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SEARCH FOR A NEW GAUGE BOSON IN π^0 LEPTONIC DECAYS WITH WASA-AT-COSY

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Abstract

The WASA-at-COSY detector has recorded a high statistic run of π^0 decays. A search for a new vector boson in the e^+e^- invariant mass spectrum of $\pi^0 \to e^+e^-\gamma$ decay has been done. No new boson has been found and an upper limit has been set in the mass range 30-100 MeV. Also a search for the rare decay $\pi^0 \to e^+e^-$ was carried out. Here 15 event candidates were found.

1 Introduction

Several astrophysical observations of positron excess [1) - 4)] suggest that a new gauge boson [5)] could exist in the MeV scale since no muon/pion excess has been found at the same time. Leptonic decays of π^0 are a good place to look for such a new boson since one can create e^+e^- pairs abundantly with low background and compare a well formulated theory . The energy range of

Table 1: *BR of observed π^0 decays* [6)]

	BR
2γ	$(98.823 \pm 0.034)\%$
$e^+e^-\gamma$ (dalitz decay)	$(1.174 \pm 0.035)\%$
$e^+e^-e^+e^-$ (double dalitz decay)	$(3.34 \pm 0.16)10^{-5}$
e^+e^-	$(6.46 \pm 0.33)10^{-8}$

e^+e^- pairs from π^0 also covers the region where a new boson could explain the discrepancy between the standard model prediction and experimental data of the muon g-2.

2 Theory

2.1 π^0 meson

The π^0 meson is the lightest known hadron and hence it only decays via electroweak interaction. The most common decay is the decay to 2γ (see tab. 1). Other known decays proceed via one or two virtual photons to electron positron pairs. The π^0 meson is a pseduscalar and hence the decay to only one e^+e^- pair is rare since it has to go via a two photon process. More common are decays via one virtual photon i.e. $e^+e^-\gamma$.

2.2 New Boson

The large amount of virtual photons in its decays makes the π^0 a good candidate for looking for a new vector boson. In the simplest model this boson is a U(1) boson with weak coupling to the ordinary photon [5)]. Extensive searches have been done for this "dark photon" by many experiments and an upper limits have been set in a wide mass range. A new light dark boson is not necessarily a vector particle. Other theories use an axial vector instead. The boson would then not bee seen as a mass peak in the lepton-antilepton invariant mass but could still enhance BR if it's involved in decays of the π^0. The discrepancy between the value found by the KTeV experiment $(7.48 \pm 0.29_{stat} \pm 0.25_{syst}) \times 10^{-8}$ [7)] and the SM prediction $(6.23 \pm 0.09) \times 10^{-8}$ [8)] of the $\pi^0 \to e^+e^-$ BR might be due to this new boson.

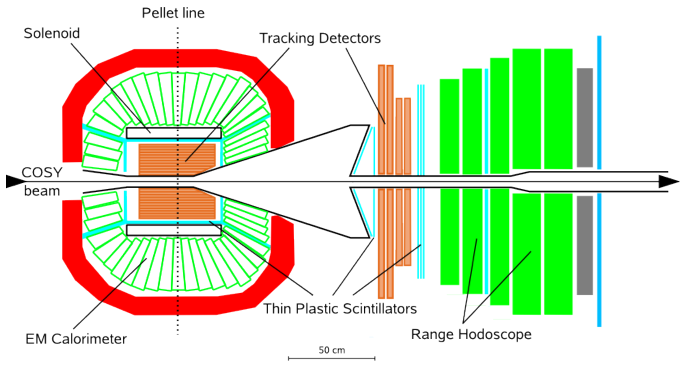

Figure 1: *Wasa-at-Cosy setup*

3 WASA-at-COSY

The WASA detector setup [9] is located at the COSY accelerator in Jülich Germany [10]. The accelerator has the possibility to accelerate protons and deuterons up to 3.7 GeV. For π^0 production the kinetic energy has been chosen to be 550 MeV. This is to maximize the production cross-section (1.12 mbarn) below the two pion threshold in pp collisions. Small pellets of frozen hydrogen serves as internal target. The advantage of pellets is to minimize external photon conversion in the target. The WASA detector consists of a forward detector (FD) for scattering products and a central detector (CD) for measurement of decays (see fig. 1). The FD measures kinetic energy in the range hodoscope, ΔE and time by plastic scintillators and angles by tracking detectors. In the CD energy are measured by the electromagnetic calorimeter, ΔE and time by plastic scintillators and the Tracking detector (MDC) measures charge, angles and momentum.

4 Results

4.1 $\pi^0 \to e^+e^-\gamma$

4.1.1 Data selection

To obtain an e^+e^- invariant mass spectrum of the $\pi^0 \to e^+e^-\gamma$ decay one could look for the $e^+e^-\gamma$ invariant mass and pp missing mass spectra respectively.

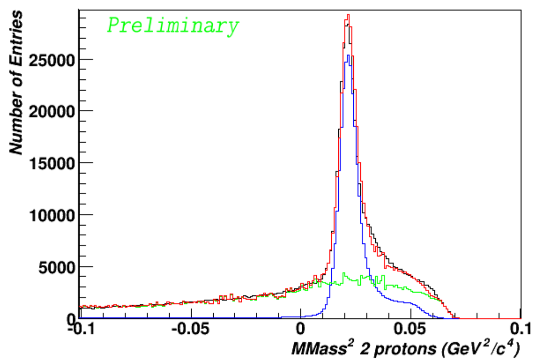

Figure 2: *Missing Mass with respect to two protons identified in the Forward Detector. Black: data, Blue: MC simulations of* $\pi^0 \rightarrow e^+e^-\gamma$*, Green MC coincidence of two elastic pp events, Red: MC sum.*

Such control samples have been selected (see fig. 2 and 3). However a larger event sample is obtained with only 1 proton in the FD, e^+e^- in the CD and no constraints on neutral tracks. The full e^+e^- mass spectrum (fig. 4) then contains $1.2 * 10^6$ $\pi^0 \rightarrow e^+e^-\gamma$ events with a background of similar size from external conversion in the decay $\pi^0 \rightarrow 2\gamma$. Background from random coincidence events with a miss identification of π^+ as e^+ is only important above 100 MeV.

The background from external conversion can be significantly reduced by the fact that almost no conversion take place in the target but most of the seen one are produced in the beryllium beam-pipe. The beam-pipe is located at a radius of 30 mm away from the target so conversion events can be suppressed by choosing tracks that intersect closer than 22 mm from the target (see fig. 5) and the e^+e^- invariant mass calculated at the beamtube should be larger than zero. The final spectrum (fig. 6) contains 500k $\pi^0 \rightarrow e^+e^-\gamma$ decays that can be used to set an upper limit for the decay $\pi^0 \rightarrow U\gamma$.

4.1.2 New boson search

The invariant mass spectrum in figure 7 does not contain any signal from a new boson and a new upper limit can bee set. The latest attempt to find the decay $\pi^0 \rightarrow \gamma U$ was done by the SINDRUM collaboration [11]. The upper

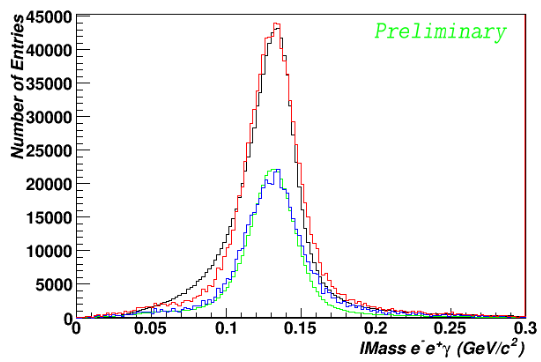

Figure 3: *Invariant Mass* γe^+e^-*. Black: data, Green: MC simulations of* $\pi^0 \rightarrow e^+e^-\gamma$*, Blue: MC pair production in* $\pi^0 \rightarrow 2\gamma$ *decay, Red: MC sum.*

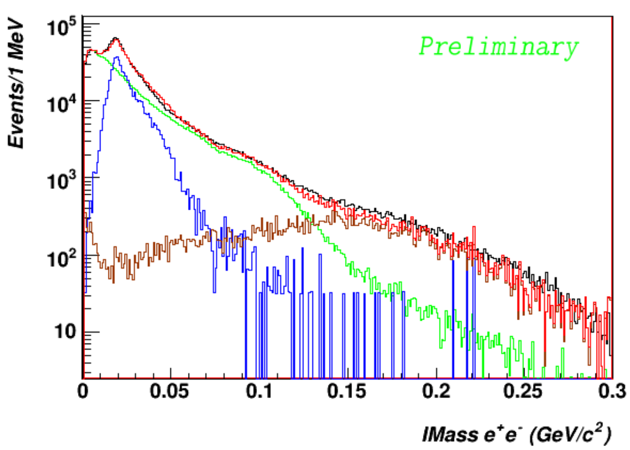

Figure 4: *Invariant Mass of* e^+e^-*. Black: data, Green: MC simulations of* $\pi^0 \rightarrow e^+e^-\gamma$*, Blue: MC pair production in* $\pi^0 \rightarrow 2\gamma$ *decay, Brown: MC Coincidence of* $\pi^0 \rightarrow e^+e^-\gamma$ *and* π^+ *decays when* π^+ *is miss identified as a positron, Red: MC sum.*

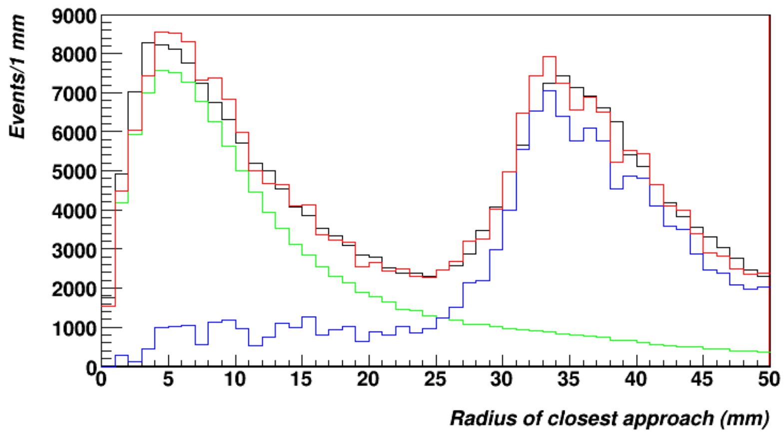

Figure 5: *Distance from target position to closest approach of an* e^+e^- *pair in MDC. Black: data, Green: MC simulation of* $\pi^0 \to e^+e^-\gamma$*, Blue: MC pair production from* $\pi^0 \to 2\gamma$ *decay, Red: MC sum.*

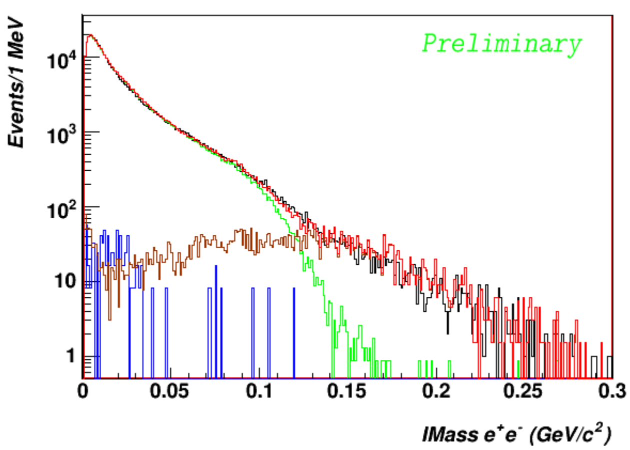

Figure 6: *Invariant Mass of* e^+e^- *after conversion reduction cuts. Black: data, Green: MC simulation of* $\pi^0 \to e^+e^-\gamma$*, Blue: MC pair production from* $\pi^0 \to 2\gamma$ *decay, Brown: MC Coincidence of* $\pi^0 \to e^+e^-\gamma$ *and* π^+ *decays when* π^+ *is misidentified as a positron, Red: MC sum.*

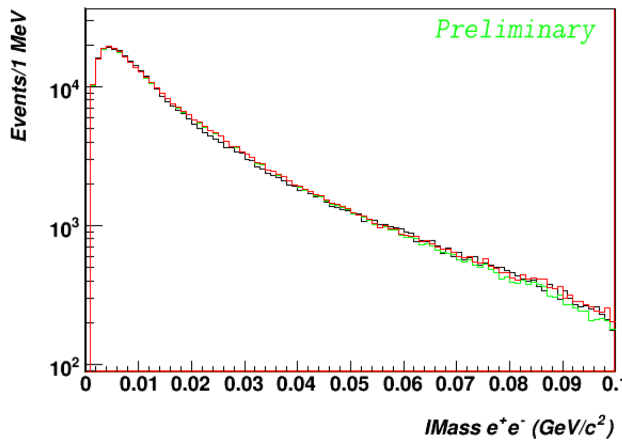

Figure 7: *Invariant Mass of* e^+e^- *after conversion reduction cuts in the range 0-100* MeV/c^2. *Black: data, Green: MC simulation of* $\pi^0 \to e^+e^-\gamma$, *Blue: MC pair production from* $\pi^0 \to 2\gamma$ *decay, Brown: MC coincidence of* $\pi^0 \to e^+e^-\gamma$ *and* π^+ *decays when* π^+ *is misidentified as a positron, Red: MC sum.*

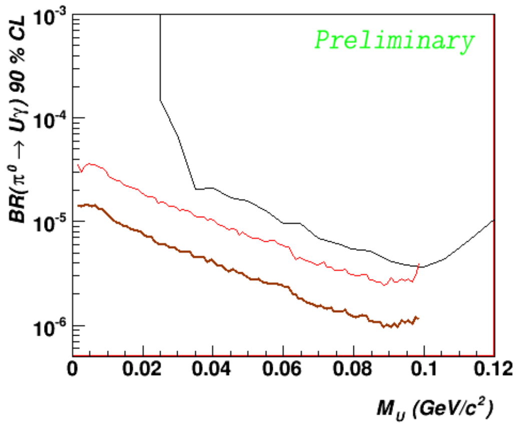

Figure 8: *U.L. for the decay* $\pi^0 \to U\gamma \to e^+e^-\gamma$. *Black: Sindrum* [11], *Red: WASA 2010, Brown: WASA 2012 (expected).*

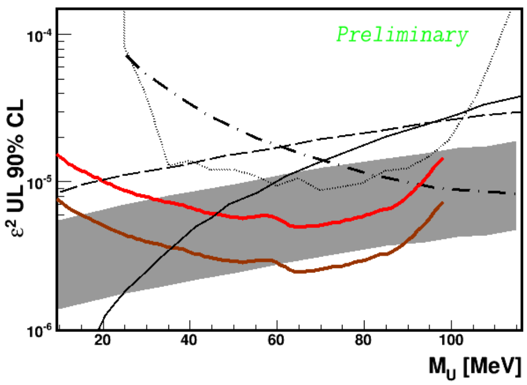

Figure 9: *U.L* ϵ^2. *Dotted: Sindrum* [11], *Red: WASA 2010, Brown: WASA 2012 (expected) Dashed: muon g-2* [13] *Black: electron g-2* [13] *Dotted dashed: KLOE* [14]. *Grey region: Motivated region within* 2σ *by discrepancy between experiment and SM prediction of muon g-2* [13].

limit then was based on a lower statistics sample only for events above 25 MeV/c^2. The new upper limit derived from this work is shown in figure 8. The WASA collaboration has also a larger data sample recorded in 2012 that are under investigation. Also a new upper limit expectation based on the known statistical improvement are presented in fig 8. The branching ratio $\pi^0 \to \gamma U$ is related to ϵ^2 by [12]:

$$\frac{\Gamma(\pi^0 \to \gamma U)}{\Gamma(\pi^0 \to \gamma\gamma)} = \epsilon^2 |F(M_U^2)|^2 \left(1 - \frac{M_U^2}{M^2}\right)^3 \tag{1}$$

where $|F(M_U^2)|^2$ is the Formfactor for the new boson. If one assumes the Formfactor to be 1 one get a new upper limit in the range 45-90 MeV.

4.2 $\pi^0 \to e^+e^-$

The decay $\pi^0 \to e^+e^-$ have a low BR. The cylindrical shape of the MDC gives an angular dependence of resolution. Choosing a limited part of the detector and cross check with the vertex resolution gives the desired resolution below 2.5%. The reconstruction efficiency are however the same as $\pi^0 \to e^+e^-\gamma$.

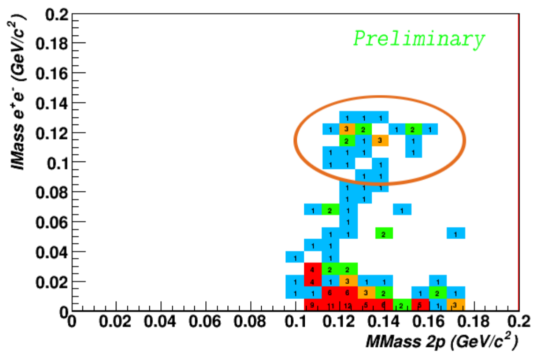

Figure 10: *Missing mass with respect to two protons in FD vs Invariant Mass of* e^+e^- *for events with no photon and high resolution.*

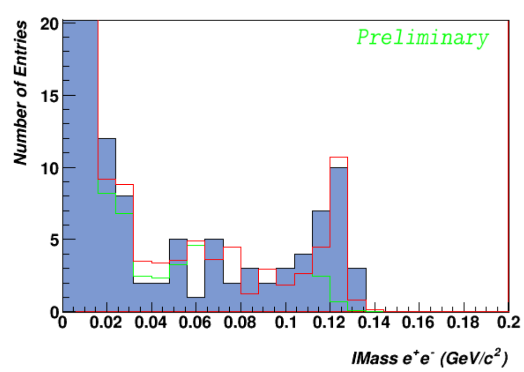

Figure 11: *Invariant Mass of* e^+e^- *after conversion reduction cuts. Blue filled: data, Green: MC simulation* $\pi^0 \to e^+e^-\gamma$*, Red: MC sum* $\pi^0 \to e^+e^-\gamma$ *and* $\pi^0 \to e^+e^-$.

This is because in $\pi^0 \to e^+e^-\gamma$ the e^+e^- lies to close to be separated from each other in a large part of phase space. The 2010 data sample contains 15 candidates. Unfortunately a to low sample to draw any conclusion so far. The sample are sensitive to calibration of the tracking device in the CD. So with the new higher statistical run from 2012 and extra effort in calibration it would be possible to find a sample in the range 75-300.

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