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FNAL Proposal
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Measurement of Direct Photon Production from p-p Collisions at Large Transverse Momentum

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Proposal Summary

Glennys Farrar has recently emphasized the importance of a measurement of the ratio γ/π of direct photon inclusive production at large p_T to that for pion production. The behavior of γ/π with beam energy, in particular, is quite different for different classes of models of large p_T production.

We propose to use a proton beam in the M2 line to study direct photon production from p-p collisions for $p_T \geqslant 2.5$ GeV/c. We show that at large p_T, even with a relatively simple detector, it is possible to get good separation of direct γ production from the copious production of γ's from π° and η° decays.

Objectives of Experiment

An enormous effort has gone into the attempt to understand hadron-hadron interactions at large p_T. Yet even basic questions such as the underlying mechanism remain unanswered. For example, Berman, Bjorken, and Kogut[1] have suggested that the interaction proceeds by the elastic, large p_T scattering of two essentially freely-propagating quarks from the initial hadrons, followed by the scale-invariant fragmentation of each of the quarks. If this were the correct mechanism the cross section at fixed p_T/s and θ_{cm} should have the behavior $E\, d^3\sigma/dp^3 \propto p_T^{-4}$. Experimentally, as is well known, the cross section falls off more like p_T^{-8}.

Various ways out of this dilemma have been proposed. Glennys Farrar[2] has nicely summarized the various efforts. She divides the proposed modifications of the BBK picture[1] into two types:

(i) Those that retain the scale-invariant fragmentation of the quarks after their large p_T scattering, but give up the scale invariance of the large p_T quark-quark scattering expected on the basis of dimensional analysis. This is the approach taken by Field and Feynman[3] and others. Farrar refers to this class as "leisurely" production because the time scale in the beam cms between the initial large p_T interaction and the hadron production is $\sim 10^{-23}\ p_T/m_o$.

(ii) Those that keep the dimensional predictions of field theory for the q-q scattering amplitude, but drop the assumption that the quarks fragment in a scale-invariant way. The CIM[4] and quark-fusion model[5] are examples of this type. Farrar refers to this class as "deep" production because the time scale defined as above is very short, $\sim 10^{-23}\ m_o/p_T$.

As a means of distinguishing between these two classes of models, Farrar[2] proposes comparing the inclusive production of direct photons and pions at large p_T. If we define

$$\gamma/\pi \equiv [Ed^3\sigma dp^3(A+B \rightarrow \gamma+X)]/[Ed^3\sigma/dp^3(A+B \rightarrow \pi^\circ+X)]$$

then Farrar makes the following predictions:

(1) Leisurely production gives $\gamma/\pi \sim \alpha$, independent of s at fixed x_T and θ_{cm}.

(2) Deep production gives $\gamma/\pi \sim \left(\frac{\alpha}{\varkappa^2} \cdot \frac{s}{m_o^2}\right) f\left(x_T, \theta_{cm}\right)$ where $\varkappa$ is the strong interaction analog of α and m_o is the mass scale parameter. Farrar estimates that in this case $\gamma/\pi \sim 10^{-1}$; however, this is just an educated guess.

Thus an experiment to measure γ/π at a single s <u>might</u> decide between the two classes of models if it is found that $\gamma/\pi \gg \alpha$, which eliminates the leisurely production models. A stronger test is to measure the s-dependence at fixed x_T and θ_{cm}. For deep production $\gamma/\pi \propto s$ while for leisurely production γ/π is independent of s.

We believe that a measurement of γ/π (at two or more beam energies) is one of the most crucial experiments in high-energy physics at this time. In the next section we show how a measurement of γ/π can be made with good accuracy even for $\gamma/\pi \sim 1\%$.

Experimental Technique

Obviously the key experimental problem is to distinguish direct photon production from the miasma of photons from π° production which is 10 to 100 times as copious. This problem is extremely difficult at small θ_{cm} and small p_T when the opening angles of the photons from π° decay are comparable to the production angles. However, as we show below, the problem appears tractable if we restrict our measurements to large p_T and $\theta_{cm} \sim 90^\circ$. Then most of the photons from π° decays are restricted to a very small cone about the π° direction and a direct γ is unlikely to be accompanied by a photon from a π° decay.

A plausible (though not necessarily optimal) experimental arrangement is shown in Fig. 1. This figure shows a γ detector centered at 90° in the cms (3.9° in the lab) for 400 GeV p-p collisions. The central part of the detector consists of perhaps 30 lead (or uranium) plates interleaved with 30 scintillators, each about 30 cm horizontally and 60 cm vertically. The pulse height from the scintillators provides a measurement of the photon energy with a resolution of about 2%. Interspersed within the detector are 4 to 6 proportional wire chambers. These are used to locate the showers and, more importantly, to identify events in which more than one photon appears in the detector. With these it should be possible to resolve two showers with vertices within 3 mm of each other. (This is to be compared with the smallest spacing of two photons from a

100 GeV π° decay which is $\approx$ 16 mm.) True proportional readout of these chambers would be helpful, though not essential, and we shall probably use a readout system we are currently developing to provide a proportional readout.

The detector is surrounded by an array of lead glass "veto" counters. (See inset of Fig. 1.) Pulse heights from these will be recorded and if a single photon in the detector is accompanied by a photon in the lead glass whose position and energy is appropriate for a π° decay the event will be discarded.

A sweeping magnet (probably with horizontal magnetic field) close to the target will be used to sweep away a large fraction of charged particles from the detector. The remaining high-momentum particles will be located by the scintillator hodoscopes and the PWC preceding the detector.

The probability of one photon from a π° decay missing the detector or lead glass veto when the other photon enters the detector can be easily estimated. In Figure 2 we show the probability of missing one photon if the other appears within an area 21 cm x 42 cm; i.e., the inner 50% of the area of the detector. We see that this probability is $\leqslant 1\%$ if $p_{lab} > 40$ GeV (or $p_T > 2.7$ GeV/c). Thus the background from π° decays from which one photon is lost seems tractable for $p_T \geqslant 2.7$ GeV/c.[6]

Another perhaps more troublesome problem is neutrons which masquerade as single photons. Here one relies on the following:

(1) The ratio n/π° as estimated from the p/π^+ ratios measured[7] at large p_T is ~ 0.35.

(2) The ratio of the radiation length to the nuclear collision length for lead is ≈ .057 (≈.051 for uranium). This means that neutrons will generally interact much later in the detector and will deposit less of their energy. Thus if we require an interaction in the first 1.5 rad. lengths and require an energy deposition profile appropriate for a high-energy γ, most of the neutrons can be eliminated.

(3) If necessary, the neutron background can be subtracted. Data for this would be obtained by running for a while with the first 1.5 rad. lengths of Pb replaced by CH_2 or Be.

Backgrounds of photons from decays of hadrons other than π°'s must also be considered. The most troublesome of these is likely to be $\eta^\circ \rightarrow 2\gamma$ which has a branching ratio of 38%. The typical opening angle of the γ's from η° decay is several times larger than those from π° decay, so the probability of missing one photon when the other appears in the inner part of the detector is correspondingly greater. Büsser et al. have measured inclusive η° and π° production at 90° in the cms at ISR energies.[8] They find that $\eta^\circ/\pi^\circ \cong 0.5$ at all energies and for all $p_T \geqslant 3$ GeV/c. Using this ratio we can estimate the probability of one photon from $\eta^\circ \rightarrow 2\gamma$ striking the detector with the other missing the detector and veto counters relative to that for π° decay.

This is shown as the dashed curve in Fig. 2. As seen from the curve the background from $\eta°$ decay is more serious than that from $\pi°$. If $\gamma/\pi = .01$, the background from misidentified $\eta° \to 2\gamma$ decays would equal or exceed the direct photon signal for $p_T \leqslant 4.5$ GeV/c. If γ/π is as small as .01, we would probably be limited to $p_T > 4$ GeV/c in our measurements of direct photon production.

Background from charged particles is not a problem except insofar as it increases accidental rates. The sweeping magnet should help this considerably, and we expect the singles rates will be determined primarily by γ's from $\pi°$'s. Estimates of the singles rates are given below.

The trigger for an event will be detection of a γ in the central detector with energy $\geqslant$30 GeV. A veto for charged particles entering the central detector might also be included. (It seems safest to leave the lead glass "vetos" out of the trigger and just record pulse-height information from them.) The recorded events will thus be mostly $\pi°$'s with $p_\pi \geqslant 30$ GeV. Single photons would be selected from the recorded triggers by means of the proportional chamber information, the energy deposition profile in the γ detector, and the lead glass pulse heights.

Event Rate and Running Time Requirements

There is now considerable information on charged particle production[7] at 90° in the cms and large p_T as well as information on γ's and $\pi°$'s at moderate p_T.[9] Thus $\pi°$ rates can be reliably estimated and γ rates can be obtained by scaling down on the basis of Farrar's estimates for γ/π° ratios. For our estimates we assume the following:

(i) At least 2×10^8 protons/pulse at 400 GeV. (We could probably handle $\sim 10^9$.)

(ii) A 15 cm long liquid hydrogen target.

(iii) A production cross section for π° approximately equal to those for π^- and π^+ obtained by Antreasyan et al.[7] at 400 GeV. (This data is approximately the same as the π° production cross section data of Carey et al.,[9] but the charged pion data goes out to larger p_T and has better statistical accuracy).

(iv) Detection efficiency $\sim$100%.

(v) A useful detector solid angle equal to half that of the central detector.[10]

With this input we estimate a rate $\approx$ 8 π°'s detected per pulse with $p_T > 2.7$ GeV/c (or $p_{lab} > 40$ GeV/c). If $\gamma/\pi^\circ \cong 0.1$ this is $\approx$ 0.8 direct γ's per beam pulse, or about 8000 events in 30 hours of running time. Even with $\gamma/\pi^\circ \sim 0.01$, we have a perfectly respectable event rate $\sim$ 800 events/30 hours.

It is also possible to make reliable estimates of the background rates in the detectors. With the sweeping magnet to sweep out low-momentum charged particles the singles rates will be determined by lowish momentum π°'s. For this estimate we can use the cross sections obtained by Carey et al.[9] for γ production at approximately 90° in the p-p cms. The γ singles rate in the central detector will be $\sim 6 \times 10^5$ per pulse of 2×10^8 protons. The proportional chambers will have a resolution time $\sim$100 ns so there will be an accidental track in the chambers $\sim$6% of the time (assuming a 1 sec. spill). This would mean that a good γ event would have a 6% chance of being lost because of an extraneous γ accompanying it. However many of these extraneous γ's can be eliminated because the energies and angles of the pair do not satisfy the kinematics for a π° decay. Thus we conclude that singles rates will be tolerable for proton fluxes of 10^8 to perhaps 10^9 per pulse.

We can get reasonable statistics at moderate p_T with a running time $\sim$100 hours at 400 GeV. However 800 hours, including 300 hours for tuning, will allow us to collect better statistics at large p_T and to study backgrounds such as neutrons. To study the s-dependence we will need at least 150 hours (preferable 200) at approximately 100 GeV. We would also like to set up and test the detector in a neutral high-energy beam on a parasitic basis. The M3 line would be fine for this purpose.

We shall provide all the detectors and the computer for data acquisition and electronics for the PWC's. Our main requests of the laboratory, aside from usage of the beam, are:

(1) the hydrogen target

(2) The sweeping magnet between the hydrogen target and the detector with an aperture $\sim$12" x 18" x 120" and a field

~10 kG. There are no significant requirements on field uniformity so this magnet could be made up out of rough-cut iron and powered with an existing set of coils. Another possibility is a modified BM 109.

(3) Fast electronics and ADC's (for the lead glass counters).

(4) A portacamp or other suitable housing for the electronics and computer.

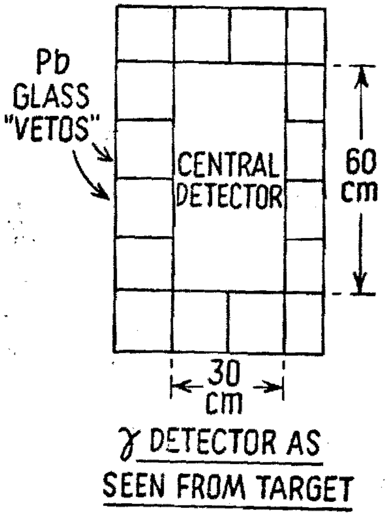
References and Footnotes

1. S. Berman, J.D. Bjorken, and J. Kogut, Phys. Rev. D4, 2381 (1971).
2. G. Farrar, Experimental Means for Distinguishing Models of Large $p_\perp$ Inclusive Scattering, California Inst. of Technology Report CALT-68-576, Jan. 1977 (unpublished).
3. R.D. Field and R.P. Feynman, California Inst. of Technology Report CALT-58-565 (to be published in Phys. Rev. D).
4. R. Blankenbecler, S.J. Brodsky, and J.F. Gunion, Phys. Lett. 42B, 461 (1972), and Phys. Rev. D8, 187 (1973).
5. P.V. Landshoff and J.C. Polkinghorne, Phys. Rev. D8, 4157 (1973).
6. The background from Dalitz decays of π°'s is expected to be an annoying but manageable problem. On the average the photon will have an energy ~ one-half that of the π°, so for a given photon energy this background must come from the "rare" π° events with still larger $p_\perp$. Background from π° events in which one photon converts in the hydrogen target is also not expected to be a serious problem. The conversion probability is $\approx$1%, but again the π° generally must have a considerably higher momentum than the "good" photons. These backgrounds should be considerably below 1% of the π°'s and can be calculated or measured in a straightforward way.
7. D. Antreasyan et al., Phys. Rev. Lett. 38, 112 (1977).
   D. Antreasyan et al., Phys. Rev. Lett. 38, 115 (1977).
8. F.W. Büsser et al., Nucl. Phys. B106, 1 (1976).
9. D.C. Carey et al., Phys. Rev. Lett. 32, 24 (1974), and Phys. Rev. Lett. 33, 327 (1974).
10. A larger part of the central detector can be used at the expense of a slightly higher probability of having a π° masquerade as a single γ. This would not be a problem at large $p_\perp$.

Figure 1

Schematic of possible experimental arrangement.

Note exaggerated transverse dimensions.



γ DETECTOR AS SEEN FROM TARGET

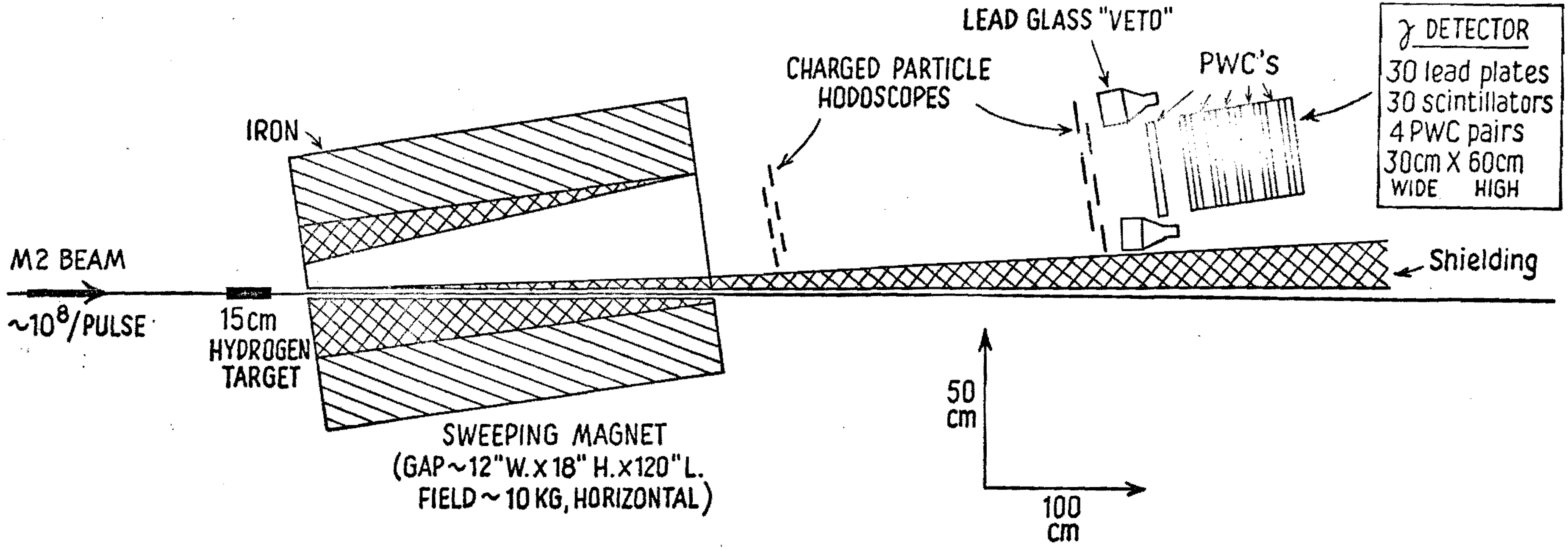
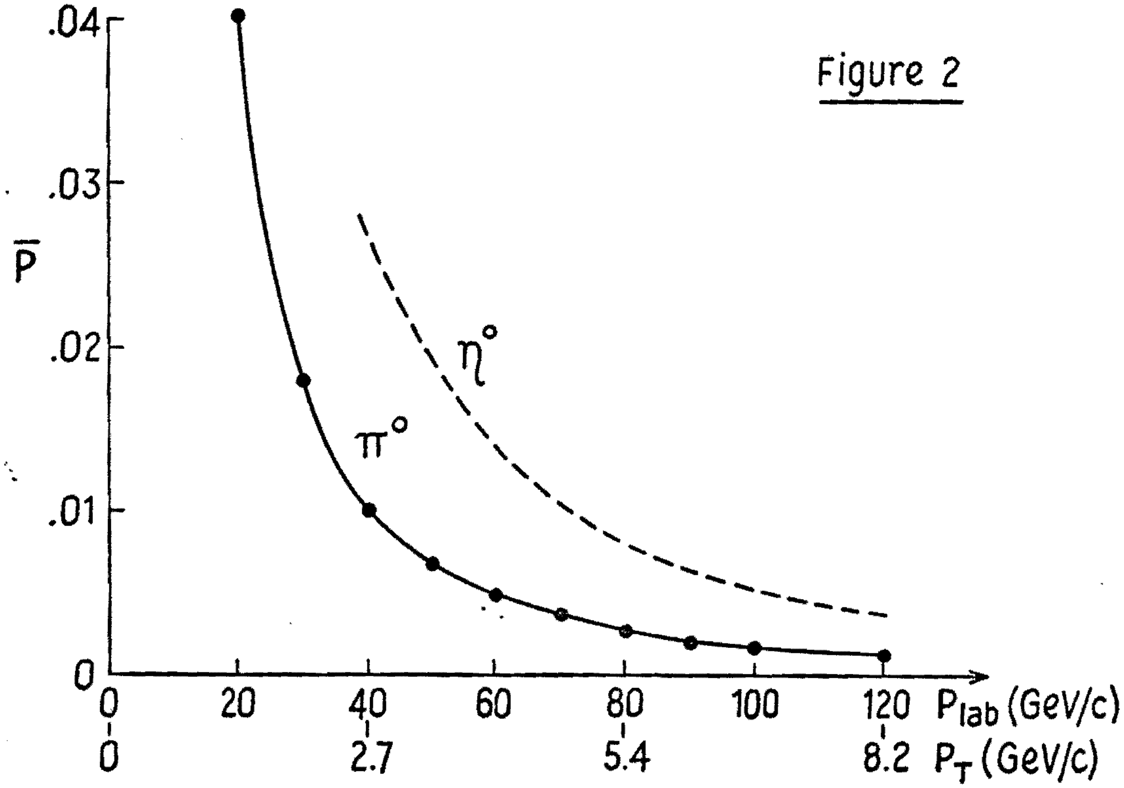


Figure 2



Approximate probability of missing one photon from a π° decay if the other appears in the inner 50% of the γ detector. The dashed curve shows the same for η° decays, including the 0.38 branching ratio for $\eta \rightarrow \gamma + \gamma$ and assuming an η/π° ratio of 0.5 from Ref. 8.

ADDENDUM TO P-551 —— JUNE 3, 1977

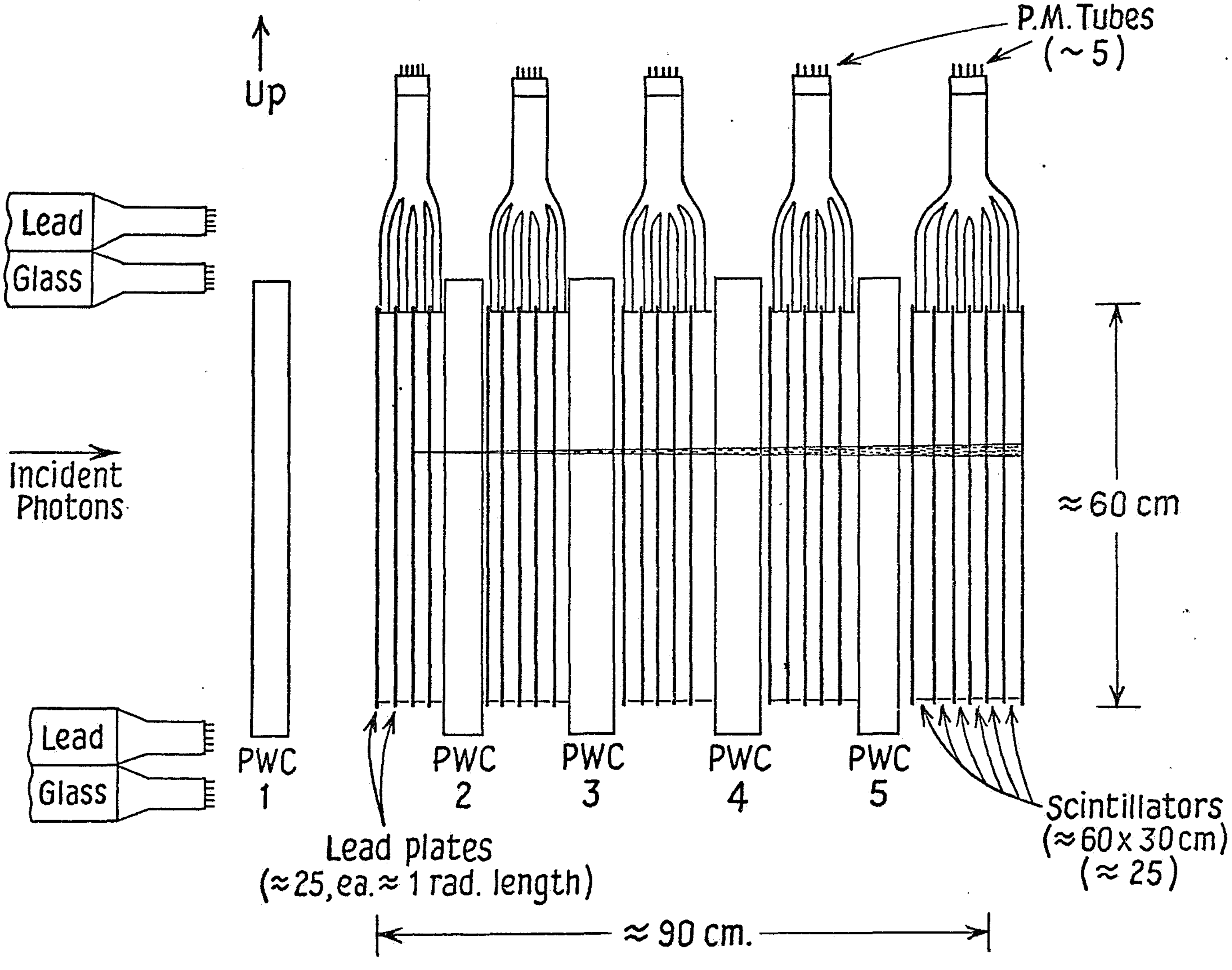
In this addendum we discuss:

I. More details of the gamma detector
II. More information concerning backgrounds from η and π° decays
III. Background from sources other than the hydrogen target
IV. Comparison with other experiments
V. Other commitments of the group
VI. Cost estimates

We also incorporate various minor improvements over our original design which reflect the information and suggestions obtained from conversation with members of the Cal.Tech.group.

I. The Gamma Detector

A more detailed schematic of the detector (side view) is shown in Fig. 1. The detector consists of approx. 25 lead plates, each ≈ 1 rad. length thick, interleaved with an equal number of scintillators. Light from groups of approx. 5 scintillators is piped to photomultipliers. The output of each photomultiplier is digitized. The summed output from all the tubes is used to determine the total energy deposited in the detector. Judging from previous experience with similar detectors we estimate that the total photon energy can be determined to better than 2% accuracy for 40 GeV photons. The variation of energy deposition with depth (≈5 samplings + PWC information) will be used to distinguish neutral hadrons from photons.



SIDE VIEW OF DETECTOR (Schematic)

FIGURE 1

The detector is preceded by a proportional wire chamber which will be used to localize charged particles entering the detector. Spaced at intervals through the detector will be perhaps four proportional wire chambers, each with approx. 100 vertical and 100 horizontal wires (3 mm spacing between vertical wires and 6 mm between horizontal wires). These chambers will use a true proportional readout system which is now being tested by our group. The chambers will provide a means of determining the energy of the individual showers if two or more enter the detector. The readout will be optimized to measure the energy of lowish energy γ's (at the expense of some saturation on high energy ones). Since the total energy is known from the scintillator pulse heights, the energy of the higher energy γ can be determined from the difference. This capability of measuring the energy of both high and low energy photons is important in understanding the background from π° decays which are most troublesome when one photon carries off most of the energy. Another significant advantage of the proportional readout is that it essentially eliminates the stereo ambiguity when two or more showers appear in the detector (unless, of course, the energies of the photons happen to be almost equal.) Thus 45° planes are not needed in the PWC's.

The proposed design shows photomultipliers on only one end of the scintillators. This means the pulse height for a given photon energy will be somewhat position dependent.

However this can be easily corrected from the PWC information.

The characteristics of the proposed detector are summarized in Sect. IV and compared to those of similar photon detectors used in previous Fermilab experiments. It should be emphasized that we do not consider the design of the detector as "frozen." We have already benefitted from consultation with other experimenters and will continue to actively seek advice.

II. Backgrounds From π° and η° Decays

The major difficulty in previous attempts to study direct photon production at FNAL and the ISR was background from $\pi^\circ \rightarrow 2\gamma$ and $\eta^\circ \rightarrow 2\gamma$ decays. This is obviously a major consideration in designing our experiment. We have made a significant reduction in the expected background compared to our original design by moving the detector 1 m. closer to the target (from ≈ 6 m. to 5 m.). This, of course means that we can obtain the same event rate with approx. 40% less beam. Figure 2 shows the expected background from $\eta^\circ \rightarrow 2\gamma$ and $\pi^\circ \rightarrow 2\gamma$ due to decays in which one photon is seen in the central 50% of the detector area and the other misses the detector and lead glass "vetos" (or has an energy <0.5 GeV). The η° curve has been multiplied by 0.38, the branching ratio for $\eta^\circ \rightarrow 2\gamma$ and by 0.5, the measured[1] ratio of η° to π° production at large p_T, so that the η° and π° curves are directly comparable. The significance of the curves can best be illustrated by an example. If direct γ production at $p_T \cong 4$ GeV/c (60 GeV/c in the lab at 68 mr) were 1% of the π° production, the

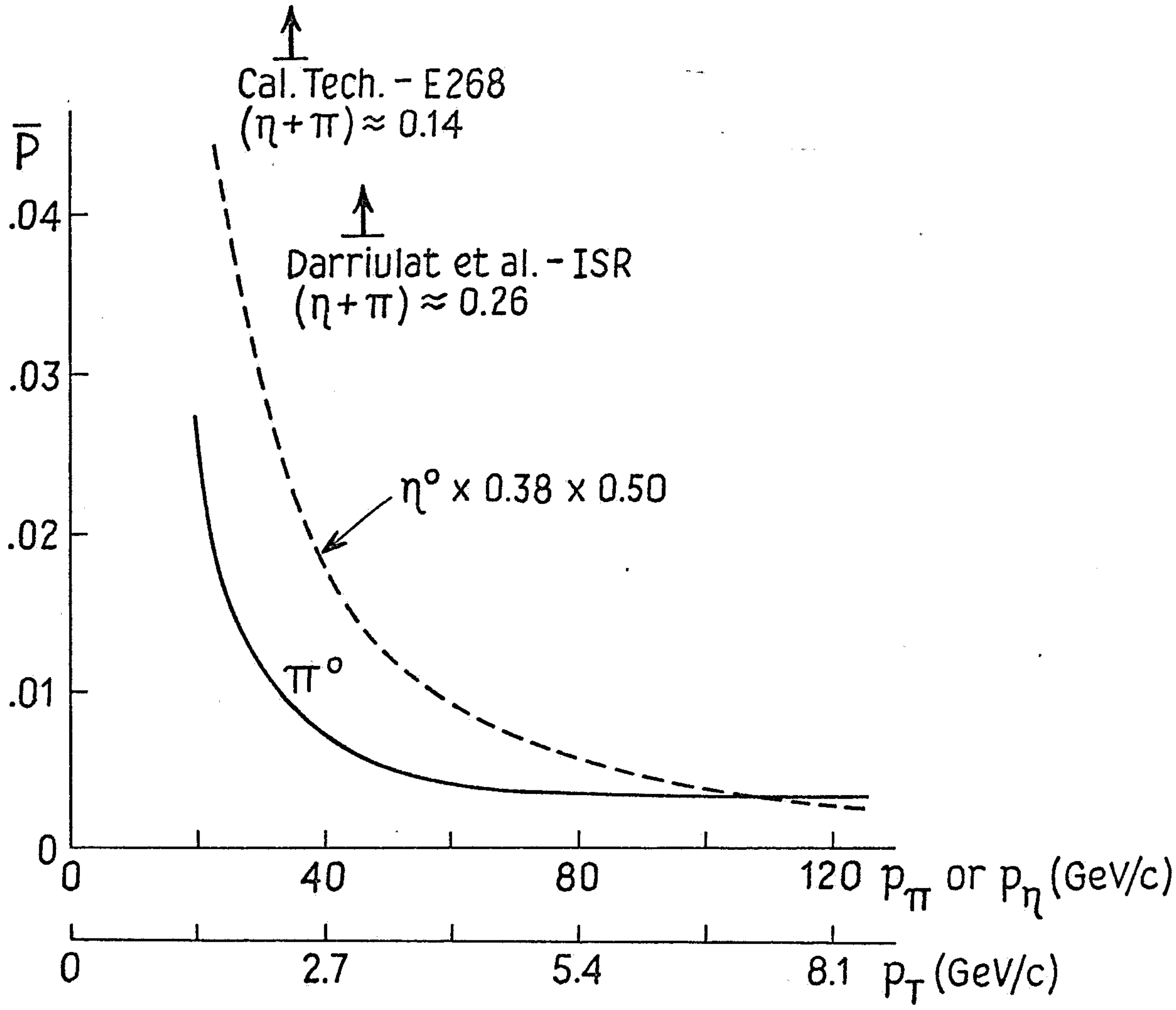


Figure 2 — The probability of missing the other photon from an $\eta^\circ \rightarrow 2\gamma$ or $\pi^\circ \rightarrow 2\gamma$ decay if one photon appears in the central 50% of the detector area. Backgrounds in previous experiments are also indicated.

background from η° decays would be equal to the direct photon signal and from π° decays would be $\approx$ 40% of the signal. At larger p_T the background situation improves rapidly. A background subtraction can of course be made, and this will allow reasonably accurate measurements down to $p_T \approx 2$ GeV/c if γ/π° is reasonably large.

For comparison we show in Fig. 2 the background levels in the experiment of Darriulat et al.[2], the only published data on direct photon production at high energies, and in the Cal Tech-LBL experiment (E-268), based on a preliminary analysis by J. Mellema.[3] Both measurements are at 90° in the cms. Neither experiment set out to measure direct photon production; the data are by-products of π° production studies. The results are summarized in Sect. IV.

Again it is important to emphasize that our design is not frozen. The $\eta+\pi$ background can in principle be lowered by moving the detector closer to the target. The price is an increase in overall singles rates relative to events because charged particles are swept away less effectively and the edge of the detector comes closer to the beam. Finding the optimum position can best be done during tuning up with beam.

III. Background From Sources Other Than the Target

The PAC panel expressed considerable concern over background from shielding near the beam downstream of the target. In fact, in E-268 non-target background from sources upstream of the target was a serious problem in their attempt to measure direct photons. Their detector was essentially nondirectional, however. To minimize this problem we can stretch out our detector somewhat along the incident photon direction to improve its directionality. We expect to be able to localize centers of showers transversely to an accuracy $\leqslant$ 1 mm.* With the detector of Fig. 1 this corresponds to an error ~10 mm at the hydrogen target in the location of the source in a plane normal to the photon direction. Thus target out background in analyzed events will be minimized if we keep all shielding >> 10 mm away from the illuminated part of the target as seen from the detector. In other words, event candidates which do not come from within 1 or 2 cm of the "hot spot" will be eliminated. Crudely this means that no shielding should be placed within about (2 cm/ .068 rad) $\cong$ 30 cm of the target as measured along the beam line.**

As far as triggering rates from non-target sources, we do not anticipate much problem from sources downstream of the target. Triggers from downstream sources would require very high p_T photons to satisfy the trigger requirement ($\geqslant$ 20 GeV photon in the detector). Upstream sources are potentially more serious as far as trigger rates, but careful design of the beam and shielding should minimize this source.

In summary, with the directionality of our detector and reasonable care in the design of shielding we believe background

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*This is the accuracy achieved with the Cal Tech-LBL detector which was several times coarser-grained than ours.

**It may be best to eliminate all shielding for several meters downstream of the target.

from nontarget sources should not be a major problem.

IV. Comparison With Other Experiments

To our knowledge no one has proposed and designed an experiment specifically to measure direct photon production at high energies. The background problems are serious enough that we believe that only an experiment specifically designed to do the experiment will produce a creditable measurement. If in fact γ/π is $\sim .01$, we worry more whether we can measure it than whether other groups can with existing detectors which are not optimized for the measurement.

Table IV-1 summarizes the status of other relevant experiments. The only published data are that of Darriulat et al.[2] and these are controversial. The E-268 experiment used what we consider the best detector for this purpose among the experiments listed. They had difficulties with non-target background and a large background from η° and π° decays. The π° background was large partially as a result of a software cut that required $E_\gamma > 2.25$ GeV that was put in early in their analysis. Lowering this cutoff would reduce the π° background considerably.

The E-95 group has no results for γ/π as yet. As we show below, their detector is less suited to the measurement than the E-268 detector and there is no reason to think they can do better. They also have the handicap of using a thin (0.8 mm) beryllium target. The use of such a thin target aggravates backgrounds from sources other than the target.

TABLE IV-1 — OTHER RELEVANT EXPERIMENTS

There have been no previous experiments specifically designed to study direct photon production at large p_T.

Darriulat et al. (ISR) — Only significant published data.
[Nucl. Phys. B110, 365 (1976)].

Start with uncorrected $\gamma/\pi \approx 0.46$; subtract background of 0.26 from $\pi^\circ \rightarrow 2\gamma$ and $\eta^\circ \rightarrow 2\gamma$ to get $\gamma/\pi = 0.20 \pm .06$.

γ/π appears to decrease with increasing s. Taken literally $\gamma/\pi \approx 0.20$ would rule out Field-Feynman model ("leisurely production") while the energy dependence is wrong for CIM ("deep production").

E-268(CIT-LBL-BNL) — 200 GeV pp and πp;
$\approx$90° cms data — [Source: J. Mellema, internal report].

Large target — empty background for $p_T \geqslant 3$ GeV limits useful data to $2.2 < p_T < 2.5$ GeV/c. Start with uncorrected $\gamma/\pi \approx 0.22$; subtract background of 0.16 from $\pi^\circ \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma$, and hadrons to get $\gamma/\pi = .06 \pm .02$ ($\pm$.02 sys. error).

$\approx$35° cms data — [Source: A. Barnes, private comm.]
$\gamma/\pi \approx 0 \pm 3\%$ ("cleaner than 90° data")

E-95 (FNAL-Johns Hopkins) —
"No results yet." — [C.T. Murphy, private comm.]
"We might be able to say $\gamma/\pi \approx 5\pm5\%$." [J. Matthews, private comm.]

Their target is also 50% thicker than our 150 mm hydrogen target when measured in radiation lengths. This aggravates the problem of π°'s simulating single γ's because one of the photons converts in the target.

In Table IV-2 we compare our proposed detector with the E-268 and the E-95 detectors. The E-268 detector is similar to ours in most characteristics except that it lacked directionality. The 2.25 GeV minimum energy for their detector was a software cut which could have been lowered, particularly if charged particles entering the detector could have been identified.

The E-95 detector consists of an array of 25 lead glass blocks, each approx. 64 mm square and 24 rad. lengths deep as seen by the incoming photons. Its lateral dimensions are somewhat smaller than ours and it is about the same distance from the target. Ahead of the lead-glass array is a lead sheet, which converts $\approx$67% of the γ's, and a PWC. Thus $\approx$67% of the time the detector can resolve two closely-spaced vertices. However, the 2 photons from the symmetric decay of a 60 GeV π° are only $\approx$ 25 mm apart at the detector. This means that much of the time only <u>one</u> of the photons from such decays will be seen in the PWC while both photons dump their energy into a single lead-glass detector element behind it. This leads to a significant background from approx. symmetric π° decays* as well as the background from

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*Nearly symmetric decays are very common because of the (1-cos θ^*) decay distribution.

TABLE IV.-2 — DETECTOR CHARACTERISTICS

	Us (proposed)	Cal. Tech - LBL (E-268)	E-95 (Cox et al.)
Type —	Pb-Scint.-PWC	Pb-Cerenkov	Pb-glass + PWC
Granularity —	≈ 3mm PWC's	10 mm(b)	64 mm(c) Pb-glass ? PWC
Vertex Resolution —	~3 mm PWC's(a) ~150 mm outer	~10 mm(a)	~64 mm(a) Pb-glass ? PWC
Spatial — Accuracy	~1 mm PWC's(a) ~150 mm outer	≈ 1 mm(b)	?
Directionality —	≈ 1.7 mr(a)	not used	~50 mr(a)
Energy Res., total — (at 40 GeV)	~2%(a)	≈ 3%(b)	≈ 3%(c)
", each shower —	~5% (PWC's)(a)	$3\%\sqrt{\frac{40}{E}}$	$3\%\sqrt{\frac{40}{E}}$(c)
Min.energy	0.5 GeV(a)	2.25 GeV(b) (software)	?

(a) Our estimate

(b) PRL 36, 1110
or private comm.
A. Barnes

(c) C.T. Murphy,
private comm.

(rare) asymmetric decays that we anticipate. In our opinion E-95 will not be able to make a creditable measurement of γ/π.

V. Other Commitments of the Group

None of us have commitments at other laboratories. Unless fortune smiles and we discover quarks trapped in nuclei or other monumental results in our presently approved experiments we anticipate that our present commitments will be essentially completed about the end of this year. In the meantime our technical support personnel are not too busy, so construction of detectors and electronics can commence essentially immediately.

We are also seeking a small number of collaborators from other groups who could contribute expertise and effort to the experiment.

VI. Cost Estimates

In our cost estimates we are including new money only. In estimating costs to our NSF grant we are not including salaries of people now being paid by the grant.

Our Costs:

PWC's - These are essentially complete.	\$ 500
PWC readout electronics (parts only) — 1000 wires at \$4/wire	\$4000
Lead-glass counters with tubes	\$6000
Scintillators for γ detector (probably acrylic) at \$35/ft^2	\$2100
Other scintillators	\$1000
Total	\$18,100

FNAL Costs

Flask and installation of hydrogen target	\$2000
Shims and installation for sweeping magnet (probably a BM109 opened up to 12" gap)	\$2000

In addition we would require a rather modest complement of PREP electronics,* portacamp or equivalent, and the usual amenities such as control console, light, heat, power, telephone, etc. No estimates for these are available at this time.

*Ball park estimate of total cost $60K.

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3. J. Mellema, Cal. Tech. Internal Report CALT-68-558.