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An Expression of Interest

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I. INTRODUCTION

We would like to express our interest in designing a compact detector specifically to exploit the discovery potential of the Superconducting Super-Collider at its highest luminosities.

In general, the cross-section for a heavy particle production is a sharply falling function of its mass. An order of magnitude in luminosity would double the mass range of potential discoveries. Since the SSC lattice can inherently produce luminosity of $2 \times 10^{34}/(cm^2\ sec)$, we take this as a basic parameter of the detector design. (The detector we have in mind can very likely handle even higher luminosity, should it be available.)

History and SSC design studies show that leptons can give a very clean signal for new discoveries, even in the midst of an extremely complicated particle production environment. The standard Higgs Boson falls into this category and we therefore use

$$H^0 \rightarrow Z^0 Z^0 \rightarrow \ell^+ \ell^- \ell^+ \ell^-$$

as an example and bench mark in the design.

At a luminosity of 2×10^{34}, there will be on average 36 interactions per bunch collision, distributed over about 10 cm along the beam direction. Each will have about 7 tracks per unit of rapidity (28 tracks per degree between $\eta = 3$ and $\eta = 2$). A Higgs Boson decaying to four electrons will be accompanied by 35 other events, each with 3 neutral pions per unit of rapidity, or about 100 showers per unit of rapidity. The instantaneous charged particle flux is about 15 GigaHz per unit of rapidity. These rates represent real challenges for inner tracking devices or calorimeters. Also, these detectors will have to be able to survive the radiation damage.

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However, we would not like to be limited to less than the maximum capability of the accelerator. We can use the highest luminosity if we concentrate on muons and place a large amount of absorbing material between the interaction point and the first active detector element. Muons will traverse the absorber, while the hadrons will not. Therefore "discovery" events involving prompt muons (e.g. $H^0 \to Z^0 Z^0 \to \mu^+\mu^-\mu^+\mu^-$) may be observable against a greatly reduced hadronic background. It is the purpose of this Expression of Interest to show that such a detector is quite feasible.

The factor of four loss in rate that comes from ignoring the e^+e^- channels is more than compensated for by the increased luminosity. For example, with muon detection at 20 times that possible for electron detection, one has a *gain* of a factor of five and more than a fifty percent higher mass reach.

We will discuss the general feasibility to design such a detector (section II) and possible options for a complete detector (section III). While no extensive simulation study has been carried out yet, we believe the physics potential for SSC mandates such study. In section IV we outline the development studies that are required.

II. BASIC CONCEPT

The idea of a muons-only detector employing very thick absorbers is not new. It goes back to the early PEP and Isabelle Studies, or before, and was examined again in the 1987 SSC Detector Workshop for a detector with the beam pipe surrounded by dense material such as tungsten[1].

The concept proposed here uses a large diameter high field solenoid and maximizes the efficiency of the magnetic field for momentum measurement by placing the tracking devices entirely outside the coil and using the beam position as one endpoint of the track. The solenoid is almost entirely filled with absorber, thus minimizing the flux of muons from pion and kaon decays. The momentum resolution for muons exiting the absorber now depends on multiple scattering and the precision of measuring the exit angle of the track. By adjusting the magnetic field, the radius, and the absorber material, the multiple scattering contribution to the momentum resolution can be minimized, while still providing the absorption that is necessary for the elimination of unwanted particles.

For such an arrangement, the multiple scattering contribution is given by[2]

$$dp_T/p_T = (.014/BR)\sqrt{(N\lambda/X_0 \sin\theta)}$$

where R is the radius of the coil, B the field, $N\lambda$ is the radial thickness of the absorber (which might be different than that of the coil), λ is the mean free path for hadronic absorption in the material, X_0 its radiation length, and θ is the polar angle of the track with respect to the beam line

We use this concept to design a compact detector. The reason for a compact central detector is the cost as well as the ability to connect to a finite forward detector with a uniformly good momentum resolution down to small angles. Fig. 1 shows[3] that is necessary to cover the angular range down to about 10° (η=2.5), well beyond the capability of the usual solenoid. Compactness and good momentum resolution in the central region can be achieved by a high field solenoidal magnet and a tracking scheme that makes maximum use of the field. The forward region will be covered

[1]R. Thun *et al*, in Proceedings of the Workshop on Experiments, Detectors, and Experimental Areas for the Supercollider, Berkeley, 1987.

[2]R.L. Lander, in Proceedings of the International Workshop on Solenoidal Detectors for SSC, KEK, 1990.

[3]Bensinger, Wang, and Yamamoto, in Workshop of Physics and Simulations for SSC Detectors, Dallas, 1990.

by an air core toroid. The compactness of the solenoid will minimize the toroid's size.

Consider a solenoidal field of 6 Tesla and radius 2 meters. The coil of such a magnet is rather thick, perhaps 40 cm (mostly Al). The $\int B \cdot d\ell$ from the origin all the way through the coil is 12.5 Tesla-meters. If iron is the absorber, this value becomes 16.5 Tesla-meters due to the 2 Tesla from the magnetization of the iron.

The multiple scattering contribution to the momentum resolution for tracks at 90 degrees is shown in Fig. 2 as a function of the thickness in hadronic absorption lengths for carbon, iron, and tungsten. The iron values include the effect of an additional 2 Tesla . Rather good resolution is obtainable using carbon or iron. Tungsten and other high Z materials are considerably worse. We will see below that 14 absorption lengths appears to be a reasonable thickness in the central region, so a resolution of 2% for carbon, 3.3% for iron, is not precluded by multiple scattering in a detector of this kind.

To attain these values, the fractional error in the angle measurement must be even smaller (it will add in quadrature). If we have 1.5m of track length, the error in the angle measurement should be something of the order 0.2mm/1.5m, or a fraction of a milliradian. The bending angle itself is given by 5 GeV/p_T. At 200 GeV this is 25 mr, so the direction can be known to about 1% or less. The track's direction with respect to the interaction point must also be known to similar precision. Therefore the trackers must be accurately referenced to the beam line. This will present a challenge, but should be possible with laser alignment techniques. Overall, it seems not unreasonable to expect to be able to hold 4% with such a spectrometer.

The flux returns through an iron yoke of inner (outer) radius 4 (5.5) meters. The field is shown in Fig 3. A crude second momentum measurement can be made to help eliminate non-prompt muons. This is important for the trigger; it also aids muon identification. Fig. 4 shows the trajectory of a p_T=10 GeV track in such a magnetic field.

The momentum resolution attainable by this spectrometer is adequate for the $H^0 \to Z^0 Z^0 \to \mu^+\mu^-\mu^+\mu^-$ search. Nodulman, Paige, and Thun[4] studied 300 GeV and 800 GeV Higgs Boson production decaying to four muons via a Z^0 pair. They took as the dominant background the chain

$$t \to \mu^+ \nu b \to \mu \nu \mu c, \text{ plus C.C.}$$

[4]Private communication.

Using p_T of the muon > 5 GeV, and selecting a m-pair mass interval 40 GeV wide centered on the Z^0 mass(i.e.± 20 GeV), they conclude that the background would be comparable to the Higgs Boson signal. The background is proportional to the square of the mu-pair mass cut; therefore, a cut of ± 5 GeV would reduce the background by a factor 16, which would make the background rather small. The momentum resolution dP/P folds into the m-pair mass resolution dM/M with a factor $1/\sqrt{2}$. Thus, a detector with a momentum resolution sigma of 4% gives a μ-pair two-σ cut of ± 5.2 GeV.

The trigger for this muons-only detector will obviously have to be a combination of one or more muons above some p_T value(s). At $2x10^{34}$, there will be many tracks exiting the absorber as a result of punch-through, decay in flight of pions and kaons, and prompt muons from heavy quark decays. We consider the detection of a heavy Higgs Boson as an example of the feasibility of this detector for new discovery physics at the SSC. Three questions are considered here. 1. The trigger rate. 2. The number of "bad" tracks that lie above the lower p_T cutoff for the desired tracks from the Higgs Boson decay. 3. The multiple hit probability due to the overall rate of tracks of any momentum passing through the tracking devices. We will make rough estimates based on the reports of Green and Hedin[5] and Roger McNeil[6]. The essential data are those of Fig. 5, where the total particle rate per degree of polar angle with respect to the beam line is given as a function of that angle. The rates are very high at $\eta = 2.5$ ($\theta = 10°$) and fall very rapidly as the angle increases. The distribution in p_T, integrated over η from 3.0 to 0 is shown in Fig. 6.

For the trigger, the p_T cutoff can be set quite high. A cutoff of 50 GeV/c for one of the four muons will still give a high efficiency for Higgs Boson triggering. The total rate from 10 - 90 degrees for a track of more than 50 GeV/c in p_T drops by six orders of magnitude to a value of about 10 Hz. This single track rate suggests that a trigger for a heavy Higgs Boson can be devised that will not be excessive as far as data collection is concerned. A proper Monte Carlo study must be done, but these data are very encouraging. A modest momentum measurement (20%) should suffice for the central trigger, since there are two independent measurements. One is provided by the track's exit angle from the coil, and the other by the bend angle through the iron yoke. The high p_T trigger tracks outside the iron (where the field is weak) will be essentially straight, so the triggering logic can be fast.

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[5]D. Green and D. Hedin,Fermilab-Pub-90/18 (1990).

[6]Private communication.

To retain high efficiency for the Higgs, muons as low as 10 GeV/c in p_T must be accepted. The rate for such tracks is about 10^4 Hz over the full angular range. If uncorrelated to the triggering event, only 1% of such tracks would fall within, for example, a one microsecond acceptance gate. Thus, there is only a 1% chance that a trigger event will be accompanied by one accidental track above $p_T = 10$ GeV/c anywhere in the detector.

The total rate for tracks of any p_T is about 80 megaHz at 2×10^{34}. If the memory time of each detector "cell" is one microsecond, then the whole detector will contain about 80 accidental tracks. These are almost all in the few GeV p_T range and so will be rejected when their momentum values are computed, but they may cause double hits in a cell. If excessive, this would render the detector ineffective. If the 80 unwanted tracks are distributed over 8000 cells in the detector, the probability of a double hit in any cell that contains a good track is 1%. There will certainly be 8000 cells in the detector. The track density is not uniform, however. At ten degrees the density is about 7 megaHz/degree, or 7 tracks/degree for a one microsecond memory time. To reduce the probability per cell to 1%, there should be 700 cells per degree at ten degrees. A ring of one degree width at ten degrees polar angle covers an area of about 10 cm x 700 cm (radial direction x circumference) at a distance of 6 meters (our typical detector). This seems adequate to allow a number of possible arrangements of 700 cells. As the polar angle is increased, the number of cells required to maintain a 1% occupancy decreases. Other factors will enter into the determination of cell sizes. This exercise, however, demonstrates that the number of cells required to eliminate the overlap of accidental tracks with "good" tracks is well within the normal design of a detector..

The effect of radiation by the high energy muons must also be considered. If there are too many delta rays accompanying a muon, these could make track finding difficult, especially in the trigger. Fig. 7 displays one hundred 200 GeV muons tracks passing through the system (arbitrarily displayed as spokes on a wheel), as simulated by GEANT. We can see that, by and large, the electrons radiated are either curled up in the magnetic field or absorbed by material. Here the thick coil actually *helps* -- The low Z material of the coil served as a filter of the low energy electrons.

The average radiation and collision energy losses can be corrected for to arrive at the original muon energy, but they will contribute to the uncertainty in the momentum measurement through the spread in the energy loss distribution. Data presented at the Tucson workshop suggest that for carbon and iron, this spread will

be small enough not to compromise a 4% momentum resolution. However, this point needs to be examined more carefully. The same comment holds for the delta ray production mentioned above.

In summary, we have considered momentum resolution, identification redundancy, high p_T trigger, and electrons from muon radiation. While this analysis has certainly been very rough indeed, we believe that it is adequate to show that there is a *very real possibility* that an absorber-filled high field compact solenoidal magnet with tracking outside the coil is an excellent cost-effective method for muon measurements at high luminosities.

III. DETECTOR SYSTEM OPTIONS AND COST

The concept developed in the last section is incompatible with good calorimetry outside the solenoidal magnet. This is just as well , because of the difficulty of working at $2 \times 10^{34}/(cm^2\ sec)$. The cost for a system with a hadron calorimeter is also very high. Just *its muon system alone*, because of its very large size outside the calorimeter, would cost more than our whole detector, and have much worse momentum resolution. However, if future technology allows measurement of electrons close to the interaction point at high luminosity (such as a diamond based calorimeter, once it is developed), then the same high p_T muon(s) trigger can be used and together increase the event rate by a factor of three. Before such a calorimeter is developed, however, the absorber here will remain a passive absorber.

Fig.8 shows a quadrant of a possible detector configuration.

The estimated cost of the central detector of Fig.8 is as follows:

- The major cost is the high field superconducting solenoidal magnet, estimated at $\$1m \times B \times V^{0.4}$ (B in Tesla and V in m^3), **$36m.**
- Iron as absorber and as flux return, 6700 tons, at $1K per ton, **$7m.**
- Tracking chamber including electronics, 500 m^2 inside flux return (4 layers) and 500 m^2 outside (2 layers), at $6K per m^2, **$6m.**
- Trigger, **$1m.**

Total cost of the central detector is about **$50m.**

The compactness of the central detector allows us to keep the size of the forward muon system from getting out of hand. To achieve the 4% momentum resolution, a system of high field toroids is our choice now. This is rather expensive (another **$50m**) and unimaginative. We hope that an alternative can be found.

Other options of the system (shown in Fig. 9) include an arrangement with a longer coil, and/or the absorber includes carbon. (The cost of a longer coil may be offset by the reduction in the outer radius of the expensive forward toroids.) The best design may be a combination of two or three different absorbers.

IV. DEVELOPMENT PROGRAM

The major development needed is for the superconducting high field solenoid. A 6 Tesla superconducting solenoidal magnet with 1m radius and 2.5 m length had been been designed by the KEK Lab and the Ishikawajima-Harima Heavy Industries Co. in Japan[7]. The limitation in size is mainly due to the need to keep the coil thin. Without the constraint on the thickness of the coil in our case, we believe larger volume is possible and the price-performance can be optimized.

Innovative ways to shape the ends of the solenoid magnet might lead to a way to replace the forward toroid system. This possibility is certainly worth exploring.

We request funds in FY 1991 to support preliminary engineering designs of a large volume superconducting high field solenoid. **$250K** is needed for the design study, by an American industrial company to be commissioned by the University of California at Davis.

Detailed simulation and background study needs to be carried out. So does the detailed design for detector elements. We also request an operating fund of **$50K** to carry out these studies

[7] S. Terada, K. Tsuchiya, H. Hirabayashi, A. Maki, *el al*, in Proceedings of the DPF Summer Study, Snowmass, 1988.

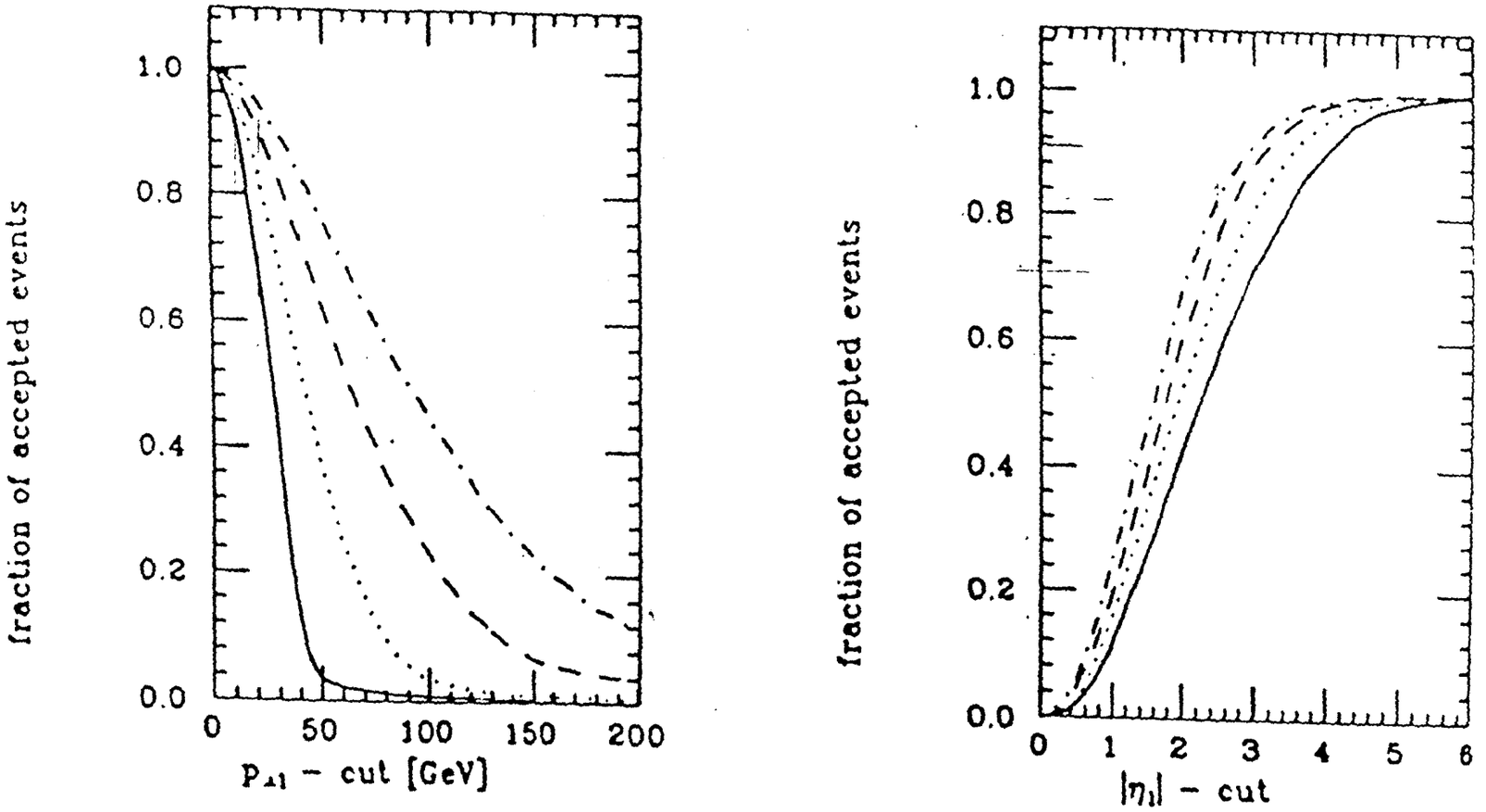
V. CONCLUSIONS

We have expressed our interest in a high field compact solenoidal magnetic detector, filled with iron or carbon absorbers and with tracking outside the coil. This detector would be feasible for precision muon measurement and fast trigger at the highest luminosity of the SSC. It is capable of exploring the highest mass discovery region of the SSC and is a good complement to the major general-purpose detector(s), at only a fraction of its (their) cost. We believe it has a place in the SSC program.

We have reason to believe the interest we have expressed is shared by many in the community.

We believe that this experiment will *open the door*[8] to the mass region inaccessible to other detectors.

[8] *10-34.*



solid: M_H = 200 GeV, dotted: M_H = 400 GeV
dashed: M_H = 600 GeV, dashed-dotted: M_H = 800 GeV

Fig. 1

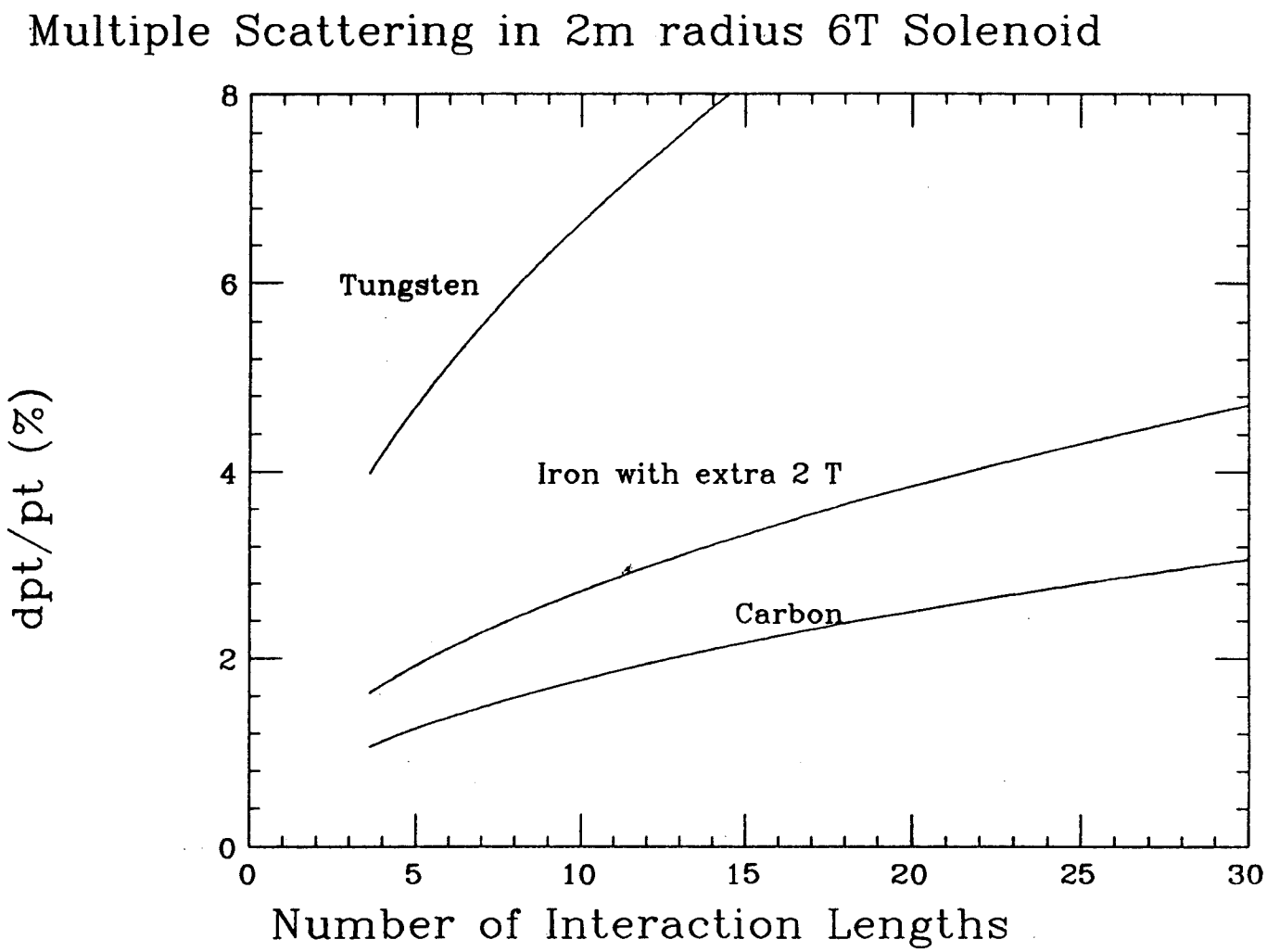

Multiple Scattering in 2m radius 6T Solenoid
dpt/pt (%)
Number of Interaction Lengths
Tungsten
Iron with extra 2 T
Carbon
0
2
4
6
8
0
5
10
15
20
25
30

Fig. 2

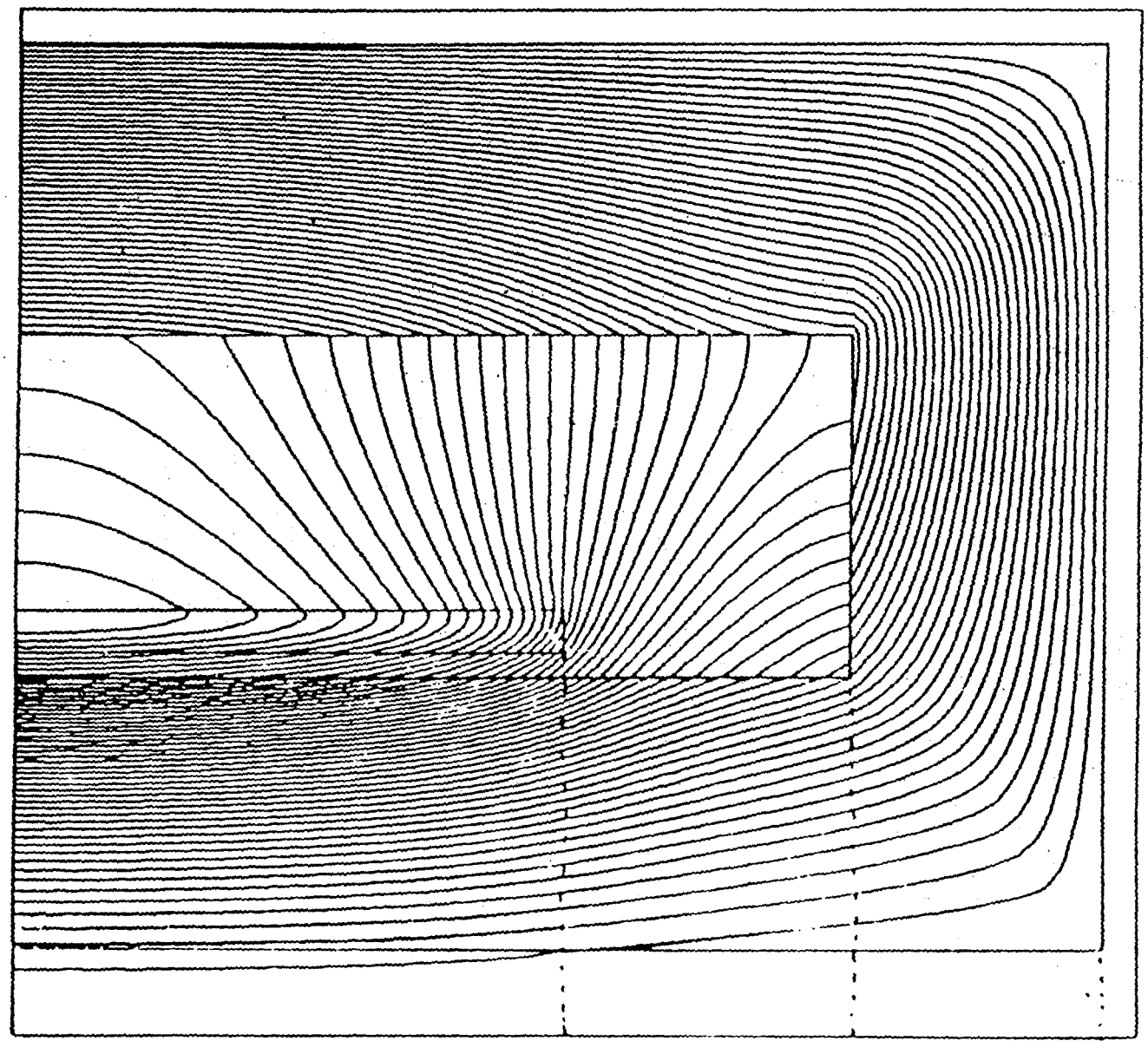


Fig. 3

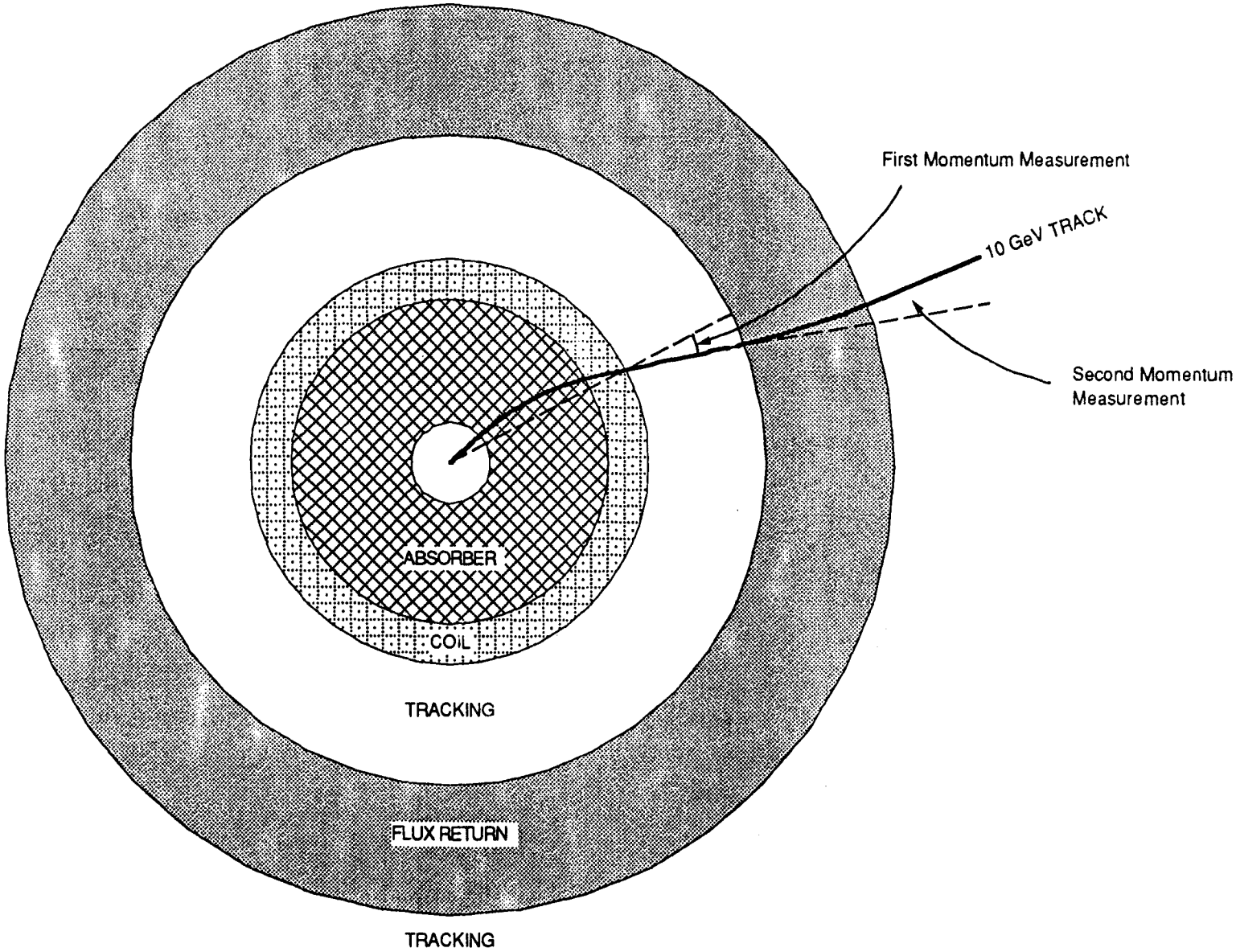

First Momentum Measurement
10 GeV TRACK
Second Momentum Measurement
ABSORBER
COIL
TRACKING
FLUX RETURN
TRACKING

Fig. 4

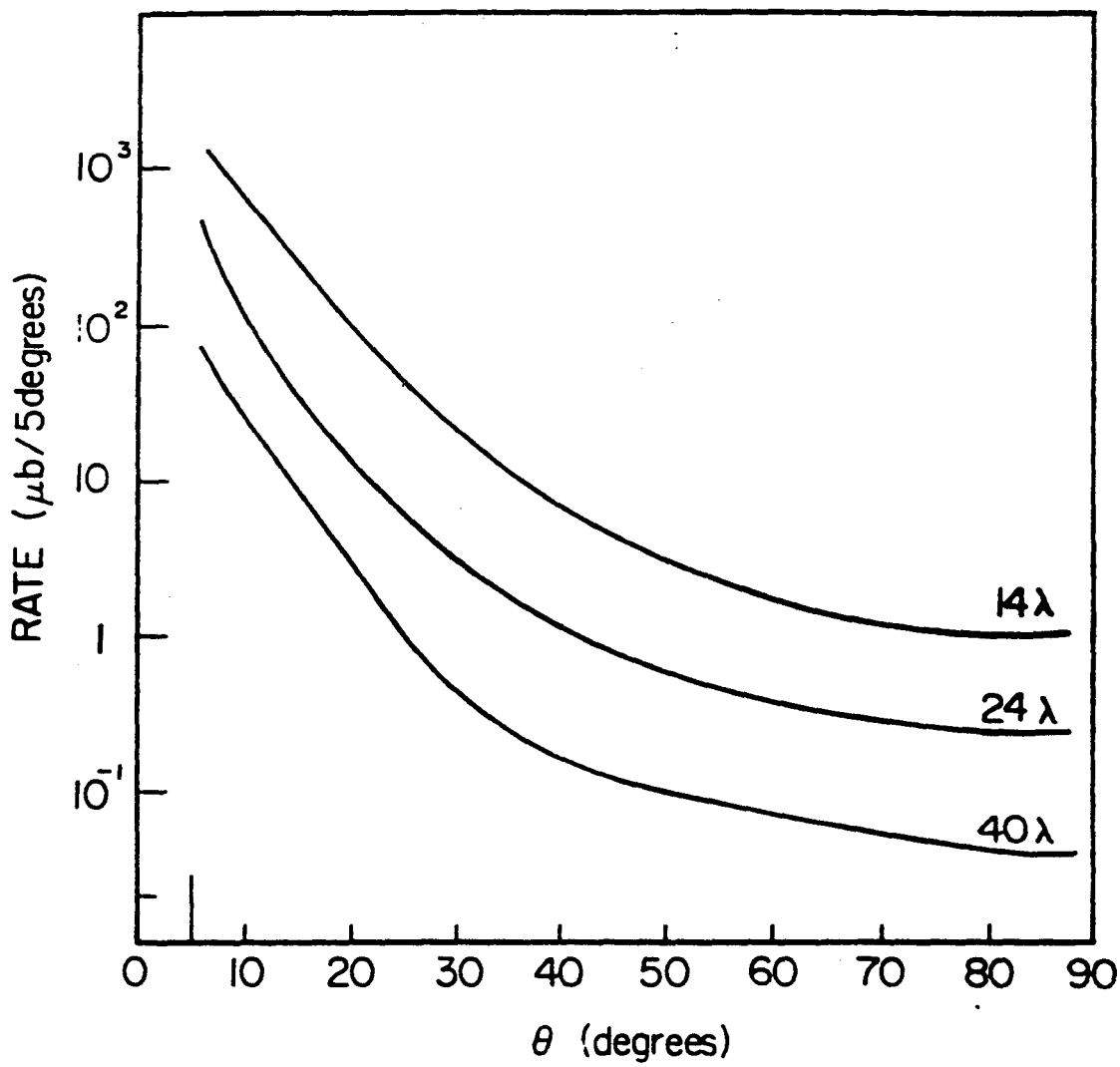

RATE (μb/5degrees)
10³
10²
10
1
10⁻¹
14λ
24λ
40λ
0
10
20
30
40
50
60
70
80
90
θ (degrees)

Fig. 5

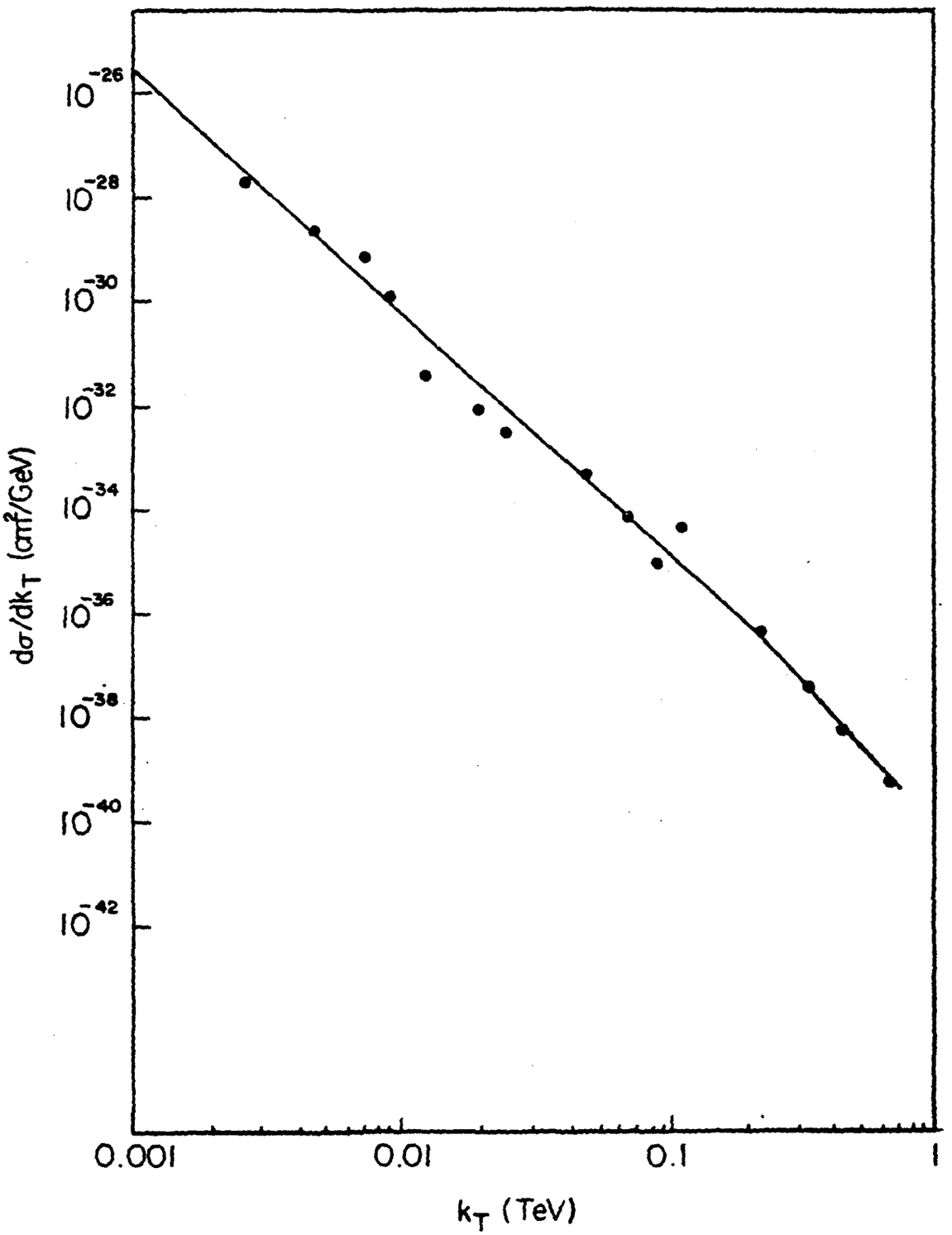

10^{-26}
10^{-28}
10^{-30}
10^{-32}
10^{-34}
10^{-36}
10^{-38}
10^{-40}
10^{-42}
$d\sigma/dk_T$ (cm²/GeV)
0.001
0.01
0.1
1
k_T (TeV)

Fig. 6 -

200 GeV μ

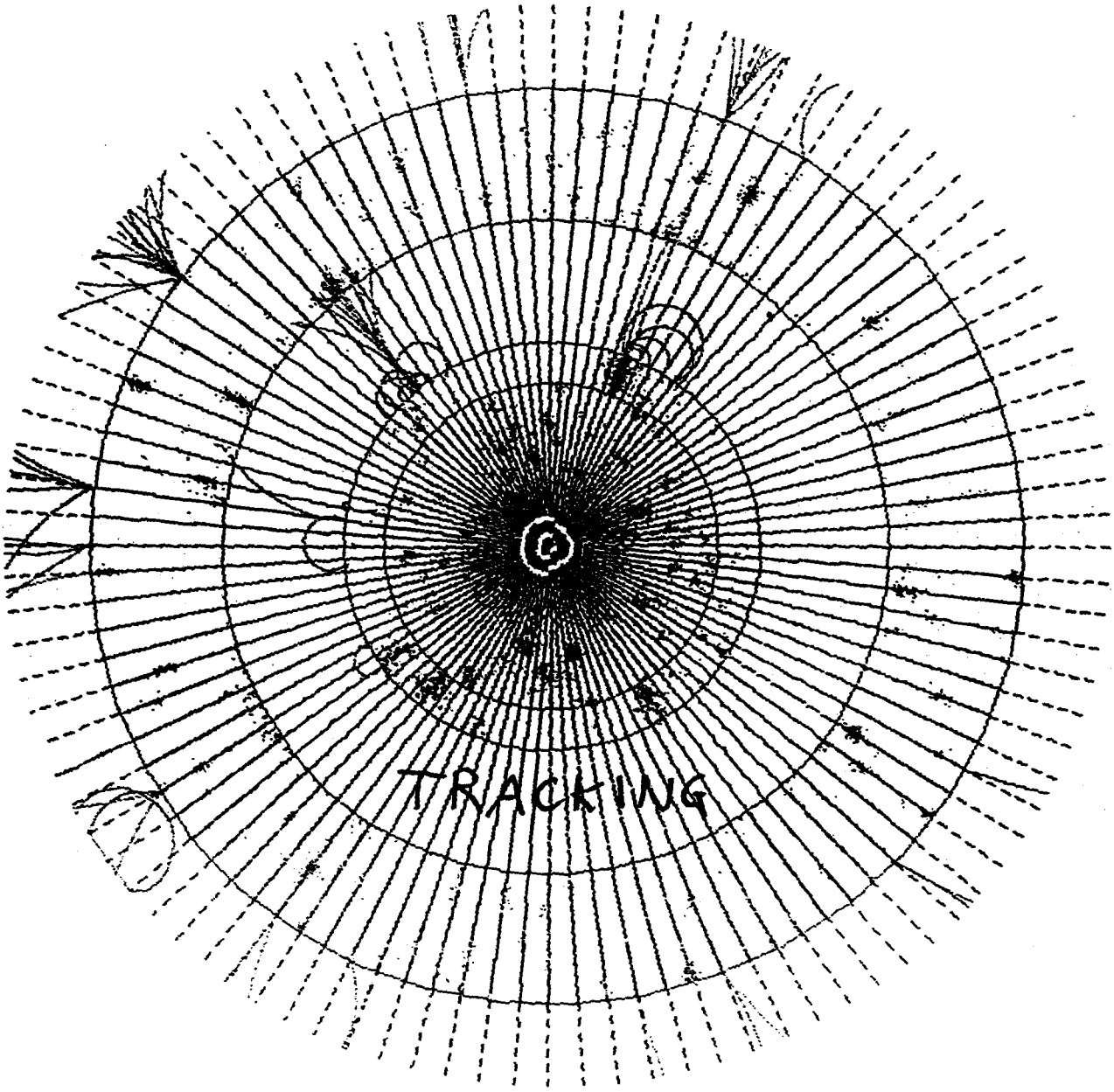


Fig. 7

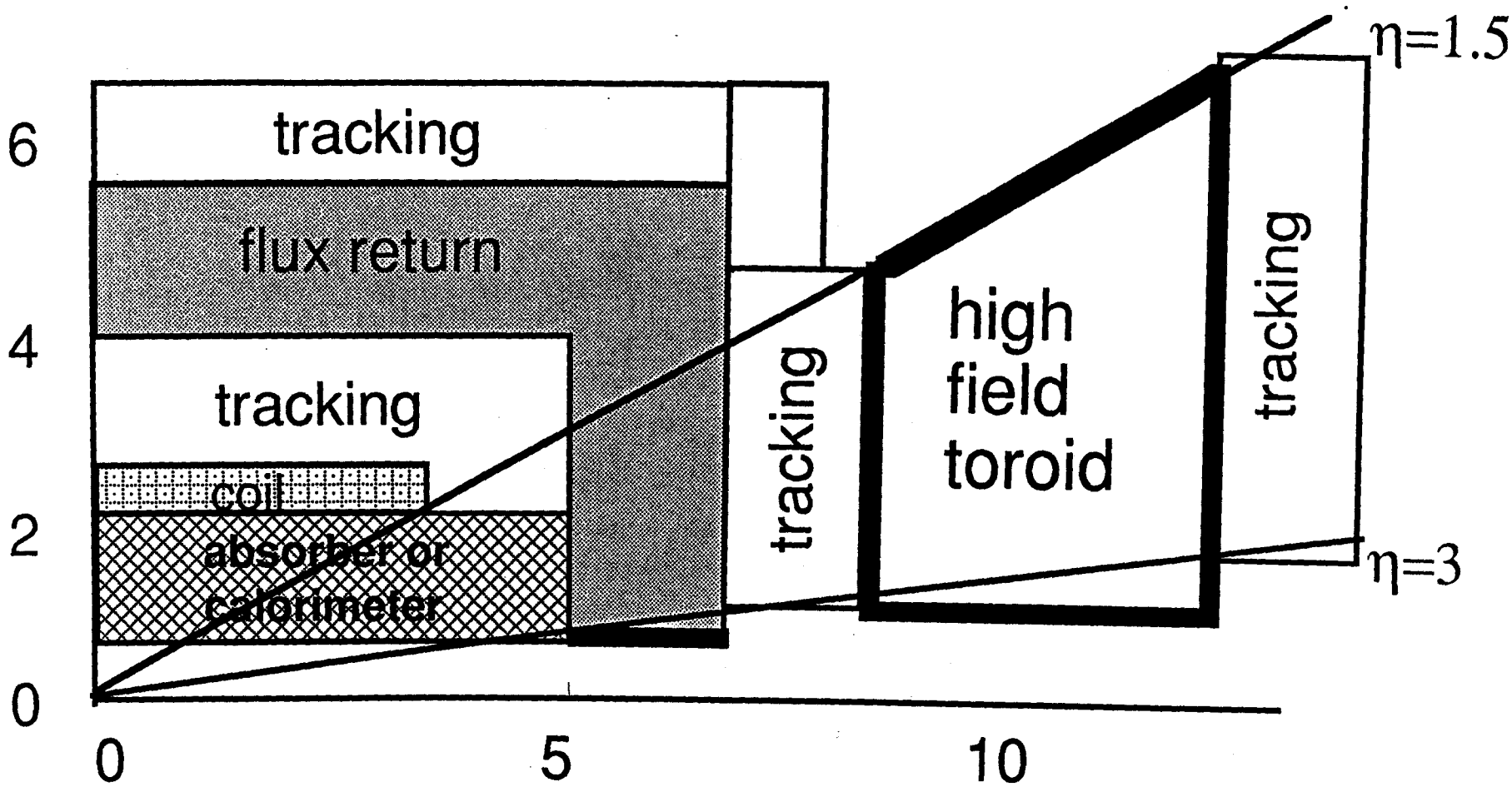

tracking
flux return
tracking
coil
absorber or
calorimeter
tracking
high
field
toroid
tracking
η=1.5
η=3
6
4
2
0
0
5
10

Fig. 8

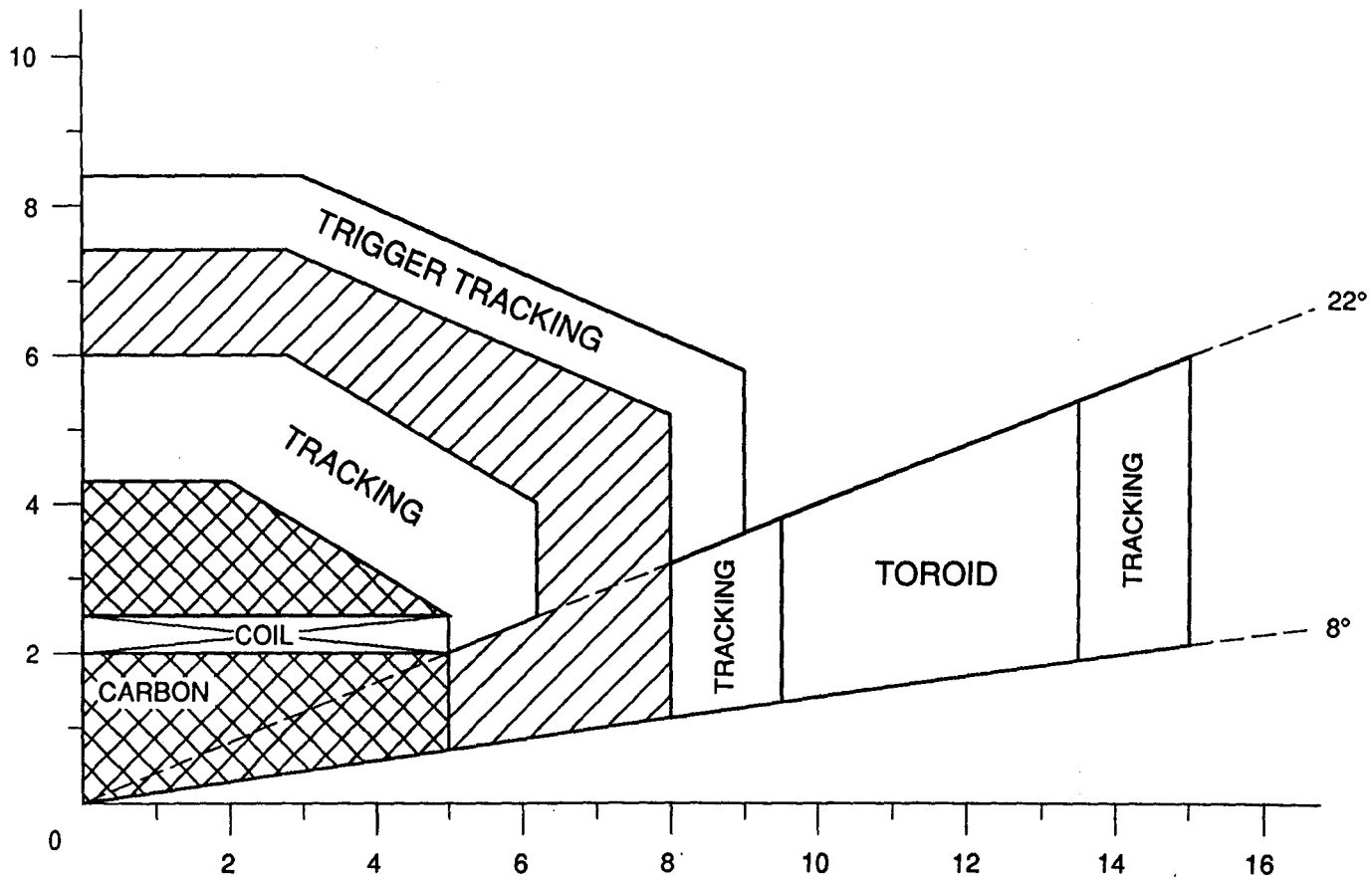

10
8
6
4
2
0
2
4
6
8
10
12
14
16
TRIGGER TRACKING
TRACKING
COIL
CARBON
TRACKING
TOROID
TRACKING
22°
8°

Fig. 9