Production of $K^*(892)^+$ in p+p collisions at 3.5 GeV

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Overview

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Properties of the $K^*(892)^+$

HADES

PDG table:

$K^*(892)$ $I(J^P) = \frac{1}{2}(1^-)$

$K^*(892)^\pm$ mass $m = 891.66 \pm 0.26$ MeV
Mass $m = 895.5 \pm 0.8$ MeV
$K^*(892)^0$ mass $m = 895.94 \pm 0.22$ MeV (S = 1.4)
$K^*(892)^\pm$ full width $\Gamma = 50.8 \pm 0.9$ MeV
Full width $\Gamma = 46.2 \pm 1.3$ MeV
$K^*(892)^0$ full width $\Gamma = 48.7 \pm 0.8$ MeV (S = 1.7)

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	$\sim$ 100 %		289
$K^0\gamma$	$(2.39\pm0.21) \times 10^{-3}$		307
$K^\pm\gamma$	$(9.9 \pm0.9) \times 10^{-4}$		309
$K\pi\pi$	$< 7 \times 10^{-4}$	95%	223

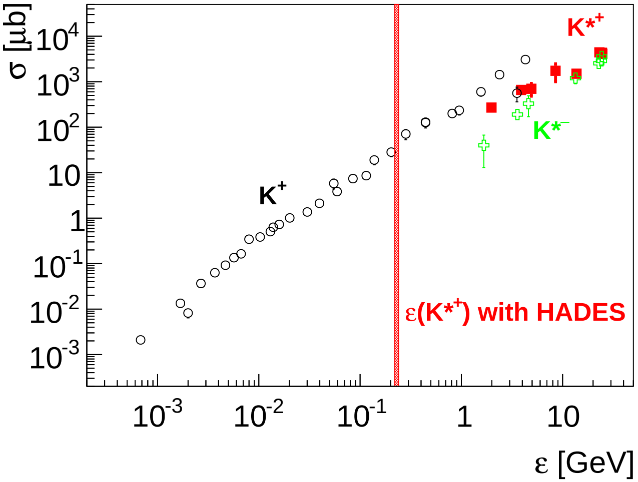
Production mechanism

- Available $\sqrt{s} \approx 3.18$ GeV
- $p + p \rightarrow p + K^*(892)^+ + \Lambda$
  - $\sqrt{s} \approx 2.95$ GeV
- $p + p \rightarrow p + K^*(892)^+ + \Sigma^0$
  - $\sqrt{s} \approx 3.02$ GeV
- $K^*(892)^+ \rightarrow K^0_S + \pi^+ \rightarrow \pi^+ + \pi^- + \pi^+$

Goal of the analysis

- To reconstruct the invariant mass spectrum (IMS) of the $K^*(892)^+$.
- To apply acceptance and efficiency corrections to the differentially extracted yield.
- To estimate the total production cross section.

Current knowledge about the $K^*(892)^+$

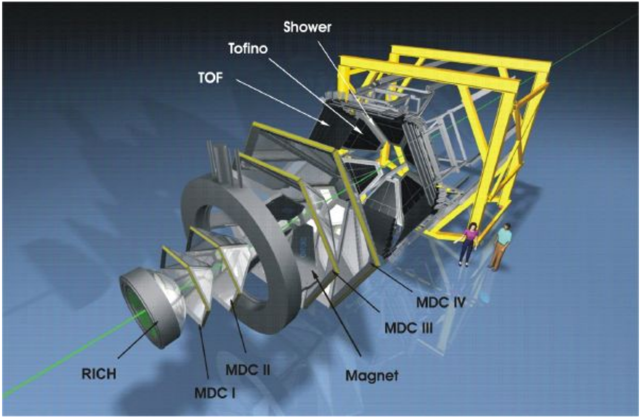


Current knowledge about the $K^*(892)^+$

- No previous measurements of the $K^*(892)^+$ at energies close to the production threshold in pp collisions.
- The result will help to constrain parameters in transport models.
- The results can be used as reference measurement to pA or even AA collisions, which will be capable of investigating in-medium effects.

The HADES experiment

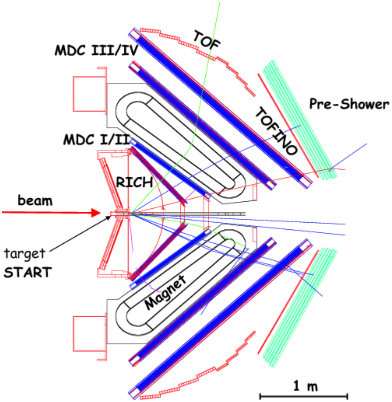
High Acceptance Di-electron Spectrometer @ GSI, Darmstadt



[http://ojs.ujf.cas.cz/ionty/hades/, 2016]

The HADES experiment

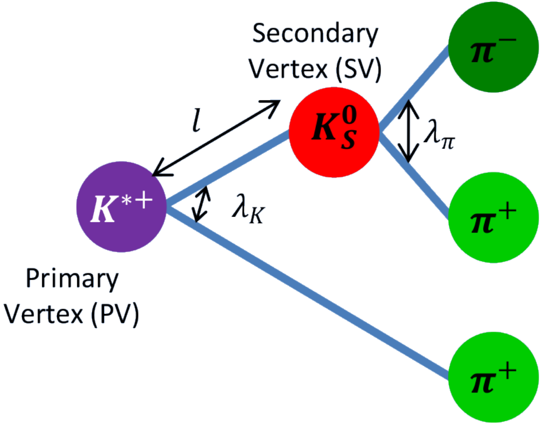
- Fixed-target experiment.
- Full azimuthal coverage, $15^\circ - 85^\circ$ in polar angle.
- Momentum resolution $1-5\%$.
- Particle ident. via dE/dx & Tof.
- $1.2 \cdot 10^9$ Events in p+p at $E_{\mathrm{beam}} = 3.5$ GeV.



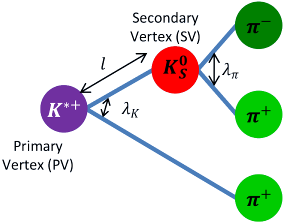
[Agakishiev et al., 2009]

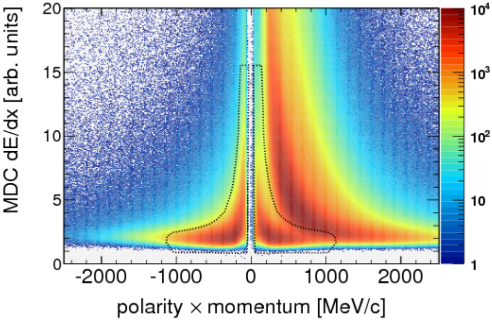
Analysis

Decay topology



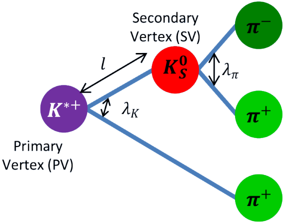
PID

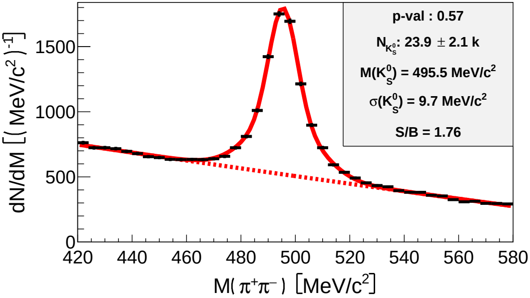




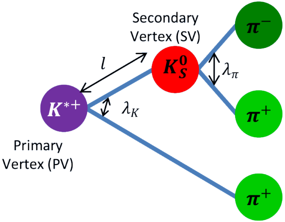
[Agakishiev et al., 2014]

IMS of the K_S^0 candidates

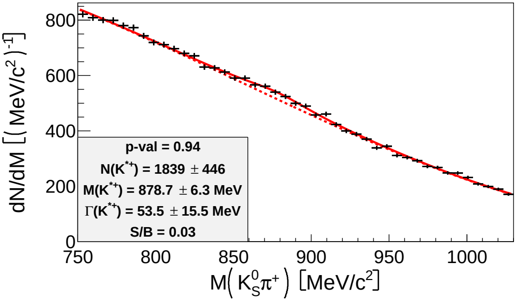




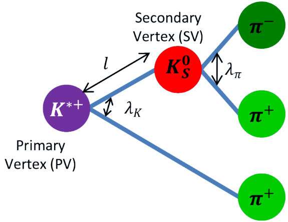
IMS of the $K^*(892)^+$ candidates



- No cut on IM($\pi^+\pi^-$).
- The signal is fitted with a Breit-Wigner function.



IMS of the $K^*(892)^+$ candidates



- With cut on IM($\pi^+\pi^-$).
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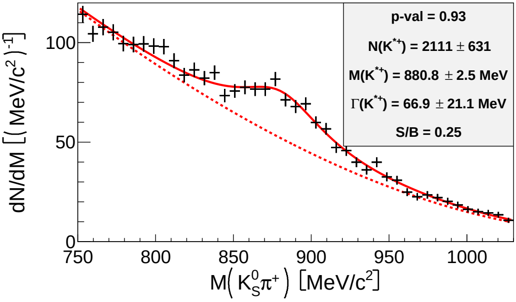

Problems with the fit

- Phase space limitations.
- Detector resolution.
- A Brei-Wigner function is incapable of modeling the signal.
- Monte-Carlo simulations are needed for further investigation.

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Simulation of the $K^*(892)^+$ production

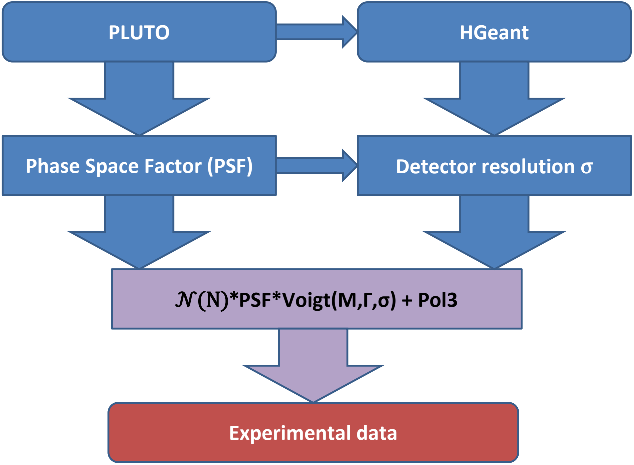
HADES

1. $p + p \rightarrow p + K^*(892)^+ + \Lambda$
2. $p + p \rightarrow p + K^*(892)^+ + \Sigma^0$

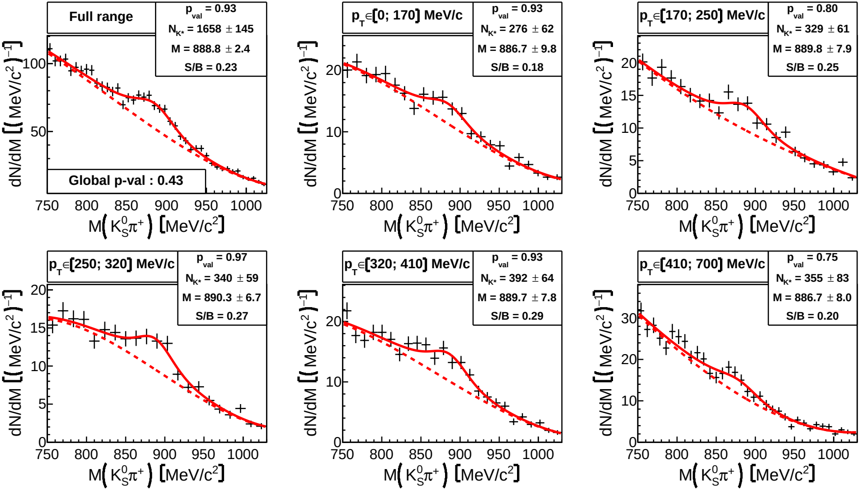
- $K^*(892)^+ \rightarrow K^0_S + \pi^+$

- Both channels are simulated with the **PLUTO** event generator.
- The response of the detector has been simulated using **HGeant**.

Work-flow


PLUTO
HGeant
Phase Space Factor (PSF)
Detector resolution σ
𝒩(N)*PSF*Voigt(M,Γ,σ) + Pol3
Experimental data

IMS of the $K^*(892)^+$ candidates



Corrections

The measured yield $n_i^{(\mathrm{exp})}$ needs to be corrected for:

- Acceptance and efficiency.
- Branching ratios.
- Normalization to pp elastic collisions.

$$\sigma_{\mathrm{tot}}^{K^{*+}} = C^{(\sigma)} C^{(\mathrm{BR})} \sum_i C_i^{(\mathrm{2ch})} n_i^{(\mathrm{exp})}$$

Acceptance and efficiency corrections

- The simulations contain two distinct production channels - which one should be used?

Acceptance and efficiency corrections

- The simulations contain two distinct production channels - which one should be used?

- Solution: mix the two channels and fit the predicted measured yields to the experimental data.

$$C_i^{(2\mathrm{ch})} = \frac{N_i^{(2\mathrm{ch})}}{n_i^{(2\mathrm{ch})}} = \frac{p^{(\Lambda)} N_i^{(\Lambda)} + p^{(\Sigma)} N_i^{(\Sigma)}}{p^{(\Lambda)} n_i^{(\Lambda)} + p^{(\Sigma)} n_i^{(\Sigma)}}$$

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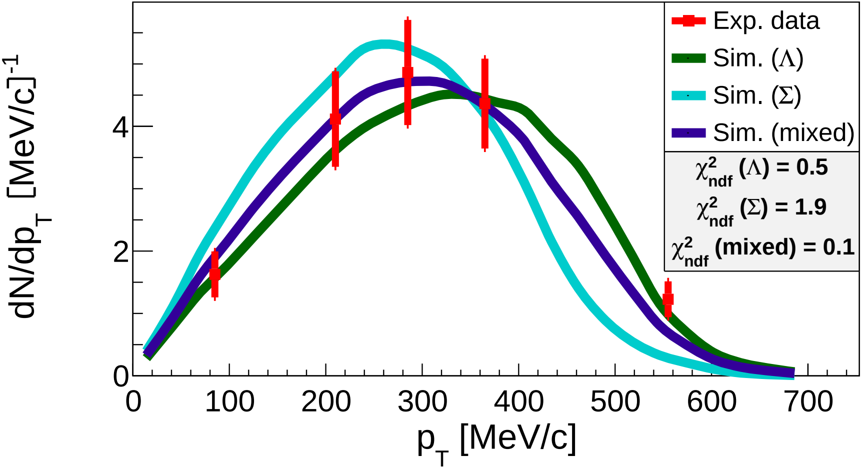
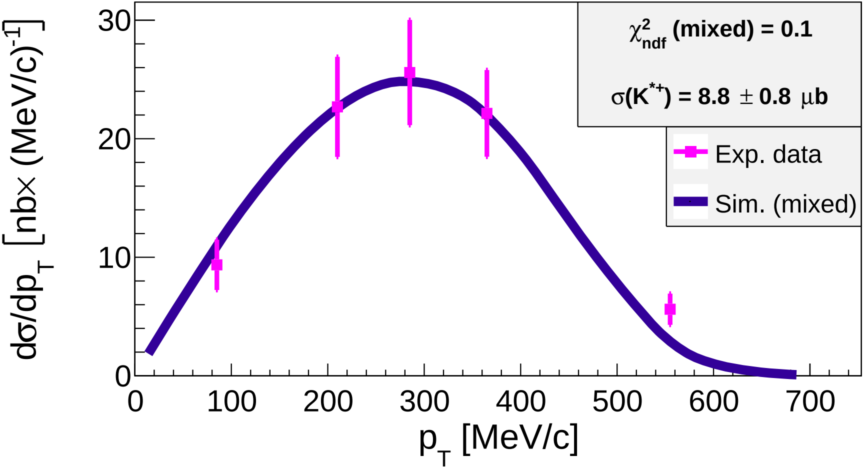
Uncorrected p_T spectrum



Corrected p_T spectrum



Systematic uncertainties

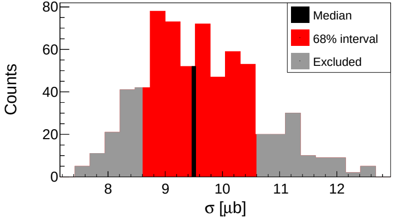
Systematic uncertainties

The idea:

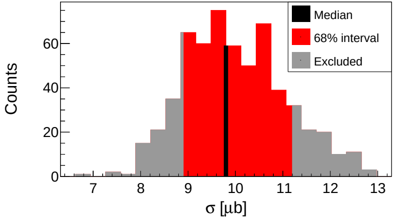
- Take many different “paths”, i.e. cut combinations.
- The deviation between the results should be considered as systematic uncertainty.
- Make a cross check with observables other than p_T.

Systematic uncertainties

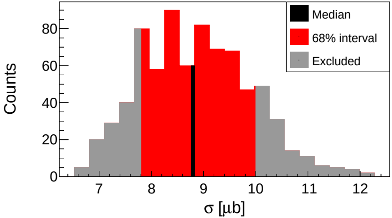
Based on p_T:



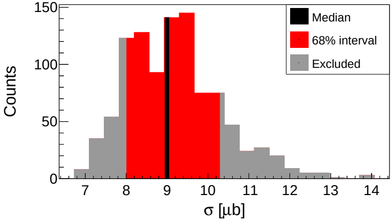
Based on p_{CM}:



Based rapidity (y):



Based on $\cos\theta_{\mathrm{CM}}$:



Systematic uncertainties

Observable	$\sigma_{K^{*+}}(\mu b)$	Σ contribution (%)
p_{T}	$9.5 \pm 0.9(\mathrm{stat})^{+1.1}_{-0.9}(\mathrm{syst})$	$40.8^{+19.0}_{-22.1}$
p_{CM}	$9.8 \pm 0.9(\mathrm{stat})^{+1.4}_{-0.9}(\mathrm{syst})$	$28.5^{+17.6}_{-14.6}$
y	$8.8 \pm 1.0(\mathrm{stat})^{+1.2}_{-1.0}(\mathrm{syst})$	n/a
$\cos\theta_{\mathrm{CM}}$	$9.0 \pm 1.1(\mathrm{stat})^{+1.3}_{-1.0}(\mathrm{syst})$	n/a

Spin-alignment

- The spin-alignment property can be investigated using the angle ϑ between the momentum of the K^{*+} particle (in LAB) and the momentum of one of its daughters (in CM).

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- In the case of no net polarization this observable should be described by:

$$W(\vartheta) = \frac{3}{4}\left[1 - \rho_{00} + (3\rho_{00} - 1)\cos^2\vartheta\right],$$

where ρ_{00} is the zero-spin projection component of the spin-density matrix.

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HADES

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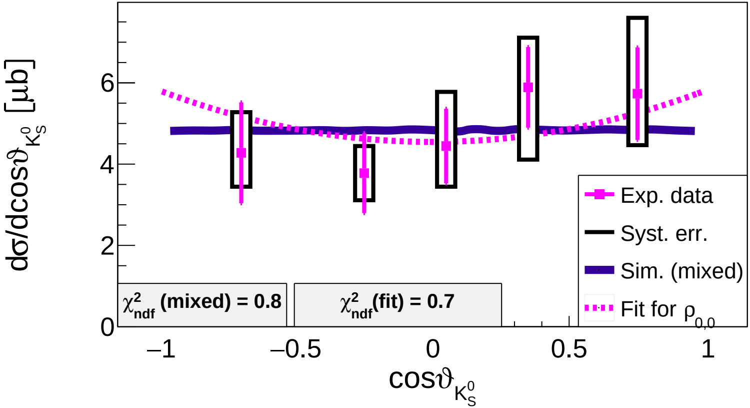
  where ρ_{00} is the zero-spin projection component of the spin-density matrix.
- In the absence of spin-alignment ρ_{00} should be $1/3$.

Spin-alignment



$$\rho_{00} = 0.39 \pm 0.09(\text{stat})^{+0.10}_{-0.09}(\text{syst}).$$

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Summary and conclusions

HADES

- The total production cross section of $K^*(892)^+$ was calculated to be:

$$\sigma_{\mathrm{tot}}(\mathrm{K}^*(892)^+) = 9.5 \pm 0.9(\mathrm{stat})^{+1.1}_{-0.9}(\mathrm{syst})\ \mu\mathrm{b}.$$

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$$\sigma_{tot}(K^*(892)^+) = 9.5 \pm 0.9(stat)^{+1.1}_{-0.9}(syst)\ \mu b.$$

- The Λ production channel seems to be dominant, however the uncertainty does not allow for an accurate estimation of the exact contribution:

$$p^{(\Lambda)} = 0.59^{+0.22}_{-0.19}.$$

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- The Λ production channel seems to be dominant, however the uncertainty does not allow for an accurate estimation of the exact contribution:

$$\mathbf{p}^{(\Lambda)} = \mathbf{0.59^{+0.22}_{-0.19}}.$$

- The result for the spin-alignment is fully compatible with the no-spin-alignment hypothesis:

$$\rho_{00} = \mathbf{0.39 \pm 0.09(stat)^{+0.10}_{-0.09}(syst)}.$$

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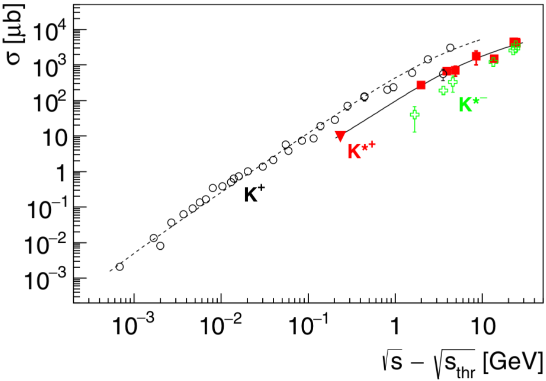
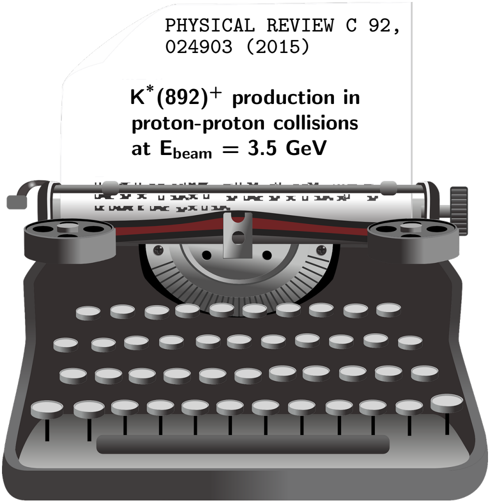
Summary and conclusions

HADES



- The fit to the K^{*+} data can be used for extrapolating the total production cross section of the particle down to an access energy of only 231 MeV.

Summary and conclusions

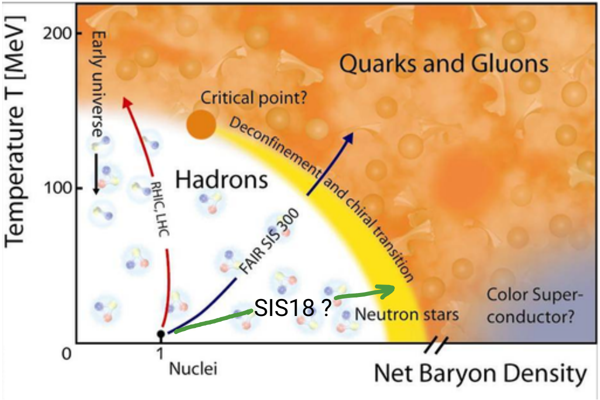


Thank you for your attention!

Veliko Tarnovo, Bulgaria

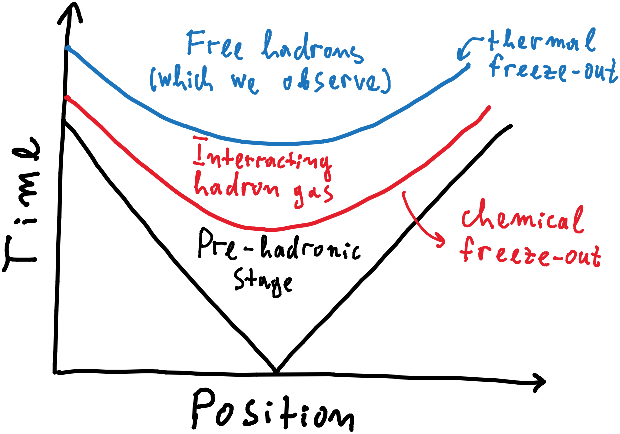
Backup

QCD phase diagram



[Bicudo et al., 2011]

Space-time evolution of HI collisions



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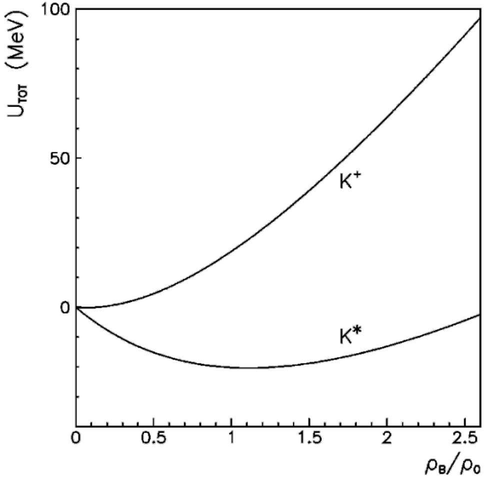
In-medium K^{*+} potential

HADES



[Tsushima et al., 2000]

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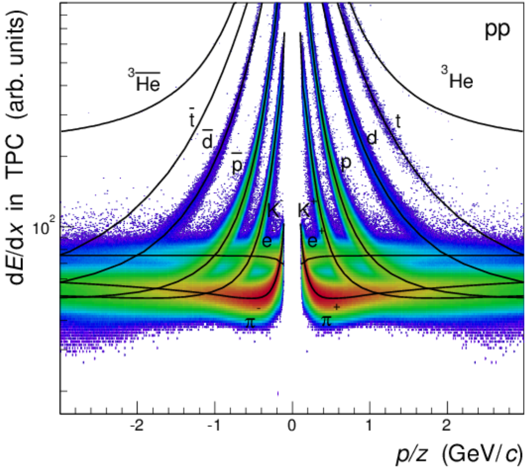
$K^*(892)^+$ production channels

HADES

#	Reaction	$\sqrt{s_{thr}}$ [MeV]	ε [MeV]
1.	$p + p \to p + \Lambda + K^{*+}$	2946	231
2.	$p + p \to n + \Sigma^+ + K^{*+}$	3021	156
3.	$p + p \to p + \Sigma^0 + K^{*+}$	3023	154
4.	$p + p \to N + Y + \pi + K^{*+}$	$\geq$3081	$\leq$96
5.	$p + p \to N + Y^* + K^{*+}$	$\geq$3214	$\leq$-37
6.	$p + p \to p + N + K + K^{*+}$	$\geq$3262	$\leq$-87

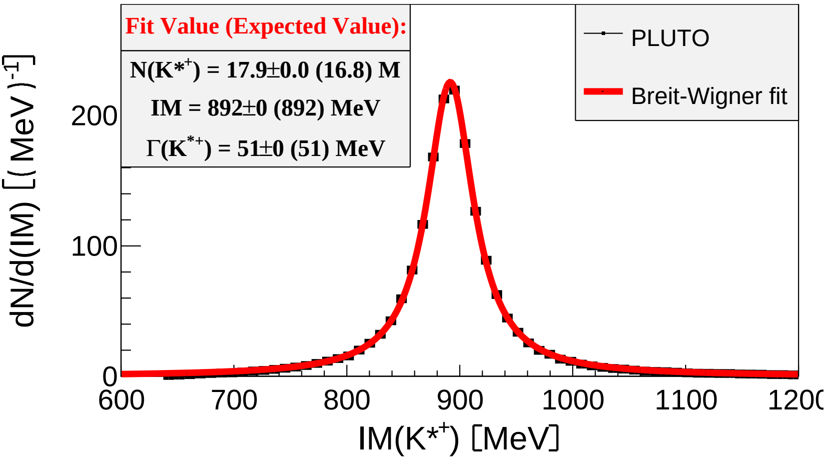
PID (example)



[Adam et al., 2016]

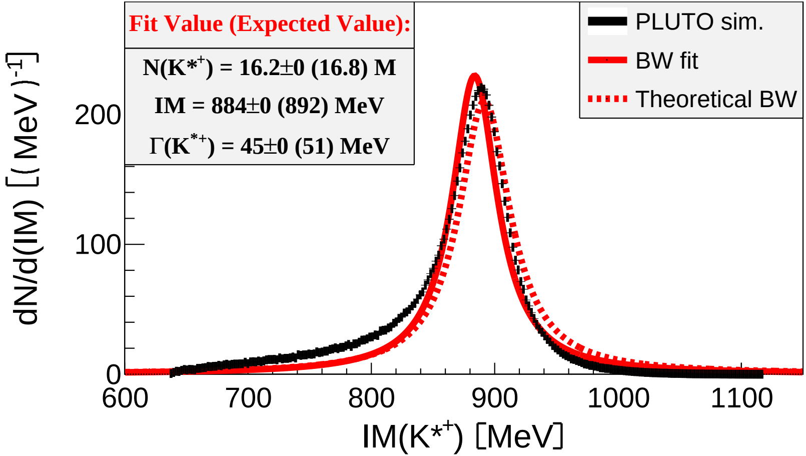
Phase space limitations

Ideal IMS (high-energy collisions):



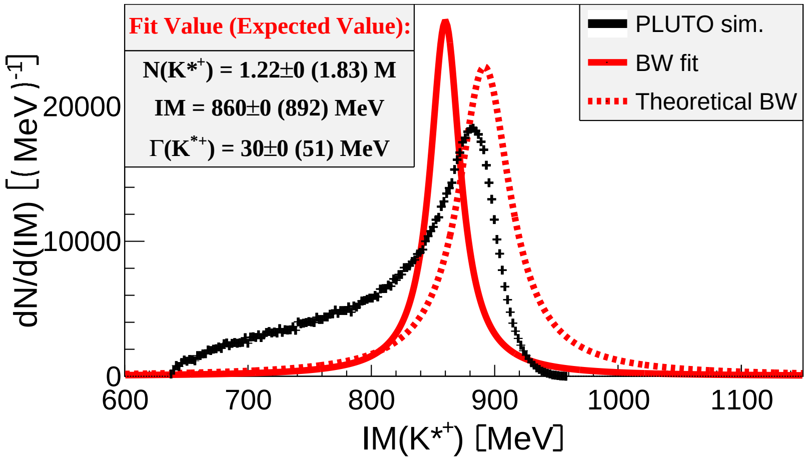
Phase space limitations

Theoretical IMS for the Λ-channel:



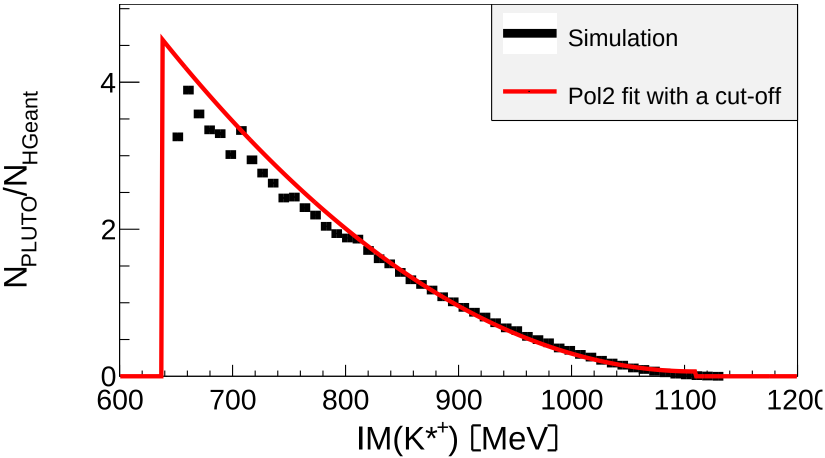
Phase space limitations

Theoretical IMS for the Λ-channel at p_T >470 MeV:



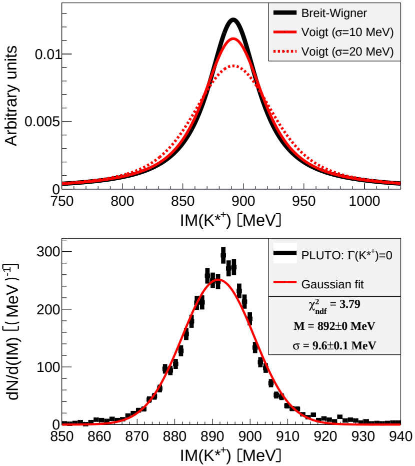
Phase space limitations

Correction function:



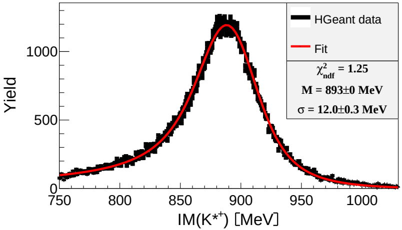
Detector resolution

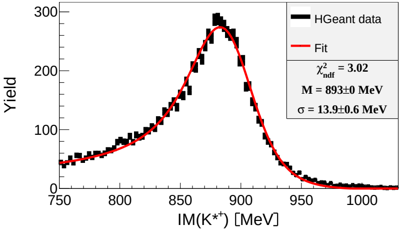
Effect of the detector resolution on IMS:



Detector resolution

HGeant fits used for fixing the resolution:





Acceptance and efficiency corrections

- Each bin (i) is corrected with a coefficient $C_i^{(2\mathrm{ch})}$.
- $C_i^{(2\mathrm{ch})}$ is estimated from the simulations using a mixture between the two production channels.
- $p(\Lambda)$ is the relative contribution of the Λ-channel.

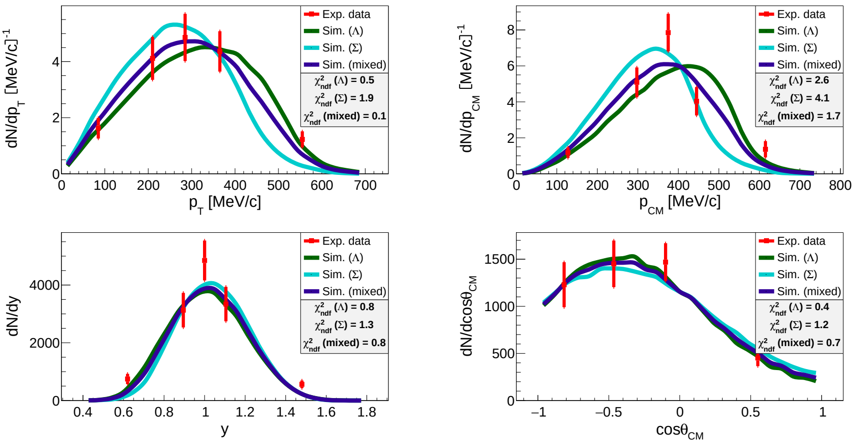
$$C_i^{(2\mathrm{ch})} = \frac{N_i^{(2\mathrm{ch})}}{n_i^{(2\mathrm{ch})}} = \frac{p^{(\Lambda)} N_i^{(\Lambda)} + p^{(\Sigma)} N_i^{(\Sigma)}}{p^{(\Lambda)} n_i^{(\Lambda)} + p^{(\Sigma)} n_i^{(\Sigma)}}$$

Acceptance and efficiency corrections

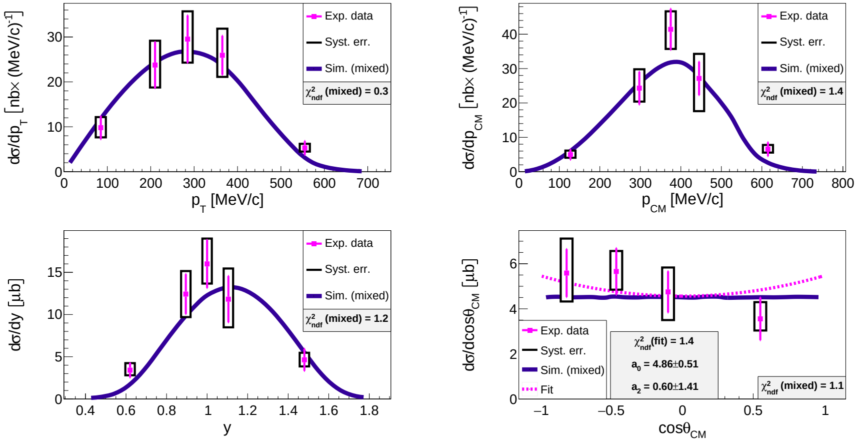
The accuracy of the correction depends on:

- Accuracy of the detector simulation.
- The refinement of the mesh discretization.
- The geometric acceptance of the detector.

Uncorrected spectra



Corrected spectra



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