Study of Belle II PID Performance

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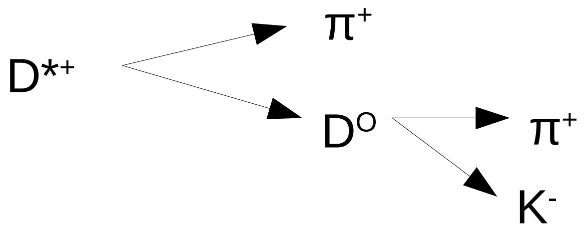
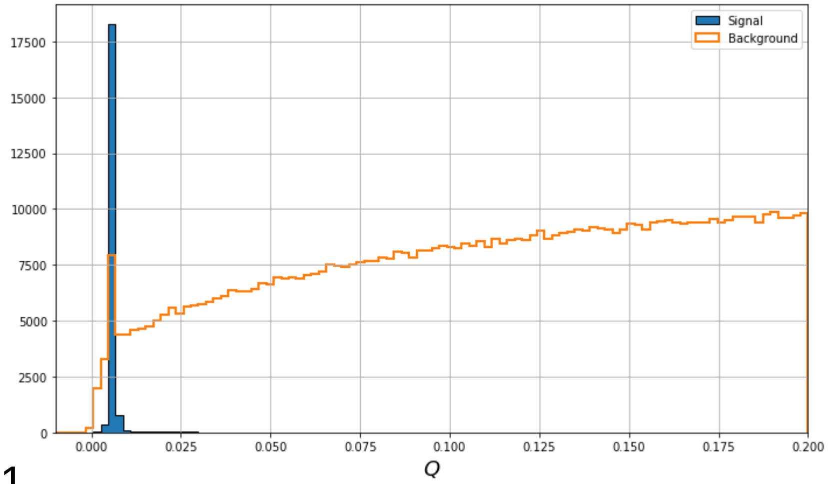
Introduction

- Goal – Understanding the Particle Identification (PID) efficiencies of Belle II detectors.



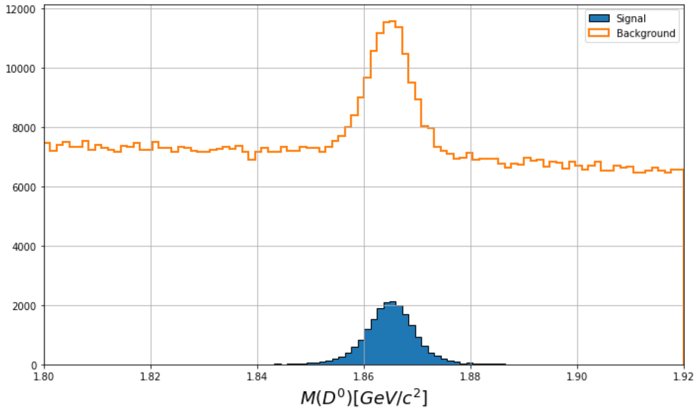
- Method: Study K and π samples from D* decays
  1. Reconstruct D^0 from Kπ with mass constrained vertex fit to the D^0. $| M(D^0) – 1.864 | < 0.0125$ GeV/c^2.
  2. Reconstruct D* from D0 π with vertex fit to the D*
  3. Require $| Q – 0.006 | < 0.002$ GeV/c^2

- Samples
  - signal MC samples with different backgrounds (BGx0, BGx1, BGx2 and BGx5)
  - Proc9 data
  - Run dependent MC (MC12c)

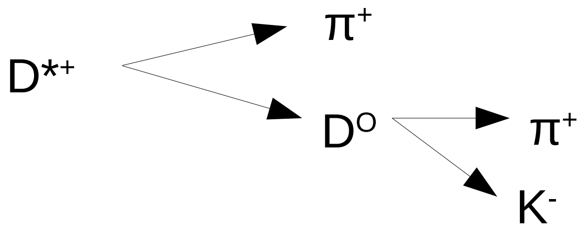


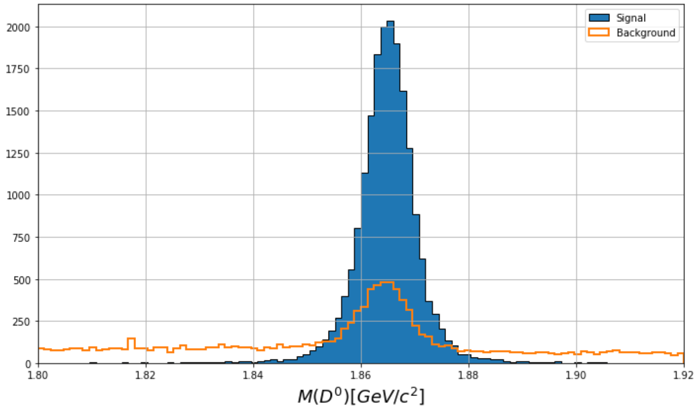
- Unless specified, all the plots in the presentation are BGx1.

Determine the cut of the samples

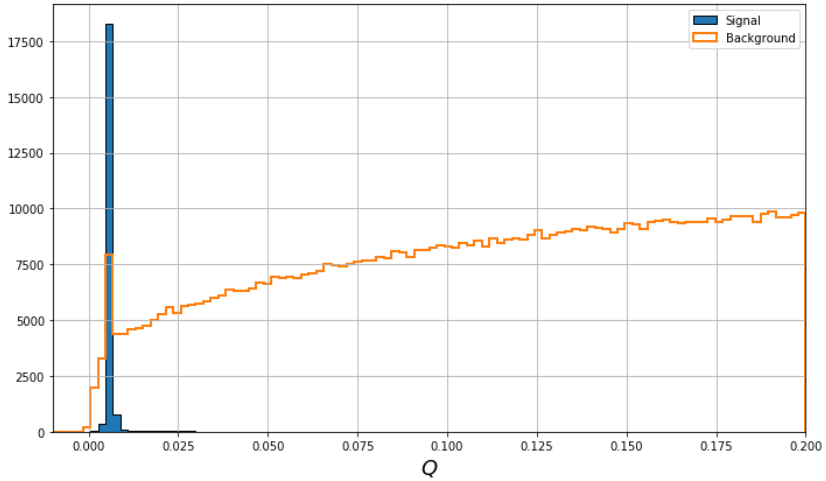


Without cut



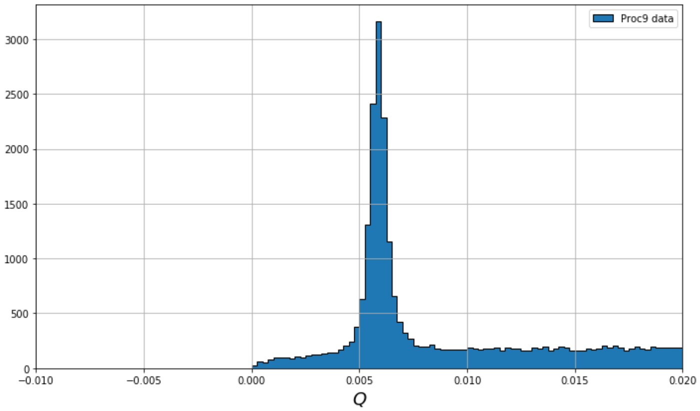


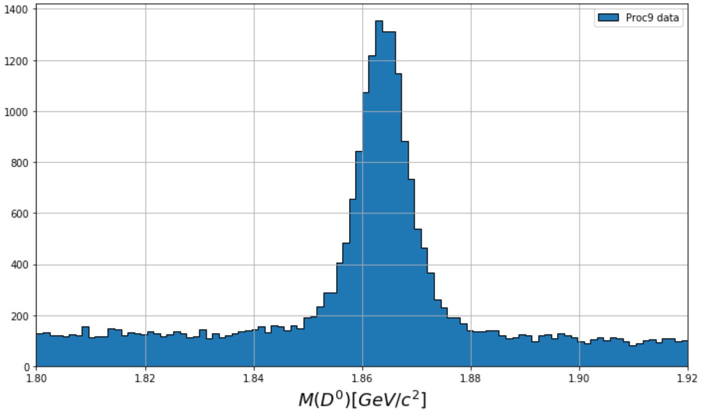
$|Q - 0.006| < 0.002\ GeV/c^2$



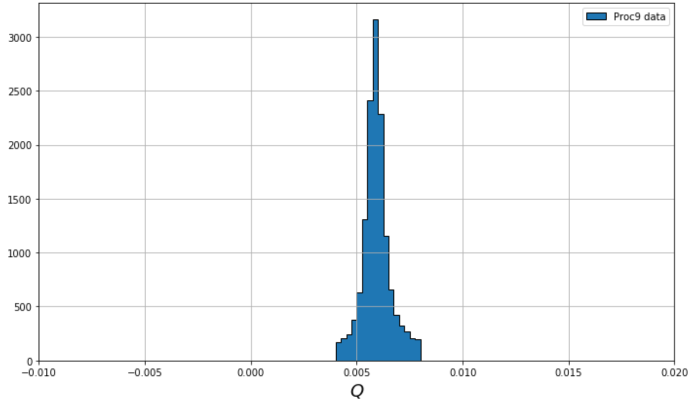
Run-dependent MC

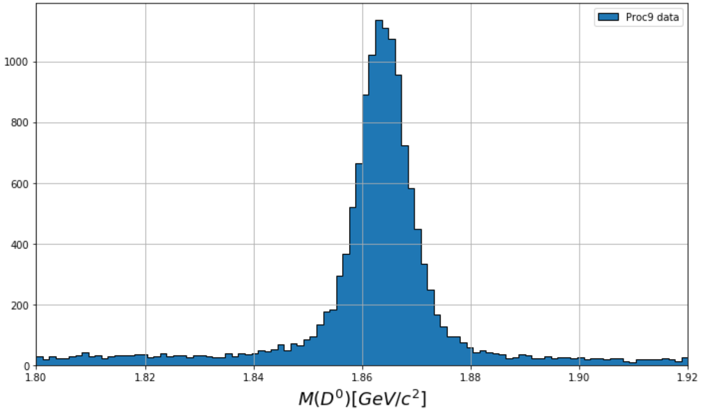
Now looking at the data (Proc 9)





Without cut

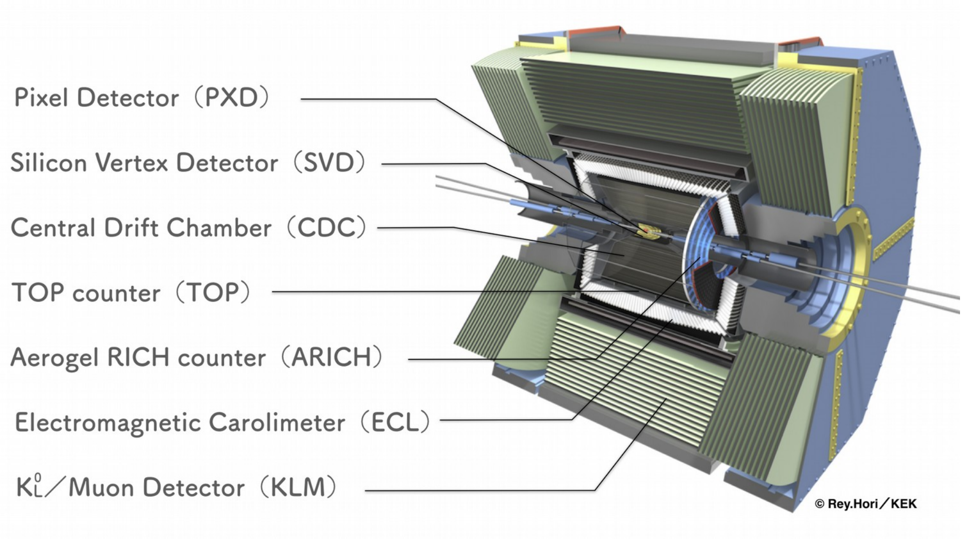




$|Q – 0.006| < 0.002\ GeV/c^2$

Belle II Detector

The Belle II detector at SuperKEKB was designed and built by an international collaboration of over 900 researchers from more than 28 countries and regions.



Component	Type	Configuration	Readout	Performance
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm $-83 \leq z \leq 159$ cm	14 k	$\sigma_{r\phi} = 100\ \mu m$, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD) $\sigma_{dE/dx} = 5\%$
TOP	RICH with quartz radiator	16 segments in ϕ at $r \sim 120$ cm 275 cm long, 2 cm thick quartz bars with 4x4 channel MCP PMTs	8 k	$N_{p.e.} \sim 20$, $\sigma_t = 40$ ps K/π separation : efficiency > 99% at < 0.5% pion fake prob. for $B \to \rho\gamma$ decays
ARICH	RICH with aerogel radiator	4 cm thick focusing radiator and HAPD photodetectors for the forward end-cap	78 k	$N_{p.e.} \sim 13$ K/π separation at 4 GeV/c: efficiency 96% at 1% pion fake prob.

Central Drift Chamber(CDC)

The role of CDC:

1. It reconstructs charged tracks and measures their momenta precisely.

2. It provides particle identification information using measurements of energy loss within its gas volume. Low-momentum tracks, which do not reach the particle identification device, can be identified using the CDC alone.

3. It provides efficient and reliable trigger signals for charged particles. The Belle CDC has worked well for more than ten years without any serious problems.

Table 6.1: Main parameters of the Belle CDC and the CDC upgrade for Belle II.

	Belle	Belle II
Radius of inner cylinder (mm)	77	160
Radius of outer cylinder (mm)	880	1130
Radius of innermost sense wire (mm)	88	168
Radius of outermost sense wire (mm)	863	1111.4
Number of layers	50	56
Number of sense wires	8,400	14,336
Gas	He–C_2H_6	He–C_2H_6
Diameter of sense wire (μm)	30	30

Time-Of-Propagation(TOP) Counter

The focusing TOP reconstructs the partial ring image from 3-dimensional information: time, x and y.
It improves the K/π separation capability of the spectrometer and able to cope with the higher background environment.

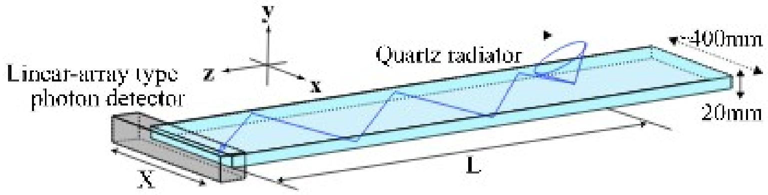


Figure 7.1: Conceptual overview of TOP counter.

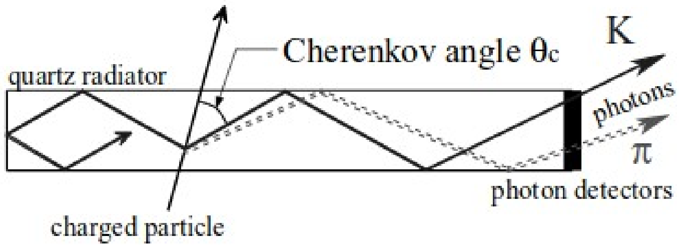


Figure 7.2: Schematic side-view of TOP counter and internal reflecting Cherenkov photons.

Aerogel Ring-Imaging Cherenkov detector (ARICH)

ARICH separate kaons from pions over most of their momentum spectrum and provide discrimination between pions, muons and electrons below 1 GeV/c.

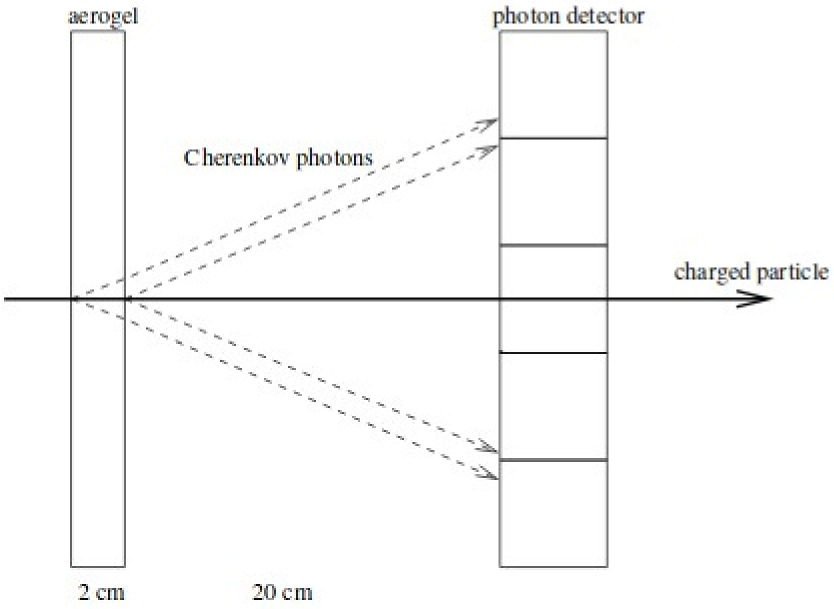


Figure 8.1: Proximity focusing ARICH - principle

Efficiency

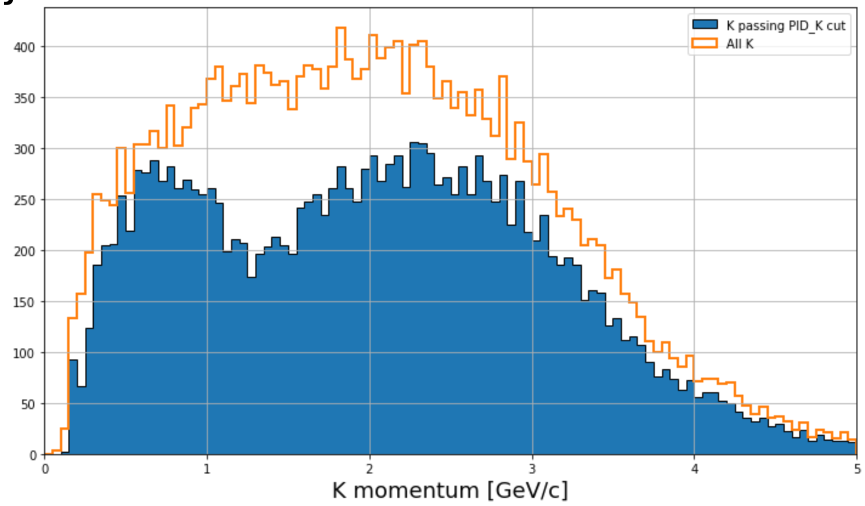
$$\text{Efficiency} = \frac{\text{Number of Kaons passing the cut}}{\text{Total number of Kaons}}$$

*   pidPairProbabilityExpert > 0.5
The likelihood ratio
{L(pdgCodeHyp)}/{L(pdgCodeHyp) + L(pdgCodeTest)}.
This is also commonly called "Binary PID" or "Binary probability"

**   Both numerator and denominator applied pidMissingProbabilityExpert cut (and mc truth matching).

***   pidMissingProbabilityExpert is a flag that returns 1 if the there is no valid likelihood from the detector list.

**** Root.TEfficiency is used for plotting.



Fake Rate

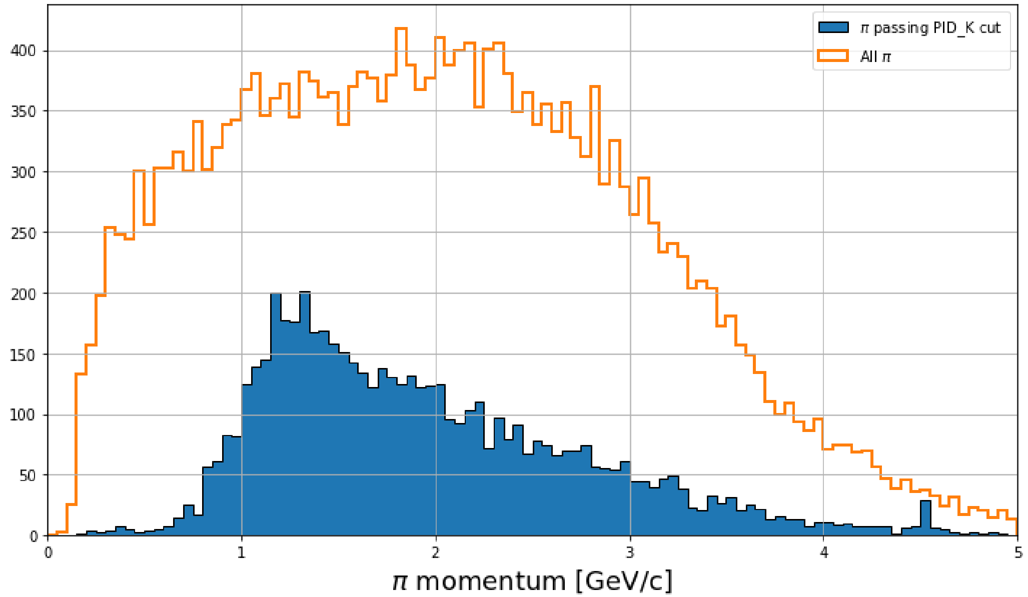
$$\text{Fake Rate} = \frac{\text{Number of Pions passing the cut}}{\text{Total number of Pions}}$$

Fake rate is the rate of Pion who "disguised" as Kaon. In another word, Pion who passes the Kaon cut.

* pidPairProbabilityExpert > 0.5

** Both numerator and denominator applied pidMissingProbabilityExpert cut (and MC truth matching).

*** Root.TEfficiency is used for plotting



MC Truth Matching

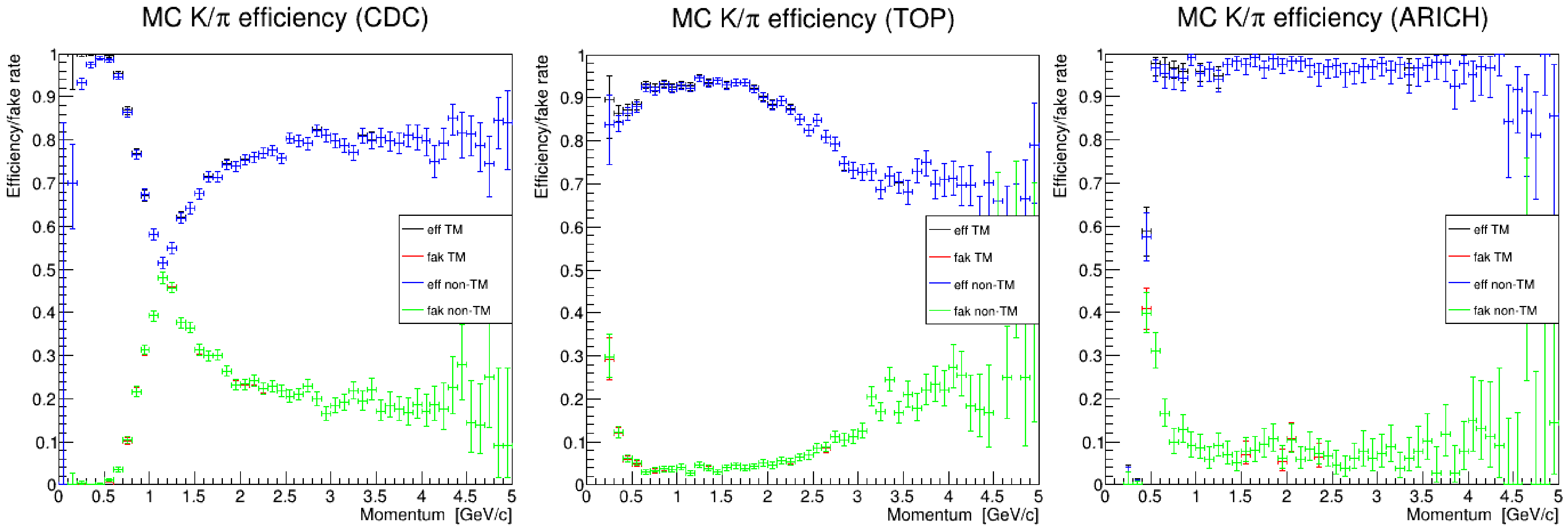
Monte Carlo(MC) Truth Matching is the matching of final state particle and final state generator particles.

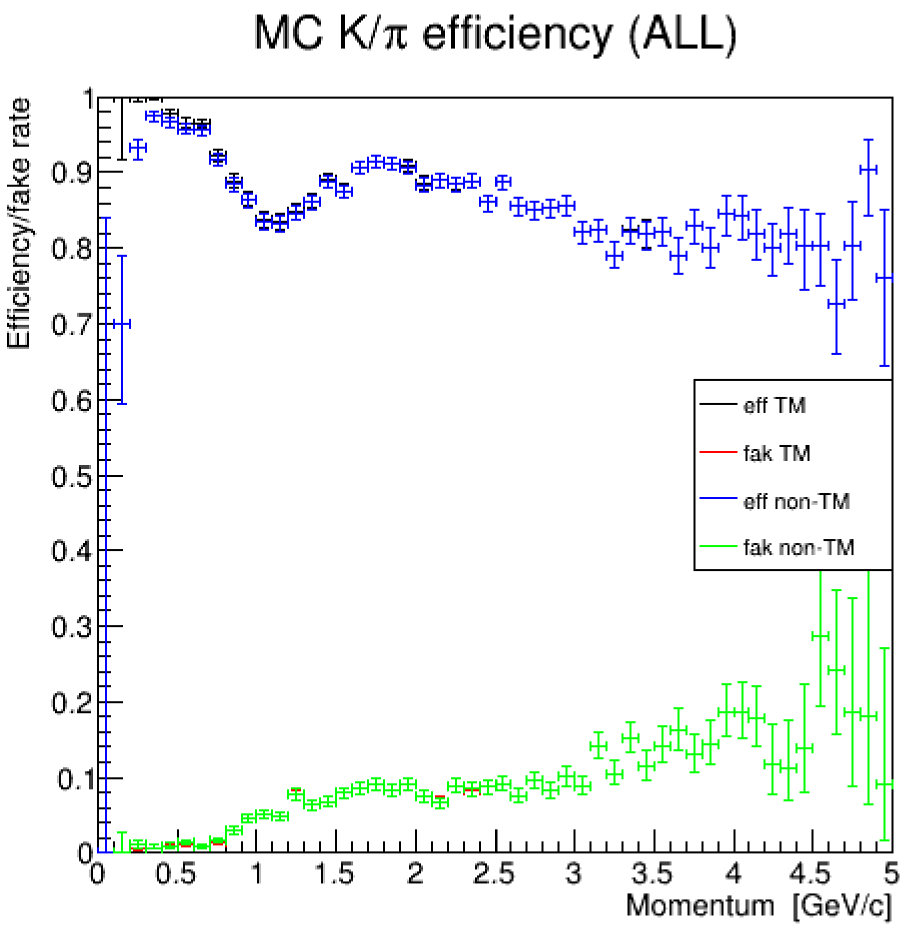
What is mcPDG?

- The PDG particle numbering scheme by the Particle Data Group (PDG) assigns a unique code to each type of particle. Particles are assigned with a positive code; antiparticles are assigned with a negative code.

e.g. π^+ mcPDG = 211 π^- mcPDG = -211

K/π efficiency for each detector




MC K/π efficiency (ALL)
Efficiency/fake rate
Momentum [GeV/c]
eff TM
fak TM
eff non-TM
fak non-TM
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.5
1.5
2
2.5
3
3.5
4
4.5
5

Does the performance degrade when the CDC is added to the TOP?

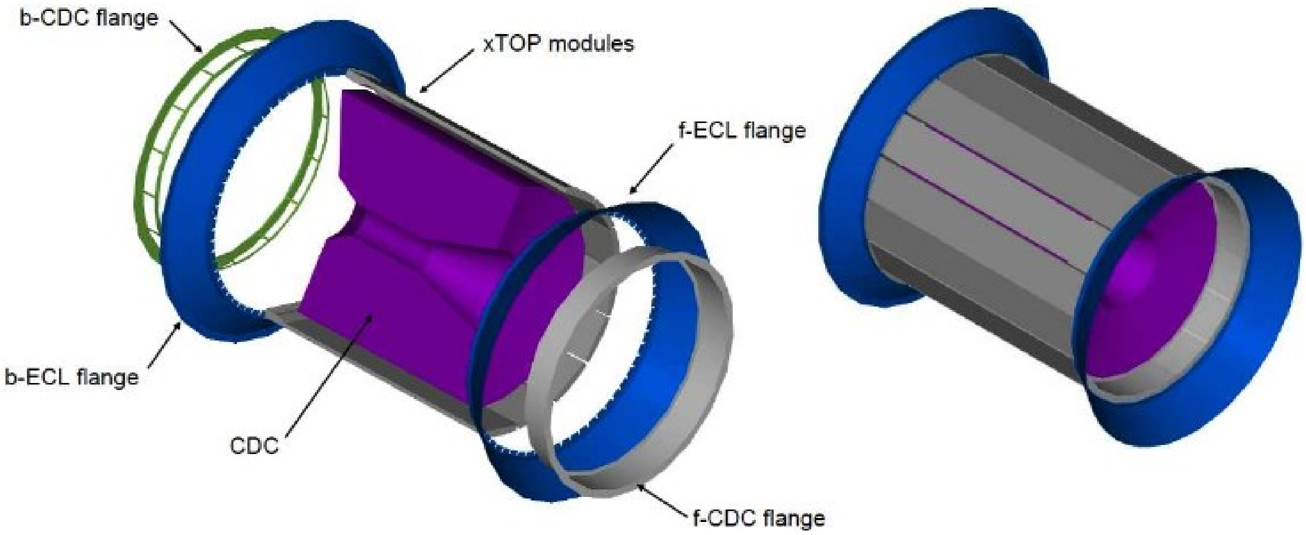
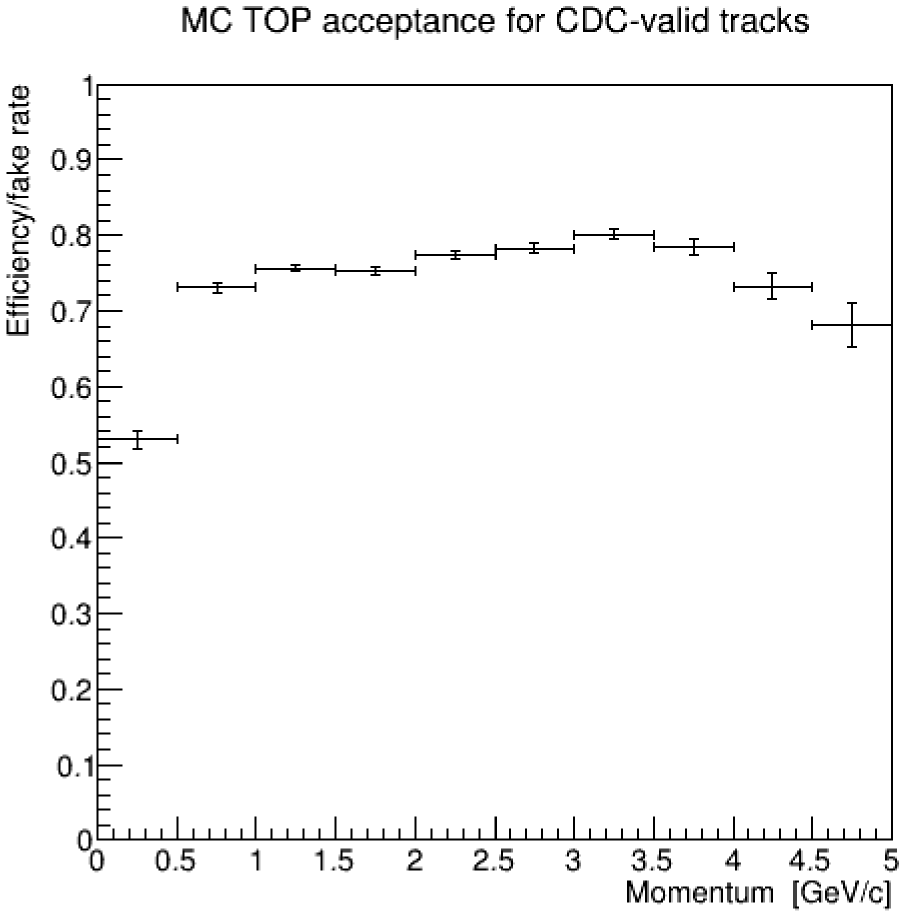


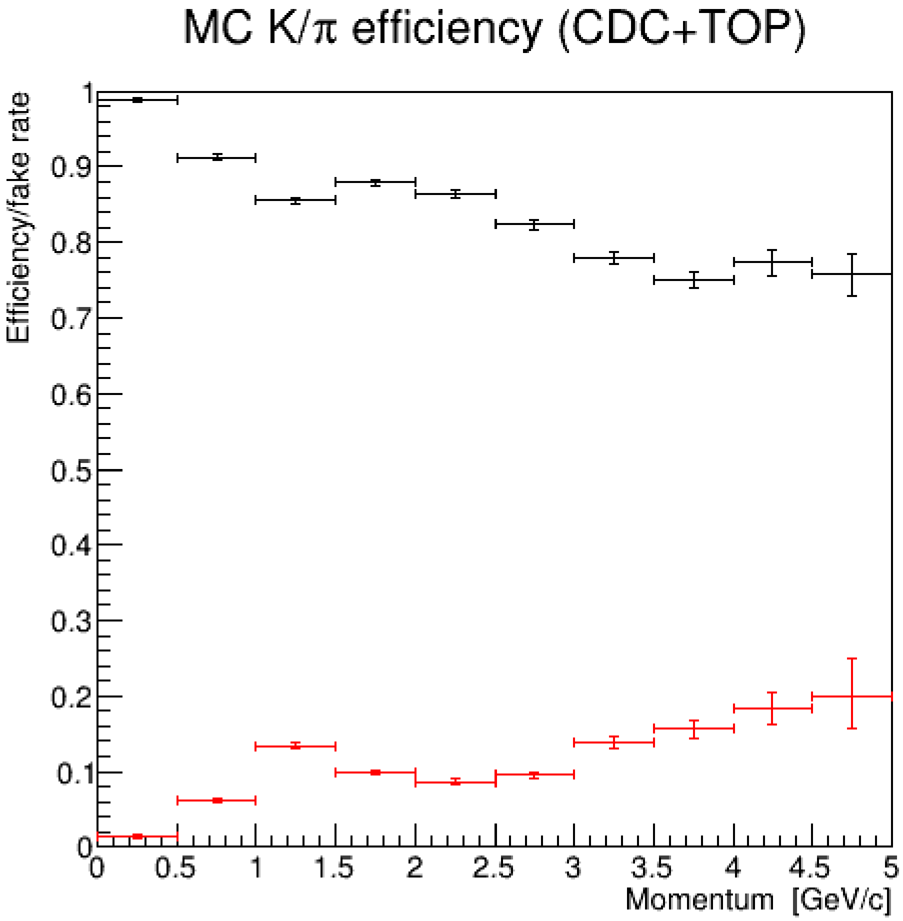
Figure 7.16: A 3D conceptual rendering of the TOP detector integrated together with the CDC. f-ECL/b-ECL flange shows the structure of ECL conical part. f-CDC/b-CDC flange is the support of CDC from ECL flanges.



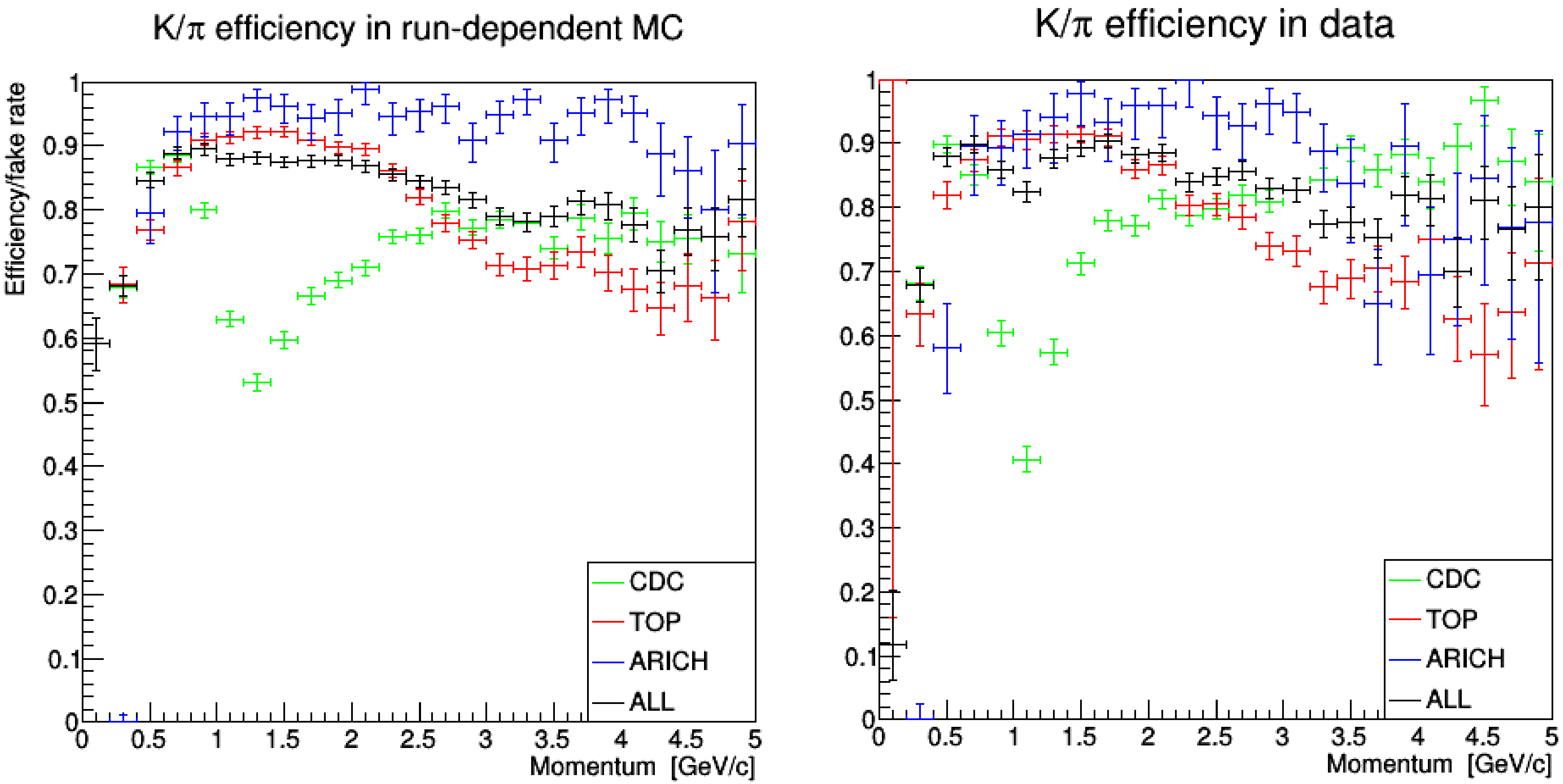
Now look at the TOP efficiency for Kaons passing through the CDC (not only TOP)

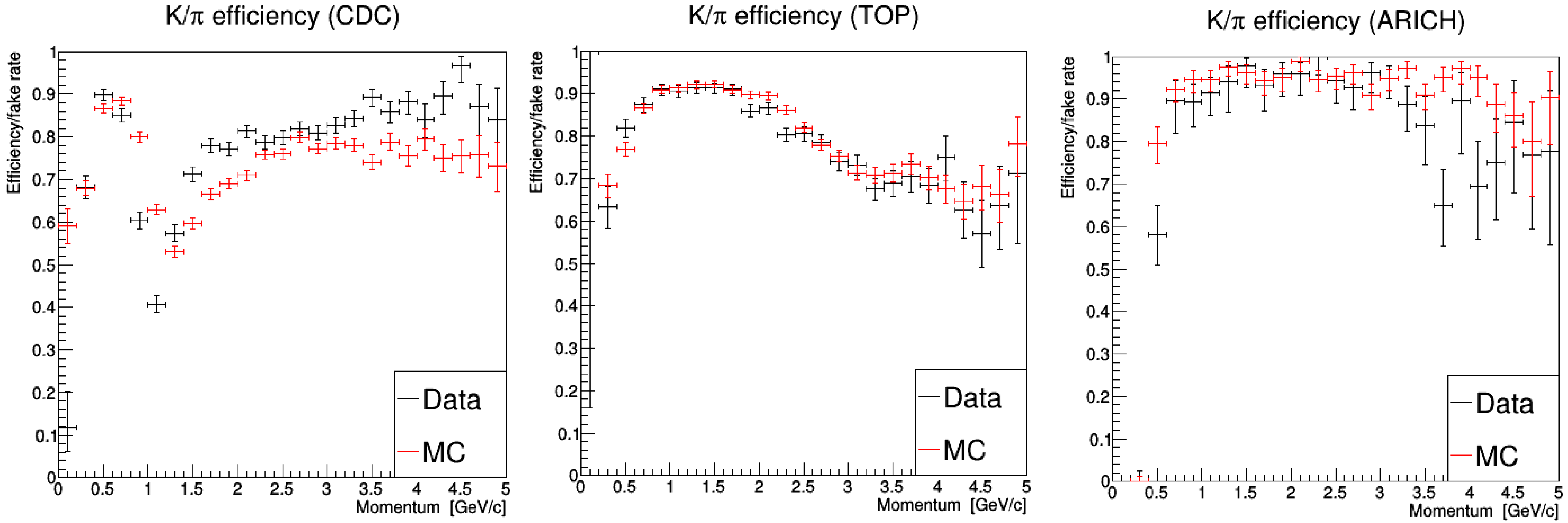
TOP misses some tracks

Tracks detected by TOP are efficiently identified



The numerator has the cut of the likelihood of Kaon passing through CDC or TOP or both

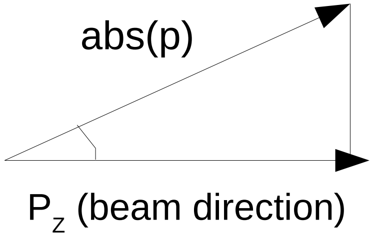

K/π efficiency in run-dependent MC
Efficiency/fake rate
Momentum [GeV/c]
CDC
TOP
ARICH
ALL
K/π efficiency in data
Momentum [GeV/c]
CDC
TOP
ARICH
ALL

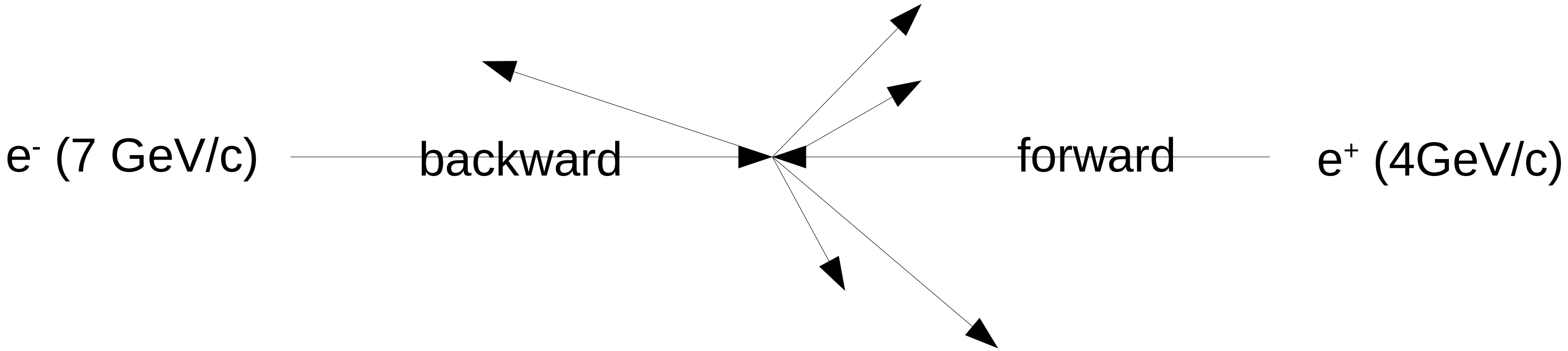


K/π efficiency (CDC)
K/π efficiency (TOP)
K/π efficiency (ARICH)
Efficiency/fake rate
Momentum [GeV/c]
Data
MC

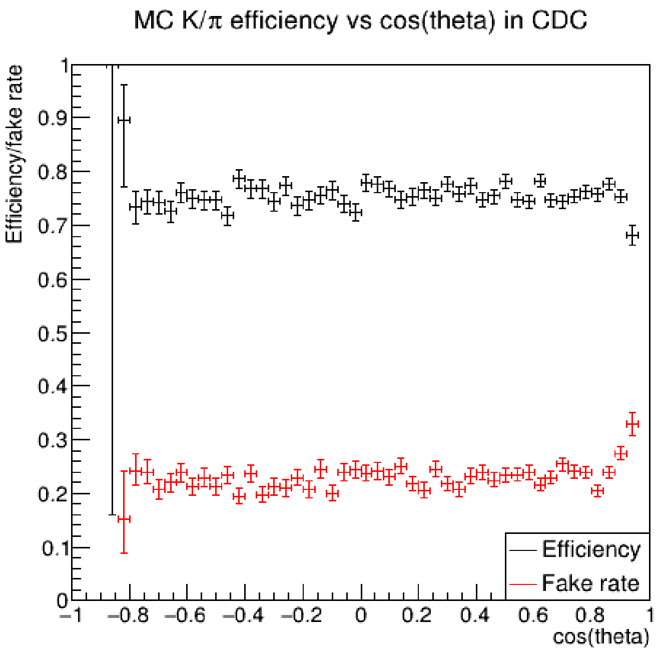
The efficiency of each detectors in different angle

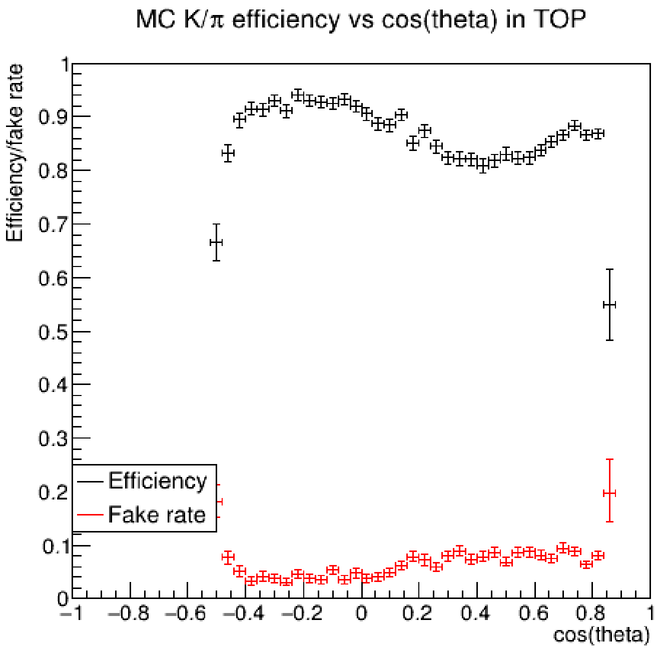
$\text{Cos(theta)} = p_Z/\text{abs}(p)$

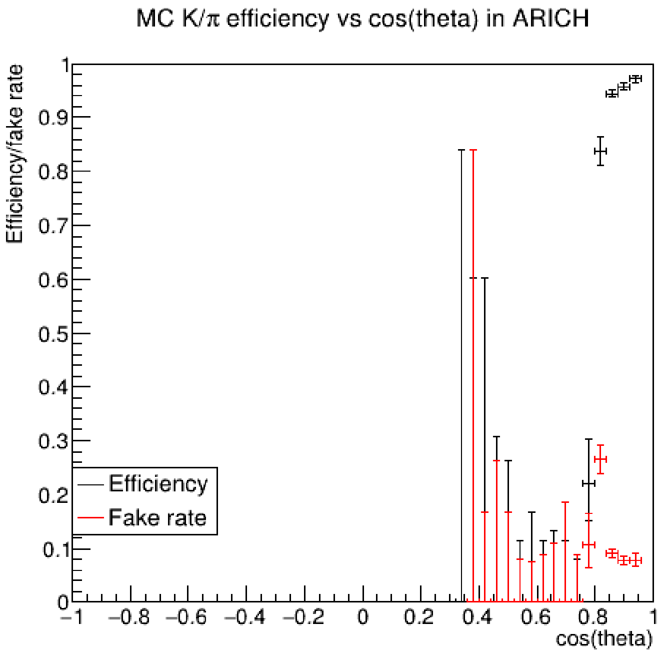




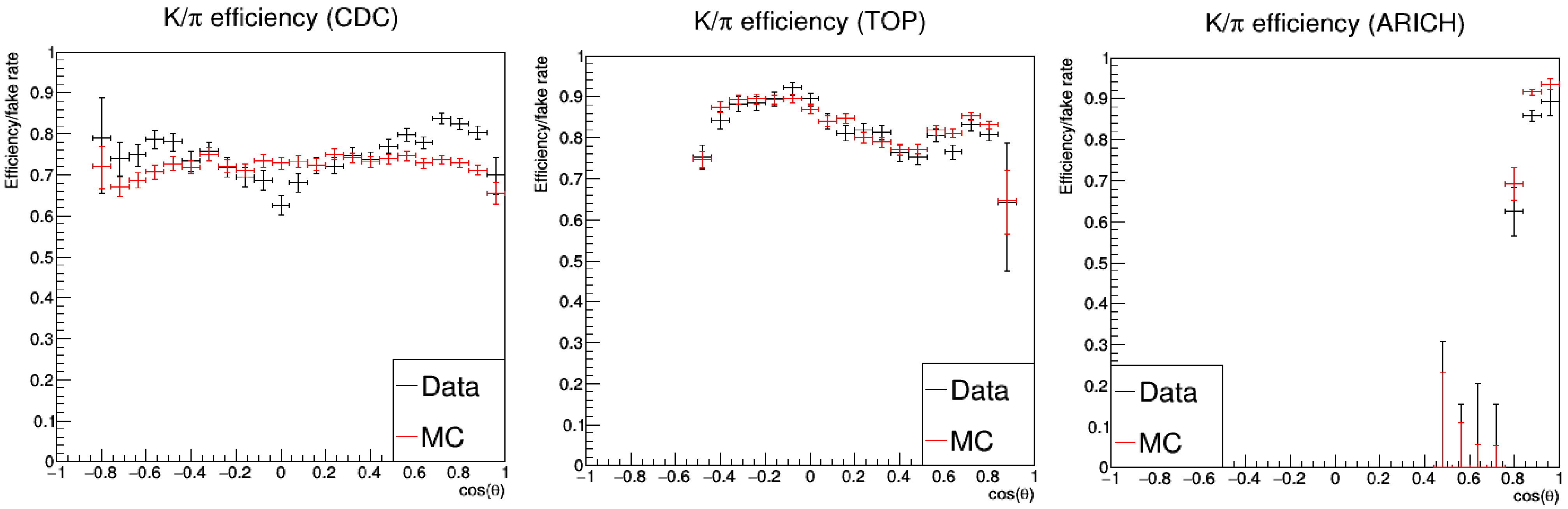
K/π efficiency versus cos(theta) (signal MC)







Data/MC(Run-dependent) comparison



Receiver Operating Characteristic(ROC) Curve

Receiver Operating Characteristic(ROC) curve is a performance measurement for classification problem at various thresholds settings. It is a plot of the true positive rate(TPR) against the false positive rate(FPR) for the different possible cutpoints.

TPR = efficiency

FPR = fake rate

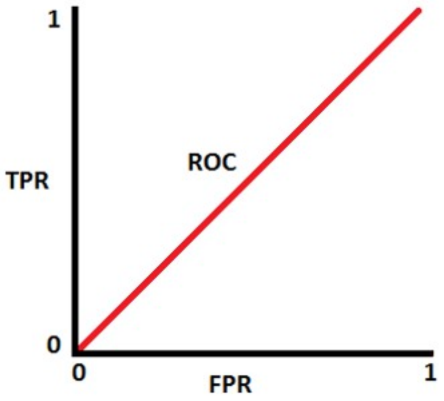
from PID tutorial:

makeROCCurve(df, cutVariable, mcPDG, extraConditions=True, bkgPDG=0)

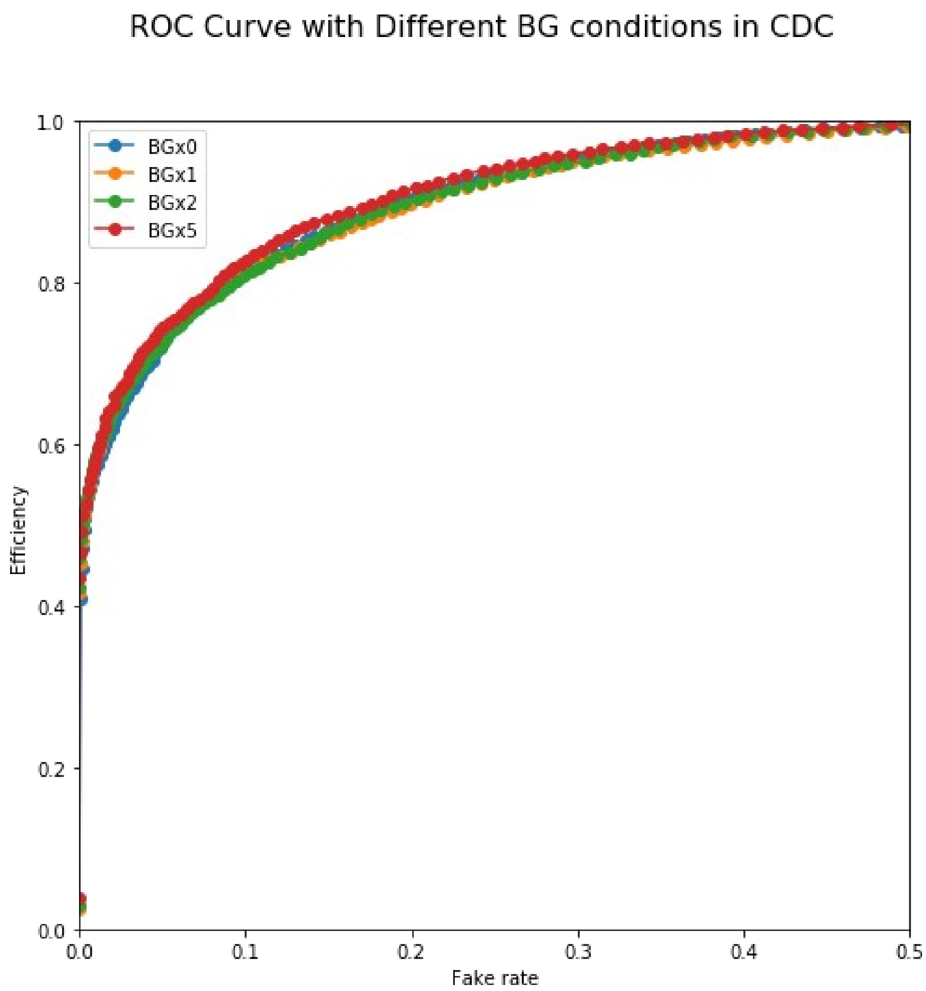
ROC shows a global efficiency verses fake rate.

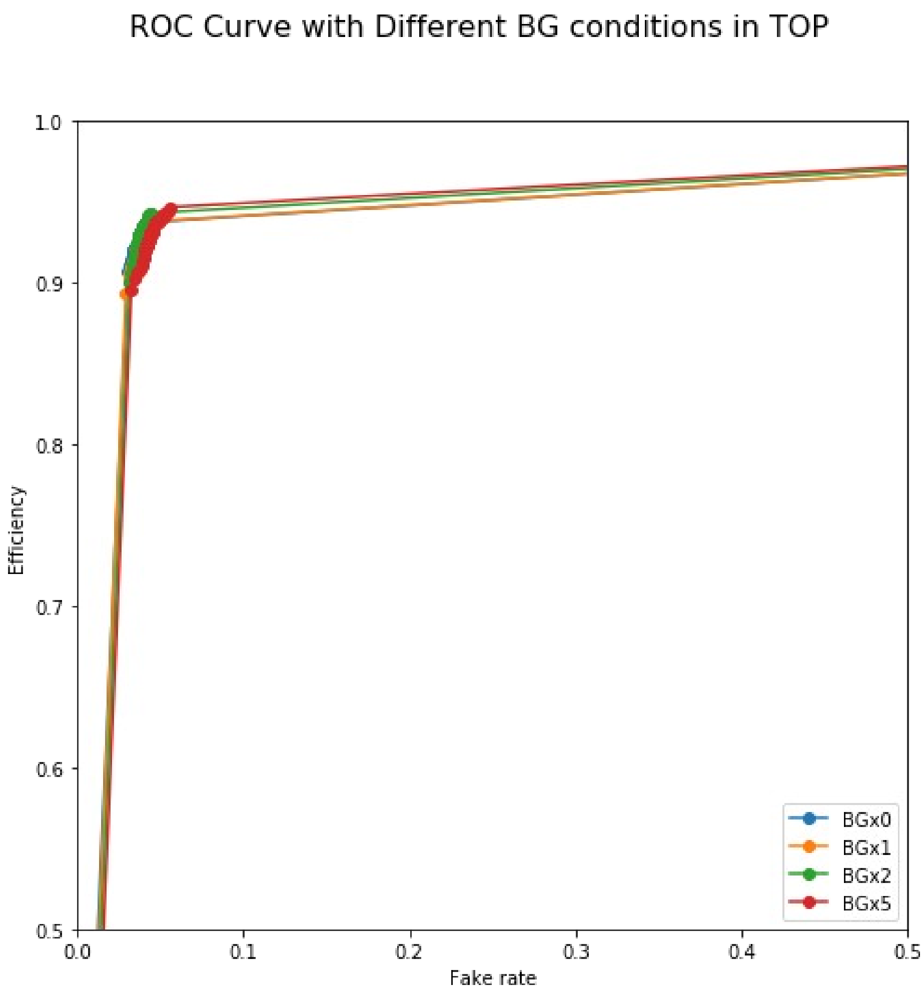
For ROC curve:

1. The closer the curve follows the left-hand border and then the top border of the ROC space, the more accurate the test.
2. The closer the curve comes to the 45-degree diagonal of the ROC space, the less accurate the test.



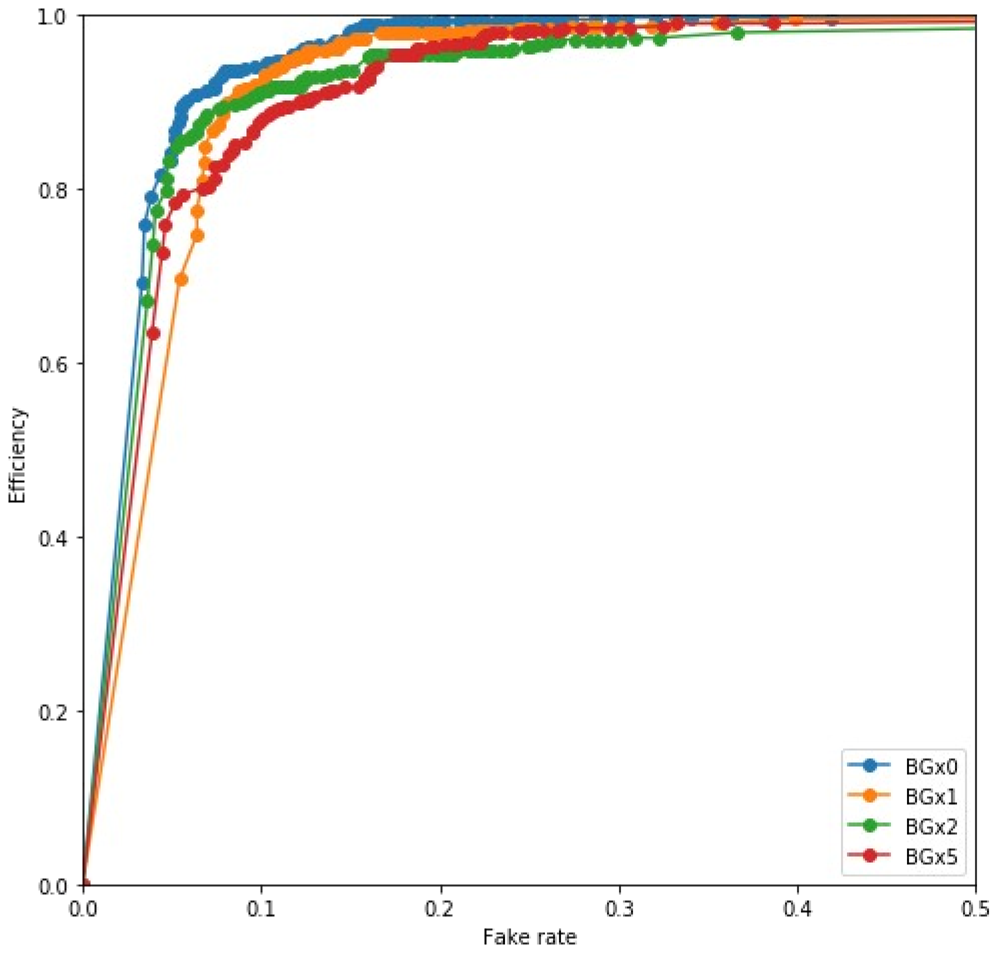
Example of case 2

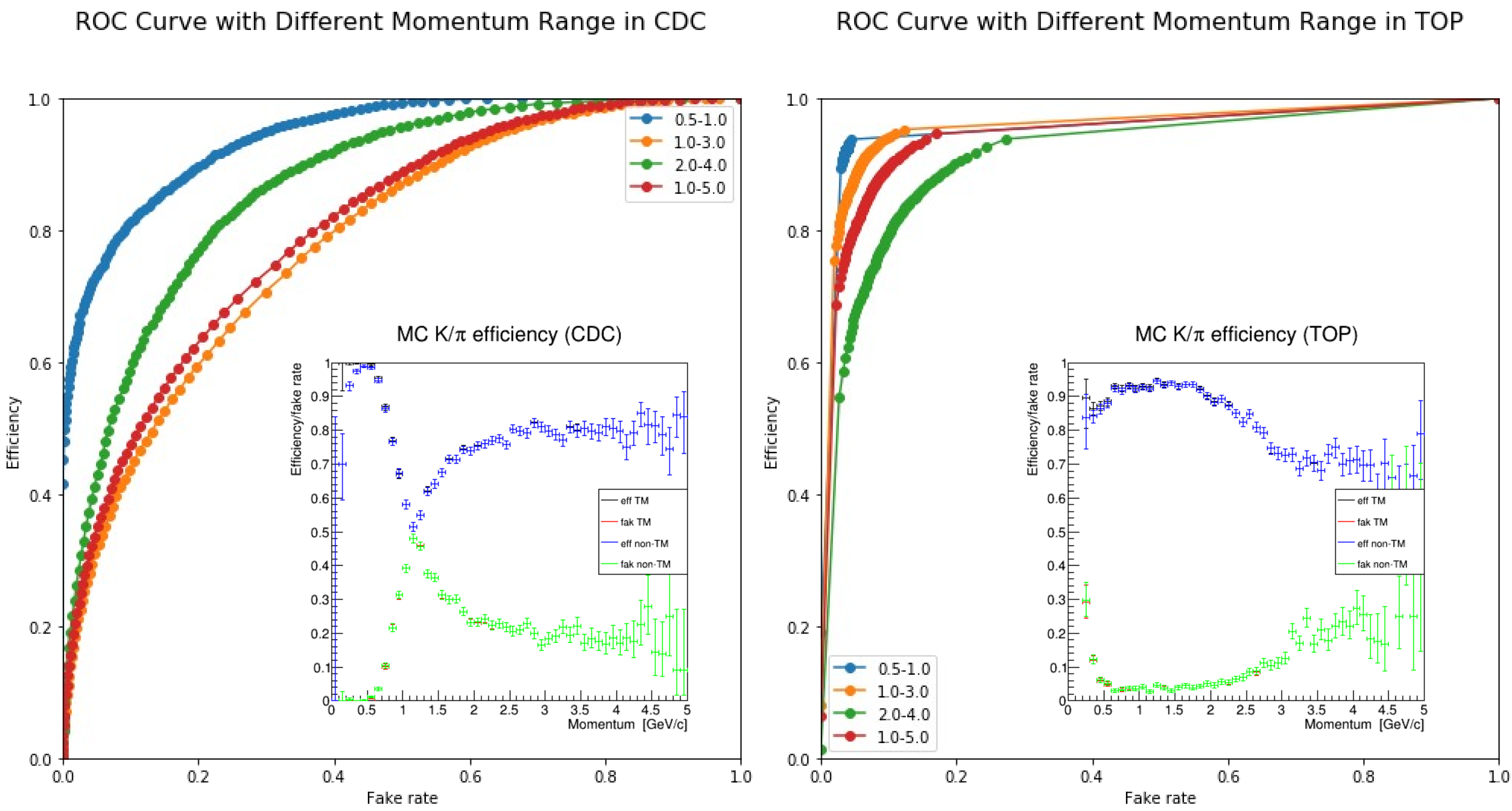




Each point in ROC is for a different cut value

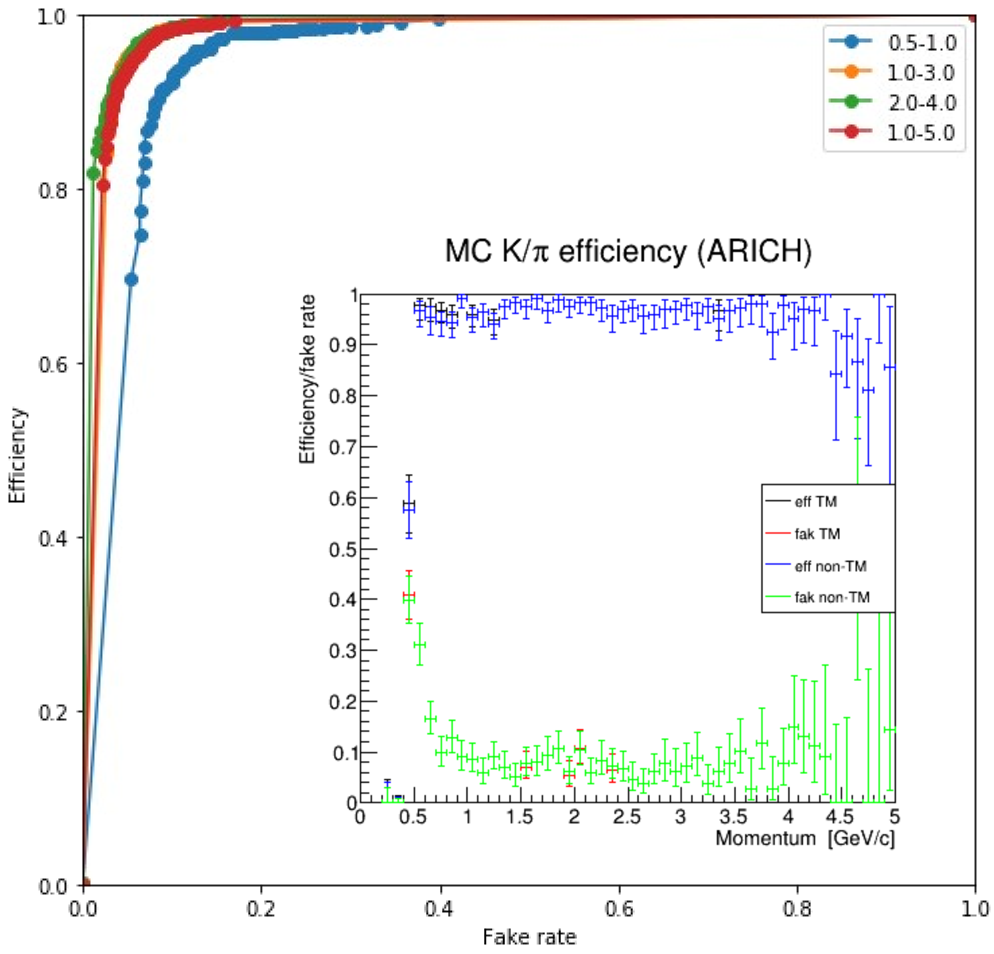
ROC Curve with Different BG conditions in ARICH





ROC Curve with Different Momentum Range in CDC
ROC Curve with Different Momentum Range in TOP
Efficiency
Fake rate
0.5-1.0
1.0-3.0
2.0-4.0
1.0-5.0
MC K/π efficiency (CDC)
MC K/π efficiency (TOP)
Efficiency/fake rate
Momentum [GeV/c]
eff TM
fak TM
eff non-TM
fak non-TM

ROC Curve with Different Momentum Range in ARICH



Conclusion

- CDC and TOP do not degrades each other performance
- CDC performs better at low and high momentum regions.
- TOP is efficiency at the momentum region 0.5 to 2.5 GeV/c.
- ARICH only works at the forward region and doesn’t works well at low momentum region lower than 0.5 GeV/c

References

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