PROCEEDINGS OF SCIENCE

π^0 decays with WASA-at-COSY

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The decay of the π^0 meson into an electron positron pair is heavily suppressed in the Standard Model (SM) with an expected branching ratio of 6×10^{-8} . The decay is therefore sensitive to contributions from physics beyond the SM. Recently, the KTeV collaboration at Fermilab has performed a precise measurement of the $\pi^0 \to e^+e^-$ decay branching ratio using a data sample of 795 events. The result is three standard deviations above the SM value. This has triggered speculations of e.g. a contribution from a light vector boson responsible for the annihilation of a hypothetical light dark matter particle. In one scenario a new light vector boson U (mass 10-100 MeV) is weakly coupled to the π^0 . This boson is expected to decay into a lepton pair and hence gives an extra contribution to the $\pi^0 \to e^+e^-$ branching ratio. The aim for WASA-at-COSY is to confirm the KTeV measurement. The status of the analysis is presented and prospects for a measurement at the KTeV sensitivity are discussed.

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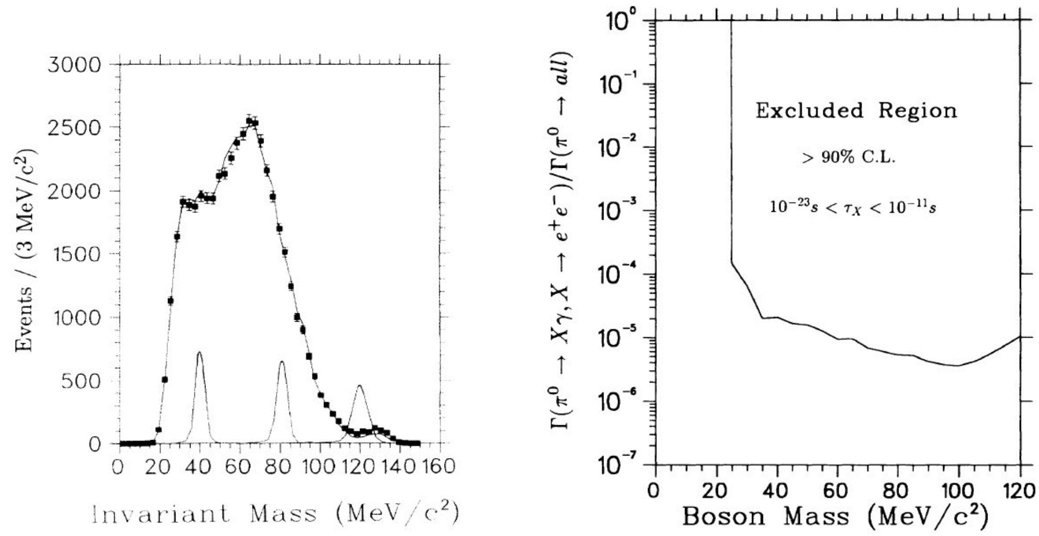

Figure 1: SINDRUM result of U boson search in $\pi^0 \to e^+e^-\gamma$[2]. Left: Distribution of e^+e^- invariant mass for class-A events which are predominantly $\pi^0 \to e^+e^-\gamma$. Right: The region of M_X this experiment can exclude, at $>90\%$ confident level, for branching ratio $\Gamma(\pi^0 \to X\gamma, X \to e^+e^-)/(\pi^0 \to all)$

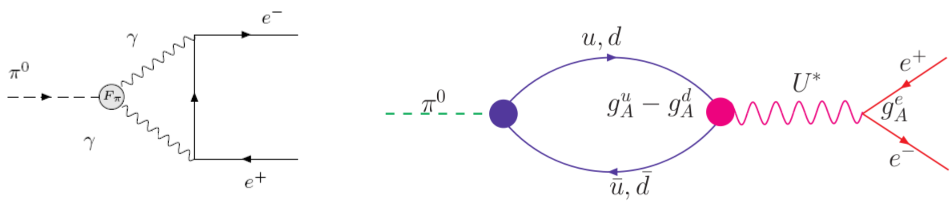

Figure 2: Feynman diagram of $\pi^0 \to e^+e^-$ in SM (left) and through a new vector boson (right)[4].

1. Introduction

Since the π^0 is the lightest known hadron and can only decay via the electroweak interaction. The most common decay is into 2γ (BR 98.82 %) and the next probable are conversion decays with one or two electron positron pairs. The transition form factor of $\pi^0 \to e^+e^-\gamma$ (BR 1.2 %) and $\pi^0 \to e^+e^-e^+e^-$ (BR 3 $\times 10^{-5}$) reveals the electromagnetic structure of the decaying meson. The e^+e^- mass distribution probes the existence of a new hypothetical boson that couples to a virtual photon[1]. The current upper limit from the $\pi^0 \to e^+e^-\gamma$ decay is set by the SINDRUM collaboration[2] based on 100.000 events above 25 MeV e^+e^- invariant mass (Fig. 1). For $\pi^0 \to e^+e^-$ the KTeV Collaboration found 795 events in $K_L \to 3\pi^0$ [3]. They measured a BR of $(7.49 \pm 0.29) \times 10^{-8}$ which exceeds the standard model prediction of $(6.23 \pm 0.09) \times 10^{-8}$[4]. This leads to some speculation about new physics. One promising theory is a proposes new boson U that couples both to quarks and leptons[5] (Fig. 2). Excess positrons from the U boson decay could also explain the intensity and shape of the 511 keV line from the galactic center[6].

2. Analysis

The aim for WASA-at-COSY is to measure the leptonic decays $\pi^0 \to e^+e^-$, $\pi^0 \to e^+e^-e^+e^-$ and $\pi^0 \to e^+e^-\gamma$. Even if $\pi^0 \to e^+e^-$ has a lower BR the decay $\pi^0 \to e^+e^-e^+e^-$ is the hardest to measure of those three. This is because leptons can only be measured in the central detector (CD) with θ above 20^o and energy above 10 MeV which lowers the acceptance for the simultaneous detection of four leptons. The π^0 is produced in proton proton collisions with WASA-at-COSY in Jülich. A one week test measurement has been performed during spring 2010. The kinetic beam energy was set to 550 MeV in order to maximize the π^0 cross section below threshold for the $pp\pi^-\pi^+$ channel. The advantage of excluding π^- production is a clean e^- sample for negatively charged tracks.

2.1 π^0 tagging

The missing mass of the two protons is used for π^0 tagging. Fig. 3 shows clear 2γ and $e^+e^-\gamma$ signals respectively. At the given energy the two protons can be detected both in the forward detector (FD, $3^o < \theta < 20^o$) and the froward part of the central detector ($20^o < \theta < 45^o$). In Fig. 4 data from the spring 2010 run are presented. The main background are two elastic proton collisions in accidental coincidence. The case of 1 proton in FD and one in CD has the largest angular acceptance (60%) but the case of two protons in the FD presently has a much higher signal to background ratio at trigger and analysis level. Therefore the main trigger was set to 2 FD. However tagging rates can be increased in a future run with improved trigger possibilities.

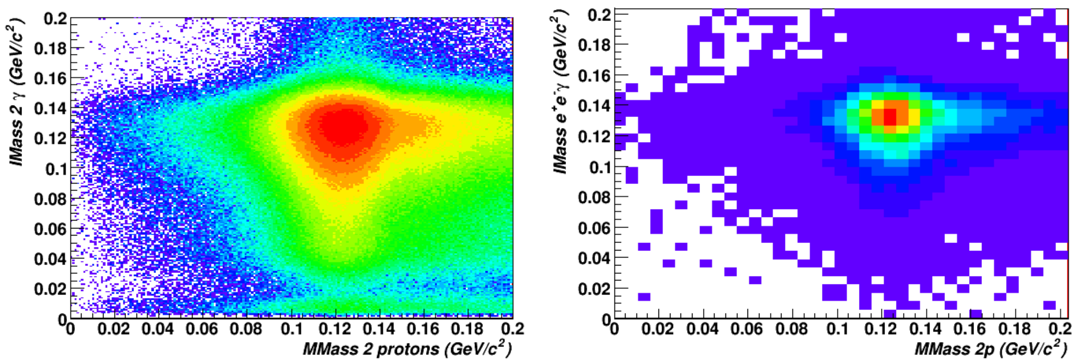

Figure 3: Invariant mass vs missing mass of two protons in the FD. Left: $\pi^0 \to 2\gamma$ Right: $\pi^0 \to e^+e^-\gamma$.

2.2 $\pi^0 \to e^+e^-\gamma$

There's about 15 million $e^+e^-\gamma$ events in the current data set. Out of those 1.5 million is reconstructed (Fig. 5). Out of those 50% is background from external conversion of one photon mainly from the $\pi^0 \to 2\gamma$ channel. The main cut for reducing such events is the vertex cut since photon conversions are most probable to occur at the beam tube 30 mm from the interaction point. After cuts 40.000 $\pi^0 \to e^+e^-\gamma$ events are left with low background and high invariant mass resolution ($\sim 4\%$). The Dalitz distribution in Fig. 6 shows no U boson peak and follows the existing $\pi^0 \to e^+e^-\gamma$ transition formfactor. Tighter vertex cuts at the expense of efficiency are possible to

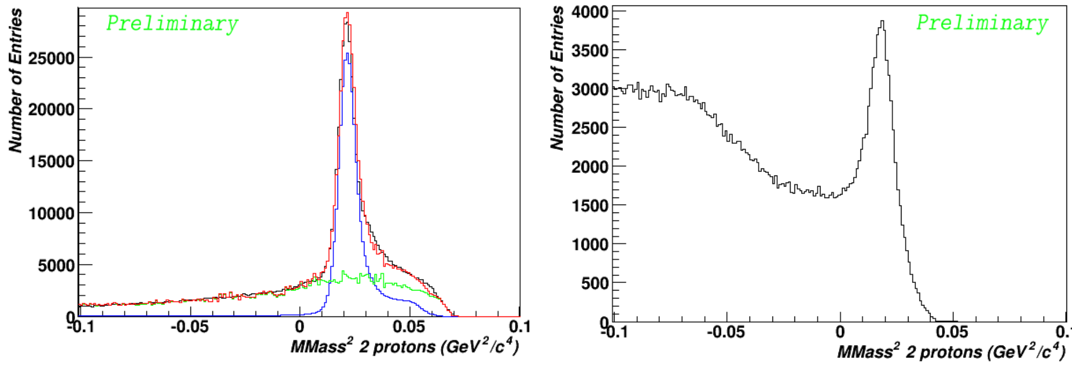

Figure 4: Missing mass squared of two protons. Left: Both protons in FD. Right: One proton in FD and one in CD.

exclude the pair production peak at 20 MeV, so that an upper limit of U boson exclusion could be set in this region.

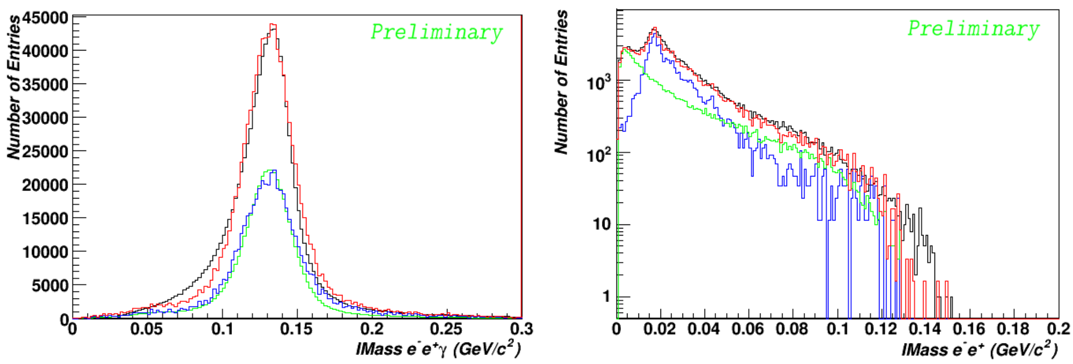

Figure 5: Left: Invariant mass distribution of $e^+e^-\gamma$. Right: Invariant mass of e^+e^- pair from the $e^+e^-\gamma$ peak. Black: Data; Green: MC $\pi^0 \to e^+e^-\gamma$; Blue: Background from pair production in the detector $\pi^0 \to (\gamma \to e^+e^-)\gamma$; Red: Total MC sample $\pi^0 \to e^+e^-\gamma$.

2.3 $\pi^0 \to e^+e^-$

In order to identify the $\pi^0 \to e^+e^-$ candidates in the high-energy tail of the $\pi^0 \to e^+e^-\gamma$ events one needs good momentum resolution. To reach the desired resolution even tighter cuts are set than in the $\pi^0 \to e^+e^-\gamma$ case. These cuts also completely remove the external conversion in this interesting π^0 region and only some remains around 20 MeV are left. A peak of 20 $\pi^0 \to e^+e^-$ event candidates is visible in the data (Fig. 7). A comparision to MC simulations show that there should be about 25 % background events from $\pi^0 \to e^+e^-\gamma$ left with a lost photon.

3. Conclusion and Outlook

From a one-week test run so far about 40.000 $\pi^0 \to e^+e^-\gamma$ events has been reconstructed. The e^+e^- mass distribution could extend the upper limit on U Boson searches to lower masses. The 15 event candidates of $\pi^0 \to e^+e^-$ after background subtraction motivate a longer production run in the future. Improved trigger conditions could give a rate of 50 $\pi^0 \to e^+e^-$ events per week.

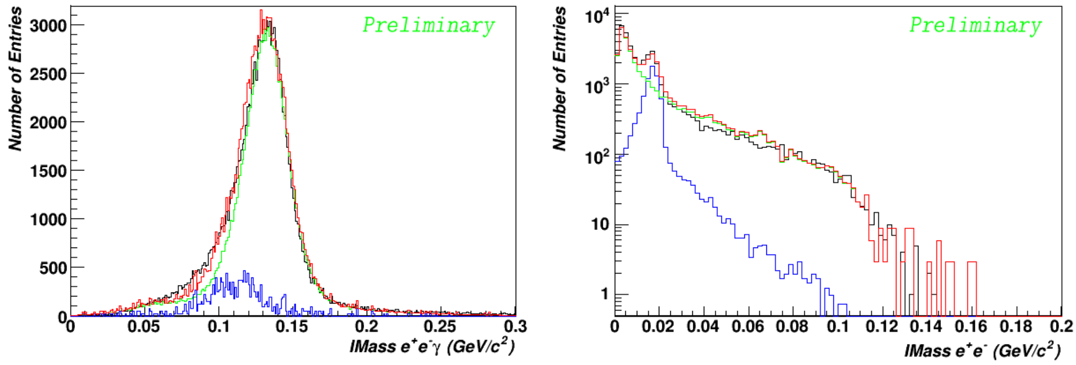

Figure 6: Same as Fig. 5 but after vertex cuts.

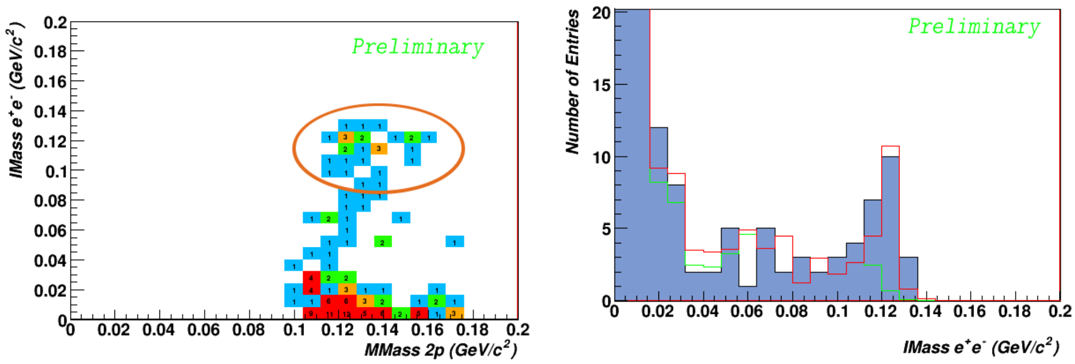

Figure 7: Left: e^+e^- invariant mass *vs.* missing mass of two protons in the FD. Right: invariant mass of e^+e^- pair in the central detector. Blue filled: Data; Green: MC $e^+e^-\gamma$ background; Red: MC simulation of $\pi^0 \to e^+e^-$ plus $e^+e^-\gamma$ and pair production background.

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