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NEW PARTICLE PHYSICS AT THE TAGGED PHOTON LABORATORY

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INTRODUCTION

This is a proposal to measure J/ψ and ψ' photoproduction on deuterium. We also plan to search for and study other high mass photoproduced particles decaying into electron/photon final states. The apparatus is essentially identical with that used in a successful test of the feasibility of this experiment during August of last summer. (This test was made while setting up the apparatus for Experiment 25, Photon Total Cross Section. It was based on a proposal, "Charmed Physics at the Tagged Photon Lab", submitted at the time of the special meeting on proposals related to the new particle discoveries in November, 1974.) The results of that test, which will be described later, show that a clean photoproduced $J/\psi \rightarrow e^+e^-$ signal can be separated from the dominant multi-π^o background (see Fig. 1). The tests also indicate a yield of approximately 1.3 J/ψ per 10^{15} 400 GeV protons on target, which is adequate to carry out the detailed measurements we now propose.

THE PHYSICS

Little is known about the photoproduction of these states beyond the fact that the J/ψ and ψ' are in fact photoproduced.[1,2,3] There are indications that the cross section of J/ψ production on nucleons may rise between the SLAC measurements[1] at 18 GeV and the Fermilab measurements[2] in the broad band photon beam around 100 GeV. However, the comparison is very difficult because of the low statistics and the fact that the high energy measurement was on beryllium and the SLAC measurement on hydrogen and deuterium. The open questions are: is the cross section in fact rising with energy above 20 Gev?; if sc, is the rise in one or more steps?; or, is it a slow continuous rise?

The data available so far seem to indicate a very flat $|t|$ dependance ($e^{b|t|}$ with b about 2½) in the incoherent part. This raises a puzzle: on the one hand we are used to thinking of the photoproduction of vector mesons as diffractive and elastic; on the other hand, how can a nucleon frequently undergo a recoil with a momentum transfer of 2 or 3 GeV^2 and not be excited? (In fact, in the data from last summer's test, we have one event with $|t| \simeq 2$ GeV^2 which is apparently elastic as determined by the recoil detector and energy balance.) Does the J/ψ differ in this regard from the lower mass vector mesons, ρ, ω, and ϕ (which have typical values of b between 5½ and 10), or is a substantial part of the high t yield in fact inelastic? One would like to experimentally separate the t dependances of the elastic and inelastic portions to find out if there really is a large high t elastic cross section, and to determine whether the total elastic production alone rises with energy.

The only measurement to date of the ψ' photoproduction cross section was at SLAC energies with very low statistics.[1] There, not far above the threshold for ψ' production, the cross section (with large errors) is a factor of two below what is expected at higher energies from the colliding beam cross sections using vector dominance and assuming $\sigma_{\psi' N} = \sigma_{\psi N}$.[4] At high energies, a few probable ψ' events have been observed by the broad band group and by us (see Fig. 1), but no cross section is yet known. Is the ψ' photoproduced at high energies as often as expected or is it suppressed by, for example, a small $\sigma_{\psi' N}$?

The various new, presumably charmonium, states observed at the storage rings[4,5] have not yet been photoproduced. (Several intriguing apparently high mass events have turned up in multi-shower mass plots from our summer test.) Can ψ'' or ψ''' or something new be observed in high energy photoproduction with increased sensitivity? Can the η_c be produced and its $\gamma\gamma$

width measured by Primakoff production? (See our November, 1974 test proposal for a discussion of η_c Primakoff production.) It is these questions we aim to answer.

Specifically, the goals of this experiment are:

a. A measurement of the photoproduction cross section of J/ψ on deuterium as a function of energy from about 35 GeV to 130 GeV based on a sample of at least 500 J/ψ events. Deuterium will be used because it gives a factor of two increase in counting rate for a very small price in nuclear complexity. The coherent nuclear cross section is about three times lower than for beryllium. Thus, there will be a considerably higher incoherent sample for the same total yield; this also makes the separation much easier.

b. A measurement of the elastic part of the J/ψ cross section as a function of energy and momentum transfer. Elastic events will be defined

   by a 12-sided barrel stave recoil detector surrounding the target;

   by energy balance using the tagged photon energy, the lead glass stack and a hadrometer;

   and by not detecting extra tracks from the same vertex in a bank of lead glass and proportional chambers.

c. A measurement of the ψ' photoproduction cross section on deuterium at a mean energy of about 60 GeV based on about 20 e^+e^- events and probably some events from such decay modes as $\pi^o\pi^o\psi$, $\psi \to e^+e^-$.

d. A search for new photoproduced high mass states which decay into electrons, photons and π^o including, perhaps, heavy

leptons. The latter would be detected by lack of energy balance when only two clean electron tracks are seen with no energy in the hadrometer.

SCHEDULE AND BEAM TIME

This physics appears to us sufficiently urgent that we would like to do this experiment the next time beam goes to the Tagged Photon Lab (scheduled for early February, 1976), and postpone for one running cycle the start of our measurements of the photon total cross section. We would do this experiment in a running period, between shutdowns, of approximately eight weeks. During such a period, we can reasonably expect 400 hours of good beam (1 sec. flattop) at 3×10^{12} 400 GeV protons per pulse (10 second cycle) and, with luck, perhaps 800 hours. Based on our test results, we would get about 1.3 J/ψ events per hour at these intensities and would thus easily meet our minimum goal of 500 events. If the ψN and $\psi' N$ cross sections are equal, and assuming VDM and the SPEAR result, we would get about one $\psi' \rightarrow e^+e^-$ for 23 ψ so that our goal of 20 ψ' is also reasonable.

TAGGED PHOTON BEAM AND APPARATUS

This experiment used photons from the tagged photon beam. Our experience, based upon the electron beam tests of April-June, is that fluxes are very close to those expected. At 90 GeV we get about 2×10^7 electrons for 3×10^{12} 400 GeV protons. In the tagging system, electrons that radiate a photon in the radiator are deflected out of the main beam by three magnets. About half the e^- energy spectrum goes into a bank of twelve lead glass and lead lucite counters which measure the scattered electron energy and thereby tag the radiated photon energy. For the total cross section experiment, where precision is the goal, a 1% radiator will probably be used. However, in order to increase photon intensities to

the levels of our tests of last summer, an 18% radiator is used. Double bremsstrahlung in this thick radiator was detected and accounted for by using the experimental apparatus as will be discussed later. Under these conditions, upwards of a million photons per pulse were tagged with energy resolution essentially dominated by the 4½% (FWHM) electron beam momentum bite.

The apparatus is shown schematically in Figure 2. It basically consists of a 1 meter D_2 target followed by 9 planes of multiwire proportional chambers rotated at various angles in front of a stack of 24" long lead glass Cerenkov counters. The MWPCs measure electron track angles and the lead glass measures the energy of showering electrons and photons. The chambers are 18 inches square with 2 mm wire pitch. The lead glass stack is made of 2½" square blocks in a 7 by 7 array with a hole for the beam in the center. Behind this hole is a lead lucite shower counter instead of lead glass. (The latter turns deep brown in a matter of hours if left in the photon beam.) Calibration of the lead glass is established by running a low intensity electron beam into each block and is maintained with a laser light pulser system.

Some additional equipment was made operational during August and will be utilized more fully in the proposed run. A 40" square hadrometer consisting of 12 scintillator planes interleaved with a total of 48" of iron is located downstream of the lead glass. Its purpose will be to reinforce the elastic criterion that the lead glass energy match the tagged photon energy by separating events with substantial hadronic energy. For the proposed run, a six inch square beam hole in the hadrometer will be backed up by a similar counter using liquid scintillator. (Called TANC, this was previously used in Experiment 75, a quark search.) Finally, we surrounded the target with a crude recoil detector consisting of four

scintillators behind 3/8" lead forming a box surrounding the full length of the target. This will be replaced by a detector with finer azimuthal resolution (12 counters) for the proposed experiment. An elastic event is one in which either no recoil counter fires (neutron target) or in which only the counter azimuthally opposite the J/ψ fires (proton target). The azimuthal resolution of the J/ψ (as measured from the e^+e^- tracks) is less than $\frac{0.1}{|t|}$ radians (worst case) for $|t| > .3$ GeV^2. A Monte Carlo study indicates that for the 12 counter recoil array, the probability of an inelastic recoil simulating geometrically an elastic recoil is about 10% for low mass N* resonances which are the worst cases.

BACKGROUND, TRIGGER AND ANALYSIS OF THE AUGUST TEST

The basic trigger for this experiment, as developed in the test, is a coincidence of a good tag with the appearance of at least 60% of the tagged photon energy in the lead glass stack outside the central hole. (In some events energy appears in the central shower counter due to double bremsstrahlung of the beam electron in the tagging radiator or to a photon radiated by an accidental beam electron. With a combination of pulse height and timing information, we can correct the incident energy for the double bremsstrahlung process.) This trigger initiates the digitization and recording of counter pulse areas and MWPC track information.

The analysis proceeded by locating showers in the lead glass and then attempting to match up the MWPC trajectories with the showers. Initial studies revealed that the biggest contribution to the high mass e^+e^- background came from one photon converting in each of two π^o decays. A detailed mapping was made of electron shower sharing between neighboring lead glass blocks. This mapping was used to calculate the mean shower position. For a π^o with one photon converting or for a charged hadron near a π^o shower, the mean shower position in general disagrees with that

predicted from the trajectory. Moreover, in many cases, the energy deposition pattern in the Pb-glass due to a π^o is incompatible with the pattern expected for a single photon or electron*. It was thus possible to reduce backgrounds by a factor of 6 above 2 GeV mass and obtain the clean J/ψ mass peak shown in Figure 1. Several planned refinements in the energy calibration and analysis will improve the mass resolution of the peak which is now about 200 MeV (FWHM).

The plot is based on most of our August data and corresponds to 5.7×10^9 good tags from 1.9×10^{16} 400 GeV protons or about 19 hours at 3×10^{12} with a ten second cycle.

While the number of events in the mass region around 3.1 GeV is not yet sufficient to answer the questions to which our proposed experiment is addressed, a study of the individual events in the peak reveals some interesting hints. For example, a $|t|$ distribution shows a peak of several events at $|t| < .1$. These are presumably coherent. This peak is consistent with our anticipated $|t|$ resolution of about .05 GeV^2 around $|t| = .1$. There is also one event at $|t| = 2.1$ GeV^2 which has all the attributes of an elastic event (no missing energy, no hadrometer signal, and a large signal in the appropriate recoil counter). Also intriguing is the one event in Figure 1 in the vicinity of the ψ' mass.

In conclusion, the test, using equipment and techniques nearly identical to that proposed here, has demonstrated that our apparatus, trigger and analysis are capable of a clean measurement of ψ and ψ' photoproduction. We feel this physics important enough to warrant approval of an early run.

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*We expect that with further work, this pattern recognition of shower data may prove useful in distinguishing π^o from γ in neutral decays of high mass states.

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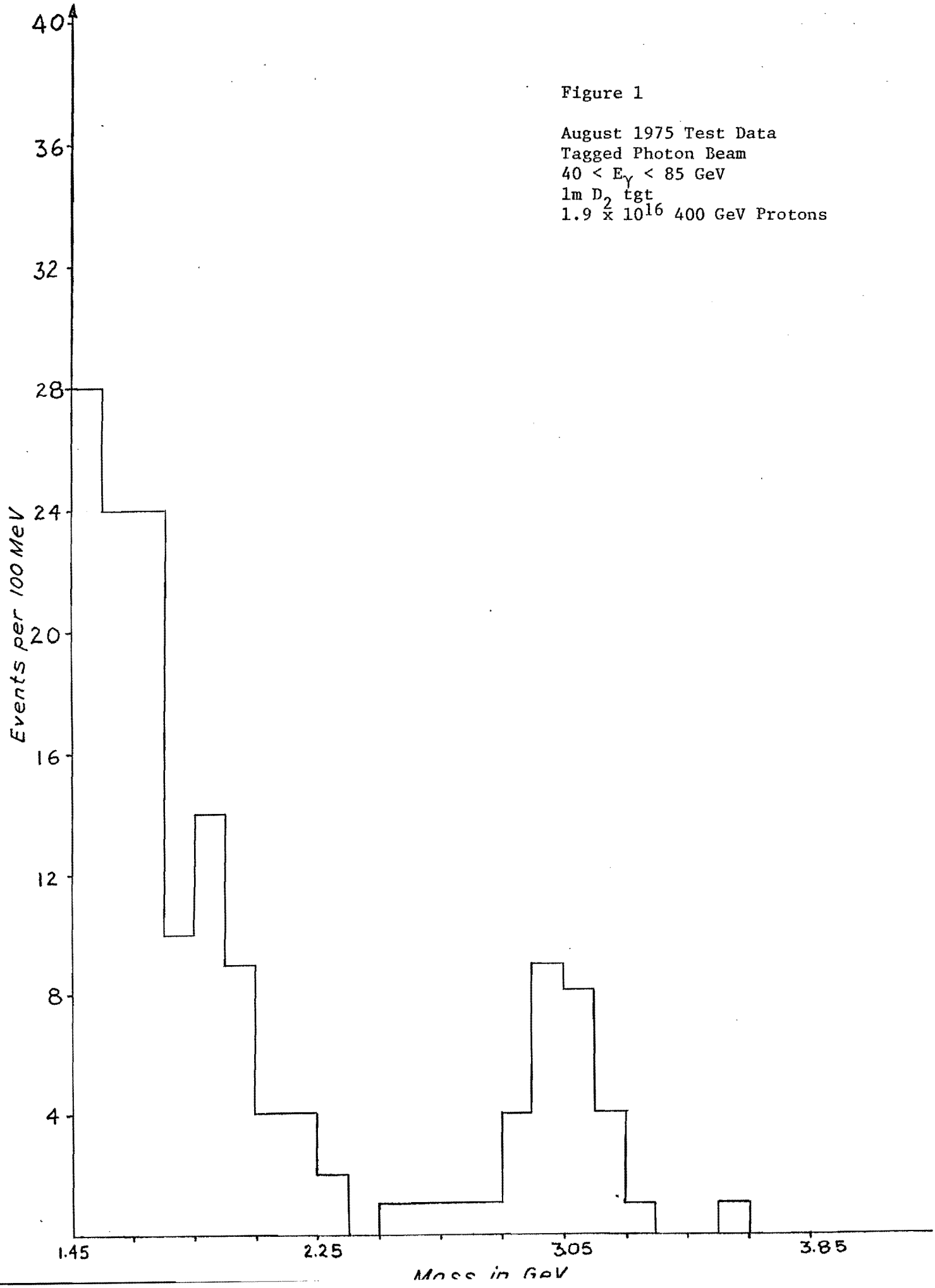

Figure 1

August 1975 Test Data
Tagged Photon Beam
$40 < E_\gamma < 85$ GeV
1m D_2 tgt
1.9×10^{16} 400 GeV Protons

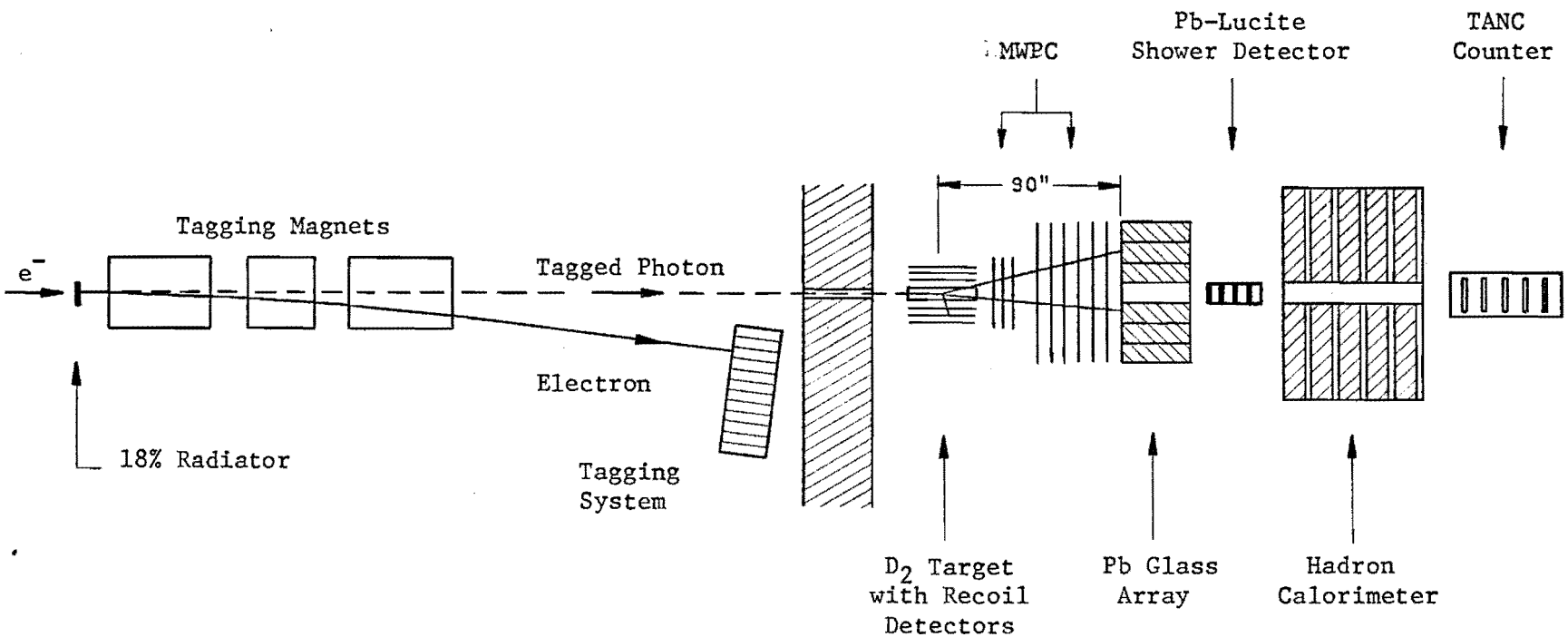
MWPC
Pb-Lucite
Shower Detector
TANC
Counter
90"
Tagging Magnets
e⁻
Tagged Photon
Electron
18% Radiator
Tagging
System
D2 Target
with Recoil
Detectors
Pb Glass
Array
Hadron
Calorimeter

Figure 2