Status of the Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$ with the CLAS g12 Data Set

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One Meson, many Opportunities

- $m_{\eta} = 0.5478$ GeV/$c^2$
- $\Gamma_{\eta} = (1.31 \pm 0.05)$ keV
- $\bar{\tau} \approx 5 \cdot 10^{-19}$ s
- $J^{PC} = 0^{-+} \implies \eta$-meson is: $C-, P-, G$- and $CP$- eigenstate
- All strong and electromagnetic decays are forbidden to first order

$\implies$ Access to rare decay processes

### Decay modes and issues

<table>
<thead>
<tr>
<th>Decay mode</th>
<th>Issue</th>
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</thead>
<tbody>
<tr>
<td>$\eta' \rightarrow \pi^+\pi^-\eta$</td>
<td>Dalitz plot analysis (See talk by S. Ghosh)</td>
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<tr>
<td>$\eta \rightarrow \pi^+\pi^-\pi^0$</td>
<td>Dalitz plot analysis</td>
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<tr>
<td>$\eta'(\gamma) \rightarrow \pi^+\pi^-\gamma$</td>
<td>Box anomaly, $\pi^+\pi^-$ FSI (See talk by G. Mbianda Njenchu)</td>
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<tr>
<td>$\eta'(\gamma) \rightarrow e^+e^-\gamma^*$</td>
<td>Single-off-shell transition form factor (See talk by M. C. Kunkel)</td>
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<tr>
<td>$\eta'(\gamma) \rightarrow \pi^+\pi^-e^+e^-$</td>
<td>CP-Violation</td>
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<td>C-Violation</td>
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$\eta' \rightarrow \pi^+\pi^-\gamma$
The Dalitz Plot

**Dimensionless Dalitz plot variables:**

\[
X = \sqrt{3} \frac{T_\pi^+ - T_\pi^-}{T_\pi^+ + T_\pi^- + T_\pi^0} \\
Y = \frac{3 T_\pi^0}{T_\pi^+ + T_\pi^- + T_\pi^0}
\]

- Decay via strong isospin violation: \( \Gamma_{meas} = \left( \frac{Q_D}{Q} \right)^4 \bar{\Gamma} \)
  - \( Q^2 = \frac{m_s^2 - \hat{m}^2}{m_d^2 - m_u^2} \), \( \hat{m} = \frac{1}{2} (m_u + m_d) \)
  - \( \bar{\Gamma} \) calculated with ChPT at Dashen limit, \( Q_D = 24.2 \)
- Dalitz plot analysis: \( \frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + dX^2 + fY^3 + gX^2Y + ...) \)
  \( \rightarrow c, e \) and \( h \) would imply C-violation
## Current Results

<table>
<thead>
<tr>
<th>Parameter:</th>
<th>−a</th>
<th>b</th>
<th>d</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theor.</td>
<td></td>
<td></td>
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<tr>
<td>ChPT (NNLO)(^{(a)})</td>
<td>1.271(75)</td>
<td>0.394(102)</td>
<td>0.055(57)</td>
<td>0.025(160)</td>
</tr>
<tr>
<td>NREFT(^{(b)})</td>
<td>1.213(14)</td>
<td>0.308(23)</td>
<td>0.050(3)</td>
<td>0.083(19)</td>
</tr>
<tr>
<td>PWA(^{(c)})</td>
<td>1.116(32)</td>
<td>0.188(12)</td>
<td>0.063(4)</td>
<td>0.091(3)</td>
</tr>
<tr>
<td>Exp.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KLOE (08)(^{(d)})</td>
<td>1.090(5)(^{+8}_{-19})</td>
<td>0.124(6)(10)</td>
<td>0.057(6)(^{+7}_{-16})</td>
<td>0.14(1)(2)</td>
</tr>
<tr>
<td>WASA(^{(e)})</td>
<td>1.144(18)</td>
<td>0.219(19)(47)</td>
<td>0.086(18)(15)</td>
<td>0.115(37)</td>
</tr>
<tr>
<td>KLOE (16)(^{(f)})</td>
<td>1.104(3)(2)</td>
<td>0.142(3)(^{5}_{-4})</td>
<td>0.073(3)(^{+4}_{-3})</td>
<td>0.154(6)(^{+4}_{-5})</td>
</tr>
</tbody>
</table>

- Calculation from JPAC\(^*\) group using the WASA-at-COSY result: 
  \[ Q = 21.4 \pm 0.4 \] \(^{(c)}\)
  - Interactive web page: [http://www.indiana.edu/~jpac/index.html](http://www.indiana.edu/~jpac/index.html)
- **Goal:** Perform Dalitz Plot analysis with CLAS g12 data set

\(^{(b)}\) S- P. Schneider et al., *JHEP*, 028, (2011)  
\(^{(d)}\) KLOE coll., *JHEP*, 05, (2008)  
\(^{(e)}\) WASA-at-COSY coll., *Phys. Rev.*, C90(045207), (2014)  
\(^{(f)}\) KLOE coll., *JHEP*, 019, (2016)
The CLAS g12 Data Set

- $E_{e, \text{beam}} = 5.714 \text{ GeV}$
- Photon beam with: $E_{\gamma, \text{beam}} \in [1.1 \text{ GeV}, 5.45 \text{ GeV}]$
- Liquid hydrogen target with 40 cm length
- Magnetic field $\sim 2 \text{ T}$
- $\sim 670$ runs in total

CLAS g12 data set in Jülich:
- $\sim 451$ runs $\approx 1 \text{ TB}$ $\rightarrow$ Corresponds to 2/3 of the total g12 data set
- Already calibrated and preselected (done by Michael C. Kunkel)
- Dedicated LMD-group at IKP-1
Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$: Basics

- Analysis performed on g12 data set in Jülich
- Applied g12 corrections (e.g. Momentum corrections, beam energy correction, calibration, fiducial cuts)
- Missing mass: $|P_{\text{beam}} + P_{\text{target}} - P_p|$ → used to monitor analysis steps
Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$: Kinematic Fit

- Tuned kinematic fitter $\rightarrow$ increased $p\_scale$ by 81% and $res\_scale$ by 77%
- Left: Kinematic fit probability for hypothesis: $\gamma p \rightarrow p\pi^+\pi^- (\pi^0)$
- Select events with Prob. $\geq 0.01$. (optimisation of this selection is ongoing)
- Right: Proton missing mass before and after applying the cut on the probability
Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$: Suppressing $\omega \rightarrow \pi^+\pi^-\pi^0$

- Cut: $M(\pi^+,\pi^-) \leq 0.45 \frac{\text{GeV}}{c^2}$ chosen according to kinematics and resolution
- Signal peak is not effected (see following slide)
- To do: X-check cut with MC simulation
Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$: Suppressing $\omega \rightarrow \pi^+\pi^-\pi^0$

- In both plots: Red: Before applying the invariant mass cut / Blue: After applying the invariant mass cut
- Right: Zoom in of the left plot
- $\omega$-contribution suppressed by a factor $\sim 2$
Analysis of $\eta \rightarrow \pi^+\pi^-\pi^0$: Signal yield

- Total g12 Jülich data set analysed ($\rightarrow 2/3$ of total g12 data set)
- Background described by 3rd order polynomial / Signal described by gaussian function
- Next step: Go for the Dalitz Plot
Towards the Dalitz Plot

Follow WASA-at-COSY analysis:

- Translate each bin of the Dalitz Plot into a global bin:
  \[
  \text{Global bin}(X, Y) = \text{FloorNint} \left( \frac{X + X_{\text{max}}}{\delta} \right) + N_{\text{bins}} \cdot \text{FloorNint} \left( \frac{Y + Y_{\text{max}}}{\delta} \right)
  \]

- Look at missing mass spectrum for each global bin and subtract non-resonant background

Note: This is not the final analysis! The intention is to define a reference (result) in order to compare future analysis steps and to x-check systematics.
Number of reconstructed $\eta \to \pi^+ \pi^- \pi^0$ events as function of the global bin number

Note: Red line shown here is not a fit

Each bin is corrected for non-resonant background

To do: Efficiency correction
The Dalitz Plot in 2D

- Left: Before background subtraction
- Right: After background subtraction
- No holes in the Dalitz Plot distribution
Reconstructed $\sim 770 \, k \, \eta \rightarrow \pi^+ \pi^- \pi^0$ events from g12 data set in Jülich (Expect $\lesssim 1 \cdot 10^6 \, \eta \rightarrow \pi^+ \pi^- \pi^0$ events in total g12 data set)

Determined background corrected Dalitz Plot

- Do simulations and perform efficiency corrections (ongoing)
  - Go for Dalitz Plot parameters
- Utilise PWA tools
- Optimise event selection (ongoing)