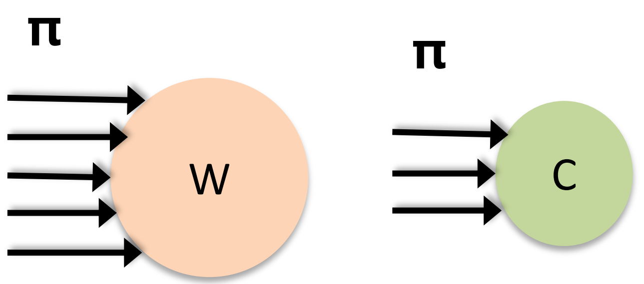
In-Medium Properties of Lambda in Pion-Induced Reactions at 1.7 GeV/c*

Steffen Maurus for the HADES Collaboration

Dense and Strange Hadronic Matter (E62)
Physik Department
Technische Universität München

*supported by SFB 1258

Pion-Induced Strange Hadron Production

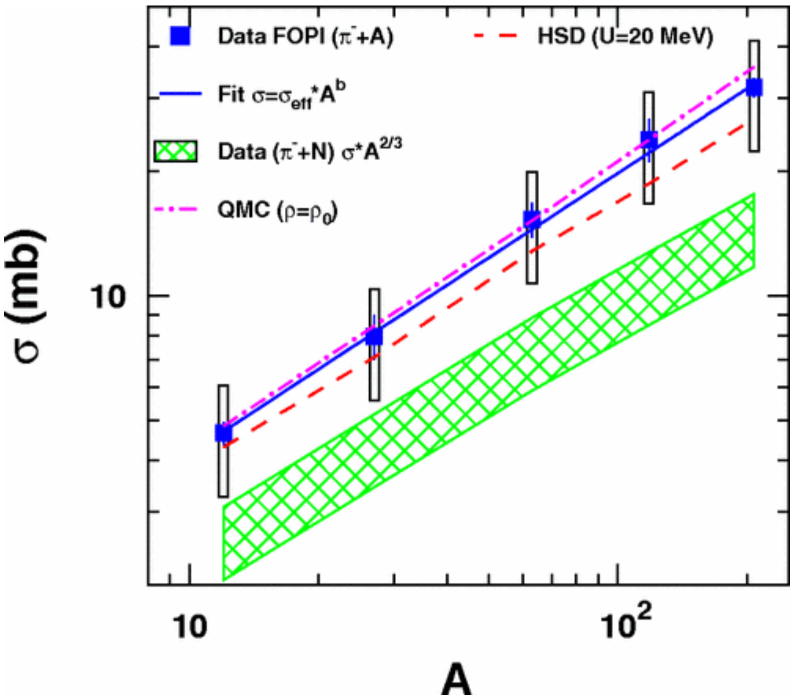


$$\lambda = 1.5 \text{ fm } (p_\pi = 1.7 \text{ GeV/c})$$

$$d_{C,W} \approx 5.5,\ 14.2 \text{ fm}$$

→ **π** is likely to undergo reactions with nucleus on the surface of the target nucleus

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



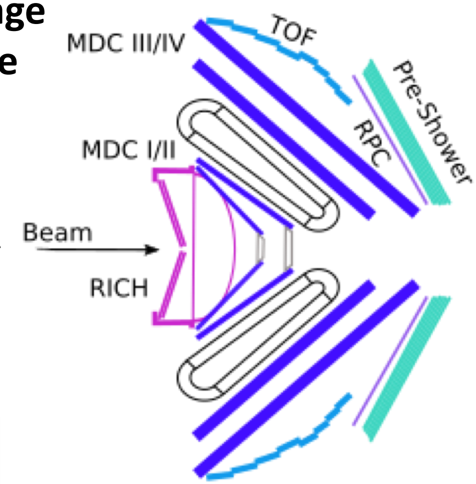
→ K^0 production scales with the surface of the nucleus in pion-induced reactions (@ 1.15 GeV/c)

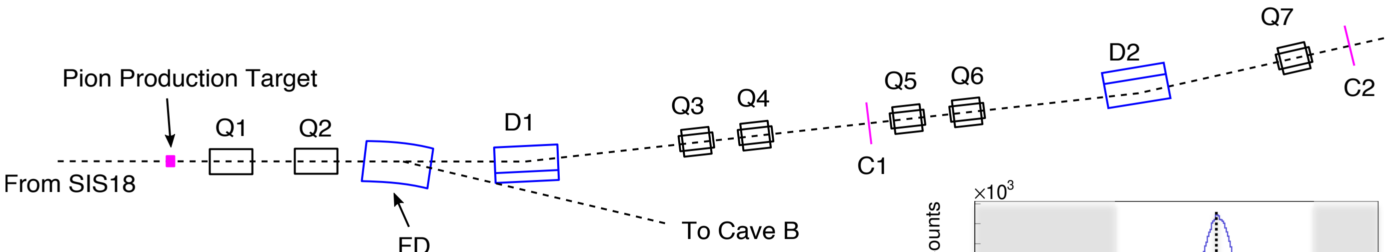
Pion Facility with HADES

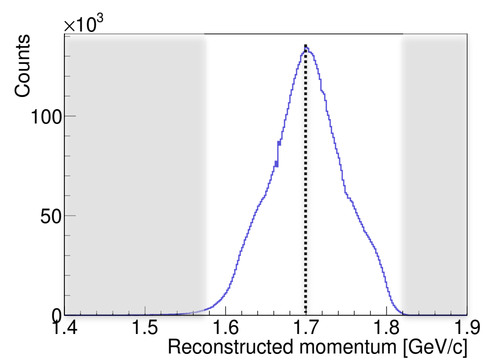
SECONDARY PION BEAM @ 1.7 GeV/c

CEnt**R**al **BE**am T**R**acker for Pi**O**n**S** (TUM)
- → **Two tracking stations (C1, C2)**
- → **High π^- rates ($\leq 10^7$ part./s)**
- → **Self-triggering and $\sigma(p_\pi) < 0.5$ %**

High **A**cceptance **DiE**lectron **S**pectrometer
- → **Full azimuthal coverage**
- → **15°–85° in polar angle**
- → **$\sigma(p) \approx (2–6)$ %**

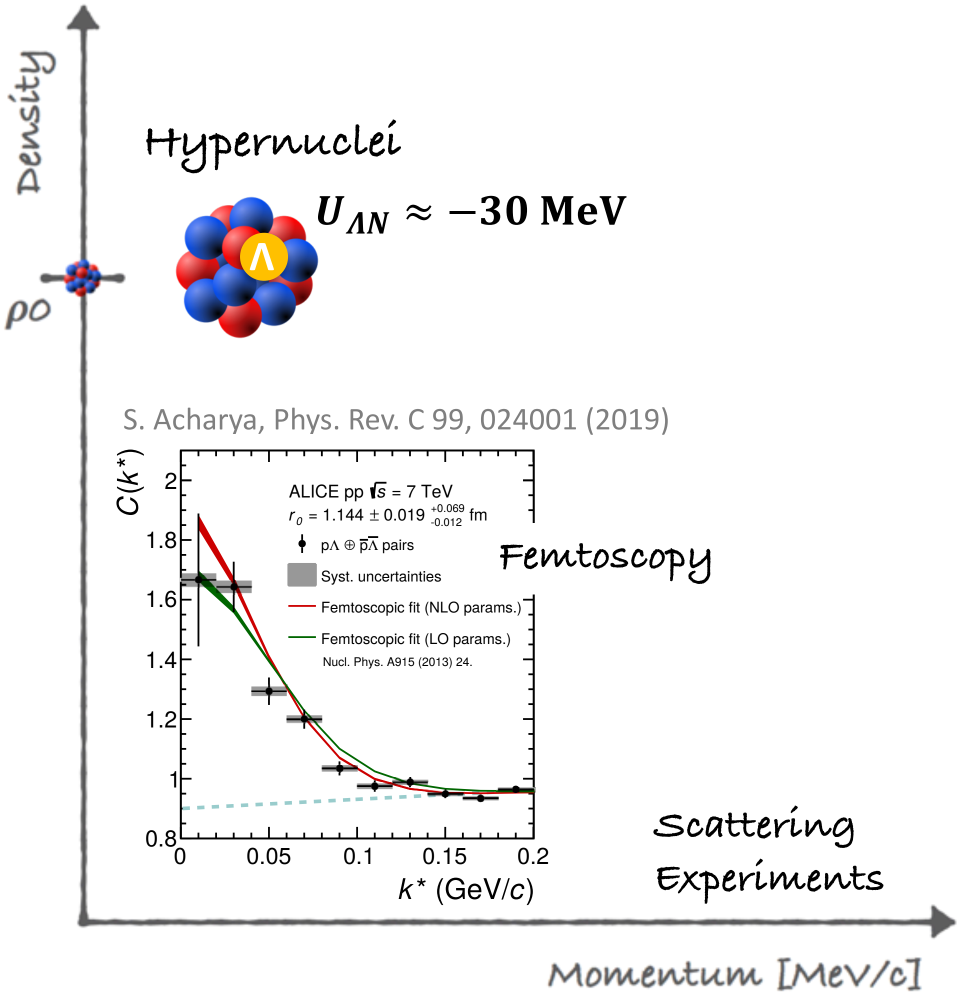




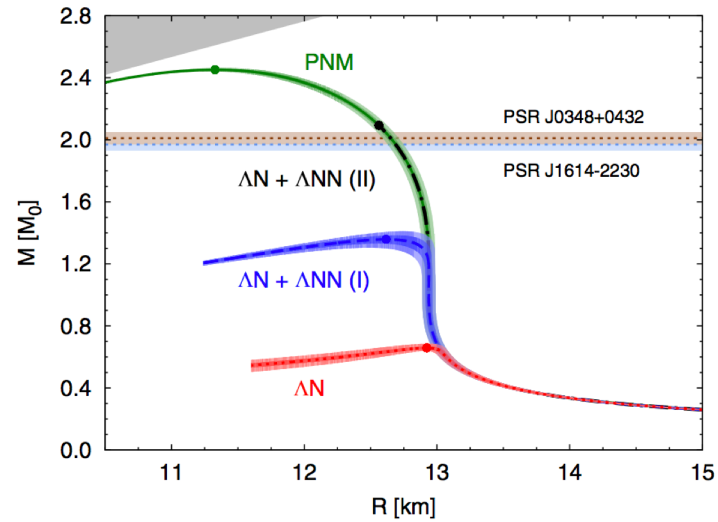


Wirth et al., Nucl. Inst. and Meth., Phy. Res. A, p. 243-244 (2016)
Adamczewski-Musch et al., Eur. Phys. J. A 53, 188 (2017)

Hyperon Stars



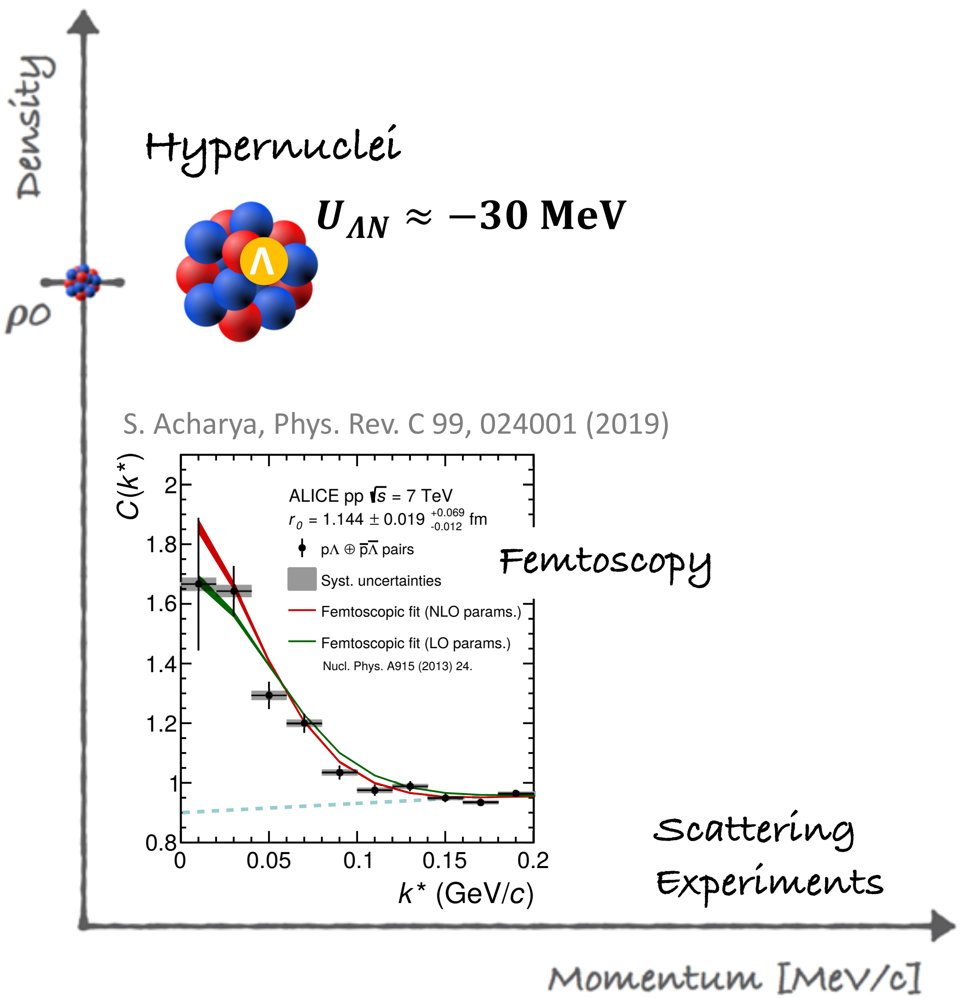
QMC: Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015)



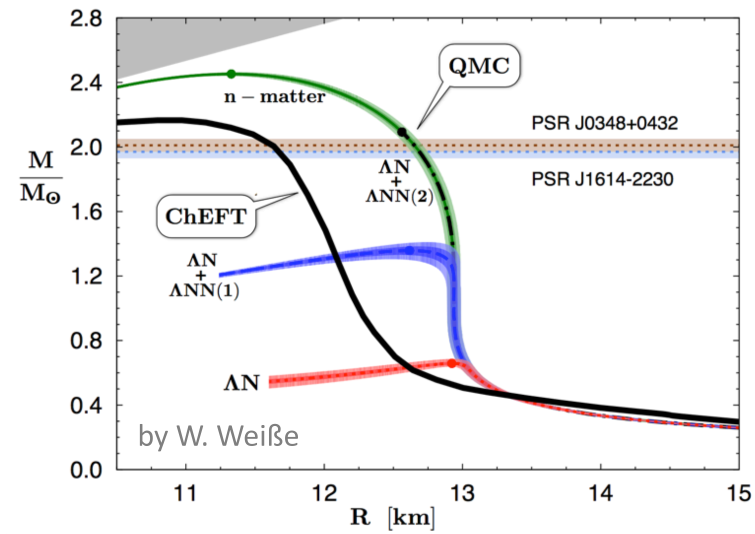
→ **QMC: Attractive ΛN interaction +** (phenom.) **repulsive ΛNN interaction**

→ Hypernuclei ($U_{\Lambda N} \approx -30$ MeV)

Hyperon Stars



QMC: Lonardoni et al., Phys. Rev. Lett. 114, 092301 (2015)
ChEFT: T. Hell et al., Phy. Rev. C 90, 045801 (2014)



→ **QMC: Attractive ΛN interaction +** (phenom.) **repulsive ΛNN interaction**

→ Hypernuclei ($U_{\Lambda N} \approx -30$ MeV)

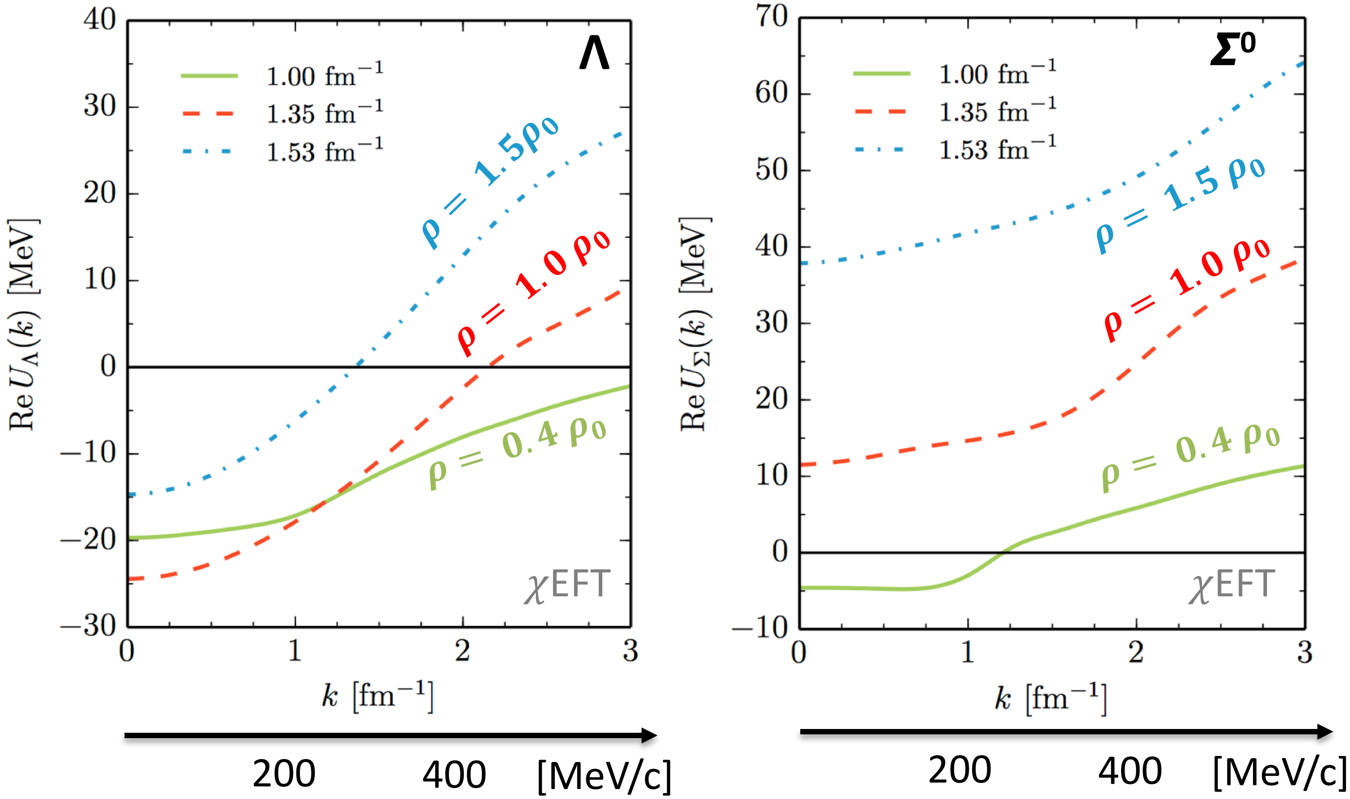
→ **ChEFT:** Scattering data

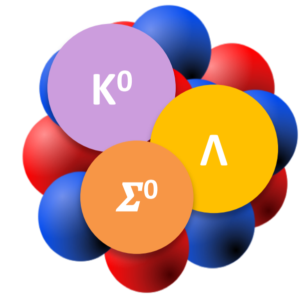
→ Further constraints on **YN** forces needed!!

→ **"Hyperon Puzzle"**

Hyperons inside Nuclear Matter

Petschauer et al., Eur. Phys. J. A 52, 15 (2016)



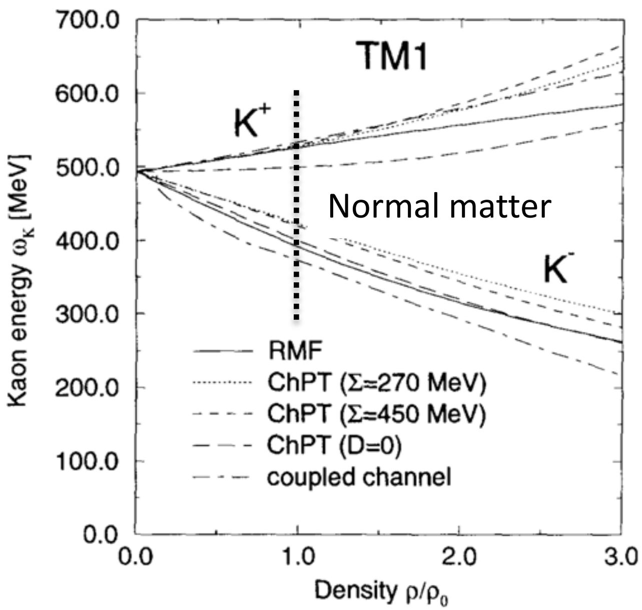


$200 \leq p_\Lambda \leq 800\ \boldsymbol{MeV}/c$

→ Λ/Σ single particle interaction within the nucleus?

Associated Kaon Productio

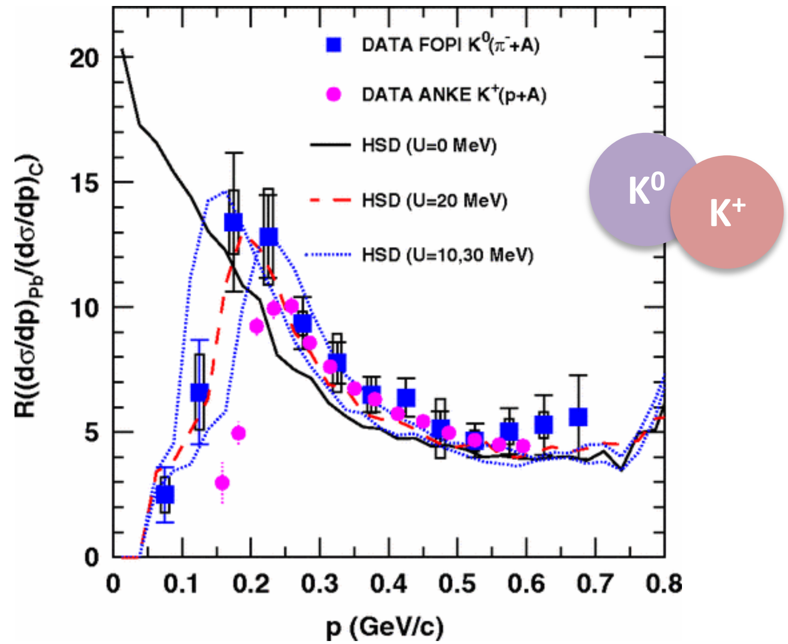
Schaffner-Bielich et al., Nucl. Phys. A 625, 325 (1997)



→ **Repulsive KN interaction**

→ **Attractive $\bar{K}N$ interaction**

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



→ Moderate **repulsive KN interaction**

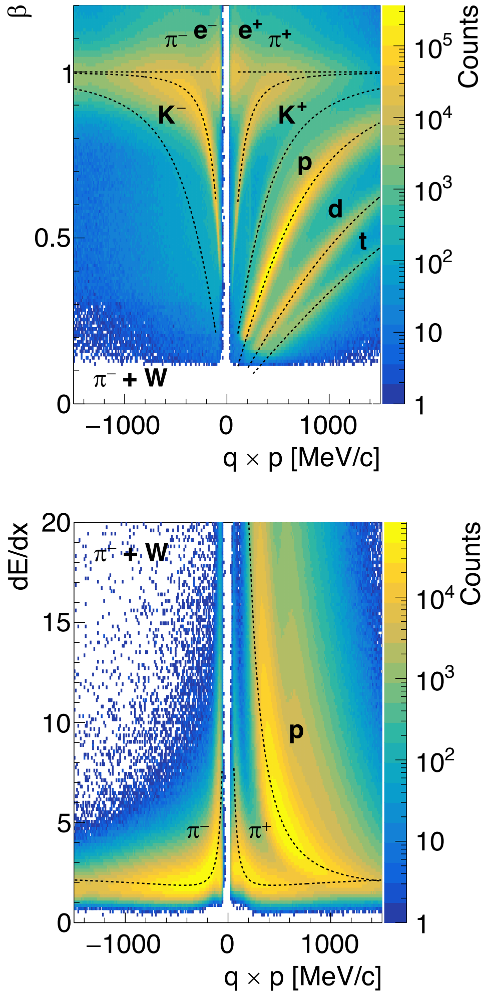
→ $U_{KN} \approx 20 - 40$ MeV

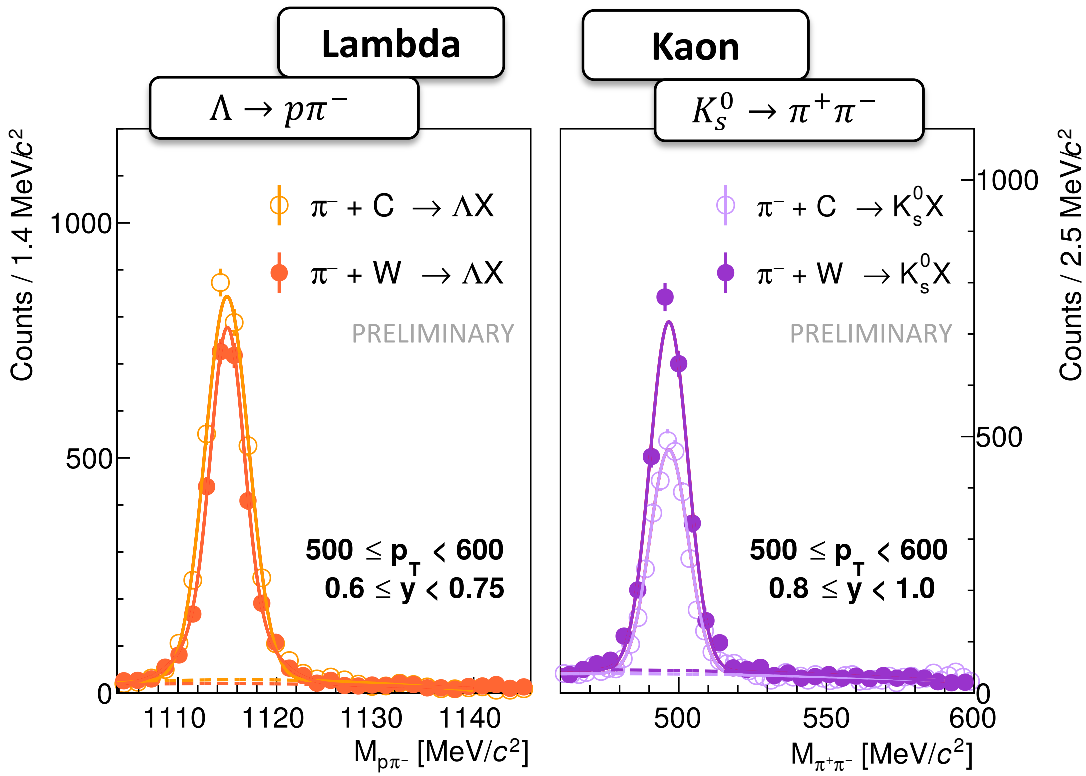
K^0_s properties: Ar + KCl, p + Nb (p + p)

Agakishiev et al. Phys. Rev. C82, 044907 (2010)

Agakishiev et al. Phys. Rev. C90, 054906 (2014)

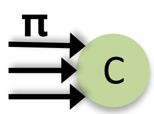
Strange Hadron Selection

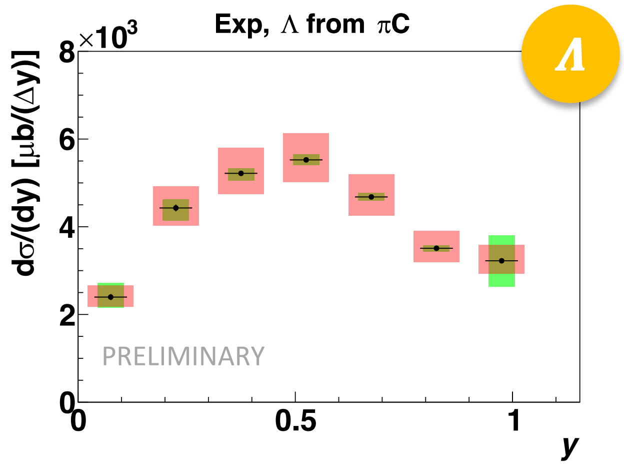


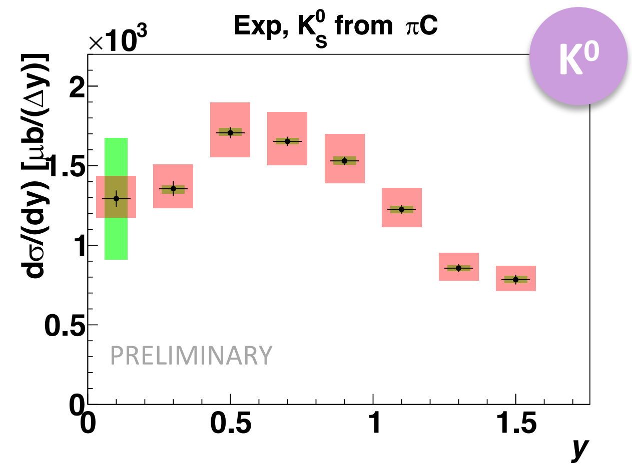


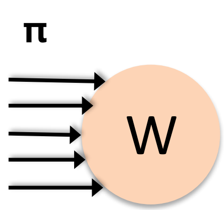
π^-+C/W

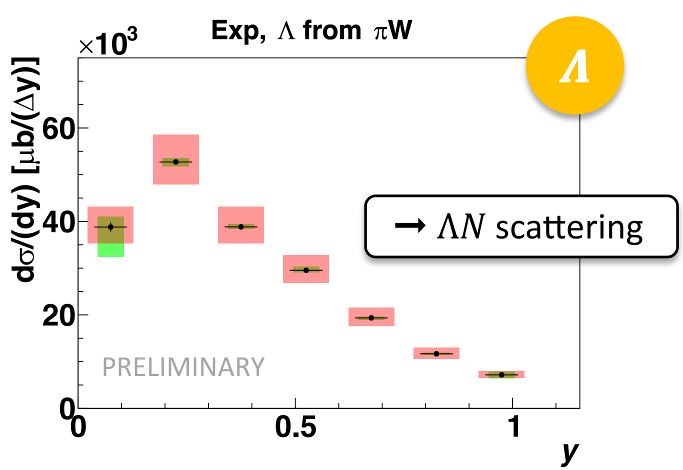
Inclusive Diff. Cross-Sections

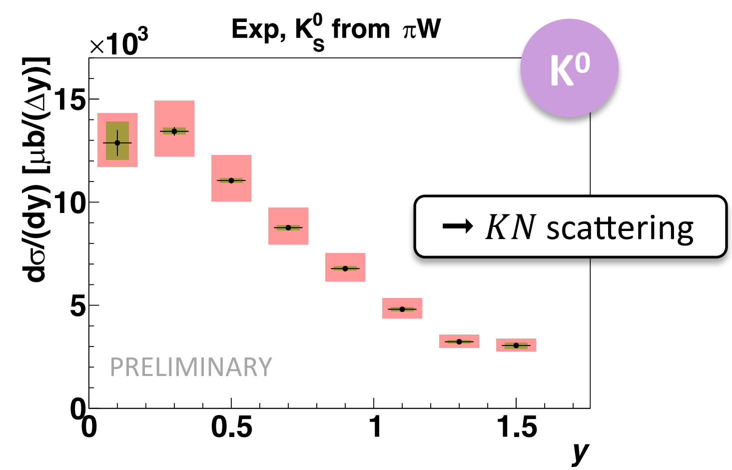








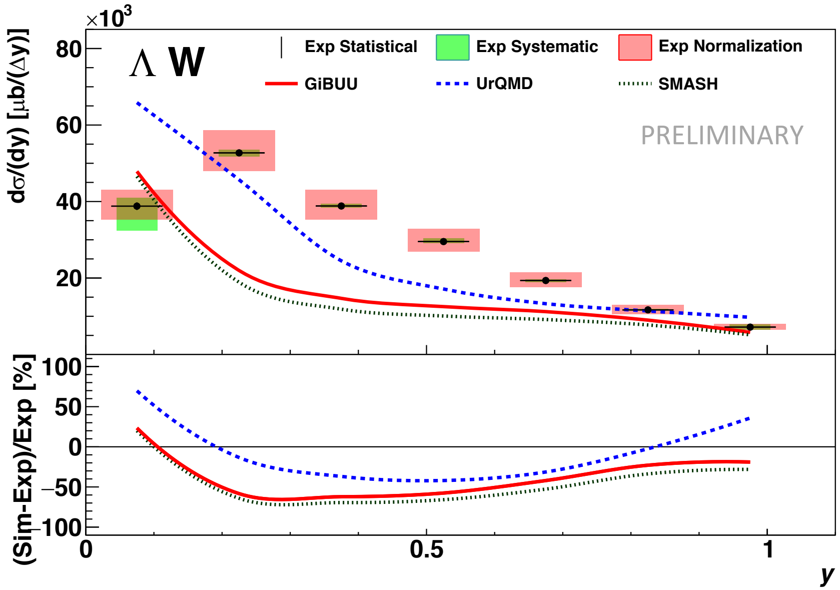


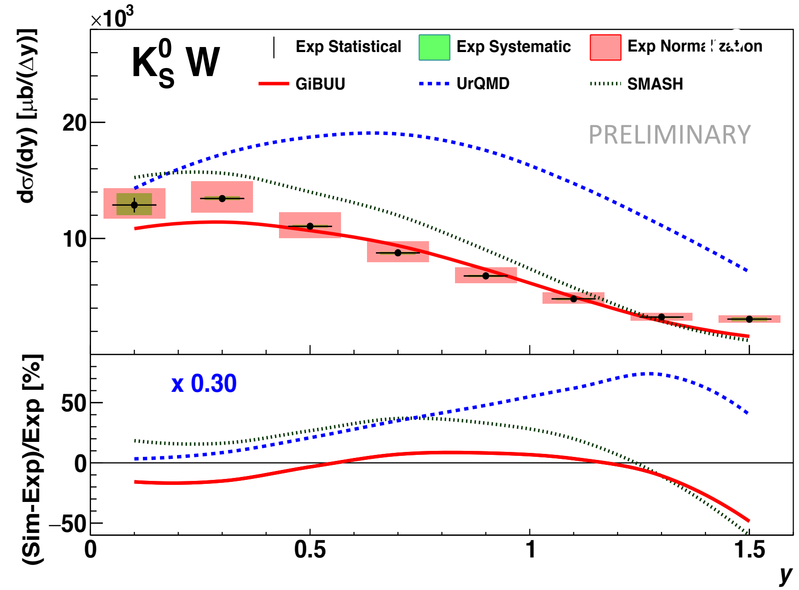


$\pi^- + W$

Inclusive Diff. Cross-Sections

K^0 Λ



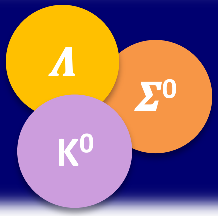


→ State-of-the-art transport model calculation over-/underestimate yields

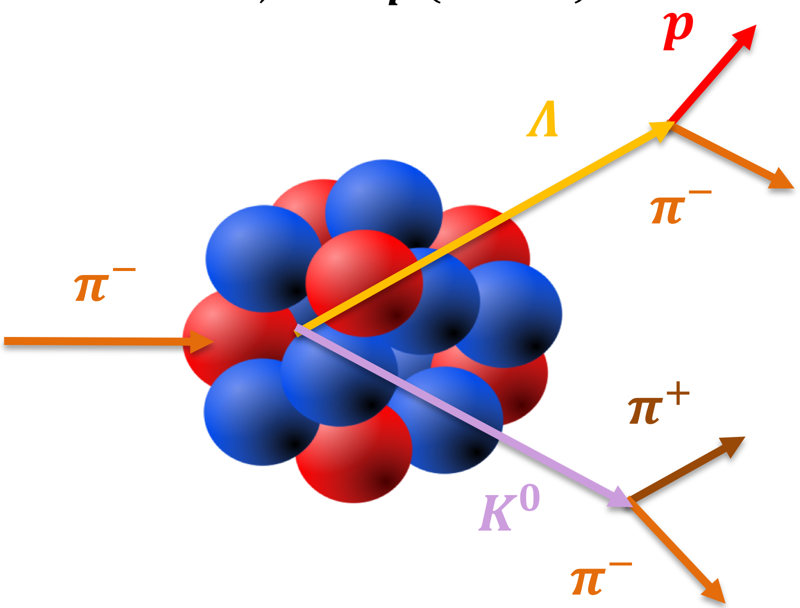
→ **Strangeness locally conserved:** associated strange baryon and meson production

→ **No conclusive description of all hadrons! → In-medium effects?**

Kaon-Hyperon Coupling



$$\pi^- + p \rightarrow \Lambda + K^0 + X$$
$$\hookrightarrow \pi^- + \pi^+ \ (\approx 69\%)$$
$$\hookrightarrow \pi^- + p \ (\approx 64\%)$$



$\pi^- + C/W$

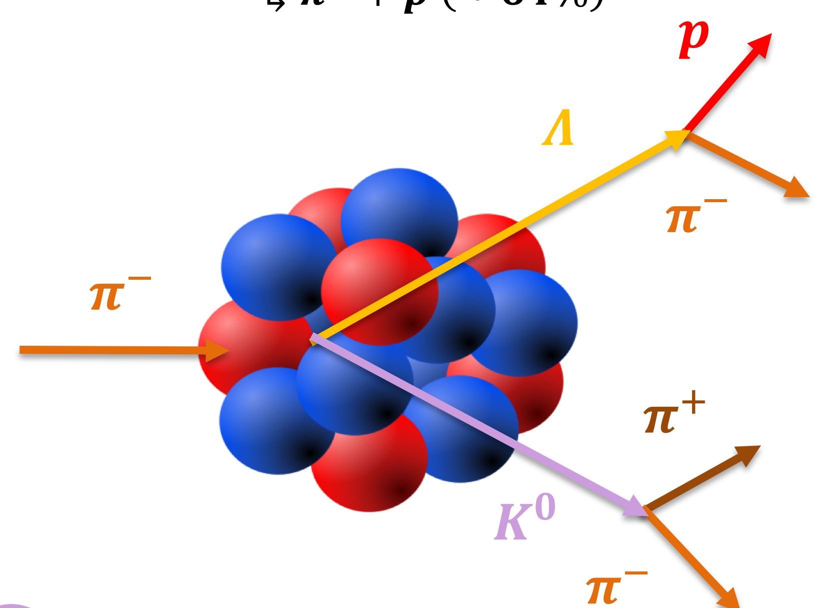
Kaon-Hyperon Coupling

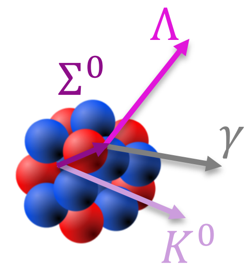
Λ Σ^0 K^0

$\boldsymbol{\pi^- + p \rightarrow \Lambda + K^0 + X}$

$\quad\quad\quad\quad\hookrightarrow \boldsymbol{\pi^- + \pi^+}$ $(\approx \mathbf{69\%})$

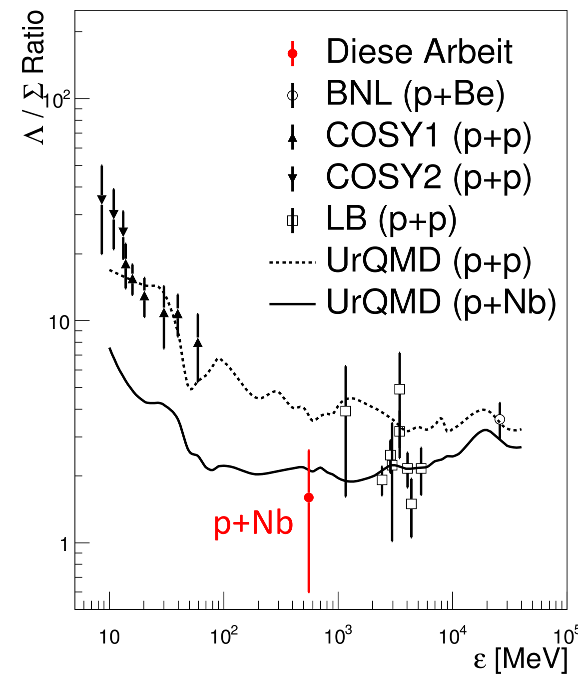
$\quad\quad\hookrightarrow \boldsymbol{\pi^- + p}$ $(\approx \mathbf{64\%})$





$\boldsymbol{\Sigma^0 \rightarrow \Lambda + \gamma}$
$(\approx \mathbf{100\%})$

Adamczewski-Musch et al.,
Phys. Lett. B 781, 735 (2018)



K^0 Kaon $(d\bar{s}, m = 498\ \mathrm{MeV})$

Λ Σ^0 Lambda $(uds, m = 1116\ \mathrm{MeV})$
Sigma $(uds, m = 1193\ \mathrm{MeV})$

→ Strangeness conservation

→ $\Lambda(\Sigma^0)$ and K^0 are entangled

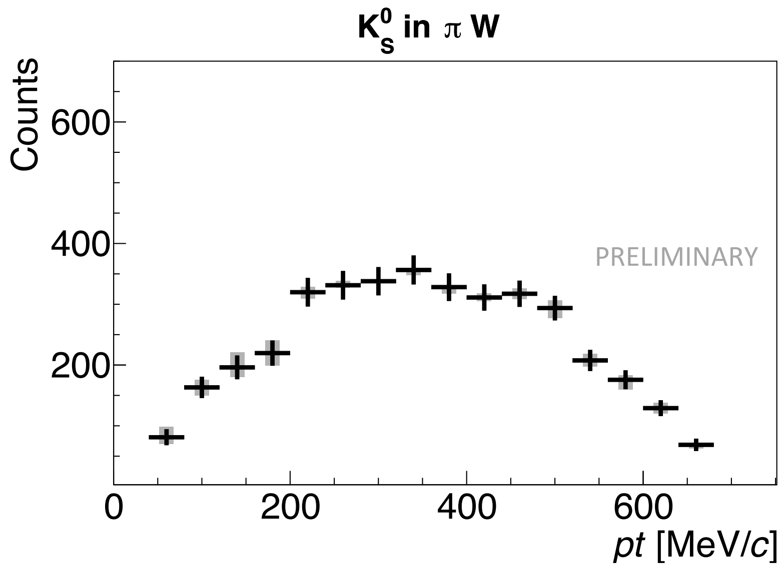
Effects of Hyperon Potentials

$\pi^- + W$

Λ Σ^0 K^0

In HADES acceptance

Transport Model: **GiBUU**



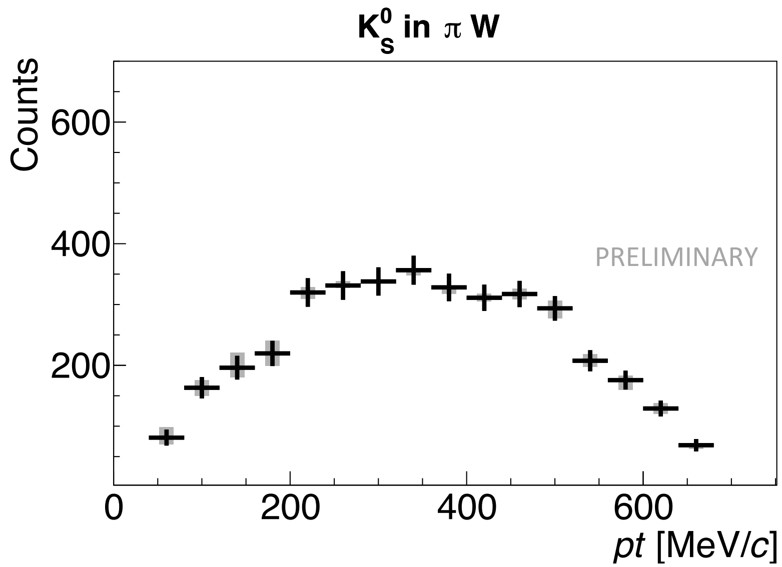
→ Full ensembles (π+C/π+W):
$K^0(\boldsymbol{p_T}, y, p, \Theta)$ and $\Lambda(p_T, y, p, \Theta)$

Effects of Hyperon Potentials

π⁻+W

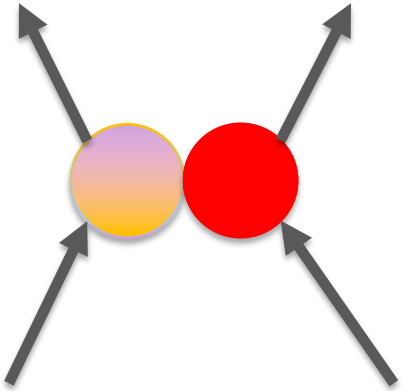
Λ Σ^0 K^0

In HADES acceptance

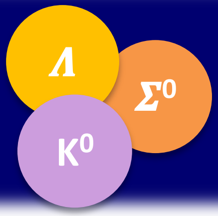


Transport Model: **GiBUU**

1. **No** $K^0/\Lambda/\Sigma^0N$ potentials **(ES(Y,K))**

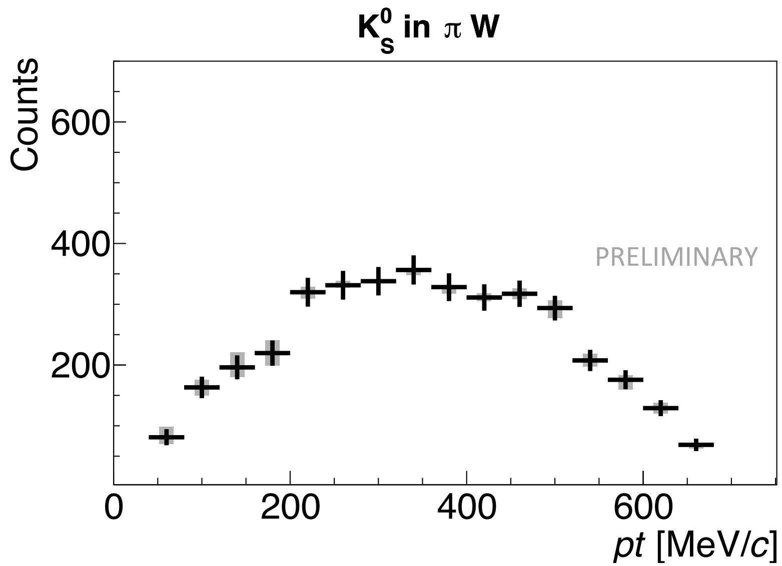


Effects of Hyperon Potentials



$\pi^- + W$

In HADES acceptance



→ **Acceptance and efficiency of HADES applied to GiBUU**

→ **Global fit of all kinematic observables:** $\boldsymbol{K^0(p_T, y, p, \Theta)}$ and $\boldsymbol{\Lambda(p_T, y, p, \Theta)}$

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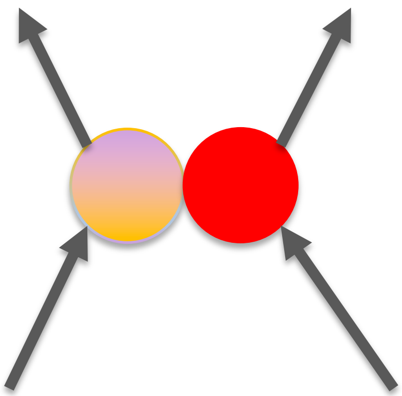
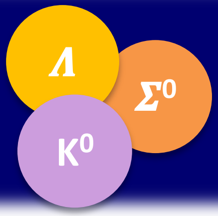
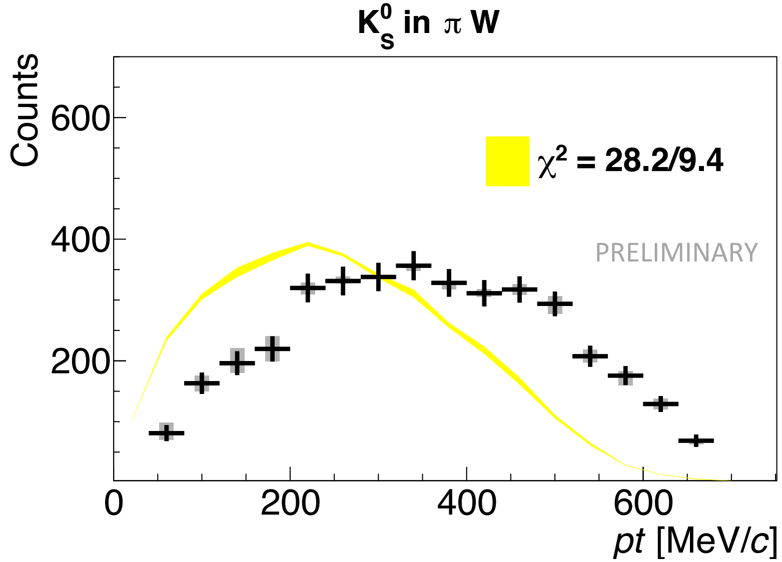


Effects of Hyperon Potentials



In HADES acceptance



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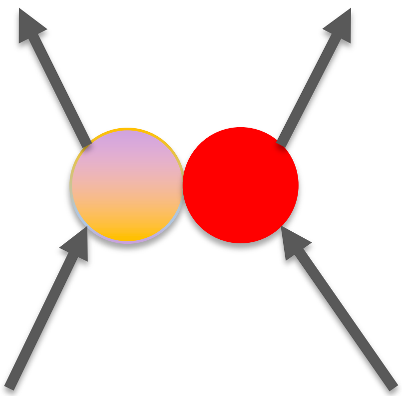
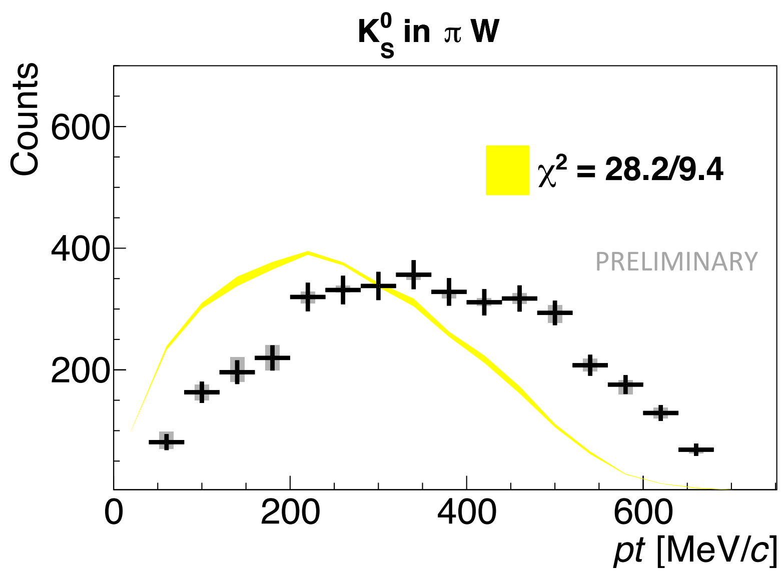


Effects of Hyperon Potentials

$\pi^- + W$

Λ Σ^0 K^0

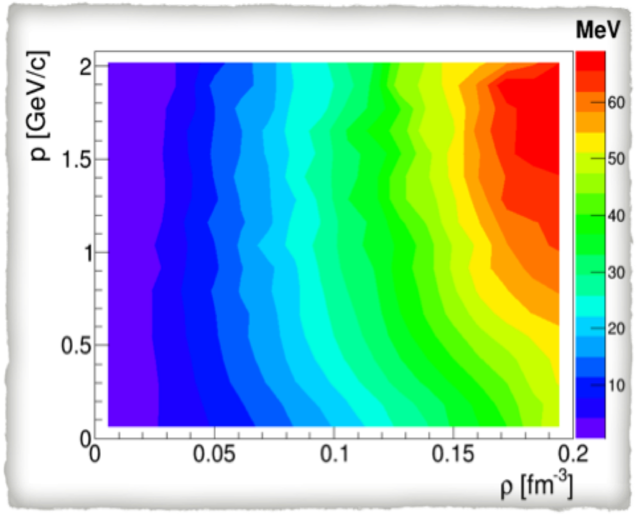
In HADES acceptance



Transport Model: **GiBUU**

1. **No** $K^0/\Lambda/\Sigma^0\mathrm{N}$ potentials **(ES(Y,K))**
2. **No** $\Lambda/\Sigma^0\mathrm{N}$ potentials **(ES(Y))**

KN potential



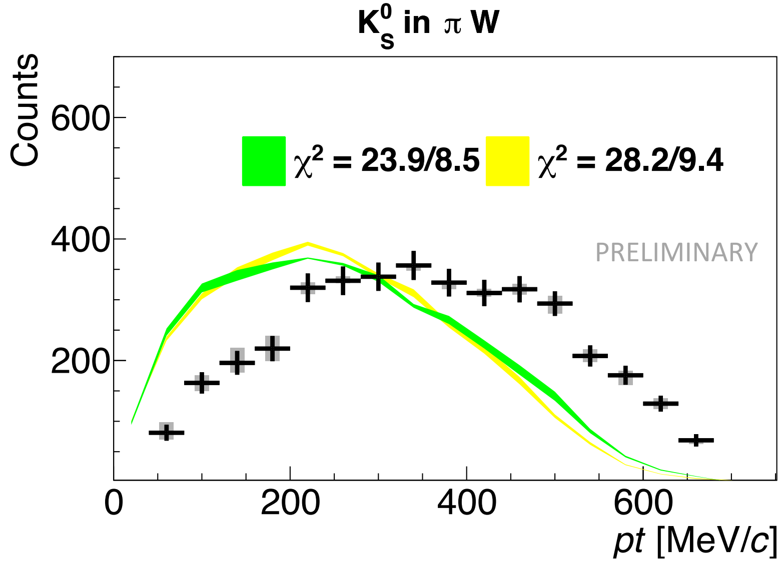
Agakishiev et al., Phys. Rev. C 90, 054906 (2014)

Effects of Hyperon Potentials

$\pi^- + W$

Λ Σ^0 K^0

In HADES acceptance



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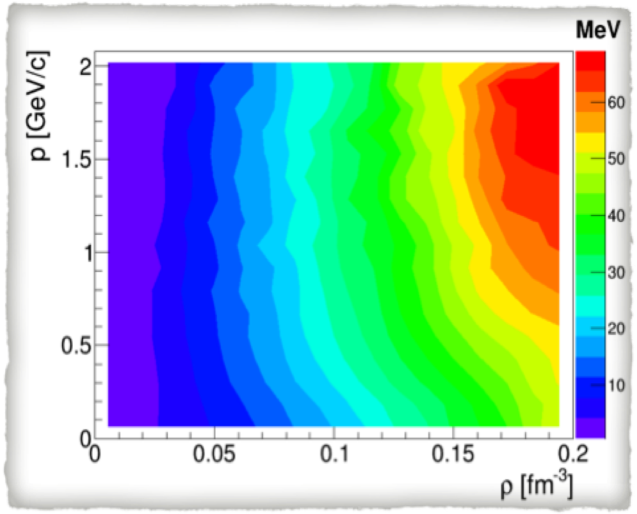

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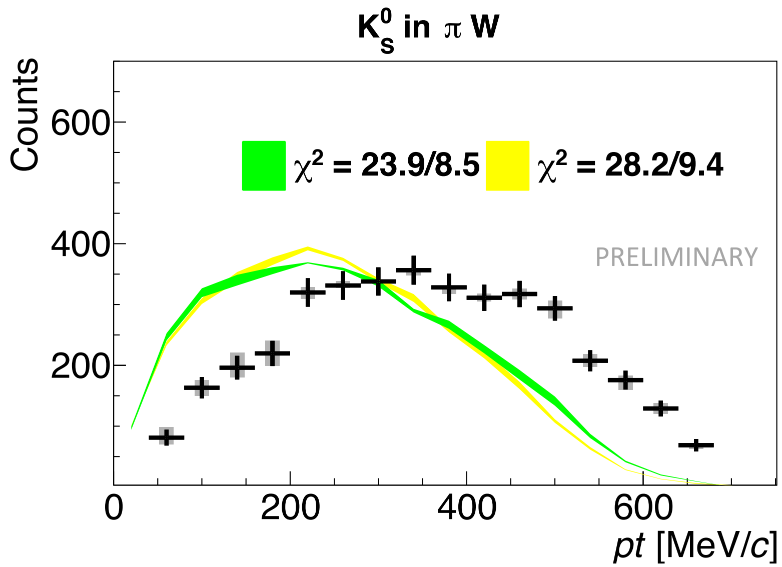
Effects of Hyperon Potentials

$\pi^- + W$

Λ Σ^0 K^0

In HADES acceptance



Transport Model: **GiBUU**

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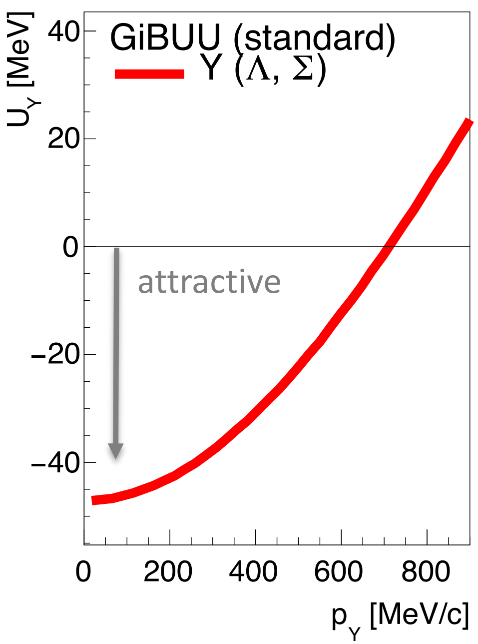
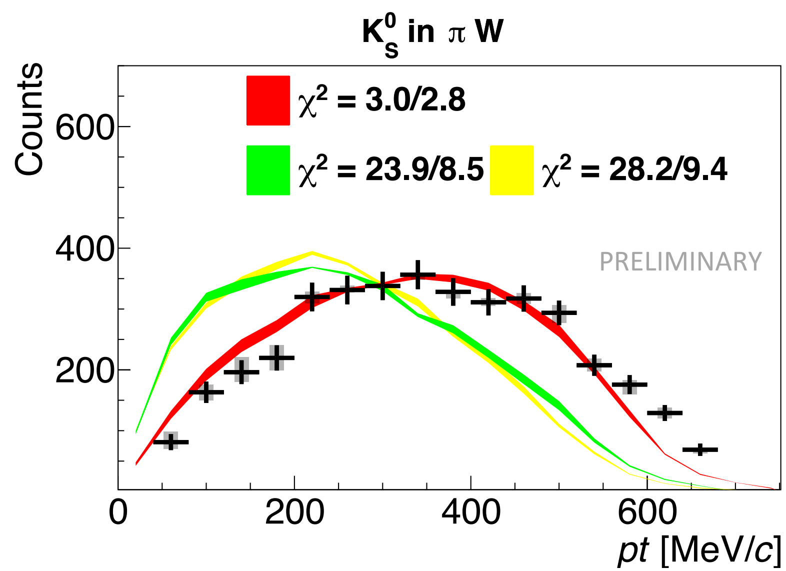
3. **Attractive** $\Lambda/\Sigma^0\mathrm{N}$ potentials **(STD)**



Effects of Hyperon Potentials

Λ Σ⁰ K⁰

In HADES acceptance



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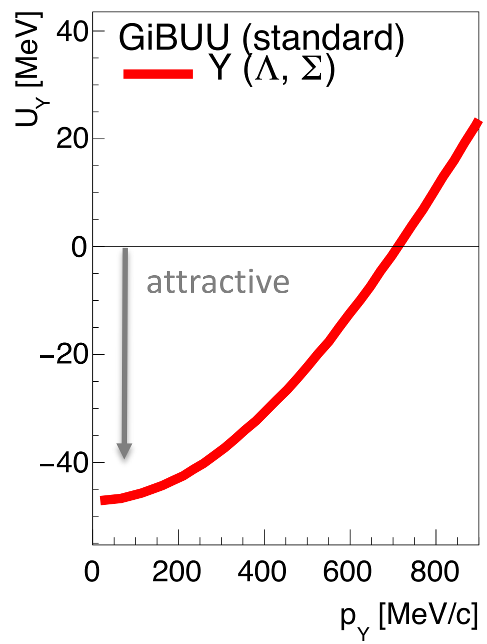
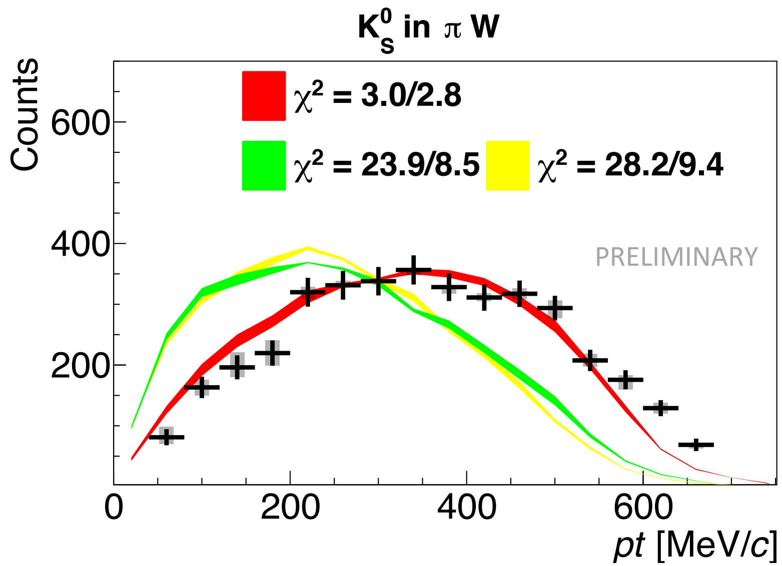


$\pi^- + W$

Effects of Hyperon Potentials

In HADES acceptance



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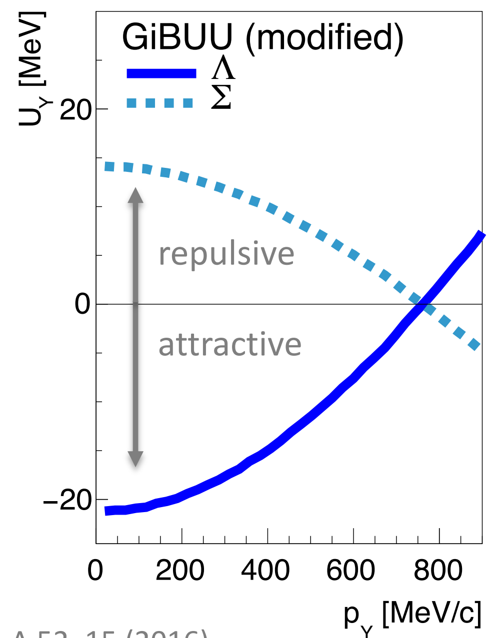
4. **Attractive** $\Lambda\mathrm{N}$**, repulsive** $\Sigma^0 N$ **(RS)**

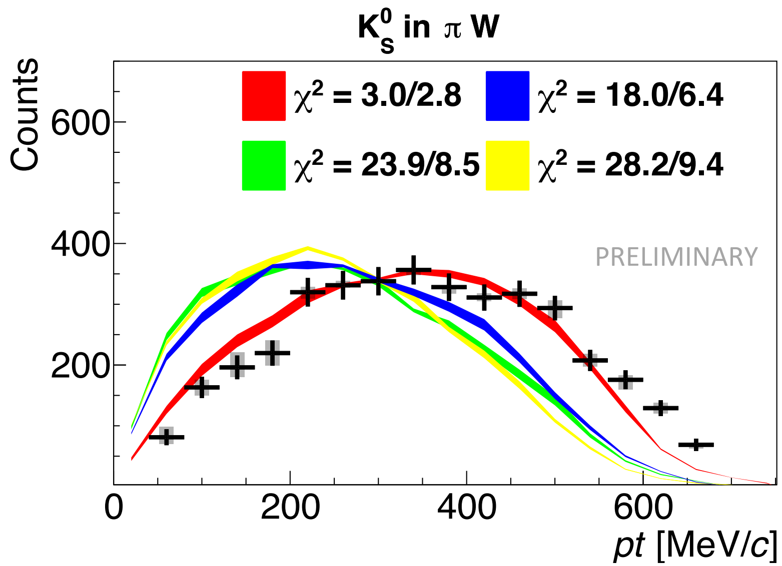


based on χEFT by Petschauer et al., Eur. Phys. J. A 52, 15 (2016)

π⁻+W

Effects of Hyperon Potentials

In HADES acceptance



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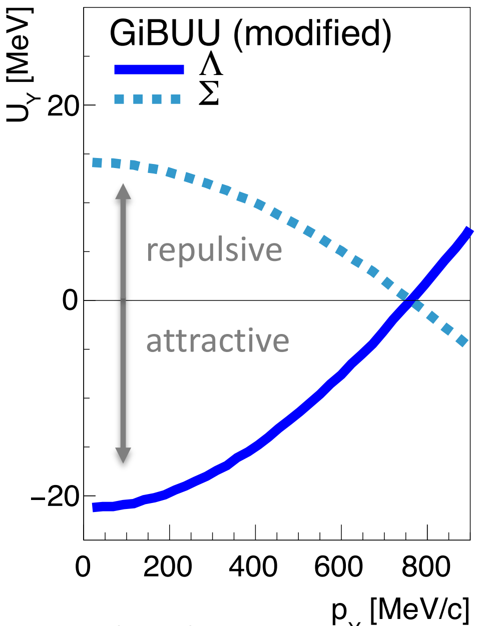

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$\pi^- + W$

Effects of Hyperon Potentials

Λ Σ^0 K^0

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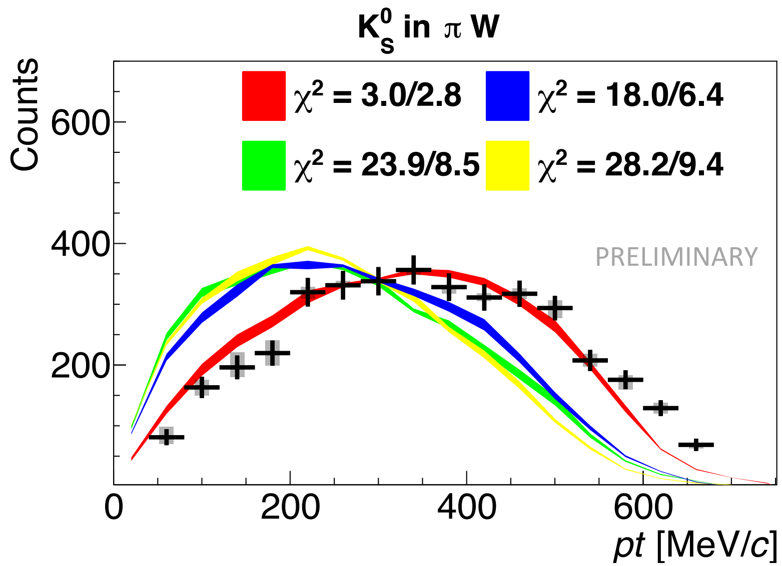

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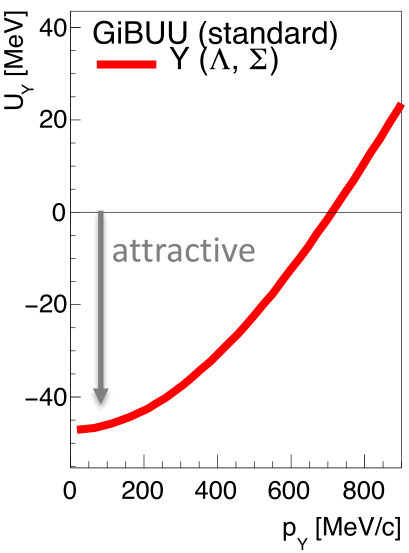

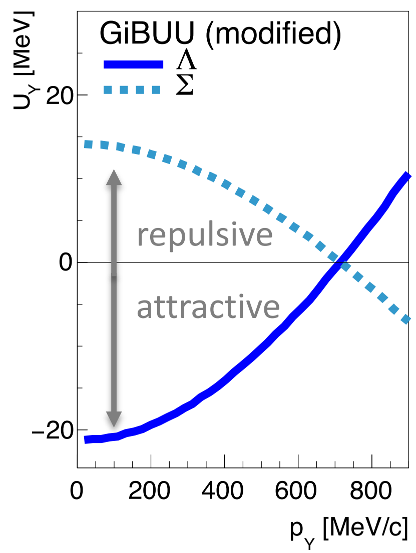

→ Data agrees best with **attractive** $\boldsymbol{\Lambda N}$ and **attractive** $\boldsymbol{\Sigma^0 N}$ potentials ($@\rho_0$)

→ Also favored for lighter target (C)

→ **Possibility of testing single particle potentials with χEFT**

based on χEFT by Petschauer et al., Eur. Phys. J. A 52, 15 (2016)

$\pi^- + W$

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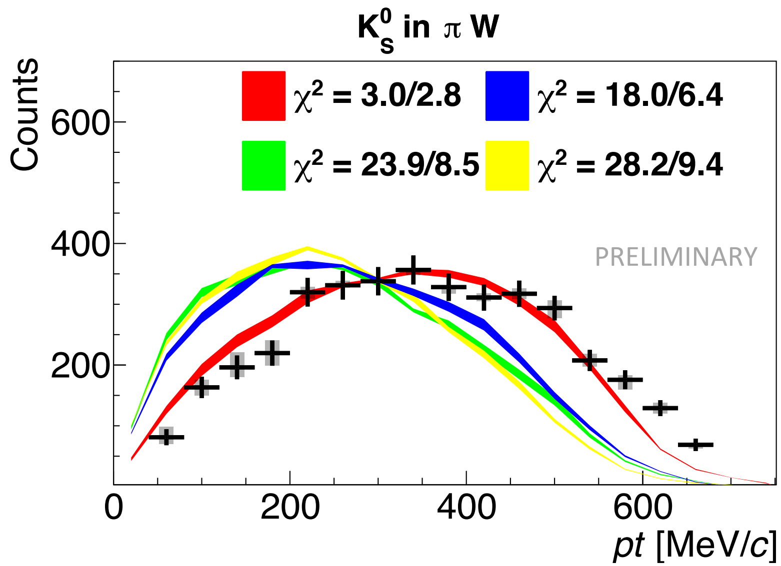
Λ Σ^0 K^0

In HADES acceptance



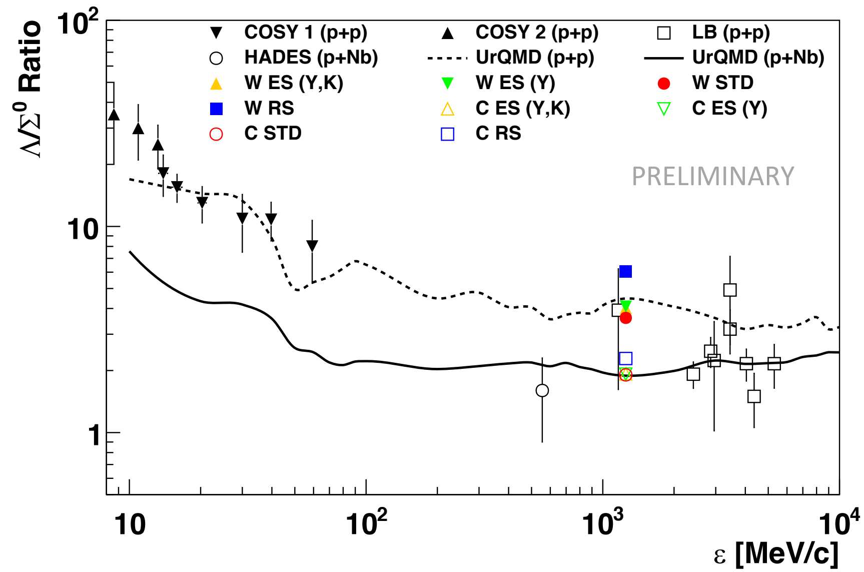
→ Data agrees best with **attractive** $\boldsymbol{\Lambda N}$ and **attractive** $\boldsymbol{\Sigma^0 N}$ potentials ($@\rho_0$)

→ Also favoured for lighter target (C)

→ **Possibility of testing single particle potentials with χEFT**

Transport Model: **GiBUU** (T. Gaitanos)

1. **No** $K^0/\Lambda/\Sigma^0$N potentials **(ES(Y,K))**
2. **No** Λ/Σ^0N potentials **(ES(Y))**
3. **Attractive** Λ/Σ^0N potentials **(STD)**
4. **Attractive** ΛN, **repulsive** $\Sigma^0 N$ **(RS)**

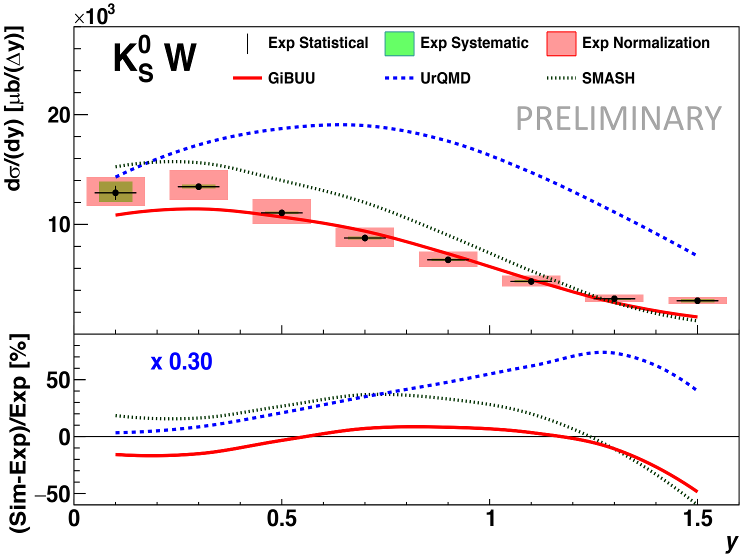


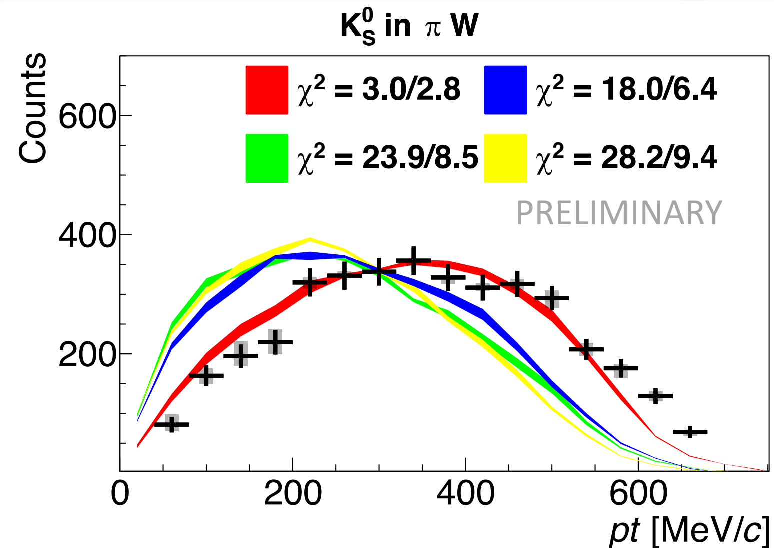
based on χEFT by Petschauer et al., Eur. Phys. J. A 52, 15 (2016)

π^-+C/W

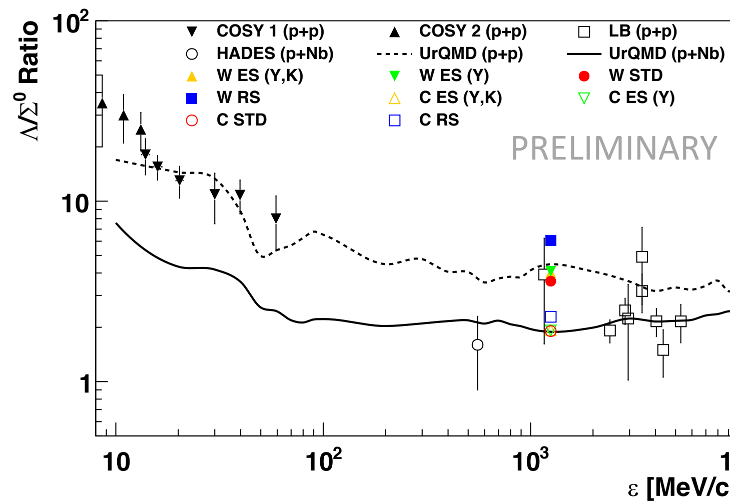
Summary

Λ Σ^0 K^0





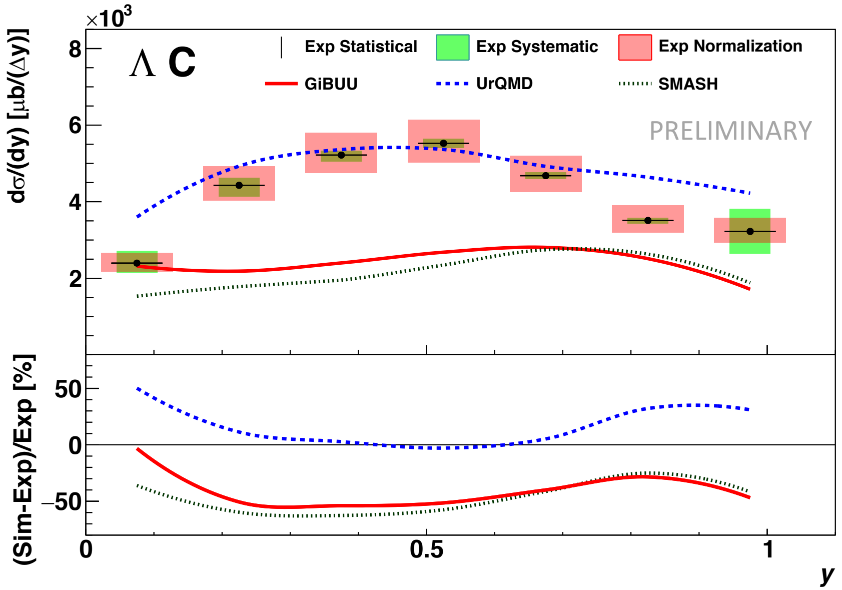
- → $K^0N/\Lambda N$ scattering in heavy target (W)
- → **Attractive** ΛN and **attractive** $\Sigma^0 N$ potentials (@ρ_0) preferred by all kinematic distributions
- → Λ/Σ^0 **ratio** disfavours attractive ΛN and repulsive $\Sigma^0 N$ potentials (@ρ_0)
- → HADES data allow to test different forms of potentials

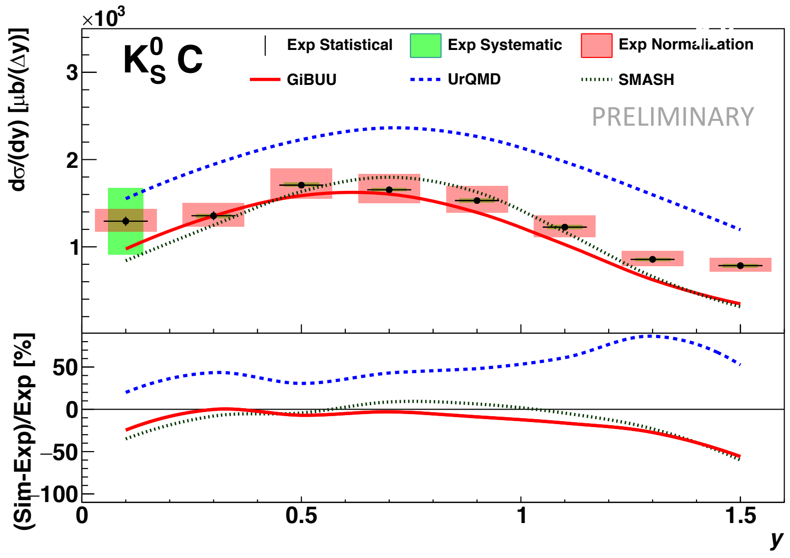


Inclusive Diff. Cross-Sections

$\pi^- + C$

K^0 Λ



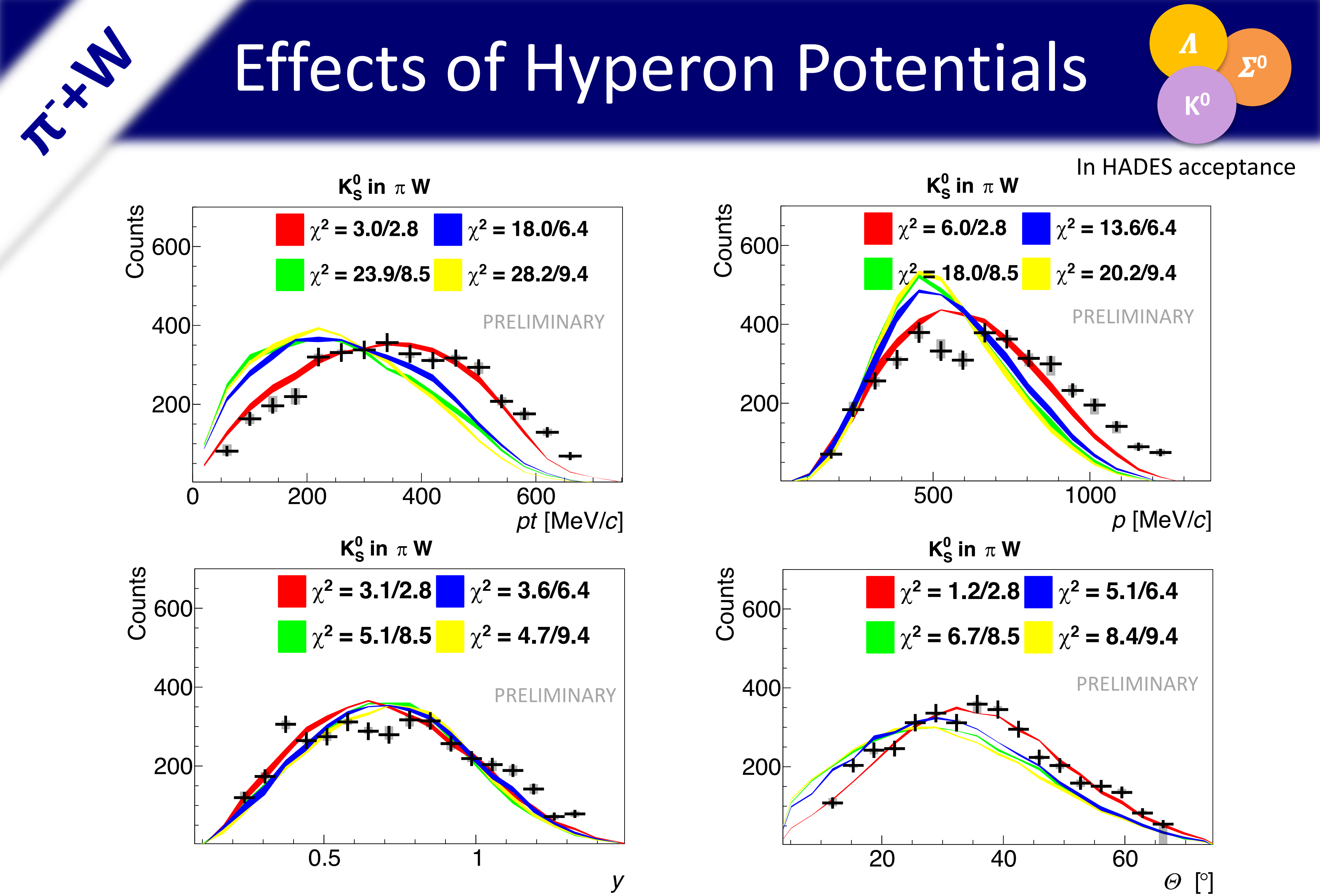


→ State-of-the-art transport model calculation over-/underestimate yields

→ **Strangeness locally conserved:** associated strange baryon and meson production

→ **No conclusive description of all hadrons! → In-medium effects?**

Effects of Hyperon Potentials

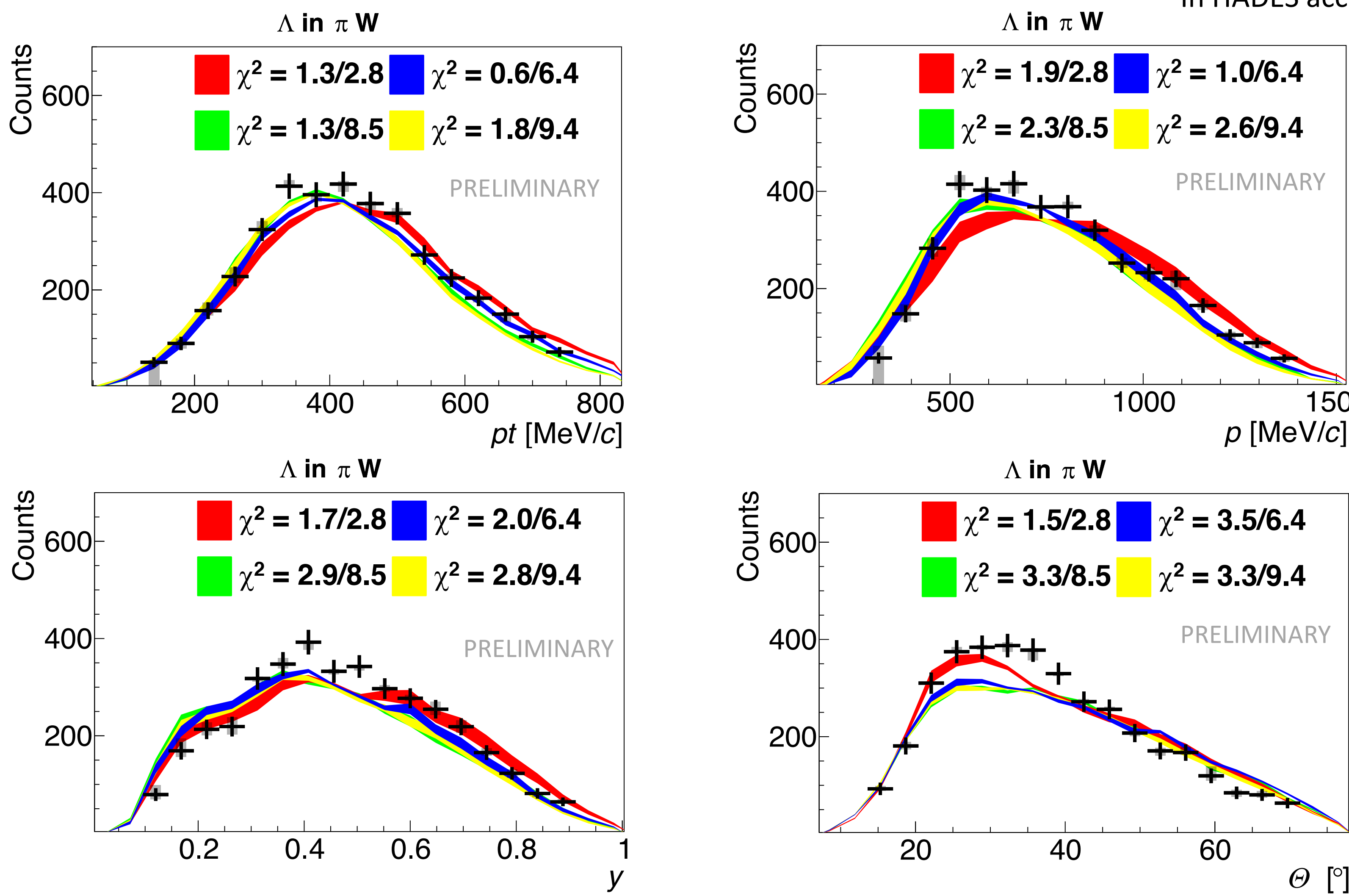


$\pi^- + W$

Effects of Hyperon Potentials

Λ Σ^0 K^0

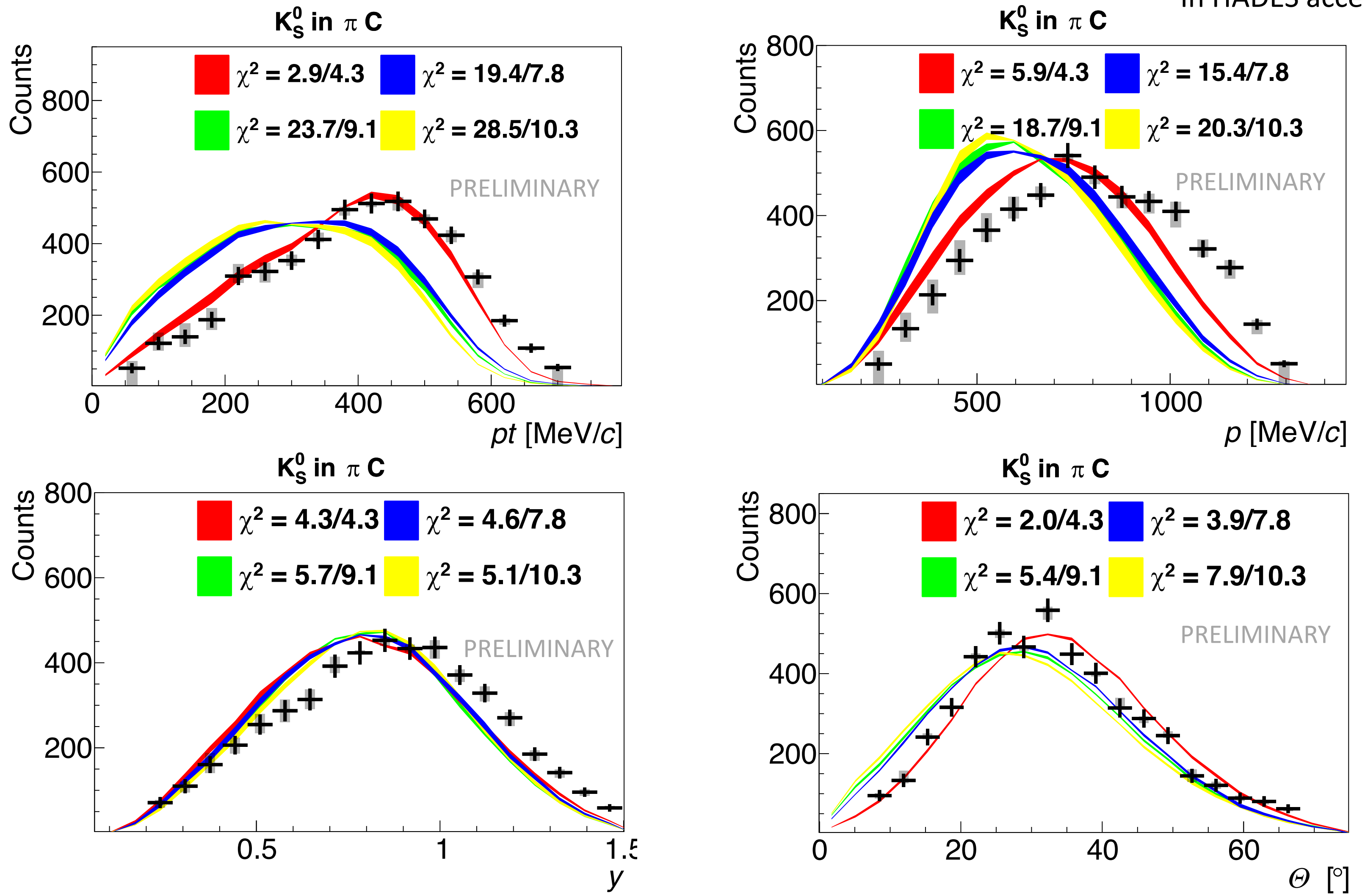
In HADES acceptance



Effects of Hyperon Potentials

Λ Σ^0 K^0

In HADES acceptance



Effects of Hyperon Potentials

π⁻+C

Λ Σ⁰ K⁰

In HADES acceptance