Update on Atmospheric Monitoring in Utah

Telescope Array Meeting

U. C. (Los Angeles)

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1. Introduction
2. Overview of Recent Studies
3. Update on New Instrumentation
4. Small Angle Mie Scattering
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7. Opportunity for Joint Auger/HiRes/TA Atmospheric Monitoring R&D

1. Introduction

Atmospheric Monitoring for Fluorescence Detector (FD) Experiments:

- Two broad categories of atmospheric monitoring:
  1. Detection and tracking of clouds
     (*update from R. Clay and B. Dawson??*)
  2. Detailed characterization of the atmosphere for accurate reconstruction of the fluorescence signal
     (*update from R. Grey and L. Wiencke??*)
     (*update from M. Chikawa and N. Hayashida??*)

- There are two distinctly different corrections to the fluorescence data:
  1. **Transmission correction**:
     (a) Light scattering in the atmosphere results in a finite transmission of light <u>from</u> the extensive air shower <u>to</u> the fluorescence telescopes
     (b) The observed light intensity, I, is related to the light intensity at the source, I_0, as follows:

$$I \sim I_0 \cdot T^m \cdot T^a \cdot (1. + H.O.)$$

where T^m is the transmission based on Rayleigh scattering (on the molecular atmosphere), T^a is the transmission based on Mie scattering (on aerosols in the atmosphere) and $H.O.$ is a higher order correction (*aka* aureole).

(c) The transmission corrections depend on the total number of scatterers between the source and the fluorescence detector <u>and</u> on the total cross sections.

2. **Scattering of air Cherenkov background light into the fluorescence signal**:
   (a) The observed light includes both air fluorescence signal plus some scattered air Cherenkov background.
   (b) The latter must be subtracted as part of the shower reconstruction/analysis.
   (c) This constitutes the second, *air Cherenkov*, correction to the fluorescence data.
   (d) The *air Cherenkov* correction depends on the local density of scatterers <u>and</u> on the differential scattering cross sections!

2. Overview of Recent Studies

- Dugway studies (mostly) use the HR2 steerable laser beam observed by HR1 or TA (at Cedar Mountain).

  1. Left *versus* Right symmetry?
     - Do we observe horizontal variations in the atmosphere transmission?
     - Learning pains from clouds and linearly polarized laser beams ...

  2. Detailed studies with linearly polarized laser light beams
     - Good progress ...
     - **Q.:** Should we continue polarization studies <u>or</u> move to circularly/randomly polarized laser beams?

3. Update on New Instrumentation

1. Steerable laser at HR1 (to be viewed by HR2 FADC system)
   - Which laser (5mJ or 50mJ per pulse)?
   - Which steering system (refurbish FE2 laser steering hardware or new commercial solution)?
   - Goal is to work to a solution that could be used at future FD sites and with the roving laser **to minimize software development work load!**

2. Horizontal attenuation length measurement at 5-wavelengths
   - Inexpensive mercury vapor light source(s) ... start with one
   - Meade ETX telescope
   - Optec SSP-7 photometer

OPTOMECHANICS RESEARCH, INC.

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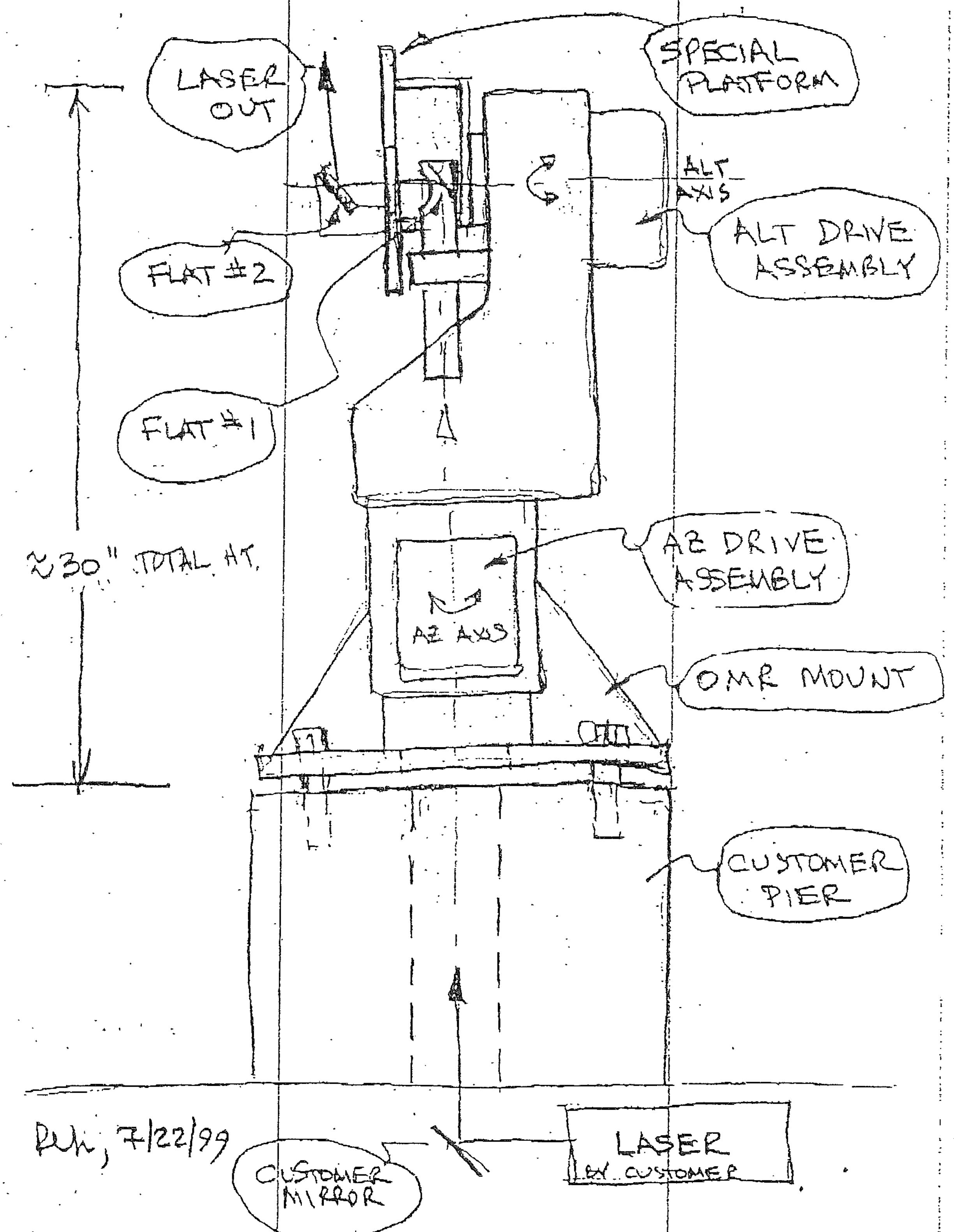
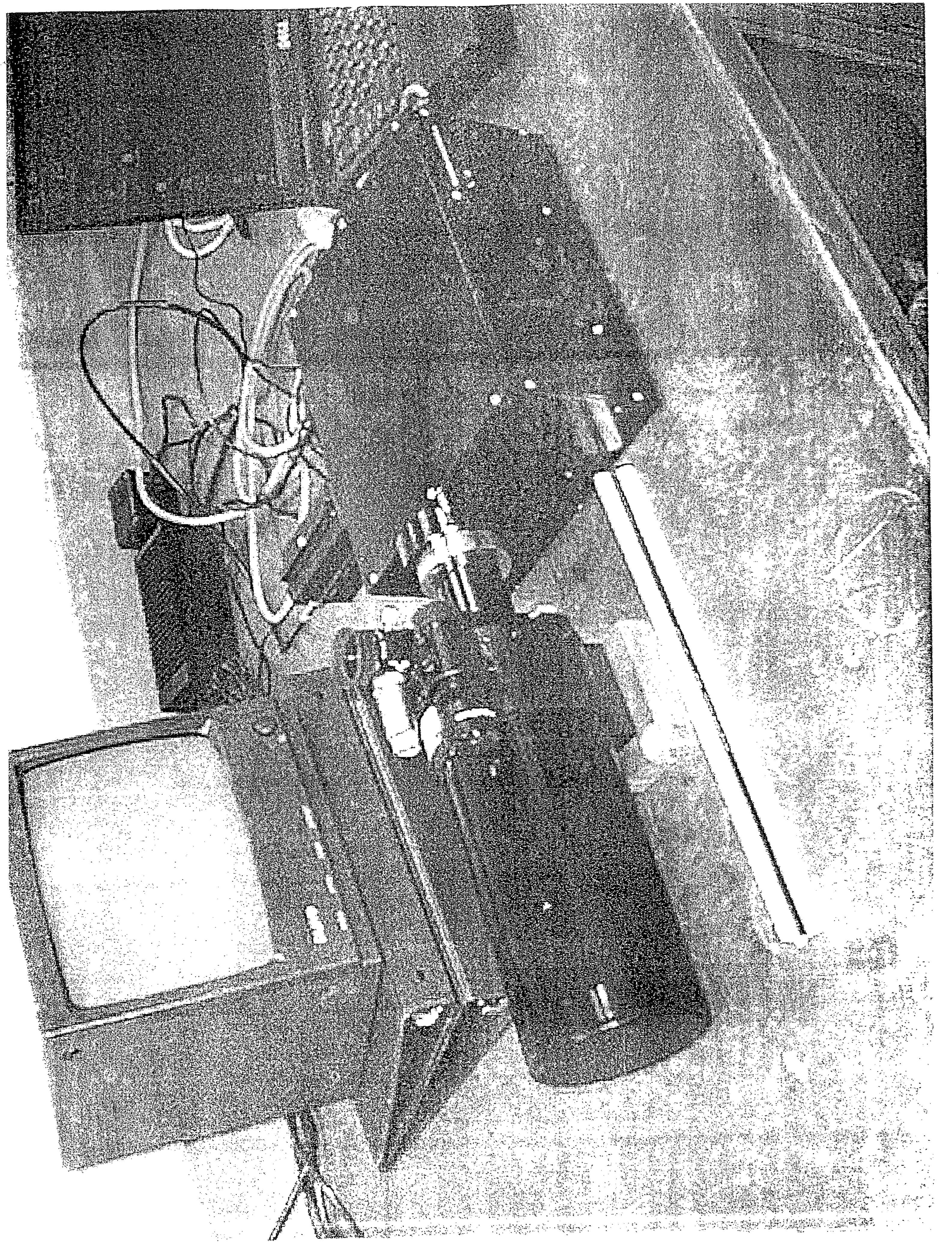
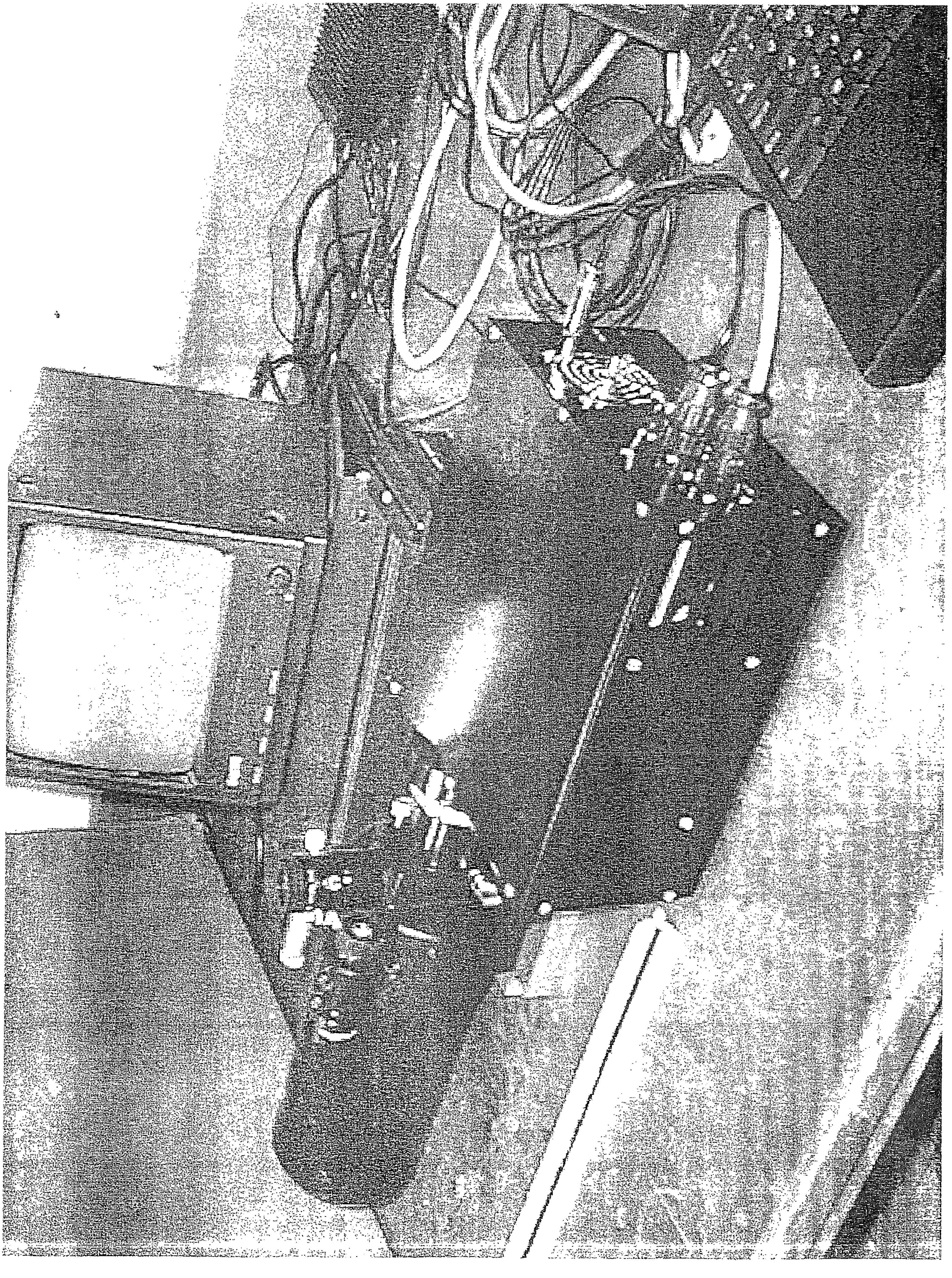
LASER STEERING SYSTEM







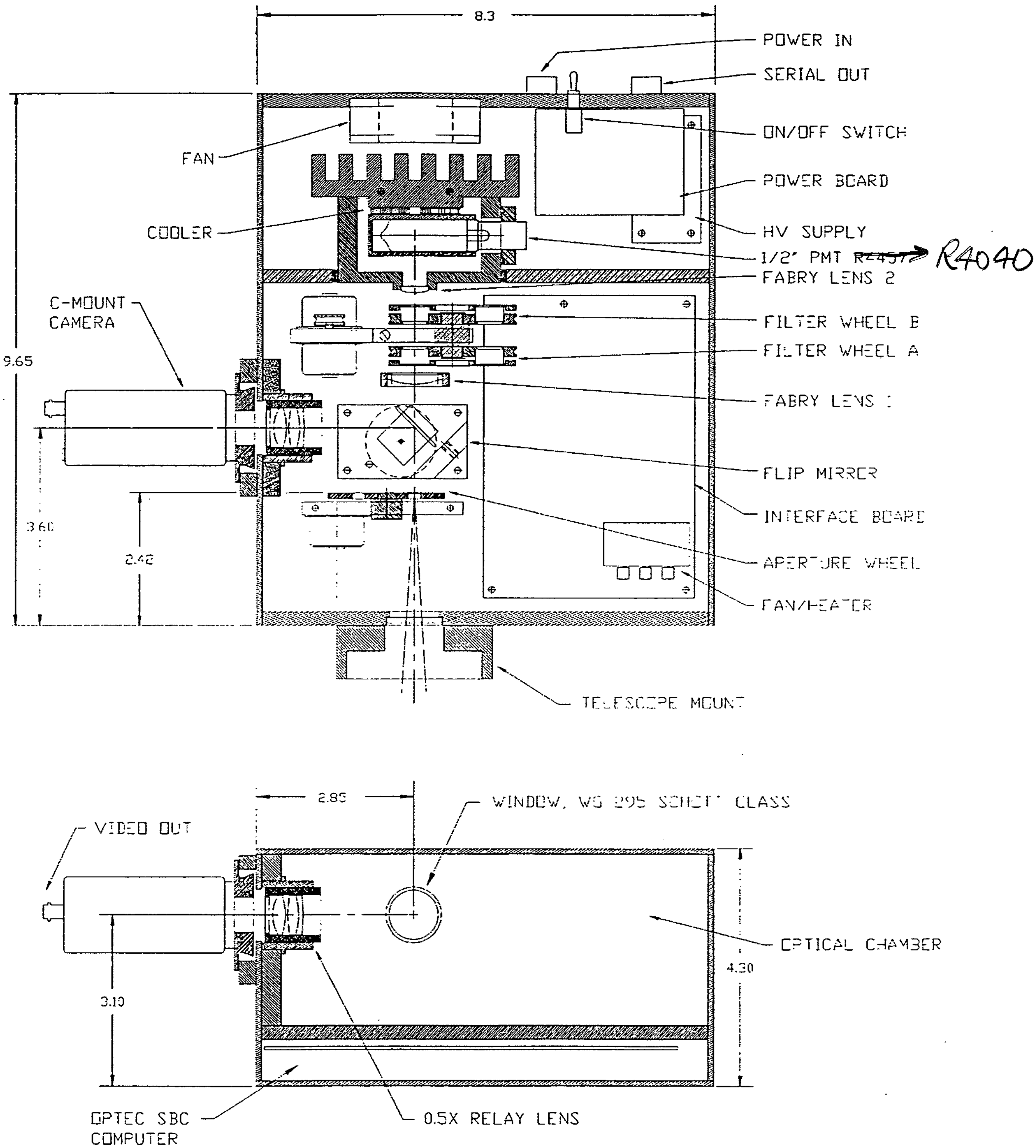
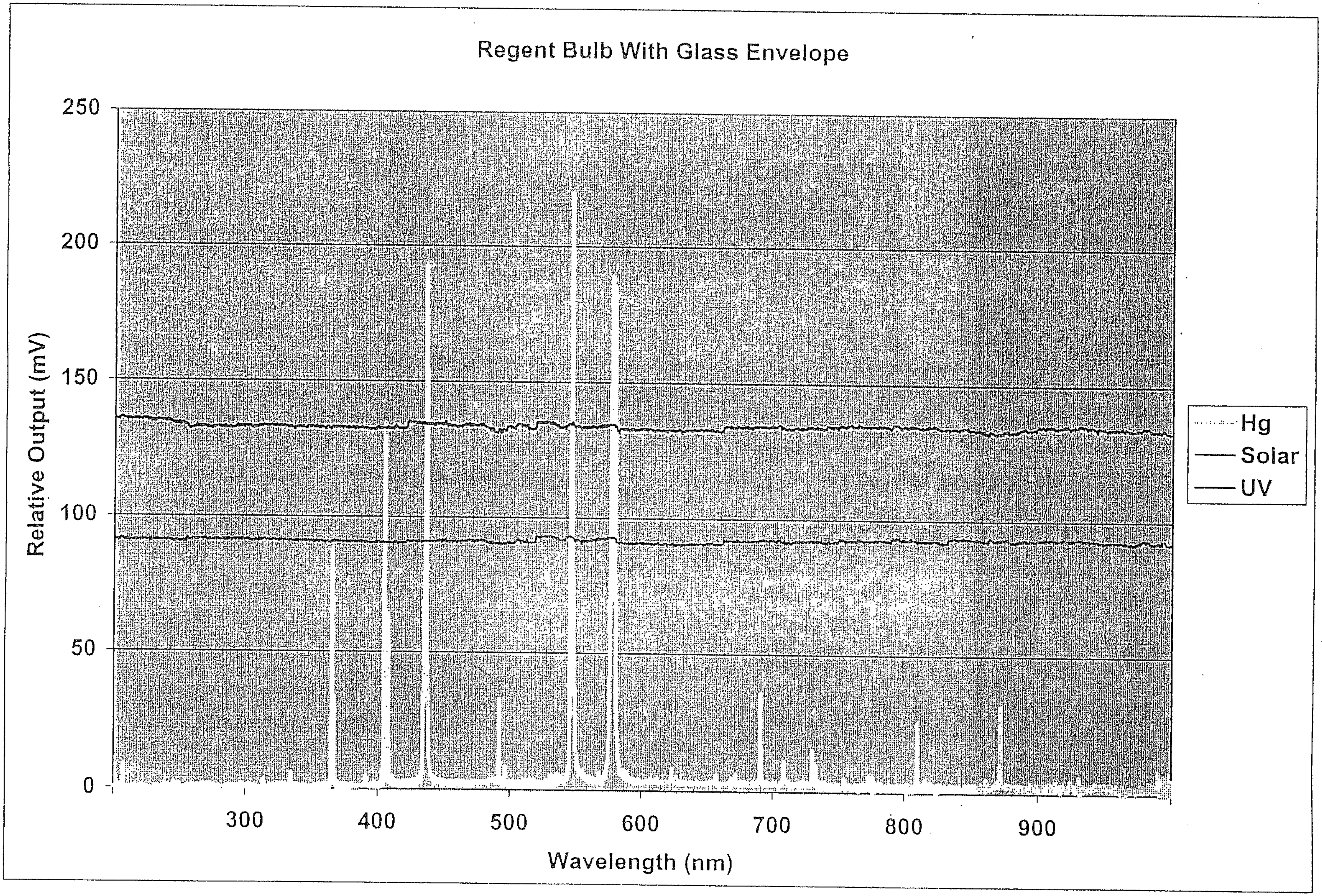
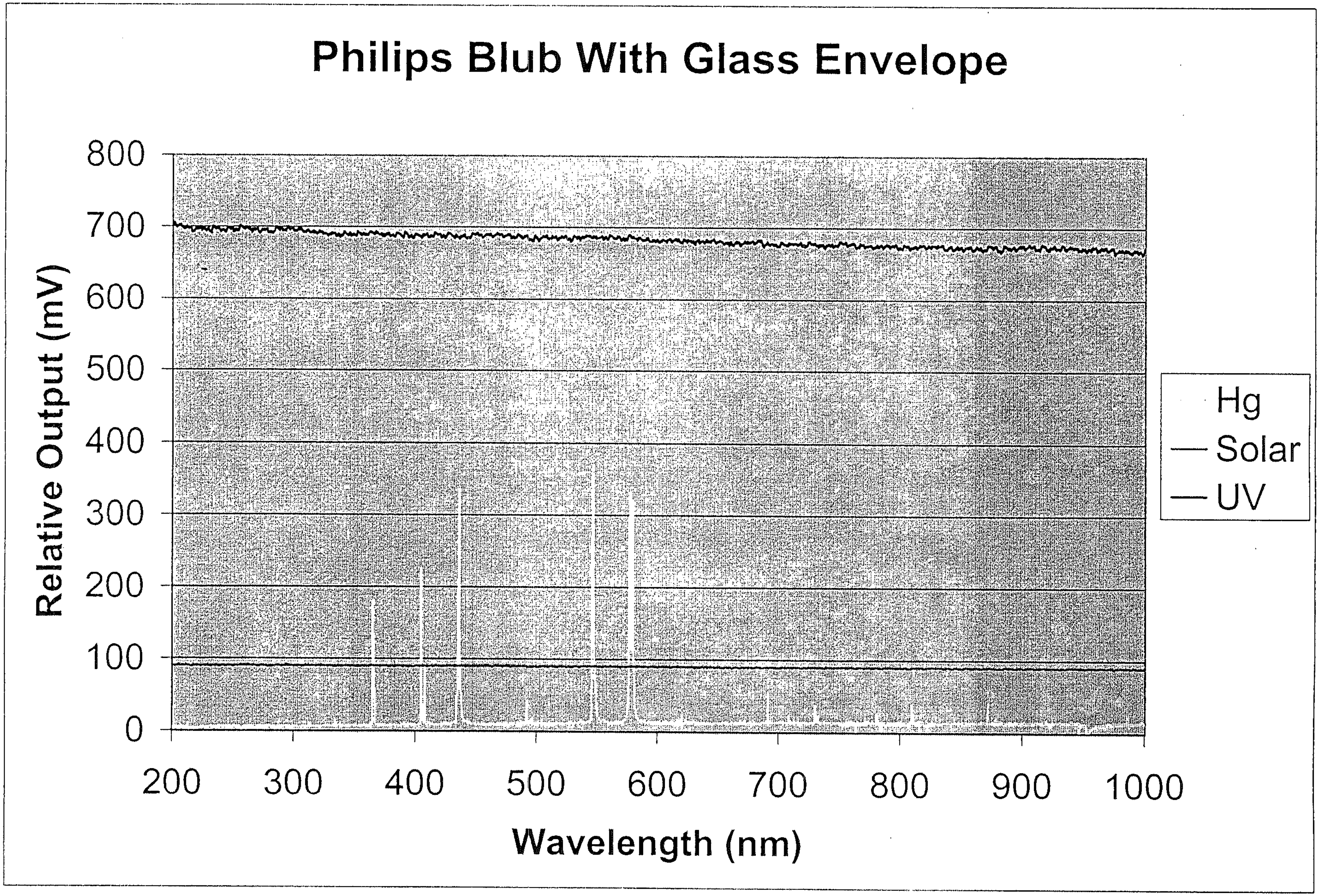


Figure 1-1. Cross-sectional view of the SSP-7 Precision Photometer

JAJM 23.


Regent Bulb With Glass Envelope
250
200
150
100
50
0
Relative Output (mV)
300
400
500
600
700
800
900
Wavelength (nm)
Hg
Solar
UV



Philips Blub With Glass Envelope
Relative Output (mV)
800
700
600
500
400
300
200
100
0
200
300
400
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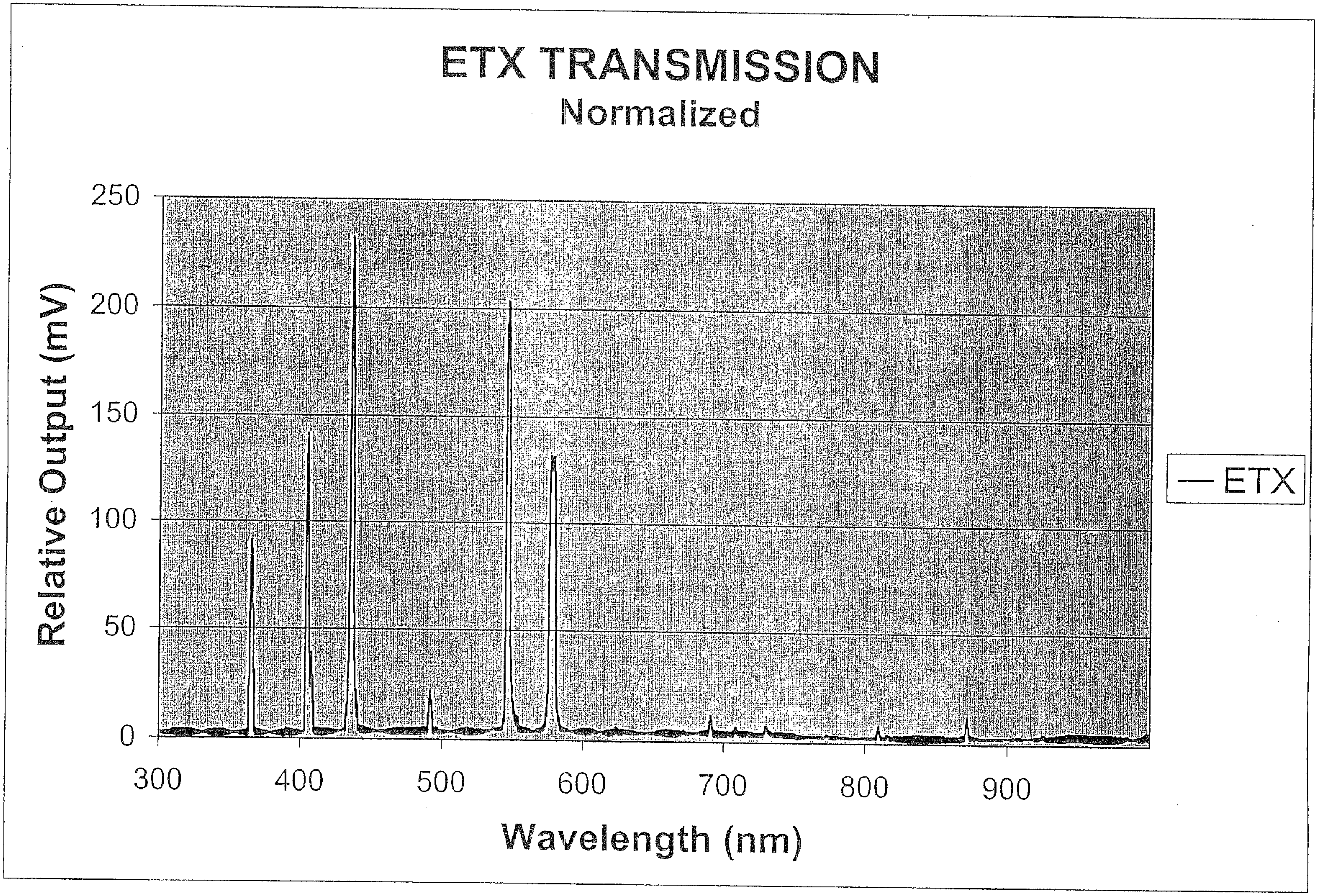
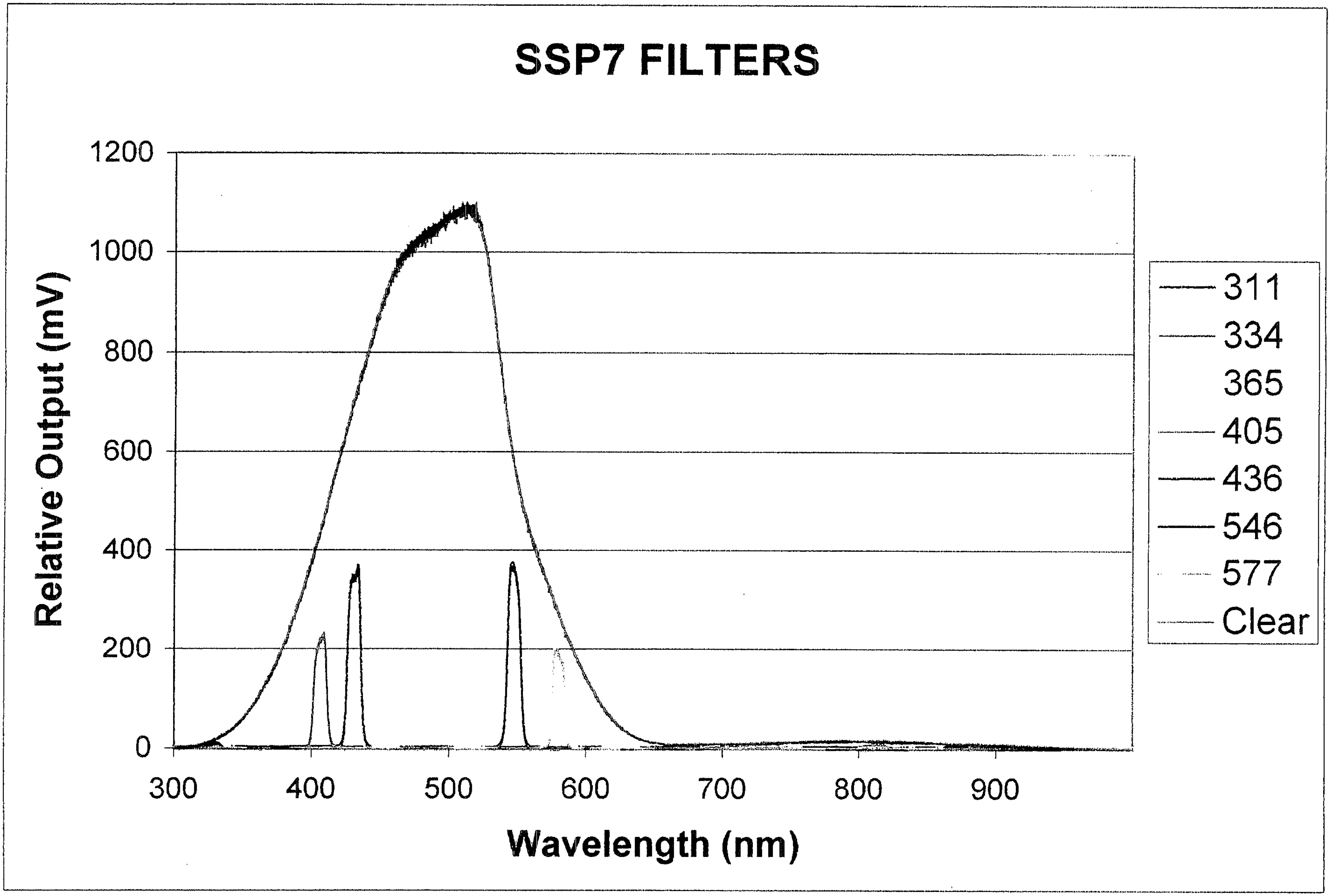
600
700
800
900
1000
Wavelength (nm)
Hg
Solar
UV



ETX TRANSMISSION
Normalized
250
200
150
100
50
0
Relative Output (mV)
300
400
500
600
700
800
900
Wavelength (nm)
— ETX


SSP7 FILTERS
1200
1000
800
600
400
200
0
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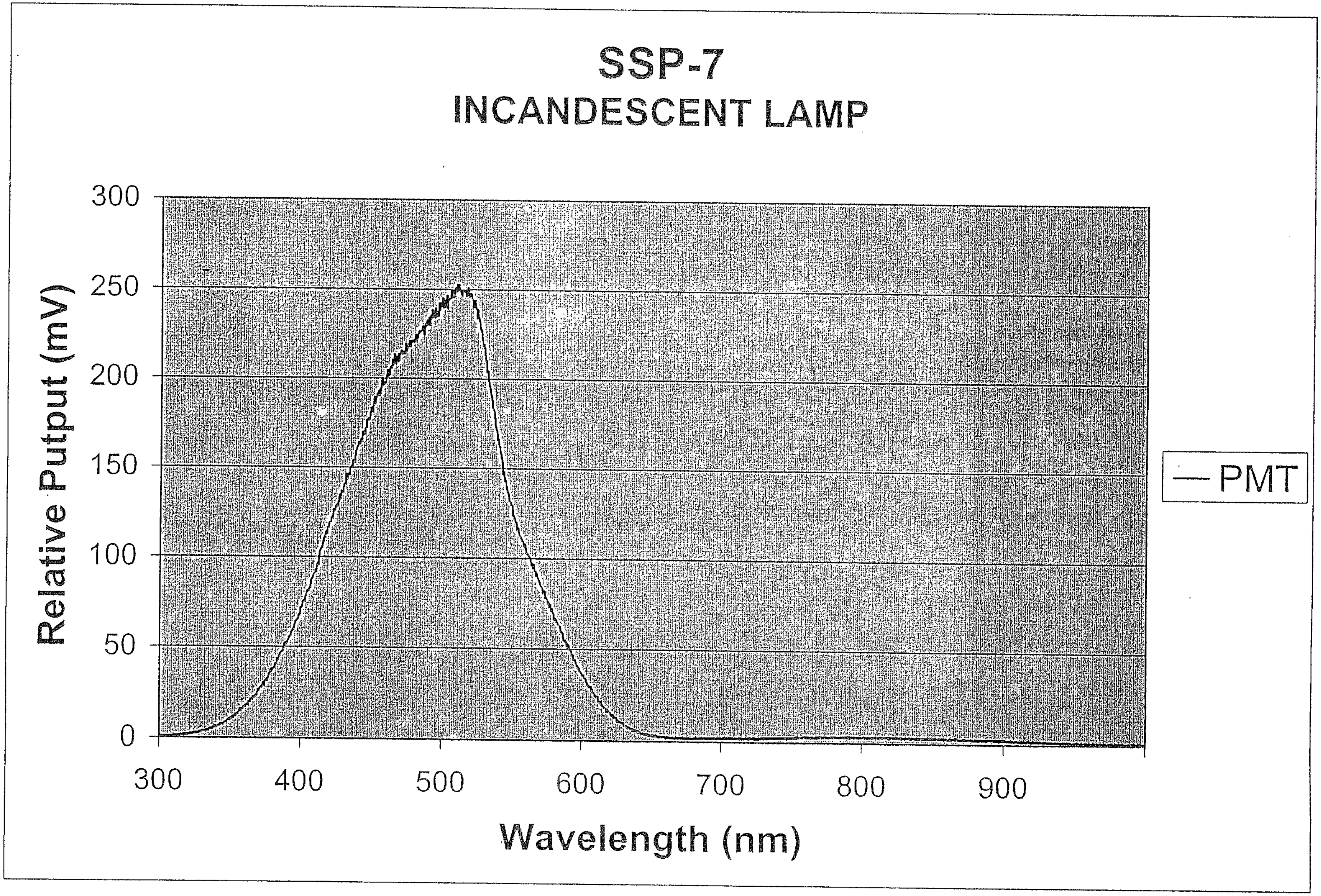
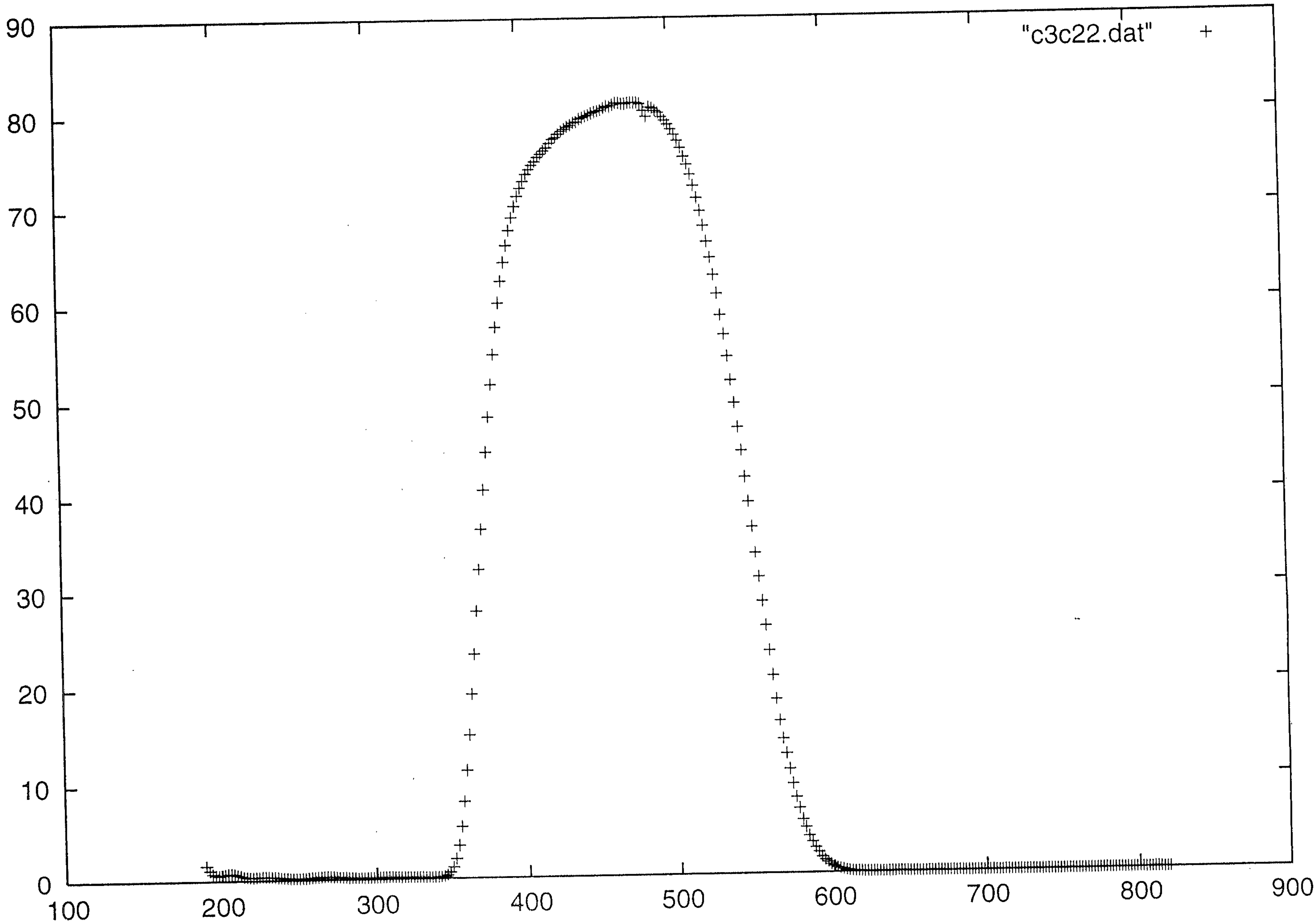
400
500
600
700
800
900
Wavelength (nm)
311
334
365
405
436
546
577
Clear


SSP-7
INCANDESCENT LAMP
Relative Putput (mV)
300
250
200
150
100
50
0
300
400
500
600
700
800
900
Wavelength (nm)
PMT


"c3c22.dat"
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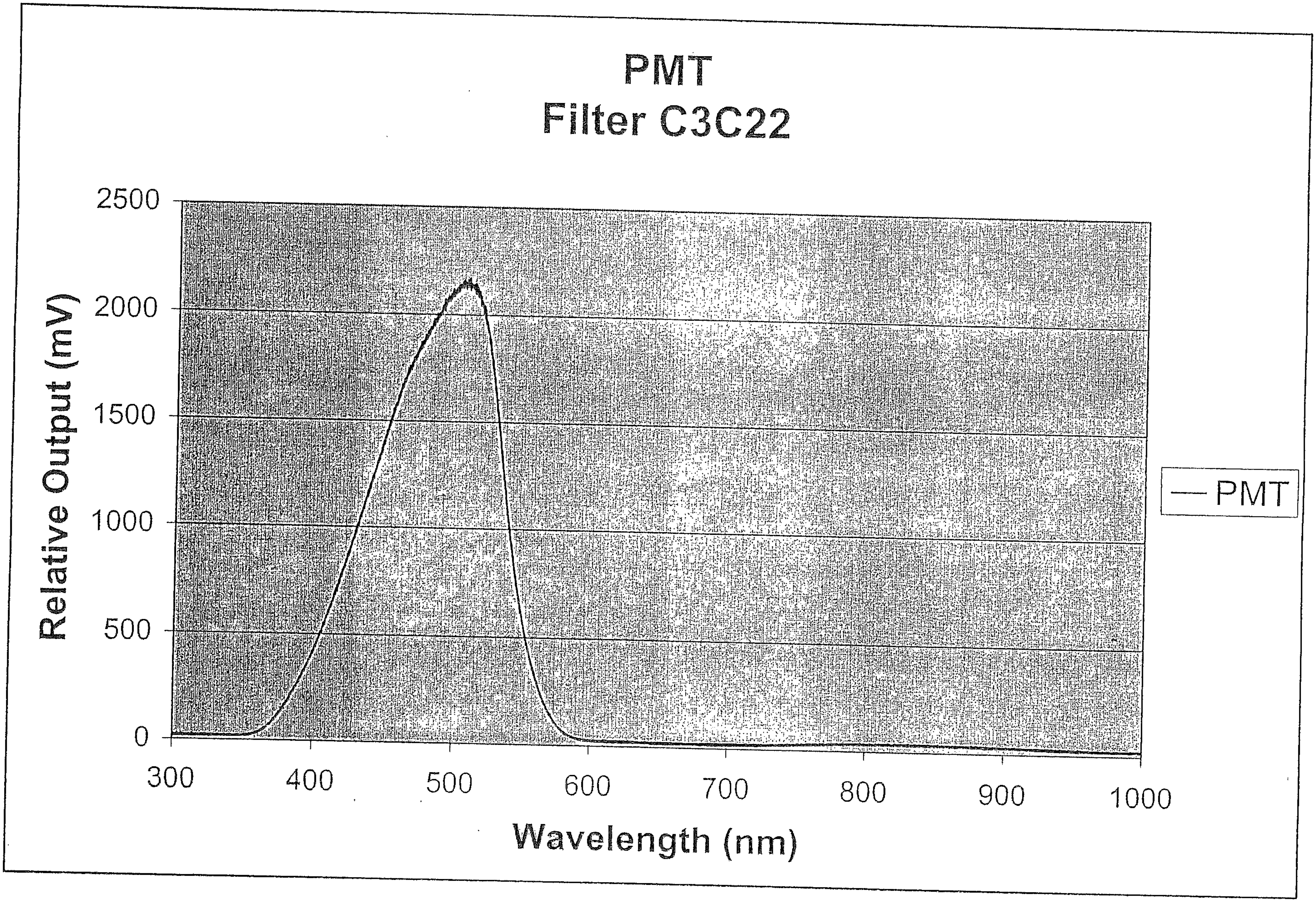
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
900

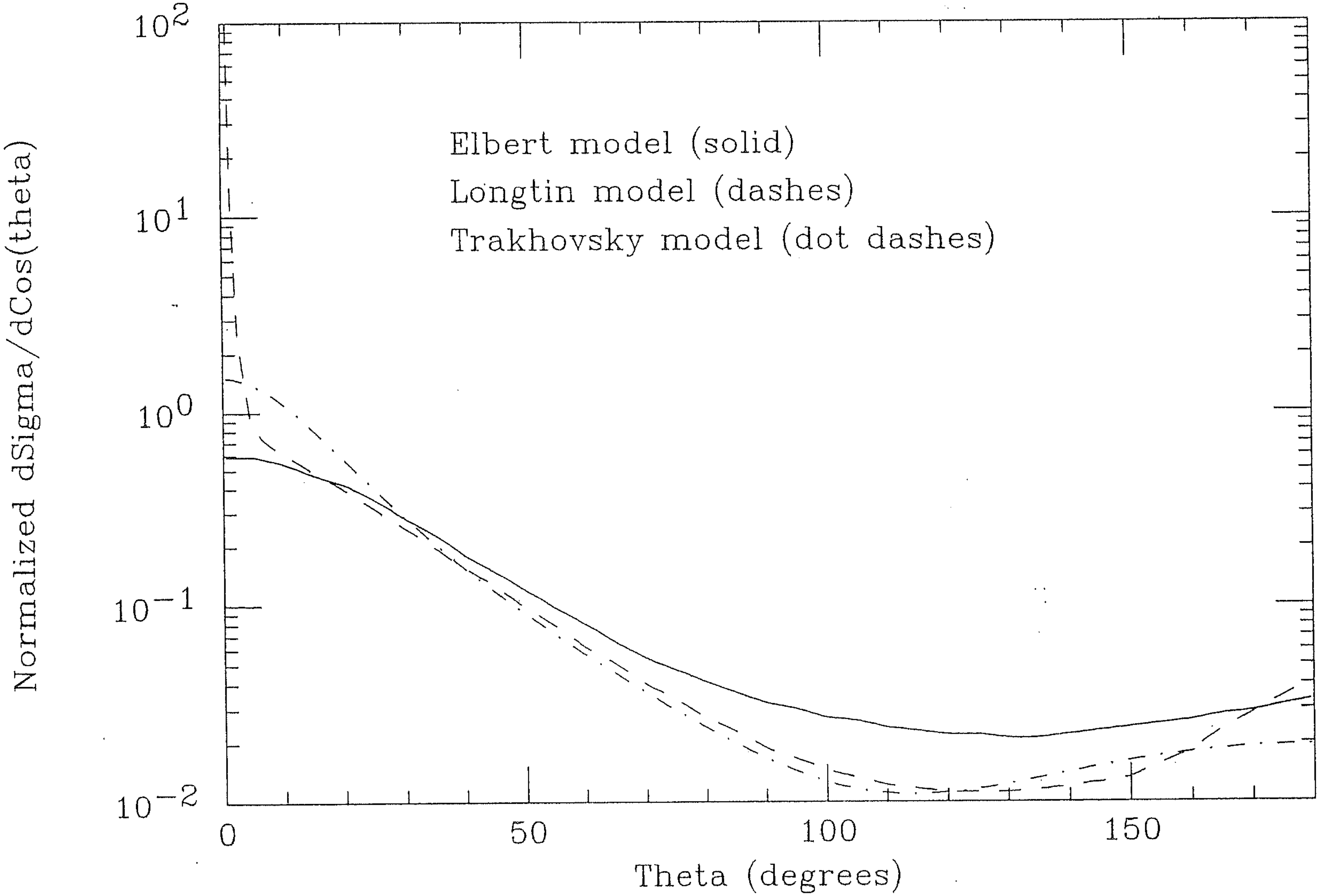

PMT
Filter C3C22
Relative Output (mV)
2500
2000
1500
1000
500
0
300
400
500
600
700
800
900
1000
Wavelength (nm)
— PMT

4. Small Angle Mie Scattering

- The Mie scattering differential cross section is needed for the *air Cherenkov* correction and to estimate *H.O.* corrections:

  1. Variations in *existing* models:
     - Elbert parameterization
     - Longtin parameterization
     - *Other ... e.g.* Trakhovsky and Oppenheim
  2. Relevant when multiple scattering important:
     - *e.g.* $Source = Source + Aureole$
     - *e.g.* Atmospheric transmission, T, measurement
  3. M. Robert's suggestion to do a first measurement (at small angles)
  4. (More) motivation for a dedicated *aerosol phase function monitor*

Model Aerosol (dSigma/dcos(theta))/Sigma_tot



Elbert & Longtin phase functions from HiRes Monte Carlo

Trakhovsky from App. Opt., 22, 1635 (1983)

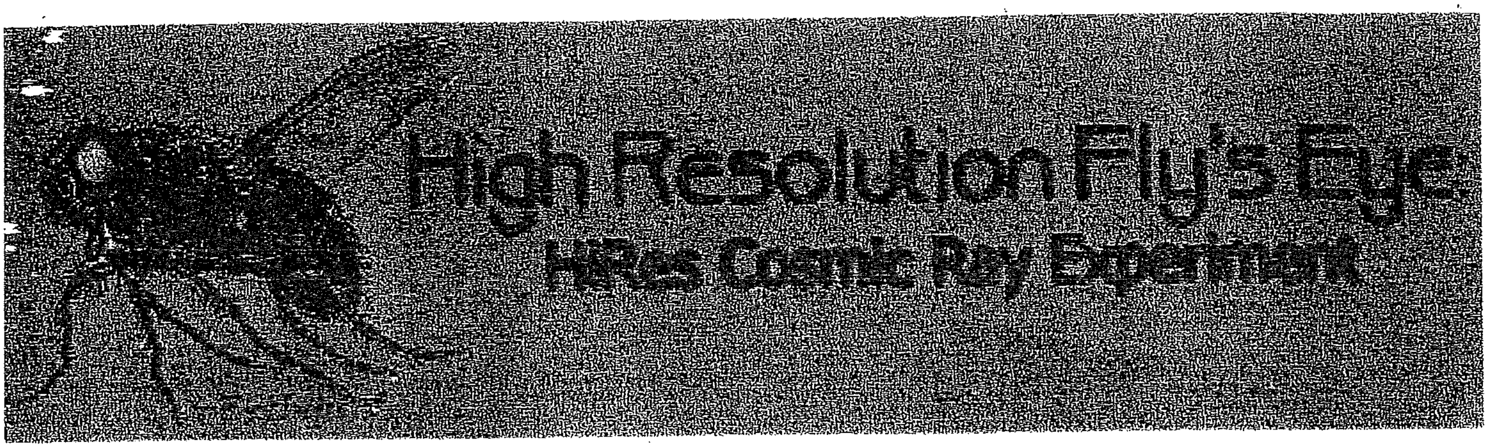
5. Molecular Atmosphere Study

1. Do we know the molecular atmosphere well enough?

   - The standard atmosphere *adiabatic model*, for use at elevations < 11km, is adequate for nearby showers.

   - For very distant showers we should use the Salt Lake City radiosonde data (*i.e.* the measured vertical profile of the atmosphere).

   - The agreement between Salt Lake City (Utah) and Reno (Nevada) radiosonde data is excellent. **This suggests that the Salt Lake City data can be used throughout the TA/HiRes experiment.**



Time Variation of the Vertical Profile of the Atmosphere for Air Flourescence Measurements

Georgianna Martin[1], John A.J. Matthews[1], Roger Clay[2],

Bruce Dawson[2] for the HiRes Collaboration.

[1]*New Mexico Center for Particle Physics, University of New Mexico, Albuquerque, NM 87131, USA*

[2]*Physics Department, University of Adelaide, South Australia, 5005*

Outline:

- Analysis motivation
- Radiosonde Data Analysis
  - Atmosperic model
    - time independent
    - time dependent
  - Radiosonde model
    - site dependence
- Conclusions

Rayleigh Transmission, T^m Correction :

Calculation - Fractional uncertainty in T^m is:

$$\frac{\Delta T^m}{T^m} \approx (\frac{1}{\cos(\theta)}) \cdot \frac{\Delta(\delta P(\Delta z))}{g * \Lambda^m(\lambda)} \tag{1}$$

where,

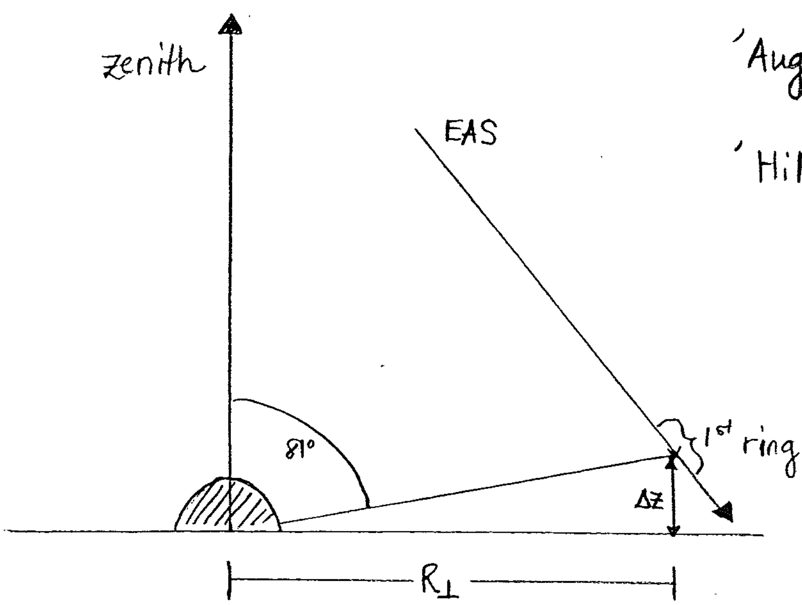
$$\Lambda(\lambda) = 2970\frac{gm}{cm^2} * (\frac{\lambda}{400\ nm})^4 \tag{2}$$

$$\delta P(\Delta z) \sim \int_0^{\Delta z} \rho(z) * g\ dz \tag{3}$$

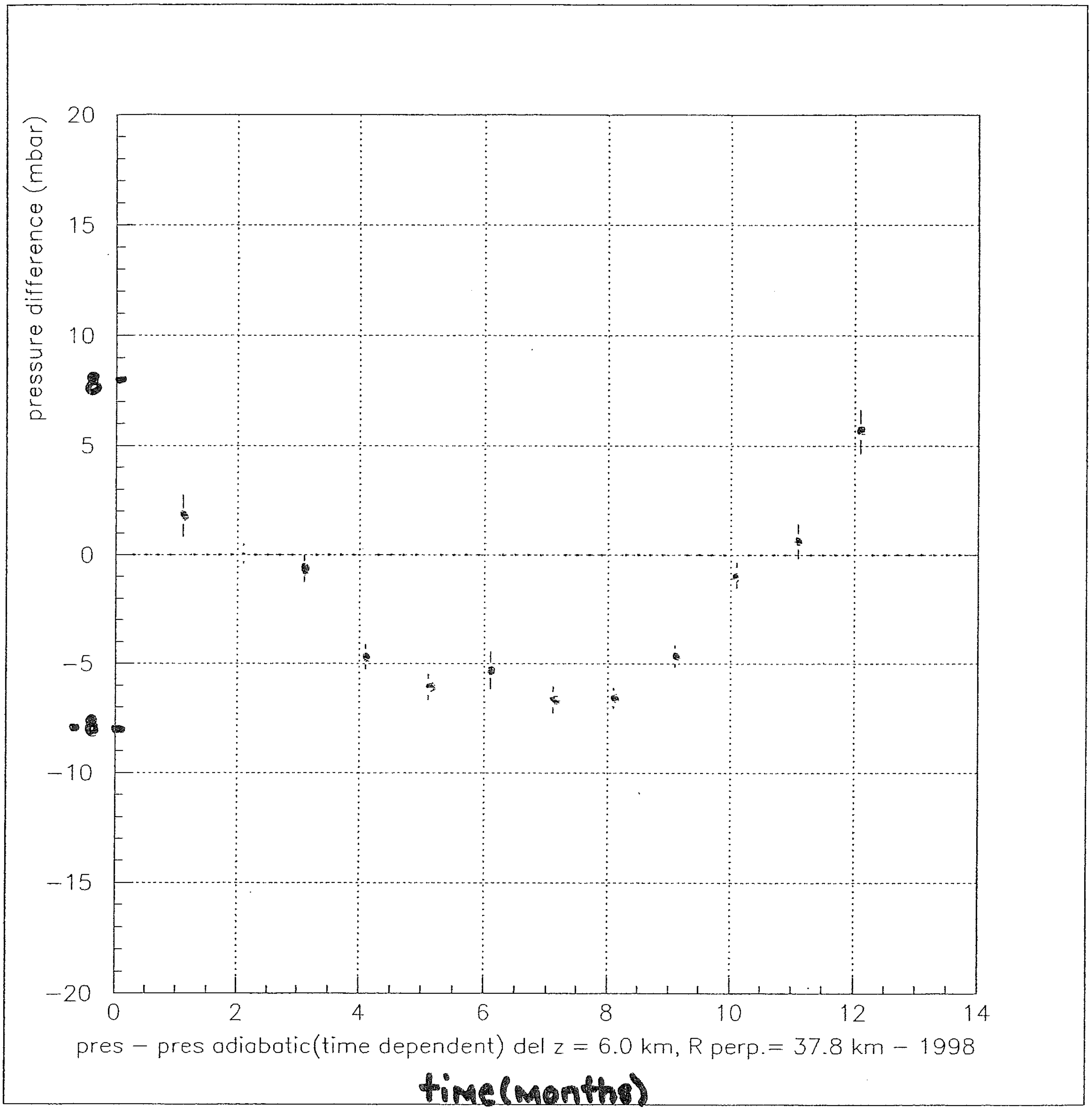
If $\frac{\Delta T^m}{T^m} < n\%$ at 350nm, near the center of the HiRes wavelength acceptance, then:

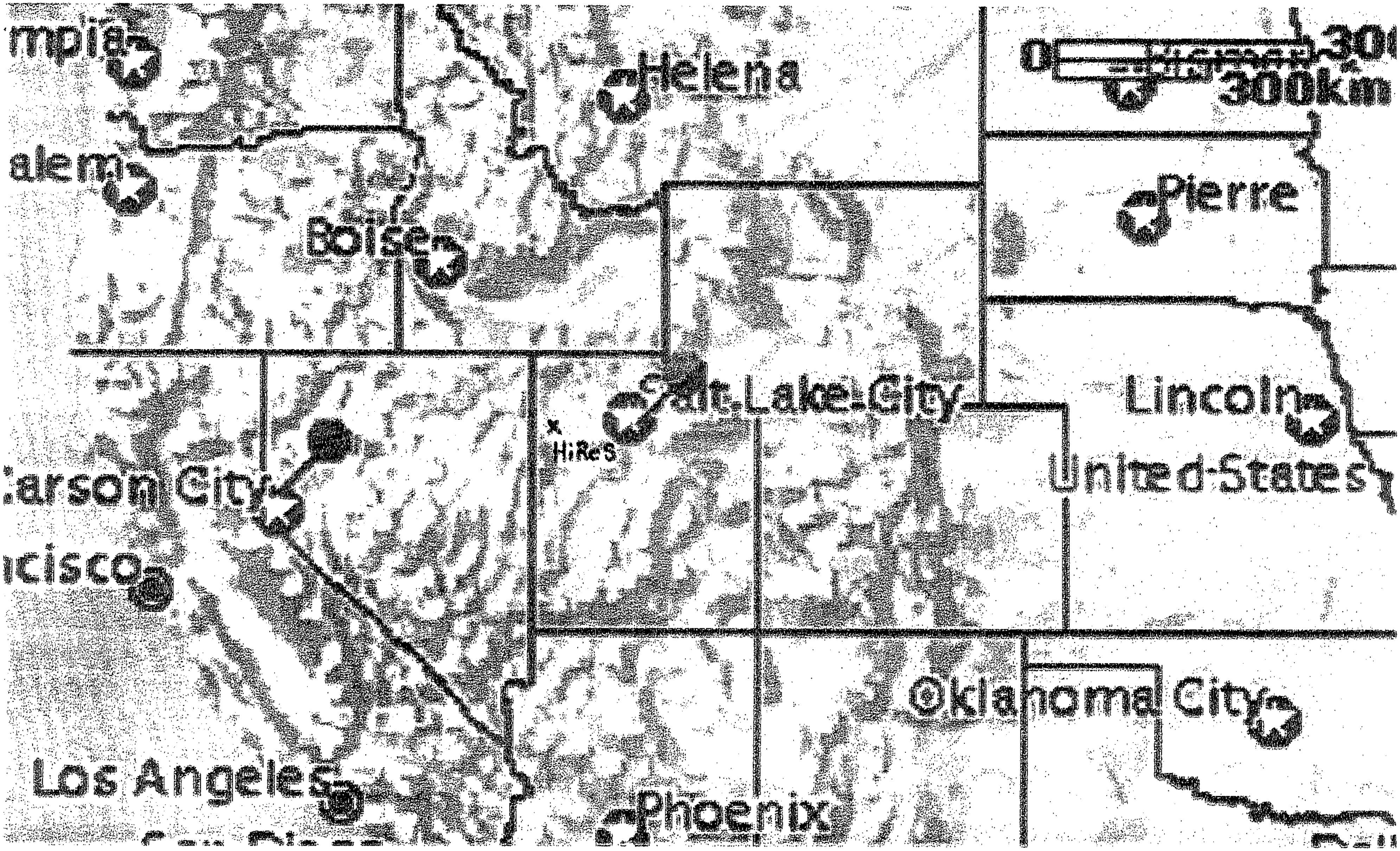
$$\boxed{\Delta(\delta P) \leq n(\%) \cdot \frac{17\ mbar}{(1/\cos(\theta))}} \tag{4}$$

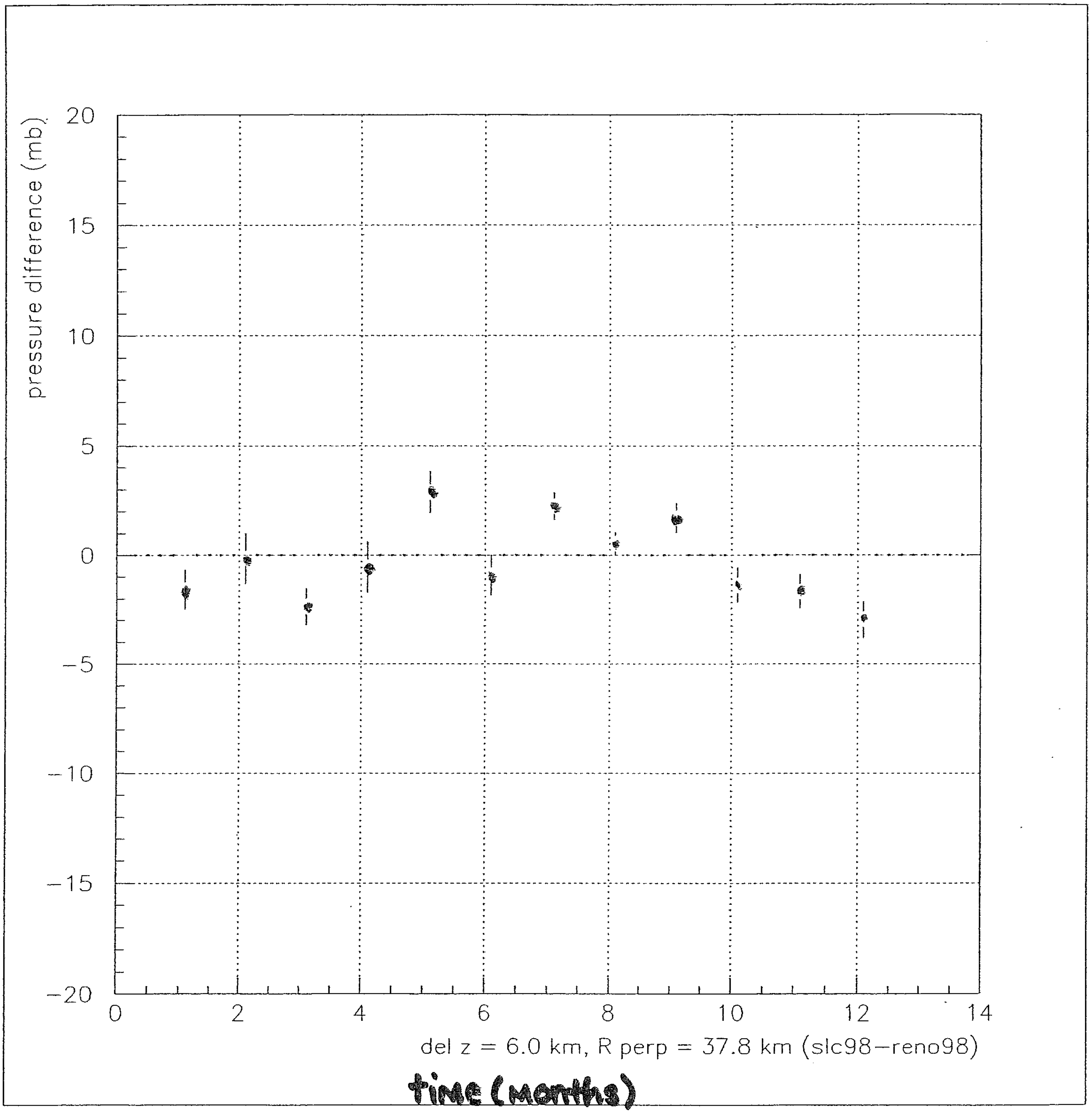
Fortunately δP must be known most precisely at small viewing angles, *i.e.* near the ground. As an example with $n = 3(\%)$ and $\theta = 81°$ (middle of HiRes ring one mirrors) then we require that $\Delta(\delta P) \leq 8$ mbar.

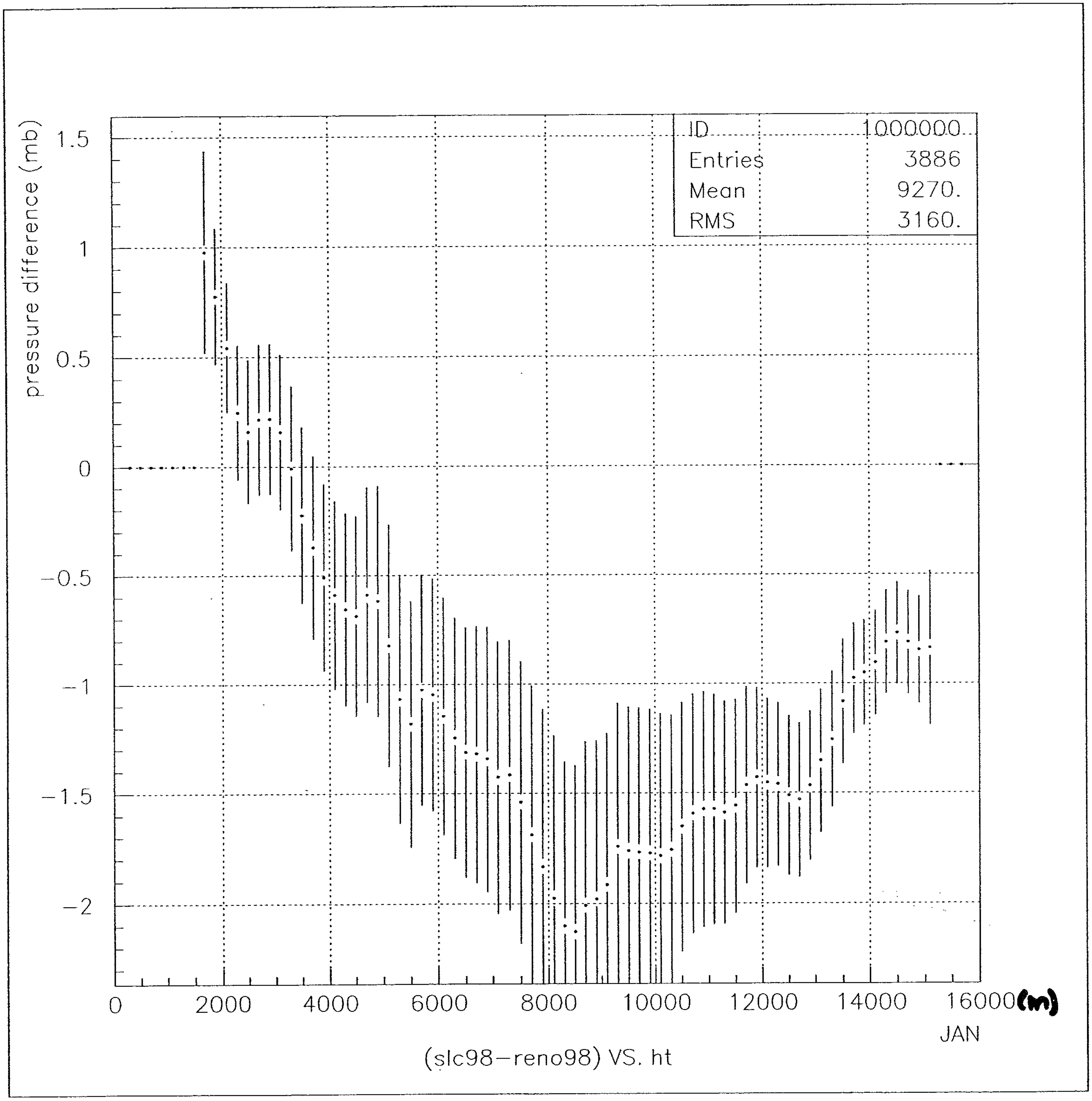


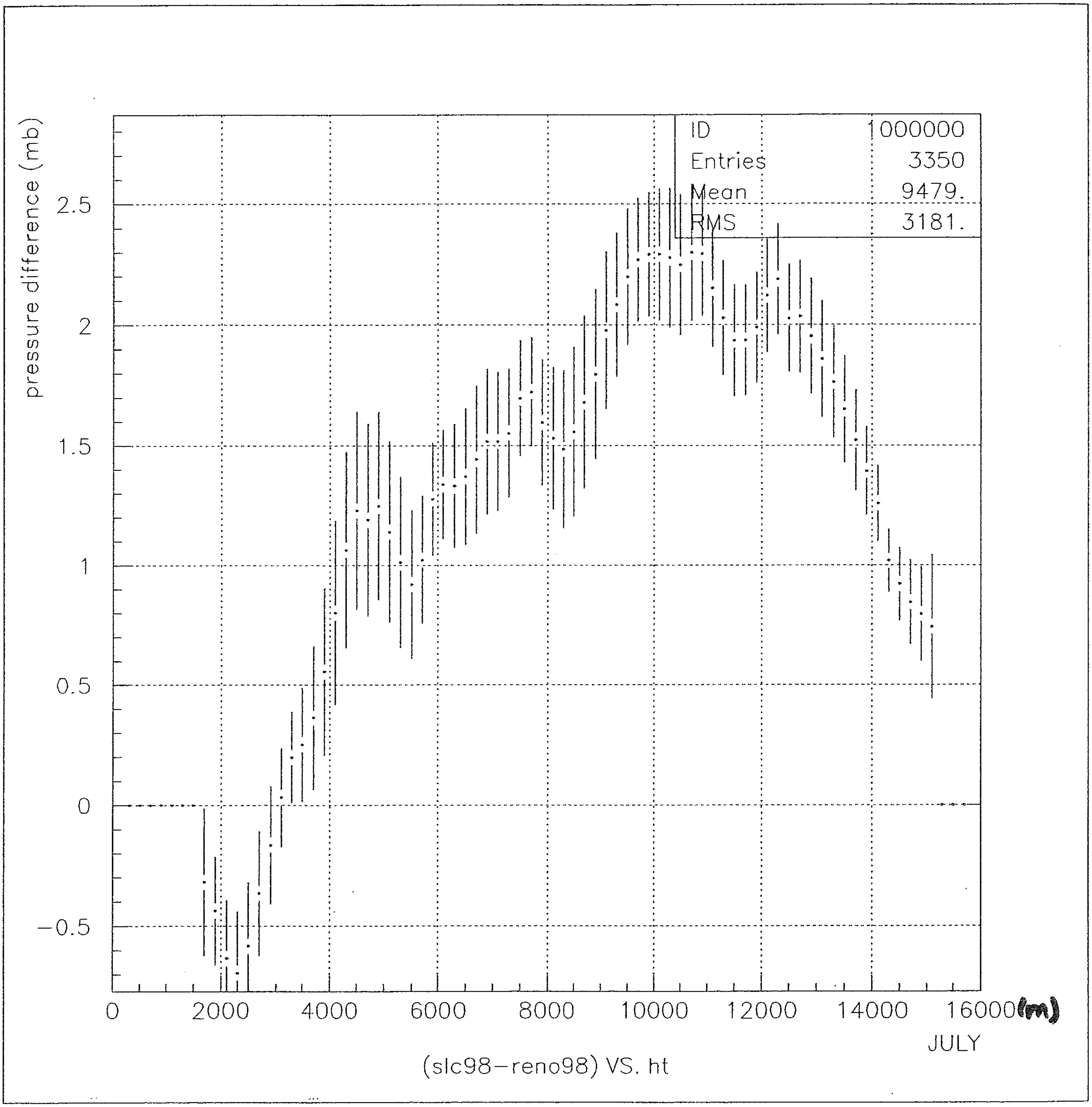
	Δz	R⊥
'Auger'	3.5 km	22.0 km
'HiRes'	6.0 km	37.8 km


pressure difference (mbar)
20
15
10
8
5
0
−5
-8
−10
−15
−20
0
2
4
6
8
10
12
14
pres − pres adiabatic(time dependent) del z = 6.0 km, R perp.= 37.8 km − 1998
time(months)


mpia
alem
Boise
Helena
Pierre
Lincoln
United-States
Salt Lake City
HiRes
Carson City
cisco
Los Angeles
Phoenix
Oklahoma City
0
300km


pressure difference (mb)
20
15
10
5
0
−5
−10
−15
−20
0
2
4
6
8
10
12
14
del z = 6.0 km, R perp = 37.8 km (slc98−reno98)
time (months)


ID 1000000
Entries 3886
Mean 9270.
RMS 3160.
pressure difference (mb)
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
2000
4000
6000
8000
10000
12000
14000
16000
(m)
JAN
(slc98−reno98) VS. ht



ID 1000000
Entries 3350
Mean 9479.
RMS 3181.
pressure difference (mb)
2.5
2
1.5
1
0.5
0
−0.5
0
2000
4000
6000
8000
10000
12000
14000
16000(m)
JULY
(slc98−reno98) VS. ht

6. *Related* FD Studies using Light Beams

1. Light scattered out of (laser) beams provides a good cross-check on FD stereo reconstruction, absolute pointing accuracy, telescope cracks/inneficiencies, ...

    - June and July *laser safari* data from Simpson Springs, 45km site, and Black Rock (*see http://www-hep.phys.unm.edu/fun5.html*)

    - **Q.:** Would a vertical flasher midway between FD sites provide a good, continuous monitor of relative energy calibrations (between the adjacent sites)?

7. Opportunity for Joint Auger/HiRes/TA Atmospheric Monitoring R&D?

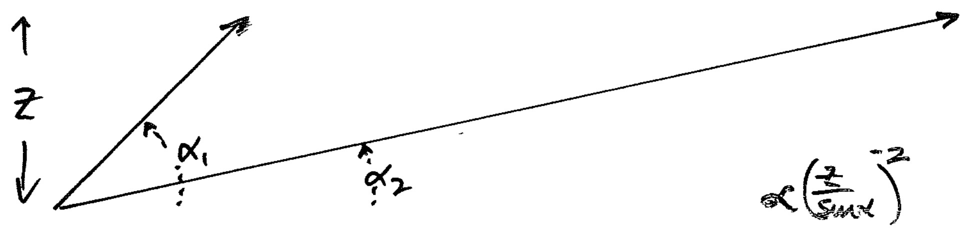
1. M. Chikawa has requested one of the TA steerable telescopes for atmospheric monitoring R&D

2. SAGENAP committee was interested in atmospheric monitoring R&D

3. Are there topics that would benefit all three collaborations?
   - Development of back-scattered LIDAR technology?
   - Development of significantly brighter xenon vertical flashers?
   - Development of a *flying flasher* ... *e.g.* a xenon flash bulb plus diffusing ball mounted on a robotic helicopter?
   - **Plus** items already requested but not (fully) funded for use in HiRes:
     (a) Hardware for laser safaris
     (b) Aerosol phase function monitor (including new interest to extend down to small angle scattering)
   - *Other* ...

LIDAR geometry

The analysis to extract the optical depth, $\tau(z)$:



$\propto \left(\frac{z}{\sin\alpha}\right)^{-2}$

$$I_{obs}(\alpha) \propto I_0 \left(T^m(z)\, T^a(z)\right)^{2/\sin\alpha} \left\{ \frac{1}{\Lambda^m(z)} \left(\frac{d\sigma/d\Omega}{\sigma}\right)^m_{180°} + \frac{1}{\Lambda^a(z)} \left(\frac{d\sigma/d\Omega}{\sigma}\right)^a_{180°} \right\} \Delta\Omega \; \Delta S$$

$\Delta S \rightarrow c\Delta t$

Take ratios:
$$\frac{I(\alpha_1)}{I(\alpha_2)} = \left(T^m(z)\, T^a(z)\right)^{\left(2/\sin\alpha_1 - 2/\sin\alpha_2\right)} \left(\frac{\sin\alpha_1}{\sin\alpha_2}\right)^2$$

Writing $T(z) = e^{-\tau(z)}$ and taking ln's:

$$\tau^m(z) + \tau^a(z) = \frac{\frac{1}{2} \ln\left[\left(\frac{\sin\alpha_2}{\sin\alpha_1}\right)^2 \frac{I(\alpha_1)}{I(\alpha_2)}\right]}{\left\{\frac{1}{\sin\alpha_2} - \frac{1}{\sin\alpha_1}\right\}}$$

and
$$\delta\left(\tau^m(z) + \tau^a(z)\right) = \frac{1}{2\left\{\frac{1}{\sin\alpha_2} - \frac{1}{\sin\alpha_1}\right\}} \left\{ \frac{\delta I(\alpha_1)}{I(\alpha_1)} \oplus \frac{\delta I(\alpha_2)}{I(\alpha_2)} \right\}$$

Best to measure at $\alpha_1 \simeq 90°$ and $\alpha_2 \simeq 5$–$6°$

molecular part that is "well known" (need P, T at z=0 ⊕ standard atmos. model)

unknown aerosol (optical depth)