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THE $\pi^- p \to \gamma\gamma n$ REACTION AND PION COMPTON SCATTERING*

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We propose to measure the two-photon capture mode of pionic hydrogen using the RMC pair spectrometer at the TRIUMF cyclotron. Currently, only an experimental upper limit of B.R. $\leq 5.5 \times 10^{-4}$ is available for the $\gamma\gamma$ capture mode Our new data will critically test the theoretical calculations and the intriguing predicted dominance of the $\pi\pi \to \gamma\gamma$ annihilation graph. More speculatively, since crossing symmetry relates $\pi\pi \to \gamma\gamma$ to $\gamma\pi \to \gamma\pi$, this threshold reaction may be a novel probe of the pion's electric polarizability. We show results of our 1997 engineering run and Monte Carlo studies for the two–photon capture mode of pionic hydrogen and carbon. We also present our preliminary upper limit for the B.R. $[\pi^- p \to \gamma\gamma n] \leq 2.8 \times 10^{-4}$.

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1. Current status of $\pi^- p \to \gamma\gamma n$

The $\pi^0 n$, γn and $e^+e^- n$ branching ratios of the pionic hydrogen atom are accurately measured (see Tab. I). For the $\gamma\gamma n$ mode, however, there is only an upper limit of the branching ratio, B.R. $\leq 5.5 \times 10^{-4}$, obtained in a JINR spark chamber experiment [2].

Although the hydrogen $(\pi^-, \gamma\gamma)$ reaction has not been observed, the nuclear $(\pi^-, \gamma\gamma)$ reaction has been measured at PSI and TRIUMF [5]. The branching ratios obtained from the two carbon $(\pi^-,\gamma\gamma)$ experiments are in reasonable agreement, Deutsch *et al.* obtained $(1.4 \pm 0.2) \times 10^{-5}$ and Mazzucato *et al.* $(1.2 \pm 0.2) \times 10^{-5}$.

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TABLE I

Capture modes and branching ratios of the pionic hydrogen atom.

Capture Mode	Branching Ratio	Reference
$\pi^- p \to \pi^o n$	0.607 ± 0.004	[3]
$\pi^- p \to \gamma n$	0.386 ± 0.002	[3]
$\pi^- p \to e^+ e^- n$	0.0069 ± 0.0003	[4]
$\pi^- p \to \gamma\gamma n$	$\leq 5.5 \times 10^{-4}$	[2]

Several authors have made tree–level calculations of the $\gamma\gamma n$ capture mode of pionic hydrogen. For the $\gamma\gamma n$ branching ratio Joseph obtained $5.1{\times}10^{-5}$, Lapidus and Musakhanov $4.0{\times}10^{-5}$, and Beder $5.1{\times}10^{-5}$ [6]. These values are roughly ten times smaller than the experimental upper limit from the JINR experiment. Beder also pointed out the importance of the pion annihilation diagram, especially at small photon opening angles (see Table 3 and Fig. 4 of Beder paper [6]).

2. Relation to Pion Compton scattering

An intriguing feature of the $\gamma\gamma n$ capture mode is the predicted dominance of the $\pi\pi \to \gamma\gamma$ annihilation diagram (Fig. 1b). One can view this Feynman diagram as the annihilation of a real pion with a virtual pion $\pi^-\pi^+ \to \gamma\gamma$ or, via crossing symmetry, as the transition of a real pion to a virtual pion via Compton scattering $\gamma\pi \to \gamma\pi$ (Fig. 1a). The four–

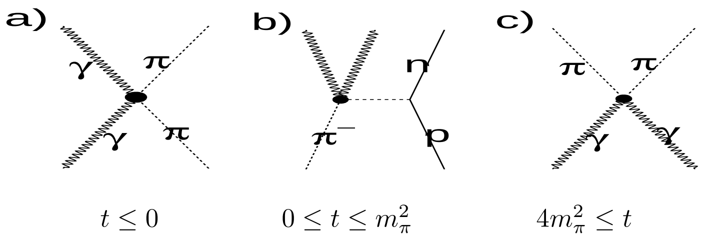

Fig. 1. a) Pion Compton scattering, b) $\pi^- p \to \gamma\gamma n$ annihilation graph c) $\gamma\gamma \to \pi\pi$

momentum transfer–squared in the $\pi^- p \to \gamma\gamma n$ reaction is $0 < t < +m_\pi^2$, compared with $t \leq 0$ for the on–shell $\gamma\pi \to \gamma\pi$ (Fig. 1a) process and $t \geq 4m_\pi^2$ for the on–shell $\gamma\gamma \to \pi\pi$ (Fig. 1c) process.

Pion Compton scattering is a probe of pion's polarizability $\alpha_E^{\pi^\pm}$ (see *e.g.* [7]). A summary of the current determinations of the pion's polarizability is shown in Table II. The extracted pion polarizabilities have large uncertainties and are (except MARK II) substantially larger than the χPT

prediction [7], $\alpha_E^{\pi^\pm} = (2.7 \pm 0.4) \times 10^{-4}\ fm^3$, which is based on a relationship between radiative pion decay $\pi \to e\nu\gamma$ and pion Compton scattering $\gamma\pi \to \gamma\pi$. This discrepancy between theory and experiment calls for more experimental attention, thus our proposal to measure two–photon capture mode of the pionic hydrogen appears timely.

TABLE II

Experimental determinations of pion electric polarizability $\alpha_E^{\pi^\pm}$

Experiment	$\alpha_E^{\pi^\pm}$ $(\times 10^{-4}\ fm^3)$	Reference
$\pi A \to \gamma\pi A$	$6.8 \pm 1.4 \pm 1.2$	Serpukhov [8]
$\pi p \to \gamma\pi p$	20 ± 12	Lebedev [9]
$\gamma\gamma \to \pi\pi$	$19.1 \pm 4.9 \pm 5.6$	PLUTO [10]
$\gamma\gamma \to \pi\pi$	2.2 ± 1.6	MARK II [10]

3. TRIUMF $\pi^- p \to \gamma\gamma n$ experiment

Using the RMC pair spectrometer [1] we propose to measure the $\pi^- p \to \gamma\gamma n$ branching ratio and its photon opening angle and energy partition dependence.

We have performed an extensive experimental and Monte Carlo studies of both pionic hydrogen and pionic carbon two–photon capture modes that included trigger tuning, acceptance optimization and background suppression [11]. These studies have proved the feasibility of the proposed experiment.

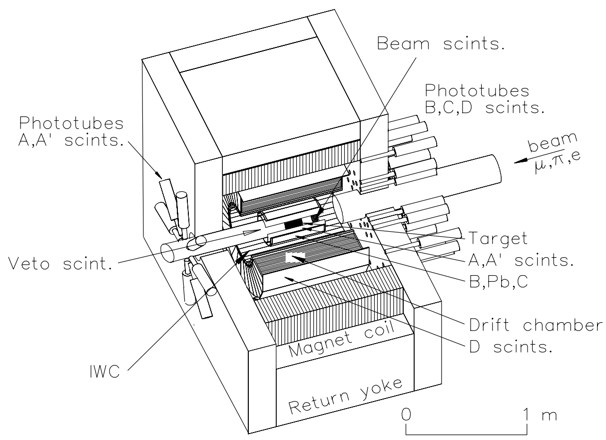

Fig. 2. Layout of the RMC photon pair spectrometer showing the liquid hydrogen target, Pb converter, cylindrical wire and drift chambers, trigger scintillators and solenoidal magnet.

Fig. 3 presents our preliminary results taken during our 1997 engineering run. Both spectra show two–photon opening angle distribution, the upper one for pionic carbon, the lower one for pionic hydrgen. The events with large opening angles ($\cos\theta\gamma\gamma \leq -0.4$) are photons from π^0 decay originating from the $\pi^- p \to \pi^0 n$ charge exchange reaction.

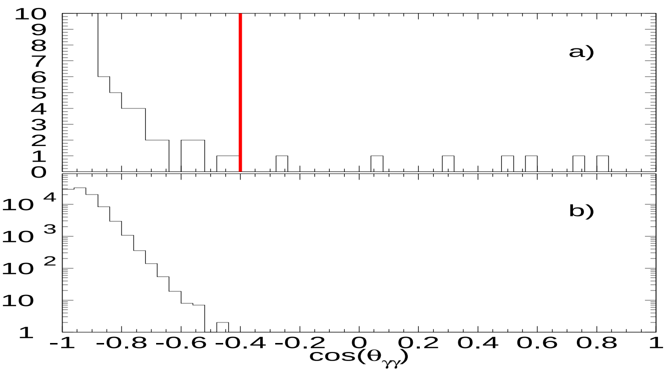

Fig. 3. Two–photon opening angle spectra: a) for pionic carbon and b) for pionic hydrogen

We have found 7 two–photon events from pionic carbon with small opening angles ($\cos\theta\gamma\gamma \geq -0.4$, see Fig. 3a) which yields B.R. $[^{12}C(\pi^-,\gamma\gamma)] = (0.8 \pm 0.3\,(\mathrm{stat.})) \times 10^{-5}$ in reasonable agreement with [5]. We also have searched for small opening angle two–photon from events pionic hydrogen and so far found none (see Fig. 3b), which results in an improved upper limit of B.R. $[\pi^- p \to \gamma\gamma n] \leq 2.8 \times 10^{-4}$.

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