Dalitz Plot Analysis of $\eta' \to \eta\pi^+\pi^-$ with GlueX Data

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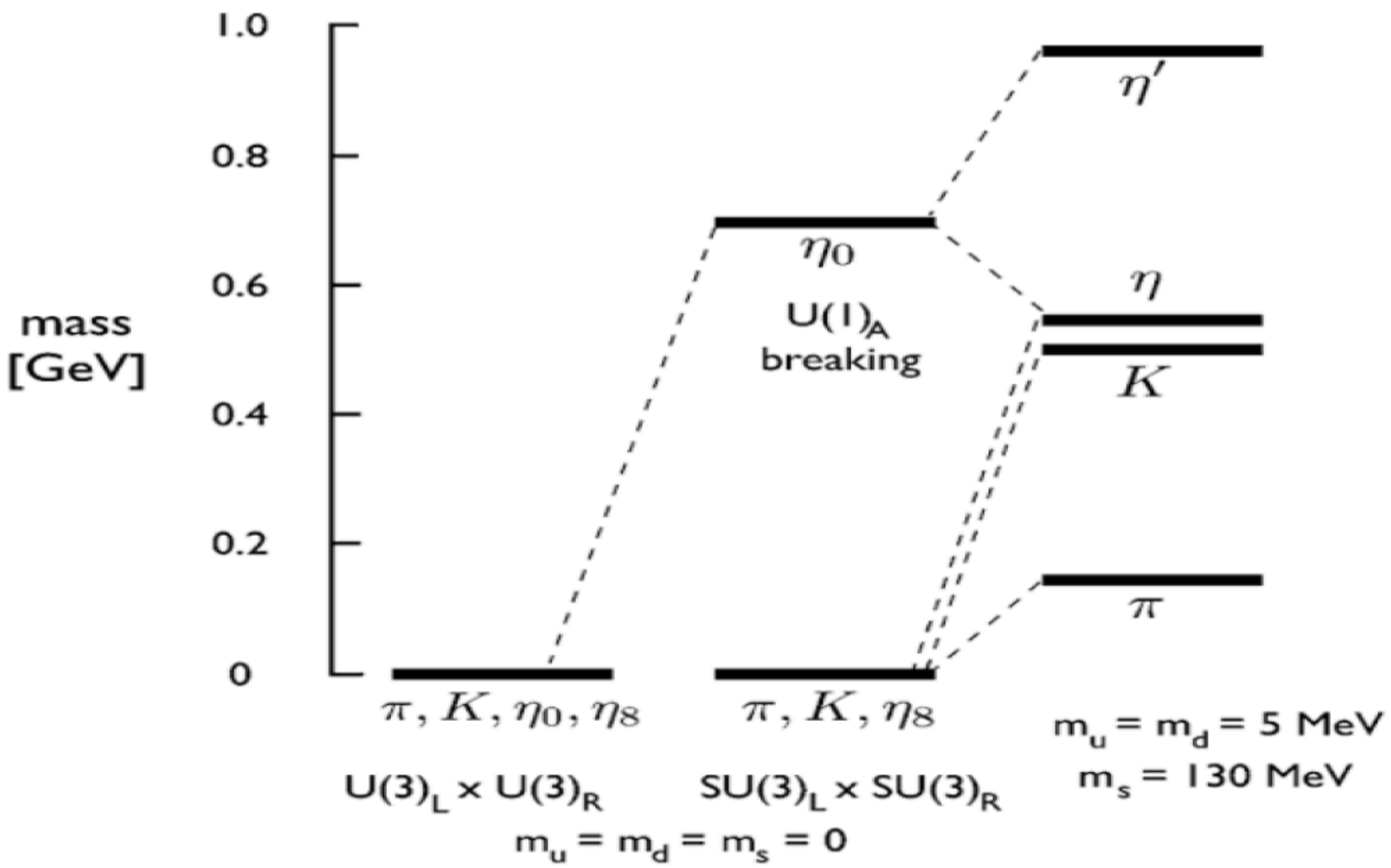
Motivation for $\eta' \to \eta\pi^+\pi^-$

- The chiral perturbation theory represents the appropriate theoretical framework to investigate low-energy hadronic physics of light meson decays.

- $\eta' \to \eta\pi\pi$ decay is a good test for extensions of $SU(3) \times SU(3)$ Chiral Perturbation Theory (ChPT) [J. Bijnens]

$$\mathcal{L}_{QCD}(q, \bar{q}, g) \to \; Effective\ theory \; \to \mathcal{L}_{ChPT}(\pi, K, \eta)$$

$$\mathcal{L}_{ChPT} = \mathcal{L}_2 + \mathcal{L}_4 + \mathcal{L}_6 + \ldots$$



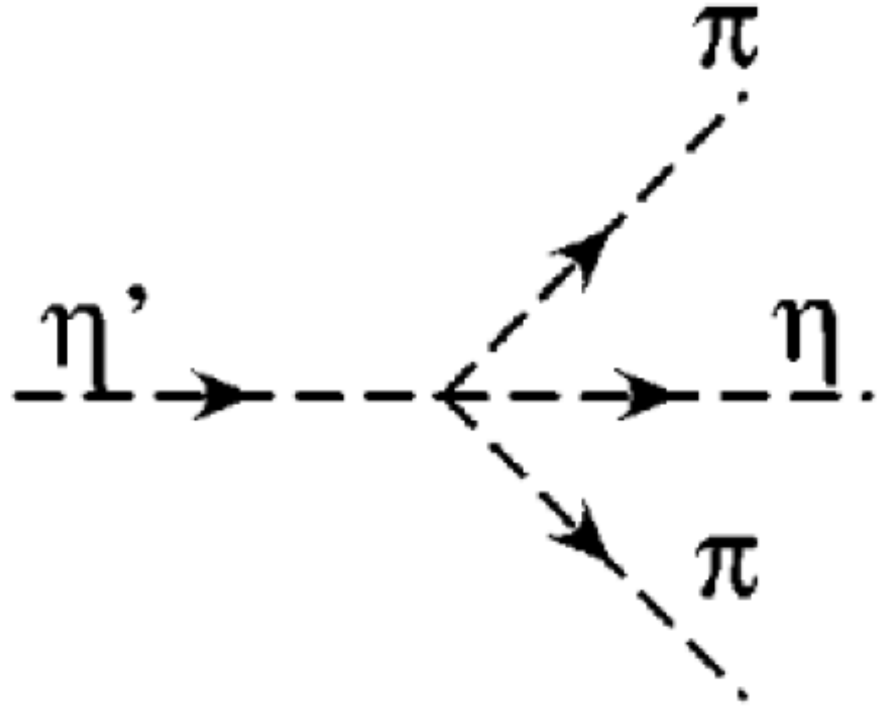
Decay width for $\eta' \to \eta\pi^+\pi^-$

M matrix elements have info of the intermediate resonances

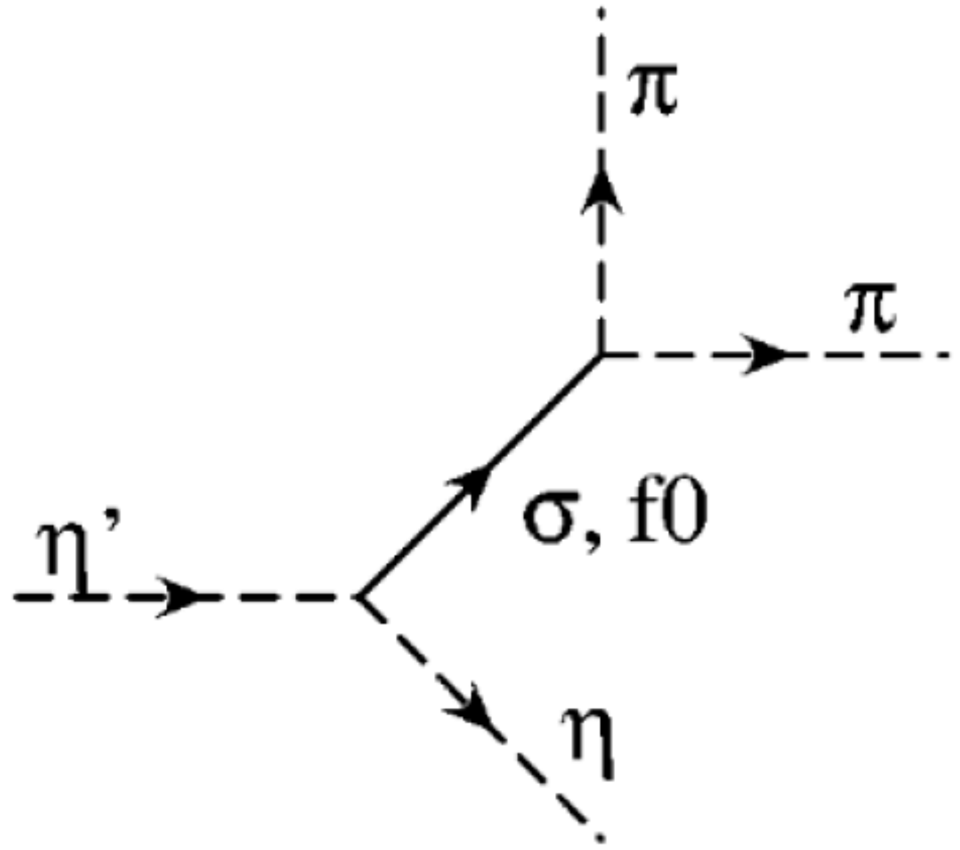
- This decay can be explained by exchange of scalar resonances: $f_0(500)$, $f_0(980)$, $a_0(980)$
    - G-parity prevents vectors from contributing

The decay of $\eta'\to\eta\pi\pi$ can be dominated by the contributions of the intermediate S-wave resonances σ, a_0 and f_0 , and their interference on the Dalitz plots

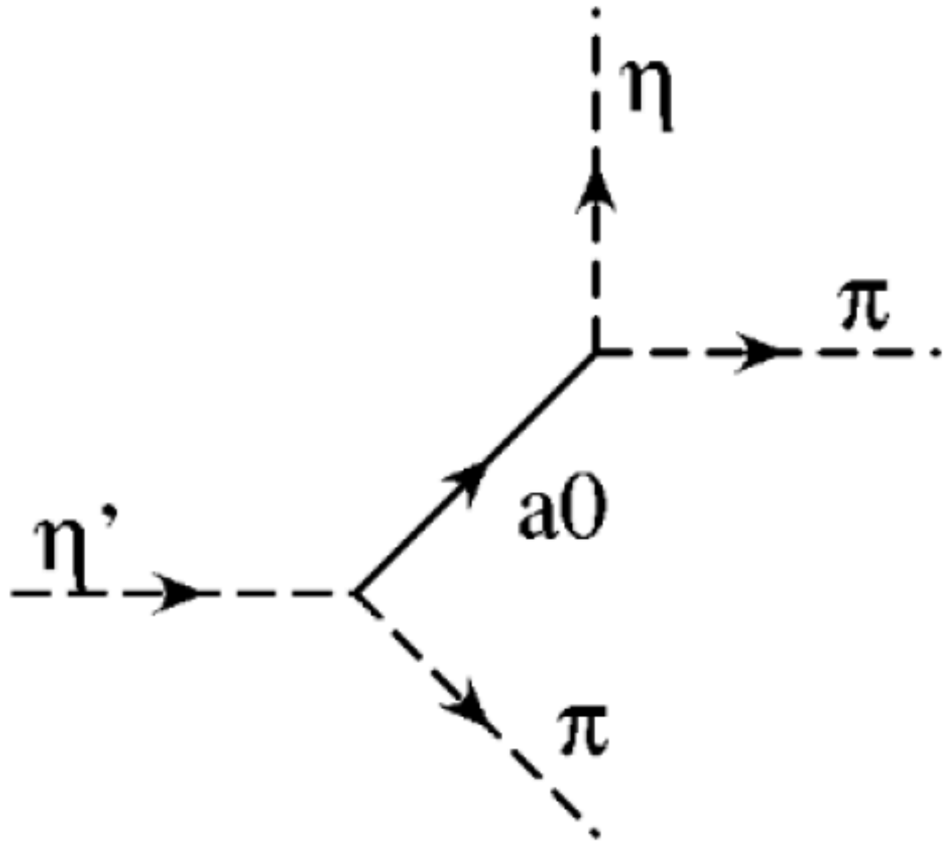
[B. Borasoy, R. Nissler]



a



b



c

$$\tau(\eta' \to \eta\pi^+\pi^-) = \frac{1}{2.m_{\eta'}} \int \mid M \mid^2 d\phi$$

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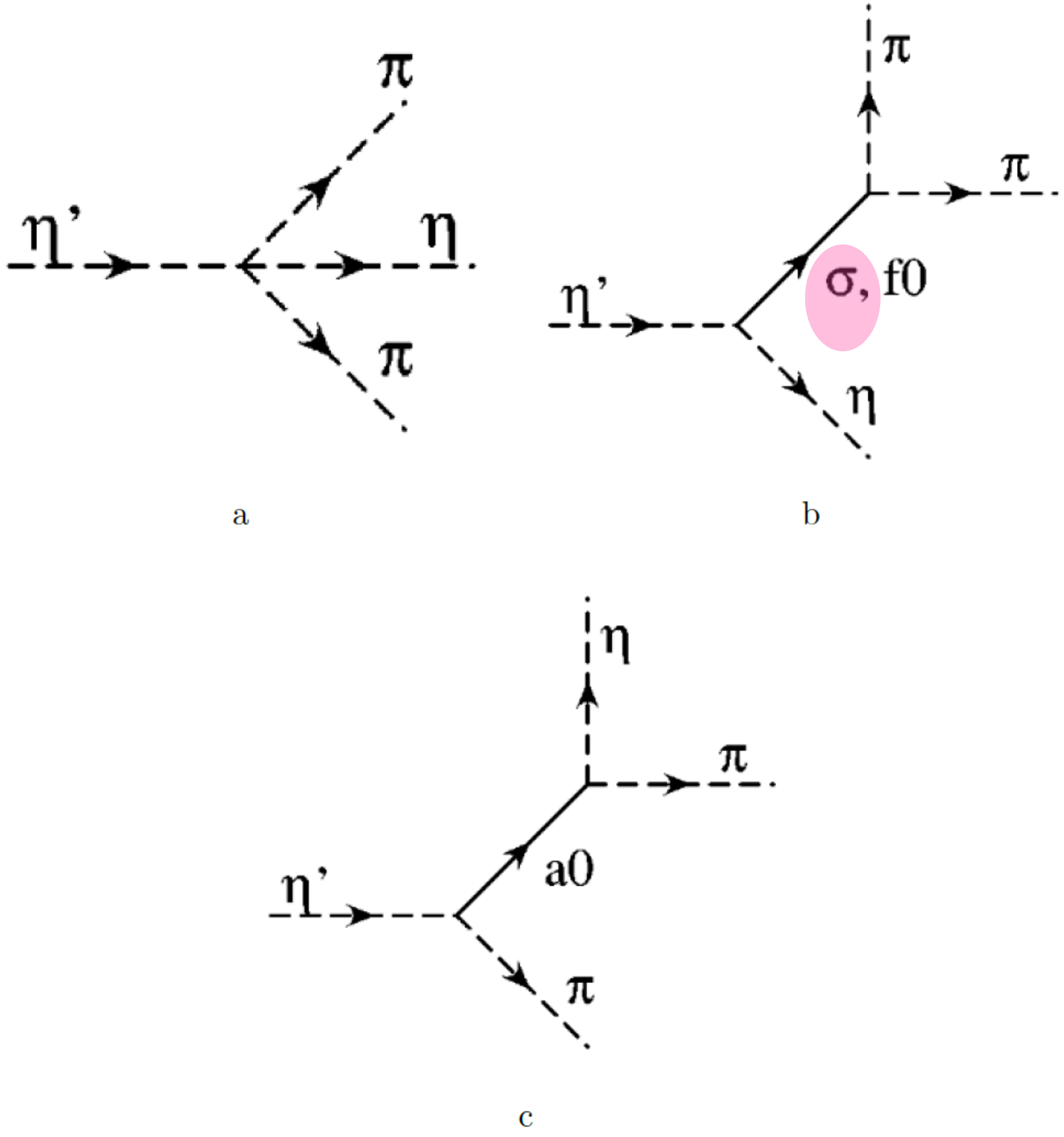
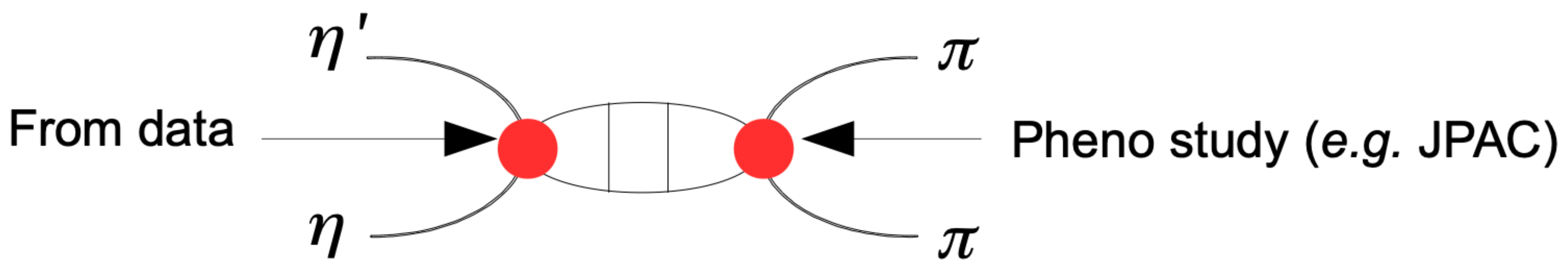
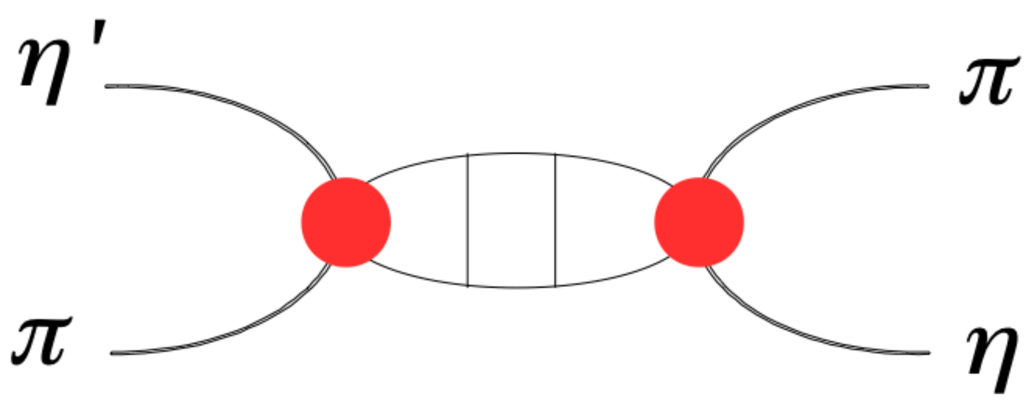


$$\tau(\eta' \to \eta\pi^+\pi^-) = \frac{1}{2.m_{\eta'}} \int |\, M \,|^2 \, d\phi$$

$\eta' \to \eta\pi^+\pi^-$

- Opportunity to constrain $\eta\pi$ scattering
  - Dispersive analysis of the decay amplitude [Bastian Kubis et al.]:

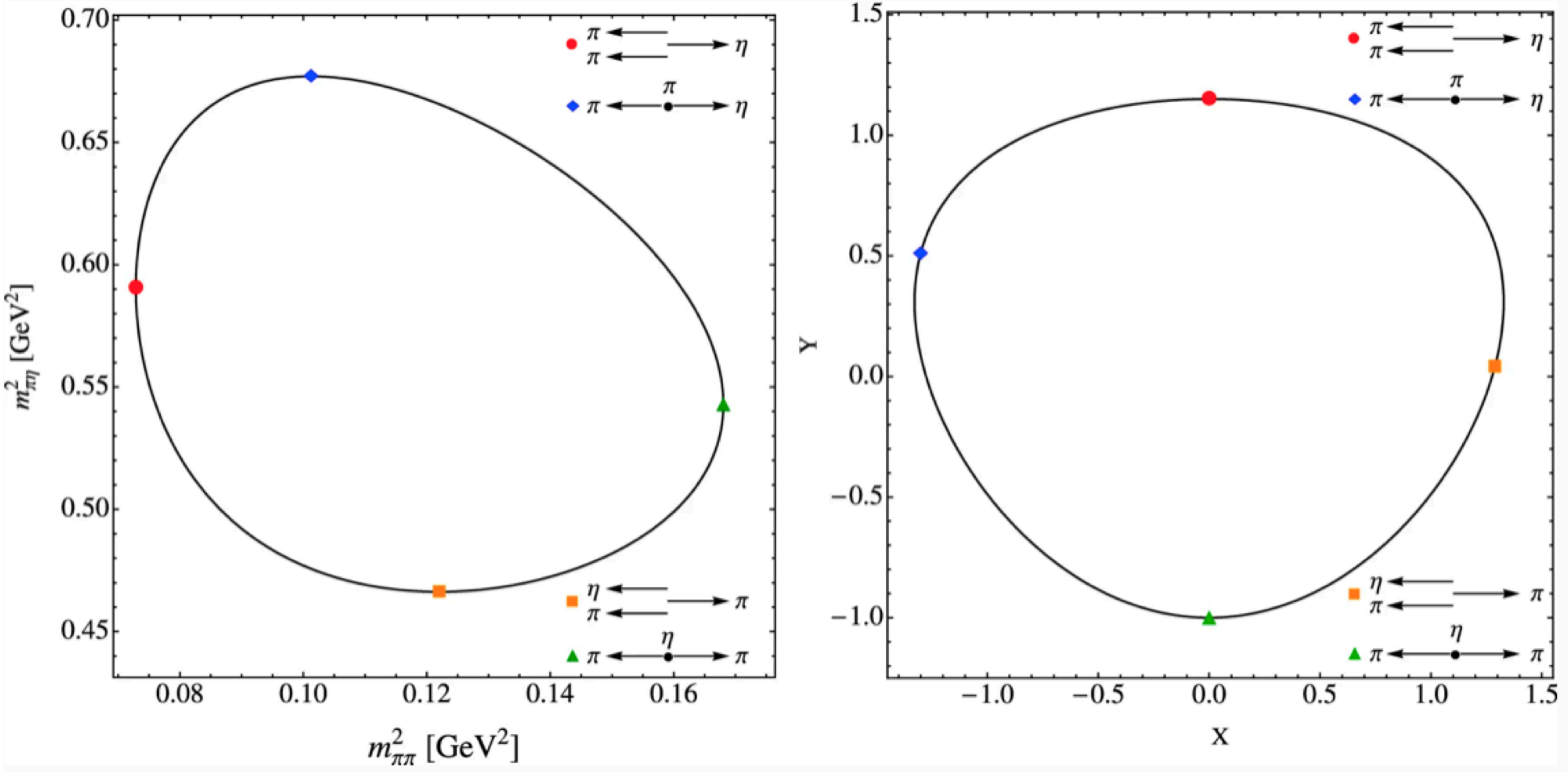




Dalitz plot boundaries

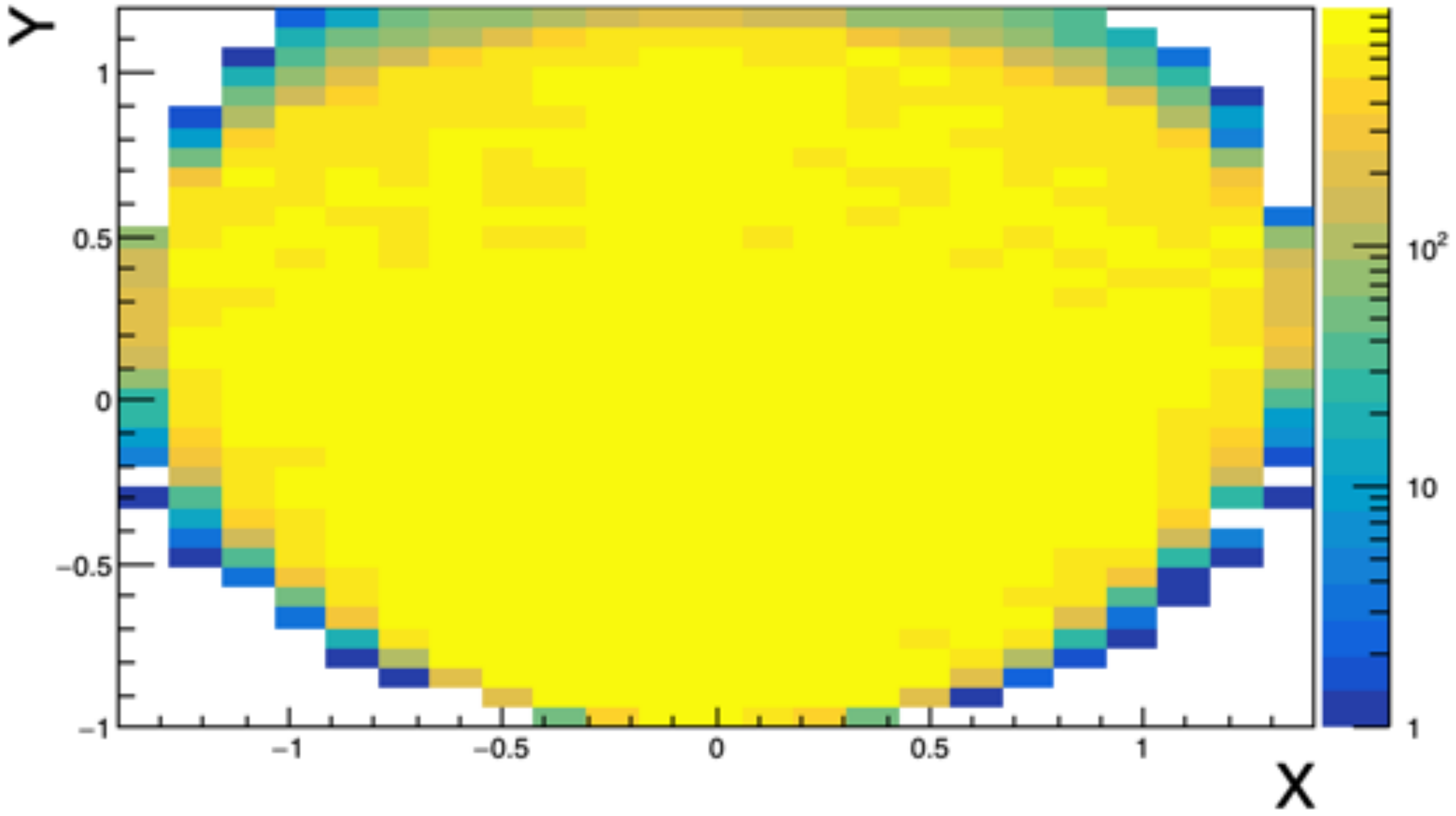
$$X = \frac{\sqrt{3}(T_{\pi^+} - T_{\pi^-})}{Q}$$

$$Y = \frac{(m_\eta + 2m_\pi)}{m_\pi} \cdot \frac{T_\eta}{Q} - 1.$$



S. Gonz.lez-Sol.s, E. Passemar, Eur. Phys. J. C 78 (2018) 758, arXiv:1807.04313 [hep-ph].

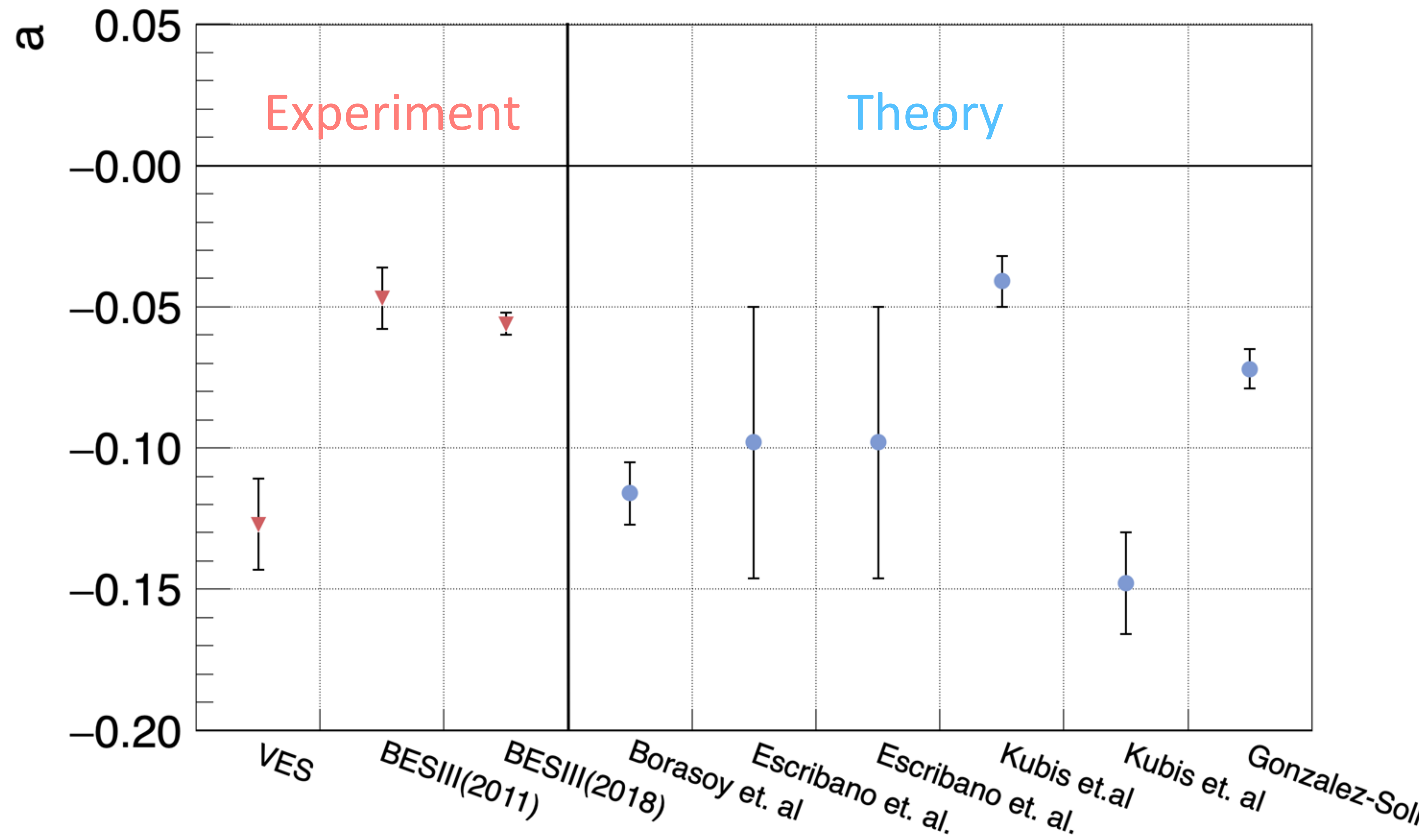
Parametrization of the Dalitz Plot

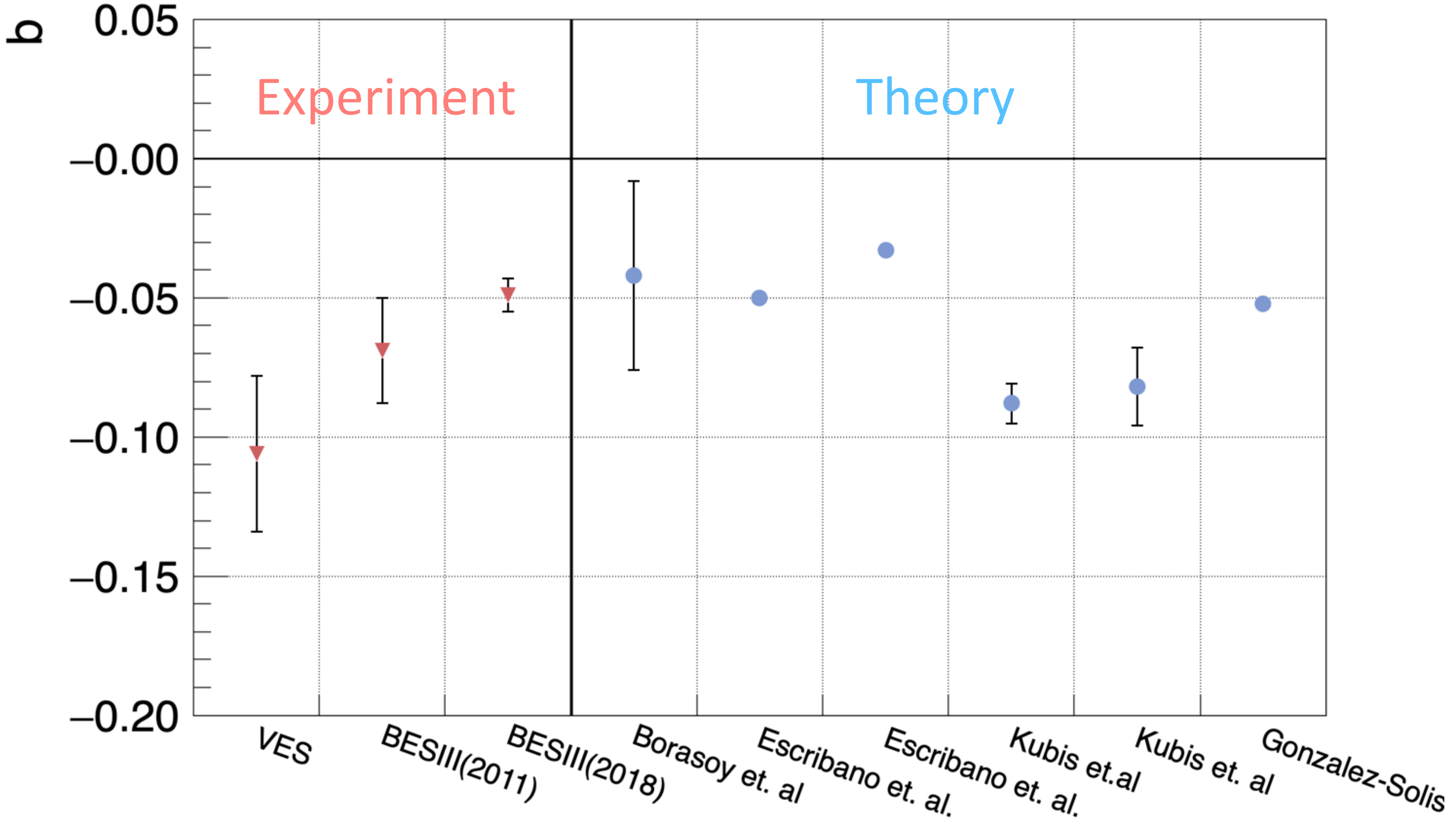


$$f(X,Y) = M^2 = A(1 + aY + bY^2 + cX + dX^2)$$

Previous experimental results and theoretical predictions

There are many discrepancies, the picture is not complete





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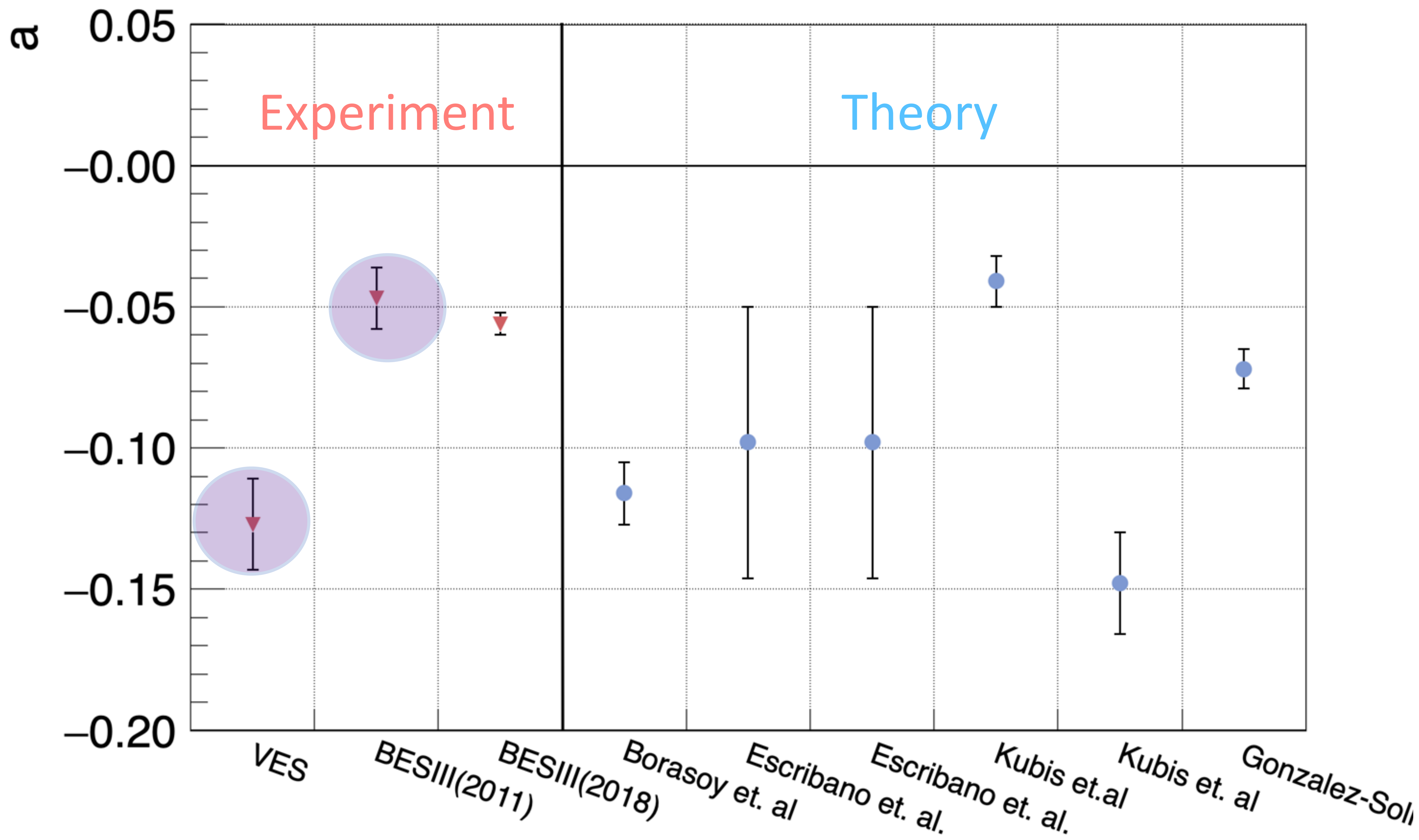
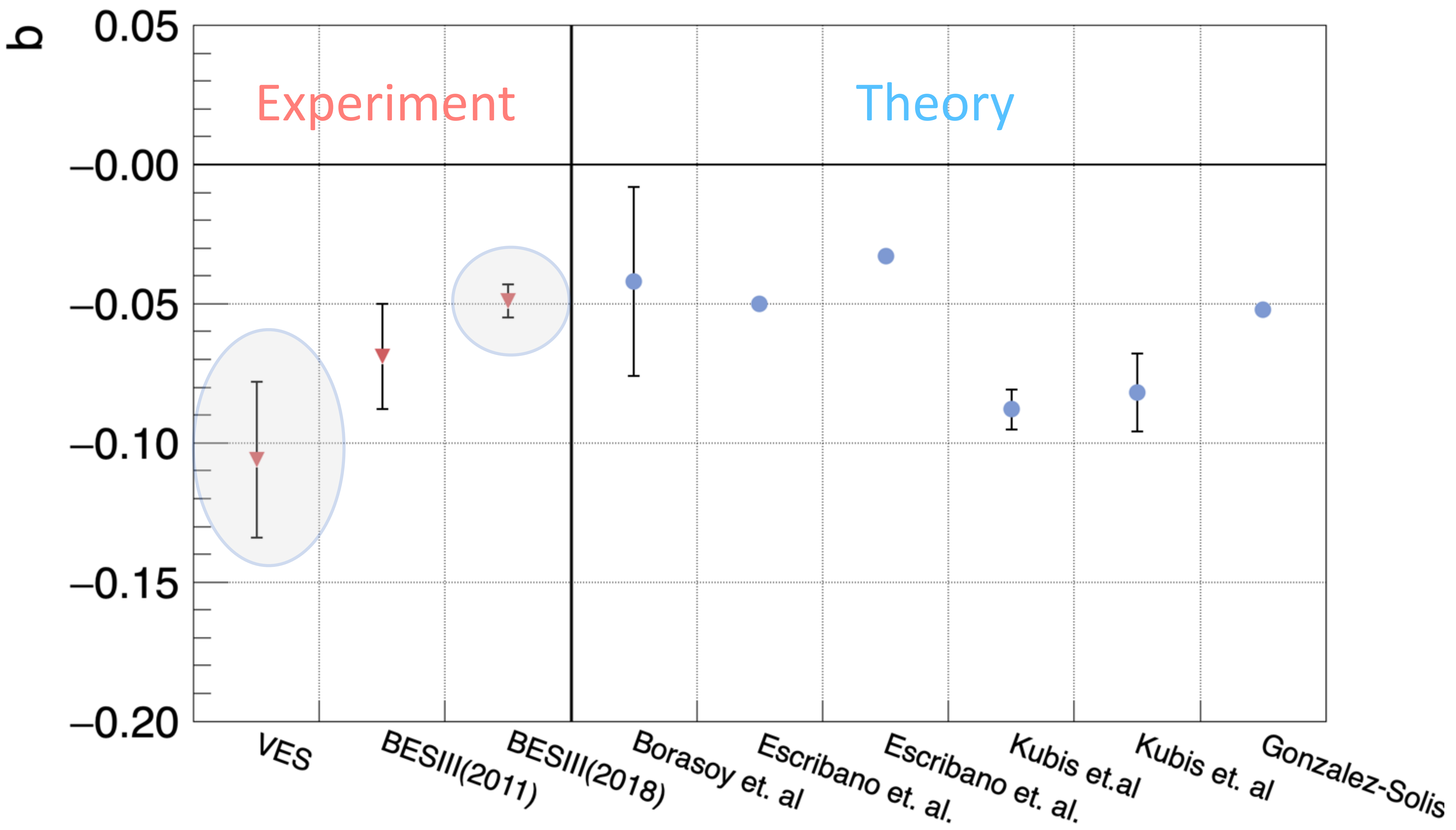
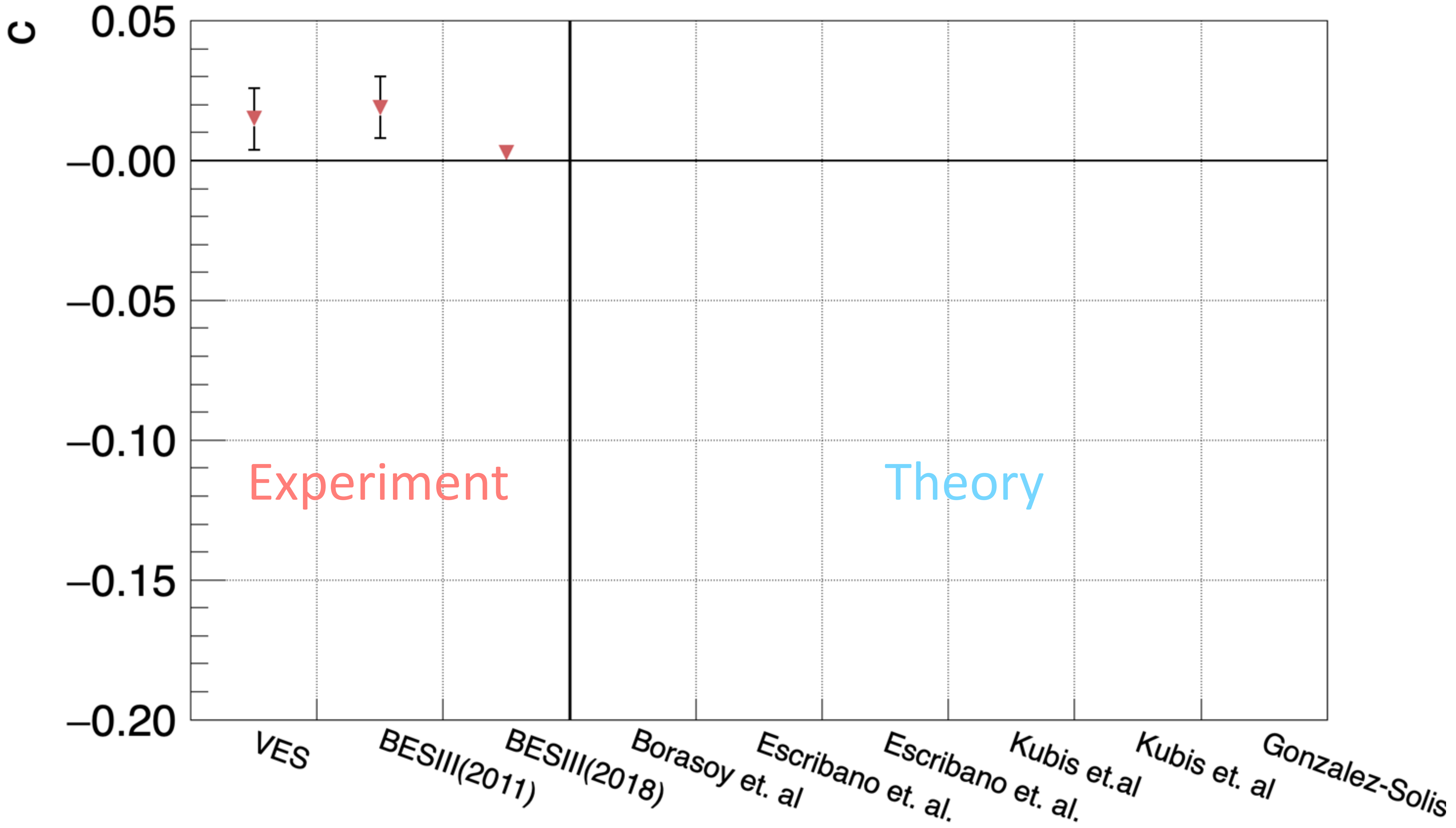
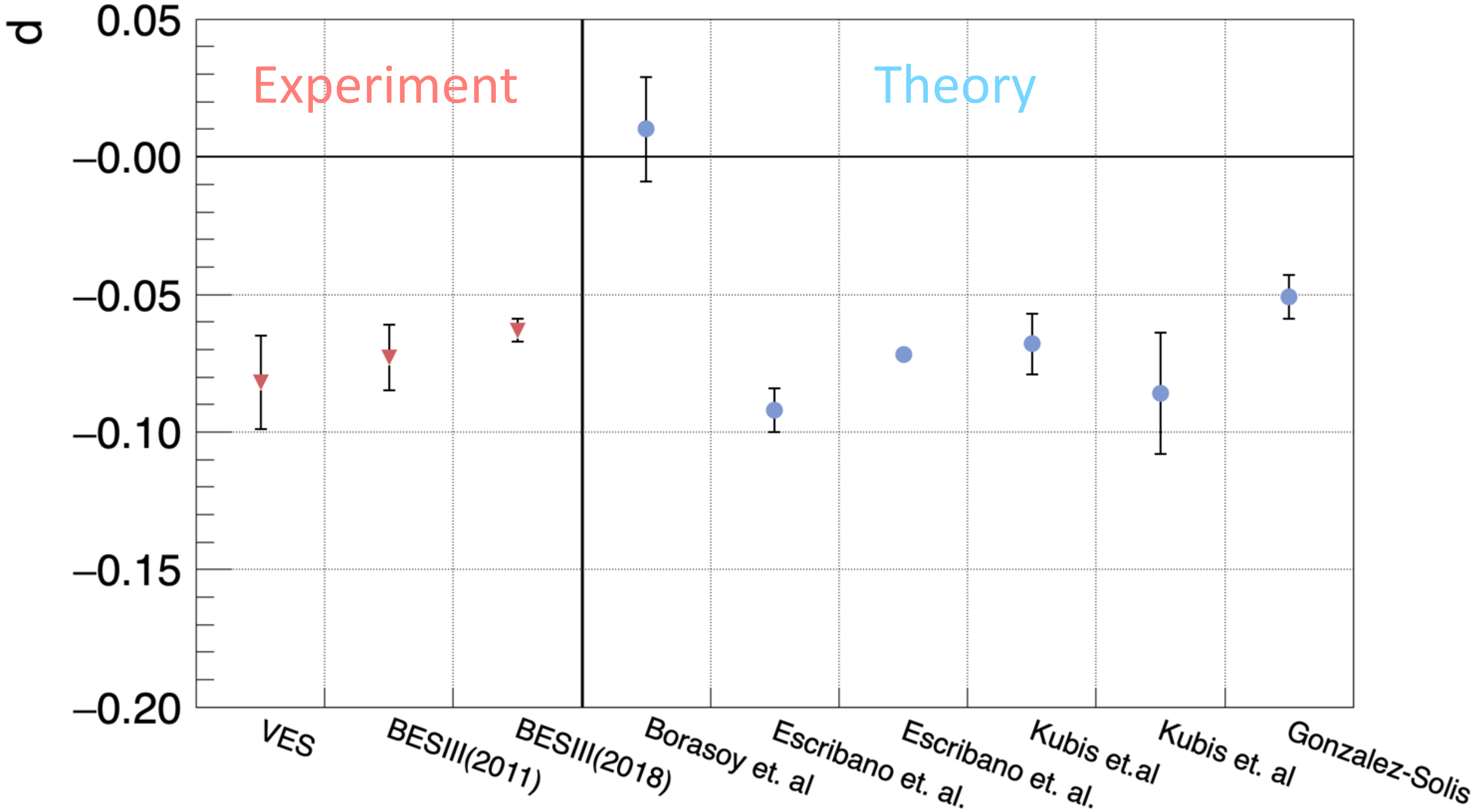




Experimental and theoretical Dalitz parameters for $\eta' \to \eta\pi^+\pi^-$





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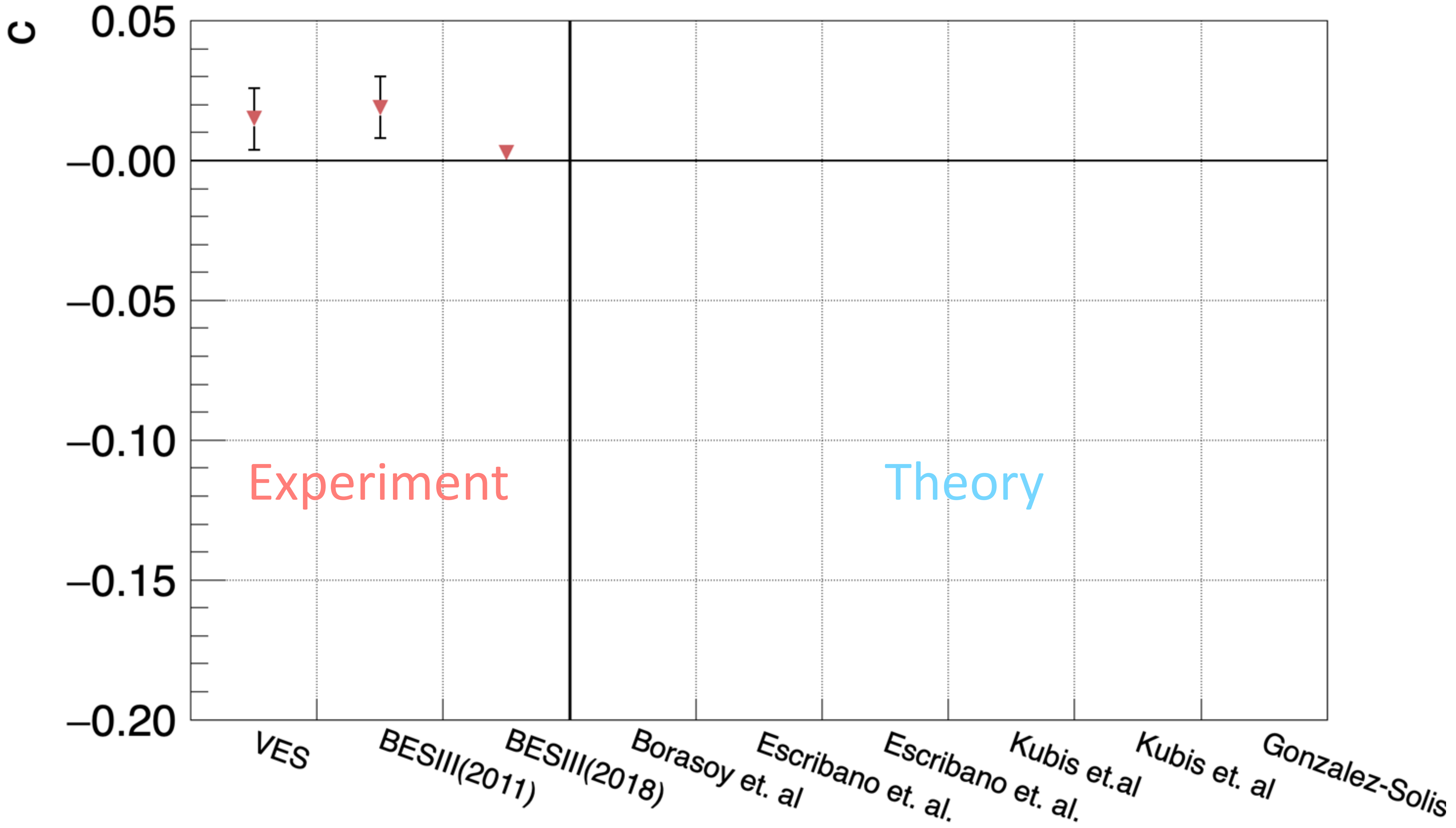
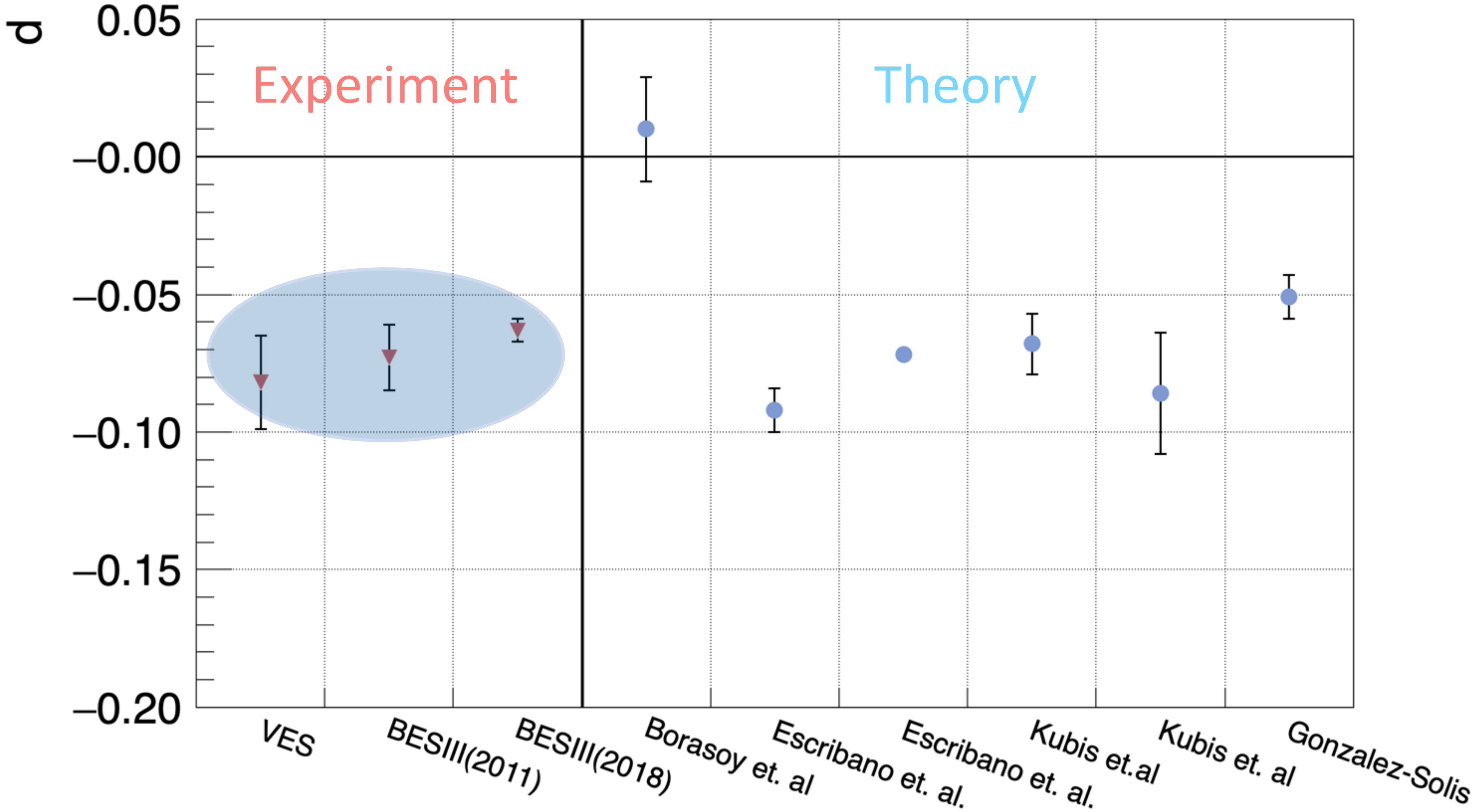
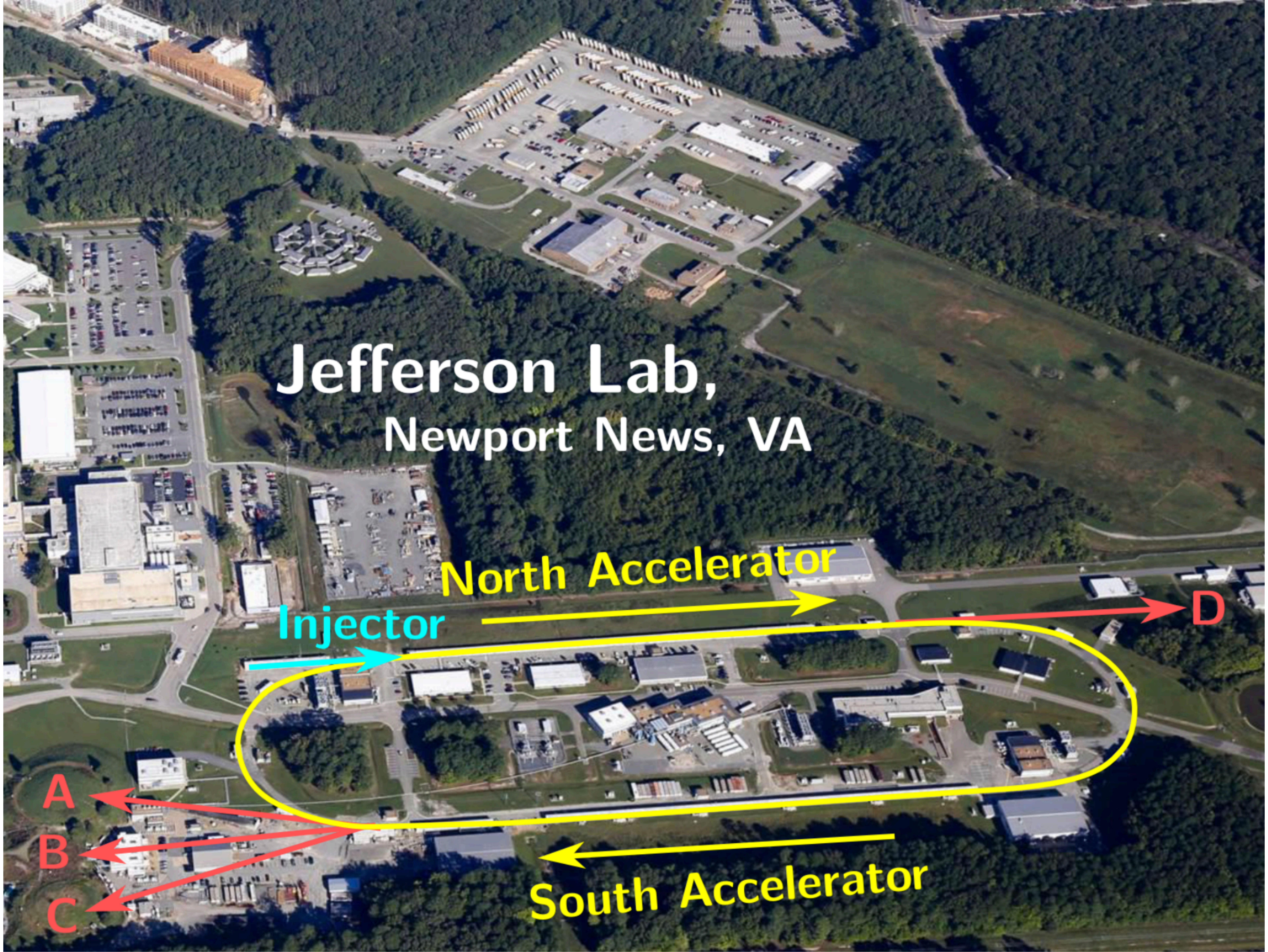
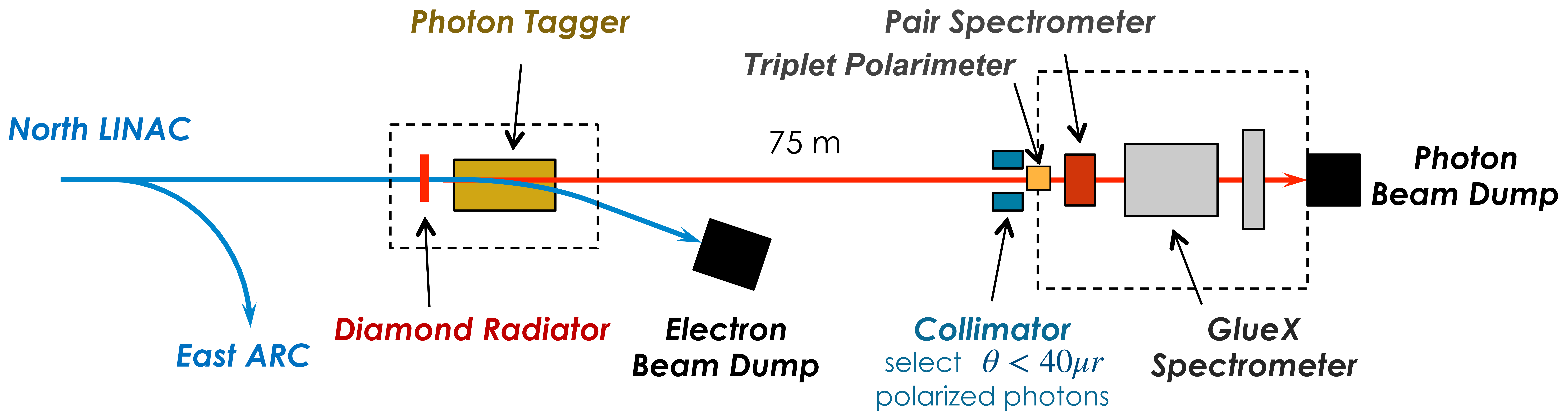


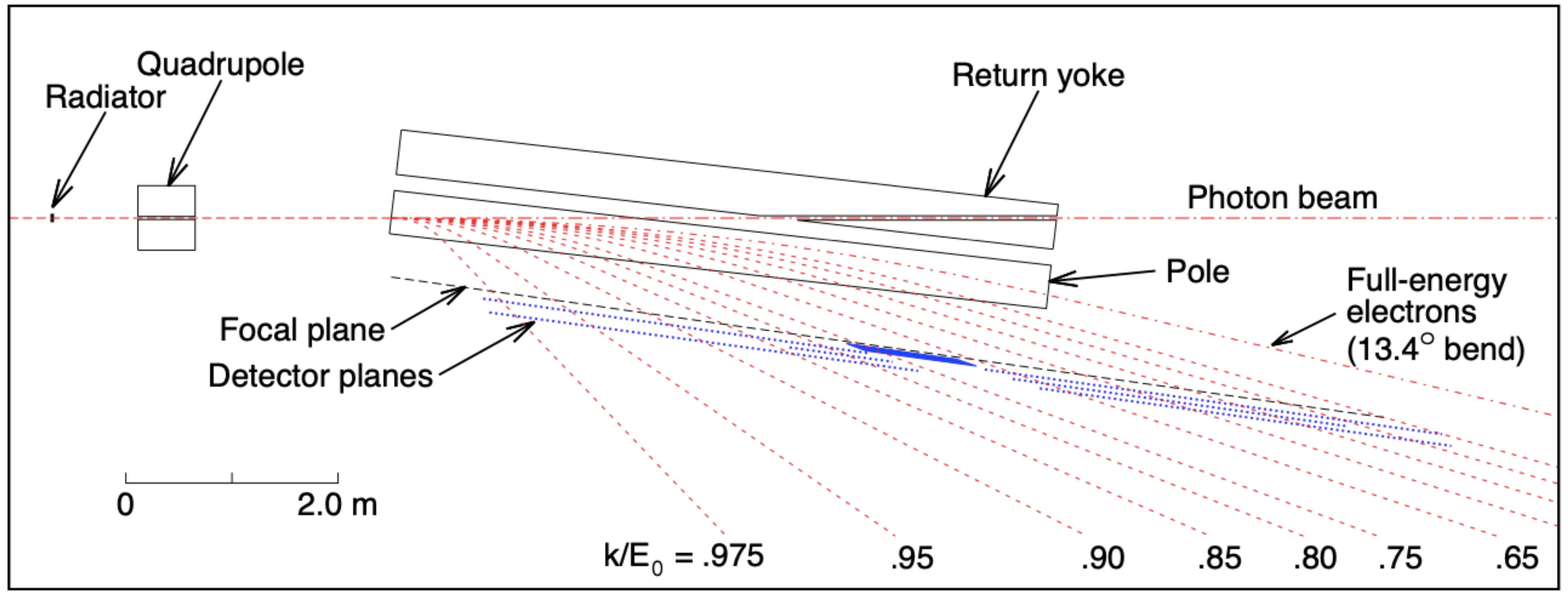



Jefferson Lab,
Newport News, VA


Jefferson Lab,
Newport News, VA
North Accelerator
Injector
D
A
B
C
South Accelerator

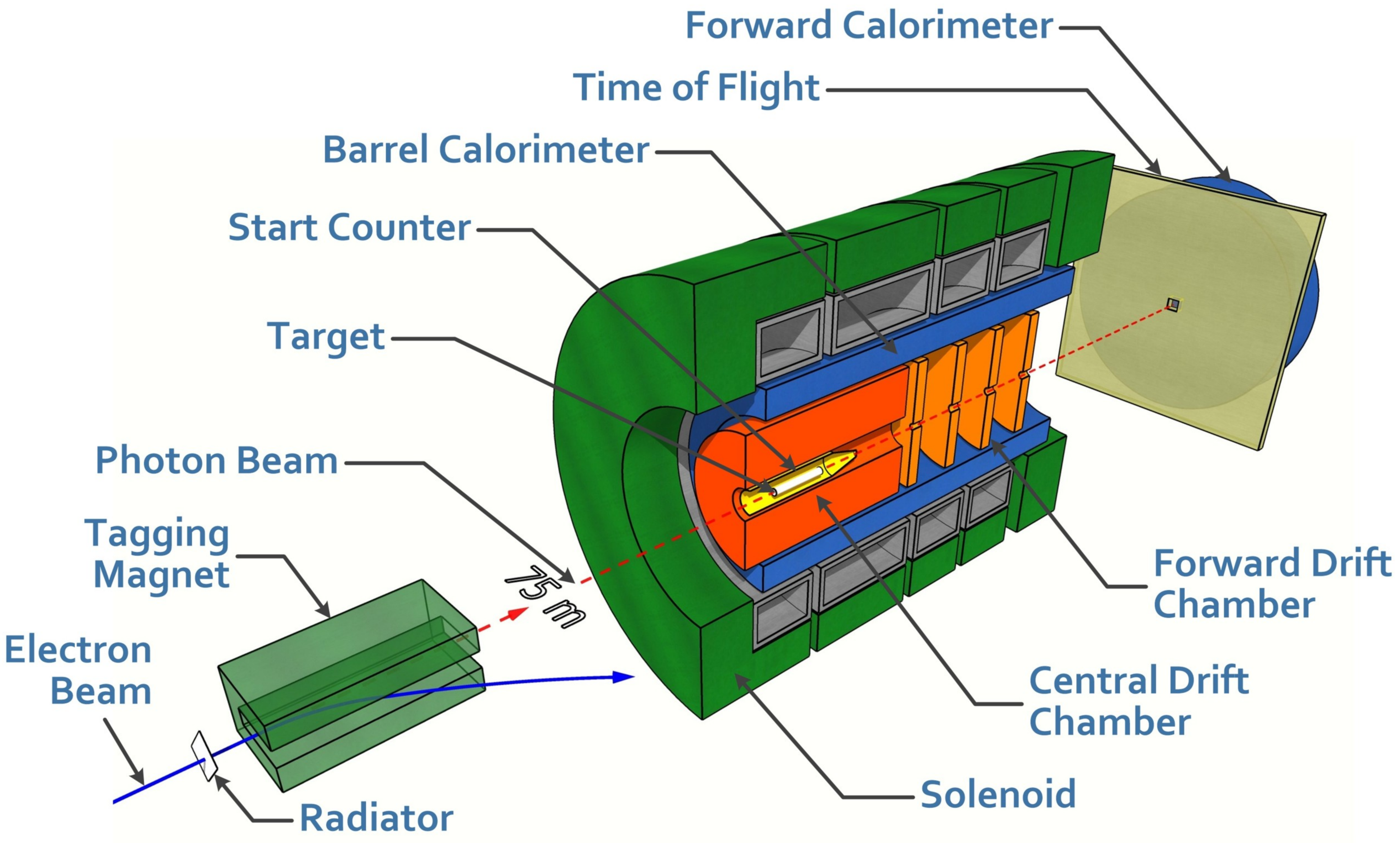
Gluex Experiment





- Coherent Bremsstrahlung of 12 GeV electron beam on 50μm radiator
- Beam energy tagged with a precision of $E_\gamma < 25$ MeV

GlueX Spectrometer



- Hermetic detector
- Exclusive reaction

Phase	Run Period	Luminosity
GlueX-I	2017-2018	439.6 pb^{-1}
GlueX-II	2020-2025?	386.2 pb^{-1} (2020)

GlueX

GlueX

- **Main Goal: Search for hybrid mesons (exotic and non-exotic). Not in this talk!**

GlueX

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GlueX

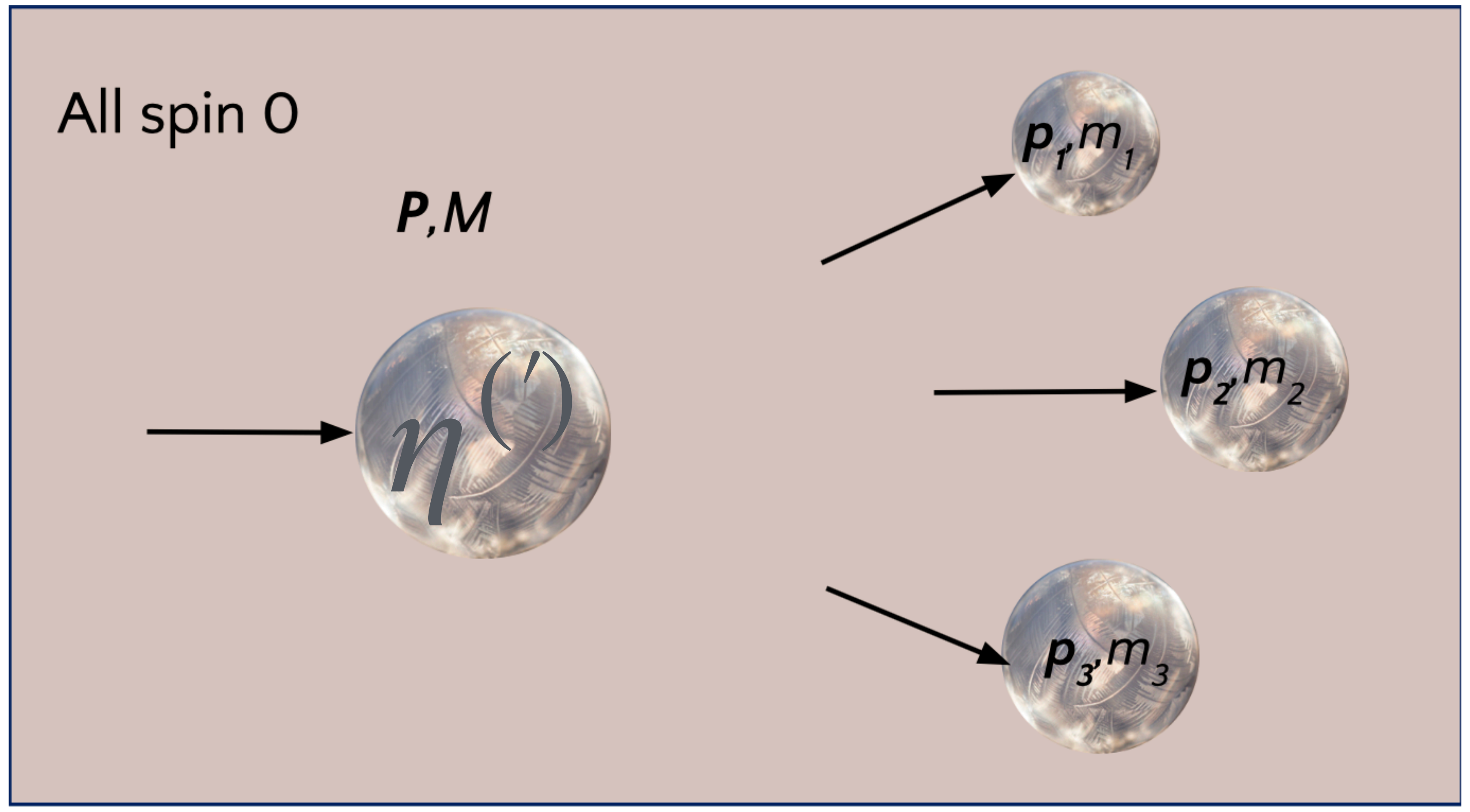
$\eta \to \pi^+\pi^-\pi^0$

Daniel Lersch
JLAB

Nizar Septian
FSU

- **Main Goal: Search for hybrid mesons (exotic and non-exotic). Not in this talk!**

- **Other physics opportunities:**
  - **Dalitz-plot analysis of light meson decays $(\eta, \eta', \omega, \text{etc.})$**



$\eta' \to \eta\pi^+\pi^-$

$\eta' \to \eta\pi^0\pi^0$

$\omega \to \pi^+\pi^-\pi^0$

Shaheli Rakshit
FSU

GlueX

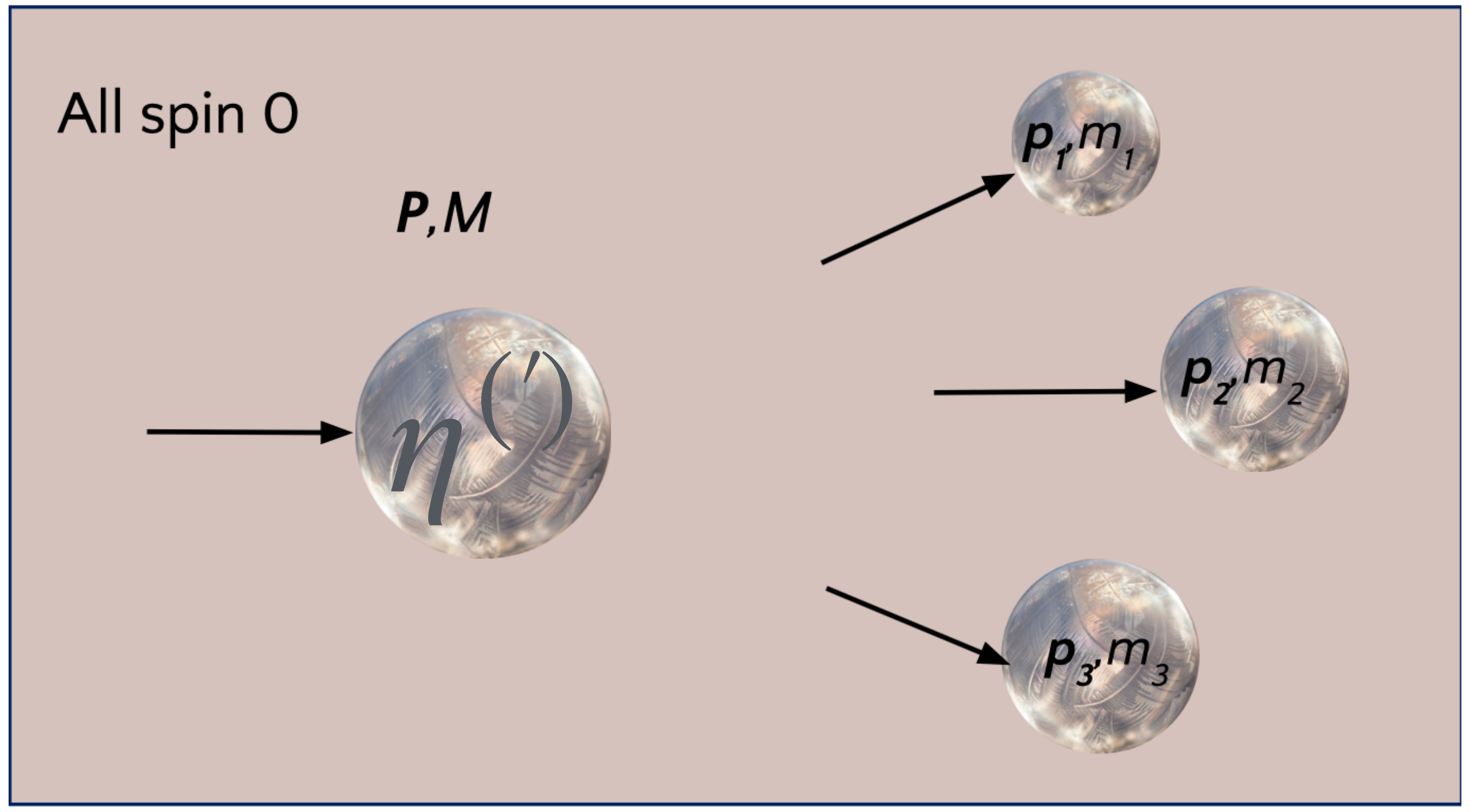
- **Main Goal: Search for hybrid mesons (exotic and non-exotic). Not in this talk!**

- **Other physics opportunities:**
  - **Dalitz-plot analysis of light meson decays $(\eta, \eta', \omega, \text{etc.})$**
  - **Hyperon studies**
  - **N***

$\eta \to \pi^+\pi^-\pi^0$

Daniel Lersch
JLAB

Nizar Septian
FSU



$\eta' \to \eta\pi^+\pi^-$

$\eta' \to \eta\pi^0\pi^0$

$\omega \to \pi^+\pi^-\pi^0$

Shaheli Rakshit
FSU

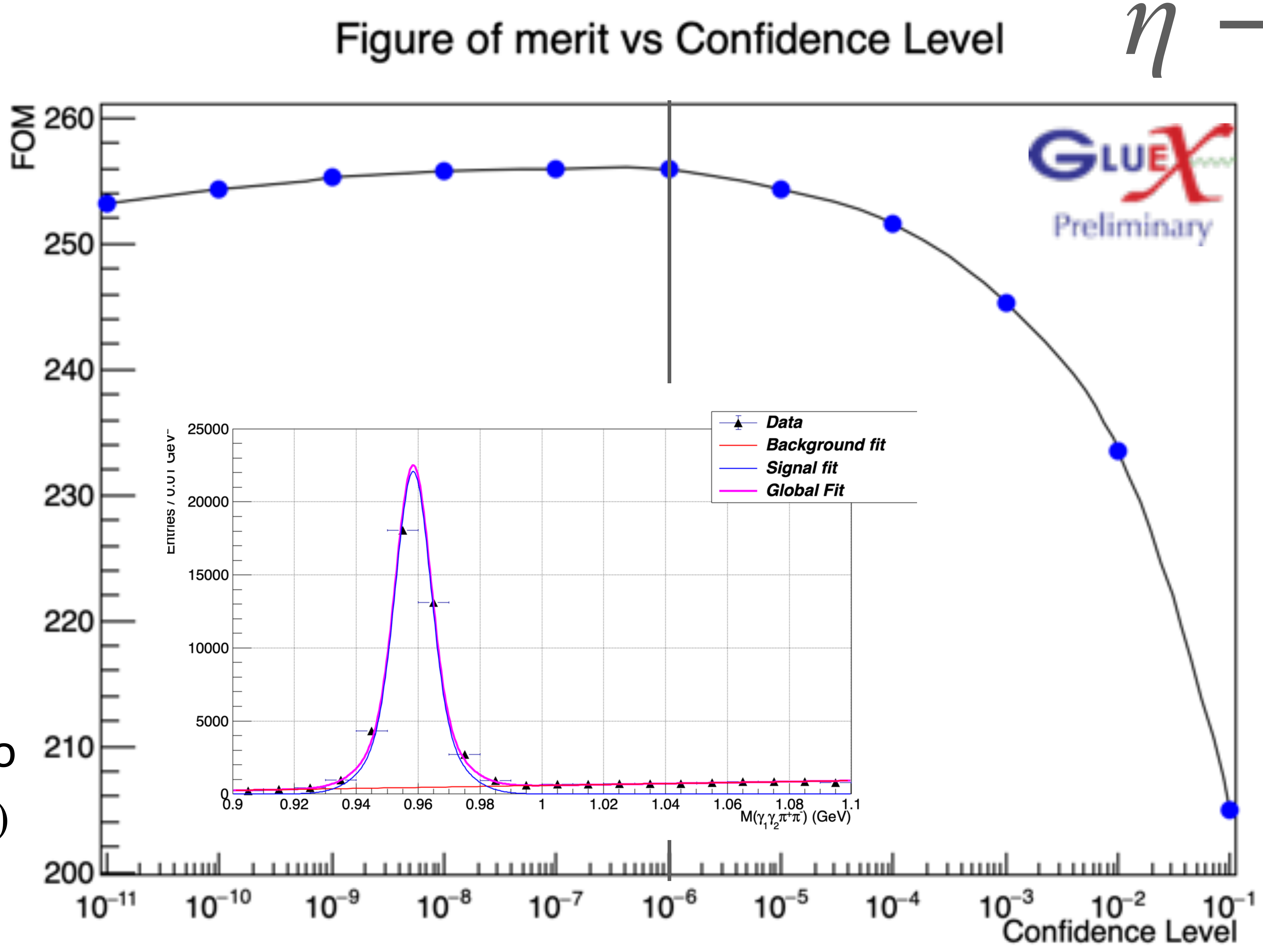
$$\gamma p \rightarrow p\eta'$$
$$\eta' \rightarrow \eta\pi^+\pi^-$$
$$\eta \rightarrow \gamma\gamma$$

Confidence level cut

$$FOM = \frac{S}{\sqrt{S+B}}$$

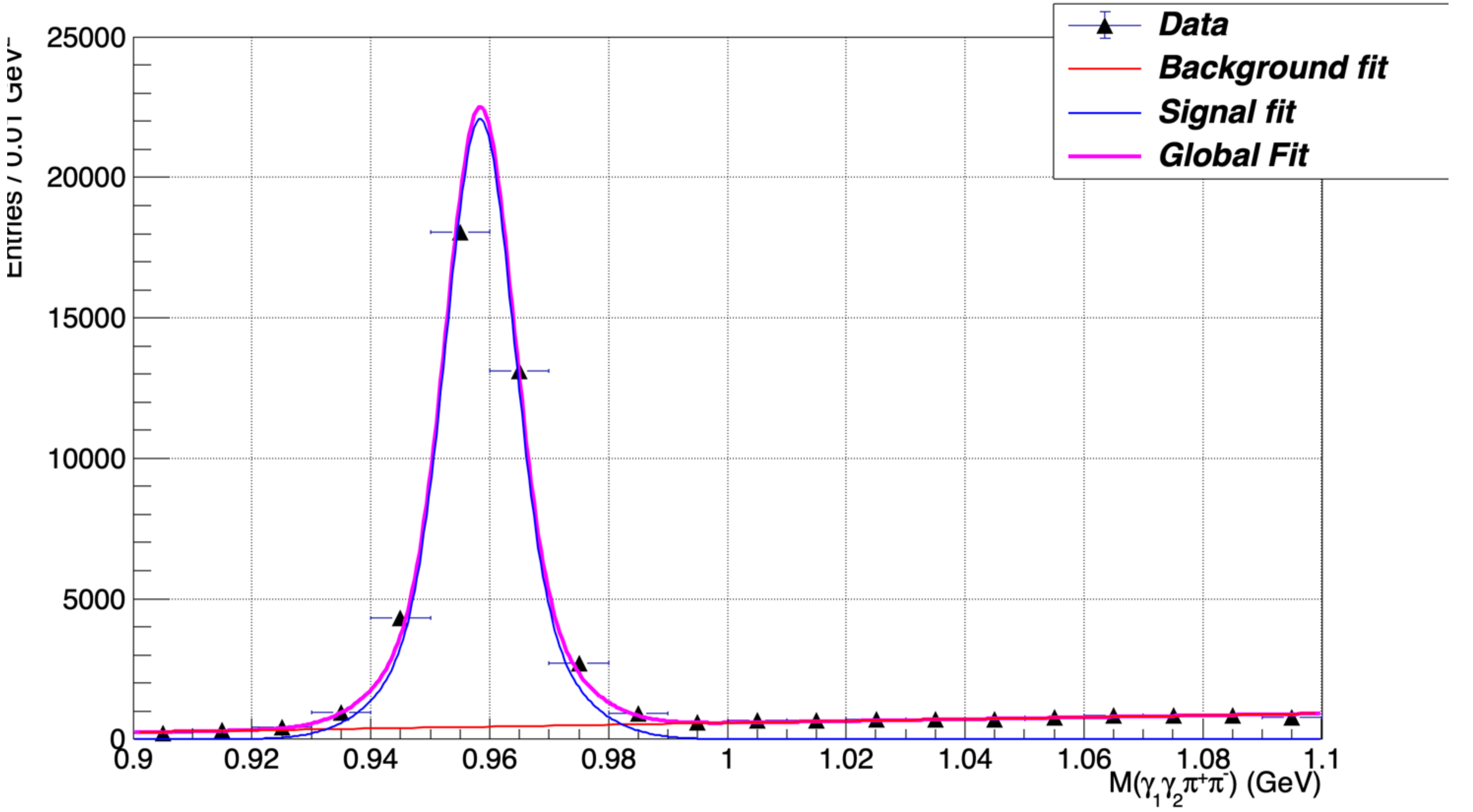
Signal fraction within 3σ is ~97.2%

- Exclusively reconstruct
- Kinematically fit 4-momentum conservation utilizing tagged photon beam energy with mass constrains on intermediate particles (η)
- Background estimated through fits to invariant mass distribution $M(\pi^+\pi^-\eta)$



Yield Estimate

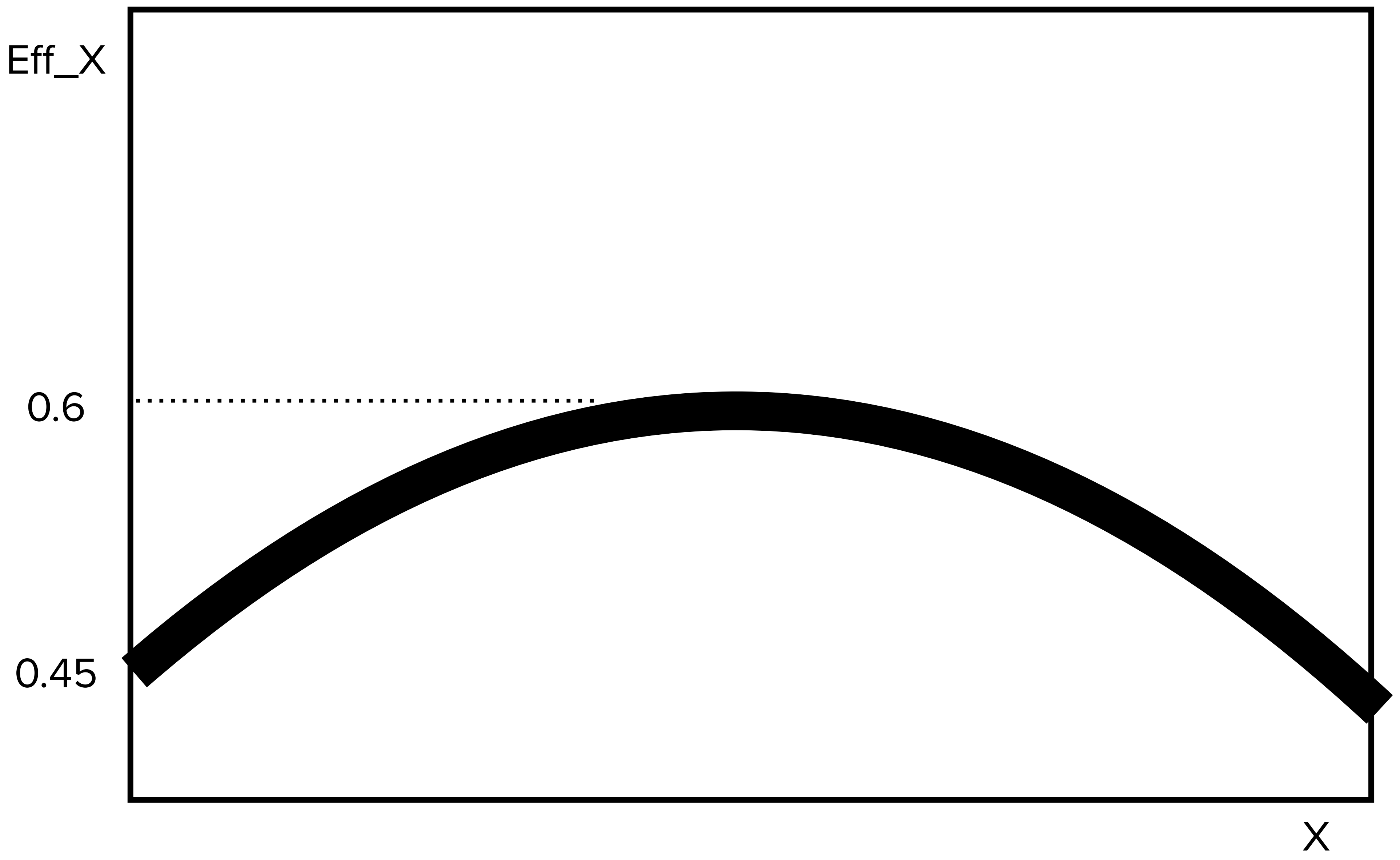
Experiment	yield $(\times 10^4)$
VES 2007	0.86
BESIII (2011)	4.4
BESIII (2018)	35.1
GlueX-I	13.6
GlueX-II	$3 \times$ GlueX-I



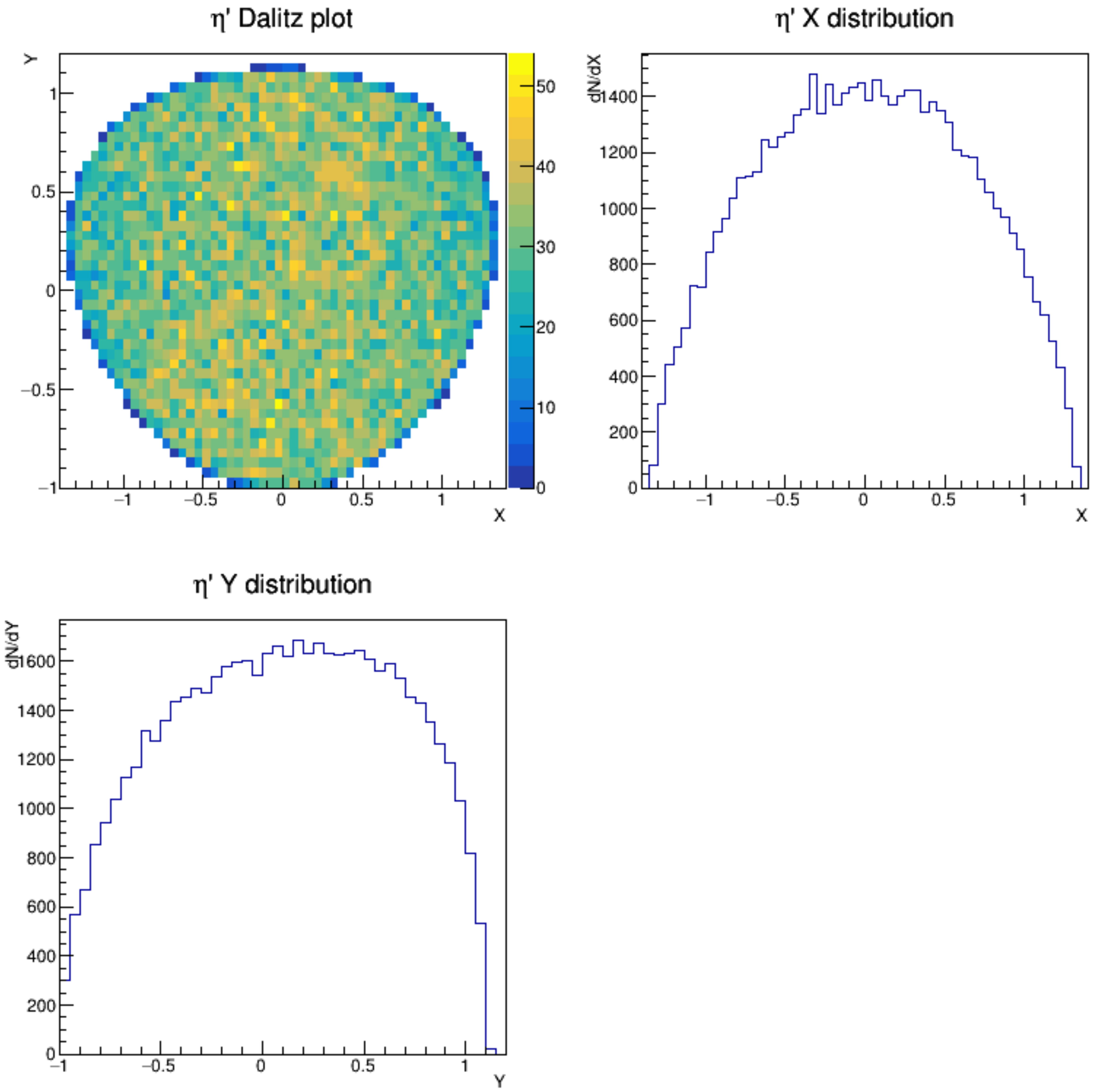
I/O Studies: Naïve acceptance

- Using AmpTools
  - Maximum likelihood event by event fitter
  - Generates pseudodata for validity and bias studies

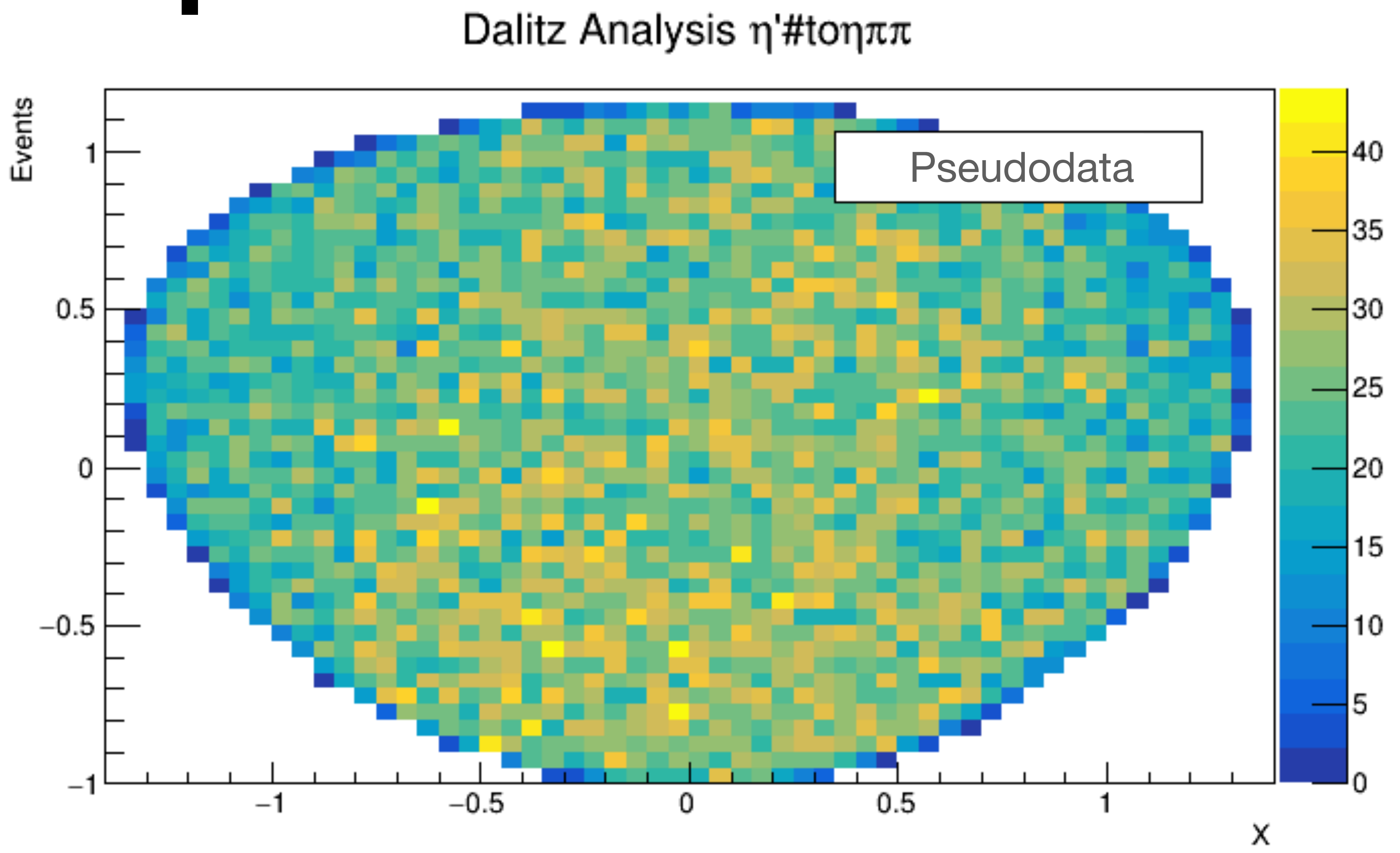
Toy Acceptance

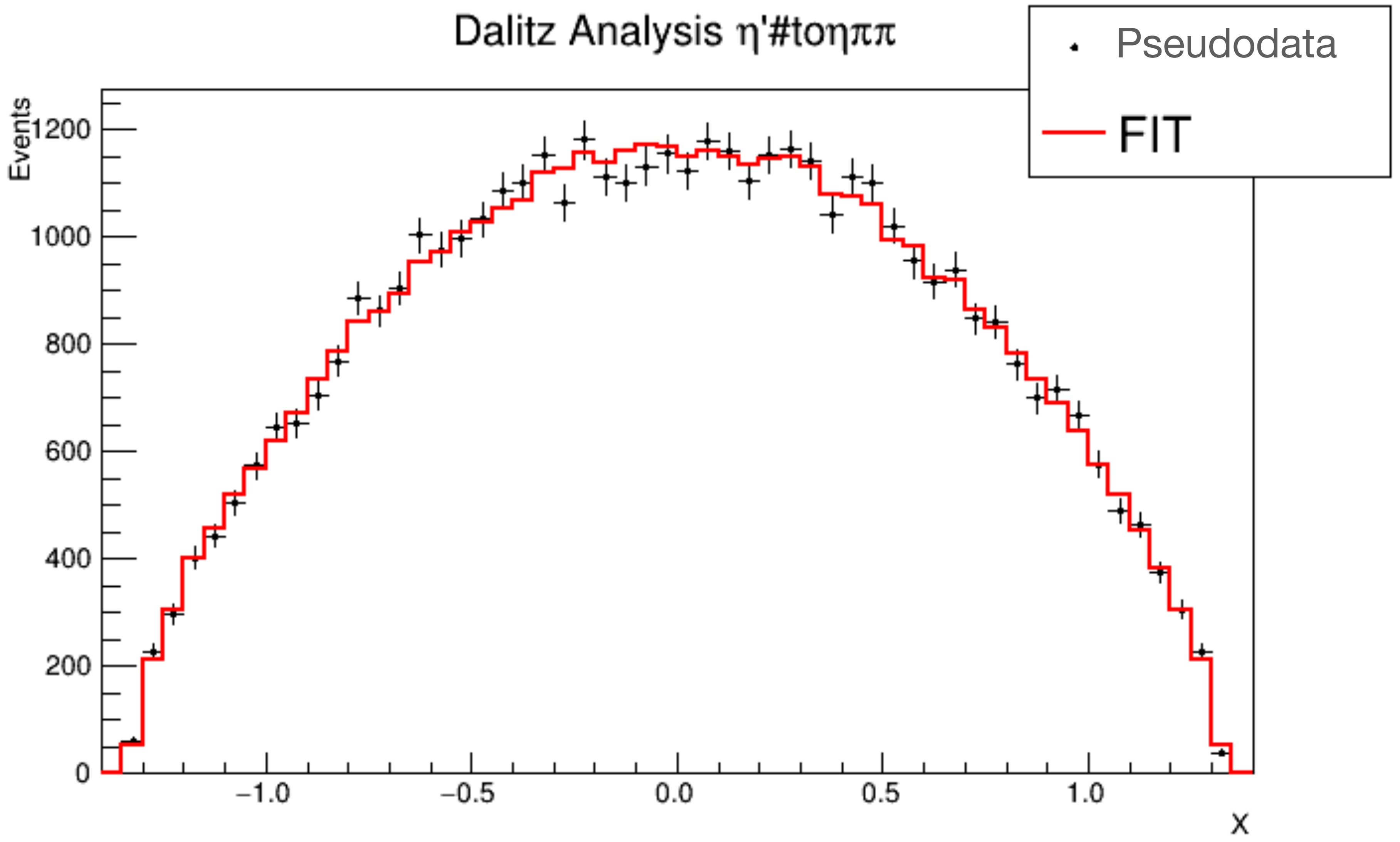


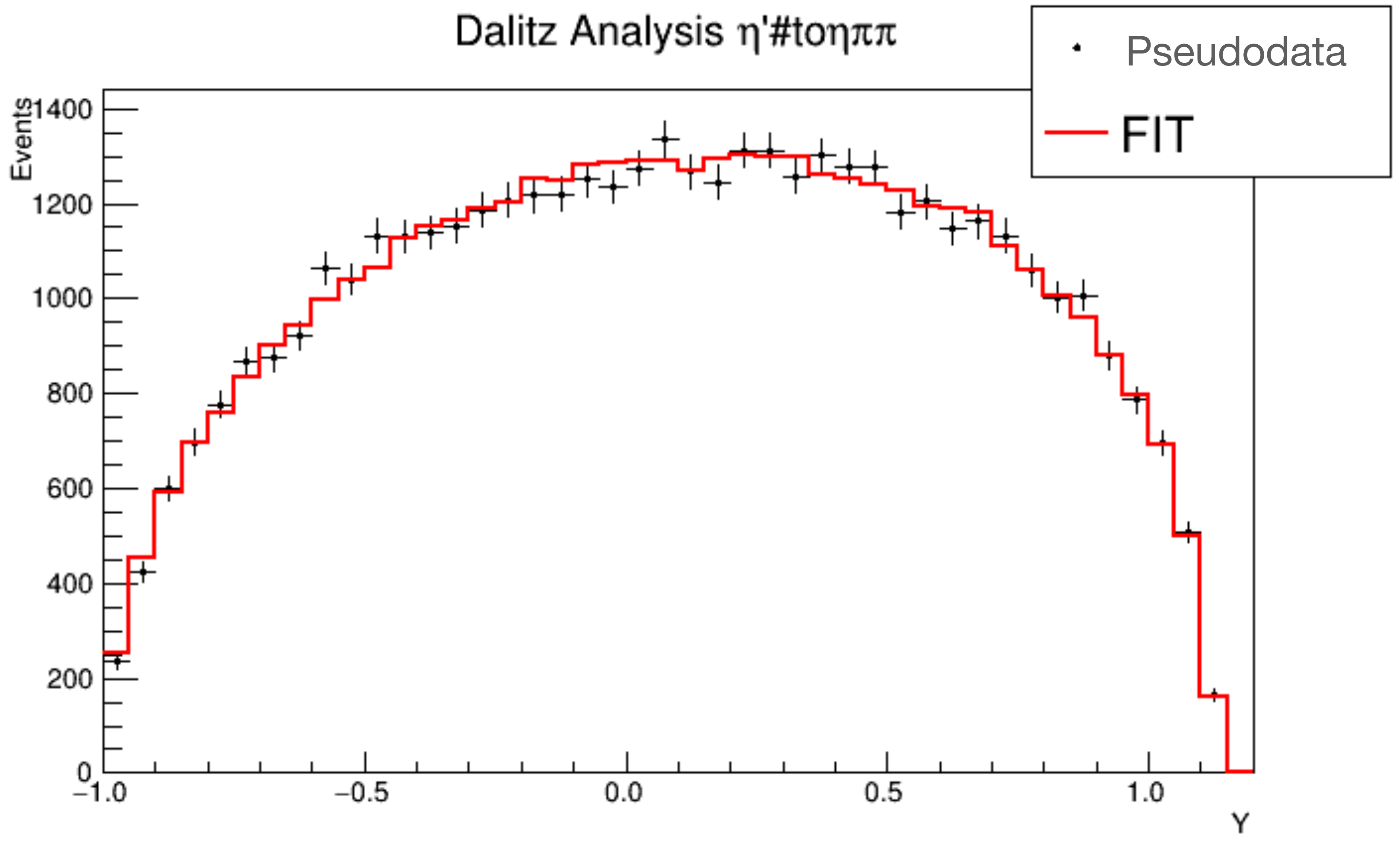
Pseudodata



Toy Acceptance





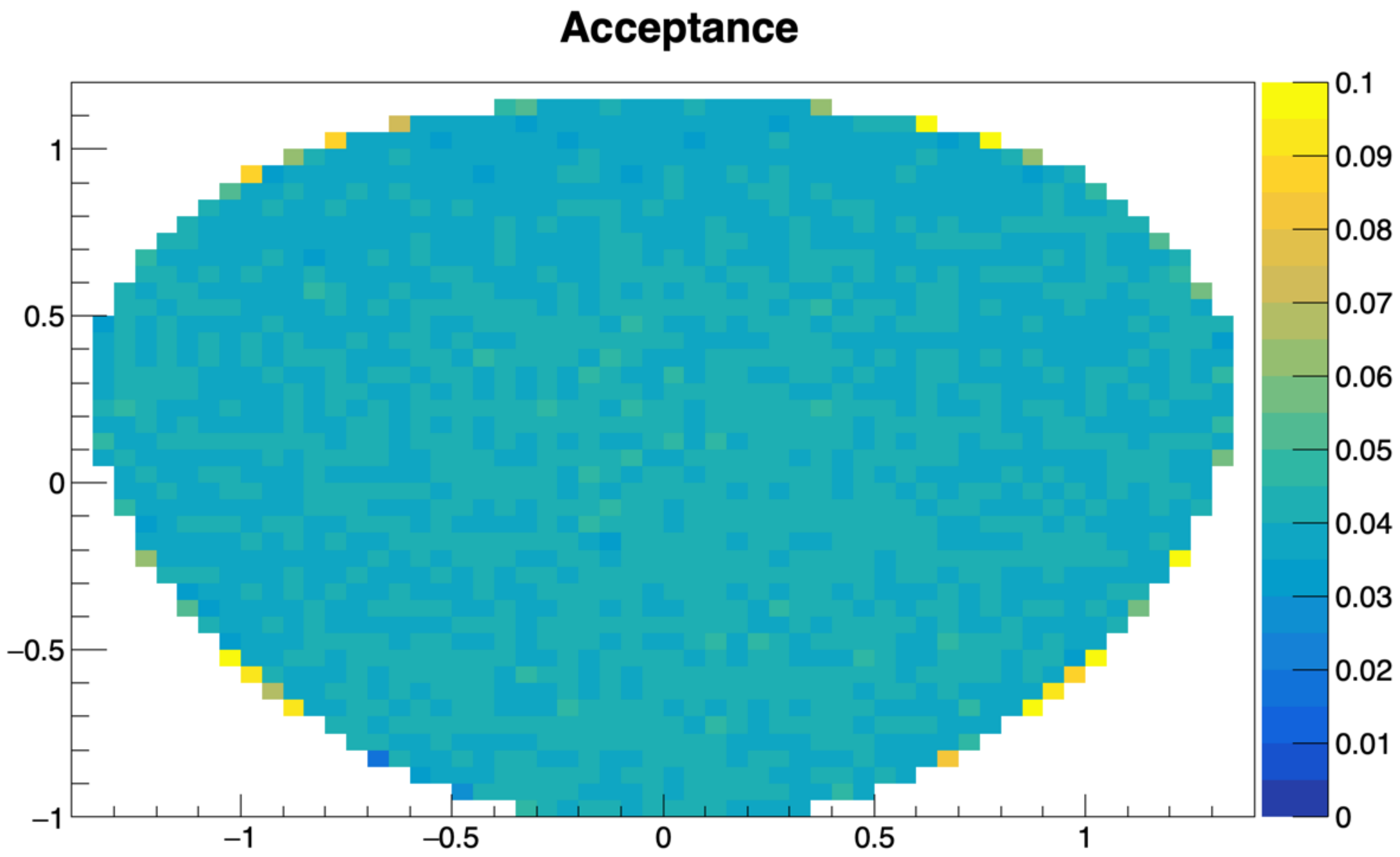


- pseudodata generated with BESIII (2018) results
- Toy Acceptance
- no background
- 100k generated MC events

Fit comparison
Minuit uncertainties

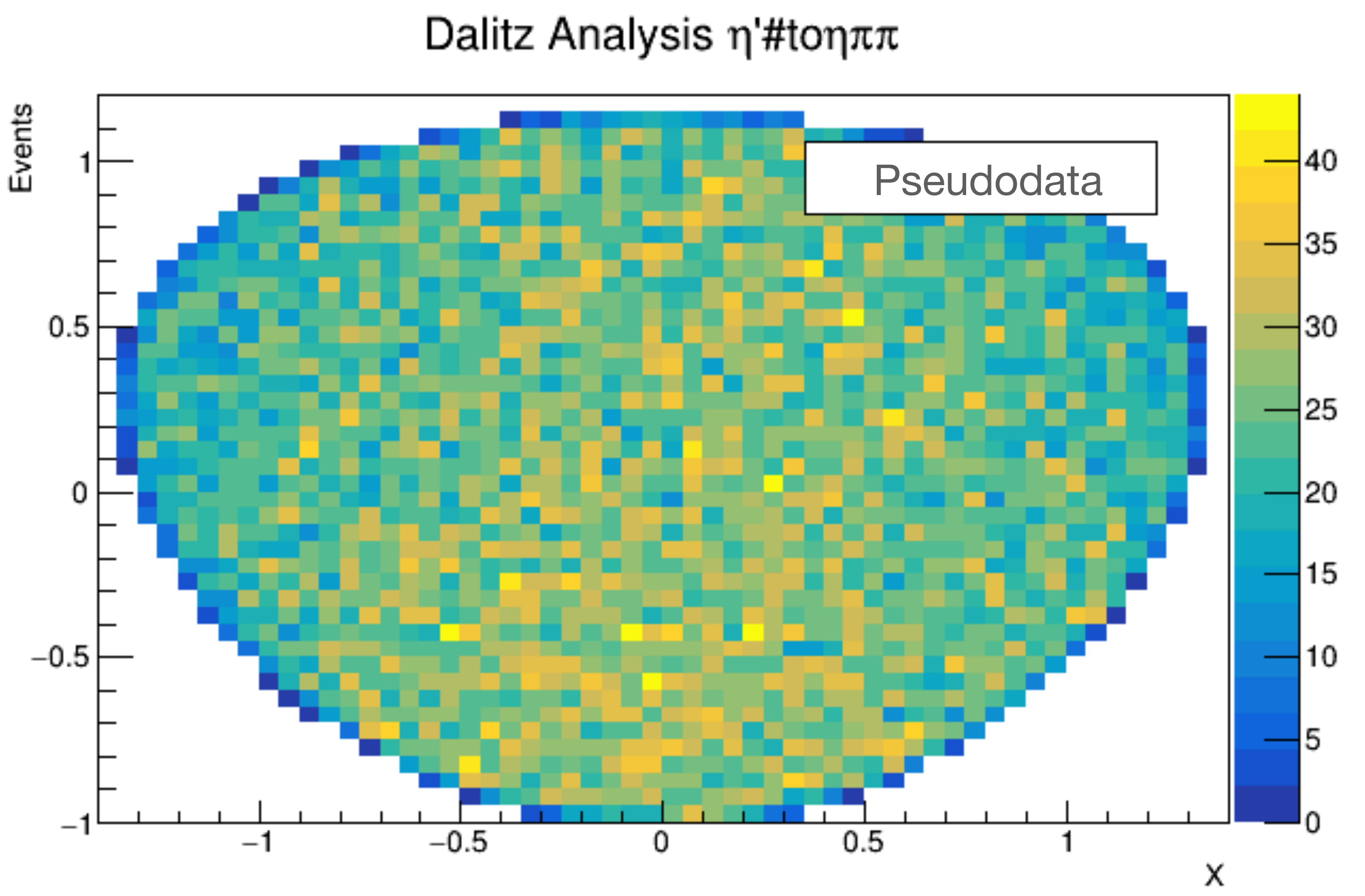
	BESIII (2018)	my Fit
a	$-5.60 \times 10^{-2} \pm 4.0 \times 10^{-3}$	$-5.22 \times 10^{-2} \pm 4.9 \times 10^{-3}$
b	$-4.9 \times 10^{-2} \pm 6.0 \times 10^{-3}$	$-4.6 \times 10^{-2} \pm 9.4 \times 10^{-3}$
c	$2.7 \times 10^{-3} \pm 2.4 \times 10^{-3}$	$2.0 \times 10^{-3} \pm 3.61 \times 10^{-3}$
d	$-6.3 \times 10^{-2} \pm 4.0 \times 10^{-3}$	$-6.69 \times 10^{-2} \pm 9.4 \times 10^{-3}$

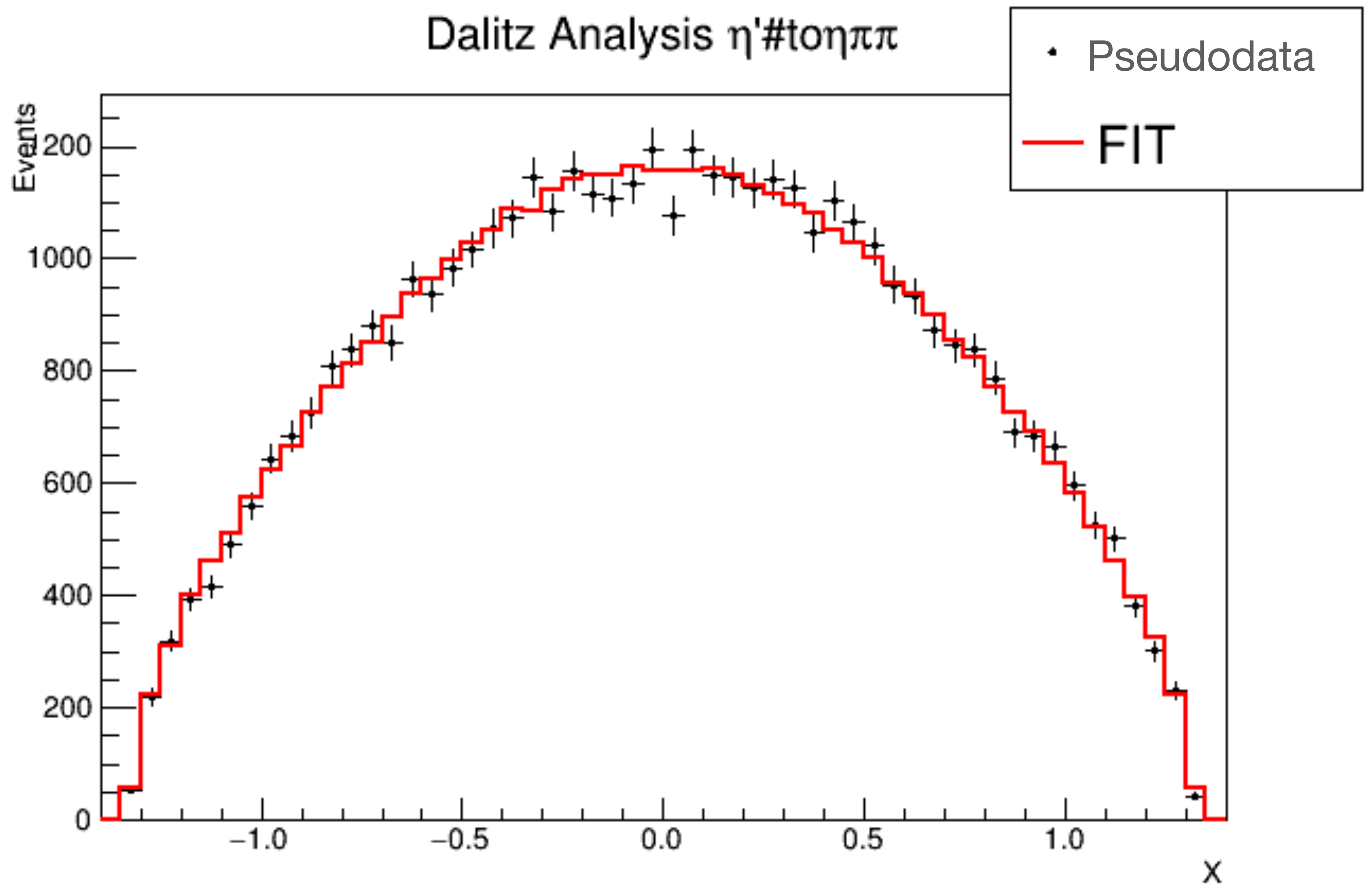
Real Acceptance:

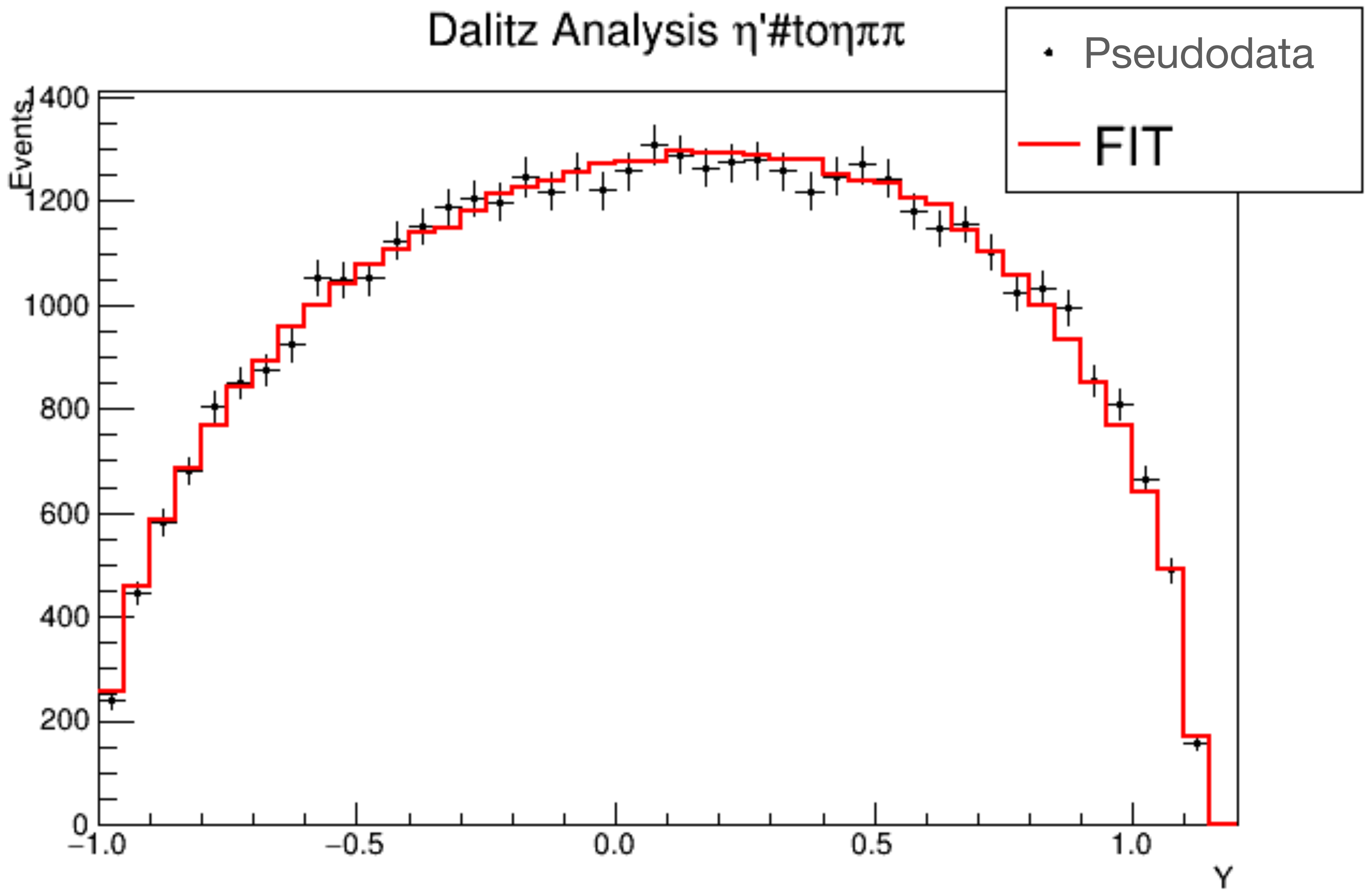


~Average acceptance is 5%

Real acceptance







- pseudodata generated with BESIII (2018) results
- Real acceptance: Laget model for the production.
- 100M generated MC events

Fit comparison

Minuit uncertainties

	BESIII (2018)	my Fit
a	$-5.60 \times 10^{-2} \pm 4.0 \times 10^{-3}$	$-5.31 \times 10^{-2} \pm 4.5 \times 10^{-3}$
b	$-4.9 \times 10^{-2} \pm 6.0 \times 10^{-3}$	$-4.53 \times 10^{-2} \pm 8.4 \times 10^{-3}$
c	$2.7 \times 10^{-3} \pm 2.4 \times 10^{-3}$	$8.41 \times 10^{-4} \pm 2.3 \times 10^{-3}$
d	$-6.3 \times 10^{-2} \pm 4.0 \times 10^{-3}$	$-5.84 \times 10^{-2} \pm 8.8 \times 10^{-3}$

Previous experiments

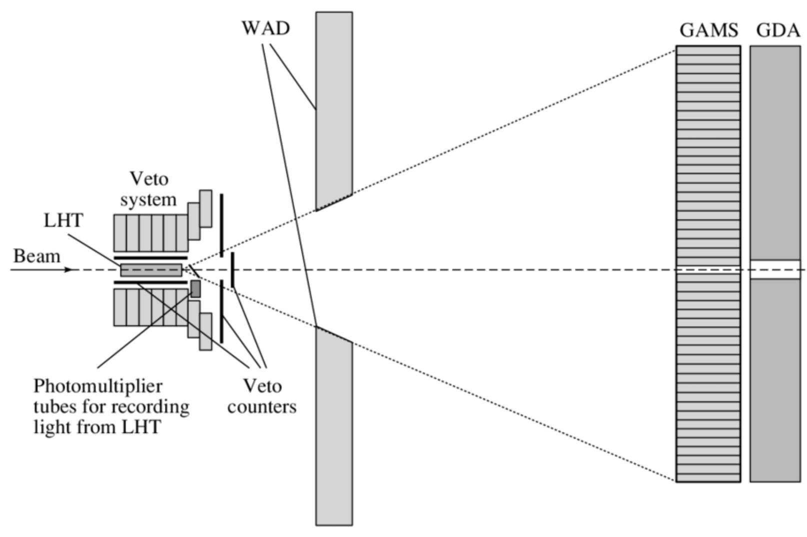
GAMS 2000
U70
Charge exchange:
$\pi^- p \to \eta' n$ $\quad 0.54 \times 10^4$

VES

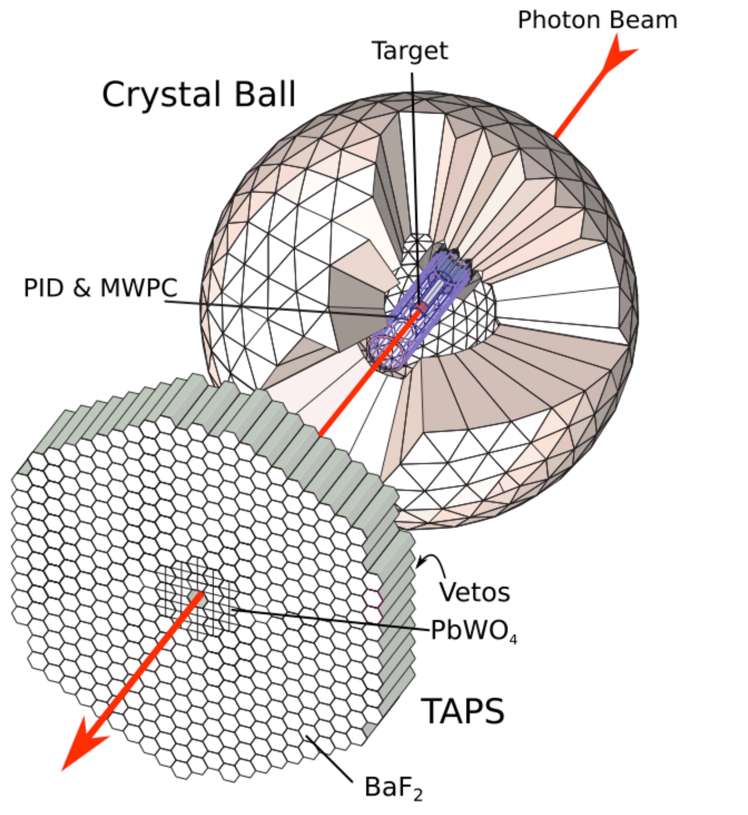
Charge exchange:
$\pi^- p \to \eta' n$ $\quad 1.4 \times 10^4$
Diffractive:
$\pi^- N \to \eta' \pi^- N$ $\quad 0.7 \times 10^4$
Phys. Lett. B **651**, 22(2007)

$$\eta' \to \eta \pi^0 \pi^0$$

GAMS 4π
U70
Charge exchange:
$\pi^- p \to \eta' n$ $\quad 1.5 \times 10^4$
Phys. At. Nucl. **72**, 231 (2009)

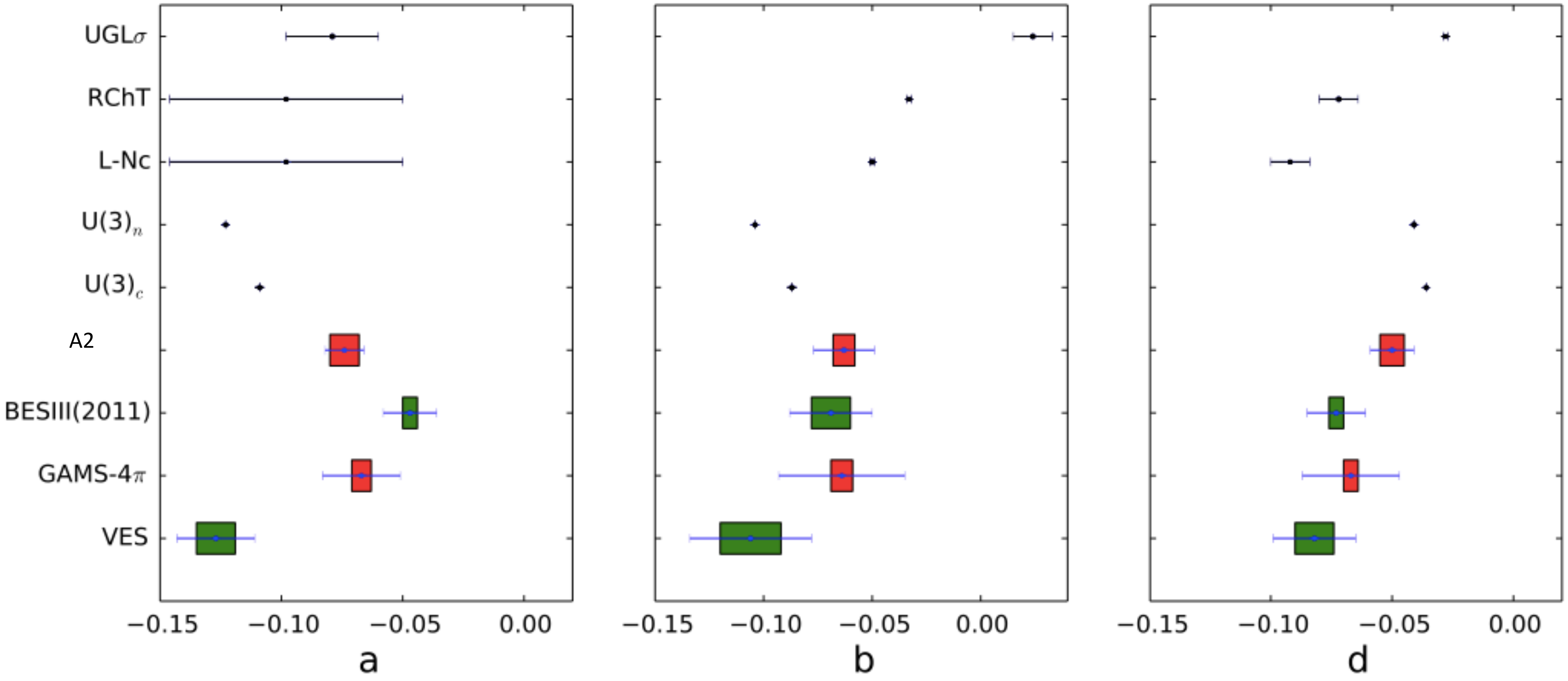


A2 Collaboration
MAMI
Photoproduced:
$\gamma p \to p \eta'$ $\quad 12.3 \times 10^4$
PRD**98**, 012001(2018)



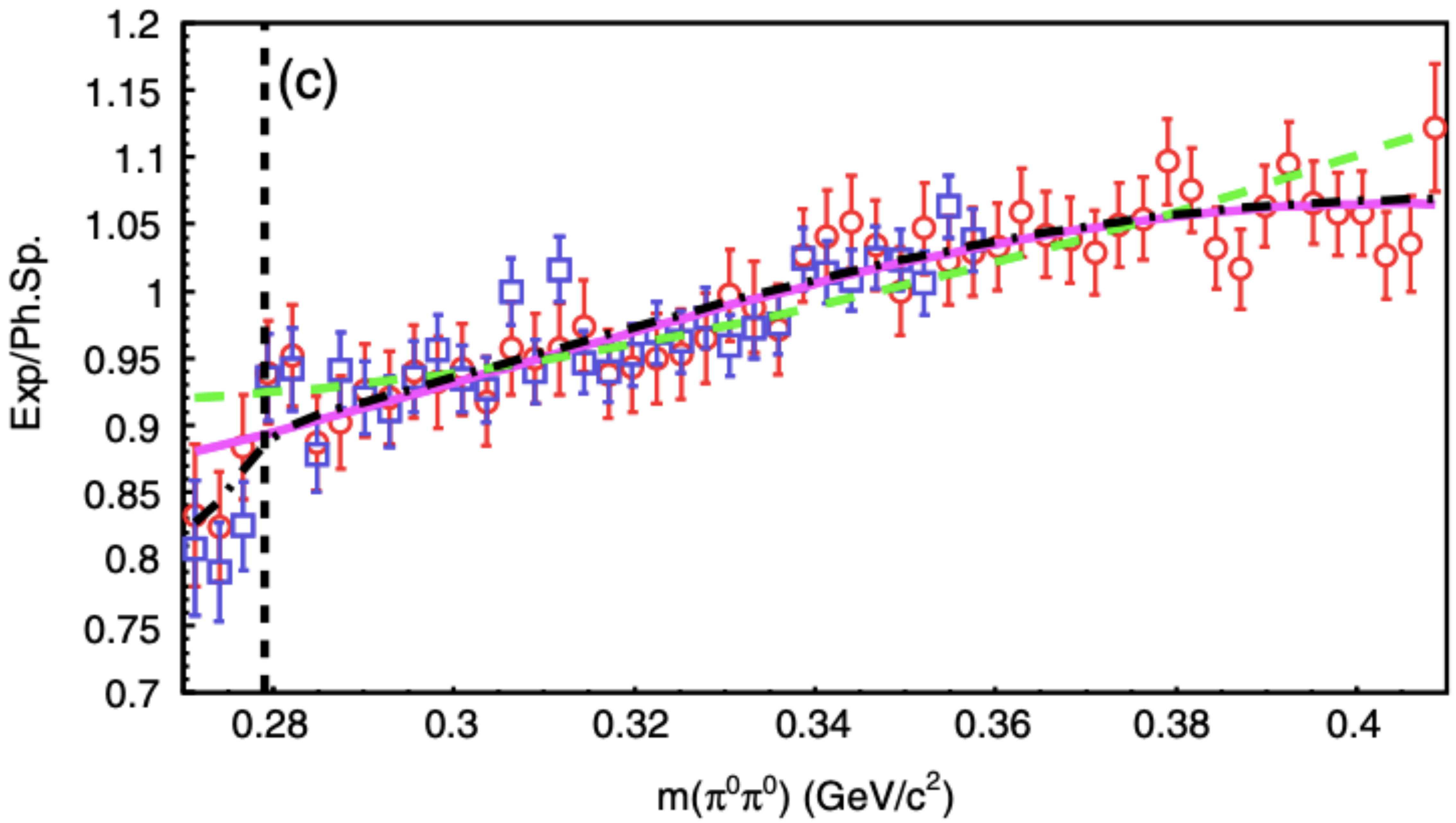
BESIII
BEPC II
$J/\psi \to \gamma \eta'$ $\quad 5.63 \times 10^4$
Background level < 1%
PRD**97**, 012001 (2018)

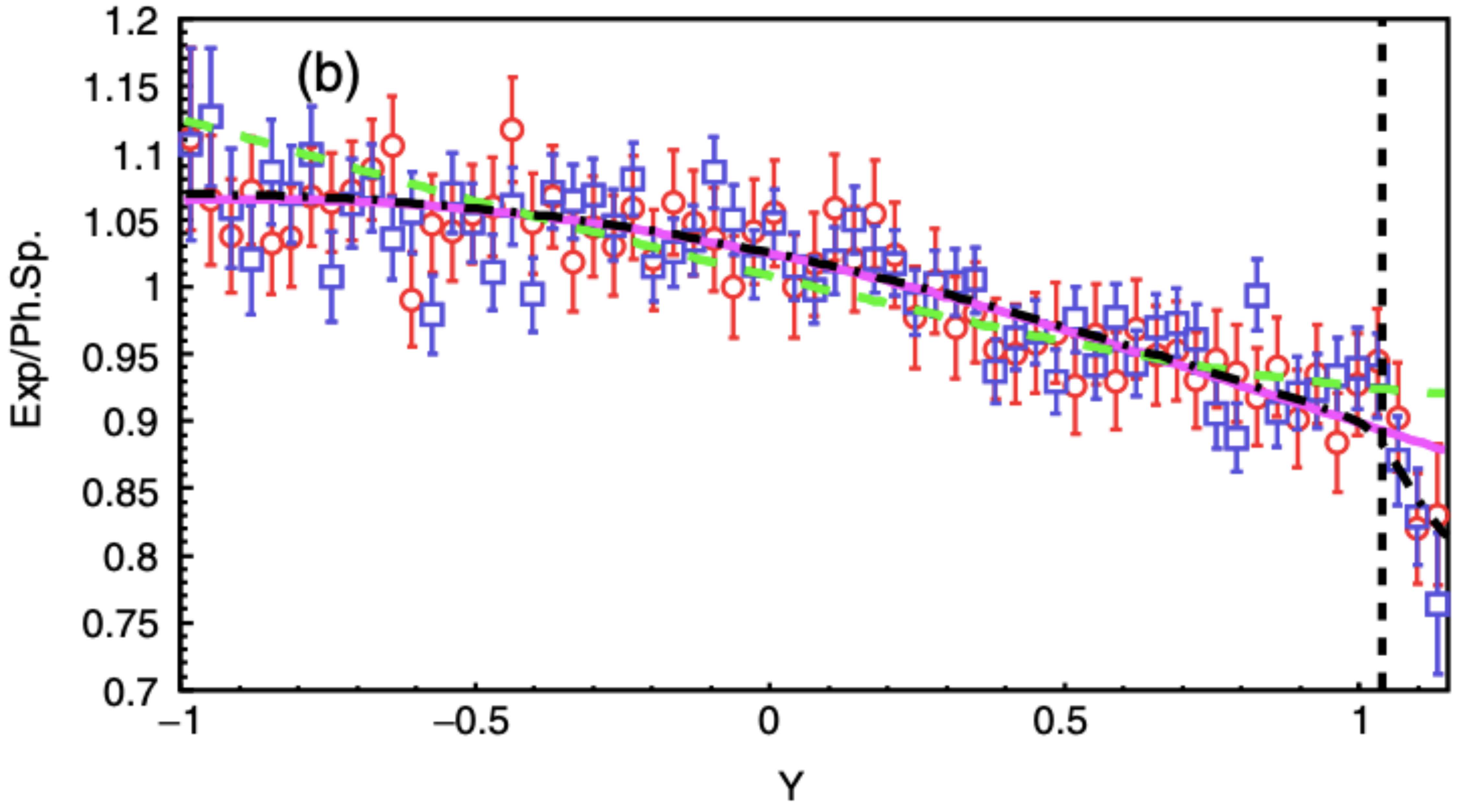
Dalitz Parameters from theory and previous measurements



From PRD98, 012001(2018)

Cusp results from A2 collaboration





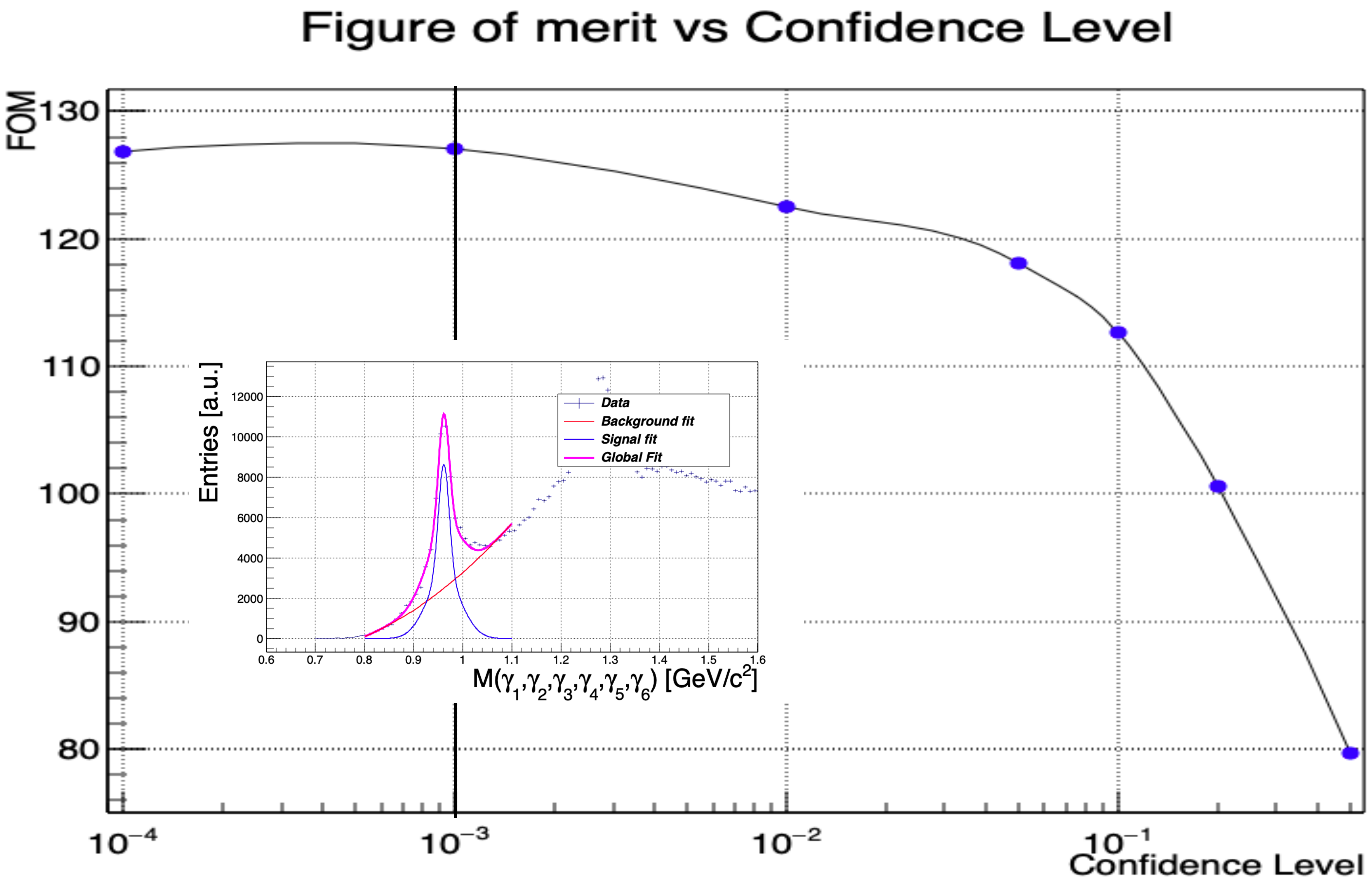
[From PRD98, 012001(2018)]

Results shown in the A2 paper. Ratio of the experimental distribution to their normalized MC Phase space. The data points represent two independent analyses presented in the paper. The vertical lines show the position of the mass of two charged pions. Green and magenta lines represent the results fit with two different parametrizations and **black** fit result with NREFT amplitude.

Optimizing $\eta' \to \eta\pi^0\pi^0$ selection at GlueX

$$FOM = \frac{S}{\sqrt{S+B}}$$

- Exclusively reconstruct $\gamma p \to \eta' p$, with $\eta' \to \eta\pi^0\pi^0 \to 6\gamma$
- Kinematically fit 4-momentum conservation utilizing tagged photon beam energy with no mass constrains on intermediate particles $(\eta,\ \pi^0)$
- Background estimated through fits to invariant mass distribution $M(6\gamma)$



Yield comparison

Experiment	Yield $(\times 10^4)$
GAMS200	0.54
GAMS	1.5
VES	2.1
BESIII(2018)	5.63
A2	12.3
GlueX-I (Our estimate)	~10*
GlueX-II	$3 \times$ GlueX-I

$$\gamma p \to p\eta'$$
$$\eta' \to \eta\pi^0\pi^0$$
$$\eta \to \gamma\gamma$$

Conclusion

- We have done a feasibility study for the Dalitz plot analysis of the charged decay $\eta' \rightarrow \eta\pi^+\pi^-$.
- We have done a yield estimation for the neutral decay of $\eta' \rightarrow \eta\pi^0\pi^0$.
- Our estimate of the yield from all GlueX- I indicates a competitive dataset with previous experiments.
- Different production processes make different systematics, this makes interesting the comparison of GlueX low energy photoproduction to the J/ψ decay at BESIII.
- Working on rejecting backgrounds.

This work is funded in part by DOE grant DE-SC0016583.
GlueX acknowledges the support of several funding agencies and computing facilities:
http://gluex.org/thanks

Backup

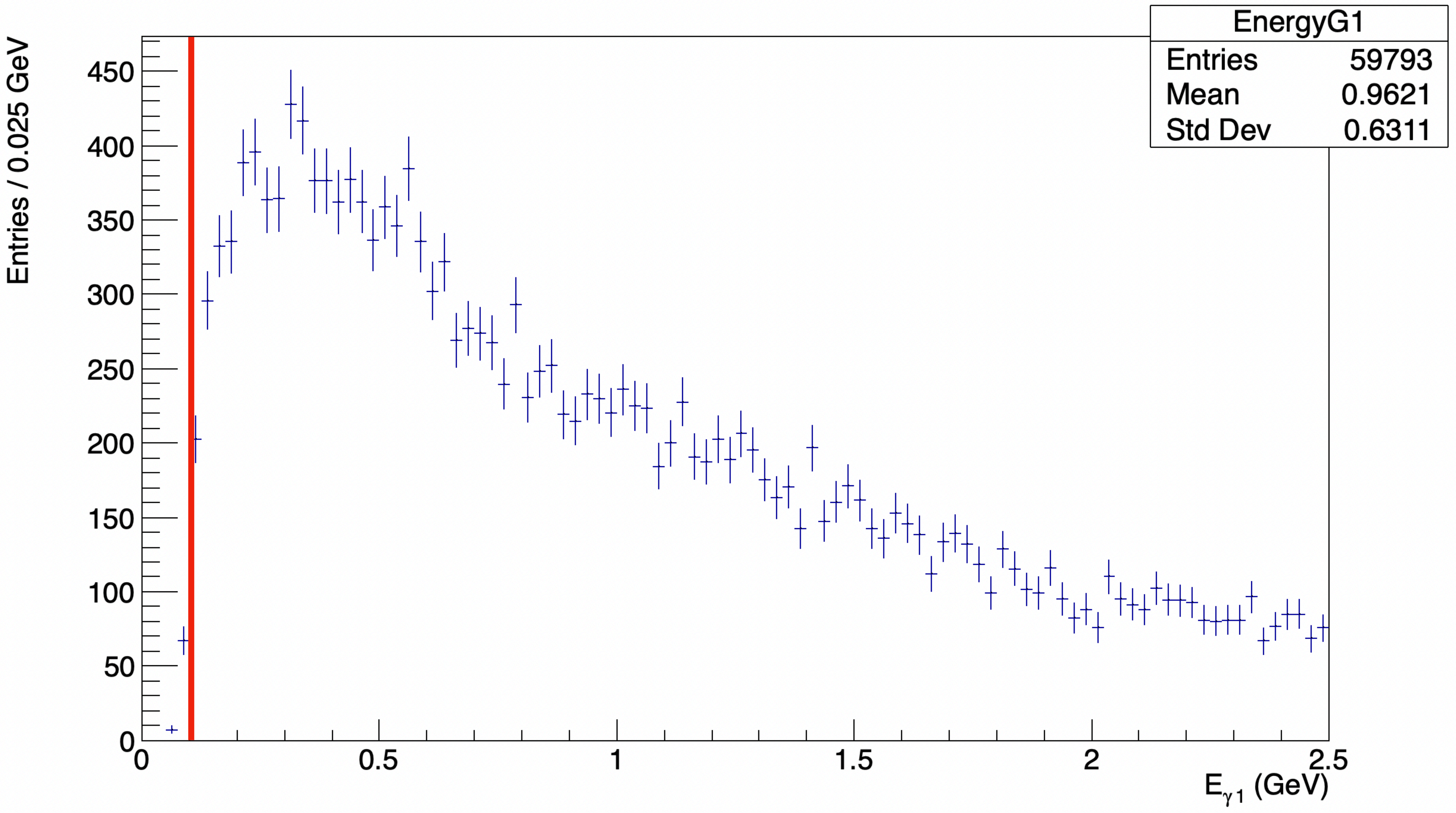
Selection

$$\gamma p \to p\eta'$$
$$\eta' \to \eta\pi^+\pi^-$$
$$\eta \to \gamma\gamma$$

cuts	value
Photon energy	$E_\gamma > 0.1$GeV
BCAL/FCAL fiducial cut	$\theta_\gamma \leq 10.3^\circ, \theta\gamma \geq 11.9^\circ$
Proton minimum momentum	$\lvert\vec{p}_\mathrm{p}\rvert > 0.3$GeV/$c$
proton, pion PID	standard CDC dE/dx cut
vertex	52cm $\leq Z \leq 78$cm
Kin fit Likelihood	$> 10^{-6}$
missing mass	$Abs(M_X) < 0.05$GeV/c^2

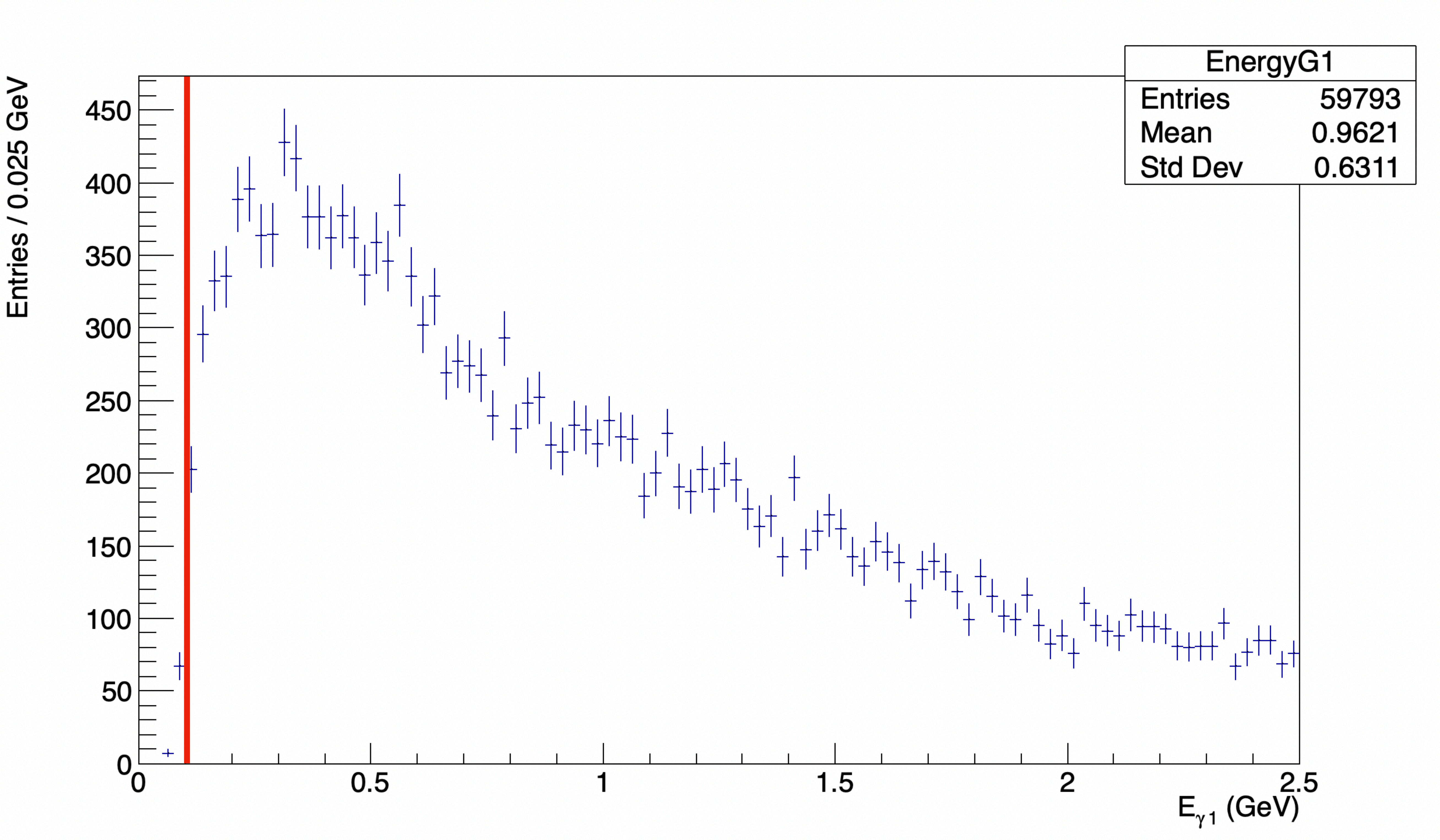
- 2017: ver 55
- m_η constrained
- pippimeta__B4

Event Selection



Event Selection

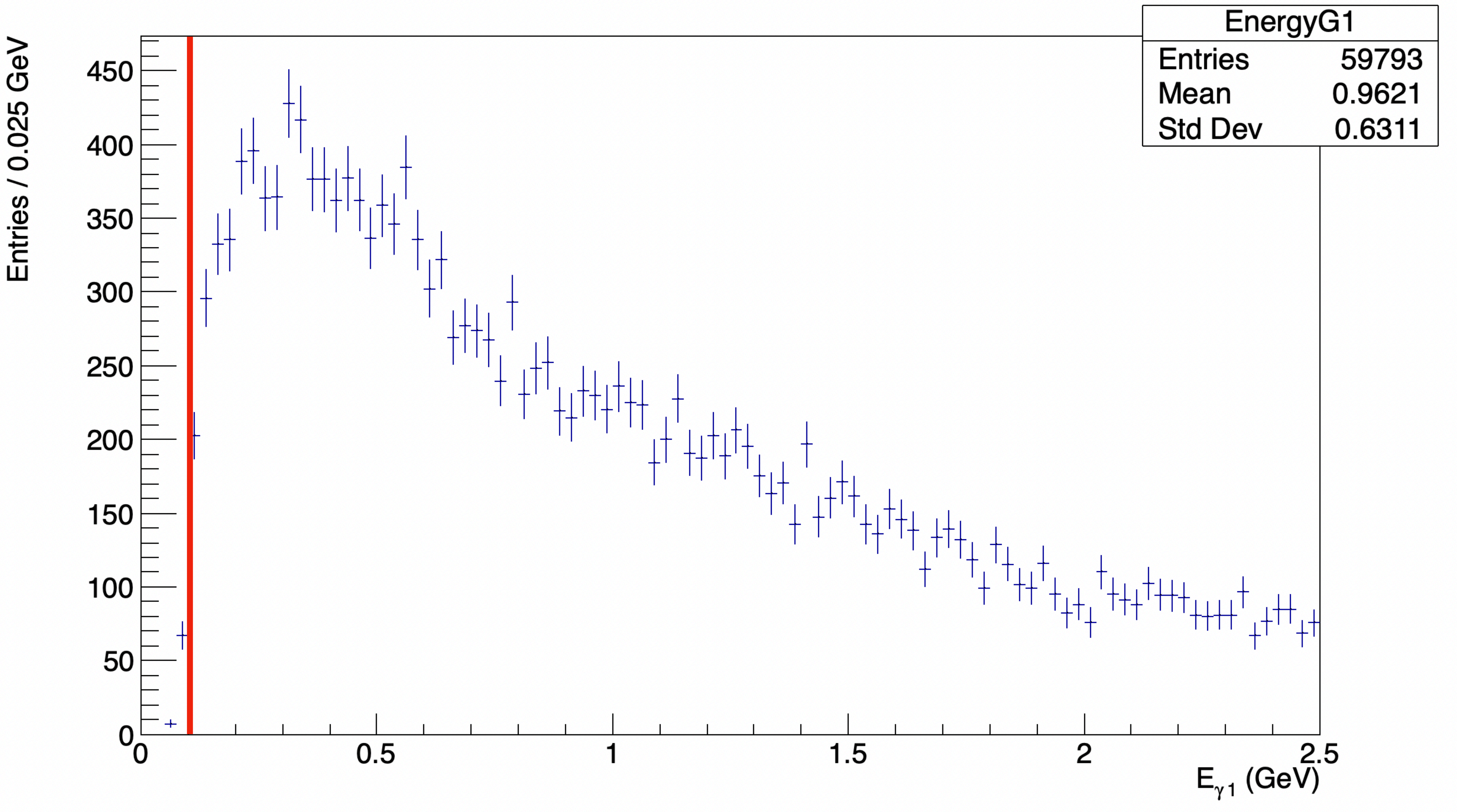
$$\gamma p \rightarrow p\eta'$$
$$\eta' \rightarrow \eta\pi^+\pi^-$$
$$\eta \rightarrow \gamma\gamma$$



Event Selection

Choosing good photons

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



Event Selection

Choosing good photons

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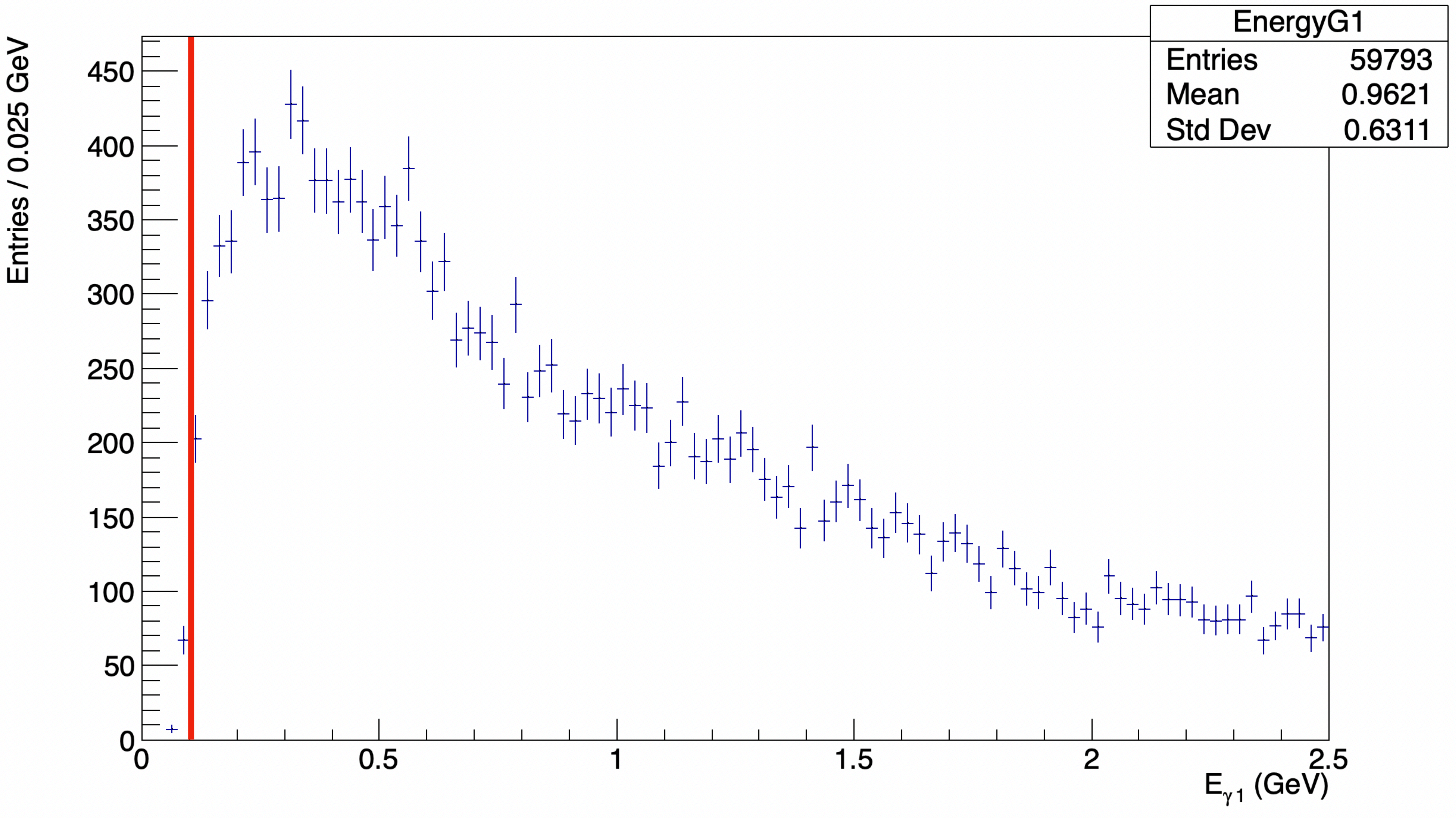
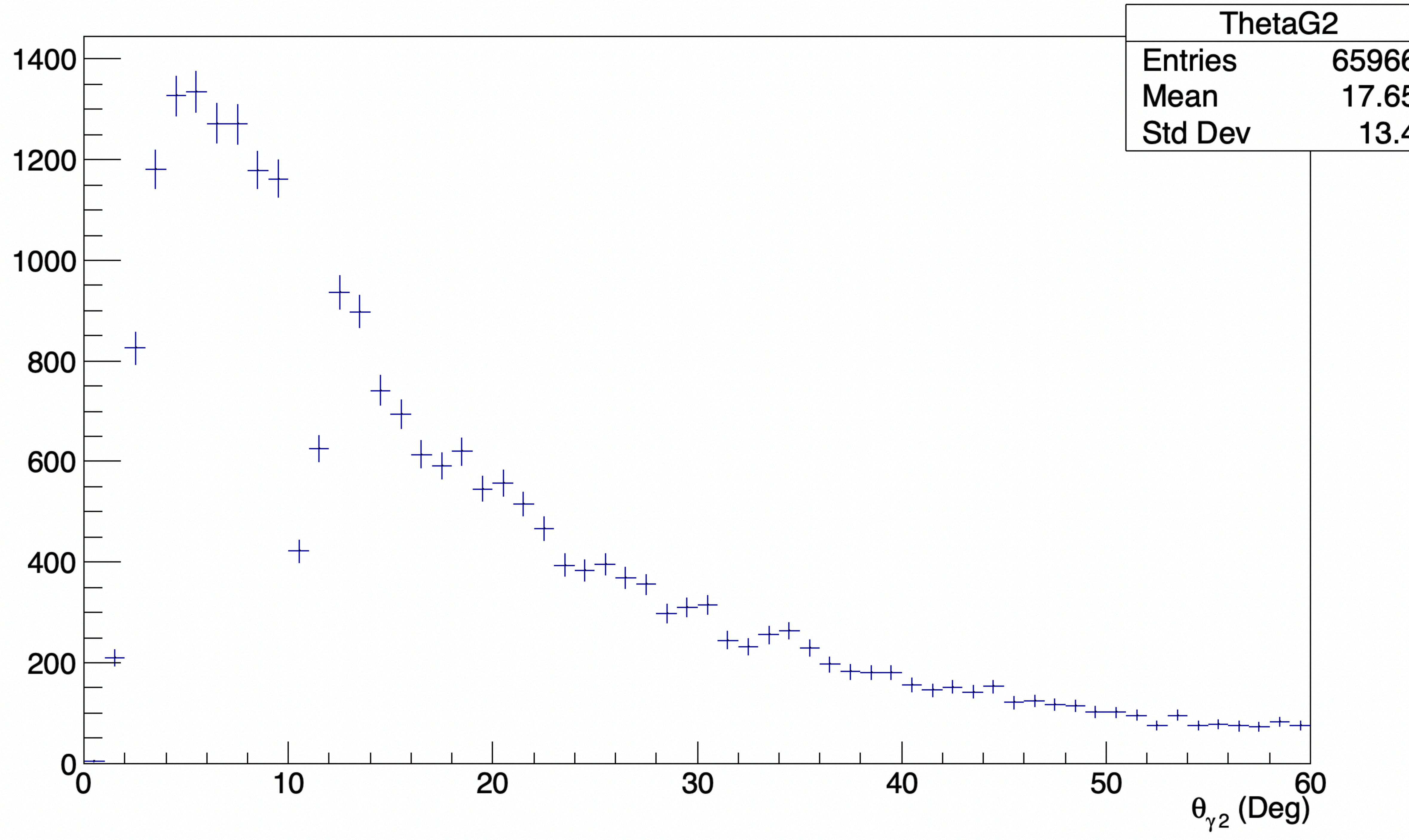




$$\gamma p \to p\eta'$$

Event Selection

$$\eta' \to \eta\pi^+\pi^-$$

Choosing good protons/ charged particles

$$\eta \to \gamma\gamma$$

$$\gamma p \rightarrow p\eta'$$

Event Selection

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

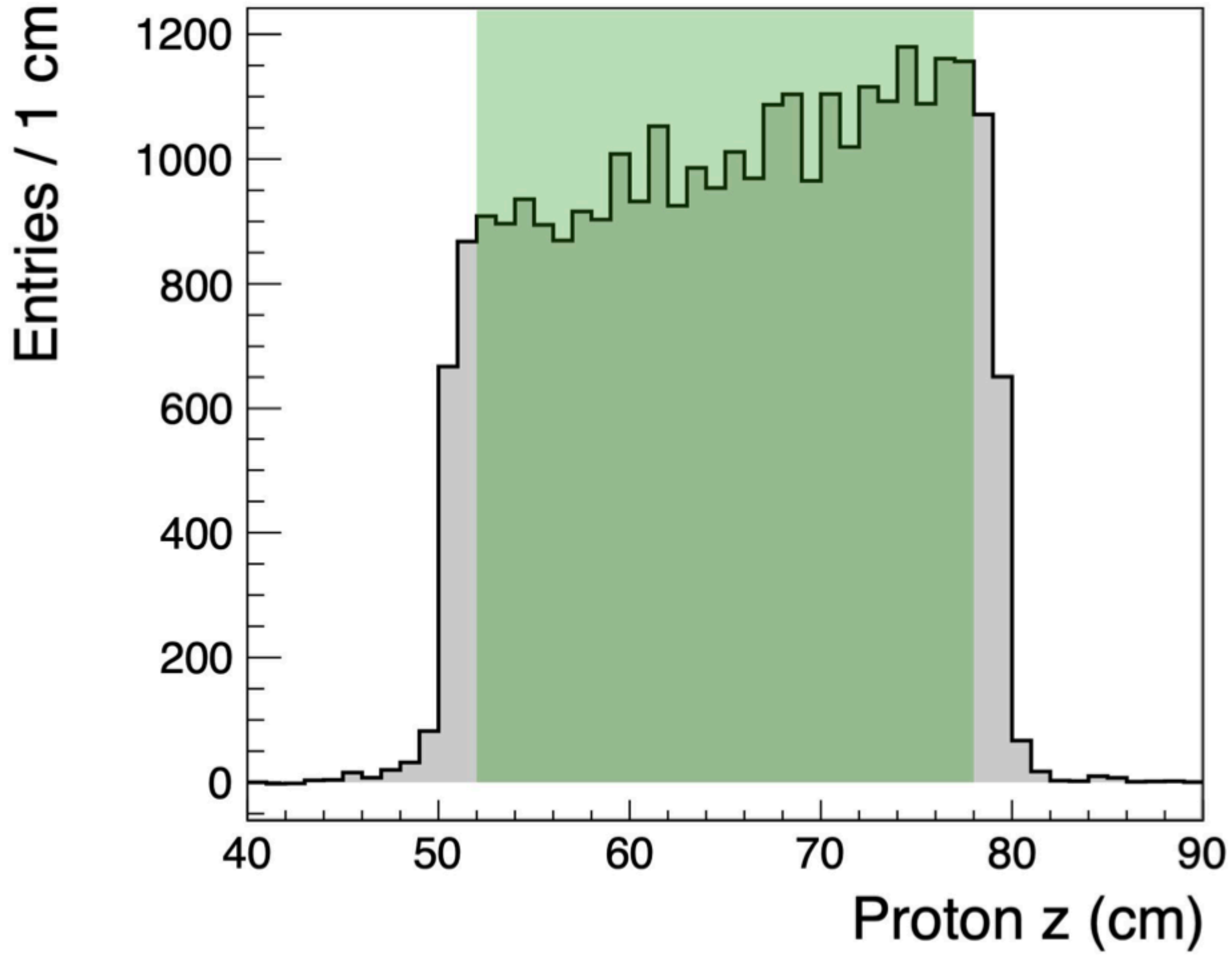
Choosing good protons/ charged particles

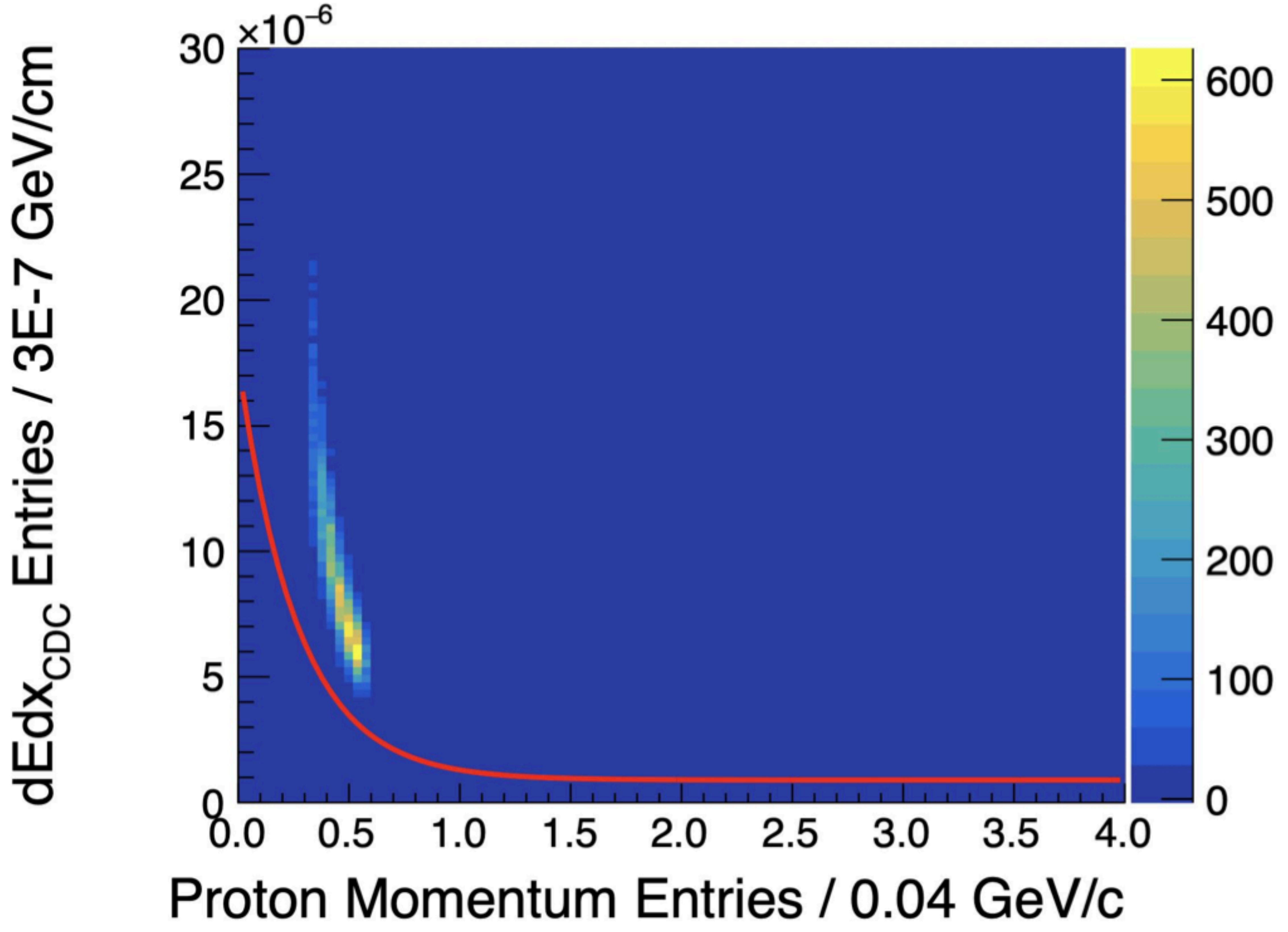
$$\eta \rightarrow \gamma\gamma$$

Event Selection

Choosing good protons/ charged particles

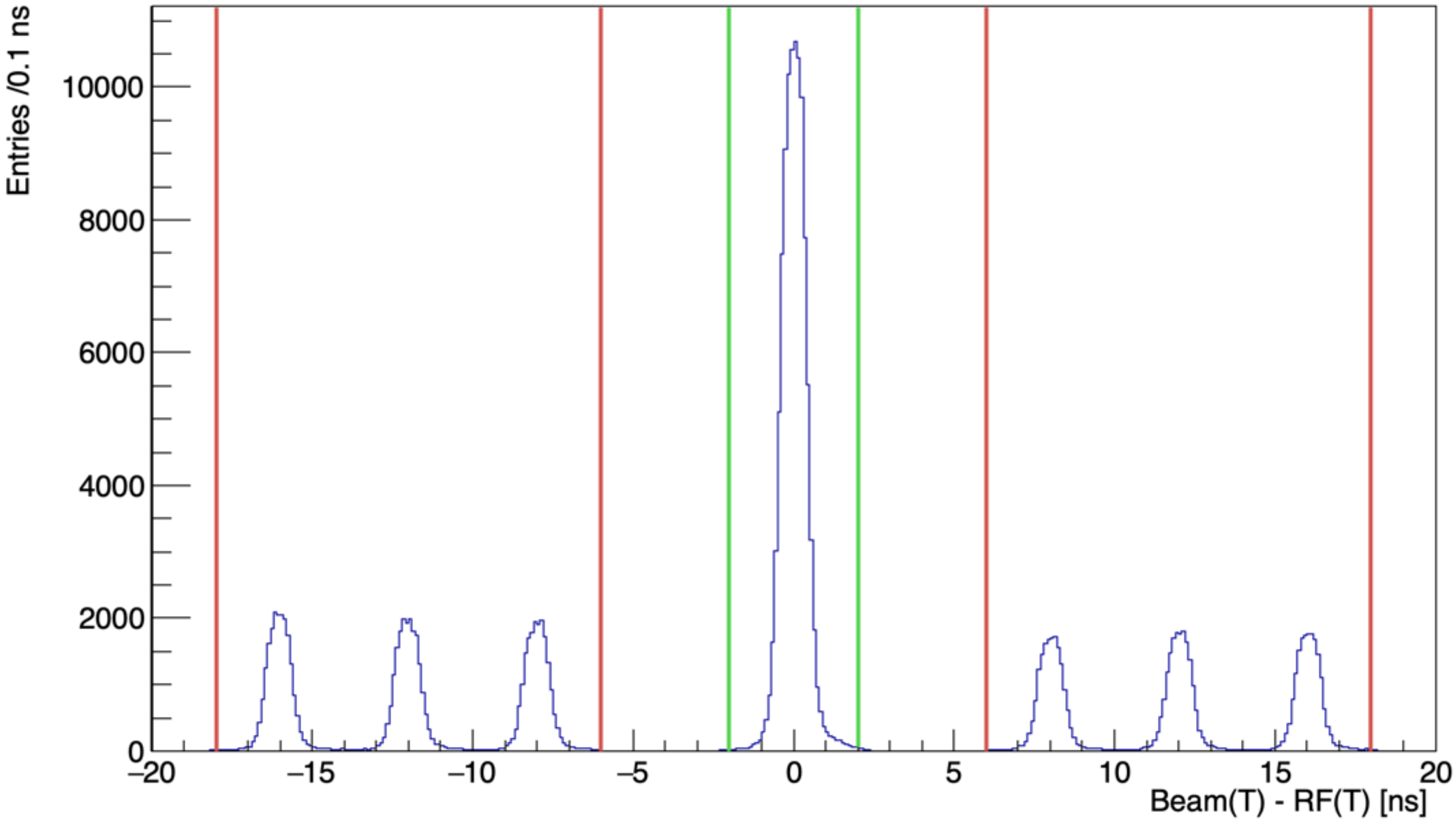
$$\gamma p \rightarrow p\eta'$$
$$\eta' \rightarrow \eta\pi^+\pi^-$$
$$\eta \rightarrow \gamma\gamma$$





Event Selection

Right incoming photon

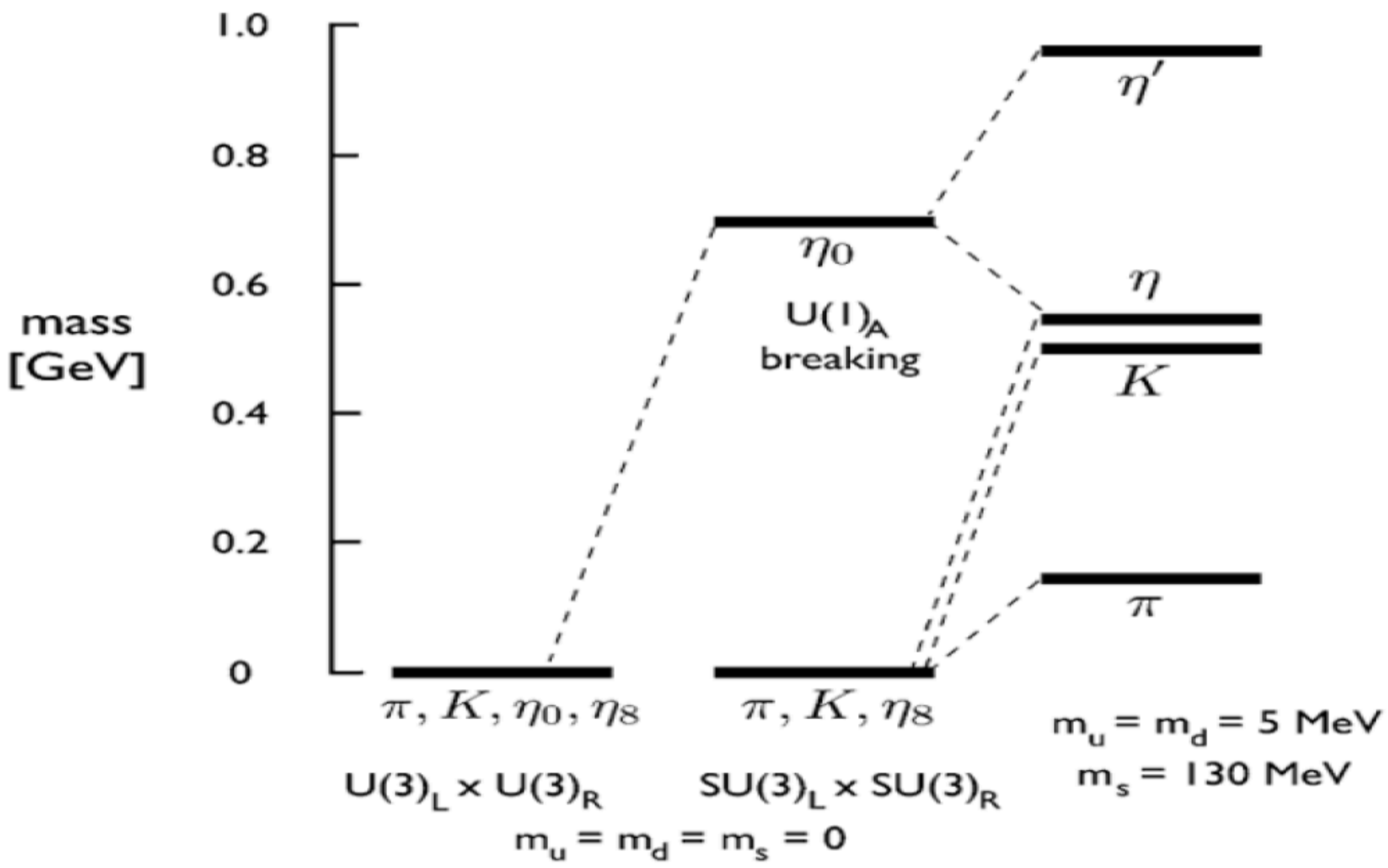


Theory

Chiral Perturbation Theory

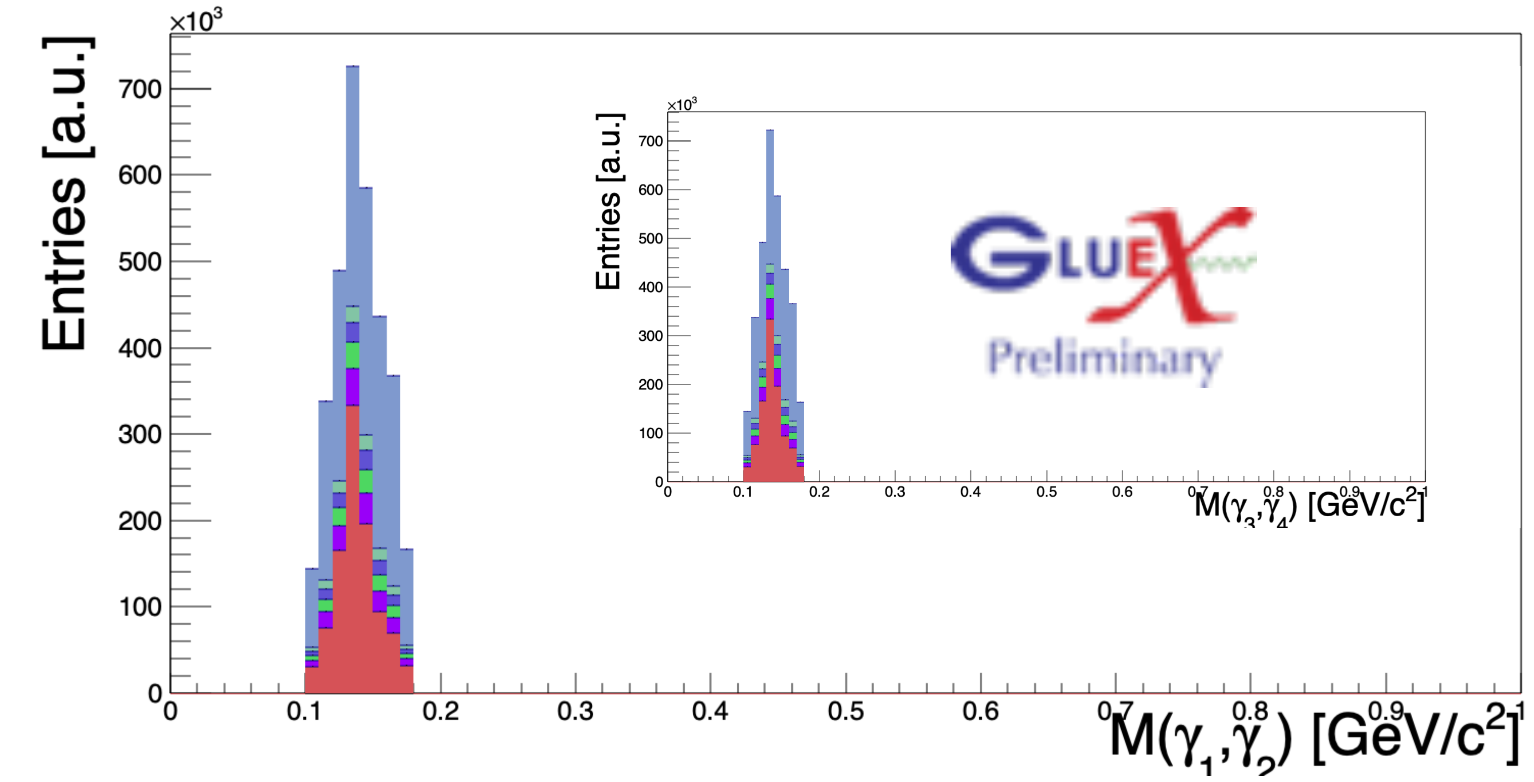
$$\mathcal{L}_{QCD}(q,\bar{q},g) \rightarrow \; Effective\ theory \; \rightarrow \mathcal{L}_{ChPT}(\pi,K,\eta)$$

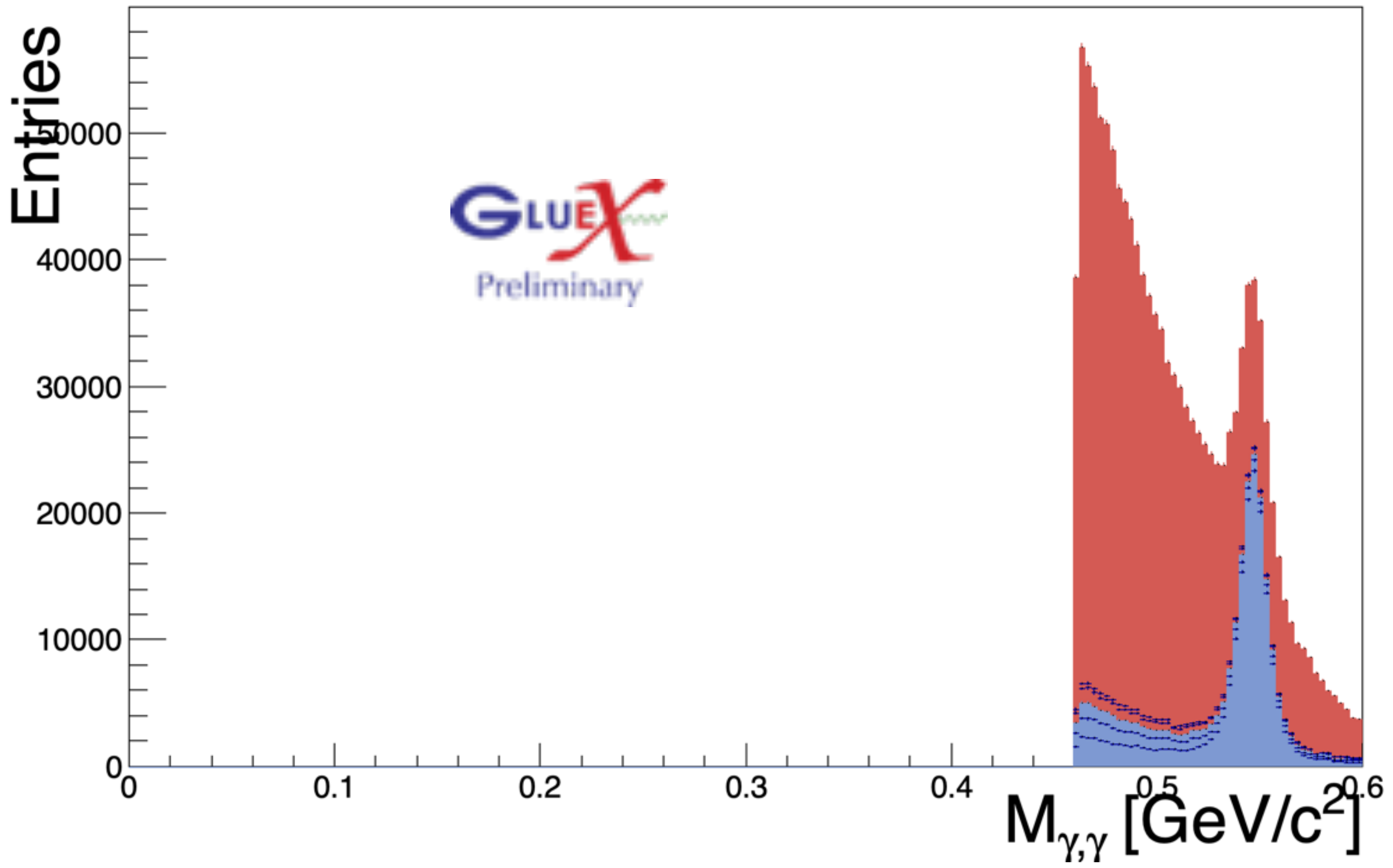
$$\mathcal{L}_{ChPT} = \mathcal{L}_2 + \mathcal{L}_4 + \mathcal{L}_6 + \ldots$$

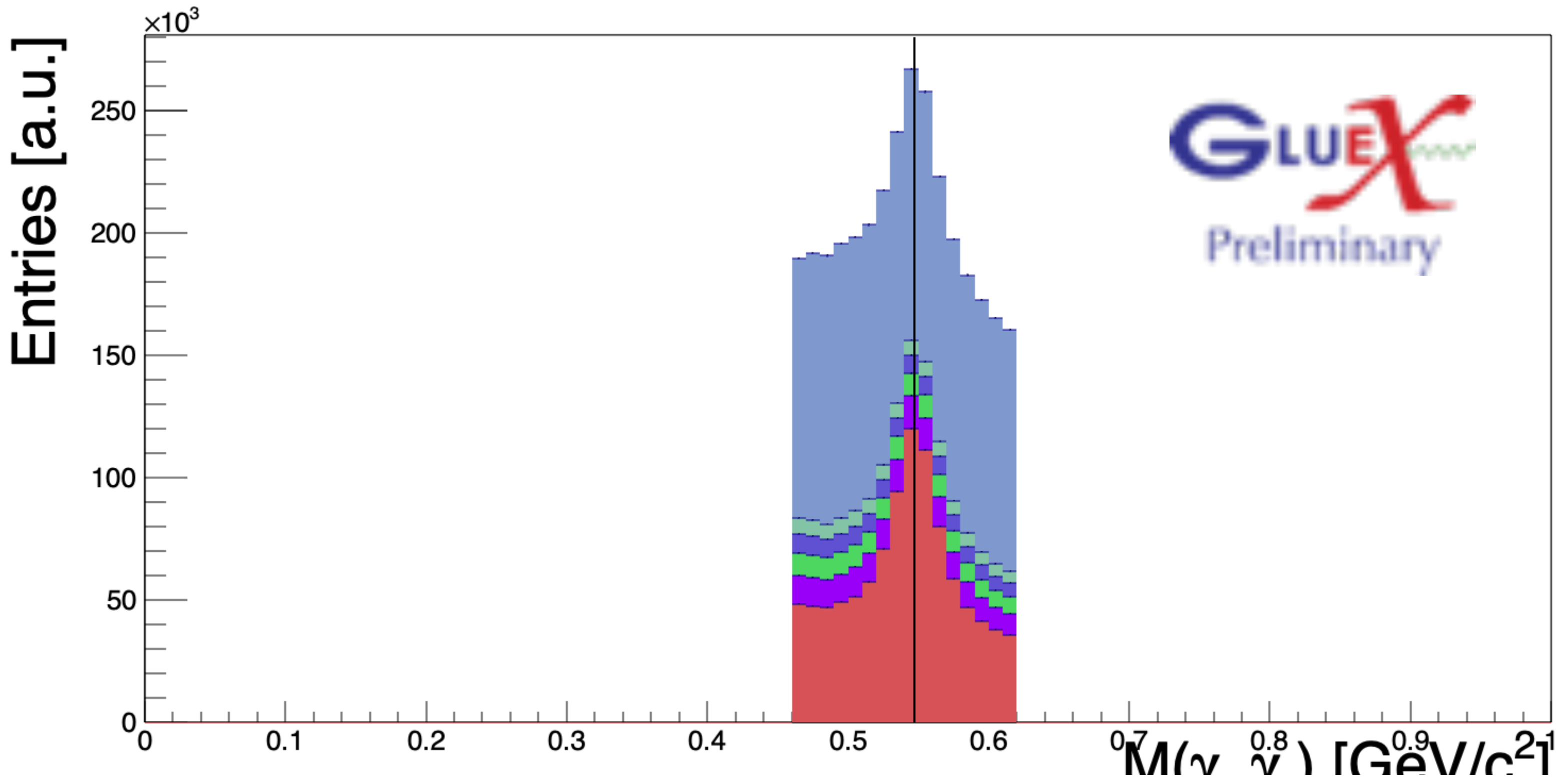


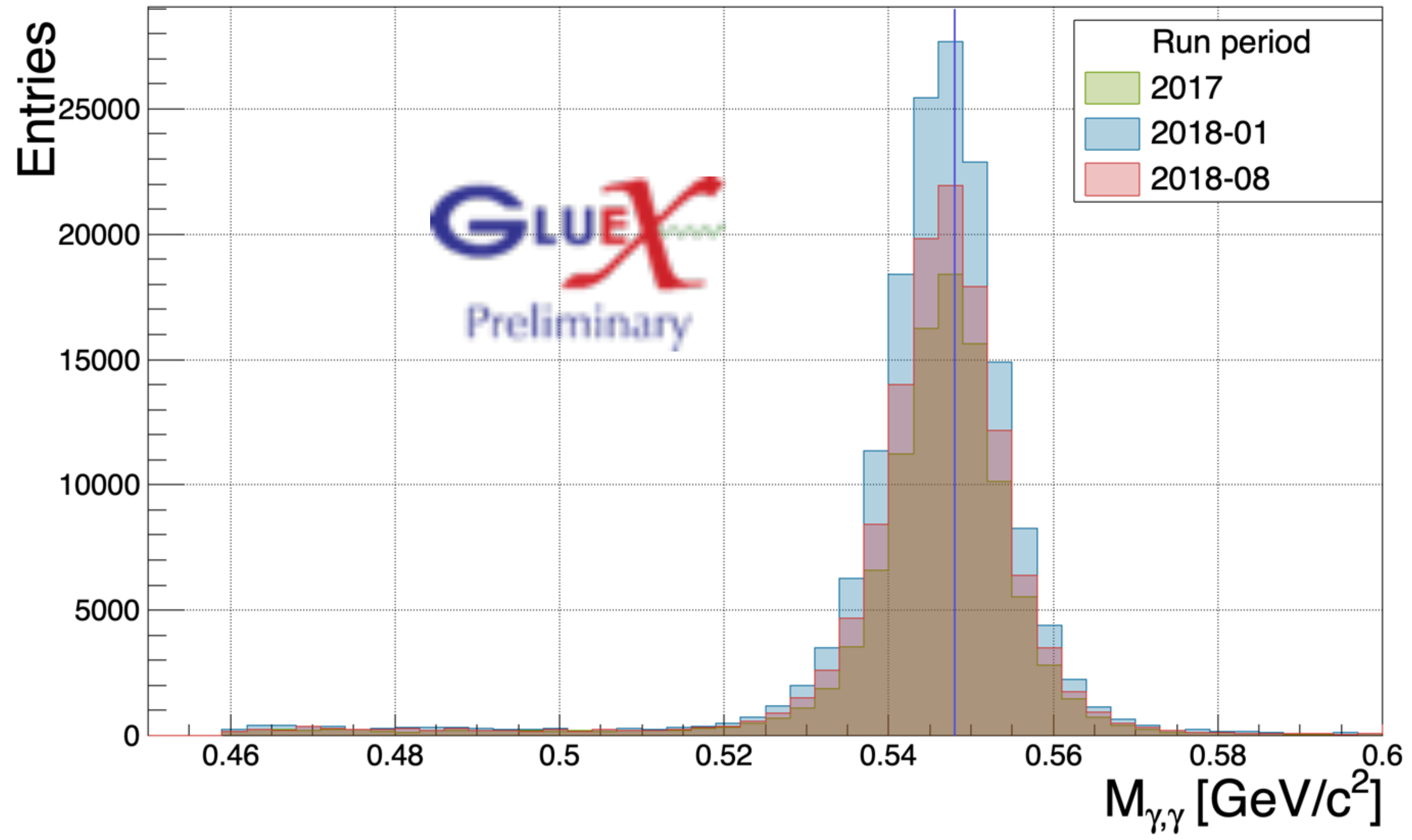
Invariant mass of intermediate particles

CHARGED DECAY: $\eta' \to \eta\pi^+\pi^-$

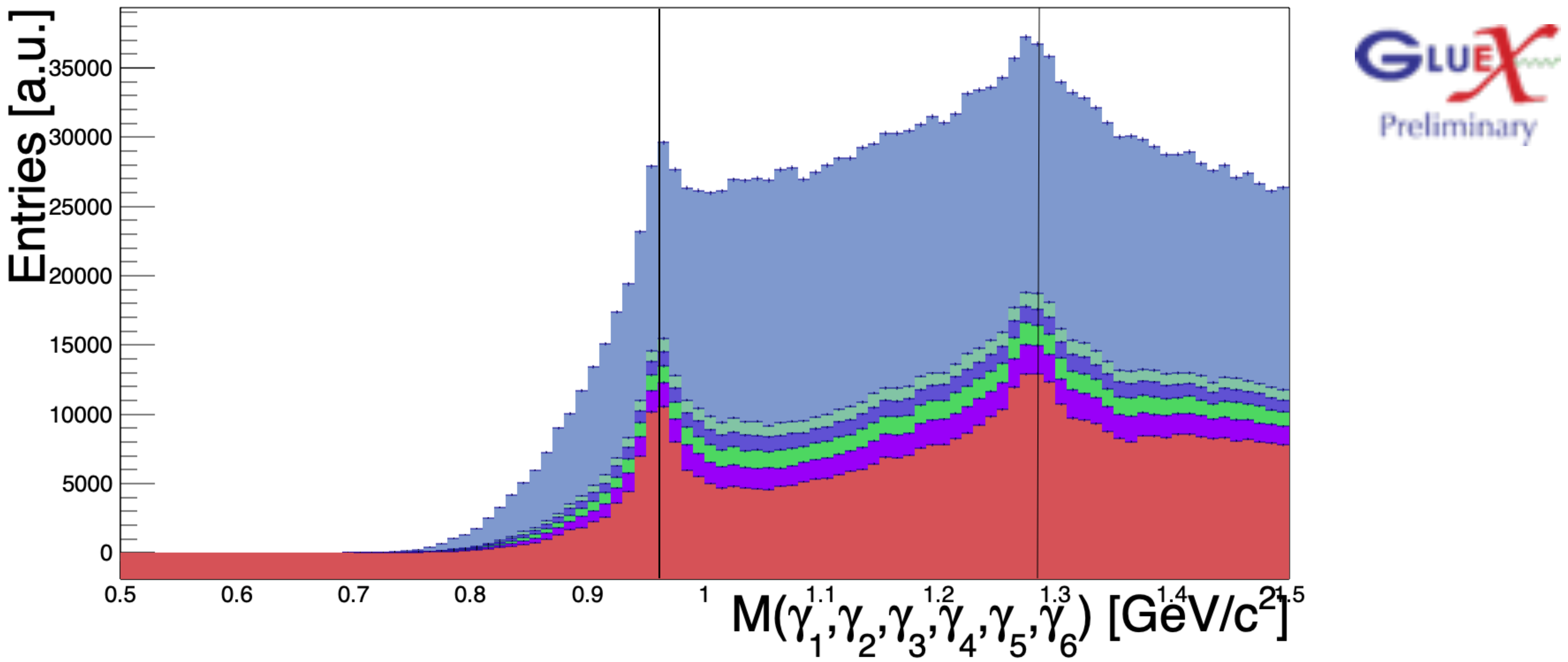




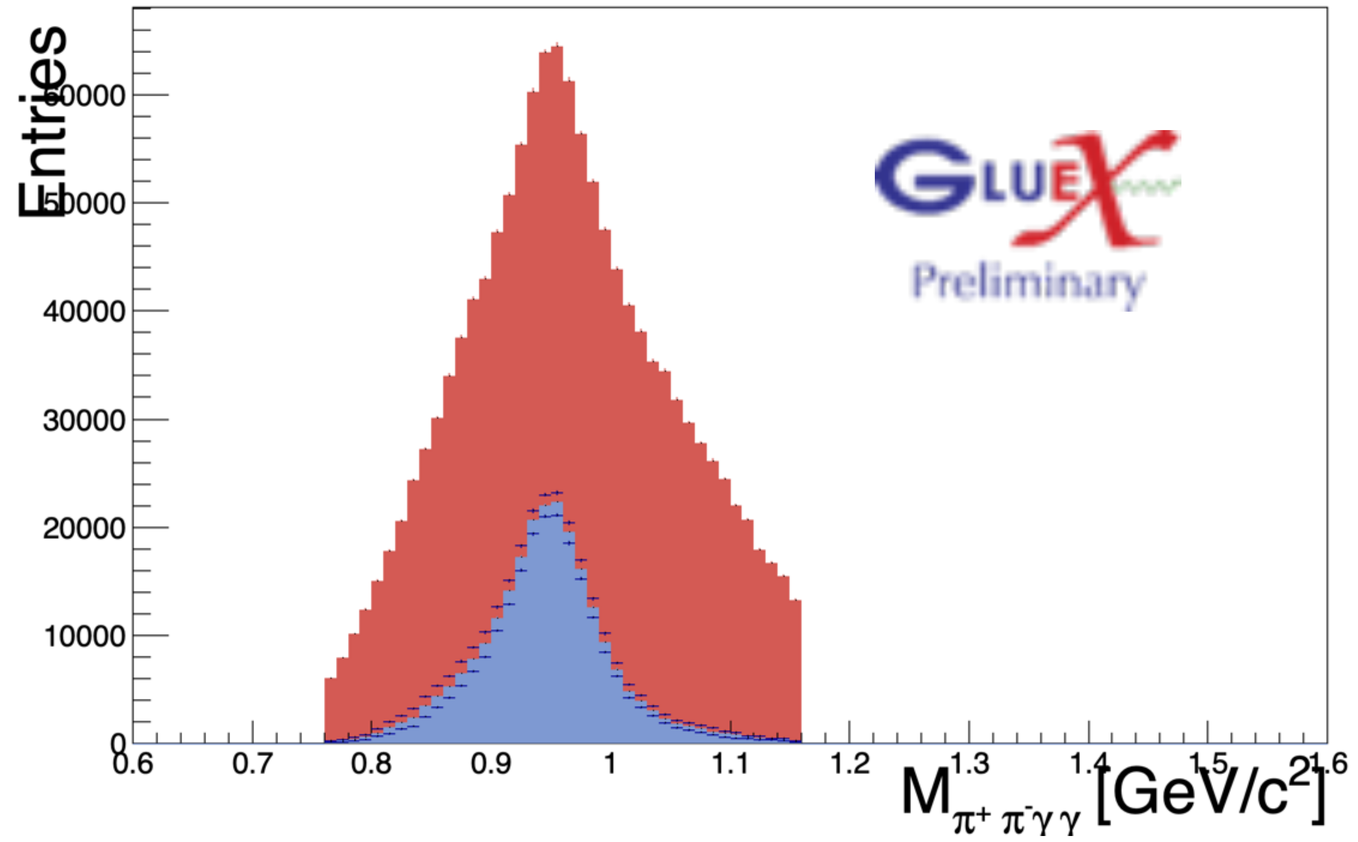


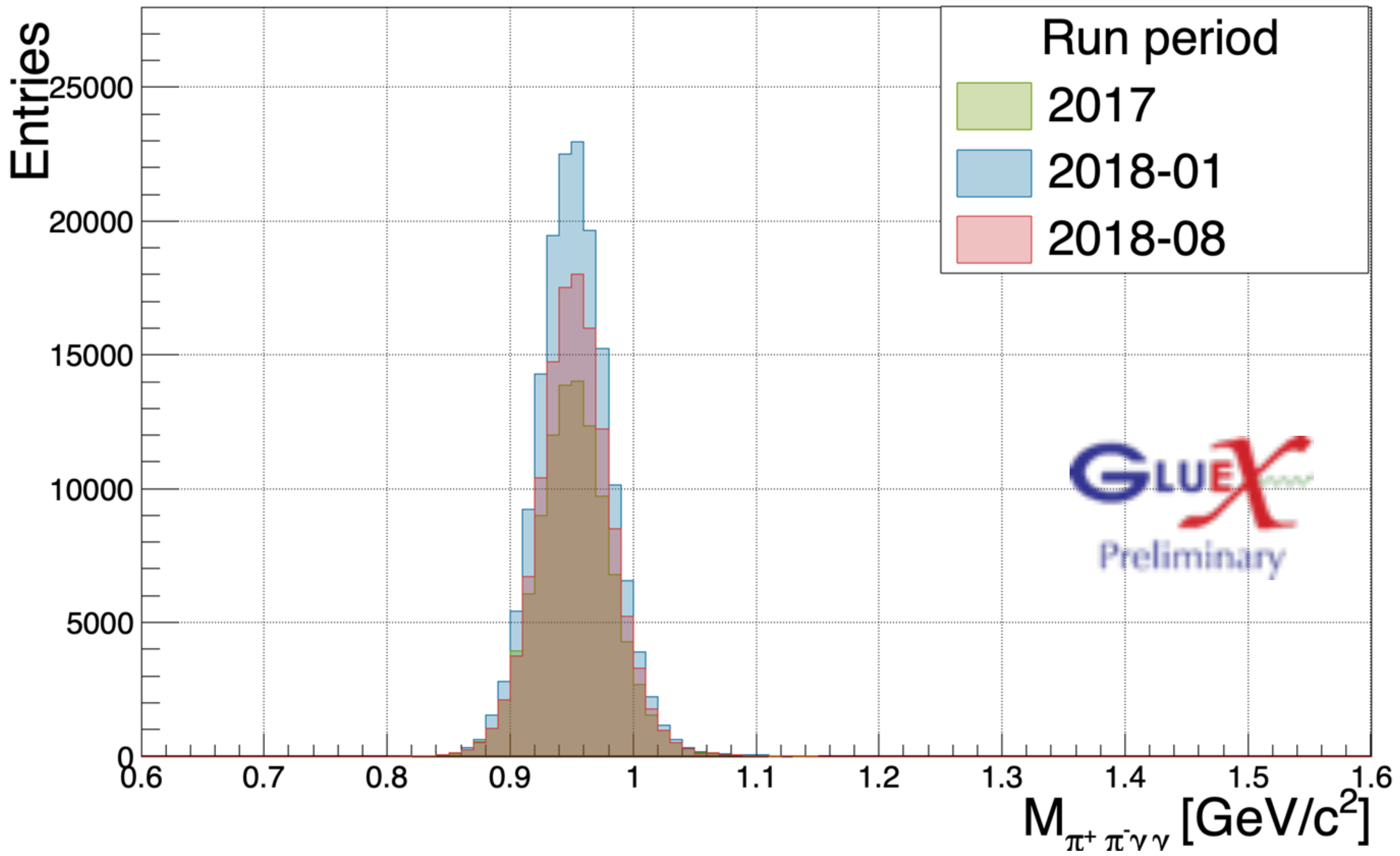


Invariant mass of η'

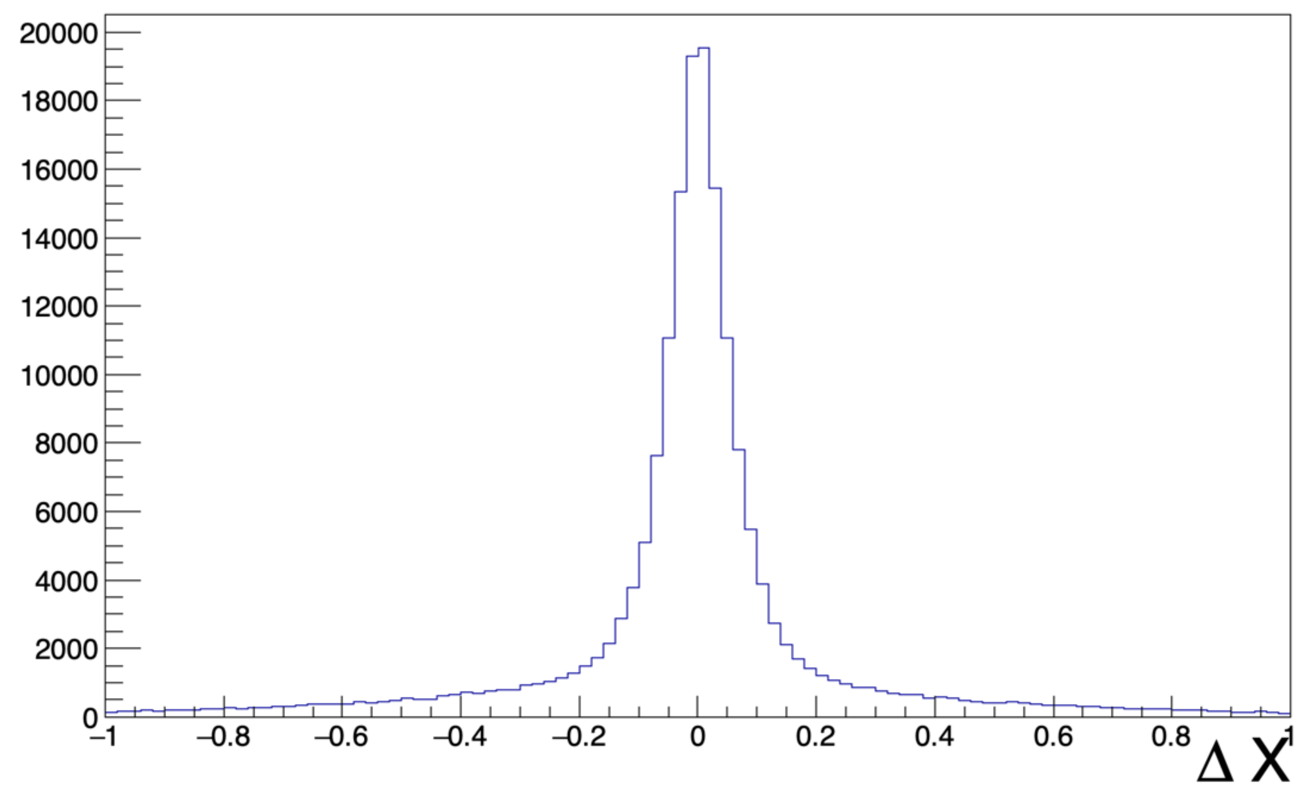


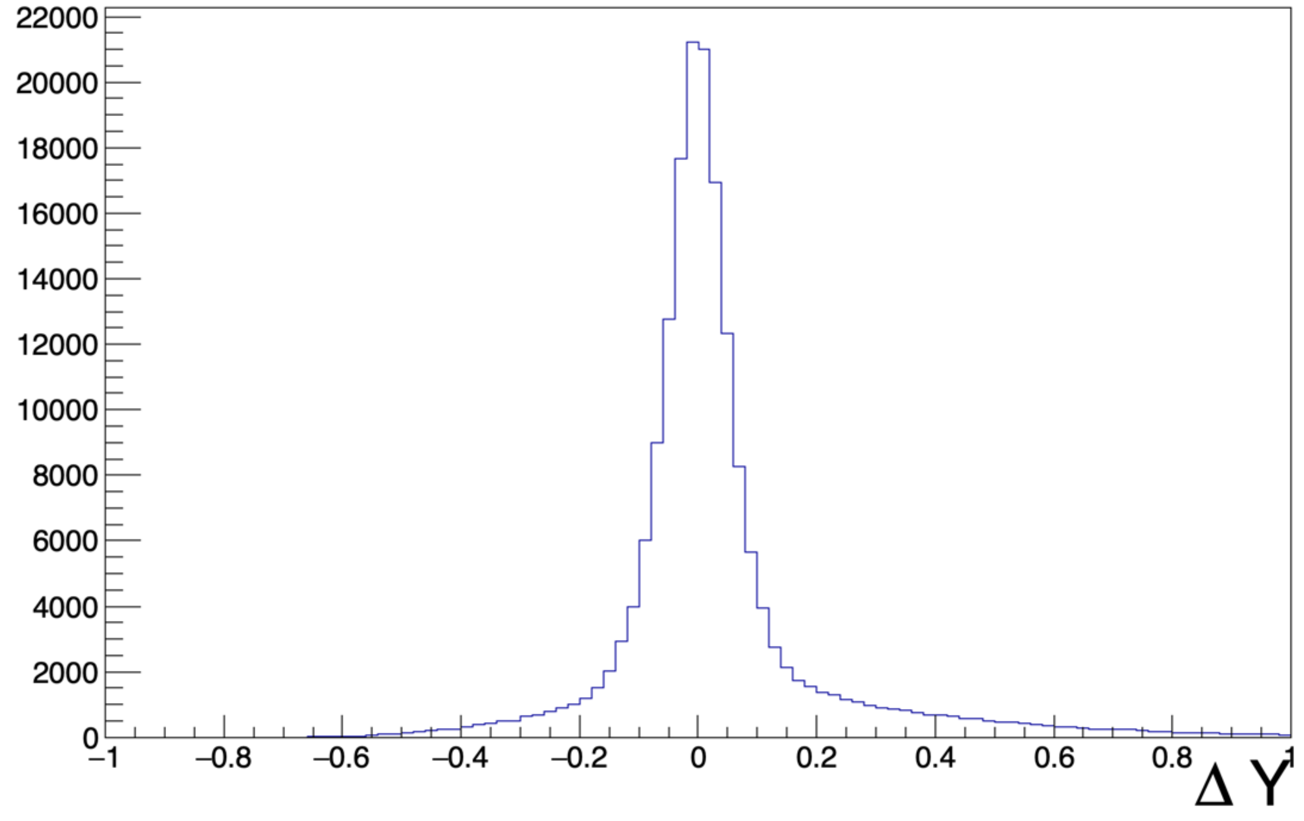
CHARGED DECAY: $\eta' \rightarrow \eta\pi^+\pi^-$



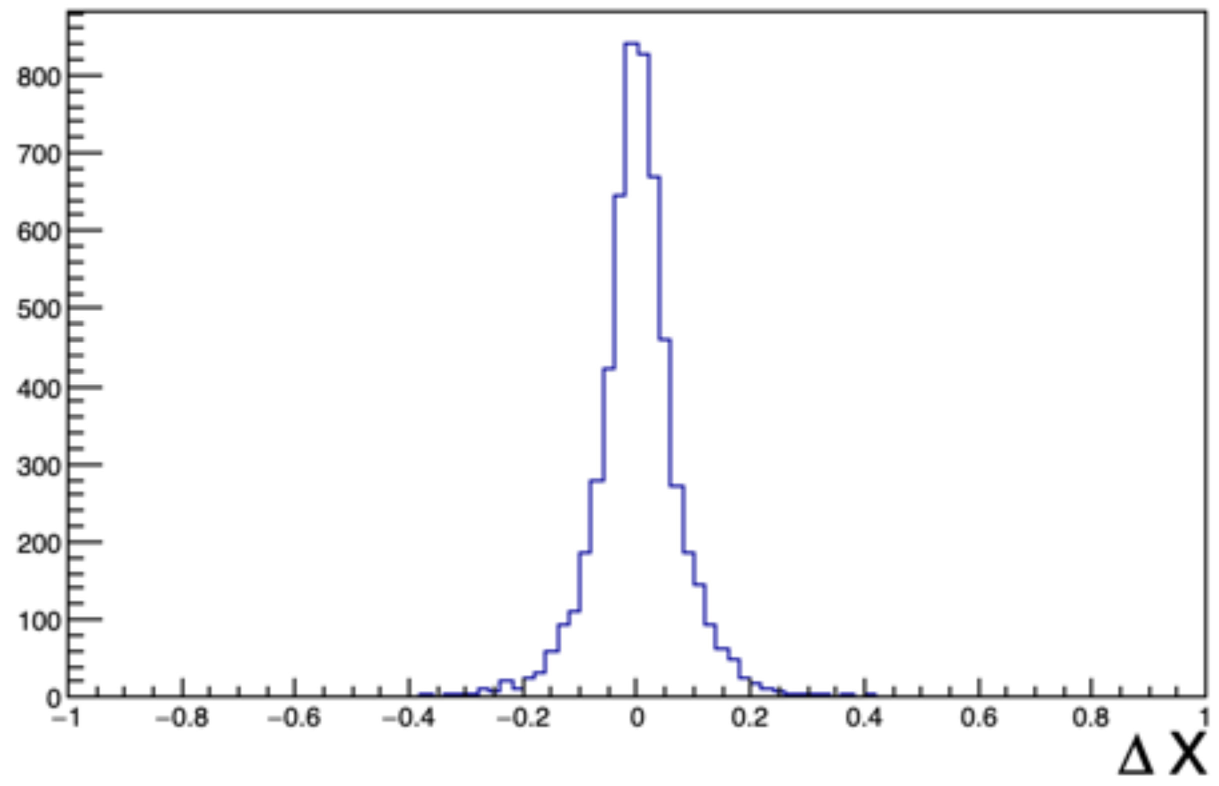


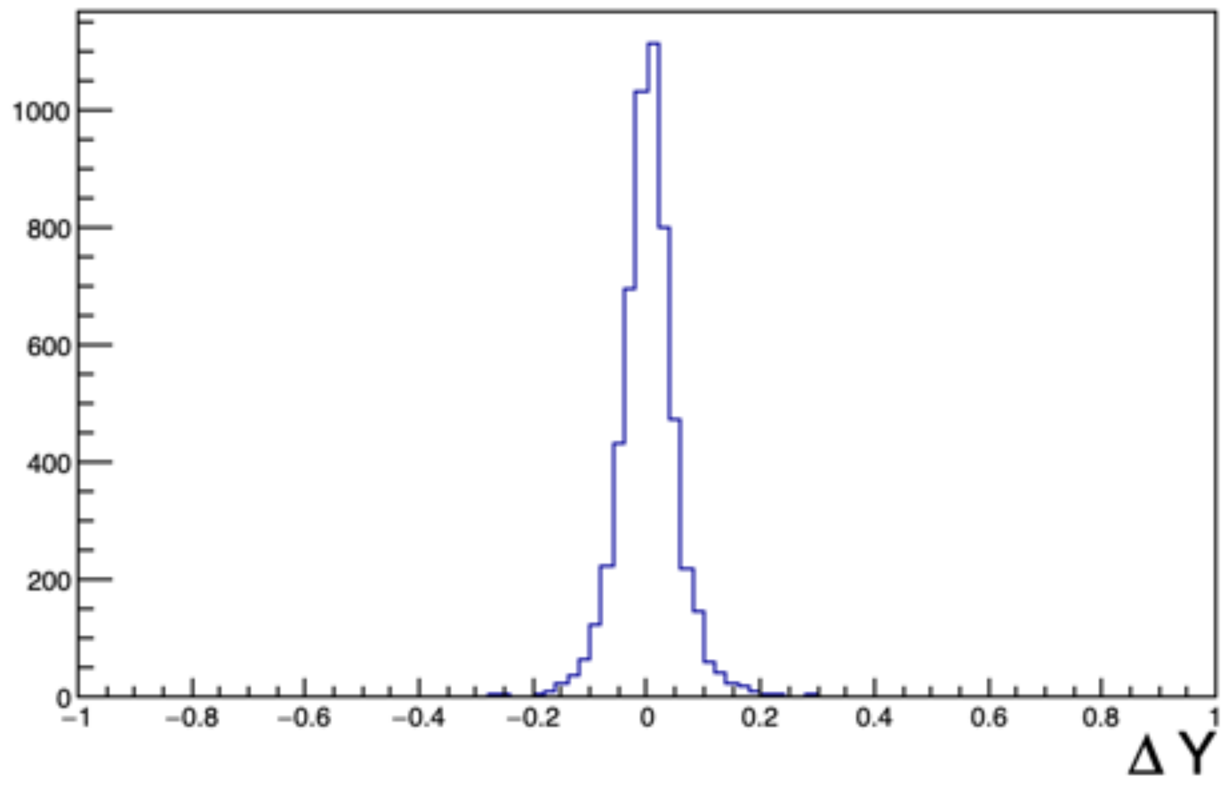
MC: binning

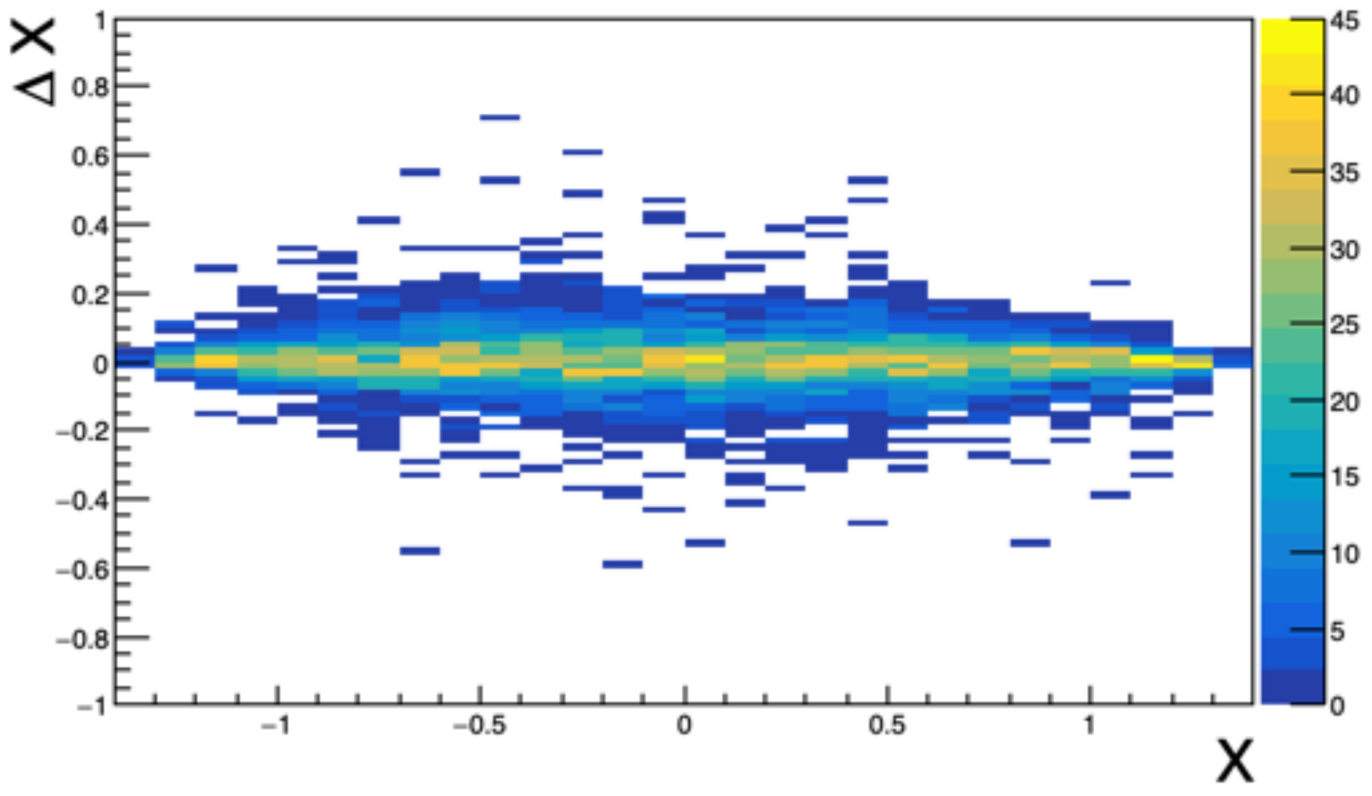


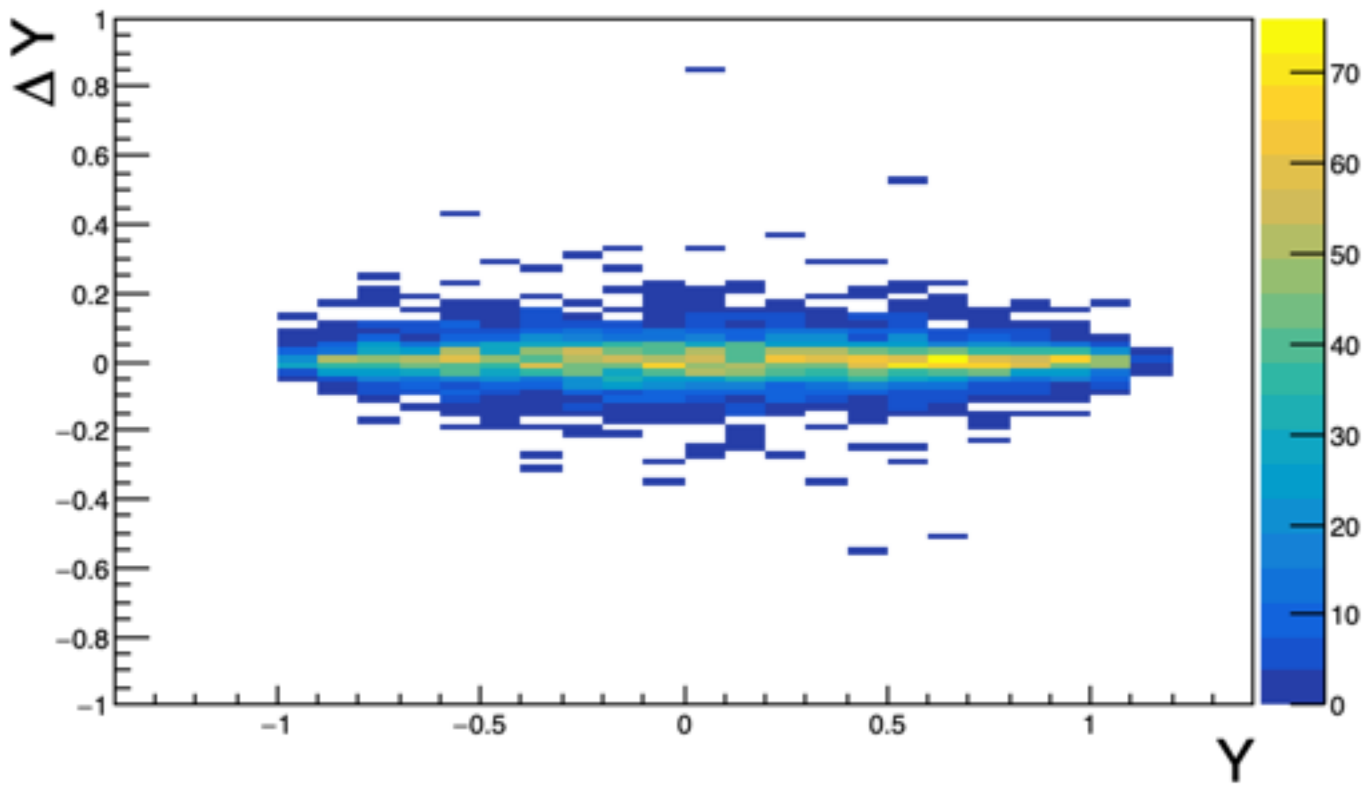


CHARGED DECAY: $\eta' \to \eta\pi^+\pi^-$







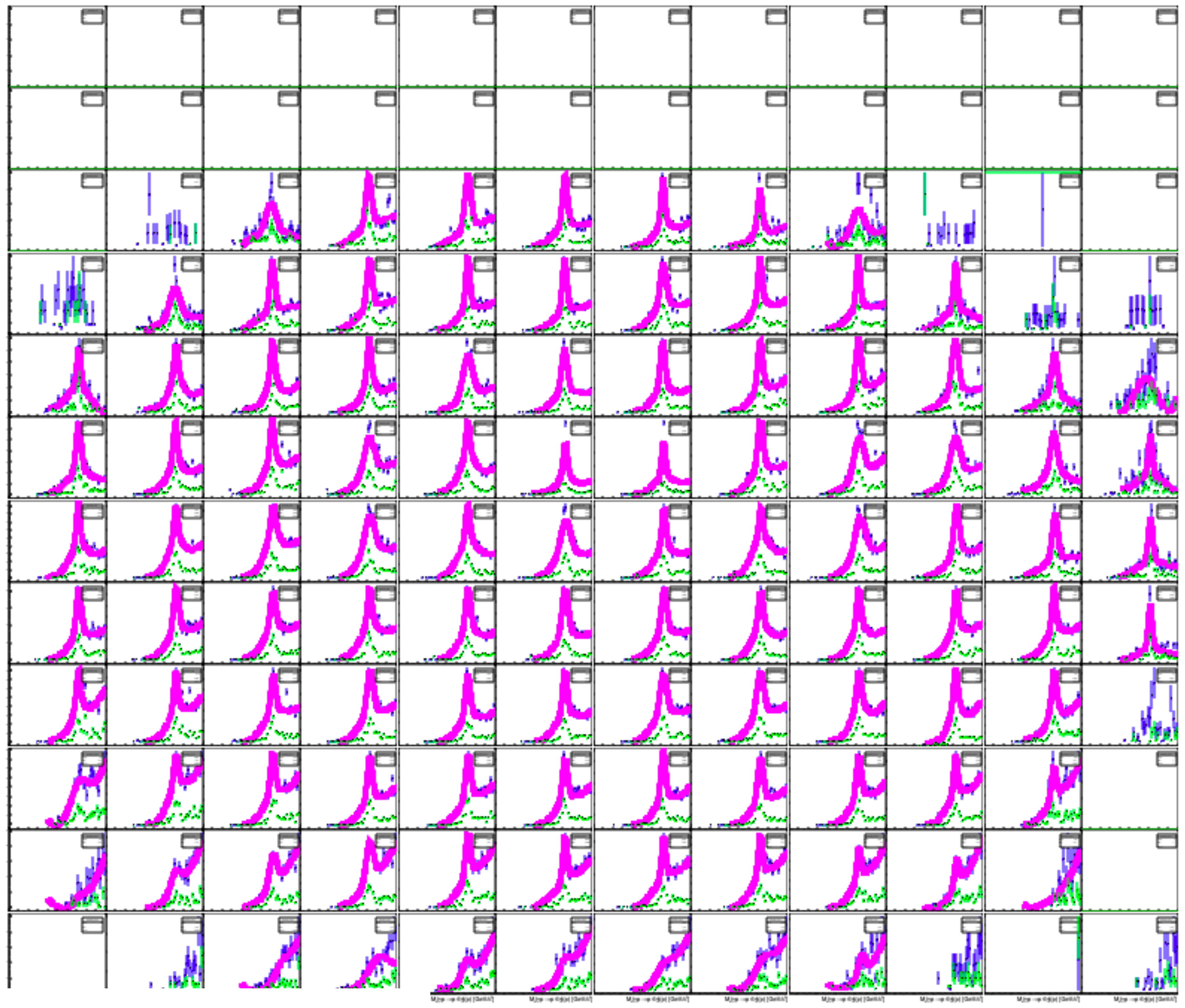


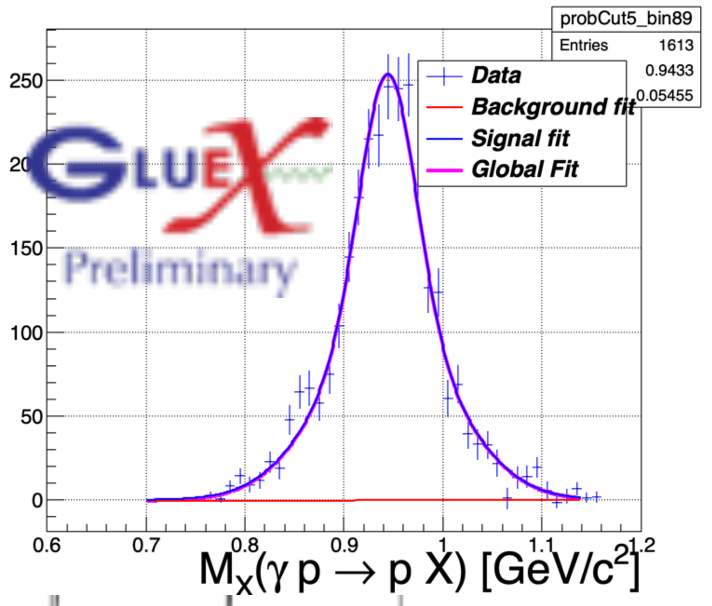
$\sigma = 0.06$ Binning $\sim 3\sigma \to 12$bins

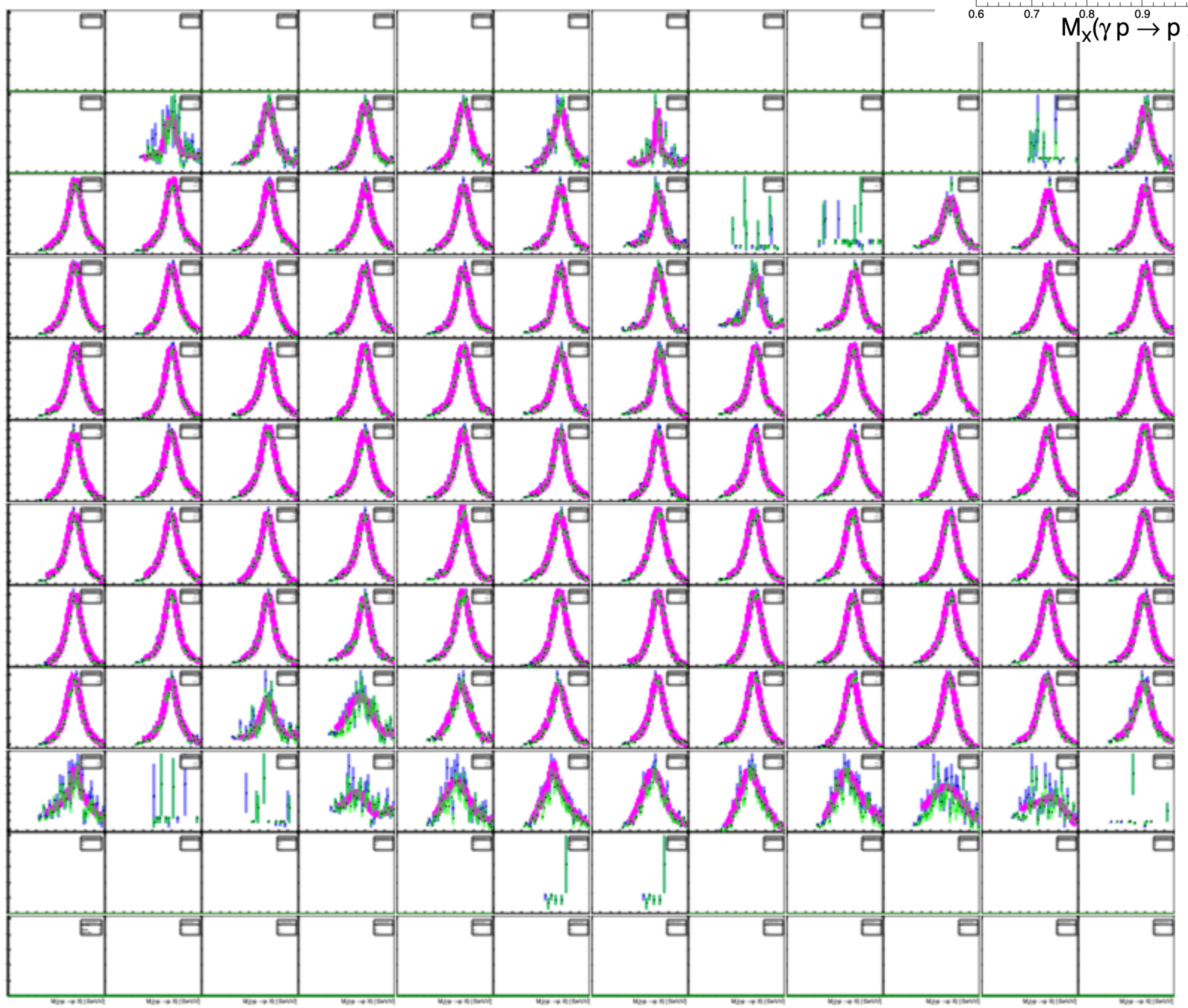
Background Subtraction

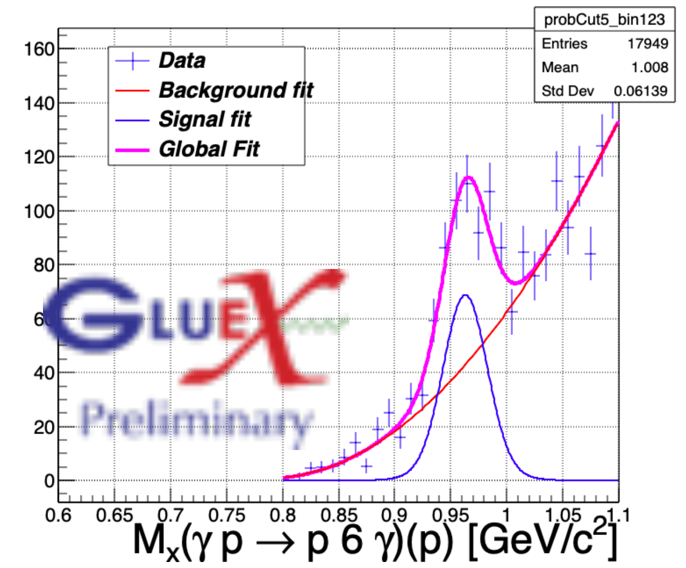
NEUTRAL DECAY: $\eta' \rightarrow \eta\pi^0\pi^0$

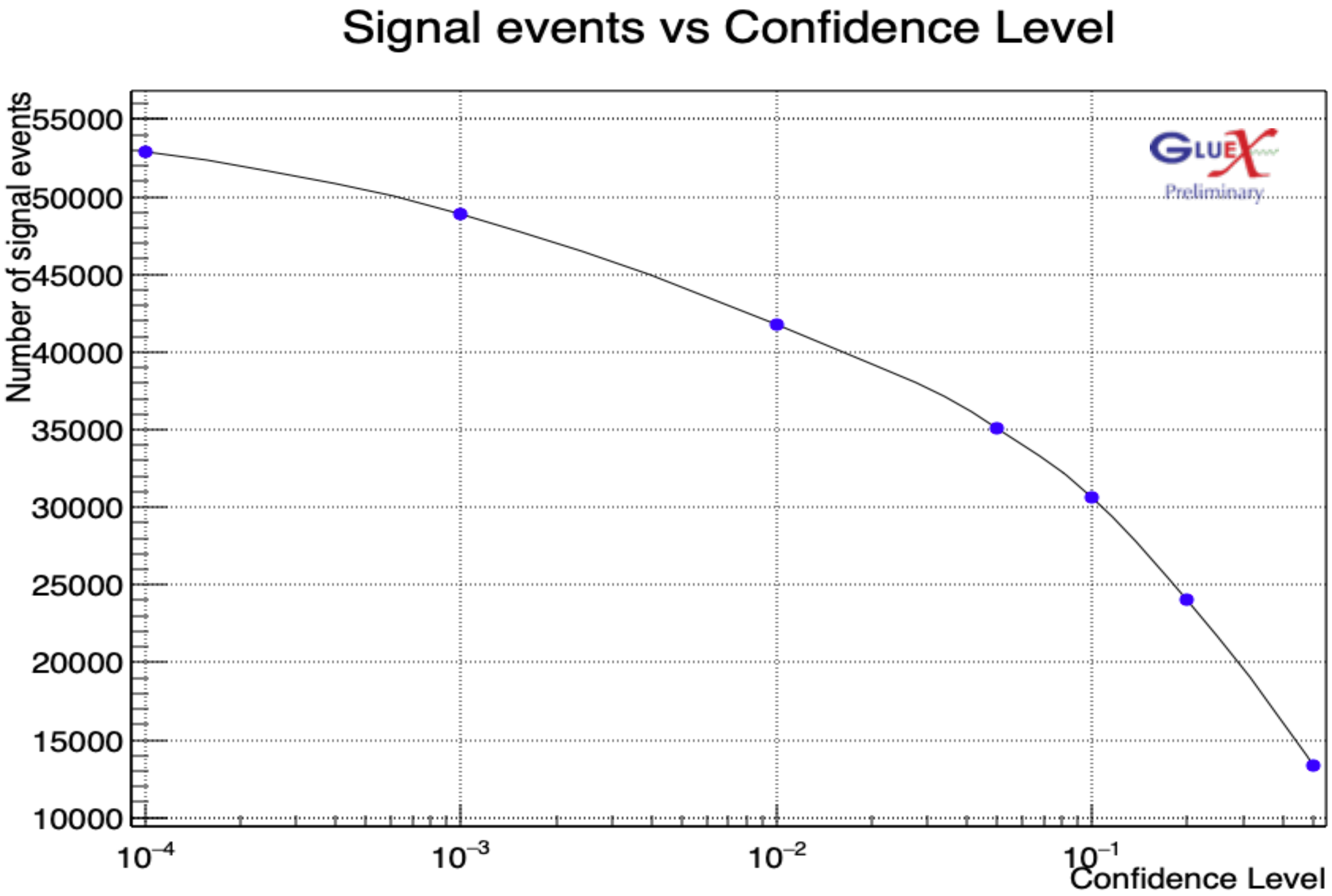
CHARGED DECAY: $\eta' \rightarrow \eta\pi^+\pi^-$











Signal events vs Confidence Level
Number of signal events
55000
50000
45000
40000
35000
30000
25000
20000
15000
10000
10^{-4}
10^{-3}
10^{-2}
10^{-1}
Confidence Level
GlueX
Preliminary