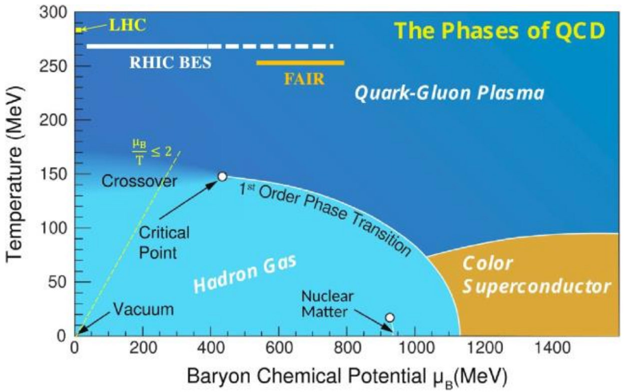
Strangeness fluctuations in the HADES experiment

FAIRness 2024

Athira Sreejith
Date: 26.09.2024

Introduction:

QCD Phase Diagram:



- Study of fluctuations of conserved charges - sensitive to phase transitions and the critical point.
- In experiment: Study of cumulants of conserved charge distributions → related to susceptibilities and correlation length from theory.
- Susceptibilities: How does the medium change under external influences
- Cumulants: Alternative to higher order moments of PDFs

P. Achenbach, et al. The present and future of QCD

Introduction:

- These conserved charges include baryon number, electric charge, strangeness etc.

- This study focuses on strangeness fluctuations in Mar19 Ag+Ag data 1.58 AGeV in HADES
  - Kaon fluctuations - used as proxy

- Need to look into kaon identification and reconstruction
  - First investigating K+, K-

Charged Kaon Reconstruction:

- Particle reconstruction using time of flight information and energy loss.
- Kaon reconstruction – challenging due to low kaon multiplicity

- Methods used for kaon reconstruction:
  - Hard cuts* based on ToF and dE/dx
  - GetPID
  - Hard cuts + GetPID

*Based on the cuts listed in Flow of charged Kaons

How does GetPID work? - Norm calculation

- For every particle type, assume that the track is of that particle type to calculate expected ToF and energy loss:

NormTime =
$$\frac{\text{Expected } \Delta t - \text{Observed } \Delta t}{\sigma}$$

NormdEdx =
$$\frac{\text{Expected } \frac{dE}{dx} - \text{Observed } \frac{dE}{dx}}{\sigma}$$

$$\text{norm} = \text{NormTime}^2 + 0.6 * \text{NormdEdx}^2$$

- Particle ID corresponding to lowest norm is assigned to the track.

Purity vs efficiency from different methods in simulation:

		Purity	Efficiency
GetPID	K+	0.31	0.61
	K-	0.06	0.60
Hard cuts	K+	0.45	0.48
	K-	0.14	0.27
GetPID + Hard Cuts	K+	0.73	0.44
	K-	0.40	0.24

- Purity = $\frac{\text{Signal (S)}}{\text{Signal+background (S+B)}}$

- Efficiency = $\frac{\text{Number of true kaons reconstructed}}{\text{Number of true kaons in the reconstructable tracks}}$

Next steps:

- Calculate moments of the particle distributions:
  - Determine no. of particles of interest in each event
  - Derive moments of resulting particle distributions
  - Disadvantage: particle misidentification – distorts the particle number distribution and thereby the moments

- The observed fluctuations will not reflect the true fluctuations due to effects like
  - Detector inefficiency
  - Particle misidentification
  - Volume fluctuations

Dealing with particle misidentification: Identity method

- Instead of hard cut, assign probabilities of a particle type to a track, and calculate higher order moments

How it works:

- Consider observable x_i of track i (eg: energy loss)

$$\rho(x_i) = \sum_j \rho_j(x_i)$$

Sum of the energy loss distributions of different particle types j

$$\omega_j(x_i) = \frac{\rho_j(x_i)}{\rho(x_i)} \in [0, 1]$$

Probability of track being of particle type j

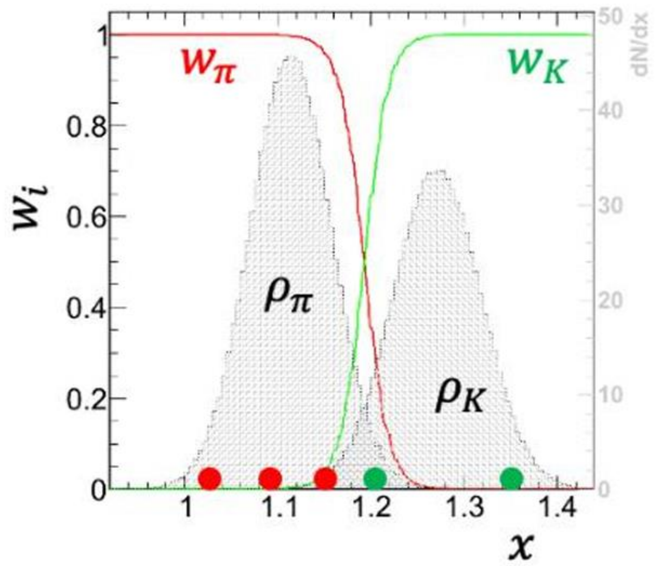
$$W_j \equiv \sum_{i=1}^{N(n)} \omega_j(x_i)$$

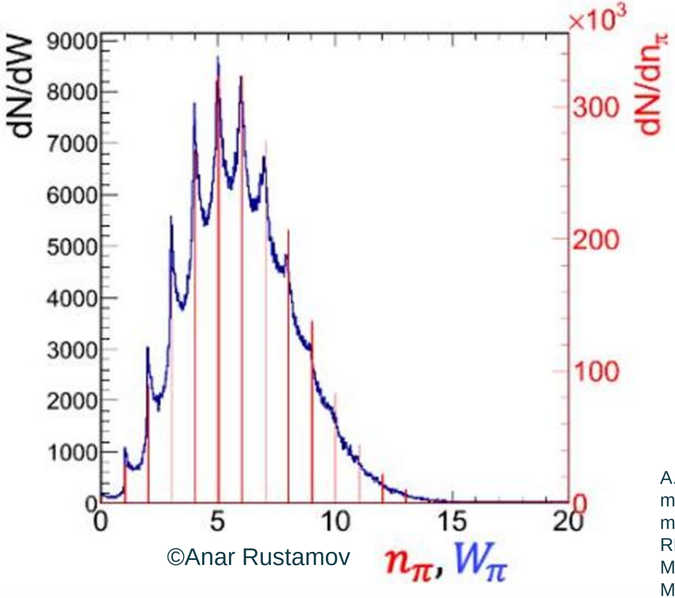
Proxy for multiplicity of particle type j
(same as multiplicity for ideal particle identification)

A. Rustamov1 and M. I. Gorenstein, Identity method for the determination of the moments of multiplicity distributions, PHYSICAL REVIEWC86,044906 (2012),

Visual representation of x, w and W:

A simple case with only two particles:





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$$\rho(x_i) = \sum_j \rho_j(x_i)$$

$$\omega_j(x_i) = \frac{\rho_j(x_i)}{\rho(x_i)} \in [0,1]$$

$$W_j \equiv \sum_{i=1}^{N(n)} \omega_j(x_i)$$

A. Rustamov1 and M. I. Gorenstein, Identity method for the determination of the moments of multiplicity distributions, PHYSICAL REVIEWC86,044906 (2012),
M. Gazdzicki, K. Grebieszkow, M. Mackowiak, S. Mrowczynski, Identity method to study chemical fluctuations in relativistic heavy-ion collisions, Phys. Rev. C83 (2011) 054907

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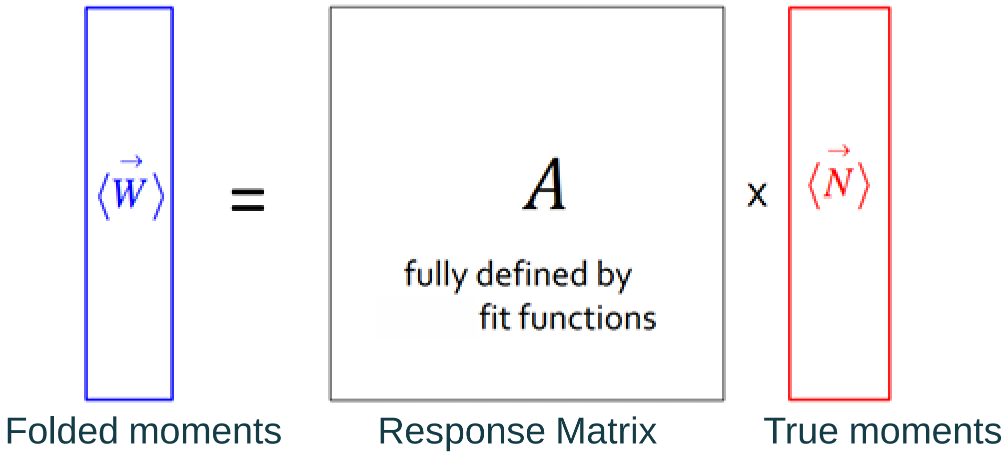
Identity method – continued:

Unfolding the true moments from the vector of measured moments.

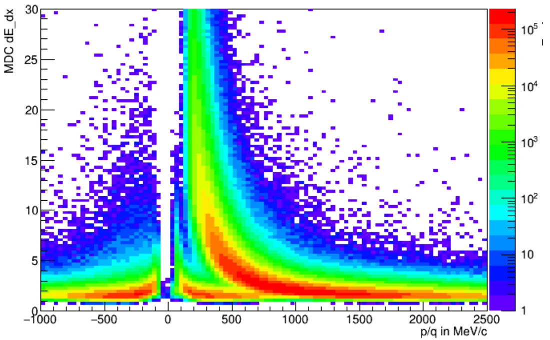


A. Rustamov, M. I. Gorenstein, Phys.Rev.C 86 (2012) 044906

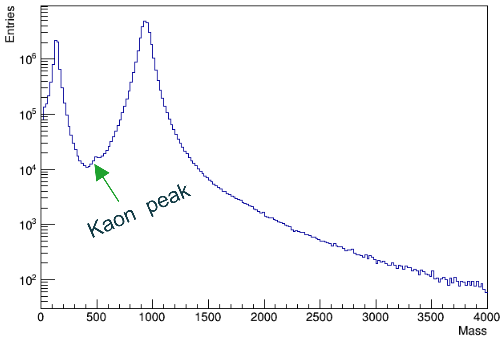
Choice of input for identity method:

No single observable sufficient for good Kaon identification.

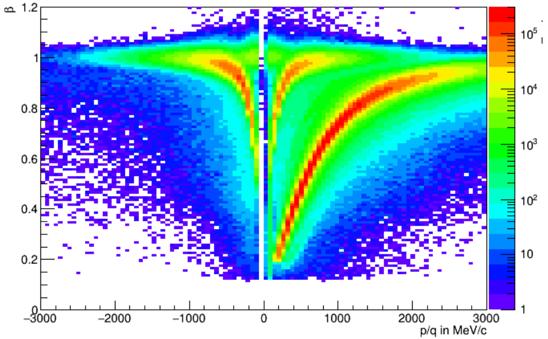
MDC Energy Loss:



Mass:



Beta-Momentum:



Kaon band – not easily visible.

Solution: Use Norm of GetPID method to combine dE/dx and ToF information

Summary and Outlook:

- Extracted purity and efficiency of charged kaon reconstruction using different cuts
- Investigated the GetPID method

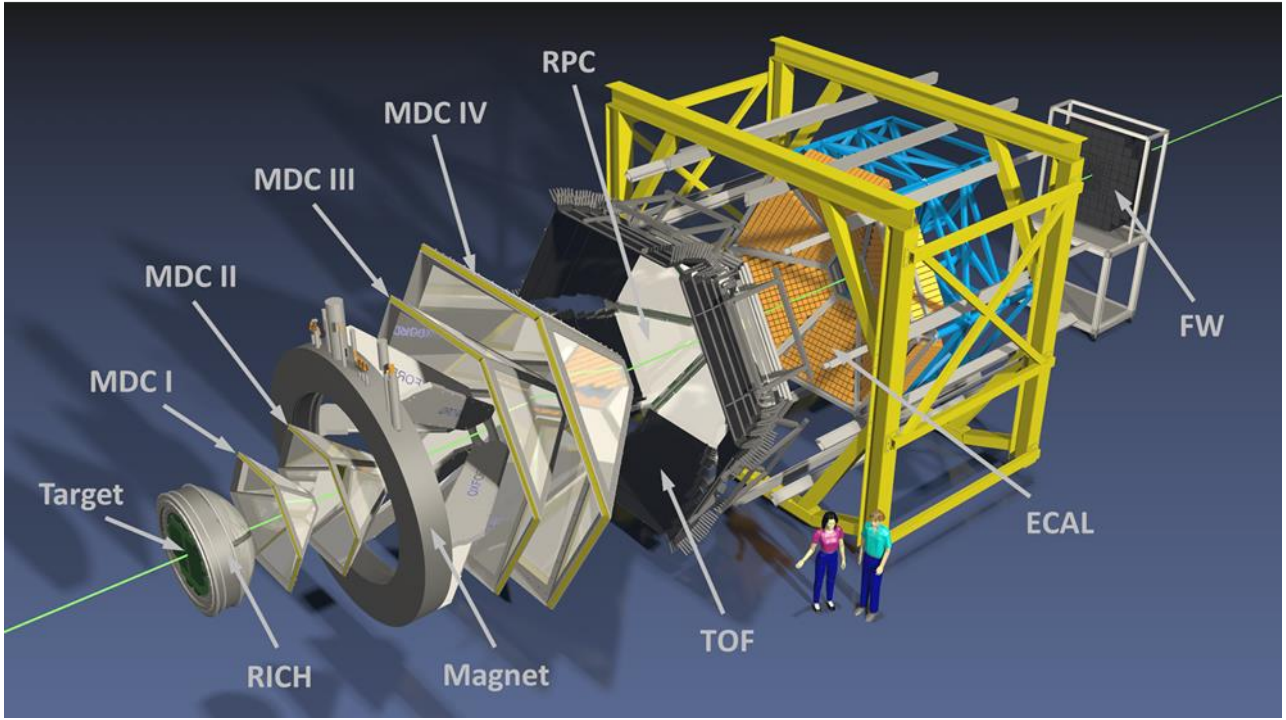
Next steps:

- Fine tune the cuts used for kaon reconstruction
- Calculation of moments using Identity method
    - Checking the output for different cut sets
    - Checking the output for different input distributions

Thank you!

Backup slides:

HADES:



Cuts used in Kaon reconstruction

Hard Cuts:

*Inspired by cuts from Jan Orlinksi

Particle	K+		K-	
System	RPC	TOF	RPC	TOF
χ^2	≤ 100			
MetaMatch Quality	≤ 2			
Number of MDC Layers	> 19			
Distance to vertex	≤ 20			
Mass	$\in (340,660)$			
Momentum	$\in (200, 1200)$	$\in (150, 900)$	$\in (200, 950)$	$\in (200, 800)$
$\frac{dE}{dx}_{MDC}$	$\in (1.9)$	$\in (1.1,17)$	-	$\in (2,5)$
$\frac{dE}{dx}_{MDC} * p$	-	$\in (580,3000)$	$\in (800, 2500)$	> 900
$\frac{dE}{dx}_{TOF} * \beta\gamma$	-	$\in (0.25, 3.2)$	-	$\in (1,2.5)$
β	$\in (0,1)$		> 0.89	
Sign (Charge)	> 0		< 0	

GetPID Method:

- Built-in function used in HYDRA - THE HADES ANALYSIS PACKAGE
- Outputs a particle ID (PID) corresponding to a candidate track (real/sim)

How does GetPID work?

1. Preselection using quality cuts
2. Calculation of *norm* using Beta-momentum and Energy loss simultaneously
3. Assign particle ID based on lowest *norm*

How does GetPID work? - Norm calculation

- For every particle type, assume that the track is of that particle type to calculate expected TOF and energy loss:

Momentum Cut

$\frac{dE}{dx}$ cut

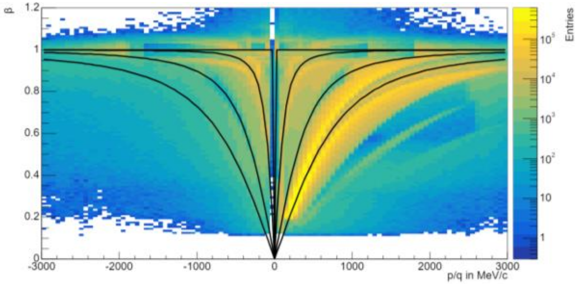
$$\text{Norm\_time} = \frac{\text{Expected } \Delta t - \text{Observed } \Delta t}{\sigma}$$

$$\text{Norm\_dEdx} = \frac{\text{Expected } \frac{dE}{dx} - \text{Observed } \frac{dE}{dx}}{\sigma}$$

$$\text{norm} = \text{Norm\_time}^2 + 0.6 * \text{Norm\_dEdx}^2$$

If no PID can be assigned, PID = -1

Beta-Momentum plot for PID = -1:



- Particle ID corresponding to lowest norm is assigned to the track.

How does GetPID() work?

Preselection using Quality cuts:

Quality Cuts:	
Meta Match Quality	> 4.5
β	> 0
X^2	∈ (0,1000)
Inner Segment X^2	> 0
Outer Segment X^2	> 0
Sign of charge	Sign(charge) of particle corresponding to that PID

How does GetPID() work? - Norm calculation

- For every particle type, assume that the track is of that particle type to calculate expected TOF and energy loss:

Momentum Cut

$$\text{Norm\_time} = \frac{\text{Expected } \Delta t - \text{Observed } \Delta t}{\sigma}$$

$\frac{dE}{dx}$ cut

$$\text{Norm\_dEdx} = \frac{\text{Expected } \frac{dE}{dx} - \text{Observed } \frac{dE}{dx}}{\sigma}$$

$$\text{norm} = \text{Norm\_time}^2 + 0.6 * \text{Norm\_dEdx}^2$$

Momentum cuts used

	TOF	RPC
K+	(60,1000)	(60,900)
K-	(85,900)	(85,800)

- Particle ID corresponding to lowest norm is assigned to the track.

Purity vs efficiency from different methods:

		Purity	Efficiency
GetPID()	K+	0.312278	0.606463
	K-	0.0635627	0.597414
GetPID() + $\chi^2 < 100$	K+	0.471359	0.574401
	K-	0.141039	0.56309
Hard cuts	K+	0.448275	0.481393
	K-	0.137757	0.270921
GetPID() + Hard Cuts	K+	0.729839	0.437539
	K-	0.400908	0.237396

$$\text{Purity} = \frac{\text{Signal (S)}}{\text{Signal + background (S + B)}}$$

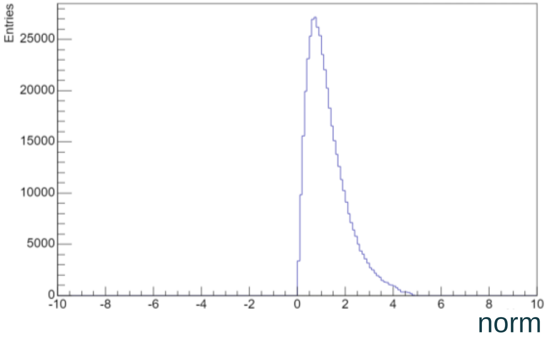
$$\text{Efficiency} = \frac{\text{Number of true kaons reconstructed}}{\text{Number of true kaons in the tracks that can be reconstructed}}$$

Norm as input for Identity Method:

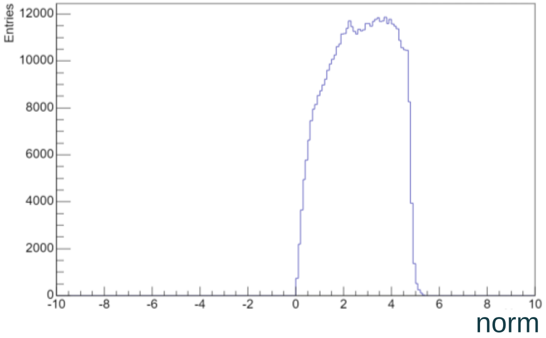
- Using GetPID-Norm value for the Kaon hypothesis (instead of all particle hypothesis)
- Advantage: Use both time of flight and $\frac{dE}{dx}$ information simultaneously.

Distribution of norm for simulated true particles:

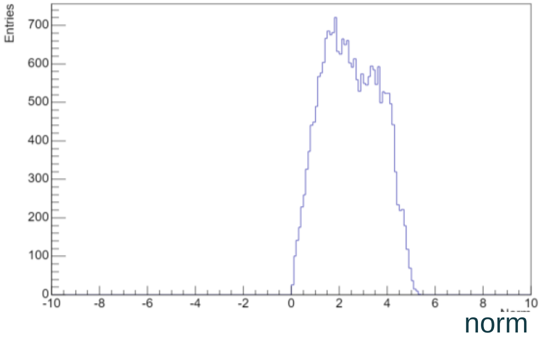
K+



Protons



π+



Identity Method:

Unfolding to find the true moments:

$$\begin{pmatrix} \langle W_1 \rangle \\ \langle W_2 \rangle \\ \dots \\ \langle W_k \rangle \end{pmatrix} = \begin{pmatrix} \overline{w_{1,1}} & \overline{w_{1,2}} & \dots & \overline{w_{1,k}} \\ \overline{w_{2,1}} & \overline{w_{2,2}} & \dots & \overline{w_{2,k}} \\ \dots & \dots & \dots & \dots \\ \overline{w_{k,1}} & \overline{w_{k,2}} & \dots & \overline{w_{k,k}} \end{pmatrix} \begin{pmatrix} \langle N_1 \rangle \\ \langle N_2 \rangle \\ \dots \\ \langle N_k \rangle \end{pmatrix}$$

$$\begin{bmatrix} \langle N_K^2 \rangle \\ \langle N_\pi^2 \rangle \\ \langle N_\pi N_K \rangle \end{bmatrix} = \left[A^{-1} \right] \times \begin{bmatrix} \langle W_K^2 \rangle - f_1(\rho_j) \\ \langle W_\pi^2 \rangle - f_2(\rho_j) \\ \langle W_\pi W_K \rangle - f_3(\rho_j) \end{bmatrix}$$

A^{-1} Defined by $\rho_j(X)$ functions

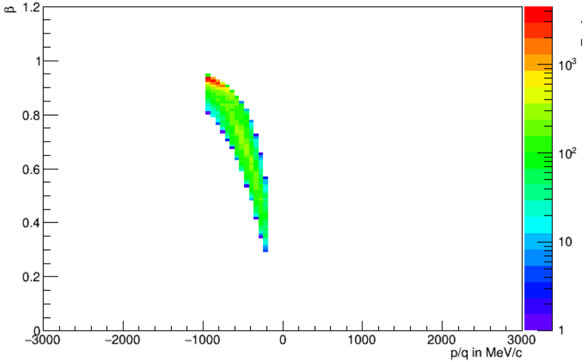
A. Rustamov, M. I. Gorenstein, Phys.Rev.C 86 (2012) 044906

Kaon Identification – Purity studies

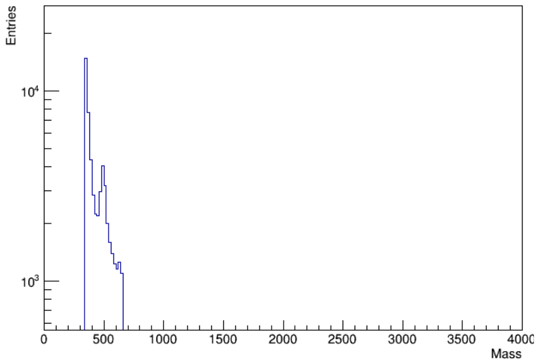
Final Spectrum after hard cuts:

- Hard Cuts, inspired by the cuts listed by Jan Orliński (XLVI HADES Collaboration Meeting)

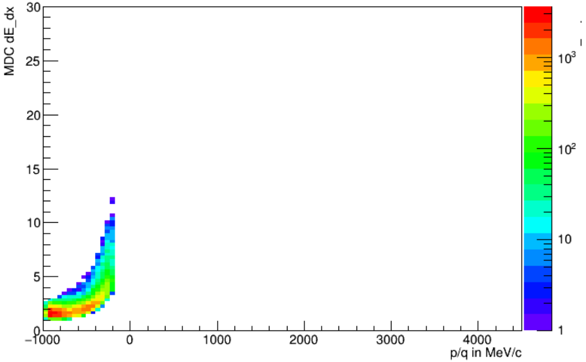
Beta-Momentum:



Mass Spectrum:



MDC Energy loss:



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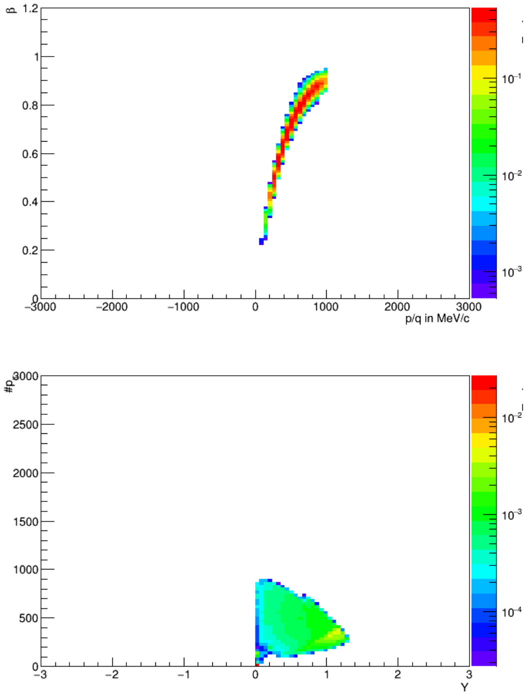
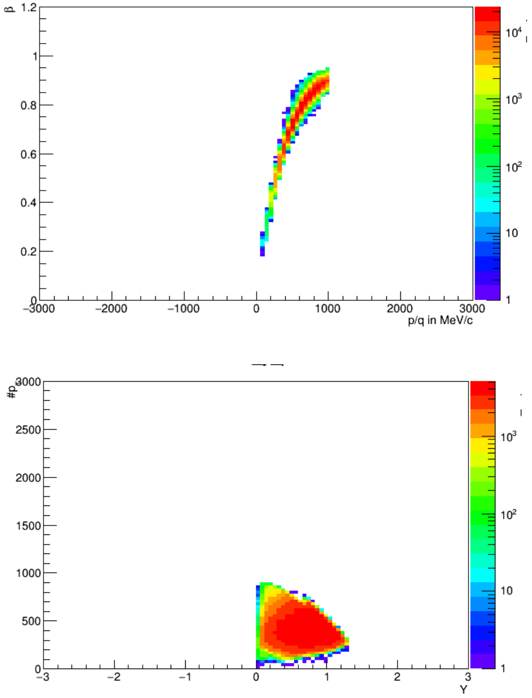
Purity of K+: Using GetPID

S/(S+B)

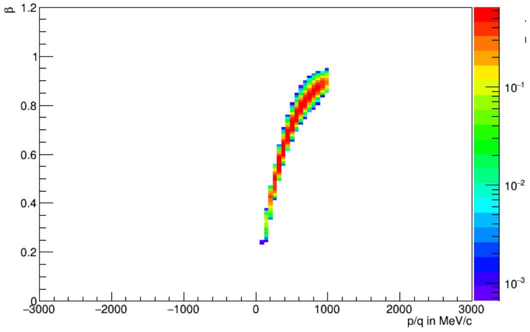


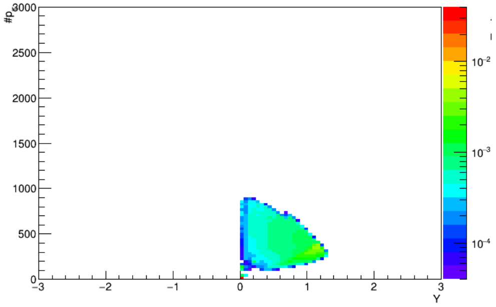
S



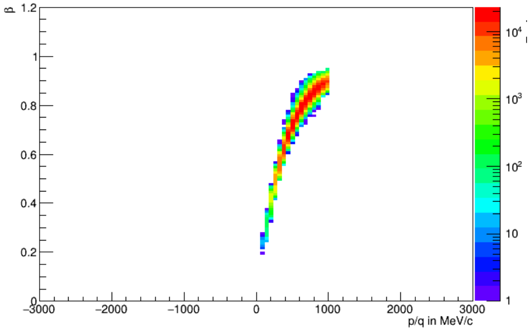
Purity of K+, GetPID + $\chi^2 < 100$:

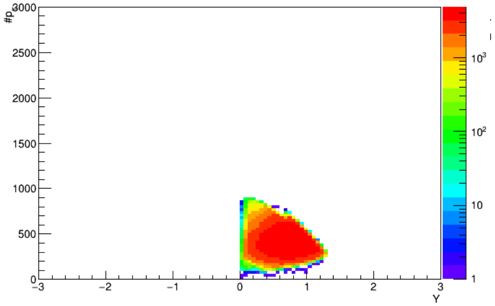
S/(S+B)





S

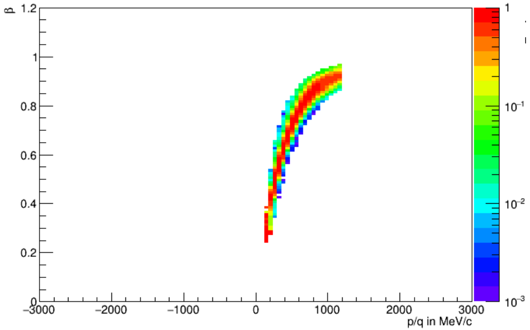


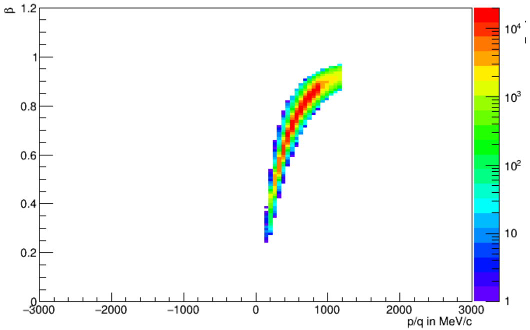


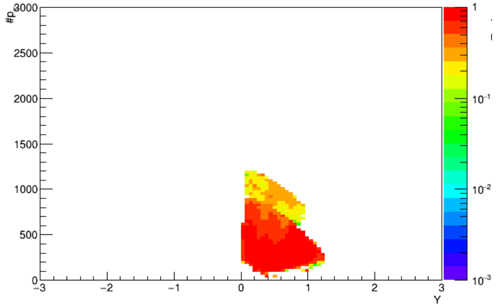
Purity of K+, All hard cuts:

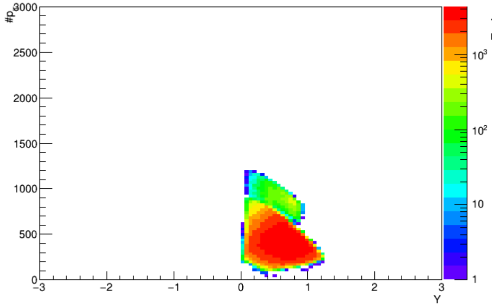
S/(S+B)

S



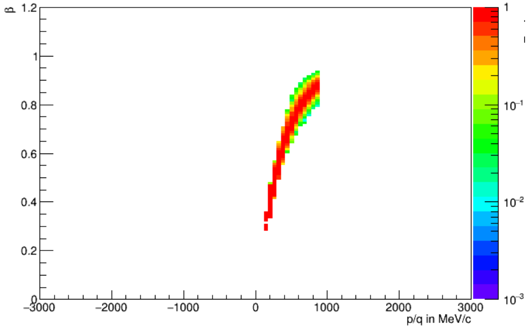


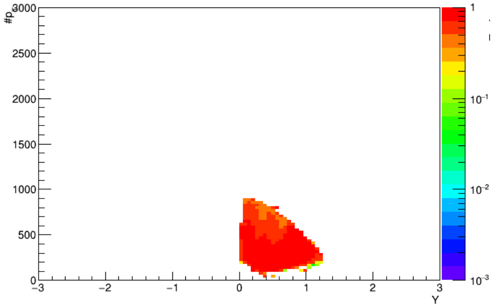




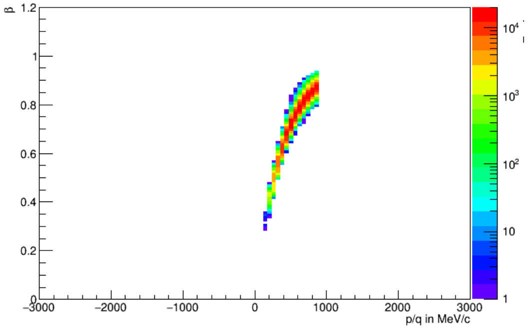
Purity of K+: Hard cuts + GetPID

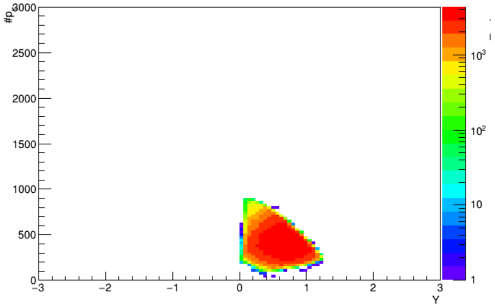
S/(S+B)





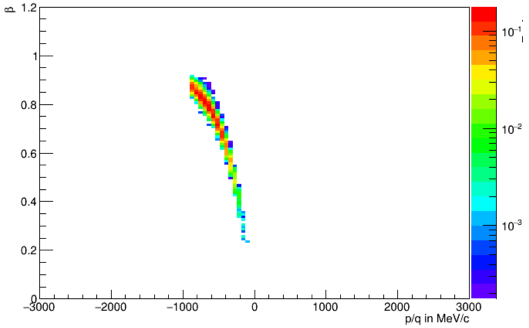
S

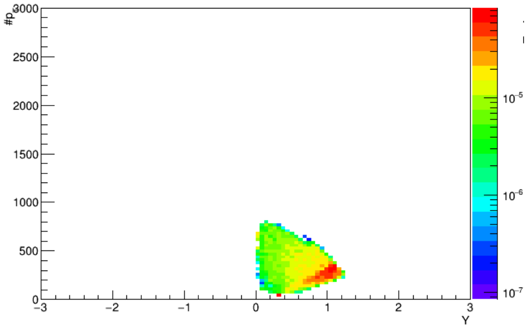




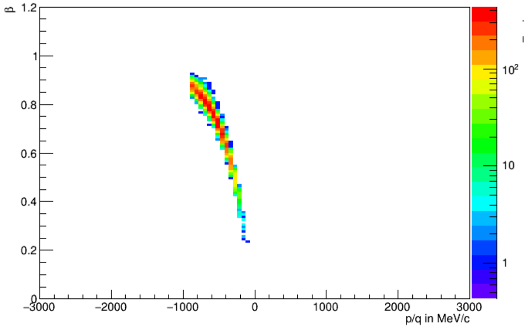
Purity of K-: Using GetPID:

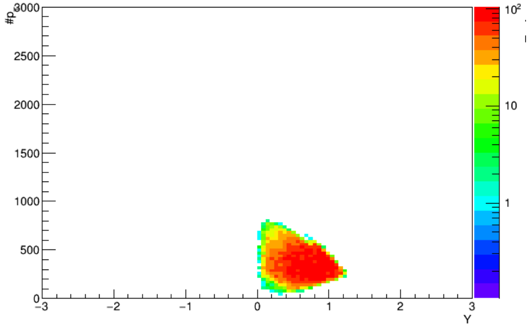
S/(S+B)





S





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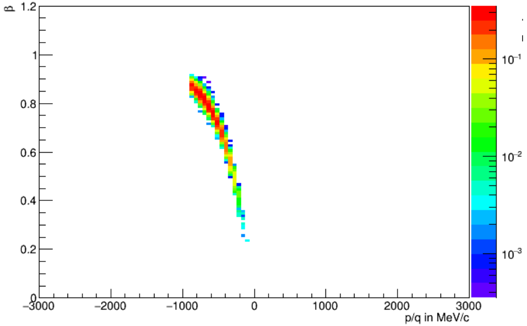
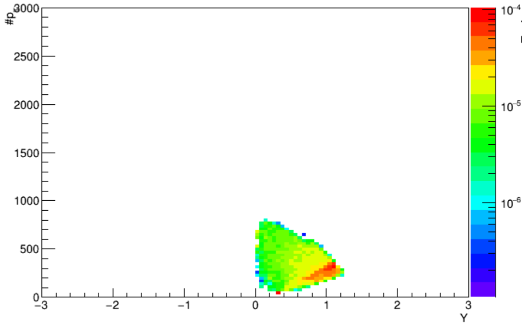
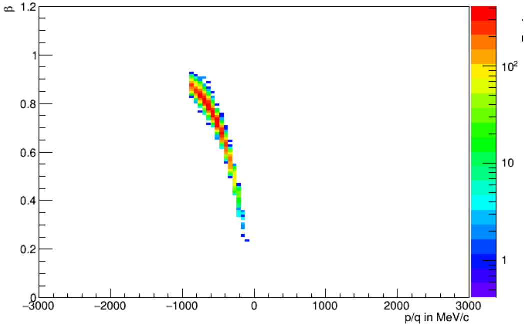
Purity of K-, $\chi^2 < 100$:

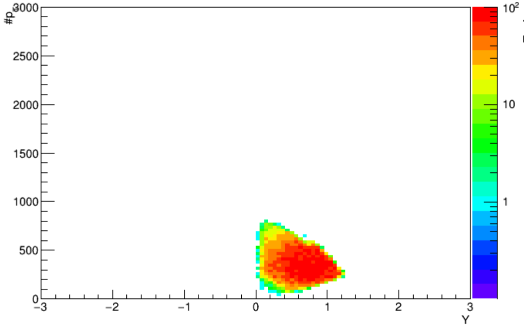
S/(S+B)





S

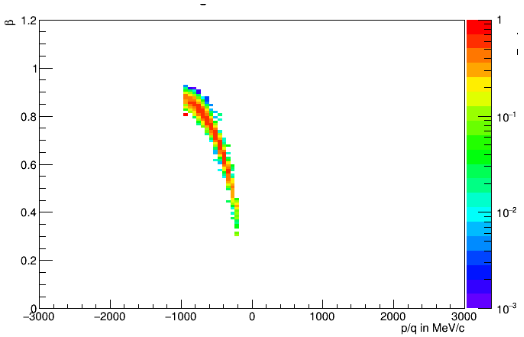


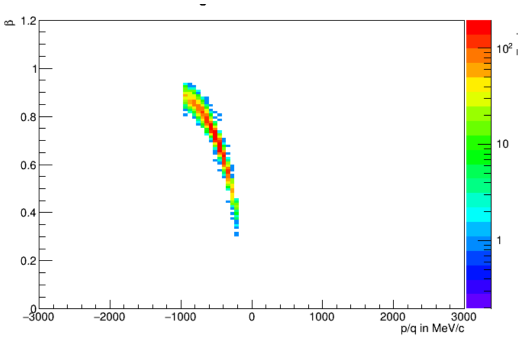


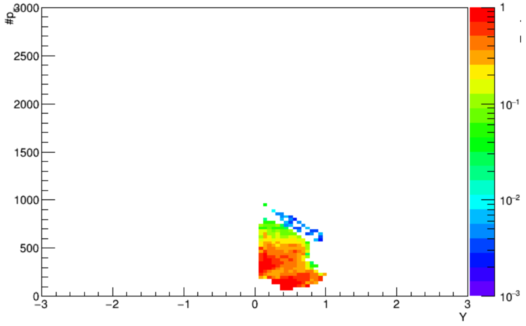
Purity of K-, All Hard Cuts

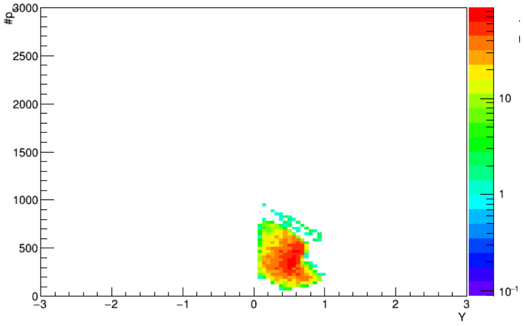
S/(S+B)

S



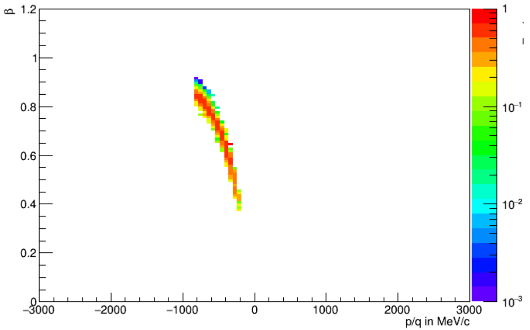


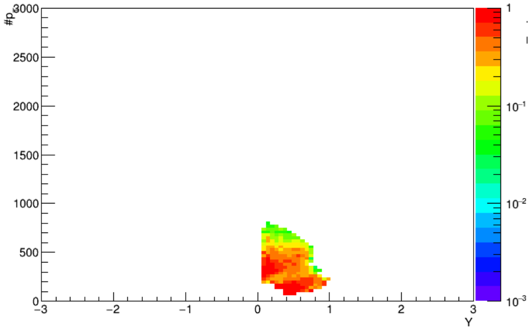




Purity of K-: Hard cuts + GetPID

S/(S+B)





S