Σ^0 PRODUCTION IN P-P COLLISION AT $\sqrt{S}$ = 3.18 GEV

Hades Collaboration Meeting

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Forschungszentrum Jülich

An overview

Motivation

- Focus on exclusive reaction of $p + p \rightarrow p + K^{+} + \Sigma^{0}$
- Results on Σ^{0} are rare compared to Λ
- A step towards measuring radiative and Dalitz decays of excited state hyperons

Dataset

- Proton beam ($E_{kinetic}$ = 3.5 GeV) on Liquid hydrogen target
- 1.2×10^{9} LVL1 recorded events

Analysis summary

Signal reconstruction

1. Time of Flight reconstruction
2. Deep Learning Based PID
3. Primary vertex reconstruction (POCA pK^+) $-65 < z[mm] < -15$ and $r[mm] < 5$
4. **HADES dataset**: Lambda Reconstruction **AND** $MM^2(p\Lambda)[GeV^2] > 0.2$
5. **FWall dataset**: $MM^2(p\Lambda)[GeV^2] > 0.2$ **AND** $-0.02 < MM^2(pK^+\Lambda)[GeV^2] < 0.02$ **AND** Lambda Reconstruction
6. Kinematic Refit

Time of Flight Reconstruction 1

Procedure

- **HADES setup was not equipped with a start detector**
- One particle at least has to be identified
- Negatively charged tracks are used to reconstruct the start time t_0
- If the track is not geometrically correlated to a ring in the RICH detector, it is assumed to be a π^-, otherwise it is assumed to be an e^-
- The start time t_0 for each event is calculated as the difference between the theoretical value and measured value.
- If more than one particle is used, then the start time is:

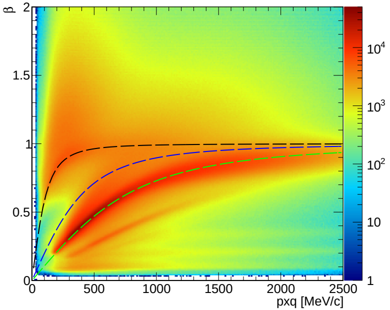
$$t_0 = \frac{\sum_i w_i \cdot t_{0,i}}{\sum_i w_i}$$

where w_i = 2.5 for ToF or w_i = 1 for ToFino systems

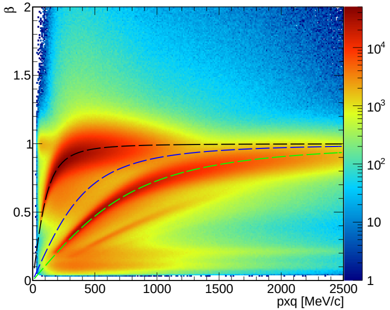
Time of Flight Reconstruction 2

- β spectrum for all positive charged tracks $q = 1$

Default t_0

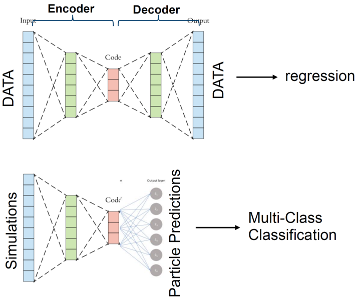


Reconstructed t_0



Particle Identification PID

- A semi-supervised learning on Data and simulation simultaneously
- A neural network in a form of an **Autoencoder**
- Two output layers **regression** + **classification**
- Input features: **momentum components**, **time of flight** and **energy loss**
- Three output nodes corresponding to p, K^+ and π^+
- Classification accuracy of 98%, 78% and 92% for p, K^+ and π^+ respectively
- A β cut is applied: $0.5 < \beta < 1.2$

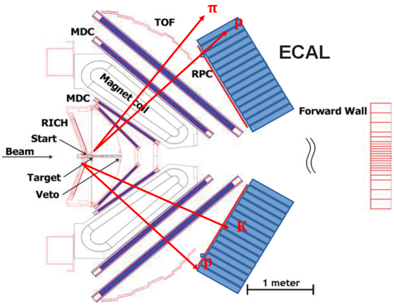


Signal Reconstruction

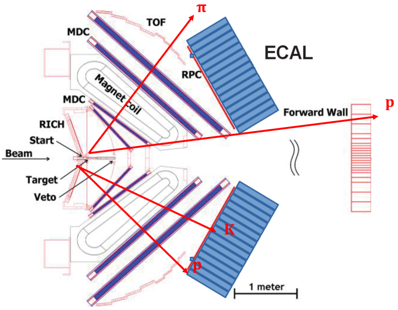
Datasets

- **HADES**: Require 2p, 1K^+ and 1π^- within HADES acceptance
- **FWall**: Require 1p, 1K^+ and 1π^- within HADES acceptance in addition to at least 1 hit in the FWall

HADES Dataset



Foward Wall Dataset

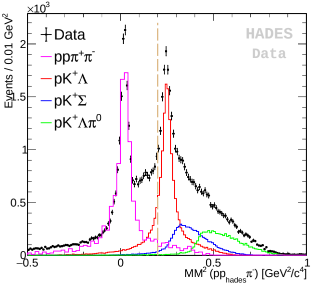


HADES Dataset 1

- Define the primary vertex as the POCA of pK^+
- primary vertex longitudinal location cut $-65 < z[mm] < -15$
- primary vertex transverse location cut $r[mm] < 5$

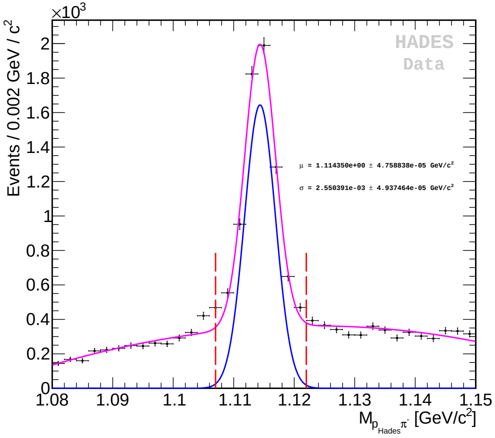
Lambda Selection

- $MTD(p, \pi^-) < 10mm$
- $d_{p,pvtx} < d_{\pi^-,pvtx}$
- $d_{\Lambda,pvtx} < 10mm$
- $MM^2(p\Lambda) > 0.2[GeV^2]$



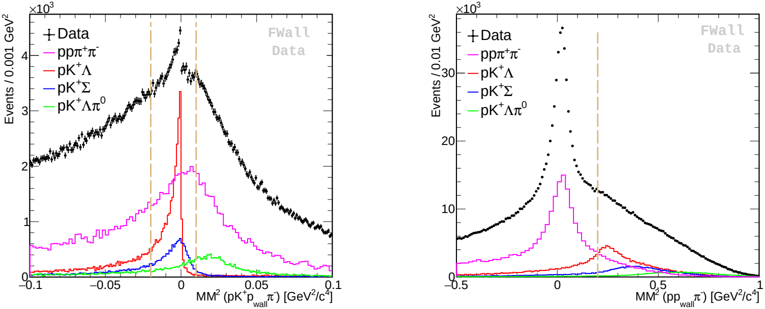
HADES Dataset 2

- Peak fitted with a Gauss and the background with a 3th order Polynomial
- 3σ mass window is applied



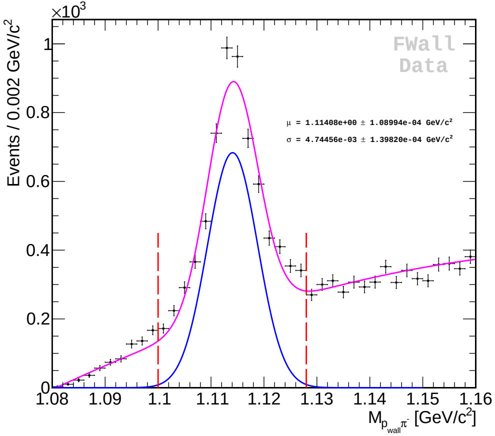
FWall Dataset 1

- $-0.02 < MM^2(pK^+p_{wall}\pi^-)[GeV^2] < 0.01$
- $MM^2(pp_{wall}\pi^-)[GeV^2] > 0.2$



FWall Dataset 2

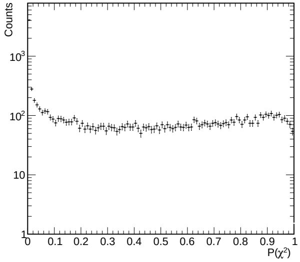
- Peak fitted with a Gauss and the background with a 3th order Polynomial
- Higher width compared to HADES dataset
- 3σ mass window is applied



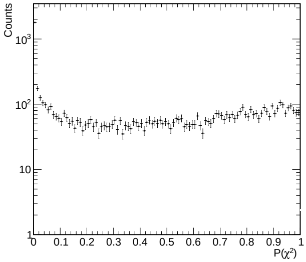
Kinematic Refit

$$f = \begin{pmatrix} (E_{p_s} + E_\pi)^2 - (P_{p_s} + P_\pi)_x^2 - (P_{p_s} + P_\pi)_y^2 - (P_{p_s} + P_\pi)_z^2 - M_\Lambda^2 \\ (E_t + E_b - \sum_{i=1}^{4} E_i)^2 - (\vec{p}_t + \vec{p}_b - \sum_{i=1}^{4n} \vec{p}_i)^2 - M_\gamma^2 \end{pmatrix} = 0$$

HADES



FWall



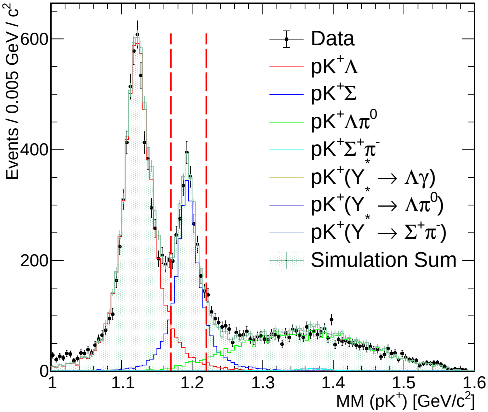
- Apply 1% confidence level cut on both data sets

Final Spectrum 1

- A list of background channels have been simulated
  - $pK^+\Sigma$ (signal channel)
  - $pK^+\Lambda$
  - $pK^+\Lambda\pi^0$ - $pK^+\Sigma\pi^0$
  - $pK^+\Sigma^+\pi^-$
  - pK^+Y^*
- Simulations are scaled to match the data bin by bin, matching is quantified by χ^2 minimization:

$$\chi^2 = \sum_{bin} \left(\frac{n_{data} - (f^{ch} \times n^{ch}_{simulation})}{\sigma_{data} + \sigma_{simulation}} \right)^2$$

Final Spectrum 2



- A mass window $1.170 < MM(pK^+)[GeV/c^2] < 1.220$ is applied to select Sigma Like events with purity of 95%

Acceptance and Efficiency Correction 1

Correction Procedure

Data correction is based on solving the Fredholm Integral equation.

$$M(x) = \int R(x, x')T(x')dx'$$

where

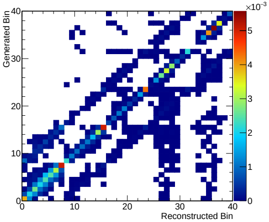
- $M(x)$ is the measured distribution (detector level data)
- $T(x)$ is the true distribution (stable particle level)
- $R(x, x')$ is the response function (response matrix)

- The response matrix is built using 2 independent variables $cos\theta_{cms}$ and P_{cms}
- The response matrix is inverted using Singular Value Decomposition (SVD)

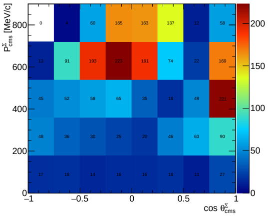
Acceptance and Efficiency Correction 2: $cos\theta_{\Sigma}^{cms}$ case

- $P_{\Sigma}^{cms} \times cos\theta_{\Sigma}^{cms}$ = 5 $\times$ 8 bins = 40 phase space bins
- Implantation in **RooUnfold** package

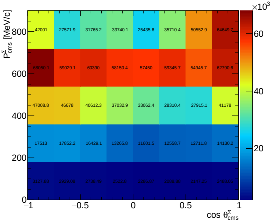
response



uncorrected



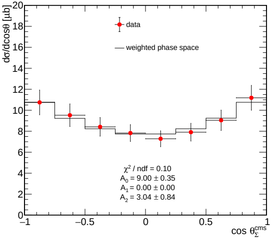
corrected

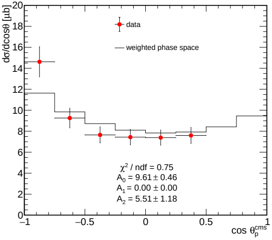


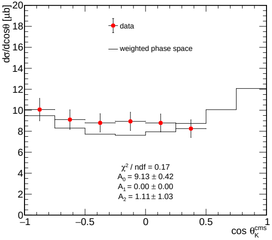
Unfolding algorithms and tests using RooUnfold, Tim Adye, arXiv:1105.1160, 2011

Angular Distributions: CMS Frames

- **Isotropic simulations are weighted by $cos\theta_{\Sigma}^{cms}$ and the Jackson angle in $p\Sigma$ rest frame to match the data**

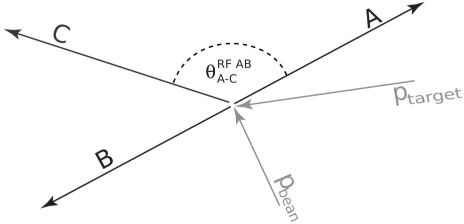






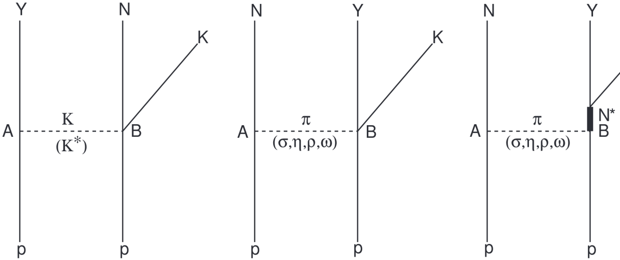
Helicity Angle Definition

- The angle between the particles A and B in the Helicity frame (rest frame) of the particles B and C
- The helicity angle distribution is a special projection of the Dalitz plot



Gottfried Jackson Angle Definition

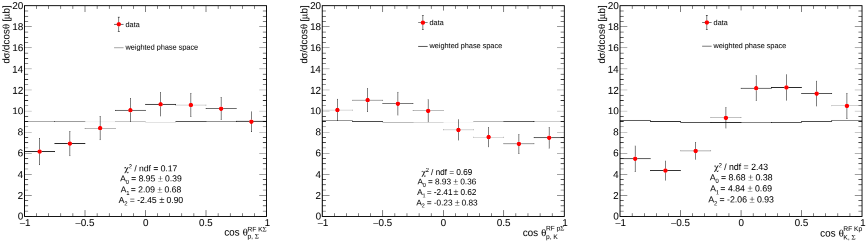
- Similar to the Helicity angle, also defined in the rest frame of two of the three particles
- Angle is defined as the angle between one of the rest frame particles and the initial proton
- In case of strange/non-strange meson exchange, the Jackson frame is equivalent to the rest frame of the exchanged meson



Production of Λ and Σ^0 hyperons in proton-proton collisions. COSY-TOF Collaboration, Eur.Phys.J.A46:27-44, 2010.

Angular Distributions: Helicity Frames 1

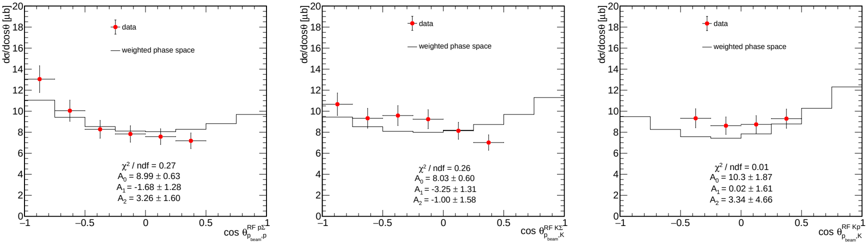
- Phase space simulations is used for the correction



- Phase space simulations can not be used to describe Helicity angular distributions

Angular Distributions: Jackson Frames 1

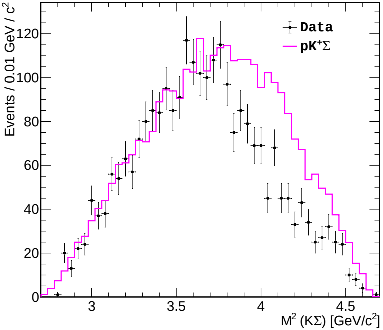
- **Phase space simulations is used for the correction**



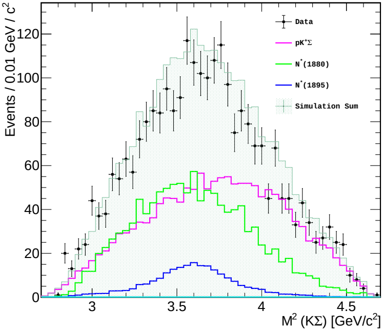
Tuning the Simulation Model 1

- A comparison between pure phase space and **phase space plus** N^* **intermediate resonances** using $M(K^+\Sigma^0)$ Dalitz variable

$\chi^2/ndf \approx 3.7$



$\chi^2/ndf \approx 1$



Tuning the Simulation Model 2

Simulation Model

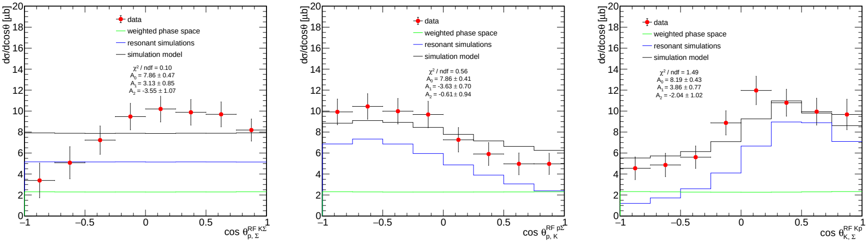
1. $p + p \rightarrow p + K^{+} + \Sigma$ 22.5%
2. $p + p \rightarrow p + (N^{*} \rightarrow K^{+} + \Sigma)$ 77.4%

N^{*} parameters taken from the PDG

Resonance	Mass - Width	J^P	BR (ΣK)	contribution
N(1875)	1875 - 200	$\frac{3}{2}^{-1}$	seen	0.0%
N(1880)	1880 - 300	$\frac{1}{2}^{1}$	10-24%	66.6%
N(1895)	1895 - 120	$\frac{1}{2}^{-1}$	6-20%	10.8 %
N(1900)	1920 - 200	$\frac{3}{2}^{1}$	3-7%	0.0 %

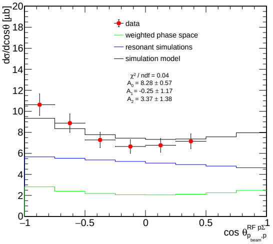
Angular Distributions: Helicity Frames 2

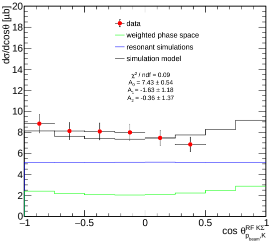
- **Correction is done using the tuned simulation model**

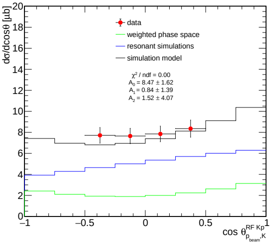


Angular Distributions: Jackson Frames 2

- **Correction is done using the tuned simulation model**

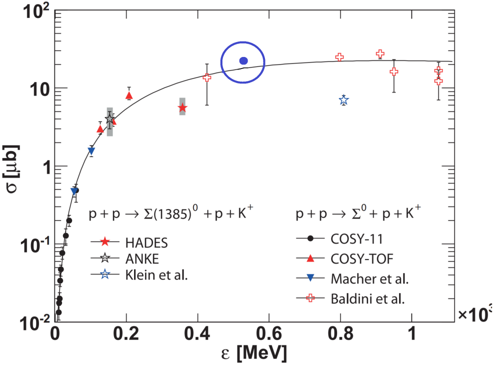






Total Production Cross Section:

- pure phase space: $\sigma_\Sigma = 17.9 \pm 0.37(stat) \pm 2.0(sys)\mu b$
- phase space + resonant: $\sigma_\Sigma = 15.9 \pm 0.33(stat) \pm 1.82(sys)\mu b$



I. Zychor et al. Shape of the $\Lambda(1405)$ hyperon measured through its $\Sigma^0\pi^0$ decay. Phys.Lett., B660:167–171, 2008.

Conclusion and Outlook

- First measurement of Σ^0 at 3.5 GeV beam energy
- Σ^0 production can not be described a pure phase space description
- N^* resonant production is the dominant, however the interference effects are not taken into account
- FSI is not taken into account in the simulation model
- A step towards measuring radiative and Dalitz decays of excited states
- The study illustrates the importance of the forward detector especially for excited states

- An analysis note is in progress
- **Future Plan: Partial Wave Analysis**

Acknowledgement

- Prof. Jim Ritman
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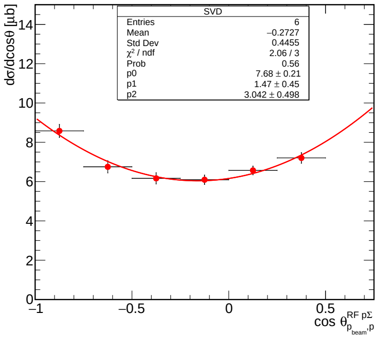
- Dr. Rafal Lalik
- Dr. Peter Wintz
- Krzysztof Nowakowski
- Dr. Jochen Markert
- All my colleagues at the IKP
- Everyone who is kind to provide help

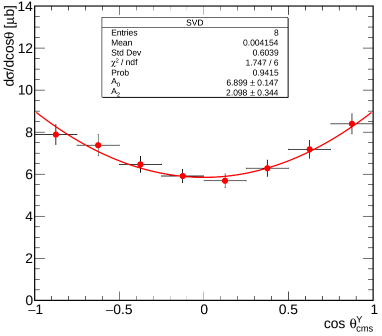
Thank you

Backups: Isotropic Phase space weighting

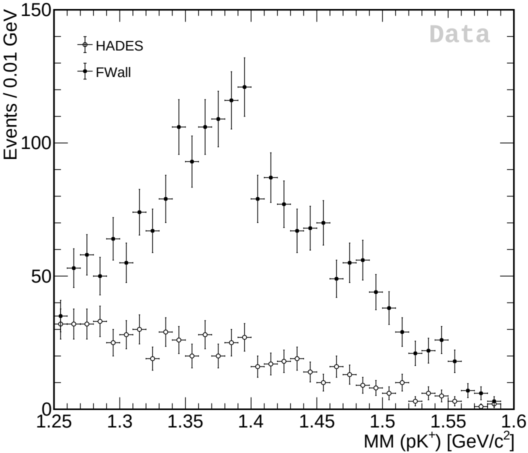
Jackson Angle in $p\Sigma$ frame



Σ CMS

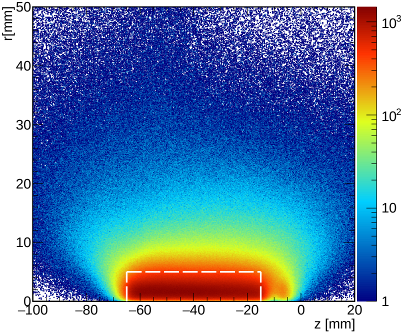


Backups: Enlargement of the resonance region

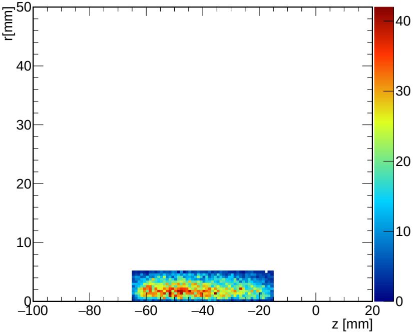


Backups: primary vertex distributions

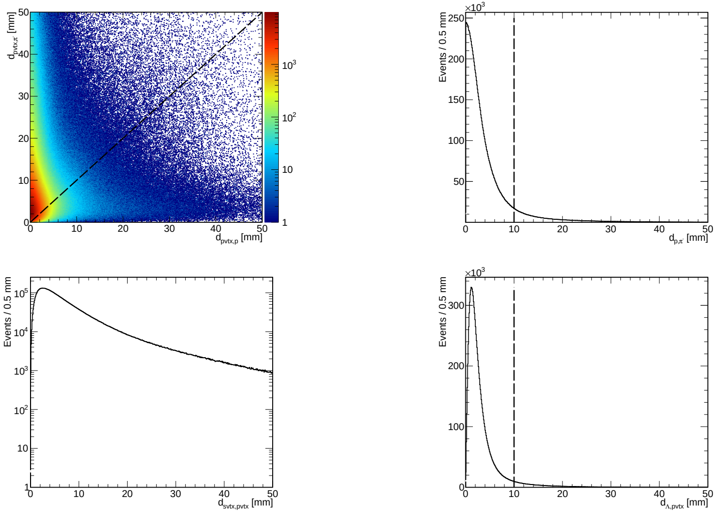
All Events



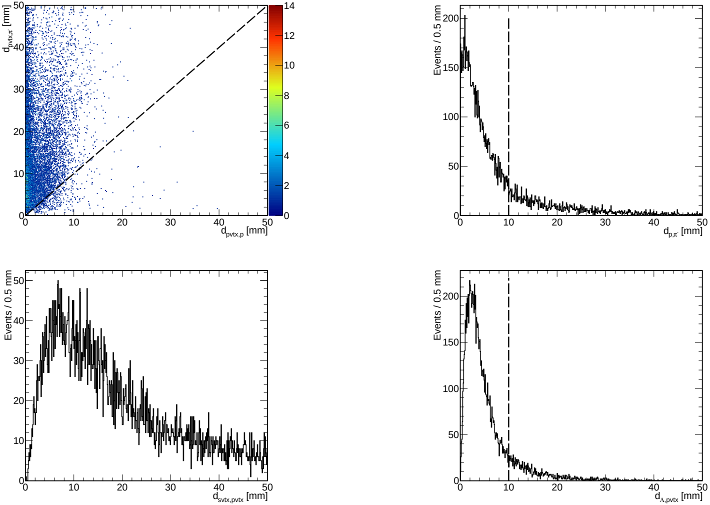
After All Cuts



Backups: Lambda off-vertex variables for all events



Backups: Lambda off-vertex variables after all cuts



Backups: Missing Mass of all particles in the HADES dataset