WARPING UP REALITY

L. Fabbietti, EMMI Workshop, Bound states and particle interactions in the 21st century

$\Lambda\Lambda$ interactions from lattice QCD and H-Dibaryon

Hartmut Wittig

- hadron spectrum is computed starting from **Correlators**

$$\sum_{x,y} e^{ip\cdot(y-x)} \left\langle O_{\rm had}(y)\, O^\dagger_{\rm had}(x) \right\rangle = \sum_n w_n(\boldsymbol{p})\, e^{-E_n(\boldsymbol{p})(y_0-x_0)} \xrightarrow{(y_0-x_0)\to\infty} w_1(\boldsymbol{p})\, e^{-E_1(\boldsymbol{p})(y_0-x_0)}$$

- Operators O: baryon or Hexaquark operators
  - Note: Hexaquark operators lead to slower convergence to the ground state

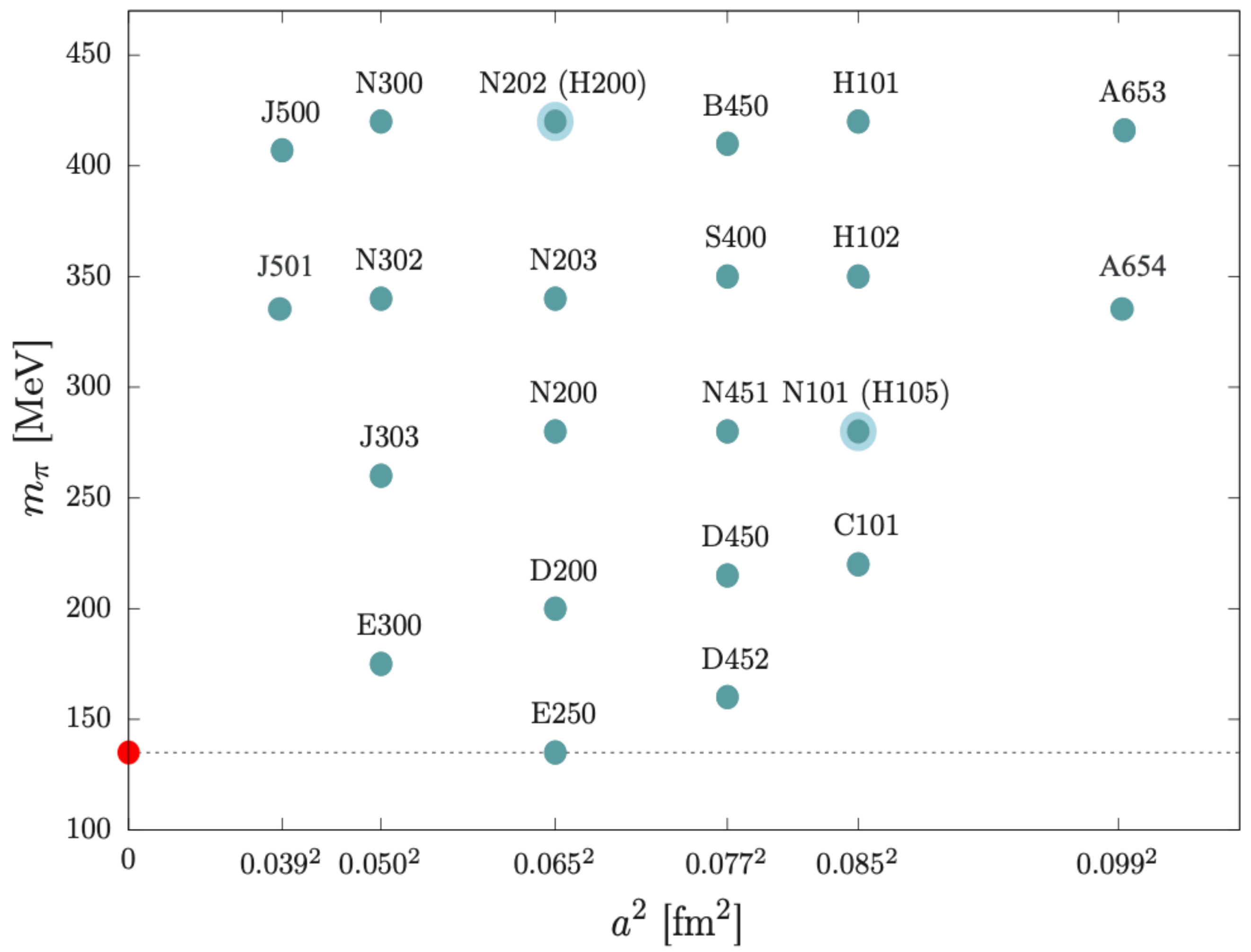
- How to get the poles of the scattering amplitude?

Calculate **Energy values** from correlator matrix → Evaluate scattering momentum → Determine the pole

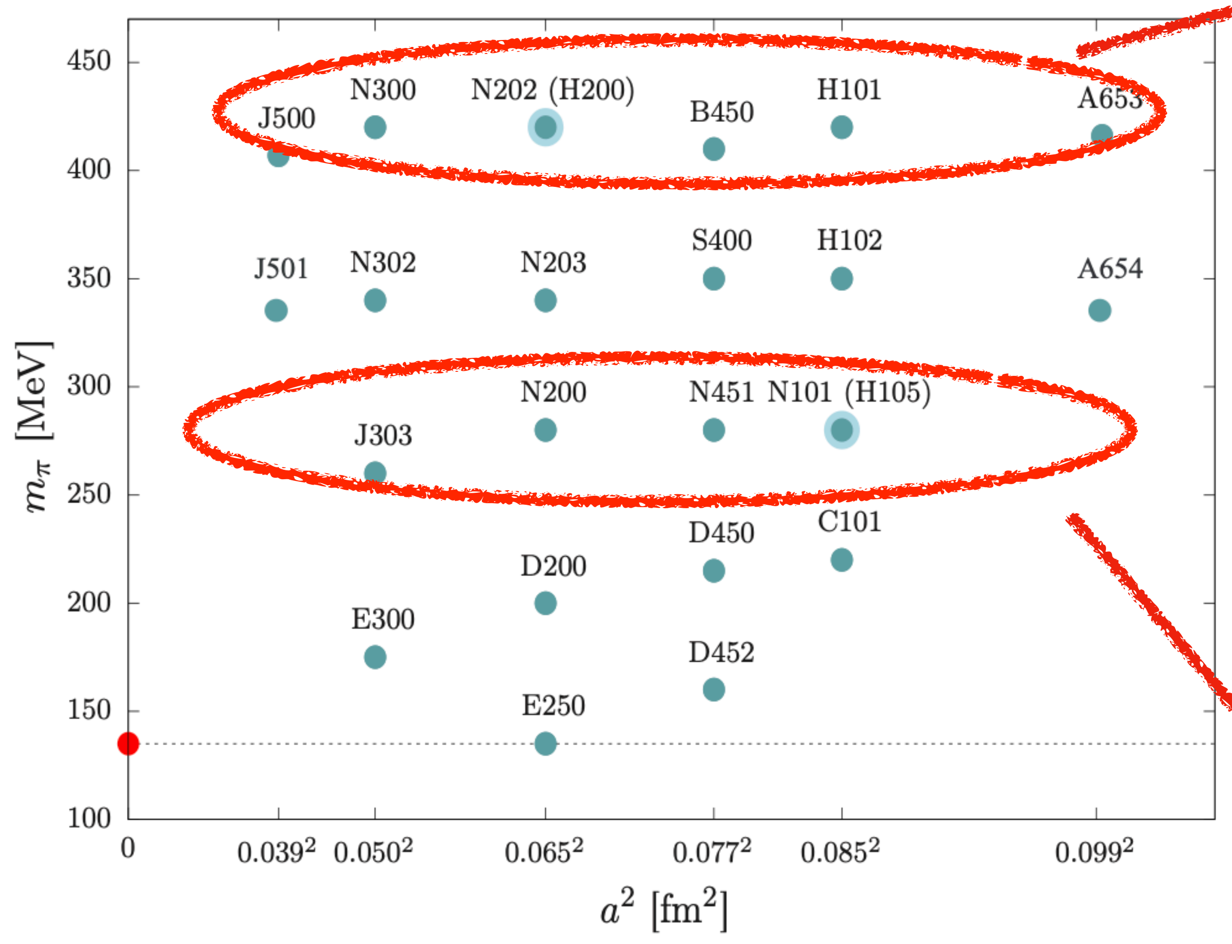
$$p^2 = \tfrac{1}{4}(E_L^2 - \boldsymbol{P}\cdot\boldsymbol{P}) - m_\Lambda^2$$

$$\mathcal{A} \propto \frac{1}{p\cot\delta(p) - ip}$$

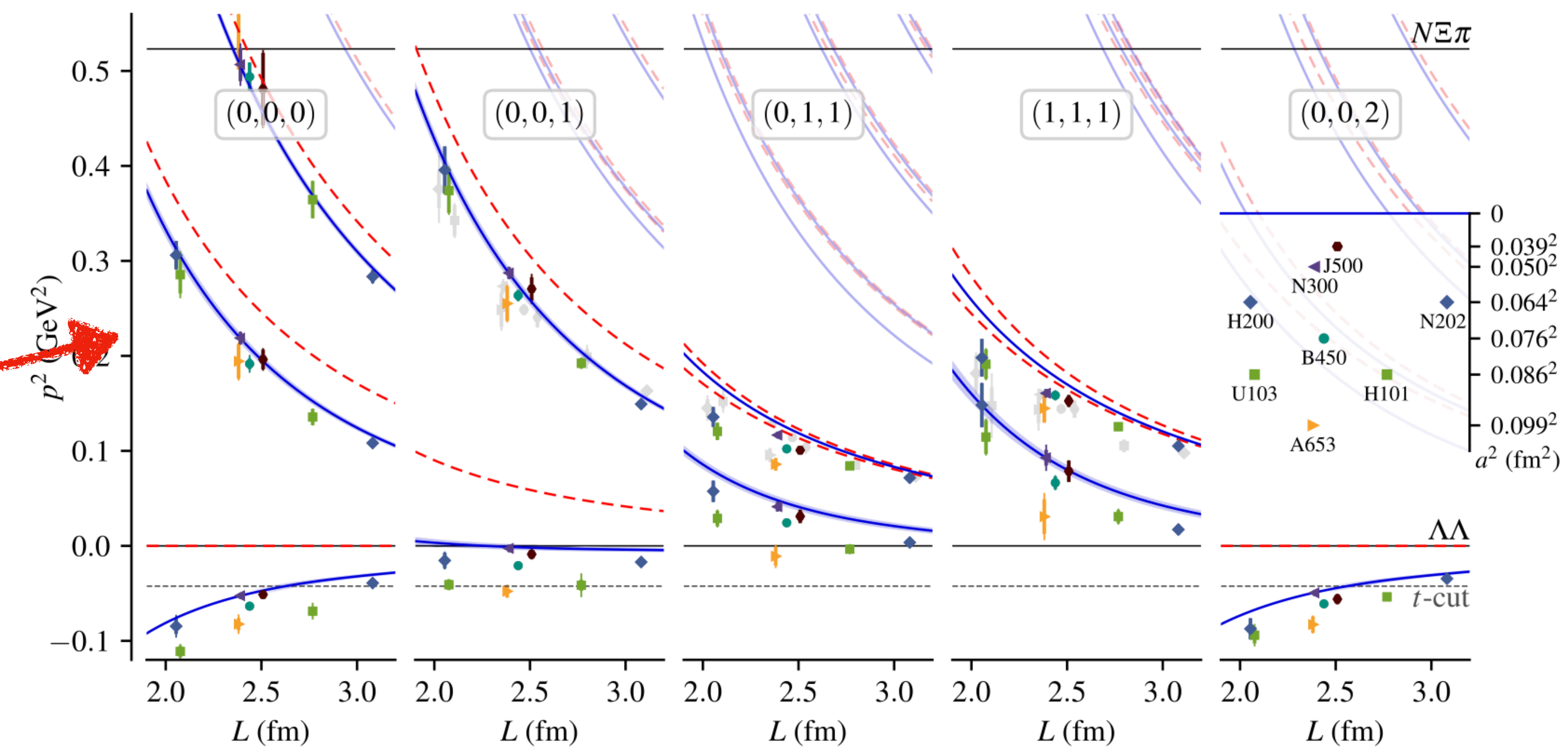
Six lattice spacings: a = 0.099 - 0.039 fm, pion masses = 130 -420 MeV



H. Wittig



Scattering momenta in finite volume in different frames: $p^2 = \frac{1}{4}(E_L^2 - \boldsymbol{P}\cdot\boldsymbol{P}) - m_\Lambda^2$

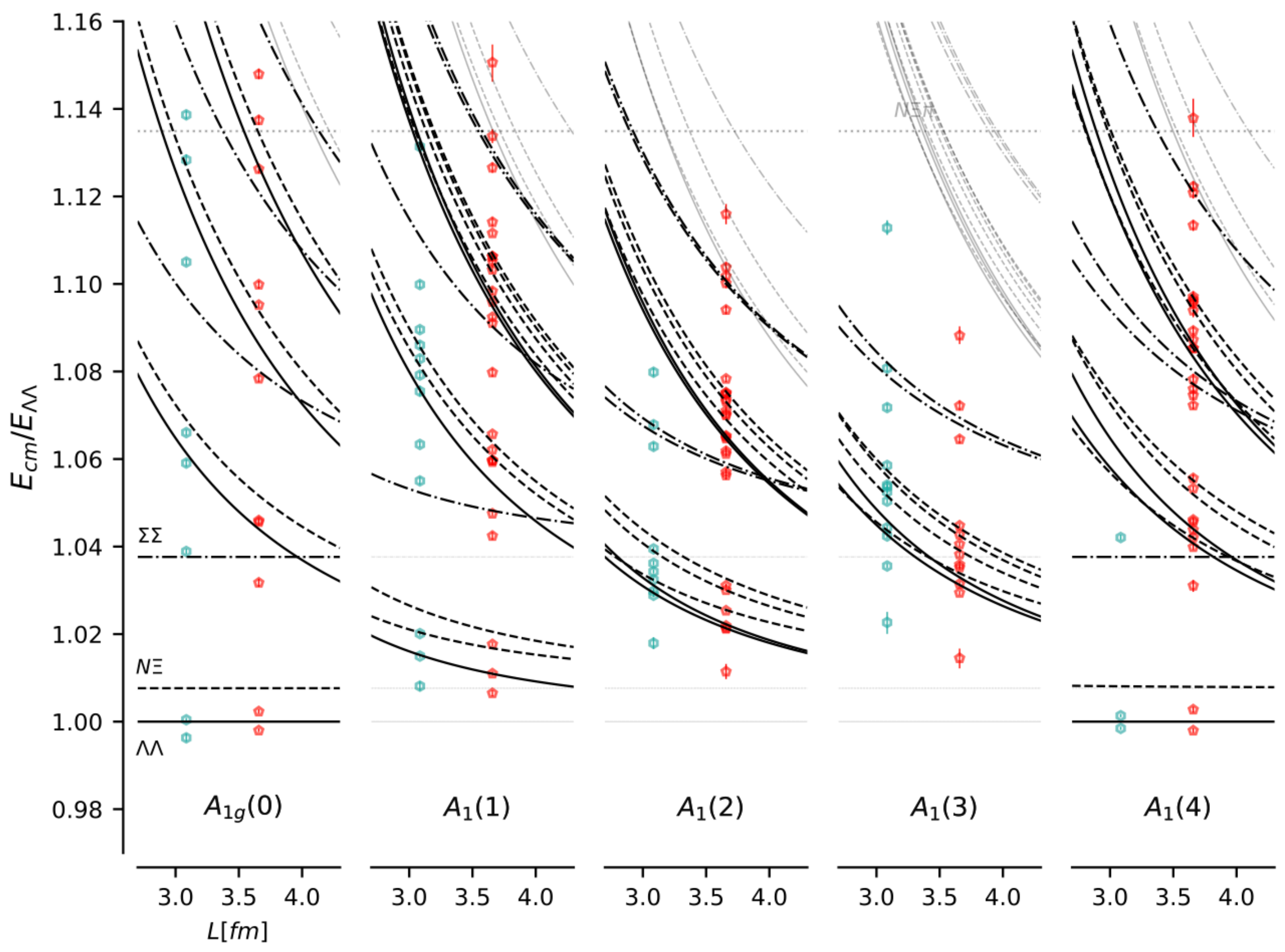


: interacting spectrum in continuum limit

: non-interacting levels

Finite-volume energy levels at decreasing pion mass:

[M. Padmanath et al., a

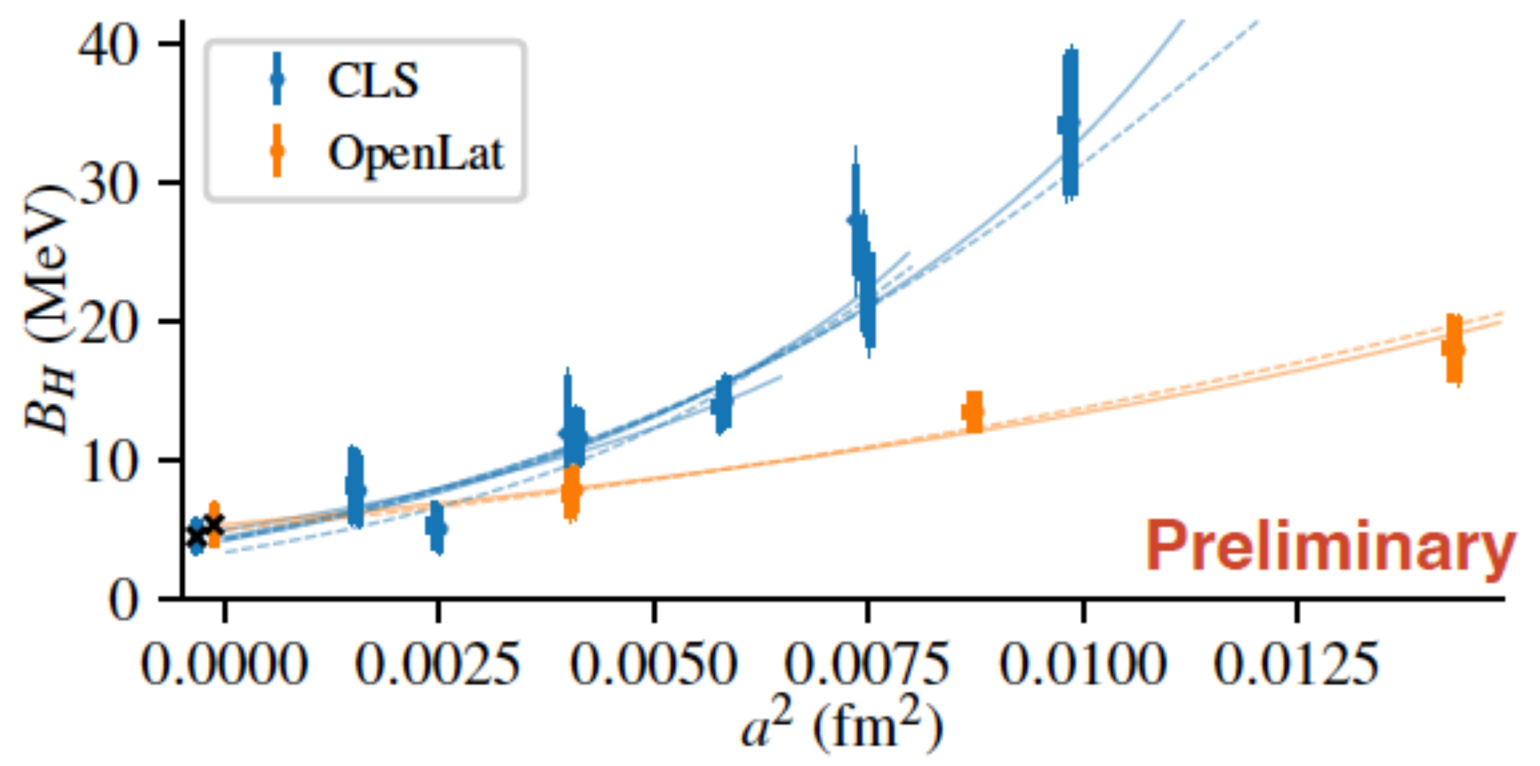


$m_\pi \sim 280$ MeV, $L = 3.1, 3.6$ fm

$a = 0.0642, 0.0762$ fm

: non-interacting levels

Money plot



$$B_H^{N_f=3} = \begin{cases} 4.56 \pm 1.13 \pm 0.63\,\text{MeV} & \text{CLS} \\ 5.41 \pm 1.56 \pm 0.24\,\text{MeV} & \text{OpenLat} \end{cases}$$

Remarks on H-dibaryon and update on ΛNN content of V_Λ

Avraham Gal

ELUSIVE Dibaron

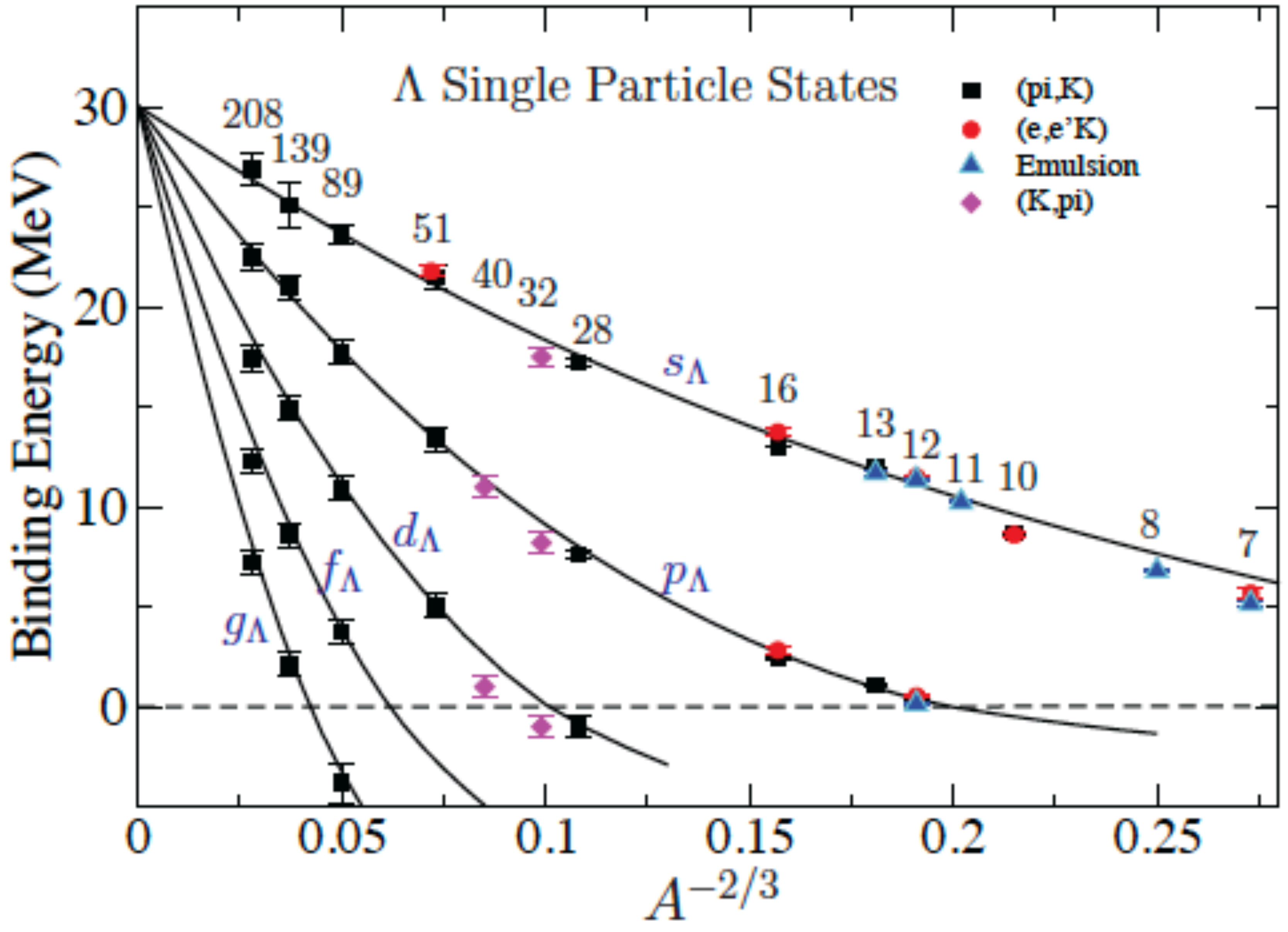
- No direct signal yet
- Femtoscopy studies constrain $\Lambda\Lambda$ scattering lenght
- Direct decay searches dont show any signal but did not explore the full phase space with sufficient precision
- Belle and Babara ruled out BS (Y(2S, 3S) decays above the $\Lambda p \pi^-$ and below Λn
- Double- Λ hypernuclei constrain the upper limit of the BE = 7 MeV

Both Gal and Wittig consider the hypothesis of the dark-matter Hexaquark candidate as irrealistic (too large binding energy needed ~360

VLambda

- Starting point: fitting hypernuclei binding energies
- WS potential -> Depth of - 30 MeV

Update: Millener, Dover, Gal PRC 38, 2700 (1988)



Woods-Saxon $V = 30.05$ MeV, $r = 1.165$ fm, $a = 0.6$ fm

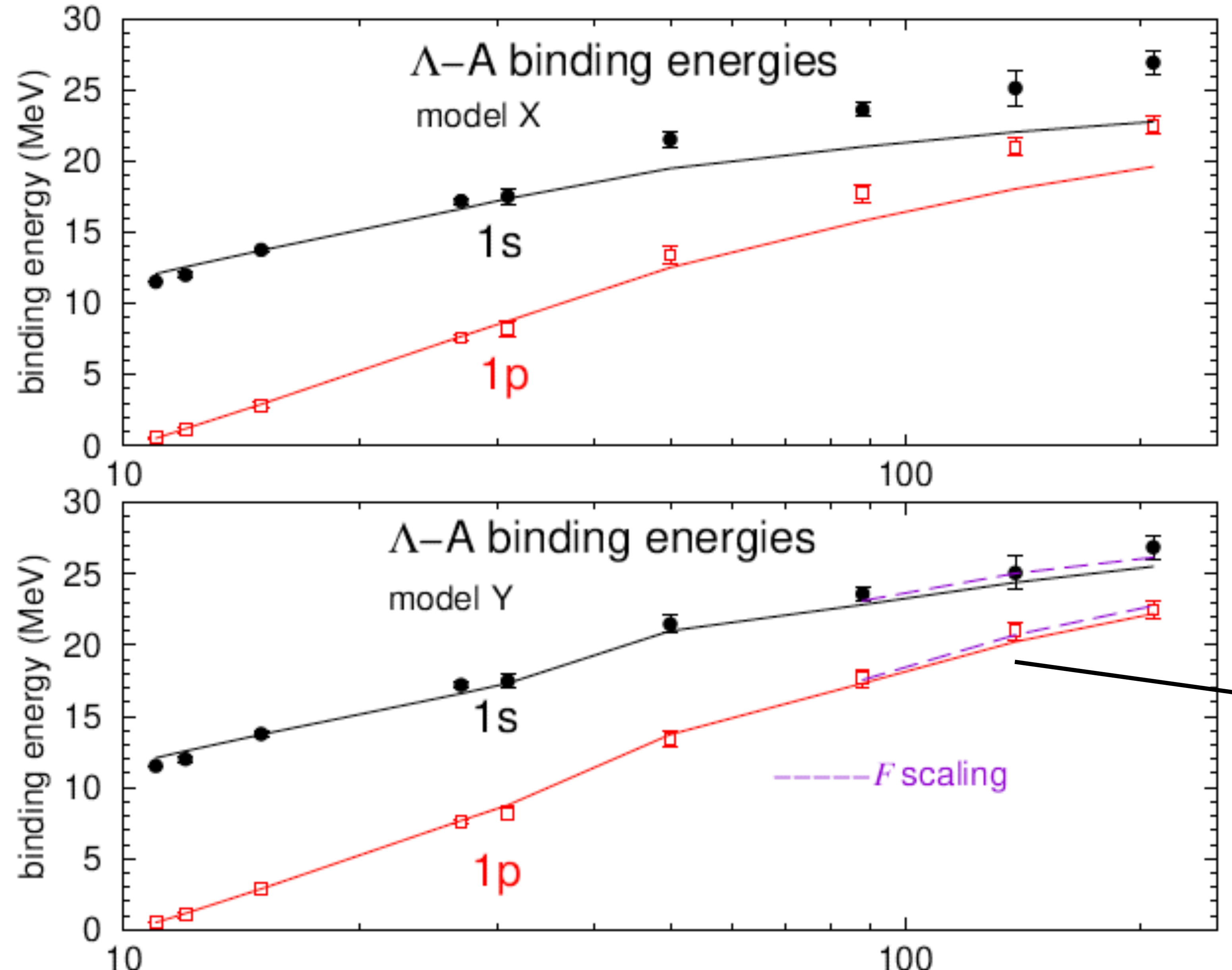
Remarks on H-dibaryon and update on ΛNN content of V_Λ

A. Gal

VLambda

- Most 2-body YN models are overbinding !
- NSC and ESC DL ~-40 MeV
- xEDT NLO19 (600) : -32.6 MeV
- xEDT N2LO23 : -33 - -38 MeV !!!
- -> Necessity of the 3-body repulsive force

Money Plot



Proposed solution: WRW Potential

$$\Lambda N \quad \Rightarrow \quad V_\Lambda^{(2)}(\rho) = -\frac{4\pi}{2\mu_\Lambda} b_0^{\rm lab}(\rho)\,\rho \qquad \rightarrow \rho^{4/3}$$

$$b_0^{\rm lab}(\rho) = \frac{b_0^{\rm lab}}{1+\frac{3k_F}{2\pi}b_0^{\rm lab}} \qquad b_0^{\rm lab} = (1+\frac{A-1}{A}\frac{\mu_\Lambda}{m_N})\,b_0$$

for Pauli correlations, with $k_F=(3\pi^2\rho/2)^{1/3}$.

$$\Lambda NN \quad \Rightarrow \quad V_\Lambda^{(3)}(\rho) = +\frac{4\pi}{2\mu_\Lambda}(1+\frac{A-2}{A}\frac{\mu_\Lambda}{2m_N})\,B_0\,\frac{\rho^2}{\rho_0}$$

UPDATE: Friedman-Gal, arXiv:2306.06973

$$\rho^2 = (\rho_{\rm sym}+\rho_{\rm exc})^2 \rightarrow (\rho_{\rm sym}^2+\rho_{\rm exc}^2).$$

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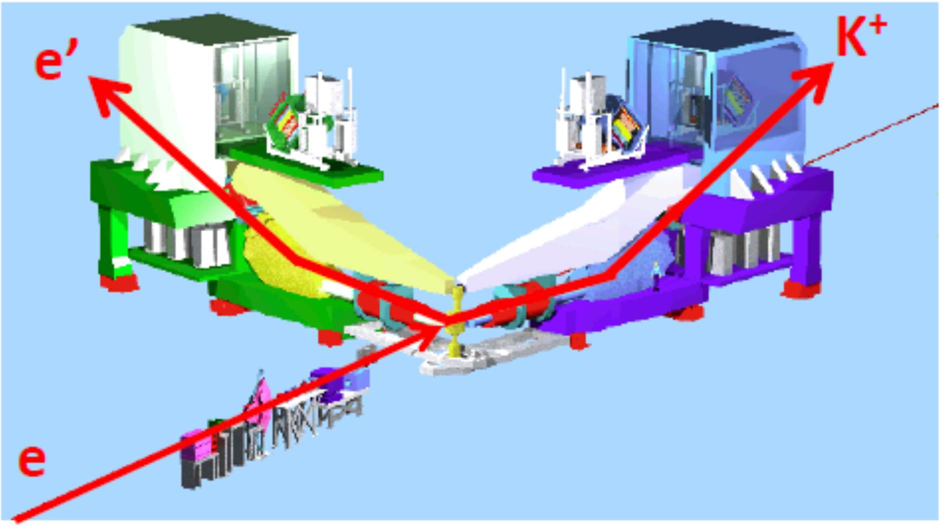
Searching for the possible Λnn resonance at JLAB

Liguang Tang

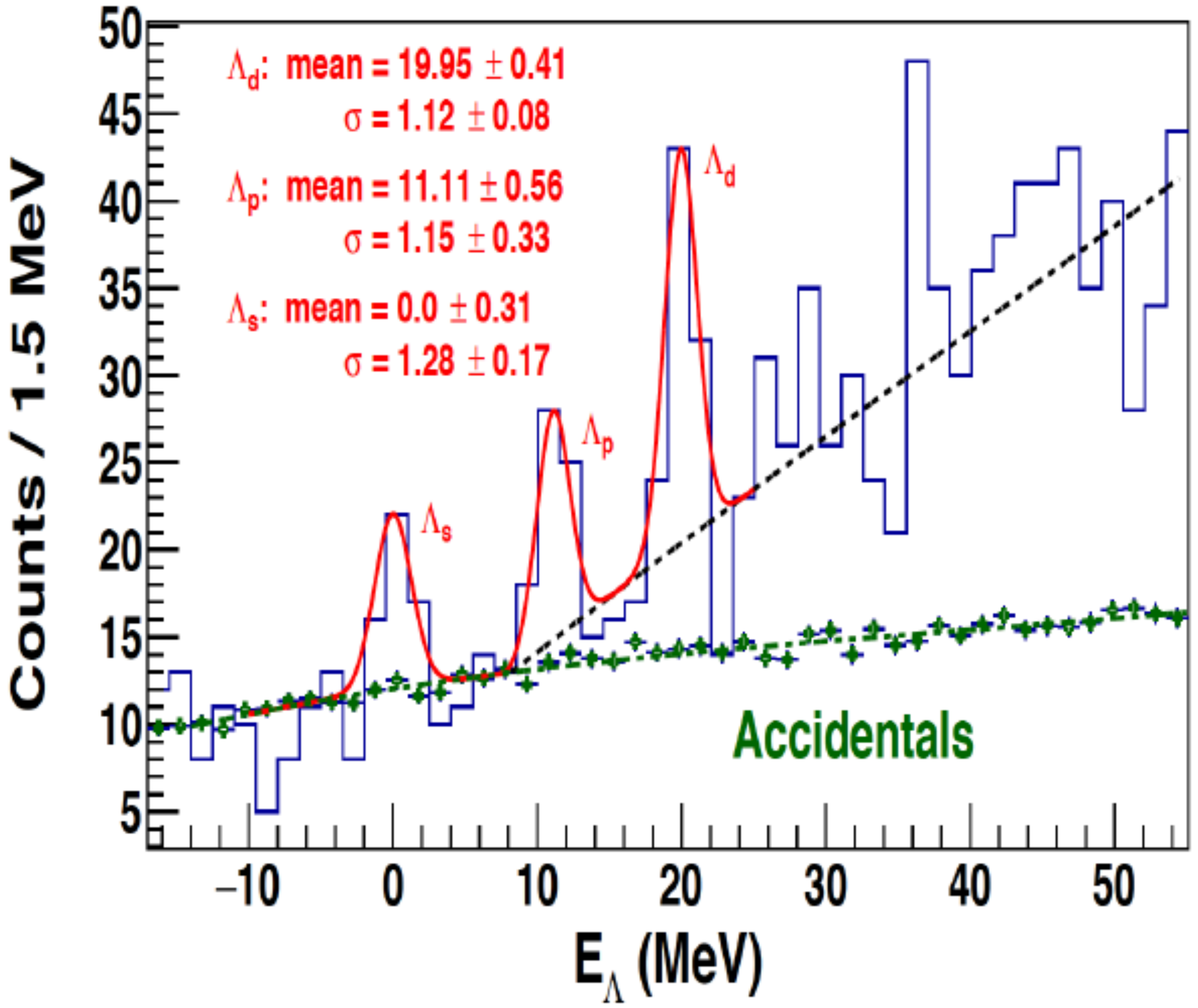
➢ Production: $^3H(e, e'K^+)(\Lambda nn)$ reaction.



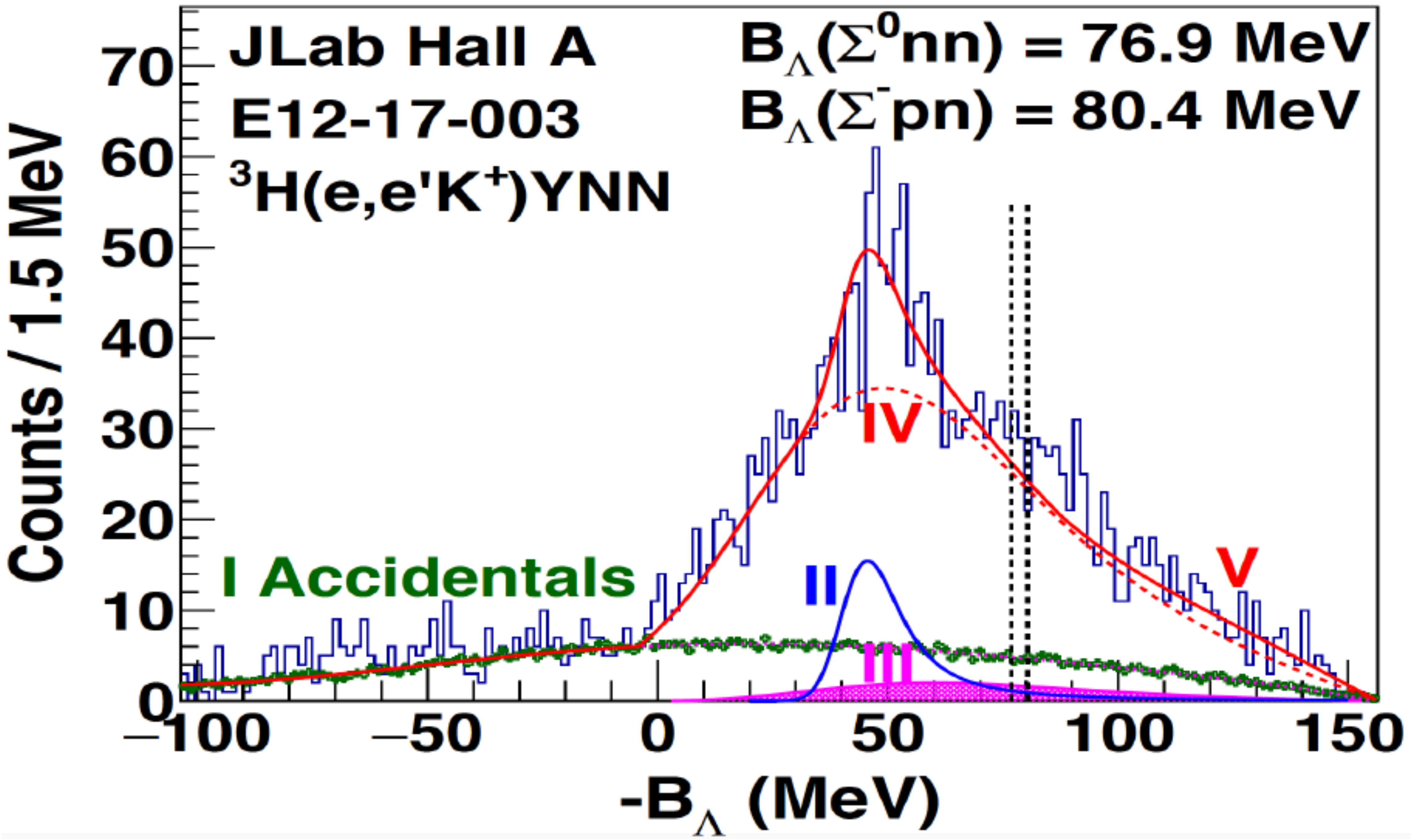
HRS path-length: 26 meters
L-HRS: Scattered electrons (e')
R-HRS: Reaction kaons (K+)
Beam Energy: 4.319 GeV
Cylindrical gas target: 25 cm

Calibration

Matrix optimization involving $^{27}{}_{\Lambda}Mg$ events



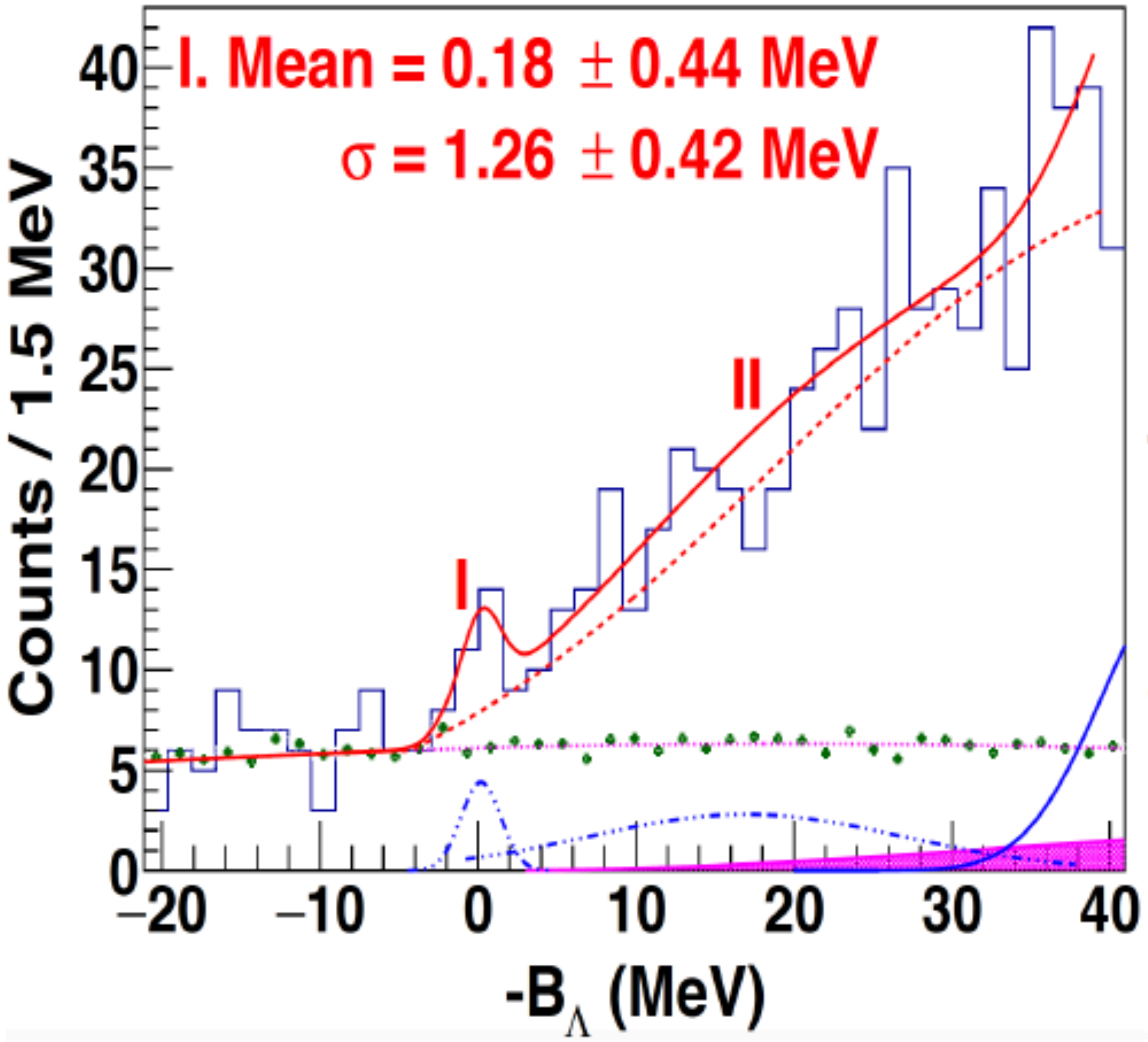
RESULTS – Λnn Spectrum

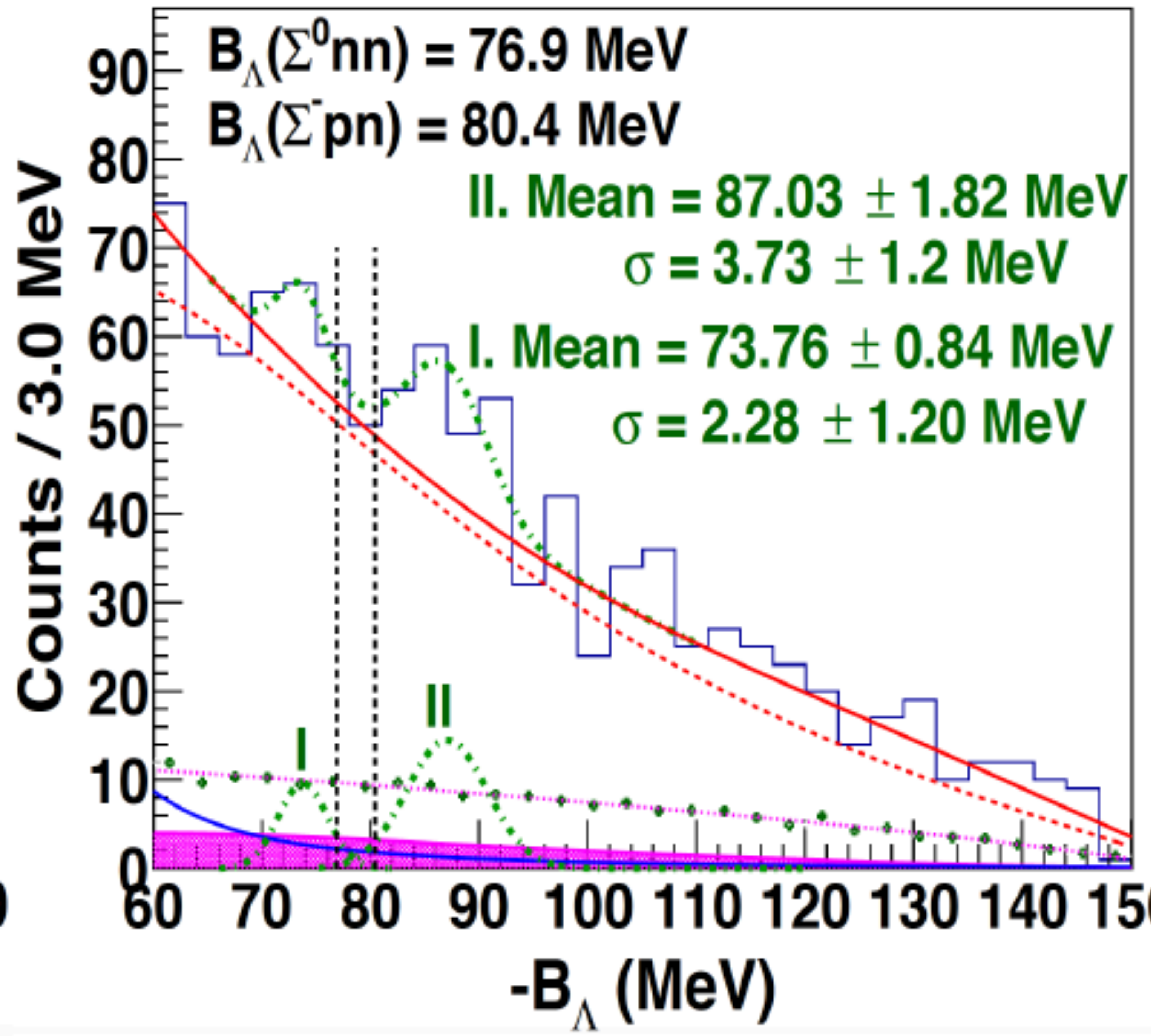


+ semi-exclusive analysis to evaluate the contamination coming

Searching for the possible Λnn resonance at JLAB

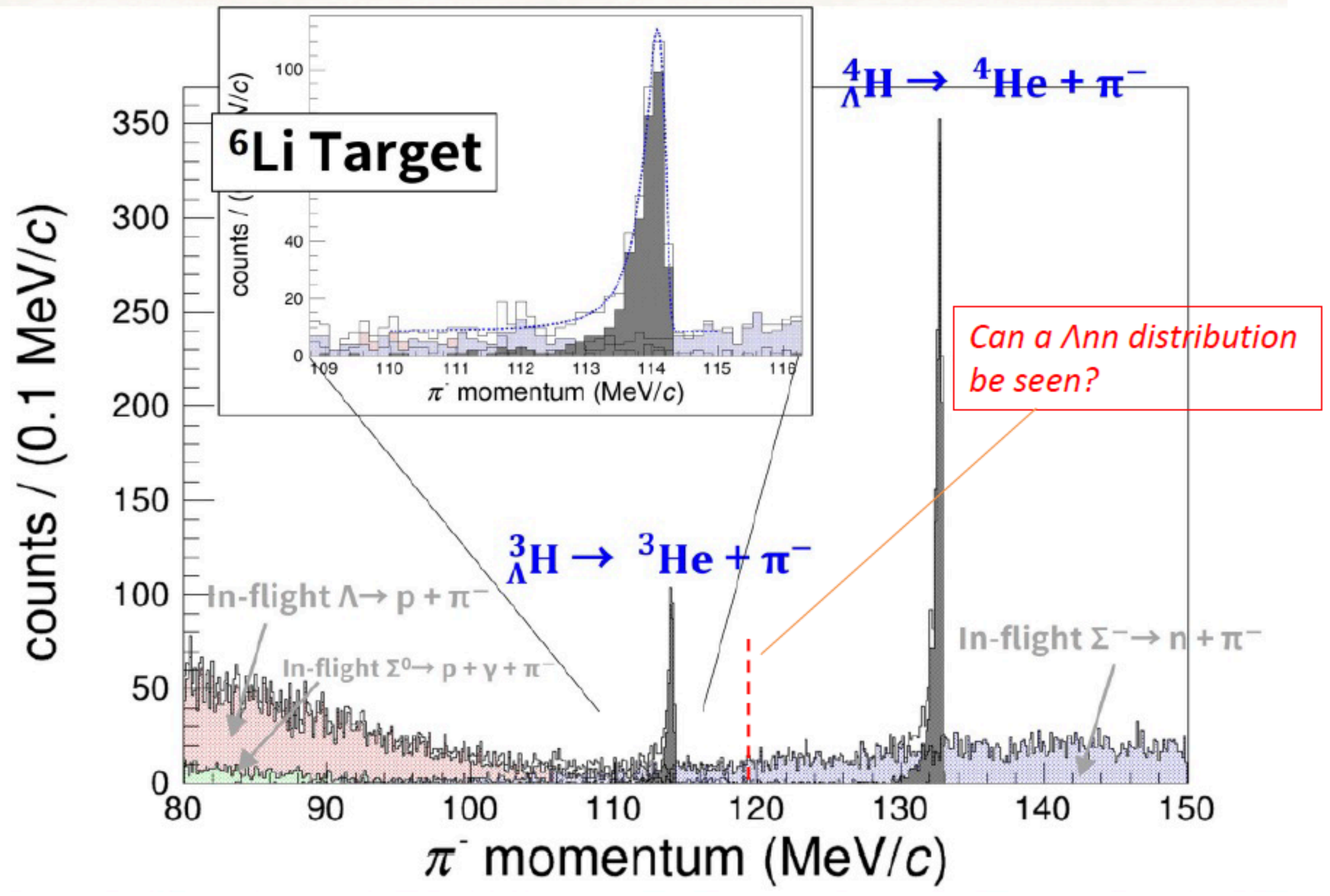
Liguang Tang





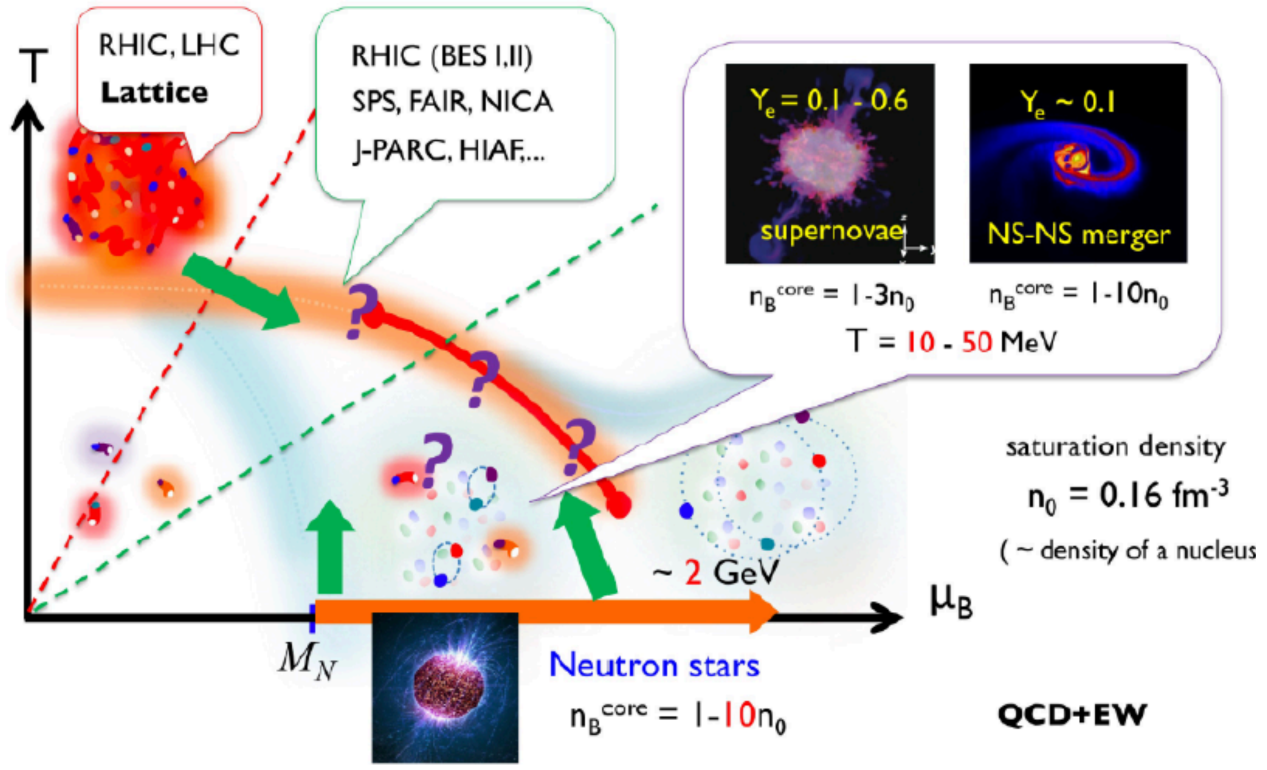
NOT CONCLUSIVE, NO SIGNIFICANCE

-> New experiment with pion spectrometer

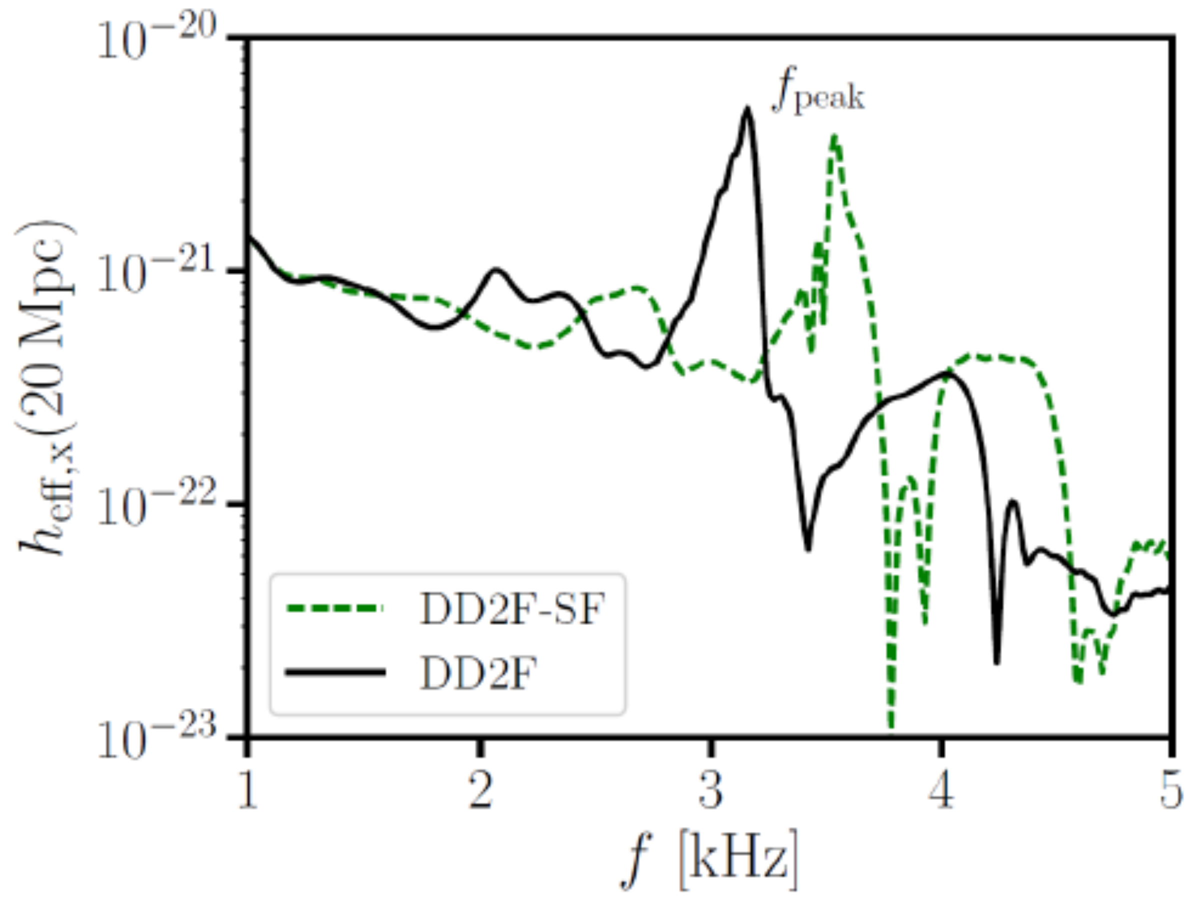


Thermodynamics of quark matterwith multi-quark clusters

David Blaschke

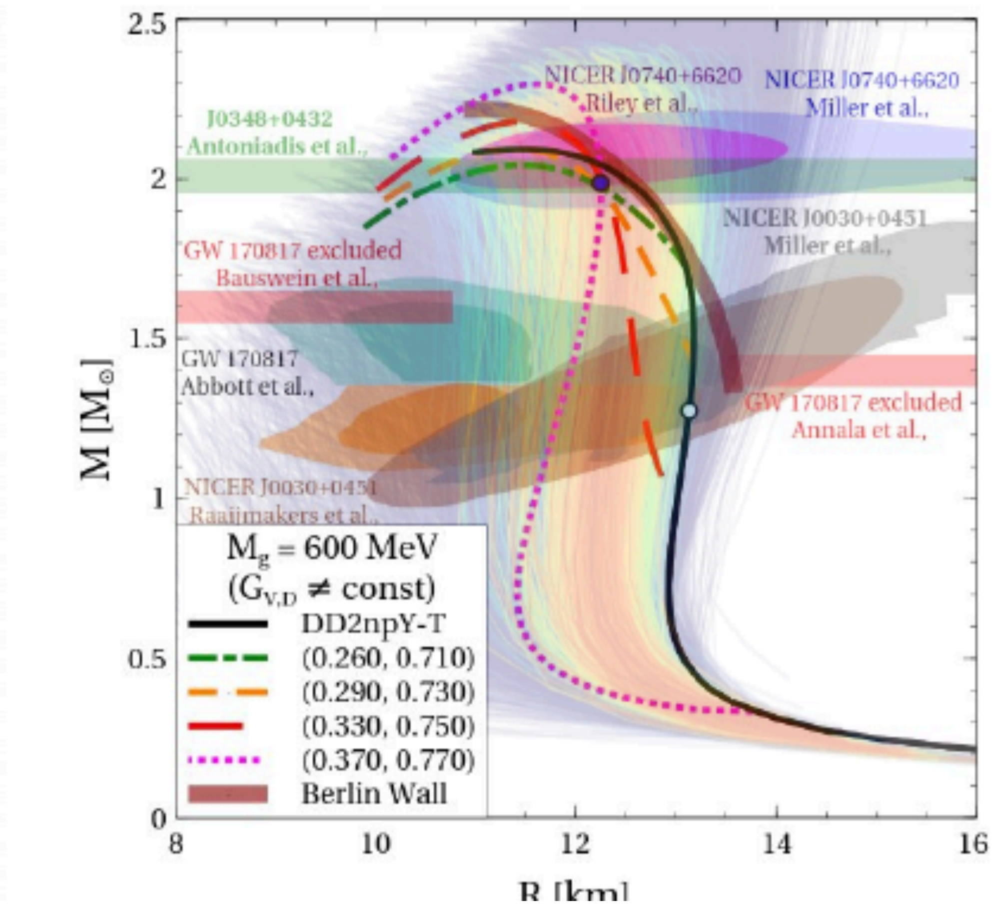


Idea: look for a phase transition at large densities and ‘low’ temperature by computing EoS for Neutron star and NS mergers



- Possible frequency signal for phase transition in post-mergers kHz regime for NS merger
- Or Supernova explosion of 50 solar masses star

- Phase transiation could also solve Berlin wall problem of nuclear EoS

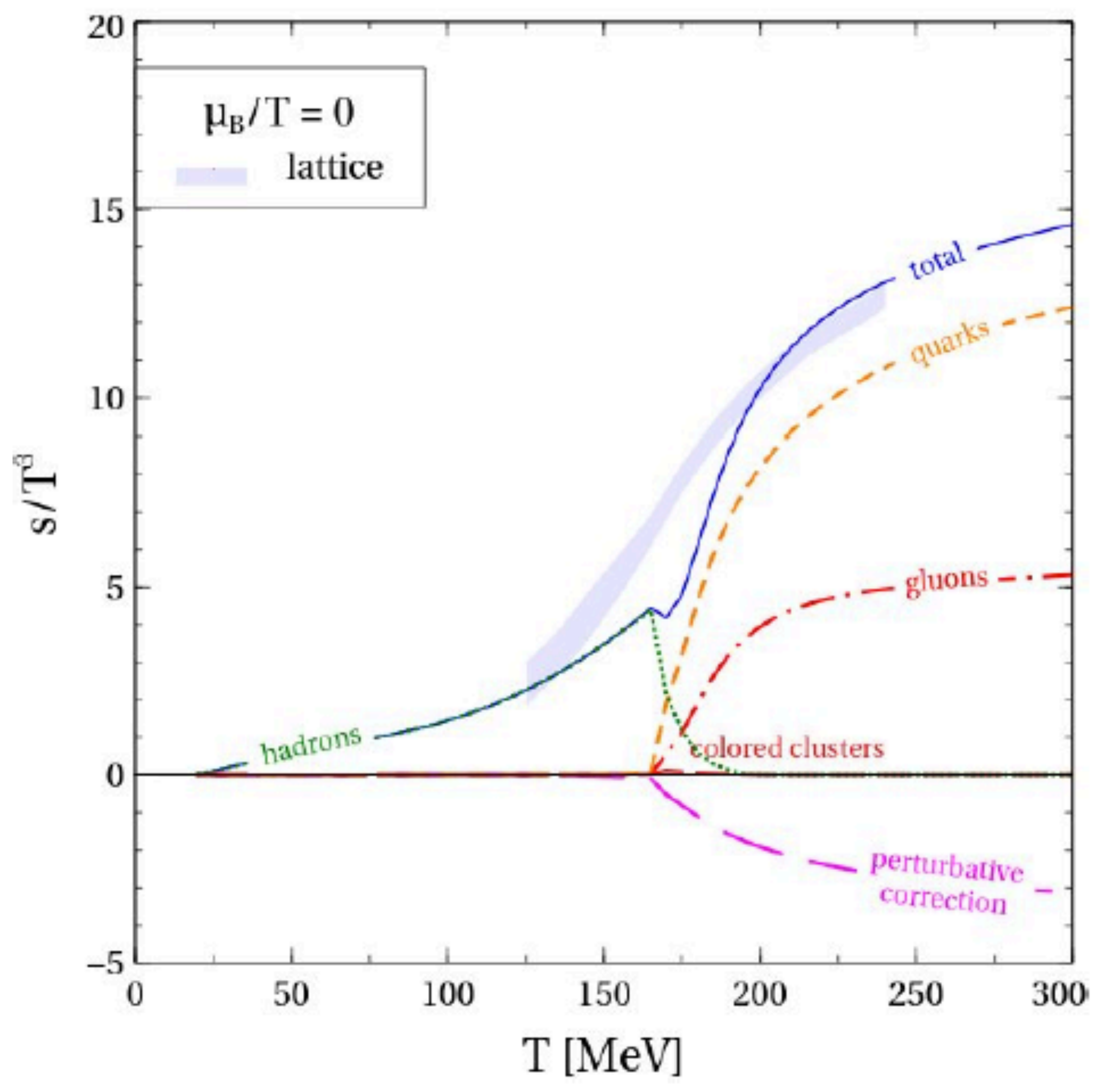


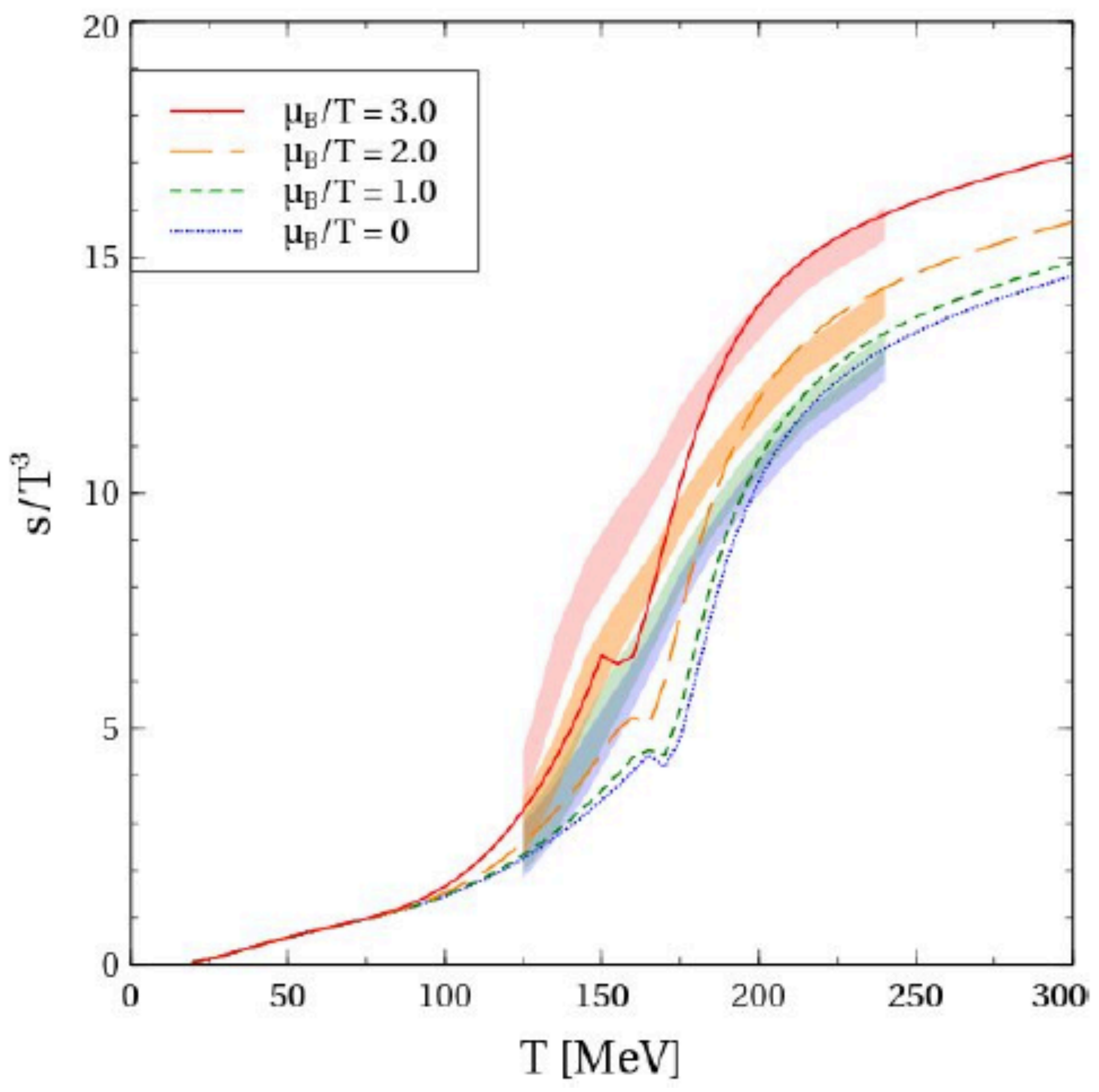
- Tool: unified approach that consider also nuclei and correlations
- -> hadron and cluster composition as a function of the thermodynamical potential
- Approach that fulfills also confinment and chiral symmetry restoration

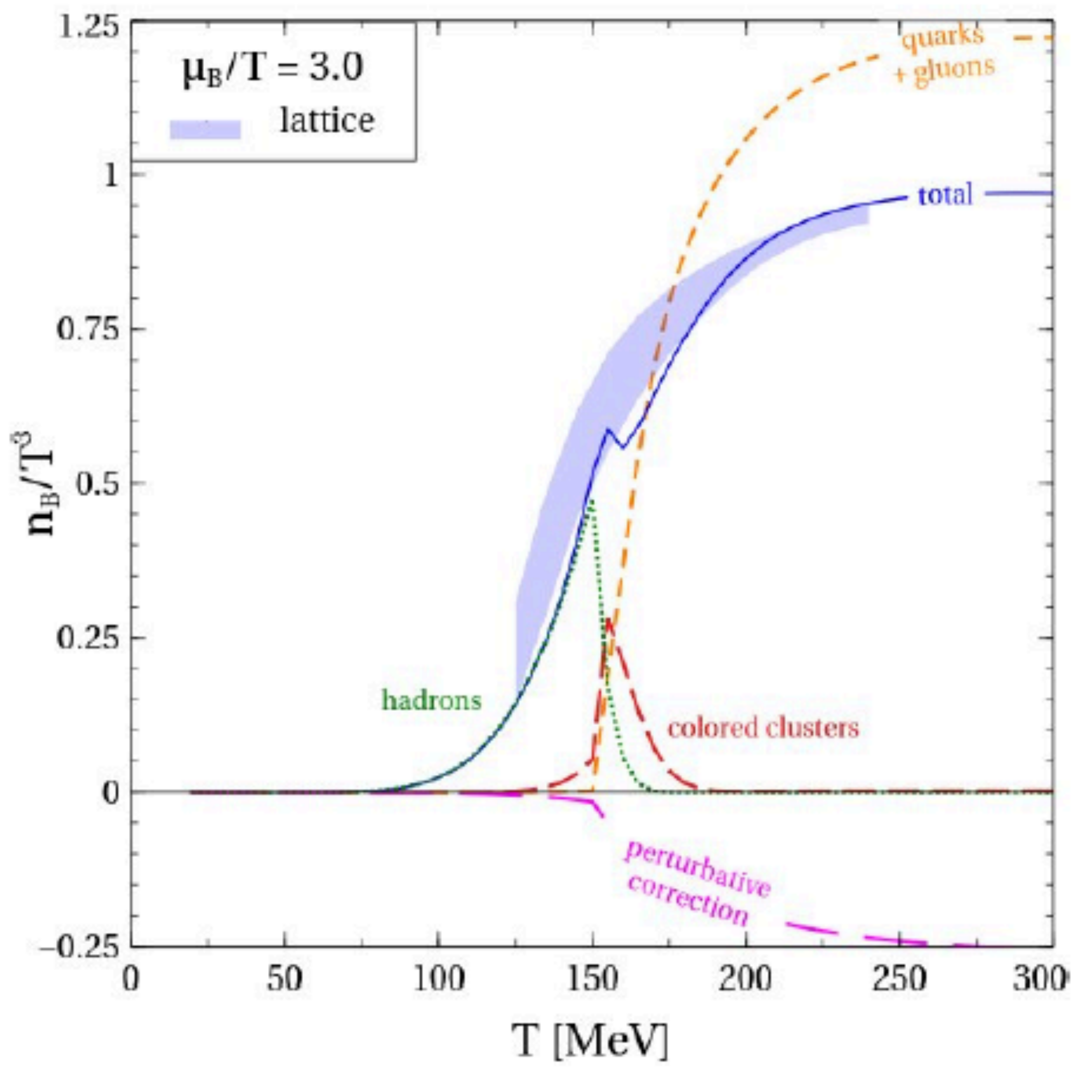
Thermodynamics of quark matterwith multi-quark clusters

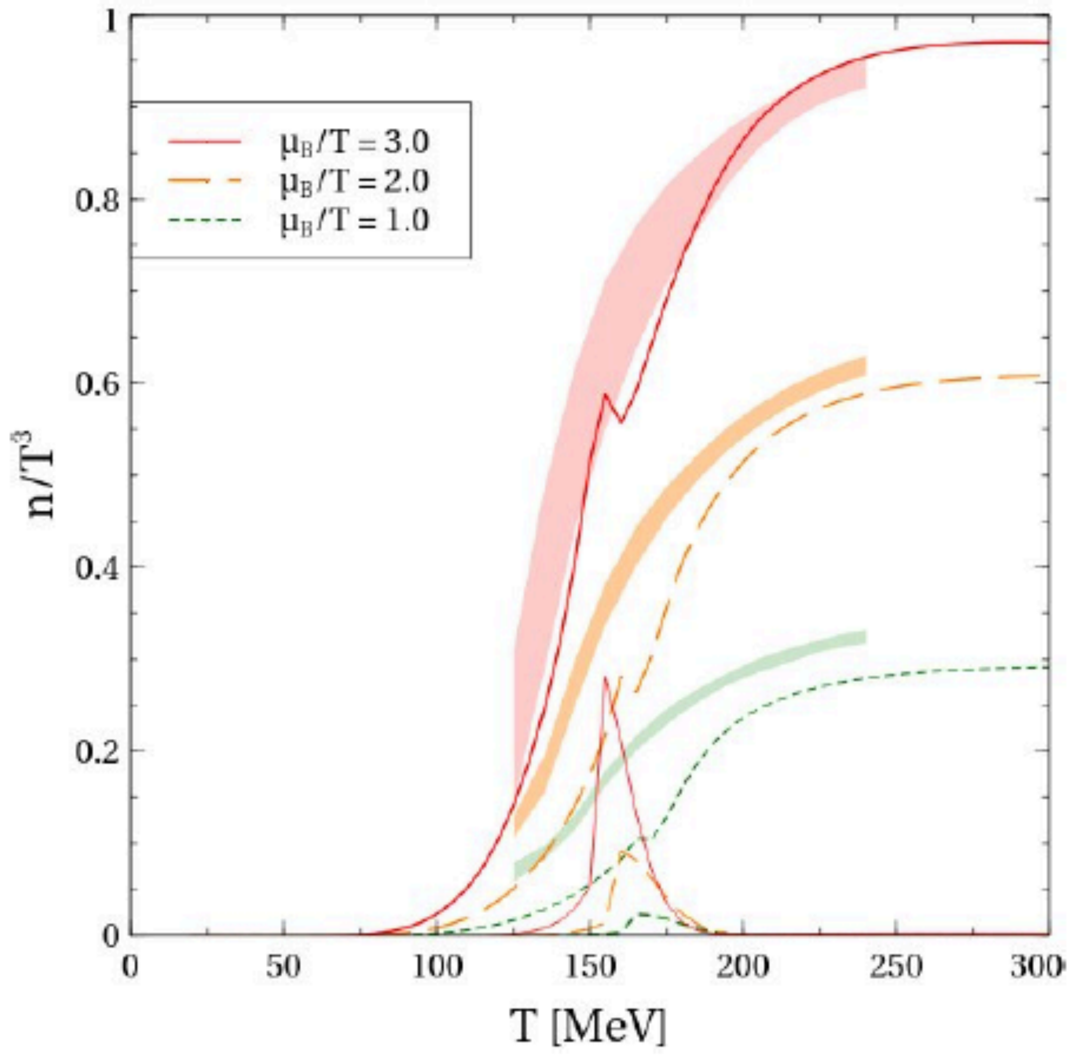
David Blaschke

Current status of the comparison to Lattice QCD







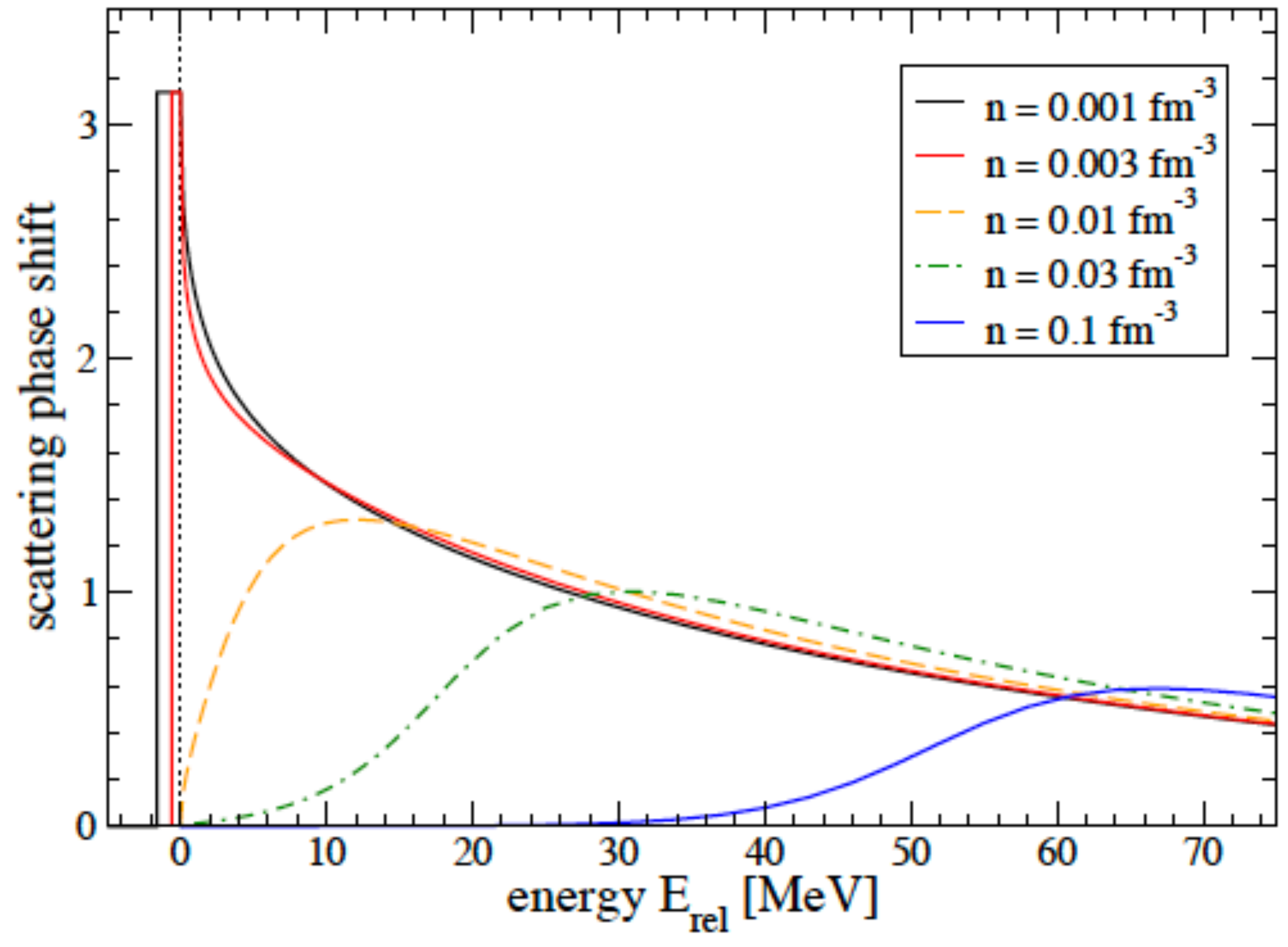


Light Clusters in hot, dense matter

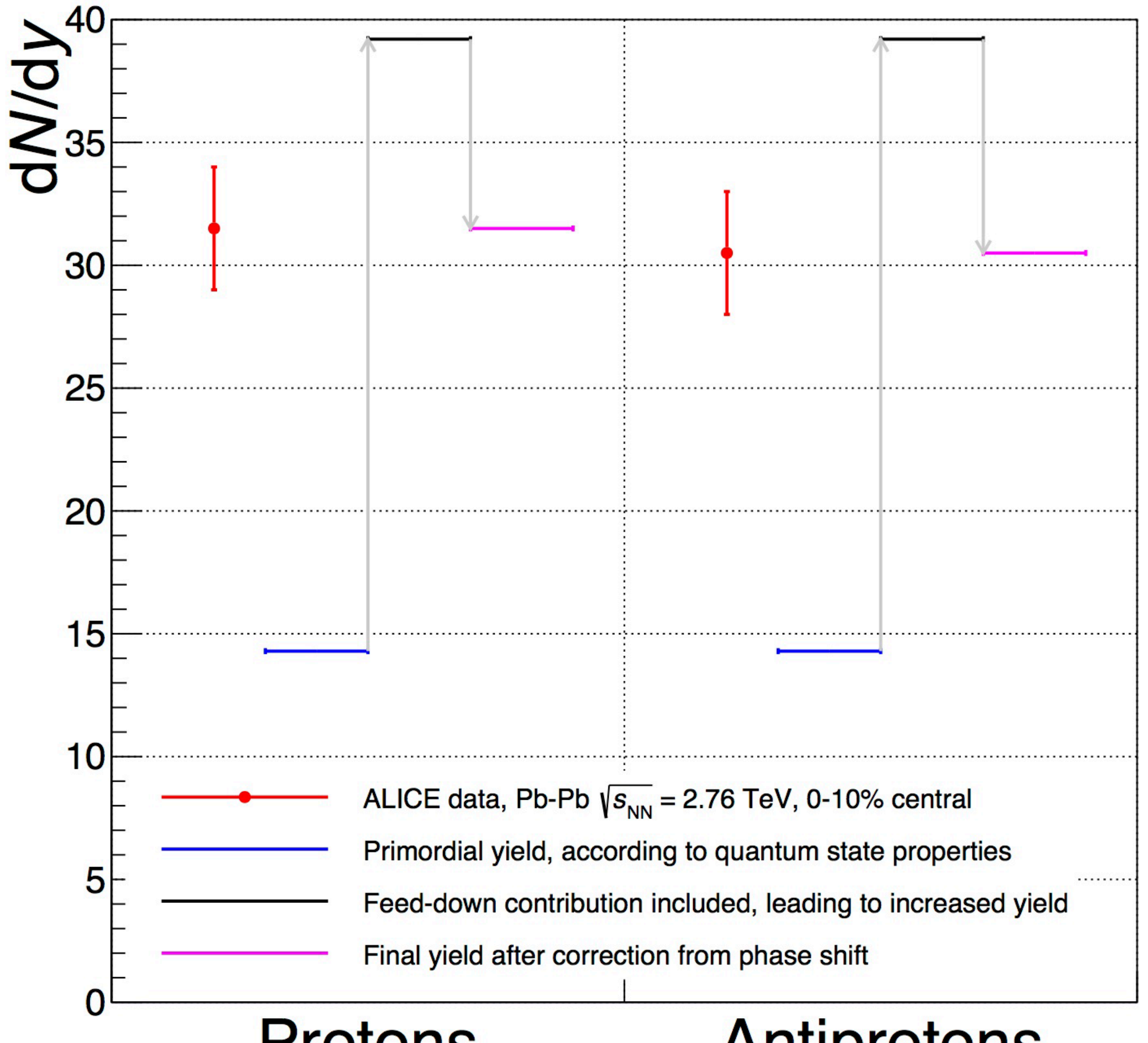
Gerd Röpke

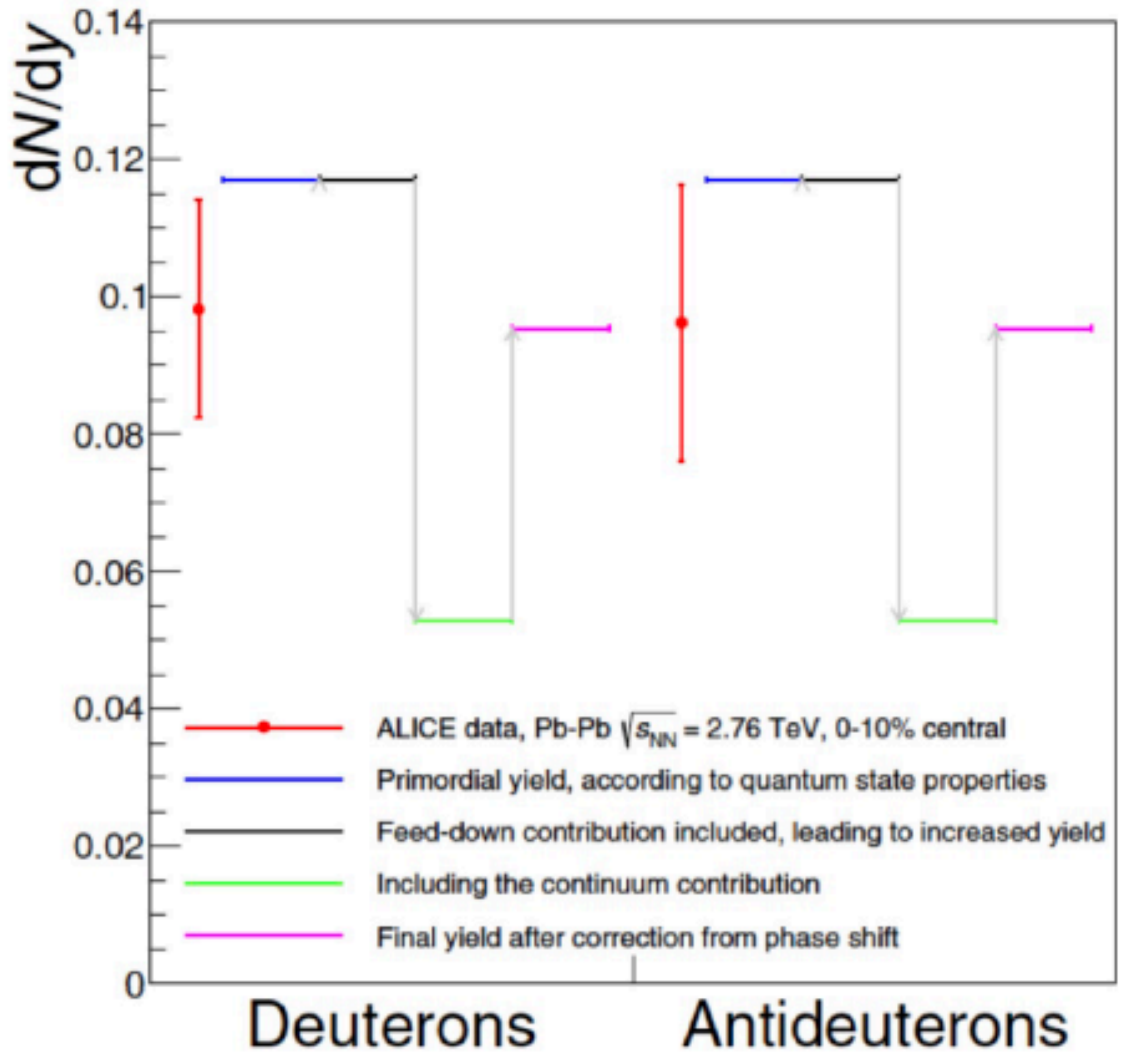
- Cluster formation in dense matter, as non equilibrium statistical ensamble
- When and where are those cluster produced ?
- Formalism that includes interactions in the spectral functions of particles
- Pauli Blocking in medium
- Bound states are included as well

Test: proton and deuterons yields as a function of the system density



Money Plots





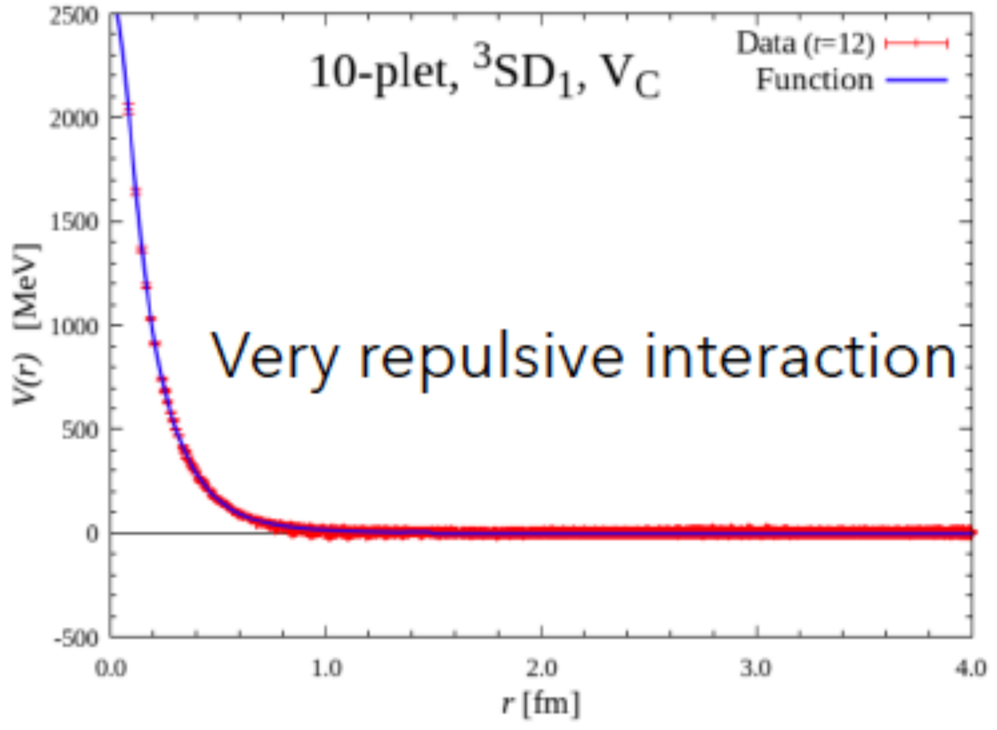
Hyperon-Nucleon scattering experiment at JPARC

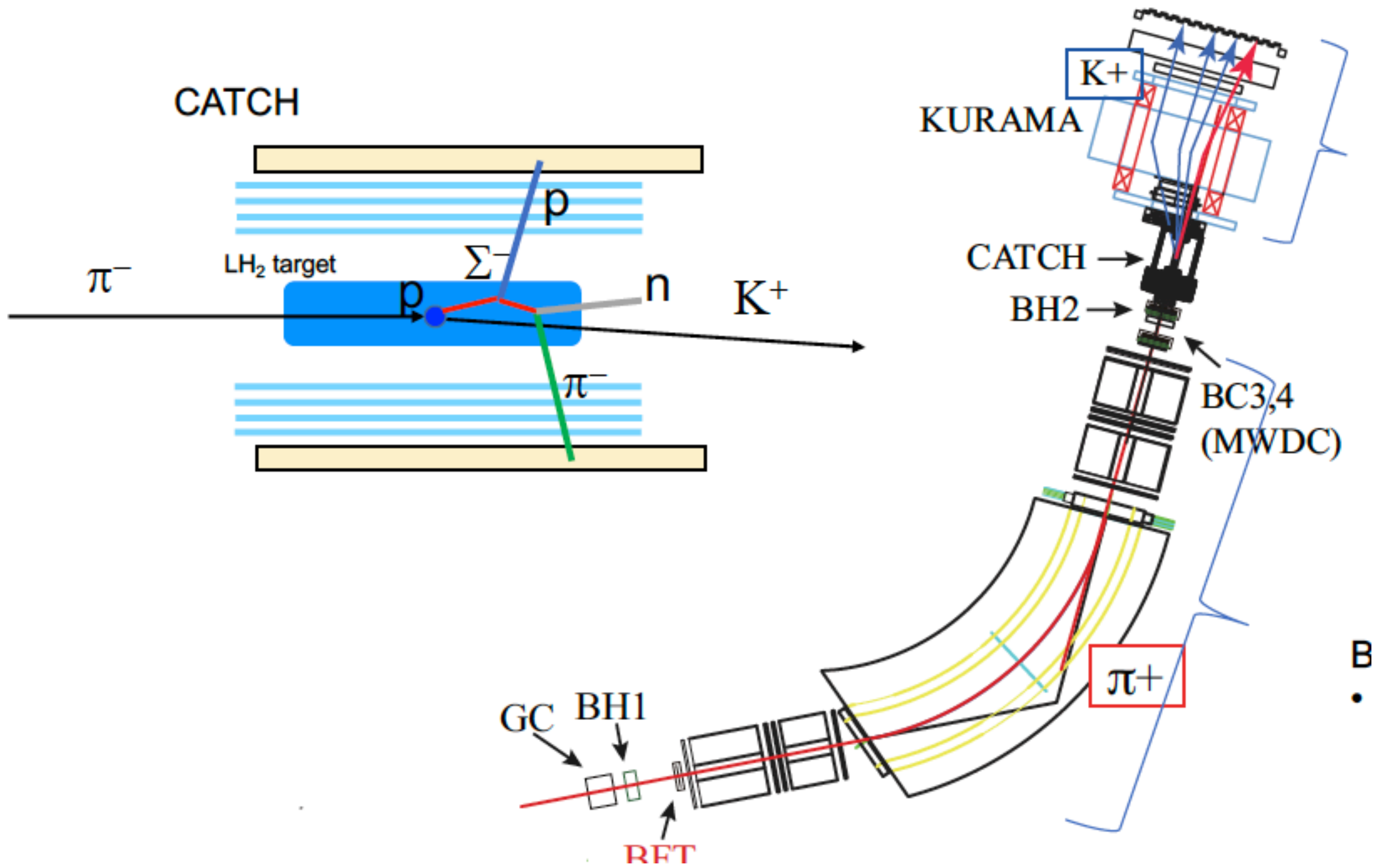
Kojii Miwa (JPARC E40, E86, E90)

1) $\Sigma^+ - p$ scattering

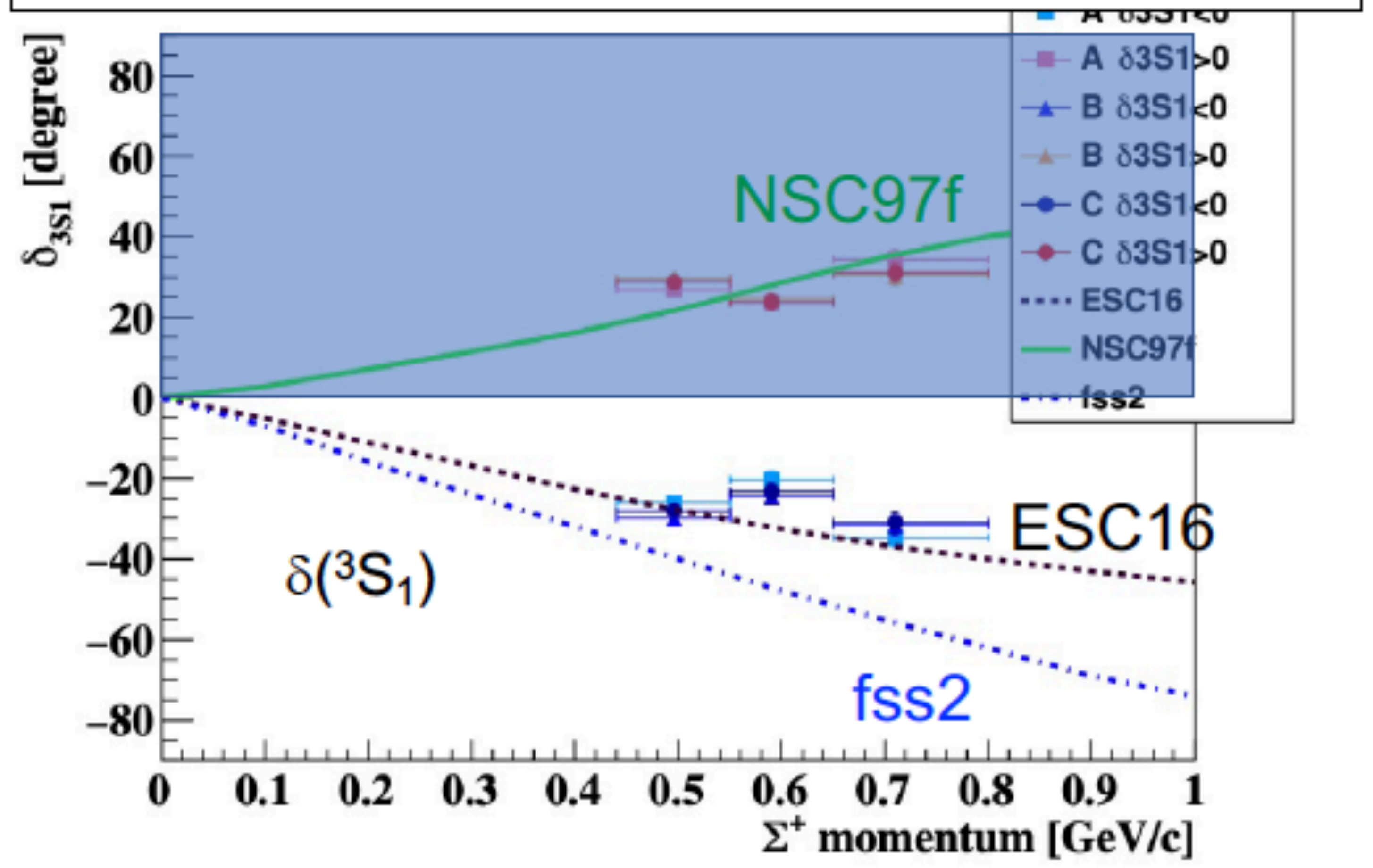
Lattice QCD calculation

T. Inoue, AIP Conf. Proc. 2130, 020002 (2019)

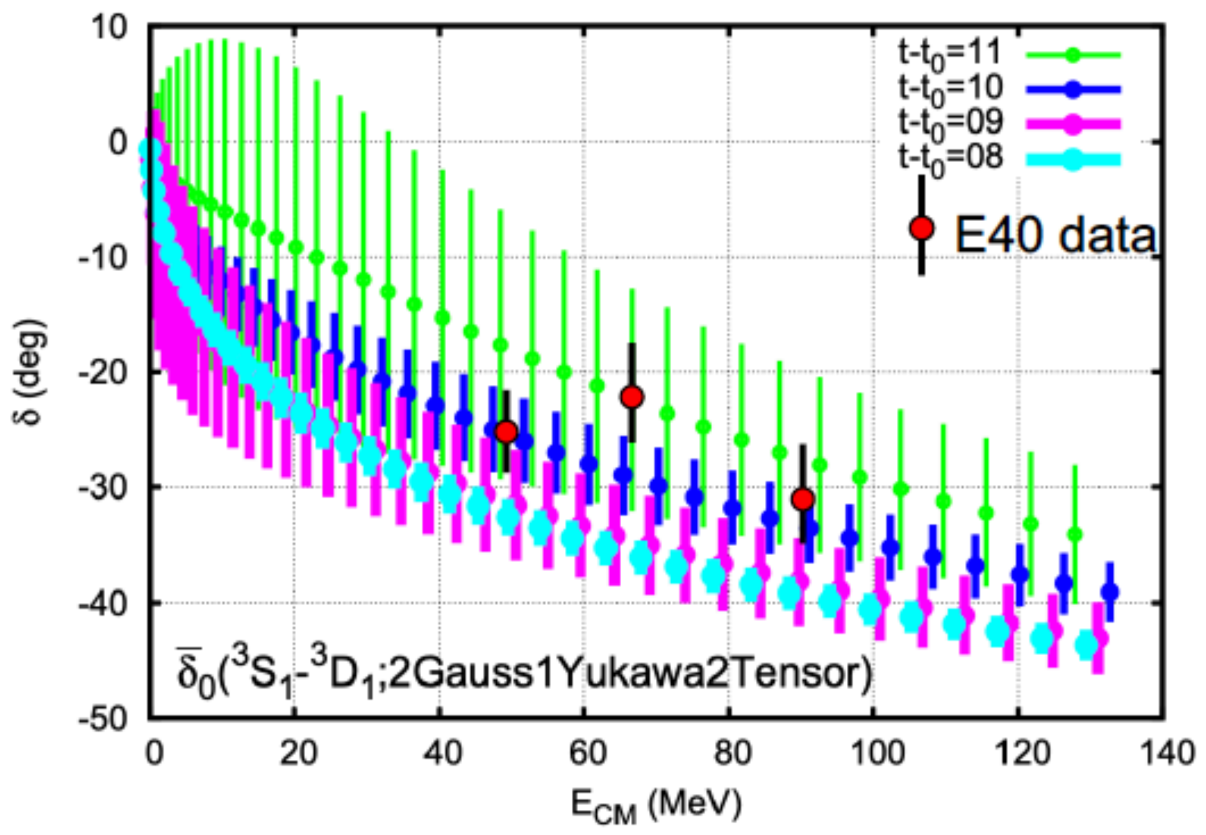




First experimental derivation of phase shift of $^3S_1$



Comparison with HAL QCD ΣN potential



H. Nemura et al., EPJ Web of Conf., 175, 05030 (2018)

Derived phase shift suggest that **the $^3S_1$ interaction is moderately repulsive**.

Hyperon-Nucleon scattering experiment at JPARC

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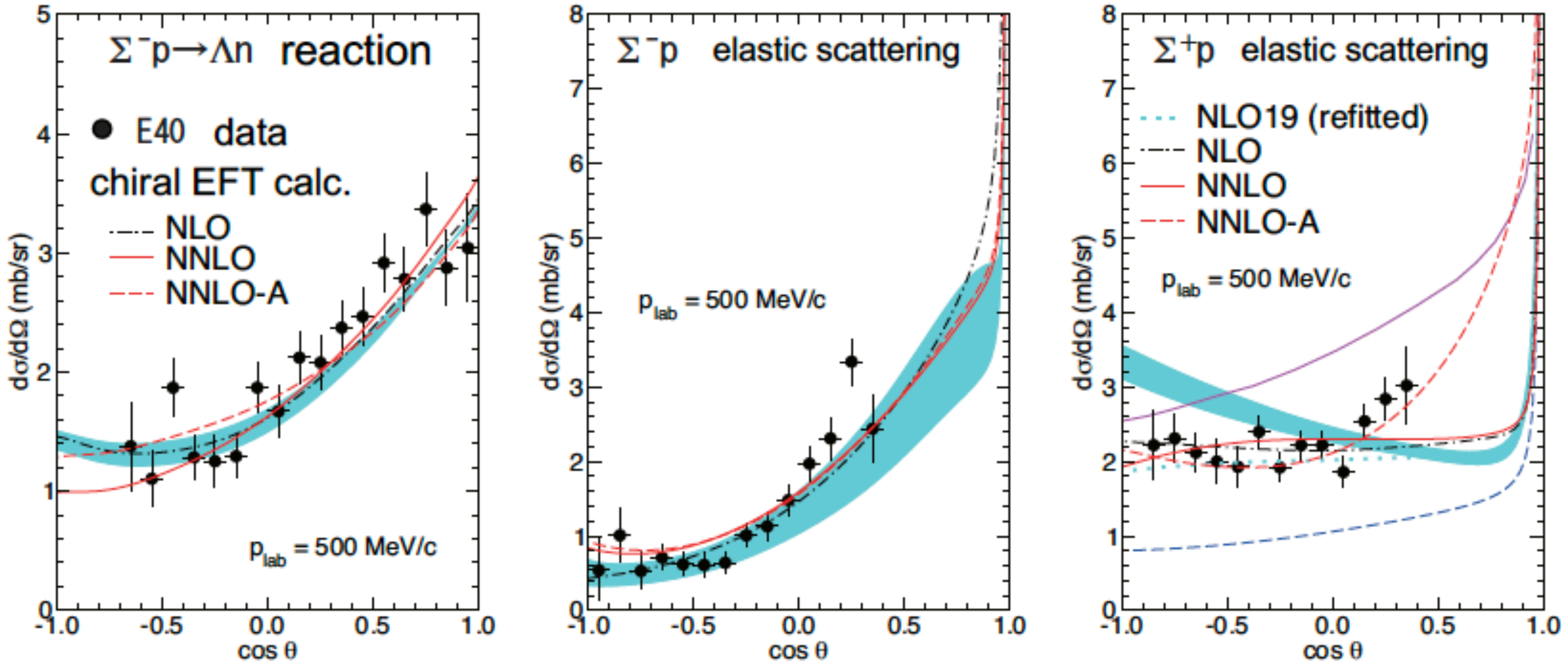
1) $\Sigma^+ - p$ scattering

Development of Chiral EFT at NNLO have got started with E40 data

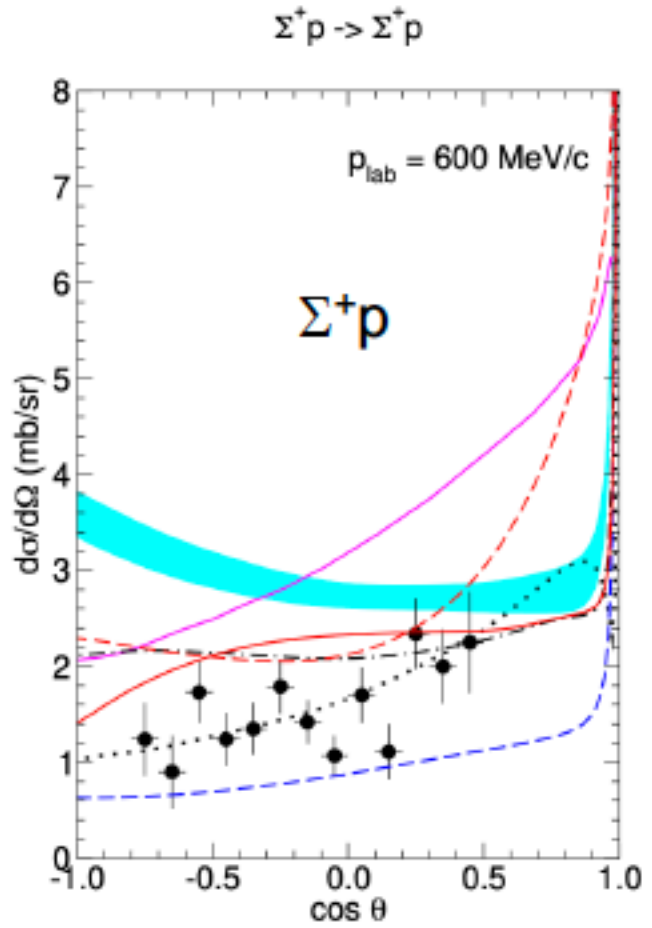


K. Miwa et al., PRL 128, 072501 (2022)

K. Miwa et al., PRC 104, 045204 (2021)

T. Nanamura et al., PTEP 2022 093D01

Difficulty at higher momentum



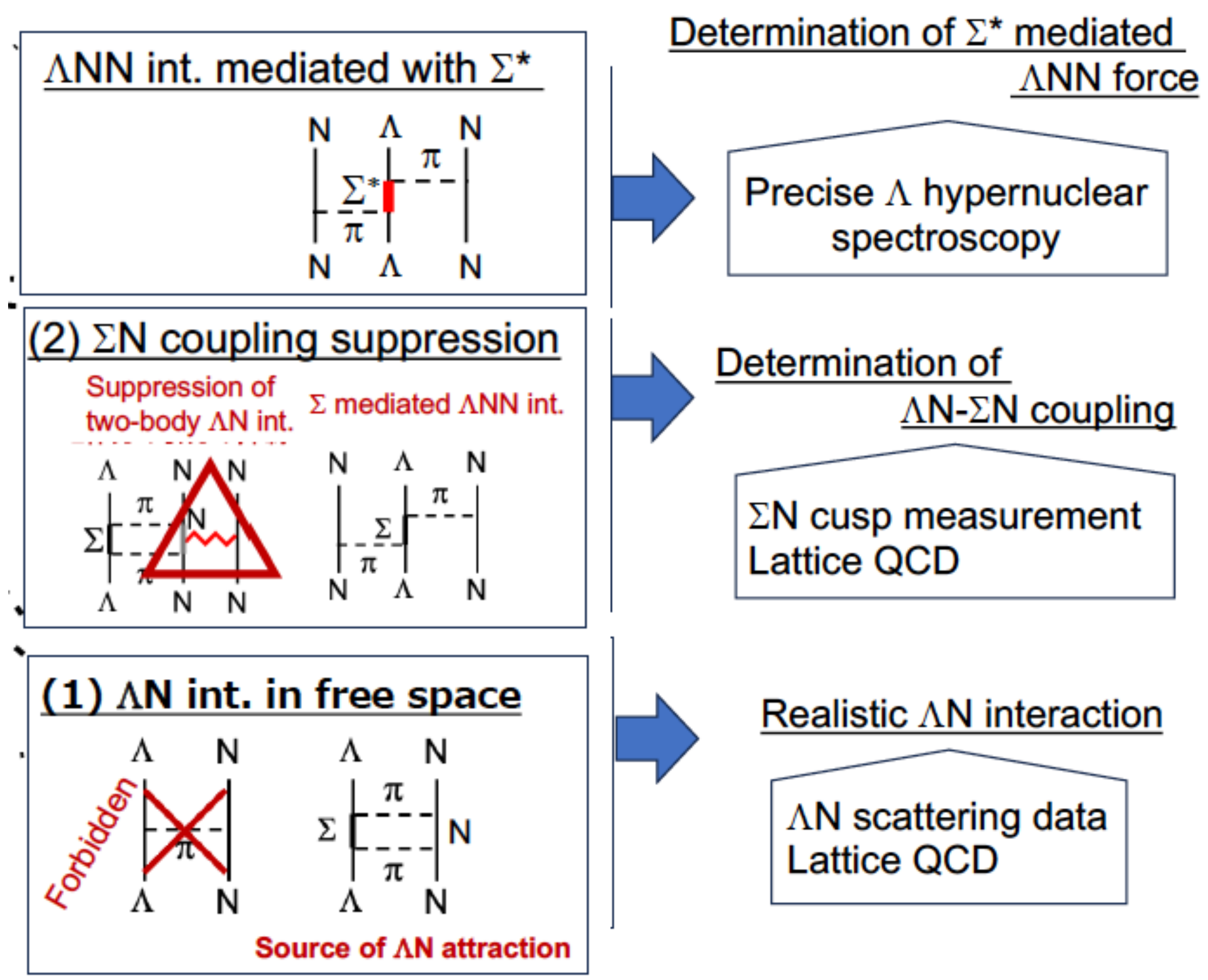
J. Haidenbauer et al., arXiv:2301.00722

But, the interactions are not uniquely determined yet.

- Quark model understimates Data
- Nijmegen model agrees withData
- NNLO anchored to new data
- Lattice compatible with new data

2) $\Lambda - p$ interaction in medium (access large density with large momentum)

- Driven by $\Sigma N - \Lambda N$ coupling



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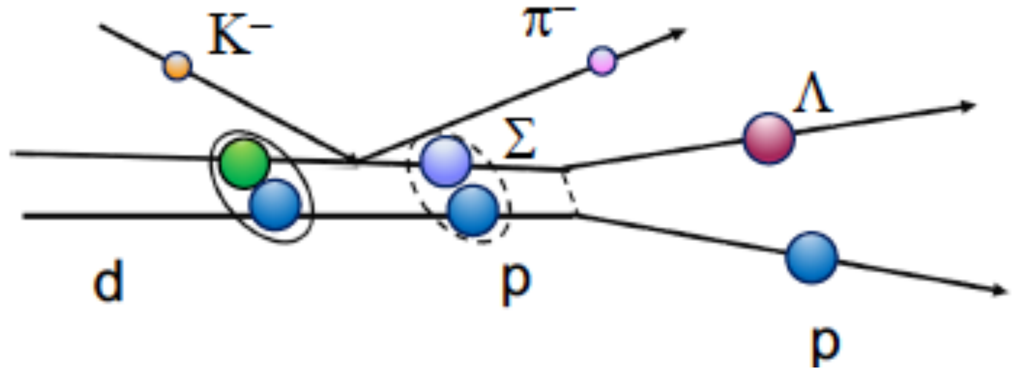
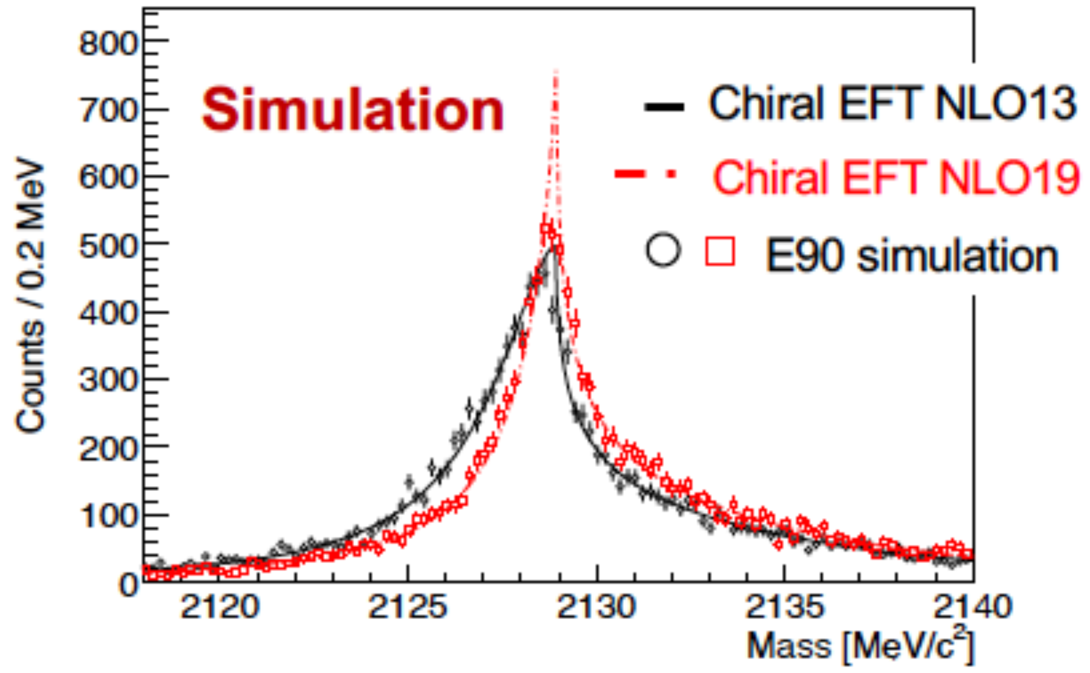
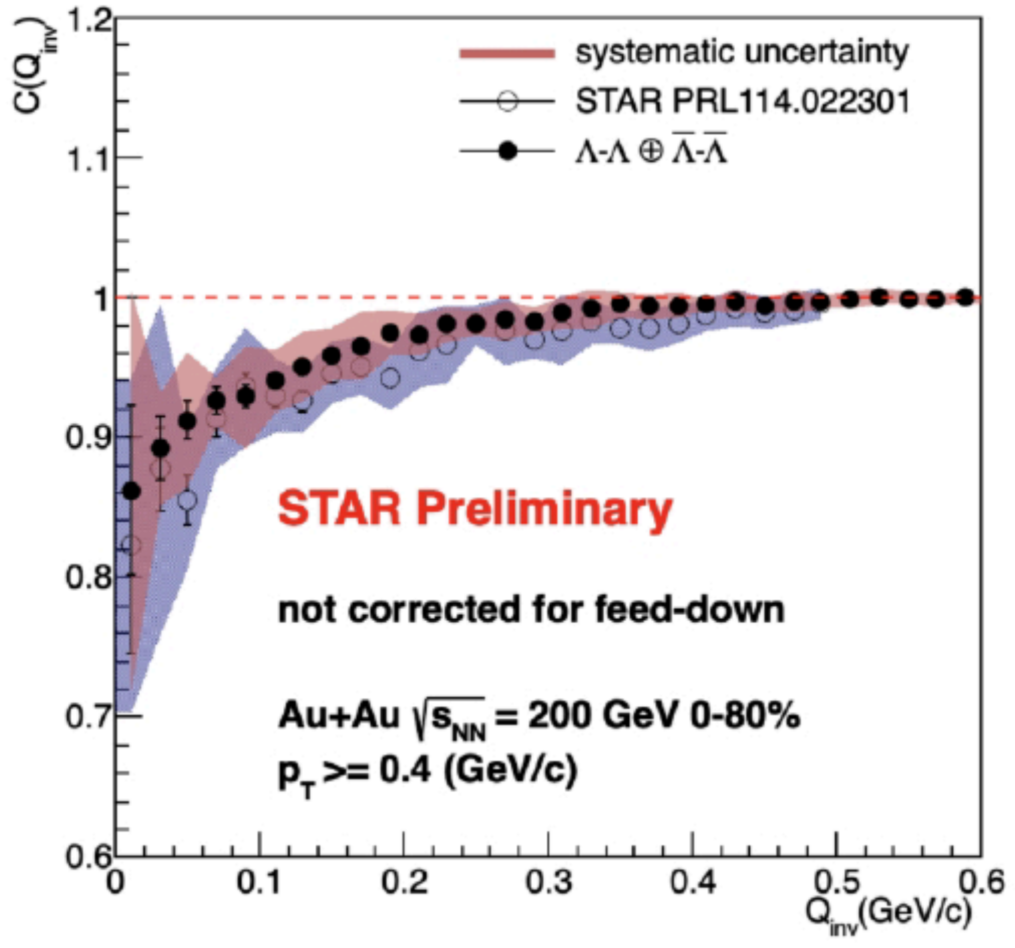




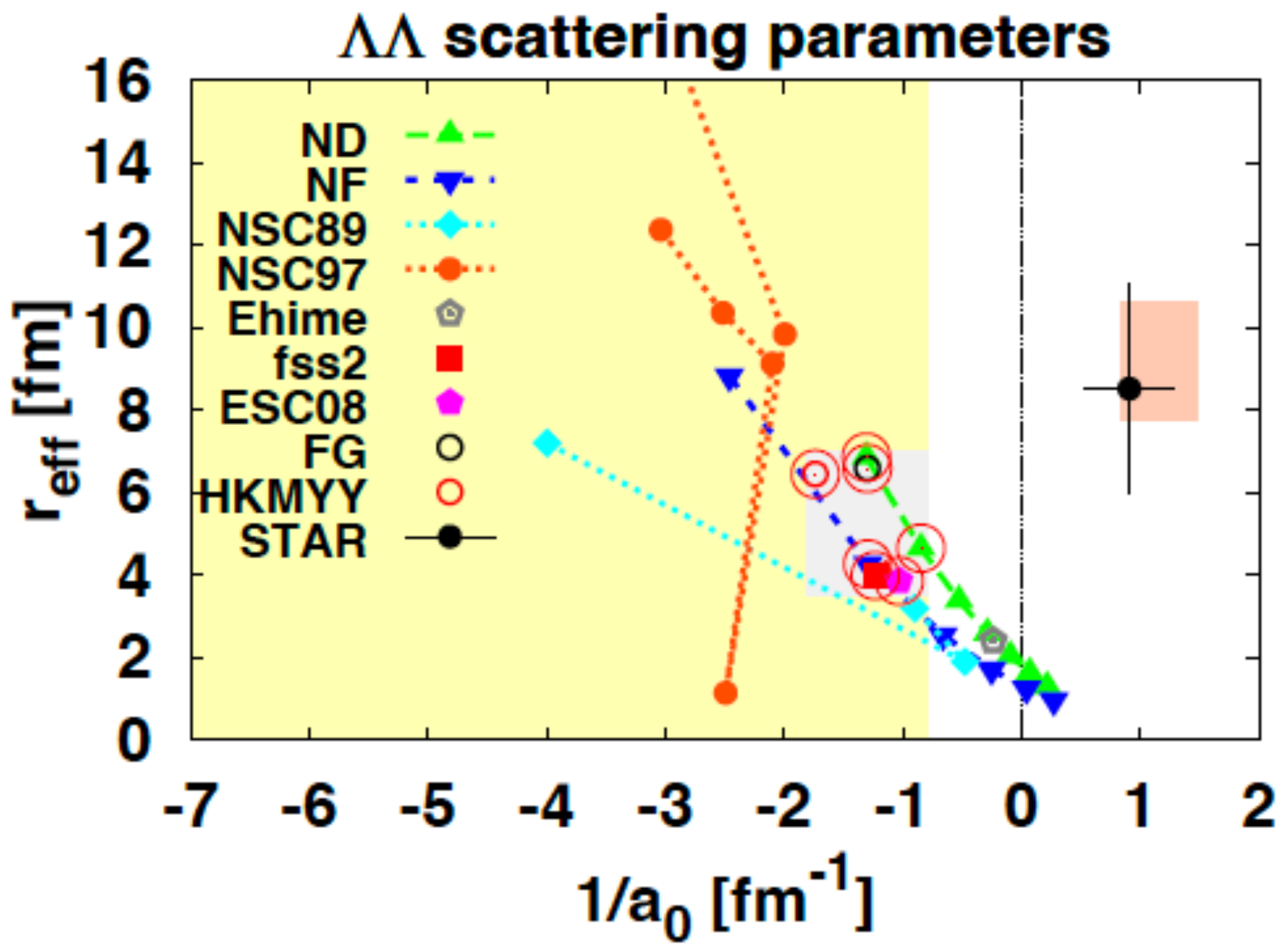
Recent Femtoscopy Measurements from STAR Experiment

Neha Shah (STAR)

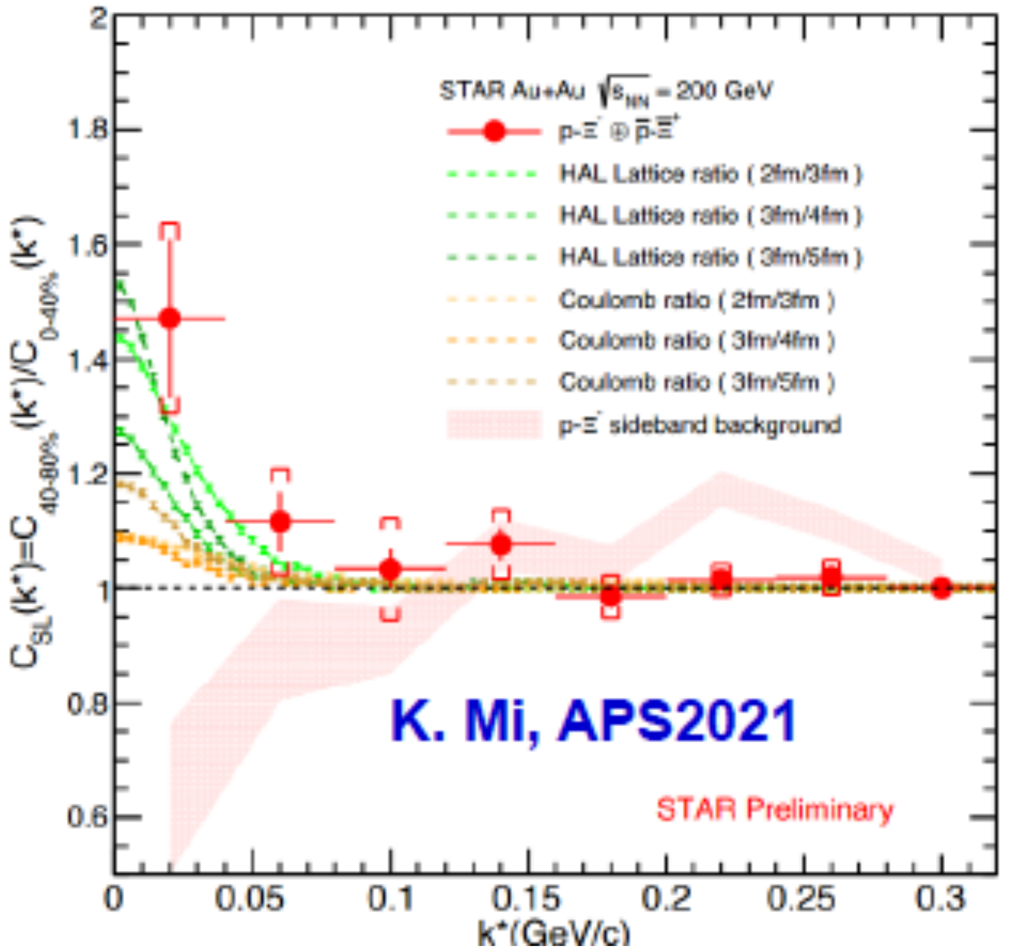
1) $\Lambda\Lambda$



Morita, Ohnishi Phys. Rev. C 91, 024916 (2015)



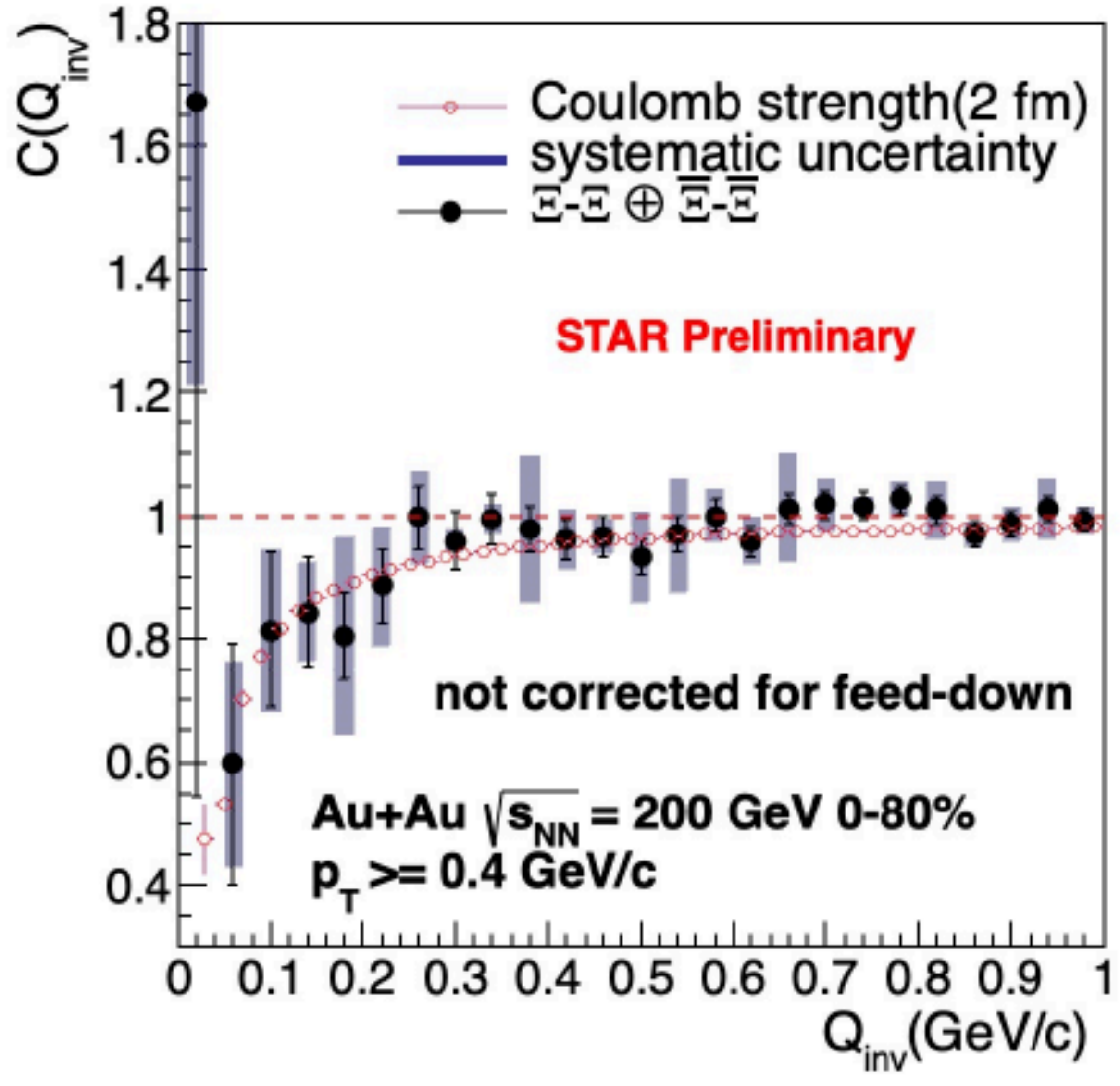
2) $p\Xi^-$



p-Ξ^- interactions from HAL-QCD collaboration are consistent with the data

3) $\Xi^-\Xi^-$

M. Isshiki, QM2022



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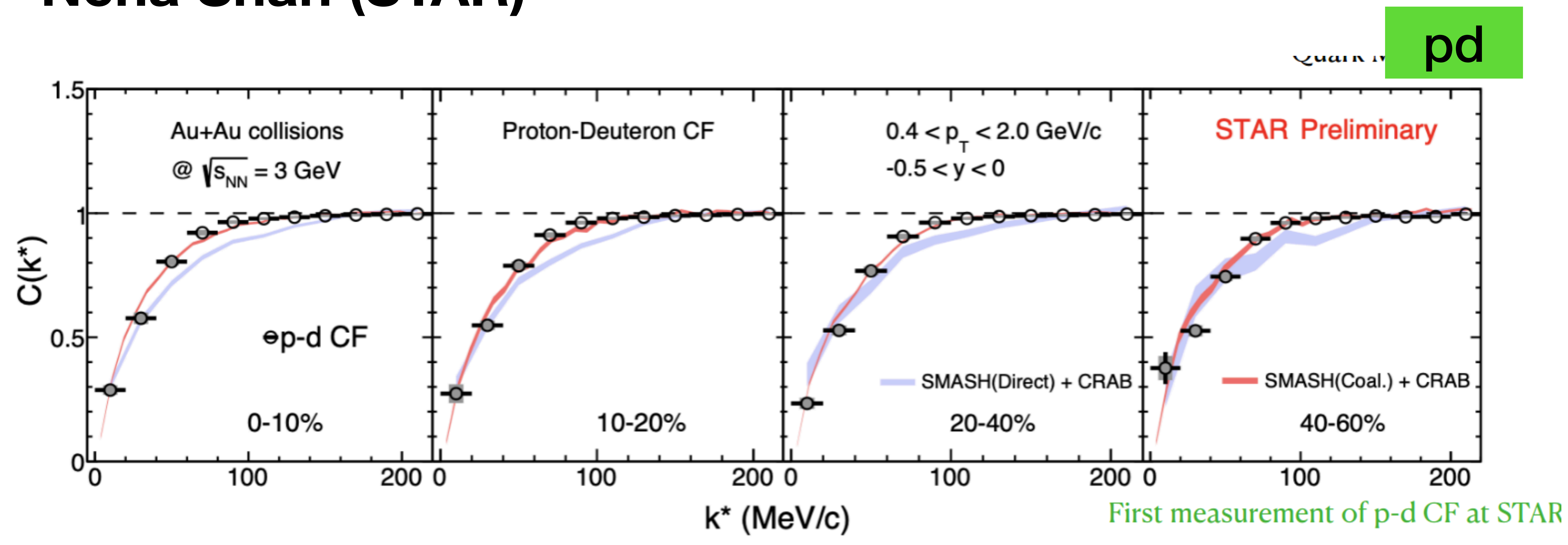
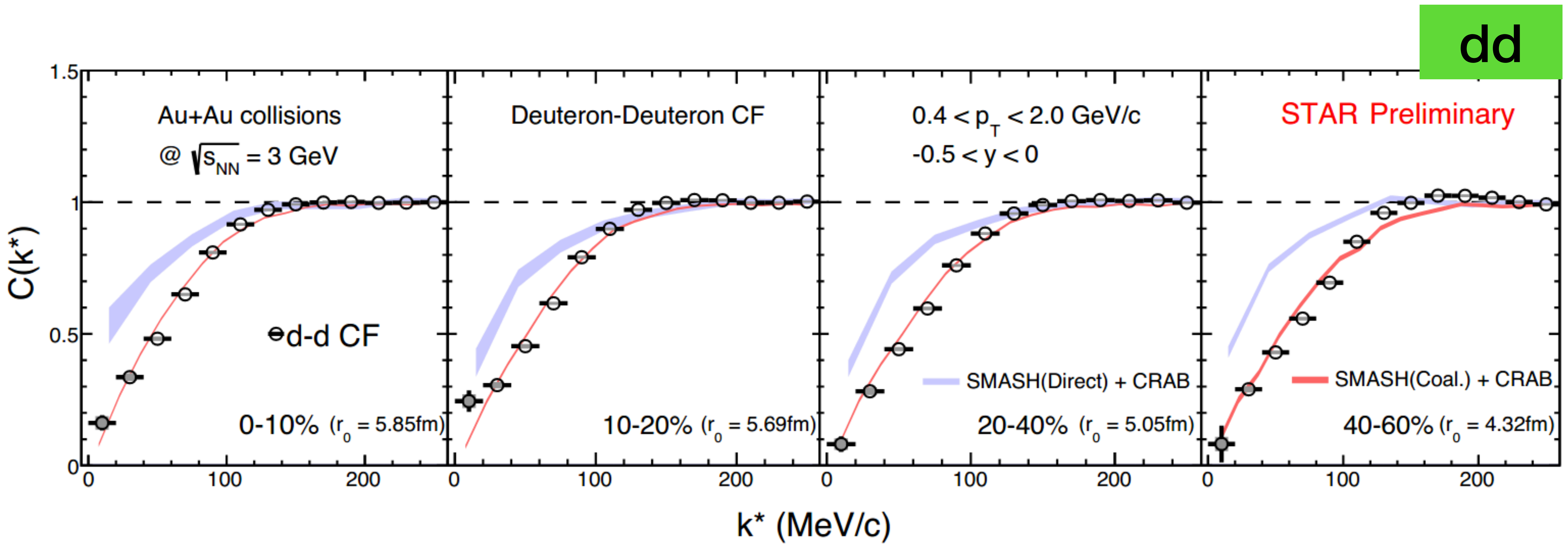


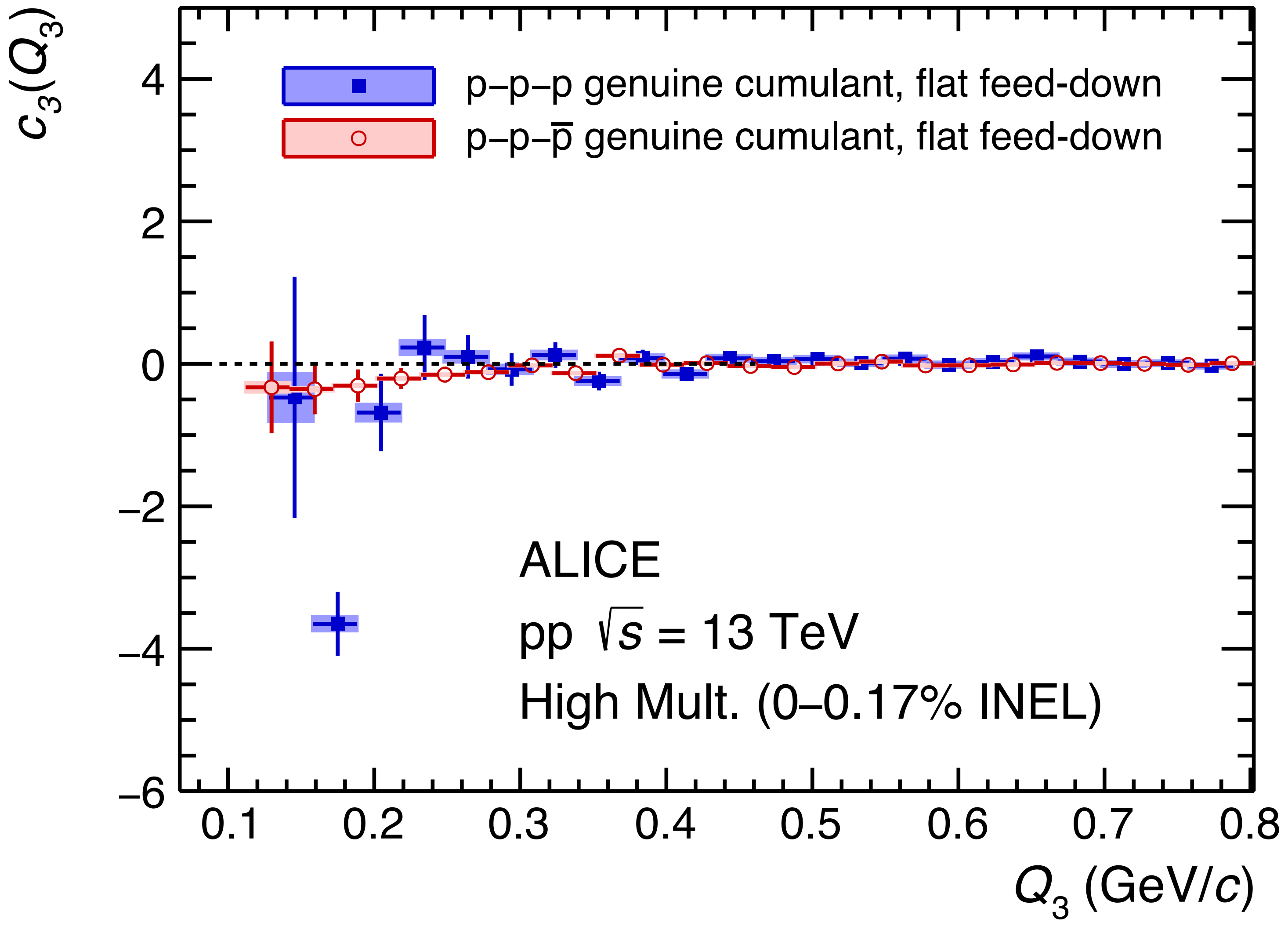


- Lednicky calculations (point-like particles) (not shown here) can describe the data 'accidentally' with large radii
- No two-body potential can describe the p-d interaction
- CF calculation using SMASH event generator with afterburner with and without coalescence
- With coalescence fits better
- For d-d larger radii are obtained and also the coalescence fits better.

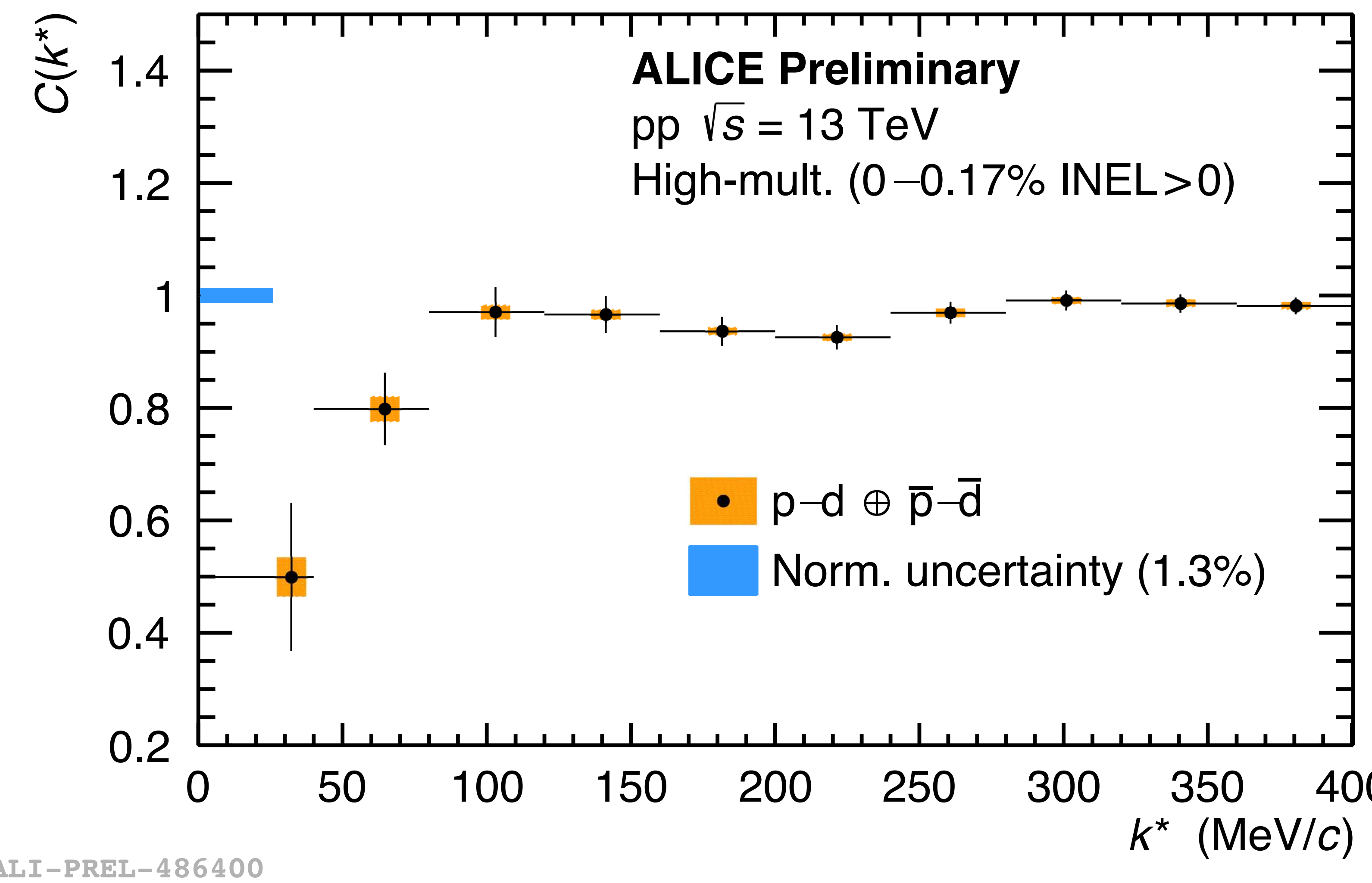
Femtoscopy and three-body systems

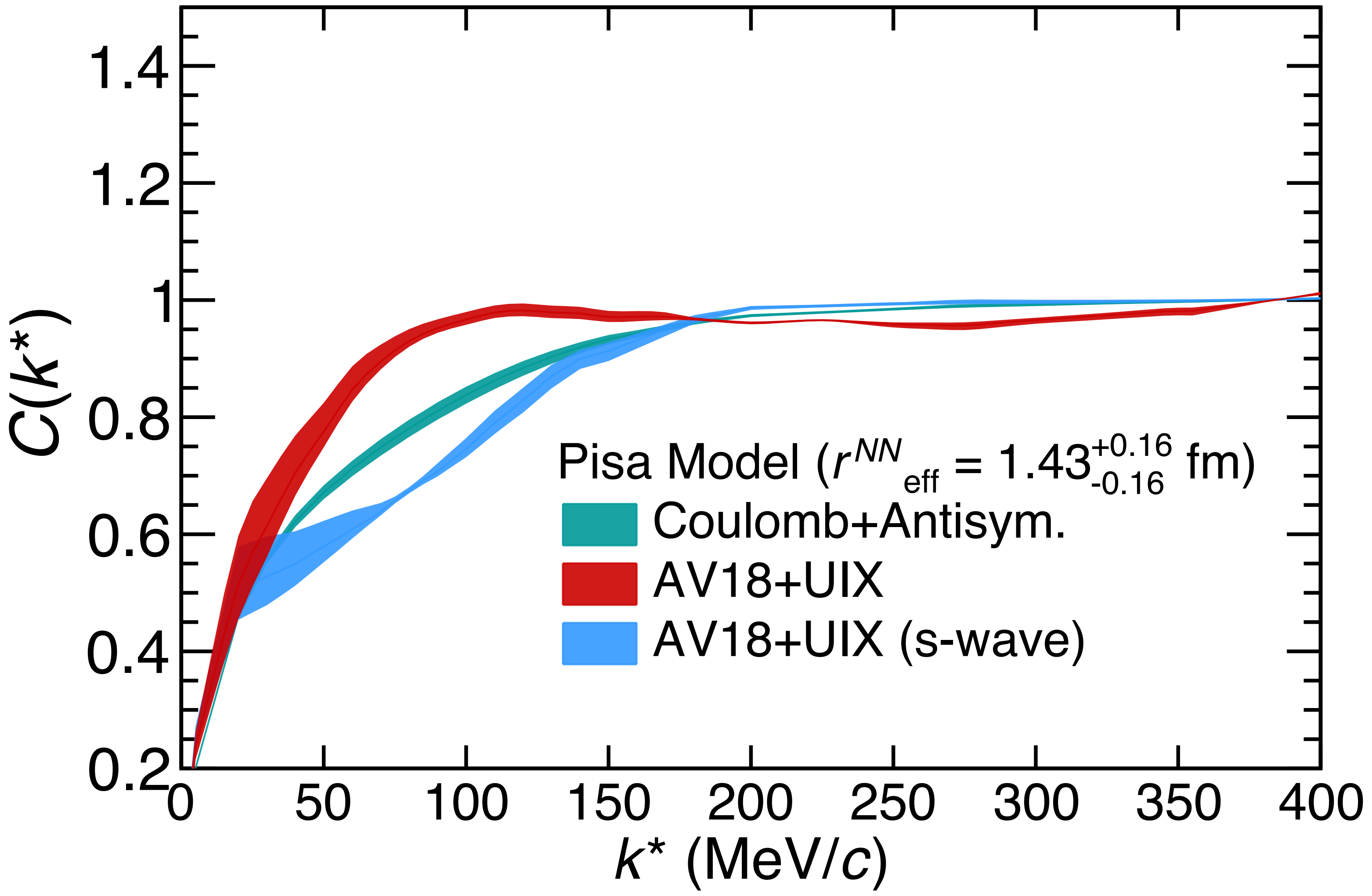
Laura Serksnyte

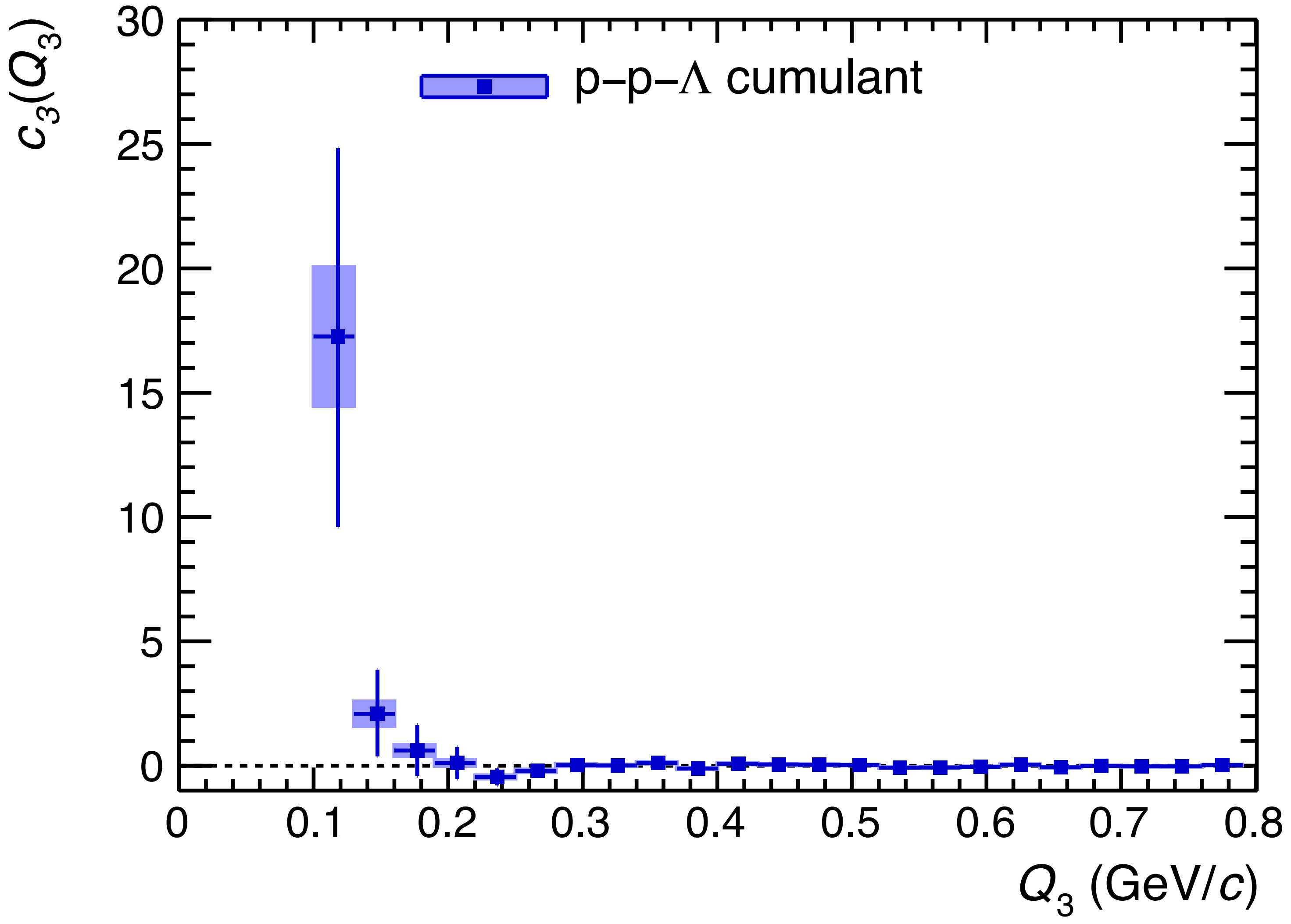
- p-d correlation function provides access to the three-body p-(p-n) system
- Three-body femtoscopy allows to study three-hadron systems:
  - p-p-Λ: compatible with two-body correlations only
  - p-p-p: 6.7σ deviation from null hypothesis - related to the antisymmetrisation of the wave function
  - p-p-$K^{+(-)}$: compatible with two-body interactions only



Up to two orders of magnitude
larger statistics expected in Run3!







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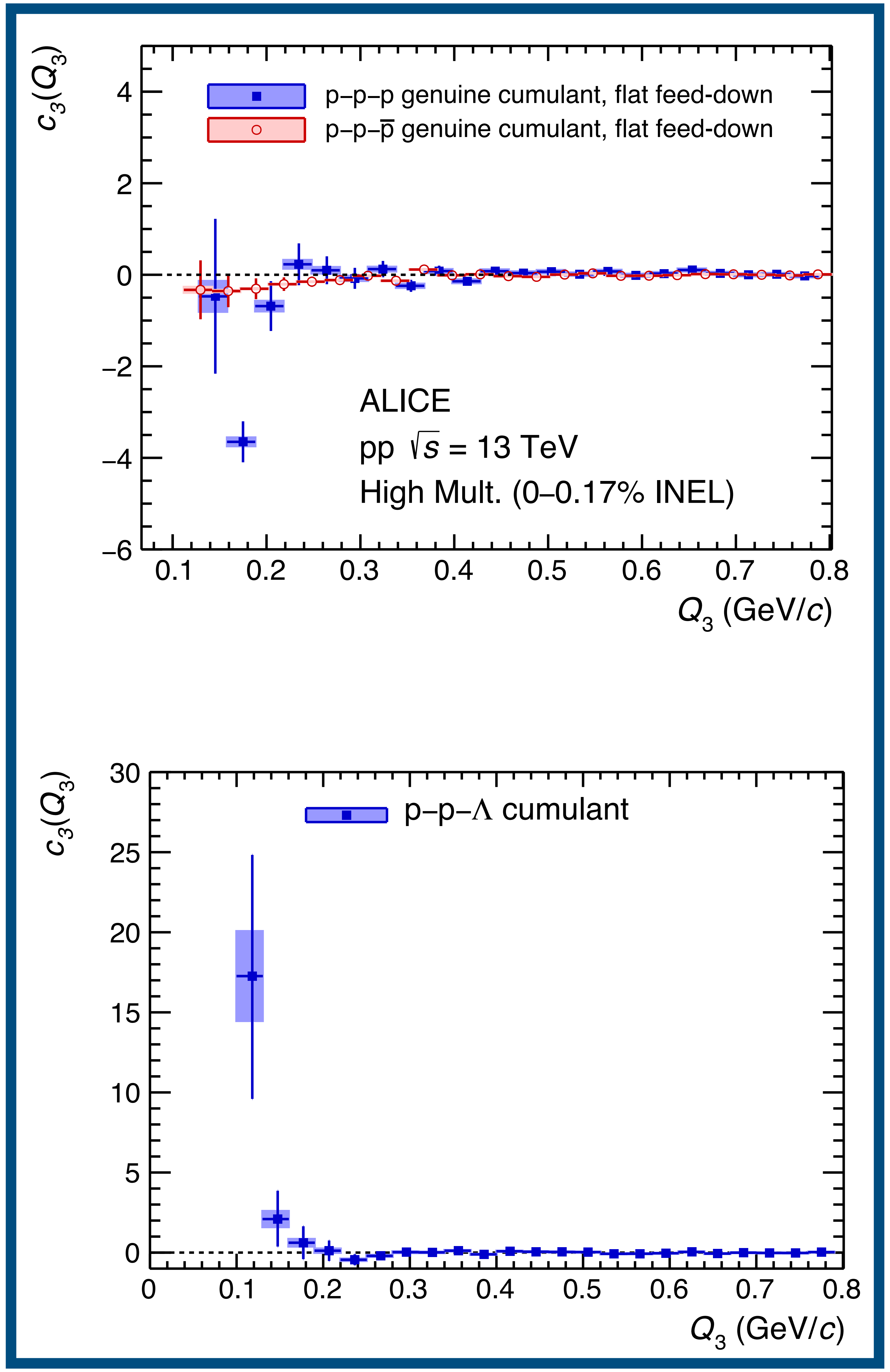
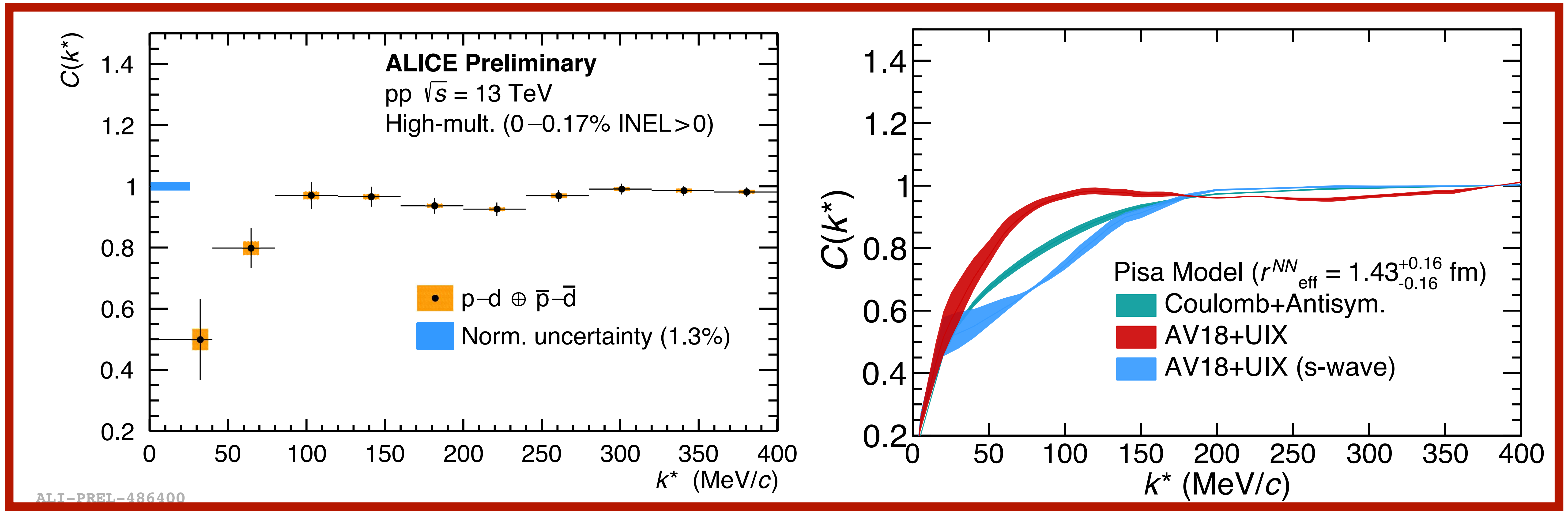


Up to two orders of magnitude larger statistics expected in Run3!

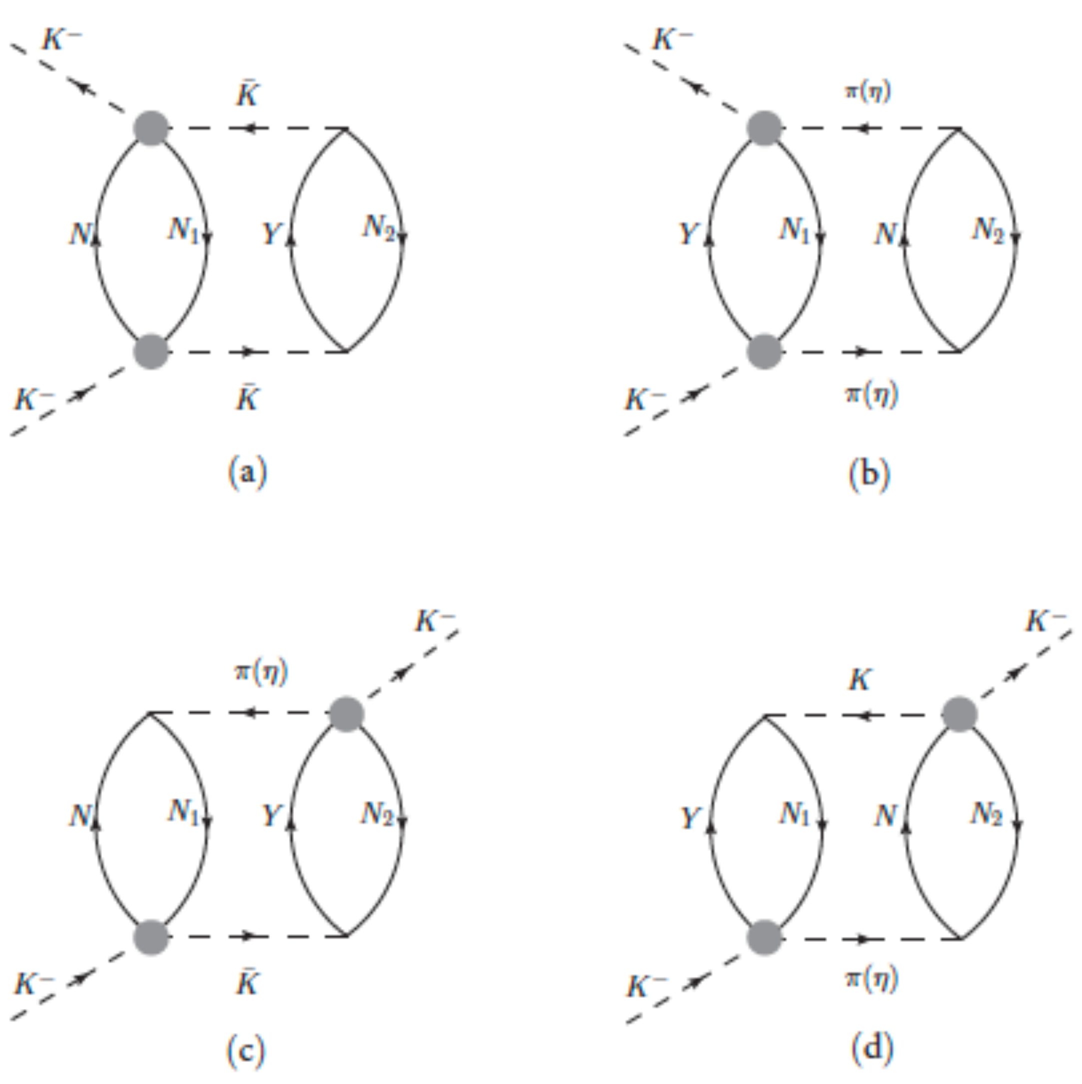


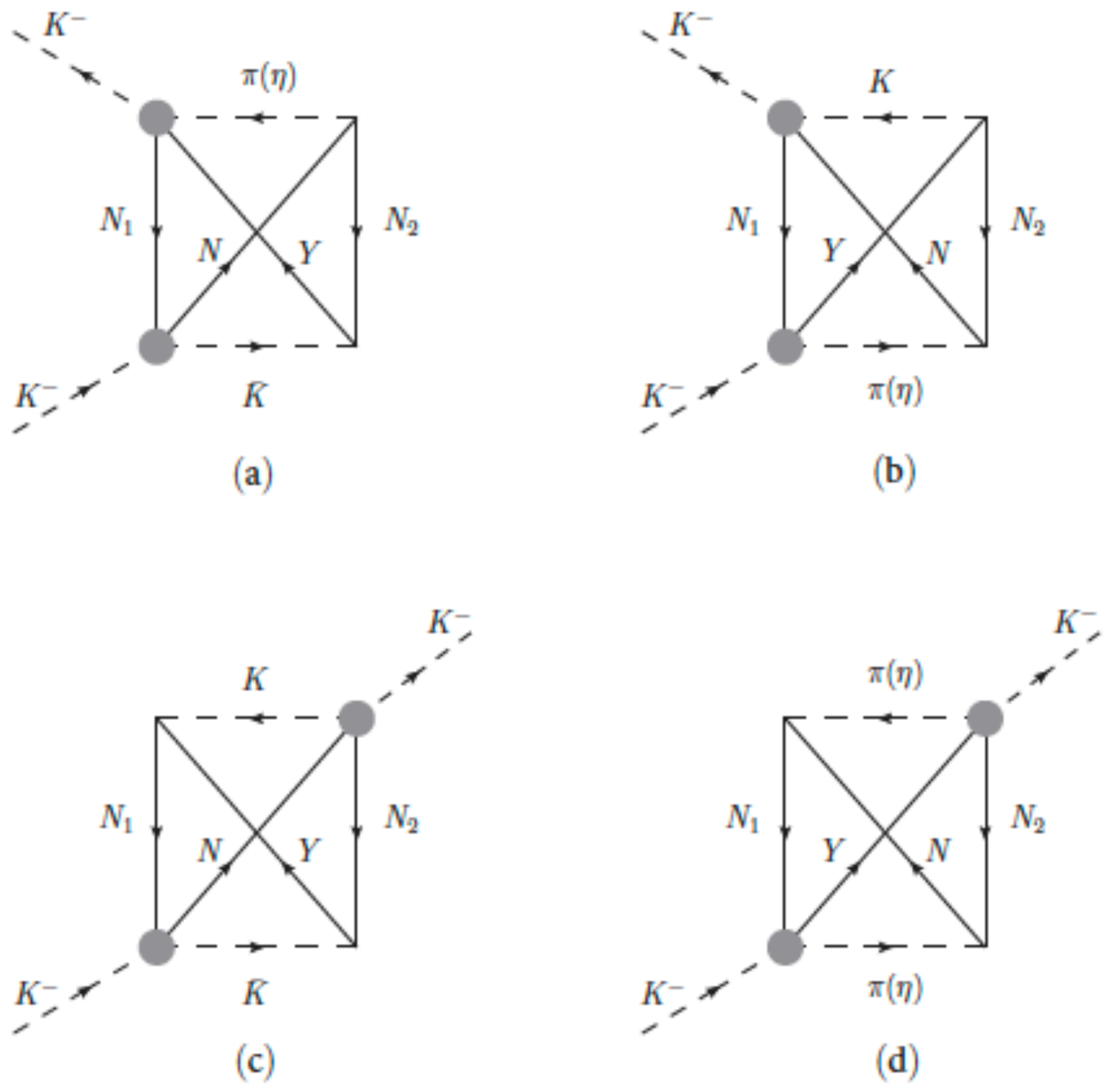
Antikaon absorption in nuclear medium

Jaroslava Obertova

- **Microscopic model** for Multi-nucleon processes K-NN instead of a phenomelogical potential $V^{\mathrm{phen}}_{K^- \mathrm{multiN}} = -4\pi B(\frac{\rho}{\rho_0})^{\alpha}\rho$,

  - Based on a meson-exchange approach
  - P and BCN chiral KN amplitudes employed
  - Pauli correlations in the medium for KN amplitudes considered
  - real part of the KNN optical potential evaluated as well
  - **KN optical potential derived within the same approach**





Antikaon absorption in nuclear medium

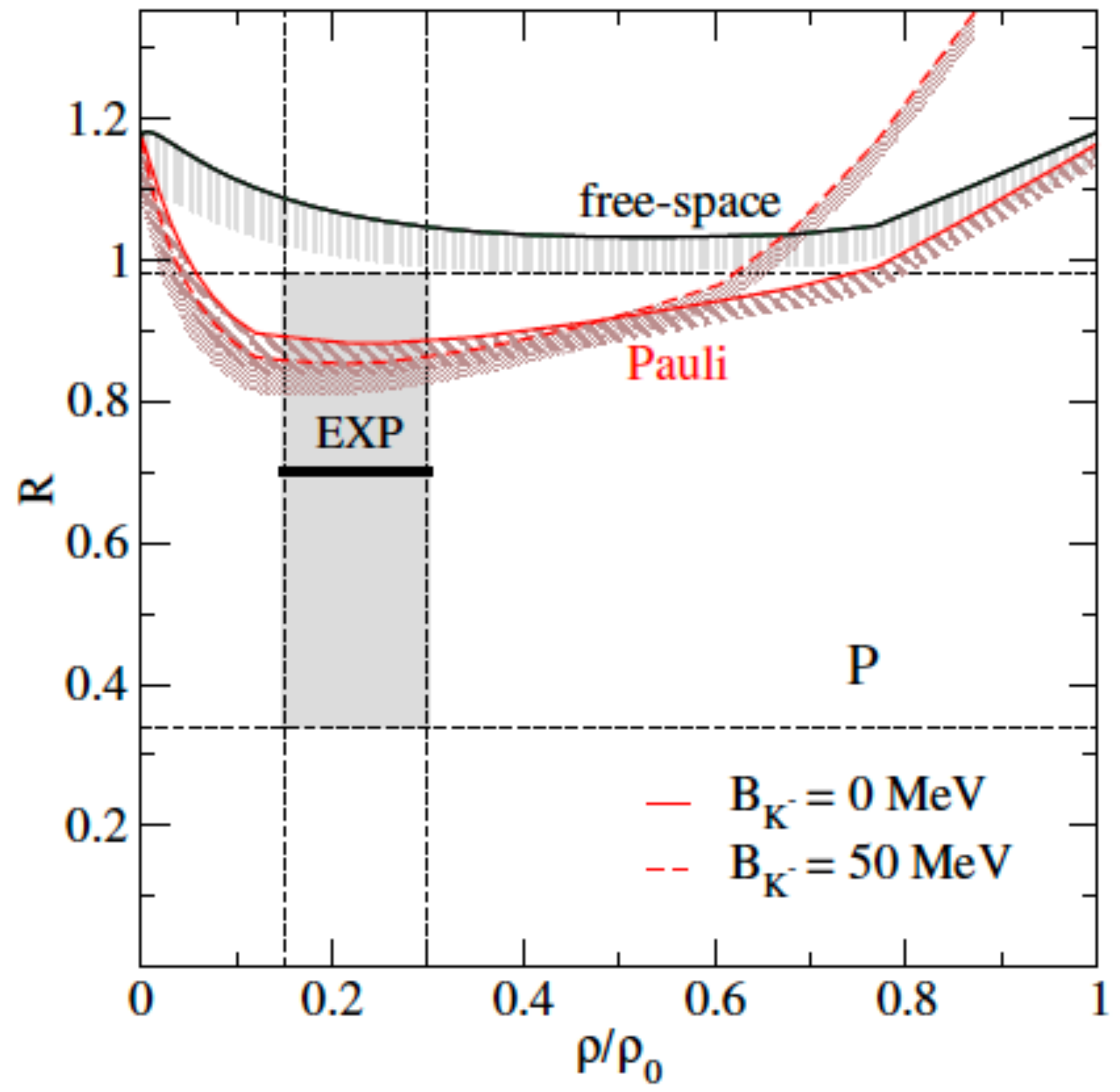
Jaroslava Obertova

- Microscopic model for Multi-nucleon processes K-NN instead of a phenomelogical potential

Result nr 1 :

Recently measured ratio *R. Del Grande et al., EPJ C79 (2019) 190*

$$R = \frac{\mathrm{BR}(K^- pp \to \Lambda p)}{\mathrm{BR}(K^- pp \to \Sigma^0 p)} = 0.7 \pm 0.2(\mathrm{stat.})^{+0.2}_{-0.3}(\mathrm{syst.})$$

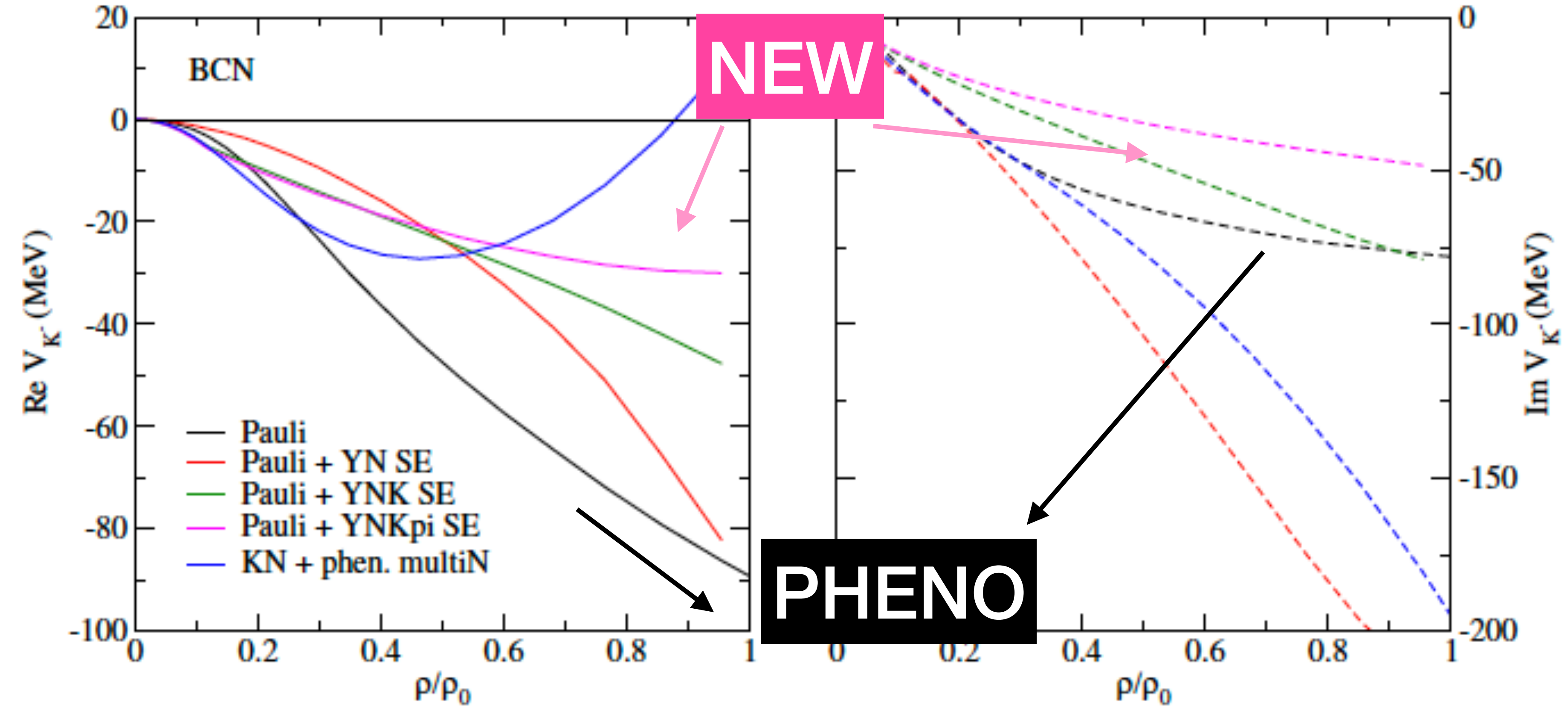


Result nr 2 :

	K^-N	$K^-N + K^-NN$	+ phen.	ReB (fm)	ImB (fm)	α
Pauli	825	565	105	-1.97(13)	-0.93(11)	1.4
WRW	2378	1123	116	-0.90(9)	0.72(10)	0.6

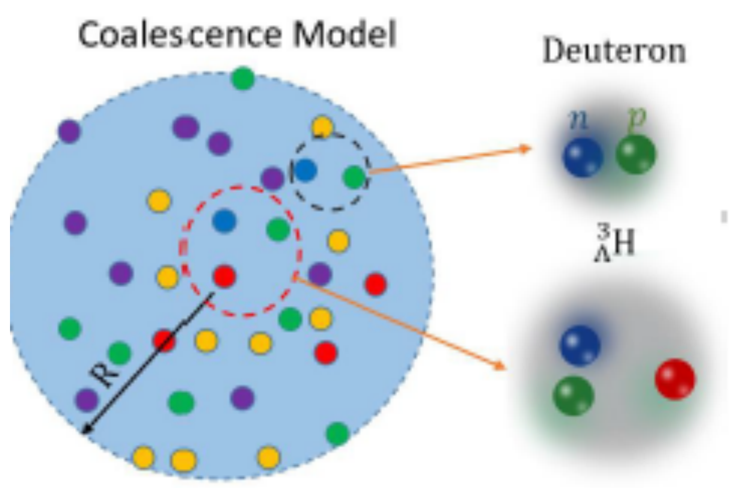
Result of the fit to 65 kaonic atoms data

Result nr 3 : In medium potential for kaons

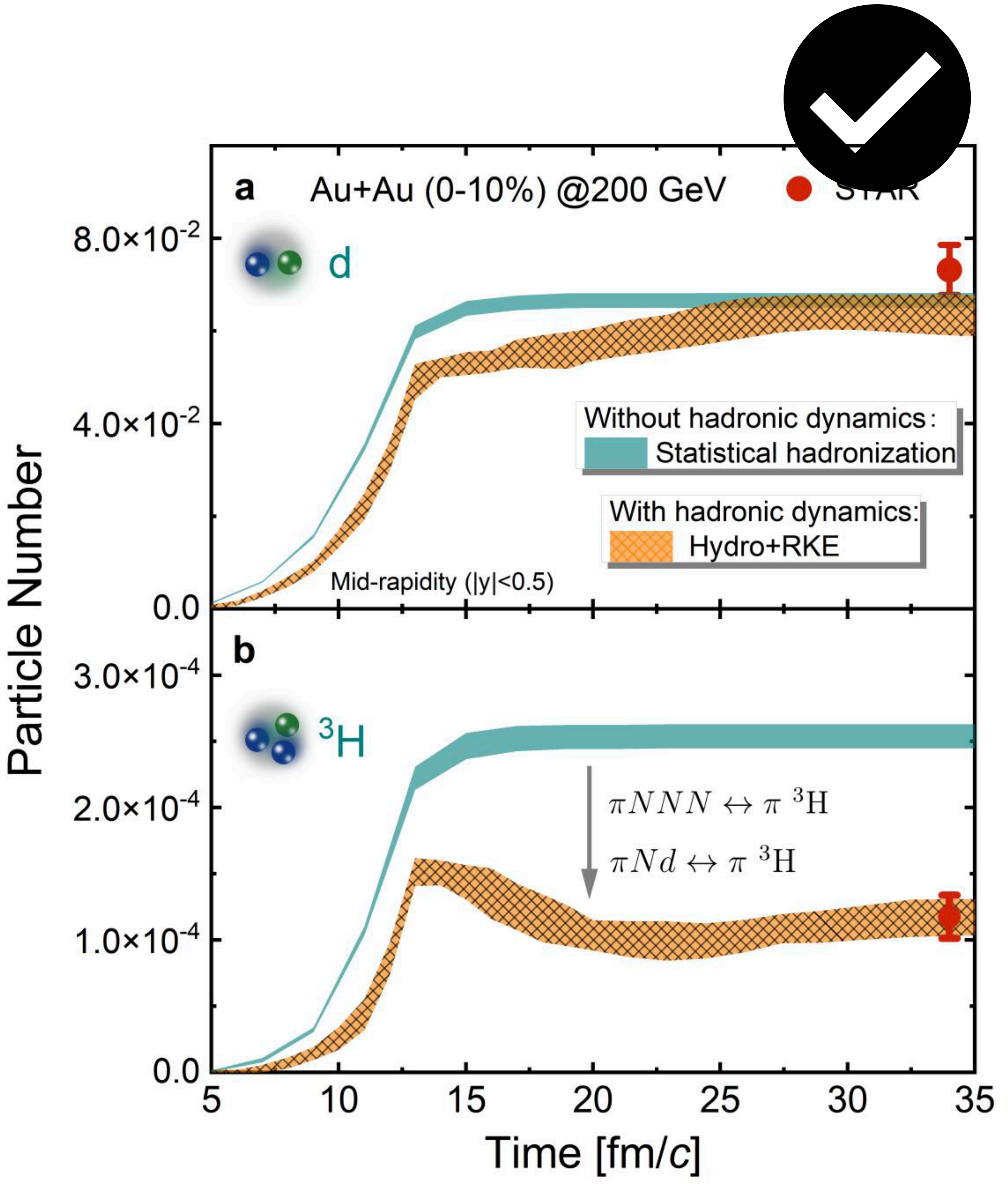


Production of (Hyper)Nuclei within a Coalescence Approach

KaiJia Sun

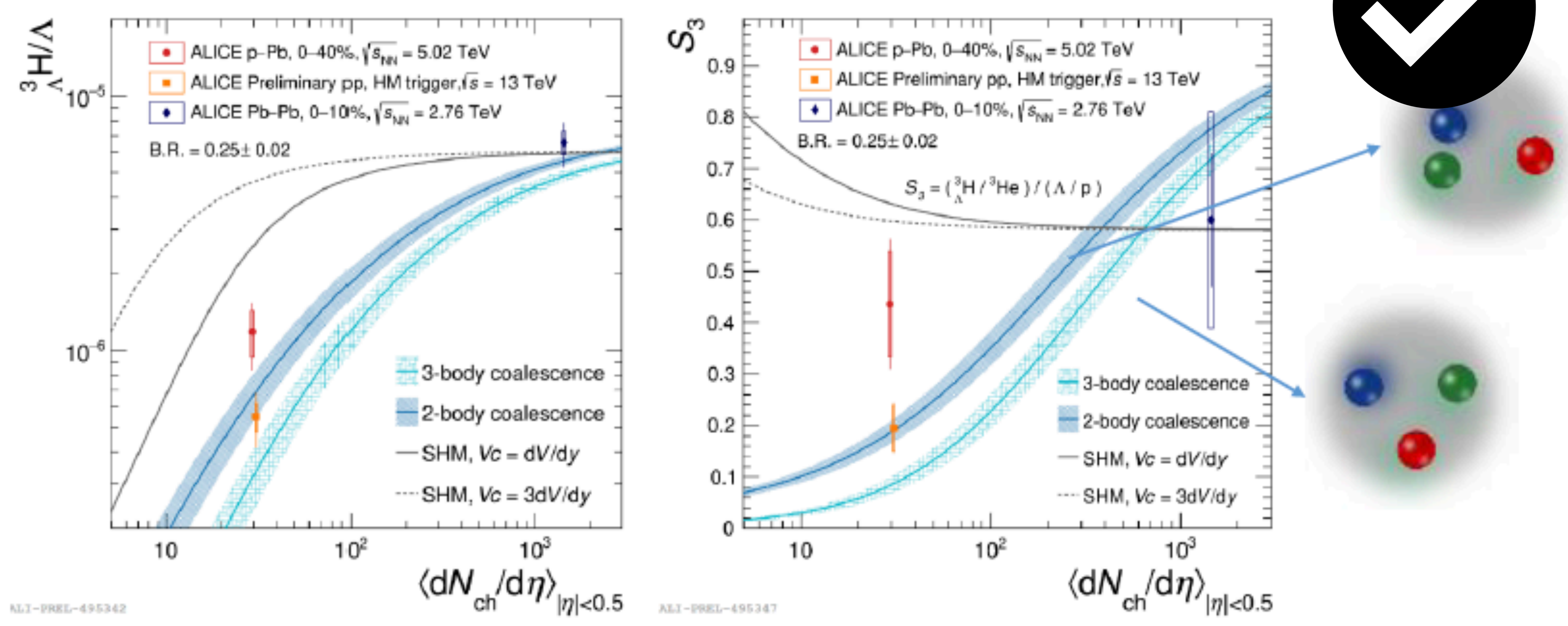


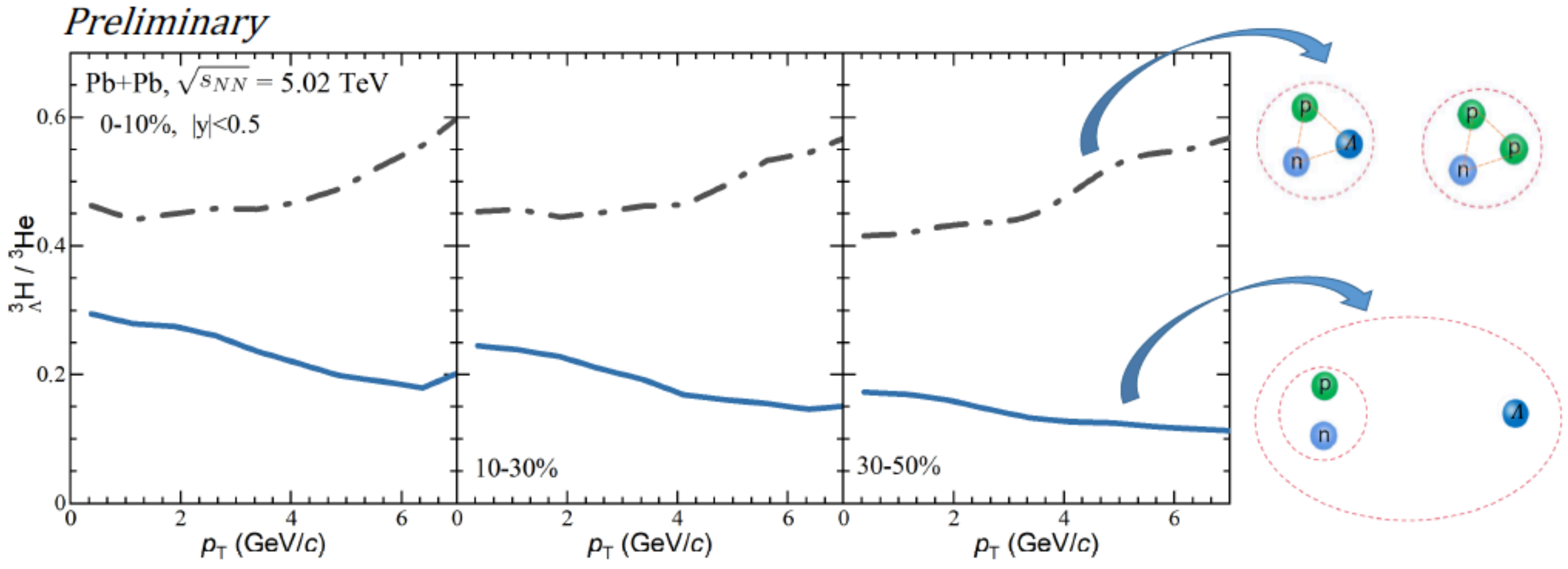
- Final State Coalescence model based on Density Matrix Formulation
- nucleon size is taken into account
- Size of the colliding system is taken into account



ALICE, Phys. Rev. Lett. 128 (2022) 25, 252003

See talk by C. Pinto





Time to see if you followed the talks
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