

HAWC Sensitivity from BOE Showers

HAWC/Milagro Collaboration Meeting

Michigan State University

John A.J. Matthews

New Mexico Center for Particle Physics

University of New Mexico

June 25, 2004

1. *Back of the Envelope* (BOE) showers:
 - Longitudinal profile ($N_e(T)$)
 - Transverse profile ($\rho_e(r)$)
2. A fraction of the signal hits the *pond* ...
3. Tibet(4500m):Milagro comparison:
 - adiabatic atmosphere ($T_{sea\ level} \approx 300K$)
 - $\int_0^r \rho_e(r) 2\pi r dr$ VS E_{shower} and zenith angle (θ)
 - $\int_0^r \rho_e(r) 2\pi r dr$ passing cut
4. Summary

1. B.O.E. showers ...

- Longitudinal shower profile: The longitudinal shower profile for an electro-magnetic shower is a function of the depth in radiation lengths, T , and/or of the related age parameter, $s(T)$:

$$N_e(T) = \left(\frac{0.31}{\sqrt{y}} \right) \cdot e^{T \cdot (1 - 1.5 \ln(s(T)))}$$

where:

- N_e is the number of charged particles,
- the depth in radiation lengths is:

$$T = X_{expt}(\theta)/36.7 \quad ((gm/cm^2)/radiation \ length)$$

and the depth of the experiment, X_{expt} , also depends on the zenith angle, θ , of the shower,

- $y = \ln \frac{E_{shower}}{E_{critical}} \equiv T^{max}$, and
- the shower age is:

$$s(T) = \frac{3}{(1 + 2 \cdot (T^{max}/T))}$$

1. B.O.E. showers ... (con't)

- Transverse shower profile: The transverse shower profile is also a function of the shower age:

$$\rho_e(r) = \frac{N_e(T)}{r_m^2} \cdot \left(\frac{r}{r_m}\right)^{s-2} \cdot \left(1 + \frac{r}{r_m}\right)^{s-4.5} \cdot \frac{\Gamma(4.5 - s)}{2\pi\Gamma(s)\Gamma(4.5 - 2s)}$$

where:

- $\rho_e(r)$ is the charged particle ($e^\pm$) track density/m²,
- the Γ functions, *etc*, normalize $\int_0^\infty \rho_e(r) 2\pi r dr = N_e(T)$, and
- r_m is the Moliere radius (in meters) in air ~ 2 radiation lengths above the experiment [with local temperature T(K) and pressure P(mbar)]:

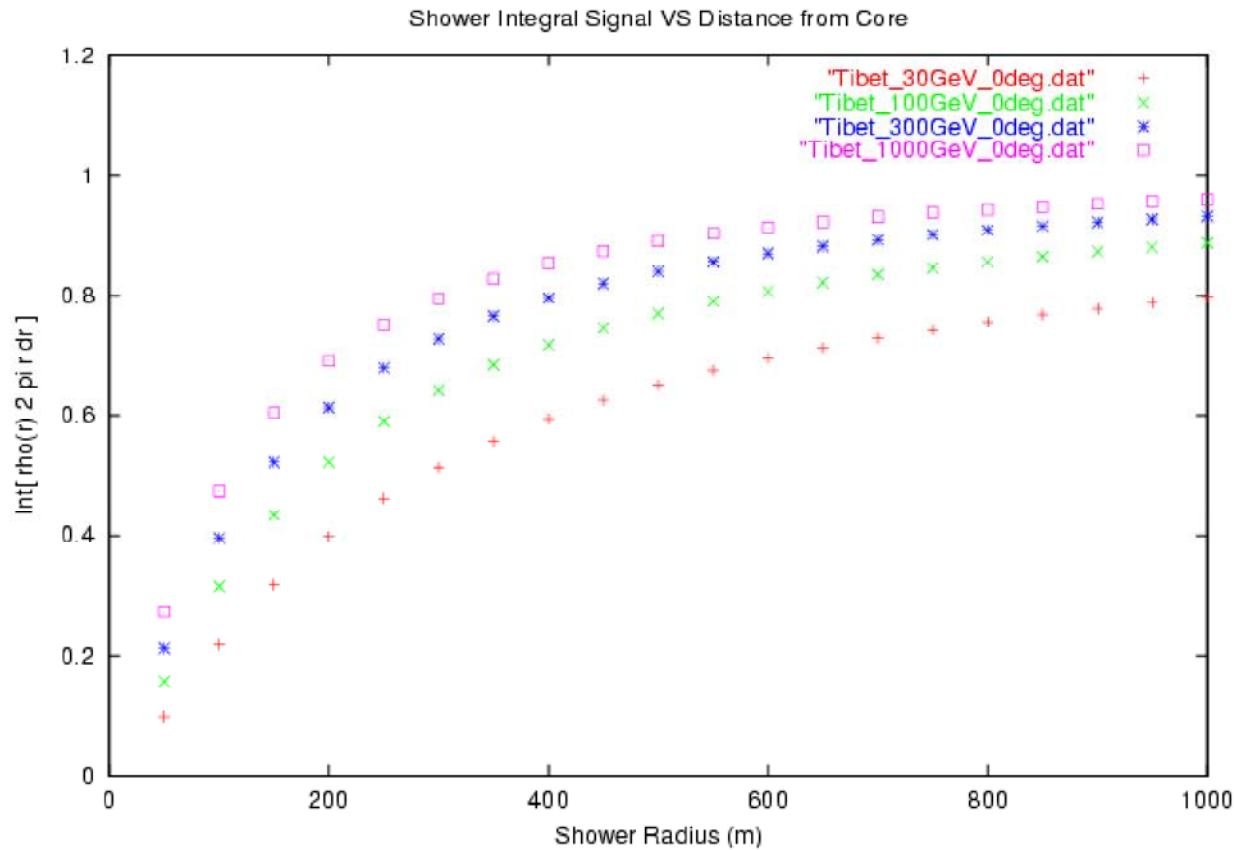
$$r_m(m) \approx 272.5 \cdot \frac{T(K) \cdot \left(\frac{P(mbar)}{73.4 \cdot \cos\theta} - 1\right)^{1./5.25588}}{(P(mbar) - 73.4 \cdot \cos\theta)}$$

The Moliere radius is the natural transverse scale set by multiple scattering:

$$r_m \equiv \frac{21MeV}{\epsilon_{crit}(MeV)} \cdot X_0$$

where ϵ_{crit} is the critical energy and $X_0 = 36.7\text{gm/cm}^2$ is the radiation length of air.

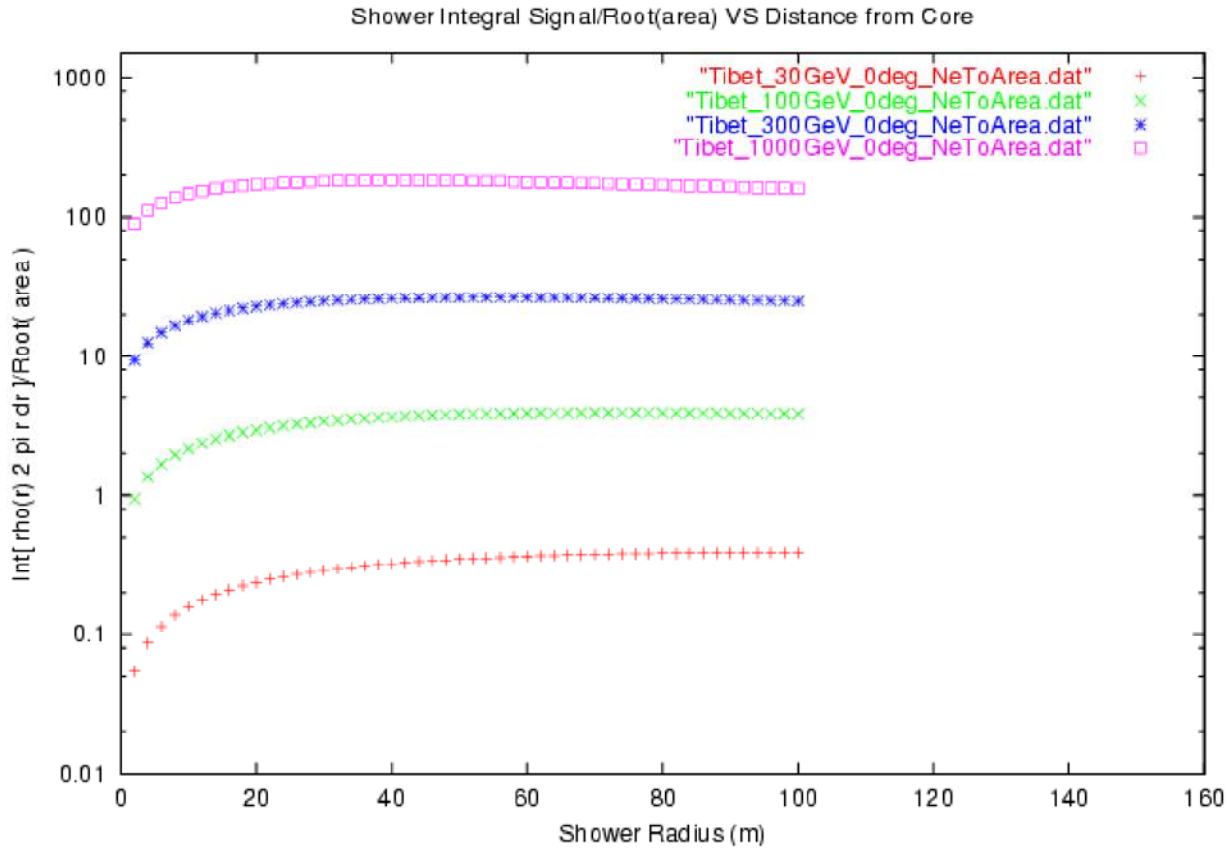
2: A fraction of the signal hits the pond ...



$\int_0^r \rho_e(r) 2\pi r dr / N_e(T)$ for Tibet site (4500m)

- Low energy showers have a “large” age (s) ... and
- For high sites the Moliere radius (r_m) is also “large” ($\sim 111\text{m}$ for Milagro and $\sim 137\text{m}$ for Tibet).
- **So most of the shower will be outside the HAWC detector!**

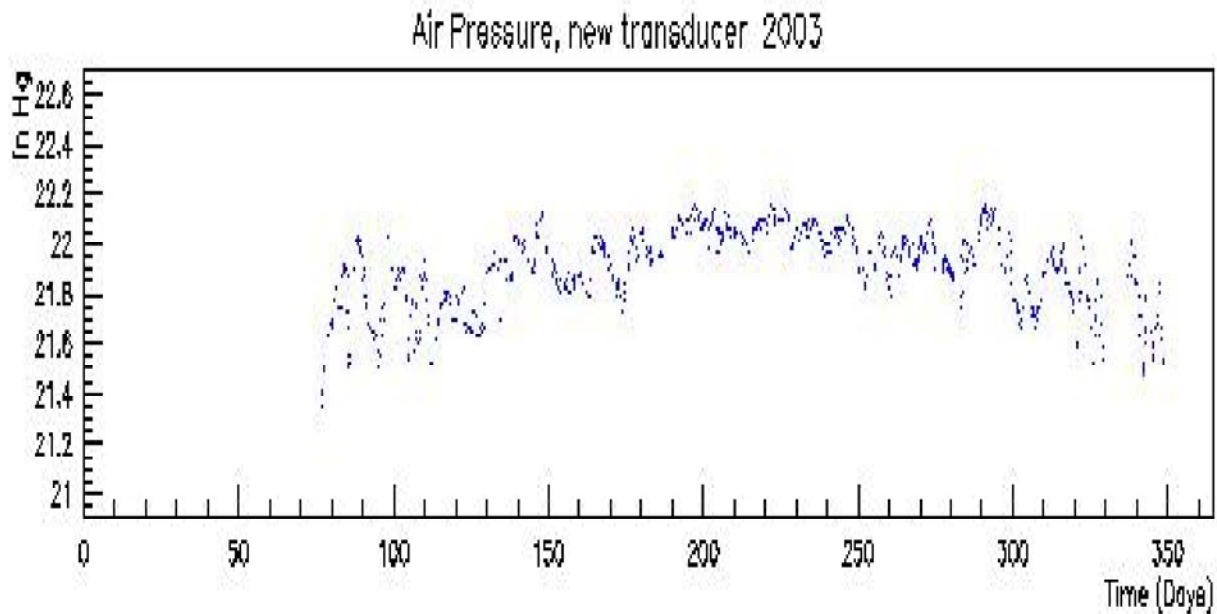
2: A fraction of the signal hits the pond ... (con't)



$\int_0^r \rho_e(r) 2\pi r dr / \sqrt{\text{area}}$ for Tibet site (4500m)

- The signal, $\int_0^r \rho_e(r) 2\pi r dr$, increases slowly with radius from the shower core (r)
- Assuming the “noise” is proportional to $\sqrt{\# \text{ of PMTs}}$ then the “signal/noise” is approximately constant for $r \gtrsim 50\text{m}$
- **In the B.O.E. model, a 200m x 200m detector matches the *brightest* part of the shower!**

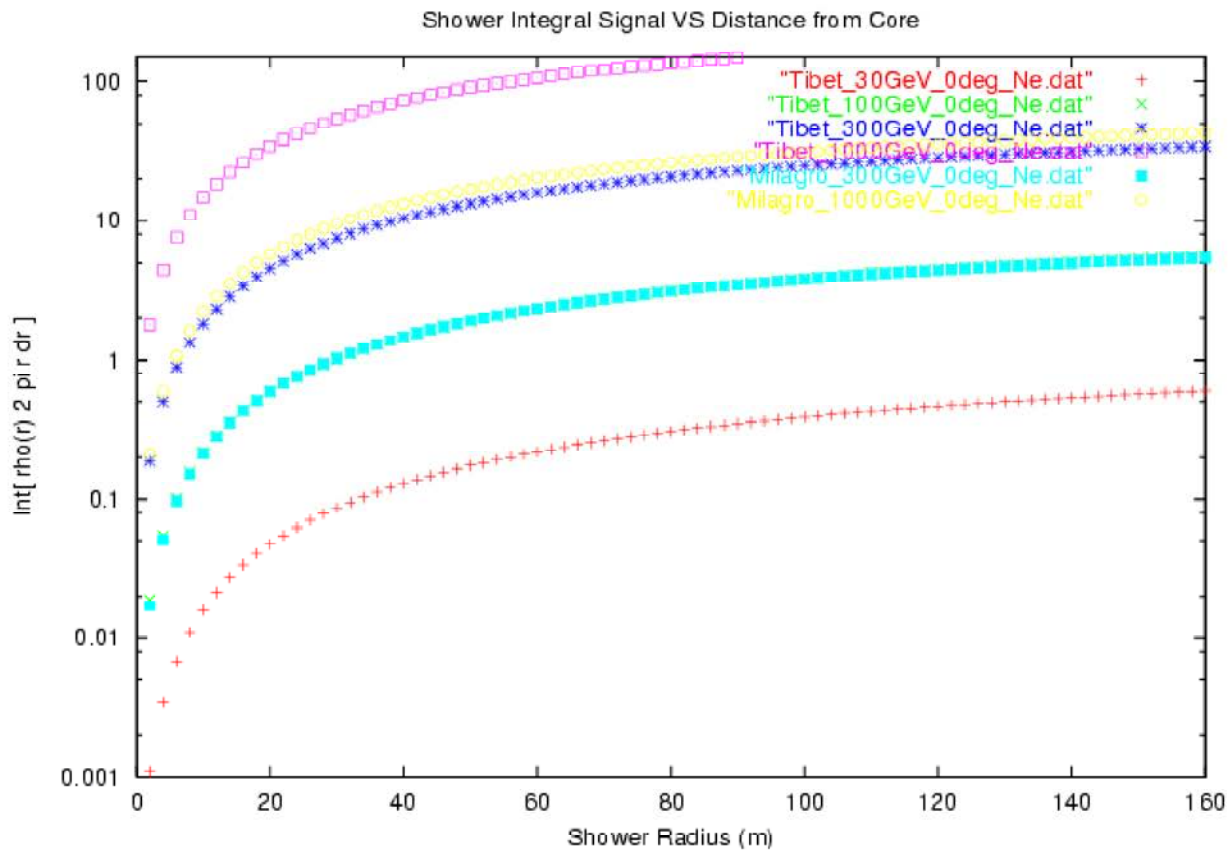
3: Tibet(4500m) : Milagro comparison



Last year of pressure data from Milagro

- Average Milagro pressure $\sim 740\text{mbar}$
- Average Tibet (4300m) pressure $\sim 605\text{mbar}$
- **Which I parameterized using the US Standard Atmosphere with $T_{sea\ level} = 300\text{K}$ giving:**
 - $X_{expt}^{Milagro} \approx 757\text{ gm/cm}^2$
 - $X_{expt}^{Tibet(4500m)} \approx 603\text{ gm/cm}^2$
- Note: X_{expt} varies by $\sim \pm 10\text{ gm/cm}^2$ with season
- And for comparison: $X_{expt}^{Tibet(4500m)} - X_{expt}^{Tibet(5000m)} \approx 38\text{ gm/cm}^2$

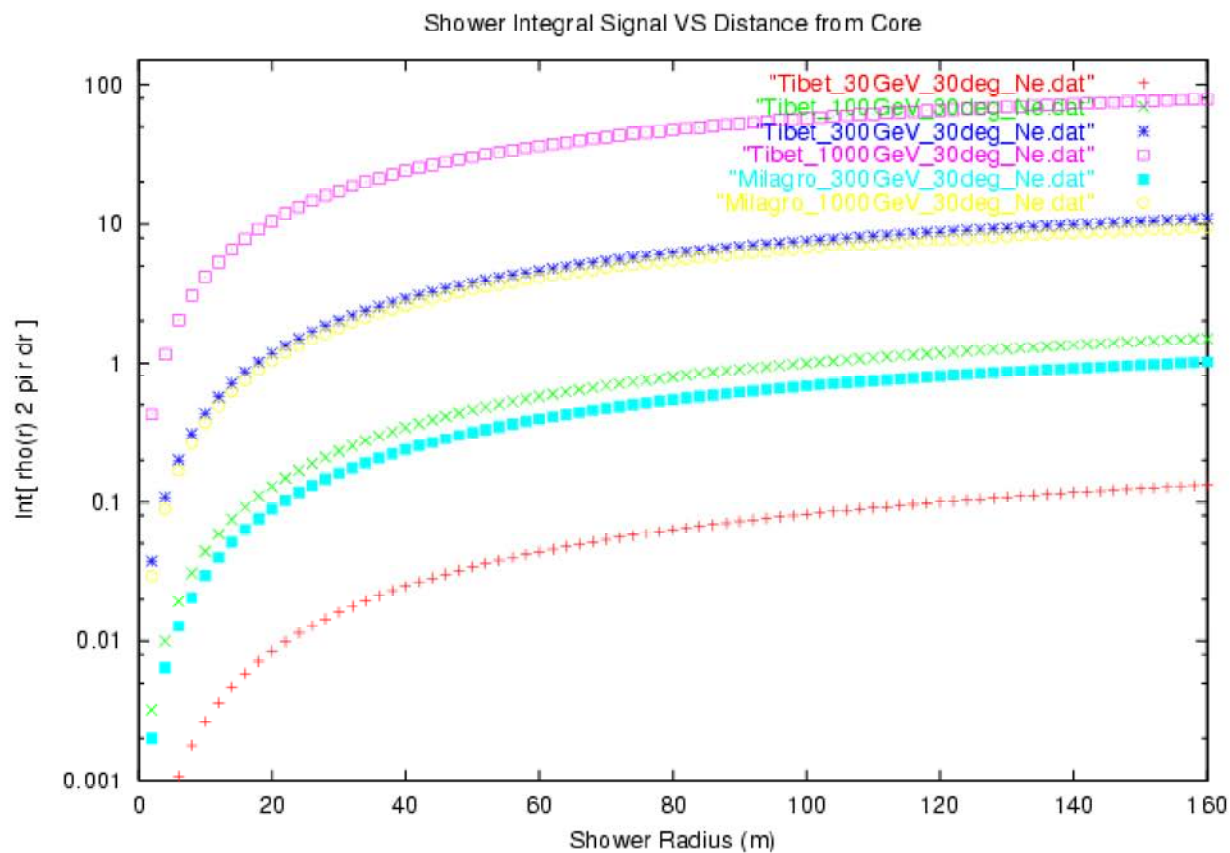
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r) 2\pi r dr$ for $\theta = 0^\circ$ **Tibet site (4500m)**

- B.O.E. “electron” signals VS distance from the core for 30 GeV, 100 GeV, 300 GeV and 1000 GeV photon showers at the Tibet site
- Also plotted are 300 GeV and 1000 GeV B.O.E. showers at the Milagro site
- **A 1000 GeV Milagro shower is brighter than a 300 GeV Tibet(4500m) shower!**

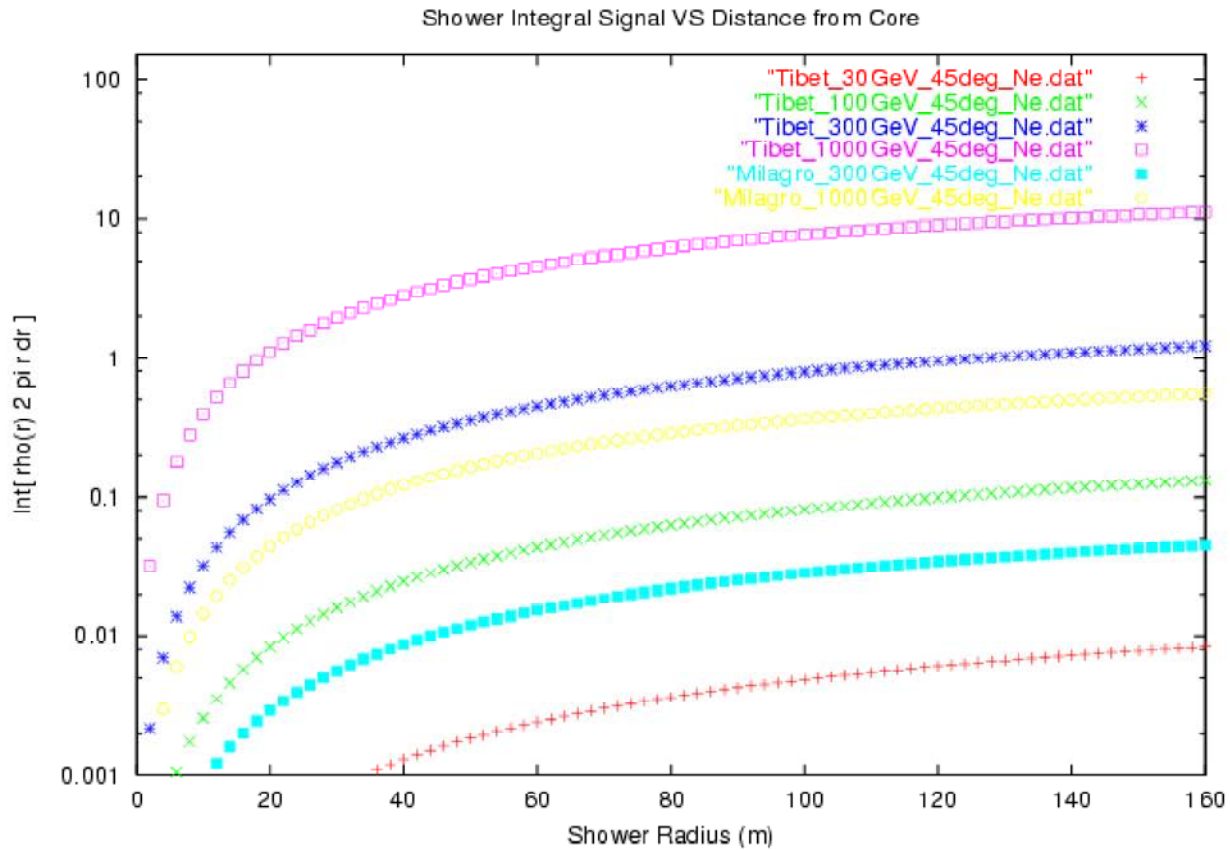
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r) 2\pi r dr$ for $\theta = 30^\circ$ **Tibet site (4500m)**

- B.O.E. “electron” signals VS distance from the core for 30 GeV, 100 GeV, 300 GeV and 1000 GeV photon showers at the Tibet site
- Also plotted are 300 GeV and 1000 GeV B.O.E. showers at the Milagro site
- **A 1000 GeV Milagro shower is the same as a 300 GeV Tibet(4500m) shower!**

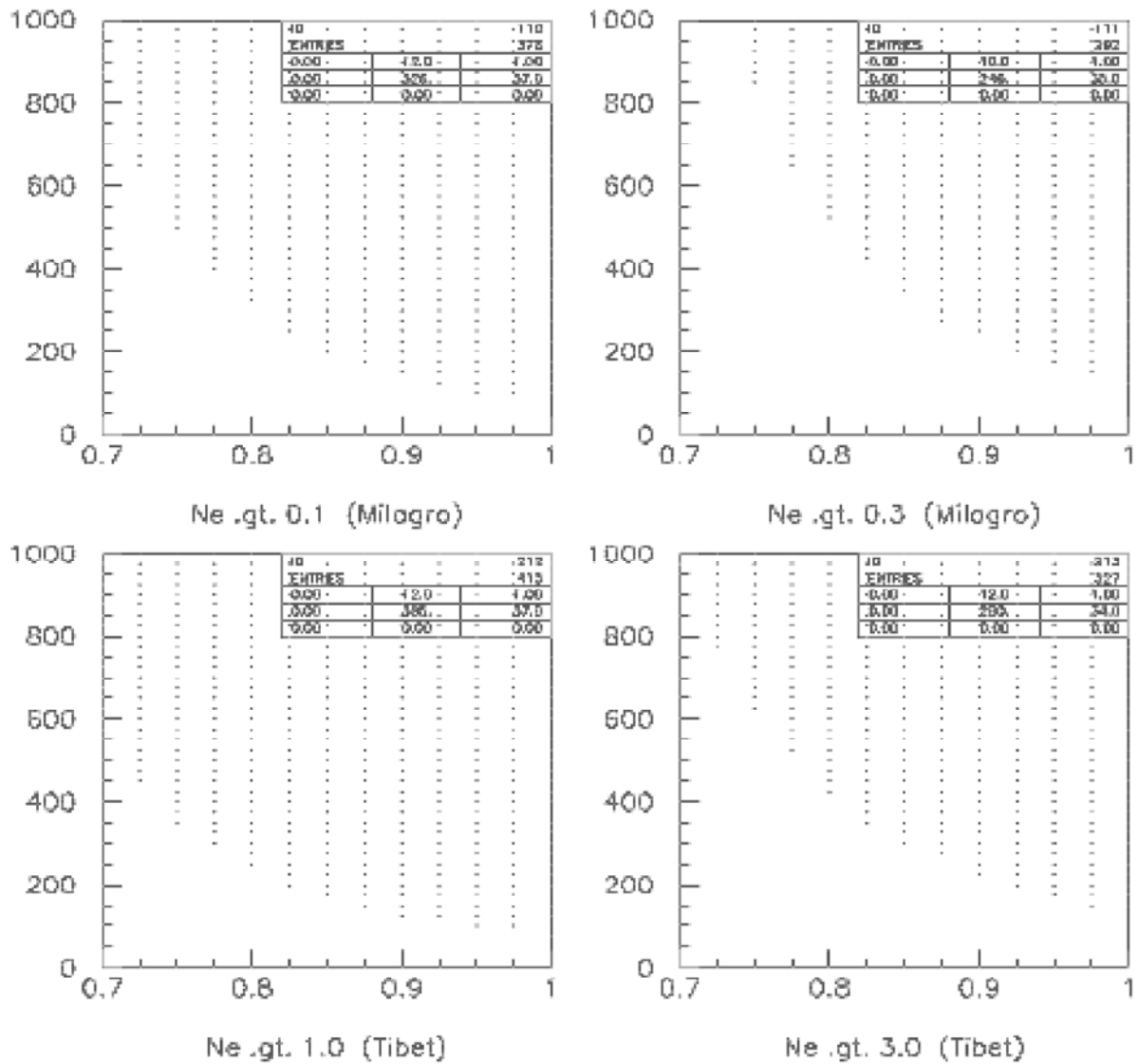
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r) 2\pi r dr$ for $\theta = 45^\circ$ **Tibet site (4500m)**

- B.O.E. “electron” signals VS distance from the core for 30 GeV, 100 GeV, 300 GeV and 1000 GeV photon showers at the Tibet site
- Also plotted are 300 GeV and 1000 GeV B.O.E. showers at the Milagro site
- **A 1000 GeV Milagro shower is fainter than a 300 GeV Tibet(4500m) shower!**

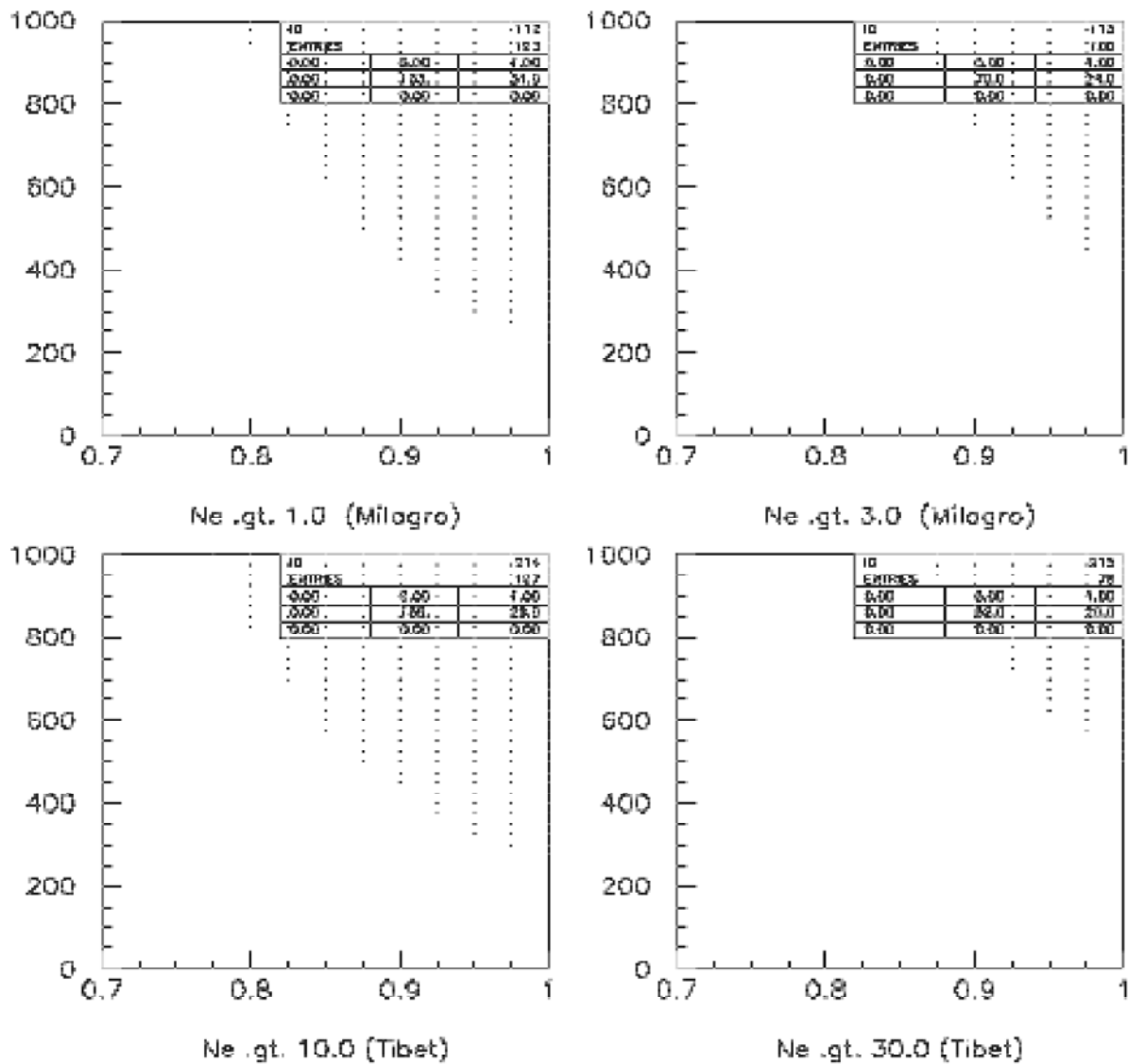
3: Tibet(4500m) : Milagro comparison (con't)



E_{shower} (GeV) *versus* $\cos(\theta)$ passing cut

- $\int_0^{50m} \rho_e(r) 2\pi r dr > \text{lower thresholds}$
- The B.O.E. model predicts $\sim 10\times$ the **signal** for Tibet(4500m) *versus* Milagro!

3: Tibet(4500m) : Milagro comparison (con't)



E_{shower} (GeV) *versus* $\cos(\theta)$ passing cut

- $\int_0^{50m} \rho_e(r) 2\pi r dr > \text{higher thresholds}$
- Again the B.O.E. model predicts $\sim 10\times$ the **signal** for Tibet(4500m) *versus* Milagro!

3. Summary

- The BOE model is an (analytic) approximation for the charged particle density in an average shower:
 - **while absolute predictions are probably unreliable**
 - **relative predictions should have some reliability**
- **BOE predictions of $\rho_e(r)$ show that HAWC Tibet(4500m) should have $3 \sim 10\times$ the signal of (HAWC at) Milagro:**
 - $\rho_e(r)$ for a Milagro 1 TeV shower $\approx$ a Tibet(4500m) 300 GeV shower
 - $\int_0^{50m} \rho_e(r) 2\pi r dr$ for Tibet(4500m) showers is $\sim 10\times$ that for Milagro showers of the same E_{shower} and zenith angle
- The simplicity of BOE calculations allow quick comparisons with other candidate sites ...