Status update on strangeness fluctuations

VIII HADES physics analysis meeting 2026

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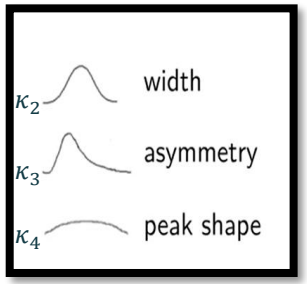
Introduction

- Fluctuations of conserved quantities can be used to probe QCD Phase Diagram
- Cumulants of experimental observables – related to susceptibilities from theory

$$\hat{\chi}_n^{N=B,S,Q} = \frac{1}{VT^3} \frac{\partial^n lnZ(V,T,\mu_{B,Q,S})}{\partial \left(\mu_N/T\right)^n} \qquad \kappa_n^q = VT^3\chi_n^q$$



- This work: **Strangeness fluctuations**
  - Looking into multiplicity distribution of Λs

Λ Reconstruction

Simulation

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Λ in simulation data:

- Ag+Ag at **1.58A GeV, SMASH**
- Total number of events: $\mathbf{10^8}$
- Λ Reconstruction channel:

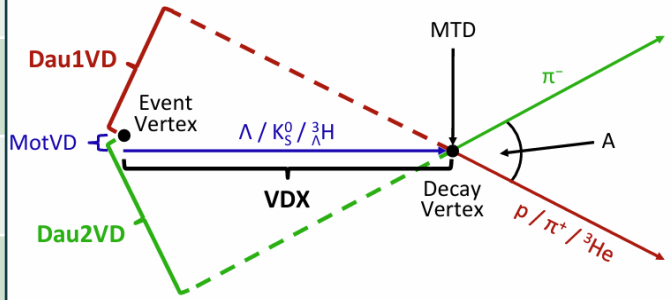
$$\Lambda^0 \rightarrow p + \pi^- \quad (\sim 64\%)$$

Analysis:

- Basic Event selection cuts
  - START hits = 1
- Basic track selection cuts
- Selected hadrons with HParticleTrackSorter
- Centrality: 0-25%
- Hard Cuts for Λ

Λ Reconstruction

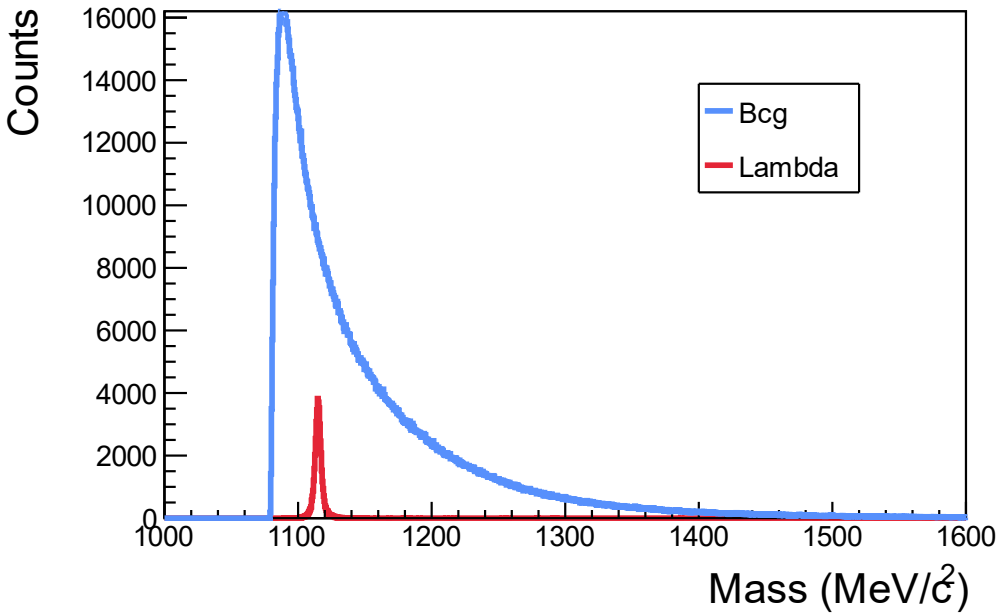
Hard Cuts used for Λ Reconstruction*		
Q_p	Charge of protons	> 0
Q_π	Charge of pions	< 0
m_p	Mass of protons	700 < m_P < 1200
m_{π^-}	Mass of pions	< 300 MeV/c^2
Dau1VD	Distance of closest approach between the trajectory of proton and the primary event vertex	> 4 mm
Dau2VD	Distance of closest approach between the trajectory of pion and the primary event vertex	> 15 mm
MotVD	Distance of closest approach between the trajectory of mother particle and the primary event vertex	< 15 mm
VDX	Distance between decay vertex and primary event vertex	> 45 mm
MTD	Distance of closest approach between trajectories of daughter particles	< 20 mm
A	Opening angle between the trajectories of daughter particles	> 15°

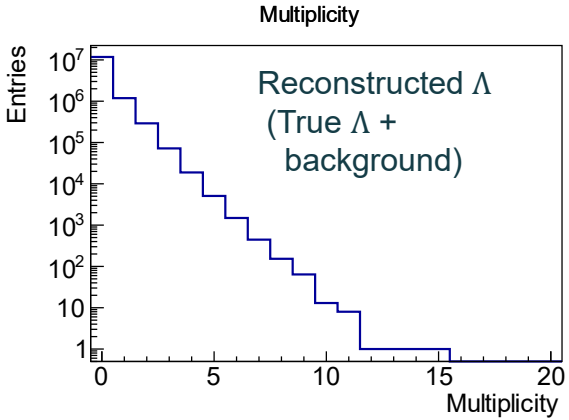


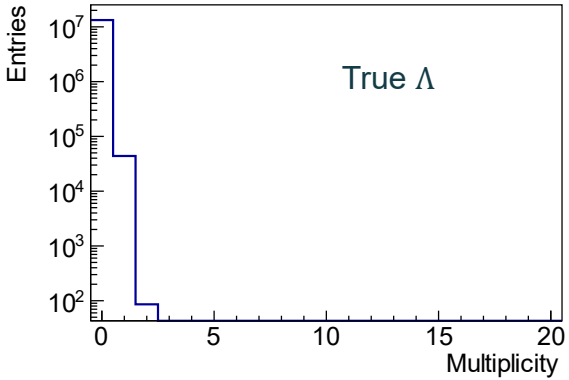
*Spies, S., *Strange hadron production in Ag+Ag collisions at 1.58A GeV*, PhD thesis, Frankfurt University, 2022. DOI: 10.21248/gups.68651.

True Λ Signal in simulations

13 million events

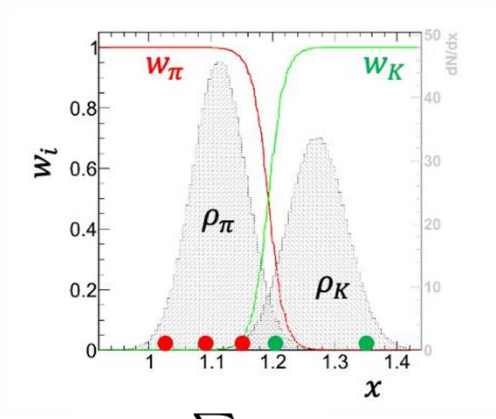


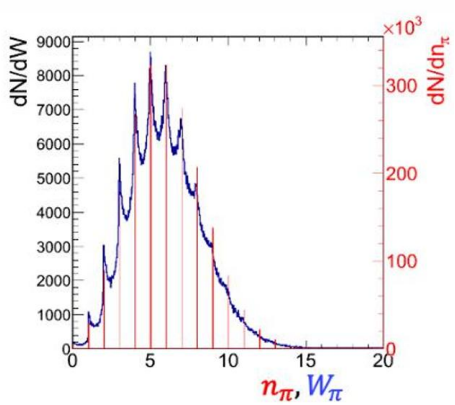




Calculating the moments - Fuzzy Logic

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





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

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

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

$$\langle \vec{W} \rangle = A \times \langle \vec{N} \rangle$$

Folded moments

A: fully defined by fit functions

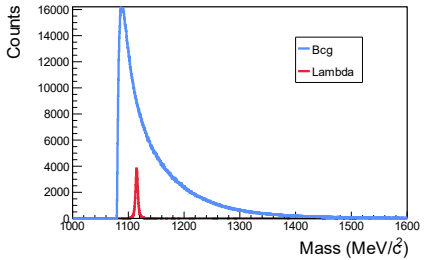
Response Matrix

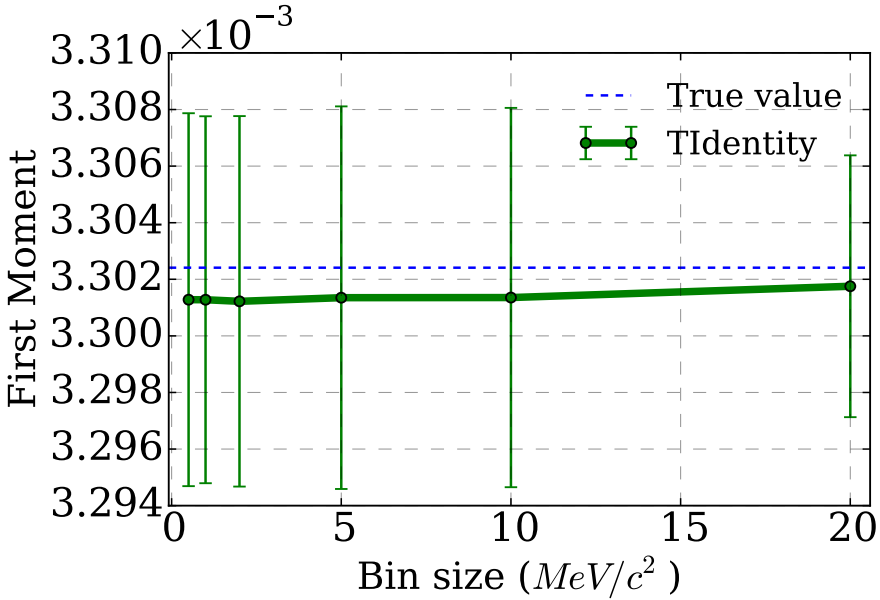
True moments

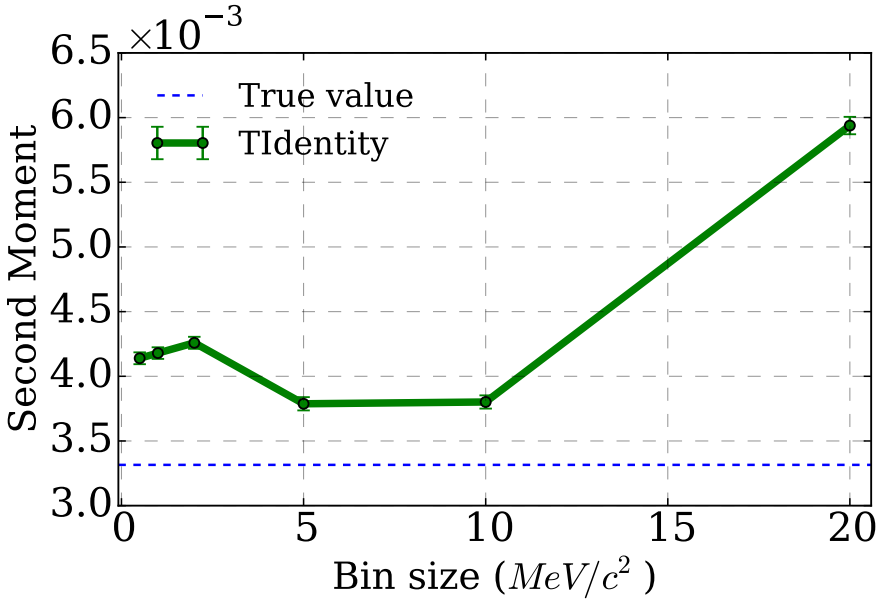
TIdentity module – software implementation

A. Rustamov and M. I. Gorenstein, PHYSICAL REVIEWC86,044906 (2012),
M. Gazdzicki, K. Grebieszkow, M. Mackowiak, S. Mrowczynski, Phys. Rev. C83 (2011) 054907
M. Arslandok, A. Rustamov,
https://www.sciencedirect.com/science/article/pii/S0168900219311222

Results







Results are not consistent with true moments for the case of second moments

Tighter topological cuts

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Tighter Vertex Cuts for Λ:

			Tighter cuts*
Dau1VD	Distance of closest approach between the trajectory of proton and the primary event vertex	> 4 mm	> 8 mm
Dau2VD	Distance of closest approach between the trajectory of pion and the primary event vertex	> 15 mm	> 26 mm
MotVD	Distance of closest approach between the trajectory of mother particle and the primary event vertex	< 15 mm	< 8 mm
VDX	Distance between decay vertex and primary event vertex	> 45 mm	> 65 mm
MTD	Distance of closest approach between trajectories of daughter particles	< 20 mm	< 10 mm
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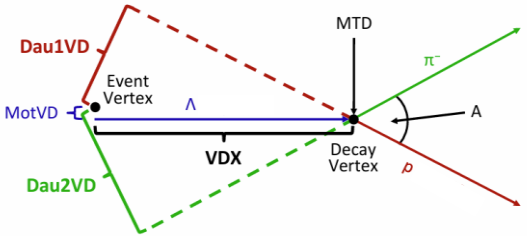

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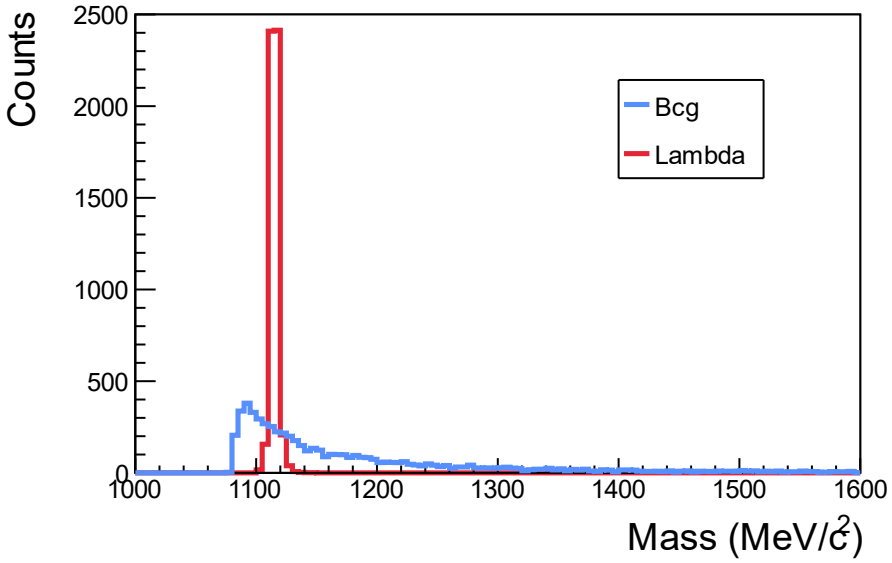
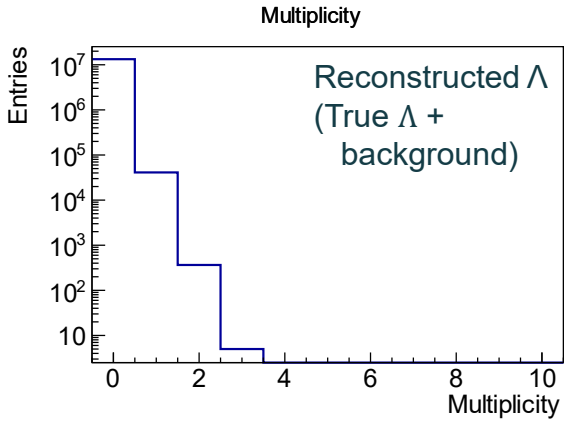
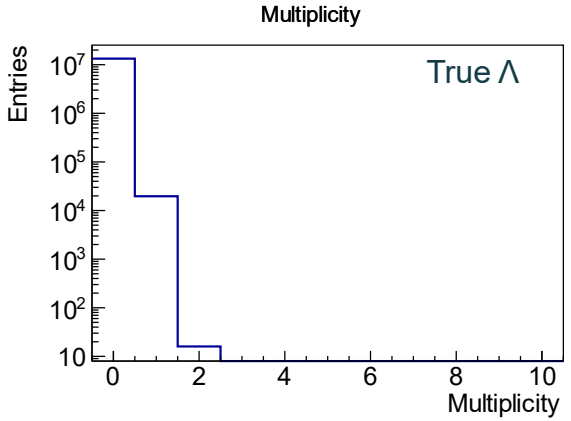
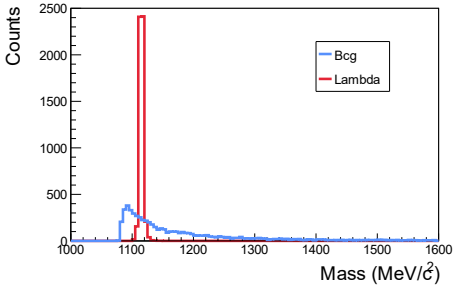
Invariant mass of the reconstructed Λ (true signal and true background)

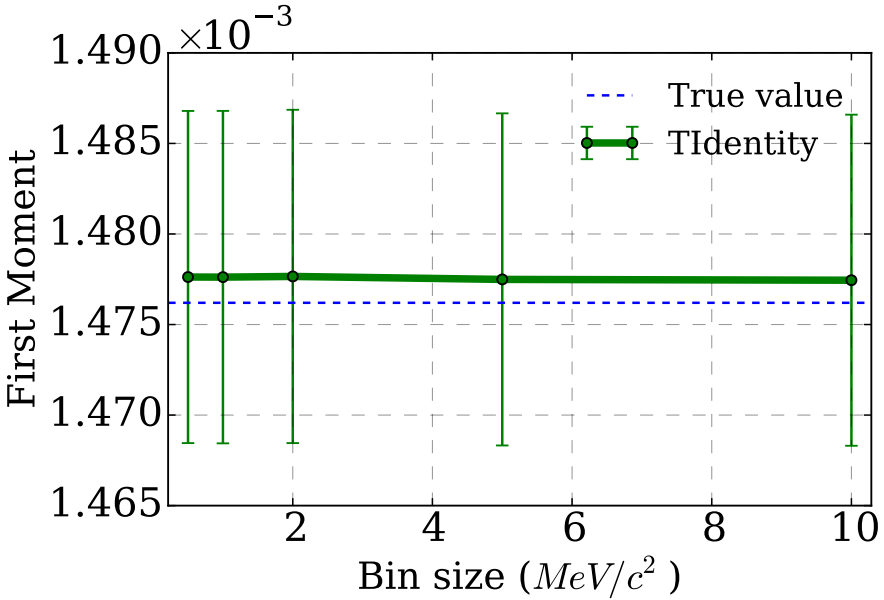


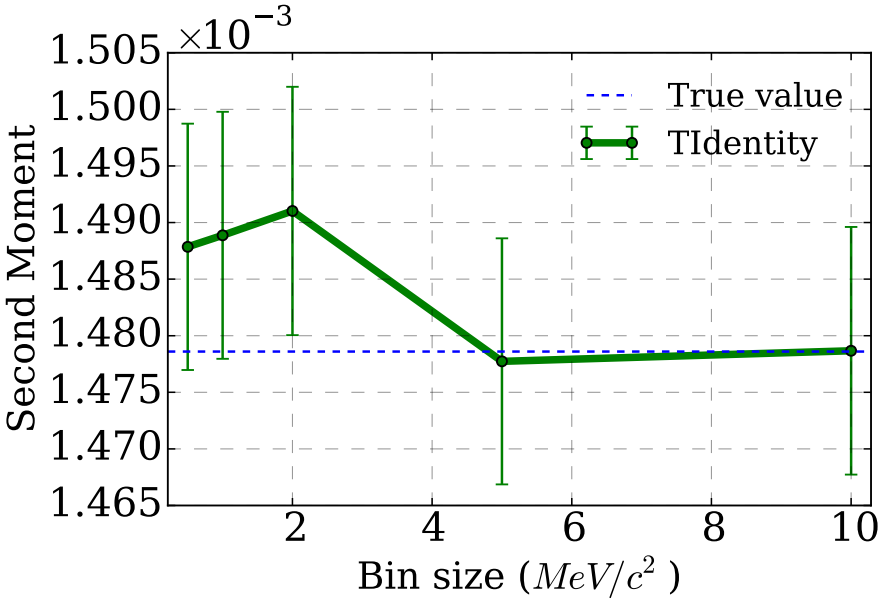




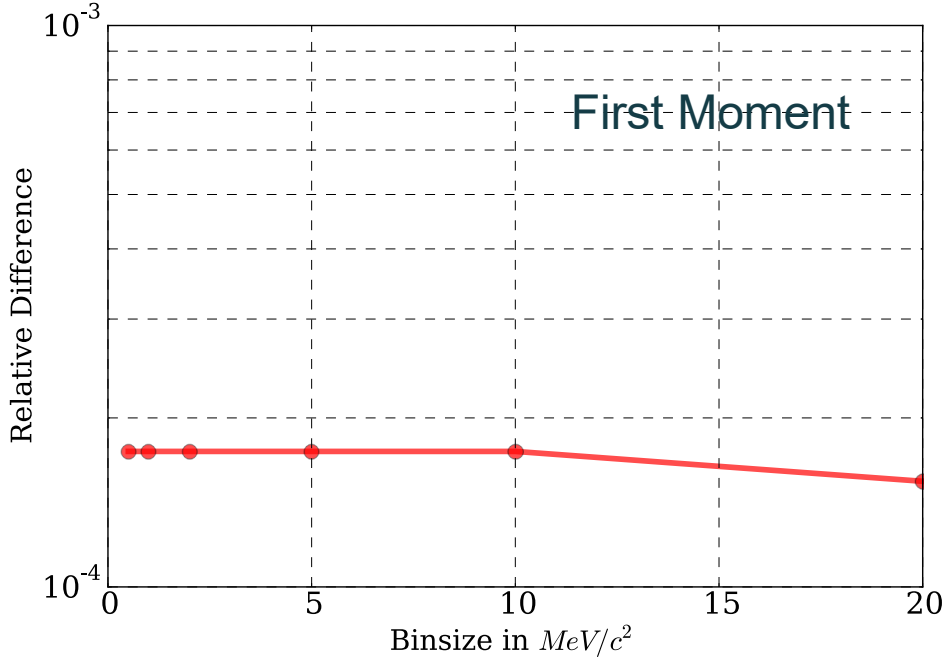
Moments obtained using true signal and true background

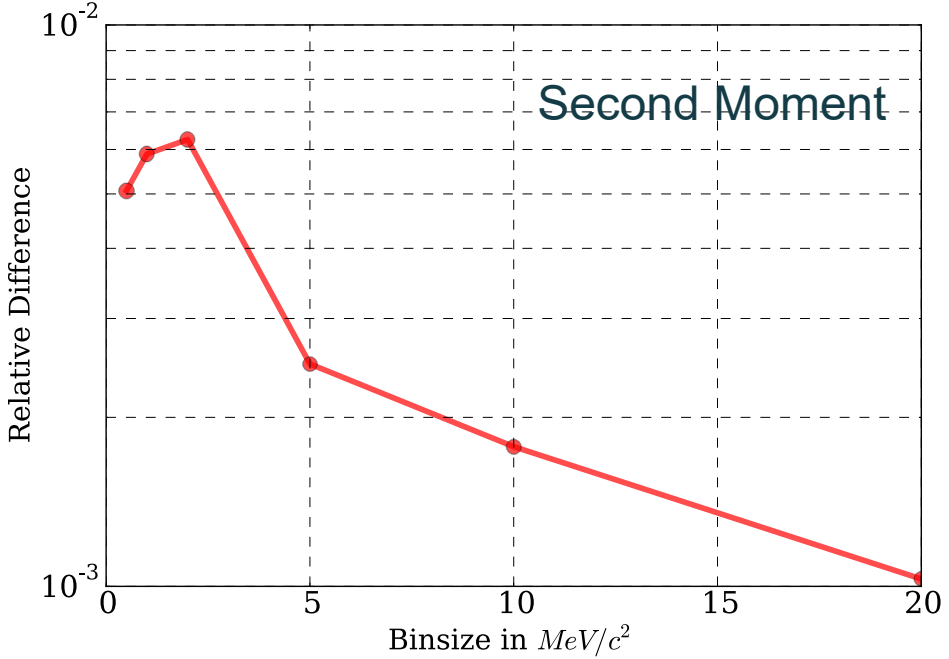






Relative difference between true moments and moments obtained





Good agreement between true moments and the moments obtained

Obtaining signal and background by event-mixing

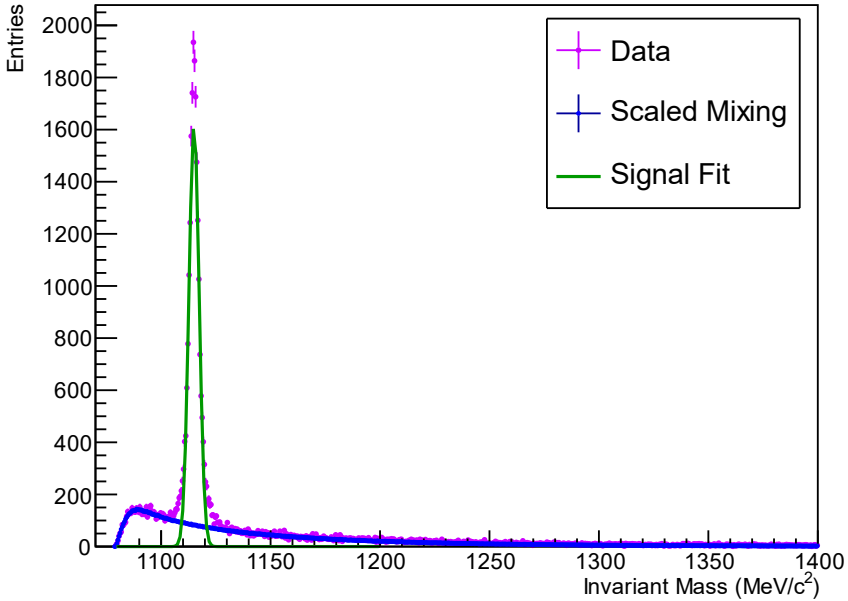
- To eliminate the non-correlated background

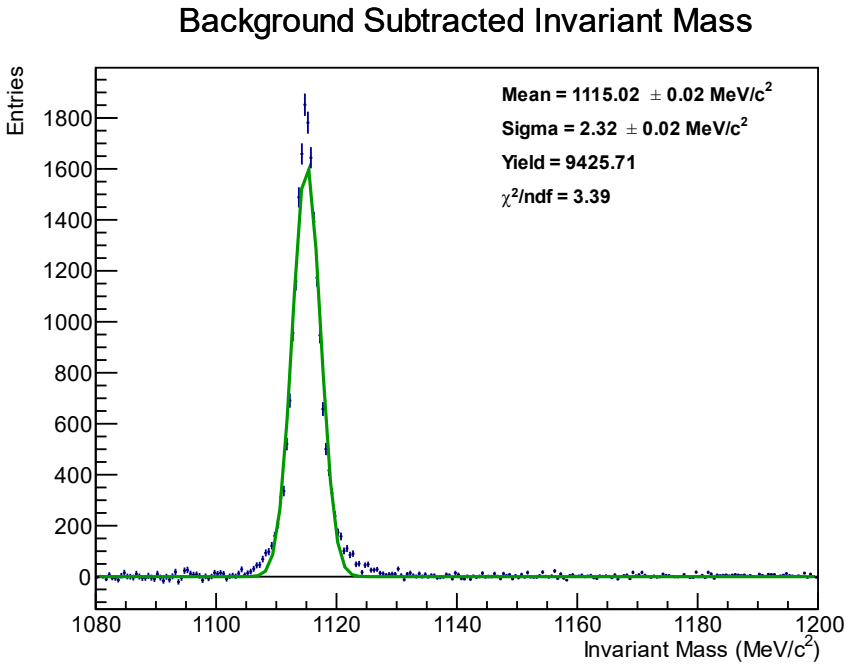
- Event-mixing within the same event classes

  - Same centrality class
    (using charged particle multiplicity)
  - Same target segment
  - Same day of data-taking

- Scale the mixed event background with scaling factor obtained via sideband analysis

Λ Signal and Background using Event Mixing





Moments:

Binsize: 5 MeV/c^2	True Moments	TIdentity Moments	Relative difference
First Moment	1.48×10^{-3}	1.44×10^{-3}	2.7 %
Second Moment	1.48×10^{-3}	1.45×10^{-3}	2.0 %

- Minimal difference seen for the moments compared to the case with true signal and background
  - The mixed event background doesn't fully reproduce side bands.
  - Possibly, the negative values in the histograms used as input for moment calculation(?).

Ag+Ag Data

1.58 AGeV

Work in Progress

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Mar19 Ag+Ag Dataset

- ~ 75 million events used

Dau1VD	Distance of closest approach between the trajectory of proton and the primary event vertex	> 8 mm
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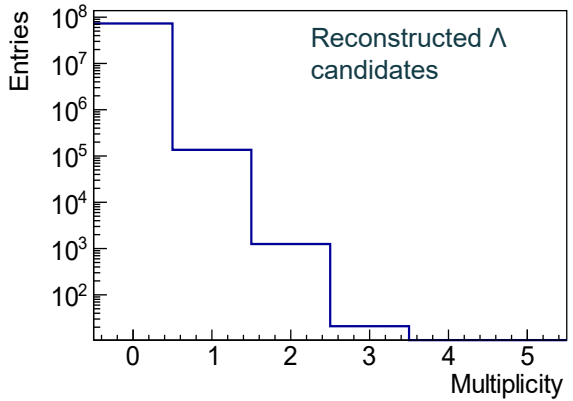
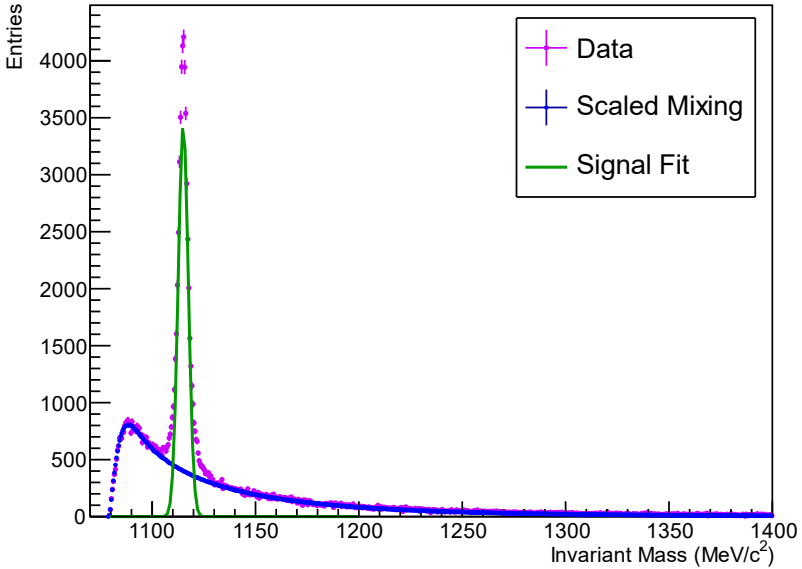
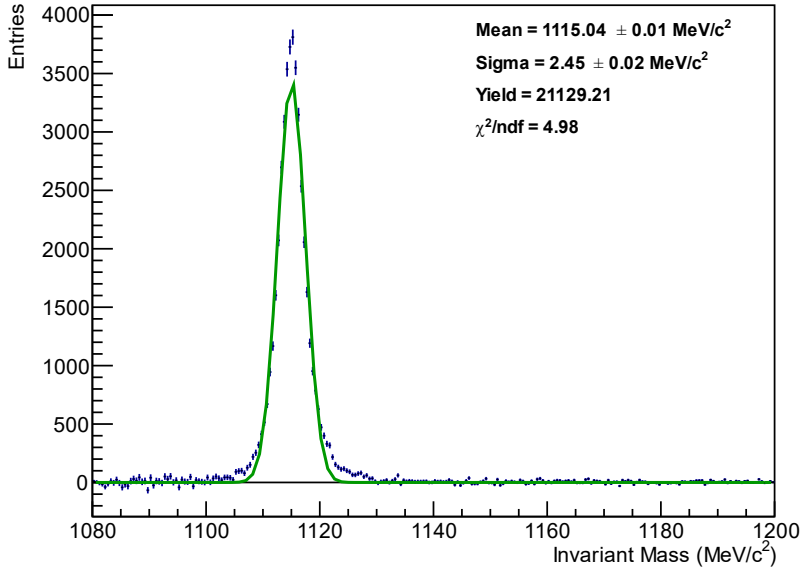


Invariant Mass of the reconstructed Λ

Invariant Mass Fit



Background Subtracted Invariant Mass



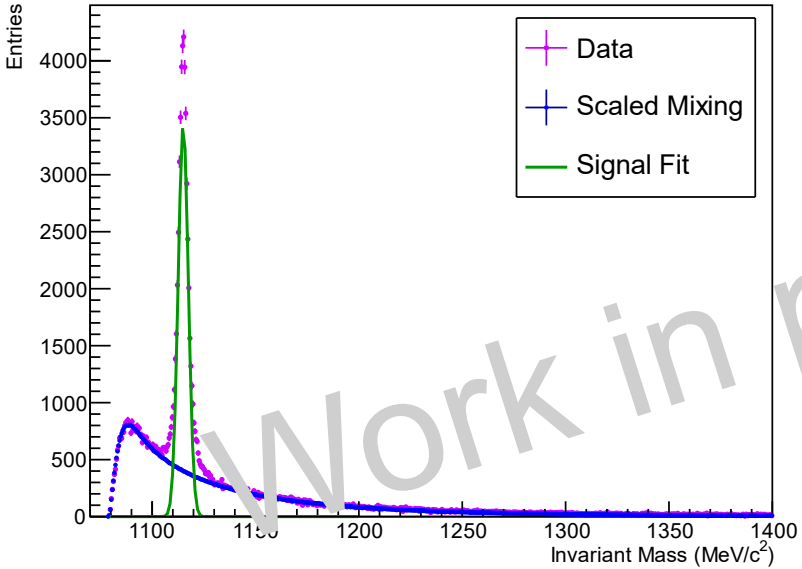
Binsize: 5 MeV/c^2	Moments obtained
First Moment	6.330×10^{-4}
Second Moment	6.344×10^{-4}

Using the number of entries in the signal histogram:

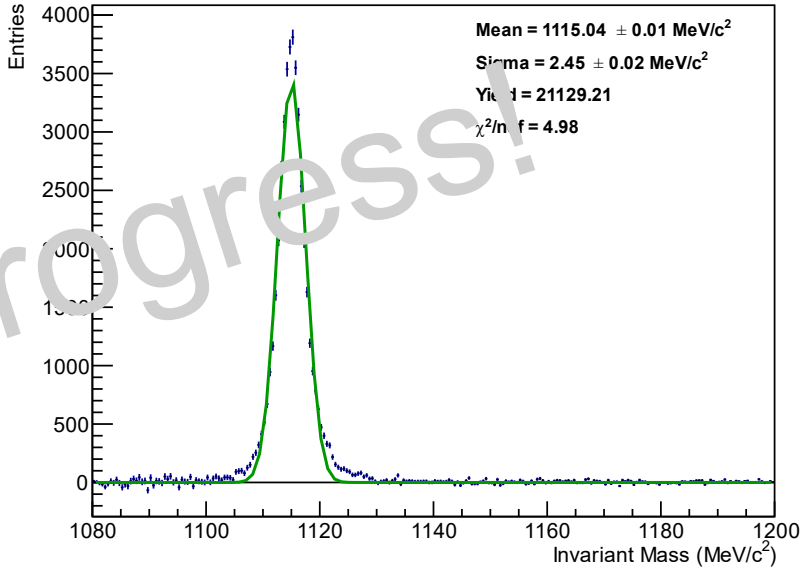
$$\frac{\text{Total number of } \Lambda}{\text{Number of Events}} = 6.330 \times 10^{-4}$$

Invariant Mass of the reconstructed Λ

Invariant Mass Fit



Background Subtracted Invariant Mass



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$$\frac{\text{Total number of } \Lambda}{\text{Number of Events}} = 6.330 \times 10^{-4}$$

Summary and Next Steps

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Summary and Outlook

Summary:

- Λ Reconstruction and moment estimation using loose and tight cuts were explored
  - The true moments were reproduced with an error of 2.7% in simulations for tight cuts
- For the tight cuts, the moments for real data was also obtained for a partial dataset

Outlook:

- Fine-tuning Λ selection
  - Improve signal to background ratio using ANN
- Λ moments as a function of rapidity
- Efficiency-Acceptance corrections

Thank you!

Backup Slides

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Event and Track Selection

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Event selection cuts

- kGoodVertexClust
- kGoodVertexCand
- kGoodSTART
- kNoSTART
- kNoVETO
- kGoodSTARTVETO
- kGoodSTARTMETA
- kNoFlashMDCP
- kGoodTRIGGER
- Target Layer between 0,14

Track selection cuts:

- isFlagBit(kIsUsed)
- kisAcceptedHitInnerMDC
- kisAcceptedHitOuterMDC
- kIsAcceptedHitMETA
- kIsAcceptedRK
- InnerSegmentChi2 > 0
- X^2 < 400
- 0 < Meta Match Quality < 3
- isAtAnyMDCEdge
- SystemUsed != -1
- MomentumOrg < 4000
- IsGoodMetaCell

Tighter Vertex Cuts

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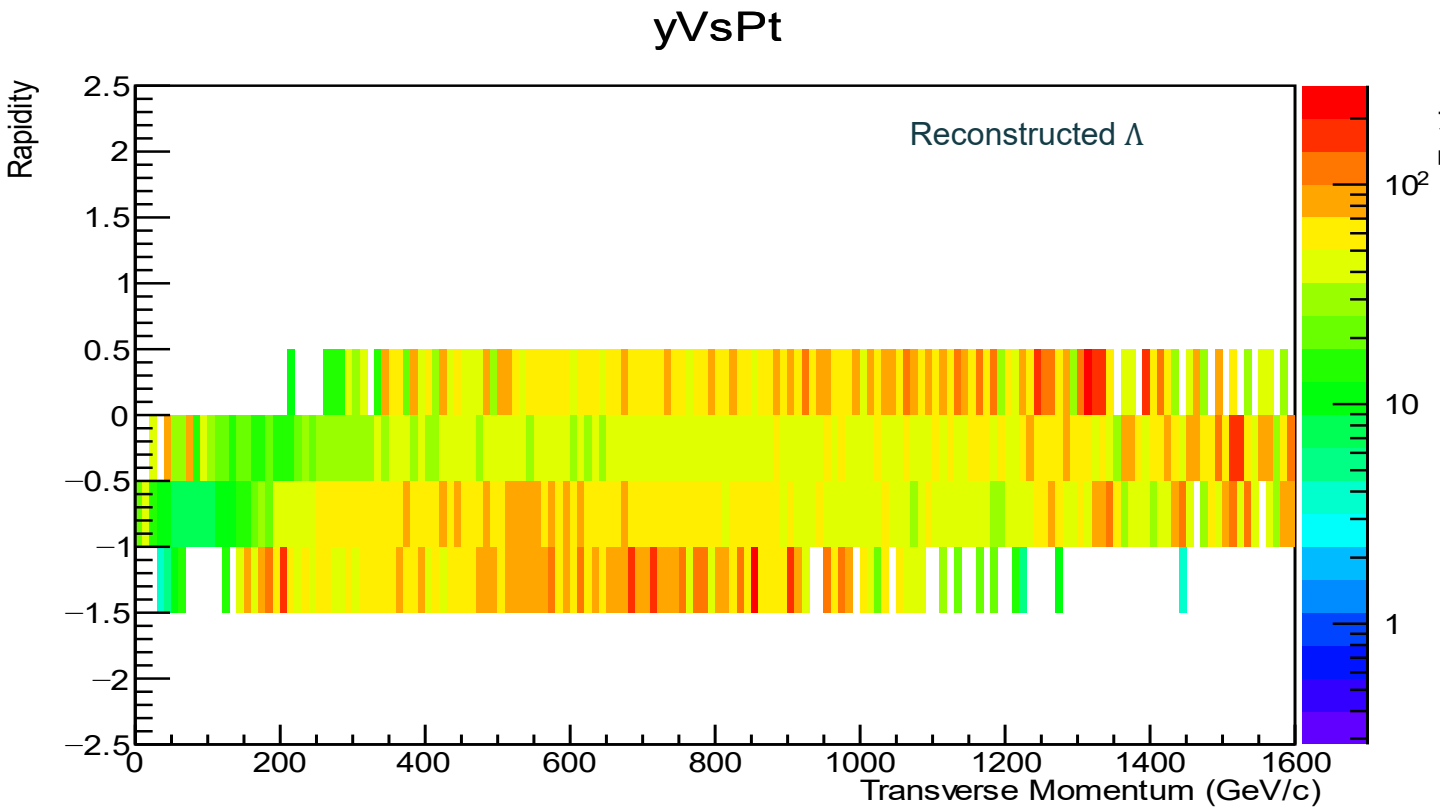
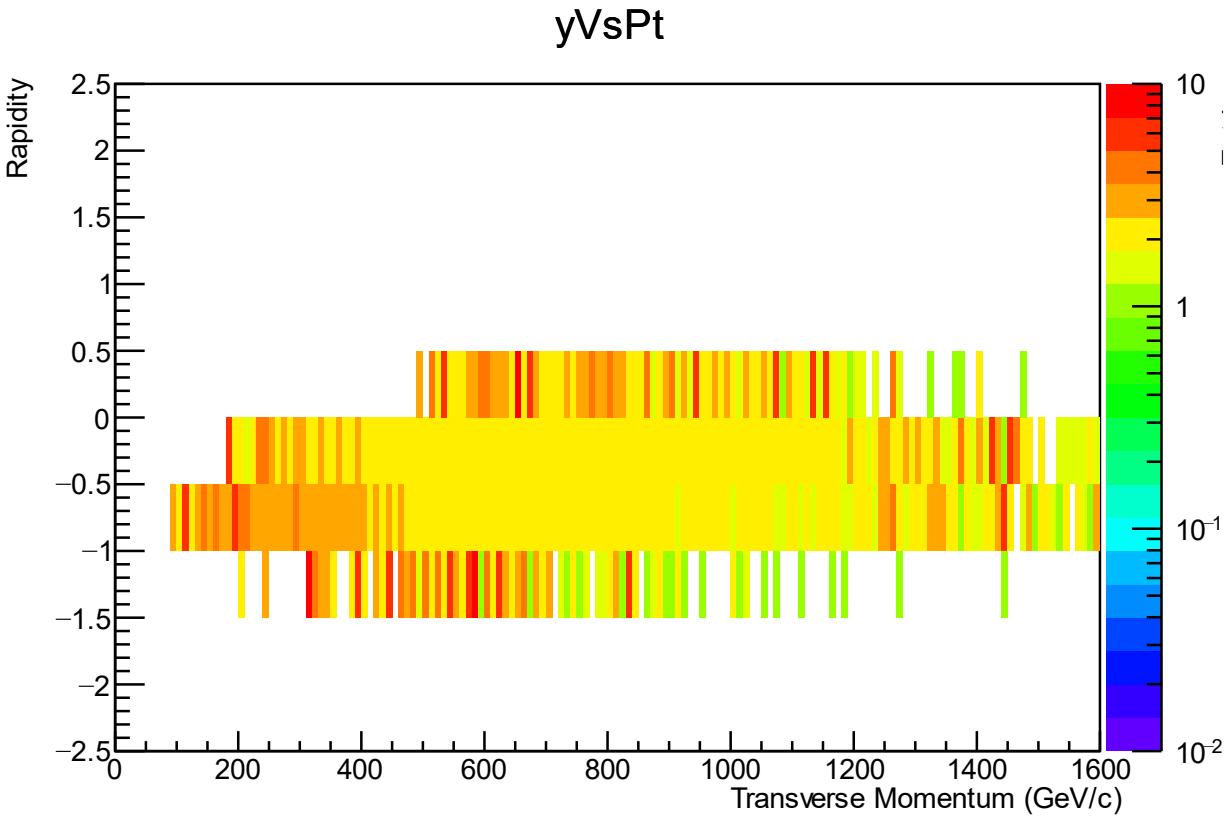
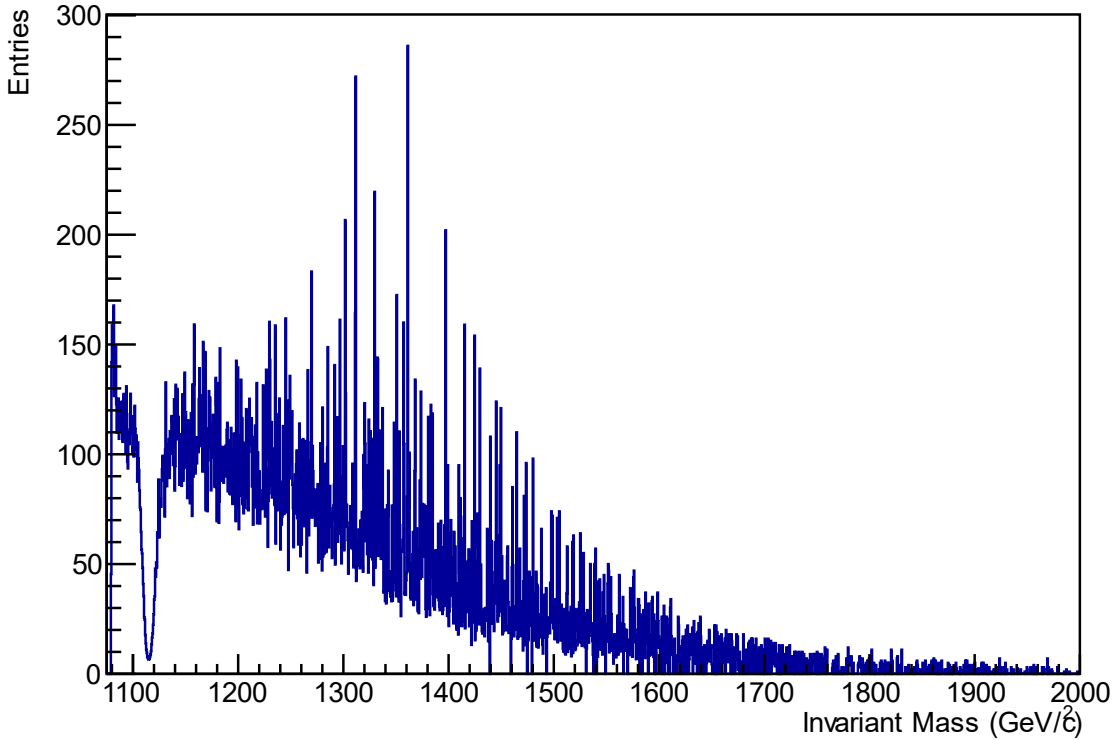
Loose vs Tight Cuts: Reconstructed Λ



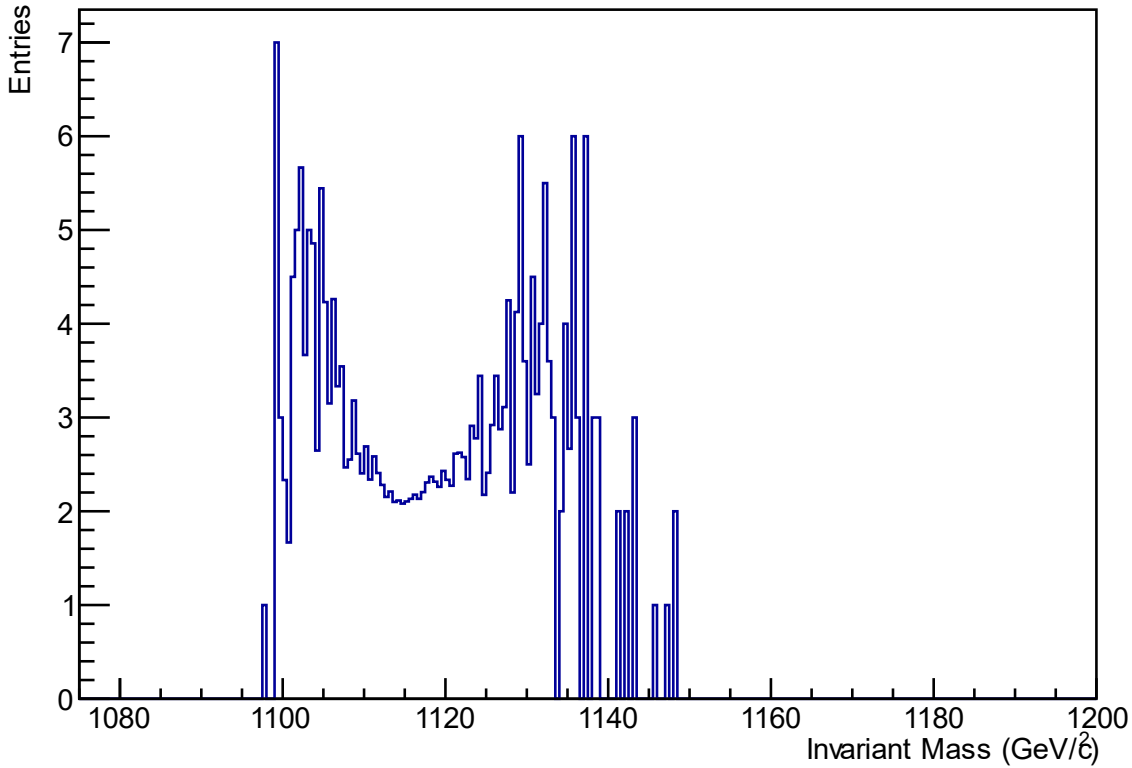
Loose vs Tight Cuts: True Λ



Loose vs Tight Cuts: Reconstructed Λ

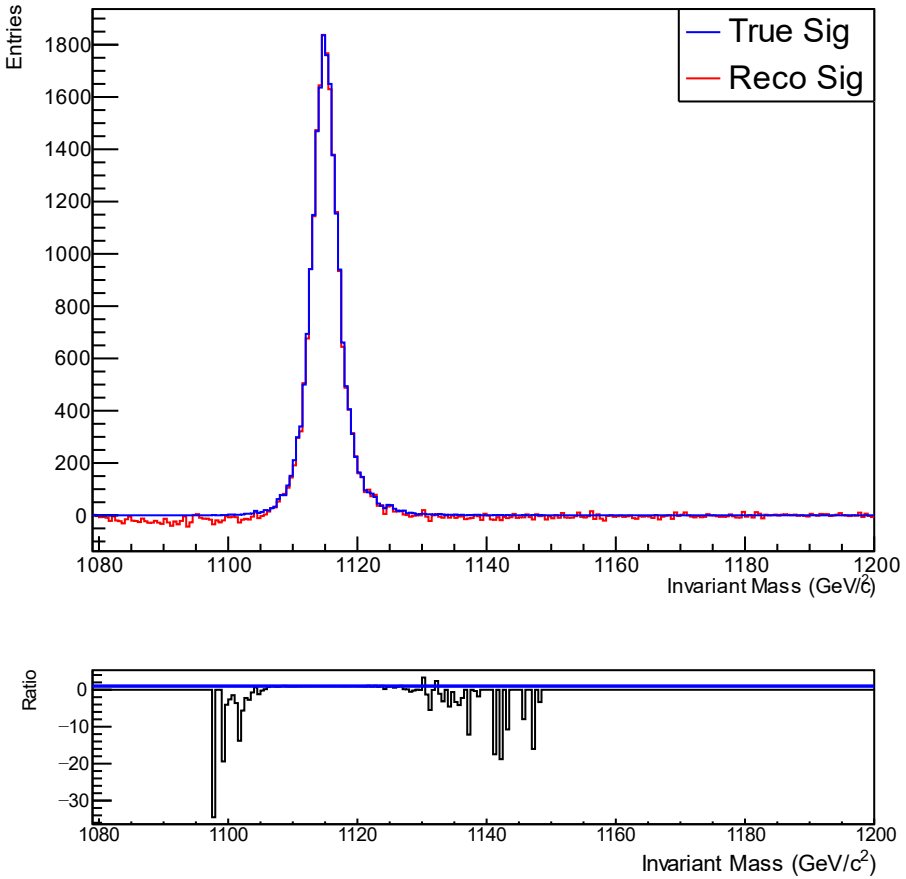


Loose vs Tight Cuts: True Λ



Reconstructed signal vs True Signal

- At the peak region, the true signal is reconstructed well for the tight cuts



Kaon Reconstruction

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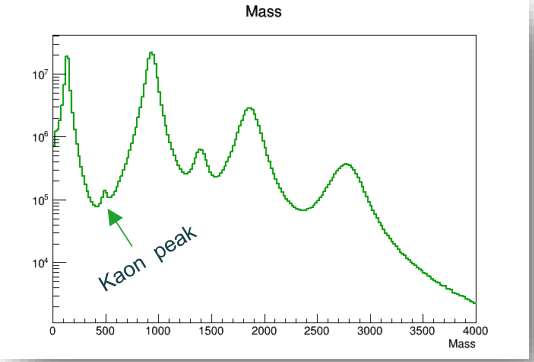
Strangeness fluctuations with Kaons

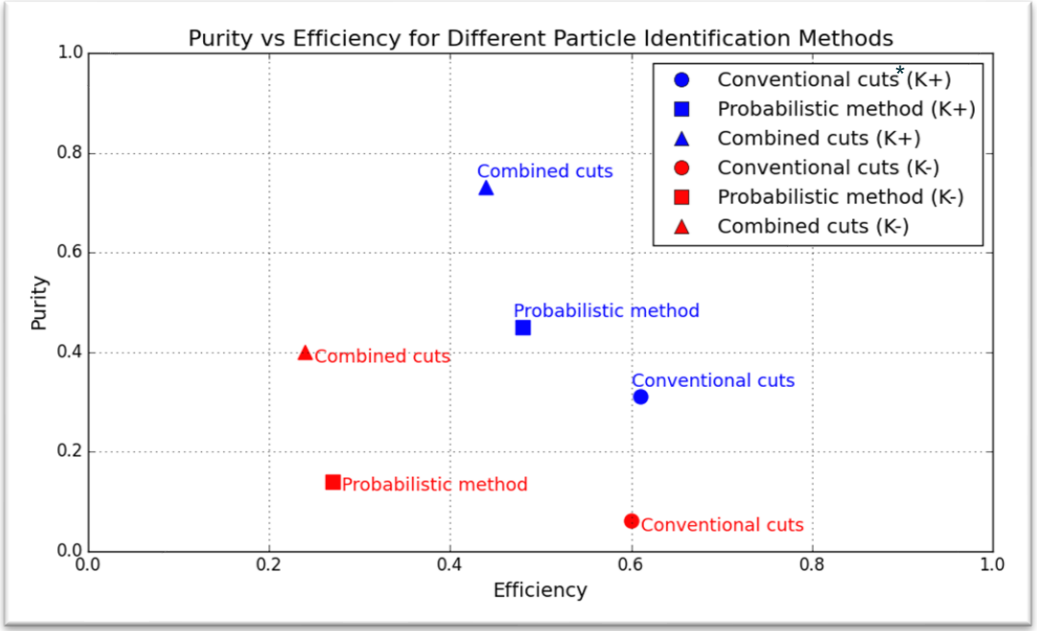
- Mar19 Ag+Ag data at 1.58 AGeV
  - Using Kaons: Lower priority
    - Low multiplicity
    - High background contribution
    - Less rapidity coverage
    - Poisson behaviour

Kaon Identification and reconstruction in Ag+Ag HADES Simulation data:

- Ag+Ag at **1.58 AGeV, SMASH**
- Total number of events: 10^7

Particle Type	Mean multiplicity per event
K+	2.5×10^{-2}
K-	6.2×10^{-4}





- Purity = $\frac{\text{Signal (S)}}{\text{Signal+background (S+B)}}$
- Efficiency = $\frac{\text{Number of true kaons reconstructed}}{\text{Number of true kaons in the reconstructable tracks}}$

*Inspired by cuts from Jan Orlinksi

Exploratory Toy Model

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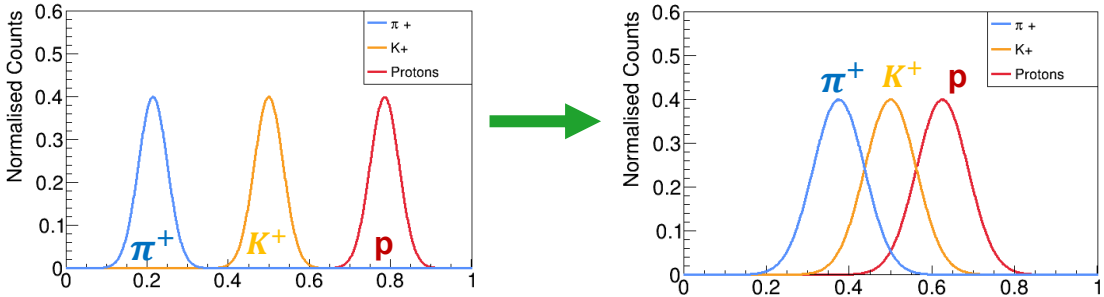
Exploratory study using Toy model

To study the effect of

- Multiplicity of signal particle (K+)
- Background contribution
- Statistics (number of events available to get the true input distributions of the particles)

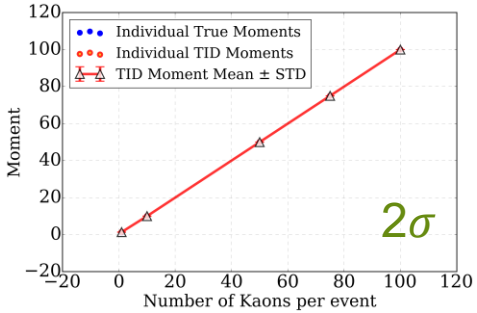


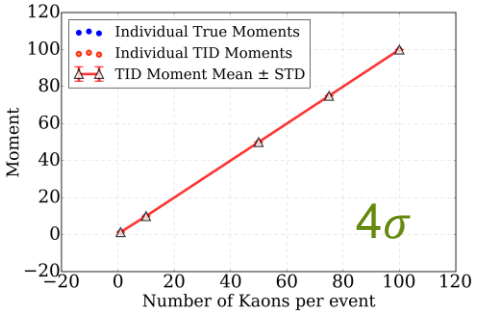
Simple Toy Model:

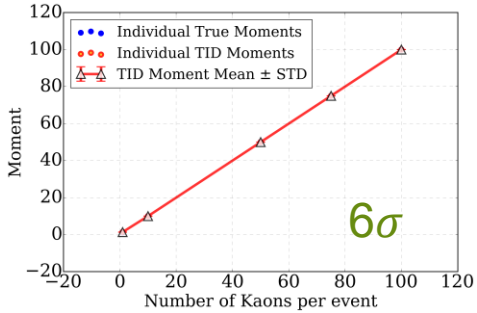
- 3 particle types per event: (π, p, K)
- π, p: drawn from a Gaussian distribution of mean 100
- Get an input distribution for Identity method (to get the moments)
- Vary mean number of kaons from {1,10,50,75,100}
- Vary degree of overlap between the particles
- Compare for different number of events

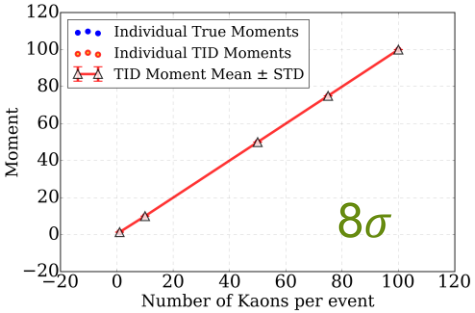
Results for 10 million events as a function of number of kaons for different peak separation:

First Moments

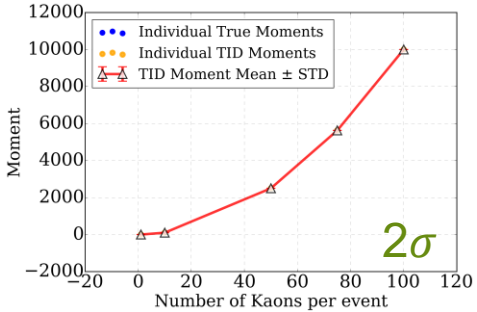


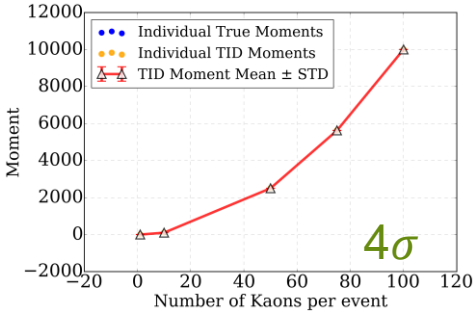


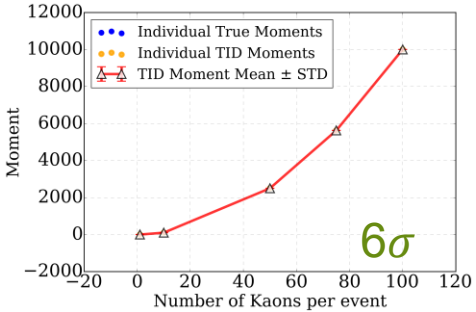


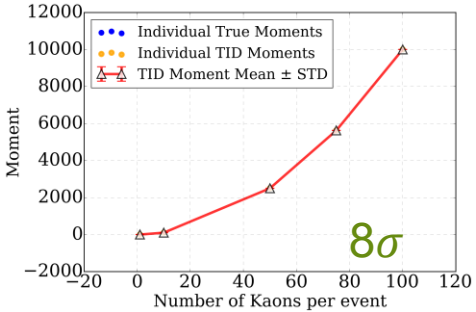


Second Moments







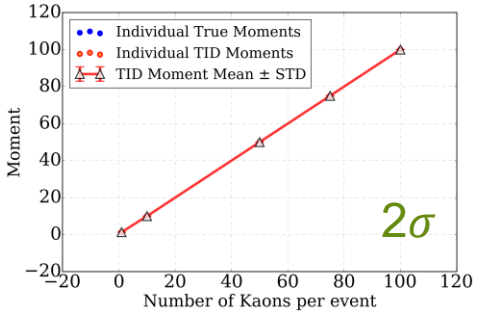


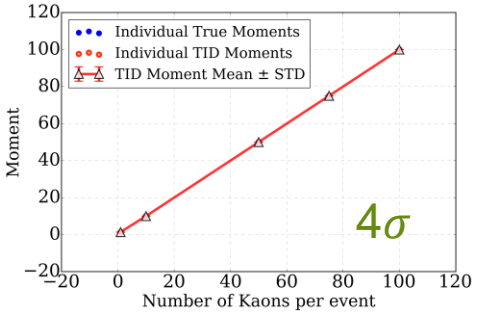
Results for 10 million events

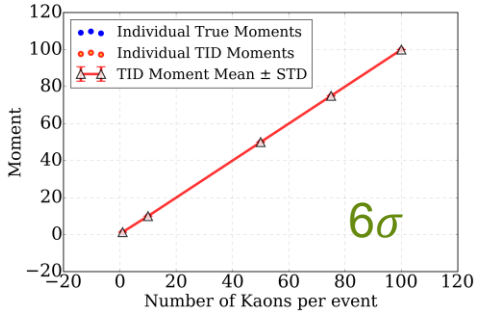
- Multiplicity of kaons
- Degree of overlap

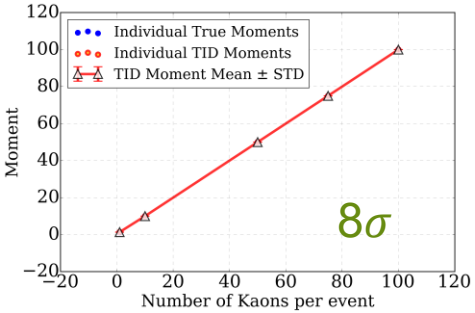
} No effect on calculated moments

First Moments

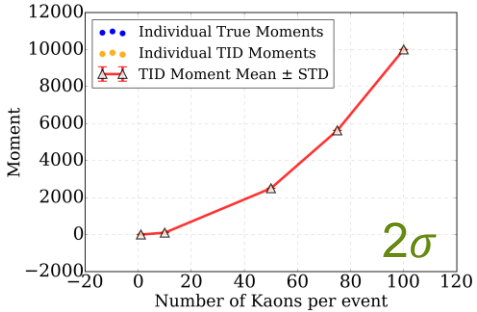


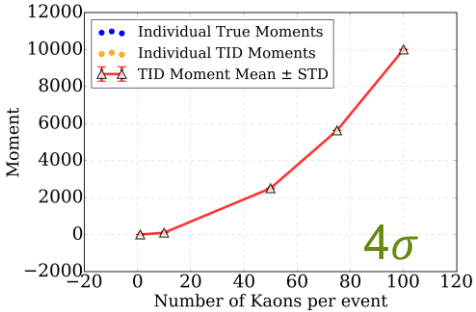


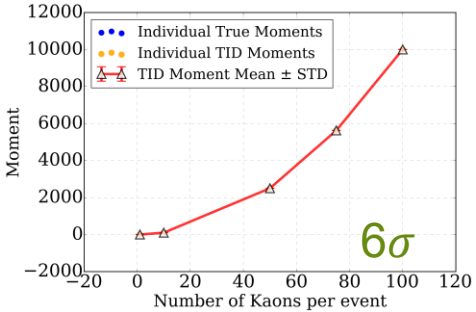


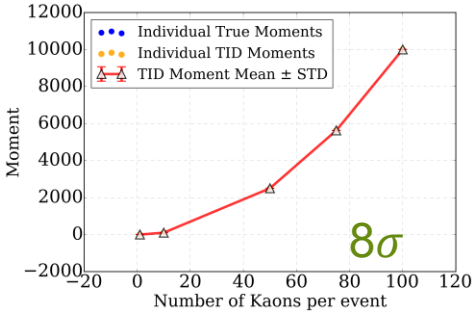


Second Moments



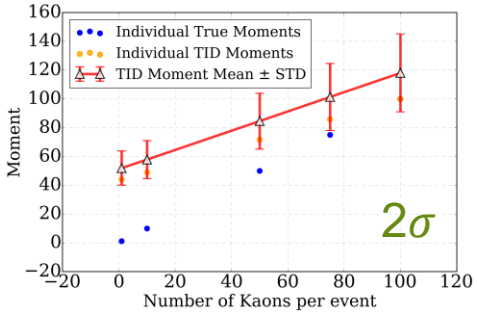


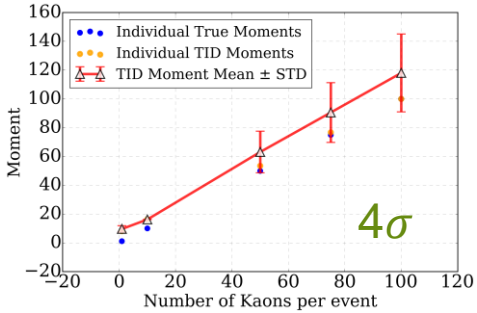


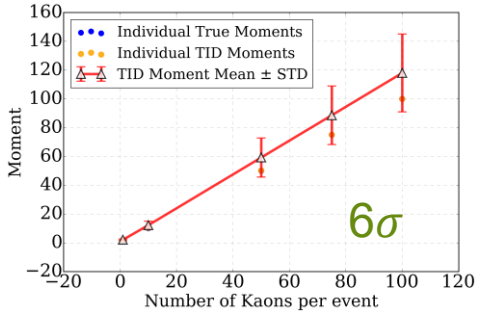


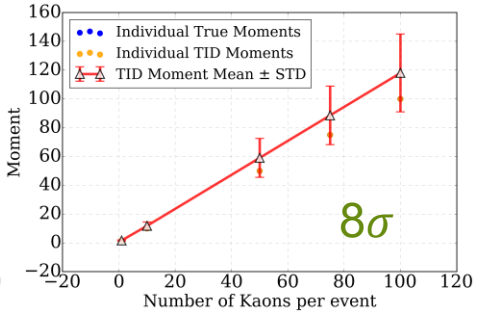
Results for 100,000 events as a function of number of kaons for different peak separation:

First Moments

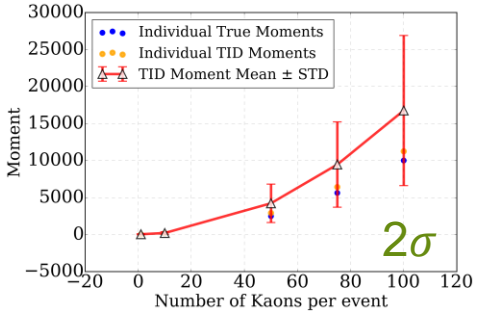


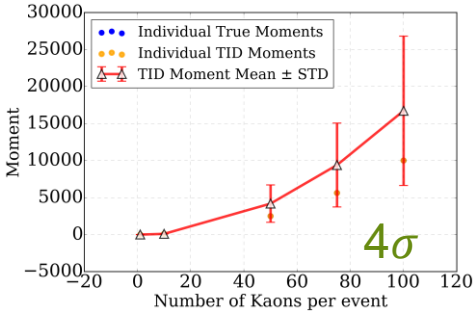


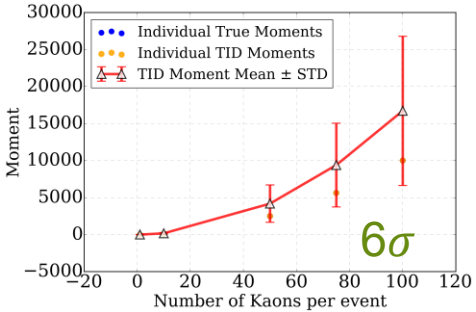


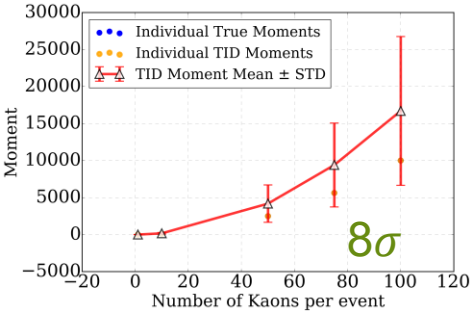


Second Moments







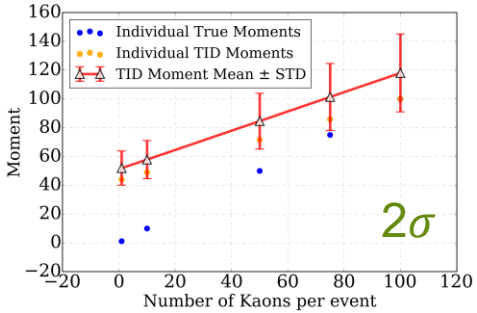


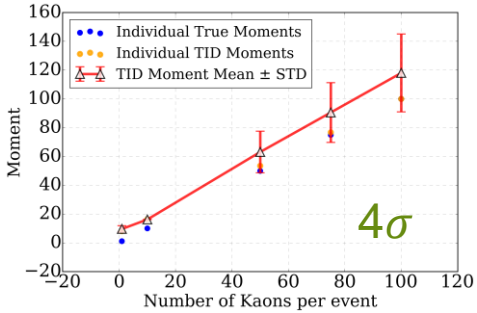
Results for 100,000 events

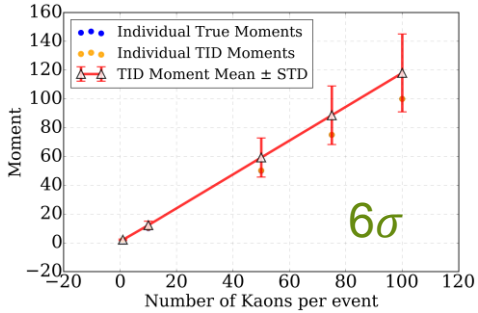
- Lower multiplicity of kaons
- Higher degree of overlap

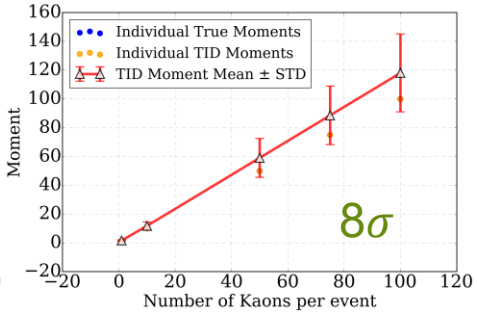
Worse Results

First Moments

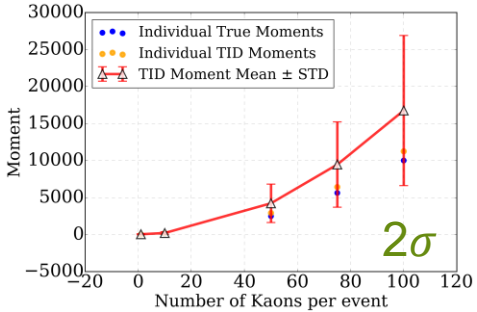


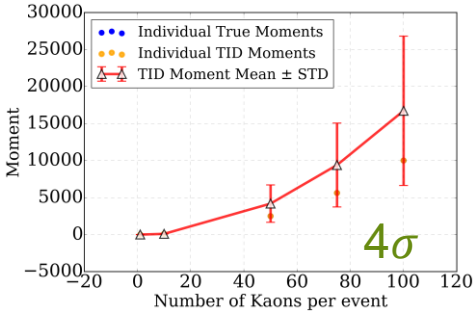


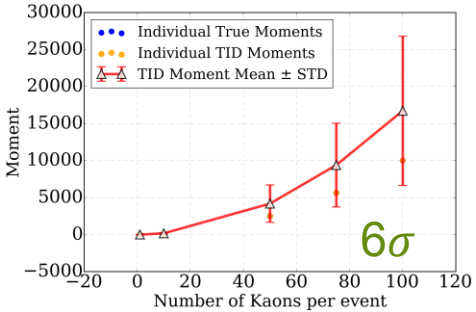


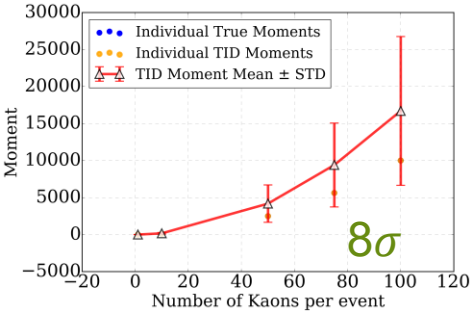


Second Moments









Main conclusions

- For high statistics, signal particle multiplicity and degree of overlap of input distribution (eg. mass) do not make any difference

- For lower statistics, we get worse results for
  - Lower multiplicity of signal particle
  - Higher degree of overlap in the input distribution

- For high multiplicity of signal particle and low degree of overlap of input distributions, Statistics do not play an important role

- Other modified toy models also showed promising results (backup slides)

Kaons in Ag+Ag Simulations

Gen6 simulations

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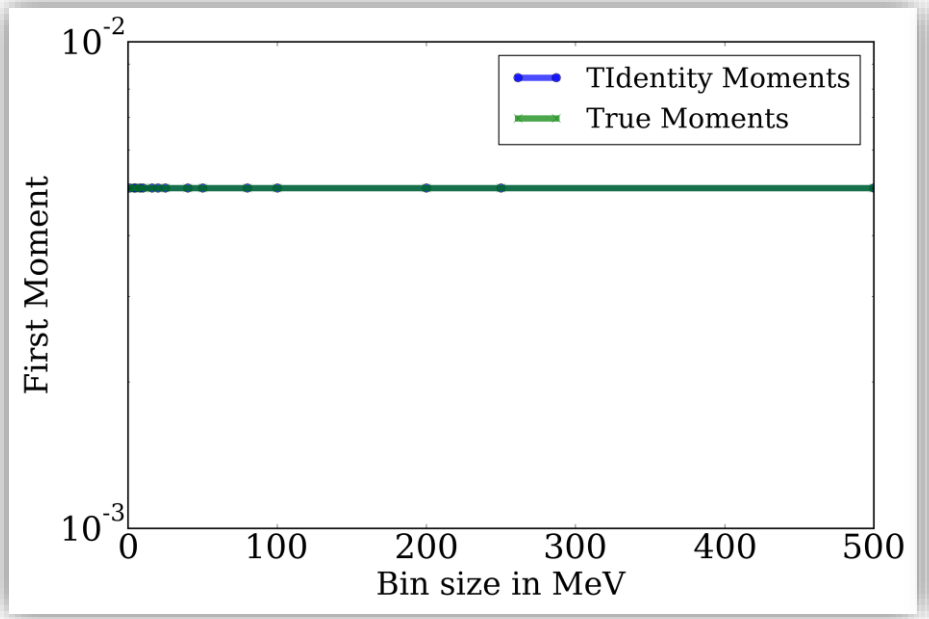
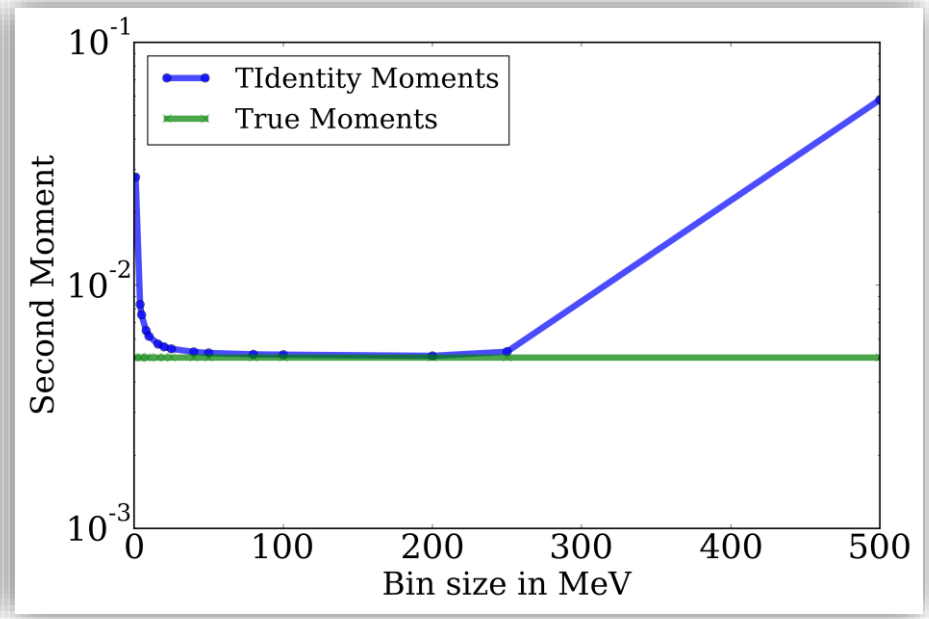
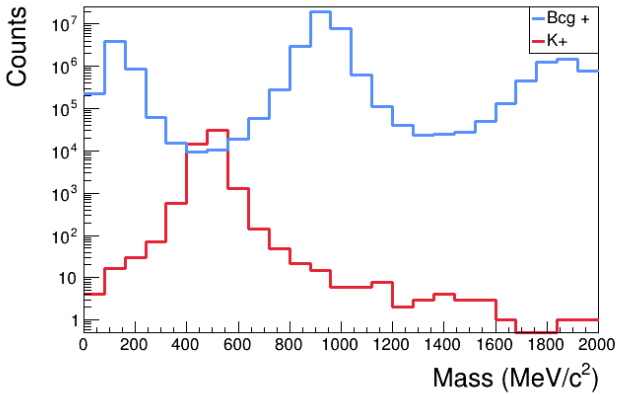
Ag+Ag Simulation: Bin size vs moment values obtained

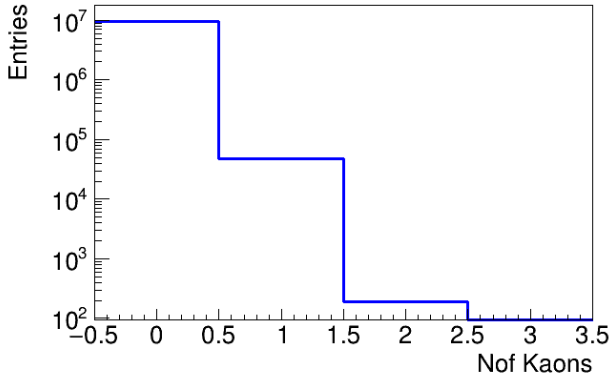
- First moment – doesn't change with the bin size
- Second moment – best agreement for bin size ~ 200





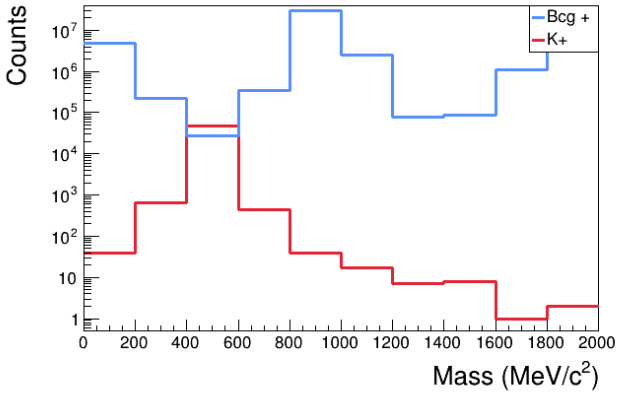
Results for 80 MeV: Moments calculated using mass distribution of signal and background particles

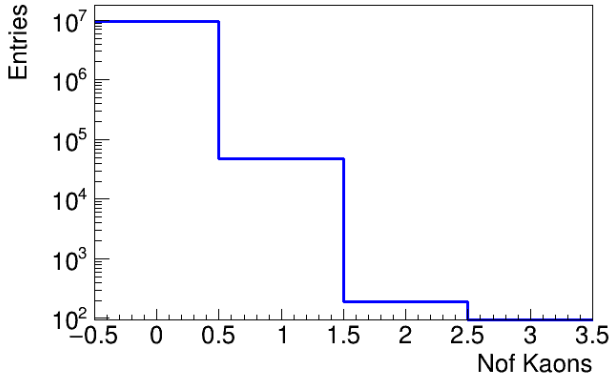




80 MeV mass bins (Best case for Toy Model)	True First Moment	TIdentity First Moment	True Second Moment	TIdentity Second Moment
	0.0050	0.0050	0.0050	0.0052

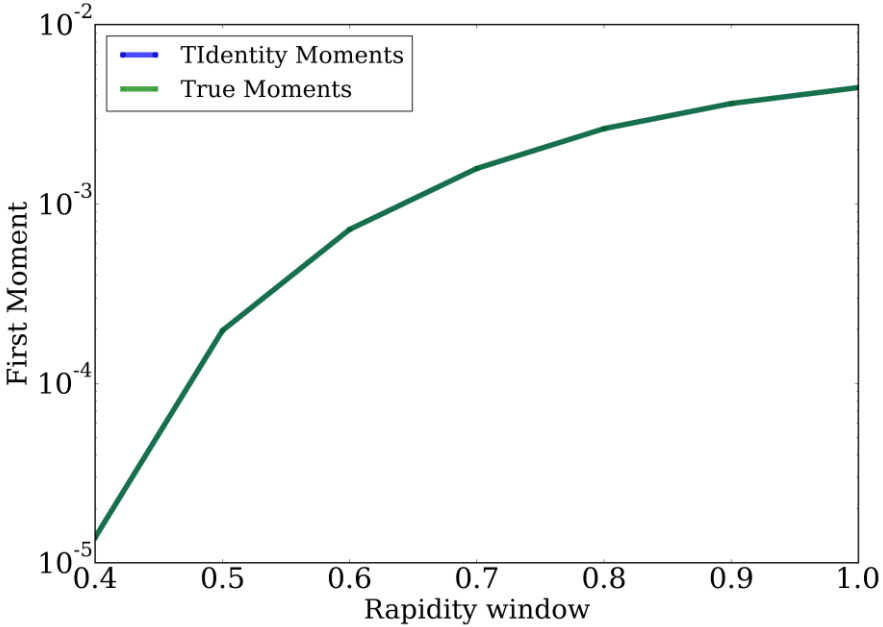
Results for 200 MeV: Moments calculated using mass distribution of signal and background particles

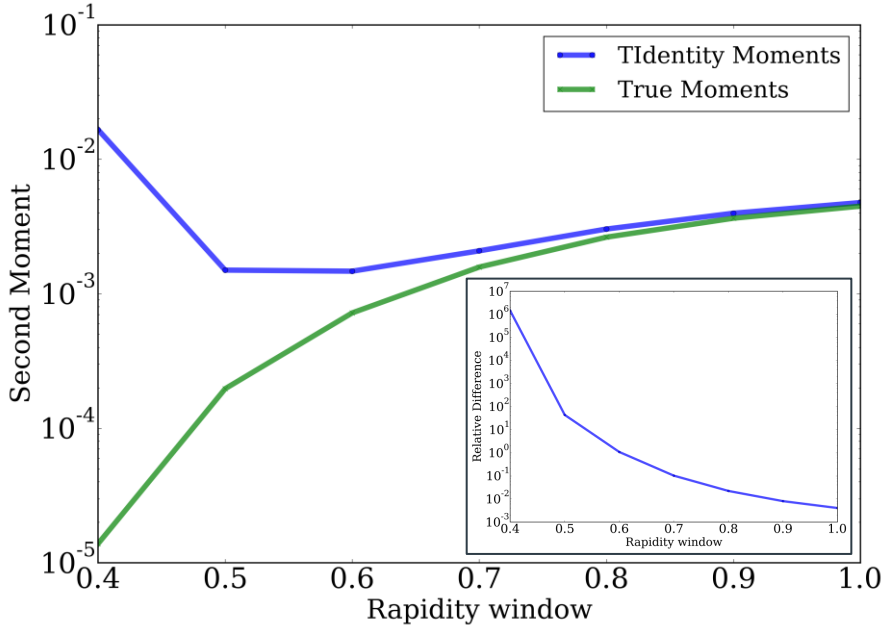




200 MeV mass bins (Best case for Ag+Ag Simulation)	True First Moment	TIdentity First Moment	True Second Moment	TIdentity Second Moment
	0.0050	0.0050	0.0050	0.0051

Rapidity Scan of the moments: True moments vs moments calculated using TIdentity Module





Rapidity Scan of the moments: True moments vs moments calculated using TIdentity Module – Relative Difference for second moment