Review of strangeness production in elementary collisions at HADES

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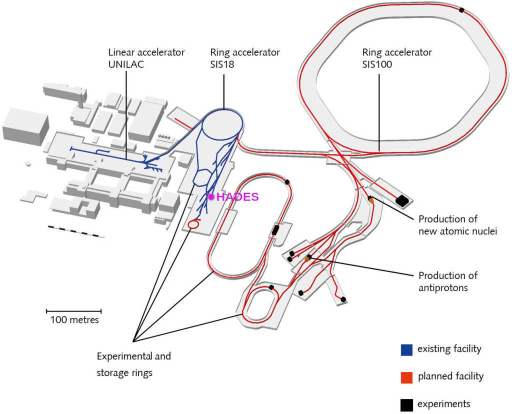
HADES

HADES – High Acceptance Dielectron Spectrometer @ GSI/FAIR

© J. Hosan, GSI/FAIR



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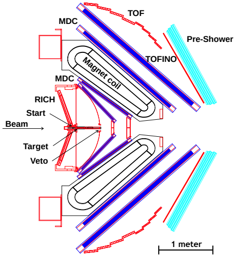
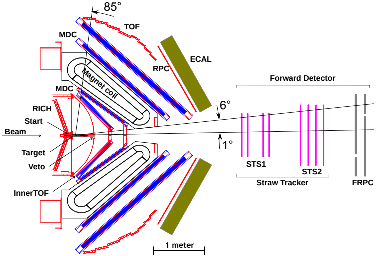
HADES experiments

HADES in 2007



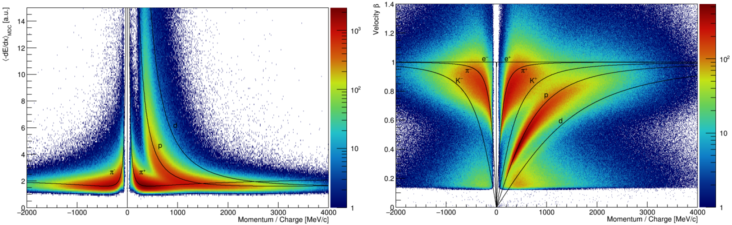
HADES in 2022



Major HADES upgrades:

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

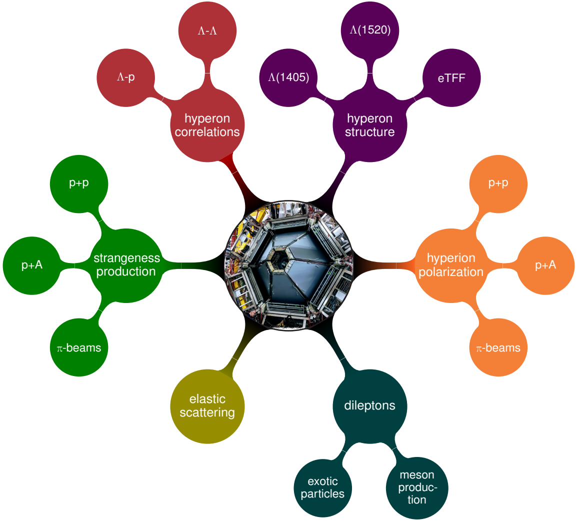
Particle identification: dEdx, β vs momentum



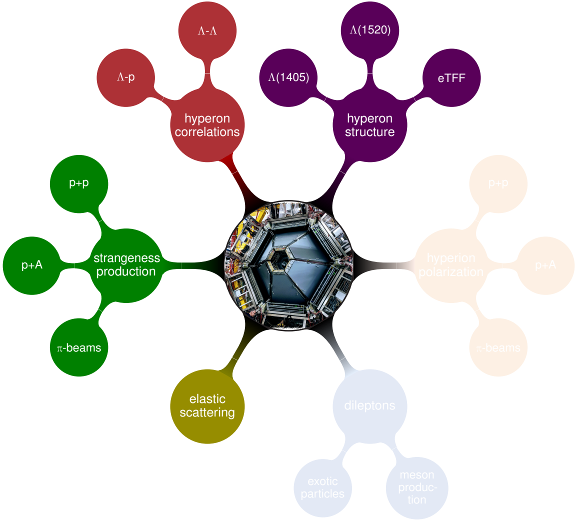
Previous experiments:

- various HI beams (Ar+KCl, Au+Au, Ag+Ag, C+C)
- 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)

HADES elementary programme



HADES elementary programme



id	pp→ reaction	$\sigma_0^{(\mathrm{id})}$ cross section [µb]	∡ var.	∡(a_2, a_4)		H	notes	fit result	
		3-body channels							
1	$\Lambda p K^+$	$35.26 \pm 0.43\ ^{+3.55}_{-2.83}$	θ^{cms}_{Λ}	0.798	0.134	✓	[16]	38.835 ± 0.026	⊤
2	$\Sigma^0 p K^+$	$16.5 \pm 20\,\%$	$\theta^{cms}_{\Sigma^0}$	0.034 ± 0.241	—		[21]+calc.	19.800 ± 0.094	⊤
3	$\Lambda \Delta^{++} K^0$	$29.45 \pm 0.08\ ^{+1.67}_{-1.46} \pm 2.06$	$\theta^{cms}_{\Delta^{++}}$	1.49 ± 0.3	—	✓	[13]	32.10 ± 0.11	⊤
4	$\Sigma^0 \Delta^{++} K^0$	$9.26 \pm 0.05\ ^{+1.41}_{-0.31} \pm 0.65$	$\theta^{cms}_{\Delta^{++}}$	0.08 ± 0.02	—	✓	[13]	8.5 ± 2.1	⊥
5	$\Lambda \Delta^{+} K^+$	$9.82 \pm 20\,\%$	$\theta^{cms}_{\Delta^{+}}$	from $\Lambda \Delta^{++} K^0$			res. mod.	11.78 ± 0.15	⊤
6	$\Sigma^0 \Delta^{+} K^+$	$3.27 \pm 20\,\%$	$\theta^{cms}_{\Delta^{+}}$	from $\Sigma^0 \Delta^{++} K^0$			res. mod.	2.6 ± 1.3	⊥
7	$\Sigma(1385)^+ n K^+$	$22.42 \pm 0.99 \pm 1.57\ ^{+3.04}_{-2.23}$	$\theta^{cms}_{\Sigma^{+*}}$	1.427 ± 0.3	0.407 ± 0.108	✓	[17]	17.905 ± 0.075	⊥
8	$\Delta(2050)^{++} n$	33 % feeding for $\Sigma^* n K^+$	θ^{cms}_{n}	1.27	0.35	✓	[17]	8.82 ± 0.13	⊤
9	$\Sigma(1385)^+ p K^0$	$14.05 \pm 0.05\ ^{+1.79}_{-2.14} \pm 1.00$	$\theta^{cms}_{\Sigma^{+*}}$	1.42 ± 0.3	—	✓	[13]	16.101 ± 0.072	⊤
10	$\Sigma(1385)^0 p K^+$	$6.0 \pm 0.48\ ^{+1.94}_{-1.06}$	$\theta^{cms}_{\Sigma^{0*}}$	from $\Sigma(1385)^+ n K^+$		✓	[17]	7.998 ± 0.069	⊤
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	⊤
13	$\Delta^{++} \Lambda(1405) K^0$	$5.0 \pm 20\,\%$	—	—	—		[23]	6.0 ± 1.6	⊤
14	$\Delta^{++} \Sigma(1385)^0 K^0$	$3.5 \pm 20\,\%$	—	—	—		[23]	4.90 ± 0.46	⊤
15	$\Delta^{+} \Sigma(1385)^+ K^0$	$2.3 \pm 20\,\%$	—	—	—		[23]	3.2 ± 1.1	⊤
16	$\Delta^{+} \Lambda(1405) K^+$	$3.0 \pm 20\,\%$	—	—	—		compl. to above	4.2 ± 1.9	⊤
17	$\Delta^{+} \Sigma(1385)^0 K^+$	$2.3 \pm 20\,\%$	—	—	—		compl. to above	3.2 ± 1.1	⊤
		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	⊤
19	$\Lambda n \pi^+ K^+$	from $\Lambda p \pi^+ K^0$		—				2.8 ± 1.5	⊤
20	$\Lambda p \pi^0 K^+$	from $\Lambda p \pi^+ K^0$		—				2.8 ± 1.4	⊤
21	$\Sigma^0 p \pi^+ K^0$	$1.35 \pm 0.02\ ^{+0.10}_{-1.35} \pm 0.09$		—		✓	[13]	1.48 ± 0.76	⊤
22	$\Sigma^0 n \pi^+ K^+$	from $\Sigma^0 p \pi^+ K^0$		—				1.48 ± 0.84	⊤
23	$\Sigma^0 p \pi^0 K^+$	from $\Sigma^0 p \pi^+ K^0$		—				1.48 ± 0.75	⊤

Phys. Rev. C 95 (2017 Jan.) p. 015207

Hyperons and strange baryonic resonances in p+p@3.5 GeV

id	pp→ reaction	$\sigma_0^{(id)}$ cross section [μb]	∡ var.	∡$(a_2,$	$a_4)$	H	notes	fit result	
			3-body channels						
1	$\Lambda p K^+$	$35.26 \pm 0.43\ ^{+3.55}_{-2.83}$	θ^{cms}_{Λ}	0.798	0.134	✓	[16]	38.835 ± 0.026	$\top$
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3	$\Lambda \Delta^{++} K^0$	$29.45 \pm 0.08\ ^{+1.67}_{-1.46} \pm 2.06$	$\theta^{cms}_{\Delta^{++}}$	1.49 ± 0.3	—	✓	[13]	32.10 ± 0.11	$\top$
4	$\Sigma^0 \Delta^{++} K^0$	$9.26 \pm 0.05\ ^{+1.41}_{-0.31} \pm 0.65$	$\theta^{cms}_{\Delta^{++}}$	0.08 ± 0.02	—	✓	[13]	8.5 ± 2.1	$\perp$
5	$\Lambda \Delta^{+} K^+$	$9.82 \pm 20\,\%$	$\theta^{cms}_{\Delta^{+}}$	from $\Lambda\Delta^{++}K^0$			res. mod.	11.78 ± 0.15	$\top$
6	$\Sigma^0 \Delta^{+} K^+$	$3.27 \pm 20\,\%$	$\theta^{cms}_{\Delta^{+}}$	from $\Sigma^0\Delta^{++}K^0$			res. mod.	2.6 ± 1.3	$\perp$
7	$\Sigma(1385)^+ n K^+$	$22.42 \pm 0.99 \pm 1.57\ ^{+3.04}_{-2.23}$	$\theta^{cms}_{\Sigma^{+*}}$	1.427 ± 0.3	0.407 ± 0.108	✓	[17]	17.905 ± 0.075	$\perp$
8	$\Delta(2050)^{++} n$	33 % feeding for $\Sigma^* n K^+$	θ^{cms}_{n}	1.27	0.35	✓	[17]	8.82 ± 0.13	$\top$
9	$\Sigma(1385)^+ p K^0$	$14.05 \pm 0.05\ ^{+1.79}_{-2.14} \pm 1.00$	$\theta^{cms}_{\Sigma^{+*}}$	1.42 ± 0.3	—	✓	[13]	16.101 ± 0.072	$\top$
10	$\Sigma(1385)^0 p K^+$	$6.0 \pm 0.48\ ^{+1.94}_{-1.06}$	$\theta^{cms}_{\Sigma^{0*}}$	from $\Sigma(1385)^+ n K^+$		✓	[17]	7.998 ± 0.069	$\top$
11	$\Lambda(1405) p K^+$	$9.2 \pm 0.9 \pm 0.7\ ^{+3.3}_{-1.0}$					[18]	7.7 ± 3.0	$\perp$
12	$\Lambda(1520) p K^+$	$5.6 \pm 1.1 \pm 0.4\ ^{+1.1}_{-1.6}$					[18]	7.2 ± 3.6	$\top$
13	$\Delta^{++}\Lambda(1405) K^0$	$5.0 \pm 20\,\%$					[23]	6.0 ± 1.6	$\top$
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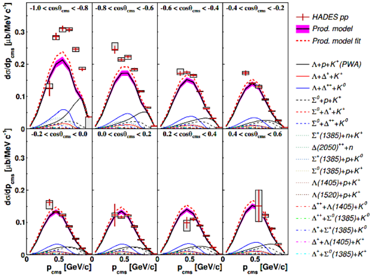
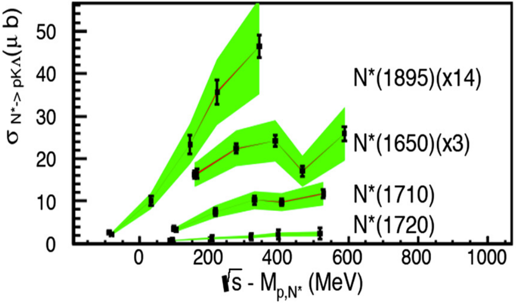
21	$\Sigma^0 p \pi^+ K^0$	$1.35 \pm 0.02\ ^{+0.10}_{-1.35} \pm 0.09$					[13]	1.48 ± 0.76	$\top$
22	$\Sigma^0 n \pi^+ K^+$	from $\Sigma^0 p \pi^+ K^0$						1.48 ± 0.84	$\top$
23	$\Sigma^0 p \pi^0 K^+$	from $\Sigma^0 p \pi^+ K^0$						1.48 ± 0.75	$\top$

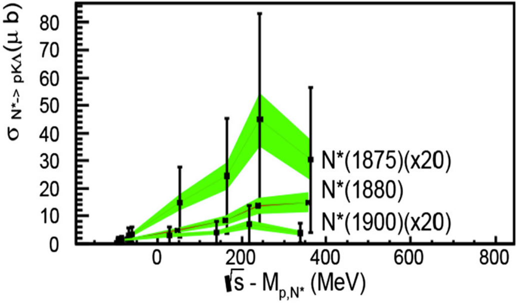


Phys. Rev. C 95 (2017 Jan.) p. 015207

$pK^+\Lambda$ combined PWA analysis

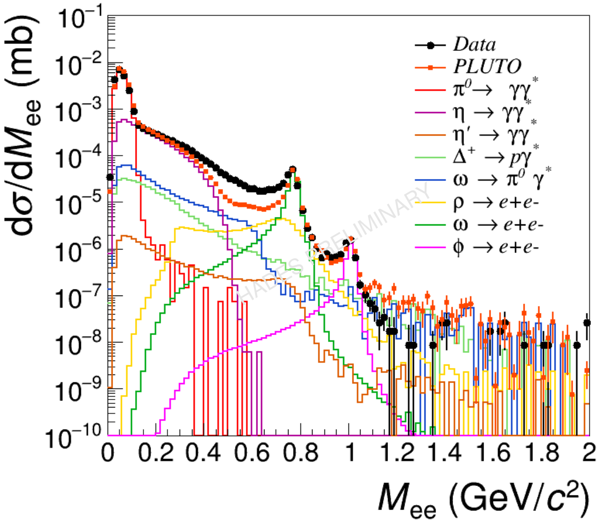
- combined PWA analysis of COSY-TOF, DISTO, FOPI and HADES
- contriution of seven N^* resonances to $pK^+\Lambda$
- 90 % of $pK^+\Lambda$ production gies via resonances



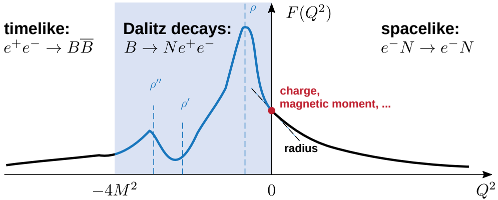


Phys. Lett. B 785 (2018) pp. 574–580

Dilepton spectra in p+p@4.5 GeV

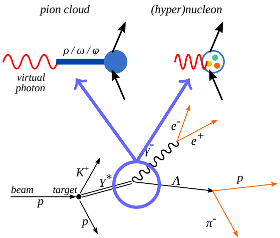


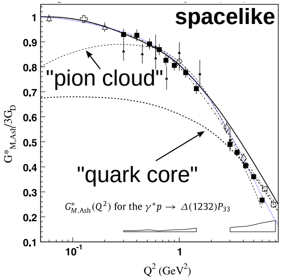
eTFF – sensitive probes of baryon internal structure



- 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 anihilation (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 measurement

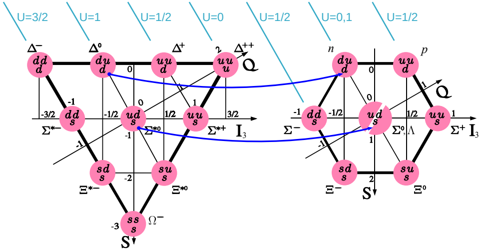




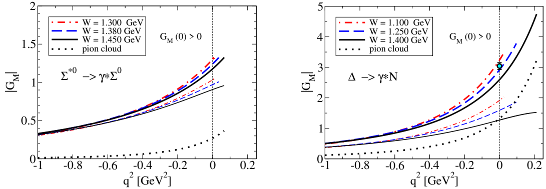
Aznauryan and Burkert, *Prog. Part. Nucl. Phys.* 67 (2012 1) pp. 1–54

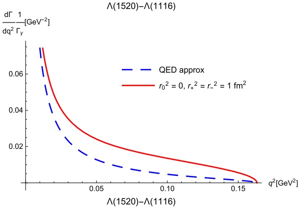
Comparison of strange and non-strange baryons

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)

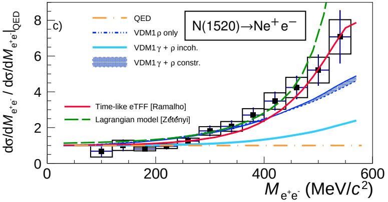


Ramalho, *Phys. Rev. D* 102 (2020 Sept.) p. 054016

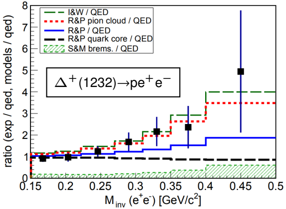




Salone and Leupold, *Eur. Phys. J. A* 57 (2021 6) p. 183



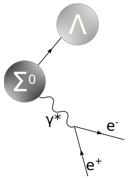
π^-+p, $\sqrt{s}$ = 1.5 GeV
arXiv: 2205.15914 (nucl-ex)

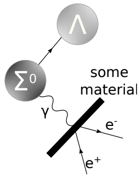


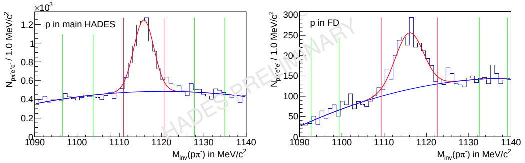
p+p@1.25 GeV
Phys. Rev. C 95 (2017 June) p. 065205

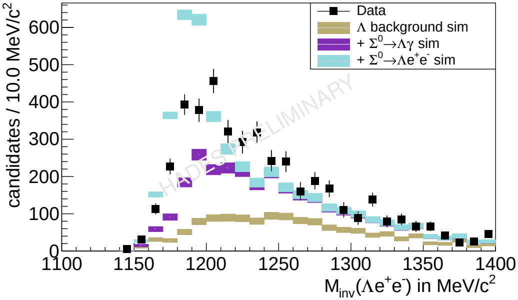
Motivation

- $\Sigma^0 \to \Lambda\gamma$ (BR=100 %)
- $\Sigma^0 \to \Lambda e^+ e^-$ (prediction: BR=0.5 %) – not observed yet
- $\Sigma(1385) \to \Lambda e^+ e^-$ (prediction: BR=1.25×10^{-2} %) – not observed yet
- $\Lambda(1520) \to \Lambda e^+ e^-$ (prediction: BR=0.85×10^{-2} %) – not observed yet



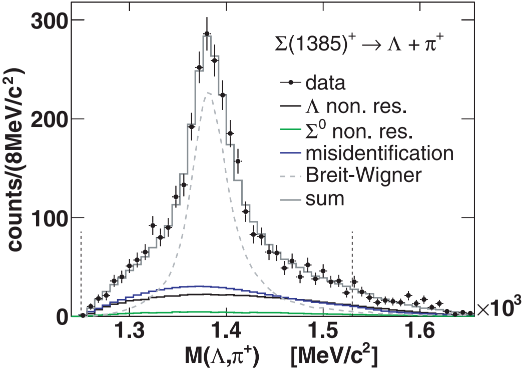






p+p@4.5 GeV: work in progress

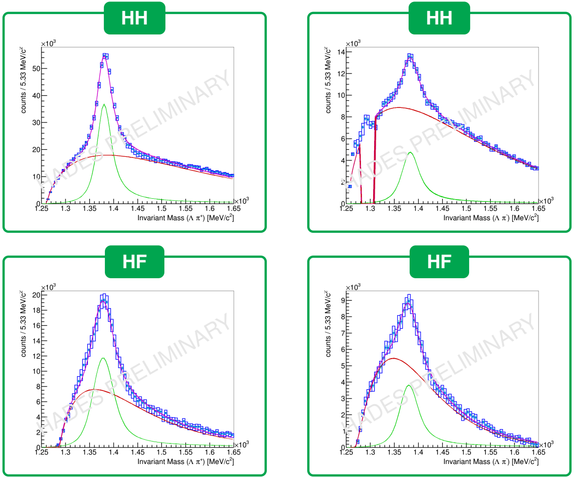
$\Sigma(1385)$ exclusive and inclusive



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

p+p@3.5 GeV: *Phys. Rev. C* 85 (2012 Mar.) p. 035203

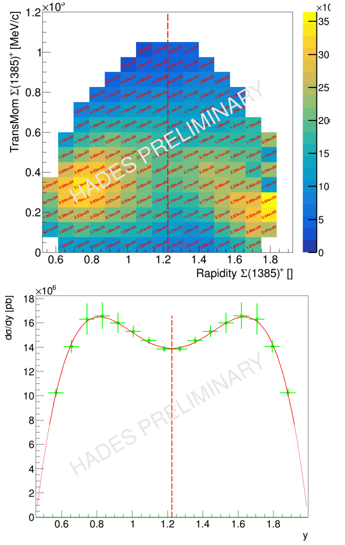
$\Sigma(1385)^+$ $\Sigma(1385)^-$



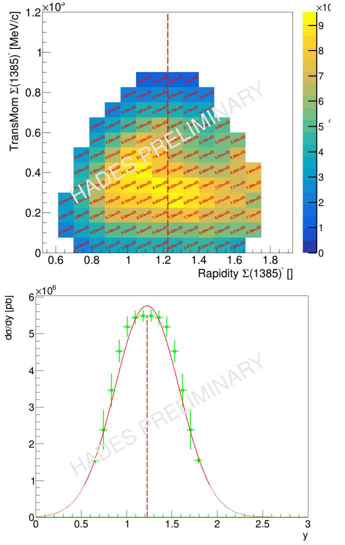
p+p@4.5 GeV: work in progress

Σ(1385) inclusive in differential cross-sections

Σ(1385)$^+$



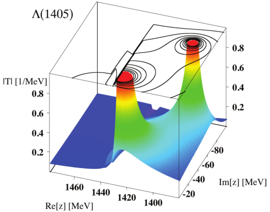
Σ(1385)$^-$



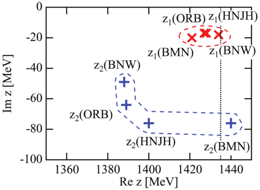
Reaction p+p→	Ratio [%]	σ_{SMASH} [μb]	σ_{exp} [μb]
$\Sigma(1385)^+ pK^0_S$	31.89	2.25	11 ± 2
$\Sigma(1385)^+ pK^0_S \pi^0$	14.81	1.05	—
$\Sigma(1385)^+ pK^+ \pi^-$	15.48	1.09	—
$\Sigma(1385)^+ nK^+$	18.22	1.29	15 ± 2
$\Sigma(1385)^+ nK^+ \pi^0$	6.80	0.48	—
$\Sigma(1385)^+ nK^0_S \pi^+$	12.76	0.90	—
$\Sigma(1385)^- pK^+ \pi^+$	99.13	1.08	—

p+p@4.5 GeV: work in progress

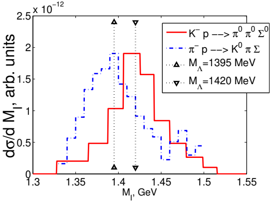
Hyperon hadronic decays – $\Lambda(1405)$



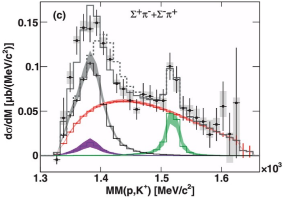
Hyodo and Jido, *Prog. Part. Nucl. Phys.* 67 (2012 1) pp. 55–98



Hyodo and Wiese, *Phys. Rev. C* 77 (2008 Mar.) p. 035204

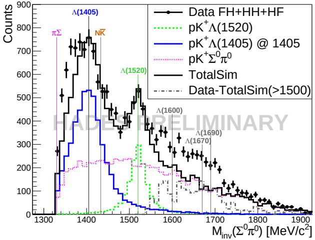


Magas and Oset and Ramos, *Phys. Rev. Lett.* 95 (2005 July) p. 052301



p+p@3.5 GeV
Phys. Rev. C 87 (2013 Feb.) p. 025201

$\Lambda(1405)$ via $\Sigma^0\pi^0 \to p\pi^- 3\gamma$

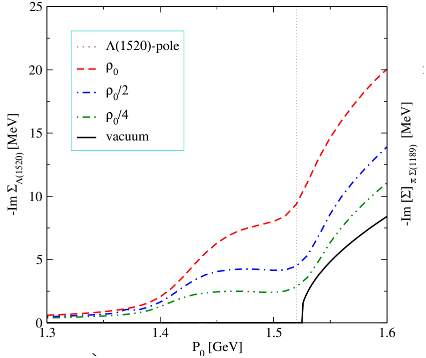


T.B.A. (via PDG):

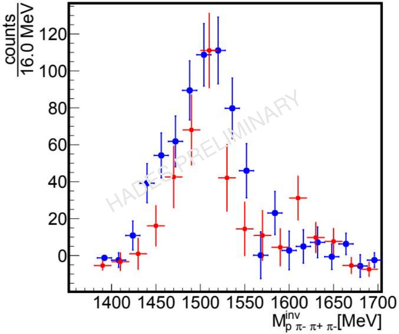
- $\Lambda(1600)$: $\Gamma \approx 200$ MeV
- $\Lambda(1670)$: $\Gamma \approx 30$ MeV
- $\Lambda(1690)$: $\Gamma \approx 70$ MeV

p+p@4.5 GeV: work in progress

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

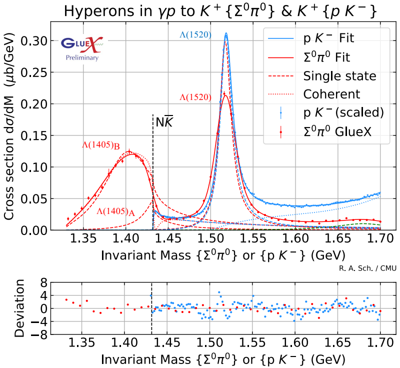


Kaskulov and Oset, *Phys. Rev. C* 73 (2006 Apr.) p. 045213



of $\Lambda(1520)$	M [MeV$/c^2$]	σ [MeV$/c^2$]	Γ [MeV$/c^2$]
p+p@3.5 GeV	1504.5 ± 4.7	14.7 ± 6.7	15.6 ± 1.0
p+Nb@3.5 GeV	1507.7 ± 3.3	14.7 ± 6.7	34.6 ± 5.2

paper in preparation



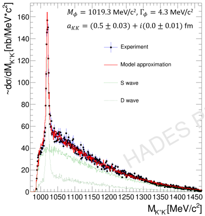
GlueX Collaboration, arXiv: 2512.04136 (hep-ex)

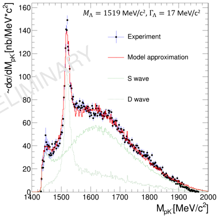
K-matrix approach

Chung et al, *Annalen der Physik* 507 (1995 5) pp. 404–430

- First attempt of K-matrix fit for $\Lambda(1405) + \Lambda(1520)$
- p+p@4.5 GeV $\rightarrow ppK^+K^-$ ($\Lambda(1520)\rightarrow K^-p$, $\varphi(1080)\rightarrow K^+K^-$)

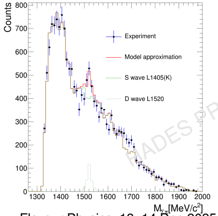
$$A = \frac{1}{1-iq_1 a_{pK}}\frac{1}{1-iqa_{KK}}(1 + c_1 BW_{\varphi(1080)} + c_2 BW_{\Lambda(1520)} + c_3 BW_{\Lambda(1405)})$$

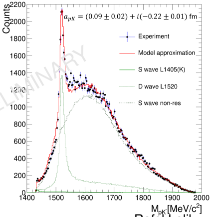




p+p@4.5 GeV: work in progress

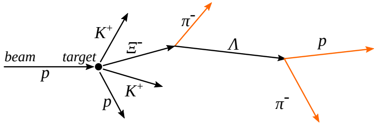
- Simultaneous fit of $\Lambda(1405)/\Lambda(1520)\rightarrow\Sigma^0\pi^0$ and $\Lambda(1520)\rightarrow pK^-$ in the K-matrix formalism for 2 coupled channels

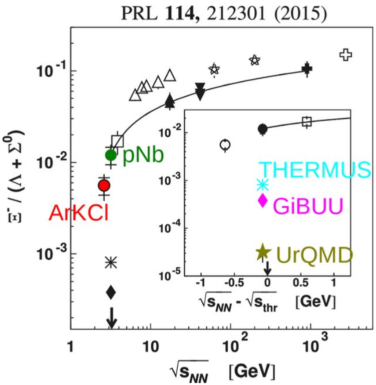


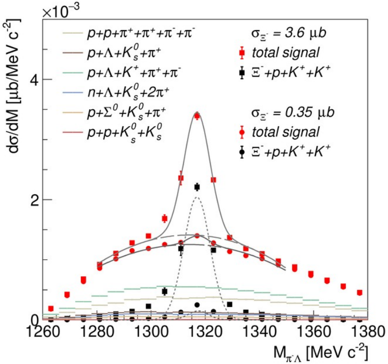


p+p@4.5 GeV: work in progress

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

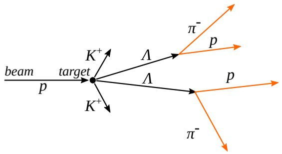




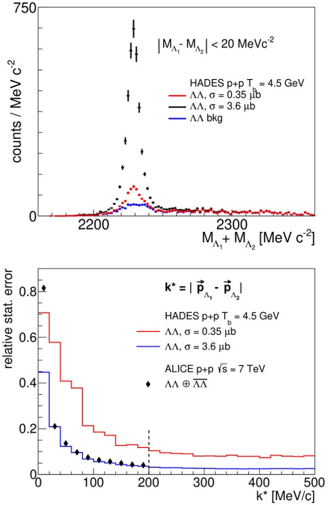


Phys. Rev. Lett. 114 (2015 May) p. 212301;
Reference HADES results with p+Nb @3.5 GeV and Ar+KCl @1.76 GeV

Projections for HADES with p+p@4.5 GeV
Eur. Phys. J. A 57 (2021 4) p. 138

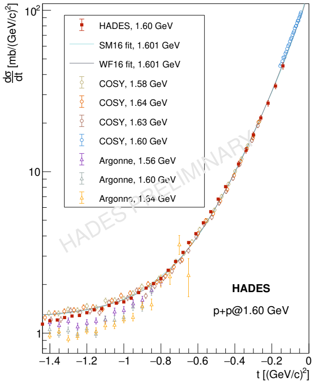


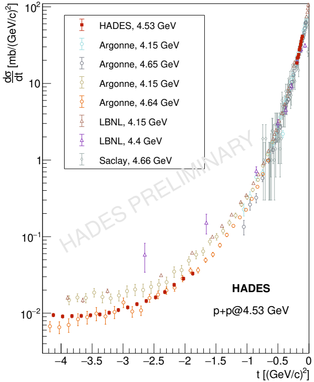
- Sensitive to Y-N and Y-Y interaction
- Complementary to PANDA program of $\Lambda\bar{\Lambda}$ at p+$\bar{\text{p}}$
- HADES measured pΛ correlations *Phys. Rev. C* 94 (2016 Aug.) p. 025201, consistent with ALICE for pΛ and $\Lambda\Lambda$ *Phys. Rev. C* 99 (2019 Feb.) p. 024001.
- ALICE identified 6M Λ and $\bar{\Lambda}$, 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

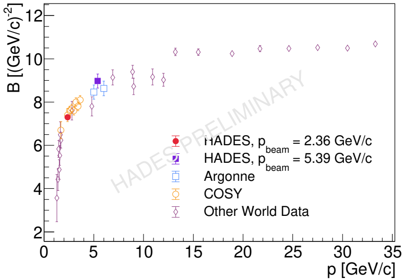


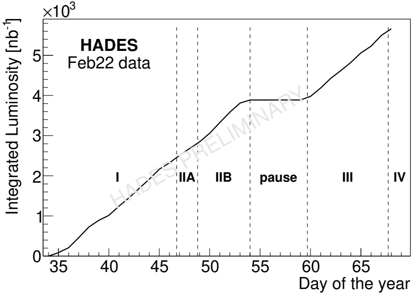
Projections for HADES with p+p@4.5 GeV
Eur. Phys. J. A 57 (2021 4) p. 138

Elastic scattering with p+p@1.58 GeV and p+p@4.5 GeV



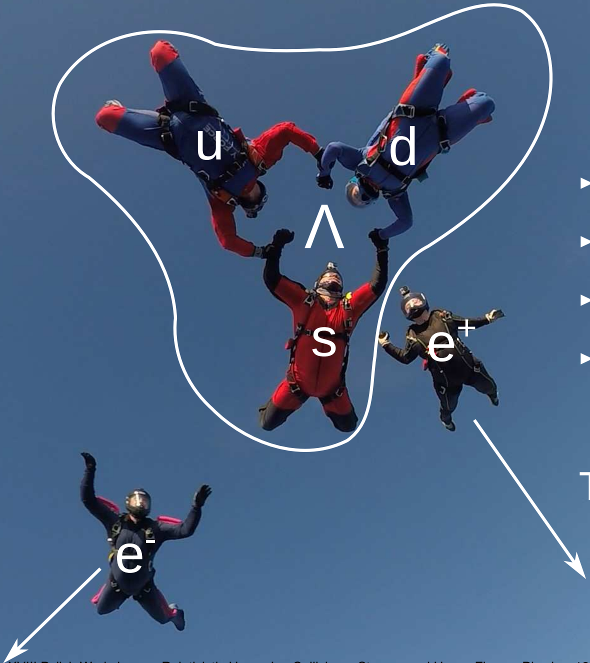






- elastic scattering data are used for cross-section normalization
- total integrated luminosity at $T = 4.53$ GeV
  $\mathcal{L} = 5660.6 \pm 0.1$ (stat) $\pm$ 226.0 (norm) $\pm$ 180.0 (sys) nb^{-1}
- total integrated luminosity at $T = 1.60$ GeV
  $\mathcal{L} = 345.1 \pm 0.1$ (stat) $\pm$ 2.7 (norm) $\pm$ 2.1 (sys) nb^{-1}

paper in preparation



SUMMARY

- HADES has a diverse research program on dileptons and hyperons.
- Excellent detector for Dalitz decays of mesons, nucleons and hyperons.
- Allows to study internal structure of particles via eTFF.
- Very good performance for identifying hadrons allows for study of hadronic decay channels.

Thank you for your attention

Bibliography I

- Cover image: © Clara Schuster/Urban Sketchers Rhein-Main
- HADES photo: © J. Hosan, GSI/FAIR

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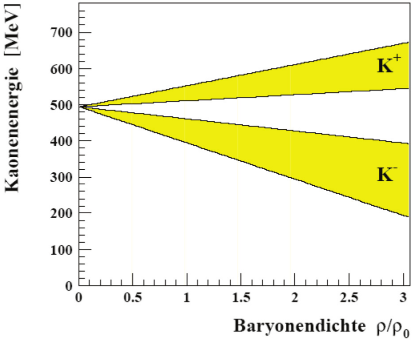
Kaons in-medium

$$\Delta m_K^2(\rho) = -\frac{\Sigma_{KN}}{f_K^2}\rho_S - \frac{\Delta f_K^2 m_K^2}{f_K^2} \pm \frac{m_k\left(\rho_u - \rho_s\right)}{4 f_K^2} + O(m_u^0, s)$$



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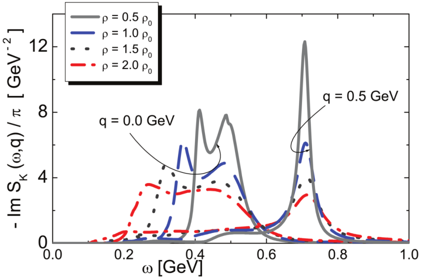
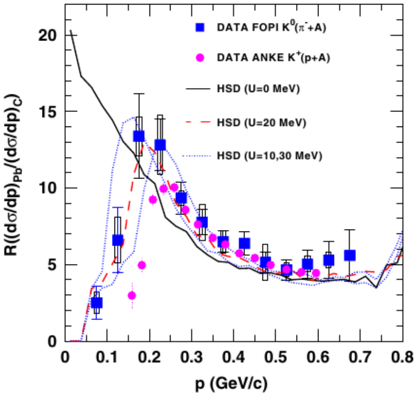


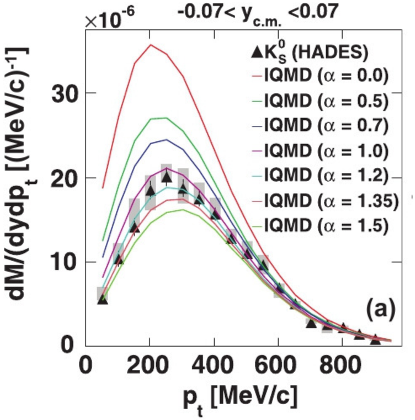
- KN potential repulsive
- $\overline{\text{K}}$N potential attractive (??) → kaonic atoms
- HI: strangeness exchange, kaons and phi absorption, coupling to Λ(1405) and Σ(1385) resonances (Y $\pi \leftrightarrow Y^* \leftrightarrow \overline{\text{K}}$N), ...

Kaon-nucleon potential

- measurements by FOPI ($\pi^- A$) and ANKE (pA) yield a average potential of 20 ± 5 MeV (HSD)
- studies by HADES in ArKCl@1.76 GeV give 40 MeV (IQMD)



PRL 102 (18 2009-05) p. 18205

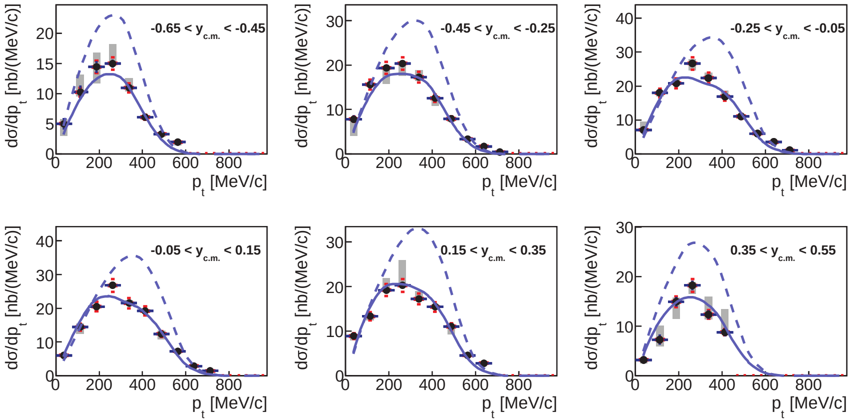


PRC 82 (4 2010-10) p. 044907

K^0_S at HADES – p+p@3.5 GeV

- studies with the GiBUU transport model
- modifications to the model (cs scalling, 5-body channels)

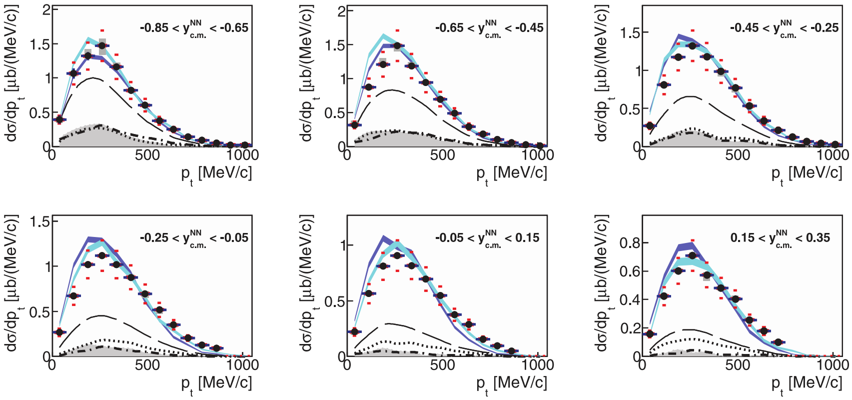
PHYSICAL REVIEW C **90**, 054906 (2014)



K^0_S at HADES – p+Nb@3.5 GeV

- KN potential effects visible in the shift of the p-spectrum
- GiBUU ChPT potential is 35 MeV, results consistent with 40 MeV

PHYSICAL REVIEW C **90**, 054906 (2014)

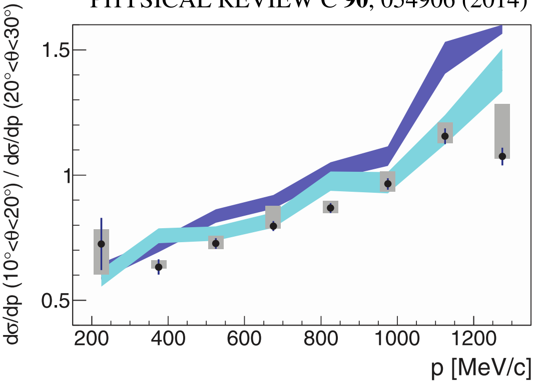


with and without ChPT KN potential

- another observable (but not independent)

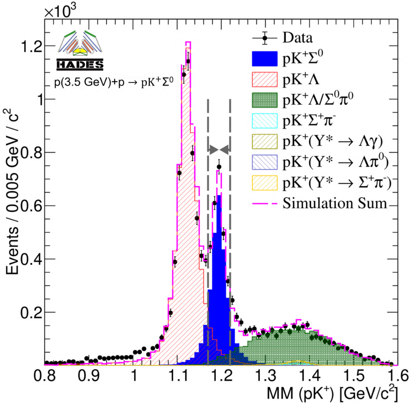
$$\mathcal{R} = \frac{d\sigma/dp(10^\circ < \theta < 10^\circ)}{d\sigma/dp(20^\circ < \theta < 30^\circ)}$$

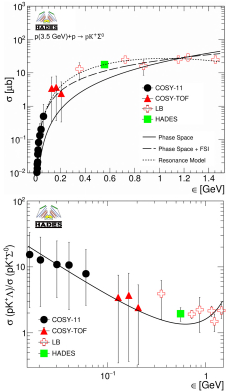
PHYSICAL REVIEW C **90**, 054906 (2014)

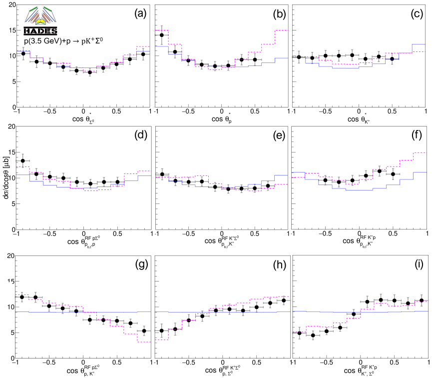


with and without ChPT KN potential

- No calorimeter in data from 2007 – p+p@3.5 GeV
- New anaylsis tools (HADES + PANDA cooperation): ◻ Neural networks; ◻ Kinematic refit







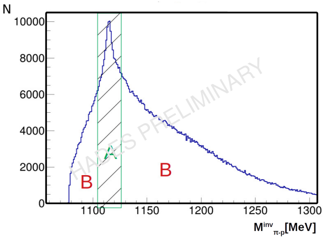
σ(p+p → pK$^+\Sigma^0$) = 17.7 ± 1.7 (stat) ± 1.6 (syst) μb

arXiv: 2301.11766 (nucl-ex) arXiv:2301.11766v1

Inclusive $\Lambda(1520)$ @ 3.5 GeV – reference for dilepton decay channel $\Lambda(1520)\to\Lambda\gamma^{*}$ ($e^{+}e^{-}$

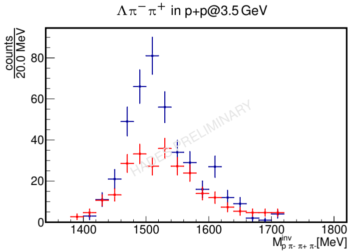
p+p@3.5 GeV and p+Nb@3.5 GeV beams (2007)

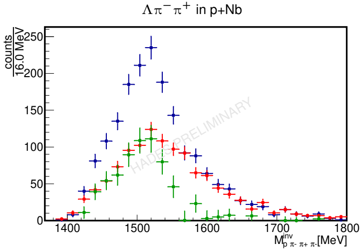
- production via $p+p\to pK^{+}\Lambda(1520)[\Lambda\pi^{+}\pi^{-}]$
- $\Lambda\pi^{+}\pi^{-}$ threshold is 220 MeV below total energy for p+p
- inclusive analysis of $p\pi^{-}\pi^{+}\pi^{-}$ final state
- dominating backgroud from $\Delta^{++}\pi^{-}\Delta^{++}\pi^{-}$ channel
- also from $p+p\to\Lambda[p\pi^{-}]K^{0}[\pi^{+}\pi^{-}]p\pi^{+}$



Λ selection

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





p+p

- data driven model

Phys. Rev. C 95 (2017 Jan.) p. 015207

no.	Channel	σ [µb]
	3-body reactions	
1	Λ(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	$\Delta^{++}\Sigma(1385)^0$K^0	$3.5 \pm 20\%$
7	$\Delta^{+}\Sigma(1385)^0$K^0	$2.3 \pm 20\%$
	4-body reactions	
8	Λpπ^+K^0	$2.57 \pm 0.02^{+0.21}_{-1.98} \pm 0.18$
9	Σ^0pπ^+K^0	$1.35 \pm 0.02^{+0.10}_{-1.35} \pm 0.09$

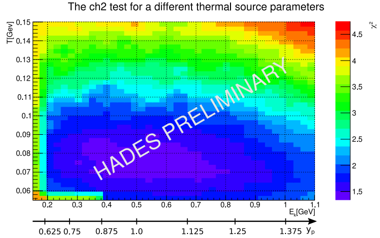
p+Nb

- with use of UrQMD model

Eur. Phys. J. A 50 (2014 May) p. 81

- no Λ(1520) production included
- but non-resonant $\Lambda\pi^-\pi^+$ can be simulated
- Λ(1520) simulated with thermal source from Pluto:

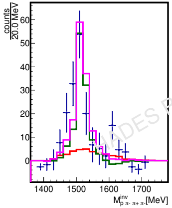
→ a static (not expanding) thermal source characterized by temperature T_s = 75 MeV and rapidity $y_s = 1.04$

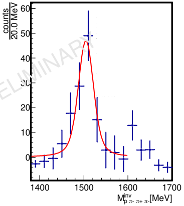


$\Lambda(1520)$ candidates

p+p

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



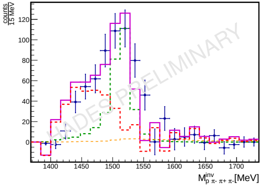


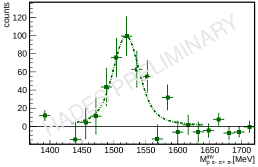
	$M_{\Lambda(1520)}$ [MeV/c^2]	$\sigma_{\Lambda(1520)}$ [MeV/c^2]
PDG	1519.5 ± 1.0	not appl.
p+p	1504.5 ± 4.7	14.7 ± 6.7
sim	1515.6 ± 2.1	11.3 ± 3.6

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

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

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

K-matrix approach

- Multi-stage fit starting from BW + nonRes
- Coupled-channel K-matrix formalism

$$T(s) = [1 - iK(s)\rho(s)]^{-1} K(s)$$

- $\rho(s)$ – phase space matrix
- $K(s)$ matrix, representing real part of scattering before unitary corrections

$$K_{ij}(s) = \sum_{n=1}^{2} \frac{g_n^{(i)} g_n^{(j)}}{M_n^2 - s}$$

- $n = 1, 2$ – indexes of poles
- $i, j \in \{0, 1\}$ – channel indices