# Event Selection for $\eta'\pi^+n$ Using BDT

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# The Channel

- Important channel for $\pi_1(1600)\rightarrow\eta'\pi^+$ searches
- $\gamma p\rightarrow\eta'\pi^+ n$ ; $\eta'\rightarrow\gamma\pi^+\pi^-$ (Branching fraction 29.3%)
  - Final state particles: $\gamma\pi^+\pi^-\pi^+ n$
- G. S. Adams *et al.* [CLEO Collaboration], "Amplitude analysis of the decays $\chi_{c1}\rightarrow\eta\pi^+\pi^-$ and $\chi_{c1}\rightarrow\eta'\pi^+\pi^-$," Phys. Rev. D **84**, 112009 (2011) [arXiv:1109.5843 [hep-ex]].

# η’ Cross Section Measurement

- Pythia events were counted to give an estimate for the expected signal to background ratio

| | Total Events | Fraction |
|---|---|---|
| Total B.G. | 1,000,000 | 100% |
| η'π+(n) inclusive | 7,677 | 0.77% |
| π+π-π+(n) | 29,964 | 3.00% |

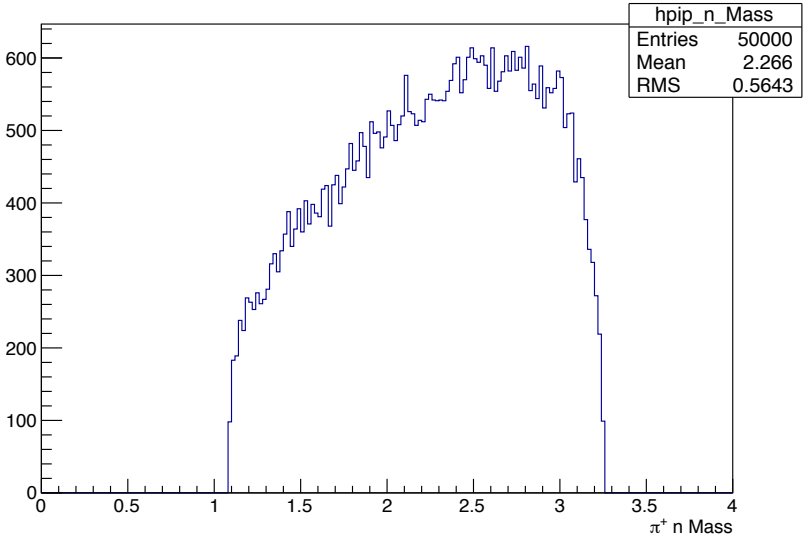
| | Total Events | Fraction | PDG Report |
|---|---|---|---|
| η'π+(n) inclusive | 7,677 | 100% | |
| η'->ϒπ+π- | 2,319 | 30.21% | 29.4% +/- 0.9% |
| η'->π+π-η | 3,387 | 44.12% | 44.6% +/- 1.4% |

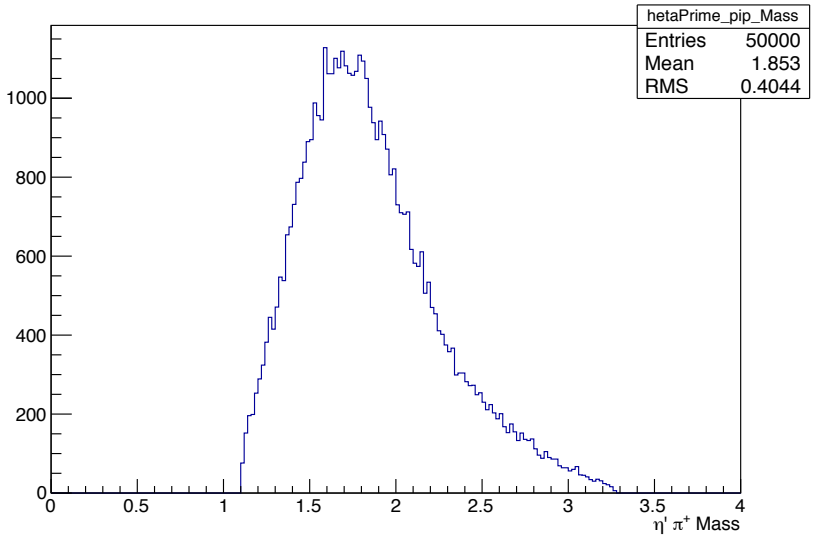
# η’ Cross Section Measurement Assumptions

- The above measurement was made for $\eta'\pi^+n$ **inclusive** events
- In addition, PYTHIA is generating a $\Delta^+(1232)$; $\Delta^+(1232)$->$\pi^+n$ resonance
- **No $\pi_1(1600)$ resonance found in PYTHIA**

# η’ Cross Section Measurement

- Therefore, a **separate signal** sample is generated with a **$\pi_1$(1600) resonance**
- Start with **50k** separate signal events and **20M PYTHIA background** (to match PYTHIA’s prediction for η'π+n inclusive signal to background ratio)
- η’$\pi^+$n inclusive events **removed** from **background** sample

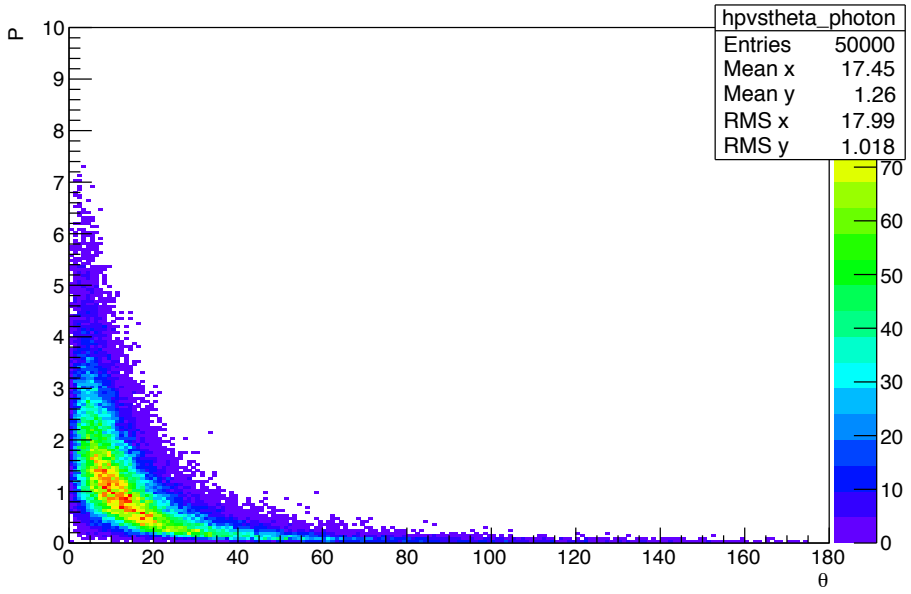


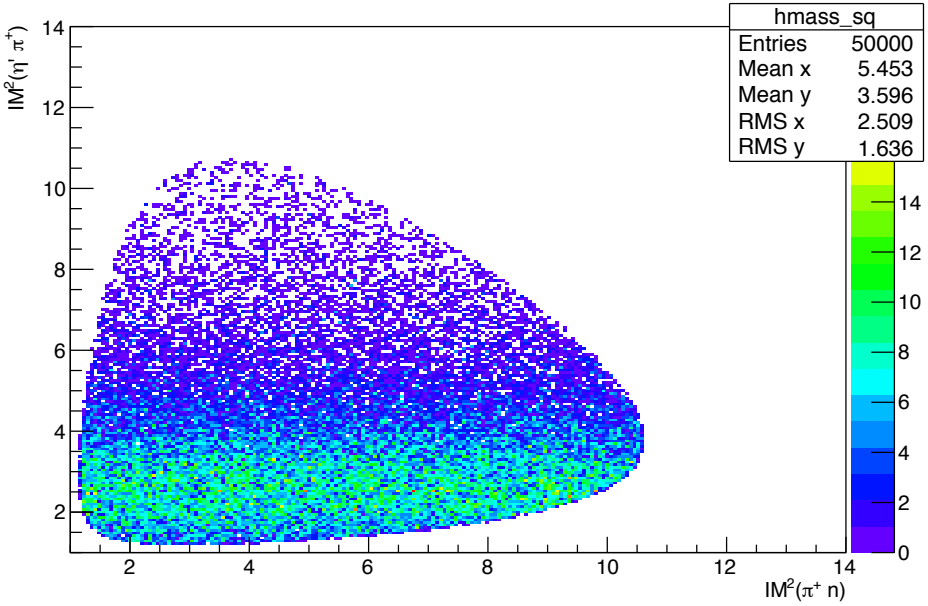

Separately Generated η’$\pi^+$n events

# Signal Sample

## P Vs. Theta Photon




## Dalitz Plot

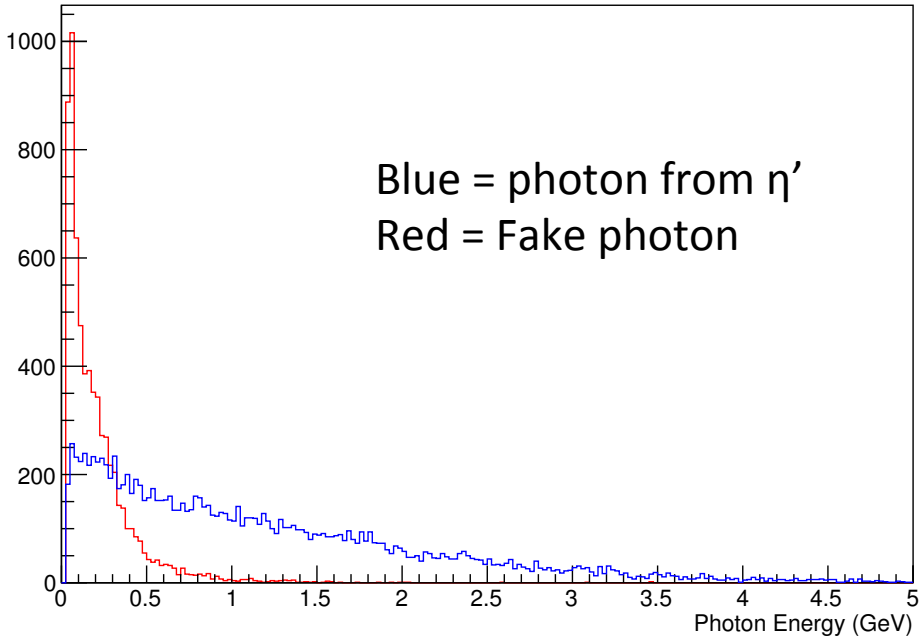


# Kinematic Fit

- A **kinematic fit** is applied to the final state particles $\gamma\pi^+\pi^-\pi^+$ for both signal and background samples
- **140k signal event-combinations and 48M background event-combinations** that pass the kinematic fit (using software from February)
- Next, event quality cuts are applied
  - Kinematic Fit F.O.M. > 0.01
  - >5 tracking degrees of freedom for each pion track
  - Tracking F.O.M. > 0.001 for each pion track
  - Energy of the Photon > 100 MeV

# Photon Energy Cut

- Within the signal sample, fake photons from final state interactions with the detectors routinely pass the event- quality cuts
- Many of these fake photons are low in energy




Signal Sample

# Multivariate Analysis

- Next, TMVA is used to further reduce the background
- Need to specify discriminating variables
- Find subsample of signal to train on that doesn't include fake photon event-combinations
- Background to train on will have $\eta'\pi^+n$ inclusive events removed

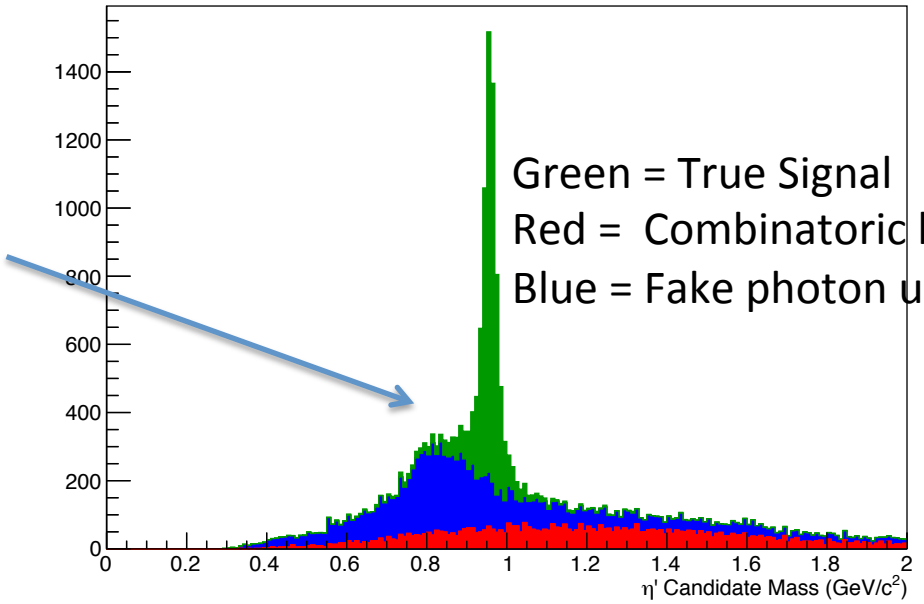
# Selecting “true signal” for TMVA

- Within the separate signal sample, there is mis-reconstructed background (fake photons) and combinatoric background
  - Combinatoric background is from the kinematic fit artificially doubling the event-combinations found by switching the 2 $\pi^+$
- For the TMVA, this subsample of our signal will be used as background

# Selecting “true signal” for TMVA

- Train only green peak as “signal” for TMVA

Histograms stacked

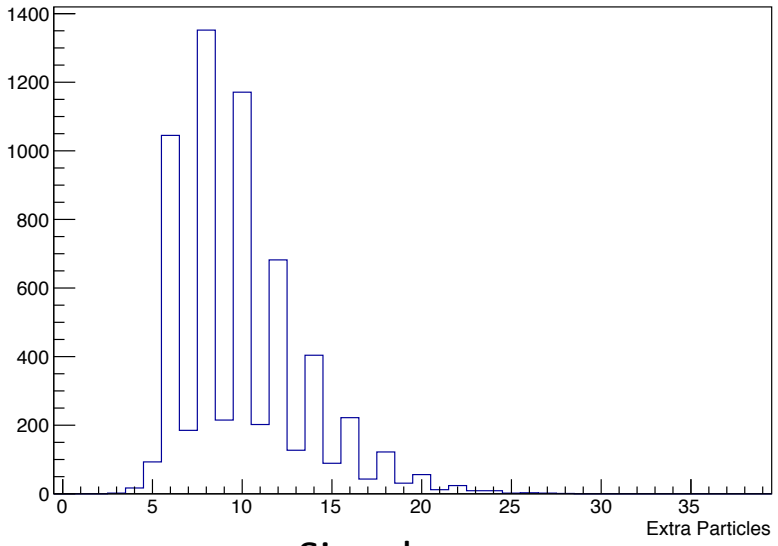


# Input Variables for TMVA

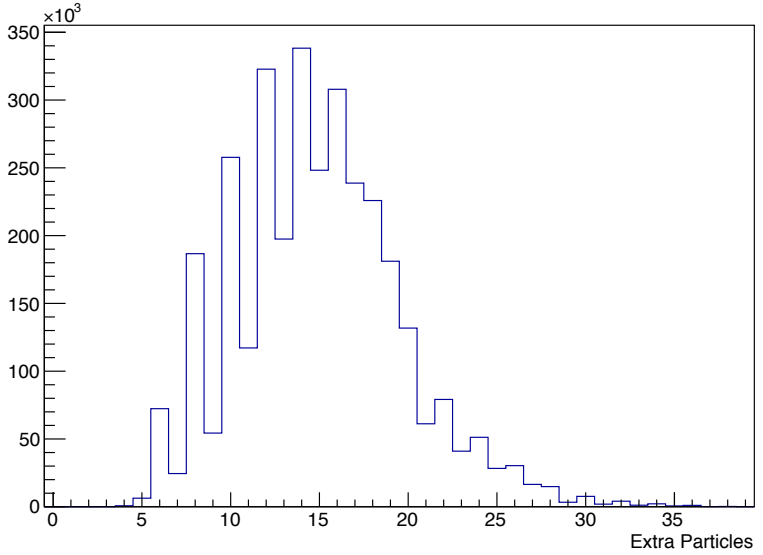
- The next step is to find discriminating variables to use in the TMVA
  - Number of unused track hypotheses
  - Number of unused photon hypotheses
  - Energy of unused photons
  - $\pi^0$ mass
  - Unused energy FCAL/BCAL, timing FOM, track quality, pion dE/dx, ext.

# Unused Track Hypotheses

- The number of unused track hypotheses is a useful discriminating variable
- For the **signal**, these are all **mis-reconstructed tracks** from final state interactions (e.g. fake photons)
- **Background** sample has channels with **more primary interaction products**



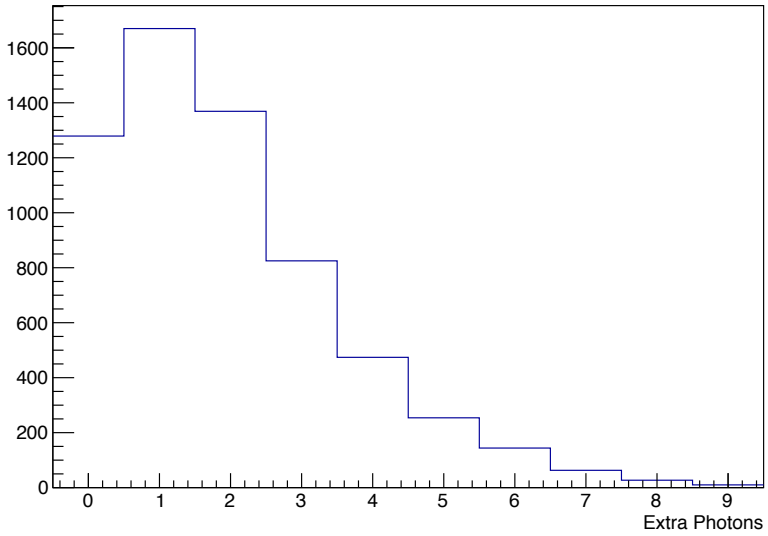

Signal



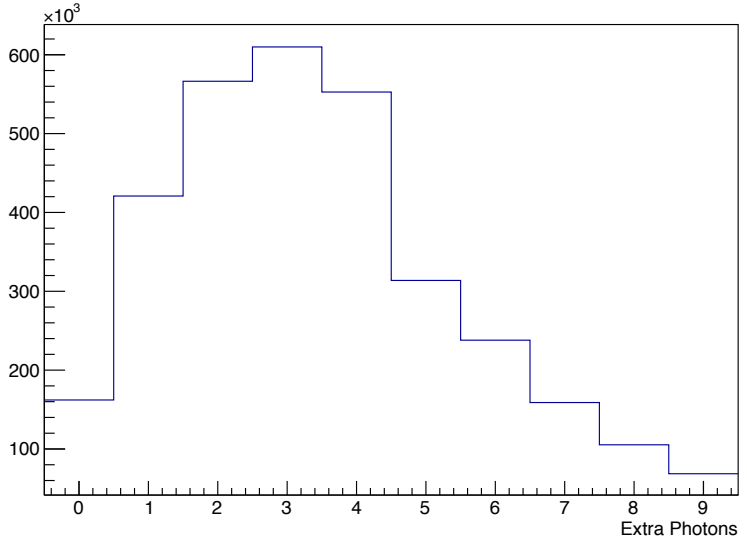

Background

# Unused Photons

- The number of unused tracks that can be reconstructed as a photon
- In **signal**, these are all **fake photons**
- In **background,** these also could come from other primary interaction decay products (e.g. **$\pi^0$ or $\eta$**)



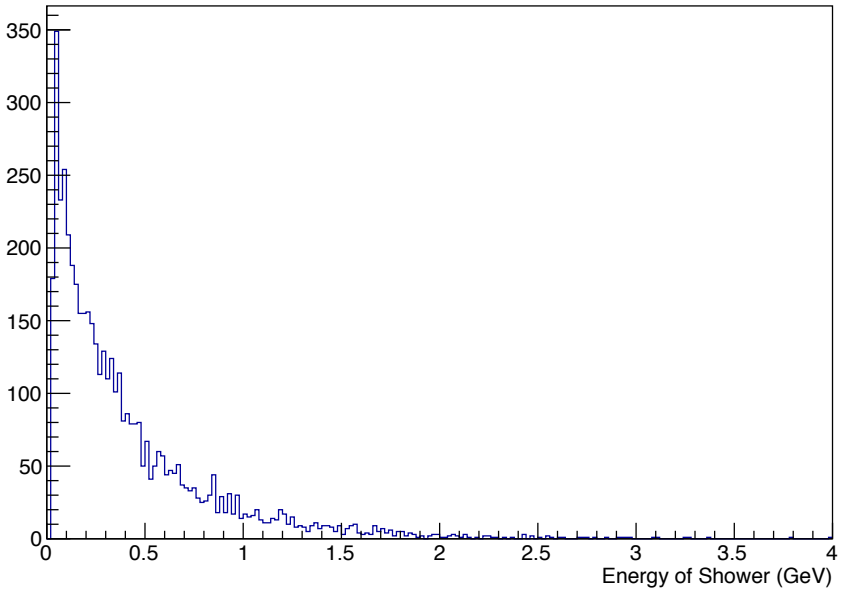

Signal



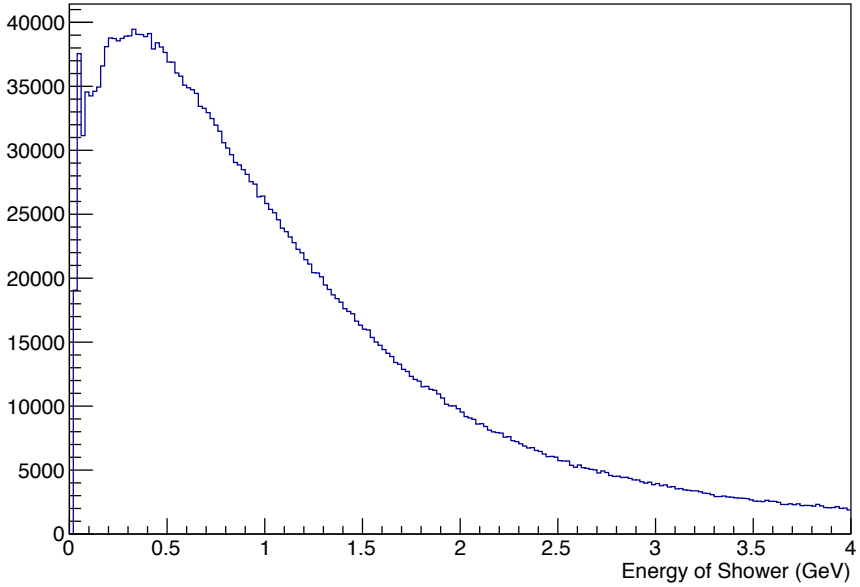

Background

# Unused Photon Energy

- The combined energy of all of the unused photons
- Histograms filled only if at least one extra photon was found



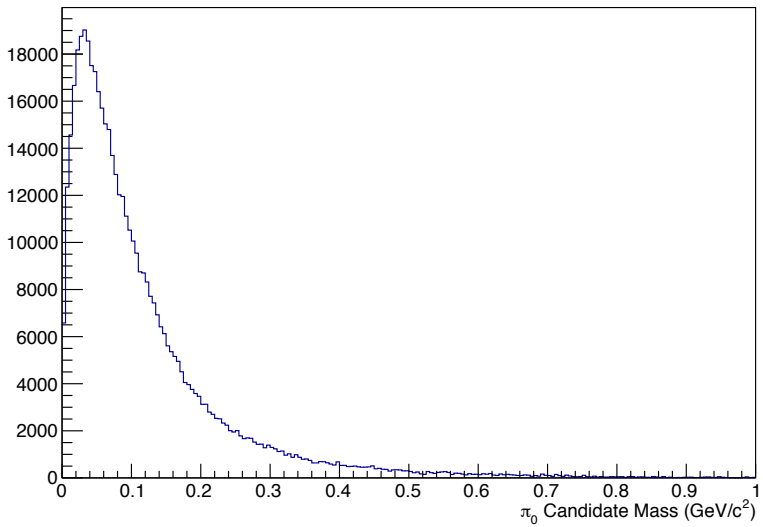

Signal



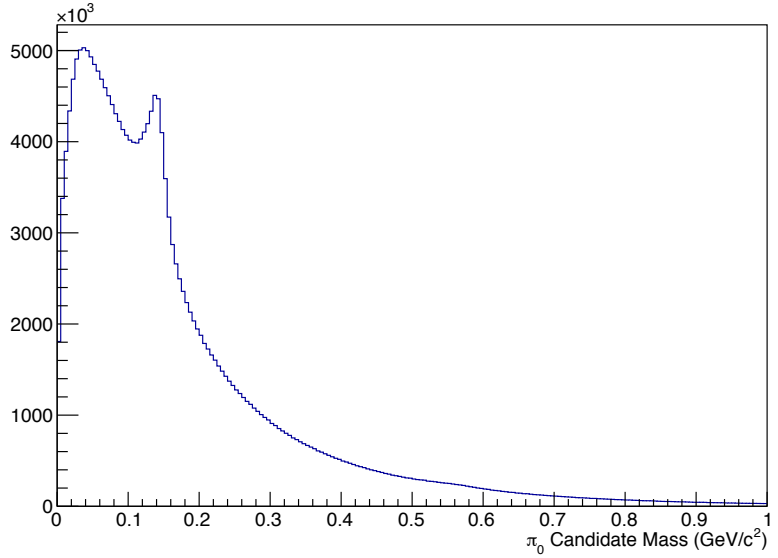

Background

# $\pi^0$ mass

- Backgrounds commonly passing the event quality cuts have extra $\pi^0$s in the final state
- Plotted below is the invariant mass of the η' photon (used in kinematic fit) and each of the other photons



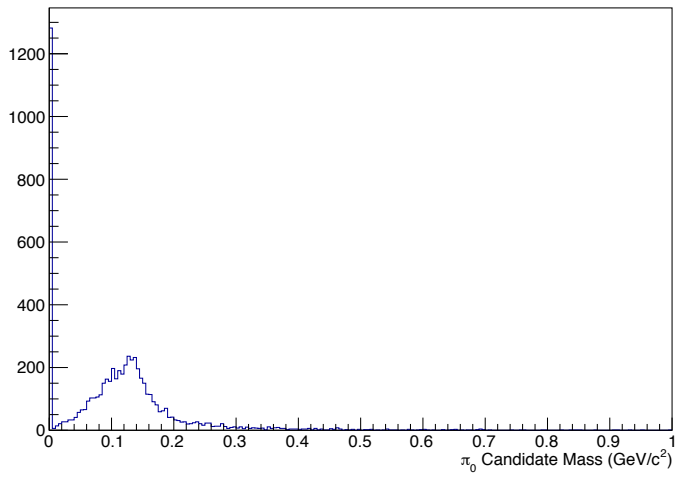

Signal



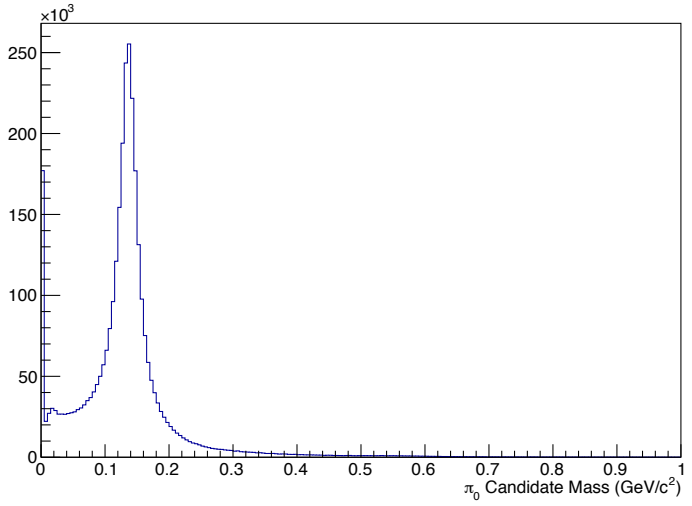

Background

# $\pi^0$ mass

- However, we cannot just plug this into the BDT (since there are multiple unused photons per event, and we can't pass in arrays to the BDT)
- Instead, after looping over all of the unused photons, I picked out the one closest to the $\pi^0$ mass and plugged that mass into the BDT




Signal



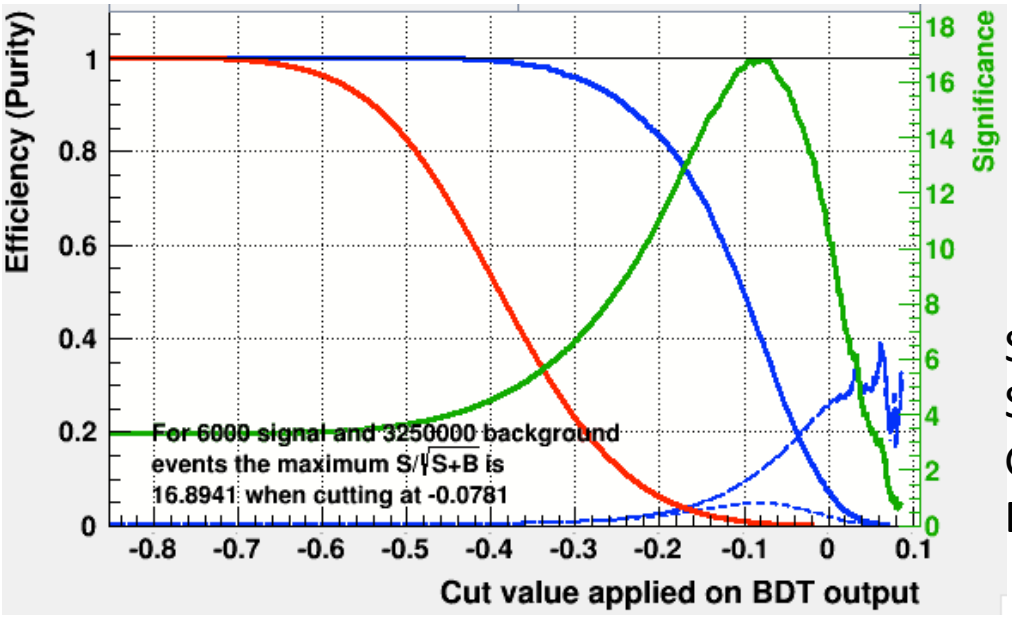

Background

# TMVA Training

- Next the TMVA is trained on these variables and more
- After the event-quality cuts and moving the mis-reconstructed and combinatoric background from the signal sample to the background there remains **6k signal event-combinations** and over **3M background event-combinations** to train on

# TMVA Results

- Cut is applied to the BDT value of highest significance

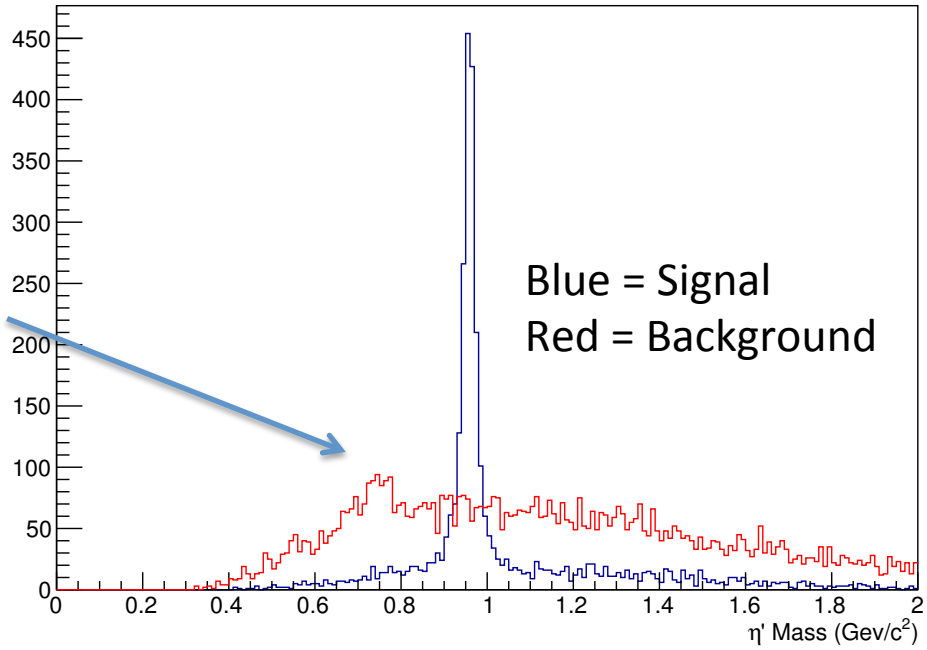



Solid Blue = signal eff.
Solid Red = background eff.
Green = significance
Dashed blue = purity

# TMVA Results

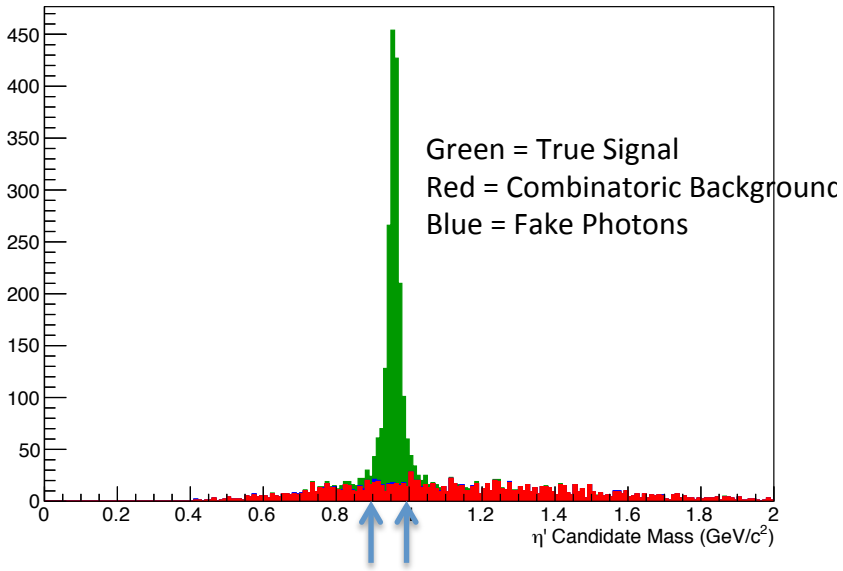
- After applying a BDT cut, there remains 3k signal events and 8k background events

Histograms not stacked

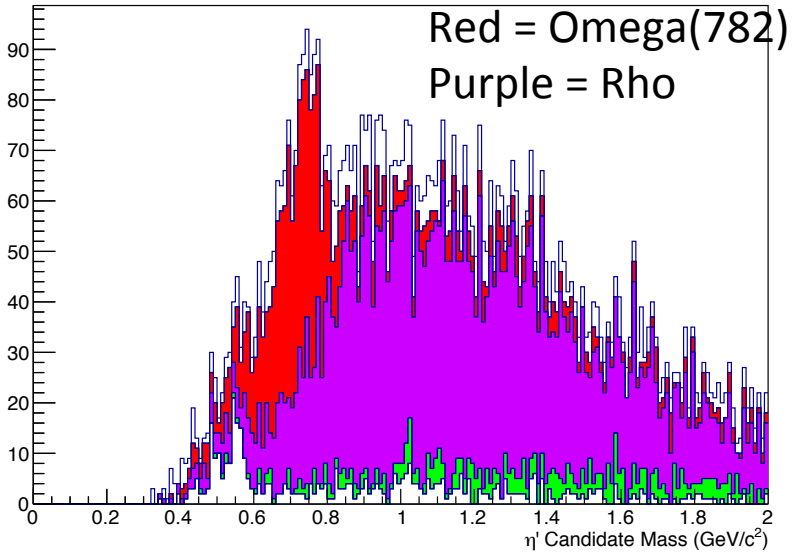


# TMVA Results

- Fake photon events mostly removed by TMVA
- Only 2 major backgrounds remain from reactions with ω and ρ. (e.g. $\omega\,\pi^+ \rightarrow \pi^+\pi^-\pi^0\pi^+ n \rightarrow \gamma\gamma\,\pi^+\pi^-\pi^+ n$ and $\rho^+\pi^+\pi^- n \rightarrow \pi^0\pi^+\pi^+\pi^- n \rightarrow \gamma\gamma\,\pi^+\pi^-\pi^+ n$)



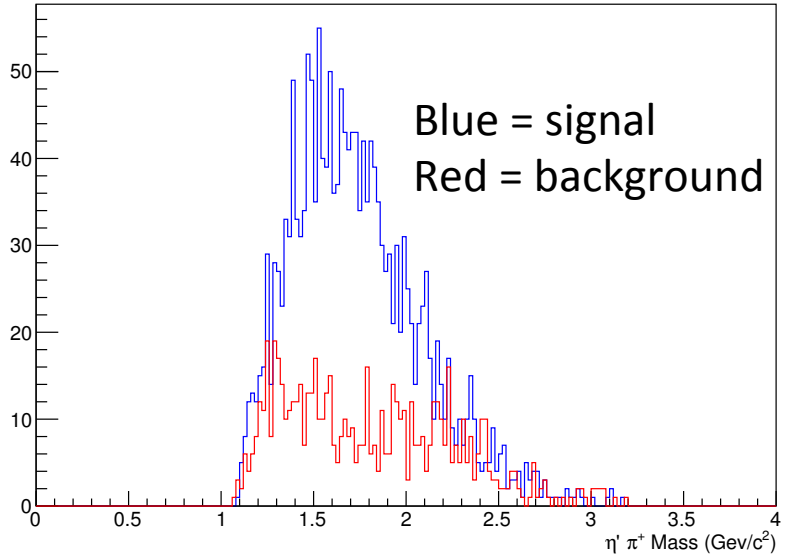

Full Signal Sample




PYTHIA Background Sample

# TMVA Results

- When cutting between 900 MeV and 1 GeV, there remains 1820 signal event-combinations and 793 background event-combinations
  - Signal efficiency of 3.64% and purity of 69.7%




| | Signal | Background | Efficiency | Purity |
|---|---|---|---|---|
| Generated Events | 50,000 | 20,000,000 | 100% | 0.03% |
| Event Comb. Found | 140,247 | 48,533,592 | | |
| Pass Quality Cuts | 17,000 | 3,250,000 | 34% | 0.50% |
| Pass BDT Cuts | 3,000 | 8,000 | 6% | 27% |
| Pass Mass Cut | 1,820 | 793 | 3.60% | 69.60% |

# Conclusions

- Much of the background can be reduced for $\gamma p \rightarrow \eta' \pi^+ n$ ; $\eta' \rightarrow \gamma \pi^+ \pi^-$ using the TMVA
- Remaining background dominated by Rho and omega(782)
- Other η' decay modes might be possible
- A document containing this analysis will be uploaded to the database
- Repeat analysis using larger data sample from the data challenge