XIth Quark Confinement and the Hadron Spectrum

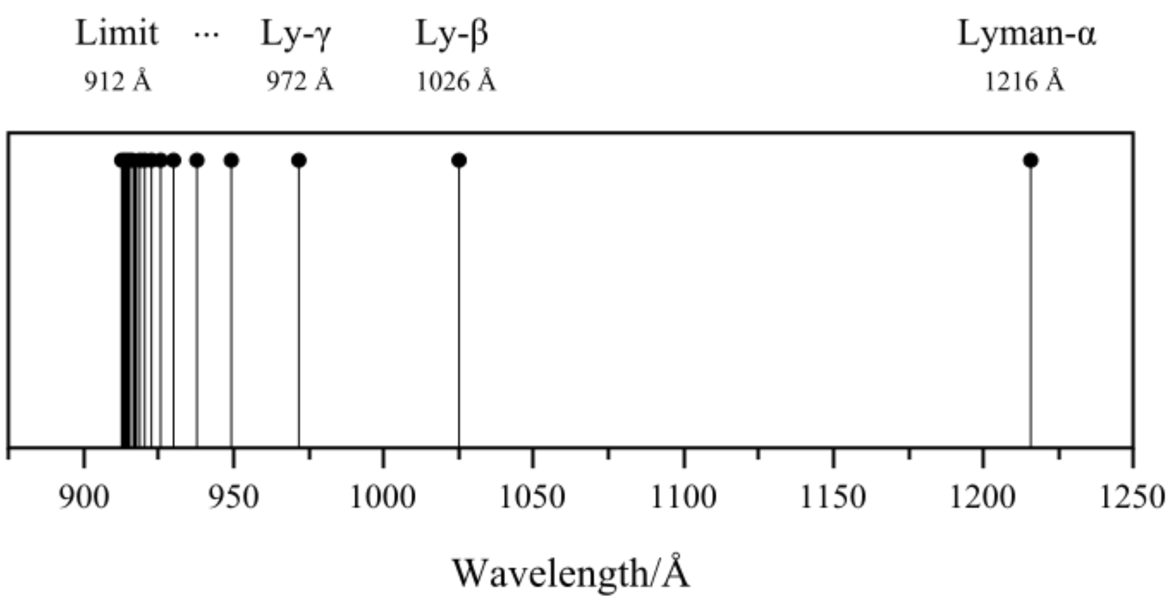
Medium effects in proton-induced strangeness production

Kirill Lapidus for the HADES Collaboration
Excellence Cluster 'Universe'
TU Munich

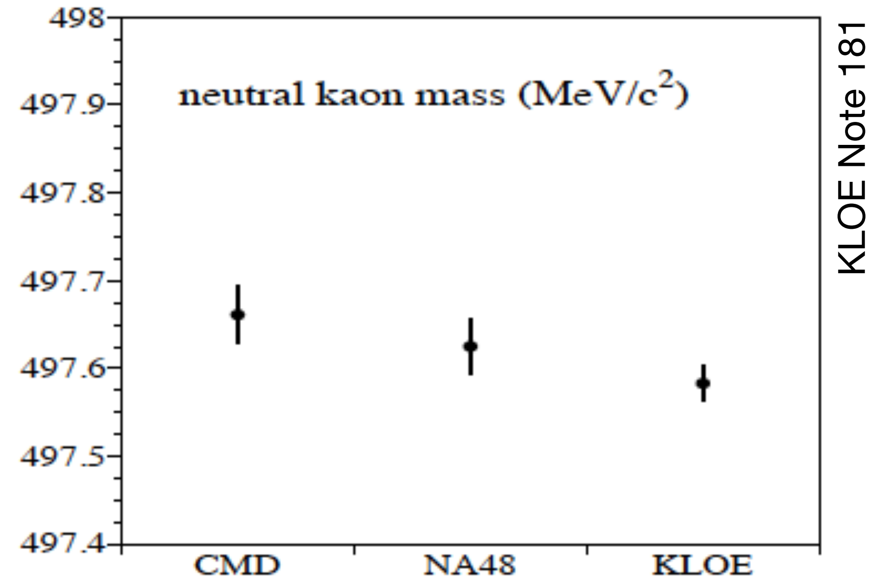
Motivation

B. Kämpfer at HADES CM 2013

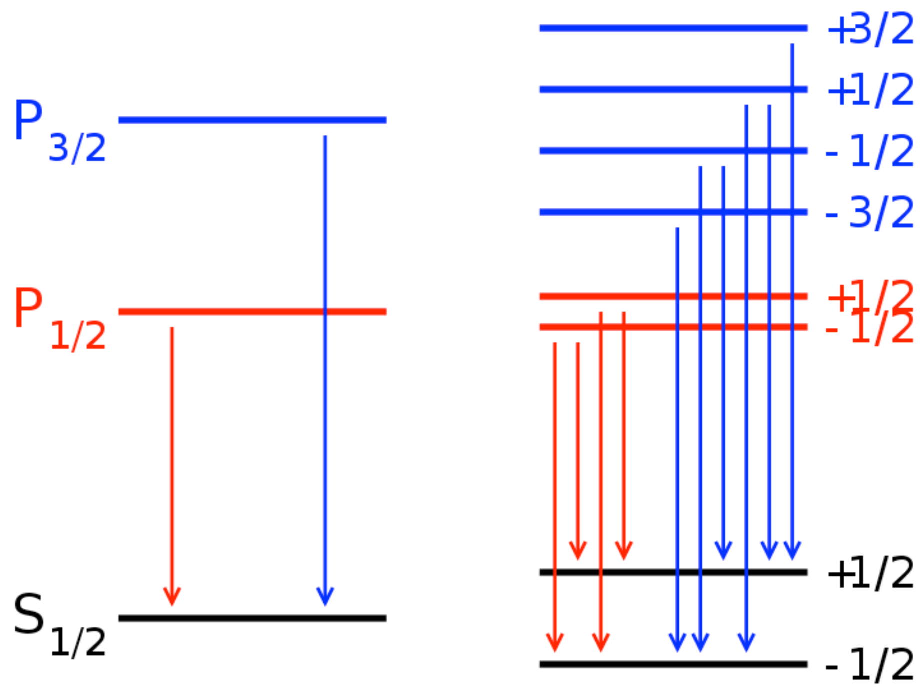
Hydrogen spectral lines

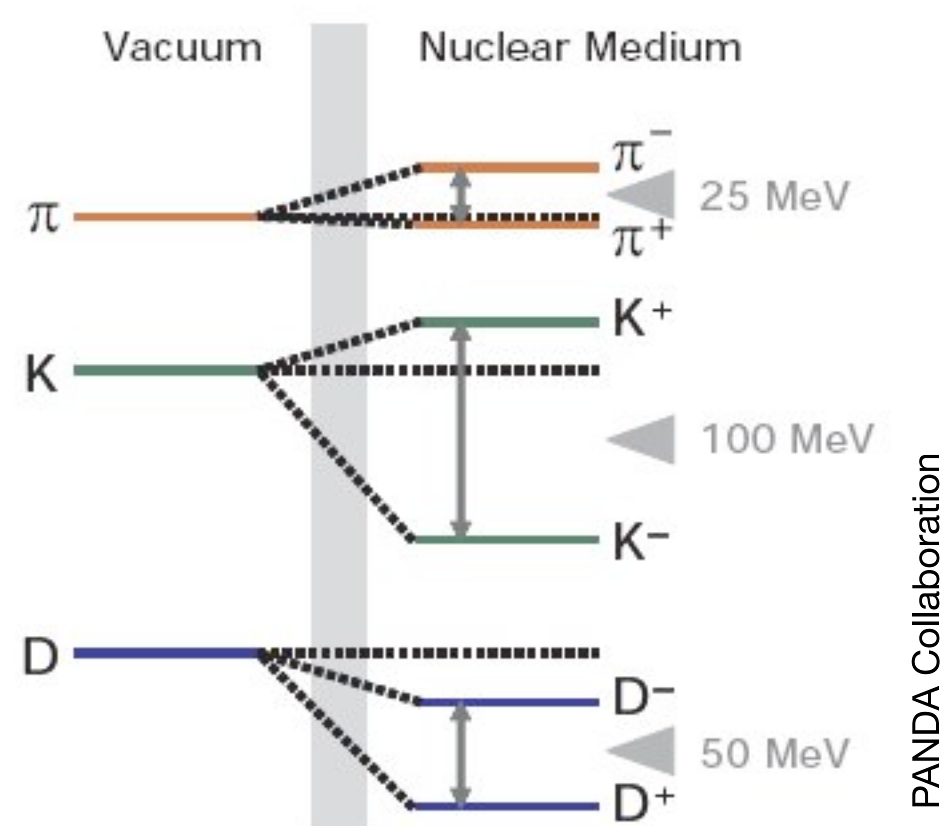


K^0 mass in vacuum



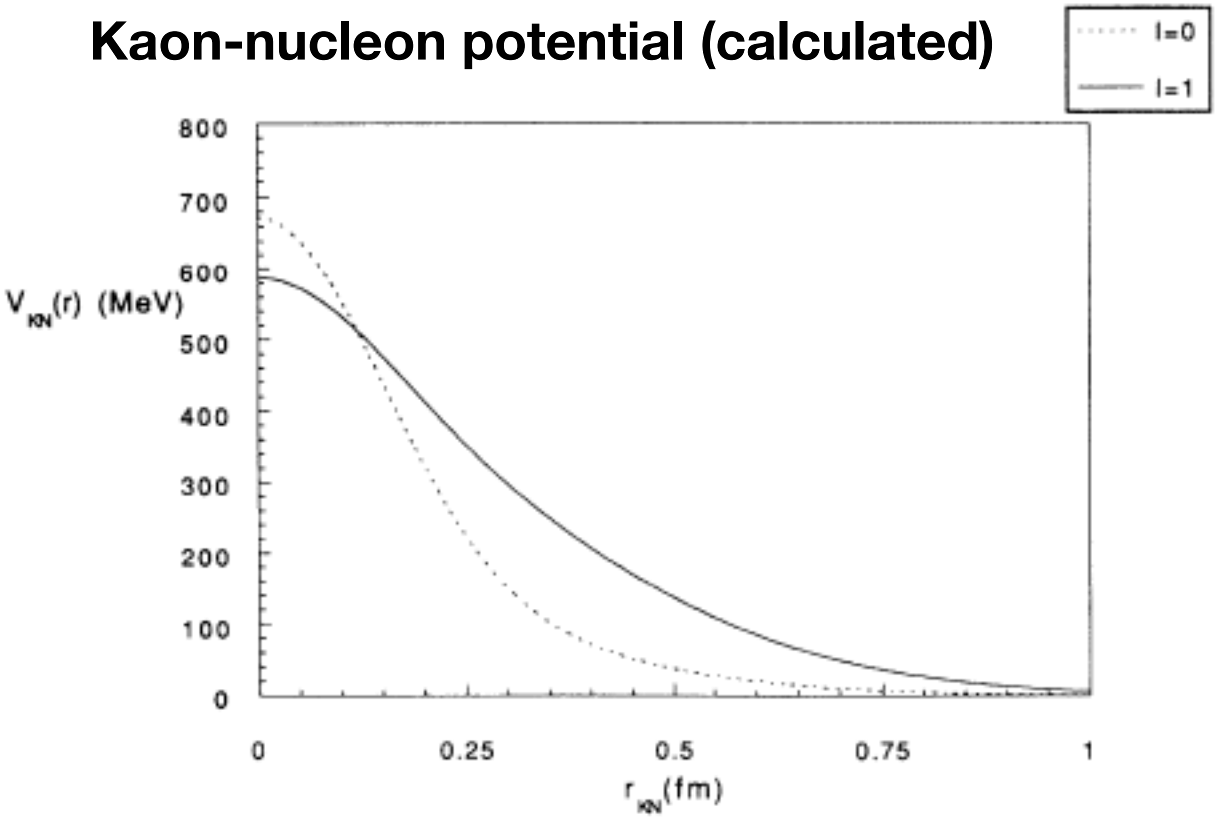
Zeeman effect





Kaon (K^+, K^0) in-medium properties

Kaon-nucleon potential (calculated)

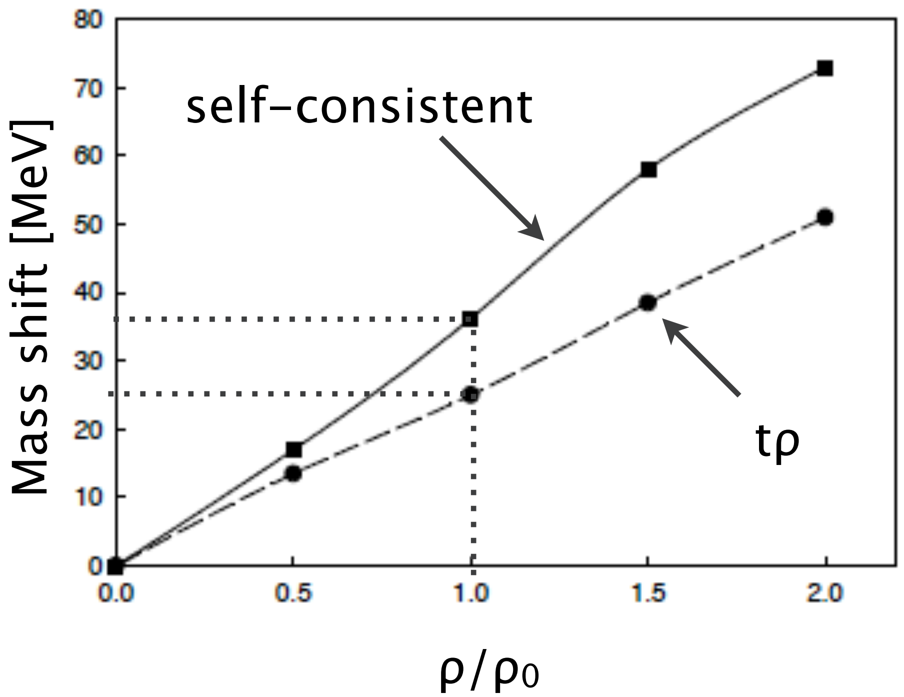


T. Barnes, E.S. Swanson Phys. Rev. C49 1994 1166.

- Repulsive kaon-nucleon potential

$\Longrightarrow$

Kaon in nuclear matter

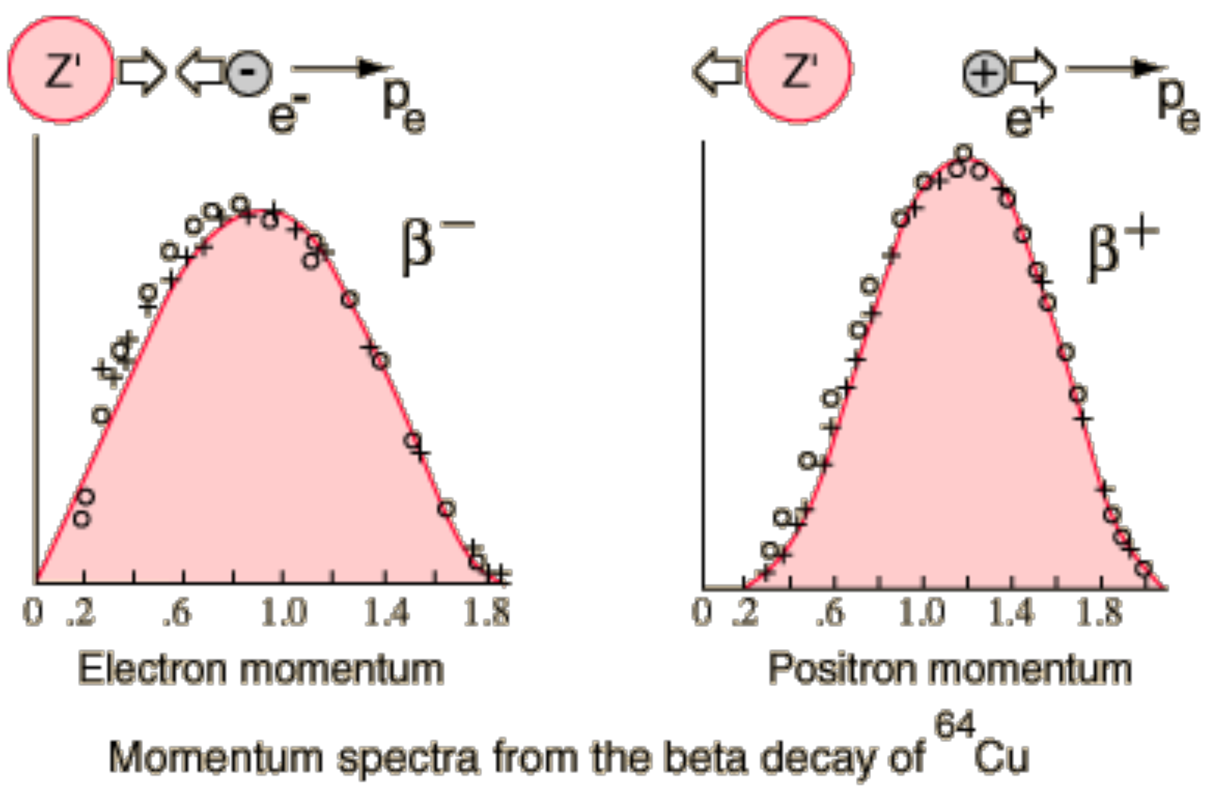


C.L. Korpa, M.F.M. Lutz Acta Phys. Hung. A22 2005 21.

- Repulsive in-medium potential, moderate increase of the effective mass

How to observe the kaon in-medium potential

An example from the electromagnetic sector:



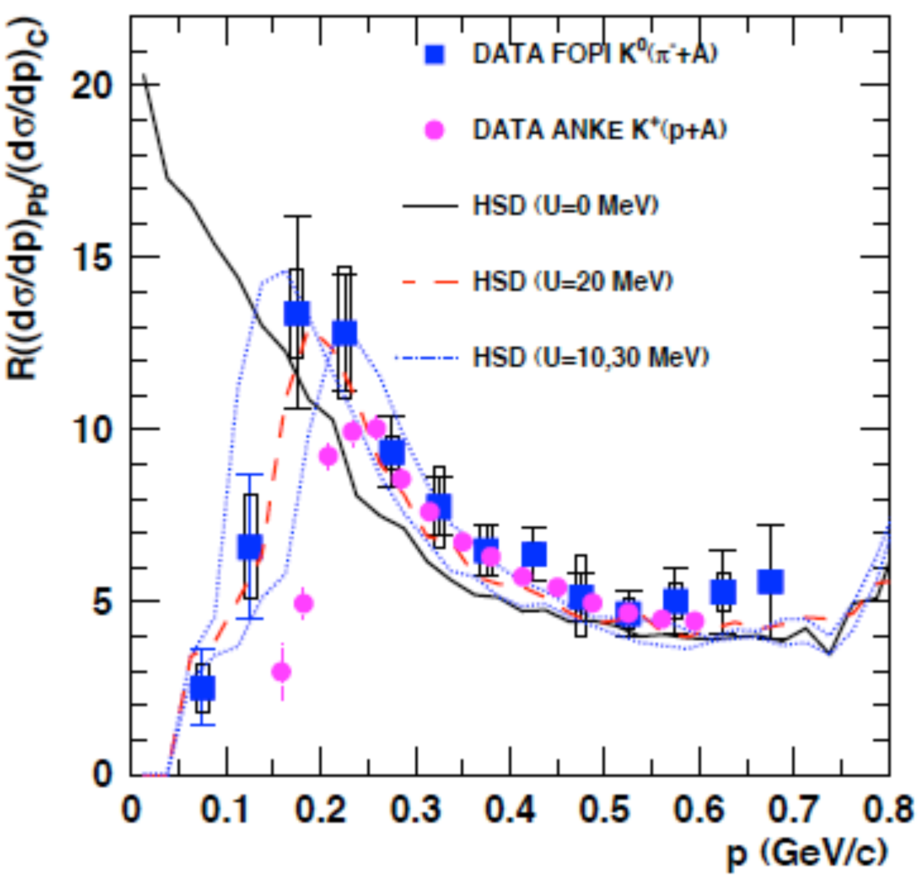
J.R. Reitz,
Phys. Rev. 77 (1950) 50.

Action of the nuclear Coulomb potential on the momentum spectra

How to observe the kaon in-medium potential

General idea: look at the kinematics of escaped kaons

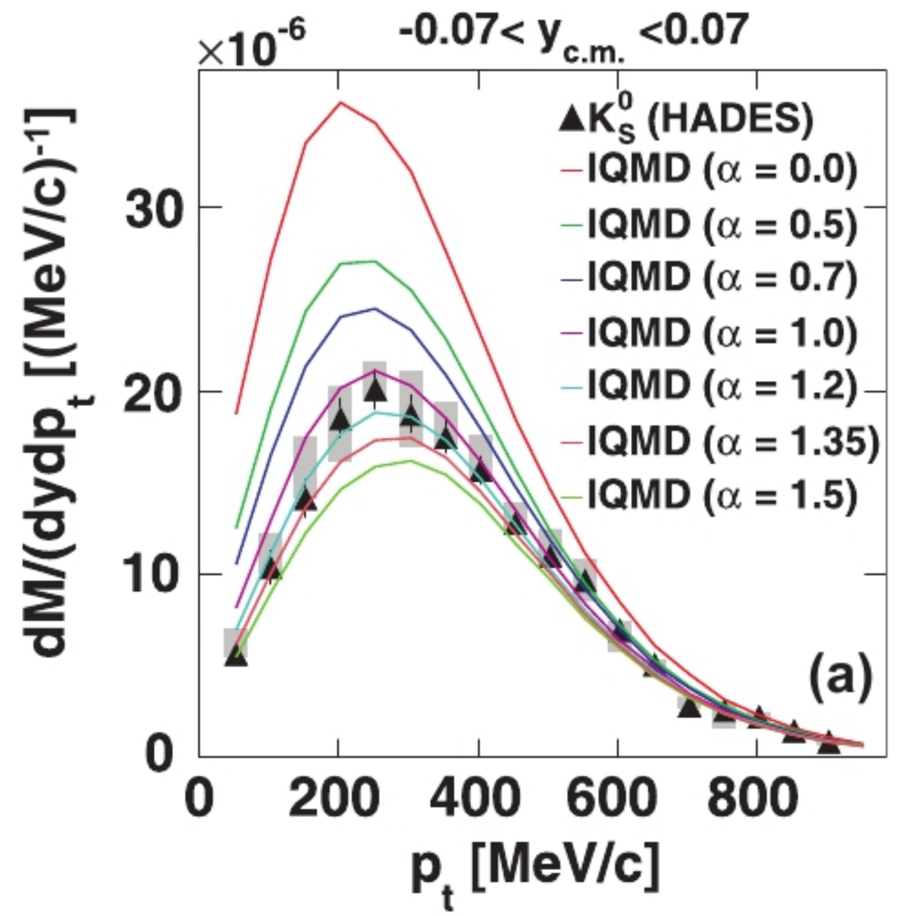
FOPI π+A, ANKE p+A



M. Benabderrahmane et al.,
Phys. Rev. Lett. 102 (2009) 182501.

U_{opt} = +20±5 MeV extracted
from comparison with transport

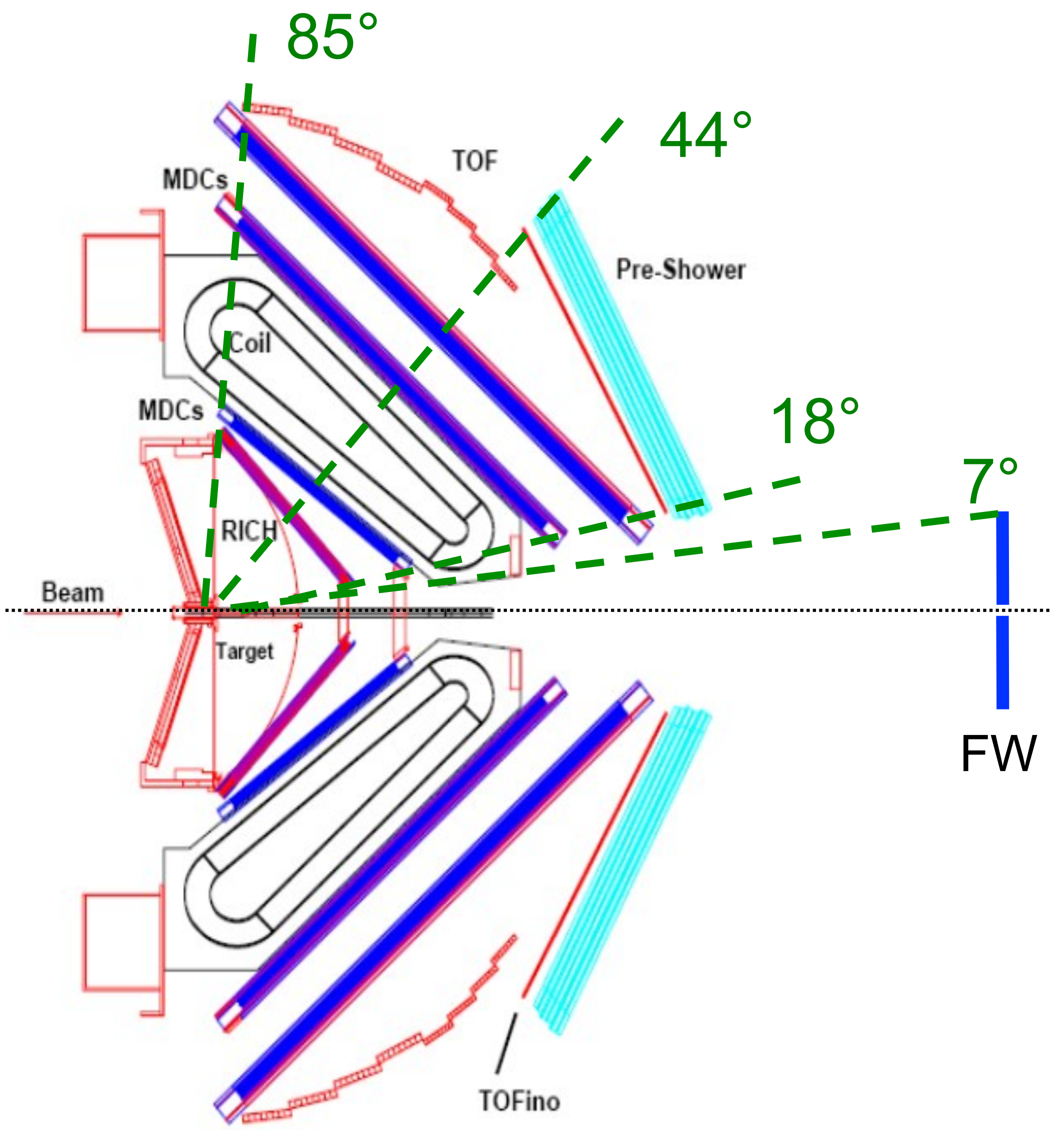
HADES Ar+KCl $K^0_S \rightarrow \pi^+\pi^-$



G. Agakishiev et al.,
Phys. Rev. C 82 (2010) 044907.

Transport simulations with
U_{opt} = +39 MeV fit the data best

The HADES experiment



High Acceptance Di-Electron Spectrometer

Location: GSI, Darmstadt

Fixed-target experiment,

SIS18, beam E_{kin} = 1—3 GeV/nucl.

Full azimuthal coverage, 18°-85° in polar angle

Sub-detectors:

- MDCs
- RICH, Time-of-flight (TOF and RPCs)
- Pre-Shower detector
- Forward Wall detector at small angles

Recent measurements of strangeness with HADES

System (energy)	Objectives
p+p (3.5 GeV)	Production of strangeness, vacuum properties of Λ(1405), search for kaonic bound states
p+Nb (3.5 GeV)	In-medium properties of strange hadrons (K, $\bar{K}$, Λ, ϕ, …)
Au+Au (1.23 GeV)	
π + C/W (1.61 GeV)	

Recent measurements of strangeness with HADES

focus of this talk

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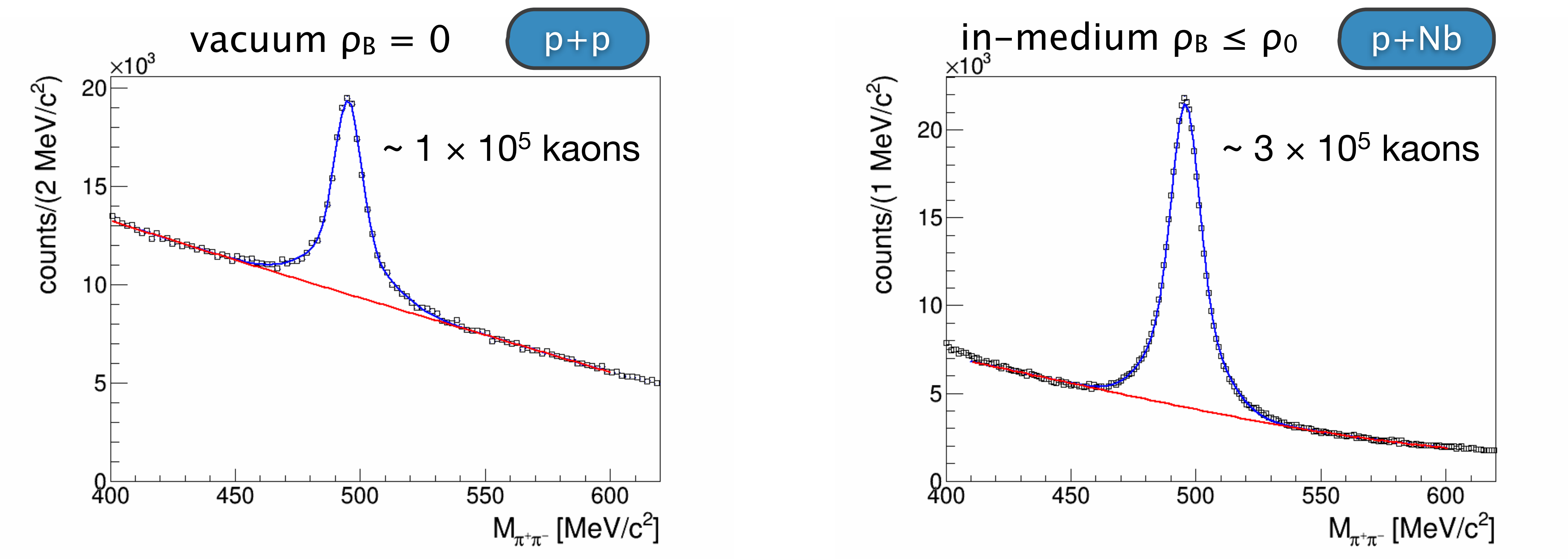
Kaon-nucleus interaction

"*Medium effects in proton-induced K^0 production*"
G. Agakishiev et al. [HADES Collaboration] arXiv:1404.7011

Neutral kaons measured by HADES in p+p and p+^{93}Nb collisions at 3.5 GeV:

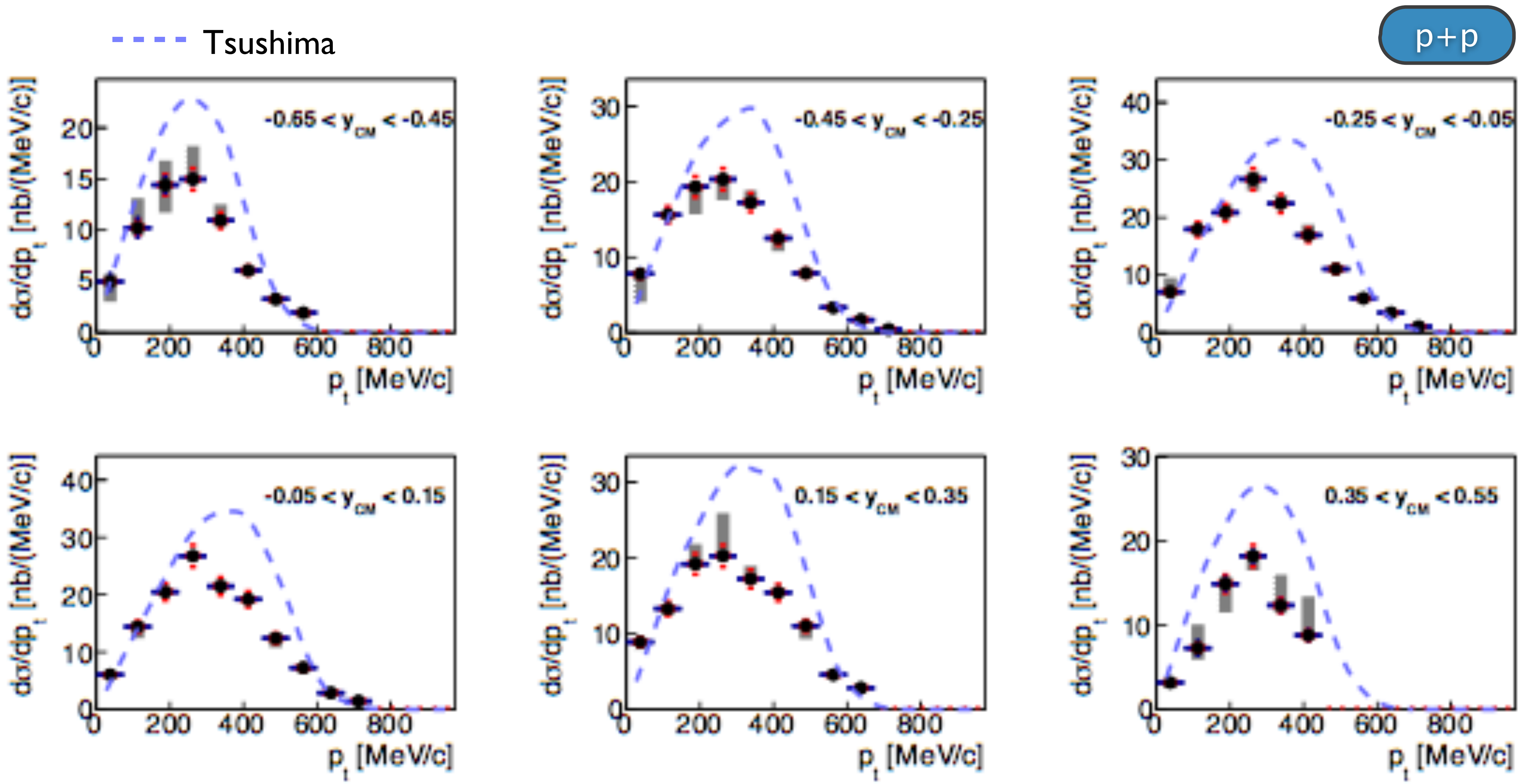
$K^0_S \rightarrow \pi^+\pi^-$



Data are interpreted with the GiBUU transport model

O. Buss et al., Phys. Rept. 512, 1 (2012)
https://gibuu.hepforge.org/

K^0 in p+p: experimental data versus resonance model by Tsushima et al.

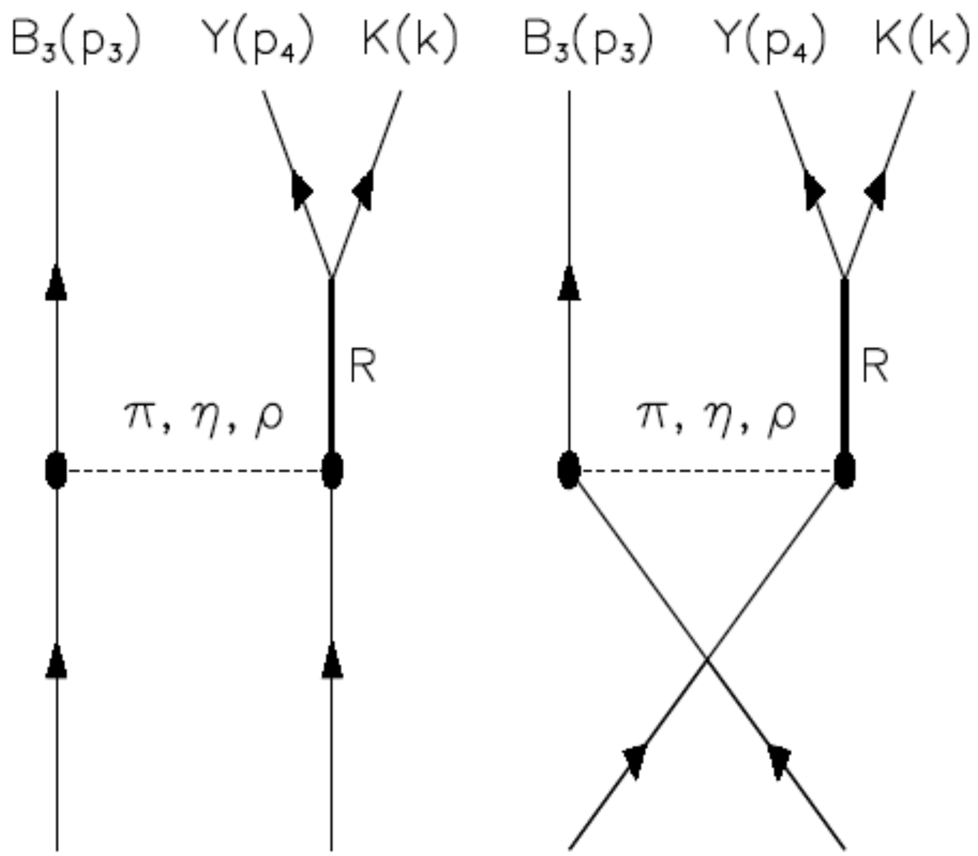


- Resonance model overestimates the inclusive yield.

* K. Tsushima, A. Sibirtsev, A.W. Thomas, G.Q. Li, PRC59 (1999) 369

Resonance model for kaon production

K. Tsushima, A. Sibirtsev, A.W. Thomas, G.Q. Li, PRC59 (1999) 369
"Resonance model study of kaon production in baryon baryon reactions for heavy ion collisions"

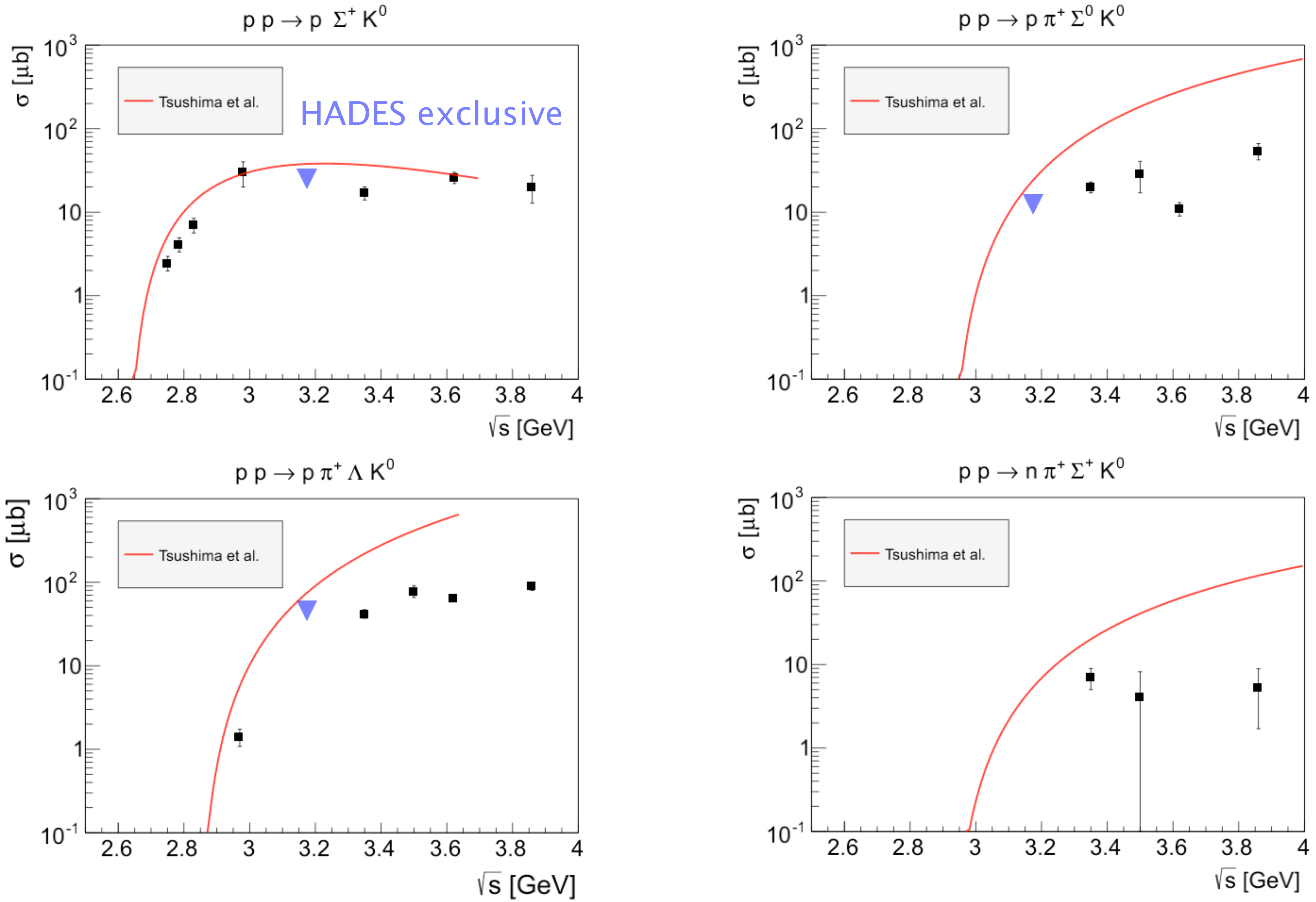


B = N or Δ

Resonance (J^P)	Width (MeV)	Decay channel	Branching ratio	Adopted value
N(1650) ($\frac{1}{2}^-$)	150	$N\pi$	0.60 – 0.80	0.700
		$N\eta$	0.03 – 0.10	0.065
		$\Delta\pi$	0.03 – 0.07	0.050
		ΛK	0.03 – 0.11	0.070
N(1710) ($\frac{1}{2}^+$)	100	$N\pi$	0.10 – 0.20	0.150
		$N\eta$	0.20 – 0.40	0.300
		$N\rho$	0.05 – 0.25	0.150
		$\Delta\pi$	0.10 – 0.25	0.175
		ΛK	0.05 – 0.25	0.150
		ΣK	0.02 – 0.10	0.060
N(1720) ($\frac{3}{2}^+$)	150	$N\pi$	0.10 – 0.20	0.150
		$N\eta$	0.02 – 0.06	0.040
		$N\rho$	0.70 – 0.85	0.775
		$\Delta\pi$	0.05 – 0.15	0.100
		ΛK	0.03 – 0.10	0.065
		ΣK	0.02 – 0.05	0.035
Δ(1920) ($\frac{3}{2}^+$)	200	$N\pi$	0.05 – 0.20	0.125
		ΣK	0.01 – 0.03	0.020

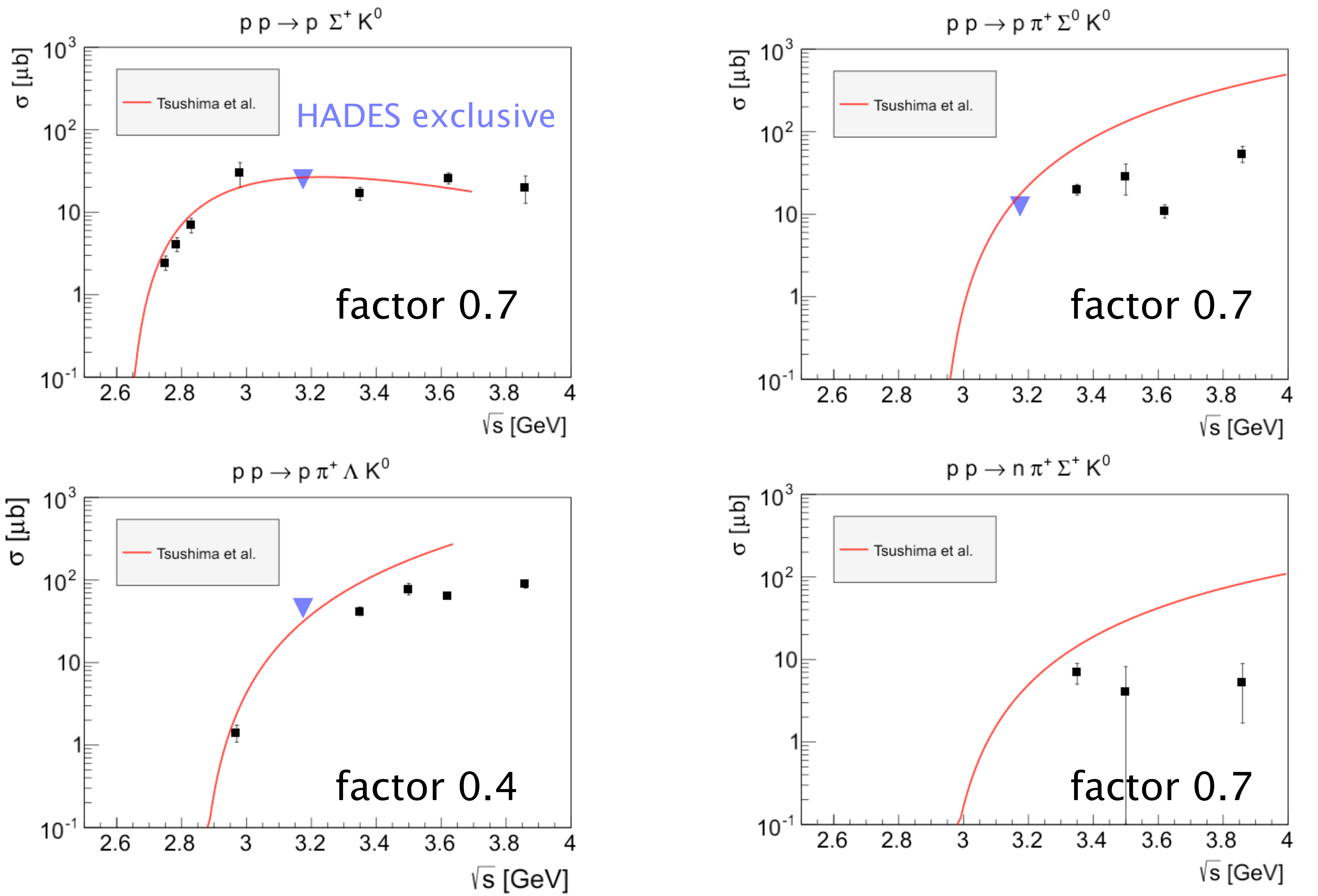
Note:
these heavy resonances are not produced in the GiBUU code, only cross sections parameterizations are used.

How well does the resonance model works



- All exclusive channels are overestimated by the model → adjust the strengths

How well does the resonance model works



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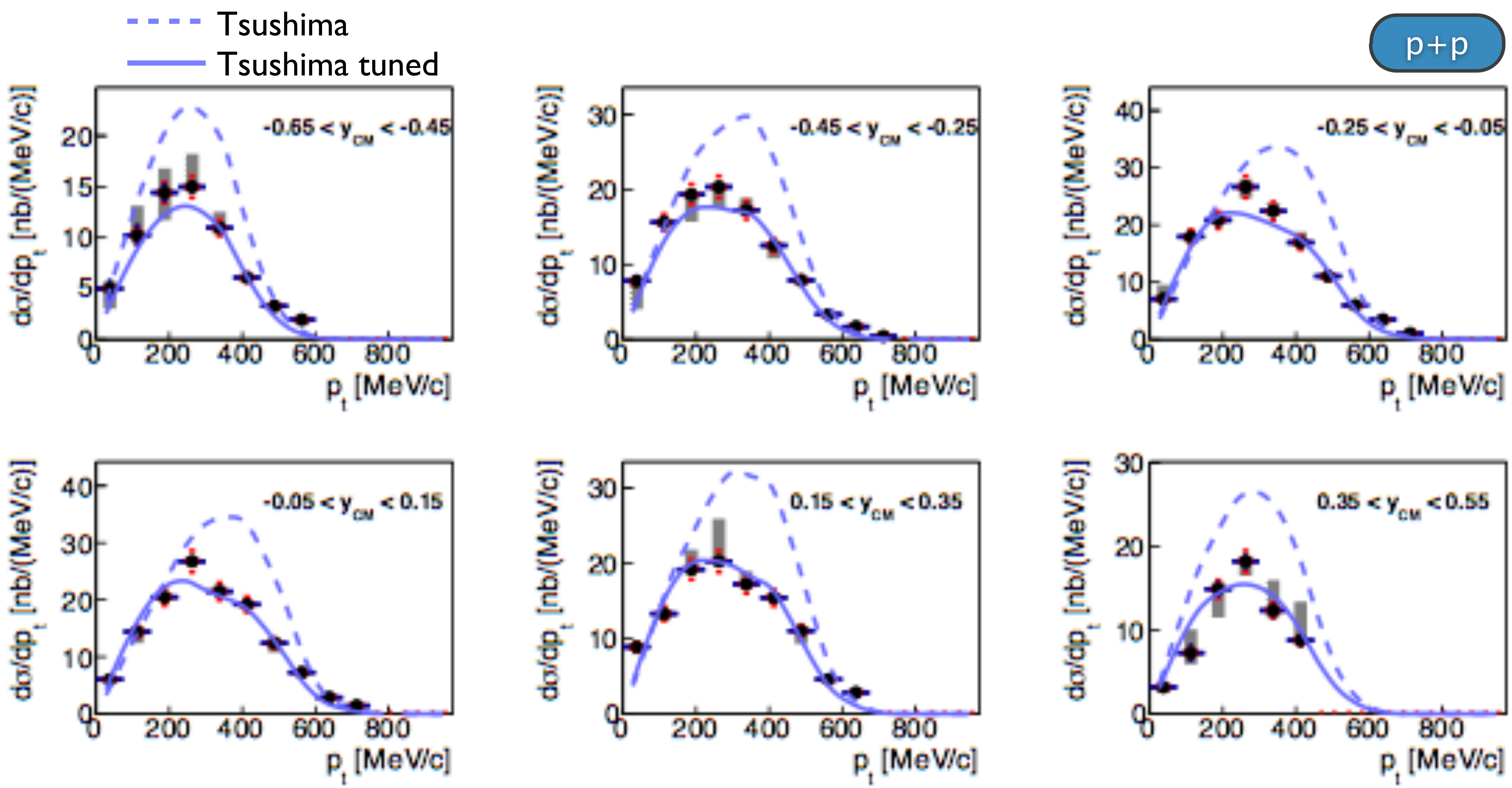
K^0 in p+p vs. tuned resonance model

p+p



- Final states with two pions (5-body) added to the model via NN → Δ^{++} Y* K, Y* is Σ(1385) or Λ(1405).
- Good description of the elementary reference.

In-medium kaon potential

cf. e.g. Y.M.Zheng et al.,
Phys. Rev. C **69** (2004) 034907

ChPT potential, ~35 MeV ($\rho=\rho_0$, k=0)

$$m_K^* = \sqrt{m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s + V_\mu V^\mu}$$

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Attractive scalar part

$$\Sigma_{KN} = 450 \text{ MeV}$$

$$f_\pi = 93 \text{ MeV}$$

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Repulsive vector part

$$V_\mu = \frac{3}{8 f_\pi^{*2}} j_\mu$$

$$f_\pi^{*2} = 0.6 f_\pi^2$$

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Single-particle energy: $E^* = \sqrt{k^{*2} + m_K^{*2}} + V_0 \quad \mathbf{k}^* = \mathbf{k} - \mathbf{V}$

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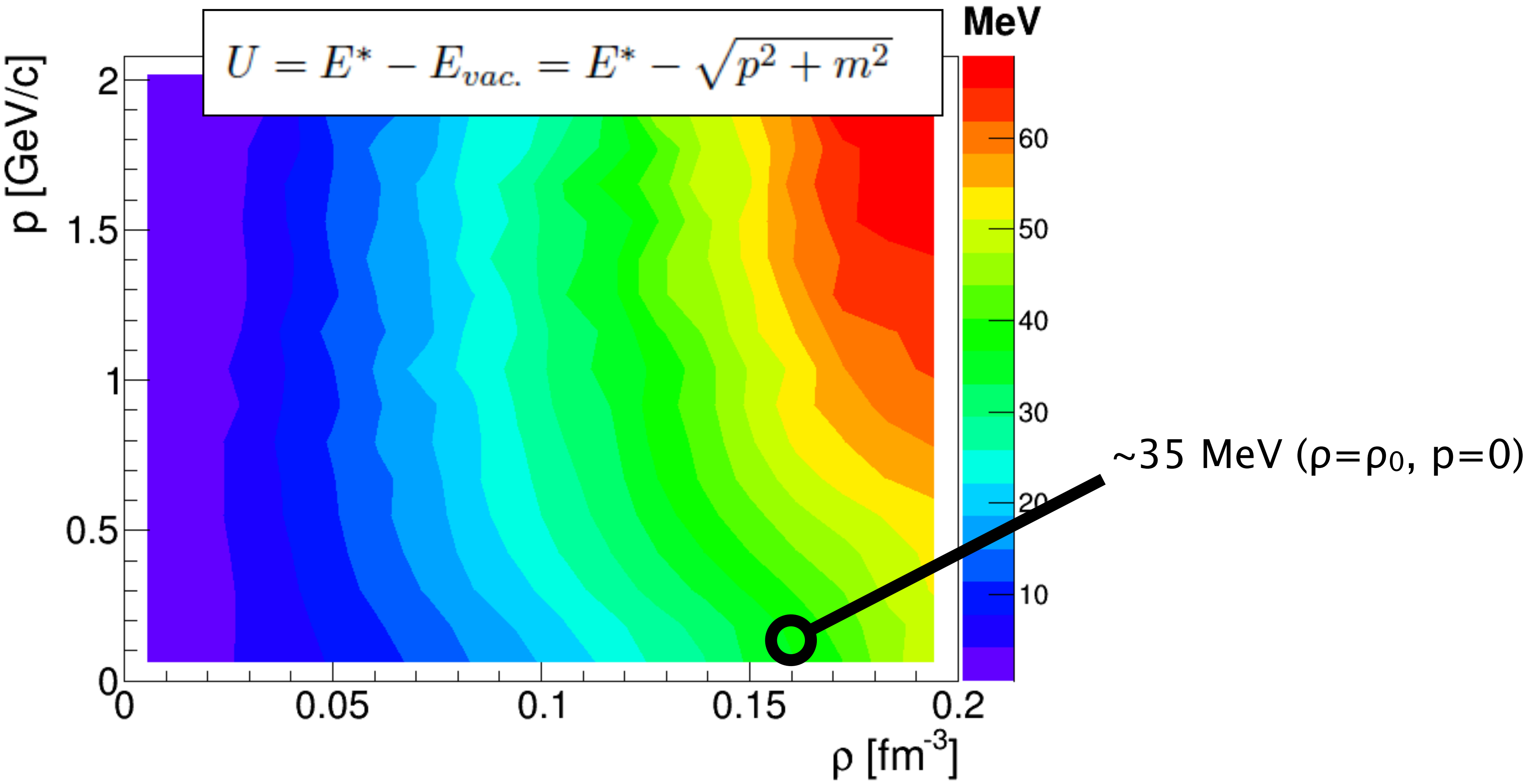
Single-particle energy: $E^* = \sqrt{k^{*2} + m_K^{*2}} + V_0 \quad \mathbf{k}^* = \mathbf{k} - \mathbf{V}$

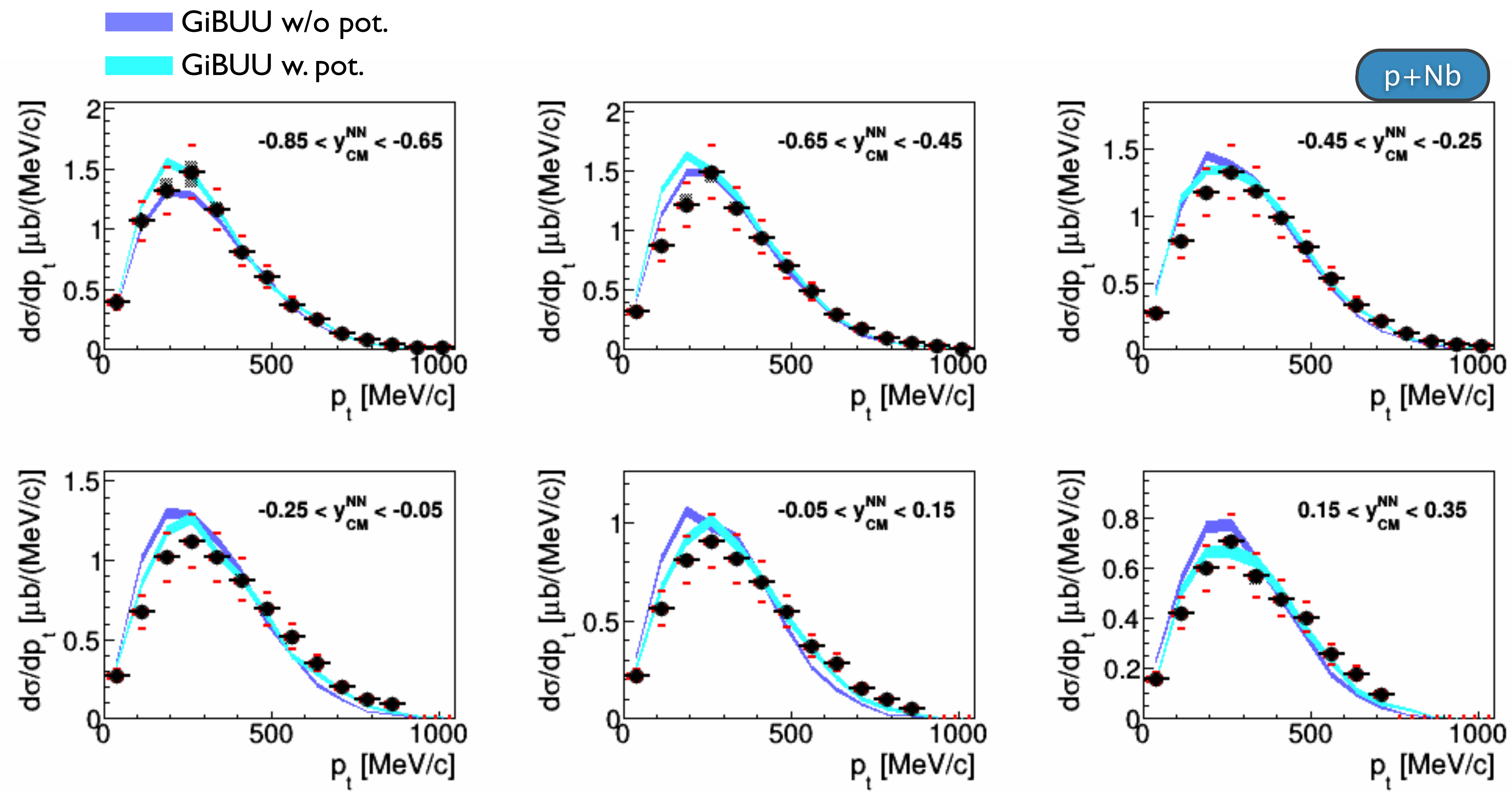
For nuclear matter at rest $\langle V_{1,2,3} \rangle = 0 \Rightarrow \mathbf{k}^* = \mathbf{k}$

$$U = \sqrt{k^2 + m^{*2}} + V_0 - \sqrt{k^2 + m_{vac.}^2}$$

In-medium kaon potential

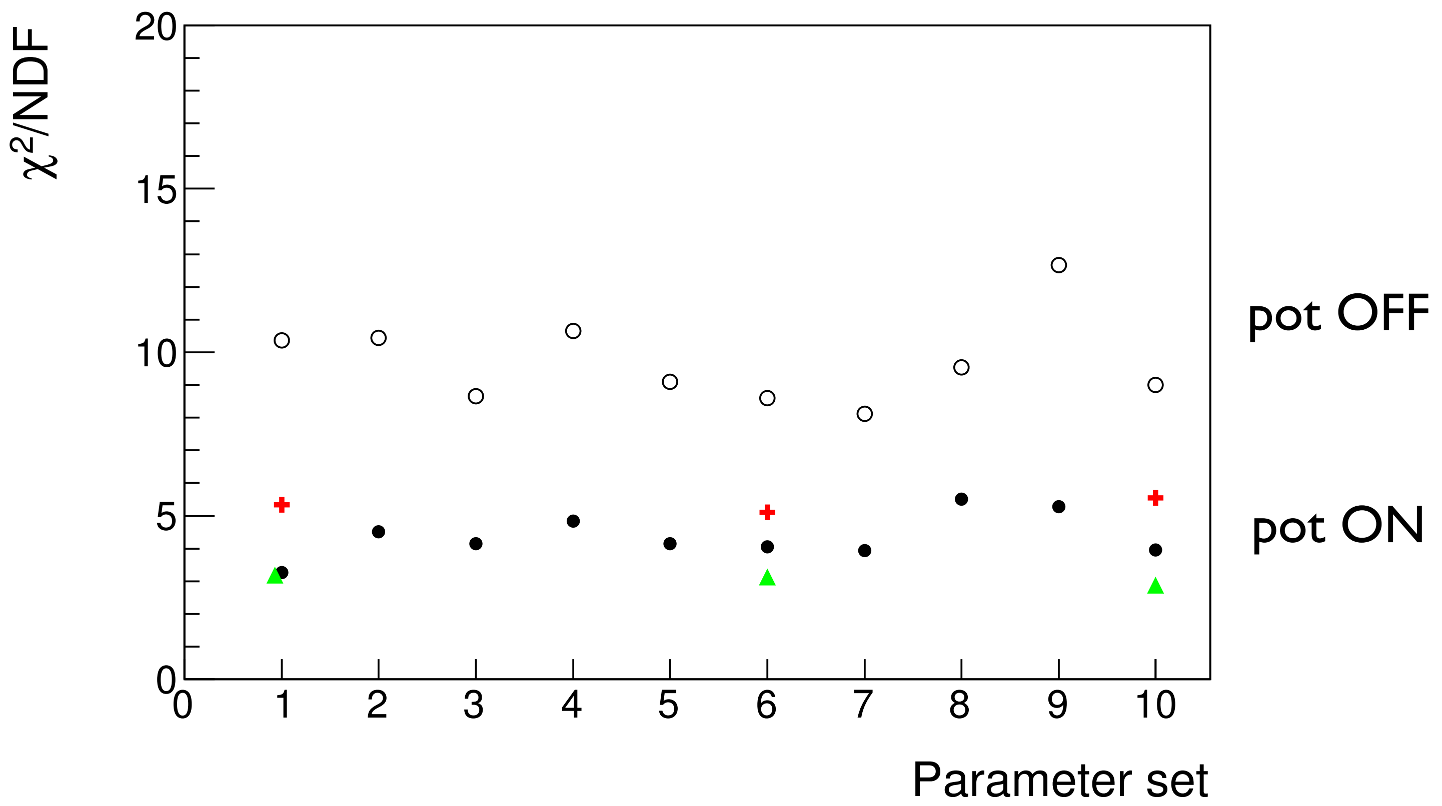


Effect of the potential in p+Nb: p_t-y



- Systematical modification of p_t–spectra owe to the repulsive potential.
- Uncertainties in the model parameters (np cross sections, …).

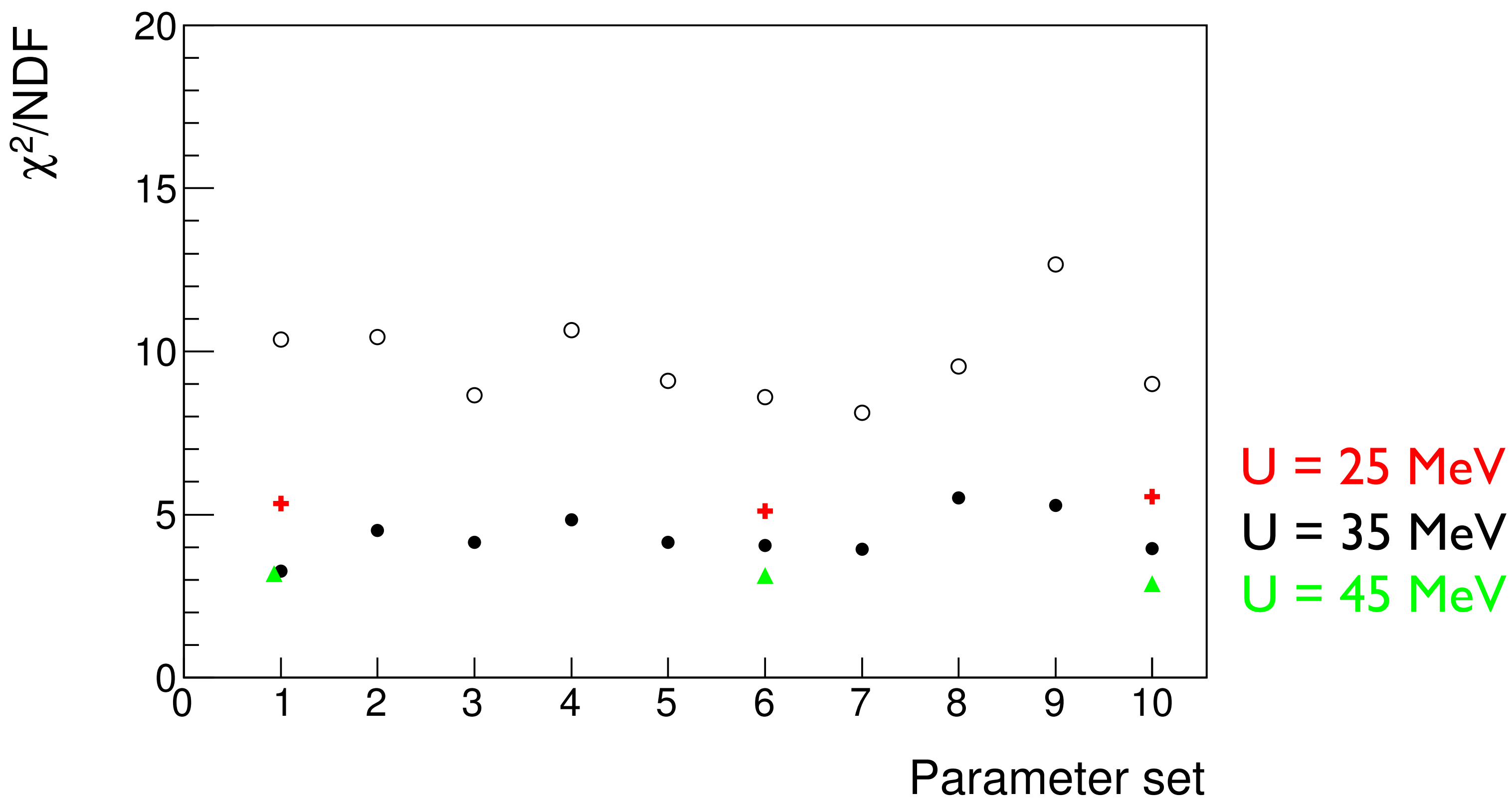
χ^2-analysis



Systematic variation of the model parameters

Set	Meaning
1	"standard"
2	ΔN +25%
3	ΔN −25%
4	πN +25%
5	πN −25%
6	np3 +25%
7	np3 −25%
8	KN +25%
9	KN −25%
10	np3 +30% & 5b −30%

χ^2-analysis



Potential strength is adjusted by changing f_π^{*2}

$$V_\mu = \frac{3}{8f_\pi^{*2}} j_\mu$$

$$U = \sqrt{k^2 + m^{*2}} + V_0 - \sqrt{k^2 + m_{vac.}^2}$$

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10	np3 +30% & 5b −30%

Results

System (energy)	Experiment	Kaon potential [MeV]
π+A (1.02 GeV)	FOPI	20 ± 5
p+A (2.3 GeV)	ANKE	20 ± 5
Ar+KCl (1.76 GeV)	HADES	39^{+8}_{-2}
p+Nb (3.5 GeV)	HADES	40 ± 5

FOPI: M. Benabderrahmane et al.,
Phys. Rev. Lett. 102 (2009) 182501.

ANKE: M. Buescher et al.,
Eur. Phys. J. A 22, 301 (2004).

HADES: ArKCl. G. Agakishiev et al.,
Phys. Rev. C 82 (2010) 044907;
pNb. arXiv:1404.7011 [nucl-ex]

Summary

- Tuned resonance model for kaon production implemented in the GiBUU code describes simultaneously pp and pNb data.

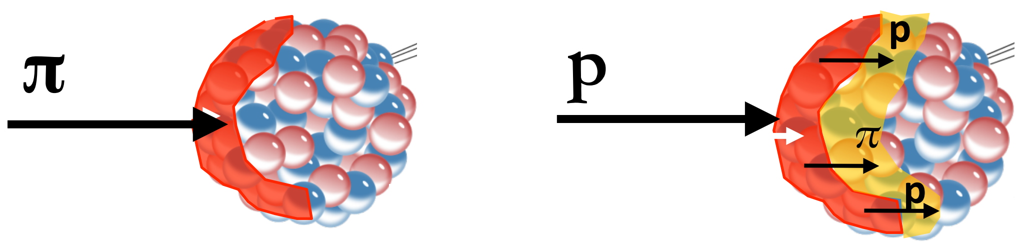
- pNb data at 3.5 GeV are sensitive to the in-medium kaon potential.

- Data are consistent with the momentum dependent ChPT potential ~35 MeV ($\rho=\rho_0$, k=0).

- Effect of the parameter uncertainties — quantitative study performed.

"*Medium effects in proton-induced K^0 production*"
G. Agakishiev et al. [HADES Collaboration] arXiv:1404.7011

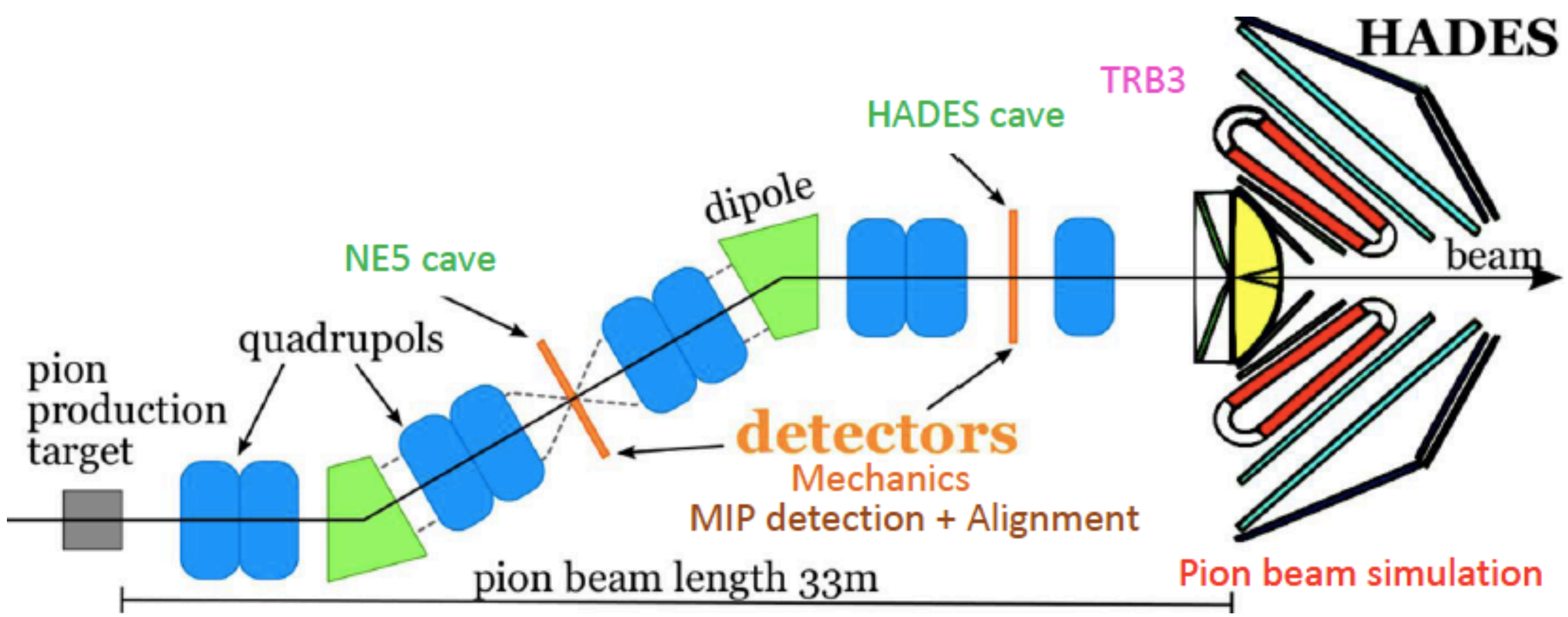
Outlook: experiments with pion beams (July 2014)



- Pion absorption mostly on the nucleus surface.
- Less model dependent.

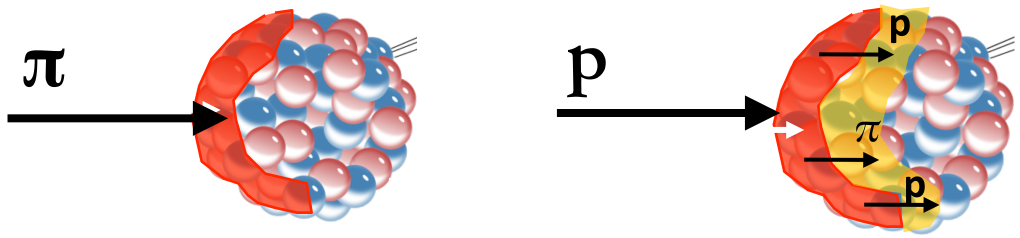
Study of Hadron-nucleon interaction

Not so easy to measure, since π-beams are secondary beams with large emittance



CERBEROS: 3-heads dog at the HADES entrance

Outlook: experiments with pion beams (July 2014)



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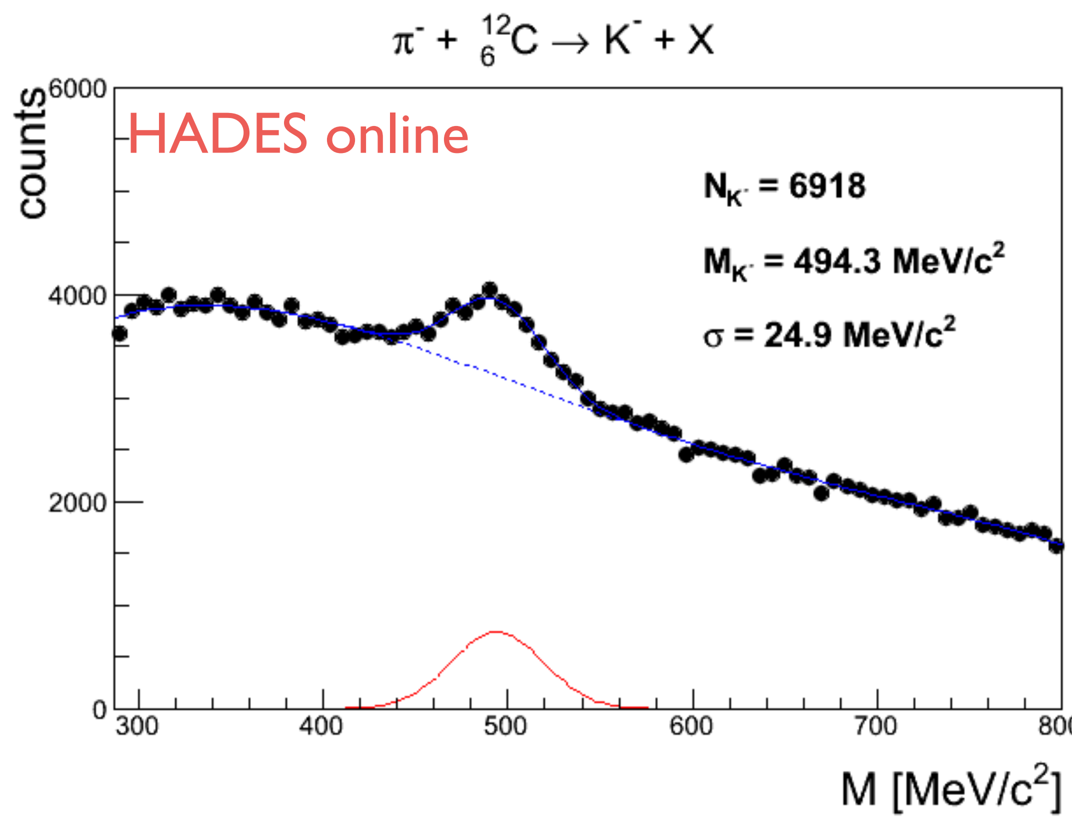
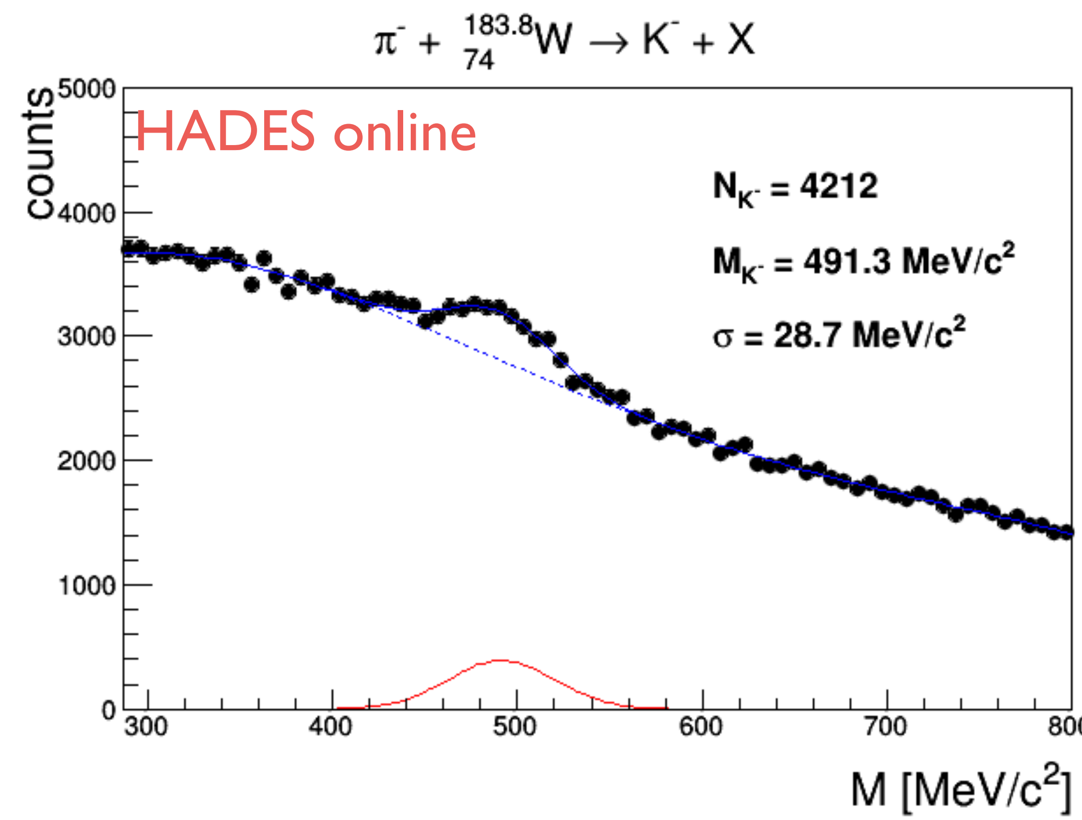


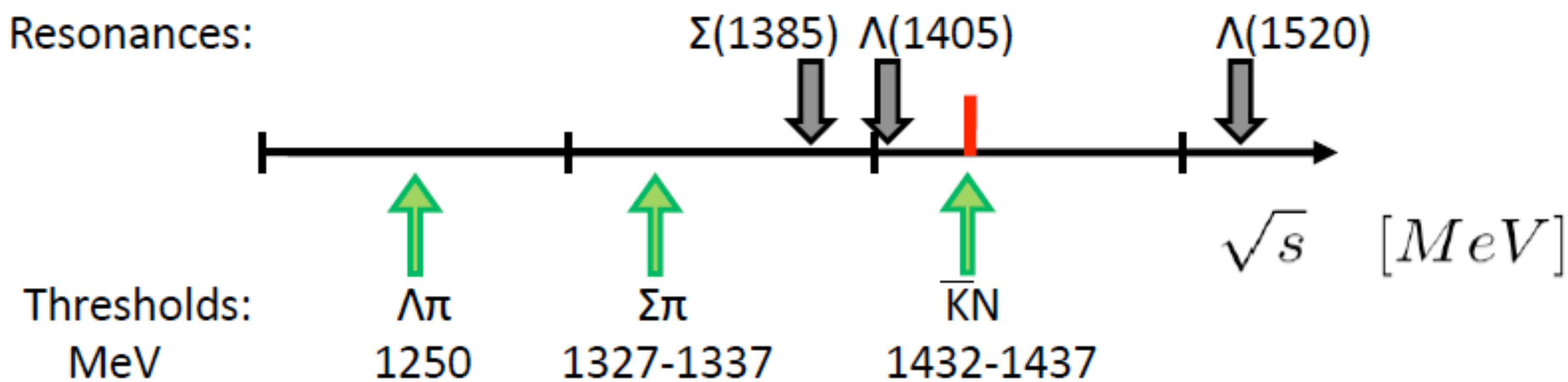


<u>First Measurement</u> of $\bar{K}$ absorption in normal nuclear matter

The HADES Collaboration

Jörn Adamczewski-Musch, Geydar Agakishiev, Claudia Behnke, Alexander Belyaev, Jia-Chii Berger-Chen, Alberto Blanco, Christoph Blume, Michael Böhmer, Pablo Cabanelas, Nuno Carolino, Sergey Chernenko, Jose Díaz, Adrian Dybczak, Eliane Epple, Laura Fabbietti, Oleg Fateev, Paulo Fonte, Jürgen Friese, Ingo Fröhlich, Tetyana Galatyuk, Juan A. Garzón, Roman Gernhäuser, Alejandro Gil, Marina Golubeva, Fedor Guber, Malgorzata Gumberidze, Szymon Harabasz, Klaus Heidel, Thorsten Heinz, Thierry Hennino, Romain Holzmann, Jochen Hutsch, Claudia Höhne, Alexander Ierusalimov, Alexander Ivashkin, Burkhard Kämpfer, Marcin Kajetanowicz, Tatiana Karavicheva, Vladimir Khomyakov, Ilse Koenig, Wolfgang Koenig, Burkhard W. Kolb, Vladimir Kolganov, Grzegorz Korcyl, Georgy Kornakov, Roland Kotte, Erik Krebs, Hubert Kuc, Wolfgang Kühn, Andrej Kugler, Alexei Kurepin, Alexei Kurilkin, Pavel Kurilkin, Vladimir Ladygin, Rafal Lalik, Kirill Lapidus, Alexander Lebedev, Ming Liu, Luís Lopes, Manuel Lorenz, Gennady Lykasov, Ludwig Maier, Alexander Malakhov, Alessio Mangiarotti, Jochen Markert, Volker Metag, Jan Michel, Christian Müntz, Rober Münzer, Lothar Naumann, Marek Palka, Vladimir Pechenov, Olga Pechenova, Americo Pereira, Jerzy Pietraszko, Witold Przygoda, Nicolay Rabin, Béatrice Ramstein, Andrei Reshetin, Laura Rehnisch, Philippe Rosier, Anar Rustamov, Alexander Sadovsky, Piotr Salabura, Timo Scheib, Alexander Schmah, Heidi Schuldes, Erwin Schwab, Johannes Siebenson, Vladimir Smolyankin, Manfred Sobiella, Yuri Sobolev, Stefano Spataro, Herbert Ströbele, Joachim Stroth, Christian Sturm, Khaled Teilab, Vladimir Tiflov, Pavel Tlusty, Michael Traxler, Alexander Troyan, Haralabos Tsertos, Evgeny Usenko, Taras Vasiliev, Vladimir Wagner, Christian Wendisch, Jörn Wüstenfeld, Yuri Zanevsky

Antikaon-nucleon interaction

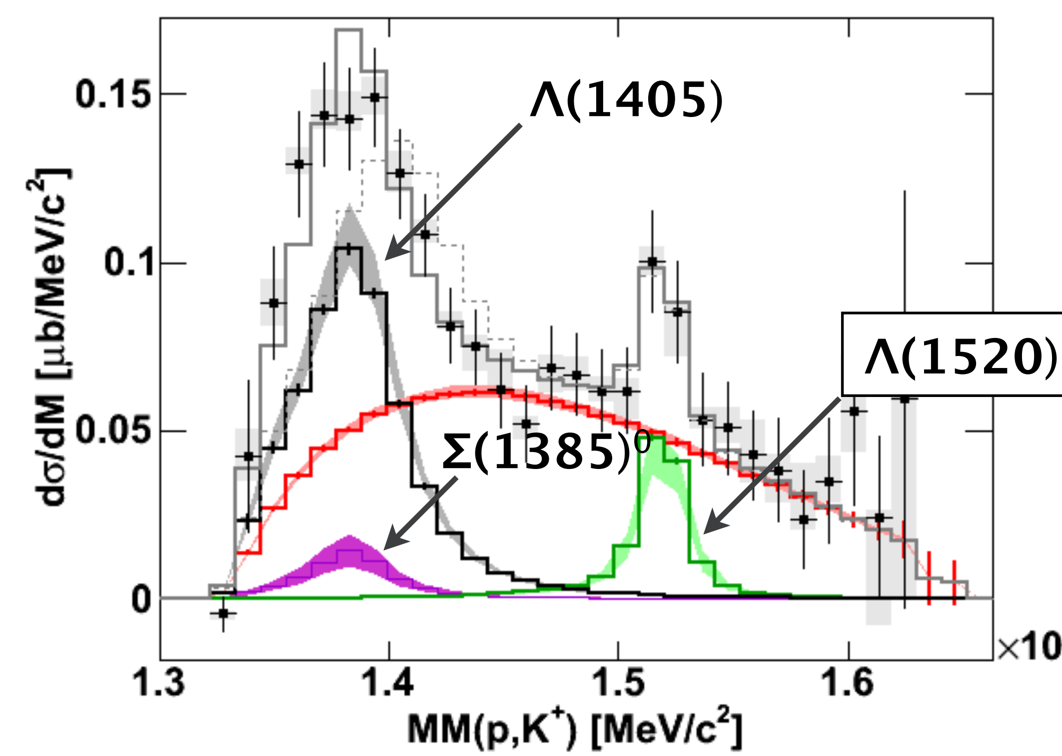


- Λ(1405) is crucial for understanding of the **free and in-medium** K̄N interaction.
- Within coupled channel approach generated as a K̄N bound state and a Σπ resonance.

HADES:

- First measurement of Λ(1405) in p+p reactions in charged decay mode.
- Mass distribution peaked below 1405 MeV/c^2.

$$p + p \xrightarrow{3.5GeV} \Lambda(1405) + K^+ + p$$
$$\hookrightarrow \Sigma^\pm + \pi^\mp$$
$$\hookrightarrow \pi^\pm + n$$



G. Agakishiev et al. [HADES] Phys. Rev. C 87 (2013) 025201.
G. Agakishiev et al. [HADES] Nucl. Phys. A 881 (2012) 178–186.
J. Siebenson, L. Fabbietti, Phys. Rev. C 88 (2013) 055201.

Resonance model for kaon production

No.	Reaction
1	$pp \to p\Lambda K^+$
2	$pn \to n\Lambda K^+$
3	$pp \to p\Sigma^0 K^+$
4	$nn \to n\Sigma^- K^+$
5	$pn \to n\Sigma^0 K^+$
6	$np \to p\Sigma^- K^+$
7	$pp \to n\Sigma^+ K^+$
8	$nn \to \Delta^- \Lambda K^+$
9	$pp \to \Delta^{++}\Sigma^- K^+$
10	$\Delta^{++}n \to p\Lambda K^+$
11	$\Delta^- p \to n\Sigma^- K^+$
12	$\Delta^{++}p \to \Delta^{++}\Lambda K^+$
13	$\Delta^+ n \to \Delta^0 \Lambda K^+$
14	$\Delta^+ p \to \Delta^+ \Lambda K^+$
15	$\Delta^{++}n \to \Delta^{++}\Sigma^- K^+$
16	$\Delta^0 p \to \Delta^+ \Sigma^- K^+$
17	$\Delta^+ n \to \Delta^+ \Sigma^- K^+$
18	$\Delta^{++}p \to \Delta^{++}\Sigma^0 K^+$
19	$\Delta^+ n \to \Delta^0 \Sigma^0 K^+$
20	$\Delta^+ p \to \Delta^+ \Sigma^0 K^+$
21	$\Delta^+ p \to \Delta^0 \Sigma^+ K^+$
22	$\Delta^+ \Delta^{++} \to \Delta^{++}\Lambda K^+$
23	$\Delta^0 \Delta^{++} \to \Delta^+ \Lambda K^+$
24	$\Delta^0 \Delta^+ \to \Delta^0 \Lambda K^+$
25	$\Delta^{++}\Delta^0 \to \Delta^{++}\Sigma^- K^+$
26	$\Delta^- \Delta^0 \to \Delta^- \Sigma^- K^+$
27	$\Delta^0 \Delta^{++} \to \Delta^+ \Sigma^0 K^+$
28	$\Delta^- \Delta^+ \to \Delta^0 \Sigma^- K^+$

Cross section parameterization:

$$\sigma(B_1 B_2 \to B_3 Y K) = a \left(\frac{s}{s_0} - 1\right)^b \left(\frac{s_0}{s}\right)^c,$$

Note: this is what's inside transport code

np-reactions isospin interrelations (one example):

$$\begin{aligned} \sigma(nn \to \Delta^- \Lambda K^+) &= \sigma(pp \to \Delta^{++}\Lambda K^0) \\ = 3\sigma(pn \to \Delta^0 \Lambda K^+) &= 3\sigma(np \to \Delta^+ \Lambda K^0) \\ = 3\sigma(pp \to \Delta^+ \Lambda K^+) &= 3\sigma(nn \to \Delta^0 \Lambda K^0), \end{aligned}$$

almost no experimental data for np!

K^0 production channels:

Number of particles	Final state	What is in the model
3-body	p Σ	p Σ
4-body	p π	Δ
	p π	Δ
	n π	Δ
	p π	

Note:
1. Pion production goes exclusively through Δ.
2. No angular anisotropies in production.