STAR Note 245
Version 1.0
March 27, 1996

A Study Of Effects of ϕ Cracks in the STAR EMC

K. Krueger, D. Underwood and T. LeCompte
Argonne National Laboratory

Abstract

The gaps between the EMC modules in STAR contribute to the background to the direct gamma signal used in measuring the gluon structure functions as well as to the ability of STAR to measure jet energies. The study of this problem has been broken down into several individual substudies, some more precise than others. We have done these studies primarily for pp collisions at $\sqrt{s}$=200 GeV, with some at $\sqrt{s}$ = 1800 GeV for comparison with an existing experiment, CDF. We find that the proposed gap sizes do not pose significant problems for direct photons with E_T above 8 GeV/c or jets at STAR.

1 Introduction

The gluon distribution in the x_{BJ} variable in nuclei may be different from the distribution in free nucleons such as the proton. Such a difference is known to exist for quarks. Understanding this distribution is important for understanding nucleus-nucleus collisions which could produce a quark gluon plasma.

Additionally, the gluons in a proton may carry a large fraction of the proton's angular momentum. The measurement of the magnitude and distribution of angular momentum carried by gluons is an important element in understanding the structure of nucleons.

The additional information from measuring the recoil jet as well as the direct photon allows full reconstruction of the kinematics of the incident partons. p_z of the gamma-jet system is simply $\sqrt{s}(x_1 - x_2)/2$ and the mass of the gamma-jet system is $\sqrt{sx_1x_2}$.

The primary method of measuring the distribution of gluons is by the quark-gluon to quark-photon Compton scattering process. The gamma rays emanating from this process are called direct photons, to distinguish them from decay products. The primary background to this process is decay gammas from π^0's and η's. The cross section for π^0's at a given p_T is typically 5 times the direct gamma cross section, although there is some p_T and x_T dependence.

There are two ways in which the background is reduced. First, there is a kinematic effect. The majority of gammas from π^0 decay carry about half the π^0 momentum. Gammas from decays which are asymmetric in the laboratory frame may carry essentially all the π^0 momentum. As the p_T of the gamma candidate increases, the background fraction from π^0 decay decreases because the π^0 spectrum falls more steeply with p_T. The signal to background ratio depends on the details of the fall-off of the π^0 and direct gamma cross sections with p_T, which are quite different at $\sqrt{s} = 200$ GeV and 1800 GeV.

Second, we look for the second gamma from π^0 or η decays in our detector, and eliminate those events in which it is found. This is not particularly straight-forward for several reasons.

For decays that are approximately symmetric in the lab frame, the two gammas are close together, roughly 2 cm, in the STAR detector for π^0 p_T above about 25 GeV. This is not so different from the typical shower size of roughly 1 cm (there are substantial fluctuations in this variable as well). We can either do detailed fits to the energy distribution in 2 dimensions, or something equivalent such as comparing the χ^2 of the test hypotheses of one and two photons, using shower shapes based on test beam data.

For asymmetric decays, the high energy gamma is a serious direct photon candidate, and the low energy gamma is hard to detect. We believe we can detect these in the high granularity shower maximum detector down to roughly 300 to 500 MeV.

In all cases, the second gamma is lost if it is in the crack between calorimeter modules, and is lost or mis-measured if it is inside the detector but near the edge of the detector. This could be a serious source of background.

2 Method of study

2.1 Part I

We have a Monte Carlo program that simulates π^0 decays going towards a 10x10 arrangement of calorimeter towers to simulate a portion of the real STAR EMC. The problem we consider is this: we want to identify direct gammas. We want these gammas to be away from the cracks to ensure proper energy measurement. If we require the direct gamma to be close to the center of a tower we also decrease the π^0 background: if a gamma from π^0 decay is near the center of the tower the other gamma will most likely also be in that tower and not in the crack. The opening angle for η is so much larger that this does not apply to them - the other photon is often in an entirely different tower. The STAR towers simulated were 24 cm by 23 cm with a 1 cm crack, equivalent to .005 radian in phi. CDF towers are larger: .26 radians in phi. CDF makes a fiducial cut of .045 radians on each side of the crack.

The Monte Carlo program does the following. It creates π^0's at a certain momentum, lets them decay and then finds out where they hit in the EMC. Each gamma is tagged as to where it hits. There are three possibilities 1) towards the center of the tower, 2) within .5cm of the edge of the tower or 3) in the crack between towers. The .5cm fiducial cut is arbitrary at this point. The cracks are assumed to be 1cm in width. The good central region of the tower is varied in size to see the effects on background. The size of the central region where good gamma candidates are required to be then is related to the efficiency (or acceptance). If you require that a good direct gamma candidate be in the central 50% of the tower your efficiency then is just 50%. Here is a table of results. The first row of the table can be read like this. The direct gamma candidate is required to be in the central 68% of a tower, as noted in column one. If this were actually one of a pair of gammas from a decay then 6.2% of the second gammas were lost in the crack, column 2, and 12.5% of the second gammas were either in the crack or within .5 cm of the crack, column 3.

Decay particle π^0			
eff.	lost in crack	lost in crack and fiducial cut	Momentum
68%	6.2%	12.5%	10GeV
52%	4.9%	9.7%	
36%	2.7%	5.2%	
68%	1.9%	4.4%	20GeV
Decay particle η			
68%	5.7%	11.7%	10GeV
48%	5.%	10%	
12%	6.6%	11%	
68%	7.0%	13%	20GeV

Conclusion: The background of gammas from π^0 decay can be reduced, at a cost of lower efficiency. Further studies, detailed in part II, indicate that misidentifying 10-20% of gammas from π^0 decays as direct gammas will still result in a reasonably pure direct gamma signal.

2.2 Part II

We wrote a Monte Carlo program to find the ratio of direct gammas to decay gammas as a function of transverse momentum. The differential cross sections were simulated using fits from Star Note SN077 and some additional fits at high p_T where needed to more closely match real data. Note that no cuts of any kind were applied to this data. This is just the relative spectra of direct gammas and decay gammas from π^0's. In practice many of the gammas from π^0 decays will be eliminated by identifying the second gamma.

$\sqrt{s} = 200$ GeV	
p_T (GeV)	number of direct gammas/decay gammas
8	.59
9	.78
10	.93
11	1.0
12	1.1
13	1.0
14	.89
15	.80
16	.70
17	.68
18	.90
19	1.1
20	1.0
21	1.2
22	1.3
23	3.3
24	2.7
25	3.7
26	3.7

Statistical errors are not provided here, but they do exist and grow with p_T.

The fact that the ratio goes up and down and then up again may or may not be seen in real data. This dip is caused by the fact that the direct gamma spectra has a different variation with p_T than the spectra of gammas from π^0 decay so that while both distributions decrease with p_T they do so at different rates. There is significant uncertainty in the total cross-sections, around 20%, which would be the dominating uncertainty in the above numbers.

For comparison we changed the fit parameters to match the cross sections at

$\sqrt{s} = 1800$ GeV to compare with CDF results. In the table below we give the ratio of photons/background as derived from Table I in *Phys.Rev.Lett.* **73**,2662(1994) and the ratio of direct gammas to decay gammas from π^0 using the Monte Carlo.

$\sqrt{s} = 1800$ GeV		
	CDF Data	Monte Carlo
p_T (GeV)	photons/background	direct gamma/decay gammas
12.3	.29	.13
17	.86	.34
19	1.1	.50
21	1.1	.65
23	1.23	1.1
25	1.63	1.2
27	2.05	1.4

The comparison between the numbers in the second and third column above show the same general trend of decreasing background with increasing p_T. The numbers would not be expected to compare exactly because CDF has built into its trigger an isolation cut on the direct gamma which would eliminate some of the background. Also it is not clear whether the numbers in their table are the actual number of triggers or whether software cuts were applied afterward to eliminate some of the π^0. We have not included η in the Monte Carlo. η's are easier to identify because of the larger opening angle and the branching ratio to two gammas is about 40% so we would expect that they would make up a smaller portion of the background.

2.3 Part III

In this section we estimate the background added to the direct gamma signal from π^0 decays after identifying as many of the π^0 as possible. We ran a Monte Carlo as above but this time eliminated gammas from identifiable π^0. We assumed that if two gammas hit in the same tower that shower max could identify the fact that there were two. We also assumed that any gamma with energy less than 300 MeV could not be identified.

With the above assumptions on the order of 80% of gammas coming from π^0 decays can be identified and eliminated. For a crack size of 1cm. the backgrounds that can not be eliminated come from the following sources:

- Soft gammas: 83%
- One gamma in crack: 15%
- One gamma near crack losing energy in crack: 2.5%

For a crack size of 1.5 cm the backgrounds that can not be eliminated come from the following sources:

- Soft gammas: 77%
- One gamma in crack: 21%
- One gamma near crack losing energy in crack: 2.2%

Interpolating between these two values for the nominal 1.4 cm crack, we get:

- Soft gammas: 78%
- One gamma in crack: 20%
- One gamma near crack losing energy in crack: 2.3%

After eliminating all gammas that are associated with decays that we can identify we find a favorable background to signal ratio for direct gammas with $p_t \geq 8$ GeV as shown in Figure 1. In Figure 2 we show the ratio $(E_1 - E_2)/(E_1 + E_2)$ where E_1 is the energy of the hard photon and E_2 is the energy of the softer photon.

Conclusion: Cracks are not our biggest problem with γ/π^0 separation. Soft photons from asymmetric decays are our biggest problem.

3 Jets

Typical jet cone sizes used are $R(\equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}) \leq 1.0$, 0.7, 0.5 and 0.4. The smallest of these has 8 ϕ cracks in a jet; the largest 20. Because these are fairly large numbers, we can treat the effects of cracks as just a statistical loss of energy - basically, they alter the sampling fraction of the calorimeter. 1.0-1.5 cm cracks cause a 4-7% loss in electromagnetic energy of a jet. Typically, we will be interested in jets with EM fractions around 60%, so this is a 2.6-3.9% loss in the total energy of the jet.

A correction will need to be applied to these jets for this missing energy. Ideally, this correction will completely compensate for the cracks. Of course, this is not the case: information is missing when particles are not detected. Let us consider the *worst* case: the uncertainty on the jet energy is the size of the average energy loss: 2.6-3.9%. This can be compared to the overall uncertainty of about 30% per jet. An additional 3.9% uncertainty, added in quadrature, changes the overall uncertainty from 30.0% $\rightarrow$ 30.25%: a relative change of less than 1%.

It is perhaps worth pointing out that the energy losses to n's and K_L^0's are around 8%, and out of cone corrections are typically 15%, depending on cone size. Both of these are substantially larger than the energy losses due to cracks.

There are some concern about long tails: should a leading π^0 be lost or mismeasured because of a crack, the entire jet will be badly measured. However, should there be a leading neutron or K_L^0, the jet will also be badly measured, and should there be a large fluctuation in the out of cone energy, the jet will also be badly measured. All of these sources of energy loss can have long tails; that's simply part of the physics of jets.

4 Conclusions

Soft gammas that are associated with hard gammas from π^0 decay are the biggest source of direct photon background. Changing the crack size between 1 cm. and 1.5 cm. does not substantially change this background level, and makes only a small change to acceptance.

The proposed crack size only minimally degrades jets: less than a percent relative increase in energy resolution.

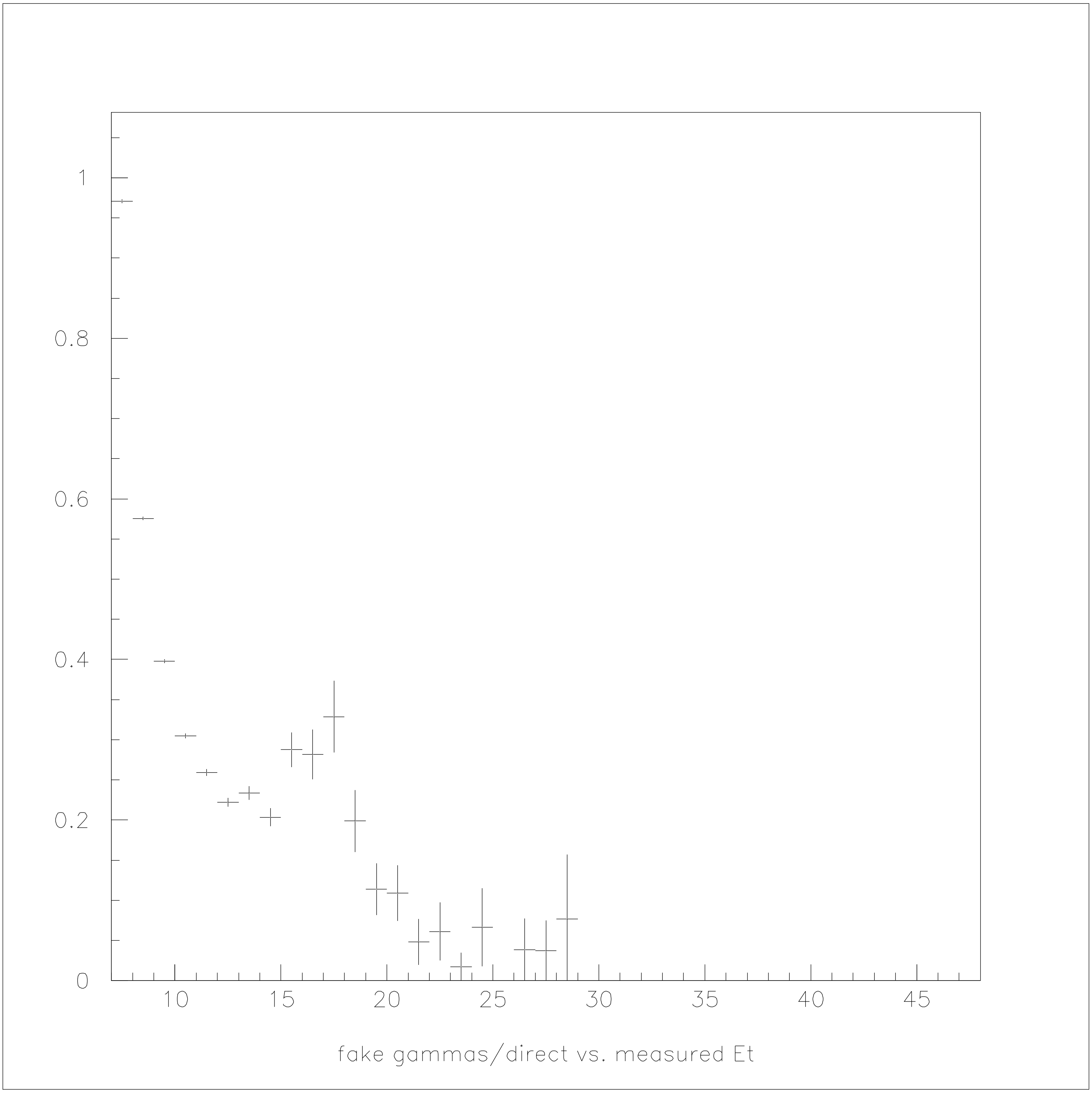

Figure 1: Background (π^0) to signal (γ) ratio for direct photons of $E_T \geq 8$ GeV

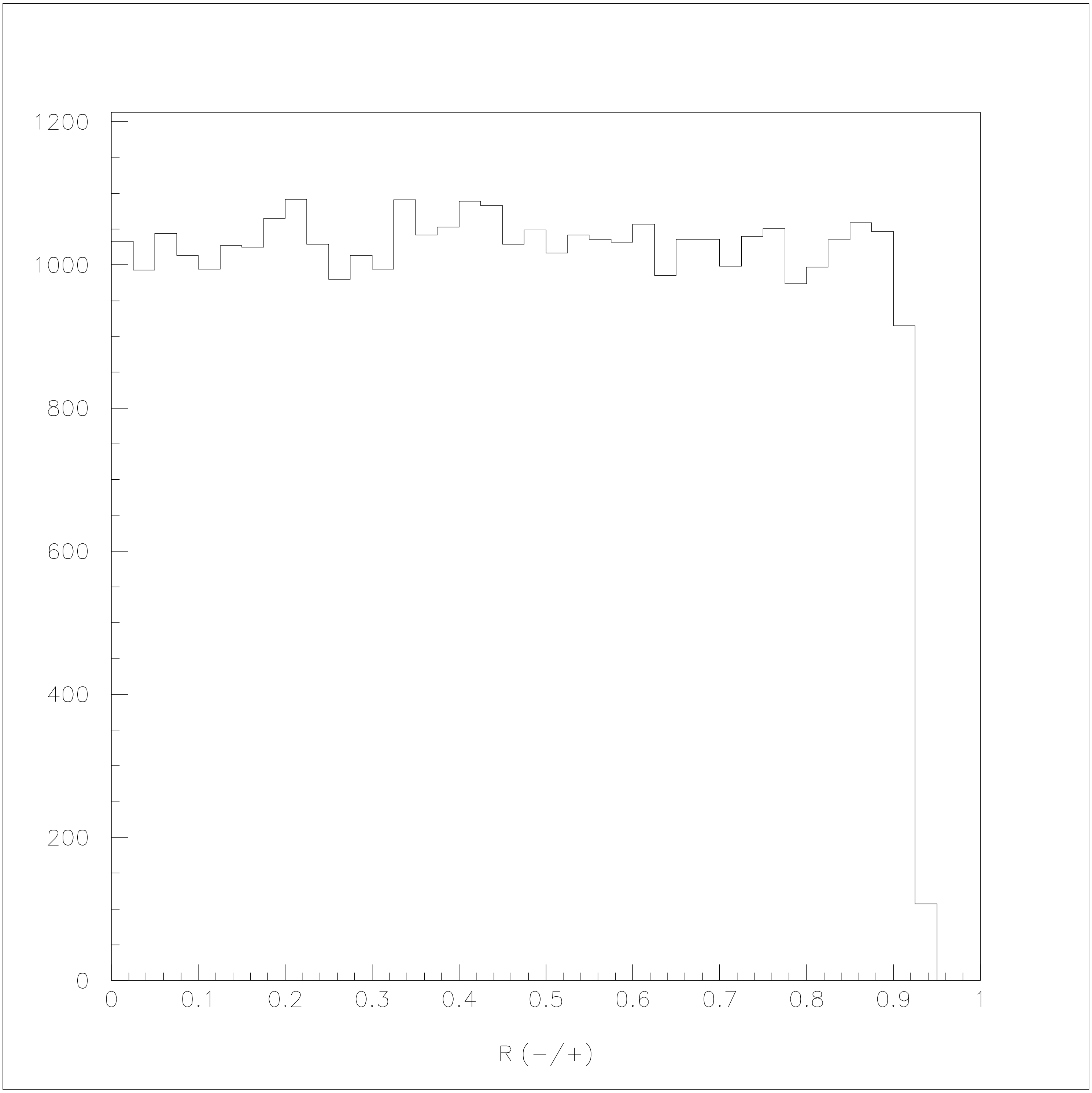

Figure 2: π^0 energy asymmetry $(E_1 - E_2)/(E_1 + E_2)$