Hyperon Feasibility Studies for PANDA and PANDA@HADES

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Outline

$\Lambda(1405)$ feasibility study at PANDA

Fall 2021

$\Lambda\Lambda$ feasibility study at HADES

Spring 2022

- Introduction and scopes
- Analysis methodologies
- Relevant results

Project supervisor: Michael Papenbrock

$\Lambda(1405)$ at PANDA

Short feasibility study, fall 2021

Introduction

Relevant for neutron star EoS

- $\Lambda(1405)$, a bound KN-state?

→ determine feasibility for future studies

Scope

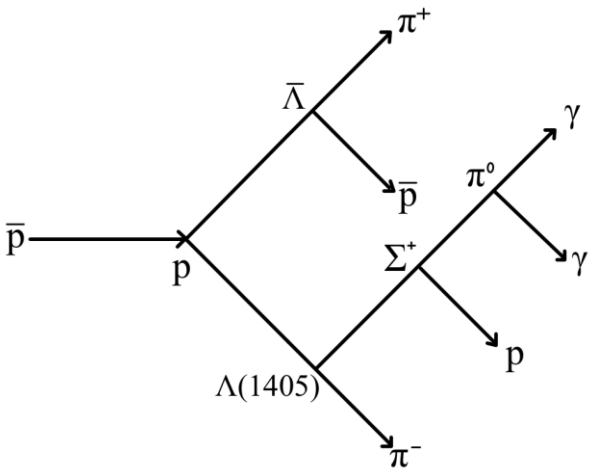
Background:

- Secondary reactions with detector material
- Misidentification background

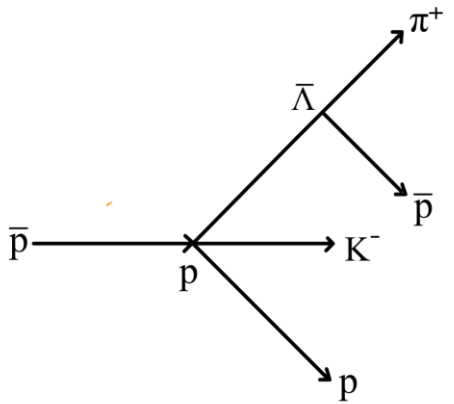
Event selections:

- Exclusive for $p\bar{p} \rightarrow pK\bar{\Lambda}$
- Inclusive for $p\bar{p} \rightarrow \Lambda(1405)\bar{\Lambda}$

$p_{beam} = 2.4\ GeV/c$



$p_{beam} = 2.5\ GeV/c$



Analysis

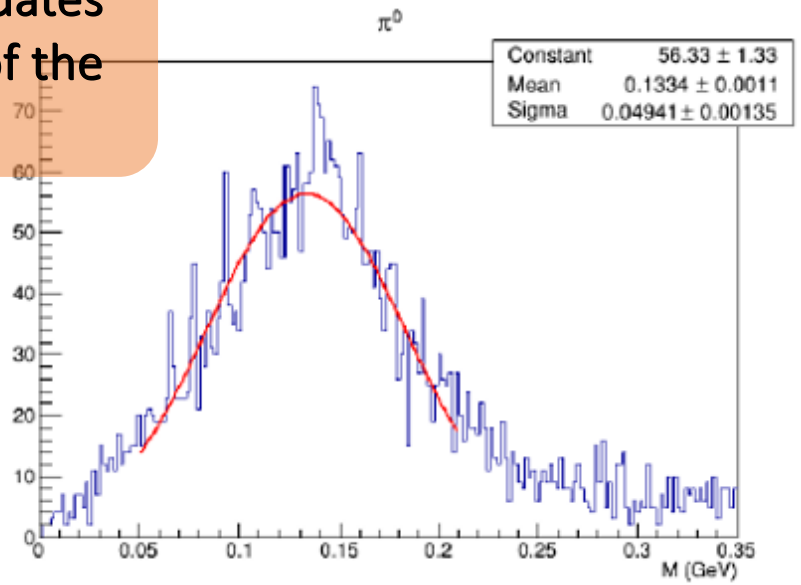
$$p\bar{p} \rightarrow \Lambda(1405)\bar{\Lambda}$$

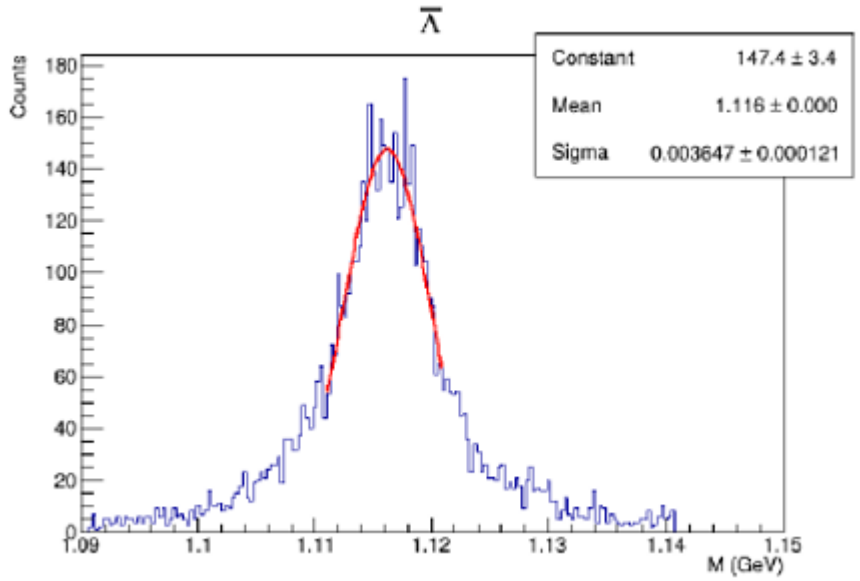
- Reconstructed FS: $p, \bar{p}, \pi^-, \pi^+$
- Invariant mass cut on $\bar{p}\pi^+$ to select $\bar{\Lambda}$ cands.
- Missing mass cut on π^0

$$p\bar{p} \rightarrow pK\bar{\Lambda}$$

- Reconstructed FS: $p, K^-, \bar{p}, \pi^+$
- Invariant mass cut on $\bar{p}\pi^+$ to select $\bar{\Lambda}$ cands.

Only candidates within 3σ of the mean





Reconstruction Efficiency

- Exclusive reconstruction: Number of times the whole reaction was reconstructed

- Inclusive reconstruction: Number of times that:
  - All of the charged final state particles were detected
  - The missing mass survived the π^0 mass cut
  - Reconstructed $\overline{\Lambda}$ survived the invariant mass cut

34.9%

$p\bar{p} \rightarrow \mathrm{p}K^-\overline{\Lambda}$ exclusive reconstruction efficiency

29.7%

$p\bar{p} \rightarrow \Lambda(1405)\overline{\Lambda}$ inclusive reconstruction efficiency

$\Lambda\Lambda$ at HADES

Master thesis project, spring 2022

Introduction

- Kinematic fitter benchmarked with promising results for single hyperon reconstruction
- How well will it perform for hyperon pairs?

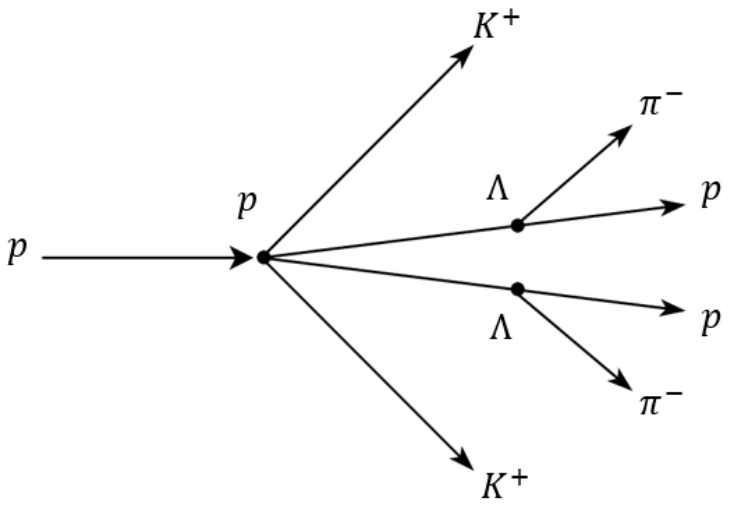
- $\rightarrow$ Perform a simulation study on $pp \rightarrow \Lambda\Lambda K^+K^+$ to determine the $\Lambda\Lambda$ reconstruciton efficiency using the kinematic fitter for femtoscopy applications

Scope

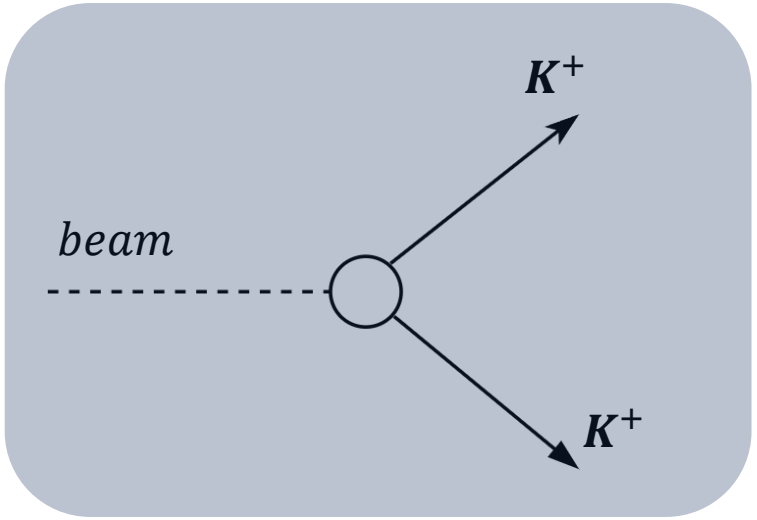
Background:

- Secondary reactions with detector material
- Misidentification background
- Combinatorial background

- Three event selections:
  - $p\pi^-p\pi^- + X$
  - $p\pi^-p\pi^-K^+ + X$
  - $p\pi^-p\pi^-K^+K^+$



The KinFit Library

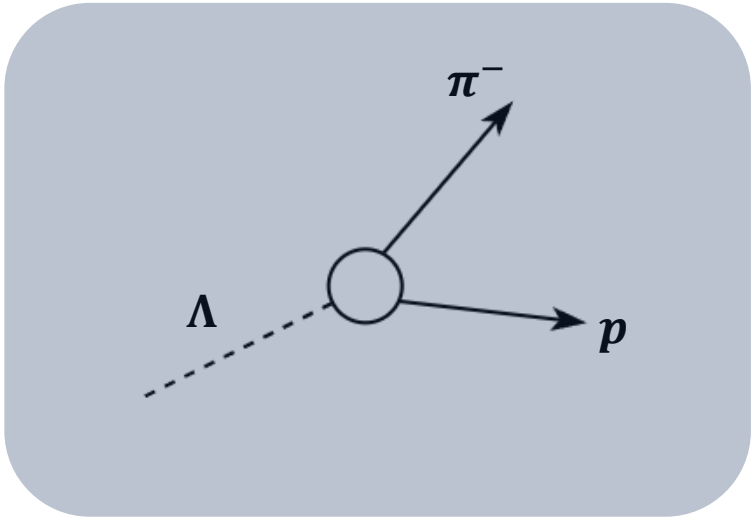


Vertex Finder

- Two charged particle tracks utilized to find a vertex
- Used to identify the primary and the decay vertex

Kinematic Fit

- Utilizes the Lagrange Multiplier Method to optimize the reconstructed $p\pi^-$ momentum under:
  - Geometric constraints, the primary and decay vertexes
  - Kinematic constraints, the conservation of momentum and energy

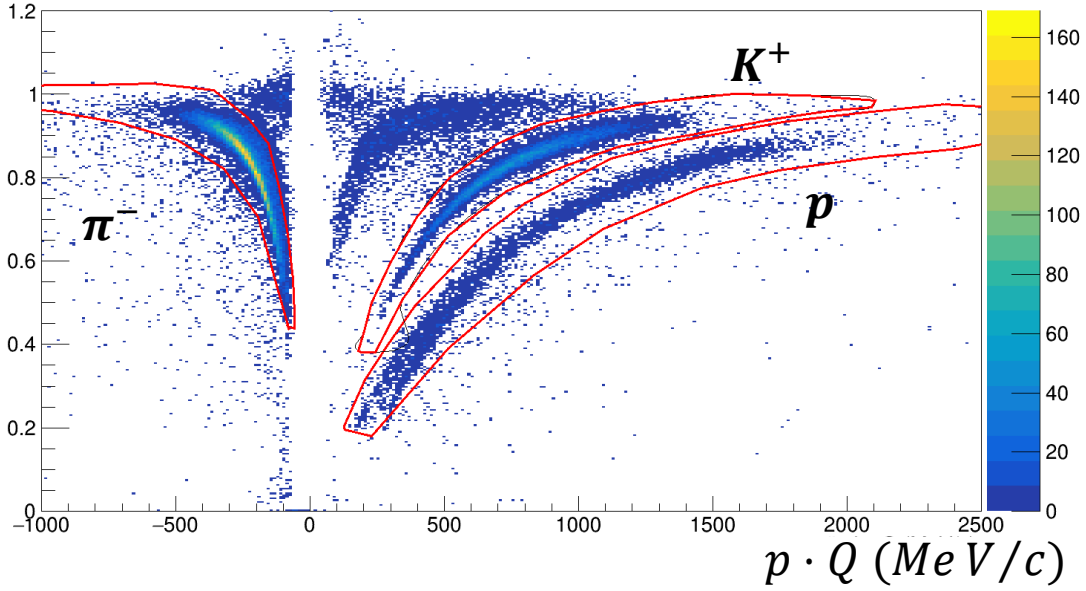


Analysis

- Lower estimate of expected events from beam time
  - $\sigma = 0.35\ \mu b$ [1]
  - $L = 5.4\ pb^{-1}$ [2]

→ $1.8 \cdot 10^6\ pp \rightarrow \Lambda\Lambda K^+K^+$ events

- PID from main detector
- Proton hypothesis for all forward detector candidates



[1] *HADES and PANDA@HADES collaborations, Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR, The European Physics Journal, 2021*

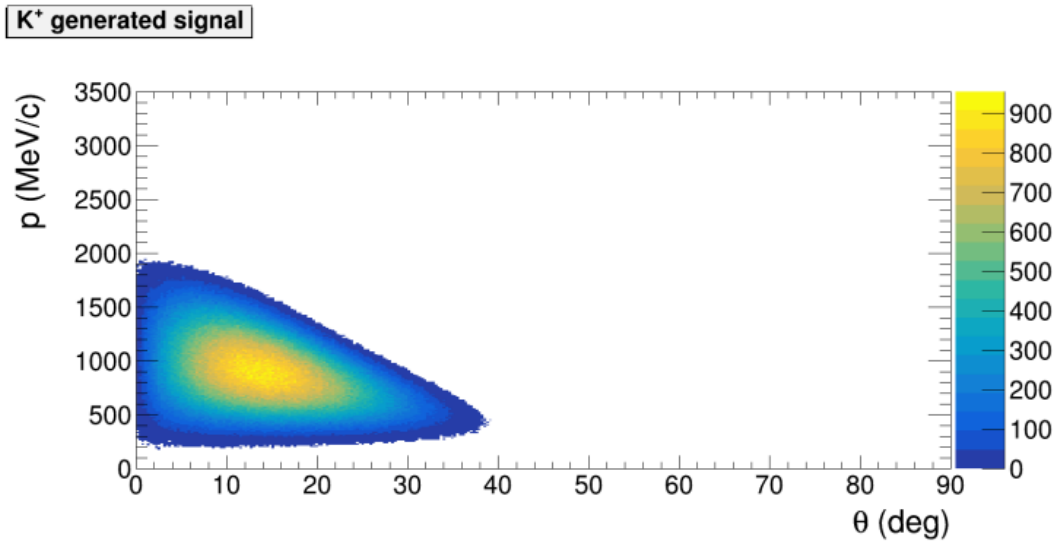
[2] *Based on Jana Rieger's estimates from pp elastic scattering*

Analysis

- $2.25 \cdot 10^6$ $\Lambda \to p\pi^-$ events
- Expected efficiency for first inclusive channel [3]

- K^+ most often emitted outside of main detector acceptance
- Limits the reconstruction efficiensy

Selection	Condition	Events	η (%)
$pp \to X$	none	1 800 000	100
$pp \to p\pi^- p\pi^- + X$	at least $2p$ and $2\pi^-$	9 727	0.54
$pp \to p\pi^- p\pi^- K^+ + X$	at least $2p$, $2\pi^-$ and $1K^+$	2 580	0.14
$pp \to p\pi^- p\pi^- K^+ K^+$	at least $2p$, $2\pi^-$ and $2K^+$	349	0.02

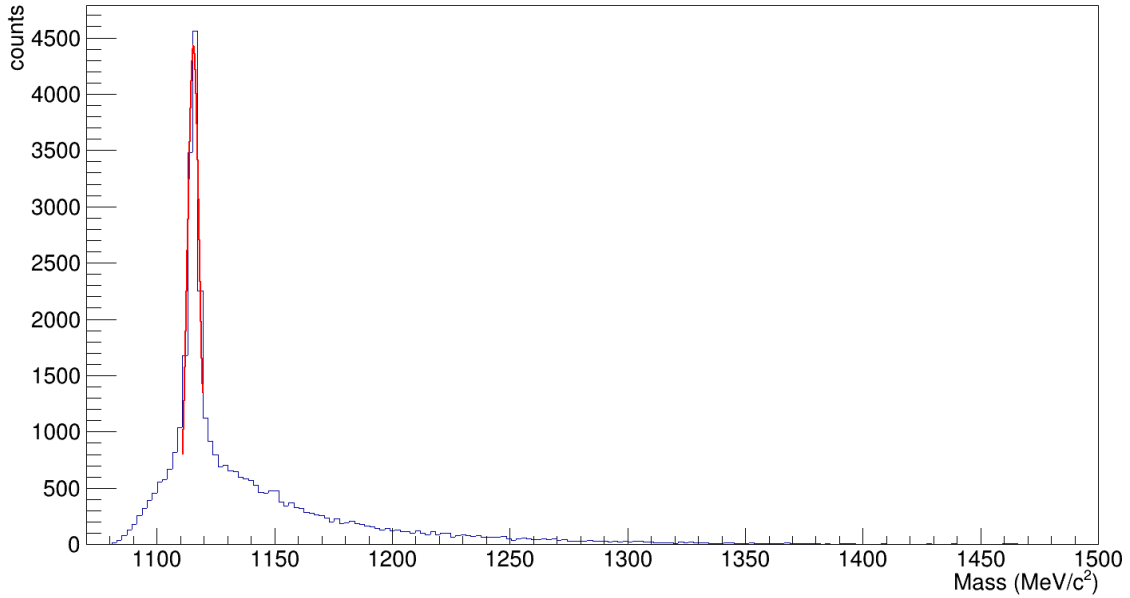


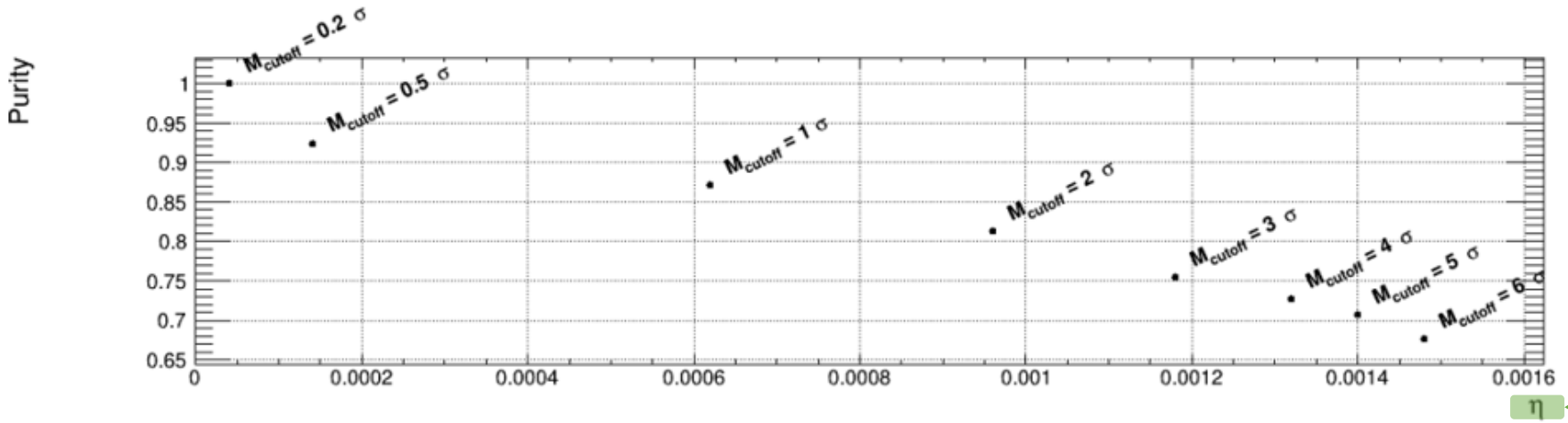
[3] *Jenny Regina, Time for Hyperons. Phd thesis, 2021*

Analysis

Mass cut: proceed only with $p\pi^-$ of invariant mass within 3σ of the Λ mass

$p\pi^-$ invariant mass distribution





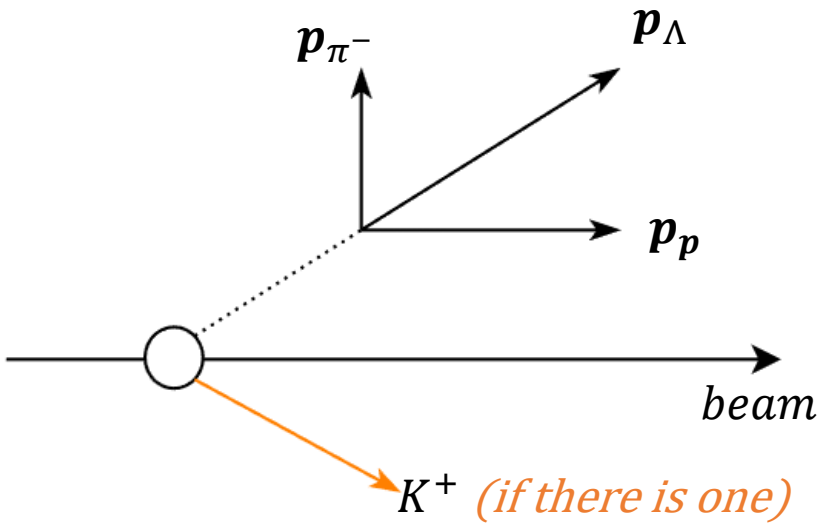
Reconstruction efficiency

Analysis

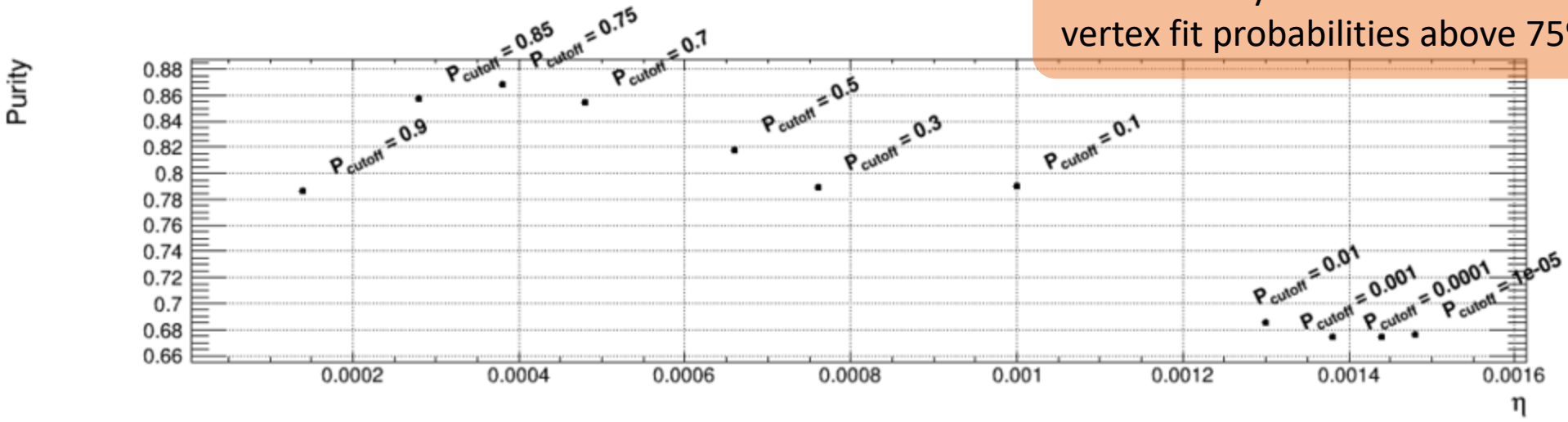
Estimate the primary vertex

- Primary vertex approximated as point-of-closest approach between the Λ- candidate and the beam-axis
- If there is one K^+, this track is included
- If there are two $2K^+$, use the KinFit vertex finder

Perform fitting



Probability cut: Proceed with vertex fit probabilities above 75%



Results

$1.8 \cdot 10^6 \quad pp \to \Lambda\Lambda K^+K^+$
$2.25 \cdot 10^6 \quad \Lambda \to p\pi^-$

Number of reconstructions close to expected[1] lower limit from beam time (1302)

Very few K^+ emitted into main detector acceptance

Λ	Gen. Signal (prim)	Gen. (prim + sec)	Reconstructed	True	Purity (%)	η (‰)
$pp \to p\pi^-p\pi^- + X$	19 454	19 769	1 404	1 094	77.9	0.78
$pp \to p\pi^-p\pi^-K^+ + X$	5 160	5246	68	59	86.8	0.04
$pp \to p\pi^-p\pi^-K^+K^+$	698	709	54	47	87.0	0.03

Significantly affected by $p\pi^-$ combinatorial background

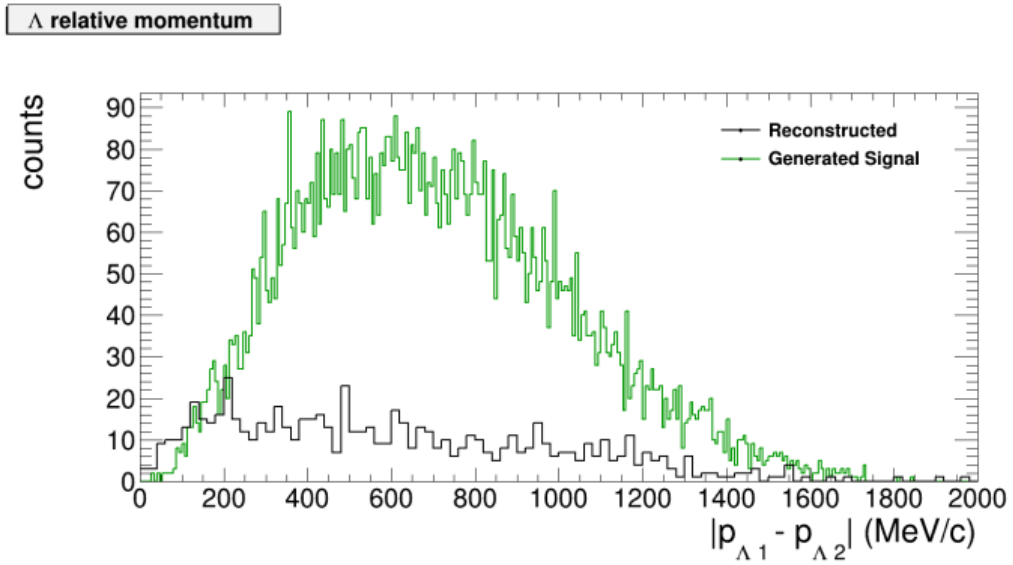
[1]*HADES and PANDA@HADES collaborations, Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR, The European Physics Journal, 2021*

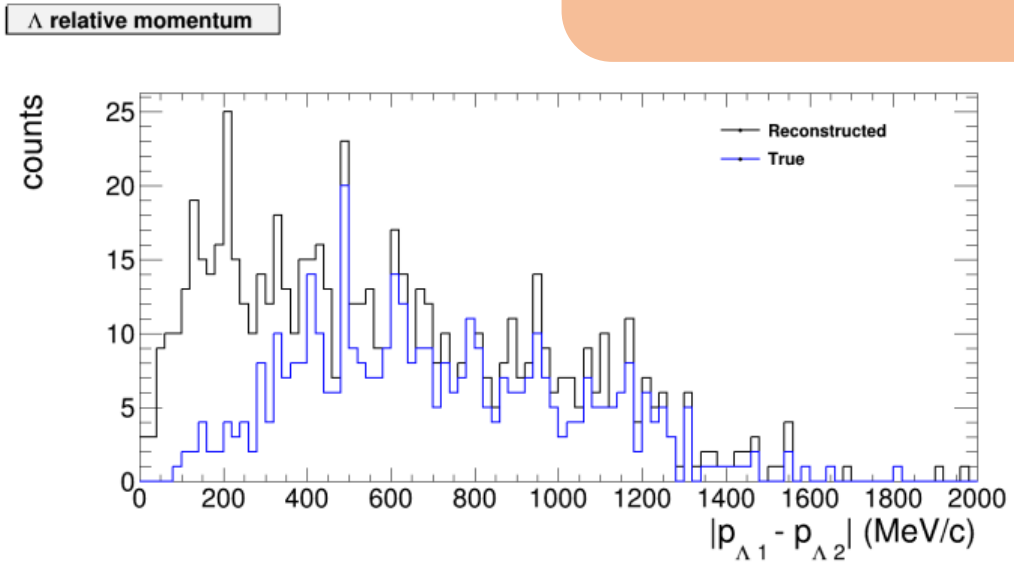
Results

Overall, around 80 %

$\Lambda\Lambda$ $q < 200\mathrm{MeV/c}$	Reconstructed	True	Purity (%)
$pp \to p\pi^- p\pi^- + X$	112	13	11.6
$pp \to p\pi^- p\pi^- + X$, $d > 30$ mm	52	9	17.3
$pp \to p\pi^- p\pi^- K^+ + X$	3	0	0
$pp \to p\pi^- p\pi^- K^+ K^+$	3	0	0

False Λ reconstructions more common in the low relative momentum region

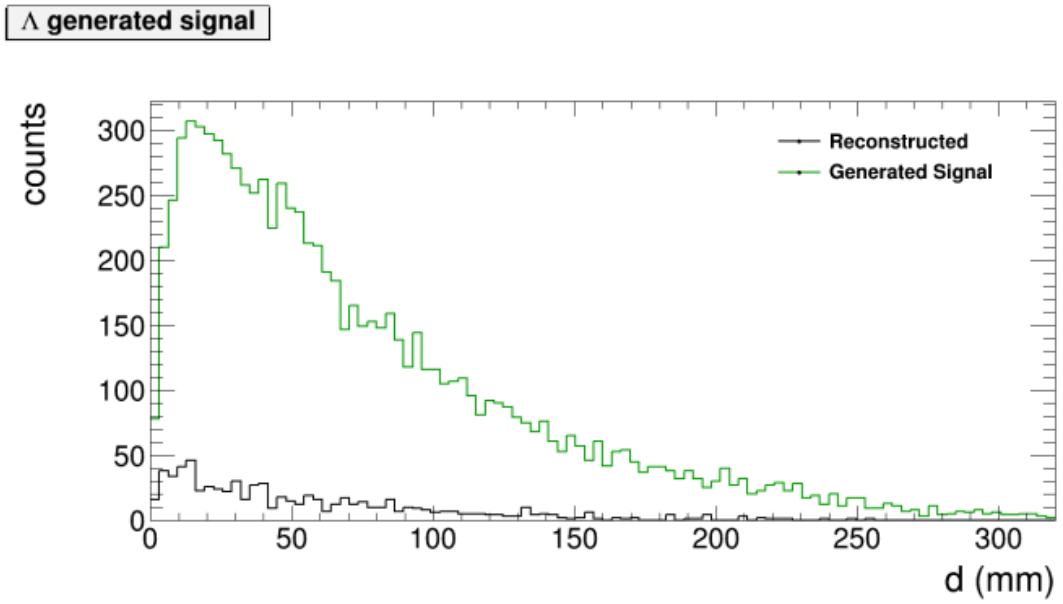


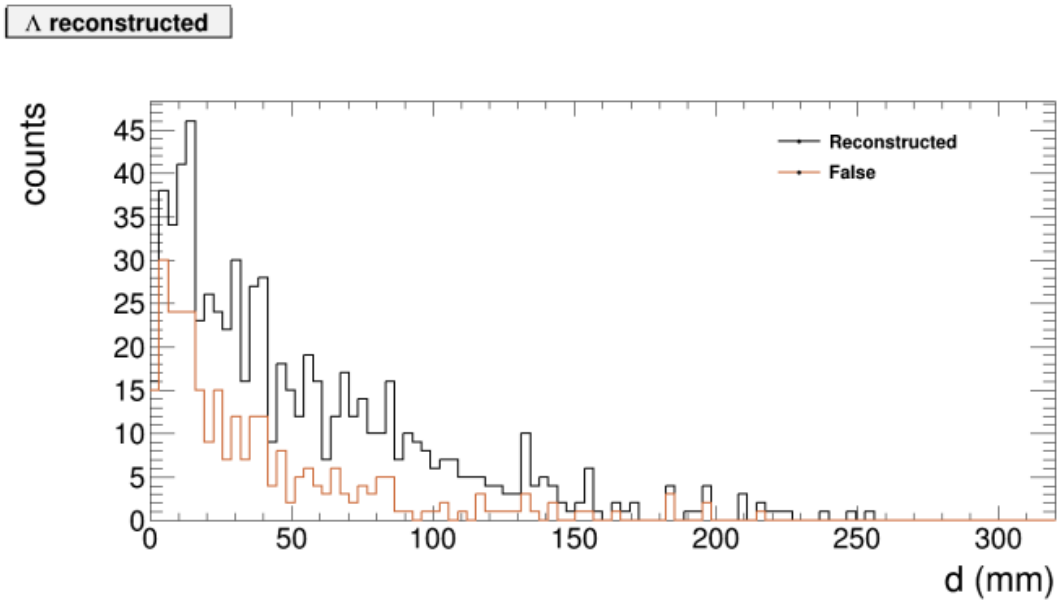


Distribution of $\Lambda\Lambda$ relative momentum. Relevant region for Femtoscopy studies is $< 200\ MeV/c$

Results

Higher concentration of false Λ reconstructions at small decay vertex distance





Distribution of the $\Lambda -$ pair decay vertex distance d

Summary

- Objective: determine the reconstruction efficiency for $\Lambda\Lambda$ using the KinFit library for femtoscopy applications
- First look into fitter performance on more complicated reaction topologies
- Reconstruction efficiency limited by K^+ emitted outside of the main detector acceptance
- Reconstruction purity improved when at least one K^+ was used in vertex estimate
- Identified the low relative momentum region as challenging due to combinatoric background

Analysis of this channel is being continued by Gandharva Appagere, Stockholm University

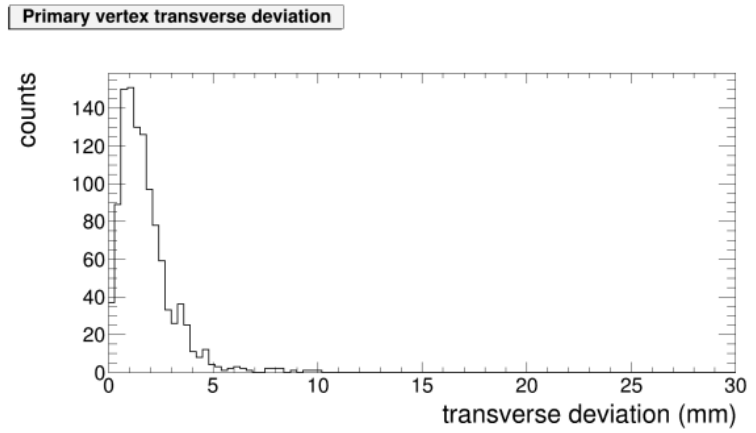
Thank you!

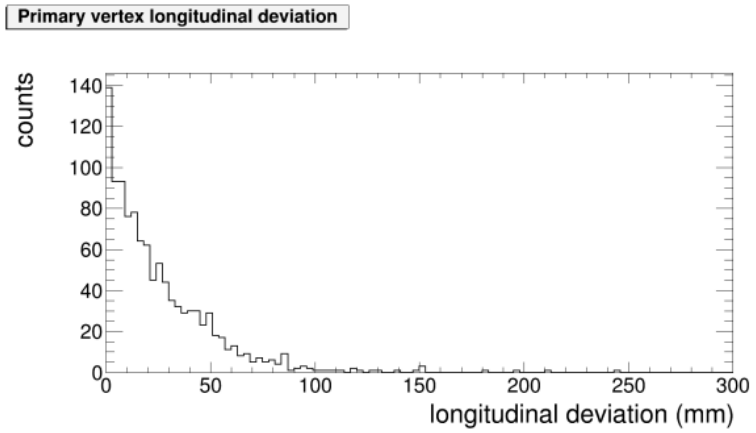
Find my thesis at: https://uu.diva-portal.org/smash/record.jsf?pid=diva2:1678990

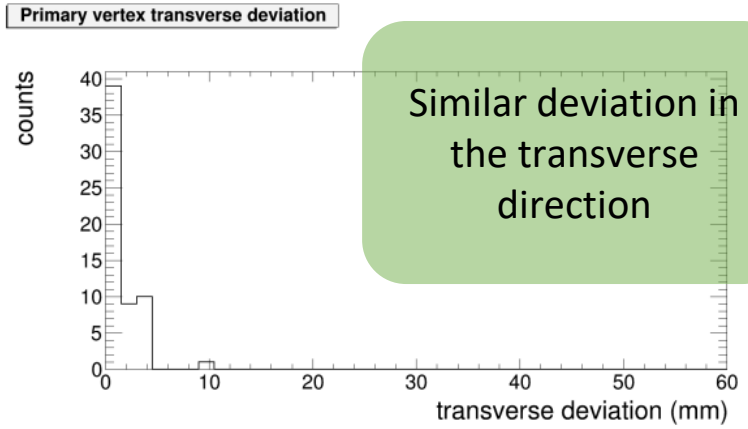
$p\pi^-p\pi^- + X$

$p\pi^-p\pi^-K^+ + X$

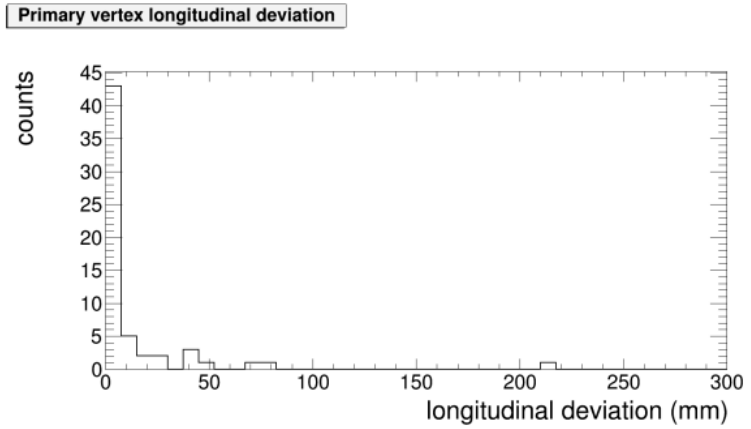
$p\pi^-p\pi^-K^+K^+$

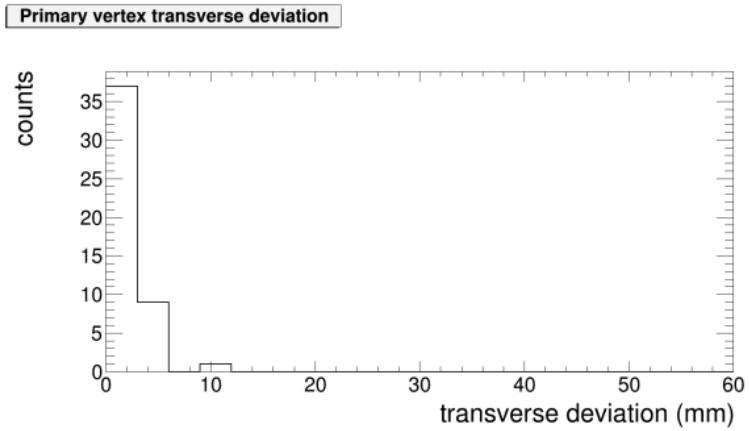


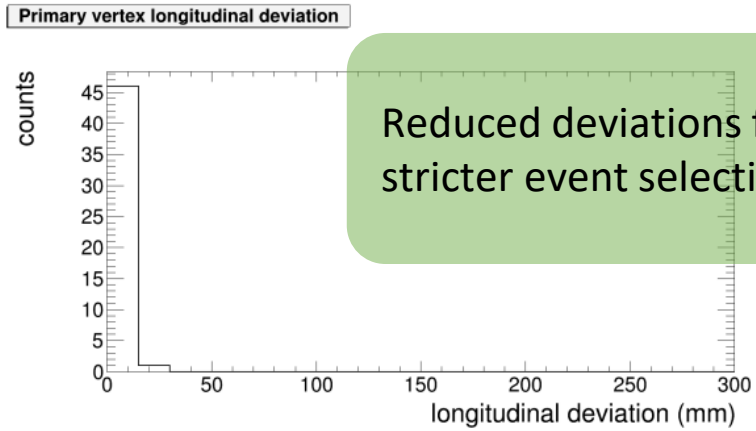




Similar deviation in the transverse direction





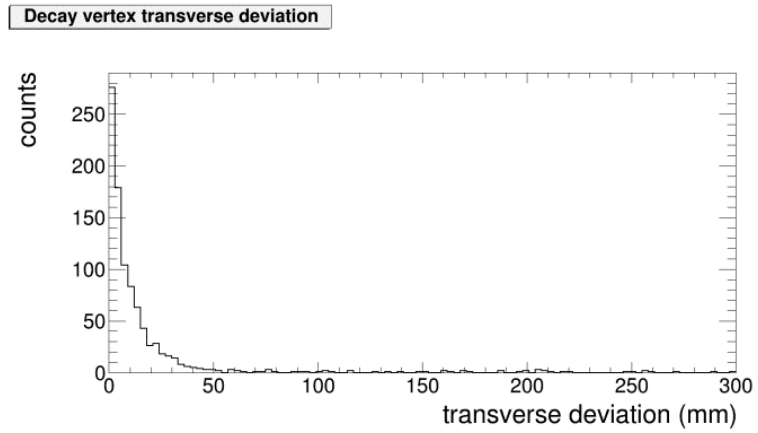


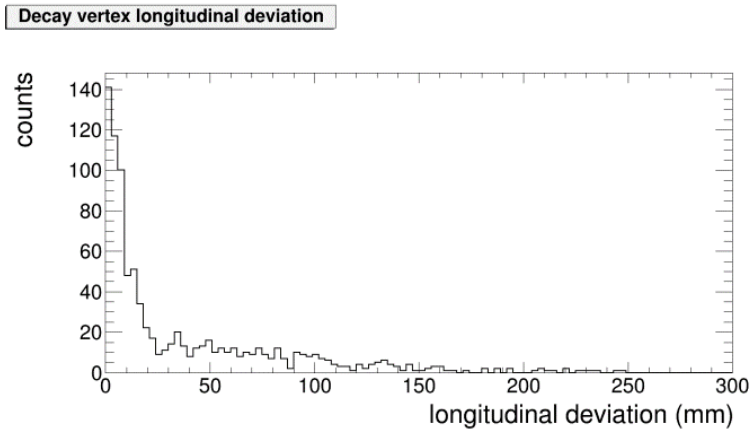
Reduced deviations for stricter event selection

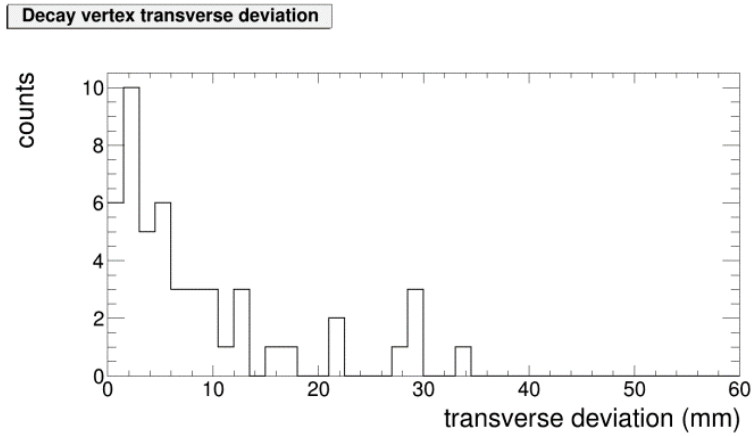
$p\pi^-p\pi^- + X$

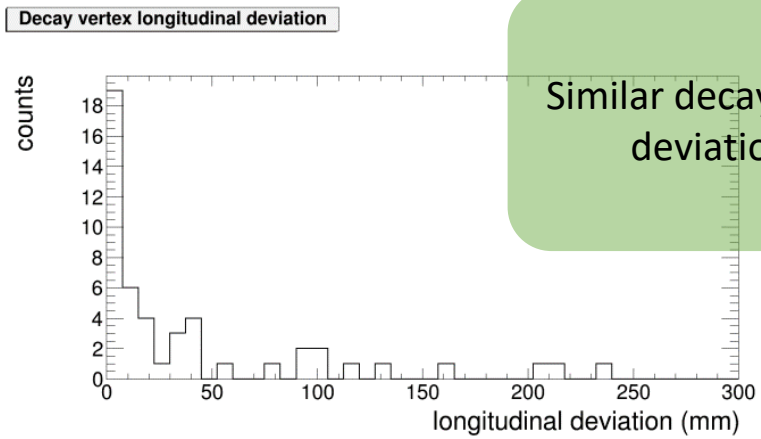
$p\pi^-p\pi^-K^+ + X$

$p\pi^-p\pi^-K^+K^+$

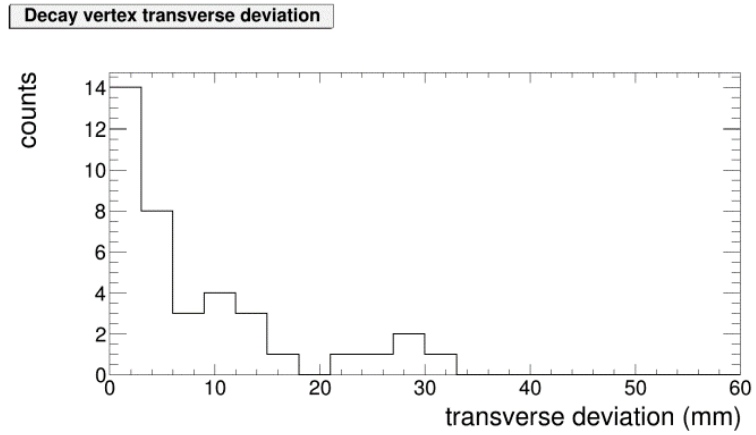


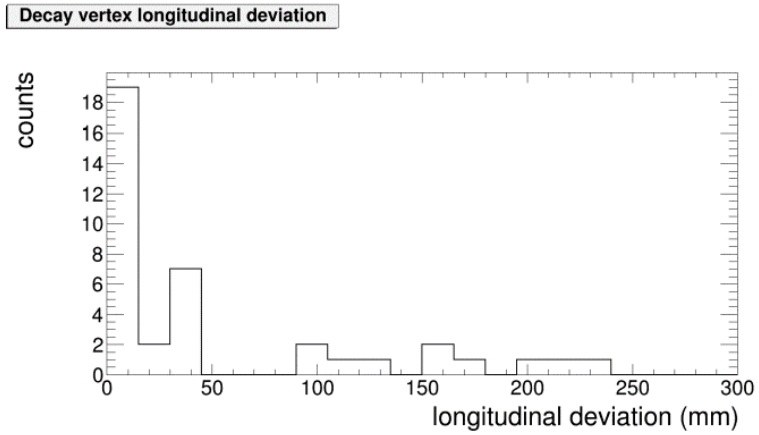






Similar decay vertex deviations





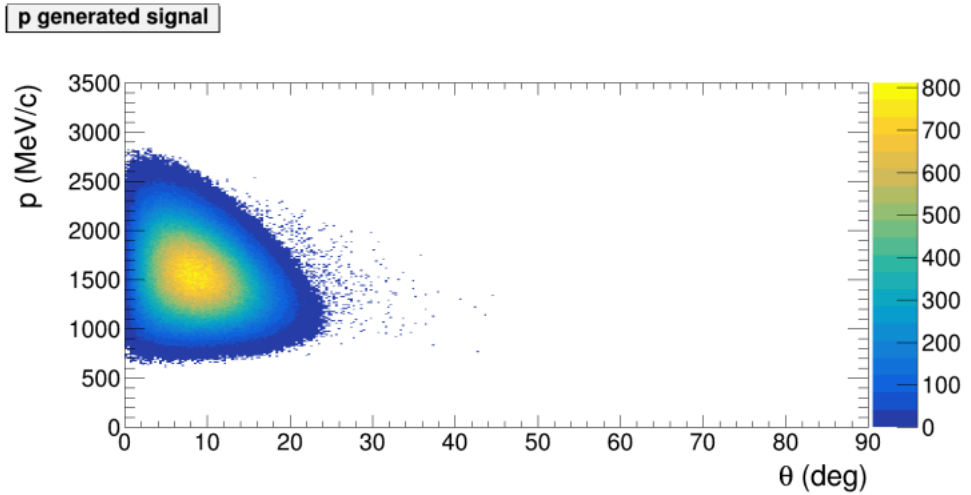
Analysis: Where are the protons?

Reconstructed protons

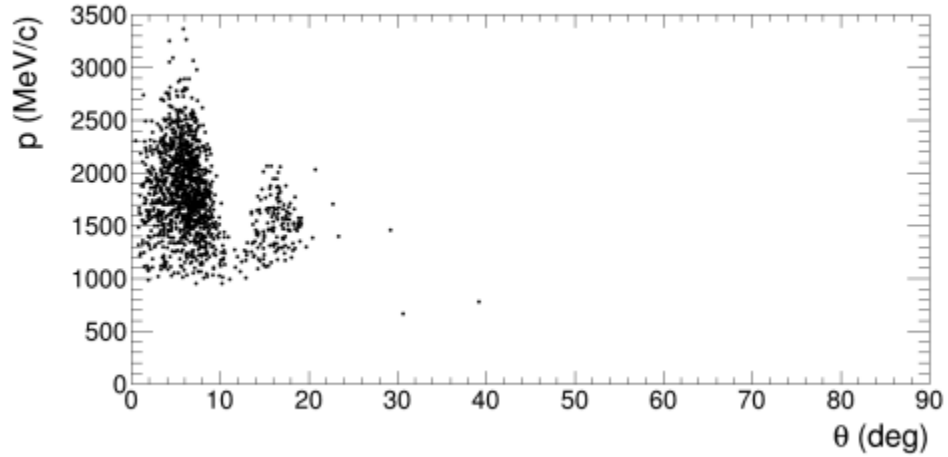
$pp \to X$	Reconstructed	True	Purity (%)	η (%)
Main	136 752	82 161	60.0	6.07
FwDet	1 113 848	593 428	48.4	49.4
$pp \to p\pi^-p\pi^- + X$				
Main	2 861	1 477	51.6	0.13
FwDet	18 036	11 465	63.5	0.80
$pp \to p\pi^-p\pi^-K^+ + X$				
Main	638	238	37.3	0.02
FwDet	4 790	3 524	73.6	0.21
$pp \to p\pi^-p\pi^-K^+K^+$				
Main	89	35	39.3	3.6e-3
FwDet	638	506	79.3	0.03

True = p from Λ decay, η = reconstruction efficiansy

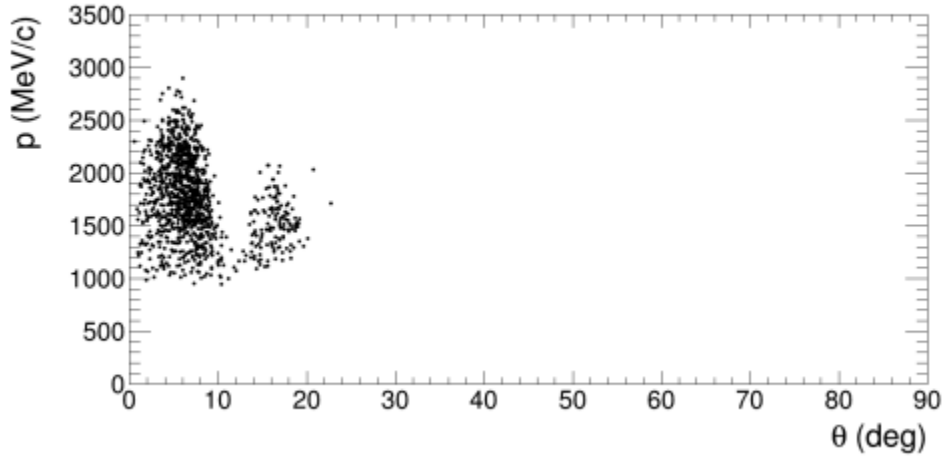
- Much higher reconstruction efficiensy in FwDet
- Stricter event selection increases FwDet purity
- Less secondary background



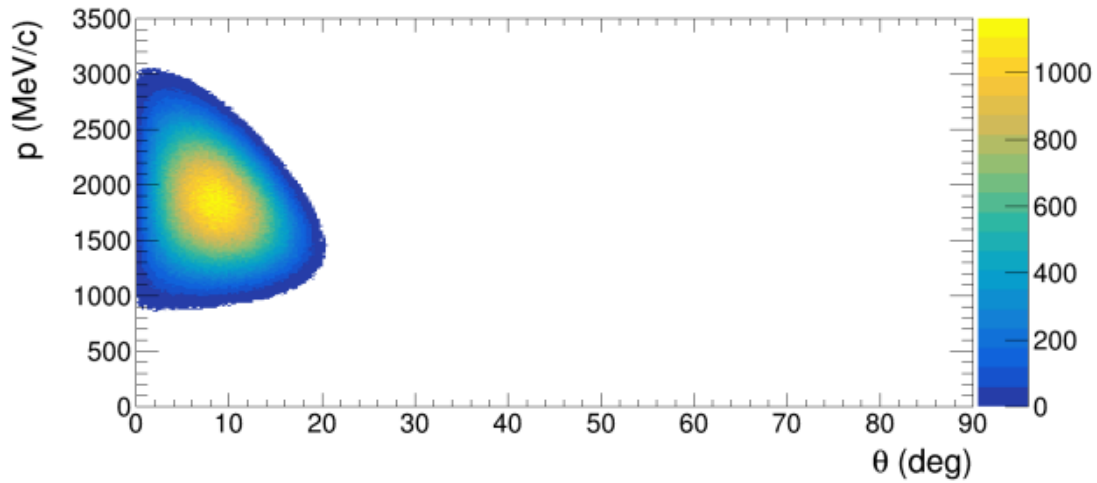
Λ



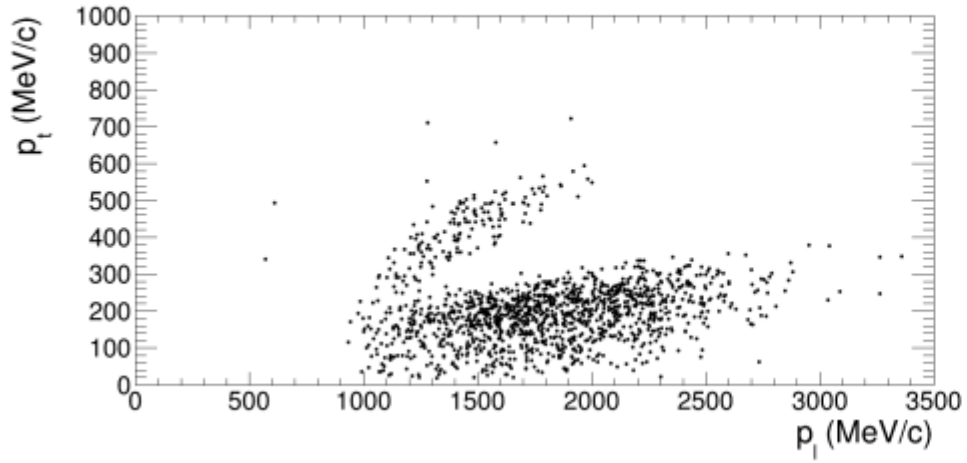
Λ true reconstruction



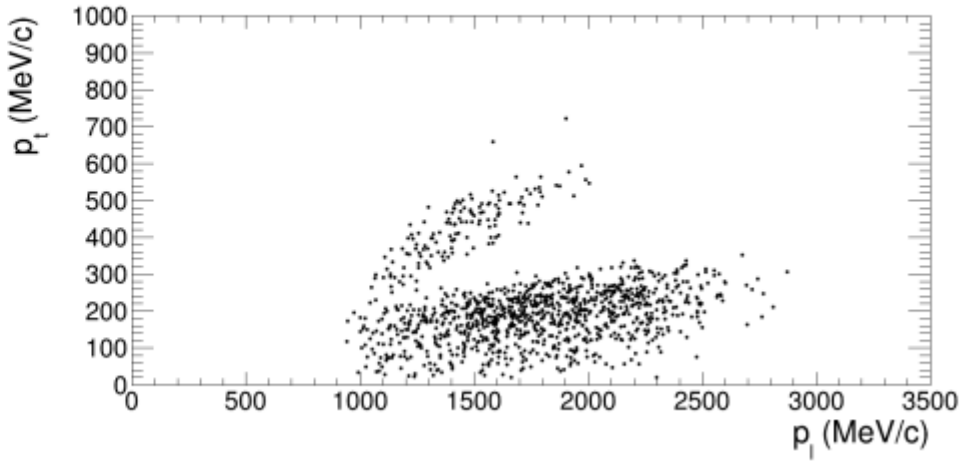
Λ generated signal



Λ



Λ true reconstructions



Λ generated signal