Hyperon Reconstruction in pp HADES Data at 4.5 GeV Beam Kinetic Energy and Perspectives for 30 GeV

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Purpose of this presentation and Outline

- Follow up on HADES overview talk on Monday
  - Many interesting hyperon channels and results shown
- To give a hint of data analysis at HADES
- Connect to PANDA physics program
- Why extend studies to higher energies?

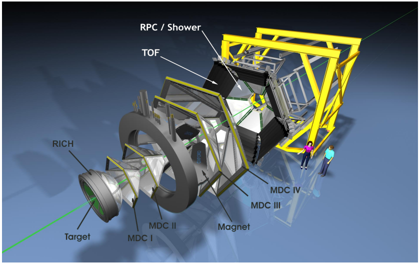
Outline

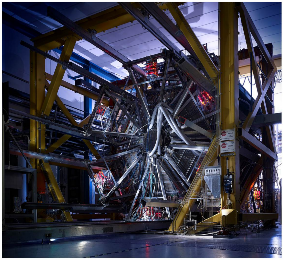
- Why are Ξ^- interesting to study?
- Current Ξ^- analysis at HADES
- Possibilities with a 30 GeV proton beam

General HADES

High-Acceptance Di-Electron Spectrometer

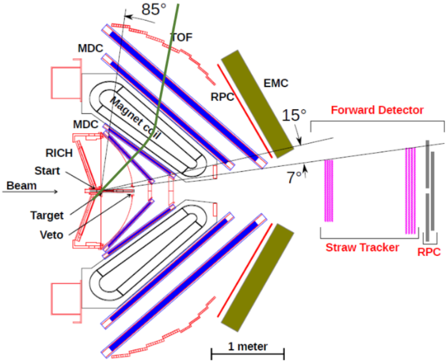
- Operating at GSI at SIS18 since 2001
- Precise spectroscopy of e^+e^- pairs and charged hadrons
- pp and heavy ion (*e.g.* Ag-Ag, Au-Au) collisions
- Main purpose: Dense nuclear matter properties via in-medium hadron properties
- Hyperon physics a hot topic lately
- Acceptance of detector: $\sim$15-85°





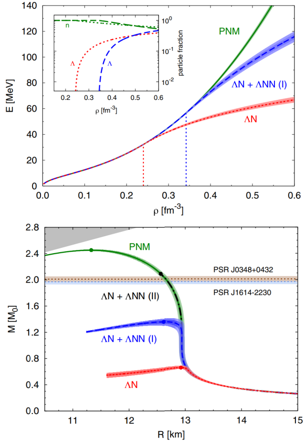
Forward Detector Upgrades

- Covers angles between $\sim$1-7°
- Straw Tracking Stations (STS)
  - Based on PANDA design
  - Geometrical track Reconstruction
  - 8 double layers of straws
- Forward Resistive Plate Chamber (fRPC) timing detector
  - Momentum estimation
  - Magnetic field free region, mass hypothesis of protons currently assumed
- Used in feb21 proton test beam data taking and feb22 proton beam physics run



Hyperons in Neutron Stars

- Neutron Stars – a very hot and interesting topic
- Hyperon Puzzle
  - Strangeness production favorable
  - Reduction of Fermi pressure
  - Softer EOS
    - Lower allowed mass compared to observed mass
- Could solve the Puzzle
  - Three-body hyperon interactions or strong repulsion in YN or YNN interactions
  - Stronger constraints on the hyperon-neutron force are necessary



PRL114, 092301 (2015)

Ξ^- Correlations

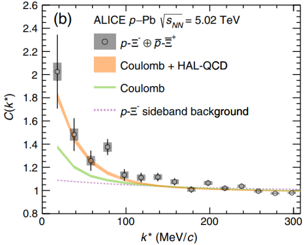
Femtoscopy studies via correlation function

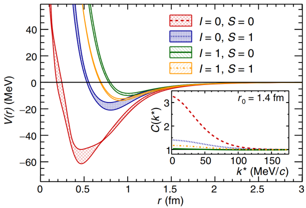
$$C(p_1, p_2) \equiv \frac{P(p_1, p_2)}{P(p_1) \cdot P(p_2)}$$

Need low relative momentum, k < 20-50 MeV

- Ξ^--N interactions predicted to affect EOS
- First Ξ^--p correlations measured at ALICE [*]
- Results imply stiffer EOS
- Need further studies in p+p and p+Ag reactions with HADES

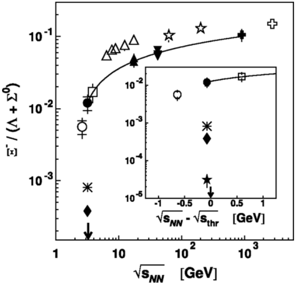
[*] PRL123, 112002 (2019)

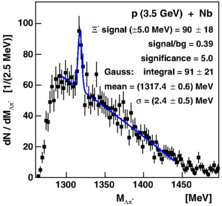




Previous HADES measurements

- Excess of sub-threshold Ξ^- production measured in Ar+KCl Reactions at 1.76AGeV [*] and p(3.5 GeV)+Nb collisions [**]
- Can be explained by resonances with significant branching fractions into the Ξ^- channel [***]
- Need spectroscopy of N$^* \rightarrow \Xi^- K^+ K^+$ in p+p reactions



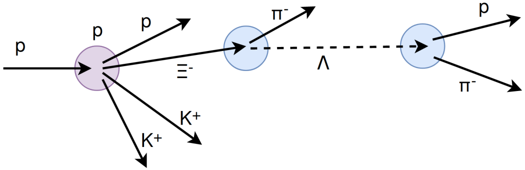


Figs. from [**]

[*] PRL 103, 132301 (2009)
[**] Phys. Rev. Lett. 114, 212301
[***] J. Steinheimer et al., J.Phys. G43 (2016) 015104

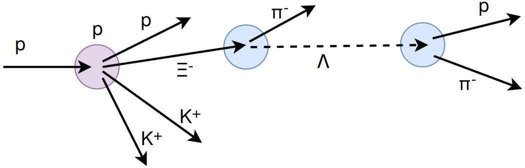
$pp \rightarrow \Xi^{-} p K^{+} K^{+}$

$p(4.5GeV)p \rightarrow \Xi^{-} p K^{+} K^{+} \rightarrow \Lambda \pi^{-} p K^{+} K^{+} \rightarrow p \pi^{-} \pi^{-} p K^{+} K^{+}$



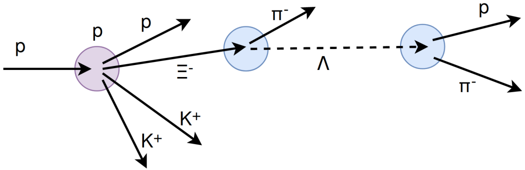
- 8×10^{3} expected number of reconstructed events
- Cross section estimates: 0.35 μb - 35 μb
- Goal of analysis
  - Cross section determination
  - Interaction studies
    - YN-potential for double strange particles
  - Spectroscopy

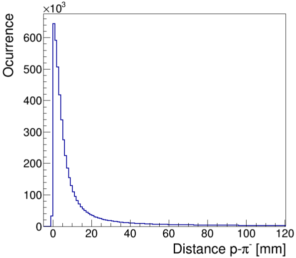
Analysis Details



- 10 000 000 events
- Very rough PID selection
  - Use mass reconstructed from tof and select particles within $\pm$ 300 MeV of nominal PDG mass
- Require at least one proton and pion

$pp \to \Xi^- p K^+ K^+$, Analysis procedure

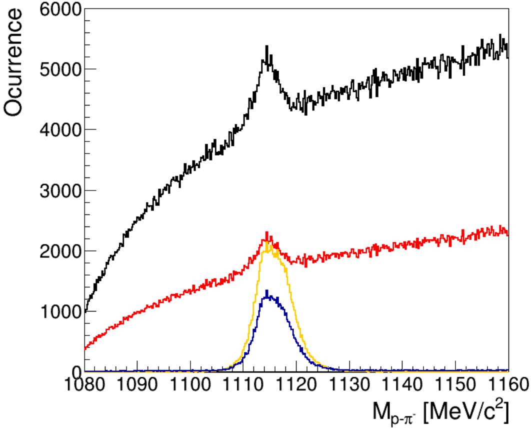




Approach 1.

- Reconstruct Λ from $p\pi^-$
- Select only combinations where closest distance is < 20 mm
- Create a neutral candidate
- Combine the best candidate in each event with an additional π^-

Λ Mass

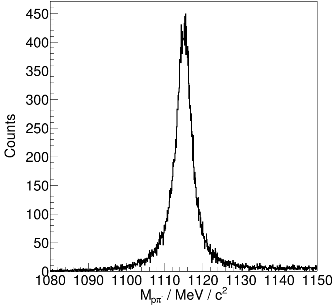


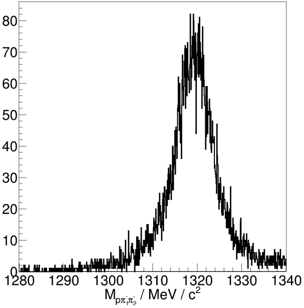
- All combinations
- Closest combinations
- All combinations that pass a mass fit $p_{fit} > 10^{-4}$
- The one combination in one event with the best fit probability

Need to find suitable variable in inclusive event to test if good Λ candidates remain - mass peak not suitable when mass constraint applied

Λ and Ξ^- Mass in Simulations

- Mass histograms without background
- Simulations give information on what resolution to expect

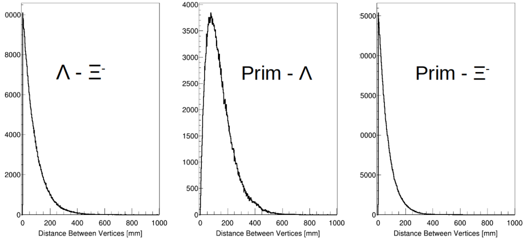




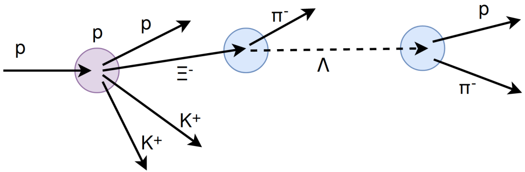
Vertex separations in Simulations

Possible additional selection: $z_{dv} - z_{pv} > 0$

- Different vertexing methods in HYDRA (HADES software)
    - Primary vertex
        - Point-of-closest approach between particles from vertex
        - Add beamline
        - Add constructed neutral particle
    - Decay vertex
        - Point-of-closest approach between particles
    - Best option under investigation for many channels in data and simulations



$pp \to \Xi^- pK^+K^+$, Analysis procedure



Approach 2.

- Find p, K^+ and K^+
- Reconstruct Ξ^- from a missing particle fit constraining primary particles to beam-target system
- See a fitted mass but needs more analysis

Benefits of higher energy proton beam

- More channels open up, *e.g.* excited Ξ or Ω^- production
- Higher cross sections for many channels
- Higher production rates with higher luminosity beam (*e.g.* 10^{11} protons per spill)
- Current analysis at HADES to observe Σ^0 Dalitz decay
  - First observation
  - Challenging due to small branching fraction (5×10^{-3}) – higher luminosities + production cross sections at higher energies important!
- Could be explored in the future with PANDA with $\bar{p}p$ collisions
- Possibility to observe Dalitz decays of excited Ξ at higher proton beam momenta?

Cascade spectroscopy

- Need more multi-strange excited baryon data for spin and parity assignment
  - PWA
- Focus on excited Ξ^- states
- Ω^- also needs investigations
- cm energy = 7.5 GeV enough to populate higher lying resonances
- Coincides well with planned measurements at PANDA with $\bar{p}p$ interactions where PANDA has contributed strongly [*]

  [*] Eur. Phys. J. A (2021) 57: 184

J^P	(D, L_N^P)	S	Octet members				Singlets
$1/2^+$	$(56,0_0^+)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1_1^-)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$ $\Sigma(1560)^\dagger$	$\Xi(?)$	$\Lambda(1405)$
$3/2^-$	$(70,1_1^-)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1_1^-)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$ $\Sigma(1620)^\dagger$	$\Xi(?)$	
$3/2^-$	$(70,1_1^-)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1_1^-)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0_2^+)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2_2^+)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2_2^+)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3_3^-)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3_3^-)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4_4^+)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	
			Decuplet members				
$3/2^+$	$(56,0_0^+)$	3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$	
$3/2^+$	$(56,0_2^+)$	3/2	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$	
$1/2^-$	$(70,1_1^-)$	1/2	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$	
$3/2^-$	$(70,1_1^-)$	1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$5/2^+$	$(56,2_2^+)$	3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
$7/2^+$	$(56,2_2^+)$	3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$	
$11/2^+$	$(56,4_4^+)$	3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	

Prog. Theor. Exp. Phys.2020, 083C01 (2020) and 2021 update

Summary and Outlook

Summary

- pp collisions at HADES offer possibilities to perform hyperon physics complementary to that at PANDA
- Example of data analysis for Ξ^-
- Higher proton beam energies beneficial – open up more channels and offer cross sections

Outlook

- Analyze full data set
- Test different vertexing methods in data and apply cuts
- Optimize error estimates for fitting

Thank you!