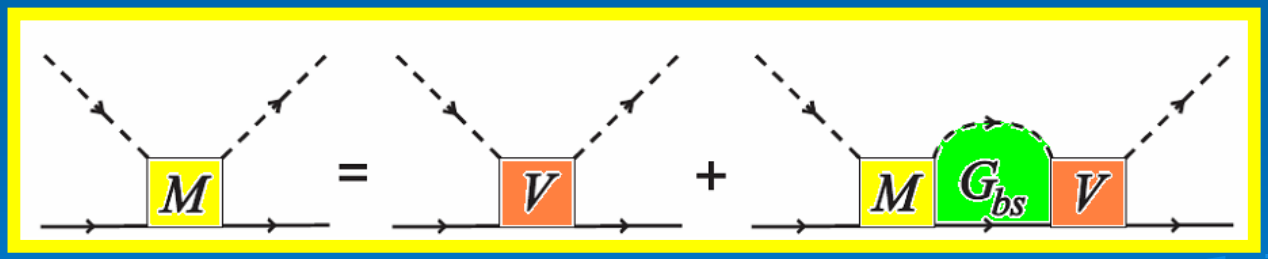
Production of Hypernuclei by Hadrons and Heavy Ions

H. Lenske
Institut für Theoretische Physik
JLU Giessen

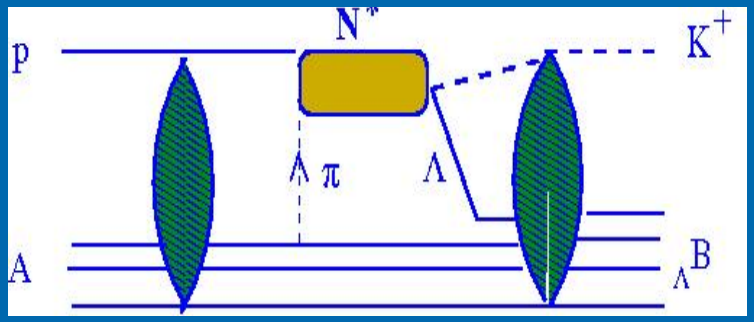
Agenda:

- Hypernuclear production by elementary probes
- Strangeness production in fragmentation reactions
- Hypernuclear production in peripheral antiproton reactions
- Summary and Outlook

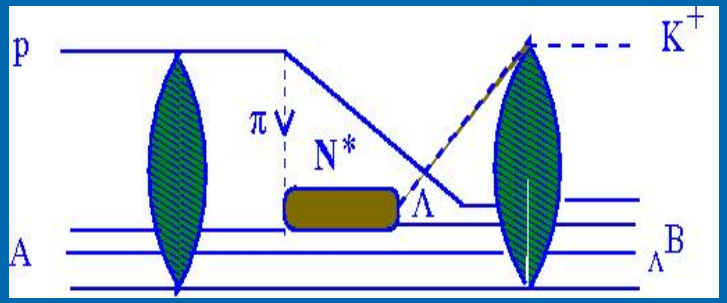
Hypernuclear Production by Elementary Probes: The Giessen Resonance Model



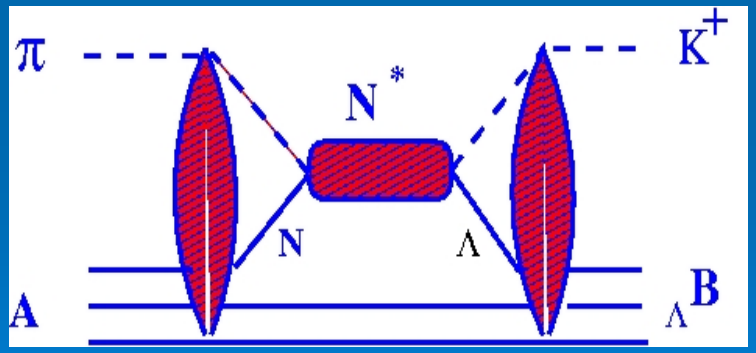
Strangeness Production by Resonance Excitation: The Giessen Resonance Model (GiR)



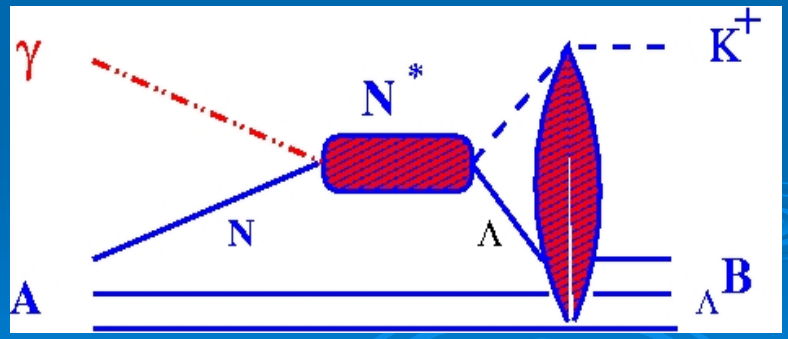
Projectile emission $A\,(p,K^+)_\Lambda B$



Target emission $A\,(p,K^+)_\Lambda B$



$A\,(\pi^+,K^+)_\Lambda B^*$



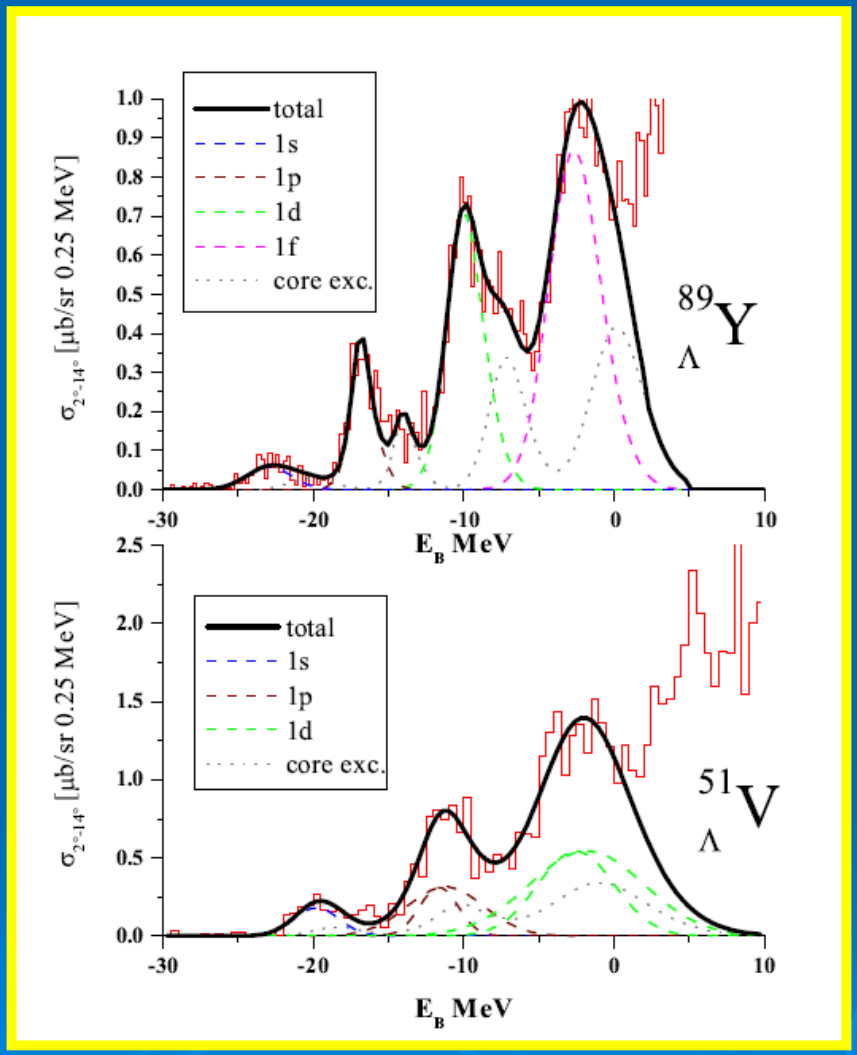
$A\,(\gamma,K^+)_\Lambda B'$

...mainly by $N^*(1650)$, $N^*(1710)$, $N^*(1720)$ resonances.

Application to (π^+,K^+) KEK-Data: GiR plus DFT
(Data: Hotchi et al.)

Λ-States in ^{89}Y:

	$^{89}_{\Lambda}$Y
$1s_{1/2}$	-22.94 ± 0.64 MeV
$1p_{3/2}$	-17.02 ± 0.07 MeV
$1p_{1/2}$	-16.68 ± 0.07 MeV
$1d_{5/2}$	-10.26 ± 0.07 MeV
$1d_{3/2}$	-9.71 ± 0.07 MeV
$1f_{7/2}$	-3.04 ± 0.11 MeV
$1f_{5/2}$	-2.26 ± 0.11 MeV



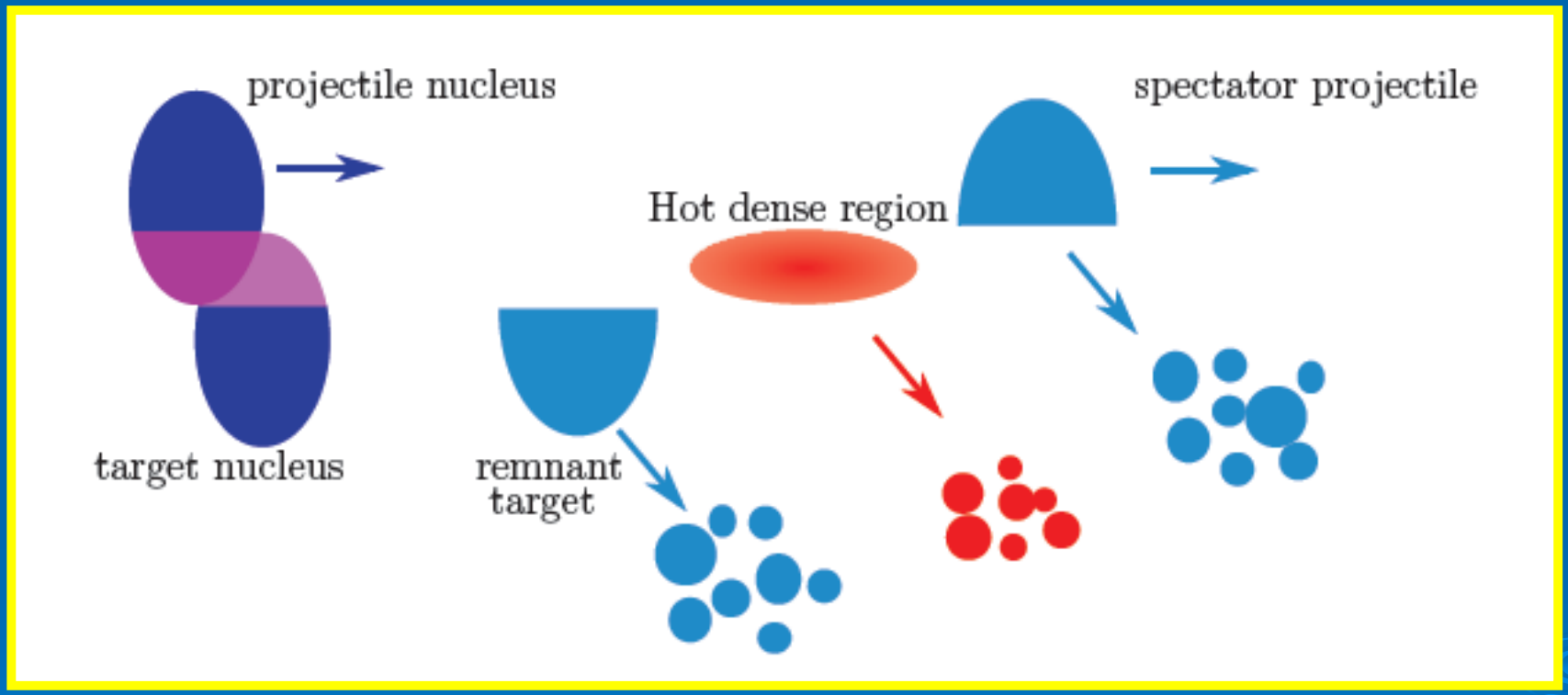
Λ-States in ^{51}V:

	$^{51}_{\Lambda}$V
$1s_{1/2}$	-19.8 ± 1.4 MeV
$1p_{3/2}$	-11.8 ± 1.3 MeV
$1p_{1/2}$	-11.4 ± 1.3 MeV
$1d_{5/2}$	-2.7 ± 1.2 MeV
$1d_{3/2}$	-1.9 ± 1.2 MeV

S. Bender, R. Shyam, HL, Nucl. Phys. A 839:51 (2010)

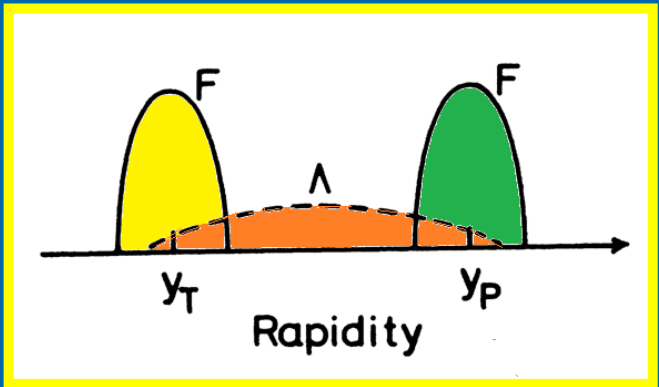
Hypernuclear Production in Fragmentation Reactions

Fragmentation Scenario
(T_{lab} > 1 AGeV)



Transport Theory plus Statistical Fragentation:

Formation of a Hypernucleus by Λ-Capture on pre-formed Fragments F:



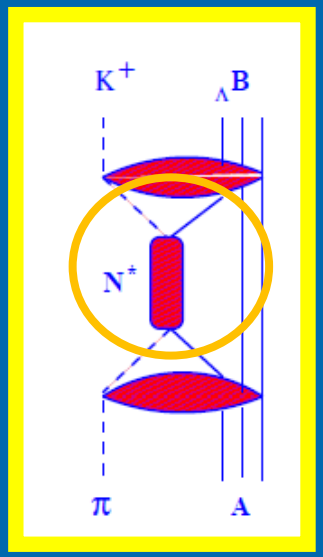
$$\frac{\gamma}{\sigma_r}\frac{d^3\sigma^{(\Lambda F)}}{dk_c^2} = \left[\frac{m_\Lambda + m_F}{m_\Lambda m_F}\right]^3 S_{\Lambda F} \left[\frac{\gamma}{\sigma_r}\frac{d^3\sigma^{(\Lambda)}}{dk_c^3}\right] \left[\frac{\gamma}{\sigma_r}\frac{d^3\sigma^{(F)}}{dk_c^3}\right]$$

Λ Production X-section

Fragment Production X-section

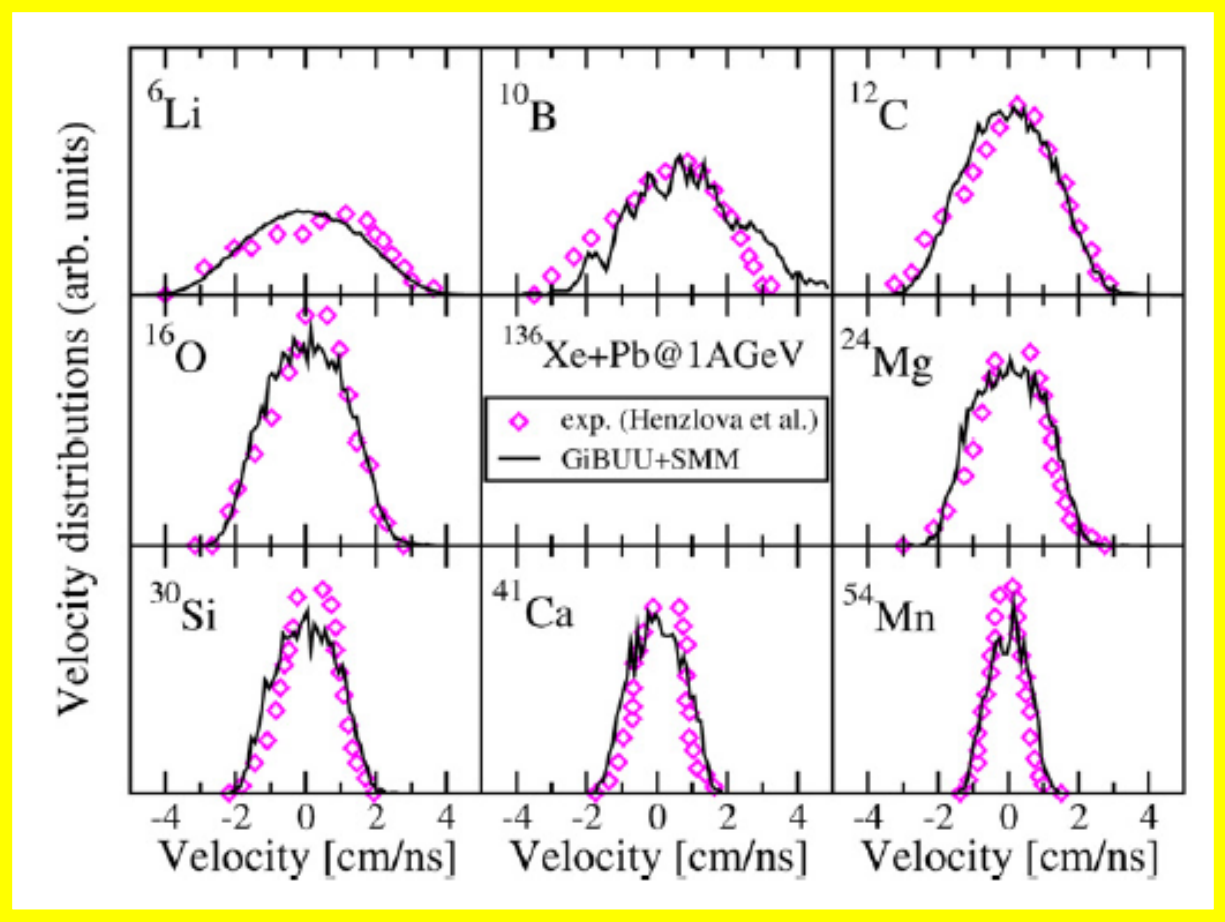
…see H.L., M. Dhar, Th. Gaitianos, Xu Cao, PPNP 98:119 (2018)

Dominant Elementary Secondary Process: Strangeness Production through N* Resonances and Rescattering



$NN \to N\Lambda K^+$	$NN \to N\Sigma K^+$	$NN \to \Delta\Lambda K^+$	$NN \to \Delta\Sigma K^+$
$N\Delta \to N\Lambda K^+$	$N\Delta \to N\Sigma K^+$	$N\Delta \to \Delta\Lambda K^+$	$N\Delta \to \Delta\Sigma K^+$
$\Delta\Delta \to N\Lambda K^+$	$\Delta\Delta \to N\Sigma K^+$	$\Delta\Delta \to \Delta\Lambda K^+$	$\Delta\Delta \to \Delta\Sigma K^+$
$\pi N \to \Lambda K^+$	$\pi N \to \Sigma K^+$	$\pi\Delta \to \Lambda K^+$	$\pi\Delta \to \Sigma K^+$
$NN \to NNK^+K^-$	$N\Delta \to NNK^+K^-$	$N\Delta \to N\Delta K^+K^-$	$\Delta\Delta \to NNK^+K^-$
$\Delta\Delta \to \Delta\Delta K^+K^-$	$\pi N \to NK^+K^-$	$\pi\Delta \to NK^+K^-$	

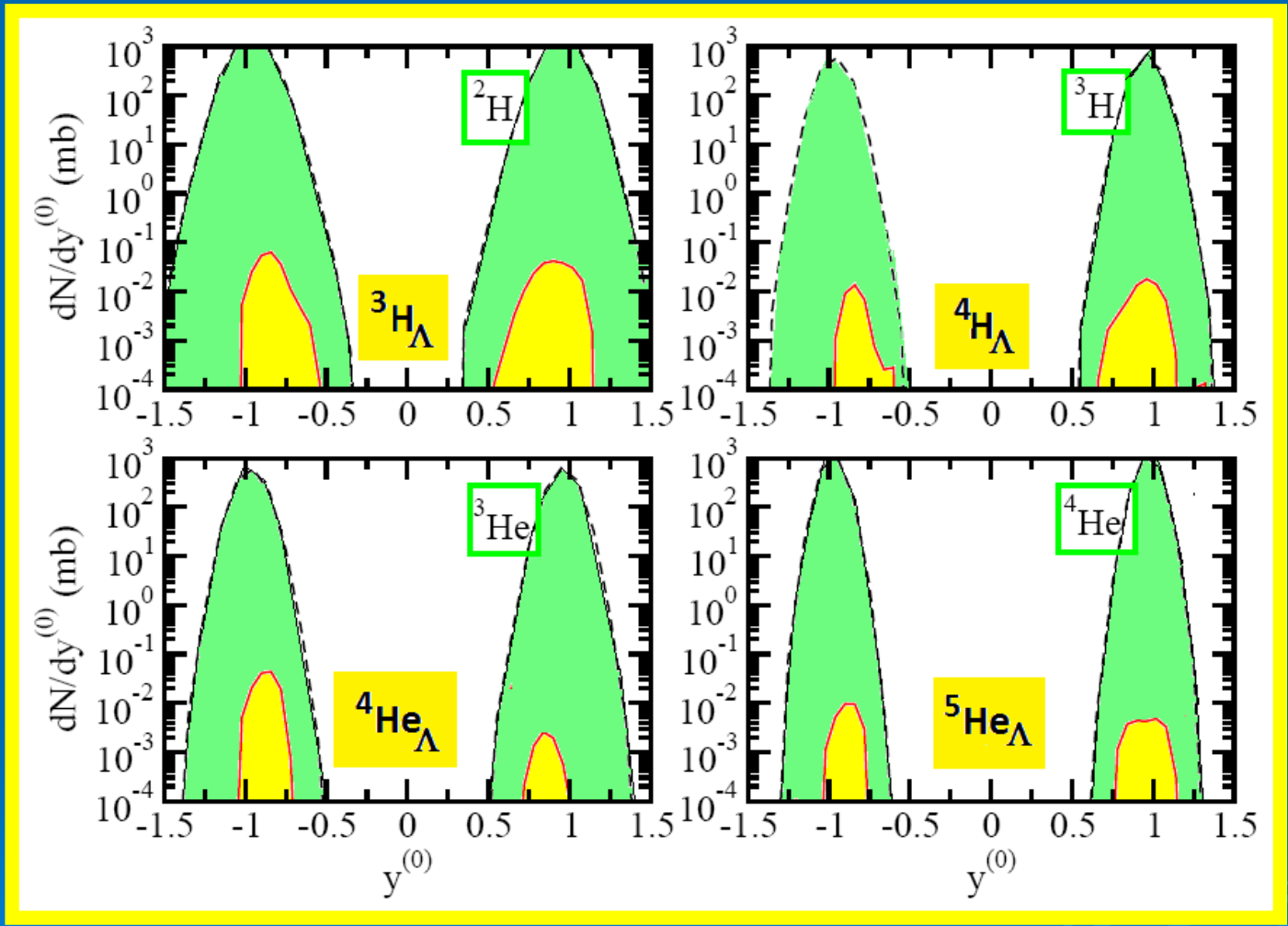
Production of Light Nuclei by GiBUU+SMM
(Data: FOPI@GSI)



Longitudinal velocity distributions in the projectile frame

Th. Gaitanos et al.: PL B663, 197 (08) & PL B675 (09) 297

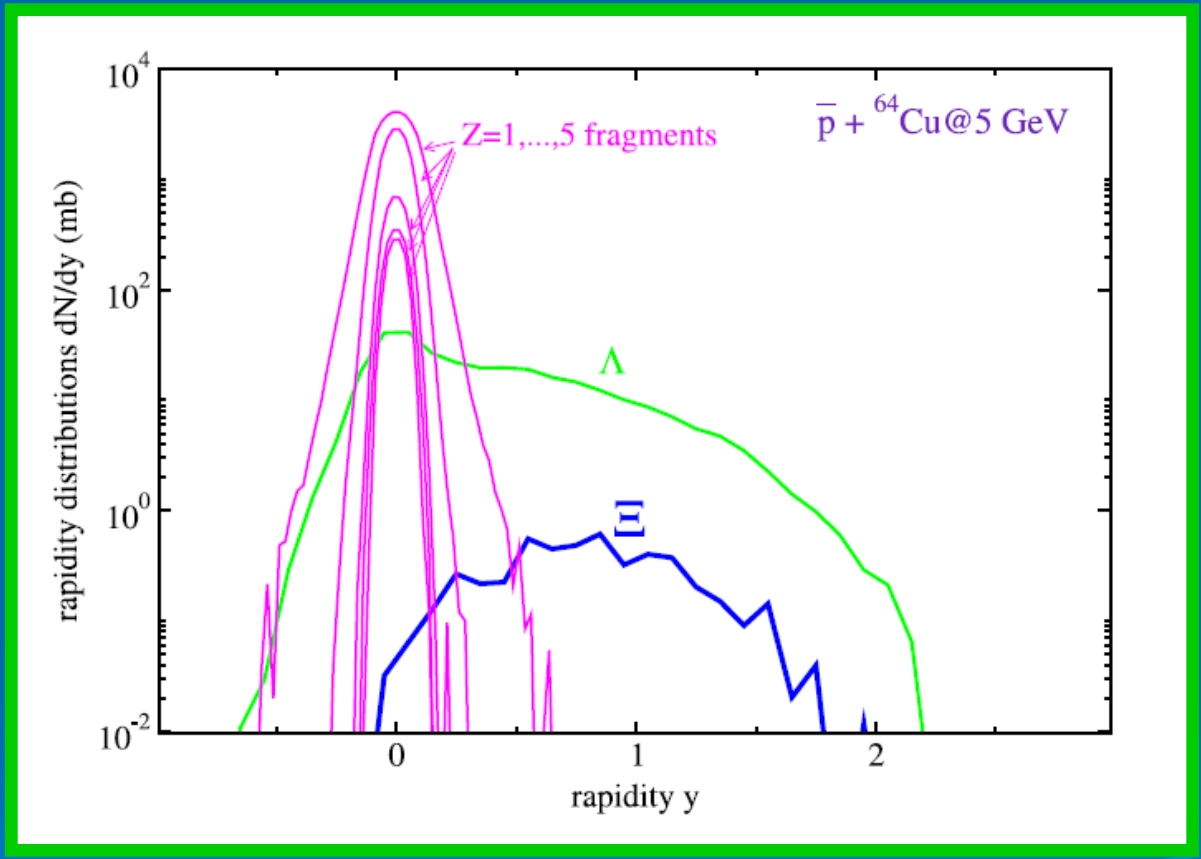
Production of Hypernuclei in $^{12}C+^{12}C$@2AGeV



Th. Gaitanos, HL, Phys. Lett. B 675, 297 (2009), NPA (2012), NPA (2016)…

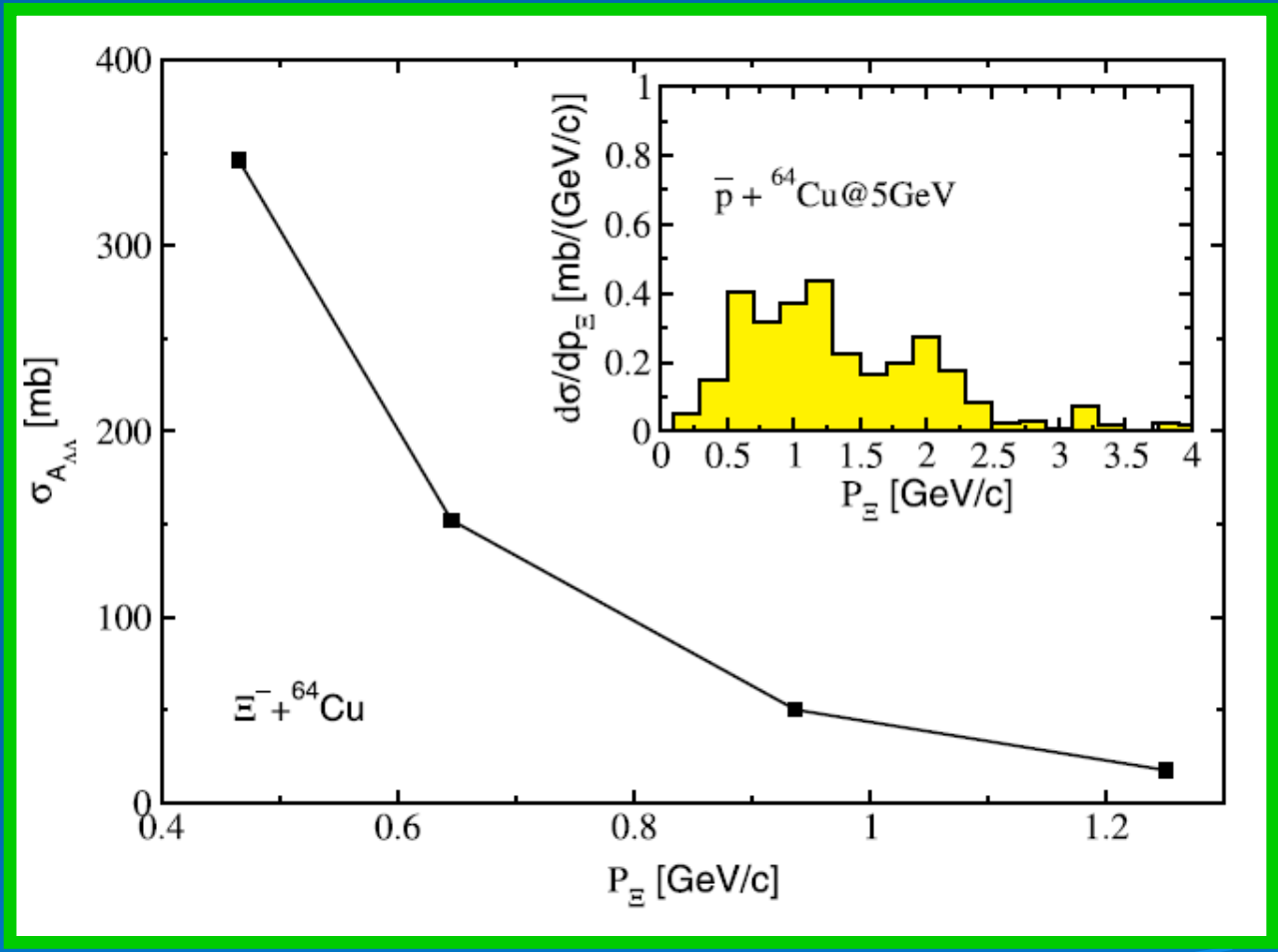
Hypernuclei from central Antiproton-Nucleus Collsisions

Fragment Rapidity Distributions in Antiproton-induced Fragmentation Reactions



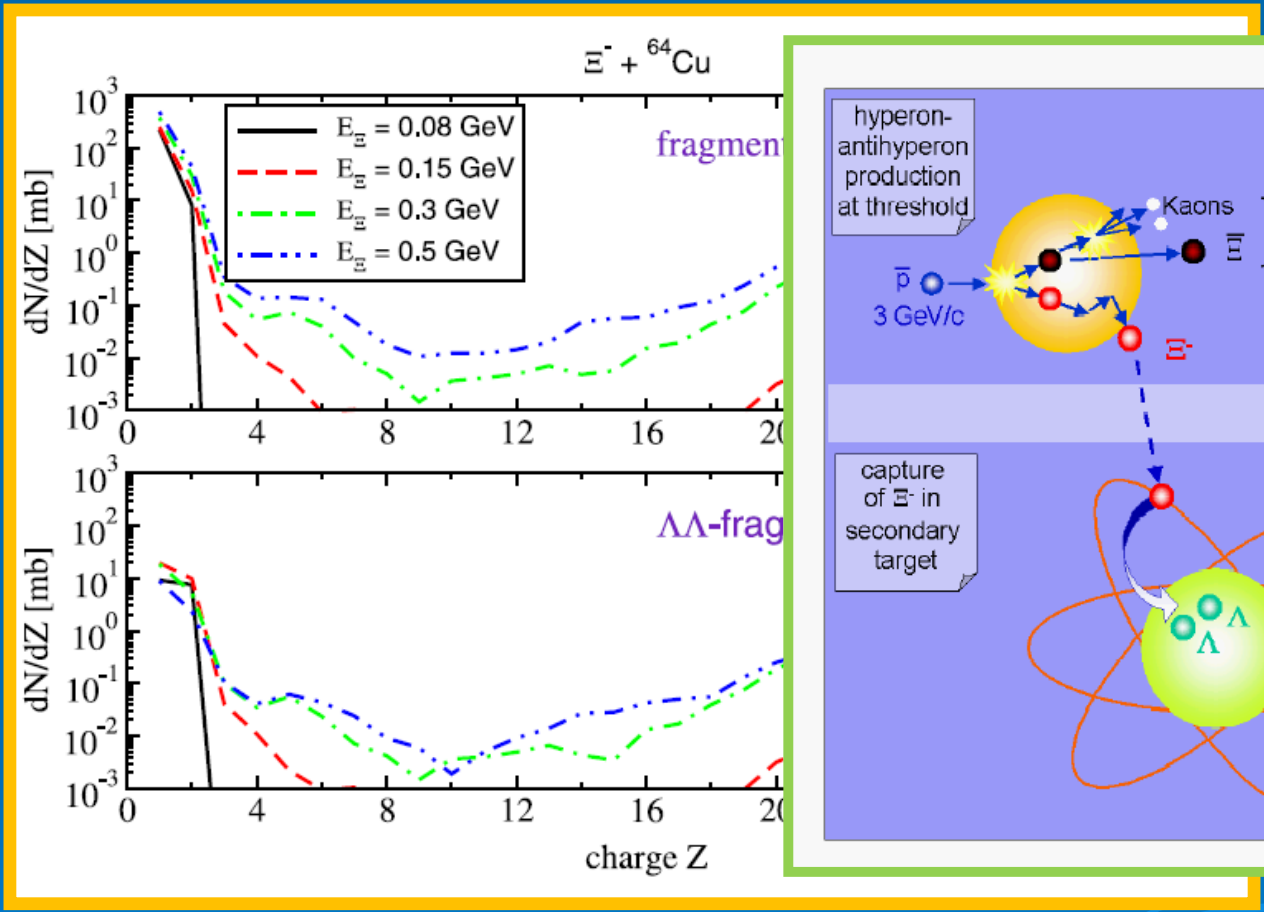
GiBUU + SMM calculations for the rapidity distributions of fragments with charge $Z = 1, \ldots, 5$ and hyperons with strangeness $S = -1$ (Λ) and $S = -2$ (Ξ), as indicated, for inclusive $\bar{p}$ + Cu@5 GeV reactions.

Preparation of the Ξ secondary beam



The insert panel shows now the Ξ-production cross section from $\bar{p}$-collisions on the first target, as indicated.

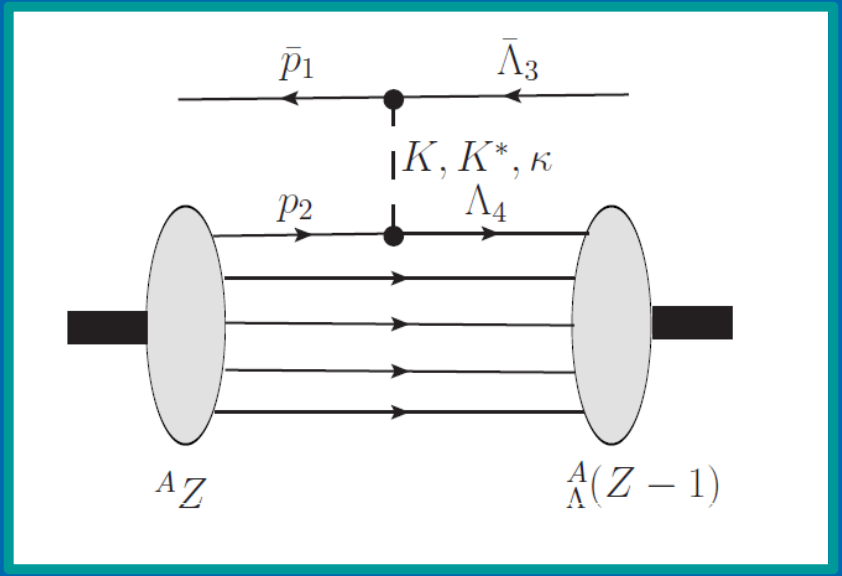
Secondary Ξ-beams from $\bar{p}$-annihilation: Nuclear Fragments and ΛΛ-Fragments



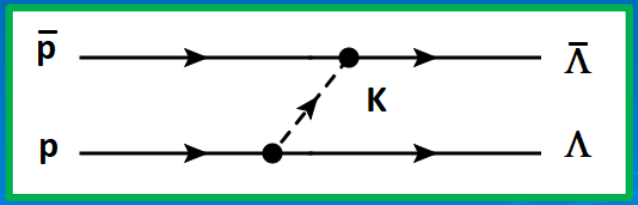
GiBUU + SMM calculations for the charge distributions of nuclear fragments (upper panel) and double-Λ clusters (lower panel) for Ξ^- + ^{64}Cu reactions at various kinetic energies of the Ξ-beam in the laboratory frame, as indicated.

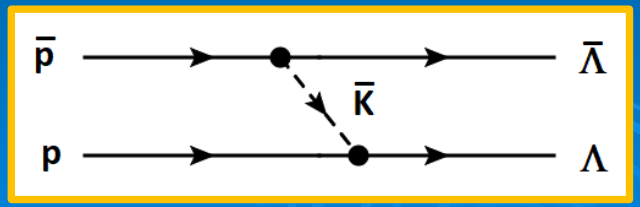
Hypernuclear Production in Peripheral $\bar{p}$A Reactions

Hadronic Scenario for Antiprotonic Hypernuclear Production by Strangeness-Transfer



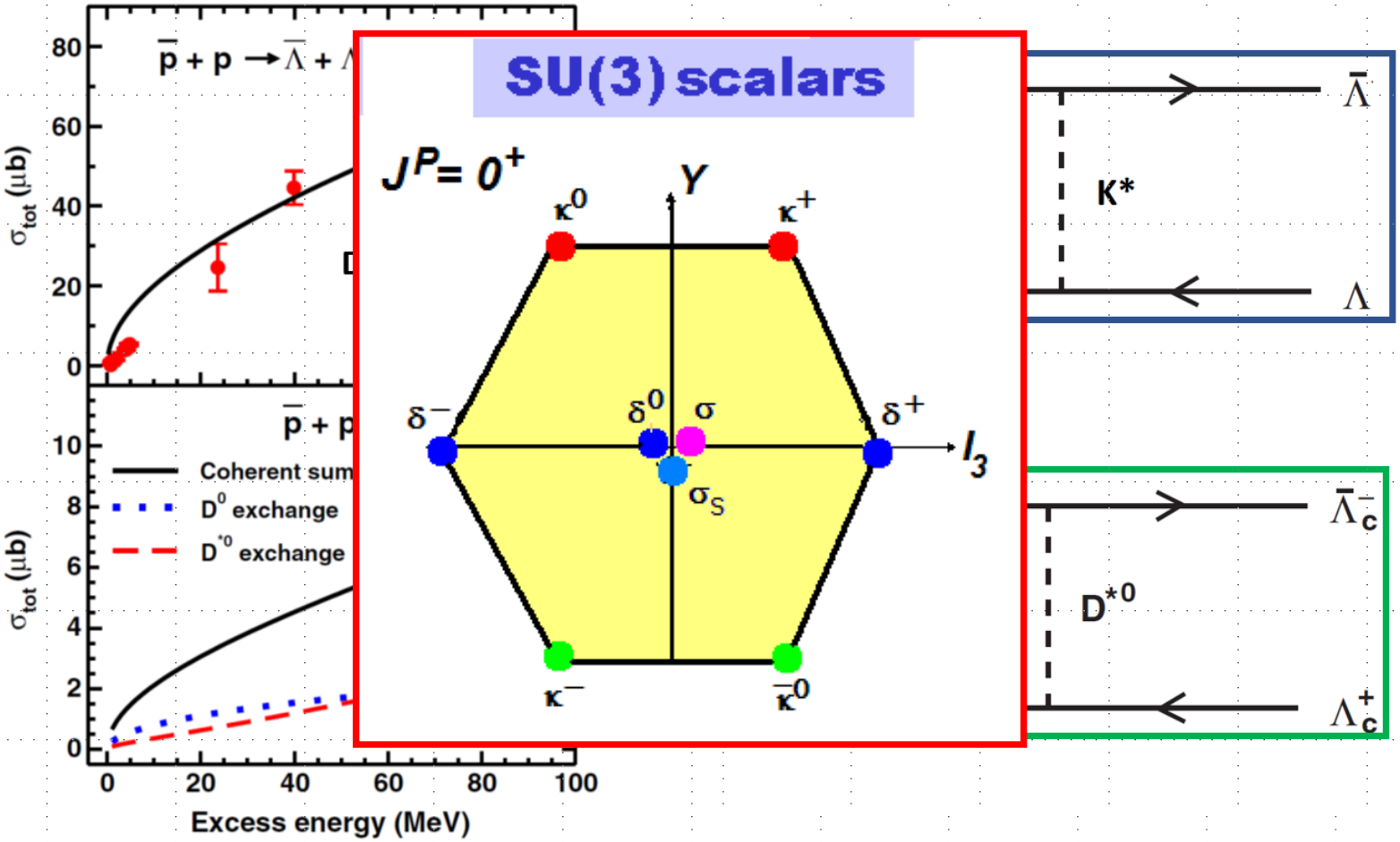
Feynman graph of the ${}^A Z(\bar{p}, \bar{\Lambda})^A_\Lambda(Z-1)$ process.





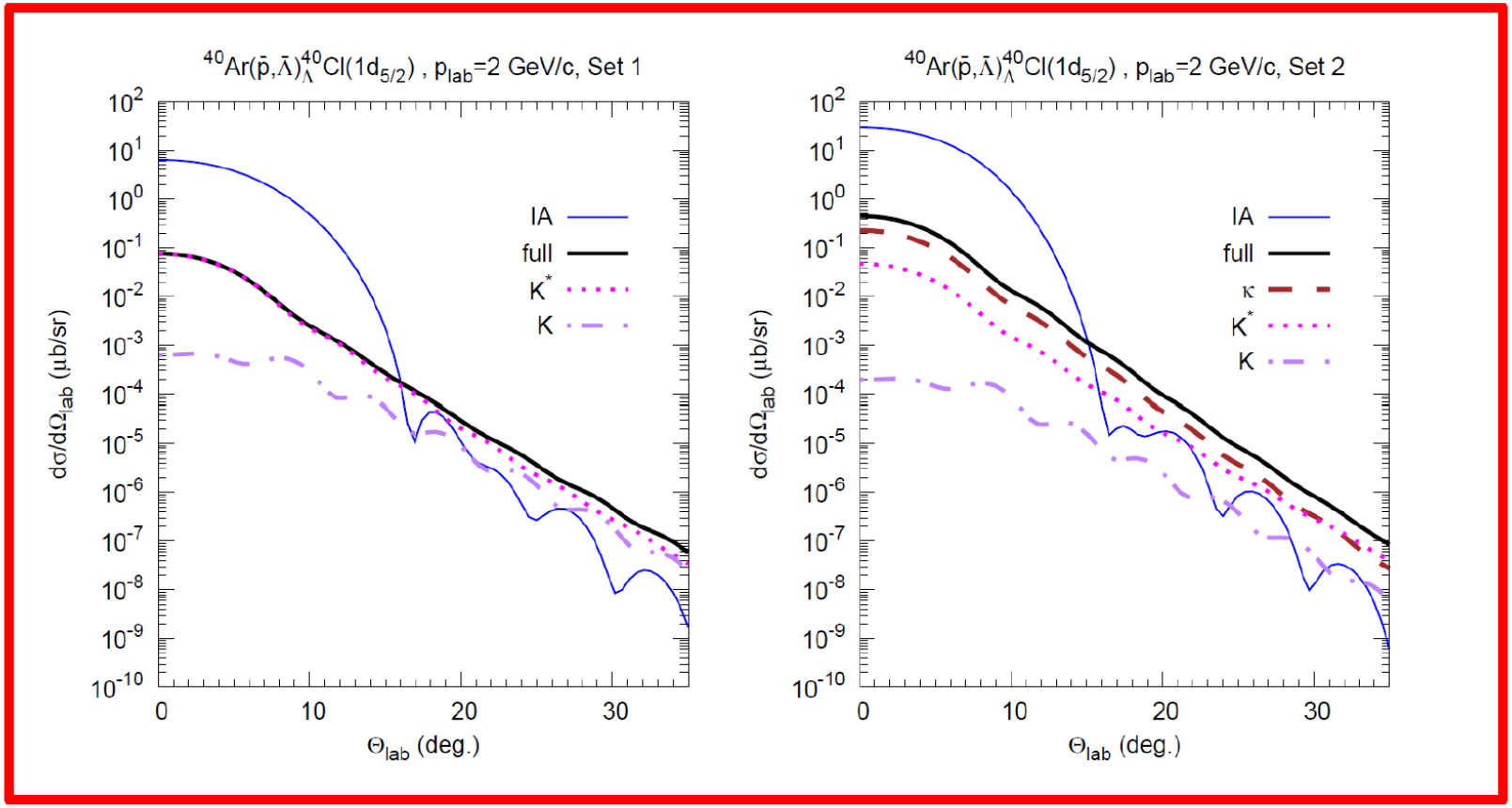
Antiproton-Proton Annihilation into Antibaryon-Baryon Pairs: The Hadronic Approach

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



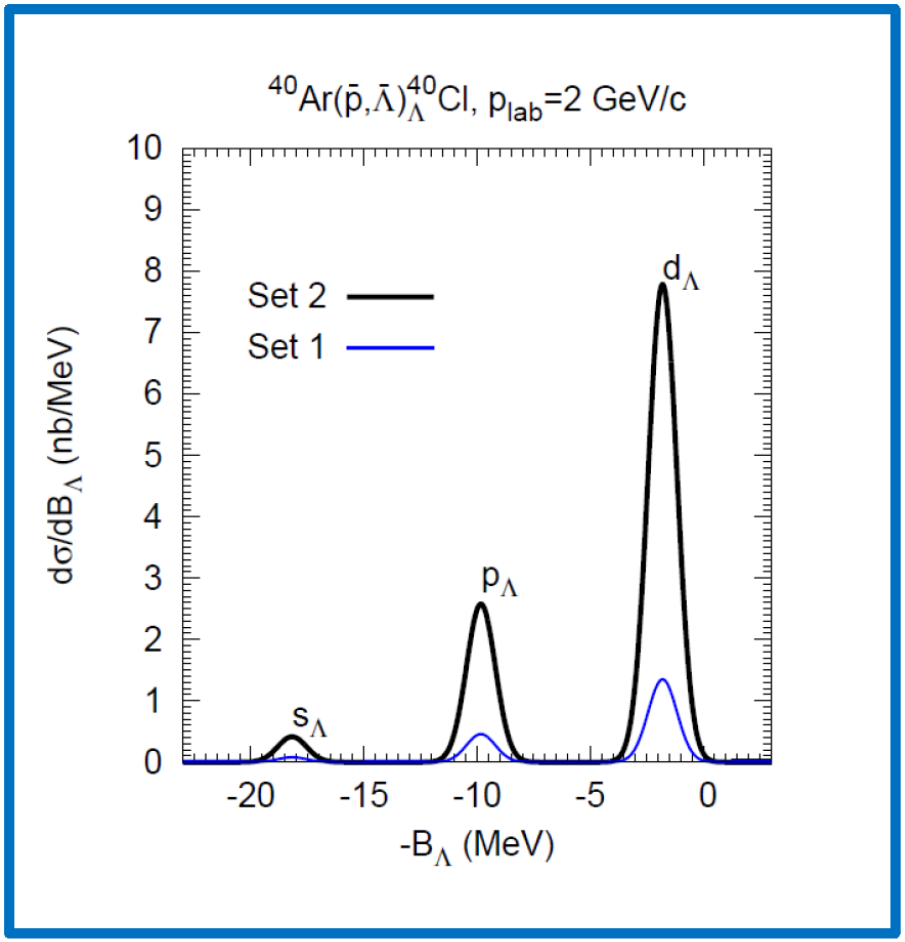
Hypernuclear Production - Meson Exchange and ISI/FSI

(A. Larionov, H.L., PLB 773 (2017) 470)



Without κ-exchange **With κ-exchange**

Hypernuclear Production
Spectral Distribution of Λ Bound States



Summary and Outlook

- **Universal scenario: Strangeness production by N* excitation**
- **Hypernuclei by elementary probes: (γ,K), (π,K), (p,K)…**
- **Fragmentation reactions with heavy ions and antiprotons**
- **Hypernuclear production in peripheral antiproton reactions**

…further reading for detailed discussions in:
H. Lenske, M. Dhar, Th. Gaitanos, Xu Cao, PPNP 98:119 (2018)

…and credits to
A. Larionov, R. Shyam, and S. Wycech

(supported by DFG, BMBF, and HIC for FAIR)