HYPERON DALITZ DECAYS

WITH PANDA@HADES

NSTAR2024
YORK

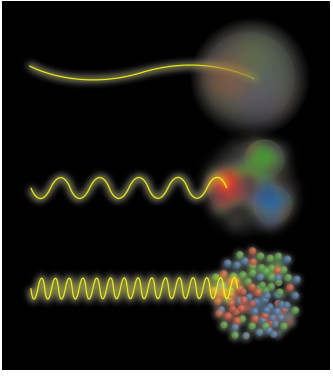
JANA RIEGER
FOR THE HADES COLLABORATION

JUNE 17-21, 2024

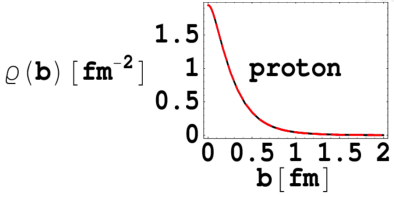
Swedish Research Council
Knut and Alice Wallenberg Foundation

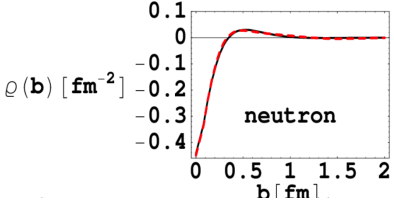
Hadron Structure

Interactions of virtual photons with hadrons reveal their inner structure



nucleon charge density
from electron-nucleon elastic scattering





G. Miller, Phys. Rev. Lett. 99, 112001

The Hype about Hyperons

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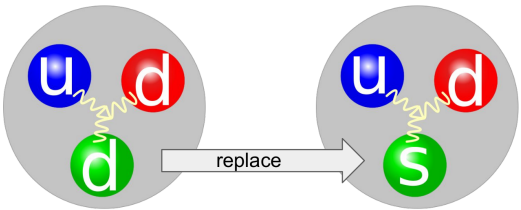
They are strange!



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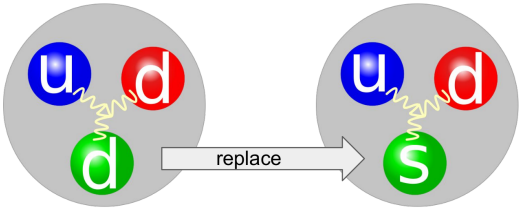
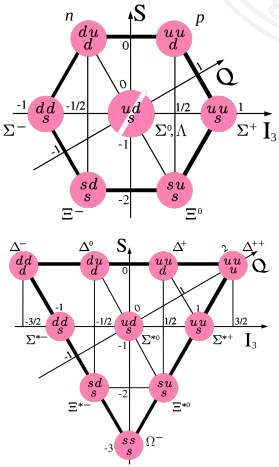


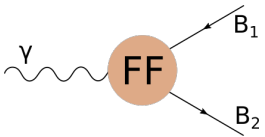
Strangeness extends the baryon spectrum



Electromagnetic Transition Form Factors

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

→ Describe non-point-like character of particles



Sensitive to **charge** and **magnetization density**

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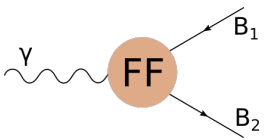

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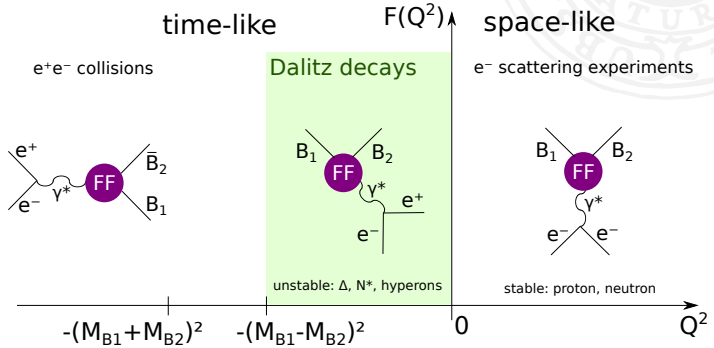

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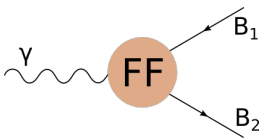

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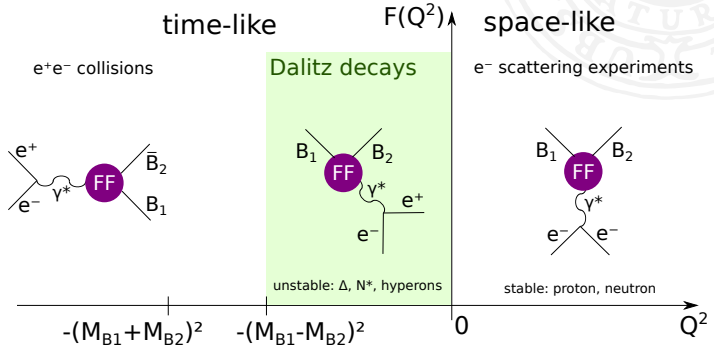

Δ and $N^*(1520)$ baryon Dalitz decay measured by HADES

Phys. Rev. C 95, 065205; arXiv:2205.15914

Talk by I.Ciepal (Tuesday plenary)

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The Fans of Baryon Transition Form Factors

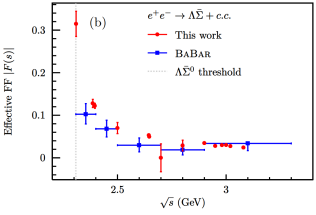
What can we learn from them?

$\Sigma^0 \to \Lambda$ Transition Form Factors

BESIII: $\mathbf{e^+e^- \to \Lambda\bar{\Sigma}^0}$

- Large $q > M_\Lambda + M_{\Sigma^0}$
- Extract effective FFs

$$F(s) = \sqrt{\frac{2\tau|G_M(s)|^2 + |G_E(s)|^2}{2\tau+1}}$$



arXiv:2308.03361 [hep-ex]

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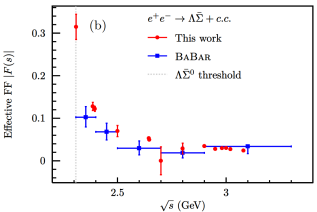
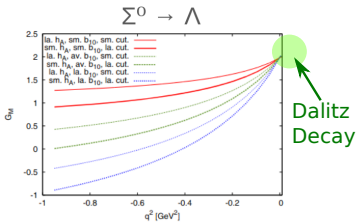


arXiv:2308.03361 [hep-ex]

HADES: $\Sigma^0 \to \Lambda e^+e^-$

Predicted BR: 0.55 % Eur. Phys. J. C (2020) 80: 218

- $q < 77\,\mathrm{MeV}$
- Extrapolate TFF to photon point
  $\to$magnetic moment
- Increase predictive power of dispersion theory



Eur. Phys. J. A (2017) 53: 117

What can we learn from them?

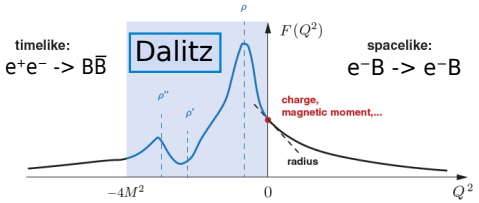
$\mathbf{\Lambda(1520)/\Sigma^0(1385) \rightarrow \Lambda e^+ e^-}$ Strange "partner" of $\mathbf{N^*(1520)}$

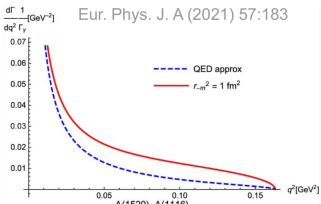
Predicted BR: 10^{-2} %

- $q < 270 - 405\,\mathrm{MeV}$
- Probe the size of hadrons
- Test vector dominance model

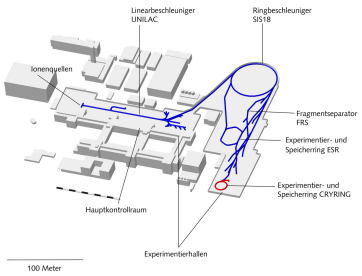
Phys. Rev. D 102, 054016

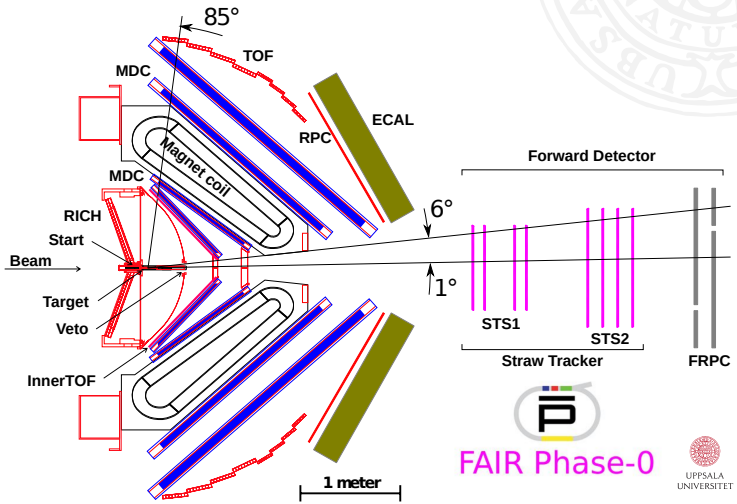
Never measured before!





P̄ANDA @HADES – Setup for *pp* @ 4.5 GeV Beam Time





Eur.Phys.J.A 57 (2021) 4, 138

FAIR Phase-0

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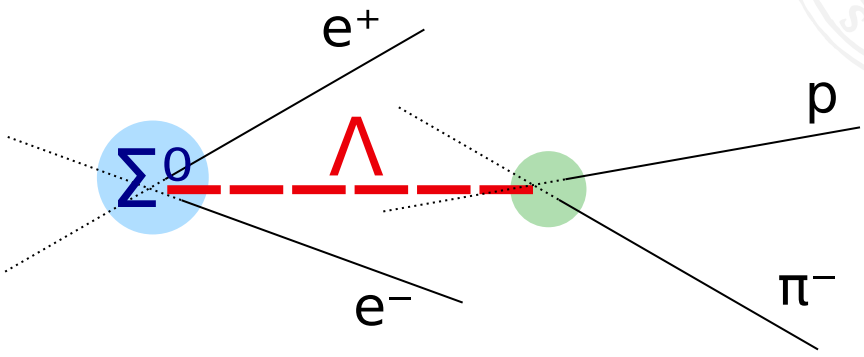
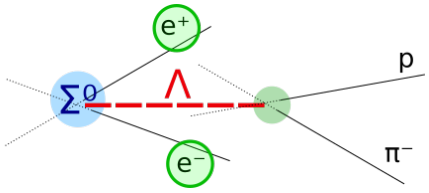
THE Σ^0 DALITZ DECAY

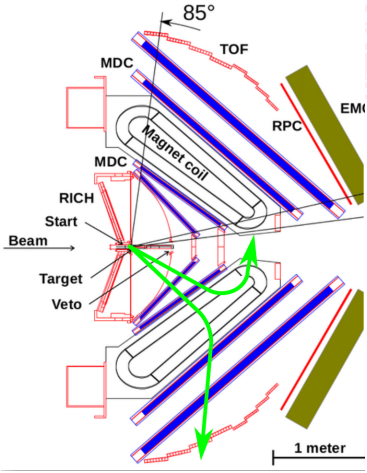


AND ITS CHALLENGES

The Slow Lepton Challenge



- Small $\Sigma^0 - \Lambda$ mass difference $\rightarrow$ slow leptons
- At least one of leptons gets bent out of acceptance by magnetic field

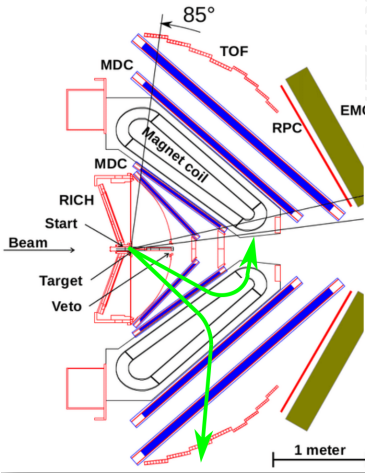


Overcome the Slow Lepton Challenge

- Require 1 full lepton track + 1 "mini-tracklet"
- Mini-tracklet: RICH ring plus hits in MDC I+II

- **Advantage:** Small $\Sigma^0 - \Lambda$ mass difference
- Full lepton track carries most of the energy
- Σ^0 can be seen in Λe invariant mass

- **Estimate mini-tracklet momentum**
- RICH ring radius depends on momentum for $p <\approx 100\,\mathrm{MeV}$
- New method in HADES – work in progress



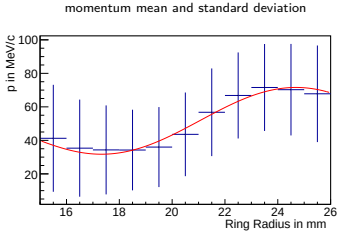
Estimation of Mini-Tracklet Momentum

Ring radius depends on momentum
for $p_e <\approx 100\,\mathrm{MeV}$

- $p_e = 20\,\mathrm{MeV} \hat{=} r = 21\,\mathrm{mm}$
- $p_e = 80\,\mathrm{MeV} \hat{=} r = 23.5\,\mathrm{mm}$

but also on polar angle.

Solution: Simulation study Angle dependent ring radius – momentum matching



Example: positrons at 34 degree

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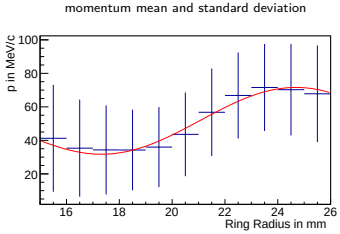

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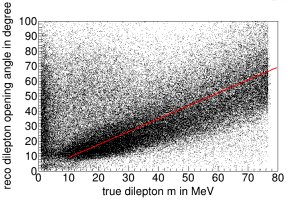
Dilepton mass – opening angle relation



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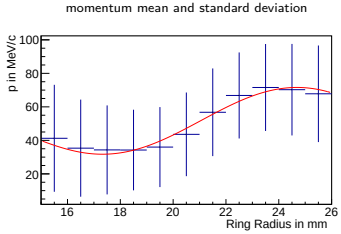

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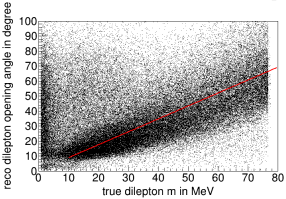
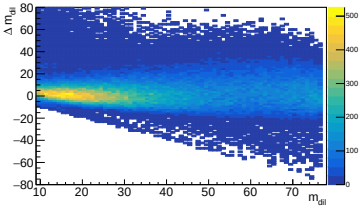


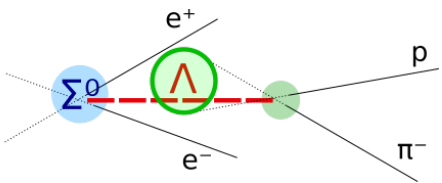
Together: Dilepton mass resolution ≈ 10 MeV



The Λ Hyperon Challenge

- Λ mean life: $2.6 \cdot 10^{-10}\,s$
- Decays in displaced vertex with $c\tau = 7.89\,\mathrm{cm}$
- Only charged decay mode (BR = 64%) seen in HADES

- Worse resolution for off-vertex tracks ($\approx 5\%$)
- p and π^- slightly slower since they travel some distance "inside" Λ



Overcome the Λ Hyperon Challenge

Event selection using special decay topology

Important variables:

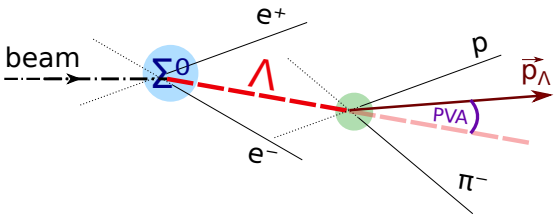
Primary Vertex

- Coordinates of POCA of e^- and beam
- Distance of closest approach of e^- and beam

Secondary Vertex

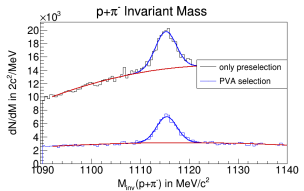
- Coordinates of POCA of p and π
- Distance of closest approach of p and π
- Opening angle of p and π

Pointing Vector Angle (PVA)

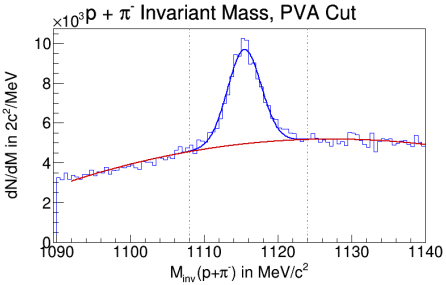


Λ Hyperon Signal – with e^+e^- pair in same event

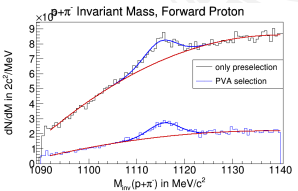
p in HADES



1. Preselection on vertices, preserves almost all Λ hyperon signal
2. Selection on PVA<0.5 for high Λ signal significance

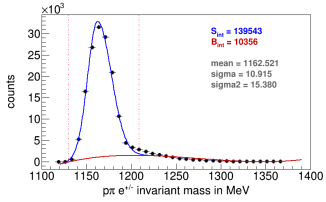


p in Forward Detector



Preliminary Result: $\Lambda e^{+/-}$ Invariant Mass

$\Sigma^0 \to \Lambda e^+ e^-$ **MC, 100 million events**



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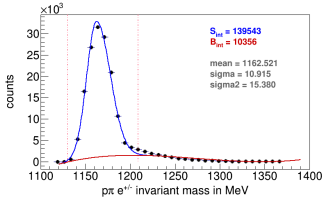
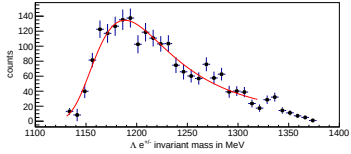


- Fit bifurcated Gaussian to signal
- Estimate background from $pp \to pK^+\Lambda\pi^0$ simulation



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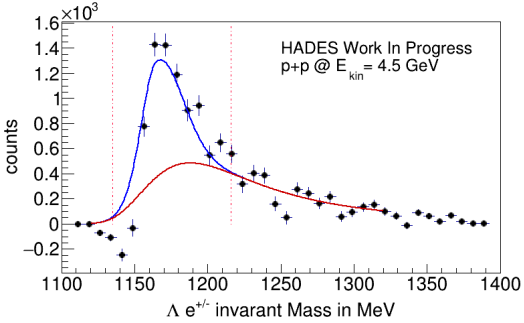
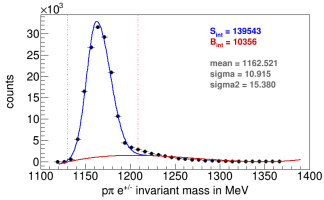
Preliminary Result: $\Lambda e^{+/-}$ Invariant Mass

pp data, 7 days, Λ sideband subtracted



- Fit signal function + background to pp data
- Parameters limited from sim result

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



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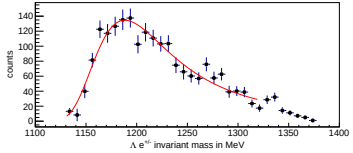
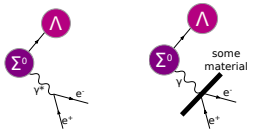
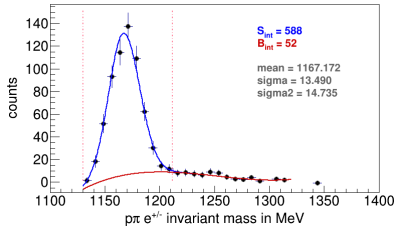


Final Challenge: Conversion



It looks basically the same.

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



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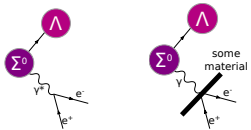

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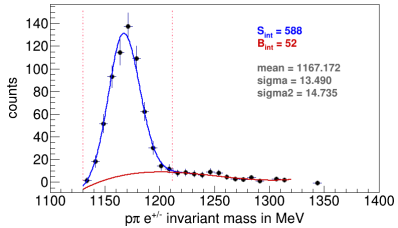
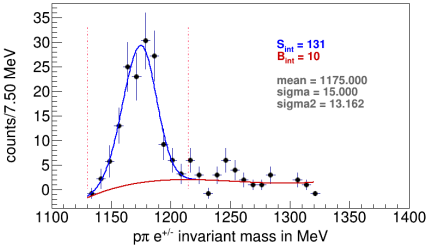


But there is hope.

- Conversion supression cut on primary vertex and RICH observables
- **Estimate from Simulation:**
  For BR= $5 \cdot 10^{-3}$: almost 3 x more Dalitz decays than photon conversion in peak



Towards the Form Factor Measurement

Needed: Differential Σ^0 decay width as a function of the di-lepton invariant mass

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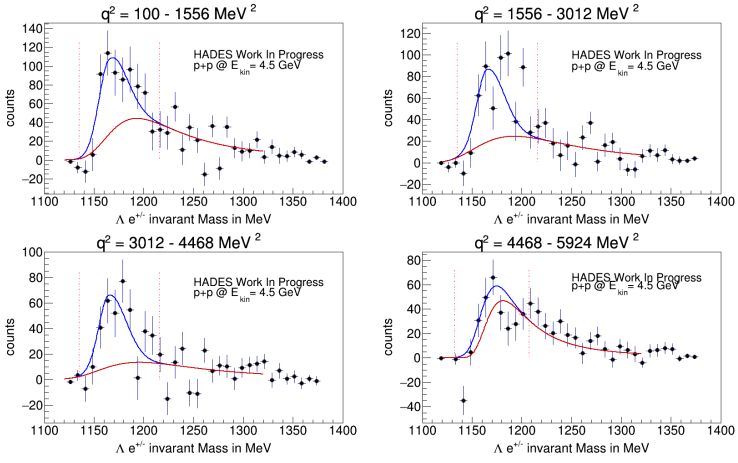
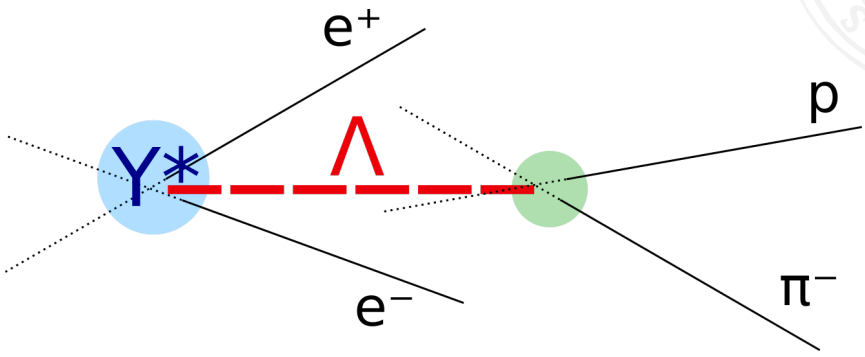


OUTLOOK ON Λ(1520) AND Σ^0(1385)



BOTH LEPTON TRACKS FULLY RECONSTRUCTED

Expectations from Simulations

- True p and π^- from Λ, e^+ and e^- in acceptance
- 500 000 MC events analyzed
- pp@4.5 GeV Luminosity: $\mathcal{L} = 6.47\,\mathrm{pb}^{-1}$

(1) PDG, Prog. Theor. Exp. Phys. 2022, 083C01 (2022)

(2) HADES, Eur. Phys. J. A (2021) 57: 138

Hyperon	$\Lambda\gamma$[1]	Λe^+e^- (prediction)	cross section[2]	# $Y^* \to \Lambda e^+e^-$
$\Sigma^0(1385)$	1.25 %	$1.25 \cdot 10^{-2}$ %	$56.2\,\mu b$	378
$\Lambda(1520)$	0.85 %	$0.85 \cdot 10^{-2}$ %	$69.6\,\mu b$	439

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Summary

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- Relatively clean Λ hyperon signal by exploiting decay topology
- Σ^0 observed in Λe^- invariant mass spectrum
- Differential measurement in q^2 possible
- **HADES can do first measurement of a hyperon electromagnetic Dalitz decay!**

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Outlook

- Fine-tune analysis
- Run on full pp@4.5 GeV data set
- Do $\Sigma^0 \to \Lambda\gamma$ analysis for normalization
- Measure **Dalitz decay branching ratio**
- Measure first estimate of **electromagnetic $\Sigma^0 - \Lambda$ Transition Form Factor** at low q^2

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

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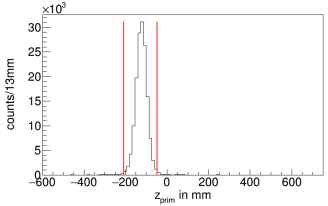
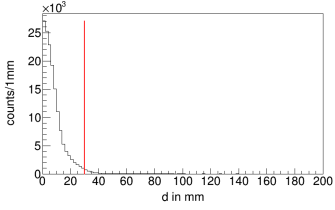
BACKUP

Geometric Λ Pre-Selection

Primary Vertex

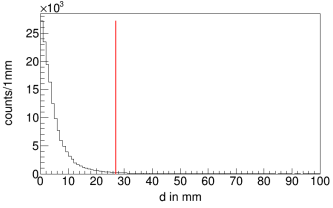


Distance of closest approach e+beam

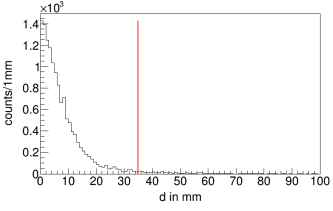


Secondary Vertex – DOCA $p+\pi^-$

p in HADES



p in Forward Detector



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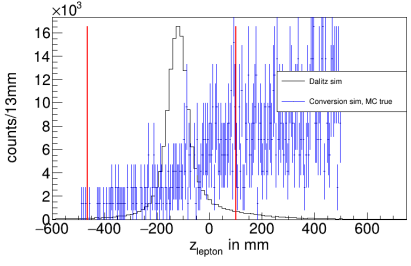
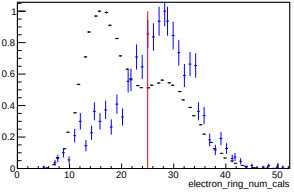
Conversion Rejection

Primary Vertex



Fired Photomultipliers in RICH Ring

track



tracklet