Meson Physics with Crystal Ball at MAMI

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Institute for Nuclear Physics
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Prague, 17th June 2013
Outline

- Crystal Ball Set-up at MAMI
- $\eta'$ Cross Sections
- Transition Form Factor from $\eta \to e^+e^-\gamma$ Revisited
- T and F Asymmetry in $\eta$ Photoproduction
- Summary
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- $E_e < 1604 \text{ MeV}$
- $\sigma_E < 0.1 \text{ MeV}$
- High current (110$\mu$A)
- High polarisation (85%)
- Duty factor 100%
- ~7000 h/year running experiments

Mainz Microtron

- ME
- MS
- A1
- A2
- RTM2
- RTM3
- HDSM

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MesonNet Workshop
Prague, 17th June 2013
A2: Real Photon Experiments:
- Glasgow tagging spectrometer
- Crystal Ball / TAPS
- hermetic photon spectrometer
- Meson Factory

A1: Electron Scattering:
- focusing magnetic spectrometers
- neutron detection, spin precession
- Kaon spectrometer (KAOS/A1)

PRISMA/SFB 1044:
- Dark Photon Search
- El.-weak Mixing Angle
Real Photons in A2

High energy resolution: $\Delta E \approx 2\text{MeV}$ at $E_{\gamma} = 883\text{ MeV}$

$\Delta E \approx 4\text{MeV}$ at $E_{\gamma} = 1558\text{ MeV}$

Linearly and circularly polarised photon-beam

Tagging range: 5.1 to 93% of $E_{\gamma}$ → Maximum energy tagged for $E_0 = 1604\text{ MeV}$ is $1491\text{ MeV}$

Data form CB@MAMI, CB@ELSA, CLAS, SAPHIR
End-Point-Tagger

- Installation of EPT during 2012

Same working principle as main tagging spectrometer

\[ E_{\gamma} \approx 1445-1595 \text{ MeV} \]

\[ \Delta E_{\gamma} \approx 2.5 \text{ MeV} \]

Non-permanent installation in front of main Tagger
Crystal Ball:
672 NaI(Tl) crystals
93.3% of total solid angle
Each crystal equipped with PMT

\[ \sigma = \frac{2\%}{E_y} \left( \frac{E_y}{GeV} \right)^{0.25} \]
\[ \Delta t = 2.5 \text{ ns FWHM} \]
\[ \frac{E_y}{GeV} \]
\[ \sigma(\theta) = 2^\circ ... 3^\circ \]
\[ \sigma(\phi) = \frac{2^\circ ... 3^\circ}{\sin(\theta)} \]

TAPS:
Up to 510 BaF$_2$ crystals
Polar acceptance: 4-20°

\[ \Delta t = 0.5 \text{ ns FWHM} \]
\[ \frac{\sigma}{E_y} = \frac{0.79\%}{\sqrt{E_y}/GeV} + 1.8\% \]
Targets

- **LH$_2$/lD$_2$** used for high rate meson production ($\eta/\eta'$)
  - Length: 3cm, 5cm, 10cm

- **$l^3$He/$l^4$He**

- **Polarised Butanol/D-Butanol**
  - Transverse and longitudinal polarisation
  - Length: 2 cm
  - Dynamic Nuclear Polarisation
  - Max. Polarisation: 90%
  - Holding field: 0.44 T
  - Relaxation time: $\tau \sim 1000h$

- **Solid Targets**
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$\eta' \rightarrow \eta \pi^0 \pi^0$ Invariant Mass

$E_\gamma = 1430 \pm 10$ MeV

$E_\gamma = 1450 \pm 10$ MeV

$E_\gamma = 1470 \pm 10$ MeV

$E_\gamma = 1490 \pm 10$ MeV

$E_\gamma = 1510 \pm 10$ MeV

$E_\gamma = 1530 \pm 10$ MeV

$E_\gamma = 1550 \pm 10$ MeV

$E_\gamma = 1570 \pm 10$ MeV

S. Prakhov (UCLA)
P. Ott (Mainz)
Using $\eta' \to \eta \pi^0 \pi^0$

\[ E_\gamma = 1450 \pm 10 \text{ MeV} \quad \text{Preliminary} \]
\[ E_\gamma = 1470 \pm 10 \text{ MeV} \quad \text{Preliminary} \]
\[ E_\gamma = 1490 \pm 10 \text{ MeV} \quad \text{Preliminary} \]
\[ E_\gamma = 1510 \pm 10 \text{ MeV} \quad \text{Preliminary} \]

\[ E_\gamma = 1530 \pm 10 \text{ MeV} \quad \text{Preliminary} \]
\[ E_\gamma = 1550 \pm 10 \text{ MeV} \quad \text{Preliminary} \]
\[ E_\gamma = 1570 \pm 10 \text{ MeV} \quad \text{Preliminary} \]

\[ \sigma_{\text{tot}} = 0.321 \pm 0.019 \mu b \]
\[ \sigma_{\text{tot}} = 0.491 \pm 0.018 \mu b \]
\[ \sigma_{\text{tot}} = 0.580 \pm 0.020 \mu b \]
\[ \sigma_{\text{tot}} = 0.680 \pm 0.022 \mu b \]

\[ \sigma_{\text{tot}} = 0.709 \pm 0.022 \mu b \]
\[ \sigma_{\text{tot}} = 0.855 \pm 0.029 \mu b \]
\[ \sigma_{\text{tot}} = 0.874 \pm 0.034 \mu b \]

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η' Programme

Status now:

- **EPT** successfully in operation
- Preliminary result for **photoproduction cross section** near threshold
- Preliminary result for $\eta'\rightarrow\eta\pi^0\pi^0$ Dalitz plot (limited statistics)
- MC background studies for $\eta'\rightarrow e^+e^-\gamma$ and first glance at data

DAQ Improvement:

- New trigger system (FPGA based)
- Faster DAQ PCs
  → Factor of 2 in speed gained
- Sep. 2013: Further DAQ upgrade
  → Additional factor of 2 in speed?

Next η' Production:

- EPT installation in beam in **summer/fall 2014**
- Beamtime estimate underway
- Measure with **x4 speed** and longer period
- Goal: 400,000 $\eta'\rightarrow\eta\pi^0\pi^0$ (Dalitz plot analysis)
  ~200-300 $\eta'\rightarrow e^+e^-\gamma$ (Transition Form Factor)

A. Denig, M. Ostrick, P. Ott, S. Prakhov, M. Unverzagt, S. Wagner
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Previous Analysis of $\eta$ TFF


- Based on kinematic cuts
- Small amount of data
- Limited photoproduction energy range

$$\Gamma^{-2} = (1.92 \pm 0.35_{\text{stat}} \pm 0.13_{\text{syst}}) \text{ GeV}^{-2}$$
New Analysis of $\eta$ TFF

- Based on kinematic fitting
- $3\times$ more data
- Full $\eta$ photoproduction range accessible at MAMI used
- 18,000 events (no proton requirement: 22,000 events)

$m(e^+e^-)=45\pm5$ MeV

$m(e^+e^-)=285\pm5$ MeV

Solid line: Pole-approximation fit Normalisation and $\Lambda$ as free parameters

$|F^2|$, $\chi^2$/ndf = 38.36/36

$p_0 = 0.9794 \pm 0.01109$

$p_1 = 1.952 \pm 0.1481$
New Result on $\eta$ TFF

S. Prakhov, M. Unverzagt et al., to be submitted to Phys. Rev. soon

$\Lambda^{-2} = (1.95 \pm 0.15_{\text{stat}} \pm 0.05_{\text{syst}}) \text{ GeV}^{-2}$ preliminary

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## Polarisation Observables T and F

<table>
<thead>
<tr>
<th>Beam</th>
<th>Target</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
</tr>
<tr>
<td>unpolarized</td>
<td>$\sigma_0$ 0 $T$ 0</td>
</tr>
<tr>
<td>linear pol.</td>
<td>$-\Sigma$ $H$ $(-P)$ $-G$</td>
</tr>
<tr>
<td>circular pol.</td>
<td>0 $F$ 0 $-E$</td>
</tr>
</tbody>
</table>

\[
\frac{d\sigma}{d\Omega}_{\text{pol}} = \frac{d\sigma}{d\Omega}_{\text{unpol}} \cdot \left\{ 1 - P_y T + P_x P_{\text{circ}} F \right\}
\]

- Disentangle Multipoles (complete experiment), perform PWAs
- s-d wave interference in T for $\eta$, isobar models predict zero interference

\[
T \sim 3 \sin \theta \cdot \left( \text{Im} \left[ A_{0+}^{*}B_{1+} \right] - \cos \theta \cdot \text{Im} \left[ A_{0+}^{*}B_{2-} \right] \right)
\]

- Double polarisation observable F not measured yet
Transverse Target Asymmetry $T$ for $\eta$

Red points: CB 2010/11
Black points: PHOENICS

Black line: $\eta$MAID-2003, isobar model
Blue line: $\eta$MAID-2003, reggeized isobar model
Red line: BG2010-02
Green line: SAID

Victor Kashevarov (Mainz)
Double Polarisation Observable F for $\eta$

First time measurement with Crystal Ball!
Victor Kashevarov (Mainz)

Black line: $\eta$MAID-2003, isobar model
Blue line: $\eta$MAID-2003, reggeized isobar model
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Preliminary
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• \( \eta' \) production at MAMI possible now
  - Preliminary results on \( \eta' \) photoproduction cross section
  - First glances on \( \eta' \rightarrow \eta\pi^0\pi^0 \) Dalitz plot and \( \eta' \) Transition Form Factor

• New determination of the Transition Form Factor in \( \eta \rightarrow e^+e^-\gamma \)
  - More than one order of magnitude more than previous A2 analysis
  - Soon to be published

• Polarisation observables with Crystal Ball
  - Precise determination of Target Asymmetry \( T \) (preliminary)
  - First determination of Double Polarisation Observable \( F \) (preliminary)

• 12 years physics programme funded through DFG (SFB 1044)
  - Broad physics programme including
    Light Meson Dynamics
    Transition Form Factors of pseudoscalar Mesons
    Polarisation Observables (long. and trans. Pol. target)