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January 11, 1982

PROPOSAL FOR A FORWARD DETECTOR FOR THE DO AREA

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DIRECTOR'S OFFICE
JAN 21 1982

PROPOSAL SUMMARY

We propose to build a detector for the DO area which emphasizes accurate calorimetry and particle tracking down to the smallest practical angles.

One of the most frequently cited signatures of new physics are events which show an apparent violation of momentum-energy conservation due to momentum carried off by missing particles other than neutrinos. For example, supersymmetric scalar quarks, if they exist, are expected to decay into their associated ordinary quark and a photino or gluino. The missing gluinos or photinos (or Goldstinos from their decay) will cause a large apparent imbalance in p_T and p_L as well as an energy deficit. This is probably the best signature for supersymmetric particles. To exploit this signature a detector with good calorimetry over the widest possible solid angle is required. In general, detectors which are sensitive to missing energy-momentum may be essential for probing new physics at Collider energies.

The proposed detector could answer very fundamental questions about the behavior of hadron interactions beyond CERN collider energies. These include the variation of multiplicity and σ_{inel} with energy, energy flow measurements, studies of jets, and searches for new phenomena such as Centauro events which are suggested by cosmic ray data.

This detector could coexist with most of the "central detectors" proposed for the DO area. It will serve as an essential complement to a central detector and will greatly enhance the new physics possibilities by allowing the selection of events most likely to contain new physics. This can be done by requiring events to satisfy criteria such as high multiplicity, little energy going down the beam pipes, or missing p_T.

Introduction

At Fermilab collider energies, most of the secondaries from a $p\bar{p}$ collision go off at angles much less than 10°. For example, about 90% of the energy from a $\sqrt{s}$ = 2000 GeV interaction will on the average appear at angles <2°, the smallest angle which the CDF detector will cover[1]. This appears to be a serious shortcoming of the CDF detector which will prevent it from addressing many basic questions about the general character of hadron-hadron collisions at very high energies and handicap it in searching for new physics. As we shall discuss below, a detector which covers small angles, such as the one proposed here, can also significantly enhance the new physics signal in a "central" detector.

In designing a small-angle detector it is important to be able to model reasonably accurately the general features of high energy hadron-hadron interactions, particularly in regard to the angular distribution of the energy flow. To do this we have adopted a Monte Carlo program used earlier for this purpose by T. Gaisser.[1] This program incorporates a model used by Wdowczyk and Wolfendale[2] and others which takes into account the violation of Feynman scaling observed at Fermilab and ISR energies (and now more dramatically at the CERN collider[3]). This model has one parameter, variously called α or β [where β is variously defined as $\beta \equiv 1-2\alpha$ or $\beta \equiv 1-\alpha$] which is a measure of the violation of Feynman scaling. For α=0 Feynman scaling is recovered, while $\alpha \approx 0.5$ corresponds to a large breakdown of Feynman scaling as might be expected from a statistical model[2]. Data from the ISR and cosmic rays suggest a value of $\alpha \approx 0.2$ (Ref. 2).

In the Monte Carlo program, longitudinal momenta of the secondaries are assumed to grow with s according to

$$\frac{P_L(s)}{P_L(s_0)} = \left(\frac{s}{s_0}\right)^{\frac{1-2\alpha}{2}} \qquad (1)$$

where s_0 is some reference energy for which data are available. Average transverse momenta are assumed to grow slowly with s in a manner suggested by cosmic ray and ISR data. The leading nucleons are assumed to obey Feynman scaling and are given a flat distribution in Feynman x.

The results of this Monte Carlo simulation for $\sqrt{s}$ = 2000 GeV collisions are summarized in Fig. 1. These curves show, for 3 values of α, the fraction of the energy which would be collected in a calorimetric detector which subtends angles down to θ_{min} in both hemispheres. For the case of $\alpha = 0.19$ only, the effect of including leading nucleons is illustrated. Since these are assumed to obey Feynman scaling their contribution is independent of α.

The angular ranges covered by the proposed CDF central and forward detectors are shown for reference. By way of illustration, the curves show that if Feynman scaling were the correct extrapolation from ISR energies (i.e., α=0) the CDF detector would only collect about 2% of the energy from a typical $\sqrt{s}$ = 2000 GeV collision.

The angle marked "Min. Practical Angle" in Fig. 1 is based on a reasonably conservative extrapolation of experience at the ISR, where detectors can be brought within 0.7 cm of the stable circulating beams.[4] We therefore assume a minimum distance of approach of 2.0 cm from beam center for detectors placed ≈20 m from the interaction point. (The straight sections at the collider are approx. 50 m long.) Figure 1 suggests that it should be possible to build a calorimetric detector which, on the average, will efficiently collect most of the energy, with the possible exception of that carried by the leading nucleons.

Figure 2 shows the region of rapidity which would be covered by our detector and by the CDF detector. Note that CDF, even with its forward detector, only covers about half the range. The detector described here with an accompanying central detector would cover essentially the entire range.

Physics Objectives

We believe the proposed detector can do significant physics both on its own and in conjunction with any "Central Detector" which we assume will coexist in the DO area.

As far as physics the proposed detector can do on its own, some of the more obvious and important things are:

(1) Searches for new particles - Various theoretical ideas such as broken supersymmetry[5] and technicolor suggest the existence of whole new classes of particles with an essentially arbitrary mass scale. Supersymmetry schemes, for example, require a scalar partner to each fermion, as well as spin 1/2 partners to the gluon and photon. Most decay modes involve a gluino or photino. The gluino, if short-lived, will decay to a gluon and Goldstino or a photino and a $q\bar{q}$ pair. The photinos and Goldstinos will not interact in the detector. The net result is an event with a large missing momentum and energy, with no associated muons. This signature seems likely to be important in theories other than supersymmetry. To exploit this signature will require a detector with the best possible calorimetry and the widest possible coverage in solid angle. This can be provided by the detector described here plus an accompanying central detector.

[Other signatures of supersymmetry [5a] would be "one-jet" (plus the beam jets) and "zero-jet" events with large missing energy and momentum.[6] These come about due to the gluon-gluino-Goldstino couplings shown in diagrams such as Fig. 3. The Goldstino(s) will typically carry off 10-20% of the available energy.]

It is clear that a central detector such as CDF which misses ~ 90% of the total energy cannot take advantage of this signature because of statistical fluctuations in the momentum carried off by the missed hadrons.

(2) General features of very high energy interactions -The proposed detector will cover angles down to about 1 mr in either hemisphere. In rapidity this corresponds to $|y| \lesssim 7.5$. (See Fig. 2.) At present, very little is known about even the most basic features of very high energy hadron-hadron interactions. The cosmic ray data are difficult to interpret or controversial. We might expect that at Collider energies the constituent quarks in the nucleons will become apparent and the events will show clear jetlike behavior. A "typical" quark in a nucleon with $\hat{x} \approx 0.3$ which undergoes a hard scatter with $p_T \approx 5$ Gev/c will produce a jet at about 1°. This would be well inside our detector — and well outside any of the contemplated central detectors. — The large range in angle and rapidity covered by the detector will allow studies of correlations between jets. These correlations can give important information on production mechanisms. This physics is much too important to give CERN a monopoly by default.

(3) Energy flow measurements - T. Gaisser[1] has emphasized the importance of these to the understanding of the general behavior of hadronic interactions at very high energies. This will contribute to the resolution of a fundamental astrophysical problem, the composition of primary cosmic rays above 10^{14} eV.

(4) Multiplicity vs. $\sqrt{s}$ - This is a basic measurement which should be continued to the highest available energies. Cosmic ray data from the Brazil-Japan group suggest a new threshold near $\sqrt{s}$ = 500 GeV. (See inset to Fig. 4 which is taken from G. Goggi, CERN-EP/81-08.)

(5) σ_{inel} vs. $\sqrt{s}$ - Again cosmic ray data from the Tien-Shan group suggest a sudden increase in the absorption length above $\sqrt{s} \cong 500$ GeV, as shown in Fig. 5. A central detector with $\theta_{min} \gtrsim 2°$ could miss this effect.

(6) Centauro events - These have been discussed at great length by many authors. As shown in Figure 4, they seem to be restricted to $\sqrt{s} \gtrsim 600$ GeV and may be just out of reach of the CERN collider.

(7) Diffractive production of new flavors - Data from the ISR suggest a large cross section for the diffractive production of Λ_c. This may occur for other heavy flavors as well. The forward region may be the best place to look for heavy baryons beyond the Λ_B. Whether this is practical for any detector without adding particle identification for K's is problematical, however.

The proposed detector would also be generally useful as a luminosity monitor. It could also serve as a veto in support of an elastic scattering experiment. If it becomes possible to move the farthest tracking chambers as close as 0.7 cm to the beam, we will be able to measure elastic scattering for $t \gtrsim 0.2\ (\mathrm{GeV/c})^2$. [At 2.0 cm, $t \gtrsim 1.0\ (\mathrm{GeV/c})^2$ is covered.]

The CDF detector may not be well suited for much of the above physics. Some of it will, of course, already have been studied at the CERN collider, but it will be important to extend these measurements another order of magnitude in equivalent lab energy at Fermilab. There also seems to be a possibility that the CERN energy is a bit too low to see the rise in multiplicity and σ_{inel} suggested by the cosmic ray data.

In the long run the most important contribution of a detector such as that proposed here might to be in the enrichment of "new physics" from a coexisting central detector. The whole philosophy of the design of the CDF detector and most of the CERN detectors is that "new physics", generally speaking the production of massive new states such as W, Z°, or $t\bar{t}$, or the particles of supersymmetric theories or technicolor, is best studied in the central region and the decay products will go off at relatively large angles. It is expected that the new physics signal will be very difficult to extract from a background of "log s" physics and "old" physics such as $s\bar{s}$, $c\bar{c}$, and $b\bar{b}$ production. <u>Any</u> additional information about an event which will help to

reduce these backgrounds in a central detector would be extremely valuable, particularly on the trigger level. This might prove crucial in separating objects like the W from the dominant background.

With the information from a detector such as we propose, the general character of individual events is immediately recognizable. The best way to use this information to reduce backgrounds in a central detector will require some experience to learn. Generally speaking to produce a massive state requires a hard $q\bar{q}$ or gg collision with the maximum possible $\hat{s}$, the center-of-mass energy squared in the $q\bar{q}$ or gg rest system. Events of this type should be characterized by:

(1) higher than average multiplicity

(2) little energy going down the beam pipes.

Our detector would be uniquely capable of answering these questions on an event-by-event basis. Selecting events which satisfy these criteria should significantly reduce the background in searches for the W, t, ... in the central detector.

In addition to the general features suggested above for identifying events richer in new physics, it is possible to define more specific criteria. For example, in searches for particles containing massive quarks such as naked top some of the decay products will go off at angles smaller than those covered by the central detector. Being able to see the decay products in the forward detector will allow selection of only those events which could plausibly contain a t and $\bar{t}$, even if only some of the decay products can be identified. In the sequence

$$p + \bar{p} \rightarrow t\bar{t} + X$$

with $t \rightarrow b + q\bar{q}$, $\bar{t} \rightarrow \bar{b} + q\bar{q}$ where q and $\bar{q}$ represent quarks lighter than b, one would expect 6 jets plus the beam jets in the final state. The chances of collecting enough of the particles to recognize the jet structure of events

like these, and even much simpler ones, is exceedingly small in a detector which misses everything within several degrees of the beam.

A very important signature of new physics is the momentum imbalance caused by neutrinos from the semileptonic decays of massive states or, as discussed earlier, by other neutral objects such as Goldstinos or photinos. A central detector which misses ~ 90% of the energy cannot make significant use of this property. If the missing p_T in an event is due only to hadrons which go out the beam "holes", the <u>maximum</u> missing p_T is related to the missing energy as shown in Fig. 6. The missing p_T from this source is quite small for the proposed detector, ~ 1 GeV. With the addition of information from the forward detectors a good measurement of missing p_T is possible and a possibly useful measure of missing p_L. This capability will be extremely useful in searching for semi-leptonic decays of W, t, etc. as well as new massive leptons produced in decays of more massive objects.

Historically, a major advantage of e^+e^- colliders in searching for new physics is that the energy of the intermediate state produced in the e^+e^- annihilation is well known. The equivalent quantity in hadron-hadron collisions is $\sqrt{\hat{s}}$, the total energy of the quarks or gluons which collide to produce a high-mass intermediate state which may then decay into massive particles. At Fermilab collider energies it should be reasonable to identify the spectator quarks or "wounded nucleons" with the leading particles in the lab systems. As shown in Figure 1 the leading nucleons go off at angles less than 1 mr. To the extent that this identification is correct, a calorimetric detector which covers angles down to 1 mr in either direction provides a direct measure of $\sqrt{\hat{s}}$. This information should be particularly useful in looking for very massive states beyond the W and Z. These will be produced mainly from hard $q\bar{q}$ collisions (rather than gg) with the spectators carrying off a small fraction of the energy.

Description of the Proposed Detector

The general philosophy of our design is to cover the largest practical angular range with calorimetry and tracking chambers. As discussed earlier, it should be possible to provide calorimetry down to an angle of about 1 mr from either beam with detectors 20 m from the interaction point which can be moved to within 2 cm of the circulating beams.

We believe the detector described here is practical, effective, and can be built at a very reasonable cost. However we also believe it would be foolish to commit ourselves to a detailed design at this early stage. That outlined here should be considered as a proof of principle.

The design is shown schematically in Figure 7. Note that the transverse dimensions are exaggerated fivefold. The detector has mirror symmetry about the interaction point and the elements cover 2π in azimuth.[7] Tracking chambers precede each of the calorimeters; these are spaced sufficiently from the upstream faces of the calorimeters to minimize problems from albedo. The farthest set of tracking chambers (T_3, T_4) and calorimeters (CAL 3) are moveable so that they can be brought in close to the beams once they are stable. To accomplish this it seems necessary to place the tracking chambers within the vacuum, or place them in rather elaborate "Roman pots", in order to minimize the amount of material the particles must go through. For the farthest calorimeters, this can be accomplished by having each of the sections A, B, C, D of CAL 3 "push" individual sections of the vacuum pipe aside. The total motion necessary is only about 5 cm which can be accommodated by having the sections of pipe connected by standard bellows. A beam's eye view of one section of this calorimeter is shown in the view from A-A.

It is assumed that each of the calorimeters will have an upstream portion made of high Z material which is read out separately. This will allow a distinction between electrons, photons, and hadrons. It should also be

possible to distinguish neutrons from charged particles. Muons can be identified by providing chambers downstream of the calorimeters, possibly preceeded by additional shielding.

The calorimeters will be segmented azimuthally and in radius. This will allow an accurate measurement of $E_{transverse}$ and energy flow. The last calorimeter is in sections so that particles produced in one of the upstream sections which leave through the beam pipe side will be captured in one of the downstream sections. Thus the calorimeters will contain the energy of forward-going particles, though crosstalk between sections will sometimes make it difficult to measure the energy of individual particles accurately. The transverse dimensions of the calorimeters are >6" oversize to contain the showers.

One important decision in the design is whether to use scintillators with shifter bars in the calorimeter or to use limited discharge wire chambers of the sort planned for CDF. The use of scintillator would allow a "fast" energy measurement which could be used as part of the trigger for the central detector. It also seems somewhat simpler to build. If it is used, precautions would have to be taken to prevent radiation damage to the scintillator during fixed target running, as occurred in the UA1 detector at CERN[3]. This does not appear to be a serious constraint as the calorimeter units are relatively small and are external to the beam pipe so they can be installed rather quickly. Wire chambers, on the other hand, would allow somewhat finer segmentation and more detailed tracking of energy flow. The decision between these alternatives will depend to some extent on the choice of central detectors.

For the region $\theta \gtrsim 6°$ we show only tracking chambers. We assume that calorimetry for $\theta \gtrsim 6°$ will be provided by the central detector, though we would be happy to go to larger angles. It may be desirable to add shielding between the calorimeters to reduce punchthrough and spray in the tracking

chambers downstream.[8]

Luminosity and Other Considerations

Since our detector would see almost the total $\bar{p}p$ cross section, event rates and luminosity are not a factor. However we envision a situation where our detector would coexist with a variety of central detector options. We favor a design for the low β quads which utilize stronger quads in the adjoining sectors of the Doubler magnets. Such a scheme is discussed in the design report for the Doubler[9]. This could provide a $\beta^* \lesssim 10$ m. (See Fig. 8.) CDF Note No. 64 also discusses similar designs which can give $\beta^* \approx 5$ m with a free space of almost 50 m. These designs are relatively inexpensive and in the spirit of the low budget DO area. Detector designs similar to the one in Fig. 7 which would allow low β quads to be installed downstream of the first or second calorimeters are also possible. This would make particle tracking beyond the quads somewhat more difficult and slightly smear the energy flow measurements. Another option would be to remove our second calorimeter entirely when the highest luminosity is desired and replace it with low β quads. The rest of our detector would still function and provide useful, though less complete information.

Requests of the Laboratory

Our calorimeter modules are fairly small. However, at present the Doubler beam pipe is only 10.5" off the tunnel floor as seen in Figure 9 which also shows the outline of the middle calorimeter from Fig. 7. The nearest calorimeters can be accommodated by extending the central detector pit; this extension need only be perhaps 20" below the present floor and could be as little as 4' wide. It should be possible to build the second and third calorimeters and vacuum pipes within the 10.5" restriction. As seen in Fig. 7 the particle trajectories remain well within 10.5" from the beam. However this limitation on the transverse dimension of the calorimeter below the beam pipe

would result in a poorer energy resolution due to shower leakage out the bottom. This constraint would also make the design of the detector considerably more difficult. One solution is to provide additional floor clearance only in the areas near the second and third calorimeters. However in the interest of overall flexibility our suggestion would be to lower the floor for the entire length of the straight section to provide at least 4 ft of clearance below the Doubler beam over a width of about 6 feet.

We would request that the Laboratory build the vacuum pipes for our detector. In the design in Fig. 7, the largest section of pipe is only approx. 2 ft in diameter. A reasonably thin window ahead of tracking chambers T2 would be needed and the beam pipes ahead of T1 and around Cal. 3 should be as thin-walled as possible. We would also request that the Laboratory assist in the design of the tracking chambers T3 and T4 inside the vacuum tank or in the design of an alternative scheme with Roman pots.

Prospects for Future Expansion of the Detector

The longer term physics prospects for a forward detector seem excellent. Any hints of new physics will have to be followed up by further studies with an improved detector. This physics is impossible to predict. We believe it is wise to start with a fairly modest detector and build on it as the circumstances warrant. Possibilities for expansion are numerous. There is plenty of space along the beam pipe to add additional tracking chambers or particle identification (e.g. -transition radiation detectors). As mentioned previously, as beam condition improve we should be able to move the detectors closer to the beams. This will greatly improve our sensitivity to missing energy, particularly if tracking chambers beyond the adjacent Doubler magnets are added. This would allow the energy of a large fraction of the leading nucleons to be measured. Future expansion would be considerably simplified if more clearance under the beam pipe is provided, as discussed earlier.

REFERENCES AND FOOTNOTES

1. T.K. Gaisser, Phys. Lett. 100B, 425 (1981). We have extended Gaisser's calculation to smaller angles using his program.

2. J. Wdowczyk and A.W. Wolfendale, Nuovo Cimento 54A, 433 (1979).

3. A. Kernan, presented at the Second Workshop on Forward Collider Physics, Madison, December 1981.

4. M. Block, Northwestern University, private communication.

5(a). G.L. Kane and J.P. Leveille, "Experimental Constraints on Gluino Masses and Supersymmetric Theories", Univ. of Michigan Preprint UM HE 81-68.

(b). G.L. Kane and J.P. Leveille, "Physics Comparisons of Some Future Accelerators", University of Michigan Preprint UM HE 81-61.

(c). G. Farrar and P. Fayet, Phys. Lett. 76B, 575 (1978).

6. The cross section for producing "zero jet" events through the process in Fig. 3a is, however, quite small. [J.P. Leveille, private communication.]

7. A design with only two calorimeters is, of course, possible. This solution might be preferable if more of the straight section is required to accommodate accelerator paraphernalia.

8. We have had discussions with Y. Muraki of the Institute for Cosmic Ray Research at the University of Tokyo about the possibility of exposing emulsion chambers at small angles to the beam to study γ rays from $\bar{p}$-p collisions. [See Y. Muraki, "Very Forward Photon Detection", CDF Report 112.] The emulsion chambers would each be only 10 cm × 10 cm exposed for about a minute at the design $\bar{p}p$ luminosity at as small an angle as possible. We would be happy to cooperate with Dr. Muraki in this exposure.

9. A Report on the Design of the Fermi National Accelerator Laboratory Superconducting Accelerator, May 1979, p. 17 ff.

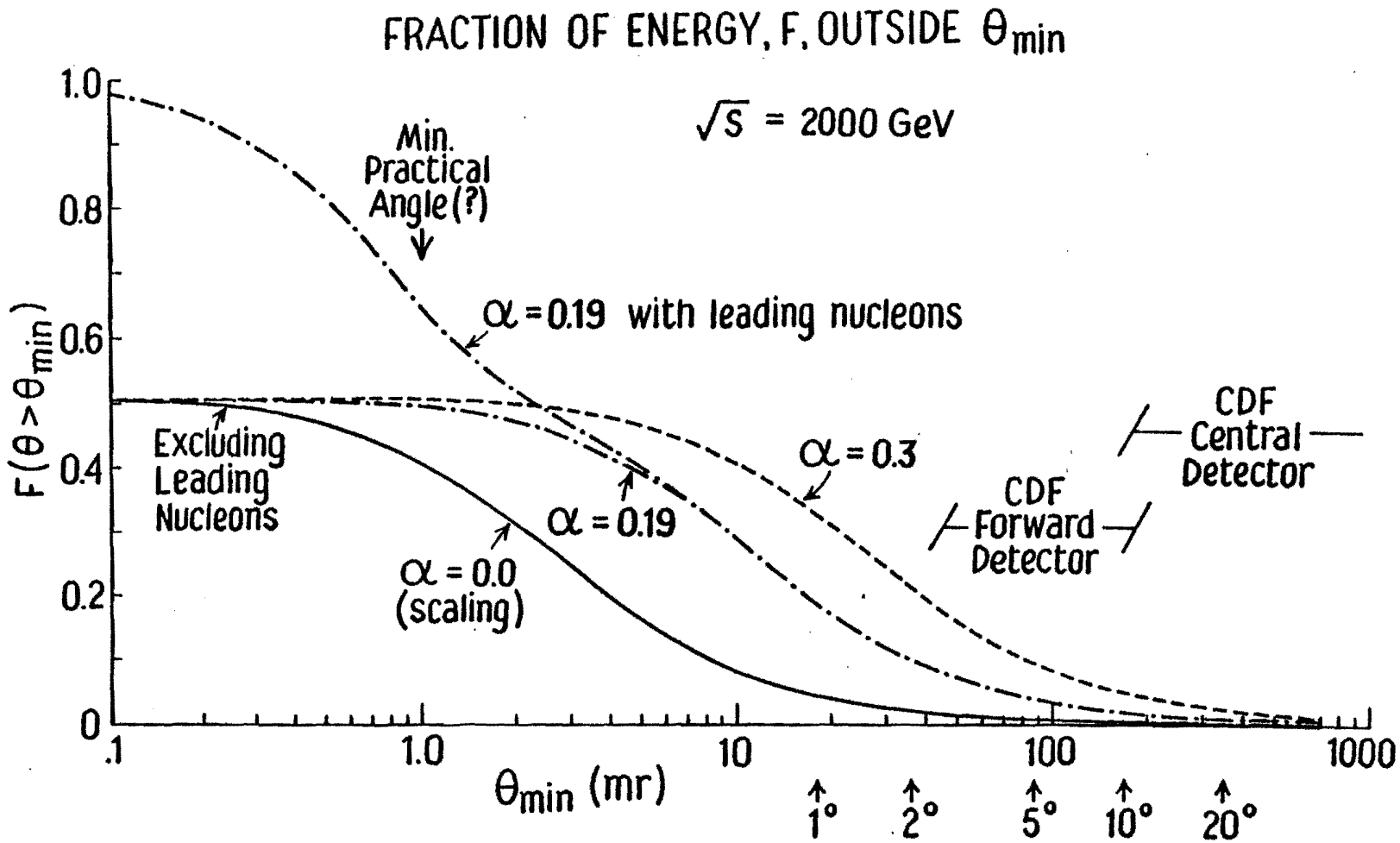


Figure 1 - The fraction of the total energy outside an angle θ_{min} for 3 values of the parameter α. The case α=0 corresponds to Feynman scaling; α=0.3 corresponds to a large deviation from Feynman scaling; α=0.19 is a reasonable estimate from ISR data. For the case of α=0.19 only, the effect of including leading nucleons is illustrated.

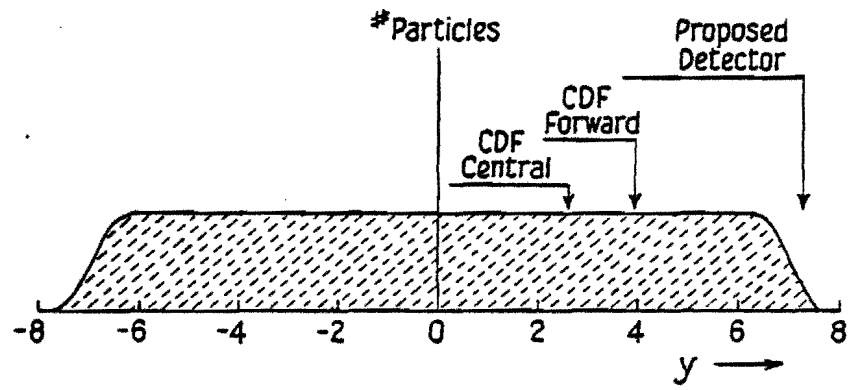


Figure 2 - The total rapidity range at $\sqrt{s}$ = 2000 GeV and the range covered by the proposed detector.

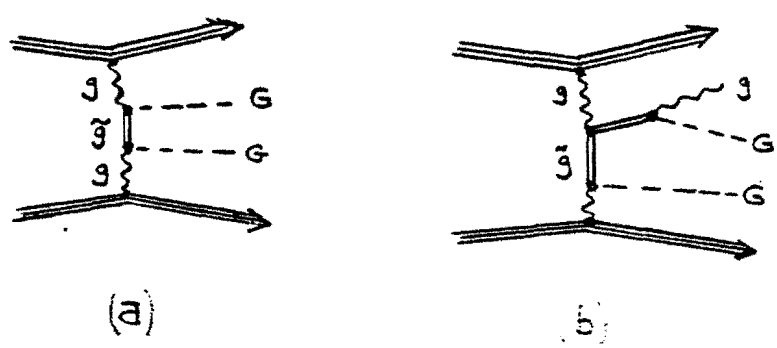


Figure 3 - Diagrams which lead to a large missing momentum and energy and no muons, [g = gluon, $\tilde{g}$ = gluino, G = Goldstino]. In (a) only the beam jets would be observed; while (b) would result in a gluon jet plus the beam jets.

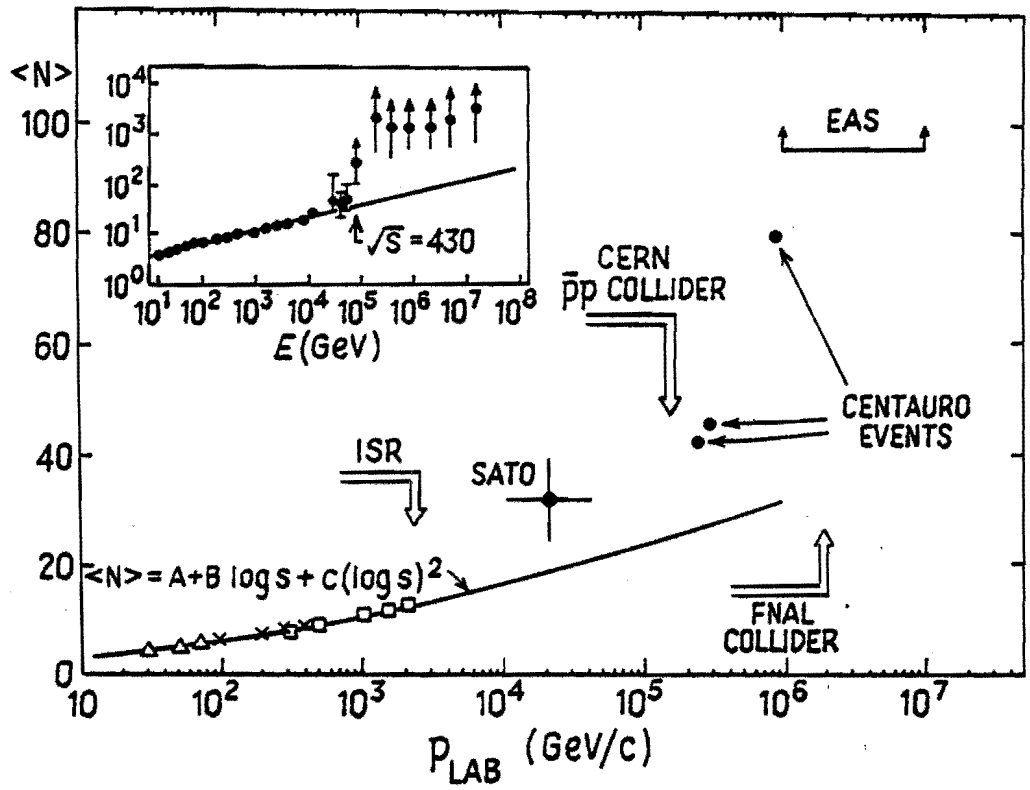


Figure 4 - Average charge multiplicity vs. lab momentum (from CERN-EP/81-08). The inset shows data from the Brazil-Japan cosmic ray emulsion experiments.

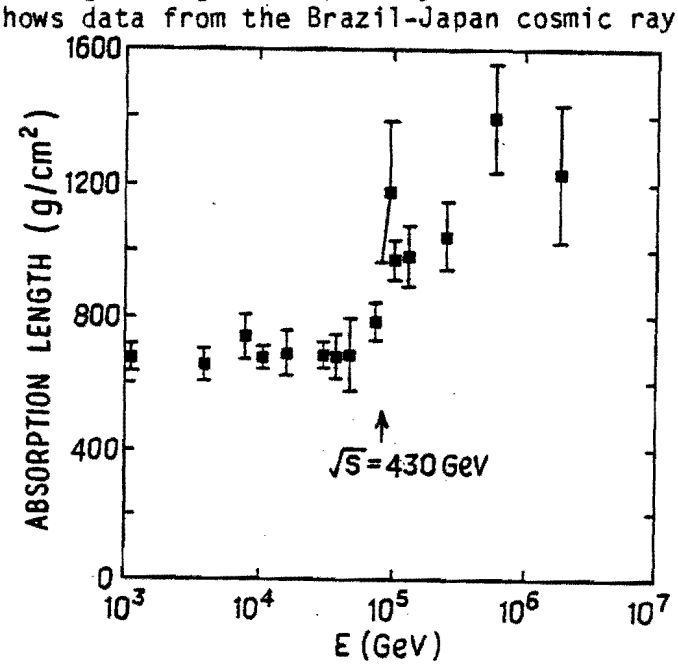


Figure 5 - Measured absorption length vs. lab energy from the Tien-Shan cosmic ray experiment.

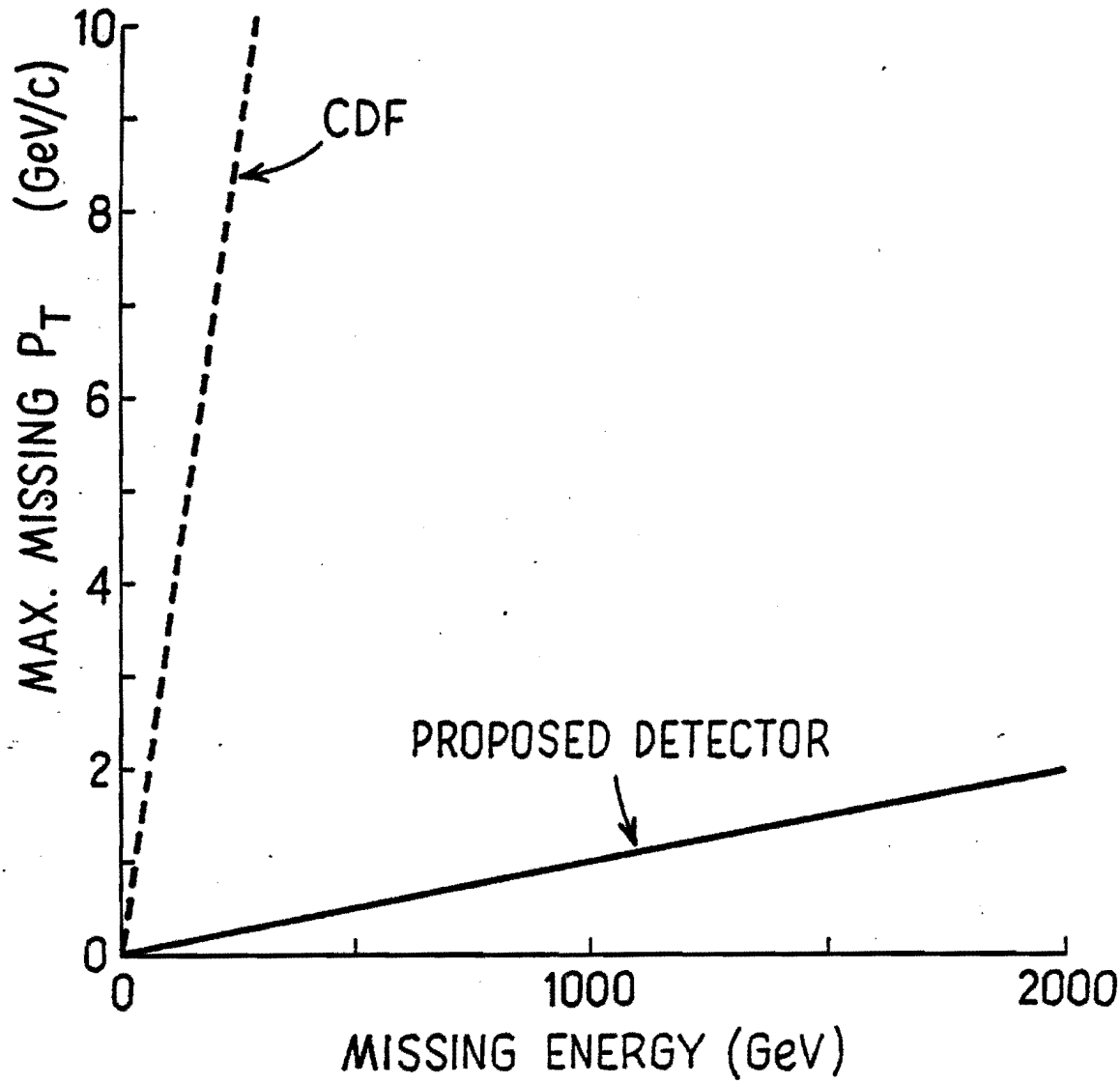


Figure 6 - Maximum missing p_T vs. missing energy for the proposed detector if $|\theta| \geq 1$ mr is covered with calorimetry. This assumes that only hadrons are missed and they all go off at θ=1 mr on the same side of the beam. Energy and angular resolution of the calorimeters are not included. Neutrinos, photinos, Goldstinos, and other noninteracting particles will generally give a missing p_T of the same order of magnitude as the missing energy.

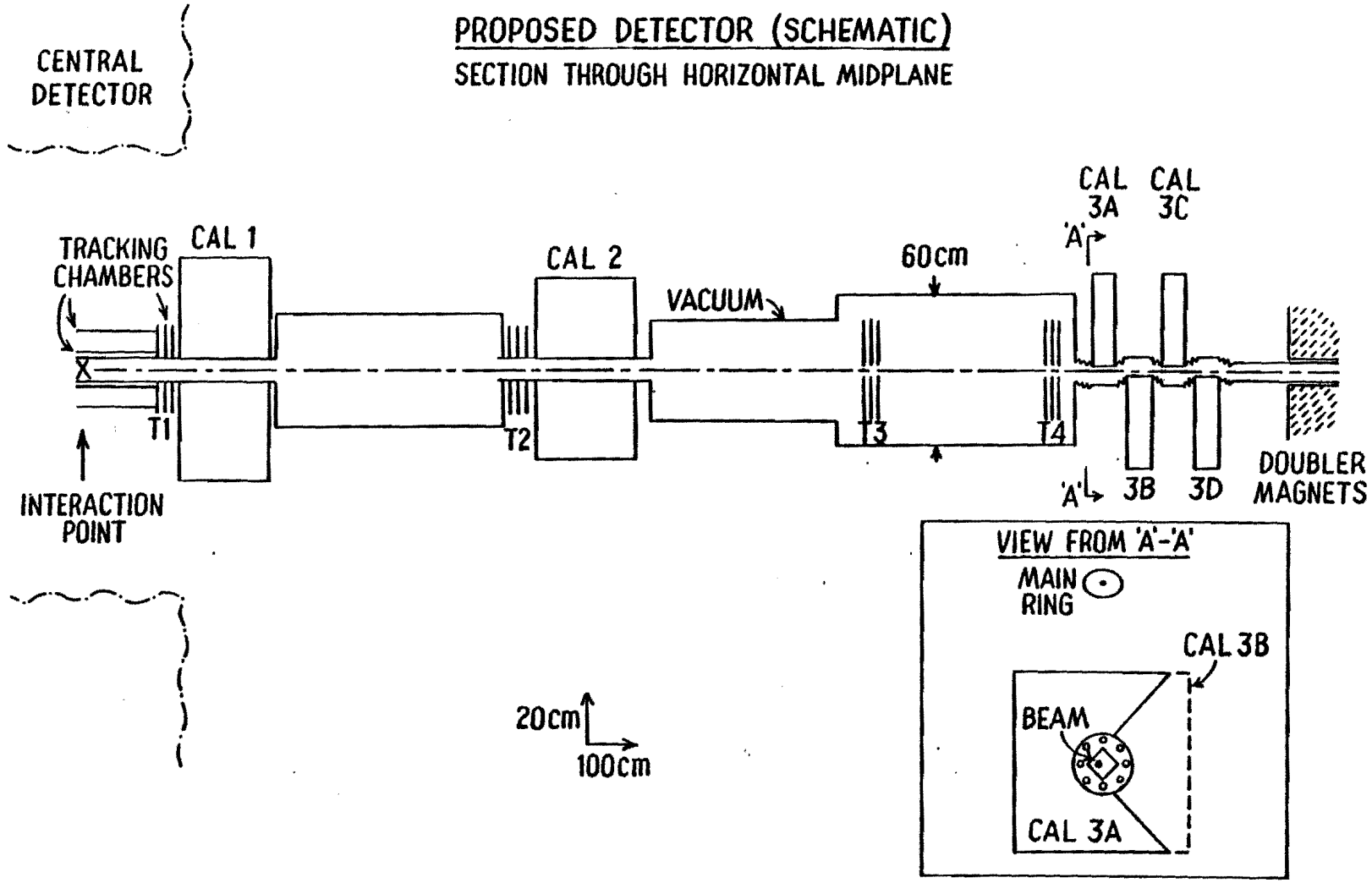
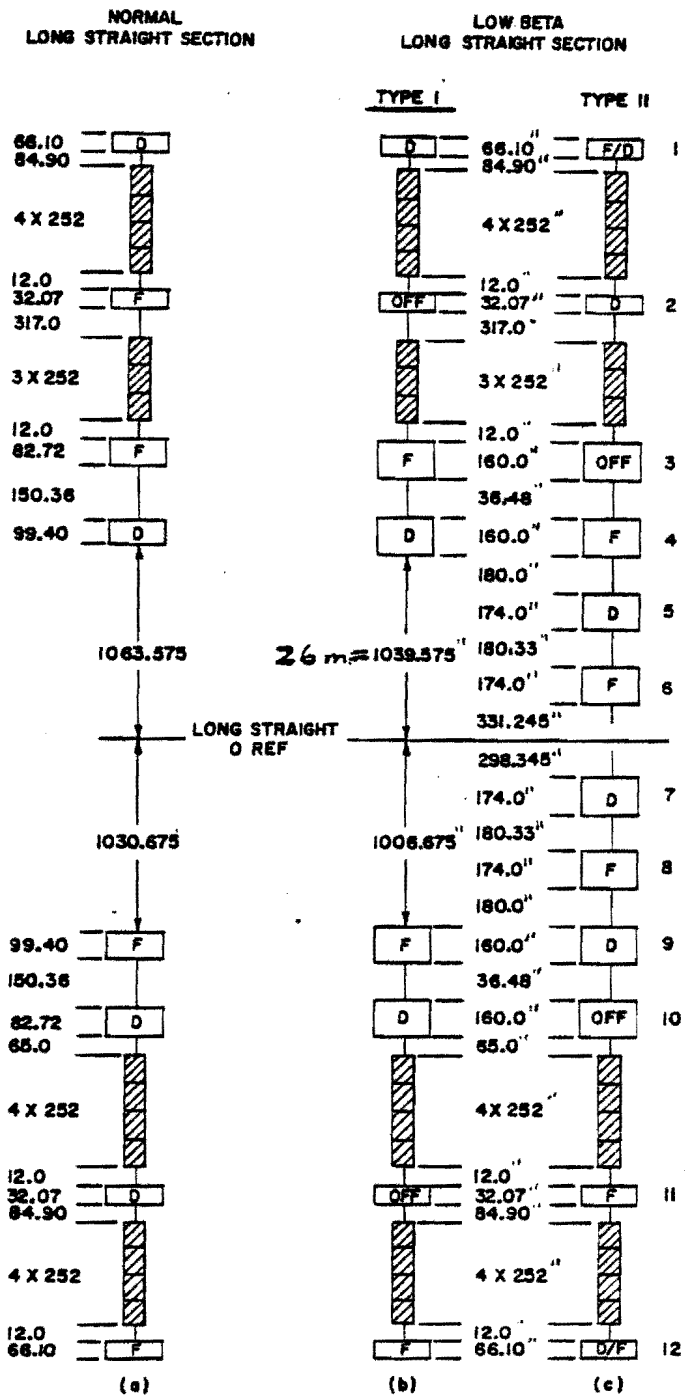


Figure 7 - Schematic of the proposed detector. Note the exaggerated transverse scale. Additional shielding and muon detectors are not shown. The inset shows a beam's eye view of one of the sections of CAL 3 which can be moved closer to the circulating beams once they are stable.



Layout of normal and two types of low-beta long straight section.

Figure 8 - A low beta option (Type I) which provides approx. 50 m of clear space along the straight section [from Fig. 2-4 of FNAL Superconducting Accelerator Design Report]. Similar designs can give $\beta^* \lesssim 5$ m.

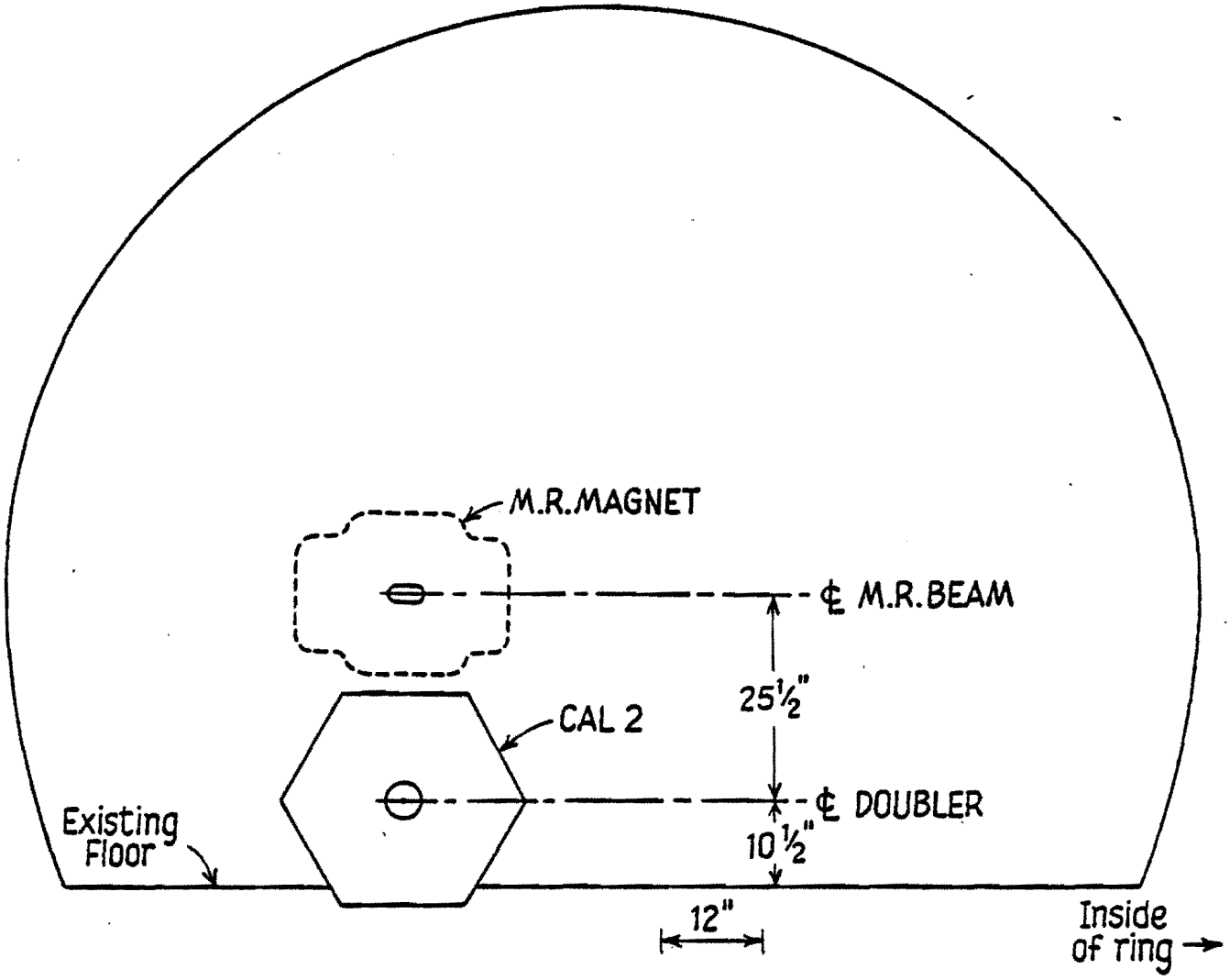


Figure 9 - Cross section through DO at the middle calorimeter, showing approximate clearances in the existing tunnel. There is ample space on either side of the Doubler, but clearance over the existing floor is a problem.

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ADDENDUM TO P-709 October 10, 1983

The original P-709 was submitted almost two years ago as a proposal for the DO area.

An Addendum which gave a more detailed experimental design was submitted on May 14, 1982. On June 1, 1982 a second Addendum was submitted; this discussed measurements of calorimeter leakage made in a test beam and showed this would not be a problem in the proposed geometry.

It now seems appropriate to propose an experiment of somewhat reduced scope for an area other than DO. Following discussions with Fermilab personnel we believe that with minor modificiations the experiment could best be installed in FO. In this Addendum we summarize the most relevant material from the original proposal and the Addenda. We also show the revised experimental arrangement proposed for the FO area.

The proposed detector will cover all solid angles between approx. 1.5 and 250 mr in the $\bar{p}$ hemisphere with electromagnetic and hadronic calorimetry. Tracking chambers will cover from approx. 40 mr in the proton hemisphere to approx. 1.5 mr in the antiproton hemisphere.

Installation of the proposed detector will require minor adjustments in the location of rf cavities for the Doubler and Main Ring. We envision moving one MR cavity to a spot several meters upstream. Two Doubler cavities which are not yet installed would be moved to different locations. Only two small shallow pits under the Doubler would be required for installation.

Introduction

Both the CDF and the detector proposed for DO are designed primarily to study reactions with small cross sections with emphasis on the central region. High luminosity quadrupoles are therefore placed close to the detector. This makes it difficult or impossible to study particles produced at small angles.

At Fermilab collider energies, most of the secondaries from a $p\bar{p}$ collision go off at angles much less than 10°. For example, about 90% of the energy from a $\sqrt{s}$ = 2000 GeV interaction will on the average appear at angles <2°, the smallest angle which the CDF detector will cover. The detector now proposed for DO will have a similar restriction. This restriction will prevent these detectors from addressing many basic questions about the general character of hadron-hadron collisions at very high energies.

In designing a small-angle detector it is important to be able to model reasonably accurately the general features of high energy hadron-hadron interactions, particularly in regard to the angular distribution of the energy flow. To do this we have adopted a Monte Carlo program used earlier for this purpose by T. Gaisser.[1] This program incorporates a model used by Wdowczyk and Wolfendale[2] and others which takes into account the violation of Feynman scaling observed at Fermilab and ISR energies (and now more dramatically at the CERN collider[3]). This model has one parameter, variously called α or β [where β is variously defined as $\beta \equiv 1 - 2\alpha$ or $\beta \equiv 1 - \alpha$] which is a measure of the violation of Feynman scaling. For $\alpha = 0$ Feynman scaling is recovered, while $\alpha \approx 0.5$ corresponds to a large breakdown of Feynman scaling as might be expected from a statistical model.[2] Data from the ISR and cosmic rays suggest a value of $\alpha \approx 0.2$ (Ref. 2).

In the Monte Carlo program, longitudinal momenta of the secondaries are assumed to grow with s according to

$$\frac{P_L(s)}{P_L(s_0)} = \left(\frac{s}{s_0}\right)^{\frac{1-2\alpha}{2}} \tag{1}$$

where s_0 is some reference energy for which data are available. Average transverse momenta are assumed to grow slowly with s in a manner suggested by cosmic ray and ISR data. The leading nucleons are assumed to obey Feynman scaling and are given a flat distribution in Feynman x.

The results of this Monte Carlo simulation for $\sqrt{s}$ = 2000 GeV collisions are summarized in Fig. 1. These curves show, for 3 values of α, the fraction of the energy which would be collected in a calorimetric detector which subtends angles down to Θ_{min} in <u>both</u> hemispheres. For the case of α = 0.19 only, the effect of including leading nucleons is illustrated. Since these are assumed to obey Feynman scaling their contribution is independent of α.

The angular ranges covered by the proposed CDF central and forward detectors are shown for reference. By way of illustration, the curves show that if Feynman scaling were the correct extrapolation from ISR energies (i.e., α = 0) the CDF detector would only collect about 2% of the energy from a typical $\sqrt{s}$ = 2000 GeV collision.

The angle marked "Min. Practical Angle" in Fig. 1 is based on a reasonably conservative extrapolation of experience at the ISR, where detectors can be brought within 0.7 cm of the stable circulating beams.[4] We therefore assume a minimum distance of approach of 2.0 cm from beam center for detectors placed ≈20 m from the interaction point. (The straight sections at the collider are approx. 50 m long.) Figure 1 suggests that it should be possible to build a calorimetric detector which, on the average, will efficiently collect most of the energy, with the possible exception of that carried by the leading nucleons.

Figure 2 shows the region of rapidity which would be covered by our detector and by the CDF detector. Note that CDF, even with its forward detector, only covers about half the range. The detector described here would cover essentially the entire range in one hemisphere.

Physics Objectives

As previously discussed, many of the particles and most of the energy from a typical interaction at $\sqrt{s}$ = 2 TeV go off at angles too small to be studied by the major detectors at BO and DO. At least one detector at the Collider should be designed to study hadron-hadron interactions down to the smallest practical angles. The proposed detector will cover angles down to about 1 mr in the $\bar{p}$ hemisphere. At present, the only accurate data at high energies are at $\sqrt{s}$ = 540 GeV from the CERN Collider. The cosmic ray data at higher energies are difficult to interpret or controversial. The results from the UA1, UA2, and UA5 detectors at CERN have gone a long way to clarify the situation. However, it is important to extend the data to the high energies available at the Fermilab Collider. Some of the specific physics questions we can address are discussed below.

Energy flow measurements—T. Gaisser[1] has emphasized the importance of energy flow measurements to the understanding of the general behavior of hadronic interactions at very high energies. This will contribute to the resolution of a fundamental astrophysical problem, the composition of primary cosmic rays above 10^{14} eV. We have used the parameterization for the breakdown of scaling employed by Gaisser and others[2] to extend Gaisser's calculation to $\sqrt{s}$ = 2000 GeV. The results are summarized in Figure 1. The cosmic ray results suggest a value for the scale breaking parameter α which is $\approx$ 0.2. The CERN UA1 data do not extend to small enough angles to allow an unambiguous fit to this parameterization[5], but would be consistent with $\alpha \approx 0.11$.

Multiplicity vs. $\sqrt{s}$—This is a basic measurement which should be continued to the highest available energies. Cosmic ray data from the Brazil-Japan group suggest a new threshold near $\sqrt{s}$ = 500 GeV. (See the inset to Fig. 3 which is taken from G. Goggi, CERN-EP/81-08). Most of the available data on multiplicity distributions at high energies are consistent with KNO scaling though data from UA5 suggest a breakdown at high multiplicities ($N_{CH} \sim 80$).

σ_{inel} vs. $\sqrt{s}$ —Again cosmic ray data from the Tien-shan group suggest a sudden increase in the absorption length above $\sqrt{s} \cong 500$ GeV. A central detector with $\Theta_{min} \gtrsim 2°$ could miss this effect.

Centauro events—These have been discussed at great length by many authors.[6] As shown in Figure 3, they seem to be restricted to $\sqrt{s} \gtrsim 600$ GeV and may be just out of reach of the CERN Collider.

Diffractive production of new flavors—Data from the ISR suggest a large cross section for the diffractive production of Λ_c. This may occur for other heavy flavors as well. The forward region may be the best place to look for heavy baryons beyond the Λ_B. Whether this is practical for any detector without adding particle identification for K's is problematical, however.

Jet properties—The proposed detector will have calorimetry down to approx. 1 mr in the $\bar{p}$ hemisphere. This will allow the study of jet properties down to the smallest practical angles, determined by the intrinsic size of the jets and confusion with the beam jets rather than by the edges of the detector.

Possible phase transition of hadronic matter to quark-gluon plasma—Hadronic matter is believe to undergo a phase transition to a quark-gluon plasma when sufficiently high densities are reached. Various experimental signatures such as the increase in the number of dileptons or

photons or strange particles have been suggested. Van Hove[7] argues that the phase transition may be signaled by the behavior of the average transverse momentum $\langle P_T \rangle$ with the average multiplicity per unit of rapidity $\Delta N/\Delta y$. the UA1 data (Fig. 4) show that $\langle P_T \rangle$ increases with increasing multiplicity and then flattens out for $\Delta N/\Delta y \sim 8$. This behavior is generally consistent with that observed in high energy cosmic ray interactions by the Brazil-Japan collaboration. Van Hove suggests that this sort of behavior is just what would be expected if a phase transition takes place. However the flattening at large multiplicity could be simply a kinematic effect due to the lack of available energy. If the flattening occurs at the same place at Fermilab energies the deconfinement transition may be the correct explanation.

The above list is certainly not complete. It does serve to emphasize that there is much to be learned about hadron-hadron interactions at Fermilab Collider energies. The main difficulty is the lack of a viable theoretical framework. Hopefully over the next several years it will become possible to extend QCD calculations to the dominant large cross section processes.

Description of the Proposed Detector

The general philosophy of our design is to cover the largest practical angular range with calorimetry and tracking chambers. As discussed earlier, it should be possible to provide calorimetry down to an angle of about 1 mr from the $\bar{p}$ beam with detectors 20 m from the interaction point which can be moved to within 2 cm or less of the circulating beams.

The design is shown schematically in Figures 5 and 6. Note that the transverse dimensions are exaggerated fivefold. The elements cover 2π in azimuth. Tracking chambers precede each of the calorimeters; these are spaced sufficiently from the upstream faces of the calorimeters to minimize problems from albedo. The farthest set of tracking chambers and calorimeters (CAL 3)

are moveable so that they can be brought in close to the beams once they are stable. To accomplish this the farthest calorimeter is split in half longitudinally (CAL3A and CAL3B). The two halves are connected to each other and to the rest of the beam vacuum pipe by flexible bellows. To move the calorimeter closer to the beam the two halves are translated laterally along with their associated tracking chambers. The total motion necessary is only about 5 cm which can be accommodated by having the sections of pipe connected by standard vacuum bellows. A beam's eye view of one of these calorimeters is shown in the inset of Fig. 5.

In order to cover the largest possible range of angles with calorimetry, CAL1 should be placed as close as possible to the interaction point and have the largest possible transverse dimensions. We therefore propose to move one of the MR rf cavities from its present position at -101" to an empty spot centered at approx. -263". As shown in Figure 6 two Doubler rf cavities can be accommodated within the proposed design. (There are six more cavities on the other side of the interaction point.) This is consistent with the present Laboratory plans which envision a total of 8 cavities for the Doubler. The proposed design also involves moving a super damper from its planned position at -940" to another place.

In order to best resolve individual showers in the calorimeters and minimize leakage out the sides, it is desirable to make the calorimeters as dense as possible. We therefore propose that at least CAL2 and CAL3 be made with uranium plates. This will give the best possible energy resolution and allow photons and electrons to be distinguished from hadrons with good efficiency. It will also be possible to distinguish neutrons from charged particles. CAL1 could be constructed with uranium plates or iron plates preceded by lead.

The calorimeters will be segmented azimuthally and in radius. This will allow an accurate measurement of $E_{transverse}$ and energy flow. The transverse dimensions of the calorimeters are $\gtrsim$ 5" oversize to contain the showers.

A possible design for the calorimeters is shown in Fig. 7 and 8. Figure 7 shows a possible arrangement for CAL3A and CAL3B. Both scintillators and wire chambers with pulse height readout are incorporated. Light from the scintillators is collected in wavebar strips which run along the periphery of the calorimeter so there is no dead space or cracks inside the useful volume of the calorimeter. Figure 8 shows the organization of scintillators in CAL1. In the design shown we assume the first section of the calorimeter has lead plates, and the remainder is iron. Three sets of photomultiplier tubes read out three separate samplings along the depth. Proportional chambers with pulse height readout, not shown in Fig. 8, would also be incorporated.

The design of the small-angle tracking chambers is straightforward. With the proposed design no chambers need be placed in the beam vacuum. The resolution and spacing would be sufficient to resolve charged particles that come from the interaction point from those which originate from calorimeters closer to the interaction point. Chambers of similar design are already in use at the ISR and CERN Collider.[8]

Tracking chambers also surround the beam pipe around the interaction point. These allow measurements of the multiplicity and angles for charged particles between 40 mr from the proton beam and 40 mr from the $\bar{p}$ beam.

Luminosity and Rates

We assume no high luminosity quads will be installed in F0. This will give a β^* of approx. 70 m. and a rather modest luminosity $\sim 10^{28}$ cm^{-2} s^{-1} compared to $\sim 3 \times 10^{29}$ at B0. The interaction rate at F0 will therefore be $\sim$ 500 Hz which is more than adequate for the physics we propose.

Requests of the Laboratory

As discussed earlier, we request that one of the Main Ring rf cavities be moved upstream. Two of the Doubler cavities would be installed in positions different from those originally planned and a super damper would be moved elsewhere. Small modifications of the rf cavity stands would be required to permit installation of our calorimeters.

Small shallow pits would be required for installation of CAL1 and CAL2. Most of the vacuum pipe through the region would be replaced with special vacuum pipe. The electronics and data acquisition computer would probably be located in the addition already planned for the RF Building.

References

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2. J. Wdowczyk and A. Wolfendale, Nuovo Cimento 54A, 433 (1979).
3. G. Arnison et al., Phys. Lett. 123B, 108 (1983).
4. M. Block, private communication.
5. T. Gaisser, private communication.
6. See, for example, J. Bjorken and L. McLerran, Phys. Rev. D20, 2353 (1979).
7. L. van Hove, Phys. Lett. 118B, 138 (1982).
8. J. Buskens et al., Nucl. Instr. and Meth. 207, 365 (1983).

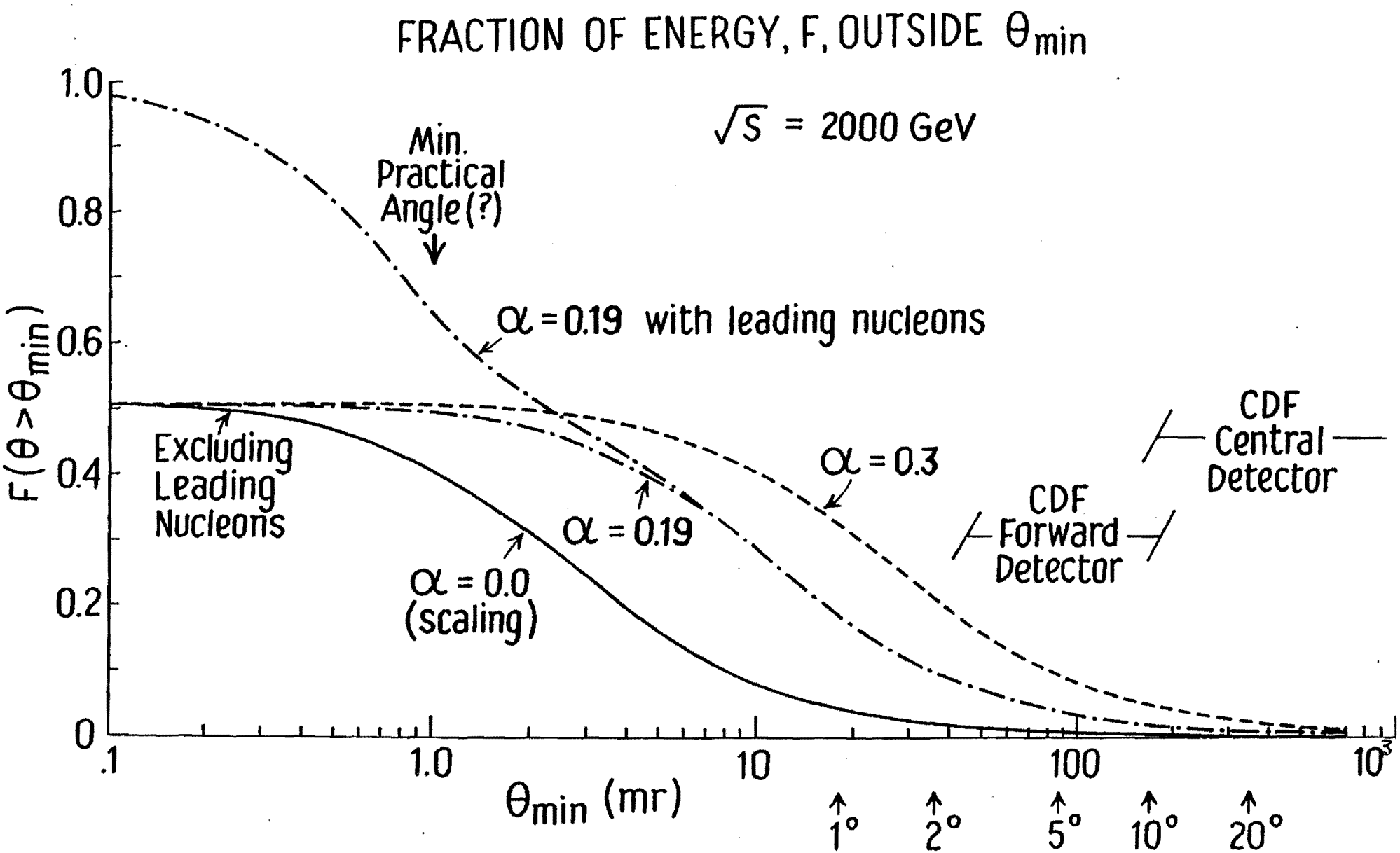

Figure 1 - The fraction of the total energy outside an angle θ_{min} for 3 values of the parameter α. The case $\alpha = 0$ corresponds to exact Feynman scaling; $\alpha = 0.3$ corresponds to a large deviation from Feynman scaling; the CERN Collider and ISR data suggest $\alpha \approx 0.19$. The detector is assumed to cover both the p and $\bar{p}$ hemisphere. For the case $\alpha = 0.19$ only, the effect of including leading nucleons is illustrated.

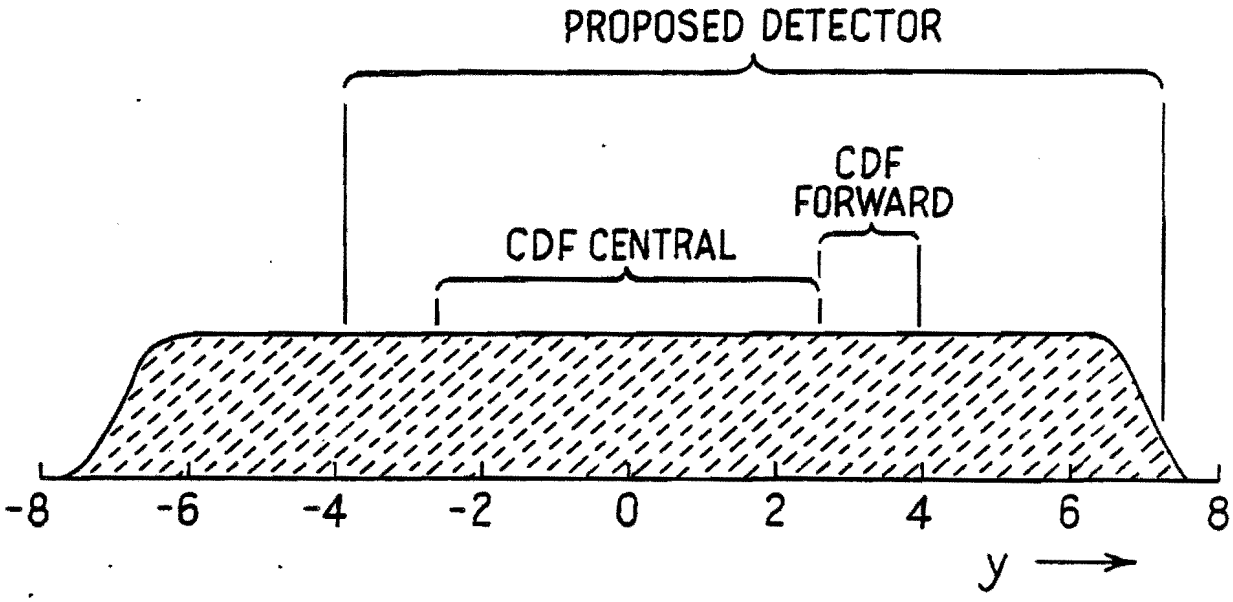

Figure 2 - The total rapidity range at $\sqrt{s}$ = 2000 GeV and the range covered by the proposed detector.

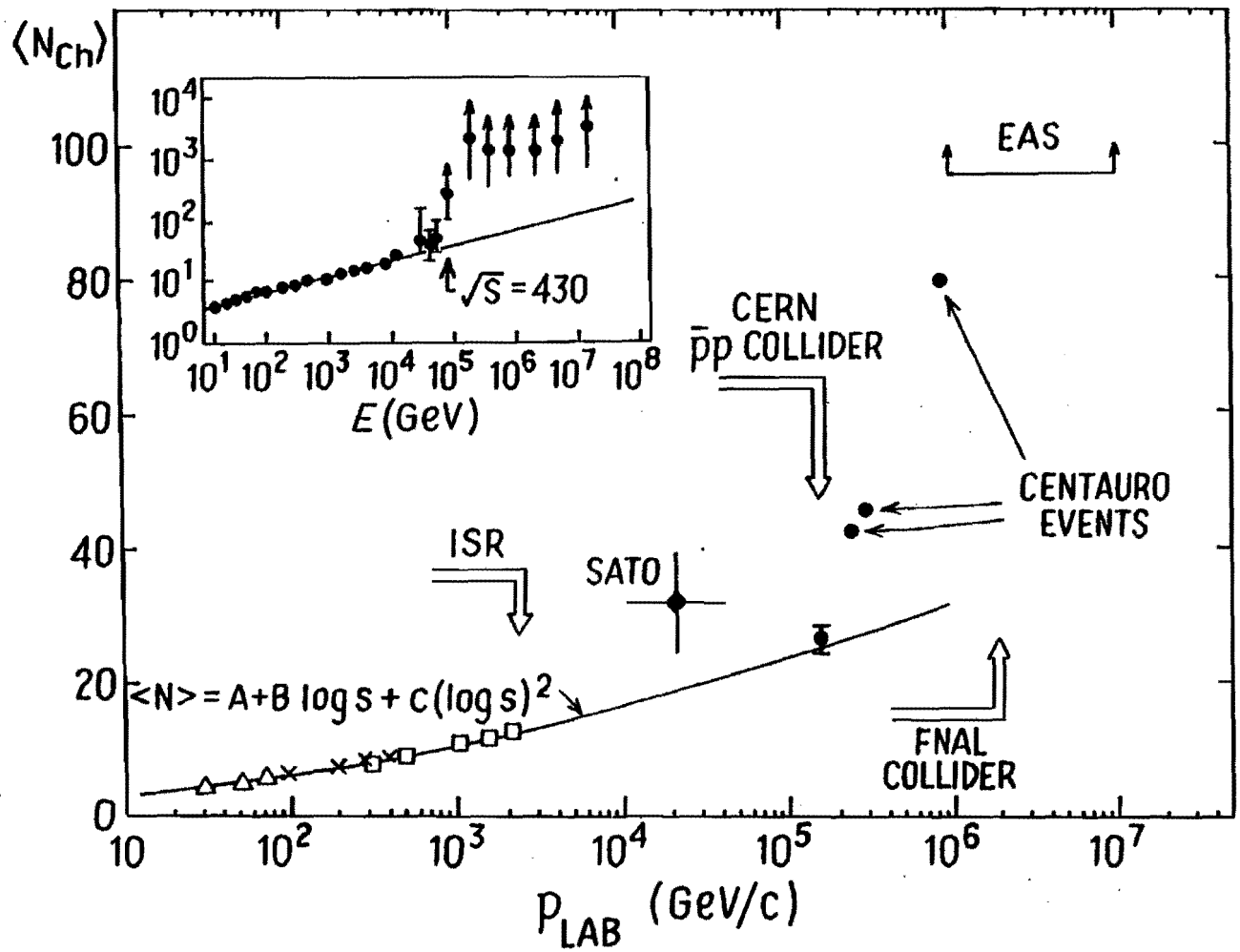

Figure 3 - Average charge multiplicity vs. lab momentum (adapted from G. Goggi, CERN-EP/81-08). The inset shows data from the Brazil-Japan cosmic ray emulsion experiments.

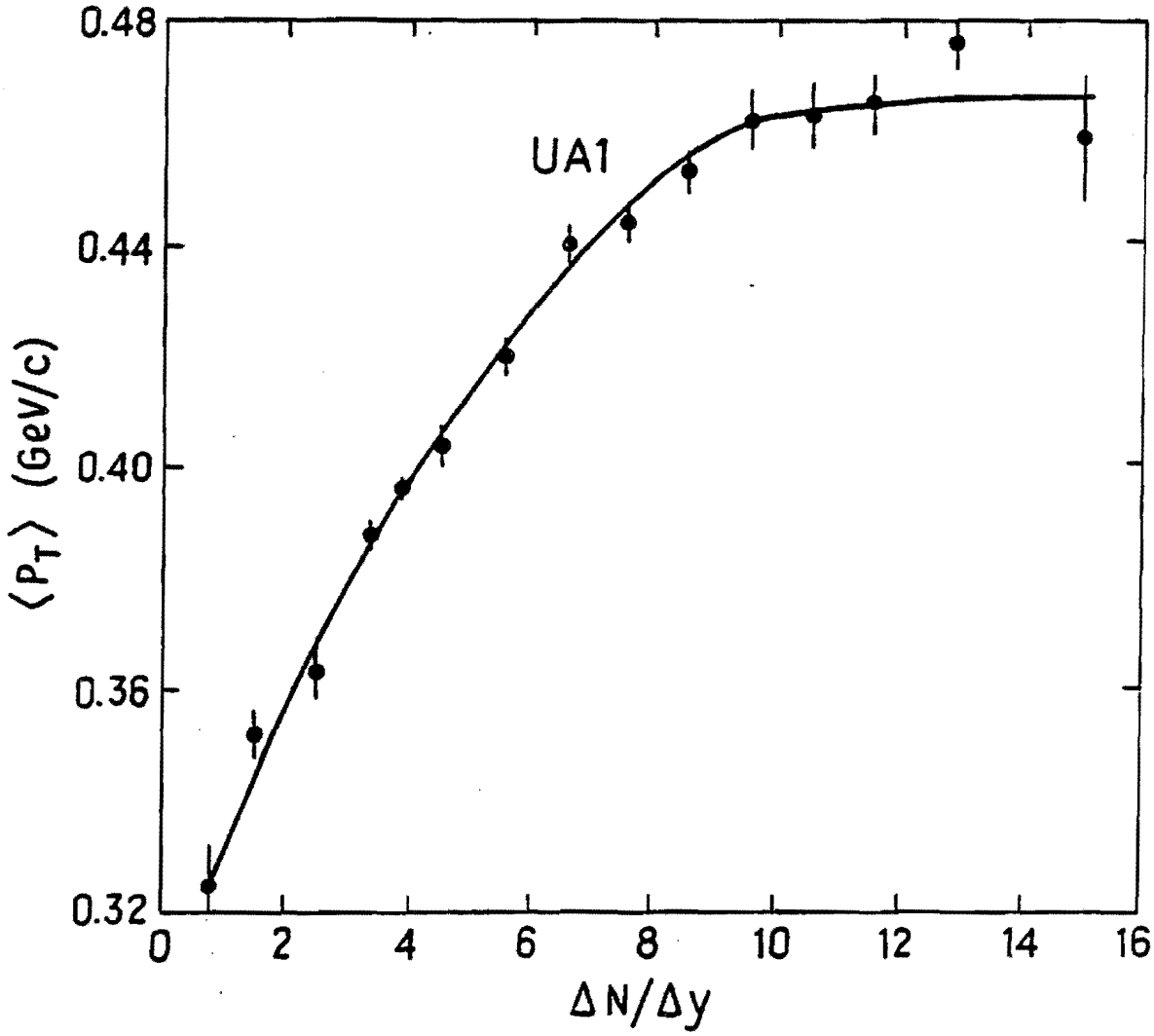

Figure 4 - Average transverse momentum vs. charge multiplicity per unit of rapidity from UA1.

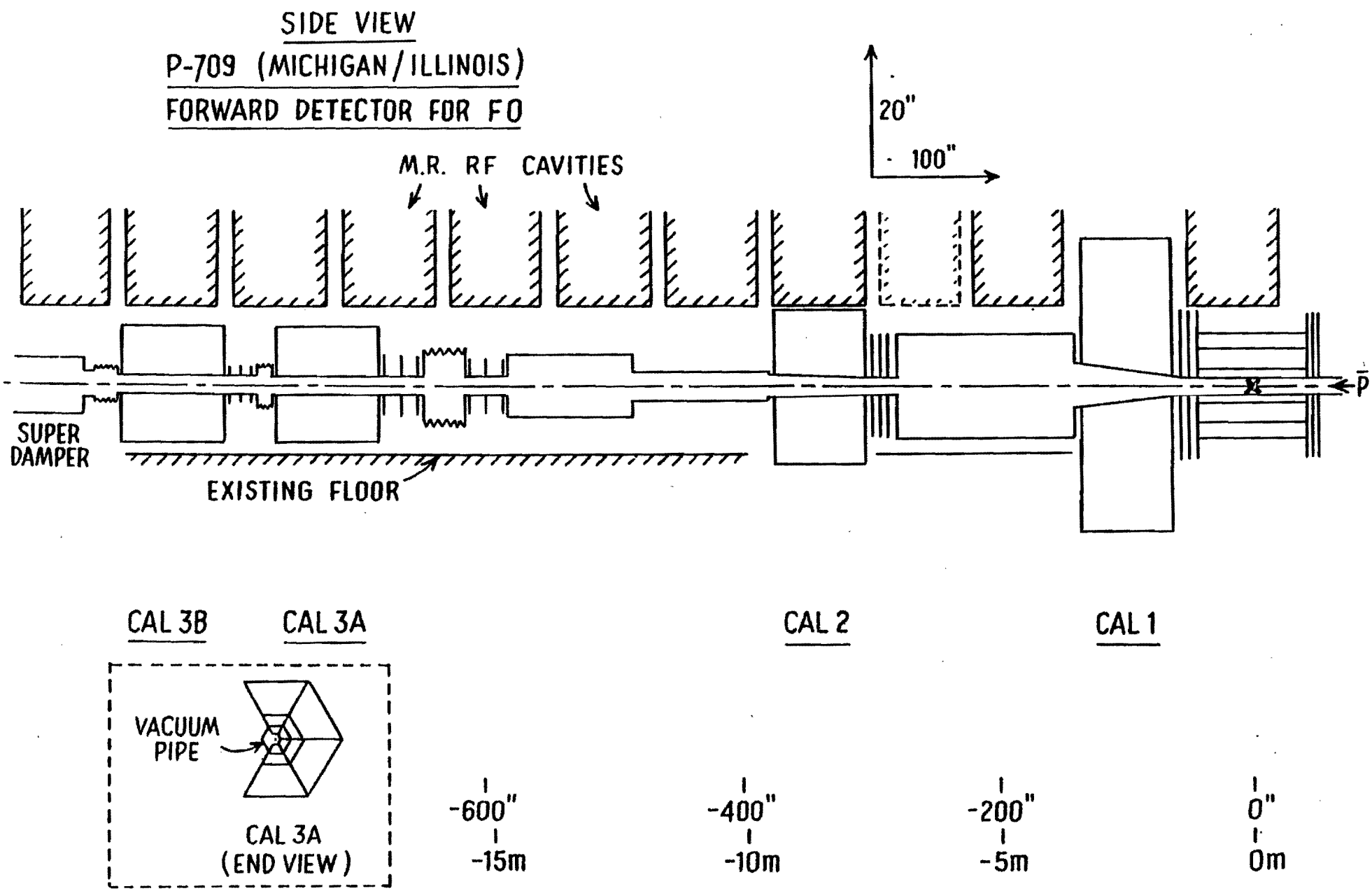

Figure 5 - Proposed detector, side view. The interaction point is on the right. Note the exaggerated transverse dimensions. The inset shows a front view of CAL3A.

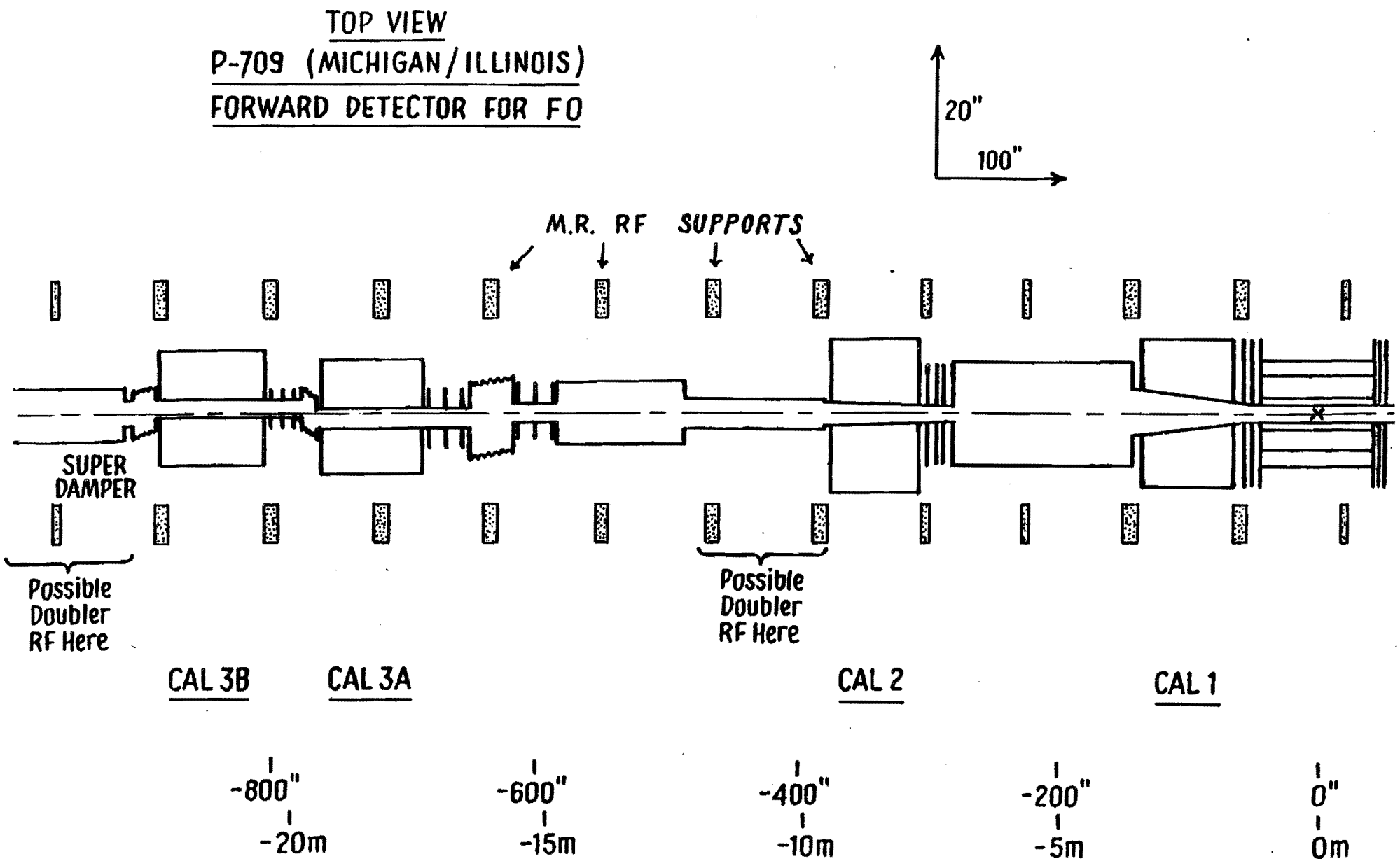

Figure 6 - Top view of the proposed detector. The two halves of CAL3 can be moved transversely closer to the beam center line.

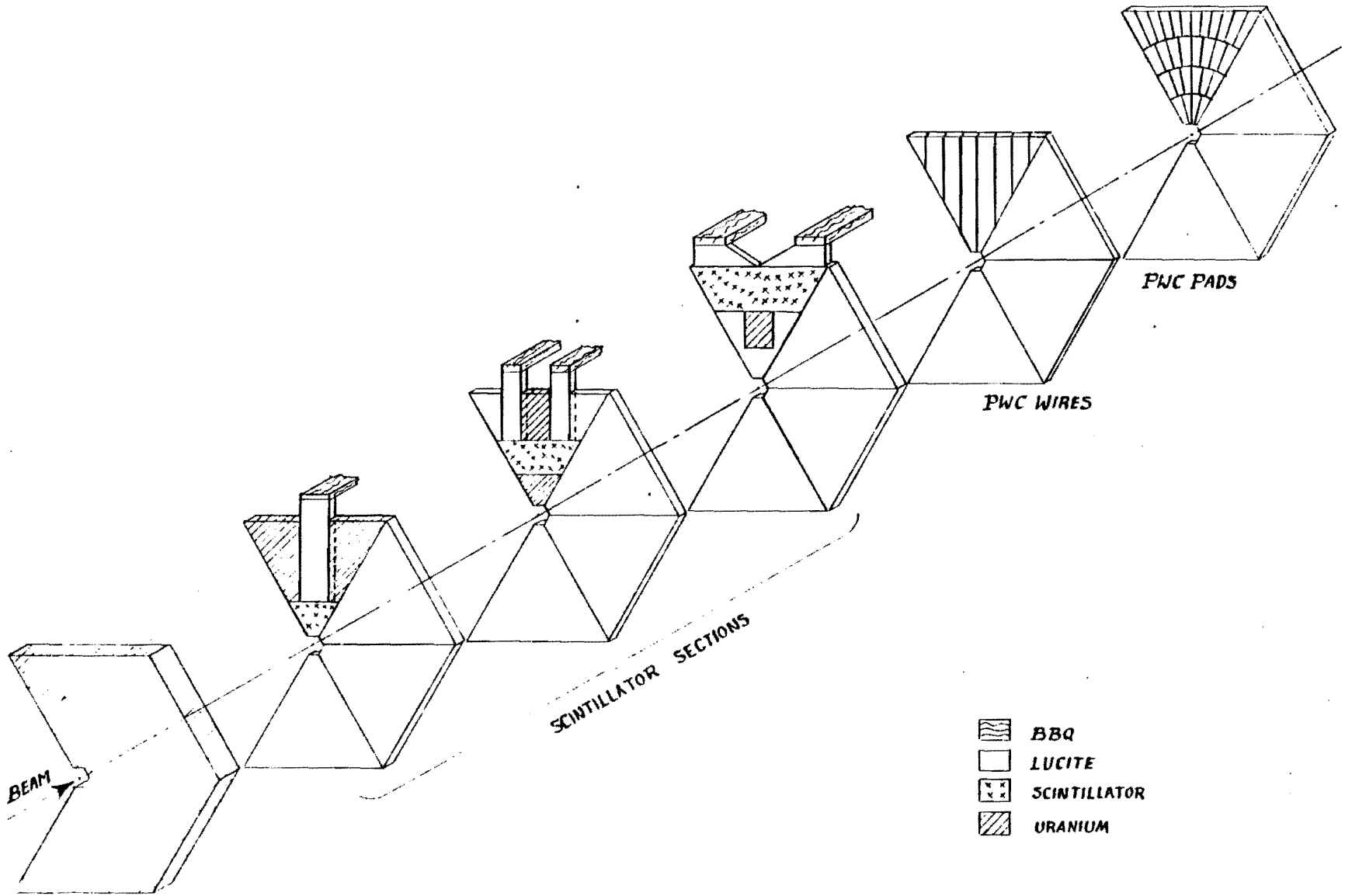

FIGURE 7

Possible design of CAL3A or CAL3B showing the segmentation of the scintillators and PWC's.

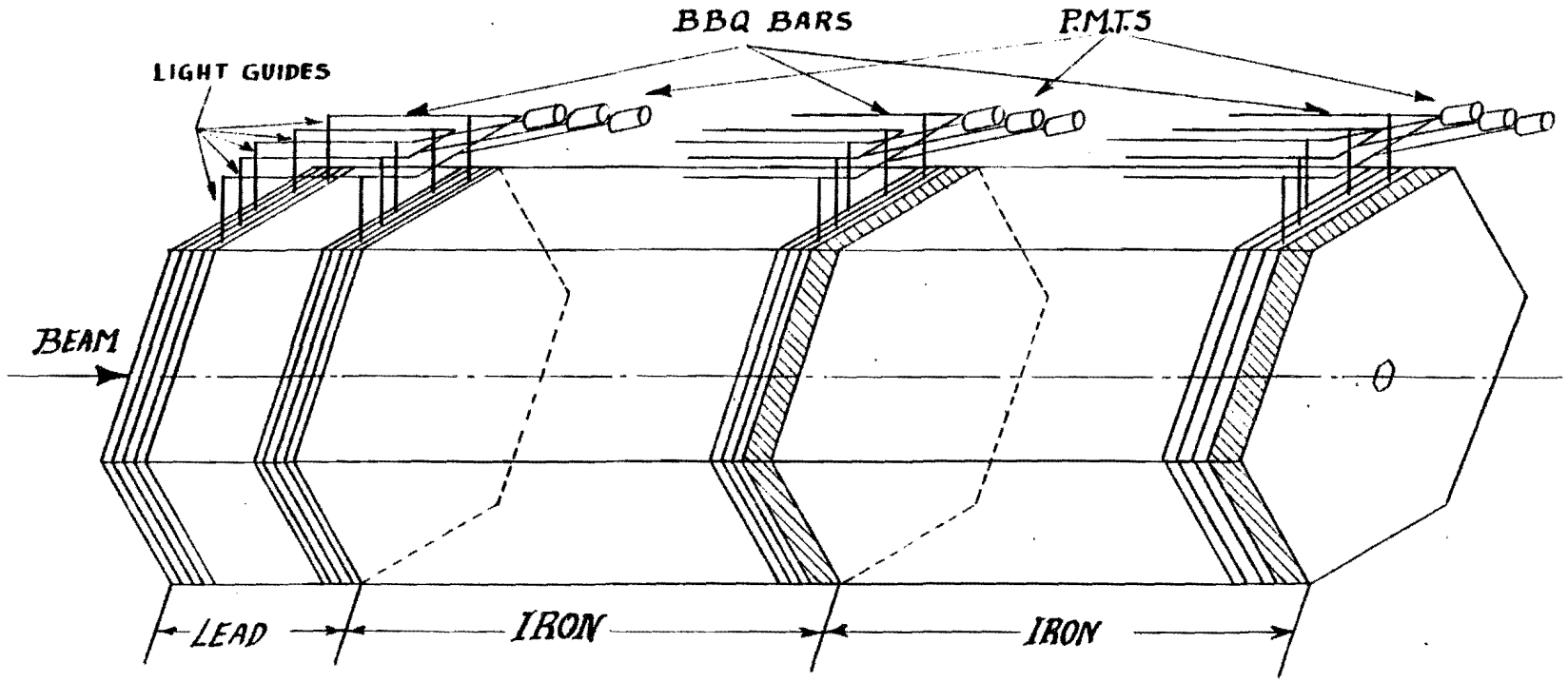

FIGURE 8

Possible design of CAL1 showing the segmentation in depth and photomultiplier tubes. The PWC's are not shown.