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

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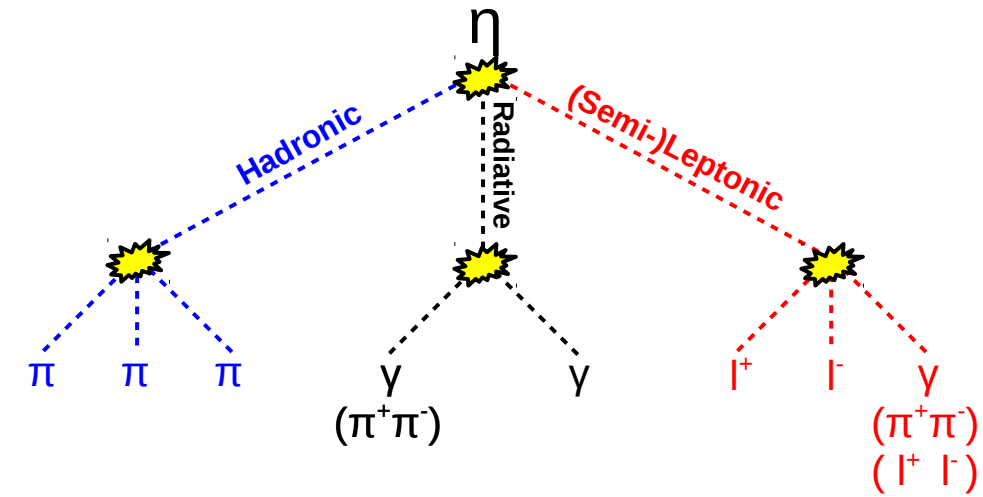
One Meson, many Opportunities

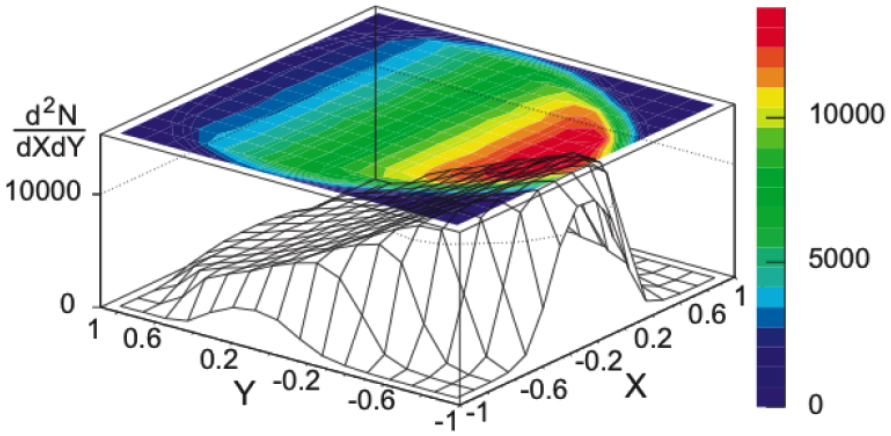
- $m_\eta = 0.5478\,\mathrm{GeV/c^2}$
- $\Gamma_\eta = (1.31 \pm 0.05)\,\mathrm{keV}$
- $\bar{\tau} \approx 5 \cdot 10^{-19}\,\mathrm{s}$
- $J^{PC} = 0^{-+} \Longrightarrow \eta$-meson is: C-, P-, G- and CP- eigenstate
- All strong and electromagnetic decays are forbidden to first order

$\Rightarrow$ **Access to rare decay processes**



Decay mode	Issue
$\eta' \to \pi^+\pi^-\eta$	Dalitz plot analysis (See talk by S. Ghosh)
$\eta \to \pi^+\pi^-\pi^0$	Dalitz plot analysis
$\eta^{(\prime)} \to \pi^+\pi^-\gamma$	Box anomaly, $\pi^+\pi^-$ FSI (See talk by G. Mbianda Njenchu)
$\eta^{(\prime)} \to e^+e^-\gamma^\star$	Single-off-shell transition form factor (See talk by M. C. Kunkel)
$\eta^{(\prime)} \to \pi^+\pi^-e^+e^-$	CP-Violation
$\eta \to e^+e^-e^+e^{-\star}$	Double-off-shell transition form factor
$\eta \to \pi^0 e^+e^-$	C-Violation

The Dalitz Plot



(d) KLOE coll., *JHEP*, 05, (2008)

Dimensionless Dalitz plot variables:

$$X = \sqrt{3}\frac{T_{\pi^+} - T_{\pi^-}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}}$$

$$Y = \frac{3T_{\pi^0}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}}$$

- 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

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

- Calculation from JPAC* group using the WASA-at-COSY result:
  $Q = 21.4 \pm 0.4$[c]

  $\star$ **Interactive web page: http://www.indiana.edu/ jpac/index.html**

- **Goal: Perform Dalitz Plot analysis with CLAS g12 data set**

(a) J. Bijnens and K. Ghorbani., *JHEP*, 11, (2007)

(b) S- P. Schneider et al., *JHEP*, 028, (2011)

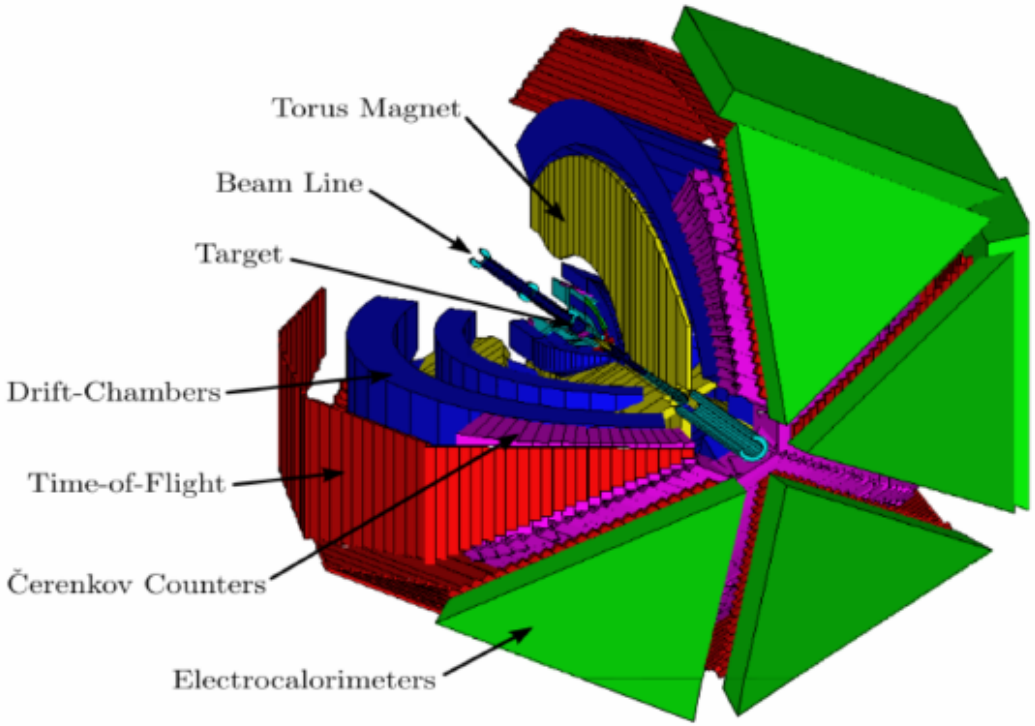
(c) Peng Guo et al., *Phys. Rev.*, D92(05016), (2015)

(d) KLOE coll., *JHEP*, 05, (2008)

(e) WASA-at-COSY coll., *Phys. Rev.*, C90(045207), (2014)

(f) KLOE coll., *JHEP*, 019, (2016)

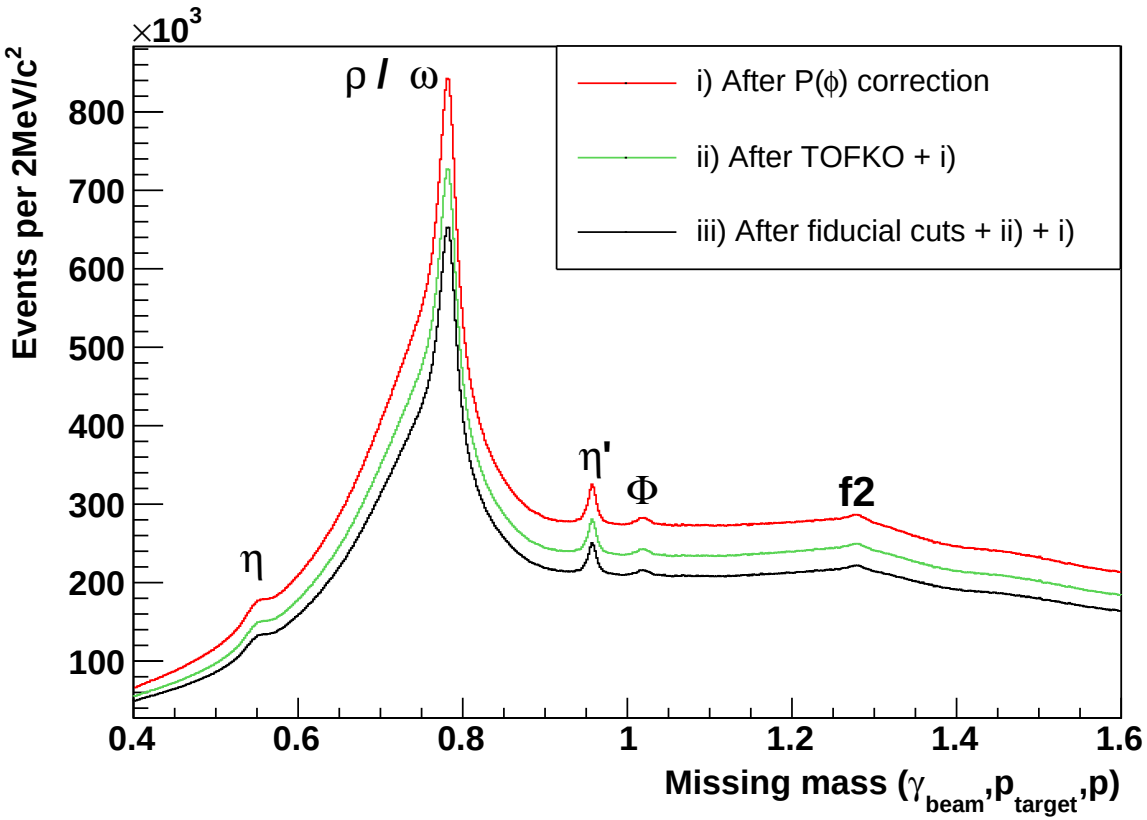
The CLAS g12 Data Set



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

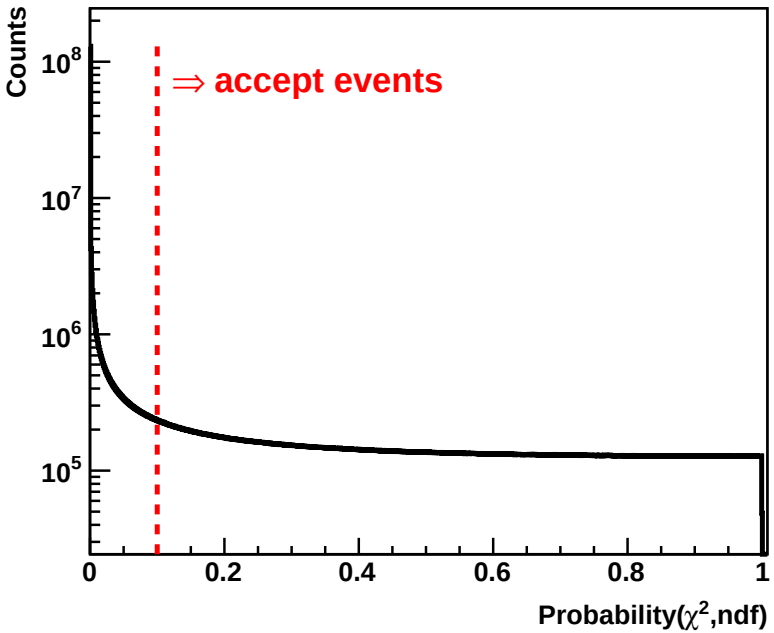
- CLAS g12 data set in Jülich:
  - ~ 451 runs $\approx 1\,\mathrm{TB} \longrightarrow$ Corresponds to 2/3 of the total g12 data set
  - Already calibrated and preselected (done by Michael C. Kunkel)
  - Dedicated LMD-group at IKP-1

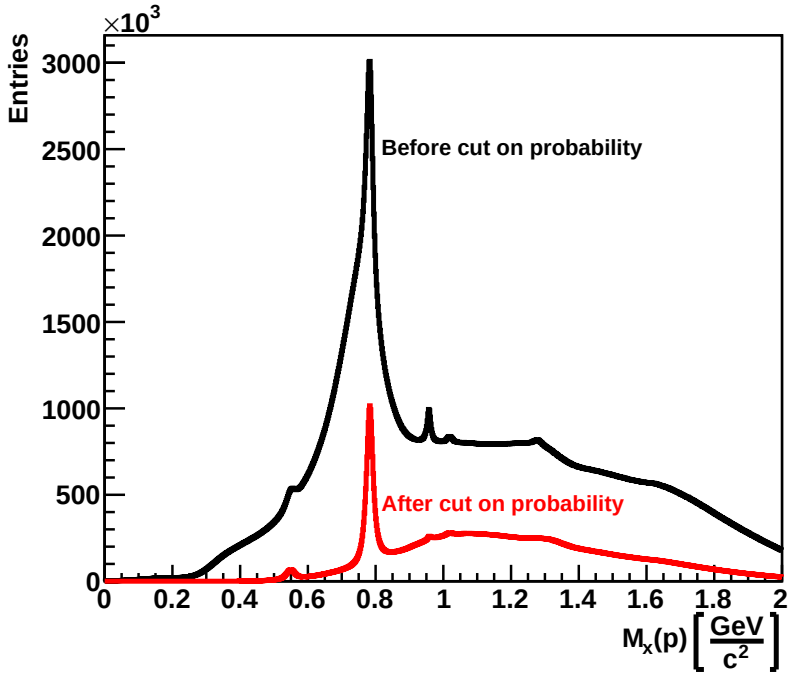
Analysis of $\eta \to \pi^+\pi^-\pi^0$: Basics



- Analysis performed on g12 data set in Jülich
- Applied g12 corrections
  (e.g. Momentum corrections, beam energy correction, calibration, fiducial cuts)
- Missing mass: $|P_{\mathbf{beam}} + P_{\mathbf{target}} - P_p| \to$ used to monitor analysis steps

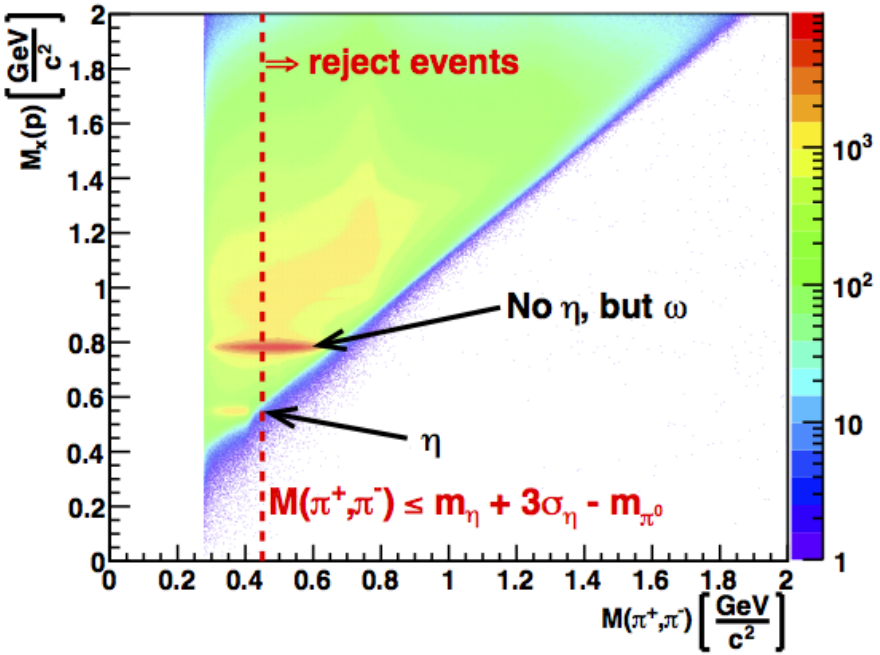
Analysis of $\eta \to \pi^+\pi^-\pi^0$: Kinematic Fit

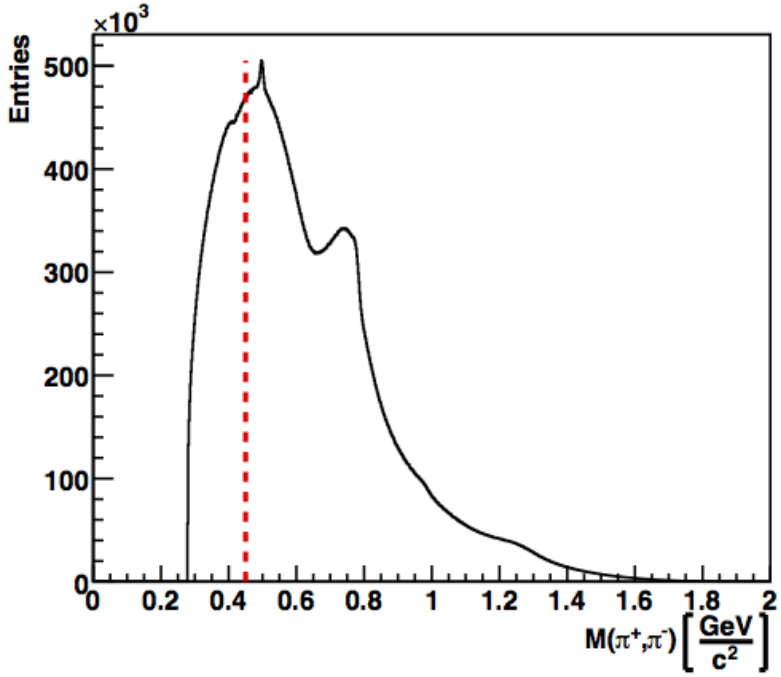




- Tuned kinematic fitter $\to$ increased p_scale by 81% and res_scale by 77%
- Left: Kinematic fit probability for hypothesis: $\gamma p \to p\pi^+\pi^-(\pi^0)$
- Select events with Prob. $\geq$ 01. (optimisation of this selection is ongoing)
- Right: Proton missing mass before and after applying the cut on the probability

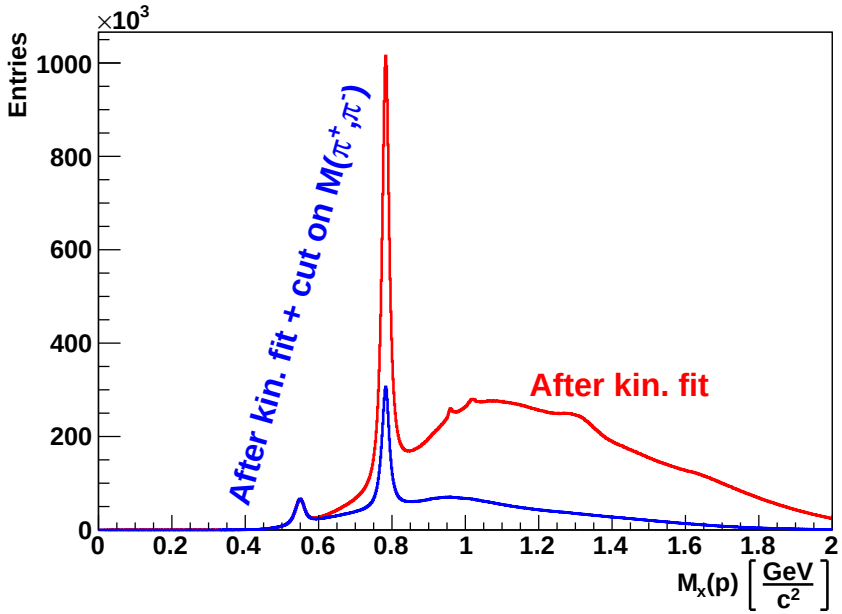
Analysis of $\eta \to \pi^+\pi^-\pi^0$: Suppressing $\omega \to \pi^+\pi^-\pi^0$

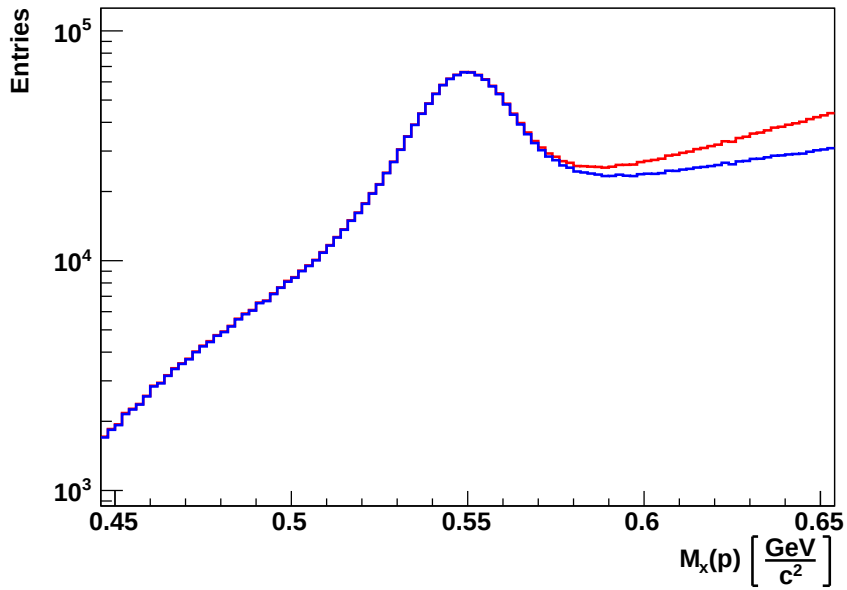




- Cut: $M(\pi^+, \pi^-) \leq 0.45 \frac{\mathrm{GeV}}{c^2}$ chosen according to kinematics and resolution
- Signal peak is not effected (see following slide)
- To do: X-check cut with MC simulation

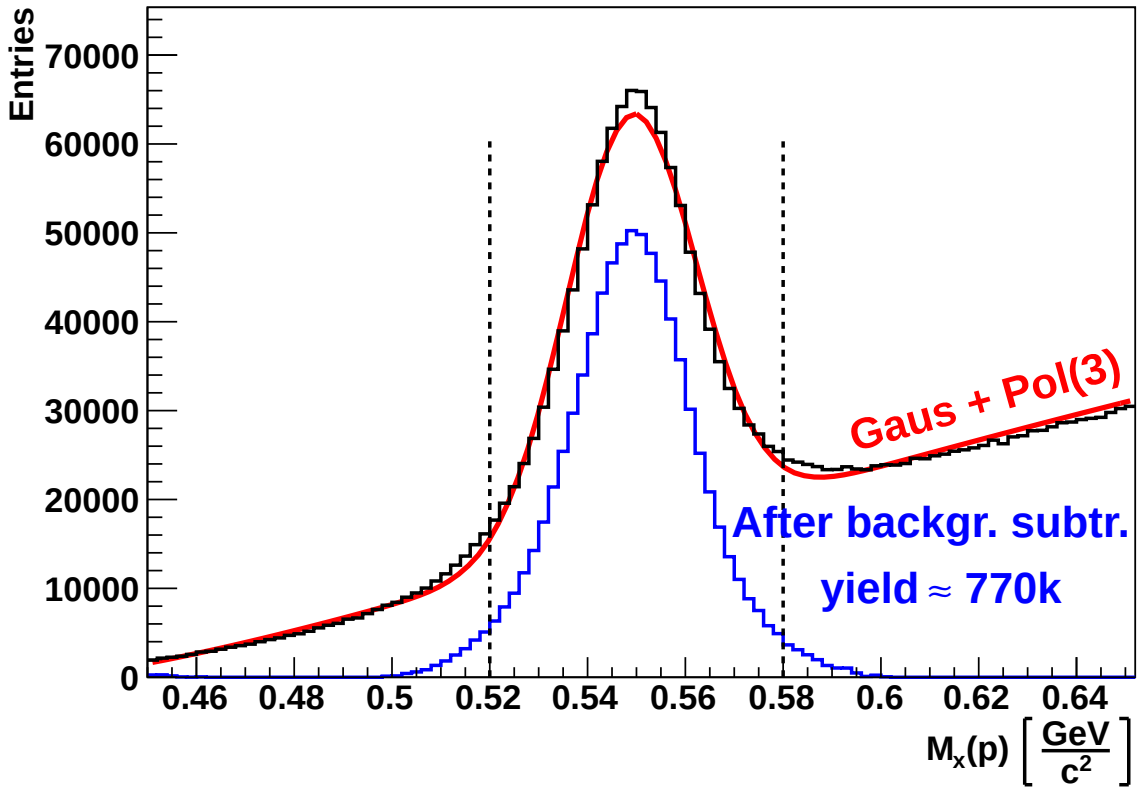
Analysis of $\eta \to \pi^+\pi^-\pi^0$: Suppressing $\omega \to \pi^+\pi^-\pi^0$





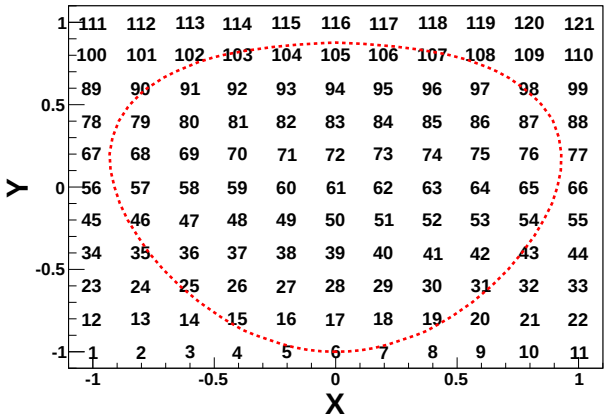
- In both plots: Red: Before applying the invariant mass cut / Blue: After applying the invariant mass cut
- Right: Zoom in of the left plot
- ω-contribution suppressed by a factor ~ 2

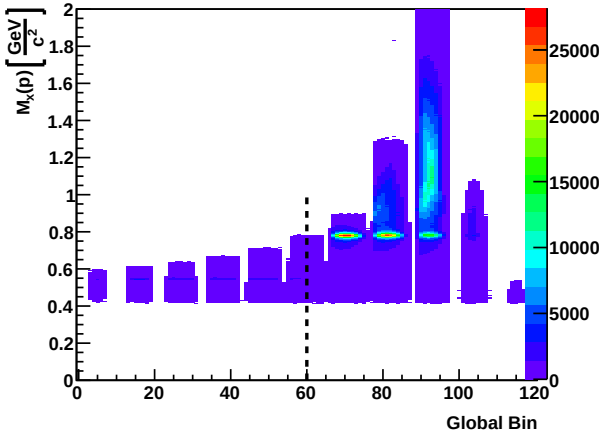
Analysis of $\eta \to \pi^+\pi^-\pi^0$: Signal yield

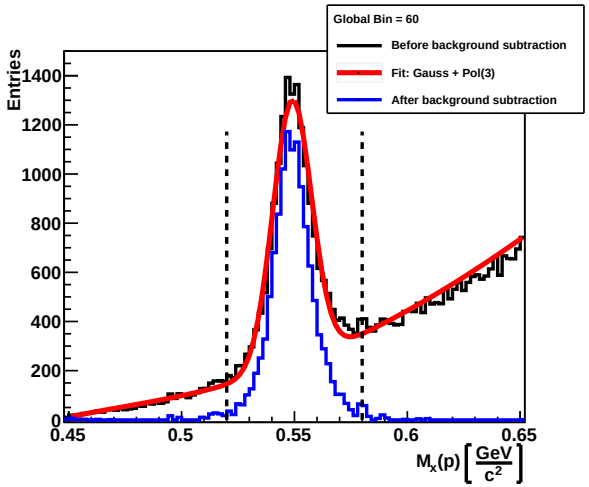


- Total g12 Jülich data set analysed ($\to$ 2/3 of total g12 data set)
- Background described by 3rd order polynomial / Signal described by gaussian function
- Next step: Go for the Dalitz Plot

Towards the Dalitz Plot

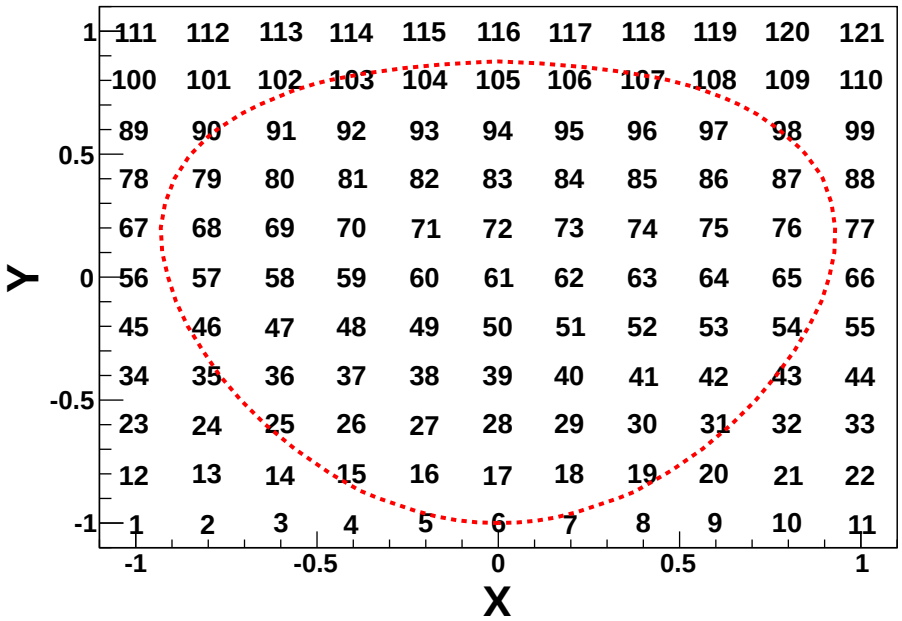


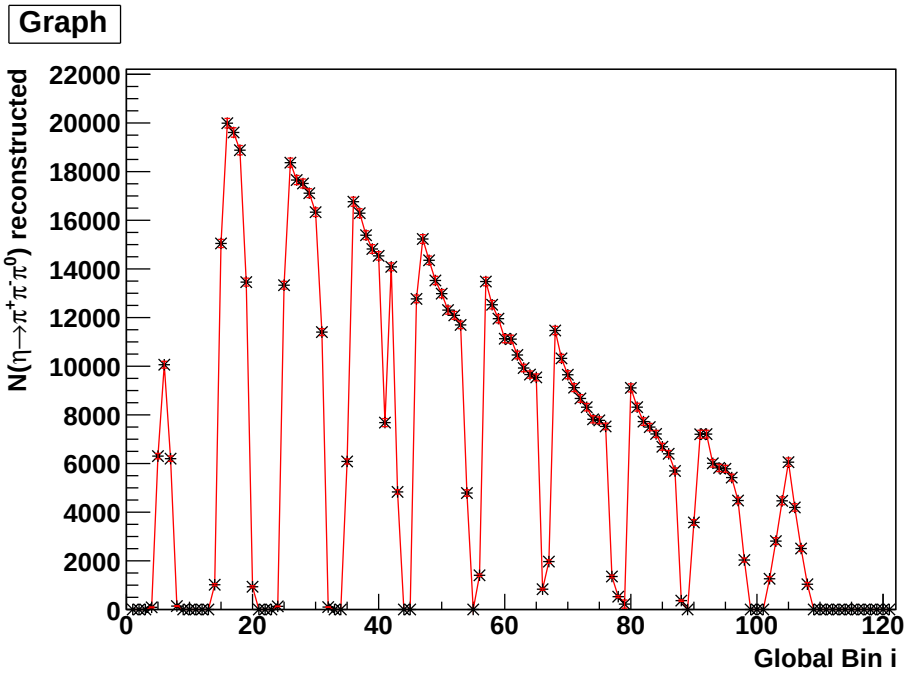




- Follow WASA-at-COSY analysis:
  - Translate each bin of the Dalitz Plot into a global bin:
    $\text{Global bin}(X, Y) = \text{FloorNint}\left[\frac{X+X_{max}}{\delta}\right] + N_{bins} \cdot \text{FloorNint}\left[\frac{Y+Y_{max}}{\delta}\right]$
  - Look at missing mass spectrum for each global bin 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

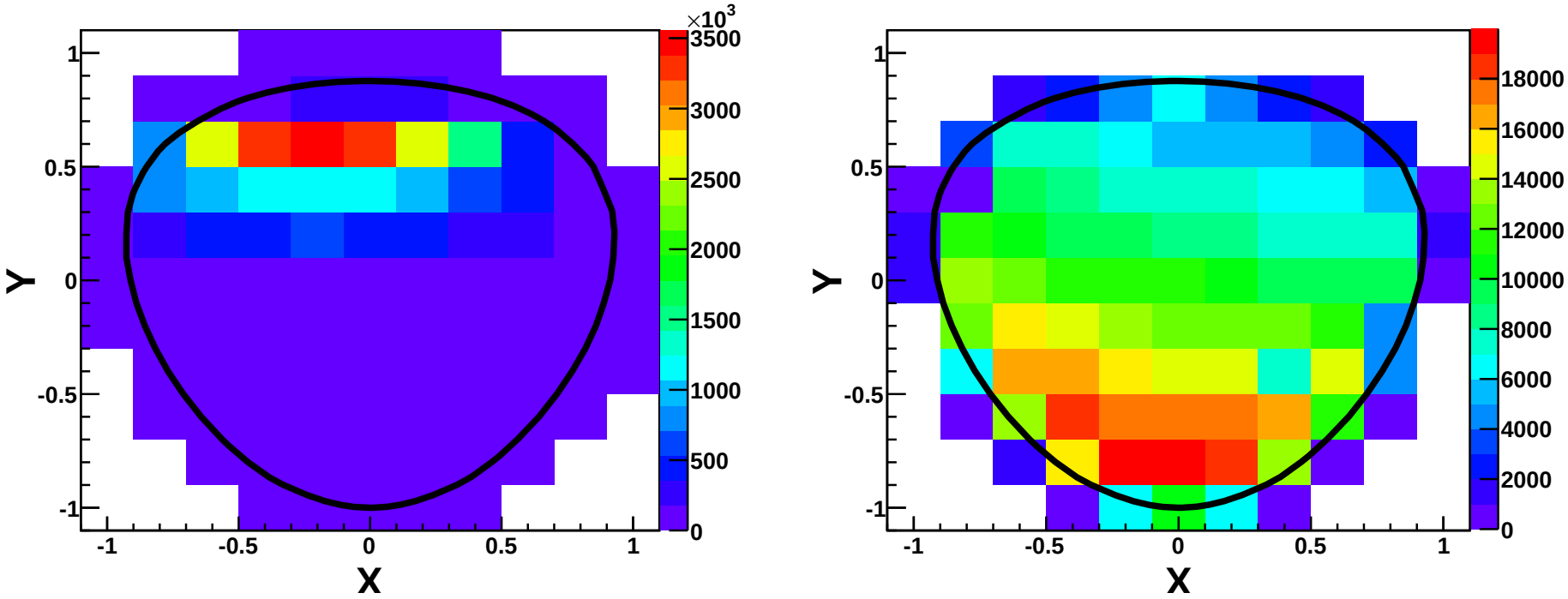
The Dalitz Plot in 1D





- 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 subtracrtion
- Right: After background subtracrtion
- No holes in the Dalitz Plot distribution

Summary and Outlook

- ☑ Reconstructed $\sim 770\,\mathrm{k}$ $\eta \to \pi^+\pi^-\pi^0$ events from g12 data set in Jülich
  (Expect $\lesssim 1 \cdot 10^6$ $\eta \to \pi^+\pi^-\pi^0$ events in total g12 data set)
- ☑ Determined background corrected Dalitz Plot
- ☐ Do simulations and perform efficiency corrections (ongoing)
  $\to$ Go for Dalitz Plot parameters
- ☐ Utalise PWA tools
- ☐ Optimise event selection (ongoing)