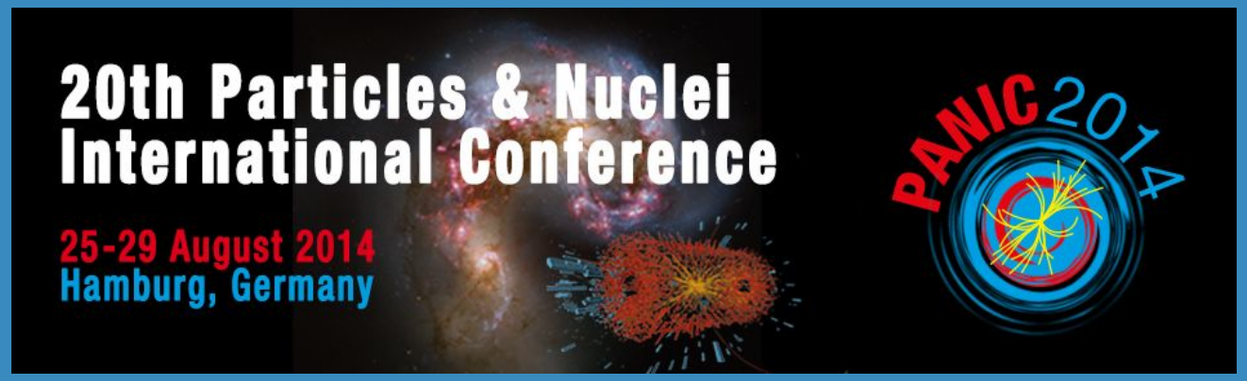


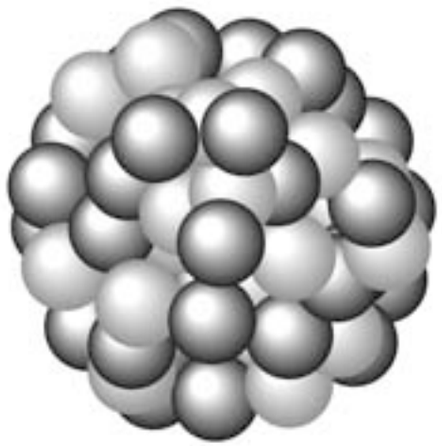
Exploring strangeness with HADES

Kirill Lapidus for the HADES Collaboration
Excellence Cluster ‘Universe’
TU Munich

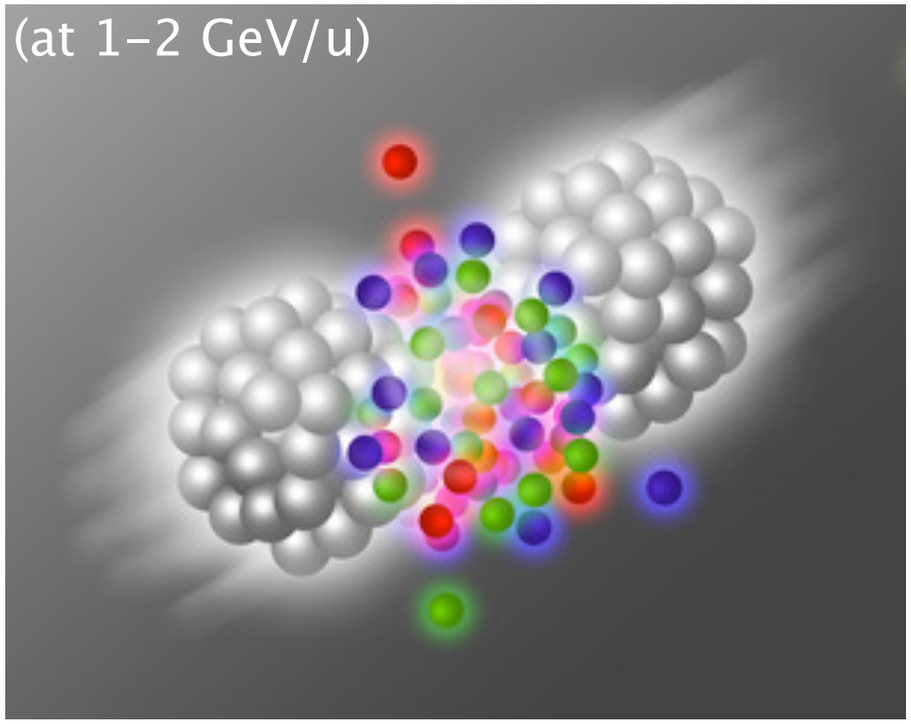
Motivation

Fundamental problem: how a strange hadron change its properties when implanted in a strongly-interacting many body system?

Nucleus $\rho_B \leq \rho_0$

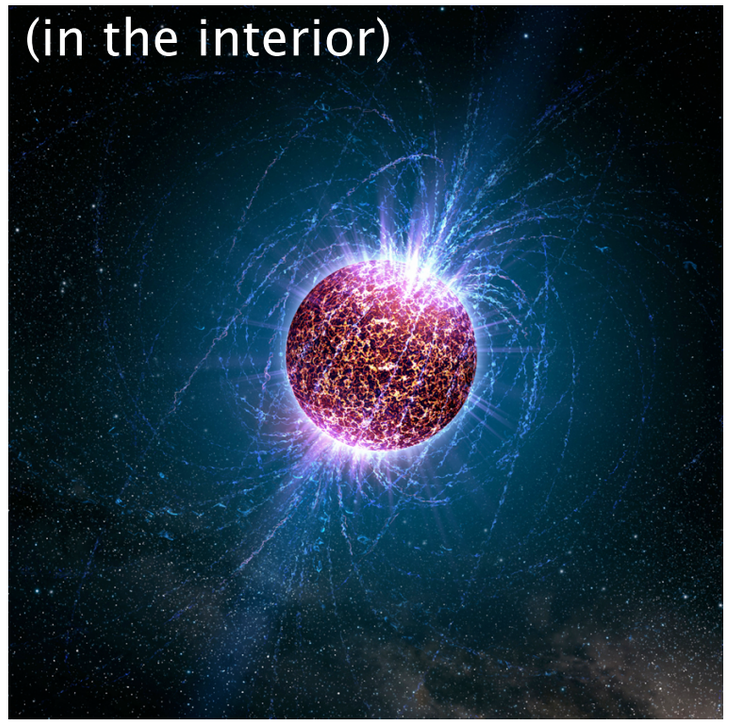


Heavy-ion collisions $\rho_B \leq 2\text{–}3\rho_0$



Vienna University of Technology

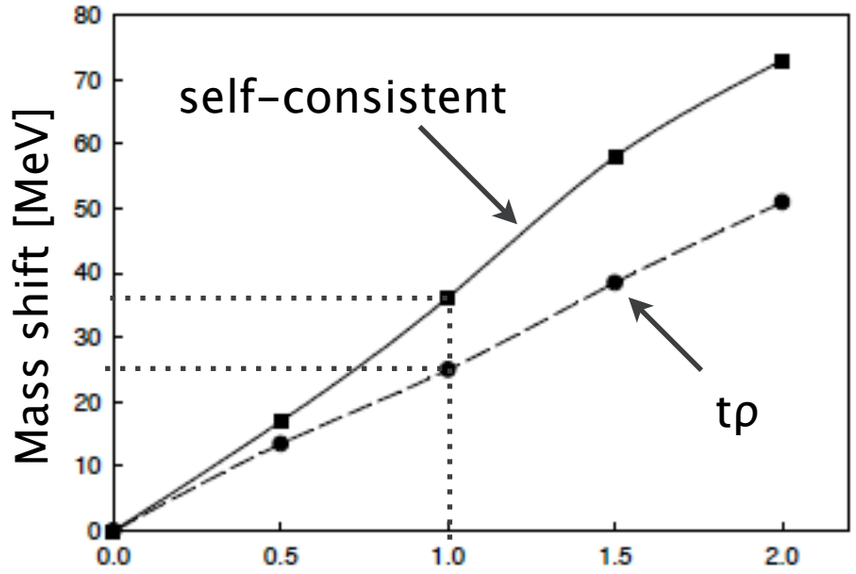
Neutron star $\rho_B \leq 3\text{–}8\ \rho_0$



Casey Reed, courtesy of Penn State

Kaon in-medium properties

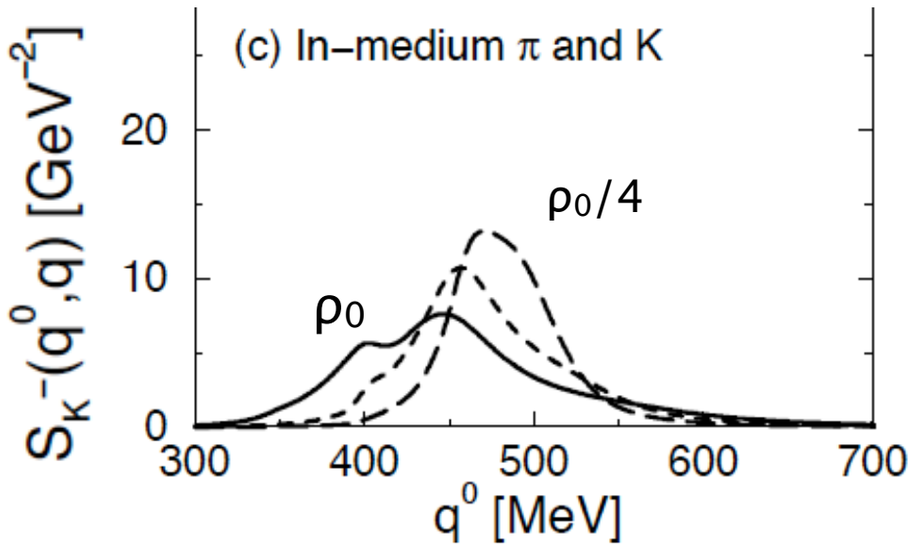
Kaon



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

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

Antikaon



A. Ramos, E. Oset
Nucl. Phys. A 671 (2000), 481.

- Attractive in-medium potential, strong decrease of the effective mass, major broadening
- Complicated in-medium spectral function due to strong coupling to resonances

Recent measurements of strangeness with HADES

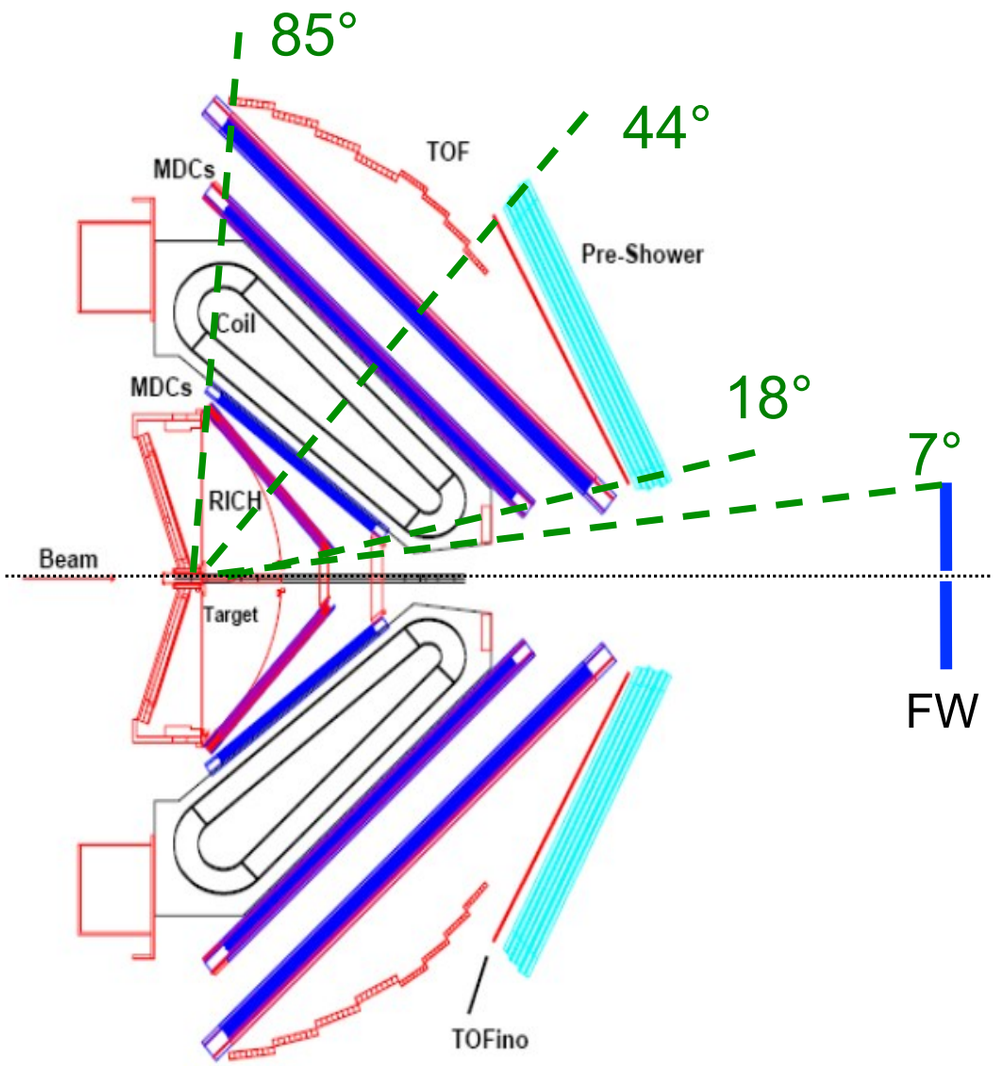
System (energy)	Objectives
p+p (3.5 GeV)	Production of strangeness, vacuum properties of Λ(1405), search for kaonic bound states
p+Nb (3.5 GeV)	In-medium properties of strange hadrons (K, $\overline{K}$, Λ, ϕ, …)
Au+Au (1.23 GeV)	
π + C/W (1.61 GeV)	

Recent measurements of strangeness with HADES

focus of this talk

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, $\overline{K}$, Λ, ϕ, …)
Au+Au (1.23 GeV)	
π + C/W (1.61 GeV)	

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:

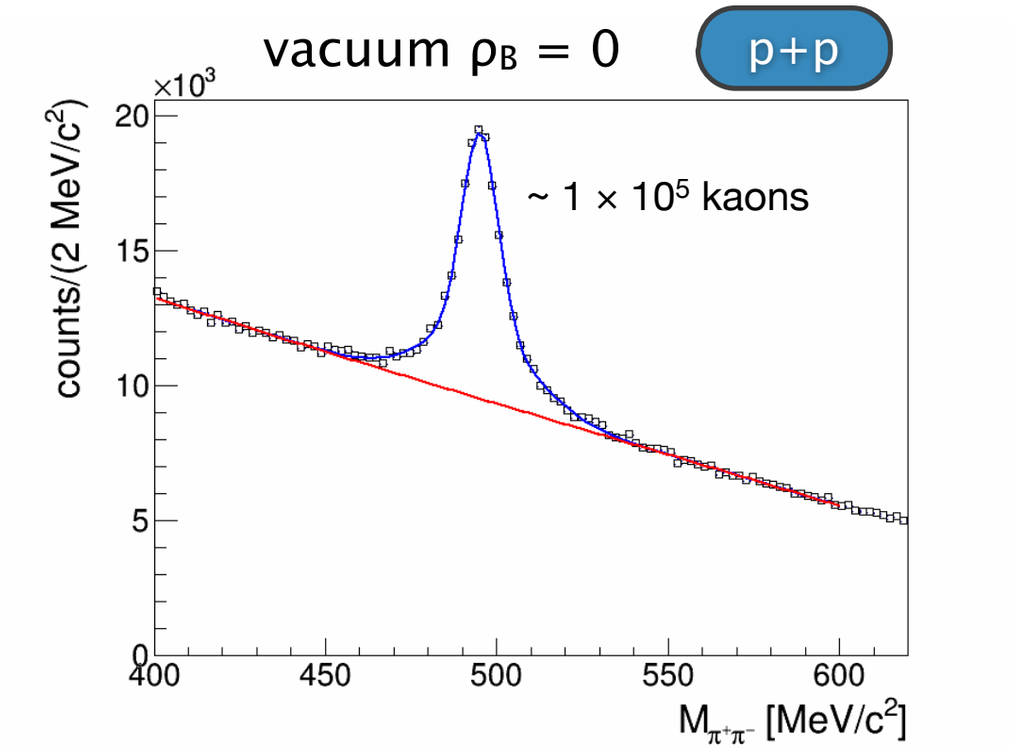
- MDCs
- RICH, Time-of-flight (TOF and RPCs)
- Pre-Shower detector
- Forward Wall detector at small angles

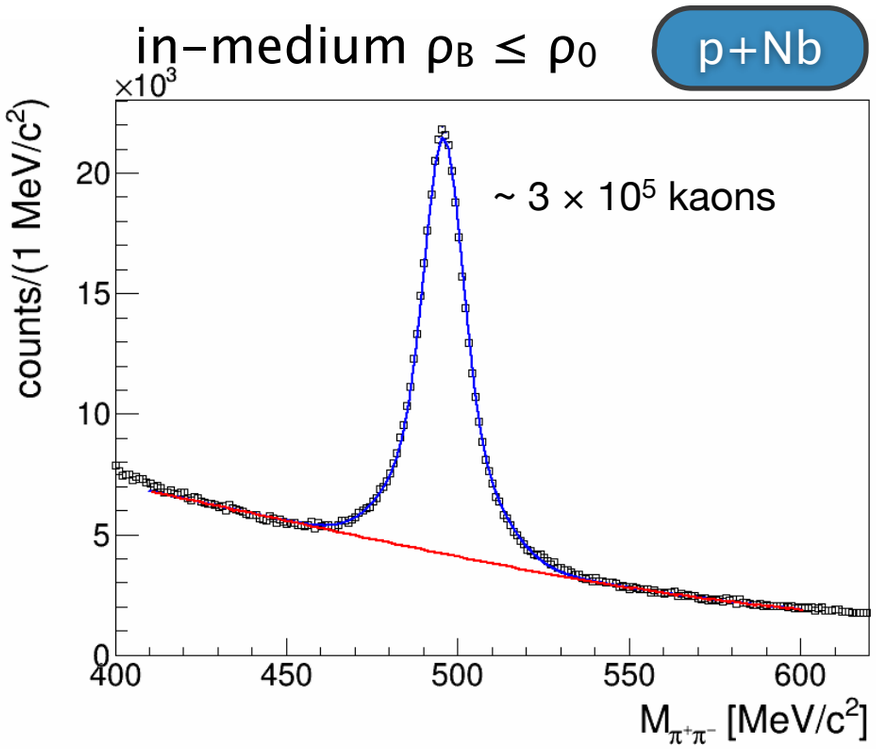
Kaon-nucleus interaction

"*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

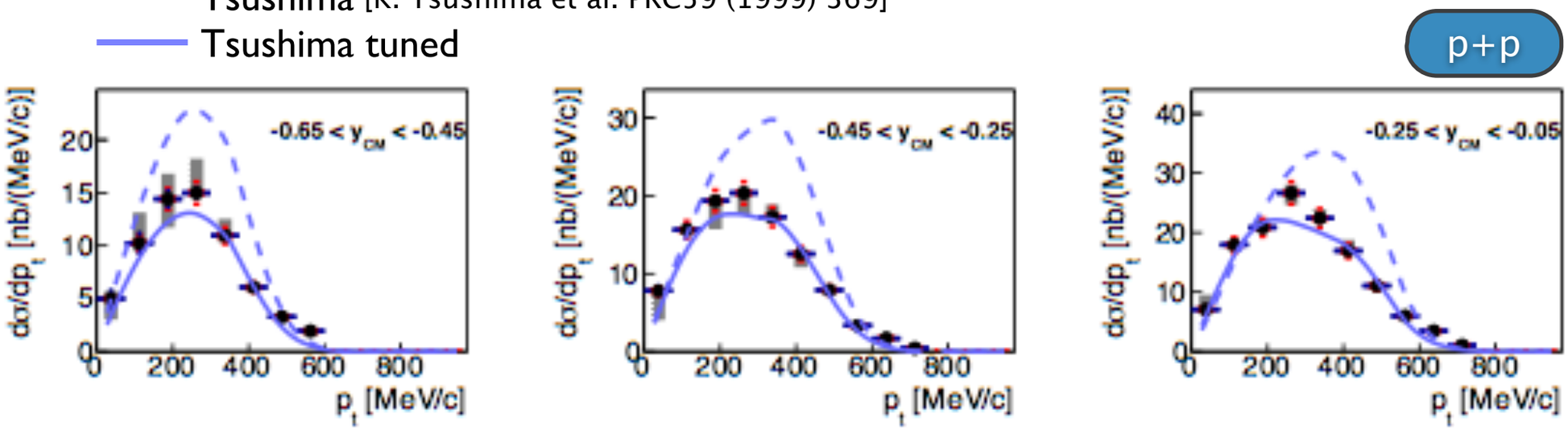
O. Buss et al., Phys. Rept. 512, 1 (2012)
http://gibuu.physik.uni-giessen.de/GiBUU/

K⁰ in p+p: reference measurement

Tsushima [K. Tsushima et al. PRC59 (1999) 369]

Tsushima tuned

p+p



- 4-body states produced via Δ-resonances (cf. previous talk by J.-C. Berger-Chen)
- 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 ($\rho=\rho_0$, $k=0$)

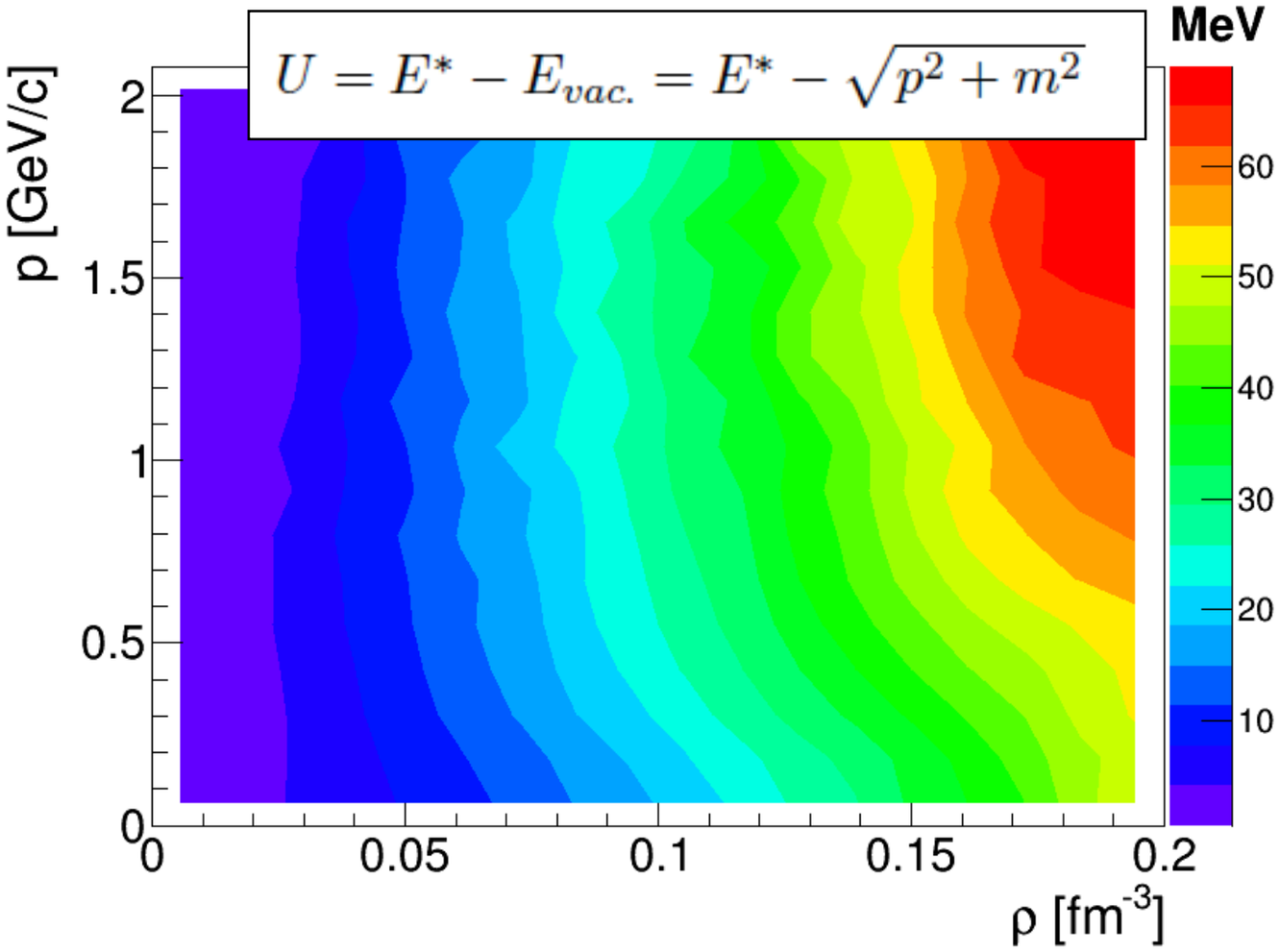
$$m_K^* = \sqrt{m_K^2 - \frac{\Sigma_{KN}}{f_\pi^2}\rho_s + V_\mu V^\mu}$$

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

$$E^* = \sqrt{k^{*2} + m_K^{*2}} + V_0 \qquad \mathbf{k}^* = \mathbf{k} - \mathbf{V}$$

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

$$f_\pi = 93 \text{ MeV} \qquad f_\pi^{*2} = 0.6 f_\pi^2$$



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

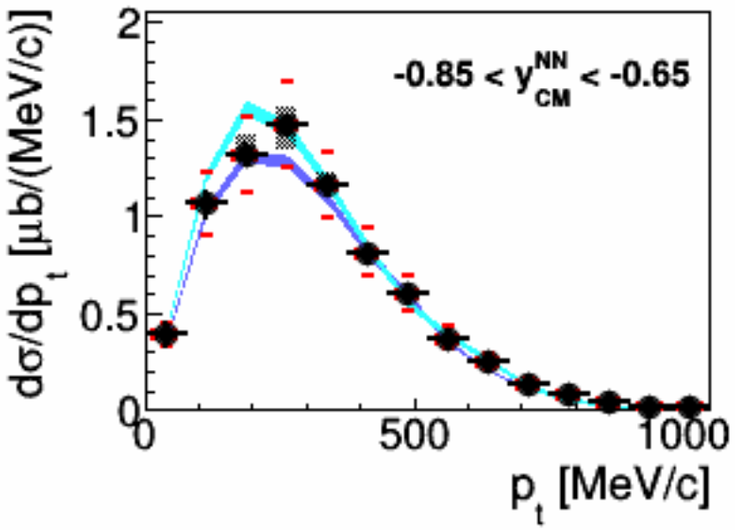
$$U = \sqrt{k^2 + m^{*2}} + V_0 - \sqrt{k^2 + m_{vac.}^2} \qquad m^* < m$$

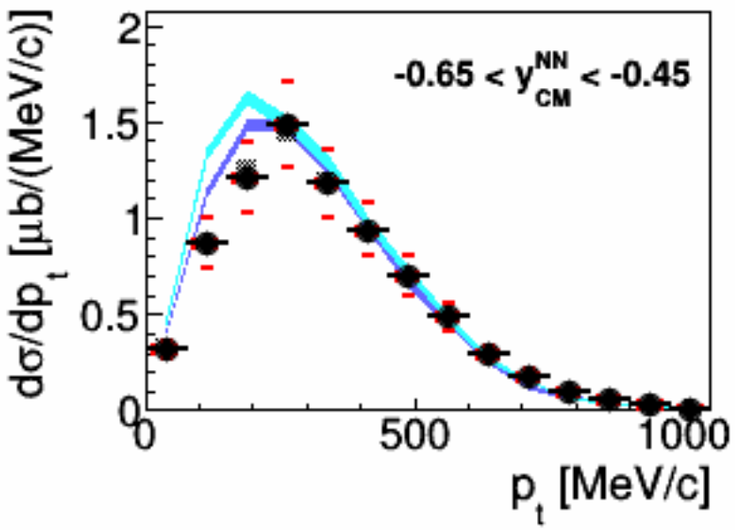
Effect of the potential in p+Nb: p_t-y

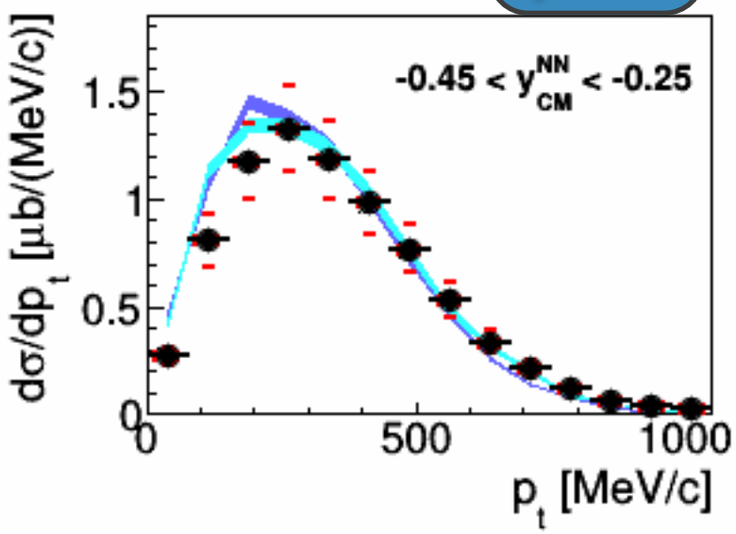
GiBUU w/o pot.

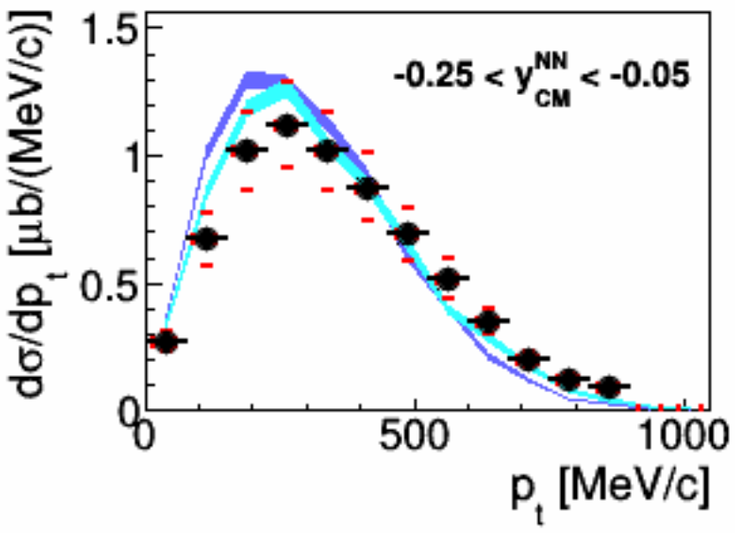
GiBUU w. pot.

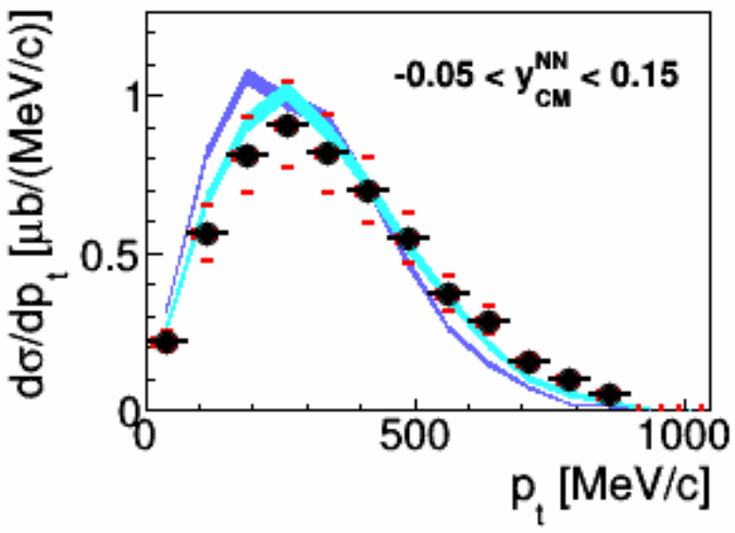
p+Nb

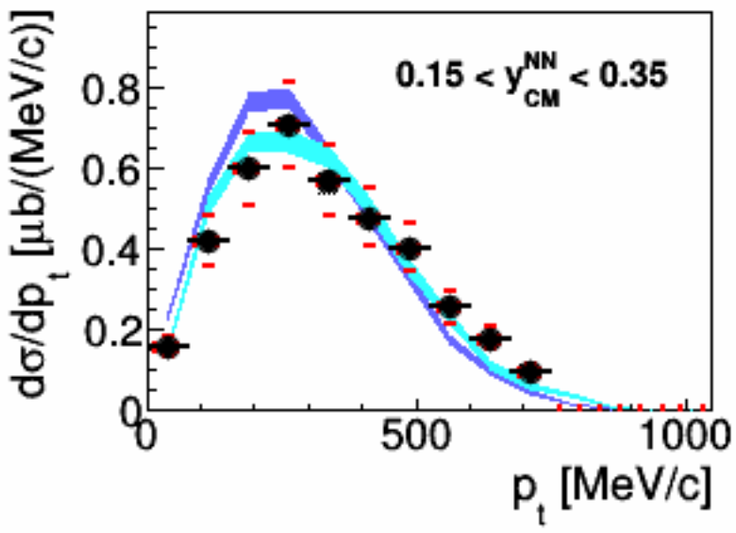






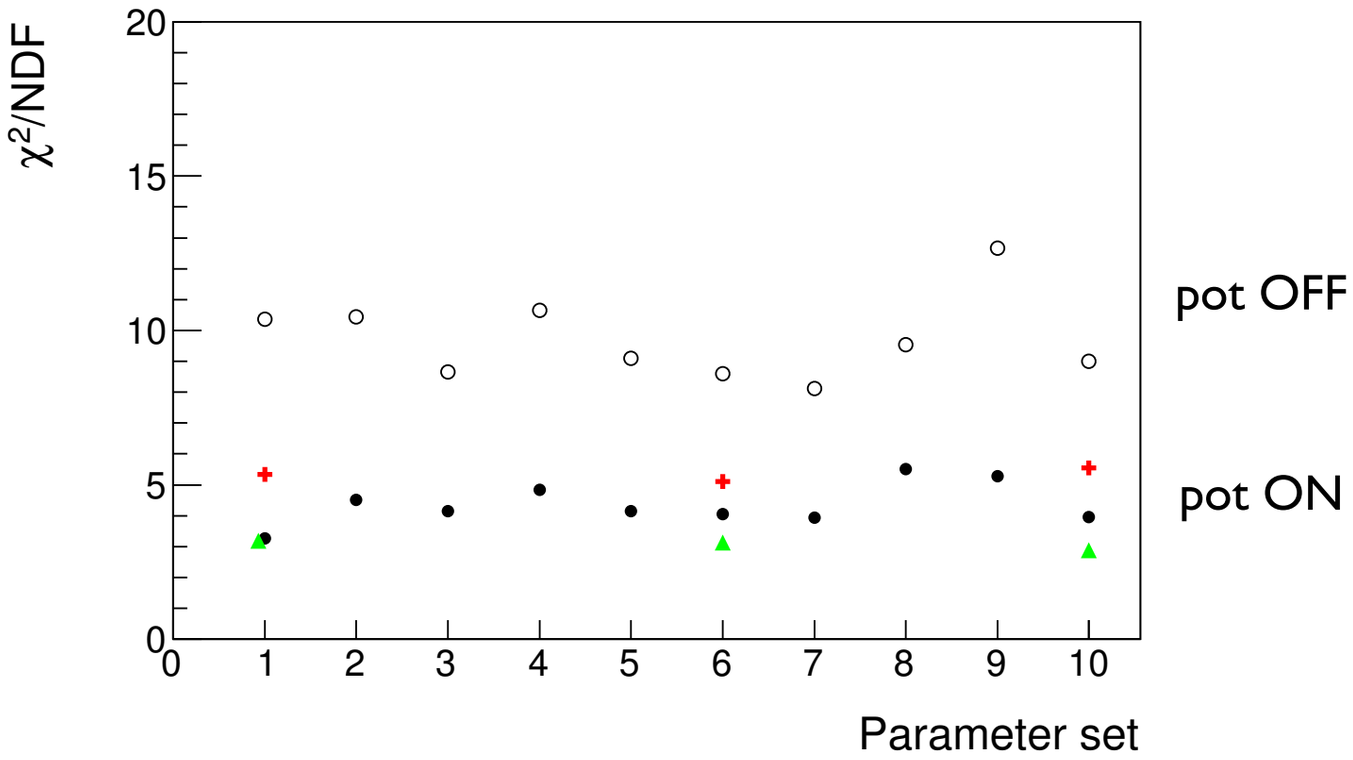






- Systematical modification of p_t-spectra owe to the repulsive potential.
- Uncertainties in the model parameters (np cross sections, …).

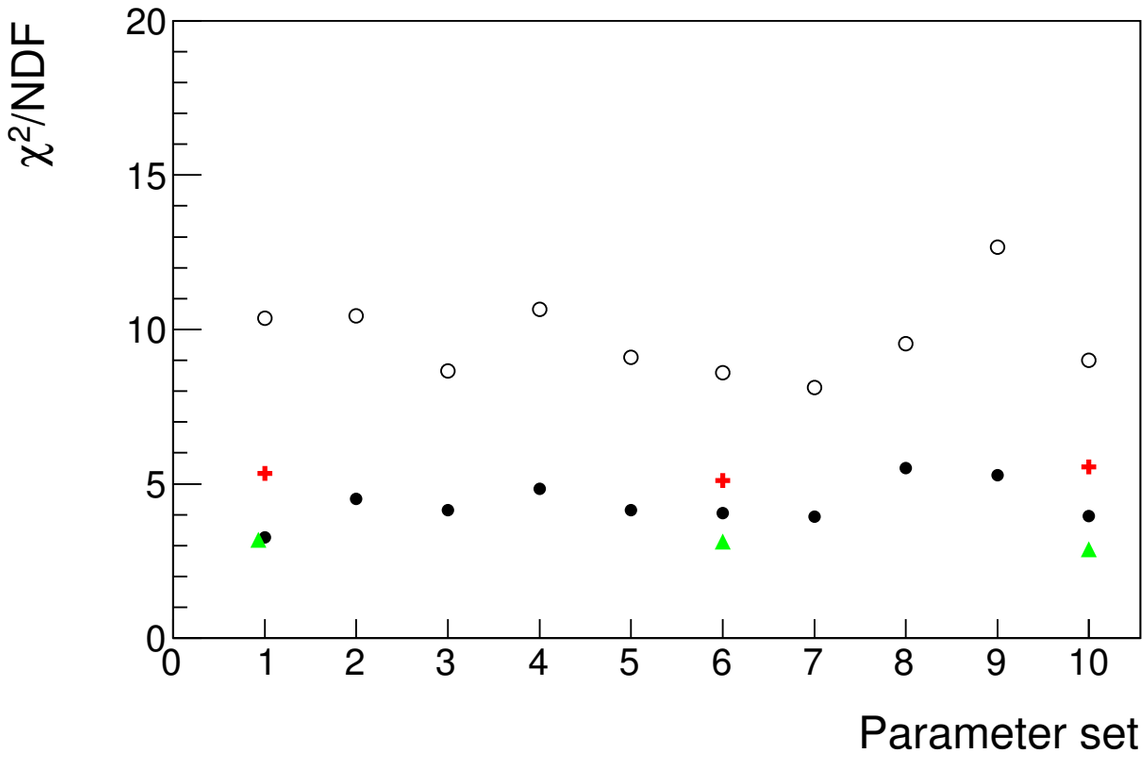
χ^2-analysis



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} :

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

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

Systematic variation of the model parameters

Set	Meaning
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7	np3 −25%
8	KN +25%
9	KN −25%
10	np3 +30% & 5b −30%

Results

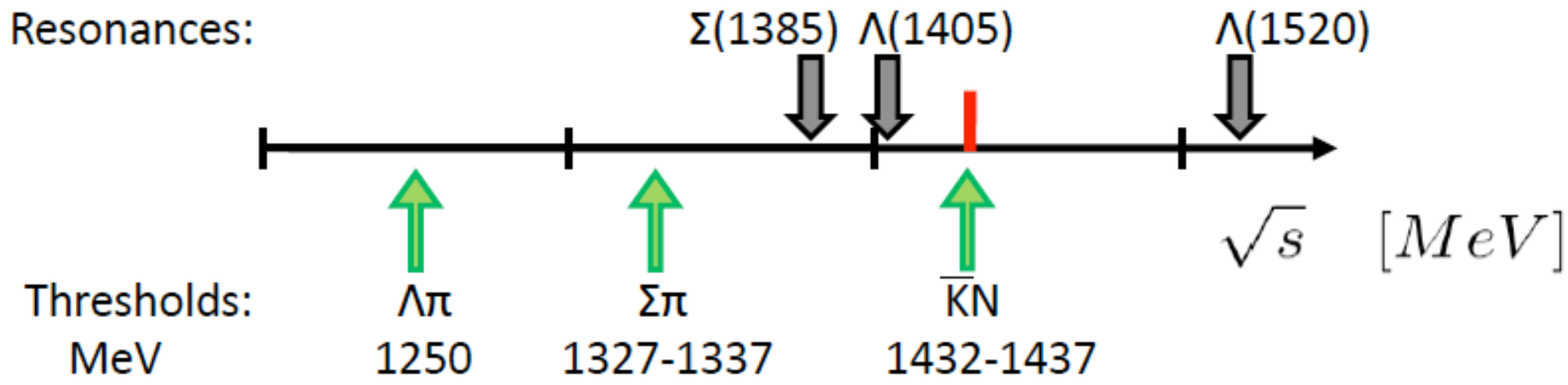
System (energy)	Experiment	Kaon potential [MeV]
π+A (1.02 GeV)	FOPI	20 ± 5
p+A (2.3 GeV)	ANKE	20 ± 5
Ar+KCl (1.76 GeV)	HADES	39^{+8}_{-2}
p+Nb (3.5 GeV)	HADES	40 ± 5

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]

Antikaon-nucleon interaction

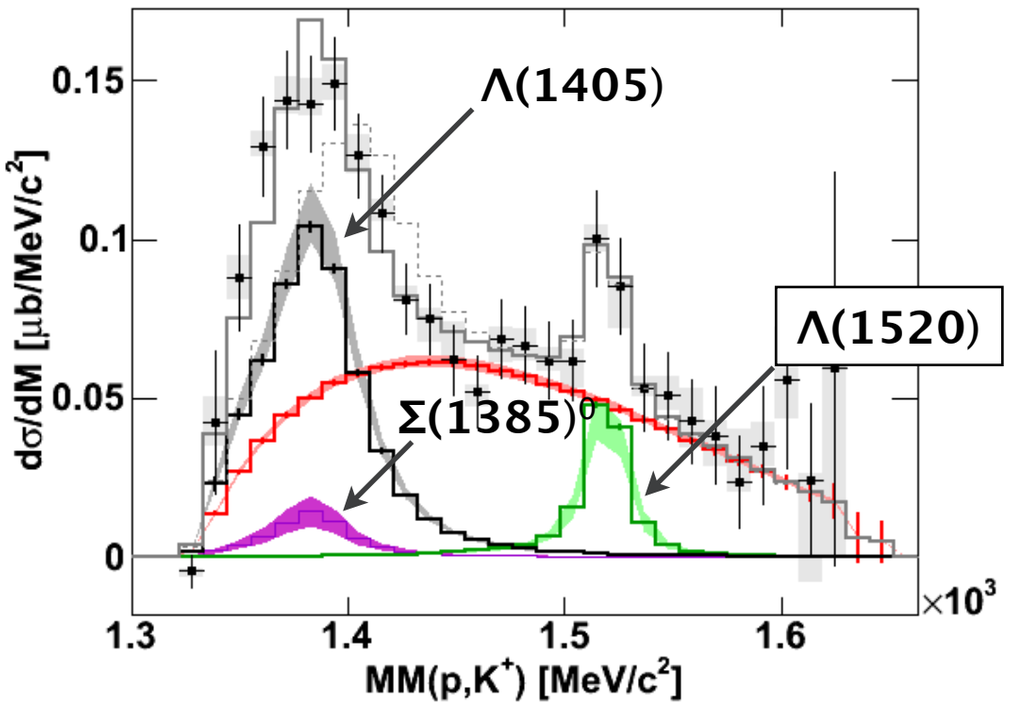


- Λ(1405) is crucial for understanding of the **free and in-medium** $\overline{K}N$ interaction.
- Within coupled channel approach generated as a $\overline{K}N$ bound state and a Σπ resonance.

HADES:

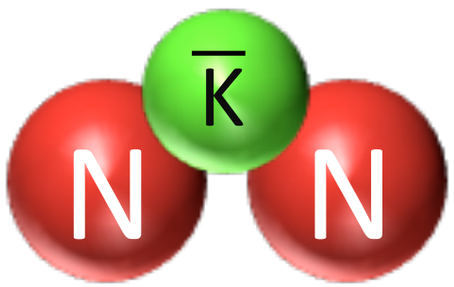
- First measurement of Λ(1405) in p+p reactions in charged decay mode.
- Mass distribution peaked below 1405 MeV/c^2.

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



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.

Hypothesis of a kaonic cluster



Property	Value
charge	+1
strangeness	-1
participants	ppK^-, $pn\overline{K}^0$
J^P	0^-

Most theoretical works predict existence of such bound state.

$B(ppK^-) \approx 14\text{-}80$ MeV
$\Gamma(ppK^-) \approx 40\text{-}110$ MeV/c^2

T. Yamazaki, Y. Akaishi Phys. Rev. C76 (2007)
A. Doté, T. Hyodo, W. Weise Nucl. Phys. A804 (2008)
A. Doté, T. Hyodo, W. Weise Phys. Rev. C79 (2009)
S. Wycech, A. M. Green, Phys. Rev. C79 (2009)
N. Barnea, A. Gal, E. Z. Liverts, Phys. Lett. B712 (2012)
N.V. Shevchenko, A. Gal, J. Mares, Phys. Rev. Lett. 98 (2007)
N.V. Shevchenko, A. Gal, J. Mares, J. Révay, Phys. Rev. C76 (2007)
Y. Ikeda, T. Sato, Phys. Rev. C76 (2007)
Y. Ikeda, T. Sato, Phys. Rev. C79 (2009)
Y. Ikeda, H. Kamano T. Sato, Prog. Theor. Phys. 124 (2010)
E. Oset et al. Nucl. Phys. A881 (2012)

main decay channel "ppK^-" → $p\Lambda$ ⇒ search in $pp \to p\Lambda K^+$ at 3.5 GeV

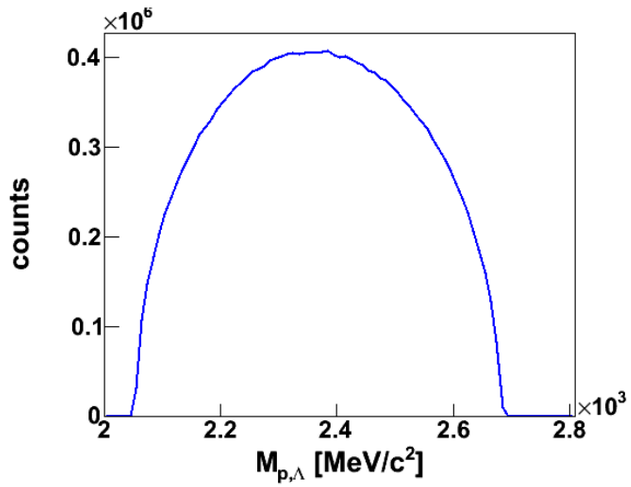
Sources of the pΛK⁺ final state in p+p collisions

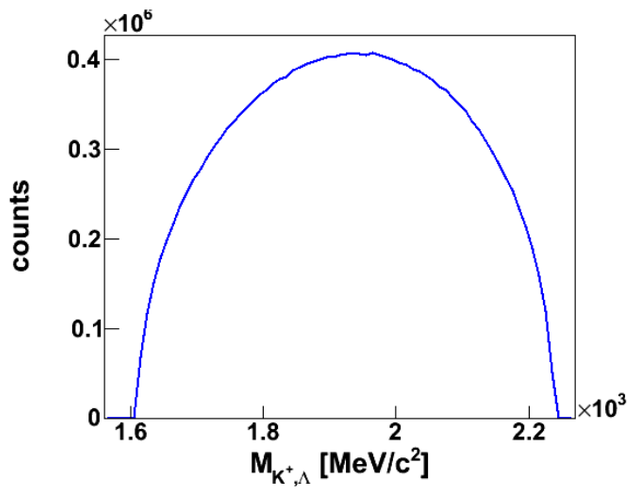
$$p + p \xrightarrow{3.5GeV} p + K^+ + \Lambda$$

$$p + p \xrightarrow{3.5GeV} N^{*+} + p$$
$$\hookrightarrow \Lambda + K^+$$
$$\hookrightarrow \Sigma^0 + K^+$$

$$p + p \xrightarrow{3.5GeV} \text{"}ppK^-\text{"} + K^+$$
$$\hookrightarrow \Lambda + p$$
$$\hookrightarrow \Sigma^0 + p$$

Simulation in 4π





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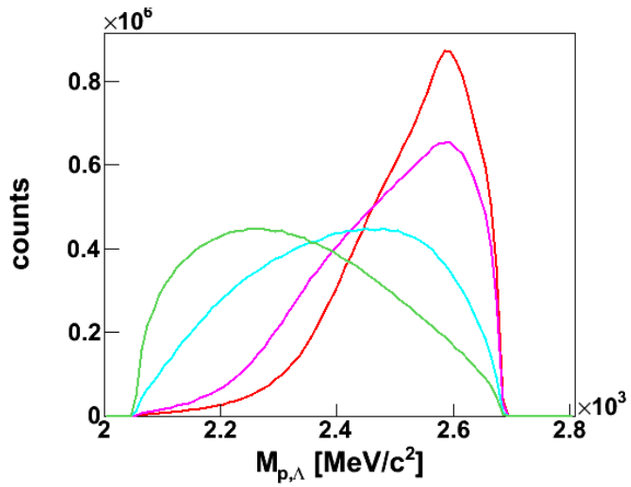
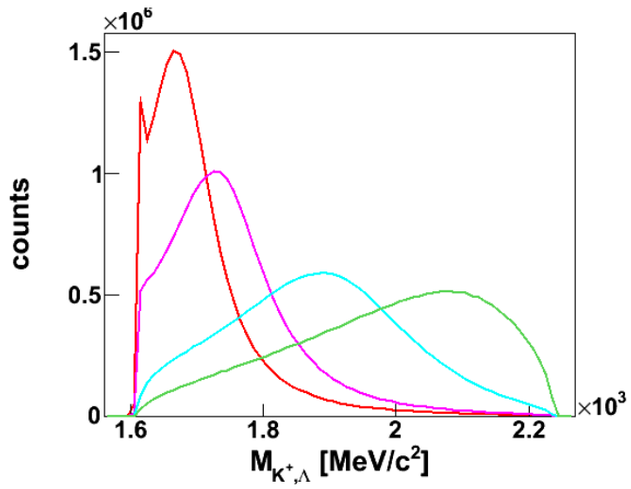
$$\hookrightarrow \Lambda + p$$
$$\hookrightarrow \Sigma^0 + p$$

Simulation in 4π

N*⁺(1650)
N*⁺(1720)
N*⁺(1900)
N*⁺(2190)





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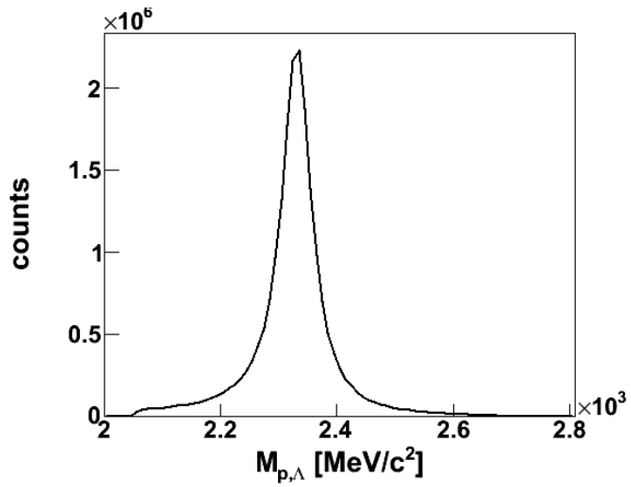
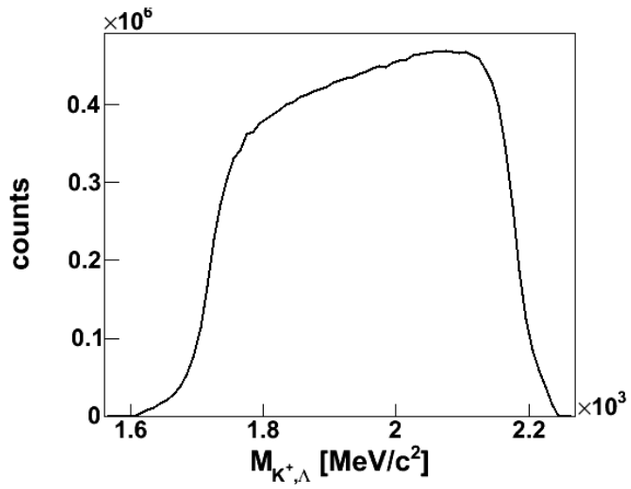
$$\hookrightarrow \Lambda + p$$
$$\hookrightarrow \Sigma^0 + p$$

Simulation in 4π





Search for kaonic cluster signal

Partial wave analysis

with the Bonn-Gatchina framework

http://pwa.hiskp.uni-bonn.de/

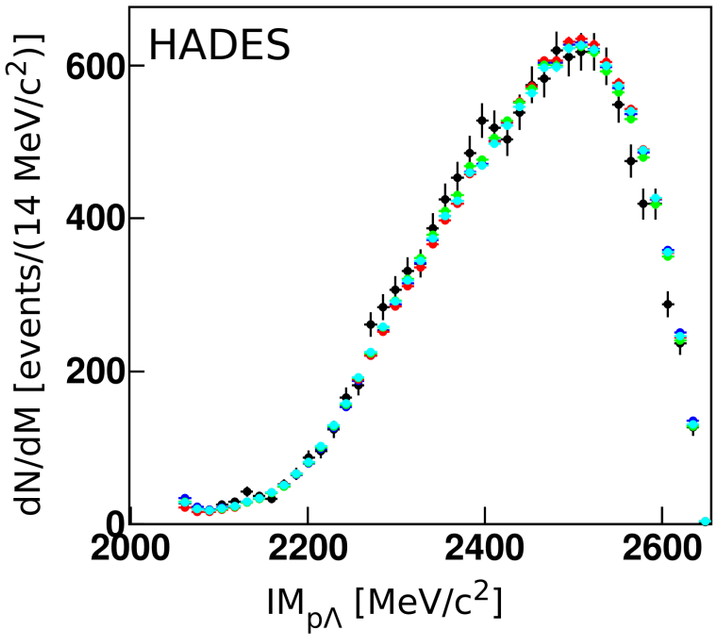
A.V. Anisovich, V.V. Anisovich, E. Klempt, V.A. Nikonov and A.V. Sarantsev
Eur. Phys. J. A 34, 129152 (2007)

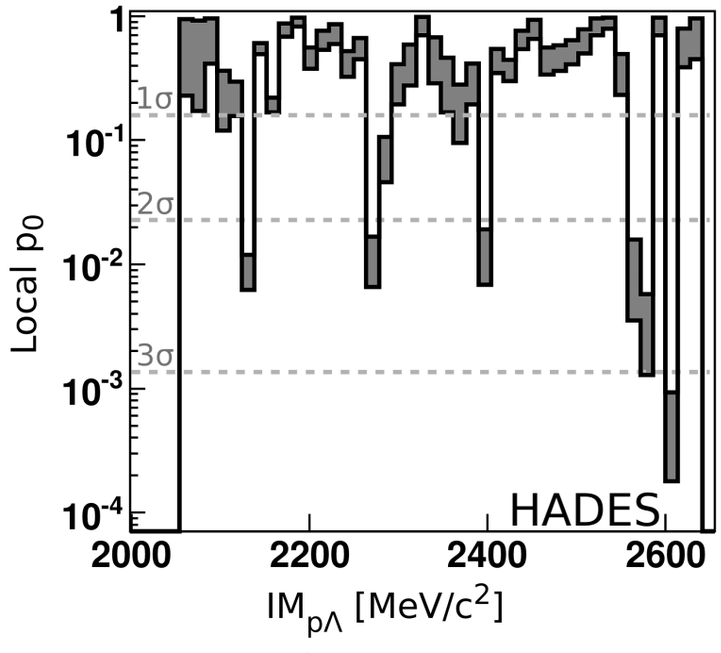
Resonances considered in the solution

Notation in PDG	old	Mass GeV/c^2	Width GeV/c^2	$\Gamma_{\Lambda K}/\Gamma_{All}$
N(1650) $\frac{1}{2}^-$	$N(1650)S_{11}$	1.655	0.150	3-11%
N(1710) $\frac{1}{2}^+$	$N(1710)P_{11}$	1.710	0.200	5-25%
N(1720) $\frac{3}{2}^+$	$N(1720)D_{13}$	1.720	0.250	1-15%
N(1875) $\frac{3}{2}^-$	$N(1875)D_{13}$	1.875	0.220	?
N(1880) $\frac{1}{2}^+$	$N(1880)P_{11}$	1.870	0.235	?
N(1895) $\frac{1}{2}^-$	$N(1895)S_{11}$	1.895	0.090	?
N(1900) $\frac{3}{2}^+$	$N(1900)P_{13}$	1.900	0.250	0-10%

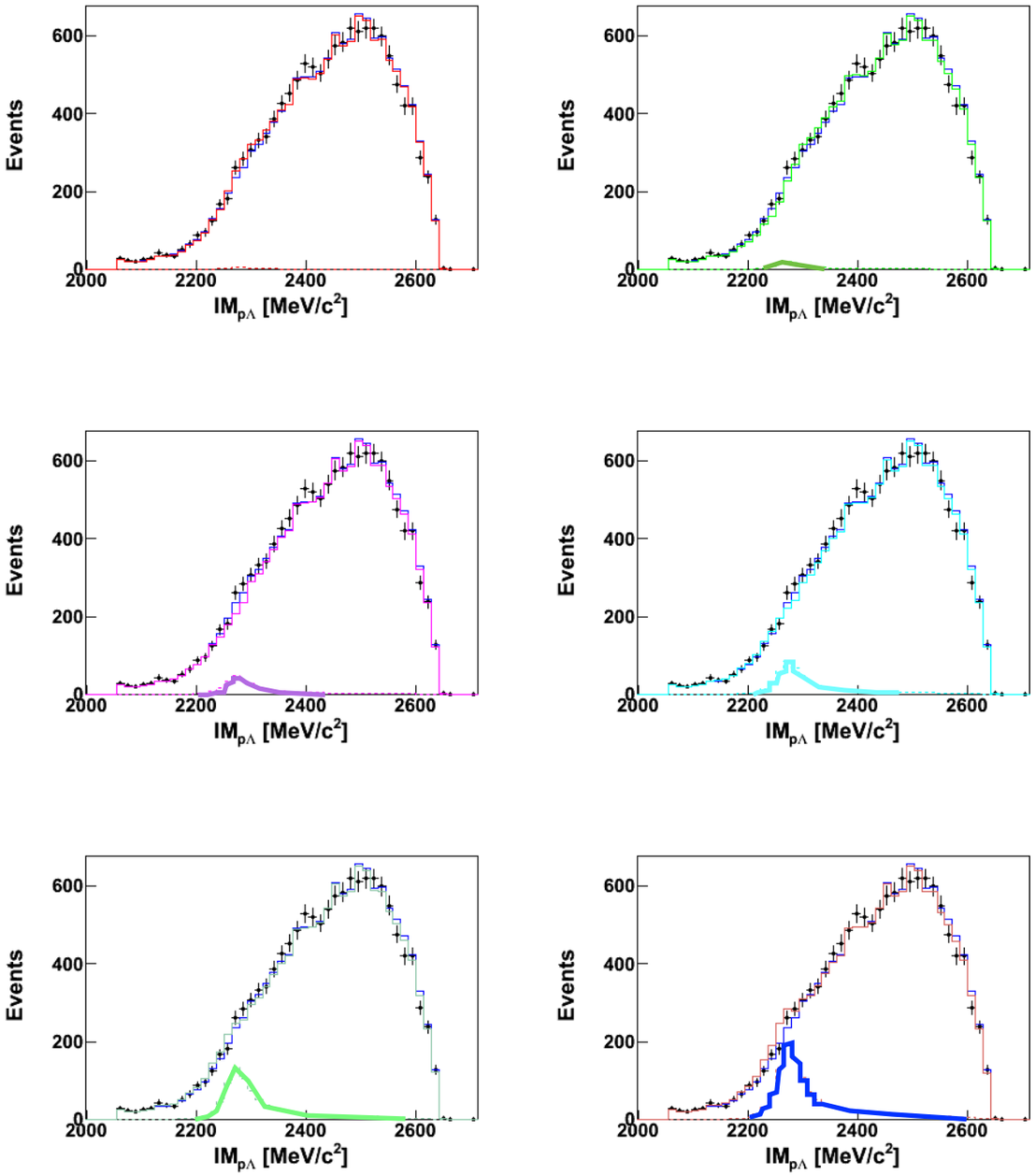
Coherent sum of baryonic resonances (plus non-resonant waves) reproduces the invariant mass spectrum well.

Not much room for the kaonic cluster in pp at 3.5 GeV.





PWA solution including the kaonic cluster



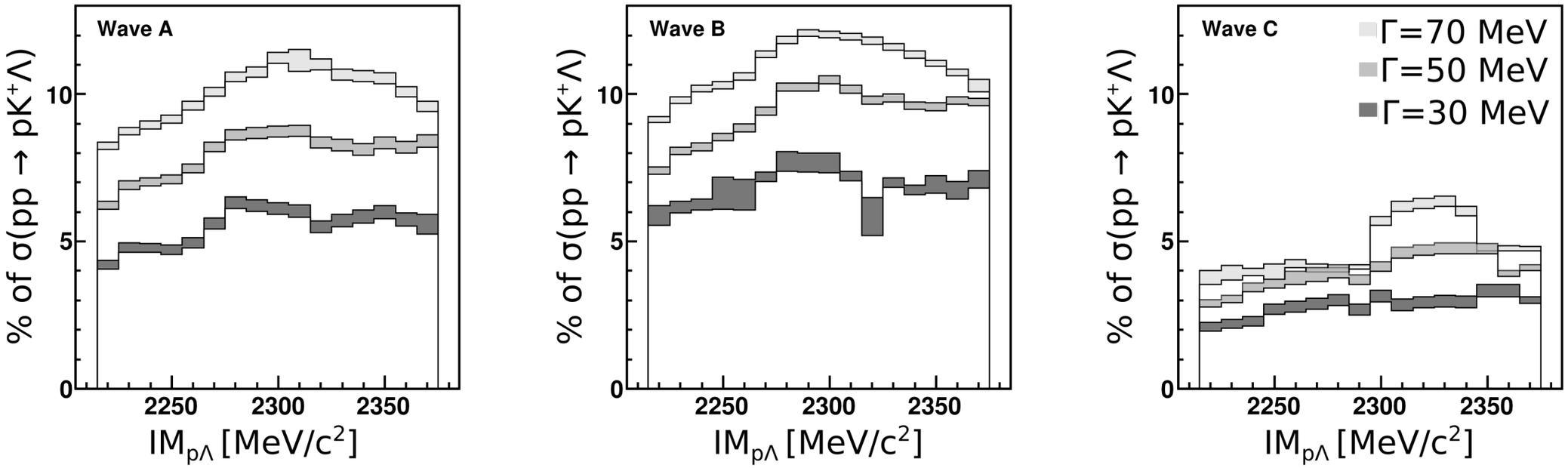
- Gradual increase of the input ppK$^-$ amplitude (fixed in the fit)
- Relative phase is a free parameter
- Calculate the χ^2 and the corresponding p-value
- $p < 0.05$ (95% CL) → threshold for the maximally allowed ppK$^-$ amplitude

Upper production limit

$$
\begin{array}{llllll}
WaveA: & {}^1S_0 \rightarrow & {}'ppK(2250) - K' & 1 & {}'S', \\
WaveB: & {}^3P_1 \rightarrow & {}'ppK(2250) - K' & 1 & {}'P', \\
WaveC: & {}^1D_2 \rightarrow & {}'ppK(2250) - K' & 1 & {}'D'.
\end{array}
$$

- Different mass/width combinations tested
- Allowed yield in percentage of the pKΛ production
- σ(pKΛ) ~ 40 ± 6 μbarn

HADES preliminary



Summary

Kaon in-medium properties:

- 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.

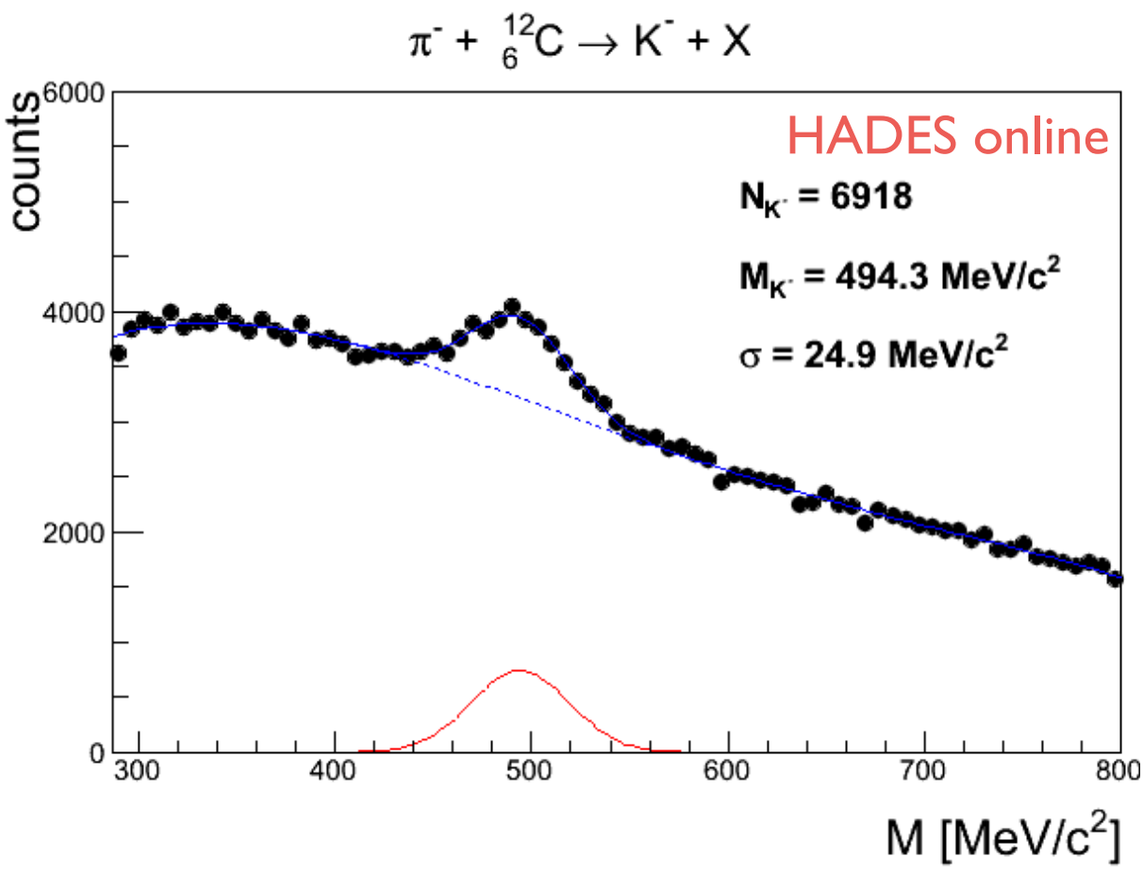
Antikaon-nucleon interaction:

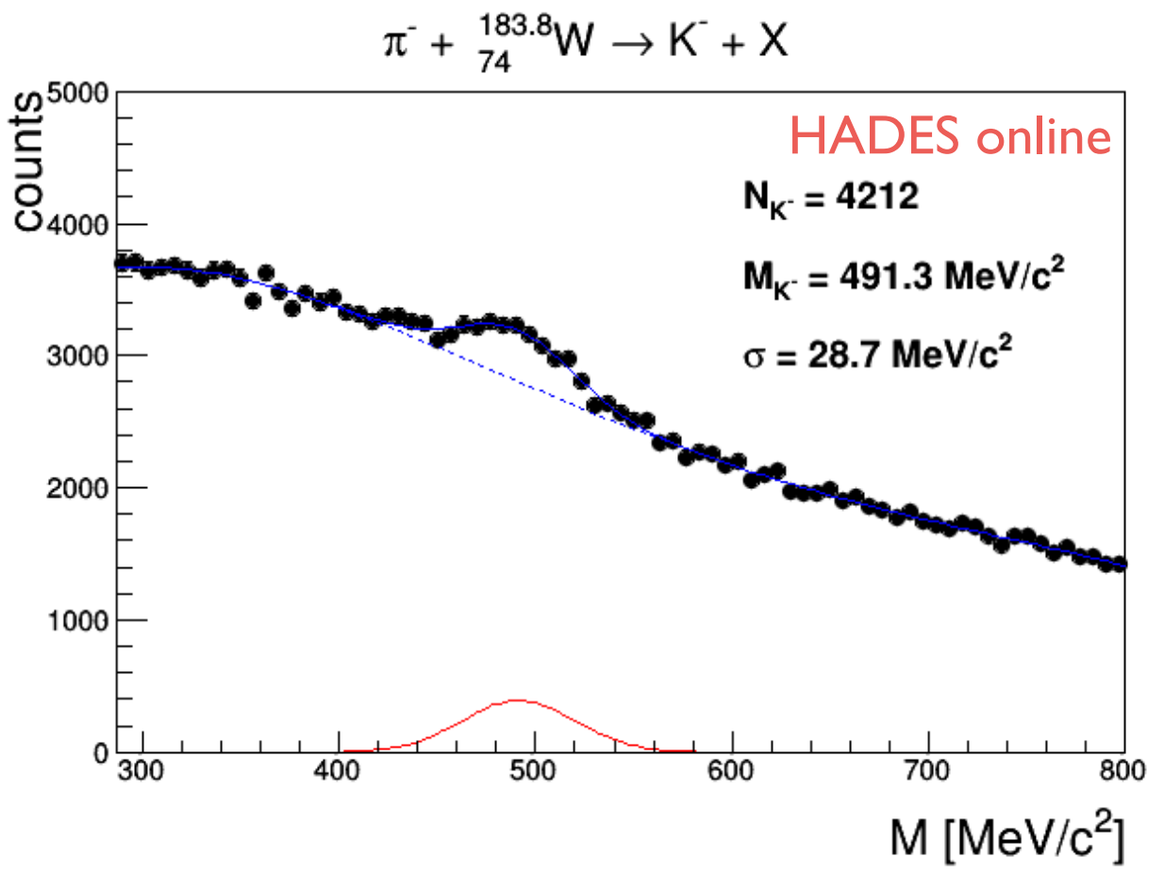
- Search for $\bar{K}NN$ bound state in pp reactions with means of PWA.
- No statistically significant signal observed.
- First coherent implementation of the $\bar{K}NN$ production.
- An upper limit of <12% of the total $pK\Lambda$ cross section is established.

Outlook: pion-nucleus reactions (July 2014)

- Continue and extend studies started in pp/pA.
- Light projectile — favorable kinematics for in-medium effects.
- Light and heavy targets (C, W).

Example of the data potential: antikaon reconstruction





The HADES Collaboration

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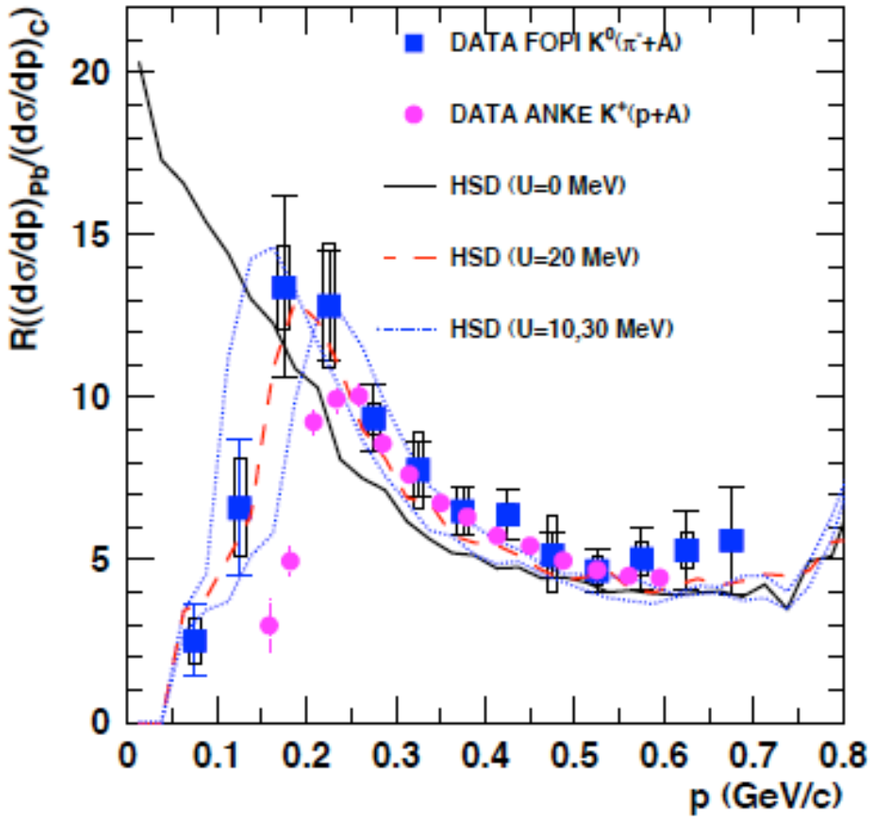
How to observe the kaon in-medium potential

General idea: look at the kinematics of escaped kaons

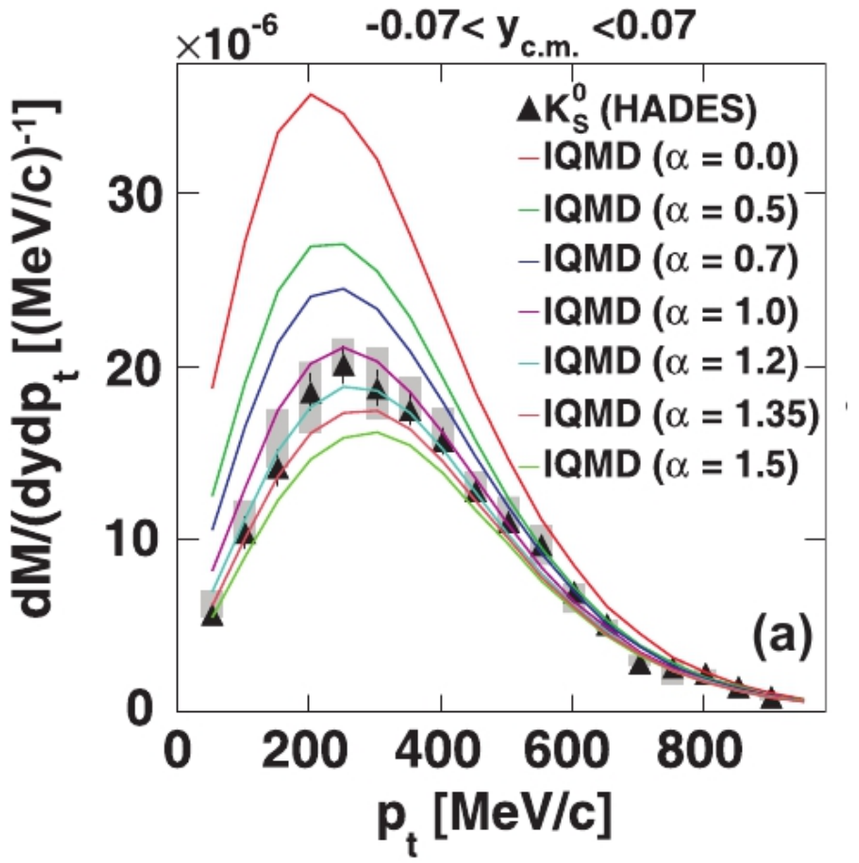
FOPI π+A, ANKE p+A



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

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

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

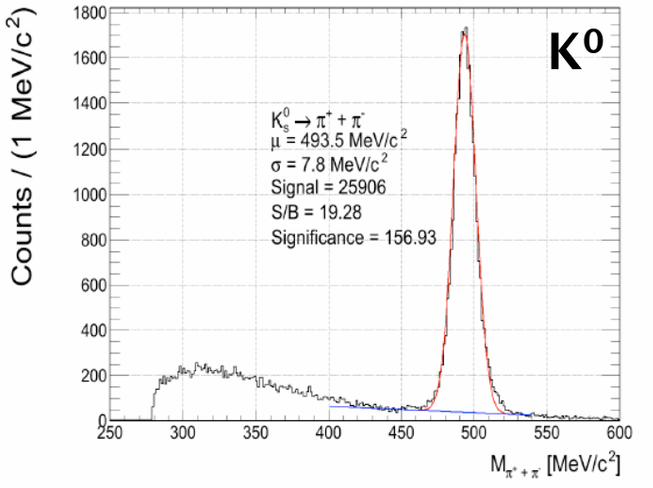


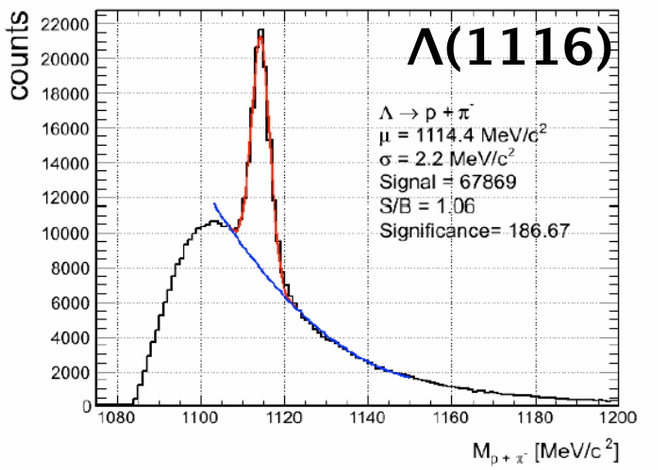
G. Agakishiev et al.,
Phys. Rev. C 82 (2010) 044907.

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

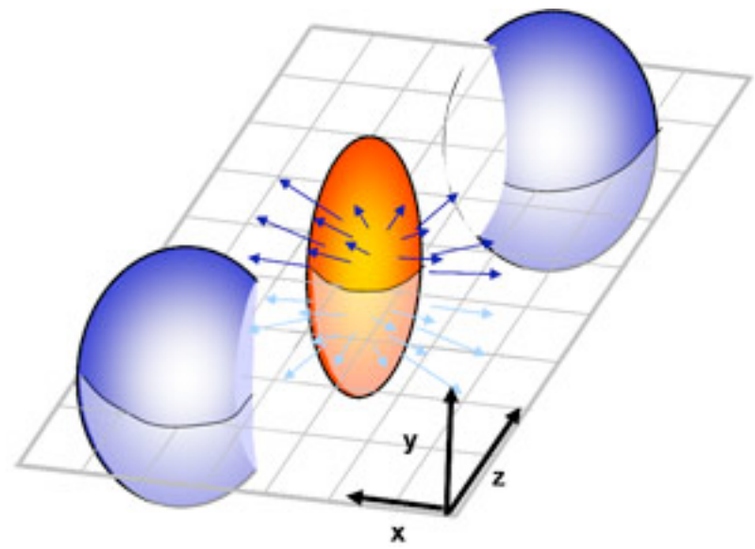
Heavy-ion collisions

May 2012: Au+Au at 1.23 GeV/u





Flow of strangeness w.r.t. reaction plane



- Reconstruct event-by-event reaction geometry.
- Look at the preferred direction of strangeness emission.
- Infer potentials from the comparison with models.

Pion-induced reactions measured with HADES