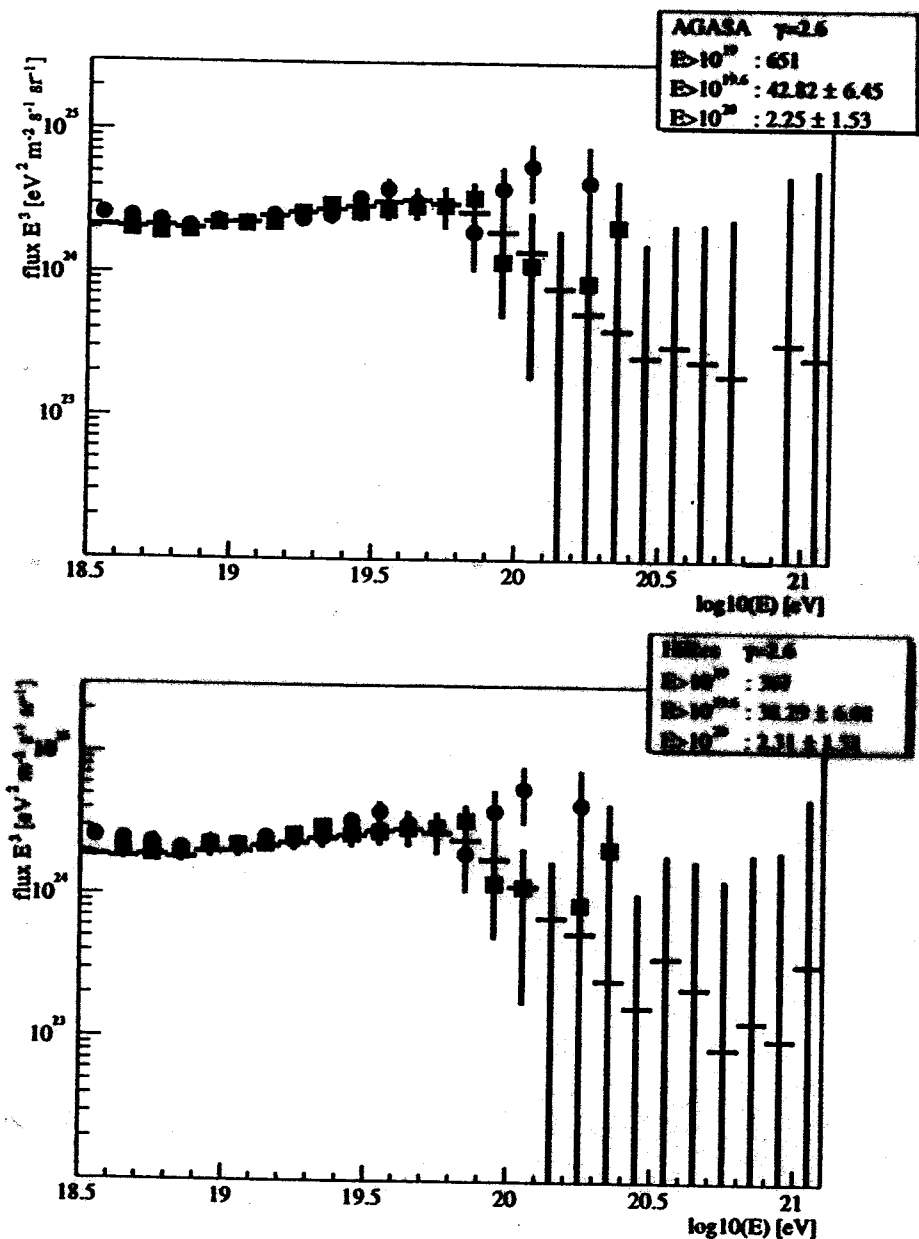


Fig. 7. Upper panel: AGASA (grey dots). lower panel: HiResI (dark squares)

... and extragalactic models should be compared to  $f_p * \Phi$  where  $f_p$  is the fraction "P/all" VS energy.

B. Wiebel-Sooth & P. Biermann, Sept 1998

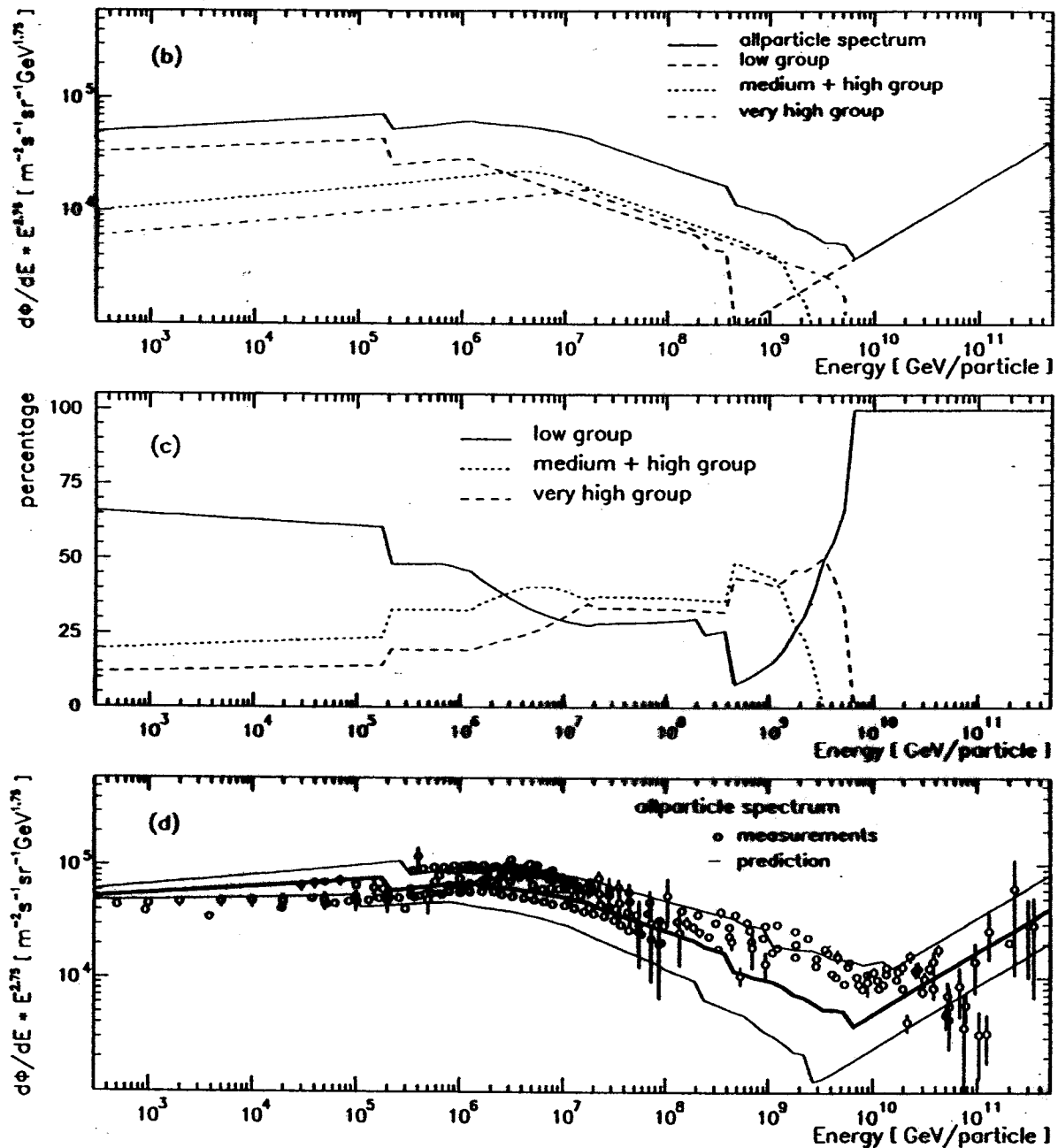


Figure 19: (a) The predicted allparticle energy spectrum (Biermann's model) with the contributions of supernovae exploding into the interstellar medium (ISM-SN), supernovae exploding into their former stellar wind (wind-SN) and radio galaxy hot spots. (b) The predicted allparticle spectrum with the contributions of several element groups. (c) The percentages of the different element groups in the allparticle flux. (d) The allparticle energy spectrum measured by the different experiments so far, with the predicted allparticle spectrum shown in (a) (thick solid line) and the error range including errors inherent in the theory (thin solid lines). Concerning the extragalactic component (radio galaxy hot spots) losses coming from interactions with the microwave background above roughly  $3 \cdot 10^{10}$  GeV have been ignored here.



# Design Report March 1997

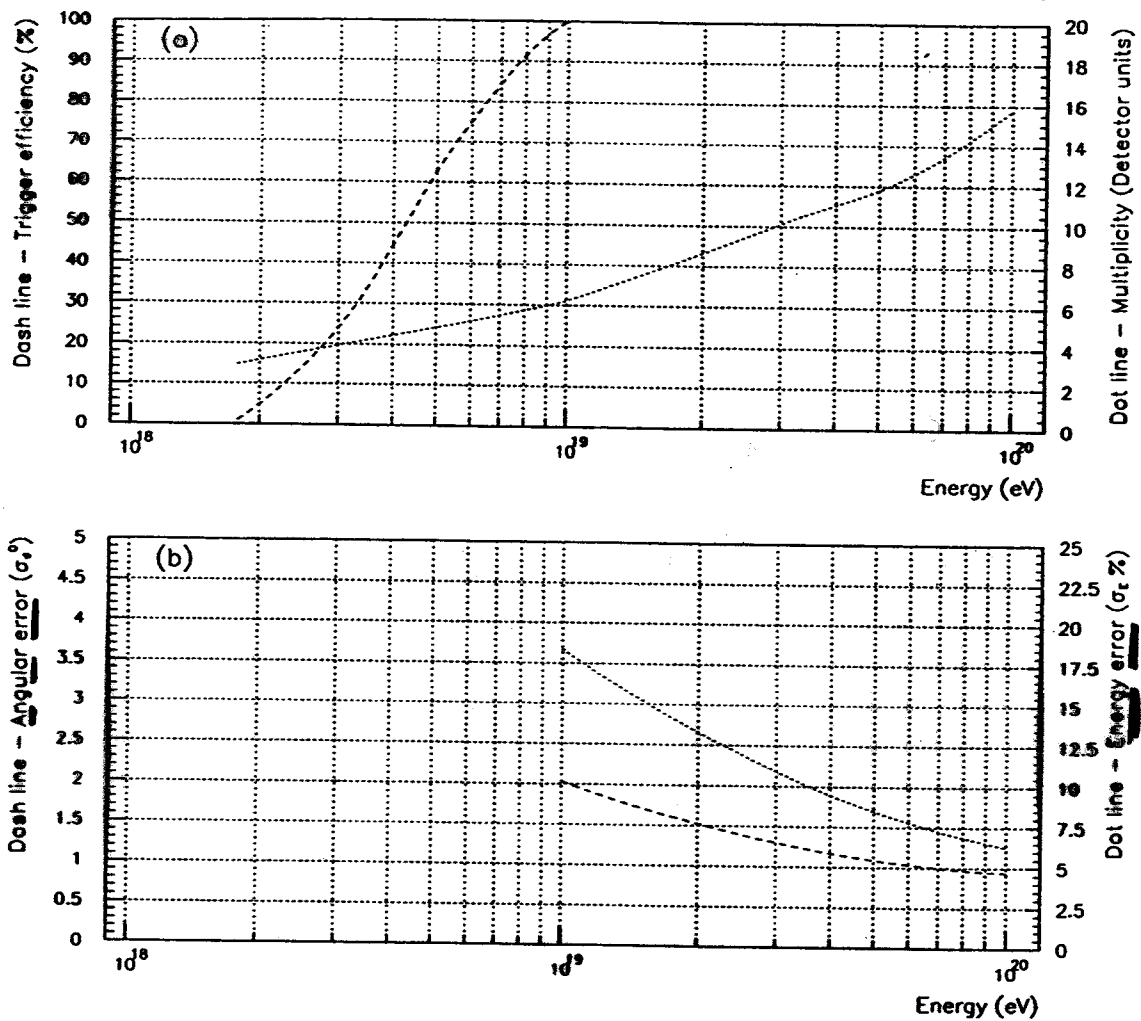


Figure 5.15: Summary of Auger Observatory water Čerenkov surface array performance as determined by reconstruction of simulated events. The upper plot shows the detector unit multiplicity and array trigger efficiency if 5 fold events are demanded, for proton showers at  $30^\circ$  (compare to last figure which used vertical showers). In the lower plot, expected reconstruction accuracy of direction and energy for vertical proton showers. The energy error plotted is only the random component due to detector physics and statistics. The estimated shower-to-shower fluctuations contribute 10% to the energy resolution, which should be added in quadrature with the values shown. The assumption of primary particle type results in a systematic shift of at most 25%. This systematic shift can be substantially corrected using rise time measurements, muon counting, and  $X_{max}$  measurements. The corrections can be calibrated and confirmed using hybrid data.

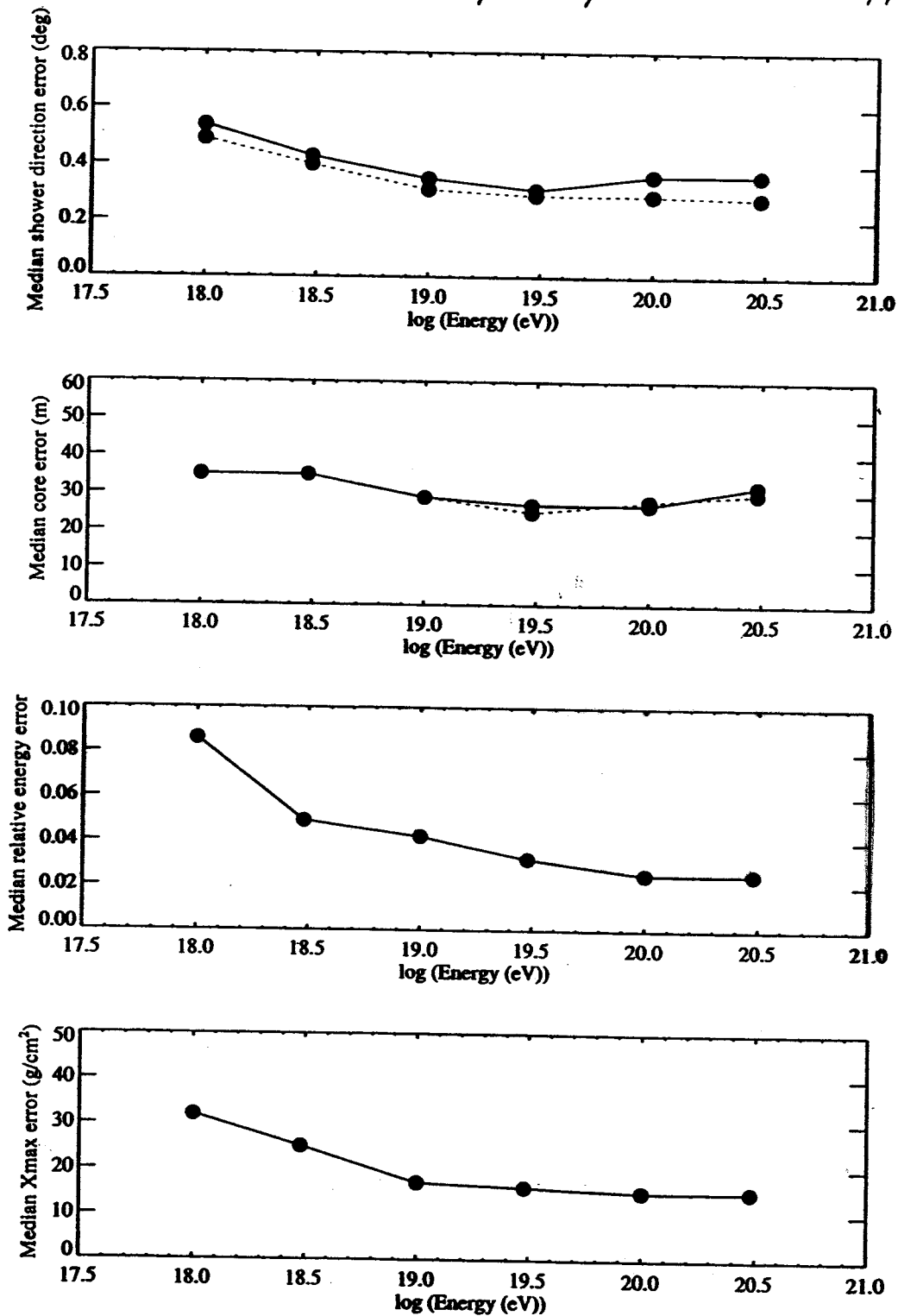


Figure 5.27: Hybrid median reconstruction errors for the three eye, 1.5° pixel system. The errors for the geometrical quantities (shower direction and core) are shown for Methods 2 (solid line) and 3 (dashed line), though the errors are almost identical. The energy and  $X_{\max}$  errors are shown for Method 2. A summary of these data, together with 90% errors, is given in Table 5.2.

