Search for Box Anomaly in
\[ \eta' \rightarrow \pi^+ \pi^- \gamma \]

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outline

• Introduction & Motivation
• Event selection
• Extraction of the signal shape
• Extraction of the efficiency curve and resolution curve
• Models to be used in the mass spectrum fitting
• Next-to-do list
Motivation

• Effective Wess-Zumino-Witten Lagrangian: summarizes and determines the effects of anomalies in current algebra (Ref[1,2]).

• Triangle anomaly

\[ A = \frac{n e^2}{96 \pi^2 f_\pi^2} \pi^0 \varepsilon^{\mu \nu \alpha \beta} F_{\mu \nu} F_{\alpha \beta} \]

• Box anomaly

\[ B = -\frac{1}{12} \frac{n}{\pi^2 f_\pi^3} \varepsilon^{\mu \nu \alpha \beta} A_\mu \partial_\nu \pi^+ + \partial_\alpha \pi^- - \partial_\beta \pi^0 \]

Preliminary Experiments results

- Observations of $\rho_0$ mass measurement via $\eta' \rightarrow \gamma\pi^+\pi^-$ in $\pi N \rightarrow \eta'N$ shows that:
  - Mass shift is as large as 20 to 30 MeV;
  - A fully mediated by $\rho_0$ mass: incomplete;
  - A non-resonance contribution $\eta' \rightarrow \gamma\pi^+\pi^-$. 

Confirmed the existence of the box anomaly with a statistical significance of 4σ.

Model 1,2 are two sets of ρ₀ parameters from the fit of e⁺ e⁻ → π⁺π⁻ cross section (Z. Phys. C 58 (1993) 31)
Other results about box anomaly in $\eta \to \pi^+ \pi^- \gamma$

$$|\mathcal{M}|^2 \sim |F(s_{\pi\pi})|^2 E^2_\gamma q^2 \sin^2(\theta)$$

$$P(s_{\pi\pi}) = 1 + \alpha s_{\pi\pi}$$

$$|FF(s_{\pi\pi})|^2 = |\tilde{F}_V(s_{\pi\pi}) P(s_{\pi\pi})|^2$$

This is from a model-independent approach about to $\eta' \to \gamma \pi^+ \pi^-$


$$\alpha = 1.89 \pm 0.25_{\text{stat}} \pm 0.59_{\text{sys}} \pm 0.02_{\text{theo}} \text{GeV}^{-2}$$
Furthermore, about $\eta \rightarrow \pi^+\pi^0\gamma$...

- A possibility to measure CP violation
- flavor conserving
- Strangeness conserving

\[
\mathcal{M} = \frac{i}{m_\eta^3} \{ -M \varepsilon_{\mu \nu \rho \lambda} p_+^\mu p_-^\nu k^\rho \epsilon^\lambda + E[(\epsilon \cdot p_+)(k \cdot p_-) - (\epsilon \cdot p_-)(k \cdot p_+)] \}
\]

Box anomaly

\[
S_1(E_\gamma, \theta) = 2 Re (E^* M) / (|E|^2 + |M|^2)
\]
\[
S_2(E_\gamma, \theta) = 2 Im (E^* M) / (|E|^2 + |M|^2)
\]
\[
E^+(\eta \rightarrow (\pi^+\pi^-)^* \rightarrow \pi^+\pi^-\gamma) = \frac{e m_\eta^3 g_{\eta\pi\pi}}{(p_+ \cdot k)(p_- \cdot k)}
\]

\[
|S_{1,2}(E_\gamma)| < 0.2 \cos \delta, 0.2 \sin \delta, \text{ and } S_3 \simeq -1
\]

- With new updated results of upperlimit $\text{Br}(\eta \rightarrow \pi^+\pi^-)$ (KLOE, 2005), $|S_{1,2}(E_\gamma)|$ may be even smaller (30 factors);


\[ \delta: \text{the relative strong phase}\]

Box anomaly diagram:

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

\[
S_{1,2}(E_\gamma) < 0.2 \cos \delta, 0.2 \sin \delta, \text{ and } S_3 \simeq -1
\]
Motivation

• With the world’s largest statistic of $\eta'$
  – Measurement of $\text{Br}(\eta'\rightarrow\pi\pi\gamma)$;
  – Measurement of contribution of box anomaly via $\eta'\rightarrow\pi\pi\gamma$;
  – Cross check of differential cross section of $\gamma P\rightarrow P\eta'$ ($W = 1.7\sim3.3\text{GeV}$);
Event selection

- Energy loss and momentum correction
- Vertex cut
  - $-100 < v^2_z < -70$
- Charged particle timing
- Fiducial and TOF cuts
- after kinematic fitting
  - $\text{Prob}(P \pi^+ \pi^-) > 0.01$
  - $\text{Prob}(P \pi^+ \pi^-) < 0.01$
  - $\text{Prob}(P\pi^+\pi^-\pi^0) < 0.01$
- Miss mass square cut of $P \pi^+ \pi^- < 0.07 \text{ GeV}^2$
- Miss Energy cut of $P e^+ e^- > 0.08 \text{ GeV}$

G12 data taken by CLAS
Run: 56605-57317
Extraction of signal

- After above selection;
- Fit for $\eta'$ in each bin of $M(\pi^+\pi^-)$;
- Interval: 5 MeV
Generate signal MC samples on every mass point of $M(\pi^+\pi^-)$ of 0 width;

- Considering the migration of each mass point, we do tuning on the MC sample by the proportion of each mass point in real $\rho^0$ shape. The mass shift & acceptance curve is given in (a);
- Fit for the resolution of MC samples of each mass point on $M(\pi^+\pi^-)$ to obtain the resolution versus the $M(\pi^+\pi^-)$, as shown in (b).
The models to be used

- $\rho$-$\omega$ mixing
- $\rho$-$\omega$ mixing with box anomaly
- Model independent approach with $\omega$ interference
Next-to-do list

• MC input & output check in extraction of the signal;
• Mass spectrum fit with considering acceptance and resolution;
• Systematic uncertainty...
BACKUP
Furthermore, about $\eta \rightarrow \pi^+\pi^-\gamma$...

- A possibility to measure CP violation
- flavor conserving
- Strangeness conserving

$$M = \frac{i}{m_\eta^3} \left\{-M_\epsilon_{\mu\nu\rho\lambda} p_+^\mu p_- ^\nu k^\rho \epsilon^\lambda + E[(\epsilon \cdot p_+)(k \cdot p_-) - (\epsilon \cdot p_-)(k \cdot p_+)]\right\}$$

**Box anomaly**

$$S_1(E_\gamma, \theta) = 2 \text{Re} (E^* M) / \left( |E|^2 + |M|^2 \right)$$

$$S_2(E_\gamma, \theta) = 2 \text{Im} (E^* M) / \left( |E|^2 + |M|^2 \right)$$

$$E^+(\eta \rightarrow (\pi^+\pi^-)^* \rightarrow \pi^+\pi^-\gamma) = \frac{e m_\eta^2 g_{\eta\pi\pi}}{(p_+ \cdot k)(p_- \cdot k)}$$

$$|S_{1,2}(E_\gamma)| < 0.2 \cos \delta, 0.2 \sin \delta, \text{ and } S_3 \simeq -1$$

- With new updated results of upperlimit $\text{Br}(\eta \rightarrow \pi^+\pi^-)$ (KLOE, 2005),
  $|S_{1,2}(E_\gamma)|$ may be even smaller (30 factors);

- A four-fermion operator is given:

$$\mathcal{O} = \frac{1}{m_\eta^3} G \bar{s}i\sigma_{\mu\nu} \gamma_5 (p - k)^\nu s \bar{u} \gamma^\mu u$$

*Box anomaly* diagram:

- CPV
- $\delta$: the relative strong phase between the terms of $M^+$ and $E^+$.

Hadron Spectroscopy Working Group, CLAS collaboration
Way II: S-B separation using Q-method

- Use a small sample to test:
  - Q-method result: fit result:
  - $N_{\text{sig}} = 394.13 \pm 21.66 \quad 391 \pm 35$
with $|\text{mm2}_\text{Ppi+pi-}| < 0.007$
Way II: S-B separation using Q-method

- The metric we selected

We choose:
\[ \cos \theta \eta' \text{ in cms} \]
\[ \cos \theta \pi \pi \text{ in } \eta' \text{ rest frame} \]

Here 4-momentum of \( \eta' \) means the recoil 4-momentum off the proton;