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A CHARGED-PION SPECTROMETER FOR THE BNL GAMMA-RAY-BEAM FACILITY

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The $(\gamma,\pi^{\pm})$ studies planned for the BNL Gamma Ray Beam Facility necessitate the detection of charged pions in the energy range $25<T_{\pi}<150$ MeV with a modest resolving power to match the photon beam energy resolution (27 MeV). The solid angle must be as large as possible, and the total path length must be as short as possible to minimize the losses due to pion decay. (The mean lifetime corresponds to L=4.87 m for T_{π}=25 MeV). Finally, a means must be provided to reject pion decay products reaching the focal plane.

A design for such a charged-pion spectrometer is presented. This design utilizes existing large aperture magnetic elements, and provides a momentum resolution of 0.68% at a solid angle of 50 msr, over a momentum range of 10%.

A layout of this QDQ spectrometer is shown in Fig. 1. The second quadrupole, which is a current-sheet device with a large rectangular aperture (15x61 cm) similar to the design of Ref. 1, makes possible the QDQ arrangement which is responsible for the large solid angle achieved here. The effective solid angle, including losses due to pions decaying over the 4 m path length, is shown in Table I.

Calculations for this design were performed with the code TRANSPORT (Ref. 2). The spectrometer solid angle is determined by a $\Delta\theta=\pm50$ mr, $\Delta\phi=\pm250$ mr geometrical acceptance. The limiting charged particle envelopes in the x (dispersive) and y (transverse) directions are shown in Fig. 2. The important matrix elements relevant to this design are listed in Table II. The resolving power, in first order, is determined by the ratio of the dispersion to the product of magnification and spot size on target: $D/(MX_{target})=205.3$, for $X_{target}=1$ cm. As can be seen from Table II, the contribution from the second-order term $(x|\theta^2)$ dwarfs the image size calculated in first order. This aberration can be corrected by ray-tracing. In order to reduce the second order term so that its contribution is equal to the first-order spot size, an angular resolution at the entrance to the spectrometer of $\Delta\theta=0.3^{o}$ is required. However, angles measured near the focal plane are larger than those at the target by the inverse of the horizontal magnification, 1/M. Thus, the angular accuracy required at the exit of the spectrometer is 1.3^{o}. This will be measured by two multiwire proportional counters (MWPC's). (Multiple scattering in the $MWPC_2$ windows introduces errors of only 0.1^{o}). Similarly, ray tracing to determine $\Delta\phi$ can be done to sufficient accuracy to make the $(x|\phi^2)$ term vanish. As can be seen from Fig. 2, the MWPC's required are of modest dimensions, 30 cm (y) by 5 cm (x), with resolution ~0.1 cm (x) by 0.5 cm (7), and are sufficient for the required ray tracing assuming a 30 cm separation between planes. The momentum resolution, resulting from this system, $\Delta p/p=0.68\%$, has been used to calculate the pion energy resolution shown in the last column of Table DI. This resolution is limited by the spot size on target. If necessary, the resolution can be improved by decreasing the γ-ray beam defining apertures, although not without a reduction in flux.

The effect of path length differences through the spectrometer (±12 cm) is negligible, yielding a contribution to the time resolution of <2 nsec FWHM.

Some of the muons from the in-flight decays of the pions will reach the focal plane. To reject such events, a pair of wire chambers ($MWPC_1$) will be installed at the entrance to the spectrometer, allowing the angles θ and ϕ to be measured to $<1^{\circ}$ (FWHM). Since the muons lie within a $>10^{\circ}$ cone of the initial pion momentum, most of them can be vetoed by comparing angles at the entrance and exit of the spectrometer. The multiple scattering resulting from these additional detectors is estimated to be $\sim 0.15^{\circ}$. Taking into account the horizontal magnification, this spread translates to $\sim 0.75^{\circ}$ at the focal plane. This angular uncertainty is still small compared with the 1.3° necessary to correct the higher-order aberrations.

1) L. Hand and W. Panofsky, Rev. Sci. Inst. 30, 927 (1959).
2) K.L. Brown and S.K. Howry, SLAC report No. 91 (1970).

TABLE I: Energy resolution and efficiency of the QDQ spectrometer for several values of the pion kinetic energy.

T_{π}(MeV)	p(MeV/c)	$\varepsilon\cdot\Delta\Omega$(msr)	ΔE(MeV)
25	87.2	22.0	0.31
50	128.3	28.6	0.59
75	163.0	32.2	0.84
100	194.7	34.6	1.08
150	253.7	37.7	1.51
250	363.7	41.1	2.31

TABLE II: Transport matrix elements for the QDQ spectrometer. A target spot size of 1 cm has been assumed in the last column. Units are cm, mr, %.

Element	Calculated Value	Contribution to Spot Size (cm)
$(x\|x)\equiv M$	-0.226	0.226
$(x\|\delta)\equiv D$	0.464	---
$(x\|\theta^2)$	-4.22×10^{-4}	1.06
$(x\|x^2)$	-0.105	2.6×10^{-2}
$(x\|\phi^2)$	-2.87×10^{-6}	0.18
$(x\|\theta\delta)$	5.78×10^{-3}	---
$(y\|y)$	-18.6	---
$(\phi\|\phi)$	-0.211	---

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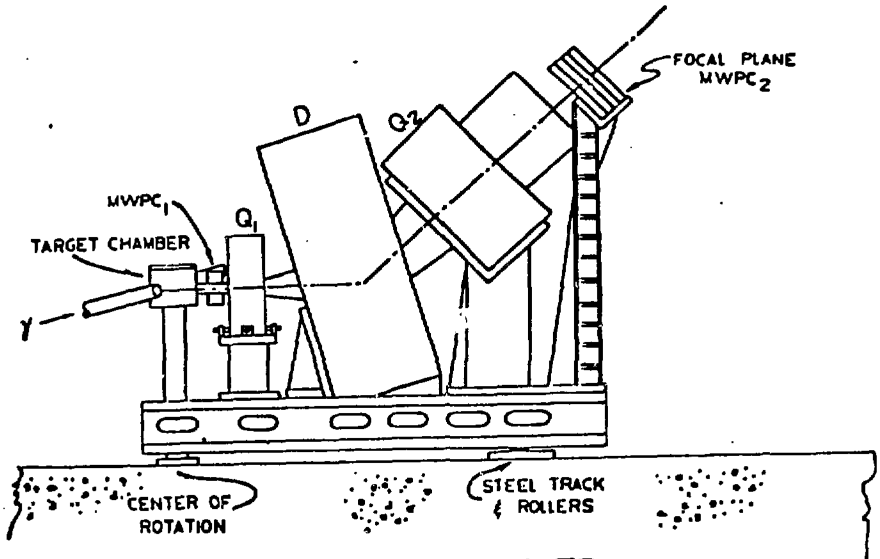

FIG. 1. QDQ PION SPECTROMETER

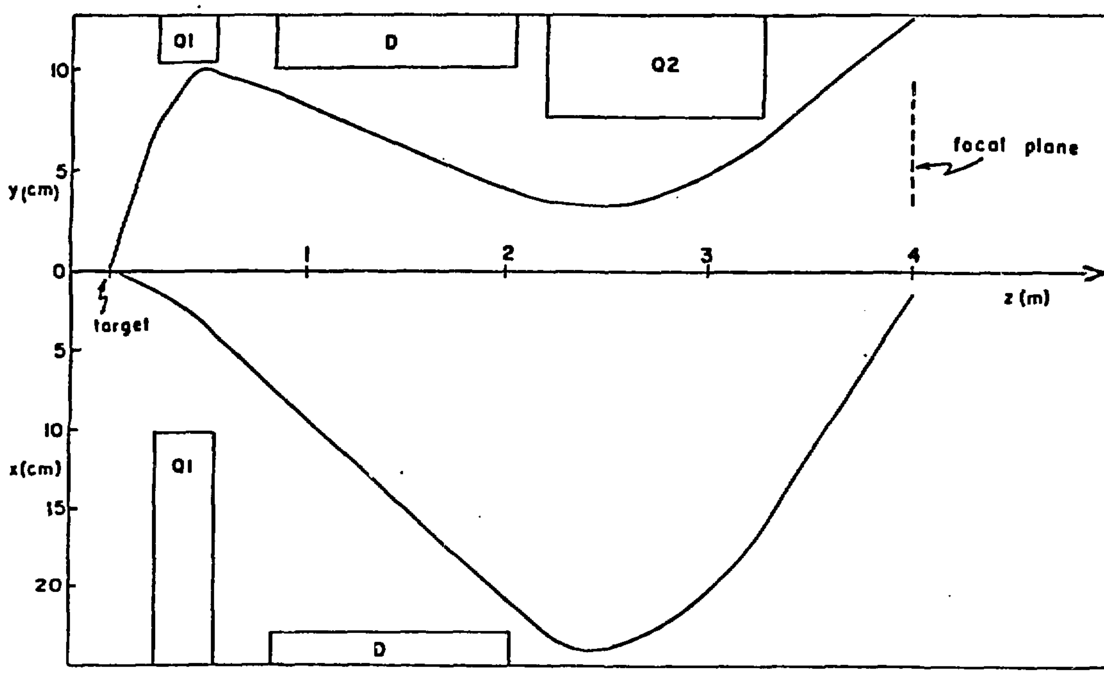

Fig. 2 Beam envelopes for the QDQ spectrometer, calculated to second order, for $\Delta\theta = \pm 50$mr, $\Delta\phi = \pm 250$mr, $\Delta p/p = 0$.