Particle Identification for Dark Photon Detection

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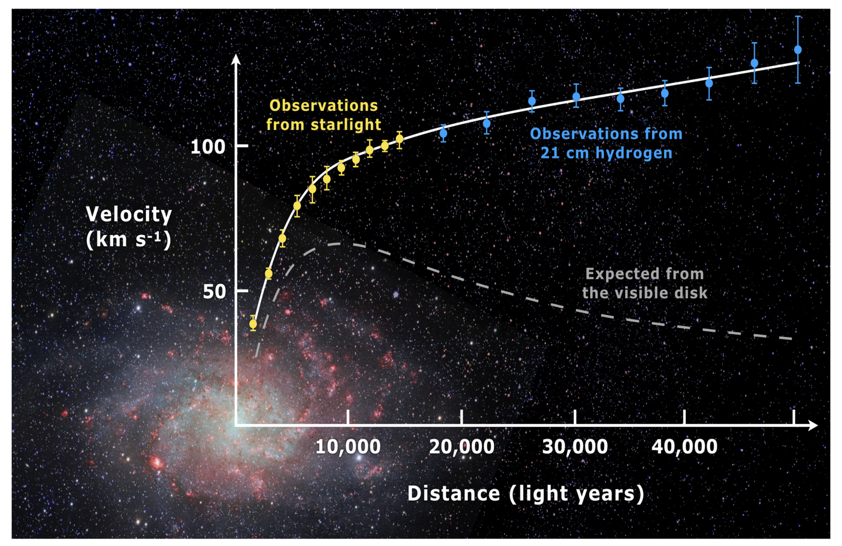
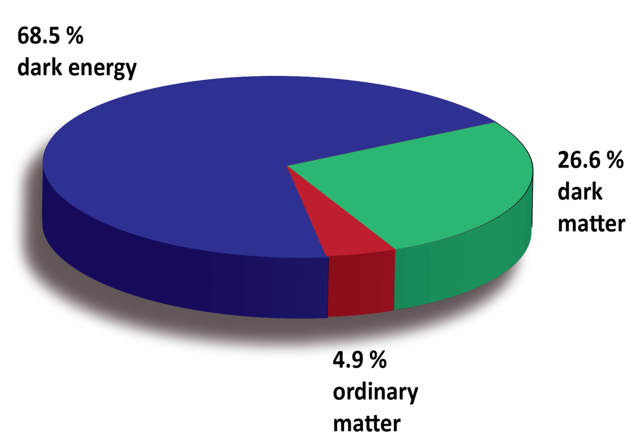
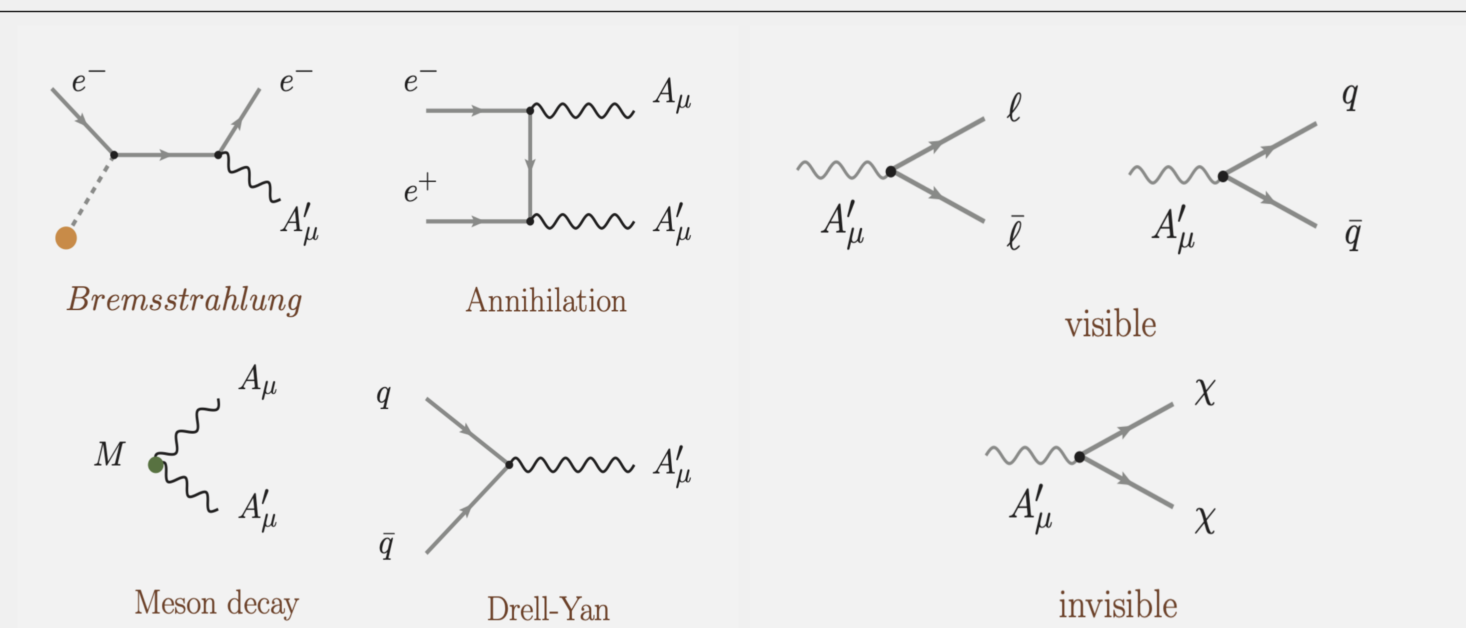
About Dark Matter





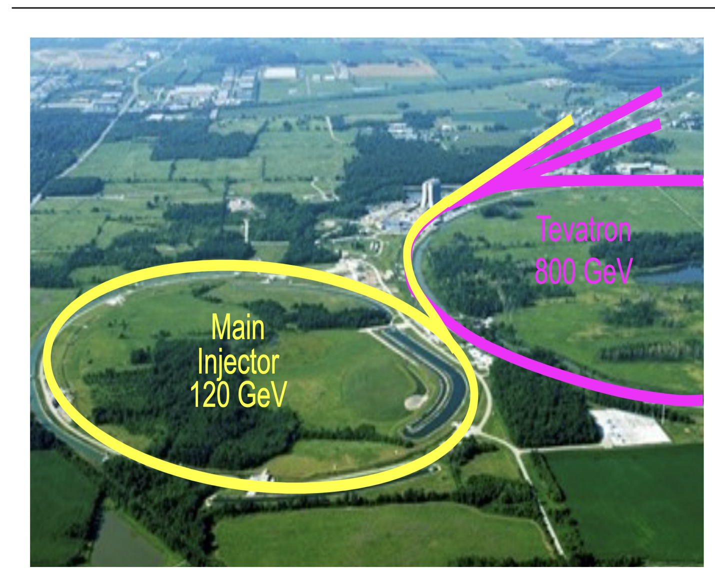
Unlike normal matter, dark matter does not interact with the electromagnetic force. This means it does not absorb, reflect or emit light, making it extremely hard to spot. In fact, researchers have been able to infer the existence of dark matter only from the gravitational effect it seems to have on visible matter.

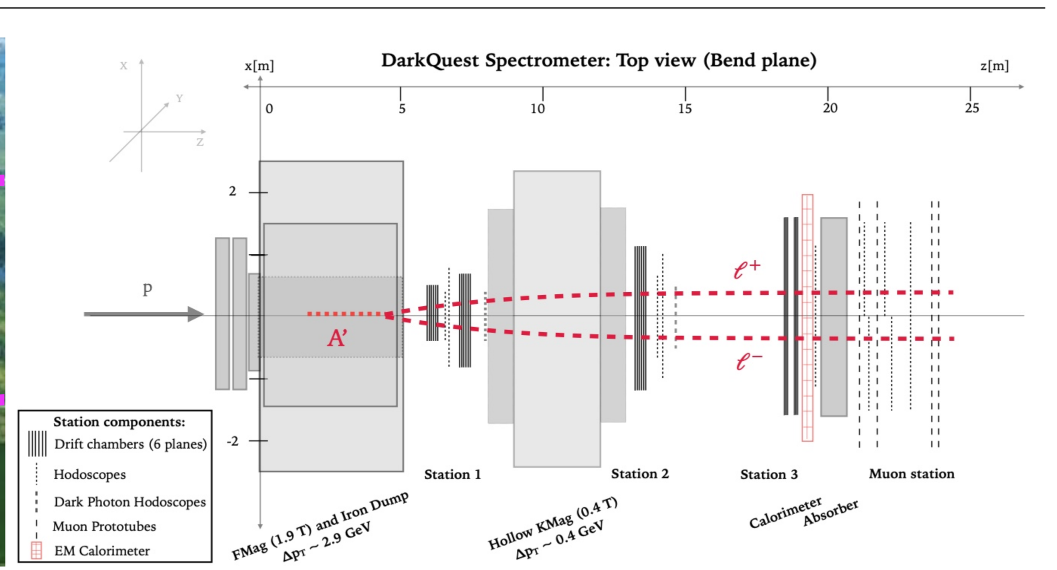
Dark Photon Production and decays



Particle ID We have developed electron and positron identification algorithms (Particle ID) to distinguish and reconstruct long-lifetime dark photon decays to electron and positrons $A' -> e^-e^+$

DarkQuest Proposal at FermiLab

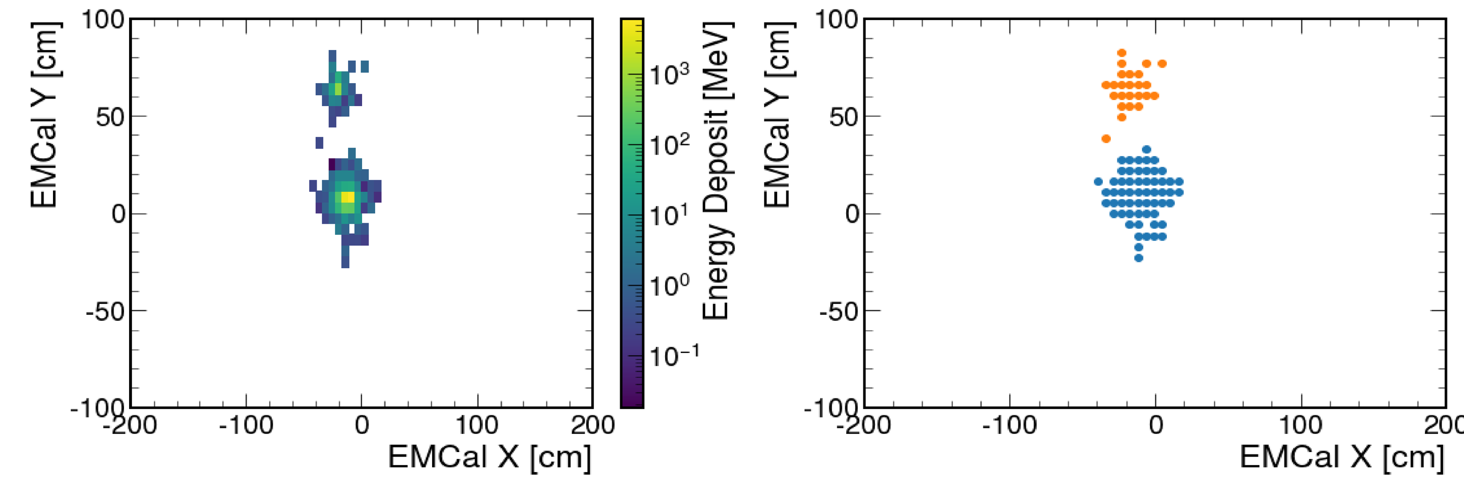




DarkQuest is a proton fixed target beam dump spectrometer experiment on the Fermilab Accelerator Complex receiving a high-intensity beam of 120 GeV protons from the Main Injector. Dark photons could be produced at DarkQuest from the collisions of the high-energy protons with nuclei in the iron dump. The A′ search will look for lepton pairs emerging from a beam dump.

A Cut Based Particle ID

To study the overall detector response to a variety of particle types, simulated particle gun samples were produced with the same "vertex" and kinematic information. In particular, 100k events were generated for each of the particle types: $\mu^-, e^-, e^+, \gamma, \pi^+, \pi^-, \pi^0$, and K_L^0.

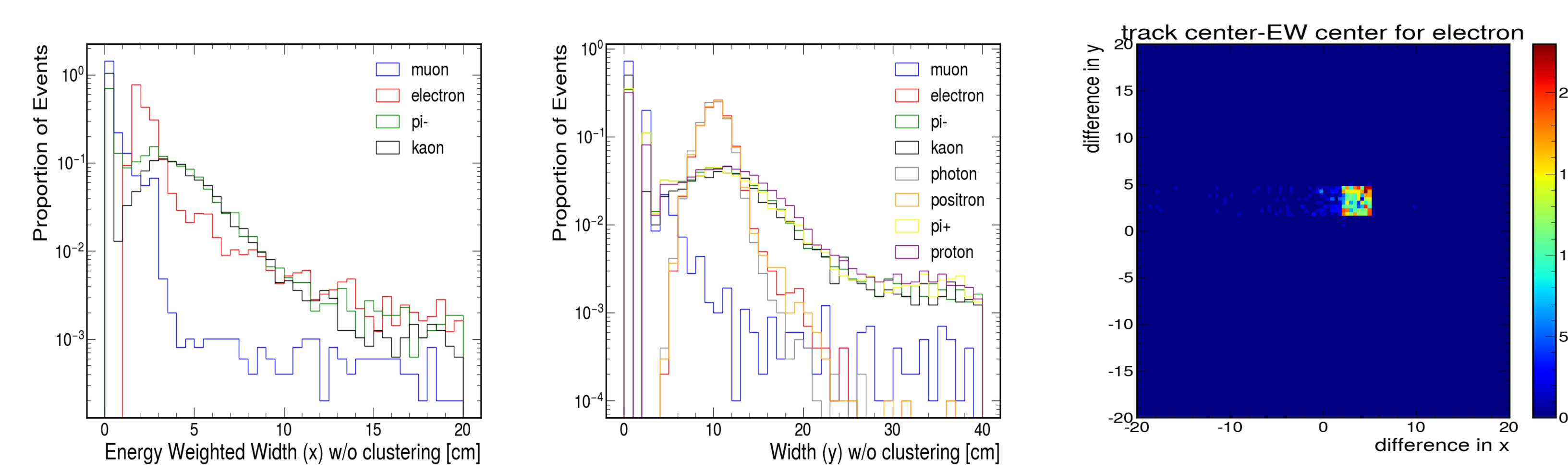


Clustering algorithms has been performed on EMCal using the Birch method. We have analyzed the leading cluster of each event. Also, linear extrapolation has been performed from st3 tracklet to EMCal, distance between Wew center and extrapolated center can be very different between different particles.

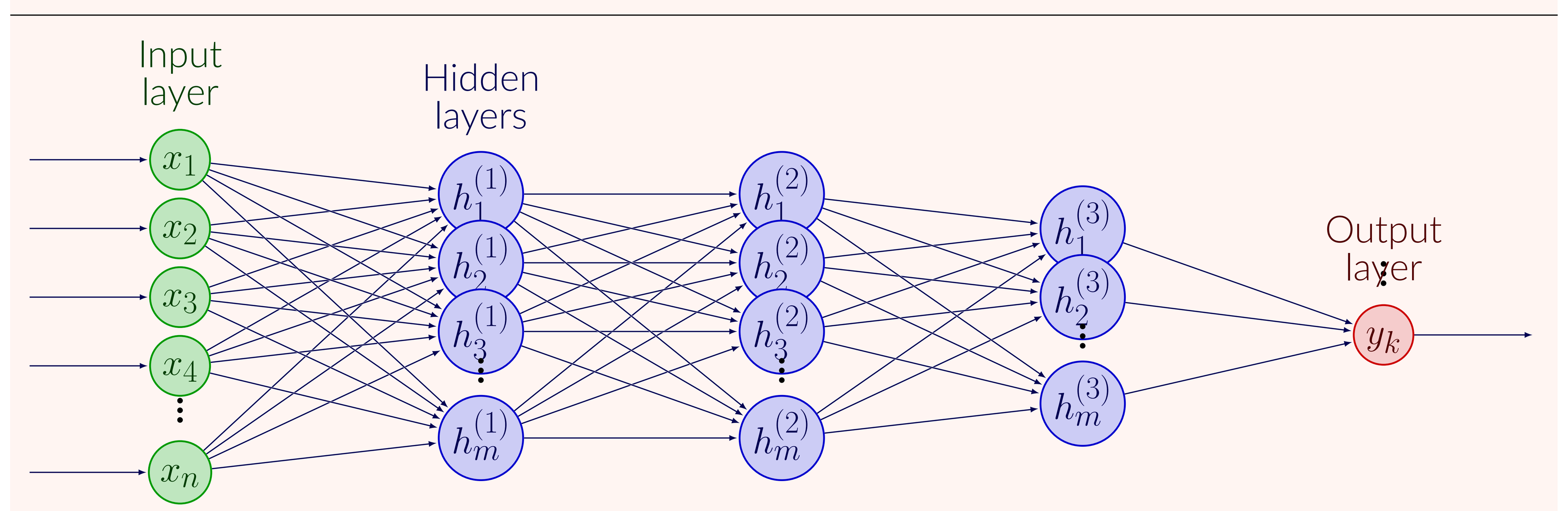
The Widths and Energy Weighted Widths (W_{EW}) of the EMCal hits are key concepts to distinguish between different particles. The width and Wew describe the shape of hits on EMCal in numeric quantities, which are calculated as follows:

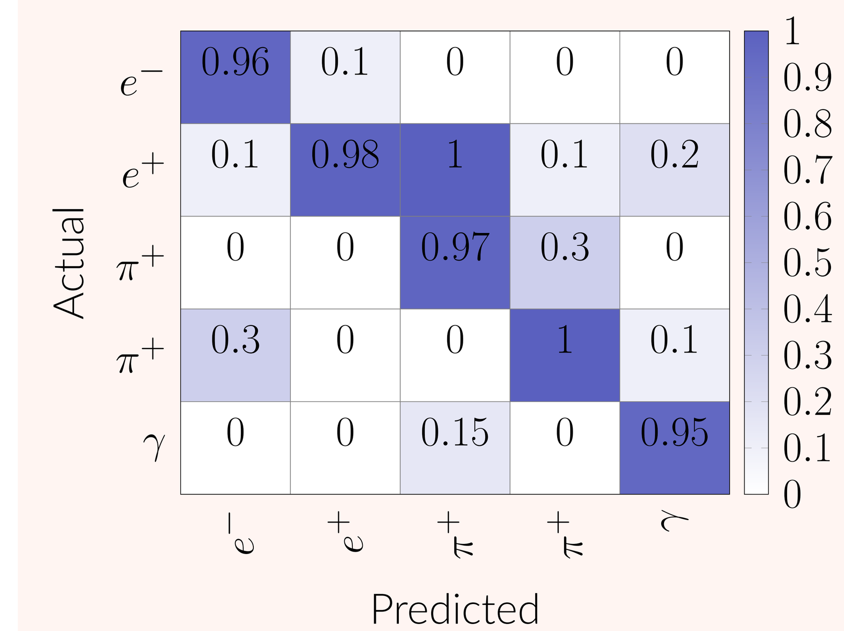
$$W_{EW} = \left(\frac{1}{E_{tot}}\sum_i E_i(x_i - \bar{x})^2\right)^{\frac{1}{2}}, \text{ where } \bar{x} = \frac{1}{E_{tot}}\sum_i E_i x_i.$$

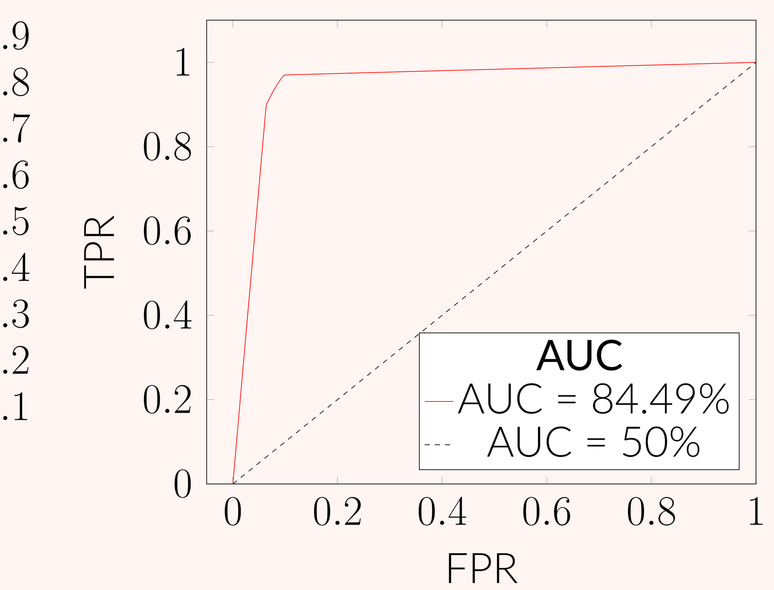
$$Width = \left(\frac{1}{N}\sum_i (x_i - \bar{x})^2\right)^{\frac{1}{2}}, \text{ where } \bar{x} = \frac{1}{N}\sum_i x_i,$$



Neural Network, Confusion Matrix and ROC Curve



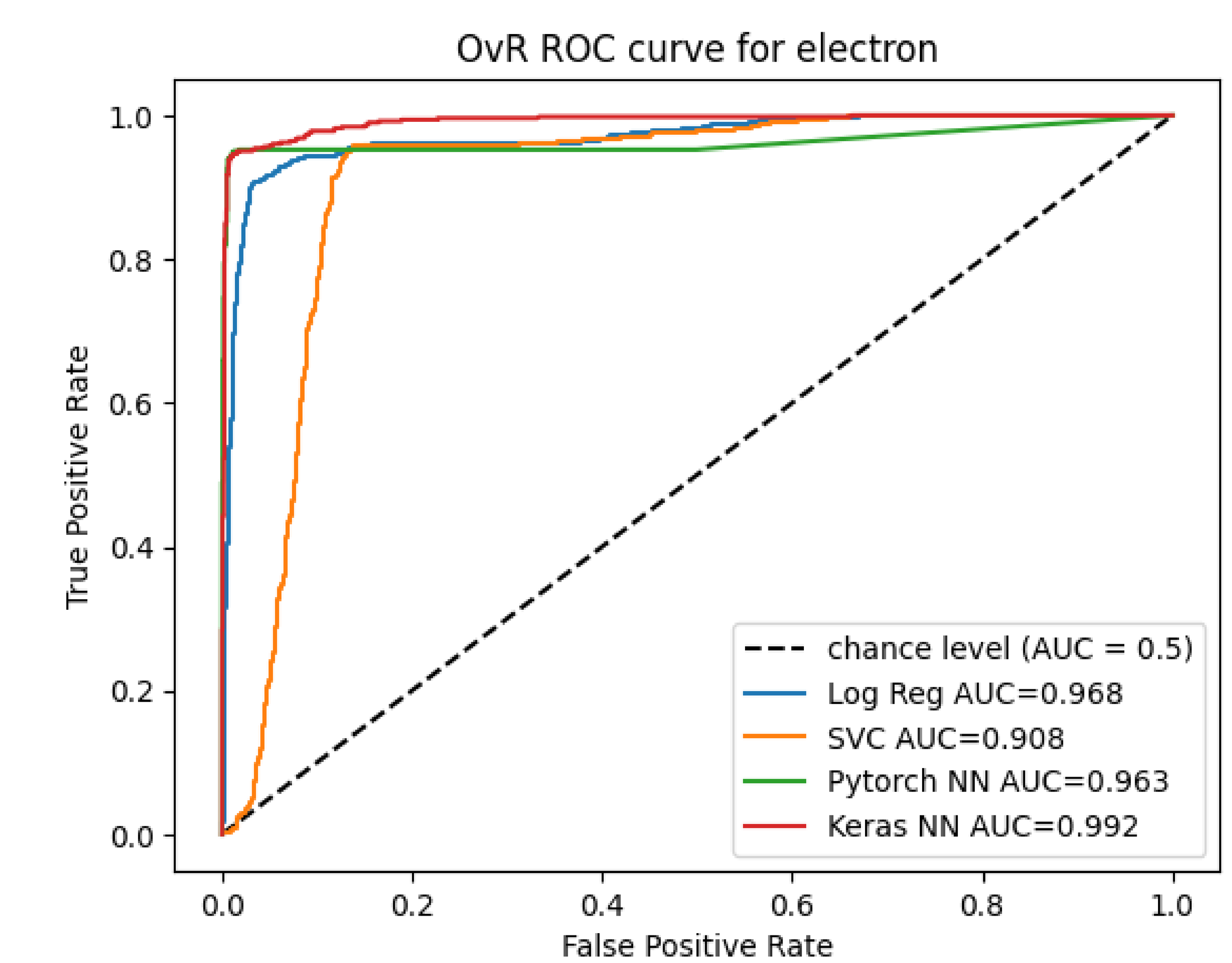




Neural network has been used to classify and recognize certain patterns of data. It has multiple layers to increase expressiveness, with activation functions allowing for differential optimization of network parameters. ROC curves typically feature true positive rate (TPR) on the Y axis, and false positive rate (FPR) on the X axis. A larger area under the curve (AUC) is usually better.

A NN-based Particle ID

The target particle we are looking for are electron and positron, all the other types are negative samples. With this configuration, we have show the OVR(one vs the rest) ROC curve for our data set including Energy-weighted width, Width, distance between extrapolated track center and WEW center, as well as cluster E divided by track momentum (E/p).



This ID shows a high performance comparing to the cut-based ID made manually with correct electron tagging rate of 60%, while expect 5% of non-electrons to be misidentified as electrons.

Summary

We have developed a promising algorithm using neural networks to reconstruct A->e-e+ decays and extended the sensitivity to discover long-lived dark photons. It will be continuously improved on aspects of recognizing particles without full track and multi-particle discriminator.