Neutral Pion Reconstruction in CH at < Eν > ~ 6 GeV

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MINERνA Experiment

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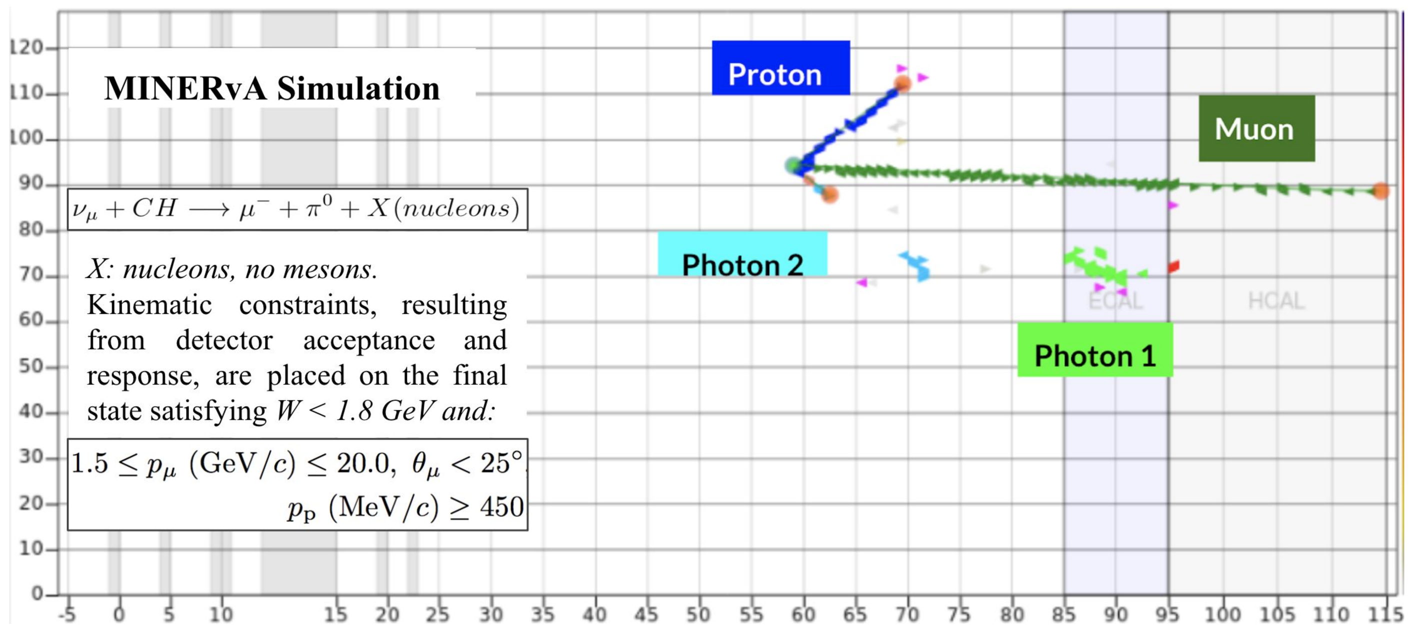
Motivations

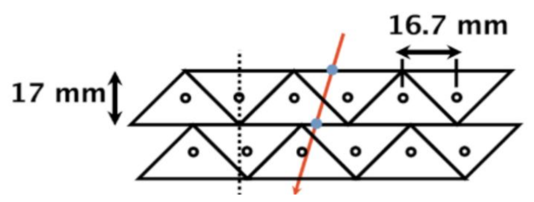
- Neutral pions can be misidentified as electrons.
- Cross-section for Delta production since Delta production with an absorbed neutral pion would appear as quasielastic-like.
- Resonance production is the most abundant interaction mechanism in DUNE energy.
- Pion kinematics is a background for neutrino oscillations analysis.
- FSI simulation models can be improved by analyzing the CC(π) scattering on different nuclei.

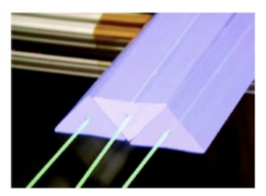
Signal Selection

Muon neutrino charged current single neutral pion event, whose final state particles are a muon and one neutral pion together with any amount nucleons (protons and neutrons).



Scintillator: triangular strips of scintillator are arranged so charged particles hit more than one strip, giving better position resolution. (~2.65mm)





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Acknowledgments

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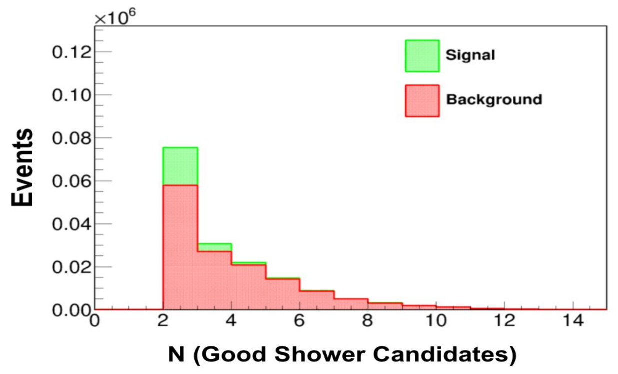
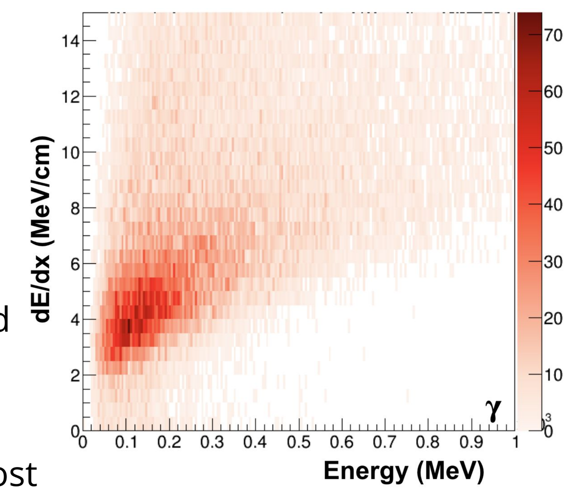
Neutral Pion Reconstruction

A pair of Electromagnetic Showers as gamma candidates produced via $\pi^0 \to \gamma\gamma$

- Clusters: nested set of hits in a single plane in the same time slice.
- The available clusters are grouped into conical regions about the neutrino interaction vertex (Bayesian Algorithm).
- With the assumption being that they arise from an electromagnetic shower originating at the neutrino interaction vertex.



Photons show a logarithmic correlation as a function of the reconstructed energy.

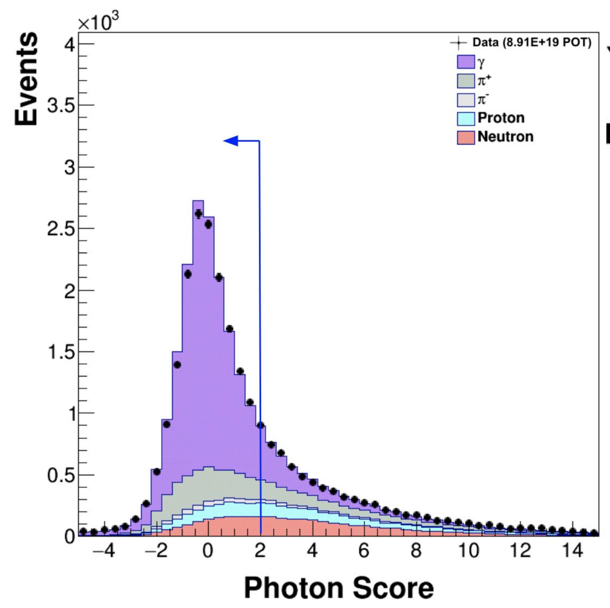


This is the most energetic gamma candidate selected.

PhotonScore:

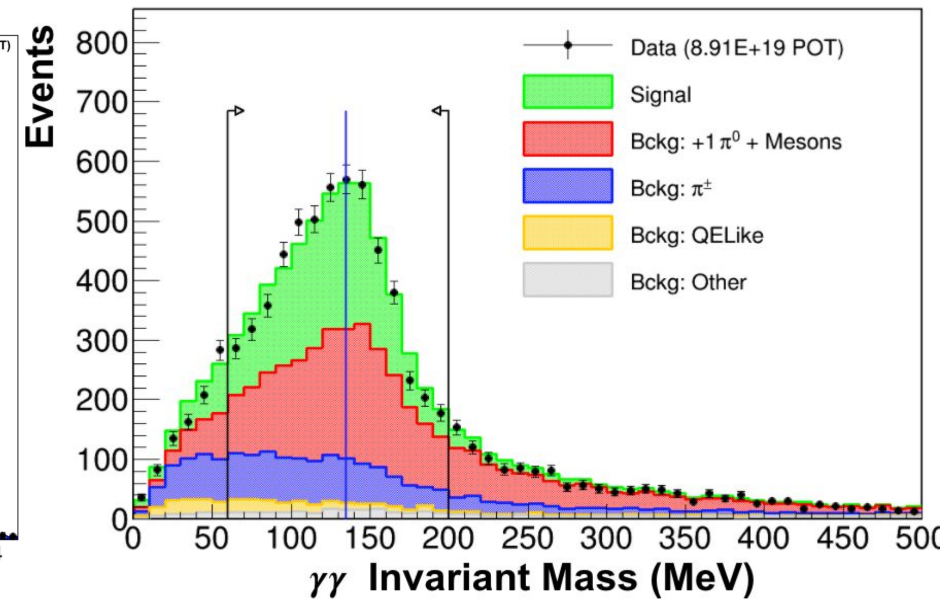
- Based on a score Z via log likelihood ratio (LLR) for the dE/dx profile for charged pions and neutral pions.
- Events having a score less than 2 are likely to be have a photon, those are selected.

$$Z = \frac{dE/dX_{obs} - \langle dE_{vis} dX_\gamma \rangle}{\sigma_{vis,\gamma}}$$



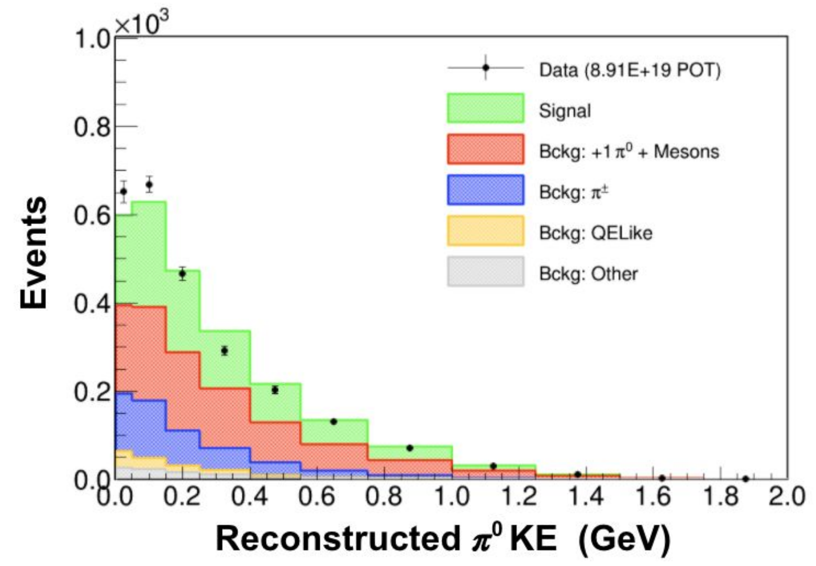
Selection:

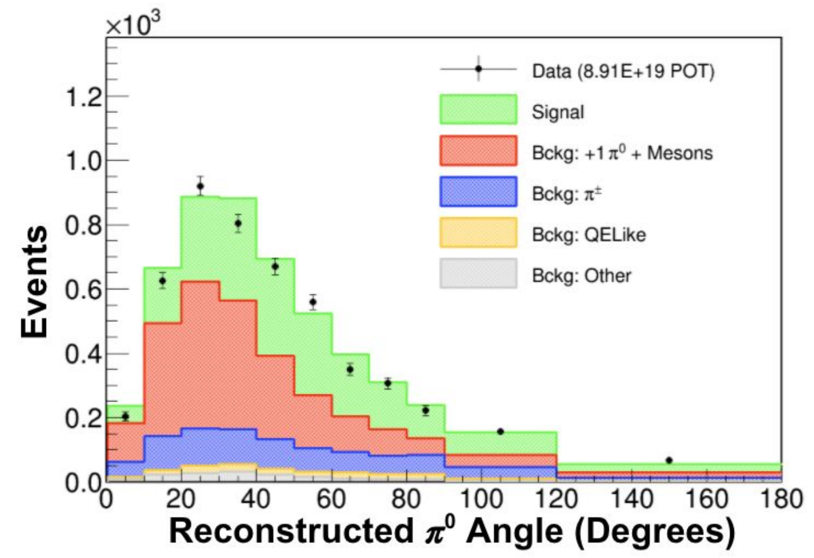
- All the selected events require one and only one neutral pion.
- The invariant mass of the selected gammas is used as a feature for selecting the neutral pion.
- The pair of gammas are most often reconstructed into a π^0 candidate between 60 < $m_{\gamma\gamma}$ < 200 MeV.



Background Type	Description	Percentage
With Pi0	More than one neutral pion and mesons	63.7
Charged Pion	Charged meson(s) and no neutral pions	25.8
QE Like	Only nucleons in final state, no Mesons	3.4
Other	None of the above	7.1
Total		100

Neutral Pion & Interaction Kinematics





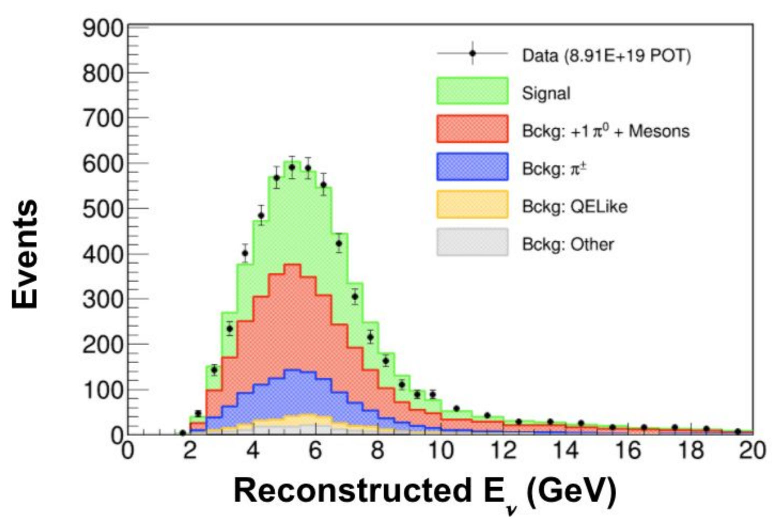
- The two most important physics processes in this analysis are pion production through baryon resonance and pion production through deep inelastic scattering (DIS).
- Pions can interact with the nuclear medium in many different ways, which affect the cross-section measurements differently.

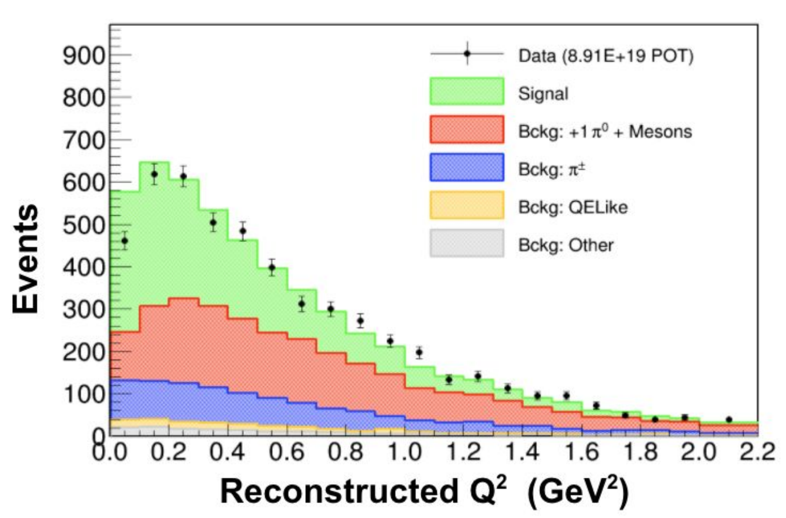
- E_ν includes all final-state particles energies as well as the kinetic energy of one proton, the vertex activity energy and any extra energy not included in the particle reconstructions.

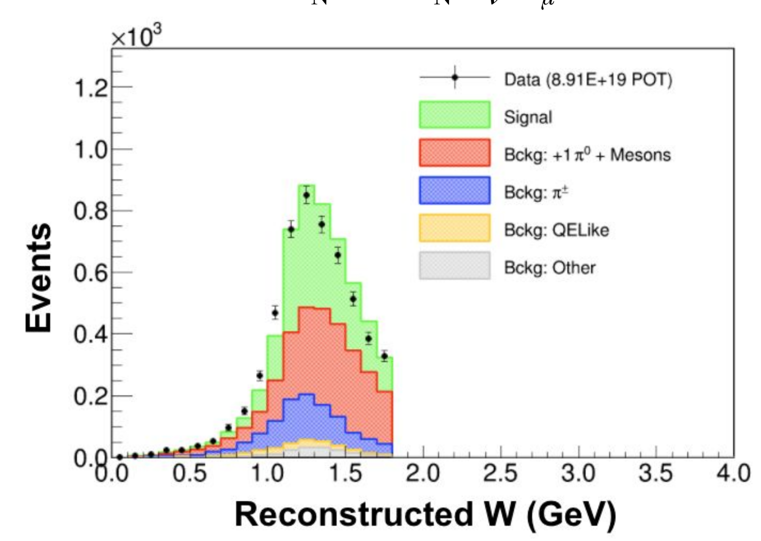
$$E_\nu = E_\mu + E_\pi + \sum T_p + E_{vertex} + E_{extra}$$

$$Q^2 = 2E_\nu (E_\mu - p_\mu \cos\theta_{\mu\nu}) - m_\mu^2$$

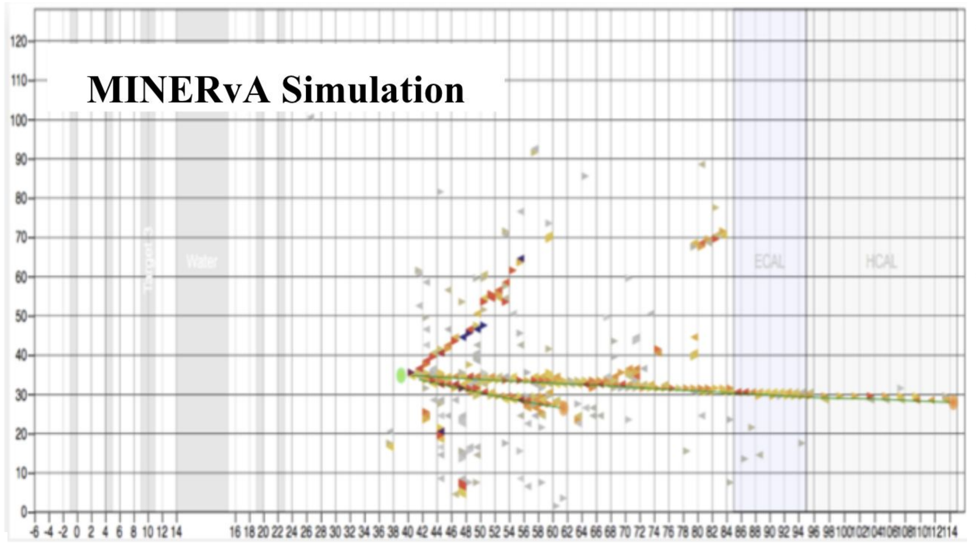
$$W = [\, m_N^2 + 2m_N(E_\nu - E_\mu) - Q^2 \,]^{1/2}$$





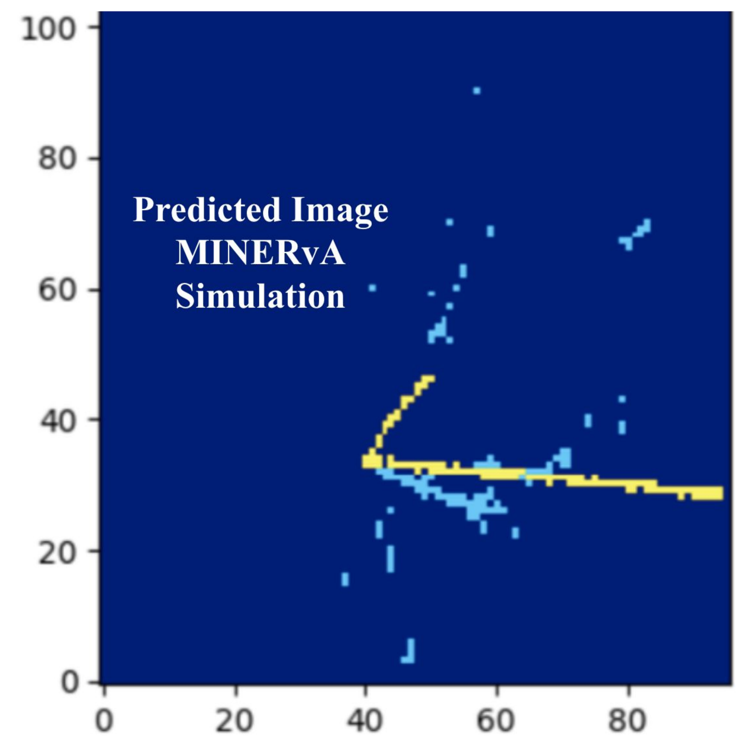


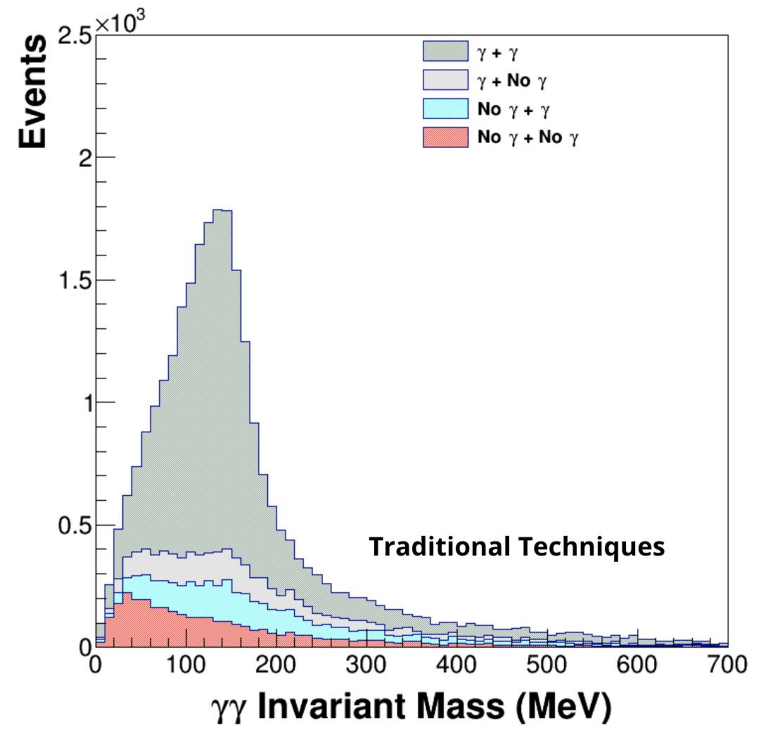
Machine Learning Approach

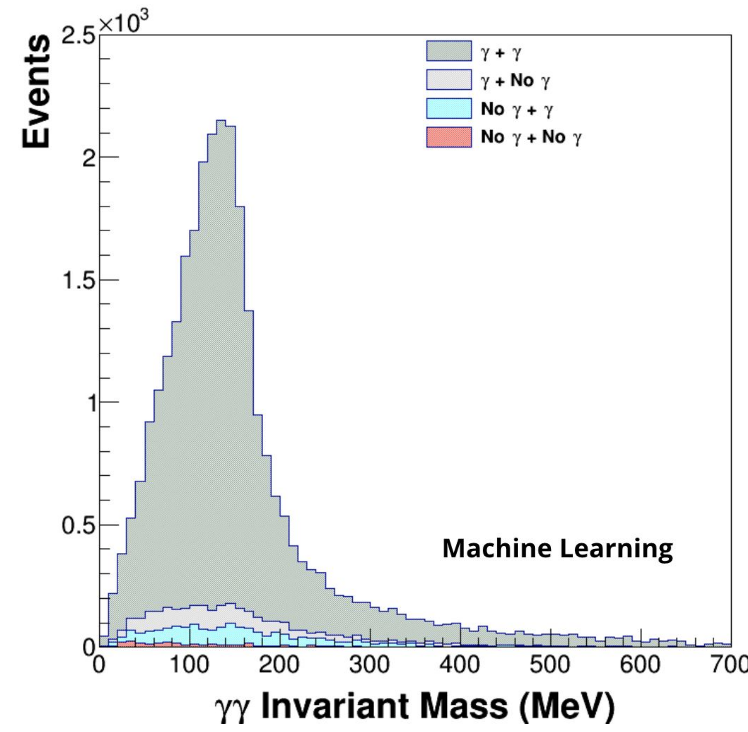


- Traditional methods were not efficient enough to distinguish between charged pions and neutral pions.
- To overcome this we use a machine learning (ML) approach via **semantic segmentation method**, similar approach as here [4,5].

- Three label classes: Electromagnetic (EM) shower. Non-electromagnetic shower(Non- EM). Neutron.
- We consider the hit point from neutron separately as neutron could be the background for the low energy photon shower.
- Employing traditional techniques are able to tag ~ 39% of signal events.
- Employing machine learning techniques are able to tag ~54% of signal events.







Summary

- The use of the ML prediction shows a better identification on the blobs that are likely to be a photon pair increasing the purity of the final selection.

Coming soon:

- Differential cross section for muo, pion and neutrino kinematic variables, also for interaction variables Q^2 and W will be reported.
- Comparisons to GENIE-based simulation.
- The effects of pion final-state interactions on these cross-sections.