Analysis of $\eta \rightarrow \pi^+\pi^-(X)$, $X = \pi 0/\gamma$ within the CLAS G12 Data Set

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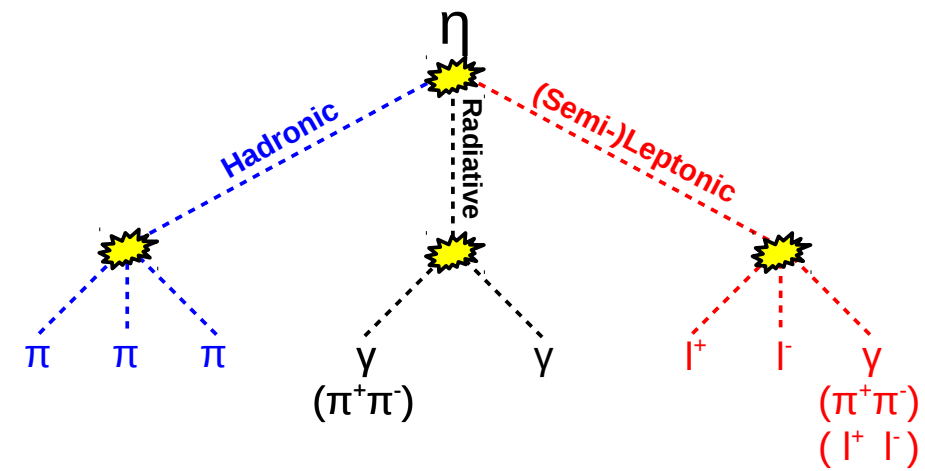
One Meson, many Opportunities

Properties of the η-meson

m_η [GeV/c^2]	0.5478
Γ_η [keV]	(1.31 ± 0.05)
$\bar{\tau}$ [s]	$5 \cdot 10^{-19}$
J^{PC}	0^{-+}

- The η-meson is a *C*-, *P*-, *G*- and *CP*-eigenstate
- All strong and electromagnetic decays are forbidden to first order
- Access to rare decay processes



Today:

1.) Analysis Status of $\eta \to \pi^+\pi^-\pi^0$

2.) Set up Analysis for $\eta^{(\prime)} \to \pi^+\pi^-\gamma$

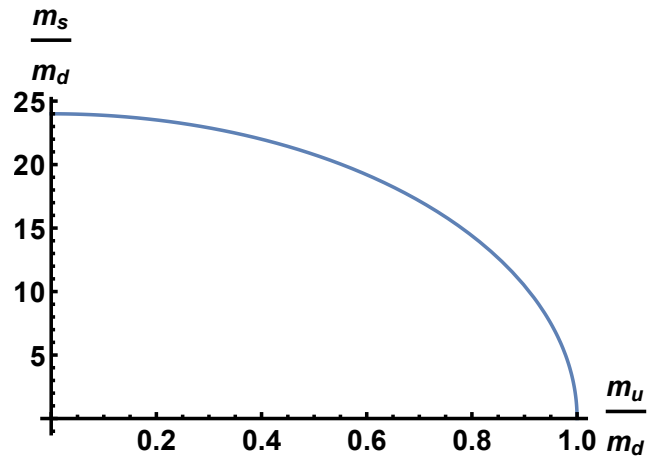
Decay Dynamics of $\eta \to \pi^+\pi^-\pi^0$

System	Isospin State $\lvert I, I_z\rangle$	C-Eigenvalue	G-Eigenvalue
η	$\lvert 0,0\rangle$	$+1$	$+1$
$(\pi^+\pi^-\pi^0)$	$\lvert 0,0\rangle$	-1	-1
$(\pi^+\pi^-\pi^0)$	$\lvert 1,0\rangle$	$+1$	-1

- Decay $\eta \to \pi^+\pi^-\pi^0$ is G-violating $\Rightarrow$ Forbidden to first order
- Decay is driven by isospin breaking part of strong interaction
  $\Rightarrow$ C is conserved
- Decay width: $\Gamma \propto Q^{-4}$

  with: $Q^2 = \left(\frac{m_s}{m_d}\right)^2 \times \left[1 - \left(\frac{m_u}{m_d}\right)^2\right]^{-1}$

$\Rightarrow$ **Determine decay width Γ $\Rightarrow$ Access to quark mass ratio**

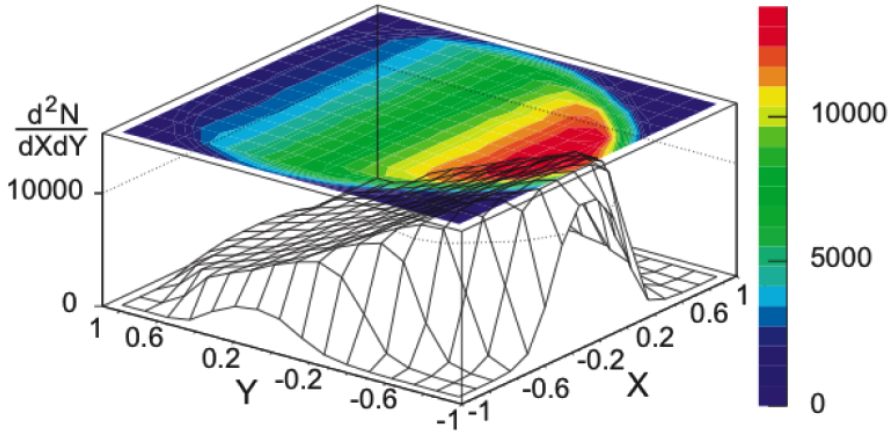


$\Downarrow$

a) Measure $\Gamma(\eta \to \pi^+\pi^-\pi^0)$, e.g. via $\frac{\Gamma(\eta\to\pi^+\pi^-\pi^0)}{\Gamma(\eta\to\gamma\gamma)}$

b) **Dalitz Plot Analysis**

Dalitz Plot Analysis of $\eta \to \pi^+\pi^-\pi^0$



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

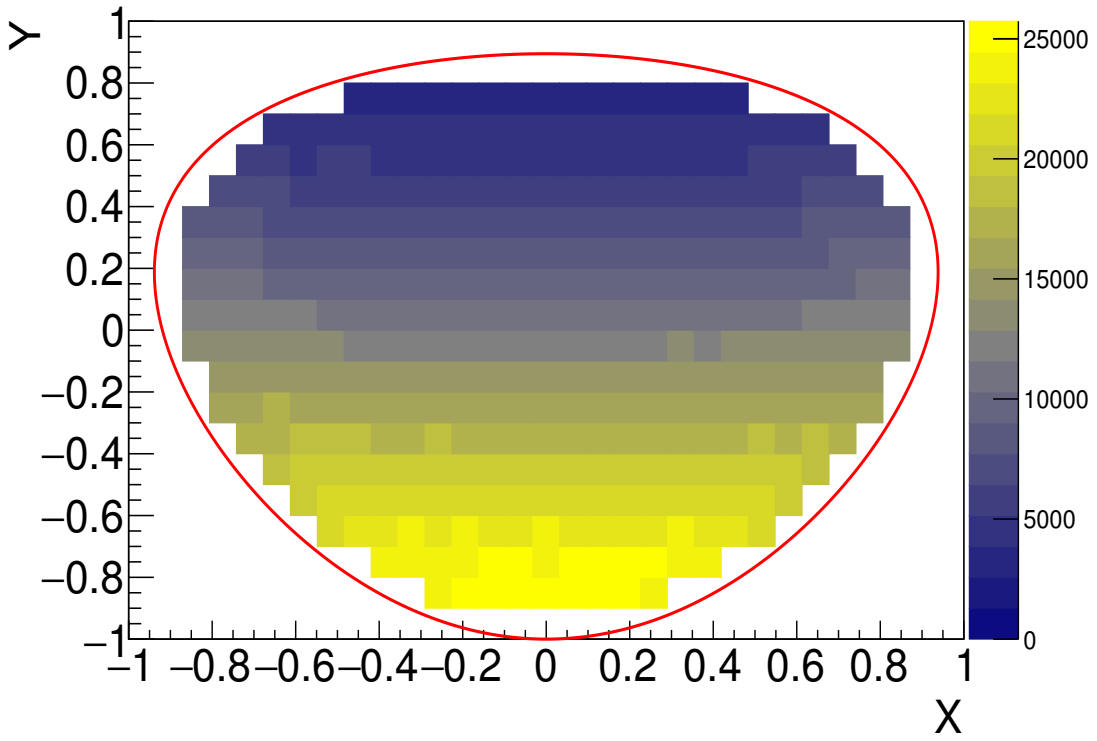
Dimensionless Dalitz Plot Variables:

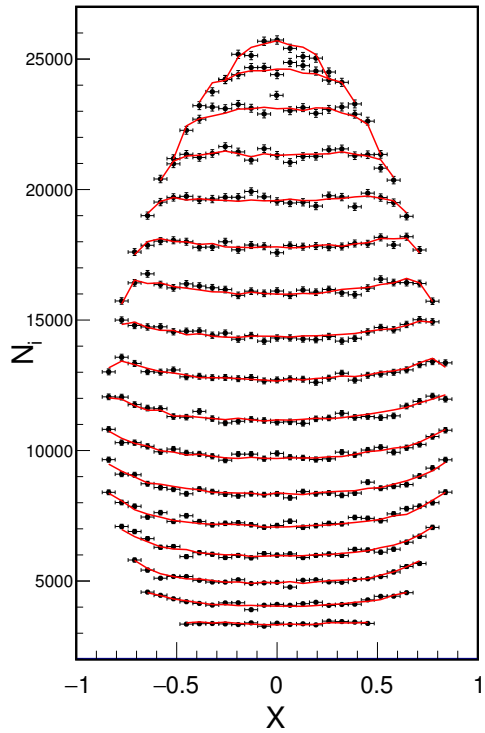
$$X = \sqrt{3}\frac{T_{\pi^+} - T_{\pi^-}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}}$$

$$Y = 3\frac{T_{\pi^0}}{T_{\pi^+} + T_{\pi^-} + T_{\pi^0}} - 1$$

- Describe three body decay by two variables (here: X and Y)
- Complete information about decay dynamics
- Parameterise decay width Γ:
  $\frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + ...)$
- $c \neq 0$ and $e \neq 0$:
  - i) Imply C-violation
  - ii) Cause asymmetries within the Dalitz Plot
- Compare Dalitz Plot parameters a,b,d,f from experiment and theory

Recent Measurements I



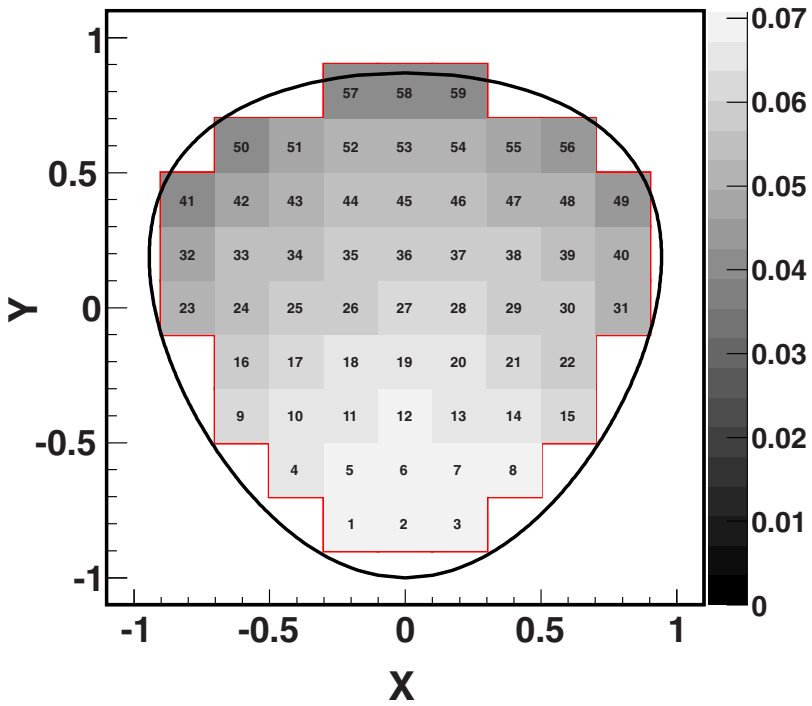


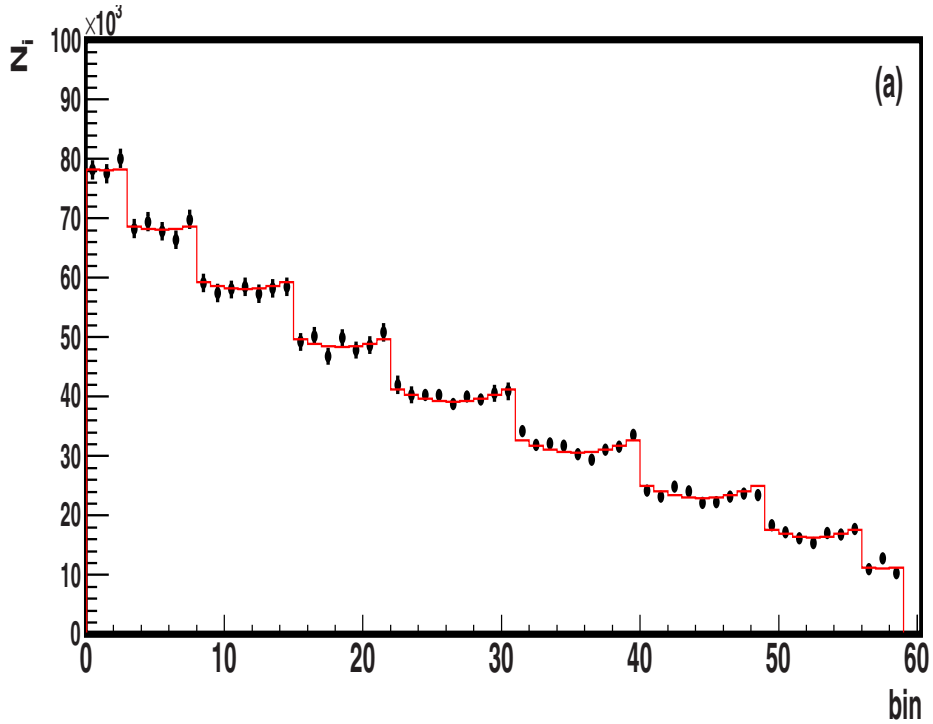
Most recent result from the KLOE-Collaboration:[(f)]

- η-Mesons produced via: $e^+e^- \rightarrow \Phi \rightarrow \eta\gamma$
- $\approx 4.7 \cdot 10^6$ $\eta \rightarrow \pi^+\pi^-\pi^0$ events in the final data sample
- Fit function: Norm $\times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$
- Determined asymmetries of the Dalitz Plot $\Rightarrow$ Consistent with zero $\Rightarrow$ No C-violation

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

Recent Measurements II





Result from the WASA-at-COSY Collaboration:[(d)]

- η-Mesons produced via: $pd \rightarrow {}^3\mathrm{He}\eta$
- $\approx 120\,\mathrm{k}$ $\eta \rightarrow \pi^+\pi^-\pi^0$ events in the final data sample
- Translate each pair (X,Y) into a global bin $i(X, Y)$
  $\rightarrow$ Obtain one dimensional Dalitz Plot
- Fit function: Norm $\times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$

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

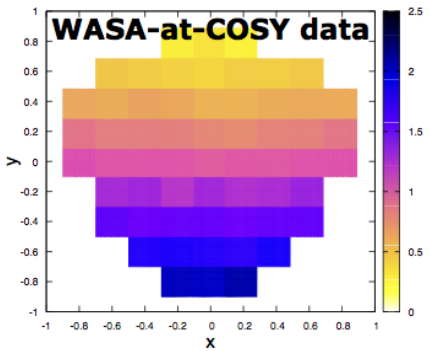
Recent Measurements and Theoretical Predictions

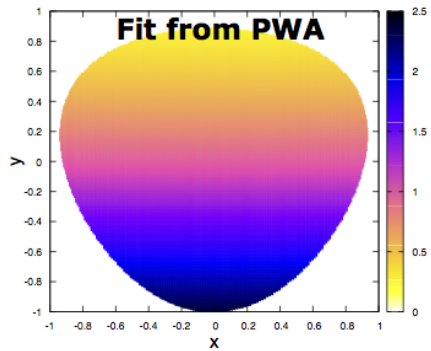
	Parameter:	$-a$	b	d	f
Exp.	KLOE (08)[a]	$1.090(5)(^{+8}_{-19})$	0.124(6)(10)	$0.057(6)(^{+7}_{-16})$	0.14(1)(2)
	WASA[d]	1.144(18)	0.219(19)(47)	0.086(18)(15)	0.115(37)
	KLOE (16)[f]	$1.104(3)(2)$	$0.142(3)(^{5}_{-4})$	$0.073(3)(^{+4}_{-3})$	$0.154(6)(^{+4}_{-5})$
Theor.	ChPT (NNLO)[b]	1.271(75)	0.394(102)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

(a) KLOE coll., *JHEP*, 05, (2008) (b) J. Bijnens and K. Ghorbani., *JHEP*, 11, (2007) (c) S- P. Schneider et al., *JHEP*, 028, (2011)

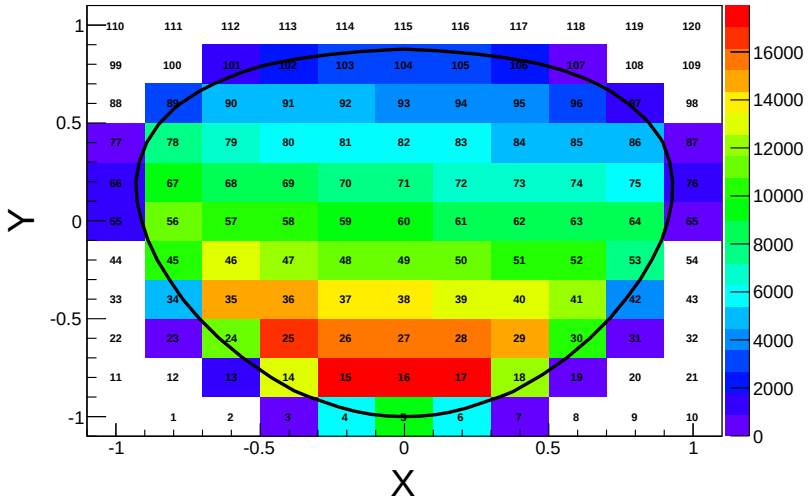
(d) WASA-at-COSY coll., *Phys. Rev.*, C90(045207), 2014 (e) Peng Guo et al., *Phys. Rev.*, D92(05016), (2015) (f) KLOE coll., *JHEP*, 019, (2016)

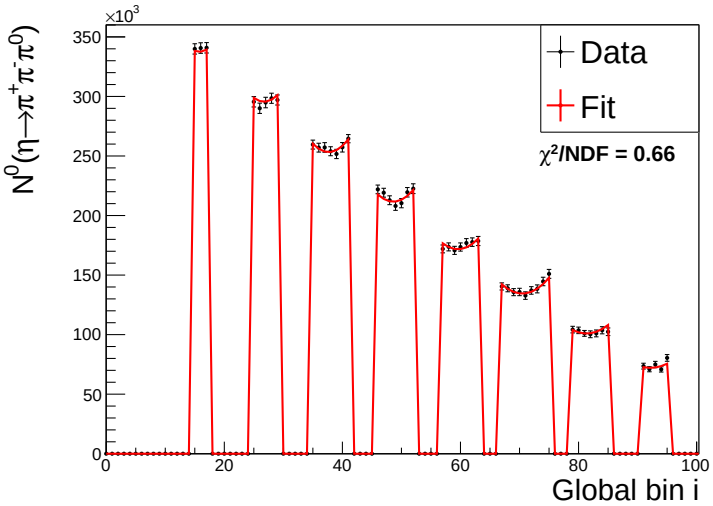
- WASA-at-COSY results used for Partial Wave Analysis (PWA) from JPAC group
  $\Rightarrow$ Direct calculation of:
  $Q = 21.4 \pm 0.4_{\mathbf{stat}}$ [e]
- **Dalitz Plot Analysis and determination of Q for $\gamma p \to p\eta[\eta \to \pi^+\pi^-\pi^0]$ with CLAS**





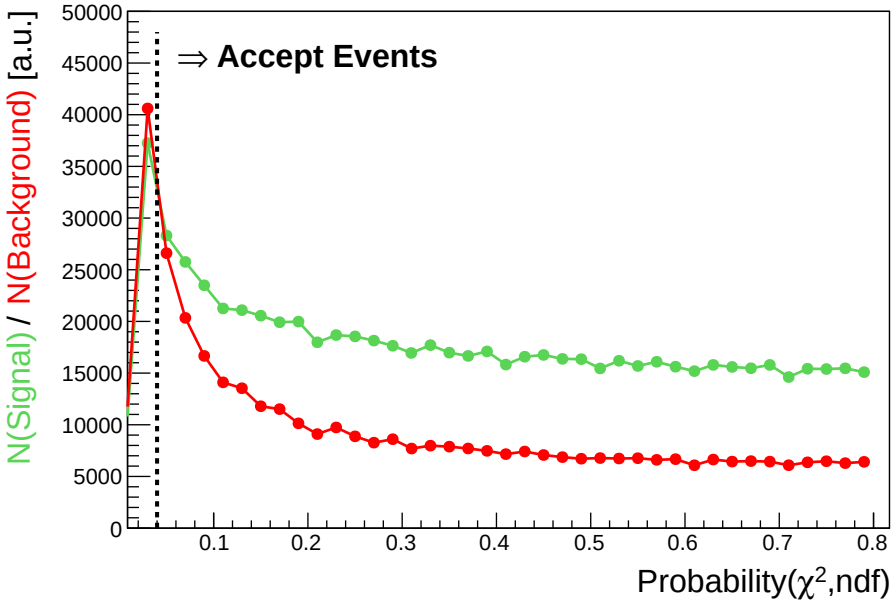
Short Reminder: Status presented at Last Meeting

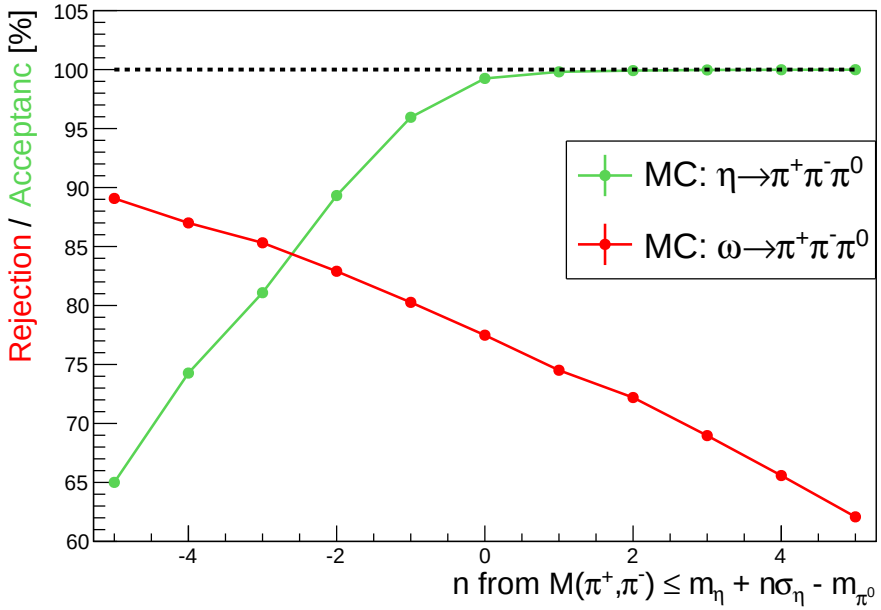




- Problems/Issues:
  - i) Analysis Parameters loosely chosen
  - ii) Parameter $c = 0.018 \pm 0.008 \neq 0$
  - iii) Overview over systematic effects missing $\leftrightarrow$ Maybe an explanation for ii)?
- Goal of this meeting:
  1. Choosing analysis parameter and define reference data set
  2. Set up machinery/procedure for determination of systematic errors and gain first insights

Analysis Parameter



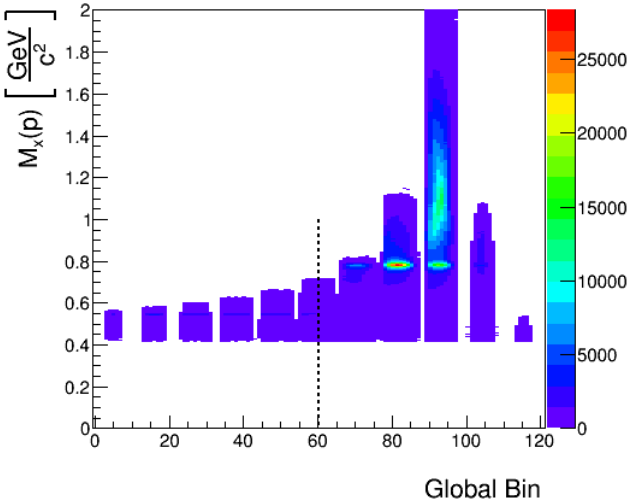


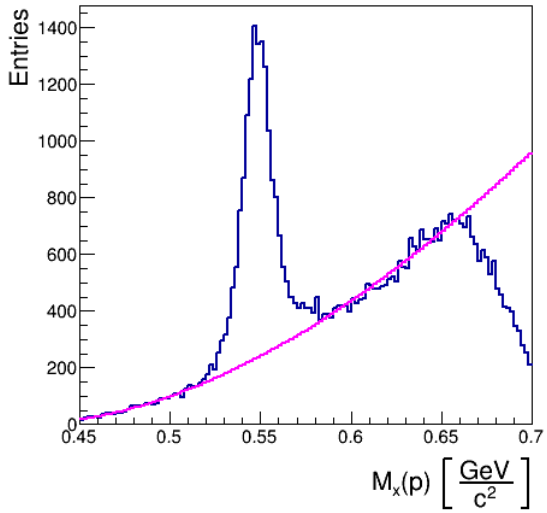
- Left:
  - Looked at $M_x(p)$-distribution in data as a function of probability intervals
  - Estimated number of signal/background events for each interval

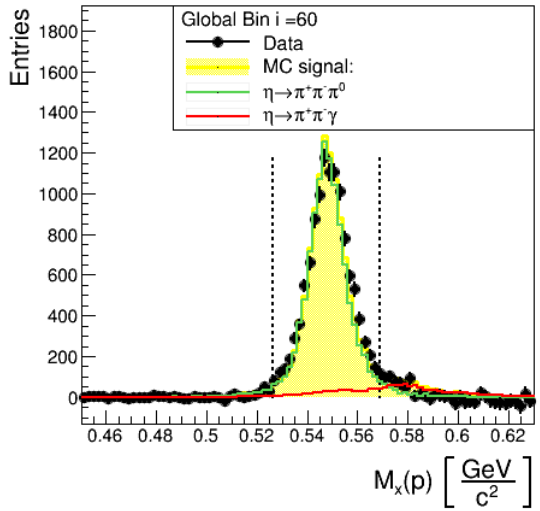
  $\Rightarrow$ Choose 4% probability cut for further event selection
- Right:
  - Use MC data to check rejection/acceptance of ω/η

  $\Rightarrow$ Choose $n = 1$ for further event selection

Background Handling and Determination of $N^0(\eta \to \pi^+\pi^-\pi^0)$

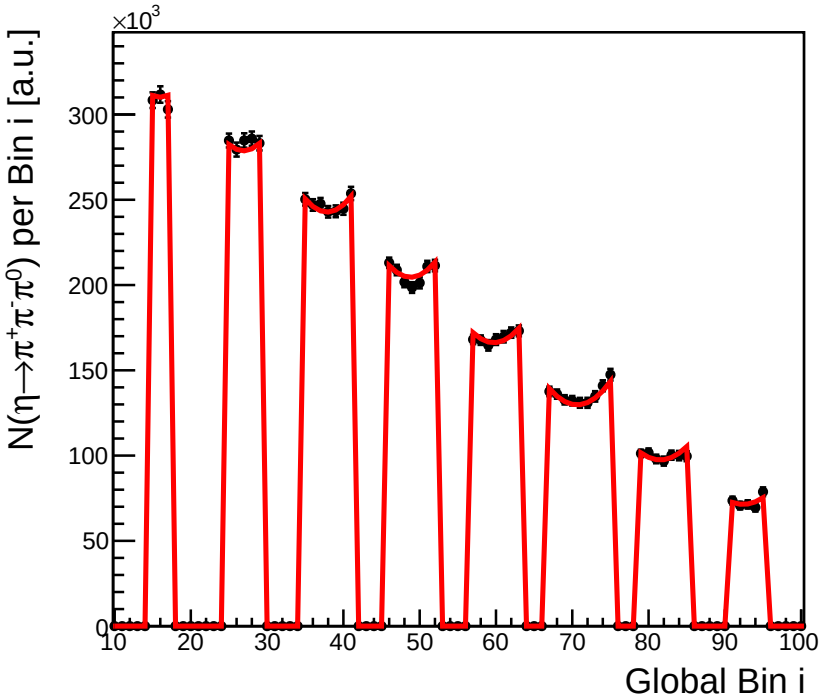


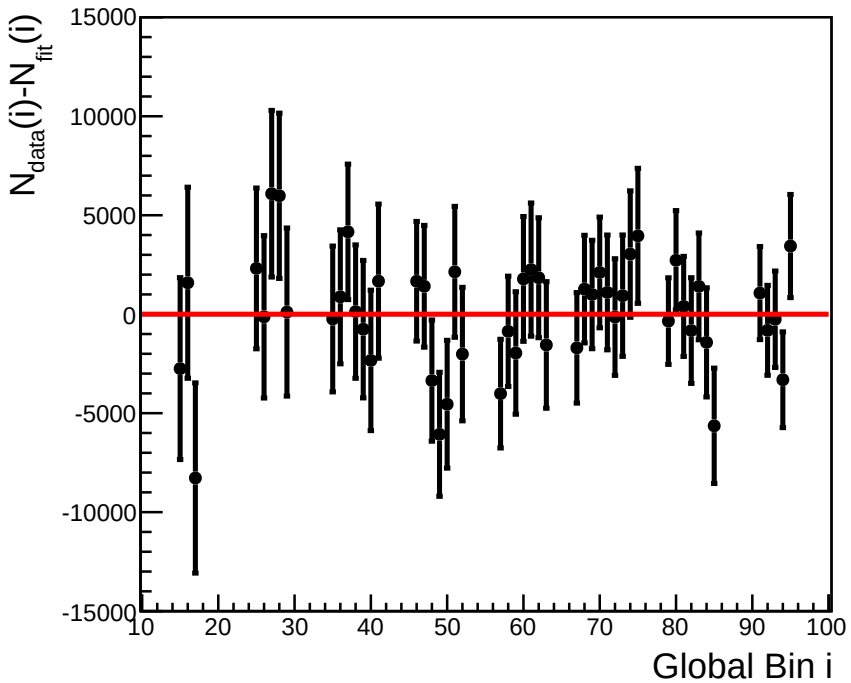




- Correct for background for each Global Bin i
- Determination of $N^0(\eta \to \pi^+\pi^-\pi^0)$:
  $N^0(\eta \to \pi^+\pi^-\pi^0)[i] = N^{fit}(\eta \to \pi^+\pi^-\pi^0)[i]/\epsilon[i]$, with: Efficiency $\epsilon[i]$
- Fit resulting distribution with: Norm $\times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$

Results and Reference Data Set





- c/e-Parameter: $c = 0.013 \pm 0.009$ and $e = 0.014 \pm 0.021$
- Use this data set as reference for systematic studies

Determining Systematic Errors: Method

1. Do analysis with analysis parameter $p_1, .., p_N$ (e.g. kinematic fit probability)
   $\Rightarrow$ Obtain reference data set with result(s): $R \pm \Delta R$
2. Redo analysis:
   a) Vary parameter p_i (e.g. beam energy) within interval $[p_{i1}, p_{ik}]$
   b) Keep remaining parameters $p_{j \neq i}$ fixed

   $\Rightarrow$ Obtain sub-data sets $i_1, .., i_k$ with result(s): $R_{im} \pm \Delta R_{im},\ m = 1, .., k$
3. Are sub-data sets $i_1, .., i_k$ statistically uncorrelated?

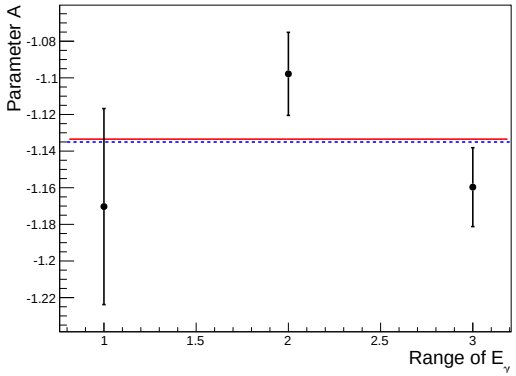
   Yes: Errors ΔR_{im} are (statistically) uncorrelated and can be treated independently
   No: Errors ΔR_{im} are (statistically) correlated and have to be corrected:
   $\Delta R_{im} \mapsto \sqrt{|\Delta R^2 - \Delta R_{im}^2|}$

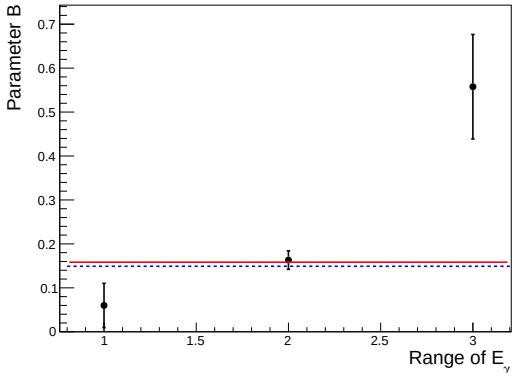
   $\Rightarrow$ Fit a straight line to $R_{im} \pm \Delta R_{im}$ and determine error σ_i from that fit
4. Repeat steps 1.-3. for remaining parameter

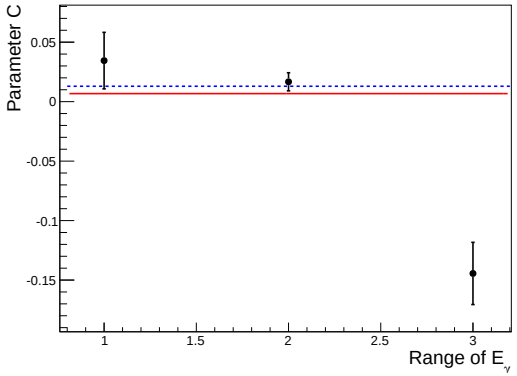
Systematic Effects: Beam Photon Energy Ranges

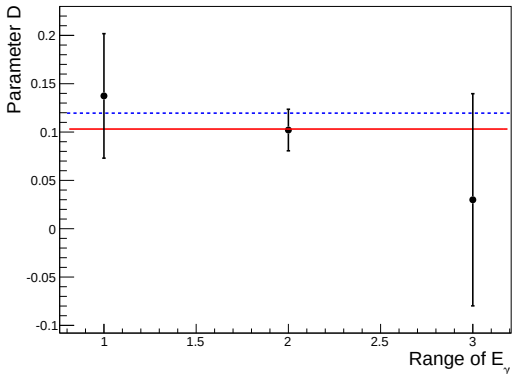
- Divided photon beam energy in three ranges:
  1: $E_\gamma < 1.3\,\mathrm{GeV}$
  2: $E_\gamma \in [1.3\,\mathrm{GeV}, 3.6\,\mathrm{GeV})$ (dead paddle region has been excluded)
  3: $E_\gamma > 3.6\,\mathrm{GeV}$
- Leave other analysis parameter unchanged
- 3 (statistical) independent data sets $\Rightarrow$ Compare to reference data set

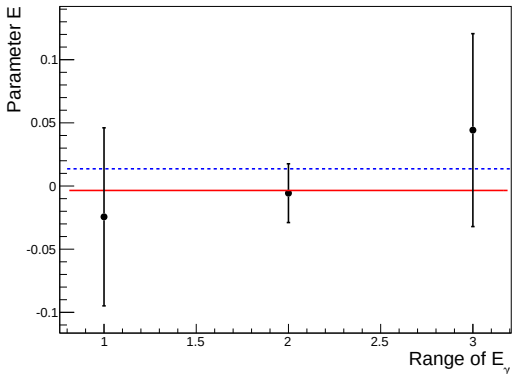
Systematic Effects: Beam Photon Energy Ranges

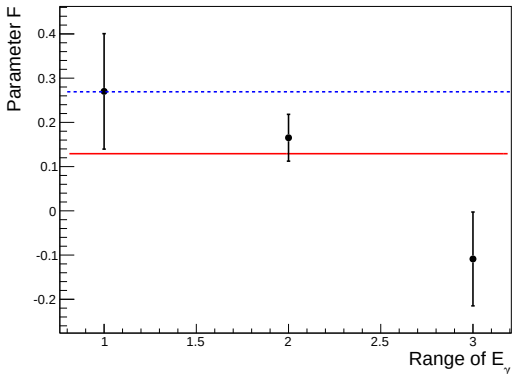


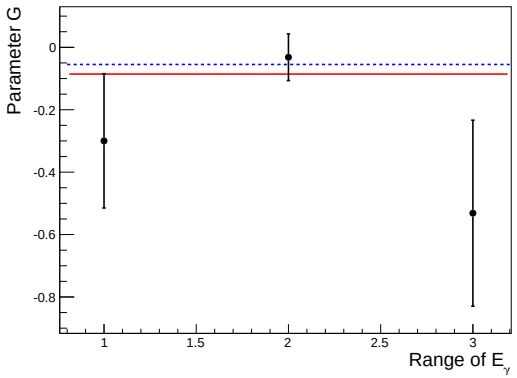








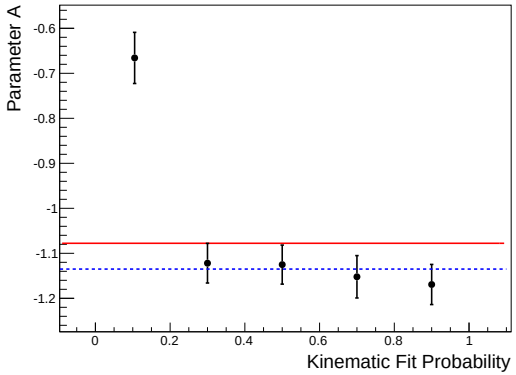


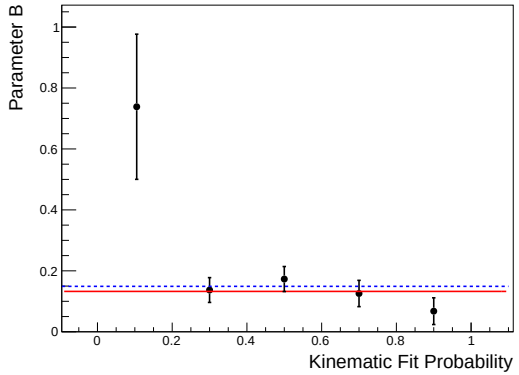


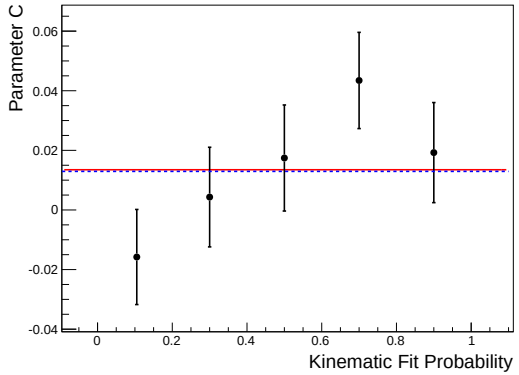
Systematic Effects: The Kinematic Fit

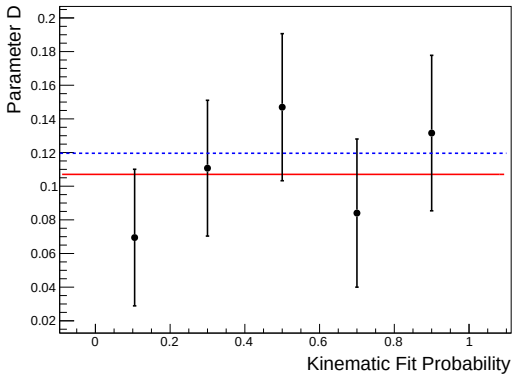
- Look at different probability intervals:
  - Interval1 $\in [1\%, 20\%)$
  - Interval2 $\in [20\%, 40\%)$
  - ...
  - Interval5 $\in [80\%, 100\%)$
- Leave other analysis parameter unchanged
- 5 (statistical) independent data sets $\Rightarrow$ Compare to reference data set

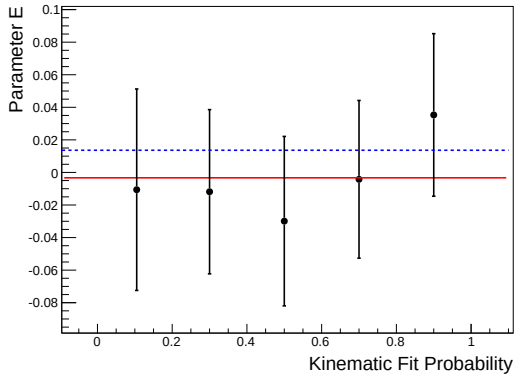
Systematic Effects: The Kinematic Fit

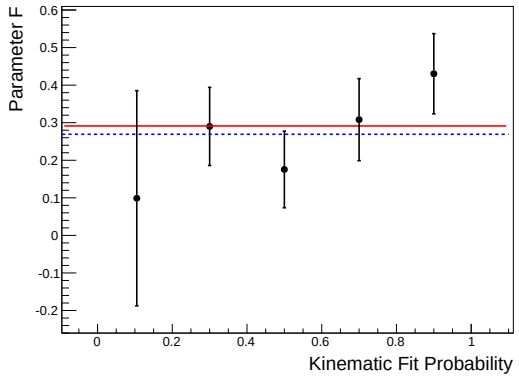


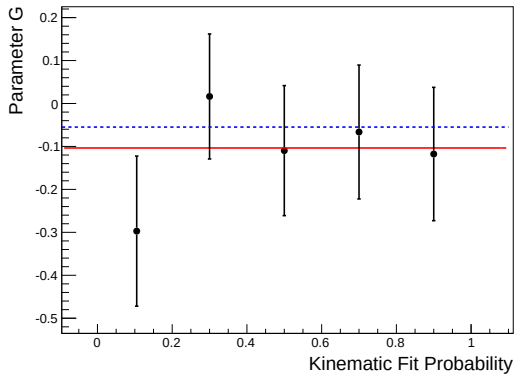








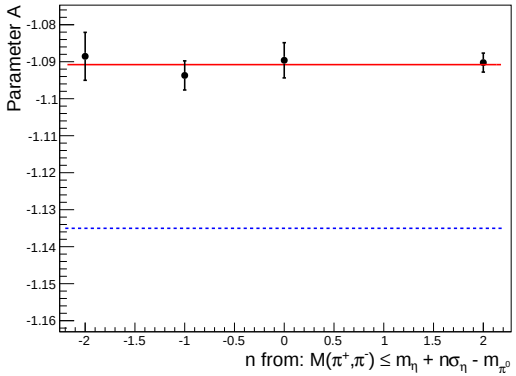


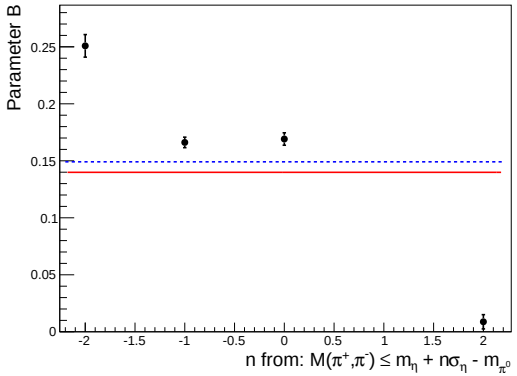


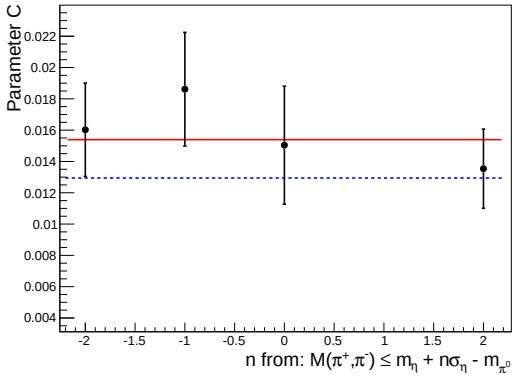
Systematic Effects: Cut on the Invariant Mass

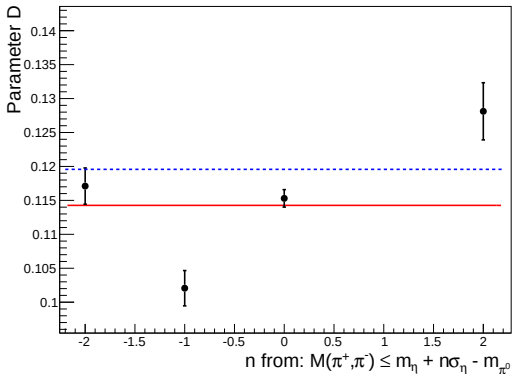
- Vary cut on invariant mass according to:
  $M(\pi^+, \pi^-) \leq m_\eta + n\sigma_\eta - m_{\pi^0}$
- With $n \in [-2, 2]$
- Leave other analysis parameter unchanged
- 5 statistical dependent data sets $\Rightarrow$ Compare to reference data set (take care of error handling)

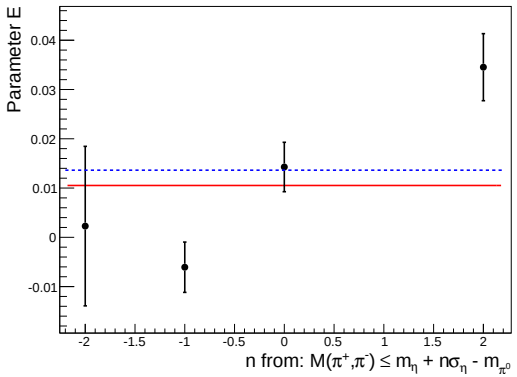
Systematic Effects: Cut on the Invariant Mass

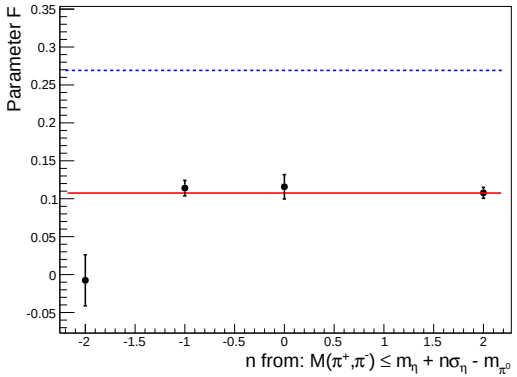


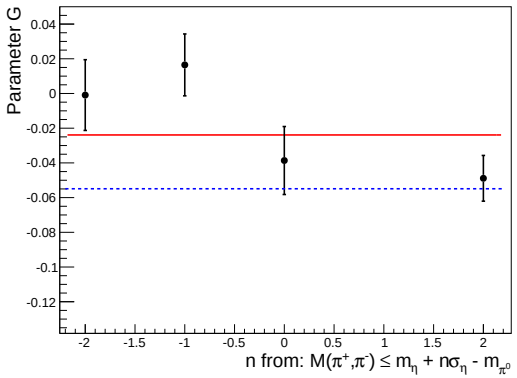








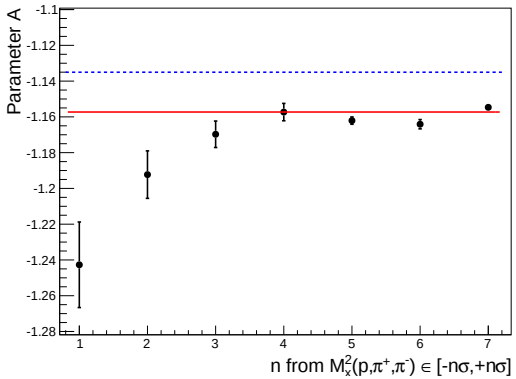


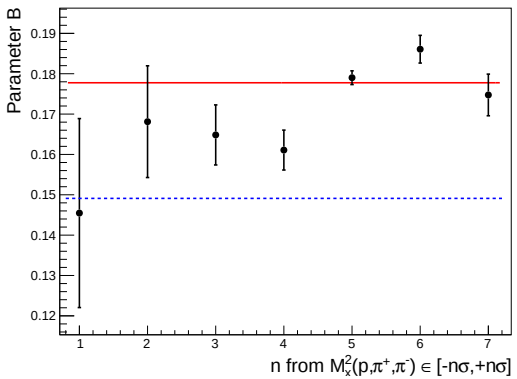


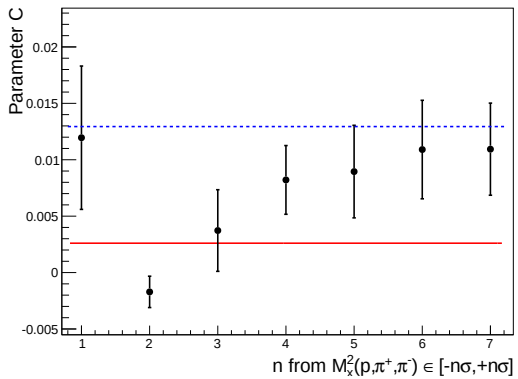
Systematic Effects: Cut on the $M_x^2(p, \pi^+, \pi^-)$-distribution

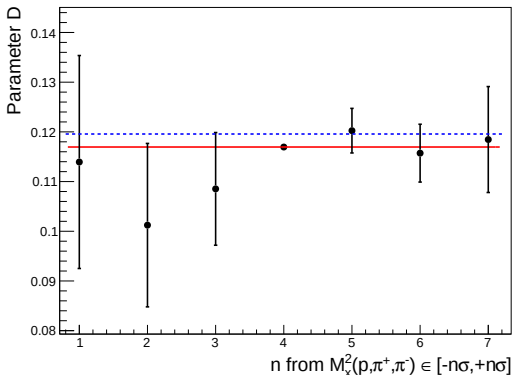
- Vary cut on $M_x^2(p, \pi^+, \pi^-)$-disstribution:
  $M_x^2(p, \pi^+, \pi^-) \in [-n\sigma_{\pi^0}, n\sigma_{\pi^0}]$
- With $n \in [-3, 3]$
- Leave other analysis parameter unchanged
- 5 statistical dependent data sets $\Rightarrow$ Compare to reference data set (take care of error handling)

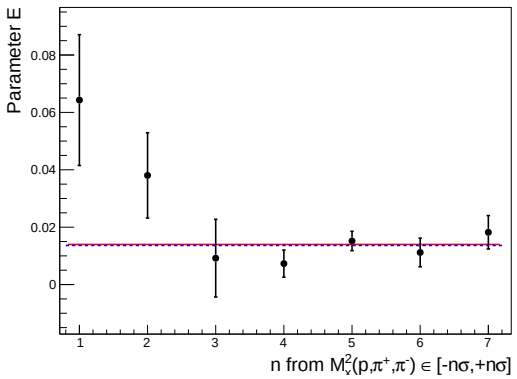
Systematic Effects: Cut on the $M_x^2(p, \pi^+, \pi^-)$-distribution

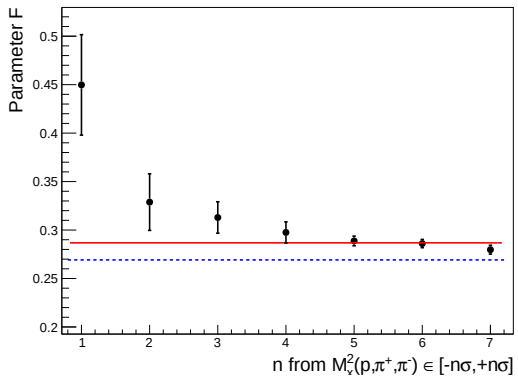


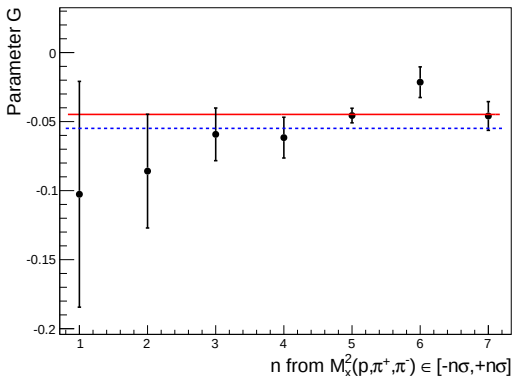












Summary of the Systematic Errors/Effects

Parameter	σ_{stat}	σ_{beam}	σ_{fit}	σ_{im}	σ_{π^0}	σ_{tot}
$a = -1.135$	± 0.021	$^{+0.042}_{-0.039}$	$^{+0.274}_{-0.159}$	$^{+0.046}_{-0.042}$	$^{0.016}_{0.060}$	$^{+0.281}_{-0.179}$
$b = 0.149$	± 0.020	$^{+0.3}_{-0.281}$	$^{+0.289}_{-0.322}$	$^{+0.118}_{-0.136}$	$^{0.045}_{-0.012}$	$^{+0.435}_{-0.449}$
$c = 0.013$	± 0.008	$^{+0.103}_{-0.115}$	$^{+0.008}_{0.007}$	$^{+0.004}_{-0.001}$	$^{+0.003}_{-0.018}$	$^{+0.103}_{-0.117}$
$d = 0.120$	± 0.020	$^{+0.004}_{-0.037}$	$^{+0.007}_{-0.032}$	$^{+0.008}_{-0.019}$	$^{+0.002}_{-0.003}$	$^{+0.011}_{-0.053}$
$e = 0.014$	± 0.021	$^{+0.004}_{-0.038}$	$^{+0.006}_{-0.040}$	$^{+0.019}_{-0.026}$	$^{+0.003}_{-0.002}$	$^{+0.021}_{-0.061}$
$f = 0.269$	± 0.048	$^{+0.057}_{-0.337}$	$^{+0.074}_{-0.030}$	$^{+0.095}_{-0.228}$	$^{+0.087}_{-0.052}$	$^{+0.159}_{-0.411}$
$g = -0.055$	± 0.068	$^{+0.038}_{-0.099}$	$^{+0.021}_{-0.118}$	$^{0.066}_{-0.004}$	$^{0.014}_{-0.006}$	$^{+0.038}_{-0.154}$

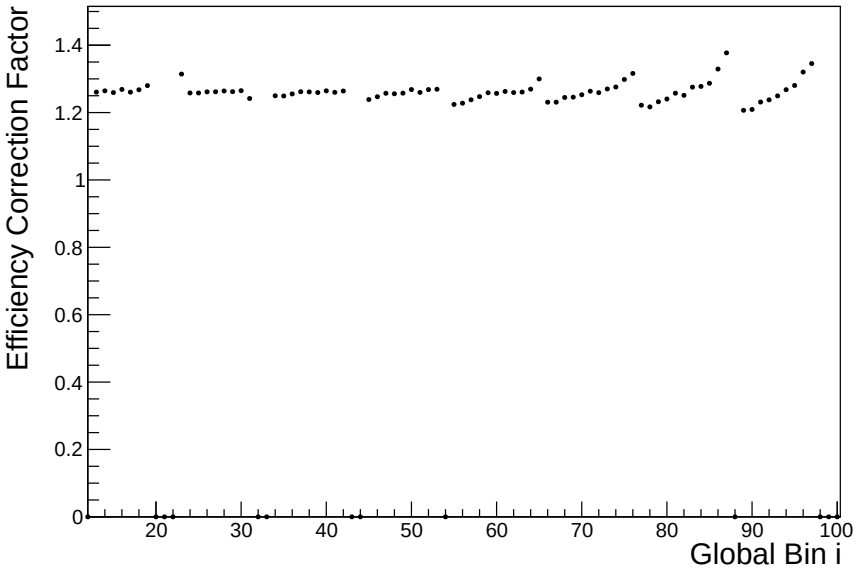
- Total systematic error: $\sigma_{tot} = \sqrt{\sigma^2_{beam} + \sigma^2_{fit} + \sigma^2_{im} + \sigma^2_{\pi^0}}$
- NOTE(S):
  - These are no final results!
  - Errors should be taken with caution
  - Systematic studies are still ongoing $\Rightarrow$ Everything might change (or not)

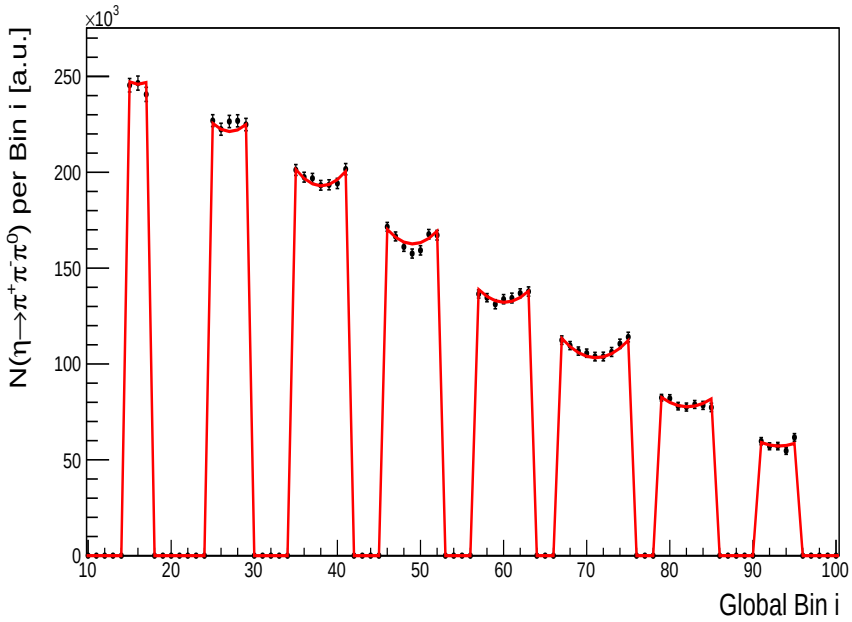
Current Status

Exp.	$-a$	b	c	d	e	f
WASA	1.144(18)	0.219(66)	$-0.007(9)$	0.086(33)	$-0.020(52)$	0.115(37)
KLOE(16)	1.095(6)	0.145(8)	0.0	0.081(9)	0.0	0.141(15)
G12 (5.0)	$1.135^{+\mathbf{0.302}}_{-\mathbf{0.02}}$	$0.149^{+\mathbf{0.455}}_{-\mathbf{0.469}}$	$0.013^{+\mathbf{0.111}}_{-\mathbf{0.125}}$	$0.120^{+\mathbf{0.032}}_{-\mathbf{0.073}}$	$0.014^{+\mathbf{0.042}}_{-\mathbf{0.082}}$	$0.269^{+\mathbf{0.207}}_{-\mathbf{0.459}}$

- Errors for parameters a, b and f are far too large
- Core-value of parameter f is far off compared to previous measurements

Outlook: Efficiency Correction

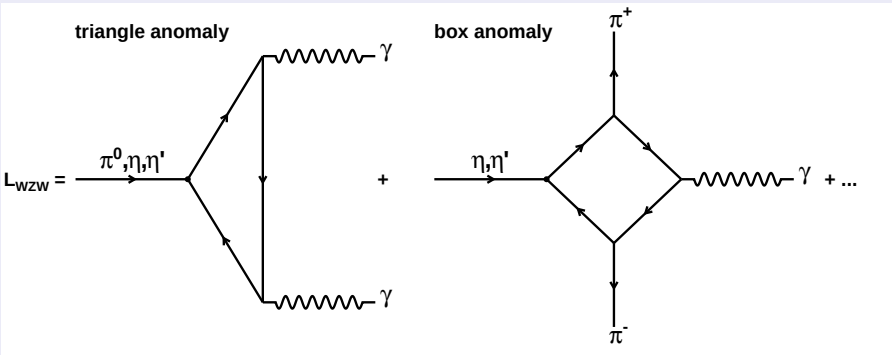




- Introduce efficiency correction fact $F(i)$ which has been determined by comparing particle momentum distributions between data and MC
- Correct efficiency: $\epsilon(i) \mapsto \epsilon(i) \times F(i)$
- Obtain: $c = 0.006 \pm 0.007$, other parameters are not affected (within the errors)
- Justification and effect of this method on systematics? (currently ongoing)

$\eta \to \pi^+\pi^-\gamma$: The Box Anomaly and $\pi^+\pi^-$ FSI

Chiral limit:[a],[b]



- Wess-Zumino-Witten Lagrangian
  (a) Wess, Zumino, *Phys. Lett*, B37(95), 1971
  (b) Witten, *Nucl. Phys.*, B223:422-432, 1983
- Decay amplitude $A_{\eta\to\pi^+\pi^-\gamma}$ is sensitive to box anomaly[c]:

$$A_{\eta\to\pi^+\pi^-\gamma} \propto \frac{e}{4\sqrt{3}\pi^2 F_\pi^3}\left(\frac{F_\pi}{F_8}\cos\theta - \sqrt{2}\frac{F_\pi}{F_0}\sin\theta\right)$$

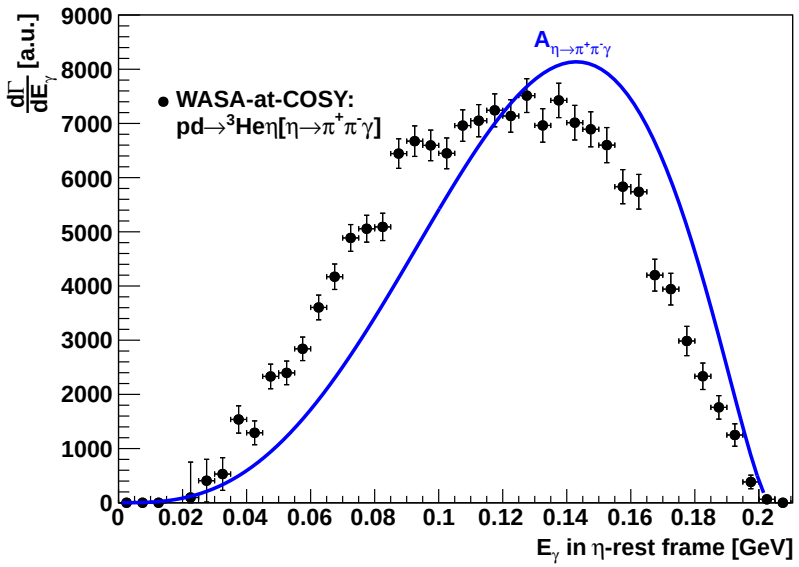
- $\Gamma^{\text{Theory}}(\eta \to \pi^+\pi^-\gamma) = 35.7\,\text{eV}$[c]
- $\Gamma^{\text{Exp.}}(\eta \to \pi^+\pi^-\gamma) = (55.3 \pm 2.4)\,\text{eV}$[d]

(c) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

(d) PDG, *Chin. Phys.*, 090001, 2014

- Photon energy distribution E_γ:[e]

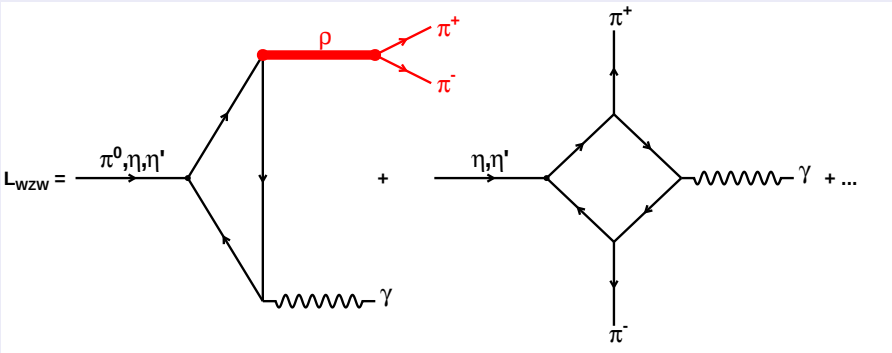
(e) WASA-at-COSY coll. *Phys. Lett.*, B707:243-249, 2012



$$E_\gamma(s_{\pi\pi}) = \frac{1}{2}\cdot\left(m_\eta - \frac{s_{\pi\pi}}{m_\eta}\right)$$

$\eta \to \pi^+\pi^-\gamma$: The Box Anomaly and $\pi^+\pi^-$ FSI

Beyond chiral limit:



- Wess-Zumino-Witten Lagrangian & $\pi^+\pi^-$ Final State Interactions
- Modification of decay amplitude:[a]

(a) F.Stollenwerk et al., *Phys. Lett.*, B707:184-190, 2012

$$A_{\eta\to\pi^+\pi^-\gamma} \times [F_{PV}(s_{\pi\pi}) \times (1 + \alpha s_{\pi\pi})]$$

$\Rightarrow$

Description of FSI: $\begin{cases} \text{by } F_{PV} & \alpha = 0 \\ \text{reaction specific}^* & \alpha \neq 0 \end{cases}$

*Input from theory

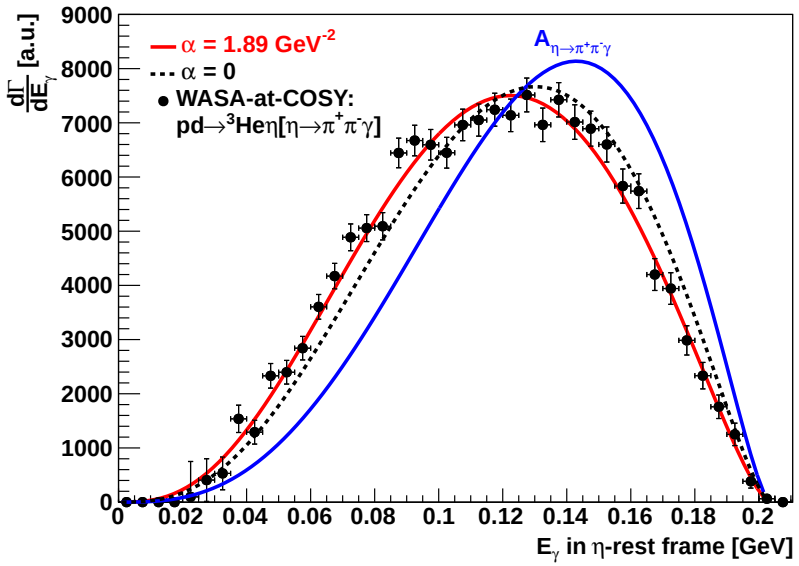
- $\Gamma^{\text{Theory}}(\eta \to \pi^+\pi^-\gamma) = 35.7\,\text{eV}$[b]
- $\Gamma^{\text{Exp.}}(\eta \to \pi^+\pi^-\gamma) = (55.3 \pm 2.4)\,\text{eV}$[c]

(b) B.R. Holstein, *Phys. Scripta*, T99:55-67, 2002

(c) PDG, *Chin. Phys.*, 090001, 2014

- Photon energy distribution E_γ:[d]

(d) WASA-at-COSY coll. *Phys. Lett.*, B707:243-249, 2012



$$E_\gamma(s_{\pi\pi}) = \frac{1}{2} \cdot \left(m_\eta - \frac{s_{\pi\pi}}{m_\eta}\right)$$

Theoretical Predictions and Recent Measurements

		$\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$	α [GeV^{-2}]
Experiment	Gormley et al.	0.202 ± 0.006	1.8 ± 0.4
	Thaler et al.	0.209 ± 0.004	-
	Layter et al.	-	-0.9 ± 0.1
	GAMS-200*	-	2.7 ± 0.1
	CRYSTAL BARREL*	-	1.8 ± 0.53
	CLEO	0.175 ± 0.013	-
	WASA-at-COSY	Preliminary: 0.206 ± 0.011	1.89 ± 0.86
	KLOE	0.1856 ± 0.003	$1.32^{\star} \pm 0.2$
	CLAS	Analysis ongoing	-
	BESIII	Analysis ongoing for η and η'	-
	WASA-at-COSY	Analysis ongoing for $pp \to pp\eta$	-
Theory	N/D	0.2188 ± 0.0088	0.64 ± 0.02
	HLS	0.1875 ± 0.0094	0.23 ± 0.01
	$(O(p^6) + 1 - \text{loop})$	0.1565 ± 0.0063	-0.7 ± 0.1
	Box anomaly	0.119 ± 0.0048	-1.7 ± 0.02

*Measured $\eta' \to \pi^+\pi^-\gamma$ * Include effects of a_2: Kubis and Plenter, Eur. Phys. J., C75: 283, 2015

Theoretical Predictions and Recent Measurements

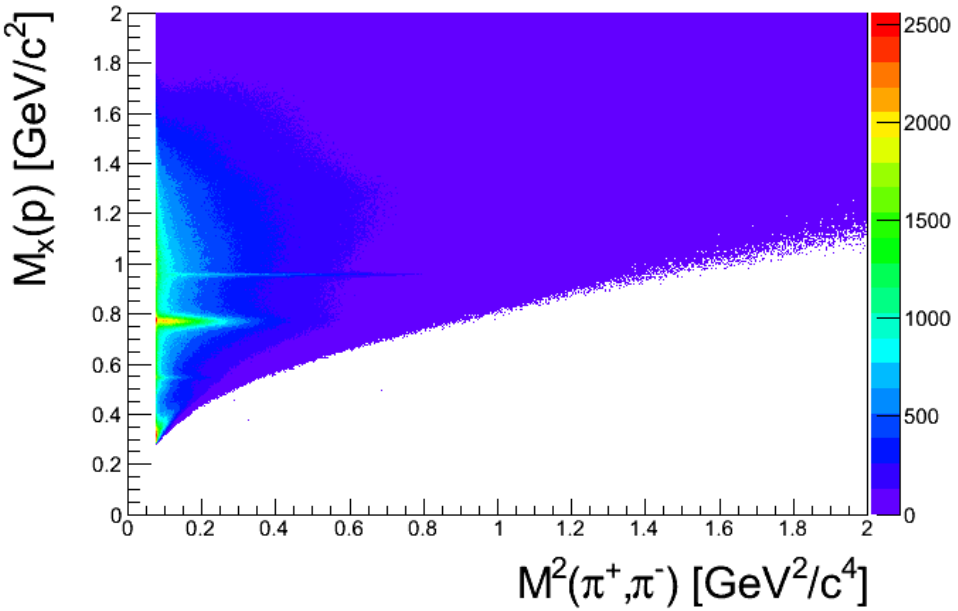
		$\Gamma(\eta \to \pi^+\pi^-\gamma)/\Gamma(\eta \to \pi^+\pi^-\pi^0)$	α [GeV^{-2}]
Experiment	*Phys. Rev.,D2:501-505, 1970*	0.202 ± 0.006	1.8 ± 0.4
	Phys. Rev.,D7:2569-2571, 1973	0.209 ± 0.004	-
	Phys. Rev.,D7:2565-2568, 1973	-	-0.9 ± 0.1
	Phys.,C50:451-454, 1991 *	-	2.7 ± 0.1
	*Phys. Lett.,B402:195, 1997**	-	1.8 ± 0.53
	Phys. Rev. Lett.,99(122001), 2007	0.175 ± 0.013	-
	Phys. Rev. Lett.,B707:243-249, 2013	-	1.89 ± 0.86
	Phys. Lett.,B718:910-914, 2013	0.1856 ± 0.003	1.32 ± 0.2
	-	-	-
	-	-	-
Theory	*Phys. Scripta*, T99:55-67, 2002	0.2188 ± 0.0088	0.64 ± 0.02
	Europ. Phys. Journal, C31:525-547, 2003	0.1875 ± 0.0094	0.23 ± 0.01
	Phys. Lett., B237:488-494, 1990	0.1565 ± 0.0063	-0.7 ± 0.1
	Phys. Scripta, T99:55-67, 2002	0.119 ± 0.0048	-1.7 ± 0.02

* Measured $\eta' \to \pi^+\pi^-\gamma$

* Include effects of a_2: Kubis and Plenter, Eur. Phys. J., C75: 283, 2015

Current Status in CLAS G12

- Setup analysis:
  - Neural Network to suppress $\pi^+\pi^-(0)$-background
  - Kinematic Fit to hypothesis $\pi^+\pi^-(\gamma)$
- Determine $M(\pi^+,\pi^-)^2$-distributions from plot on the right hand side (ongoing $\rightarrow$ first results expected soon)
- Concept for determination of systematic errors already setup
- To Do:
  1. Validation/Justification of analysis steps
  2. Determination of α and $\Gamma(\eta \rightarrow \pi^+\pi^-\gamma)/\Gamma(\eta \rightarrow \pi^+\pi^-\pi^0)$
  3. Also go for analysis of $\eta' \rightarrow \pi^+\pi^-\gamma$ (already visible in right plot)



Summary and Outlook

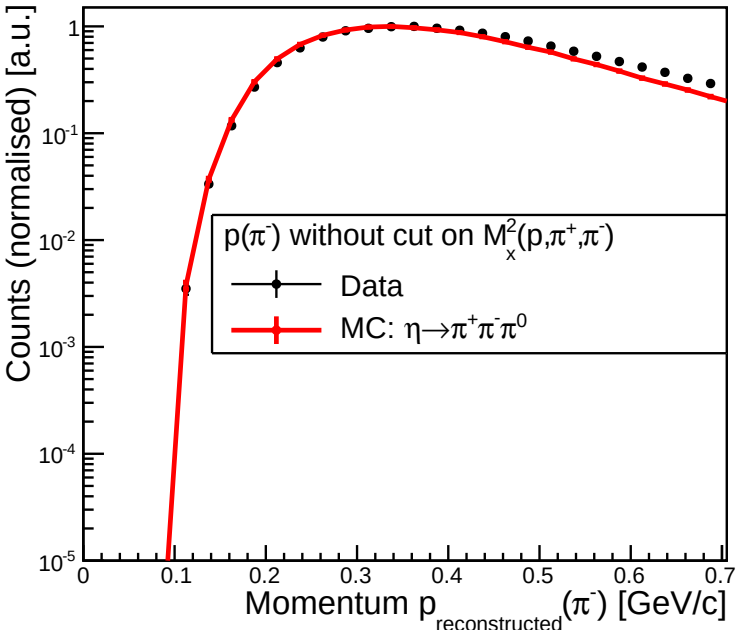
$\Rightarrow$ Analysis of $\eta \to \pi^+\pi^-\pi^0$:

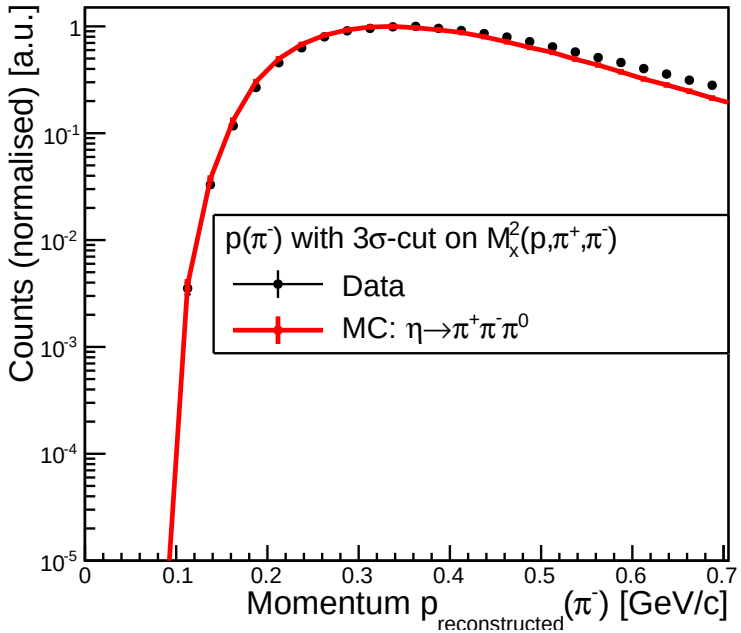
- Defined reference analysis parameter and data set
- Set up method for determination of systematic errors:
  - ★ Nearly completely automated
  - ★ At current stage:$\sim$ half a day (including analysis of the complete g12 data set) for determining systematic errrors
  - ★ Further systematic checks can be added
- Determined systematic errors for four different analysis parameter
  $\Rightarrow$ More to come (e.g. background handling)
- Final results (and errors!) still need further investigation

$\Rightarrow$ Analysis of $\eta^{(\prime)} \to \pi^+\pi^-\gamma$:

- Set up preliminary reconstruction plan
- Determination of α-parameter ongoing

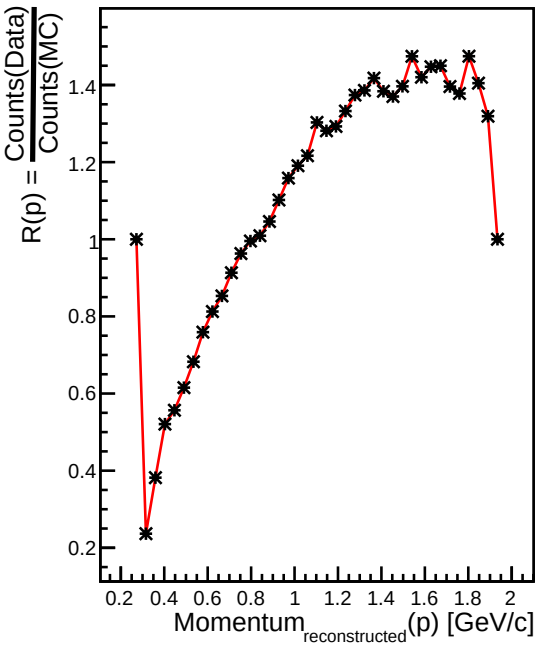
Backup: Momentum Distributions

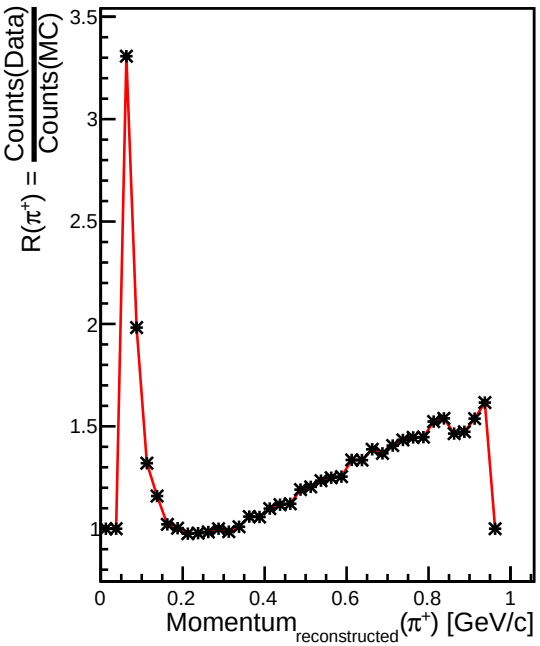


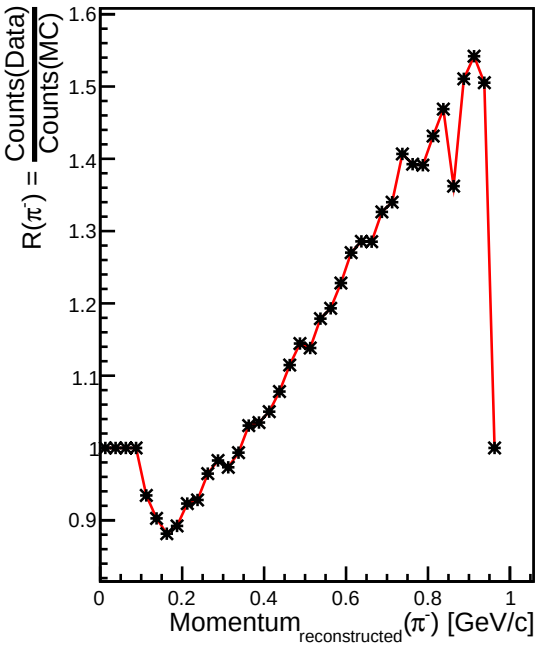


- Distributions already corrected for non-resonant and $\eta \to \pi^+\pi^-\gamma$ background
- Left: Before cut on $M_x^2(p, \pi^+, \pi^-)$ / Right: After cut on $M_x^2(p, \pi^+, \pi^-)$
- Next step/test: Use distributions shown in top left and define a momentum dependent correction factor: $R(i) \equiv \frac{\text{Counts(Data)}}{\text{Counts(MC)}}$, $i = p, \pi^+, \pi^-$

Backup: Momentum Dependent Corrections



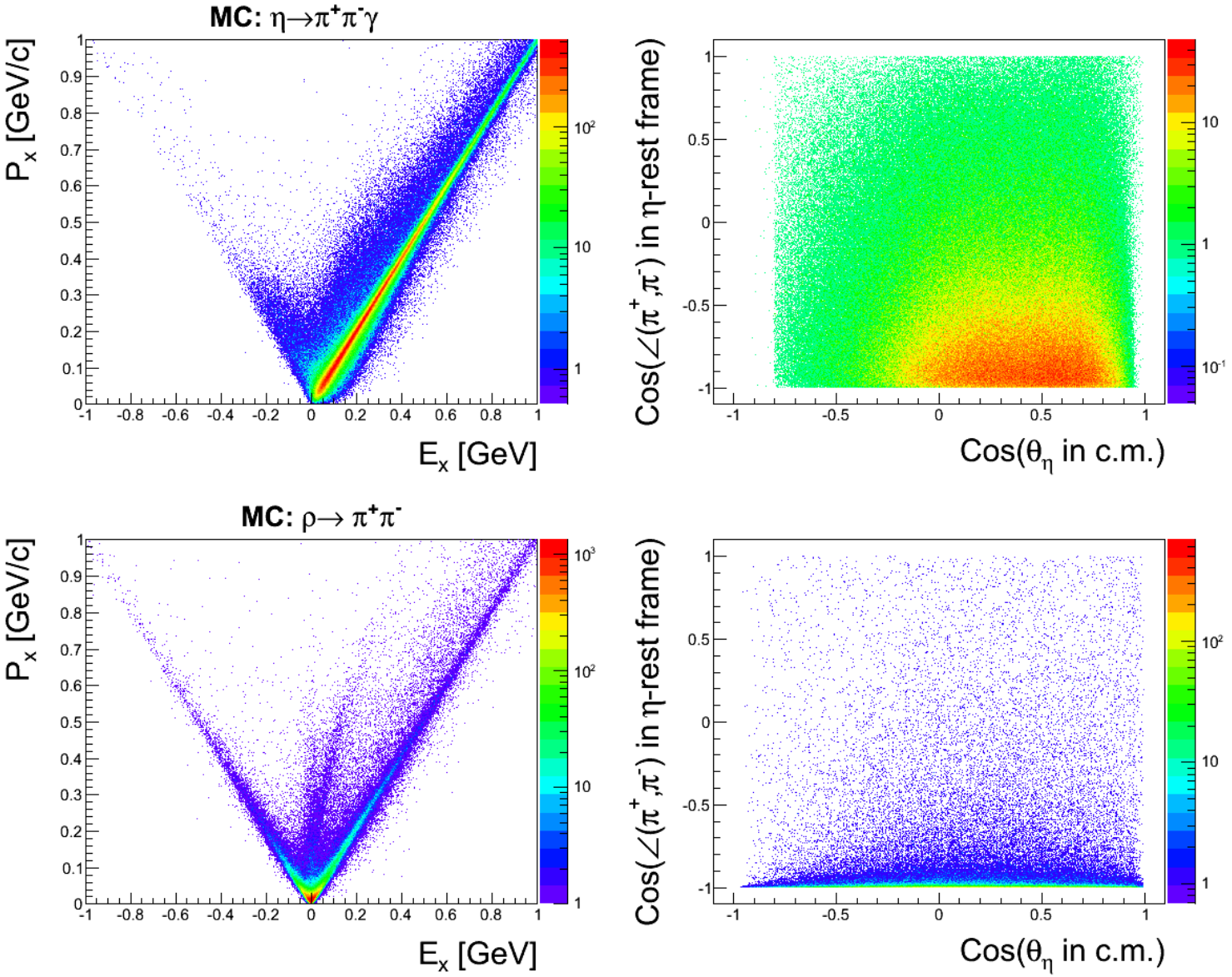




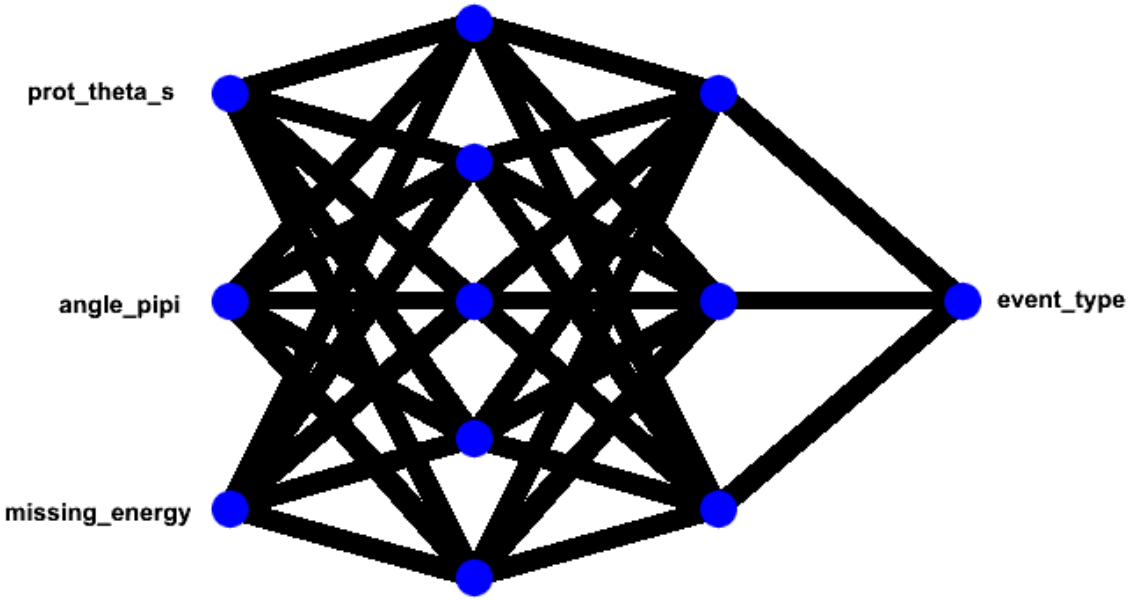
- Look at ratio: $R(i) \equiv \frac{\text{Counts(Data)}}{\text{Counts(MC)}} = f(\text{Momentum(i)}),\ i = p, \pi^+, \pi^-$
- Define event-based weighting factor: $F \equiv R(p) \times R(\pi^+) \times R(\pi^-)$
- Use F for weighting histograms, when analysing MC data
- Determine efficiency correction (see next slide)

Backup: Reconstruction of $\eta \to \pi^+\pi^-\gamma$-events

Defining discrimination variables

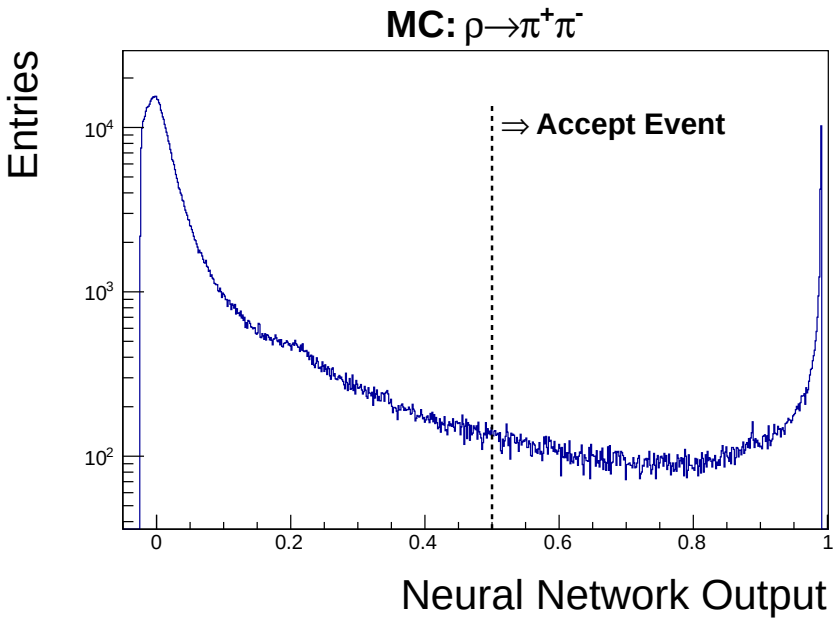


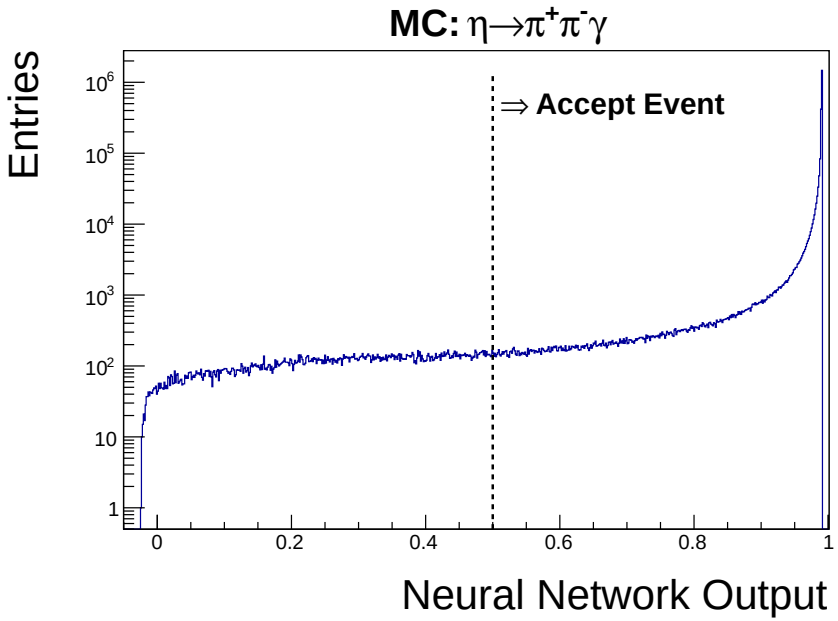
Backup: Multivariable-Analysis: Neural Networks



- One could define separate cuts on the discrimination variables
- But those variables are often correlated $\Rightarrow$ Multivariable-Analysis
- Use an artificial neural network with:
  - prot_theta_s $=$ Cos(θ_η(in c.m.))
  - angle_pipi $=$ Cos($\angle(\pi^+, \pi^-)$in η-rest frame)
  - missing_energy $= E_x$
  - event_type $= 1$ for $\eta \to \pi^+\pi^-\gamma$ and 0 for $\rho \to \pi^+\pi^-$

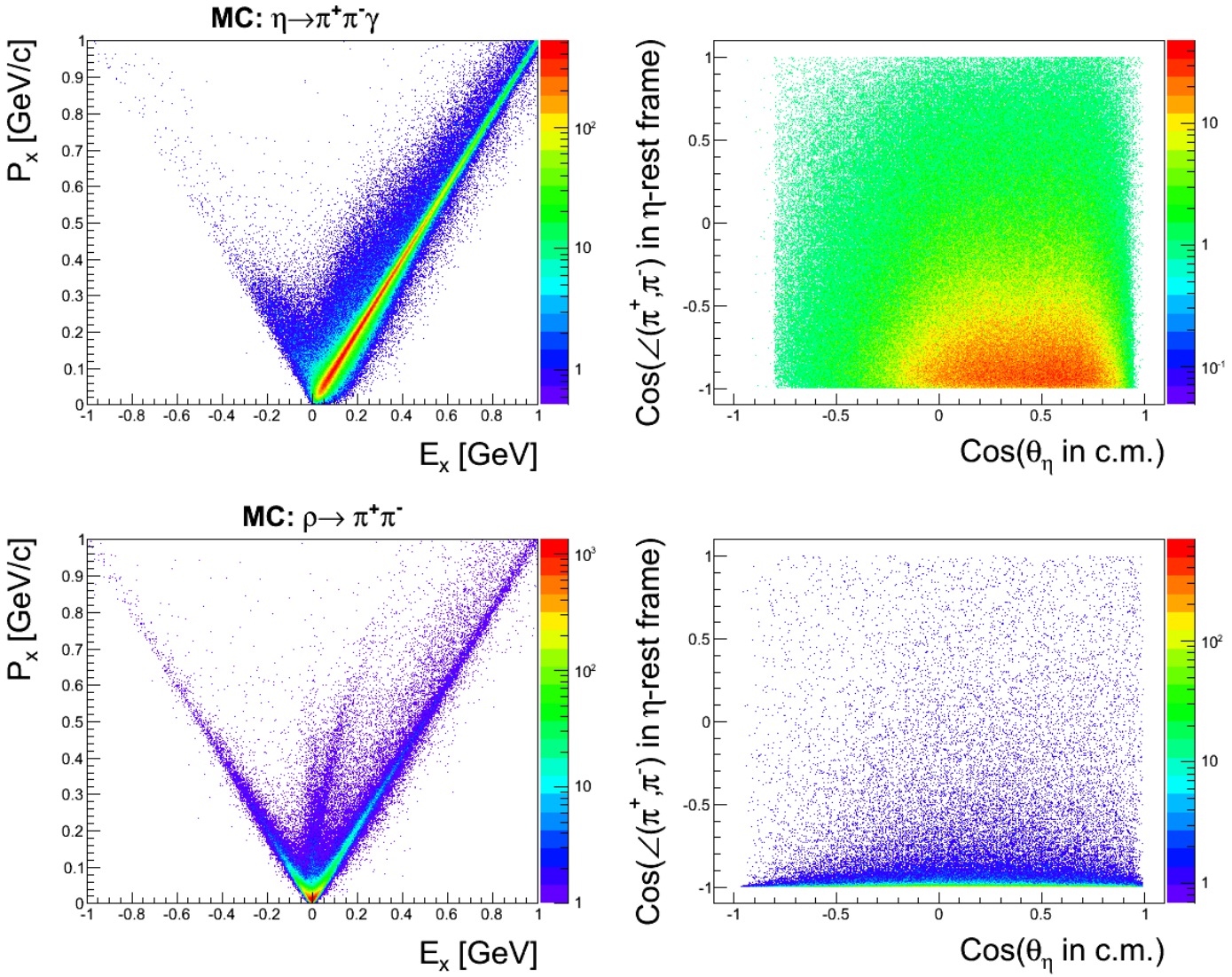
Backup: Neural Network Output





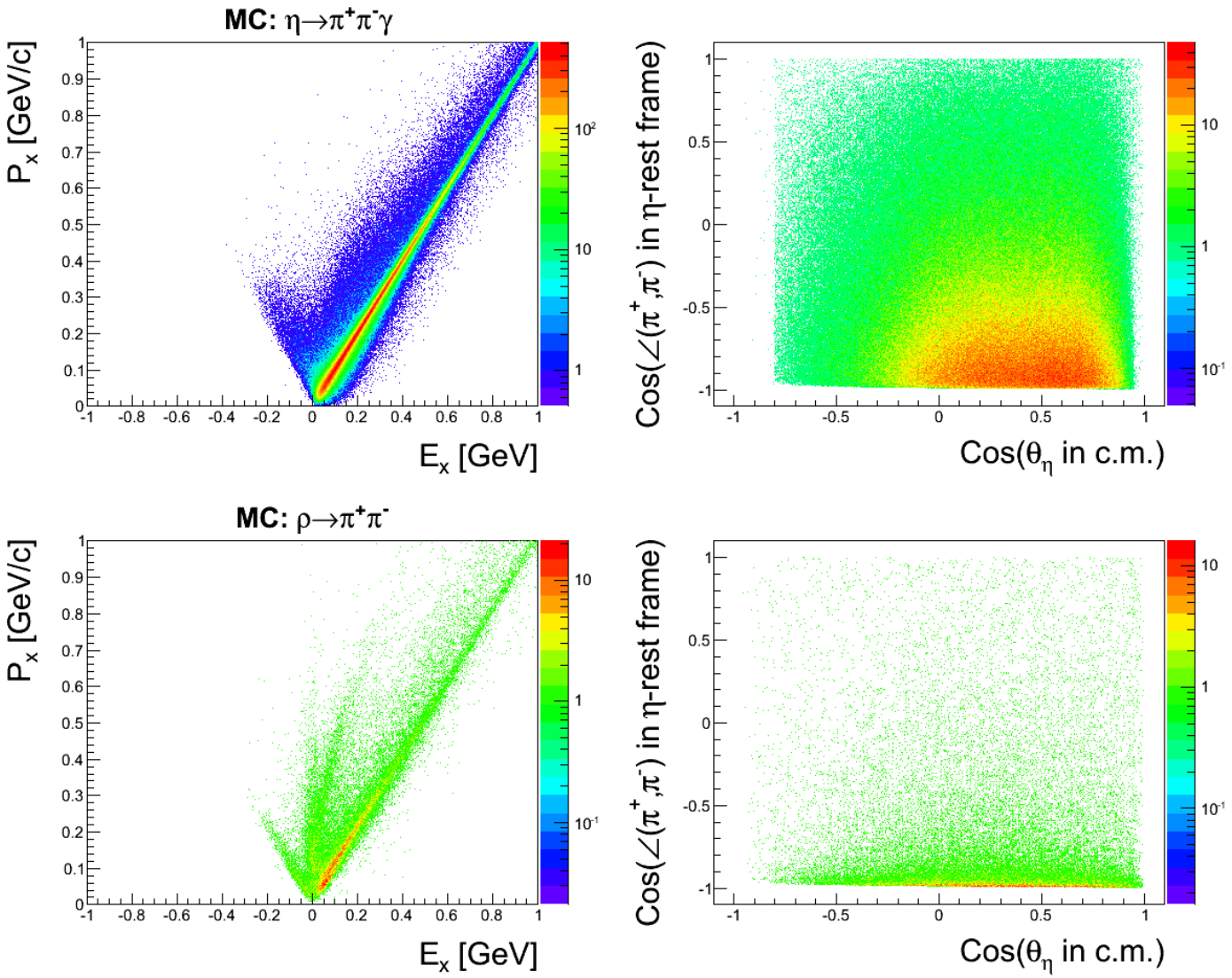
- Network has been trained with MC data where the event type is known
- After training the network, obtain output variable which is a function of the variables defined in the beginning
- Reject events with output less than 50%

Backup: What is cut away?



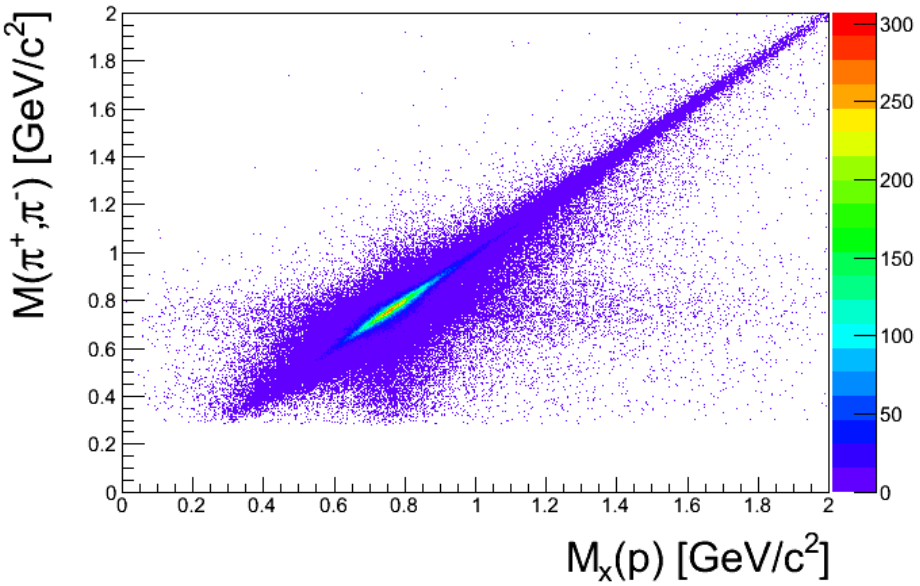
Before cutting on the neural network output

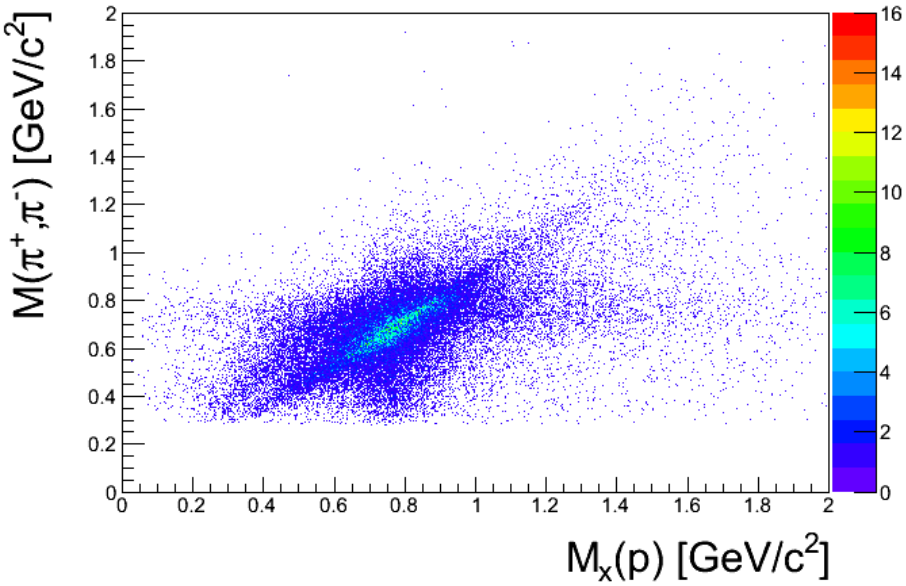
Backup: What is cut away?



Before cutting on the neural network output

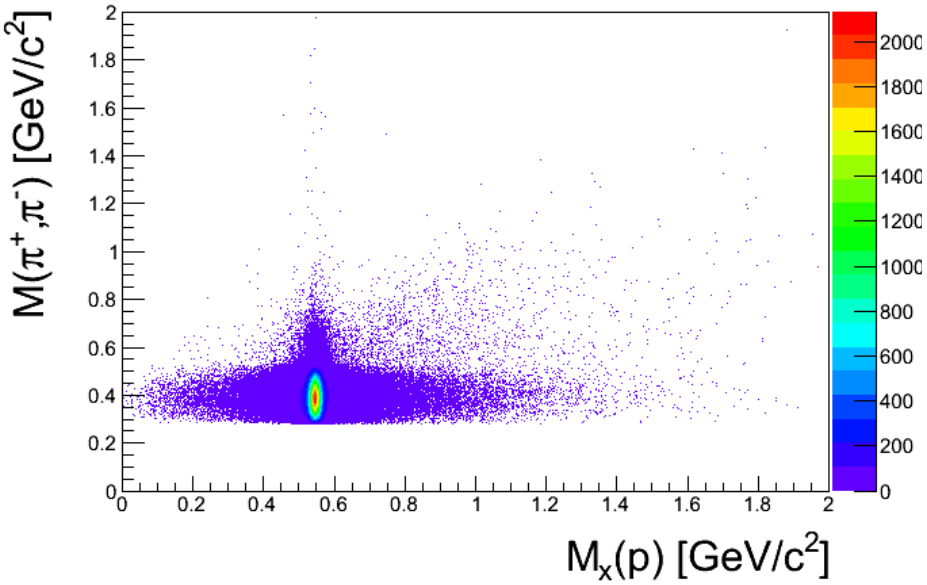
Backup: Masses and Acceptances: MC $\rho \to \pi^+\pi^-$

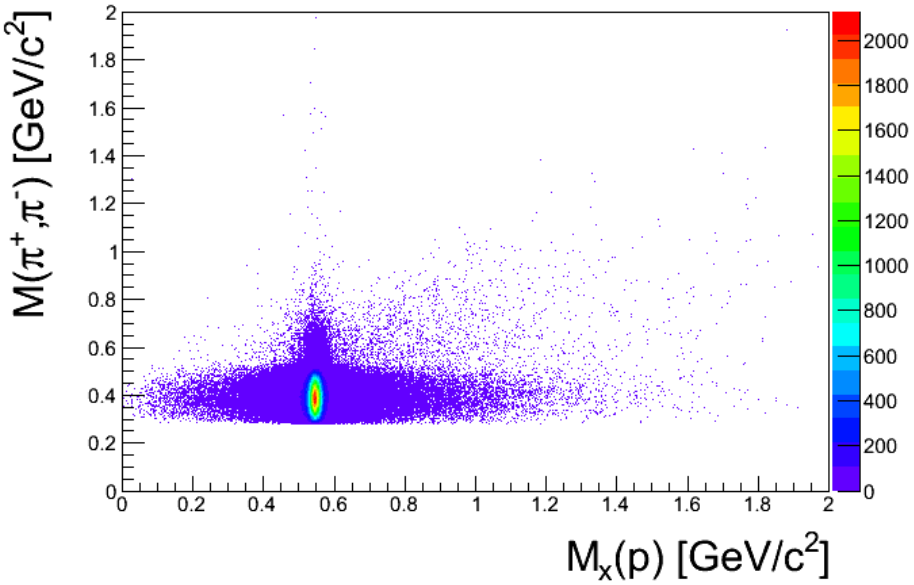




- Left: wifthout cut / right: with cut
- $\approx$ 5% events are accepted

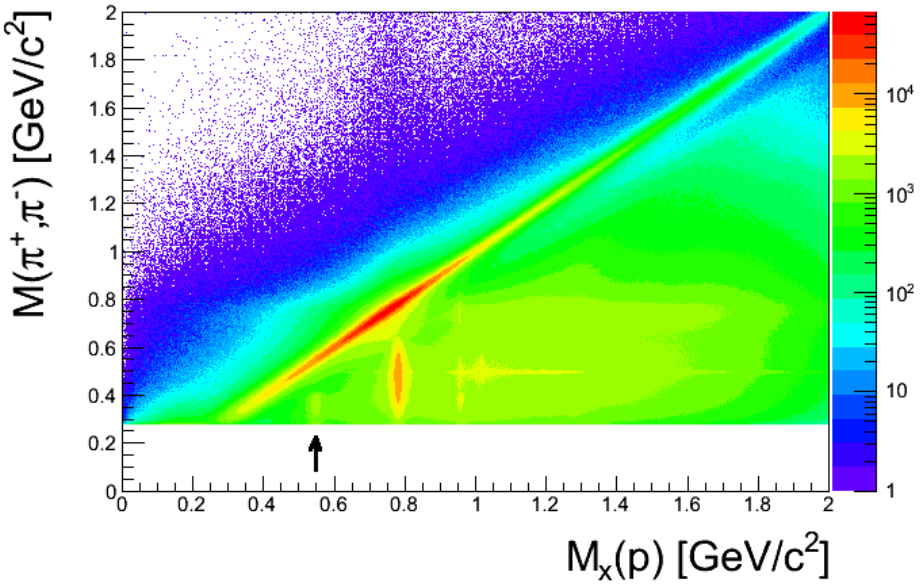
Backup: Masses and Acceptances: MC $\eta \to \pi^+\pi^-\gamma$

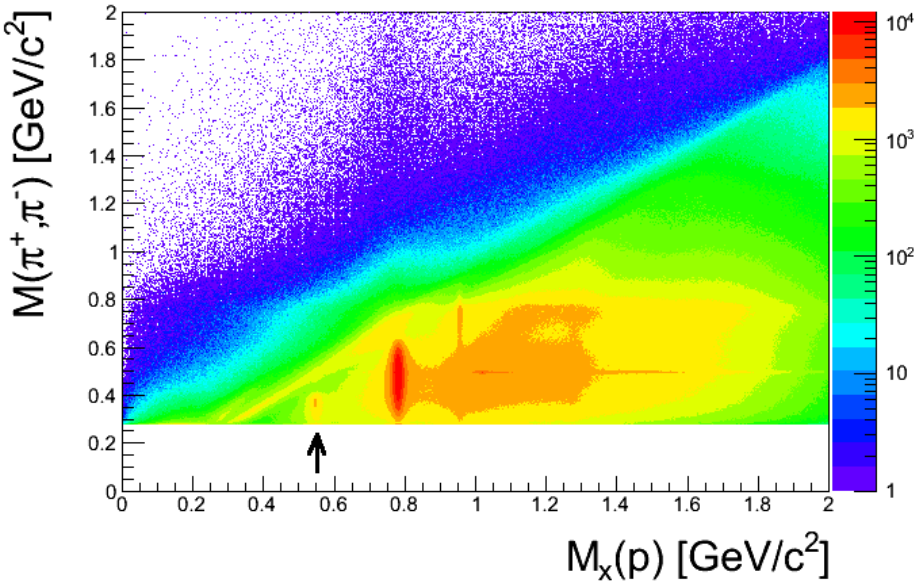




- Left: wifthout cut / right: with cut
- $\approx$ 98% events are accepted

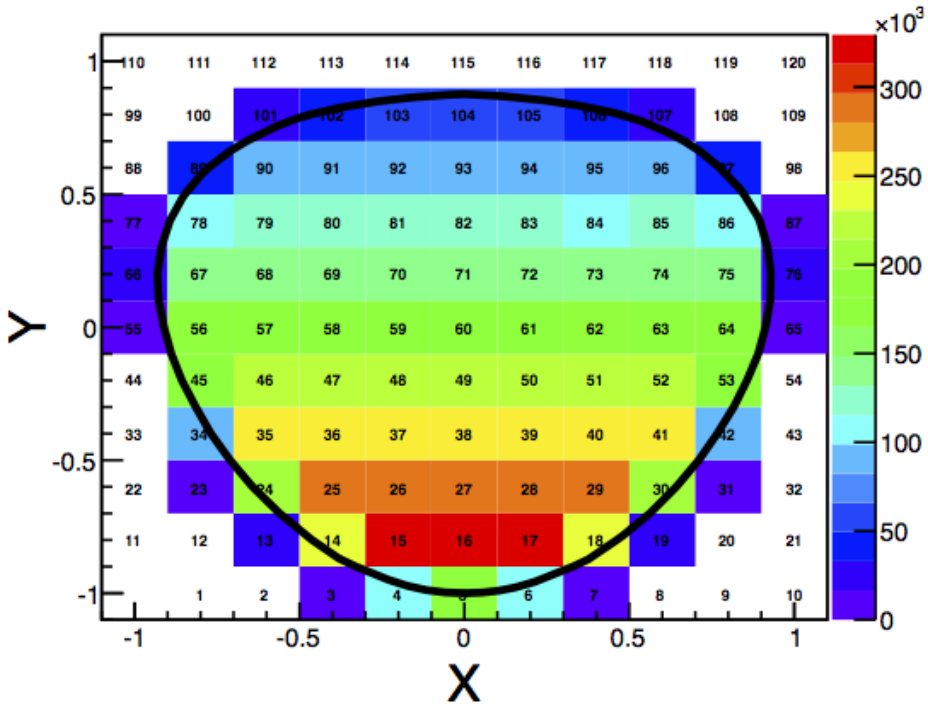
Backup: Application to Data

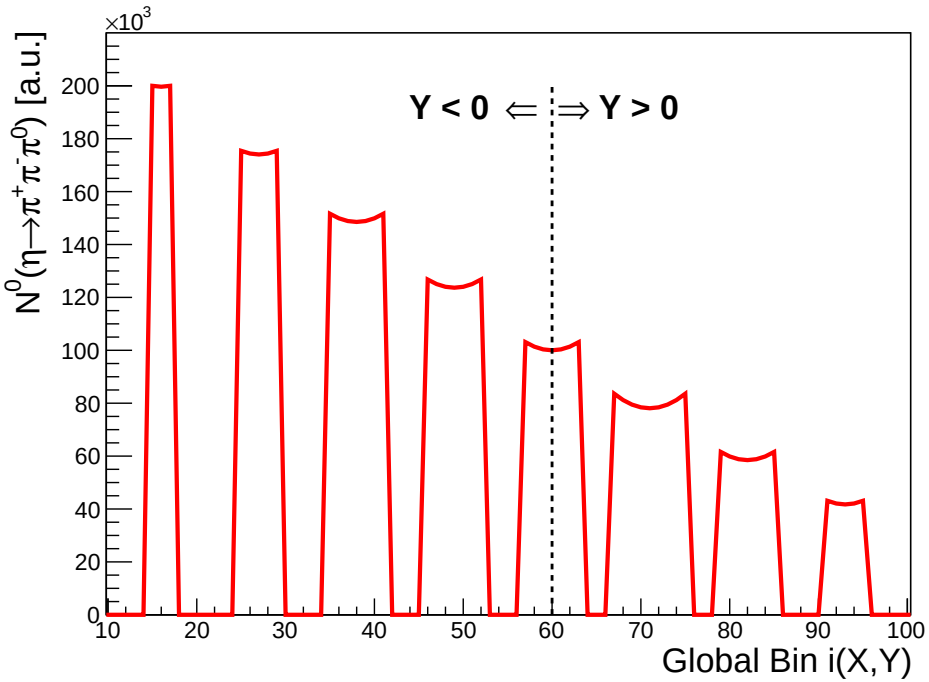




- Left: wifthout cut / right: with cut
- η-signal clearly visible now
- Reduced $\pi^+\pi^-(0)$-background

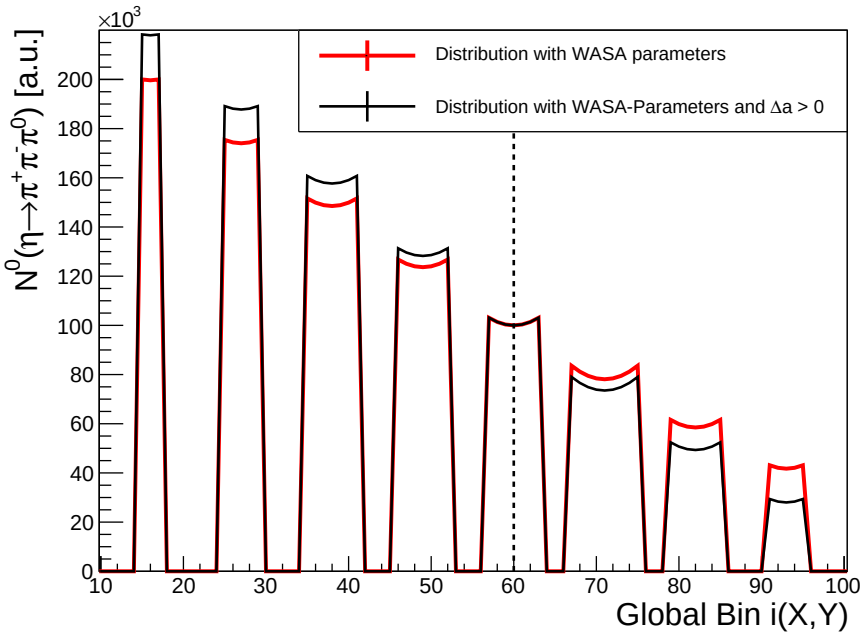
Backup: Features of the 1D Dalitz Plot

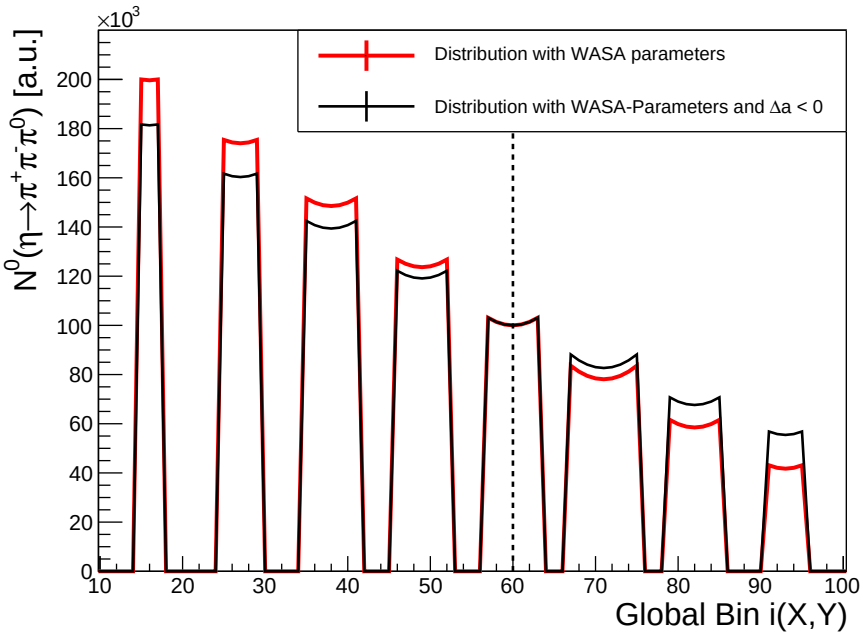




- Look at 1D Dalitz Plot with WASA-at-COSY values for a,b,d and f
- Center of Dalitz Plot is at $i(0,0) = 60$
- $\frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3)$

Backup: Features of the 1D Dalitz Plot





- Look at 1D Dalitz Plot with WASA-at-COSY values for a,b,d and f
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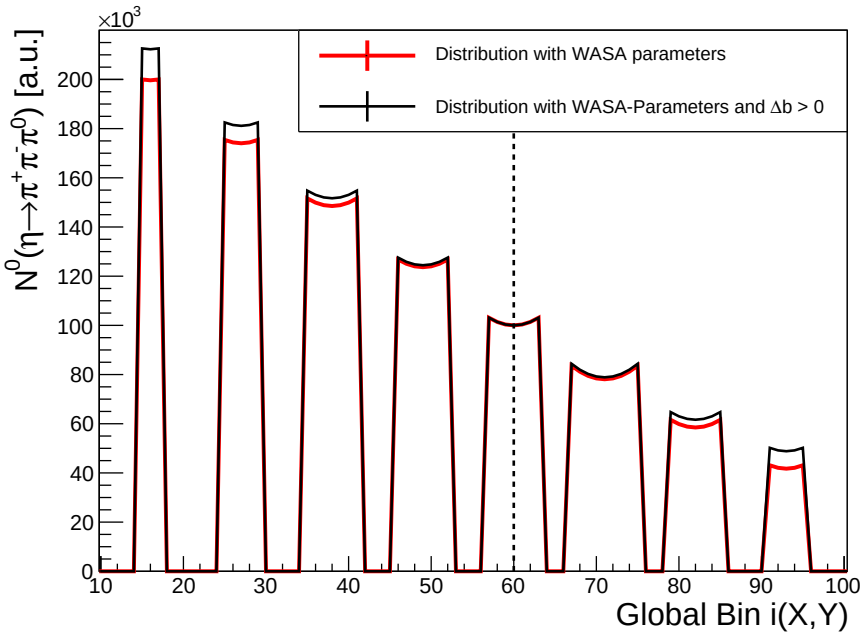

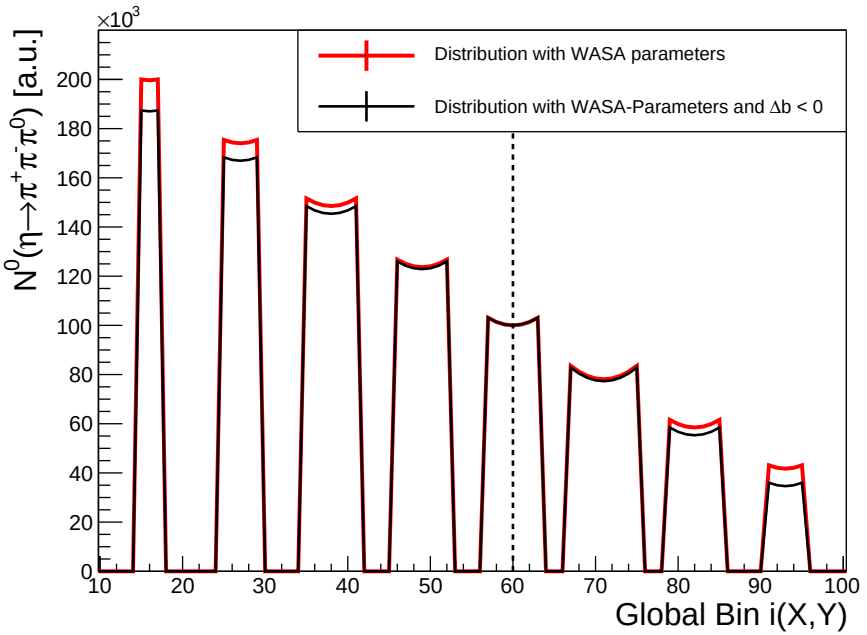

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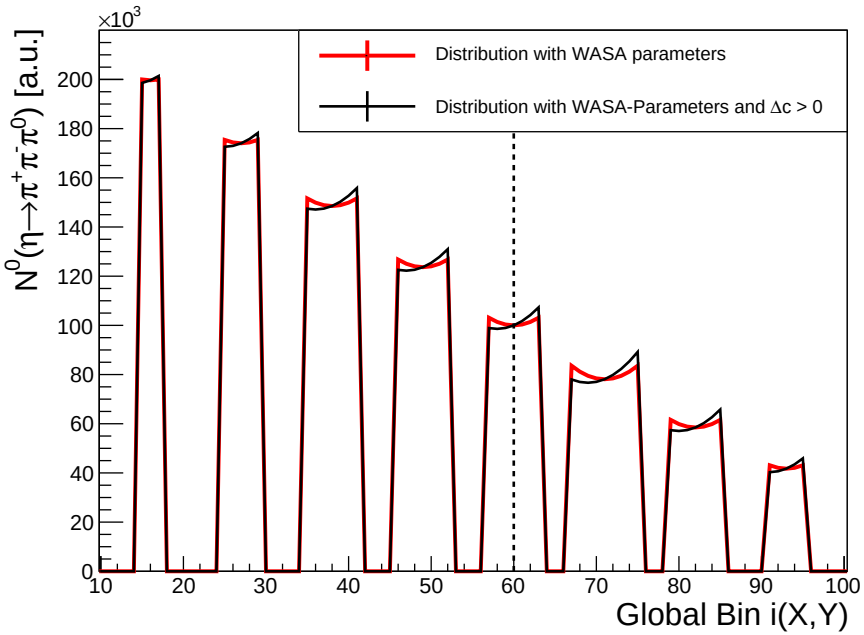

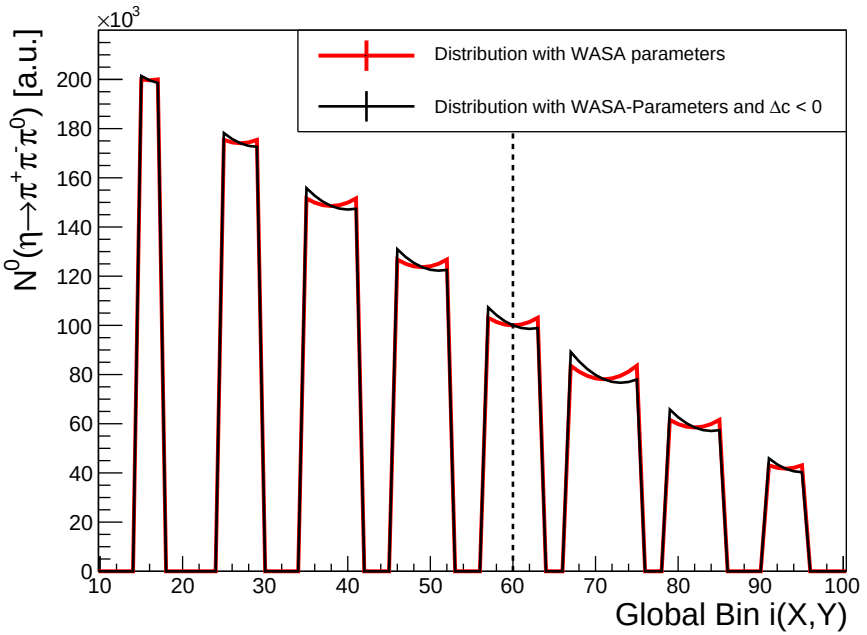

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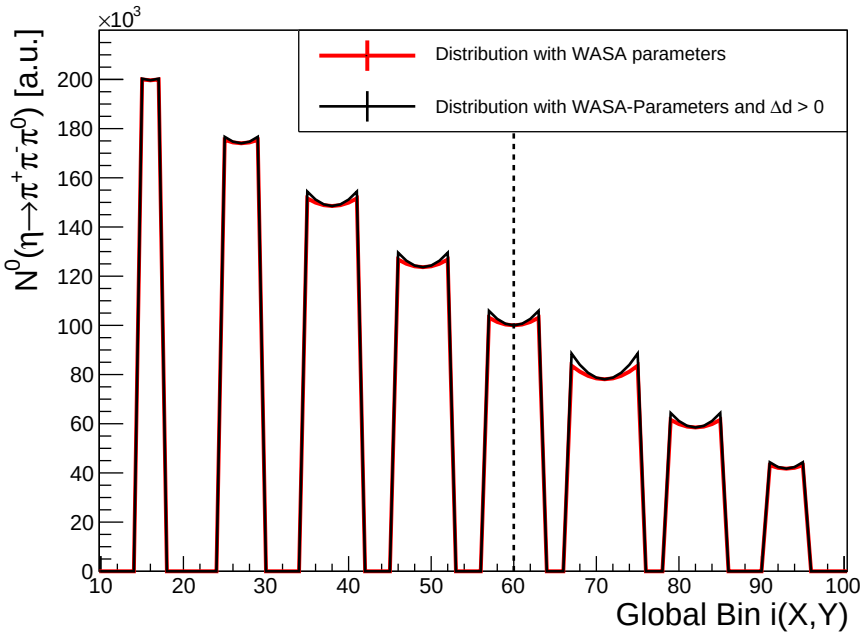

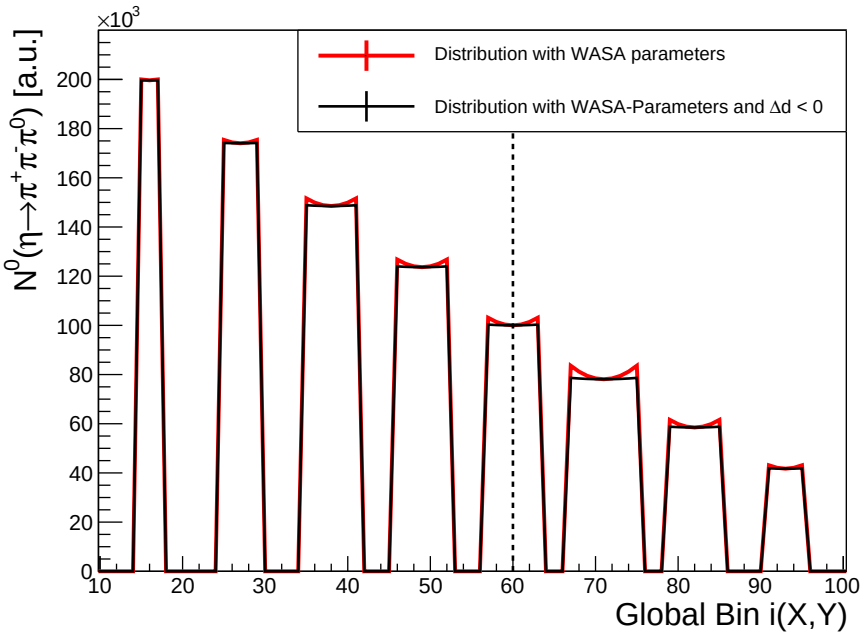

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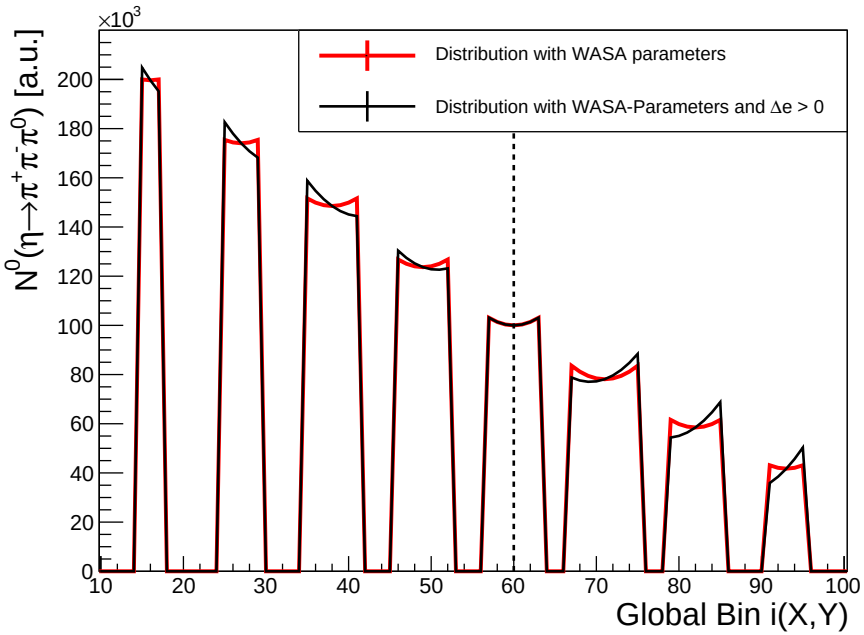

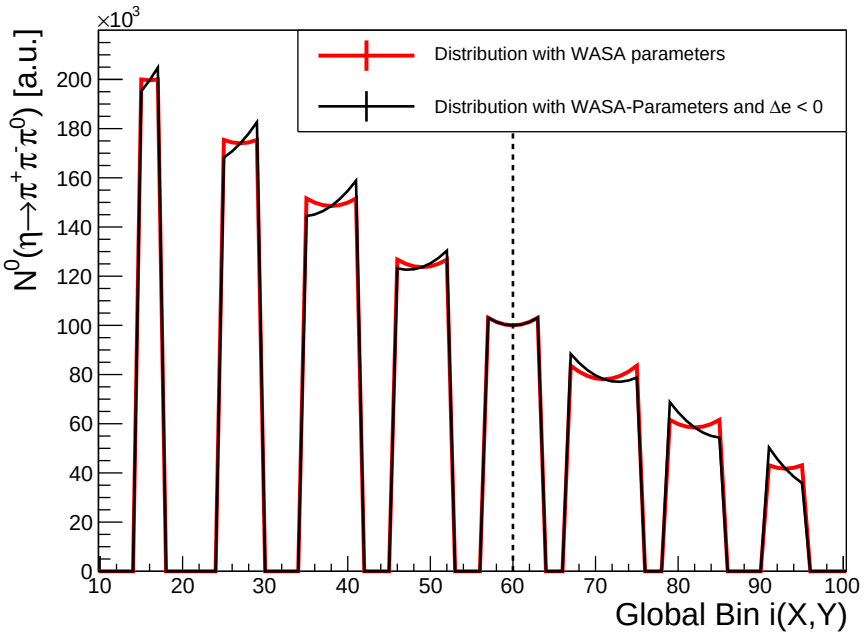

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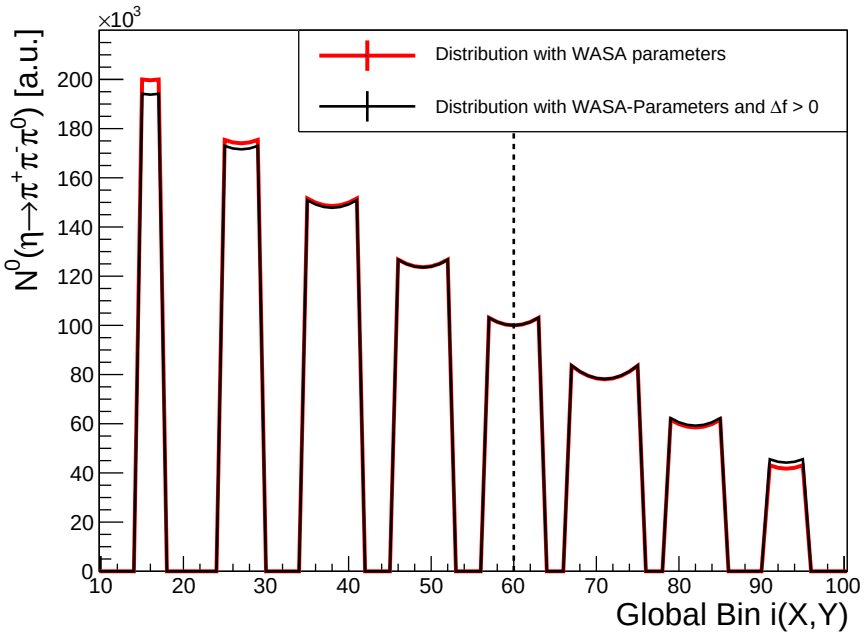

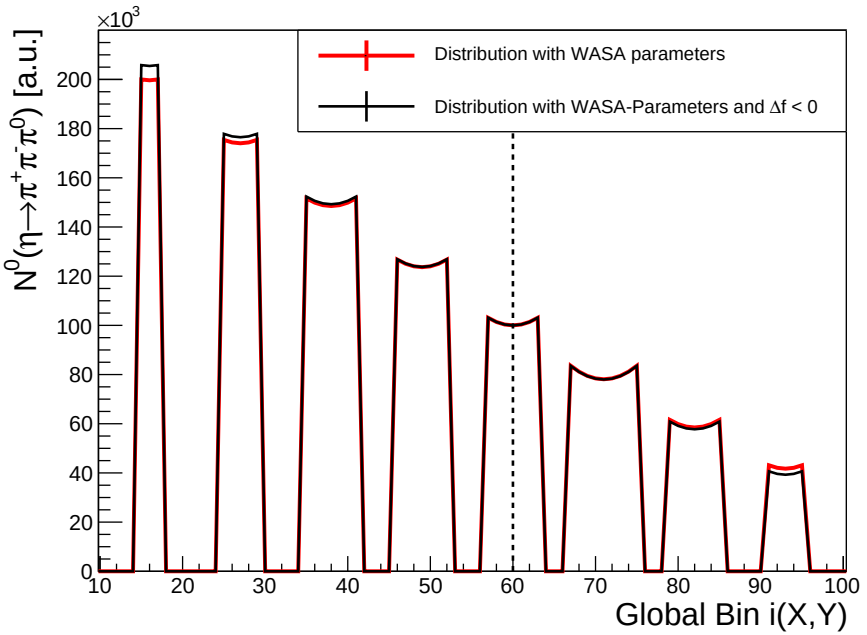

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