FERMILAB-PROPOSAL-0834

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UNIVERSITY OF
ROCHESTER

COLLEGE OF ARTS AND SCIENCE
DEPARTMENT OF PHYSICS AND ASTRONOMY

October 19, 1990

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Box 500
Batavia, IL 60510

<u>Letter of Intent</u>

Dear John:

I am responding to your call for proposals focusing on the not yet officially scheduled first post-1991 fixed target run with this Letter of Intent. Regrettably, due to an extremely frustrating confluence of events, I find myself simply unable to prepare by your deadline a document that either does justice to our past accomplishments, or provides a fully documented case for our future intentions.

Nevertheless, a clear consensus has emerged within the E706 collaboration in favor of continuing our ongoing program of direct photon experimentation into the 1992/93 time period. Stated succinctly, a majority of the collaboration believes that it is essential to carry out an additional data run if we are to achieve the goals that motivated us to propose the experiment initially and devote many arduous years to constructing the sophisticated E706 apparatus.

What is considerably less clear at this time, however, is precisely where the experiment will stand relative to achieving its overall goals at the end of the 1991 half of the present fixed target run. This uncertainty arises from several different sources:

(1) **The unconscionable budgetary impasse in Washington.** Not only are the startup date and duration of the 1991 fixed target run at present highly uncertain, but so is the date on which we will begin taking physics quality data using our still to be installed liquid hydrogen target.

(2) **Lack of knowledge concerning the nuclear dependence of direct photon production.** You will recall that in order to maintain the experiment's large rapidity acceptance, and to preserve the geometric focusing of the LAC, we are installing a liquid hydrogen target which is only 15 cm in length. We intend to use this target in conjunction with sufficient beryllium to maintain our overall interaction rate at ~10%. Consequently, only about 15% of our 1991 data will involve hydrogen. This should be adequate to determine whether anomalously large nuclear dependence is present in the data, but the statistical significance of our $pp^{+}\gamma^{+}\ldots$ results will be seriously undermined if such an effect is in fact detected.

Stated differently, if our hydrogen and beryllium results are consistent, then we can combine them and thereby gain a factor of 7 in overall statistics. If, however, they are inconsistent, then we will require further running for two reasons:

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(a) To obtain sufficient pp and $\pi^{\pm}p$ data to achieve the statistical precision we need to accomplish the experiment's QCD goals;

(b) To investigate the nuclear dependence of direct photon production for its own sake, specifically by carrying out a direct hydrogen/deuterium comparison with negligible relative systematic uncertainties. Such a study would be uniquely sensitive to any differences in the gluon structure of the proton and neutron.

(3) **Unpleasant surprises.** These are always possible (inevitable?) in real life experimentation. For example, in our 1990 running we encountered totally unexpected radiation safety problems (undetected during our 1988 running) that ultimately cost us the ability to tag the $K^-$ component of our beam during this running period. Basically, this problem arose because we were forbidden to collimate our beam at experimentally useful intensities. Thus, our Cherenkov counter, which had successfully tagged Ks during our 1988 run, was unable to do so in 1990 due to greatly increased average beam divergence. This was an extremely frustrating experience for us, since we would otherwise have acquired a $K^-$ sample in 1990 that was larger than the $\pi^-$ sample acquired in 1988, and this data would have been totally unique. This unfortunate episode serves to graphically illustrate the hazards of basing ones future plans on yet to be achieved results. It is worth emphasizing that to date the experiment has acquired no primary proton data, no data employing a hydrogen target, and only a small sample of positive data at 530 GeV/c using a less than optimum LAC readout (see comments made below in (3)). Thus, there is certainly no lack of opportunity for unanticipated setbacks to occur.

For these reasons, I will not attempt in this letter to guess the precise demarcation between the data sample we expect to collect in 1990/91, and what we propose to obtain in the 1992/93 time frame. Nor, in the absence of an official schedule for the 1992/93 fixed target run, will I present a detailed chronological plan for the analysis of the overall experiment, except to state that, if the next run actually occurs in the 1992/93 time frame, the analysis of this follow-on data will very naturally mesh with completion of the analysis of our combined 1990/91 data. I am pleased to report that our understanding of the 1988 data is rapidly approaching the level where we will be comfortable with submitting our results for journal publication. While it has taken us longer to get to this point than we naively expected at the outset, it is important to realize that it would have made absolutely no scientific sense for us to have rushed the publication process, particularly in a relatively mature field.

I will focus instead in this letter on summarizing the physics goals of the overall experiment; goals which cannot fully be achieved without one more data run.

(1) Measurement of the gluon structure function of the nucleon. The leading diagram for the reaction $pN \rightarrow \gamma + \ldots$ is QCD-Compton scattering ($g+q \rightarrow \gamma + q$). This reaction is directly sensitive to the gluon structure of the nucleon. In particular, inclusive direct photon production provides a complementary method for investigating the substructure of the nucleon, relative to deep inelastic scattering experiments, which are directly sensitive to only the nucleon's quark content. This complementarity of the two experimental techniques is depicted in Fig. 1,[1] which compares the sensitivity of direct photon production and deep inelastic scattering in determining the fundamental QCD parameters $\eta_g$ and $\Lambda$.

Experiment E706 was designed to be the most precise direct photon experiment ever carried out in its kinematic domain ($0.2 \leq X_T \leq 0.6$), which spans the especially interesting overlap region between earlier fixed target experiments and results obtained at the ISR. Fig. 2 presents the inclusive direct photon cross section for proton incident data acquired by E706 during the first 6 weeks of 1988. (Some engineering data was acquired by the experiment in 1987, but none of this data was ultimately judged of sufficient quality to merit inclusion in our ACP analysis pass.) Although this data sample represents only a tiny fraction of the statistics we ultimately expect to acquire (the positive data displayed in Fig. 2 is equivalent in sensitivity to what was achieved in just 4 days of data taking during our 1990 negative beam running), it is already competitive with, indeed in many respects superior to, earlier experimental results.

The data displayed in Fig. 2 were all acquired at a single incident energy. This is not adequate to separate $p_T$ and $X_T$ dependent effects. In 1991, we plan to split our running between incident momenta of 530 and 800 GeV/c to address such issues. Within its kinematic range, the experiment will be unprecedented in acquiring data over a significant range of $\sqrt{s}$ with consistent systematics, but we will thereby, of course, correspondingly reduce our statistics at each energy. Furthermore, as discussed above only about 15% of our data sample will truly be $pp \rightarrow \gamma + \ldots$, and thus immune from nuclear dependent effects. For these reasons, additional proton running is very likely to be essential if the experiment is to have the desired impact on the determination of the gluon structure of the nucleon.

(2) Measurement of the gluon structure of mesons. From a QCD perspective, studying the gluon content of mesons is no less fundamental than measuring nucleon structure functions. In principle, E706 can investigate the gluon content of $\pi^-$, $\pi^+$, $K^-$, and possibly $K^+$ mesons. Fig. 3 displays the inclusive direct photon cross section in $\pi^-$Be collisions from our 1988 data sample. The $p_T$ and $X_T$ span of this data is unique, and moreover the data is at a $\sqrt{s}$ significantly higher than all previous experiments, which are bunched together in a relatively narrow energy range. In 1990, we accumulated in excess of an order of magnitude more data than is presented in Fig. 3. Full scale

reconstruction of this data sample has not yet begun (our target date for ACP processing is the beginning of 1991, using reconstruction software superior to that employed for the 1988 data sample, but not yet totally optimized to take full advantage of the improved LAC readout). We have, however, processed small subsamples of 1990 data for a variety of purposes.

Fig. 4 displays the two photon mass distribution in the $\pi^0$ mass region for a sample of 1990 data equivalent to less than 6 hours of running. The FWHM of this peak is 7.8 MeV; the shoulder at high mass is an artifact of our decision to save processing time by turning off the charged particle tracking software during this particular reconstruction pass. As a result, we were unable to impose a vertex cut on these events. As discussed earlier in this letter (under "unpleasant surprises"), we were forced to run with a divergent beam during 1990. As a result, a significant sample of our triggers arise from upstream interactions. When photon pairs from such events are misinterpreted as originating from our target, they reconstruct to an artificially high mass. Analysis of data reconstructed with the tracking software turned on confirms that all of these events will be removed once we impose a vertex cut on accepted events. It is worth pointing out that the $\pi^0$ and $\eta$ mass resolutions achieved by E706 in our 1988 analysis (8 and 20 MeV/$c^2$, respectively) are superior to that achieved in earlier direct photon experimentation (except for our own prototype experiment E629).

A second important check on the quality of our most recent data sample is provided by a direct comparison of yields from the high $p_T$ triggers employed in 1988 and 1990. Fig. 5 presents this comparison for inclusive $\pi^0$ production (even preliminary direct photon cross sections take much longer to emerge from the analysis chain). The open circles are our 1988 data, and the crosses are for events collected using one of our 1990 triggers. Even at this very early stage of the data analysis, the level of agreement is excellent, which makes us fully confident of the overall quality of our 1990 sample of $\pi^-$Be data.

(3) <u>Study of the inclusive production of $\gamma$ + jet events (including $\gamma+\gamma$ production).</u> This is a very important area that directly impacts on both (1) and (2) above, but which has barely been touched experimentally.[3] Experiment E706 was proposed with this physics very much in mind. Fig. 6 presents a schematic of the E706 apparatus as it presently exists. Many of the improvements that were made to the spectrometer between 1988 and 1990 were designed to improve our ability to detect and measure awayside jets produced in association with high $p_T$ direct photons. (The "awayside jet" in two photon production is, of course, just a second direct photon. Although the detailed analysis is complicated by the necessity of coping with $\pi^0$ and $\eta$ contamination of both jets, studying this reaction occurs naturally in the course of the experiment's inclusive direct photon analysis.)

Charged particle tracking has been enhanced by the addition of an xy pair of upstream SSD planes with 25 $\mu$m strips in their central regions, and by augmenting the downstream PWC tracking system by two xy straw tube drift chambers with approximately 300 $\mu$m resolution. The LAC readout was also improved in ways that will significantly enhance its capability for measuring the $\pi^0$ and $\eta$ component of awayside jets. Since such jet constituents generate relatively low energy showers (in contrast to triggering particles, which are essentially jets in and of themselves), their measurement was greatly compromised by our need during the 1988 running to suppress the readout of all LAC channels falling below a preassigned cutoff of approximately 175 MeV. By upgrading our PDP11-based LAC data acquisition system to a FASTBUS-based system, and by replacing our CDF-designed MX readout controllers by faster, cheaper, and more reliable units of our own design, we have been able to greatly increase the parallelism of the LAC readout. As a result, we now readout the entire LAC for each event.

Fig. 7 illustrates the potential improvement in shower reconstruction thereby made possible. These plots are pulse height distributions (in GeV) in radial and azimuthal strips of individual LAC quadrants for specific events recorded in 1990; the dashed lines represent the readout cutoff employed in 1988. Fig. 7(a) is characteristic of quadrants containing a triggering shower, and demonstrates that the reconstruction of large energy showers is not seriously compromised by the suppression of low pulse height channels. (Thus, the inclusive $\gamma$, $\pi^0$ and $\eta$ cross section results from our 1988 data are not overly sensitive to the readout cutoff employed.) Fig. 7(b) is more characteristic of quadrants containing showers produced by an awayside jet; here there are not only more showers, but each is on average of relatively low energy. As can be seen, much potentially valuable information is gained by reading out the entire LAC, particularly in non-triggering quadrants.

We are presently carrying out a major revision of our LAC reconstruction software to take full advantage of our improved capability for measuring low energy showers. Once this is completed (in approximately mid-1991), we will be able to define awayside jets using charged particles, $\pi^0$s, and $\eta$s. This will permit us to determine the rapidity of individual jets more accurately than just using charged particles alone. It is important to note that next-to-leading order calculations have recently become available for $\gamma$+jet processes.[3] We believe that one of the major contributions of E706 will be studying this physics, particularly if we run long enough to acquire sufficiently high statistics at large $p_T$, where the jet definition is the cleanest, and residual $\pi^0$ contamination in the single photon sample is smallest. In this context, it is also worth emphasizing that analyzing data as a function of two variables (e.g. $p_{T,\gamma}$ and $y_\gamma$, natural variables for the analysis of $\gamma$ + jet events), requires significantly higher statistics than does a single variable analysis.

(4) Quark and gluon fragmentation studies. The two leading diagrams for direct photon production result in away-side jets of different origin. Specifically, QCD-Compton scattering produces quark jets, whereas quark/antiquark annihilation ($\bar{q} + q \to \gamma + g$) yields gluon jets. In principle, this provides a useful means for separating these two classes of jets.

Fig. 8 displays the $\gamma/\pi^0$ ratio for $\pi^-$Be and pBe data acquired by the experiment in 1988. The dramatic rise at high $p_T$ in the $\pi^-$ case relative to what is observed in the p case is presumably due to the increased importance of valence u-quark annihilation. This supports the use of a transverse momentum cut to vary the relative fraction of awayside jets of quark and gluon origin in $\pi^-$Be data. An alternate way to address this same issue is to carry out a direct comparison of jets produced in $\pi^+$ and $\pi^-$ collisions. Both these techniques are quite different from methods employed in $e^+e^-$ interactions to achieve the same end, and it is clearly important to investigate in detail the consistency of results obtained by these different procedures.

As mentioned above in (3), the study of awayside jets improves significantly as the $p_T$ of the data sample increases. It is important to realize that the statistical benefit at high $p_T$ values of further running can be expected to increase faster than linearly with increased running time. Several factors will determine the precise statistical benefit achieved:

(a) **Raising the $p_T$ trigger threshold for the experiment.** For this strategy to be effective, improvements would have to be made in our rejection of muon induced events at the trigger stage (we have numerous methods of eliminating such events in the course of the data analysis) to avoid saturating our livetime with background events. We are presently evaluating what appears to be a cost effective technique by which improved muon rejection could be achieved in a future experimental run.

(b) **Further speedup of our data acquisition system.** While really large improvement factors would probably be very expensive to achieve, relatively inexpensive changes to the data acquisition system (such as the use of faster ADCs in the LAC readout) could still produce significant benefits (roughly a factor of two reduction in this component of the overall readout).

(c) **Directing more beam to MWest.** Labwide proton economics limited the amount of primary beam allotted to all experiments in the latter half of the 1990 fixed target run. The Laboratory's plans call for the LINAC upgrade to be completed prior to the first post-1991 fixed target run. This will significantly raise the total primary beam intensity, and hopefully to at least some extent alleviate this problem (although it's presumably safe to assume that there will seldom be more primary protons than experimenters request!).

(d) **Raising the accelerator energy for fixed target running.** Although I know of no commitment to raise the primary beam energy for a future fixed target run, such a change would be of particular benefit to E706, by virtue of the very rapid rise with incident energy of particle production cross sections at high $X_T$.

I would like to close with the following observation. Nearly a decade ago, we submitted to Fermilab a proposal to carry out a comprehensive investigation of direct photon production, which was designed to be superior to preceding experiments of this type. After an unusually intensive 9-month review, which involved the submission of a revised proposal and a special PAC presentation session devoted exclusively to comparing alternate means of carrying out this specific line of experimentation, the experiment was approved in December 1981. While it is certainly true that neither party to the subsequent negotiations between the experimenters and the Laboratory ever anticipated the time scale of the experimental program that would ultimately evolve, both sides of the ensuing arrangement have every reason to be extremely pleased with what has thereby been created.

Experiment E706 has provided unambiguous evidence that it is indeed capable of generating data that provide unique insight into QCD hadronic structure and dynamics. Moreover, the phenomenology of direct photon production has continued to evolve to accommodate the increased precision of the available experimental data. Specifically, next-to-leading order QCD calculations are now available, not only for inclusive direct photon cross sections, but also for inclusive photon plus jet production. In addition, several global QCD analysis efforts, which combine data from different types of experiments to extract nucleon structure functions, have recently been organized.[4] Equally important, no competing experiment has in the interim been executed, or even proposed, that would make the results of E706 redundant. Thus, the only challenge that we face at the present juncture is to confirm our mutual commitment to achieving the goals that motivated us to initially embark upon the project. I am absolutely confident that experiment E706, under whatever number it completes its destiny (it started out as P695), can be one of Fermilab's success stories.

Sincerely,

Paul

Paul F. Slattery
Spokesperson E706

## References

1. P. Aurenche et al., Phys. Rev. D39, 3275 (1989).
2. The only published data on inclusive $\gamma$+jet cross sections that comes readily to mind is from the ISR: T. Akesson et al., (the AFS collaboration), Z. Phys. C34, 293 (1987).
3. H. Baer et al., Phys. Lett. B234, 131 (1990).
4. In addition to ref. 1, recent references from ongoing efforts of this sort include: P. N. Harriman et al., Phys. Rev. D42, 798 (1990) and J. G. Morfin and W.-K. Tung, Fermilab-Pub-90/74 (April 1990), submitted to Z. Phys. C.

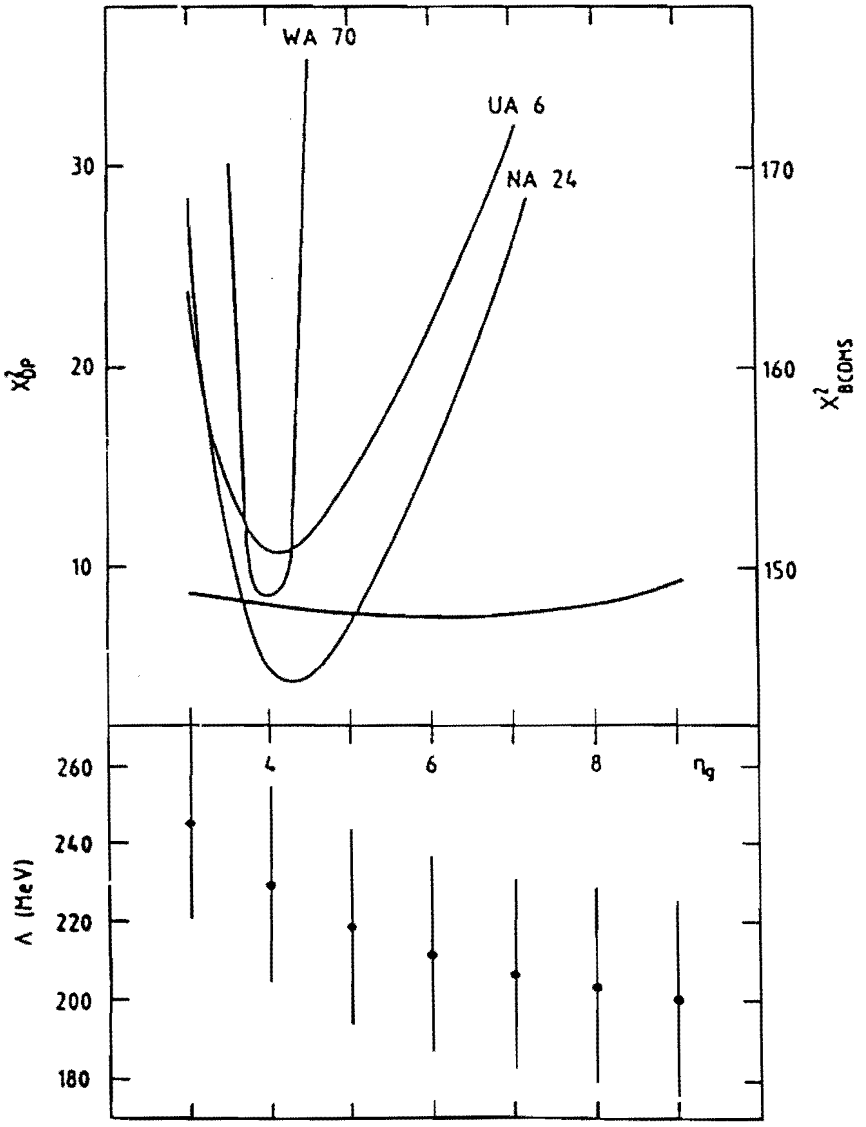

Fig. 1. The $\chi^2$ of fits to deep inelastic scattering (BCDMS) and direct photon data (DP: WA70, UA6 and NA24) as a function of $\eta_g$, along with the variation of the fitted value of $\Lambda$. This figure is taken from ref. 1, and further details may be found there.

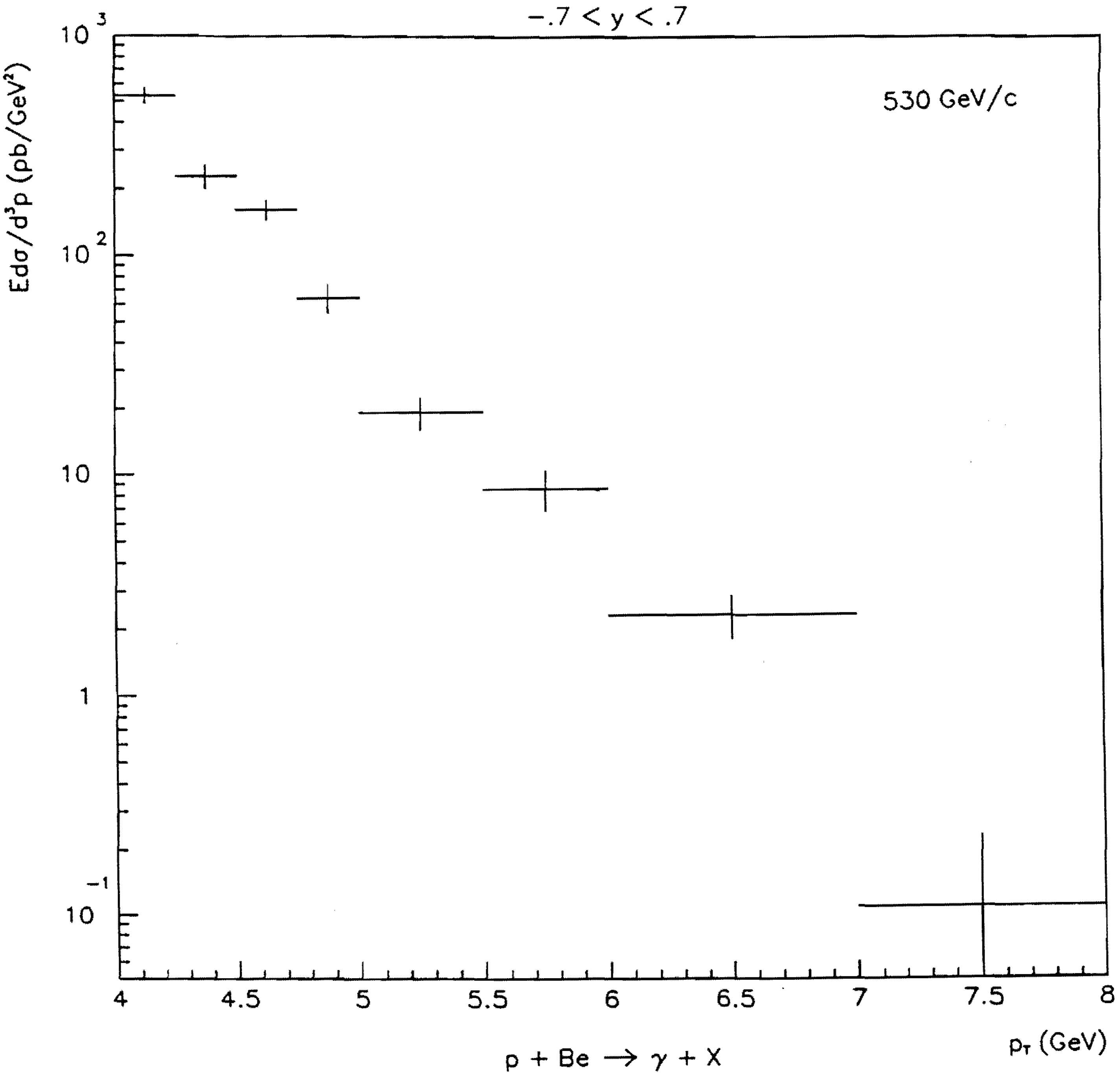

Fig. 2. The invariant differential cross section per nucleon for the inclusive production of direct photons in pBe collisions at 530 GeV/c. Data are from the 1988 data run of experiment E706.

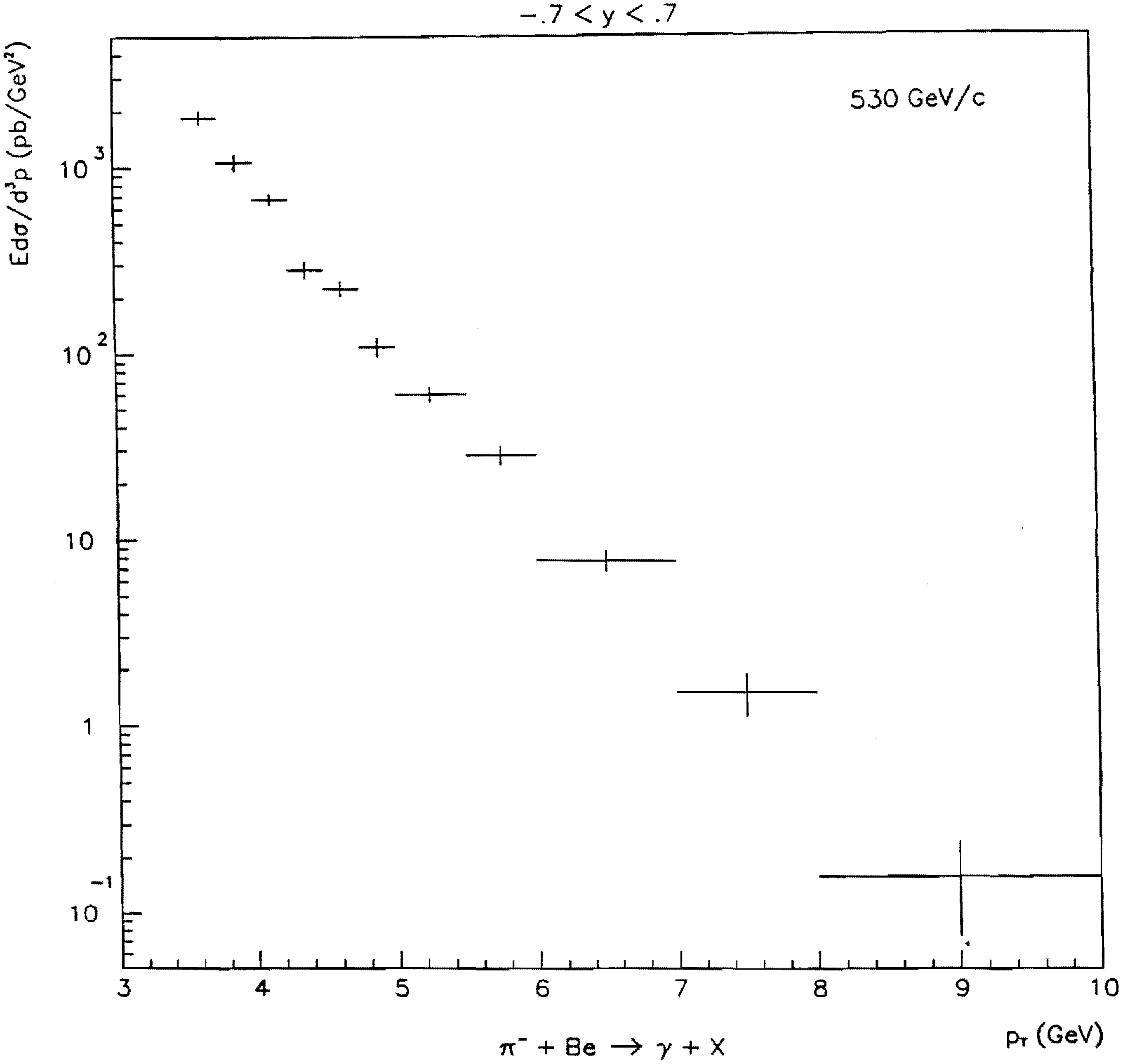

Fig. 3. The invariant differential cross section per nucleon for the inclusive production of direct photons in $\pi^-$Be collisions at 530 GeV/c. Data are from the 1988 run of experiment E706.

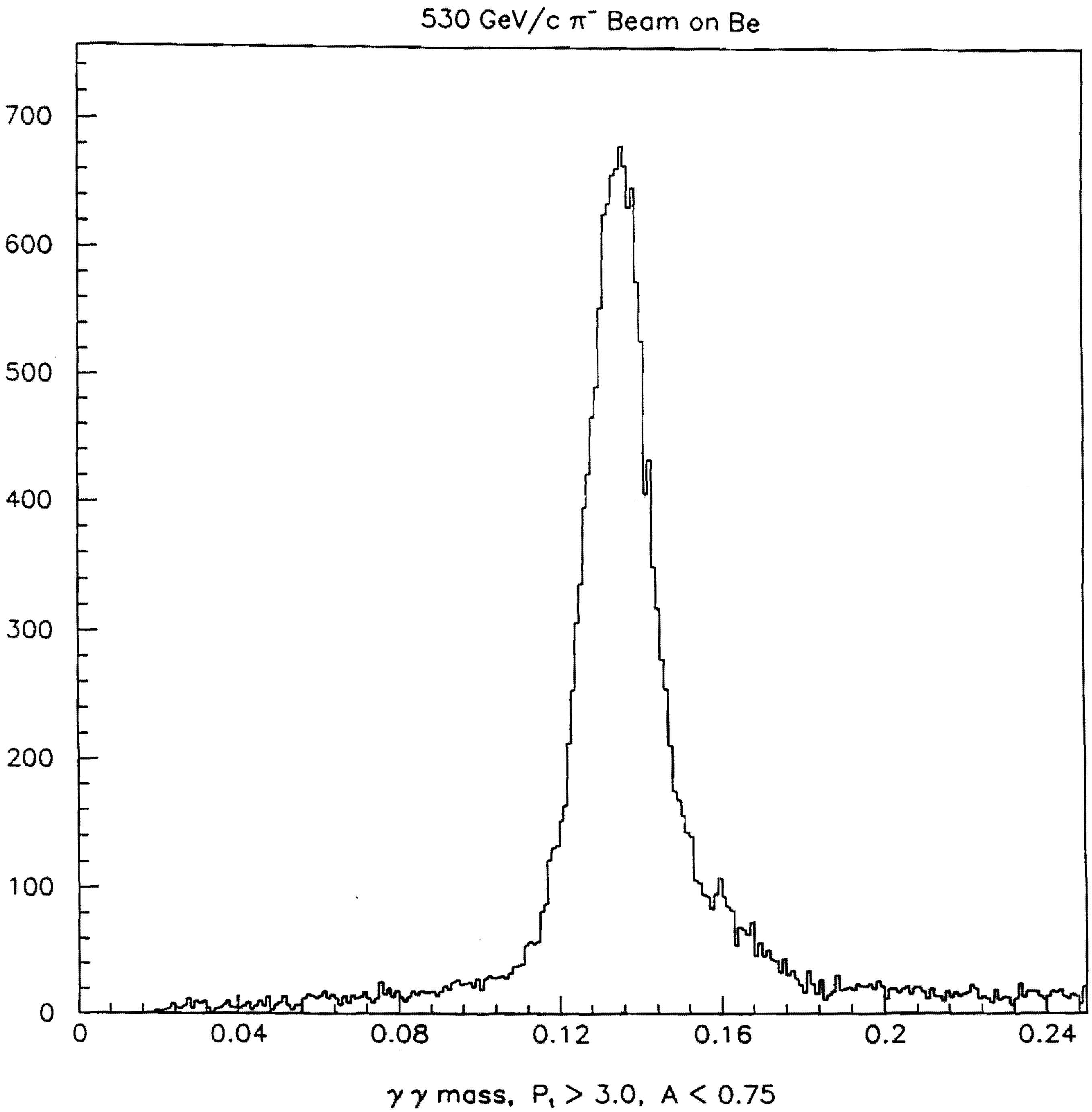

Fig. 4. Very preliminary data from the 1990 run of experiment E706 displaying the $\gamma\gamma$ mass distribution in the $\pi^0$ mass region. (See text for details.)

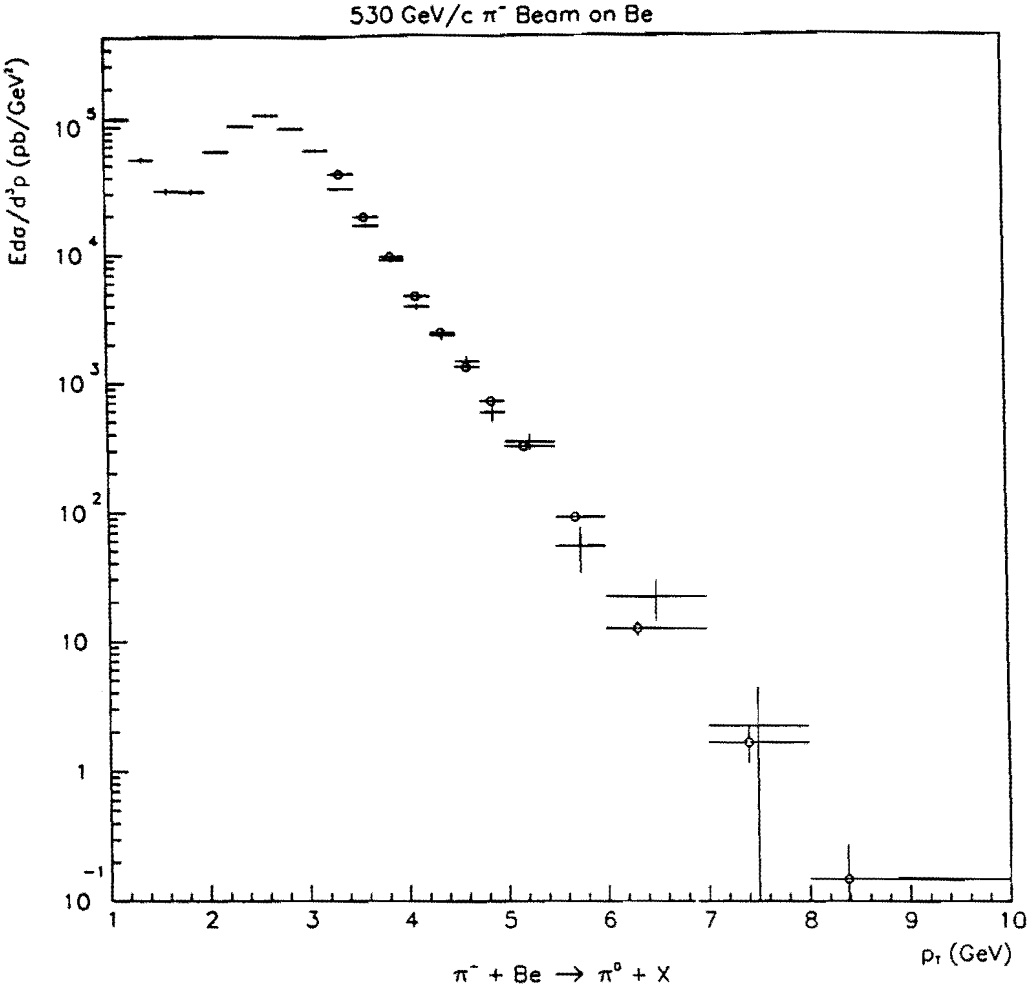

Fig. 5. Comparison between the high $p_T$ electromagnetic triggers employed in the 1988 and 1990 data runs of experiment E706. Open circles are results from the 1988 run (with a low $p_T$ cutoff). Crosses are uncut data from one of the triggers employed during the 1990 run. Shown in each case is the invariant differential cross section for inclusive $\pi^0$ production in $\pi^-$Be collisions at 530 GeV/c.

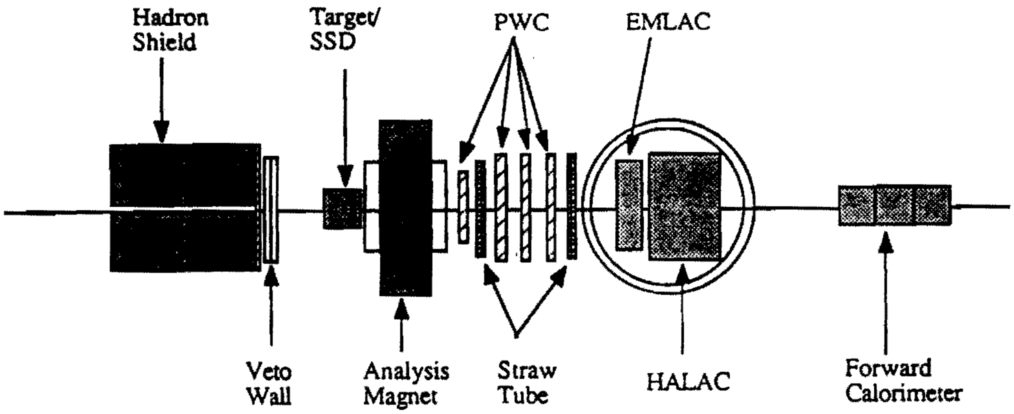

Fig. 6. Schematic layout of the E706 spectrometer in the configuration employed during the experiment's 1990 data run.

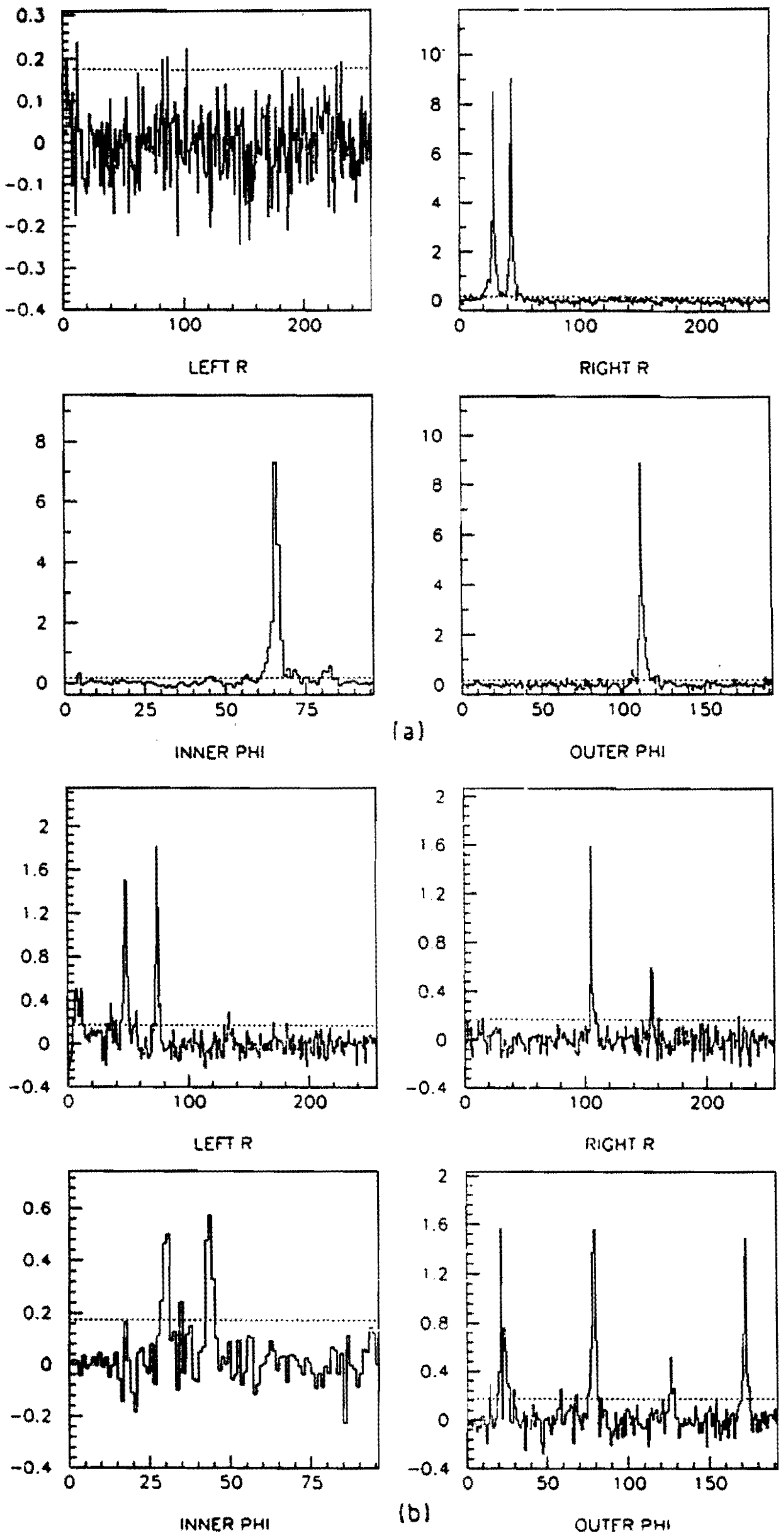

Fig. 7. (a) LAC pulse height distributions for the 4 subregions of a representative triggering quadrant for 1990 data taken by E706. Dashed line represents the lower limit for LAC readout in 1988. (b) LAC pulse height distributions for the 4 subregions of a non-triggering quadrant. Horizontal scales are strip numbers, and vertical scales are in GeV. (See text for more details.)

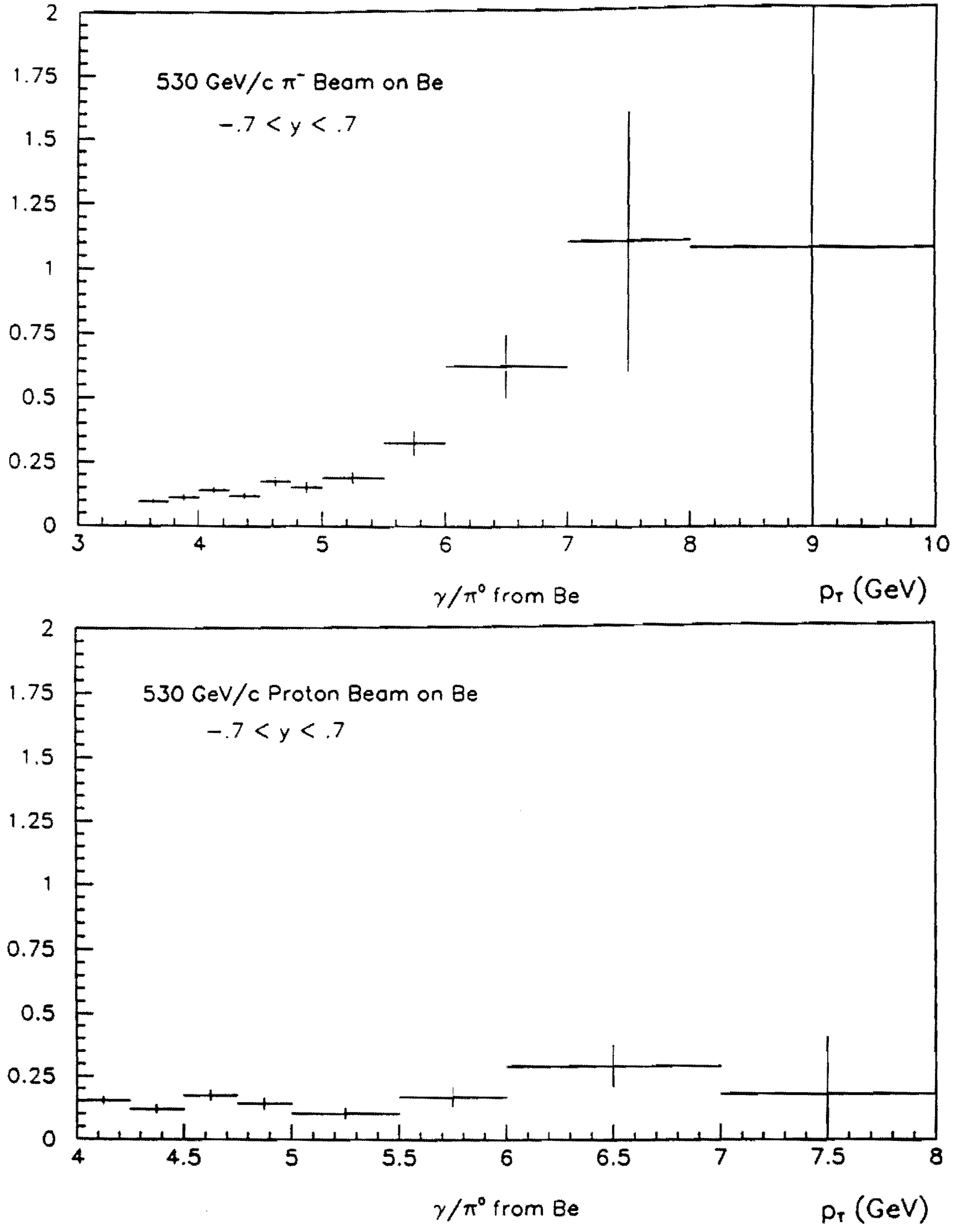

**Fig. 8.** $\gamma/\pi^0$ ratios as a function of $p_T$ for $\pi^-$Be and pBe collisions at 530 GeV/c. Data are from the 1988 data run of experiment E706, and have been corrected for backgrounds arising from $\pi^0$ and $\eta$ decays.