MEASUREMENT OF BEAM POLARIZATION BY "PRIMAKOFF POLARIMETER"

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Abstract

Polarization of newly constructed polarized proton beam at Fermilab has been measured with a "Primakoff polarimeter" for the first time. The preliminary result showed the beam was polarized as designed and the Primakoff polarimeter was proved to be useful for high energy polarized proton and anti-proton beam.

It is not trivial to measure the proton polarization at high energy above 100 GeV, because the analyzing power of the proton-proton elastic scattering, which has been widely used for low energy polarimeter, goes to practically zero as the energy increases. The idea of the "Primakoff polarimeter" to measure the polarization of high energy proton was first proposed by D.Underwood[1]. It is well known as the Primakoff effect that "X"-particle coherent production by a nuclear Coulomb field is related to the photo production of the "X"-particle or a radiative decay width of the "X"-particle.[2] This relation can be applied not only for the cross section but also polarization effects. The asymmetry of π^0 production by polarized protons in a nuclear Coulomb field is equivalent to the asymmetry of the π^0 photo production from a polarized proton target,[3] which is called as a target asymmetry, at the same CM energy of π^0p system. (Fig.1)

There are several data of the target asymmetry at low energies which shows the asymmetry of as high as 90% between Δ and N^* resonances.[4)] Fig.2 shows the average values of the target asymmetry obtained from the data as a function of π^0p invariant mass. The large value of the polarization analyzing power is expected at the π^0p invariant mass of around 1.4 GeV which is important as a polarimeter not only because of the statistics but to be free from the systematic error.

We have to detect a forward scattered proton and π^0 from a lead target with t resolution of less than 0.001 $(GeV/c)^2$ to identify the Coulomb process. The apparatus of the Primakoff polarimeter is shown schematically in Fig.3. The π^0 is detected with a fine segmented leadglass calorimeter which consists of 156 leadglass blocks. The size of each block is 3.8x3.8x45 cm. The calorimeter was calibrated by using an electron beam. The energy resolution was 7.5% in FWHM at 30 GeV and the rms position resolution was 2 mm. The gain of the phototubes are monitored by using a Xe-lamp and NaI doped with Am-α light sources The scattered angle and momentum of protons are measured with 1mm spacing MWPCs(BI,BK,PC1,PC2) and 2mm spacing MWPCs(PC5,PC6,PC13,PC14,PC15) and a magnet(BM109). The target is 3mm thick lead surrounded by lead-scintillator sandwitch veto counters.

The trigger consists of a proton in one of the four scintillation counters (TP1(L,R,U,D)), energy deposit of more than 20 GeV in the corresponding segmented location (R,L,D,U) of the leadglass calorimeter, veto counters to kill the multiparticle events and upstream tagging counters to confirm the properly tagged beam particle. The trigger rate was about 600 events/spill at the primary intensity of 10^{12} protons/spill.

The measurement was made in December 1987 and January 1988. Approximately 1×10^6 events were recorded onto tapes and analyzed to estimate the beam polarization. We also took some data with Cu and C targets to study the background from the diffraction process and with anti-proton beam. The analysis is still underway, so it should be noted that the following results are preliminary. Through the π^0 , proton track and vertex reconstruction, about 50k events are left for further analysis. The $\pi^0 p$ invariant mass distribution at $|t'|<0.001$ $(GeV/c)^2$ shows clear peak at the Δ mass and a bump due to a N^* resonance.(Fig.4) It is similar to the energy dependence of the γp - $\pi^0 p$ cross section at low energy. Fig. 5 shows $d\sigma/dt$ at the Δ-mass region. The Coulomb production cross section has a very sharp peak at $|t'| \sim 10^{-5}$ $(GeV/c)^2$ and rapidly decreases as t'/t^2 ,where $t'=t-t_{min}$. The observed slope in t'-distribution shows our detection resolution which is close to the expected value from the simulation.

The proton beam is initially polarized in the horizontal plane and rotated by the snake magnets to get vertically polarized beam at the target position. The field of the snake magnets are reversed every 10 spills to avoid the left-right detector asymmetry. For simplicity, the beam is separated into 2 regions by using tagging information, namely, "polarized beam" ($|P_B|>30\%$) and "unpolarized beam" ($|P_B|<30\%$). The average values of these two beams are expected to be 45% and 0%, respectively.

The events at the kinematical region of $|t'|< .001$ $(GeV/c)^2$ and $1.34< M(\pi^0 p)<1.50$ GeV was used to obtain the beam polarization. The observed raw asymmetry with the "polarized" beam was -0.082 ± 0.025. The raw asymmetries of various conditions are summarized below;

$\varepsilon=-0.082 \pm 0.025$ $|t'|<.001$, $1.34< M(\pi^0 p)<1.50$, "polarized beam"

$\varepsilon=-0.002 \pm 0.022$ $|t'|<.001$, $1.34< M(\pi^0 p)<1.50$, "unpolarized beam"

$\varepsilon=+0.006 \pm 0.014$ $|t'|<.001$, $1.10< M(\pi^0 p)<1.34$, "polarized beam"

$\varepsilon=+0.014 \pm 0.028$, $.0025<|t'|<.006$, $1.34< M(\pi^0 p)<1.50$, "polarized beam"

The second asymmetry is consistent with zero because of the unpolarized beam. The third one is the asymmetry at Δ-mass region where the target asymmetry is almost zero. The forth one is the asymmetry at higher t'-region where the dominant process is not Coulomb but diffractive dissociation by the strong interaction and null asymmetry is expected in this reaction. The latter three asymmetries are consistent with zero within statistics which shows we observed no systematic asymmetry. The observed asymmetry is already much larger than the statistical fluctuation although the accuracy is still not good enough and the asymmetry is rather small.

The reason of the small asymmetry is the background events due to the diffractive dissociation by the strong interaction. The cross section can be written as a sum of the Coulomb and strong amplitudes. To obtain the ratio of Coulomb and strong cross section, the cross section data was fitted by the following function folded by the experimental t resolution,where the interference term is neglected in the present analysis.

$$d\sigma/dt = |F_c|^2 + |F_s|^2, \qquad |F_c|^2 = c_1 e^{-bt}, \qquad |F_s|^2 = c_2 \Gamma t'/t^2.$$

The cross section at $1.34< M(\pi^0 p)<1.50$ GeV is shown with the strong cross section obtained by the fit to indicate its contribution in Fig. 6. The dilution factor of the analyzing power ($(|F_c|^2 + |F_s|^2)/ |F_c|^2$) was 2.6 at $|t'|<.001$, which gives the effective analyzing power of about 20%. Thus we obtained the preliminary value of the beam polarization as 40 ± 12 (%). The systematic error in the estimation of the dilution factor of the analyzing power is +14 -11%. The present result is consistent with the designed value (45 %).

In order to improve the accuracy, we are trying to improve the t-resolution by polishing up the π^0 reconstruction program and to analyze the data of Cu and C target together to get better estimation of the strong interaction background. Finally I want show the data taken with the anti-proton beam.(Fig. 7) Because of the short beam time, the statistics is poor but the Primakoff process was clearly observed for the first time with the anti-proton beam.

In summary, we have observed polarization asymmetry in the coherent π^0 production by a nuclear Coulomb field known as the Primakoff process for the first time. The primakoff polarimeter was proved to be useful for high energy polarized proton and anti-proton beam. The preliminary result shows the beam polarization is 40 ±12 % and it is consistent with the designed value of the MP beam line. Further analysis is still in progress.

References;

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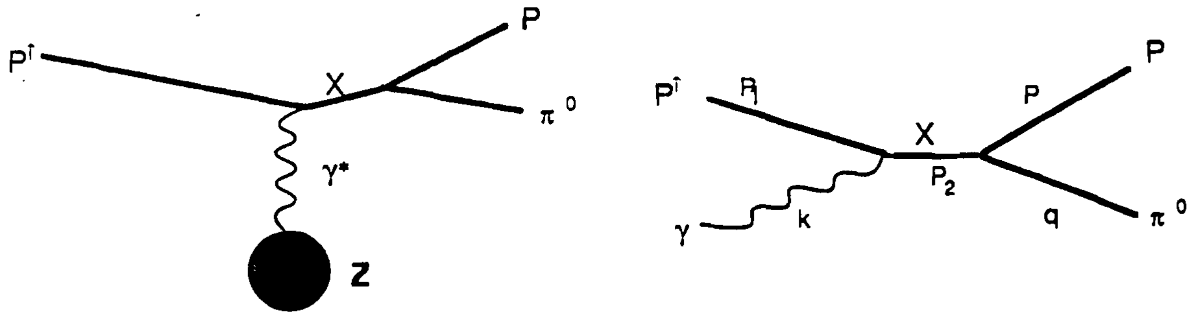

Fig.1 Coherent Coulomb production and photo production

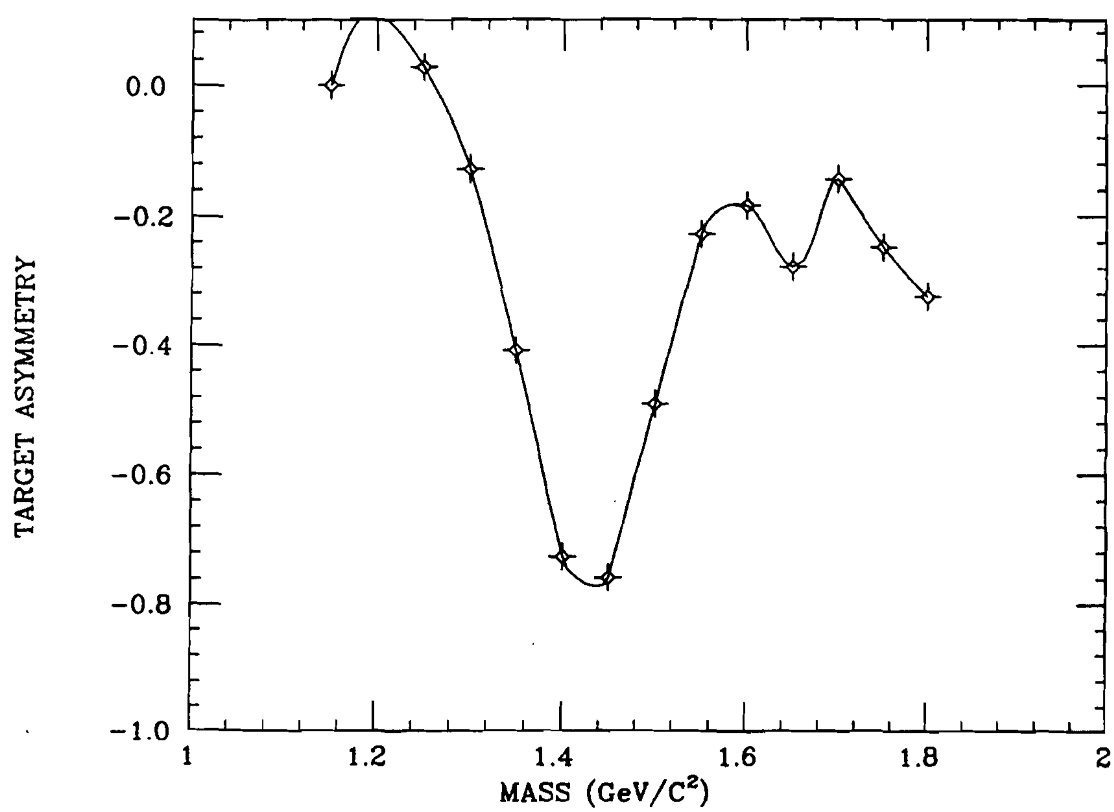

Fig.2 Average value of target asymmetry of low energy photo production. (60°-120°)

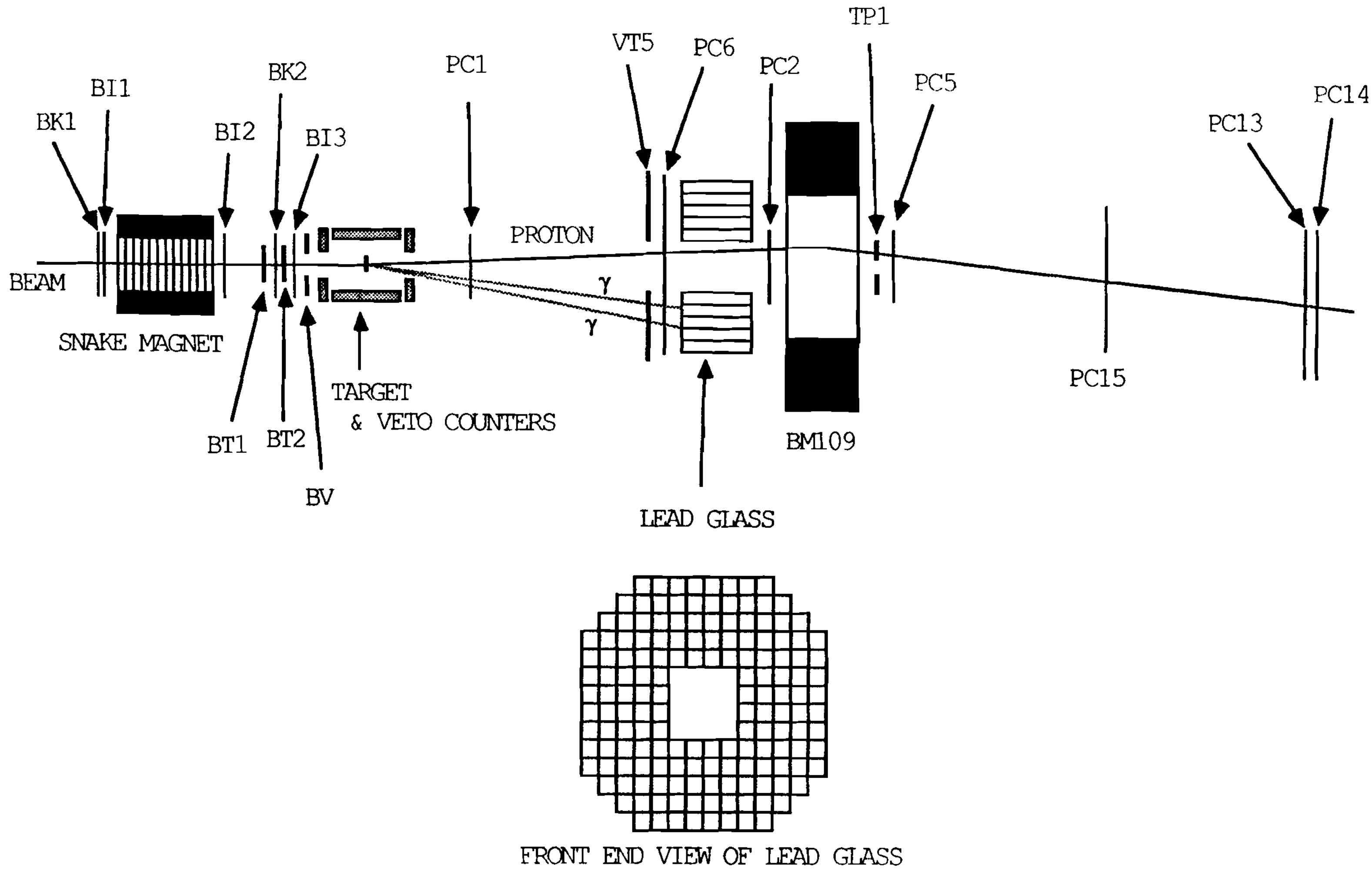

Fig. 3 Schematic view of the Apparatus

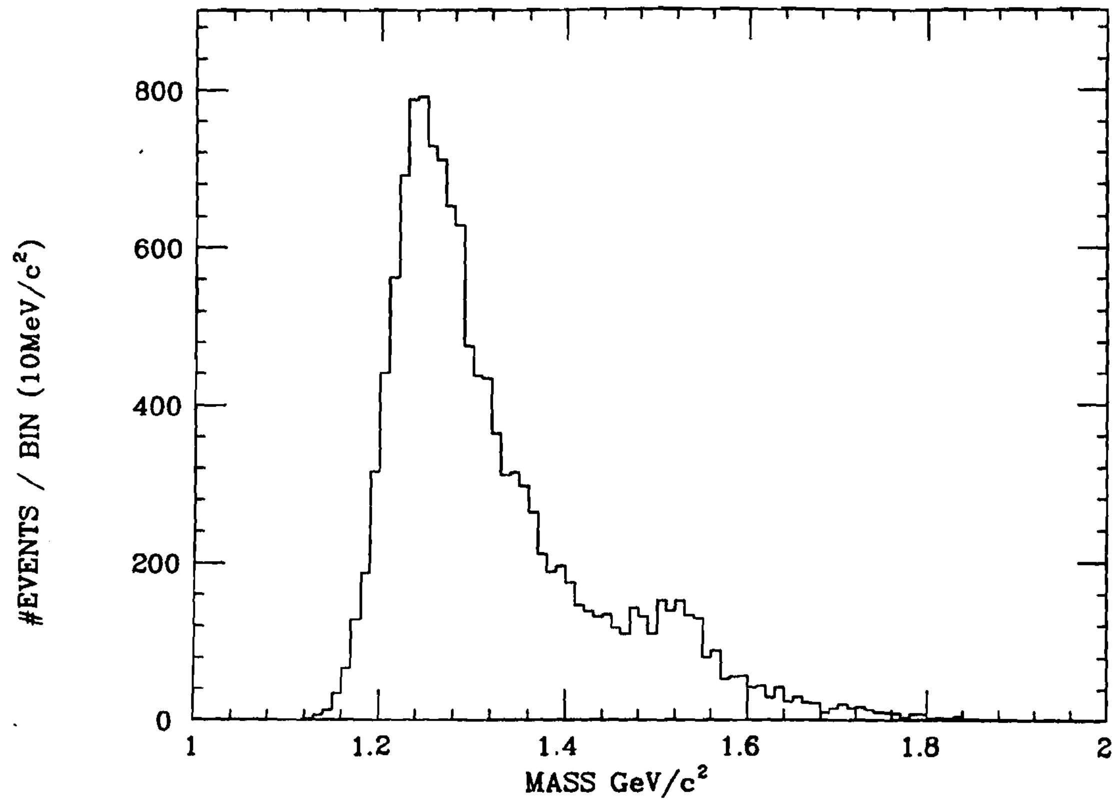

Fig.4 π^0P Invariant Mass Distribution at $|t'| < 0.001$ $(GeV/c)^2$)

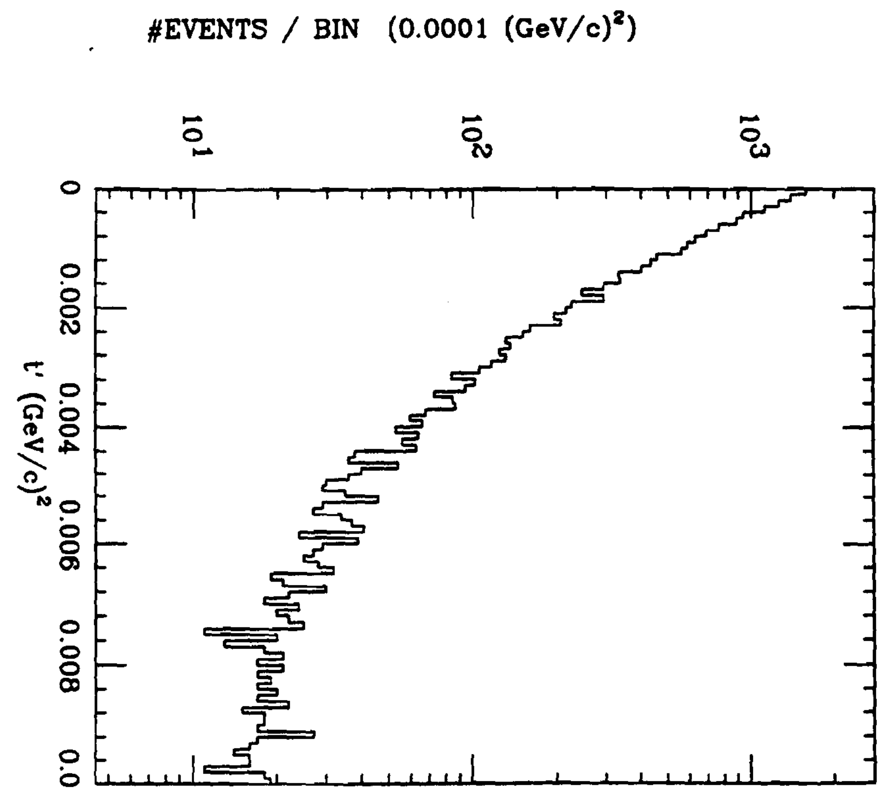

Fig. 5 $d\sigma/dt$ at Δ-Mass Region

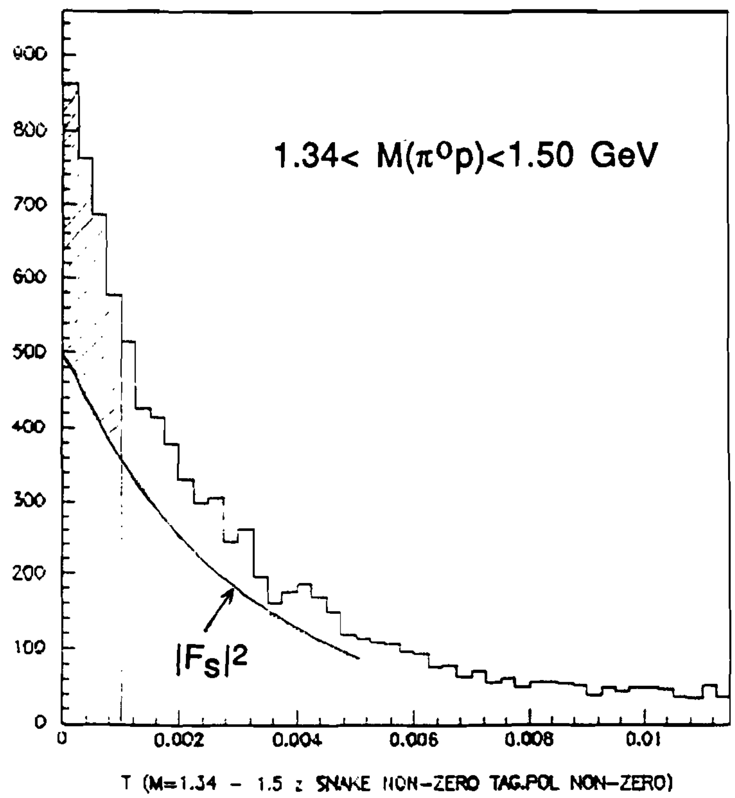

Fig.6 Signal(Coulomb) to noise(strong) ratio

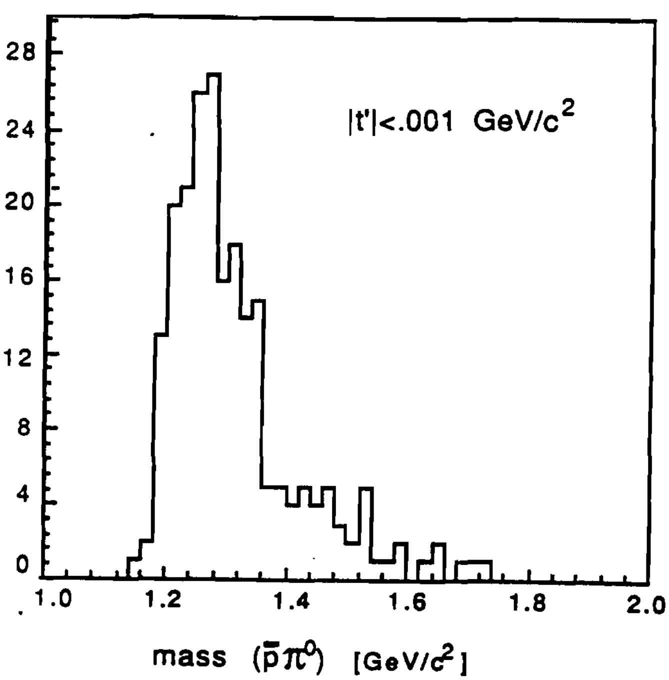

Fig.7 Primakoff Events by Anti-Proton