Results on $\pi^0$ and $\eta$ TFF from WASA-at-COSY

- Status of WASA-at-COSY
- $\pi^0 \rightarrow e^+e^−γ / e^+e^−$
- $\eta \rightarrow π^+π^−γ$
- $\eta \rightarrow e^+e^−γ / e^+e^−e^+e^− / e^+e^−$
- Outlook

Andrzej Kupść
Uppsala University

EINN2013 Paphos, October 29, 2013
WASA Proposal 1987:
key experiments: \( \pi^0, \eta \rightarrow e^+e^- \)
WASA detector

NIM A594,339
Meson production

\[
p_{d} \rightarrow 3\text{He}X \quad O(\mu b) \quad 0.4\mu b \quad 85\text{nb} \quad 0.6\text{nb}
\]

\[
p_{p} \rightarrow p p X \quad 1 \text{ mb} \quad 10\mu b \quad 10\mu b \quad 300\text{nb}
\]

\[L < 10^{32} \text{cm}^{-2} \text{s}^{-1} = 0.1 \text{ nb/s}\]
Meson tagging

Meson tagging

Missing Mass $^3\text{He}$
2008+2009
$p+d$ 1.0 GeV/c$^2$
$\sim 30 \times 10^6$ events in peak

$pd \rightarrow ^3\text{He}\eta$

$\text{Missing Mass} = \sqrt{(E_{\text{in}} - E_{\text{out}})^2 - (P_{\text{in}} - P_{\text{out}})^2}$

$2$ FD protons

Selection of
$\eta \rightarrow \pi^+\pi^0$
2010 1.4 GeV/c$^2$
$p+p$

$pp \rightarrow pp\pi^0$

Preliminary
Cut based selection: 72,000 signal events

With kinematical fit: 5,600 signal events (1/3 of collected data)

L. Heijkenskjöld, S. Sawant, F. Anjum Khan

$E_{\gamma_1}, E_{\gamma_2} > 230\text{MeV}$

no strong condition on decay system!

J. Zlomanczuk
Decay products
Low energy QCD

$\Gamma (P \rightarrow \gamma \gamma )$  

$F_P (q_1^2, q_2^2)$

**Dark photon (U boson)**

$\gamma^* \rightarrow \pi^0, \eta$

$\omega \rightarrow \pi^0, \gamma^*$

$e^+ e^- \rightarrow \pi^0 \omega$

$\phi \rightarrow \eta \gamma^*$

$\eta \rightarrow \pi^0, \gamma^*$

$\eta' \rightarrow \gamma^*$

$\mu \rightarrow \nu \gamma^*$

**Access to $q^2 < 0$**

**LbL for $\alpha \mu$**
Analysis: $\pi^0 \rightarrow \gamma e^+ e^-$
Vertex r 20 mm + PID

$\pi^0 \rightarrow e^+ e^- \gamma$  $\pi^0 \rightarrow \gamma \gamma$ (mm)
Extraction of: $\pi^0 \rightarrow \gamma U \rightarrow \gamma e^+e^-$

\[ N^d_i / N_{Tot} = \sum_j S_{ij} \varepsilon_j \nu_j (\pi^0 \rightarrow e^+e^-\gamma) + S_{ik} \varepsilon_k \beta_k \]
Analysis: $\pi^0 \rightarrow \gamma e^+ e^-$

- $5 \times 10^5 \pi^0 \rightarrow e^+ e^- \gamma$
- extract $F = 1 + aq^2 / m_{\pi}^2$
- $\Delta a / a (\text{stat}) \approx 0.3$

- $>5 \times 10^6 \pi^0 \rightarrow e^+ e^- \gamma$
  (2013 data)

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

PhD C-O. Gullström
History of $\pi^0 \to e^+ e^-$ measurements

- Unitary bound (model independent) $BR \geq 4.75 \times 10^{-8}$
- Experiment: KTeV (794 events from $K_L \to 3\pi^0$):
  \[
  BR(\pi^0 \to e^+ e^-) = (6.44 \pm 0.25_{stat} \pm 0.22_{syst}) \times 10^{-8}
  \]
  \[
  BR_{\text{no-rad}}(\pi^0 \to e^+ e^-) = (7.48\pm0.29_{stat}\pm0.25_{syst}) \times 10^{-8}
  \]

PRD75:012004(07)
Analysis: $\pi^0 \rightarrow e^+e^-$

Data prel.

$\pi^0 \rightarrow e^+e^- (arb)$

Fine tuned cuts

$\gamma$ veto + MMpp cut

Data

MC
$\eta$ decays

- $pd \rightarrow ^3He\eta$ data ($3 \times 10^6$):
  - $\eta \rightarrow \pi^+\pi^-\gamma$
  - $\eta \rightarrow \pi^+\pi^-\pi^0$
  - $\eta \rightarrow e^+e^-\gamma$
  - BR: $\pi^+\pi^-\gamma/e^+e^-\gamma/e^+e^-\pi^+\pi^-/e^+e^-e^+e^-$

- $pp \rightarrow pp\eta$:
  - 18w running, $>5 \times 10^8$

C.F. Redmer, P. Adlarson, F.S. Bergmann, D. Coderre, M. Hodana, P. Wurm
$\eta \rightarrow \pi^+ \pi^- \gamma$

\[
\frac{d\Gamma}{ds} = \left| A (1 + \alpha s + \ldots) F_V(s) \right|^2 K_P(s)
\]

\[e^+ e^- \rightarrow \pi^+ \pi^-\]

$\alpha = 1.89 \pm 0.25_{\text{stat}} \pm 0.59_{\text{syst}} \text{ GeV}^{-2}$

[WASA PLB707 (2012) 243]

$\alpha = 1.31 \pm 0.08_{\text{stat}} \pm 0.40_{\text{syst}} \text{ GeV}^{-2}$

[KLOE PLB718 (2013) 910]
Analysis: $\eta \rightarrow \gamma e^+ e^-$

$\eta \rightarrow \gamma \gamma$

$\eta \rightarrow \gamma e^+ e^-$

<5% data (2012)

basic sel.

M. Berlowski, D. Pszczel, A. Goswami
Analysis: \( \eta \rightarrow \gamma e^+e^- \)

**WASA-at-COSY**
- \( pd \rightarrow 3Hn\eta \) (1/3 data)
  - selective cuts
  - \( \sim 520 \text{ ev (prel.)} \)
  - reanalysis KFit
- \( pp \rightarrow pp\eta \) (1/9 data)
  - cuts/ KFit
  - expect:
    - 50k – 100k \( \eta \rightarrow e^+e^-\gamma \)

\[ \begin{align*}
\text{Counts} & \quad \text{1.0GeV } p+d \\
\text{based on } 10^7 3Hn\eta \\
\text{MC sum: } & \quad \eta \rightarrow e^+e^+\gamma \\
& \quad \eta \rightarrow \gamma\gamma \\
& \quad \eta \rightarrow \pi^\pm\pi^\mp \\
& \quad \eta \rightarrow 3\pi^0
\end{align*} \]
\[ \eta \rightarrow e^+ e^- \]

### Table

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Conclusions/Outlook

- Last experiments 2014
- Finished data taking on $\pi^0, \eta$:
  $>5 \times 10^7 \pi^0 \rightarrow e^+e^-\gamma$
  $50k - 100k \eta \rightarrow e^+e^-\gamma$