HAWC Sensitivity from BOE Showers

HAWC/Milagro Collaboration Meeting

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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 ($T_{sea\ level} \approx 300$K)
   - $\int_0^r \rho_e(r) 2\pi r dr$ 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, $s(T)$:

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

where:

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

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

    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:

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

where:

- $\rho_e(r)$ **is the charged particle ($e^{\pm}$) track density/m^2**,
- 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 $\sim$ 2 radiation lengths above the experiment [with local temperature T(K) and pressure P(mbar)]:

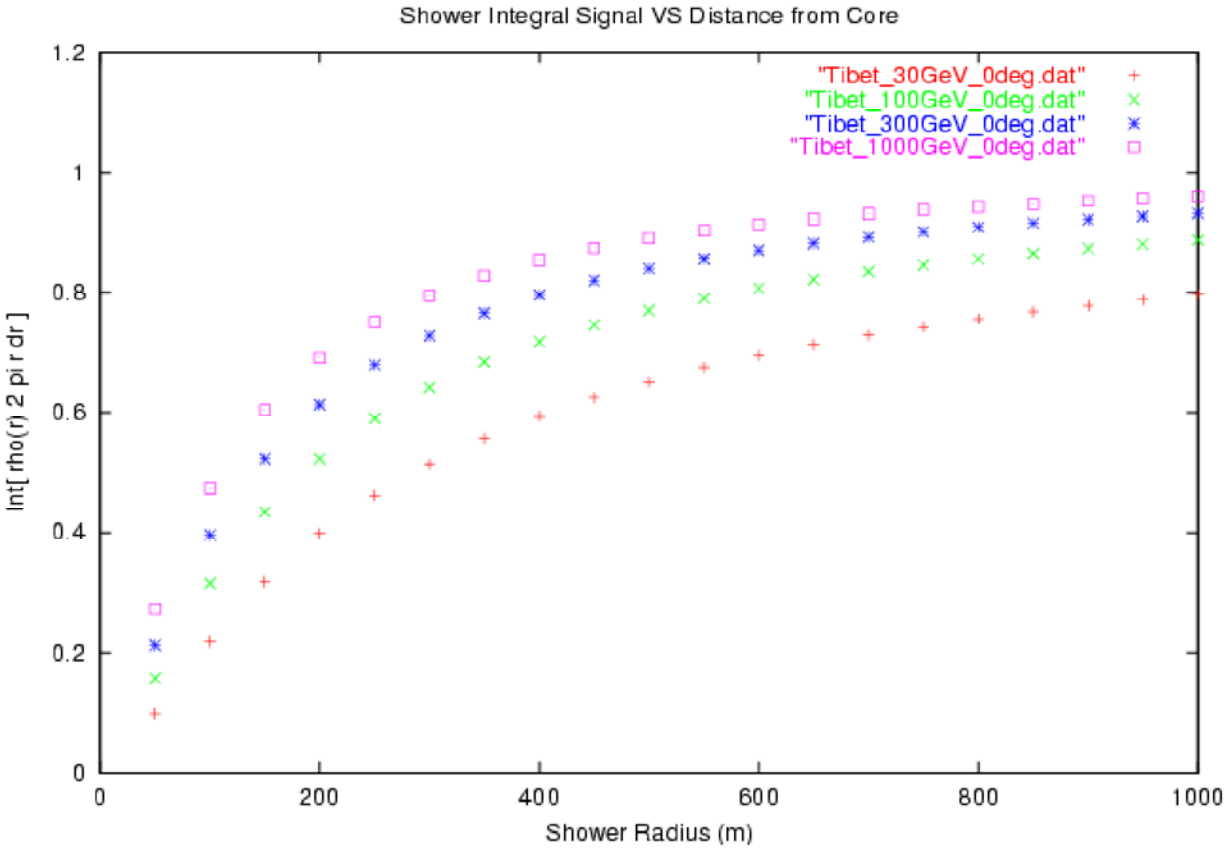
$$r_m(m) \;\approx\; 272.5\cdot\frac{T(K)\cdot(\frac{P(mbar)\;-\;73.4\cdot cos\theta}{P(mbar)})^{1./5.25588}}{(P(mbar)\;-\;73.4\cdot cos\theta)}$$

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.

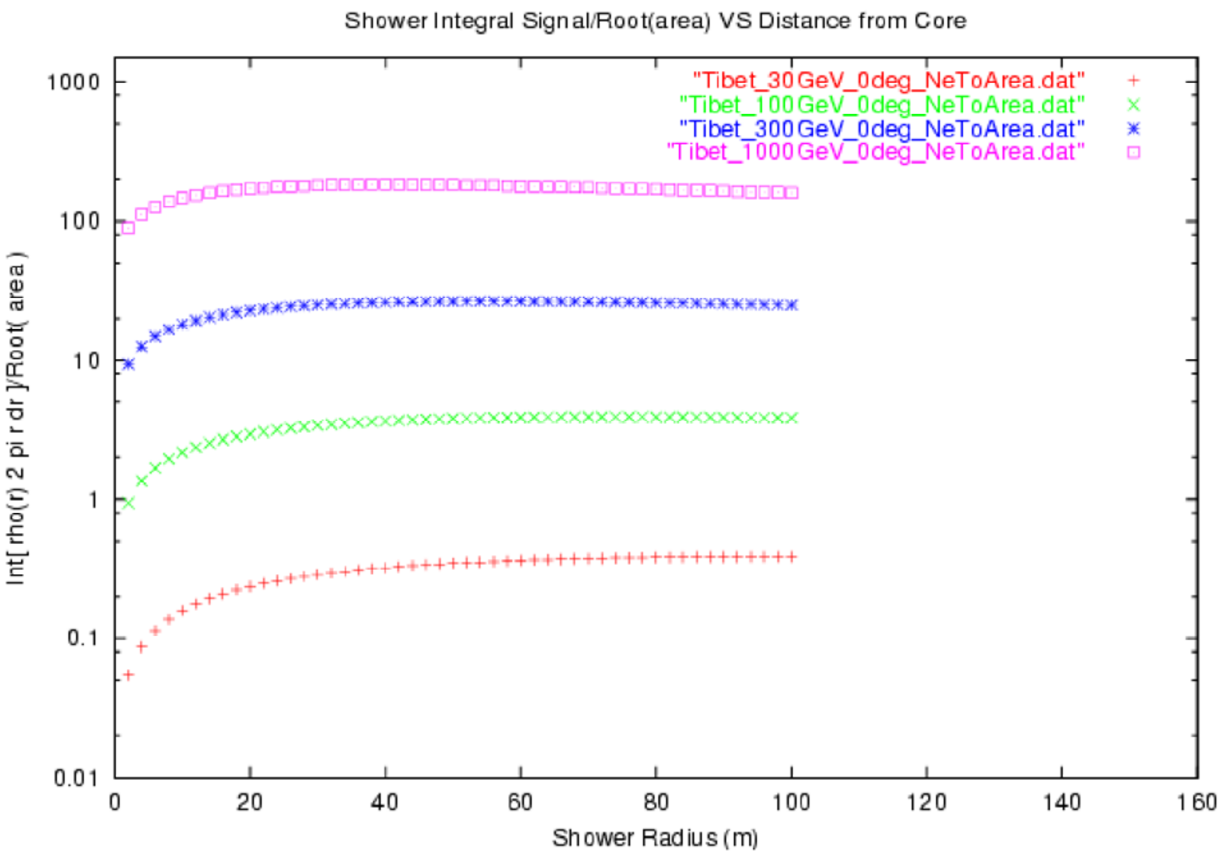
2: A fraction of the signal hits the pond ...



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

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

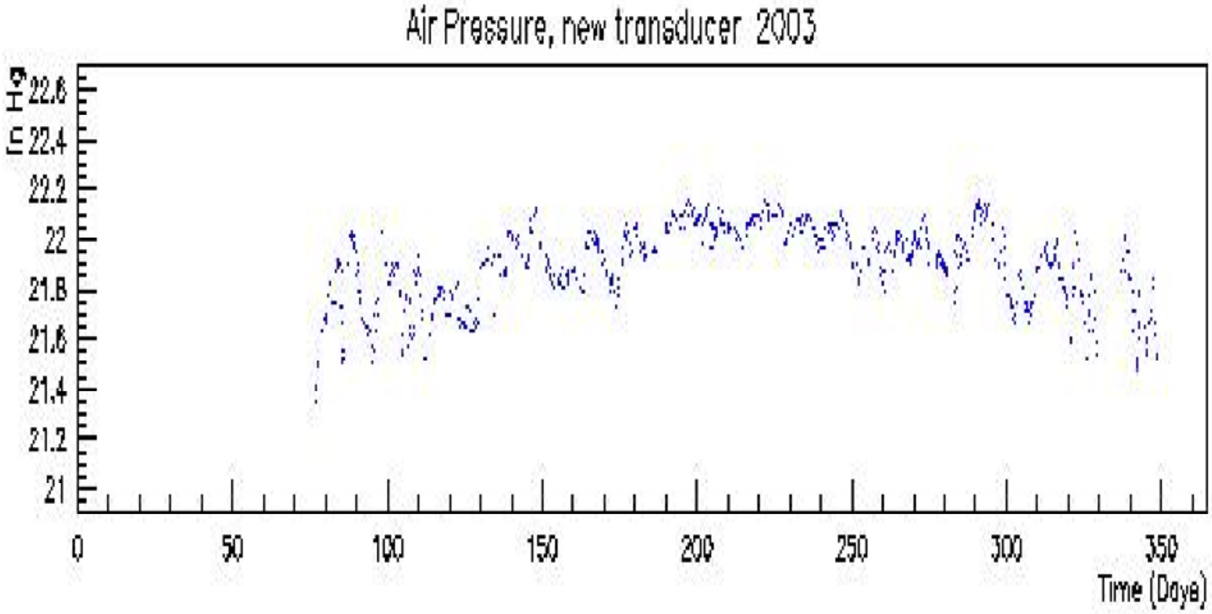
2: A fraction of the signal hits the pond ... (con't)



$\int_0^r \rho_e(r) 2\pi r dr / \sqrt{area}$ **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 $\sqrt{\# \ of \ PMTs}$ then the "signal/noise" is approximately constant for $r \gtrsim 50$m
- **In the B.O.E. model, a 200m x 200m detector matches the *brightest* part of the shower!**

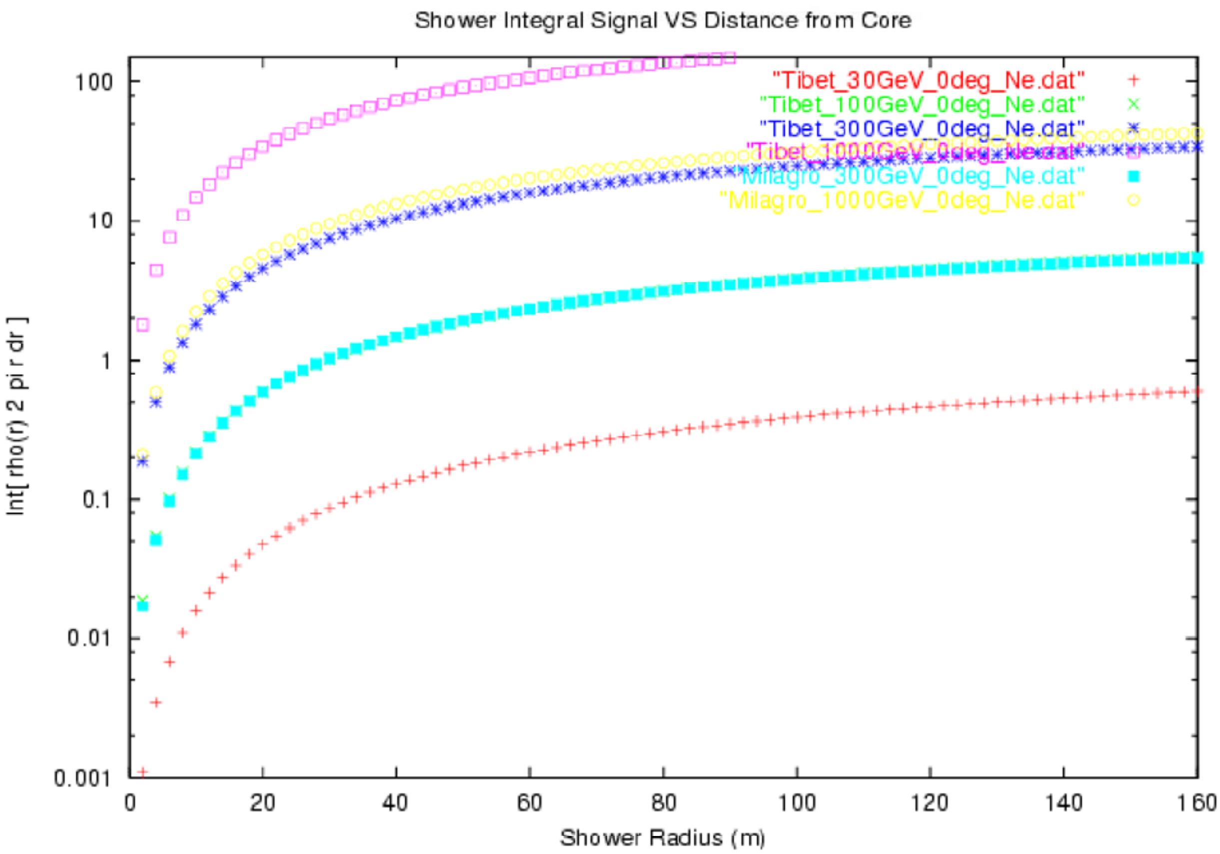
3: Tibet(4500m) : Milagro comparison



Last year of pressure data from Milagro

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

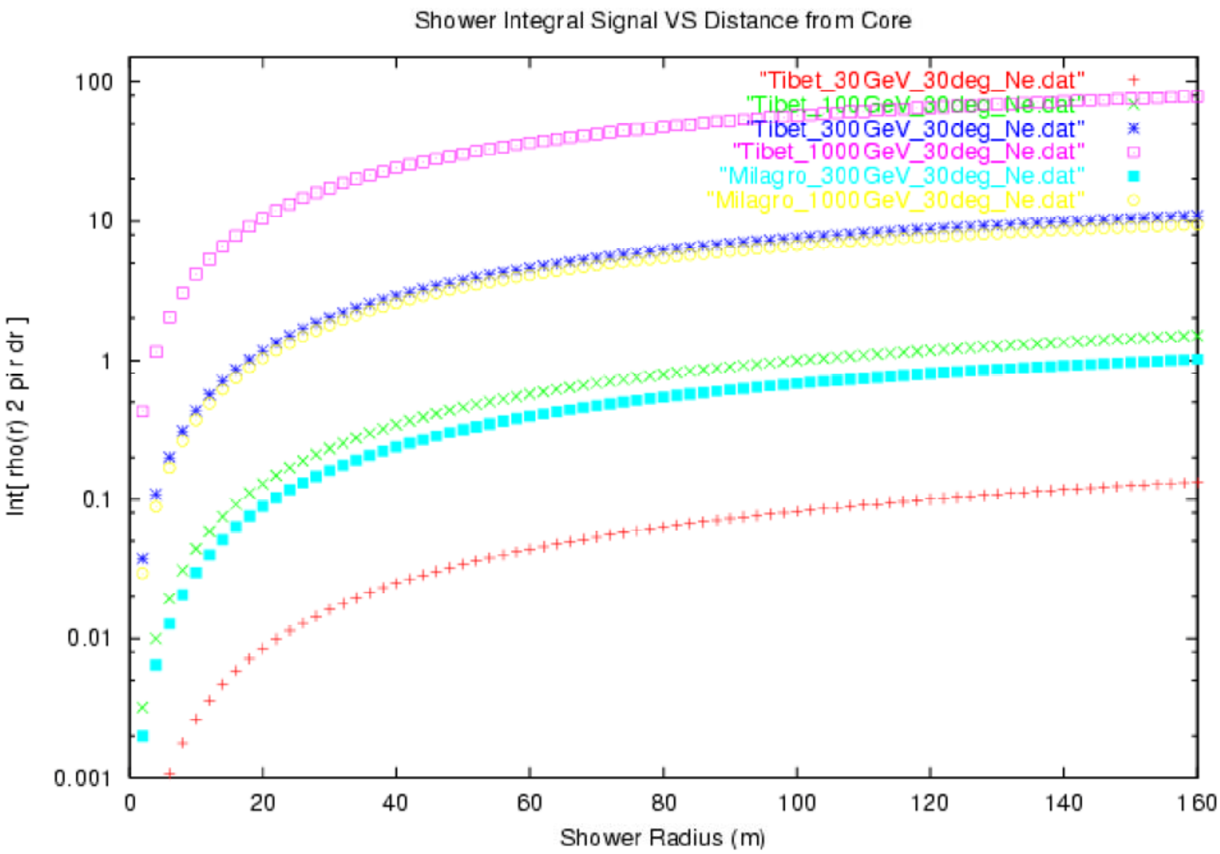
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r)2\pi r dr$ **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!**

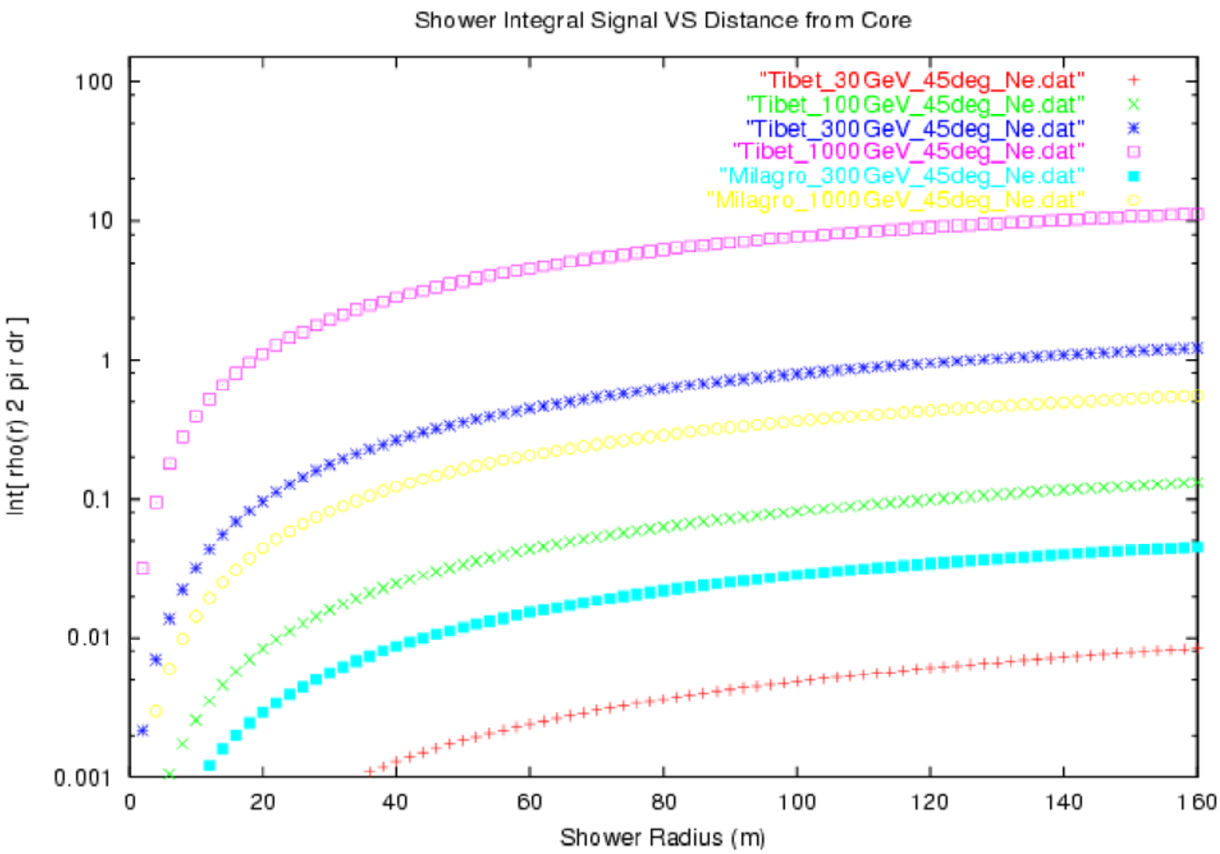
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r) 2\pi r dr$ **for** $\theta = 30°$ **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!**

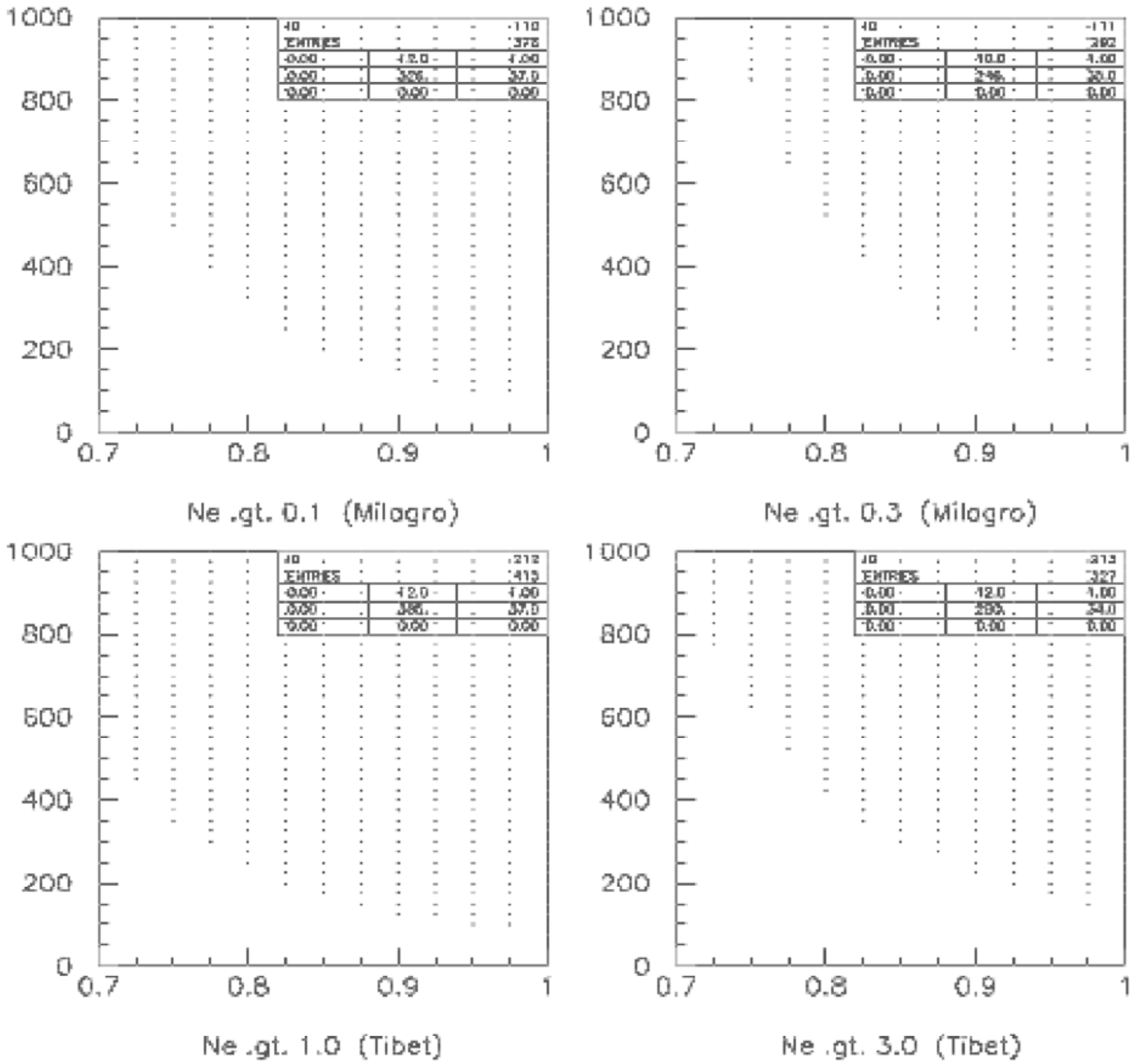
3: Tibet(4500m) : Milagro comparison (con't)



$\int_0^r \rho_e(r) 2\pi r dr$ **for** $\theta = 45°$ **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!**

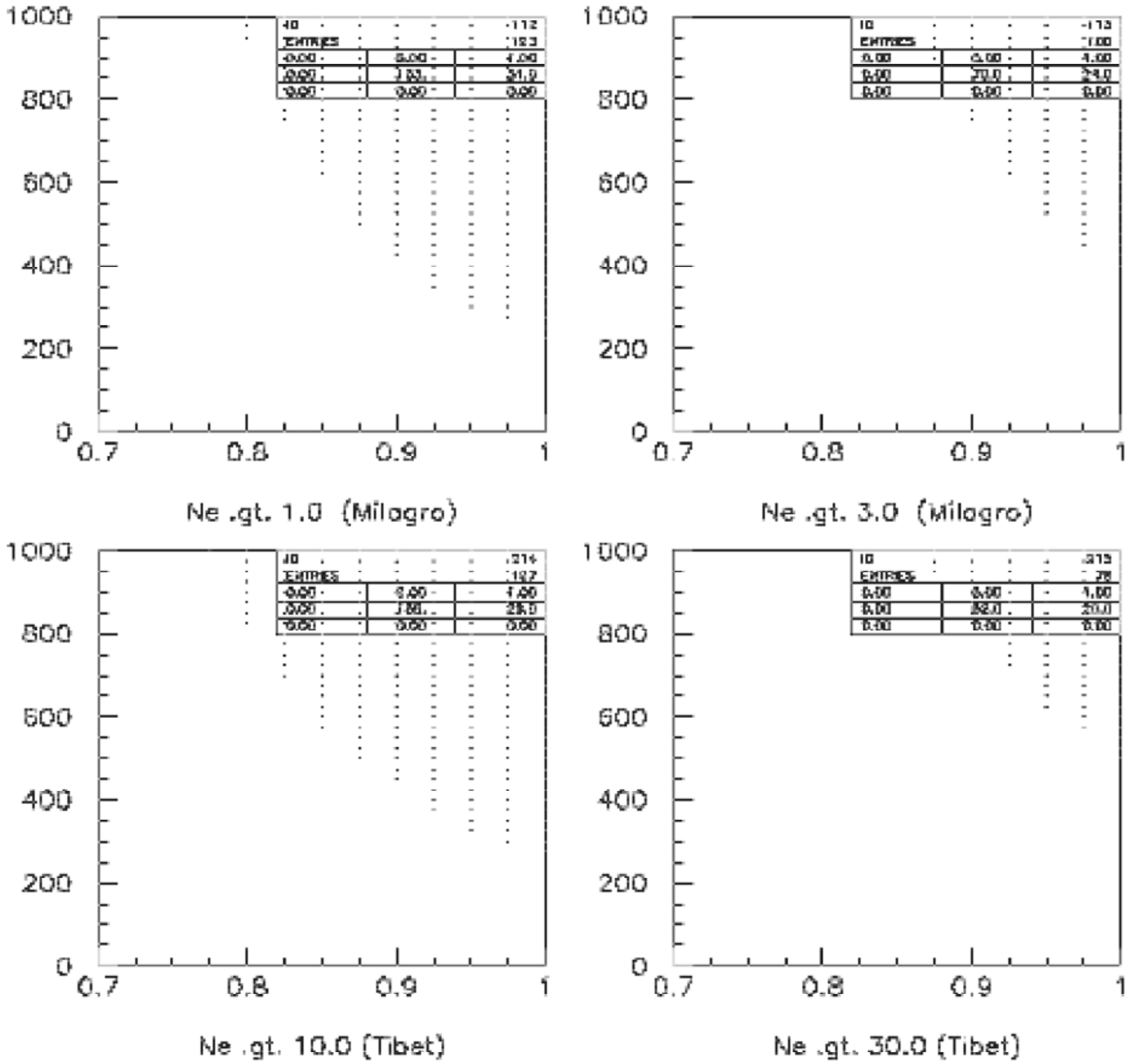
3: Tibet(4500m) : Milagro comparison (con't)



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

- $\int_0^{50m} \rho_e(r) 2\pi r dr \;\; > \;\;$ *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 \ \ > \ \ $ *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 ...