Hypernuclear and Resonance Production in Heavy Ion Collisions

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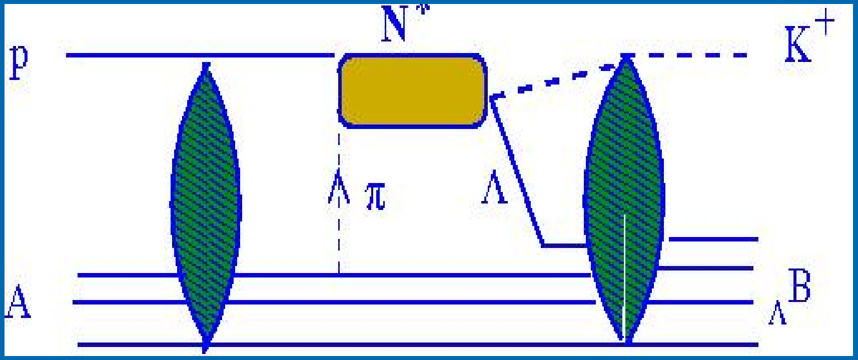
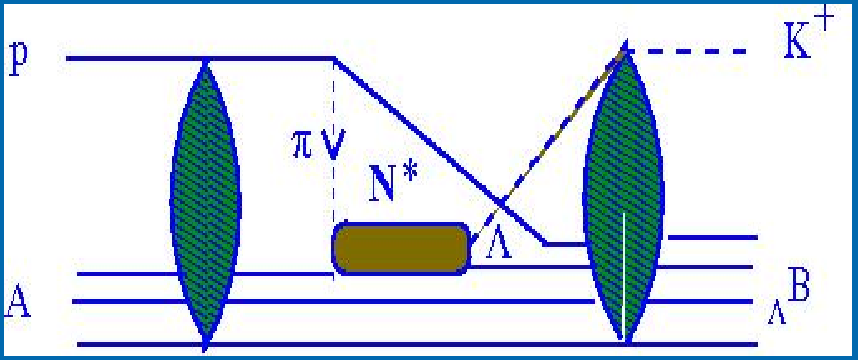
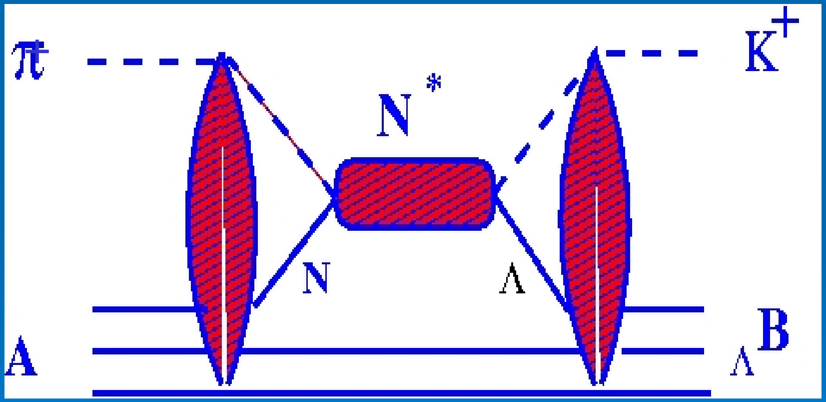
Strangeness Production at “GSI”-Energies : The Giessen Resonance Model



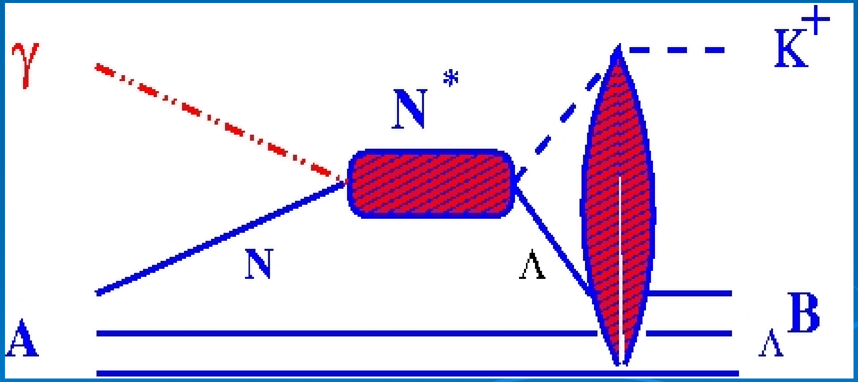
Target emission $A\,(p,K^+)_\Lambda B$



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



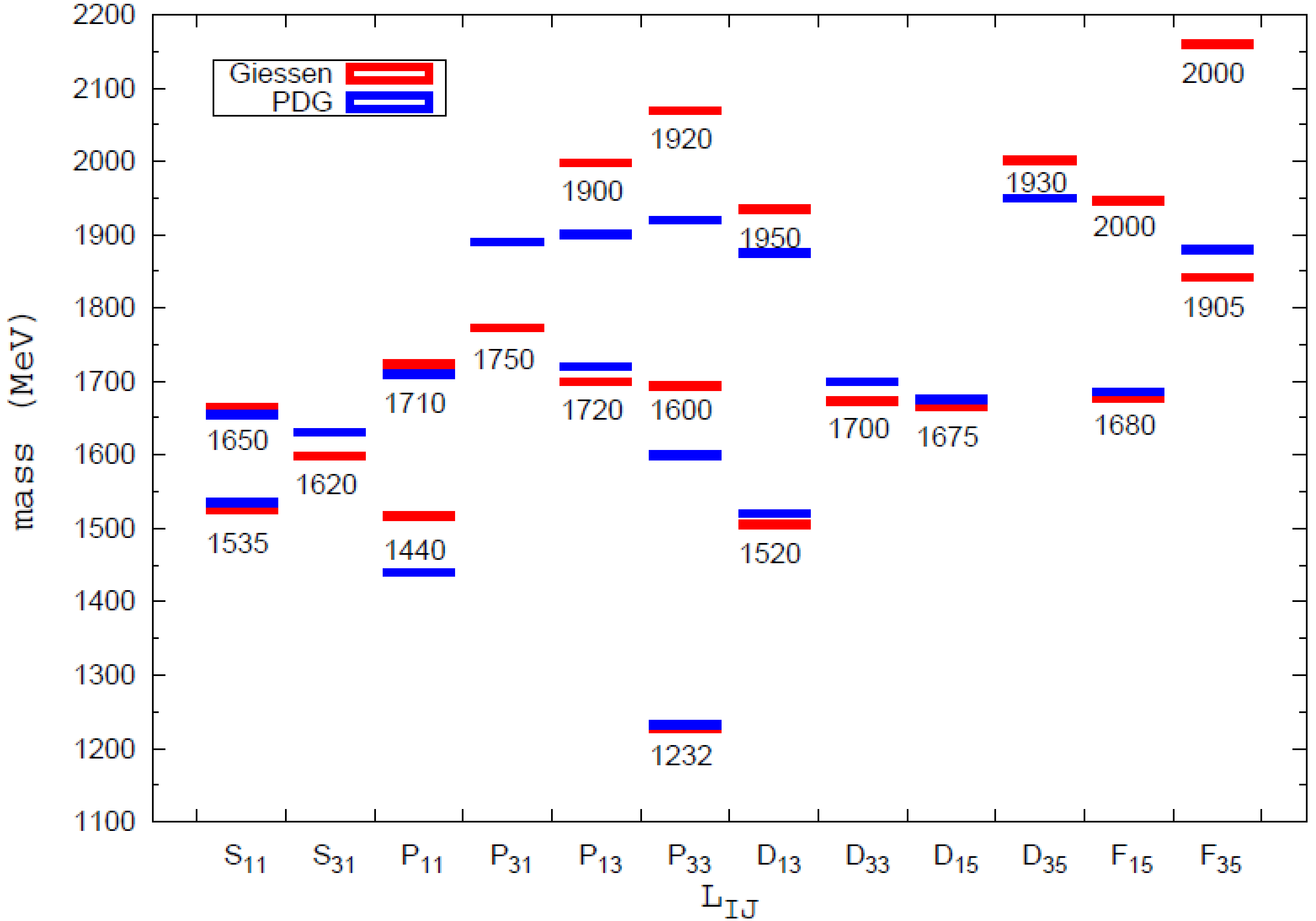
$A\,(\pi^+,K^+)_\Lambda B^*$



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

R. Shyam, H.L., PRC77 (2008) 052201; NPA839 (2010) 51; PRC81 (2010) 015204; PRD90 (2014) 1, 014017; PRD 93 (2016) 034016.

GiM Nucleon Resonance Level Scheme

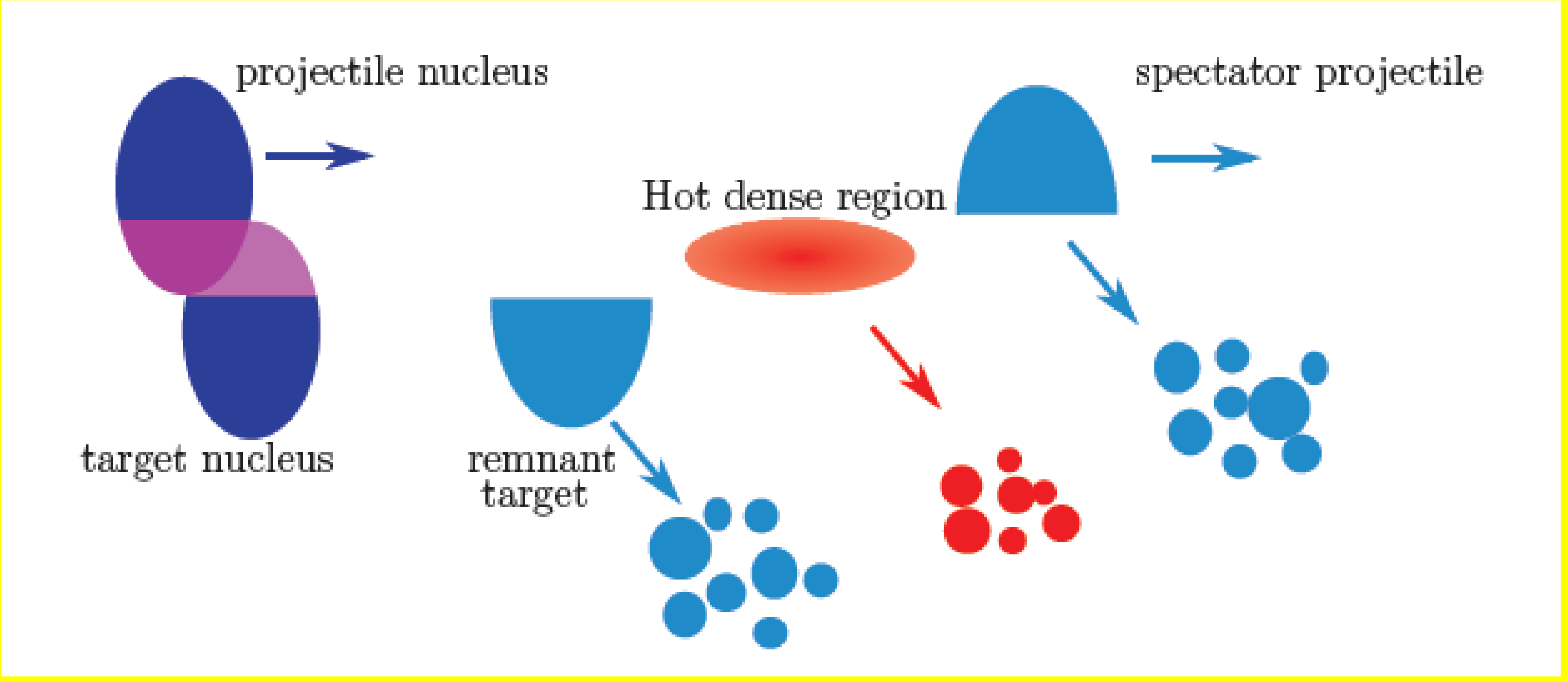


Agenda:

- Fragmentation in Heavy Ion Collisions
- S=-1 Hypernuclear Production in Heavy Ion Collisions
- S=-2,-3 Multi-Strangeness Production
- Nucleon Resonance Excitation in Peripheral Heavy Ion Collisions

Fragmentation Reactions

Scenario of a fragmentation reaction (T_{lab}>1AGeV)



GiBUU Transport Theory & SMM Grand Canonical Fragmentation Approach
(Bondorf, Mishustin, Botvina)

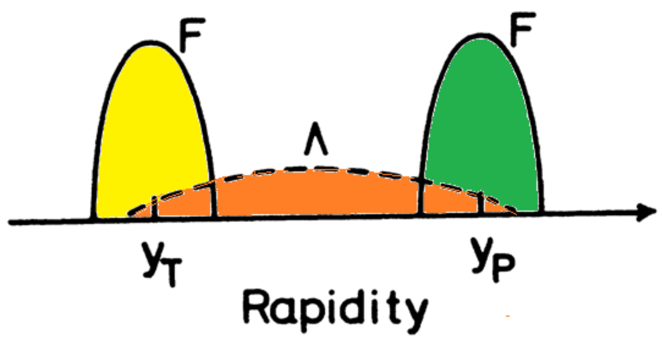
Gaitanos, Lenske, Phys. Lett. B 675, 297 (2009); Phys. Lett. B 663, 197 (2008)…

GiBUU: O. Buss, Th. Gaitanos, et al., Phys. Rept. 512 (2012) 1

Formation of a Hypernucleus through Capture of a Λ by a pre-formed Fragment F:

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

Structure | GiBUU | SMM

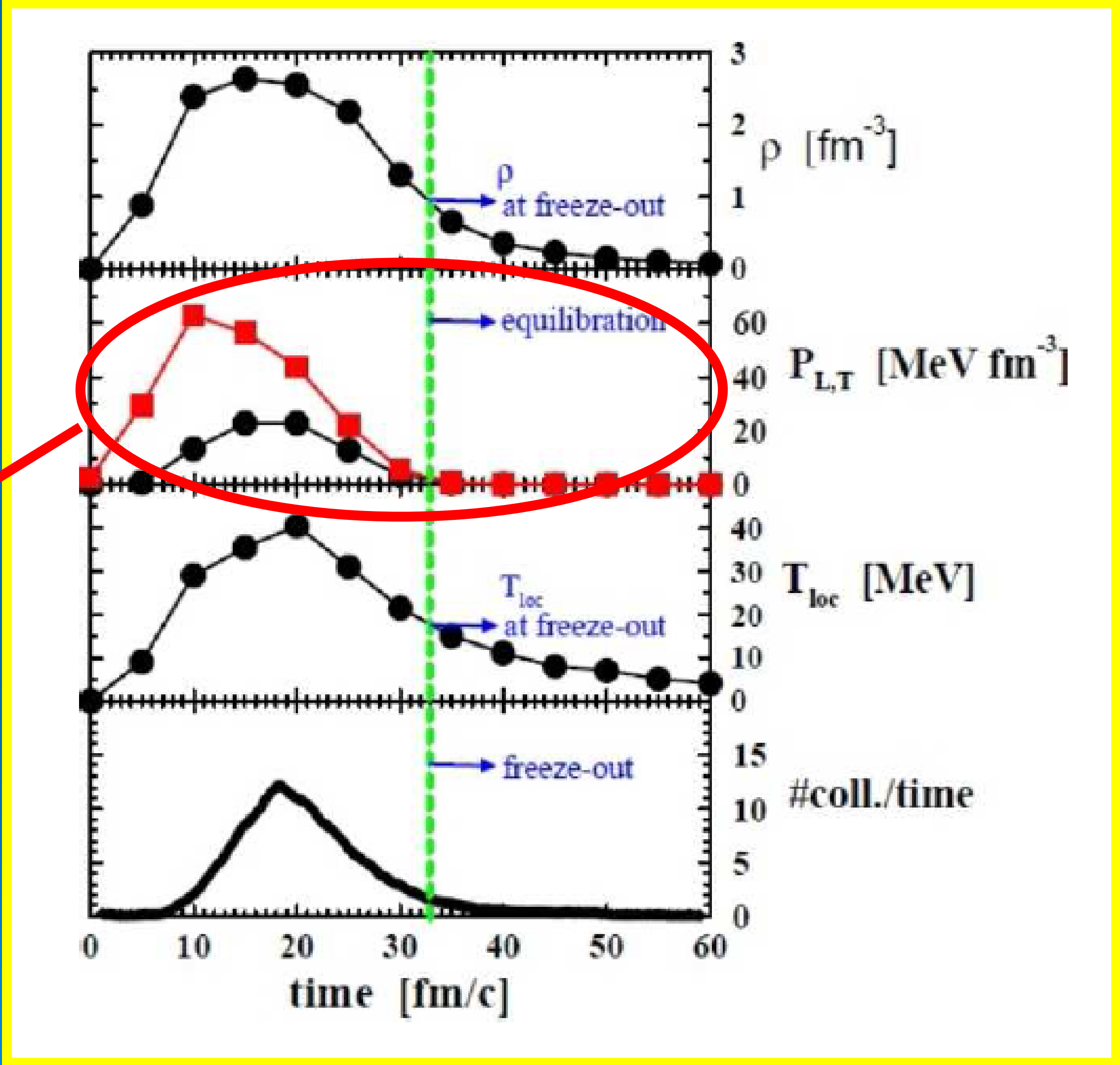


Λ Production X-section

Fragment Production X-section

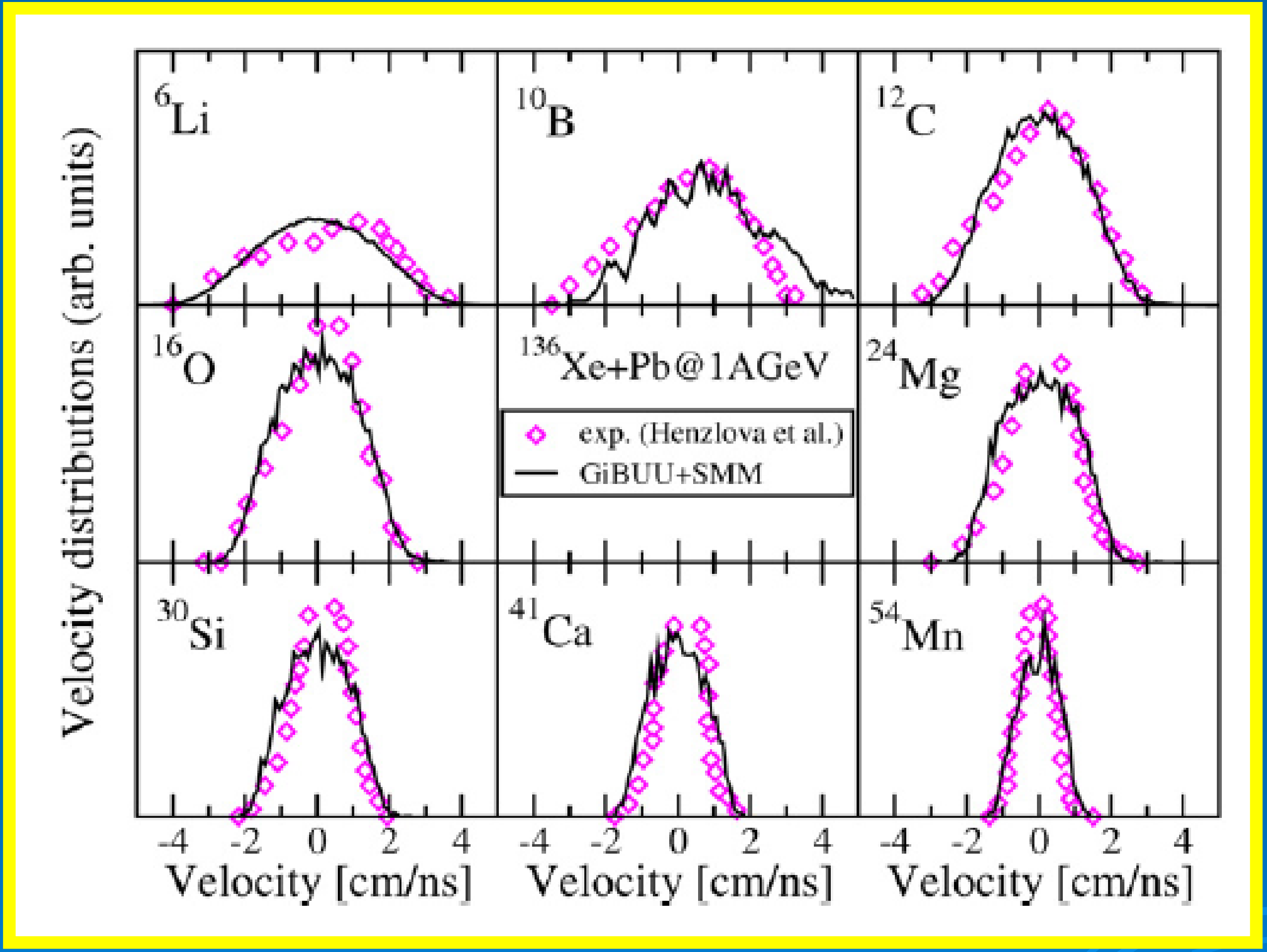
M. Wakai, H. Bando, M. Sano, Phys. Rev. C 38 (1988) 748.

Time Evolution of the System Au+Au@0.6AGeV



Defines onset of fragmentation: GiBUU→SMM

Production of Light Nuclei from ^{136}Xe+Pb by GiBUU+SMM (FOPI data)



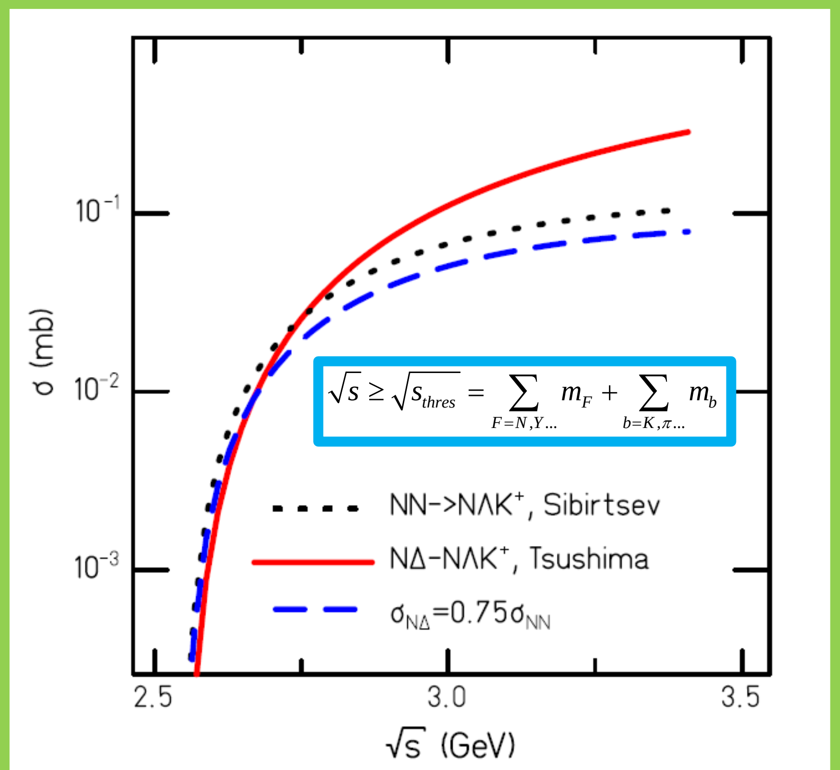
Longitudinal velocity distributions in the projectile frame

Th. Gaitanos, H.L. et al.: PLB663, 197 (2008) & PLB675 (2009) 297

Strangeness Production in Baryonic Matter

$$e.g.\ \ N + N \rightarrow N^{*} + N \rightarrow Y + N + K$$

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

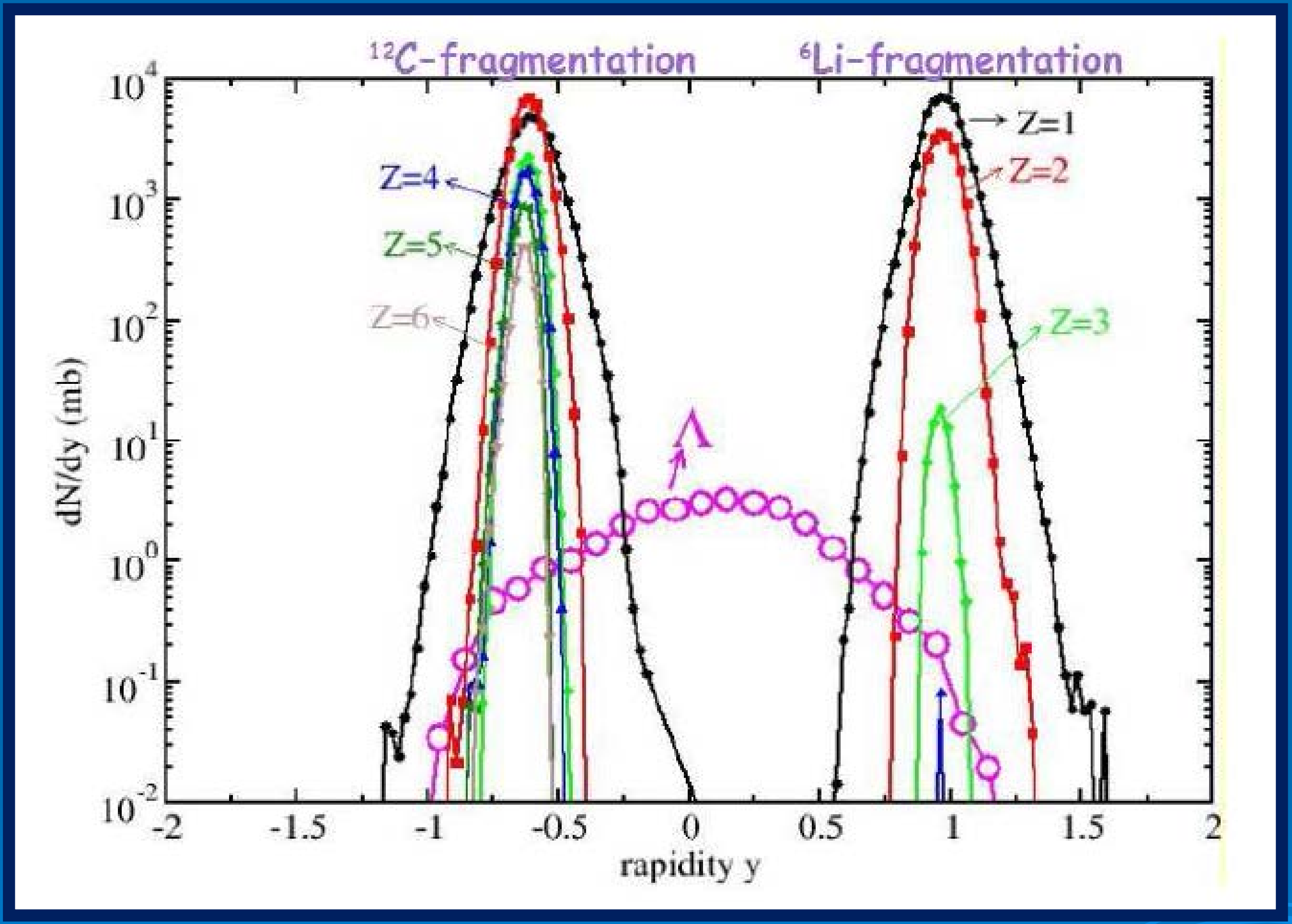


…see also:

Christoph Hartnack *et al.*
Physics Reports 510 (2012) 119-

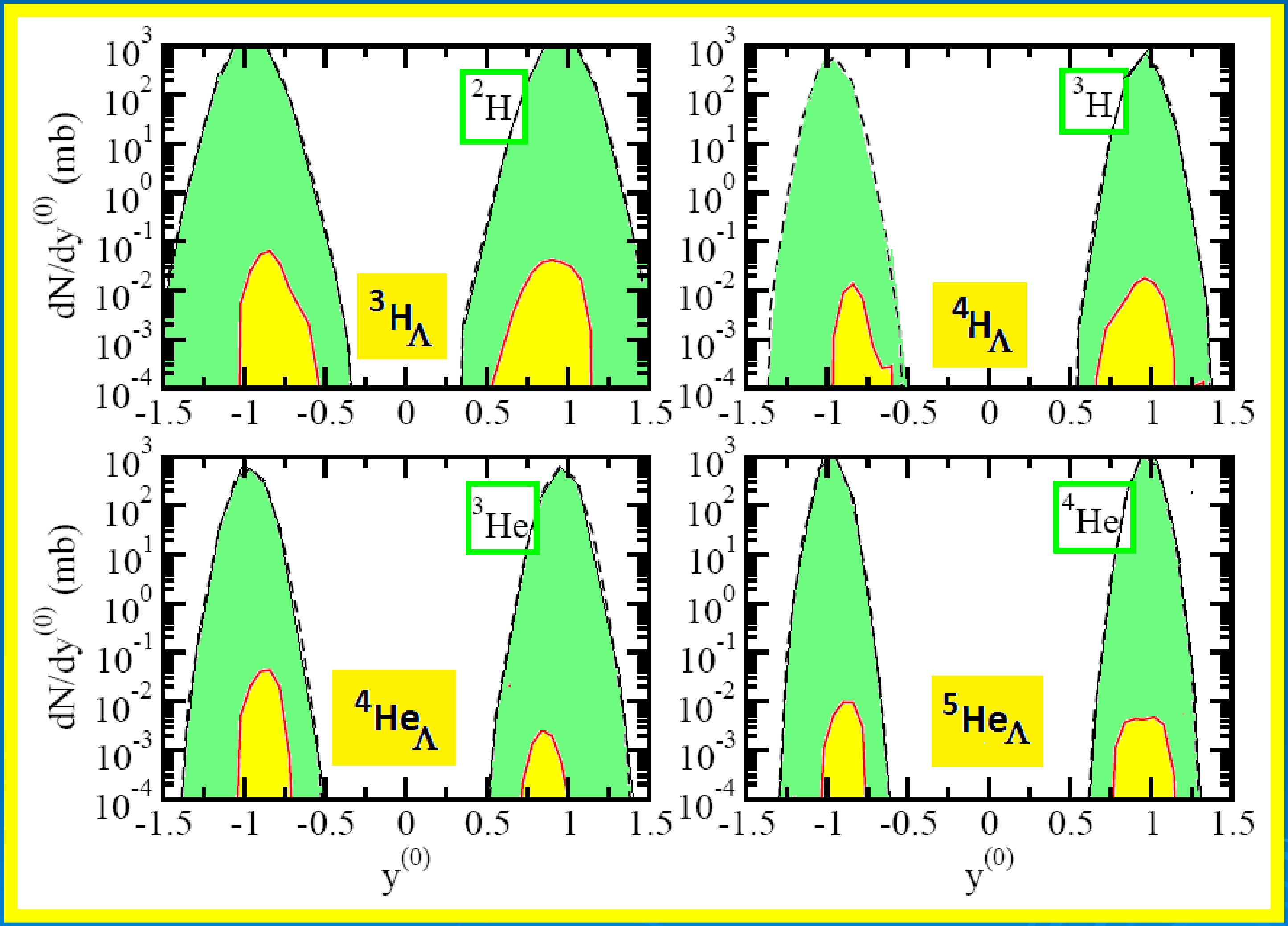
Production of Fragments and Hyperons in $^{6}Li+^{12}C$@2AGeV

(Experiments by HypHI Collaboration@(S)FRS)



- Fragment distributions from projectile and target
- Overlapping distributions of Λ hyperons and fragments
- Formation of hypernuclei by capture

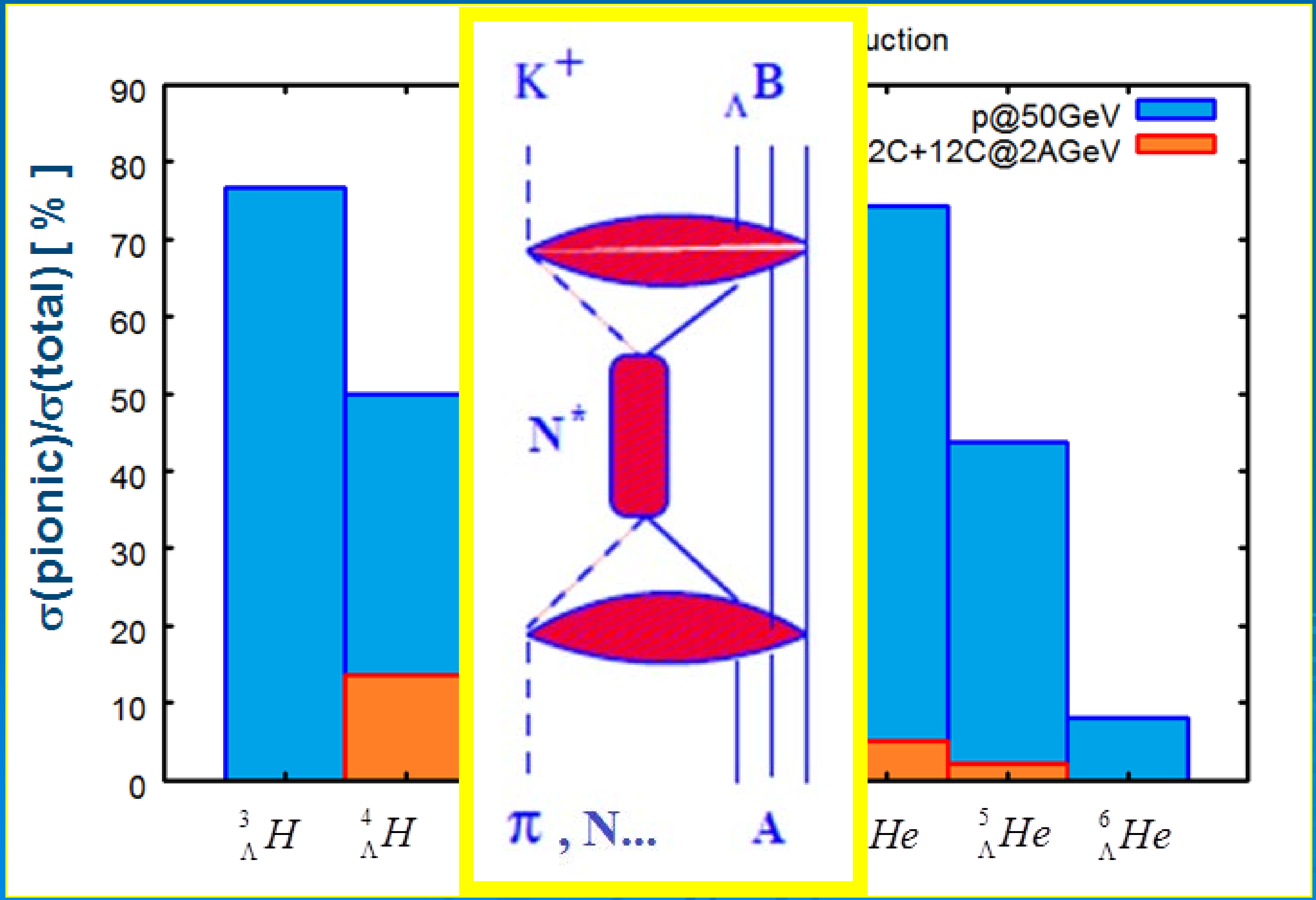
Production of Hypernuclei in $^{12}C+^{12}C$@2AGeV



Th. Gaitanos, HL et al., Phys. Lett. B 675, 297 (2009), NPA 914 (2013) 405; PLB 737 (2014) 256, NPA 954 (2016) 308; J.Mod.Phys. In print

Where do the Hyperons come from?

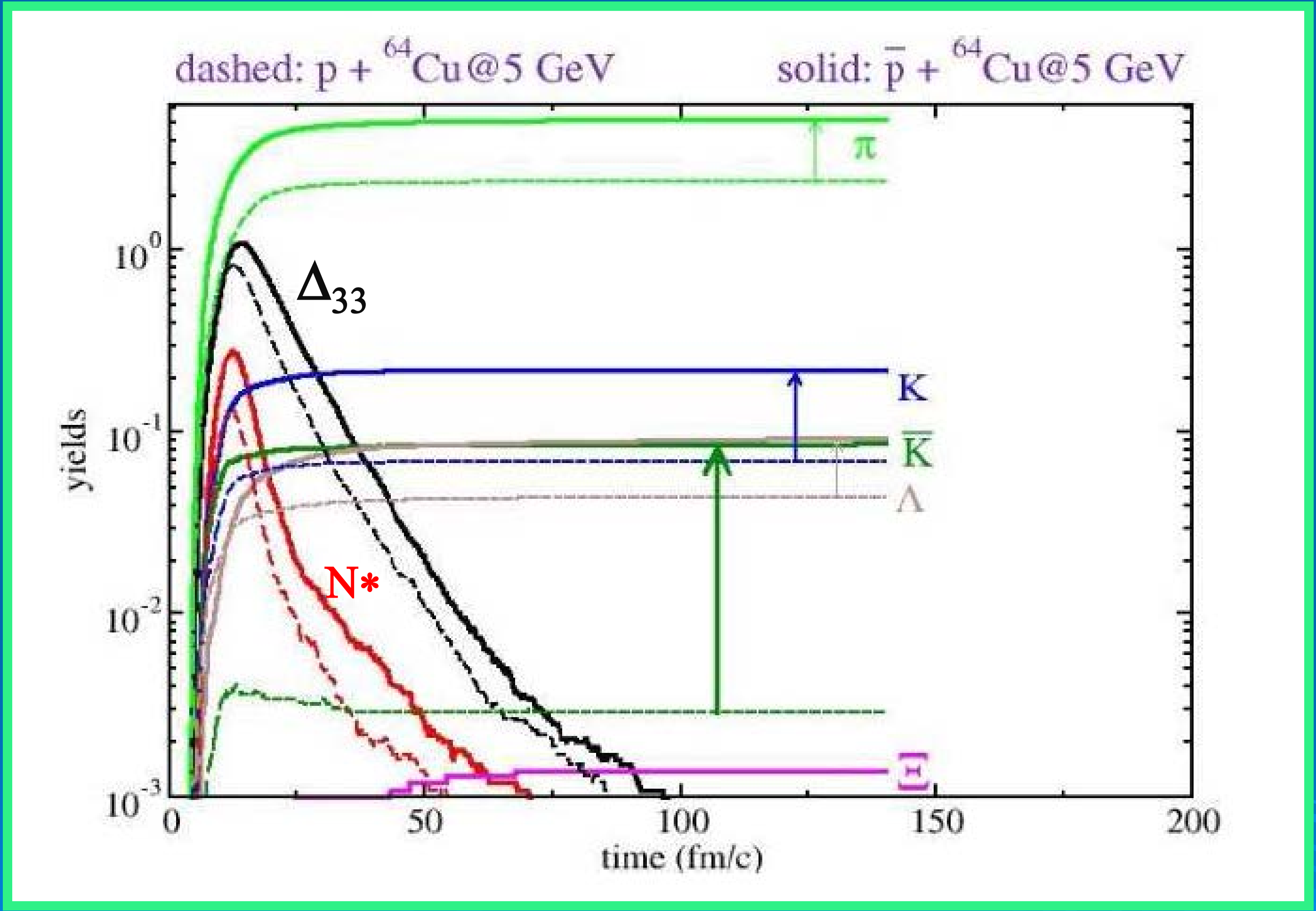
- primary (resonance) production: N+N→N+N*→N+Y+K
- secondary (pionic/mesonic) production: π+N→N*→Y+K



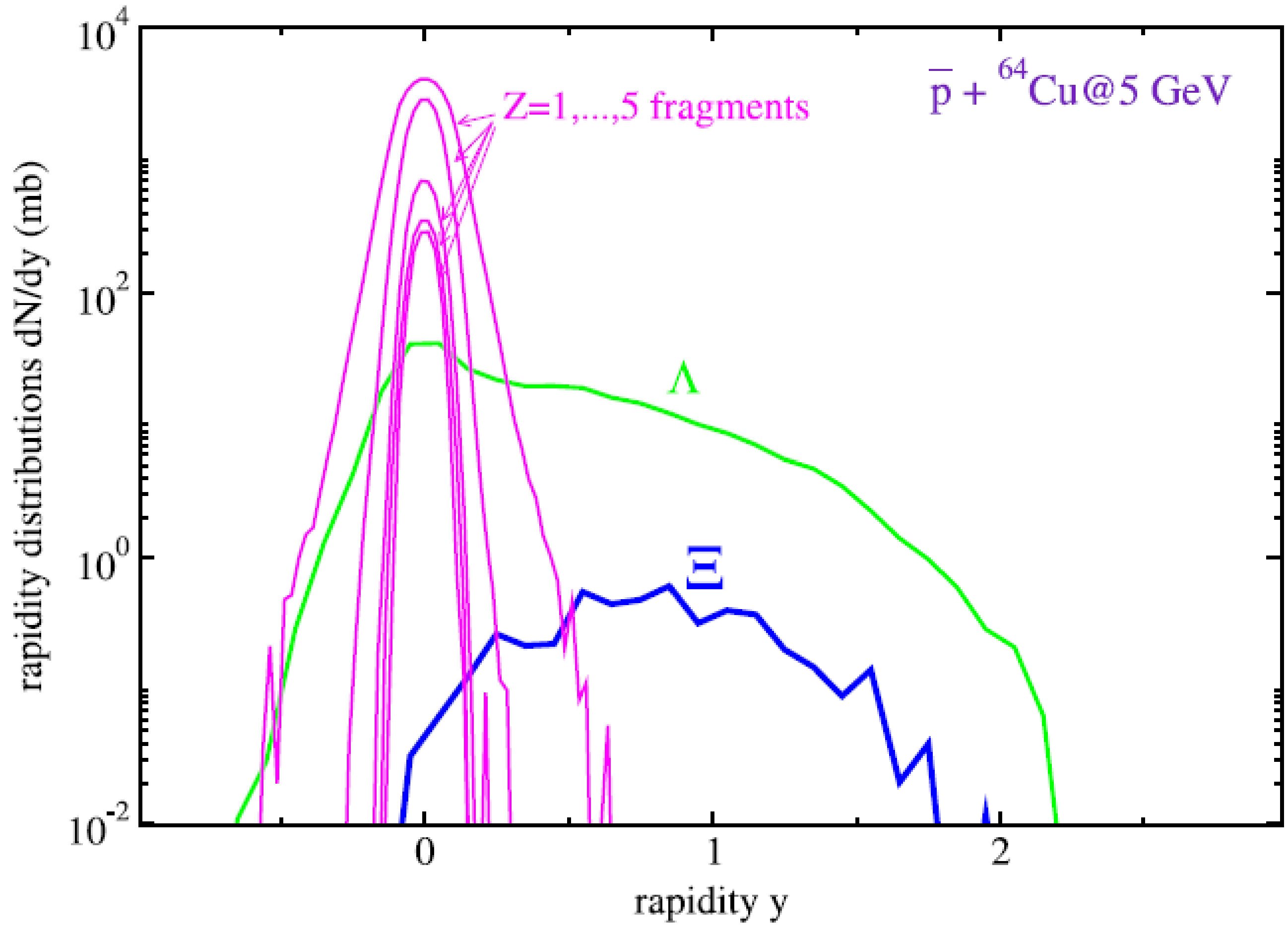
Th. Gaitanos, HL, et al., Phys. Lett. B 675, 297 (2009))

Multistrange Hypernuclei from Antiproton-Annihilation

Time Evolution and Strangeness Yield

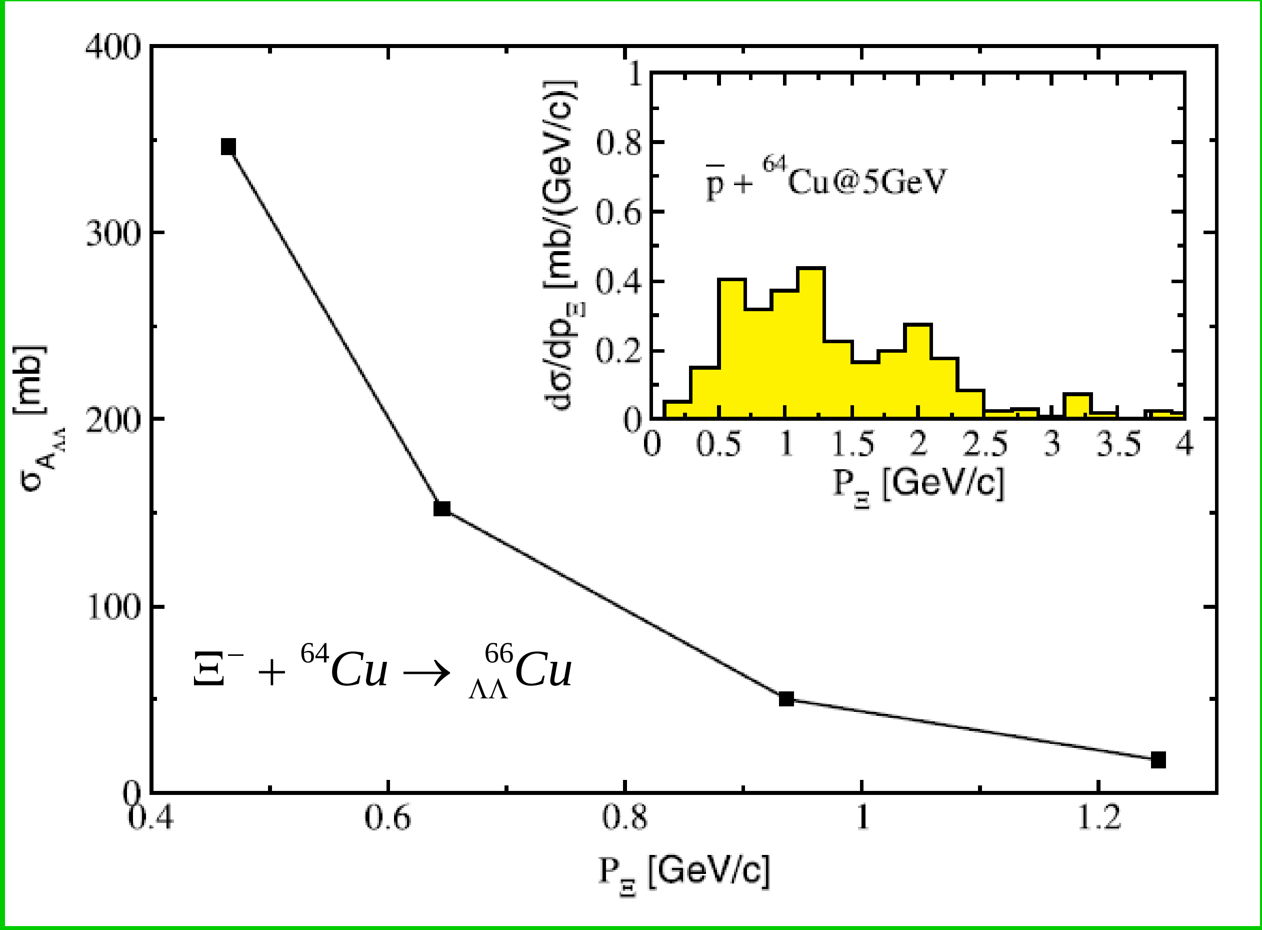


Fragment Rapidity Distributions



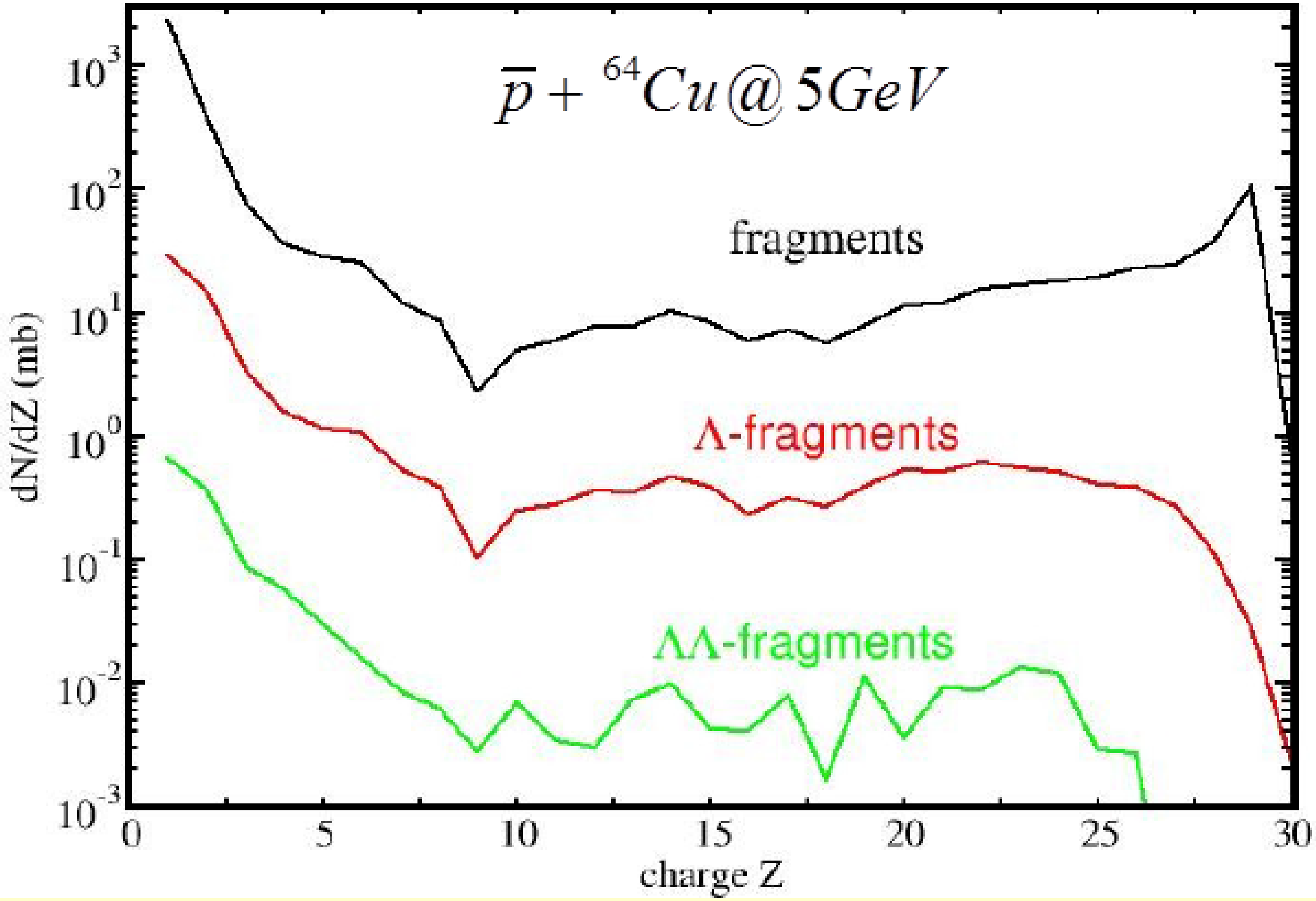
GiBUU + SMM calculations for the rapidity distributions of fragments with charge $Z = 1, \ldots, 5$ and hyperons with strangeness $S = -1$ (Λ) and $S = -2$ (Ξ), as indicated, for inclusive $\bar{p} + \mathrm{Cu}@5$ GeV reactions.

Hypernuclei@PANDA
ΛΛ Nucleus Formation by Ξ secondary beams

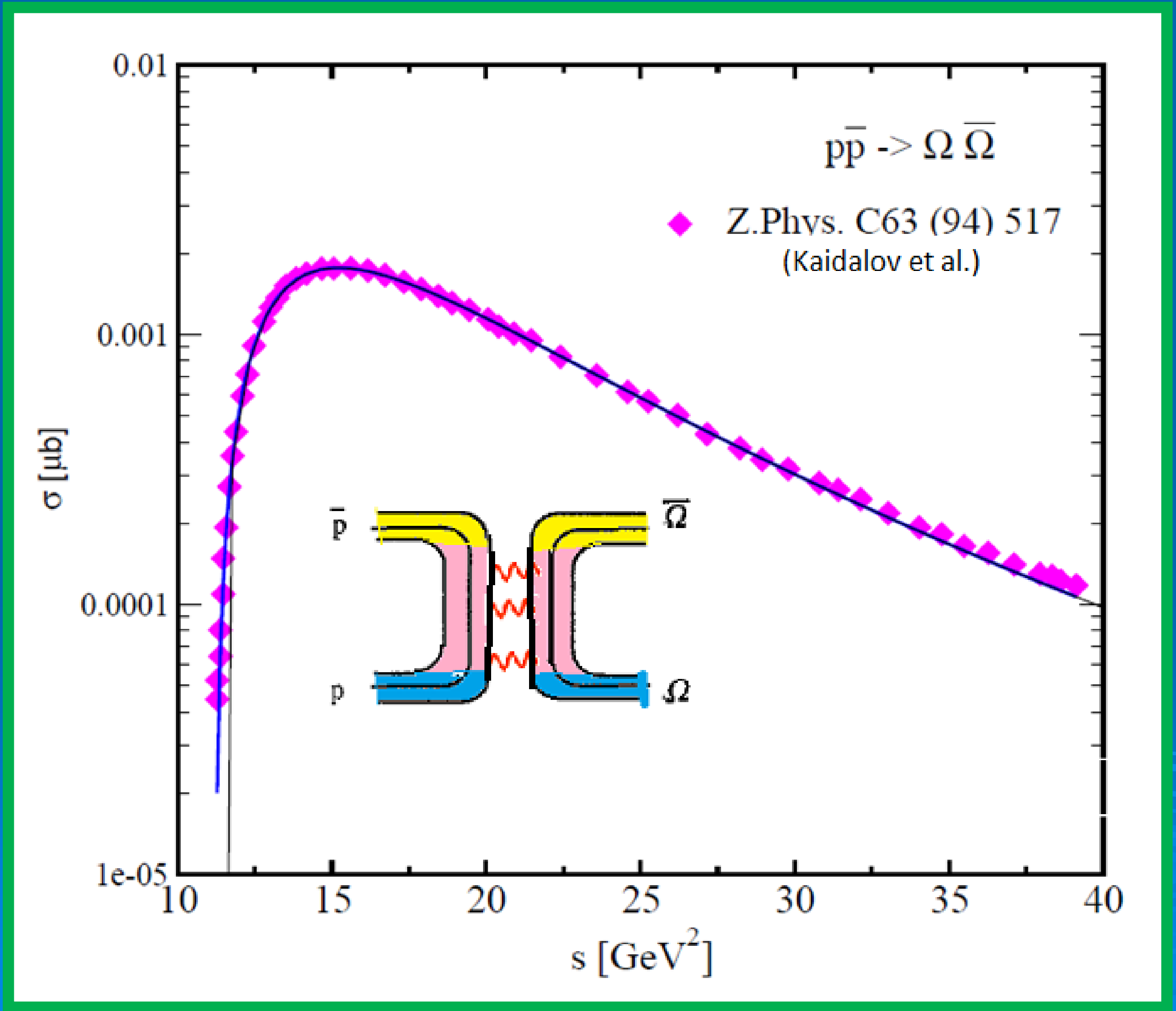


The insert panel shows the Ξ-production cross section from $\bar{p}$-collisions on the first target, as indicated.

Hypernuclei@PANDA
S=-1 and S=-2 Hypernuclear Yields in Antiproton Annihilation on a Nucleus

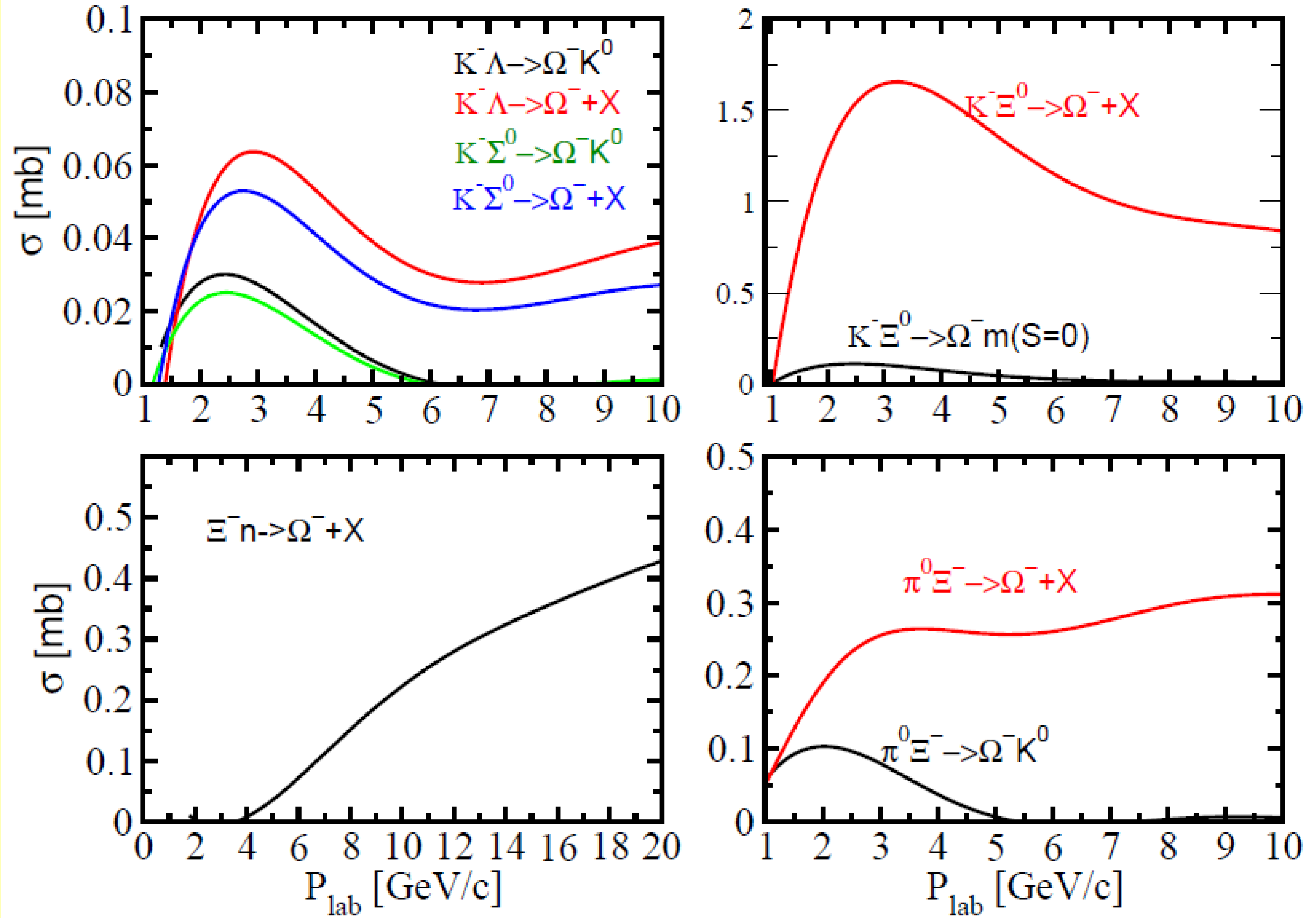


S=-3 Ω(1672)-Production in Antiproton-Proton Annihilation: Direct Production?



Secondary and *Ternary* Routes to Nuclear Ω^- - Production

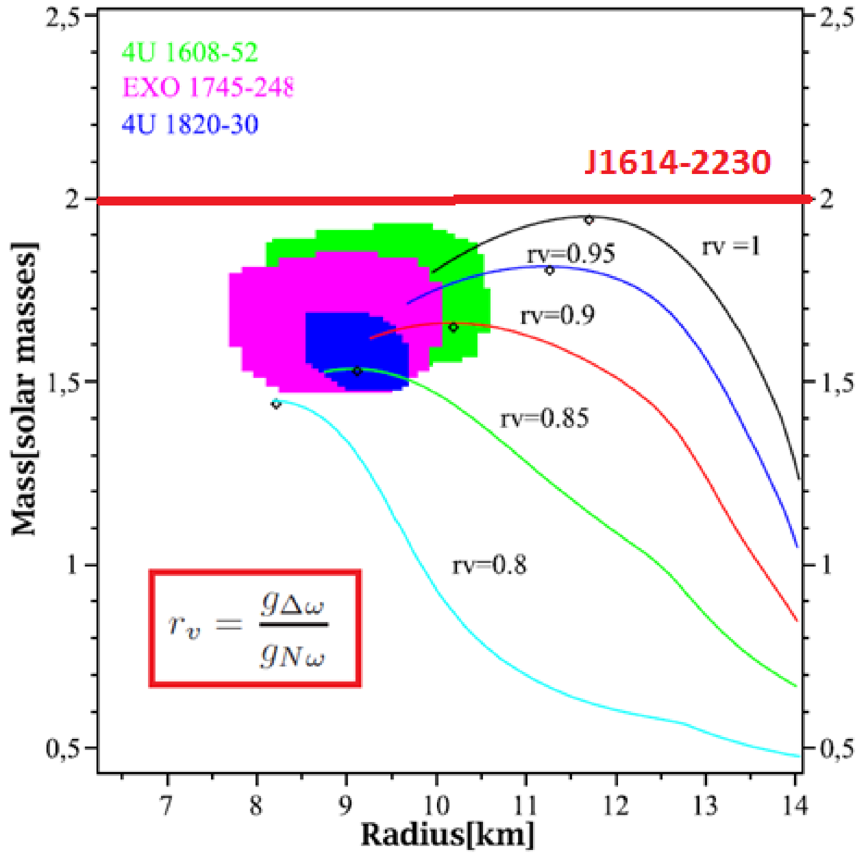
Dominance of Strangeness Accumulation:



NPA 954 (2016) 308; J.Mod.Phys. In print

Nucleon Resonance Excitation in Heavy Ion Collisions

The „Resonance Puzzle"
Δ's in Neutron Stars



Mass-Radius-relationship of Neutron stars for various couplings of the Δ resonances, starting from $r_v = 1$ (upper line) to 0.8 (lowest line). Also included are the 1-σ errorbars for measured neutron stars . The black diamond on each curve represents the maximum stable configuration

Schürhoff, Schramm,Dexheimer, 2010; A. Drago et al. (2014), HL, J. Wilhelm (2016),…

Nucleon Resonance Excitation in HI-SCE Reactions at the FRS@GSI

$^{112}_{50}Sn \rightarrow ^{112}_{49}In(p^{-1}n)$

$^{112}_{50}Sn \rightarrow ^{112}_{51}Sb(n^{-1}p)$

Projectile:

np^{-1}

$\Delta^0 p^{-1}$

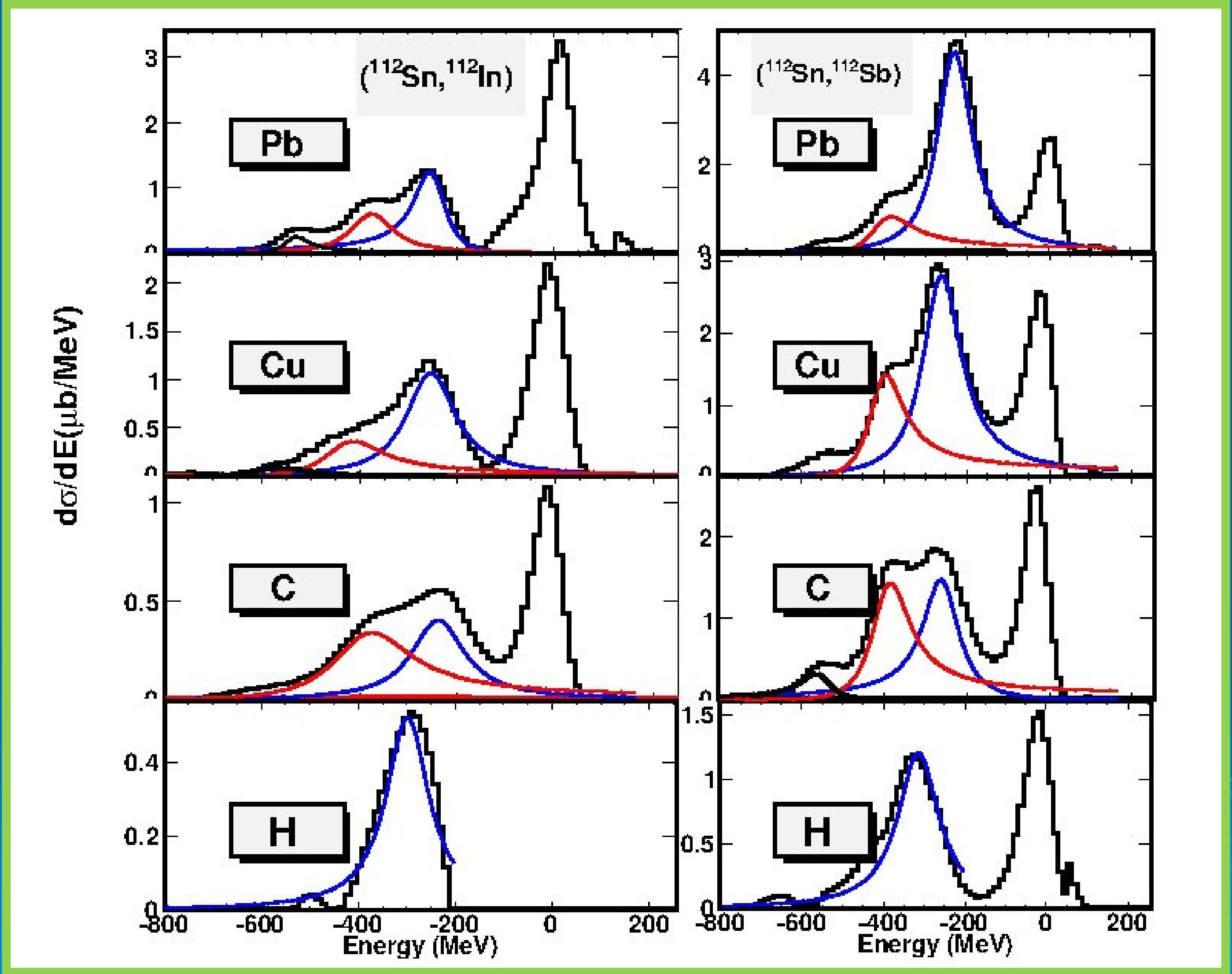
$\Delta^- n^{-1}$

Target:

pn^{-1}

$\Delta^+ n^{-1}$

$\Delta^{++} p^{-1}$



Projectile:

pn^{-1}

$\Delta^+ n^{-1}$

$\Delta^{++} p^{-1}$

Target:

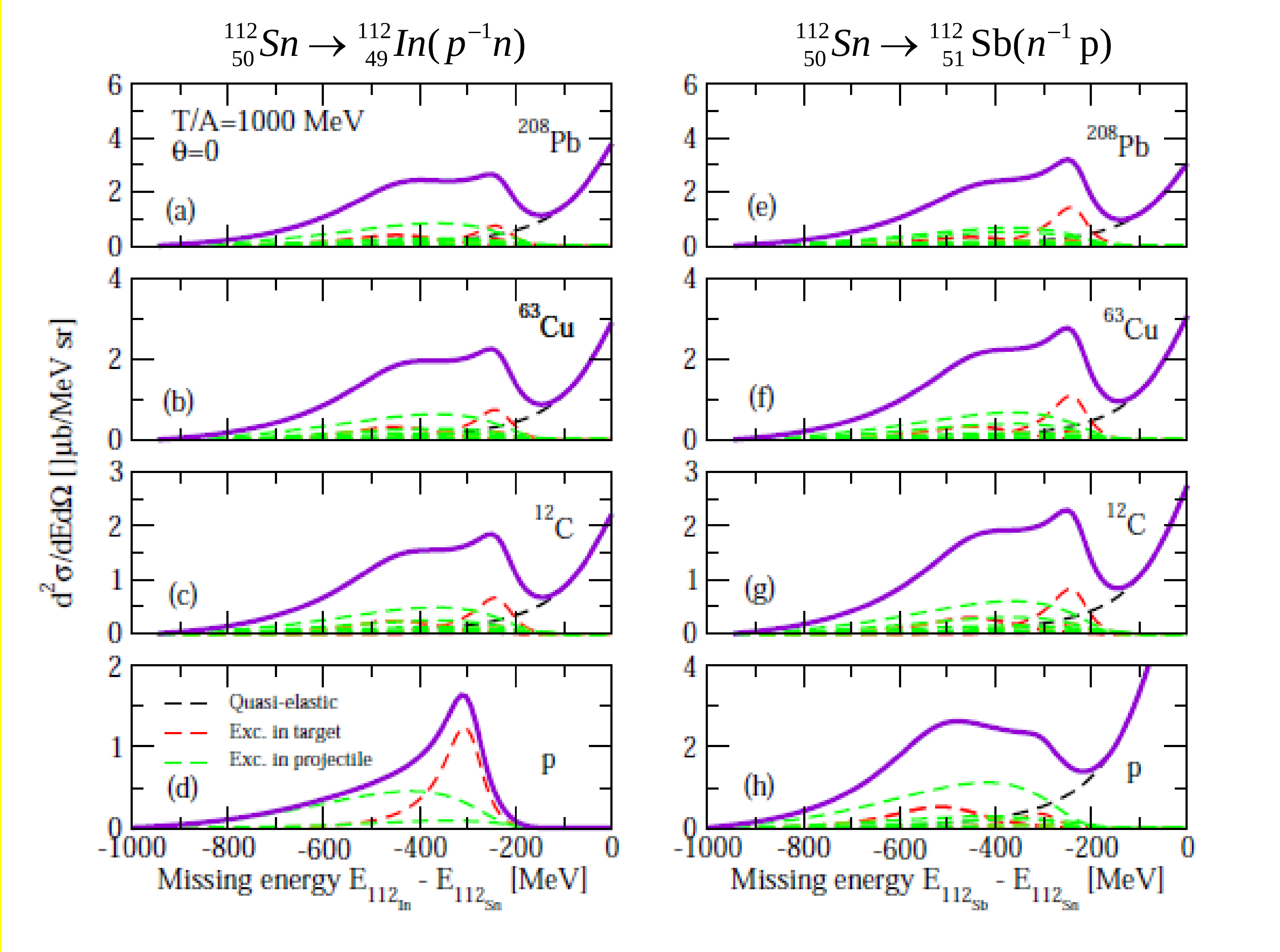
np^{-1}

$\Delta^0 p^{-1}$

$\Delta^- n^{-1}$

Data: J. Benlliure et al., JPS Conf. Proc. 6, 020039 (2015). (S363 collaboration)

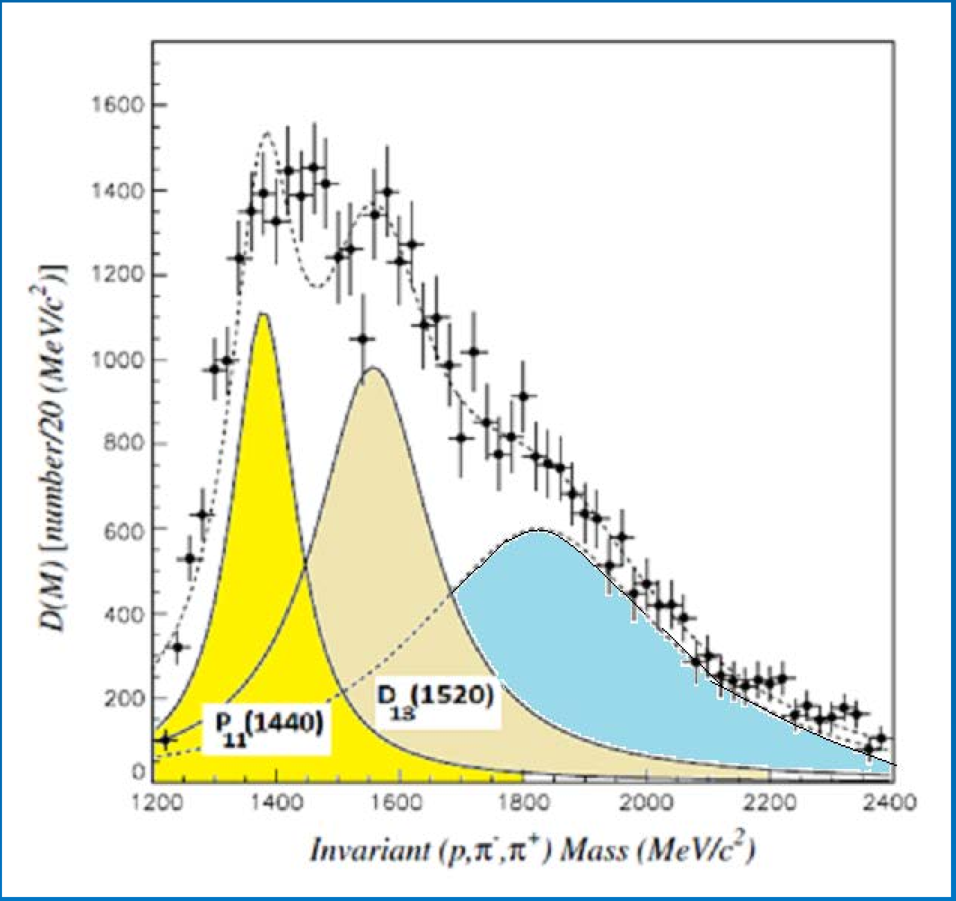
Results for SCE Reaction of ^{112}Sn on various Targets



I. Vidana, H. Lenske et al., EPJ WoC 107, 100030 (2016)

Higher Resonances In peripheral A+A Collisions: Dubna Synchrophasotron $^{12}C+^{12}C$ @ 4.2 AGeV

(Krpic et al., EPJ A20 (2004) 351)



	M (MeV/c^2)	Γ (MeV/c^2)
$N(1440)$	1380 ± 10	130 ± 20
$N(1520)$	1550 ± 20	230 ± 30
The 3rd peak	1810 ± 30	510 ± 40

Summary and Outlook

- **Strangeness production through baryon resonances**
- **Heavy Ion collisions and hypernuclear fragmentation**
- **Multi-Strangeness S=-2,-3 production by antiprotons**
- **Dominance of hadronic strangeness accumulation scenarios**
- **Nucleon resonance production in HI collisions**
- **Charmed mesons and hyperons (**→ PRD (2015), PRD (2016)**)**

…together with:

Madhumita Dhar, Theo Gaitanos, Alexei Larionov, Radhey Shyam, Issac Vidana

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