Upper Bound on Ultra–high Energy Cosmic Neutrino Fluxes Obtained by Akeno Giant Air Shower Array

S. Yoshida, N. Sakaki, and the AGASA collaboration

1. General Characteristics of ν – Induced EAS
2. Horizontal EAS Reconstruction and the Xmax Resolution
3. Hadron Background and the ν Detection Aperture
4. AGASA Data
5. ν Flux Bound *etc*

Main Reactions to initiate EAS

ν_e

Charged Current

$\nu_e N \longrightarrow e + X$

- Emg Shower
- Hadronic Shower

ν_μ

Charged Current

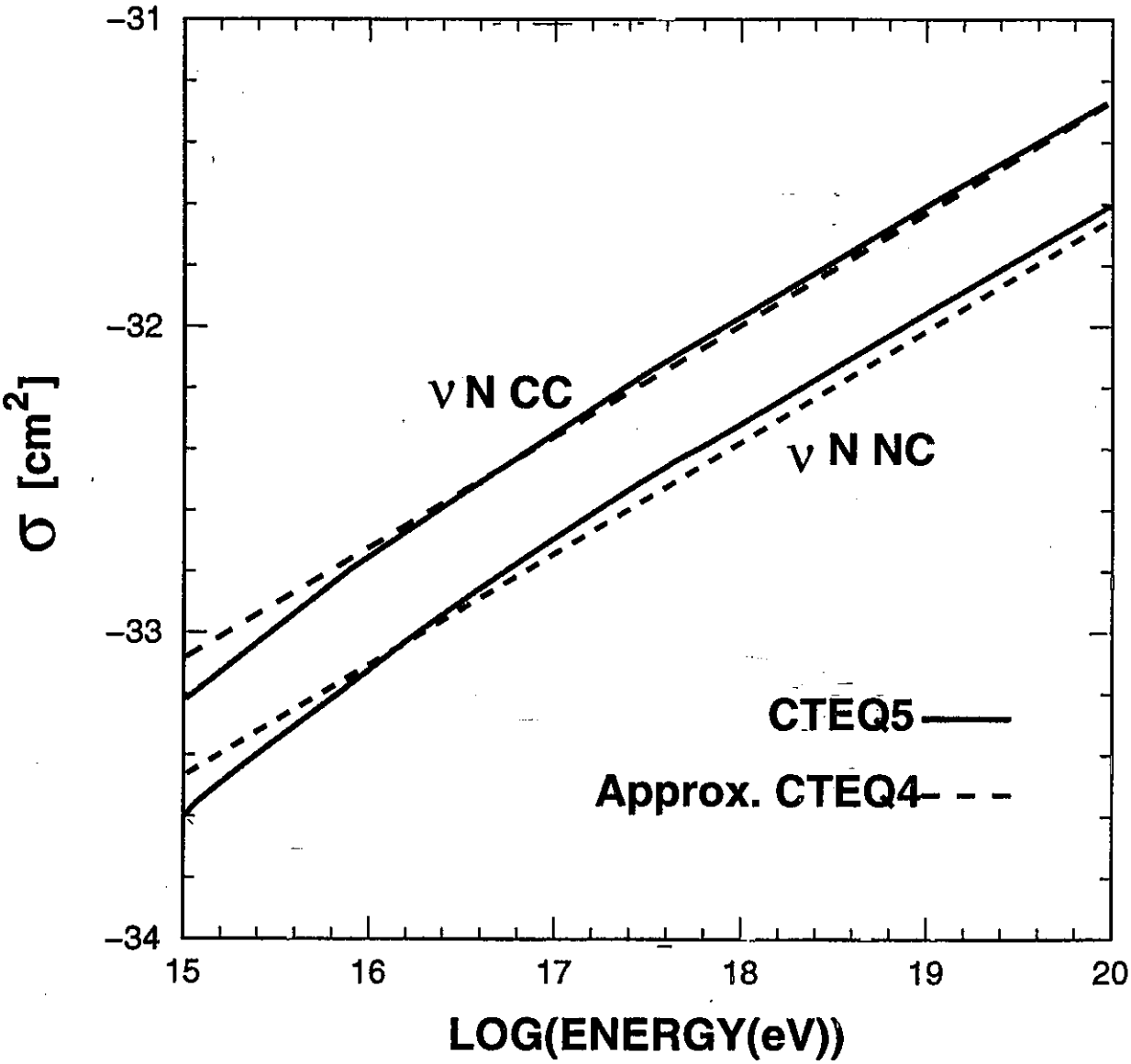
$\nu_\mu N \longrightarrow \mu + X$

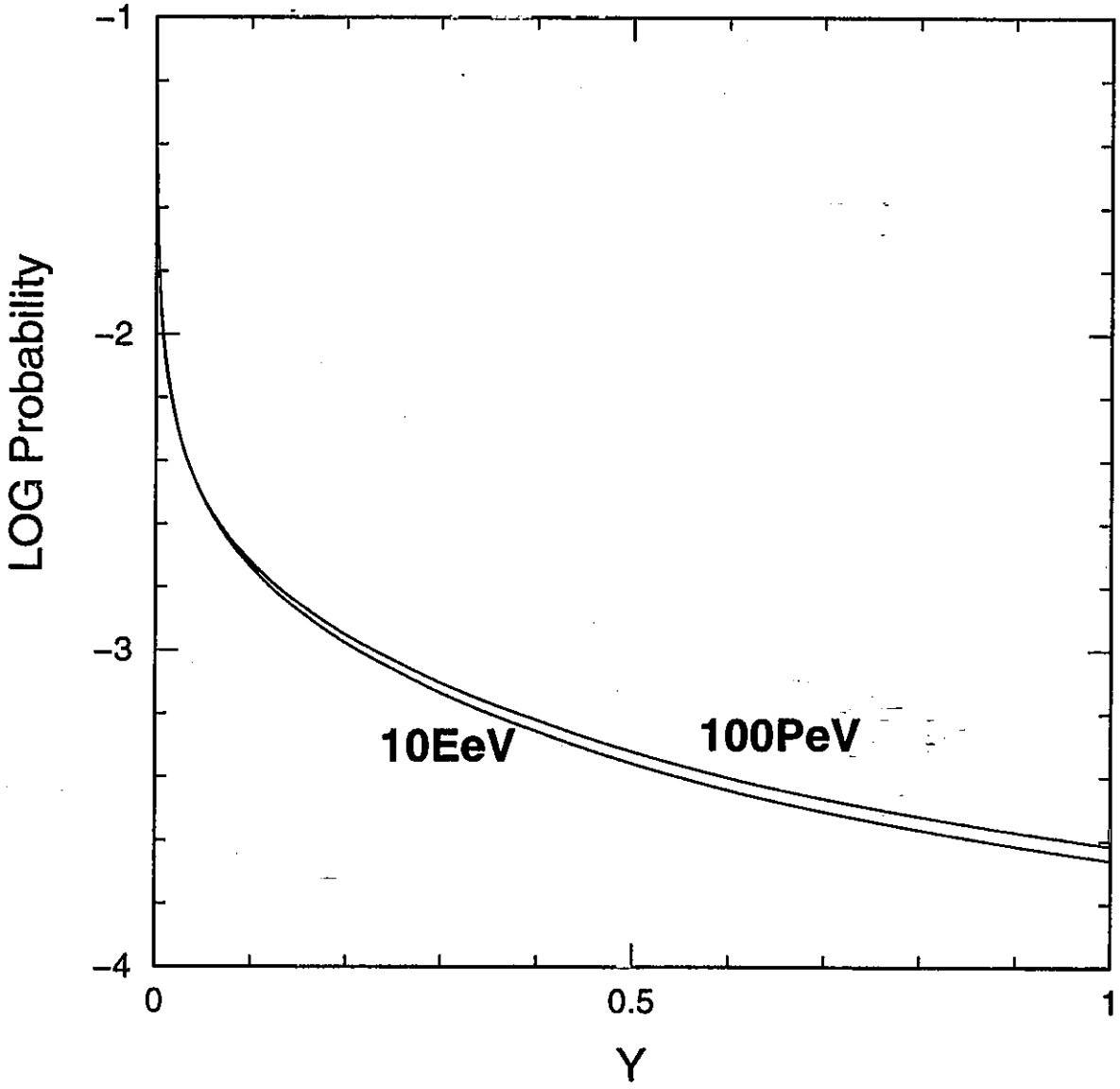
- Bremsstrahlung
- Hadronic Shower

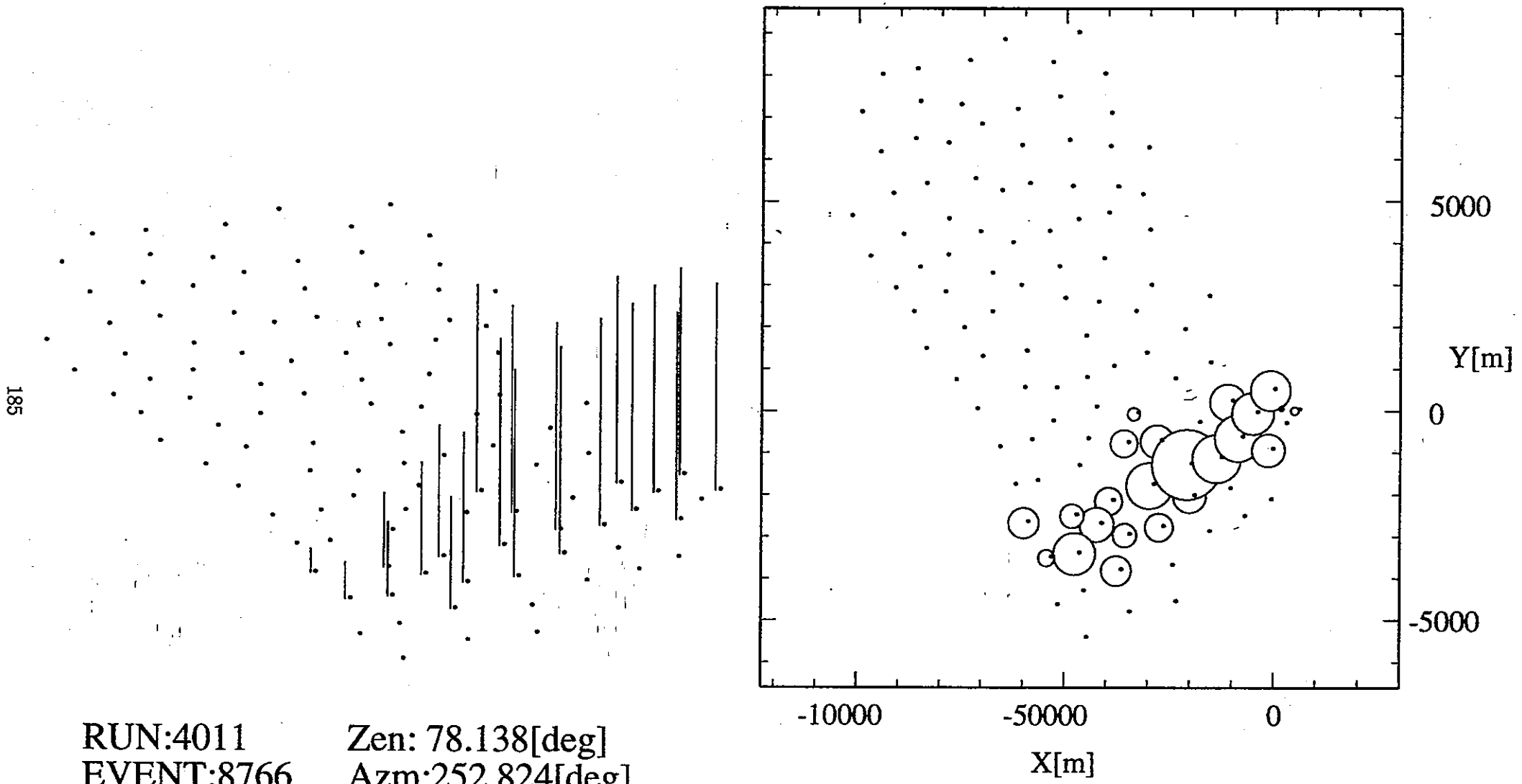
Neutral Current

$\longrightarrow \nu_\mu + N$

- Hadronic Shower

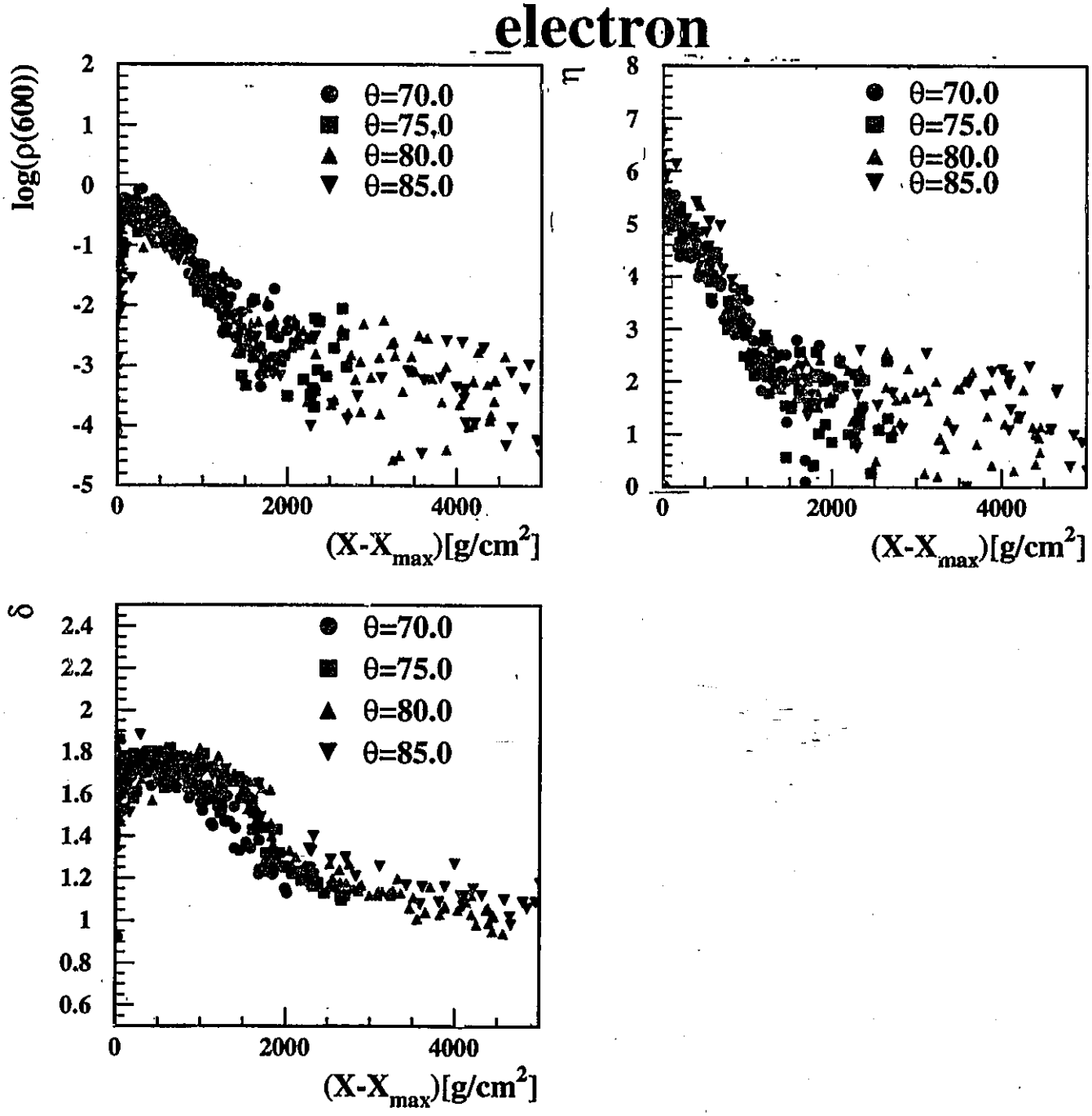

−31
−32
−33
−34
σ [cm²]
ν N CC
ν N NC
CTEQ5
Approx. CTEQ4
15
16
17
18
19
20
LOG(ENERGY(eV))


LOG Probability
−1
−2
−3
−4
0
0.5
1
Y
10EeV
100PeV

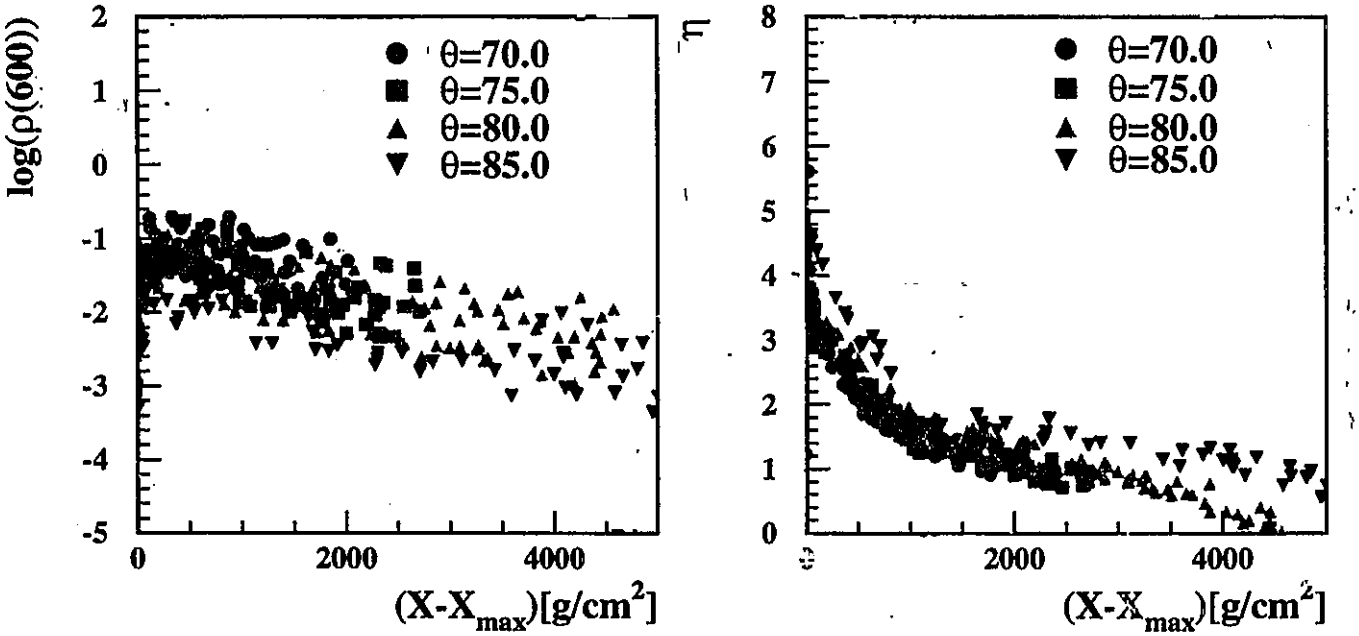


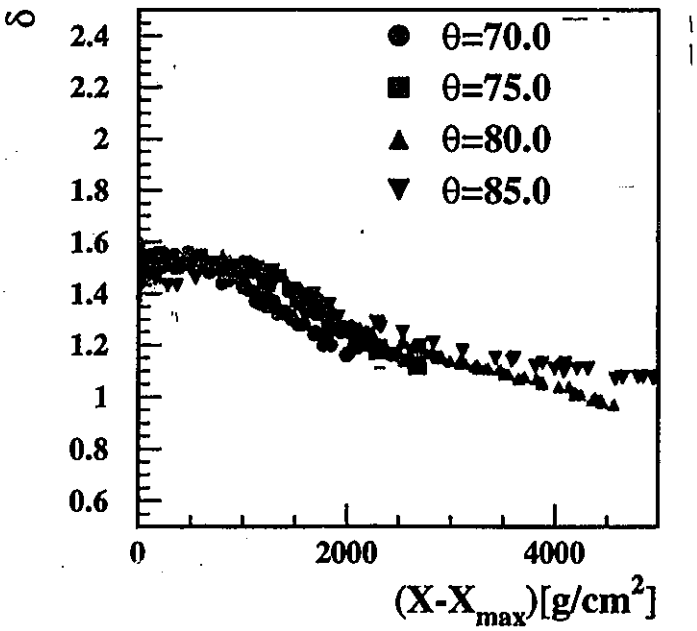
RUN:4011 Zen: 78.138[deg]
EVENT:8766 Azm:252.824[deg]
DATE:980707 Chi:0.85
TIME:155646

ν
p

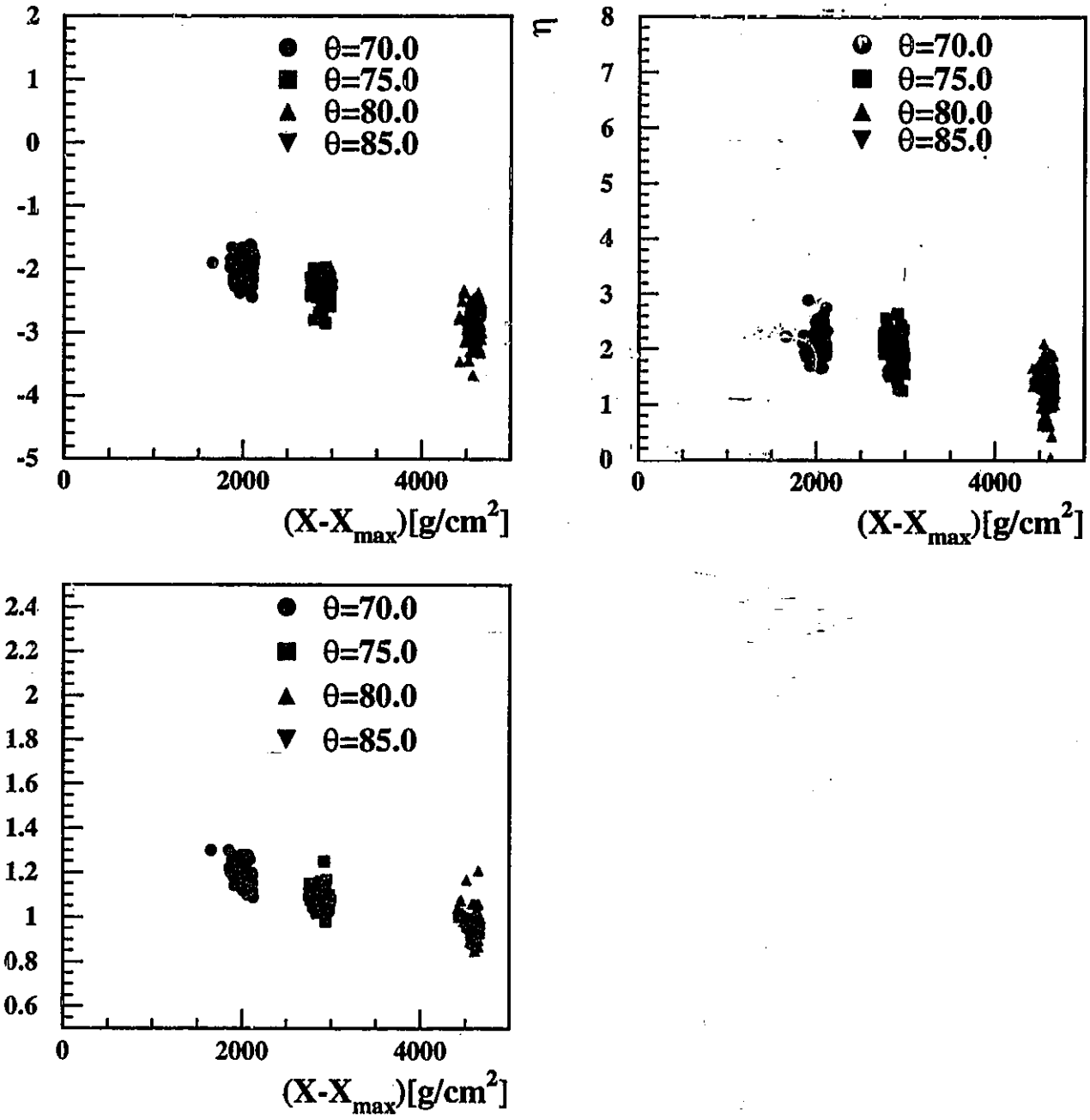

electron
log(ρ(600))
η
δ
θ=70.0
θ=75.0
θ=80.0
θ=85.0
(X-X_max)[g/cm^2]
0
2000
4000

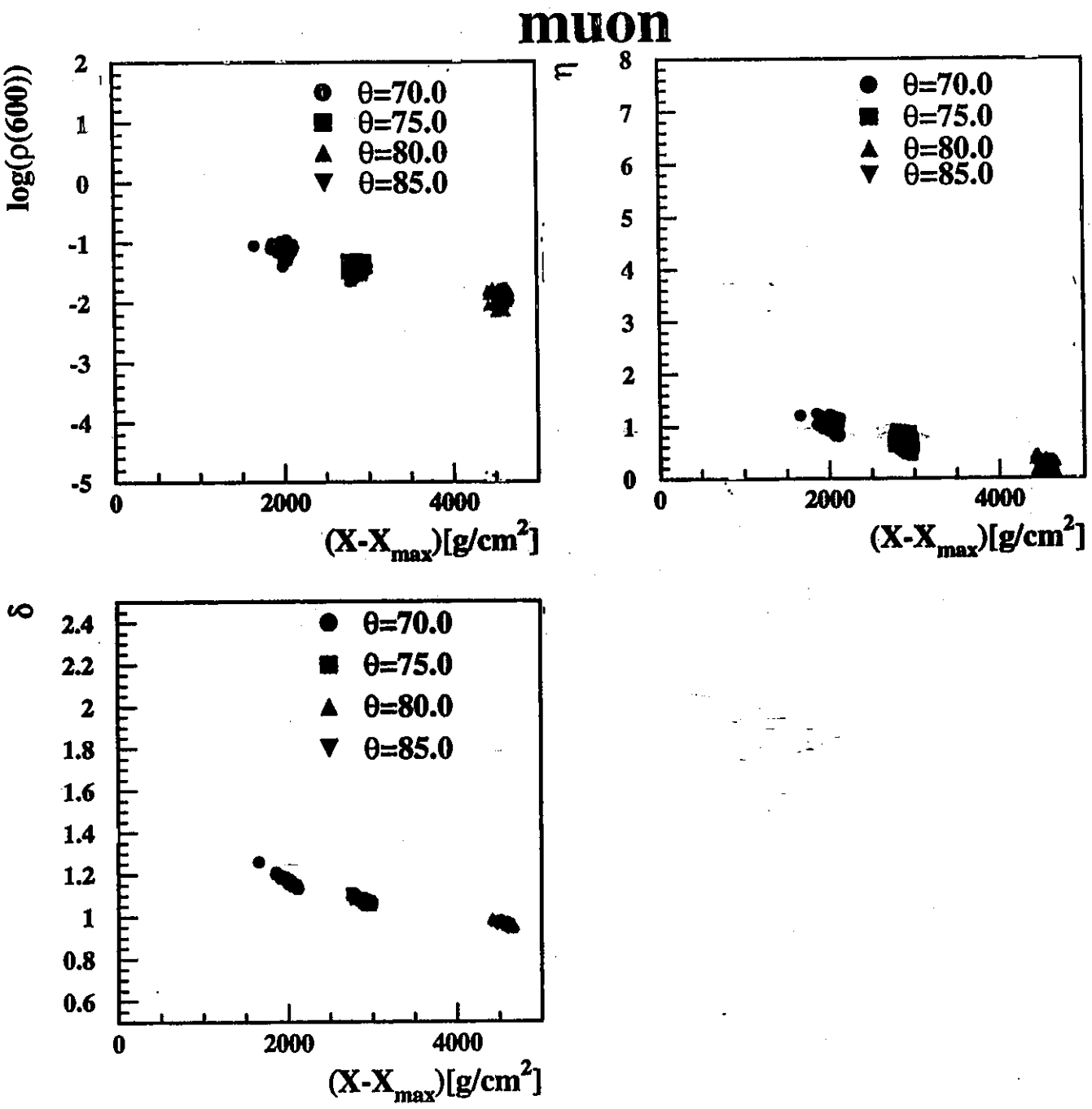
muon


log(ρ(600))
η
θ=70.0
θ=75.0
θ=80.0
θ=85.0
(X-X_max)[g/cm^2]

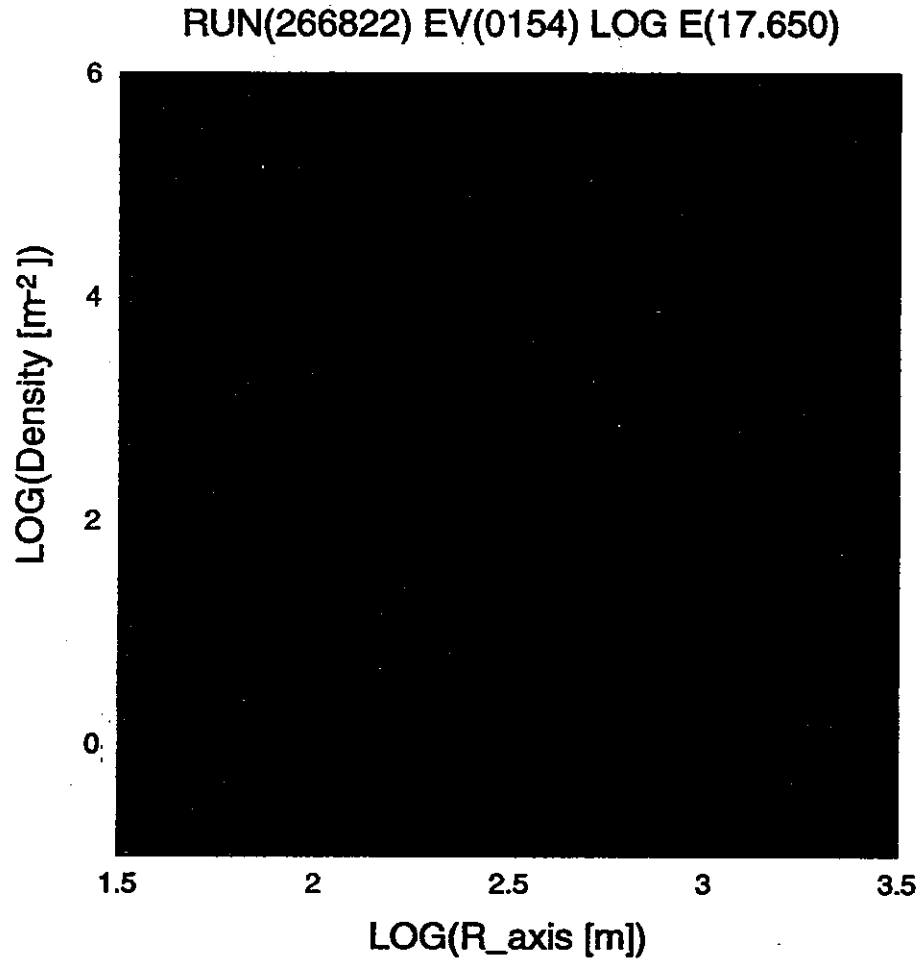

δ
θ=70.0
θ=75.0
θ=80.0
θ=85.0
(X-X_max)[g/cm^2]

electron

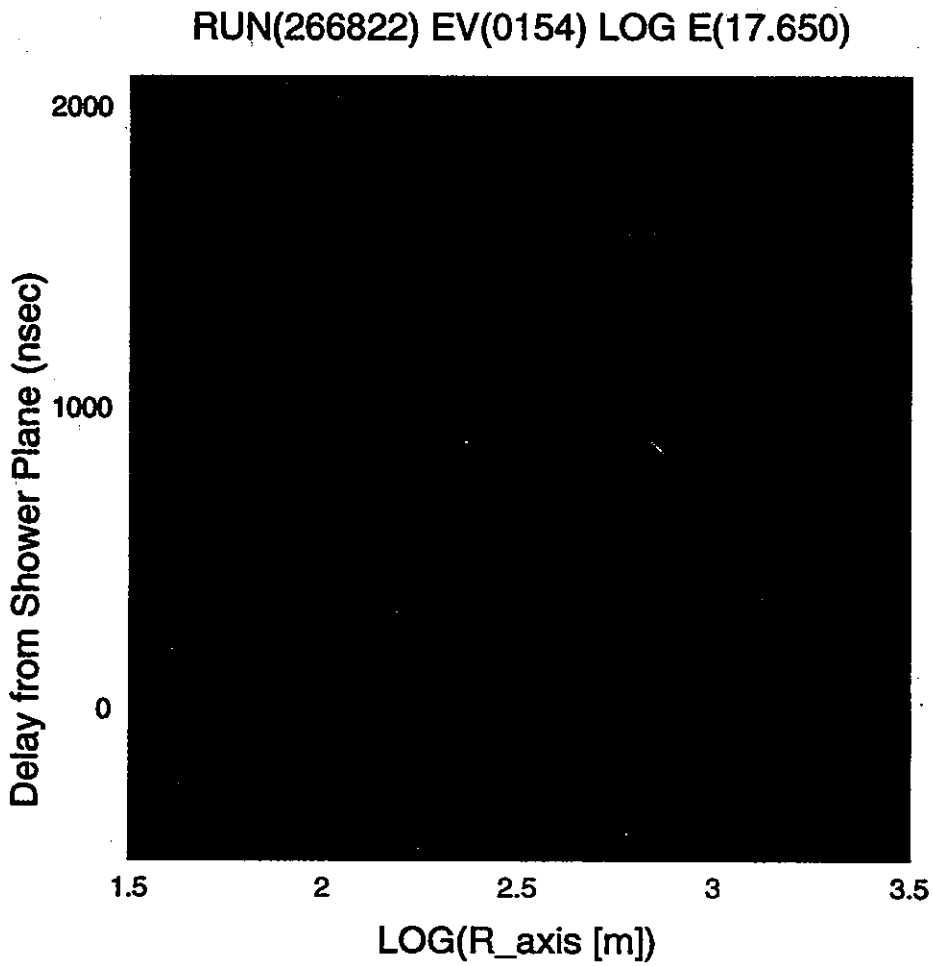



muon
log(ρ(600))
θ=70.0
θ=75.0
θ=80.0
θ=85.0
(X-X_max)[g/cm²]
η
δ

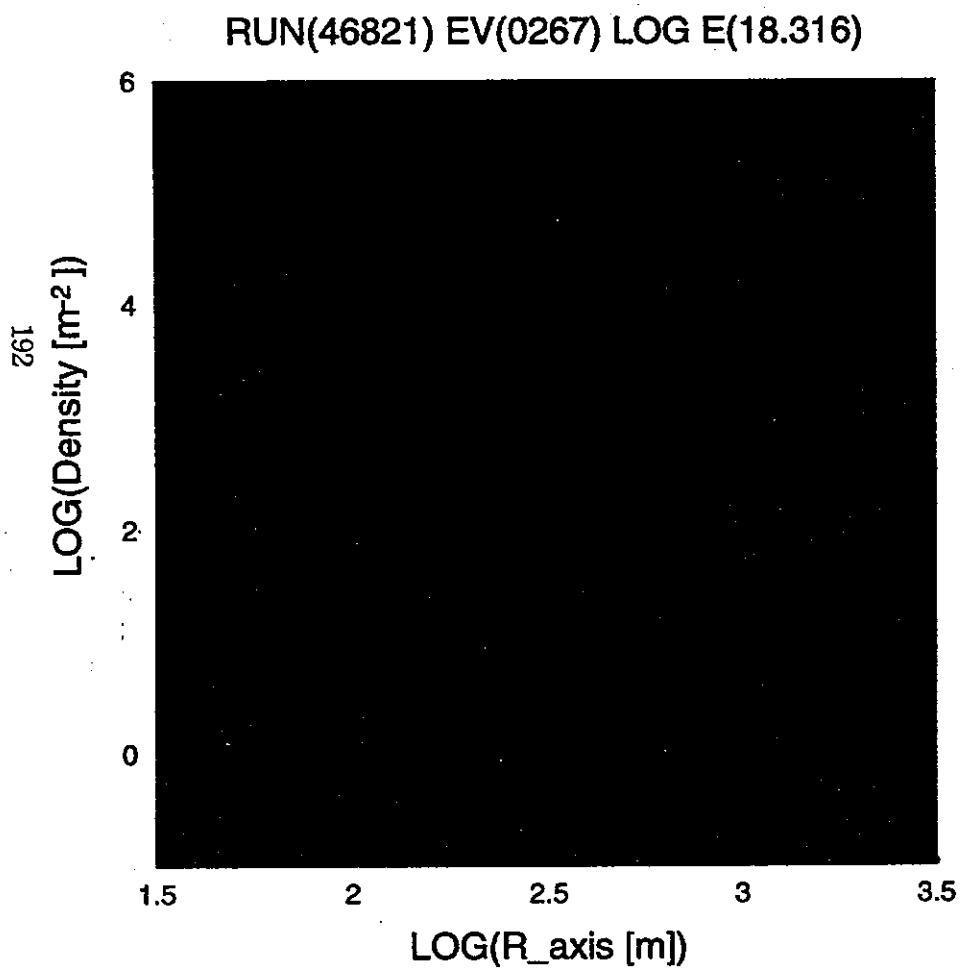
zenith= 73.58 77.11 Xmax=3347.27 4125.39 [g] flag(2)
ev_number(154) energy= 17.65
chi–ft 4.242e+00 chi–LDF 8.668e–01



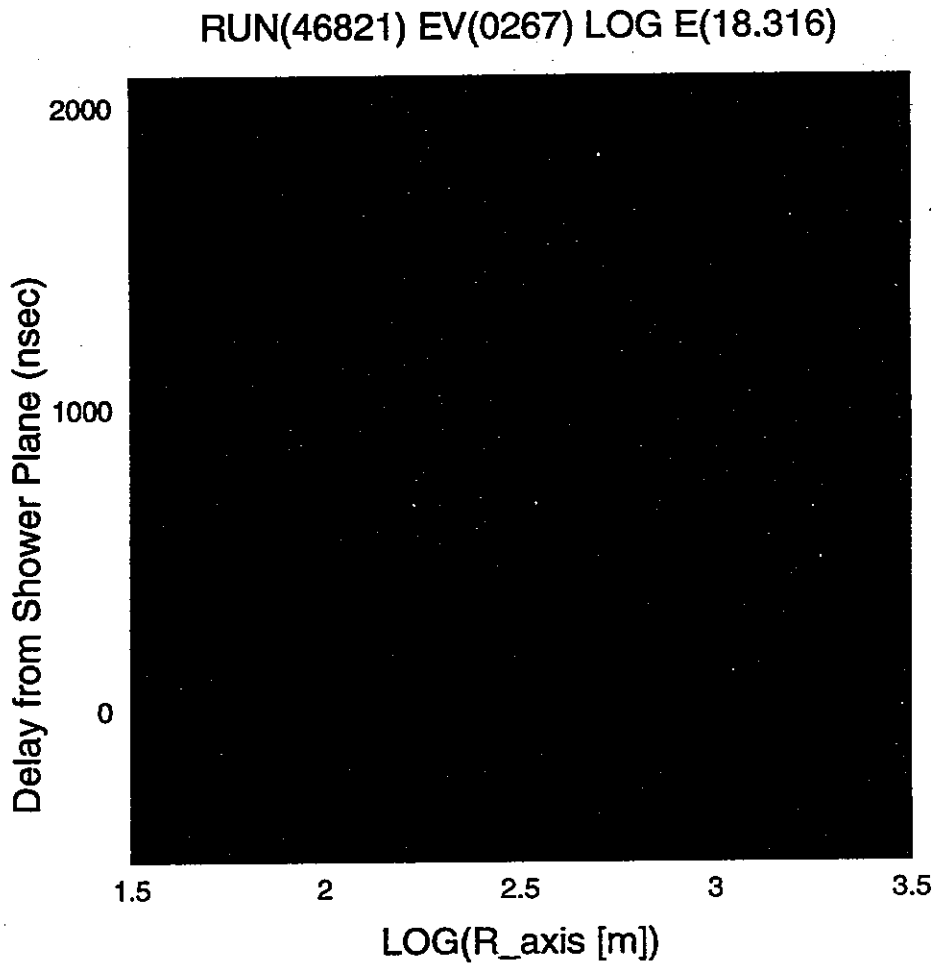
zenith= 73.58 77.11 Xmax=2871.76 4125.39 [g] flag(2)
chi–ft 4.242e+00 chi–LDF 8.668e–01



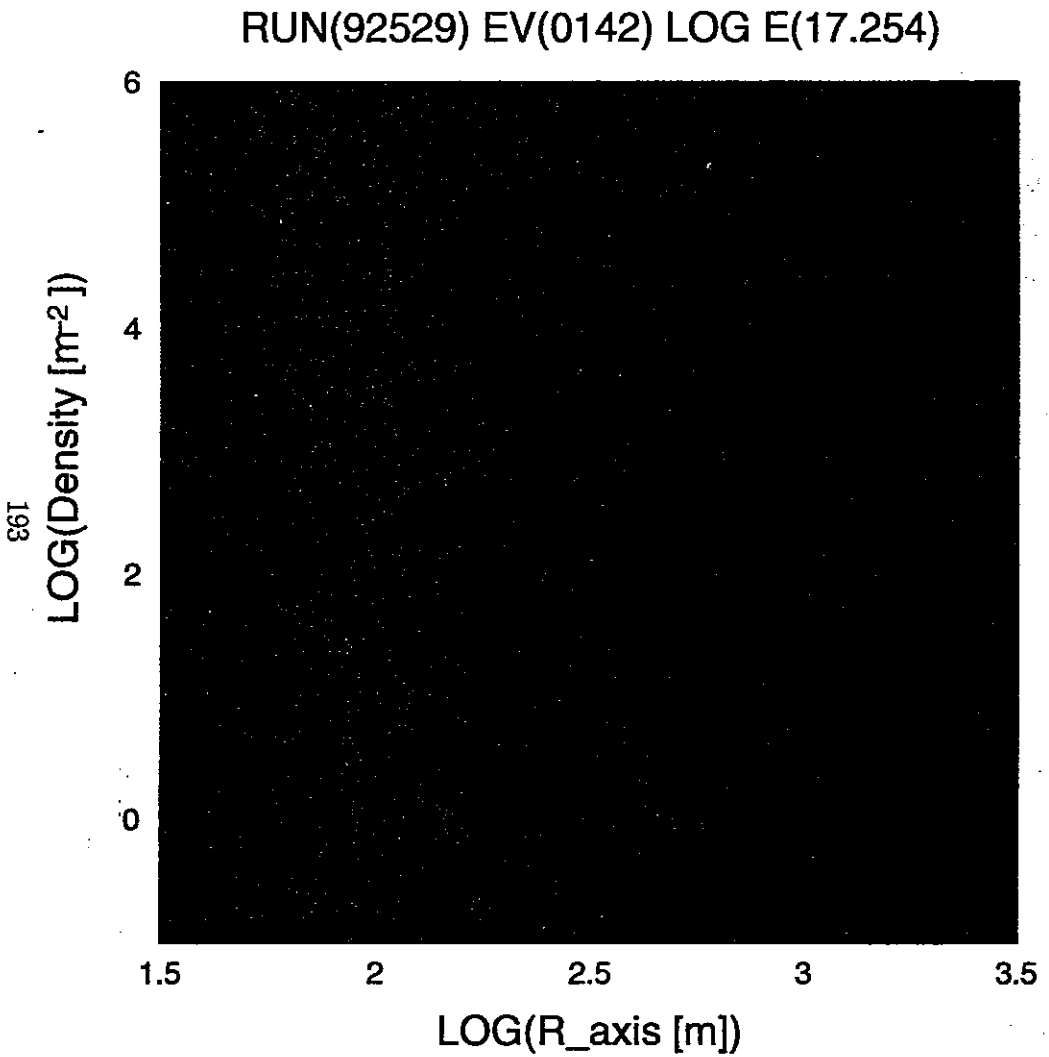
zenith= 71.44 72.11 Xmax=2776.45 3011.73 [g] flag(2)
ev_number(267) energy= 18.32
chi-ft 1.500e+01 chi-LDF 3.665e-01



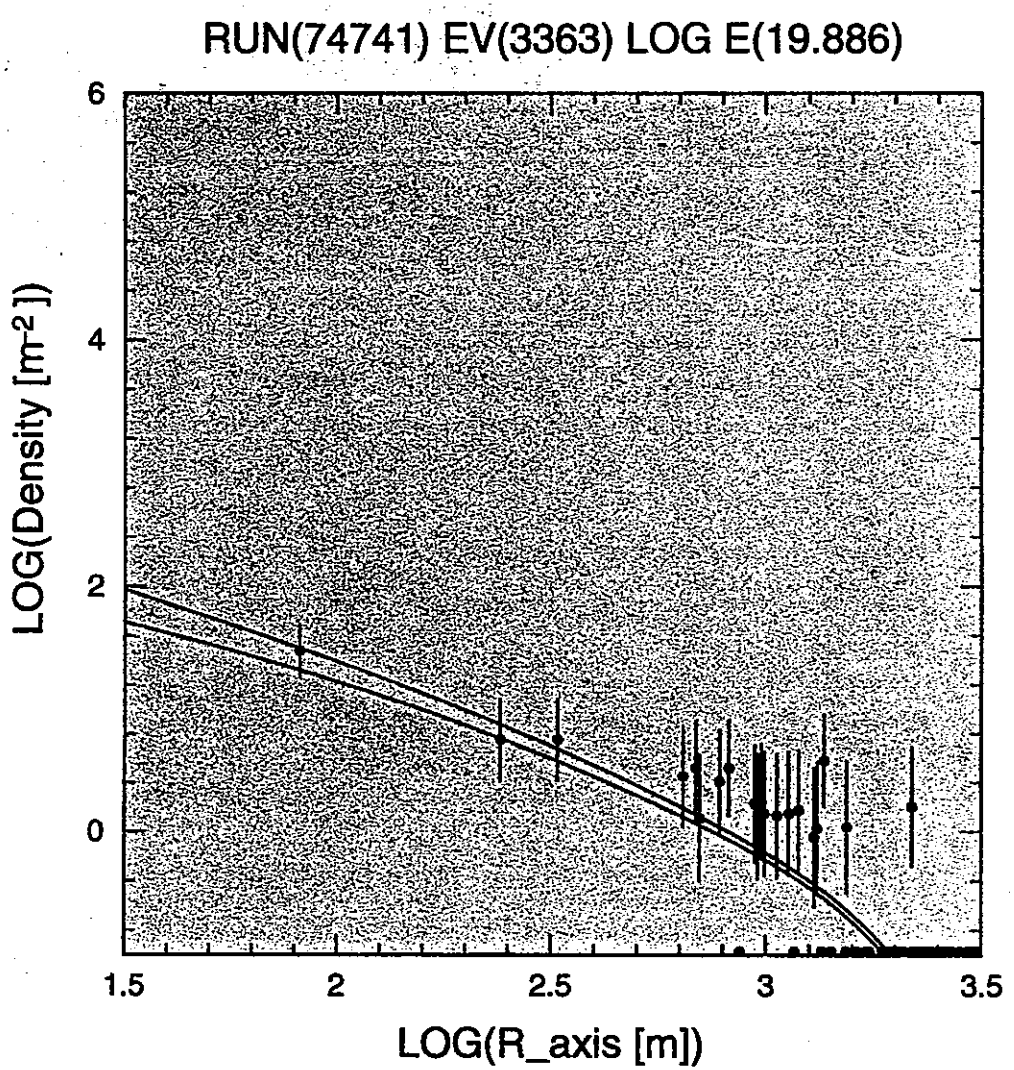
zenith= 71.44 72.11 Xmax=2551.75 3011.73 [g] flag(2)
chi-ft 1.500e+01 chi-LDF 3.665e-01

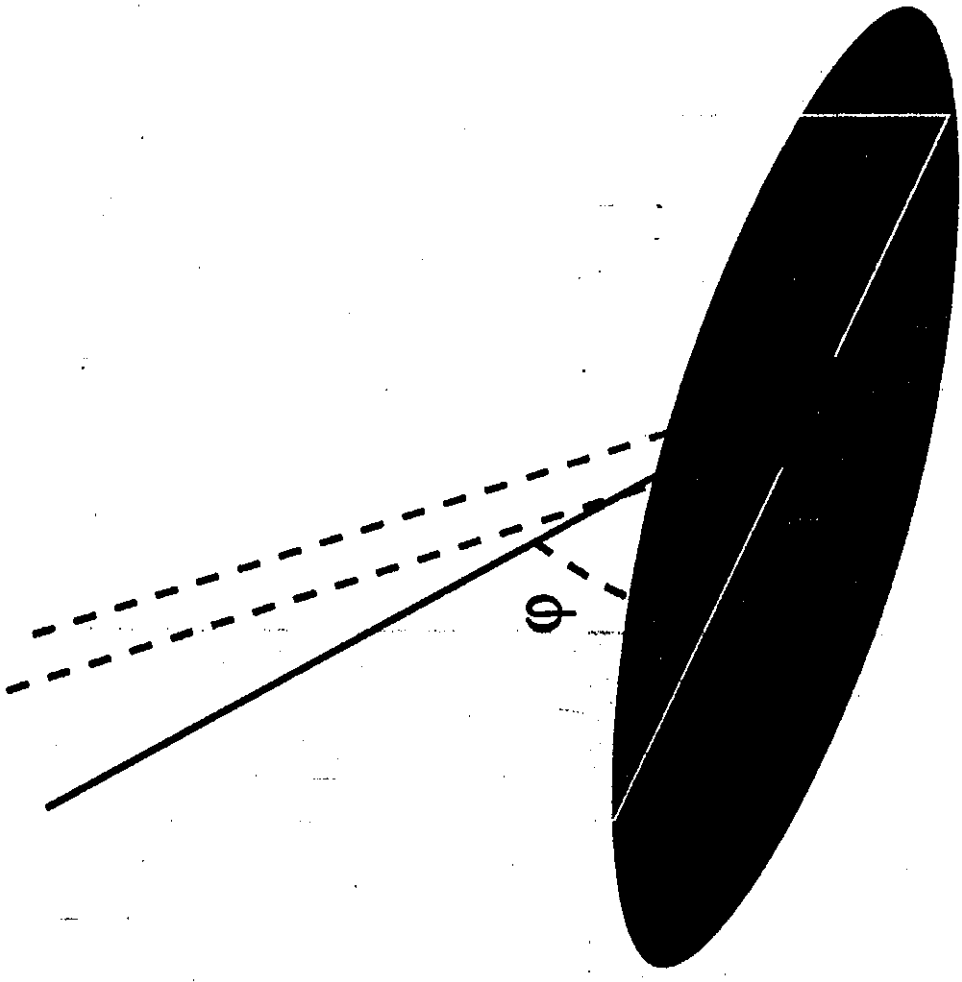


zenith= 80.85 81.04 Xmax=5781.17 5657.87 [g] flag(2)
chi–ft 4.681e+00 chi–LDF 1.851e+00



zenith= 72.38 70.75 Xmax=1287.29 853.94 [g] flag(2)
chi–ft 9.141e–01 chi–LDF 7.967e–01




φ

The Xmax is the paremeter in the fitting procedure?

For reduction of number of parameters

Lateral Distribution Fitting

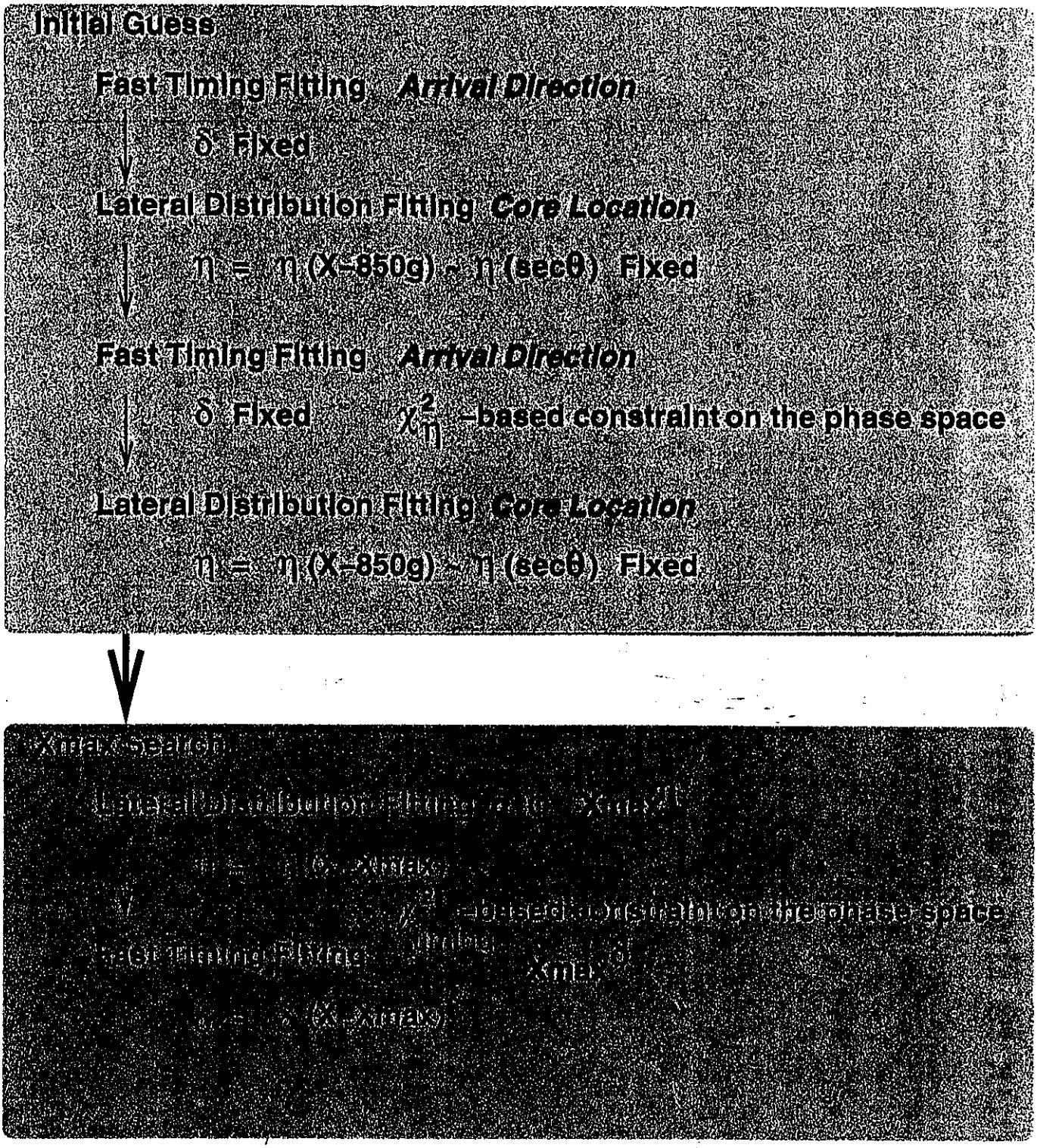
$$\rho_{e\mu} = \sum_{i} w_i(X - X_{max})\, C_i(E(X - X_{max}))\, F_i(E, \eta(X - X_{max}))$$

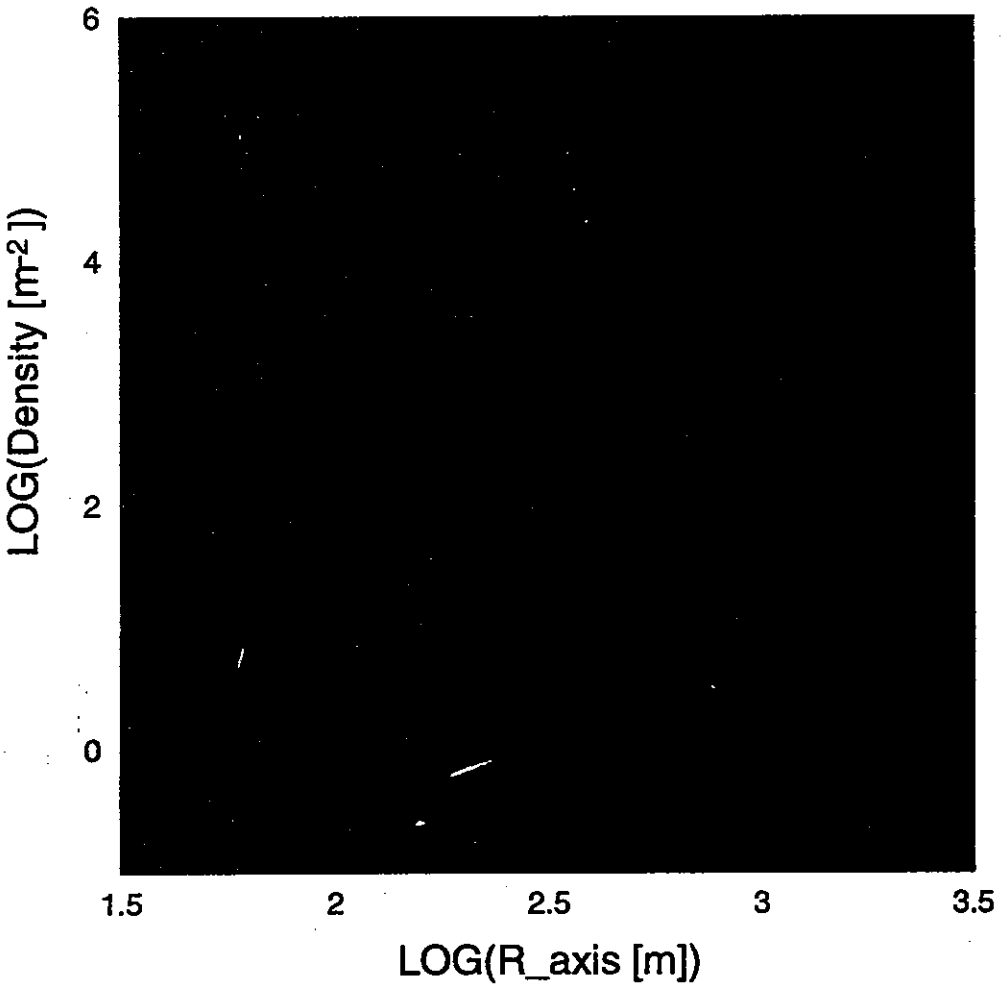
Component *Energy Scale* *Lateral Distribution*

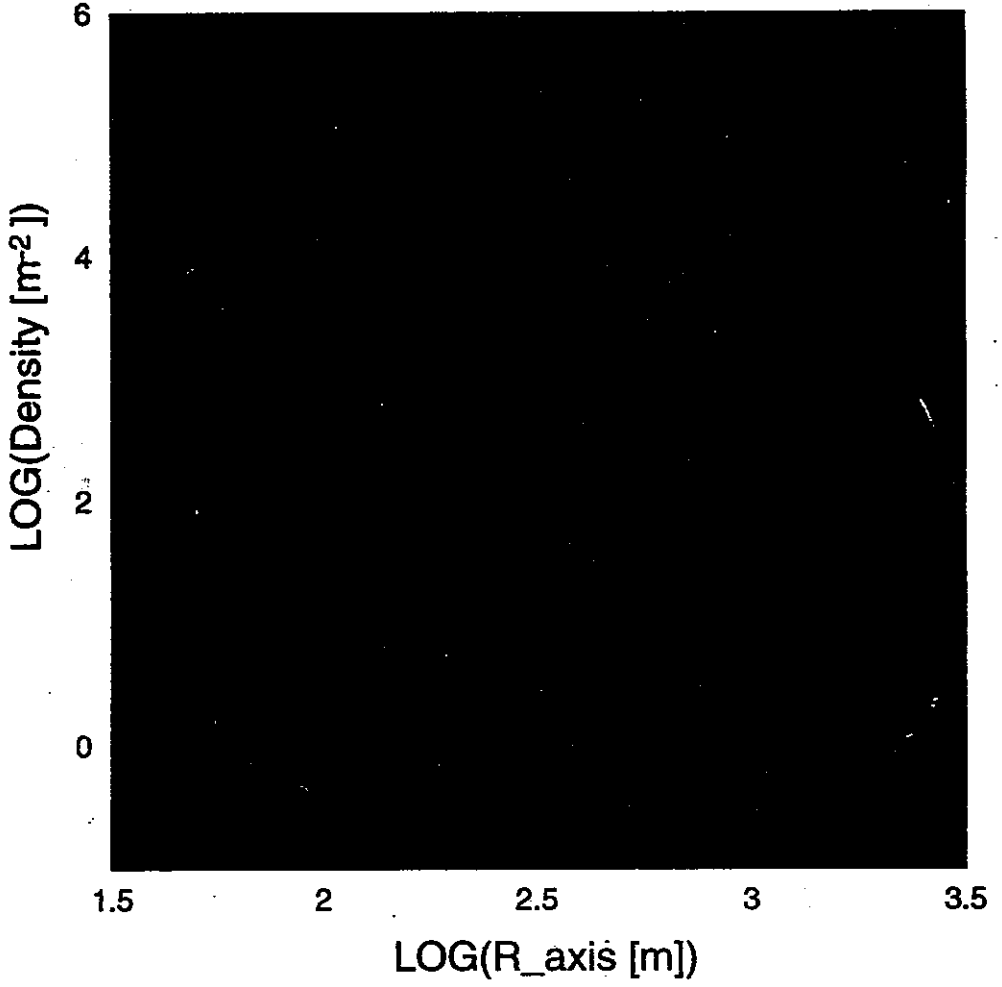
Fast Timing Fitting

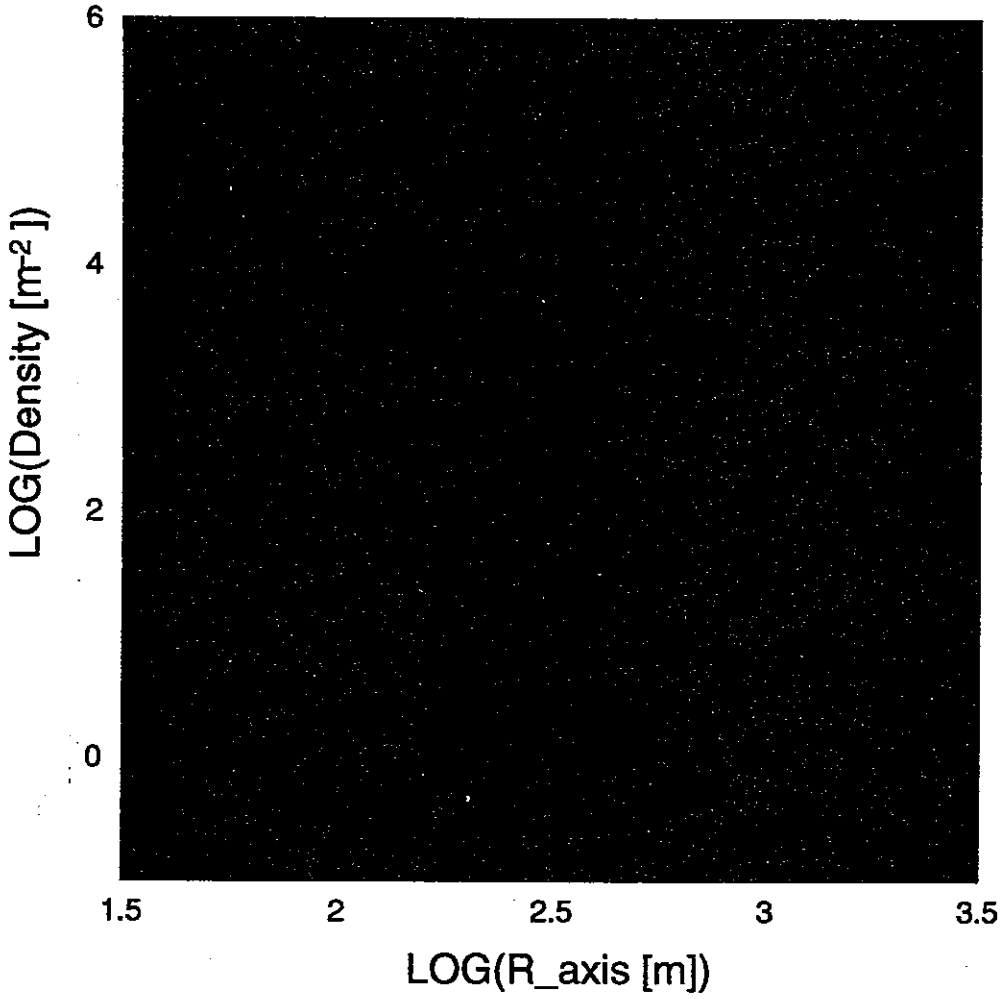
$$\tau_{e\mu} = f(\delta(X - X_{max}))$$

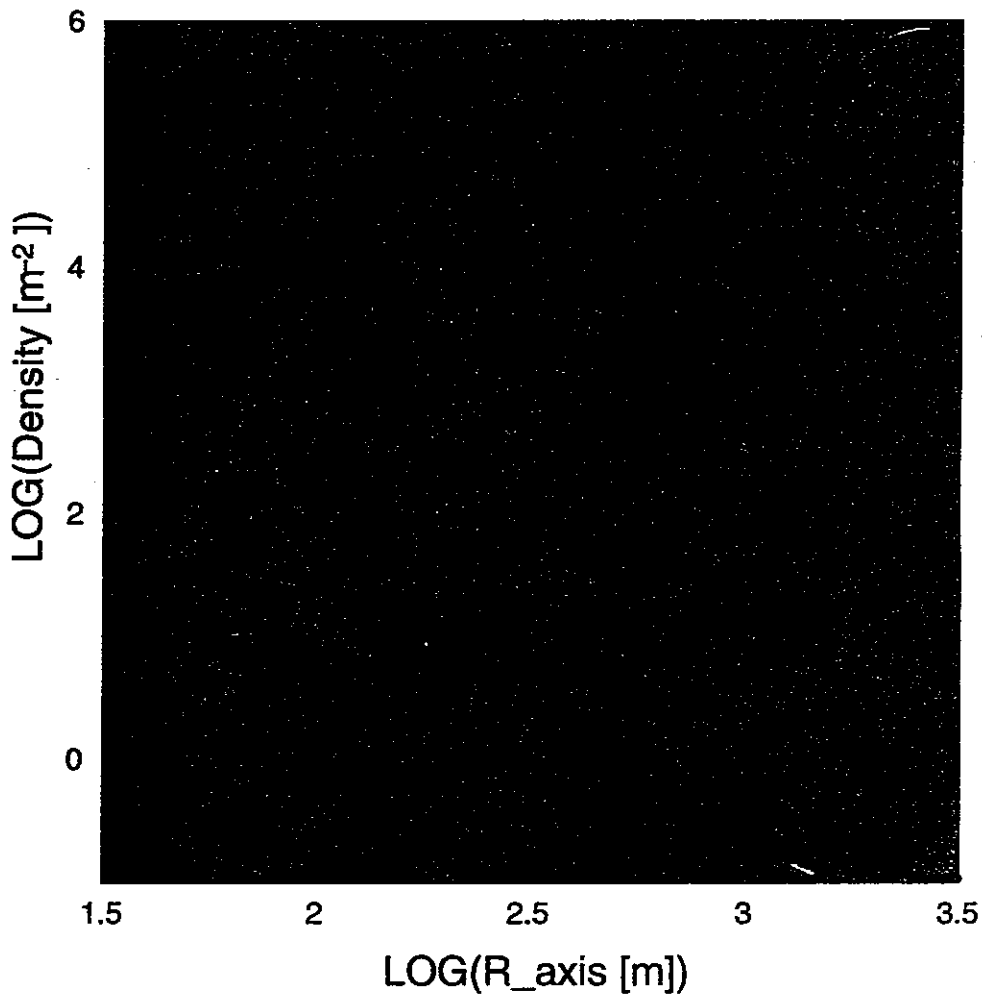
The Reconstruction Procedure

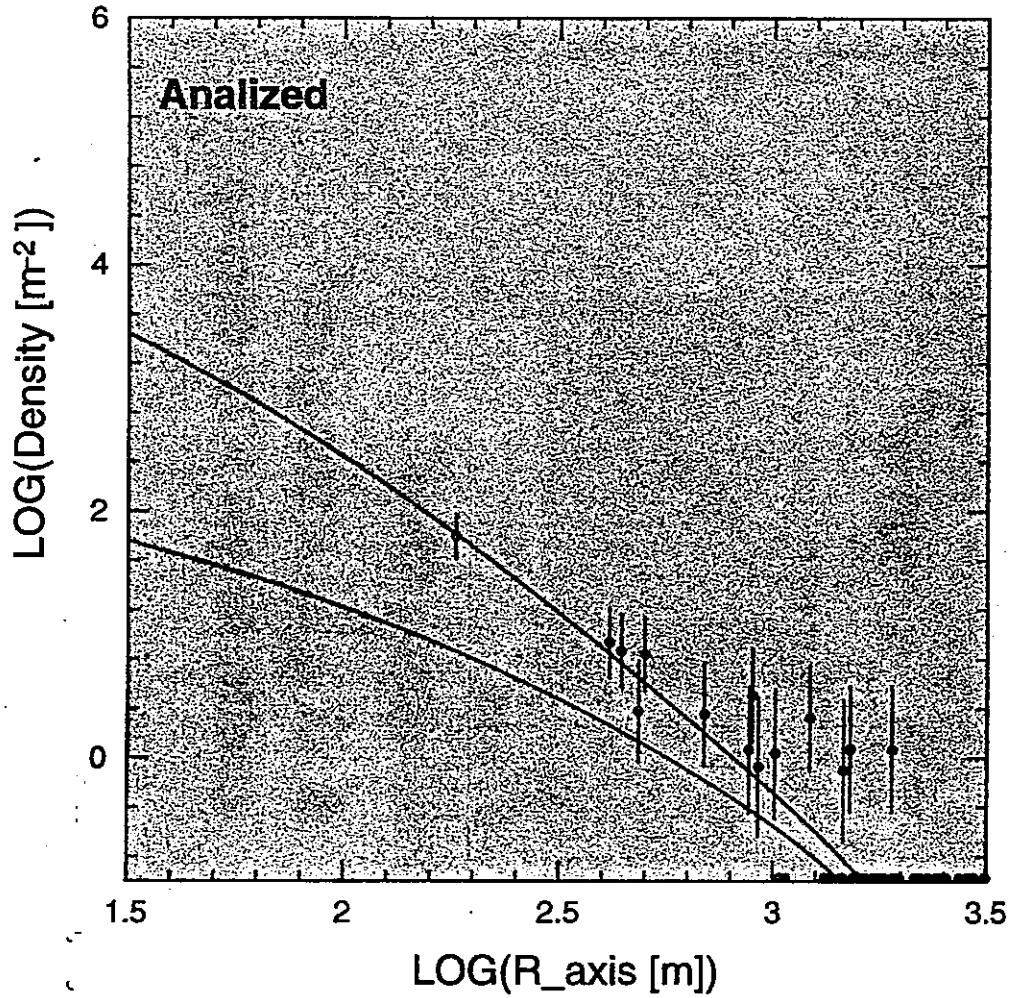


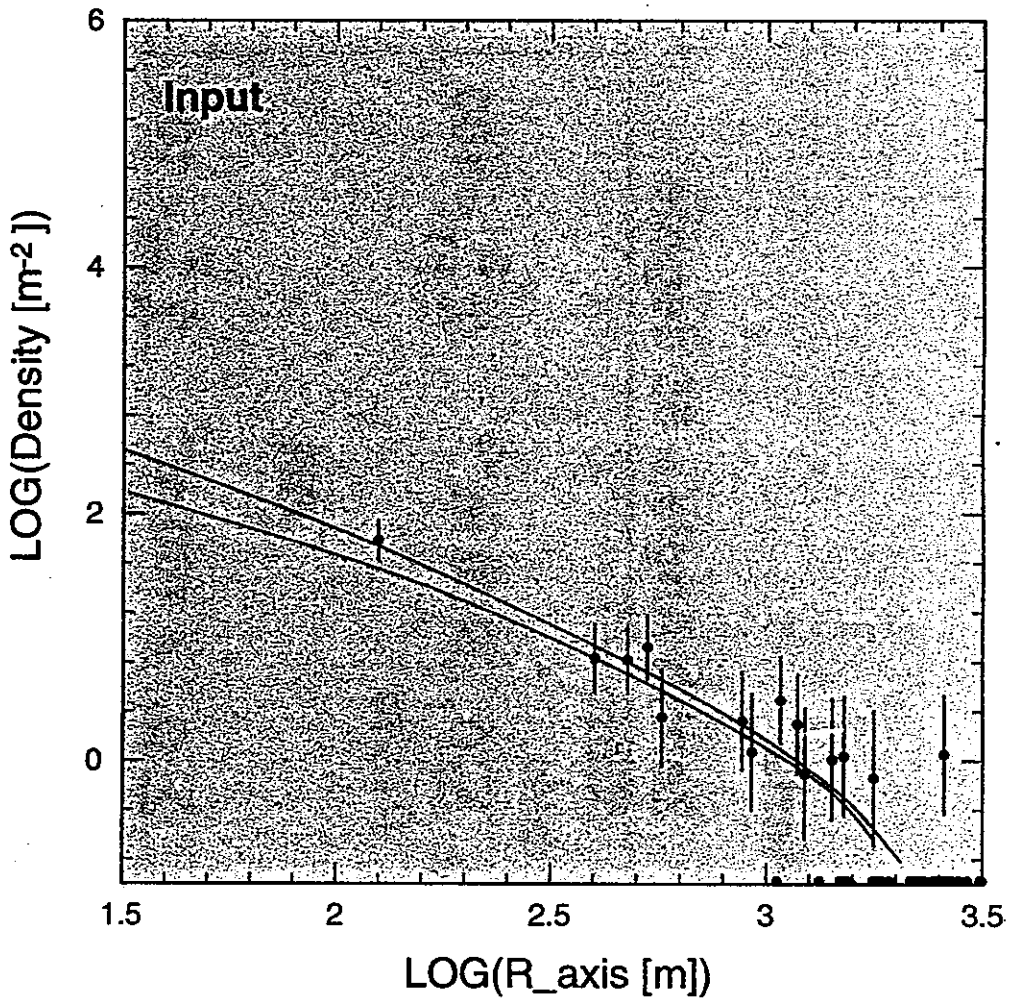

6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


Analized
LOG(Density [m-2])
LOG(R_axis [m])
6
4
2
0
1.5
2
2.5
3
3.5


Input
LOG(Density [m-2])
LOG(R_axis [m])
6
4
2
0
1.5
2
2.5
3
3.5

HAS Data Criteria

Zenith Angle > 65 degree
Nhit >= 7

Particle Density Sum

$$\sum_{\rho_i > 10} \rho_i > 50\ m^{-2} \qquad \chi^2_{FT} < 100 \qquad \chi^2_{\rho} < 1$$

OR

$$\sum_{\rho_i > 100} \rho_i > 100\ m^{-2} \qquad \chi^2_{FT} < 100$$

OR

$$\sum_{\rho_i > 100} \rho_i > 1000\ m^{-2}$$

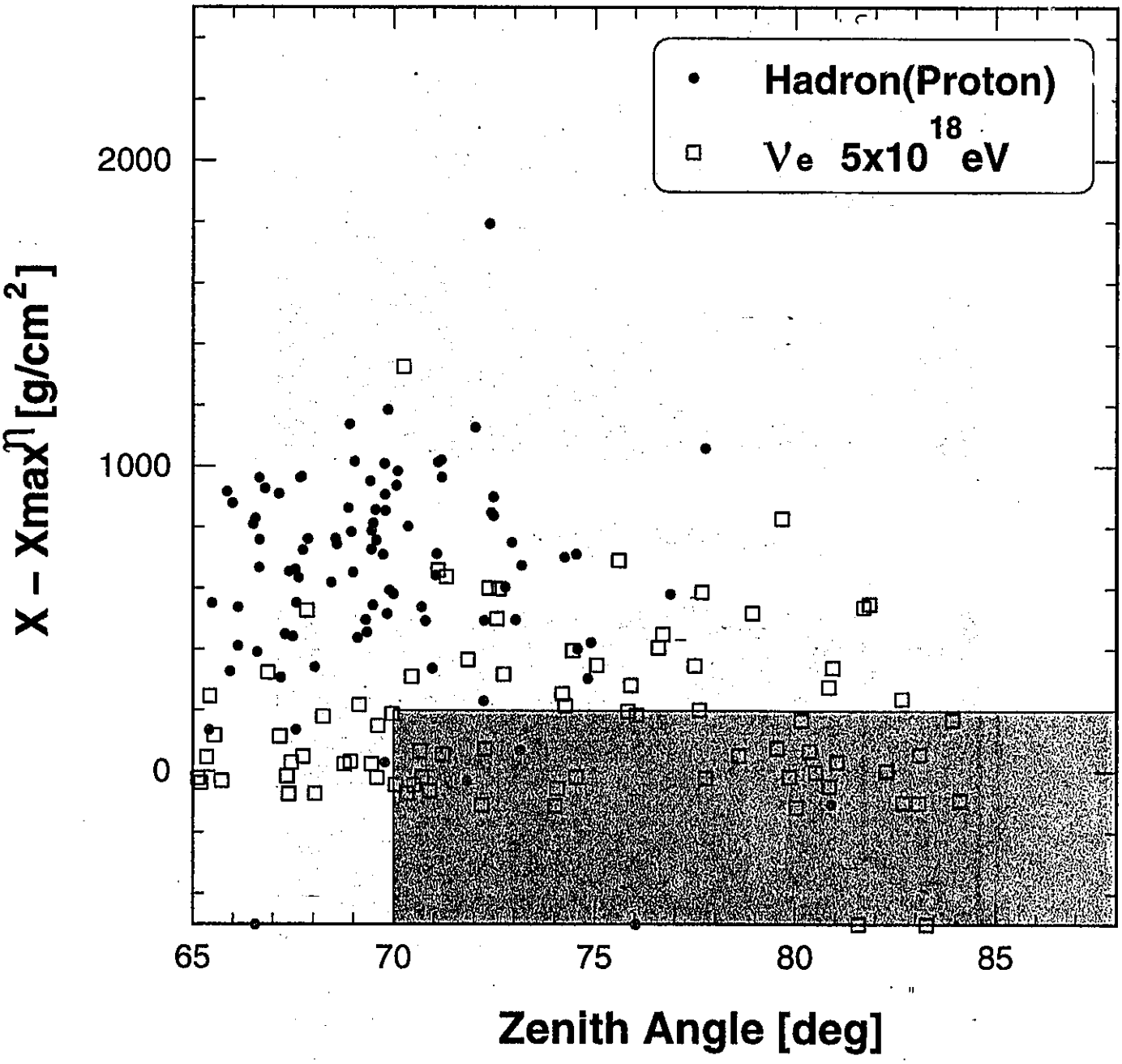
Hit Sum

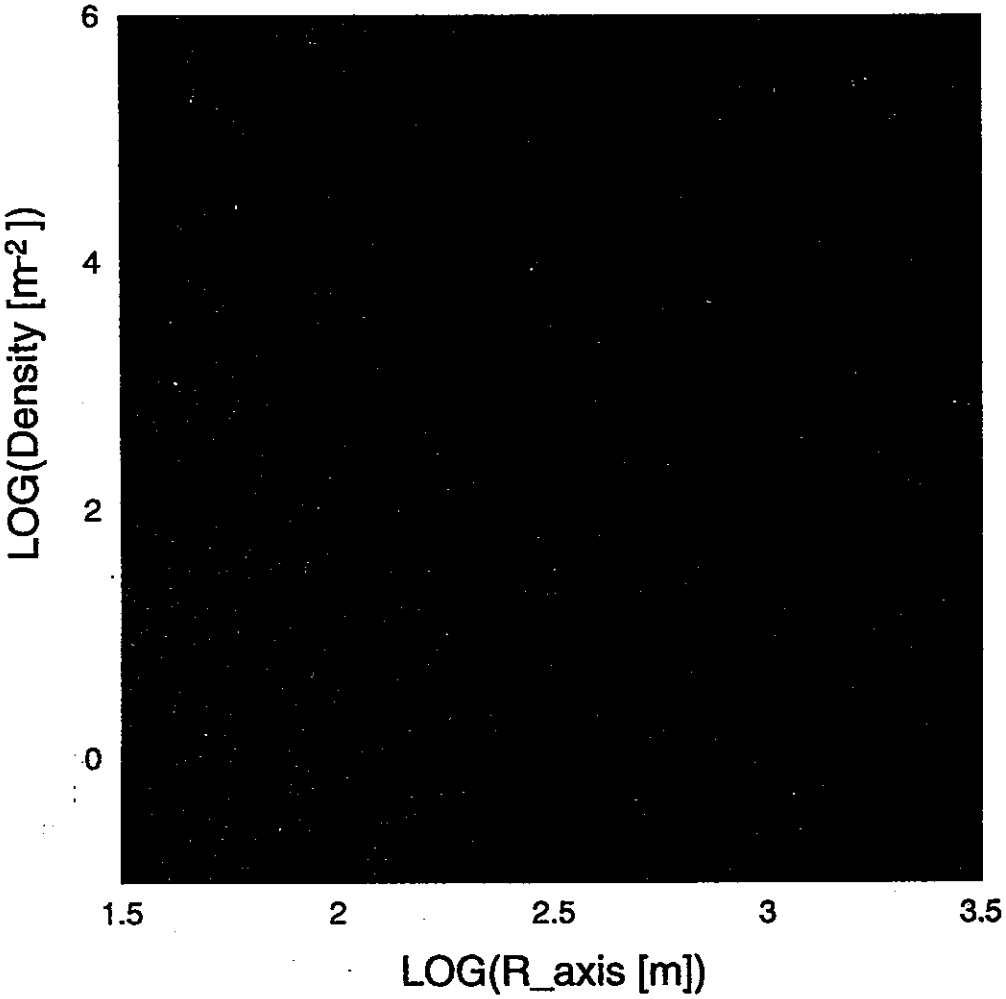
$$\sum_{\rho_i > 10} >= 3$$

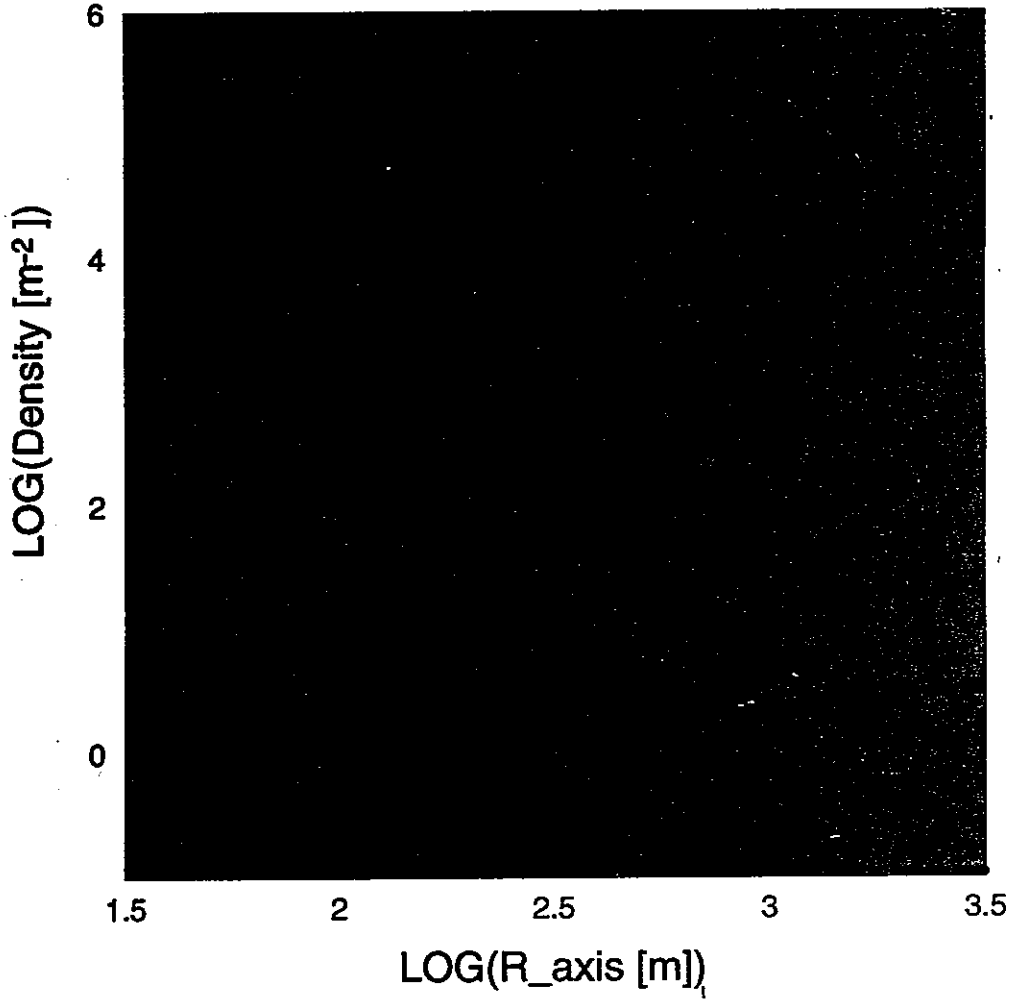
ν domain

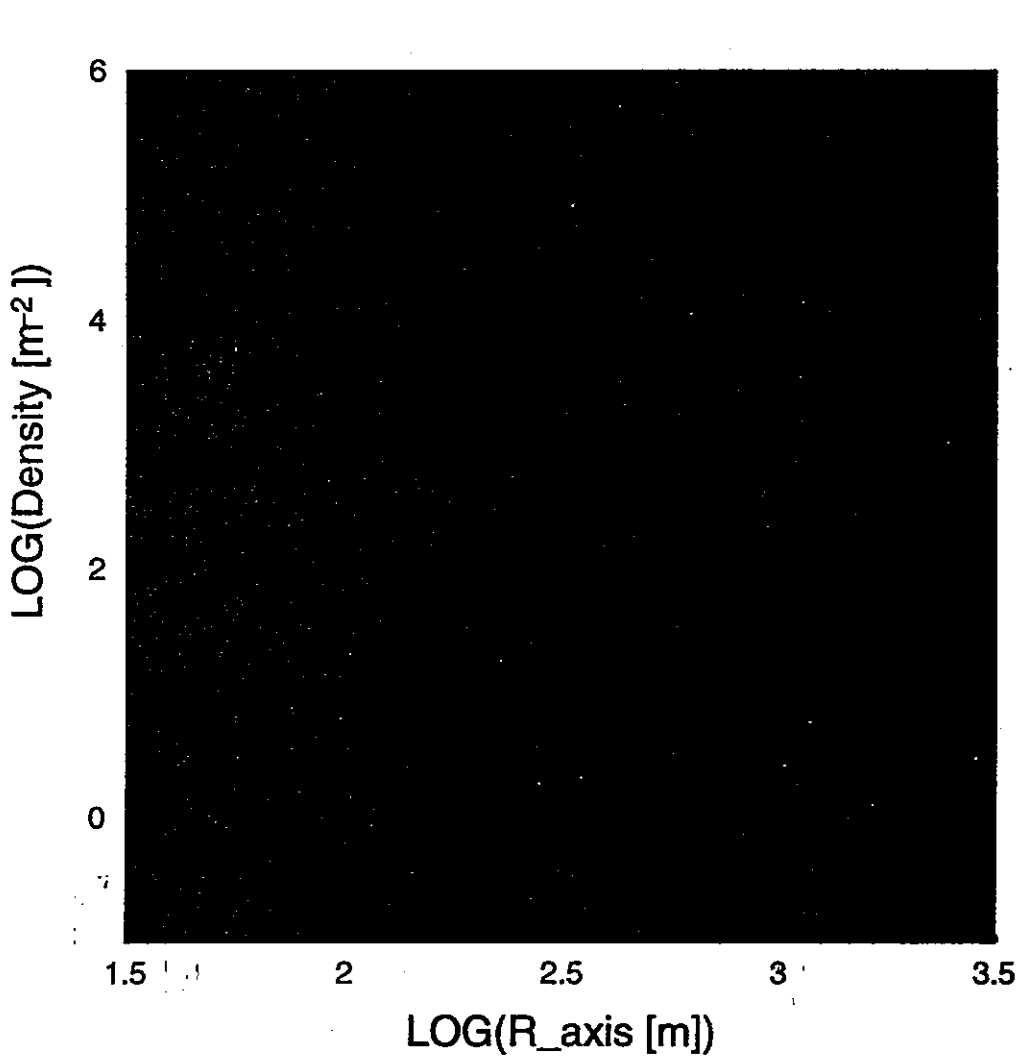
$$X - X^{\eta}_{max} < 200\ g/cm^2$$

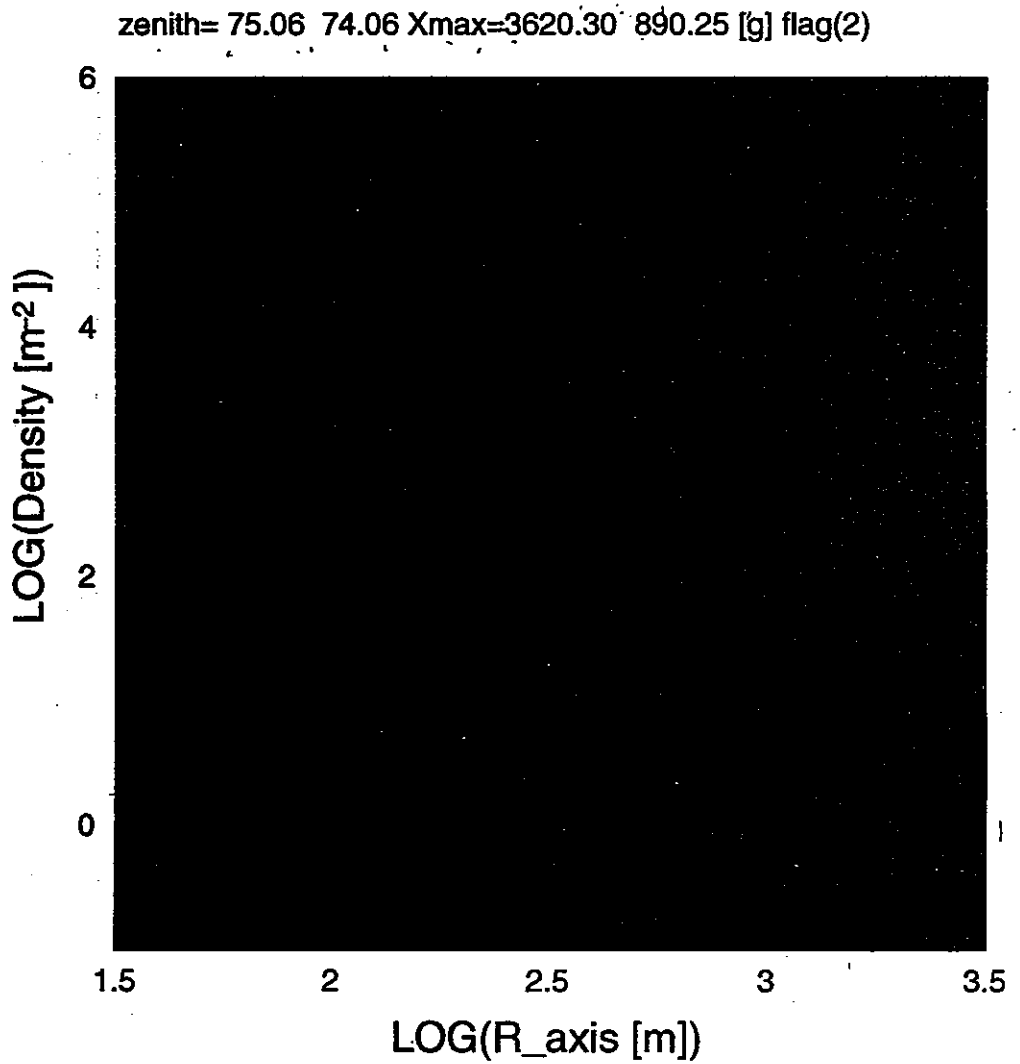
Zenith Angle > 70 degree

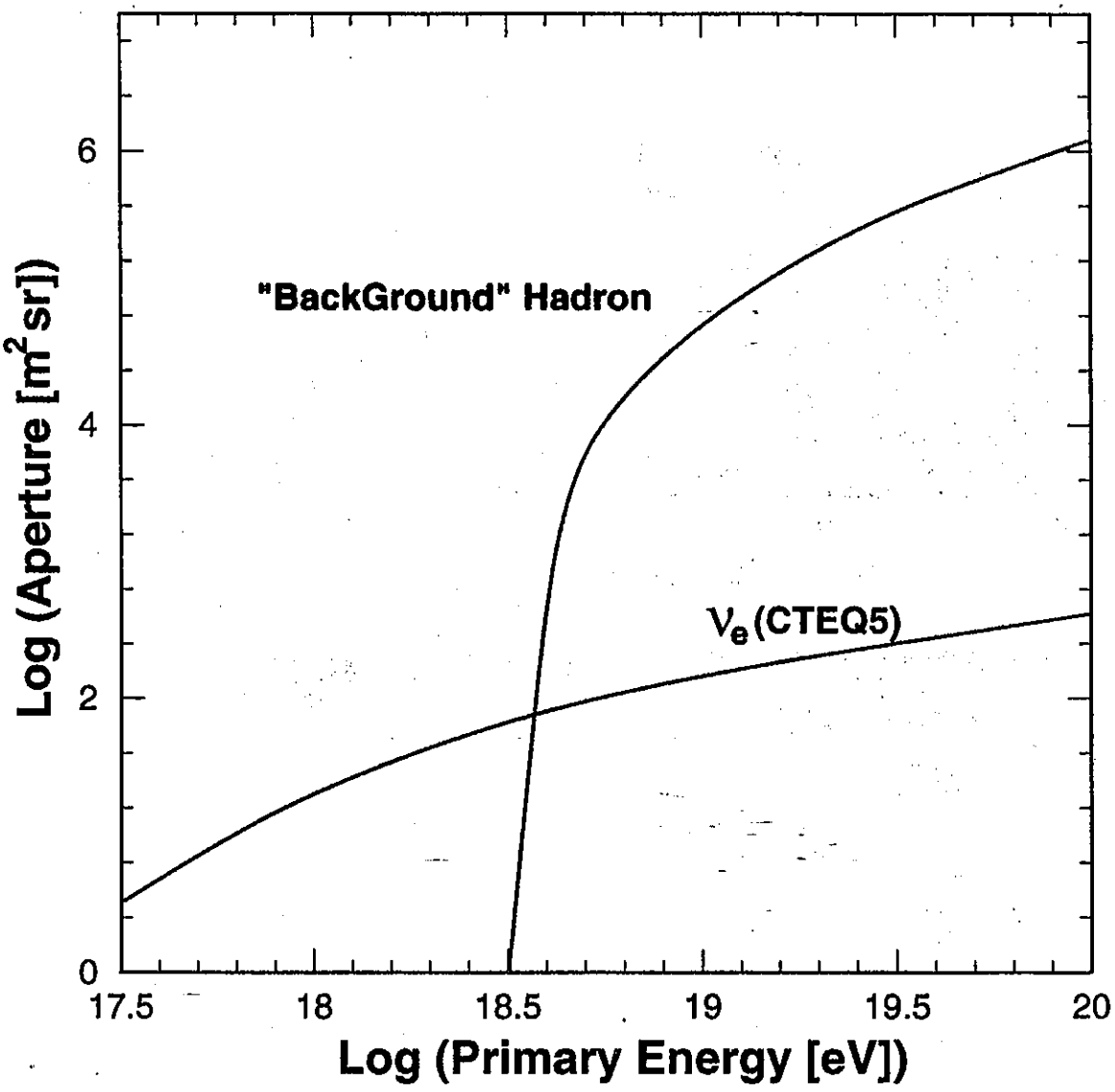

Hadron(Proton)
νe 5x10^18 eV
2000
1000
0
65
70
75
80
85
X – Xmax^η [g/cm^2]
Zenith Angle [deg]


6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


6
4
2
0
LOG(Density [m-2])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


6
4
2
0
LOG(Density [m^{-2}])
1.5
2
2.5
3
3.5
LOG(R_axis [m])


zenith= 75.06 74.06 Xmax=3620.30 890.25 [g] flag(2)
6
4
2
0
LOG(Density [m^{-2}])
1.5
2
2.5
3
3.5
LOG(R_axis [m])



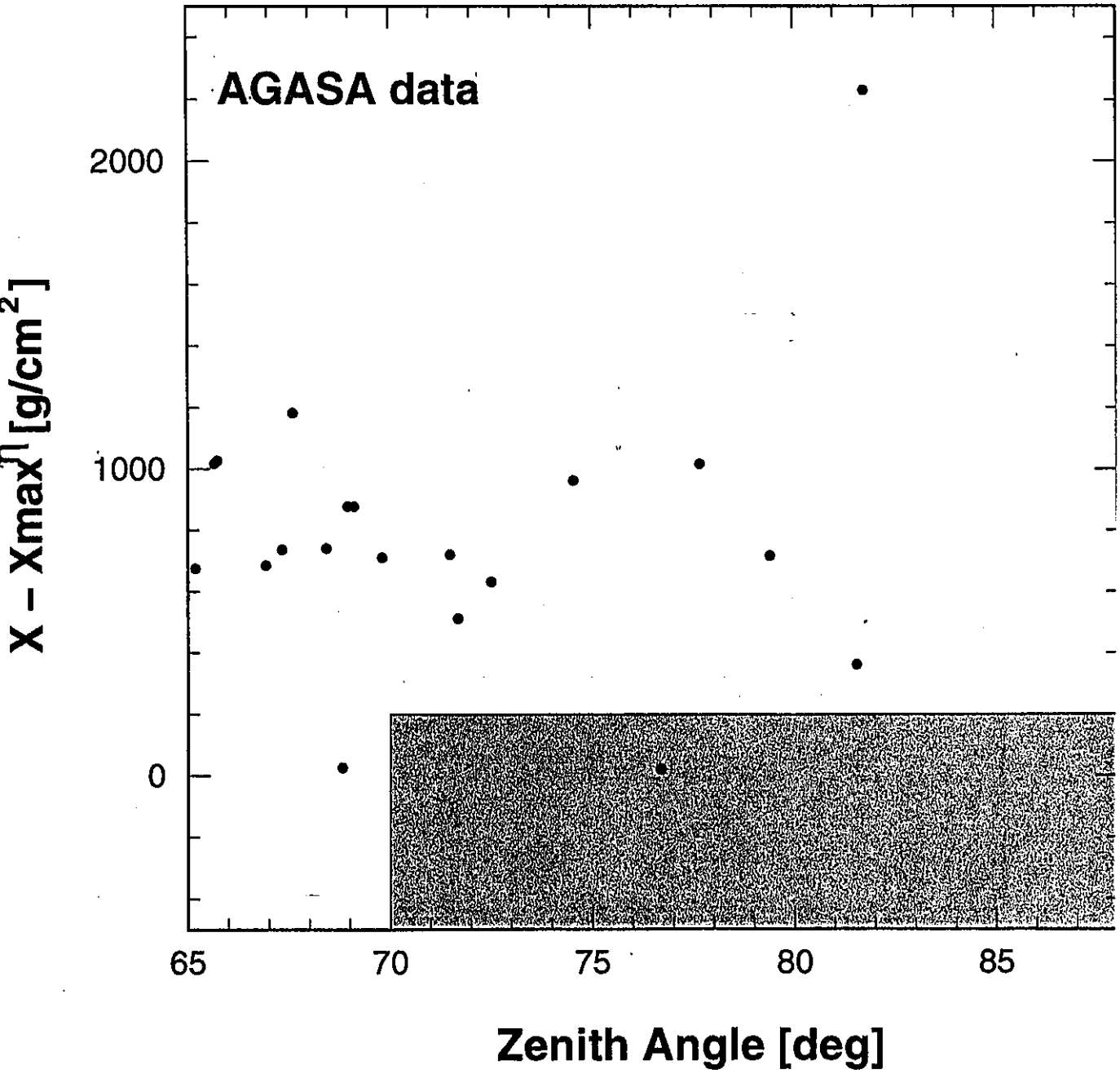
ν TARGET Volume

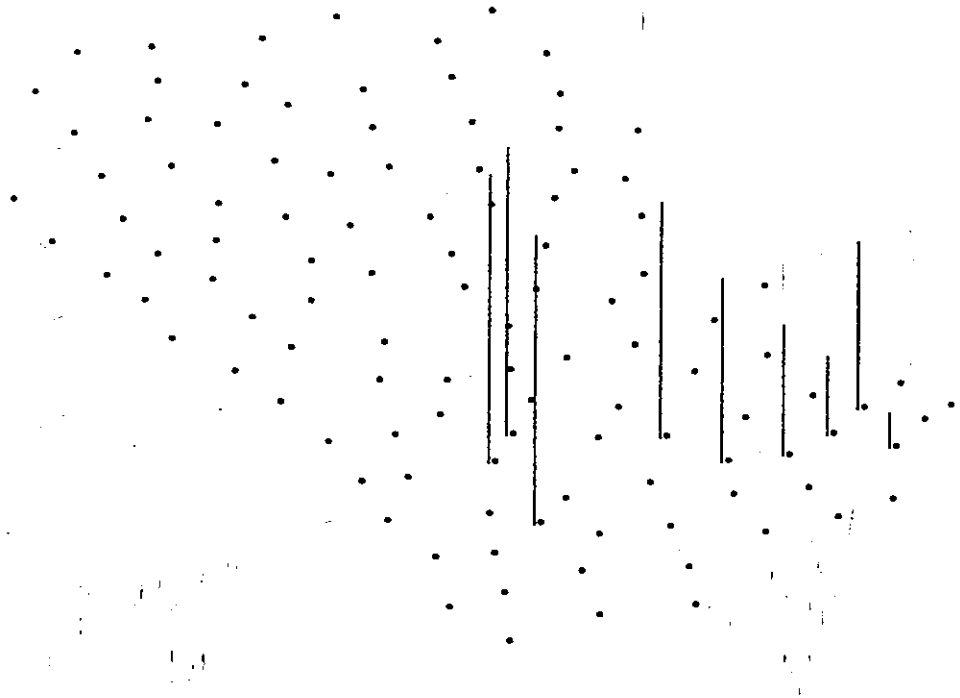
$\sim 10^8 \frac{g}{ton} \cdot sr = 0.1\ km^3\ w.e$ @ 10^{19} eV

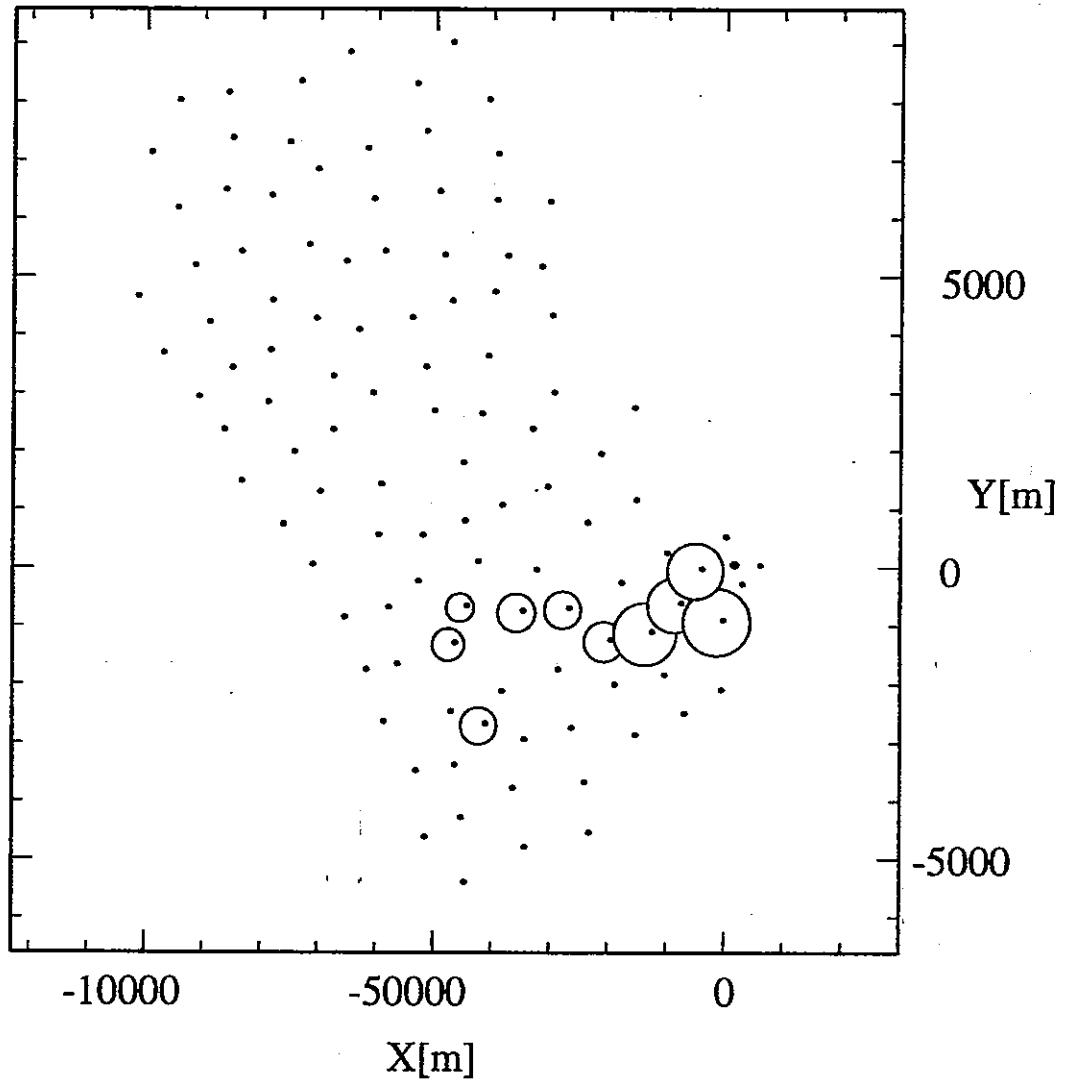
AGASA Data Set

RUN 0001 – RUN 6490 (13/12/1995 – 30/11/2000)

Live Time 1710.5 days

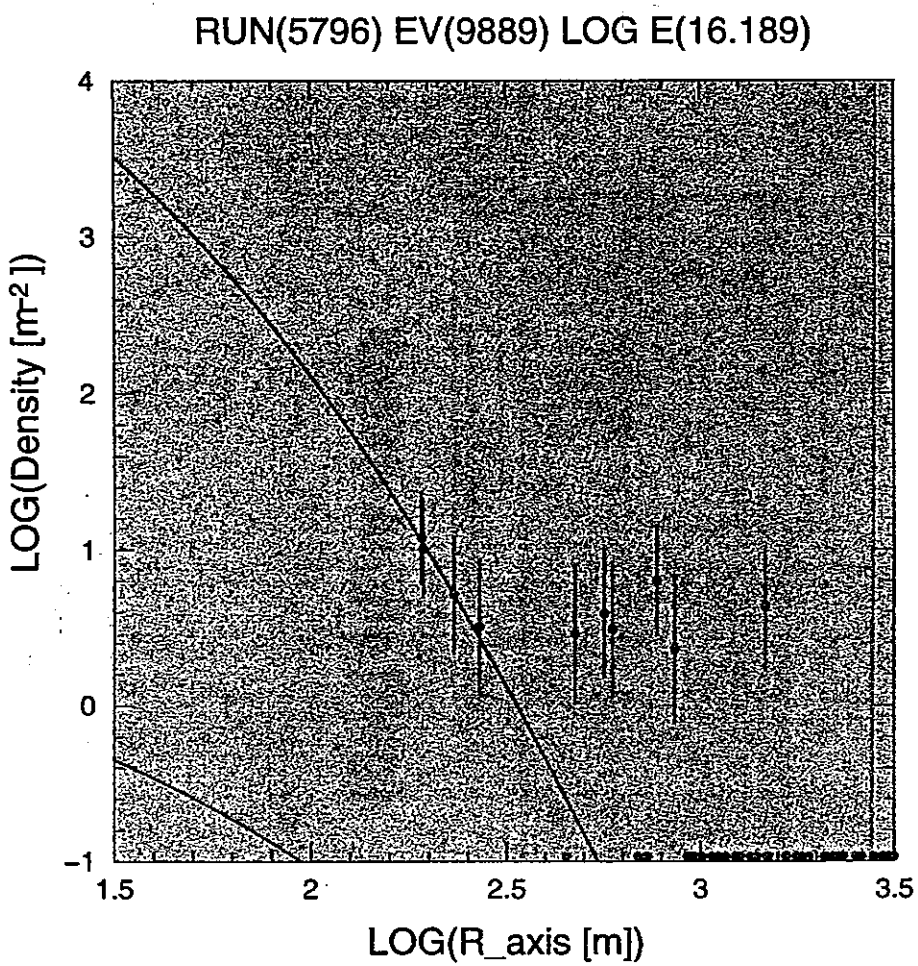

AGASA data
2000
1000
0
65
70
75
80
85
X – Xmax^η [g/cm^2]
Zenith Angle [deg]



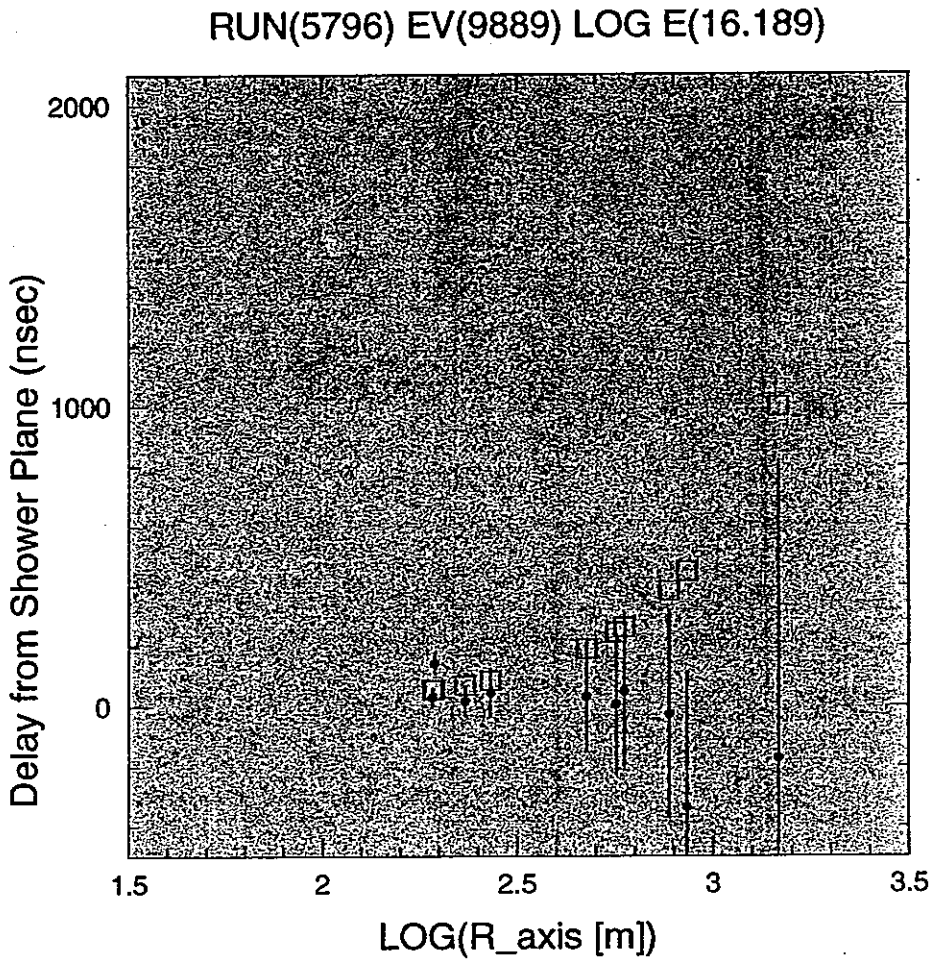


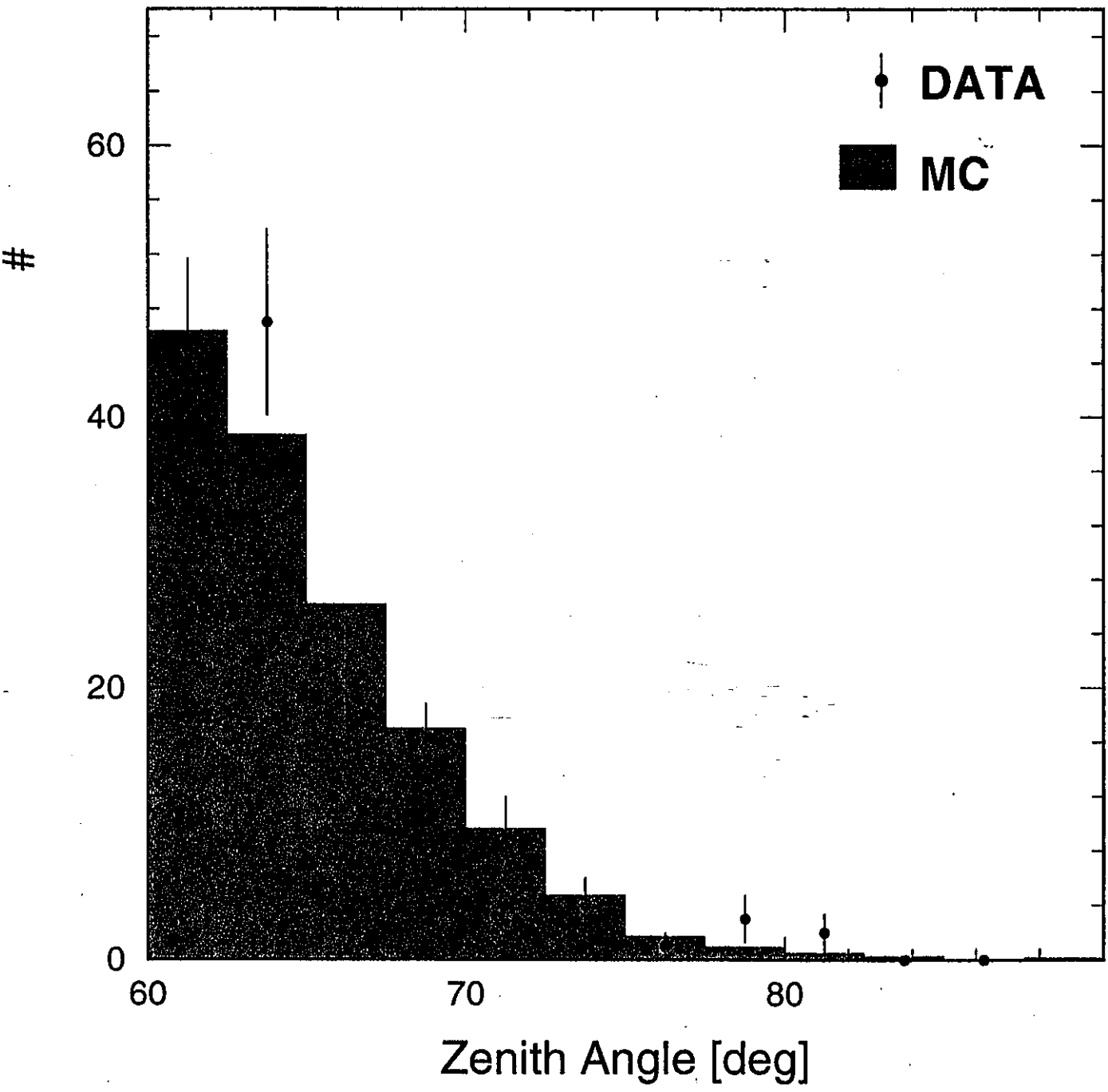
RUN:5796 Zen: 73.474[deg]
EVENT:9889 Azm: 79.786[deg]
DATE:330 Chi:1.02
TIME:183231

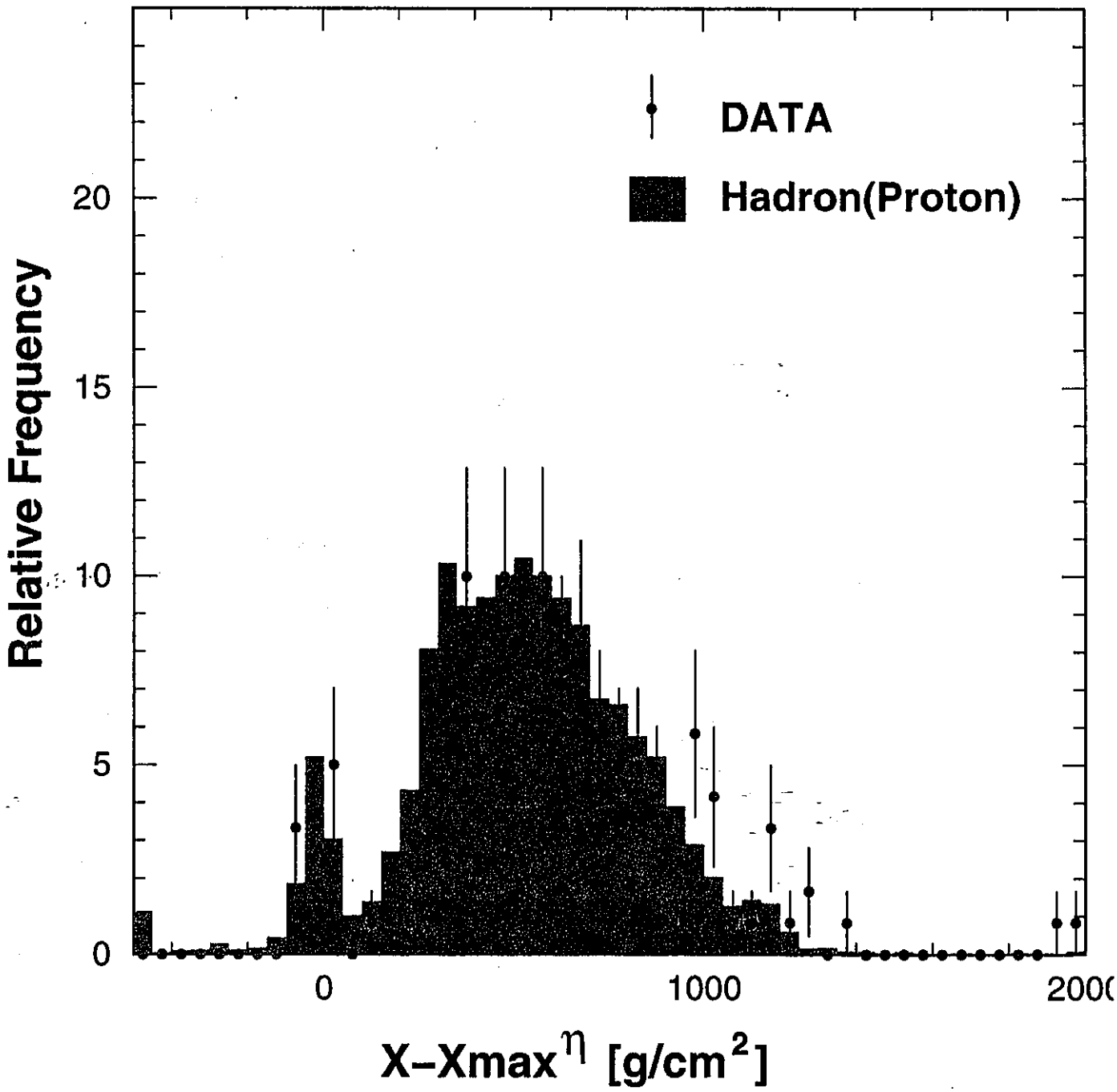
zenith= 76.70 73.47 Xmax=3998.88 850.00 [g] flag(1)
ev_number(9889) energy= 16.19
chi–ft 2.385e+00 chi–LDF 5.936e–01

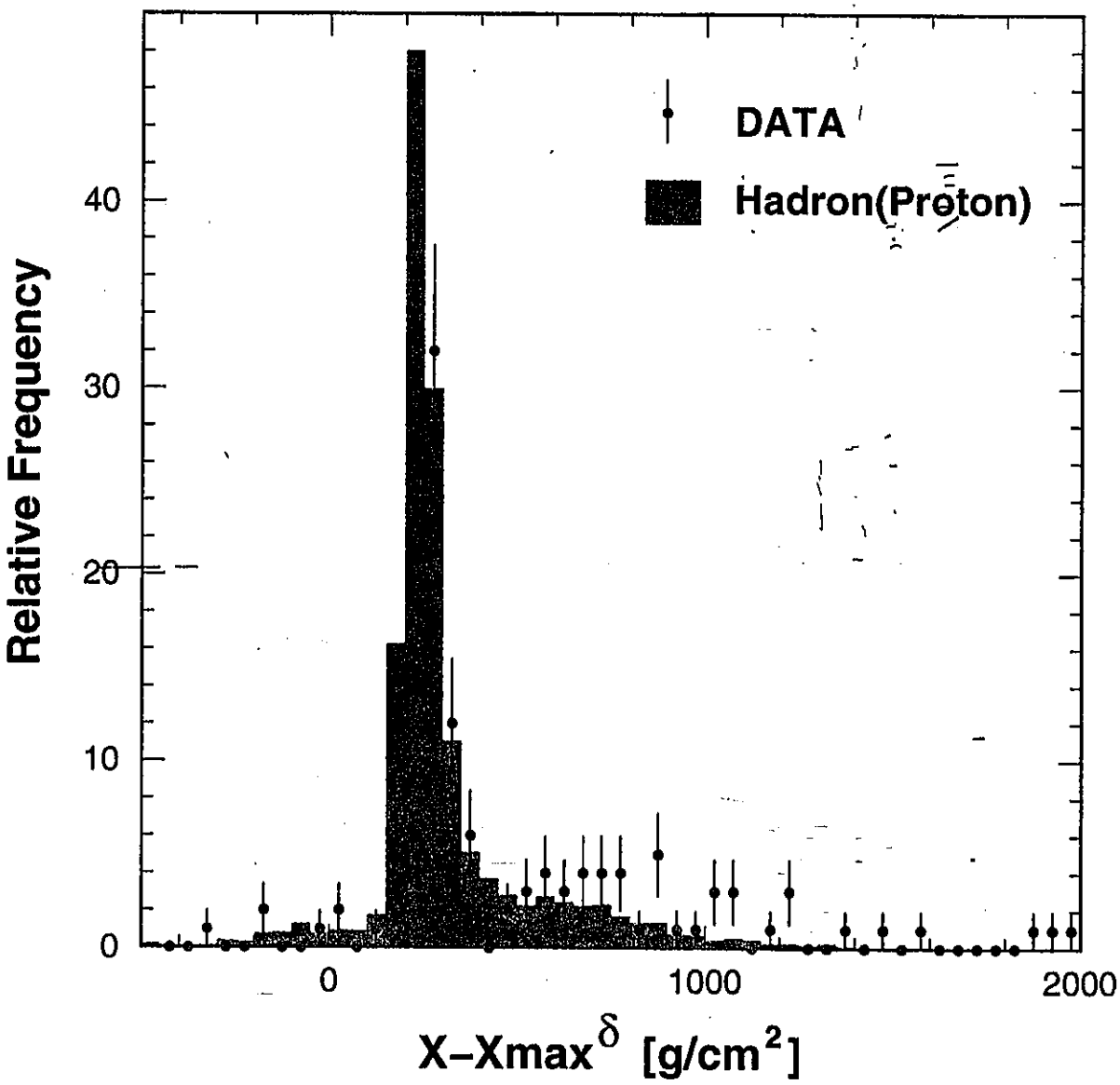


zenith= 76.70 73.47 Xmax=3349.53 850.00 [g] flag(1)
chi–ft 2.385e+00 chi–LDF 5.936e–01




DATA
MC
#
60
40
20
0
60
70
80
Zenith Angle [deg]


DATA
Hadron(Proton)
Relative Frequency
20
15
10
5
0
0
1000
200(
X–Xmax$^{\eta}$ [g/cm^2]


DATA
Hadron(Proton)
Relative Frequency
40
30
20
10
0
0
1000
2000
X–Xmax$^{\delta}$ [g/cm^2]

Number of Events

	MC Prediction(No νs)	Stat.	Syst.	AGASA DATA	
HAS +	129	$^{+10}_{-1}$	$^{+60}_{-48}$	147	
ν domain	0.52	$^{+0.14}_{-0.07}$	$^{+0.28}_{-0.19}$	1	Pch 6.1×10^{-1}

Sys. Uncert.

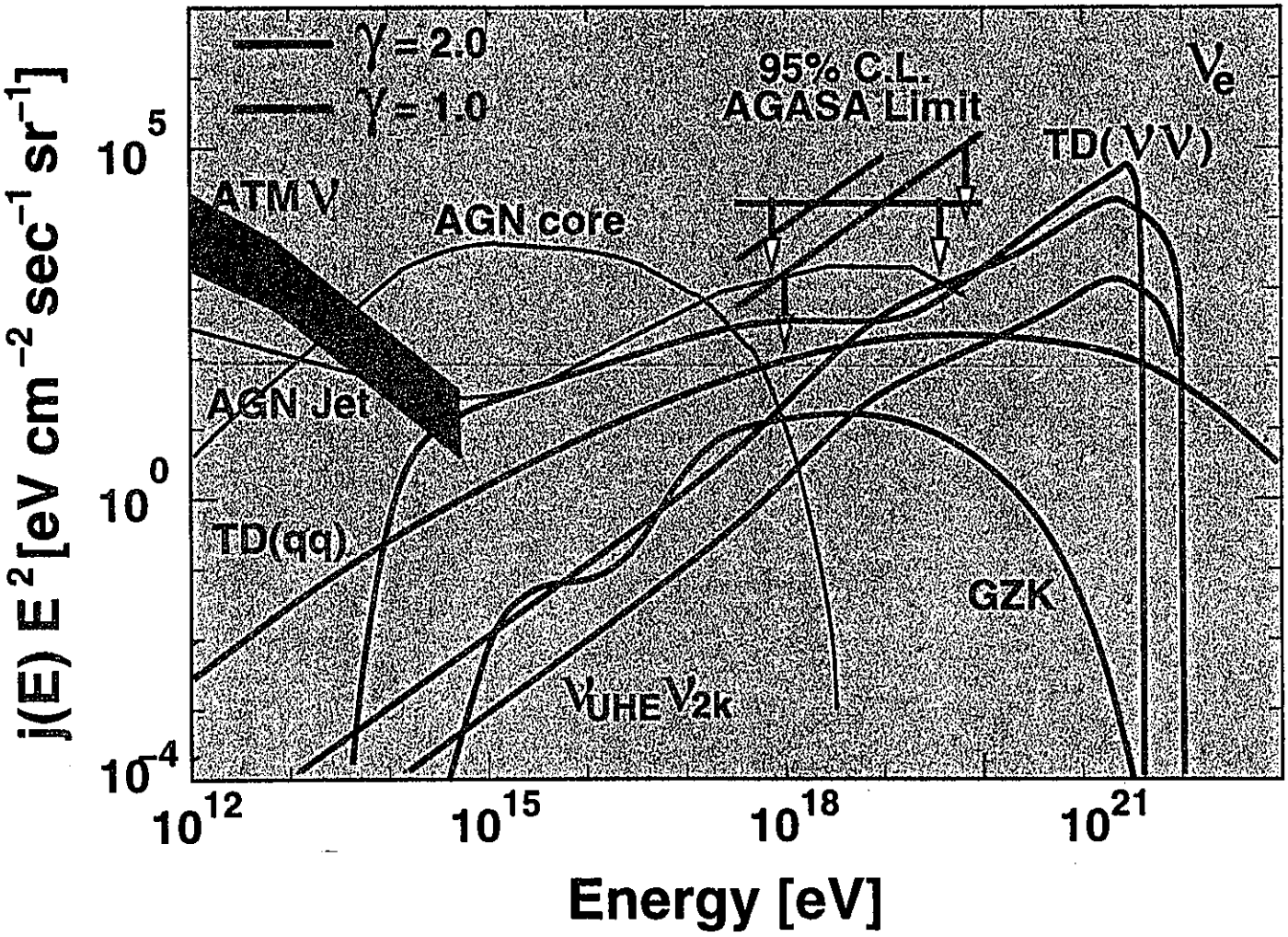
⟵ Cosmic Ray Intensity

⟵ Energy Scale (Uncert. on the S600 attenuation)

95% C.L.

ν_e $F(>3\times10^{17}\,eV) <$ 5.1×10^{-10} $[m^{-2}\,sec^{-1}\,sr^{-1}]$ $\gamma=2.0$

9.4×10^{-11} $[m^{-2}\,sec^{-1}\,sr^{-1}]$ $\gamma=1.0$


γ = 2.0
γ = 1.0
95% C.L.
AGASA Limit
ν_e
TD($\nu\nu$)
ATM ν
AGN core
AGN Jet
TD(qq)
GZK
ν_{UHE} ν_{2k}
10^5
10^0
10^{-4}
10^{12}
10^{15}
10^{18}
10^{21}
j(E) E^2 [eV cm^{-2} sec^{-1} sr^{-1}]
Energy [eV]