Hyperons electromagnetic form factors with HADES

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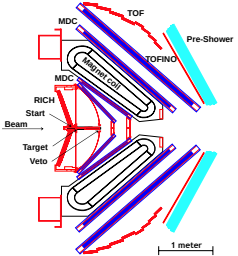
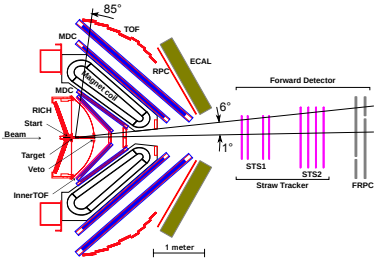
QNP
September 6th 2022

HADES in 2007



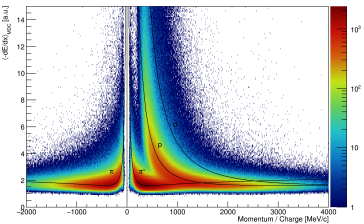
HADES in 2022

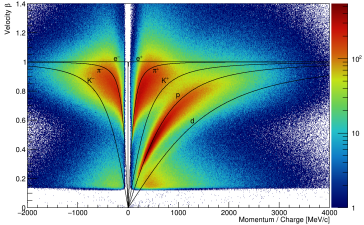


Major HADES upgrades:

- RPC (2010)
- Pion Tracker (2014)
- ECAL (2017-2021)
- RICH upgrade (2018)
- Forward Detector (2021)
- iTOF (2021)
- new START (2021)

Particle identification: dEdx, β vs momentum



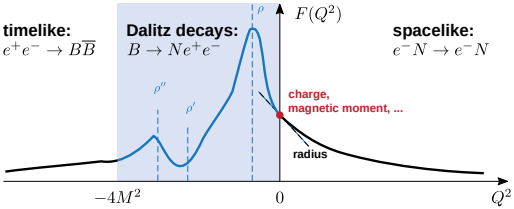


Previous experiments:

- various HI beams (Ar+KCl, Au+Au, Ag+Ag)
- light system beams:
  - p+p@3.5 GeV ('07)
  - p+Nb@3.5 GeV ('07)
  - π^-+p /π^-+A ('14)
  - p+p@4.5 GeV ('22)

Electromagnetic transitions form-factors (eTFF)

- Sensitive probe of hyperon internal structure
- Measurements of eTFF



→ Space-like region $|Q^2| > 0$ is inaccessible for excited hyperons (as a target or beam)

→ Time-like high $|Q^2|$ is probed by electron-positron anihillation (BaBar, CLEO-C, BESIII)

→ Time-like low $|Q^2|$ available via Dalitz decays

HADES is an excellent experiment for a Dalitz decay measurements

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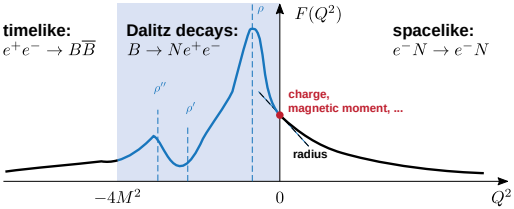

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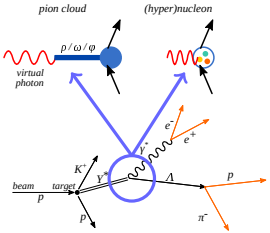
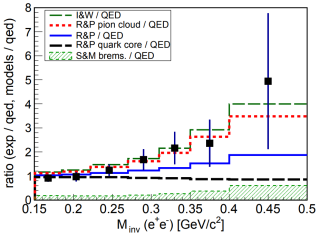
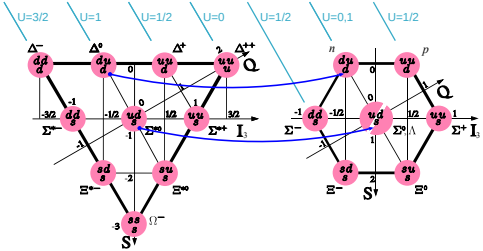


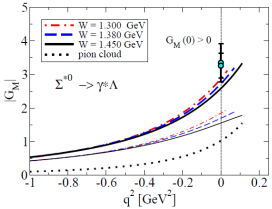


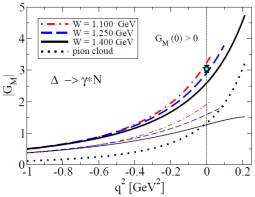
Phys.Rev. C95 (2017) no.6, 065205

Comparison of strange and non-strange baryons

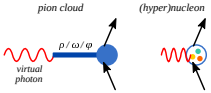
i.e. $\Delta(1232) \rightarrow Ne^+e^-$ (measured by HADES) with $\Sigma(1385)^0 \rightarrow \Lambda e^+e^-$ - (flavor sym. partner of Δ in SU(3))







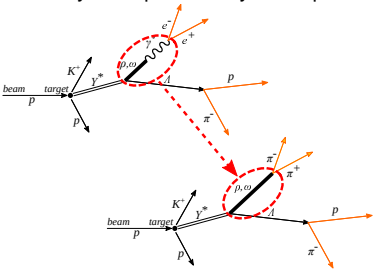
G. Ramahlo, arXiv: 2002.07280v1



Importance of pion cloud at small q^2

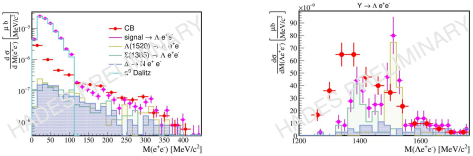
Hyperon electromagnetic/hadronic decays

- Tests VDM hypothesis (coupling to ρ,ω) for hyperons.
- ππ decays complementary to dileptons.



- Independent Λ(1520) reconstruction via $\Lambda\pi^-\pi^+$ decay (BR = 6 %), and
- Σ(1385) via Λπ (BR = 87 %)

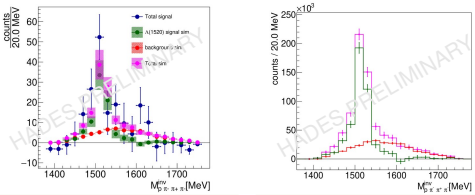
Radiative decay $Y \to \Lambda e^+ e^-$



Projections for HADES with p+p@4.5 GeV; Expected: ~300 events/Y

Hadronic decay $\Lambda(1520) \to \Lambda\pi^+\pi^-$ + X

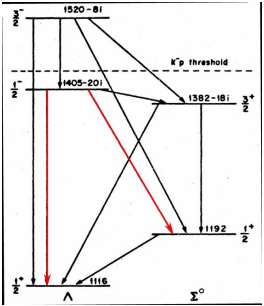
pp → Λ(1520)+X → Λπ⁺π⁻+X



Reference HADES results from p+p@3.5 GeV (t.b.pub.)

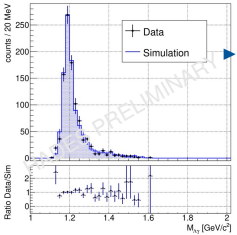
Projections for HADES p+p@4.5 GeV; Expected: ~500k events

Hyperon electromagnetic decays



- Complementary to Dalitz decay
- Y internal structure sensitive to $\Lambda\gamma/\Sigma^0\gamma$ transition rates
- $\Sigma(1385)^0$ and $\Lambda(1520)\to\Lambda\gamma$ measured by CLAS

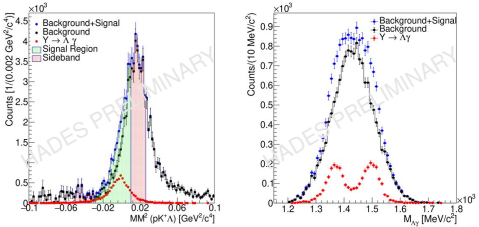
Σ^0 production



- Reconstruction of Σ^0 as reference for Λ production and feed-down in $Y\to\Lambda e^+e^-$

Recent HADES results for $\Sigma^0\to\Lambda\gamma$ with p+p@3.5 GeV (t.b.p)

Radiative decays of $Y\to\Lambda\gamma$



Projections for HADES with p+p@4.5 GeV; Expected: 1500 events

Expected count rates in p+p@4.5 GeV

Electromagnetic hyperon decays ($\Lambda\gamma^*$ and $\Lambda\gamma$)			
$\Sigma(1385)^0 \to \Lambda e^+ e^-$	$\Lambda(1520) \to \Lambda e^+ e^-$	$\Sigma(1385) \to \Lambda\gamma$	$\Lambda(1520) \to \Lambda\gamma$
302	352	1484	1559

Hyperon hadronic decays		
$\Lambda(1405) \to \Sigma^0\pi^0 \to \Lambda\ 3\gamma$	$\Lambda(1405) \to \Sigma^\pm\pi^\mp$	$\Lambda(1520) \to \Lambda\pi^-\pi^+$
3.6×10^4	7.2×10^4	5.2×10^5

Production of double and hidden strangeness		
$\Xi^- \to \Lambda\pi^-$	$\Lambda\Lambda$	$\varphi \to K^+K^-$
$(4.7 - 47.6) \times 10^4$	$(0.62 - 6.17) \times 10^4$	3.1×10^6

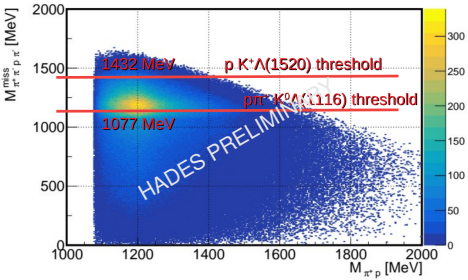
Inclusive measurement of hadrons and dielectrons				
$M_{ee} < 0.15\,\mathrm{GeV}/c^2$	$M_{ee} > 0.15\,\mathrm{GeV}/c^2$	$\omega \to e^+e^-$	$\varphi \to e^+e^-$	$M_{ee} > 1.1\,\mathrm{GeV}/c^2$
5.72×10^6	7.41×10^5	5.8×10^4	1.86×10^3	69

Eur. Phys. J. A (2021) 57: 138

$\Lambda(1520)$ production at 3.5 GeV – reference for dilepton decay channel

p+p@3.5 GeV and p+Nb@3.5 GeV beams (2007)

- production via p+p→pK$^+\Lambda(1520)[\Lambda\pi^+\pi^-]$
- $\Lambda\pi^+\pi^-$ threshold is 220 MeV below total energy for p+p
- inclusive analysis of p$\pi^-\pi^+\pi^-$ final state
- dominating backgroud from $\Delta^{++}\pi^-\Delta^{++}\pi^-$ channel
- also from p+p→$\Lambda[p\pi^-]K^0[\pi^+\pi^-]p\pi^+$



$\Lambda(1520)$ production at 3.5 GeV – reference for dilepton decay channel

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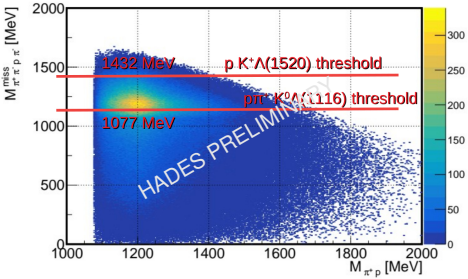
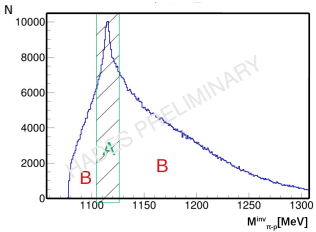
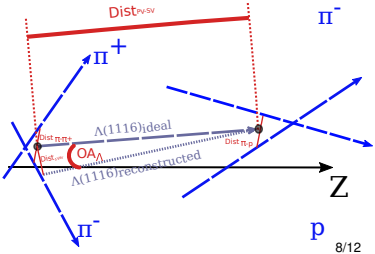


Λ selection



- TMVA based selection
- A set - $M \in (1015, 1025)$
- B set - outside above
- no simulations required



$\Lambda(1520)$ production at 3.5 GeV – reference for dilepton decay channel

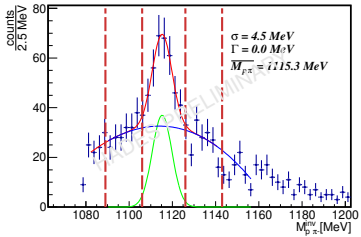
Λ selection

- topological cuts selected by TMVA

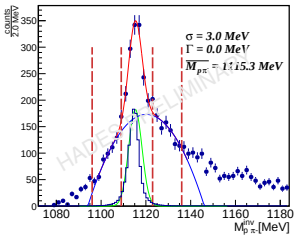
$\Lambda(1520)$ selection

- sideband analysis for $\Lambda(1520)$ signal

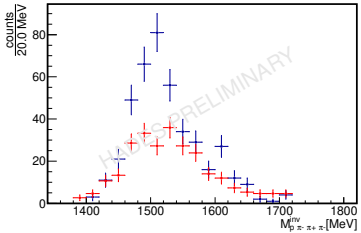
Λ in p+p



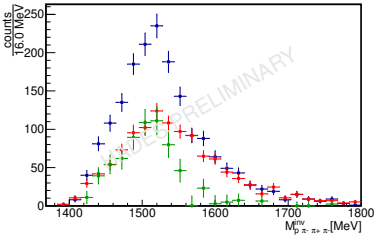
Λ in p+Nb



$\Lambda\pi^-\pi^+$ in p+p



$\Lambda\pi^-\pi^+$ in p+Nb



Cross-sections normalizations

p+p

- data driven model

J. Aamczewski-Musch et al. (HADES), Phys. Rev. C 95, 015207 (2017)

no.	Channel	σ [μb]
	3-body reactions	
1	$\Lambda(1520)pK^+$	$5.6 \pm 1.1 \pm 0.4^{+1.1}_{1.6}$
2	$\Lambda\Delta^{++}K^0$	$29.45 \pm 0.08^{+1.67}_{-1.46} \pm 2.06$
3	$\Sigma^0\Delta^{++}K^0$	$9.26 \pm 0.05^{+1.41}_{0.31} \pm 0.65$
4	$\Sigma(1385)^+pK^0$	$14.05 \pm 0.05^{+1.79}_{-2.14} \pm 1.00$
5	$\Delta^{++}\ \Lambda(1405)K^0$	$5.0 \pm 20\%$
6	$\Delta^{++}\Sigma(1385)^0K^0$	$3.5 \pm 20\%$
7	$\Delta^+\Sigma(1385)^0K^0$	$2.3 \pm 20\%$
	4-body reactions	
8	$\Lambda p\pi^+K^0$	$2.57 \pm 0.02^{+0.21}_{-1.98} \pm 0.18$
9	$\Sigma^0p\pi^+K^0$	$1.35 \pm 0.02^{+0.10}_{-1.35} \pm 0.09$

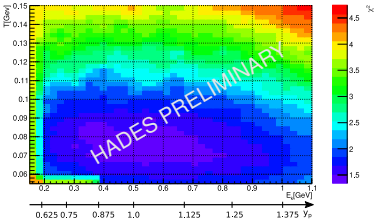
p+Nb

- with use of UrQMD model

G. Agakishiev et al. (HADES) Eur. Phys. J. A. 50 (2014)

- no $\Lambda(1520)$ production included
- but non-resonant $\Lambda\pi^-\pi^+$ can be simulated
- $\Lambda(1520)$ simulated with thermal source from Pluto:
- $\rightarrow$ a static (not expanding) thermal source characterized by temperature T_s = 75 MeV and rapidity y_s = 1.04

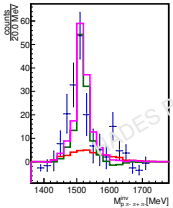
The ch2 test for a different thermal source parameters

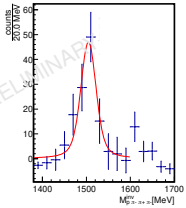


$\Lambda(1520)$ candidates

p+p

- red – non-resonant $\Lambda\pi^+\pi^-$ background
- green – $\Lambda(1520)$ signal





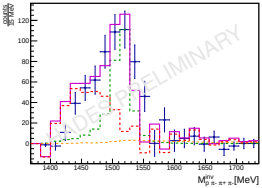
	$M_{\Lambda(1520)}$ [MeV/c^2]	$\sigma_{\Lambda(1520)}$ [MeV/c^2]
PDG	1519.5 ± 1.0	not appl.
p+p	1504.5 ± 4.7	14.7 ± 6.7
sim	1515.6 ± 2.1	11.3 ± 3.6

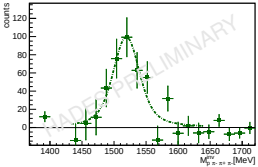
$$\sigma_{p+p\to\Lambda(1520)X} = 7.1 \pm 1.1 \pm {}^{0.0}_{2.14}\ \mu b$$

p+Nb

- red – URQMD non-resonant $\Lambda\pi^+\pi^-$ background
- green – $\Lambda(1520)$ signal
- orange – $\Sigma(1385)$ signal

of $\Lambda(1520)$	M [MeV/c^2]	σ [MeV/c^2]	Γ [MeV/c^2]
p+p	1504.5 ± 4.7	14.7 ± 6.7	15.6 ± 1.0
p+Nb	1507.7 ± 3.3	14.7 ± 6.7	34.6 ± 5.2

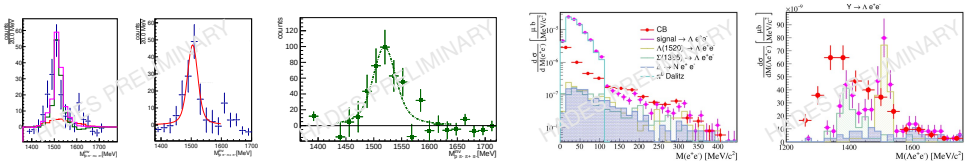




$$\sigma_{p+Nb\to\Lambda(1520)X} = 4.97 \pm 0.45 \pm {}^{3.58}_{2.53}\ mb$$

Summary

- Hades can provide first data of hyperon Dalitz decay
- The 3.5 GeV (2007) data provide reference measurements of $\Lambda(1520) \rightarrow \Lambda\pi^+\pi^-$
- The 4.5 GeV (2022) data will allow for the first hyperon Dalitz decays of $\Lambda(1520)$ and $\Sigma(1385)$



- $\Lambda(1520)$ from 3.5 GeV paper is being written, expect it for 2023
- First hyperon Dalitz data from p+p@4.5 GeV to be also expected in 2023, stay tuned