$e/\pi/\mu$ Separation in the Charged Pion Polarizability Experiment @ GlueX Hall D

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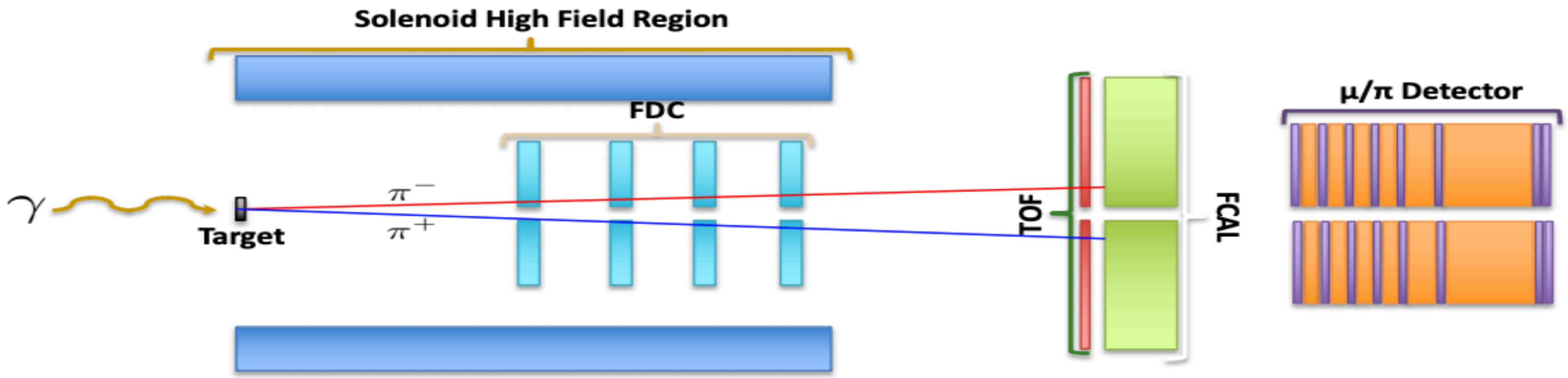
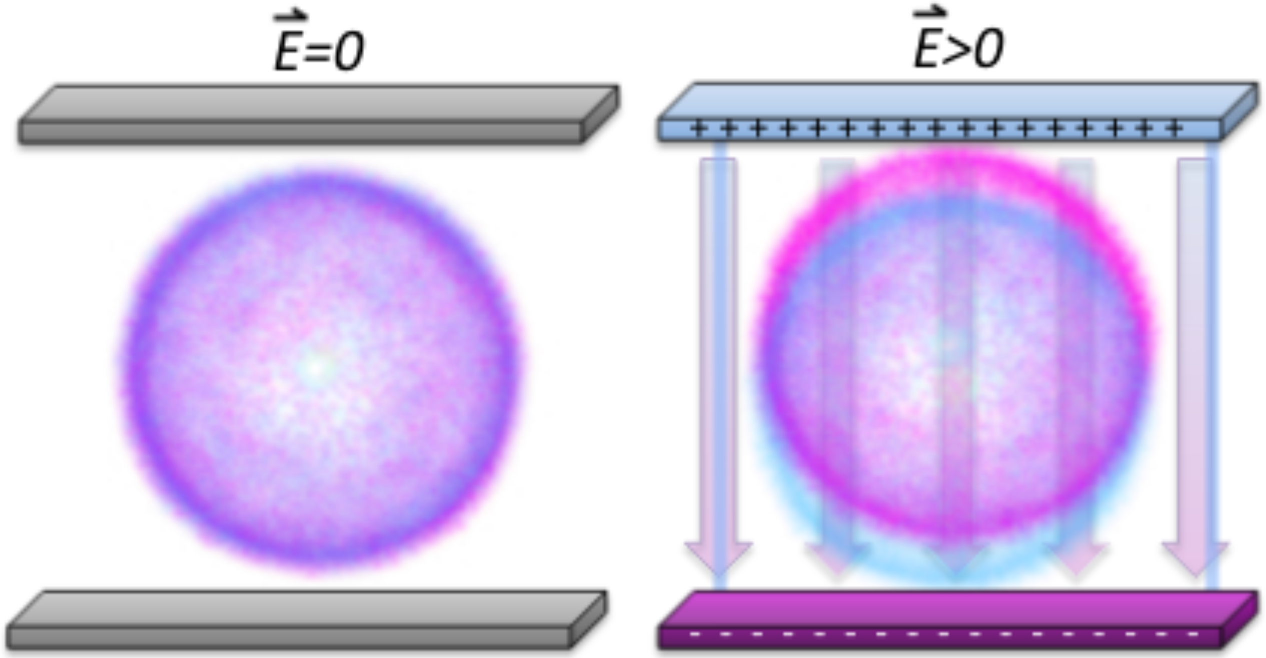


Charged Pion Polarizability

Thought Experiment: place a pion in a parallel plate capacitor at very high electric field

Polarizability: Ease in which an external field may induce a dipole moment in a particle

Property which reflects nature of internal structure of particle



$$E \approx \frac{0.1\ \text{GeV}}{1\ \text{fm}} = 10^{23}\ \text{Volts/m}$$

Elastic form factors tell us about ground state properties
Polarizabilities encode information about the excited states

$$\vec{p} = -\alpha\vec{E}$$

$$\vec{\mu} = \beta\vec{H}$$

At low energy, QCD is formulated as ChPT, an effective field theory with π's as mediators

pQCD	ChPT
$E \gg 1\text{GeV}$	$E \ll 1\text{GeV}$
gluons	π^+, π^-, π^0

Among theoretical predictions for nucleon and meson polarizabilities, charged pion polarizability (CPP) ranks as the most constrained prediction:

$\mathcal{O}(p^4)$ prediction: $\alpha_\pi = -\beta_\pi = \dfrac{4\alpha_{\text{EM}}}{m_\pi F_\pi^2}\left(L_9^r - L_{10}^r\right) \approx \dfrac{F_A}{F_V}$

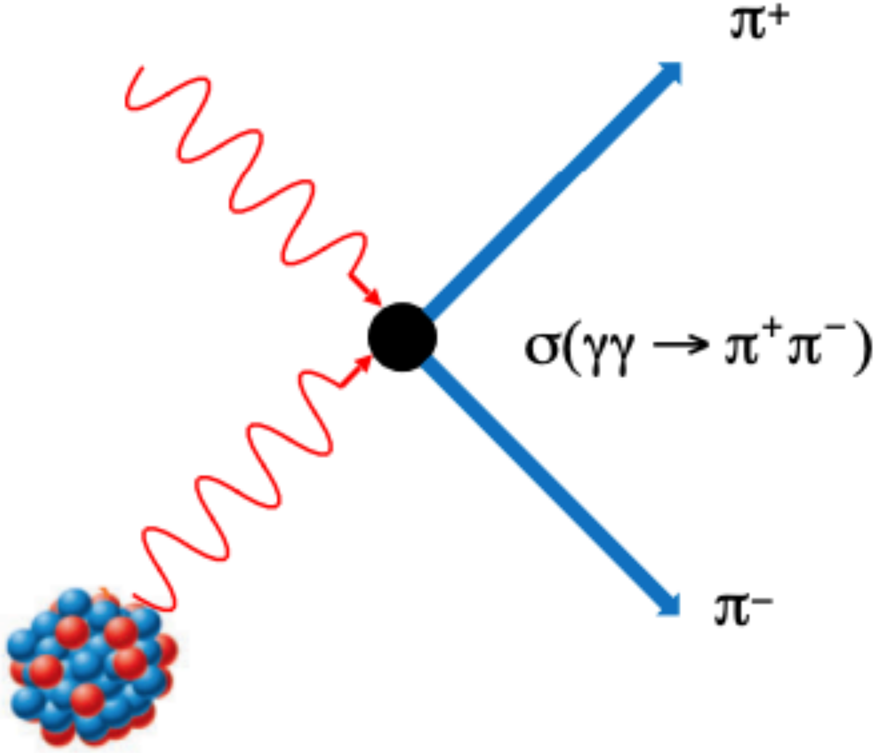
where F_A and F_V are the weak FFs in $\pi^+ \to e^+\nu\gamma$

$$\alpha_\pi - \beta_\pi = 5.6 \pm 0.2 \times 10^{-4}\ \text{fm}^3$$

https://doi.org/10.1103/PhysRevD.40.2378.

If we had a pion target, then we could use Compton scattering to test this prediction…

Use crossing symmetry ($x \leftrightarrow t$) to relate $\sigma(\gamma\pi^+ \rightarrow \gamma\pi^+)$ to $\sigma(\gamma\gamma \rightarrow \pi^+\pi^-)$ and Primakoff reaction to measure $\sigma(\gamma\gamma \rightarrow \pi^+\pi^-)$



Sensitive to the polarizabilities

$$\frac{d^2\sigma_{Prim}}{d\Omega dM_{\pi\pi}} = \frac{2\alpha Z^2}{\pi^2}\frac{E_\gamma^2\beta^2}{M_{\pi\pi}}\frac{sin^2\theta}{Q^4}\left|F(Q^2)\right|^2\left(1+P_\gamma cos2\phi_{\pi\pi}\right)\sigma(\gamma\gamma\rightarrow\pi\pi)$$

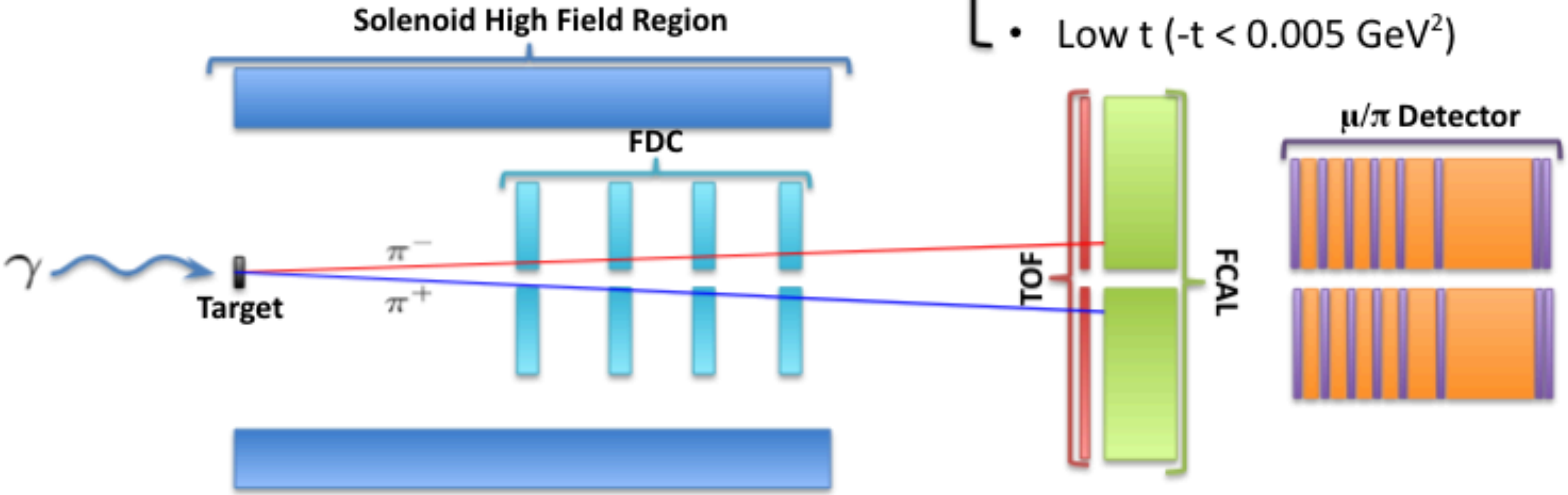
GlueX Experimental Setup

$$\gamma\gamma \xrightarrow[Z(\gamma,\pi^+\pi^-)Z]{} \pi^+\pi^-$$ Signal reaction

$$\gamma\gamma \xrightarrow[Z(\gamma,\mu^+\mu^-)Z]{} \mu^+\mu^-$$ Normalization

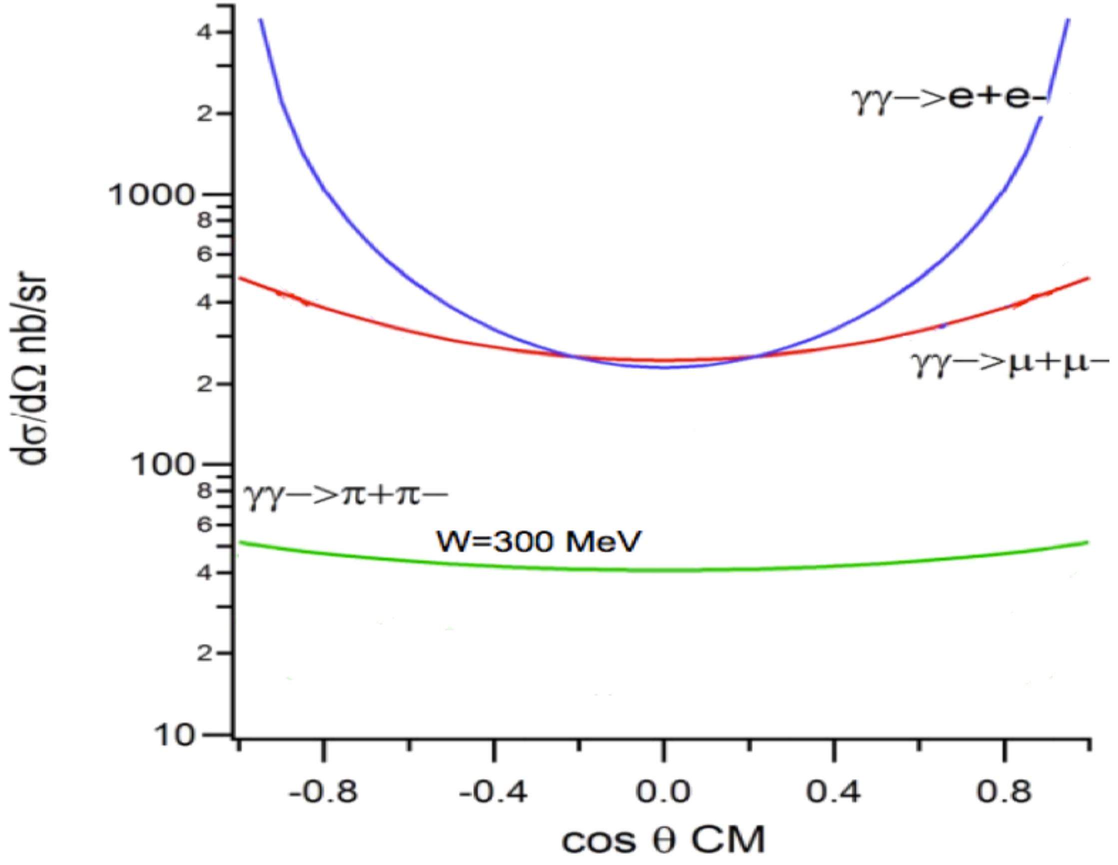
$$\gamma\gamma \xrightarrow[Z(\gamma,\pi^o)Z]{} \pi^o$$ Beam polarization

- All occur via the Primakoff effect (interaction with the Coulomb field of nucleus)
- All result in very forward going particles
- Low t ($-t < 0.005$ GeV^2)

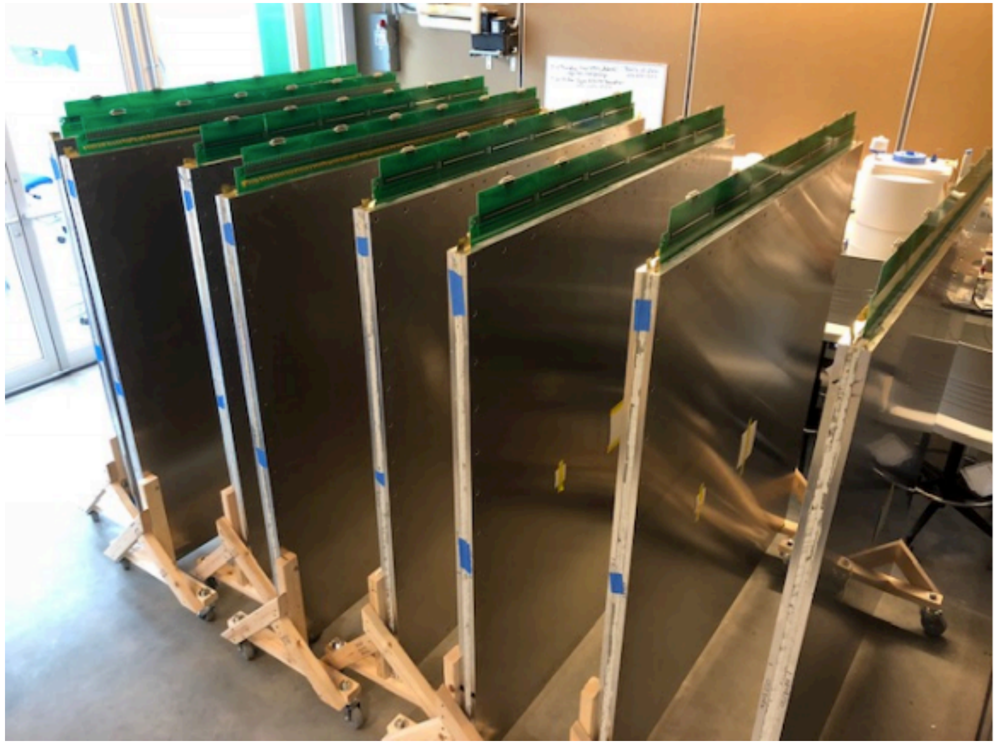


l^+l^- Backgrounds

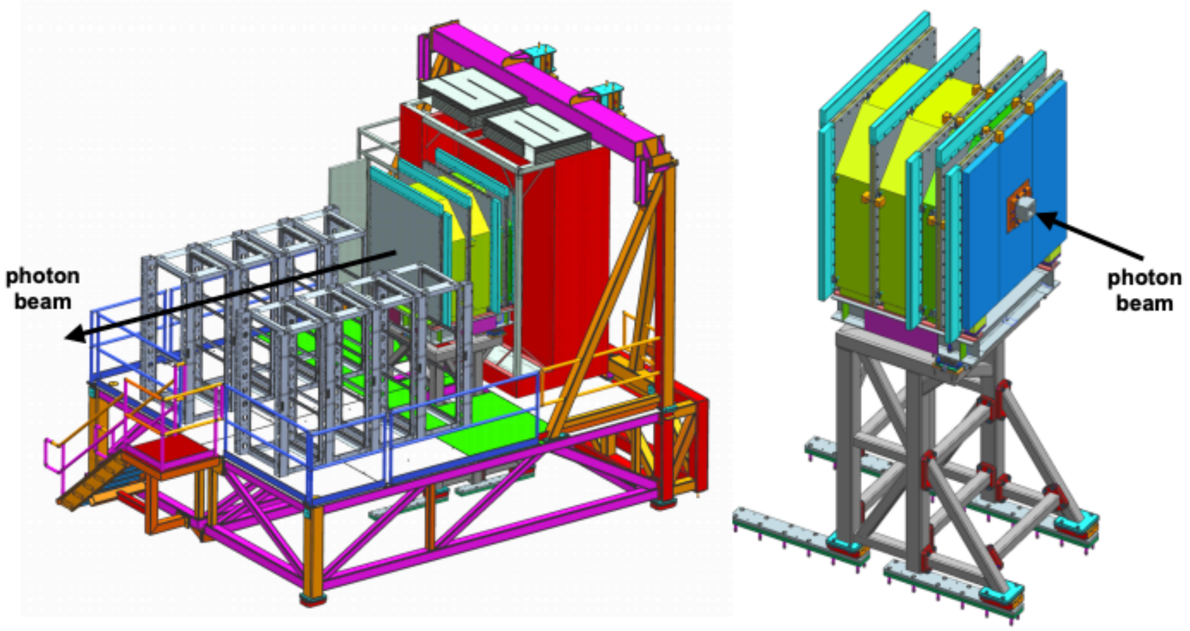
- $\mu^+\mu^-$ (background) are produced ~10x more often than $\pi^+\pi^-$ (signal)
- To measure a cross section to a few percent means reducing a 10x bigger background to less than a few 1/10 of a percent
- GlueX detector has no way of distinguishing between $\mu^+\mu^-$ and $\pi^+\pi^-$ events at this level
- A new detector that works in tandem with GlueX is required



Construction of Muon Chambers for CPP



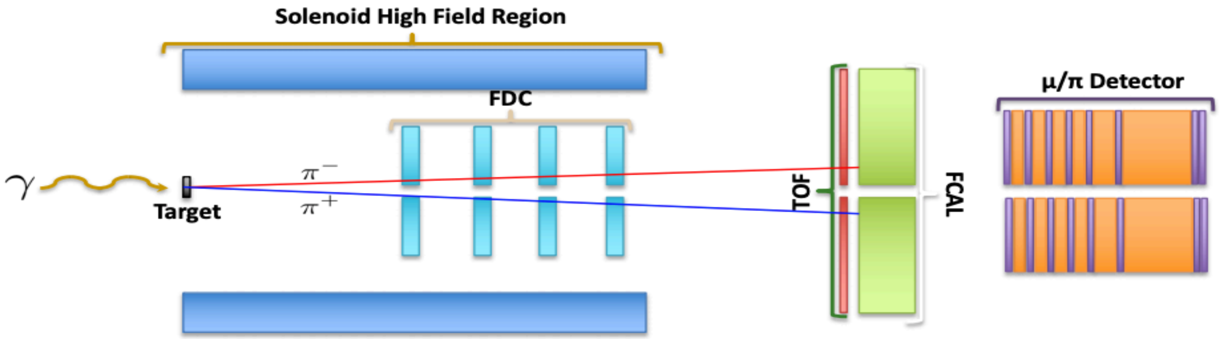
- Engineering design for detector installation in Hall D



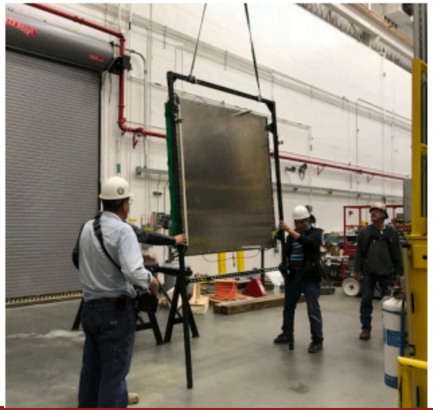
8 MWPC detectors have been assembled.
6 to be installed in Hall D for CPP running.

Neural Net for μ/π Separation

- Need to combine dissimilar information from FCAL (hits, showers) and MWPCs (wires hit, charge on wire) into one number you can cut on.
- Currently no experimental data with MWPCs, efforts are simulation based

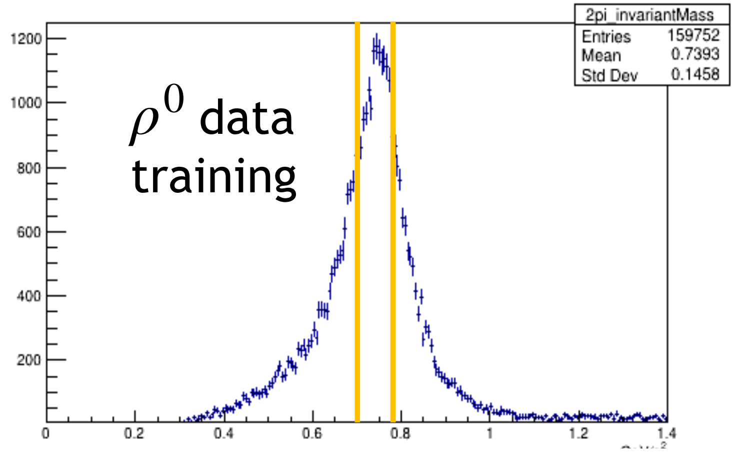


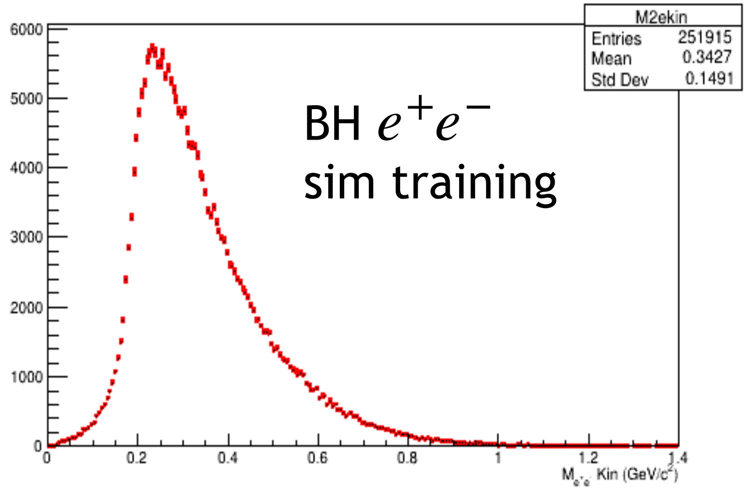
✓ Early 2018 beam test in Hall D during GlueX running established that chambers can operate in this environment

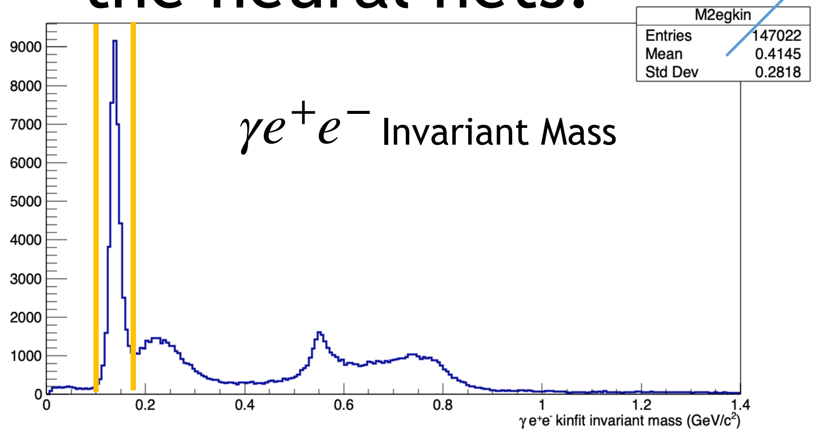


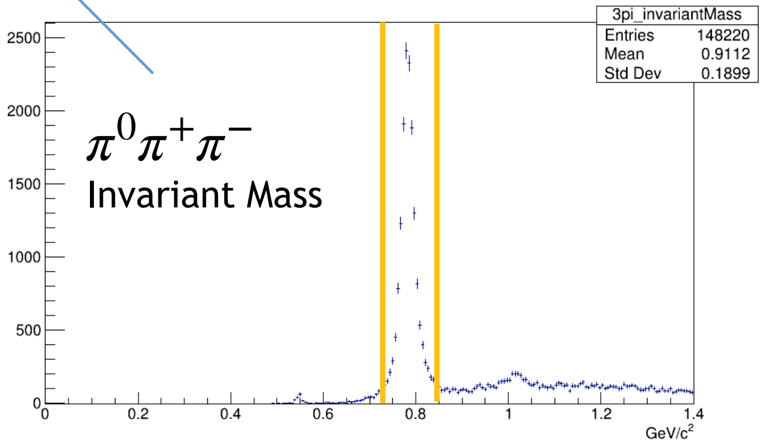
MVA for Electron/Pion Separation Summary

- 2 Multi-layer perceptron neural nets—one for e-/π- separation, one for e+/π+.
- Train on ρ^0 pions (700 MeV < W < 770 MeV) and simulated Bethe-Heitler electron pairs
- Use $\pi^0 \rightarrow \gamma e^+ e^-$ and $\omega(782) \rightarrow \pi^0 \pi^+ \pi^-$ reactions as a way to test performance of the neural nets.





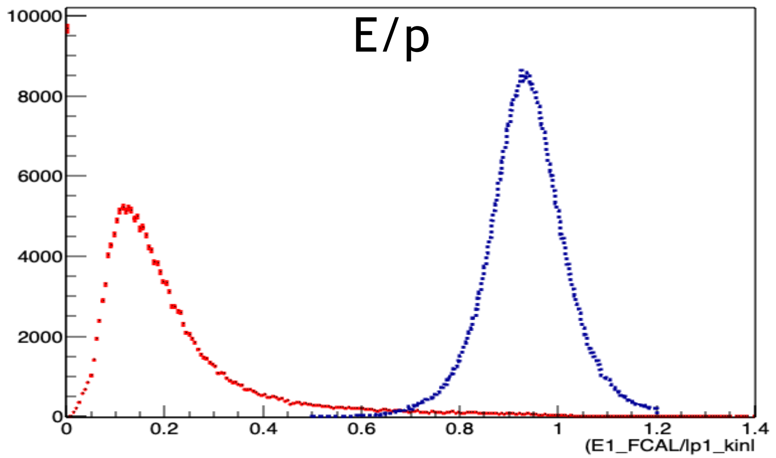


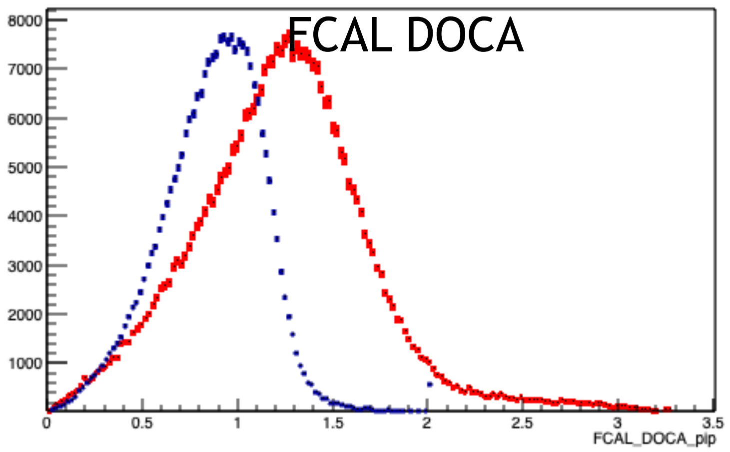


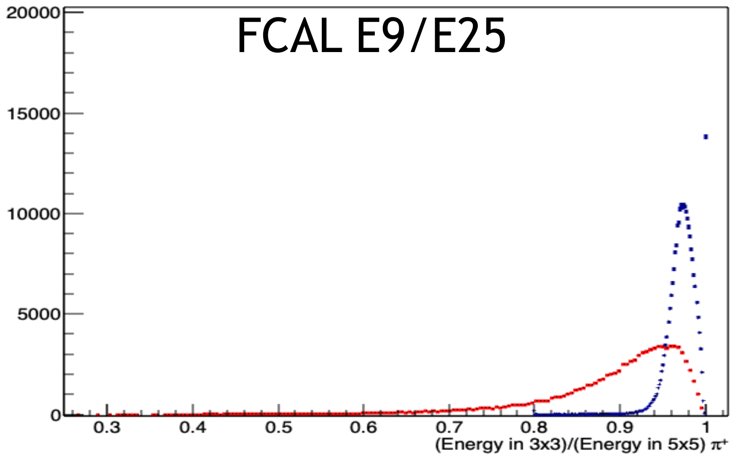
Training For e/π Classification

e^+e^- (BH) Simulation

$\rho^0 \to \pi^+\pi^-$, 2018-01 GlueX Data







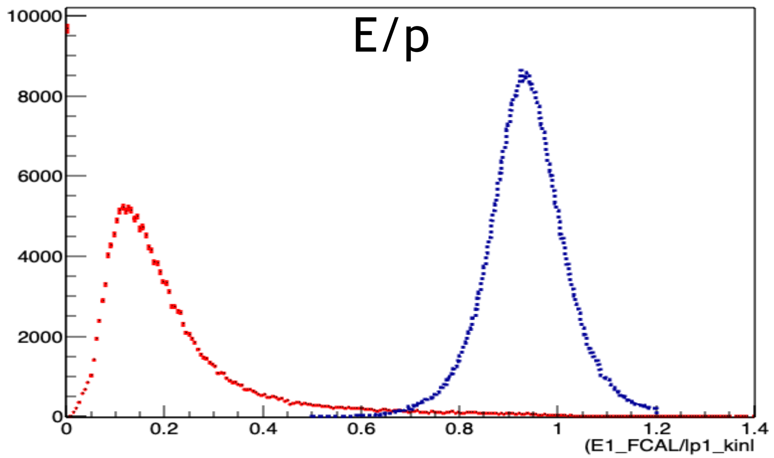
3 calorimetry based training variables:

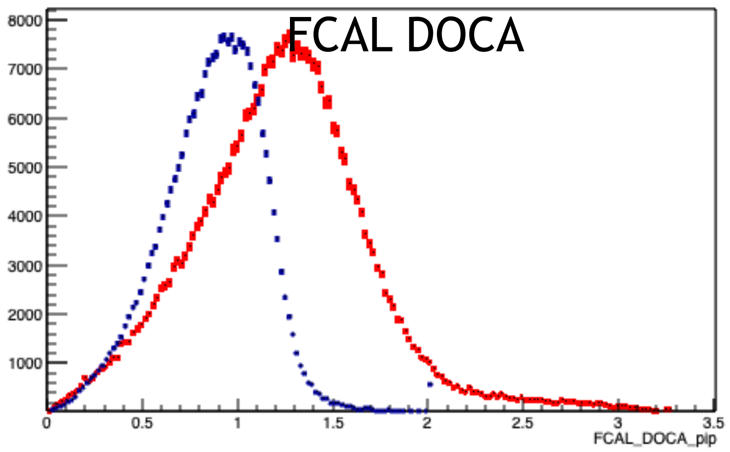
1. FCAL Energy/track momentum (kin fit)
2. Distance of Closest Approach (distance from centroid of shower to track projection)
3. E9/E25 shower ratio: ratio of energy in a 3x3 grid divided by 5x5 grid.

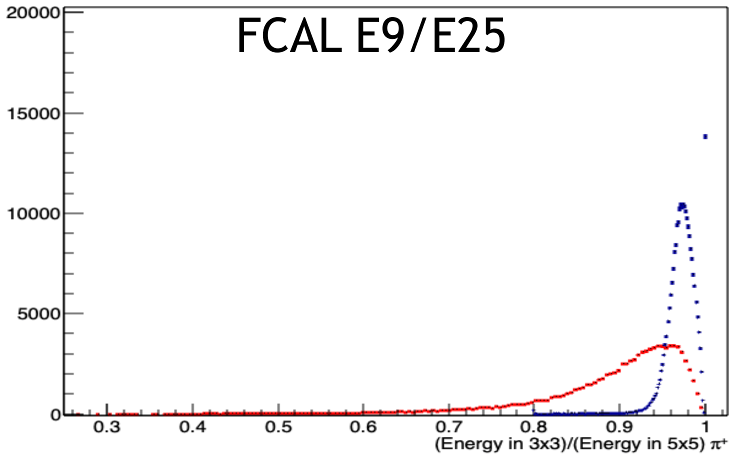
TRAINING FOR e/π CLASSIFICATION

e^+e^- (BH) Simulation

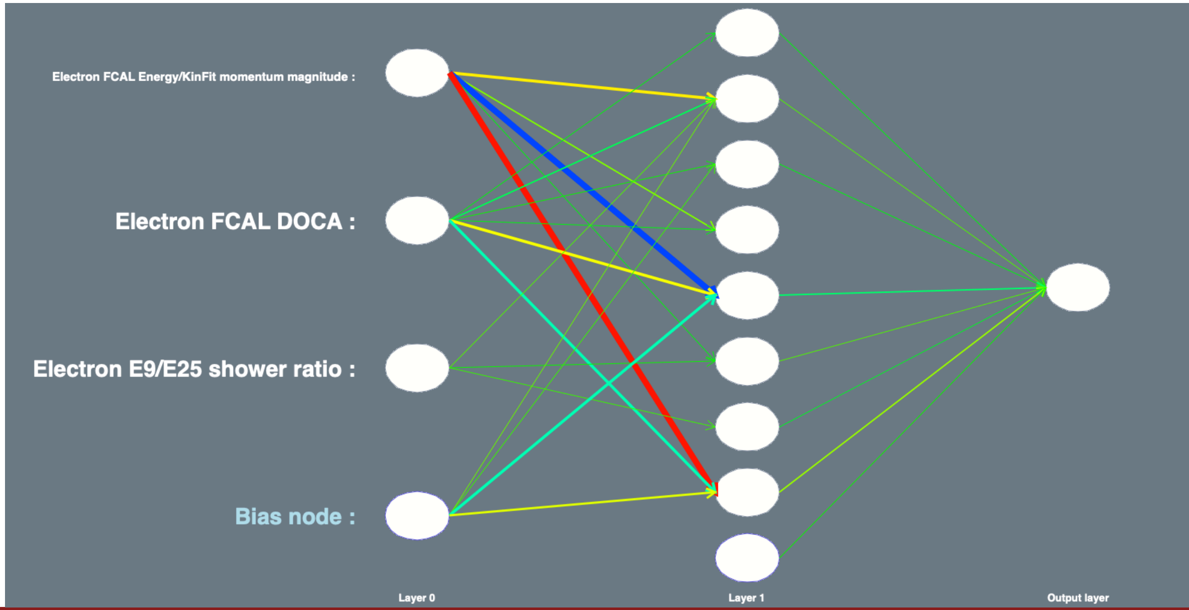
$\rho^0 \to \pi^+\pi^-$, 2018-01 GlueX Data







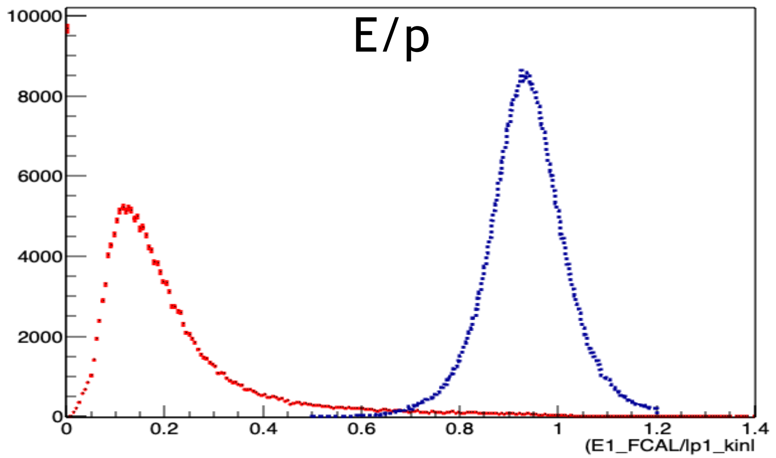
TMVA Config: MLP with 9 Hidden layers, tanh activation function

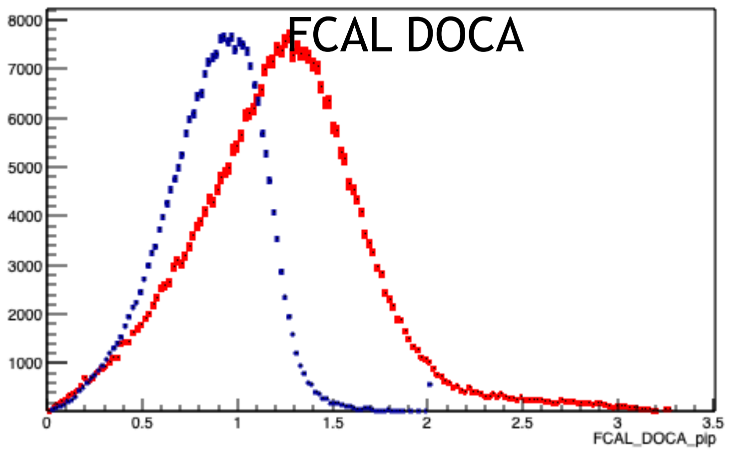


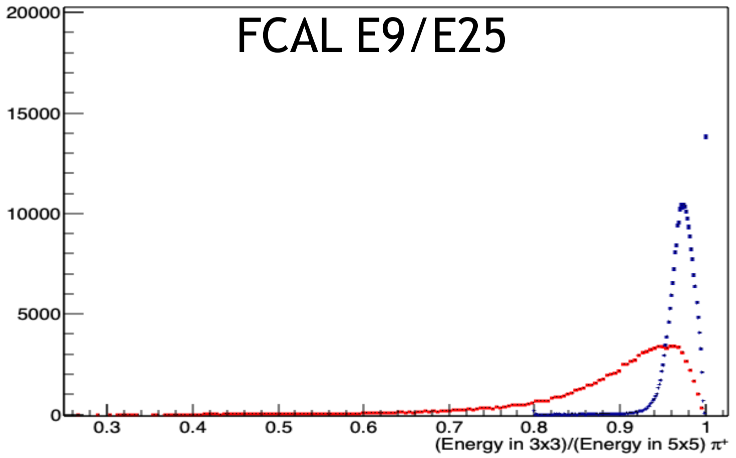
Training For e/π Classification

e^+e^- (BH) Simulation

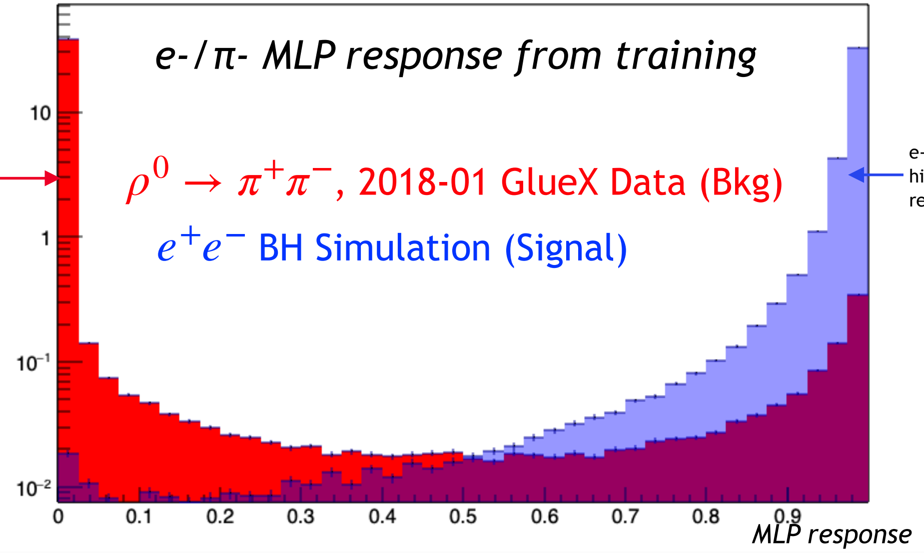
$\rho^0 \rightarrow \pi^+\pi^-$, 2018-01 GlueX Data



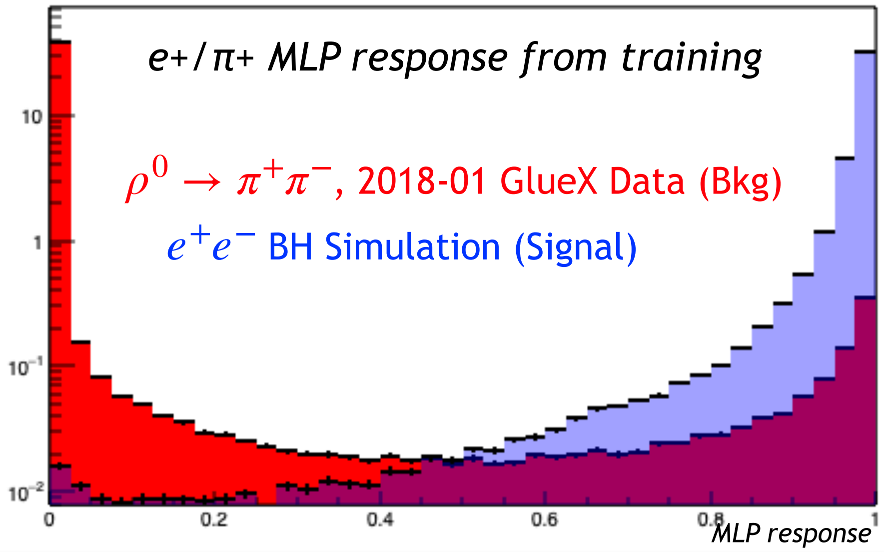




π- have low MLP response



e- have high MLP response



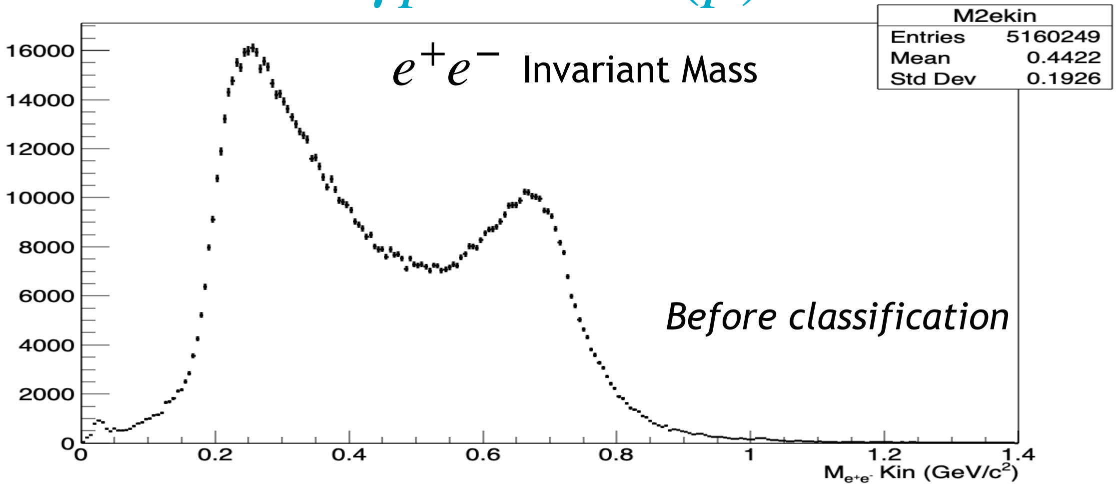
A fraction of pions from the training sample will look like electrons in calorimeters due to charge exchange reaction, and $\rho^0 \rightarrow e^+e^-$

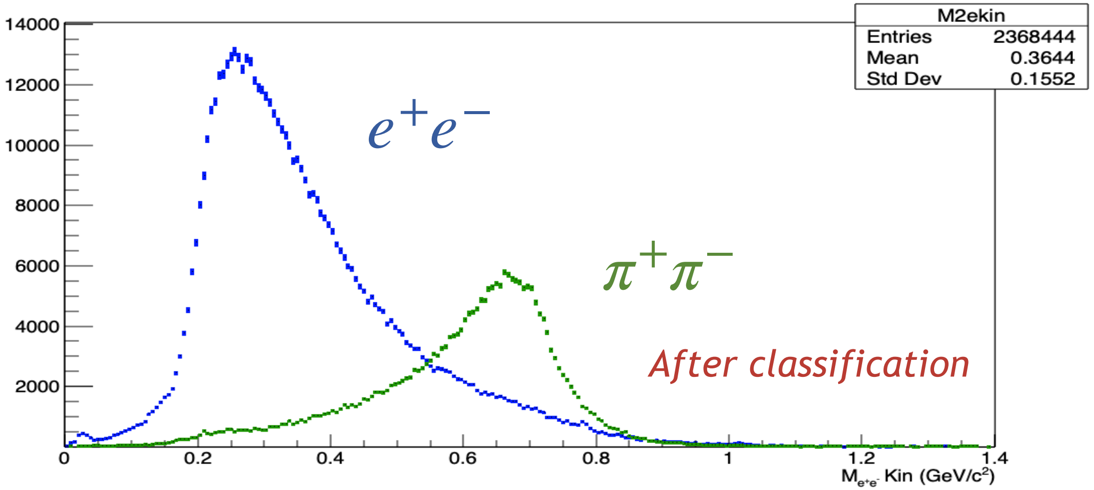
Benchmark Studies

LEFT: 2018 GlueX data containing BH pairs and ρ^0. Use NN to classify and separate.

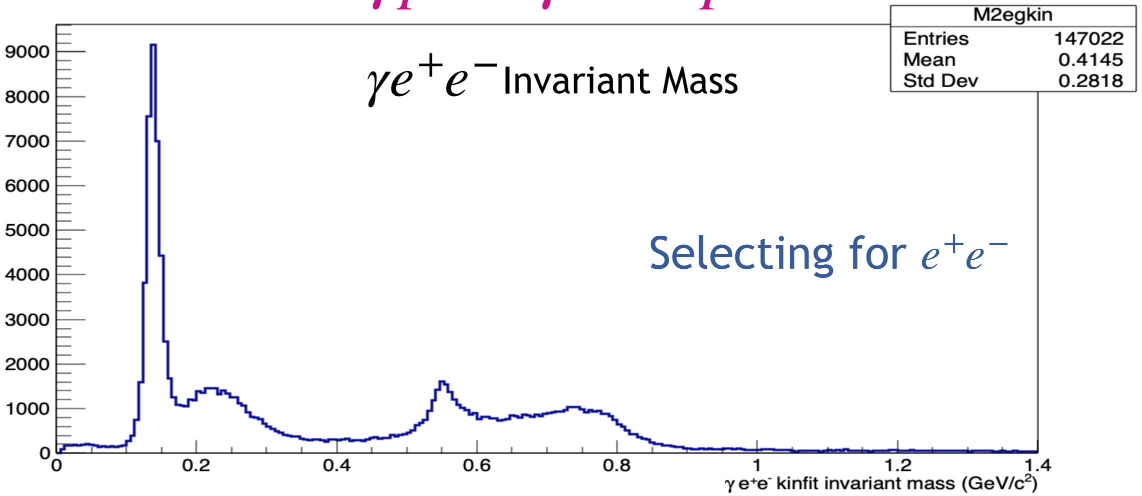
RIGHT: 2018 GlueX data containing π^0 Dalitz decay. Select for pions and see how many e^+e^- pairs from π^0 get through.

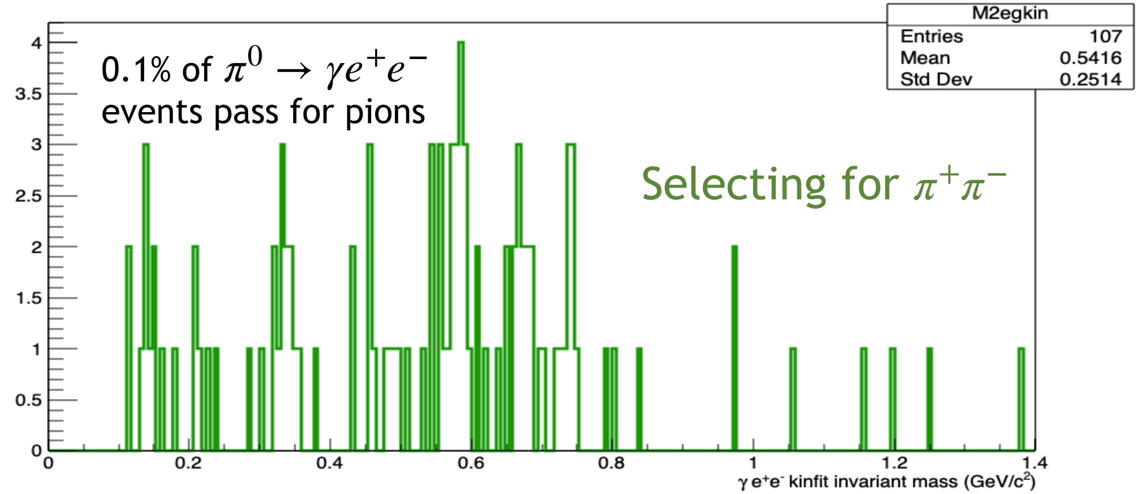
$\gamma p \rightarrow e^+e^-(p)$





$\gamma p \rightarrow \gamma e^+e^-p$



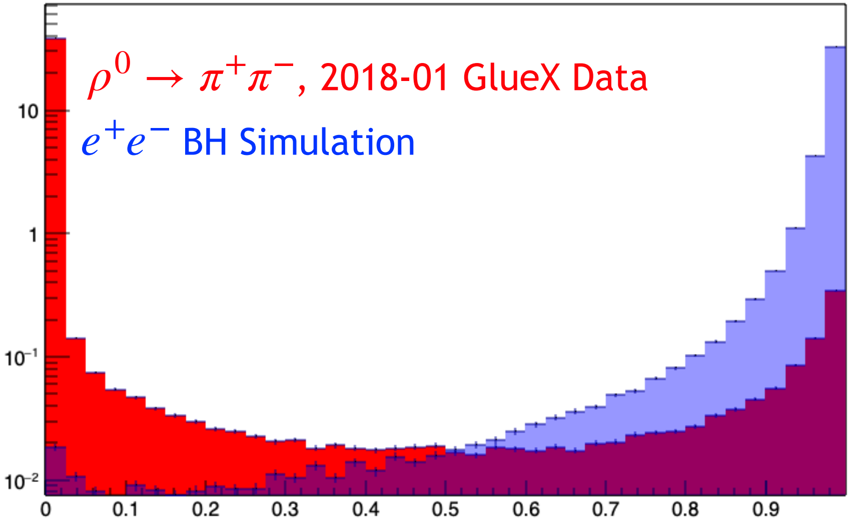


Same neural net and cut on NN response used in both studies

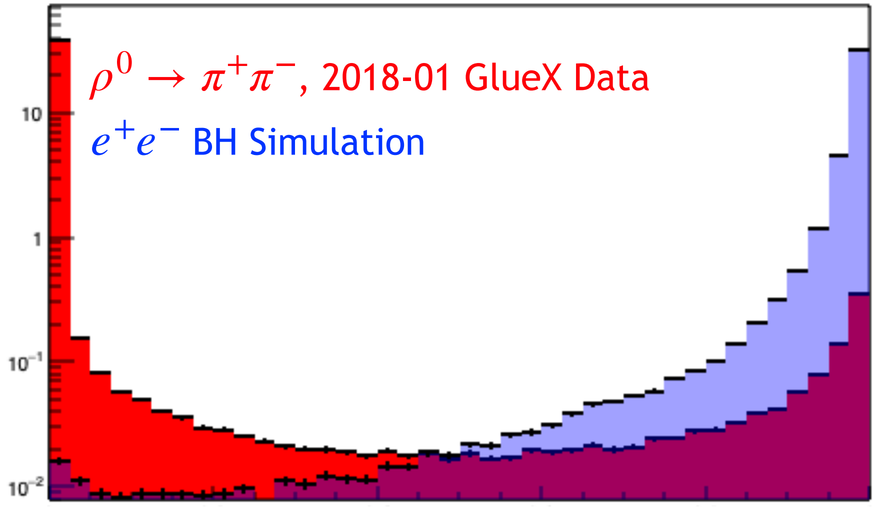
BENCHMARK STUDIES

Two neural nets, one for classifying the positive track, one for the negative track

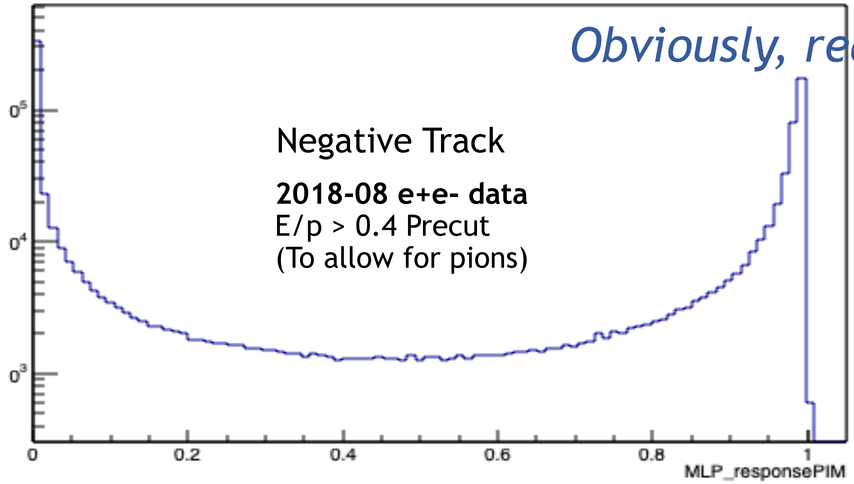
e-/π- MLP response from training

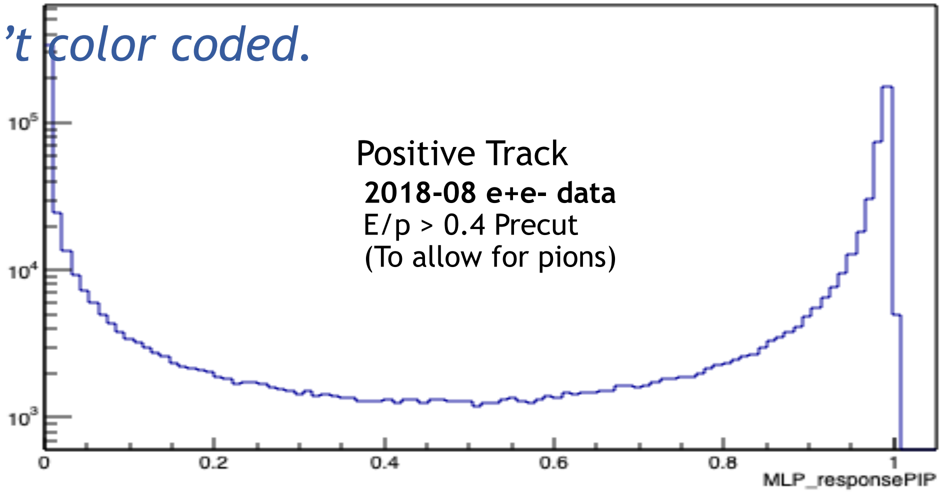


e+/π+ MLP response from training



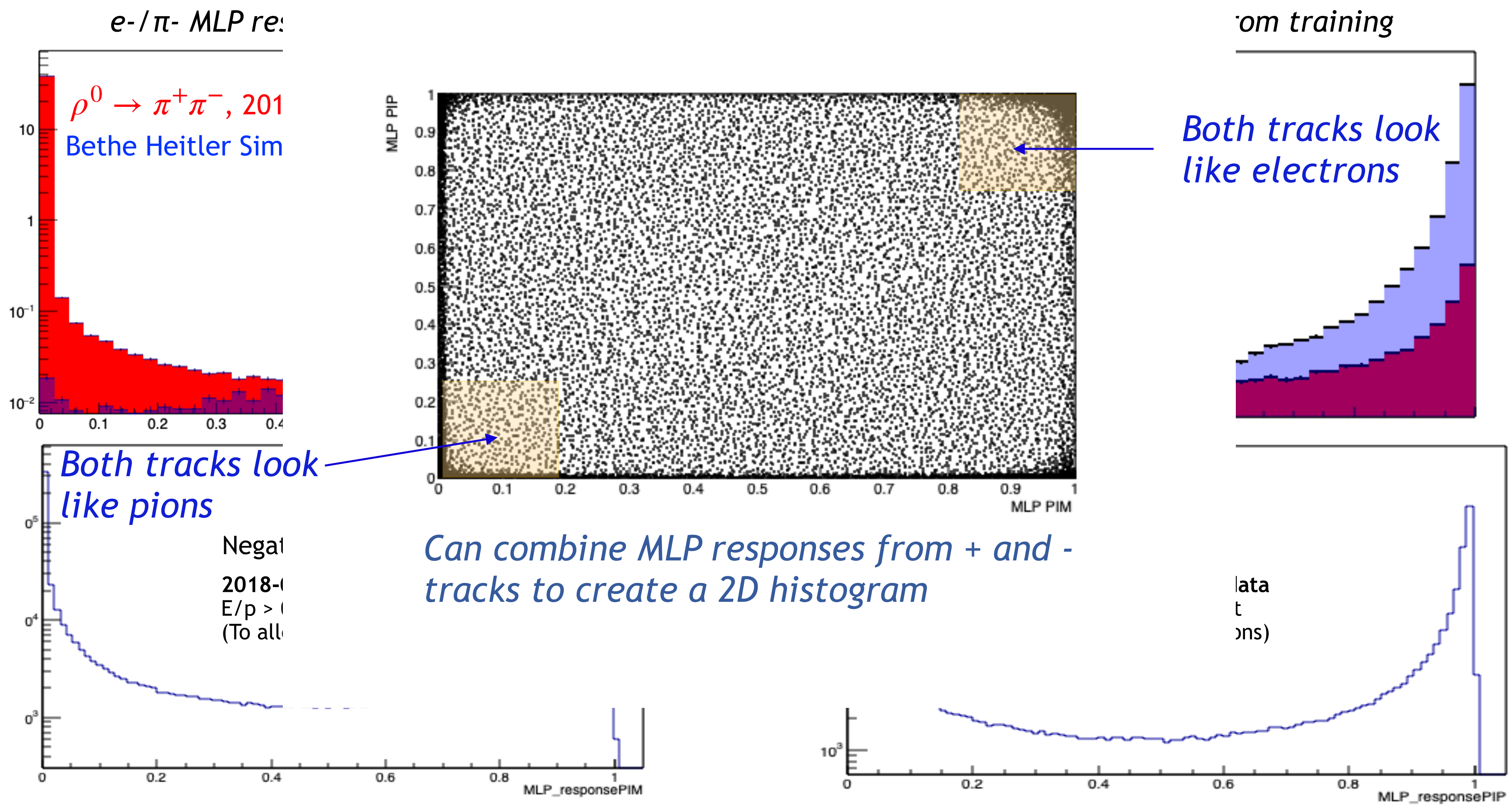
Obviously, real data isn't color coded.





Benchmark Studies

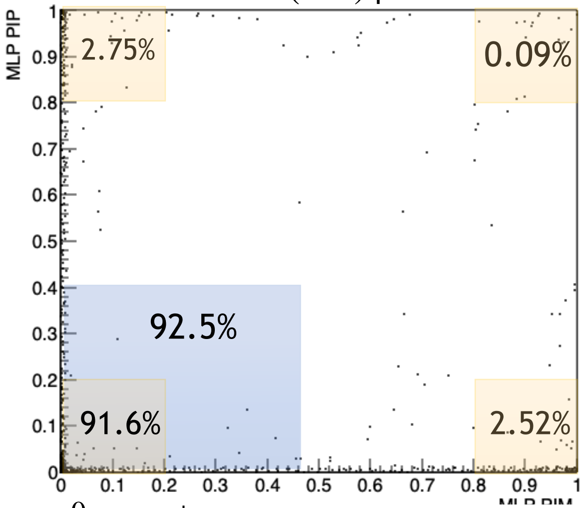
Two neural nets, one for classifying the positive track, one for the negative track



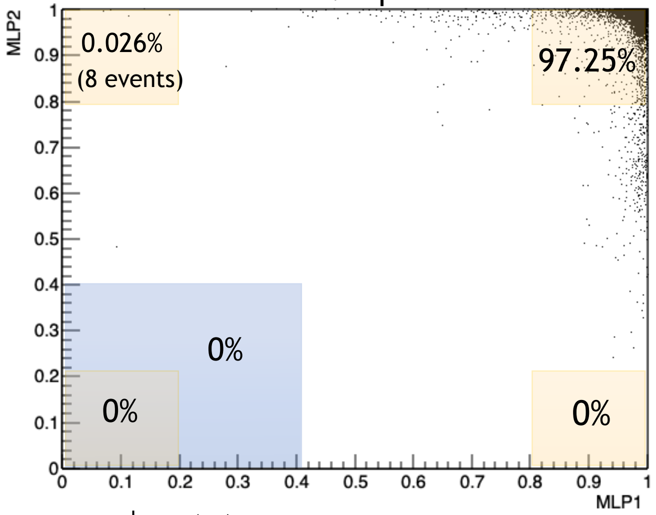
Can combine MLP responses from + and - tracks to create a 2D histogram

What Box Plots look like for pure samples

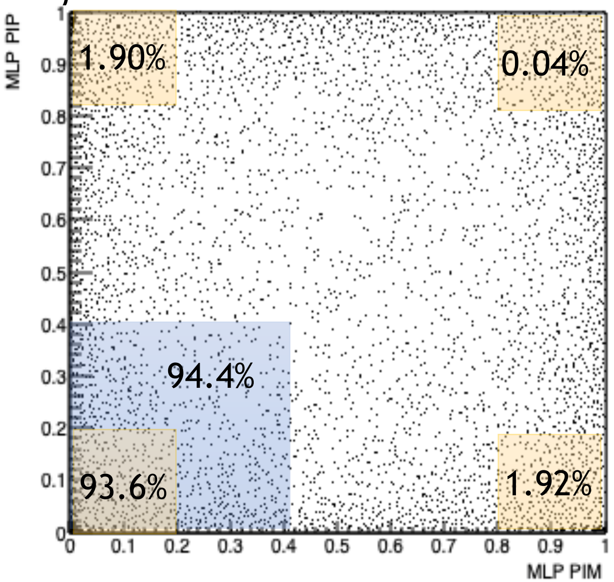
$\Omega(782) \to \pi^+\pi^-\pi^0$, 2018-01 GlueX Data, Cut on $\Omega(782)$ peak



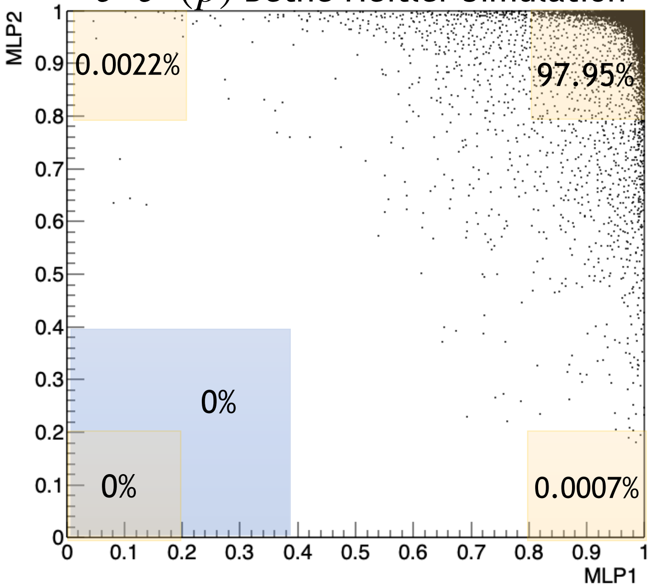
$\pi^0 \to \gamma e^+e^-$, 2018-01 GlueX Data, cut on π^0 peak



$\rho^0 \to \pi^+\pi^-$ 2018-01 GlueX Data



$e^+e^-(p)$ Bethe Heitler Simulation



Summary

- l^+l^- Backgrounds in the CPP experiment necessitate use of ML
  - $\mu^+\mu^-$ neural net is in development right now
  - Used e/π separation as launching point that could be used with real data
- CPP set to run Spring 2022.