Review of Detector Background for a Muon Collider

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Highest Energy Muon Collider Workshop

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Acknowledgements

- This talk is a review of previous presentations on detector backgrounds for a muon collider. Nothing here is new.
- Input comes from
  - Snowmass 1996 Feasibility Study
  - Published Status Report (1999)
  - Rosario Muon Collider Workshop (May 1997)
  - UCLA workshop (July 1997)
  - $\mu^+ \mu^-$ Collider Conference, San Francisco (Dec 1997)
  - Muon Collider Collaboration Meeting, St.Croix (May 1999)
- Contributors to background studies:
  - I. Stumer
  - O. Benary
  - N. Mokhov
  - S. Geer
  - P. Lebrun
  - R. Palmer
  - S. Kahn

Detector Background Introduction

- Muon decay backgrounds are expected to be high:

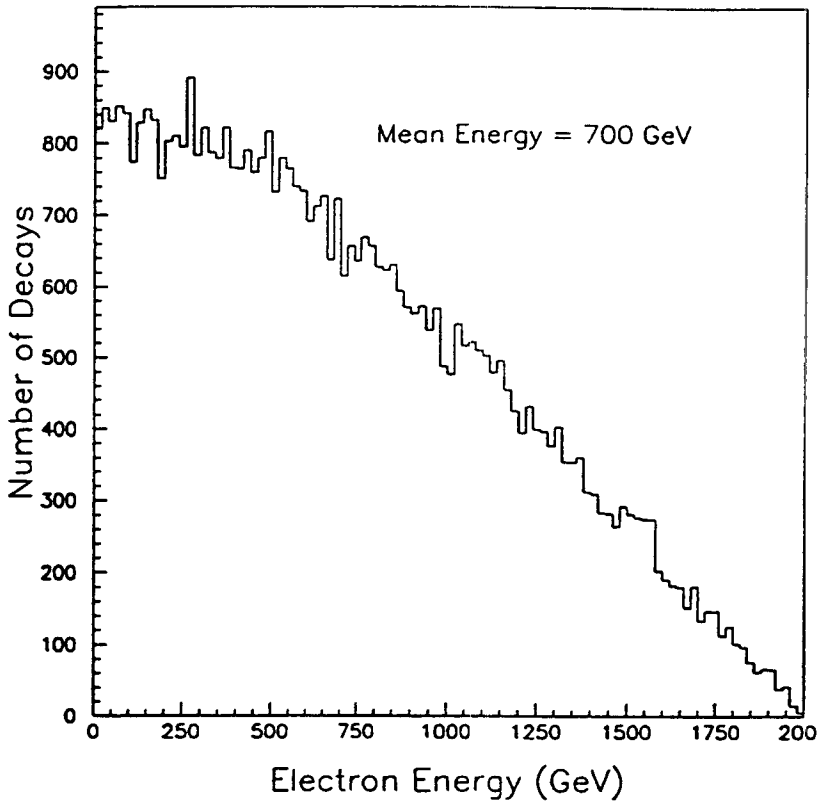
Collider	μ per bunch	Decays/meter
50×50 GeV	4×10^{12}	1.6×10^{7}
250×250 GeV	2×10^{12}	1.6×10^{6}
2×2 TeV	2×10^{12}	2×10^{5}

- The effort to minimize the backgrounds will have strong influence on:
  - Design of Detector
  - Design of Final Focus for IR

Background Sources

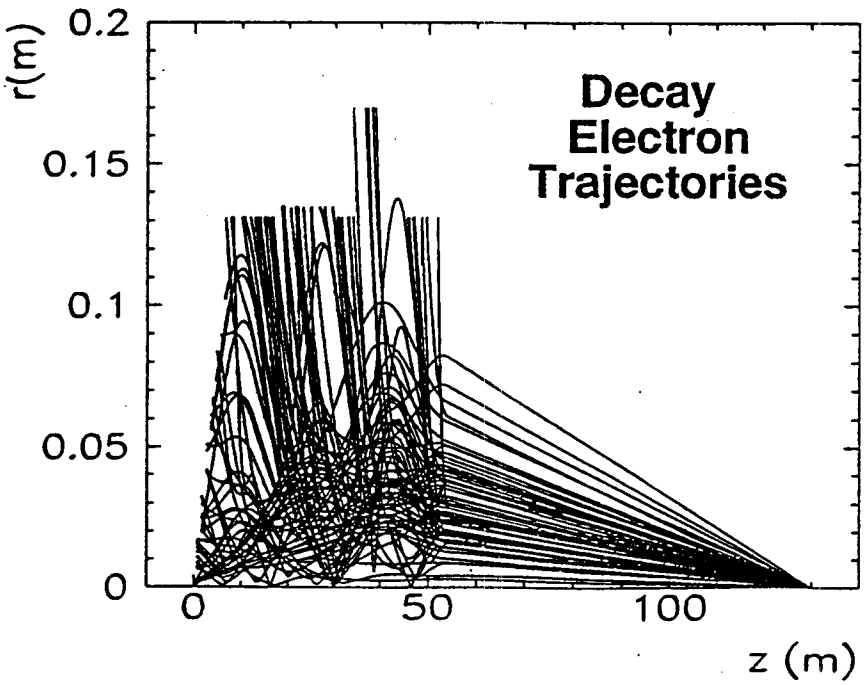
- Muon Decay Background
  - Electron Showers
    - Lepto-Production of Hadrons not included
      - Not important for 2×2 TeV or smaller
      - Could be important at 100 TeV collider
  - Synchrotron Radiation
  - Photonuclear Interaction
    - Source of hadrons
  - Bethe-Heitler muon production
- Beam Halo
  - Beam Scraping Design
  - Collider Sources
- Beam Beam Interactions
  - Believed to be small

Muon Decay Backgrounds



2 x 2 TeV Muon Collider

- 2×10^{12} muons/bunch
- 2×10^{5} decays / m
- Mean decay electron energy = 700 GeV



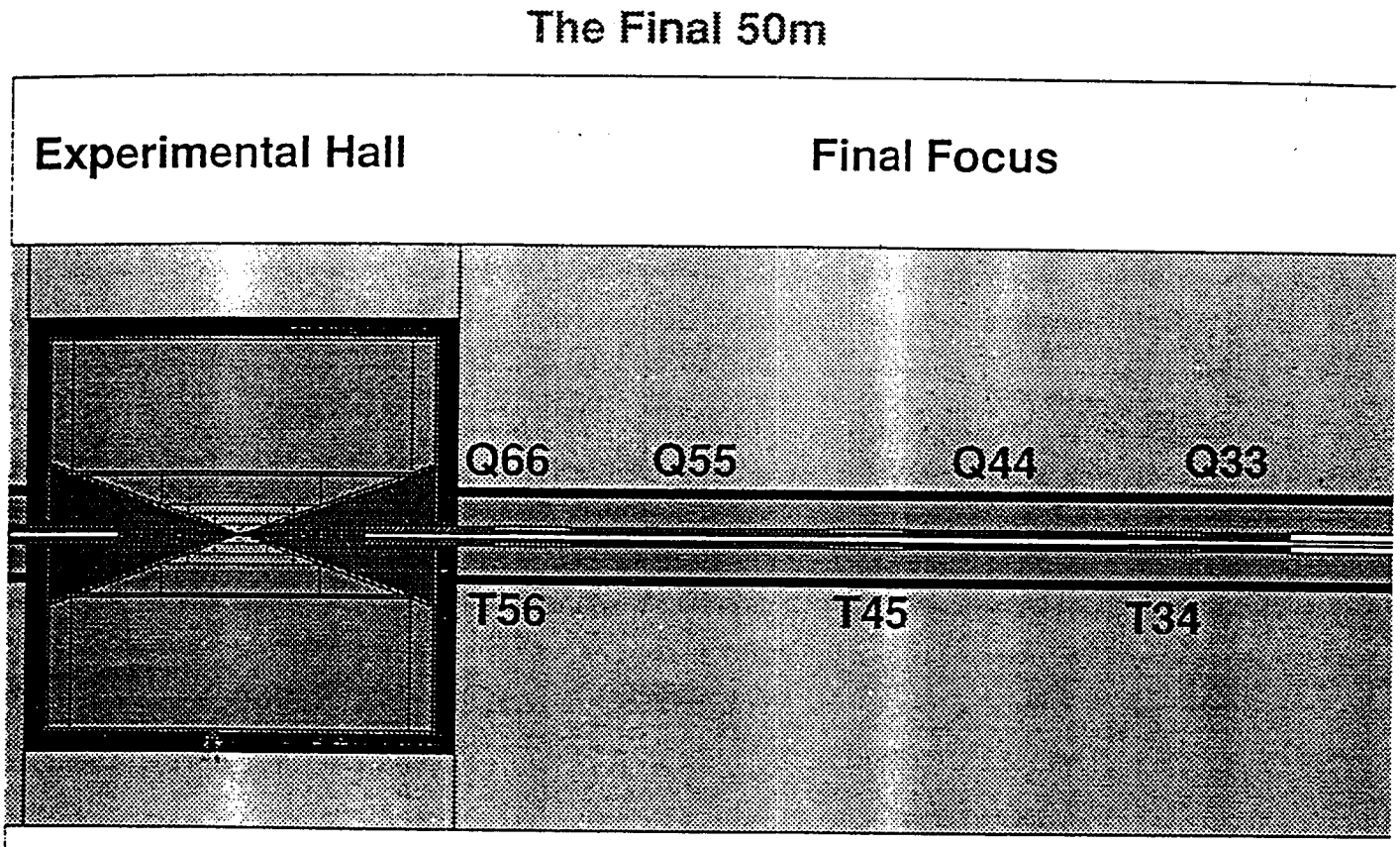
Electron decay angles are O(10) microradians.

Therefore, in the final focus section, decay electrons tend to stay in the beampipe until they see the final focus Quad fields etc.

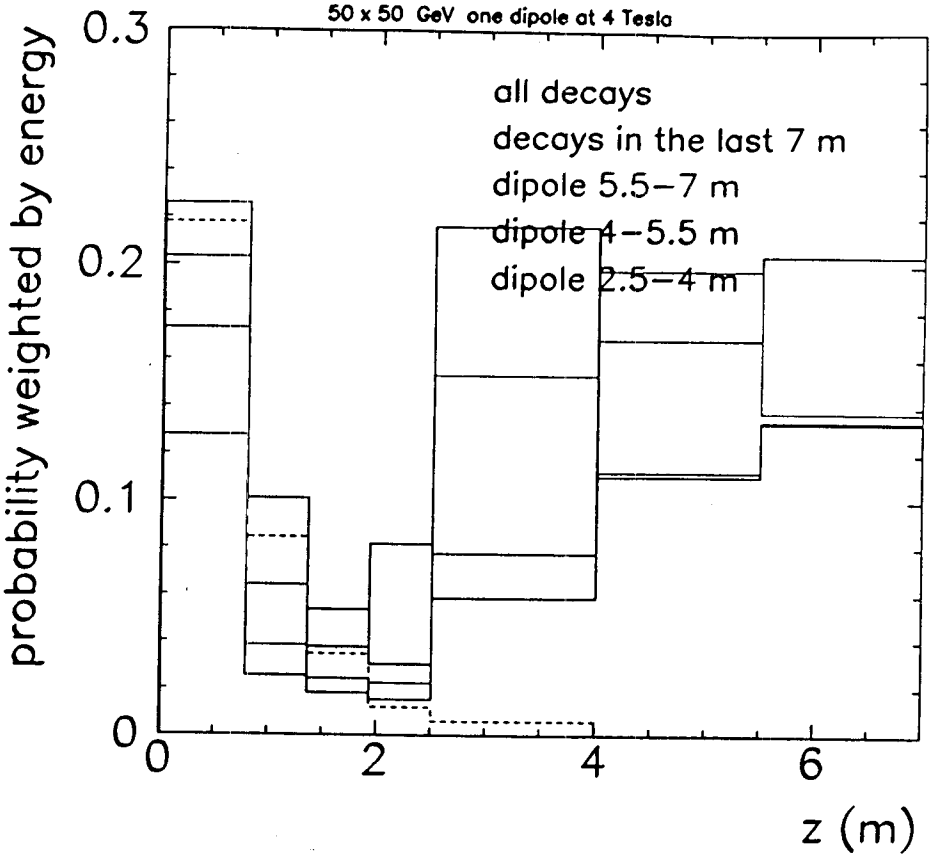
Shielding Configuration to Reduce Backgrounds

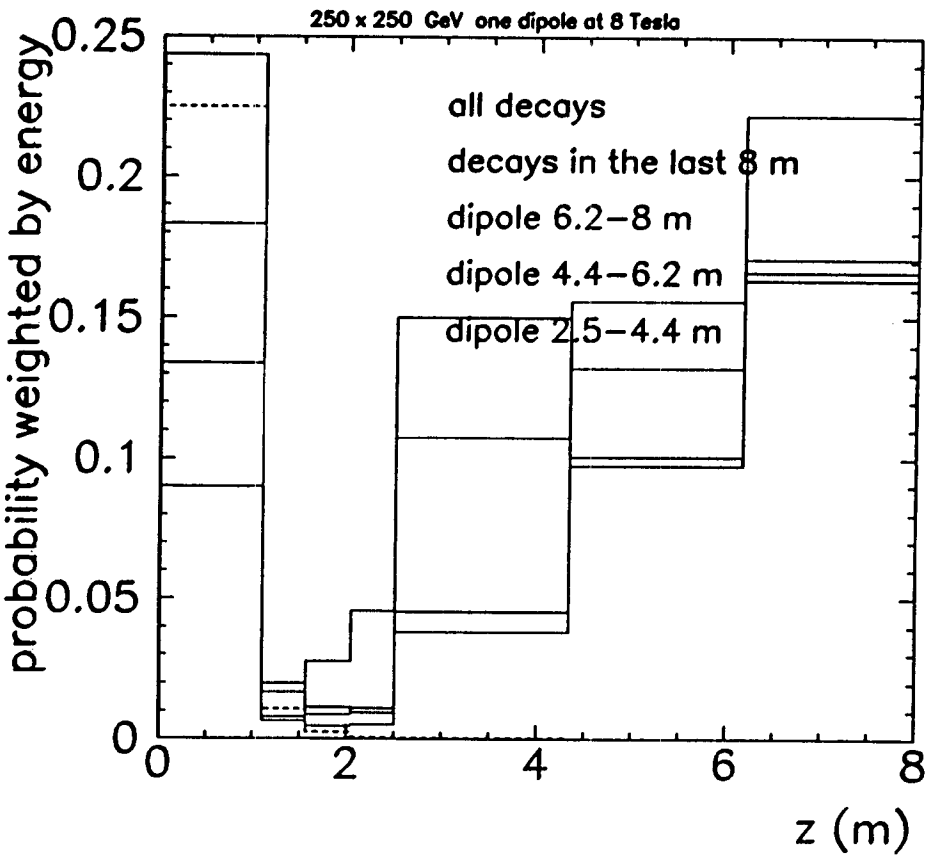
- 20 degree conical tungsten shield in forward/backward direction.
- Expanding inner cone from minimum aperture point is set at 4 σ beam size.
- Inverse cone between IP and min aperture point is set to 4 σ beam divergence.
  - Designed so detector does not see surfaces struck by incident electrons.
- Inner surface of each shield shaped into collimating steps and slopes to maximize absorption of electron showers.
  - Reduces low energy electrons in beam pipe.
- High field sweeping dipole magnets placed upstream of 1st quadrupole. These dipoles have collimators inside to sweep decay electrons in advance of final collimation.

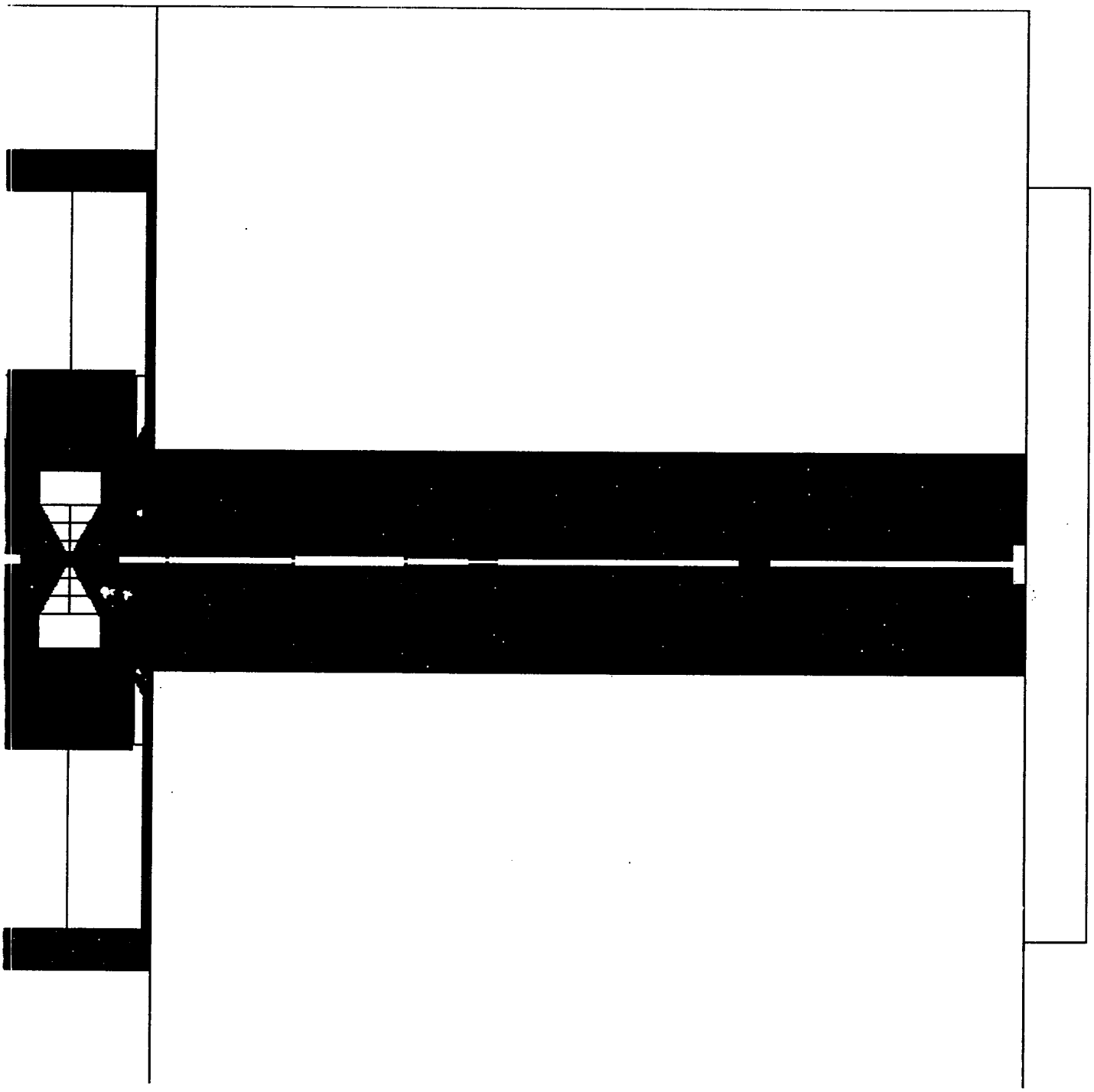
GEANT Calculation: The last 130m is simulated



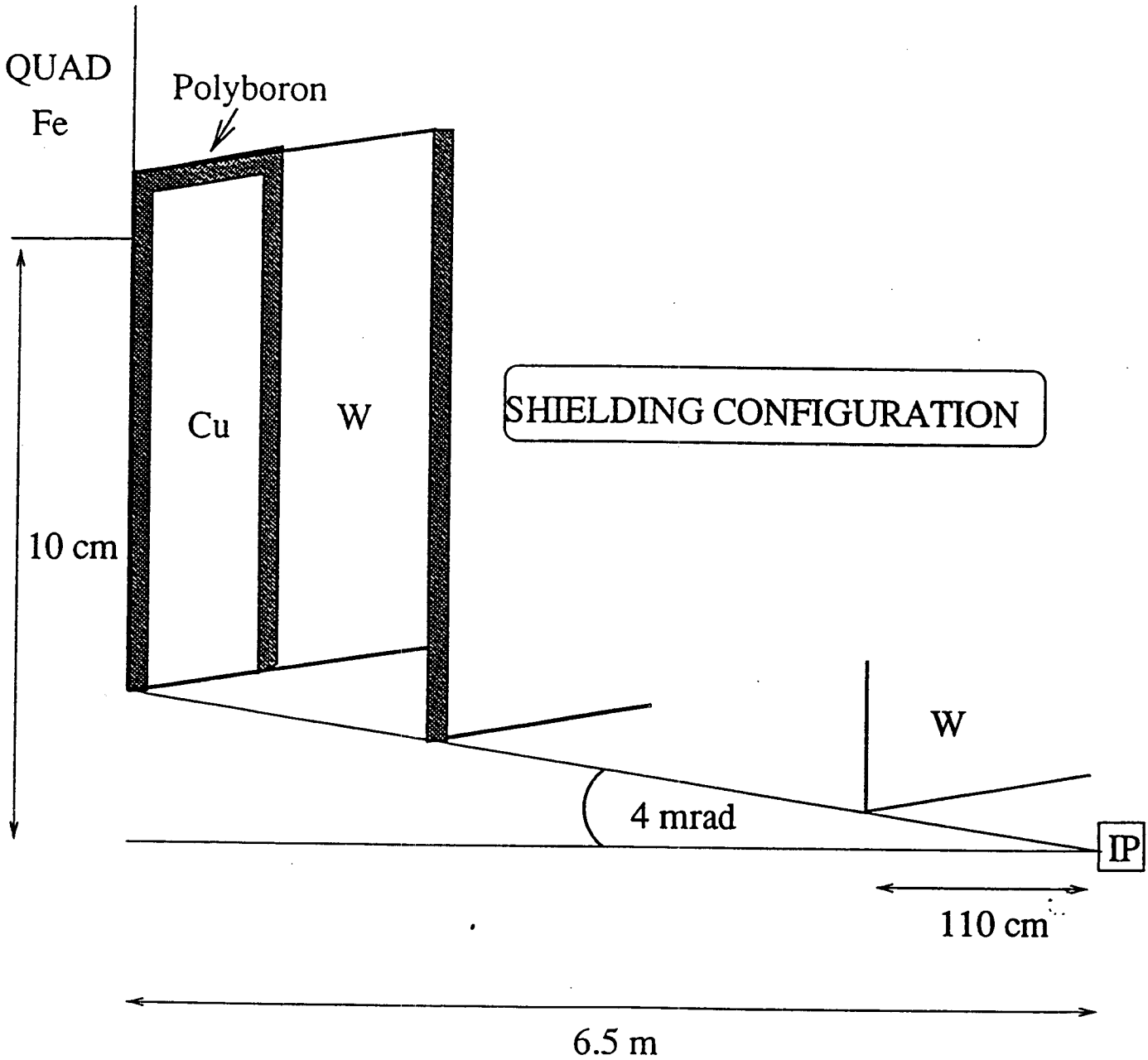
- 4 QUADS: Q33, Q44, Q55, Q66
- Snowmass configuration: 3 Toroids to deflect Bethe–Heitler muons and scrape backgrounds (inner aperature = 4σ): T34, T45, T56
- Post–Snowmass configuration: Toroids removed and dipoles added to straight section .... this reduces backgrounds by an order of magnitude (except for the Bethe–Heitler muons).


50 x 50 GeV one dipole at 4 Tesla
all decays
decays in the last 7 m
dipole 5.5–7 m
dipole 4–5.5 m
dipole 2.5–4 m
probability weighted by energy
z (m)
0
0.1
0.2
0.3
0
2
4
6


250 x 250 GeV one dipole at 8 Tesla
all decays
decays in the last 8 m
dipole 6.2–8 m
dipole 4.4–6.2 m
dipole 2.5–4.4 m
probability weighted by energy
z (m)
0
0.05
0.1
0.15
0.2
0.25
0
2
4
6
8

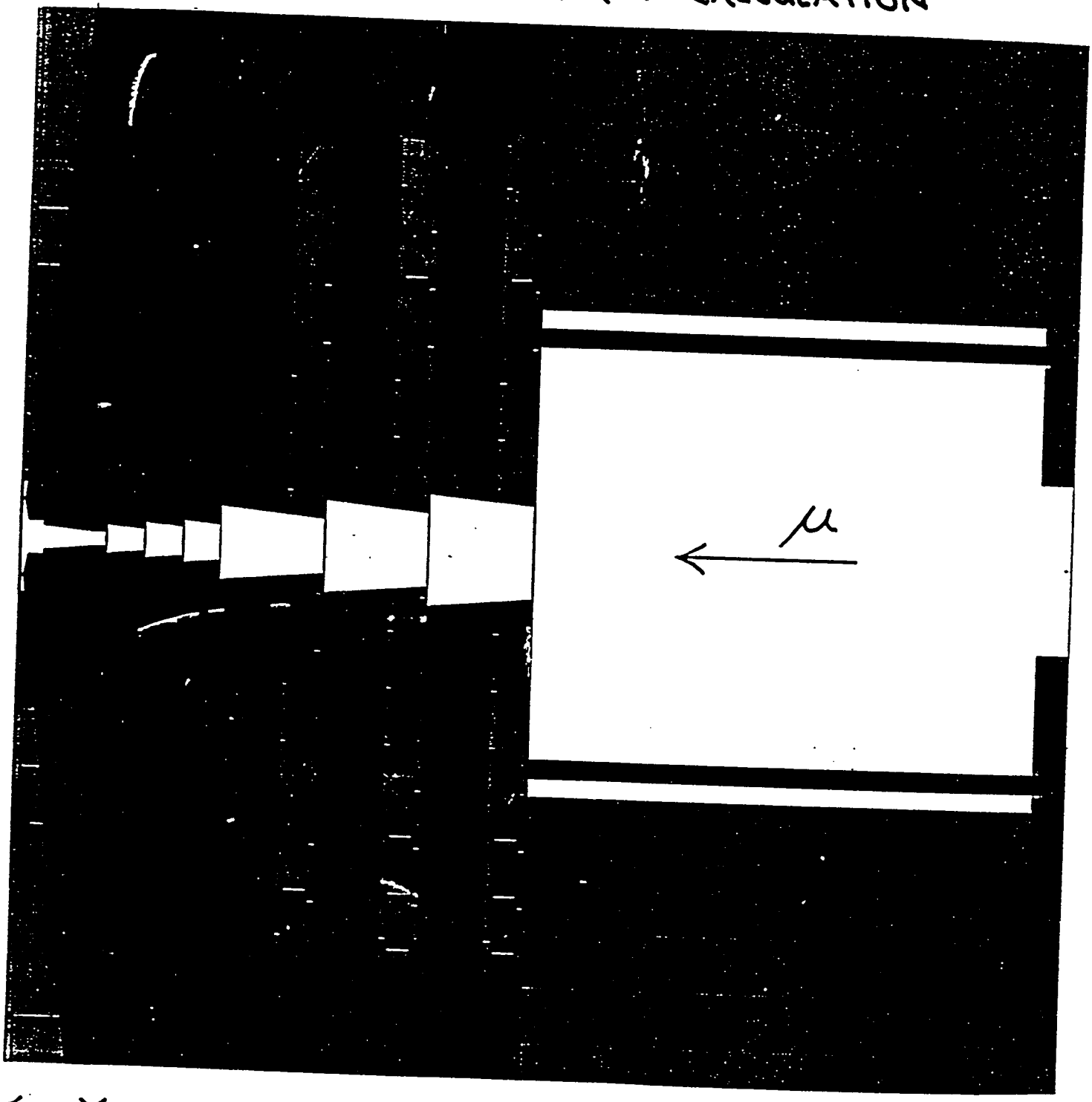


Shielding Configuration Implemented in GEANT Background Calculation



SNOWMASS CONFIGURATION

TUNGSTEN SHIELDING : GEANT CALCULATION



2% 30% 62%

OF THE DECAY ELECTRONS INTERACT IN THE REGIONS AS INDICATED, & 10% PASS THROUGH THE IP WITHOUT HITTING ANY SHIELDING.

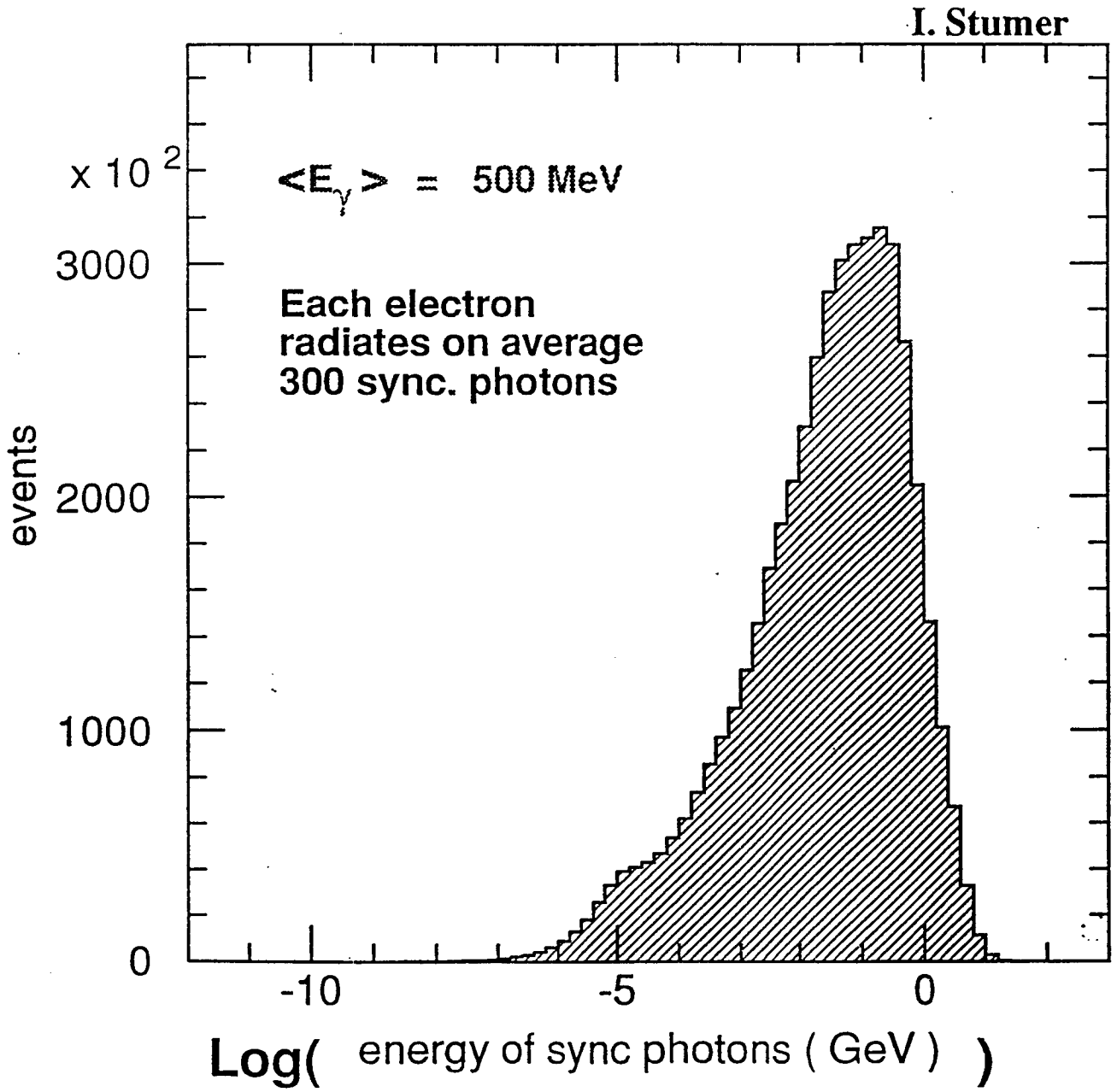
detectors
2 cm
P
4 m
detectors

Configuration Parameters

Parameter	50 × 50 GeV	250 × 250 GeV	2 × 2 TeV
Shield Angle	20°	20°	20°
Open Space To IP	6 cm	3 cm	3 cm
Min Aperture Point	80 cm	1.1 m	1.1 m
R_{iris}	0.8 cm	0.5 cm	
Distance to 1st Quad	7 m	8 m	6.5 m

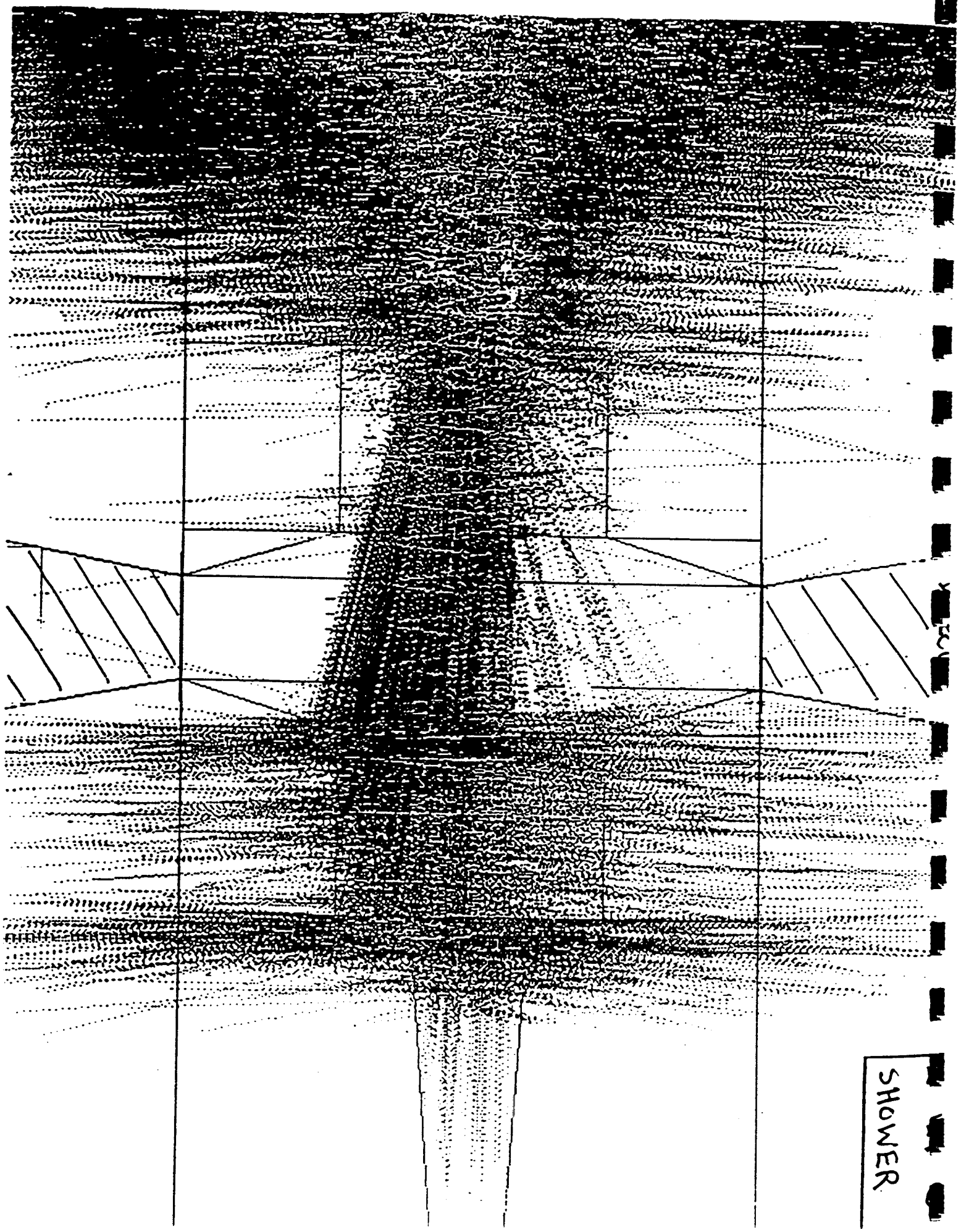
Synchrotron Radiation

- The decay electrons radiate synchrotron photons as they propogate through the fields in the final focus region, loosing on average about 20% of their energy:



- However, the resulting background in the detector region is small compared with other backgrounds.

I.22



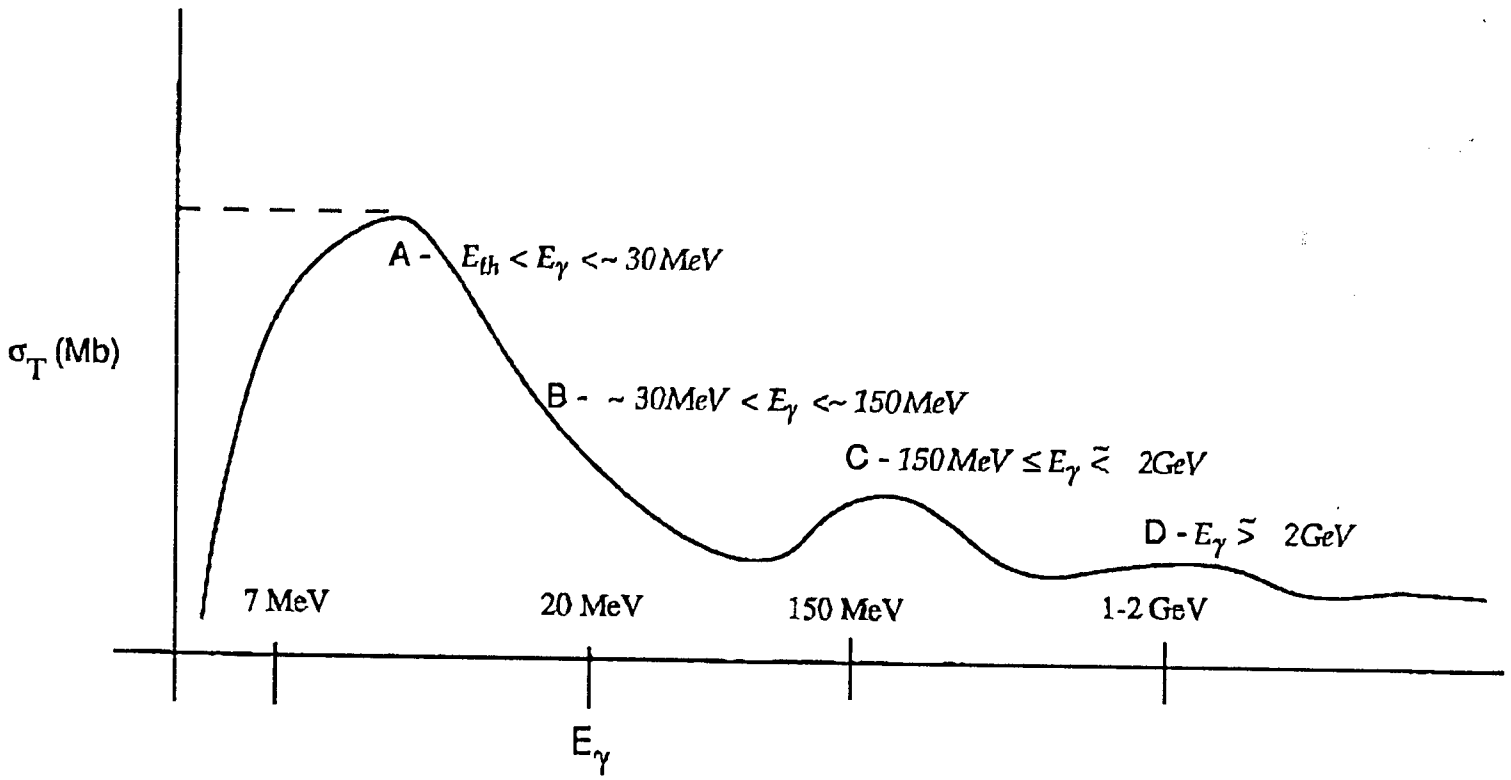
Photonuclear Interactions

- Primary source of hadron production
- Probability for photo production is small relative to other processes
  - Large number of photons released per crossing make this an important background.
- Different mechanisms in different energy bands:
  - Giant Dipole Resonance Region
    - $5 < E_\gamma < 30$ MeV
    - produce ~1 neutron
  - Quasi-Deuteron Region
    - $30 < E_\gamma < 150$ MeV
    - produce ~1 neutron
  - Baryon Resonance Region
    - 150 MeV $< E_\gamma < 2$ GeV
    - produce π's and nucleons
  - Vector Dominance Region
    - $E_\gamma > 2$ GeV
    - produce ρ^0 that decay to π's
- GEANT modified to include photonuclear production

Gamma Nuclear Interaction Models

There are four distinctive energy regions associated with gamma nuclear interactions. There are

- Giant Dipole Resonance Region — A
- "Quasi-deuteron" Region — B
- Meson Region — C
- Quark Fragmentation Region — D



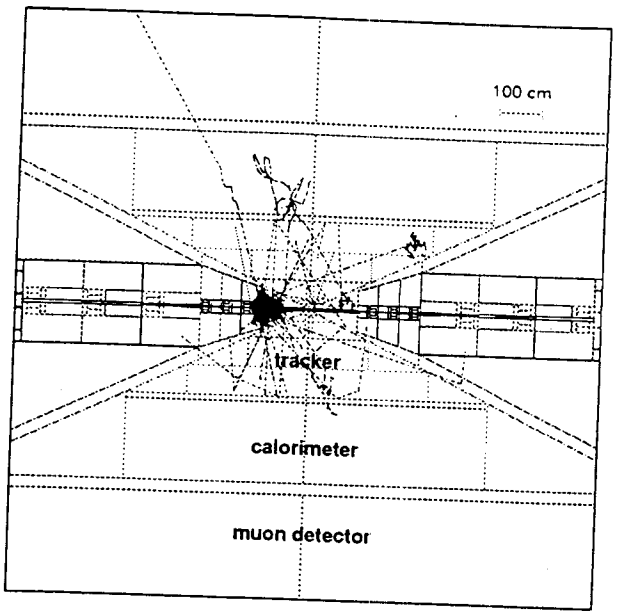


Figure 9.29: Neutron distribution in xz plane.

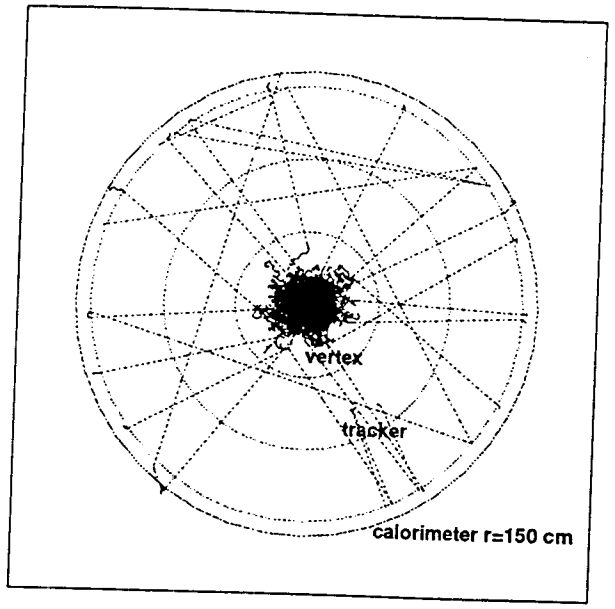


Figure 9.30: Neutron distribution normal to beams at z=0.

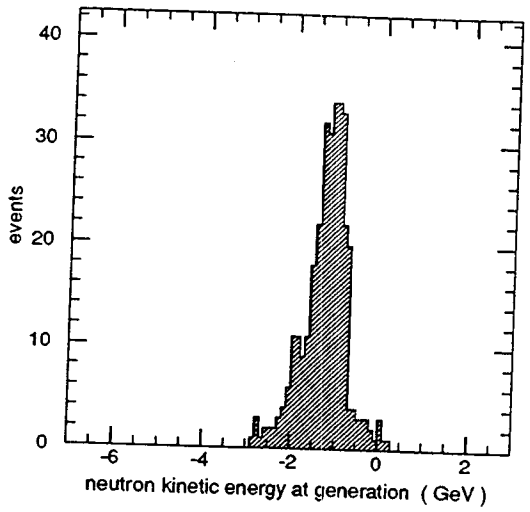


Figure 9.27: Log of generated neutron energy spectrum.

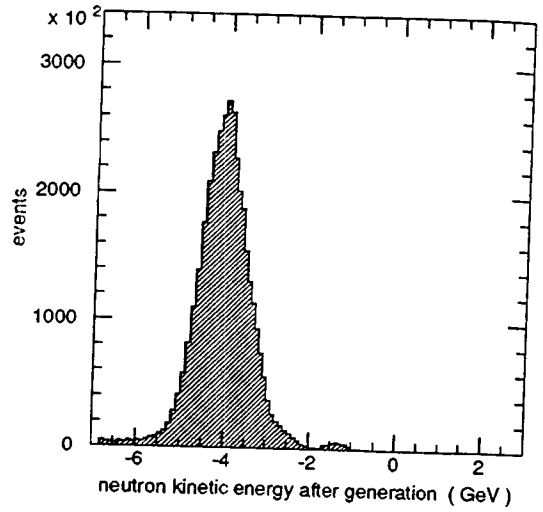
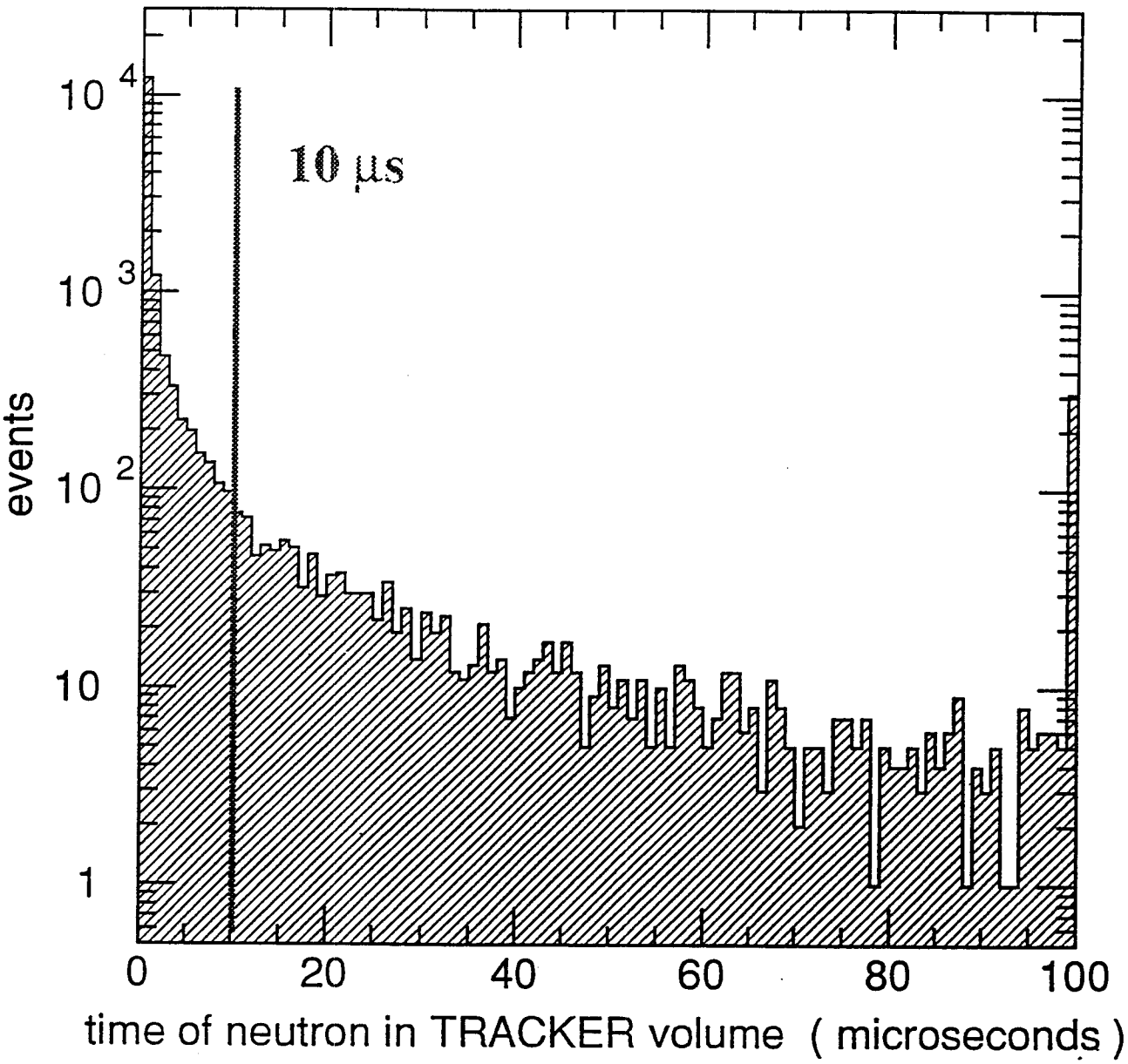


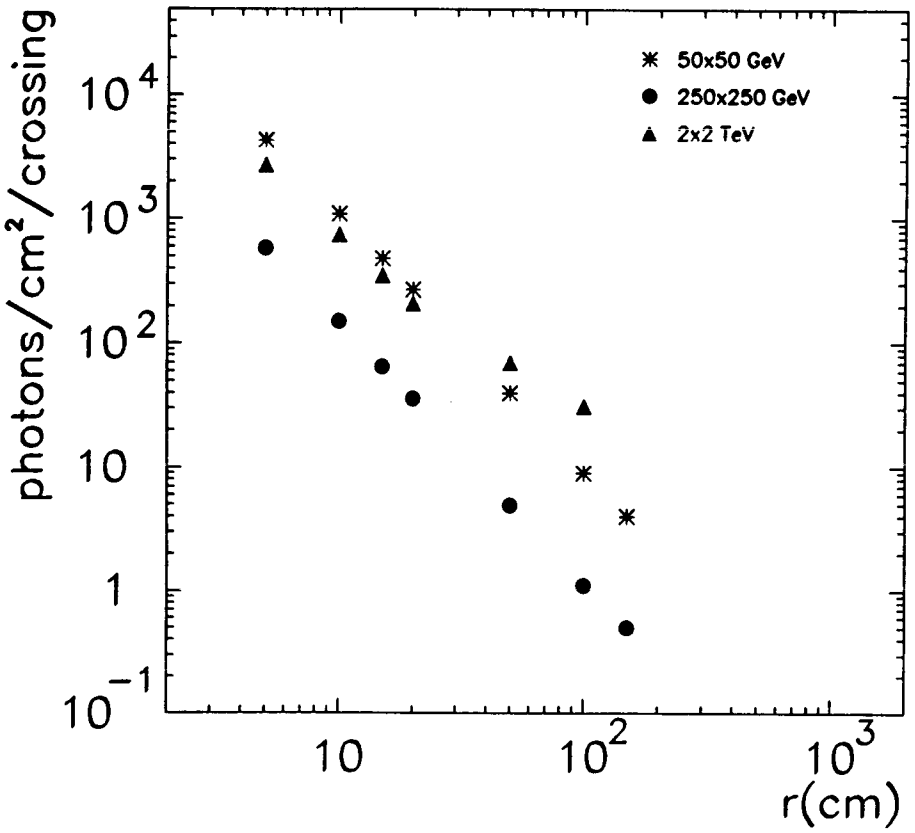
Figure 9.28: Log of neutron energy in the detector region.

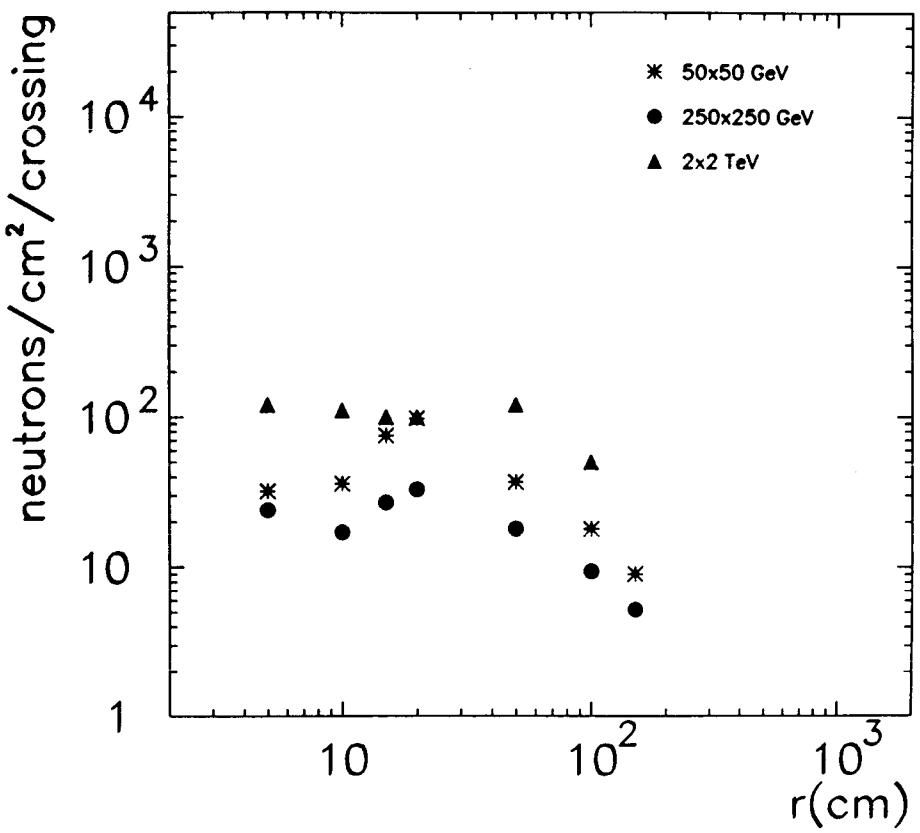
GEANT Result: Neutrino flux time distribution for neutrons in the tracking volume.

I. Stumer



- **The neutron flux has fallen by 2 orders of magnitude before the next bunch–bunch crossing at t = 10μs**


photons/cm²/crossing
10⁴
10³
10²
10
1
10⁻¹
10
10²
10³
r(cm)
50x50 GeV
250x250 GeV
2x2 TeV


neutrons/cm²/crossing
10⁴
10³
10²
10
1
10
10²
10³
r(cm)
50x50 GeV
250x250 GeV
2x2 TeV

Radial Fluences at 50x50 GeV

particles/cm^2/crossing for two bunches of $10^{12}\mu$'s each

radius (cm)	*photons*	*neutrons*	*protons*	*pions*	*electrons*	*muons*
5	4300	32			3.8	0.15
10	1100	36		0.24	0.3	0.07
15	480	75		0.11		0.03
20	270	98		0.09		0.007
50	40	37	0.05	0.015		0.0004
100	9	18	0.005			0.0002
150	4	9	0.02			.21e-5
muon						.24e-6
threshold	40 keV	40 keV	10 MeV	10 MeV		

Radial Fluences at 2 × 2 TeV

particles/cm^2/crossing for two bunches of $10^{12}\mu$'s each

Radius cm	γ	n	p	π	e	μ
5	2700	120	0.05	0.9	2.3	1.7
10	750	110	0.20	0.4	-	0.7
15	350	100	0.13	0.4	-	0.4
20	210	100	0.13	0.3	-	0.1
50	70	120	0.08	0.05	-	0.02
100	31	50	0.04	0.003	-	0.008
150						0.003
Muon						0.0003
Threshold	25 KeV	40 KeV	10 MeV	10 MeV		

Background hits and occupancy at 50x50 ~~T~~GeV

Assume 2 bunches of $10^{12}\mu$'s each for hits, 4×10^{12} for occupancy

For silicon vertex assume 300x300 micron^2 pads

rad (cm)	*photons* (/cm^2)	*neutrons* (/cm^2)	*charged* (/cm^2)	*Hits* (/cm^2)	*Occup all*	*Occup charged*
5	13	0.03	4	17	6.1 %	1.4 %
10	3.3	0.04	0.6	4	1.4 %	0.2 %
15	1.4	0.07	0.14	1.6	0.6 %	0.05 %
20	0.8	0.1	0.10	1.0	0.4 %	0.04 %
50	0.1	0.03	0.065	0.2	0.07 %	0.02 %
100	0.03	0.02	0.005	0.06	0.02 %	0.002 %
150	0.01	0.01	0.02	0.04	0.014 %	0.007 %

Background hits and occupancy at 250x250 GeV

for hits we assume 2 bunches of $10^{12}\mu$'s each

for occupancy we assume 2 bunches of 4 $10^{12}\mu$'s each

radius (cm)	*photons*	*neutrons* per cm^2	*charged particles*	*Hits*	*Occupancy* %
Silicone vertex					
5	7.5		1.11	8.6	3.1
10	2.0		0.32	2.3	0.8
15	0.9		0.18	1.1	0.4
20	0.5		0.09	0.6	0.2
50	0.08		0.02	0.1	0.04
100	0.02		0.007	0.03	1.e-4

Hit Density in a Vertex Detector

- Consider a layer of Silicon at a radius of 10 cm. The GEANT results for the radial particle fluxes per crossing yield:

I. Stumer

750 photons/cm^2	–>	2.3 Hits/cm^2
110 neutrons/cm^2	–>	0.1 Hits/cm^2
1.3 charged tracks/cm^2	–>	1.3 Hits/cm^2
TOTAL		3.7 Hits/cm^2

- –> 0.4% occupancy in 300 x 300 μm^2 pixels.

- The corresponding numbers at 5cm radius are 13.2 Hits/cm^2 –> 1.3% occupancy.

- This doesnt sound too bad. For comparison, SLD has about 40 Hits/cm^2 on the inner layer of their CCD detector.

Beam Halo Background

- Since each beam has 2×10^{12} muons, a small beam halo that could get into the detector would be very troublesome.
- Tracking studies with very limited statistics have been performed:
  - Samples of 200 μ's with x, x', y or y' > 3.5, 4, 4.5, 5, … σ were tracked through the 2 TeV lattice.
  - No μ's in the samples less than 5 σ appeared in the detector region.
  - These results are not complete at this time.
- The beams will be scraped at 3 σ 180° from the IR.
- More work needs to be done on the halo.

Bethe-Heitler Muons

- Electrons interacting with the beam pipe wall or tungsten shielding can produce muon pairs. We call this muon pairs Bethe-Heitler μ's.
- These μ's can penetrate the shielding to reach the detector.
- Some Bethe-Heitler μ's will cross the calorimeter and produce catastrophic bremsstrahlung losses that could put spikes in the energy distribution.
- *Time of Flight* information:
  - Fast timing can remove B-H μ's in *Central Calorimeter.*
  - Significant number of B-H μ's in *Forward Calorimeter* are likely to be in time with signal.
- *Fine Segmentation* in both *longitudinal* and *transverse* directions will be necessary to distinguish B-H background from signal.

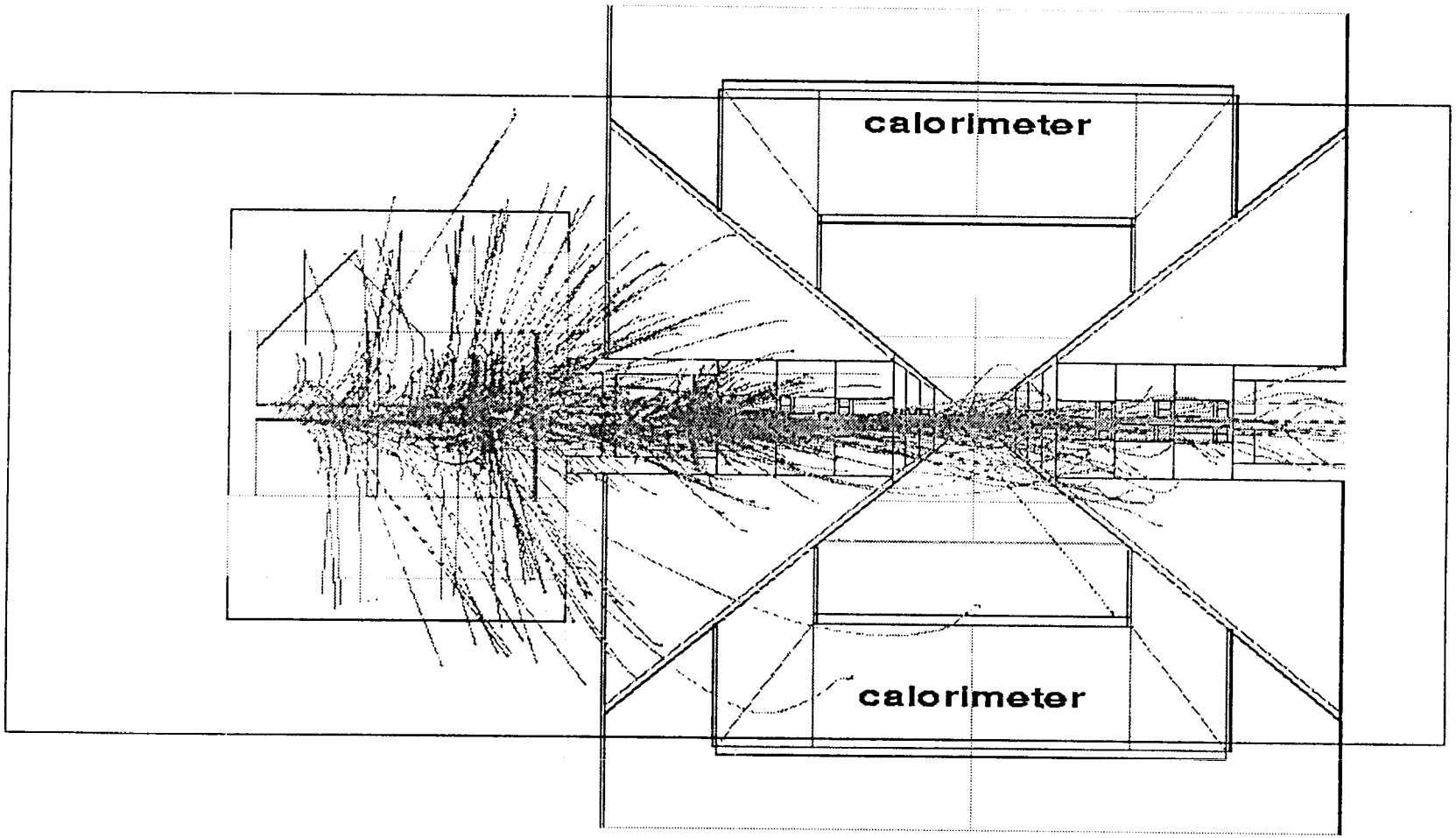


FIG. 68. Trajectories of typical Bethe-Heitler muons from their source in the shielding around the beam pipe to the detector for a 100 GeV CoM collider. As indicated in the text the scale is extremely distortedΓthe total horizontal length is ≈ 20 m and the outer edge of the calorimeter is ≈ 4 m. Notice that $< 0.5\%$ of the tracks end in the calorimeter (see table XVII).

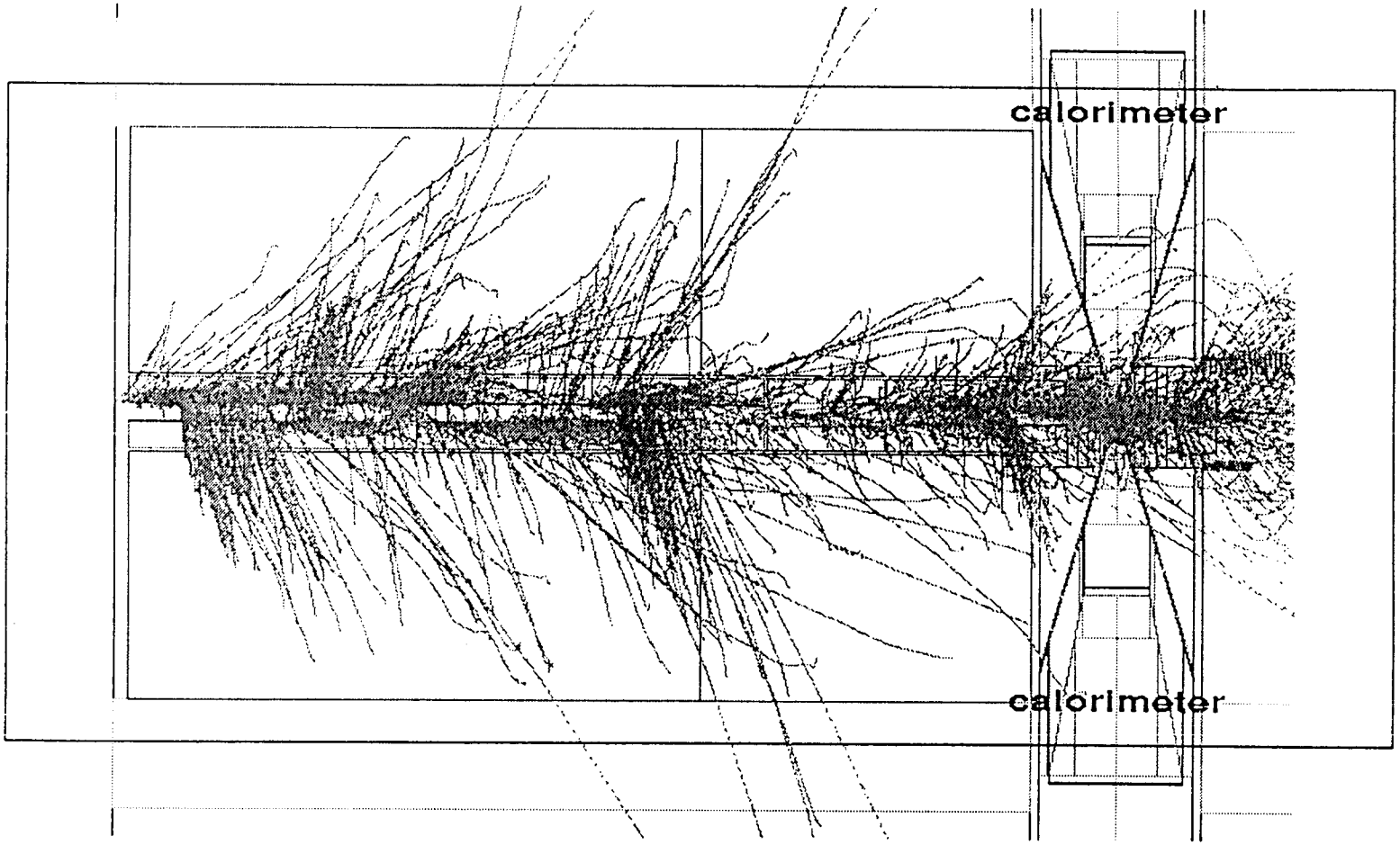


FIG. 67. Trajectories of typical Bethe-Heitler muons from their source in the shielding around the beam pipe to the detector for a 4 TeV CoM collider. As indicated in the text the scales are extremely distortedΓthe total horizontal length is $\approx$ 130 m and the outer edge of the calorimeter is $\approx$ 4 m. Notice that $<$ 1% of the tracks end in the calorimeter (see table XVII).

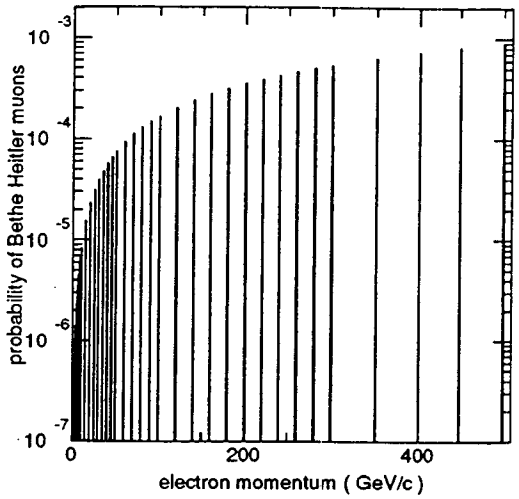


Figure 9.21: Probability of an electron to generate a muon on a thick tungsten target.

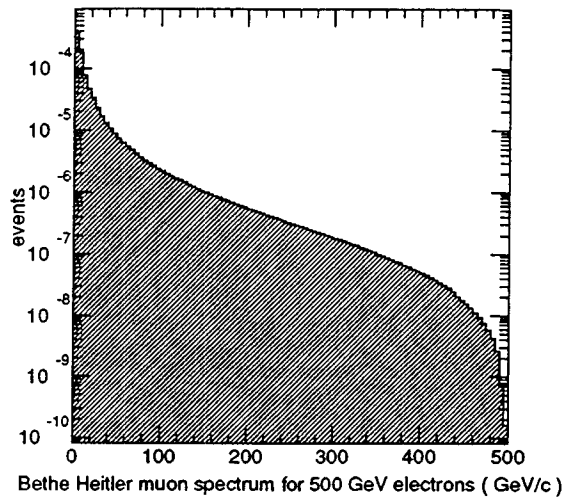


Figure 9.22: Muon momentum spectrum produced by a 500 GeV electron.

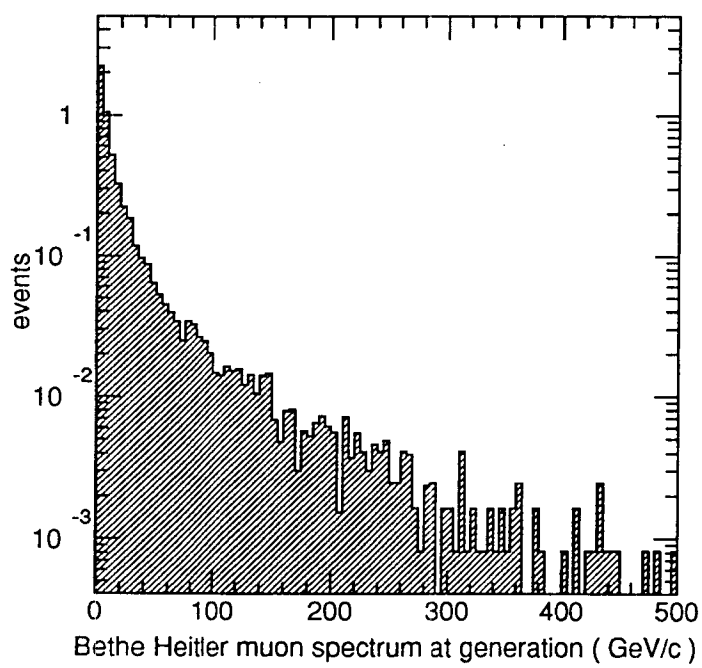
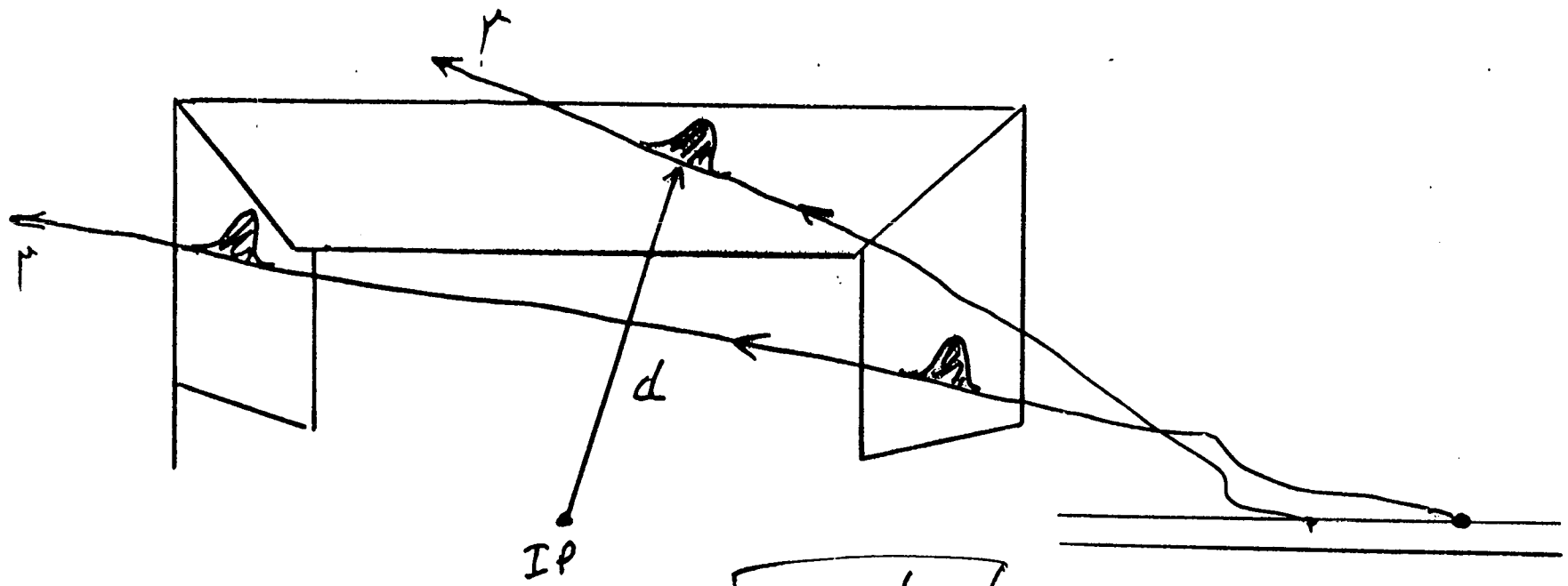


Figure 9.23: Bethe-Heitler muon spectrum in the final focus region.



— USE 1 nsec AS TIME UNIT $\boxed{t_0 = \frac{d}{c}}$

1 nsec ≈ TIME DEVELOPMENT OF ECM SHOWER

≈ SIZE OF A HADRONIC CALORIMETER CELL

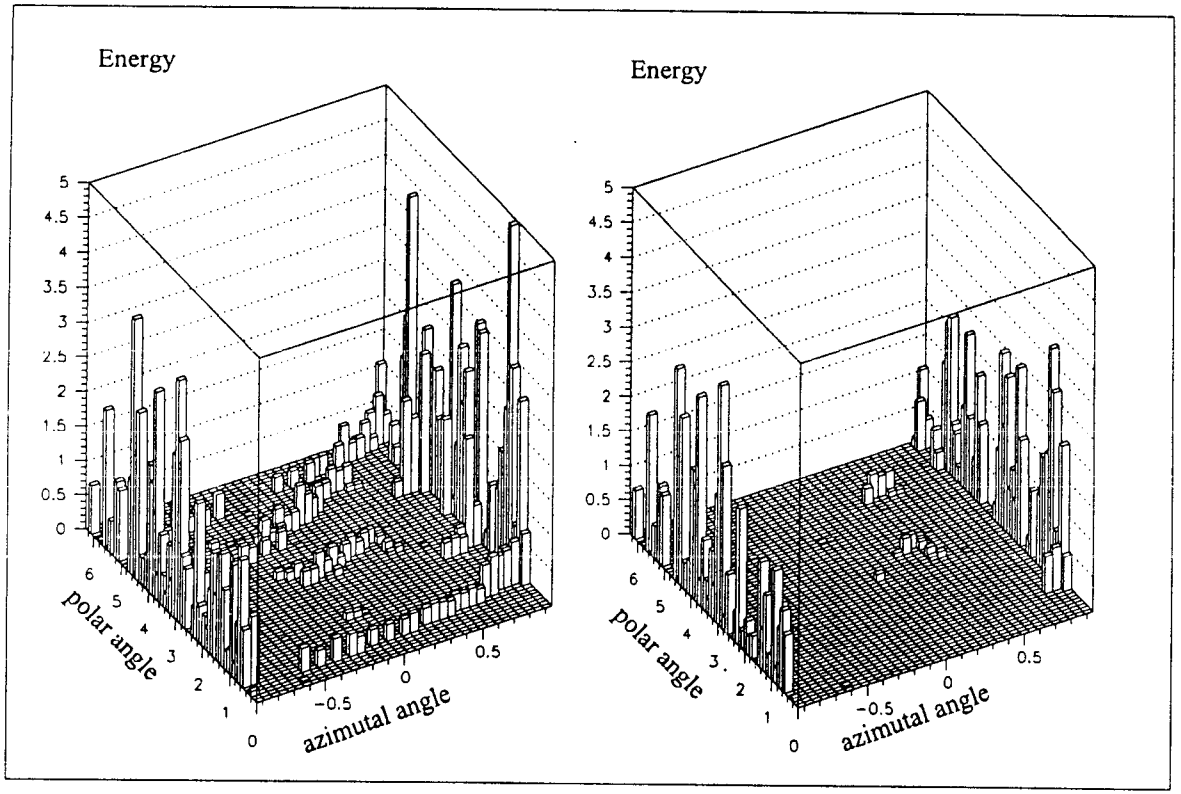


FIG. 70. Left hand plot shows the energy deposition from Bethe-Heitler muons *vs.* the cosine of the polar angle and azimuthal angle in the calorimeter for a 0.5 TeV CoM collider. Right hand plot shows the same distributions with a 1 ns timing cut.

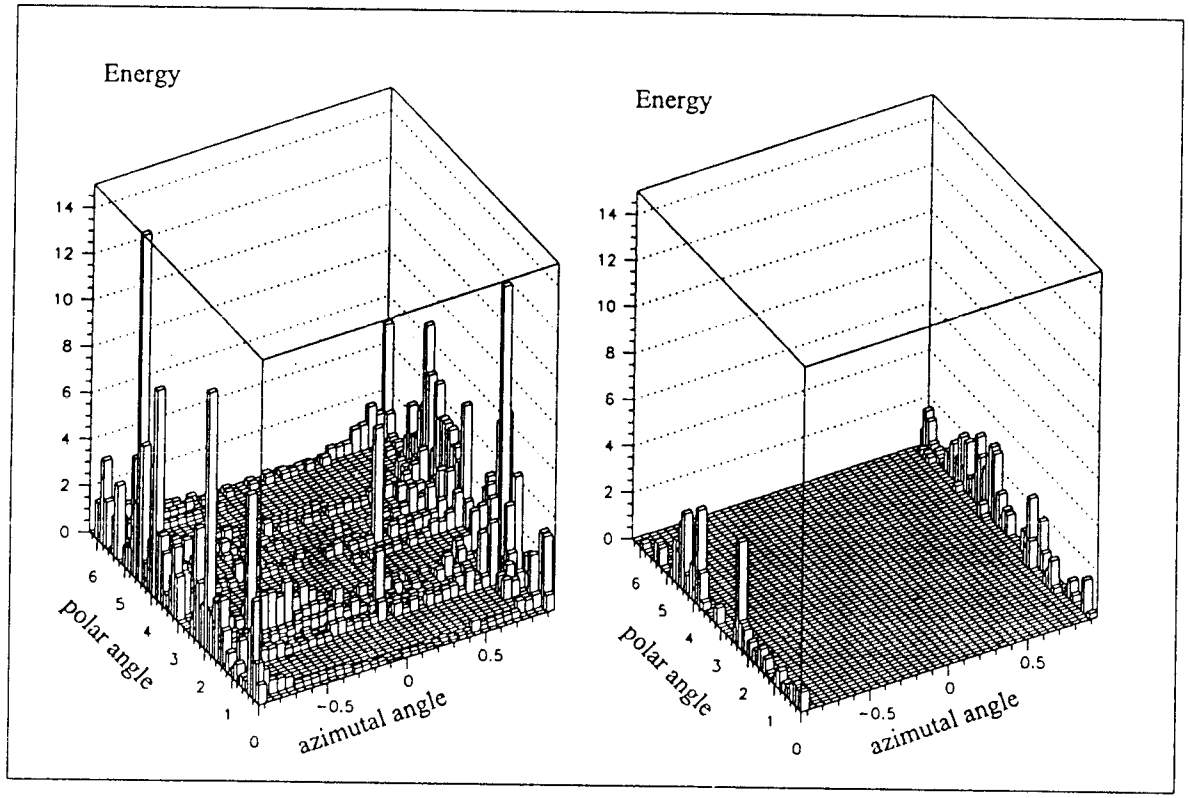


FIG. 69. Left hand plot shows the energy deposition from Bethe-Heitler muons *vs.* the cosine of the polar angle and azimuthal angle in the calorimeter for a 4 TeV CoM collider. Right hand plot shows the same distributions with a 1 ns timing cut.

F. Bethe-Heitler muons

TABLE XVII. Bethe-Heitler Muons

CoM Collider Energy (TeV)	4	0.5	0.1
Assumed source length (m)	130	33	20
μ ($p_{muon} > 1$ GeV/c) per electron	5.4×10^{-4}	8.3×10^{-5}	9.6×10^{-6}
Beam μ's per bunch	2×10^{12}	2×10^{12}	4×10^{12}
Bethe-Heitler μ's per bunch crossing ($\times 10^3$)	28	17.5	6.1
$< p_{muon} >$ initial (GeV)	22	9.5	4.4
μ's entering calorimeter	220	160	25
$< p_{muon} >$ (GeV)	15.4	6.3	1.8
$< E_{dep} >$ (GeV)	2.9	1.3	0.4
Total E_{dep} (GeV)	640	210	10
E_{dep} pedestal subtracted (GeV)	50	25	1
Fluctuation in E_{dep} (GeV)	55	15	1
E_{trans} pedestal subtracted (GeV)	15	15	.5
Fluctuation in E_{trans} (GeV)	40	8	0.5

The GEANT/MARS studies [44Γ211Γ215] also found a significant flux of muons with quite high energiesΓfrom μ pair production in electromagnetic showers (Bethe-Heitler). Figures 67 and 68 show the trajectories of typical muons from their sources in the shielding around the beam pipe to the detector. Figure 67 is for a 4 TeV CoM colliderΓ where the muons have high energy and long path lengths. A relatively long (130 m) section of beam pipe prior to the detector is shown. Figure 68 is for the 100 GeV CoM collider for whichΓsince the muons have rather short path

Background Concerns for the Highest Energy μ Collider

- Expect the Bethe-Heitler μ spectrum to be harder.
  - Higher Momentum
  - Larger rate
- Expect more hadron background
  - Leptoproduction of hadrons will become important.
- Should build 1.5 × 1.5 TeV or 2 × 2 Tev muon collider first to study these backgrounds first (and perhaps do some physics.)