Inclusive Λ Hyperon Production In Proton-Proton Reactions At 3.5 GeV Measured With Hades

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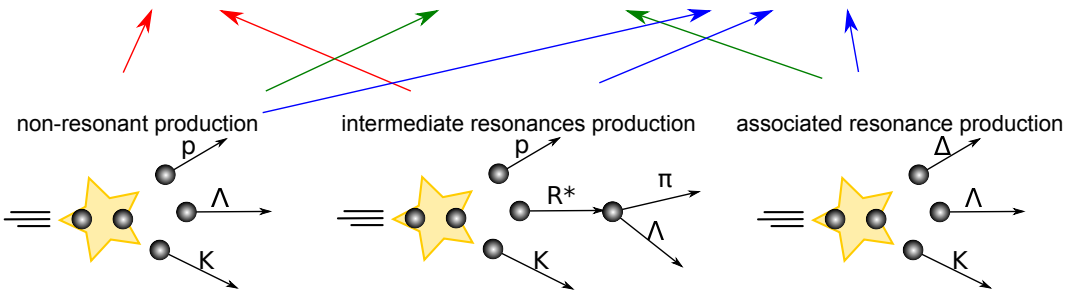
Λ production

- Resonances play significant role in the low energy QCD sector ($\sqrt{s} < 5$ GeV) reactions.

- $pp \to pK^+\Lambda$ ≈10 %
- $pp \to pR \to pK^+\Lambda$ ≈90 %

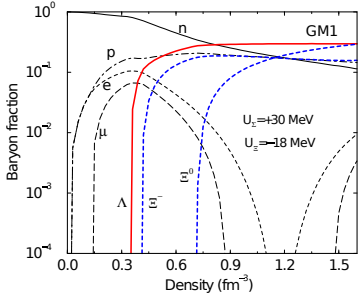
- $pp \to K^0\Lambda p\pi^+$ ≈10 %
- $pp \to K^0\Lambda\Delta^{++}$ ≈90 %

- $pp \to \Lambda(1405)\Delta^{++}K^0$ ≈90 %
- $pp \to \Lambda\pi^0 p\pi^+ K^0$ ≈10 %

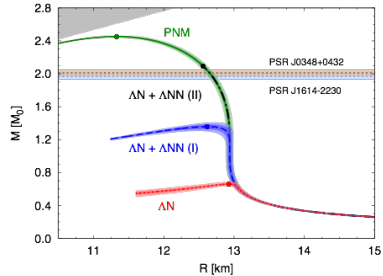


Studying Λ in proton+proton reactions

- Pin down contribution of Λ^*, Σ^*, Δ^+, Δ^{++} and N^* resonances in the beam kinetic energy regime of 3.5 GeV.
- Tuning of transport models (GiBUU, UrQMD) and calculations.
- Production in elementary system as input for ΛN interaction in nucleus ($\rho \approx \rho_0$) and neutron stars ($\rho \gg \rho_0$).



Phys. Rev. C 53 (1996) 1416



Phys. Rev. Lett. 114, 092301

ΛN – attractive, ΛNN – repulsive ?
(Λp scattering from $\pi^- + A \rightarrow \Lambda + K$ data in Hades)

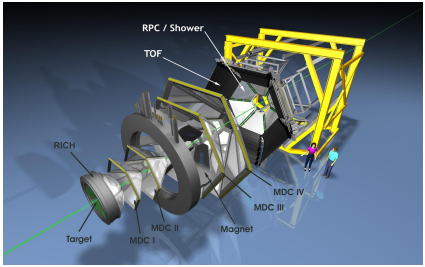
Λ production channels

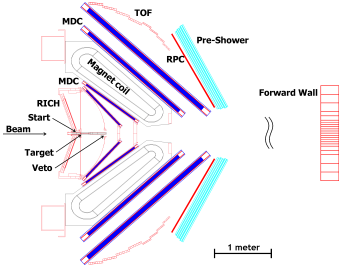
pp → reaction	cross section [μb]	anisotropy	HADES meas.	notes
		3-body channels		
$\Lambda + p + K^+$	36.26	✓	✓	[1]
$\Sigma^0 + p + K^+$	15.5	✓		[2]
$\Lambda + \Delta^{++} + K^0$	29.45	✓	✓	[3]
$\Sigma^0 + \Delta^{++} + K^0$	9.26	✓	✓	[3]
$\Lambda + \Delta^+ + K^+$	9.82	✓		from res. mod.
$\Sigma^0 + \Delta^+ + K^+$	3.27	✓		from res. mod.
$\Sigma(1385)^+ + n + K^+$	22.42	✓	✓	[4]
$\Sigma(1385)^+ + p + K^0$	14.05	✓	✓	[3]
$\Sigma(1385)^0 + p + K^+$	6.0	✓	✓	[5]
$\Lambda(1405) + p + K^+$	9.2	✓	✓	[4]
$\Lambda(1520) + p + K^+$	5.6	✓	✓	[4]
$\Delta^{++}\Lambda(1405)K^0$	5.0			[6]
$\Delta^{++}\Sigma(1385)^0K^0$	3.5			[6]
$\Delta^{+}\Sigma(1385)^+K^0$	2.3			[6]
$\Delta^{+}\Lambda(1405)K^+$	2.3			compl. to above
$\Delta^{+}\Sigma(1385)^0K^+$	2.3			compl. to above
		4-body channels		
$\Lambda + p + \pi^+ + K^0$	2.98		✓	[3]
$\Lambda + n + \pi^+ + K^+$	2.21			fit res. mod.
$\Lambda + p + \pi^0 + K^+$	1.72			fit res. mod.
$\Sigma^0 + p + \pi^+ + K^0$	1.34		✓	[3]
$\Sigma^0 + n + \pi^+ + K^+$	2.21			fit res. mod.
$\Sigma^0 + p + \pi^0 + K^+$	1.72			fit res. mod.

[1] G. Agakishiev et al. *PL* B742 (2015).
[2] M. Abdel-Bary et al. *EPJ* A46 (2010). [Erratum: EPJA46,435(2010)].
[3] G. Agakishiev et al. *PR* C90 (2014).
[4] G. Agakishiev et al. *PR* C85 (2012).
[5] G. Agakishiev et al. *PR* C87 (2013).
[6] G. Agakishiev et al. *PR* C90 (2014).

HADES – **H**igh **A**cceptance **D**i-**E**lectron **S**pectrometer

See G. Agakishiev et al. EPJ A41 (2009) for details





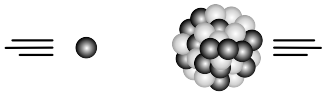
- located in GSI Helmholtzzentrum for Heavy Ion Research, Darmstadt, Germany
- fixed-target experiment
- SIS18, beams up to
  - 3.5 GeV for protons
  - 1.25 AGeV for Au
  - 0.6 GeV/c to 2 GeV/c for charged pions

- 85 % of azimuthal coverage
- polar angle interval from 18° to 85°
- forward coverage of 0° to 7°
- momentum resolution 1 % to 4 %
- very efficient PID (i.e. kaons) via dE/dx, TOF

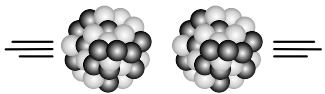
Experimental production of Hyperons

- low energy (close to the threshold $\sqrt{s_{\mathrm{NN}}} \rightarrow \sqrt{s_{\mathrm{thr}}}$) experiments allow to reach large densities

p+p  $\sigma_{\mathrm{prod.}}$

p+Nb  $\sigma_{\mathrm{prod.}} + \sigma_{\mathrm{scat.}}$ density $\sim \rho_0$

Agakishiev et al. Eur. Phys. J. A50 (2014) 81

Au+Au  $\sigma_{\mathrm{prod.}} + \sigma_{\mathrm{scat.}}$ density $\sim 3\rho_0$

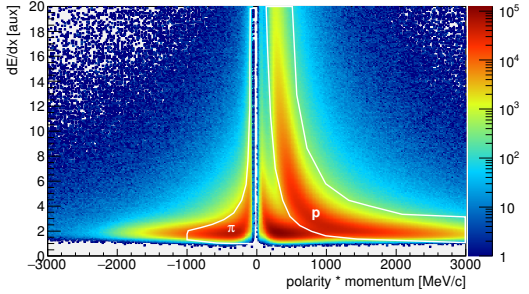
Λ reconstruction in HADES

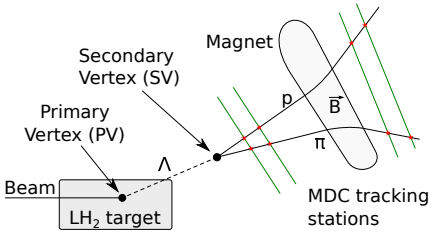
- production in LH_2 target region
- reconstruction via $\Lambda \rightarrow p\pi^-$ decay
- tracking in four layers of Multiwire Drift Chambers
- particle identification with dE/dx and momentum (magnetic field)

Λ decay modes:

$p\pi^-$	63.9 ± 0.5%
$n\pi^0$	35.8 ± 0.5%

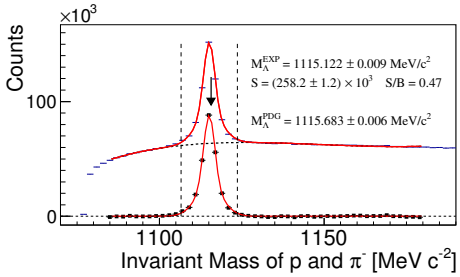
- $c\tau$ = 78.9 mm
- PV res = 3.8 mm
- SV res = 1.8 mm

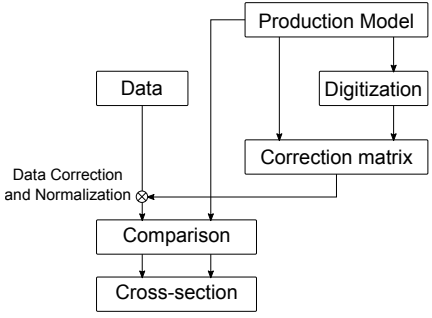




Invariant mass and analysis chain

- Several topological cuts are applied to purify the sample





- S = ~ 258*k* Λs
- S/B = 0.47

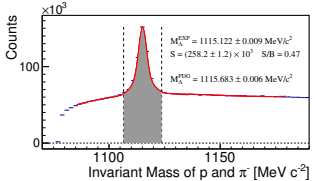
Conducted differential analyses

- p_t-y^{cms}
- p^{cms}-cos θ^{cms}

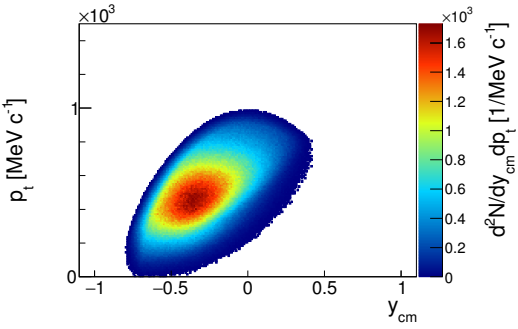
Cross-check analysis

- Full phase-space

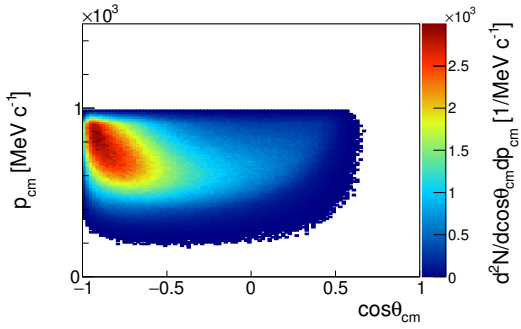
Kinematical distributions from data



- Only data within the 3σ range are used.

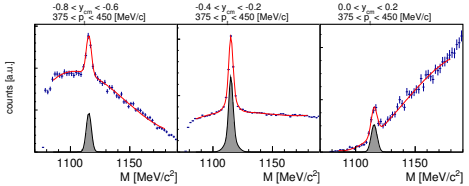


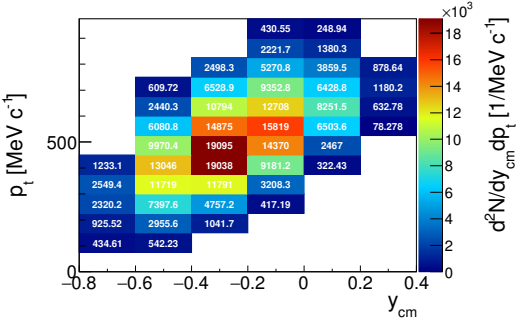
p_t-y_{cms} correlation



p_{cms}-cos θ_{cms} correlation

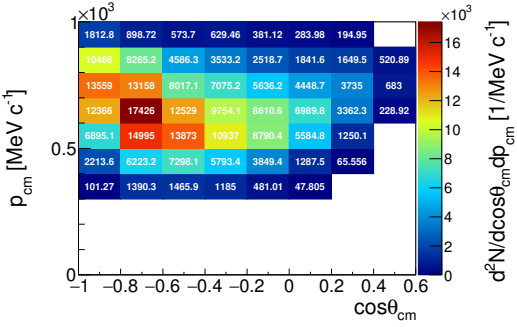
Kinematical distributions from data





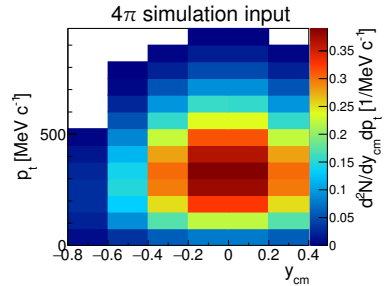
p_t-y_{cms} correlation

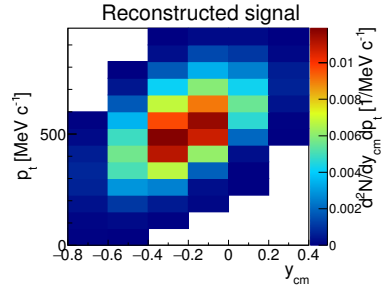
- Fit of the (π^-,p) invariant mass distribution in each (p_t-y_{cms}) or (p_{cms}-cos θ_{cms}) bin → extraction of signal (see figures below).



p_{cms}-cos θ_{cms} correlation

Geometrical acceptance and reconstruction efficiency





Corrections procedure:

1. All channels are simulated with weights equal to their cross sections and anisotropy (SIM sample).
2. Further they are filtered with the HADES acceptance and efficiency (FSS sample)
3. Æ = FSS/SIM determines correction matrix
4. Data correction in each bin: $D^{\mathrm{corr}} = D^{\mathrm{meas}}/Æ$

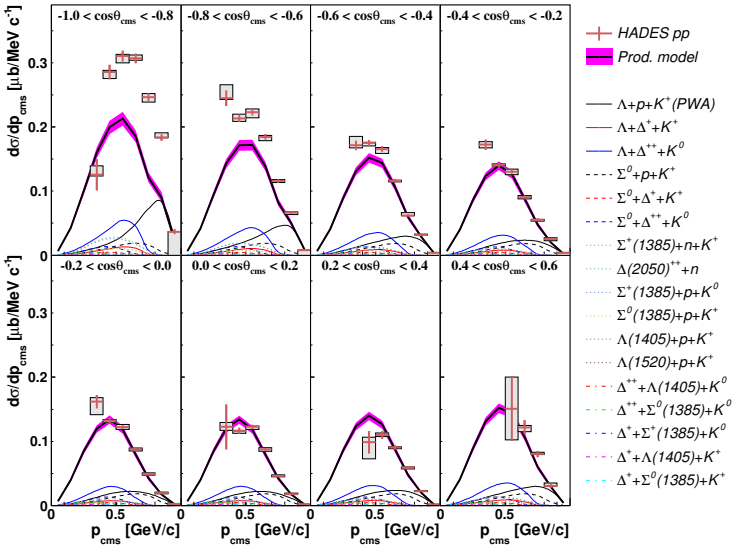
Normalization:

- Data are normalized to total proton-proton elastic cross-section.
  A. Rustamov, AIP Conf. Proc. 1257, 736–740 (2010)
- The normalization uncertainty is ±7.3 %.

Data corrected in such a way can be compared with 4π simulations (within the acceptance only).

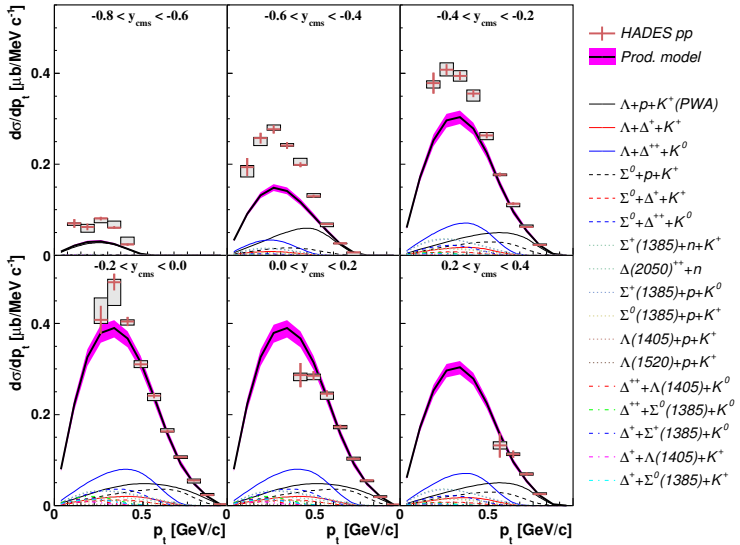
Experimental data and production model

$p^{cms} - \cos\theta^{cms}$



Experimental data and production model

$P_t - y^{cms}$

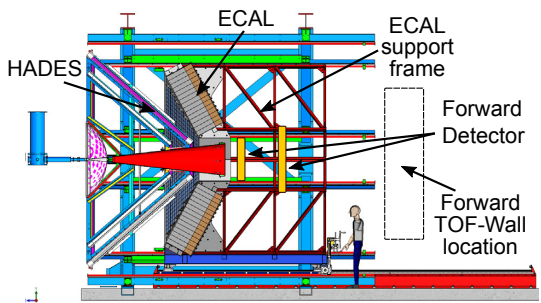


Although model is based on solid experimental results from various exclusive channels, a few of them are based only on approximations:

- $pK\Sigma^0$ – production anisotropy (absent) was extrapolated from COSY measurement at 2.95 GeV beam energy.
- The Δ^+ channels were approximated with the measurements of the Δ^{++} channels: factor 3 from the isospin rule for the cross section, the same anisotropy.
- $\Delta^+(\Delta^{++})Y^*$ cross section approximated with another HADES analysis, no anisotropy constrained.

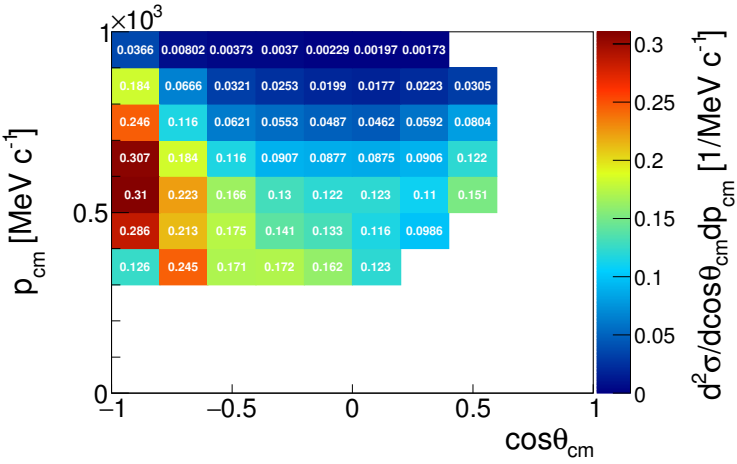
HADES upgrade (to be ready in 2018):

- Electromagnetic Calorimeter (ECAL) – reconstruction of $\Sigma^0 \to \Lambda + \gamma$
- Forward Detector (FD) – bigger acceptance required by Δ^+ channels



Extraction of the total cross section

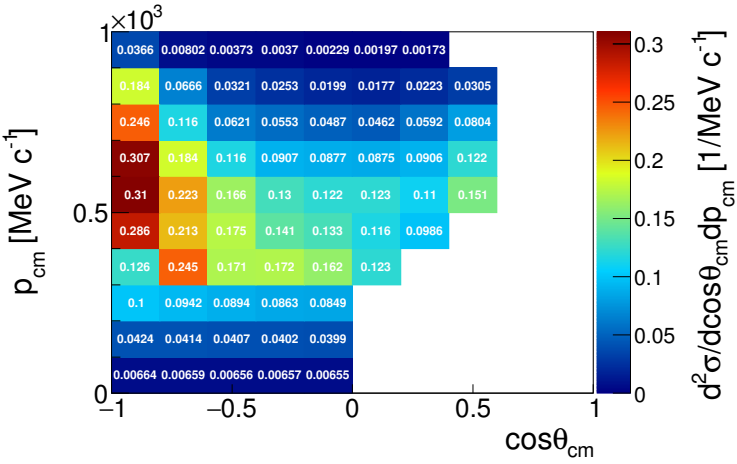
for cos θ distribution



Experimental distribution

Extraction of the total cross section

for cos θ distribution

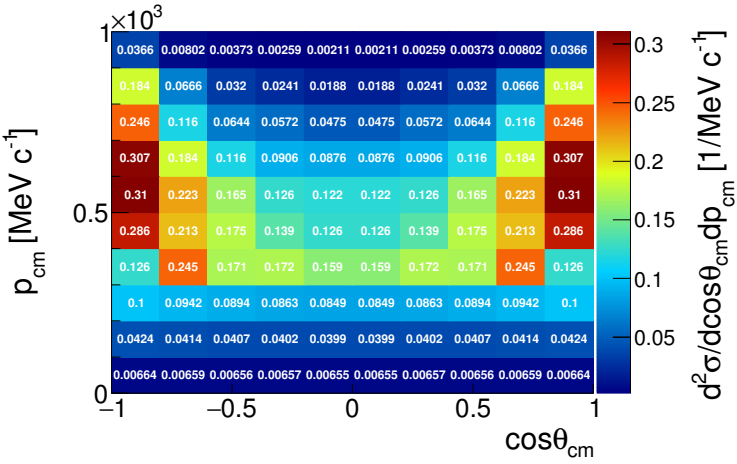


With simulation extrapolation

Data fully cover one hemisphere. We need to mirror the spectrum over cos θ_{cms} = 0 to cover full phase-space. Overlapping points are averaged with error weights.

Extraction of the total cross section

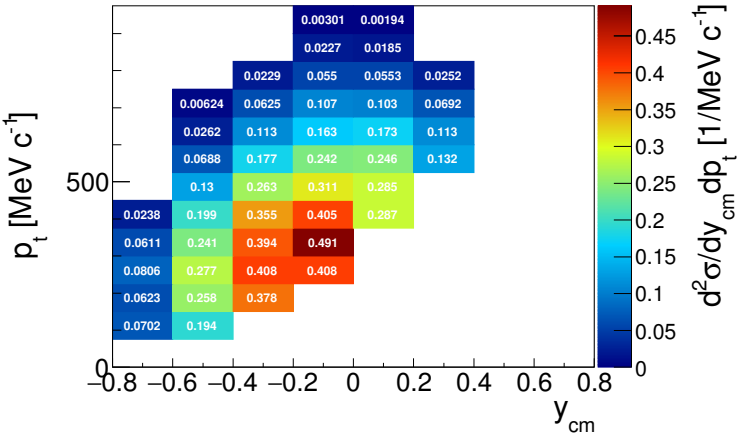
for cos θ distribution



After mirroring

Extraction of the total cross section

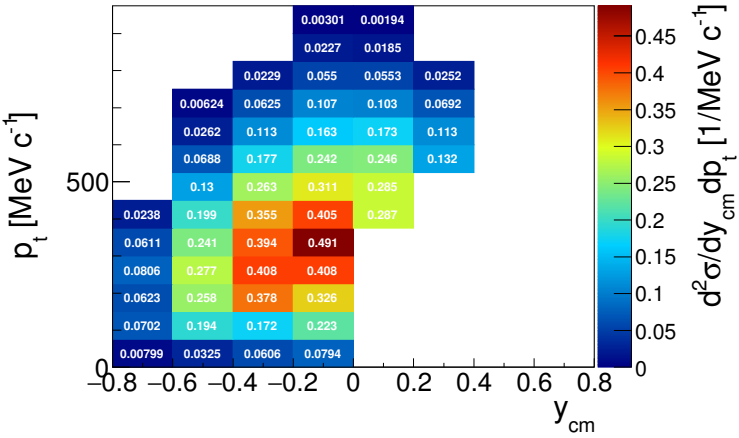
for *y* distribution



Experimental distribution

Extraction of the total cross section

for *y* distribution

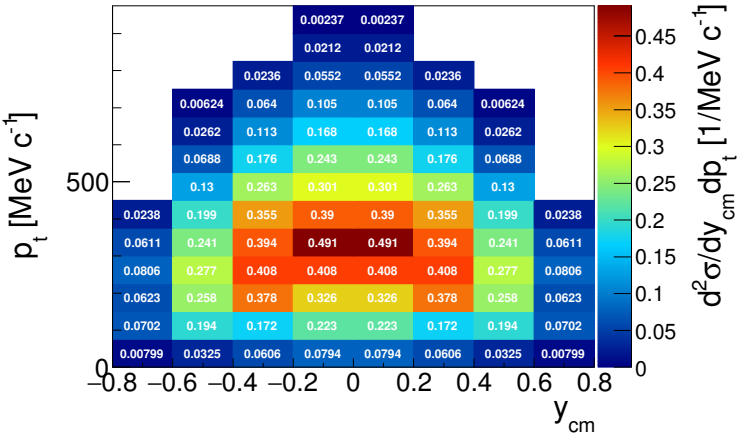


With simulation extrapolation

Data fully cover one hemisphere. We need to mirror spectrum over $\cos\theta_{\mathrm{cms}} = 0$ to cover full phase-space. Overlapping points are averaged with errors weights.

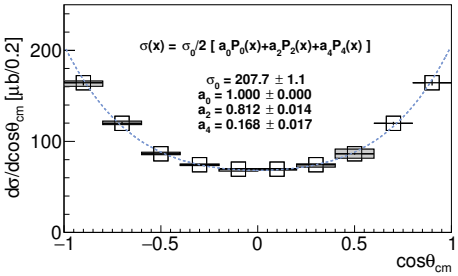
Extraction of the total cross section

for *y* distribution

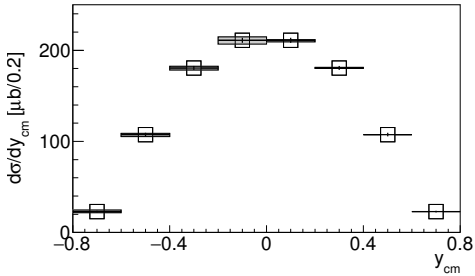


After mirroring

$\sigma(pp \to \Lambda + X)$ cross section extraction



σ = 205.8±1.5 $^{+7.1}_{-8.7}$±8.4 $^{+0.3}_{-0.4}$ μb



σ = 208.8±1.1 $^{+5.0}_{-5.8}$±8.3 $^{+0.5}_{-0.6}$ μb

- cross-section
  - ± exp. statistical
  - ± exp. syst. (corrections)
  - ± exp. syst. (normalization)
  - ± model extrapolation

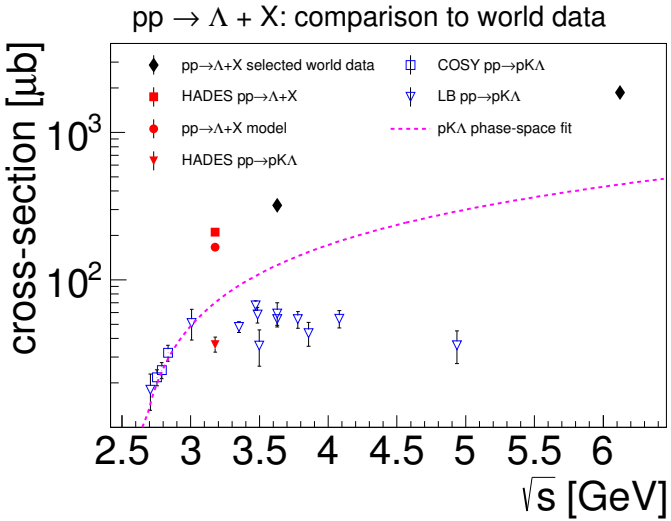
- simple average:

$$\sigma(pp \to \Lambda + X) = 207.3 \pm 1.3\ ^{+6.0}_{-7.3} \pm 8.4\ ^{+0.4}_{-0.5}\ \mu b$$

- cross-check analysis:

$$\sigma(pp \to \Lambda + X) = 201.9 \pm 4.1\ ^{+7.6}_{-8.0} \pm 14.7\ \mu b$$

World data


pp → Λ + X: comparison to world data
pp→Λ+X selected world data
HADES pp→Λ+X
pp→Λ+X model
HADES pp→pKΛ
COSY pp→pKΛ
LB pp→pKΛ
pKΛ phase-space fit
cross-section [μb]
10^3
10^2
2.5
3
3.5
4
4.5
5
5.5
6
√s [GeV]

Summary

- Cross section of the Λ production was estimated to:

$$\sigma(\mathrm{pp} \to \Lambda + X) = 207.3 \pm 1.3\ ^{+6.0}_{-7.3} \pm 8.4\ ^{+0.4}_{-0.5}\ \mu\mathrm{b}.$$

- Differential cross section has been determined → significant anisotropy is found for the Λ production.

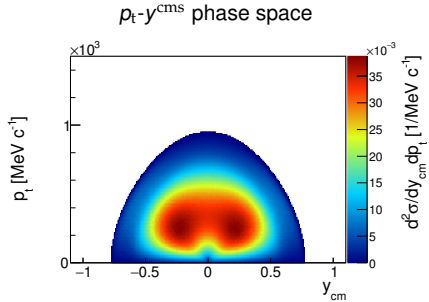
- Model accuratly describes experimental spectra in range $-0.6 < \cos\theta_{\mathrm{cms}} < 0.6$ and for $p > 500\,\mathrm{MeV/c}$.
- But undershoots data in backward direction at $\cos\theta_{\mathrm{cms}} < -0.6$.

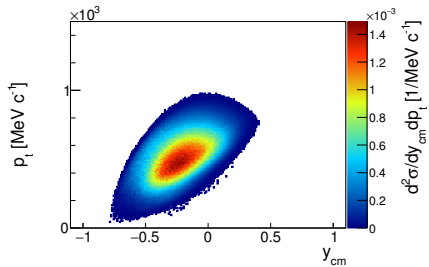
- Looking forward for the future experiments at HADES with ECAL and FD, also p+p.

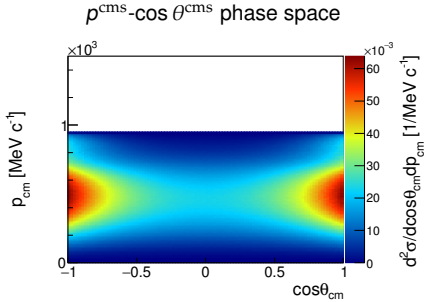
Thanks to all HADES collaborators

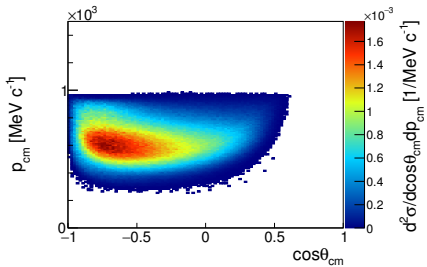
Differential distributions of the model

Production model, all channels summed coherently



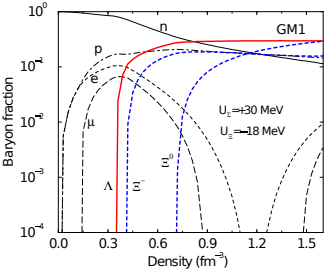




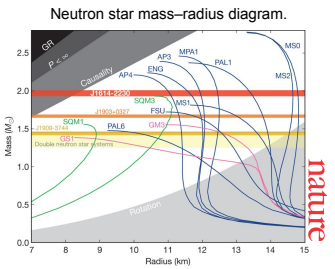


Hunting for Λ in proton-proton reaction

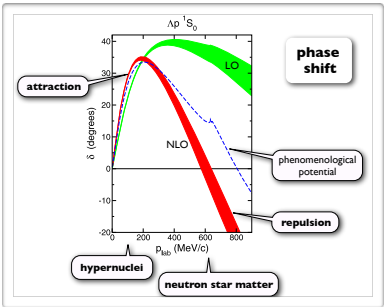
Motivation



Phys. Rev. C 53 (1996) 1416



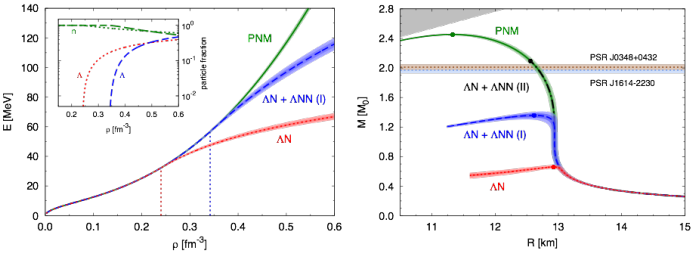
PB Demorest *et al. Nature* **467**, 1081-1083 (2010) doi:10.1038/nature09466



EPJ Web of Conf. 73 (2014) 05012

Hunting for Λ in proton-proton reaction

Motivation



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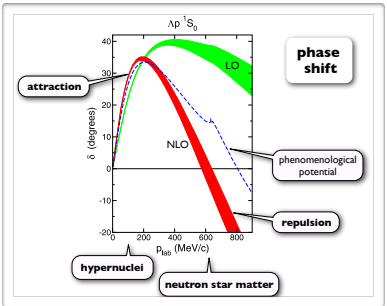

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