

FD Atmospheric Absorption Corrections: Overview and Issues

Auger Event Reconstruction Workshop

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Atmospheric Corrections...

~ ordered by importance

1) Clouds:

- * Cloud monitors: steerable IR cameras
- * Shoot-the-shower: " LIDARS

2) Transmission corrections:

- * aerosols: steerable LIDAR's
(HAMS, star monitor)
[vertical laser beams ... proposed]
- * molecular: weather stations
radiosondes ... new Karlsruhe initiative
- * gone: —

3) Air Cherenkov correction:

- * to the above add: APF light source(s)

4) Multiple scattered light, consistency check, ...

Probably need at least one, steerable, "5 mJ/pulse"
UV laser sited away from FD's.

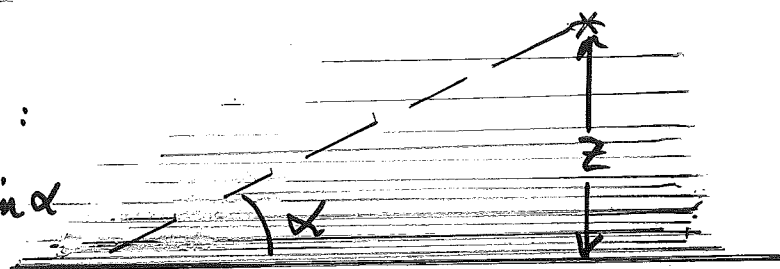
5) Other atmospheric effects, issues, ...

- * fluorescence efficiency (ϕ, T)
- * "Where is the grammar?"

"Transmission 101"

For 1-D atmospheres:

$$T(z, \alpha) = e^{-\tau(z)/\sin \alpha}$$



$$\tau(z) \equiv \int_0^z \frac{dz}{\Lambda(z)} \leftarrow \text{"local" attenuation length}$$

molecular: $\Lambda(z, \lambda) = \frac{2974 \text{ gm/cm}^2}{\rho(z)} \cdot \left(\frac{\lambda}{400 \text{ nm}} \right)^4 \approx 18.4 \text{ km}$
 @ 360 nm and $z=0$

aerosol: (model) $\Lambda(z) = \begin{cases} \Lambda(0) & z \leq h_m \leftarrow \text{mixing height} \\ \Lambda(0) e^{-(z-h_m)/h_a} & \leftarrow \text{scale height} \end{cases}$
 horizontal extinction length

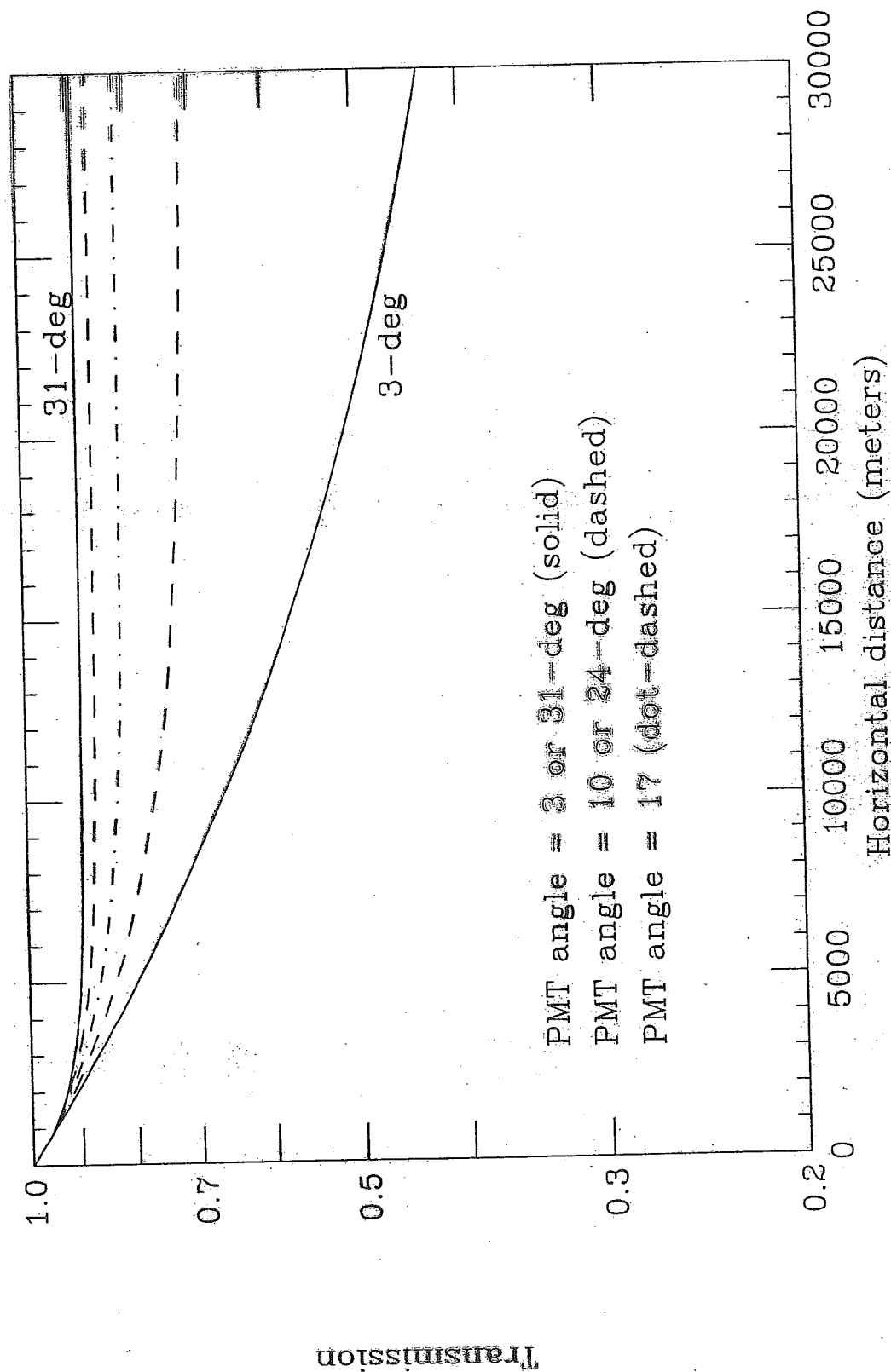
$$\tau(z \gg h_m, h_a) = \frac{h_m + h_a}{\Lambda(0)}$$

$$\approx \frac{1 \text{ km}}{25 \text{ km}} = 0.04 \text{ (Hilles-Utah)}$$

∞ for much of the shower:

$$T^a \equiv e^{-\tau(0)/\sin \alpha}$$

UV Transmission versus Distance (Mie)



How well do we know the corrections?

Quite well IF the atmosphere is the same as in our Monte Carlo

Not so well based ONLY on our atmosphere measurements.

EXAMPLE... B.O.E. estimate of $\frac{\Delta E}{E} = \frac{\Delta I^{\text{source}}}{I^{\text{source}}} = \frac{\Delta T}{T}$:

molecular: use $T(z, \alpha) = T(z, 90^\circ)^{1/\sin \alpha}$

$$\text{then: } \frac{\Delta T}{T} = \frac{1}{\sin \alpha} \frac{\Delta T(z, 90^\circ)}{T(z, 90^\circ)}$$

$$\therefore \frac{\Delta T(z, 90^\circ)}{T(z, 90^\circ)} \lesssim \underset{\substack{\uparrow \\ 0.1 \sim 0.2}}{\sin \alpha} \times \frac{\Delta T}{T} \approx \underline{\underline{0.005 \sim 0.01}} \text{ (...OK?)} \\ \uparrow \leq 0.05 \text{ goal}$$

aerosol:

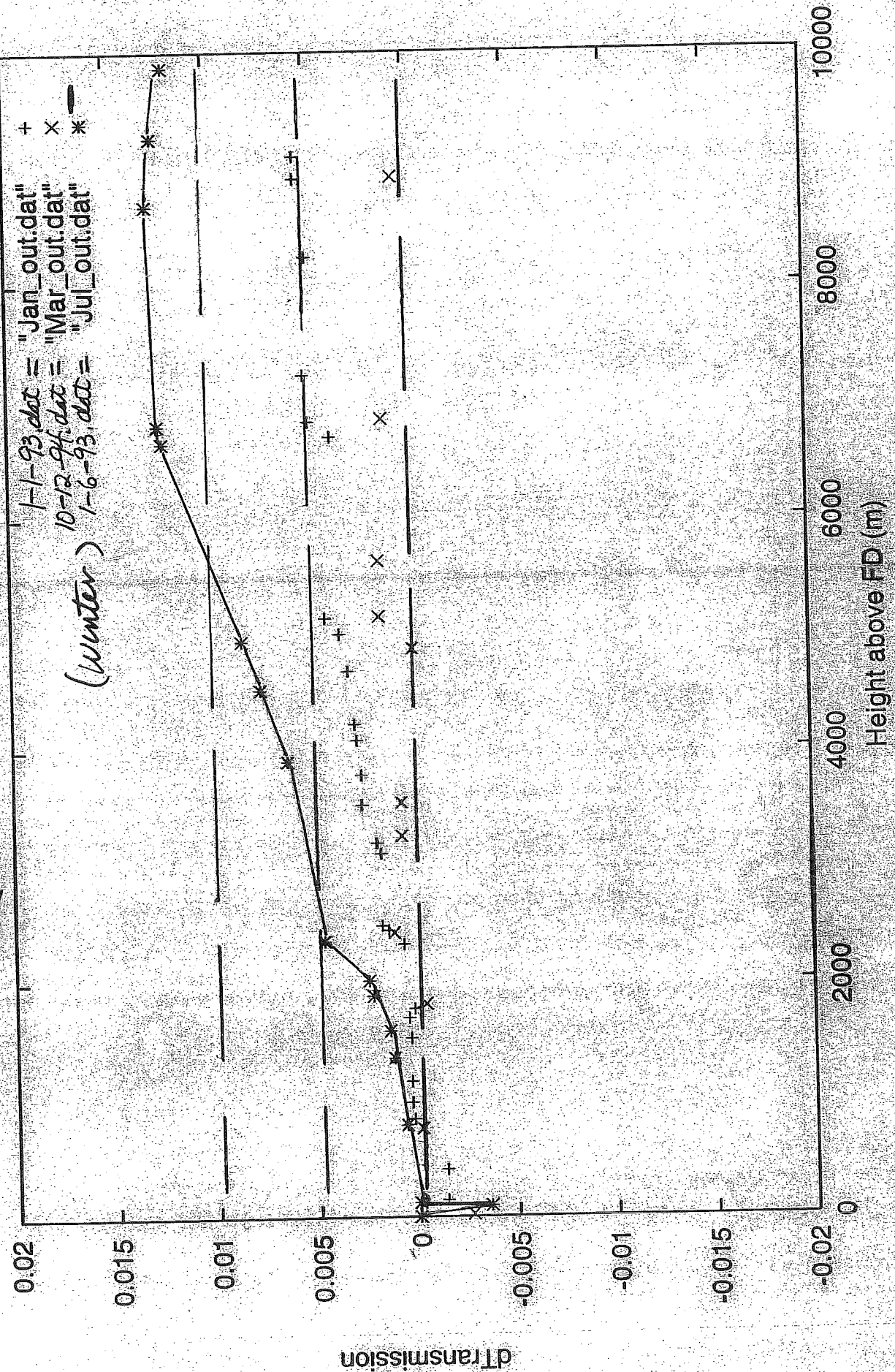
$$\frac{\Delta T}{T} = \frac{1}{\sin \alpha} \Delta \epsilon$$

① For Auger we do not know $\Delta \epsilon$! (... maybe soon:)

② For $\frac{\Delta T}{T} < 0.1$ then $\Delta \epsilon < \sin \alpha \frac{\Delta T}{T} \approx 0.01 \sim 0.02$ †
 $\uparrow \quad \quad \uparrow$
 $0.1 \sim 0.2 \quad \epsilon < 0.1 \text{ goal}$

† NB: $\epsilon_{\text{Hiles 1999}}^{(\infty)} - \epsilon_{\text{Hiles 2002}}^{(\infty)} \approx 0.05$
 $\uparrow \quad \quad \uparrow$
a model measurements

RADIOSOUP Mendoza Rayleigh Transmission VS Adiabatic Model



A "not unreasonable" estimate of $\frac{\Delta T^a}{T^a}$:

IF the (exponential) scale height of the "Malargue" atmosphere is $h_a = 1 \pm 0.5$ km, then:

$$\delta z^a(\infty) = \frac{0.5 \text{ km}}{\Lambda_{\text{HAM}}^a} \lesssim 0.025 \quad \text{for } \Lambda_{\text{HAM}}^a > 20 \text{ km}$$

$$\text{or: } \frac{\Delta T^a}{T^a} \lesssim \frac{0.025}{0.1 \sim 0.2} = 13 \sim 25\%^\dagger$$

Caveats:

- 1) Λ_{HAM}^a needs to be calibrated
- 2) Until we analyze the LIDAR data (or vertical laser data) we do not know h_a .

[†] Consistent w/ studies done by B. Dawson
"re"-analyzing E.A. events w/ different atmospheres.

AVOD ($\equiv \tau^a(z)$) Light Sources (M. Roberts)

- ✓ simple geometry and analysis
- ✓ variety of F.D. cross checks "for free"

Dominant uncertainties:

$$(1) \frac{\delta I^{\text{laser}}}{I^{\text{laser}}} \lesssim 0.1$$

$$(2) \frac{\delta \varepsilon^{\text{FD}}}{\varepsilon^{\text{FD}}} \lesssim 0.1$$

$$(3) \frac{\delta \rho^m}{\rho^m} \oplus \frac{\delta \left(\frac{1}{\sigma} \frac{d\sigma}{dz} \Big|_R + \frac{\Lambda^m}{\Lambda^a} \frac{1}{\sigma} \frac{d\sigma}{dz} \Big|_m \right)}{\left(\frac{1}{\sigma} \frac{d\sigma}{dz} \Big|_R + \frac{\Lambda^m}{\Lambda^a} \frac{1}{\sigma} \frac{d\sigma}{dz} \Big|_m \right)} \lesssim 0.1$$

$$(4) \delta \tau^m(z) \lesssim 0.005$$

Then:

$z(\text{km})$	$\delta \tau^a(z)$	} for laser at 34km from (each) F.D.
1	.007	
2	.011	
3	.015	
4	.019	

↑ estimated measurement
precision / F.D.

Consistent with

$$\delta \tau^a(z) \leq 0.01 \sim 0.02$$

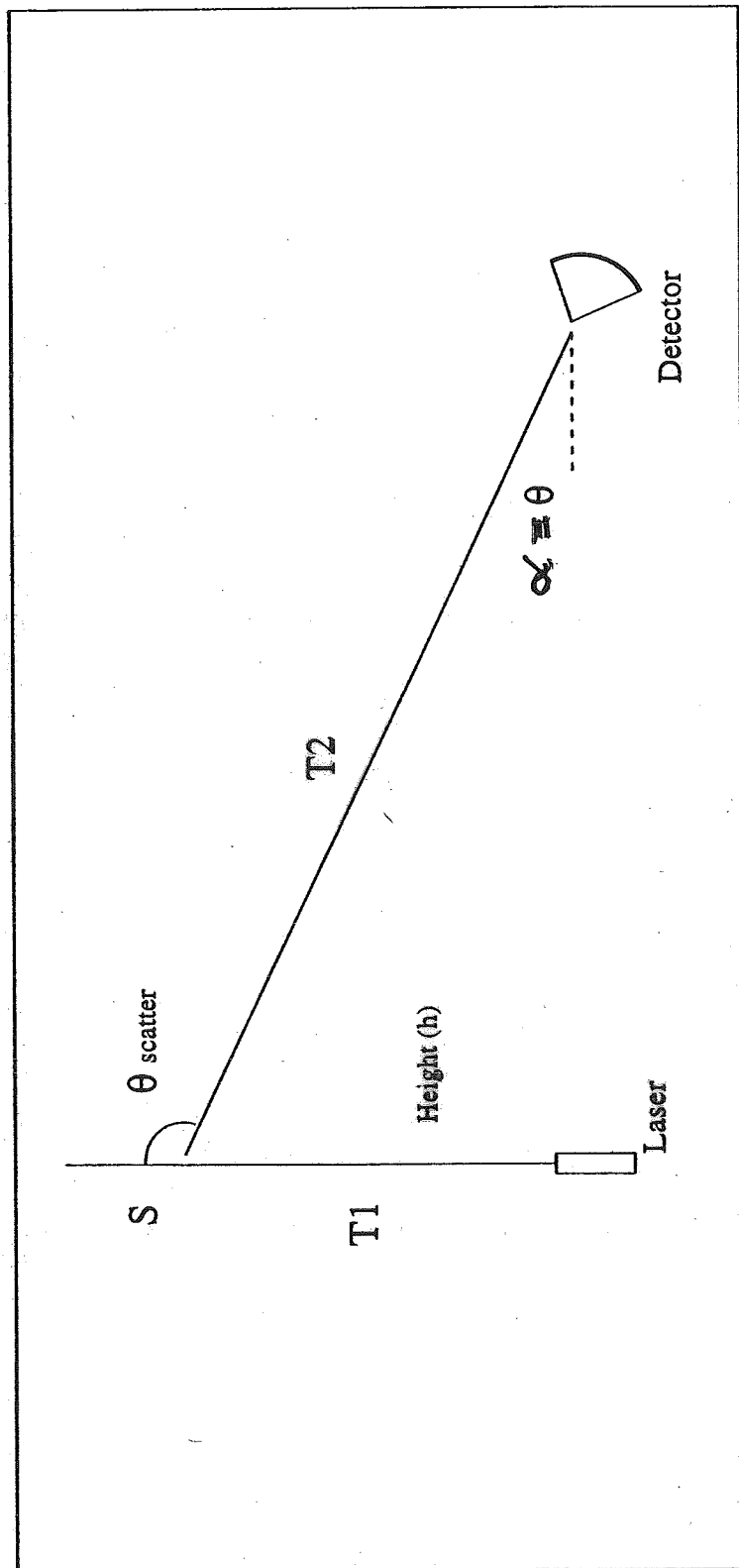
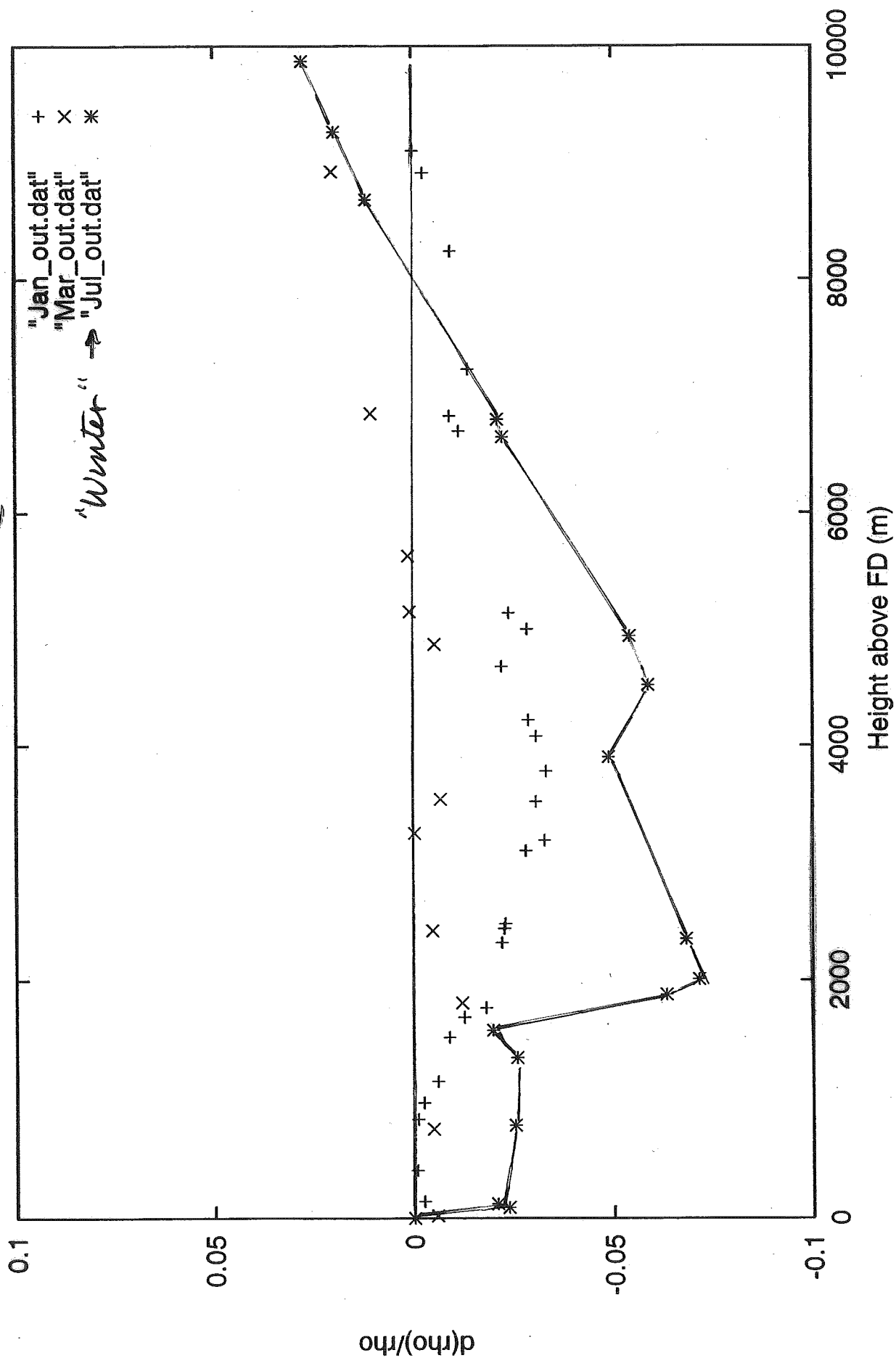
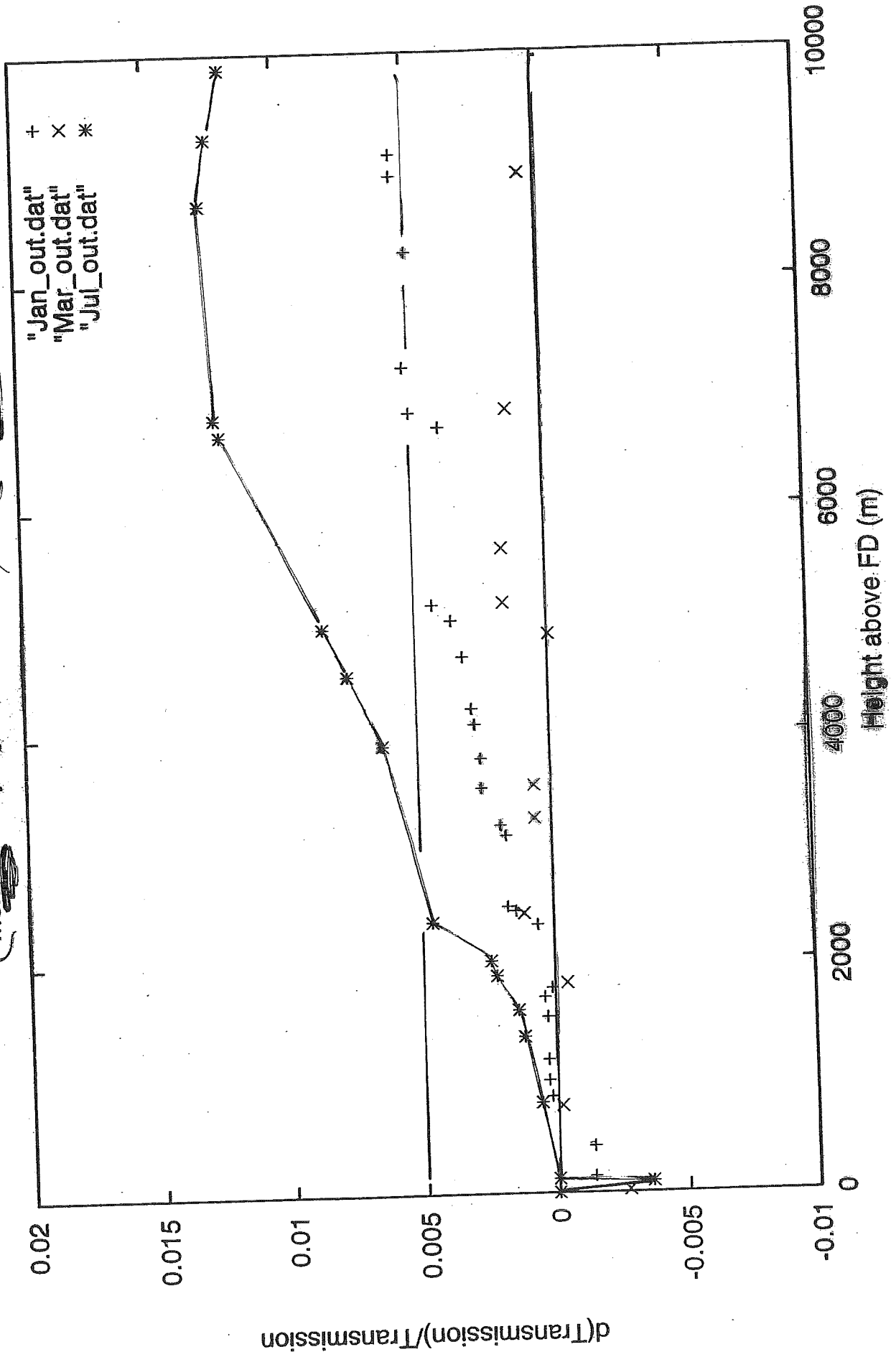


Figure 3: Measurement of aerosol optical depth with vertical laser beams. The amount of light measured at the detector at height h is determined by the vertical transmission ($T1$) to h , the scattering (S) at h and the transmission ($T2$) back to the detector.

RADIOSONDE
 (Mendoza Rayleigh Air Density VS Adiabatic Model)



Radio.sonde (Mendoza Rayleigh Transmission) VS (Adiabatic Model)



The basics (... what happens in detail) :

■ Fluorescence Detector (FD) telescopes observe $\gamma_{i,j}^{\text{OBS-FD}}$ photons in telescope "i", pixel "j"

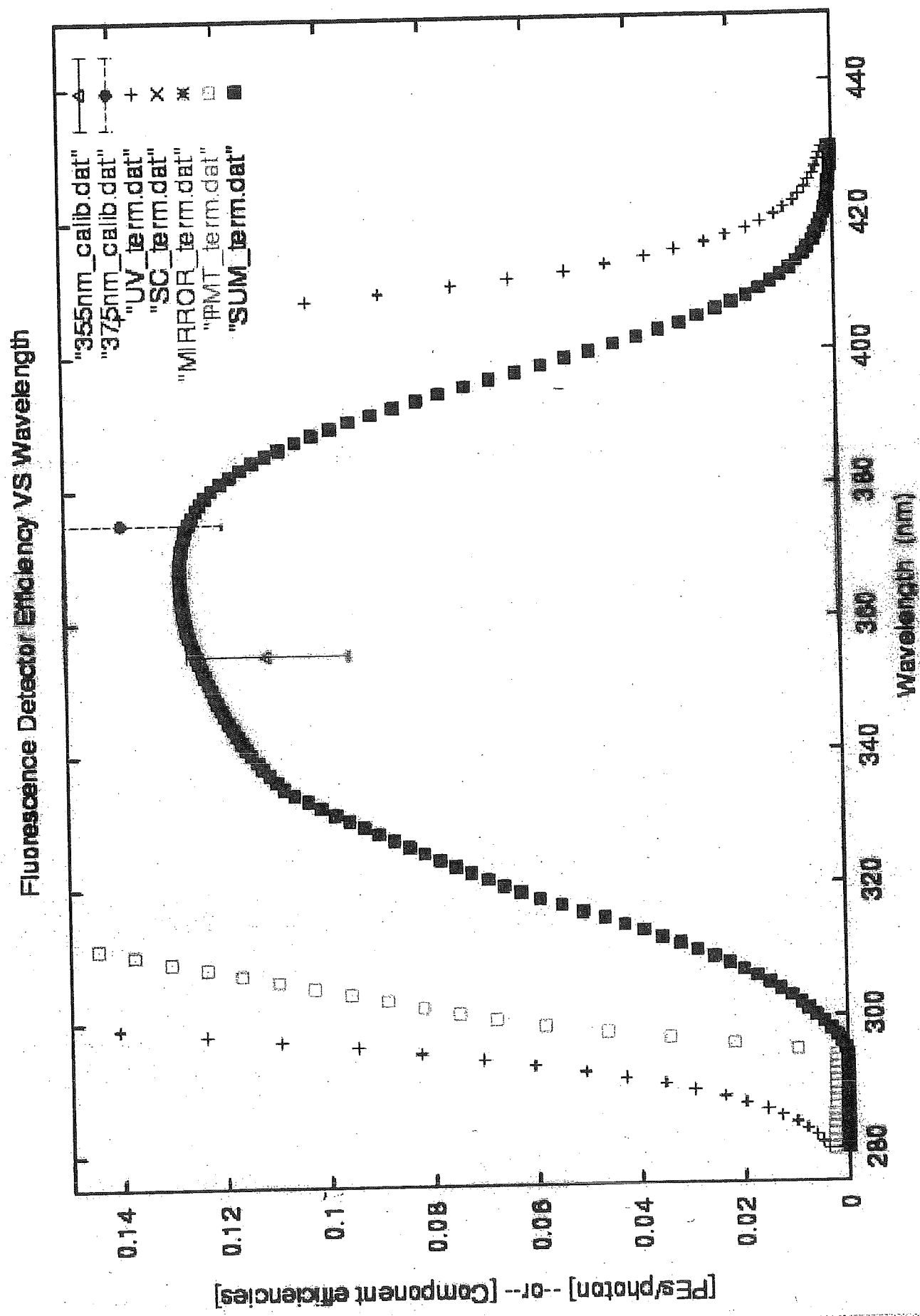
■ Once the shower geometry is reconstructed then we can correct $\gamma_{i,j}^{\text{OBS-FD}}$ to $\gamma_{i,j}^{\text{OBS-SOURCE}}$ at the shower:

$$\gamma_{i,j}^{\text{OBS-SOURCE}} \propto \frac{\gamma_{i,j}^{\text{OBS-FD}}}{\sum_k T^a(\lambda_k) T^m(\lambda_k) T^o(\lambda_k) \epsilon_{i,j}(\lambda_k) f(\lambda_k)}$$

where: (1) T^a, T^m, T^o are aerosol, molecular, and ozone transmissions,

(2) $\epsilon_{i,j}(\lambda_k)$ is the telescope efficiency,

(3) $f(\lambda_k)$ is the fraction of light (at the source) in each wave length "bin".



Comments:

a) $T(\lambda)^a \sim \text{constant with wavelength}$;
 $T(\lambda)^m$ and $T(\lambda)^o$ are smallest at "short"
wavelengths, $\lambda \sim 300\text{nm}$, thus "skewing"
the FD wavelength acceptance to
"longer" wavelengths.

b) $f(\lambda_k)$ are evaluated "iteratively"
as the amount of air Cherenkov light
is estimated at each depth in the
shower.

... and your point is?

- many details that must not become
"lost with time"

- ✓ notes discussing/documenting each "piece"

- ✓ data-bases (to track each "piece" with
time)

T. Abu Zayyed, May 2000

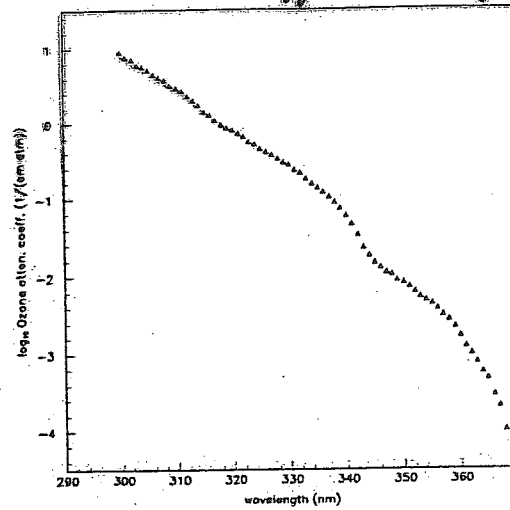


Figure 6.4. The Ozone attenuation coefficient as a function of wavelength.

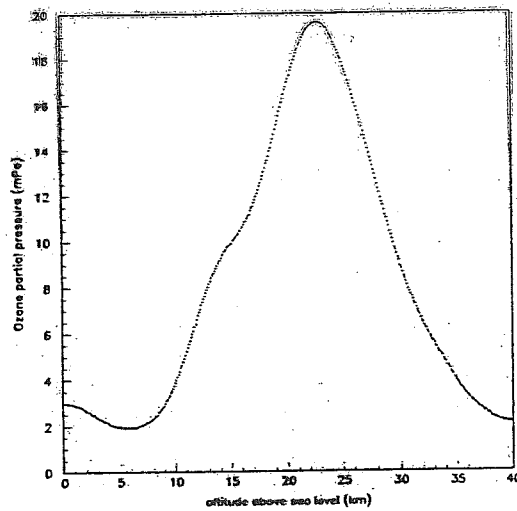


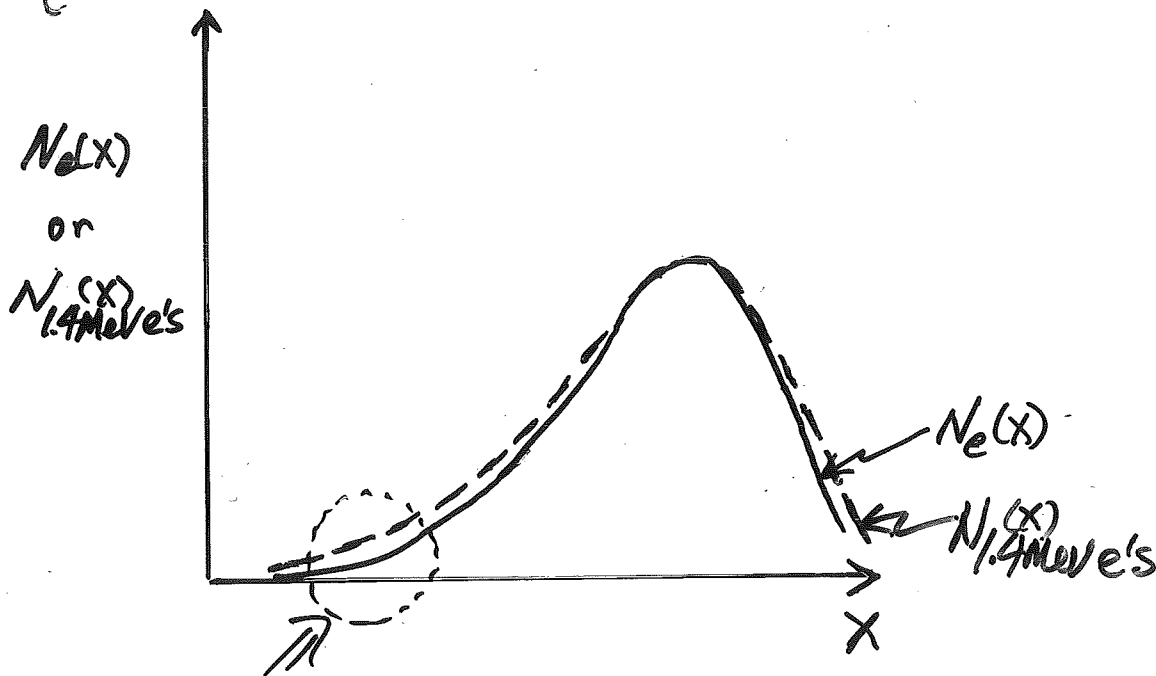
Figure 6.5. Ozone concentration as function of altitude.

... the devil is in the details ...

Given the number of "RECONSTRUCTED" UV photons, $\gamma^{\text{obs-source}}(\gamma/m)$, at the shower, then :

$$N_{1.4\text{MeV e's}}(x) \equiv \frac{\gamma^{\text{obs-source}}(x) \text{ (photons/m)}}{\gamma_{1.4\text{MeV e}^-}(\text{local } g, T) \text{ (photons/m/1.4MeV e}^-)}$$

Atmospheric fluorescence efficiency (ie the "calibration")
(FOR THE SAME WAVELENGTH RANGE USED IN THE ANALYSIS!)



$$\text{Scale factor} = \left\langle \frac{dE}{dx}(S(x)) \text{ MeV/gm/cm}^2 \right\rangle_{\text{showers}} \leftarrow \text{pw shower "electron"}$$

$$(\text{collisional}) \frac{dE}{dx} \Big|_{1.4\text{MeV e's}} \text{ MeV/gm/cm}^2$$

Thus: $N_e(x) = N_{1.4\text{MeV}e^\pm}^{(x)} \leftarrow \frac{\frac{dE}{dx}|_{1.4\text{MeV}e^\pm}}{\langle \frac{dE}{dx}(s(x)) \rangle_{\text{showers}}}$

Yes but "what do we mean by $N_e(x)$ "?

- Is it the number of $e^\pm$ above the simulation cutoff (eg 0.1 MeV in C. Song et al)?
- Is it an optimal quantity to fit with the Gaisser-Hillas parameterization?
- Is it the optimal estimator for air Cherenkov flux (ie $N_e(x)$ above air Cherenkov threshold)?

...

Thus input needed from simulations including:

① TOTAL collisional energy loss: $\frac{\Delta E}{\Delta x}(s(x))$ MeV/gm/cm²

② EFFECTIVE $e^\pm$ flux above air Cherenkov threshold: $N_e^{\text{eff}}(s(x))$

③ ...

Then eg $\langle \frac{dE}{dx}(s(x)) \rangle_{\text{showers}}^{\check{c}} \equiv \frac{\frac{\Delta E}{\Delta x}(s(x))}{N_e^{\check{c}}(s(x))}$

is available for analyzing the fluorescence data.

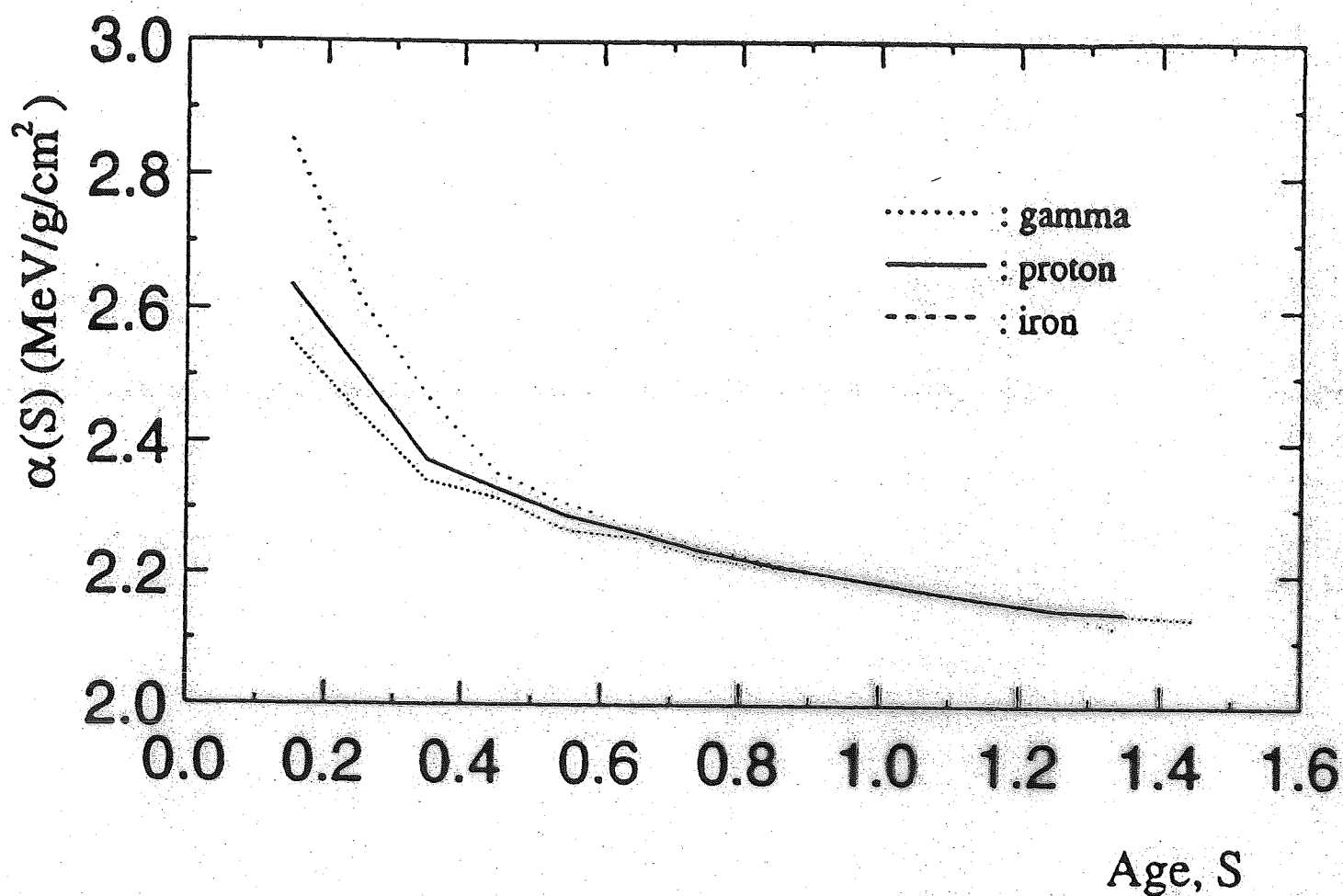


Fig. 2. The mean ionization loss rate dE/dX as function of S for γ -ray, proton, and iron-induced showers at 10^{17} eV.

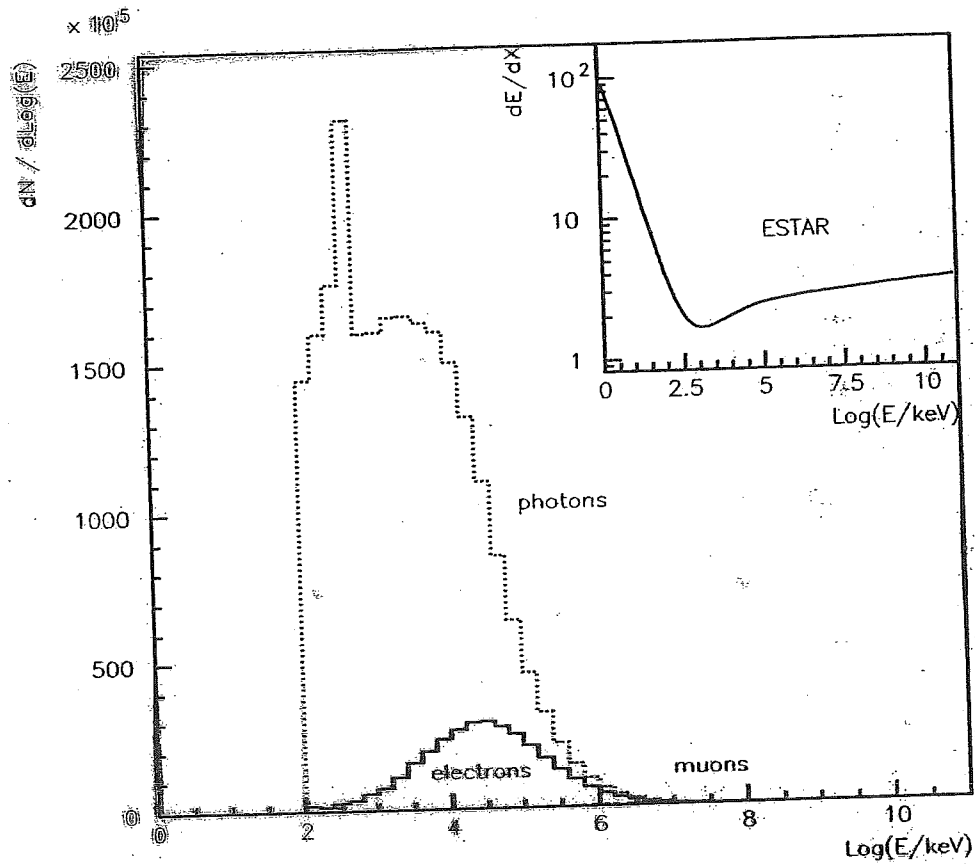


Figure 1: The mean energy spectra of photons, electrons and muons at $S = 1$ for 200 proton showers at 10^{17} eV. The spike in the photon spectrum corresponds to electron-positron annihilation. The inset shows the energy loss rate (in MeV/g/cm²) by ionization of electrons in dry air over the same energy range as the main figure. The ESTAR code produced by US National Institute of Science and Technology (NIST) was used below 10 GeV[10] and this curve is extrapolated into the region above 10 GeV.

	With $\mu^+\mu^-$ & γN			Without $\mu^+\mu^-$ & γN		
E_0 , eV	E_{cal}/E_0	N_μ	N_{max}	E_{cal}/E_0	N_μ	N_{max}
10^{16}	0.888 ± 0.004	$(2.146 \pm 0.795)10^3$	$(8.324 \pm 0.392)10^5$	0.897 ± 0.003	0.000 ± 0.000	$(8.448 \pm 0.413)10^6$
10^{17}	0.888 ± 0.005	$(2.823 \pm 1.369)10^4$	$(7.881 \pm 0.339)10^7$	0.898 ± 0.004	0.000 ± 0.000	$(7.967 \pm 0.392)10^7$
10^{18}	0.889 ± 0.004	$(3.185 \pm 0.916)10^5$	$(7.439 \pm 0.271)10^8$	0.898 ± 0.003	0.000 ± 0.000	$(7.558 \pm 0.281)10^8$

Table 1: Results of CORSIKA simulations of gamma-ray induced air showers at three primary energies. The right-hand half of the table shows results from simulations where photo-nuclear and muon pair production processes have been switched off. The uncertainties shown are root mean squared errors.

E_0 , eV	E_{loss}/E_0	$E_e(<0.1 \text{ MeV})/E_0$	$E_\gamma(<0.1 \text{ MeV})/E_0$	E_{cal}/E_0
10^{16}	0.888 ± 0.003	0.090 ± 0.001	0.010 ± 0.001	0.888 ± 0.004
10^{17}	0.884 ± 0.005	0.090 ± 0.001	0.012 ± 0.003	0.888 ± 0.005
10^{18}	0.876 ± 0.007	0.092 ± 0.002	0.018 ± 0.005	0.889 ± 0.004

Table 2: Results from a study of energy conservation within CORSIKA. Gamma-ray showers were simulated at three primary energies E_0 . E_{loss} refers to the energy lost to the atmosphere through ionization by charged particles with energies above 0.1 MeV. The fraction of the primary energy carried by sub-0.1 MeV electrons and photons is shown in the next two columns. The fraction of primary energy determined by the calorimetric equation (final column) is consistent with E_{loss}/E_0 . Again, all uncertainties are r.m.s.

Then when we evaluate the shower energy:

$$E_{\text{shower}} = \int N_e^{\text{fit}}(x) \left\langle \frac{dE}{dx}(S(x)) \right\rangle_{\text{showers}} dx$$

eg from
Cassier-Hillas
profile with air
Cherenkov "subtracted"

$E_{\text{vis}} \leftarrow \sim 0.9$ to correct for
lost $\mu^\pm, \nu's, n's$

To go back to our "roots" substitute:

$$N_e^{\text{fit}}(x) \left\langle \frac{dE}{dx}(S(x)) \right\rangle_{\text{shower}} = N_{1.4\text{MeV}}^{\text{fit}}(x) \left. \frac{dE}{dx} \right|_{1.4\text{MeV}}$$

$$\text{Then: } E_{\text{shower}} = \left. \frac{dE}{dx} \right|_{1.4\text{MeV}} \frac{\int N_{1.4\text{MeV}}^{\text{fit}}(x) dx}{E_{\text{vis}}}$$

THIS can come outside
the integral as it is a constant.

$$\text{Where: } N_{1.4\text{MeV}}^{\text{fit}}(x) = \frac{\gamma^{\text{obs-corrected}}(x)}{\gamma_{(S,T)}^{1.4\text{MeV}}} \leftarrow \begin{array}{l} \text{"corrected" observed} \\ \text{signal} \end{array}$$

$\leftarrow$ fluorescence efficiency of
our "roots"

I urge we use this "presentation" as it makes the connection between what we observe, the calibration, and what we determine (E_{shower}) most transparent.

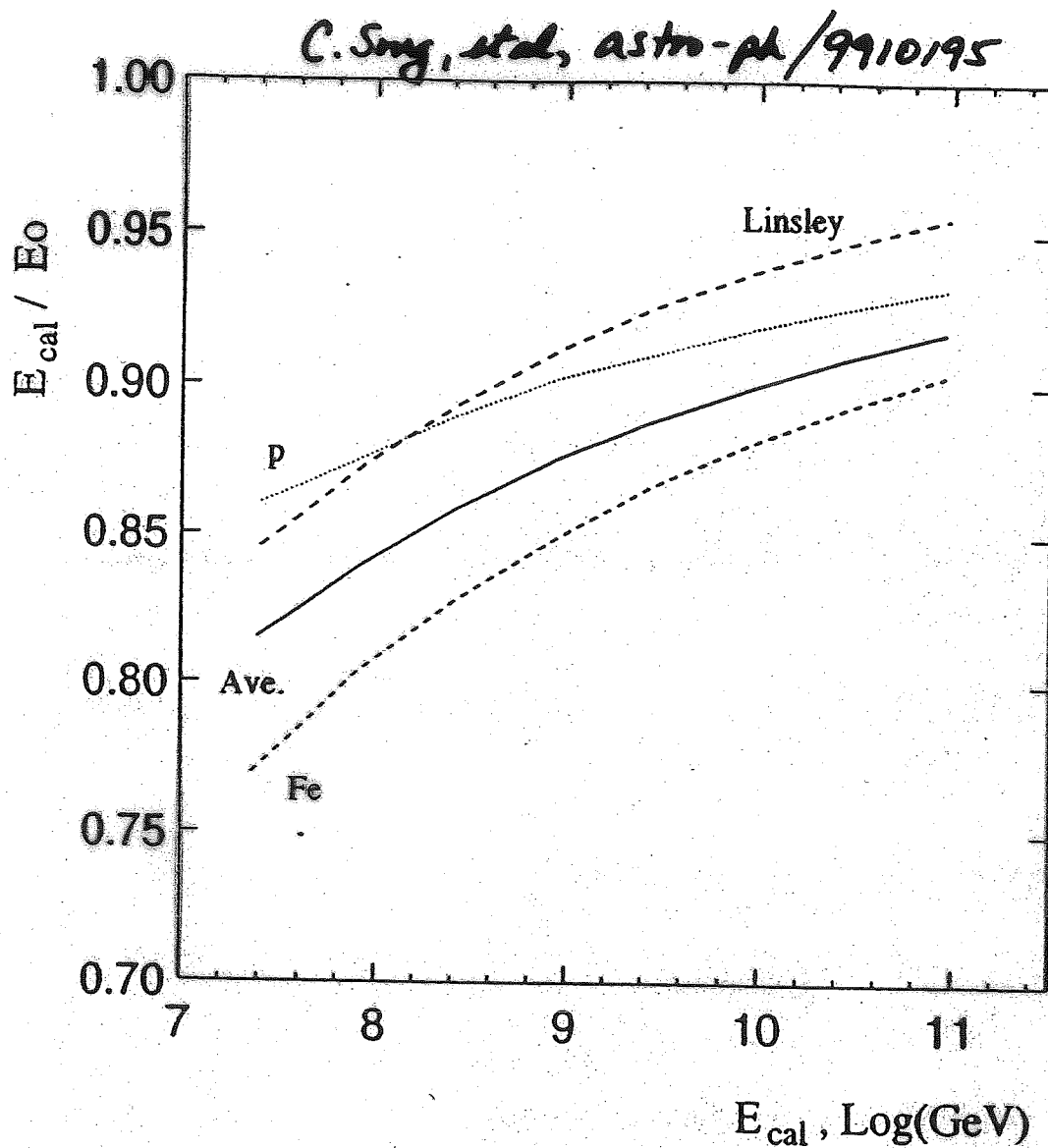


Figure 4: The functions for correcting the calorimetric energy to the primary energy, as a function of calorimetric energy. Shown are the corrections for proton showers (dotted line) and iron showers (short dashed line) and an average of the two (solid line). For comparison, Linsley's function is also shown.

Summary:

1) We do not know the aerosol transmission corrections for the E.A. data.

✓ A not unreasonable model would estimate the ST^a uncertainty to the shower energy to 13~25%.

✓ Why?

Too few dedicated, focused people involved ... This needs to change!

2) There are many details in the fluorescence analysis ... that impact studies in areas other than atmospheric monitoring:

✓ next generation air fluorescence efficiency measurements

✓ shower simulations must be able to simulate "air fluorescence signal"

↗ These need to be clearly documented so all the pieces "fit".