Λ hyperon production in proton-proton reactions at 3.5 GeV measured with HADES

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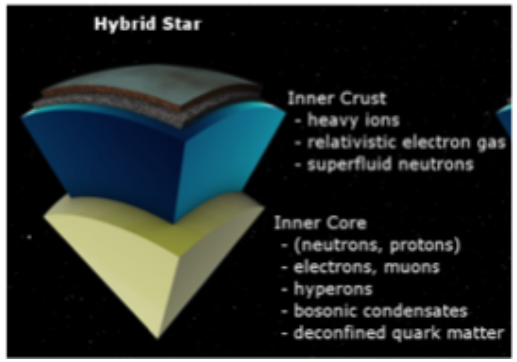
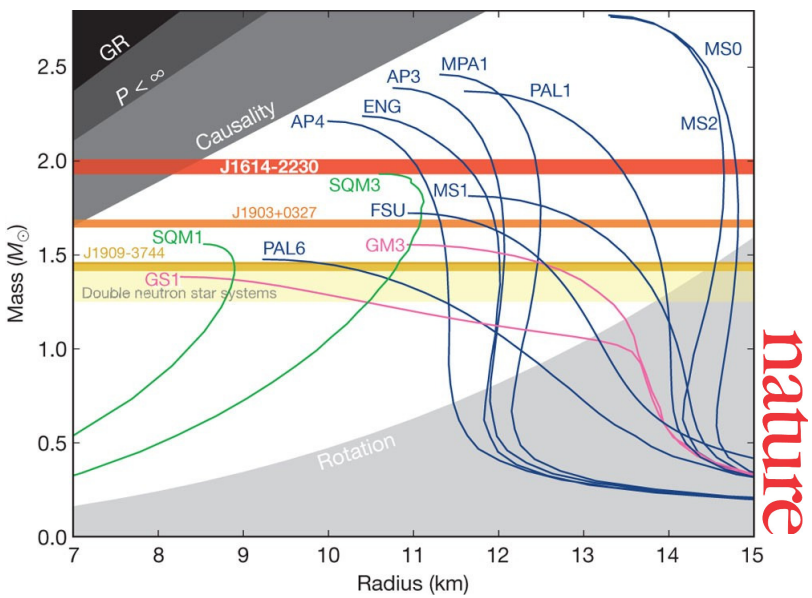
Neutron stars

- $R \approx 10 - 15\,\mathrm{km}$
- $M \approx 1.5\,\mathrm{M_{sun}}$

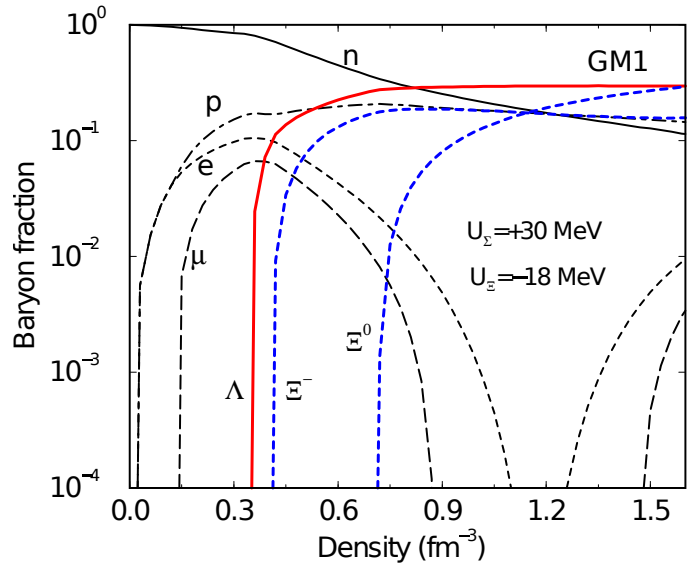


- Very high density in the interior
- Production of strangeness is energetically favourable
- It relieves the Fermi pressure of neutrons and protons
- But. . . a decrease of the pressure softens the Equation of State

Neutron star mass–radius diagram.



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



J. Schaffner and I.N. Mishustin, Phys. Rev. C 53 (1996) 1416

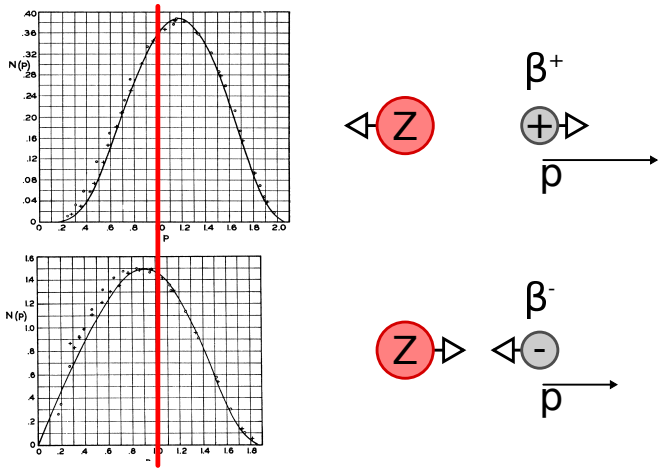
- Many body interactions: YN, YNN
- Repulsive core of Λ interactions

Potential probing

- Example in the electromagnetic sector

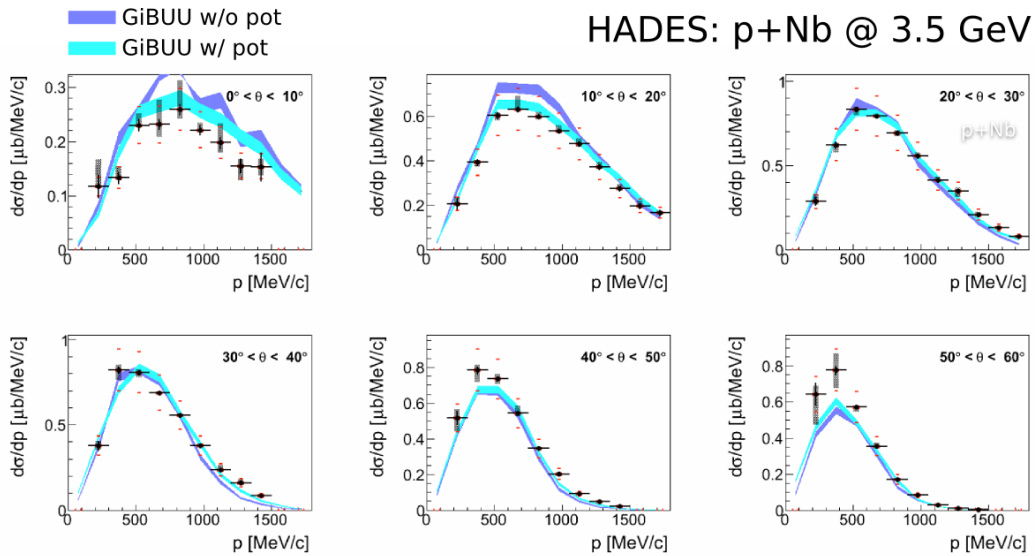
Beta decay of ^{64}Cu

- Coulomb potential reflected in momenta spectrum of electrons and positrons



J.R. Reitz, Phys. Rev. 77 (1950) 50.

- strangeness sector – K^0 in-medium repulsion

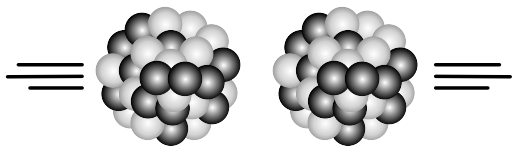


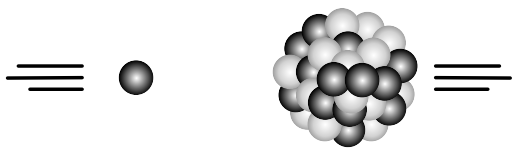
Phys. Rev. C 90, 054906

General idea:
look at kinematics of escaped particles

Experimental production of Hyperons

- low energy ($\sqrt{s}_{\mathrm{NN}} \rightarrow \sqrt{s}_{\mathrm{thr}}$) experiments are favoured
- produced Λs have lower momentum – feel medium for longer time

A+A reaction  $\sigma_{\mathrm{prod.}} + \sigma_{\mathrm{scat.}}$

N+A reaction  $\sigma_{\mathrm{prod.}} + \sigma_{\mathrm{scat.}}$

N+N reaction  $\sigma_{\mathrm{prod.}}$

Production channels

id	pp → reaction	cross section [μb]	⊿	H	notes
		3-body channels			
40	$\Lambda + p + K^+$	45.0	✓	✓	[1]
pwa	$\Lambda + p + K^+$	36.26	✓	✓	[2]
60	$\Sigma^0 + p + K^+$	15.5	✓		
68	$\Lambda + \Delta^{++} + K^0$	29.45	✓	✓	[3]
400	$\Sigma^0 + \Delta^{++} + K^0$	9.26	✓	✓	[3]
401	$\Lambda + \Delta^+ + K^+$	9.82	✓		from res. mod.
402	$\Sigma^0 + \Delta^+ + K^+$	3.27	✓		from res. mod.
72	$\Sigma(1385)^+ + n + K^+$	22.42	✓	✓	[4]
77	$\Sigma(1385)^+ + p + K^0$	14.05	✓	✓	[3]
88	$\Sigma(1385)^0 + p + K^+$	6.0	✓	✓	[5]
44	$\Lambda(1405) + p + K^+$	9.2	✓	✓	[4, 2]
111	$\Lambda(1520) + p + K^+$	5.6	✓	✓	[4]
		4-body channels			
55	$\Lambda + p + \pi^+ + K^0$	2.98		✓	[3]
58	$\Lambda + n + \pi^+ + K^+$	2.21			fit res. mod.
61	$\Lambda + p + \pi^0 + K^+$	1.72			fit res. mod.
66	$\Sigma^0 + p + \pi^+ + K^0$	1.34		✓	[3]
410	$\Sigma^0 + n + \pi^+ + K^+$	2.21			fit res. mod.
411	$\Sigma^0 + p + \pi^0 + K^+$	1.72			fit res. mod.

References

[1] G. Agakishiev et al. *Hyperfine Interactions* 210.1-3 (2012).

[2] Eliane Epple. PhD thesis. TU München, 2014.

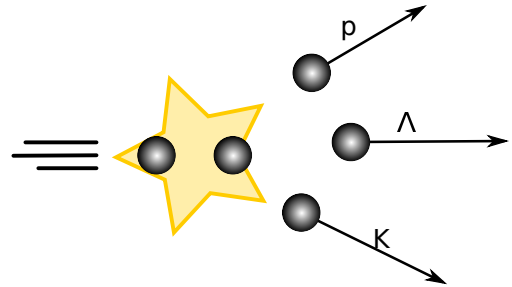
[3] G. Agakishiev et al. *PRC* 90 (2014).

[4] G. Agakishiev et al. *PRC* 85 (2012).

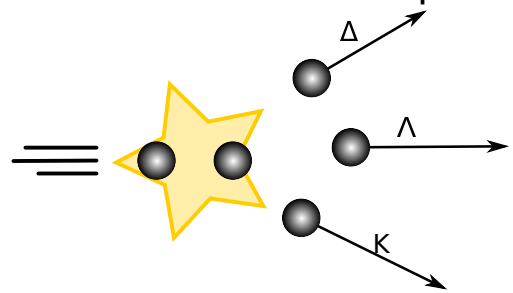
[5] G. Agakishiev et al. *PRC* 87 (2013).

Phys. Rev. C 59:369–387, 1999

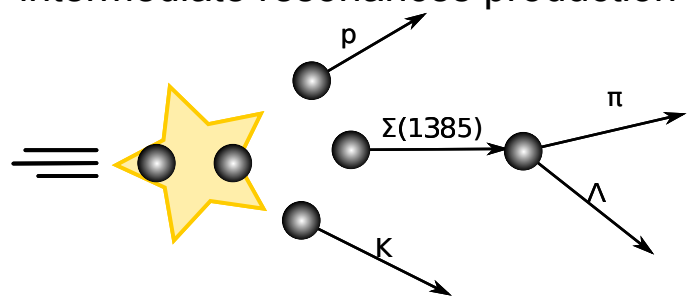
non-resonant production



associated resonant production



intermediate resonances production



Hunting for Λ

Motivation

- Production in elementary system as input for Λ-N interaction in nucleus
- Pin down contribution of Λ^*, Σ^*, Δ^+, Δ^{++} and N^* resonances in the energy regime around 3.5 GeV
- Tuning of transport models

Λ Properties:

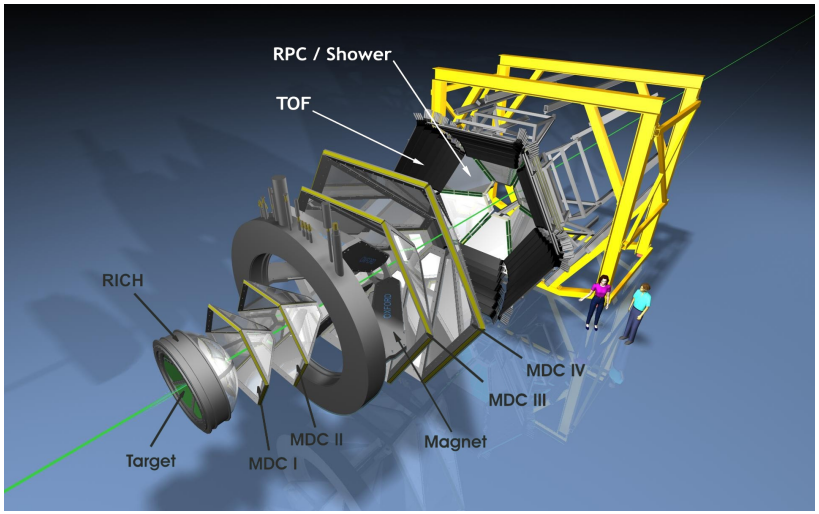
Λ^0 = uds, S=-1, I(J^P) = 0$\left(\frac{1}{2}^+\right)$

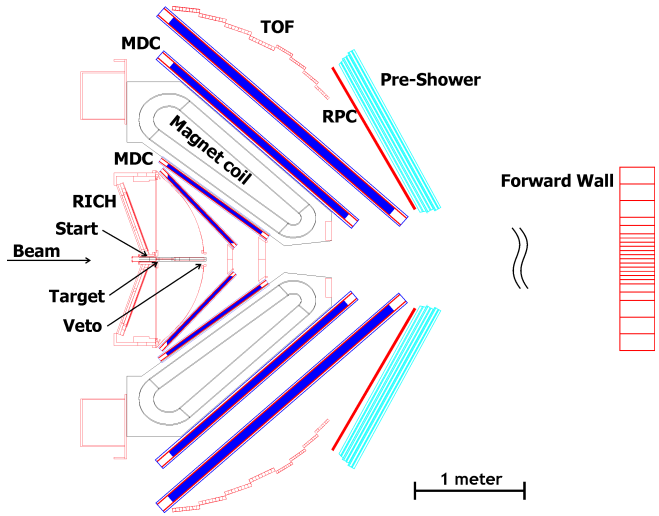
$M_\Lambda = 1115.683 \pm 0.006$ MeV/c^2

$\tau = 2.631 \pm 0.020 \times 10^{-10}$ s

HADES

High **A**cceptance **D**i-**E**lectron **S**pectrometer



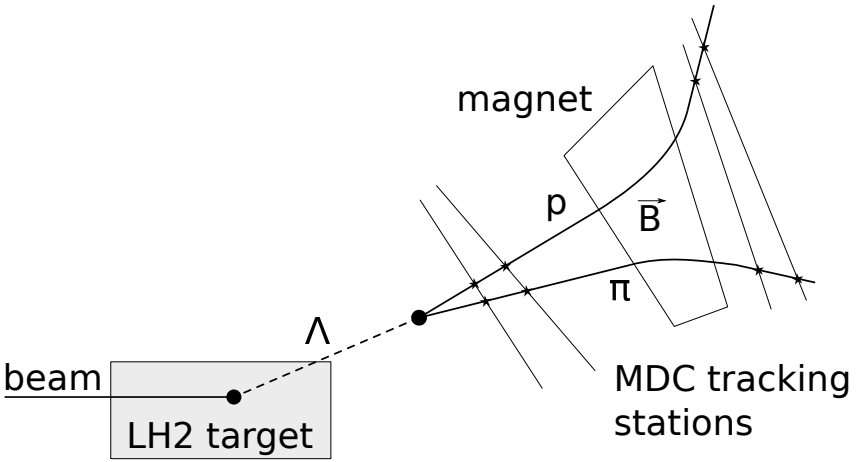


High **A**cceptance **D**i-**E**lectron **S**pectrometer

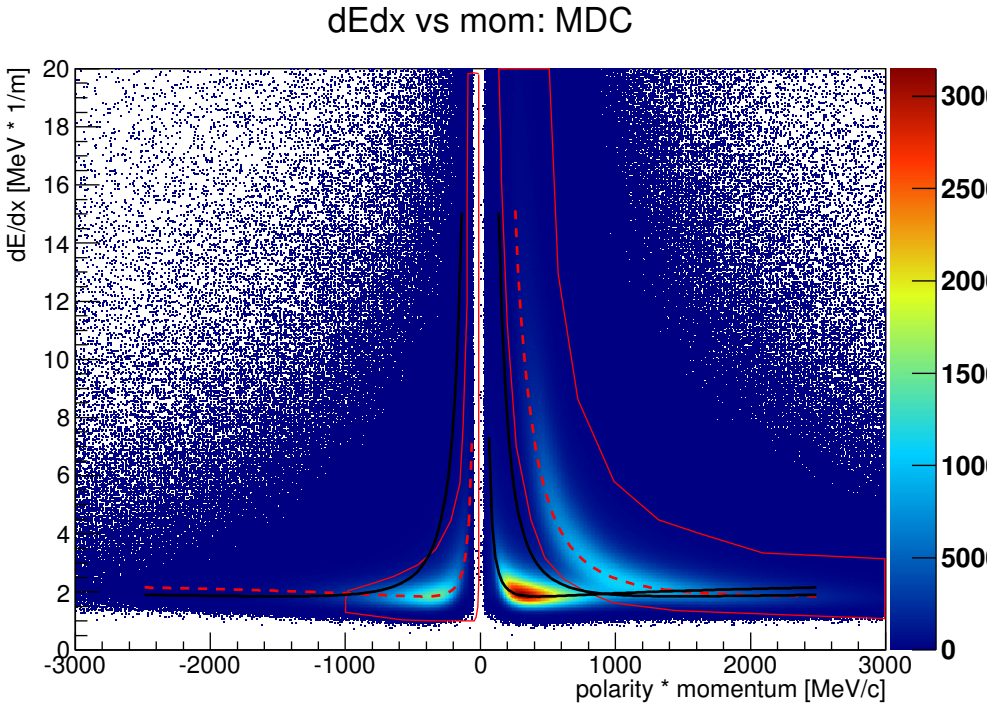
- located in GSI Helmholtzzentrum for Heavy Ion Research, Darmstadt, Germany
- fixed-target experiment
- SIS18, beam energies up to
  - 3.5 GeV (protons)
  - 1.25 AGeV (Au)

- 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
- e/π separation with RICH

Λ Reconstruction in HADES

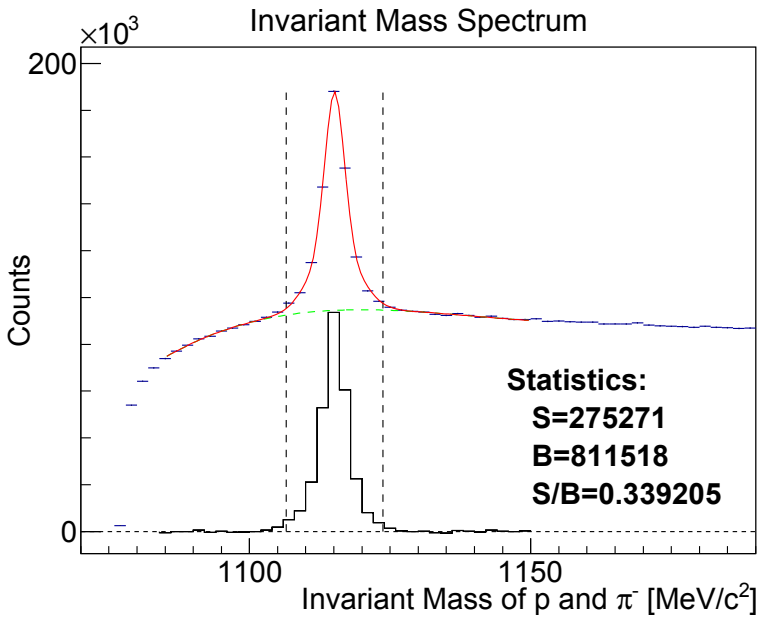


- production in LH2 target region
- reconstruction via proton-π^- decay products
- tracking in four layers of Multiwire Drift Chambers
- particle identification with dE/dx and momentum (magnetic field)



Invariant Mass and differential distribution

Λ-signal yield after differential mass fitting



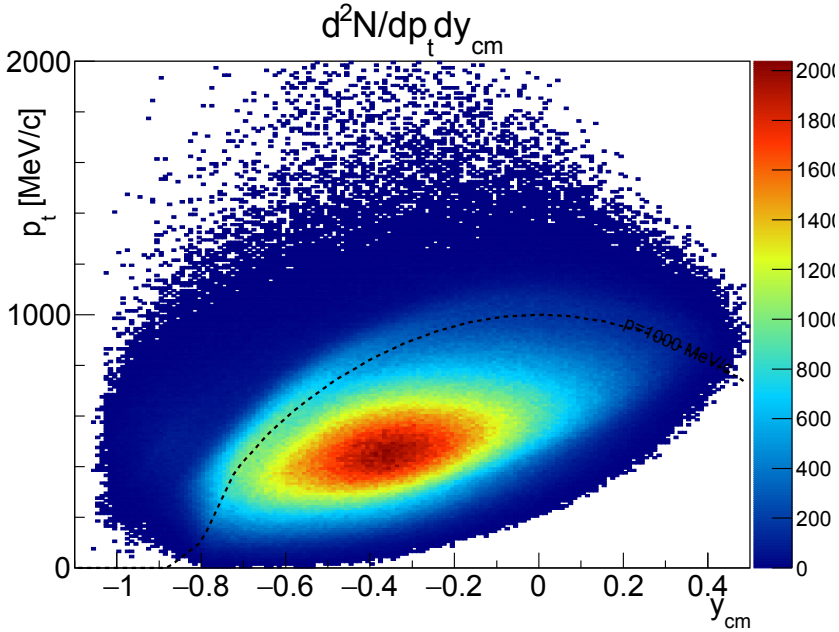
- number of reconstructed Λs : $\sim 275k$
- S/B ratio: 0.34

Conducted differential analyses

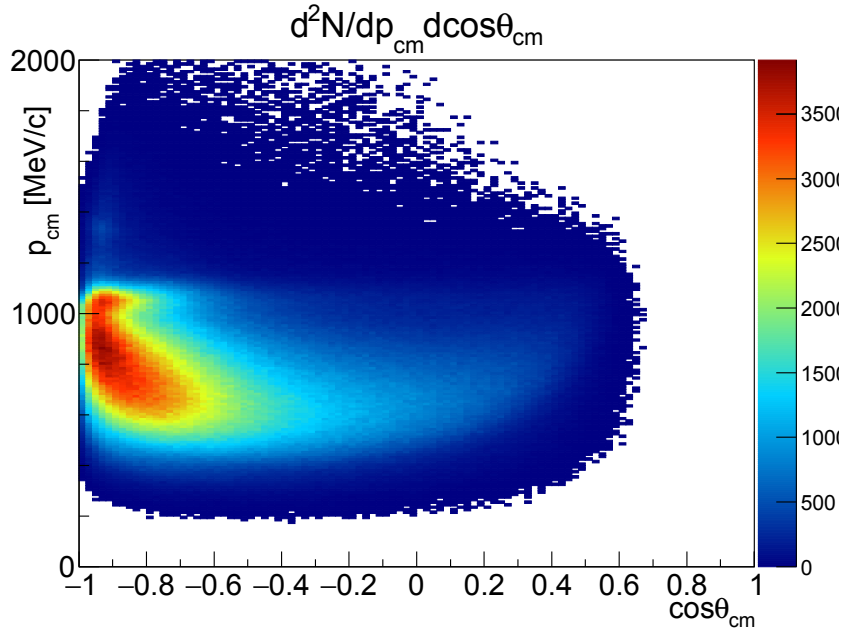
- p_t-y^{cms}
- p^{cms}-cos θ^{cms}

Invariant Mass and differential distribution

p_t-y^{cms} phase space



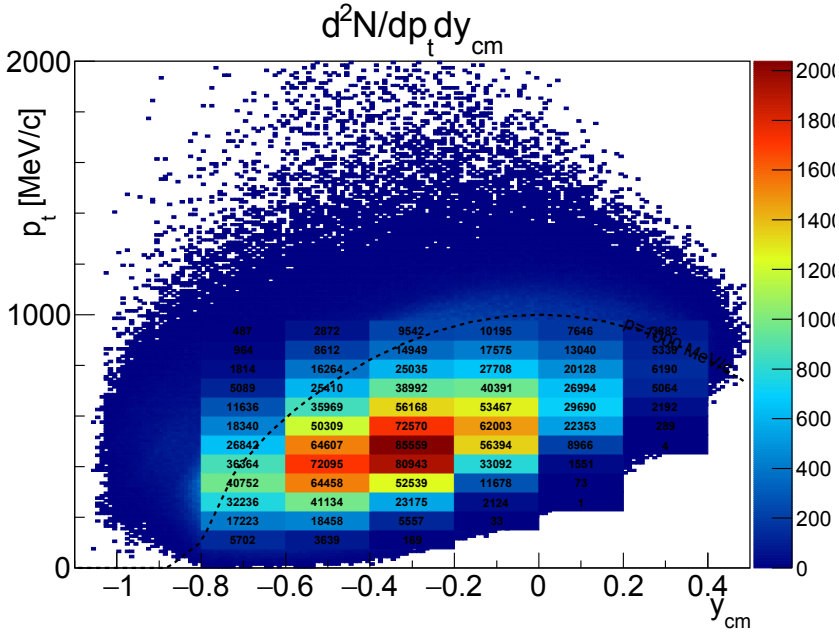
p^{cms}-cos θ^{cms} phase space



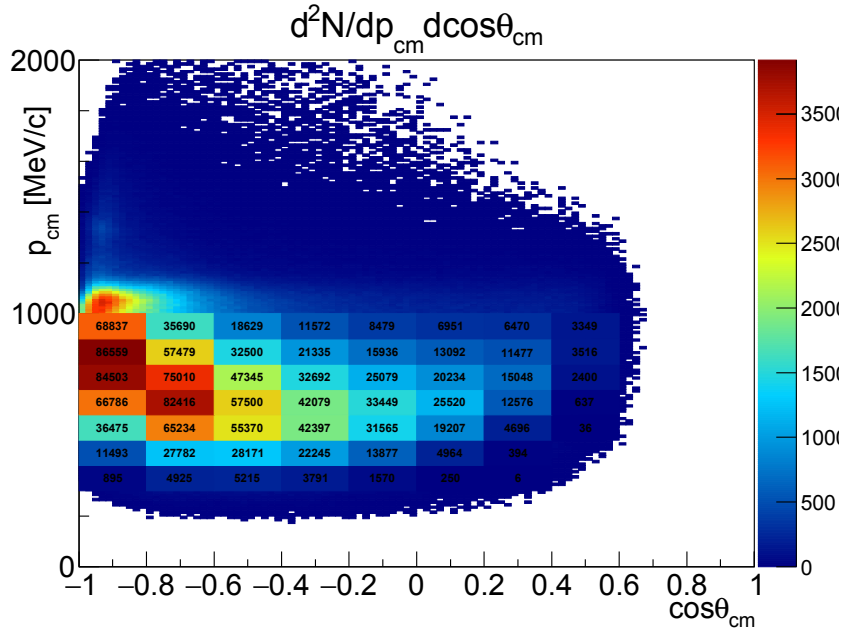
- Total collected signal in phase-space distribution (signal + background)
- Rebinning of the interesting phasespace (limits from kinematics)
- Differential fit in the phase-space bins → leads to signal yield in each bin

Invariant Mass and differential distribution

p_t-y^{cms} phase space



p^{cms}-cos θ^{cms} phase space



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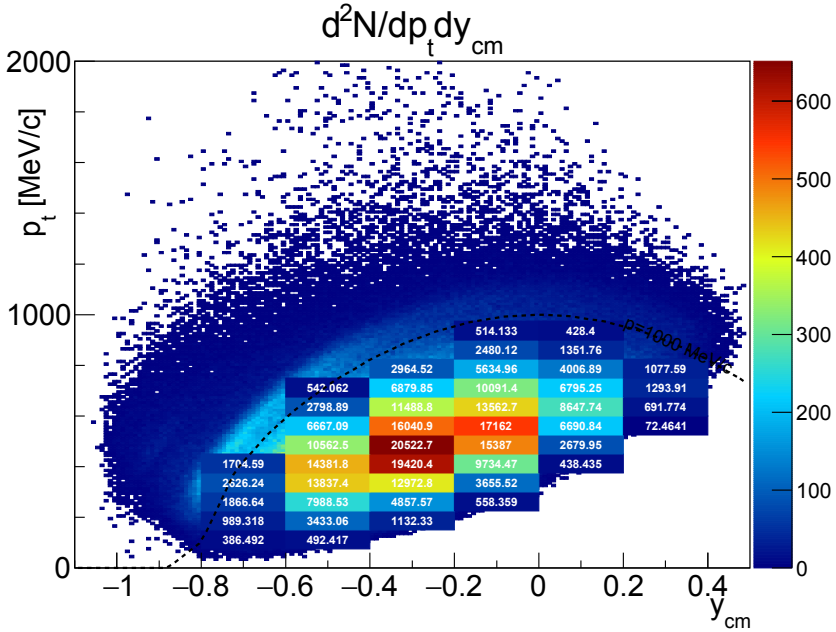
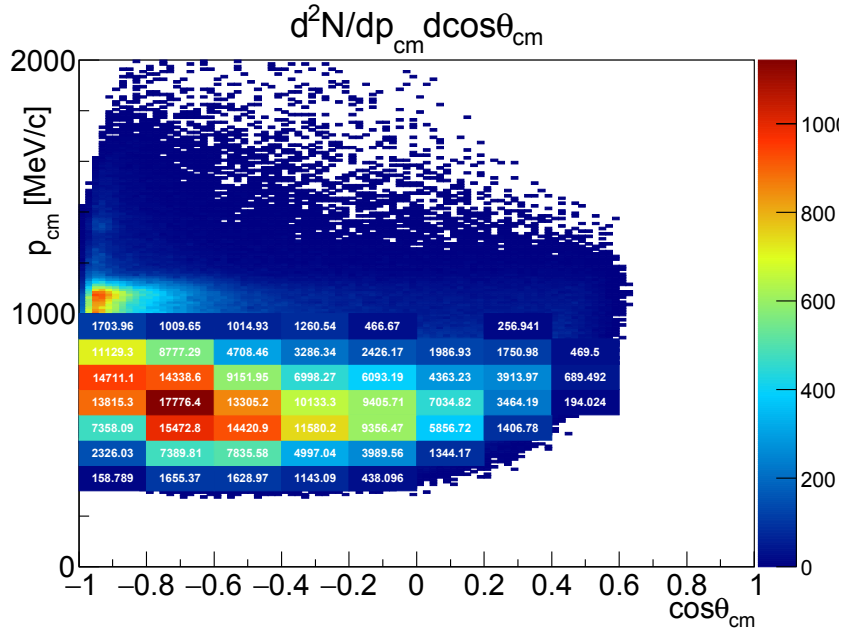


p^{cms}-cos θ^{cms} phase space



- Total collected signal in phase-space distribution (signal + background)
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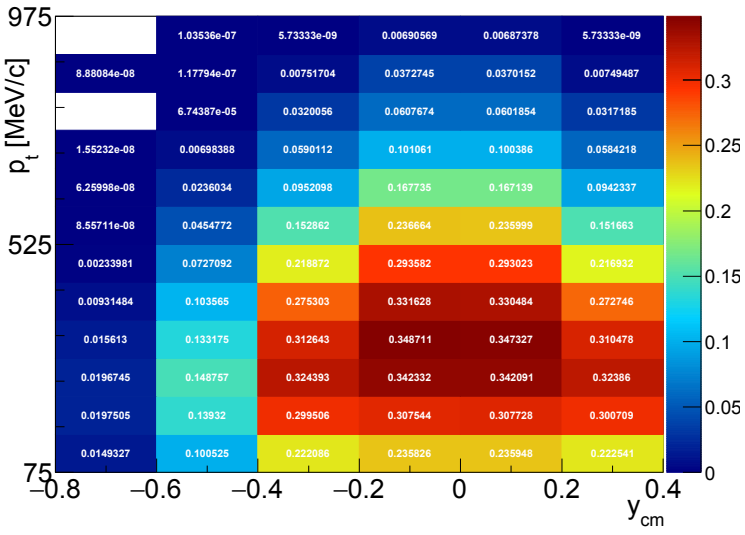
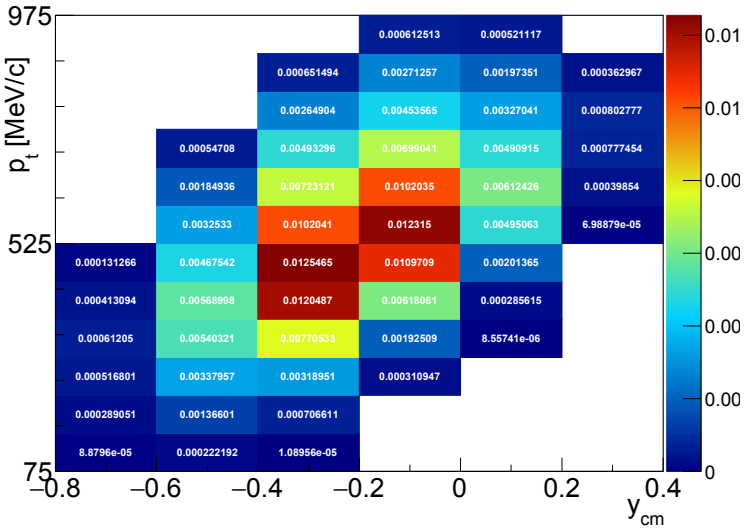
Efficiency and acceptance corrections with Pluto

Ideal simulation of Λ production in hadron coctail



Simulation of Λ production in the HADES acceptance



Corrections procedure:

1. All channels (events) are simulated with Geant (sim sample)
2. Further they are filtered for HADES acceptance and efficiency (fss sample)
3. Each channel of sim(fss) samples is weighted by its σ
4. Weighted channels are summed to total SIM(FSS) sample
5. $Æ = FSS/SIM$ determines correction matrix
6. Data correction: $D^{acc+eff}/Æ = D^{4\pi/acc}$

Normalization:

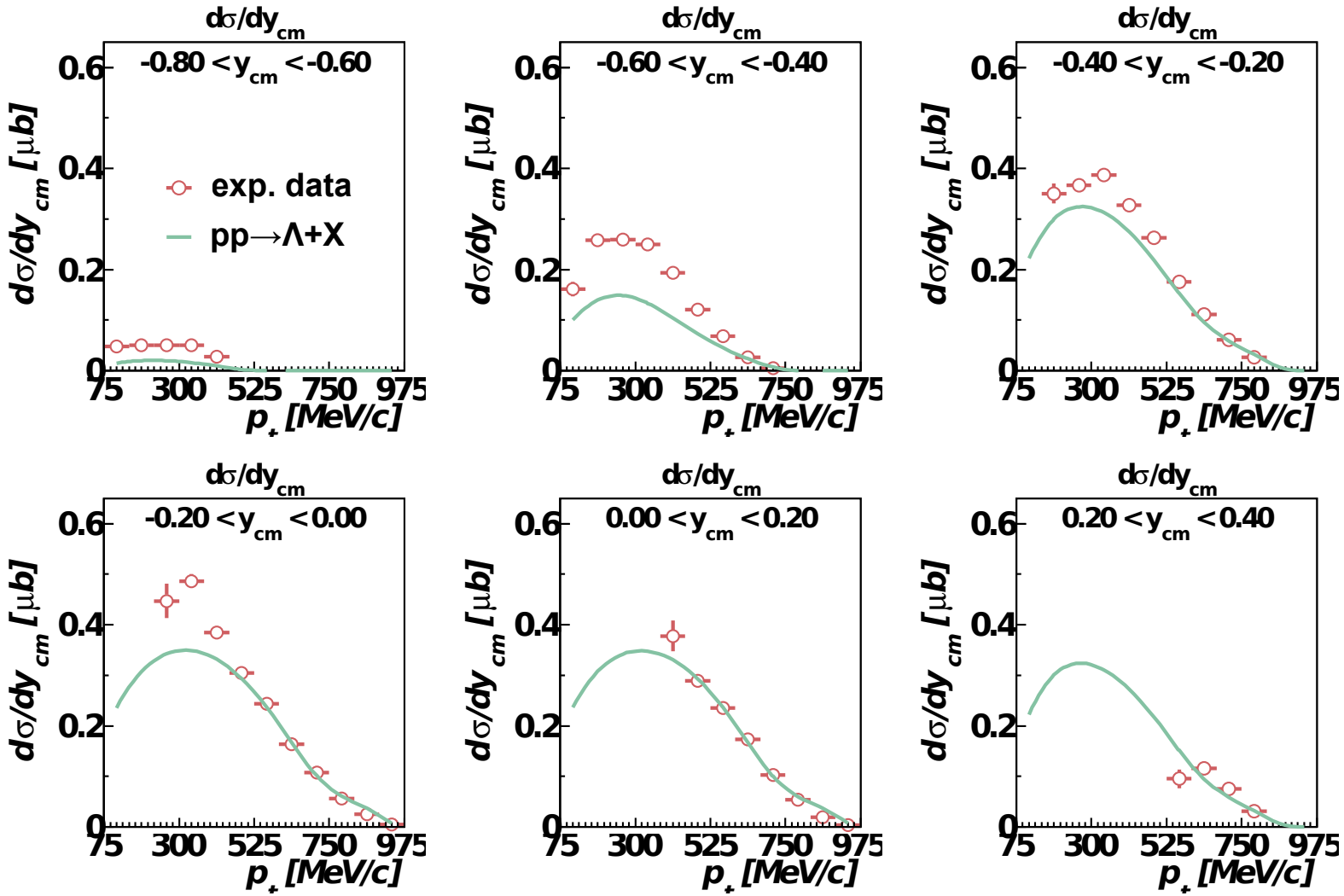
- data are normalized to total proton-proton elastic cross-section

Data corrected in such way can be compared with 4π simulations.

HADES data and simulation model comparison

$P_t - y^{cms}$

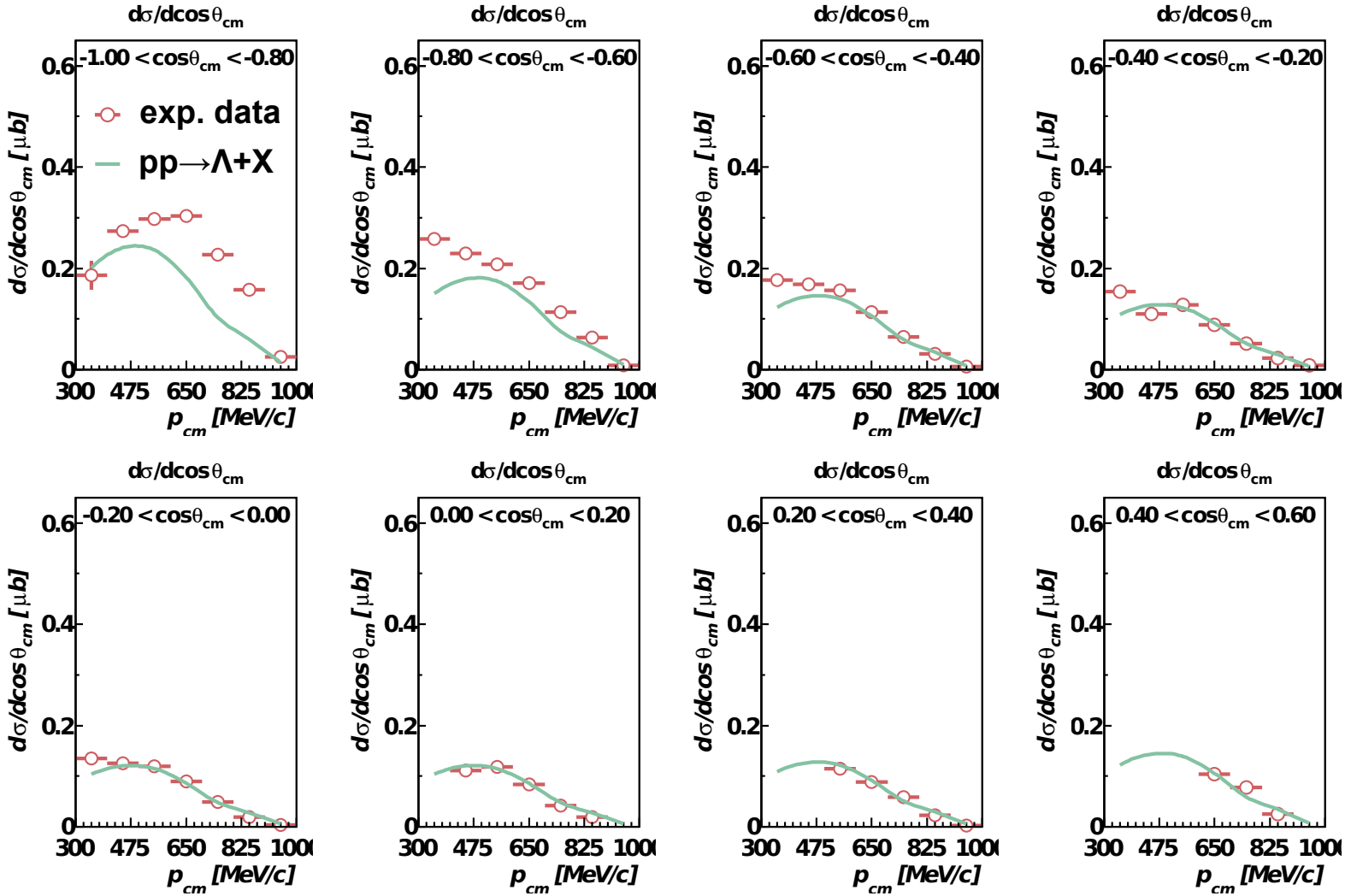
pKΛ with PWA, statistical errors only



HADES data and simulation model comparison

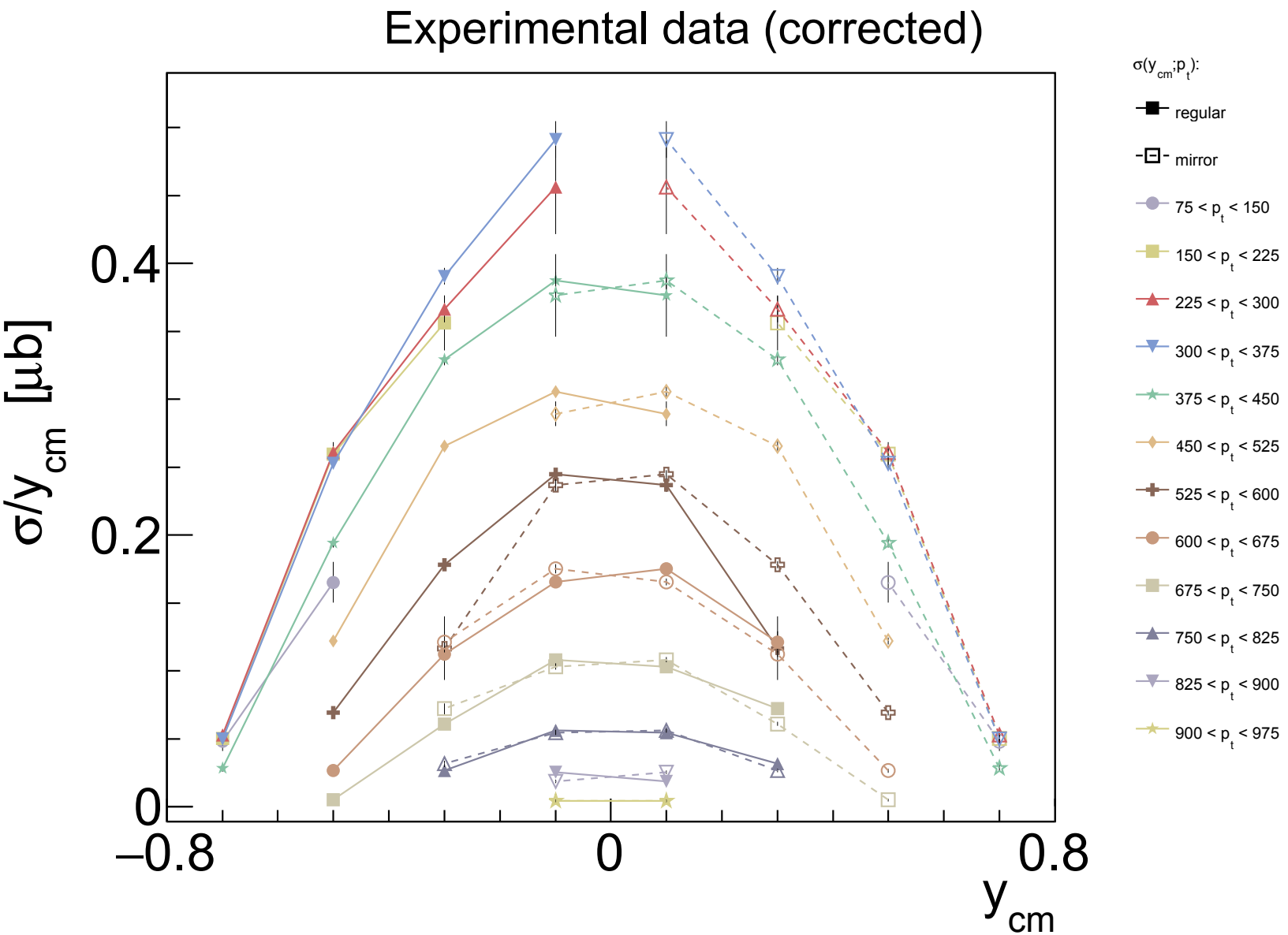
$P^{cms} - \cos\theta^{cms}$

pKΛ with PWA, statistical errors only



Symmetry check

- particle production in proton-proton CM system should reflect symmetry $f(-x) = f(x)$



Summary

Summary

- Total Λ production model based on exclusive production channels is implemented with Pluto at 3.5 GeV beam energy.
- Model accuratly describes experimental spectra in range $-0.6 < \cos\theta^{\mathrm{cms}} < 0.6$.
- But undershoots data in backward direction at $\cos\theta^{\mathrm{cms}} < -0.6$

Outlook

- Understand discrapencies between experimental data nad simulation, in the backward directions.
- Systematic error studies.
- Extract total production cross-section.

Other Hades talks at SQM15:

- Monday - Laura Fabbietti
- Tuesday - Manuel Lorenz
- Thursday - Oliver Arnold

Thanks to all HADES collaborators