

Strangeness and Charm Production by Antiprotons

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Agenda:

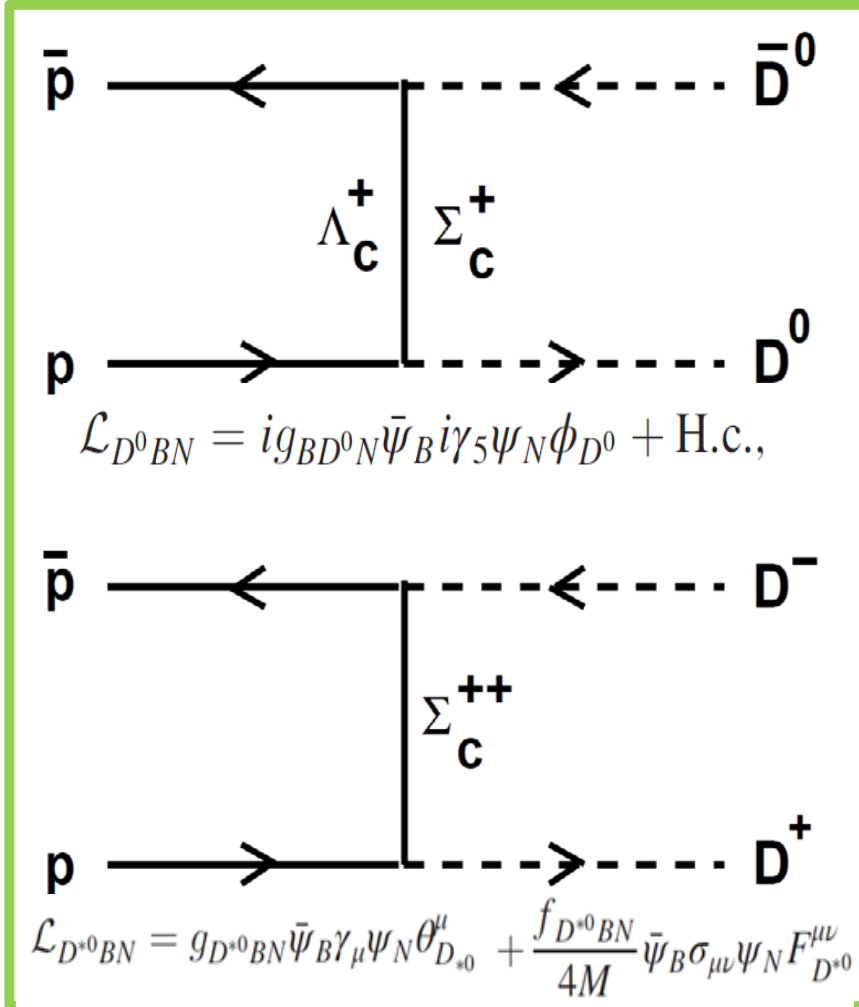
- Charm and strangeness production in antiproton-nucleon annihilation
- Covariant Lagrangian description of $(\bar{p}, \bar{\Delta})$ reactions
- Evidence for $\frac{\omega}{K^*}$ meson-exchange in $(\bar{p}, \bar{\Delta})$ reactions
- Hypernuclear production by coherent antiproton-nucleus reactions
- Multi-Strangeness $S=-2,-3$ production in antiproton-nucleus collisions
- Outlook

Elementary Reactions

The Hadronic Production Scenario:

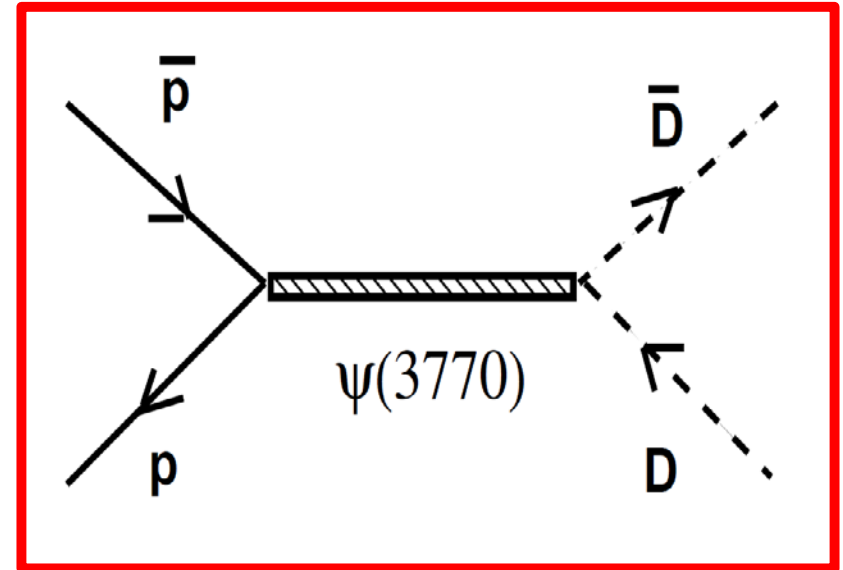
t-channel Baryon Exchange and s-Channel Resonance Production

(R. Shyam, H.L. Phys. Rev. D93 (2016) 034016)



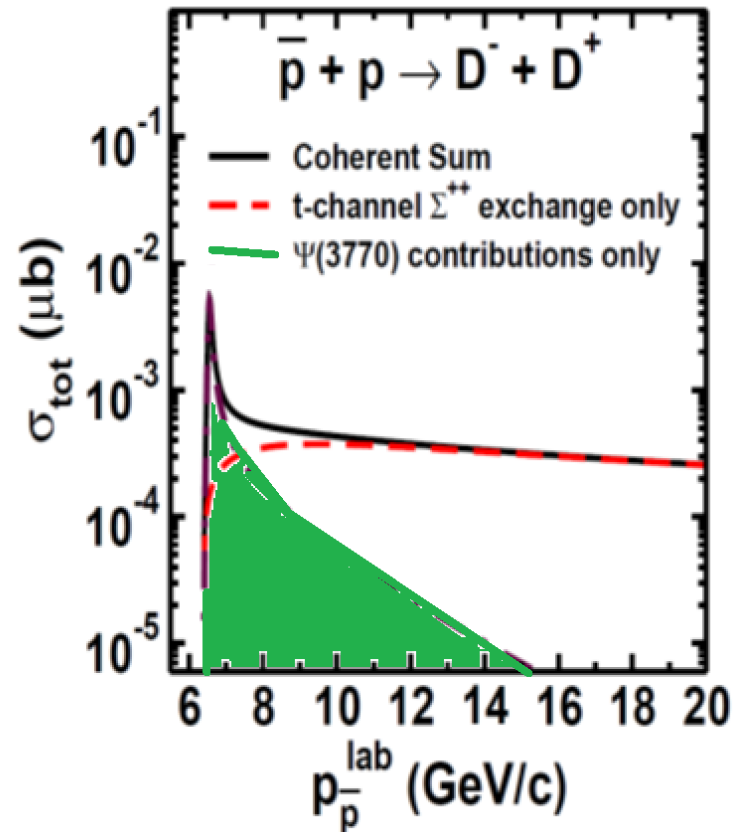
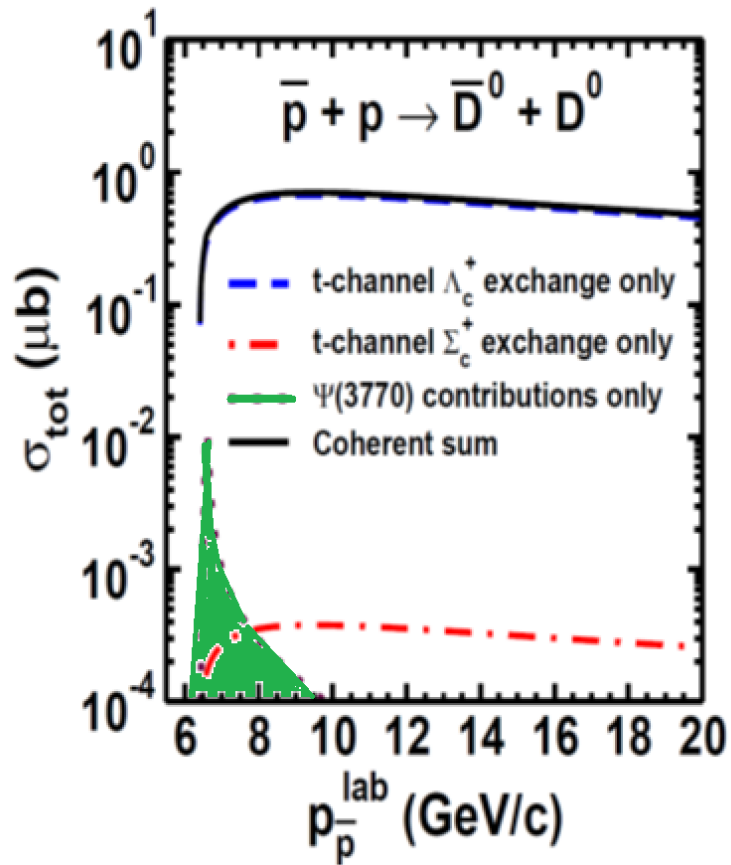
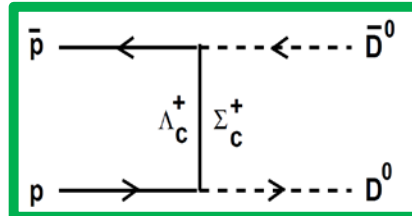
$$\mathcal{L}_\mu^{\Psi \bar{p} p} = g_{\Psi \bar{p} p} \left[\bar{\psi}_{\bar{p}} (\gamma_\mu + \frac{\kappa_\Psi}{2M} \sigma_{\mu\nu} \partial^\nu \theta_\Psi^\mu) \psi_p \right].$$

+



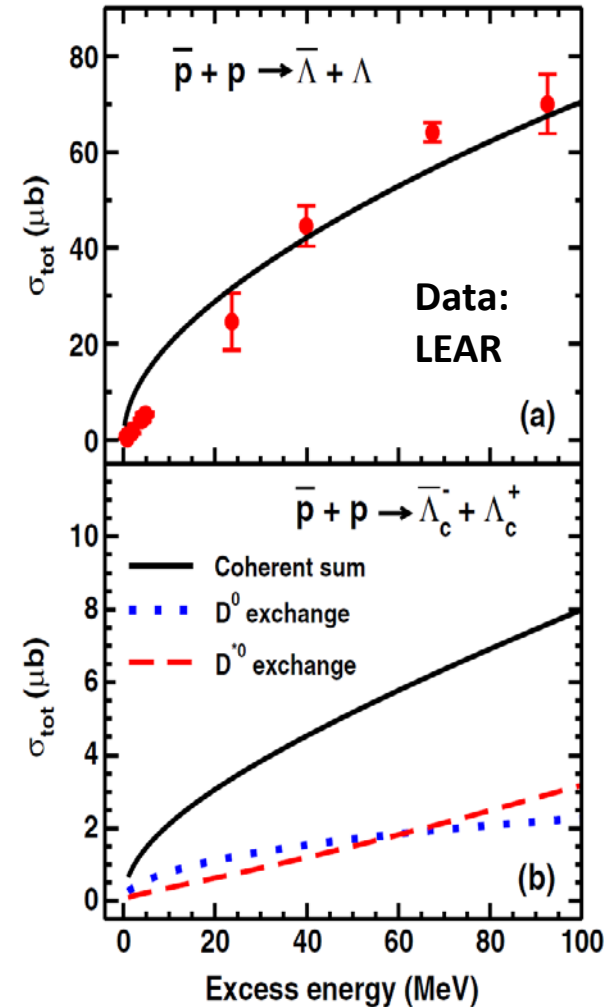
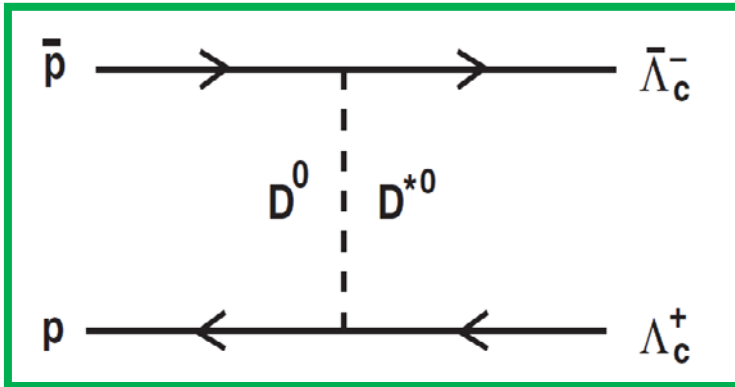
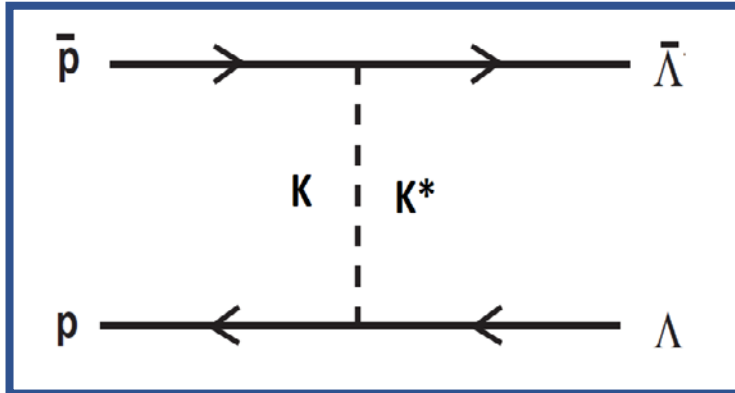
$$\mathcal{L}_{\Psi \bar{D} D} = g_{\Psi \bar{D} D} (\Phi_{\bar{D}} \partial_\mu \Phi_D) \theta_\Psi^\mu.$$

Open Charm Production by Baryon Exchange



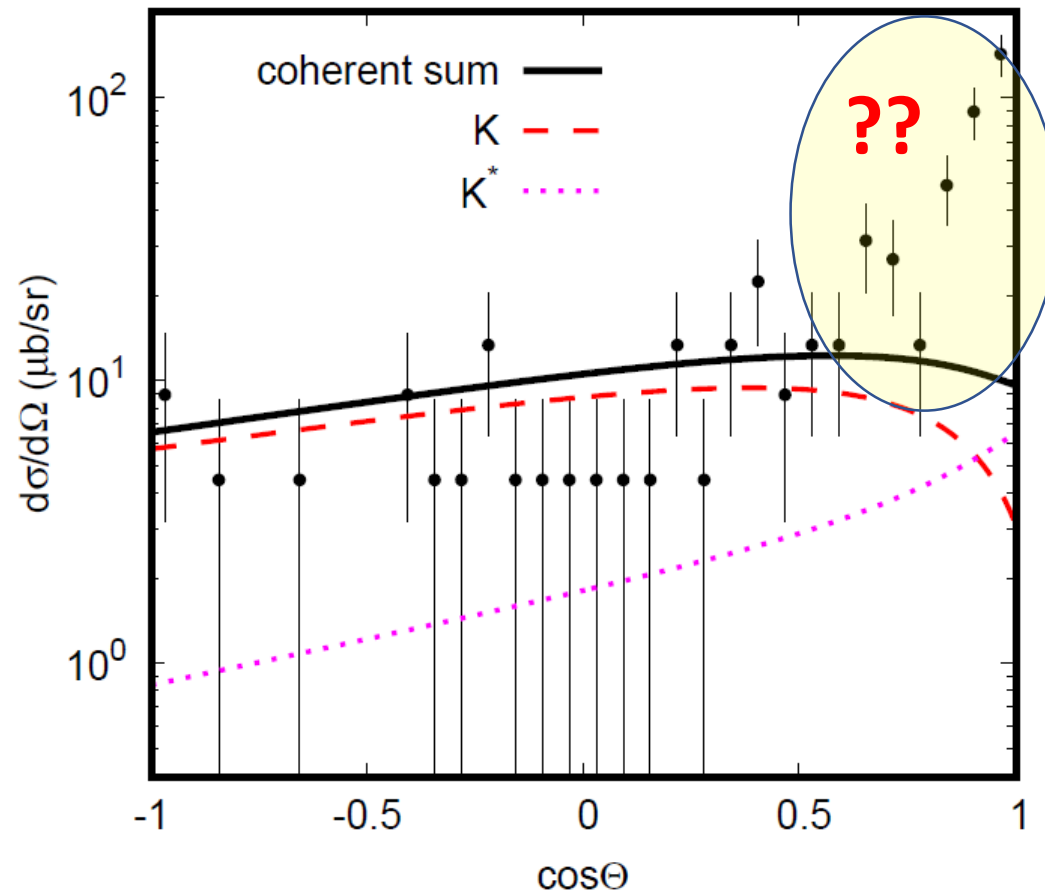
Antiproton-Proton Annihilation into Antibaryon-Baryon Pairs:

(R. Sham, H.L., PRD 90 (2014) 014017 & PRD 93 (2016) 034016, A.Larionov, H.L., PLB 773 (2017) 470)

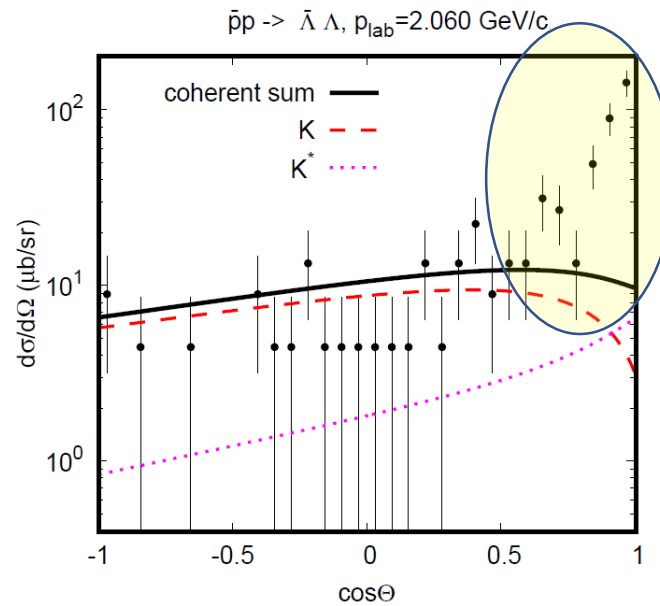


Lambda-AntiLambda Production by K and K* Exchange

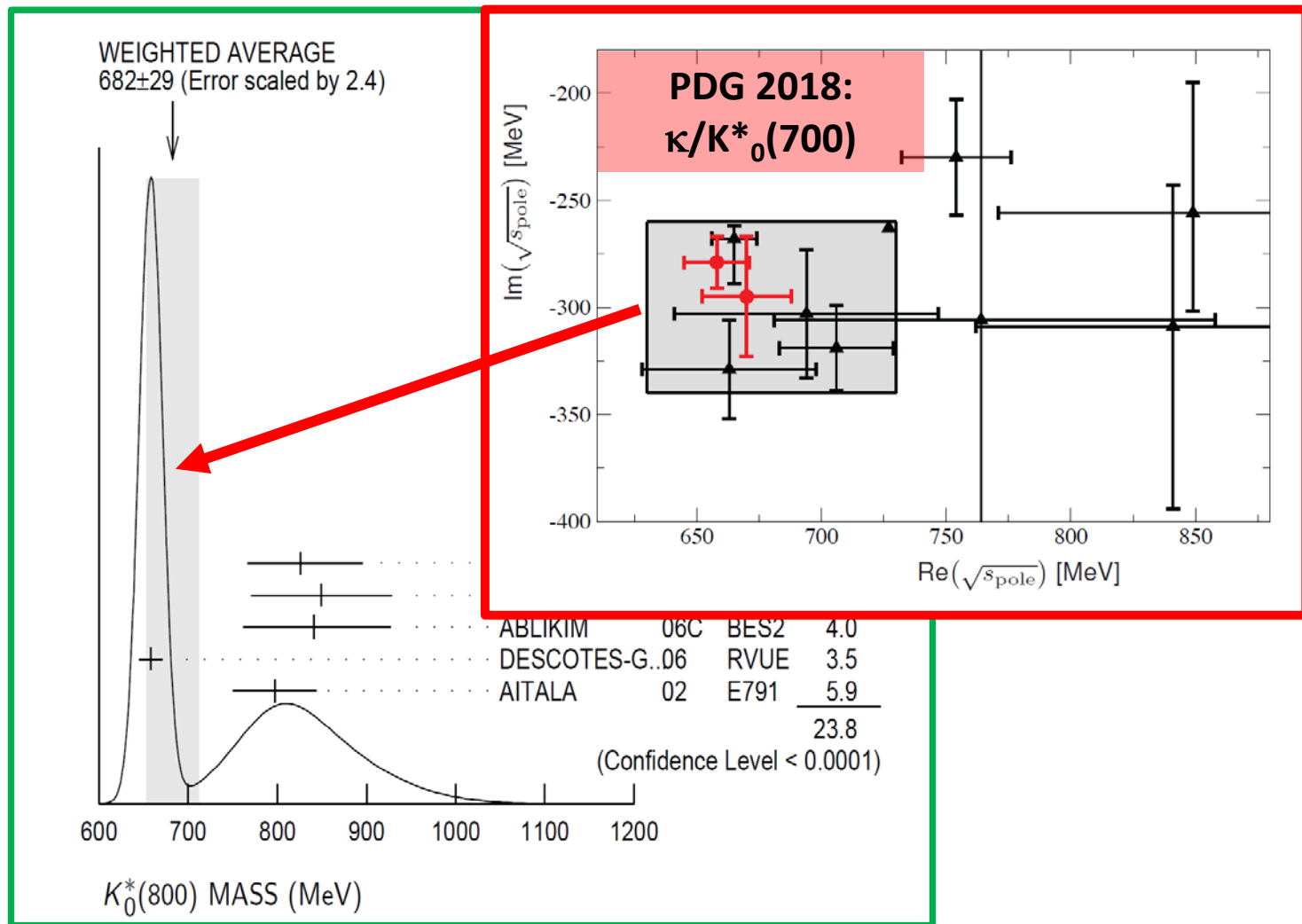
$\bar{p}p \rightarrow \bar{\Lambda} \Lambda$, $p_{\text{lab}} = 2.060 \text{ GeV}/c$



Evidence for „κ“-Exchange



Scalar $[K,\pi]_{0+}$ $|S|=1$ Configuration: $\kappa/K^*_0(800)$ Spectral Function



(PDG 2016/2018)

The Interaction Lagrangian

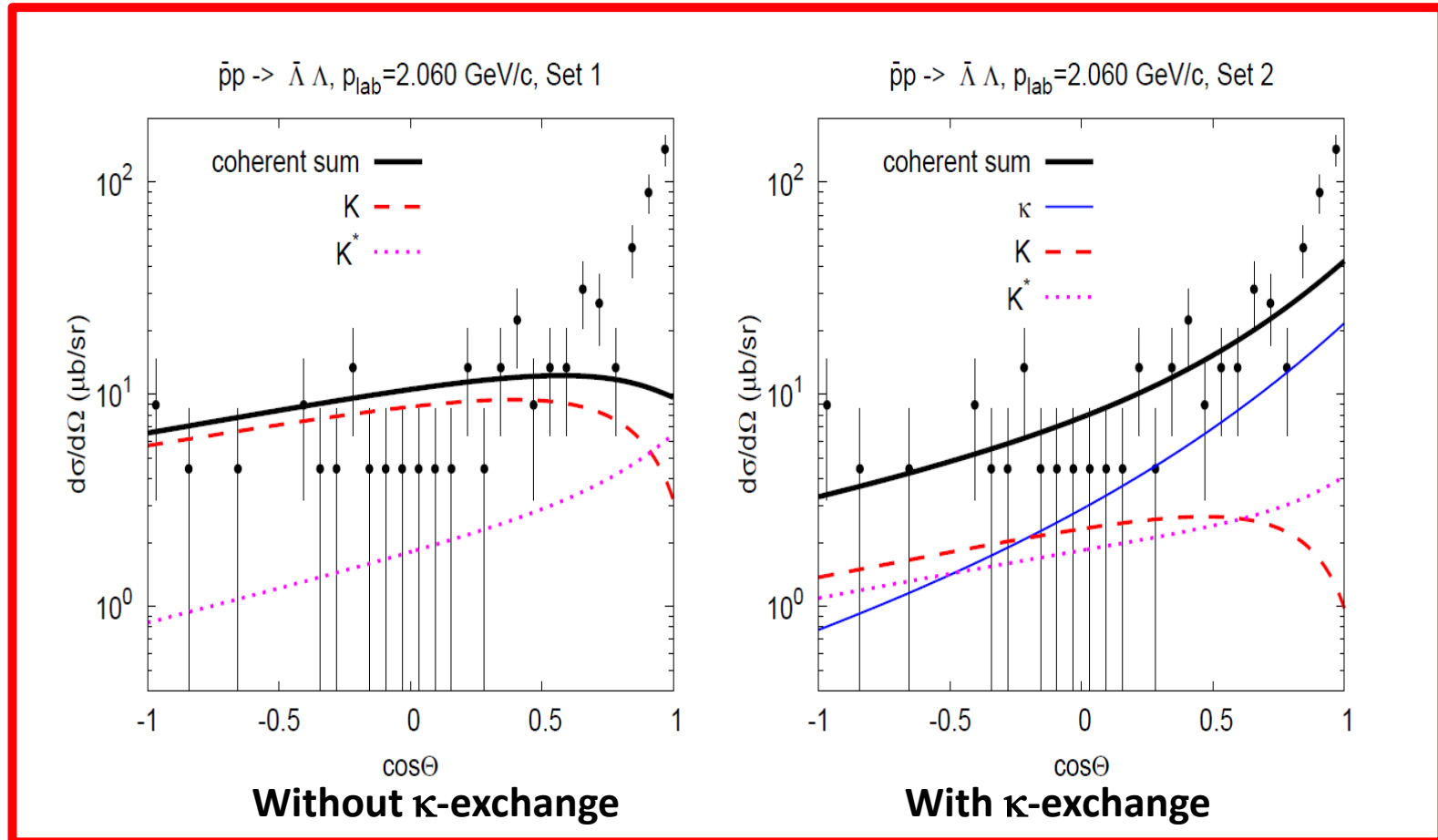
$$\begin{aligned}\mathcal{L}_{K N \Lambda} &= -i g_{K N \Lambda} \bar{N} \gamma^5 \Lambda K + \text{h.c.} , \\ \mathcal{L}_{K^* N \Lambda} &= \bar{N} \left(G_v \gamma^\mu - \frac{G_t}{m_N + m_\Lambda} \sigma^{\mu\nu} \partial_\nu^{K^*} \right) \Lambda K_\mu^* + \text{h.c.} \\ \mathcal{L}_{\kappa N \Lambda} &= -g_{\kappa N \Lambda} \bar{N} \Lambda \kappa + \text{h.c.} .\end{aligned}$$

SU(3)-based coupling constants:

$$\begin{aligned}g_{K N \Lambda} &= -g_{\pi N N} \frac{3 - 2\alpha_{PS}}{\sqrt{3}} , \\ G_{v,t} &= -G_{v,t}^\rho \frac{3 - 2\alpha_{E,M}}{\sqrt{3}} , \\ g_{\kappa N \Lambda} &= -g_{\sigma N N} \frac{3 - 2\alpha_S}{3 - 4\alpha_S} ,\end{aligned}$$

Elementary Reaction and Data

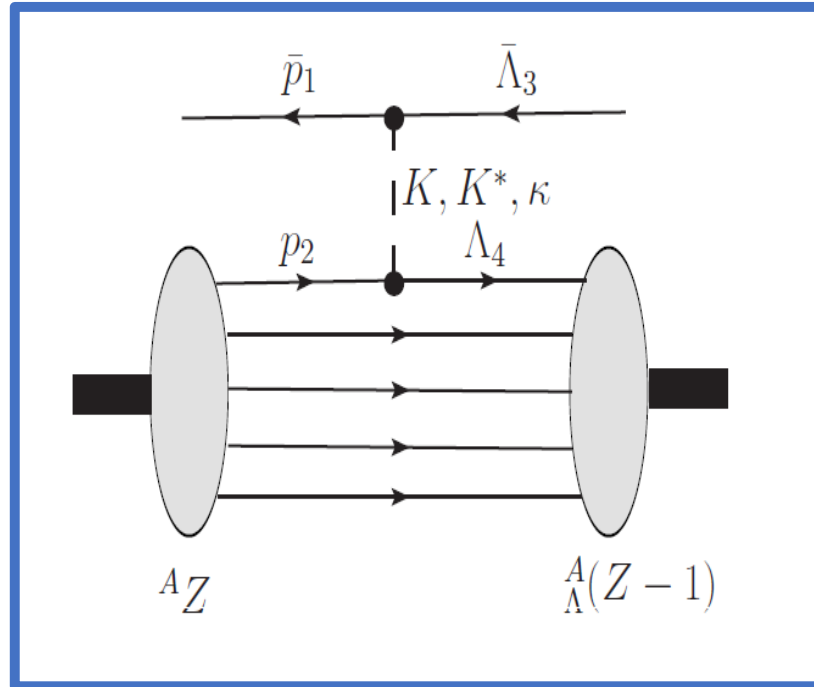
Differential Cross Sections



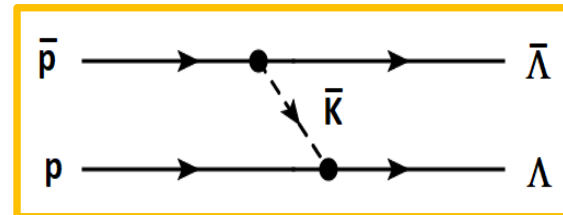
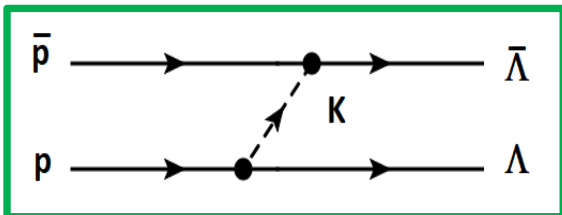
Evidence for $\kappa/K^*(800)$, i.e. correlated scalar $[K,\pi]$, exchange!

Antiprotonic Hypernuclear Production

Hypernuclear Production by Strangeness-Transfer



Feynman graph of the $A_Z(\bar{p}, \bar{\Lambda})_{\Lambda}^A(Z-1)$ process.



Antiproton-Nucleus Reaction Amplitude Including ISI and FSI Nuclear Interactions

$$\begin{aligned}
 i\mathcal{M}_K &= -g_{K\Lambda}^2 F_K^2(q^2) \sqrt{\Omega} \bar{u}_{-p_1, -\lambda_1} \gamma^5 u_{-p_3, -\lambda_3} \frac{i}{q^2 - m_K^2} \int d^3r e^{-iqr} \bar{\psi}_4(\mathbf{r}) \gamma^5 \psi_2(\mathbf{r}) F_A(\mathbf{r}) \\
 i\mathcal{M}_{K^*} &= -F_{K^*}^2(q^2) \sqrt{\Omega} \bar{u}_{-p_1, -\lambda_1} \Gamma^\mu(-q) u_{-p_3, -\lambda_3} iG_{\mu\nu}(q) \int d^3r e^{-iqr} \bar{\psi}_4(\mathbf{r}) \Gamma^\nu(q) \psi_2(\mathbf{r}) F_A(\mathbf{r}) \\
 i\mathcal{M}_\kappa &= g_{\kappa N\Lambda}^2 F_\kappa^2(q^2) \sqrt{\Omega} \bar{u}_{-p_1, -\lambda_1} u_{-p_3, -\lambda_3} \frac{i}{q^2 - m_\kappa^2 + im_\kappa \Gamma_\kappa} \int d^3r e^{-iqr} \bar{\psi}_4(\mathbf{r}) \psi_2(\mathbf{r}) F_A(\mathbf{r})
 \end{aligned}$$

ISI and FSI reaction coefficients

$$F_A(\mathbf{r}) = F_{\bar{p}}(\mathbf{r}) F_{\bar{\Lambda}}(\mathbf{r})$$

...coupling to other annihilation channels \rightarrow attenuation factors:

$$\Omega \sim e^{-\text{Im}(U_B)} \sim e^{-\lambda \sigma_{\text{reac}}}$$

...see A.Larionov, H.L., Nucl.Phys. A957 (2017) 450

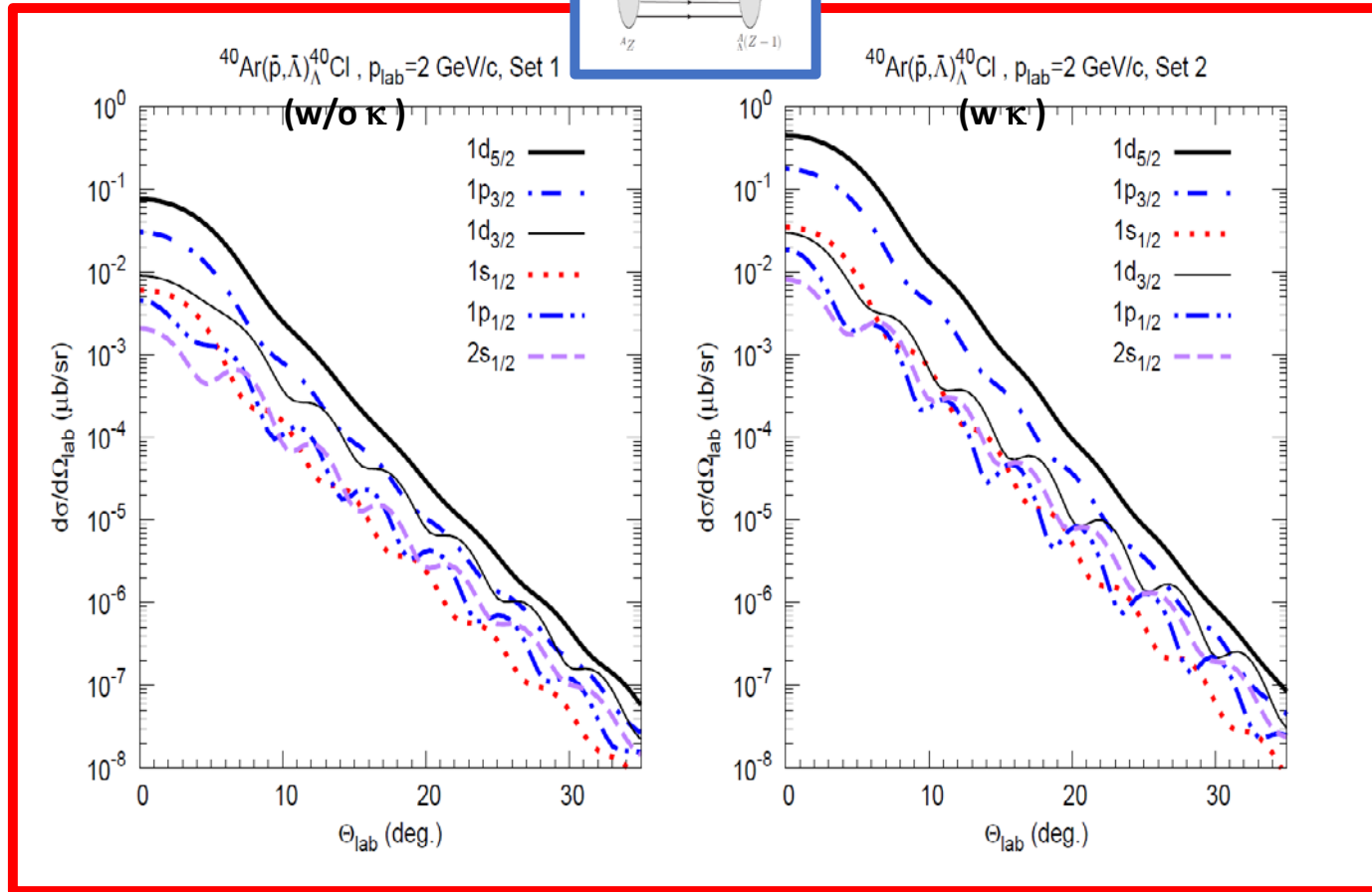
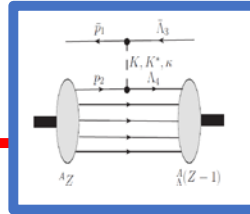
Hypernuclear Production by Antiprotons on ^{40}Ar



→ PANDA @ FAIR ←

Hypernuclear Production on ^{40}Ar

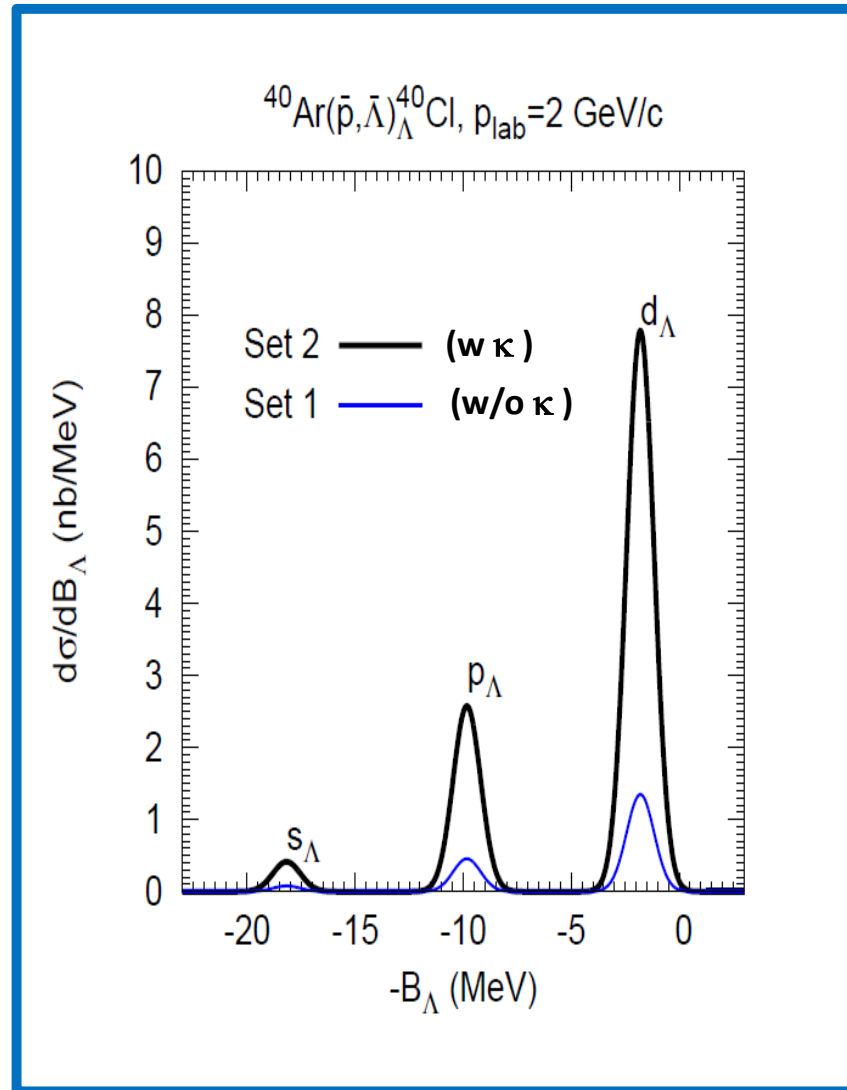
Differential Cross Sections for Λ (RMF) Bound States



Without κ -exchange

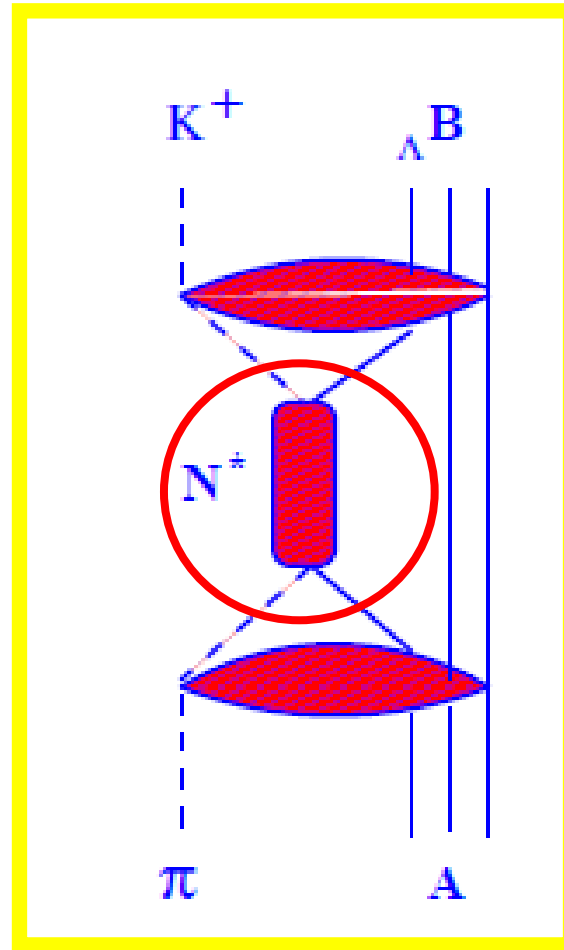
With κ -exchange

Spectral Distribution of Λ Bound States



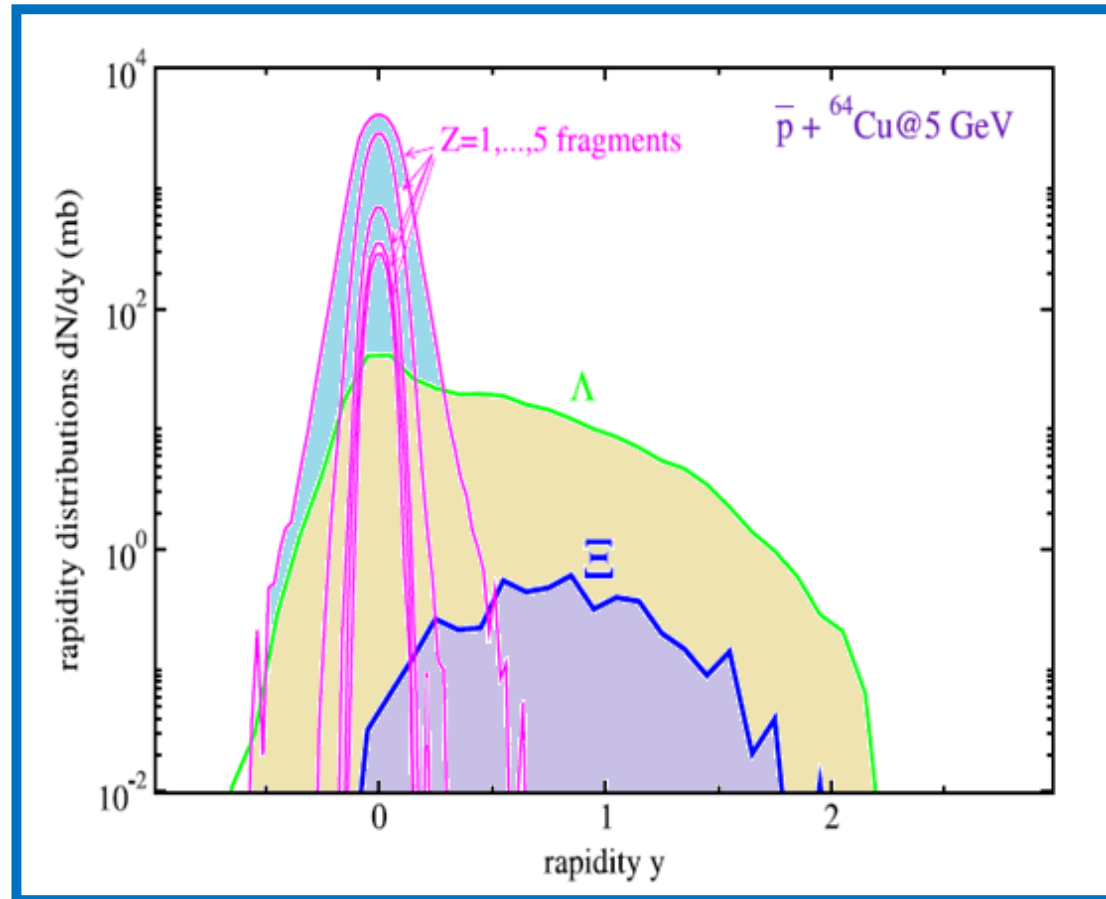
The $S=-2$ and $S=-3$ Sectors: Ξ and Ω^- Production in Central Collisions

Antiproton Annihilation \rightarrow Meson-rich Environment!



**Important Secondary Process:
Strangeness Production through Resonances**

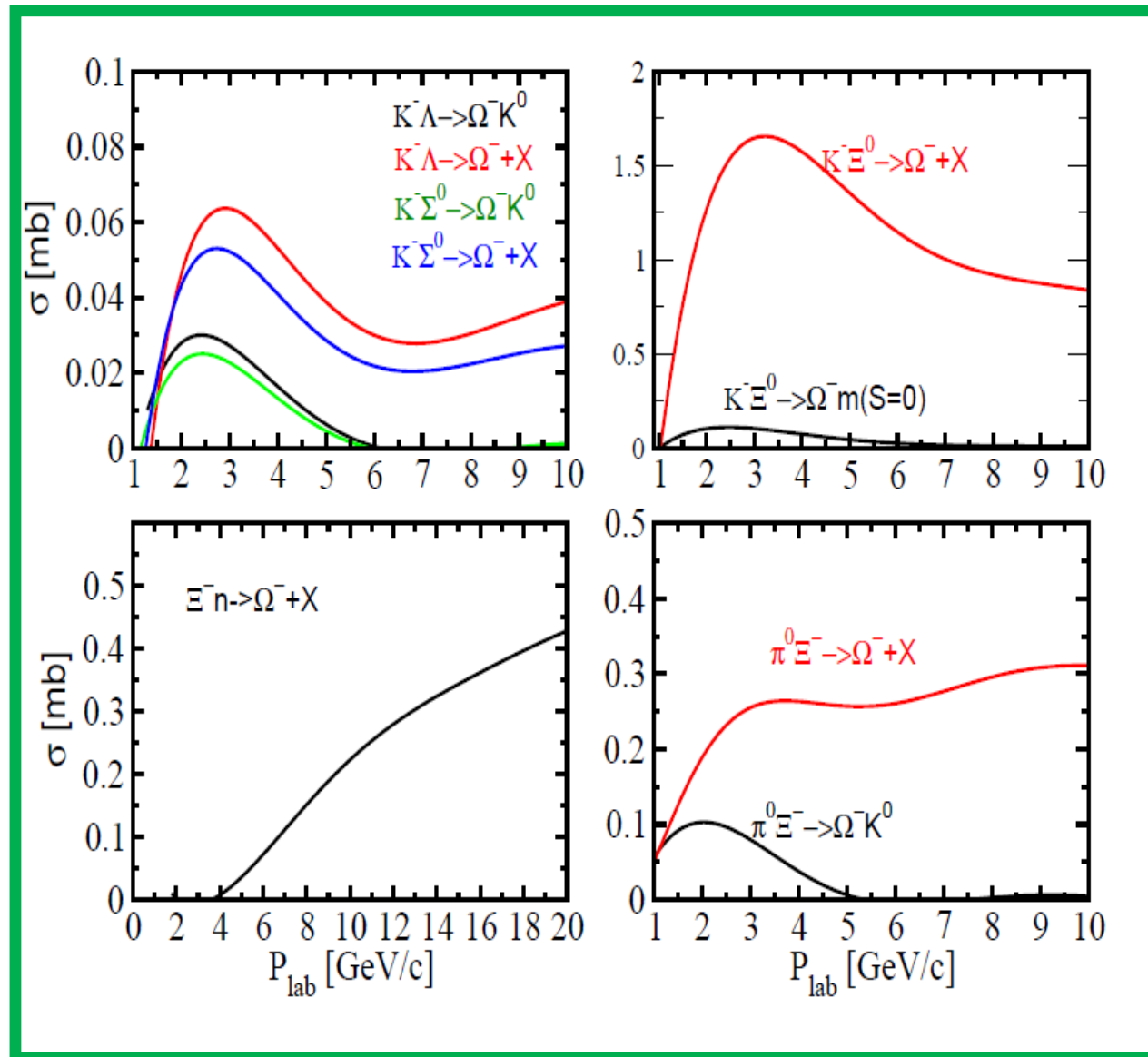
GiBUU Transport Theory plus Statistical Multi-Fragmentation Model



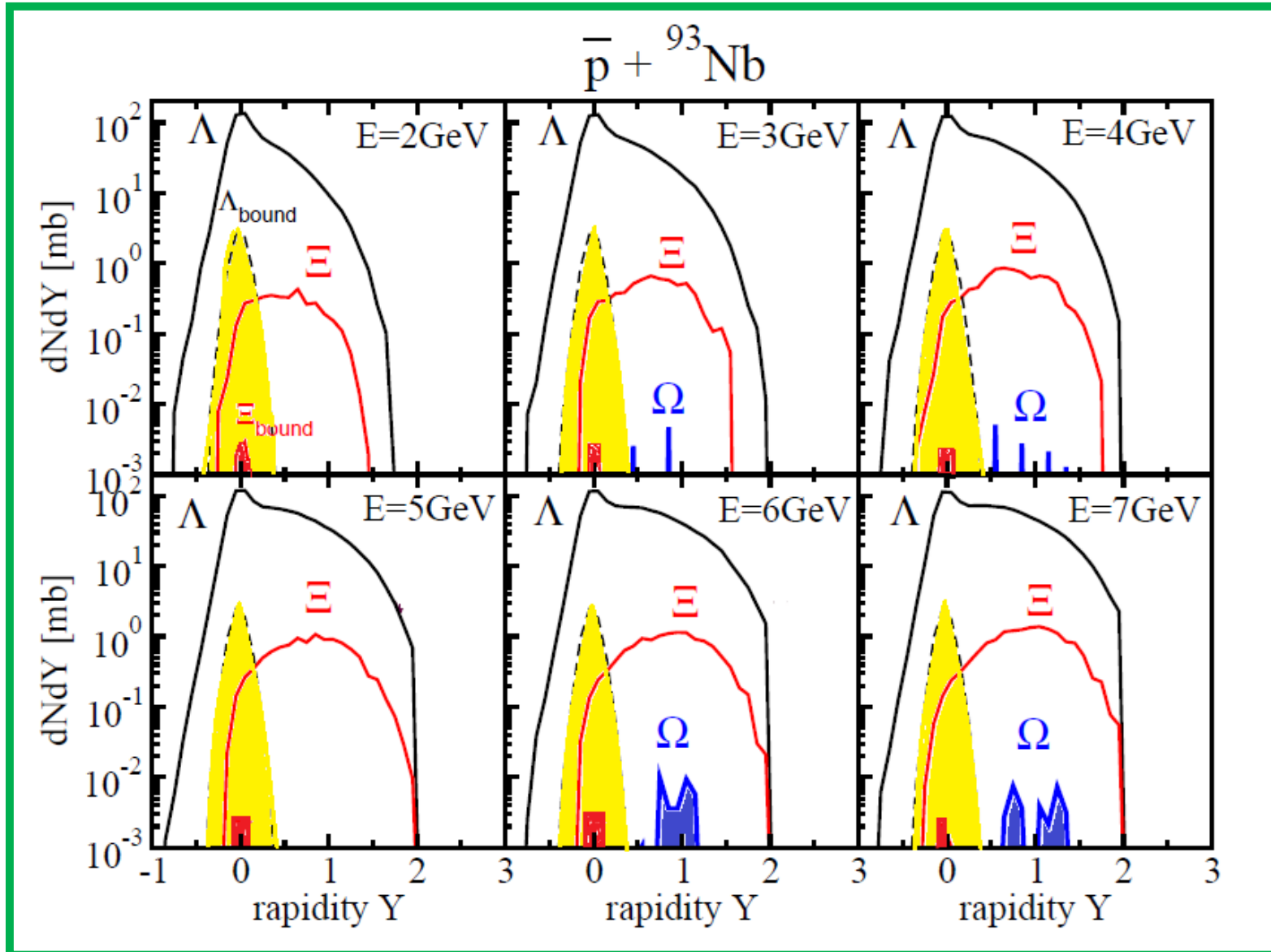
GiBUU + SMM calculations for the rapidity distributions of fragments with charge $Z = 1, \dots, 5$ and hyperons with strangeness $S = -1$ (Λ) and $S = -2$ (Σ), as indicated, for inclusive $\bar{p} + \text{Cu}@5 \text{ GeV}$ reactions.

→ H. L. et al., PPNP 98 (2018) 119

In-Medium Ω^- Production by Secondary Reactions

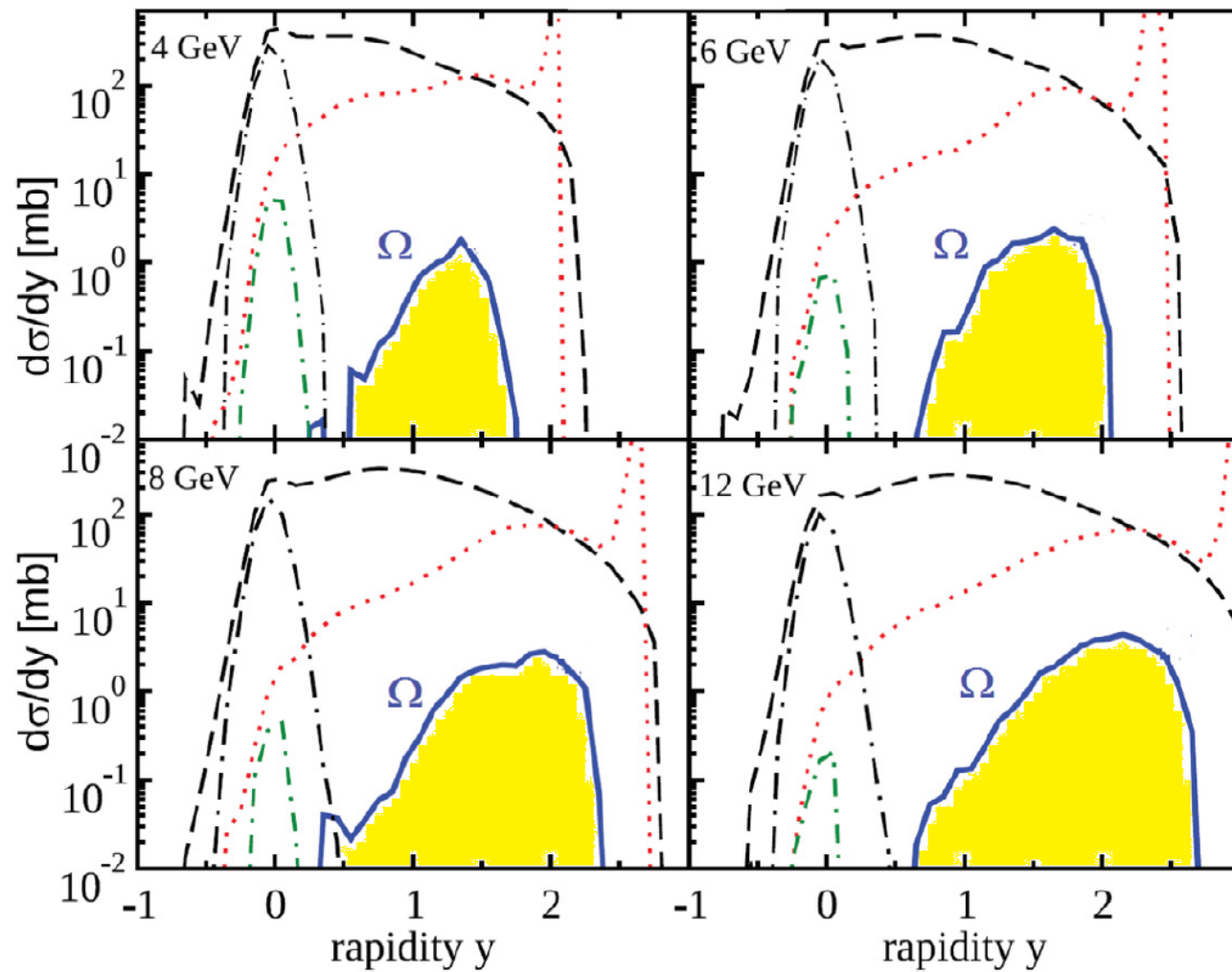


Λ , Ξ , Ω^- Production in Antiproton-Nucleus Collisions



Ω^- Production on Nuclear Targets by Secondary Ξ^- -Beams

$\Xi^- + {}^{64}\text{Cu}$



T. Gaitanos, H. Lenske et al., Nuclear Phys. A 954 (2016) 308

Summary and Outlook

- Strangeness and charm production in elementary reactions
- Correlated $[K,\pi]_{0+}$ exchange by $\kappa/K^*_0(700)$ meson exchange
- Hypernuclear production by quasi-elastic strangeness exchange
- Multi-Strangeness production in central antiproton-nucleus collisions
- *Study further the $[K,\pi]_{0+}$ channel*
- *Double- Λ Hypernuclei (\rightarrow PPNP 98 (2018) 119)*
- *Charmed hypernuclei?*

**...with most essential contributions by
Theo Gaitanos, Alexei Larionov, and Radhey Shyam!**

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