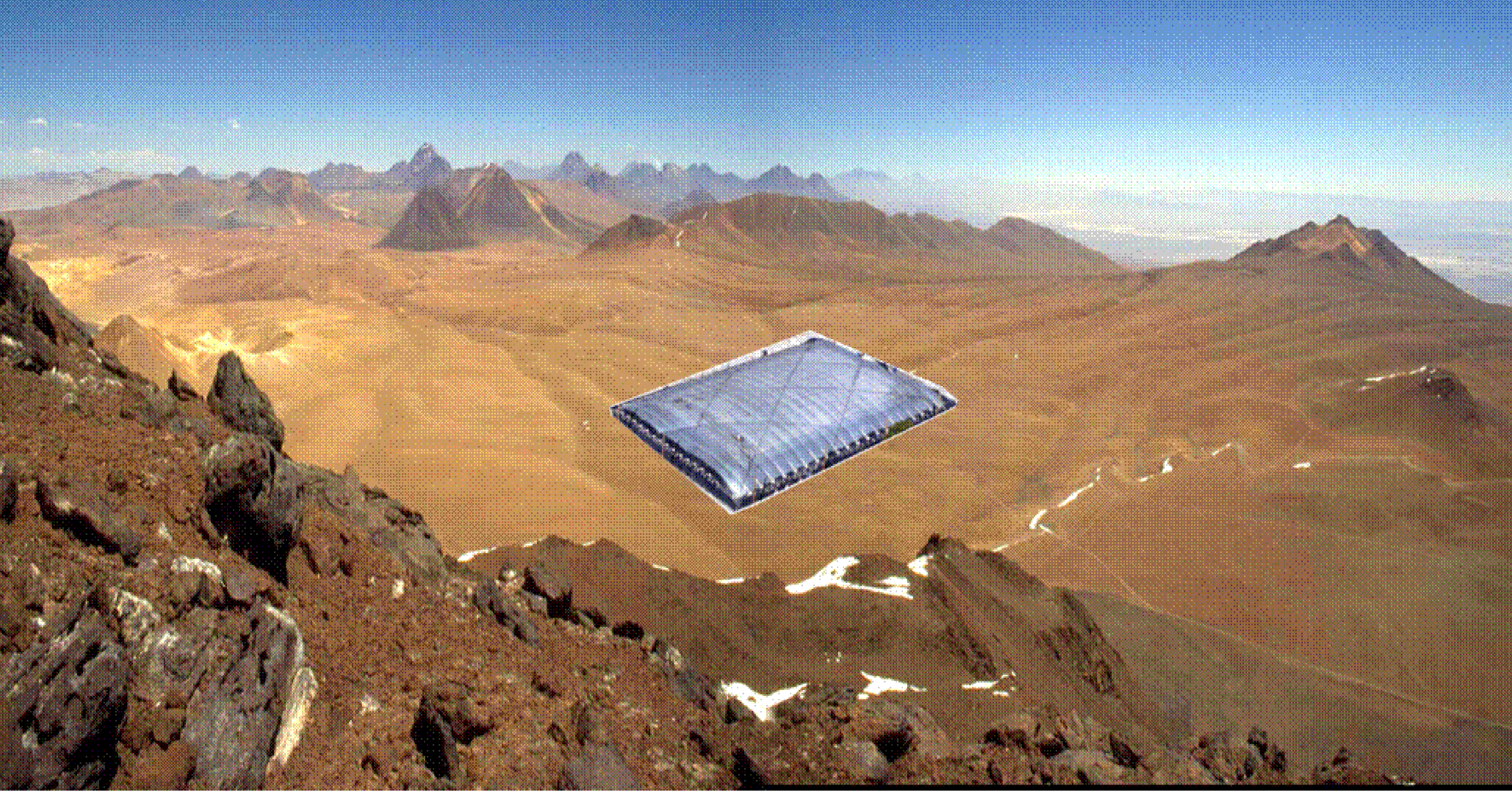
The Next Generation All-Sky VHE Gamma-Ray Telescope



Physics Goals

- Gamma-Ray Burst Studies
  - Detect GRBs > 25 GeV
  - Detect GRBs to z~1
  - Quantum Gravity Probe
- AGN Studies
  - Monitor all AGN in fov
  - Detect AGN to z > 0.3
  - Sensitivity to ~15 minute flares
- Discovery
  - Time domain astronomy at VH energies
  - New sources unseen at other wavelengths

Performance Requirements

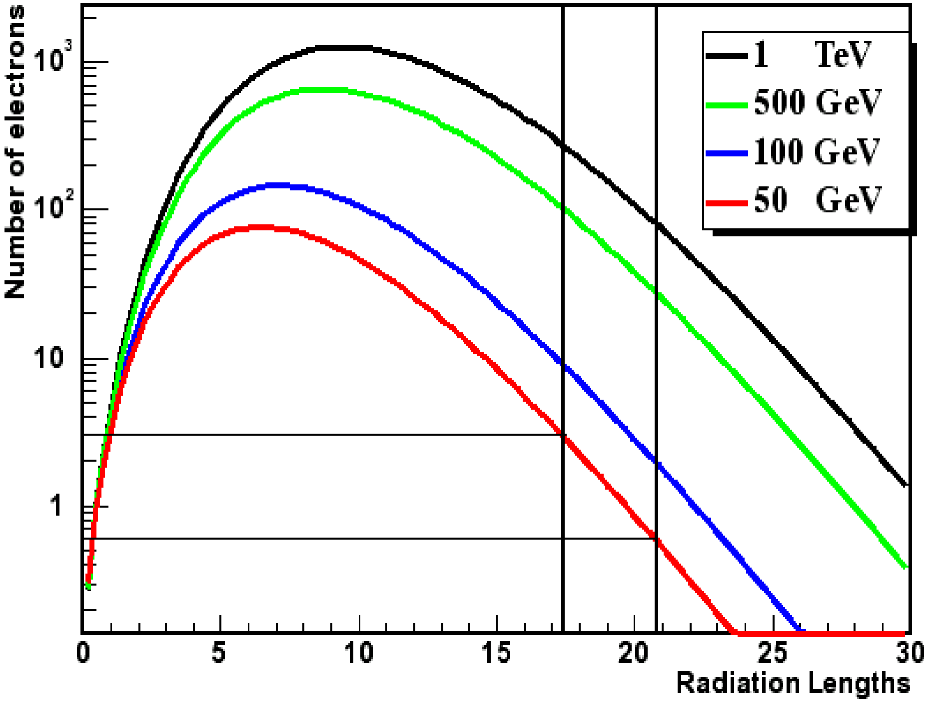
- GRBs
  - Energy threshold near ~20 GeV
    - Near known energy
    - Able to see large distances (z~1)
  - All-sky/All-time
    - Ability to see prompt emission
- AGN
  - Large area & low threshold
    - Ability to detect distant AGN (z~0.3)
    - Sensitivity to short transients
- Large field of view (~2 sr)
- ~100% duty cycle
- Crab sensitivity >5σ/sqrt(day) - >100σ/sqrt(year)

Critical Parameters

- Effective Area
- Energy Threshold
- Angular Resolution
- Energy Resolution
- Background Rejection

Air shower physics sets fundamental limitations!

Approximation B

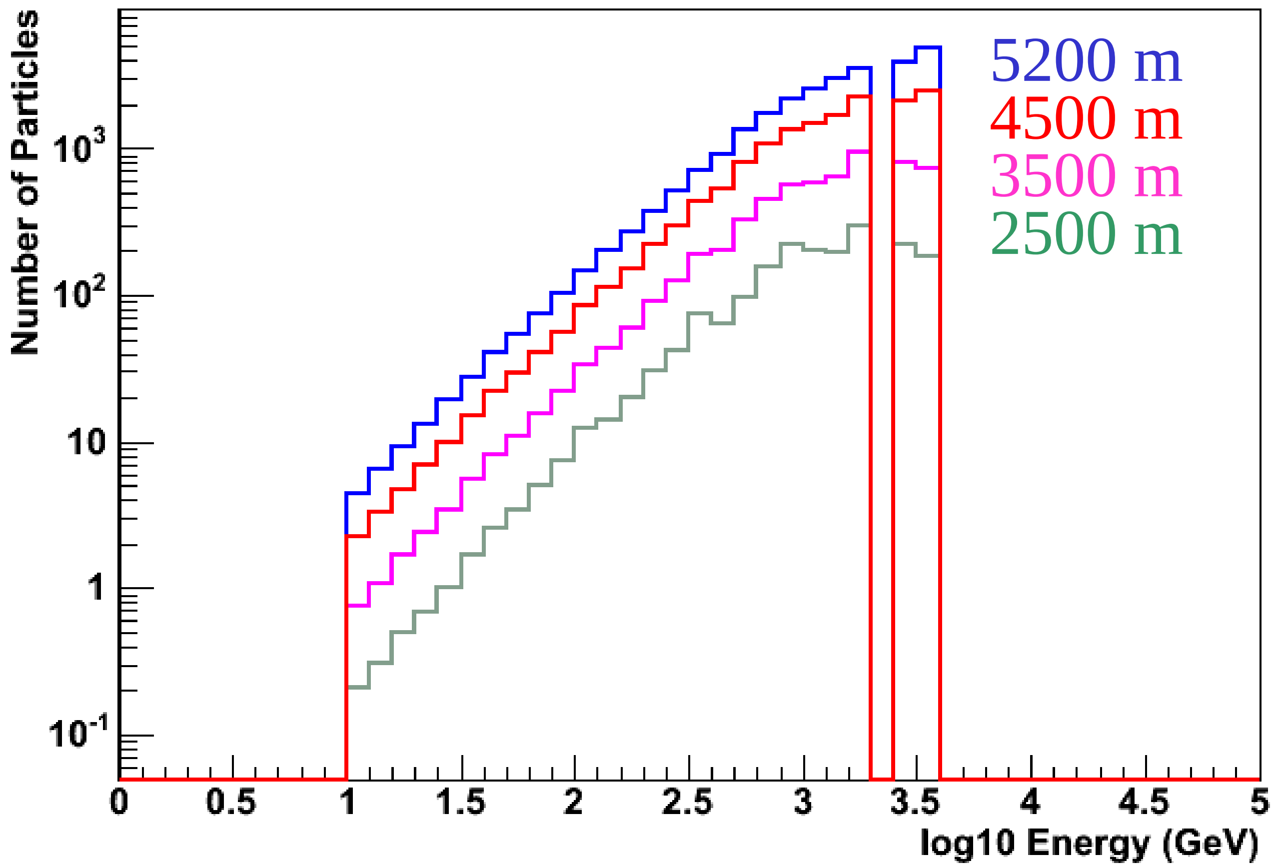


Approximation B is not enough to understand detector design parameters

- Fluctuations are critical
- Resolutions unknown
- Background rejection

Use CORSIKA

CORSIKA: Altitude Effect



5200 = 2*x*4500

4500 = 3*x*3500

3500 = 3*x*2500

$E_{particle}$>300 keV

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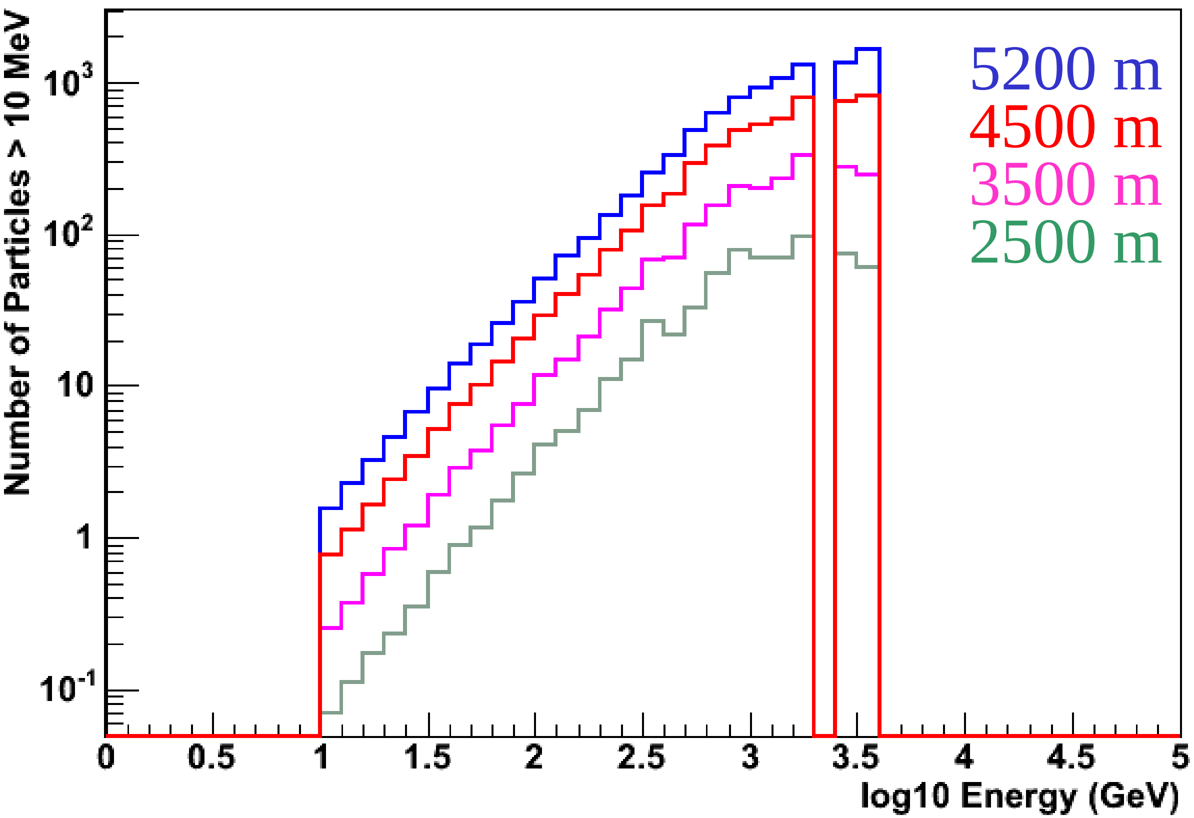
CORSIKA: Altitude Effect (cont'd)



5200 = 2*x*4500

4500 = 3*x*3500

3500 = 3*x*2500

$E_{particle}$>10 MeV

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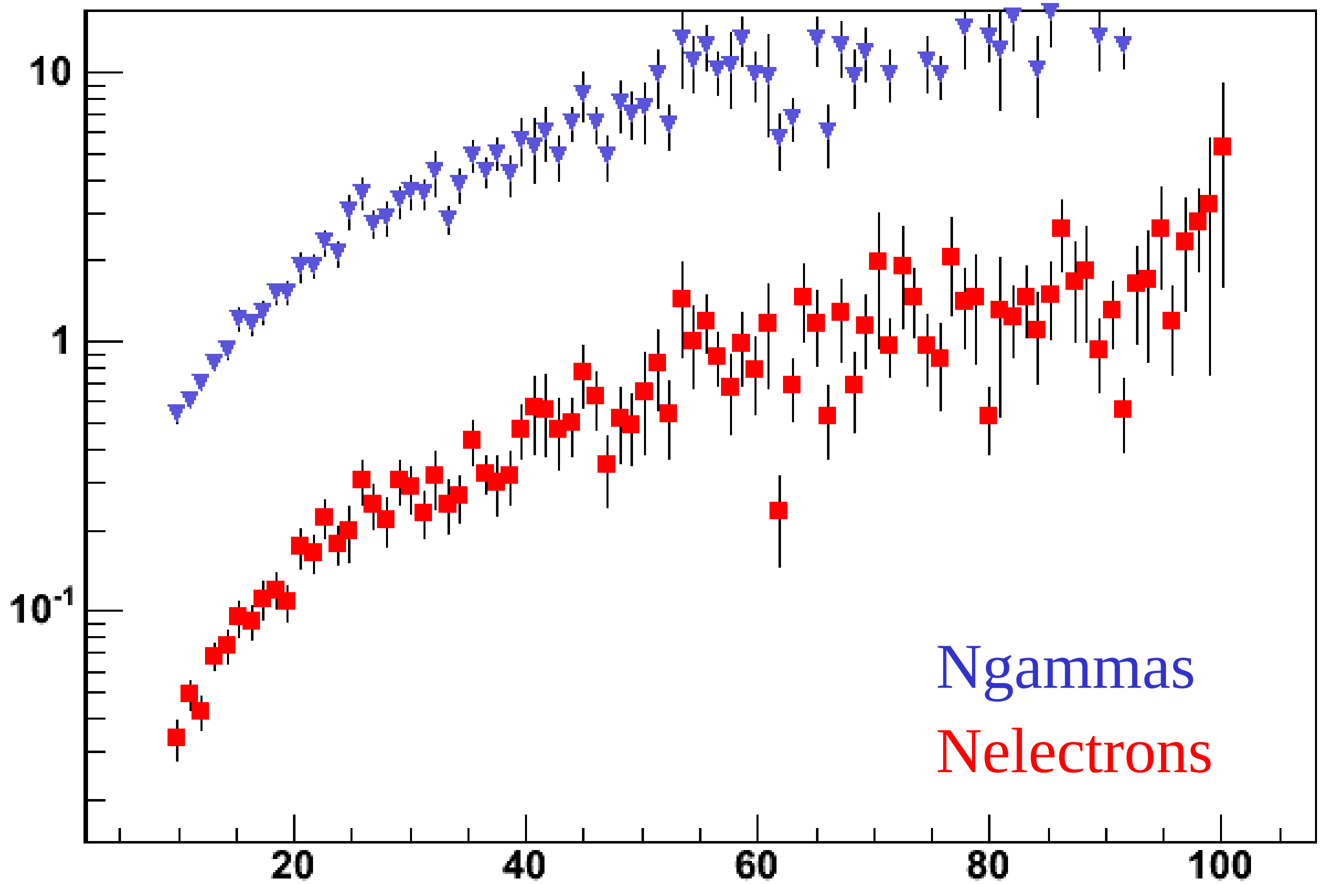
CORSIKA: Electron/Photon



Primary Energy (GeV)

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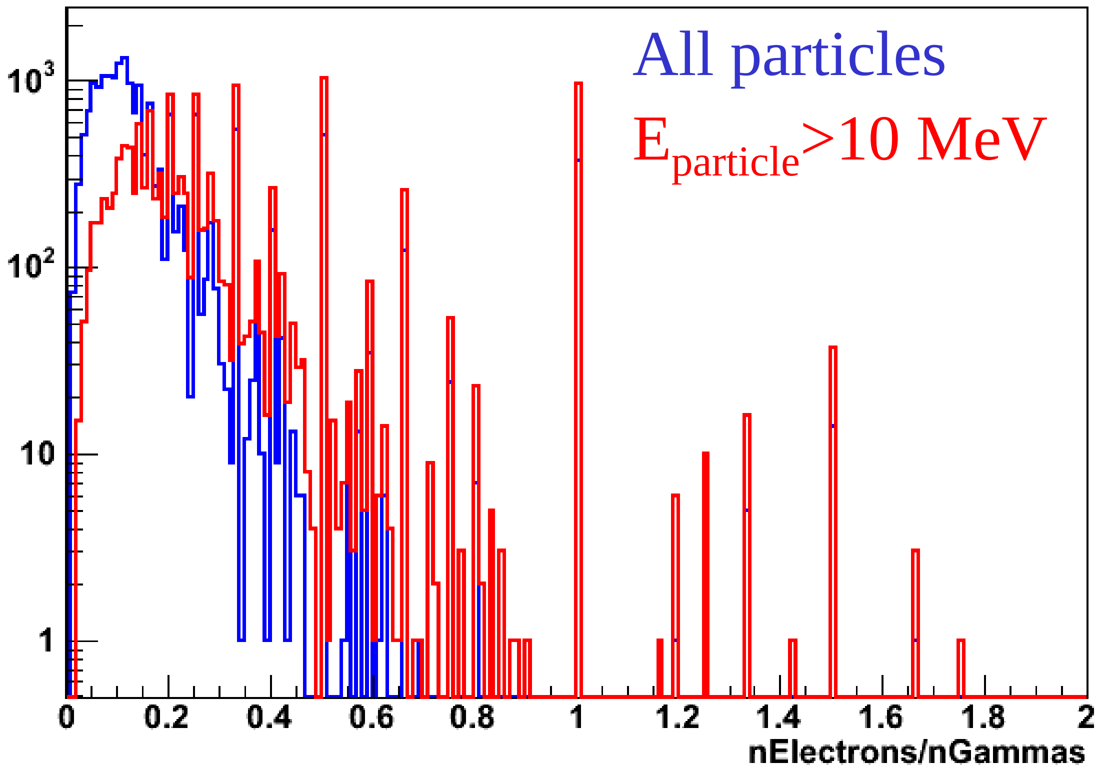
CORSIKA: Electron/Photon

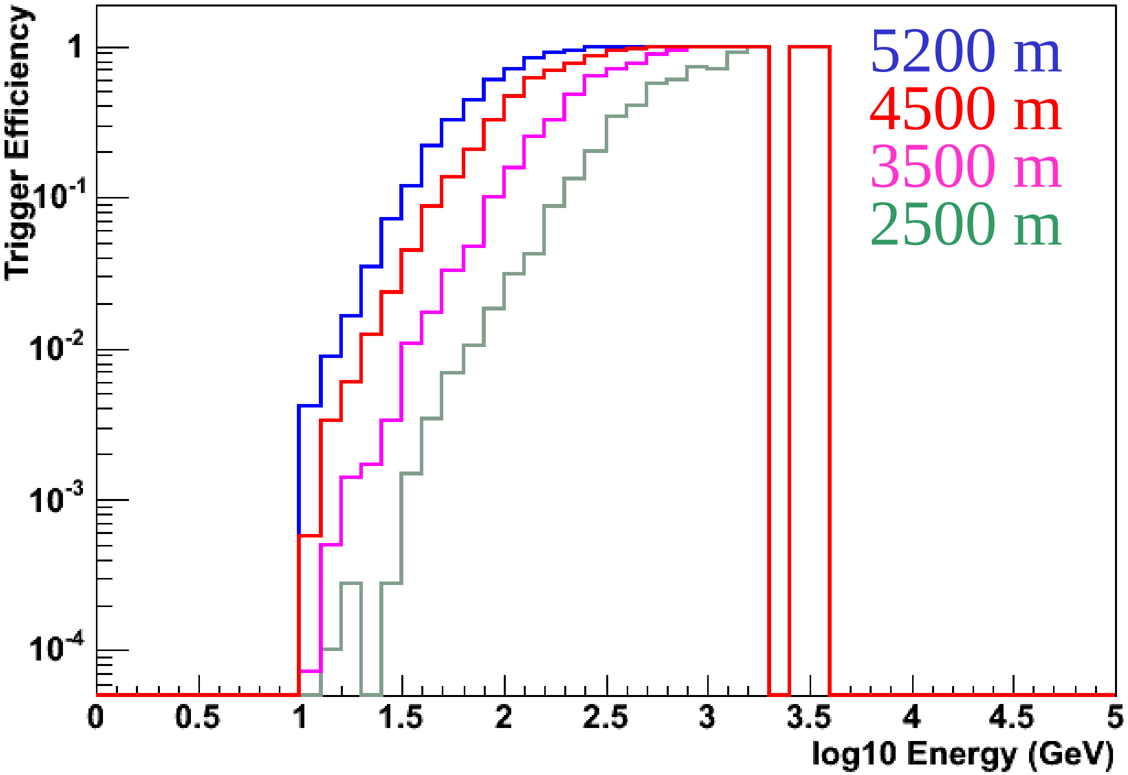


Photons 5-10*x* more plentiful.

CORSIKA: “Event Trigger”

- Assume
  - Q.E. *x* Water efficiency = 0.15
  - 260 photons/cm generated in water
  - 2 MeV/cm energy loss
  - 3.5E-3 photo-detector coverage
- Obtain
  - 15 MeV / PE
  - (Milagro proposal had 10 MeV/PE)
- Trigger
  - $E_{particle}$>770 keV (Cherenkov Threshold)
  - Radius < 100 m
  - Detection Probability = $E_{particle}/15$
  - Require 50 “Hits”

CORSIKA: Altitude Effect (cont'd)



5200 = 2*x*4500

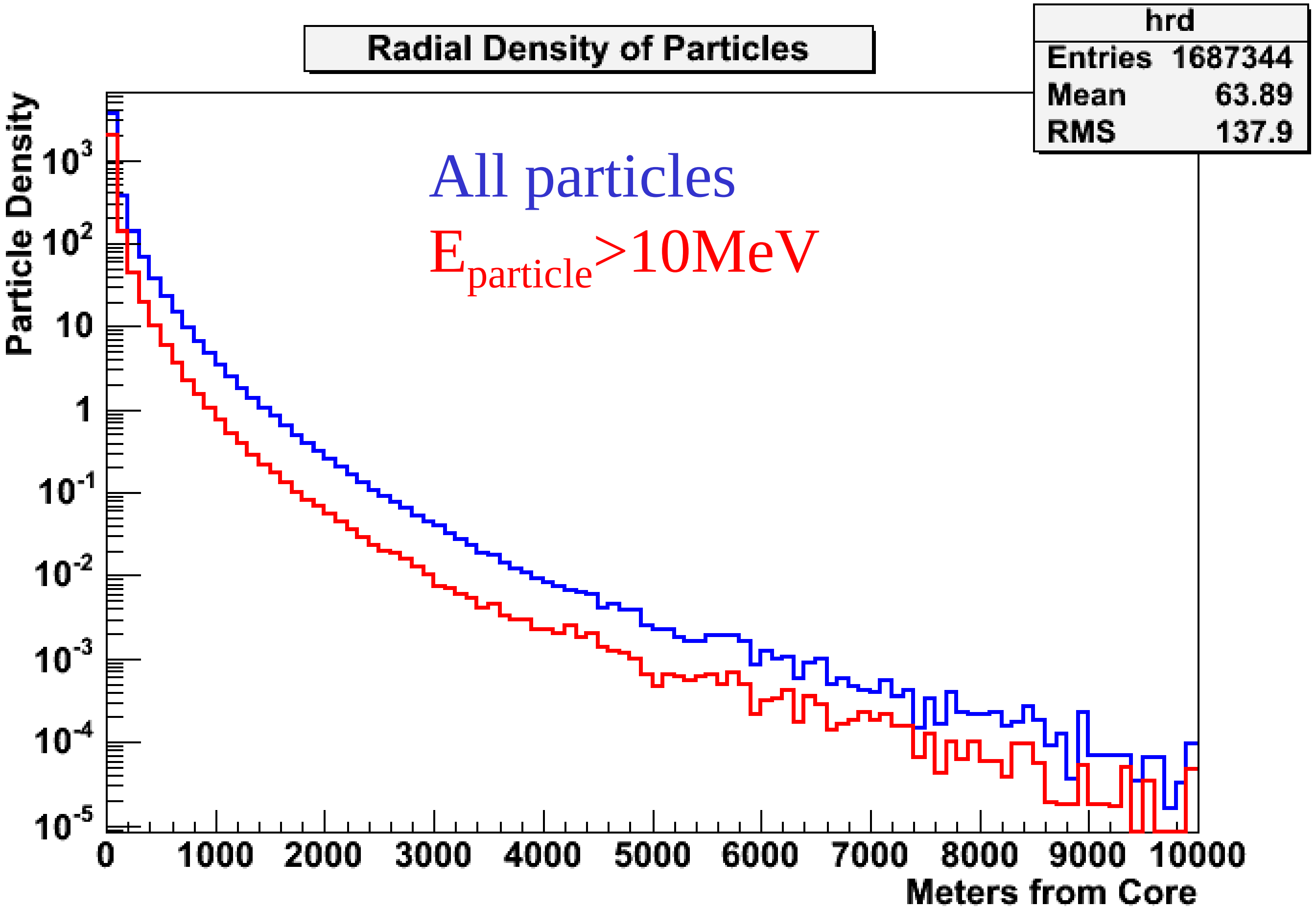
4500 = 3*x*3500

3500 = 3*x*2500

At low energy the effect is larger

"Trigger" Probability

CORSIKA: Particle Distribution



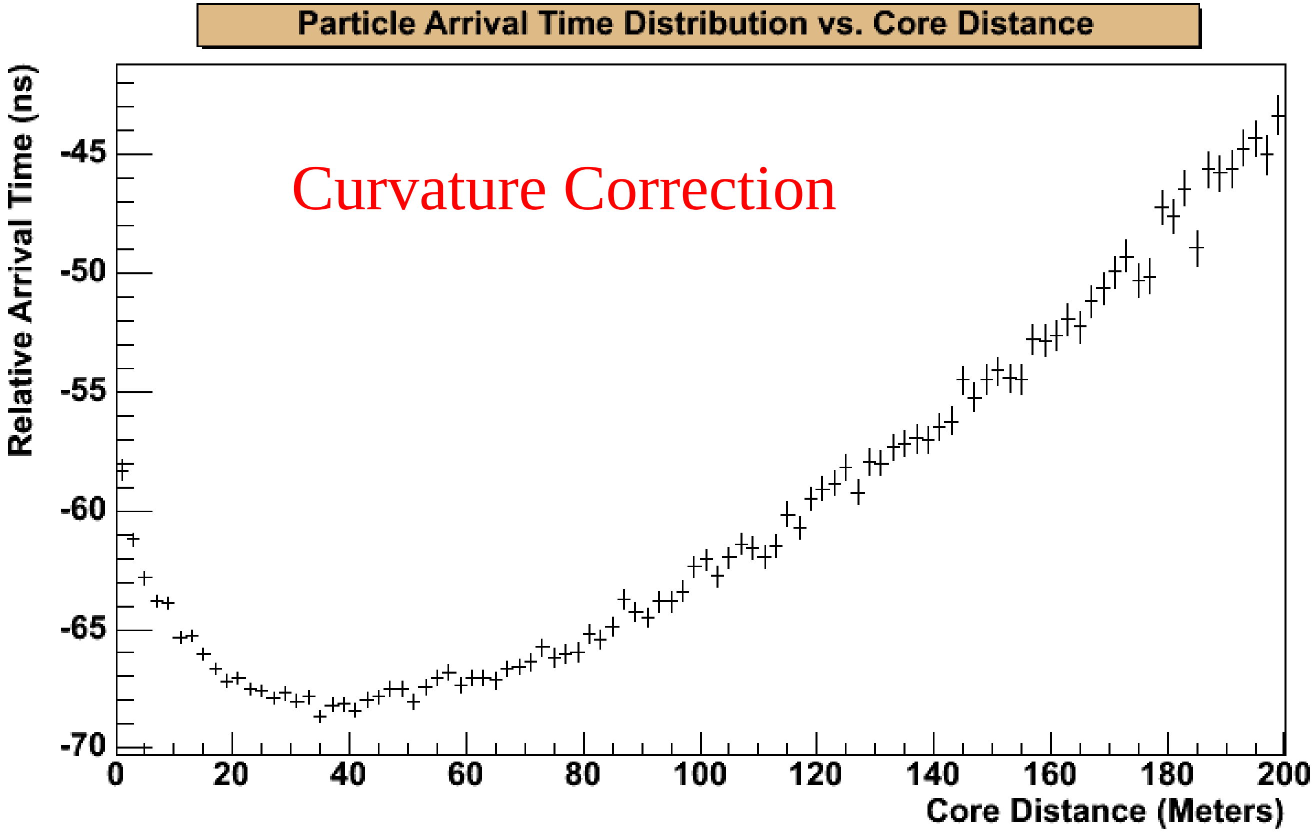
Effect of Altitude: Conclusions

- Each km of atmosphere decreases the number of e-m particles by a factor of 3
- A decrease in the # of e-m particles translates into a similar decrease in trigger efficiency
- The effective area for gamma rays increases by a factor of 3 for each km gain in elevation.
- Need to detect photons with high efficiency

CORSIKA: Angular Resolution

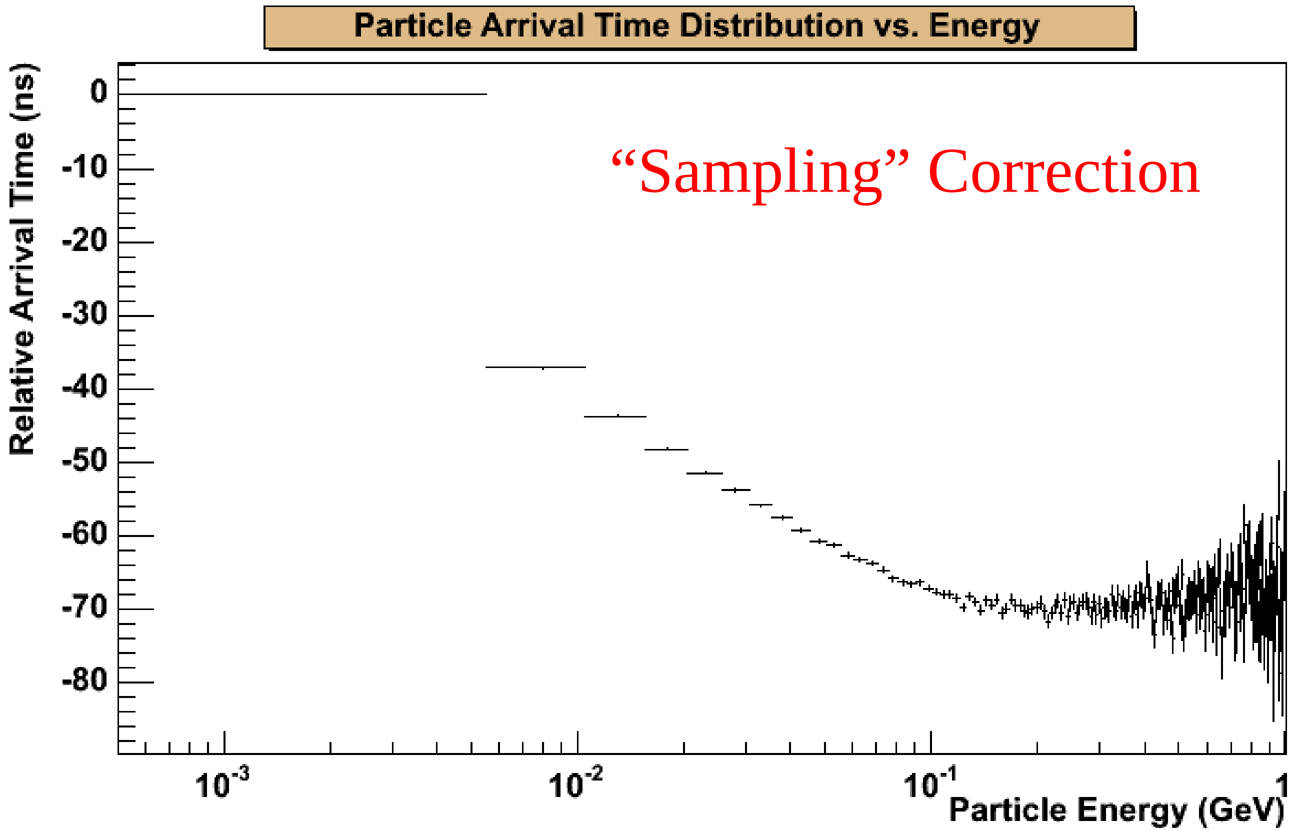
- Use zenith showers for simplicity
- “Trigger” on event
- Use particle times and positions
- Determine curvature correction
- Determine “sampling” correction
- Optimize “chi” cuts and E_{min} (min. particle energy to use)
- Fit event direction

Particle Arrival Times



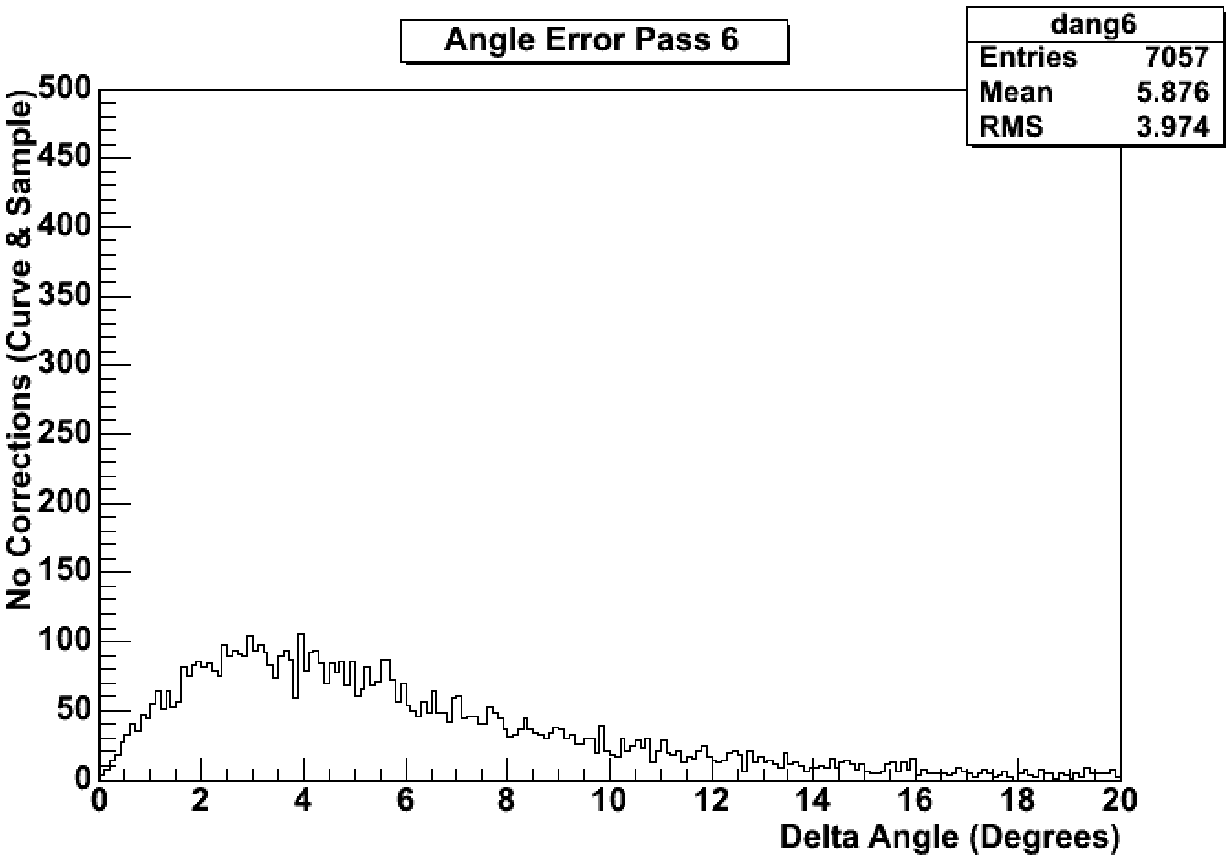
For each event time is measured relative to the average particle arrival time.

Particle Arrival Times (cont'd)



For each event time is measured relative to the average particle arrival time.

Direction Fitting: No Corrections



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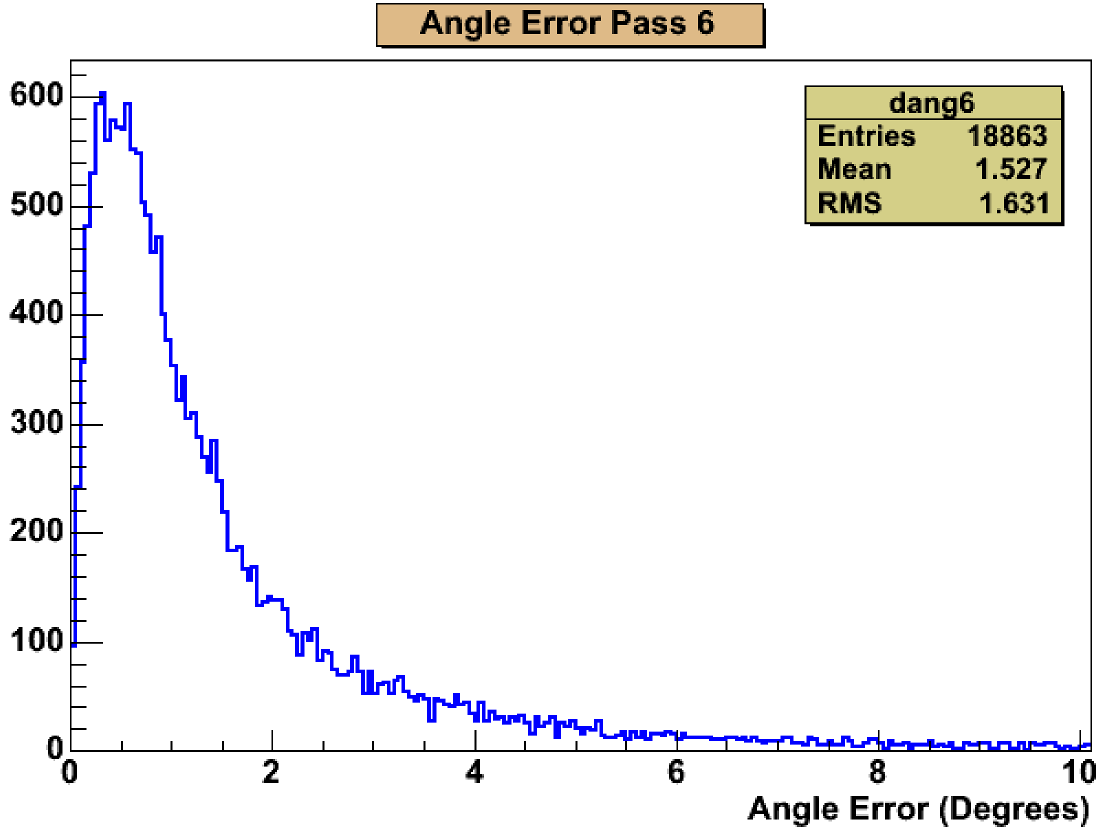
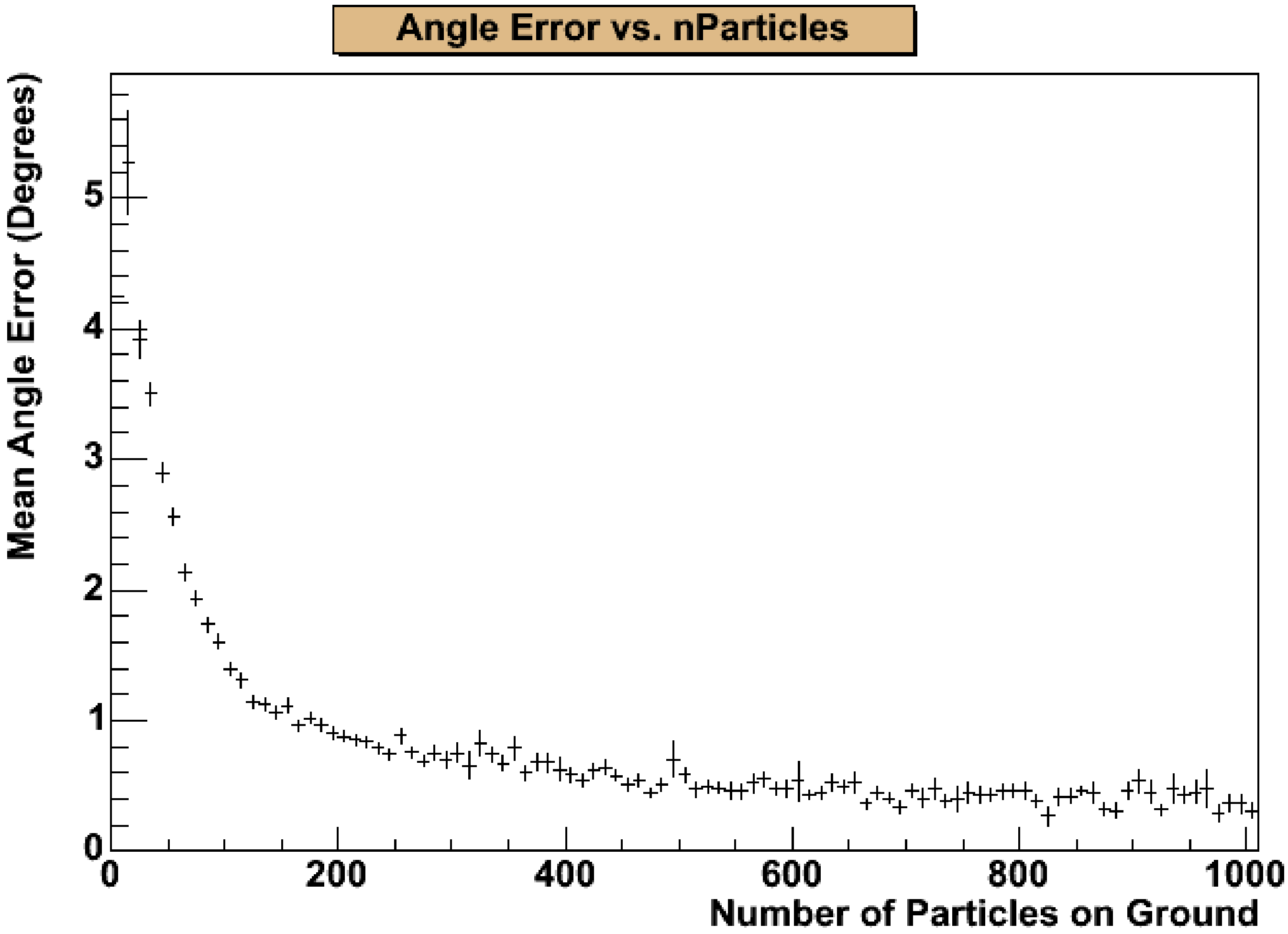
Direction Fitting: After Optimization



Angle Error vs. nParticles



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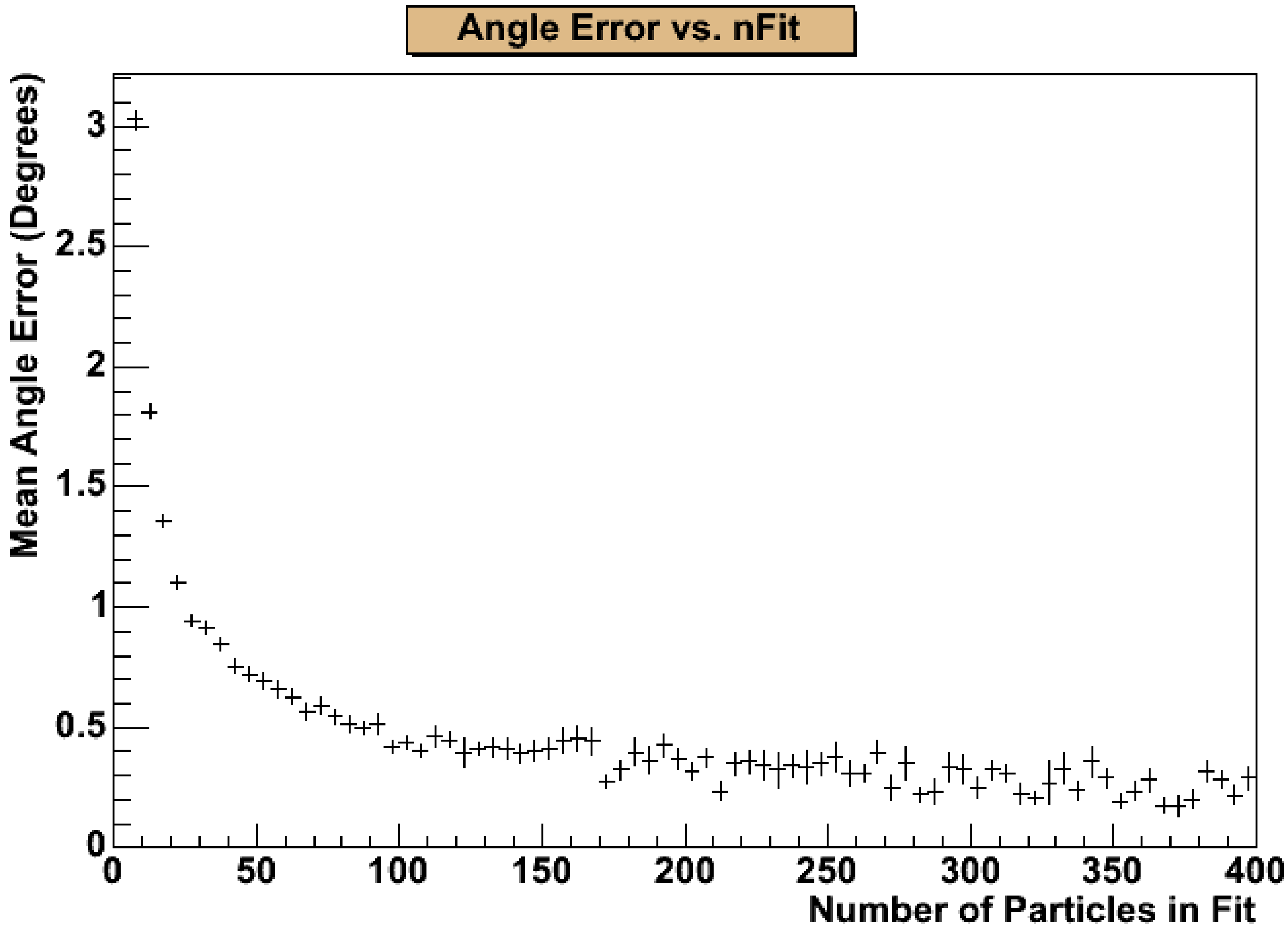
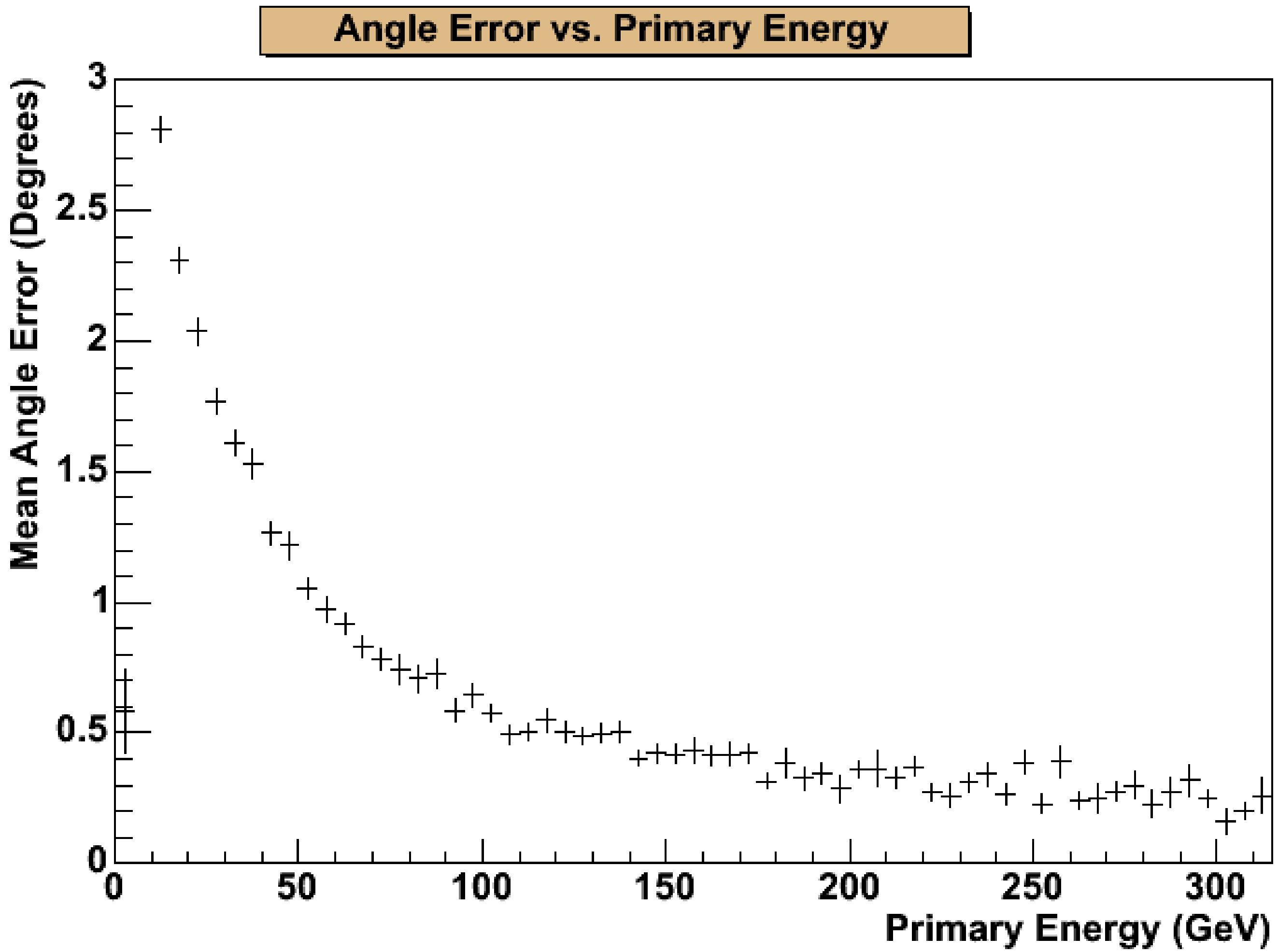
Angle Error vs. nFit



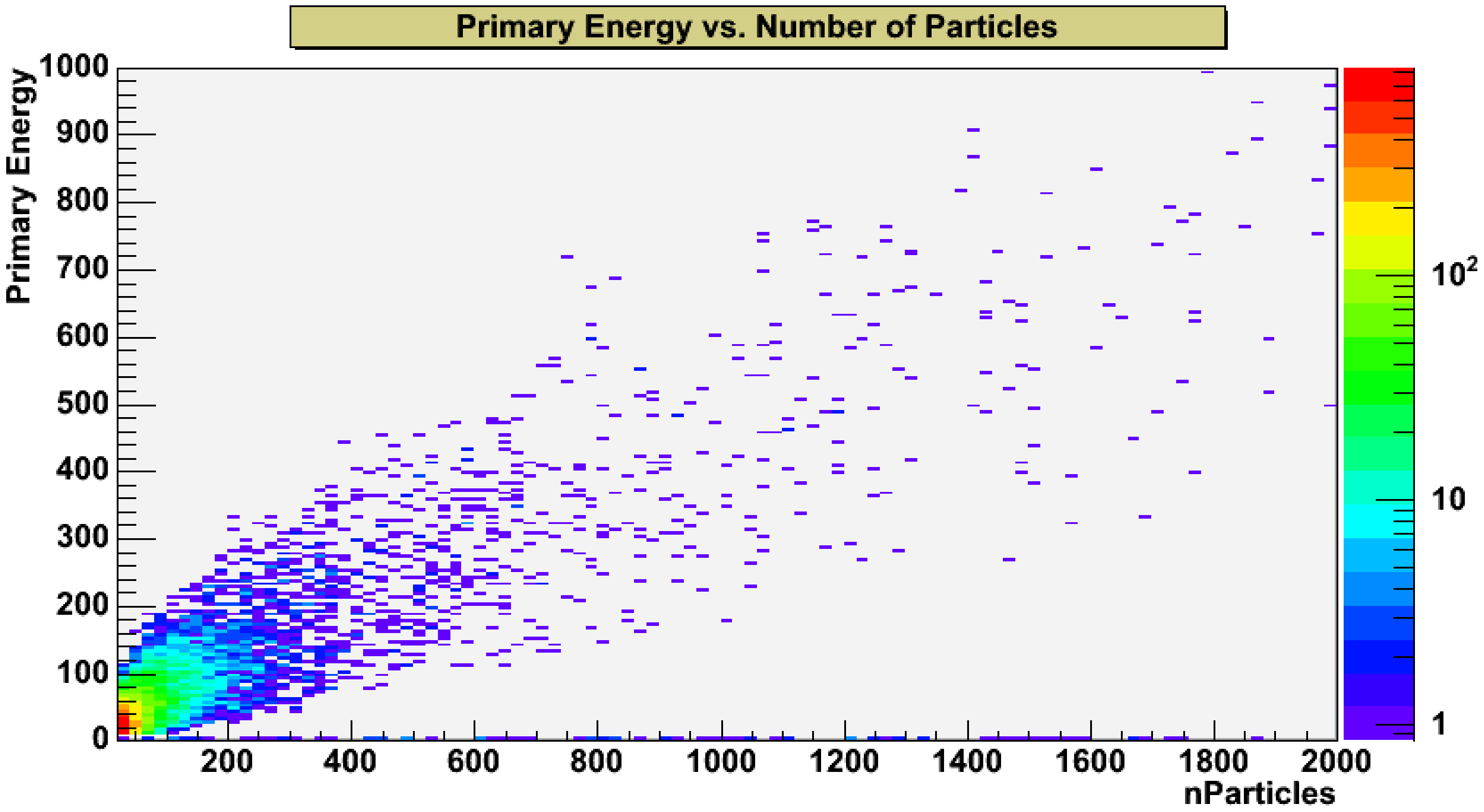
Angle Error vs. Primary Energy



Angle Fitting: Conclusions

- Curvature is not as simple as we thought
- Sampling is not as simple as we thought
- Fundamentally limited by # of particles reaching the ground and their time spread
- ~0.25 degree seems to be the limiting resolution at high particle numbers

CORSIKA: Energy Resolution



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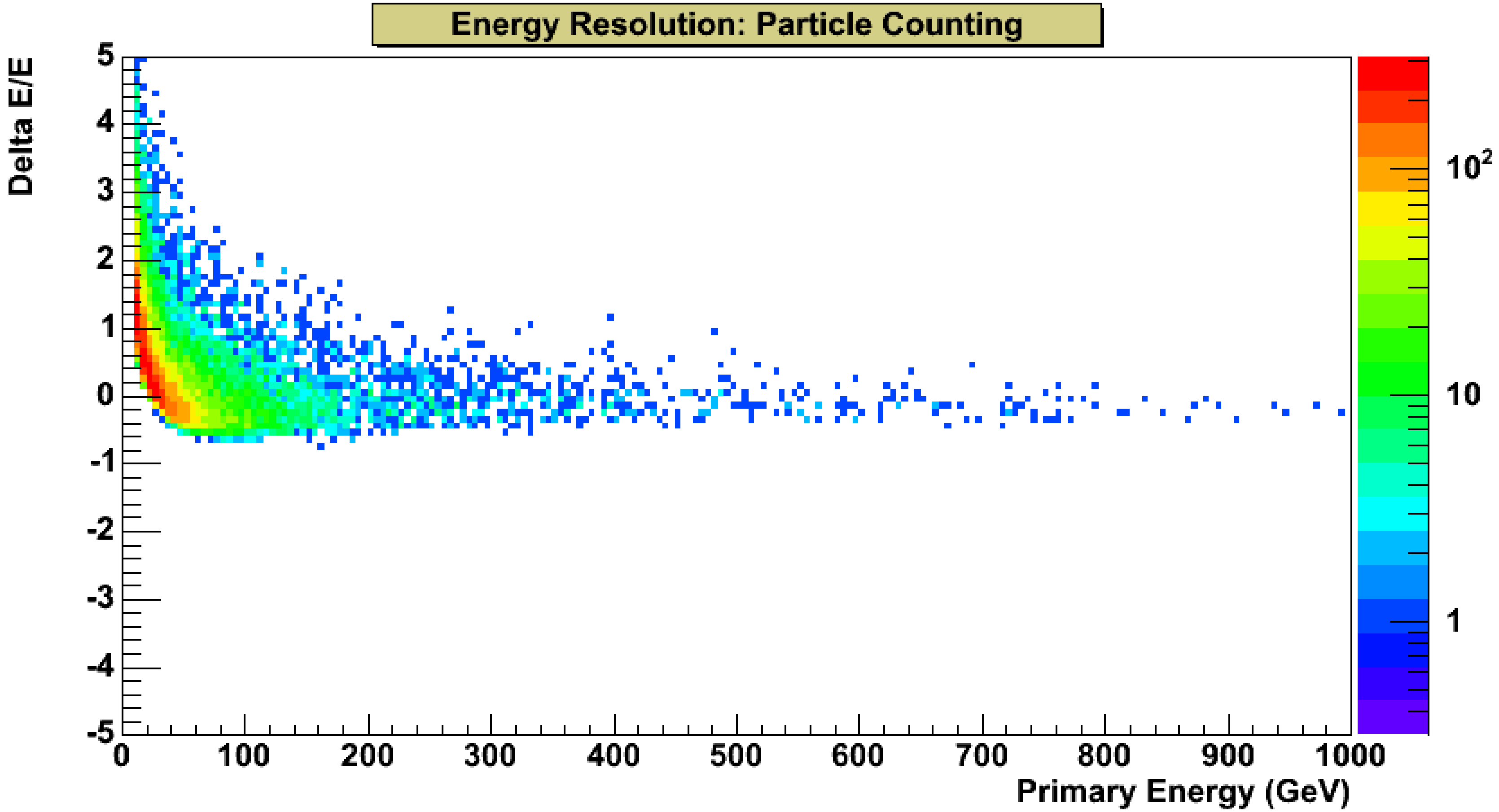
CORSIKA: Energy Resolution



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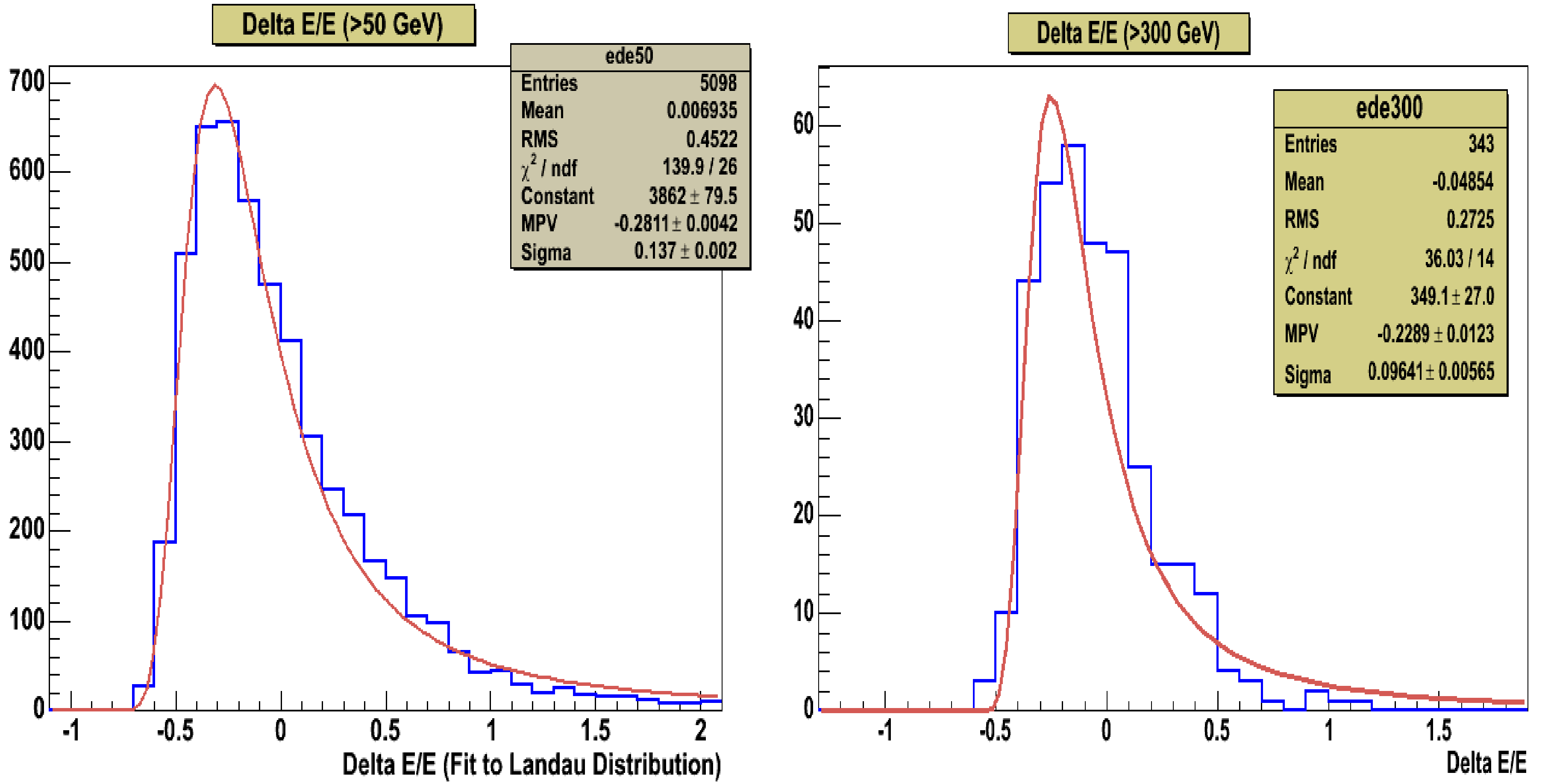
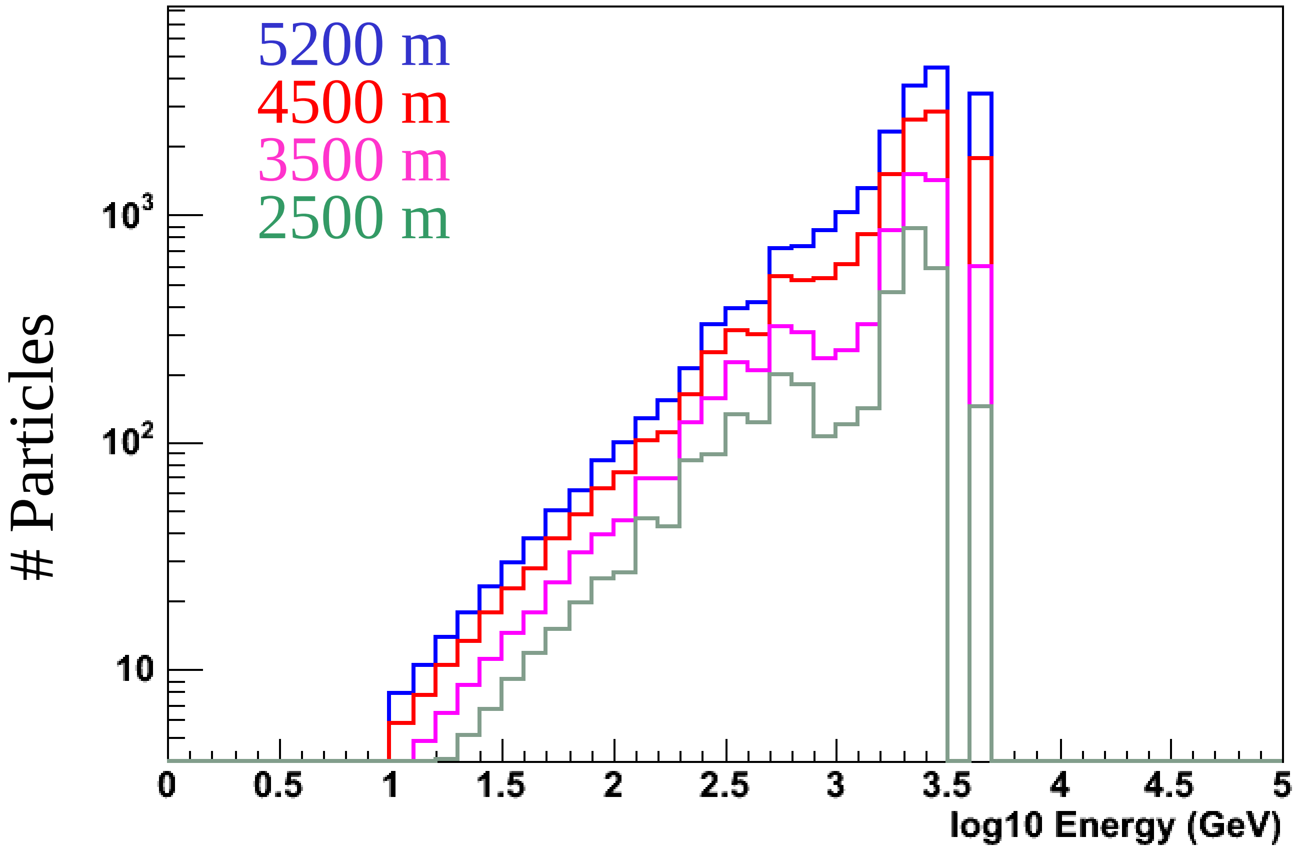
CORSIKA: Energy Resolution



Energy Resolution: Conclusion

- Good energy resolution (~25%) is possible
- Counting particles is better than measuring total energy
- Energy resolution improves rapidly with energy

Proton Background

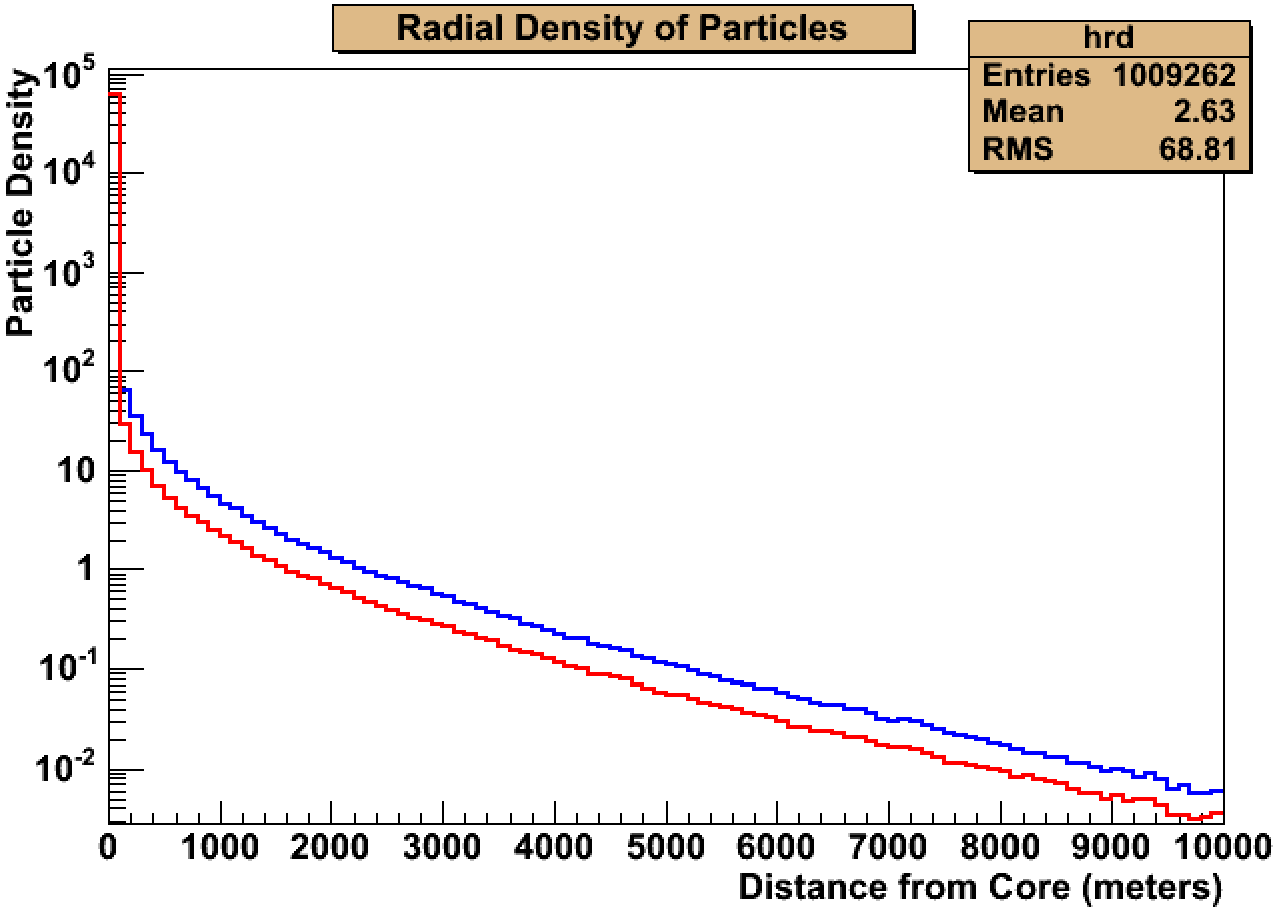


5200 = 1.3*x*4500

4500 = 1.8*x*3500

3500 = 1.8*x*2500

Proton Showers



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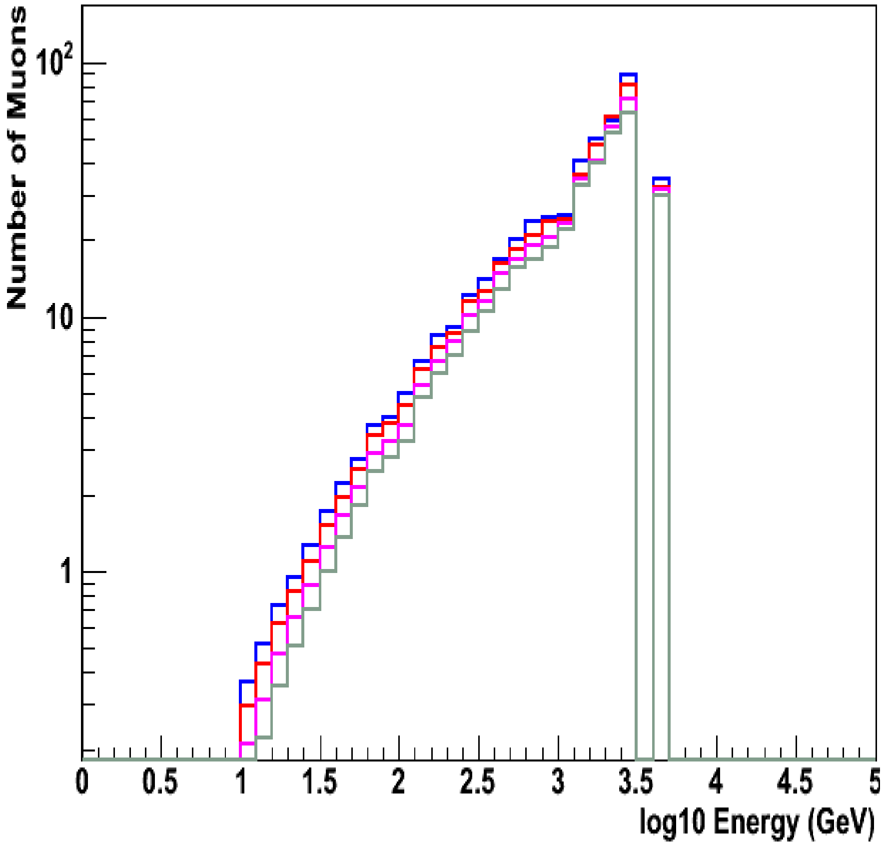
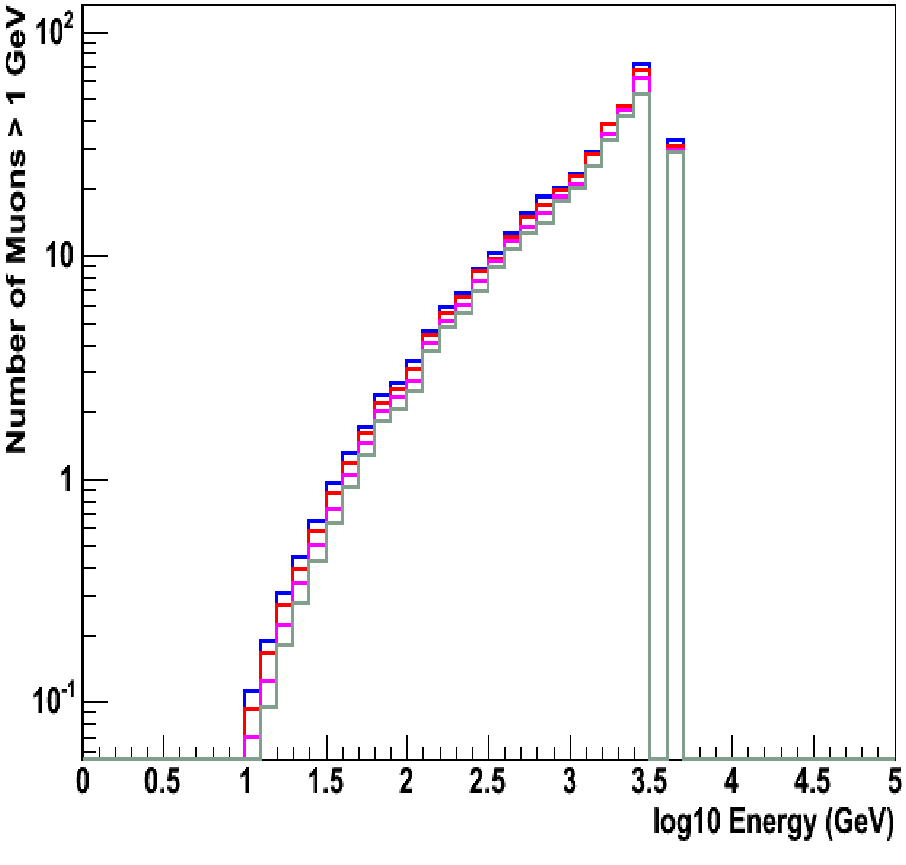
Muons in Proton Showers





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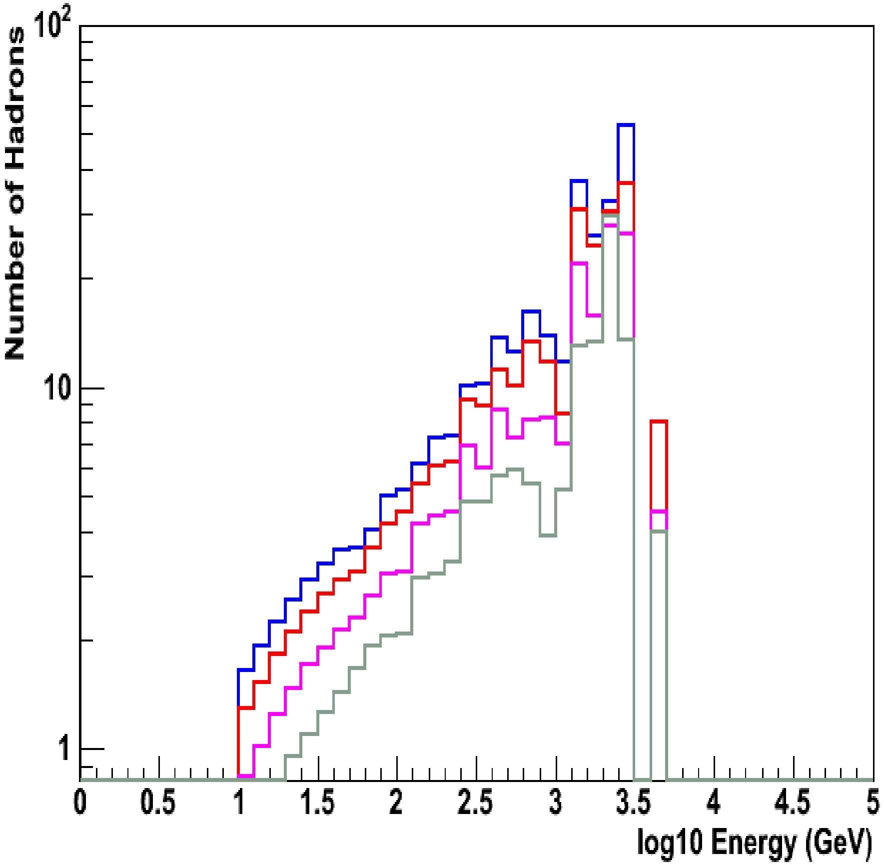
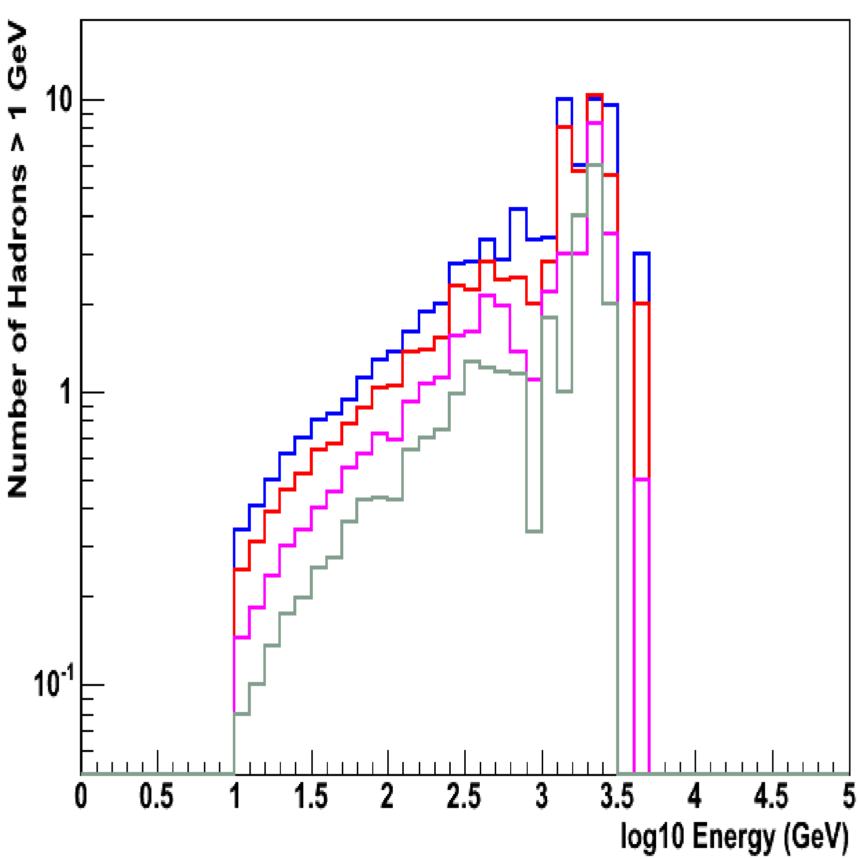
Hadrons in Proton Showers





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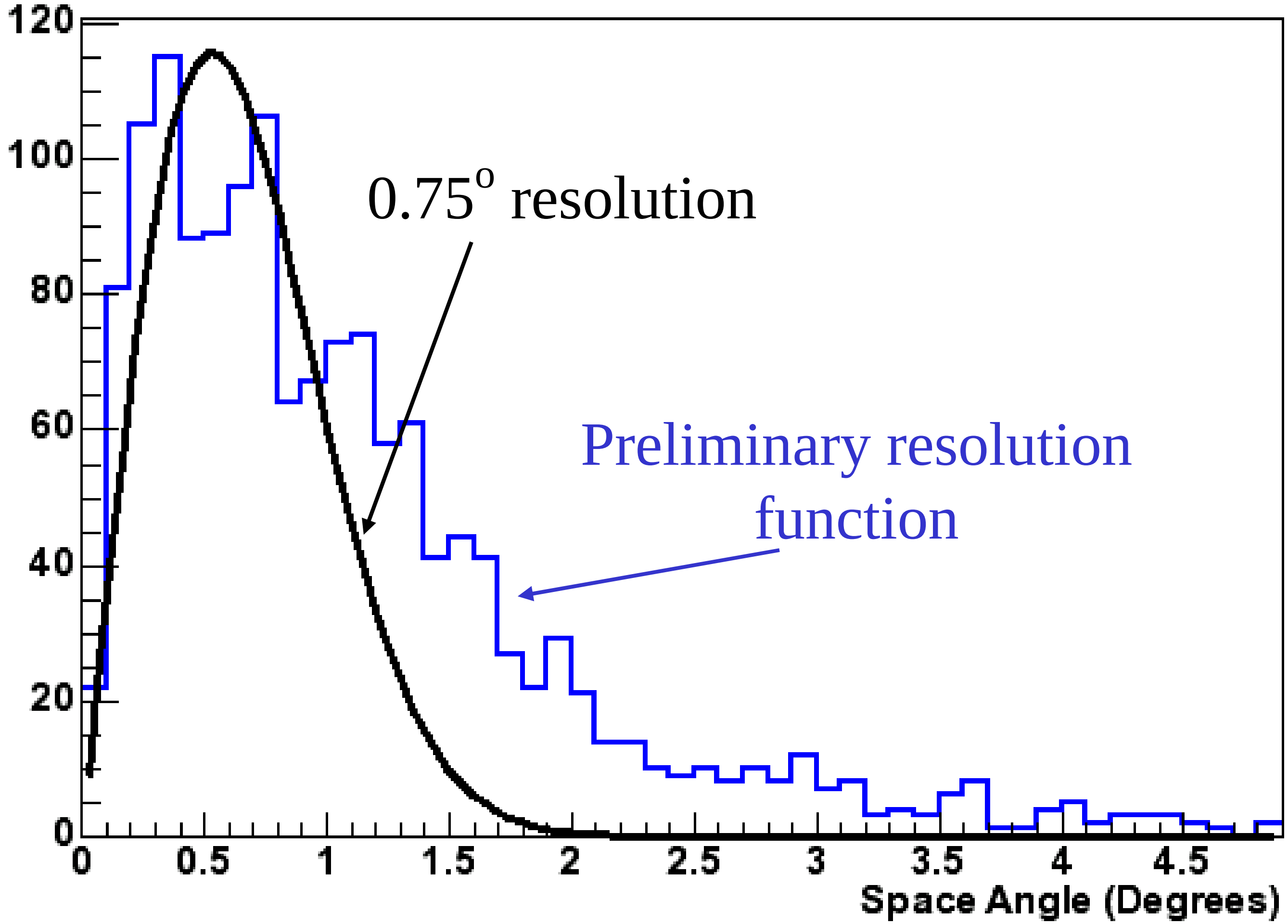
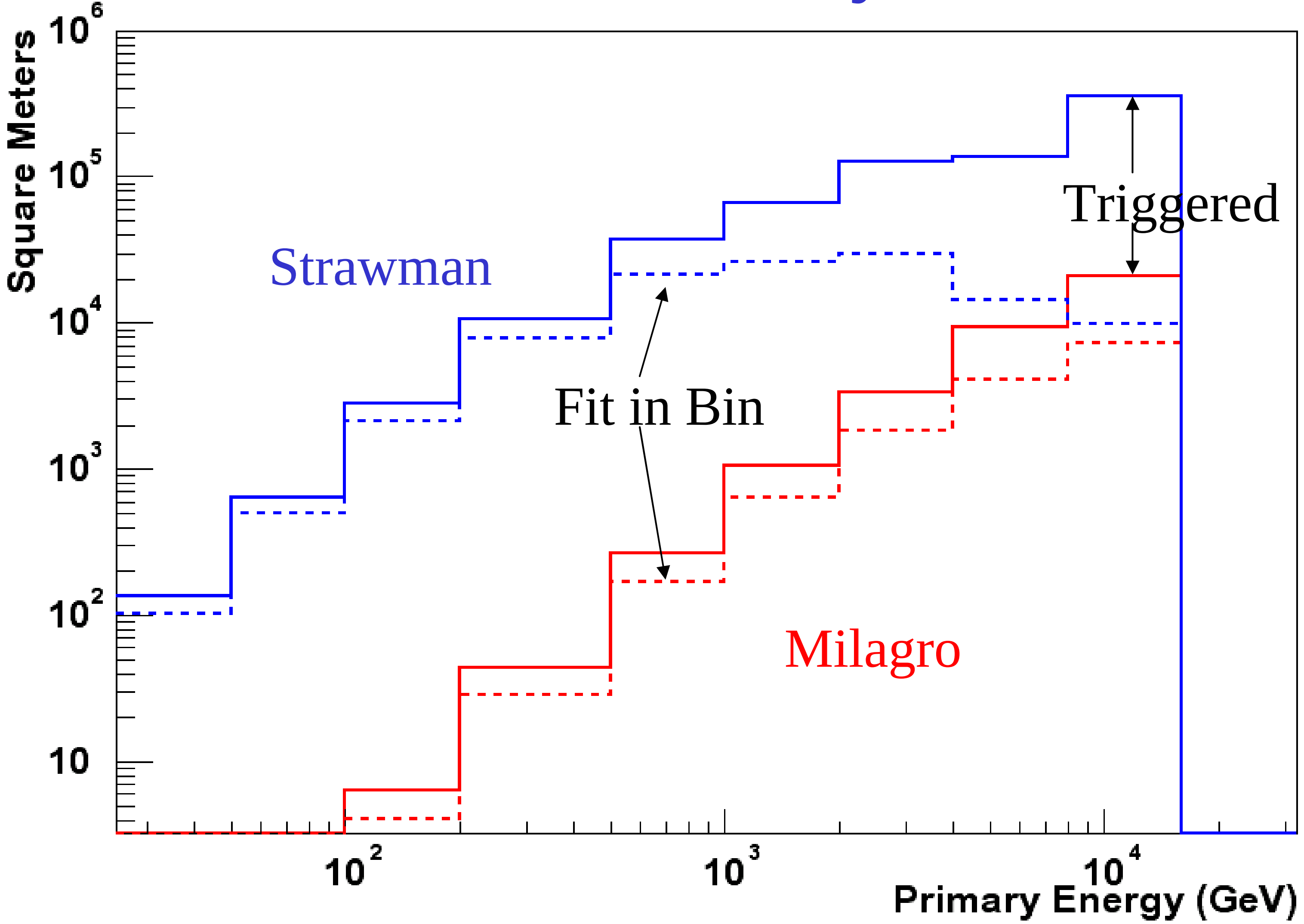
Background Rejection: Conclusions

- #particles vs. altitude grows slower than e-m showers
- At low energy few muons present
- Muon number ~independent of altitude
- Hadrons present at low energies
- Hadron number strong altitude dependence
- More work needed for morphology
- More work needed on e-m component

Angular Resolution



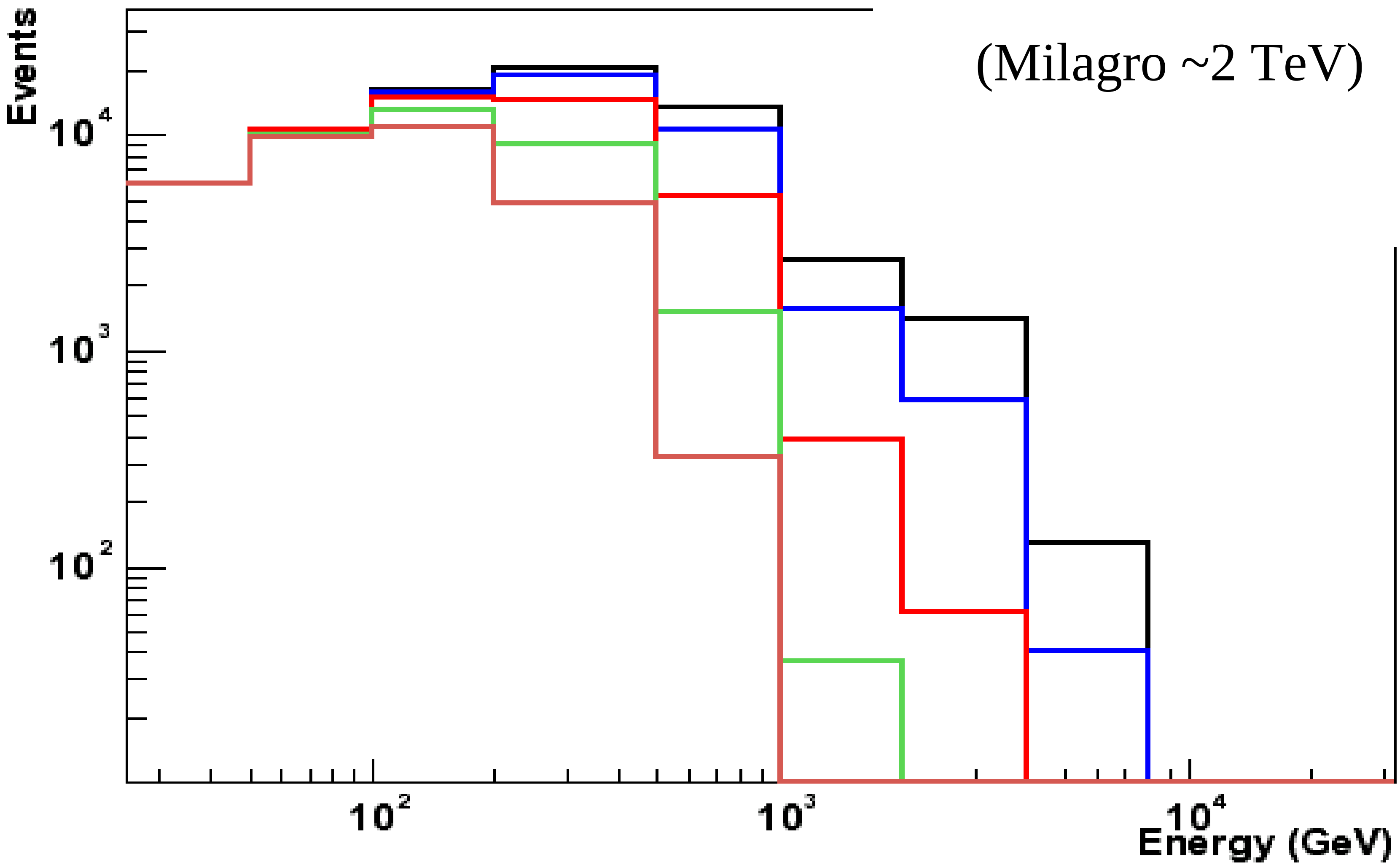
Effective Area vs. Energy: Gamma Rays



Energy Distribution of Fit Events

Median Energy 350 GeV

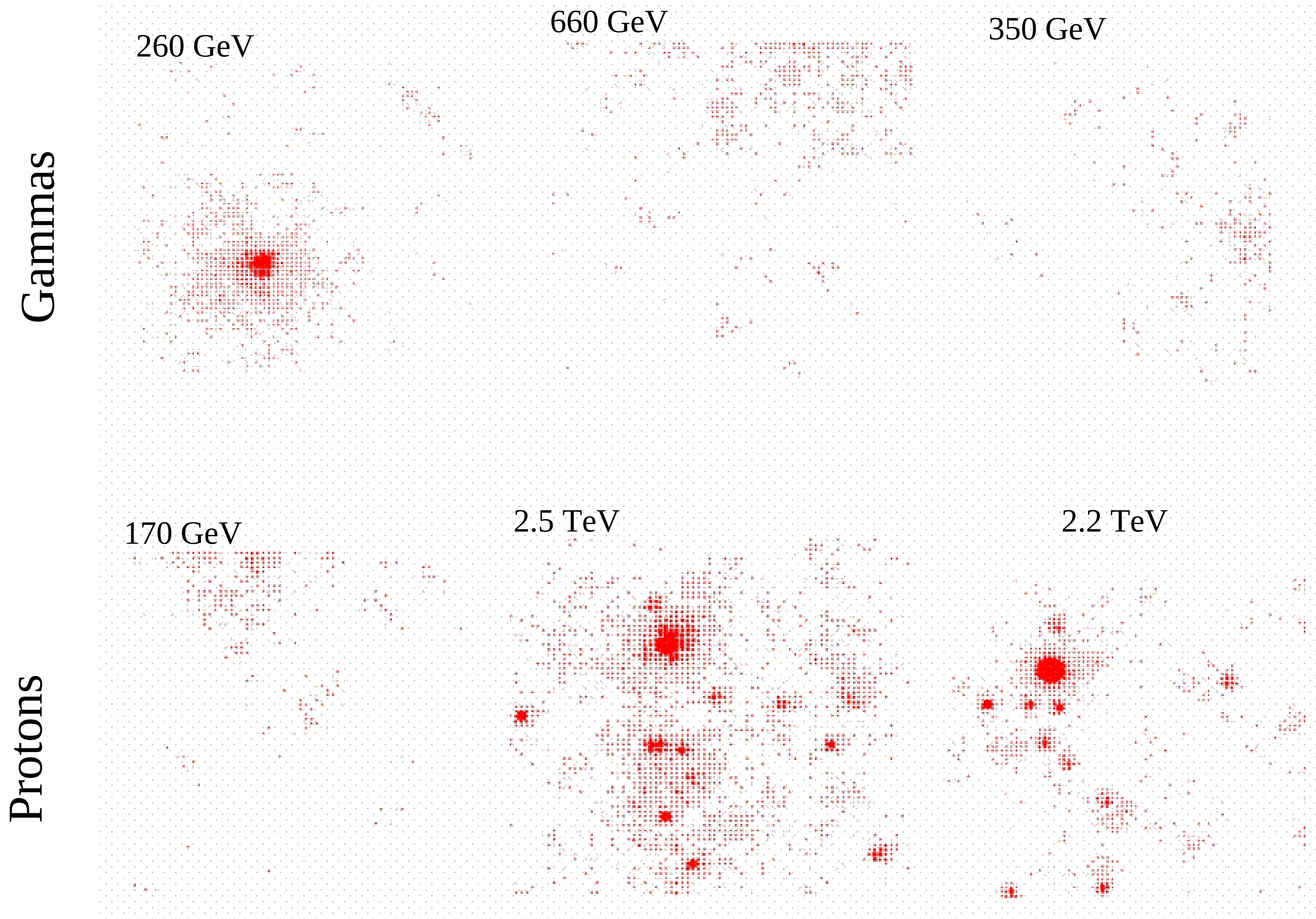
(Milagro ~2 TeV)



Background Rejection

- Estimate total rate (due to background) by scaling proton response from Milagro
  - 120 kHz trigger rate expected
- As in Milagro use bottom layer information to detect penetrating component of hadronic showers.
- Small clumps of intense light indicate presence of penetrating component

Pulse Heights in Bottom Layer



Background Rejection

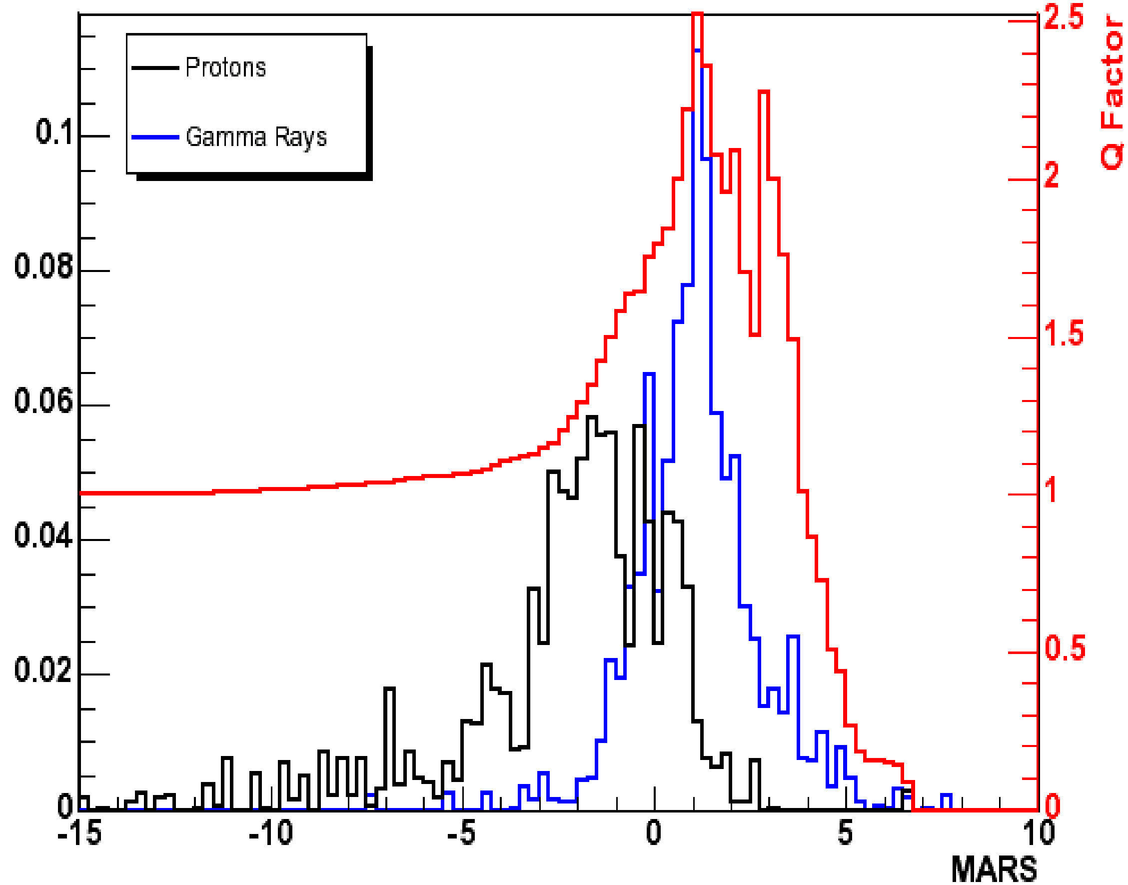
Use 4 parameters:
nTop, nBot2, nBot8, sumPEBot

MARS: J. Friedman

Reject 95% of protons

Accept 55% of gammas

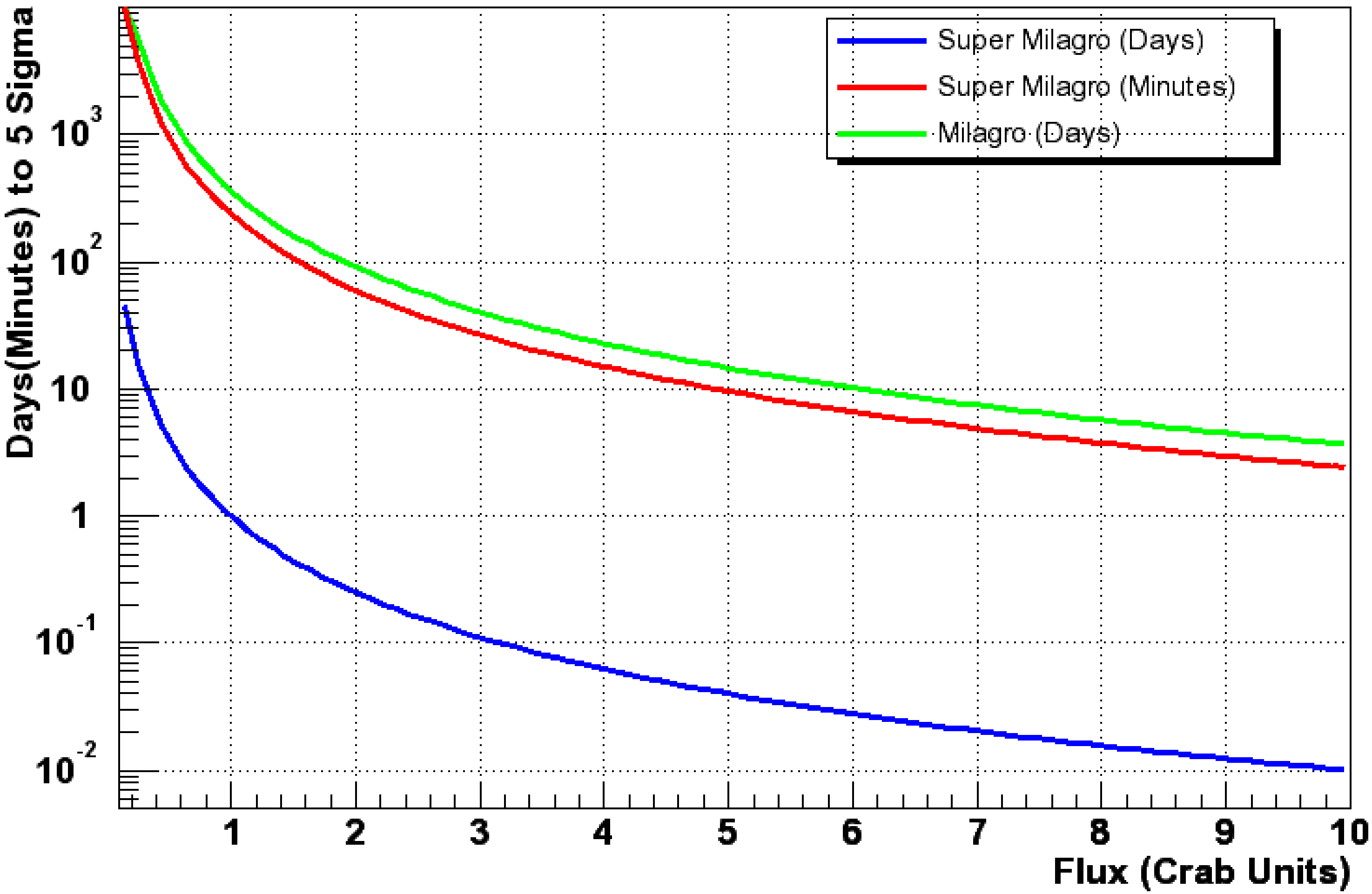
2.5*x* improvement in sensitivity



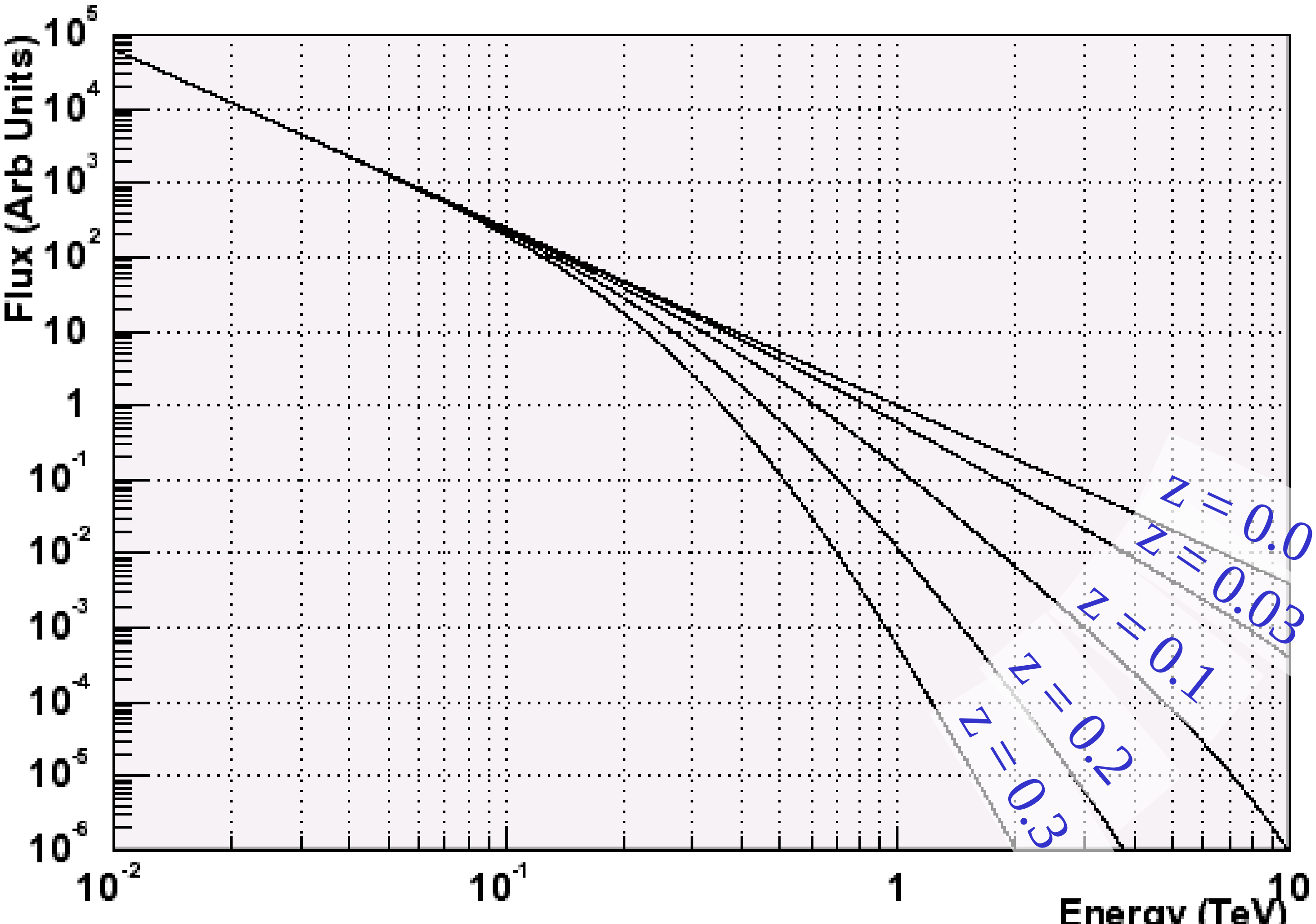
D.C. Sensitivity: Galactic Sources

- Crab Spectrum: $dN/dE = 3.2 \times 10^{-7} E^{-2.49}$
  - 0.22 (0.12) Hz of gammas from Crab raw (cut)
  - Whipple 0.025 Hz
  - Veritas-4 0.5 (.12) Hz raw (cut)
- Background rate 80 (4) Hz raw (cut)
- 3 σ/sqrt(day) raw data
- 7.5 σ/sqrt(day) cut data
  - 140 σ/sqrt(year)
- 35 mCrab sensitivity (all sky) in one year
  - Whipple: 140 mCrab per source
  - VERITAS: 15 mCrab per source ($E^2 dN/dE > 1.4 \times 10^{-12}$ ergs $cm^{-2} s^{-1}$ @ 1 TeV – best sensitivity)

Transient Sensitivity: Galactic Sources

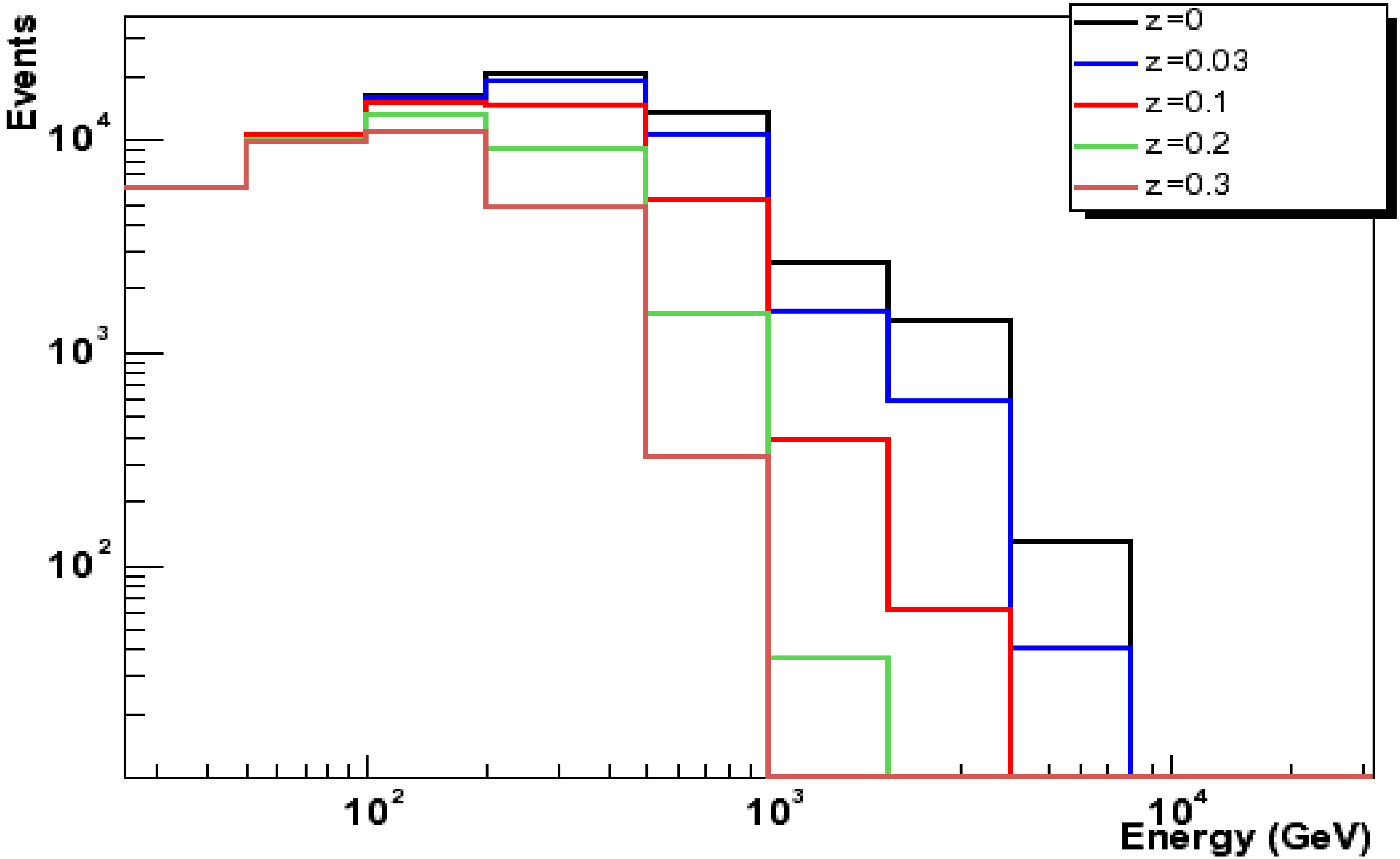


Effect of IR Absorption on Distant Sources

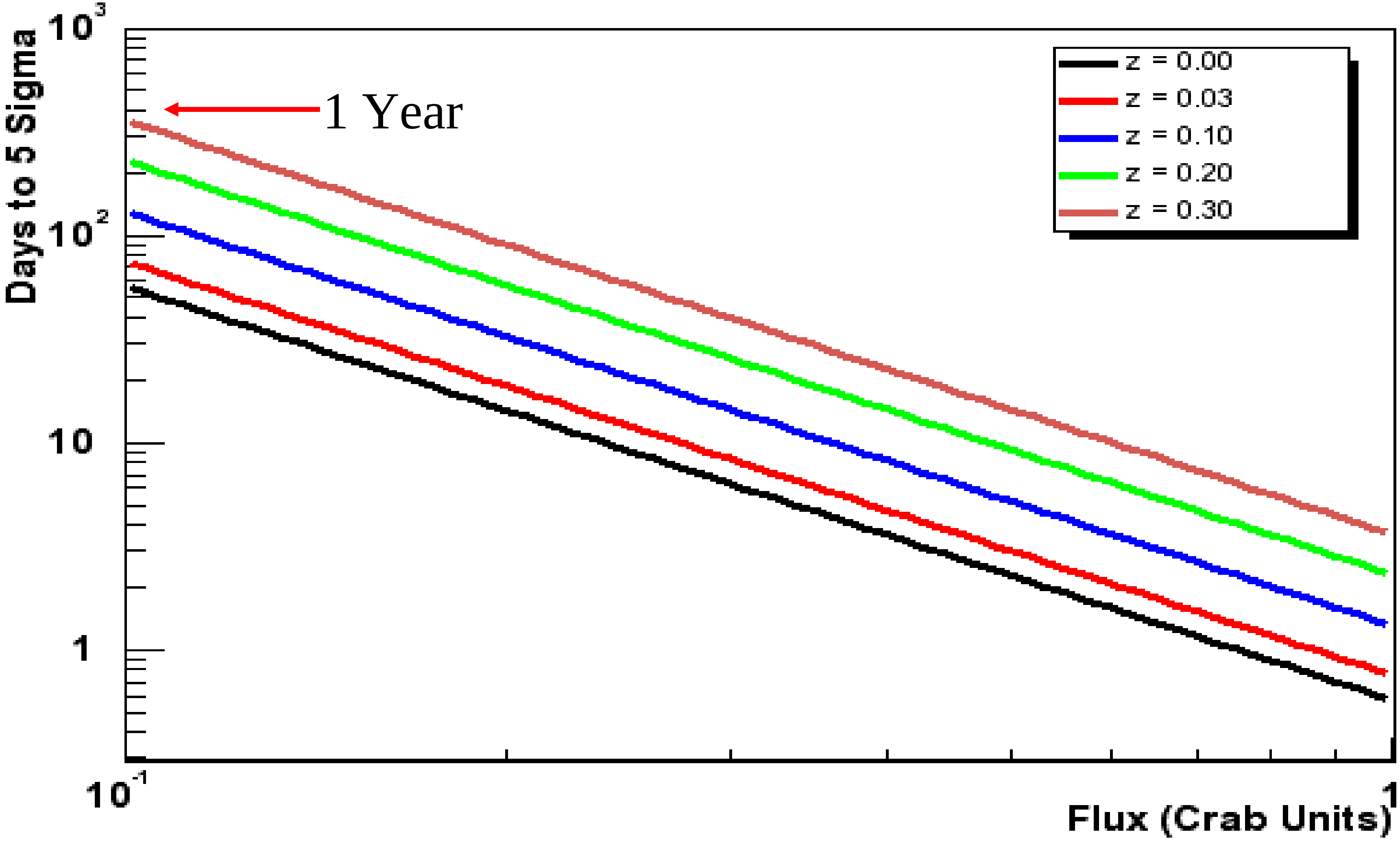


Ieeting

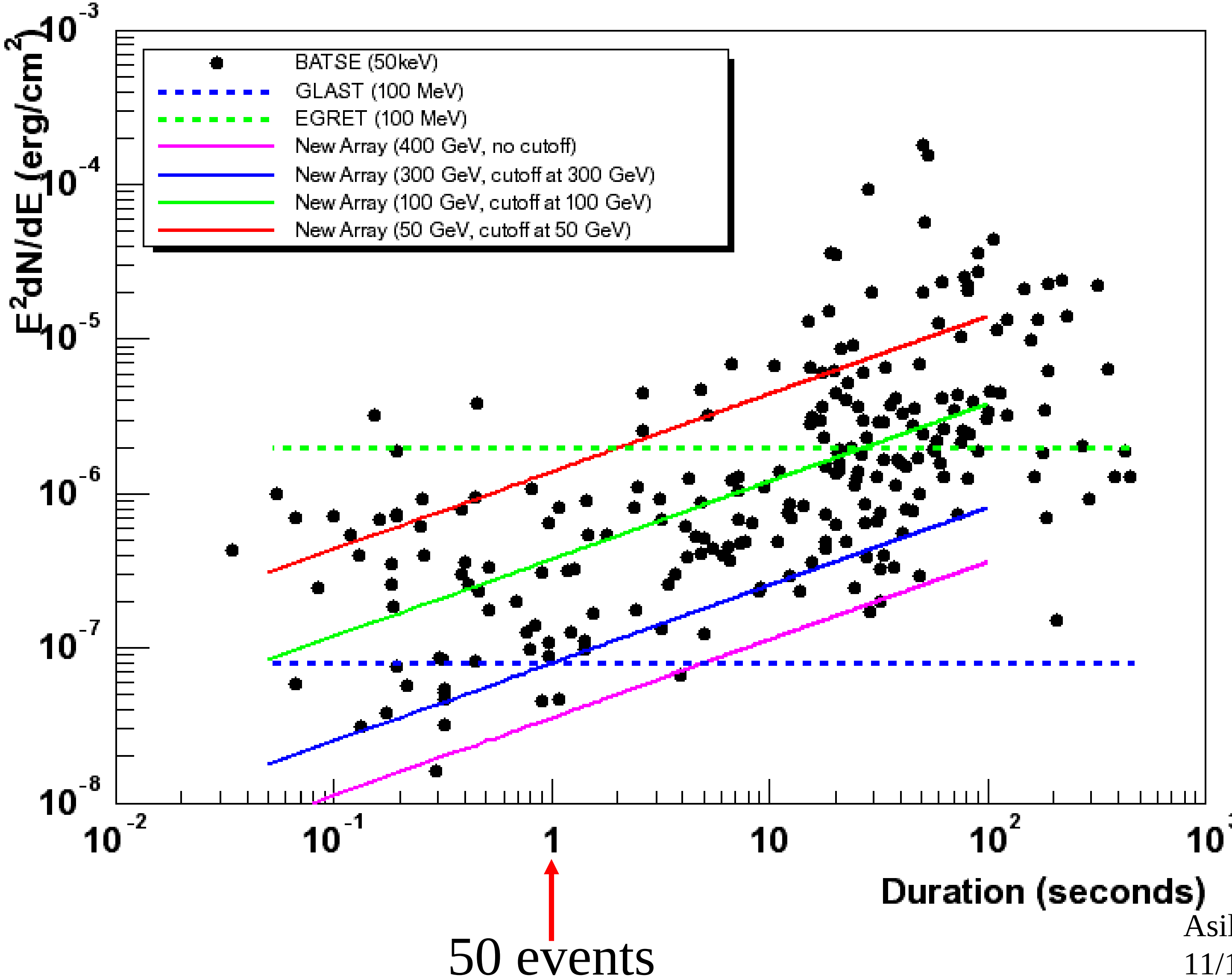
Energy Distribution of Fit Events



AGN Sensitivity



Gamma Ray Burst Sensitivity



Conclusions

- A large area, high altitude all sky VHE detector can:
  - Instantaneous sensitivity comparable to Whipple
  - D.C. sensitivity approaching VERITAS
  - AGN sensitivity to z = 0.3
  - GRB sensitivity to <50 GeV
  - GRB sensitivity to z~1
  - Detect a significant number of GRBs
- Continuing work
  - Background rejection (low energy)
  - Improved event reconstruction
  - Detailed detector design (electronics, DAQ, infrastructure)
  - Reliable cost estimate needed (~$30M???)
  - Site survey

Work Plan

- Monte Carlo of 5200m site
- More MC of 4500m site
- Paper submitted by March
- Proposal to NSF next September cycle
- Need work assignments for the paper and the proposal
- Interested parties?
  - Columbia (Stefan, Reshmi)
  - UNM (John Matthews)
  - Milagro people (???)