FERMILAB PROPOSAL NO. 457

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Search for μ's, K^o's or Characteristic Hadron Signatures and Masses in Coincidence with Single Directly Produced Electrons

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Abstract

We propose to investigate the anomalous production of leptons in hadron reactions using the FNAL cyclotron magnet facility in conjunction with a direct electron trigger. The large aperture of the magnet plus the existing detector array will make it possible to study the topology of the anomalous events for distinctive signatures such as invariant mass peaks or accompanying μ's or K^o's. The use of an electron trigger instead of a muon trigger allows better offline noise suppression as well as overall event reconstructability.

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(Phase I)

This phase is a test of several untried techniques related to the use of a direct electron trigger with the cyclotron magnet facility. Given that the results of these tests are satisfactory, we intend to submit a full proposal along the lines of the accompanying Phase II outline.

The tests concern the offline rejection of Dalitz pair electrons by our system (see Phase II outline), and require only minor modifications to the existing cyclotron magnet spectrometer:

A. The ability to follow tracks to a vertex wholly within the magnet must be tested. We propose to do this using computer-aided scanning. The presently available 1m X 1m proportional chambers would be configured inside the magnet for a run with a solid target placed at the front edge of the magnet.

B. The detection efficiency and unambiguous spatial measurement of photons in the magnetostrictive spark chambers can be tested simultaneously with "A". It will be necessary to intersperse the chambers with lead sheets in the present locations.

To carry out these tests, we make the following requests of FNAL:

1. Permission to reconfigure the proportional chambers inside the cyclotron magnet.

2. 100 hours of running time with a 100 GeV pion beam incident on a solid target.

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(Phase II)

I. Introduction

There are many searches underway at FNAL and elsewhere to find out what is produced with the anomalous single leptons in hadron reactions.

A low-noise μ-trigger can be made only by blocking the background $\pi \rightarrow \mu\nu$ decays over nearly half the solid angle, but this prevents the observation and mass reconstruction of multi-prong hadron products.

A low-noise e-trigger is harder to achieve, but the backgrounds are such that their repression need not interfere with the reconstruction of multi-prong hadron states. This proposal is for an electron trigger with good on-line and excellent off-line noise rejection, leaving full solid angle for observing associated multi-hadron states. This low-noise e-trigger will remain excellent for tagging eμ coincidences even when a half-plane is blocked off to suppress the μ-decay background.

II. Physics

The recently discovered narrow width resonances are most easily explained by postulating the presence of a new and heavy quark with a new quantum number. The narrowness is then explained by a Zweig rule disallowing decays into the usual mesons. The new mesons do not possess a new quantum number that would be carried by the quark, i.e., they are all of the type $c\bar{c}$ (c is the new quark).

An extension of this idea would lead one to expect new particles carrying this new quantum number, c. Like strange particles, they would only decay weakly into c = 0 particles (e.g. π-mesons). One would also expect semi-leptonic decays of these particles leading to the appearance of directly produced charged leptons.[1]

Experimental evidence suggests that there are charged leptons in hadronic events whose source is incompatible with their production by pairs (Lederman, Stanford Lepton Photon Conference, August, 1975).[2] These two phenomena taken together suggest that "charmed" mesons are present in hadron reactions. The level of anomalous charged lepton production (e or μ to $\pi = 10^{-4}$) suggests that the fraction of events with such particles followed by a decay into charged lepton is one in 1600.

Further evidence for this hypothesis is seen in the experiments at SPEAR.[3] An increase in hadron production relative to μ-pair production in e^+e^- annihilation is seen as the total of c-of-m energy increases beyond 4 GeV. This can be interpreted as an energy threshold in charmed particle pair production. Unfortunately, these experiments have found no evidence for unique mass states when they reconstruct masses from the charged particles that they measure. It would be expected that charmed states would decay down to the lowest mass state which would decay hadronically as well as semileptonically.

The purpose of the experiment in its second phase would be to find events containing a directly produced charged lepton (e or μ) with the expectation of seeing the topology, character, and energy distribution in such events and to ensure that the events to be observed contain a rich sample of such directly produced particles. We include the possibility that such events are produced in pairs (e^+e^- or $\mu^+\mu^-$), or even as eμ pairs.

The SPEAR experience[3] indicates that the search for unique mass states is difficult even with a presumably rich sample of "charmed" particles. We will require that the event sample to be used for mass-or odd signature-searches be relatively uncontaminated by conventional events masquerading as direct lepton production (i.e., signal/background ≈1 or better). We also require a large efficiency (∿90%) for finding and measuring charged tracks.

III. Problems and Solutions

A. μ-Trigger

Events triggered on μ-mesons suffer from a background coming from π-decays in flight. Various methods can be used to minimize or select out such events.

1) An absorber may be placed close to the target to minimize the π flight paths; this unfortunately will mask analysis of other particles leaving the target.

2) With good enough event reconstruction, the kink from the decay may be seen in some fraction of the events. If the decay occurs in a magnetic field, a change in curvature may be detected as well. This technique requires high precision measurements

which are not available in any apparatus we know of.

At best, these methods will produce a sample of events where there is a comparable amount of π decay background.

B. e-Trigger

The e-trigger presents two large problems:

1) Electrons are present from Dalitz decay of the π^0 (1 in 80 decays therefore 3 in 80 events -- $\overline{n}(\pi^0) \simeq 3$ at 100 GeV). The target itself and other materials convert some of the π^0 gamma rays,

2) The electron is usually identified in a high Z shower counter (an electro-photometer). π-mesons through nuclear interactions will occasionally give a hadronic shower whose pulse height is nearly equal to that from the same momentum electron. This becomes severe, considering the relatively large number of π's produced. (10^4 to 1).

We propose to purify our electron trigger and the later off line event selection by the following methods:

1) Trigger on high $p_\perp$ electrons. The Dalitz electrons, by virtue of momentum degeneration, are reduced relative to π's by the amount $\sim(25\ p_\perp^2)$ (Appendix I)

2) Hadronic showers can be selected out of electron showers by noting their late development and lack of containment in lead. Rejection ratios of the order of 10^3 have been achieved with a relatively simple apparatus. Rejection ratios of the order of 10^2 in a simple trigger appear feasible. (Appendix II)

3) A suitable photon detector will frequently measure the second γ-ray from the π^0 decay. The small mass of the π results in this γ-ray being near the electron in angle. Events with a γ-ray near the electron production angle will be excluded. (Appendix IIIA)

4) Our detector will frequently detect the extra electron in the Dalitz decay. (Appendix IIIB)

5) An electron may be detected by the insertion of a radiator into the magnetic field which gives rise to detectable photons coming off tangent to the electron trajectory. Rejection ratios against hadrons as high as 10^5 have been achieved.[4] We plan to use this system.

IV. Experimental Apparatus

We propose to do this experiment in the μ-meson area utilizing the apparatus that has been developed around the ex-Chicago cyclotron. To this we add a combination electrophotometer and hadrometer for use as a trigger. The layout is shown in Figs. 1 and 2. We will not describe those parts of the apparatus that have been used in previous experiments. They have been battle tested and are understood.

For the purposes of this experiment, the target will be brought in close to the edge of the magnet for the following reasons:

1) The reconstruction of a hadronic particle which decays into hadrons will be more efficient since the magnet intercepts more particles. The percentage of particles whose momentum may be analyzed is increased by placing proportional wire chambers inside the magnet.

2) By placing the target closer to our detector, the angle that a π^0-gamma must make is increased, thus demanding a higher $p_\perp$ component, and thereby decreasing this source of unwanted triggers without reducing the desired triggers.

The electrophotometer is very similar to one built by the Cal Tech group.[5] It has the capability of measuring energy and the location of two or more showers. This location is important since a criterion for electron recognition is that the bremstrahlung photon be seen in the bending plane of the electron, and that its location be on a tangent to the electron trajectory at the radiator. The pulse height is useful for triggering purposes; the high bending power of the magnet (p transverse = 2.25 GeV/c) gives a high energy correlation between particle energy and entry position into the electrophotometer. We may use pulse height criteria on our trigger. Combining this information with the radial disposition of the lower edge of the trigger, we set a minimum requirement on $p_{\perp}$. The layout of the detector looking up the beam is shown in Fig. 3.

Behind the electrophotometer (EP) place a hadrometer (HD). Its purpose is to veto hadronic showers. A test of this combination (EP + HD) shows that a rejection factor of 10^2 or better can be achieved against hadrons by demanding no pulse height in the HD(App.II) We will also sample the shower at 2,4, and 6 radiation lengths. It has been shown that a further reduction against hadrons(factor of about 10) can be achieved; this comes about since the development of an electromagnetic shower is more regular due to the larger number of particles involved. We may use this pulse height cut in our trigger if necessary to reduce our trigger rate. A more refined analysis utilizing the measured momentum of the incoming particle can be done off-line. We also reserve the option of utilizing the two shower requirement (bremsstrahlung photon + electron shower) in our trigger. This would only be done if our trigger rates are found to be too high, preferring to leave the trigger as open as possible.

We will add lead sheets in between the 2m x 4m magnetostrictive spark chambers (5 of them) so that they may act as photon and electron detectors. The former will be used to veto events where a gamma ray plus the triggering electron could be interpreted as π^0 decay products. We will also use the information for possible hadron mass reconstruction. The electron detection is used to check whether it is the other directly produced lepton to be paired with the triggering electron. The lead sheets will not cover the section in front of the electrophotometer.

We will place a large area detector at the base of the magnet on the downstream side. It will be used to detect μ-meson candidates that penetrated the magnet iron. It will be used in coincidence with the electron trigger for that part of the experiment devoted to μe coincidences. This layout is shown in Fig. 1 .

The lead radiator to identify electrons is placed 1 meter from the downstream end of the magnet. It has a counter in front of it to eliminate triggers from conversion electrons produced in it.

A counter with Pb cover to induce electron showers is placed at the side of the magnet as an aide in the identification and location of the second Dalitz electron.

V. Counting Rates and Backgrounds

To obtain the counting rates, we have used the cross-sections published by J. Cooper et al. for 102 GeV/c pp collisions.[6] We assume a beam of 10^6 π^- mesons/burst and 2 x 10^5 bursts, which is equivalent to about 500 hours. We take a target with a reaction probability of 2% and a γ conversion probability of 1.2%.

We take a minimum $p_\perp$ of 0.7 GeV/c and an energy interval between 7.5 and 15 GeV. The number of π's reaching the electron detector is 270/burst. The number of Dalitz electrons is 0.6/burst. Taking the ratio of e/π as 10^{-4}, we will get 2.7 x 10^{-2} anomalous electron events/burst. We expect that our detector biases against π's by at least a factor of 100, so that our total trigger rate is 3.3/burst. (The details of the numerics are in Appendix I).

VI. Off-line Analysis

A. Elimination of π's

An important element of this proposal is that we can reduce the data quickly in the off-line analysis stages. The detection of the bremstrahlung gamma ray involves simple algorithms--such as one particle in but two showers present. Their spacing (particularly the minimum spacing) and absolute positions are roughly predictable, since the entry position is a good measure of the energy of the particle. The correction due to bremsstrahlung can be made from the measured pulse height. We believe this can be done by computer and will not require hand scanning. After this stage, we will be left with the Dalitz events, and "real" events (6×10^4 and 2.7×10^3 respectively). An equal number of events have been eliminated for failure to produce a detectable photon.

B. Elimination of Dalitz events

The computer programs can reduce the data to real positions. We will know the position of the appearance of γ-rays converted in the MSC photometer. We have a good measure of the production angle of the electron. The elevation angle will be measured by the E.P.. The horizontal angle is measured by the photon and electron position with the photon pulse height used to make a correction for the energy of the electron after radiating. We may apply the γ-ray veto condition (Appendix IIIA) without scanning. We assume that the unobserved Dalitz electron carried a small amount of energy. If it carried a major portion of the π^0 energy, the π^0 energy was greater than assumed, and the photon has a greater chance of being found in a spatial angular cone around the initial electron direction. We expect to reduce the Dalitz decay contamination by a factor of 5. A further reduction factor will be applied in the final stage. At this point, our remaining sample contains 1.2×10^4 Dalitz decays and 2.4×10^3 "reals". We lose 12% of the "reals" from chance γ-rays of other π^0's.

Through all the above steps, a visual scan of a subsample of events will check on the reliability of our processing.

C. Further Reduction of Dalitz Events

The remaining events will be subject to a visual scan. We have developed and are developing programs that follow a particle trajectory in a magnet field. The scanner will be aided by a computer selected track. The search for another track (the second Dalitz electron) coplanar with the first should be relatively easy. Our selection of high $p_\perp$ events has helped us; the electron tracks are well outside the "jet". For example, the tracks are 2 cm off axis 30 cm downstream of the target. We expect to see a Dalitz electron with a momentum as low as 0.5 GeV/c and probably less. Naturally, a kinematic selection must be made, so as not to eliminate expected directly produced charged lepton pairs (Drell-Yan events). This discovery will cut our Dalitz contamination down by a factor of about 6 or better, leaving us with <2000 Dalitz events and 2500 "reals".

D. Final Analysis

These remaining events will be analyzed for the presence of another charged lepton, strange particles, gross energy imbalance (missing neutrino), and unique masses from the associated hadrons. It is important that we have elected to place the target essentially inside the magnet field with detection chambers directly downstream. For a 100 GeV event, we will be able to detect and measure >93% of all charged tracks.[6] We can pull such tricks as selecting events which conserve charge, thereby eliminating more of the residual Dalitz events.

For hadron mass reconstruction, we have a large detection solid angle. We calculate that only 13% of the solid angle is uncovered for a particle produced at x = o. This inefficiency is approximately 2.5 times less than exists at SPEAR. The combination of our trigger and detection efficiency will be the most favorable we know of for finding the decay of well-defined mass into many charged hadrons.

VII Requests (Phase II)

A. Apparatus

We request the use of the full apparatus around the Chicago cyclotron. We wish to rearrange the detectors as shown in Fig. 1.

B. Beam Time

1. Parasite time with a trickle beam of π's and e's variable from 5 to 100 GeV/c.

150 hours

2. Running with 100 GeV/c π^- at 10^7/burst

150 hours

3. Running with 100 GeV/c π^- at 10^6/burst

350 hours

C. Target

16 ± 4 cm target of H_2 placed as shown in Fig. 1.

APPENDIX I

Suppression of Dalitz Pairs by a $p_\perp$ Cut

We start with a distribution for π-mesons.

$$\frac{dp_\pi}{p_\pi} \, e^{-bp_\pi\theta} d\Omega$$

We neglect the small transverse momenta from π^0 decay and $\gamma \to e^+e^-$. The distribution for a Dalitz electron of one or the other sign is:

$$\int_{p_\gamma = p_e}^{\infty} \int_{p_\pi = p_\gamma}^{\infty} \frac{dp_\pi}{p_\pi} \frac{dp_\gamma}{p_\pi} \frac{dp_e}{p_\gamma} e^{-bp_\pi\theta} d\Omega$$

If we make the substitutions

$$p_\gamma = p_e + w, \qquad p_\pi = p_\gamma + u$$

we have two integrals of the type

$$\int_0^{\infty} \frac{e^{-z}}{(a+z)^m} dz \approx \frac{1}{a^m} \quad \text{if } a>>1$$

We get the distribution of electrons

$$\frac{dp_e}{p_e} \frac{1}{(b\theta p_e)^2} e^{-b\theta p_e}$$

APPENDIX II

Hadron Rejection with Calorimeters

We have made use of the excellent compendium of data provided by the FNAL May 1975 Calorimeter Conference.[7] In particular, H. Haggerty has shown the behavior of a mixed e and π beam on a detector consisting of an electrophotometer (6" of lead) followed by a hadrometer. He makes a scatter plot of pulse height in one versus the other. If a cut is made for very small pulse height in the hadrometer, very few (∿1%) π events survive. If a ± 10% cut is made around the proper electron energy, there appears to be a negligible number of π survivors if one extrapolates simply.

In addition, J. Appel[7] reported that in a lead-glass detector, of those hadronic events which gave a comparable pulse height to the electrons of the same energy, the pulse height at 2.3 and 4.6 radiation lengths is discernibly different (lower) for hadronic events. It appears that a rejection of hadrons by a factor of ten is possible.

APPENDIX III

Dalitz Pair Elimination

A. Photon Veto

The π^0 mesons which contribute to the Dalitz background are not limited in their high energy limit so much by the π^0 spectrum as they are by the $p_\perp$ cut. It is a good assumption to take decay photons and electrons colinear; the energy distribution of the second Dalitz electron, ε_2, and the other photon, k, is

$$dn_{e_1} dn_K \, \alpha e^{-b\theta(k + \varepsilon_2 + \varepsilon_1)} \quad , \quad \varepsilon_\pi = \varepsilon_1 + \varepsilon_2 + k$$

The drop off in the π spectrum is dominated by this exponential. The source of losses comes from either too large an angle, ψ, for the photon or too low an energy, k, for detectability. Integration for the photon alone gives

$$\text{Efficiency} = e^{-b\theta k_{min}}$$

$$\psi_{max} = \alpha \, m/\varepsilon_1$$

$$k_{min} = \frac{1}{\alpha^2} \; \varepsilon_1$$

$\theta\varepsilon_1 = p_\perp$ (taken at the cut off)

We take $\alpha = 3.75$ to get $k_{min} = .71$ GeV

Eff = .80

We also calculate the probability that a photon from a π^0 decay in the same event falls within the cone alluded to above. We assume that the electron has a transverse momentum, $p_\perp$. We approximate the circular cone by the square and

$$\sqrt{p_{\perp x}^{\;2} + p_{\perp y}^{\;2}} \approx p_{\perp x}$$

x is defined by the electron-beam plane.

$$\mathcal{J} = \text{Prob. of a } \pi^0\gamma = \frac{\sqrt{\pi}\, b m_\pi \beta}{3\pi}\, e^{-bp_\perp}\, 2 \sinh 1/2\sqrt{\pi}\, b\, m_\pi \beta$$

Table I

Values of the probability for a chance π^0 γ-ray

	$\beta \rightarrow$	2.5	3.0	3.5	4.0
$(p_\perp = 0.5)$	$\rightarrow$	.106	.172	.267	.41
$(p_\perp = 0.7)$	$\rightarrow$	.043	.070	.109	.167

For a suppression of 80% of the Dalitz decays (α between 2.5 and 3.0) we expect to lose 12% of good events.

B. Detection Efficiency for the Second Dalitz Electron

The probability of eliminating the second Dalitz pair will rely on finding the second electron and then determining within the measuring error that the e^+e^- virtual mass is characteristically small. With the proportional chambers in the magnet we expect to pick up particles with a momentum as low as .5 GeV/c. This is a radius of curvature of 1.11 meters; such a particle will traverse 3 or more proportional chambers. This will give an efficiency for detection of about 95%. We must then reconstruct the mass; this spectrometer has achieved mass resolutions of ±30 MeV; this was done with straight flight paths before and after the magnet. Though we do not have the first flight path our main measurement relies on a good vertical angular measurement, which is easily done. We are also utilizing lower momentum particles than is usual so we do not expect much deterioration in mass measurement. In effect we are looking to see whether a second electron was emitted within a small cone angle ($\psi < .4m\pi/\varepsilon_1$) of the first electron. The probability for such a chance event is small.

In addition we have placed counters along the side of the magnet to reveal that this second particle is indeed an electron. We will quote our second electron pick up efficiency on the basis of an electron detected in this counter. We use the efficiency of Appendix IIIA

$$dn_2 \; \alpha \; e^{-b\theta(k+\varepsilon_2+\varepsilon_1)} d\varepsilon_2$$

$$\text{Eff} = e^{-b\theta\varepsilon_{2\,min}} - e^{-b\theta\varepsilon_{2\,max}}$$

The higher energy electrons are detected by traversing lead radiators interspersed in the magnet giving rise to photons in the above detector and/or curvature changes in the magnet. We estimate we would pick up an electron with as low an energy as .5 GeV. Therefore

$$\text{Eff} = e^{-bp_\perp \frac{\varepsilon_{2\,min}}{\varepsilon_1}} = .85 \quad .$$

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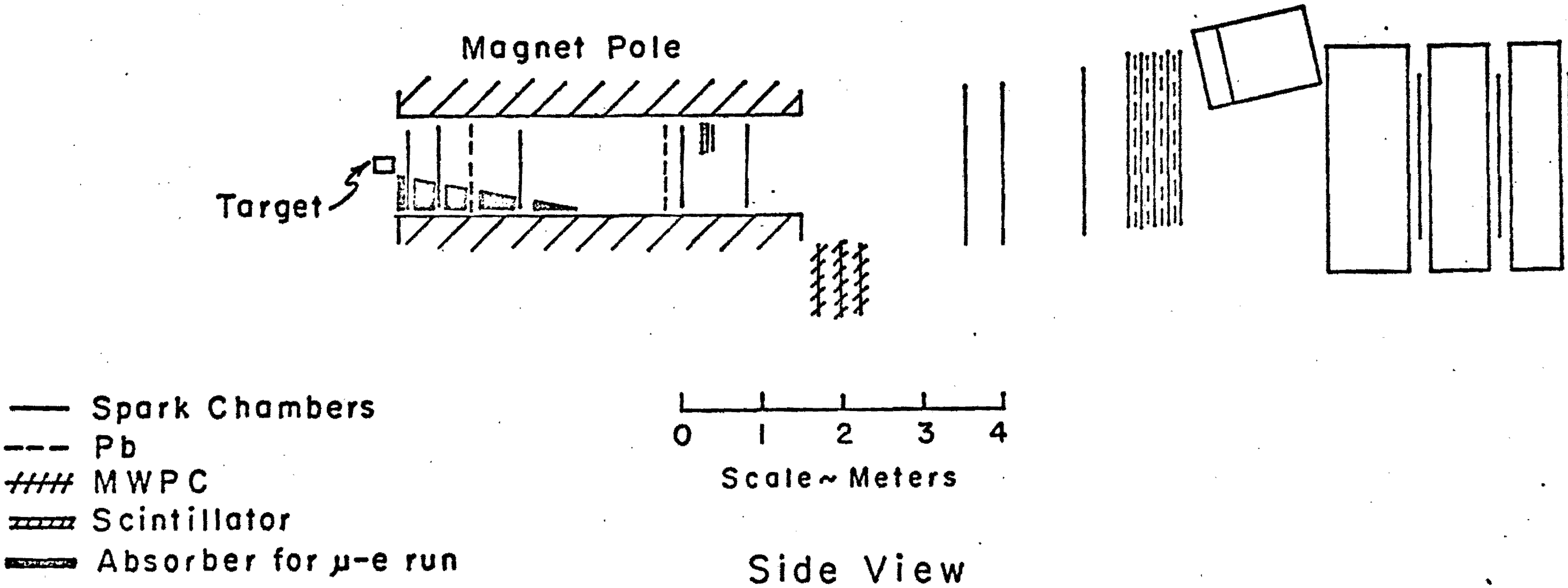
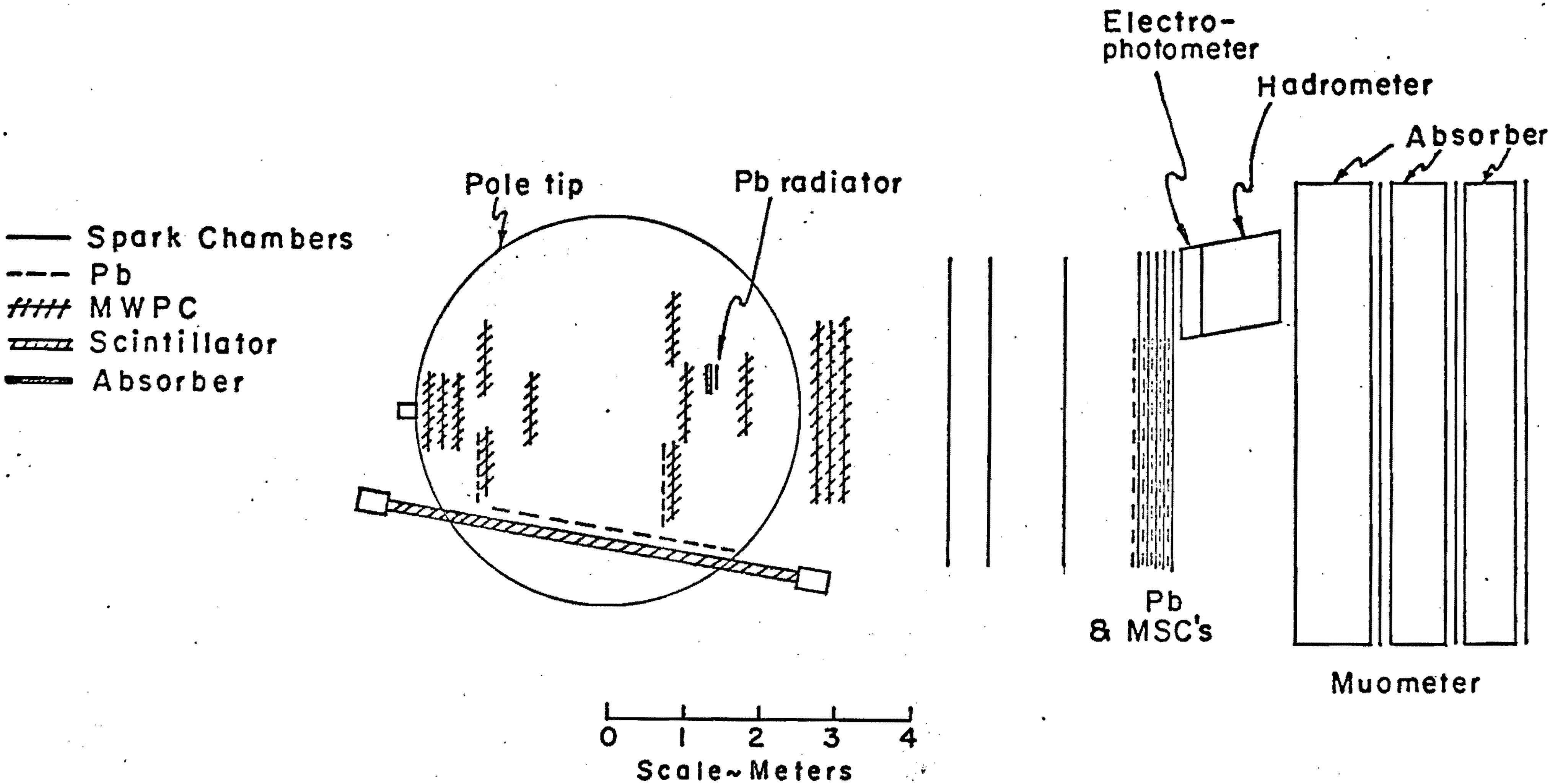


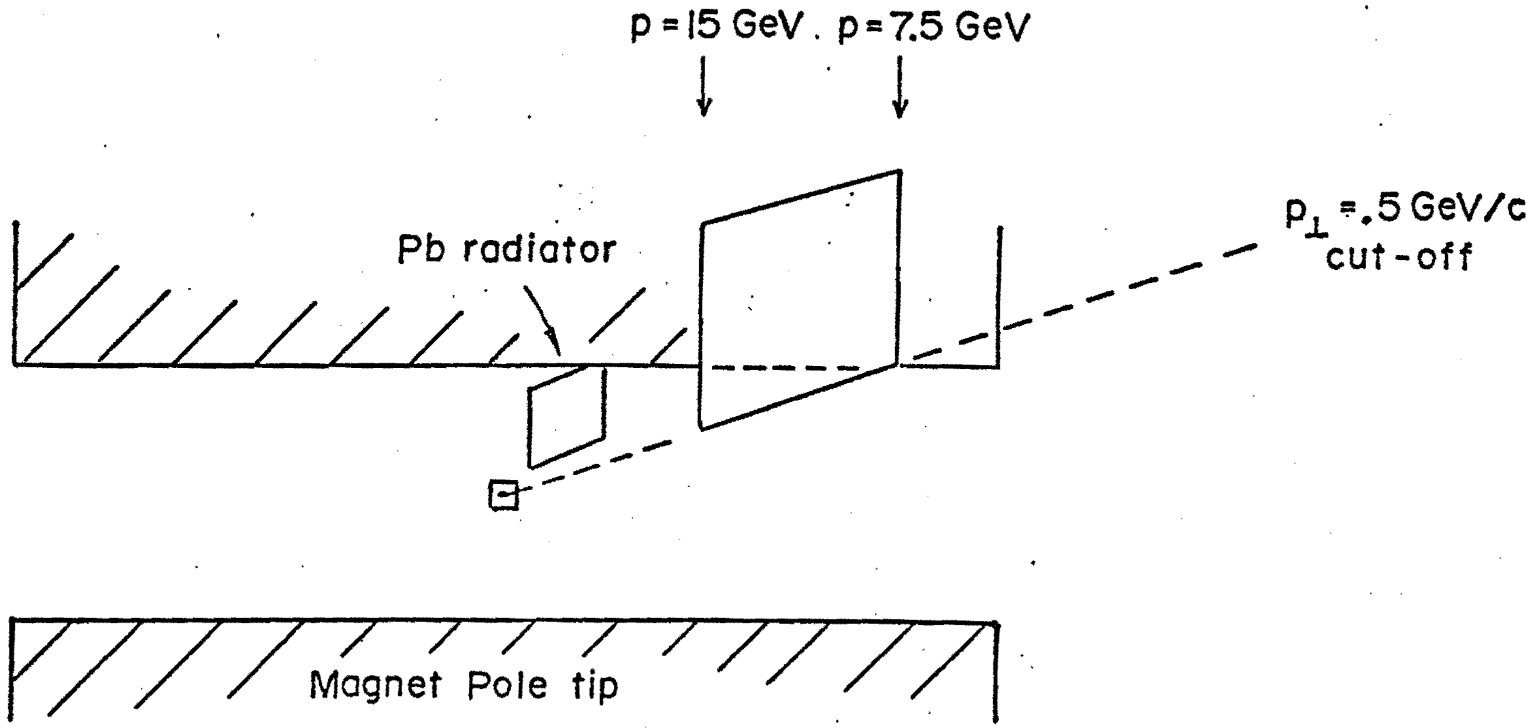
Side View

Fig. 1



Plan View

Fig. 2



Target View

Fig. 3