HYPERON DALITZ DECAYS

WITH PANDA@HADES

SWEDISH NUCLEAR PHYSICISISTS' MEETING
UPPSALA

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OCTOBER 23, 2023

Swedish Research Council

Knut and Alice Wallenberg Foundation

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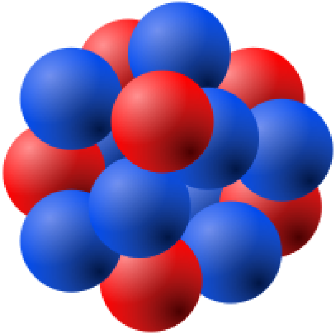
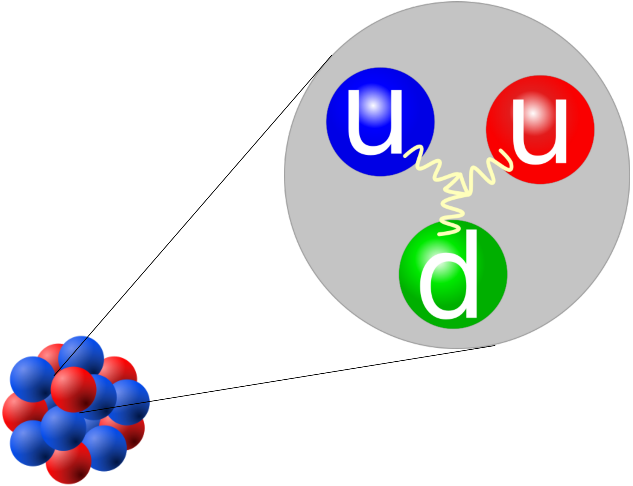
Motivation



Motivation



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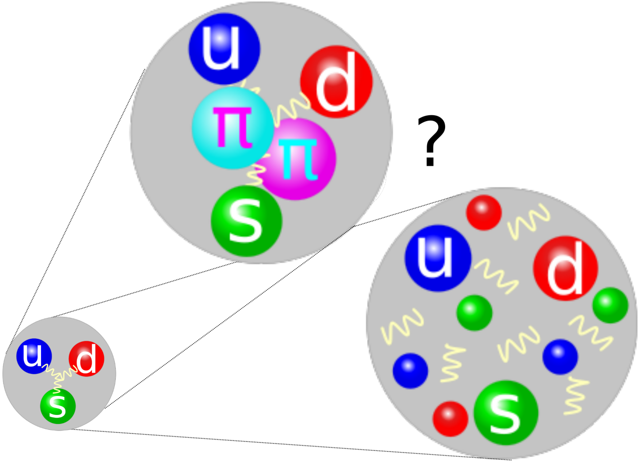
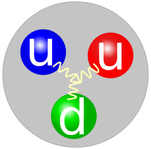
Motivation: Hadron Structure

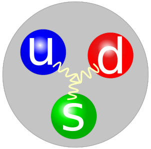


Hyperons

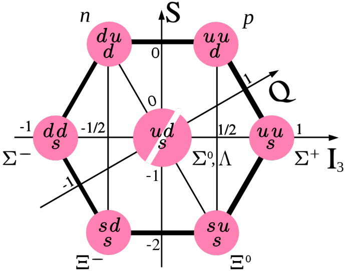
What if we add strangeness?

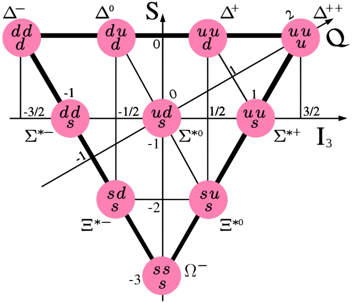


proton



Λ





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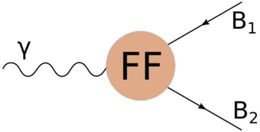
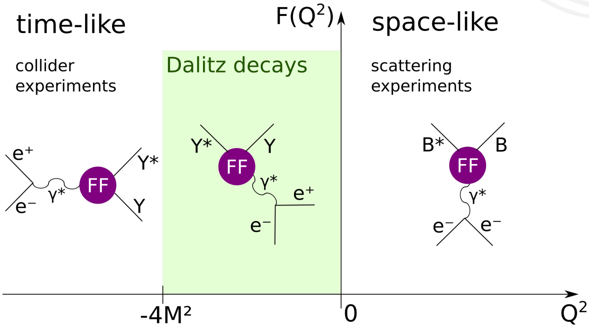
Motivation:
Time-Like Electromagnetic Transition Form Factors

Coupling of virtual photon to hadron, dependent on four-momentum transfer $Q^2 = -q^2$

$\rightarrow$ Describe non-point-like character of particles



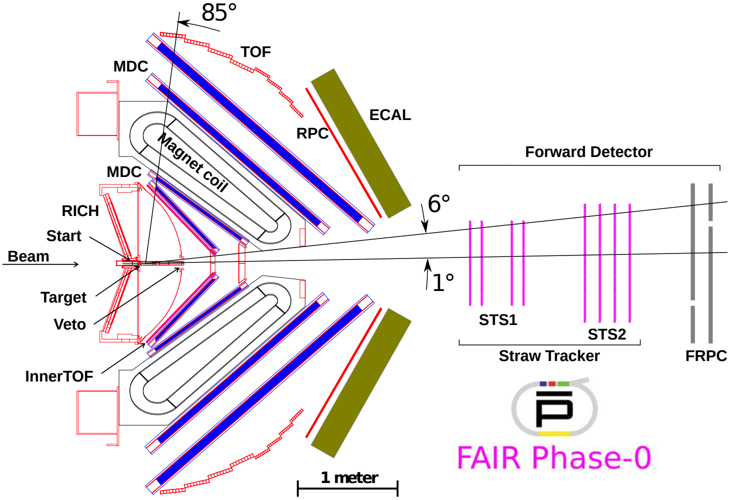


Branching Ratios

- Hyperon electromagnetic Dalitz decays not observed yet
- Predicted to be $\approx 1\,\%$ of radiative decay
- Background from photon conversion of same order

Hyperon	$\Lambda\gamma$	$\Lambda e^+ e^-$ (prediction)
Σ^0	100%	0.5 %
$\Sigma^0(1385)$	1.25 %	$1.25 \cdot 10^{-2}\,\%$
$\Lambda(1520)$	0.85 %	$0.85 \cdot 10^{-2}\,\%$

$\bar{\text{P}}$ANDA @HADES – Setup for *pp* @ 4.5 GeV Beam Time

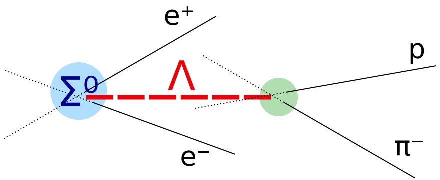


General Event Selection – Dalitz Decays

Event must contain at least

- 1 electron
- 1 positron
- 1 proton (Forward or HADES)
- 1 pion

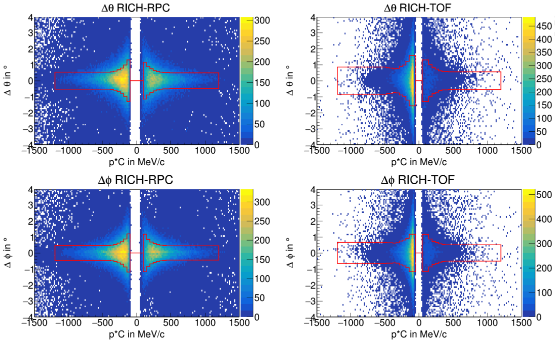
Hyperon Dalitz decay



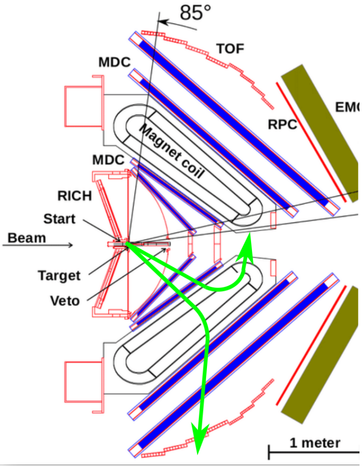
Full Lepton Tracks

Selection

- Tracks flagged as leptons
- z(vertex)>-1000mm
- RICH r(ring)>17mm
- 2σ RICH-META $\Delta\theta$ cut
- 2σ RICH-META $\Delta\phi$ cut



The Idea Behind Mini Tracklets



Challenges:

- Low $\Sigma^0 - \Lambda$ mass difference $\rightarrow$slow leptons
- Escape detector in magnetic field

Idea:

- Require 1 full lepton track + 1 mini-tracklet
- Mini-tracklet = RICH ring + MDC I+II
- Assign charge opposite to fully detected lepton
- Cleanup: 2σ RICH-Track cuts in θ and ϕ

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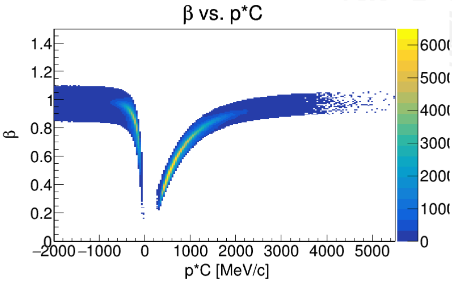
Hadron Selection

- **PID** cut around theoretical β vs. p
- **Missing mass** of detected particles
  $MM(p+\pi^- + e^{+/-}) > M(p+K) - 20\,\text{MeV}$
  $(M(p+K) = 1432\,\text{MeV})$
- **Invariant mass** of Λ daughters
  $1060\,\text{MeV} < M(p+\pi^-) < 1170\,\text{MeV}$



+ protons from Forward Detector

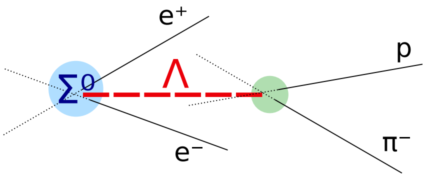
Σ^0 Dalitz Specific Selection

Safe cuts from kinematics: 0 signal loss

- $m_p + m_K < MM(\Lambda e^{+/-}) < 2300\,\mathrm{MeV}$
- $p_{e^{+/-}} < 450\,\mathrm{MeV}$
- Mini tracklet polar angle $< 90^\circ$

Cleanup cuts, chosen from simulation

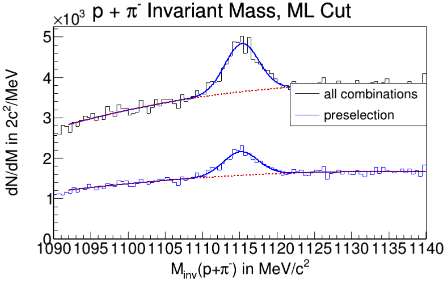
- e^+e^- track distance (primary vertex)
- z coordinate of primary vertex
- Vertex distance
- $p\pi^-$ track distance (secondary vertex)



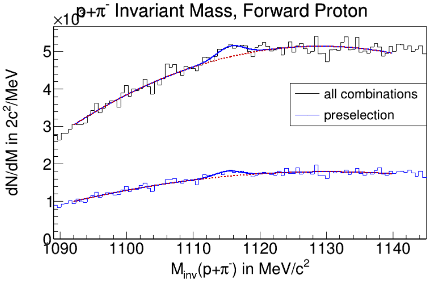
Λ Selection – Machine Learning based

Step 1: Apply pre-selection cuts

Dalitz+Conversion
pp data, 7 days

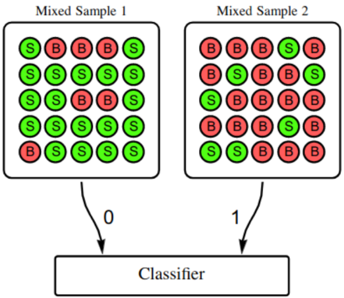


proton in Forward Detector
pp data, 7 days



TMVA Analysis

Training on DATA



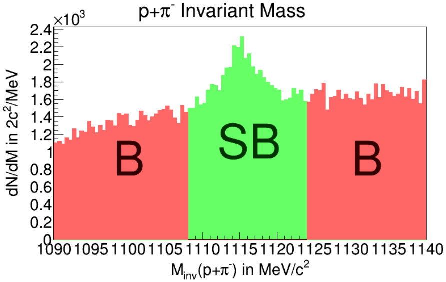
Classification without labels: Neymann-Pearson Lemma: the optimal classifier is the ratio of probabilities of the event being signal and background respectively, or any classifier that is monotonically related to it

Λ Selection – ML based

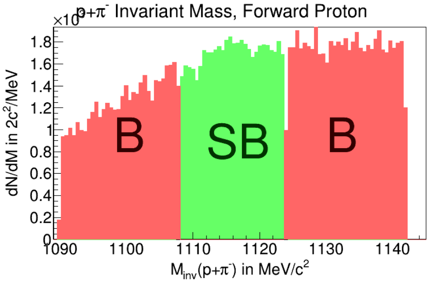
Step 2: Divide the pp data, 7 days into S+B and B sample

Signal + Background: $1108 < m_\Lambda < 1124$
Background: $1090 < m_\Lambda < 1108$ or $1124 < m_\Lambda < 1142$

proton in HADES
pp data, 7 days



proton in Forward Detector
pp data, 7 days



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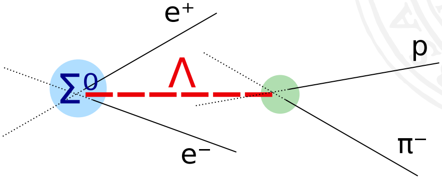
Λ Selection – ML based



Step 3: Define input variables

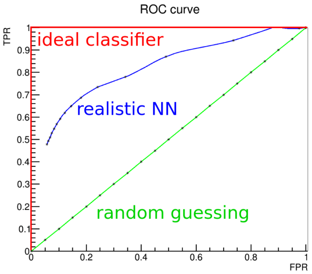
- Opening angle of p and π
- Opening angle of e^+ and e^-
- Coordinates of POCA of e^+ and e^-
- Coordinates of POCA of p and π
- Distance of closest approach of e^+ and e^-
- Distance of closest approach of p and π
- Pointing vector angle

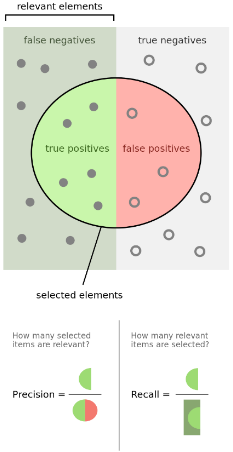
TMVA Evaluation

ROC Curve

Illustrate the performance of a trained network

- **True Positive Rate** (TPR):
  True positives / all positives
- **False Positive Rate** (FPR):
  False positives / all negatives





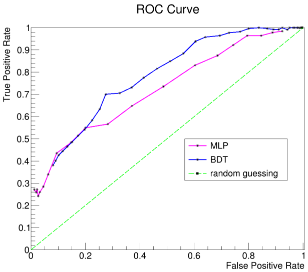
Λ Selection – ML based

Step 4: Perform the training

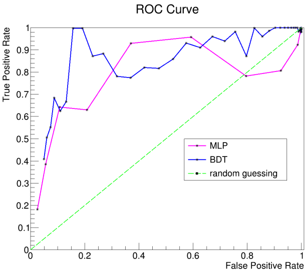
Train on 200 000 events
Training methods that have been applied:

Boosted Decision Tree and **Multi Layer Perceptron, 4x4 Layers**

proton in HADES
pp data, 7 days



proton in Forward Detector
pp data, 7 days



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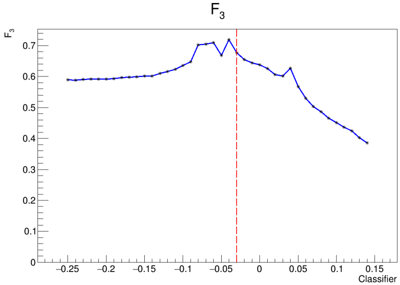
Λ Selection – ML based

Step 5: Find the best cut position

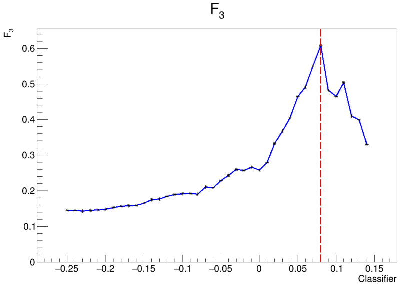
$$F_\beta = (1+\beta^2)\frac{\text{precision}\cdot\text{recall}}{\beta^2\cdot\text{precision}+\text{recall}}$$

Use F_β with $\beta = 3$ for **Boosted Decision Tree**

proton in HADES
Maximum at classifier = -0.03



proton in Forward Detector
Maximum at classifier = 0.08



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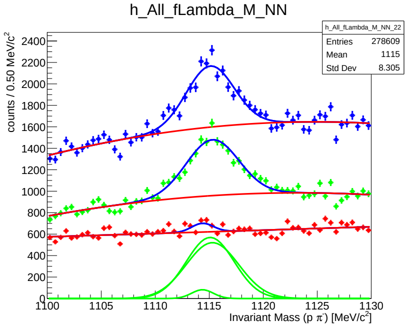
Λ Selection – ML based

Step 5: Find the best cut position

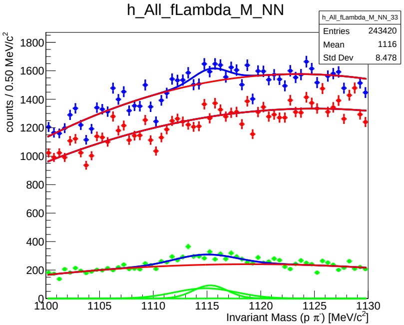
proton in HADES

Maximum at classifier = -0.03



proton in Forward Detector

Maximum at classifier = 0.08



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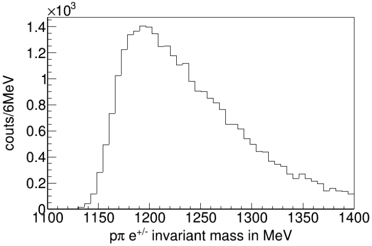
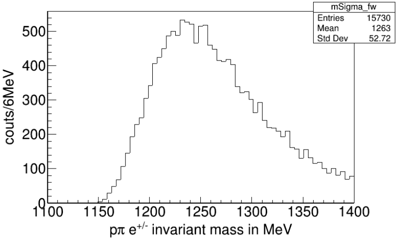
$\Lambda e^{+/-}$ Invariant Mass Spectrum

pp data, 7 days

proton in HADES



proton in Forward Detector



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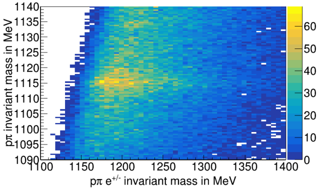
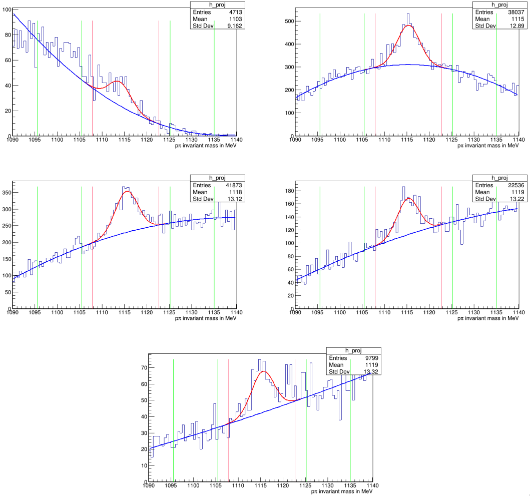
Sideband Analysis

p in HADES



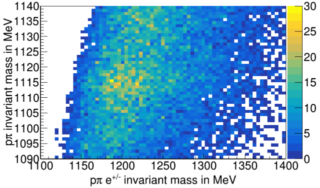
Divide into 5 $p\pi^{-}e^{+/-}$ invariant mass regions

→ Can be done bin by bin with full data set

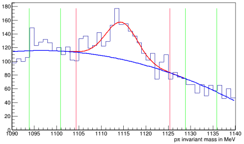


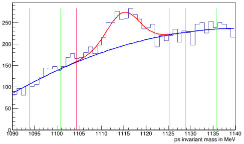
Sideband Analysis

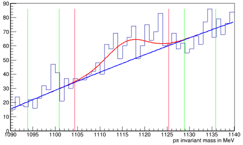
p in Forward Detector



Divide into 3 $p\pi^- e^{+/-}$ invariant mass regions







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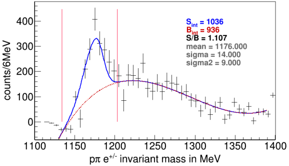
$\Lambda e^{+/-}$ Invariant Mass, Sideband Subtracted

Only Lambda selection

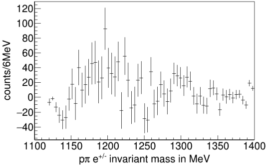
- Fit bifurcated Gaussian to signal
- Limit parameters from sim result
- Fit signal function + pol3 background to pp data, 7 days

pp data, 7 days

p in HADES

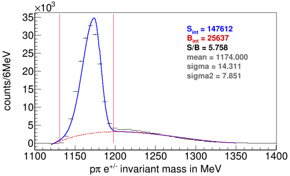


p in Forward Detector

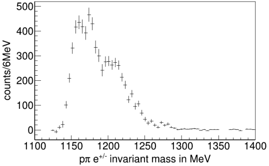


pp sim, 100 million events

p in HADES



p in Forward Detector



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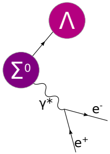
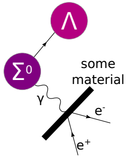
$\Lambda e^{+/-}$ Invariant Mass, Sideband Subtracted

Only Lambda selection

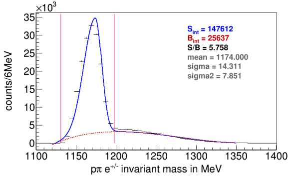
- Fit bifurcated Gaussian + pol3 background
- For BR$= 5 \cdot 10^{-3}$: almost 5 x more Dalitz decays than photon conversion in peak
- No conversion events in Forward Detector



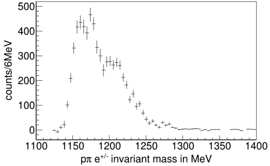


pp sim, $\Sigma^0 \to \Lambda e^+ e^-$,
100 million events

p in HADES

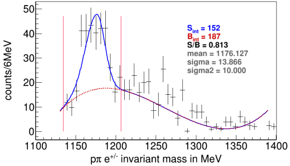


p in Forward Detector

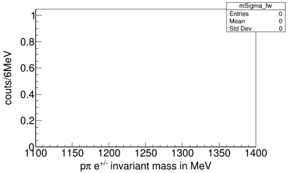


pp sim, $\Sigma^0 \to \Lambda\gamma$,
100 million events

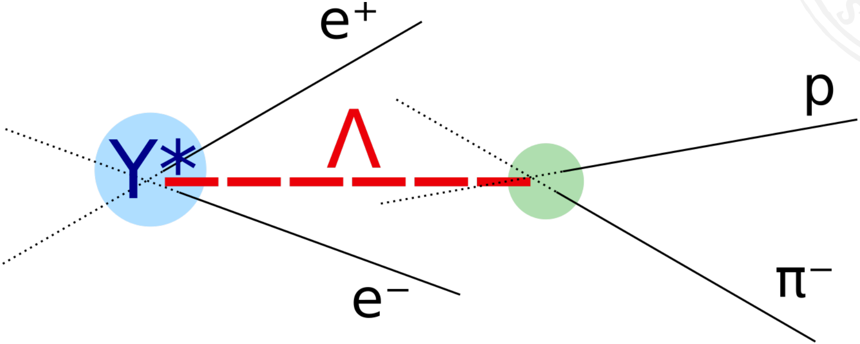
p in HADES



p in Forward Detector



A GLANCE ON HEAVY HYPERONS



BOTH LEPTON TRACKS FULLY RECONSTRUCTED

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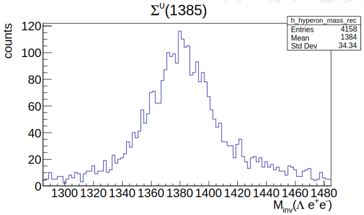
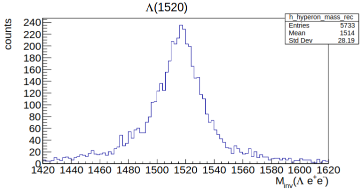
Expectations from Simulations

- True $+$ and π^- from Λ, e^+ and e^- in acceptance
- 500 000 events analyzed
- Assumed Luminosity $\mathcal{L} = 6.47\,\mathrm{pb}^{-1}$





Hyperon	$\Lambda\gamma$	Λe^+e^- (prediction)	cross section	expected counts
$\Sigma^0(1385)$	$1.25\,\%$	$1.25\cdot10^{-2}\,\%$	$56.2\,\mu b$	378
$\Lambda(1520)$	$0.85\,\%$	$0.85\cdot10^{-2}\,\%$	$69.6\,\mu b$	439

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Conculsions and Outlook

- Inclusive analysis with mini tracklet seems promising
- Boosted Decision Trees make good background suppression possible while preserving much of Λ signal
- Clear Σ^0 after side-band analysis
- **HADES can do first measurement of the Σ^0 Dalitz decay!**

Outlook

- Fine-tune analysis
- Run on full pp@4.5 GeV data set
- Do $\Sigma^0 \to \Lambda\gamma$ analysis
  $\to$ Measure Dalitz decay branching ratio
  $\to$ Measure electromagnetic Transition Form Factor
  (find estimation of mini-tracklet momentum)

- Do full analysis for Heavy hyperon Dalitz decays
  $\to$ Measure upper limit of Dalitz decay branching ratio

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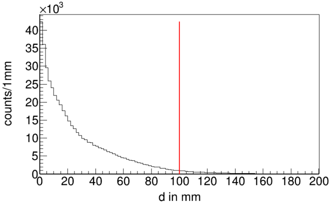
BACKUP

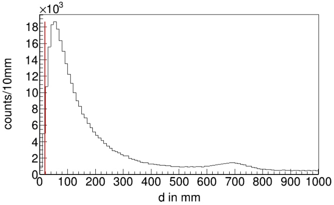
Σ^0 Dalitz Specific Selection – p in HADES

Use Simulations to select good cut positions

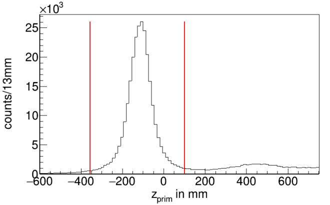
e^+e^- track distance $< 100\,\mathrm{mm}$ (primary vertex)



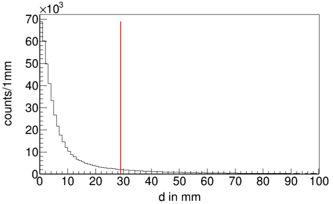
Vertex distance $> 19\,\mathrm{mm}$



$-357\,\mathrm{mm} < z_{\mathrm{prim}} < 100\,\mathrm{mm}$



$p\pi^-$ track distance $< 29\,\mathrm{mm}$ (secondary vertex)



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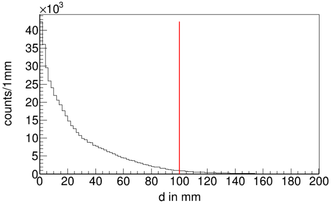
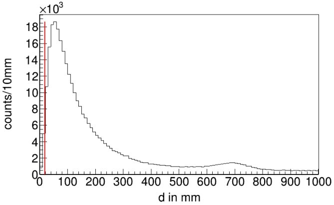
Σ^0 Dalitz Specific Selection – p in HADES

Use Simulations to select good cut positions

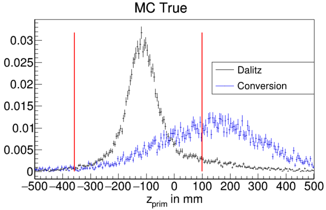
e^+e^- track distance $< 100\,\mathrm{mm}$ (primary vertex)



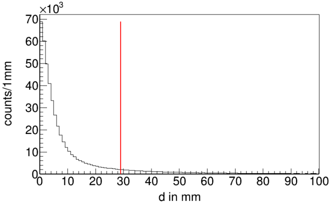
Vertex distance $> 19\,\mathrm{mm}$



$-357\,\mathrm{mm} < z_{\mathrm{prim}} < 100\,\mathrm{mm}$



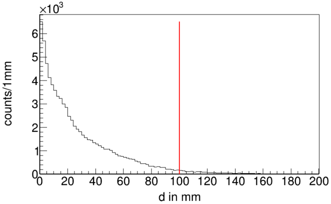
$p\pi^-$ track distance $< 29\,\mathrm{mm}$ (secondary vertex)



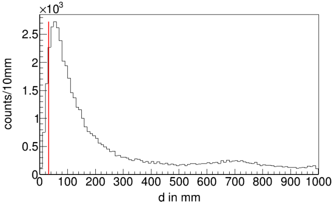
Σ^0 Dalitz Specific Selection – p in Forward Detector

Use Simulations to select good cut positions

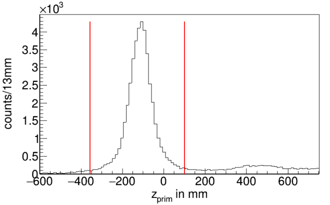
e^+e^- track distance $< 100\,\mathrm{mm}$ (primary vertex)



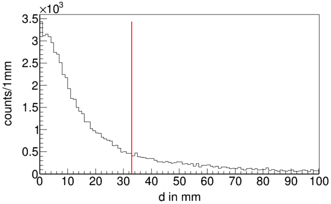
Vertex distance $> 33\,\mathrm{mm}$



$-357\,\mathrm{mm} < z_{\mathrm{prim}} < 100\,\mathrm{mm}$



$p\pi^-$ track distance $< 33\,\mathrm{mm}$ (secondary vertex)



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