

Update on the Dalitz Plot Analysis of: $\eta \rightarrow \pi^+ \pi^- \pi^0$ with the CLAS6 g12 Data Set

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

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

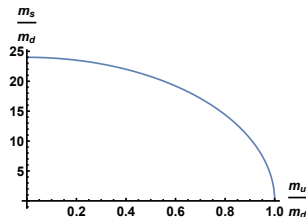
- Decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ is G-violating $\Rightarrow$ Forbidden to first order
- Decay is driven by isospin breaking part of strong interaction
 $\Rightarrow$ C is conserved
- Decay width: $\Gamma \propto Q^{-4}$

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

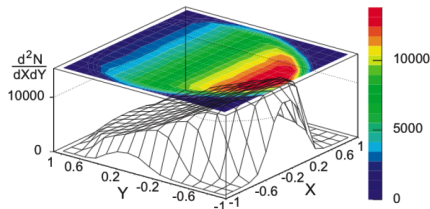
$\Rightarrow$ **Determine decay width $\Gamma \Rightarrow$ Access to quark mass ratio**



- Measure $\Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)$, e.g. via $\frac{\Gamma(\eta \rightarrow \pi^+ \pi^- \pi^0)}{\Gamma(\eta \rightarrow \gamma \gamma)}$
- Dalitz Plot Analysis



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



(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 :

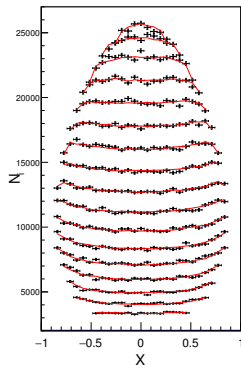
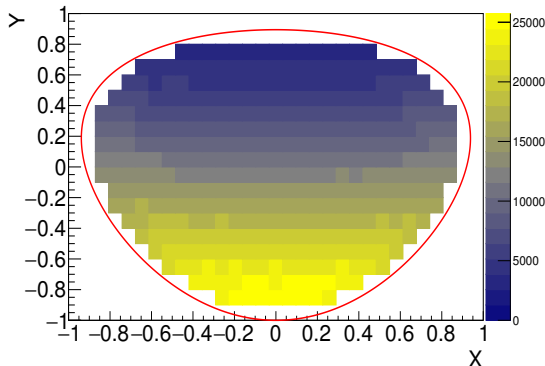
$$\frac{d^2\Gamma}{dXdY} \propto (1 + aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + \dots)$$

- $c \neq 0$ 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

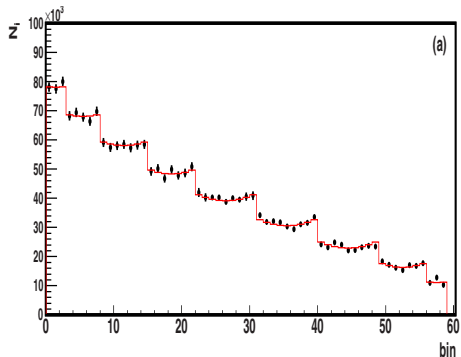
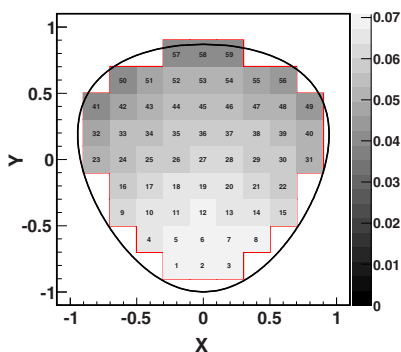


Most recent result from the KLOE-Collaboration:^(f)

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

(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)
	PWA ^(g)	1.077(29)	0.170(8)	0.060(2)	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)

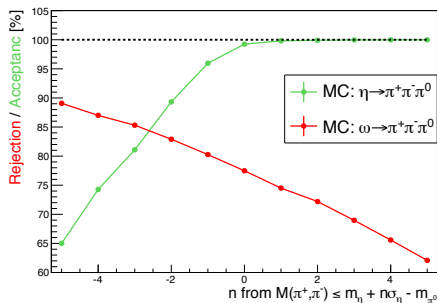
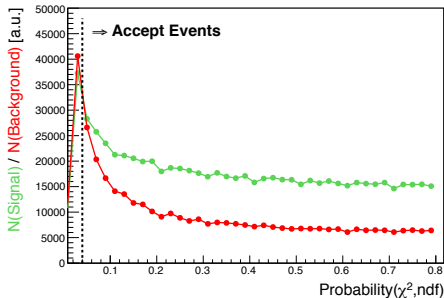
(g) Peng Guo et al., arXiv: 1608.01447v3, (2017)

● WASA-at-COSY: $Q = 21.4 \pm 1.1$ ^(e)

● KLOE: $Q = 21.7 \pm 1.1$ ^(g)

● Dalitz Plot Analysis and determination of Q for $\gamma p \rightarrow p\eta[\eta \rightarrow \pi^+\pi^-\pi^0]$ with the CLAS G12 data set

Reconstruction of $\eta \rightarrow \pi^+\pi^-\pi^0$ -Events



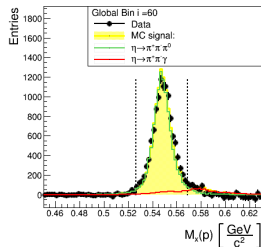
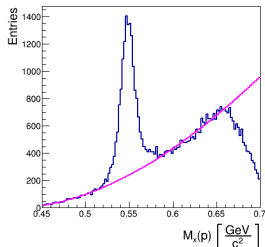
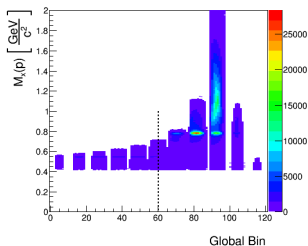
i) Kinematic Fit:

Prob. $\geq 4\% \Rightarrow$ Chosen according to best ratio: $S/(S+B)$

ii) Rejection of $\omega \rightarrow \pi^+\pi^-\pi^0$:

$M(\pi^+, \pi^-) \leq m_\eta + 1\sigma_\eta - m_{\pi^0} \Rightarrow$ Chosen according to 100% acceptance for $\eta \rightarrow \pi^+\pi^-\pi^0$ and 70% rejection of $\omega \rightarrow \pi^+\pi^-\pi^0$

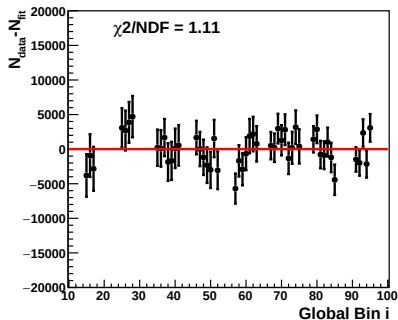
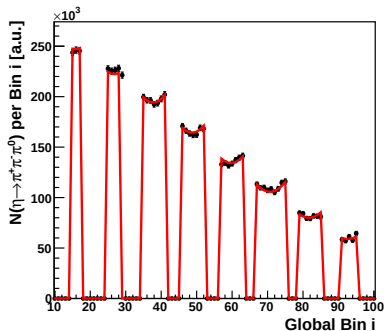
Background Handling and Determination of $N^0(\eta \rightarrow \pi^+\pi^-\pi^0)$



- Correct for background for each Global Bin i
- Determination of $N^0(\eta \rightarrow \pi^+\pi^-\pi^0)$:

$$N^0(\eta \rightarrow \pi^+\pi^-\pi^0)[i] = N^{fit}(\eta \rightarrow \pi^+\pi^-\pi^0)[i]/\epsilon[i], \text{ with: Efficiency } \epsilon[i]$$
- Fit resulting distribution with: $\text{Norm} \times (1 + aY + bY + cX + dX^2 + eXY + fY^3)$

Dalitz Plot Parameter for $\eta \rightarrow \pi^+\pi^-\pi^0$



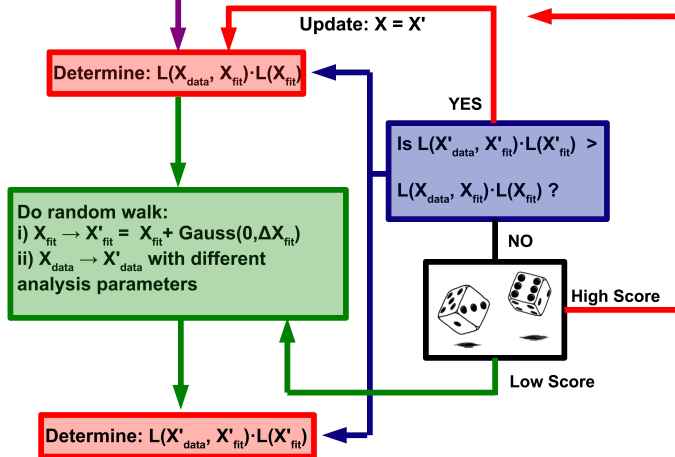
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WASA	1.144(18)	0.219(19)(47)	0.0	0.086(18)(15)	0.115(37)
KLOE(16)	1.104(5)(2)	0.142(3)($^{+5}_{-4}$)	0.0	0.073(3)($^{+4}_{-3}$)	0.154(6)($^{+4}_{-5}$)
G12	1.102(20)(13)	0.127(18)(5)	0.011(7)(7)	0.106(19)(5)	0.248(45)(10)

- Parameter e is 0
- Dalitz Plot Asymmetry $A = \frac{N^+ - N^-}{N^+ + N^-} = (0.9 \pm 2.9) \cdot 10^{-3}$
- Systematic uncertainties determined via random walk analysis

Reminder: Systematic Uncertainties: Random Walk Analysis

- Approach: Random walk around reference result
- Problem: How to choose reference results $\Leftrightarrow$ Bias!

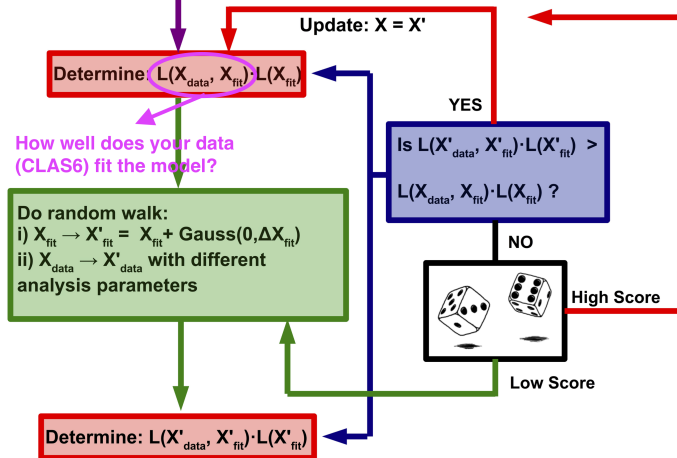
Calculate DP Parameters from reference analysis/results



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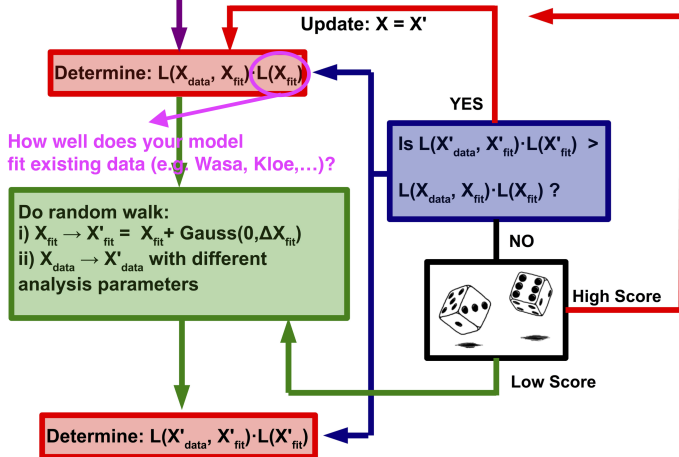
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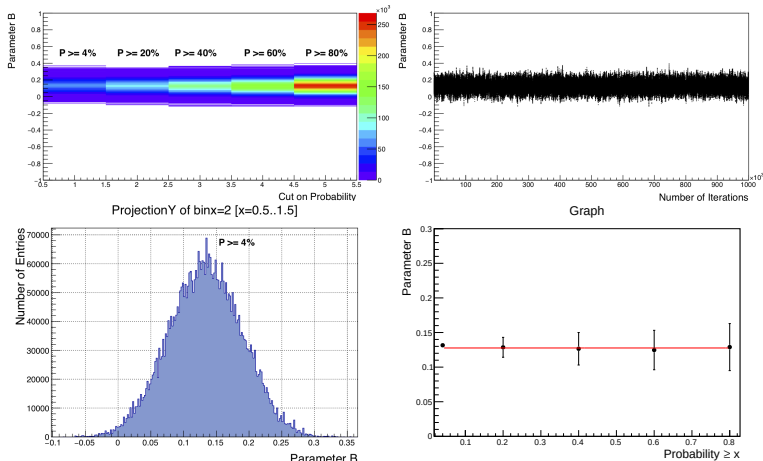
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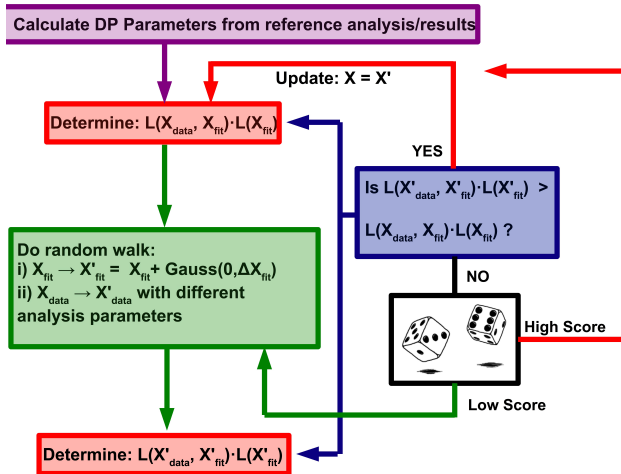
Reminder: Results after the Random Walk



- Biased reference values $\rightarrow$ Change of strategy
- (Possible) Correlation of errors not taken into account

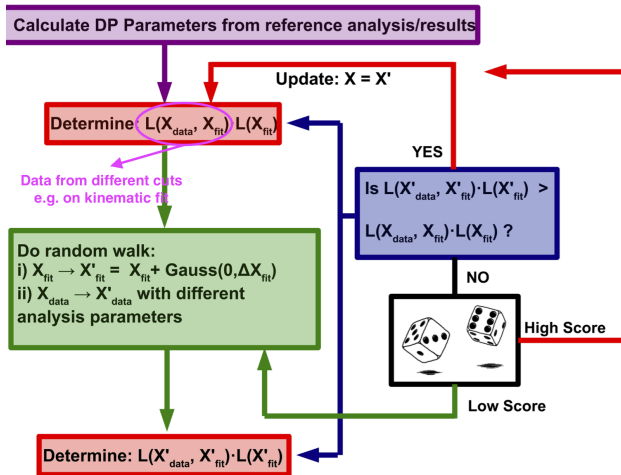
Updated Random Walk Analysis

- Approach: Random walk around different cut results
- Use reference analysis for comparison $\Leftrightarrow$ Consistency within analysis
- No bias from other experiments



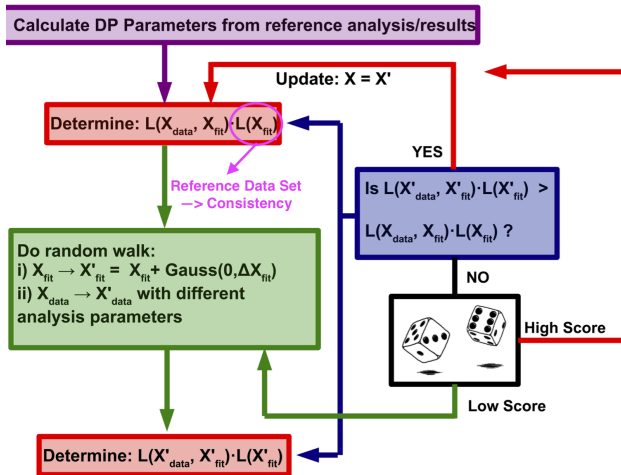
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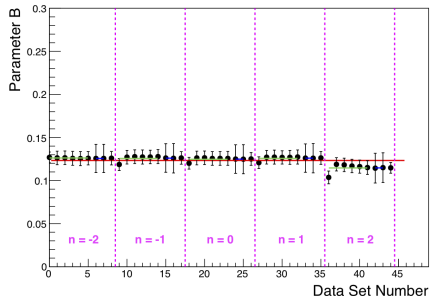
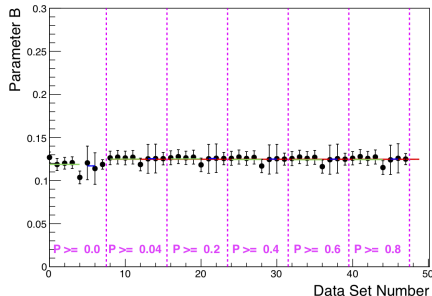


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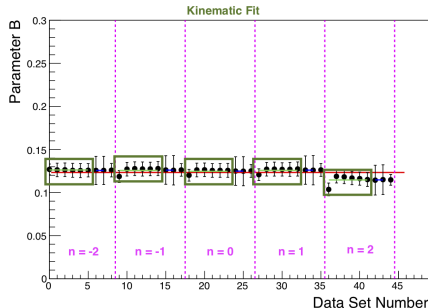
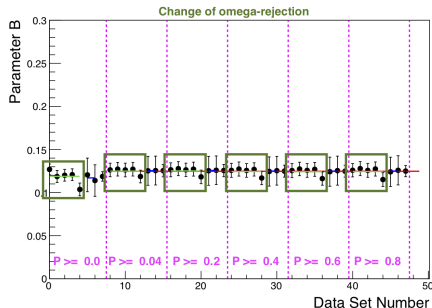


Correlations between Systematic Errors



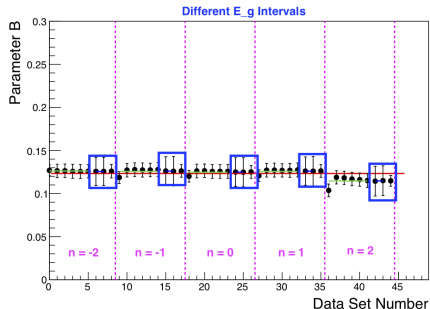
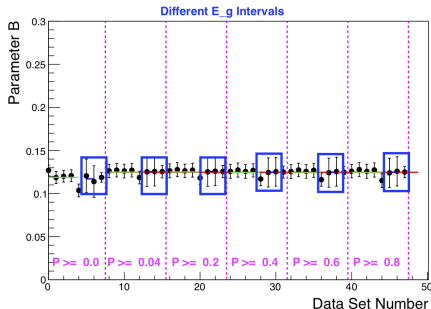
- Left: Systematics related to the kinematic fit: $P \geq X$
- Right: Systematics related to the ω rejection:
 $M(\pi^+, \pi^-) \leq m_\eta + n\sigma_\eta - m_{\pi^0}$, $n \in [-2, 2]$
- Correlations:
 - ▶ Cluster-wise behavior/variation
⇒ Describe systematics related to the current variable
 - ▶ Variations inside a cluster
⇒ Describe systematics NOT related to the current variable

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Current Results

Parameter	$\sigma_{stat}[10^{-3}]$	$\sigma_{kFit}[10^{-3}]$	$\sigma_{\omega}[10^{-3}]$	$\sigma_{E_{\gamma}}[10^{-3}]$	$\sigma_{sys,tot}[10^{-3}]$
$a = -1.102$	20	8	6	11	10
$b = 0.127$	18	3	7	2	8
$c = 0.011$	7	4	2	1	4
$d = 0.106$	19	1	6	1	6
$f = 0.248$	45	20	26	7	33

- Total systematic error now: $\lesssim 13\%$
- Correlations have been taken care of

Summary and Outlook

- Refined estimation of systematic errors:
 - ▶ Reduced bias in error estimation
 - ↔ Results from other experiments are not included
 - ▶ Include (possible) correlation between errors
 - ▶ Errors are in a “reasonable ” range, compared to beginning of this analysis (40% vs. 13%)
- Still missing / ongoing:
 - ▶ Number of Dalitz Plot bins ↔ Resolution
 - ▶ Analysis Note

