Search for Box Anomaly in $\eta' \to \pi^+ \pi^- \gamma$

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On behalf of Juelich group

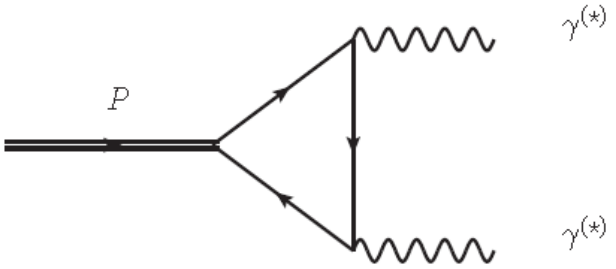
outline

- 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

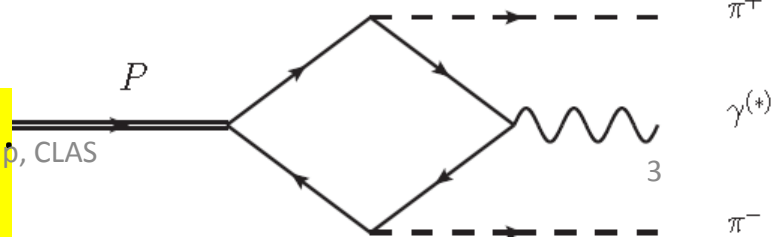
- Effective Wess-Zumino-Witten Lagrangian: summarizes and determines the effects of anomalies in current algebra (Ref[1,2]).
- Triangle anomaly

$$A = \frac{ne^2}{96\pi^2 f_\pi^2}\pi^0 \varepsilon^{\mu\nu\alpha\beta} F_{\mu\nu} F_{\alpha\beta}$$



- Box anomaly

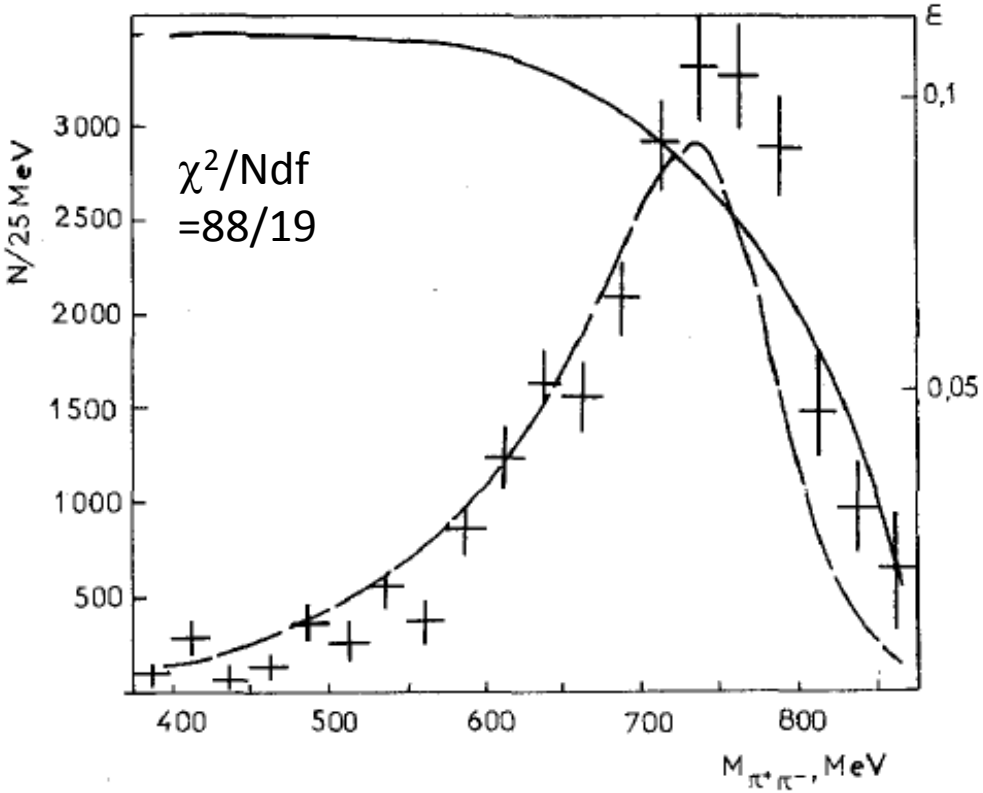
$$B = -\frac{1}{12}\frac{n}{\pi^2 f_\pi^3}\epsilon^{\mu\nu\alpha\beta} A_\mu \partial_\nu \pi^+ \partial_\alpha \pi^- \partial_\beta \pi^0$$



[1] J. Wess and B. Zumino, Phys. Lett. B37, 95 (1971).
[2] E. Witten, Nucl. Phys. B223, 422 (1983).

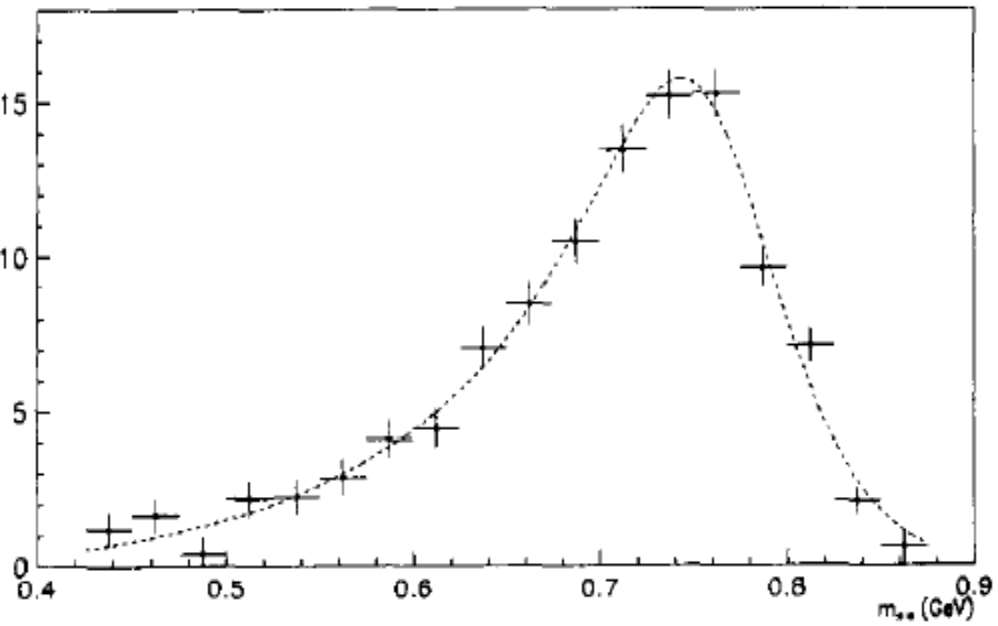
Preliminary Experiments results

- Observations of ρ_0 mass measurement Via $\eta' \to \gamma\pi^+\pi^-$ in $\pi N \to \eta' N$ shows that:
  - Mass shift is as large as 20 to 30 MeV;
  - A fully mediated by ρ_0 mass: incomplete;
  - A non-resonance contribution $\eta' \to \gamma\pi^+\pi^-$.



Z. Phys. C - Particles and Fields 50, 451-454 (1991)

Results from CB



Crystal Barrel Collaboration / Physics Letters B 402 (I997) 195-206

$$\frac{d\Gamma_X}{dm} = \frac{1}{48\pi^3}\left|\frac{2G_\rho(m)F_X}{D_\rho(m)} + E_X\right|^2 k_\gamma^3 q_\pi^3$$

$$D_\rho(m) = (m_\rho^2 - m^2) - i m_\rho \Gamma_\rho(m)\,,$$

$$G_\rho(m) = \sqrt{6\pi \frac{m m_\rho}{q_\pi^3}\Gamma_\rho(m)}\,,$$

$$\Gamma_\rho(m) = \Gamma_\rho(m_\rho)\left[\frac{q_\pi(m)}{q_\pi(m_\rho)}\right]^3\left[\frac{m_\rho}{m}\right]^\lambda$$

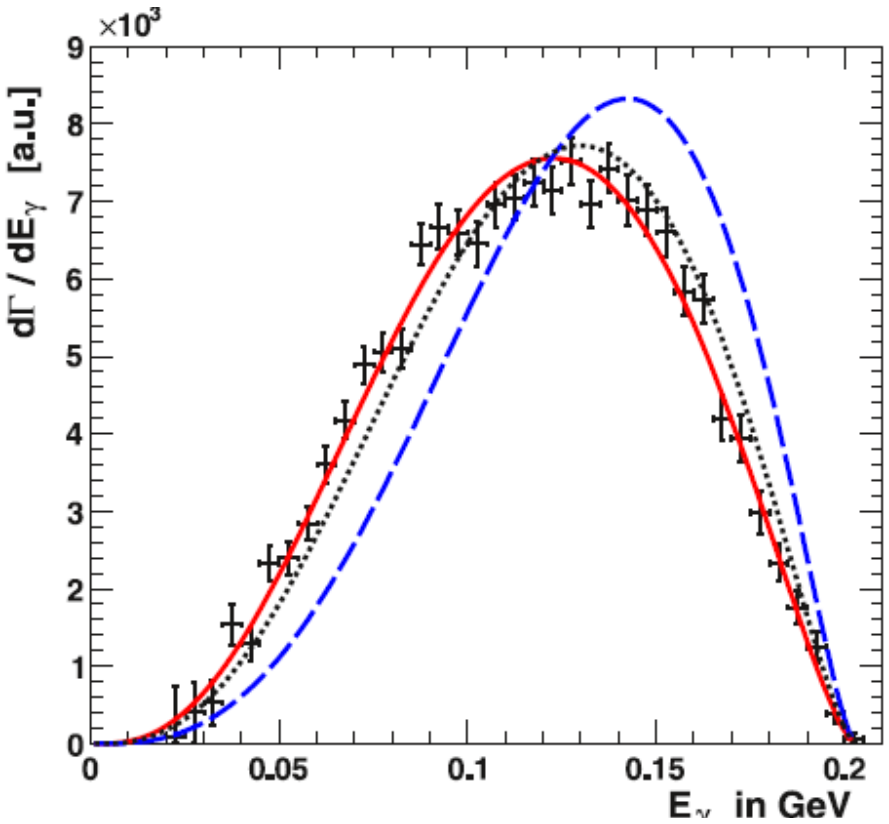
	Model M_1	Model M_2
$E_{\eta'}/F_{\eta'}$	-12.11 ± 1.22	-4.55 ± 1.22
$E_{\eta'}$	-4.96 ± 0.50	-1.95 ± 0.52
$F_{\eta'}$	0.41 ± 0.03	0.43 ± 0.03
χ^2/dof	20.5/17	19.9/17
E_η/F_η	$-10.64^{+2.49}_{-2.07}$	$+13.48^{+3.80}_{-3.25}$
E_η	$-4.39^{+1.15}_{-1.00}$	$-3.64^{+1.10}_{-0.97}$
F_η	0.41 ± 0.05	-0.27 ± 0.03
χ^2/dof	13/14	8/14

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

Model 1,2 are two sets of ρ_0 parameters from the fit of $e^+ e^- \rightarrow \pi^+\pi^-$ cross section (Z. Phys. C 58 (1993) 31)

Other results about box anomaly in $\eta \to \pi^+\pi^-\gamma$

WASA-at-COSY Collaboration, Physics Letters B 707 (2012) 243–249



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

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

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

This is from a **model-independent** approach about to $\eta' \to \gamma\pi^+\pi^-$ Physics Letters B 707 (2012) 184–190)

$$\alpha = 1.89 \pm 0.25_{stat} \pm 0.59_{sys} \pm 0.02_{theo}\ \mathrm{GeV}^{-2}$$

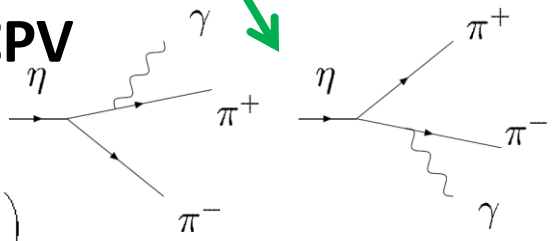
Furthermore, about $\eta \to \pi^+\pi^-\gamma$...

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

Mod.Phys.Lett. A17 (2002) 1489-1498

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

CPV



Box anomaly

$$S_1(E_\gamma,\theta) = 2Re\,(E^*M)\,/\,\left(|E|^2+|M|^2\right)$$
$$S_2(E_\gamma,\theta) = 2Im\,(E^*M)\,/\,\left(|E|^2+|M|^2\right)$$
$$E^+(\eta\to(\pi^+\pi^-)^*\to\pi^+\pi^-\gamma) = \frac{em_\eta^3 g_{\eta\pi\pi}}{(p_+\cdot k)(p_-\cdot k)}$$

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

δ: the relative strong phaseb between the terms of M^+ and E^+ .

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

Motivation

- With the world's largest statistic of η'
  - Measurement of Br($\eta' \to \pi\pi\gamma$);
  - Measurement of contribution of box anomaly via $\eta' \to \pi\pi\gamma$;
  - Cross check of differential cross section of $\gamma P \to P\eta'$ (W = 1.7~3.3GeV);

Event selection

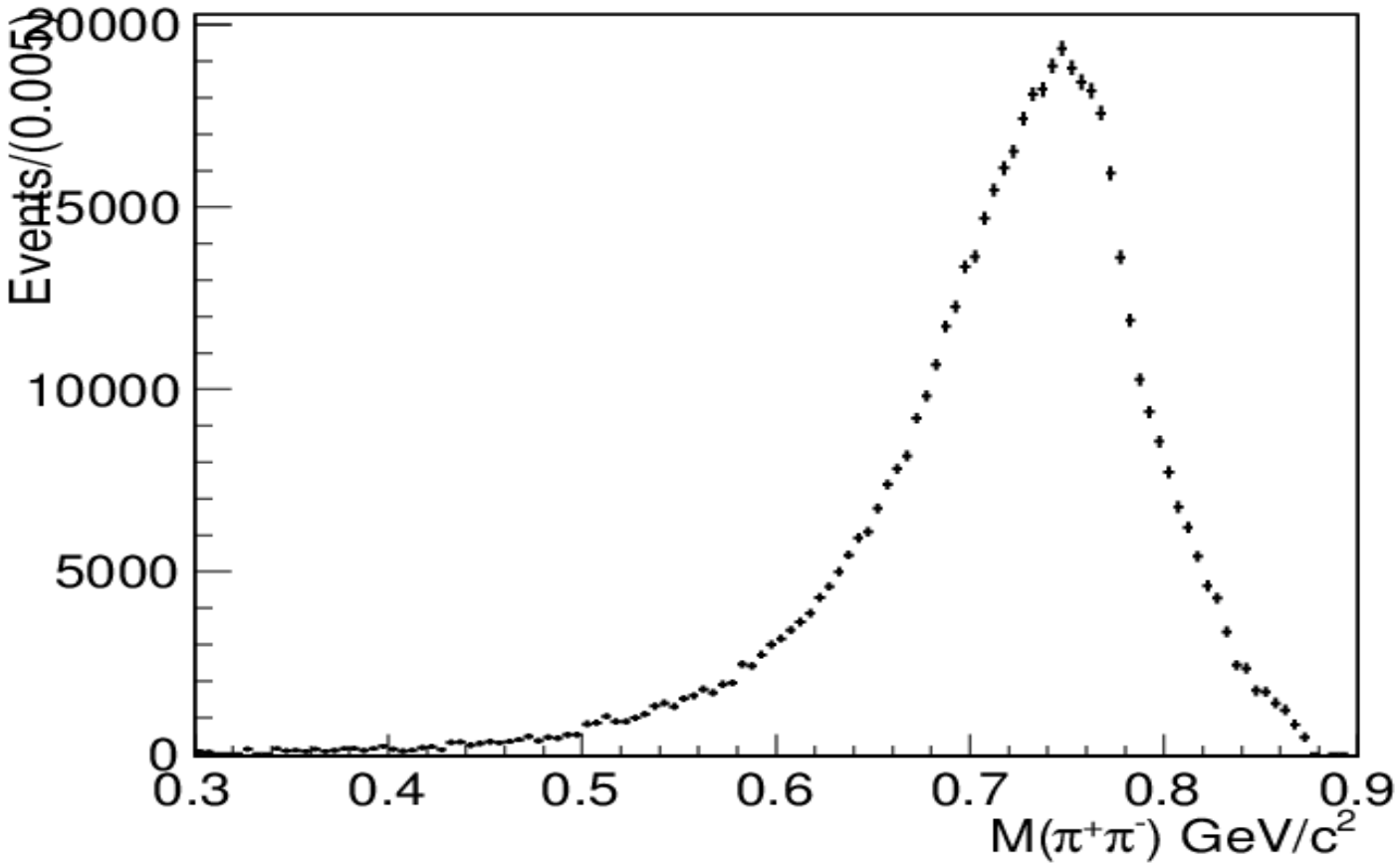
- Energy loss and momentum correction
- Vertex cut
  - $-100<v^2_z<-70$
- Charged particle timing
- Fiducial and TOF cuts
- after kinematic fitting
  - Prob(P $\pi^+\pi^-\gamma$)>0.01
  - Prob(P $\pi^+\pi^-$)<0.01
  - Prob(P$\pi^+\pi^-$ π^0)<0.01

G12 data taken by CLAS
Run: 56605-57317

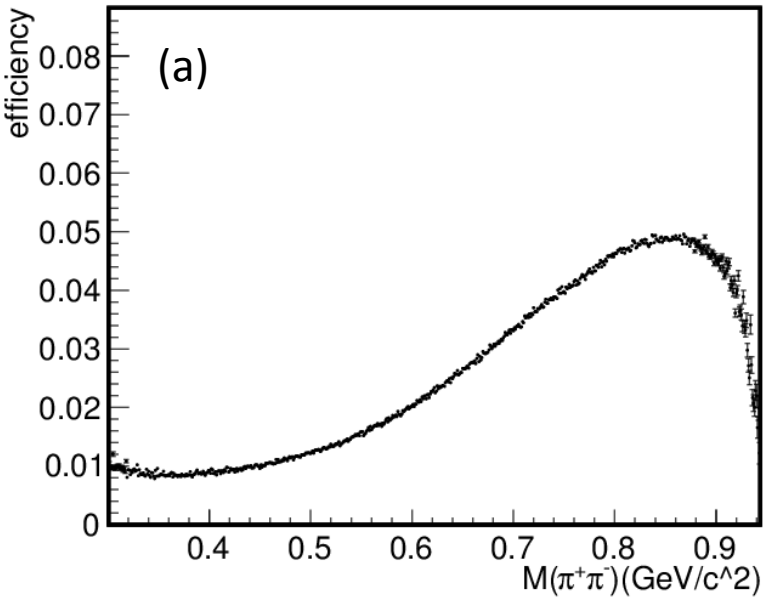
- Miss mass square cut of P π^+ π^- <0.07 GeV^2
- Miss Energy cut of P e^+ e^- >0.08 GeV

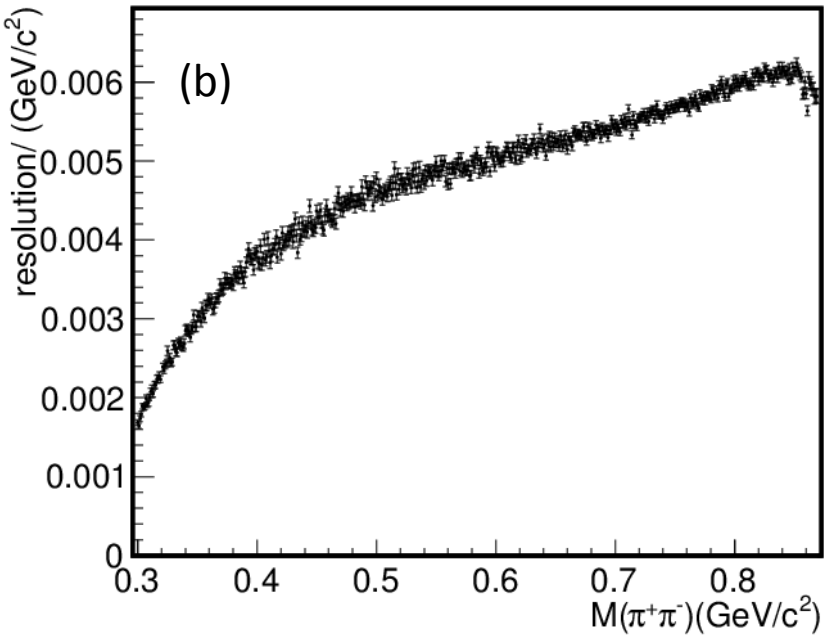
Extraction of signal

- After above selection;
- Fit for η'in each bin of M($\pi^+\pi^-$);
- Interval : 5 MeV



Extraction acceptance curve and resolution curve

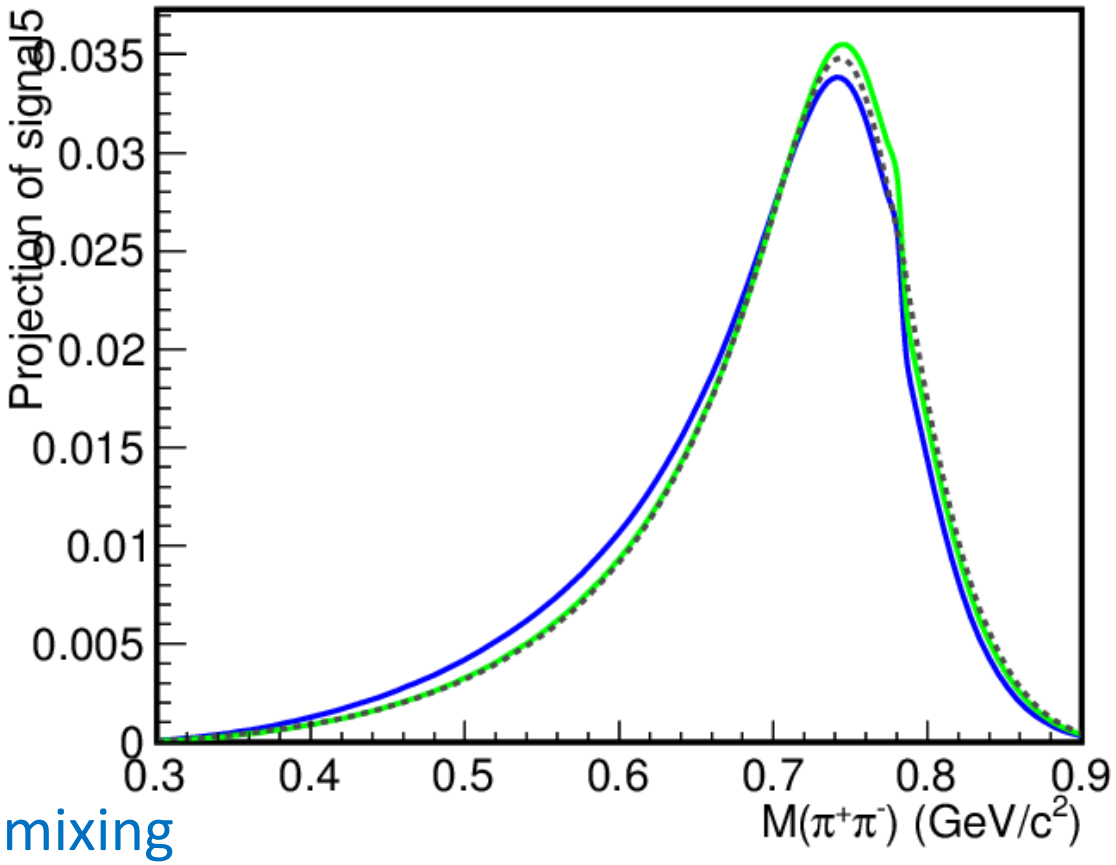




Generate signal MC samples on every mass point of $M(\pi^+\pi^-)$ of 0 width;

- Considering the migration of each mass point, we do tuning on the MC sample by the proportion of each mass point in real ρ^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



- ρ-ω mixing
- ρ-ω mixing with box anomaly
- Model independent approach with ω interference

Next-to-do list

- MC input& output check in extraction of the signal;
- Mass spectrum fit with considering acceptance and resolution;
- Systematic uncertainy…

BACKUP

Furthermore, about $\eta \to \pi^+\pi^-\gamma$...

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- **flavor conserving**
- **Strangeness conserving**

Mod.Phys.Lett. A17 (2002) 1489-1498

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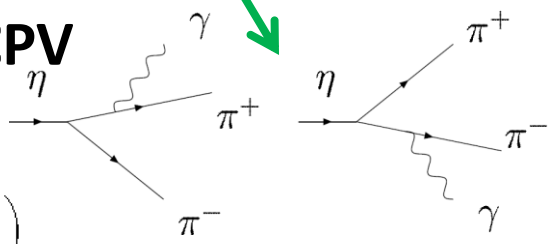
CPV



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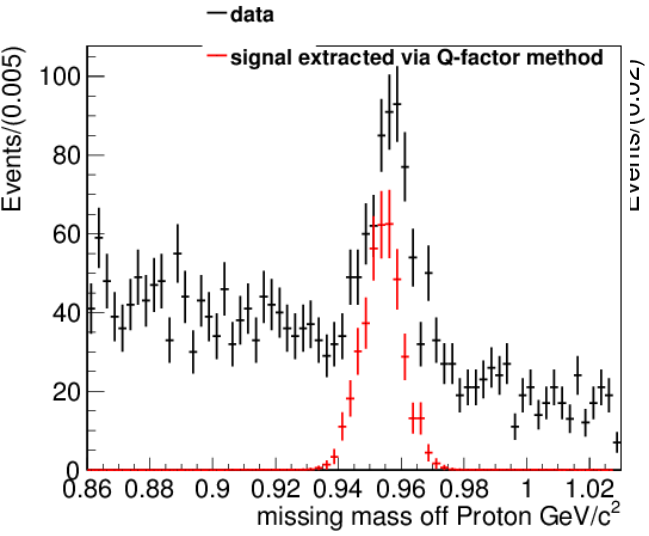
$$|S_{1,2}(E_\gamma)| < 0.2\cos\delta,\ 0.2\sin\delta, \quad \text{and } S_3 \simeq -1$$

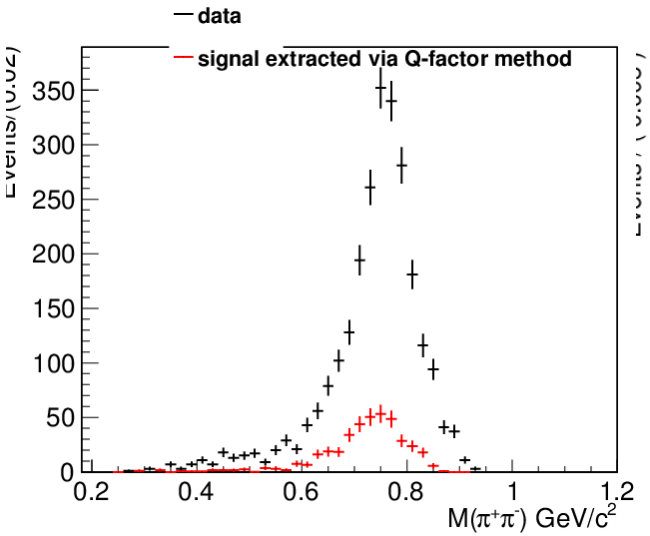
δ: the relative strong phaseb between the terms of M^+ and E^+ .

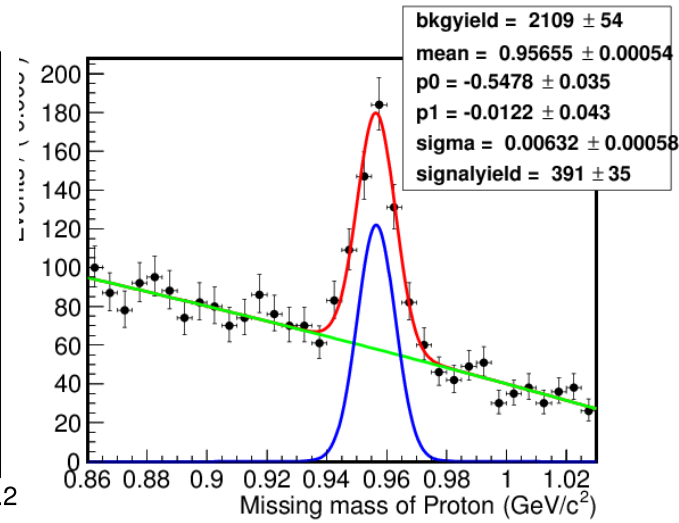
- **With new updated results of upperlimit Br($\eta\to\pi^+\pi^-$) (KLOE, 2005) , $|S_{1,2}(E_\gamma)|$ may be even smaller (30 factors);**
- **A four-fermion operator is given,** $\mathcal{O} = \frac{1}{m_\eta^3} G\,\bar{s}i\sigma_{\mu\nu}\gamma_5(p-k)^\nu\, s\,\bar{u}\gamma^\mu u$

Way II: S-B seperation using Q-method

- Use a small sample to test:

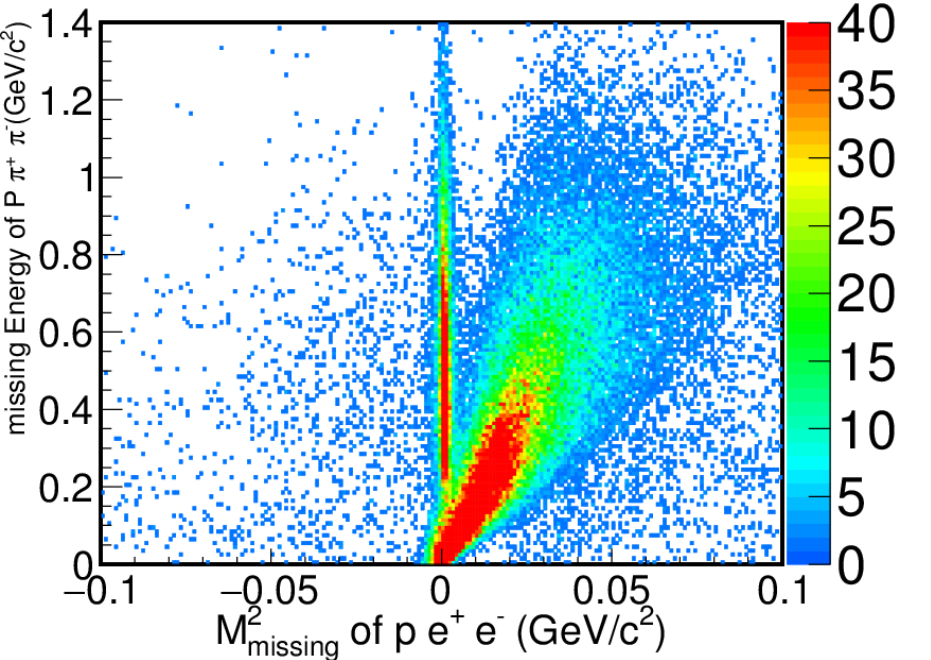


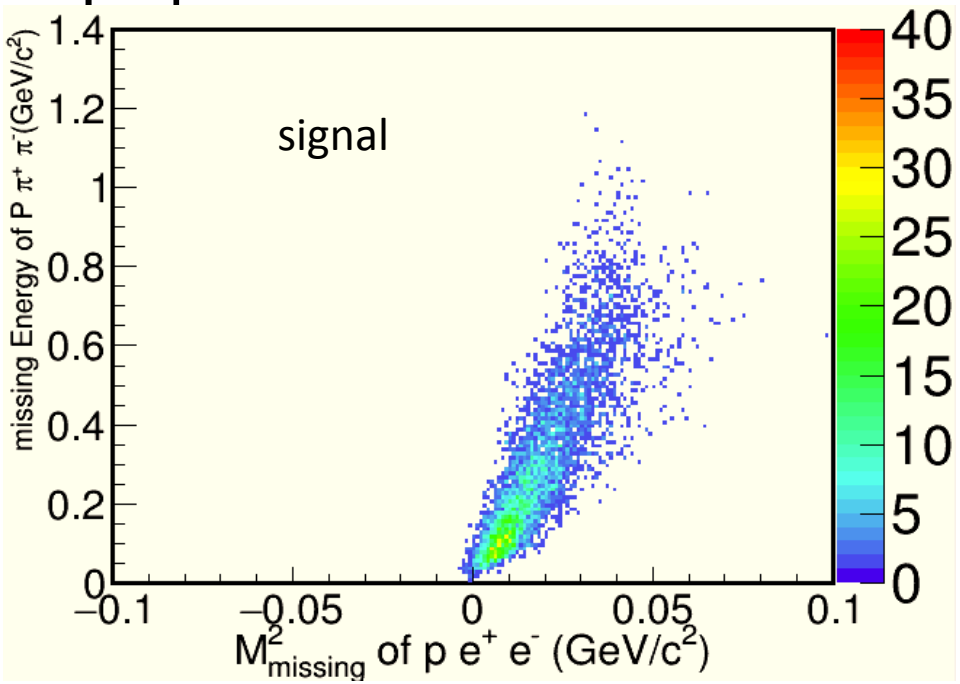


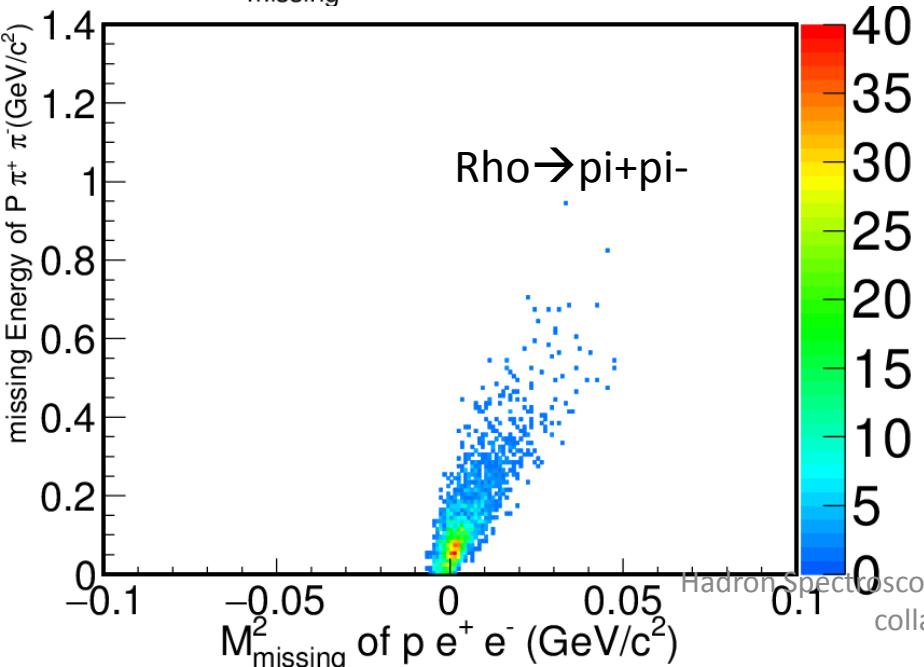


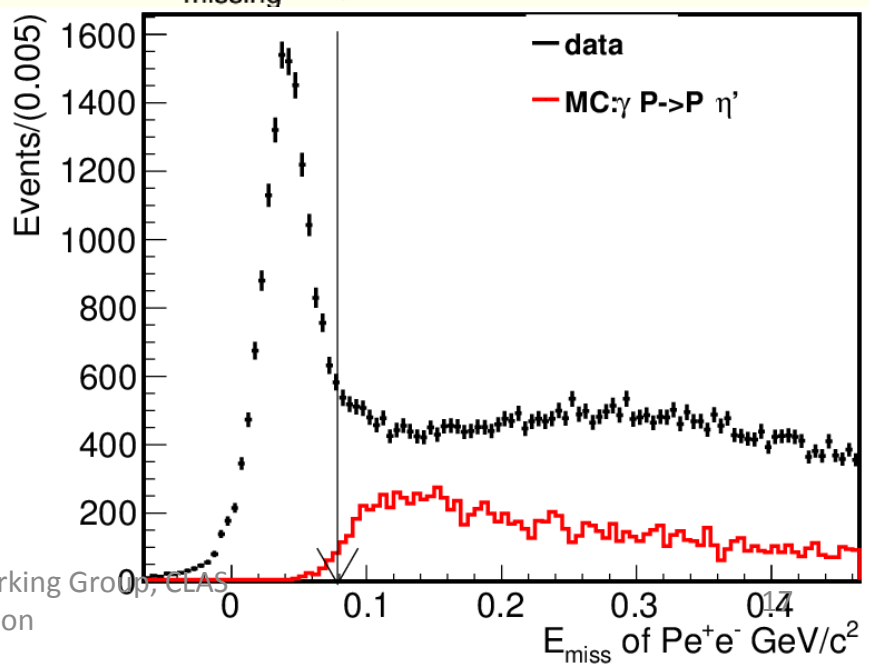
- Q-method result: fit result:
- Nsig= 394.13+/-21.66 391+/-35

with |mm2_Ppi+pi-|<0.007



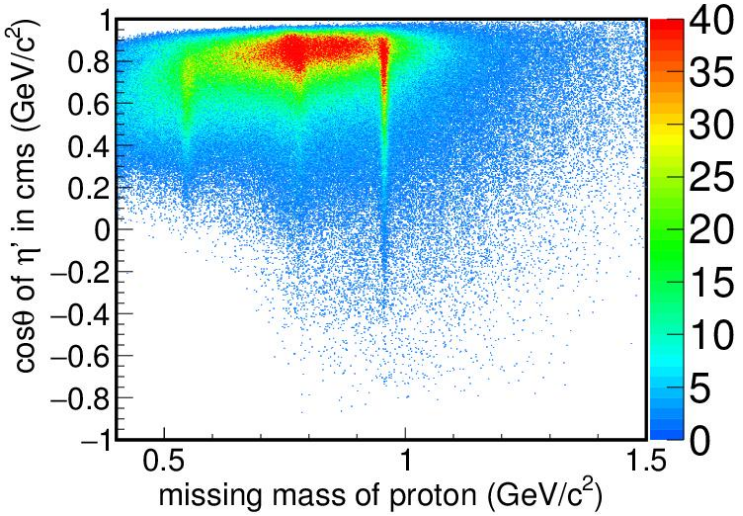


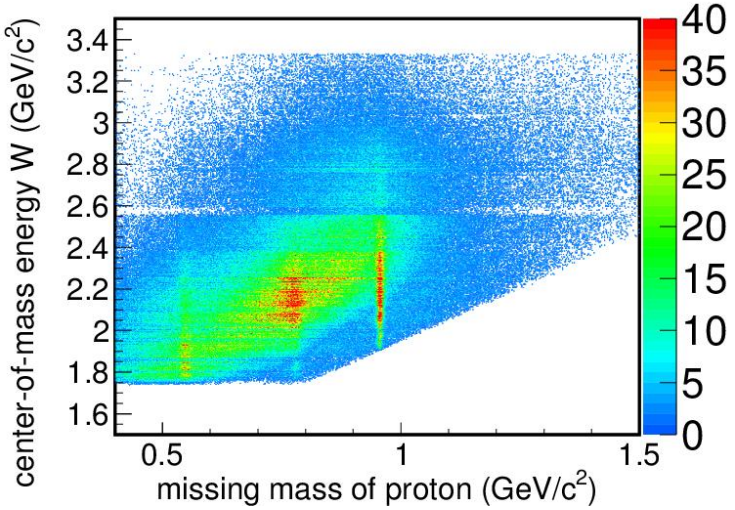


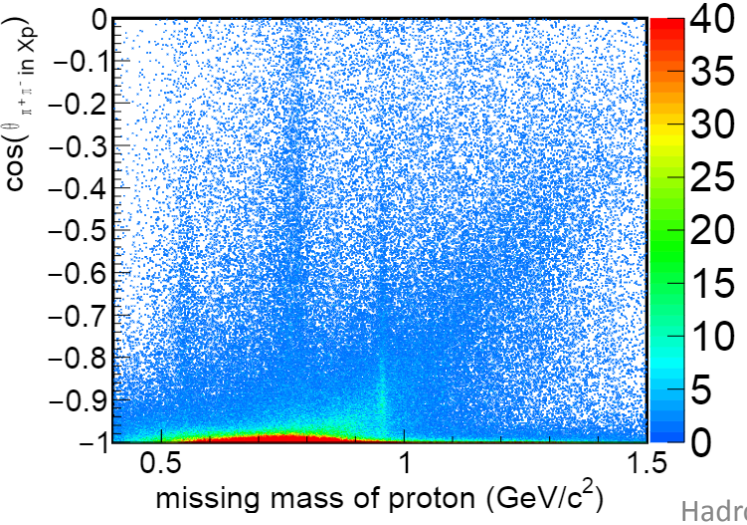


Way II: S-B seperation using Q-method

- 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 η' means the recoil 4-momentum off the proton;