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# Position Resolution of Pion Showers in ECAL

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## *Introduction*

This note describes an analysis of test beam and monte carlo data to determine the accuracy with which the barycenter of an isolated pion shower can be measured in ECAL. The work is motivated by $\tau$ physics , where one of the main problems is to distinguish the single pion decay of a $\tau$ from the $\rho$ decay mode followed by $\rho \rightarrow \pi \, \pi^0$ . It has been shown using SIMDST that a cut on the distance between track impact piont and ECAL cluster position is very efficient at separating the two decay modes. However the shower simulation in SIMDST is not expected to be highly accurate , and even the full GALEPH may not describe well the rare hadron showers in which there is a large energy deposit a long way from the shower center. Test beam data was taken at a large range of energies with pions in ECAL so it is possible to test these monte carlos against reality.

In order to measure $\mathrm{Sin}^2\theta_W$ to an accuracy of 0.002 by $\tau$ polarisation it is necessary to know the efficiency for reconstructing isolated pions to better than 4% in the energy range from a few GeV up to 45 Gev .

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## *The Test Beam*

### The Data

The data were taken in 1987 and '88 as part of the joint ECAL/HCAL tests which are described in more detail in Aleph note 88 − 010. Figure 1 shows the test beam setup and the coordinate system used. The pion beam hit the centre of an end cap petal at 30 degrees to the perpendicular so that it is parallel to the projective towers. In this region of the petal the pad size is 10 * 11 mrad ( or 30 * 33 mm ), which is a bit smaller than average. No use has been made of the HCAL part of the events except to plot some energy distributions and check that they look reasonable . Pion beam data at 3 , 5 , 7 , 10 , 20 and 30 GeV has been used.

### Analysis of the Wire Chambers

The hit position was measured with two wire chambers ( the Saclay chambers ) which each had a resolution of 1 mm , so their error can be neglected. The beam particles travel almost parallel to the beam axis , so their position in the two chambers is highly correlated. A cut on this correlation was used to reject most noise in the chambers.

### Analysis of the Calorimeter

Clusters were formed using the algorithm from JULIA with a cluster starting threshold of 60 MeV and a continuation threshold of 30 MeV. The starting threshold has to be low in order to be sure of including minimum ionising particles. Clusters were sorted into the following types ;

- a cluster consisting of just one storey is assumed to be due to noise so it is called **bad**
- the cluster nearest to the beam impact point is called the **main** cluster
- all others were called **satellite** clusters

The energies in the 4 towers nearest to the hit position were also summed without any threshold cut. In order to insure that there was really one and only one beam particle hitting ECAL in each event the following cuts were made:

1. The 4 − tower − sum in stack 1 must be greater than 30 MeV. The most probable energy deposit of a non − interacing pion in stack 1 is 65 MeV. This cut will remove less than 4 % of good events and virtually all events in which a beam particle did not really hit the 4 tower region.

2. If there is a satellite cluster which has energy in all three stacks ( ie. it is penetrating ) then the event is rejected because this satellite is probably a second beam particle.

3. If one of the satellites has more energy than the main cluster the event is rejected for the same reason as above.

The percentage of events failing these cuts is shown as a function of energy in figure 2. This shows that the quality of the beam is better at high energies , but even at 3 GeV only 20% of events are rejected by these cuts . In events which pass , the shower energy and barycenter is formed from the sum of all good clusters. The mean number of clusters per event increases slightly with energy from 1.95 at 3 GeV to 2.17 at 30 GeV . About 60% of events consist of just one cluster.

With electromagnetic showers it is possible to make a correction to the shower position which removes the bias due to the pad size [ Aleph note 88 − 67 ]. No correction of this sort has been used in this analysis and it is doubtful whether such a correction is possible for hadron showers because they do not have a well defined shape.

## Results

Figure 3 shows a typical distribution of the distance in mm between the stack 1 barycenter and the beam hit position. There is no significant difference between the X and Y projections of this distance. The main peak has a width of 12 mm which is just due to the pad size , but there are long tails which contain a few percent of the events.

THE MAIN PEAK can be fitted with a Gaussian up to 2 $\sigma$ . Figure 4 shows how the value of $\sigma$ varies with energy and with the number of stacks used to form the barycenter. The smooth curves in figure 4 are fits with the function $\sigma(\text{energy}) = Q + R * \exp(-\text{energy}/T)$ . The parameters Q , R and T are;

| | Q ( mm ) | R ( mm ) | T ( GeV ) |
|---|---|---|---|
| Stack 1 only | 11.4 | 3.6 | 7.6 |
| Stacks 1 and 2 | 9.4 | 10.4 | 8.5 |
| All three stacks | 8.2 | 19.7 | 8.3 |

THE TAILS dominate the barycenter resolution beyond 2 $\sigma$ . They are due to showers in which a hadron is produced at a large angle to the initial pion. This hadron may travel several cm from the shower axis before depositing its energy. Figues 5a,5b and 5c show the same events as figure 3 , but divided into three classes according to the depth of the start of the shower;

- If 4−tower−sum( stack 1 ) > 300 MeV then the shower starts in stack 1
- elseif 4−tower−sum( stack 2 ) > 500 MeV then the shower starts in stack 2
- else the shower starts in stack 3 or later

Not surprisingly , a shower which starts in stack 1 has a broader barycenter resolution than a non−interacting pion. It is a bit more surprising that the stack 1 barycenter is affected by whether the pion interacts in stack 2. This must be caused by hadrons being scattered backwards from stack 2 into stack 1.

Figures 6 , 7 and 8 show how the effect of a cut on the barycenter displacement varies with energy and with the number of stacks used to form the barycenter. It is a cut of this sort which will probably be used to select the $\tau$ decay mode. When only stack 1 is used the fraction of events in the tail is low and has little dependence on energy. For example a cut at 67 mm ( 22 mRad ) will accept about 95% of single pions .

If one includes stack 2 in the barycenter measurement most of the energy of the $\pi^0$ ( in $\rho \rightarrow \pi \pi^0$ ) will contribute to the barycenter. This may improve the sensitivity of the barycenter cut to the $\tau$ decay mode. However the acceptance would vary from 92% to 97% with energy .

Using stack 3 as well gives no advantage at all.

## *GALEPH Data*

Two thousand events were generated with GALEPH 220 at each of the test beam energies. The events were single $\pi^-$ fired into the same region of an endcap module as was used in the test beam. They were analysed in exactly the same way as the test beam data except that the true position of the pion was calculated from the 'VERT' bank. The cuts used to clean up the test beam were also applied to this data and the percentage of events failing these cuts has been added to figure 2 by hand. This shows that the cut requiring at least the energy of a mip in stack 1 is removing some good events at low energies , but only 5% of GALEPH events are cut at 3 GeV . The mean number of clusters per event was 1.66 at 3 GeV and 2.04 at 30 GeV. So GALEPH is generating slightly too few clusters .

### Results

The general features of the position resolution in Galeph are similar to the test beam results. For example figure 9 is the GALEPH equivalent to figure 5. The important quantity is the fraction of events failing a cut on barycenter displacement and this has been added by hand to figures 6 , 7 and 8 . There is a serious disagreement between GALEPH and the test beam data about the fraction of events which are in the tail of the barycenter distribution. The GALEPH tails are too low by almost a factor 2 at all energies , whichever stacks are used to make the barycenter. I have tried switching off the shower parameterisation in GALEPH with the option RUNC 'ECAL' 0 0 0 0 0 0 . Two thousand events were generated at 5 and 20 GeV with this option. The effect is to slightly reduce the fraction of events in the tails and reduce the number of satellites.

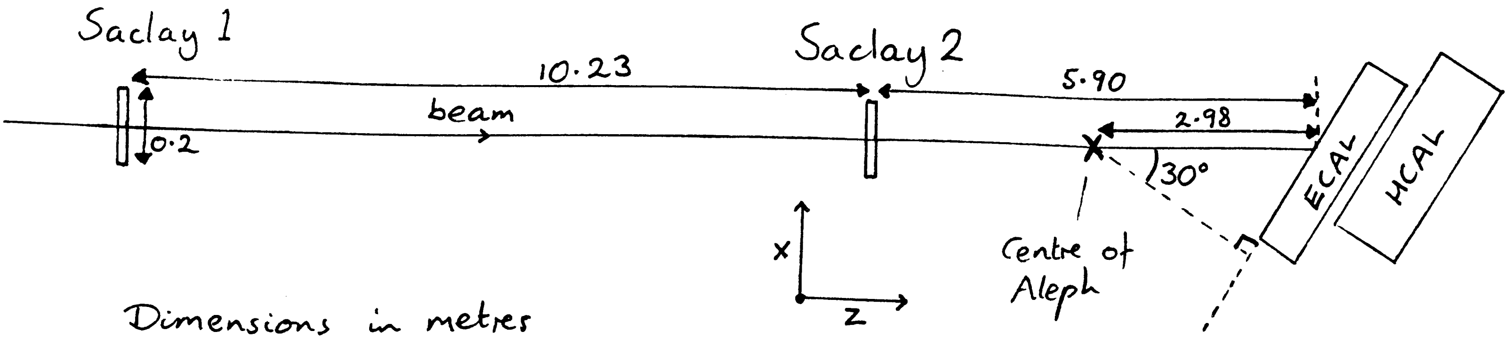
## *Energy deposit in stack 1*

An alternative method which has been suggested to distinguish the $\pi$ and $\rho$ decay modes is to cut on the energy deposited in stack 1. Most pions will pass through stack 1 without interacting. A cut on the stack 1 energy will efficiently reject events containing photons , at the expense of losing the few pions which do interact. This cut has been tried on test beam and GALEPH data with the results shown in figure 10. There is rather close agreement , providing that the cut is chosen high enough to be well above the Landau spectrum of energy deposited by non − interacting pions ( eg. 600 MeV ) . If the cut is lower there is not good agreement because the Landau spectrum is not well simulated by GALEPH.

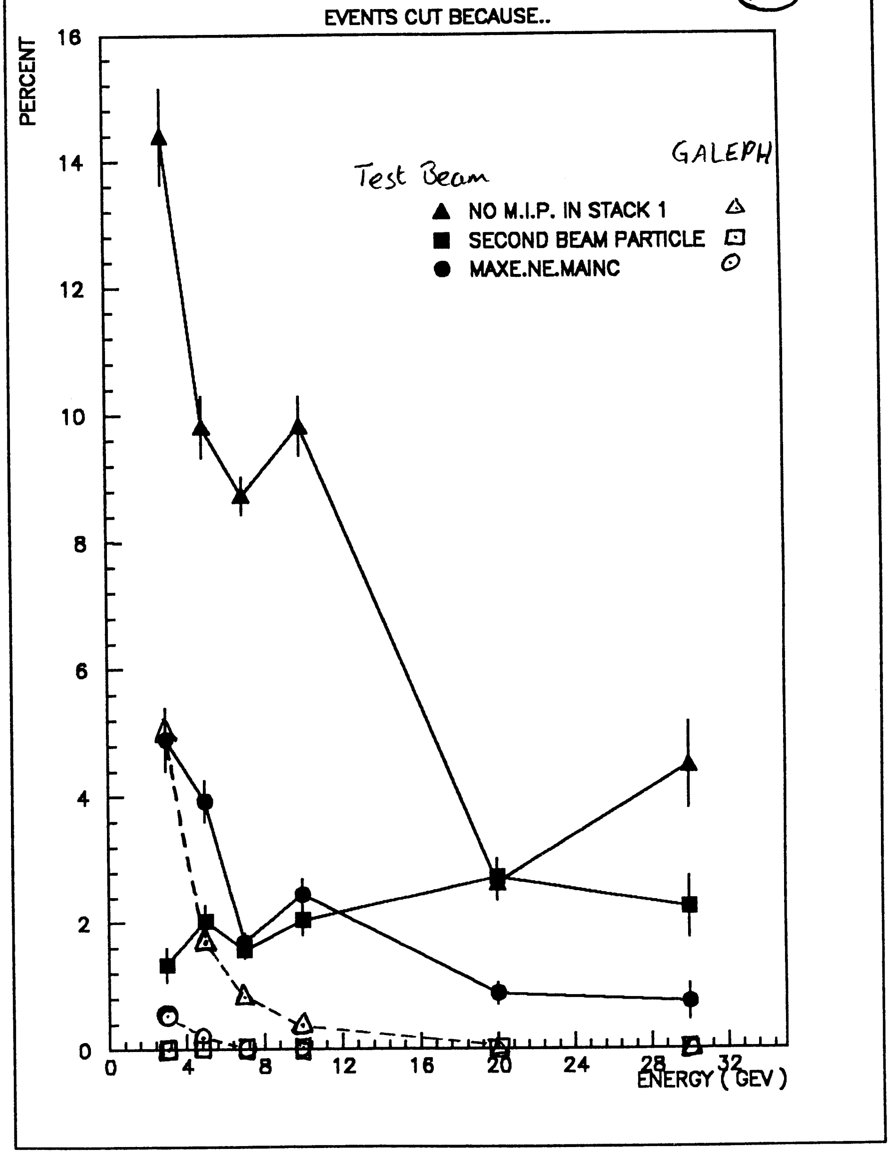
## *CONCLUSIONS*

The position resolution of pion showers in ECAL can be determined from test beam data covering the range of energies needed for $\tau$ physics. A knowlege of the single pion acceptance to a level of 2 % looks possible to achieve . At present there are differences in acceptance of up to 6% between test beam and GALEPH for a cut which might be used in a $\tau$ analysis ( eg. a cut at 67mm on the stacks 1 + 2 barycenter ) . This is good enough for the '89 data but not for a high precision measurement of the $\tau$ polarisation .

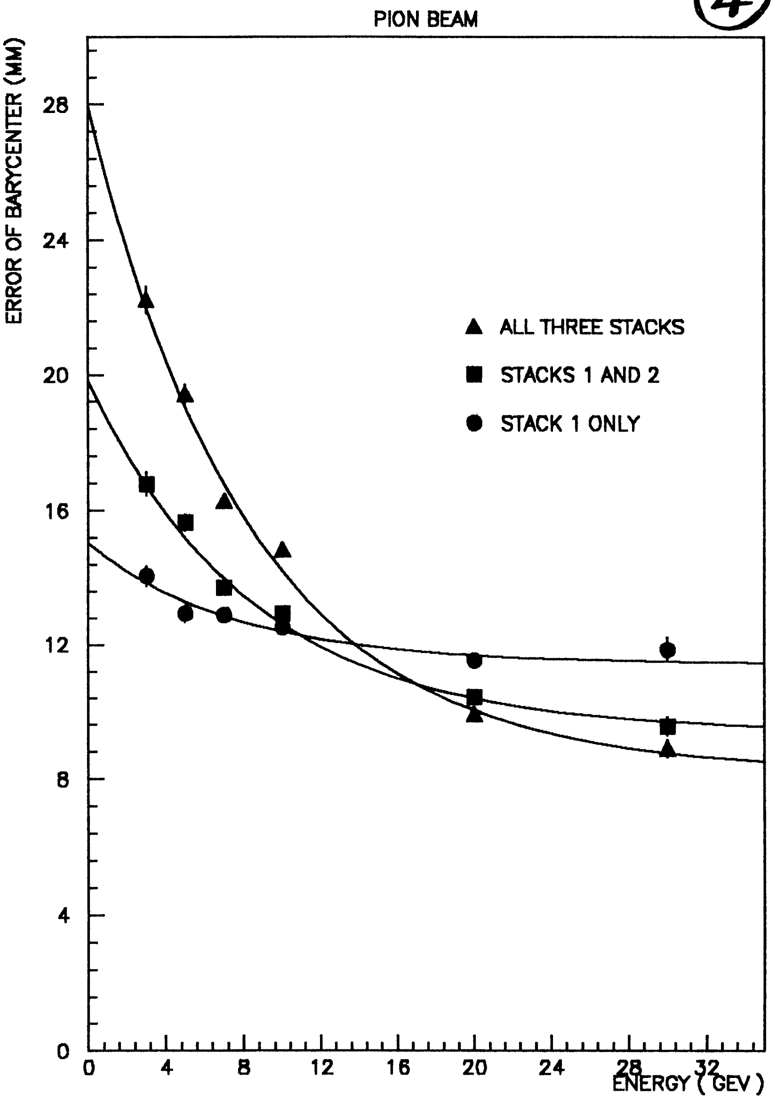
①


Saclay 1
10.23
Saclay 2
5.90
2.98
beam
0.2
30°
x
z
Centre of Aleph
ECAL
HCAL
Dimensions in metres

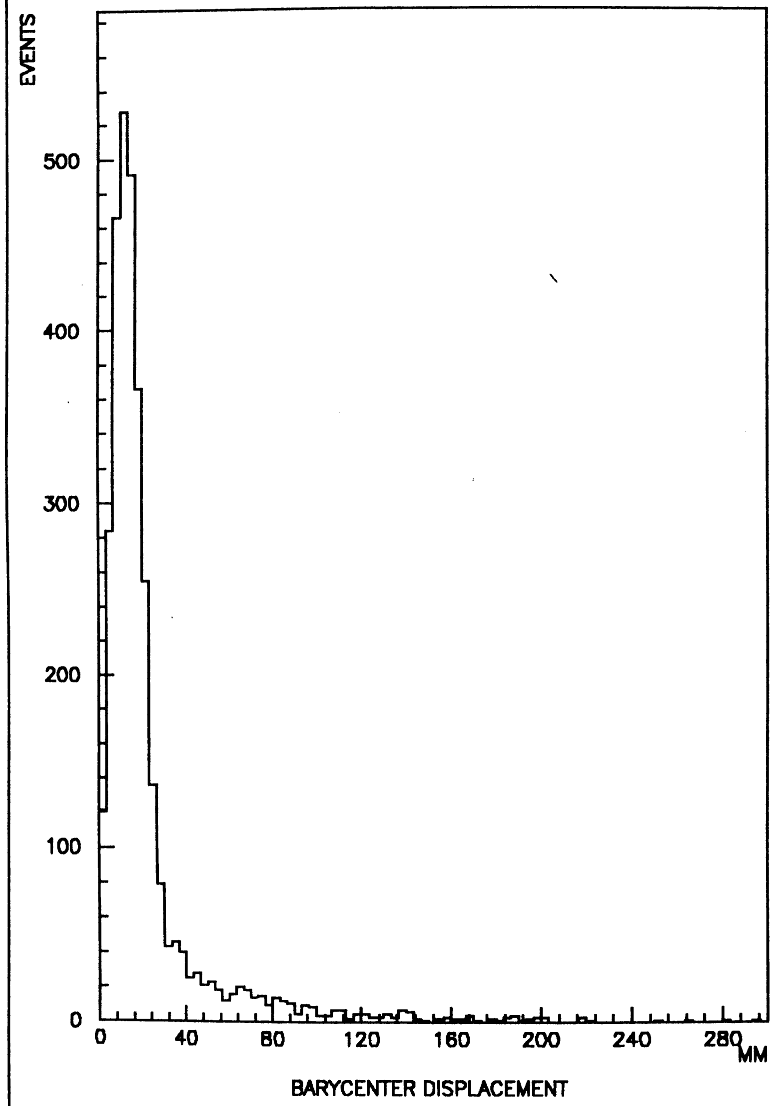
②


EVENTS CUT BECAUSE..
PERCENT
16
14
12
10
8
6
4
2
0
0
4
8
12
16
20
24
28
32
ENERGY ( GEV )
Test Beam
GALEPH
▲ NO M.I.P. IN STACK 1 △
■ SECOND BEAM PARTICLE □
● MAXE.NE.MAINC ○

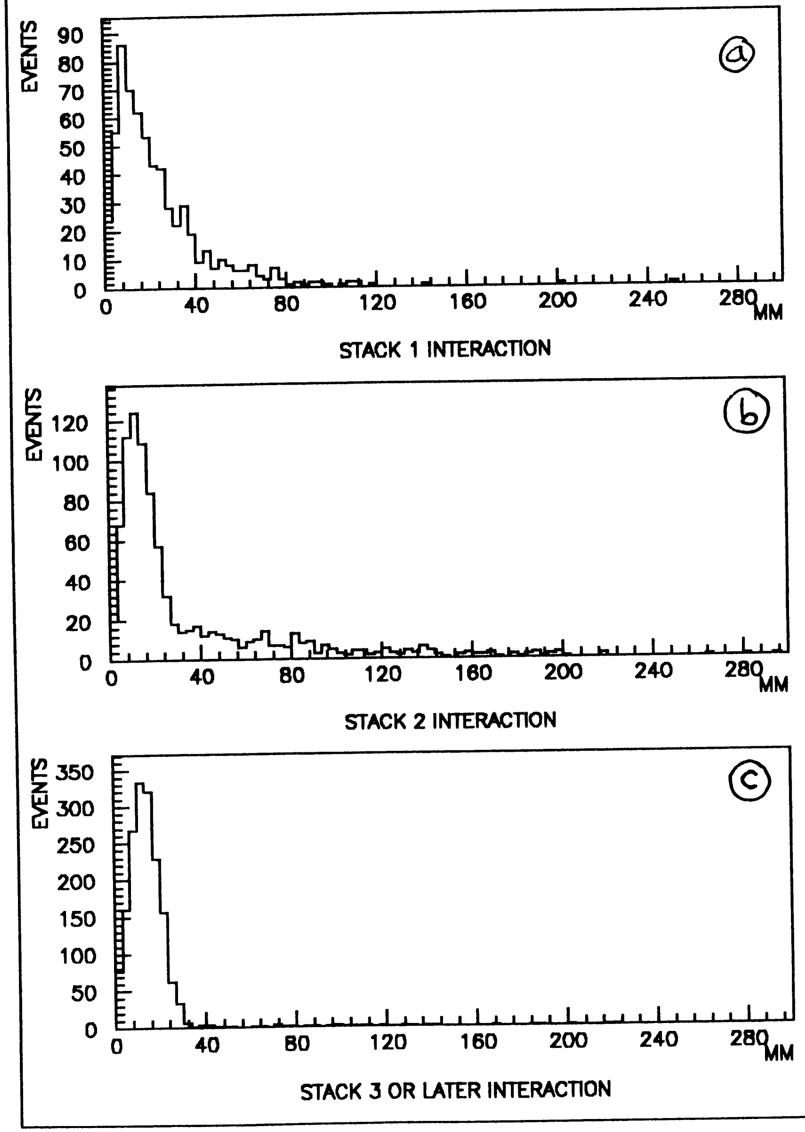
④


PION BEAM
ERROR OF BARYCENTER (MM)
0
4
8
12
16
20
24
28
0
4
8
12
16
20
24
28
32
ENERGY ( GEV )
▲ ALL THREE STACKS
■ STACKS 1 AND 2
● STACK 1 ONLY

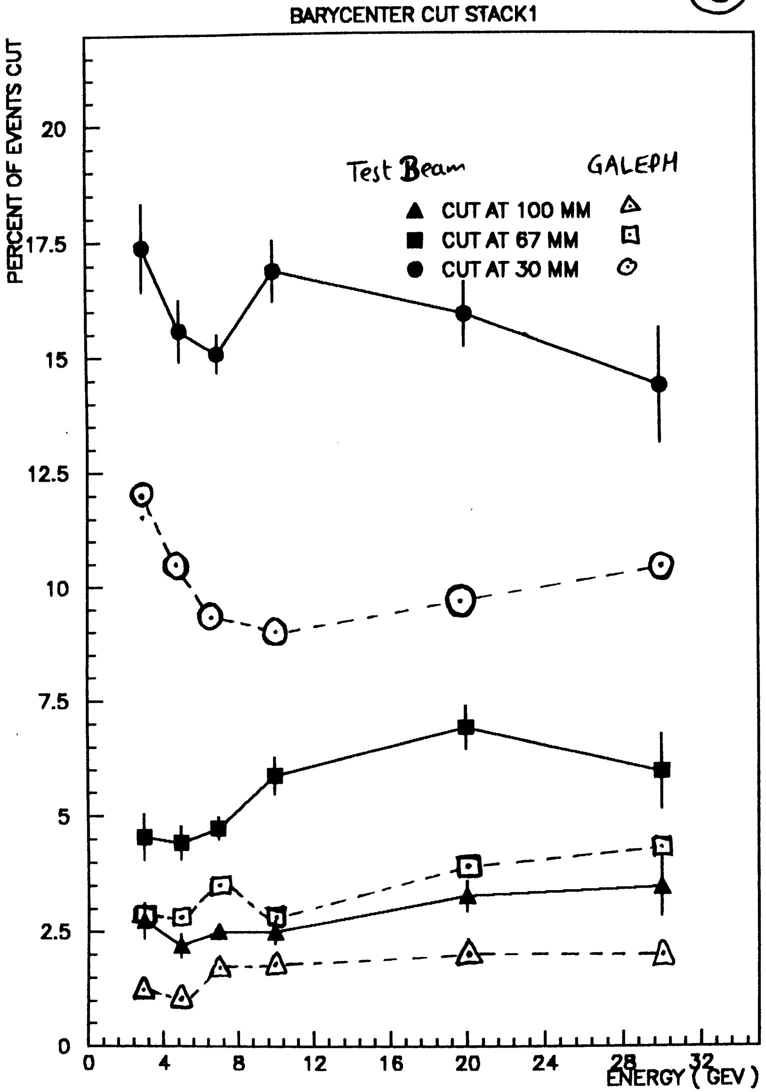
20 GeV $\pi^-$ Test Beam ③



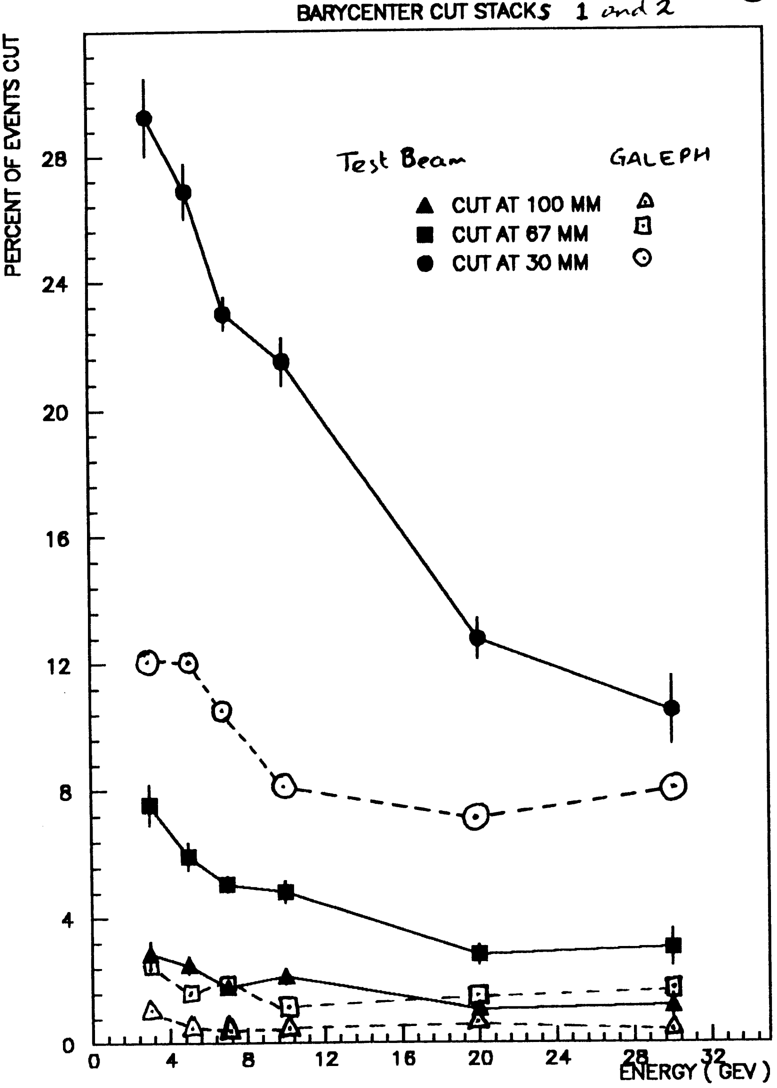
20 GeV $\pi^-$ Test Beam ⑤



⑥


BARYCENTER CUT STACK1
PERCENT OF EVENTS CUT
0
2.5
5
7.5
10
12.5
15
17.5
20
Test Beam
GALEPH
▲ CUT AT 100 MM △
■ CUT AT 67 MM ☐
● CUT AT 30 MM ⊙
0
4
8
12
16
20
24
28
32
ENERGY ( GEV )

⑦


BARYCENTER CUT STACKS 1 and 2
PERCENT OF EVENTS CUT
0
4
8
12
16
20
24
28
Test Beam
GALEPH
▲ CUT AT 100 MM △
■ CUT AT 67 MM ☐
● CUT AT 30 MM ⊙
0
4
8
12
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20
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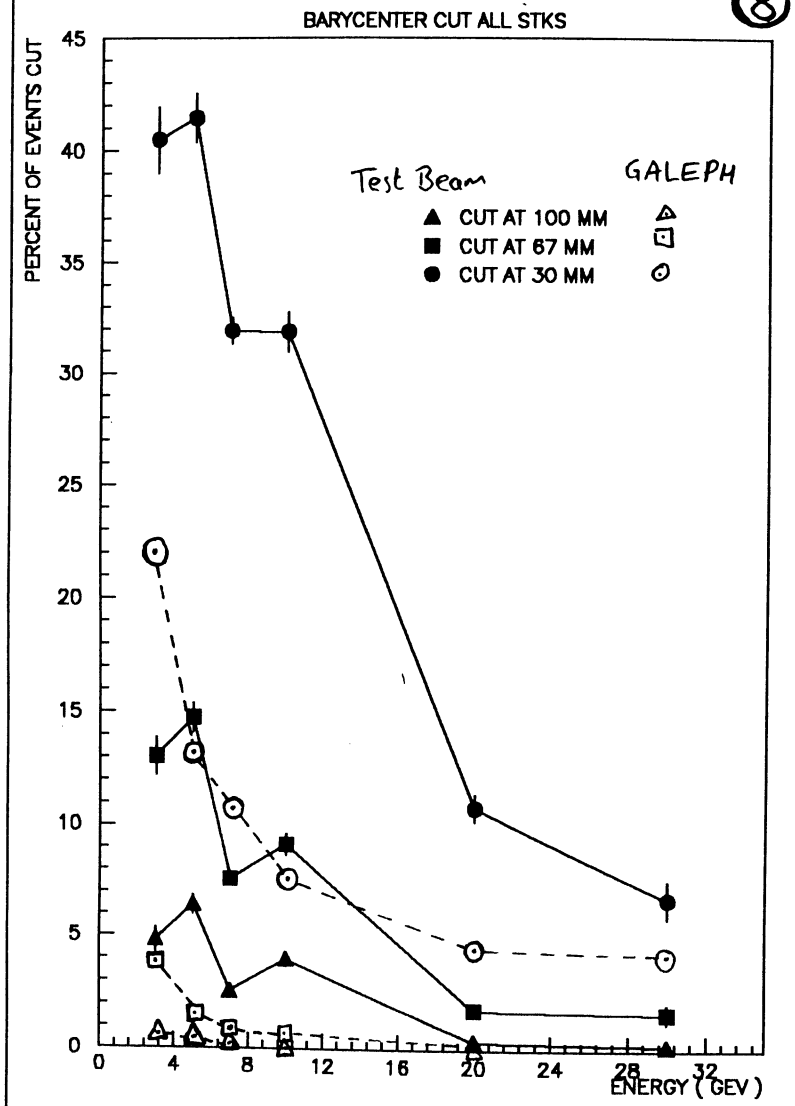
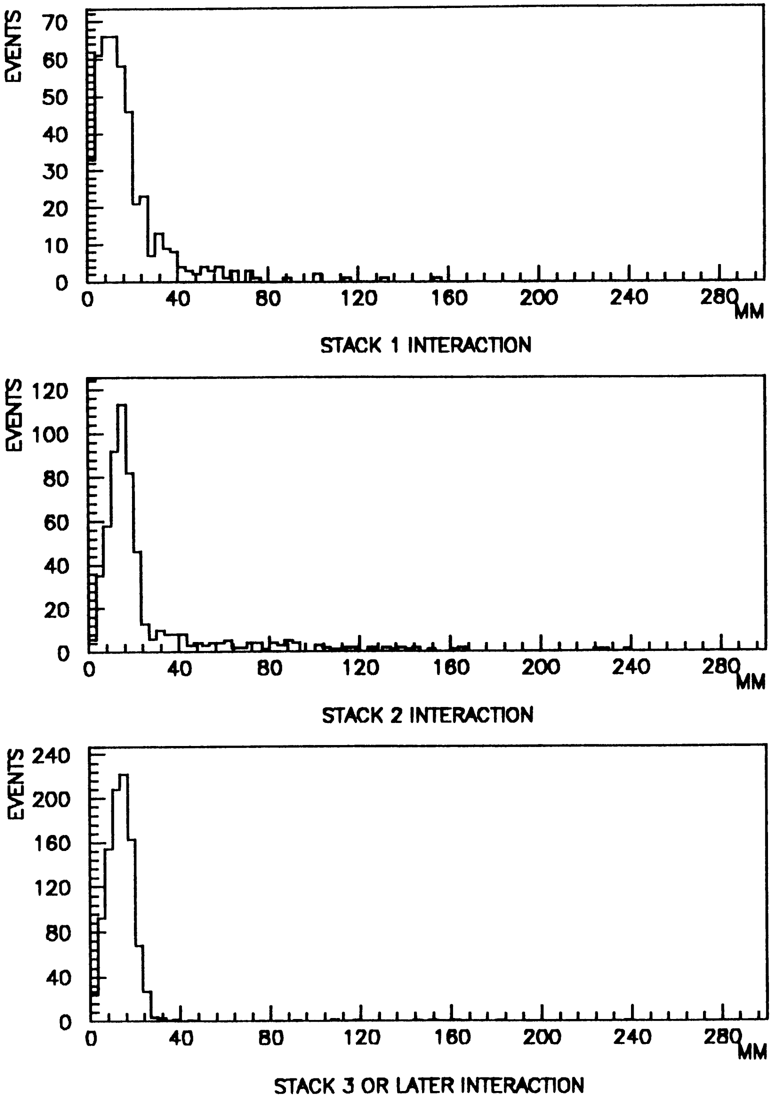
28
32
ENERGY ( GEV )

⑧

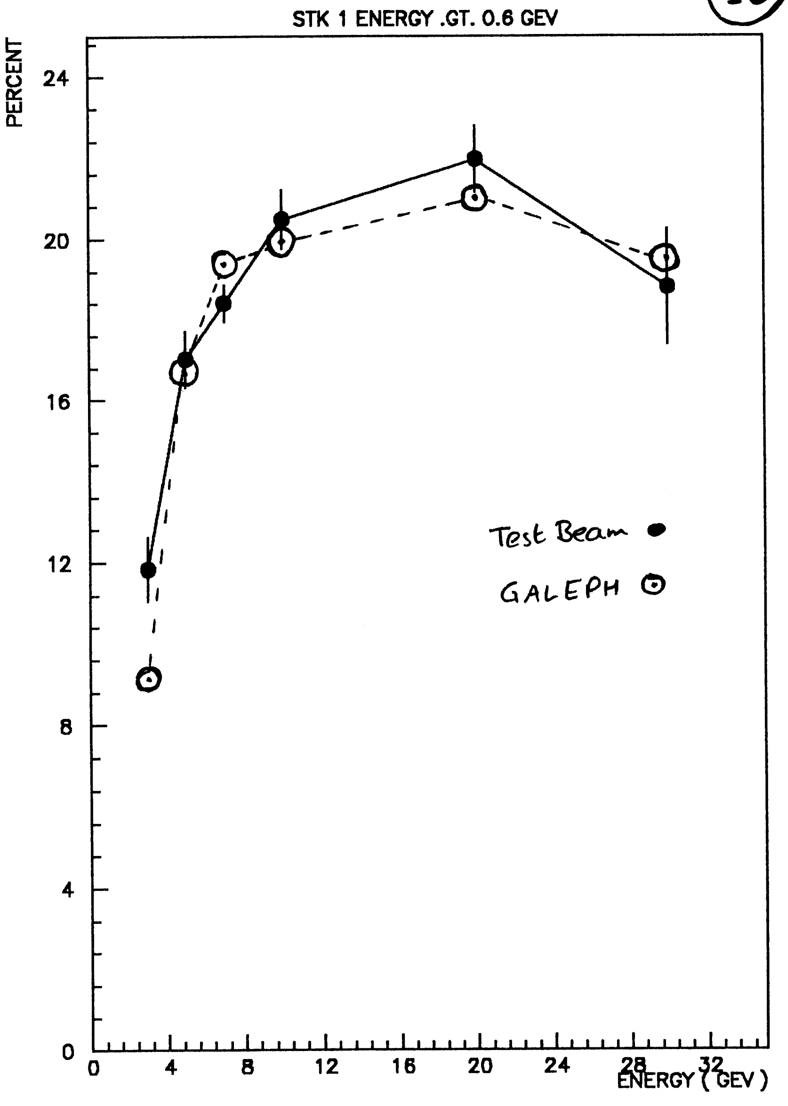

BARYCENTER CUT ALL STKS

⑨

20 GeV π⁻ GALEPH



⑩


STK 1 ENERGY .GT. 0.6 GEV
PERCENT
0
4
8
12
16
20
24
0
4
8
12
16
20
24
28
32
ENERGY ( GEV )
Test Beam ●
GALEPH ⊙