



# Decay Kinematics for $\eta$ Simulations

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# Outline

- Basics of  $\eta$  decay kinematics for a few modes
  - Probably review for some, sorry
- And their implementation within GlueX software framework
- Top four decay modes implemented, more on to-do list



# Simulation Framework

- genEtaRegge handles  $\eta$  production
  - Can input kinematics EvtGen handles  $\eta$  decays
  - for each decay mode in this framework
  - Also, by default uses PHOTOS for final state radiation
- For 3+ body decay modes, the kinematics may deviate from phase space quite significantly!



# Decay Modes Implemented (so far)

- $\eta \rightarrow \gamma\gamma$  (is just phase space, nothing to add)
- $\eta \rightarrow \pi^+\pi^-\pi^0$  (all work by Sean + Daniel)
- $\eta \rightarrow \pi^0\pi^0\pi^0$  (new)
- $\eta \rightarrow \pi^+\pi^-\gamma$  (updated)



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

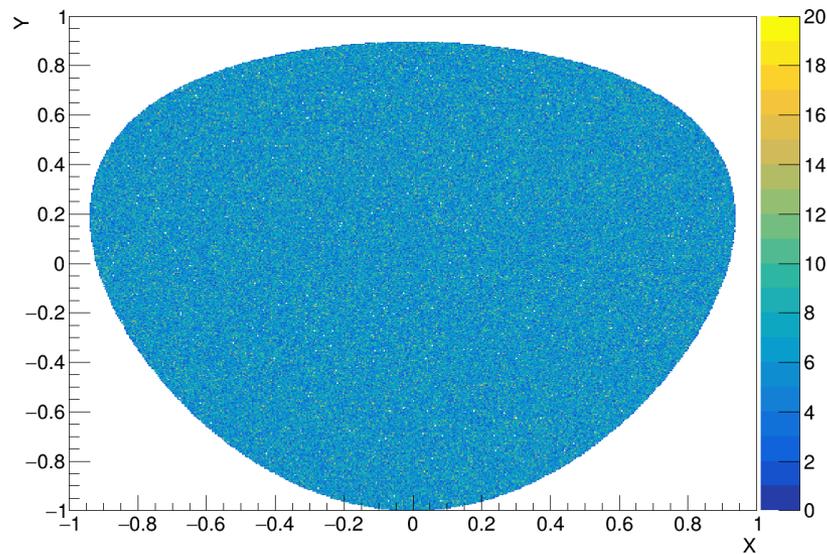
- Kinematic distribution usually expressed in terms of Dalitz parameters  $X, Y$ 
  - $X \propto \pi^+, \pi^-$  momentum difference in rest frame
  - $Y \propto \pi^0$  momentum in rest frame
- Distribution of events (amplitude squared) expressed as Taylor expansion  
 $|A(X, Y)|^2 = N (aY + bY^2 + cX + dX^2 + eXY + fY^3 + gX^2Y + \dots)$
- Inputs to EvtGen:  $a, b, \dots, f, g$  constants measured from past experiments
  - Use “ETA\_DALITZ\_GLUEX”.
  - Not “ETA\_DALITZ”! This is from the 70’s.



# $\eta \rightarrow \pi^+ \pi^- \pi^0$ Dalitz Distribution

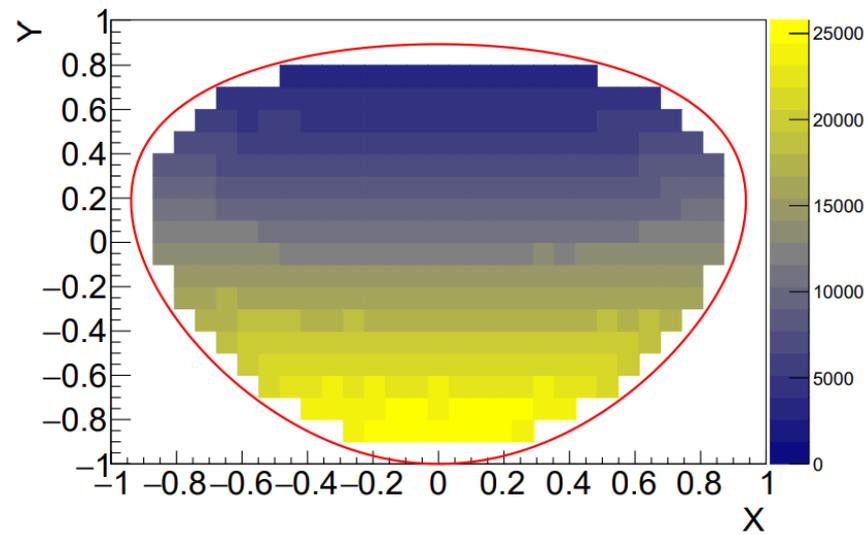
Phase space

$\pi^+ \pi^- \pi^0$  Dalitz Distribution



KLOE

<https://arxiv.org/pdf/1601.06985.pdf>

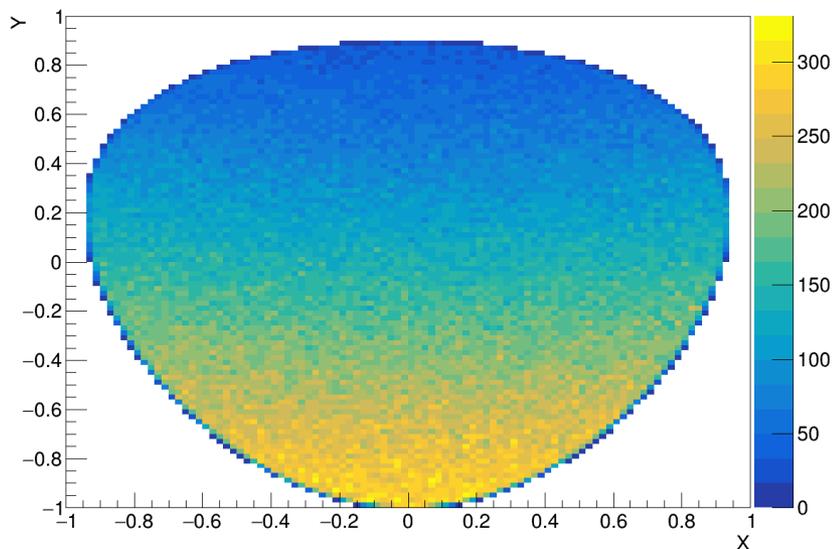




# $\eta \rightarrow \pi^+ \pi^- \pi^0$ Dalitz Distribution

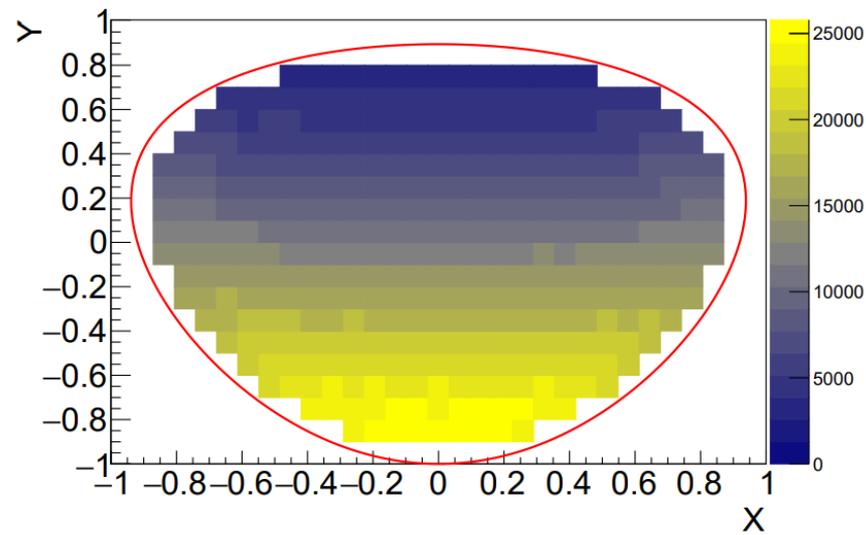
“ETA\_DALITZ\_GLUEX”

$\pi^+ \pi^- \pi^0$  Dalitz Distribution



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<https://arxiv.org/pdf/1601.06985.pdf>





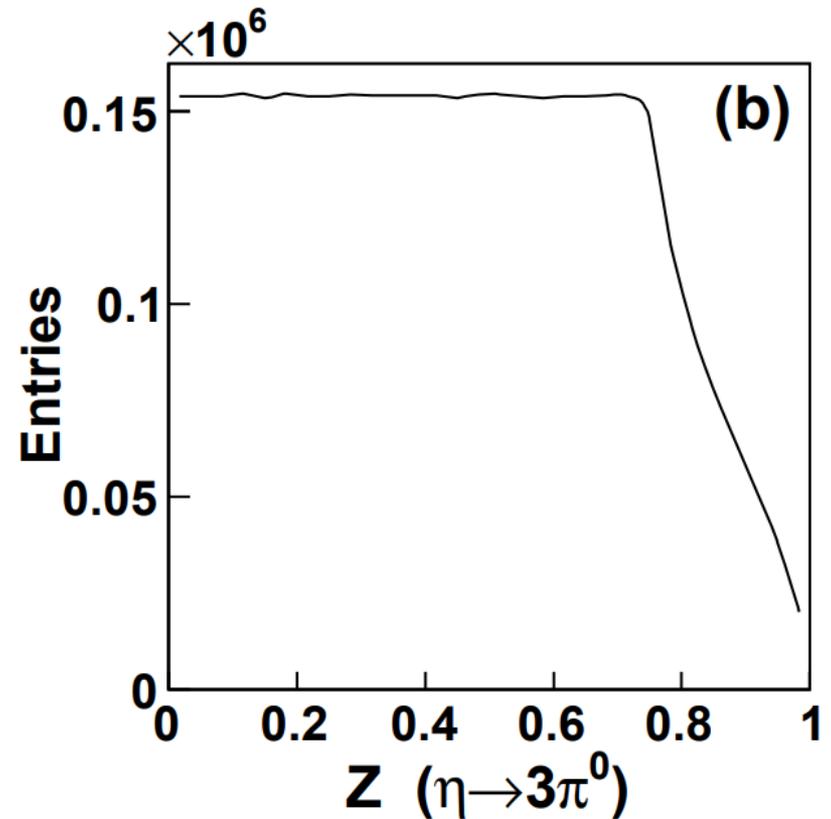
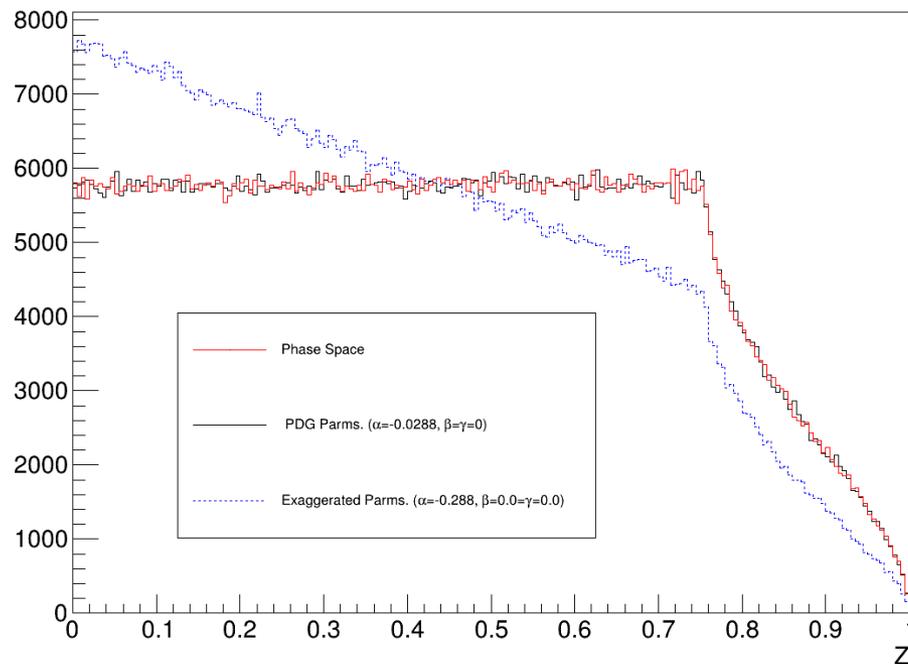
$$\eta \rightarrow \pi^0 \pi^0 \pi^0$$

- Same formalism as  $\eta \rightarrow \pi^+ \pi^- \pi^0$ 
  - Except the three  $\pi^0$ s are identical particles
  - Only radial direction of (X,Y) plot matters ( $z \equiv X^2 + Y^2$ )
- Event distribution:
  - $|A(z)|^2 = N(1 + 2\alpha z + \beta z^{3/2} \sin(3\phi) + 2\gamma z^2 + \dots)$
  - Input parameters  $\alpha, \beta, \gamma$
- Deviations from phase space quite small
  - $\alpha$  measured reasonably well
  - $\beta, \gamma$  small, less precisely known



# Z distribution

$\pi^0\pi^0\pi^0$  Dalitz Z





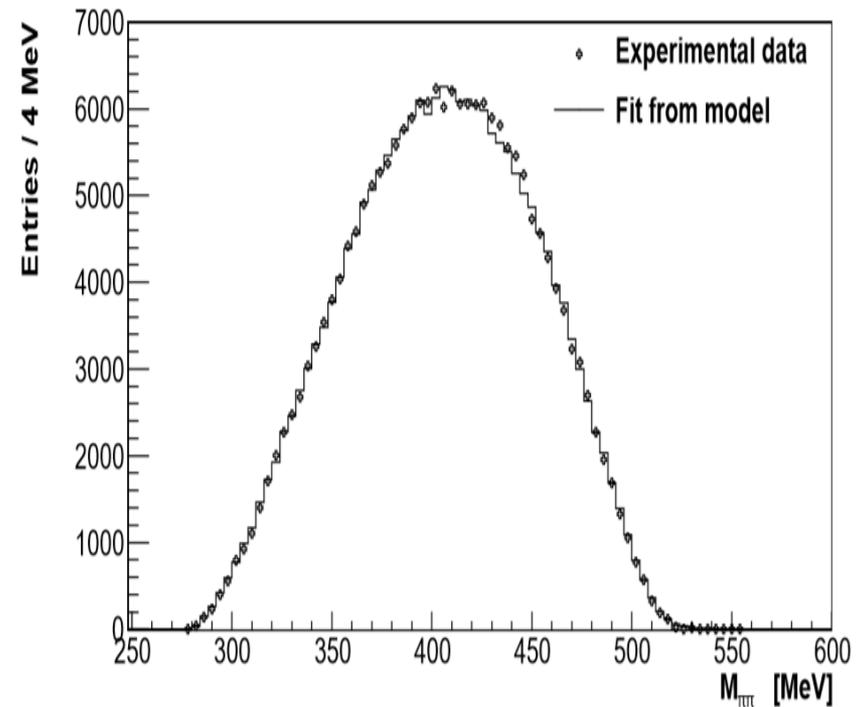
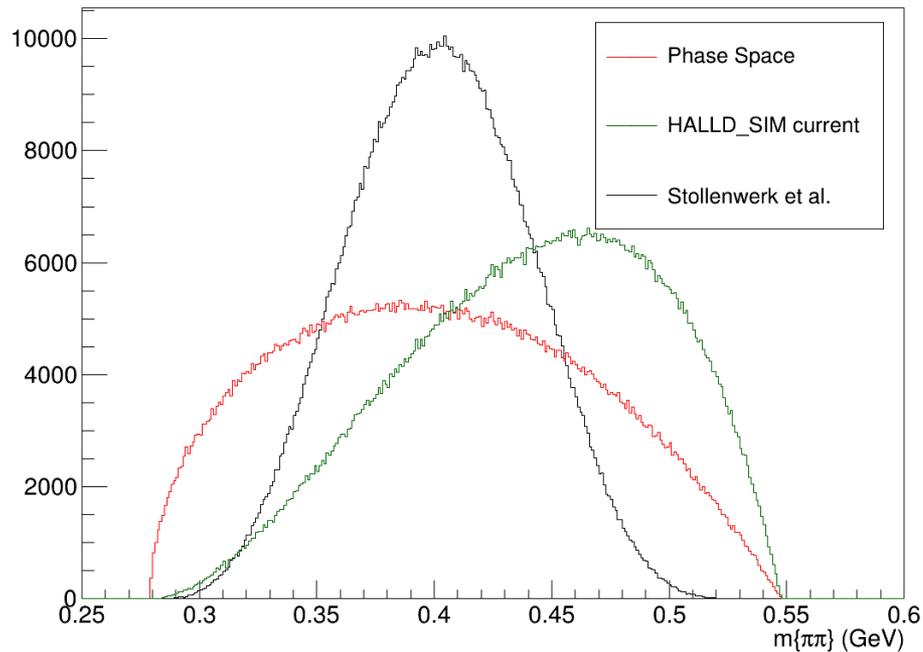
$$\eta \rightarrow \pi^+ \pi^- \gamma$$

- Assuming P-wave dominance
- Event distribution as a function of  $s_{\pi\pi} (\equiv m_{\pi\pi}^2)$ :
  - $A(s) = |P(s)F_V(s)|^2 \Gamma_0(s)$
  - $P(s)$  a process specific part, must be measured
  - $F_V$  vector form factor, process independent
  - $\Gamma_0$  kinematical factors
- Quantities described:  $m_{\pi\pi}$  and  $E_\gamma$  distributions
- Ref: F. Stollenwerk et al. <https://arxiv.org/abs/1108.2419v3>



# $\eta \rightarrow \pi^+ \pi^- \gamma: m_{\pi\pi}$ Distribution

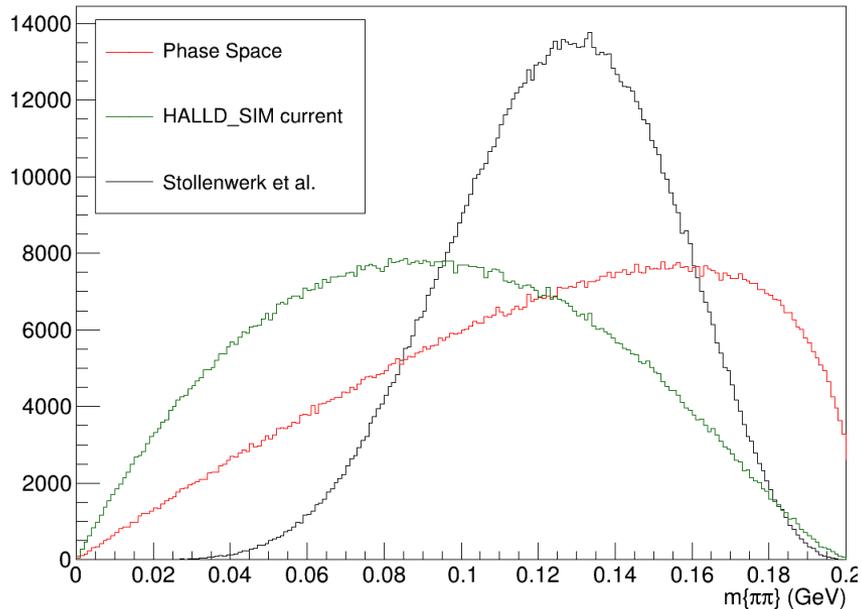
$m_{\pi\pi}, \eta \rightarrow \pi\pi\gamma$





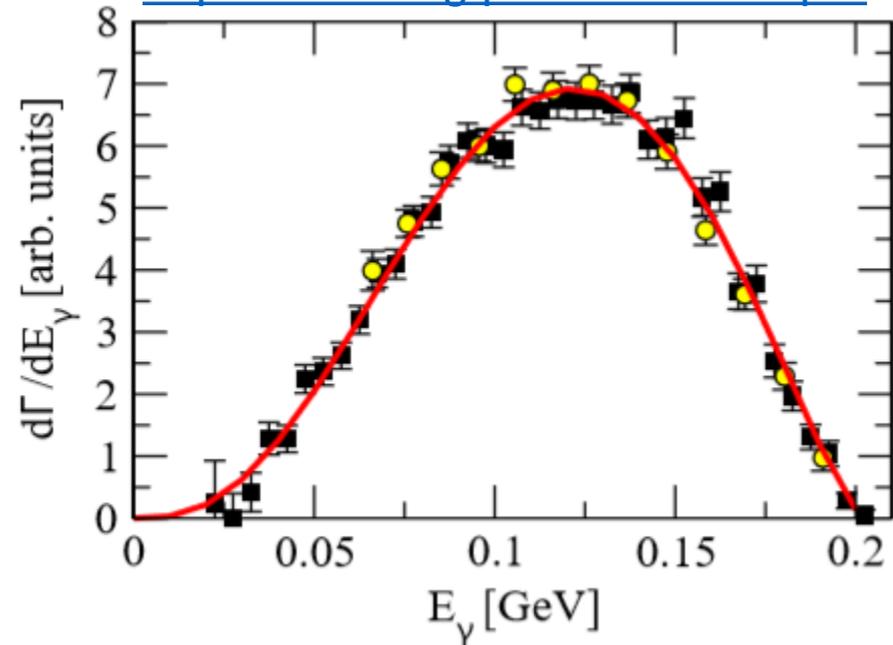
# $\eta \rightarrow \pi^+ \pi^- \gamma: E_\gamma$ Distribution

$E_\gamma$  in  $\eta$  cm,  $\eta \rightarrow \pi\pi\gamma$



WASA-at-COSY

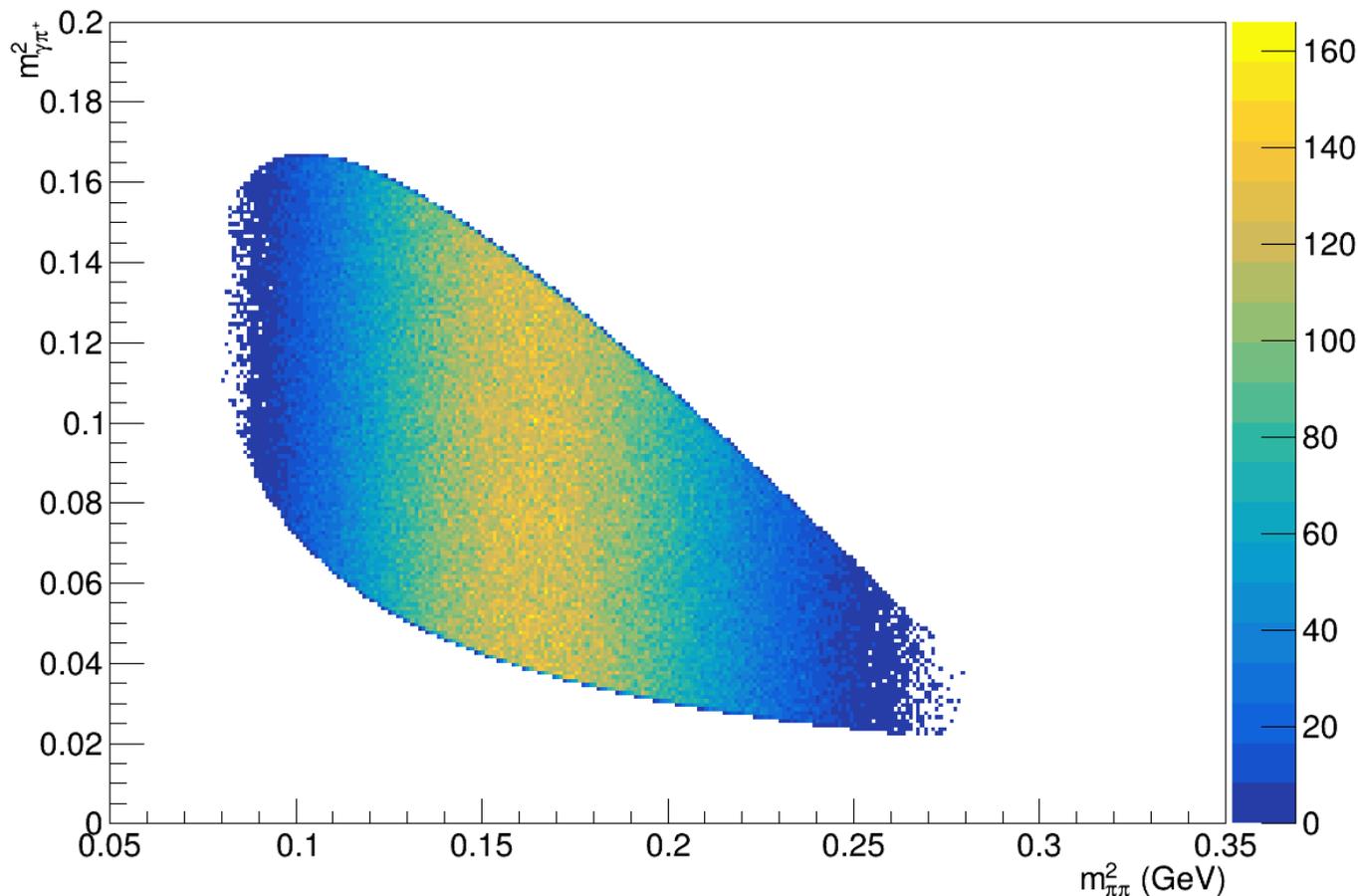
<https://arxiv.org/pdf/1107.5277.pdf>





# Dalitz Mass<sup>2</sup> Plot, $\eta \rightarrow \pi^+ \pi^- \gamma$

$\eta \rightarrow \pi\pi\gamma$  Dalitz



This ok for  $\pi^+ \pi^-$  in a P-wave?



# $\eta$ Decay Modes to go

Kinematics for

- $\pi^0 \gamma \gamma$  *Help Requested!*
- $\gamma e^+ e^-$  and  $\gamma \mu^+ \mu^-$
- $\pi^+ \pi^- e^+ e^-$



# Backup: How To Create $\eta$ Decay Model

- All development happens in HALLD\_SIM repository
  - `$HALLD_SIM_HOME/src/libraries/EVTGEN_MODELS`
  - Add model here (follow examples)
  - Be sure to recompile `genEtaRegge` and `decay`
- Run `genEtaRegge` with