GEM TN-93-405

Muon Performance Meeting - SSCL

March 26, 1993

Abstract:

Agenda, attendees, and presentations of the Muon Performance Meeting held at the SSC Laboratory on March 26, 1993.

TO: Muon Performance Simulators
FROM: Frank Taylor/Mike Marx/Harvey Newman
SUBJECT: Draft Agenda for Muon Performance Meeting 3/26/93
DATE: 3/22/93

Time of Meeting: Friday 3/26/93 9:00 AM to 5:00 PM
Place of Meeting: SSCL - CCD Room

Purpose of Meeting:

Interested parties to discuss the performance simulations of the GEM Muon System.

Draft Agenda:
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(0) General Remarks and Agenda Checkout: [Frank Taylor] 9:00-9:05

(1) Pattern Recognition Studies: [Roger McNeil convener] 9:05-10:30
- o number of clean hits vs position, background type, etc.
- o chamber counting rates and occupancy
- o two track resolution

(2) Muon Momentum Resolution Studies: [Larry Rosenson convener] 10:30-12:00
- o GEANT studies
  - hit level Monte Carlo and reconstruction
- o parametric studies
  - eta and phi dependence (X0 budget, L-angle, etc.)
  - resolution with vertex constraint
  - resolution with missing 1st and 2nd SL, etc.
  - resolution with central tracker
- o knowledge requirement of B-field
- o muon sign resolution (eta, phi dependence)

LUNCH

(3) Trigger Studies: [Maged Atiya convener] 13:00-14:30
- o simulation of trigger hardware
  - bend-plane-segmentation needed
  - momentum threshold resolution vs Pt and eta
  - timing resolution
  - trigger element segmentation (theta and phi)
- o accidental triggers from background

(4) Simulation of Physic Test Cases: [Renyuan Zhu convener] 14:30-16:00
- o Higgs --> 4 mu resolution
  - dependence on X0, calorimeter fluctuations, coverage
- o Z' --> 2 mu resolution
  - mass resolution and coverage
- o Heavy quark physics
  - t, b, c etc.

(5) Discussion and Action Items: [Group] 16:00-17:00
Note: It is the duty of the convener to put together what has been done on the subject and to either give a summary talk or ask expert speakers to make short presentations. Interested speakers are encouraged to contact the conveners.

Attendees	Institution	e-Mail
Bill W. Mayes	University of [illegible]	Mayes@[illegible]
Yuri Fisyak	Moscow State Univ.	Fisyak@sscvx1
Vladimir Gavrilov	ITEP/SSCL	GAVRILOV@SSCVX1
Michael Marx	SUNY/SSC	MARX@SSCVX1
TORRE WENAUS.	LLNL.	WENAUS@PDSF
HONG JOO KIM	~~U of~~ LSU	HJKIM@SSCVX1
Frank Paige	SSCL	paige@sscvx1
Harvey Newman	Caltech	newman@cithex
[illegible]	[illegible]	[illegible]
Frank Taylor	MIT	FET@MITLNS
Peter Lingos	SSCL	[illegible]
Jenny Thomas	SSCL	JTHOMAS@SSCVX1
Ren-yuan Zhu	CALTECH	ZHU@CITHEX
Andrey Ostapchuk	SSC/ITEP	OSTAPCHUK@SSCVX1
VLADIMIR GLEBOV	SSCL	GLEBOV@SSCVX1
M. Atiya	BNL	atiya@BNL787

3/26/72

2. Muon Backgrounds

Hadron Punchthrough - Calorimeter depth

Main Sources of charged particles in muon system (exiting calorimeter)

- Prompt Muons from heavy quark decay
- Muons from decays of π/K in inner tracker

} Muon enter Calorimeter

- Hadron Punchthrough } hadron enters calorimeter

Calorimeter depth beyond that needed for resolution serves to suppress hadron punchthrough.

Criteria for gauging calorimeter depth:

1. Overall rate of charged particles exiting calorimeter from hadron punchthrough should be much less than (factor of 2 used) than sum of rate from prompt and decay muons

2. Rate of charged particles above some P_T threshold (~10 GeV/c) from punchthrough should be much less than rate from prompt muons + decay muons

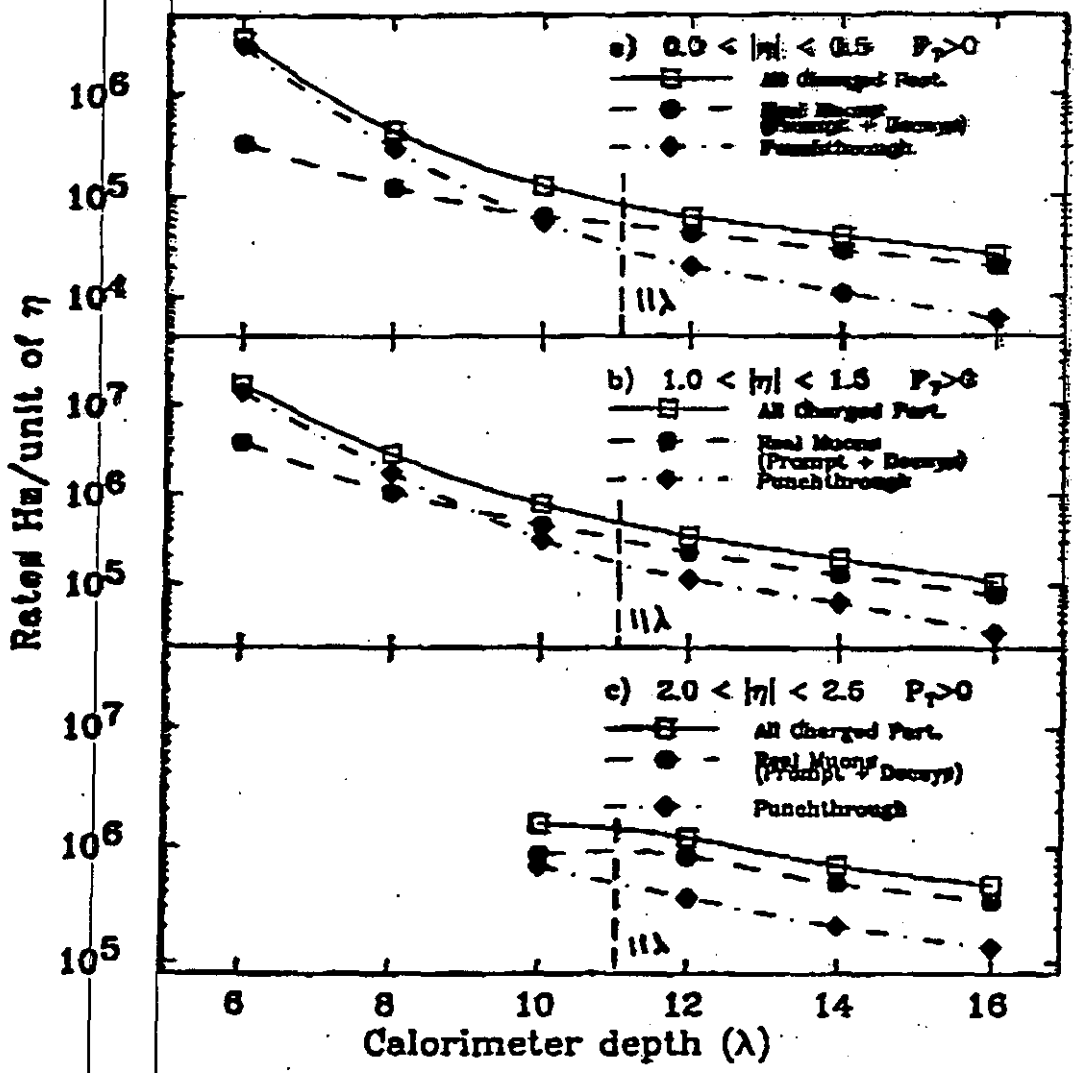
3. Charged particle rate must be much less than CSC limiting rate - depends on design.

   $\ll 3\%$ occupancy

   1 $< 1\%$ occupancy. why?

Overall Charged Particle rates in 3 rapidity intervals

Tracking volume: 95cm radius, 4.4m long



Criteria 1 satisfied at $\gtrsim 11\lambda$ $0 \le |\eta| \le 2.5$

In the forward region, rate dominated by decays of π/K

Charged particles spoil many layers at a time in a superlayer if near the muon (± 3 strip width)

∴ 6-strip occupancy in a particular CSC Chamber = Muon Track segment inefficiency in that Cha

In endcap charged particles not swept away

∴ $1-\left(\text{6-strip Charged part occupancy}\right)^3$ = Track Reconstruction Efficiency (SL1,2,3)

$$\text{Eff} \sim 1 - \text{occ}^3_{\text{6-strip}}$$

1%	occ	⇒	Eff	=	97%	No EM background No Neutron/γ included.
2%	occ	⇒	Eff	=	94%	
3%	occ	⇒	Eff	=	91%	
5%	occ	⇒	Eff	=	86%	
10%	occ	⇒	Eff	=	73%	

Is that the only consideration?

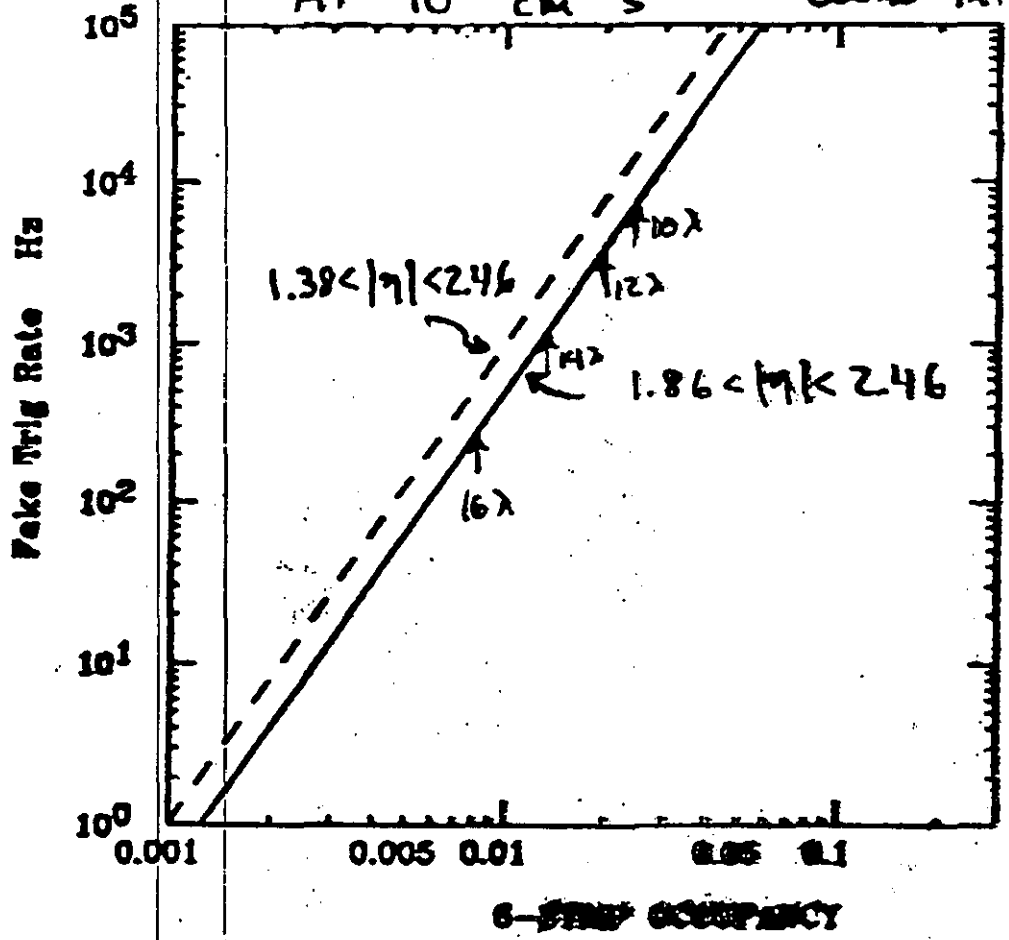
No! Fake triggers...

Fake Triggers due to overlap of low-mom. tracks

Consider Narrow ($p_T > 20\,GeV/c$) trigger window ($\pm$ 3 Strips)

Fake trigger rate from 3 tracks $\sim$ $\left(\text{6-Strip Occupancy}\right)^3$

At $10^{34}\,cm^{-2}\,s^{-1}$ 300 ns integration time



This is a minimum rate.

Doesn't include rate for 2 low-momentum tracks

Assumes tracks random in ϕ, θ in single event but tracks correlated in jets.

So, you want 6-Strip Occ < 1%

Table 4. CSC single and 6 strip occupancy in two rapidity intervals as a function of calorimeter depth.

$0.9 < |\eta| < 1.34$ → OK, Criterion 3

Calorimeter thickness (λ)	6	8	10	12	14
Rate per Strip (Hz) Strip size 350 cm × 0.5 cm	33000	6600	2200	800	480
Single Strip Occupancy 300 nsec integration time	1.3%	0.20%	0.066%	0.26%	0.014%
6-strip Occupancy	8.0%	1.2%	0.40%	0.16%	0.08%

$1.37 < |\eta| < 2.46$ → OK Criterion 3

Calorimeter thickness (λ)	10	12	14	16
Rate per Strip (Hz) Strip size ~~350~~ 93 cm × 0.5 cm	13100	10500	6640	4320
Single Strip Occupancy 300 nsec integration time	0.39%	0.32%	0.20%	0.13%
6-strip Occupancy	2.3%	1.9%	1.2%	0.8%

$1.38 < |\eta| < 1.86$

Rate per Strip	4000	2000
Occ single-strip	.12	.09%
6-strip	.8%	.4%

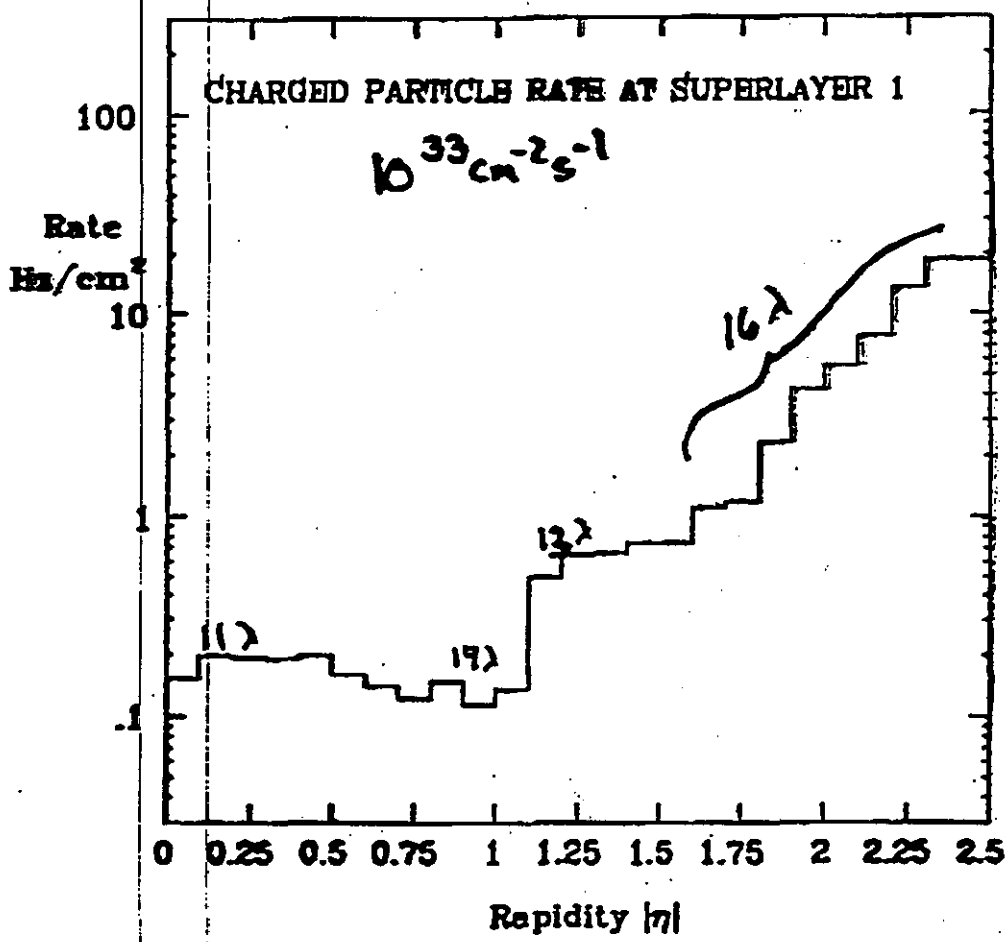
Table 4. Depth Requirements imposed by Criteria 1, 2, and 3

Criteria	Minimum Depth required $\eta=0$	Minimum Depth required $\eta=1.3$	$\eta=1.9$	Minimum Depth required $\eta=2.5$
1	11	11	11	11
2	10	10	10	10
3	8	10	14	16

GEM Calorimeter Thicker than this.

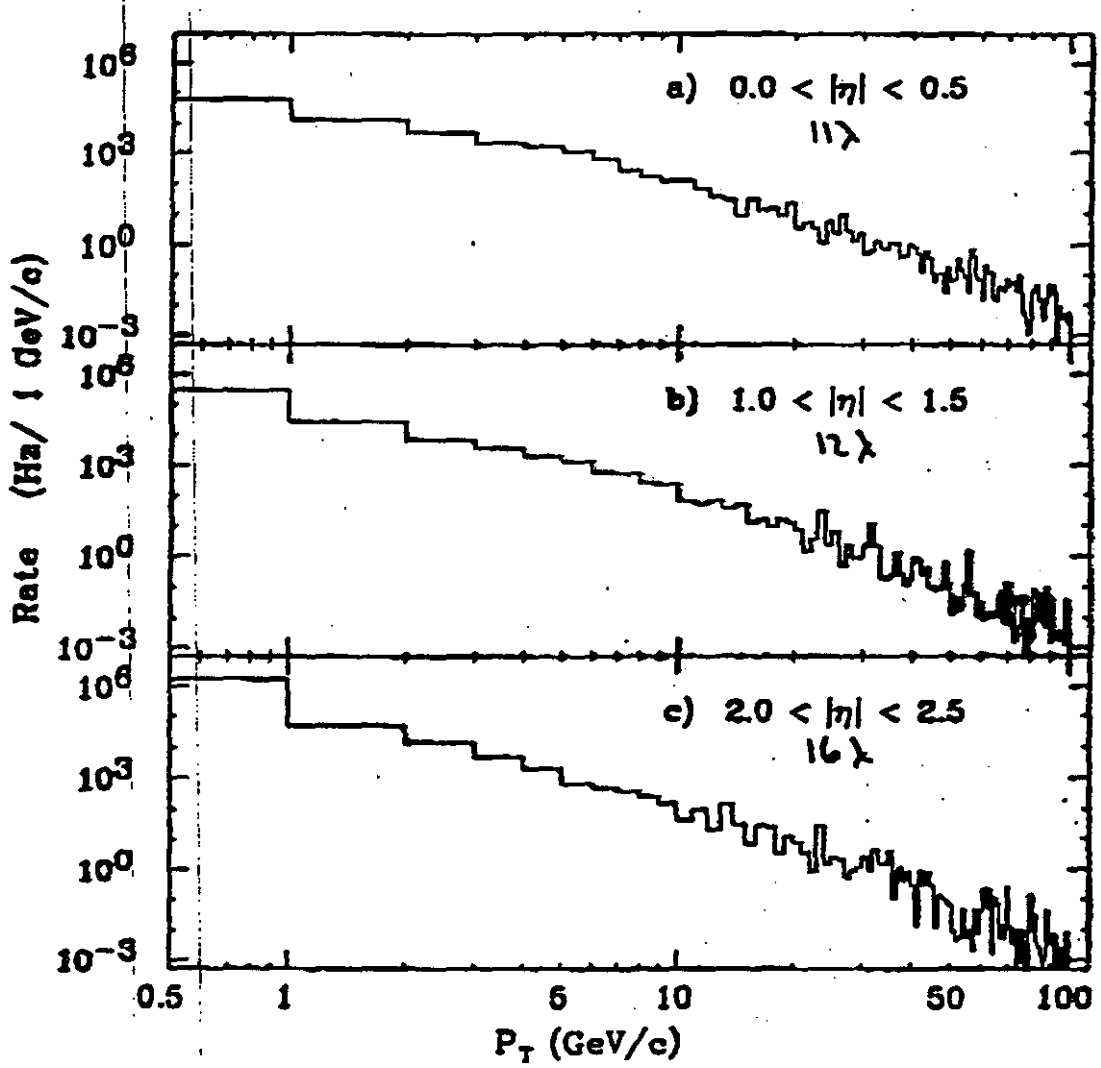
Charged particle rates in GEM muon system after baseline 2 Calorimeter

Fig 4.2.4.2



P_T of charged particles in GEM muon system

Fig 4.3.2.3



Requires sharp trigger thresholds

Uncorrelated neutron backgrounds

Occupancy in CSC from random n/γ hits is

$$R_{n/\gamma} \times \varepsilon_{n/\gamma} \times A_{channel} \times \Delta t_{INT\ charge} = \text{Occupancy}$$

↑ fluence ↑ det eff ↑ area ↑ integ time

An occupancy >3% leads to loss of reconstruction efficiency

neutron/γ detection efficiency

Table 3

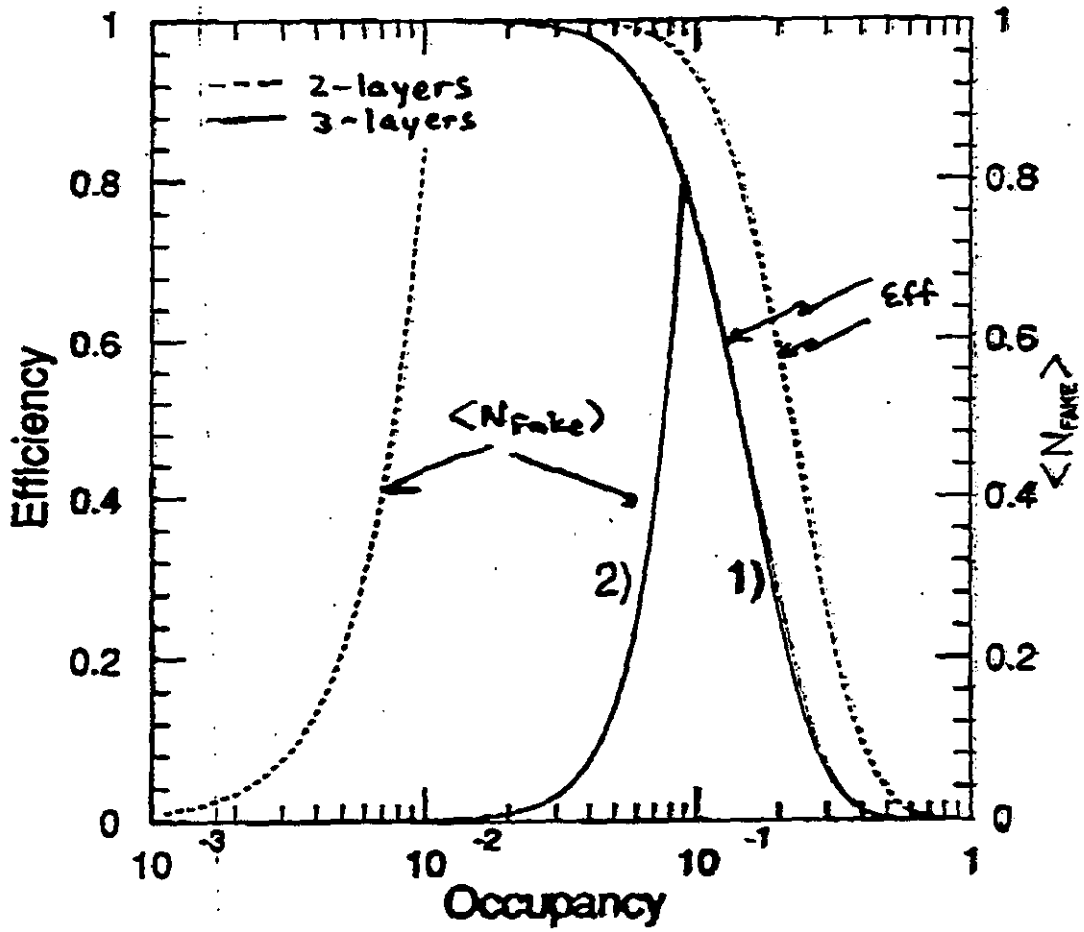
Sensitivity of CSC to thermal and fast neutrons and gammas (in units of 10^(-3))

Superlayer	gas gap thick. Barrel/Endcap (mm)	sensitivity to: thermal neutrons	fast neutrons	gammas
Inner	5 / 5	0.8	0.4	8.
Middle	8 / 7	0.9	0.6	10.
Outer	10 / 10	1.0	0.8	12.

The Average neutron/gamma path length in gas gap is assumed to be in twice the gas gap.

Efficiency & fake rate in 6-layer Superlayer

Due to randoms.



Expected Occupancies in the barrel region

Conditions/parameters:

- 10^4 n/cm²-s uniform in η/ϕ 50% thermal, 50% fast
- 1×10^4 γ/cm²-s " " "
- Δt_{INT} = 300 nsec

Largest CSC chamber in outer barrel Superlayer
3.5m long Strip pitch/gap = 10mm

Table 4

Rates in a single barrel CSC layer due to thermal/fast neutrons and gammas (in units of Hz/cm^2) and occupancies per one strip of barrel muon chambers for integration time equal 0.3 nsec. Neutron rate of 10^4Hz/cm^2 uniform was used and gamma rate of 2*10^4Hz/cm^2. Equal fraction of thermal and fast neutrons used.

Superlayer	CSC rates caused by:				Occupancy per one strip	~~% strip occup~~
	thermal neut	fast neut	gammas	total		
Inner	4	2	80 ~~16~~	86 ~~22~~	0.52% ~~0.11%~~	~~0.77%~~
Middle	4	3	100 ~~20~~	108 ~~26~~	0.68% ~~0.18%~~	~~1.3%~~
Outer	5	4	120 ~~24~~	129 ~~33~~	0.4% ~~0.25%~~	~~2.5%~~

<3%, but not by much!

Muon- induced electromagnetic showers

Muons passing through mat'l produce showers δ-rays, γ, e^+e^-, hadr

3 sources of material

- Calorimeter (final layers important)
- Muon system frames and structures
- Muon chamber mat'ls (G10, Gas, ...)

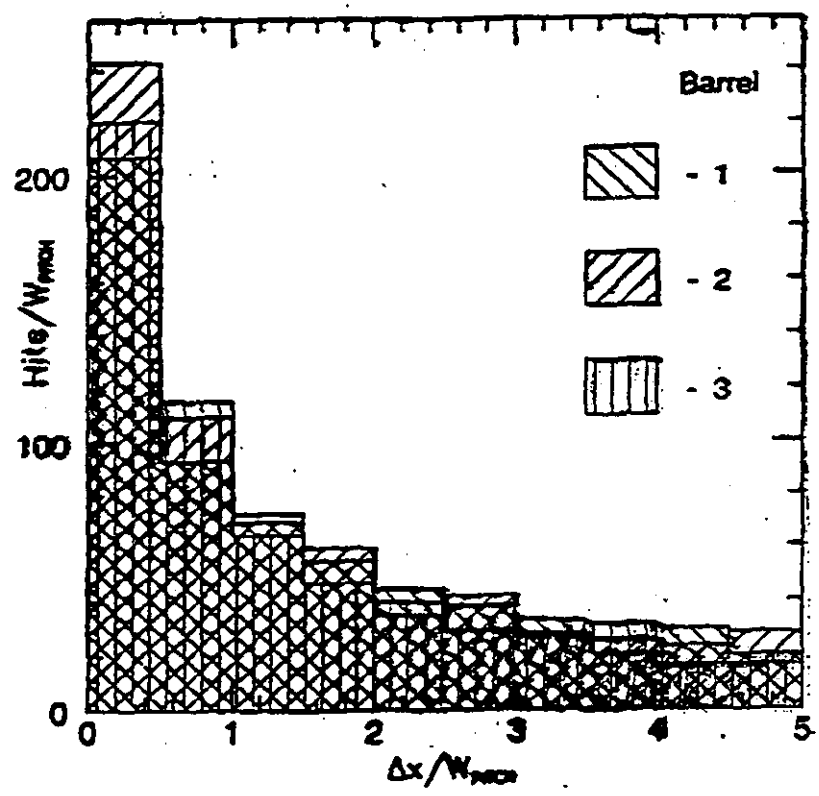
These mat'ls are in SIGEM

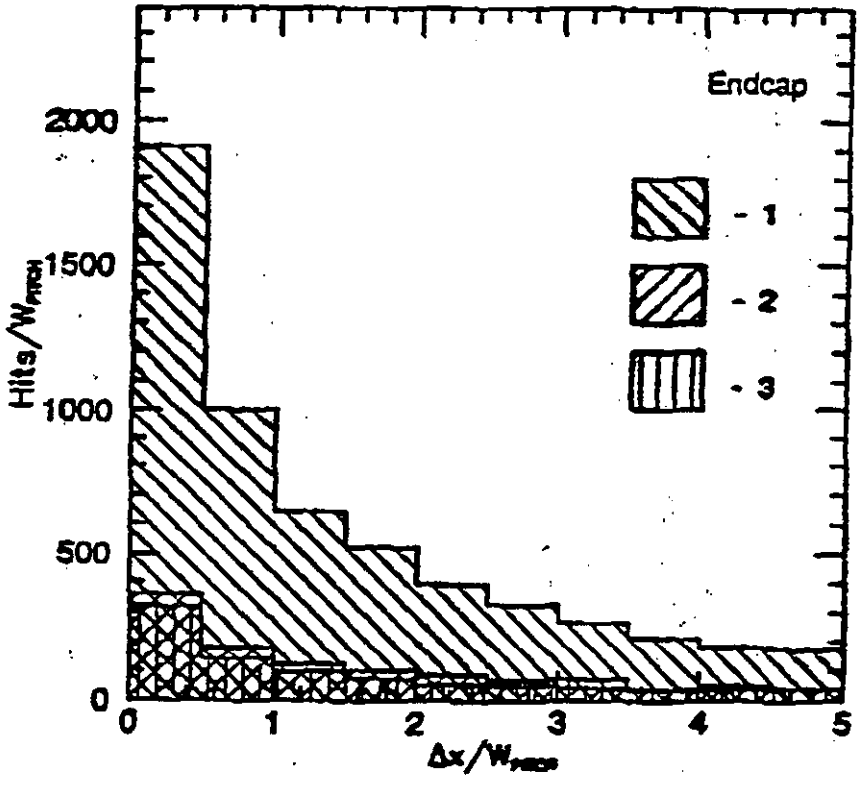
GEANT Simulation verified by experimental data

In barrel region, B field sweeps out charged em particles

Leave air gap to reduce em background

Baseline 2 Calorimeter ends R = 370 cm
Baseline 2 Muon system minimum R = 390 cm
~75% of em particles do not reach layer 1

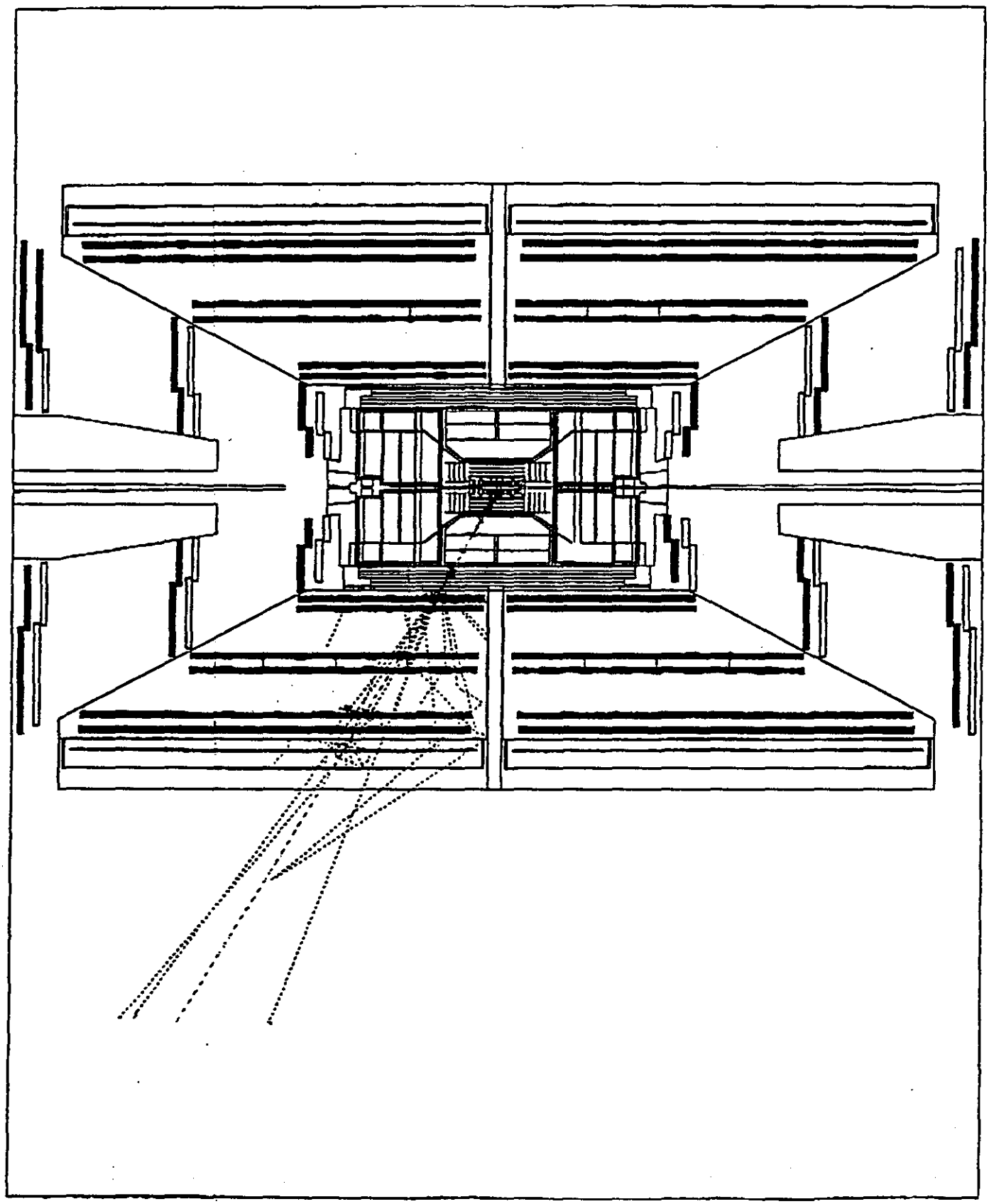

Barrel
- 1
- 2
- 3
200
100
0
Hits/W_mch
0
1
2
3
4
5
Δx/W_mch


Endcap
- 1
- 2
- 3
2000
1500
1000
500
0
Hits/W_mch
0
1
2
3
4
5
Δx/W_mch

Simulations

- GEANT EM cuts = 10 keV
- Analysis procedure 3/6
  $|\Delta x| < 3W$

  R. McNeil
  P. Dingus
  Yu. Fisyak
  A. Golutvin
  A. Ostapchuk
  C. Yanagisawa
  V.G.
- SIGEM - detail layout
  Yu. Fisyak
- Running SIGEM & analysis
  V. Balagura
  P. Dingus
  V.G.



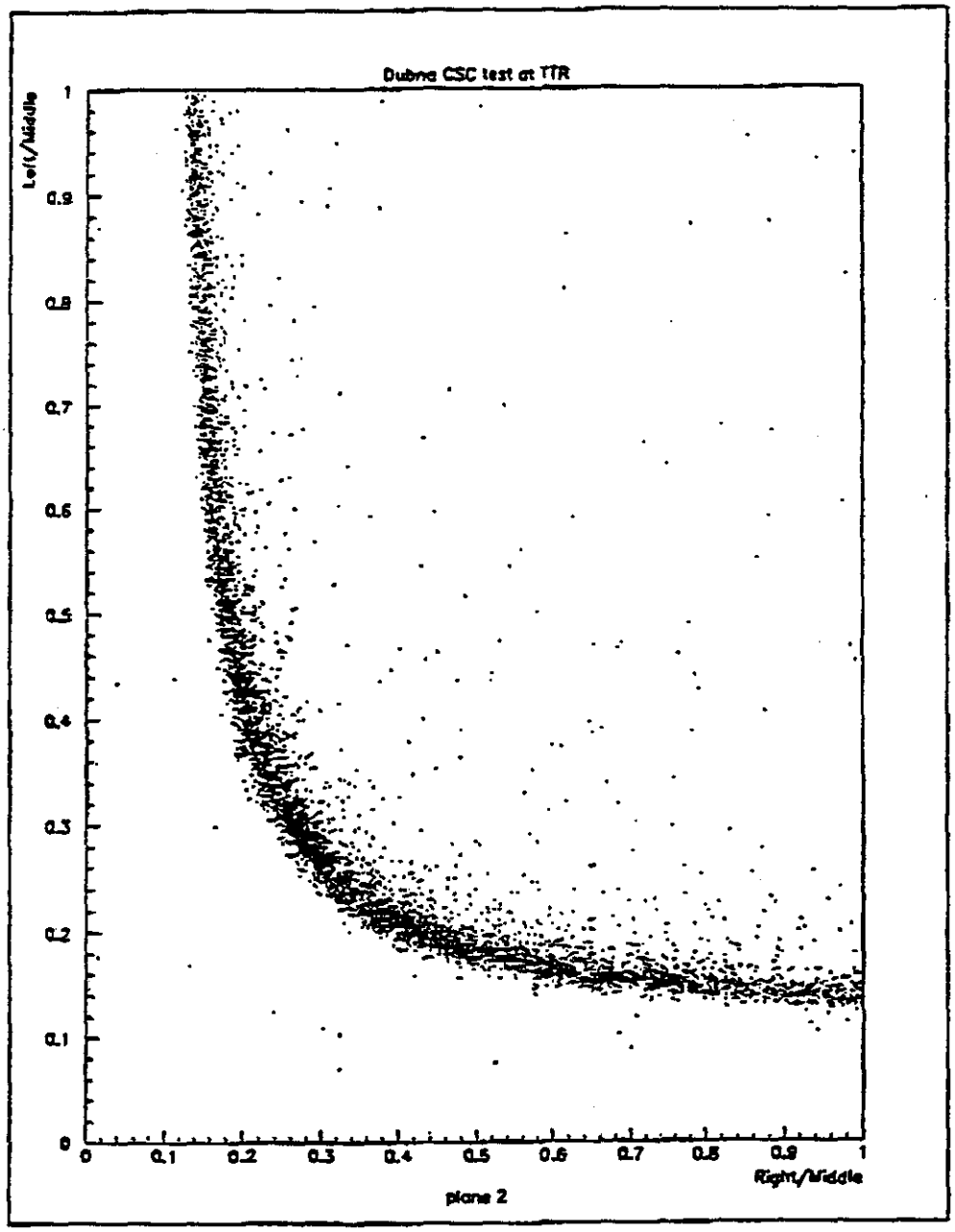
Two track resolution

Single track or two tracks?

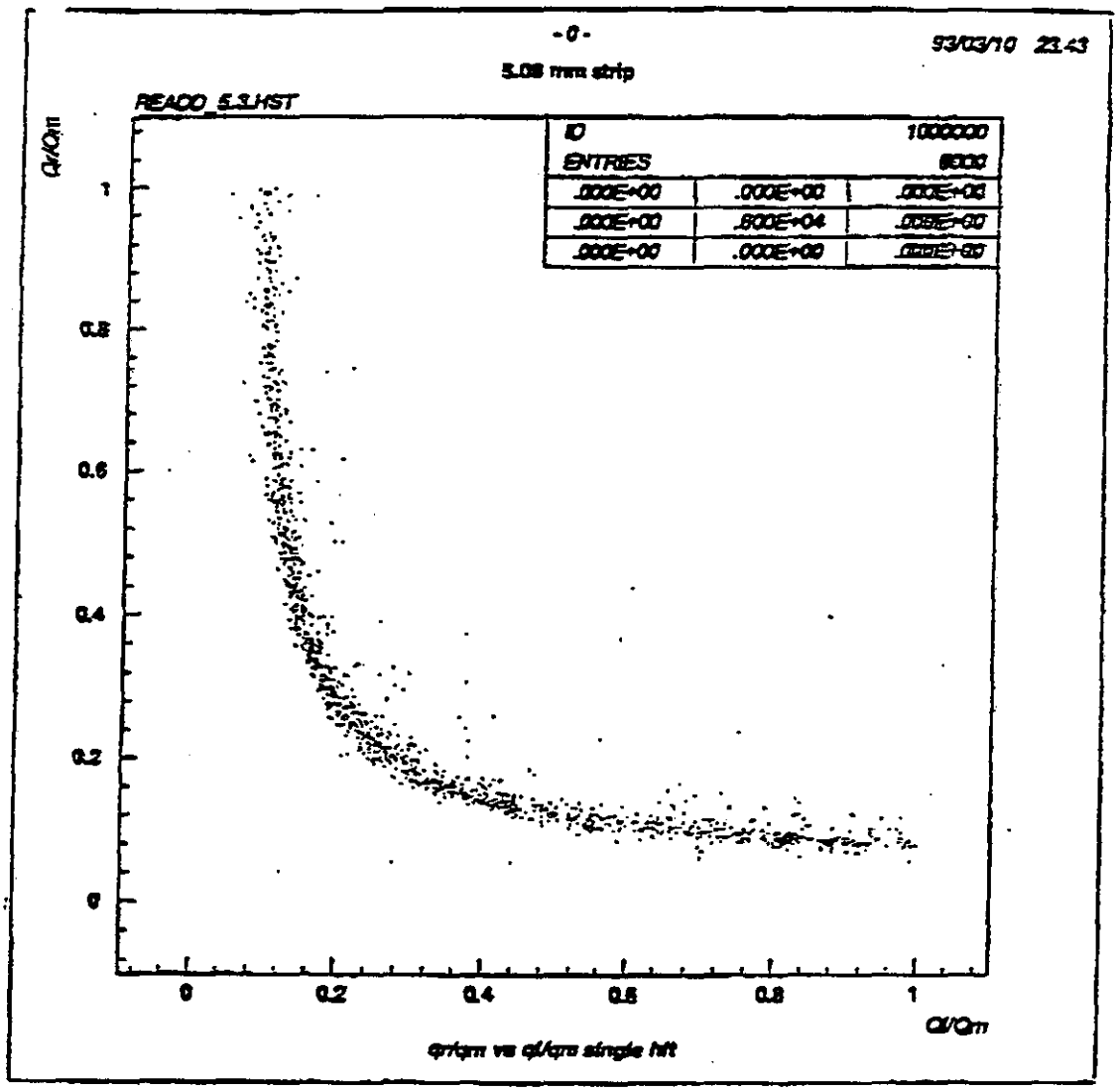
Spatial resolution for each of two close tracks?

Single track vs two tracks

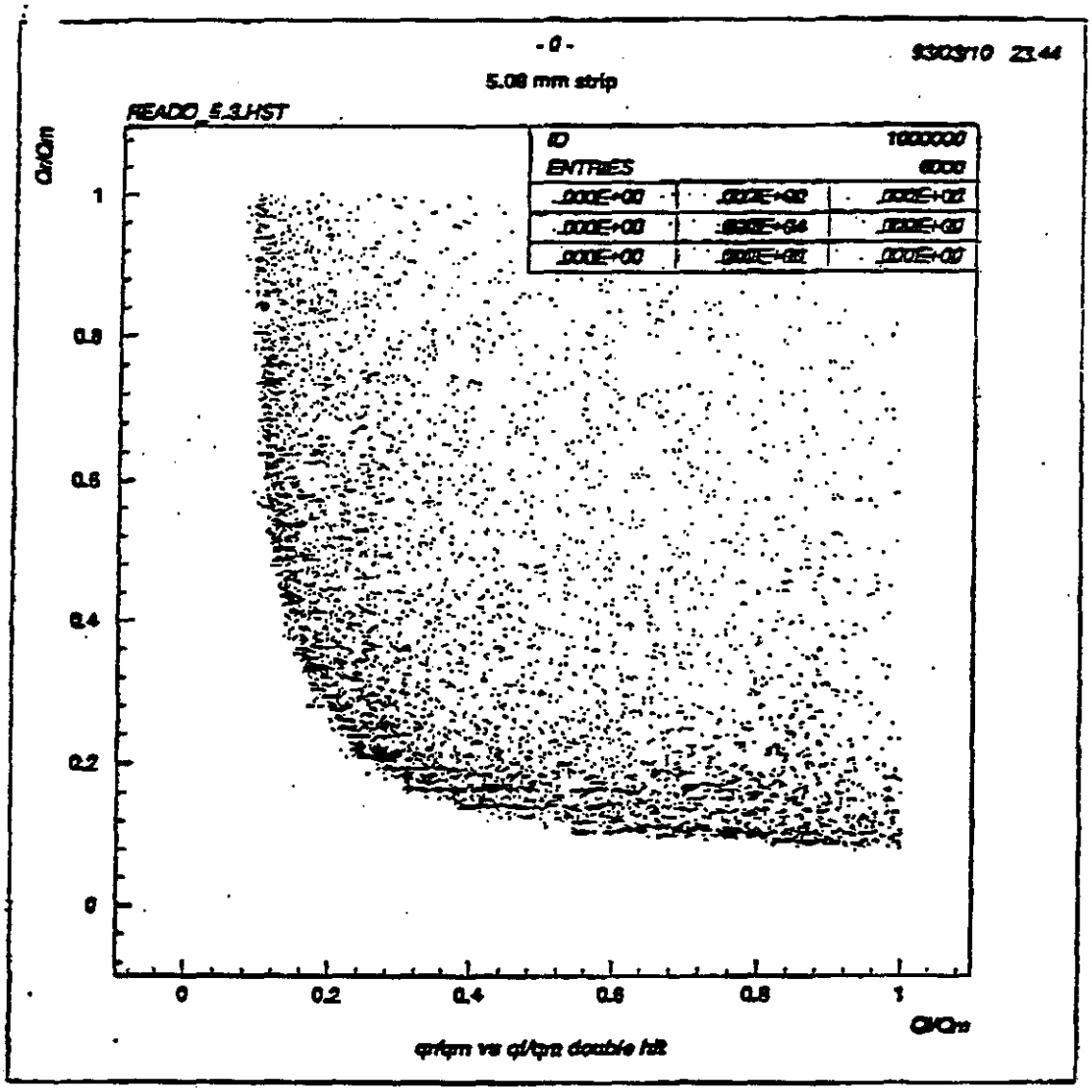
- Shape (width) of cluster
- R/M vs L/M plot
- Cluster charge
- Time information (for accidental hits)
- Residuals from track segment fit


Dubna CSC test at TTR
Left/Middle
Right/Middle
plane 2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

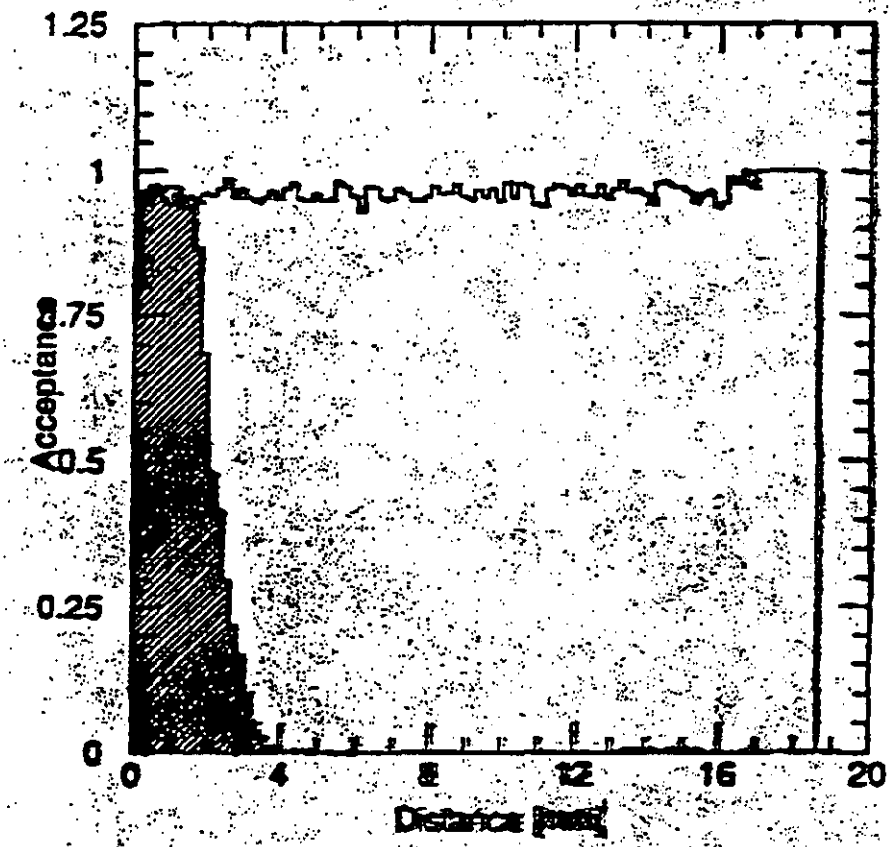
BNL CSC prototype
TTR test



BNL CSC prototype
event mixing

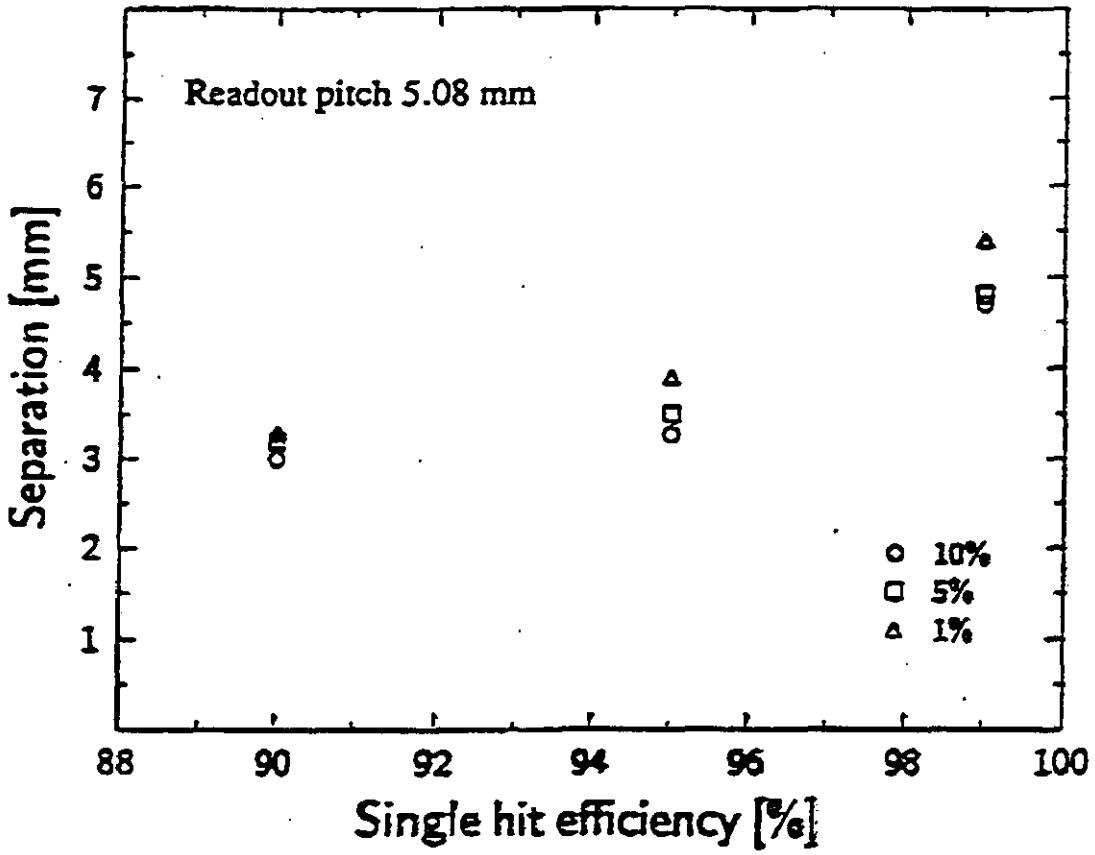


BNL CSC prototype
event mixing



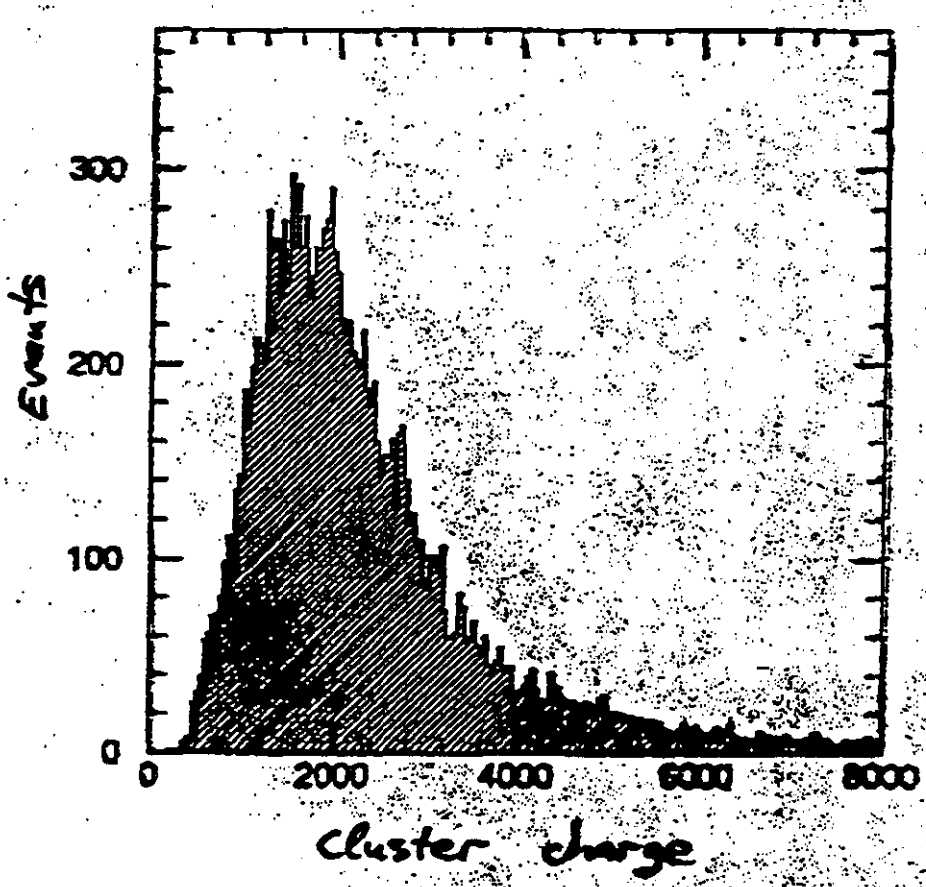
Two track and one track acceptance. Hatched - two track

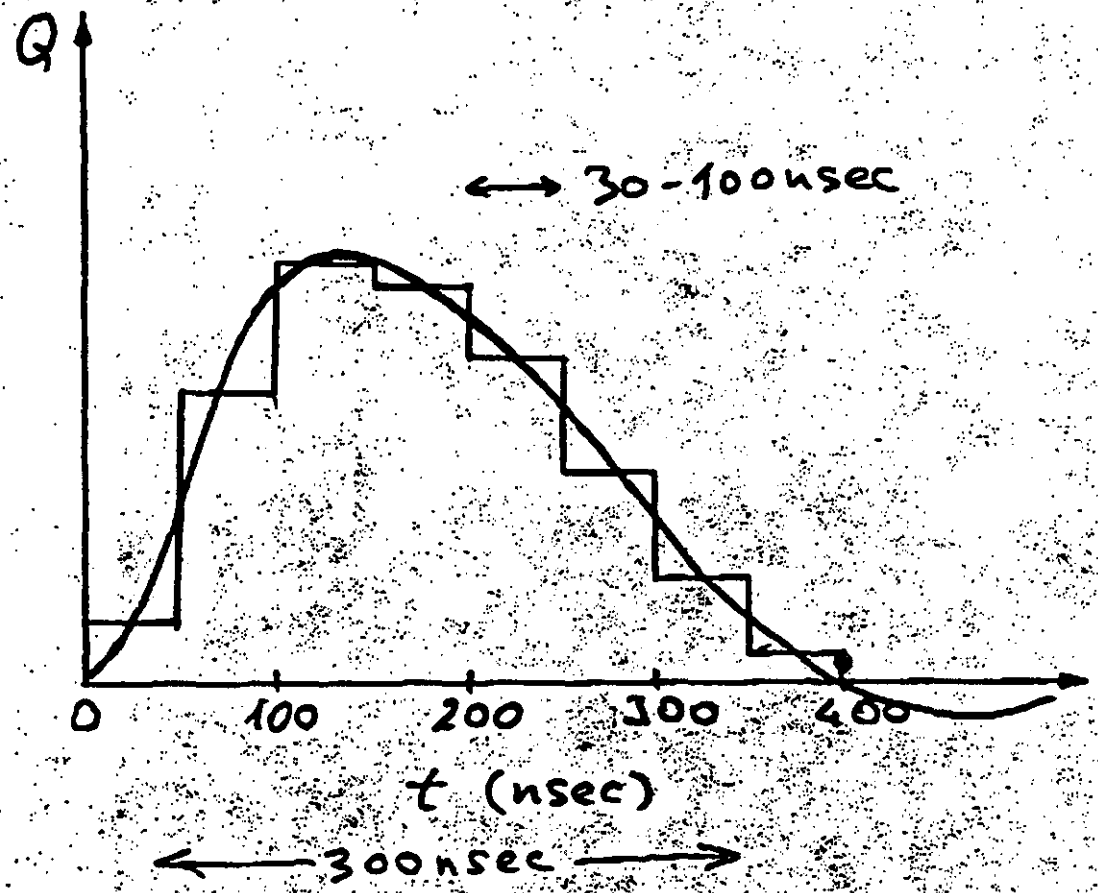
BNL CSC prototype
event mixing



Double track resolution as a function of single track efficiency for three different levels of double track contamination

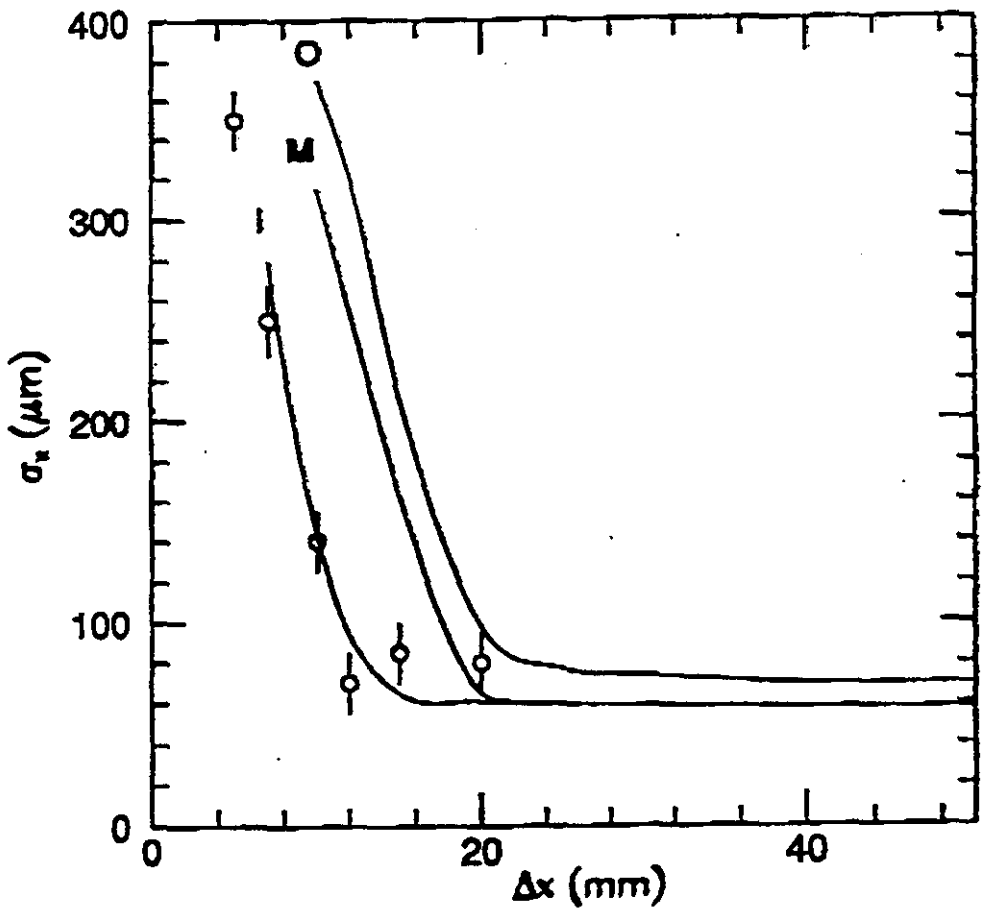
BNL CSC prototype
TTR test

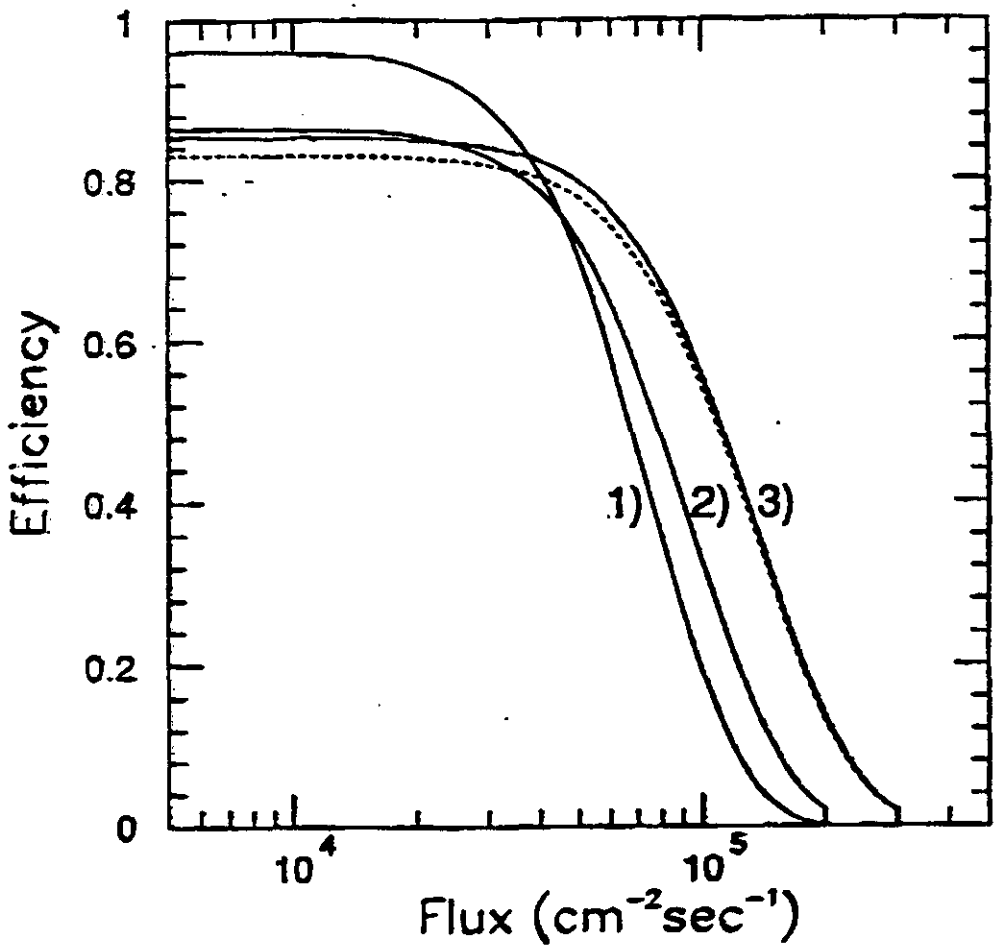



Q
30-100nsec
0
100
200
300
400
t (nsec)
300nsec

V. Cherniatin

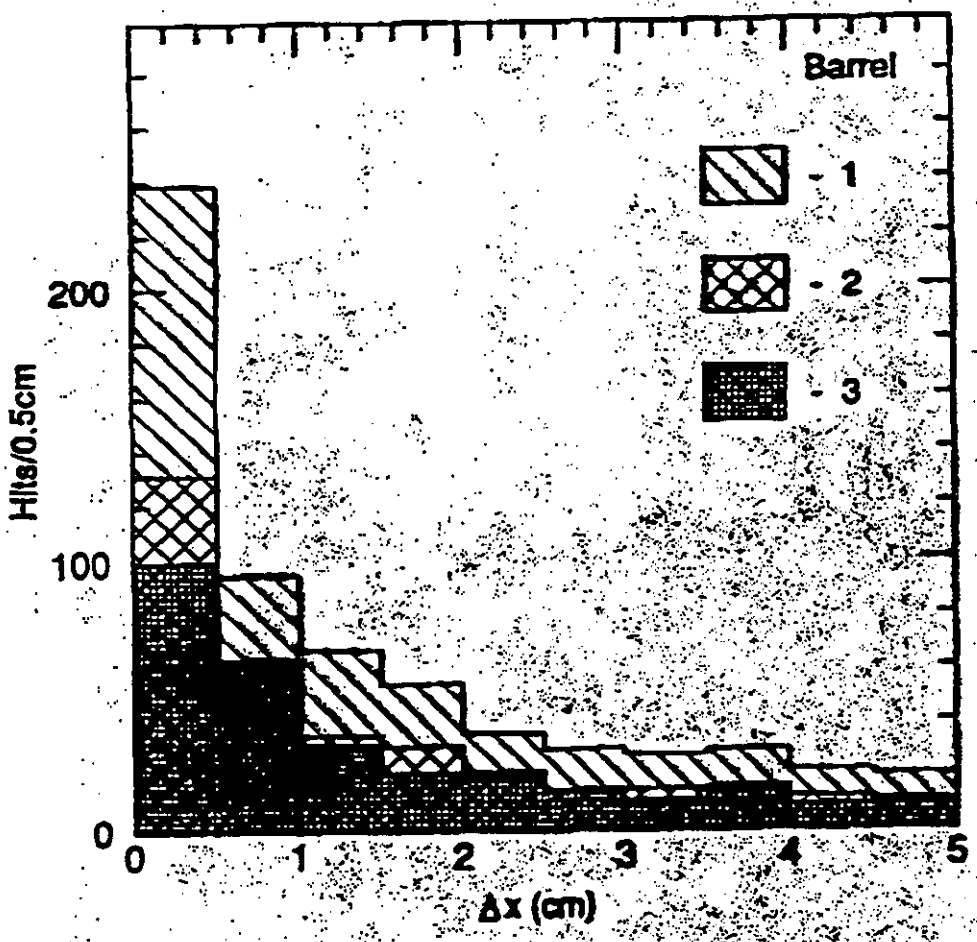
MC & BNL CSC prototype
event mixing

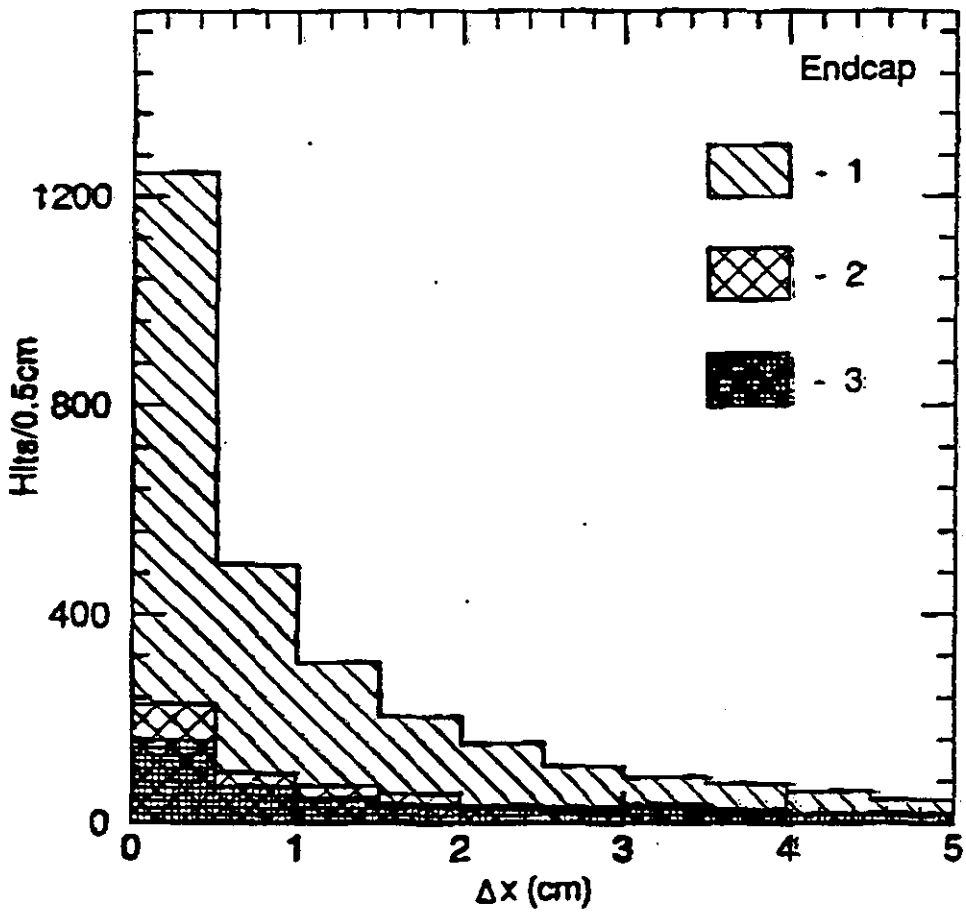


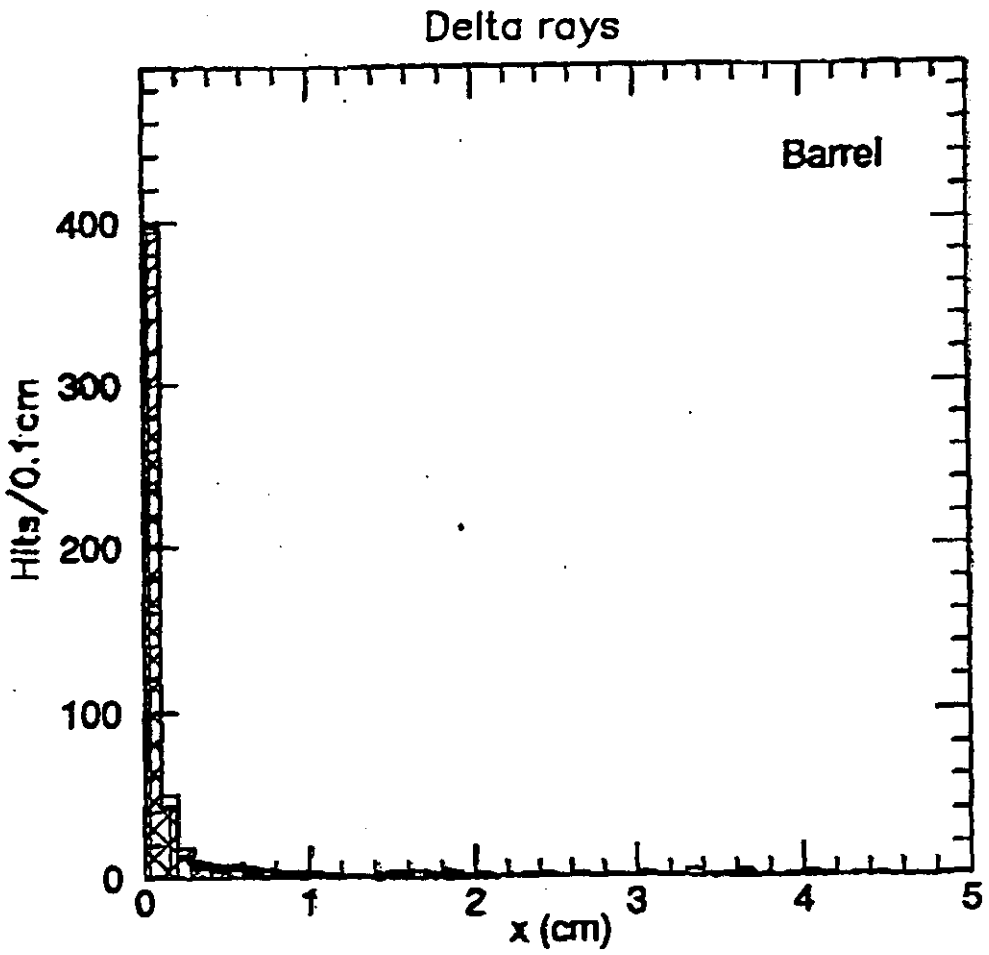

1
0.8
0.6
0.4
0.2
0
Efficiency
1)
2)
3)
10^4
10^5
Flux ($cm^{-2}sec^{-1}$)

Analysed statistics (isolated muons)

	P_T(GeV)	Barrel	Endcap
μ^+	20	4K	4K
	100	3K	3K
	500	3K	3K
	1000	2K	2K
μ^-	500	2K	

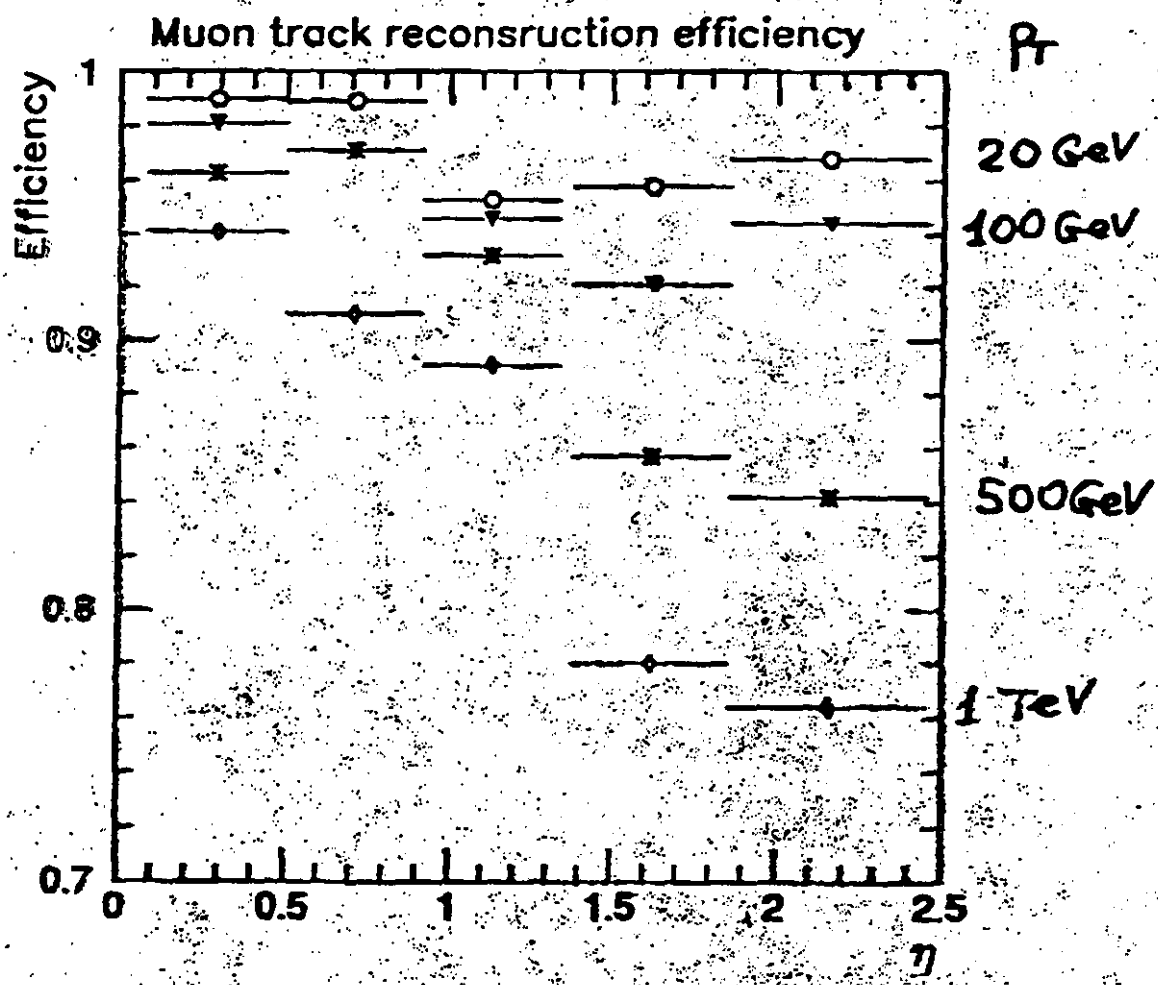

Barrel
- 1
- 2
- 3
200
100
0
Hits/0.5cm
0
1
2
3
4
5
Δx (cm)

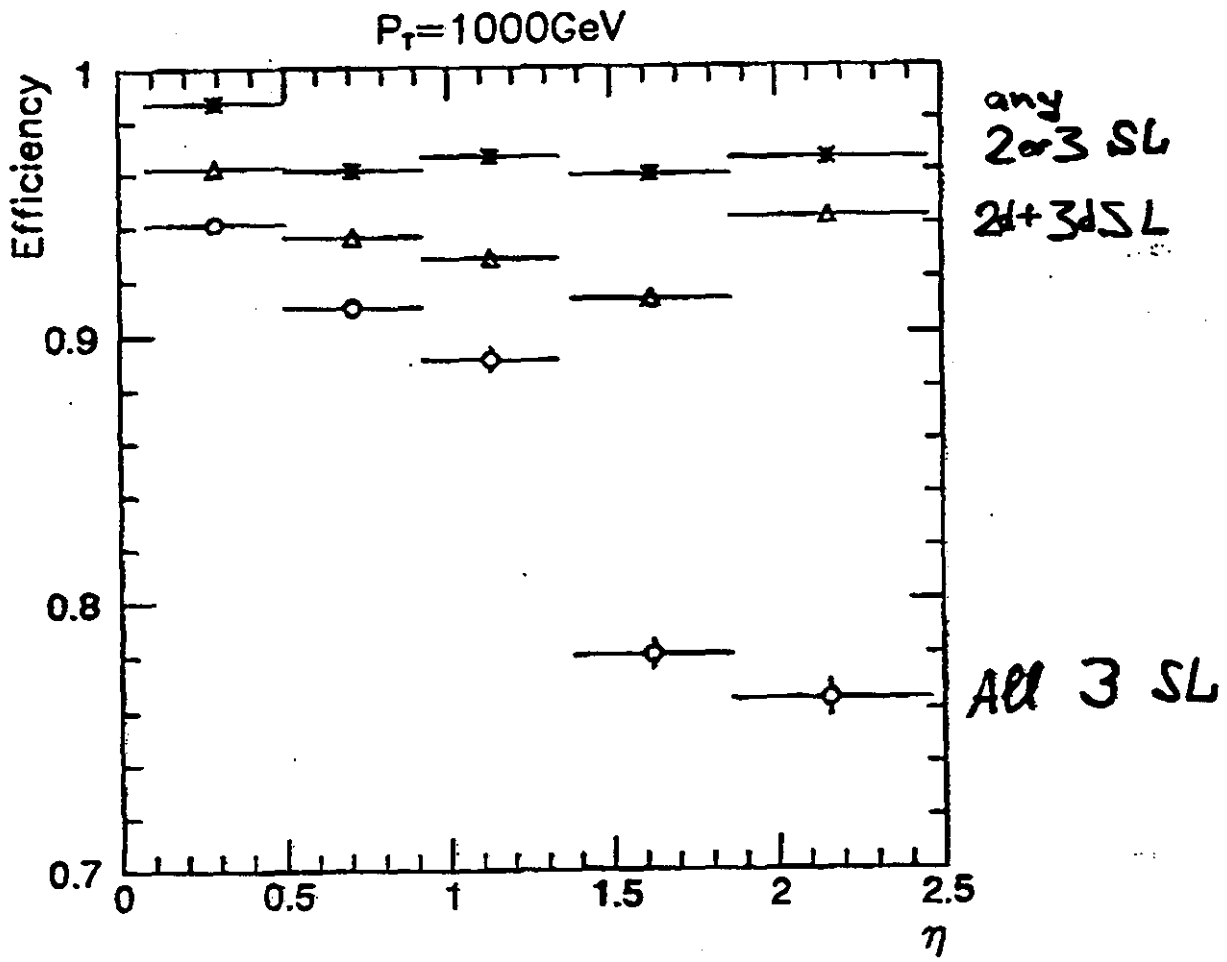

Endcap
- 1
- 2
- 3
1200
800
400
0
Hits/0.5cm
0
1
2
3
4
5
Δx (cm)


Delta rays
Barrel
Hits/0.1cm
400
300
200
100
0
0
1
2
3
4
5
x (cm)

Isolated muon

$p_T = 20\,GeV - 1\,TeV$



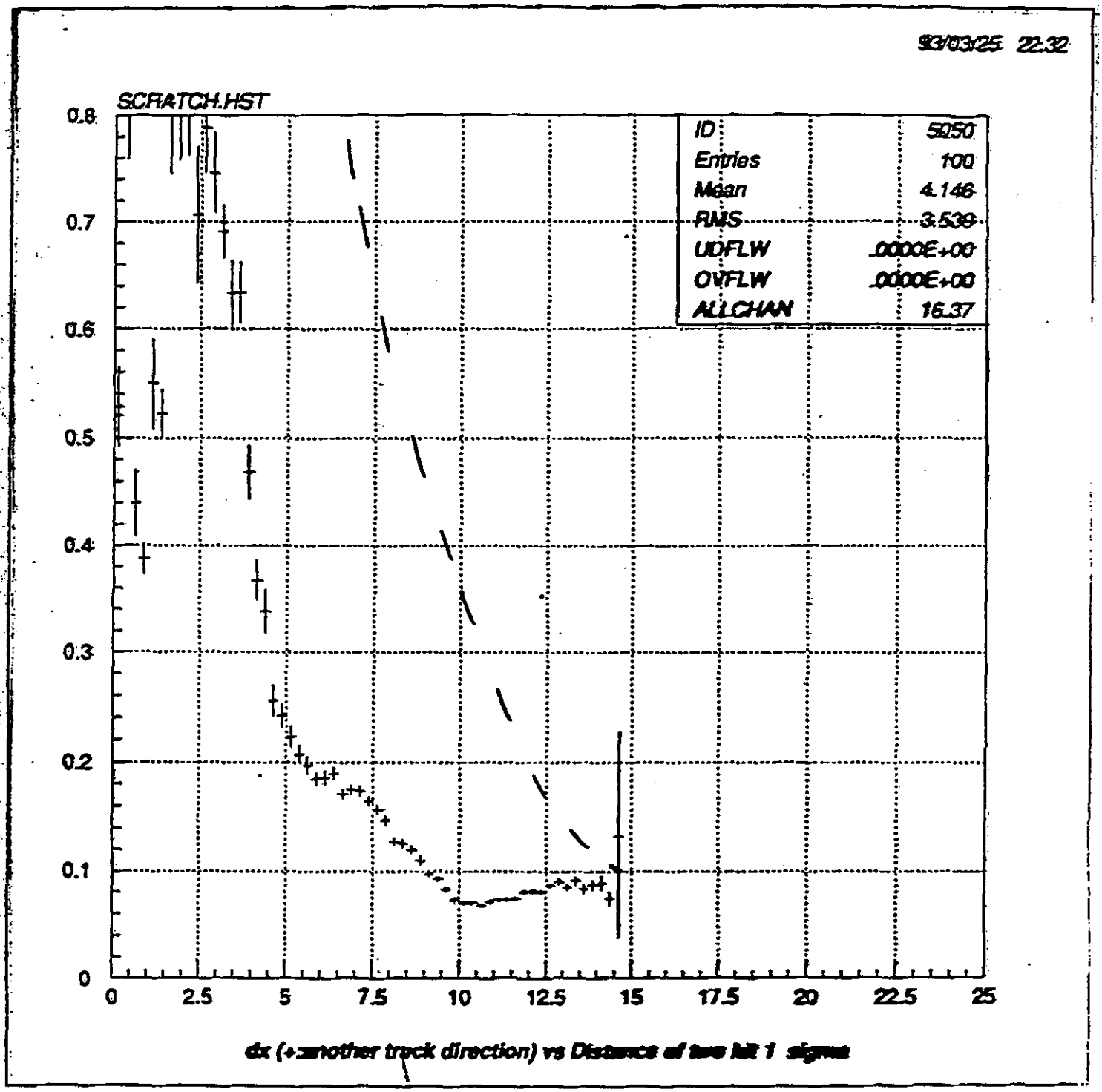

P_T=1000GeV
Efficiency
1
0.9
0.8
0.7
0
0.5
1
1.5
2
2.5
η
any 2 or 3 SL
2d+3d SL
All 3 SL

J. Thomas

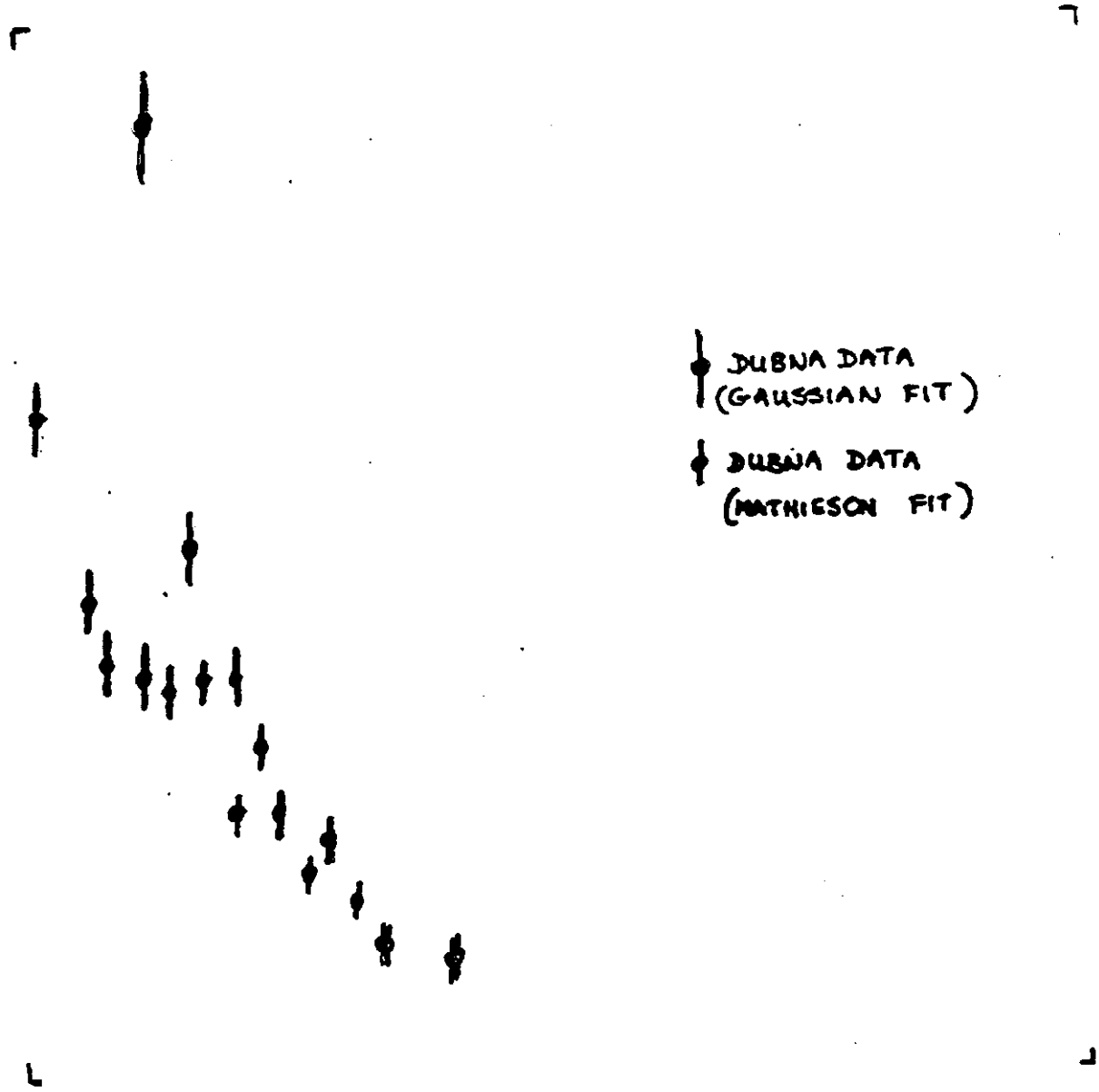
Aki

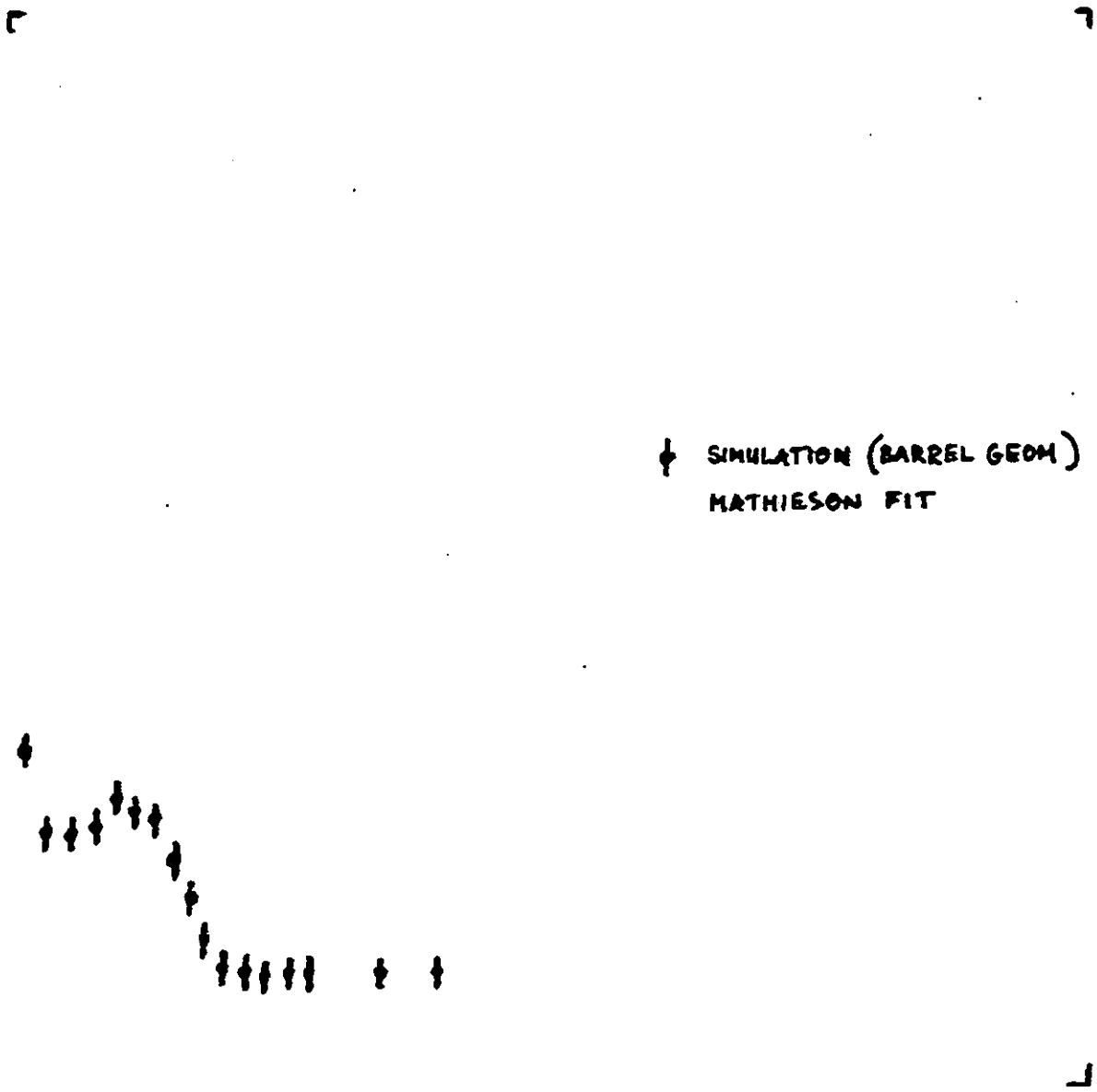
EVENT MIXING

@ BNL

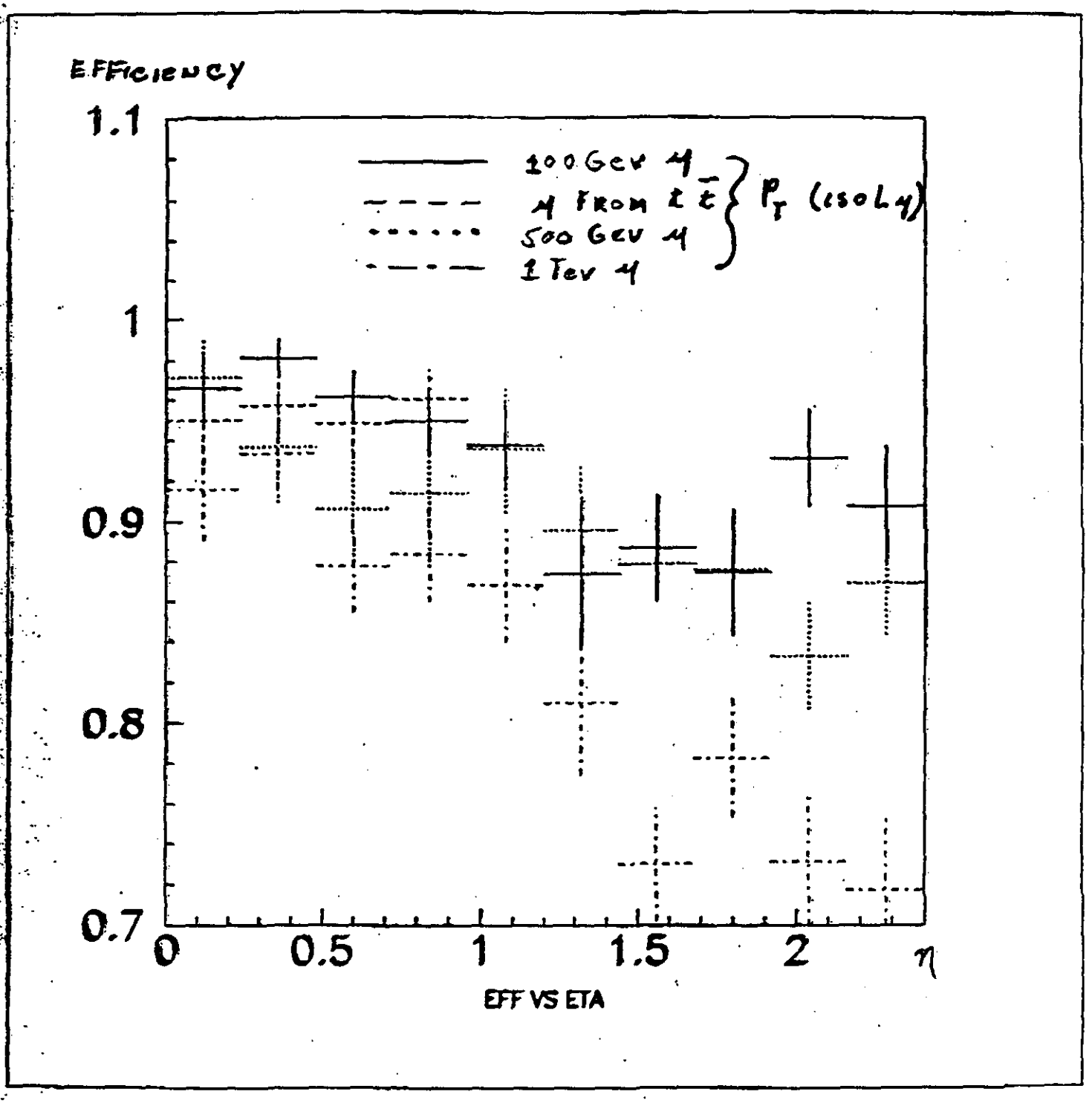


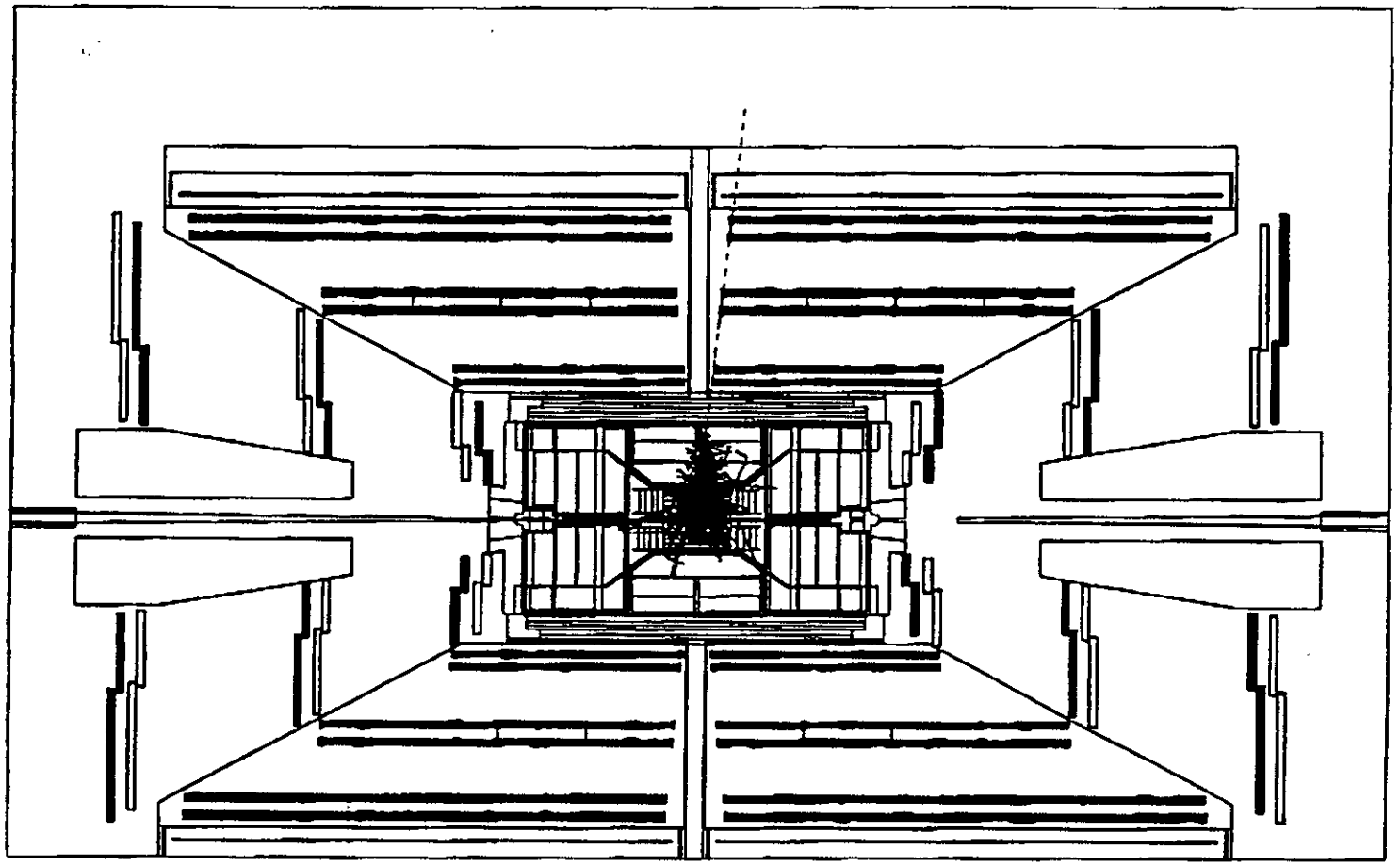
EVENT MIXING ADDS NOISE TWICE

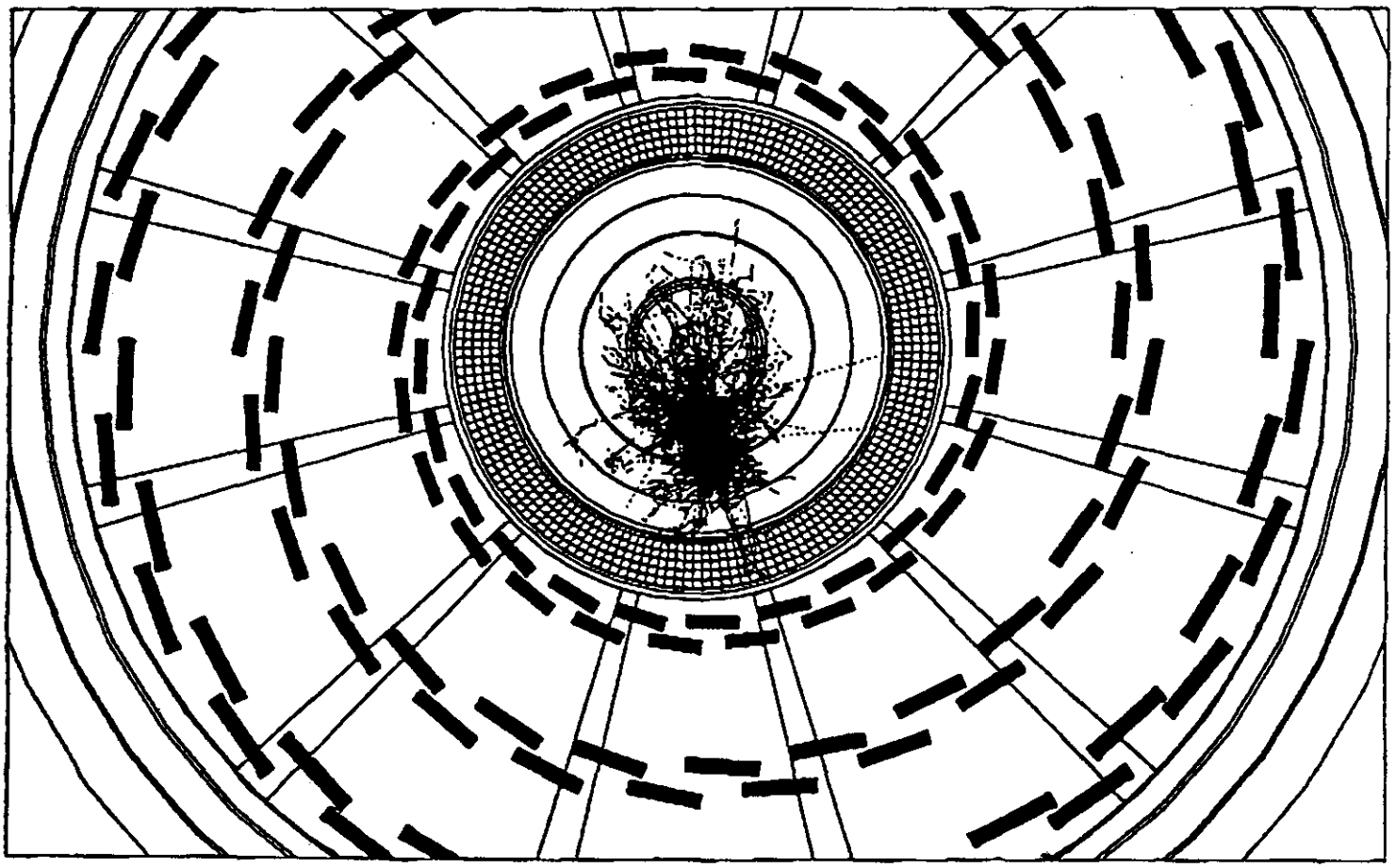


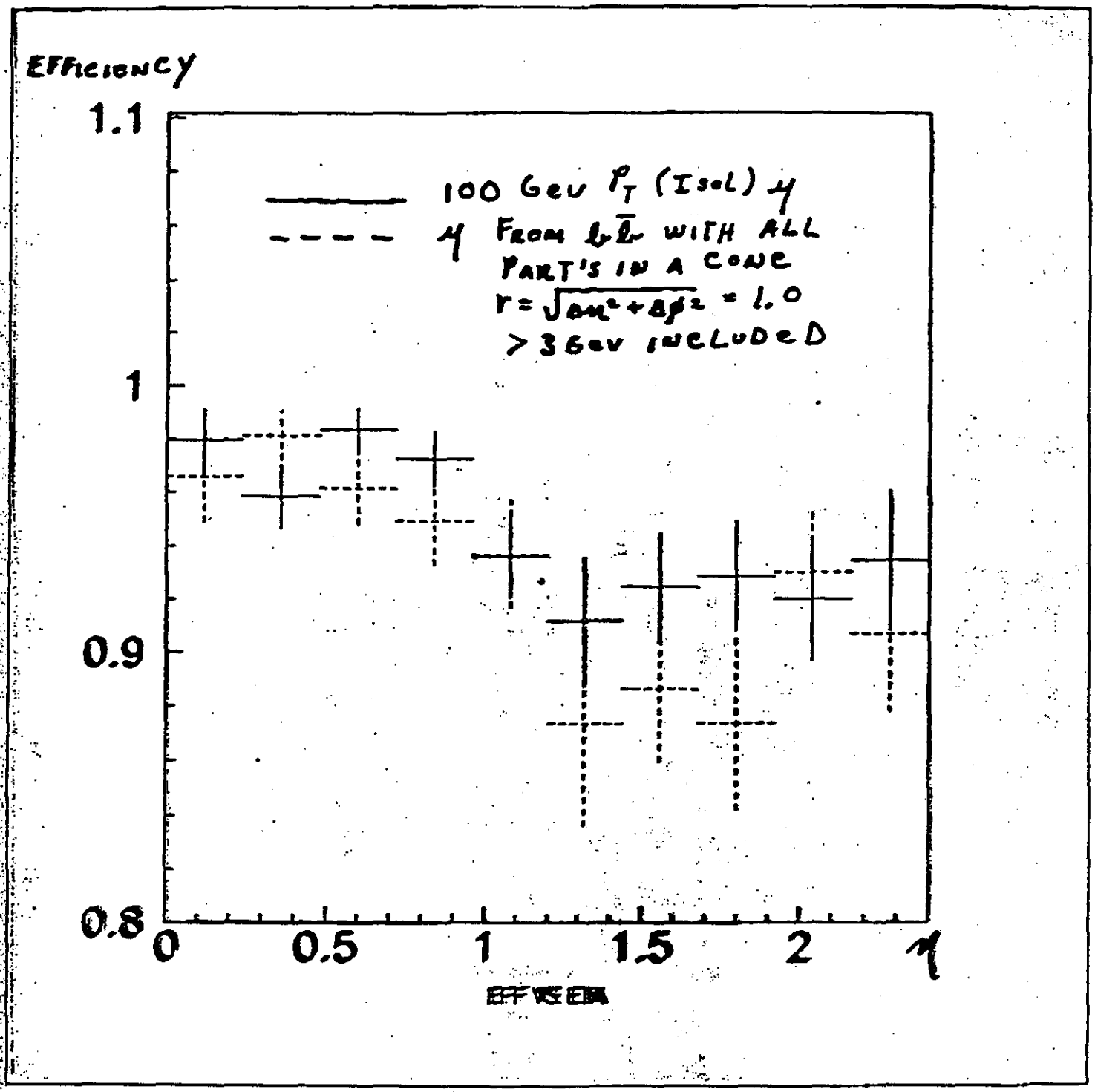

SIMULATION (BARREL GEOM)
MATHIESON FIT

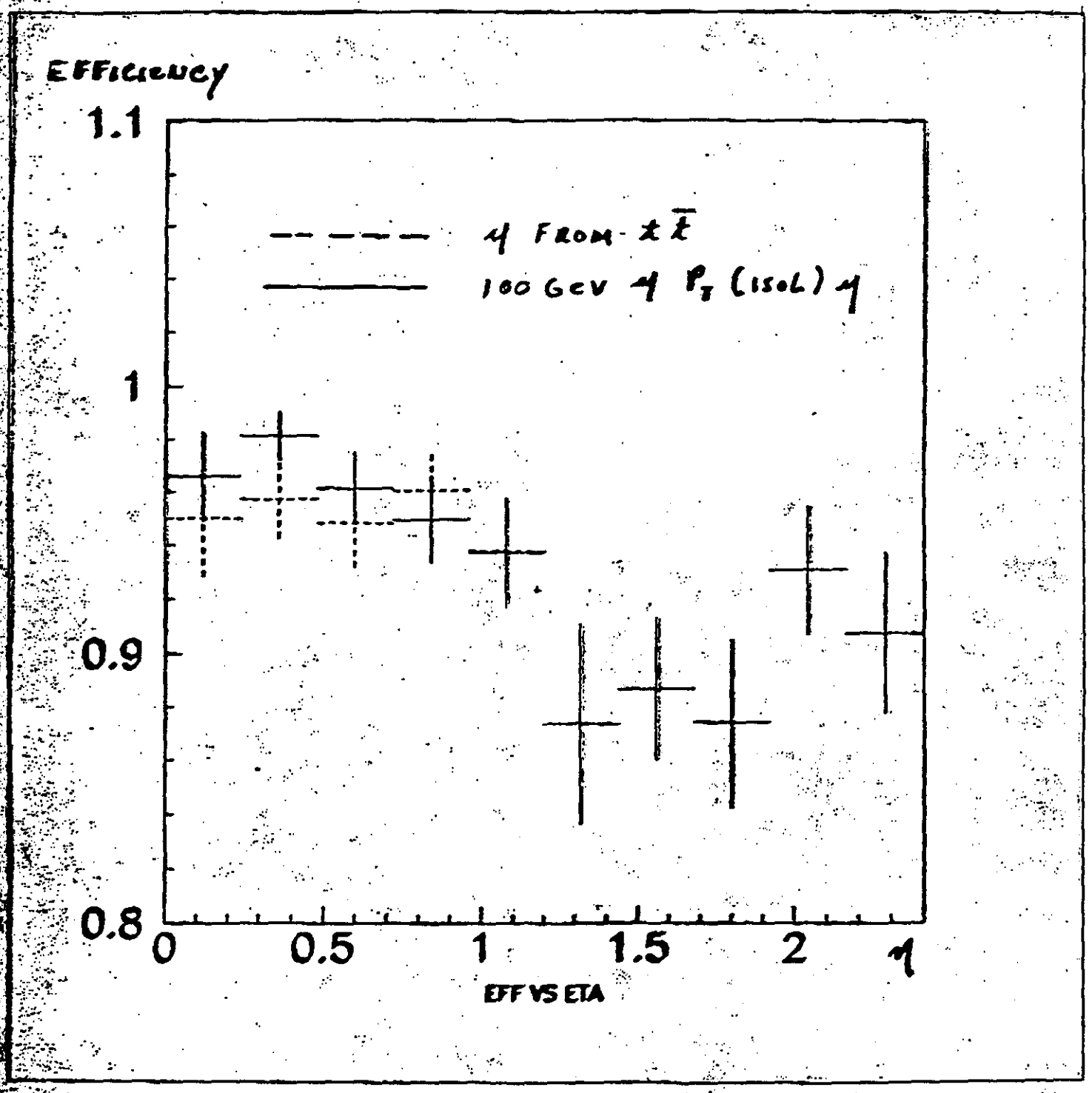
V. G , V. Balagura, Peter Dingus
3/26/93








EFFICIENCY
1.1
1
0.9
0.8
0
0.5
1
1.5
2
η
100 GeV P_T (ISOL) η
η FROM $b\bar{b}$ WITH ALL PART'S IN A CONE
$r = \sqrt{\Delta\eta^2 + \Delta\phi^2} = 1.0$
> 3 GeV INCLUDED

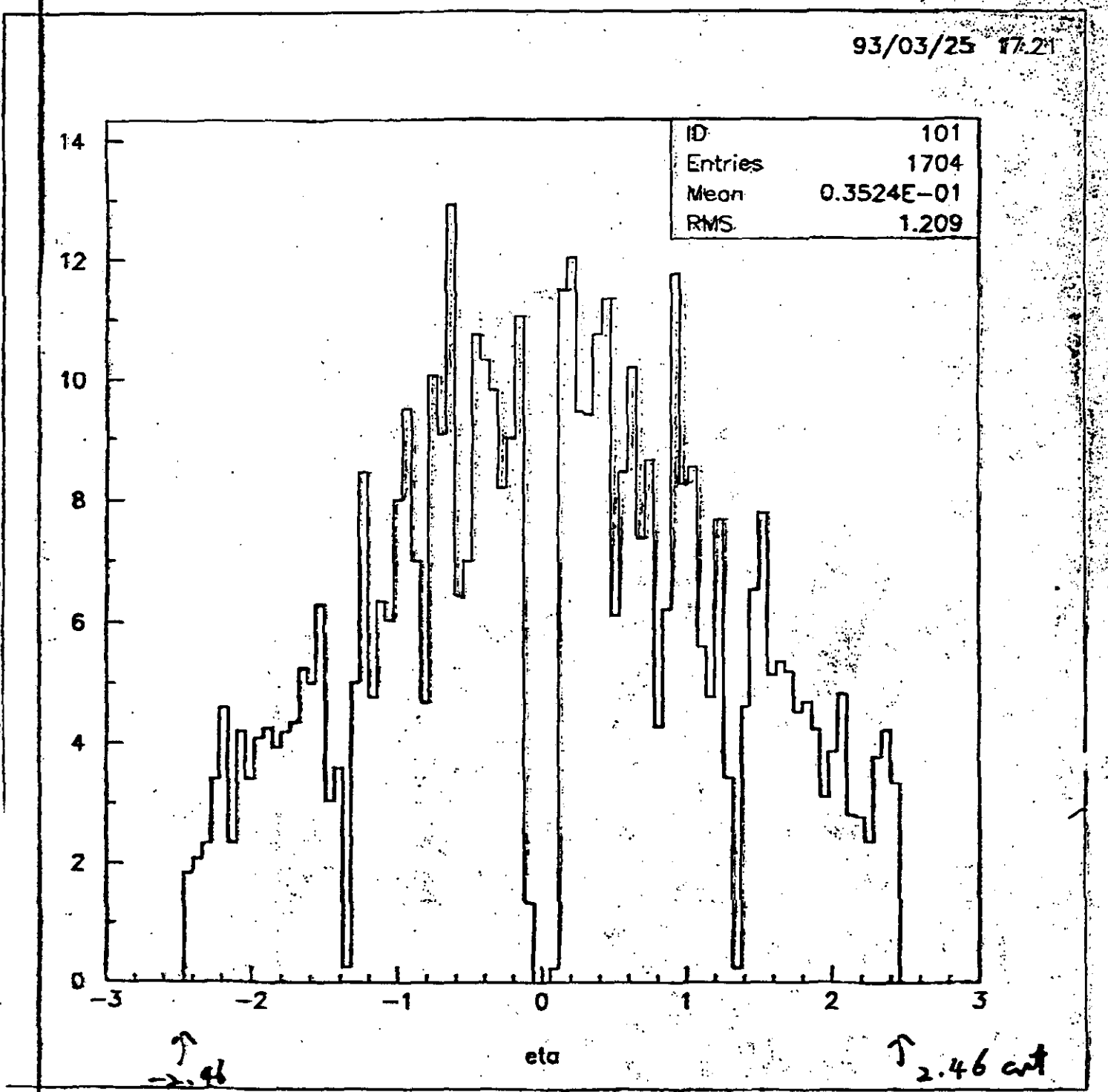

EFFICIENCY
1.1
1
0.9
0.8
0
0.5
1
1.5
2
η
η FROM $t\bar{t}$
100 GeV η P_T (ISOL) η
EFF VS ETA

```
-----------------------------------------------------------------
Higgs 150 GeV
-----------------------------------------------------------------
ntot=        1000
# of analysized evt =          533
 SL1,2,3     SL2,3      Any2SL       Any1SL
        0:  0.1876173E-02 0.1876173E-02        0.              0.
        1:  0.2251407E-01 0.2063790E-01 0.9380863E-02 0.7504690E-02
        2:  0.1688555     0.1407129     0.9005629E-01 0.6378987E-01
        3:  0.3996248     0.3921201     0.3602251     0.3320825
        4:  0.3977486     0.4352720     0.5309569     0.5853658
        5:  0.9380863E-02 0.9380863E-02 0.9380863E-02 0.1125704E-01
        6:          0.            0.            0.              0.
3 Good SL1,2,3 and 1 Good SL any 2=          0.
3 Good SL1,2,3 and 1 Good SL any 1=          0.
# of low P (at least 1 P<1GEV in SL1)=          4
-----------------------------------------------------------------
Higgs 400 GeV
-----------------------------------------------------------------
ntot=        1000
# of analysized evt =          638
 SL1,2,3     SL2,3      Any2SL       Any1SL
        0:  0.4702194E-02 0.4702194E-02 0.4702194E-02        0.
        1:  0.2507837E-01 0.1097179E-01 0.4702194E-02 0.3134796E-02
        2:  0.1269592     0.1112853     0.6583072E-01 0.4858934E-01
        3:  0.4122257     0.3902821     0.3463950     0.3197492
        4:  0.4247649     0.4733542     0.5673981     0.6175548
        5:  0.6269592E-02 0.9404388E-02 0.1097179E-01 0.1097179E-01
        6:          0.            0.            0.              0.
3 Good SL1,2,3 and 1 Good SL any 2=          0.
3 Good SL1,2,3 and 1 Good SL any 1=          0.
# of low P (at least 1 P<1GEV in SL1)=          0
-----------------------------------------------------------------
HIggs 800 GeV
-----------------------------------------------------------------
ntot=         700
# of analysized evt =          546
 SL1,2,3     SL2,3      Any2SL       Any1SL
        0:  0.1648352E-01 0.1465201E-01 0.9157510E-02 0.1831502E-02
        1:  0.3113553E-01 0.1831502E-01 0.1098901E-01 0.9157510E-02
        2:  0.1263736     0.1007326     0.7326008E-01 0.5677656E-01
        3:  0.3901099     0.3644689     0.3168498     0.3003663
        4:  0.4358974     0.5000000     0.5860806     0.6282051
        5:          0.    0.1831502E-02 0.3663004E-02 0.3663004E-02
        6:          0.            0.            0.              0.
3 Good SL1,2,3 and 1 Good SL any 2=          0.
3 Good SL1,2,3 and 1 Good SL any 1=          0.
# of low P (at least 1 P<1GEV in SL1)=          0
```

efficiency distribution

$H \to 4\mu$ with $|\eta| < 2.46$

η distribution on Higgs decay to 4 μ at 150 GeV



V. Ostapchuk
03.26.93

Vertex Constraint: Alignment Problems

Two problems for the current GEM alignment scheme:

a. There are no monitors, measuring relative coordinates of muon chambers and IP.

b. Projective straightness monitors don't measure relative positions of muon chambers inside one tower, they measure false sagitta only.

Is it possible to solve both these problems with sufficient statistics of single muons?

Yes - in EndCaps ; Highly probably - in Barrel.

Table I Rates of single muons: number of particles per hour

$$L = 10^{33}\ cm^{-2}\ s^{-1}$$

	Tower I	Tower II	Tower III	Tower IV	Tower V
$P_t > 5$ GeV/c	80,000	70,000	60,000	50,000	240,000
$P_t > 10$ GeV/c	22,000	20,000	16,000	13,000	68,000
$P_t > 15$ GeV/c	5,500	4,800	4,000	3,300	16,000
$P_t > 25$ GeV/c	1,100	950	800	660	3,200
$P_t > 50$ GeV/c	55	48	40	33	160

Determination of chamber positions with respect to each other

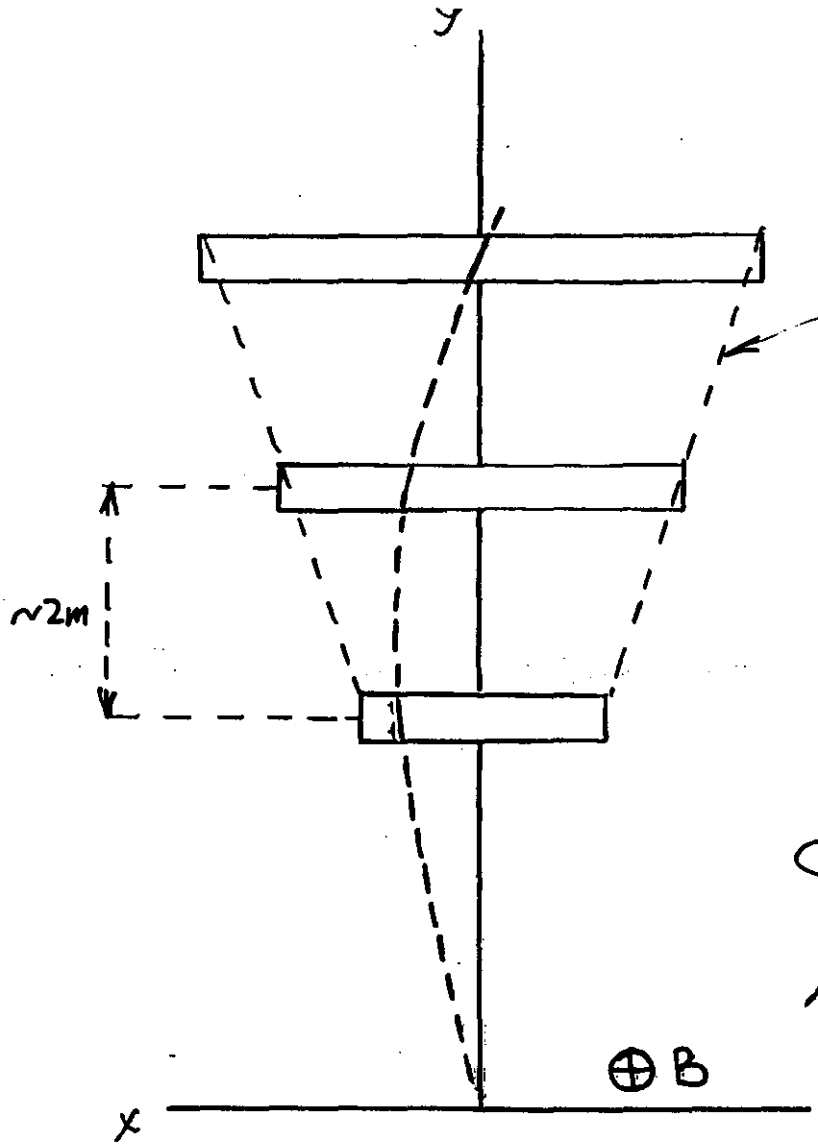
Relative positions of Middle and Outer SL's with respect to Inner SL (base) are characterized by parameters:

D_x - displacement in x-direction;
D_y - displacement in y-direction;
R_x - rotation around x-axis;
R_y - rotation around y-axis;
R_z - rotation around z-axis.

Accuracy of these parameters knowing, adequate to 200 μm vertex constraint is:

$\sigma(D_x) \lesssim 30\,\mu$
$\sigma(D_y) \lesssim 300\,\mu$
$\sigma(R_x) \lesssim 0.5$ mrad
$\sigma(R_y) \lesssim 0.05$ mrad
$\sigma(R_z) \lesssim 1$ mrad

Procedure for these parameters determination with the using of experimental data could be the following.



straightness monitors

P_t - sagitta measurement

$\sigma(x) \approx \frac{75\mu}{\sqrt{6}} \simeq 30\mu$

$\sigma(A_x) \simeq \frac{75\mu}{15cm} \simeq .5\,mrad$

$\sigma(x^{pred}) \sim .5\,mrad \times 2m \sim 1\,mm$

$N_{stat} \simeq \left(\frac{1mm}{30\mu}\right)^2 \simeq 10^3$

For $D_x, D_y << 1m$ and $R_x, R_y, R_z << 1\,rad$

$$\Delta x \equiv x^{mes} - x^{pred} = -D_x + A_x D_y - z A_x R_x + z R_y - x A_x R_z$$

$$\Delta A_x \equiv A_x^{mes} - A_x^{pred} = A_x A_z R_x - A_z R_y + (1 + A_x^2) R_z$$

We will minimize two sums:

$$\Phi_x = \sum_{i=1}^{N_{st}} (\Delta x)^2$$

$$\Phi_A = \sum_{i=1}^{N_{st}} (\Delta A_x)^2$$

Monte Carlo results for $N_{st} = 10^3$:

$\sigma(D_x) \simeq 60\,\mu$

$\sigma(D_y) \simeq 400\,\mu$

$\sigma(R_x) \simeq 1$ mrad

$\sigma(R_y) \simeq 0.05$ mrad

$\sigma(R_z) \simeq 0.02$ mrad

It means, statistics of several thousand of any particles, detected by all three superlayers of given tower, is sufficient.

Determination of muon tower position with respect to IP

Number of prompt muons, necessary for the vertex resolution of 200μ, is determined by multiple scattering in calorimeter.

L. Rosenson made these estimations for muons of different transvers momentum.

Table II Number of prompt muons required for vertex location to 200μm

	Tower I & II	Tower III & IV	Tower V
$p_t = 15$ GeV/c	25,000	35,000	11,000
$p_t = 25$ GeV/c	8,000	14,000	4,000
$p_t = 50$ GeV/c	2,000	3,500	1,000

Comparing Table I and Table II :

For $p_t \geq 15$ GeV/c : run 5 hours (total $N_{st} \simeq 7 \cdot 10^6$)

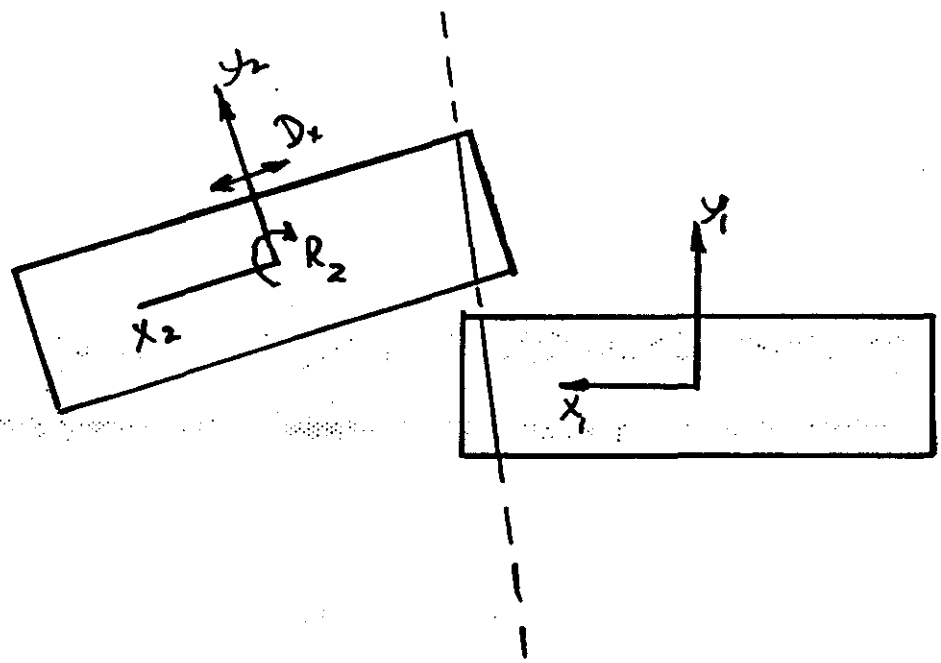
For $p_t \geq 25$ GeV/c : run 10 hours (total $N_{st} \simeq 2.5 \cdot 10^6$)

For $p_t \geq 50$ GeV/c : run 50 hours (total $N_{st} \simeq 6 \cdot 10^5$)

Possible developments of this scheme:

1. Aligument of muon towers with respect to the central tracker first (necessary statistics is approximately the same). Determination of IP position with respect to CT in every run with small statistics (no multiple scattering).

2. Aligument of overlapping chambers from different sectors first.



$$\sigma(R_z) \lesssim \frac{200\mu}{4\,m} = 50\ \mu rad \Rightarrow N_{st}^{tower} \simeq 1000$$

$$p_t \geq 5\ GeV/c \Rightarrow 1\ hour\ run \Rightarrow N_{st}^{tot} \simeq 3\cdot 10^5$$

Dedicated trigger!!

After this procedure of chambers coupling, the determination of IP position with respect to each "belt" of towers requires ~50 times less statistics.

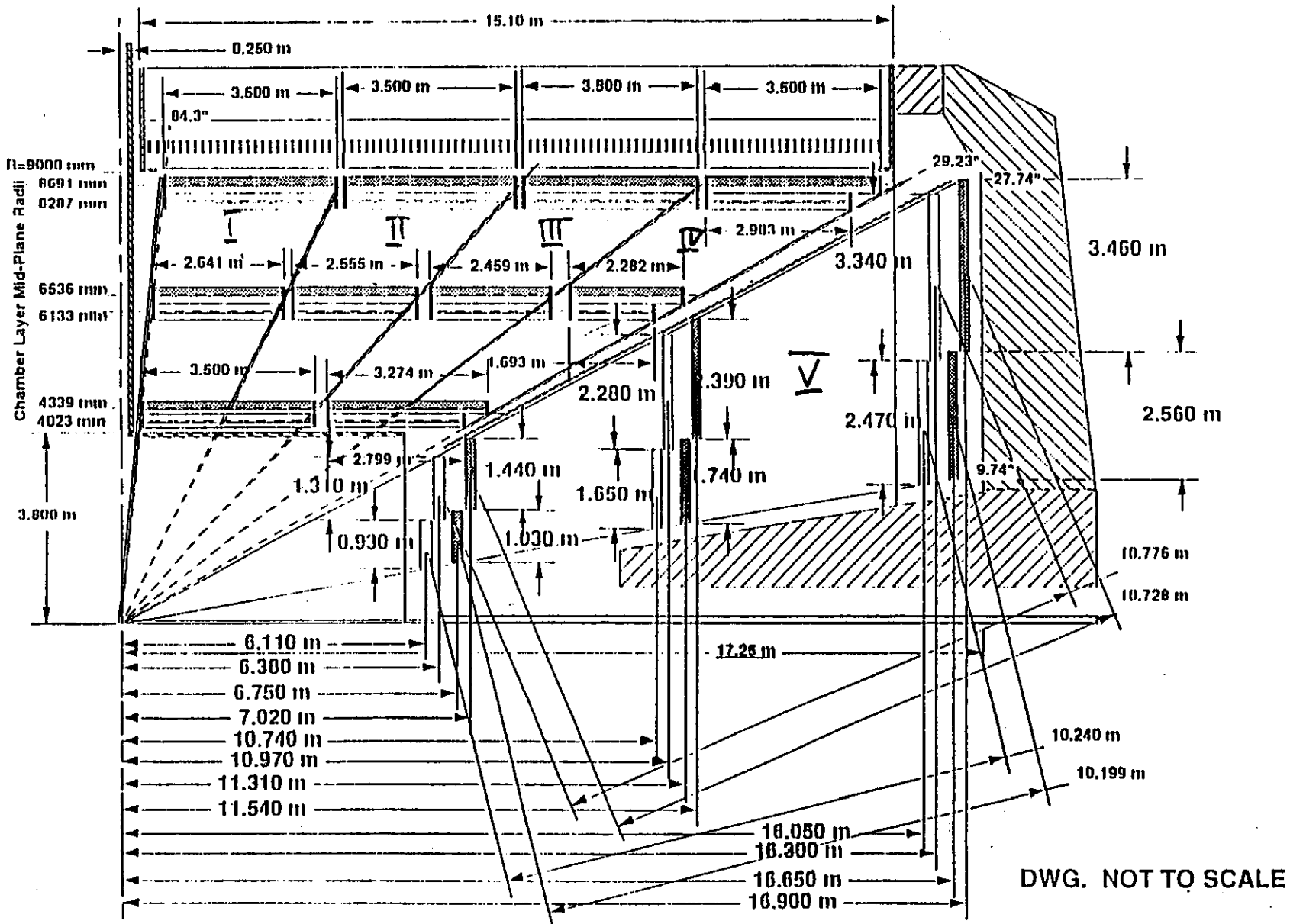
<u>It is necessary to clarify</u>:

- stability of muon system in a hundred μm region with respect to CT;
- trigger issues;
- efficiency of the global fit procedure

<u>Conclusions:</u>

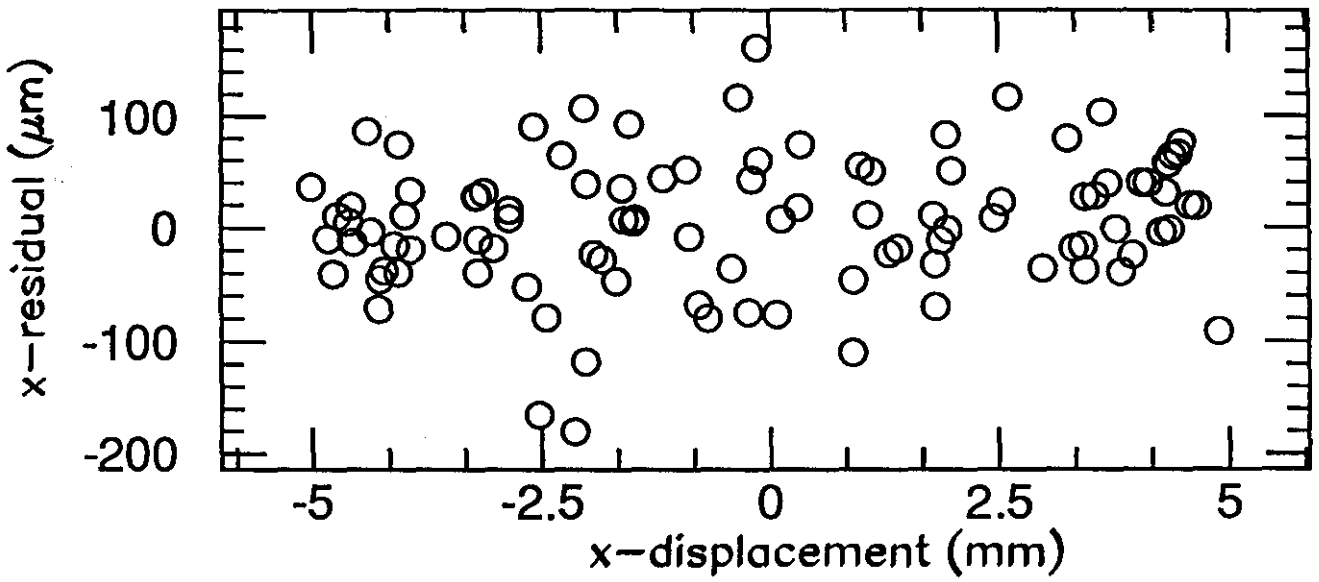
The problem of 200μm vertex constraint implementation looks accessible for the current GEM alignment scheme if:

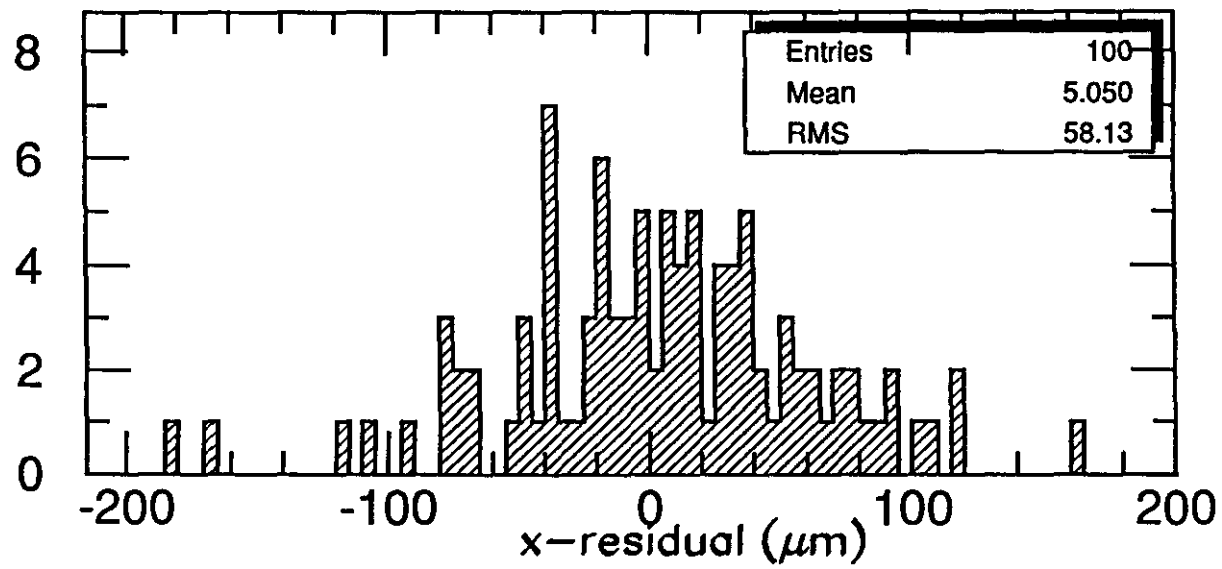
- $L \simeq 10^{33}\ cm^{-2} s^{-1}$;
- muon system is stable within 100μm range during several hours;
- trigger is flexible and powerful (processor rand

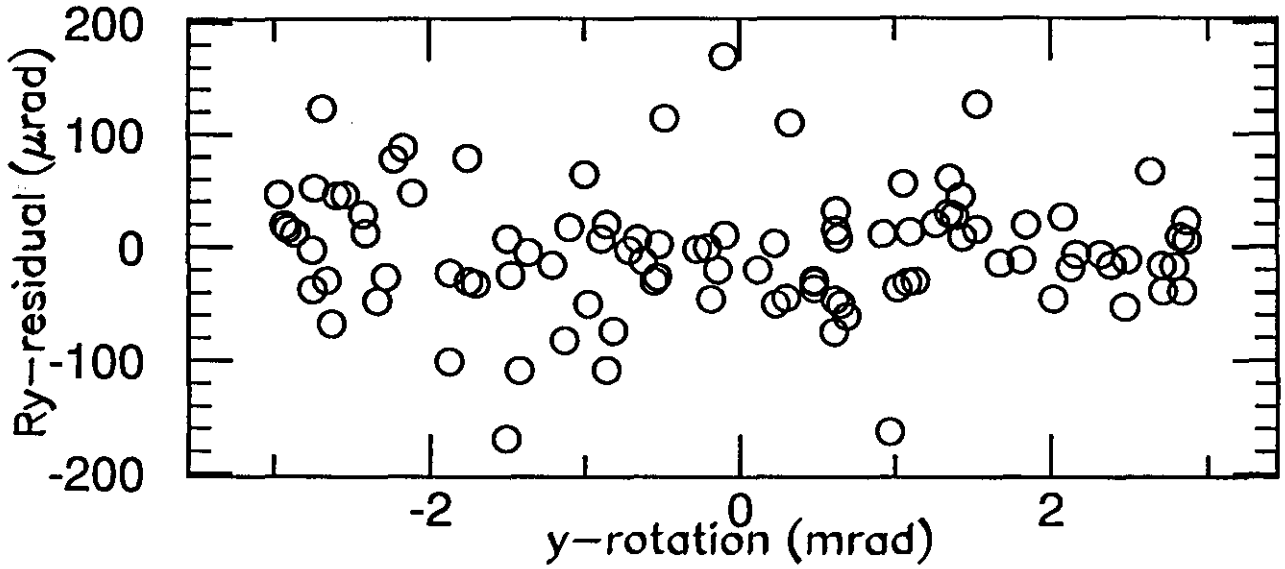


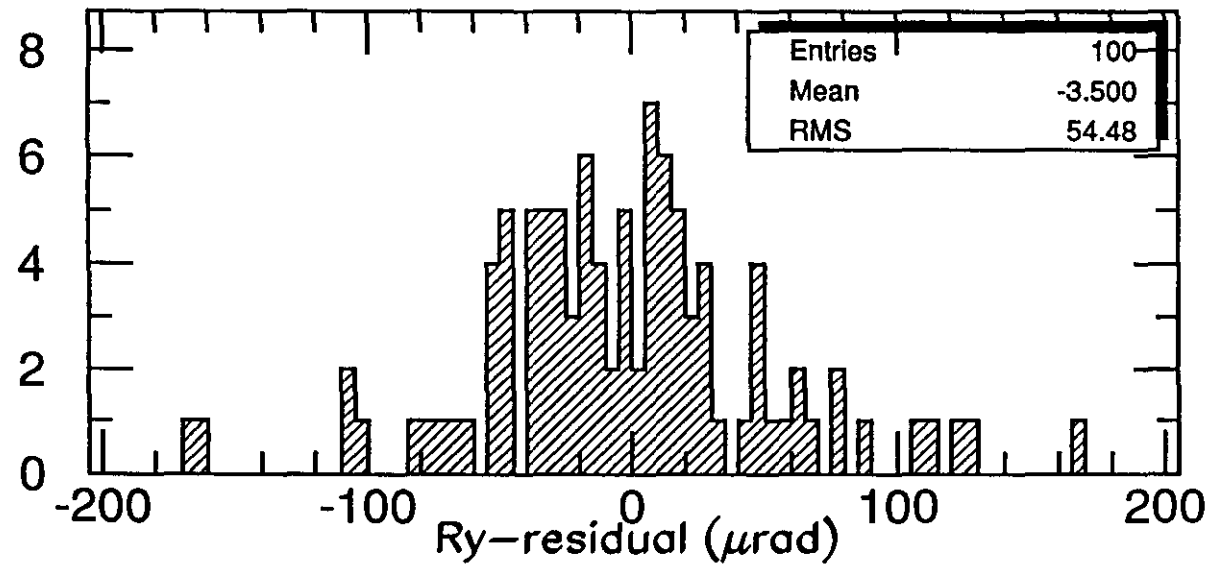
PROJECTIVE ALIGNMENT
WITH RADIAL SUPPORT PLATES
IN BARREL
(SYSTEM DIMENSIONS)

F. HIMDLETT
03 Mar. '93


x−residual (μm)
100
0
-100
-200
-5
-2.5
0
2.5
5
x−displacement (mm)


Entries 100
Mean 5.050
RMS 58.13
8
6
4
2
0
-200
-100
0
100
200
x−residual (μm)


200
100
0
-100
-200
Ry−residual (μrad)
-2
0
2
y−rotation (mrad)


Entries 100
Mean -3.500
RMS 54.48
8
6
4
2
0
-200
-100
0
100
200
Ry−residual (μrad)

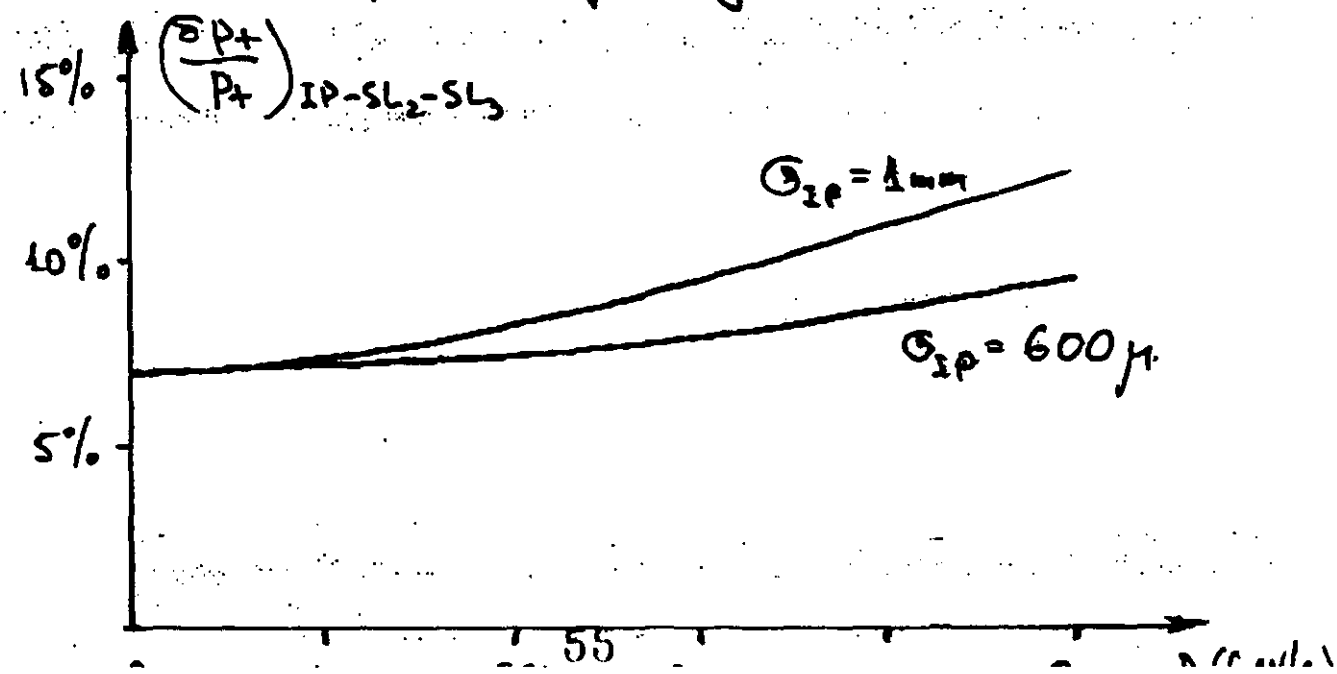
(1)

Vertex constraint ~ 1mm

The vertex constraint has two different impacts on the momentum resolution of muon system:

1. It can improve momentum resolution in TeV region. This task requires 200μm vertex resolution
2. It makes possible to measure transverse momentum with reasonable from the physical benchmark processes ($H \to ZZ^* \to 4\mu$; $H \to ZZ \to 4\mu$) point of view accuracy, when one of superlayers is lost. This task requires several times worse vertex resolution!

Momentum resolution with vertex constraint 600μ and 1mm and no first superlayer.



(2')

Vertex constraint 600 - 1000 μm requires 3-5 times worse accuracy of chamber relative position knowing (local alignment). This accuracy can be achieved with statistics of 100 particles per tower (several minuts run).

Required statistics of prompt muons for vertex location with accuracy 600 ÷ 1000 μm is 10 - 25 less, than for 200 μm case. This task is obviously achievable for luminosity $L = 10^{33}\ cm^{-2} s^{-1}$, and, very probably, even for Luminosity $L = 10^{32}\ cm^{-2} s^{-1}$.

<u>Conclusions</u>.

1. Vertex constraint $\lesssim$ 1000 μm is very useful.
2. Location of IP with this accuracy is obviously achievable task.

μ SYSTEM PERFORMANCE:

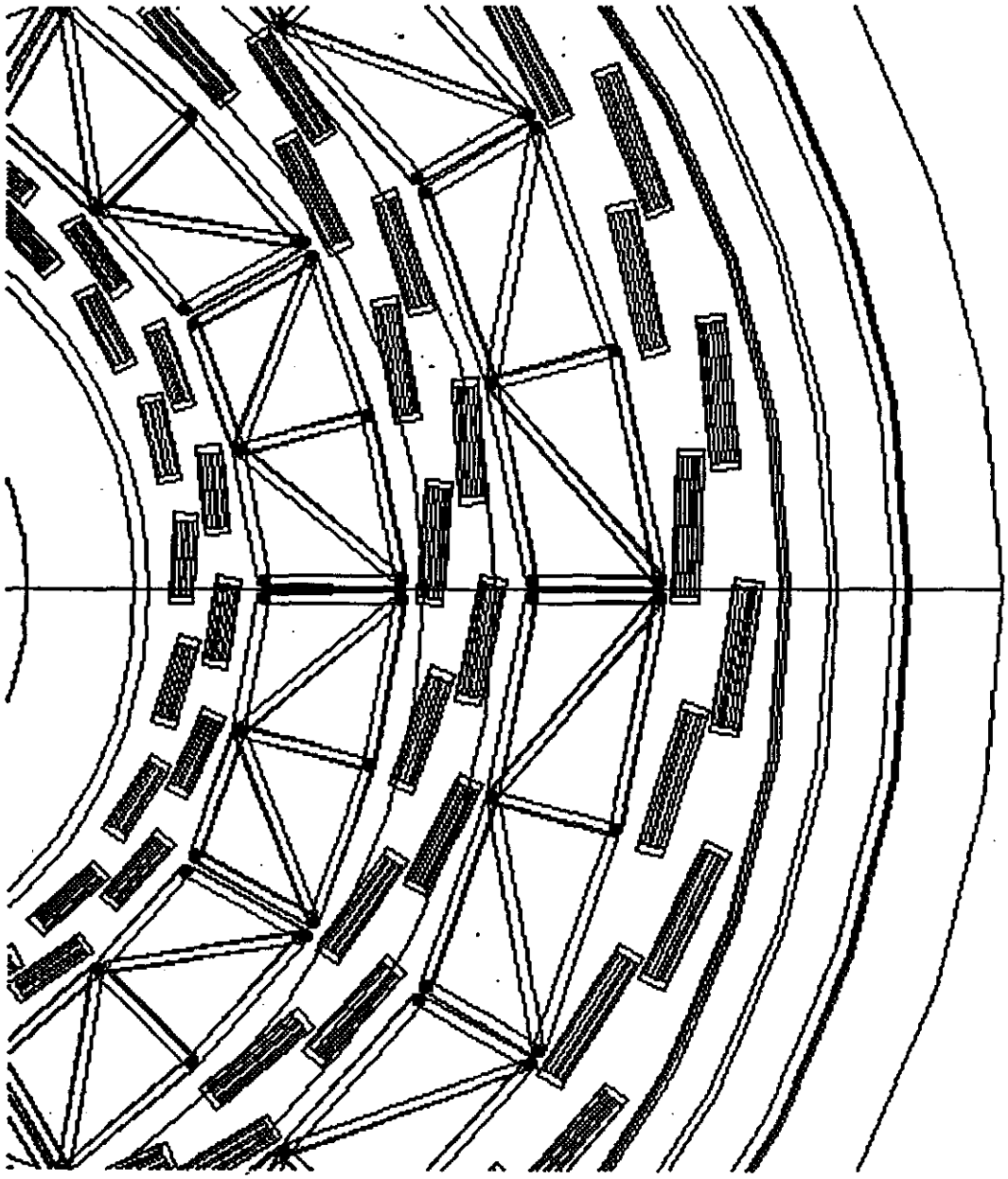
- GEANT SIMU & PARAMETRIZATION OF $\delta p_T / p_T$ AND ACCEPTANCE (USED W GEMFAST)

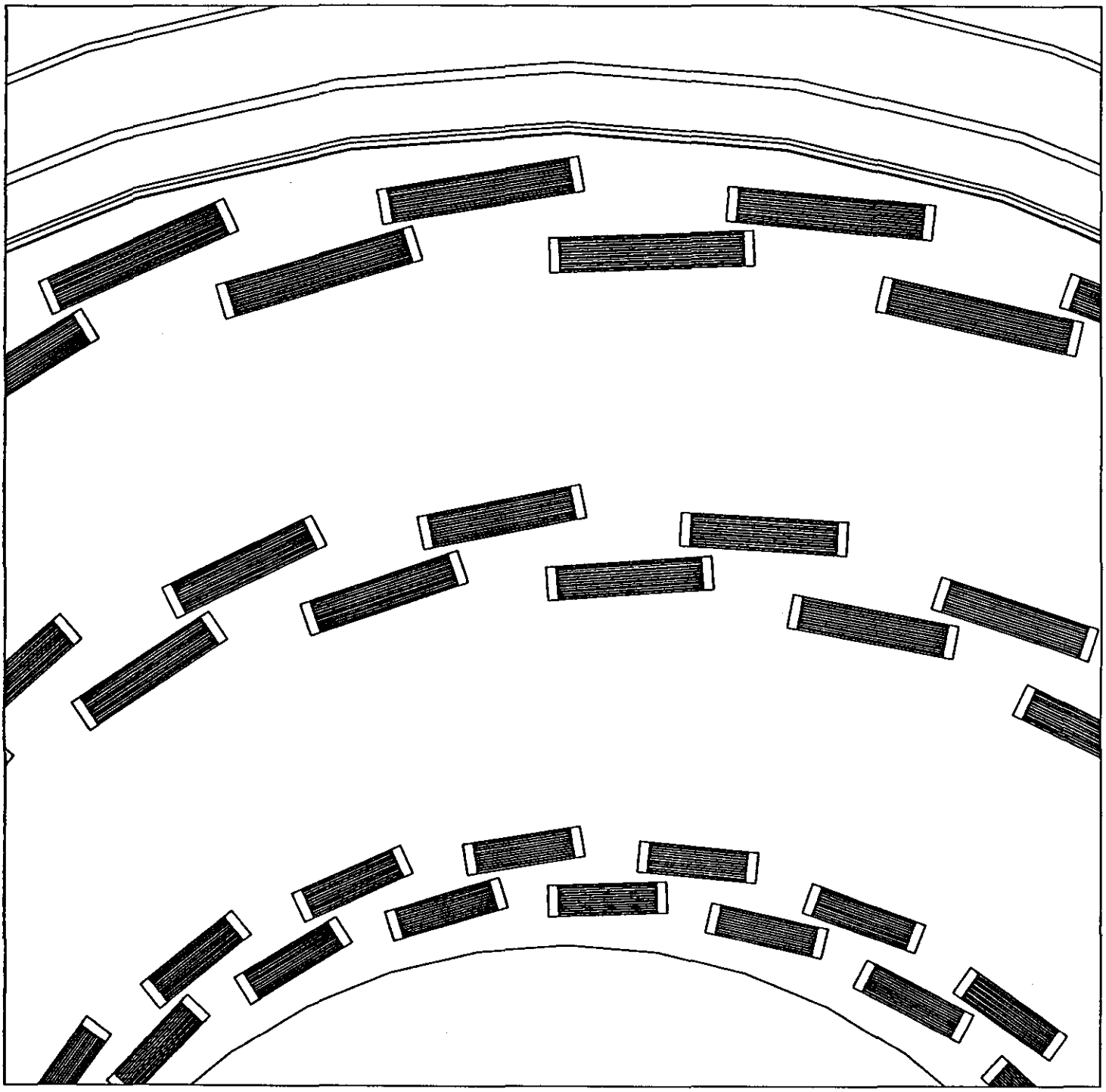
- NEW RESULTS FROM FULL RECONSTRUCTION OF SIGEM-SIMULATED MUONS

1. WENAUS
MAR 26 93.

GEMFAST:

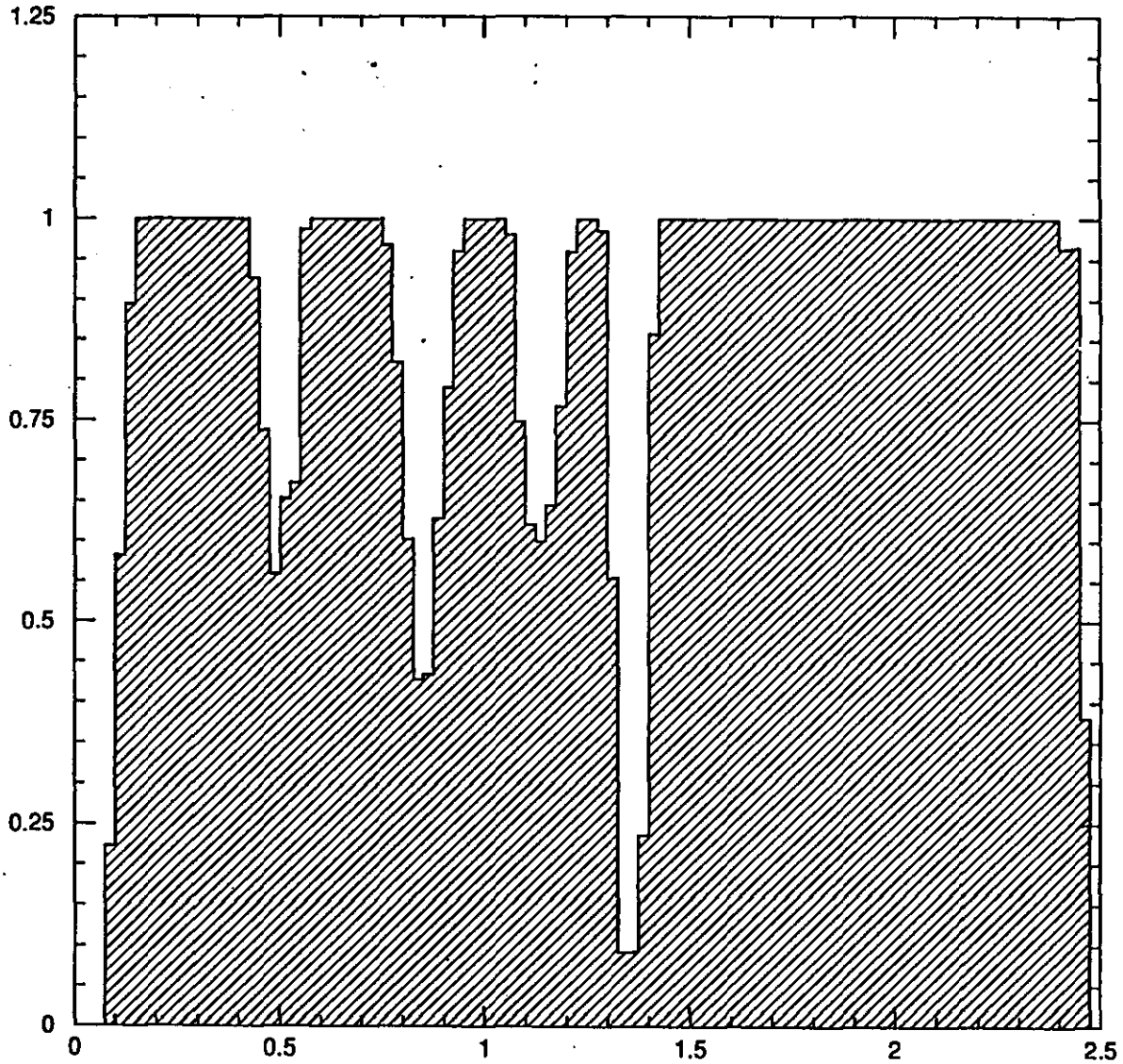
- PARAMETRIZATION IN η, φ, p_T OF MOMENTUM RESOLUTION AND ACCEPTANCE (NHIT/SL ≥ 3)
- PARAM BASED ON FULL, DETAILED GEANT SIMULATION OF 3/3/92 MUON DETECTOR
  - INTRINSIC RES 75μ EVERYWHERE
  - 50μ INT, 25μ EXT ALIGN ERRS
  - MS CONTRIB. OF <u>ALL</u> MATERIAL ALONG TRAJECTORY, INCL. SUPPORT STRUCTS + FRAMES
  - PROCEDURE:
    - TRACK μ USING FIELD MAP (v 600); GEANE DOES TRACKING
    - MEASURE SAGITTA AND $\Delta s/s$
    - FOR HITS/SL, COUNT TRACK INTERCEPTS WITH GAS GAPS



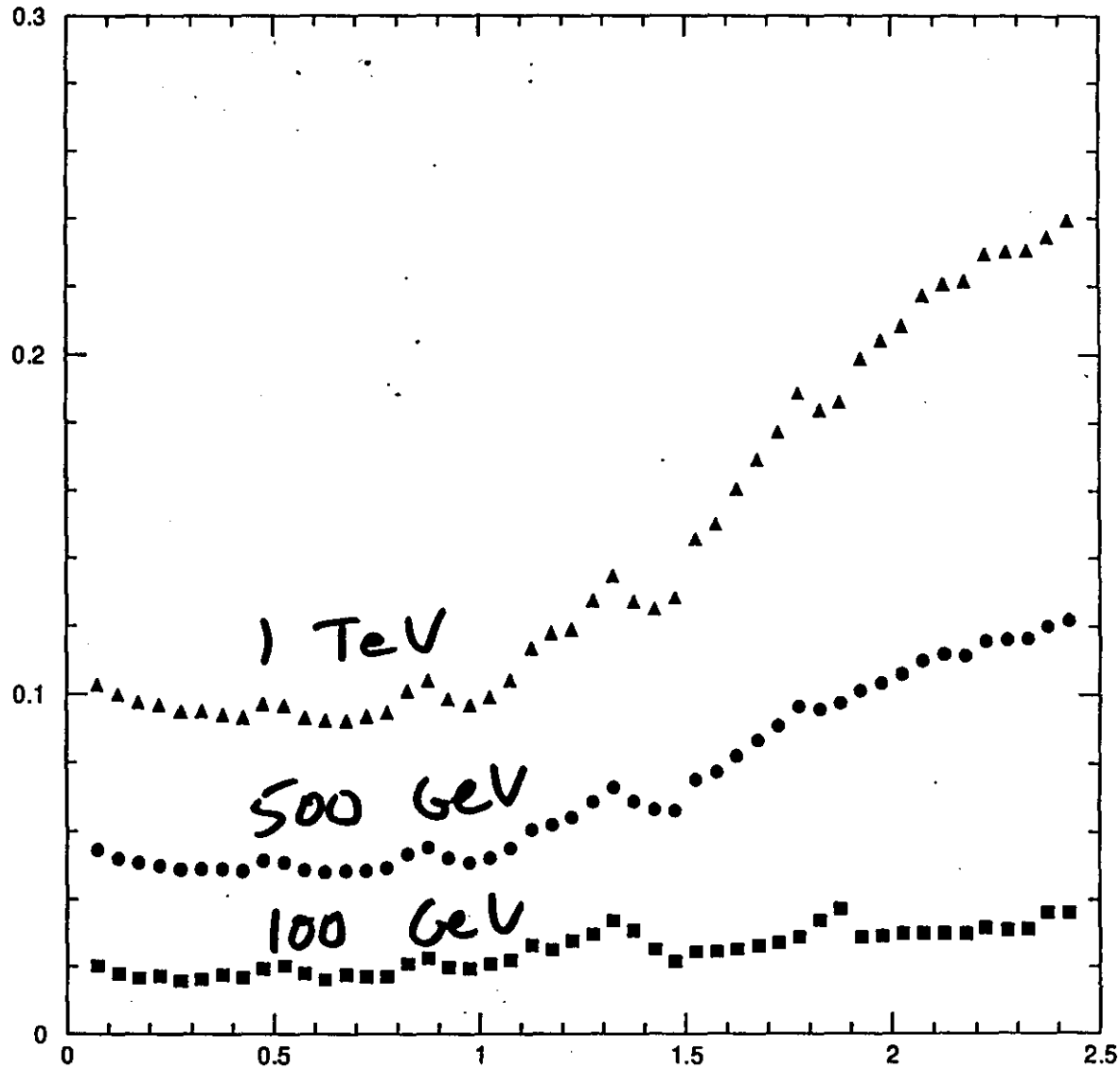


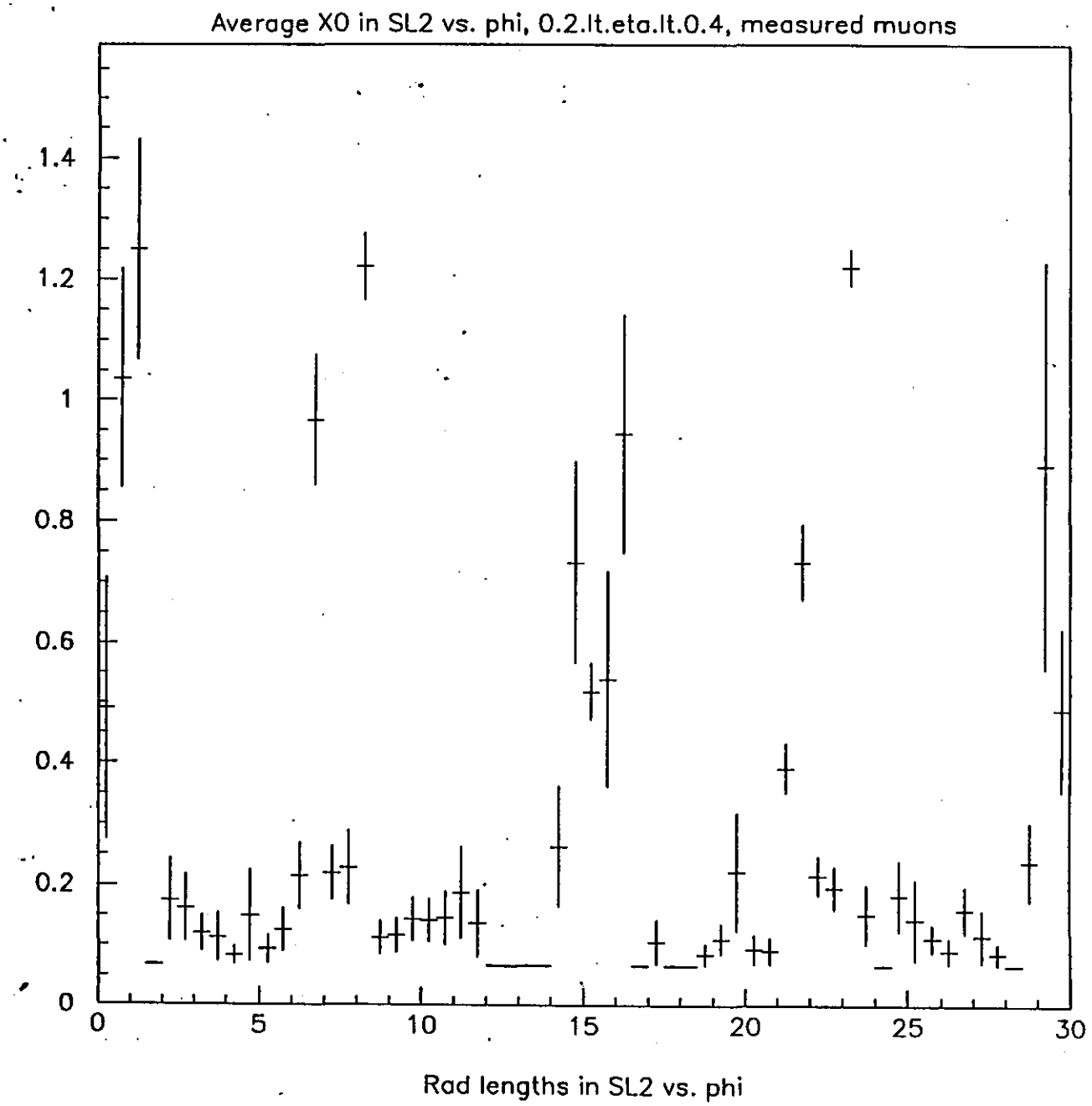
85.5% IN $0 < \eta < 2.5$

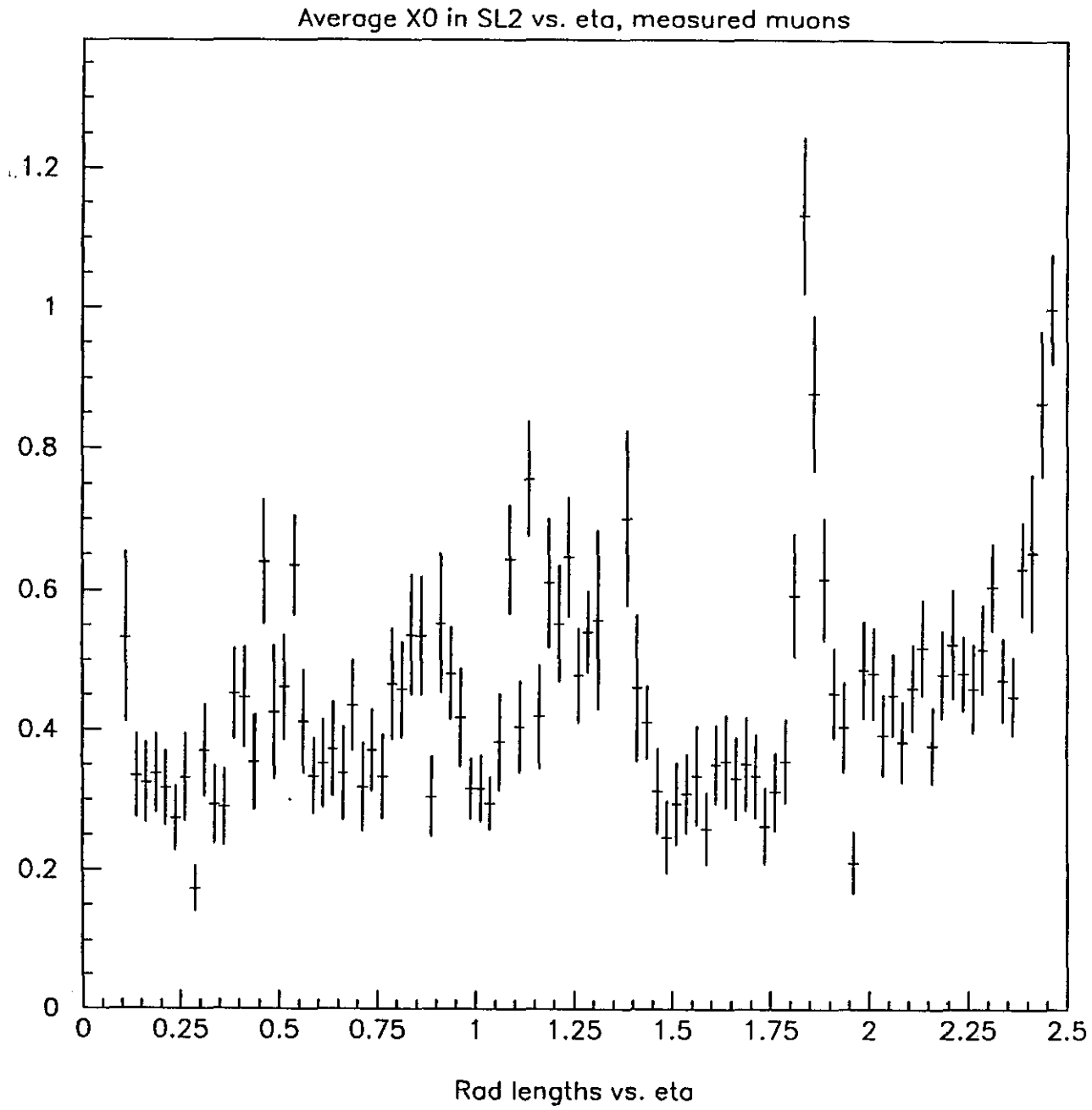
GEMFAST muon acceptance

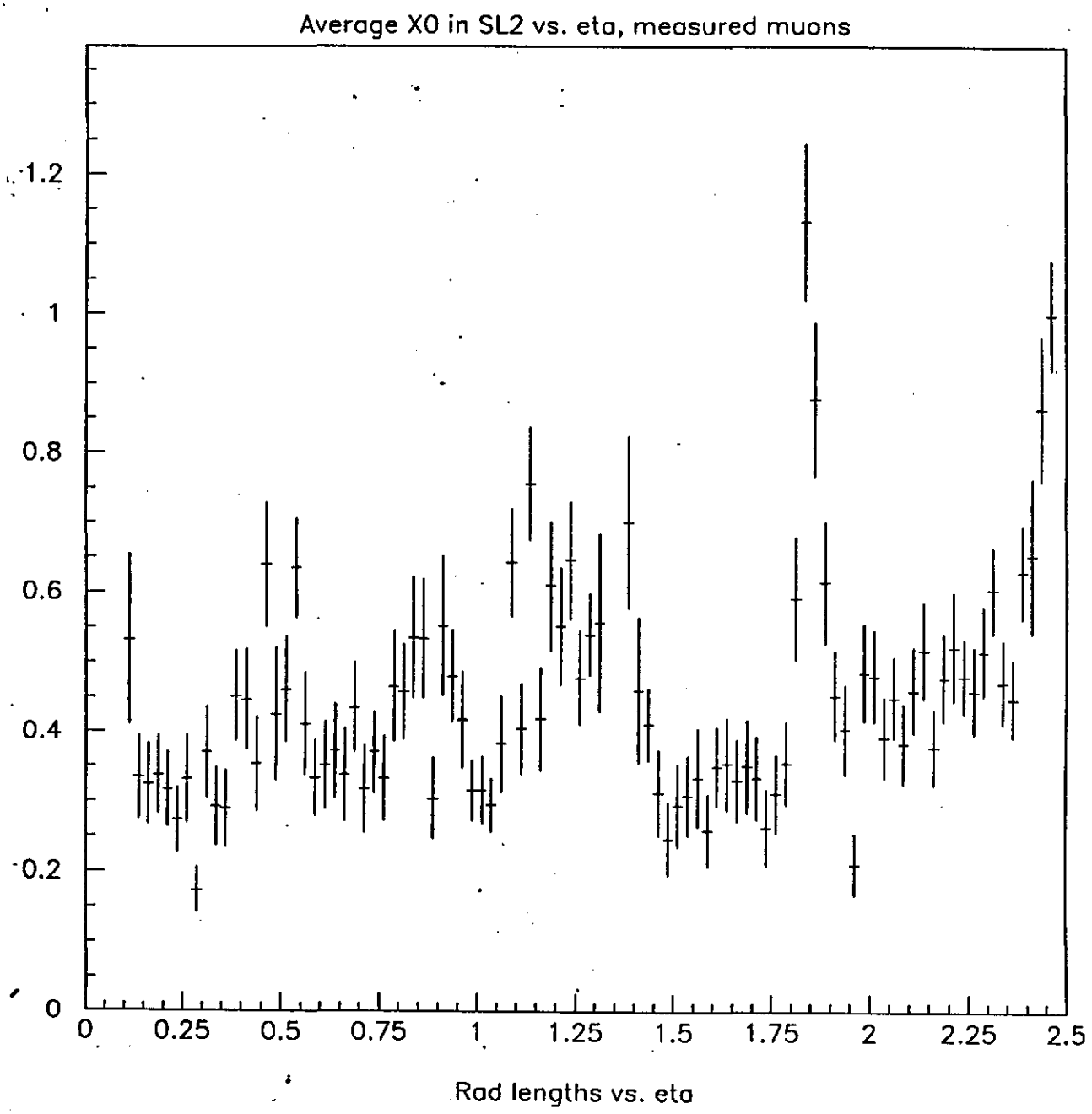


GEMFAST momentum resolution vs. eta

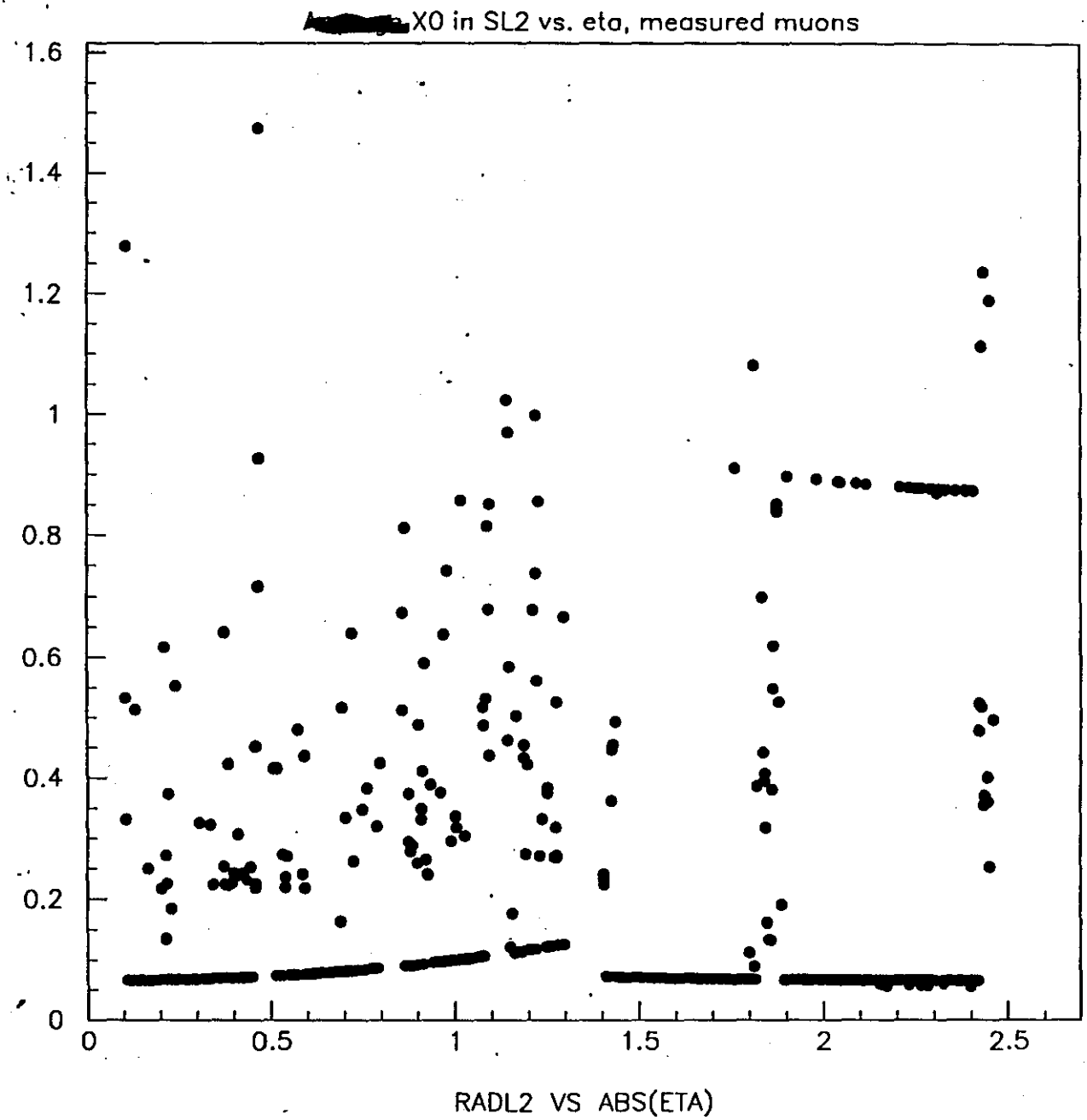



Average X0 in SL2 vs. phi, 0.2.lt.eta.lt.0.4, measured muons
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Rad lengths in SL2 vs. phi

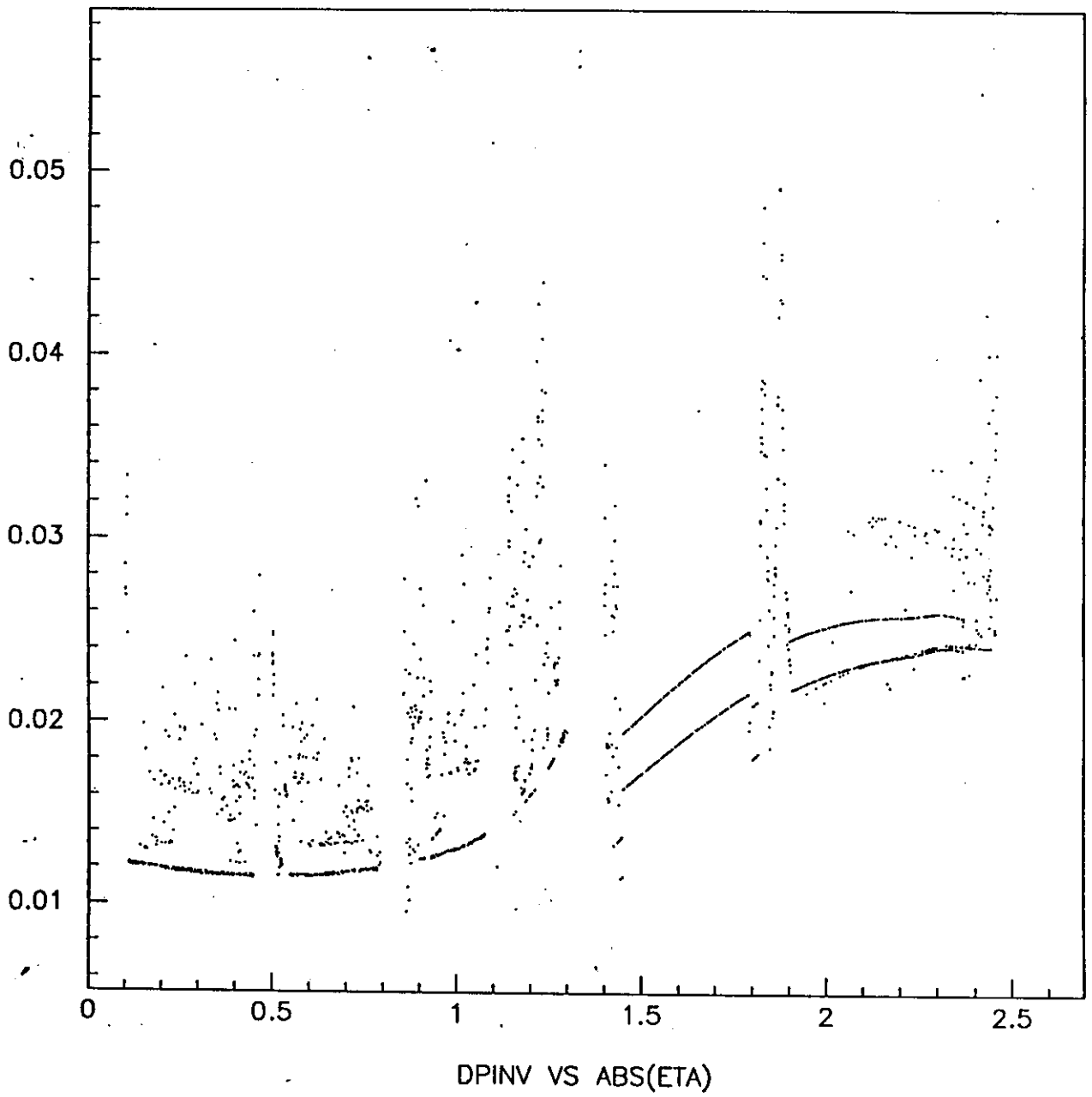

Average X0 in SL2 vs. eta, measured muons
1.2
1
0.8
0.6
0.4
0.2
0
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
Rad lengths vs. eta


Average X0 in SL2 vs. eta, measured muons
1.2
1
0.8
0.6
0.4
0.2
0
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
Rad lengths vs. eta

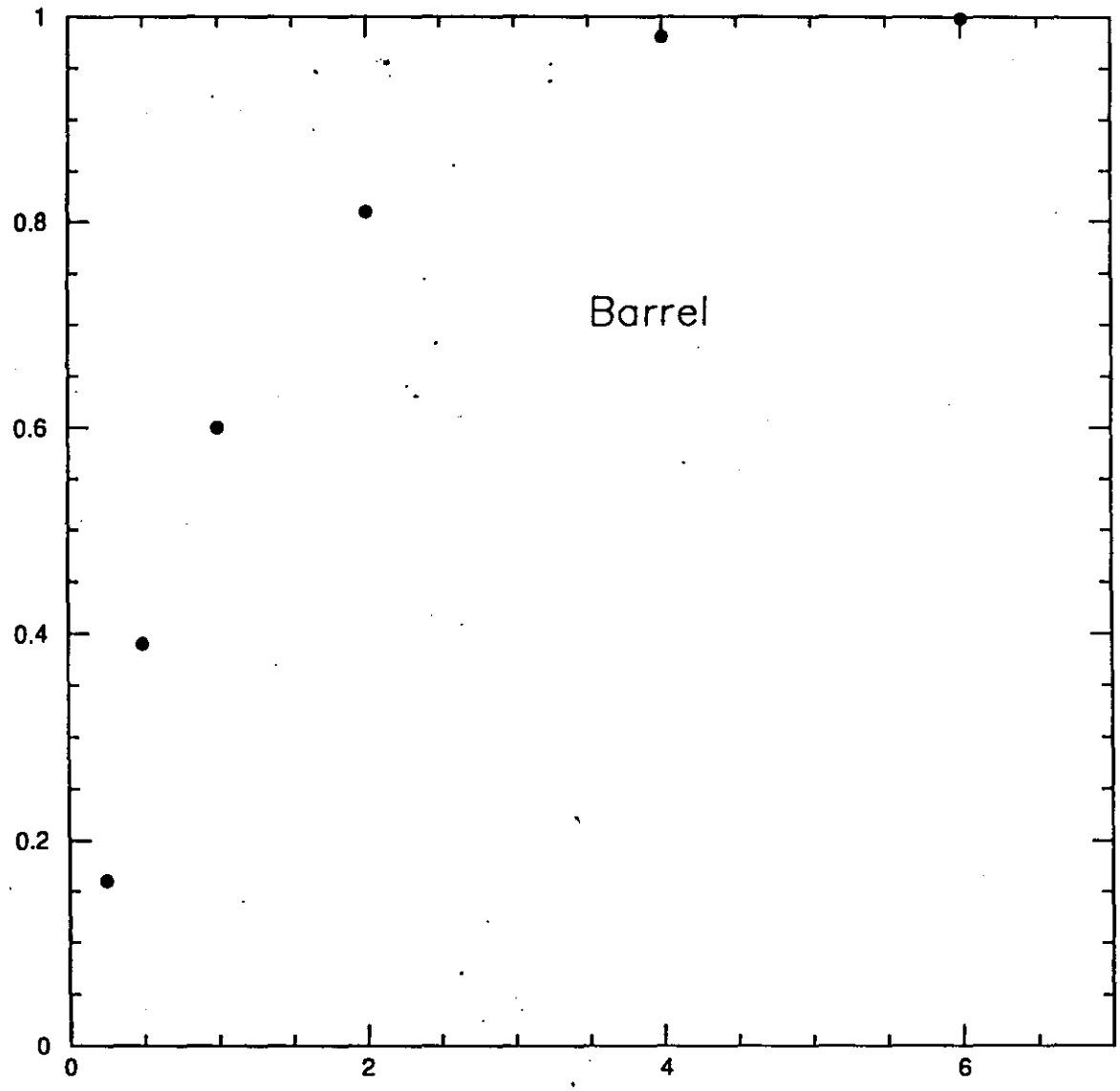
$2^\circ < \varphi < 6.5^\circ$



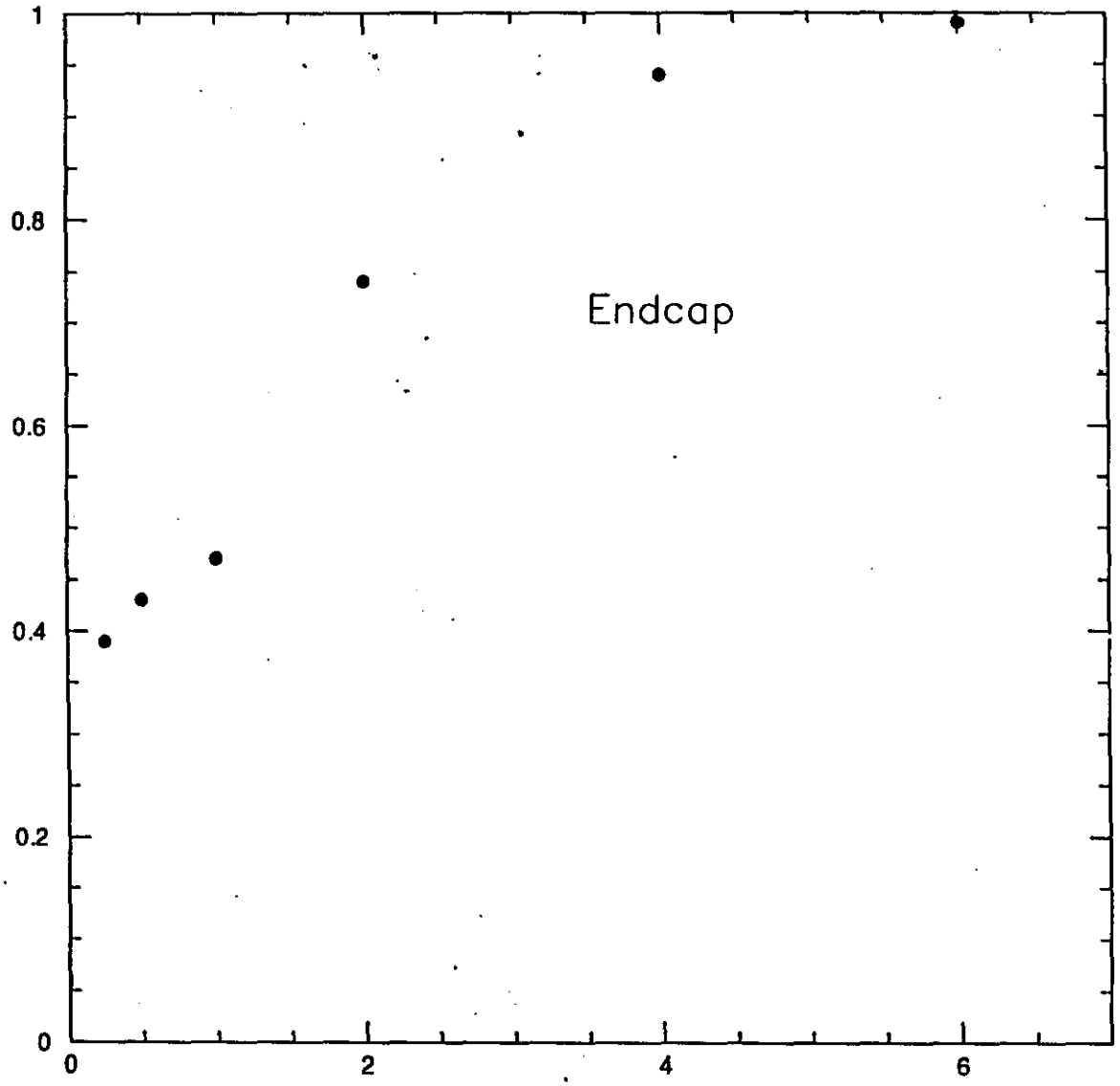
$\frac{dY_p}{Y_p}$ $P_T = 100$ GeV $2° < \varphi < 5.5°$

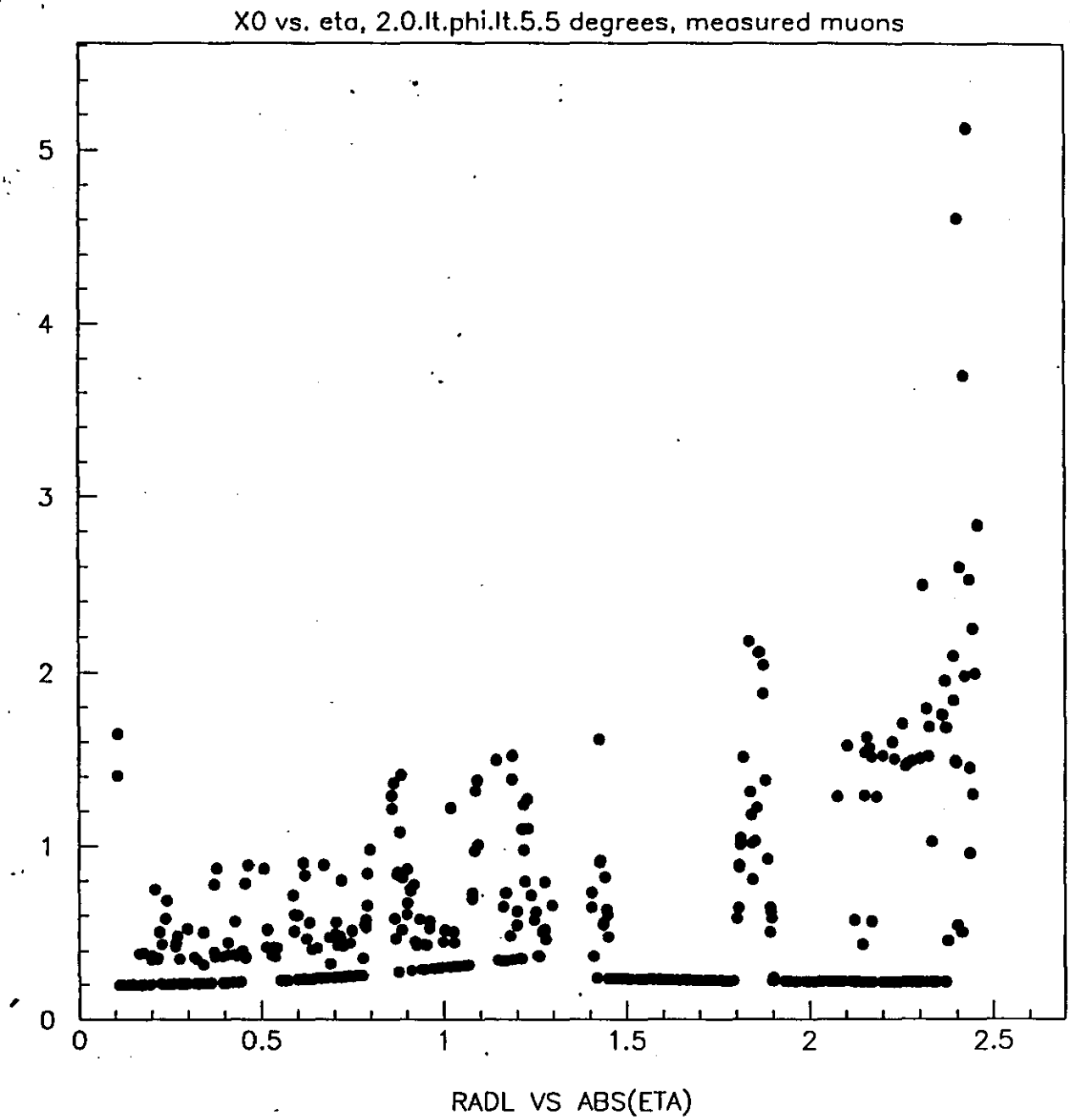


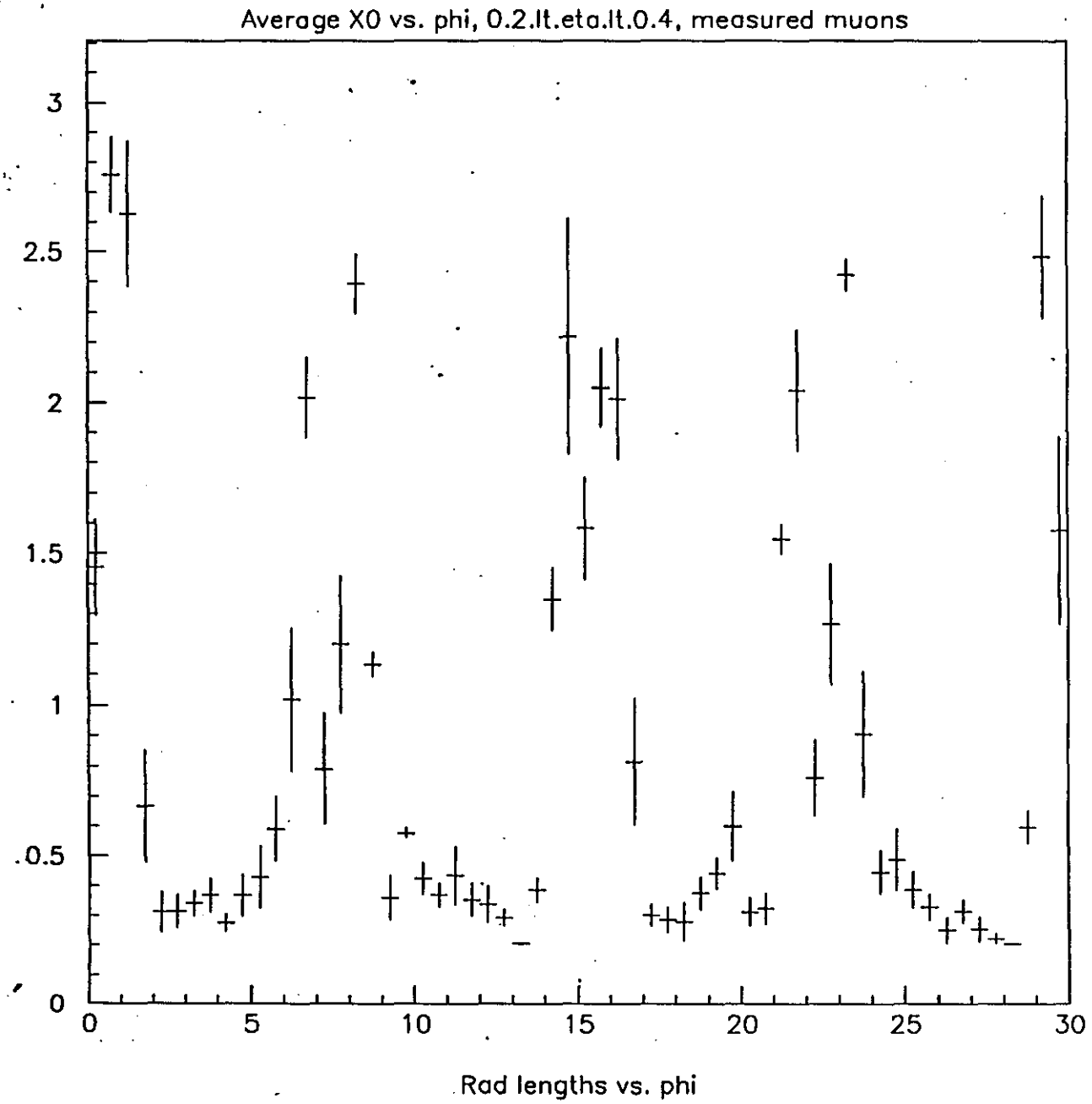
Fraction of muon system with less than RADCUT X0, vs. RADCUT



Fraction of muon system with less than RADCUT X0, vs. RADCUT




X0 vs. eta, 2.0.lt.phi.lt.5.5 degrees, measured muons
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
RADL VS ABS(ETA)


Average X0 vs. phi, 0.2.lt.eta.lt.0.4, measured muons
3
2.5
2
1.5
1
.0.5
0
0
5
10
15
20
25
30
Rad lengths vs. phi

FULL MUON RECO

COMPLETE μ RECO FROM (x, y, z) HITS WORKING.

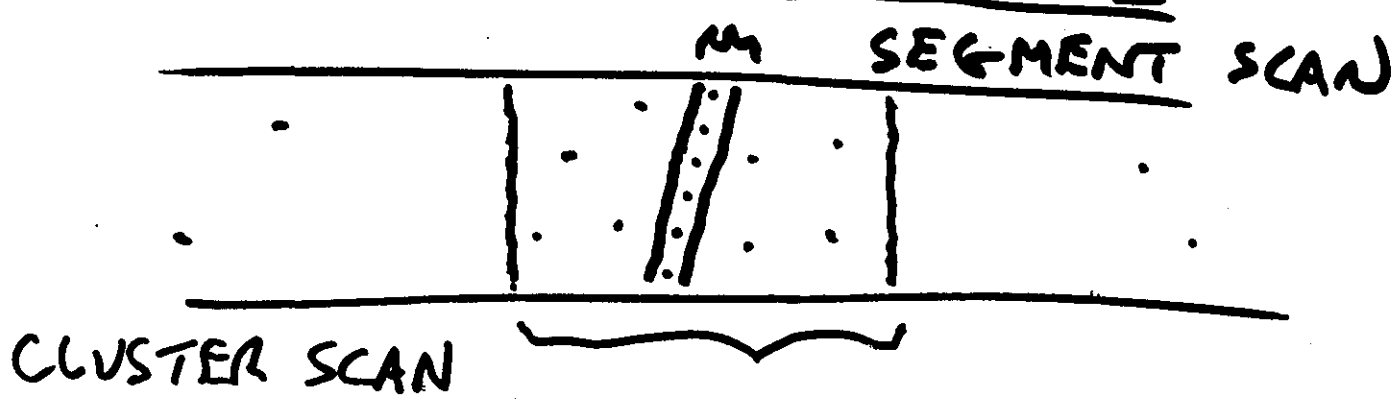
PROCEDURE:

1) FIND HIT CLUSTERS IN EACH SL
2) IN EACH CLUSTER, LOOK AT HIT-TO-HIT SLOPES: HISTOGRAM & LOOK FOR PEAKS

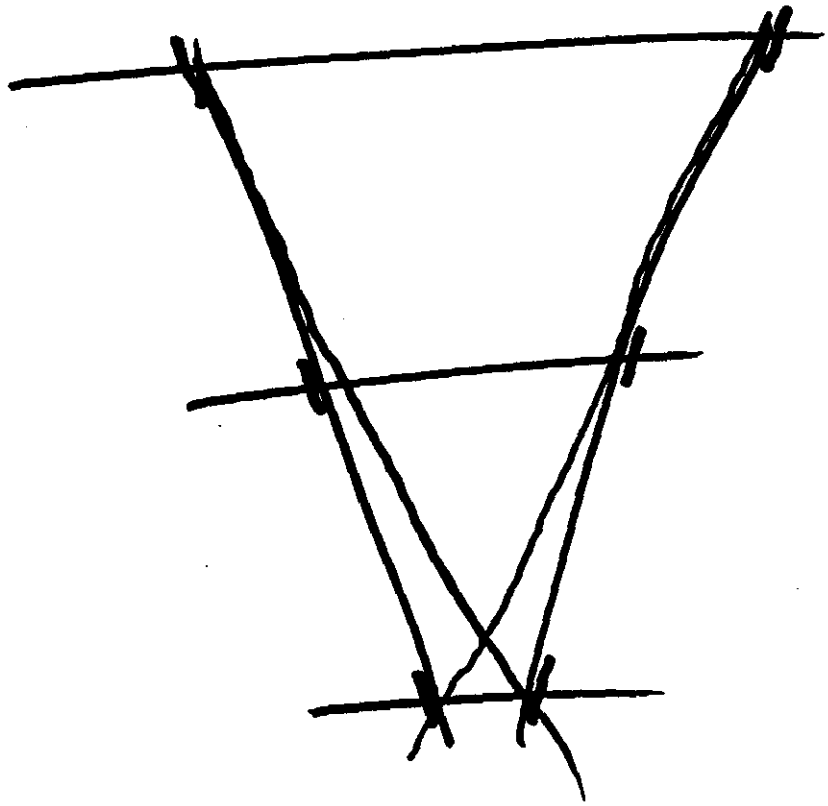
   $\Longrightarrow$ OBTAIN PROSPECTIVE SEGMENT SLOPES

3) RESCAN HITS WITH NARROW, ANGLED WINDOW AT PREFERRED SLOPE

   $\Longrightarrow$ FIND TRACK SEGMENTS



4) GO THROUGH COMBINATORICS OF SEGMENT MATCHING



- SL SEGMENTS PROVIDE CENTROID + LOCAL SLOPE
- CALCULATE HELIX FROM CENTROIDS AND APPLY χ^2 CUT ON COMPARISON OF LOCAL + HELIX SLOPES AT EACH SL

$\Rightarrow$ OBTAIN GOOD μ CANDIDATES

5) USE GEANE AND SEGMENT CENTROIDS + SLOPES W/ERRORS TO FIT MOMENTUM

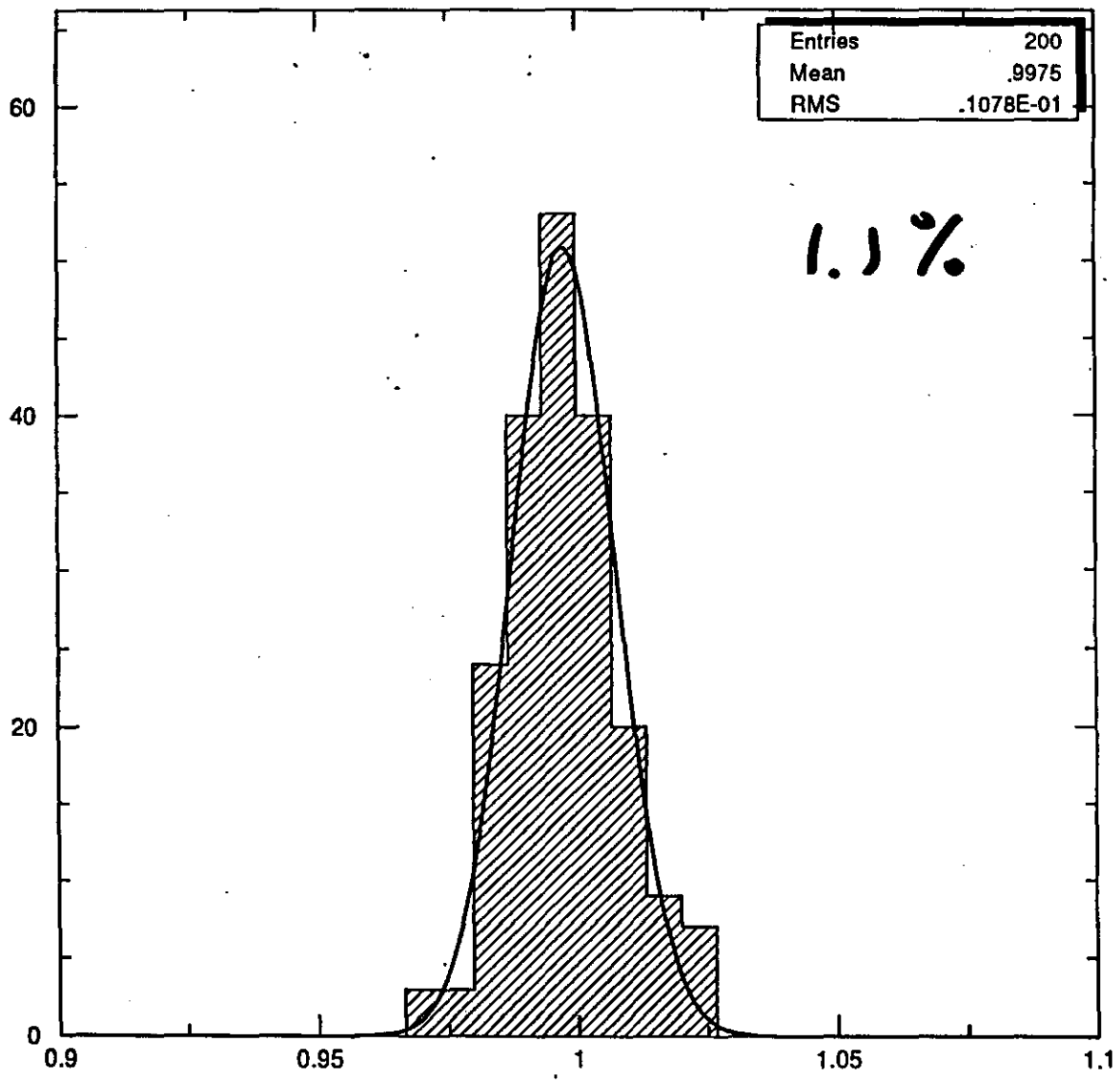
- ONE GEANE PREDICTION PLANE AT EACH SL
  - TRACK FROM SL1 → SL3
  - UPDATE PARAMS
  - RETRACK; CONVERGES IN 3 ITERS.

⇒ RESULT IS FITTED TRACK PARAMS AT SL1.

CAN THEN BACKTRACK THROUGH CALO, ACCUMULATE E LOSS, MATCH TO CT.

BAR p_T 100 GeV
$\theta = 75°$ $\varphi = 3°$

Reconstructed momentum/True momentum

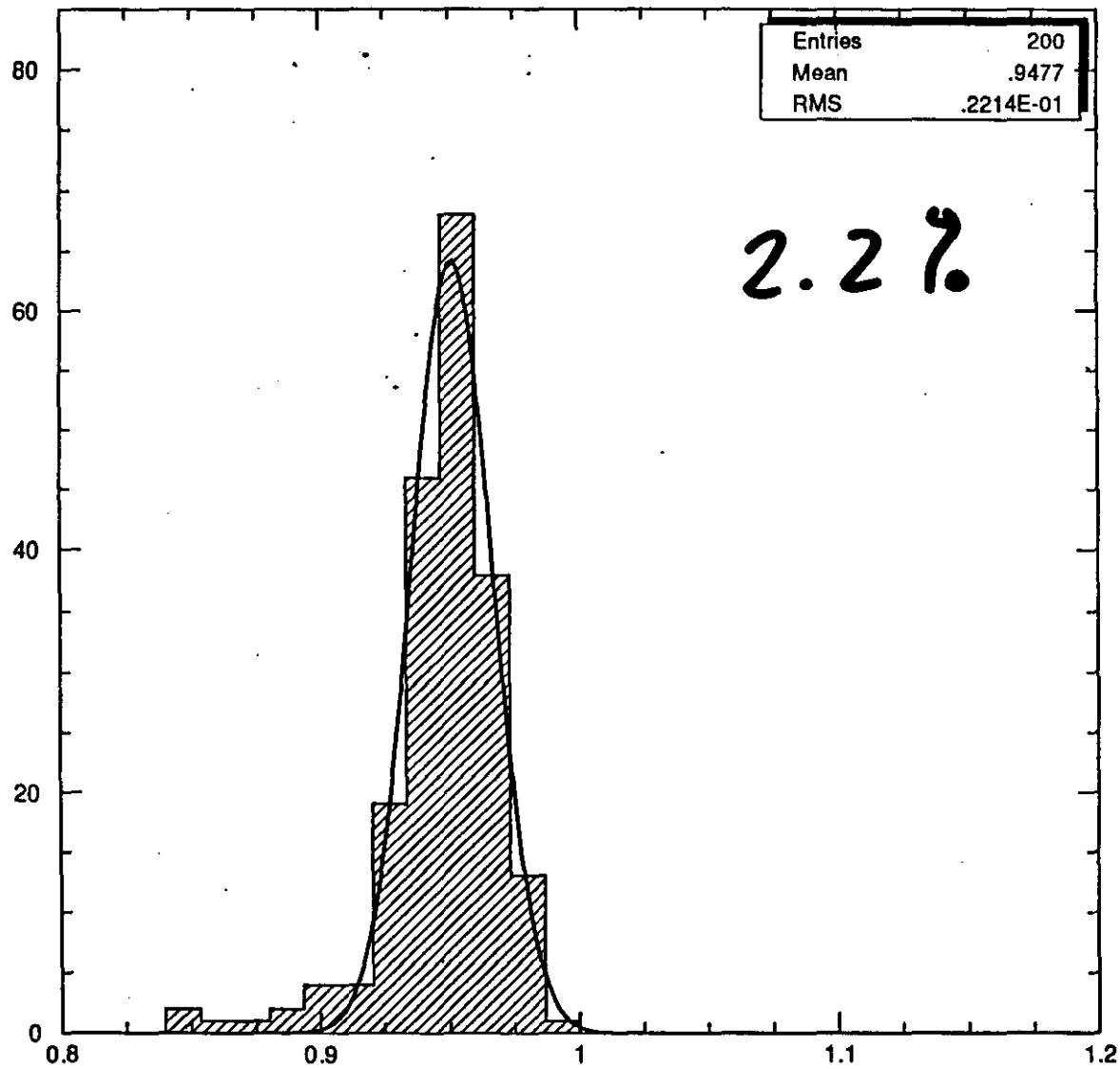


CALO IN

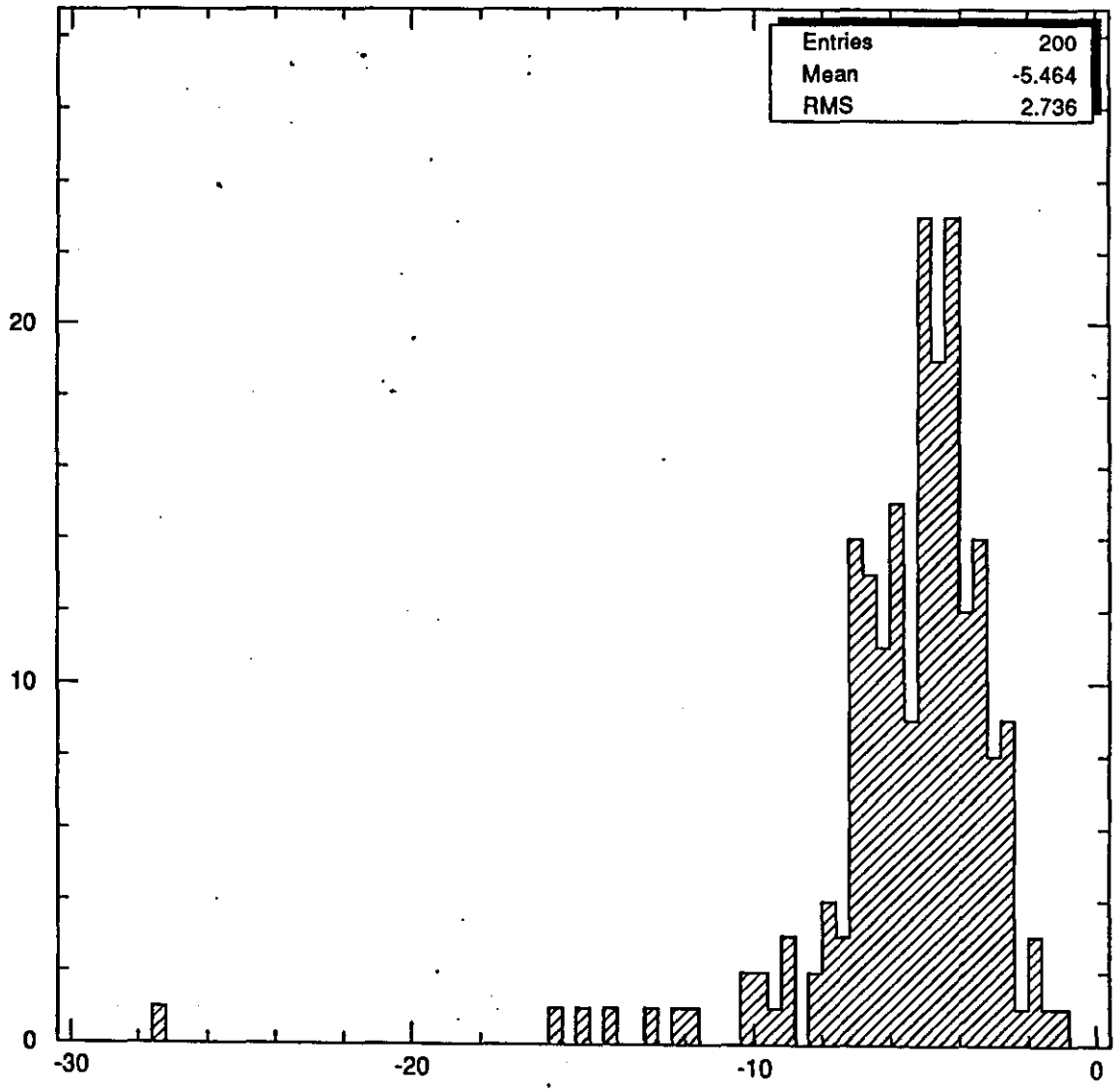
$P_T = 100$ GeV

$\theta = 75°$ $\varphi = 3°$

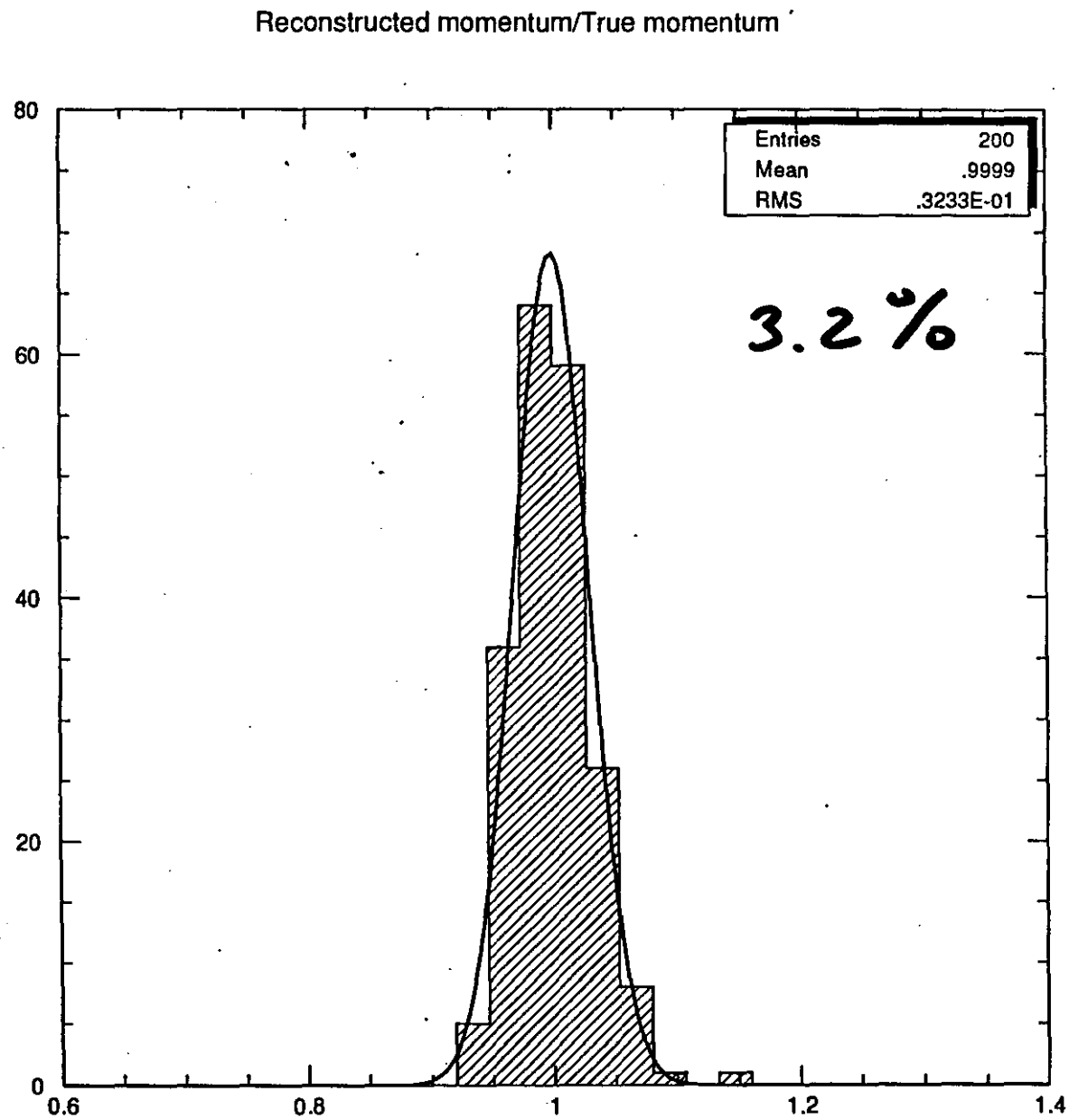
Reconstructed momentum/True momentum



Reco mom - True mom



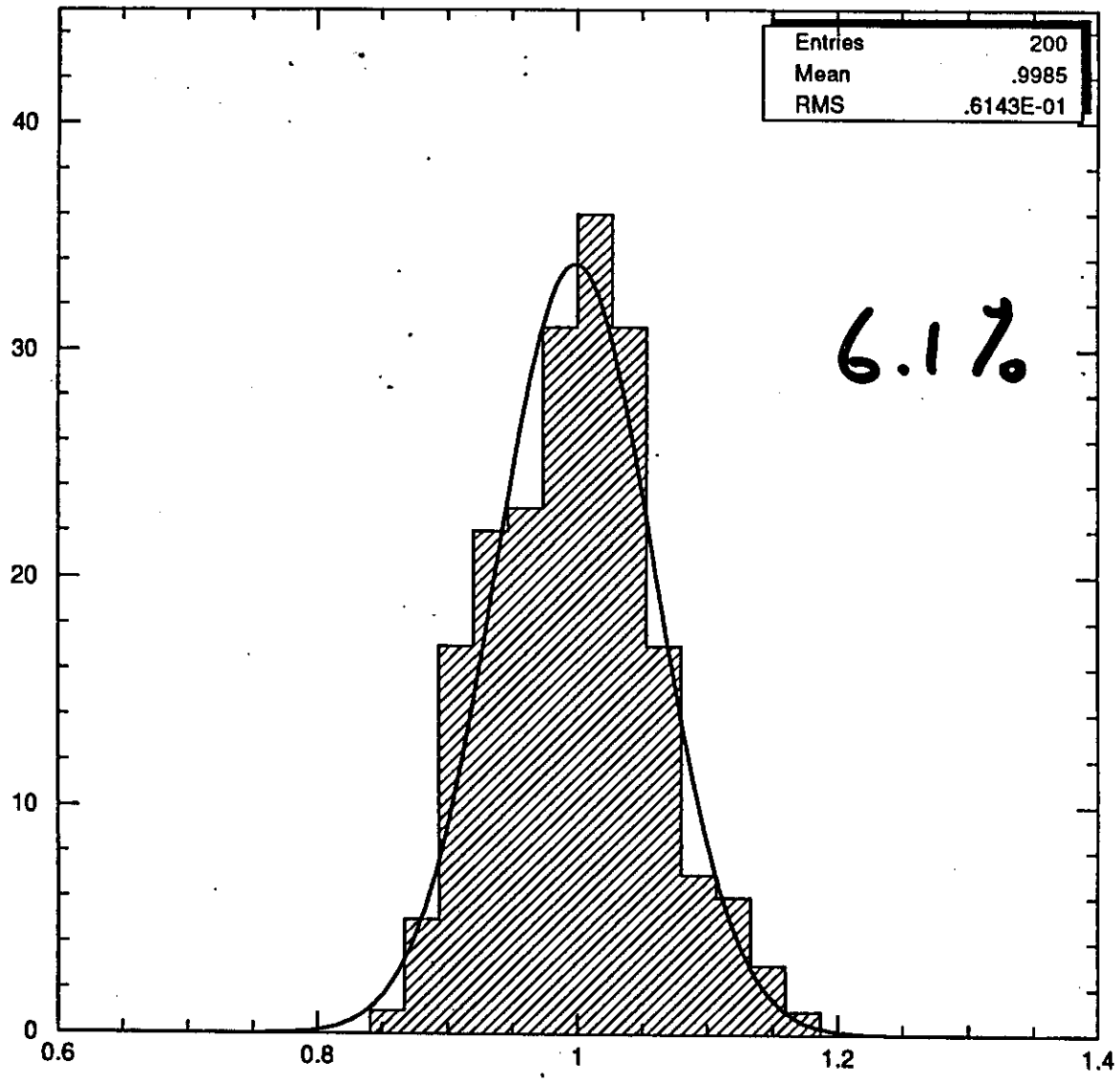
BAR $p_T = 500$ GeV
$\theta = 75°$ $\varphi = 3°$



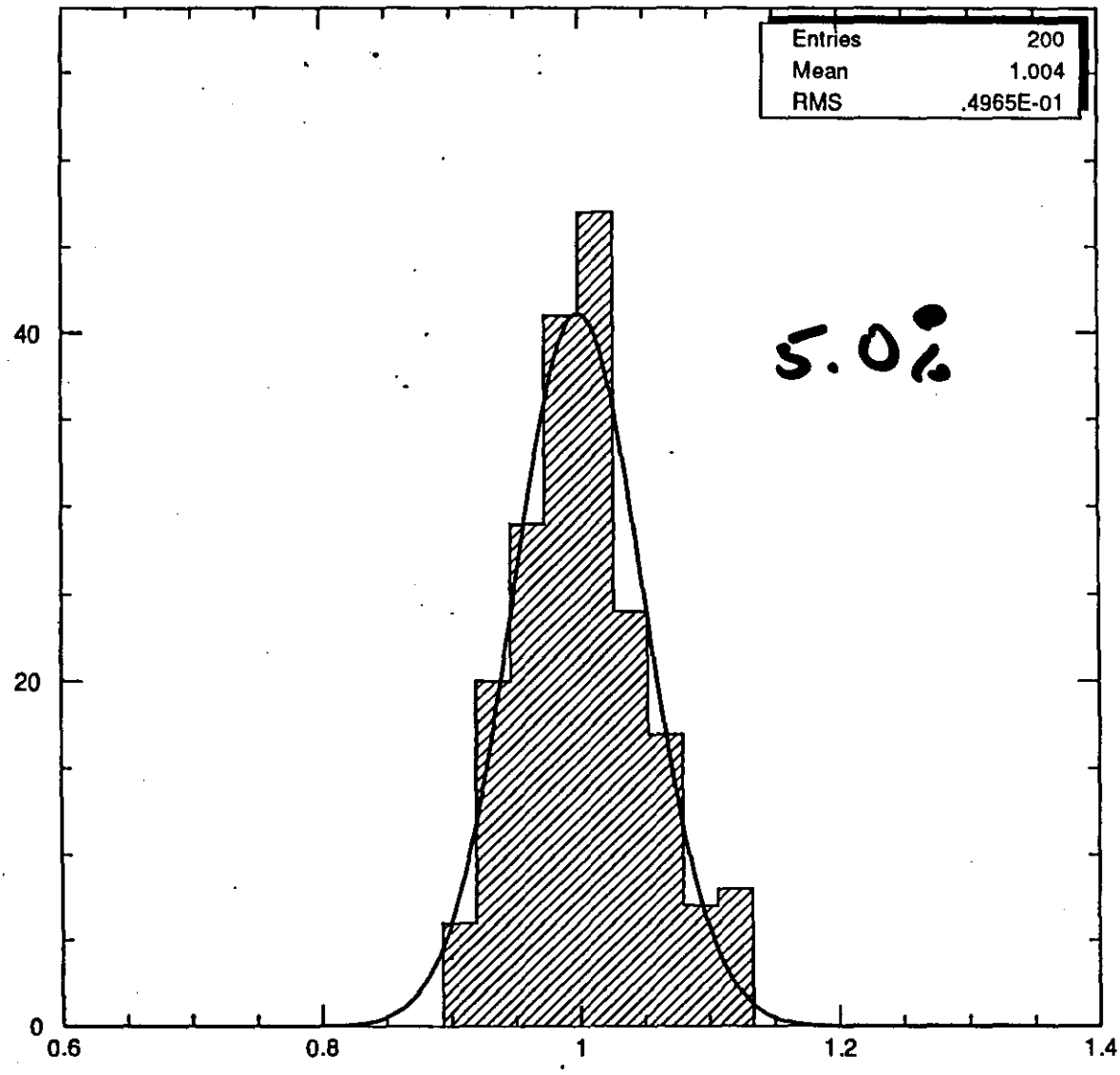
BAR $P_T = 1$ TeV

$\theta = 75°$ $\varphi = 3°$

Reconstructed momentum/True momentum

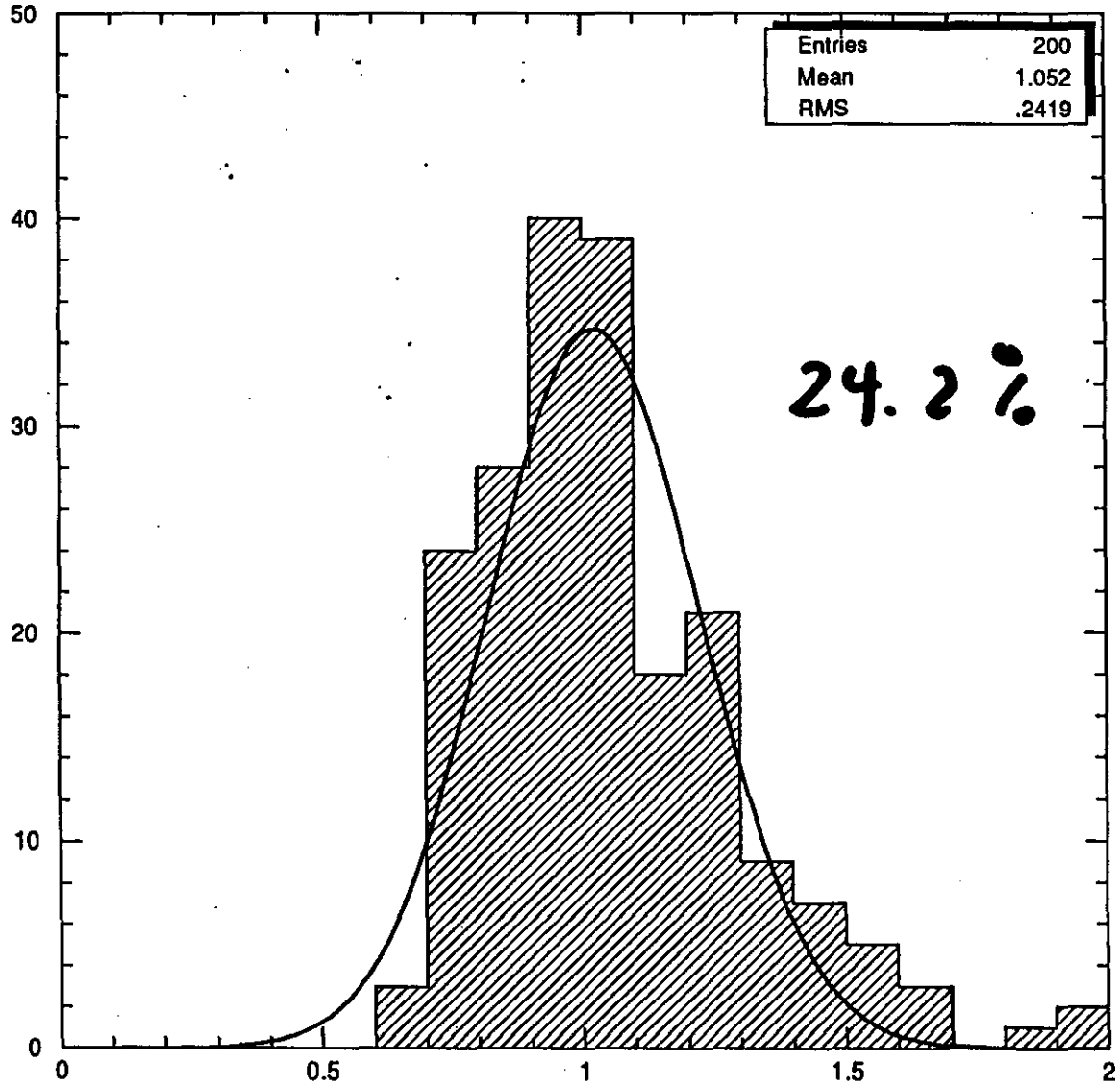


CAP p_T 100 GeV
$\theta = 15°$ $\varphi = 3°$.



CAP $p_T = 500$ GeV

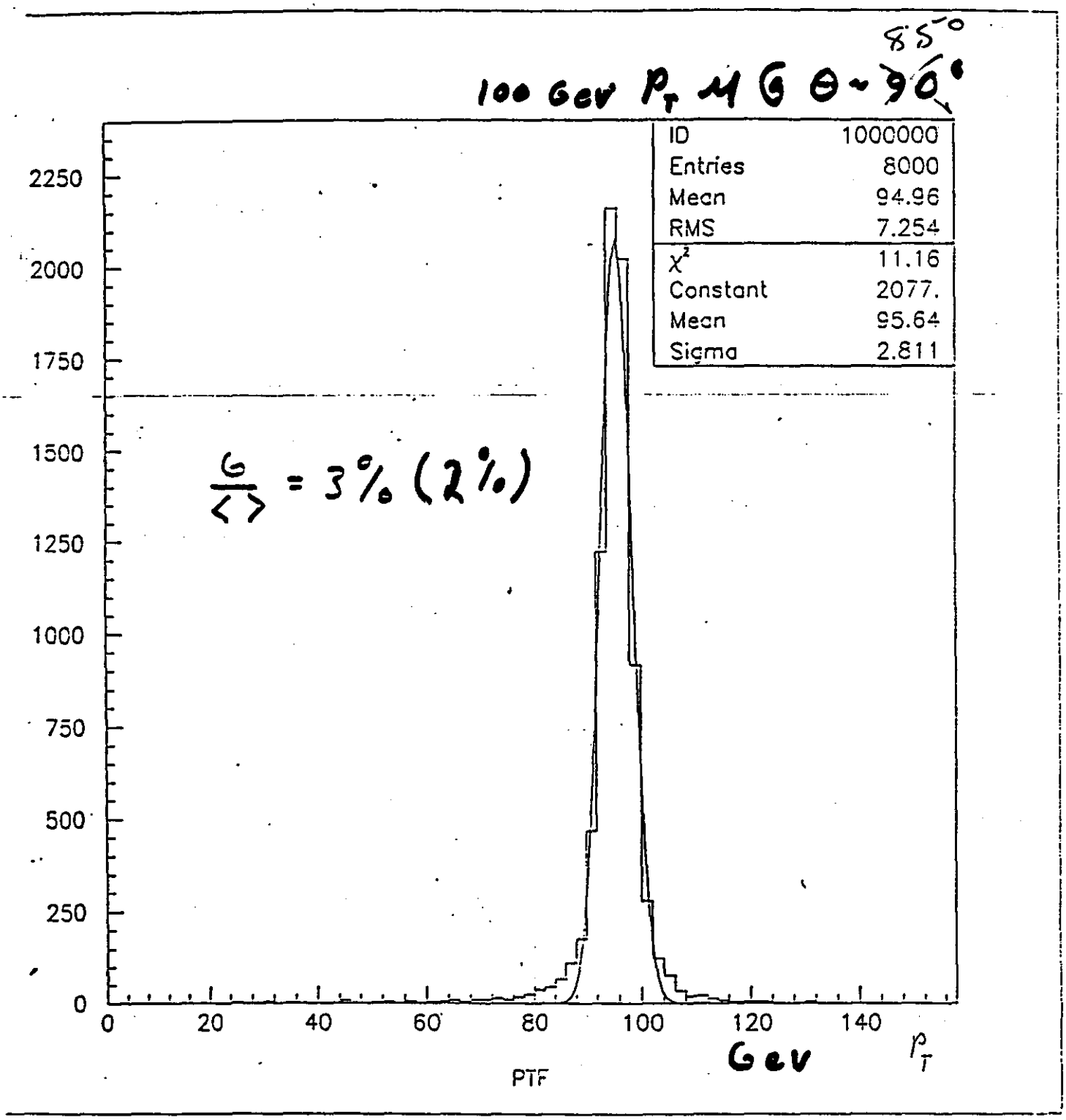
$\theta = 15°$ $\varphi = 3°$



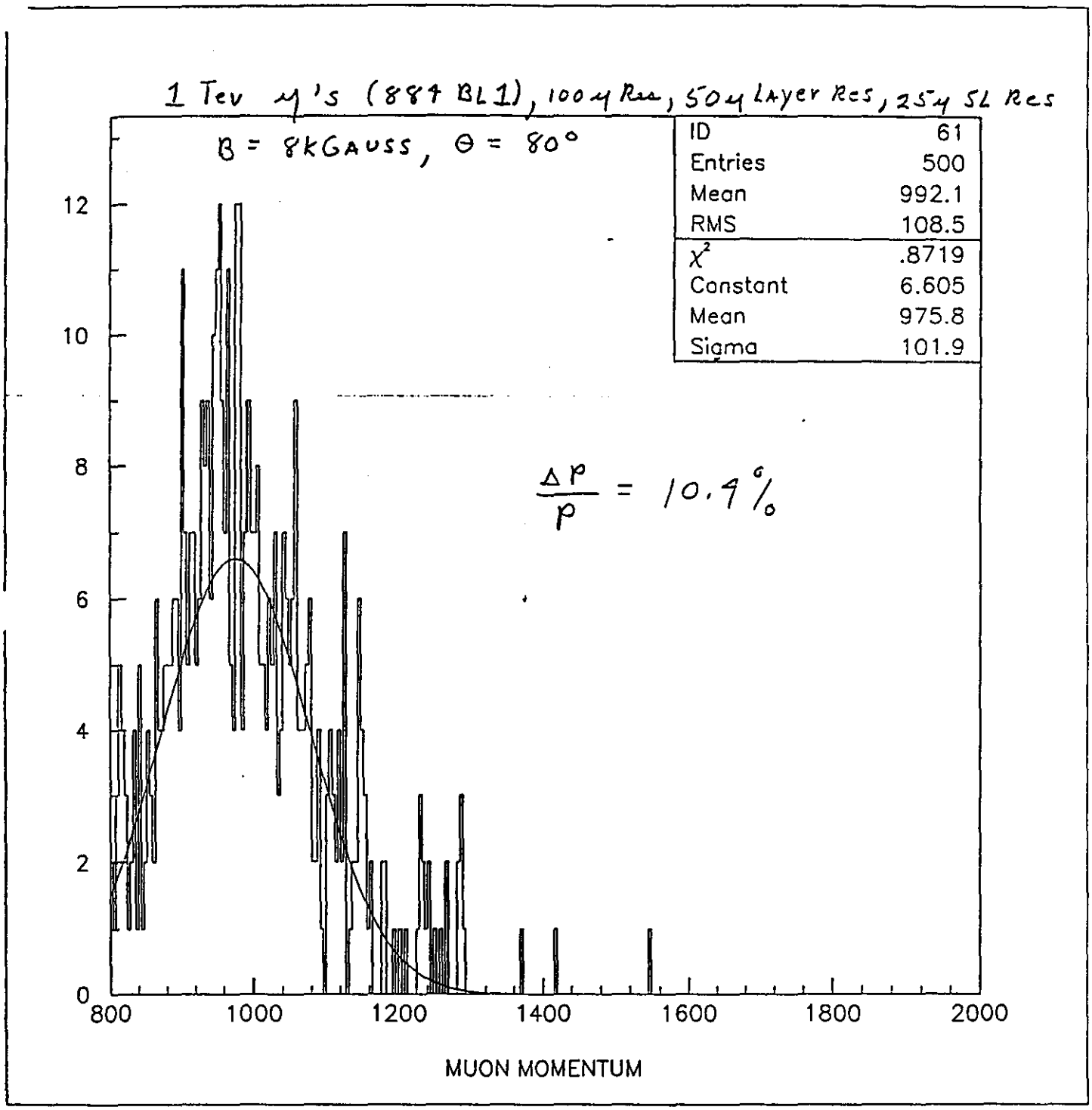
PRIORITIES:

- DEBUG ENDCAP FIT + UNDERSTAND BARREL RES.
- RUN THE RECO ON $H \to 4\mu$ DATA SET
- RUN ON FULL-BACKGROUND SINGLE μ DATASETS + COMPARE $\delta p/p$, RECO EFFICIENCIES w/ EXPECTATIONS
- BACK TRACK TO VERTEX
  - MEASURE RES'N ON VERTEX FOR VERTEX CONSTRAINT
  - COUNT ELOSS IN R=.1 CONE
- TUNE + IMPROVE PATTERN RECOGNITION.

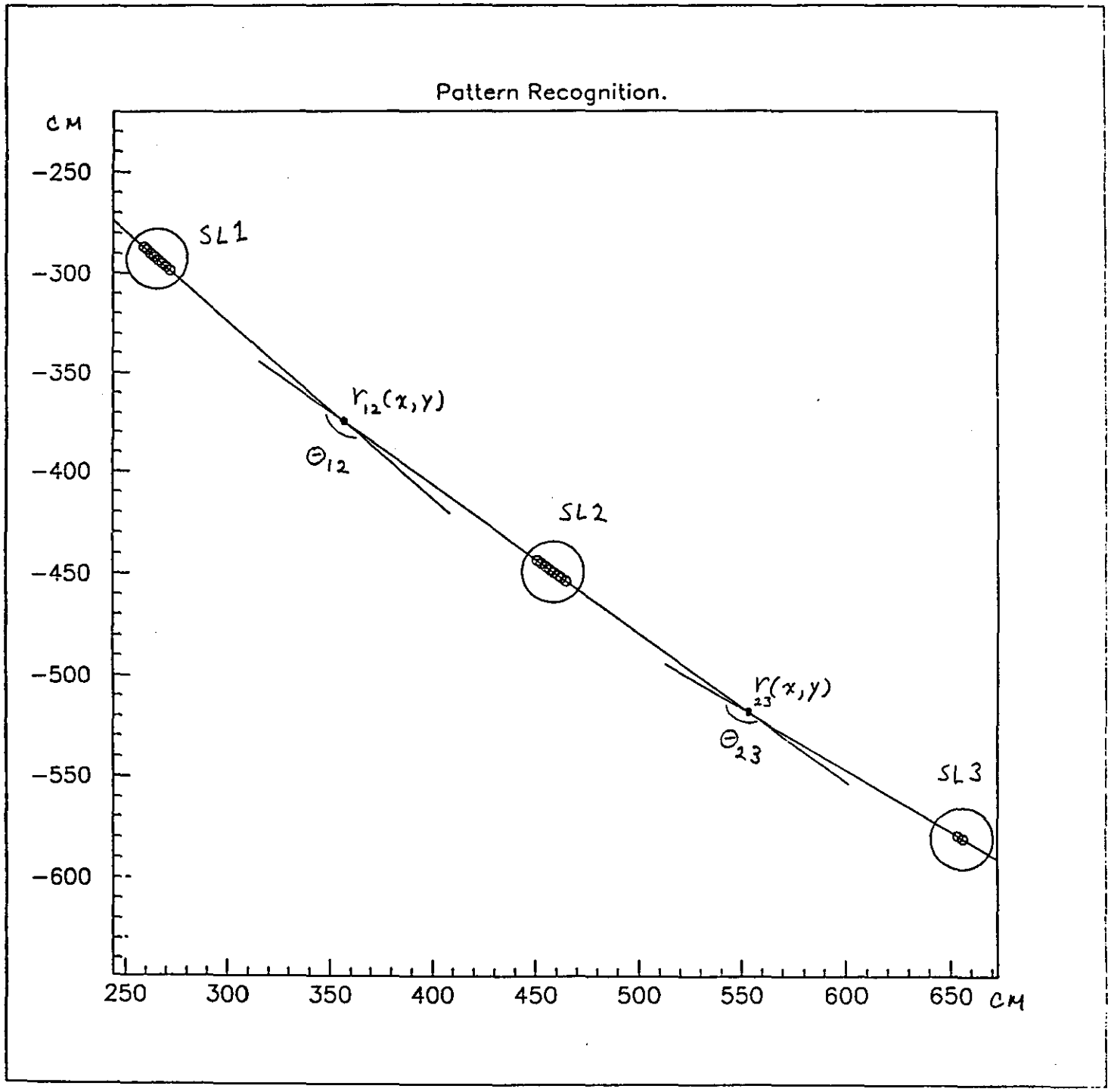
Chin Tu Wu, Peter Dingus
3/26/93

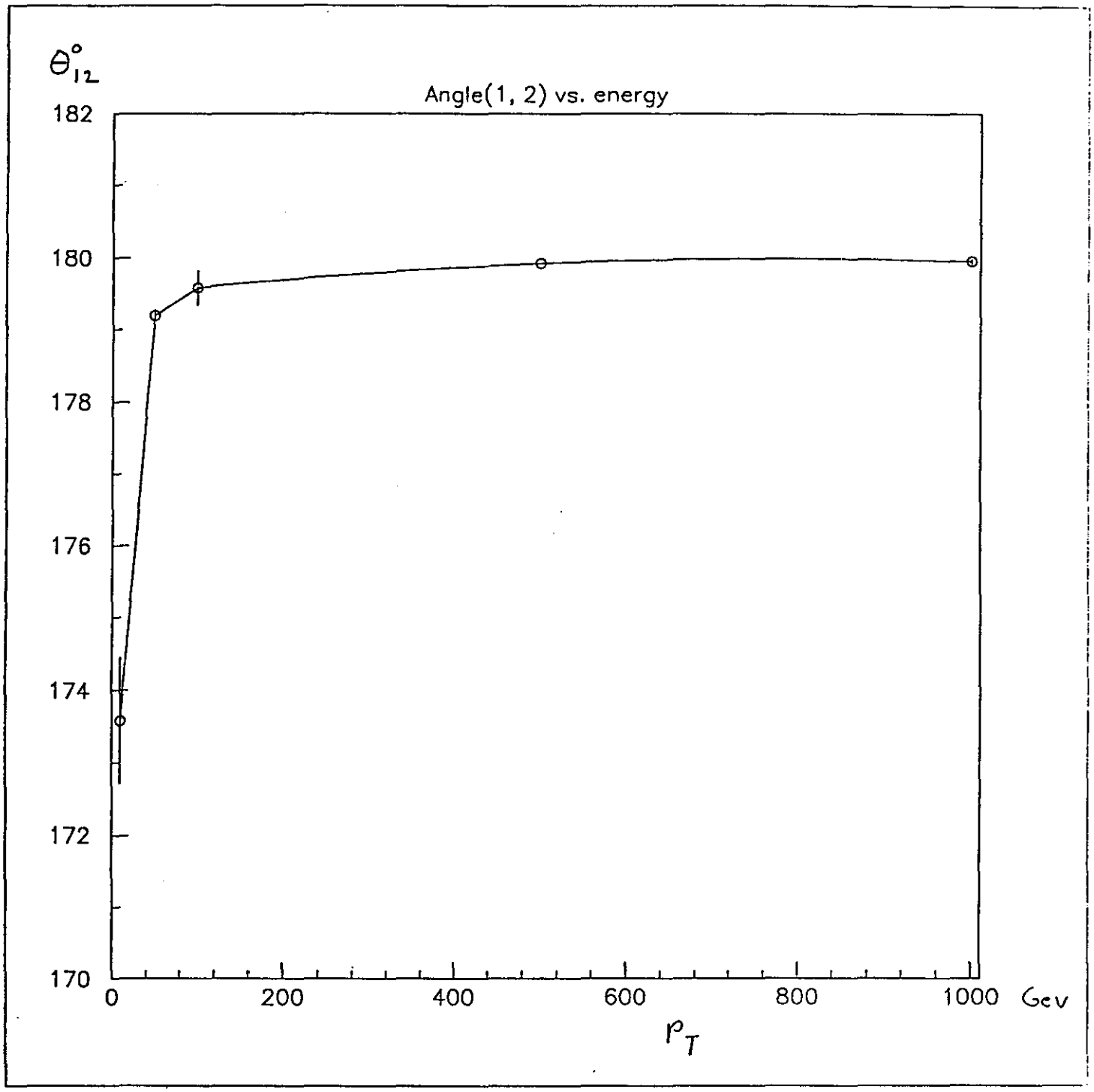


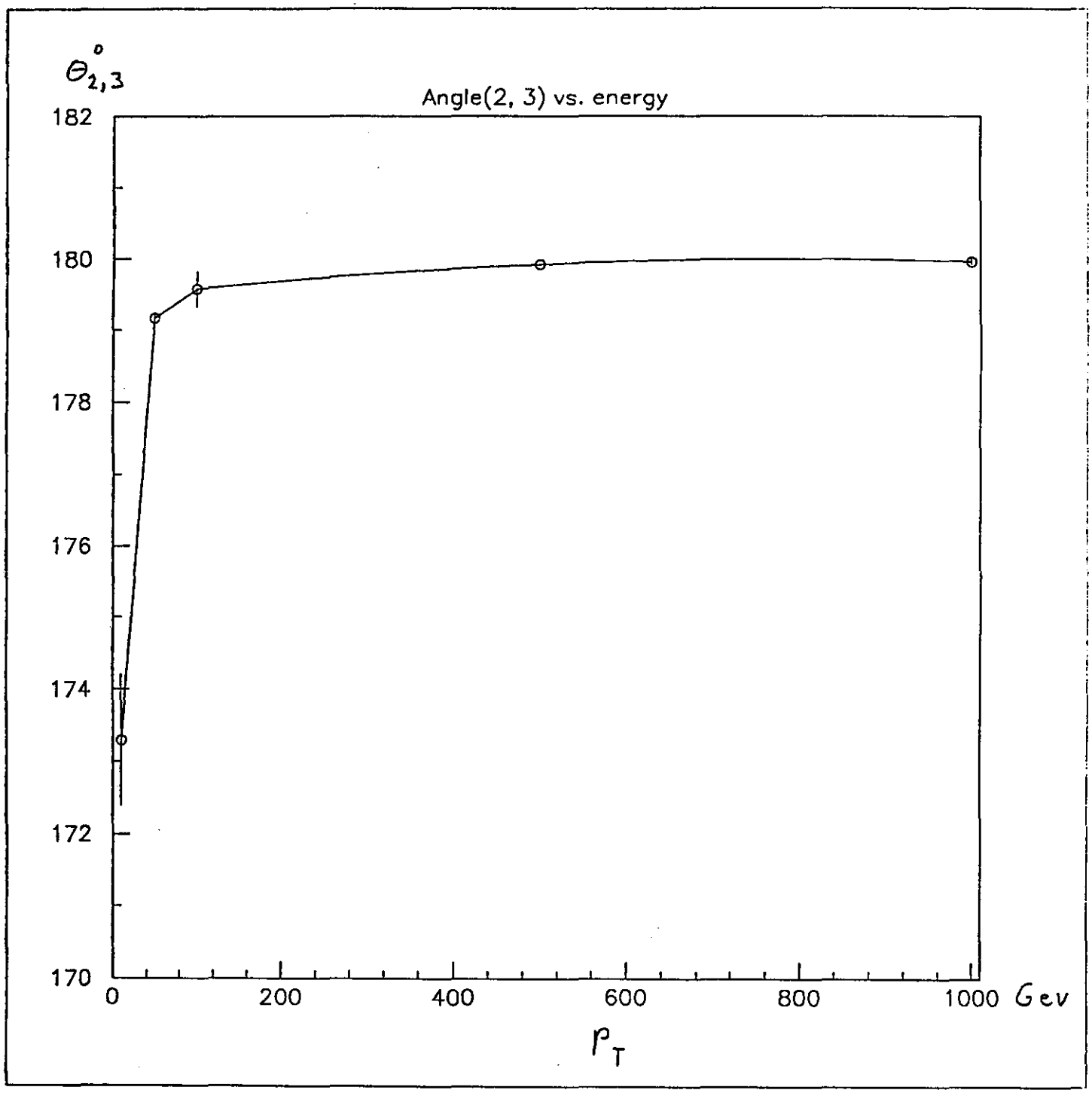
Homogeneous $B\hat{z}$

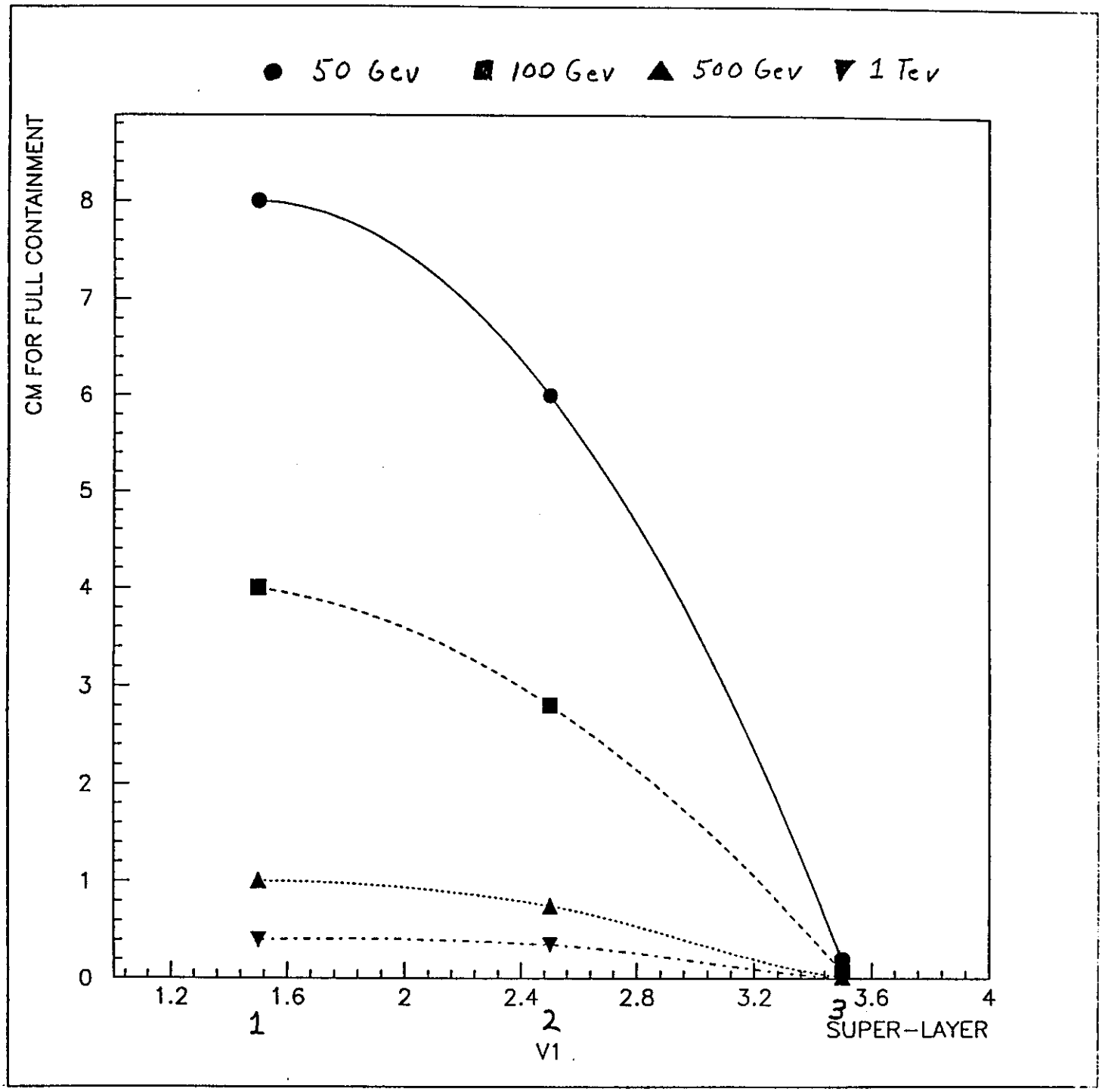


10 Gev μ's (P_T)


Pattern Recognition.
CM
-250
-300
-350
-400
-450
-500
-550
-600
250
300
350
400
450
500
550
600
650
CM
SL1
SL2
SL3
$r_{12}(x,y)$
Θ_{12}
$r_{23}(x,y)$
Θ_{23}


θ°_{12}
Angle(1, 2) vs. energy
182
180
178
176
174
172
170
0
200
400
600
800
1000
Gev
p_T

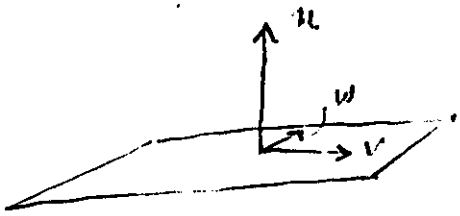

$\theta^{o}_{2,3}$
Angle(2, 3) vs. energy
182
180
178
176
174
172
170
0
200
400
600
800
1000
Gev
P_T



ϕ ROAD BETWEE MUON
HITS ON 3RD SUPERLAYER AND
IP IN RESIDUALS ON ALL
THREE SUPER LAYERS

```
MOMENTUM = 976.4919 — on Plane 4 SL3 (8,8,4) PLANES
CHNAME, CHDETN = MUB1MCD1
NTOT, HITS, NSL =  18 22 18
CHNAME, CHDETN = MUB2MCD2
NTOT, HITS, NSL =  35 18 17
CHNAME, CHDETN = MUB3MCD3
NTOT, HITS, NSL =  44 11 9
fitting starting point  382.6175537109375 5.28866577148438
177.699951171875 1.24999972060322E-03 1.33160019365882E-02
.4643188118934631
starting momentum  800.0000178813938 ← INITIAL GUESS
CONV COR, PLANI(3,JSTOP-1)
    .37423E+03     .79832E+02     .17770E+03
    .37423E+03     .79832E+02     .17770E+03
number of preditions  1
plane  1 reached as  1
position
    .37619E+03     .80248E+02     .17863E+03
    .37619E+03     .80249E+02     .17863E+03
ISEC,ISL,IPL,ICEL =  1 1 2 33 ← Where Are we (Sector, Slayer, Plane, Cell)
CONV COR, PLANI(3,JSTOP-1)
    .37619E+03     .80249E+02     .17863E+03
    .37619E+03     .80249E+02     .17863E+03
number of preditions  1
plane  1 reached as  2
position
    .37864E+03     .80770E+02     .17979E+03
    .37864E+03     .80772E+02     .17979E+03
ISEC,ISL,IPL,ICEL =  1 1 3 33 ←
CONV COR, PLANI(3,JSTOP-1)
    .37864E+03     .80772E+02     .17979E+03
    .37864E+03     .80772E+02     .17979E+03
number of preditions  1
plane  1 reached as  3
position
    .38157E+03     .81398E+02     .18118E+03
    .38157E+03     .81398E+02     .18118E+03
ISEC,ISL,IPL,ICEL =  1 1 4 34 ←
CONV COR, PLANI(3,JSTOP-1)
    .38157E+03     .81398E+02     .18118E+03
    .38157E+03     .81398E+02     .18118E+03
number of preditions  1
plane  1 reached as  4
position
    .38353E+03     .81816E+02     .18211E+03
    .38353E+03     .81816E+02     .18211E+03
ISEC,ISL,IPL,ICEL =  1 1 5 34 ←
CONV COR, PLANI(3,JSTOP-1)
    .38353E+03     .81816E+02     .18211E+03
    .38353E+03     .81816E+02     .18211E+03
number of preditions  1
plane  1 reached as  5
position
    .38646E+03     .82442E+02     .18350E+03
    .38646E+03     .82442E+02     .18350E+03
ISEC,ISL,IPL,ICEL =  1 1 6 34 ←
CONV COR, PLANI(3,JSTOP-1)
    .38646E+03     .82442E+02     .18350E+03
    .38646E+03     .82442E+02     .18350E+03
number of preditions  1
plane  1 reached as  6
position
    .38890E+03     .82964E+02     .18466E+03
    .38891E+03     .82964E+02     .18466E+03
ISEC,ISL,IPL,ICEL =  1 1 7 34 ←
CONV COR, PLANI(3,JSTOP-1)
```

GEANE RUN FOR 1 TEV μ @ θ=8°, FOR GEM BASELINE L



$1/p$
du/dw ← TRACK PARAMETERS
dv/dw
v
w

IMPLEMENTATION OF KALMAN FILTER USING GEANE.

```
    .38890E+03      .82964E+02      .18466E+03
    .38891E+03      .82964E+02      .18466E+03
number of preditions  1
plane  1 reached as  7
position
    .39135E+03      .83486E+02      .18582E+03
    .39135E+03      .83487E+02      .18582E+03
ISEC,ISL,IPL,ICEL =  1 1 8 35
CONV COR, PLANI(3,JSTOP-1)
    .39135E+03      .83486E+02      .18582E+03
    .39135E+03      .83487E+02      .18582E+03
number of preditions  1
plane  1 reached as  8
position
    .60752E+03      .12955E+03      .28843E+03
    .60749E+03      .12971E+03      .28844E+03
ISEC,ISL,IPL,ICEL =  1 2 1 53
CONV COR, PLANI(3,JSTOP-1)
    .60748E+03      .12971E+03      .28844E+03
    .60749E+03      .12971E+03      .28844E+03
number of preditions  1
plane  1 reached as  9
position
    .60991E+03      .13023E+03      .28959E+03
    .60991E+03      .13023E+03      .28959E+03
ISEC,ISL,IPL,ICEL =  1 2 2 54
CONV COR, PLANI(3,JSTOP-1)
    .60991E+03      .13023E+03      .28959E+03
    .60991E+03      .13023E+03      .28959E+03
number of preditions  1
plane  1 reached as  10
position
    .61286E+03      .13086E+03      .29099E+03
    .61286E+03      .13086E+03      .29099E+03
ISEC,ISL,IPL,ICEL =  1 2 3 54
CONV COR, PLANI(3,JSTOP-1)
    .61286E+03      .13086E+03      .29099E+03
    .61286E+03      .13086E+03      .29099E+03
number of preditions  1
plane  1 reached as  11
position
    .61531E+03      .13138E+03      .29215E+03
    .61531E+03      .13139E+03      .29215E+03
ISEC,ISL,IPL,ICEL =  1 2 4 54
CONV COR, PLANI(3,JSTOP-1)
    .61531E+03      .13139E+03      .29215E+03
    .61531E+03      .13139E+03      .29215E+03
number of preditions  1
plane  1 reached as  12
position
    .61726E+03      .13180E+03      .29308E+03
    .61726E+03      .13181E+03      .29308E+03
ISEC,ISL,IPL,ICEL =  1 2 5 54
CONV COR, PLANI(3,JSTOP-1)
    .61726E+03      .13180E+03      .29308E+03
    .61726E+03      .13181E+03      .29308E+03
number of preditions  1
plane  1 reached as  13
position
    .62020E+03      .13243E+03      .29447E+03
    .62020E+03      .13244E+03      .29447E+03
ISEC,ISL,IPL,ICEL =  1 2 6 55
CONV COR, PLANI(3,JSTOP-1)
    .62020E+03      .13243E+03      .29447E+03
    .62020E+03      .13244E+03      .29447E+03
number of preditions  1
```

```
plane  1 reached as  14
position
    .62264E+03      .13295E+03      .29564E+03
    .62264E+03      .13296E+03      .29564E+03
ISEC,ISL,IPL,ICEL =  1 2 7 55
CONV COR, PLANI(3,JSTOP-1)
    .62264E+03      .13296E+03      .29564E+03
    .62264E+03      .13296E+03      .29564E+03
number of preditions  1
plane  1 reached as  15
position
    .62509E+03      .13348E+03      .29680E+03
    .62509E+03      .13348E+03      .29680E+03
ISEC,ISL,IPL,ICEL =  1 2 8 55
CONV COR, PLANI(3,JSTOP-1)
    .62509E+03      .13348E+03      .29680E+03
    .62509E+03      .13348E+03      .29680E+03
number of preditions  1
plane  1 reached as  16
position
    .84664E+03      .18074E+03      .40197E+03
    .84659E+03      .18101E+03      .40197E+03
ISEC,ISL,IPL,ICEL =  1 3 1 74
CONV COR, PLANI(3,JSTOP-1)
    .84659E+03      .18101E+03      .40197E+03
    .84659E+03      .18101E+03      .40197E+03
number of preditions  1
plane  1 reached as  17
position
    .84903E+03      .18153E+03      .40313E+03
    .84903E+03      .18154E+03      .40313E+03
ISEC,ISL,IPL,ICEL =  1 3 2 75
CONV COR, PLANI(3,JSTOP-1)
    .84903E+03      .18154E+03      .40313E+03
    .84903E+03      .18154E+03      .40313E+03
number of preditions  1
plane  1 reached as  18
position
    .85099E+03      .18196E+03      .40406E+03
    .85099E+03      .18196E+03      .40406E+03
ISEC,ISL,IPL,ICEL =  1 3 3 75
CONV COR, PLANI(3,JSTOP-1)
    .85099E+03      .18196E+03      .40406E+03
    .85099E+03      .18196E+03      .40406E+03
number of preditions  1
plane  1 reached as  19
position
    .85392E+03      .18259E+03      .40545E+03
    .85392E+03      .18259E+03      .40546E+03
ISEC,ISL,IPL,ICEL =  1 3 4 75
 chi2s  1 3.26757421873052 48.64970878528408 48.61300392378507
3.670486149901313E-02
CONV COR, PLANI(3,JSTOP-1)
    .37423E+03      .79831E+02      .17770E+03
    .37423E+03      .79832E+02      .17770E+03
number of preditions  1
plane  1 reached as  1
position
    .37619E+03      .80249E+02      .17863E+03
    .37619E+03      .80249E+02      .17863E+03
ISEC,ISL,IPL,ICEL =  1 1 2 33
CONV COR, PLANI(3,JSTOP-1)
    .37619E+03      .80249E+02      .17863E+03
    .37619E+03      .80249E+02      .17863E+03
number of preditions  1
plane  1 reached as  2
```

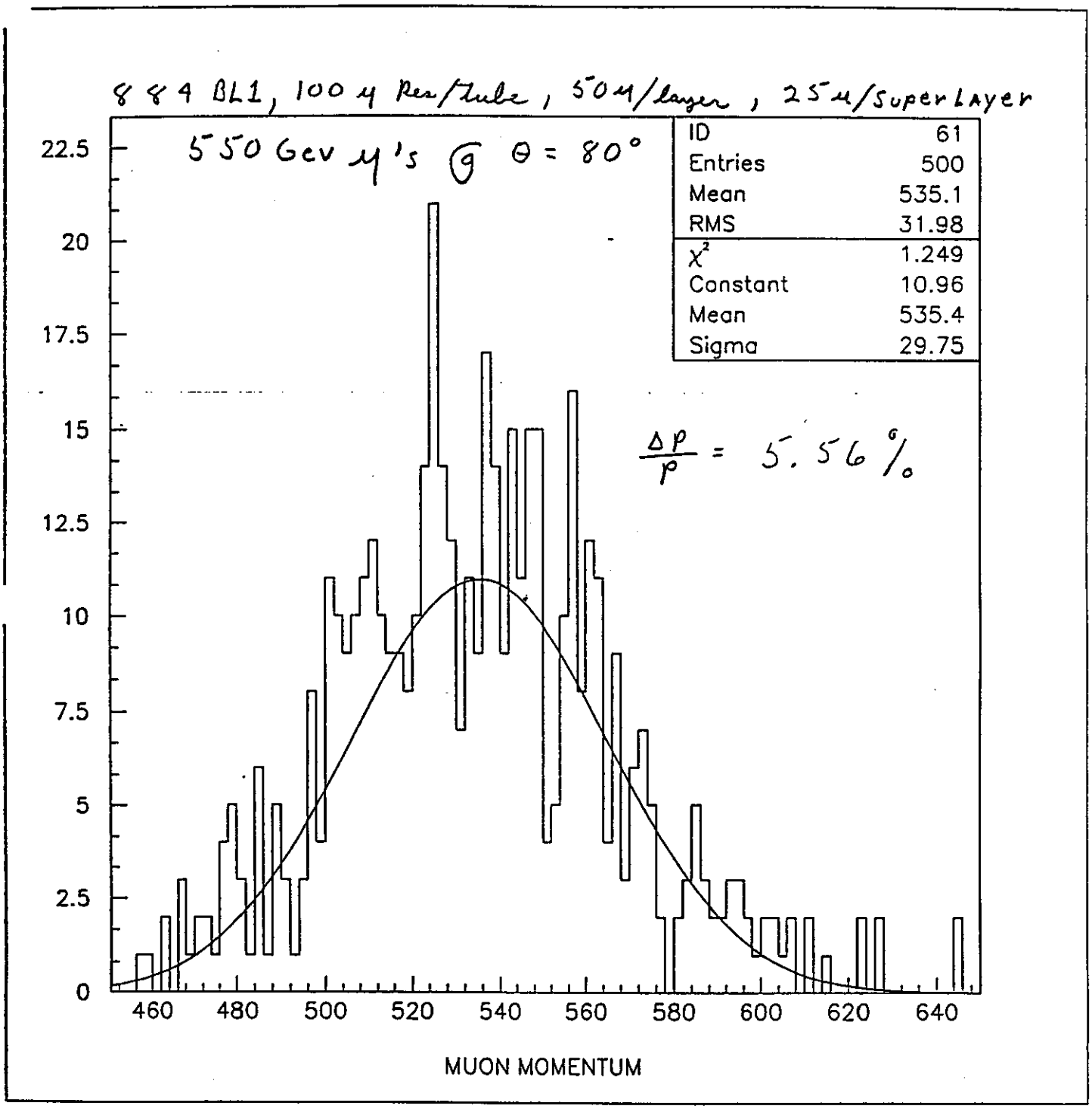
```
    .84659E+03      .18101E+03      .40197E+03
number of preditions  1
plane  1 reached as  17
position
    .84903E+03      .18154E+03      .40313E+03
    .84903E+03      .18154E+03      .40313E+03
ISEC,ISL,IPL,ICEL =  1 3 2 75
CONV COR, PLANI(3,JSTOP-1)
    .84903E+03      .18154E+03      .40313E+03
    .84903E+03      .18154E+03      .40313E+03
number of preditions  1
plane  1 reached as  18
position
    .85099E+03      .18196E+03      .40406E+03
    .85099E+03      .18196E+03      .40406E+03
ISEC,ISL,IPL,ICEL =  1 3 3 75
CONV COR, PLANI(3,JSTOP-1)
    .85099E+03      .18196E+03      .40406E+03
    .85099E+03      .18196E+03      .40406E+03
number of preditions  1
plane  1 reached as  19
position
    .85392E+03      .18259E+03      .40545E+03
    .85392E+03      .18259E+03      .40546E+03
ISEC,ISL,IPL,ICEL =  1 3 4 75
 chi2s  2 9.244597170405058E-03 3.543555751199705E-02
2.703868089453331E-02 8.396876617463728E-03
fitpoint  382.6175537109375 5.28825643706959 177.6994034117325
-1.027326690036595E-03 1.400517896224531E-02 .4643140320899077
fit momentum  -973.400194600588
```

$.3\% = \frac{\Delta P}{P}$

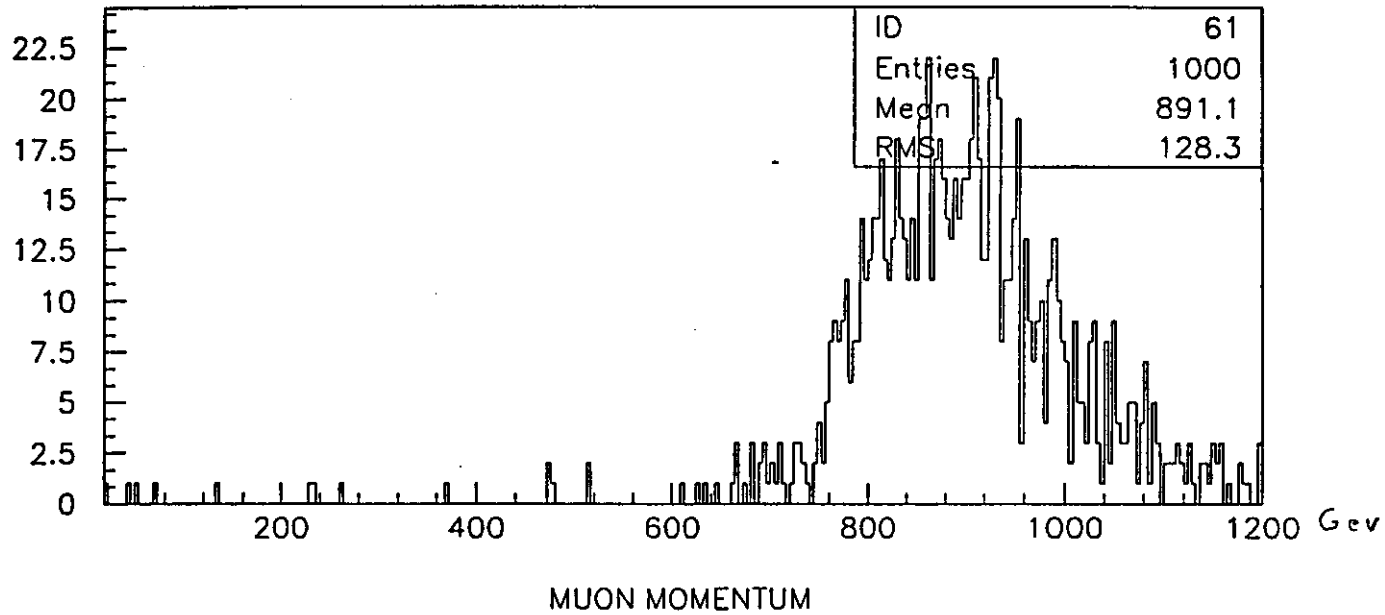
Event listing (summary)

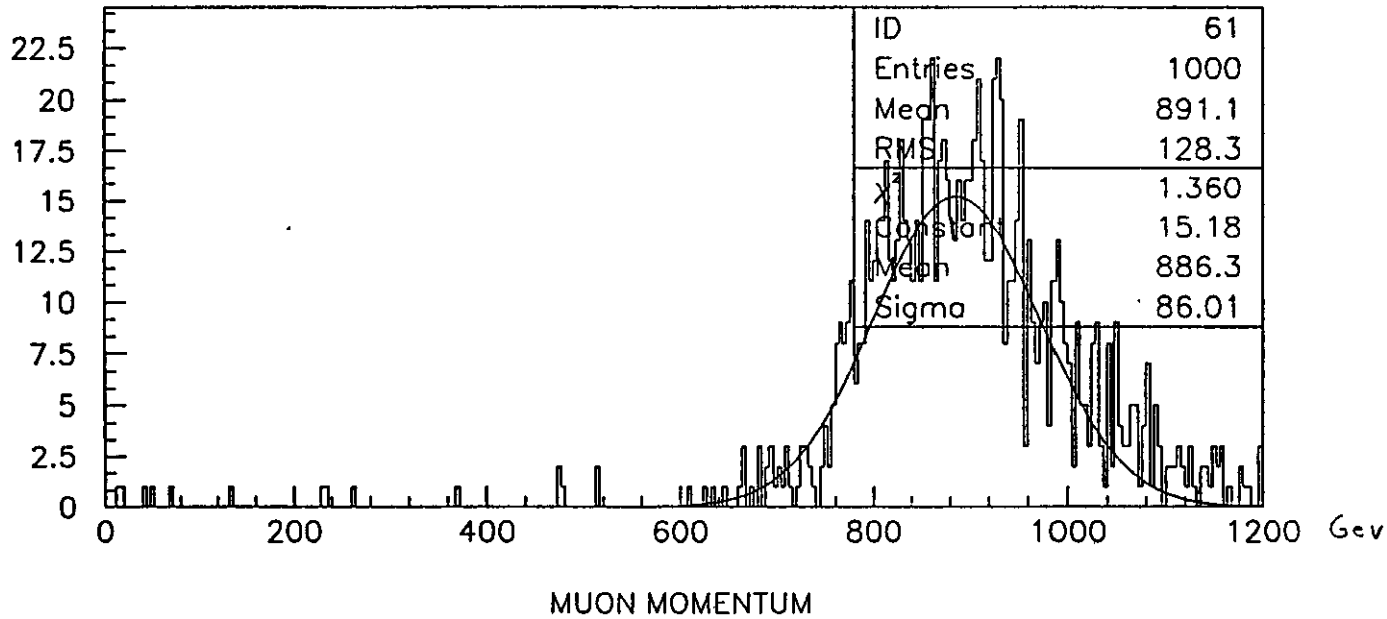
I	particle/jet	KS	KF	orig	p_x	p_y	p_z	E	m
1	mu-	1	13	0	902.506	170.854	395.337	1000.000	.100
		sum: -1.00			902.506	170.854	395.337	1000.000	.000

```
IMU, ICNT, IFMU =  1 1 1
MOMENTUM =  987.2346
CHNAME, CHDETN = MUB1MCD1
NTOT, HITS, NSL =  21 38 21
CHNAME, CHDETN = MUB2MCD2
NTOT, HITS, NSL =  40 24 19
CHNAME, CHDETN = MUB3MCD3
NTOT, HITS, NSL =  48 8 8
fitting starting point  382.6182556152343 -3.25254058837891
164.676025390625 1.249999972060322E-03 -9.253302589058876E-03
.4304171204566955
starting momentum  800.0000178813938
CONV COR, PLANI(3,JSTOP-1)
    .37590E+03      .71455E+02      .16468E+03
    .37590E+03      .71455E+02      .16468E+03
number of preditions  1
plane  1 reached as  1
position
    .37836E+03      .71920E+02      .16575E+03
    .37836E+03      .71924E+02      .16575E+03
ISEC,ISL,IPL,ICEL =  1 1 2 30
CONV COR, PLANI(3,JSTOP-1)
    .37836E+03      .71924E+02      .16575E+03
    .37836E+03      .71924E+02      .16575E+03
number of preditions  1
plane  1 reached as  2
position
```

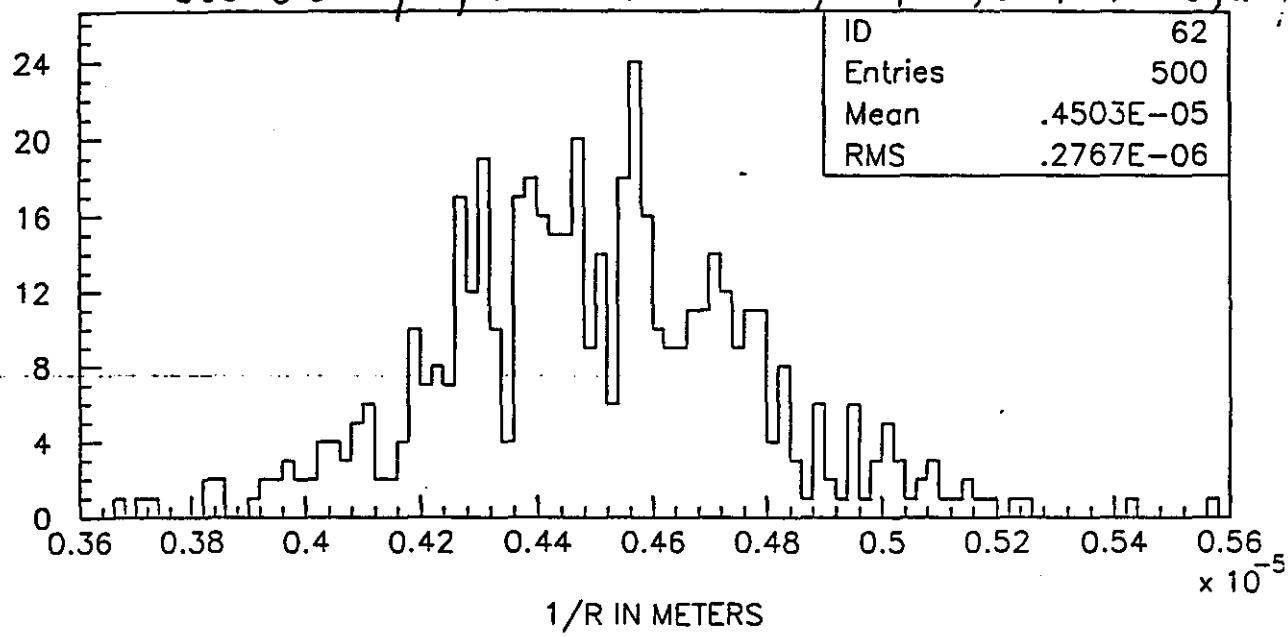

8 8 4 BL1, 100 μ Res/Tube, 50 μ/layer, 25 μ/SuperLayer
550 GeV μ's @ θ = 80°
ID 61
Entries 500
Mean 535.1
RMS 31.98
χ² 1.249
Constant 10.96
Mean 535.4
Sigma 29.75
Δp/p = 5.56 %
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
460
480
500
520
540
560
580
600
620
640
MUON MOMENTUM

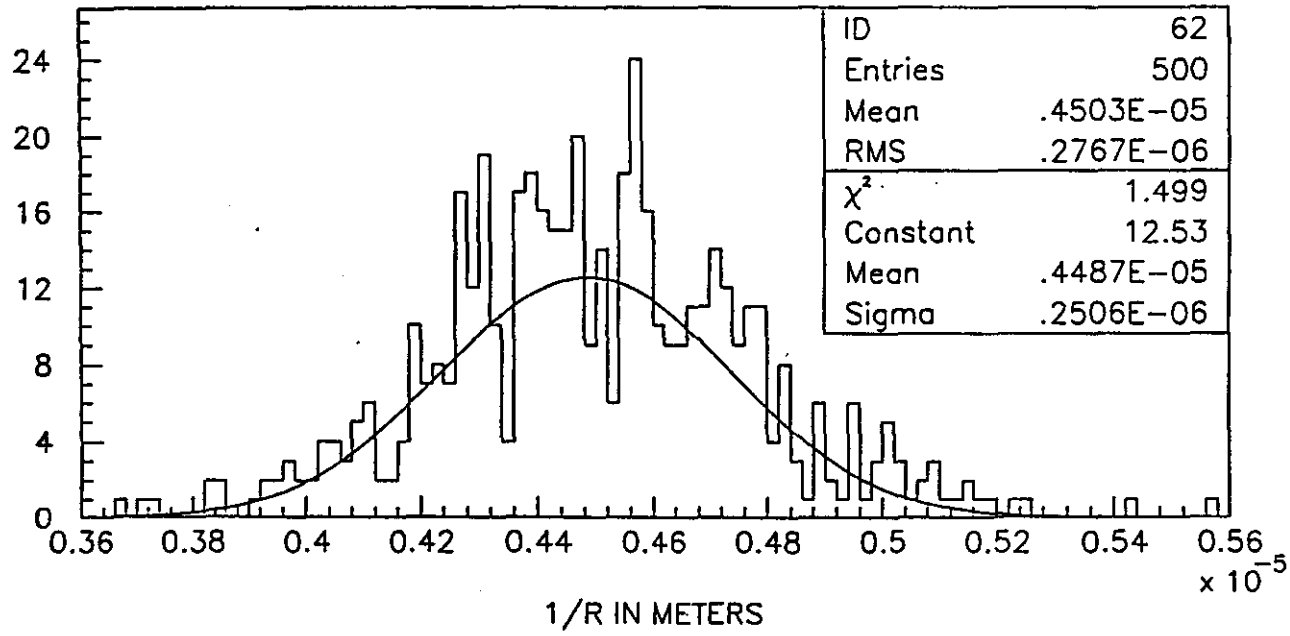
1 Tev @ θ = 80° (884 Baseline.1.)



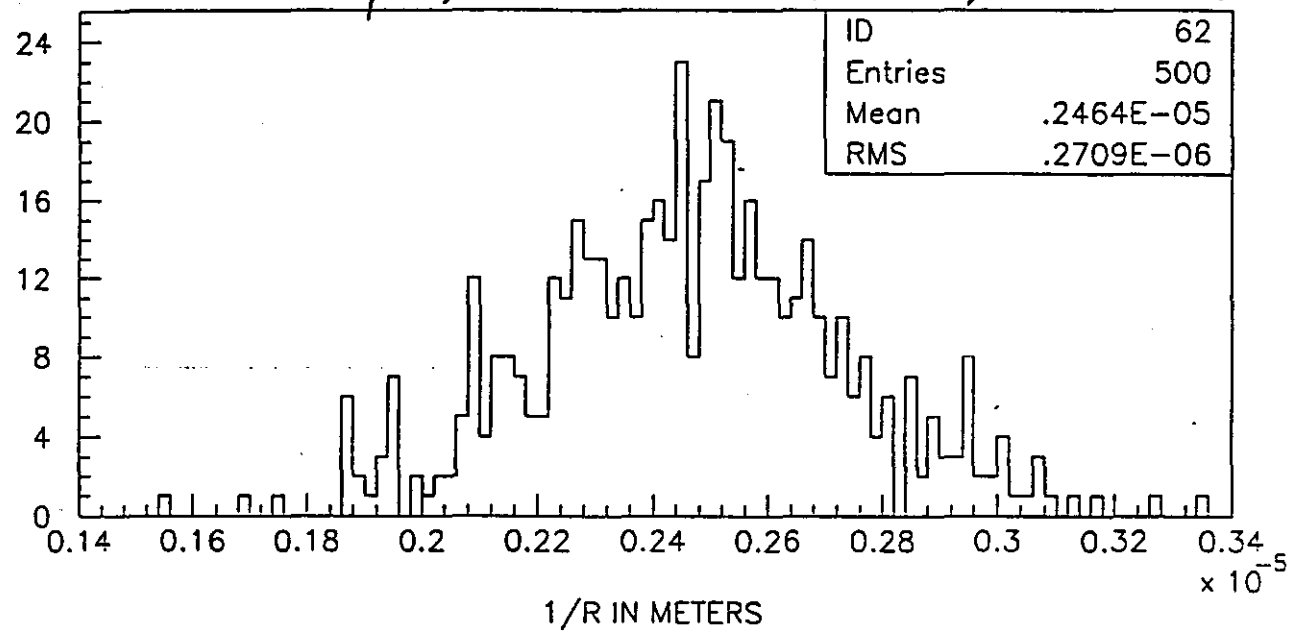


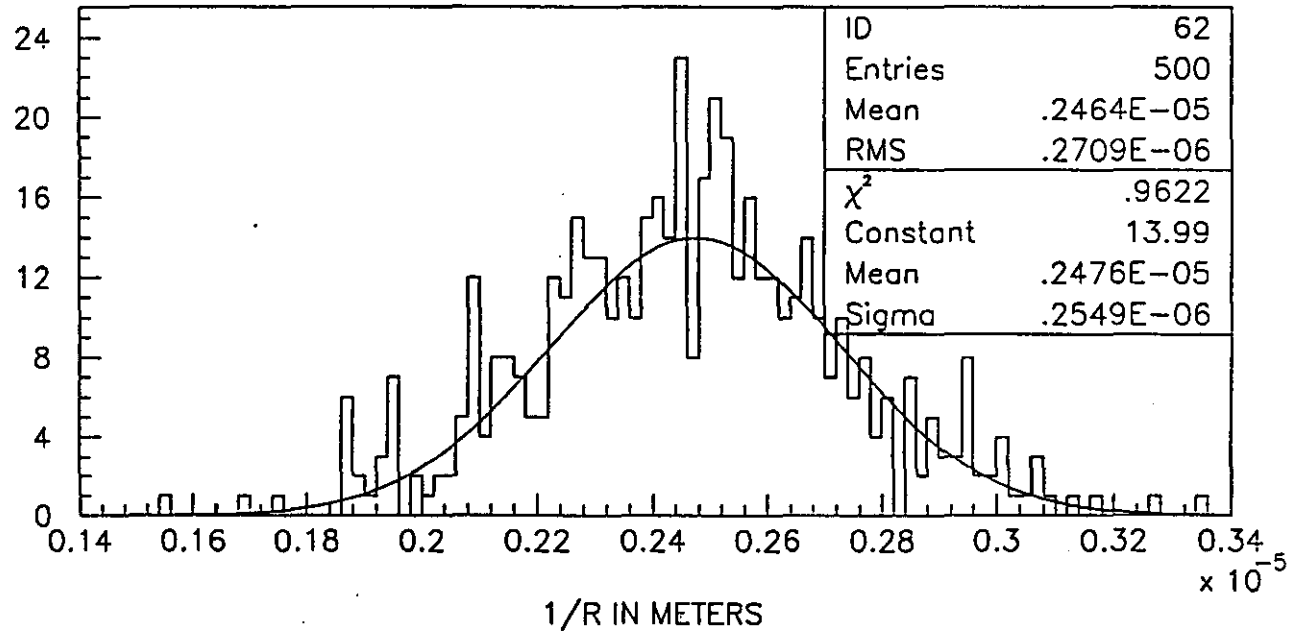
500 Gev μ's, 889 PLANES(BL1), 100μ Res, 50μ LayerRes, 25μ SLRes





1 Tev μ's, 884 Planes (BL1), 100μ Res, 50μ Layer Res, 25μ Sl Res





Charge Determination
For 1 Tev μ

gem

γeμ

Presentation by:

Y. Fisyak

Geant Based Muon Tracking, Resolution and Fitting

Global fit YF

CT + MUON

1. Kalman filter

Status : Coded in SIGEM frame

Now : debuging for 1μ

Monday : test phase

2. TOR ? dp/p for 1μ

3. by end of May $\rightarrow$ dp/p

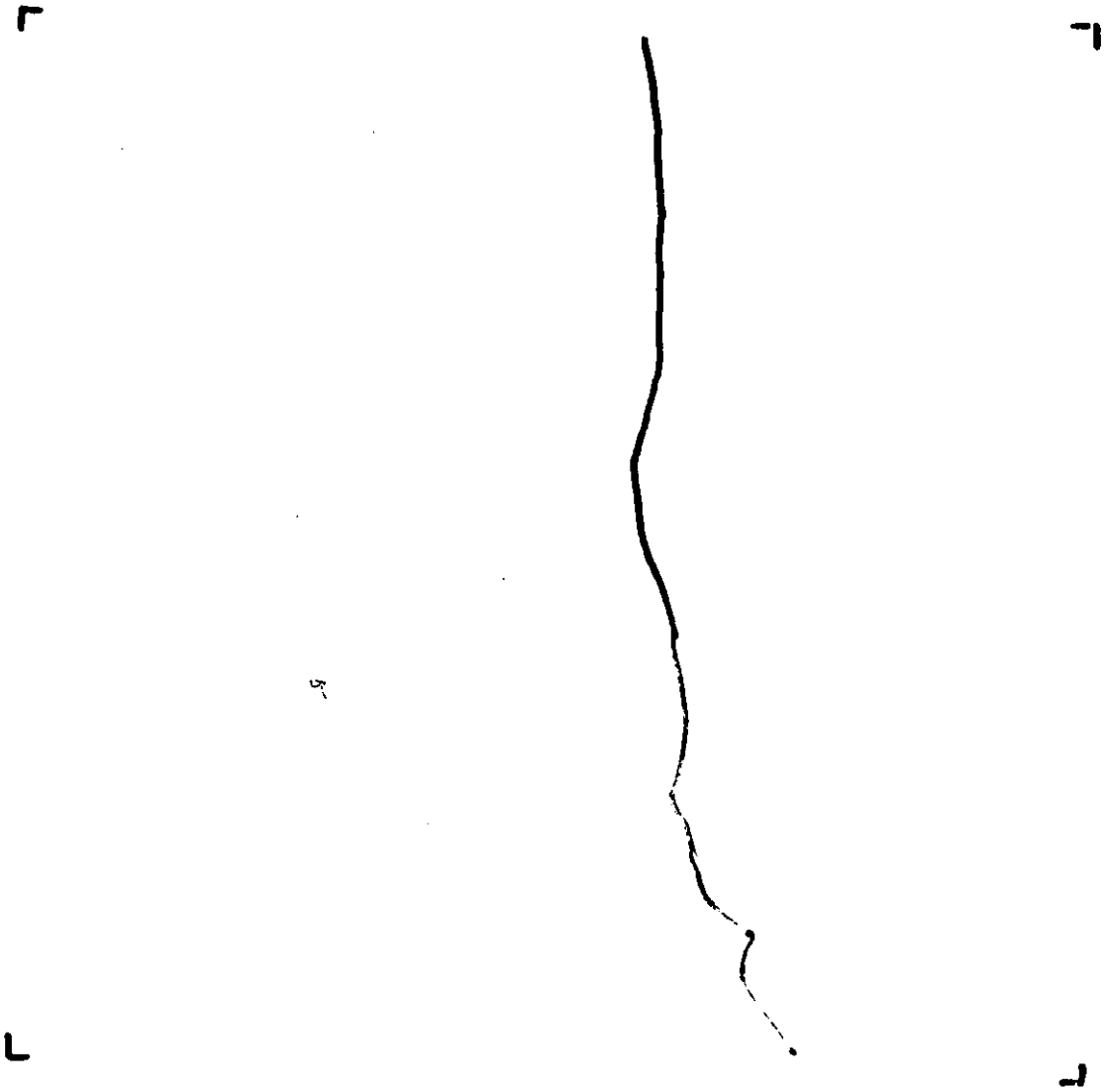
$H \rightarrow 4\mu$

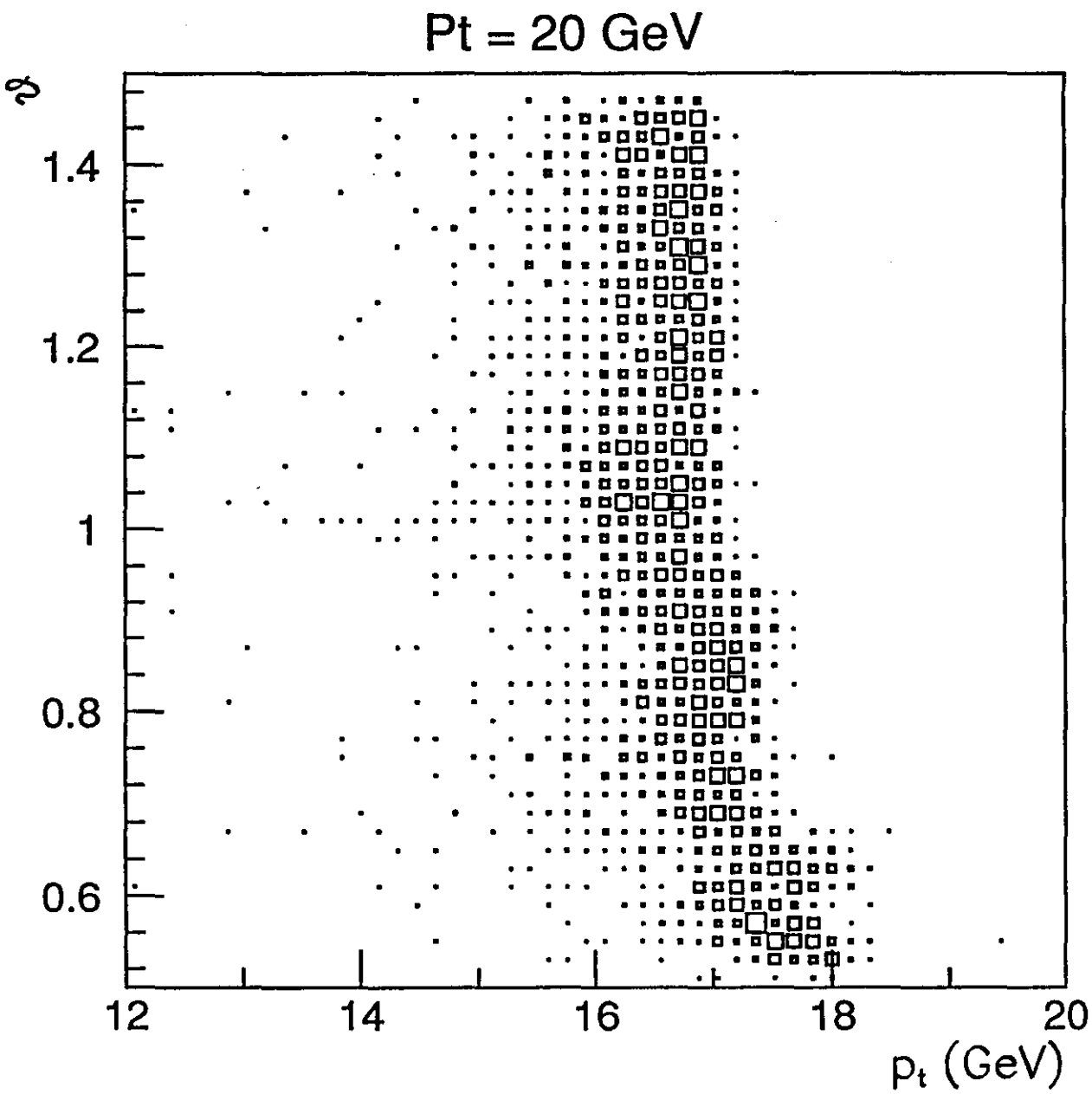
4. By end of July

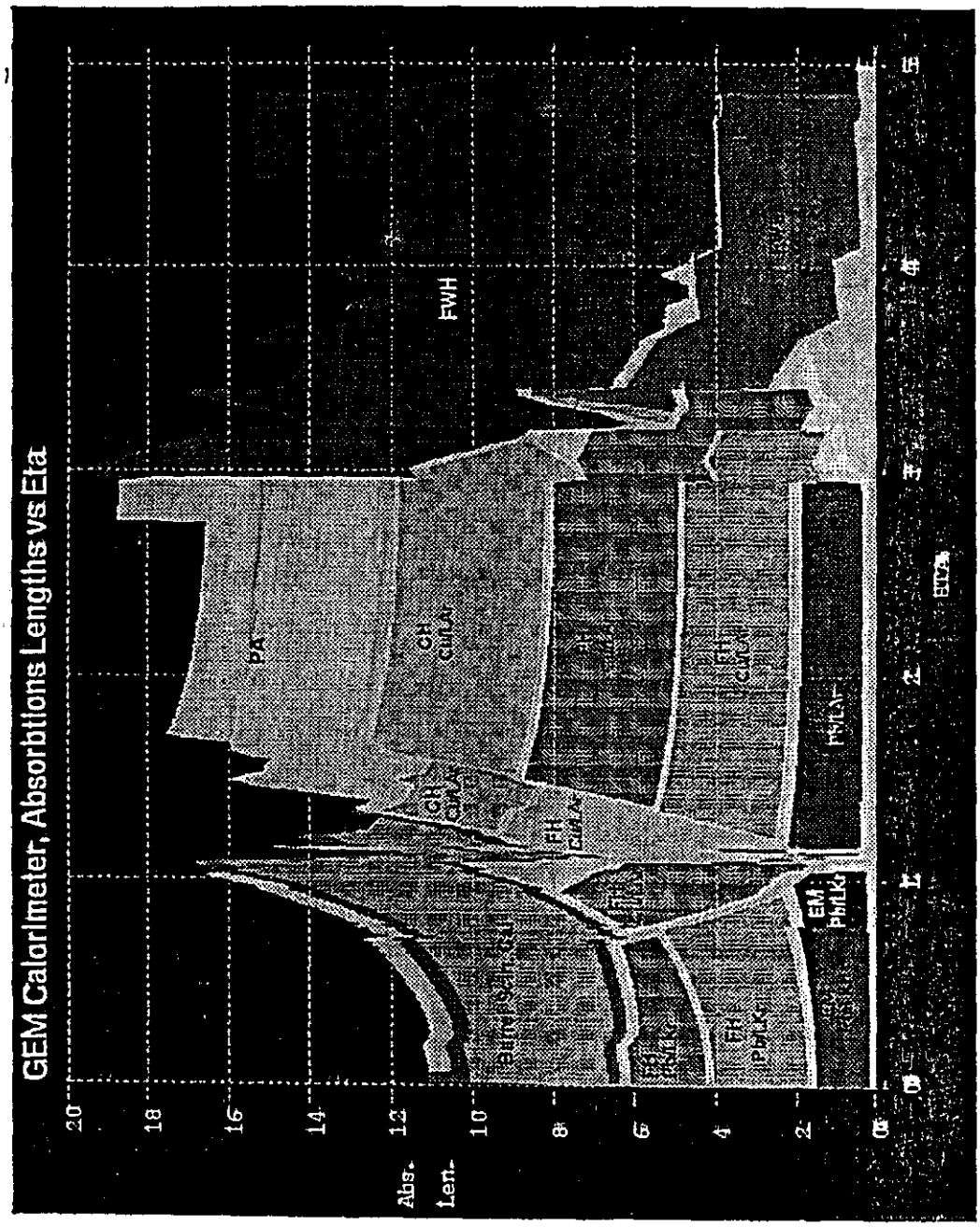
+ digitization

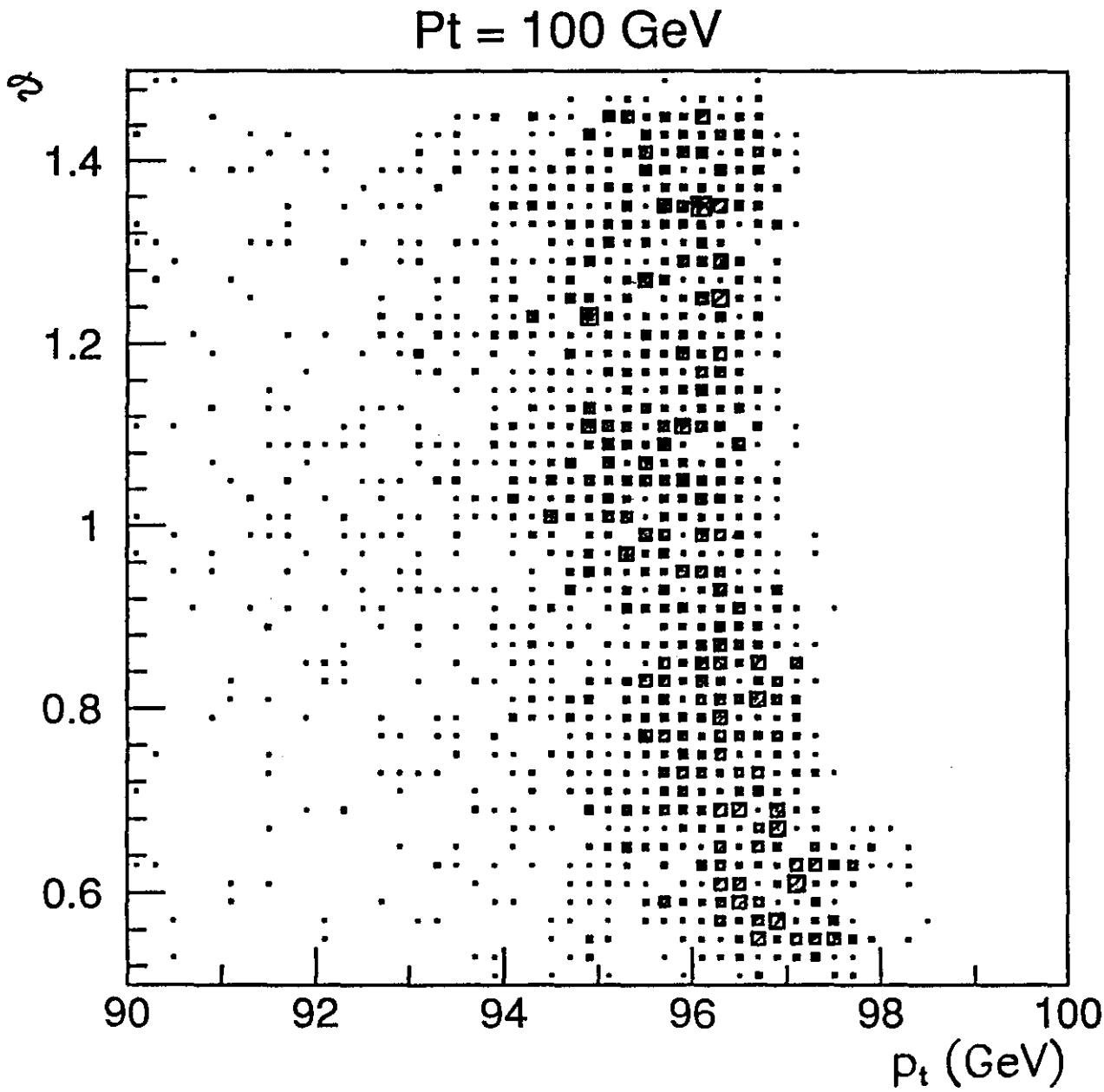
+ cluster finding

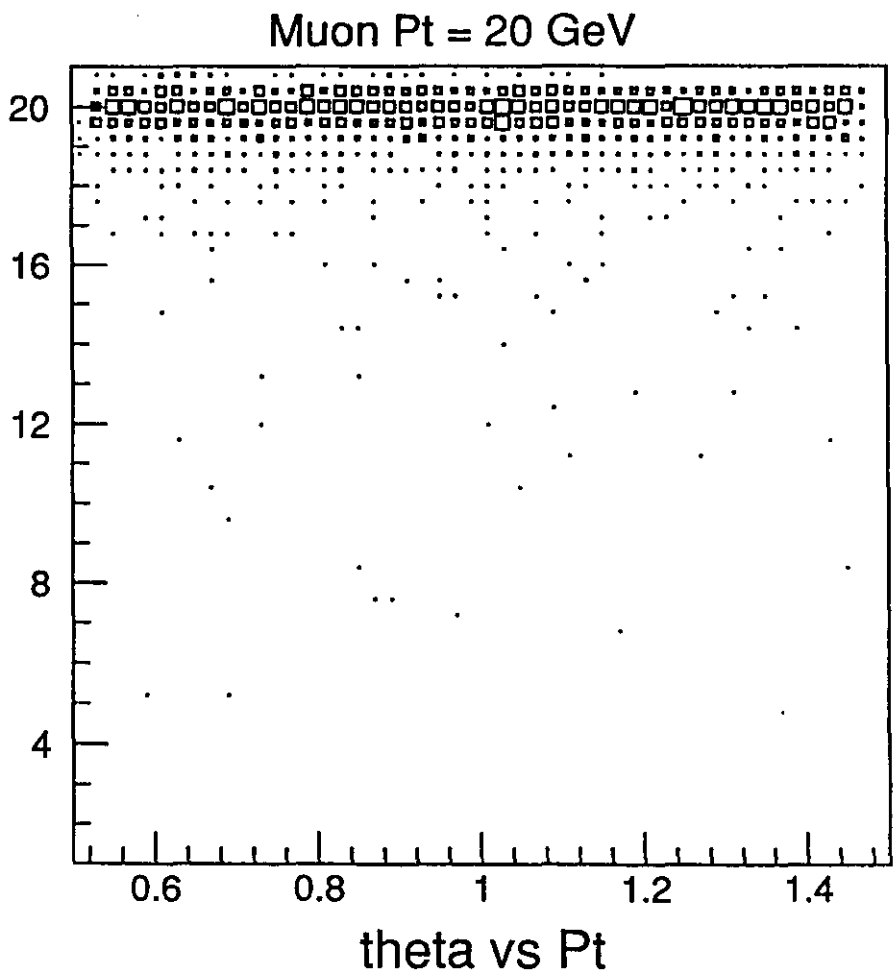
+ global fit

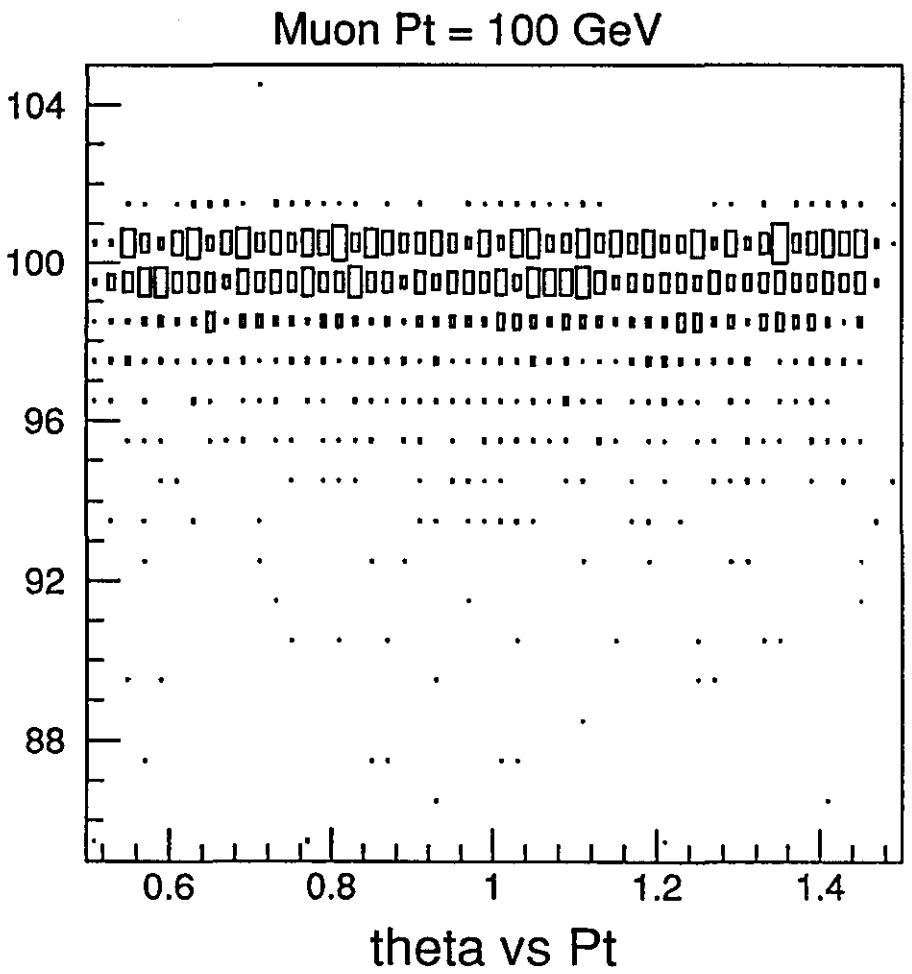


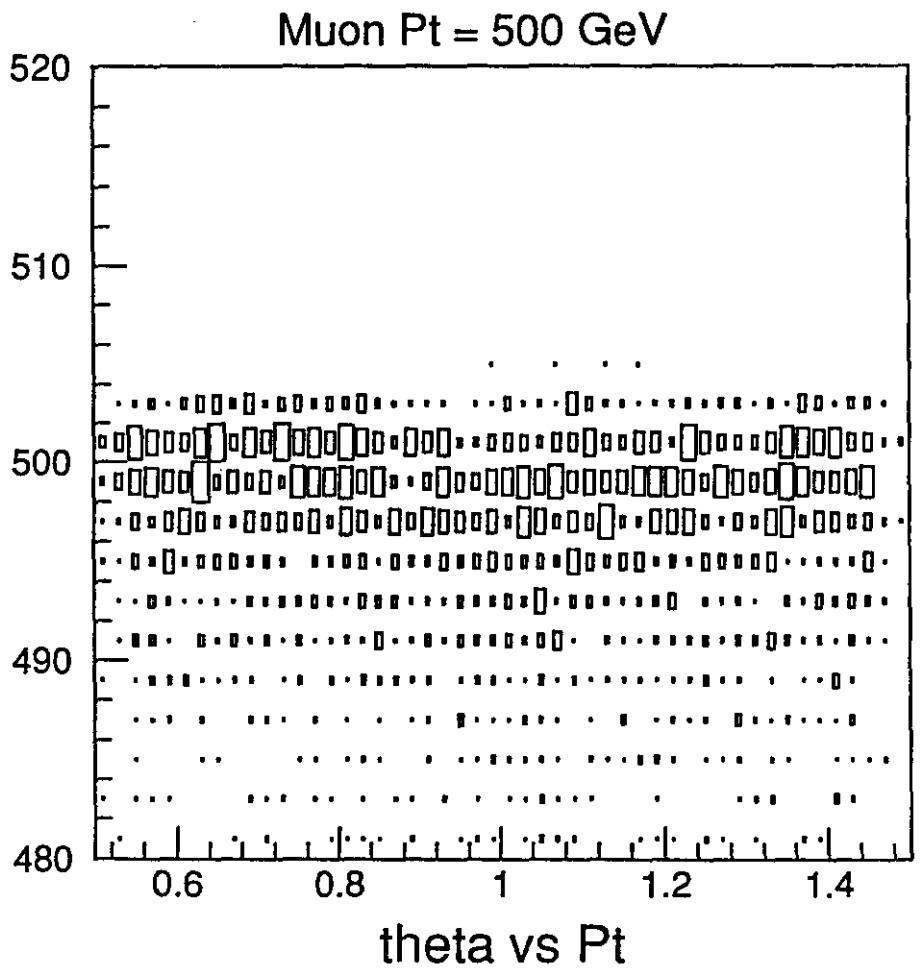

Pt = 20 GeV
η
1.4
1.2
1
0.8
0.6
12
14
16
18
20
p_t (GeV)

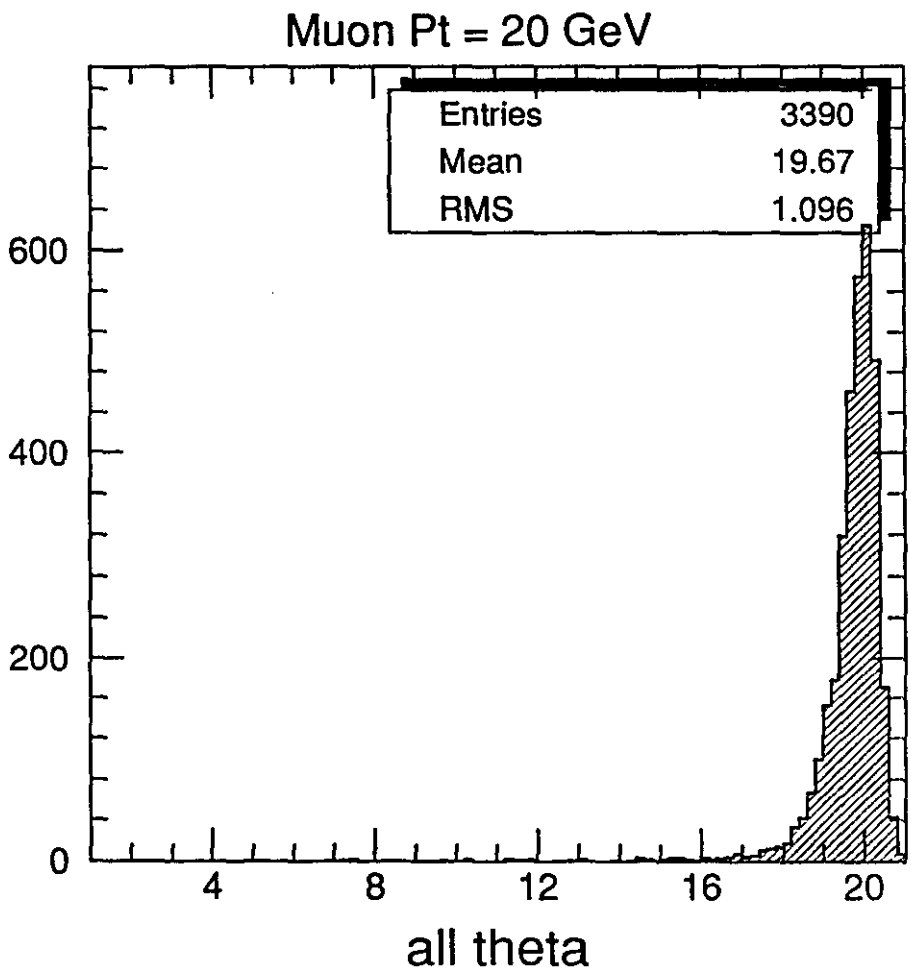

GEM Calorimeter, Absorbtions Lengths vs Eta
Abs.
Len.
20
18
16
14
12
10
8
6
4
2
0
PA
CH
FH
FWH
EM
PbFLKr

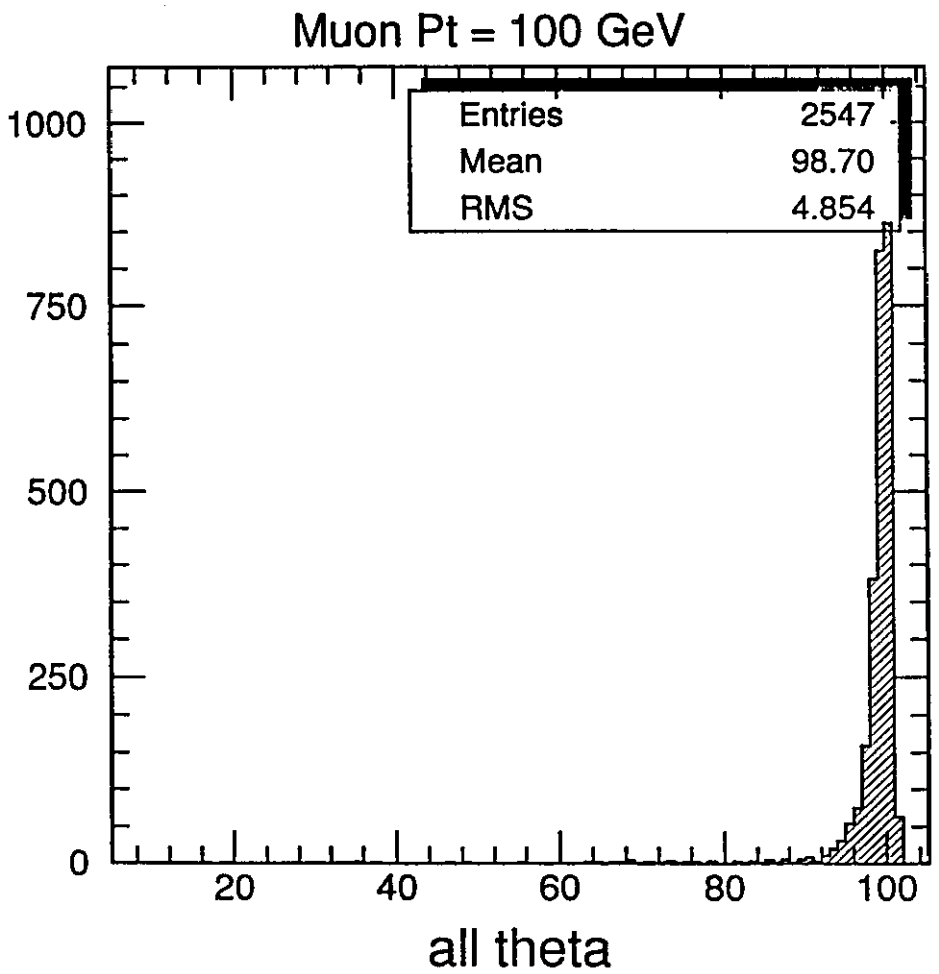

Pt = 100 GeV
1.4
1.2
1
0.8
0.6
90
92
94
96
98
100
p_t (GeV)

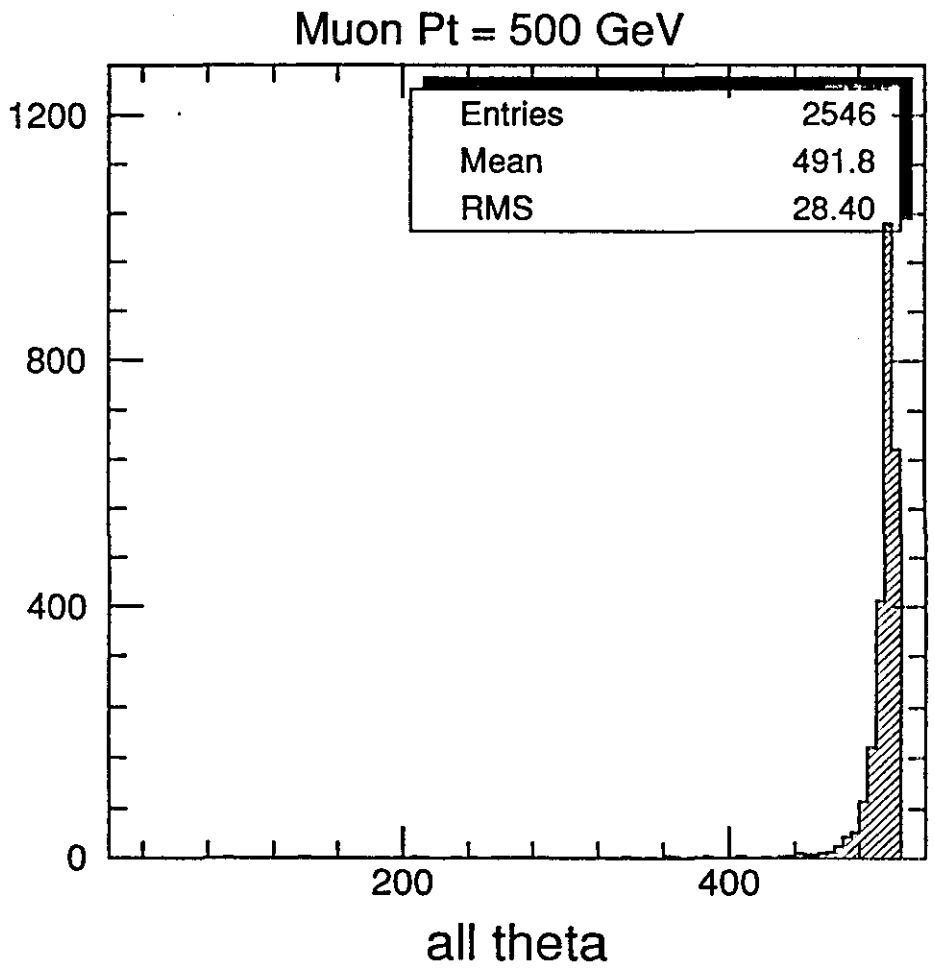

Muon Pt = 20 GeV
20
16
12
8
4
0.6
0.8
1
1.2
1.4
theta vs Pt

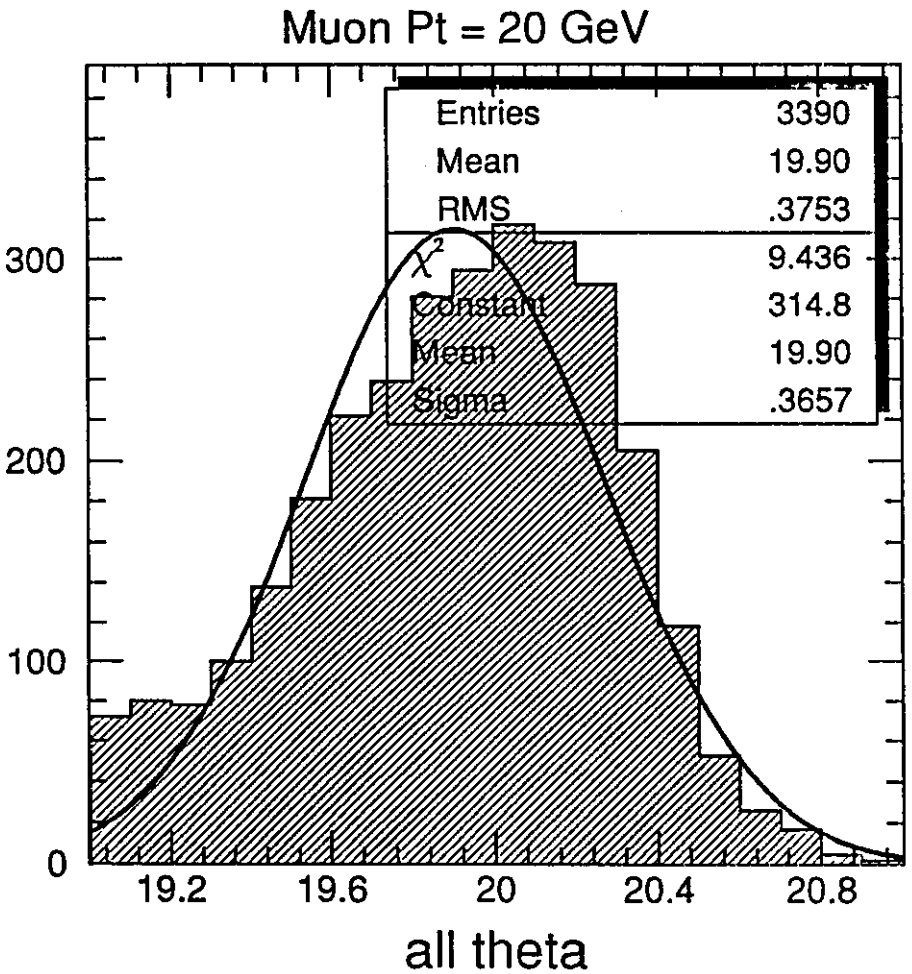

Muon Pt = 100 GeV
104
100
96
92
88
0.6
0.8
1
1.2
1.4
theta vs Pt

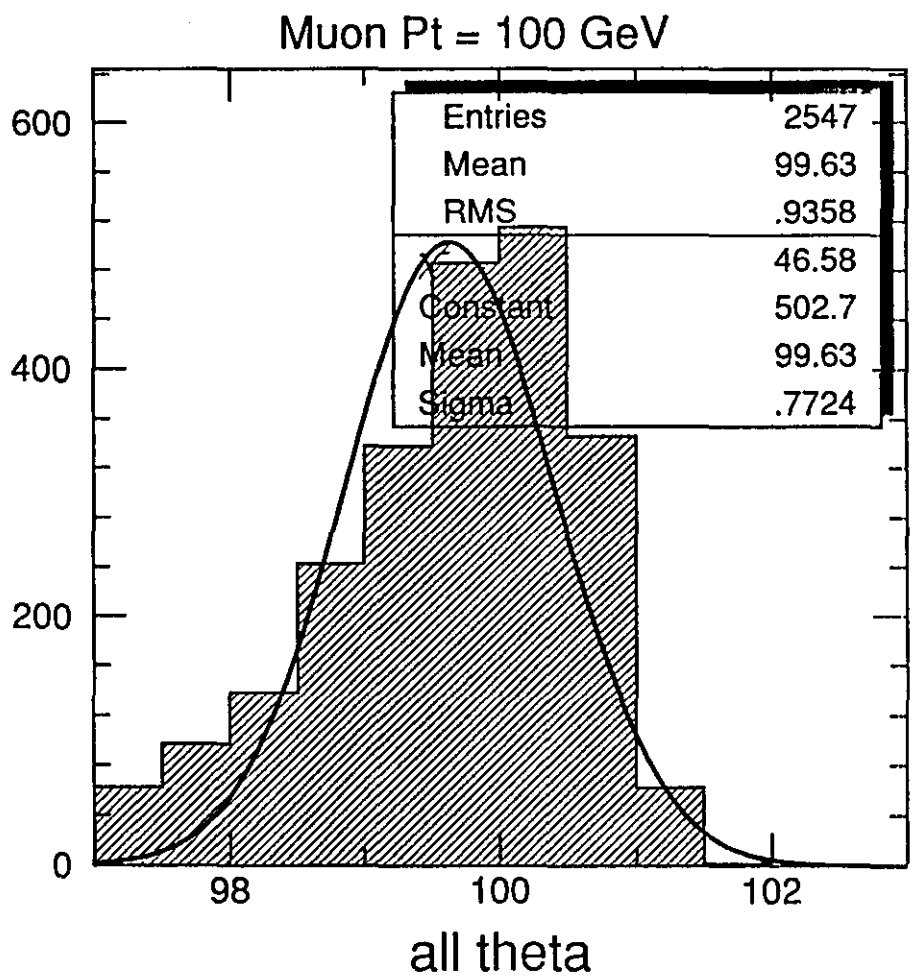

Muon Pt = 500 GeV
520
510
500
490
480
0.6
0.8
1
1.2
1.4
theta vs Pt

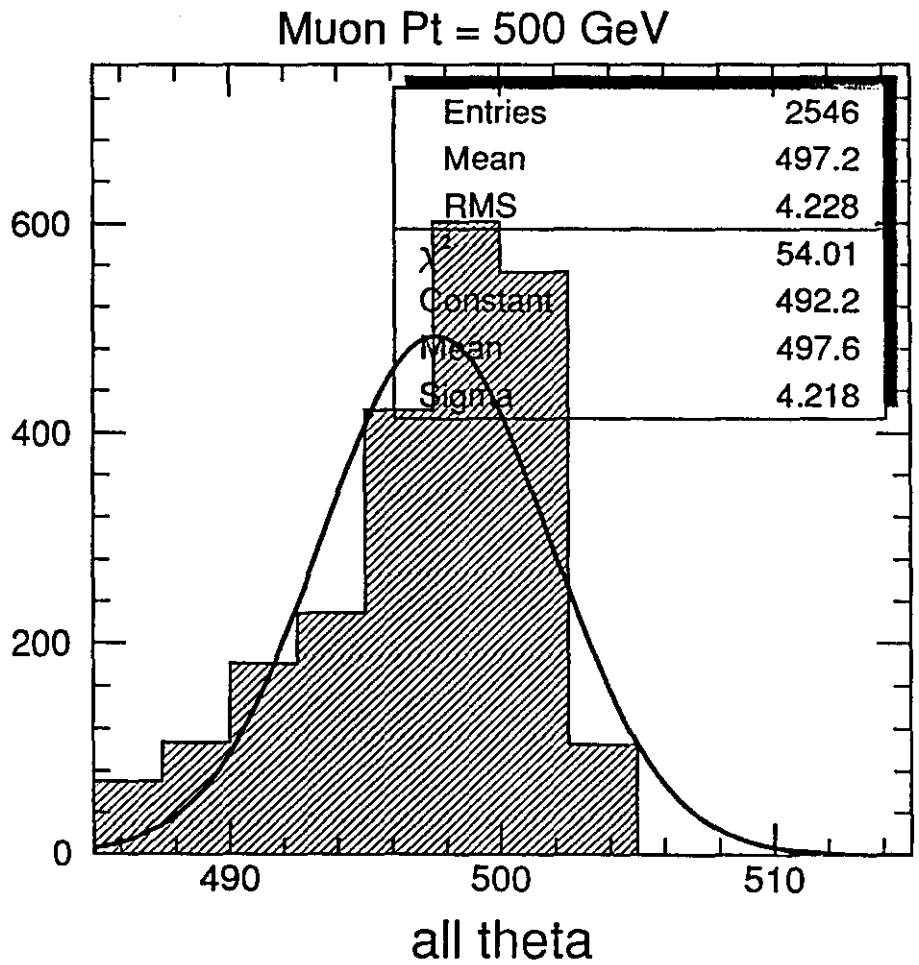

Muon Pt = 20 GeV
Entries 3390
Mean 19.67
RMS 1.096
600
400
200
0
4
8
12
16
20
all theta


Muon Pt = 100 GeV
Entries 2547
Mean 98.70
RMS 4.854
1000
750
500
250
0
20
40
60
80
100
all theta


Muon Pt = 500 GeV
Entries 2546
Mean 491.8
RMS 28.40
1200
800
400
0
200
400
all theta


Muon Pt = 20 GeV
Entries 3390
Mean 19.90
RMS .3753
χ^2 9.436
Constant 314.8
Mean 19.90
Sigma .3657
300
200
100
0
19.2
19.6
20
20.4
20.8
all theta


Muon Pt = 100 GeV
Entries 2547
Mean 99.63
RMS .9358
χ² 46.58
Constant 502.7
Mean 99.63
Sigma .7724
600
400
200
0
98
100
102
all theta

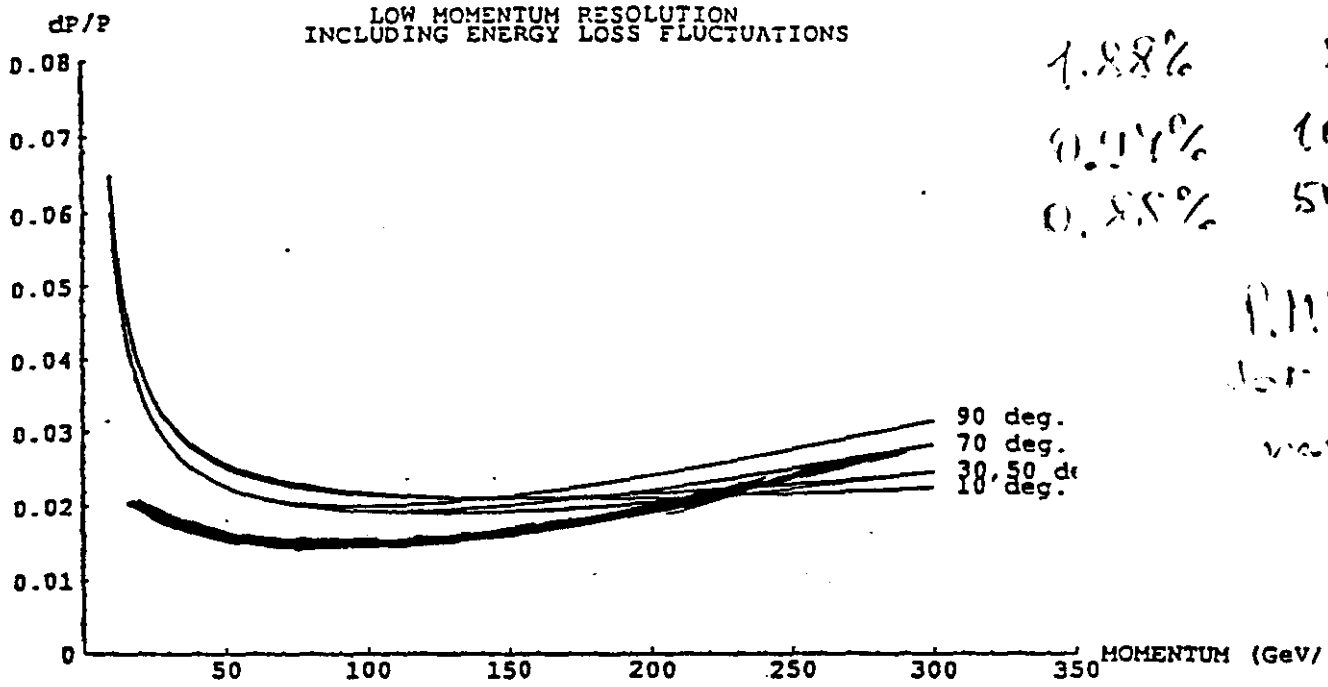

Muon Pt = 500 GeV
Entries 2546
Mean 497.2
RMS 4.228
χ^2 54.01
Constant 492.2
Mean 497.6
Sigma 4.218
600
400
200
0
490
500
510
all theta

$\left(\frac{\delta p_T}{p_T}\right)_{dE/dx}$ p_T

1.88% 20 GeV

0.97% 100 GeV

0.85% 500 GeV



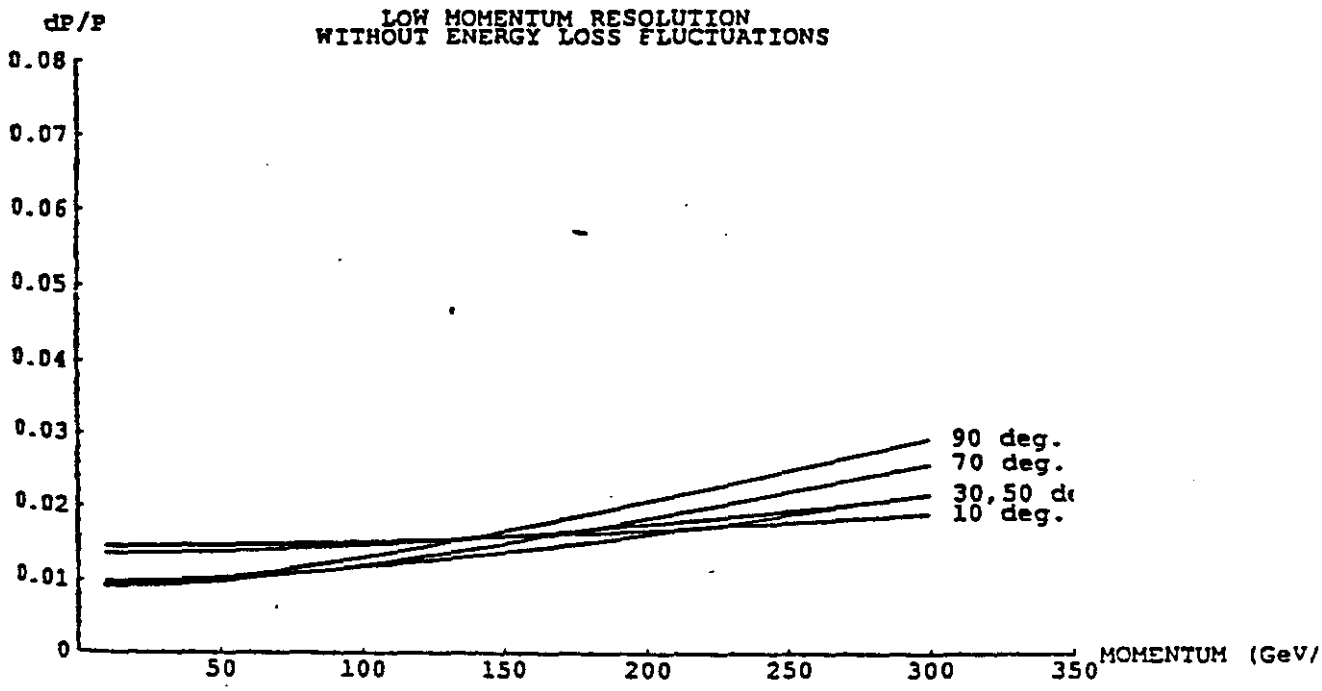


Fig. 4.3.1a

GEM Muon System?

Renyuan Zhu
Caltech

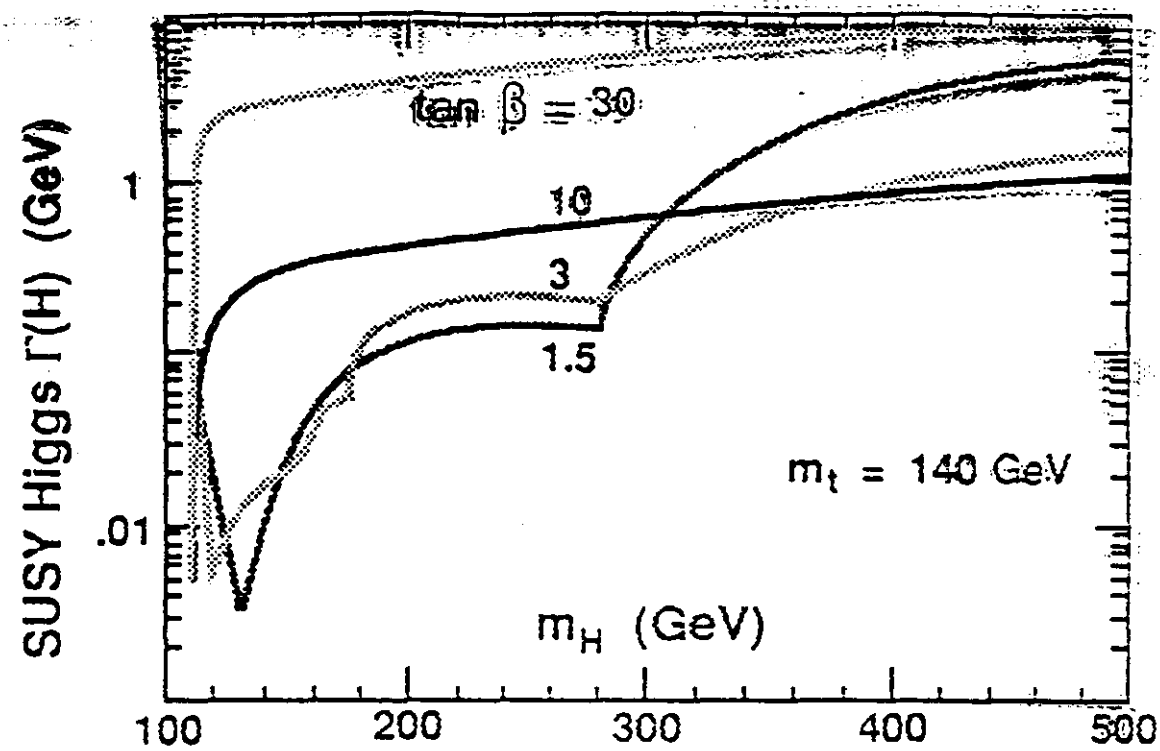
GEM Muon Performance Meeting

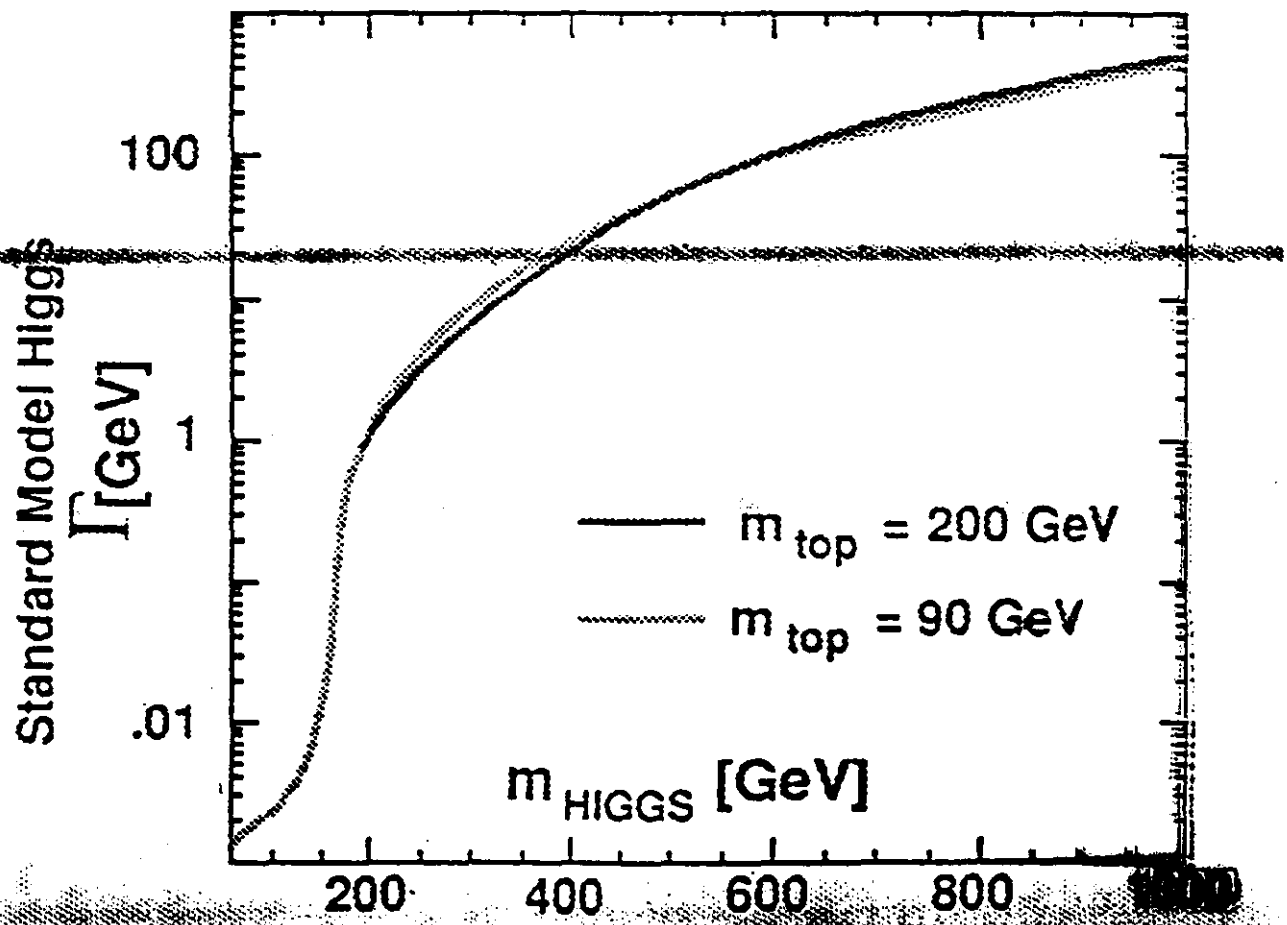
March 26, 1993

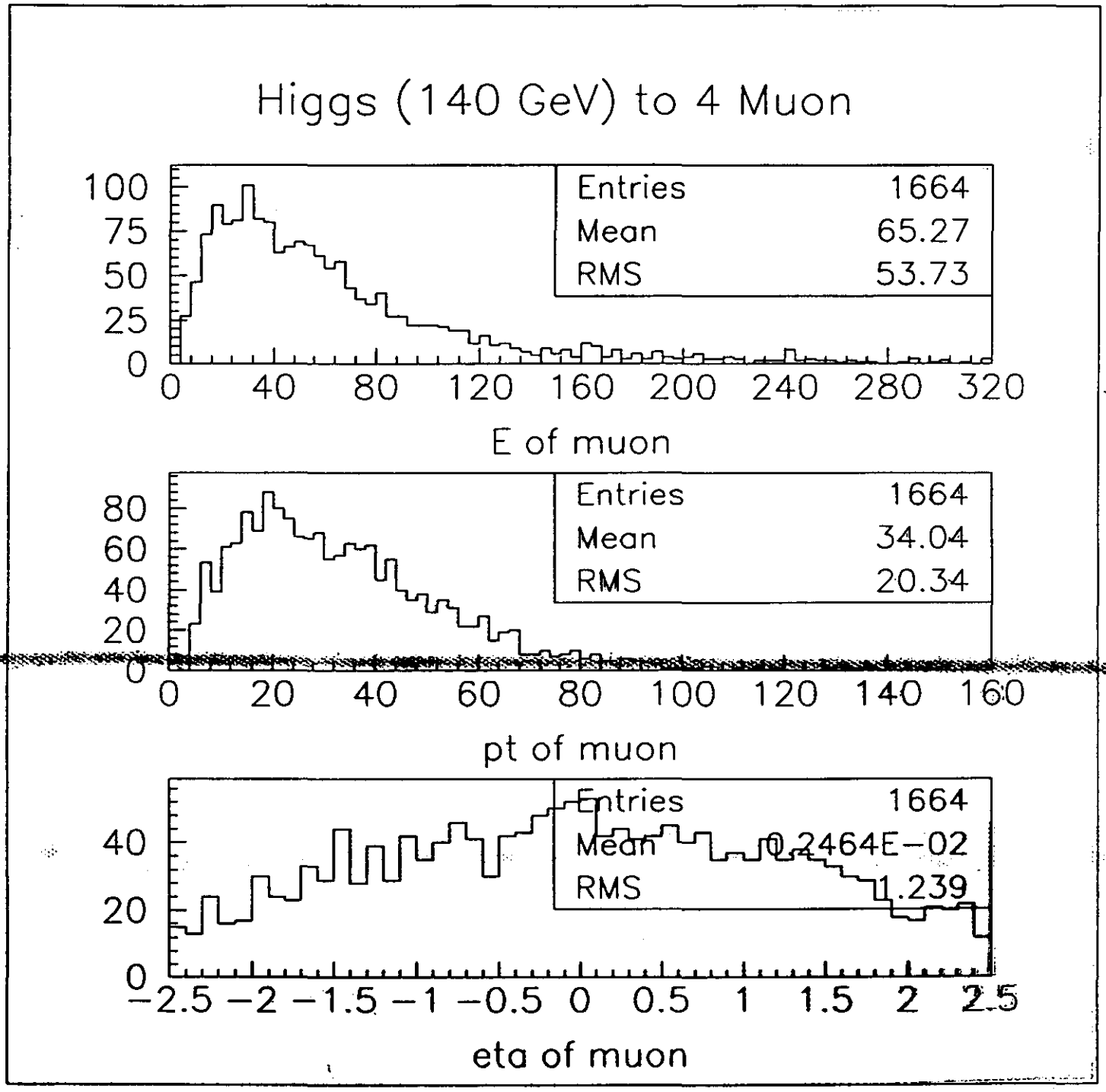
- Unique Physics Role;
- GEM versus SDC: worse in two ends;
- Low End Solution:
  REDUCE MATERIAL IN THE MIDDLE LAYER!!!
  REDUCE MATERIAL IN CENTRAL TRACKER!!!
- High Energy Solution:
  Understand better the SDC system.

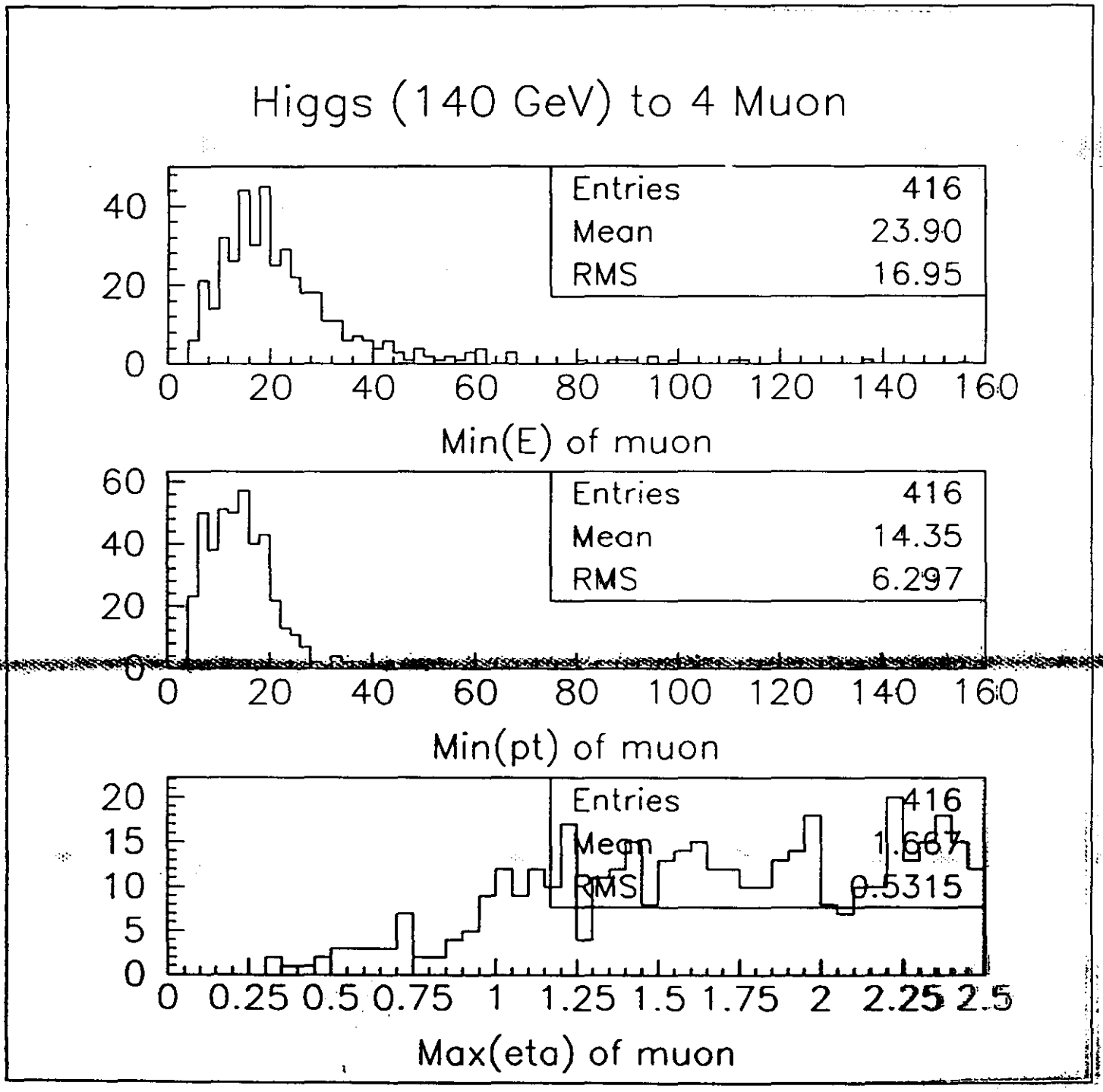
Muon Physics

- High Luminosity ⇒ **Handle Surprises**;
- $H \to \mu^+\mu^-\mu^+\mu^-$ and $e^+e^-\mu^+\mu^-$ searches:
  - Coverage ($|\eta|$, 2.5), Dynamical range ($p_t > 5$ GeV) and 1% resolution at low p (< 100 GeV);
- Distinguish SM Higgs from SUSY:
  - SUSY Higgs is narrow: < 3 GeV, comparing with 10 GeV from SM, for 300 GeV Higgs, i.e. 0.4 to 1.2% mass resolution.
  - Need resolution from both electron and muon channel in the middle p range (100–1000 GeV).
- $Z' \to \mu^+\mu^-$ Searches:
  - Mass peak is much better in electron channel;
- Z' Asymmetry, WW strong scattering:
  - Need resolution at high p (> 1 TeV).
- Muon in jets:
  - b tagging: inclusive muon;
  - CP vialation with B_d or $\bar{B}_d \to J/\psi K^0_s$:
    Looking one inclusive μ, a pair of μ and $\pi^+\pi^-$
    Trigger [illegible]

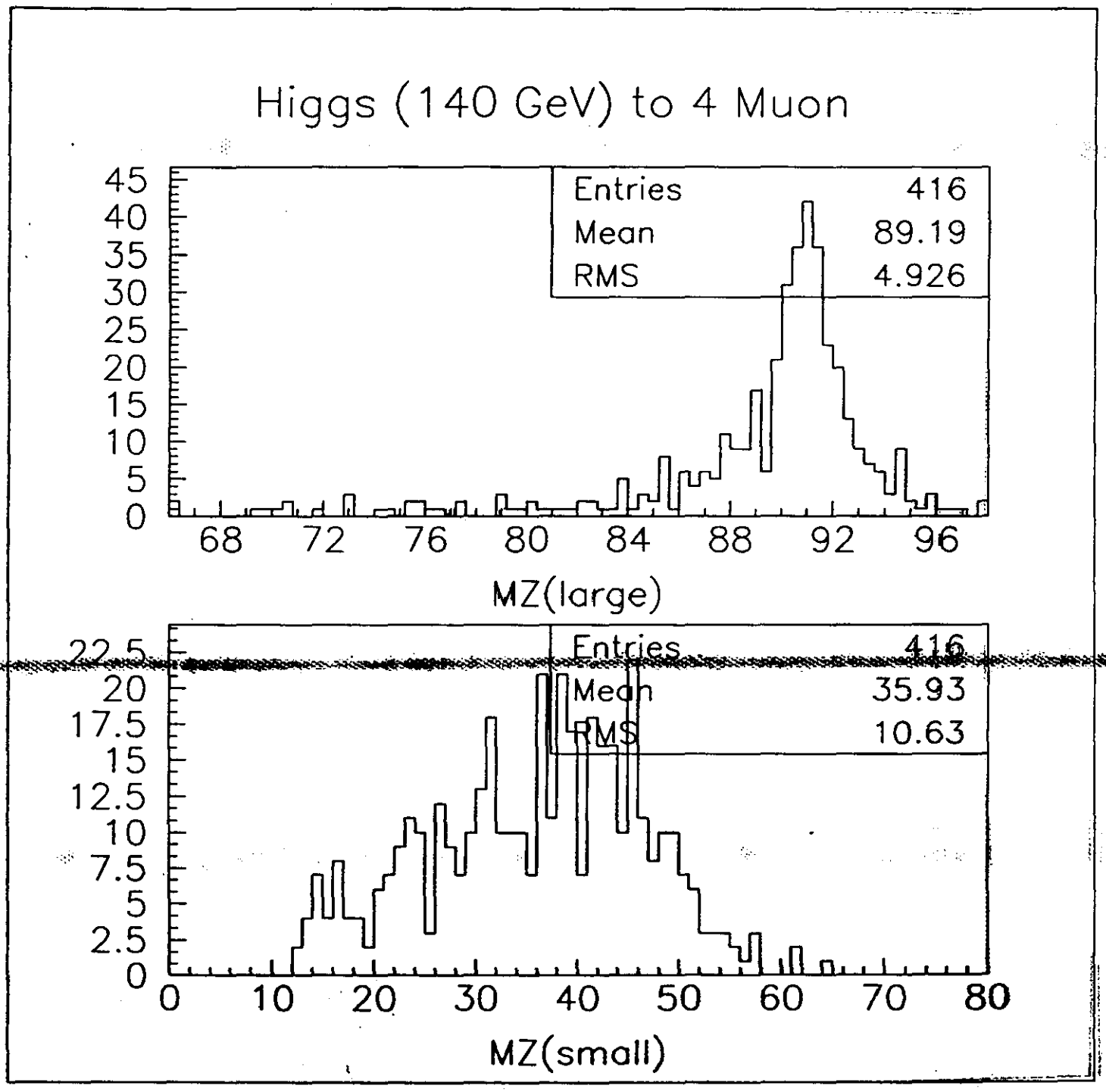

tan β = 30
10
3
1.5
m_t = 140 GeV
SUSY Higgs Γ(H) (GeV)
1
.01
m_H (GeV)
100
200
300
400
500


Standard Model Higgs
Γ[GeV]
100
1
.01
m_top = 200 GeV
m_top = 90 GeV
m_HIGGS [GeV]
200
400
600
800

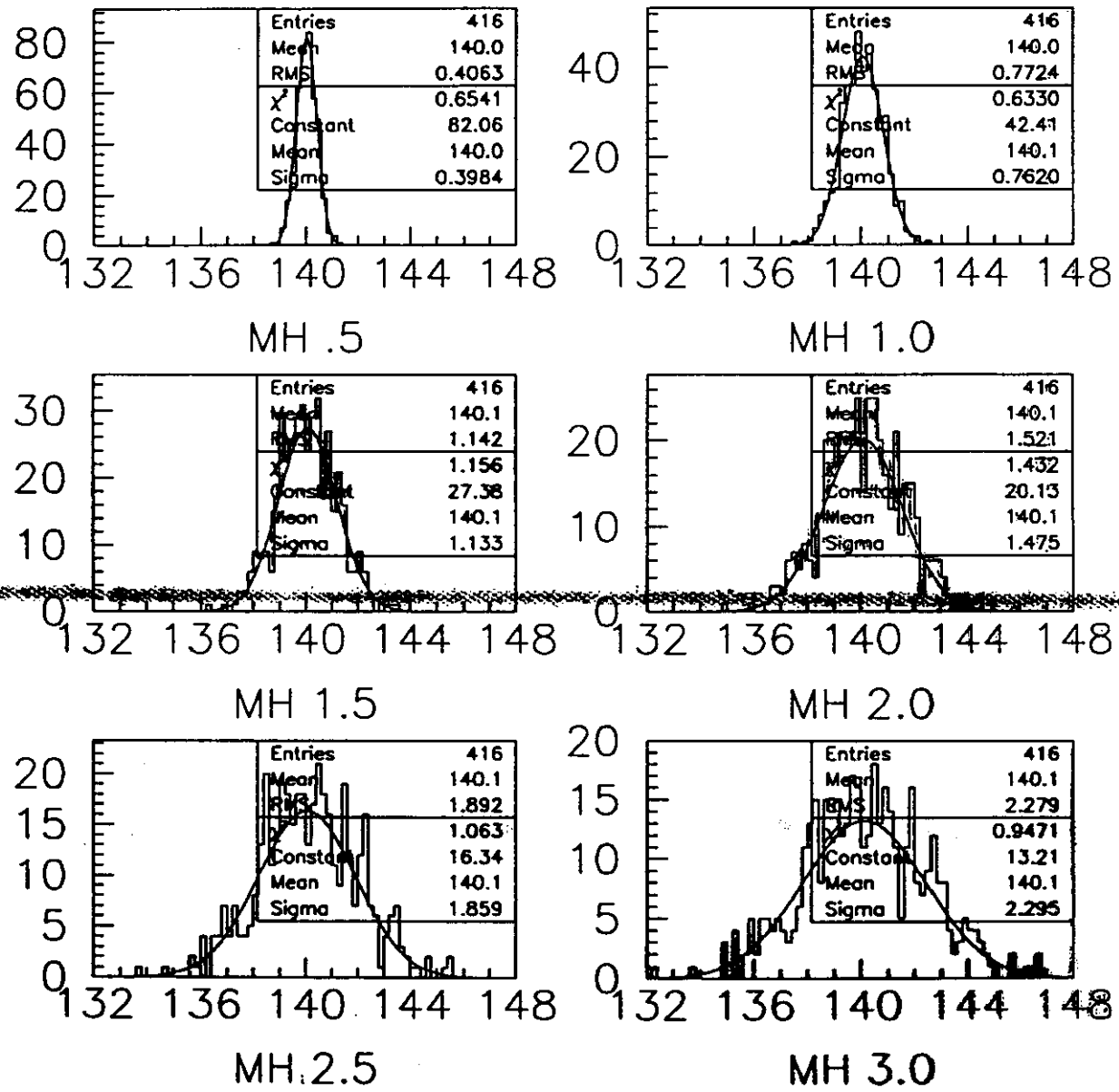

Higgs (140 GeV) to 4 Muon
Entries 1664
Mean 65.27
RMS 53.73
E of muon
Entries 1664
Mean 34.04
RMS 20.34
pt of muon
Entries 1664
Mean 0.2464E−02
RMS 1.239
eta of muon

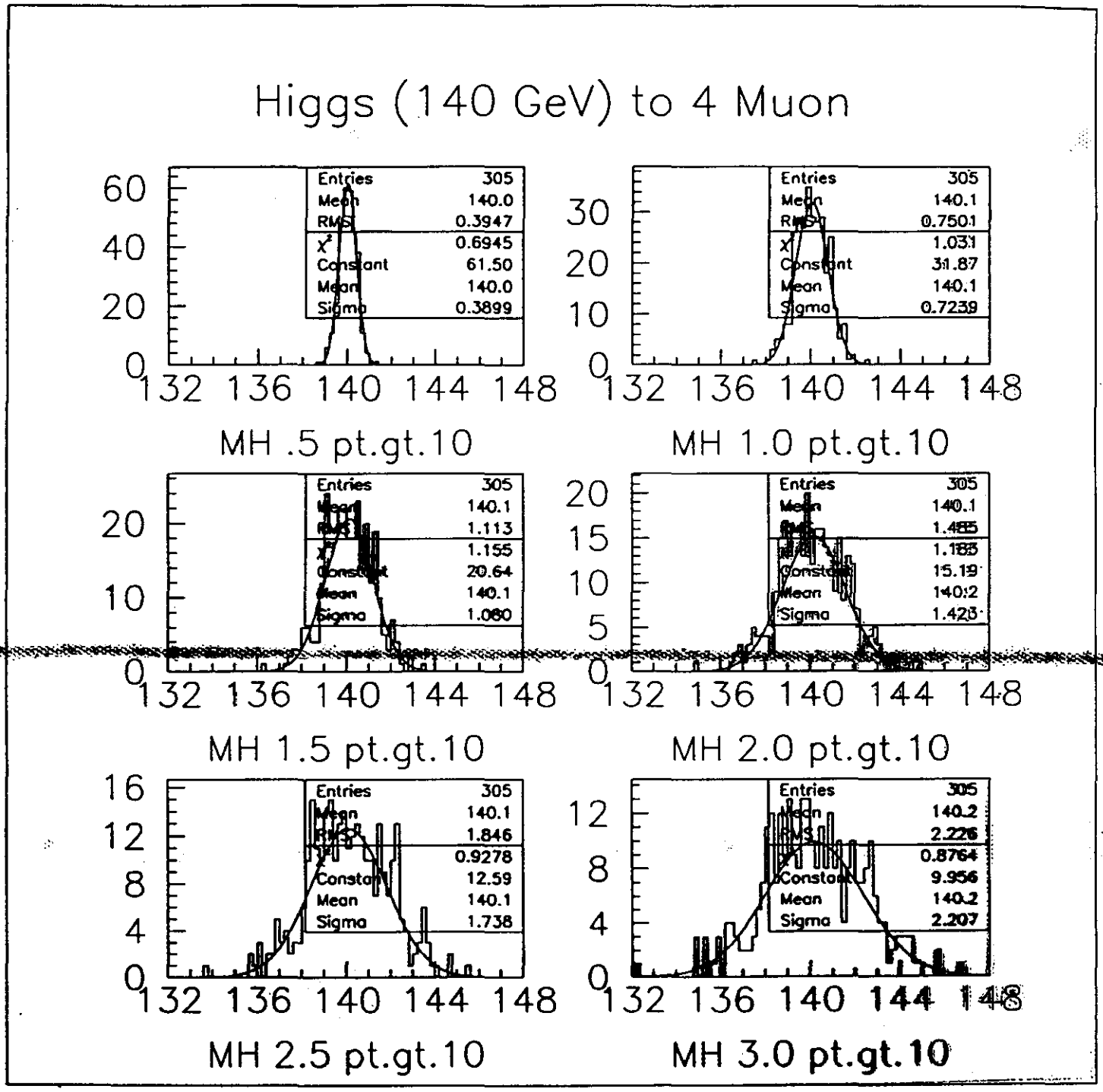

Higgs (140 GeV) to 4 Muon
Entries 416
Mean 23.90
RMS 16.95
Min(E) of muon
Entries 416
Mean 14.35
RMS 6.297
Min(pt) of muon
Entries 416
Mean 1.667
RMS 0.5315
Max(eta) of muon

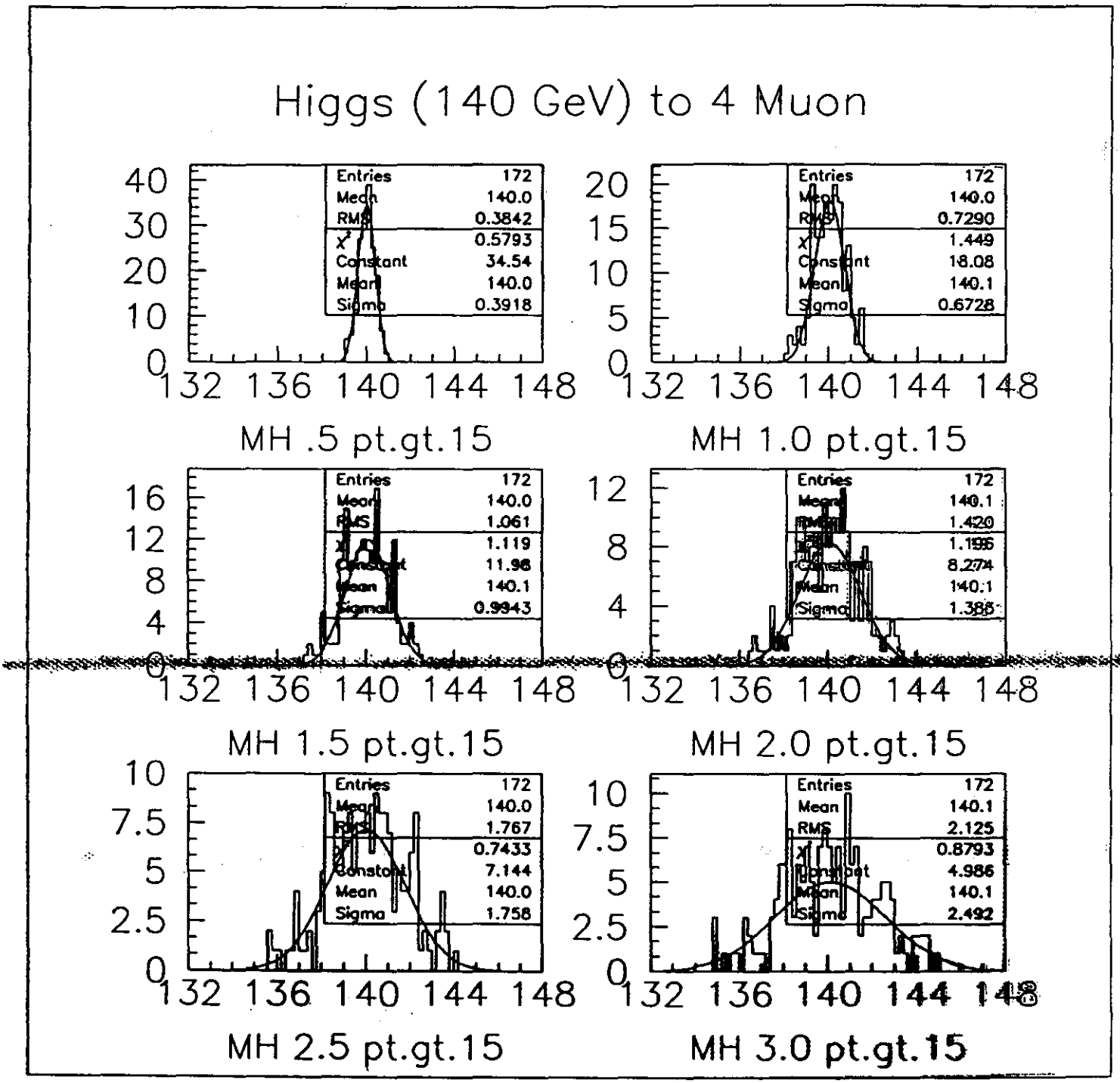
Z mass constraint : [illegible]



Higgs (140 GeV) to 4 Muon




Higgs (140 GeV) to 4 Muon
Entries 305
Mean 140.0
RMS 0.3947
χ² 0.6945
Constant 61.50
Mean 140.0
Sigma 0.3899
MH .5 pt.gt.10
Entries 305
Mean 140.1
RMS 0.7501
χ² 1.031
Constant 31.87
Mean 140.1
Sigma 0.7239
MH 1.0 pt.gt.10
Entries 305
Mean 140.1
RMS 1.113
χ² 1.155
Constant 20.64
Mean 140.1
Sigma 1.080
MH 1.5 pt.gt.10
Entries 305
Mean 140.1
RMS 1.485
χ² 1.183
Constant 15.19
Mean 140.2
Sigma 1.423
MH 2.0 pt.gt.10
Entries 305
Mean 140.1
RMS 1.846
χ² 0.9278
Constant 12.59
Mean 140.1
Sigma 1.738
MH 2.5 pt.gt.10
Entries 305
Mean 140.2
RMS 2.226
χ² 0.8764
Constant 9.956
Mean 140.2
Sigma 2.207
MH 3.0 pt.gt.10


Higgs (140 GeV) to 4 Muon
Entries 172
Mean 140.0
RMS 0.3842
χ² 0.5793
Constant 34.54
Mean 140.0
Sigma 0.3918
MH .5 pt.gt.15
Entries 172
Mean 140.0
RMS 0.7290
χ² 1.449
Constant 18.08
Mean 140.1
Sigma 0.6728
MH 1.0 pt.gt.15
Entries 172
Mean 140.0
RMS 1.061
χ² 1.119
Constant 11.98
Mean 140.1
Sigma 0.9943
MH 1.5 pt.gt.15
Entries 172
Mean 140.1
RMS 1.420
χ² 1.196
Constant 8.274
Mean 140.1
Sigma 1.388
MH 2.0 pt.gt.15
Entries 172
Mean 140.0
RMS 1.767
χ² 0.7433
Constant 7.144
Mean 140.0
Sigma 1.758
MH 2.5 pt.gt.15
Entries 172
Mean 140.1
RMS 2.125
χ² 0.8793
Constant 4.986
Mean 140.1
Sigma 2.492
MH 3.0 pt.gt.15

GEM versus SDC

- Muon Resolution:

p_t^μ (GeV)	1	10	30	100	400	1000	2000
SDC (%)	0.25	0.4	1.1	1.9	5.2	10(?)	14(?)
GEM (%)	3.5 (CT)	2	2	2	4.2	10	20

- Low momentum end: $\sigma(M_H)$

M_H (GeV)	SDC (GeV)	GEM (GeV)
140 (μ)	0.8	1.6 (now)
140 (e)	1.9→0.8	1.1

- High momentum end: $\sigma_{M_{Z'}}/M_{Z'}$

$M_{Z'}$ (GeV)	SDC (%)	GEM (%)
800/4000 (e)	0.7	0.35
800 (μ)	3.2	3
4000 (μ)	9.5(?)	14

GEM LoI : $\sigma(M_H) = 1$ GeV

$\frac{\sigma P_\mu}{P_\mu} \doteq 1.4\%$

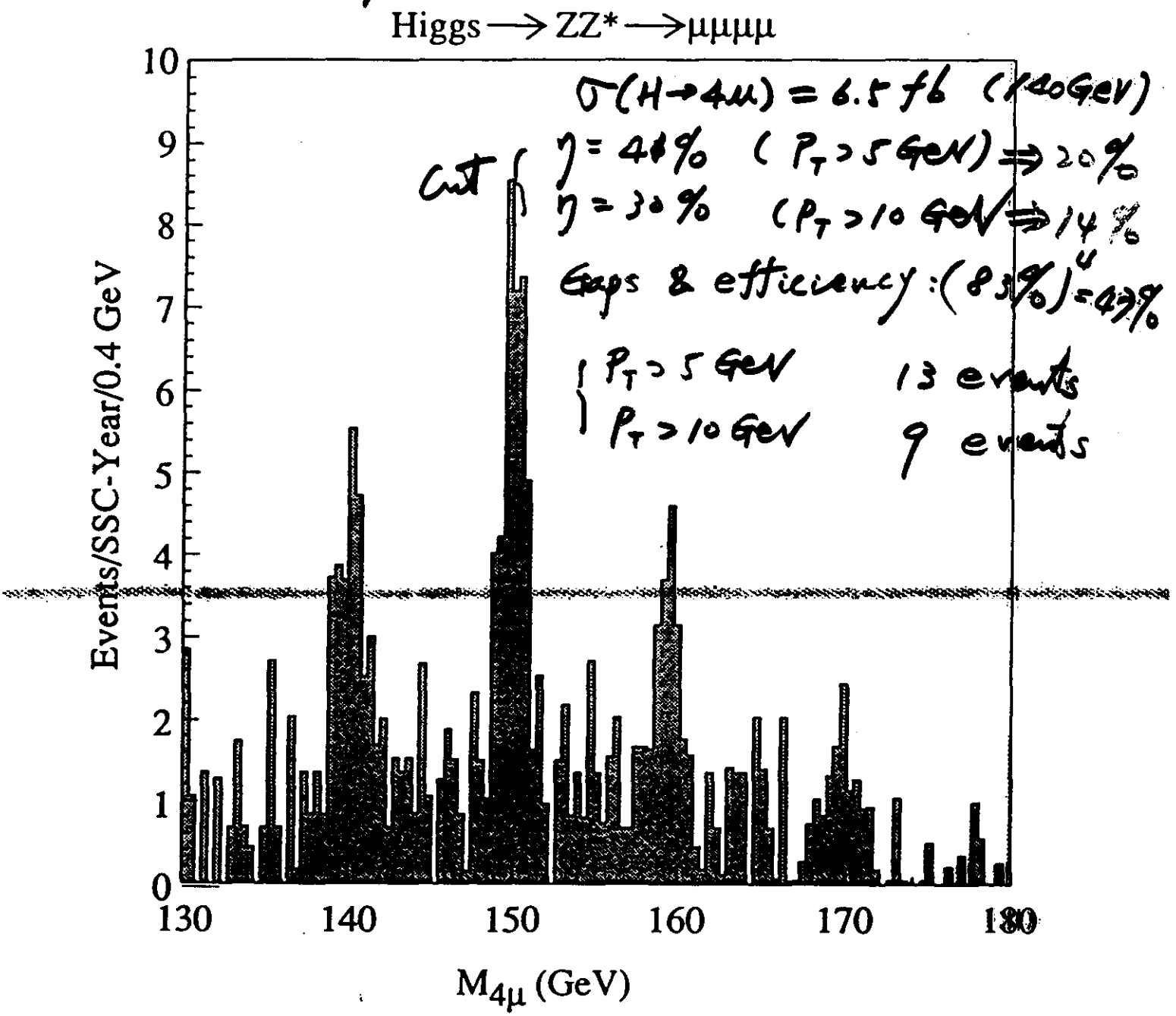


Figure 3.2-2 Mass distribution for H → ZZ* → $\mu^+\mu^-\mu^+\mu^-$ (M_H = 140, 150, 160, 170 GeV)

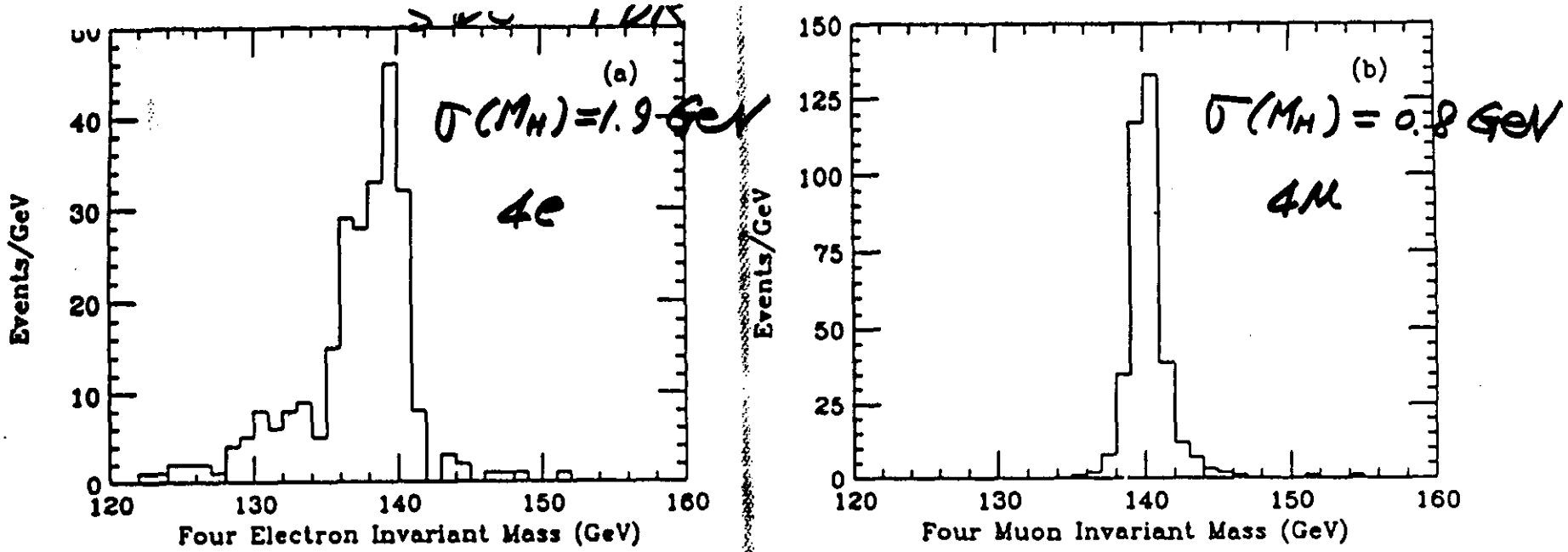


FIG. 3-17. The invariant mass reconstructed by the SDC tracking system for ZZ^* decaying to four leptons for a Higgs mass of 140 GeV. The plots contain events which have been passed through a detailed simulation of the tracking system, and contain the effects of material in the tracking volume, which severely degrades the performance for electrons due to the induced bremsstrahlung. (a) the mass distribution for the $4e$ final state. (b) the mass distribution for the 4μ final state.

Mass resolution

For the SDC baseline detector, in the kinematic region relevant for $H \rightarrow ZZ^*$ decays, the parametrized tracking resolution is significantly better than the calorimeter resolution. For $M_{\text{Higgs}} = 140$ GeV, the four-muon mass resolution is almost identical to that of the four-electron mass measured with the tracking system, and is 0.8 GeV. The four-electron mass resolution measured with the calorimeter is 1.9 GeV for the same Higgs mass. For the muon final states, it is possible to take full advantage of this resolution. However, for final states with electrons, the parametric resolution is degraded by the passage of the electrons through the material in the tracking volume and the subsequent induced bremsstrahlung. A detailed simulation, described in Chapter 4, and summarized in Fig. 3-17, indicates the severity of the effect. For the calorimete[illegible] even at a p_t of 10 GeV, the bremsstrahlung photon and the original electron will almost always lie wit[illegible] 10 cm of each other, and henc[illegible] included in the 2×2 cell array used to reconstruct the energy (alt[illegible]gh the track will no longer poi[illegible]ctly to the centroid of the energy cluster in the calorimeter). Th[illegible] calorimeter energy measuren[illegible] largely immune to the bremsstrahlung effects which degrade th[illegible]

Table 3-16

A summary of the properties of a number of different models for a new Z boson (all in the context of a general E_6 model). A new Z with the Standard Model couplings to quarks and leptons is also included for reference. The widths are in GeV, and the production cross sections are in pb, including only events within $\pm\Gamma$ of the peak, and not including any efficiency or acceptance factors. The cross section includes the expected branching ratio to the e^+e^- final state, assuming that the new Z decays only to Standard Model particles.

$\frac{\sigma(M_{Z'})}{M_{Z'}} = (0.2-0.5)\%$

Property	$\cos\alpha = -0.6$	Z_η	Z_ψ	Z_χ	SM Couplings
$\Gamma(M = 800$ GeV)	8.5	5.0	4.2	9.2	21.4
$\Gamma(M = 4000$ GeV)	42.3	25.2	21.0	46.2	106.9
$\sigma(M = 800$ GeV)	2.1	1.2	1.1	2.4	4.3
$\sigma(M = 4000$ GeV)	0.004	0.0032	0.0027	0.0051	0.010

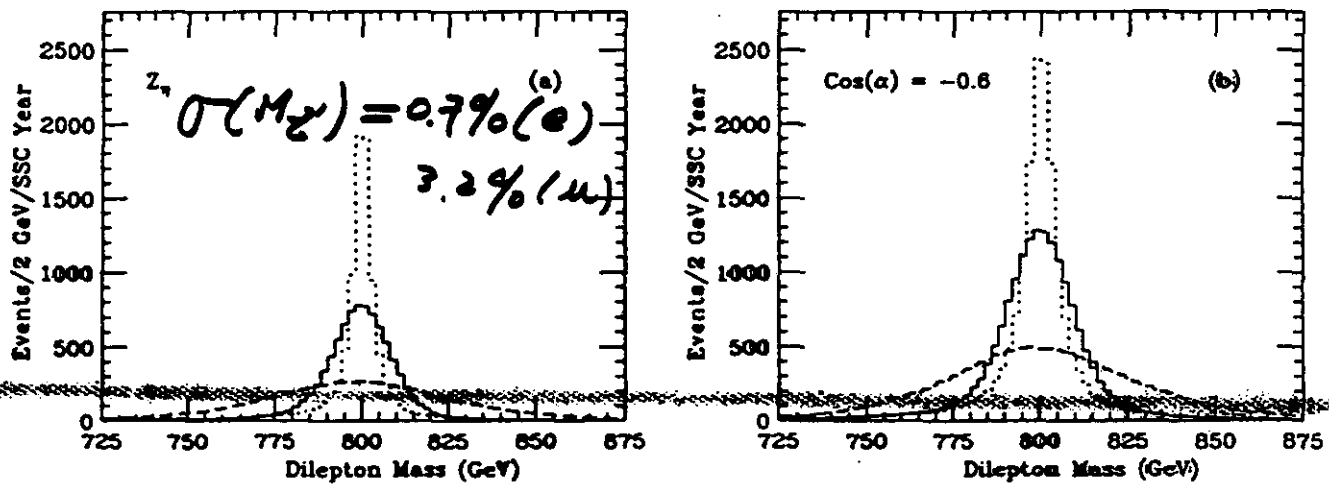
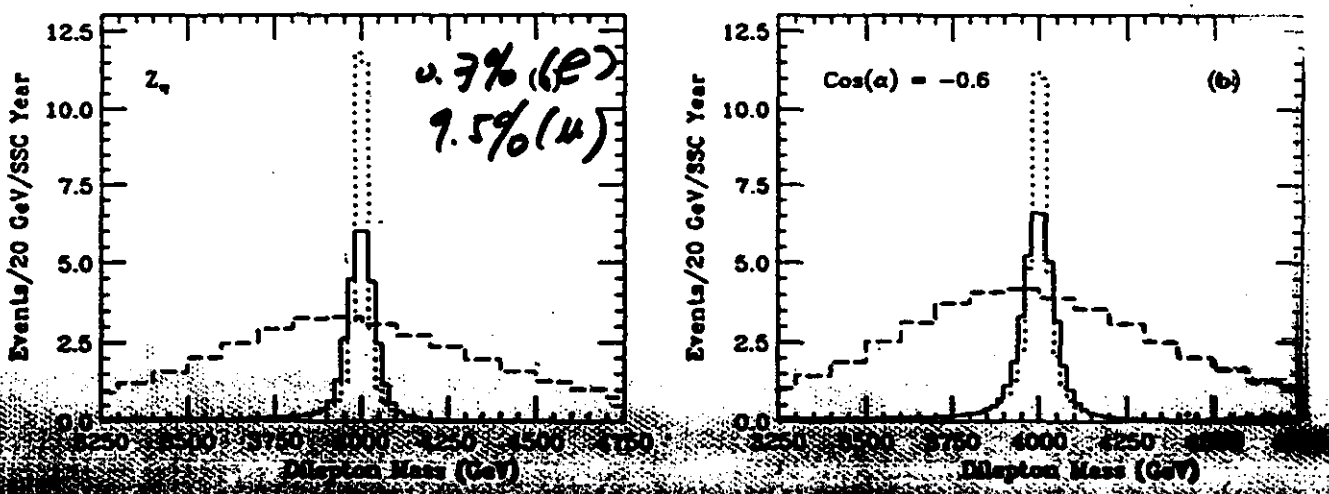


FIG. 3-75. The cross section $d\sigma/dM$ for the production of an $\ell^+\ell^-$ pair for perfect resolution (dotted), the SDC resolution for electron pairs (solid), and the SDC resolution for muon pairs (dashed), as a function of the lepton pair invariant mass. The background is from the continuum production of lepton pairs (Drell-Yan). (a) The peak corresponds to a Z_η with a mass of 800 GeV. (b) The peak corresponds to a new Z with $\cos\alpha = -0.6$ and a mass of 800 GeV.



GEM LoI

$\sigma(M_{Z'}) = 40$ GeV (1%)

$Z' \to e^+e^-$

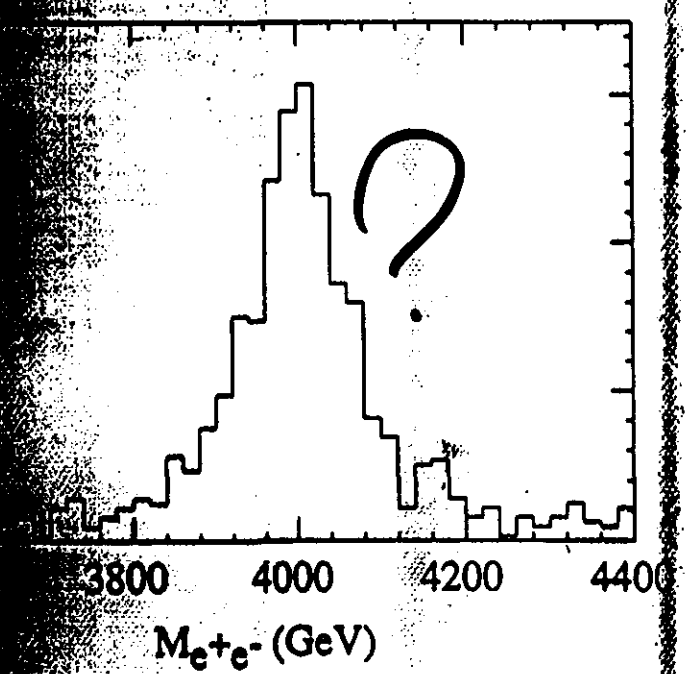


Figure 3.6-2 $Z^{0\prime} \to e^+e^-$ for $M_{Z'} = 4$ TeV, including GEM resolutions, for $\int \mathcal{L}\,dt = 10^{41}\,\mathrm{cm}^{-2}$

$\sigma(M_{Z'}) = 500$ GeV (1%)

$Z' \to \mu^+\mu^-$

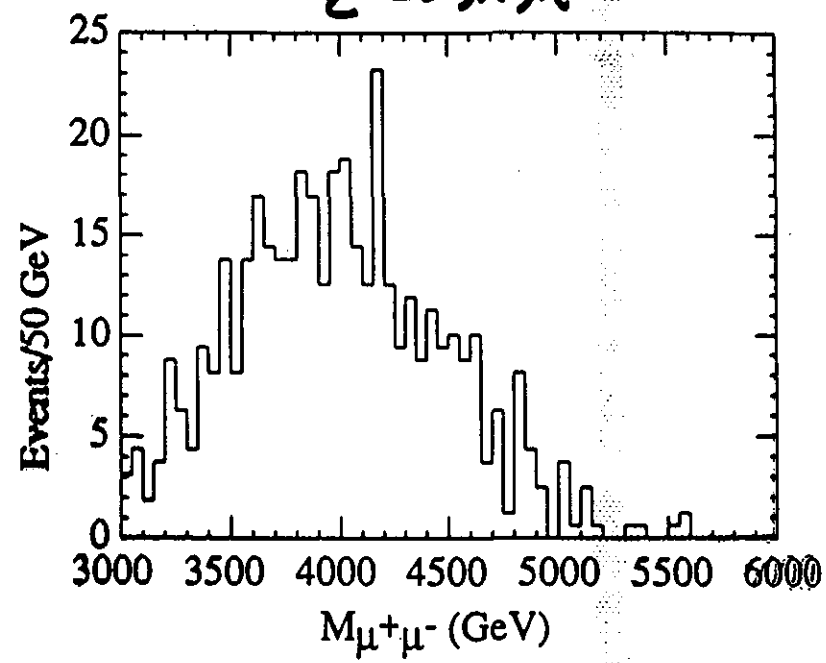


Figure 3.6-2 $Z^{0\prime} \to \mu^+\mu^-$ for $M_{Z'} = 4$ TeV, including GEM resolutions for $\int \mathcal{L}\,dt = 10^{41}\,\mathrm{cm}^{-2}$

SDC Muon

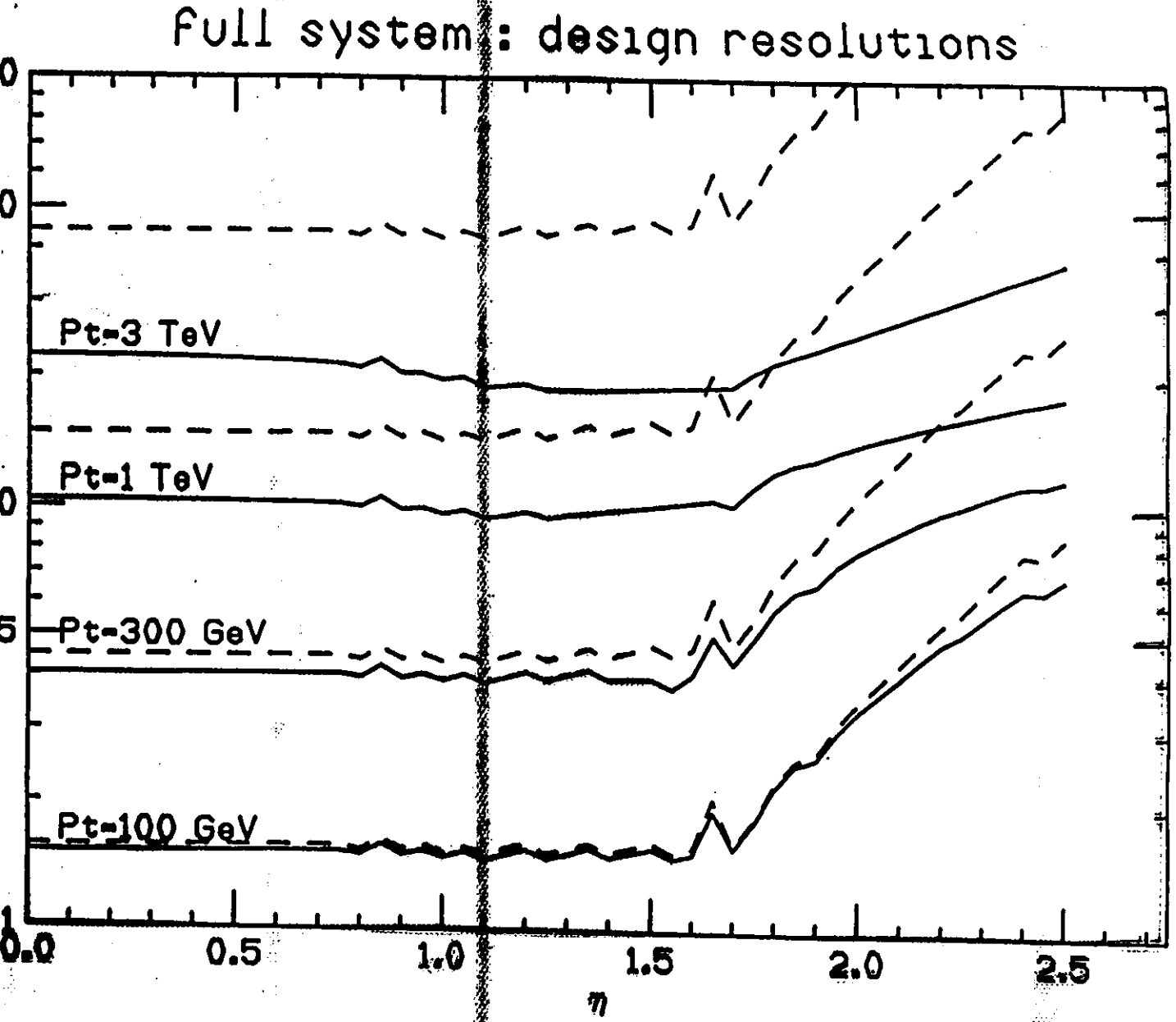


Fig. 5

SDC TDR Tracker

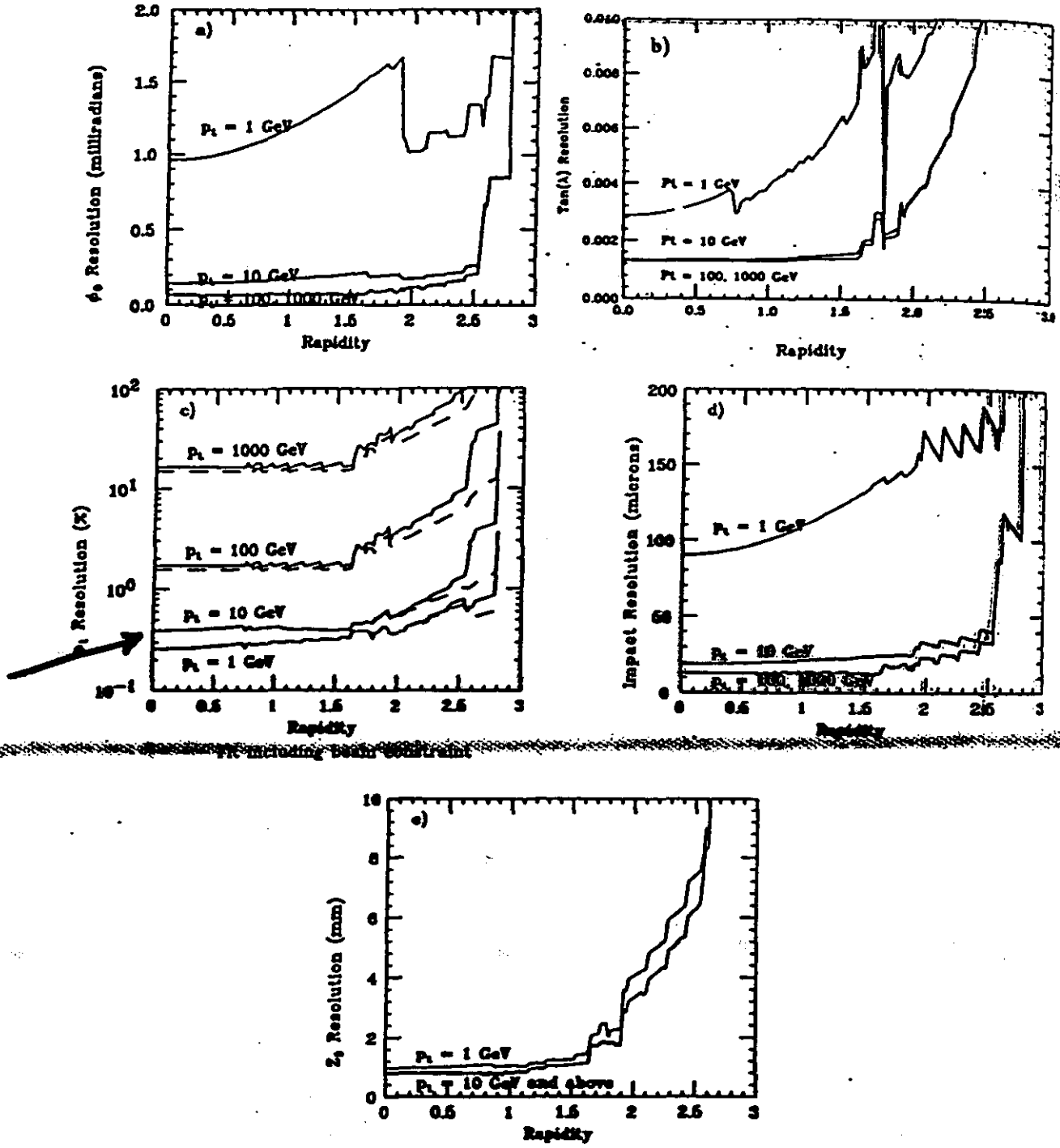


FIG. 4-6. Track parameter errors vs. rapidity for several values of p_t. Parameters are: a) cotangent of the polar angle of the track at its point of origin, b) azimuthal angle ϕ_0, c) transverse momentum p_t, d) impact parameter b, and e) axial position z_0.

GEM Baseline

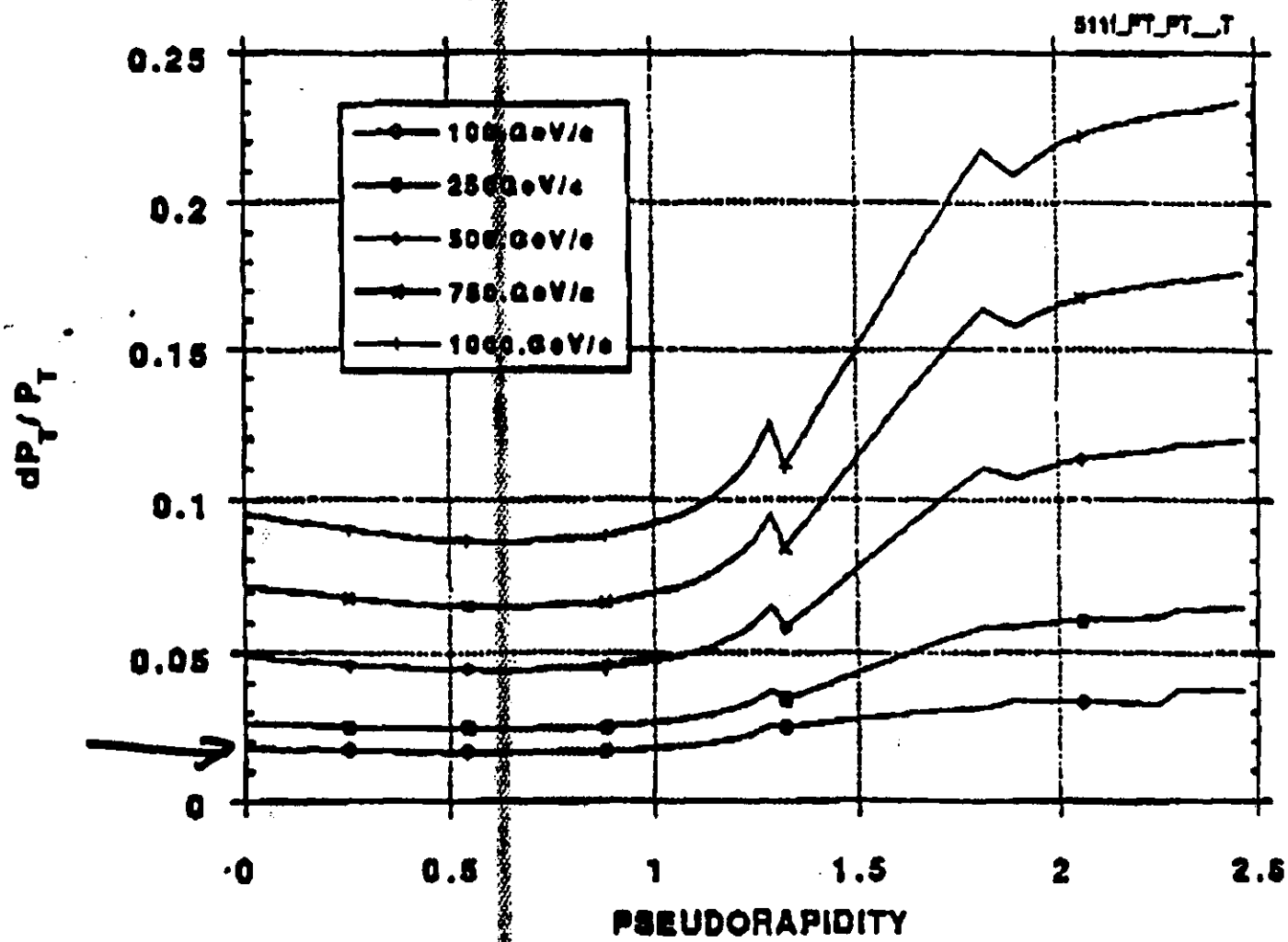


Fig. 3-1.1: The resolution for constant transverse momentum, shown as a function of pseudo-rapidity, $|\eta|$.

GEM Tracker

Design Parameters for the Central Tracker (cont'd)	
Momentum Resolution at high momenta (measurement limited)	$\Delta p / p^2 \sim (1 \text{ to } 3) \times 10^{-3}$ (GeV / c)$^{-1}$
at low momenta (multiple scattering limited)	$\Delta p / p \sim 2$ to 4% ← Now 3.5%
Vertex Resolution along beam direction impact parameter	$\delta z \sim 1$ mm $\delta b \sim 30\ \mu$m above 10 GeV/c

Physics Processes	Id. Primary Vertex	e/γ Separation	e,μ,γ Isolation Cuts	e/h Separation	Muon Momentum Check	e± Sign Separation	Secondary Vertex	Low Momentum Track	Full Event Reconstr.
$H^0 \to \gamma + \gamma$	X	X	X						
$H^0 \to e^+e^-l^+l^-, e^+e^-\nu\bar{\nu}, e^+e^-$ jetjet	X	X	X	X		X			
$H^0 \to \mu^+\mu^-l^+l^-, \mu^+\mu^-\nu\bar{\nu}, \mu^+\mu^-$ jetjet	X		X		X				
Gluino Pair Prod $\tilde{g}\tilde{g} \to e^\pm e^\pm, \mu^\pm e^\pm$	X	X	X	X	X	X			
Techni eta $\eta_T \to b + \bar{b}$ or $t + \bar{t}$	X		X				X		
WW Scattering $W^\pm W^\pm \to e^\pm e^\pm, \mu^\pm e^\pm$	X	X	X	X	X	X			
$Z^1 \to e^+e^-$ Asymmetry	X	X	X	X		X			
B Physics, e.g. $B \to \Psi$, etc.	X						X	X	X
Top Physics $t \to W + b$, etc.	X		X				X	X	X

CENTRAL TRACKER PHYSICS STUDIES

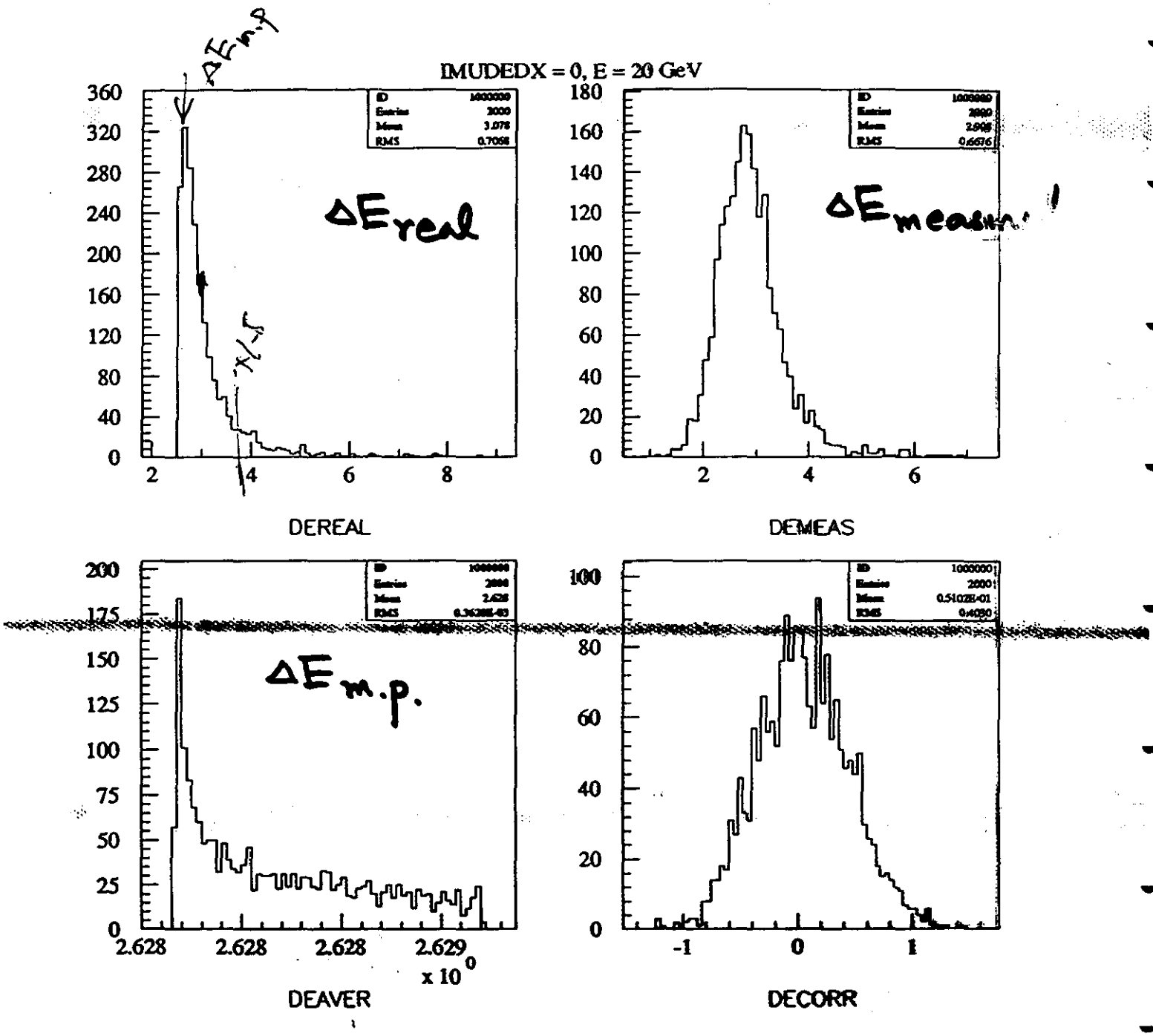
Muon Momentum Measurement

$$p_{rec} = p_\mu + \Delta E$$

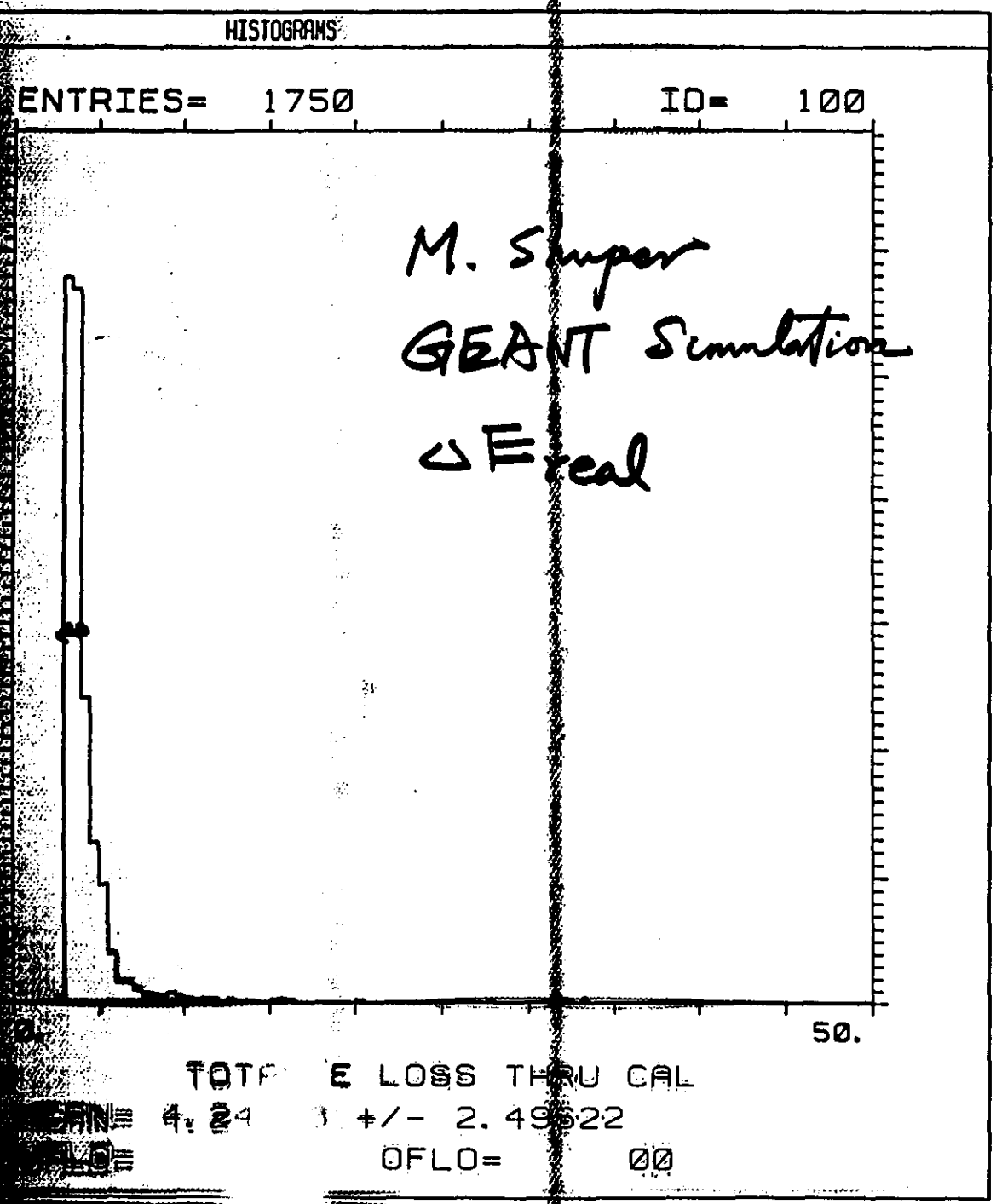
$$\delta p_{rec} = \delta p_\mu \oplus \delta(\Delta E)$$

- $\delta p_{rec}/p_{rec} = 1\%$: $\delta p_\mu/p_{rec}$ and $\delta(\Delta E)/p_{rec} < 1\%$;
- $\Delta E/p_{rec}$ can reach <1%:
  - Real ΔE has narrow width and a Landau tail;
  - Use calculated mean energy loss instead of measured ΔE when $\Delta E_{meas} < k\Delta E_{m.p.}$, reducing effects from noise, calorimeter resolution and bremsstrahlung;
  - Calculated mean energy loss is a function of k and the dE/dx distribution;
  - Contribution of ΔE to 140 GeV Higgs mass width is 700 MeV, corresponding to 1% in $\delta(\Delta E)/p_{rec}$.
- $\delta p_\mu/p_{rec}$ should be improved from 2% to 1%:
  - **Reduce material in the middle layer;**
  - Combine with CT: Improve CT's low p resolution from 3.5% to < 2%.

ΔE R. McNeil in GEMFAST



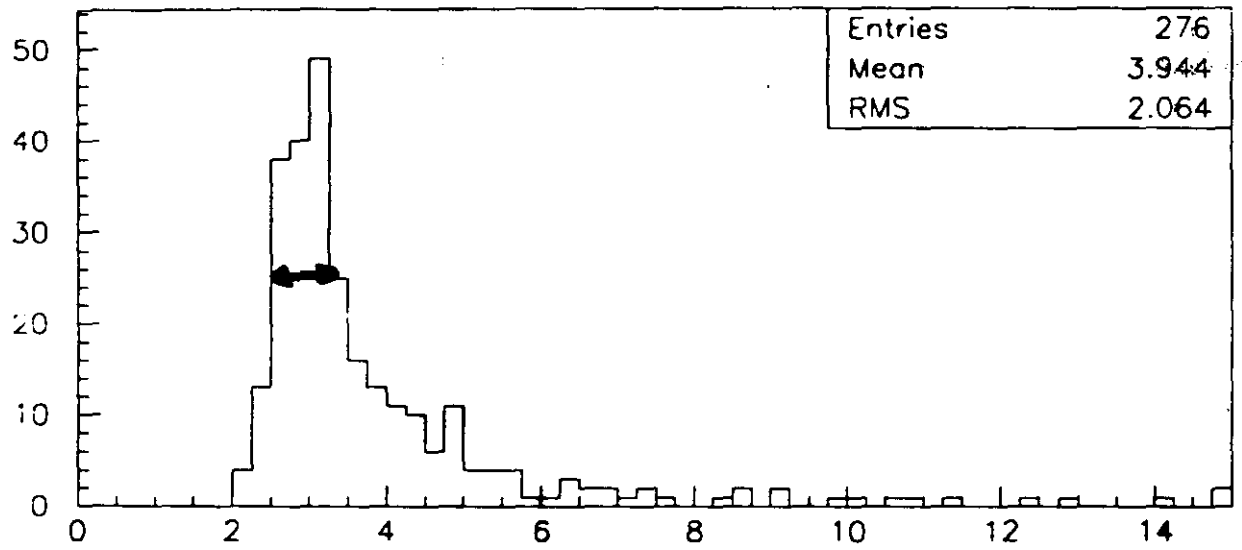
[redacted]


HISTOGRAMS
ENTRIES= 1750
ID= 100
M. Shuper
GEANT Simulation
ΔE real
50.
TOTAL E LOSS THRU CAL
+/- 2.49622
OFLO= 00

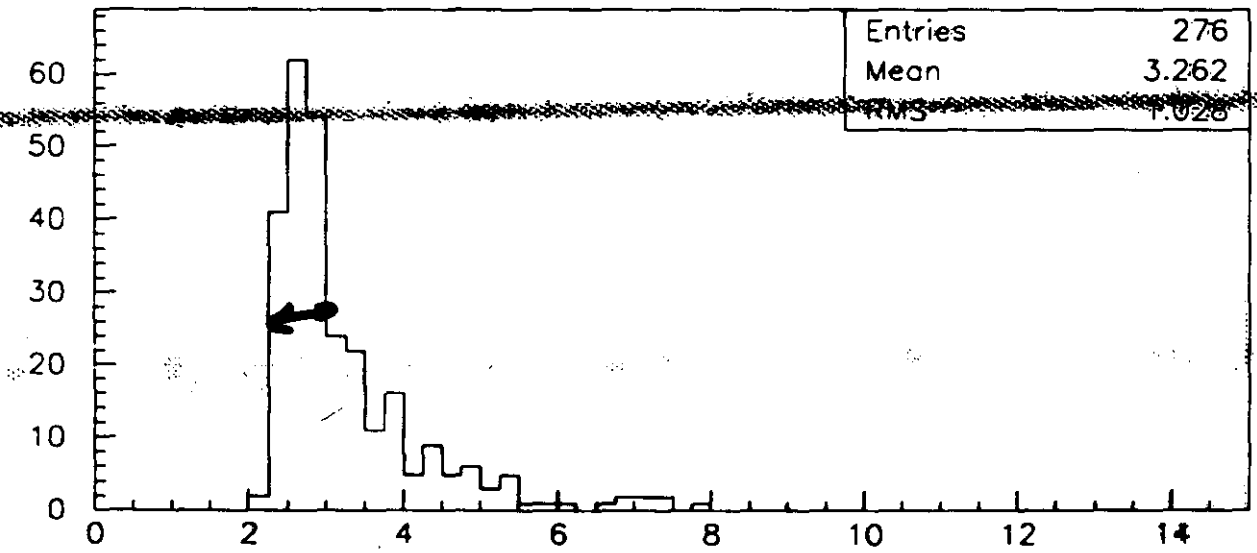
JAGUAR

GEMFAST Parametrization

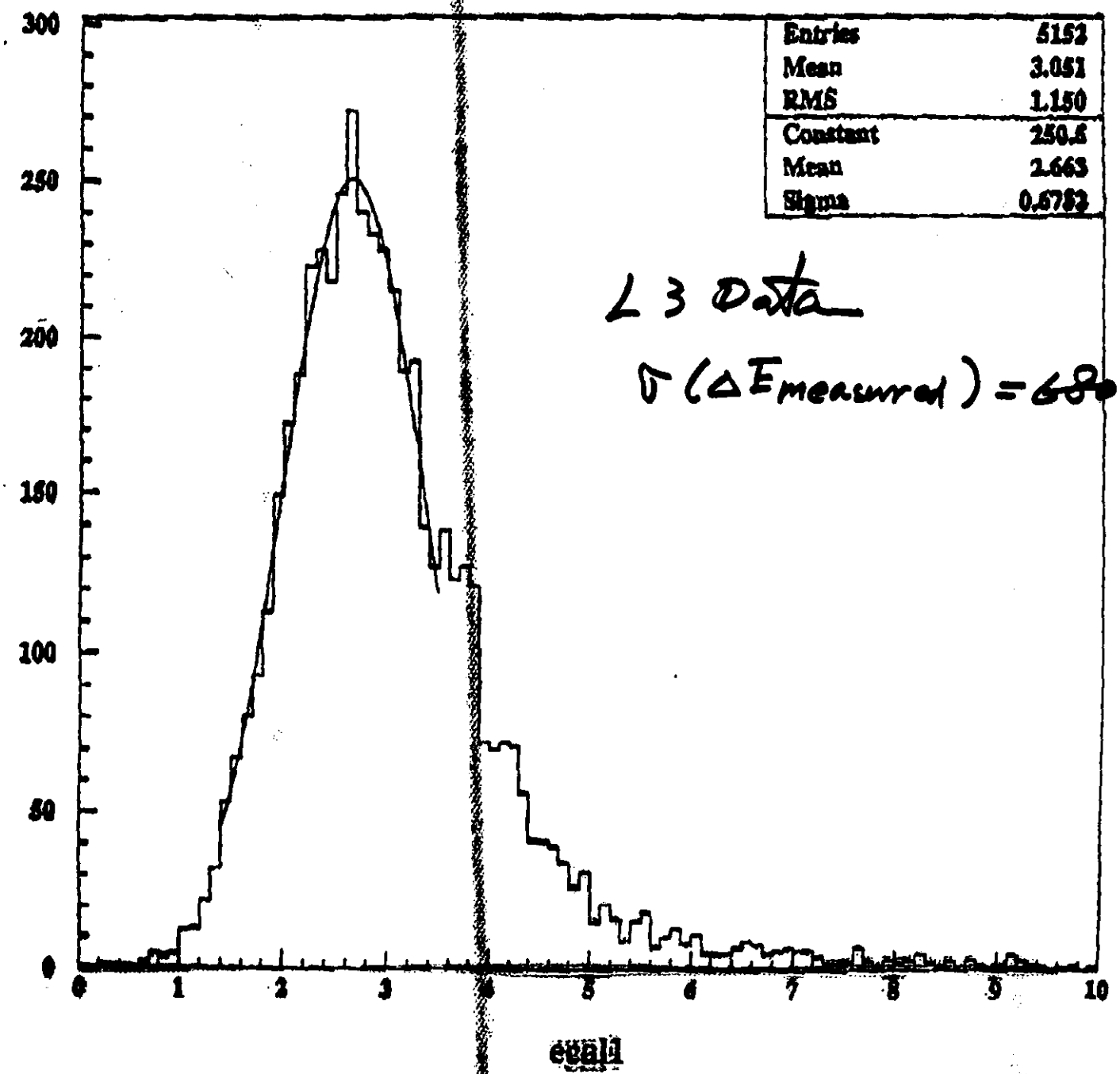
ΔE_{real}



Barrel Eloss – Dingus 50 GeV

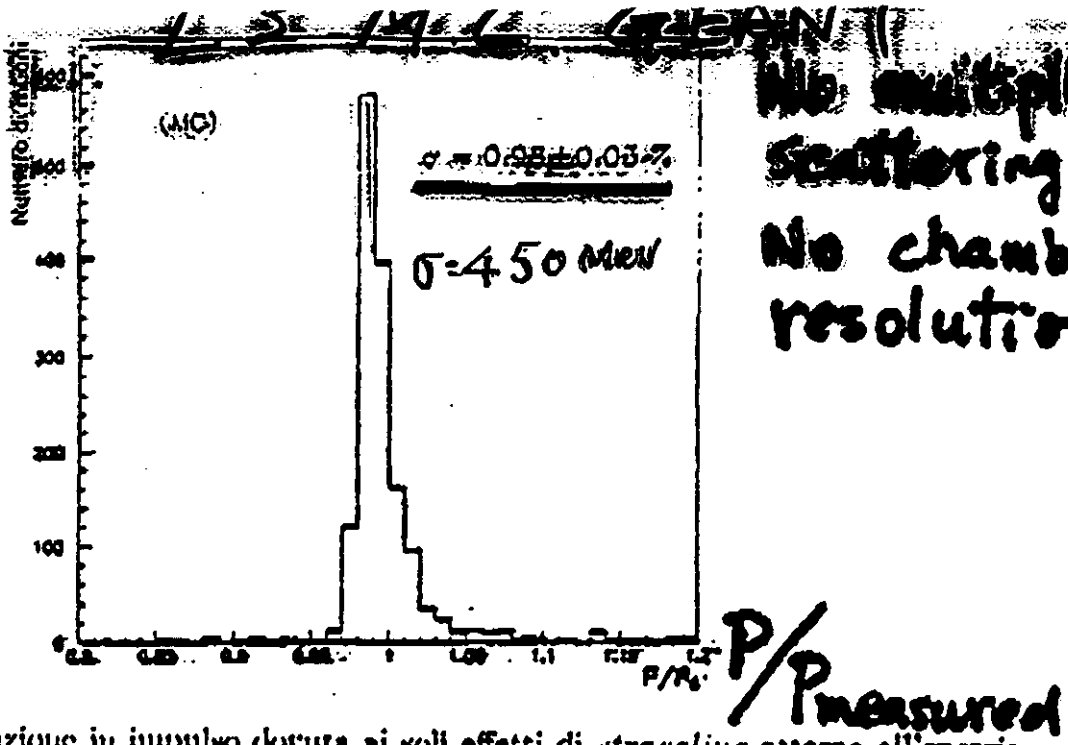


Barrel Eloss – McNeil 50 GeV



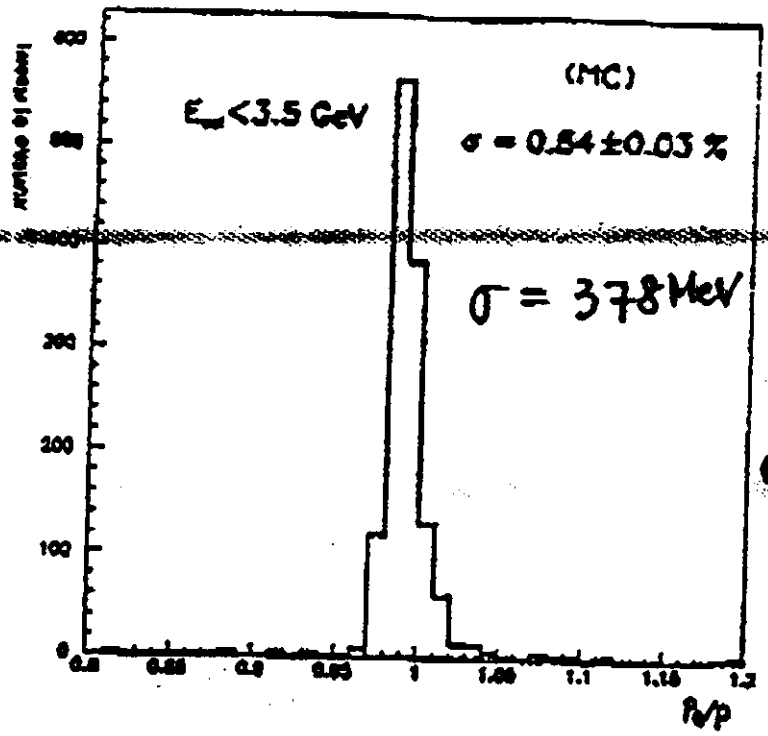
L3 Data

$\sigma(\Delta E_{measured}) = 680$ MeV



No multiple scattering.
No chamber resolution.

gura 3.6: Risoluzione in impulso dovuta ai soli effetti di *straggling* attorno all'energia edia persa per ionizzazione



Same as above.
but cut at $E_{cal} < 3.5$
This cut will loss 20% events

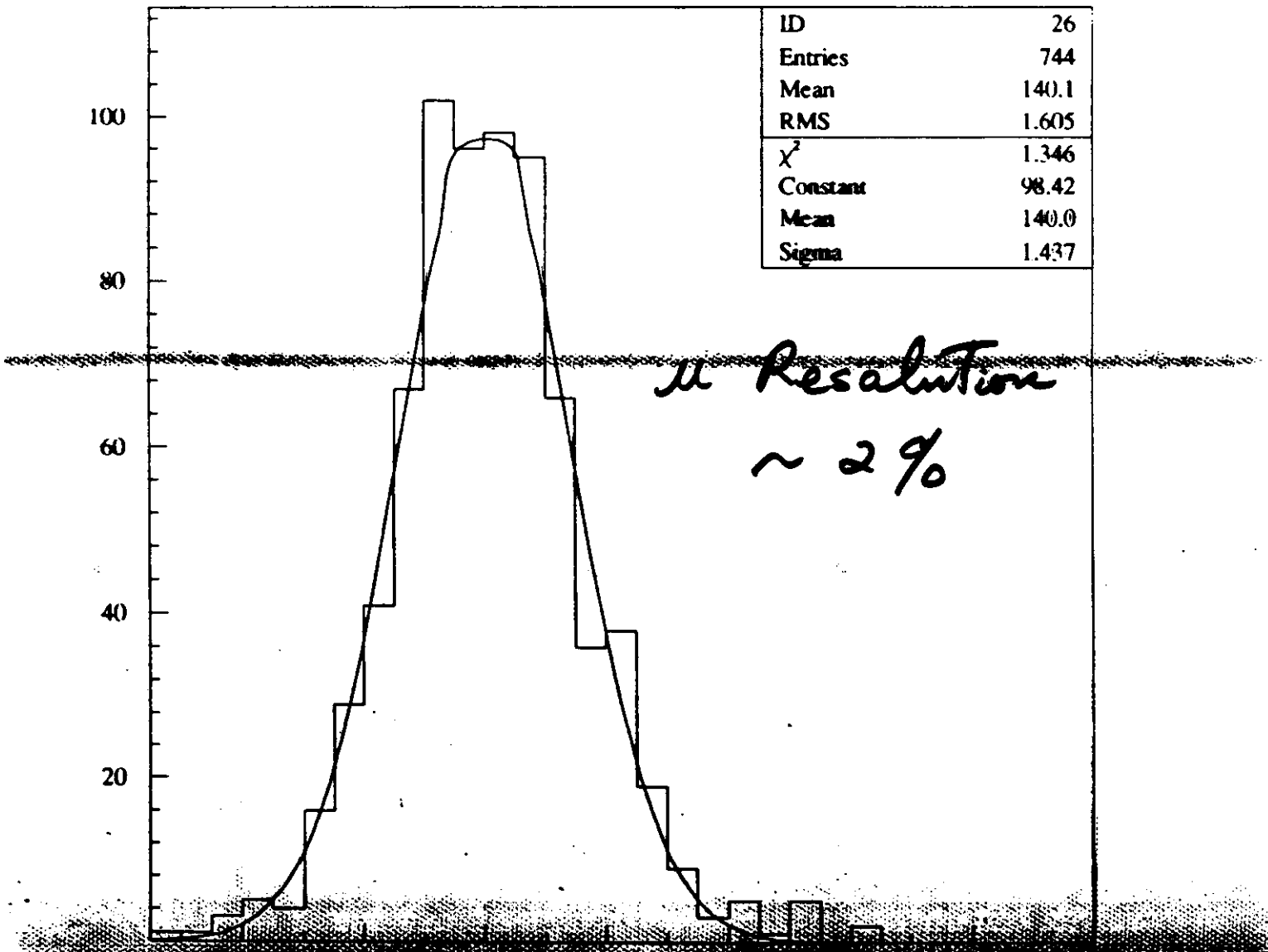
ıra 3.7: Risoluzione in impulso dovuta ai soli effetti di *straggling* attorno all'energia lia persa per ionizzazione dopo aver tagliato gli eventi che rilasciano più di 3.5*GeV/c* calorimetro adronico

GEM Muon System

$H \to 4\mu$ (140 GeV)

4 Vector Smearing with

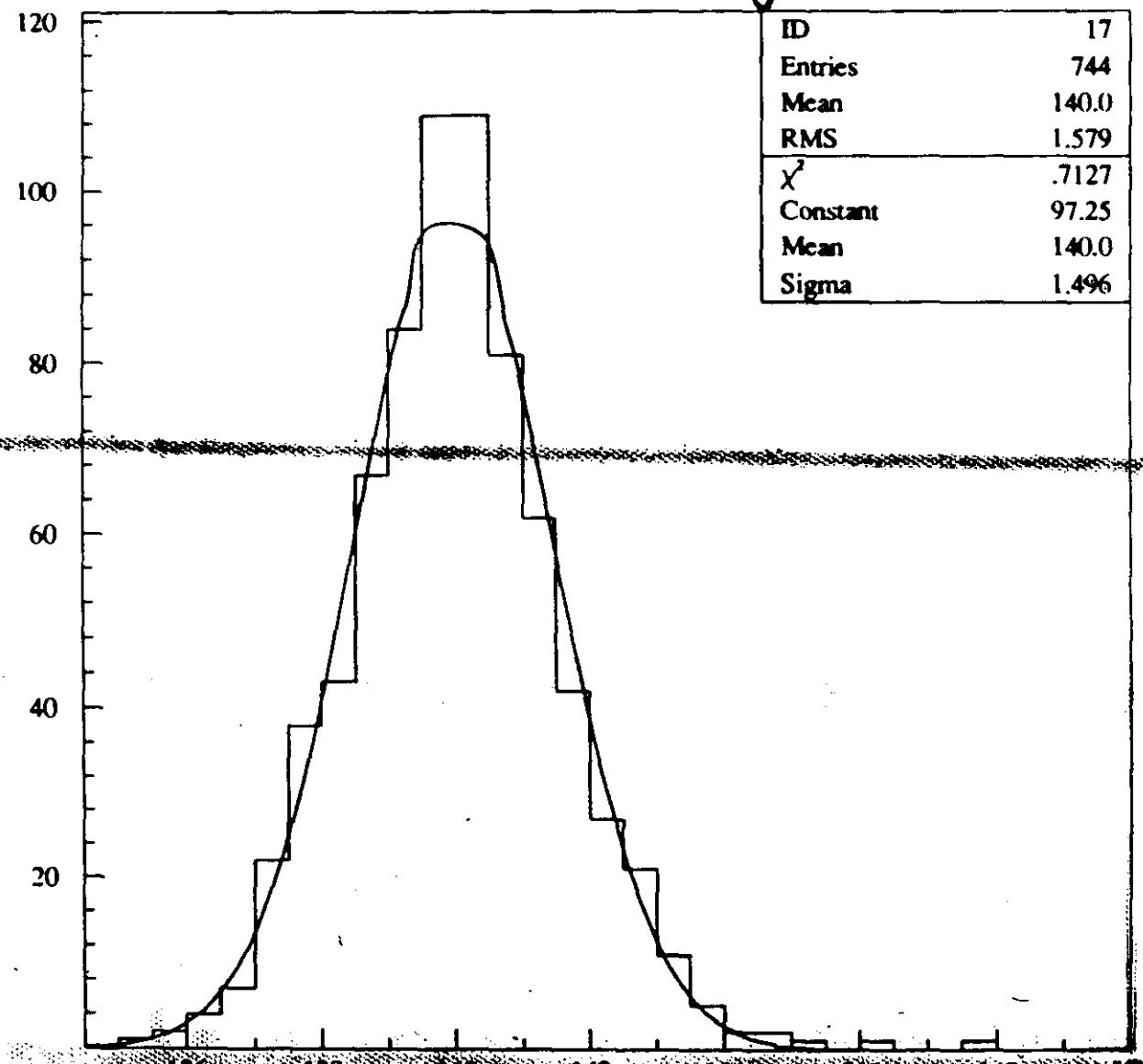
μ Resolution in GEMPNST



$H \to 4\mu$ (140 GeV)

$\frac{dE}{dx}$: Average

ΔE : Average



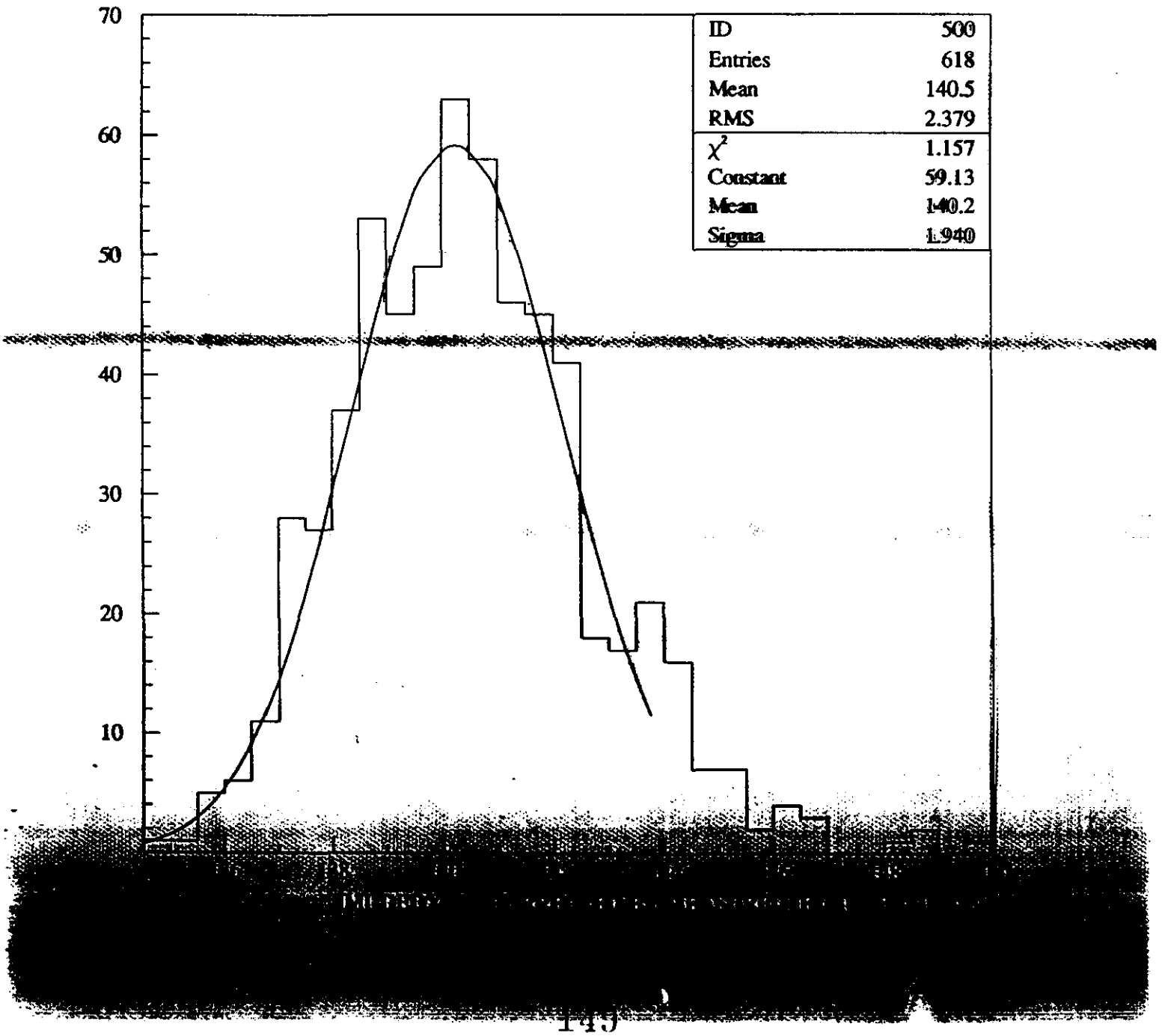
MUDEDX – CORRECTED BY AVERAGE

$\sigma(\Delta E) = \sqrt{1.94^2 - 1.44^2} = 1.3$ GeV

$H \to 4\mu$ (140 GeV)

$\frac{dE}{dx}$: McNeil

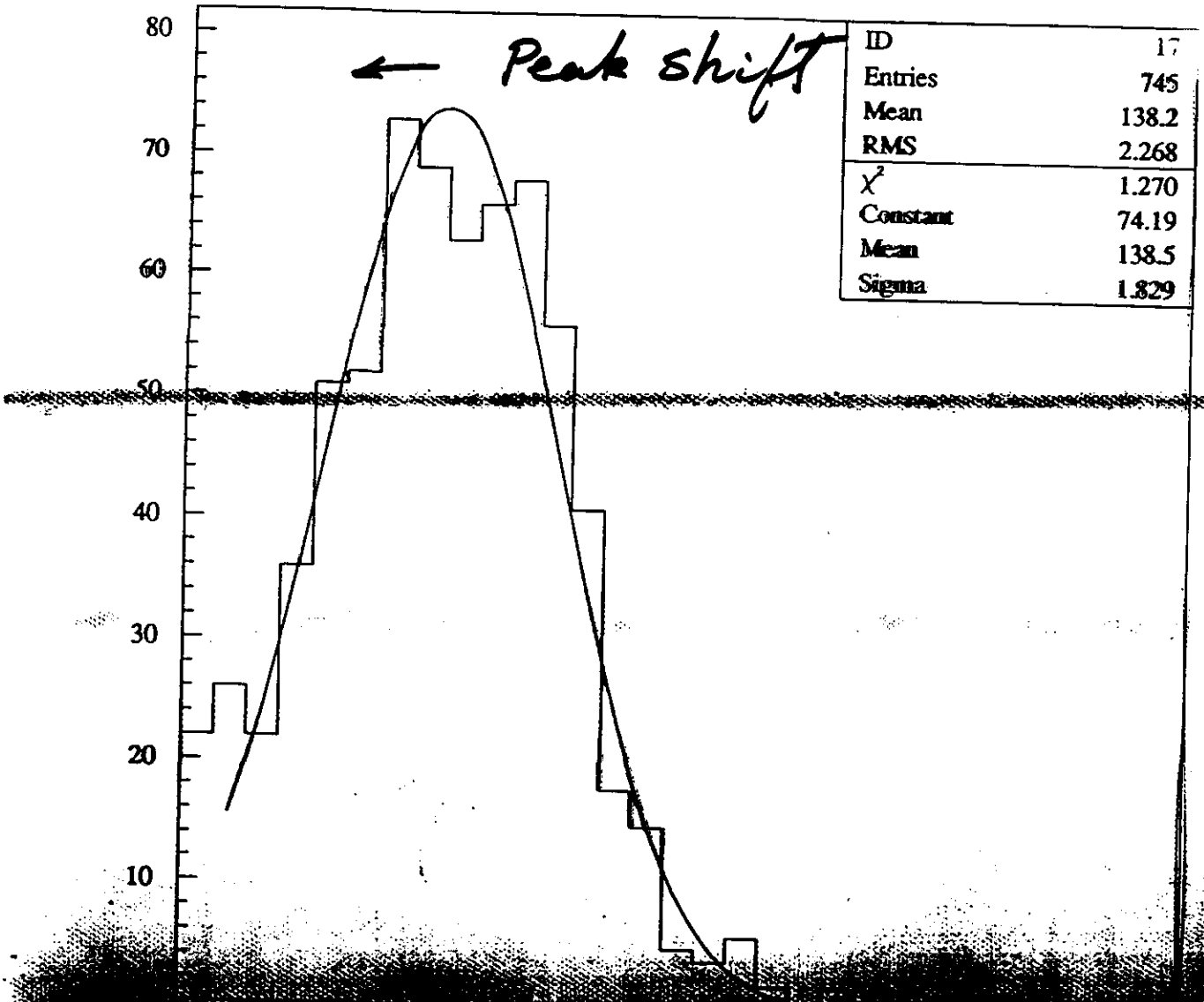
ΔE : measured (all $E_T > 5$ GeV)



$H \rightarrow 4\mu$ (140 GeV)

$\frac{dE}{dx}$: McNeil

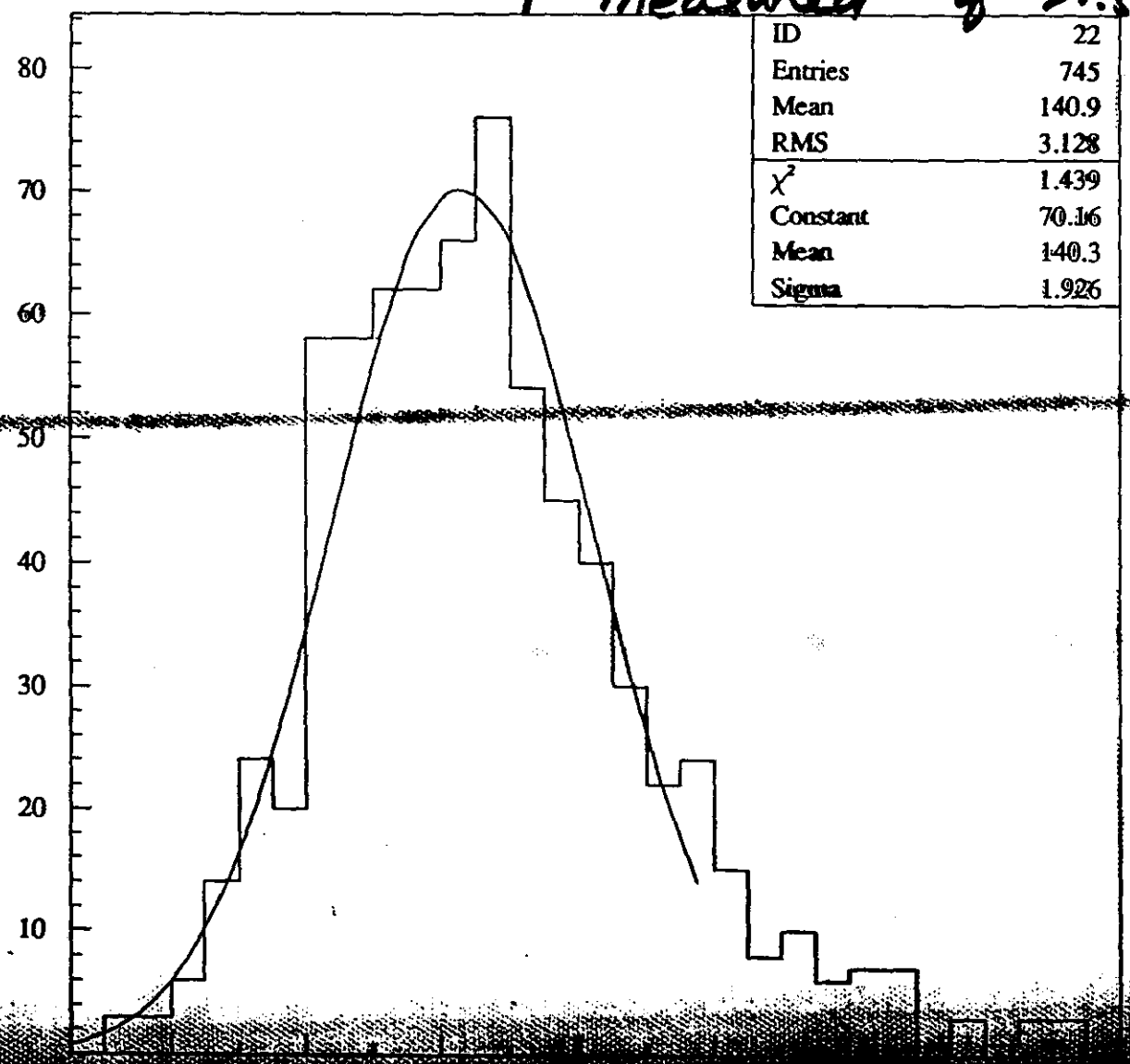
ΔE : Calculated



$H \to 4\mu$ (140 GeV)

$\frac{dE}{dx}$: McNeil

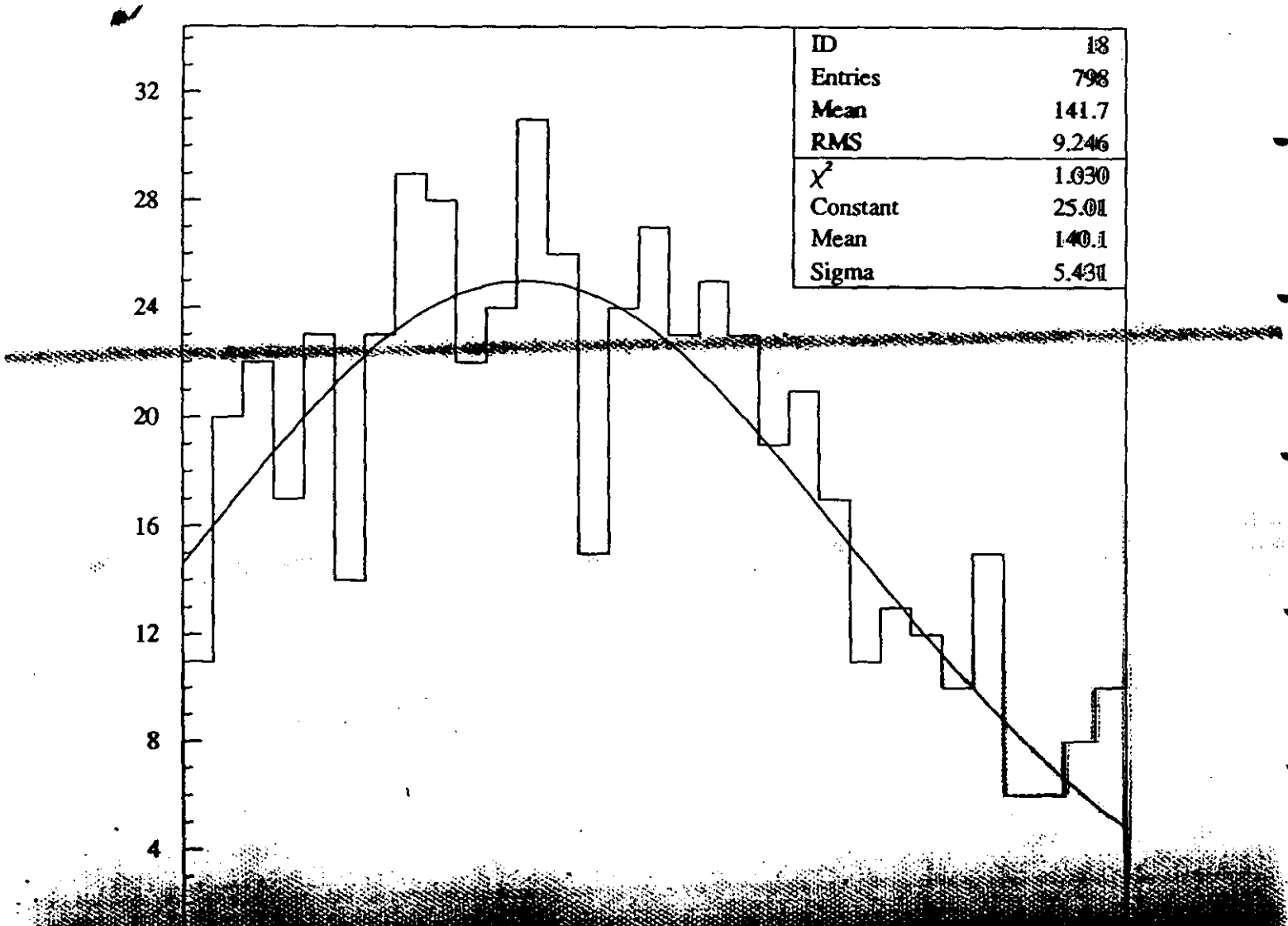
ΔE : { Calculated if $< 1.5 E_c$
Measured if $> 1.5 E_c$



$H \rightarrow 4\mu$ (140 GeV)

Central Tracker Resolution

Use CT ?

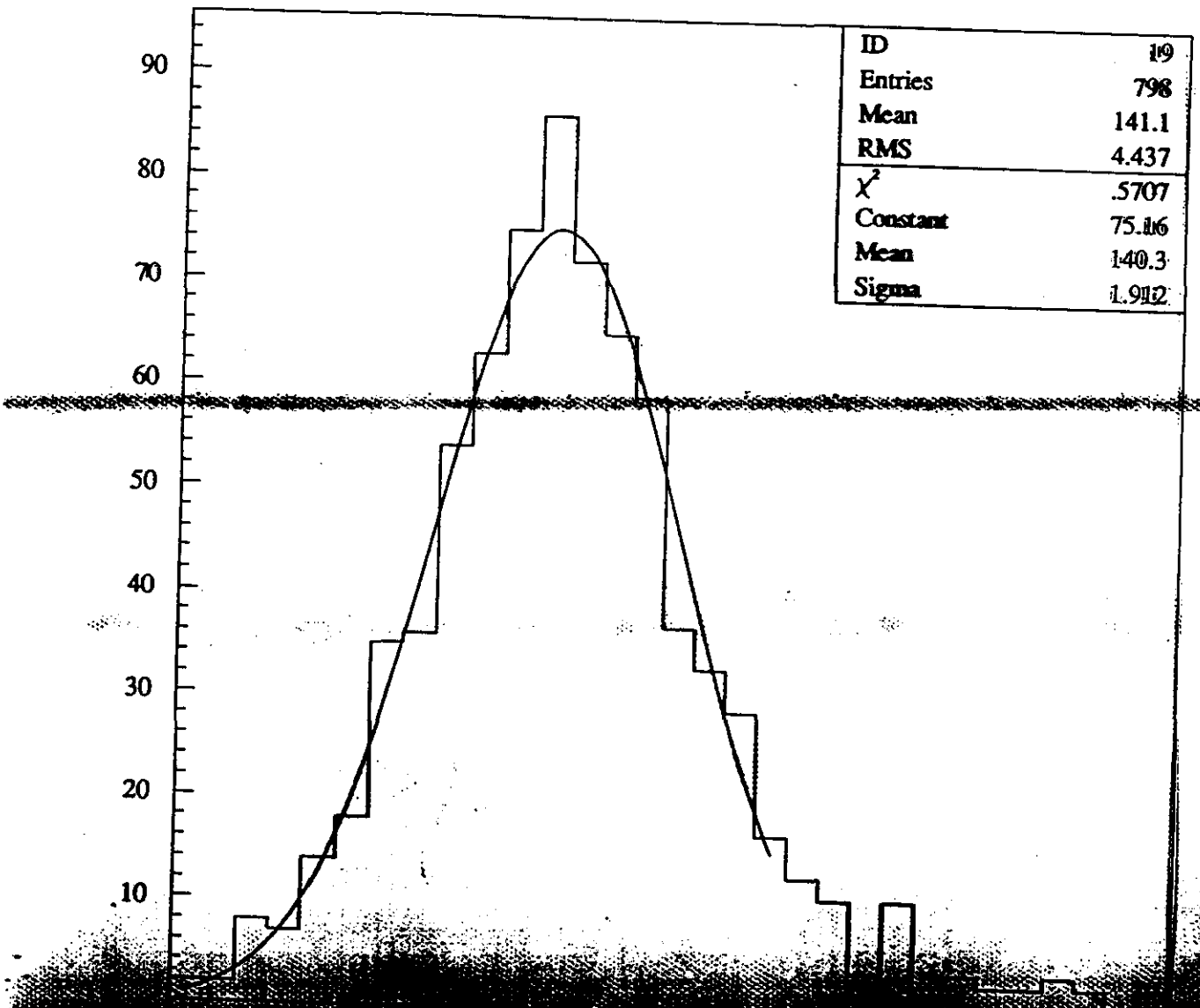


$H \rightarrow 4\mu$ (140 GeV)

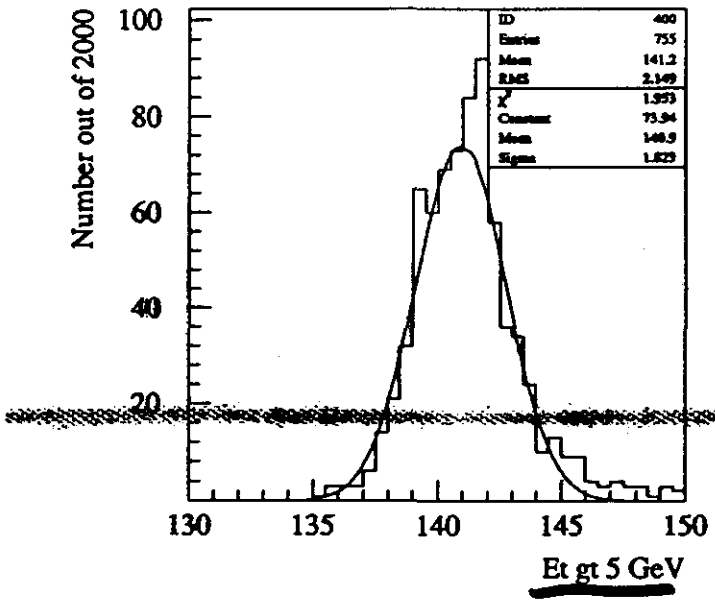
$P_T^{\mu} < 15$ GeV : CT

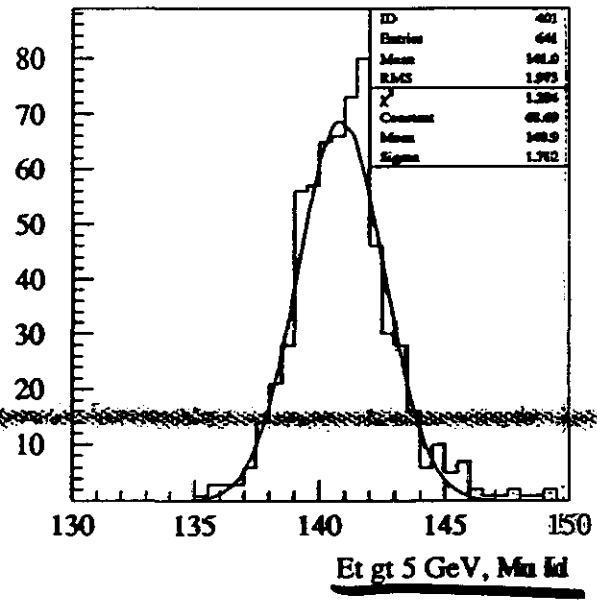
$P_T^{\mu} > 15$ GeV : Muon

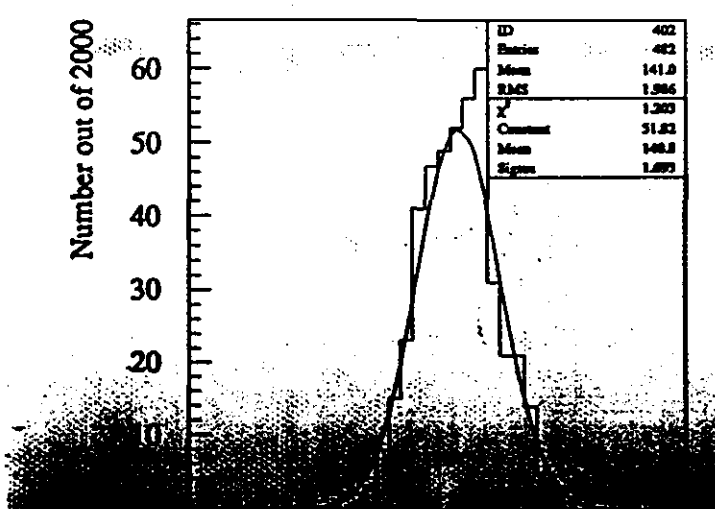
USE CT?

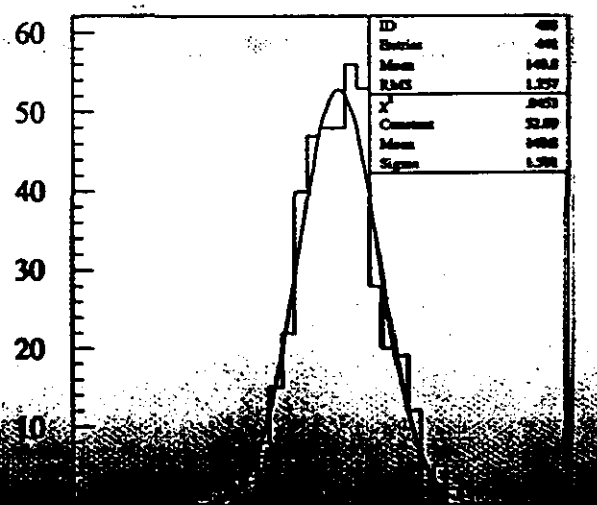


$\sigma(M_H) = 1.82$ GeV 1.311 GeV





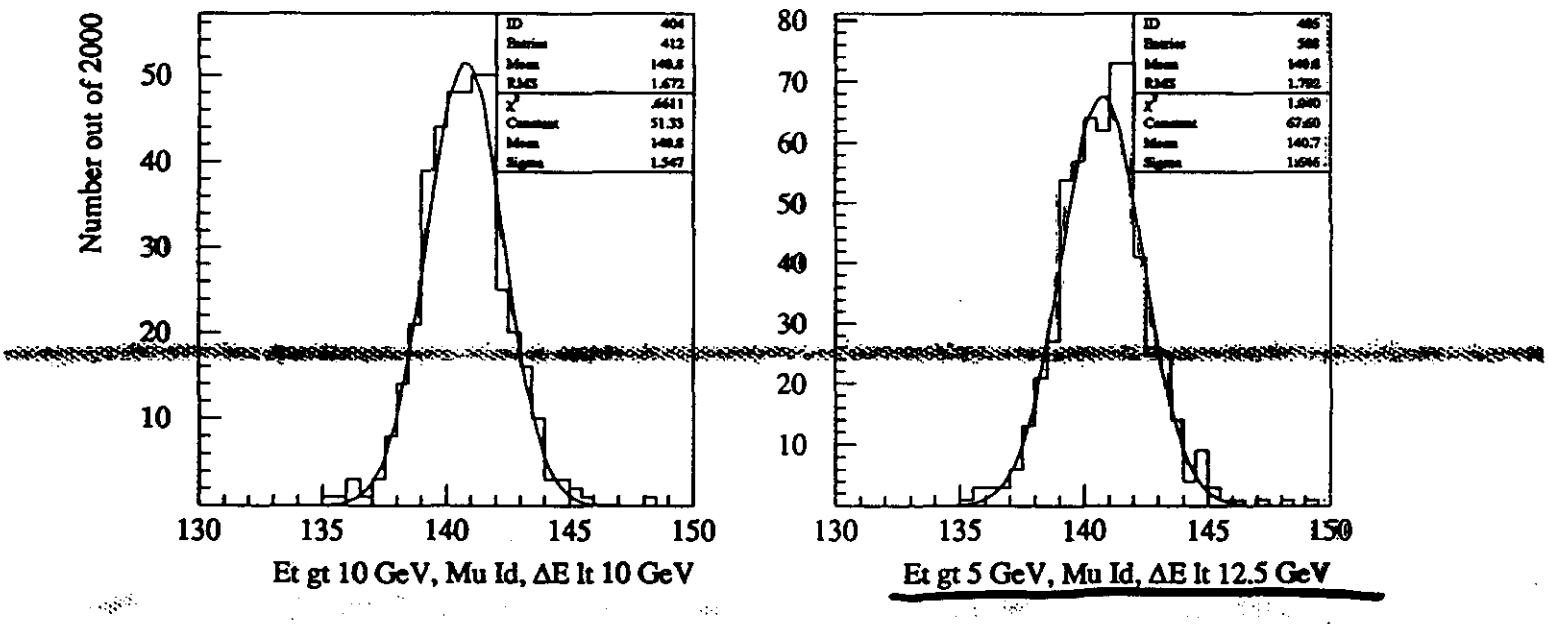


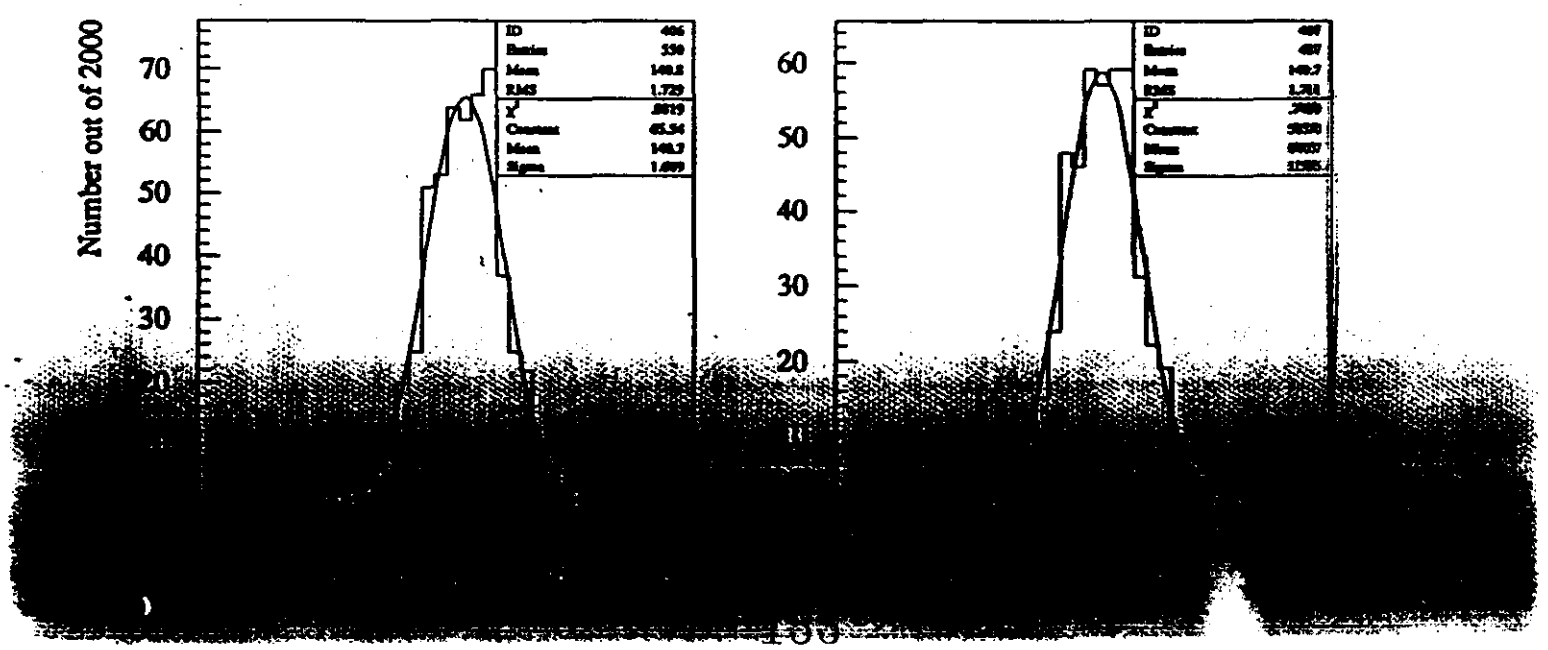


GEMTFRSTT

$\sigma(M_H) = 1.65$ GeV, 1.61 GeV

$$\sigma(\Delta E) = \sqrt{1.61^2 - 1.44^2} = 720\,\text{MeV}$$





Conclusion

- The intrinsic muon chamber resolution is 2% at low p, while dE/dx contribution to Higgs mass of 140 GeV corresponds to 1%.

- The dE/dx contribution can be further reduced by finding a function which deconvolutes the measured dE/dx spectrum to the real dE/dx.

- The constant term of GEM muon measurement thus is entirely dominated by the chamber itself.

- The bad constant term is caused by materials in the middle layer of muon system, i.e. average 30% X_0 according to Torre.

- Solution:
  - **REDUCE MATERIAL IN THE MIDDLE LAYER!!!**
    Get rid of overlap;
  - Combining muon with CT. However, CT has 3.5% constant term:
    REDUCE MATERIAL IN CENTRAL TRACKER!!!