Summary Talk

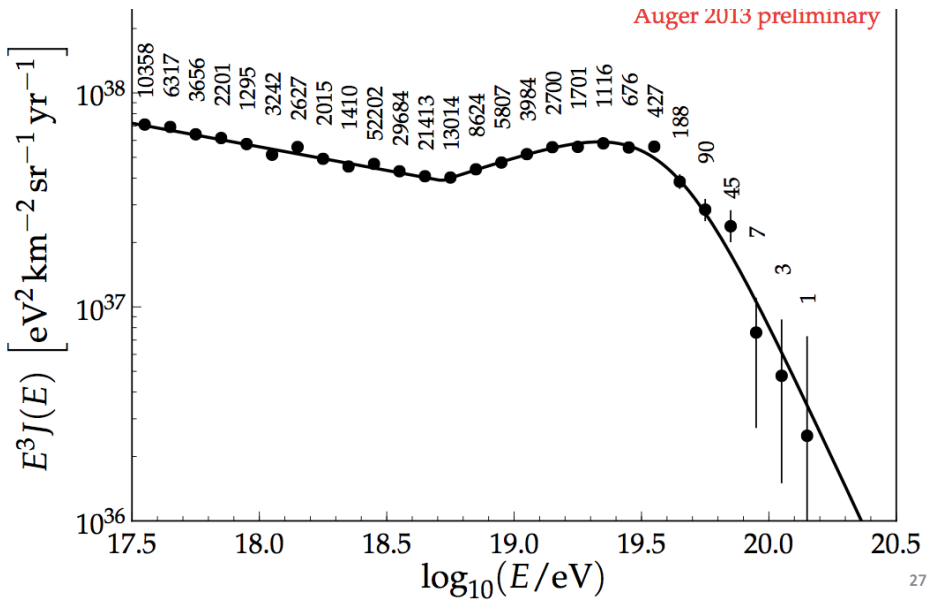

"By the Rivers of Babylon (We sat and wept as we remembered Zion)"
Psalm (1/alpha)
P. Sokolsky
UHECR2014 Springdale

Things that caught my eye…

- After ~ 6300 talks on cosmic rays (since 1982)

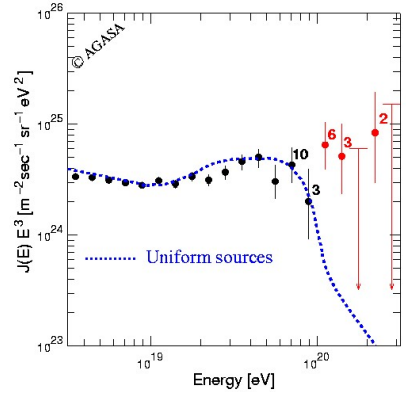
Forgive my jaundiced eye….

PAO Combined Spectrum

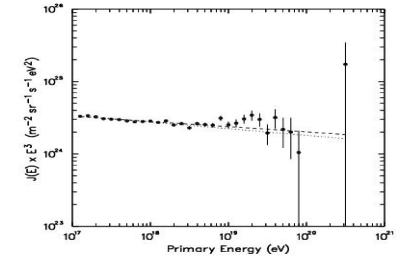


27

Big Progress!

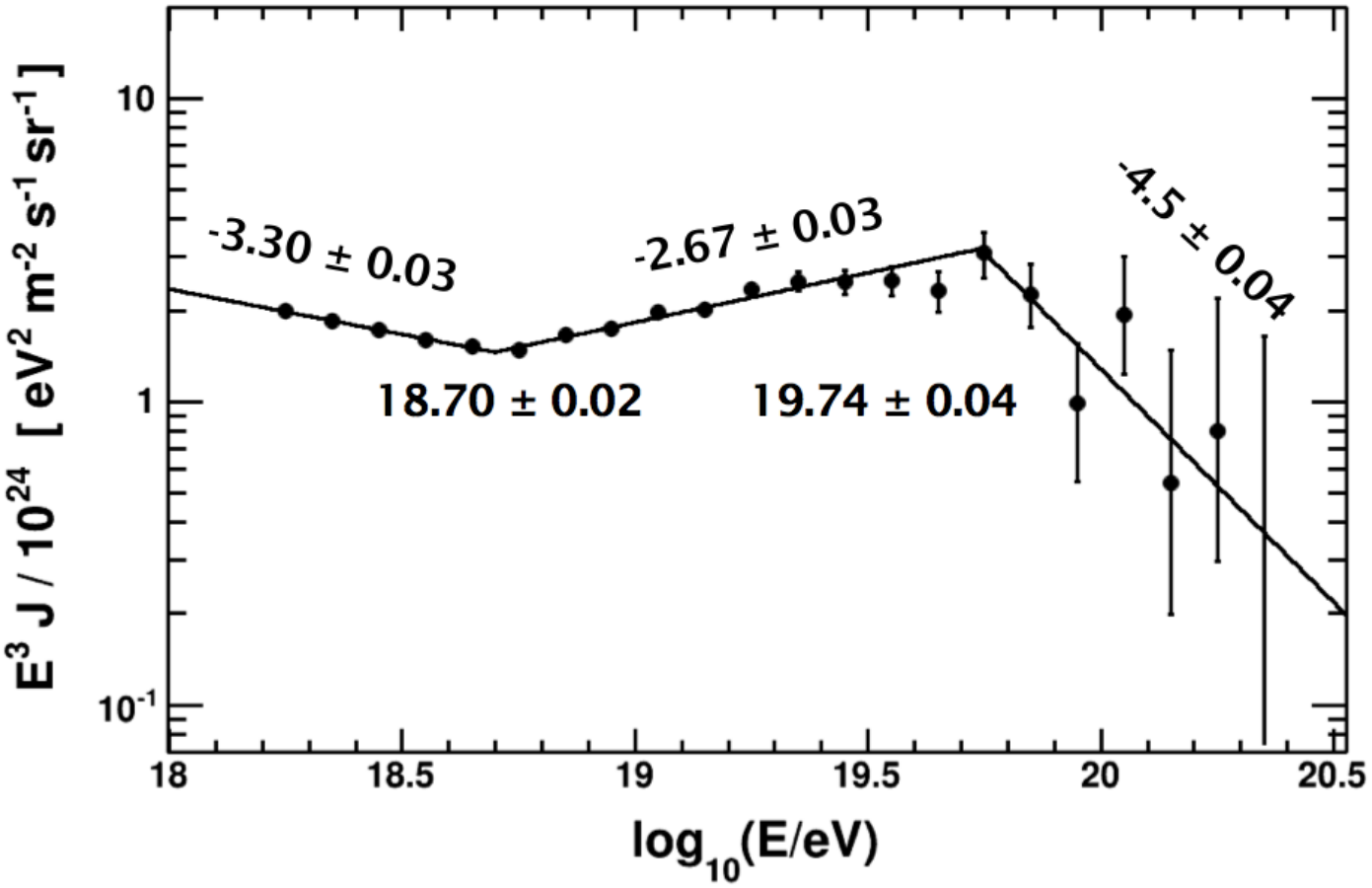


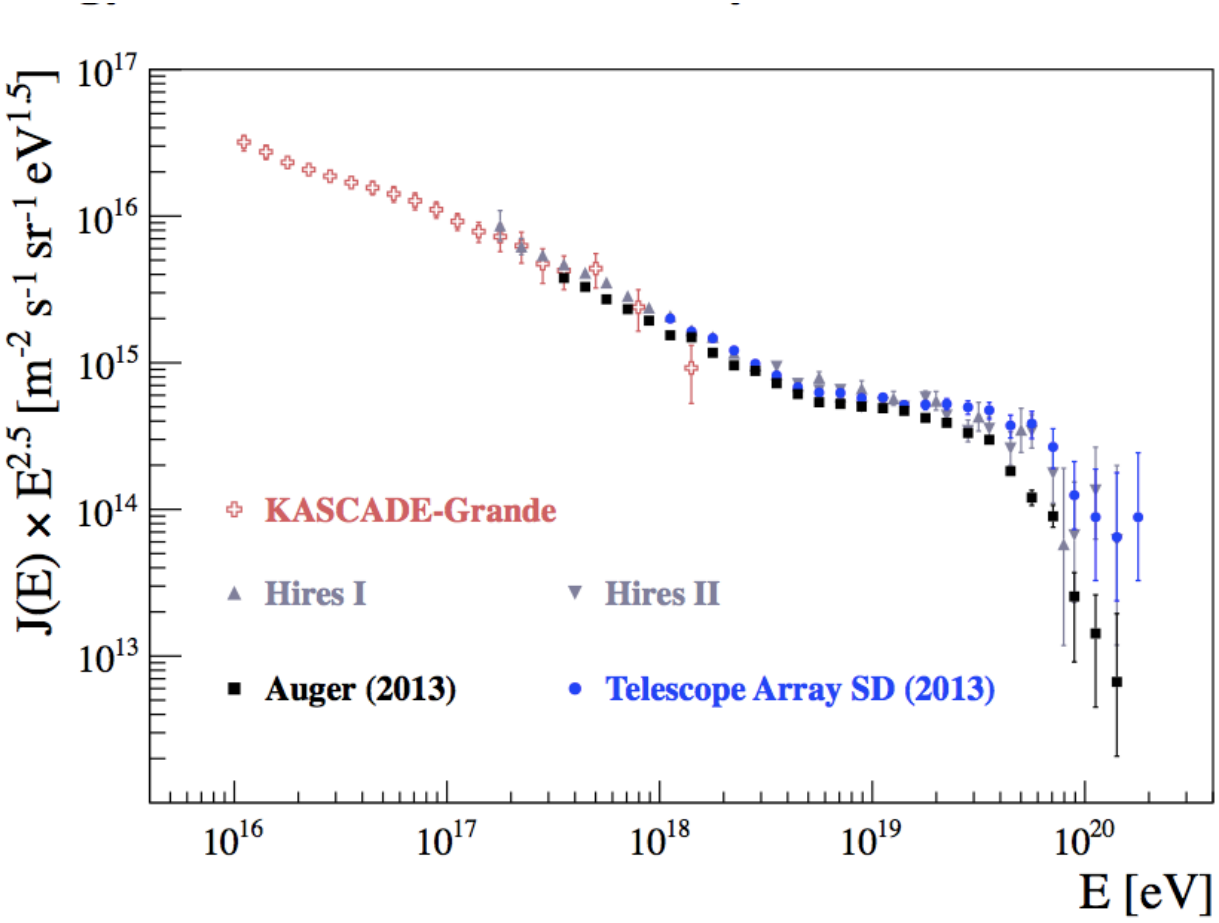
AGASA



Fly's Eye Mono

TA 6 year spectrum




$J(E) \times E^{2.5}$ [m^{-2} s^{-1} sr^{-1} eV$^{1.5}$]
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
KASCADE-Grande
Hires I
Hires II
Auger (2013)
Telescope Array SD (2013)
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
E [eV]

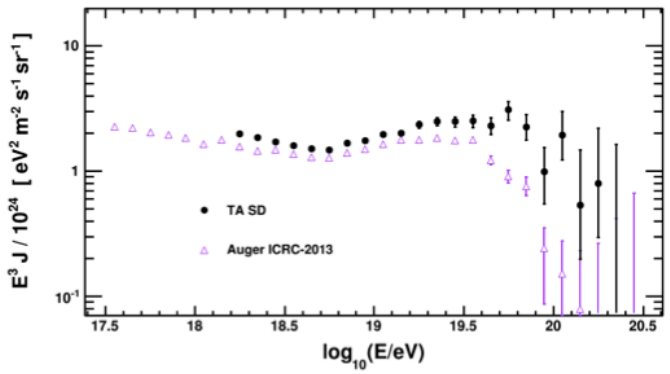
General agreement (after energy scale shift) except at highest energies

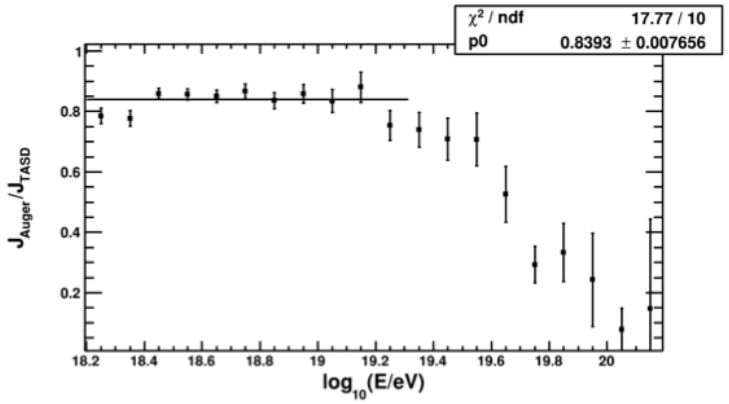
- Systematics or Real Difference?
- Non-linear energy scale (no evidence fo
- Change in cutoff shape as function

of latitude?

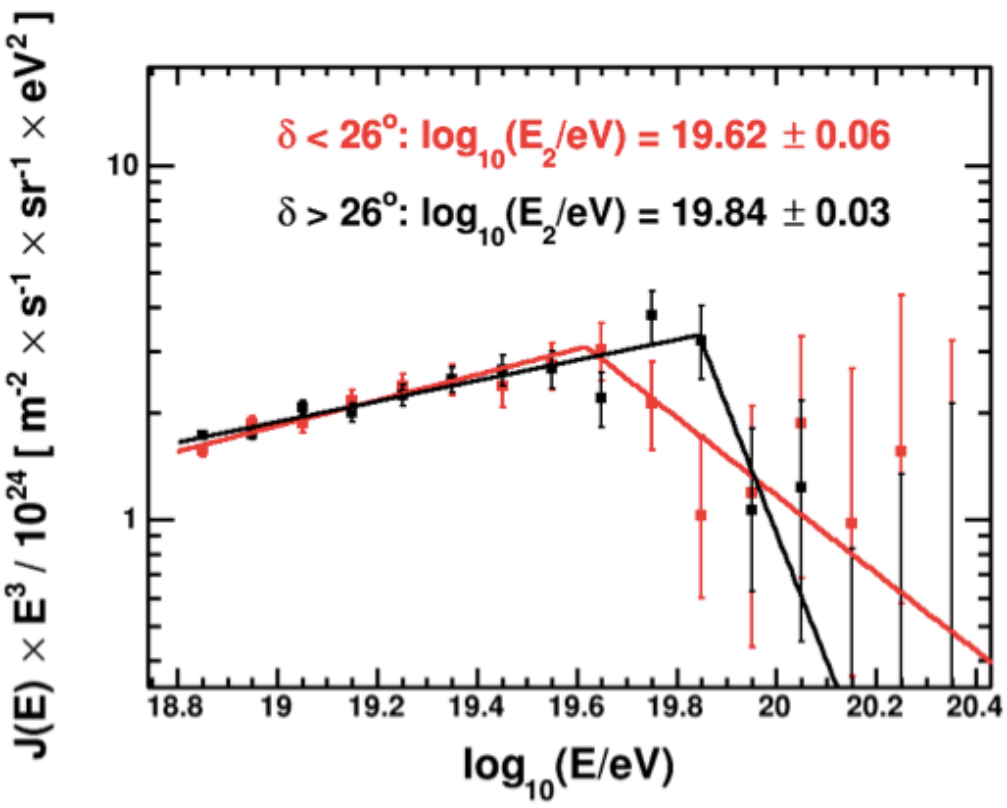
(no evidence in PAO, but possible in TA)

- Influence of Hot Spot?

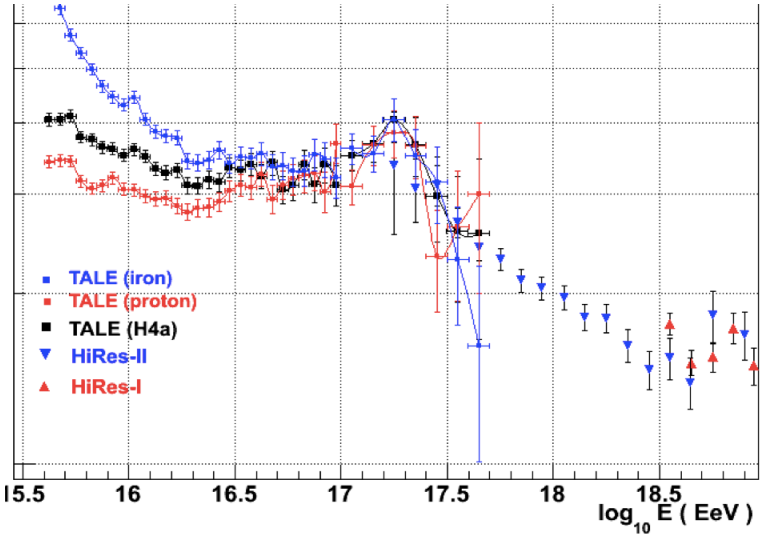


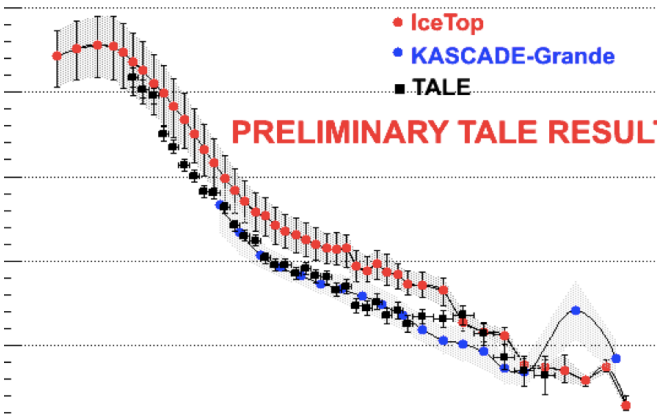


Possible slope change with declination?

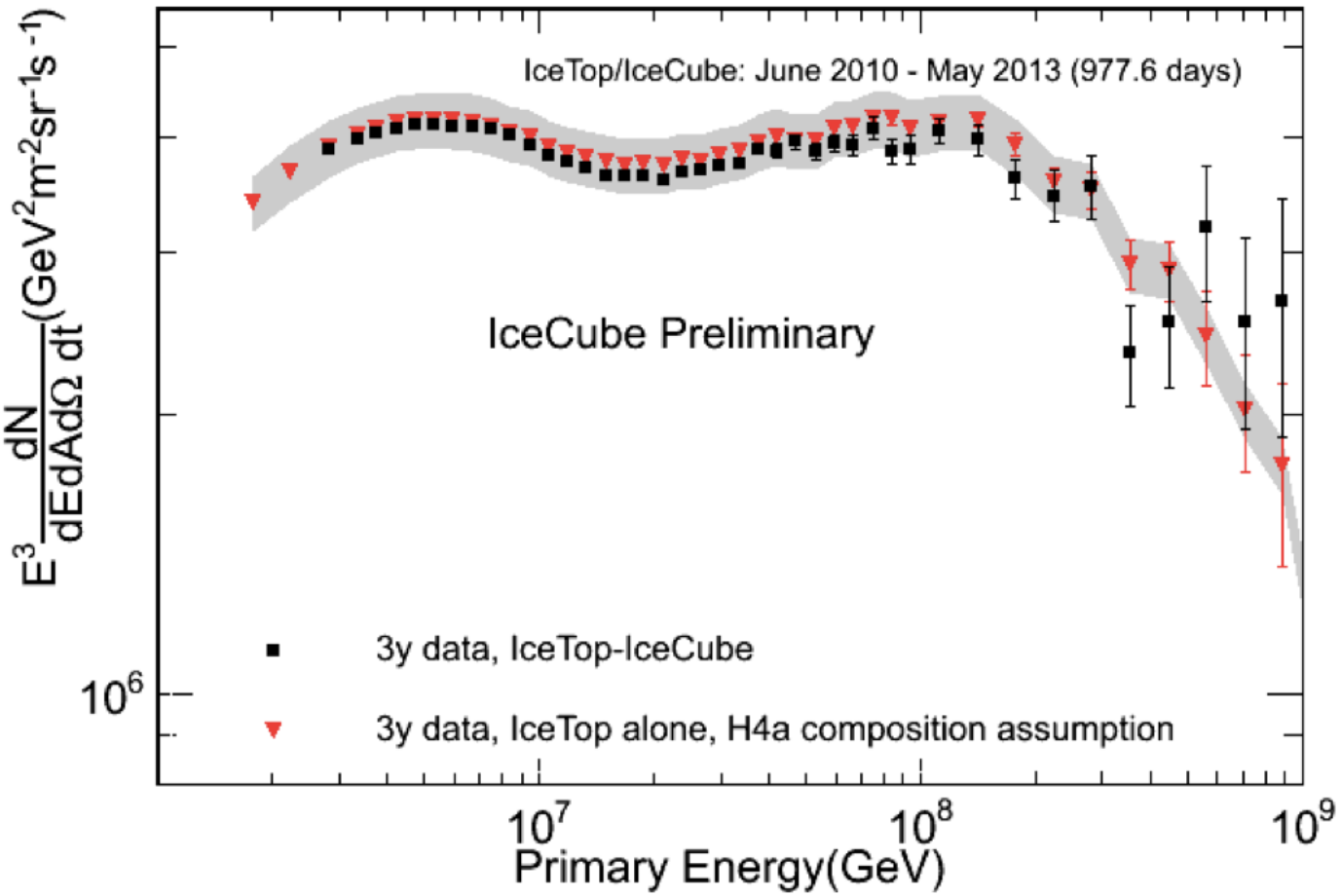


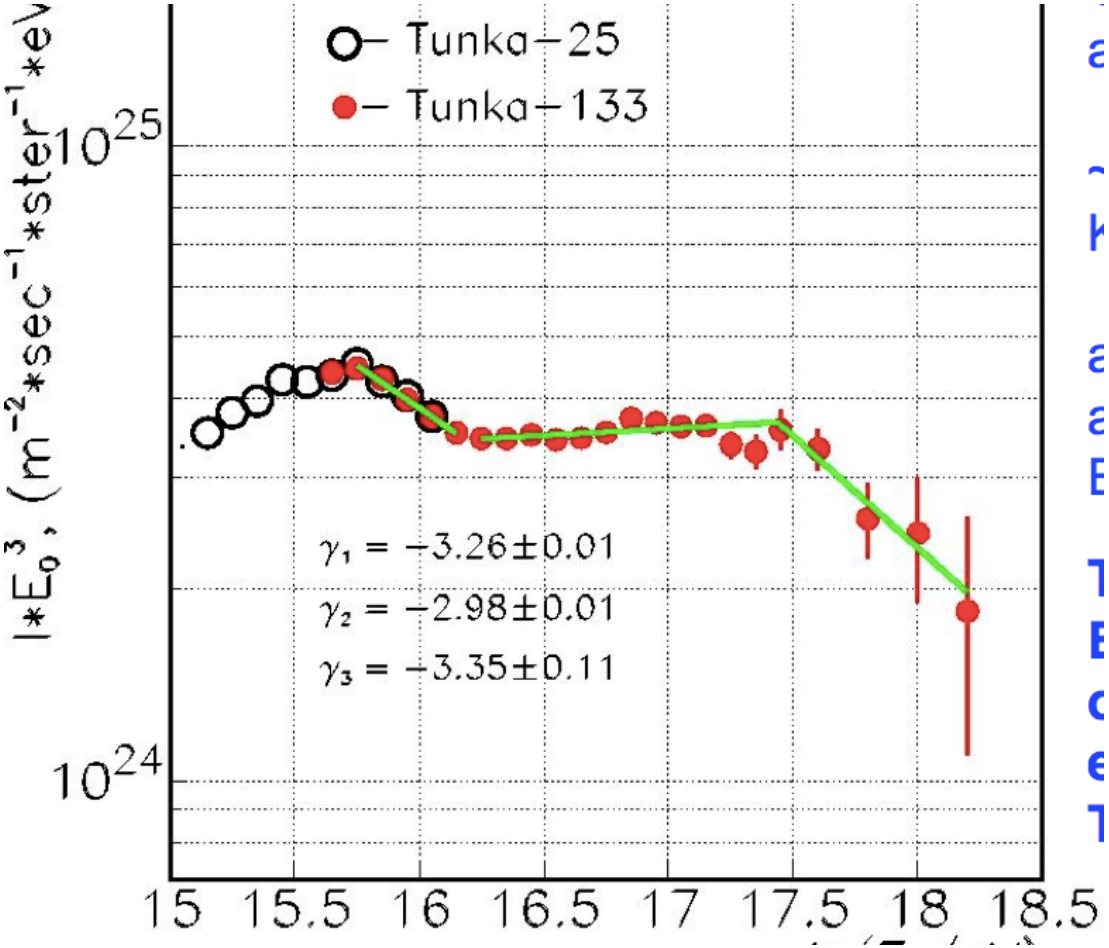
Lower energies – search for Galactic/ Extragalactic transition



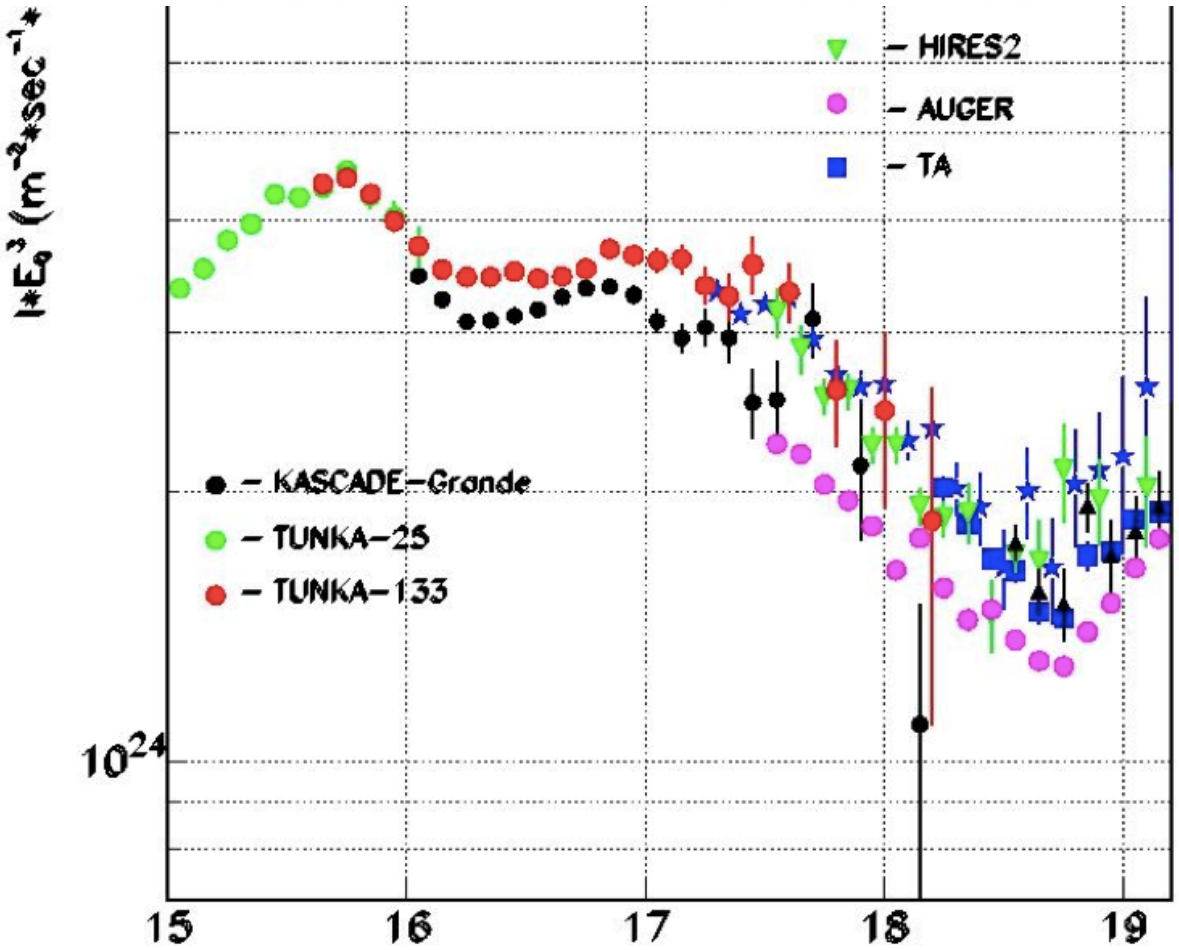


Surprising new Cherenkov reconstruction technique!


IceTop/IceCube: June 2010 - May 2013 (977.6 days)
IceCube Preliminary
3y data, IceTop-IceCube
3y data, IceTop alone, H4a composition assumption
$E^3 \frac{dN}{dE dA d\Omega dt}$ (GeV^{2}m^{-2}sr^{-1}s^{-1})
10^6
10^7
10^8
10^9
Primary Energy(GeV)

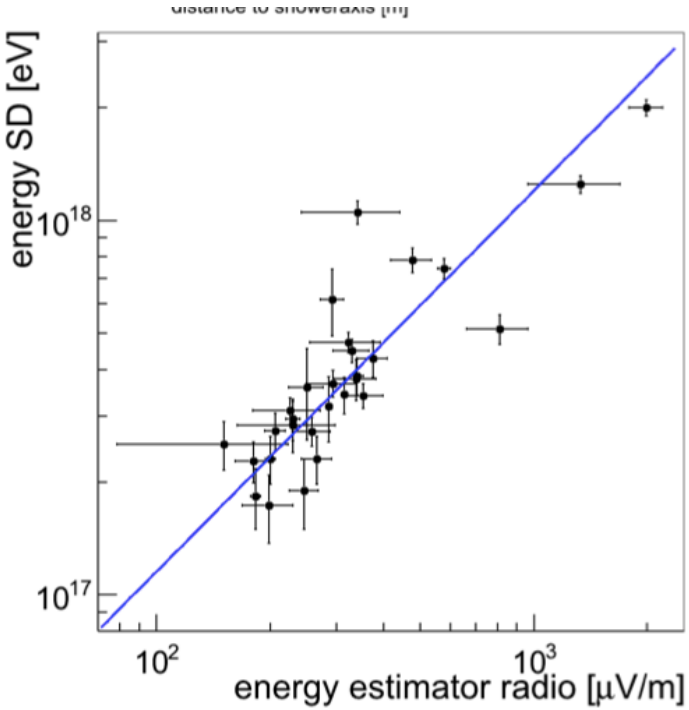

Tunka–25
Tunka–133
$\gamma_1 = -3.26 \pm 0.01$
$\gamma_2 = -2.98 \pm 0.01$
$\gamma_3 = -3.35 \pm 0.11$
$I*E_0^3$, $(m^{-2}*sec^{-1}*ster^{-1}*eV$
10^{25}
10^{24}
15
15.5
16
16.5
17
17.5
18
18.5

Not your father's power law

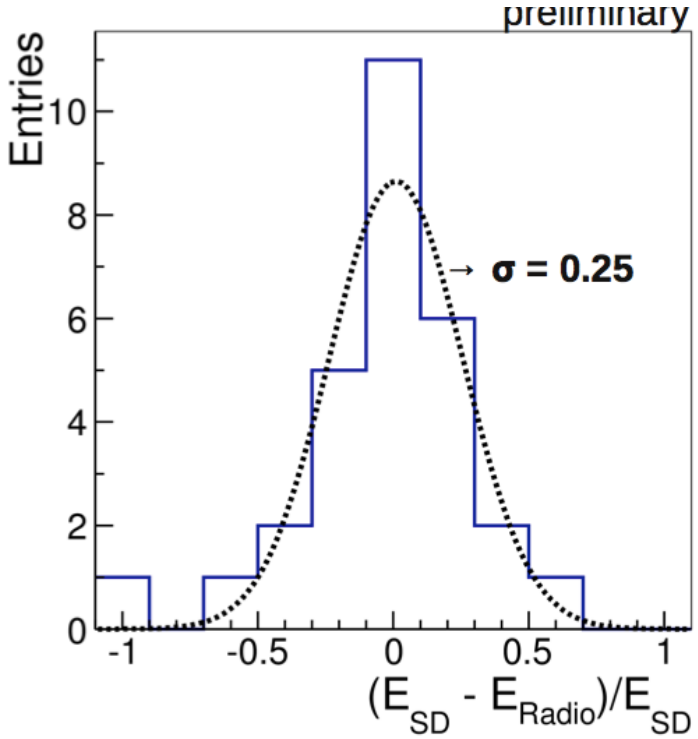


New Approaches

- Lofar – Arena – promising progress in shower reconstruction (E and Xmax) -

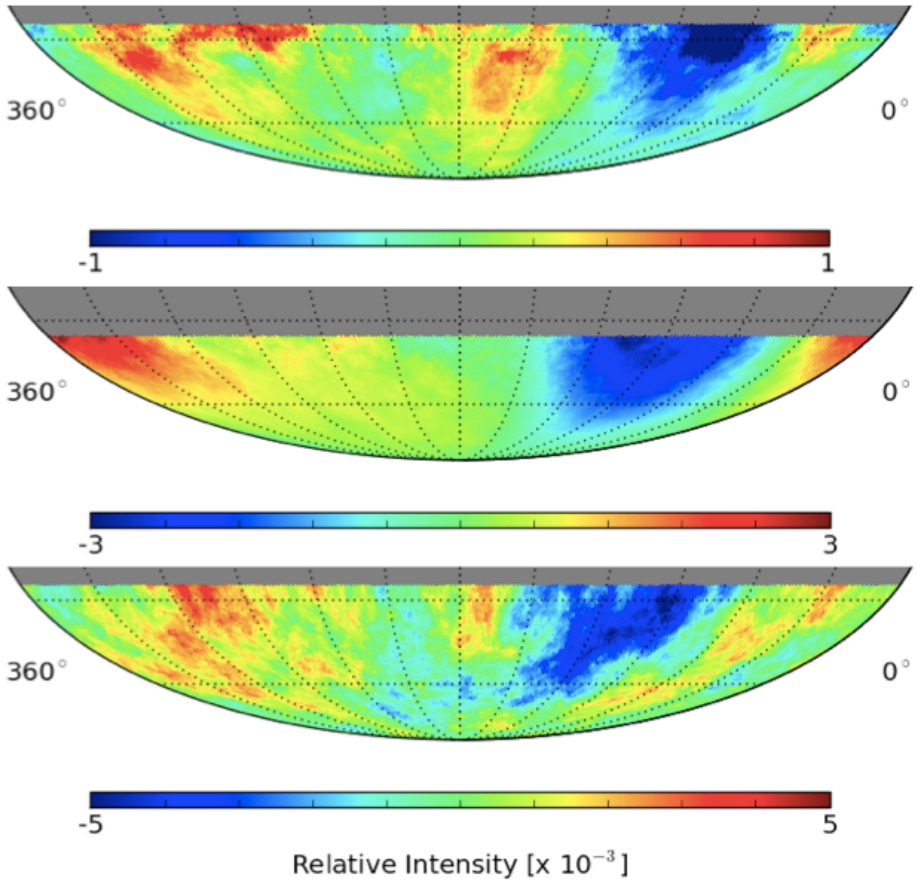


C. Glaser, ARENA (2012)



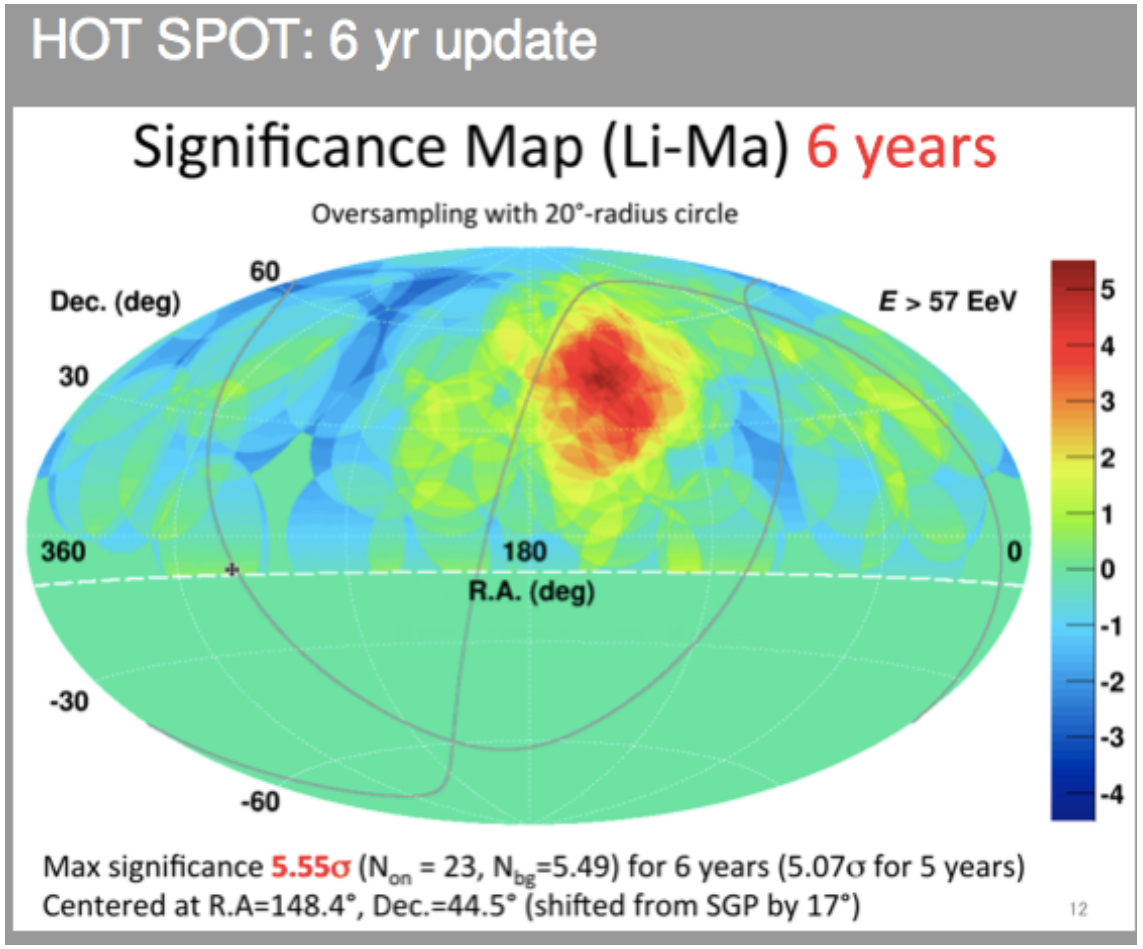
Low energy anisotropy

- IceCube 1.2 PeV
  - -1×10^{-3} to 1×10^{-3}
- IceTop 2 PeV
  - -3×10^{-3} to 3×10^{-3}
- IceCube 4.5 PeV
  - -5×10^{-3} to 5×10^{-3}



Completely unexpected – what does it mean?

Almost a significant anisotropy at UHE!



Unexceptional sources – what does it mean?

Global Anisotropy

- TA/PAO joint working group – multipole expansion studies. So far no real departures from isotropy
- Global 20 deg oversampling search would be very interesting -

Comments on “Composition”

- We measure Xmax, not composition
- The first step is to be sure we understand the systematics in Xmax accurately.
- We have three “modern” experiments: HiRes, PAO and TA.
- Is the data consistent?

Systematics

- Acceptance biases
- Reconstruction biases
- Atmospheric biases
- HiRes/PAO/TA very different in first two.

Comparison to “composition” hypotheses

- Choose hadronic models
- Choose analysis philosophy
- Devise cuts to minimize detector acceptance and reconstruction bias (tight cuts) PAO
- Use loose data cuts and simulate effect of biases thru detailed MC, generating simulated data and passing thru identical analysis (HiRes/TA)

PAO approach

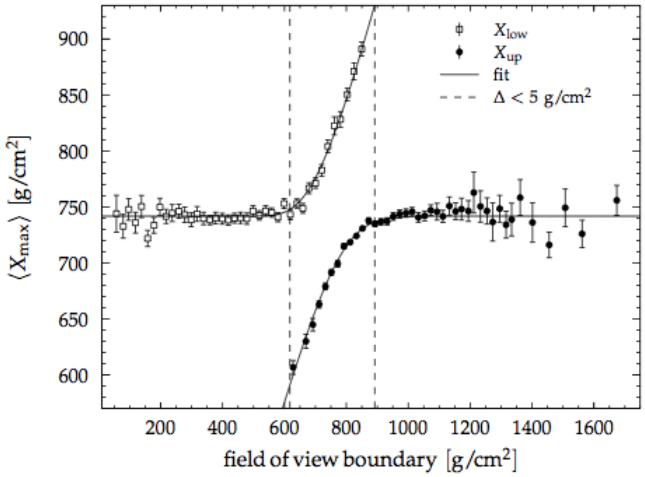


Figure 3: $\langle X_{max} \rangle$ for showers binned in X_l and X_u in the energy interval $10^{18.1}$ to $10^{18.2}$ eV. The solid line shows a fit with the truncated mean of an exponential function folded with a Gaussian [76], and the dashed line indicates the field-of-view value at which this function deviates by more than 5 g/cm^2 from its asymptotic value.

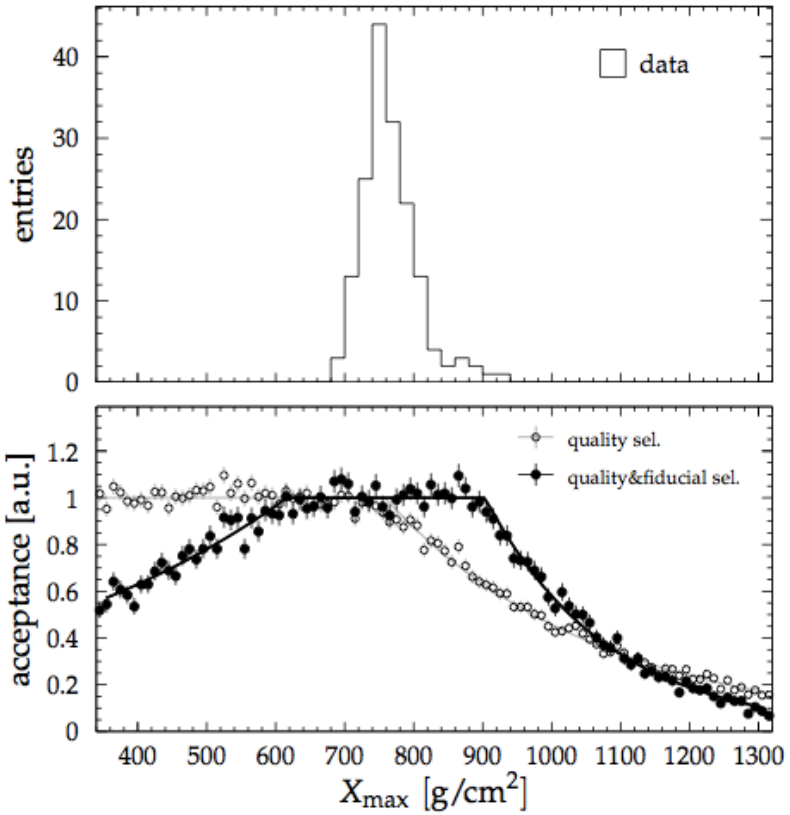


Figure 5: Upper panel: measured X_{max} distribution (full selection, $19.0 < \lg(E/\,\mathrm{eV}) < 19.1$). Lower panel: relative acceptance after quality cuts only (open markers) and after quality and fiducial cuts (filled markers). The parameterizations with Eq. (7) is indicated by lines.

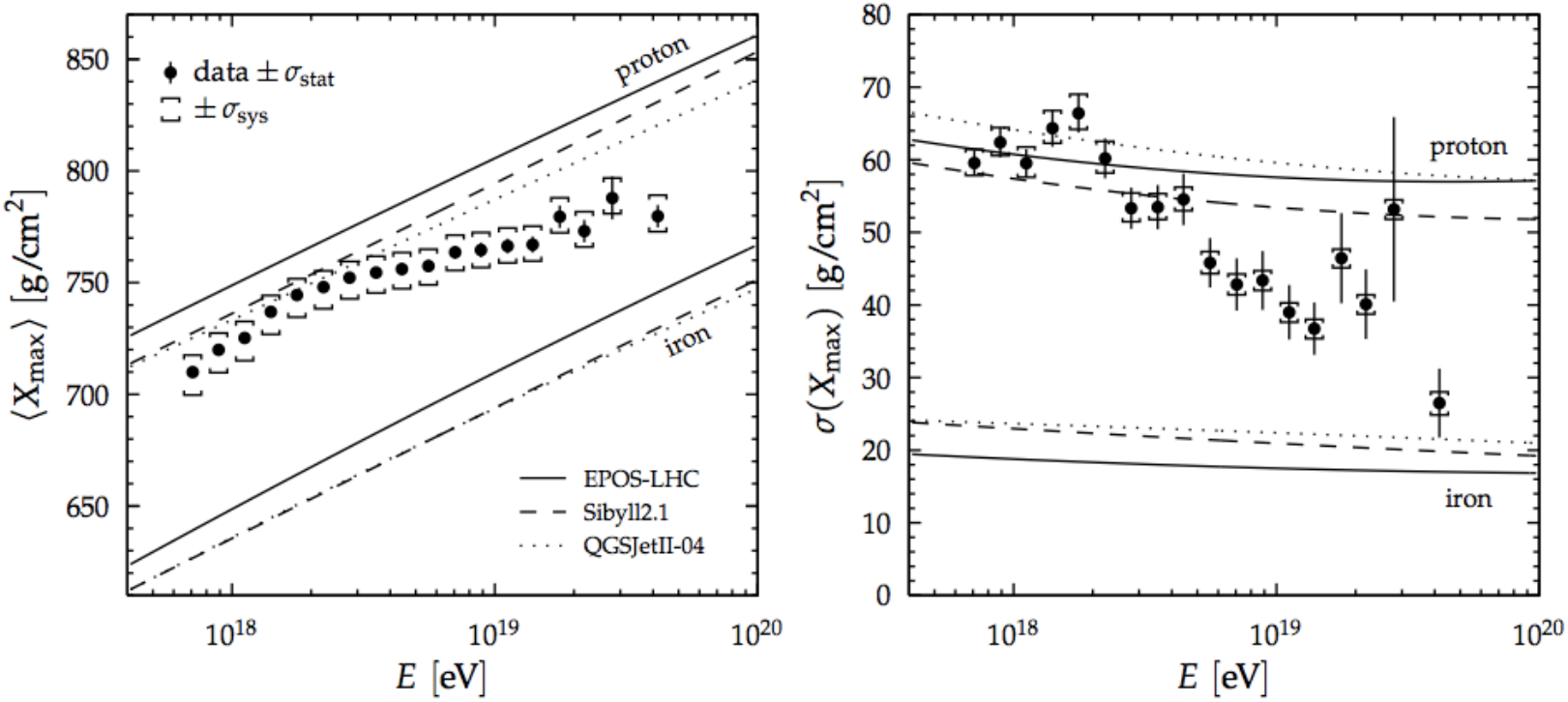
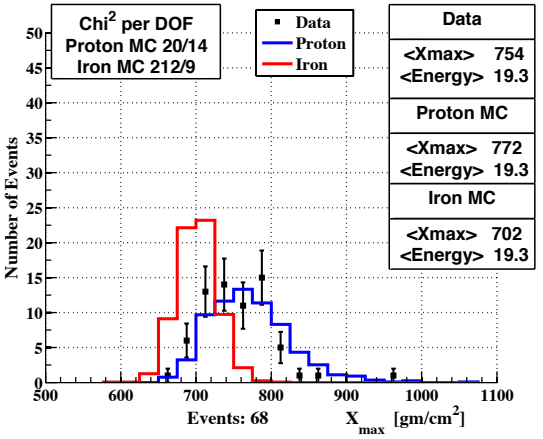
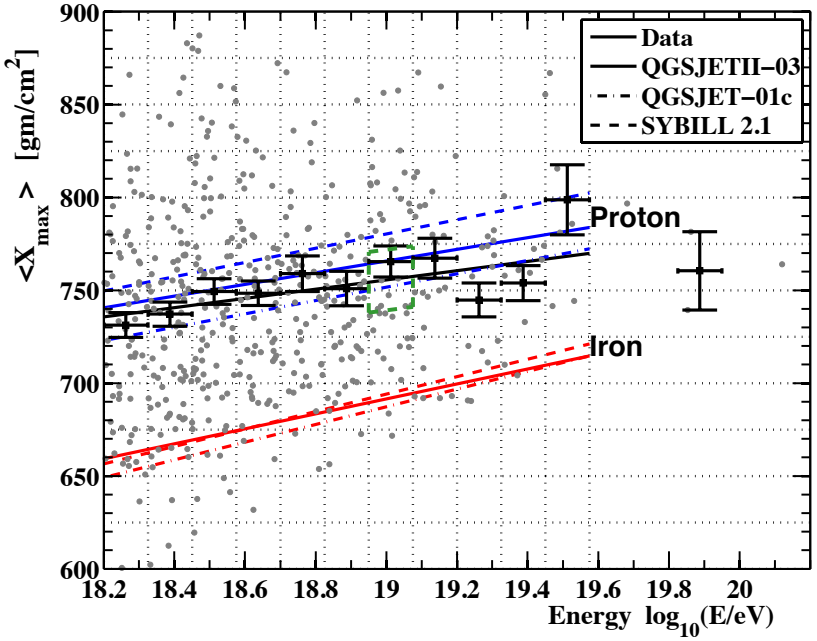
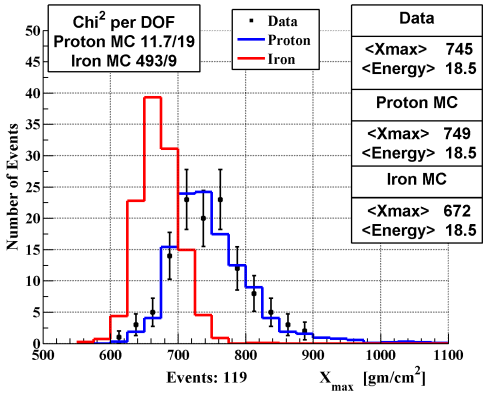


Figure 13: Energy evolution of the first two central moments of the $X_{\max}$ distribution compared to air-shower simulations for proton and iron primaries [80, 81, 95–98].

TA hybrid approach





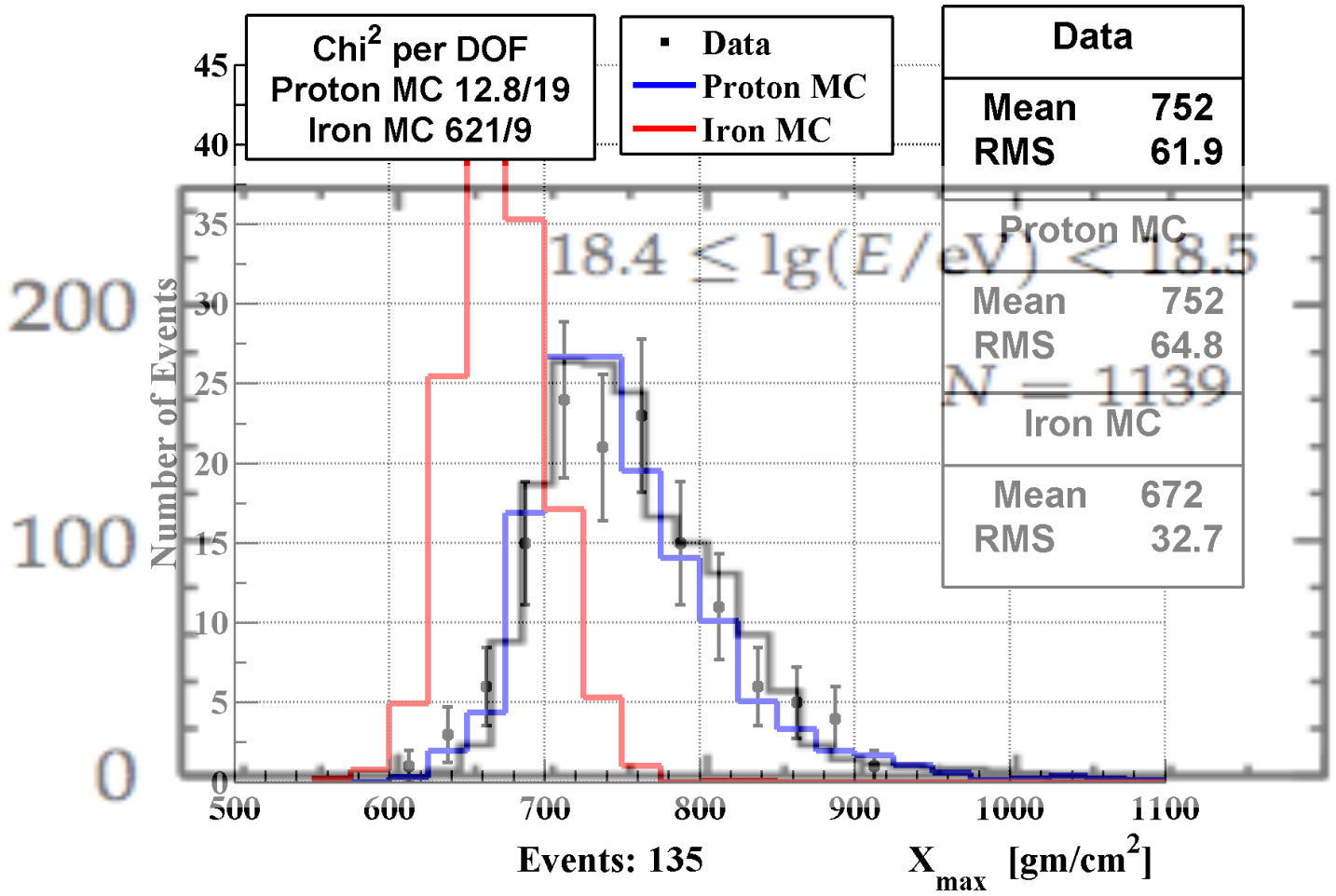


Cut data compared to fully simulated composition hypotheses

The Mystery of Agreement

- Measured elongation rates for TA and PAO agree well.
- “Composition” interpretation different (at least at high energies).
- TA and PAO have different acceptances in Xmax
- What’s going on?
- Look at agreement region (in interpretation)

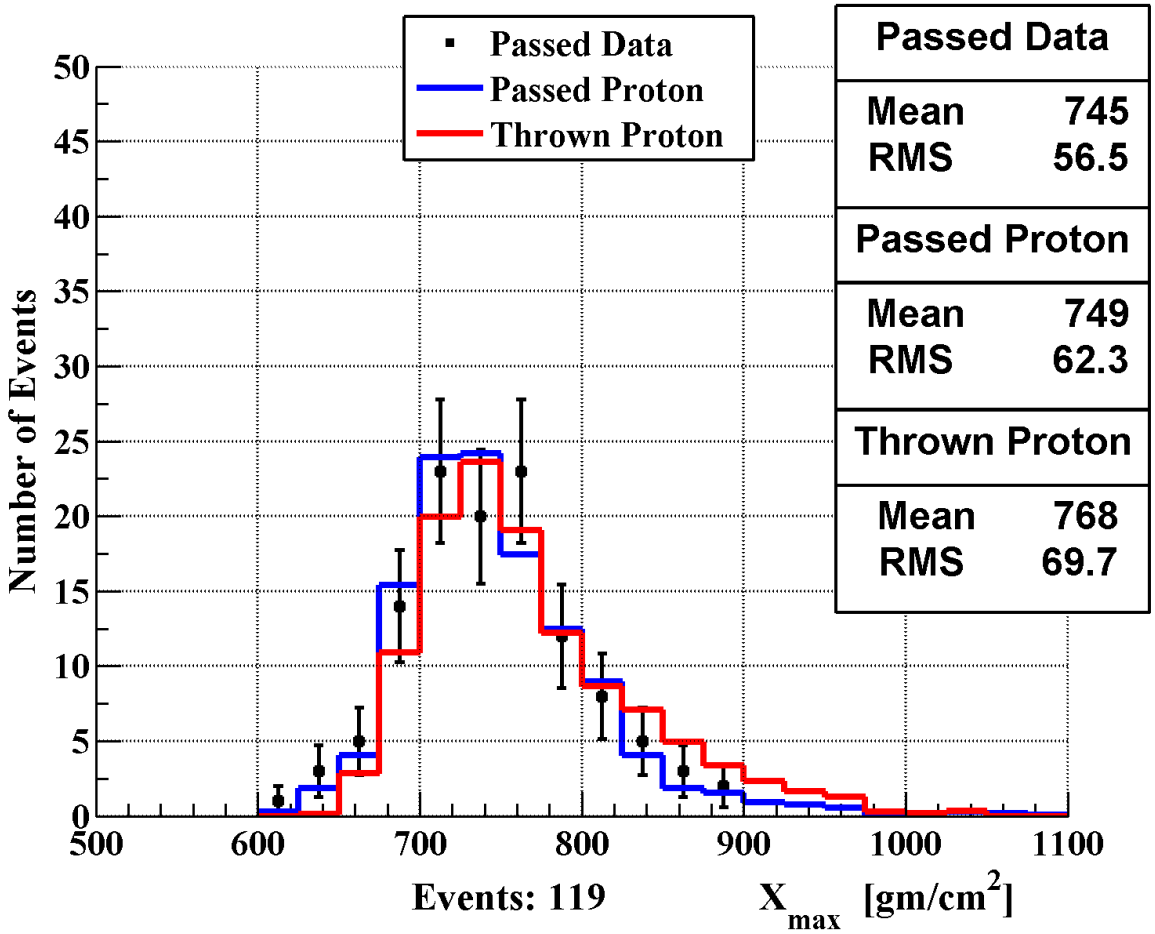
TA hybrid vs PAO 18.4-18.6



Acceptance shifts depend on position in the sky of thrown or “true” events

- QGSJetII-03, p, He, N, Fe thrown
- Look at shift in mean Xmax due to acceptance, reconstruction and cuts – 18.4-18.6
- Protons: 17 gm/cm2
- He: 11
- N: 2
- FE: -4

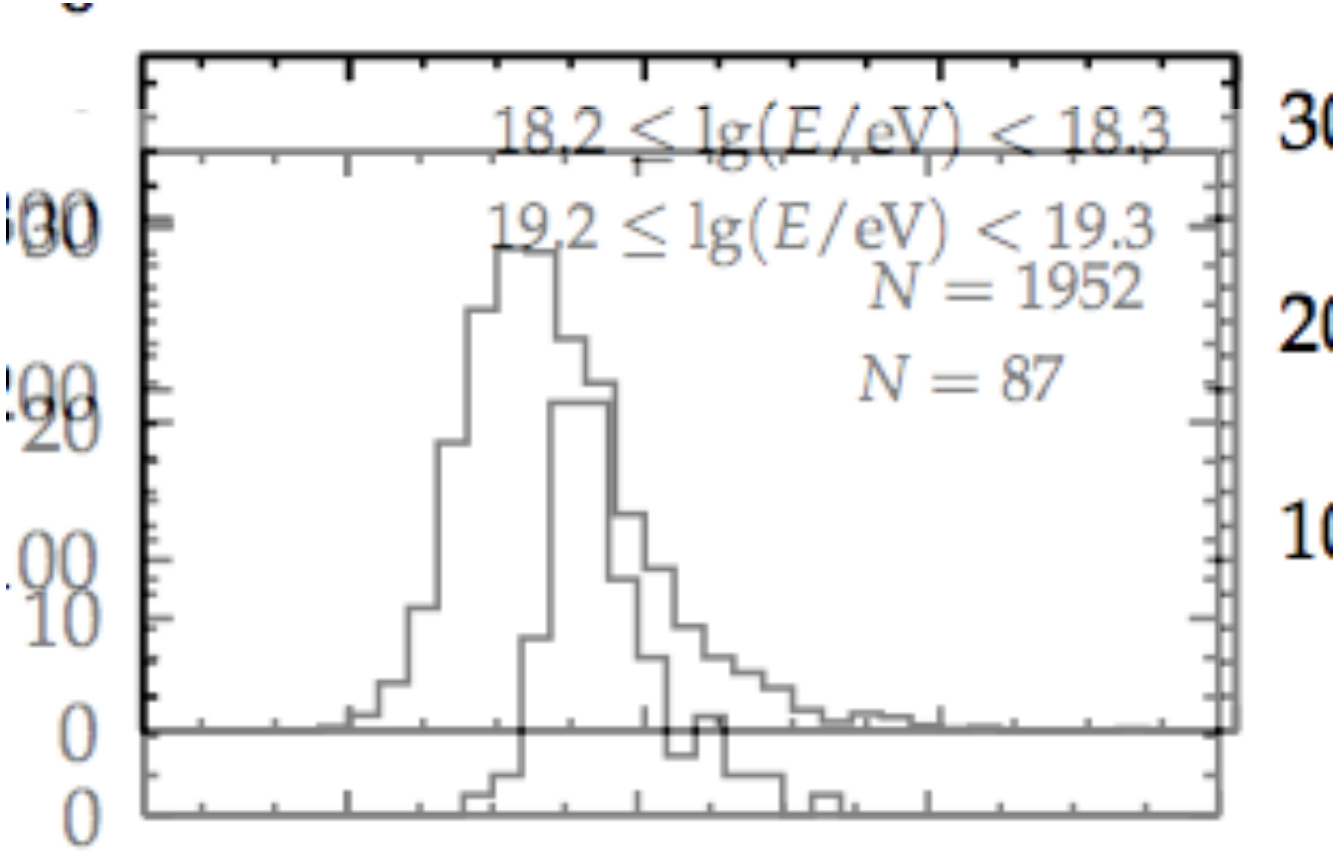
Acceptance/Reconstruction/cuts effect at 18.4



Compare TA hybrid and PAO at 18.4

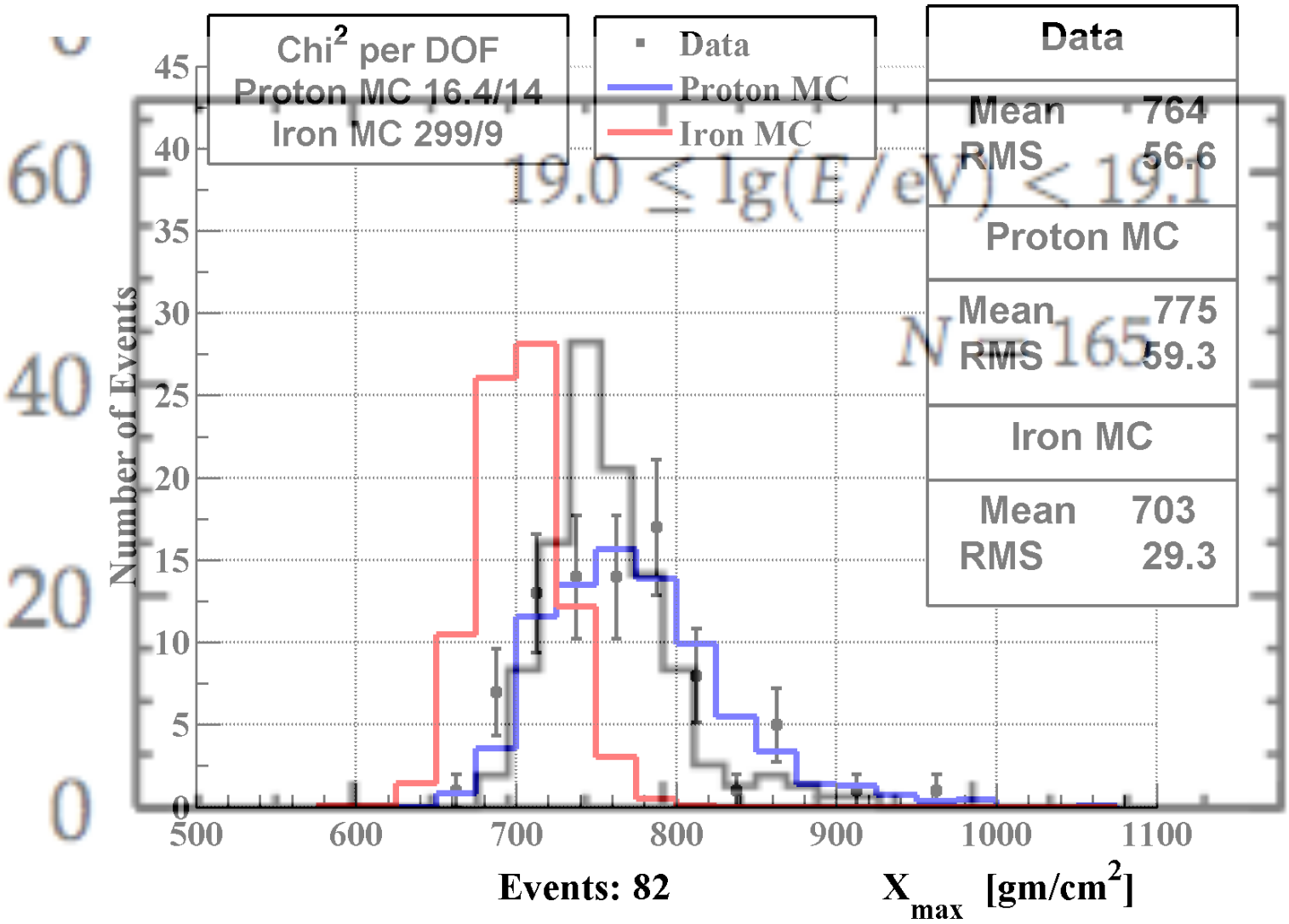
- PAO is unbiased: result >~80% protons
- TA biased: Xmax agrees with biased proton predictions
- Both TA data and biased proton agree very well with PAO unbiased distribution.
- Expect bias in mean to be ~ 15 gm/cm2 for QGSJetII-03 protons.
- Actual effect is entirely due to small changes in tail! **Bulk of data is not biased**
- We may say that this implies the net systematic difference in Xmax determination between PAO and TA hybrid is < 10 gm/cm2 (from rise of distributions)
- Biases essentially disappear if composition is heavier

PAO Xmax distributions very different low vs high energy



Note tails are more pronounced at 19.2 (30% vs 15% of data)

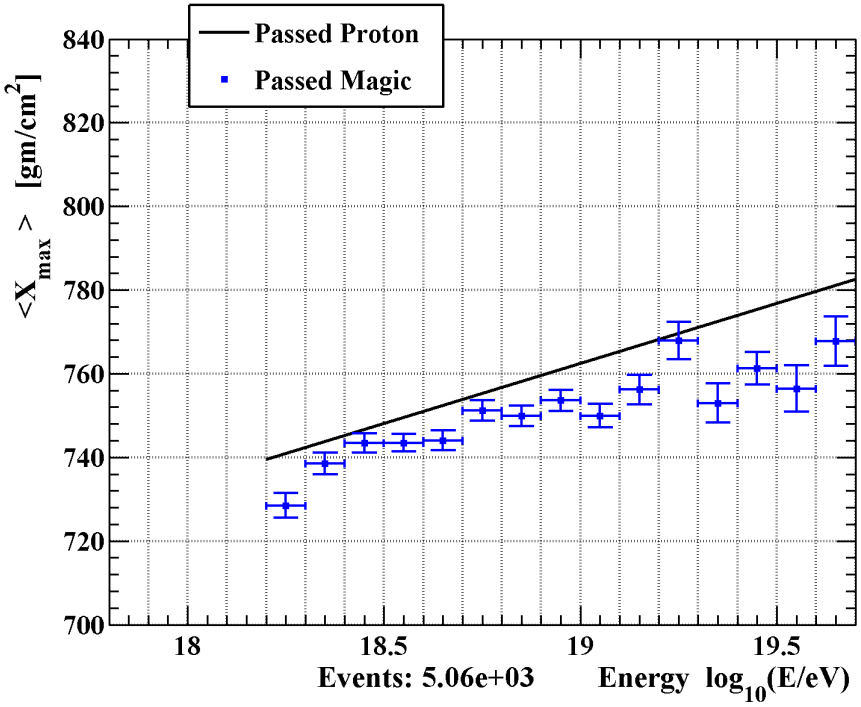
19.0 and greater

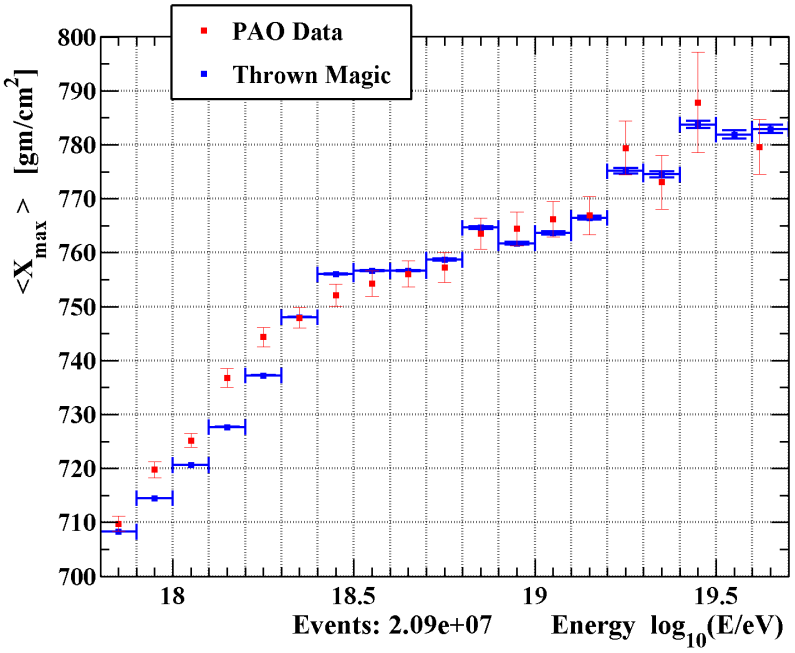


Carrying PAO data to TA

- Suitcase: MC mix which largely reproduces PAO data
- Input mix into TA detector MC
- Predict what TA should see
- Can be done for hybrid and stereo
- Current realization used QGSJetII-03: essentially proton and He above 10^19 eV

PAO Magic mix vs protons in MD hybrid

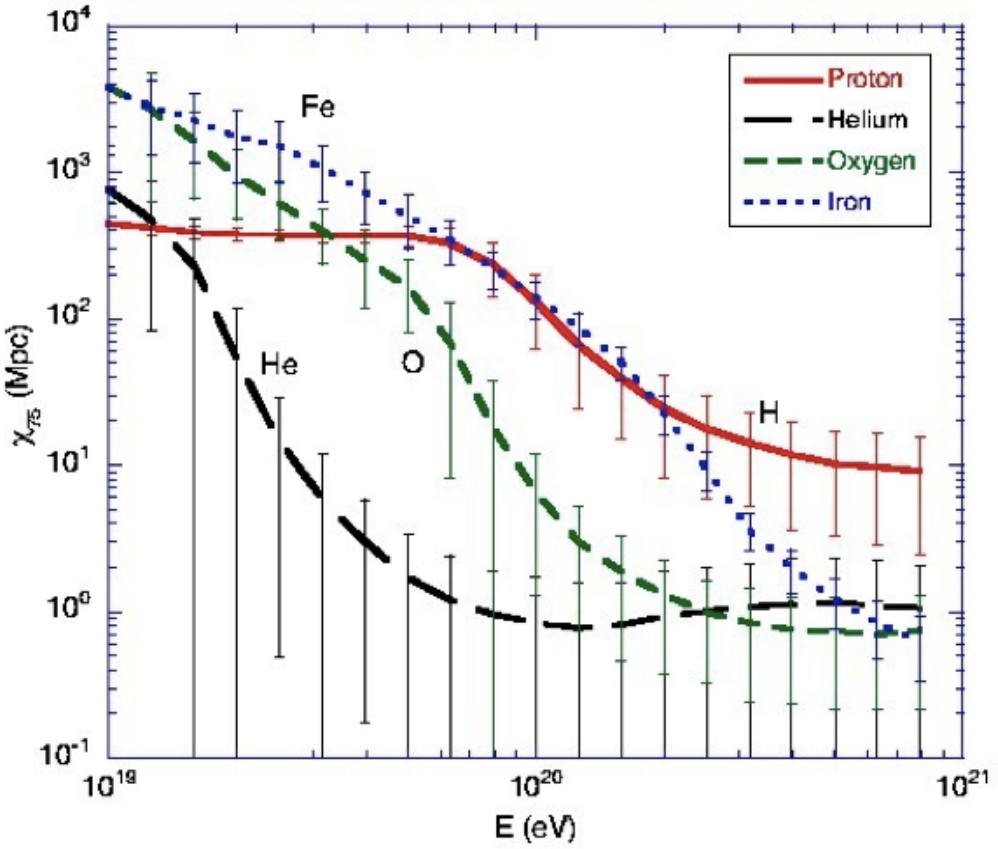




Can we really distinguish p vs He?

- Old days: try to distinguish edges of nucleosynthesis (p/Fe) ~ 80 gm/cm2 separation. Can be done. But its not Fe
- Now:" Prelium" vs CNO? p vs He ~ 20 gm/cm2
- But astrophysicaly protons and He very different:
- Can "prelium" be protons with somewhat different hadronic interactions? G. Farrar

Interaction lengths of p,He,O and Fe



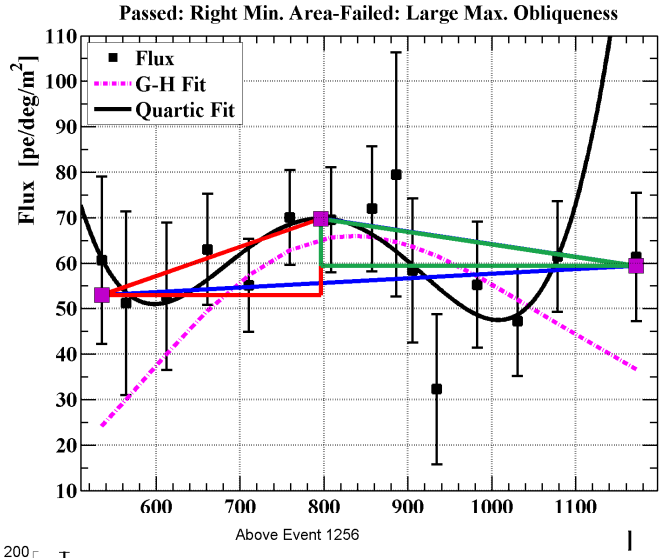
Biases caused by acceptance and cuts

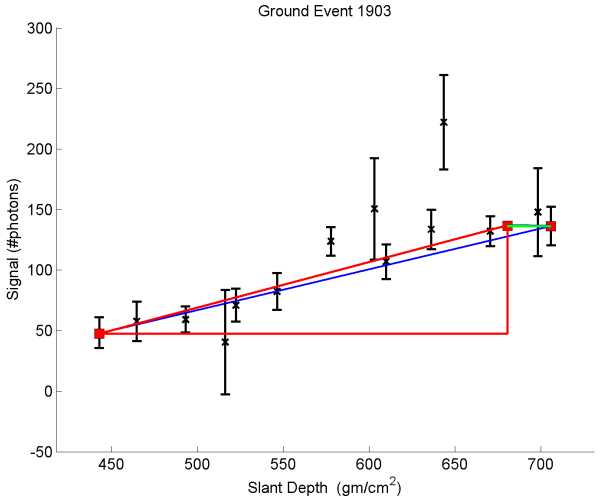
- Do we understand what we are throwing away?
- Composition hypothesis must explain good and bad events.
- Particularly important with protons because they have large deep Xmax tails. Cutting out such tails can mislead us about composition.

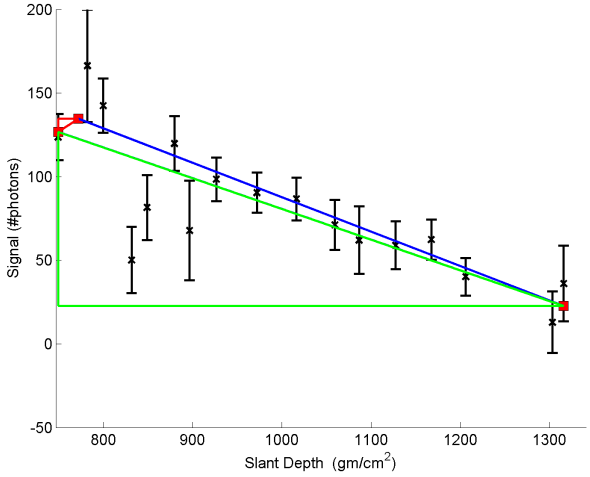
TA hybrid events that are cut out

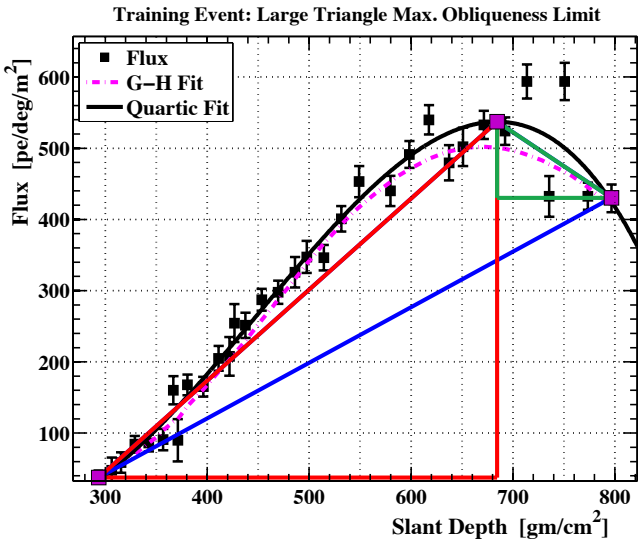
- Xmax above FOV
- Xmax below FOV
- “Flat” events whose Xmax is poorly resolved

What do the bad events looks like?

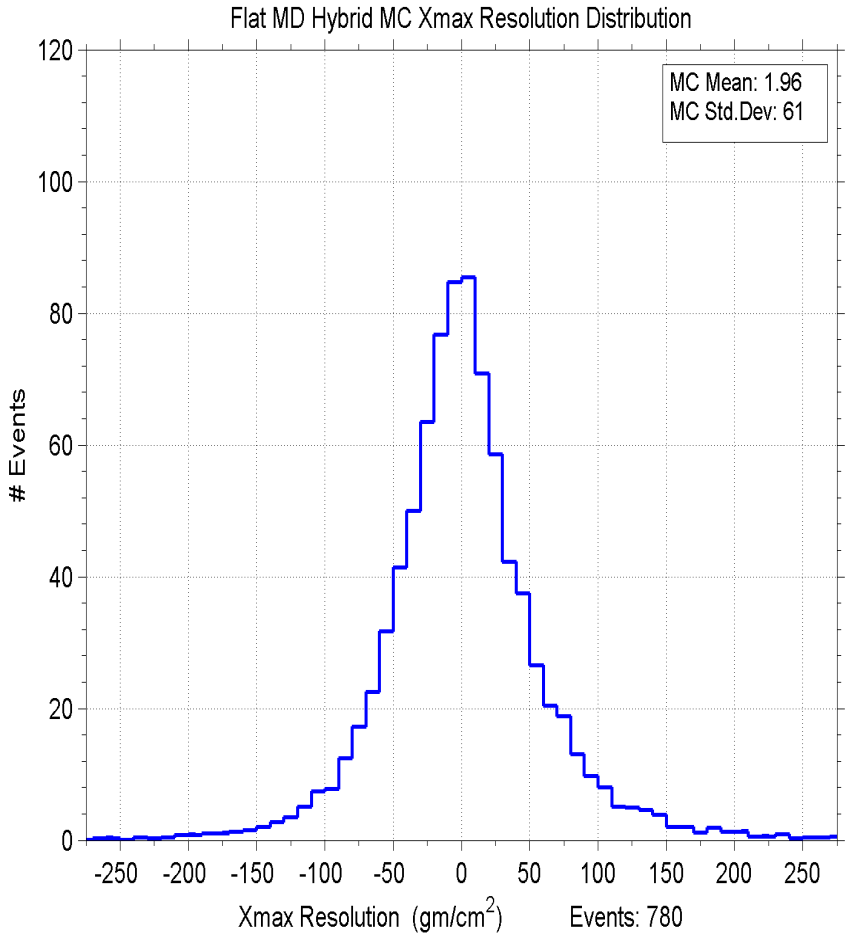




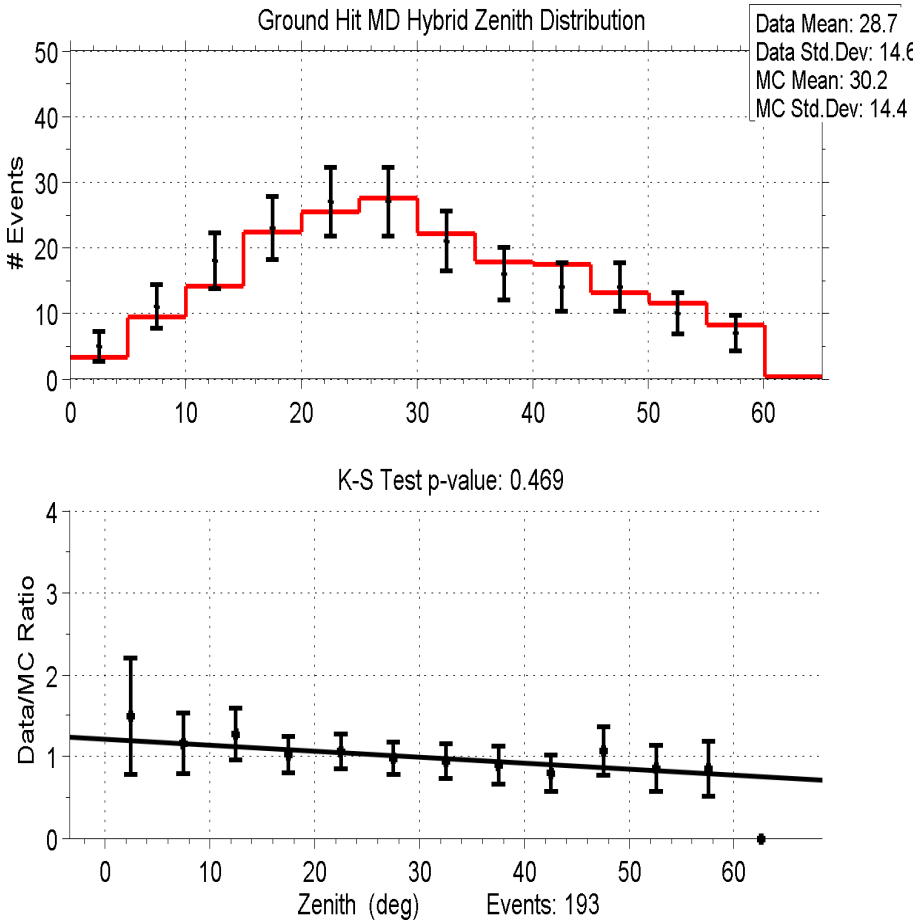


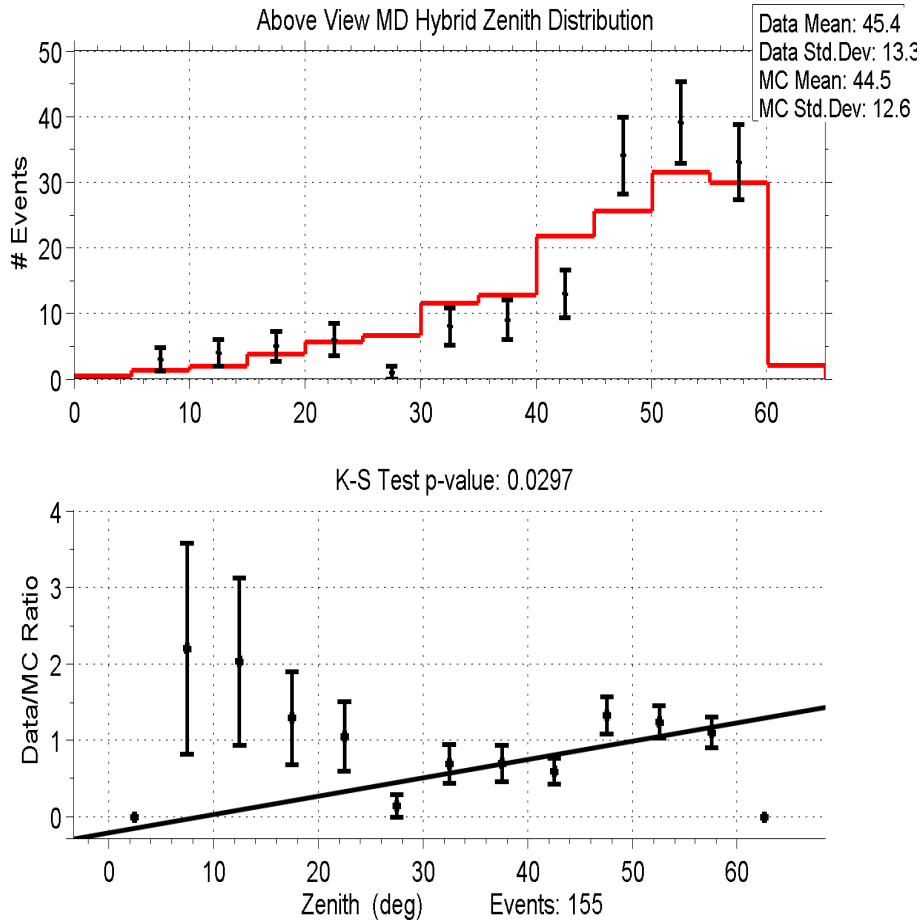


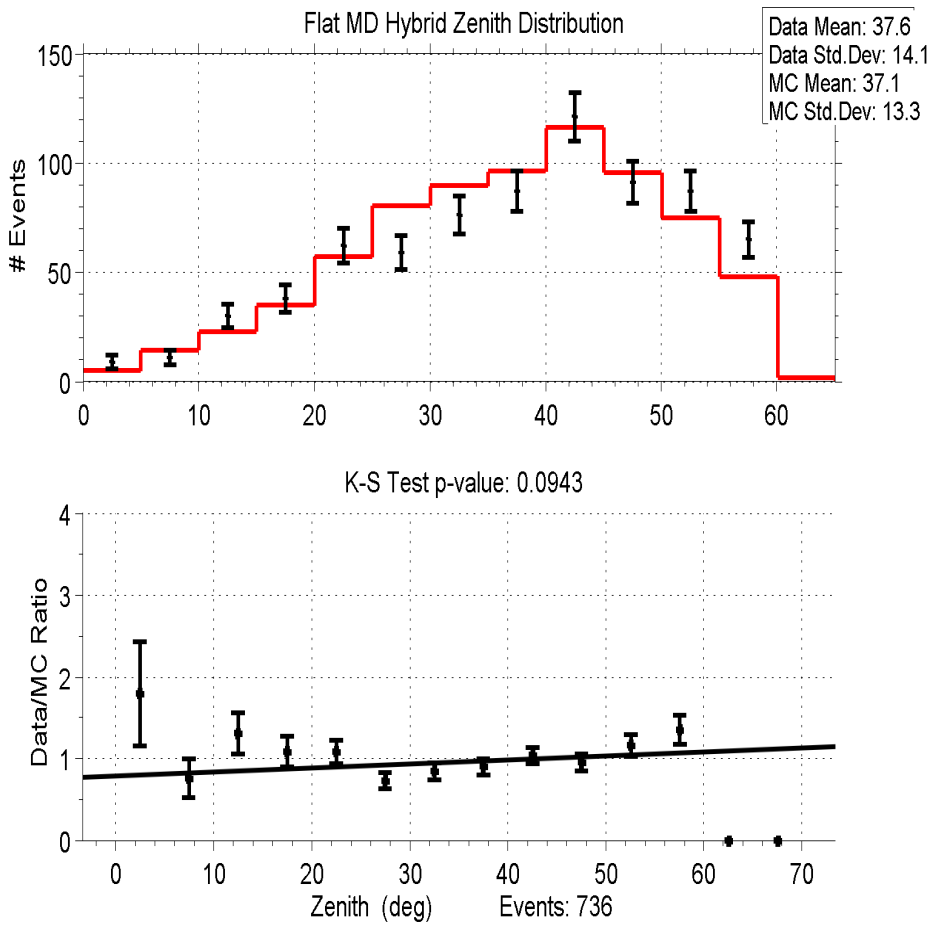
These “bad” events can still be fit with G-H. MC shows that the resolution In Xmax is much worse that “good” events

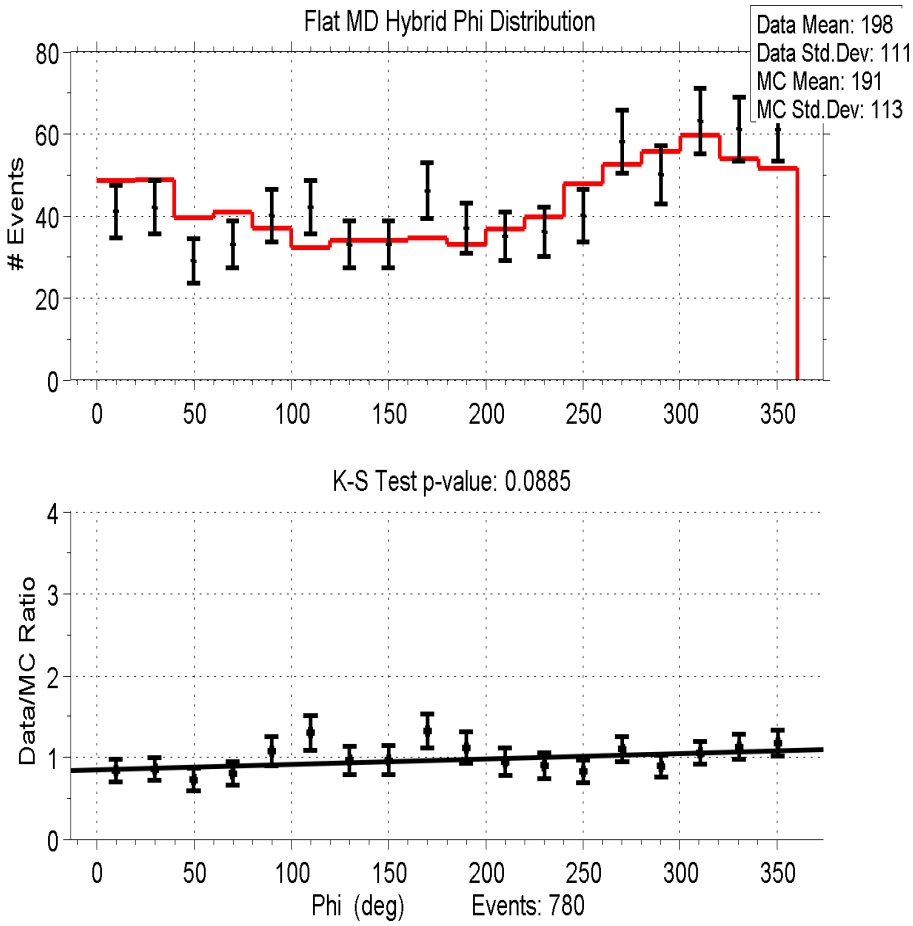


Zenith Distributions

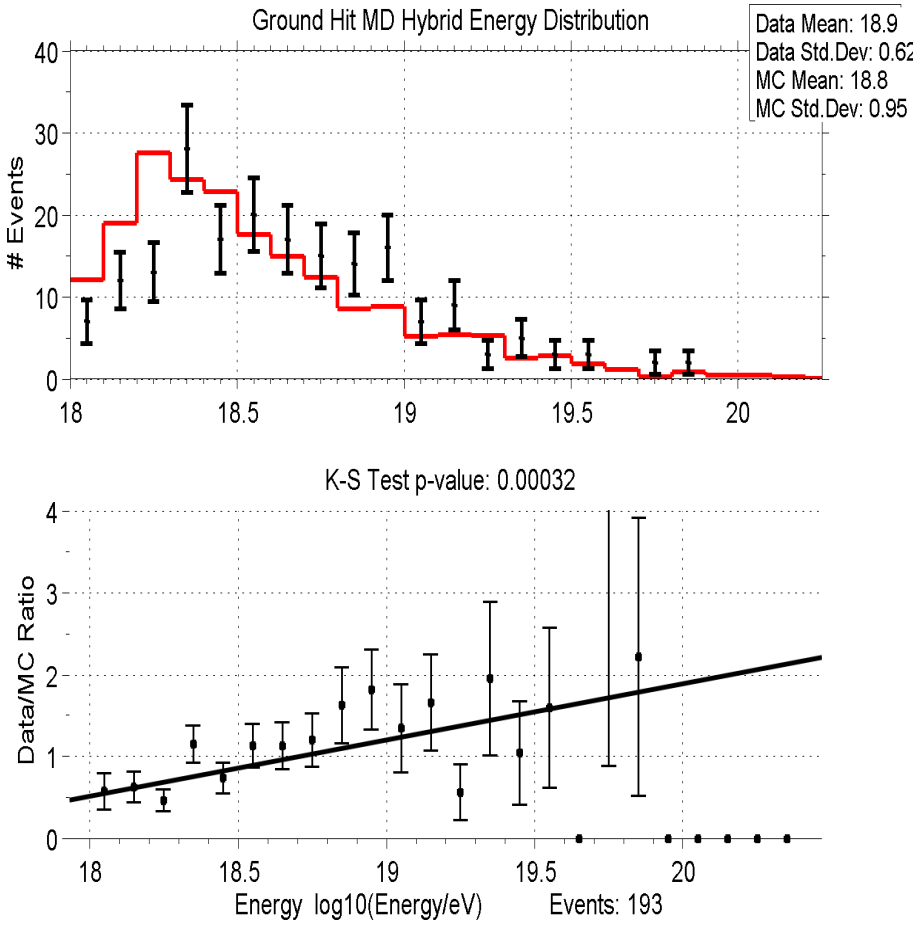


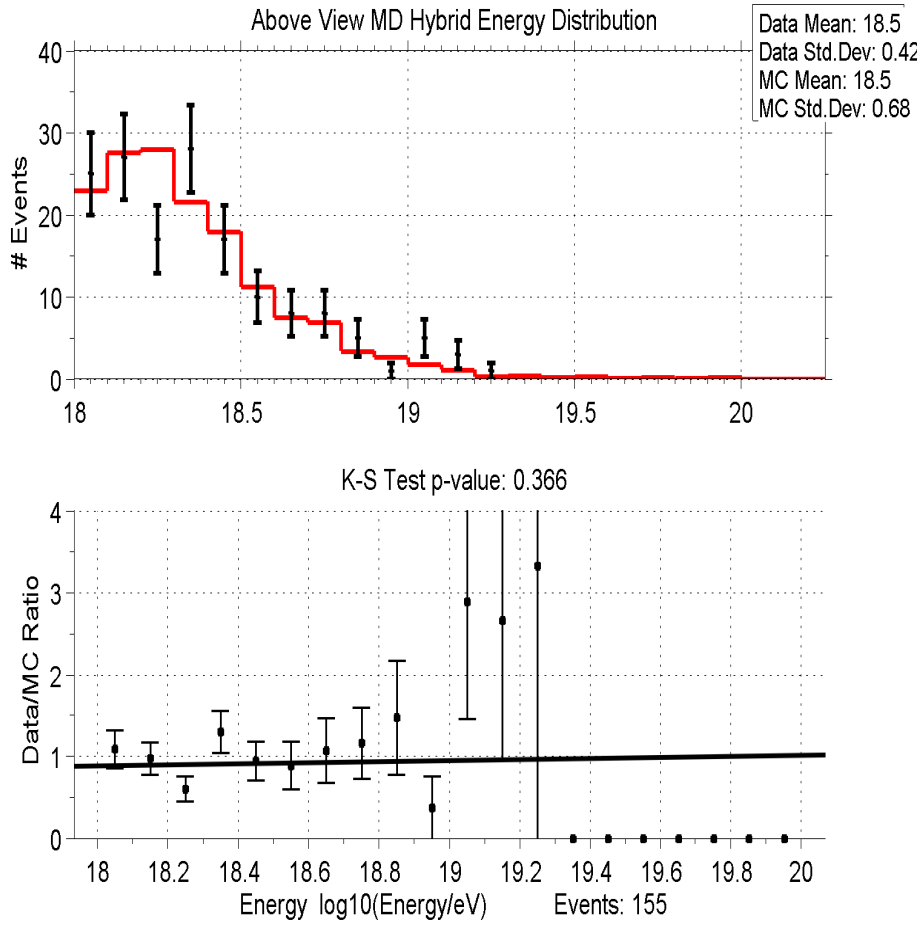


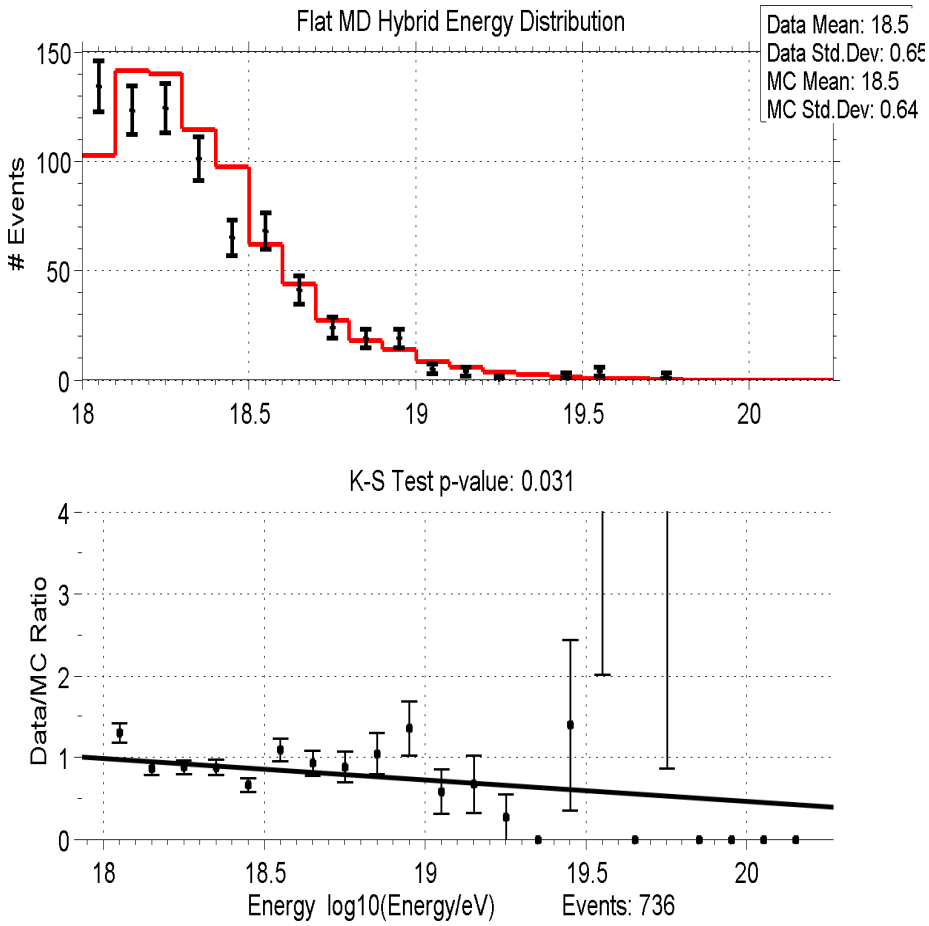

Flat MD Hybrid Zenith Distribution
Data Mean: 37.6
Data Std.Dev: 14.1
MC Mean: 37.1
MC Std.Dev: 13.3
Events
150
100
50
0
0
10
20
30
40
50
60
K-S Test p-value: 0.0943
Data/MC Ratio
4
3
2
1
0
0
10
20
30
40
50
60
70
Zenith (deg)
Events: 736


Flat MD Hybrid Phi Distribution
Data Mean: 198
Data Std.Dev: 111
MC Mean: 191
MC Std.Dev: 113
Events
0
20
40
60
80
0
50
100
150
200
250
300
350
K-S Test p-value: 0.0885
Data/MC Ratio
0
1
2
3
4
Phi (deg)
Events: 780

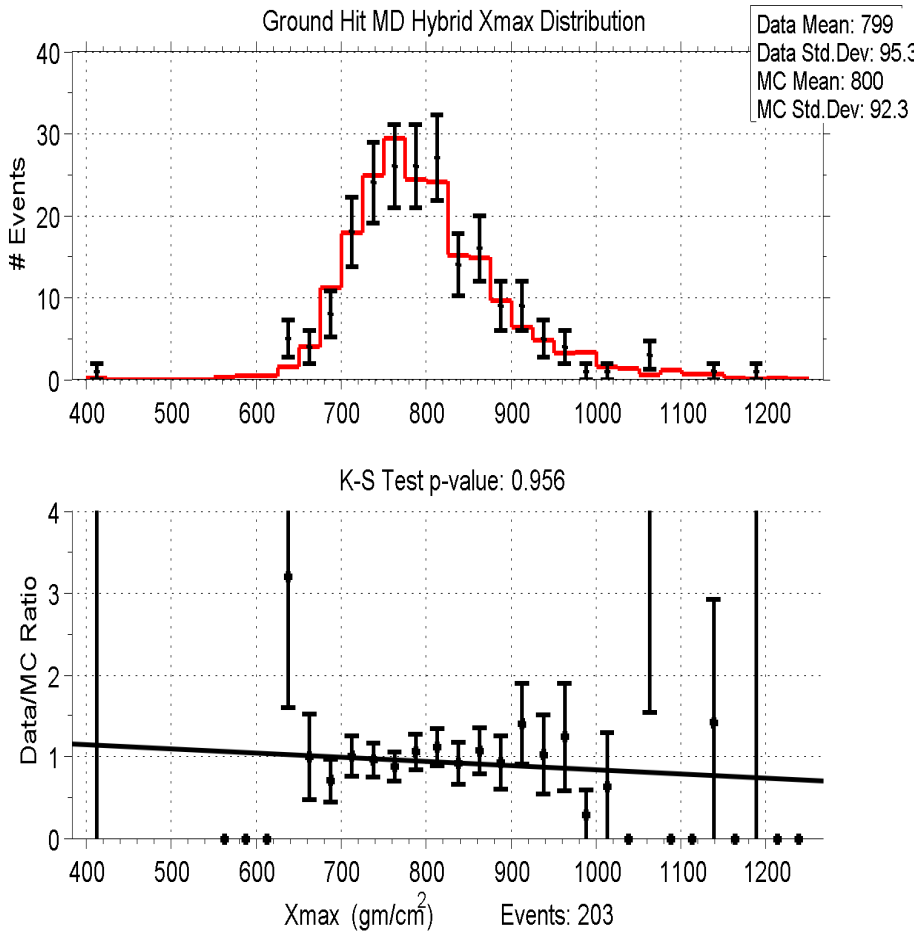
Energy Distributions

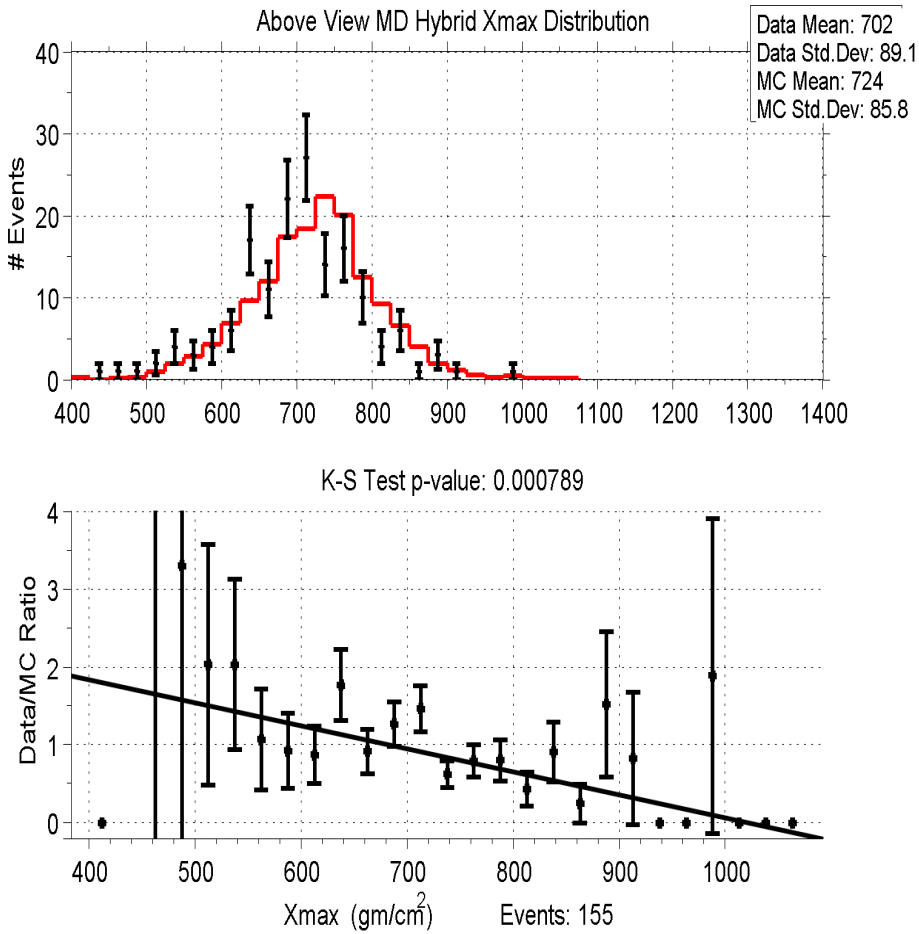


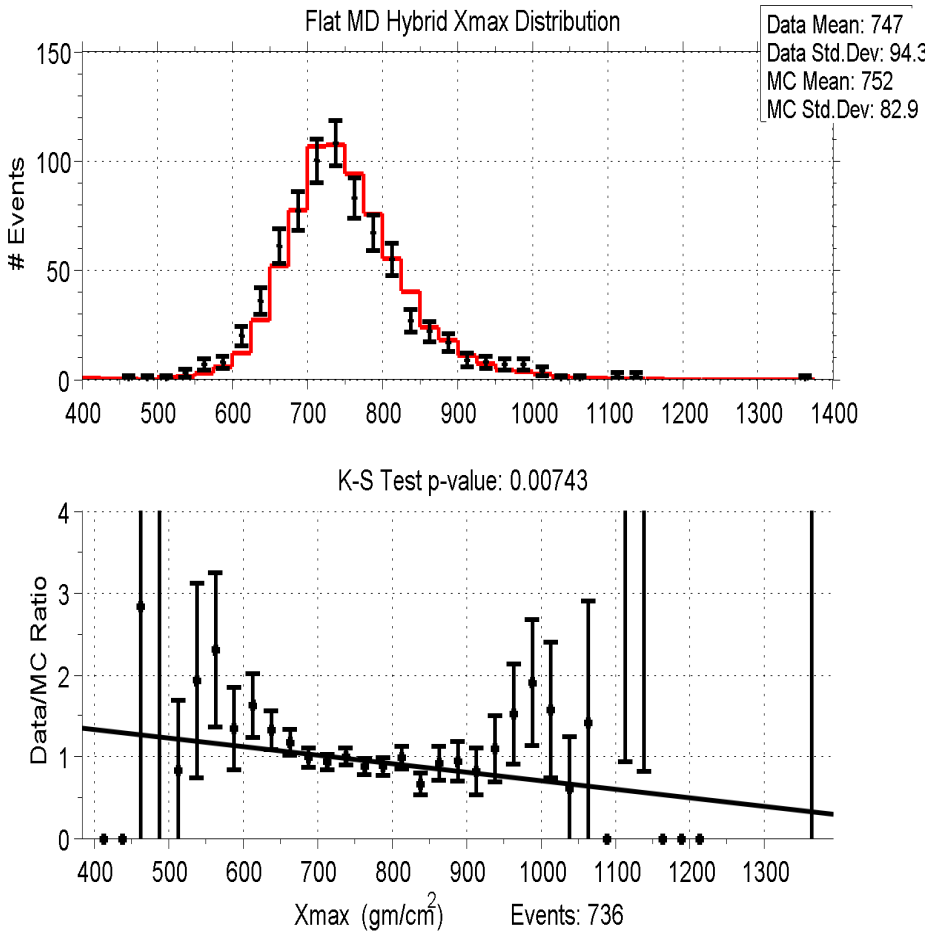



Flat MD Hybrid Energy Distribution
Data Mean: 18.5
Data Std.Dev: 0.65
MC Mean: 18.5
MC Std.Dev: 0.64
Events
150
100
50
0
18
18.5
19
19.5
20
K-S Test p-value: 0.031
Data/MC Ratio
4
3
2
1
0
18
18.5
19
19.5
20
Energy log10(Energy/eV)
Events: 736

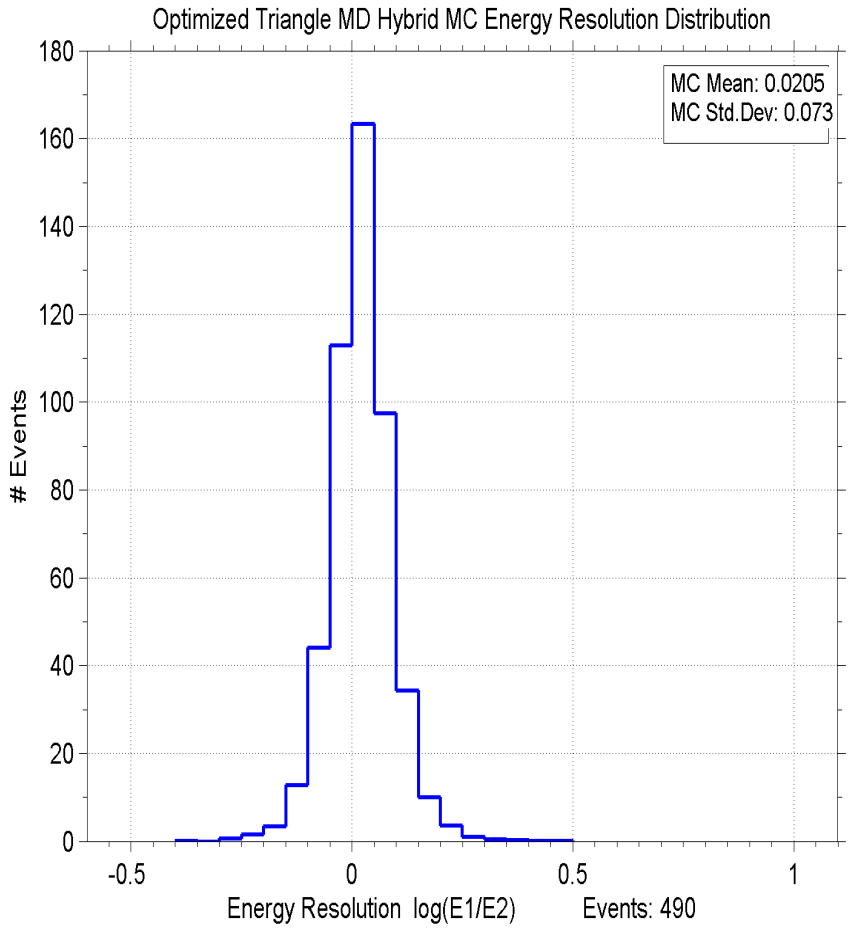
Xmax Distributions

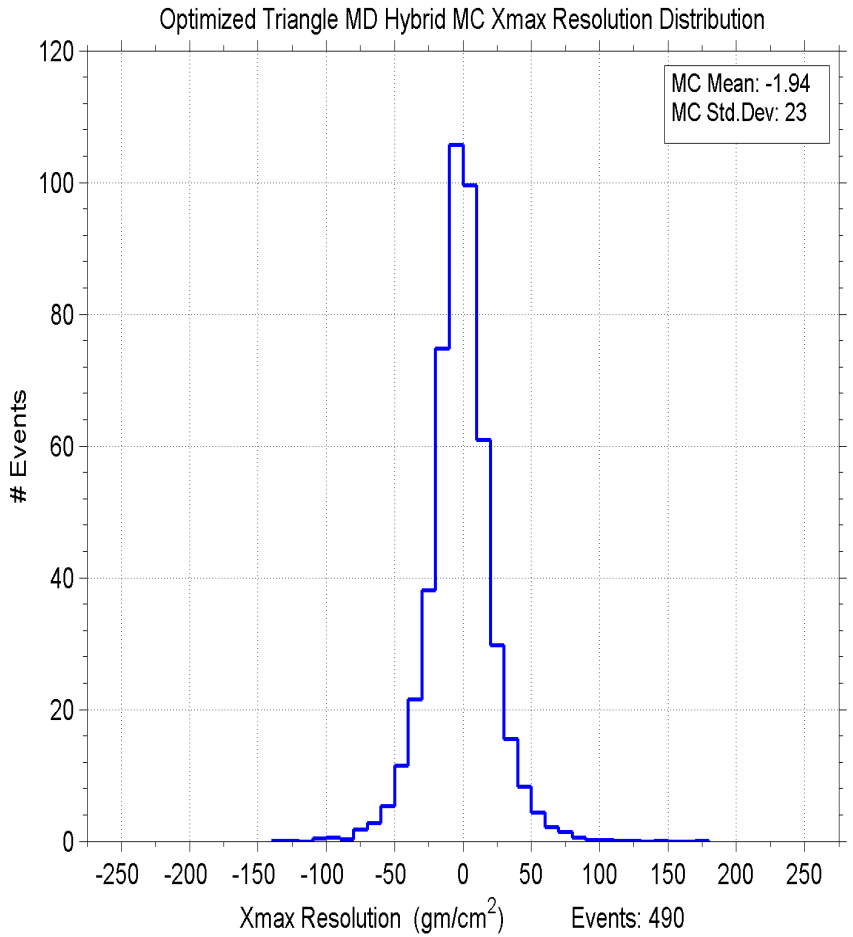




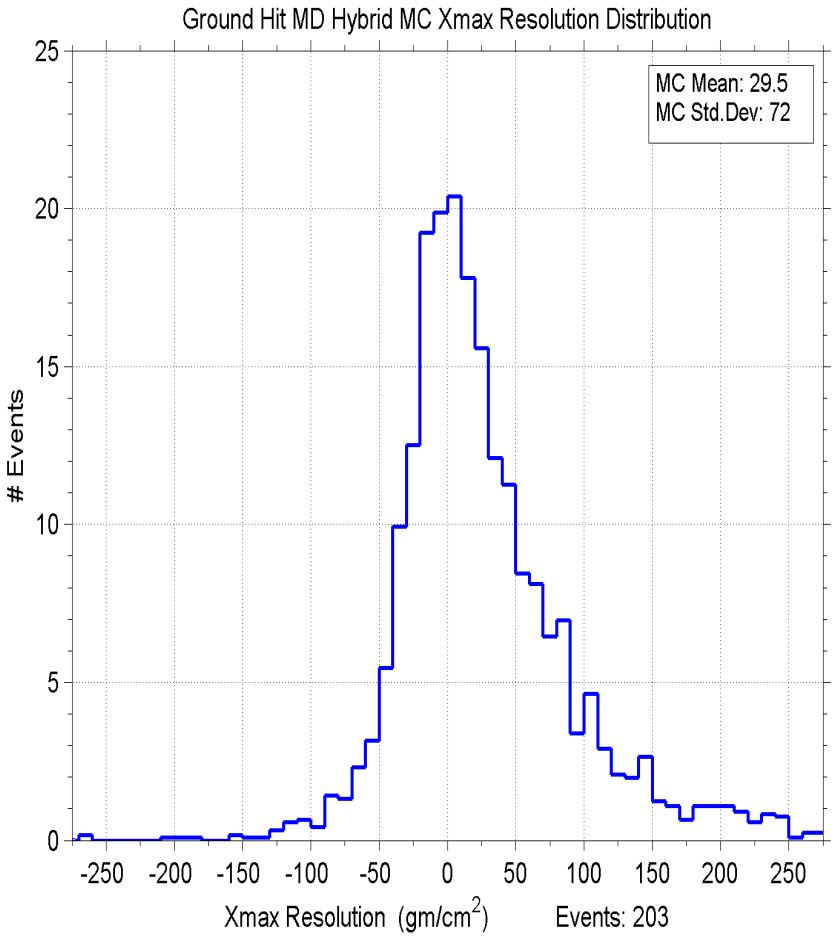

Flat MD Hybrid Xmax Distribution
Data Mean: 747
Data Std.Dev: 94.3
MC Mean: 752
MC Std.Dev: 82.9
Events
150
100
50
0
400
500
600
700
800
900
1000
1100
1200
1300
1400
K-S Test p-value: 0.00743
Data/MC Ratio
4
3
2
1
0
400
500
600
700
800
900
1000
1100
1200
1300
Xmax (gm/cm2)
Events: 736

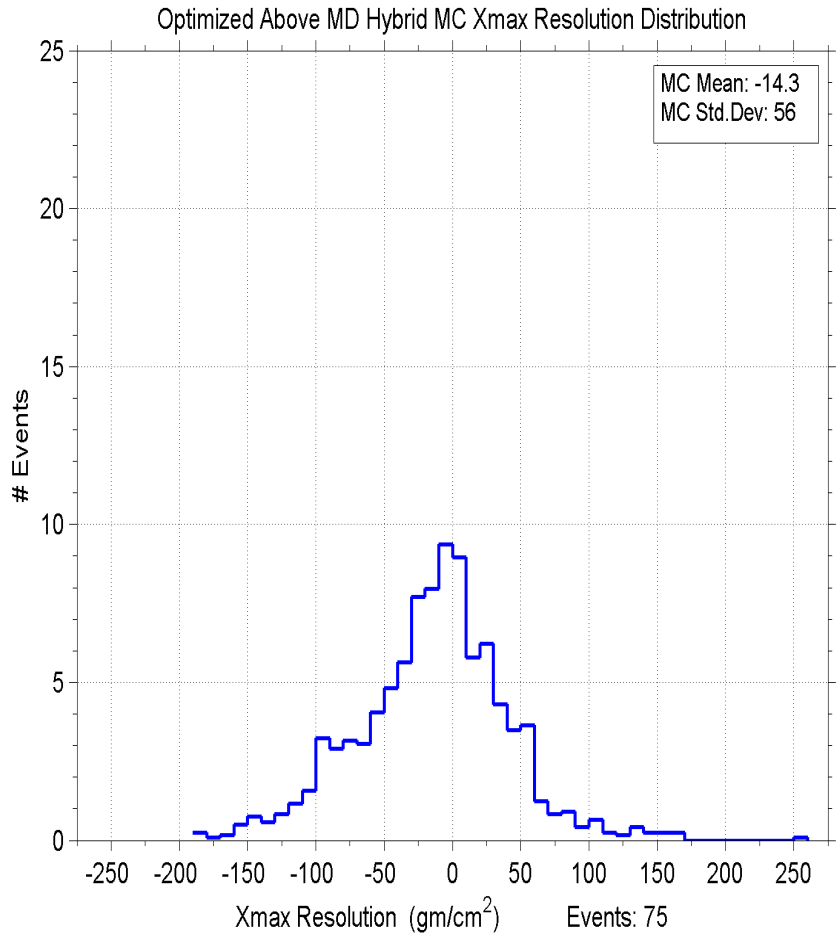
Clear Xmax Event Resolutions



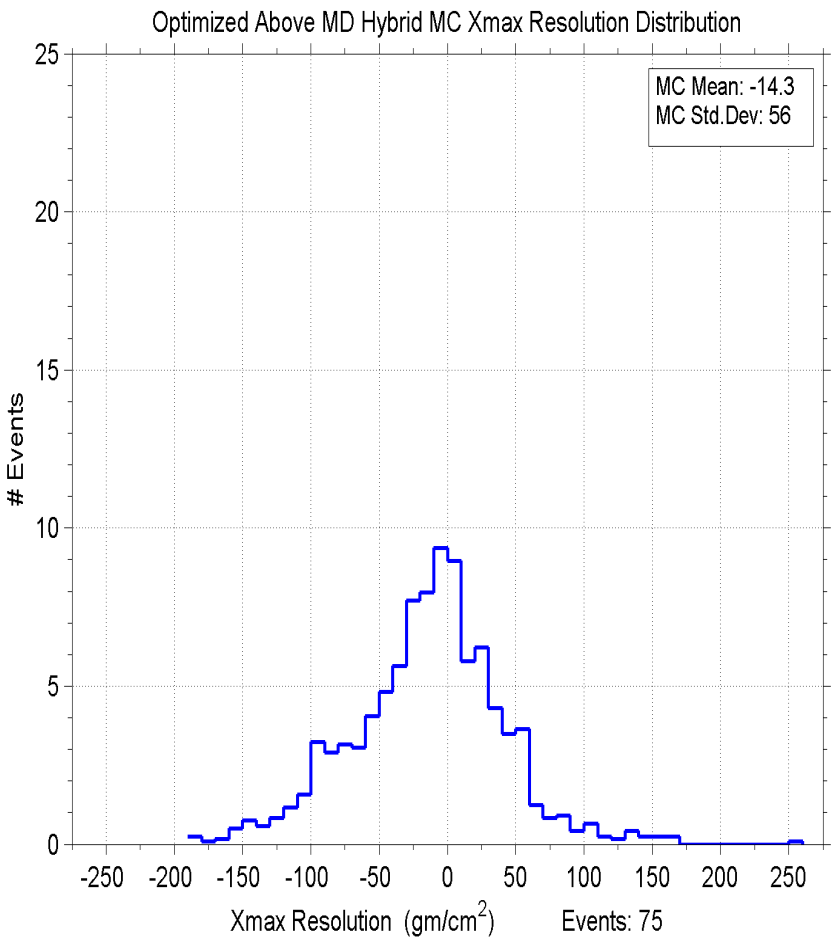


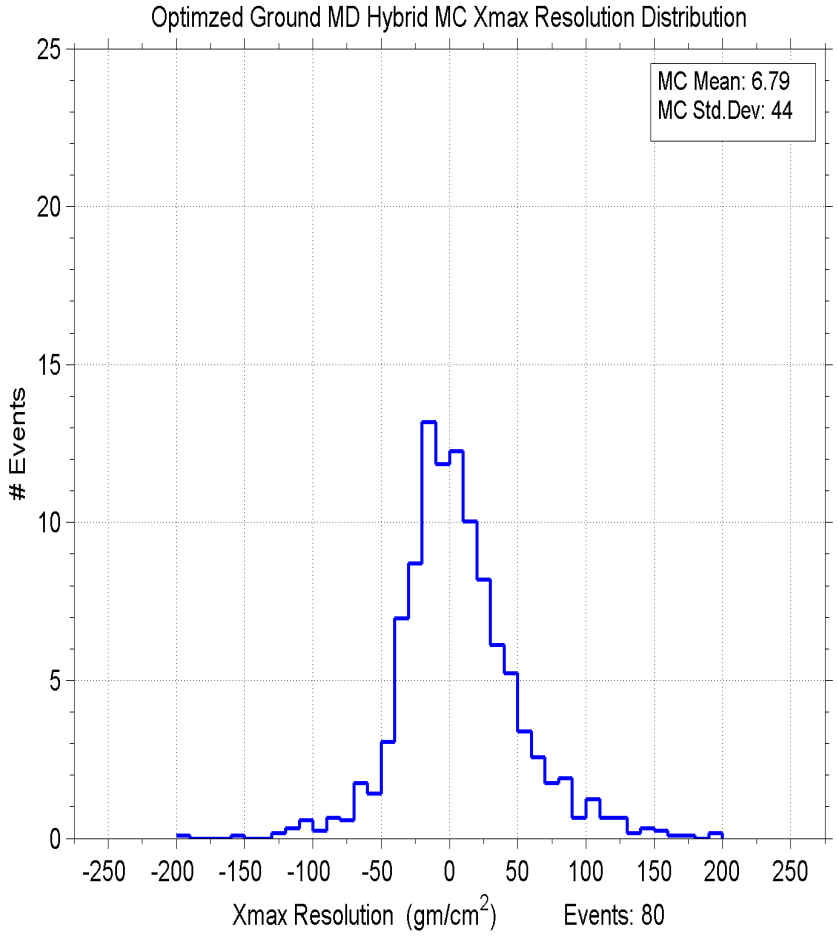
Xmax Resolutions





After Geometry Cut



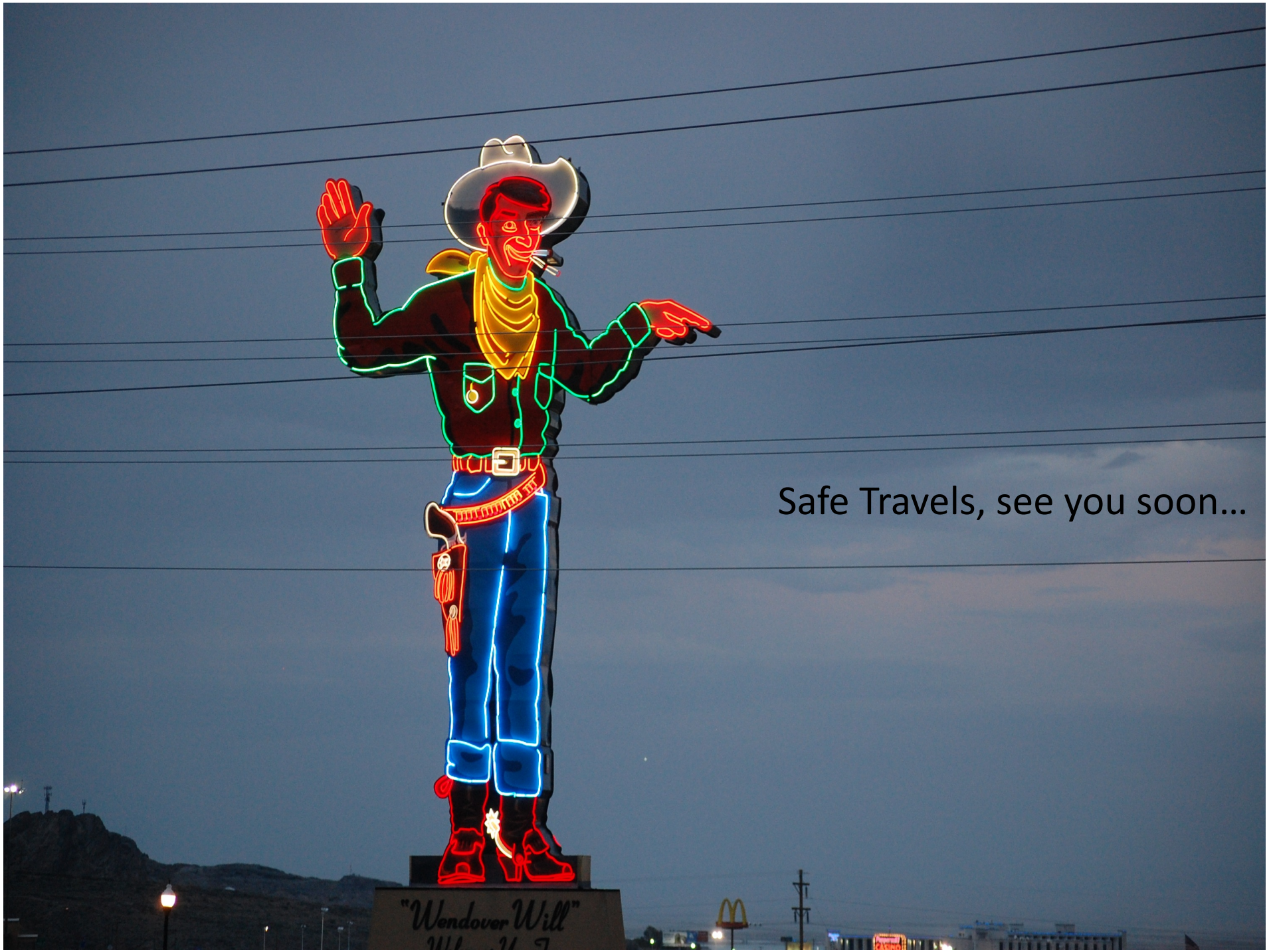


Bad events can be accurately modeled by proton QGSJetII-03

- What does it mean?
- Is there sensitivity to models and/or composition?
- In particular, do deep events (ground hitting) carry information?
- Constrain energy from SD and refit GH with one parameter- improved Xmax resolution?

Can we increase our acceptance for deep events?

- Use pure fluorescence – mono or stereo – use large zenith angle events. Increase available slant depth
- Include events that hit the ground. Constrain GH by SD energy. Is the rate consistent with model expectations?
- Go to lower altitudes – Death Valley 768 mmHg (760 mmHg sea-level) 1036 gm/cm2
- ~1200 gm/cm2 at 30 degree zenith angle.



Safe Travels, see you soon…