Typical Analysis Workflow

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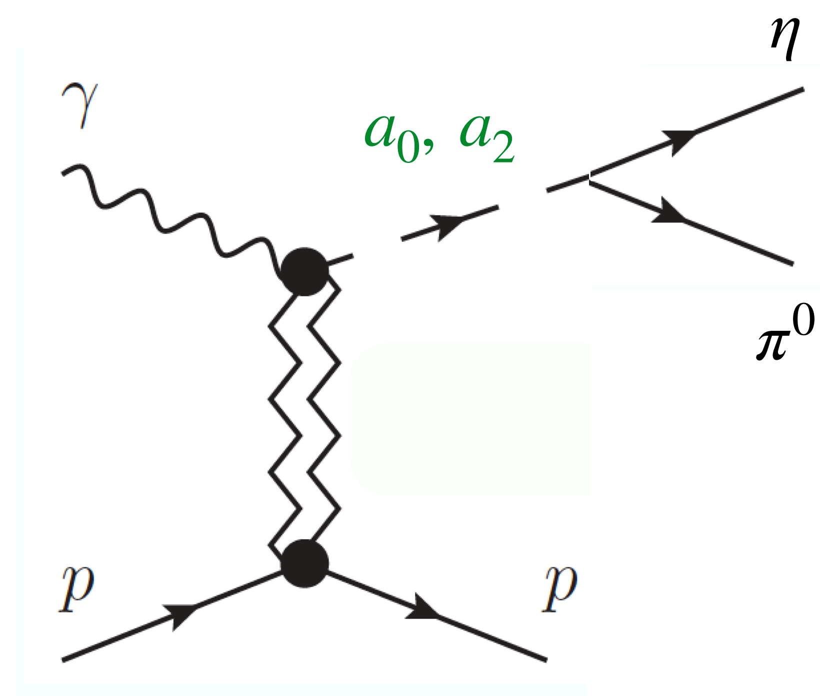
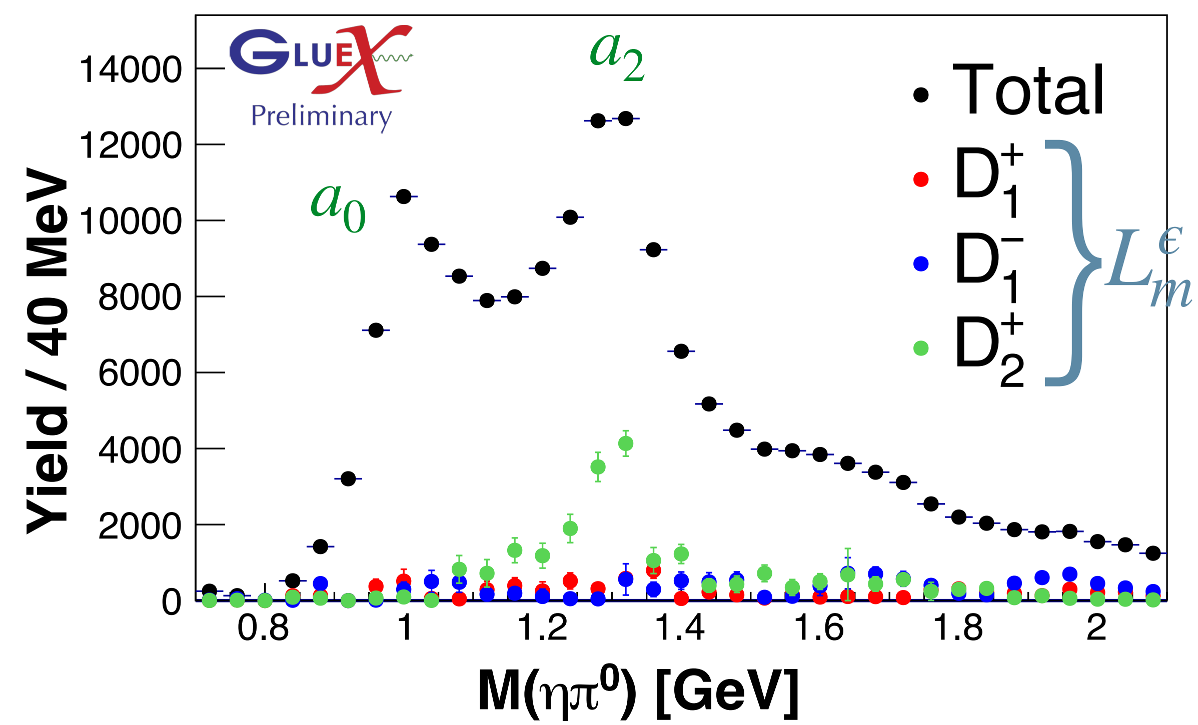
CHARTERED 1693

Big picture analysis strategy

- **Goal:** obtain pure sample of $\gamma p \to \eta\pi^0 p$ to study contributing amplitudes

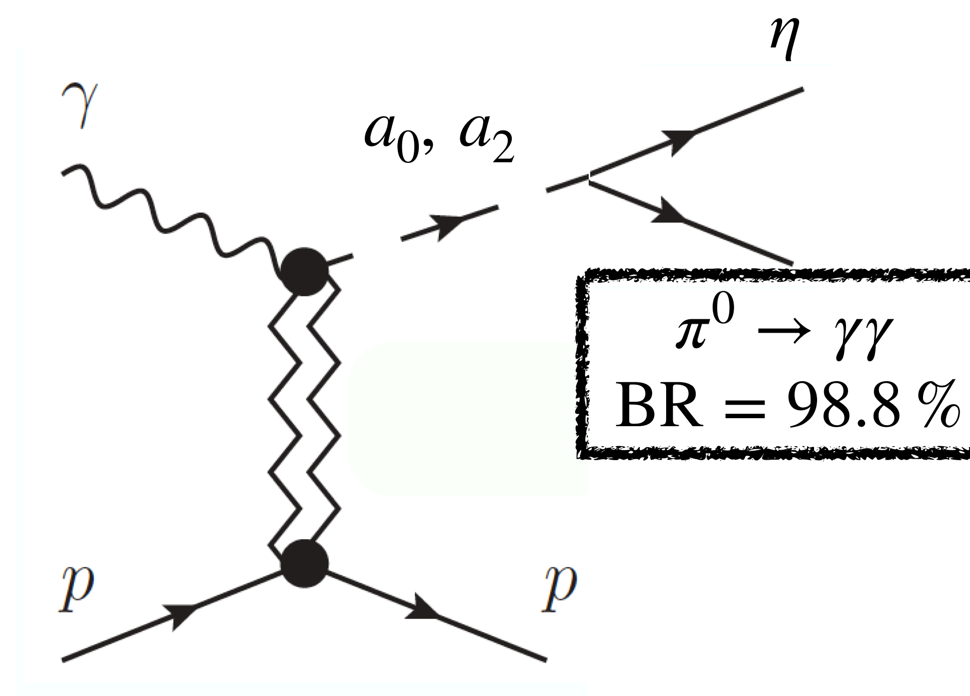
- **Necessary steps:**
  - Choose appropriate ReactionFilter and Kinematic Fit options
  - Apply selection criteria (i.e. cuts) which efficiently reject background but keep signal of interest
  - Statistically subtract remaining background, not removed by cuts
  - Measure yield for cross section or fit angular distributions for beam asymmetry or amplitude analysis





How to reconstruct your final state?

	Mode	Fraction (Γ_i/Γ)
Neutral modes		
Γ_1	neutral modes	$(72.12 \pm 0.34)\%$
Γ_2	2γ	$(39.41 \pm 0.20)\%$
Γ_3	$3\pi^0$	$(32.68 \pm 0.23)\%$
Charged modes		
Γ_8	charged modes	$(27.89 \pm 0.29)\%$
Γ_9	$\pi^+\pi^-\pi^0$	$(22.92 \pm 0.28)\%$
Γ_{10}	$\pi^+\pi^-\gamma$	$(4.22 \pm 0.08)\%$

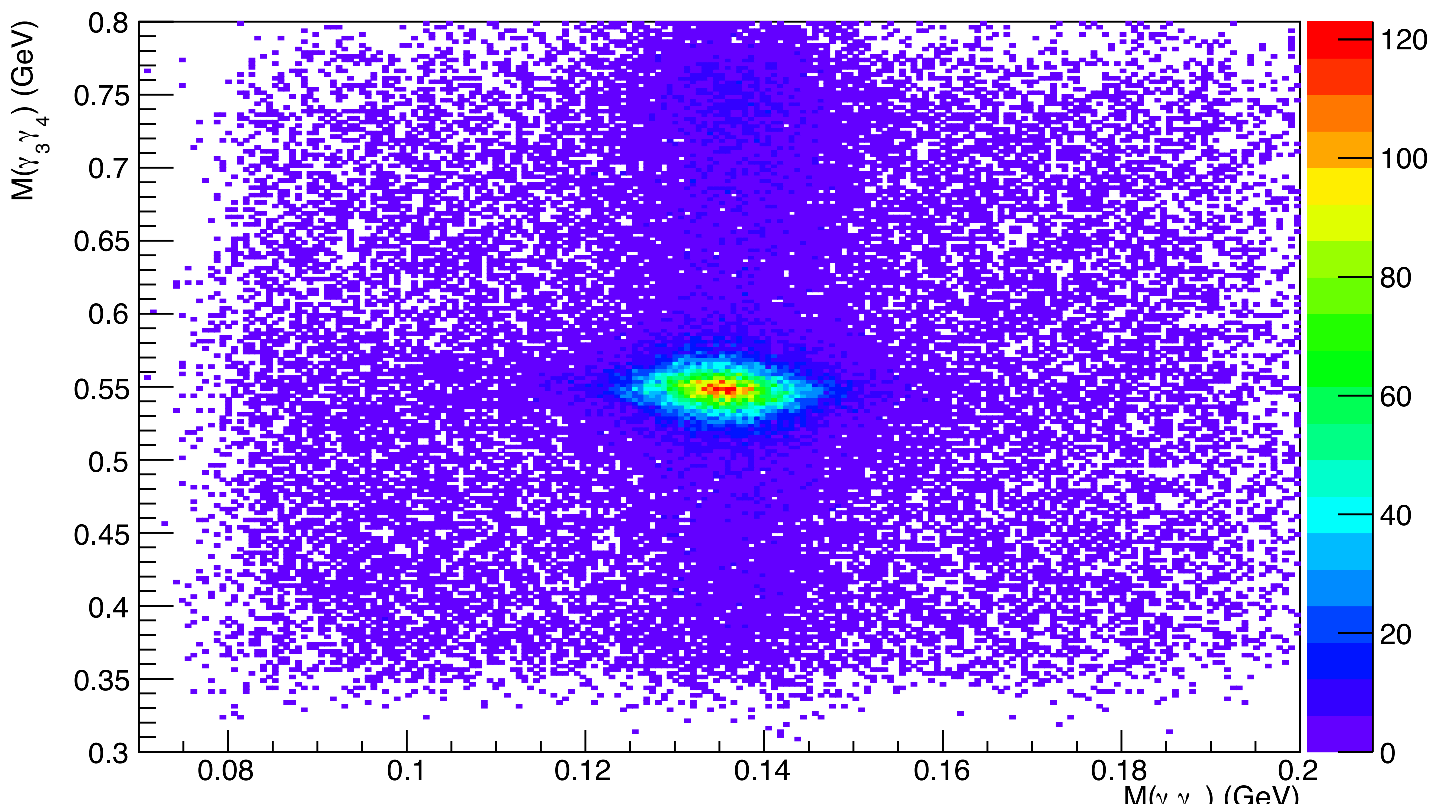


- **Exclusive:** if at all possible, reconstruct all final state particles!
- **Decay modes:** large branching ratio and simpler to reconstruct preferred
  - Comparison of multiple decay modes provides systematic cross check, which is a major strength of GlueX
- For this tutorial we'll use exclusive $\gamma p \to \eta\pi^0 p$ with $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$

ReactionFilter, Kinematic Fit and Mass Constraints

- ReactionFilter is an analysis plugin to define the reaction you intend to study and write ROOT trees for analysis (see Beni's talk)
- $\gamma p \to \eta\pi^0 p$ with decays $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$ specify the reaction with
  - `Reaction1 1_14__7_17_14`

Signal Reaction: $\gamma p \to \eta\pi^0 p,\ 4\gamma p$



Neither π or η constrained: **`B4_M17_M7`**

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- $\gamma p \to \eta\pi^0 p$ with $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$: `Reaction1 1_14__7_17_14`

- What Kinematic Fit flags should we use?

  - `Reaction1:Flags` **`B4_M17_M7`** `or B4_M7 or B4_M17 or B4`

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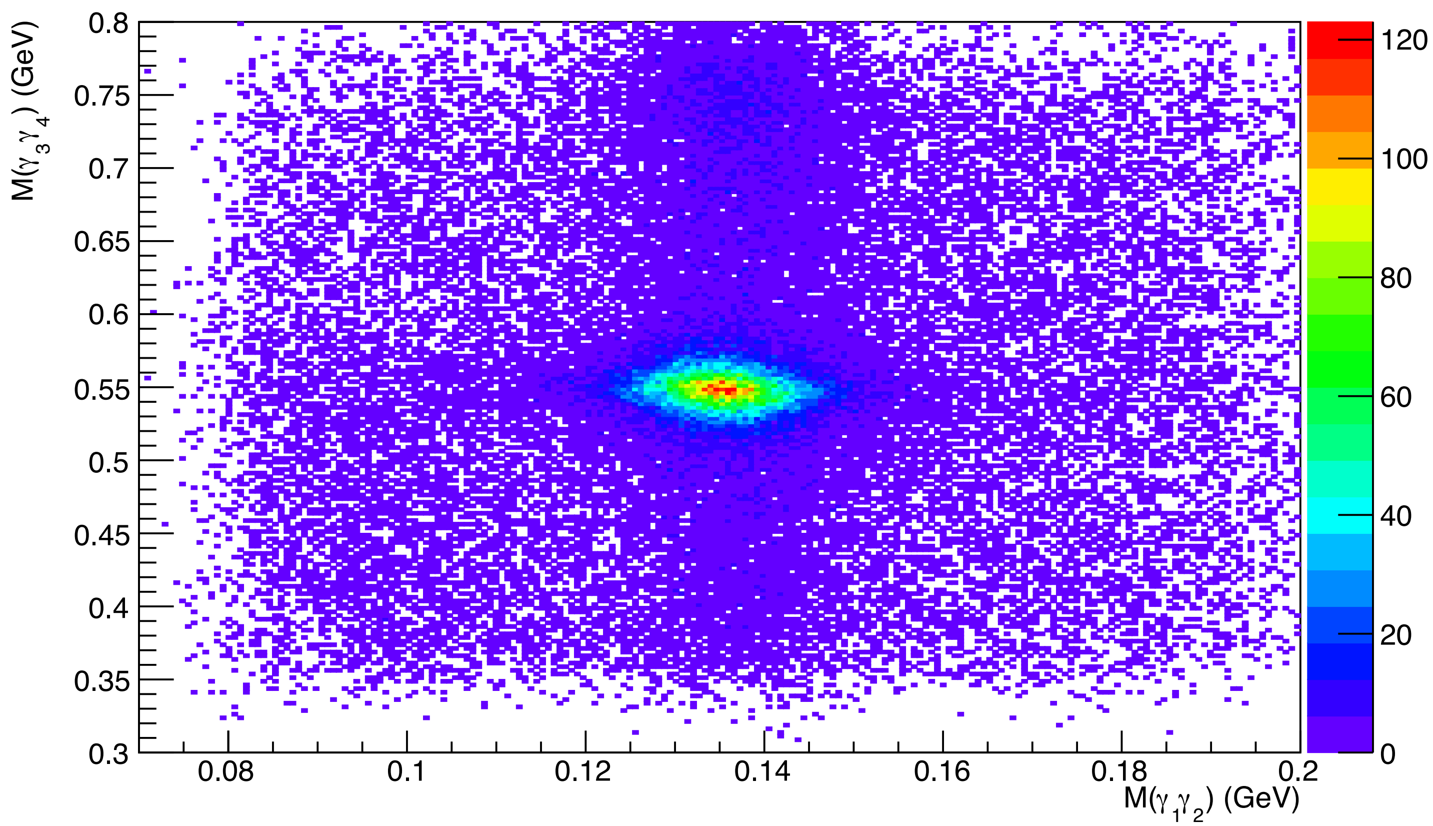

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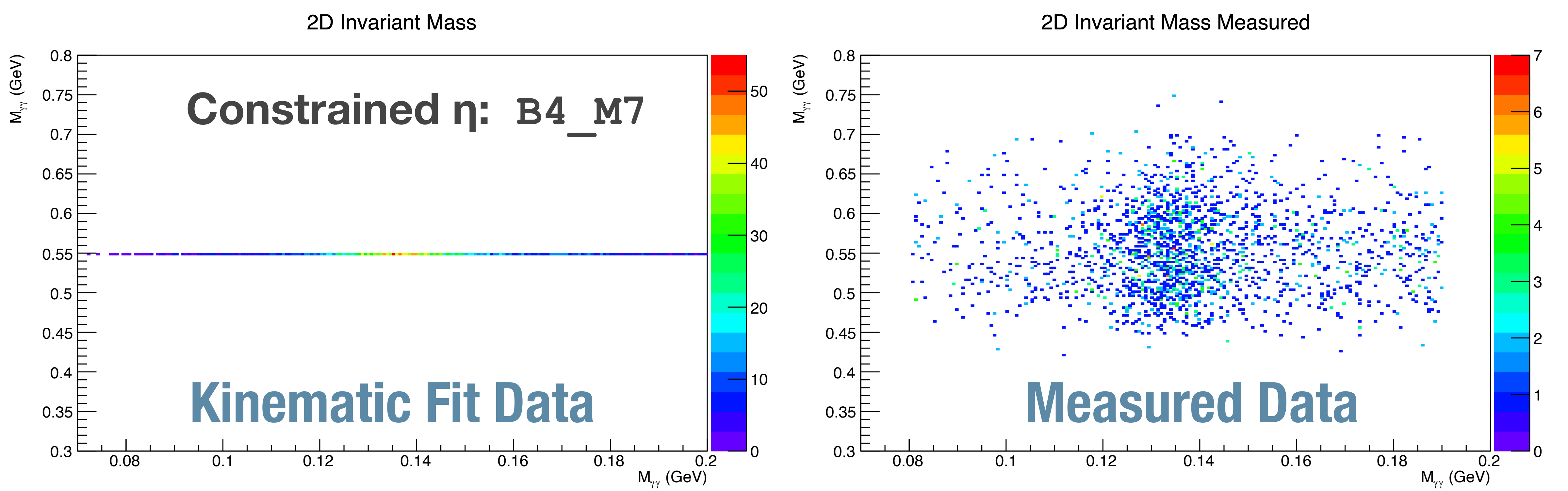
- $\gamma p \to \eta\pi^0 p$ with $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$: `Reaction1 1_14__7_17_14`
- What Kinematic Fit flags should we use?
  - `Reaction1:Flags B4_M7_M17 or` **`B4_M7`** `or B4_M17 or B4`

Background Reaction: $\gamma p \to \omega\pi^0 p,\ 5\gamma p$



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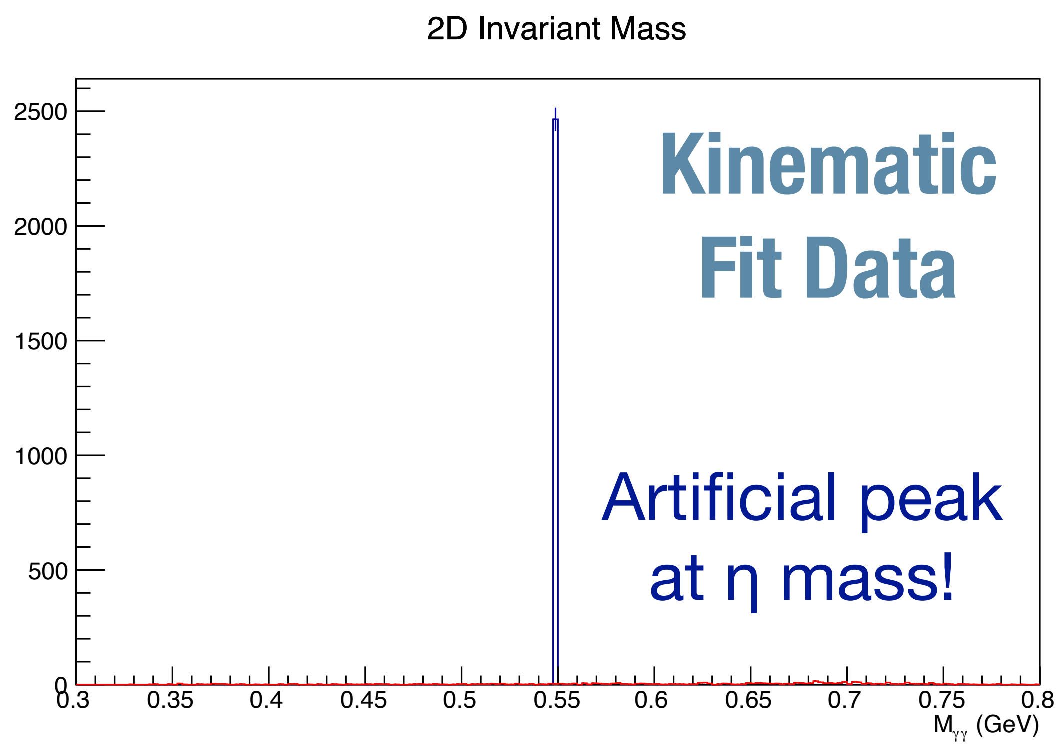

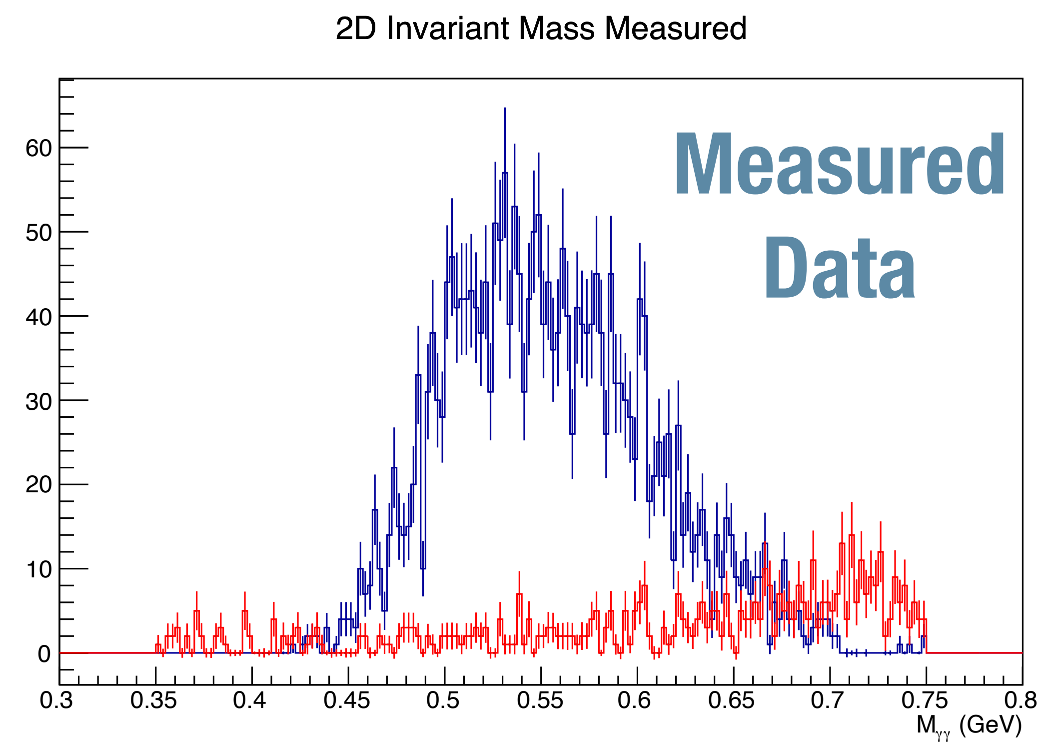

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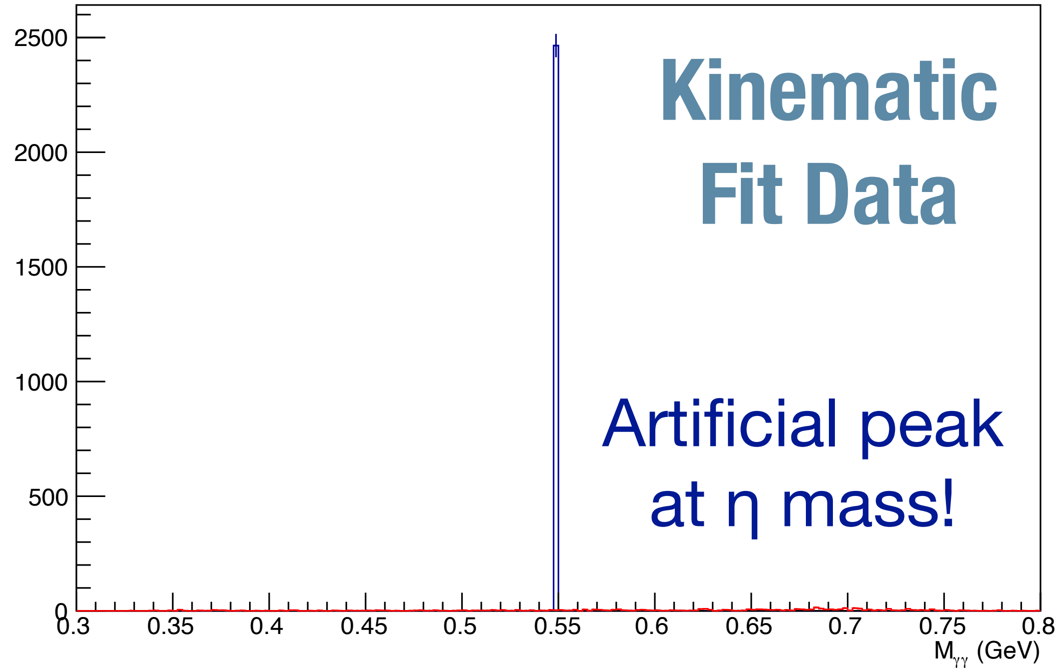
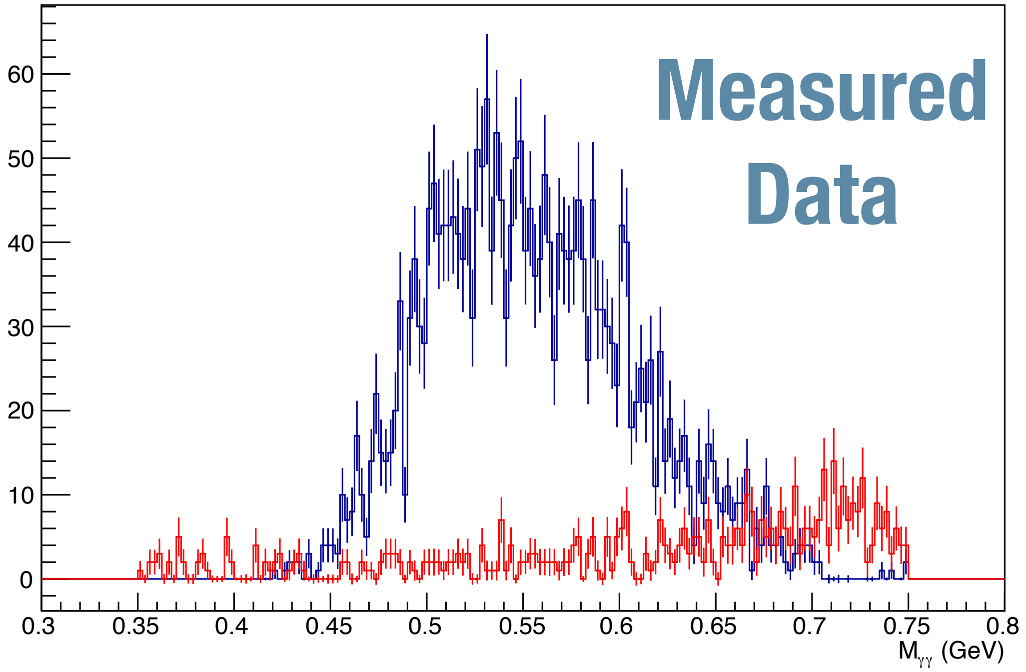
Take home message: leave at least one mass un-constrained!

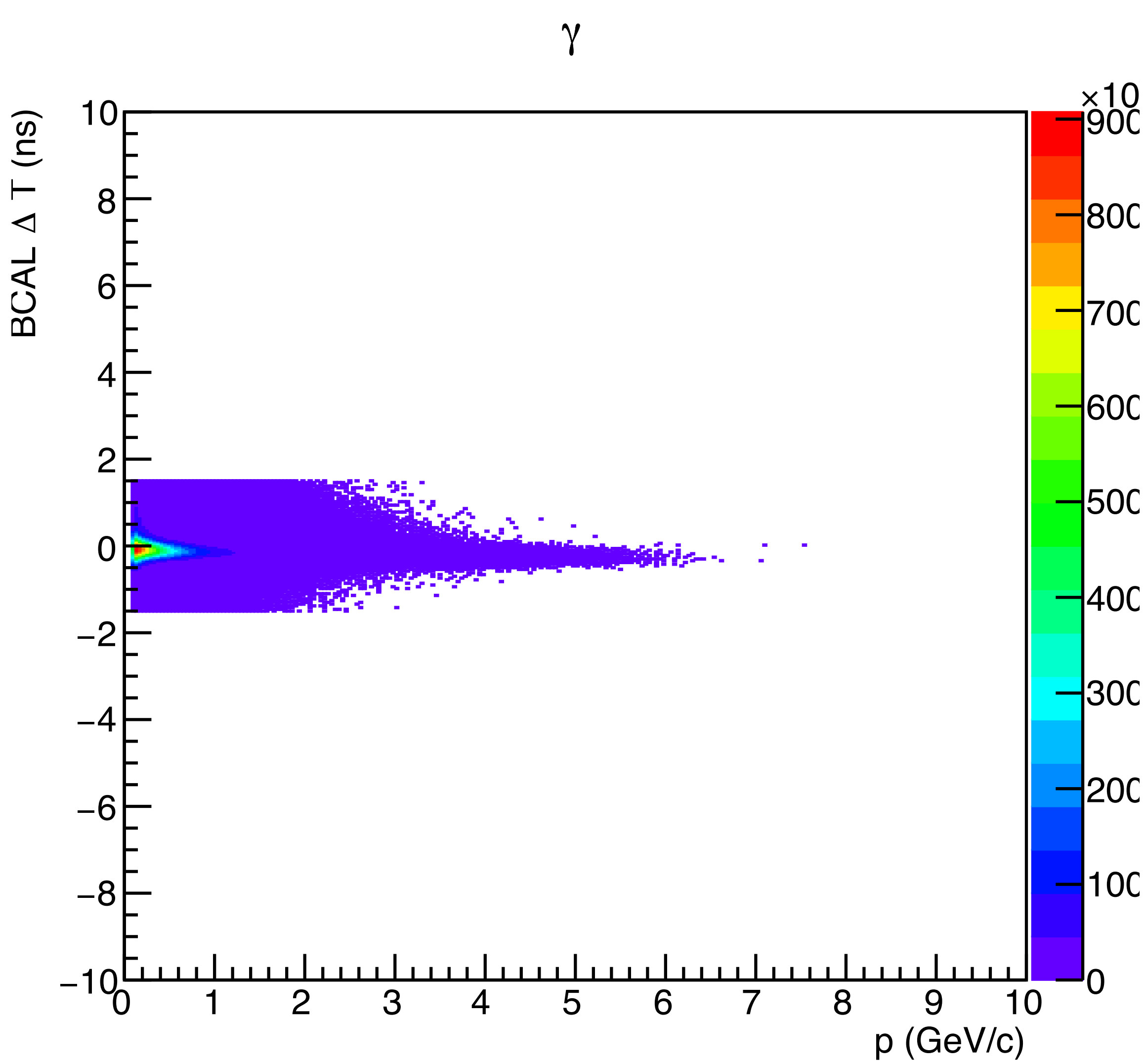


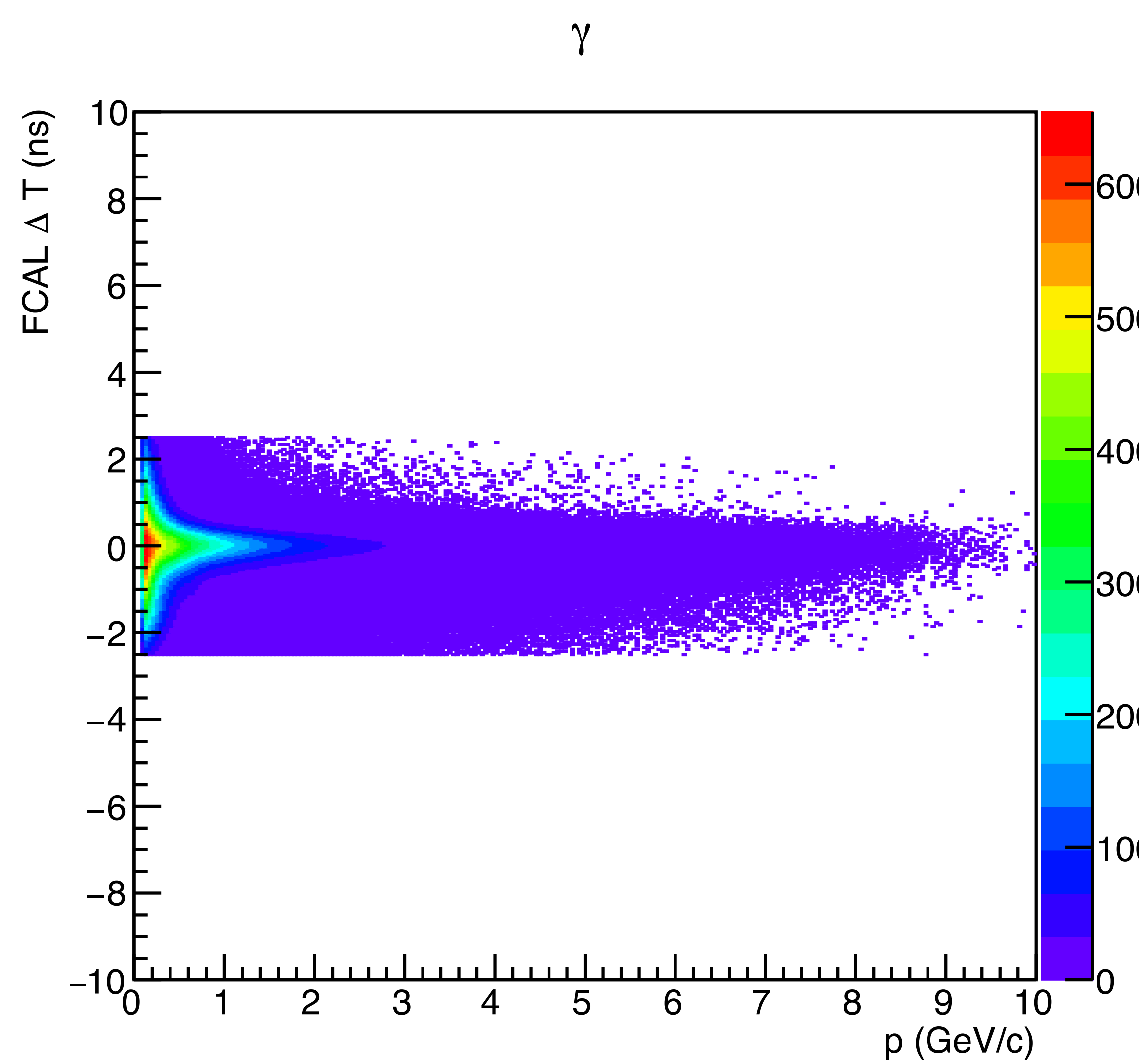


Event selection 101

- [Analysis Launch Cuts:]() "loose" cuts that are already applied in ReactionFilter by default

PID	BCAL/RF Δt (ns)	TOF/RF Δt (ns)	FCAL/RF Δt (ns)	SC/RF Δt (ns)
γ	±1.5	NA	±2.5	NA
p	±1.0	±0.6	±2.0	±2.5





Event selection 101

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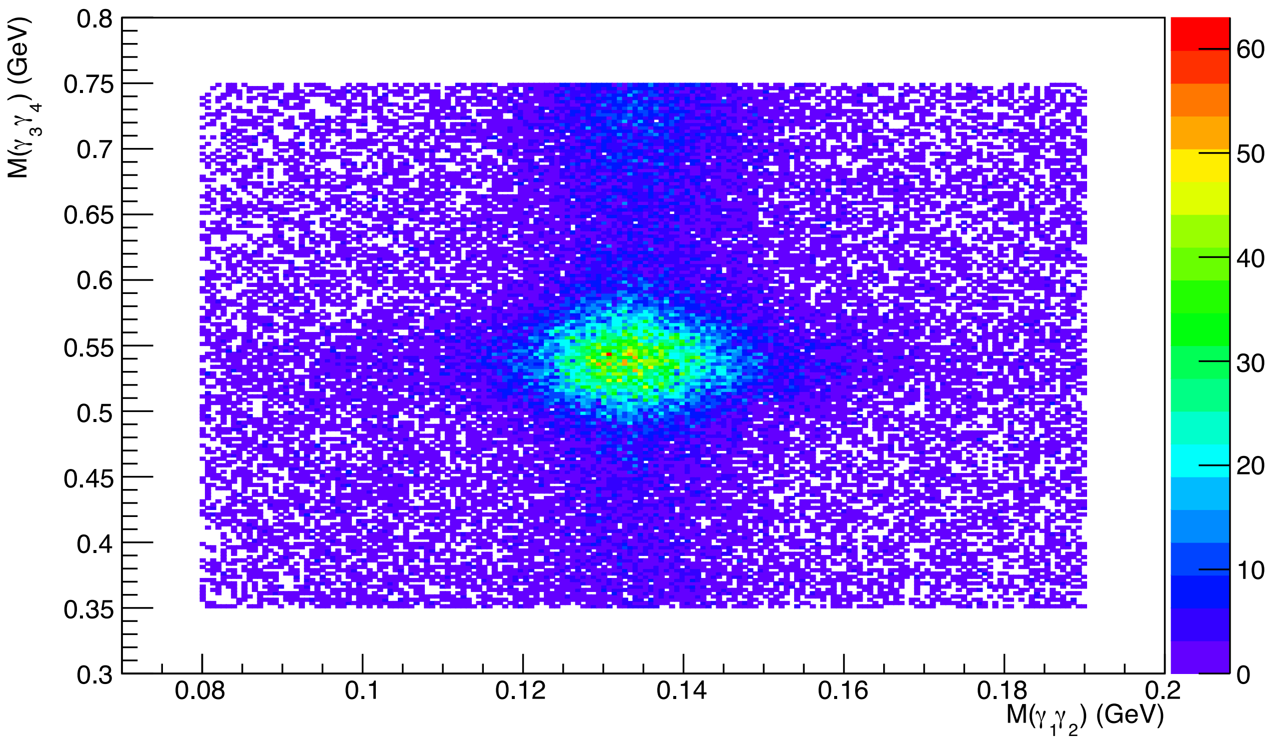
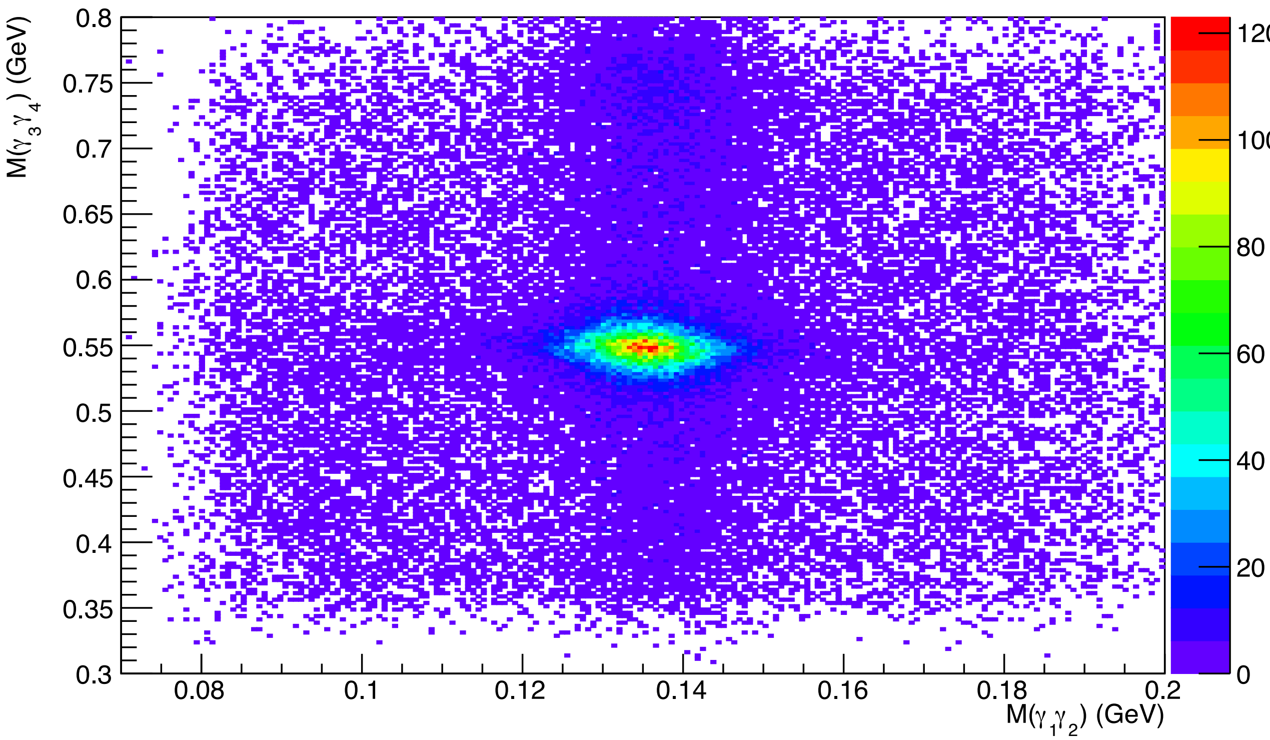
PID	Invariant Mass (GeV/c^2)
π^0	0.08 < IM < 0.19
K_S	0.3 < IM < 0.7
η	0.35 < IM < 0.75

Measured Data



Kinematic Fit Data

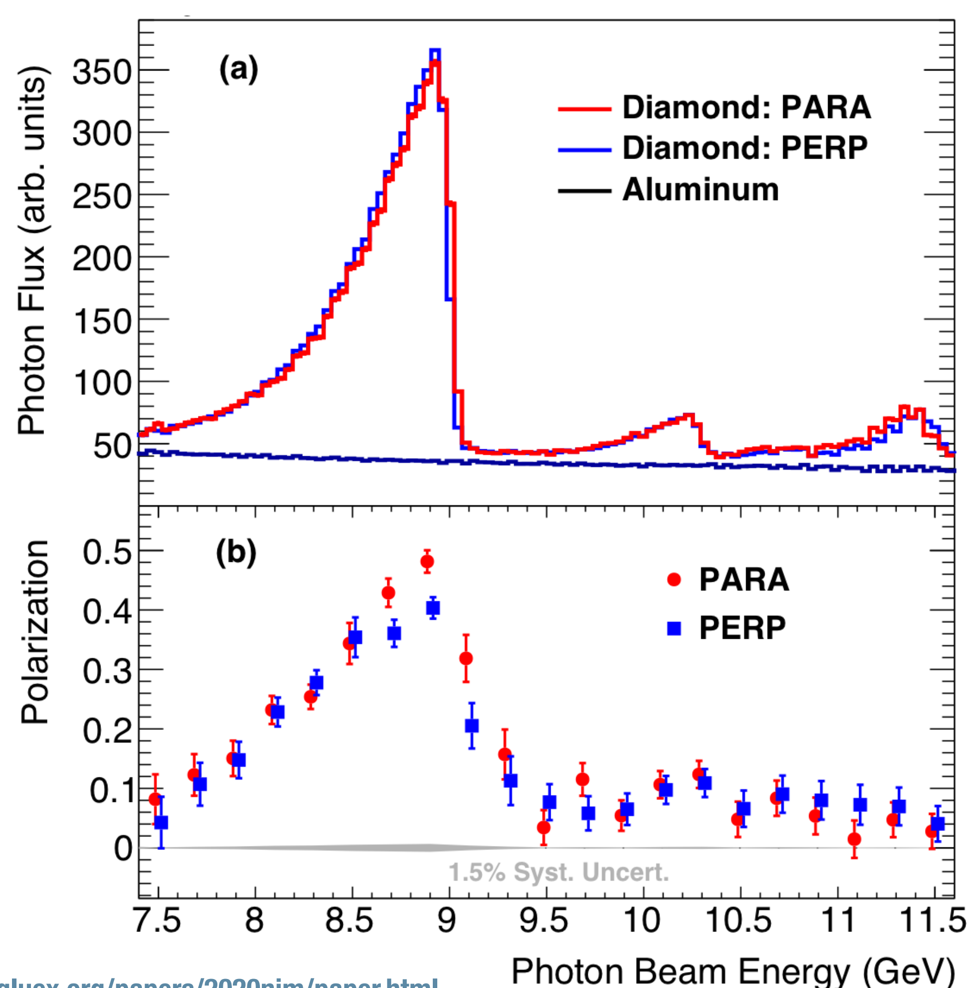


Event selection 101

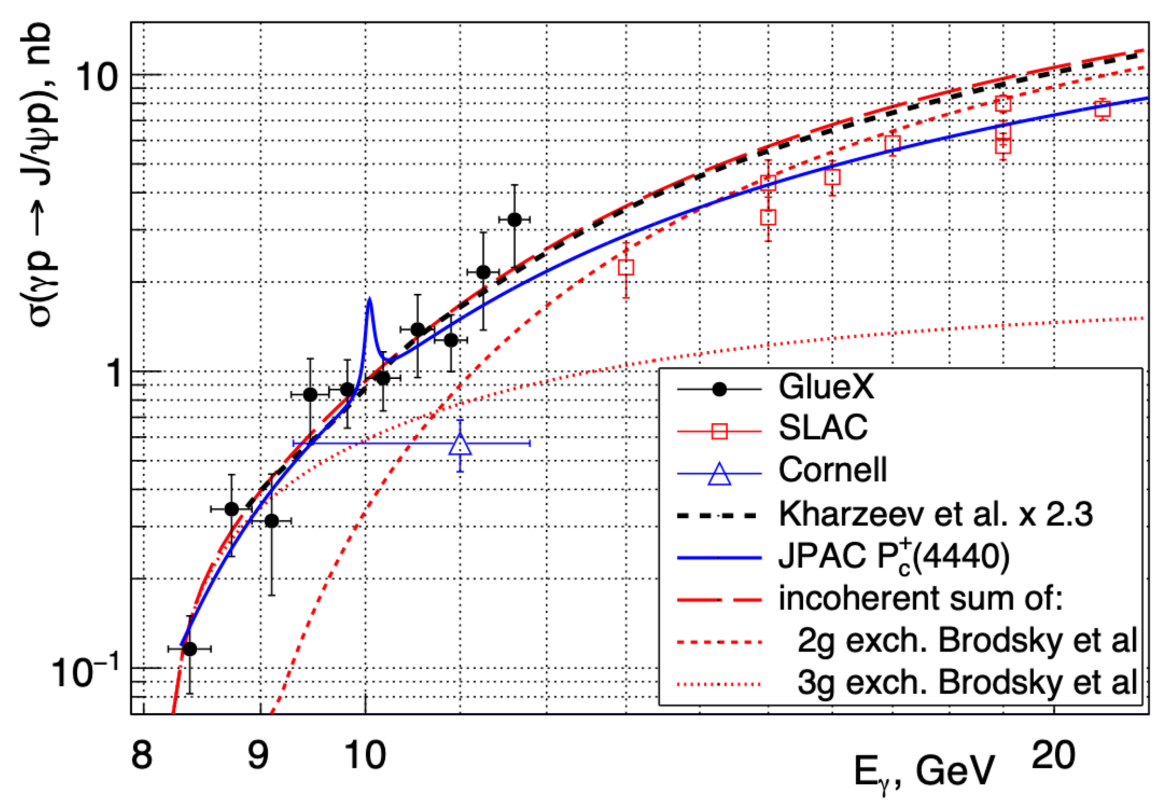
- Analysis Launch Cuts: “loose” cuts that are already applied in ReactionFilter by default
- Common event selections applied by individual analyzers
  - Kinematic Fit χ^2/NDF, Particle ID, Beam energy, Unused tracks or showers, etc.
- Simulation is a powerful tool to choose your cuts
  - Background MC with bggen or other dedicated generators for background processes
  - Signal MC to study efficiency and resolutions

Beam energy selection

- Linearly polarized photons: beam asymmetry or amplitude analysis (see Matt's talk)
- Energy-dependence of production: cross section
- Energy-dependence of detection: systematic comparisons (e.g. branching ratio) between different beam energy regions



http://www.gluex.org/papers/2020nim/paper.html



http://www.gluex.org/papers/2019jpsi/paper.html

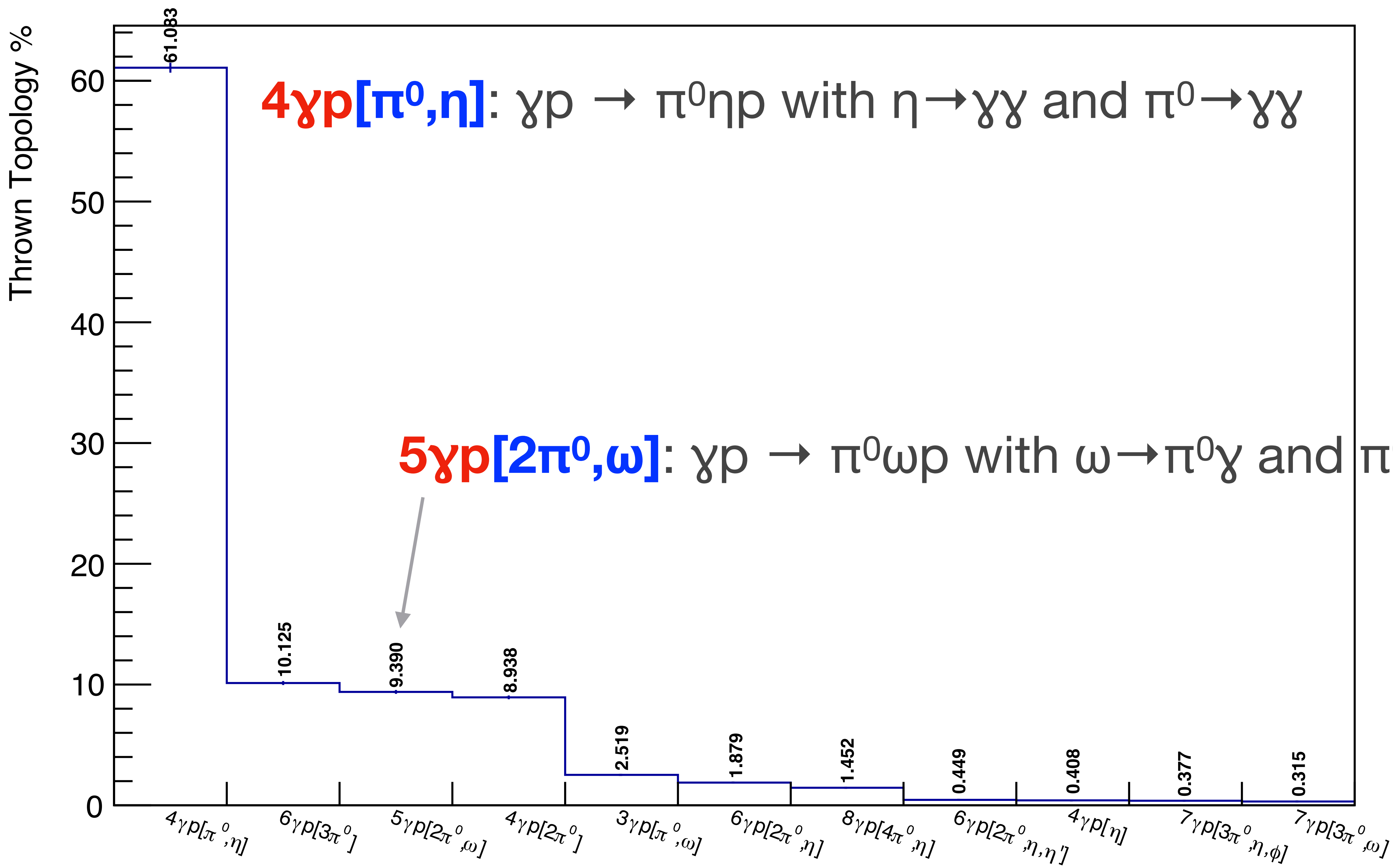
Studying backgrounds with bggen

- ***bggen*: a inclusive MC generator for "all" photoproduction processes based primarily on PYTHIA (some caveats)
- In simulation we know the truth information, so we can cheat and sort events by their reaction or "topology"
  - DSelector library `Get_ThrownTopologyString()` unique TString for for each topology: **NumFinalState[Decaying]**
  - Signal topology $\gamma p \to \pi^0 \eta p$ with $\eta \to \gamma\gamma$ and $\pi^0 \to \gamma\gamma$ corresponds to: **$4\gamma p[\pi^0,\eta]$**
  - Example background topology $\gamma p \to \pi^0 \omega p$ with $\omega \to \pi^0 \gamma$ and $\pi^0 \to \gamma\gamma$ corresponds to: **$5\gamma p[2\pi^0,\omega]$**

https://github.com/JeffersonLab/hd_utilities/tree/master/AnalysisHowTo/ThrownTopology

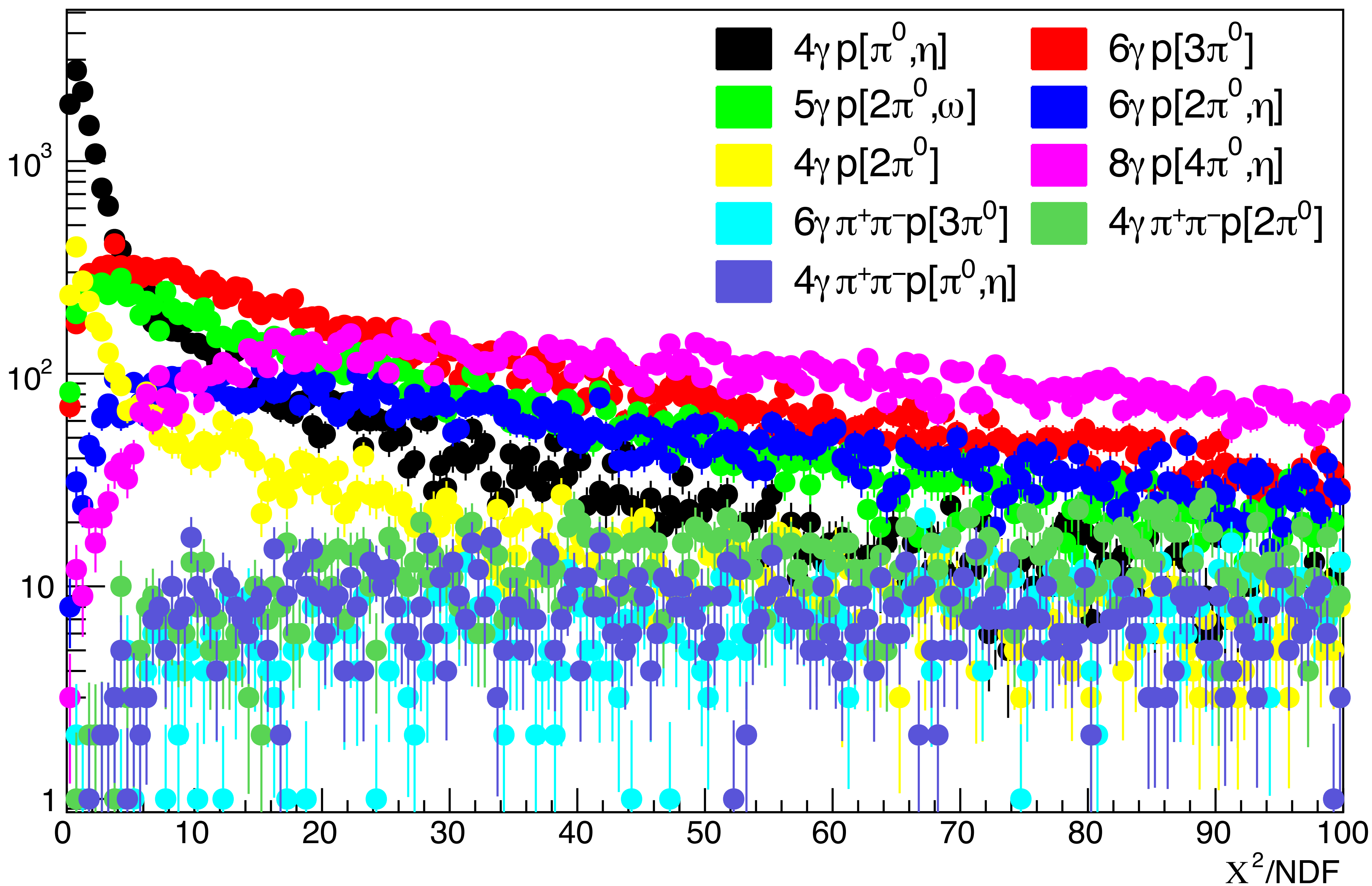
Identify leading backgrounds

- DSelector library `Get_ThrownTopologyString()` unique TString for for each topology: **NumFinalState[Decaying]**



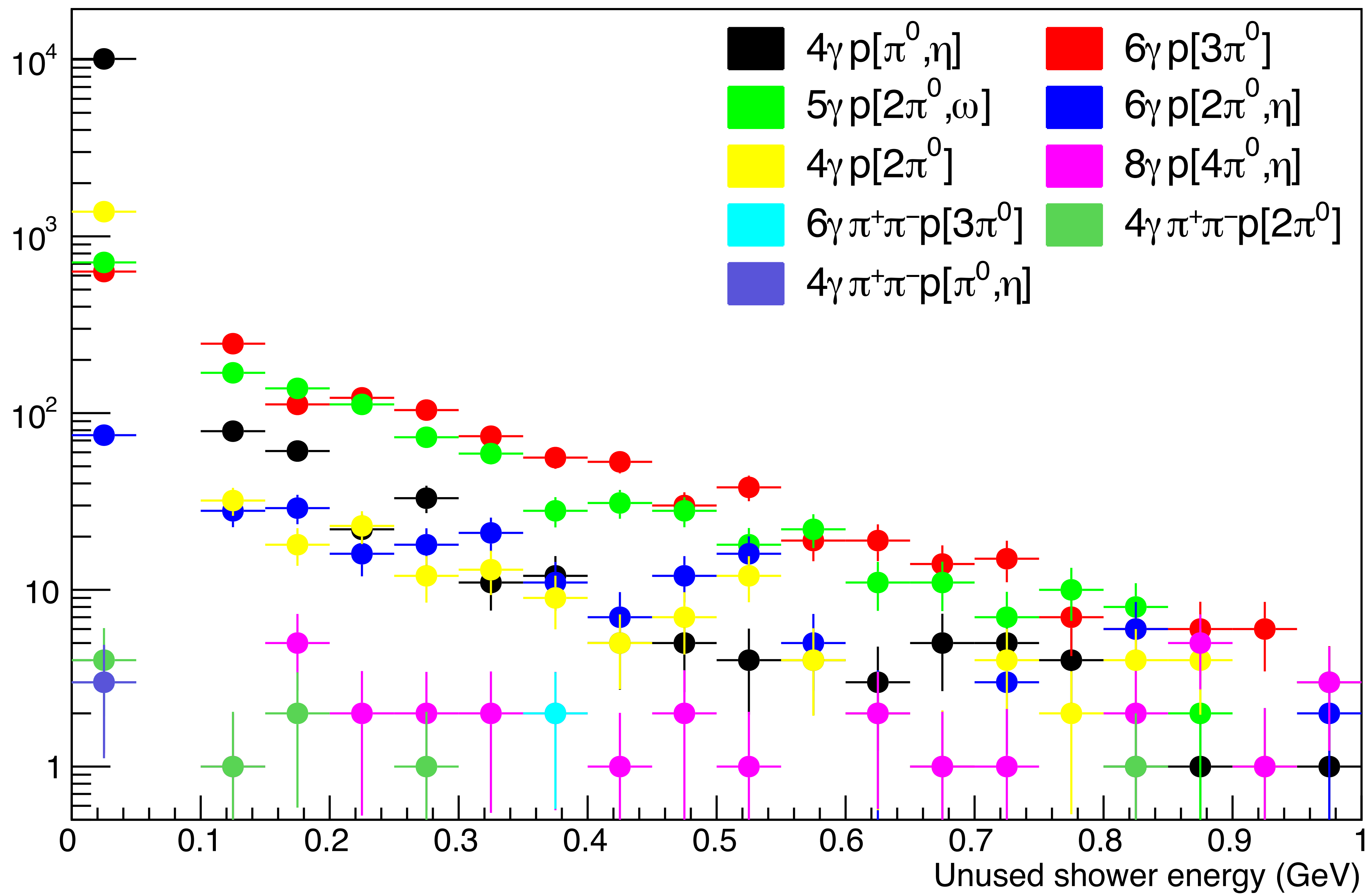
Identify variables to reject backgrounds

- **Kinematic Fit** χ^2/NDF: background topologies less consistent with **4γp** final state



Identify variables to reject backgrounds

- **Unused Shower Energy:** many background topologies have extra showers leading to measured unused energy

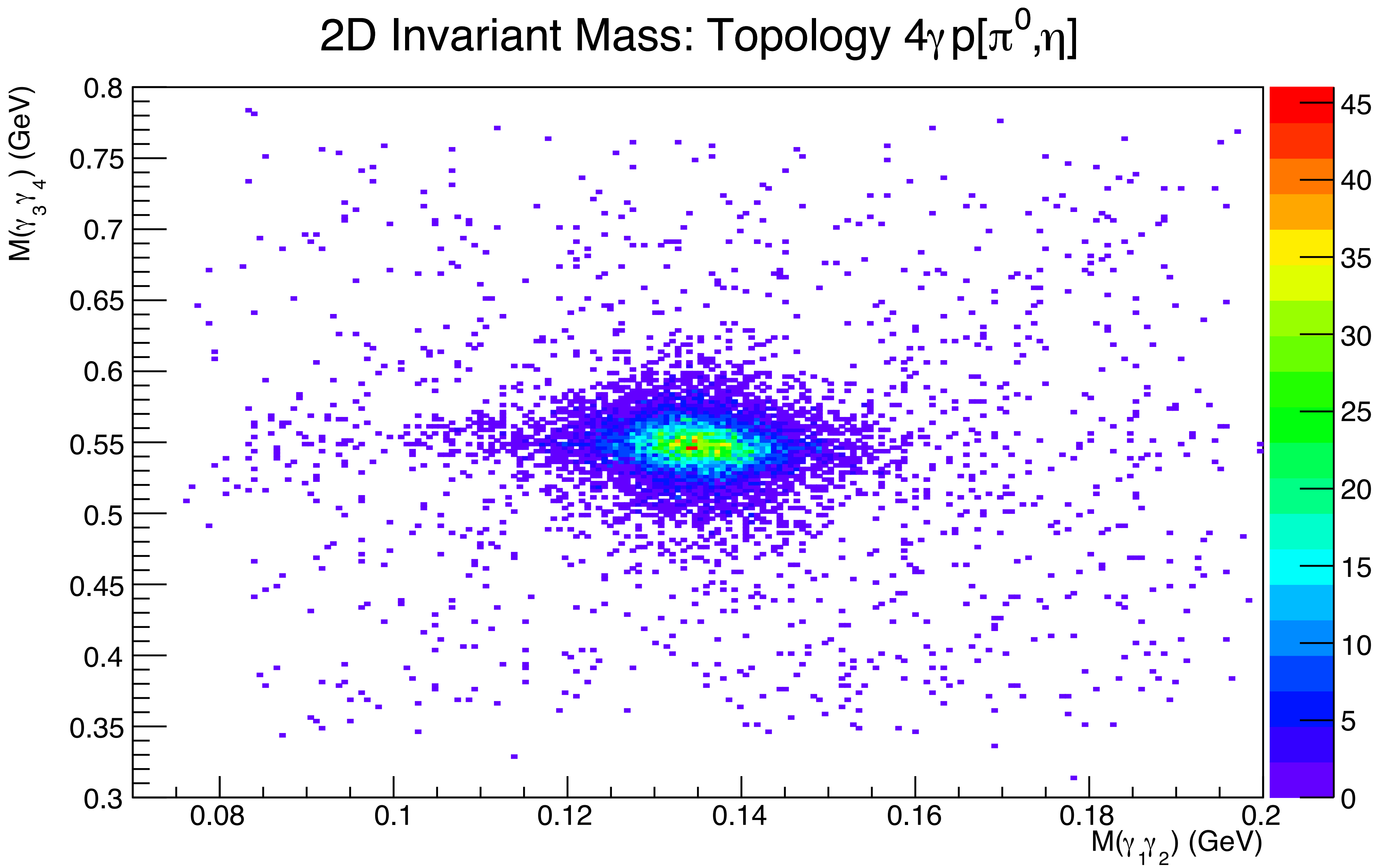


Correctly paired photons $4\gamma p[\pi^0,\eta]$

```
//Step 1
TLorentzVector locPhoton1P4 = dPhoton1Wrapper->Get_P4();
TLorentzVector locPhoton2P4 = dPhoton2Wrapper->Get_P4();
//Step 2
TLorentzVector locPhoton3P4 = dPhoton3Wrapper->Get_P4();
TLorentzVector locPhoton4P4 = dPhoton4Wrapper->Get_P4();
```

Assumed π^0

Assumed η



"Correctly" paired photons 5γp[2π⁰,ω]

```
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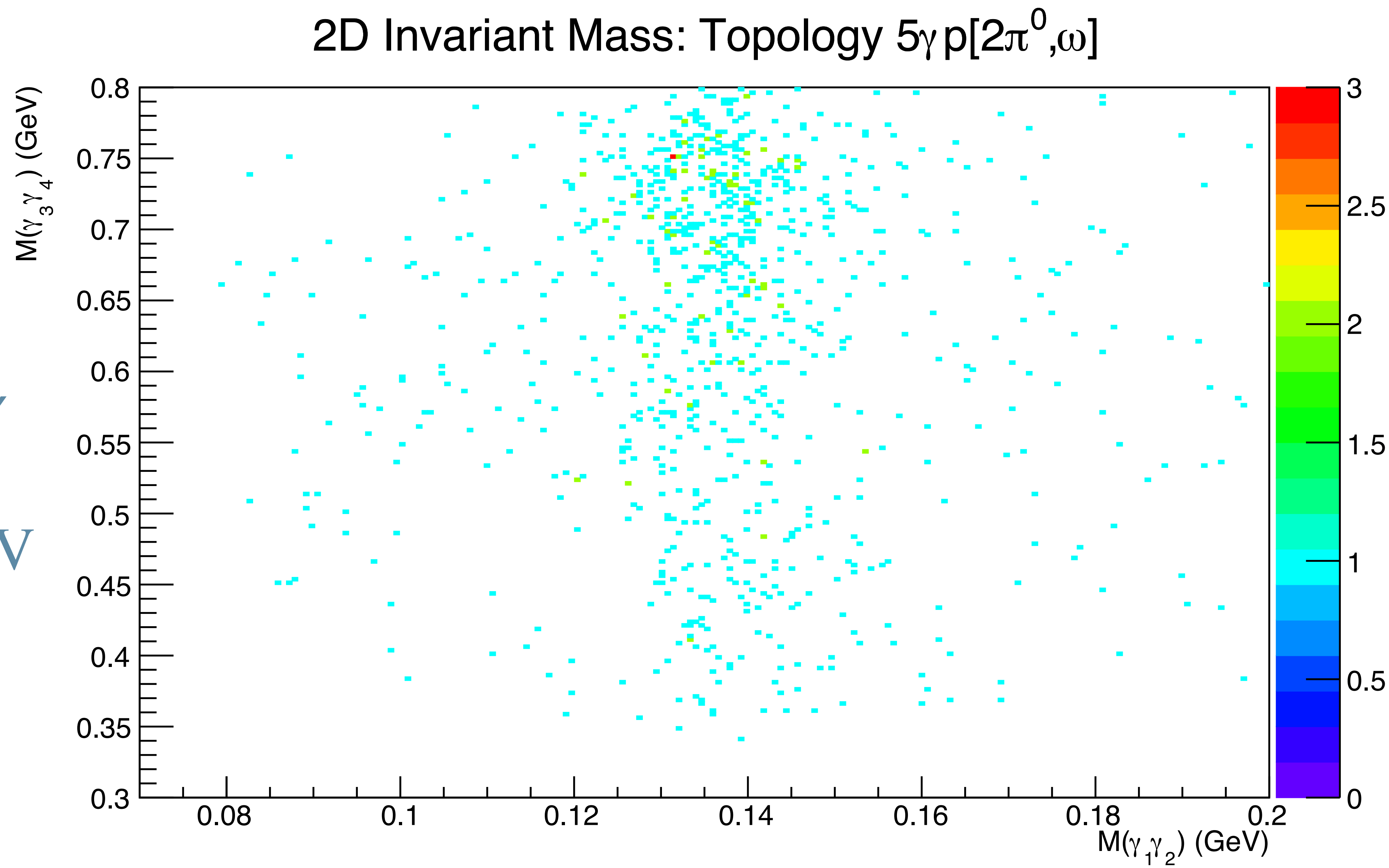

Lose extra γ in

$\omega \to \pi^0\gamma \to 3\gamma$

$m_\omega = 0.782$ GeV

Incorrectly paired photons 4γp[2π⁰]

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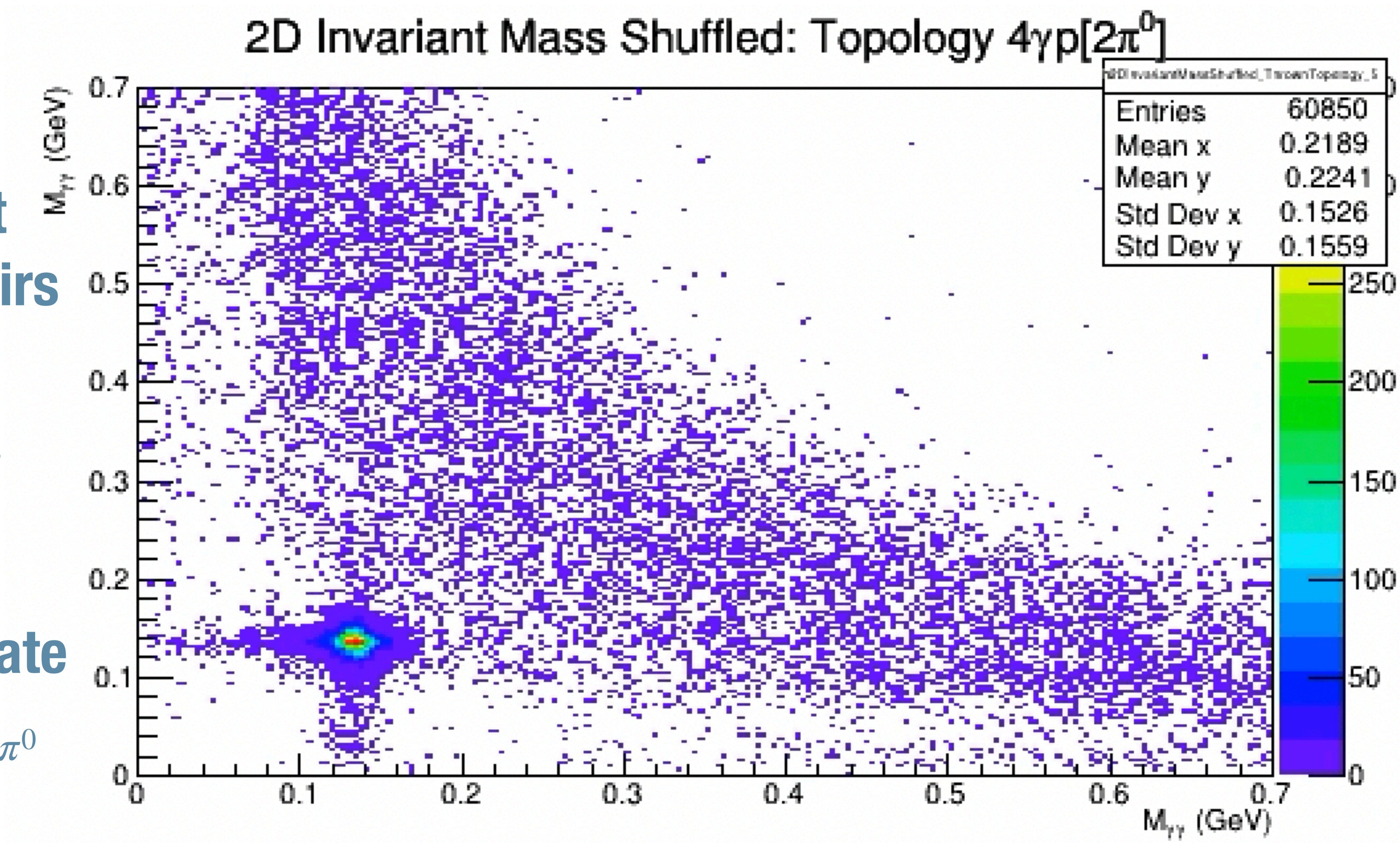
Instead plot alternative pairs

$\gamma_1\gamma_3$ **vs** $\gamma_2\gamma_4$

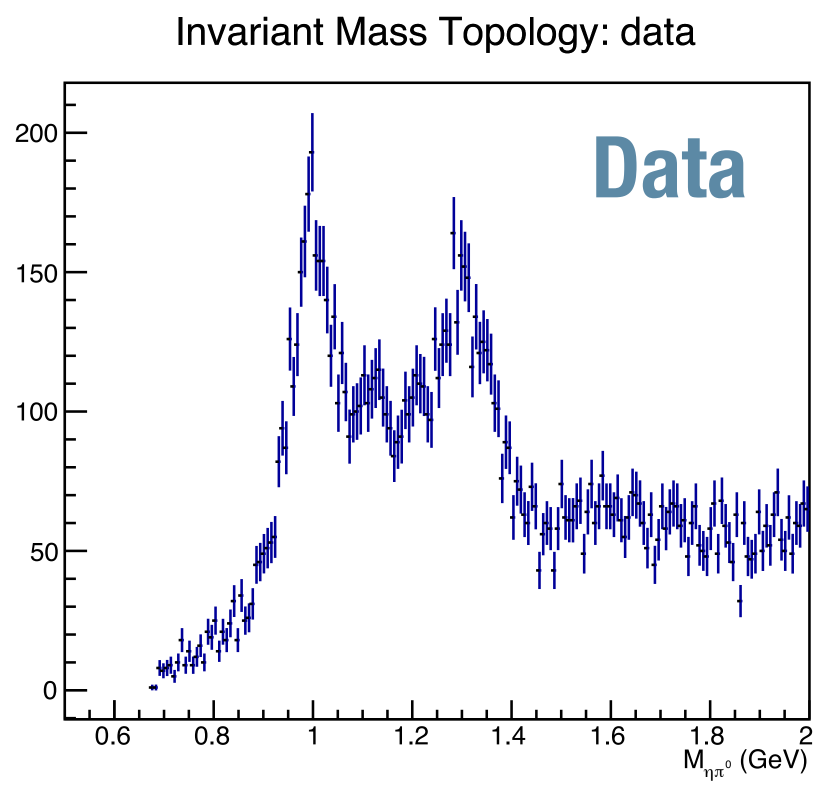
$\gamma_1\gamma_4$ **vs** $\gamma_2\gamma_3$

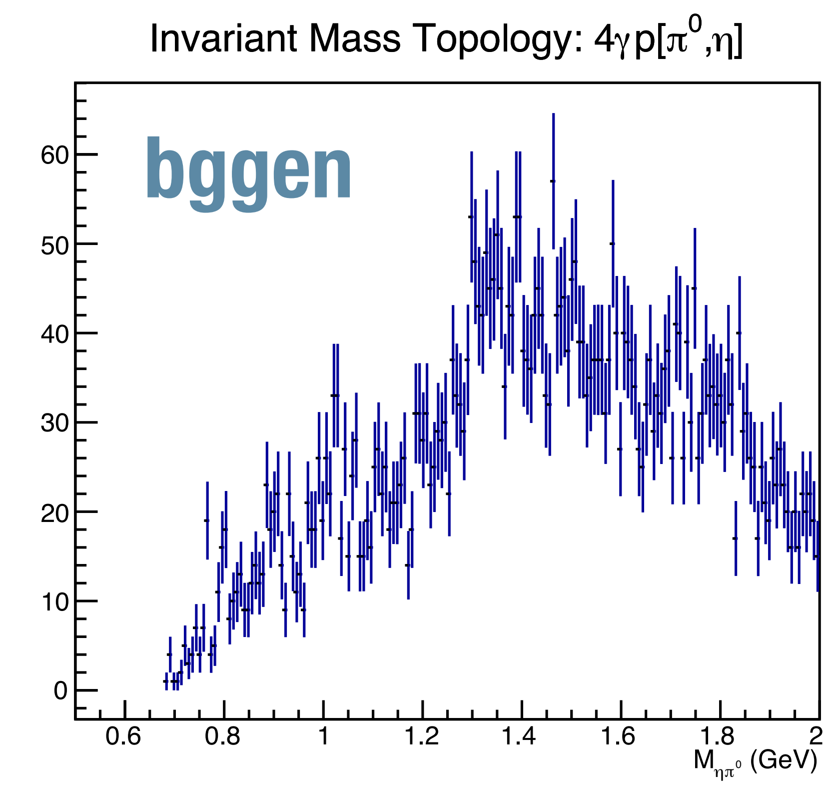
If these alternate pairs have m_{π^0} then reject



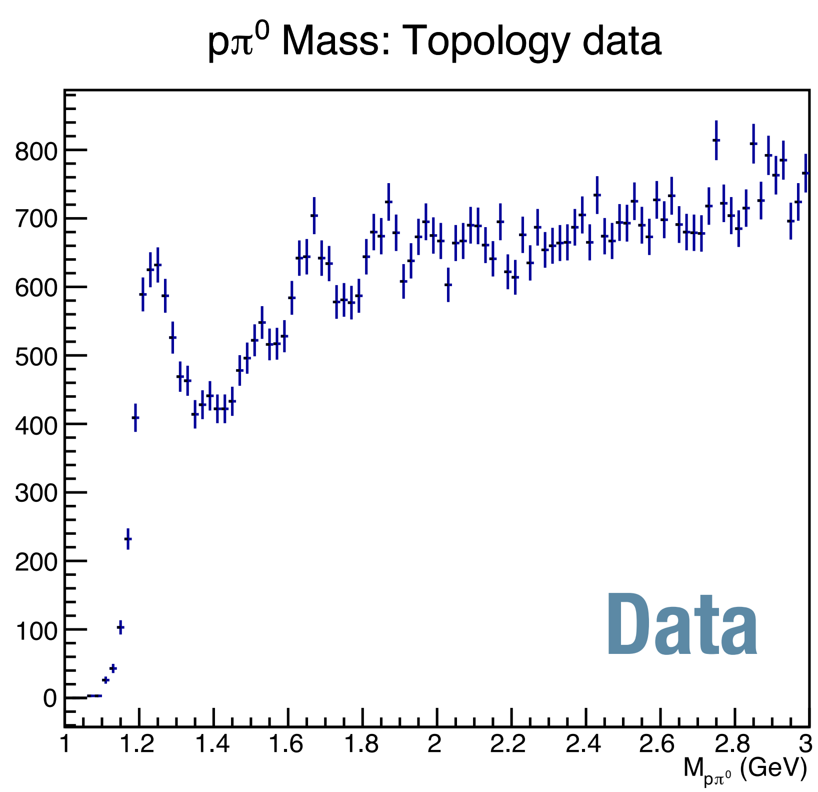
What might bggen be missing?

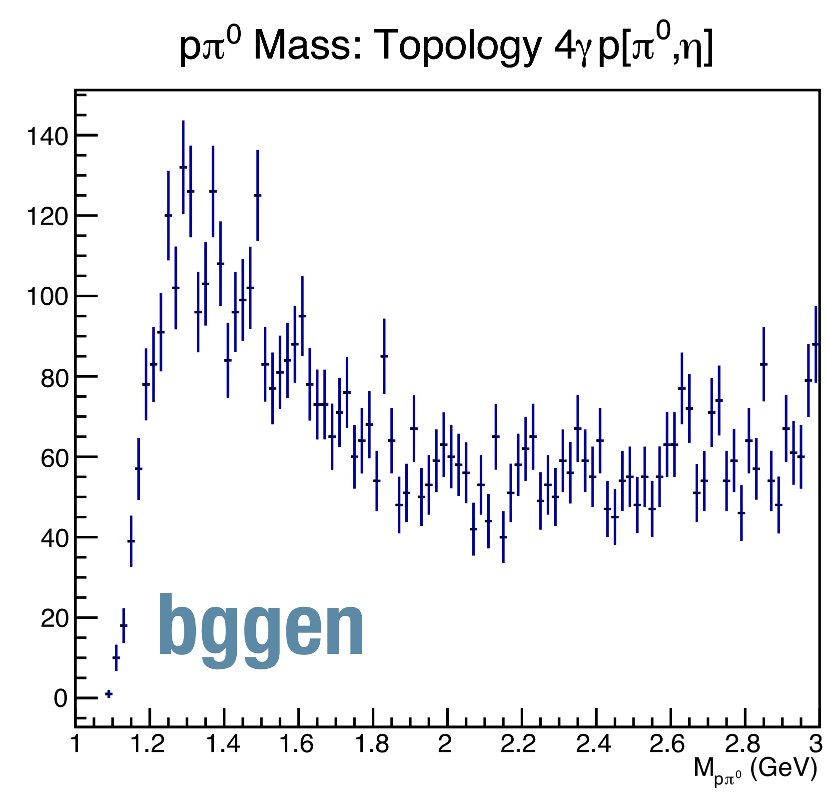
- Meson resonances: a's, b's, f's, h's, etc.





- Baryon excitations: Δ, N*, etc.

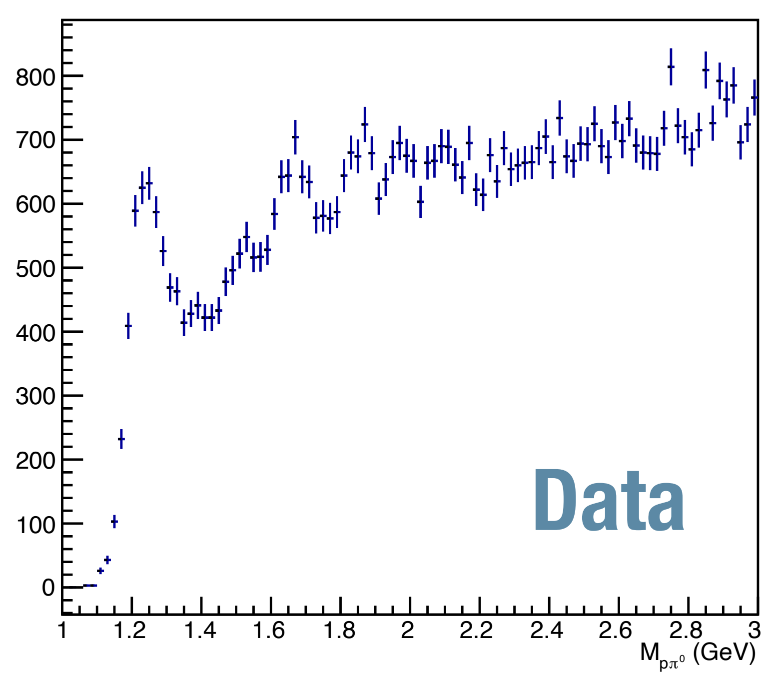


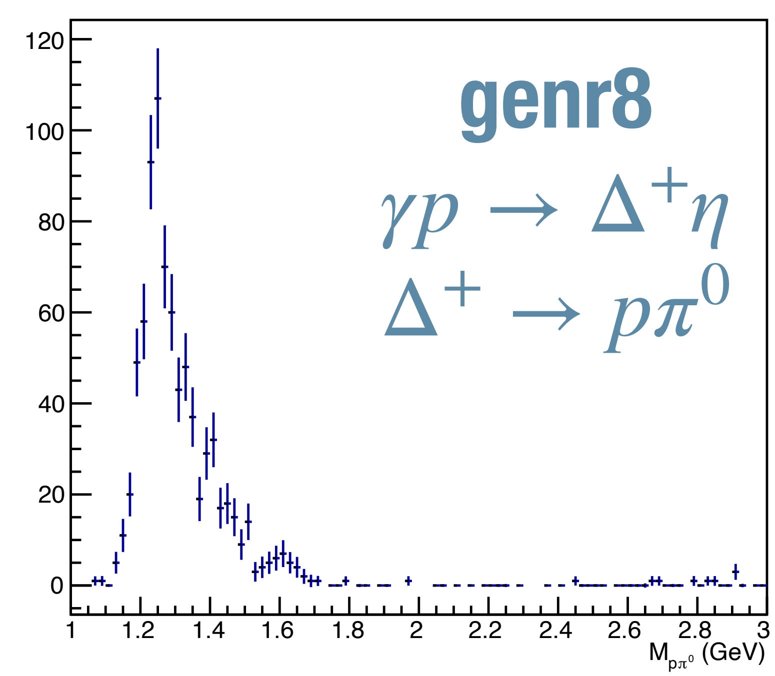


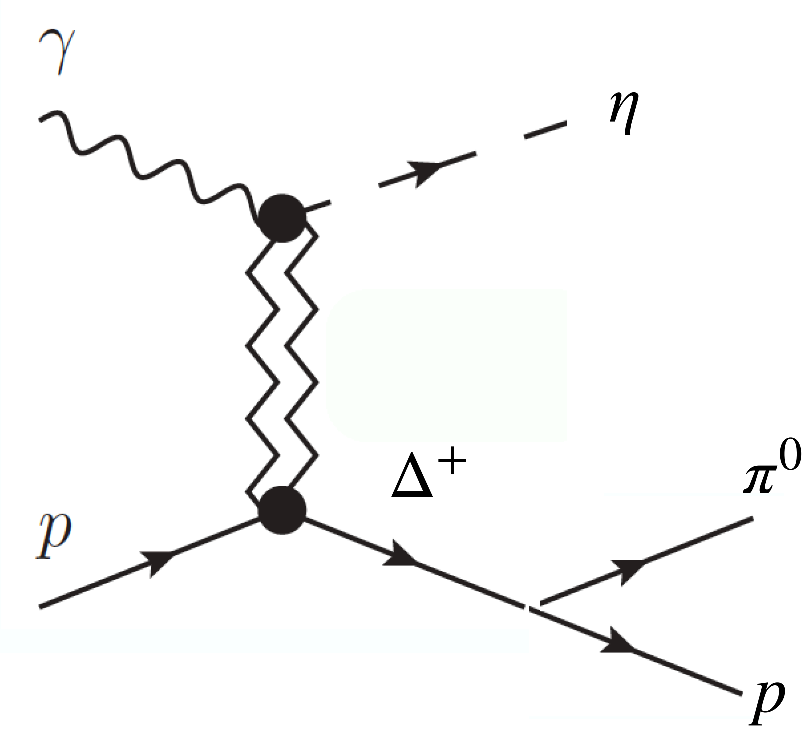
Simulate analysis-specific backgrounds

- If bggen isn't a good enough model for the background in your analysis, you can simulate them individually more accurately
- Use MCWrapper to generate samples (see Peter's talk)
  - Large scale - use web form, e.g. need ~10M+ events
  - Small scale - run interactively (ifarm or institution), e.g. ~10k events to study background distribution (~1 hour turnaround)

```
gluex_MC.py MC.config 30496 10000
```







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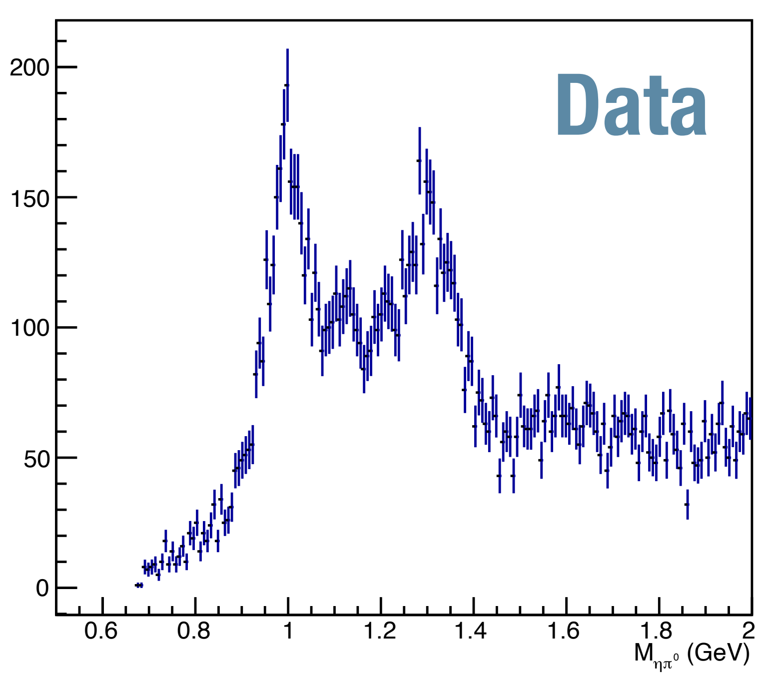
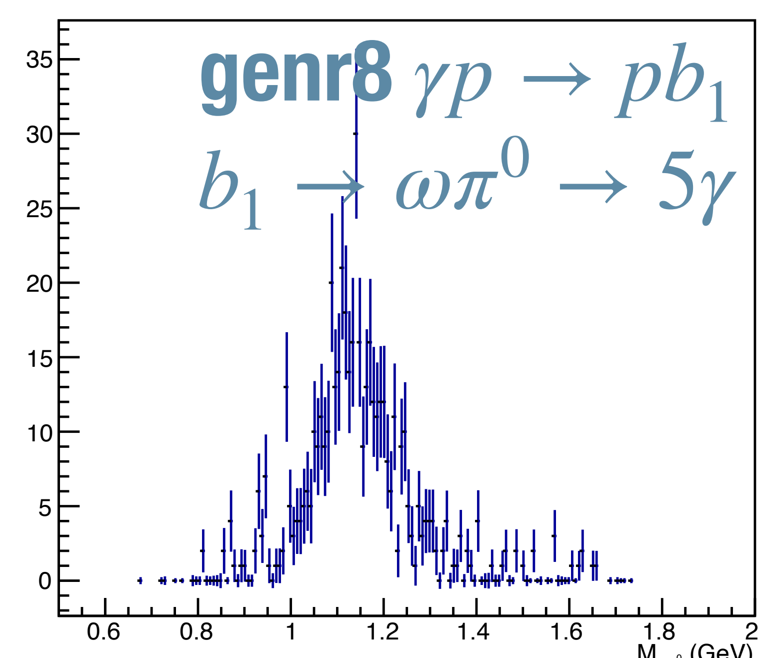
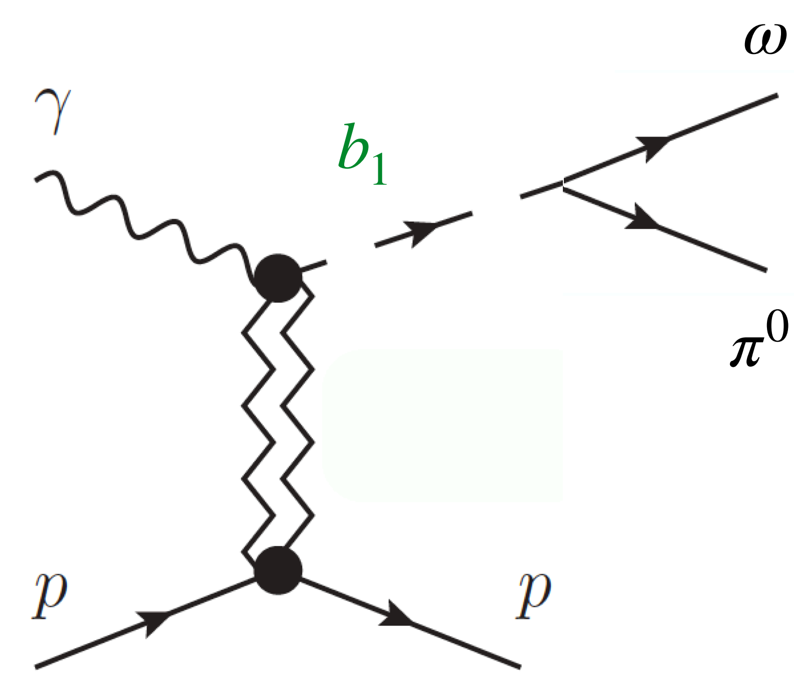




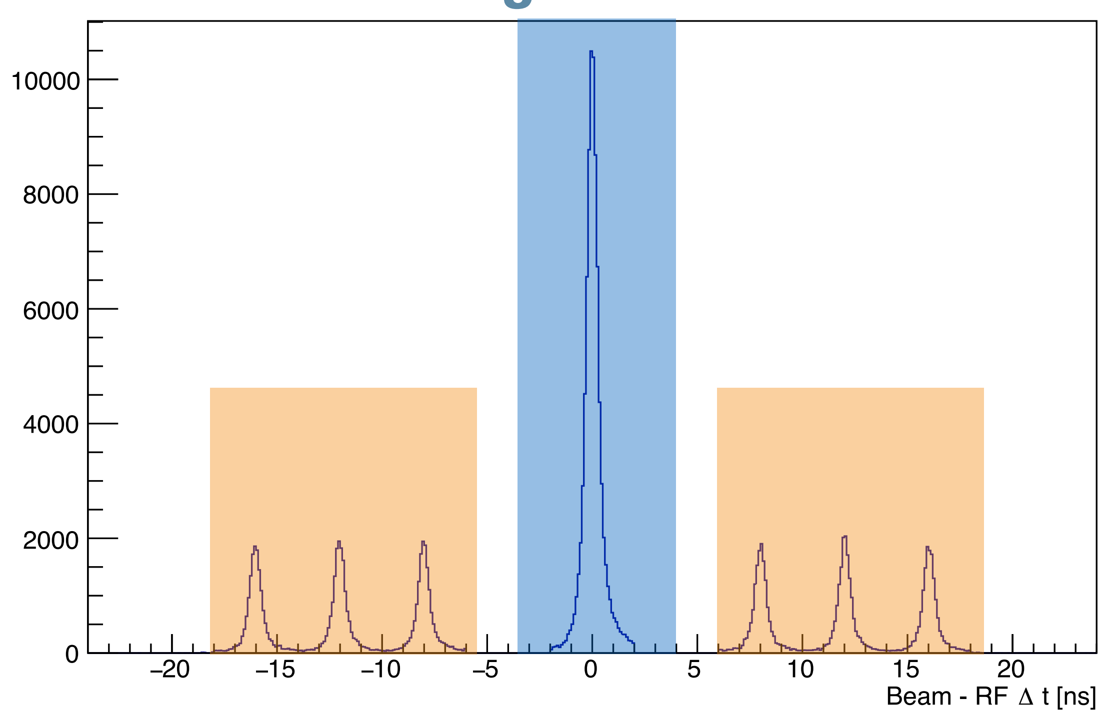
$m_{b_1} = 1.235$ GeV



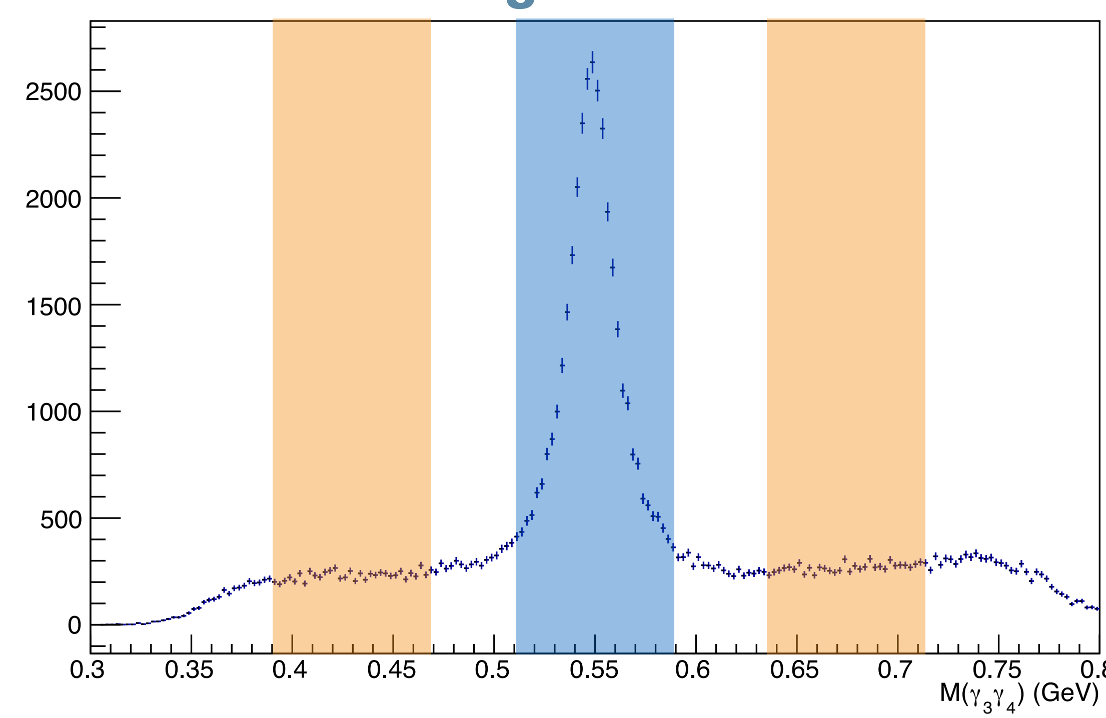
Subtracting remaining backgrounds

- Some backgrounds will remain that we cannot reject on an event-by-event basis
- Instead we statistically subtract them by either subtracting histograms or weighting events
  - e.g. accidental subtraction, mass sideband subtraction

weight = -1/6



weight = -1/2



- After subtraction can compare signal MC and data

Simulate of signal process

- We have better models for many physics processes than what's in bggen: realistic *t*-slope, beam energy dependence, angular distributions, etc.
- Phasespace samples are needed for numerical integrals in amplitude analysis (see Matt's talk)
- What can we learn from signal MC?
  - Efficiency corrections needed for cross sections and amplitude analysis

$$\epsilon(\vec{x}) = \frac{\#\ observed(\vec{x})}{\#\ generated(\vec{x})}$$

  - Reconstruction resolutions: mass, decay angles, etc.

What type of trees should I use?

- **PART format tree** (1 entry per event): see Beni's talk
  - Output of ReactionFilter, input to DSelector
- **Flat tree** (1 entry per combo): see Lawrence's talk
- **FSRoot** (1 entry per combo): see Malte's talk
- Reduce dataset footprint whenever possible
  - Write subset of analysis trees with first pass event selection with DSelector or FlattenFSRoot
  - Goal is to make iterations quickly