ML-PID framework for the CBM experiment

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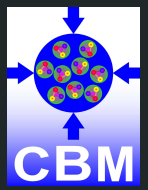
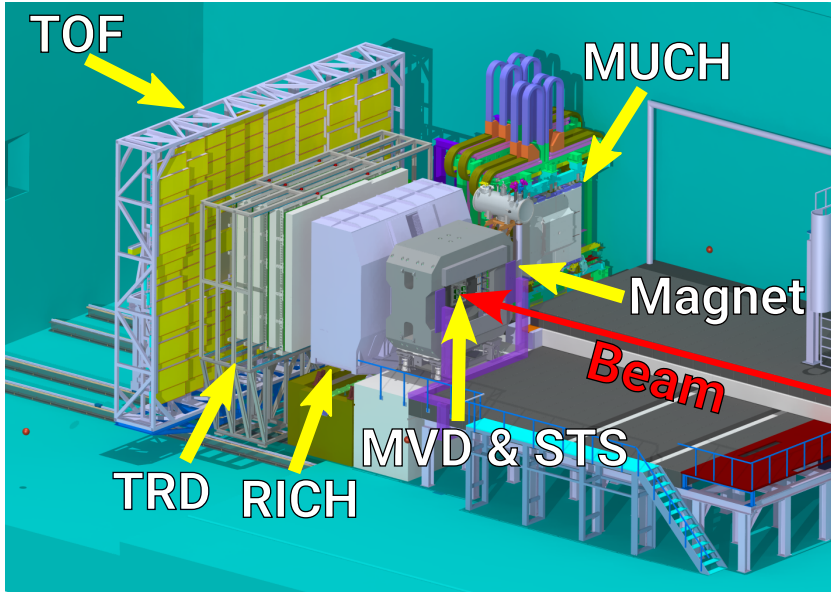
2nd GSI/FAIR AI Workshop 2026,
GSI, Darmstadt



BERGISCHE
UNIVERSITÄT
WUPPERTAL

CBM detector :

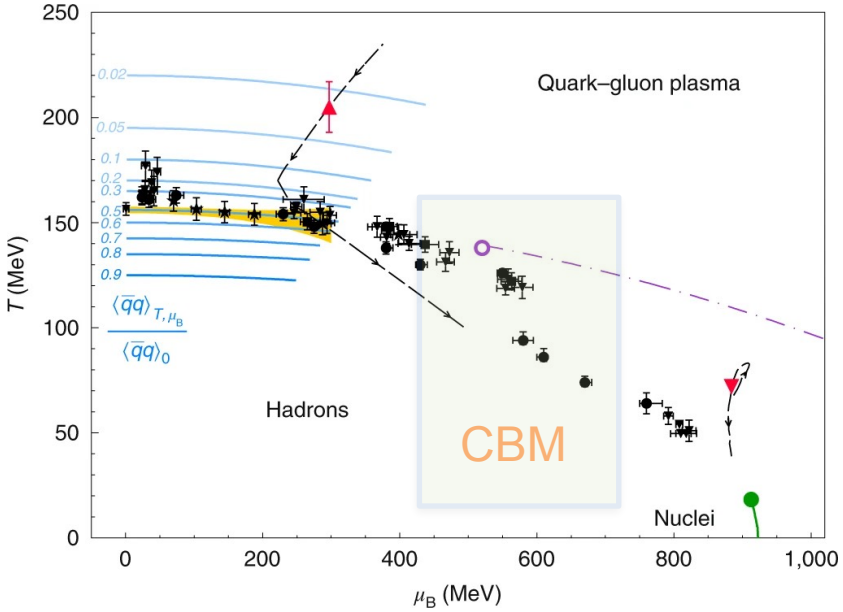


MVD - Micro vertex detector
STS - Silicon tracking system
RICH - Ring Imaging Cherenkov detector
MUCH - Muon chamber
TRD - Transition radiation detector
TOF - Time of flight
FSD - Forward spectator detector

- The Compressed Baryonic Matter is an upcoming fixed target experiment at FAIR (Facility for Antiproton and Ion Research) designed to explore QCD matter at high baryonic density as formed in the initial stages of a Heavy-ion collision.
- High interaction rate : max. 10 MHz (Hadron setup)
- Free streaming readout.
- Fast and efficient online 4D reconstruction and event selection.
- Tracking acceptance : Polar - 2.5^0 - 25^0, Azimuthal - Full

Hadron setup :
Tracking - STS (8 stations)
PID - STS + (RICH)+ TRD + TOF

QCD Phase diagram:



HADES Collaboration, Nature Phys. 15 (2019) 10, 1040

- Systematic exploration of QCD phases:

  -($\sqrt{s_{NN}}$ = 2.7 - 4.9 GeV, Au-Au).

  - Event by event fluctuations and correlations.

  - Multi-differential flow.

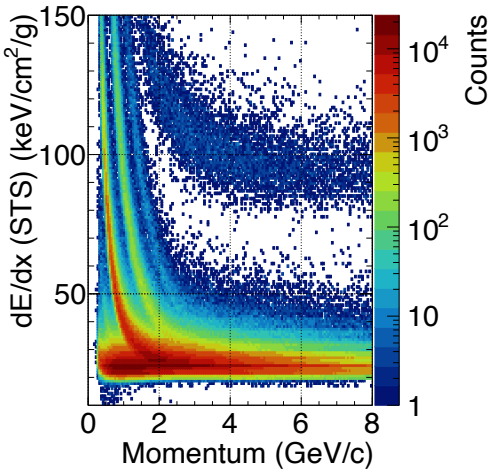
  - Dileptons ($e^+ + e^-$ and $\mu^+ + \mu^-$ pairs).

  - (Multi-) strange hyperons and hypernuclei.

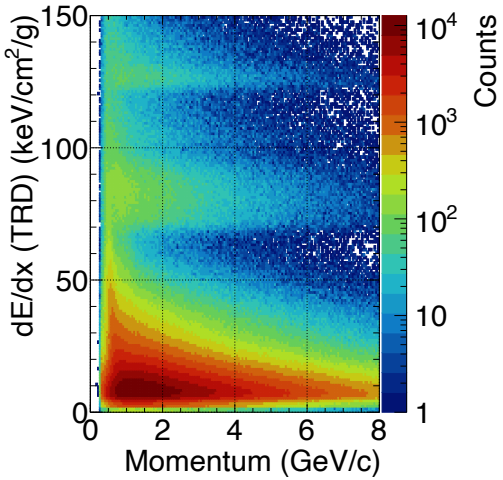
Reconstruction of rare probes at high interaction rate

→ Facilitated by excellent particle identification capability.

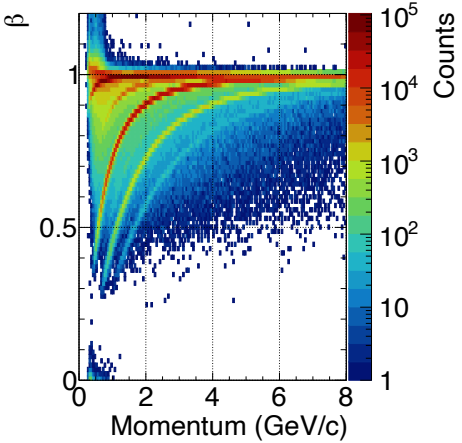
Global hadron identification scheme:



STS



TRD



TOF

Optimal combination of PID informations from all the detectors,

replacing conventional cut based PID scheme -> 10 features

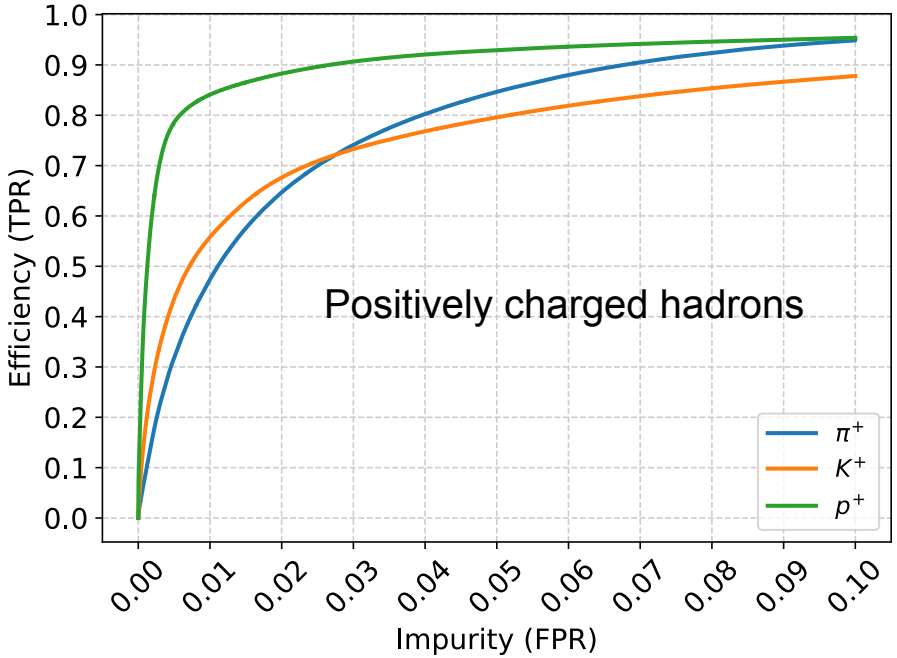
Realisation:

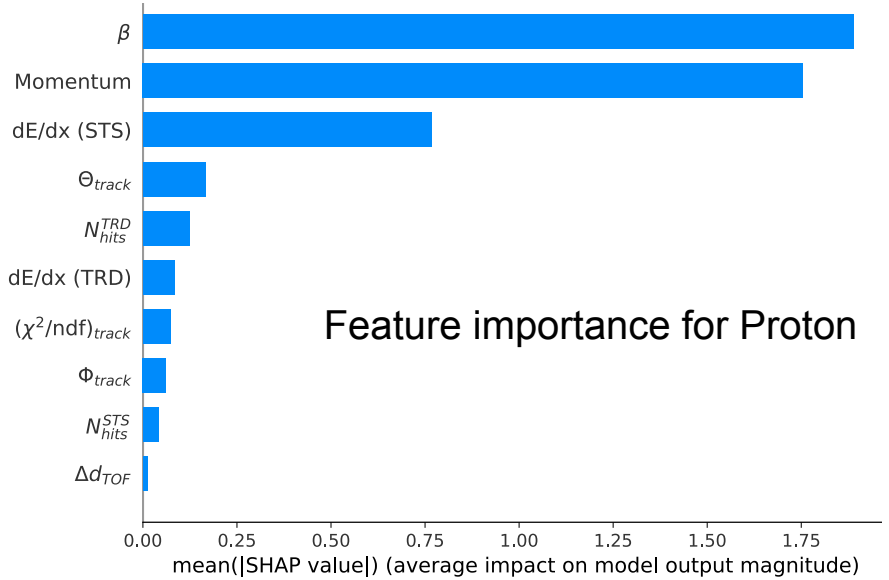
- 6 models for bulk hadrons: $p^{\pm}, K^{\pm}, \pi^{\pm}$.
- Models: Gradient boosted decision trees (XGBoost).
- Models are foreseen to work for different collision systems and energy

  → Momentum independent training (Uniform distribution).

Validation on testing dataset-1:

10^6 UrQMD events, Central (0-5%) Au-Au @ $\sqrt{s_{NN}} = 4.9$ GeV





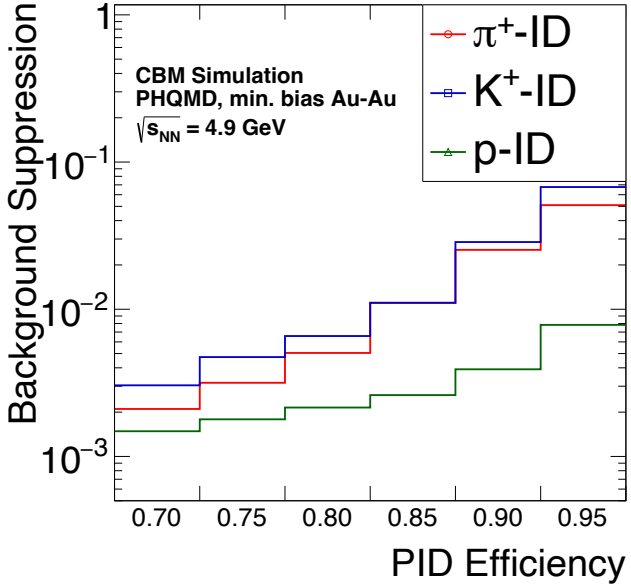
→ Velocity and momentum are the key features.

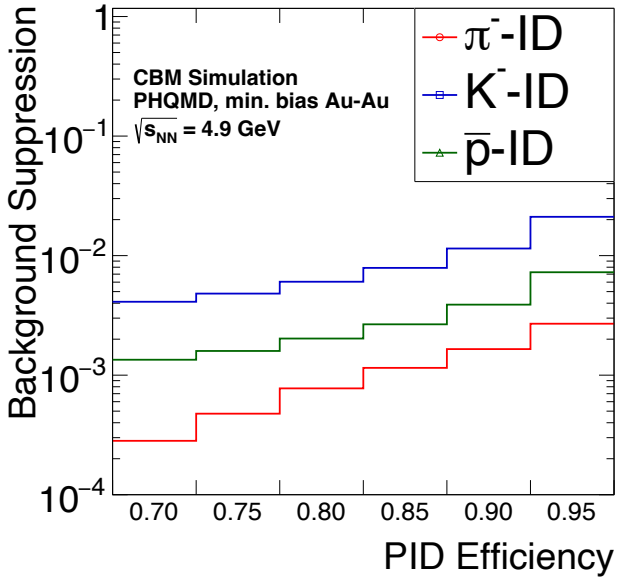
→ False positive rate < 0.02, True positive rate ~ 60 %.

Similar responses are observed for other particles.

Deployment inference - Analysis framework:

- Trained models are deployed in the CBM software framework (CBMROOT) via ONNX runtime.
- Data: 10^6 **PHQMD events, minimum bias Au-Au @** $\sqrt{s_{NN}} = 4.9$ **GeV (Dataset 2).**



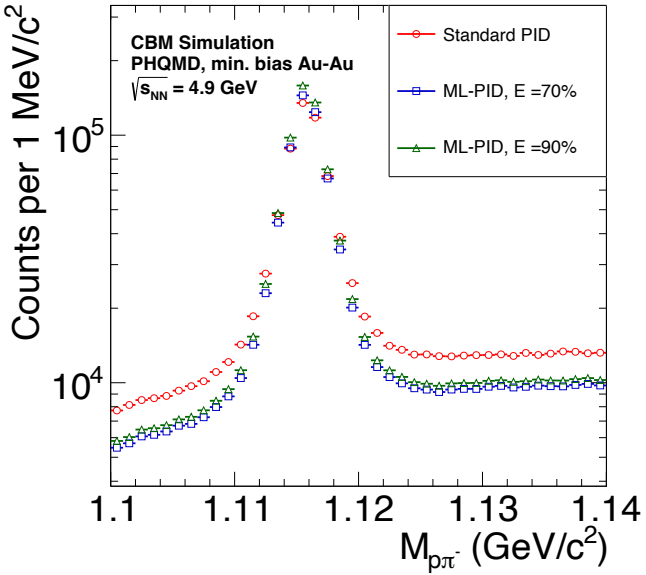


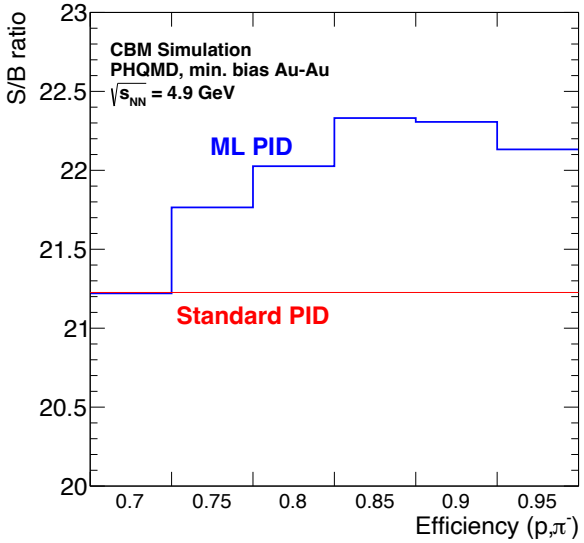
$$Suppression = \frac{Mis-identified}{Total}$$

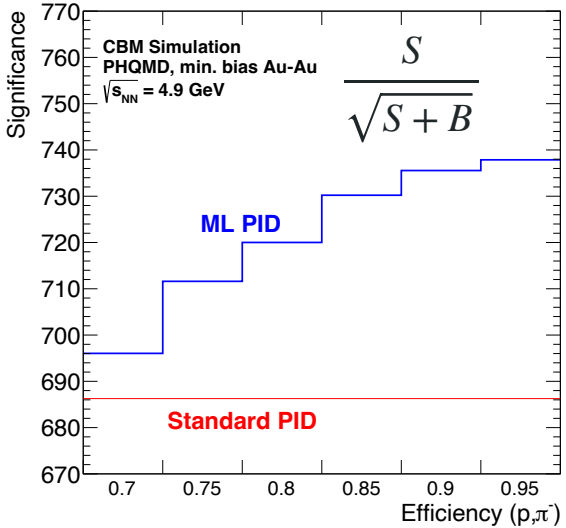
Background suppression ~ O(1/100) for + tracks , O(1/1000) for π^-

Reconstruction of Weak decay: Application

- KFParticle package is used for decay topology reconstruction. $\Lambda \rightarrow p + \pi^-$







Improvement in both figure of merits → **First iteration of PID framework for CBM is efficient.**

Next steps:

- Integrate into CBMROOT analysis chain.
- Test with the vertical test (higher statistics) dataset.

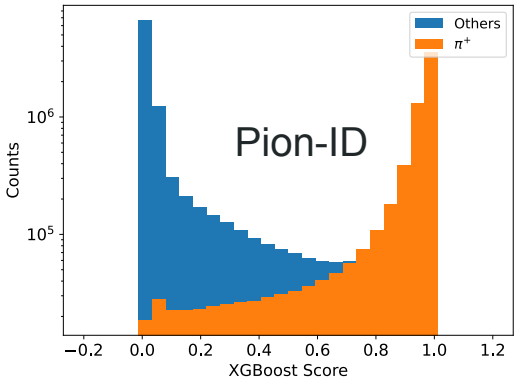
Contribution to EUCAIF:

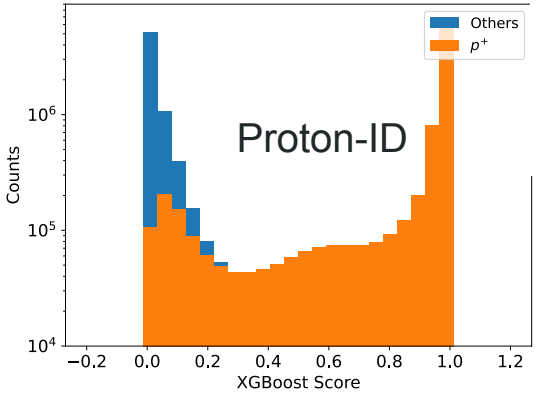
Poster/talk is uploaded here: https://indico.physi.uni-heidelberg.de/event/1277/contributions/4173/.

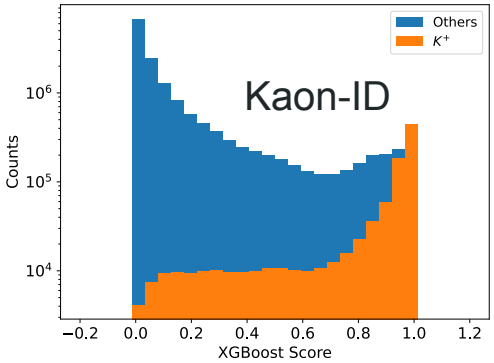
Thank you

Status update: Increased statistics and retrained

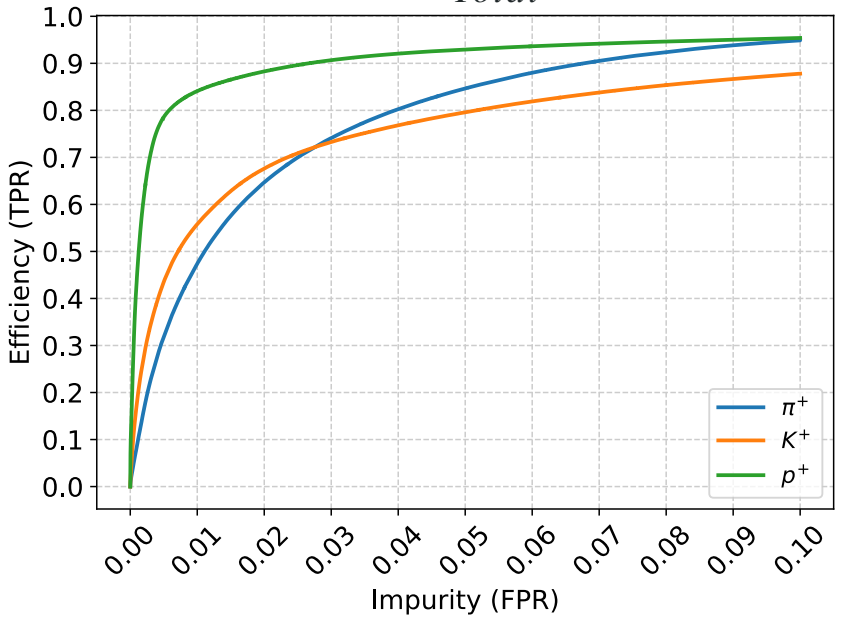
Results: Testing dataset: 1×10^6 UrQMD central 12A GeV.





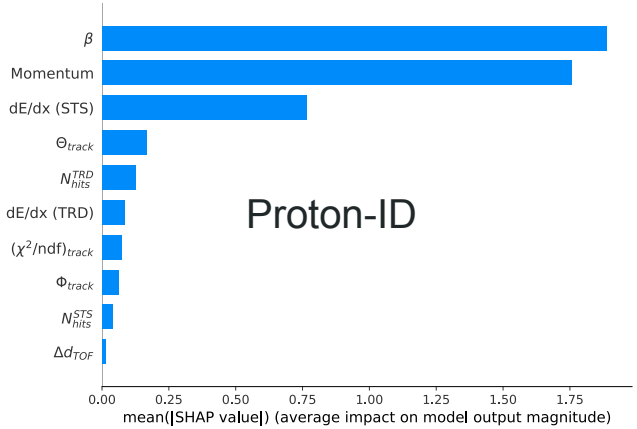


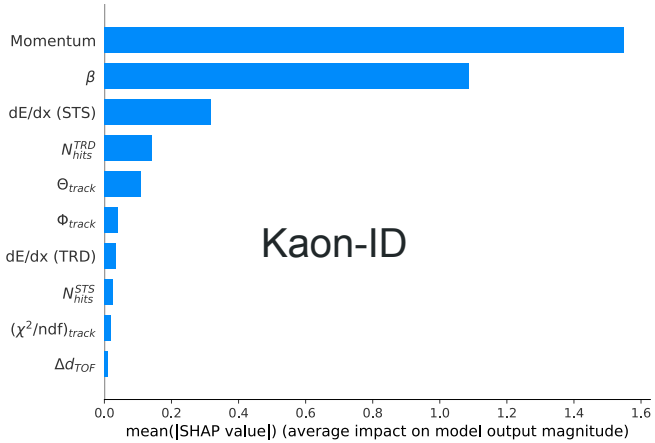
$$Impurity = \frac{Mis - identified}{Total}$$

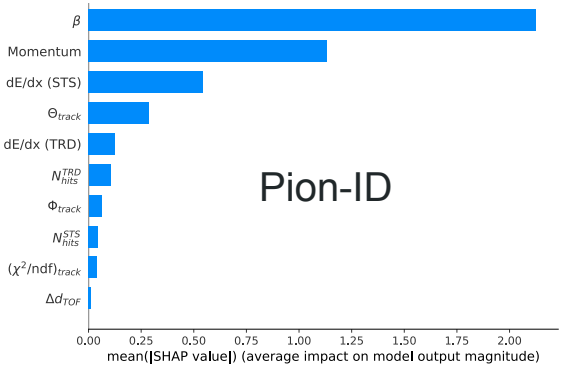


ROC Curve -> Good performance

SHAP: Testing dataset: 1×10^6 UrQMD central 12A GeV.



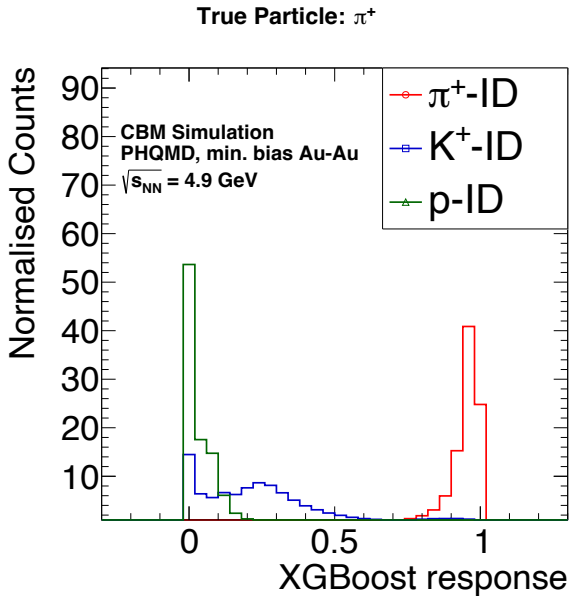


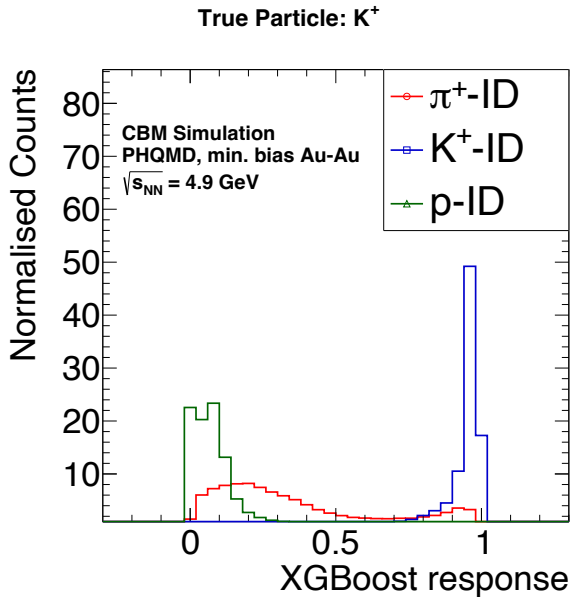


Interplay between momentum and Velocity.

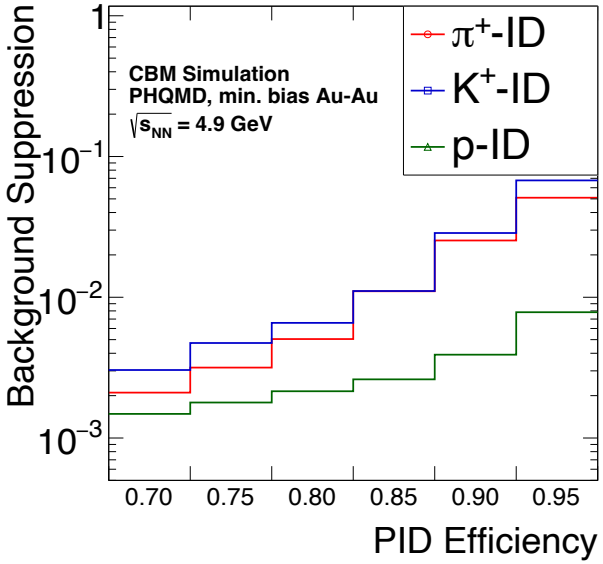
Results: Testing dataset: 1×10^6 PHQMD min. Bias 12A GeV.

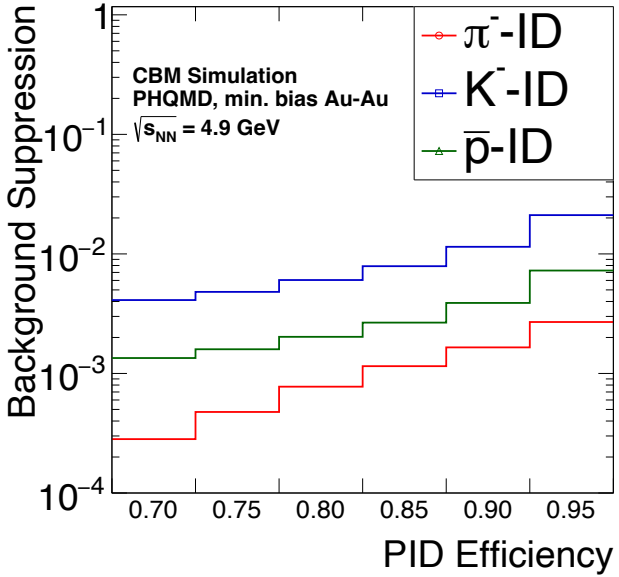
```
/lustre/cbm/prod/gen/phqmd/auau/pbeam12agev/mbias/all_clusters/
```





Suppression: Testing dataset: 1×10^6 PHQMD min. Bias 12A GeV.



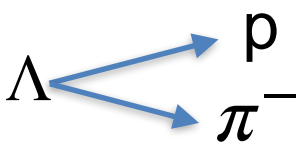


$$Suppression = \frac{Mis - identified}{Total}$$

Background suppression ~ O(100) for + tracks

O(1000) for p-

Benchmark channel:

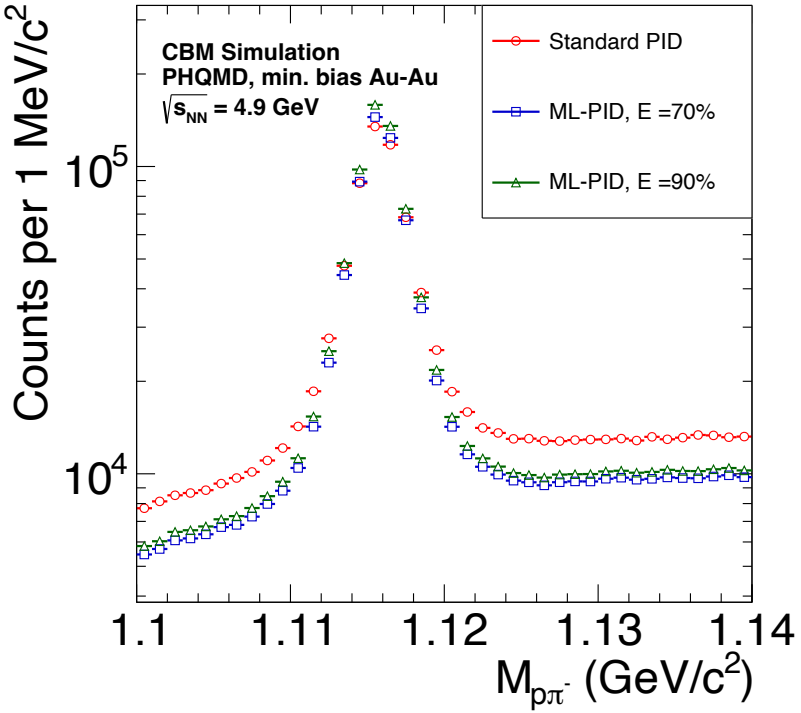


- Using KFParticle Finder in CBMROOT with help of Yingjiye.
- Standard TOPO cuts.

```
kfParticleFinder->SetChiPrimaryCut2D(0.); //16.
  kfParticleFinder->SetChi2Cut2D(3); //3.
  kfParticleFinder->SetLdLCut2D(5.); //10.

  kfParticleFinder->SetLdLCutCharmManybodyDecays(5.); //5.
  kfParticleFinder->SetChi2TopoCutCharmManybodyDecays(5); //5.
  kfParticleFinder->SetChi2CutCharmManybodyDecays(6); //6.
```

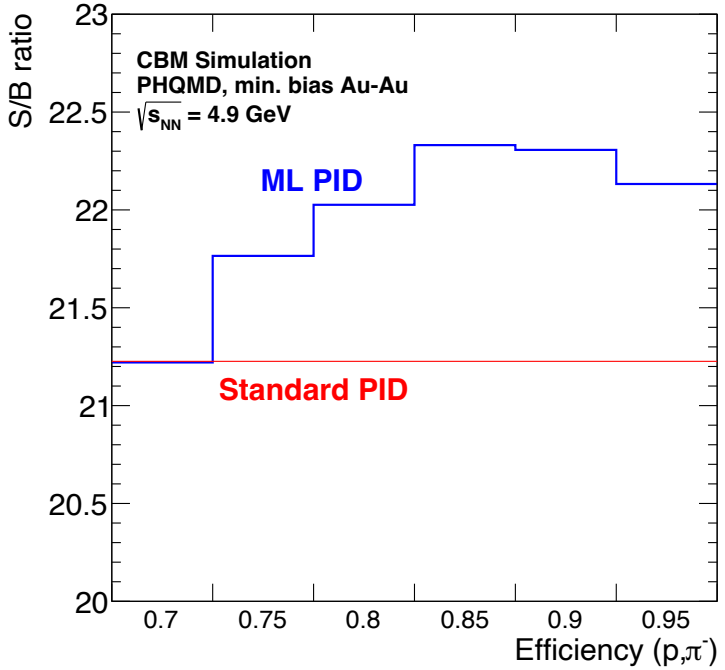
Results:

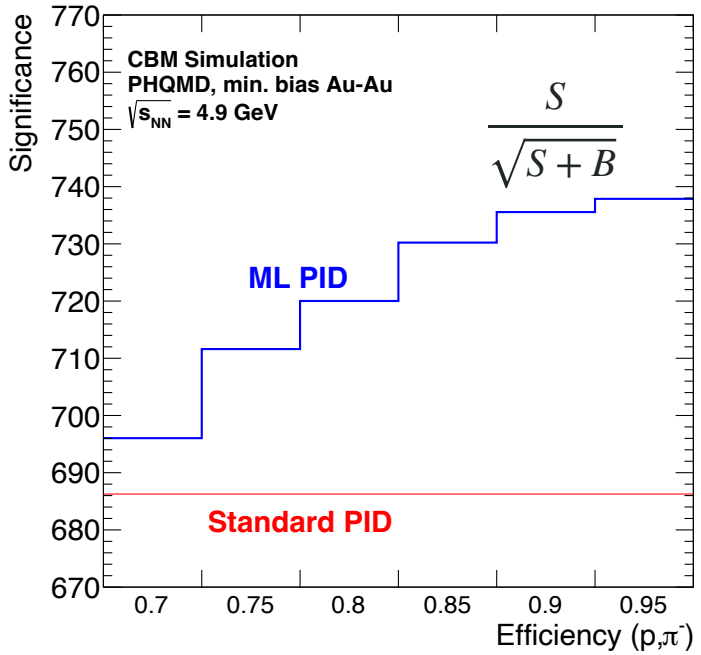


Clear improvement in Signal region and suppression in background.

Results:

- Signal is fitted with Gaussian and yield upto $\mu \pm 5\sigma$ is calculated





Improvement in both figure of merits.

Next steps:

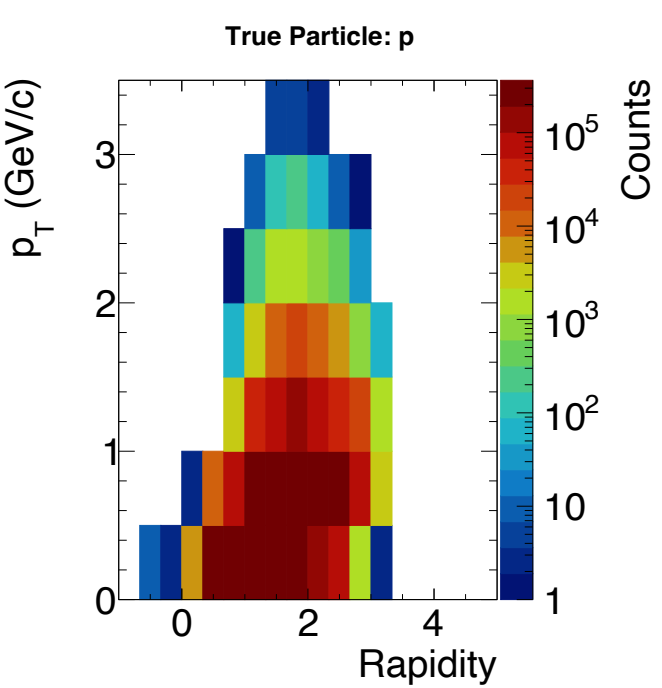
- Integrate into CBMROOT
- Test with the vertical test dataset.

Contribution to EUCAIF:

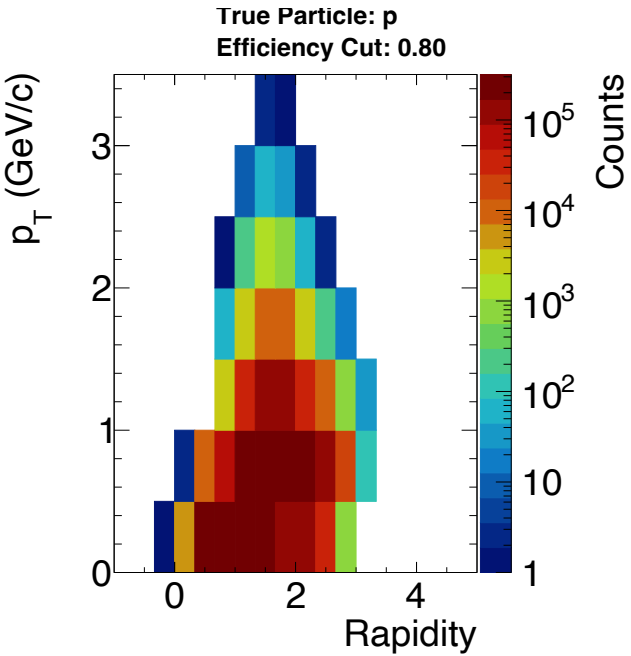
Poster is uploaded here: https://indico.gsi.de/event/25725/ also in this meeting indico.

Please send me your valuable comments/suggestions.

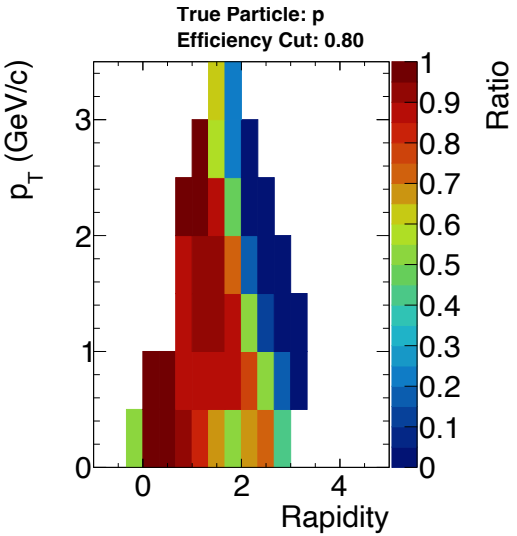
Phase space:



Before

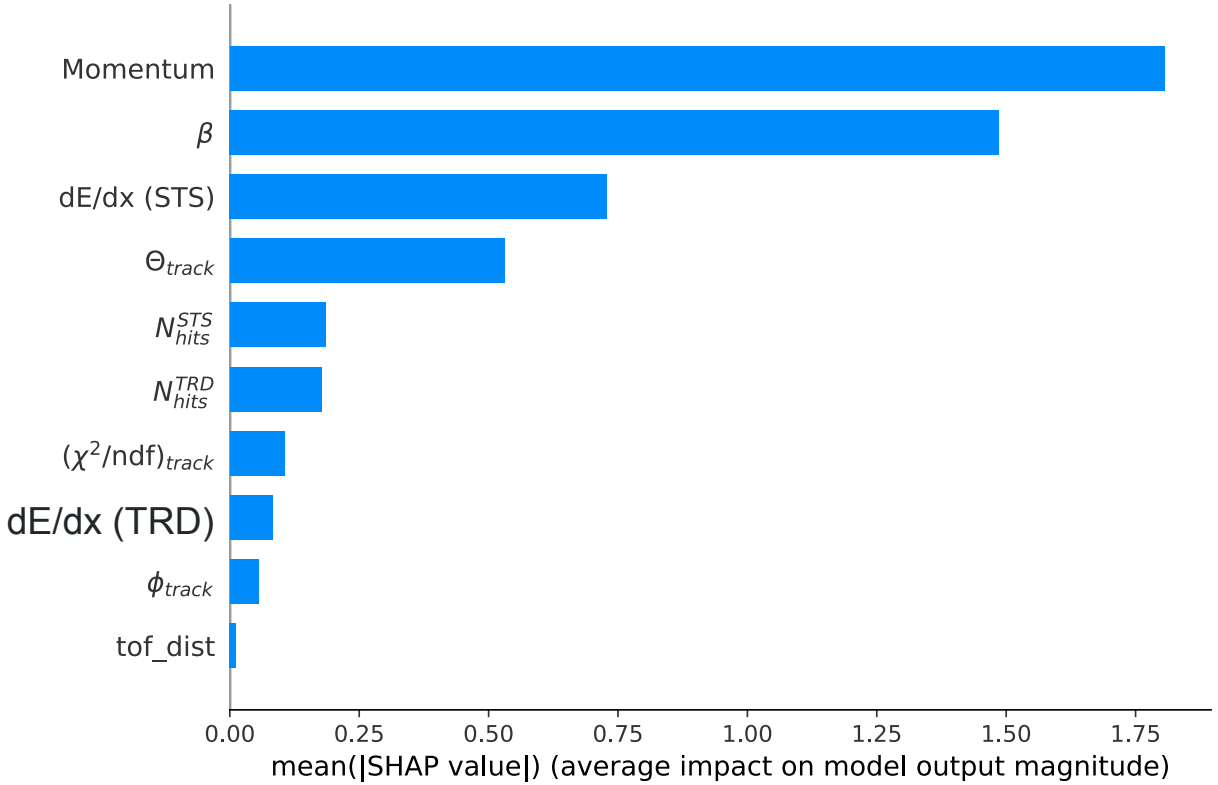


After

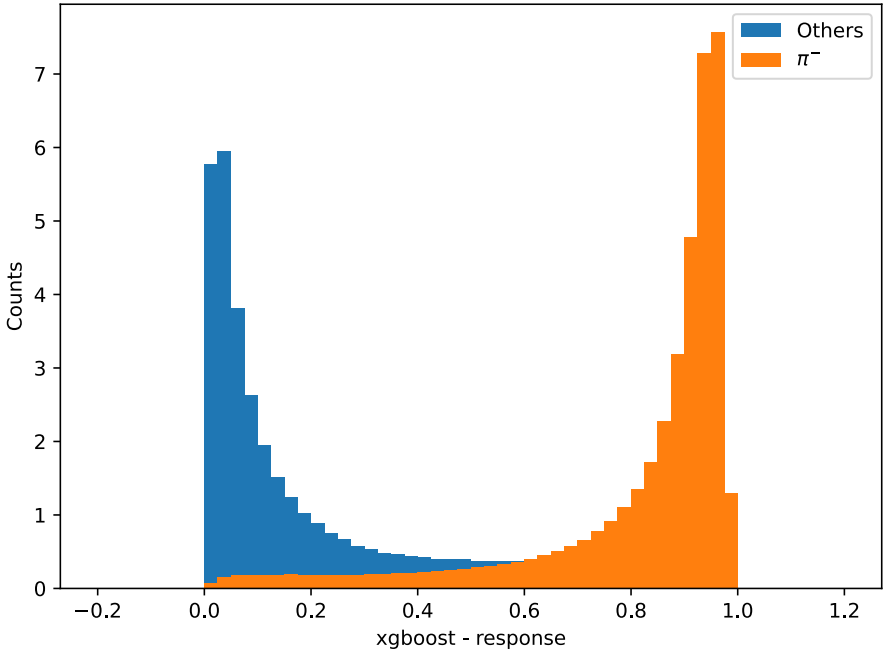


Ratio

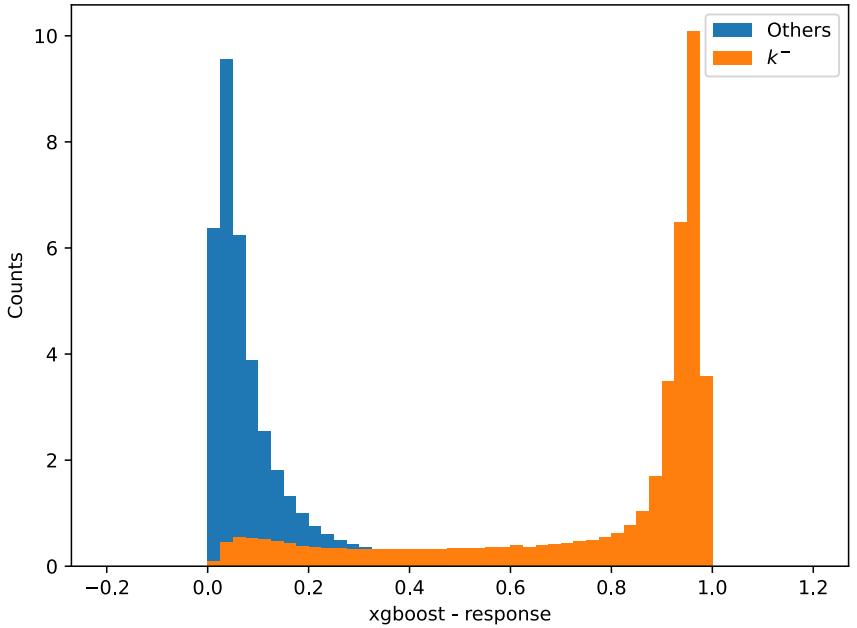
Results: XGBOOST-proton



Results: XGBOOST-pion



Response for pion



Response for kaon

Next steps:

- Training data sample :
  - UrQMD generated particles: Central (0-5%) Au-Au collisions @ $\sqrt{s_{NN}} = 4.1$ GeV.
  - Enriched with $K^{\pm}, p^{-}, \Lambda, \bar{\Lambda}$ to mitigate class imbalance and account for secondary decays.
  - 6×10^5 true + 6×10^5 false for each particle species → balanced data.
- All the hyper-parameters are optimised by a combination of grid and random search methods with 3 fold cross-validation.

Why not RICH?

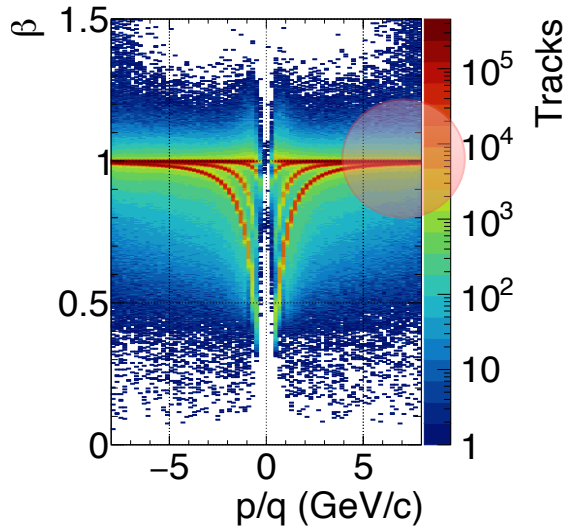
RICH

N_{hits}^{ring}

R_{ring}

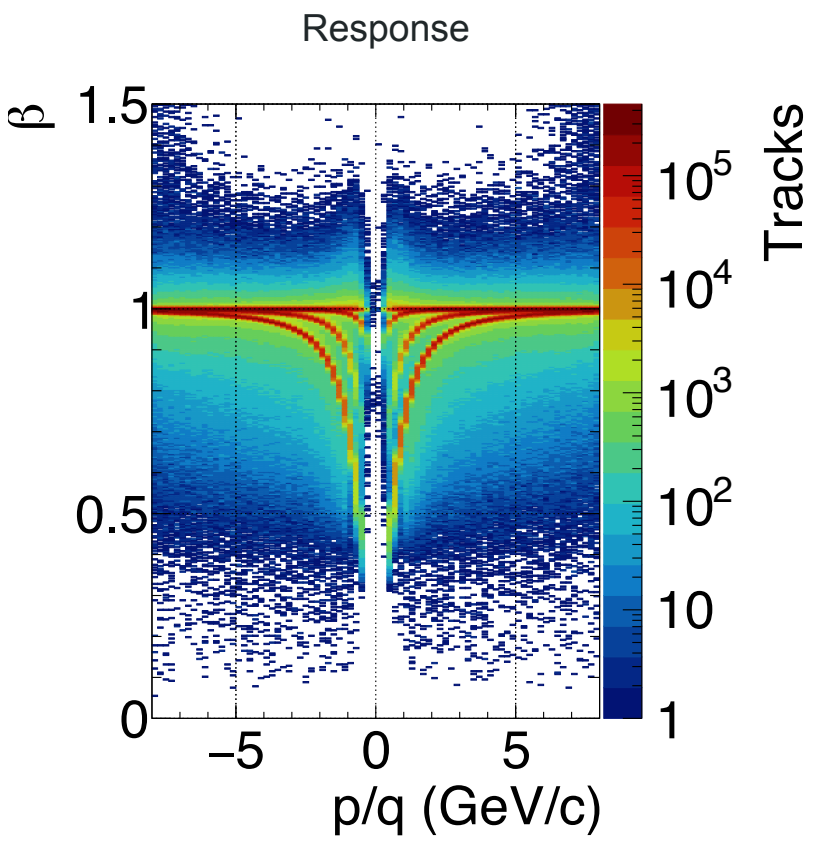
$\Delta d_{ring-track}$

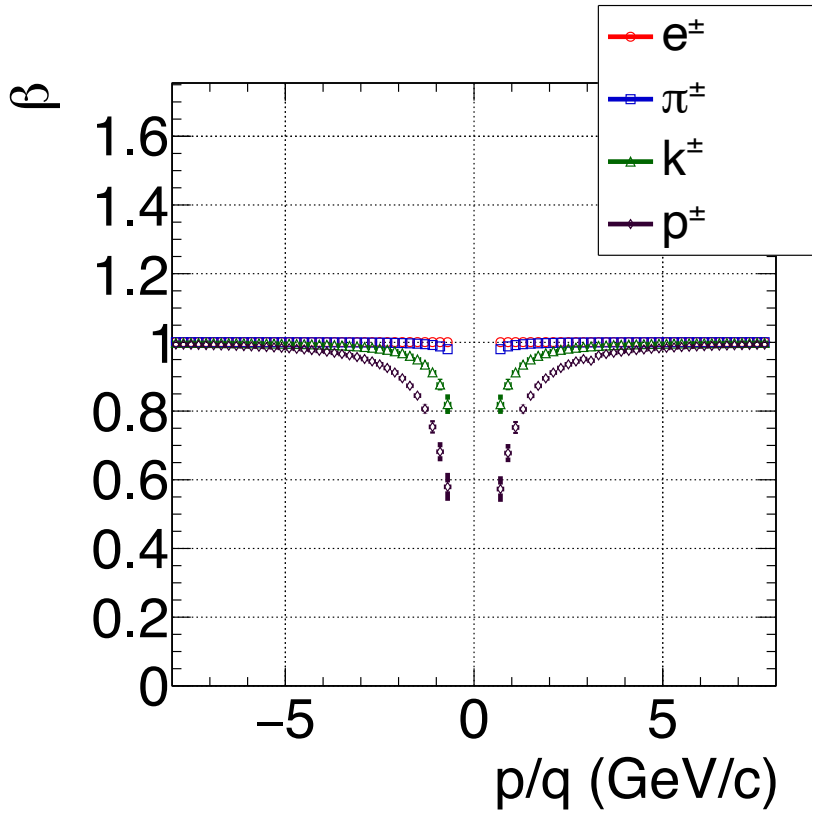
?



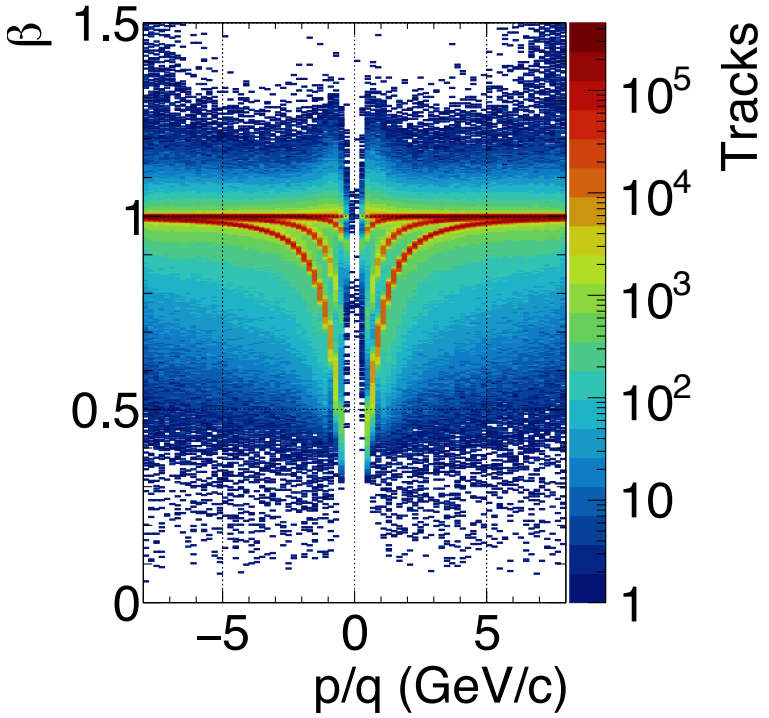
- Cherenkov threshold of 4.7 GeV/c for pions, 16 MeV/c for electrons.
- Electron veto until 6 GeV/c.
- Pion ID from 4.5-6 GeV/c.

TOF response: Single particle response

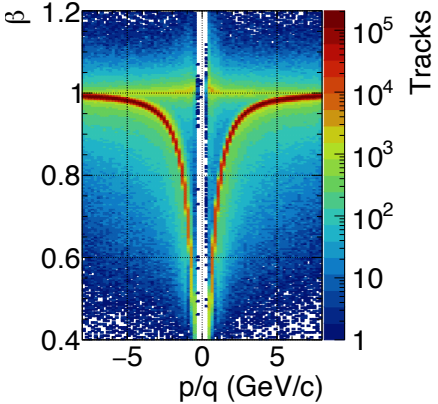




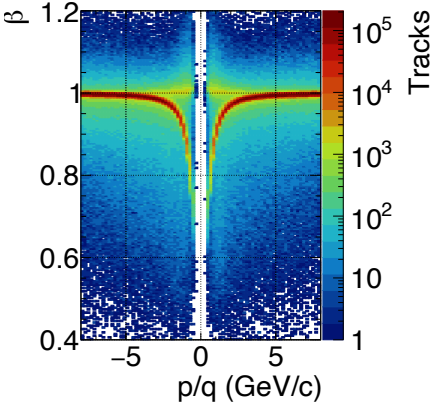
TOF response: Single particle response



All particles



Protons



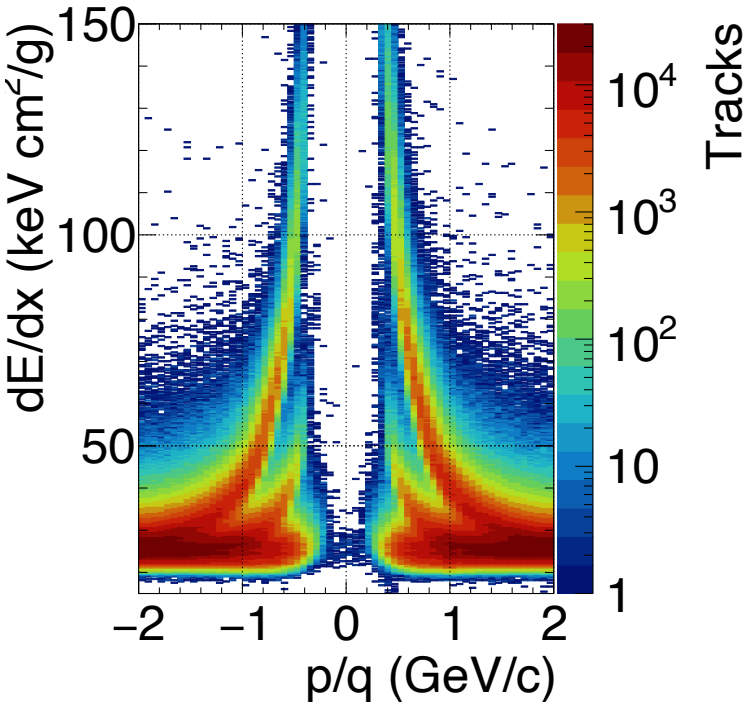
Kaons

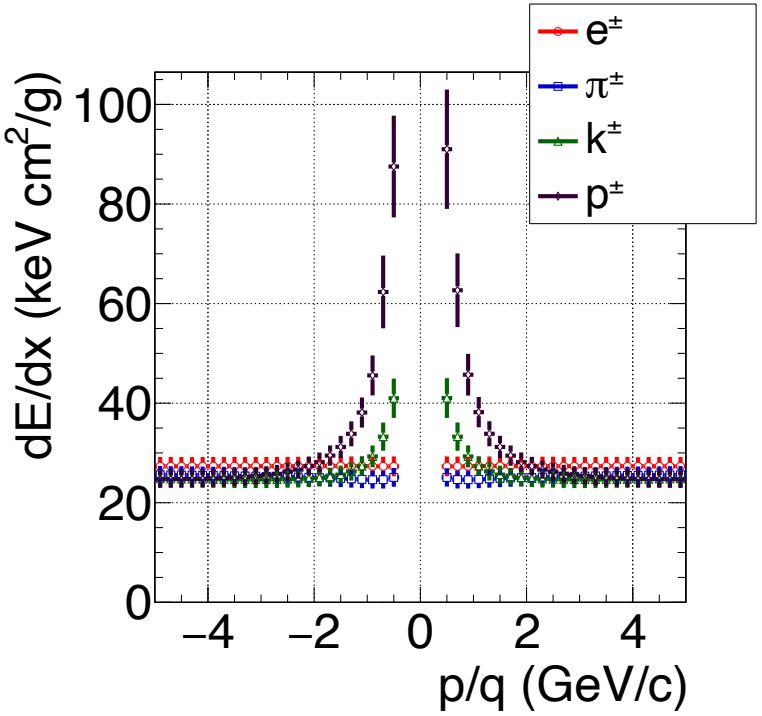
Mismatches in single particle level

->Hadronic interaction (?)

-> Partially reduced by $\Delta d_{TOF,hit-track}$

STS response: Single particle response





Important for low momentum protons

TRD response: Single particle response