Dimuon Invariant Mass Spectra with the Muon Telescope Detector (MTD) at STAR in p+p collisions at $\sqrt{s}$ = 200 GeV

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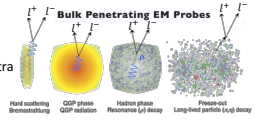
Abstract

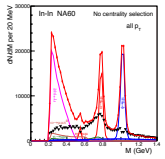
Dileptons (l^+l^-) are produced throughout all stages of heavy-ion collisions (HIC) through various production mechanisms. Since leptons have a small interaction cross section with the strongly interacting medium, they carry pristine information about the medium's properties. Dileptons produced within the intermediate mass region (IMR, $M_\phi < M_{l^+l^-} < M_{J/\Psi}$) result predominantly from the decay of correlated charm but also arise from thermal radiation of the hot and dense medium. The inverse slope parameter of the thermally produced dileptons in the IMR provides a measurement of the medium's temperature at early times which is free from radial flow effects [1]. The installation of the Muon Telescope Detector (MTD) at STAR allows a measurement of the dimuon ($\mu^+\mu^-$) production in HICs over a large invariant mass range for the first time. Data has been collected with the full MTD from Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and from p+p collisions at $\sqrt{s}$ = 200 GeV. These two datasets allow for new opportunities to measure the dimuon invariant mass spectra at STAR. Before any dimuon measurements can be made, muons must be identified. This poster presents muon identification employing Deep Neural Networks (DNN) and compares it with other multi-variate techniques. Applications of the DNN technique for data-driven purity measurements are discussed.

Introduction and Motivation

Dileptons provide an excellent penetrating probe of the medium

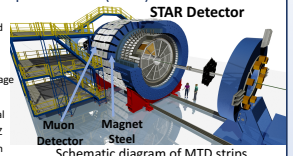
- Leptons interact through the electromagnetic force, not via strong force – they carry pristine information about the medium's properties
- Dilepton pairs are created throughout the entire lifetime of the system – physics from all stages can be probed by studying the invariant mass spectra
- NA60's dimuon measurements in In+In [2] showed that precise dilepton measurements can provide information about chiral symmetry restoration and the created medium's temperature at early times

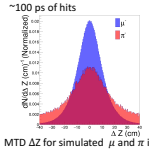




Muon Telescope Detector (MTD) at STAR

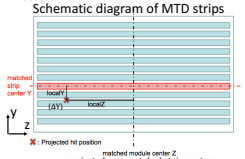
- Multi Resistive Plate Chamber (MRPC) based detector installed outside magnet
- Efficient for p_T>1.0 GeV/c
- Provides ~45% azimuthal coverage in $|\eta| < 0.5$
- Provides hit location with spatial resolution of ~2cm in ΔY and ΔZ
- Provides precise time resolution ~100 ps of hits





MTD ΔZ for simulated μ and π in p+p collisions at $\sqrt{s}$=200 GeV

Schematic diagram of MTD strips

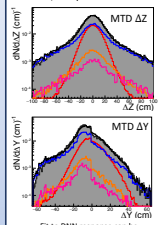


$$\Delta Y = y_{local}^{projected} - y_{local}^{matched\ strip\ center}$$

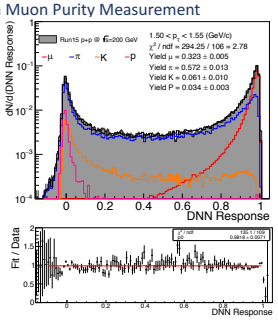
$$\Delta Z = z_{local}^{projected} - z_{local}^{measured}$$

Data Driven Muon Purity Measurement

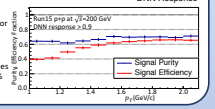
1. Evaluate DNN for tracks in data (grey)
2. Generate signal and background templates by evaluating DNN on simulated tracks
3. Template fit the data distribution (grey) to extract the yield of μ, π, K, and p.



Fit to DNN response can be projected back onto input variables to verify the fit quality



Single track PID efficiency and purity for a tracks with a DNN response > 0.9 in p+p collisions at $\sqrt{s}$=200 GeV. This cut is provides approximately 65-70% signal purity at all p_T.



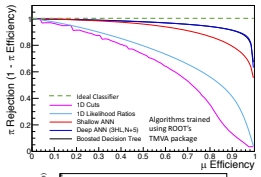
Multivariate Muon Identification

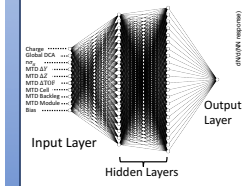
Compare multivariate algorithms for identification of muons with MTD

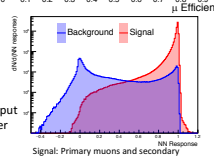
Classifiers are compared by observing their background rejection power as a function of signal efficiency.

Deep Neural Networks (DNN) and Boosted Decision Trees (BDT) are found to be significantly more powerful than traditional techniques.

DNNs are found to be (1-5%) better than BDTs and DNNs are more robust against small differences between MC and data.





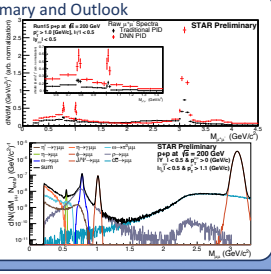


Signal: Primary muons and secondary muons that decay inside tracking detector

Background:
- π, K, p punch through
- $\pi \to \mu + \nu$ and $K \to \mu + \nu$ decays outside tracking detector

Summary and Outlook

- Top: Raw $\mu^+\mu^-$ invariant mass spectra in p+p collisions at $\sqrt{s}$=200 GeV for traditional PID and for DNN PID.
- DNN PID substantially improves the significance of the ω, ϕ, and $\Psi(2S)$ resonances.
- Bottom: The simulated $\mu^+\mu^-$ invariant mass spectra for p+p collisions at $\sqrt{s}$ = 200 GeV for the MTD's kinematic acceptance.
- The $c\bar{c}$ contribution is determined using the Pythia Event Generator[3].
- Final background and efficiency estimations are in progress.



References

[1] R. Rapp, and H. van Hees, Phys. Lett. B, **753** (2016).
[2] NA60 Collaboration, Arnaldi, R., Banicz, K. et al. Eur. Phys. J. C, **711** (2009)
[3] Torbjörn Sjöstrand, Stephen Mrenna and Peter Skands, JHEP 05 (2006)

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The STAR Collaboration
drupal.star.bnl.gov/STAR/presentations

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Muon Identification using Neural Networks with the Muon Telescope Detector at STAR

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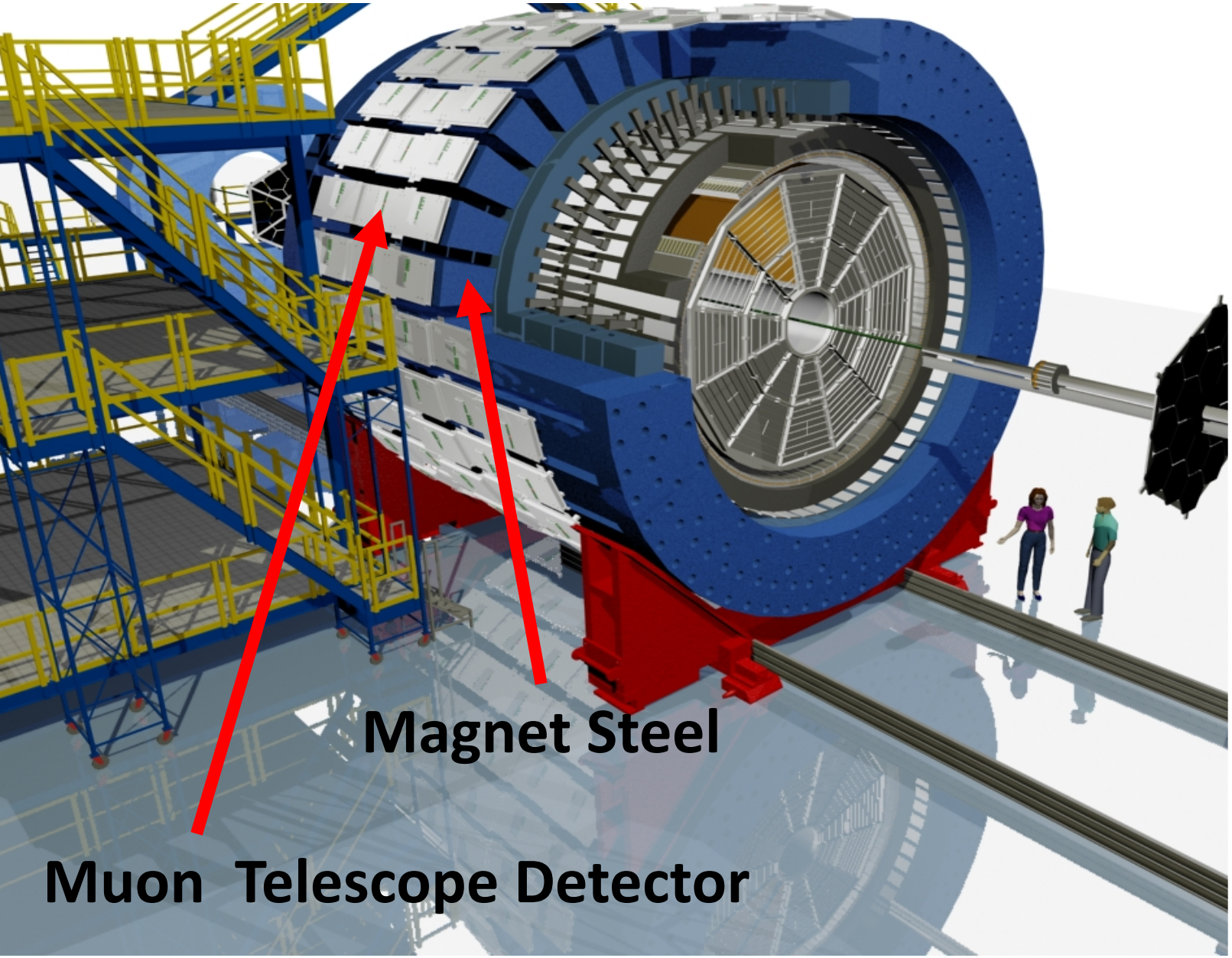
Venezia 2018 Quark Matter

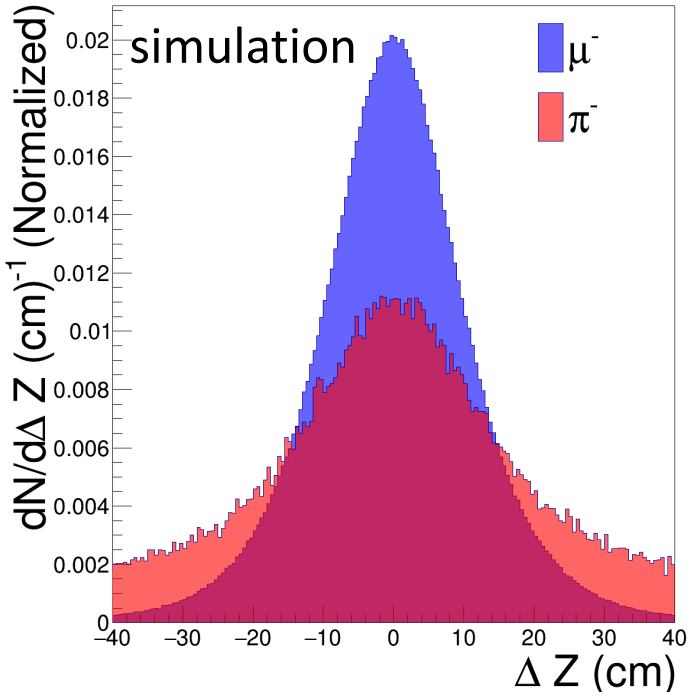
STAR Detector with MTD

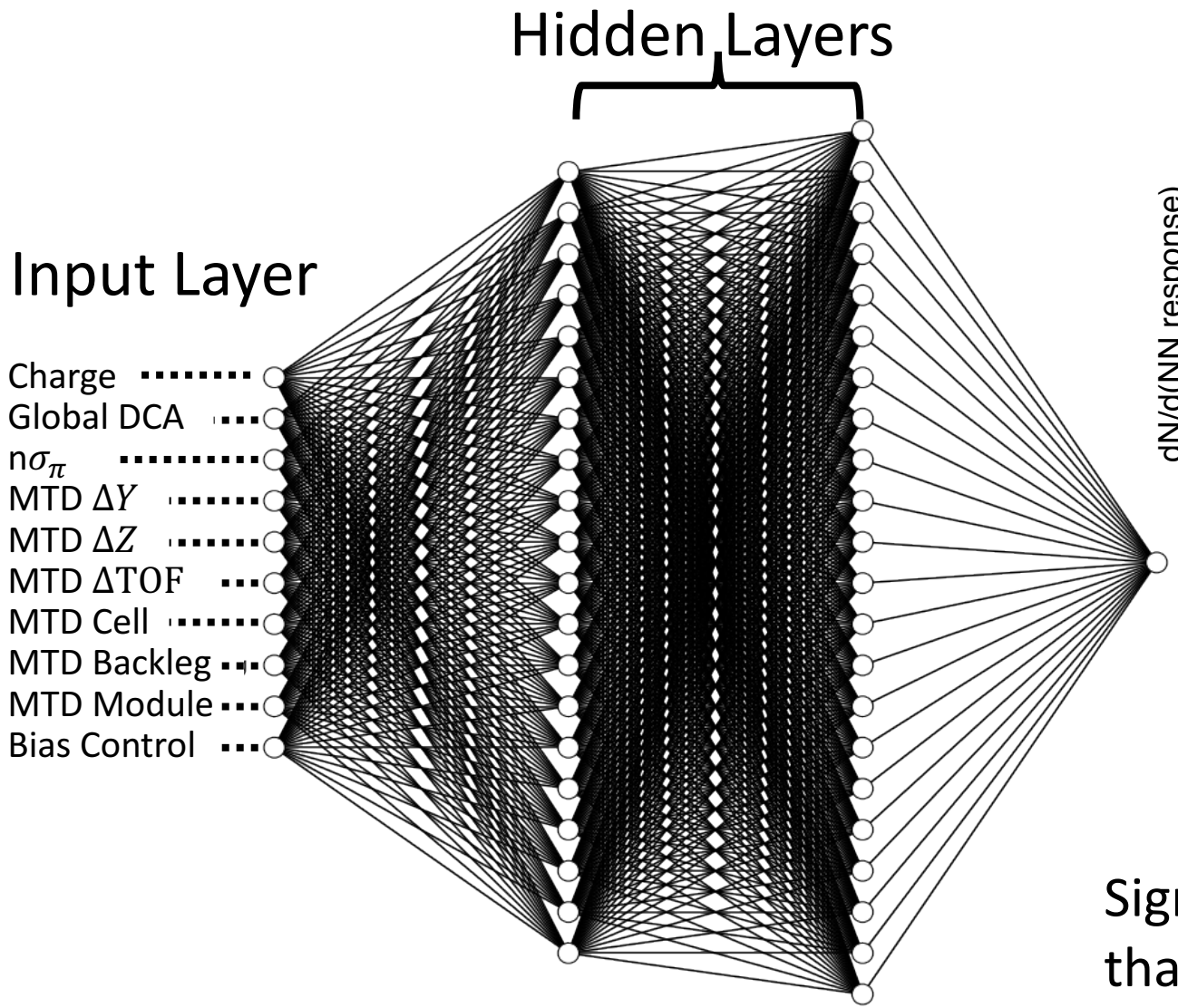


MTD is a Multigap Resistive Plate Chamber (MRPC) based detector installed outside magnet steel

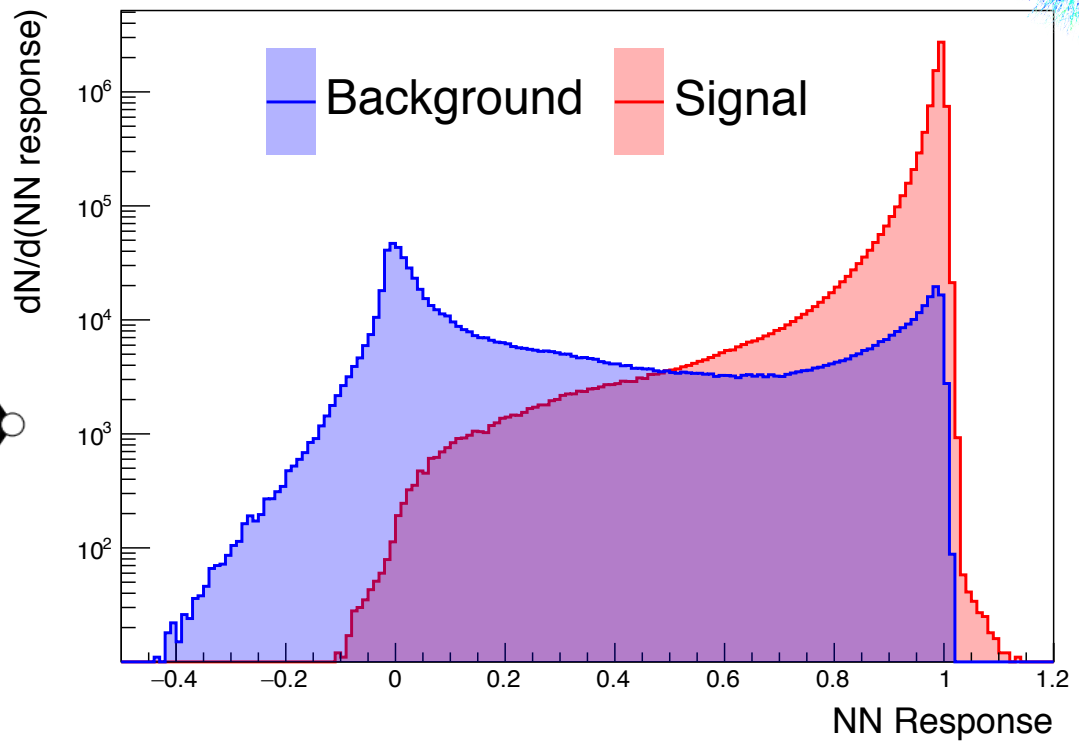
Particle identification information:

- Hit location with spatial resolution of ~ 1-2cm in ΔY and ΔZ
- Precise time resolution ~100 ps of hits





Neural Network Response



Signal: Primary muons and secondary muons that decay inside tracking detector

Background:

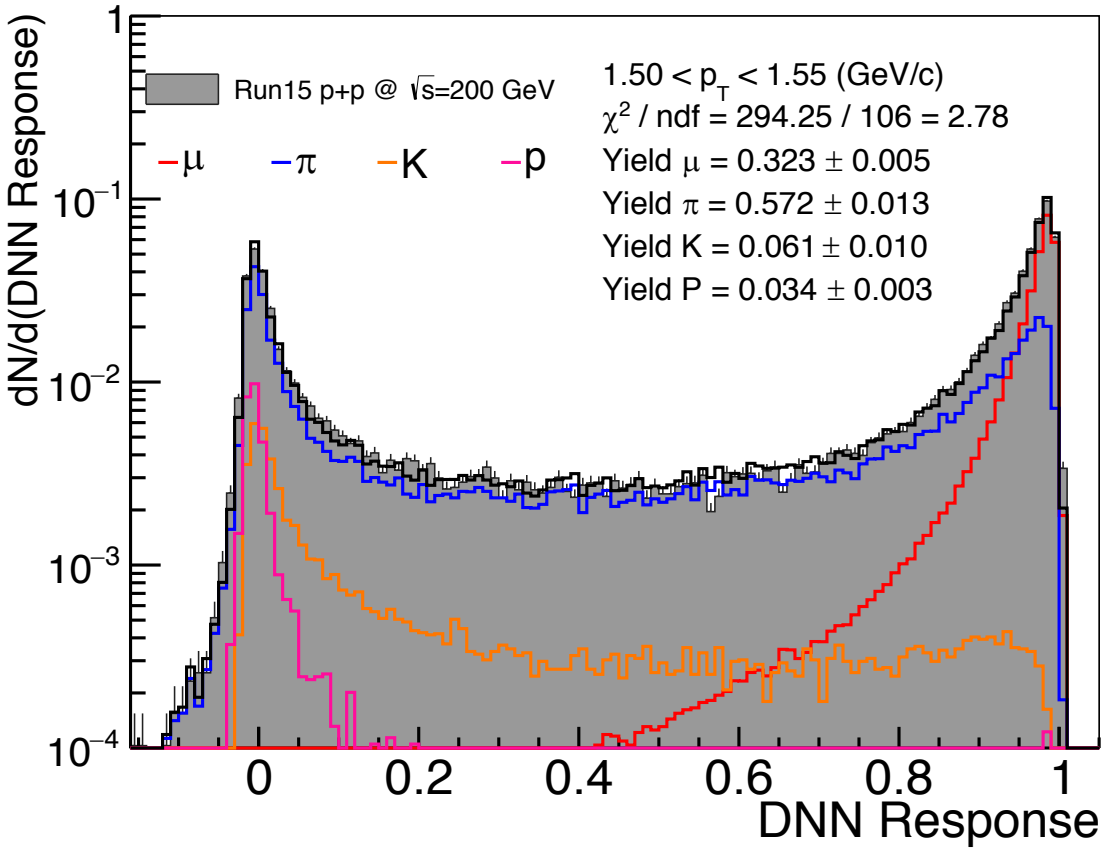
- π, K, p punch through
- $\pi \rightarrow \mu + \nu$ and K $\rightarrow \mu + \nu$ decays outside tracking detector

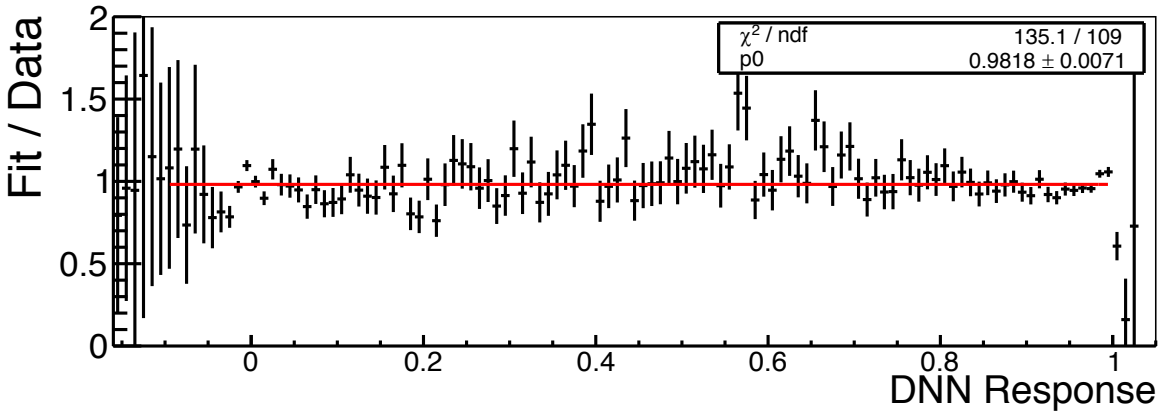
How is the network architecture decided?

➜ **optimize** signal vs. background separation power on a grid of #hidden layers and #neurons in each layer + prefer simplest architecture

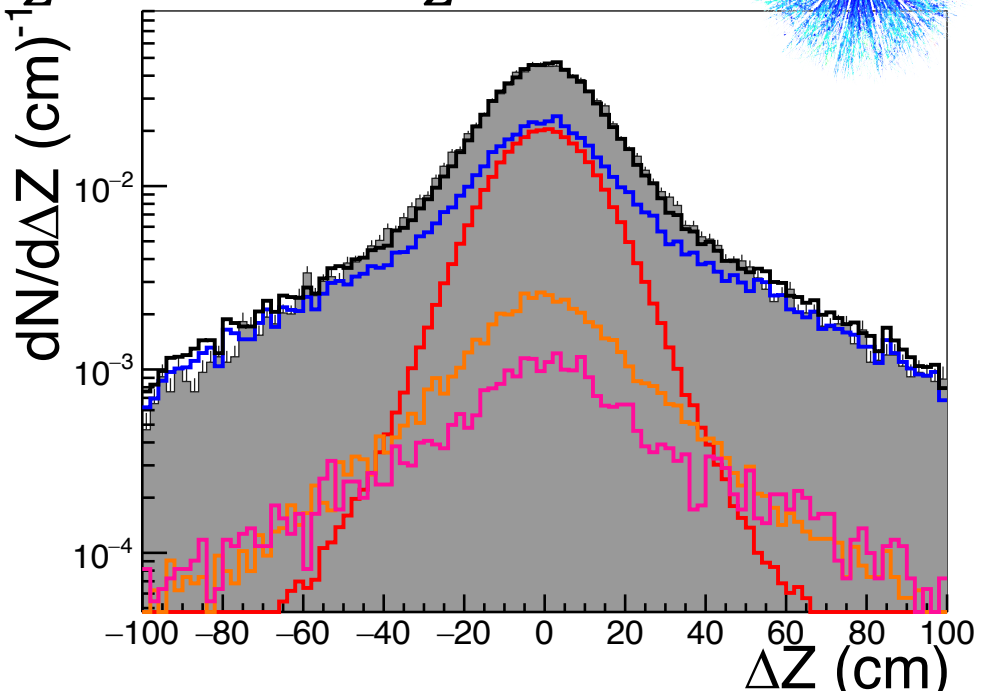
Example: MTD ΔZ

$$\Delta Z = z^{projected} - z^{measured}$$

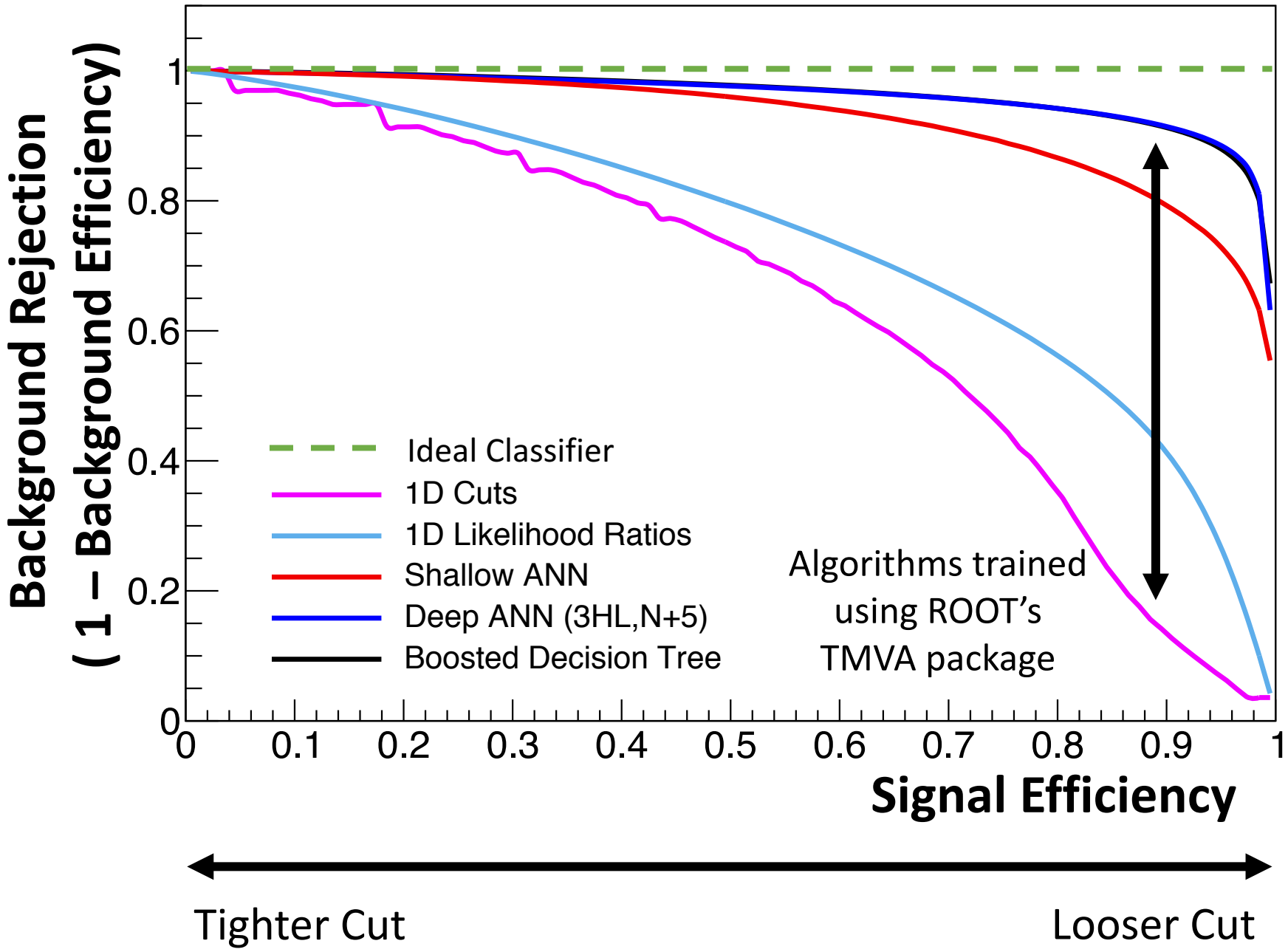




Project DNN fit back onto input variables



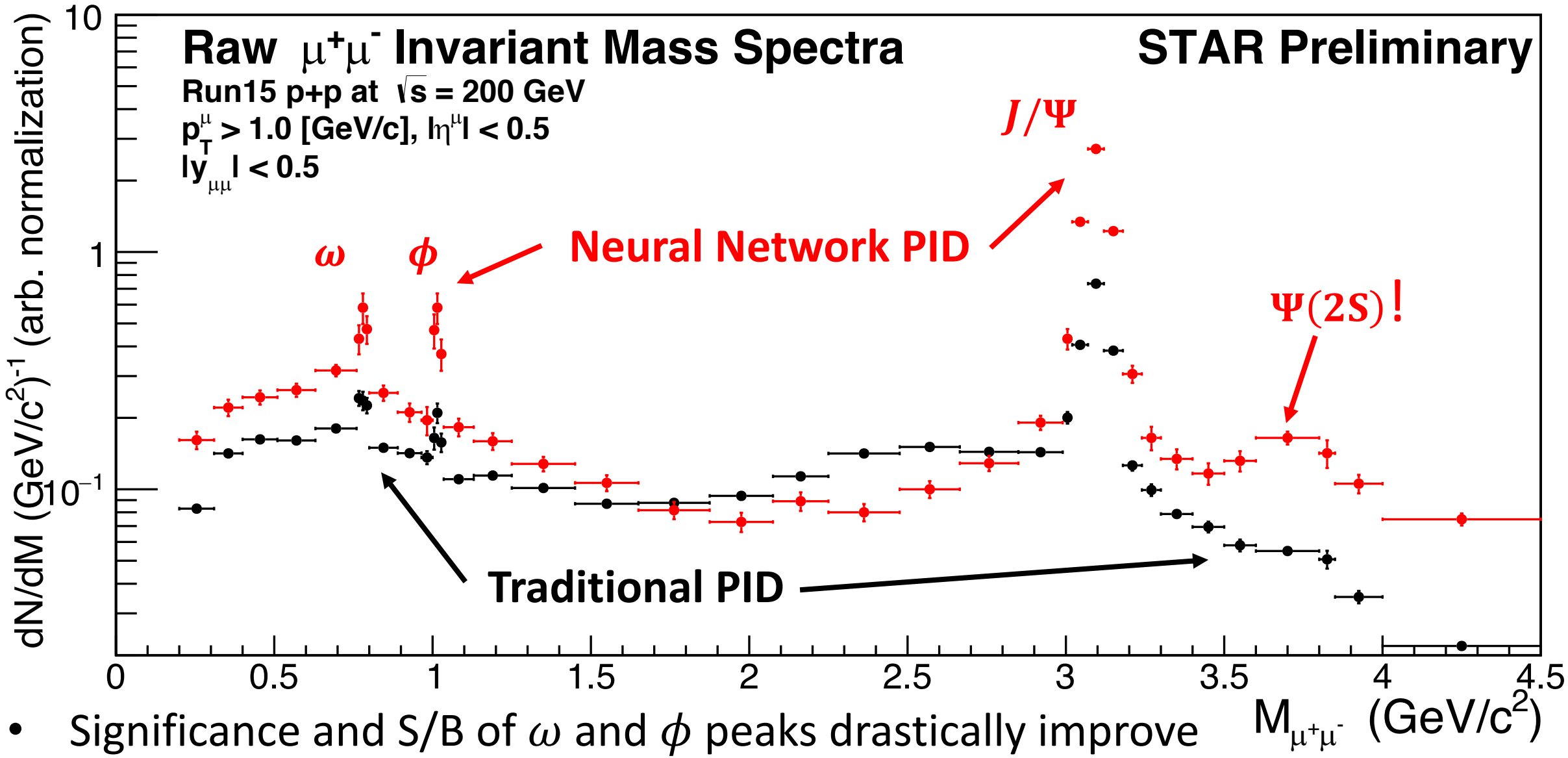
1. Apply DNN to muon candidate tracks in data (grey)
2. Generate signal and background templates by evaluating DNN on MC tracks
3. Template fit the data distribution (grey) to extract the yields of μ, π, K, and p.



Comparison of several techniques shows that Deep Neural Networks perform the best (up to 5% better than BDT for low p_T tracks)

Monte Carlo shows that DNN vastly out-performs traditional PID techniques

Can we see this improvement in the data?



- Significance and S/B of ω and ϕ peaks drastically improve
- Measurement of $\Psi(2S)$ possible with neural net PID

➜ Neural network clearly out-performs traditional identification techniques