Review of the strangeness physics programme at HADES
Past and future perspectives

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Warszawa
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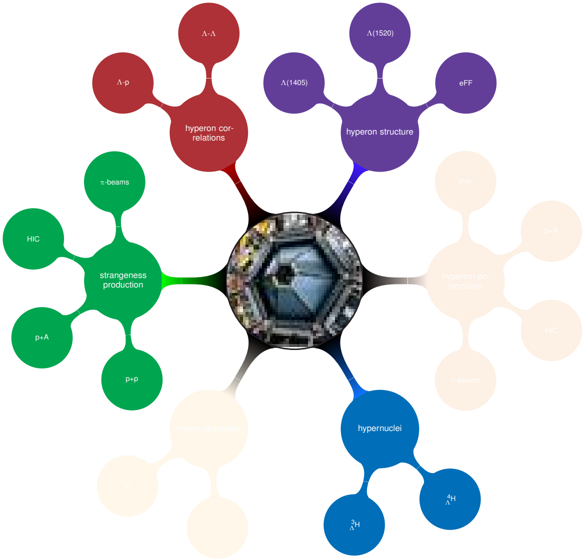
Λ-Λ
Λ-p
hyperon correlations
Λ(1520)
Λ(1405)
eFF
hyperon structure
π-beams
HIC
strangeness production
p+A
p+p
p+p
p+A
hyperion polarization
HIC
π-beams
meson absorption
K
φ
hypernuclei
$^{3}_{\Lambda}$H
$^{4}_{\Lambda}$H

HADES strangeness programme



Outline

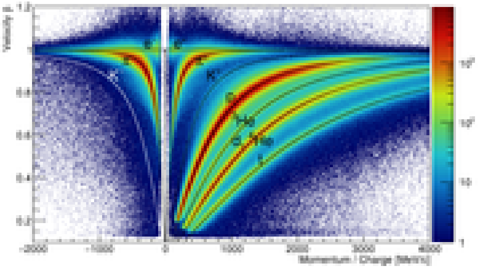
Heavy Ions Collisions

p+p at 3.5 GeV

p+p at 4.5 GeV

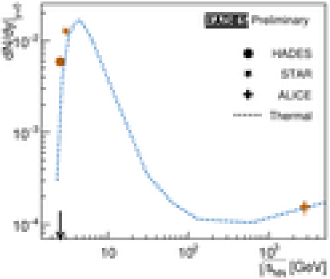
Hades

Summary



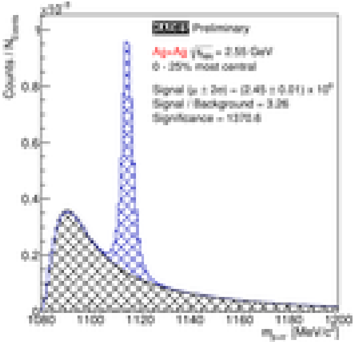
- 2012: Au+Au @ 1.23 AGeV ($\sqrt{s_{NN}}$ = 2.42 GeV)
  7 billion events
- 2019: Ag+Ag @ 1.58 AGeV ($\sqrt{s_{NN}}$ = 2.55 GeV)
  14 billion events

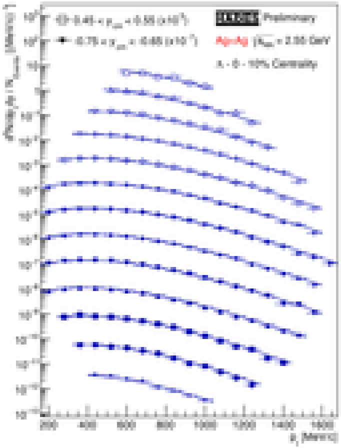
- Strangenes production close to free NN threshold:
  $N+N \rightarrow Y+N+K$ – $\sqrt{s_{NN}}$ = 2.55 GeV
  $N+N \rightarrow N+N+K+\overline{K}$ – $\sqrt{s_{NN}}$ = 2.86 GeV
- Strangeness exchange process:
  $Y+\pi \rightarrow N+\overline{K}$

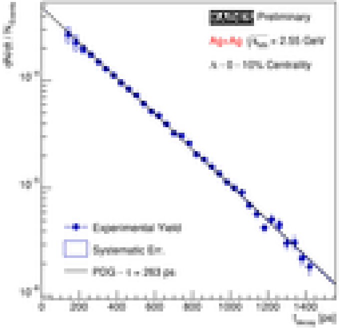


- Production of Hypernuclei favored by baryon dominance of the fireball:
  1. Produce Λ
  2. Λ must find nucleons
- Sweet spot for hypernuclei production is below 10 GeV – FAIR energies

Λ hyperon in Ag+Ag

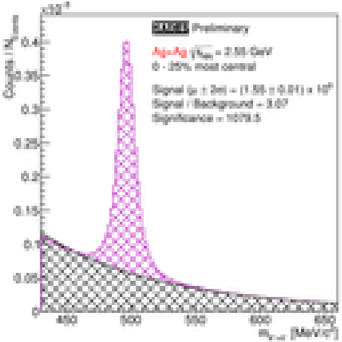


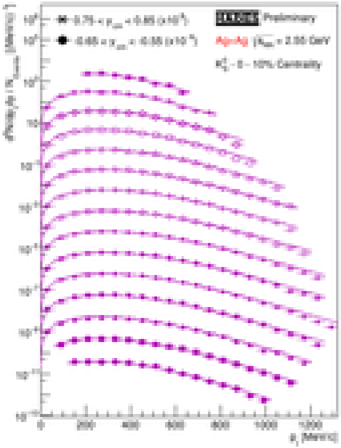


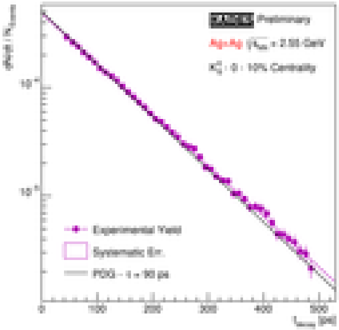


$\tau = 262 \pm 2 \pm 3$ ps
compatible with PDG

K^0 meson in Ag+Ag







τ = 91 ± 1 ± 1 ps
compatible with PDG

hypertriton – ${}^{3}_{\Lambda}$H

- mass = 2991 MeV c^{-2}
- binding energy $B({}^{3}_{\Lambda}\mathrm{H})$ = 0.79 MeV/A
- decay branches:

decay channel	BR [%]
${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$	27
${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \pi^{0}$	13
${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{p} + \pi^{-}$	40
${}^{3}_{\Lambda}\mathrm{H} \rightarrow \mathrm{d} + \mathrm{n} + \pi^{0}$	20

- world average lifetime 211 ± 9 ps

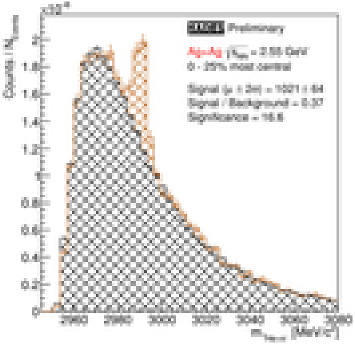
hyperhydrogen-4 – ${}^{4}_{\Lambda}$H

- mass = 3923 MeV c^{-2}
- binding energy $B({}^{4}_{\Lambda}\mathrm{H})$ = 2.63 MeV/A ≈ 3.3 $\mathrm{B}({}^{3}_{\Lambda}\mathrm{H})$
- decay branches:

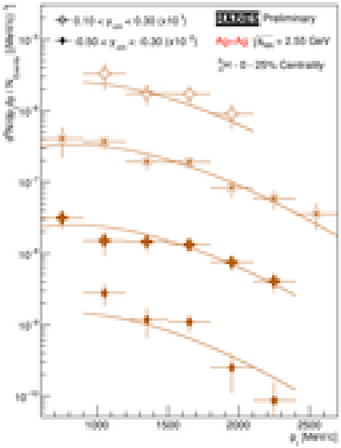
decay channel	BR [%]
${}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$	50
${}^{4}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \mathrm{p} + \pi^{-}$	33
${}^{4}_{\Lambda}\mathrm{H} \rightarrow \mathrm{t} + \mathrm{n} + \pi^{0}$	17

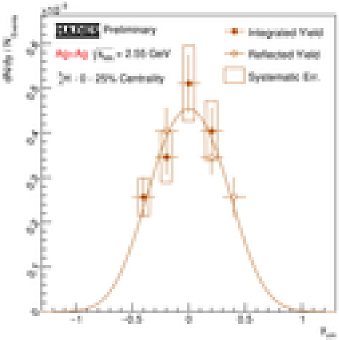
- world average lifetime 218 ± 5 ps

Hypertriton in HIC: ${}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$

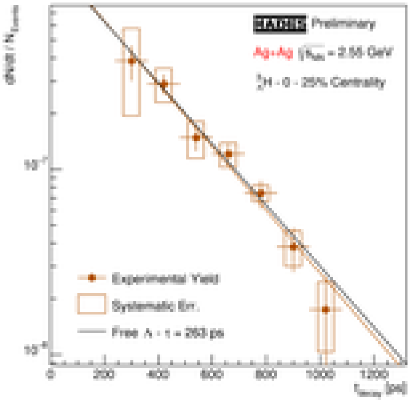


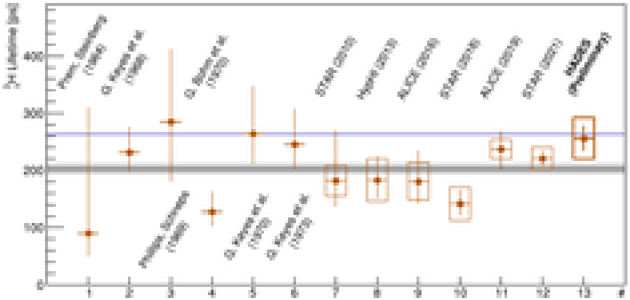
Multidifferential analysis possible





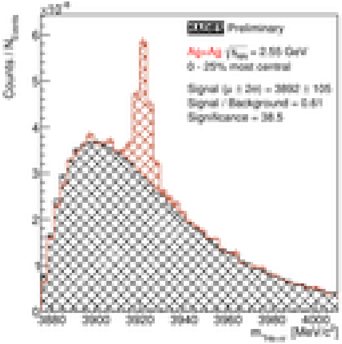
First measurement at mid-rapidity at this energy



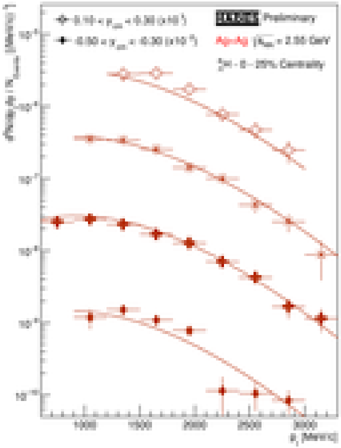


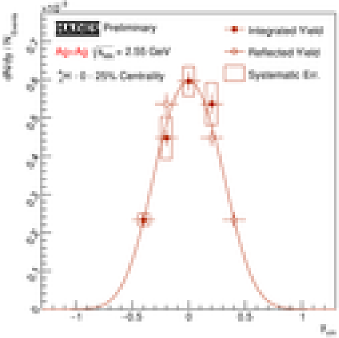
lifetime of 256 ± 22 ± 36 ps compatible with free Λ

Hyperhydrogen-4 in HIC: ${}^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$

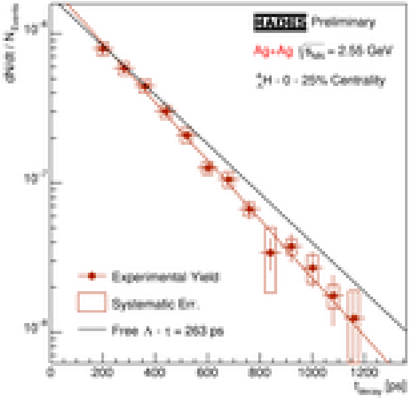


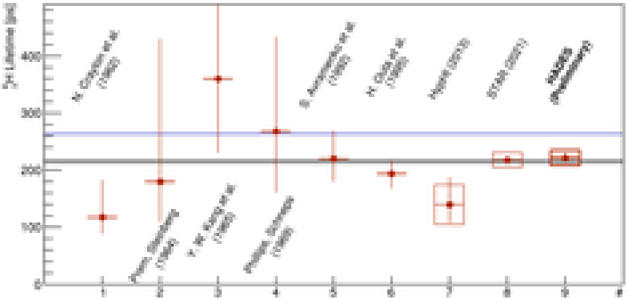
Multidifferential analysis possible



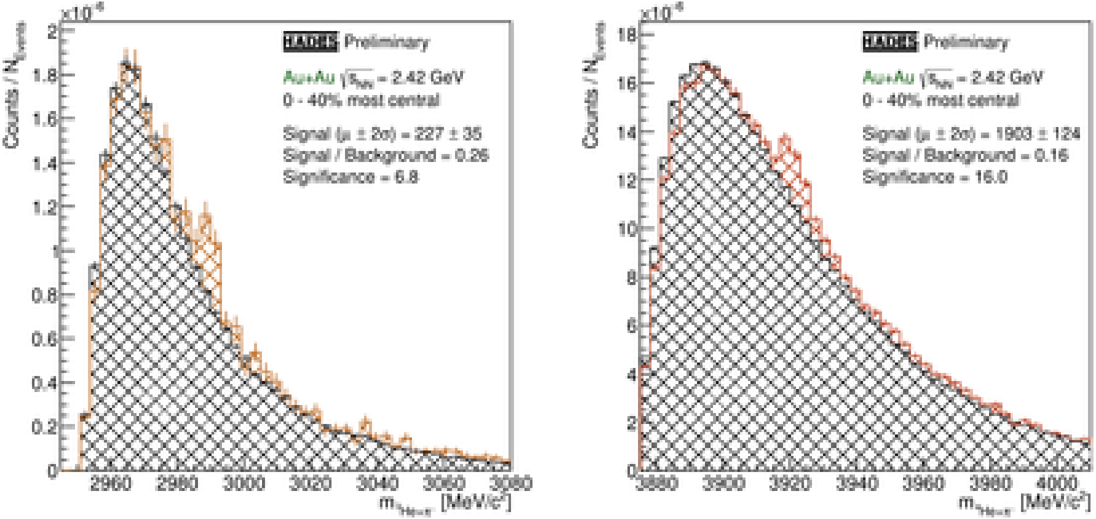


First measurement at mid-rapidity at this energy





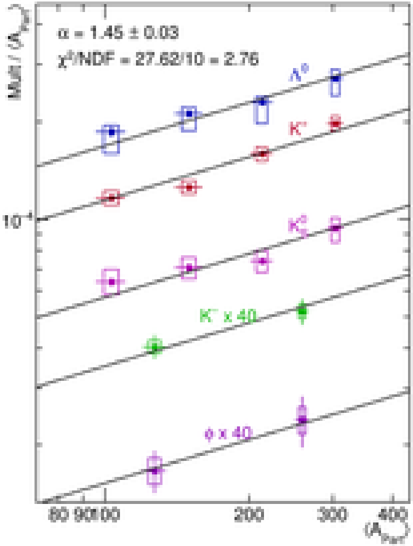
lifetime of 222 ± 8 ± 13 ps compatible with earlier measurements



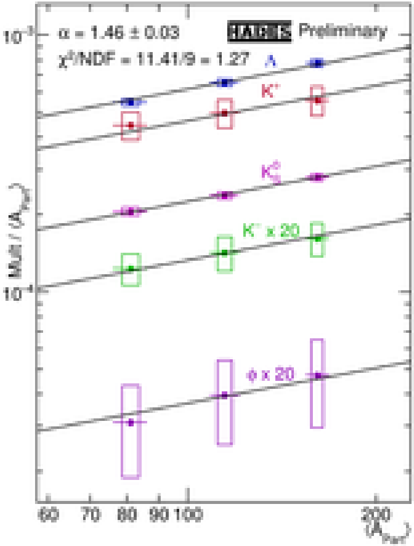
Lowest energy at which Hypernuclei were ever reconstructed in HIC

Strangeness yields

Au+Au: PLB 793 (2019) 457-463

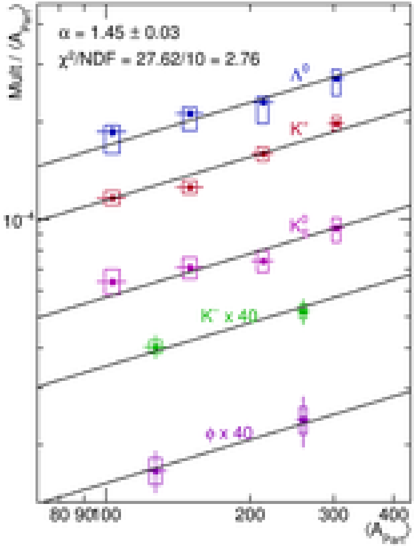


Ag+Ag

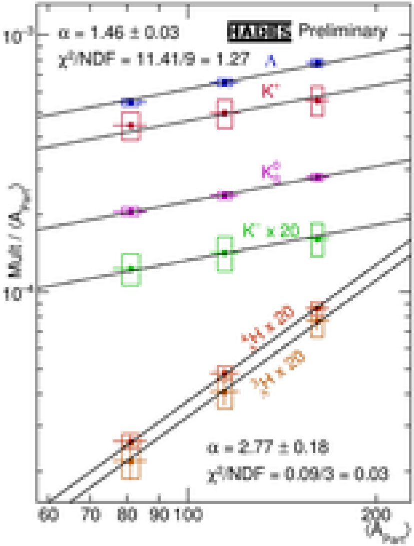


Strangeness yields

Au+Au: PLB 793 (2019) 457-463



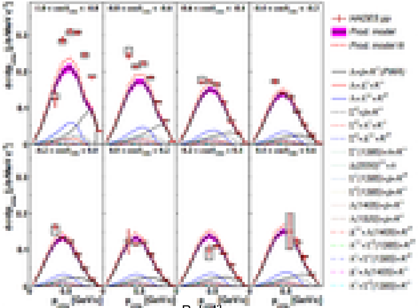
Ag+Ag



Outline

id	pp→ reaction	$\sigma_i^{(id)}$ cross section [μb]	∡ var.	∡(a_2, a_4)		H	notes	fit result	
		3-body channels							
1	$\Lambda p K^+$	$35.26 \pm 0.43\ ^{+3.55}_{-2.83}$	σ_{Λ}^{cms}	0.798	0.134	✓	[16]	38.835 ± 0.026	T
2	$\Sigma^0 p K^+$	$16.5 \pm 20\,\%$	$\sigma_{\Sigma^0}^{cms}$	0.034 ± 0.241	—		[21] + calc.	19.800 ± 0.094	T
3	$\Lambda \Delta^{++} K^0$	$29.45 \pm 0.08\ ^{+1.67}_{-1.46} \pm 2.06$	$\sigma_{\Delta^{++}}^{cms}$	1.49 ± 0.3	—	✓	[13]	32.10 ± 0.11	T
4	$\Sigma^0 \Delta^{++} K^0$	$9.26 \pm 0.05\ ^{+1.41}_{-0.31} \pm 0.65$	$\sigma_{\Delta^{++}}^{cms}$	0.08 ± 0.02	—	✓	[13]	8.5 ± 2.1	⊥
5	$\Lambda \Delta^{+} K^+$	$9.82 \pm 20\,\%$	$\sigma_{\Delta^{+}}^{cms}$	from $\Lambda \Delta^{++} K^0$			res. mod.	11.78 ± 0.15	T
6	$\Sigma^0 \Delta^{+} K^+$	$3.27 \pm 20\,\%$	$\sigma_{\Delta^{+}}^{cms}$	from $\Sigma^0 \Delta^{++} K^0$			res. mod.	2.6 ± 1.3	⊥
7	$\Sigma(1385)^+ n K^+$	$22.42 \pm 0.99 \pm 1.57\ ^{+3.04}_{-2.23}$	$\sigma_{\Sigma^{+*}}^{cms}$	1.427 ± 0.3	0.407 ± 0.108	✓	[17]	17.905 ± 0.075	⊥
8	$\Delta(2050)^{++} n$	33 % feeding for $\Sigma^* n K^+$	σ_{n}^{cms}	1.27	0.35	✓	[17]	8.82 ± 0.13	T
9	$\Sigma(1385)^+ p K^0$	$14.05 \pm 0.05\ ^{+1.79}_{-2.14} \pm 1.00$	$\sigma_{\Sigma^{+*}}^{cms}$	1.42 ± 0.3	—	✓	[13]	16.101 ± 0.072	T
10	$\Sigma(1385)^0 p K^+$	$6.0 \pm 0.48\ ^{+1.94}_{-1.06}$	$\sigma_{\Sigma^{0*}}^{cms}$	from $\Sigma(1385)^+ n K^+$		✓	[17]	7.998 ± 0.069	T
11	$\Lambda(1405) p K^+$	$9.2 \pm 0.9 \pm 0.7\ ^{+3.3}_{-1.0}$	—	—	—	✓	[18]	7.7 ± 3.0	⊥
12	$\Lambda(1520) p K^+$	$5.6 \pm 1.1 \pm 0.4\ ^{+1.1}_{-1.6}$	—	—	—	✓	[18]	7.2 ± 3.6	T
13	$\Delta^{++} \Lambda(1405) K^0$	$5.0 \pm 20\,\%$	—	—	—		[23]	6.0 ± 1.6	T
14	$\Delta^{++} \Sigma(1385)^0 K^0$	$3.5 \pm 20\,\%$	—	—	—		[23]	4.90 ± 0.46	T
15	$\Delta^{+} \Sigma(1385)^+ K^0$	$2.3 \pm 20\,\%$	—	—	—		[23]	3.2 ± 1.1	T
16	$\Delta^{+} \Lambda(1405) K^+$	$3.0 \pm 20\,\%$	—	—	—		compl. to above	4.2 ± 1.9	T
17	$\Delta^{+} \Sigma(1385)^0 K^+$	$2.3 \pm 20\,\%$	—	—	—		compl. to above	3.2 ± 1.1	T
		4-body channels							
18	$\Lambda p \pi^+ K^0$	$2.57 \pm 0.02\ ^{+0.21}_{-1.98} \pm 0.18$		—		✓	[13]	2.8 ± 1.5	T
19	$\Lambda n \pi^+ K^+$	from $\Lambda p \pi^+ K^0$		—				2.8 ± 1.5	T
20	$\Lambda p \pi^0 K^+$	from $\Lambda p \pi^+ K^0$		—				2.8 ± 1.4	T
21	$\Sigma^0 p \pi^+ K^0$	$1.35 \pm 0.02\ ^{+0.10}_{-1.35} \pm 0.09$		—		✓	[13]	1.48 ± 0.76	T
22	$\Sigma^0 n \pi^+ K^+$	from $\Sigma^0 p \pi^+ K^0$		—				1.48 ± 0.84	T
23	$\Sigma^0 p \pi^0 K^+$	from $\Sigma^0 p \pi^+ K^0$		—				1.48 ± 0.75	T

id	pp→ reaction	$\sigma_{i}^{(id)}$ cross section [μb]	∡ var.	∡(a_2, a_4)		H	notes	fit result	
			3-body channels						
1	ΛpK^+	$35.26 \pm 0.43\ ^{+3.55}_{-2.83}$	σ_{Λ}^{cms}	0.798	0.134	✓	[16]	38.835 ± 0.026	$\top$
2	$\Sigma^0 pK^+$	$16.5 \pm 20\,\%$	$\sigma_{\Sigma^0}^{cms}$	0.034 ± 0.241	—		[21] + calc.	19.800 ± 0.094	$\top$
3	$\Lambda\Delta^{++}K^0$	$29.45 \pm 0.08\ ^{+1.67}_{-1.46} \pm 2.06$	$\sigma_{\Delta^{++}}^{cms}$	1.49 ± 0.3	—	✓	[13]	32.10 ± 0.11	$\top$
4	$\Sigma^0\Delta^{++}K^0$	$9.26 \pm 0.05\ ^{+1.41}_{-0.31} \pm 0.65$	$\sigma_{\Delta^{++}}^{cms}$	0.08 ± 0.02	—	✓	[13]	8.5 ± 2.1	$\perp$
5	$\Lambda\Delta^{+}K^+$	$9.82 \pm 20\,\%$	$\sigma_{\Delta^{+}}^{cms}$	from $\Lambda\Delta^{++}K^0$			res. mod.	11.78 ± 0.15	$\top$
6	$\Sigma^0\Delta^{+}K^+$	$3.27 \pm 20\,\%$	$\sigma_{\Delta^{+}}^{cms}$	from $\Sigma^0\Delta^{++}K^0$			res. mod.	2.6 ± 1.3	$\perp$
7	$\Sigma(1385)^+ nK^+$	$22.42 \pm 0.99 \pm 1.57\ ^{+3.04}_{-2.23}$	$\sigma_{\Sigma^{+*}}^{cms}$	1.427 ± 0.3	0.407 ± 0.108	✓	[17]	17.905 ± 0.075	$\perp$
8	$\Delta(2050)^{++}n$	33 % feeding for $\Sigma^* nK^+$	σ_{n}^{cms}	1.27	0.35	✓	[17]	8.82 ± 0.13	$\top$
9	$\Sigma(1385)^+ pK^0$	$14.05 \pm 0.05\ ^{+1.79}_{-2.14} \pm 1.00$	$\sigma_{\Sigma^{+*}}^{cms}$	1.42 ± 0.3	—	✓	[13]	16.101 ± 0.072	$\top$
10	$\Sigma(1385)^0 pK^+$	$6.0 \pm 0.48\ ^{+1.94}_{-1.06}$	$\sigma_{\Sigma^{0*}}^{cms}$	from $\Sigma(1385)^+ nK^+$		✓	[17]	7.998 ± 0.069	$\top$
11	$\Lambda(1405)pK^+$	$9.2 \pm 0.9 \pm 0.7\ ^{+3.3}_{-1.0}$					[18]	7.7 ± 3.0	$\perp$
12	$\Lambda(1520)pK^+$	$5.6 \pm 1.1 \pm 0.4\ ^{+1.1}_{-1.6}$					[18]	7.2 ± 3.6	$\top$
13	$\Delta^{++}\Lambda(1405)K^0$	$5.0 \pm 20\,\%$					[23]	6.0 ± 1.6	$\top$
14	$\Delta^{++}\Sigma(1385)^0K^0$	$3.5 \pm 20\,\%$					[23]	4.90 ± 0.46	$\top$
15	$\Delta^{+}\Sigma(1385)^+K^0$	$2.3 \pm 20\,\%$					[23]	3.2 ± 1.1	$\top$
16	$\Delta^{+}\Lambda(1405)K^+$	$3.0 \pm 20\,\%$					id. to above	4.2 ± 1.9	$\top$
17	$\Delta^{+}\Sigma(1385)^0K^+$	$2.3 \pm 20\,\%$					id. to above	3.2 ± 1.1	$\top$
18	$\Lambda p\pi^+K^0$	$2.57 \pm 0.02\ ^{+0.21}_{-1.98} \pm 0.18$					[13]	2.8 ± 1.5	$\top$
19	$\Lambda n\pi^+K^+$	from $\Lambda p\pi^+K^0$						2.8 ± 1.5	$\top$
20	$\Lambda p\pi^0K^+$	from $\Lambda p\pi^+K^0$						2.8 ± 1.4	$\top$
21	$\Sigma^0 p\pi^+K^0$	$1.35 \pm 0.02\ ^{+0.10}_{-1.35} \pm 0.09$					[13]	1.48 ± 0.76	$\top$
22	$\Sigma^0 n\pi^+K^+$	from $\Sigma^0 p\pi^+K^0$						1.48 ± 0.84	$\top$
23	$\Sigma^0 p\pi^0K^+$	from $\Sigma^0 p\pi^+K^0$						1.48 ± 0.75	$\top$

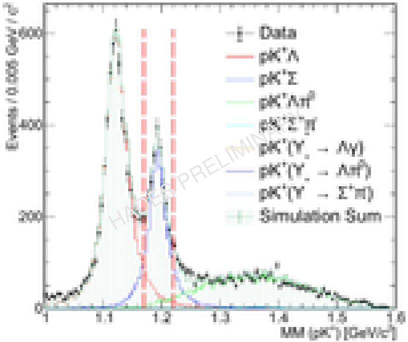


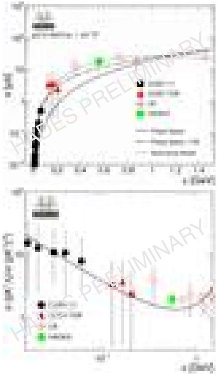
New results from 3.5 GeV – Σ^0 exclusive

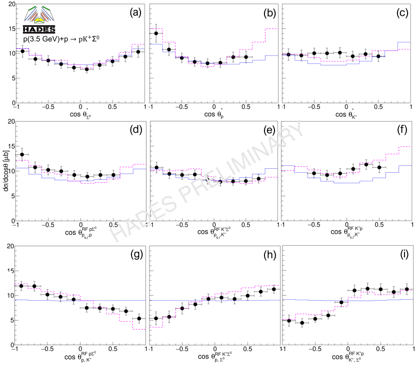
- new reactions are analyzed → new anaylsis tools for HADES are being developped (HADES + PANDA cooperation):

→ Neural networks (K. Sumara, W. Esmail, K. Nowakowski)

→ Kinematic refit (W. Esmail, J. Riegier. J. Regina)





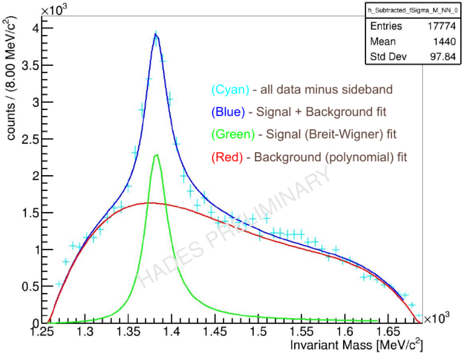


$\sigma(p{+}p \rightarrow pK^+\Sigma^0) = 17.7 \pm 1.7(\text{stat}) \pm 1.6(\text{syst})\ \mu b$

arXiv:2301.11766v1

New results from 3.5 GeV – $\Sigma(1385)^+$ inclusive

Inclusive analysis

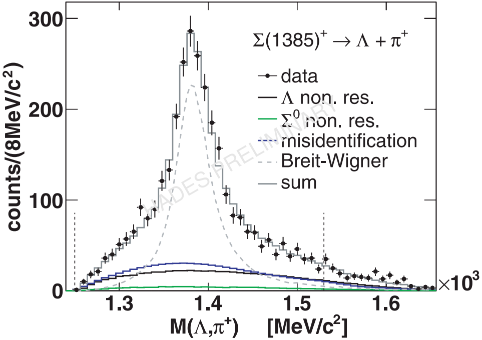


$$M_0 = 1382.96 \pm 0.59 \text{ MeV/c}^2$$

$$\Gamma_0 = 32.7 \pm 1.9 \text{ MeV/c}^2$$

$$\text{Yield} = 15010 \pm 540 \text{ counts}$$

PHYSICAL REVIEW C **85**, 035203 (2012)

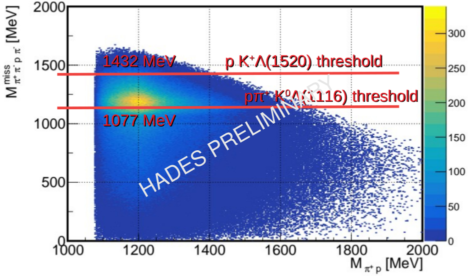


$$\sigma_{p+p\to nK^+\Sigma(1385)^+} = 22.27 \pm 0.89 \pm 1.56^{+3.07}_{-2.10}\ \mu b$$

- data from p+p @3.5 GeV are most important sources for projections for p+p @4.5 GeV

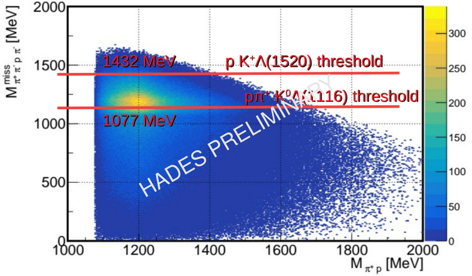
p+p@3.5 GeV and p+Nb@3.5 GeV beams (2007)

- production via p+p$\to$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$\to\Lambda$[pπ^-]K$^0[\pi^+\pi^-]$pπ^+

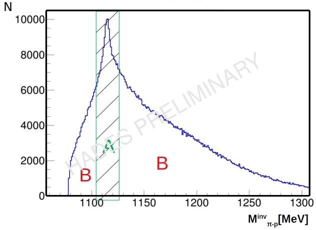


p+p@3.5 GeV and p+Nb@3.5 GeV beams (2007)

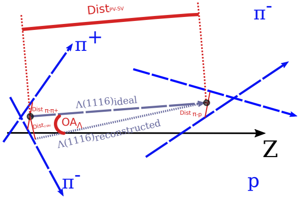
- production via p+p→pK$^+$Λ(1520)[Λ$\pi^+\pi^-$]
- Λ$\pi^+\pi^-$ threshold is 220 MeV below total energy for p+p
- inclusive analysis of p$\pi^-\pi^+\pi^-$ final state
- dominating backgroud from $\Delta^{++}\pi^-\Delta^{++}\pi^-$ channel
- also from p+p→Λ[pπ^-]K^0[$\pi^+\pi^-$]pπ^+



Λ selection



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



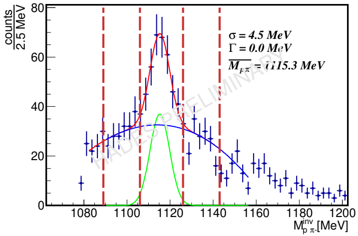
Λ selection

- topological cuts selected by TMVA

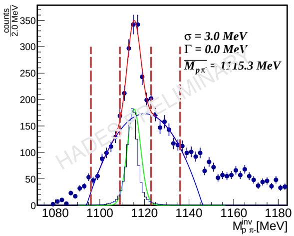
Λ(1520) selection

- sideband analysis for Λ(1520) signal

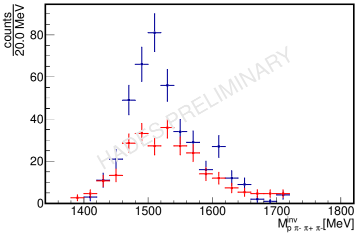
Λ in p+p



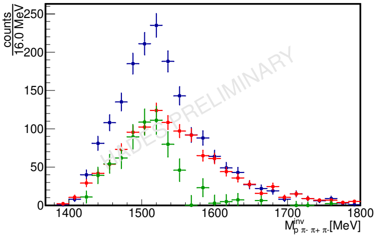
Λ in p+Nb



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



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



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	$\Sigma^0p\pi^+K^0$	$1.35 \pm 0.02^{+0.10}_{-1.35} \pm 0.09$

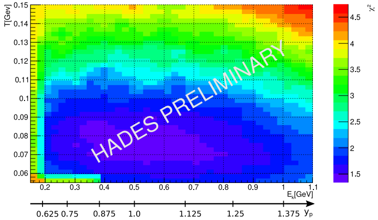
p+Nb

- 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

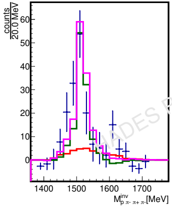
The ch2 test for a different thermal source parameters

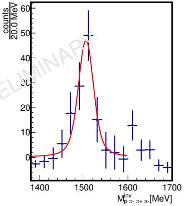


Λ(1520) candidates

p+p

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





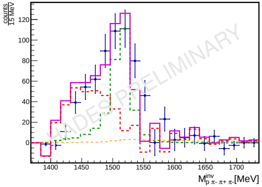
	$M_{\Lambda(1520)}$ [MeV/c^2]	$\sigma_{\Lambda(1520)}$ [MeV/c^2]
PDG	1519.5 ± 1.0	not appl.
p+p	1504.5 ± 4.7	14.7 ± 6.7
sim	1515.6 ± 2.1	11.3 ± 3.6

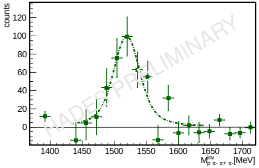
$$\sigma_{p+p\to\Lambda(1520)X} = 7.1 \pm 1.1 \pm {}^{0.0}_{2.14}\ \mu b$$

p+Nb

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

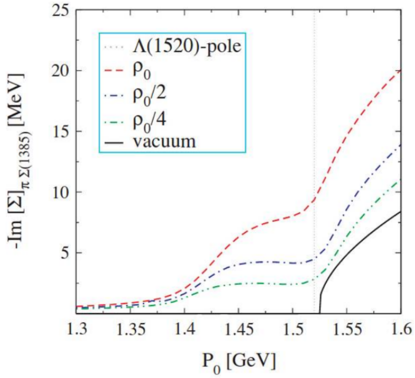
of Λ(1520)	M [MeV/c^2]	σ [MeV/c^2]	[MeV/c^2]
p+p	1504.5 ± 4.7	14.7 ± 6.7	15.6 ± 1.0
p+Nb	1507.7 ± 3.3	14.7 ± 6.7	34.6 ± 5.2



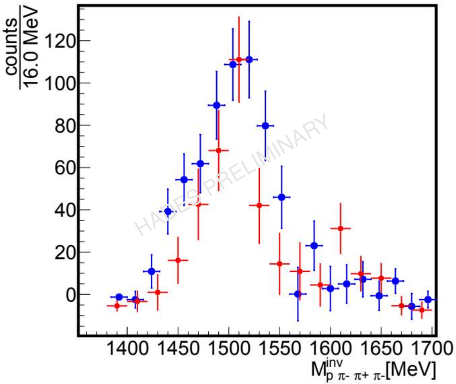


$$\sigma_{p+Nb\to\Lambda(1520)X} = 4.97 \pm 0.45 \pm {}^{3.58}_{2.53}\ mb$$

- is $\Lambda(1520)$ a $\Sigma(1385)\pi$ molecule?
- studies of in-medium modifications of $\Lambda(1405)$



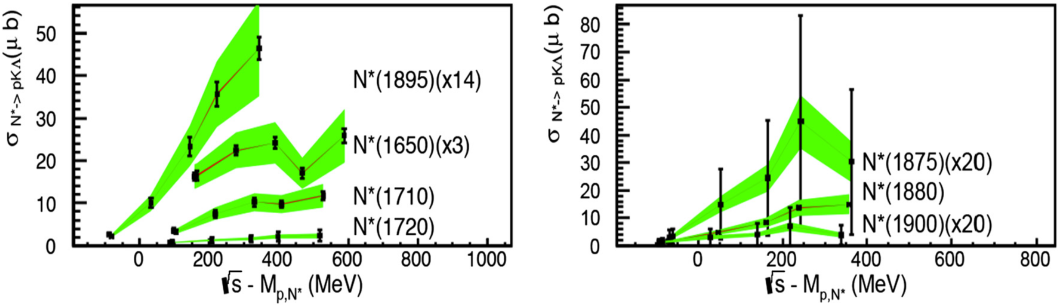
Phys. Rev. C 73, 045213 (2006)



of $\Lambda(1520)$	M [MeV/c^2]	σ [MeV/c^2]	[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

$pK^+\Lambda$ combined PWA analysis

- combined PWA analysis of COSY-TOF, DISTO, FOPI and HADES
- contriution of seven N^* resonances to $pK^+\Lambda$
- 90 % of $pK^+\Lambda$ production gies via resonances



Phys. Lett. B 785, 574-580 (2018)

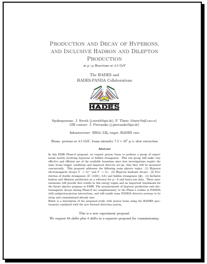
Outline

G-PAC 44: HADES III

Production and decay of hyperons, and inclusive hadron and dilepton production in p+p reaction at 4.5 GeV

1. Hyperon electromagnetic decays $Y \rightarrow \Lambda\gamma^{*}$ and $Y \rightarrow \Lambda\gamma$
2. Hyperon hadronic decays
3. Production of double (Ξ^{-}, $\Lambda\Lambda$) and hidden strangeness (φ)
4. Inclusive hadron and dilepton production as a reference for p+A and heavy-ion data

p+p experiment executed in February-March 2022



PRODUCTION AND DECAY OF HYPERONS, AND INCLUSIVE HADRON AND DILEPTON PRODUCTION

in p+p Reactions at 4.5 GeV

The HADES and HADES-PANDA Collaborations

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Infrastructure: SIS18, LH_2 target, HADES cave

Beam: protons at 4.5 GeV, beam intensity 7.5×10^7 p/s, slow extraction

Abstract

In this FAIR Phase-0 proposal, we request proton beam to perform a group of experiments mostly involving hyperons or hidden strangeness. This run group will make very effective and efficient use of the available beamtime since four investigations require the same beam/trigger conditions and improved detector set-up, thus they will be measured concurrently. This proposal addresses the following main physics topics: (1) Hyperon electromagnetic decays $Y \rightarrow \Lambda\gamma^*$ and $Y \rightarrow \Lambda\gamma$. (2) Hyperon hadronic decays. (3) Production of double strangeness ($\Xi^-(1321)$, $\Lambda\Lambda$) and hidden strangeness (ϕ). (4) Inclusive hadron and dilepton production as a reference for p+A and heavy-ion data. These measurements will provide first results in this energy region and an important benchmark for the future physics program at FAIR. The measurements of hyperon production and electromagnetic decays during Phase-0 are complementary to the Phase-1 studies at PANDA with antiproton-proton interactions, and will enable some PANDA detector systems to be setup and commissioned already now.
Below is a description of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

This is a new experiment proposal.
We request 84 shifts plus 4 shifts in a separate proposal for commissioning.

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article - Experimental Physics

Production and electromagnetic decay of hyperons: a feasibility study with HADES as a phase-0 experiment at FAIR

(HADES collaboration and PANDA@HADES collaboration)

Received: 15 October 2020 / Accepted: 4 February 2021
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Communicated by Frank Maas.

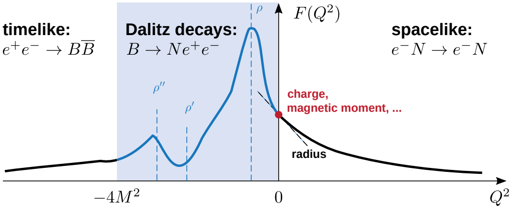
Production and electromagnetic decay of hyperons: a feasibility study with HADES as a Phase-0 experiment at FAIR

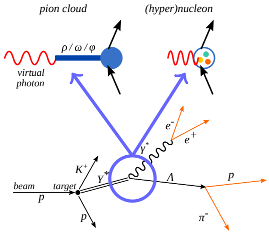
HADES + HADES@PANDA collaborations

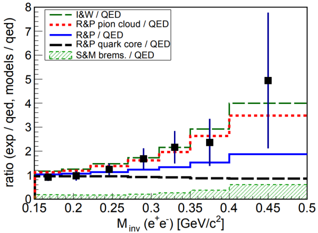
`Eur.Phys.J.A57,138(2021)`

Electromagnetic transitions form-factors (eTFF)

- eTFF are sensitive probes of hyperon internal structure







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

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

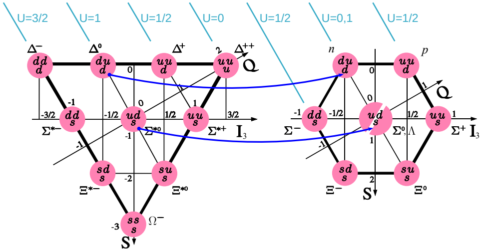
→ Time-like high $|Q^2|$ is probed by electron-positron anihillation (BaBar, CLEO-C, BESIII)

→ Time-like low $|Q^2|$ available via Dalitz decays in HADES, sensitivity to Vector Meson (ρ/ω/φ) – Vector Dominance Model → pion/kaon cloud contributions

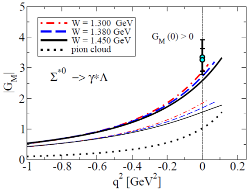
HADES is an excellent experiment for a Dalitz decay measurements

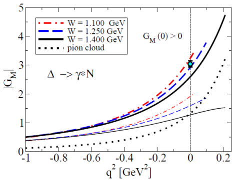
Comparison of strange and non-strange baryons

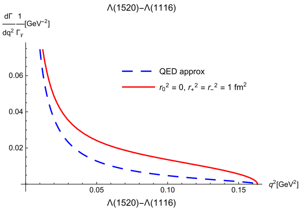
i.e. $\Delta(1232)\to Ne^+e^-$ / $\Sigma(1385)^0\to\Lambda e^+e^-$ and $N^*(1520)\to Ne^+e^-$ / $\Lambda(1520)\to\Lambda e^+e^-$ (flavor sym. partners)

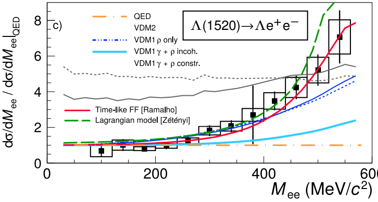


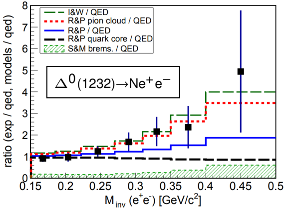
G. Ramahlo, arXiv: 2002.07280v1









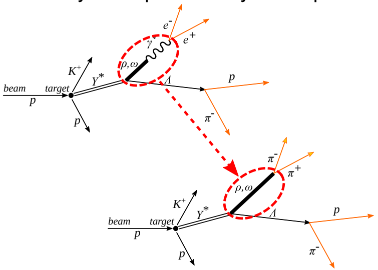


EPJA A 57, 183 (2021)

π^-+p, $\sqrt{s}$ = 1.5 GeV, arXiv:2205.15914v2

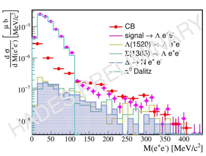
p+p@1.25 GeV, PRC95 (2017) 6, 065205

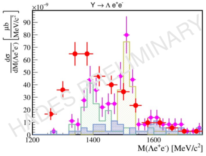
- Tests VDM hypothesis (coupling to ρ,ω) for hyperons.
- $\pi\pi$ decays complementary to dileptons.



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

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

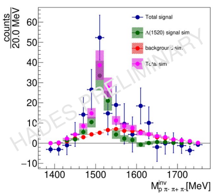


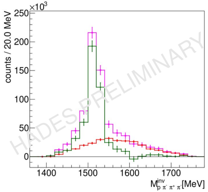


Projections for HADES with p+p @4.5 GeV; Expected: ~300 events/Y

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

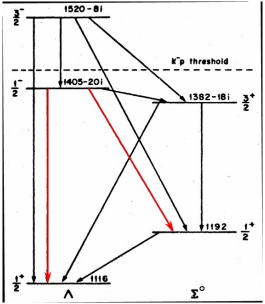
pp → Λ(1520)+X → Λπ⁻π⁺+X





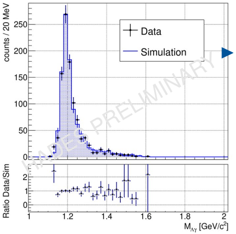
Reference HADES results from p+p @3.5 GeV (t.b.pub.)

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



- 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

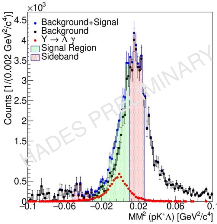
Σ^0 production

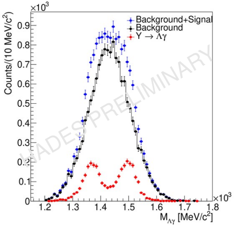


- Reconstruction of Σ^0 as reference for Λ production and feed-down in $Y\to\Lambda e^+e^-$

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

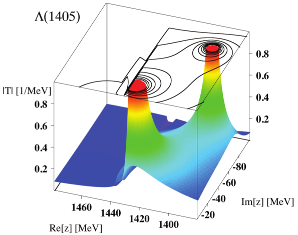
Radiative decays of $Y\to\Lambda\gamma$



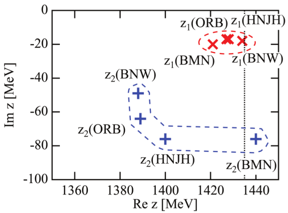


Projections for HADES with p+p @4.5 GeV;
Expected: 1500 events

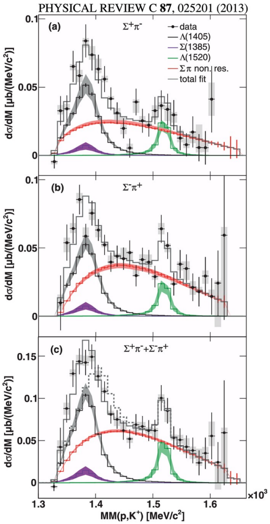
Hyperon hadronic decays - $\Lambda(1405)$



Prog.Part.Nucl.Phys., 67:55–98, 2012.



Phys.Rev., C77:035204, 2008.

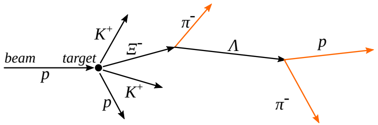


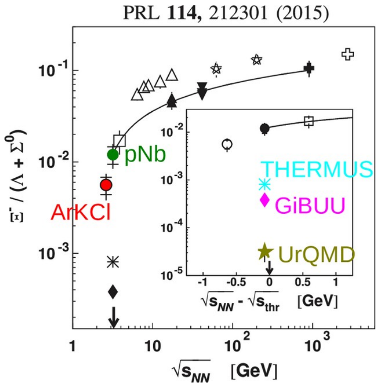
Reference HADES results with p+p @3.5 GeV

- $\Sigma\pi$ decays of $\Lambda(1405)$ are sensitive tests of its structure
- Line shape of $\Lambda(1405)$ ruled by two poles:
  - Σ-π (pp beams [HADES, ANKE])
  - K-N (K beams [LEPS] and electro-production [CLAS])
- $\Lambda(1405)$ measured in HADES in pp@3.5 GeV via $\Sigma^{\pm}\pi^{\mp}$
- $\Sigma^{\pm}\pi^{\mp}$ also allowed for $\Sigma(1385)^{+}$ → overlap of mass peaks
- ECAL allows to measure $\Lambda(1405)$ via $\Sigma^0\pi^0 \to p\pi^-3\gamma$, which is not allowed for $\Sigma(1385)^0$
- HADES can improve statistical precision by two orders of magnitude

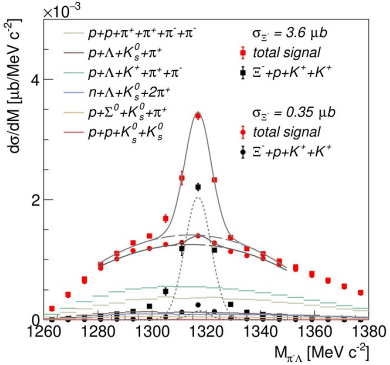
Double strangeness reactions – Ξ^- production

- Motivated by HADES-puzzle of Ξ^- enhancement in p+Nb and Ar+KCl
- Production through intermediate high mass (>2 GeV c^{-2}) baryonic or hyperon resonance ?? → pp data needed



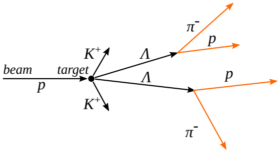


Reference HADES results with p+Nb @3.5 GeV and Ar+KCl @1.76 GeV

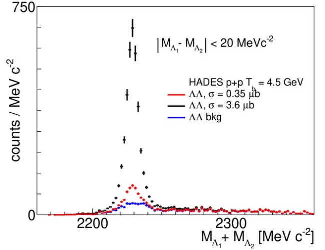


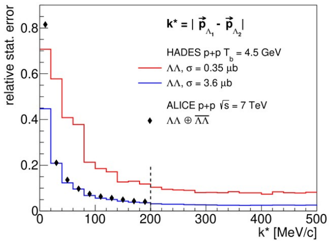
Projections for HADES with p+p @4.5 GeV

Double strangeness reactions – ΛΛ production



- Sensitive to Y-N and Y-Y interaction
- Complementary to PANDA program of ΛΛ at p+$\overline{\text{p}}$
- HADES measured pΛ correlations (Phys.Rev. C94 (2016) no.2, 025201), coherent studies with ALICE for pΛ and ΛΛ (Phys. Rev. C 99, 024001)
- ALICE identified 6M Λ and $\overline{\Lambda}$, but only a small fraction in the interesting region of $k^{?} < 200\,\text{MeV}\,c^{-1}$
- In HADES smaller contribution from feed-down of higher excited states, and smaller source-size corrections





Projections for HADES with p+p @4.5 GeV

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

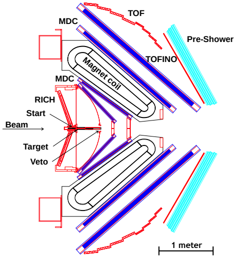
Inclusive measurement of hadrons and dielectrons				
$M_{ee} < 0.15\,\mathrm{GeV}/c^2$	$M_{ee} > 0.15\,\mathrm{GeV}/c^2$	$\omega \to e^+ e^-$	$\varphi \to e^+ e^-$	$M_{ee} > 1.1\,\mathrm{GeV}/c^2$
5.72×10^6	7.41×10^5	5.8×10^4	1.86×10^3	69

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

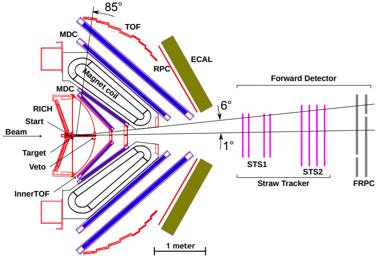
Outline

HADES – High Acceptance Dielectron Spectrometer

HADES in 2007



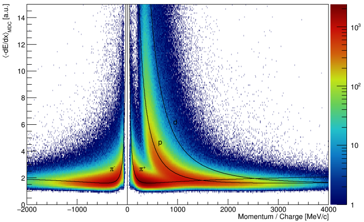
HADES in 2022

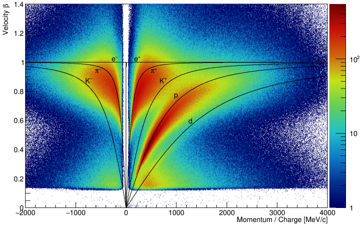


Major HADES upgrades:

- 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



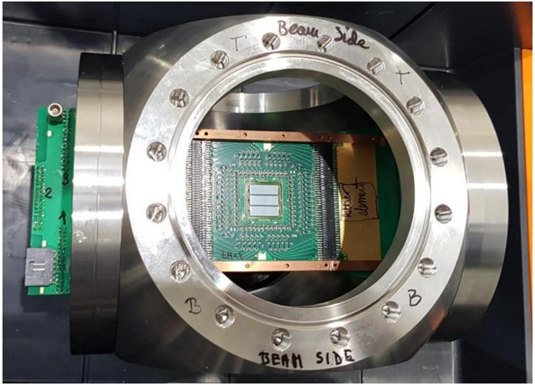


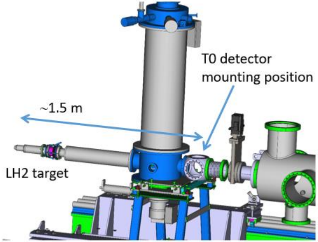
Previous experiments:

- 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)

START system

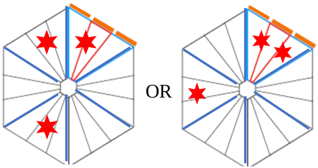
Low Gain Avalanche Detectors for the HADES reaction time (T) detector upgrade
(Eur. Phys. J. A (2020) 56: 183)

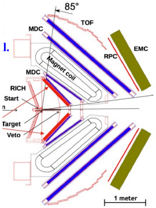


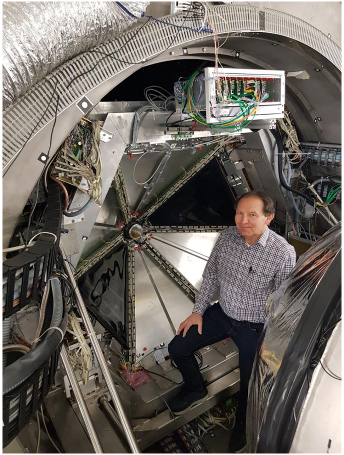


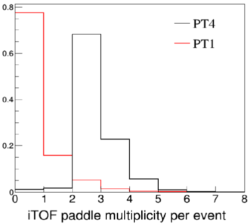
- timing < 100 ps
- PCB in the beam vacuum
- rate capability 10^8 p/s
- 2 cm x 2 cm, 96 channels
- pitch 387 µm

- new trigger detector
- main goal – suppres empty events in HADES
- can also serve as a secondary T0





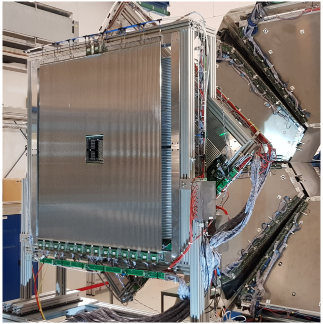




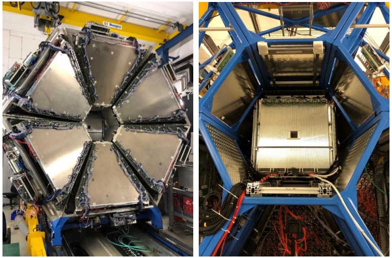
PT1: HADES META MULT >= 2
PT4: HADES META MULT && ITOF

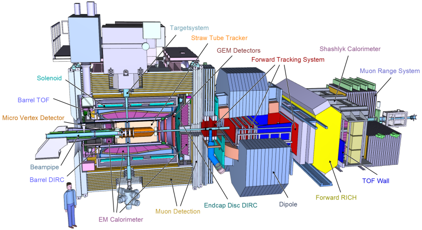
STS1

STS2



STS1 installation in ECAL frame





- FZ Juelich/IPN Orsay
- 704 straws
- PANDA-STS straws

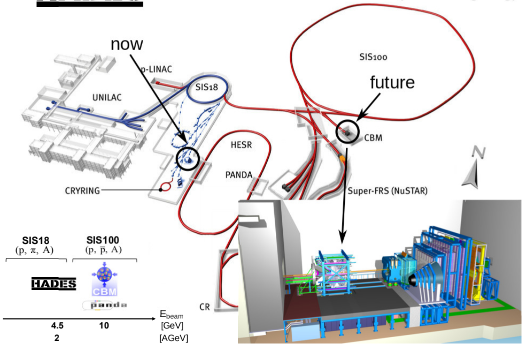
- UJ Kraków
- 1024 straws
- PANDA-FT straws

Also:

- INP FAS – gas system for HADES FD/PANDA FT

Outline

HADES - first detector of FAIR Phase-0 (2018-ongoing)



- HADES has rich hyperon program in HIC and elementary reactions.
- HADES has unique dilepton and hadron measurement capabilities.
- HADES can provide first data of hyperon Dalitz decay.