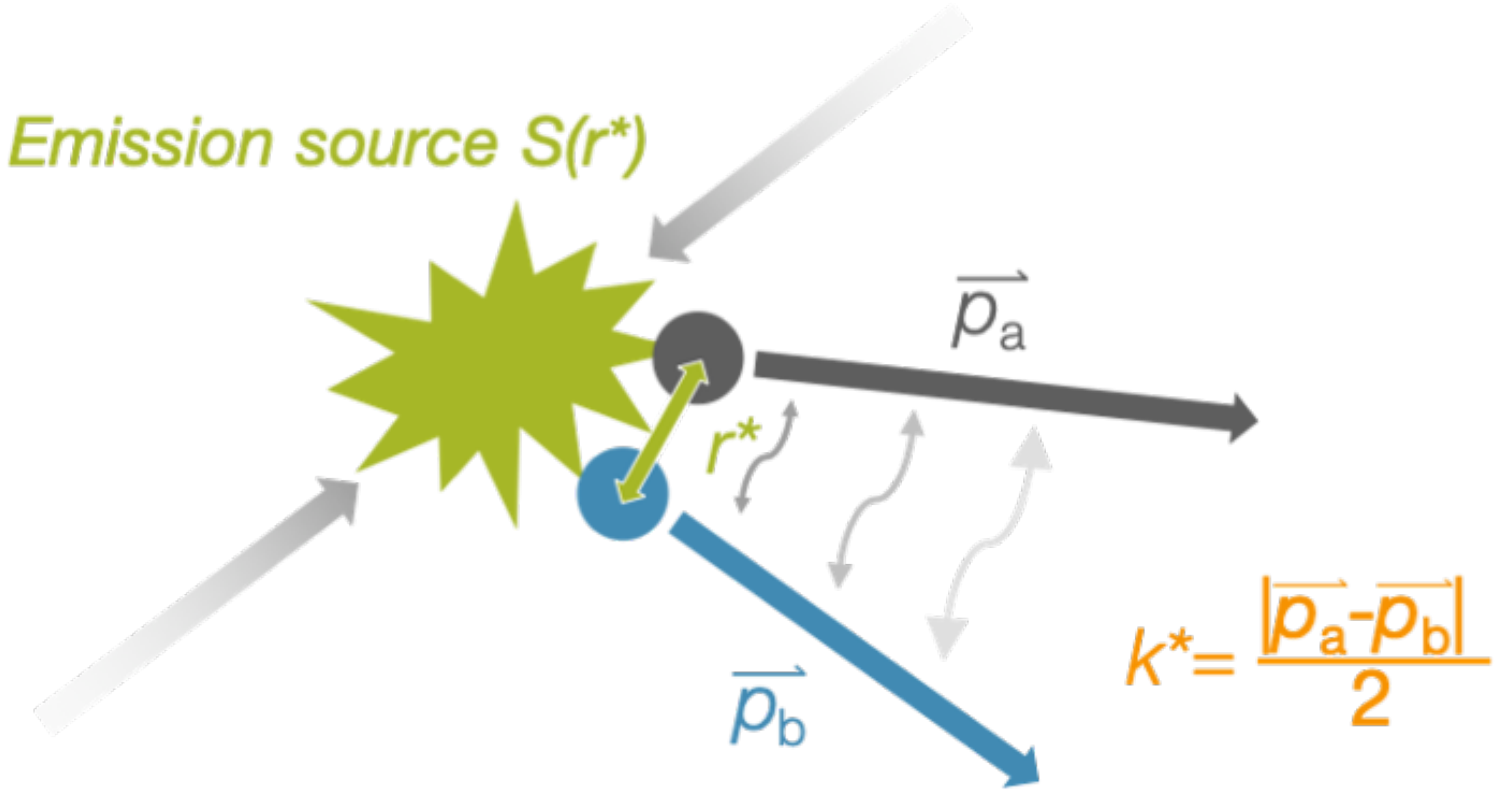
Recent Femtoscopy Measurements from STAR experiment at RHIC

Ke Mi
Central China Normal University
Heidelberg University
2023/02/15

- Recent measurements
  - Strange hyperons correlation
  - Light nuclei correlation

EMMI Workshop: 4th Workshop on Anti-Matter, Hyper-Matter and Exotica Production at the LHC, 13-17 Feb, 2023

Femtoscopy



⇒ Femtoscopy is inspired by Hanbury Brown and Twiss interferometry, but different scale (~several fm)

→ Spatial and temporal extent of emission source

→ Final-state Interactions (Coulomb, Strong interaction)

→ Bound state

✓ Two-particle correlation function:

Model — *Experimental*

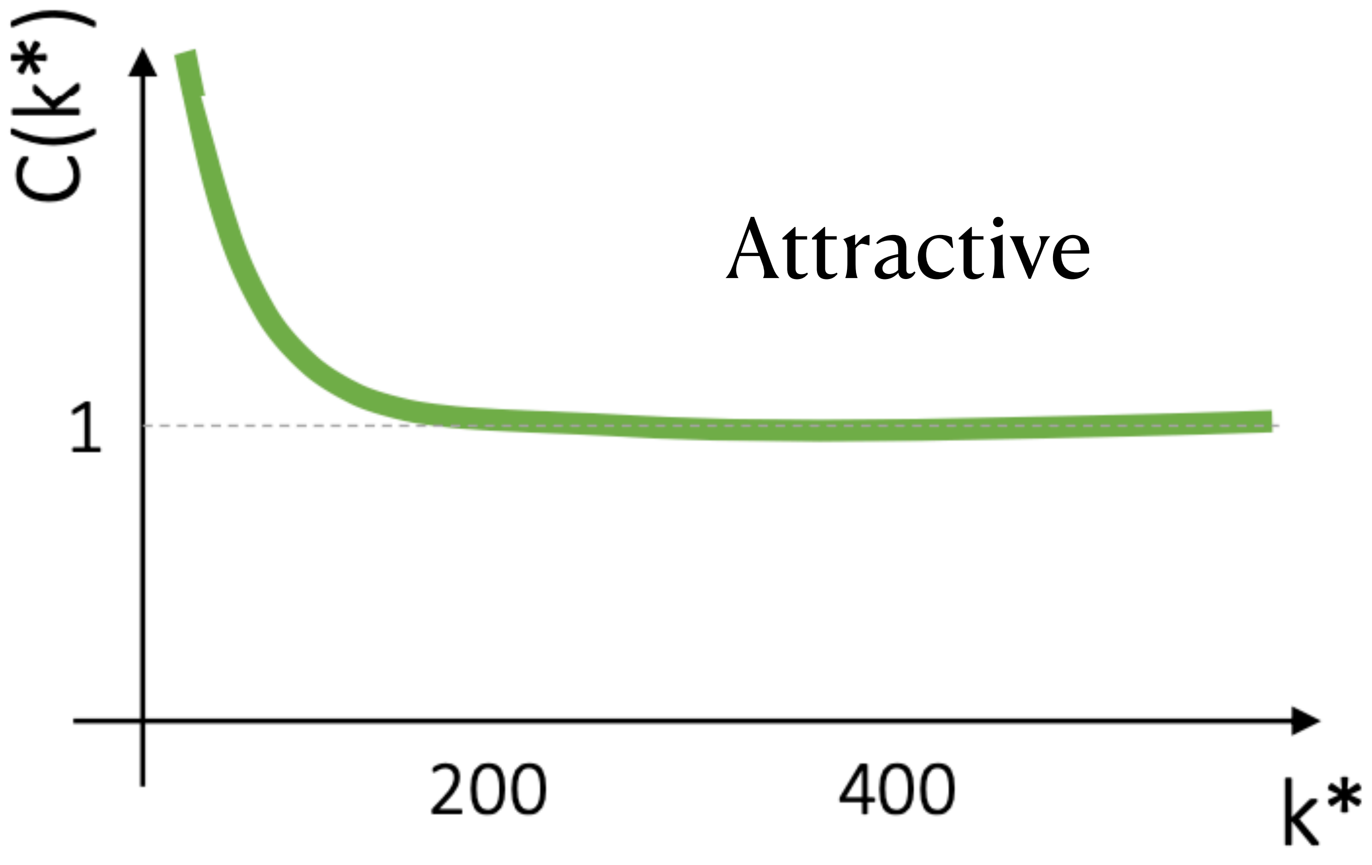
$$C(k^*) = \int S(\vec{r})|\Psi(\vec{k}^*,\vec{r})|^2 d^3\vec{r} = \frac{N_{same}(k^*)}{N_{mixed}(k^*)}$$

$S(\vec{r})$: *Source function*

$\Psi(\vec{k}^*,\vec{r})$: *Pair wave function*

$k^* = \frac{1}{2}|\vec{p}_a - \vec{p}_b|$, *relative momentum*

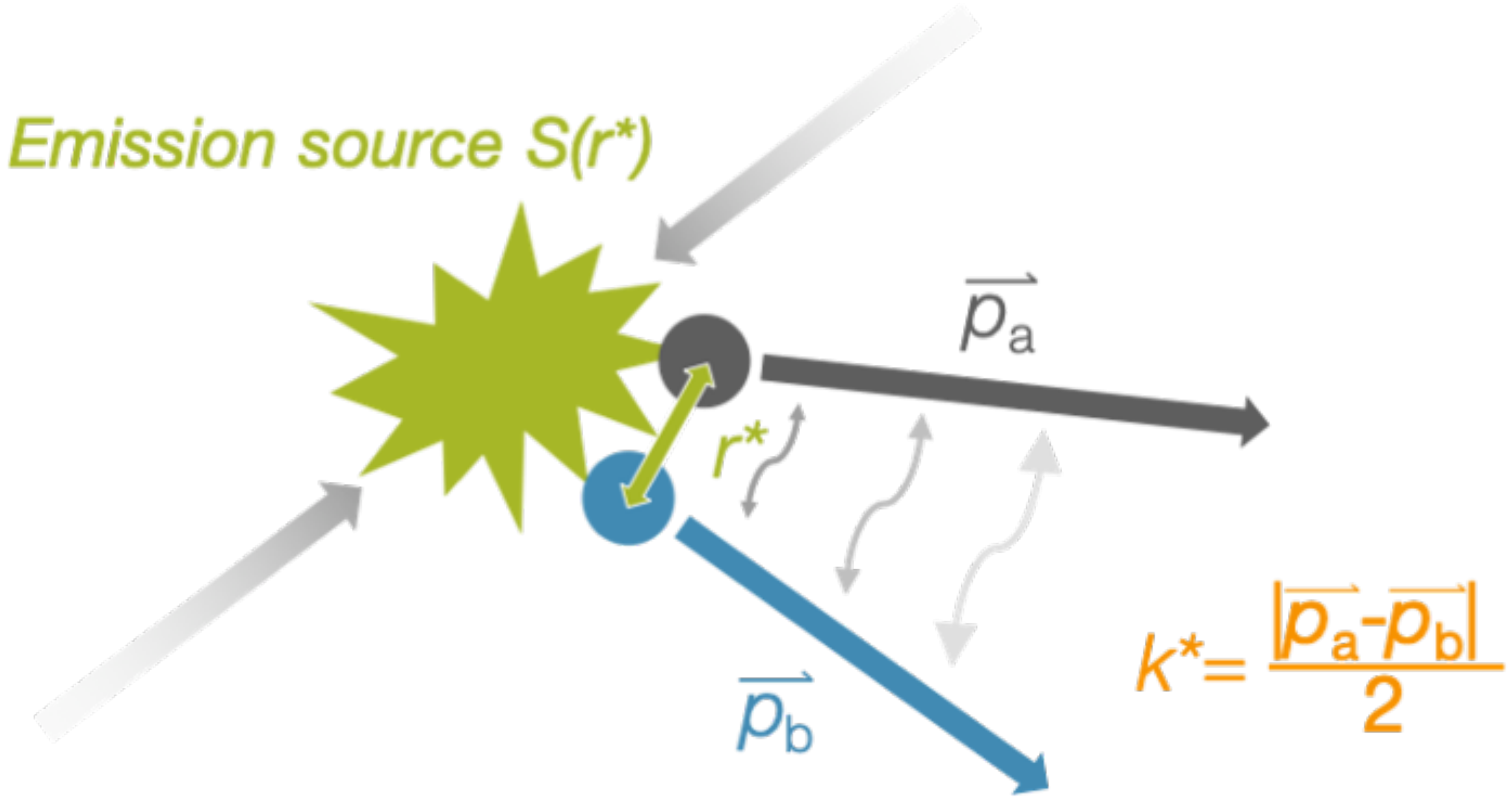
$\vec{r}$: *relative distance*



Nature 178 1046-1048(1956)

ALICE Coll. Nature 588, 232–238 (2020)

Femtoscopy



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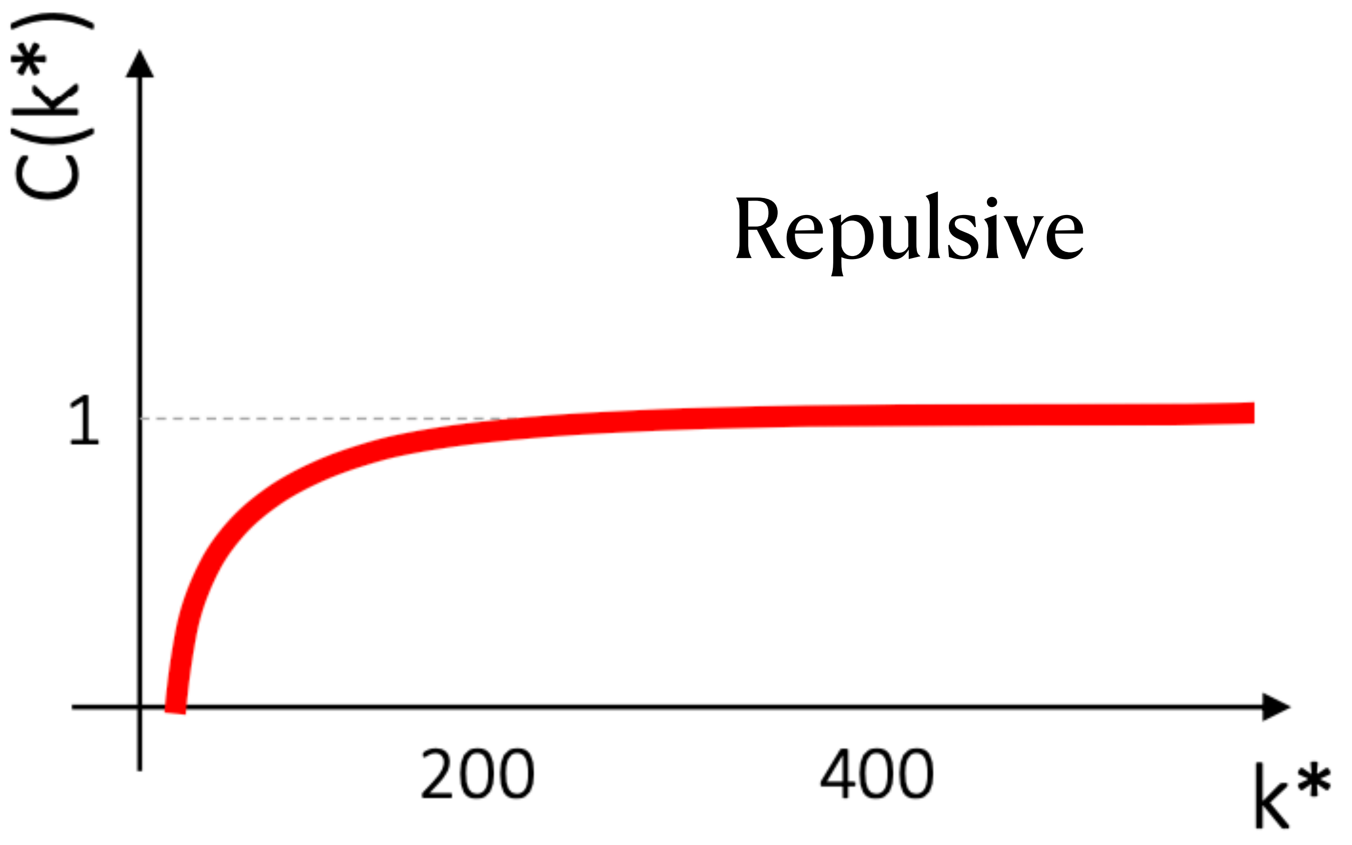
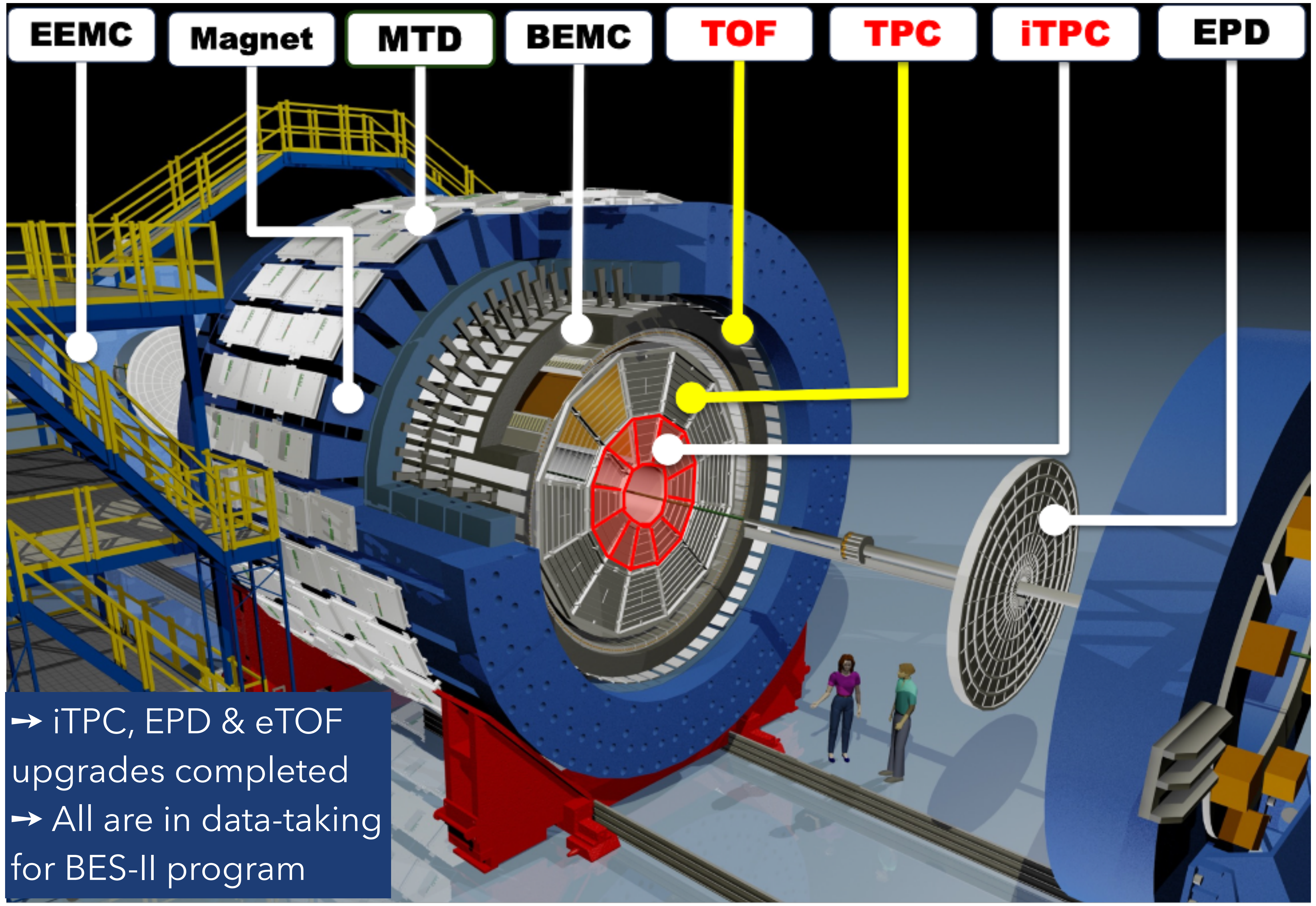


Nature 178 1046-1048(1956)

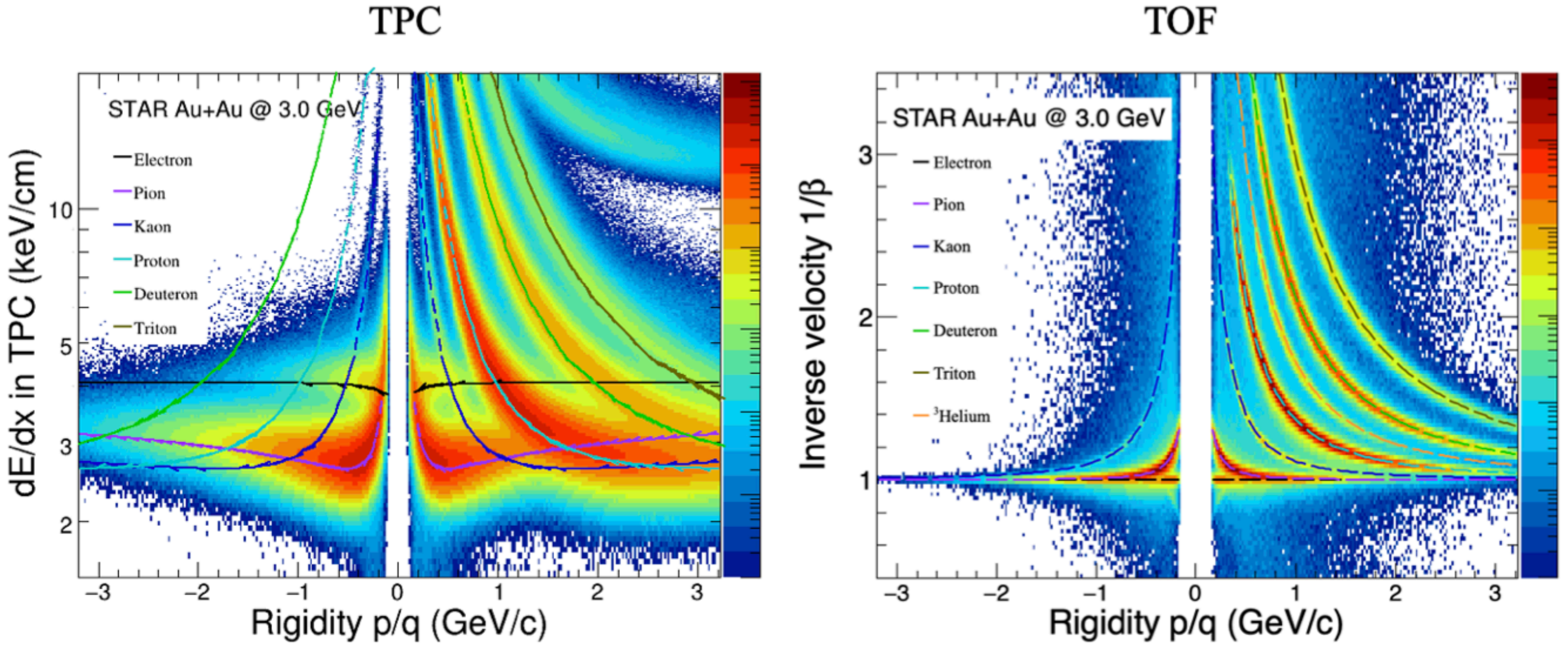
ALICE Coll. Nature 588, 232–238 (2020)

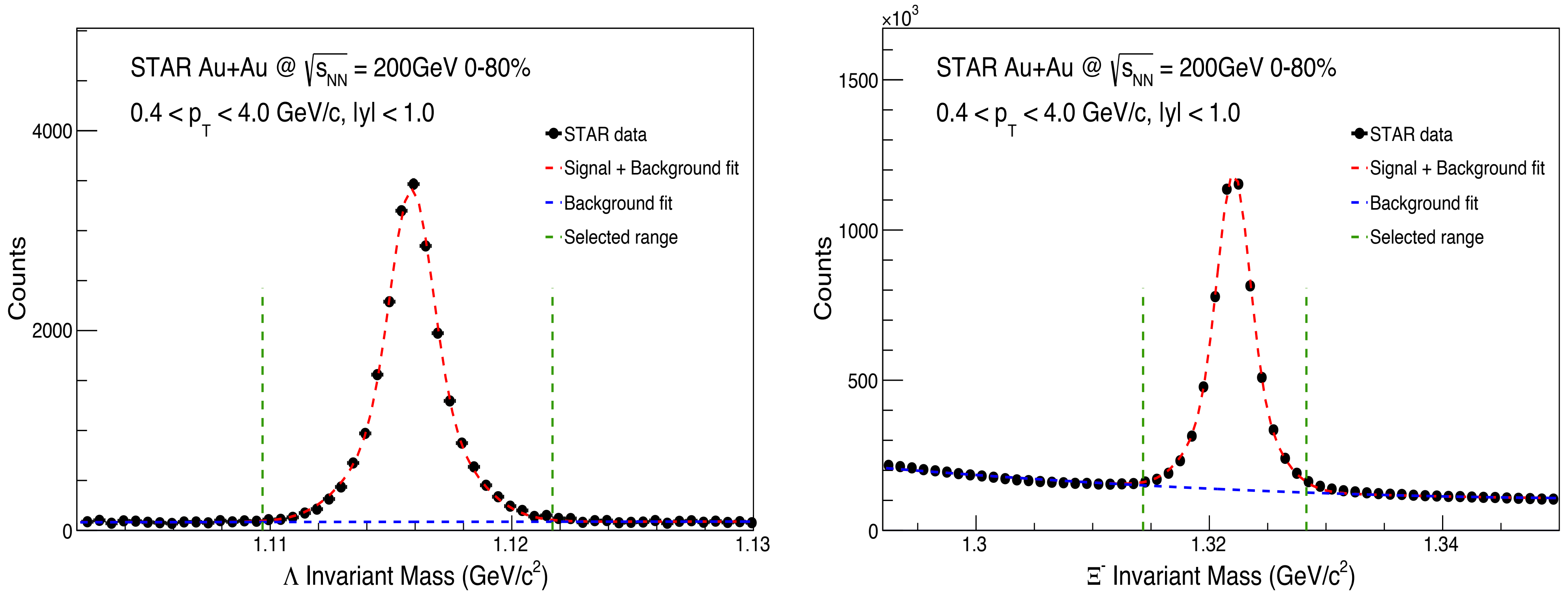
STAR detector



→ iTPC, EPD & eTOF upgrades completed
→ All are in data-taking for BES-II program

→ Excellent Particle Identification
→ Large, Uniform Acceptance at Mid-rapidity





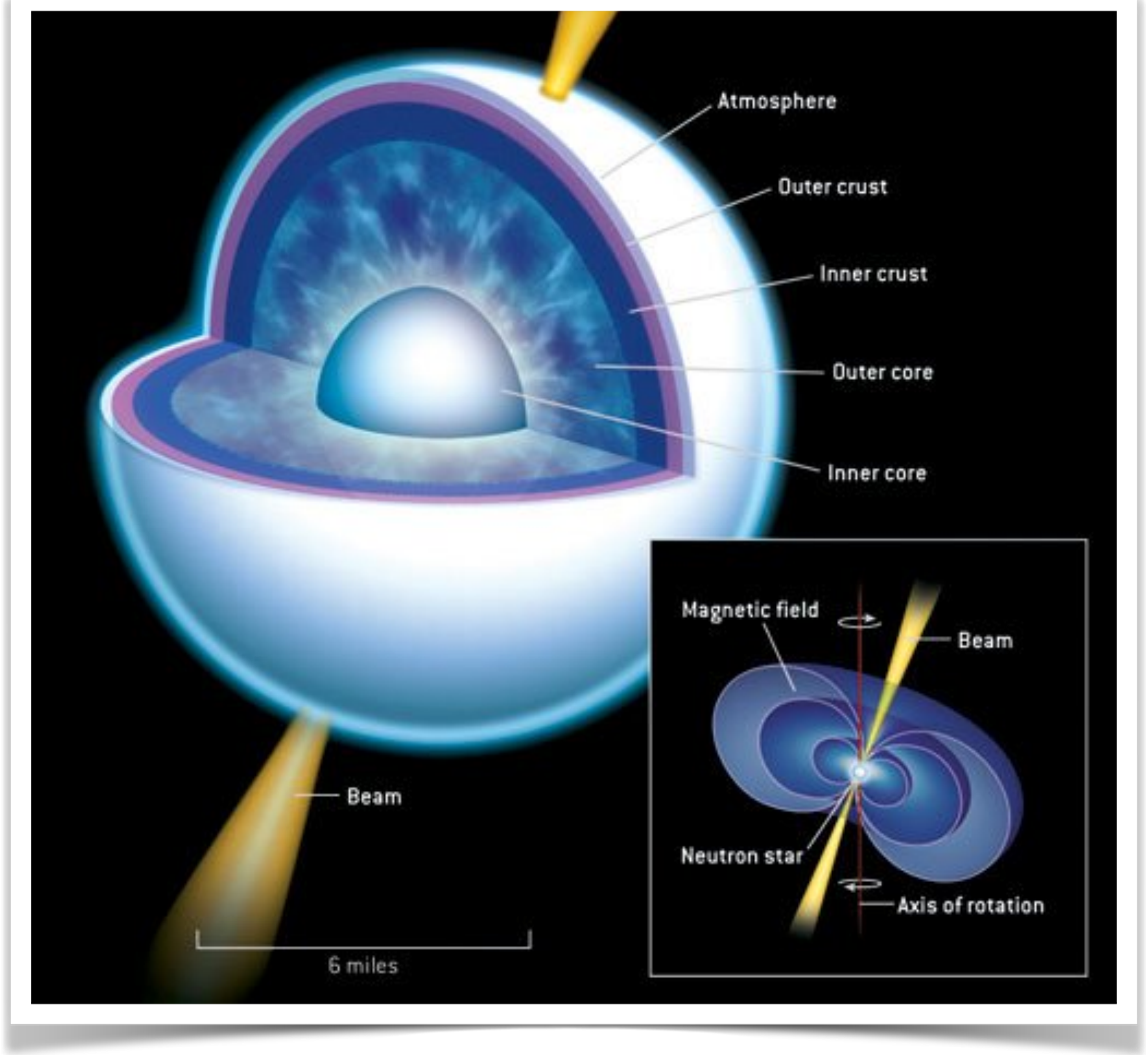
Y-N and Y-Y Interactions

Hyperon-Nucleon (Y-N) and Hyperon-Hyperon (Y-Y) interactions are important for study the exotic hadronic states

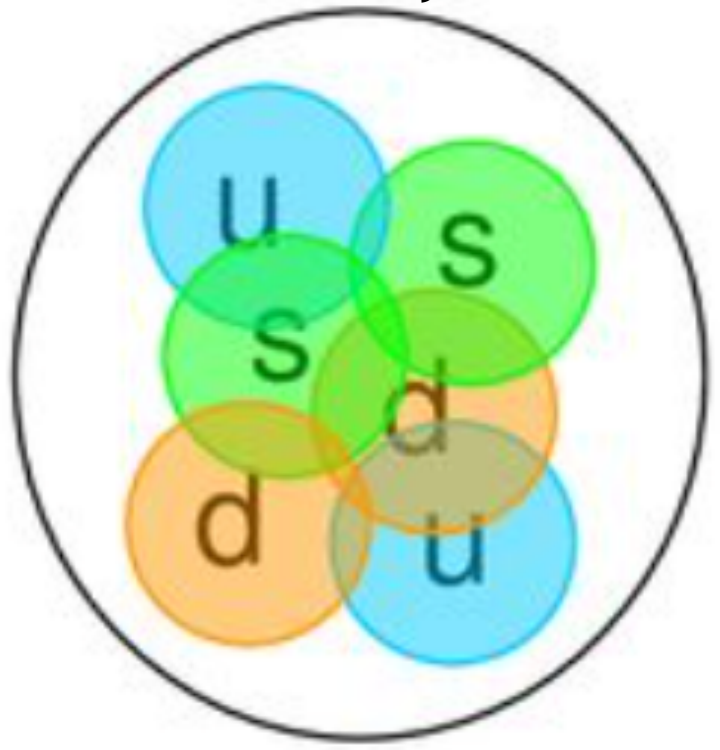
|s|	1	2	3	4
Pair	ΛN	ΞN, ΛΛ	PΩ	ΞΞ

- Input for EoS of nuclear matter in neutron stars with hyperons
- Constraints for hypernuclei and effective QCD in (multi)strange sector
- Exotic bound states as H-dibaryon?

Neutron Star

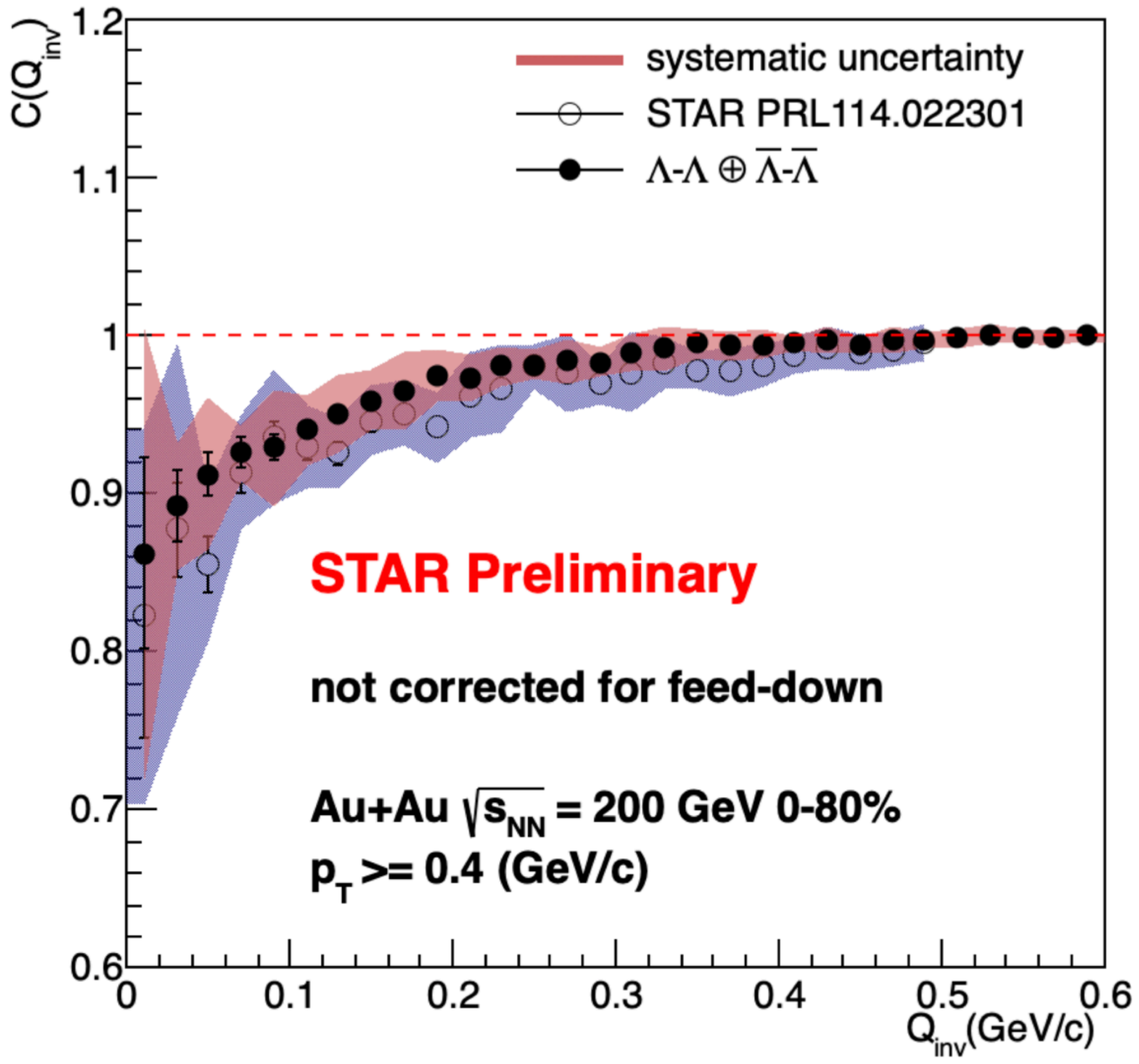


H-dibaryon



Rev. Mod. Phys. 89, 015007; T. Hatsuda et al., NPA967, 865 (2017); J. Haidenbauer et al., Eur. Phys. J. A 51: 17 (2015)

Λ-Λ Correlation (|S| = 2)



⇒ New result with high statistics data ~4 times larger than that in previous study

STAR Coll, Phys.Rev.Lett, 114(2015) 022301
ALICE Coll, Phys.Lett.B 797 (2019) 134822
EPJ Web of Conferences 259, 11015 (2022)

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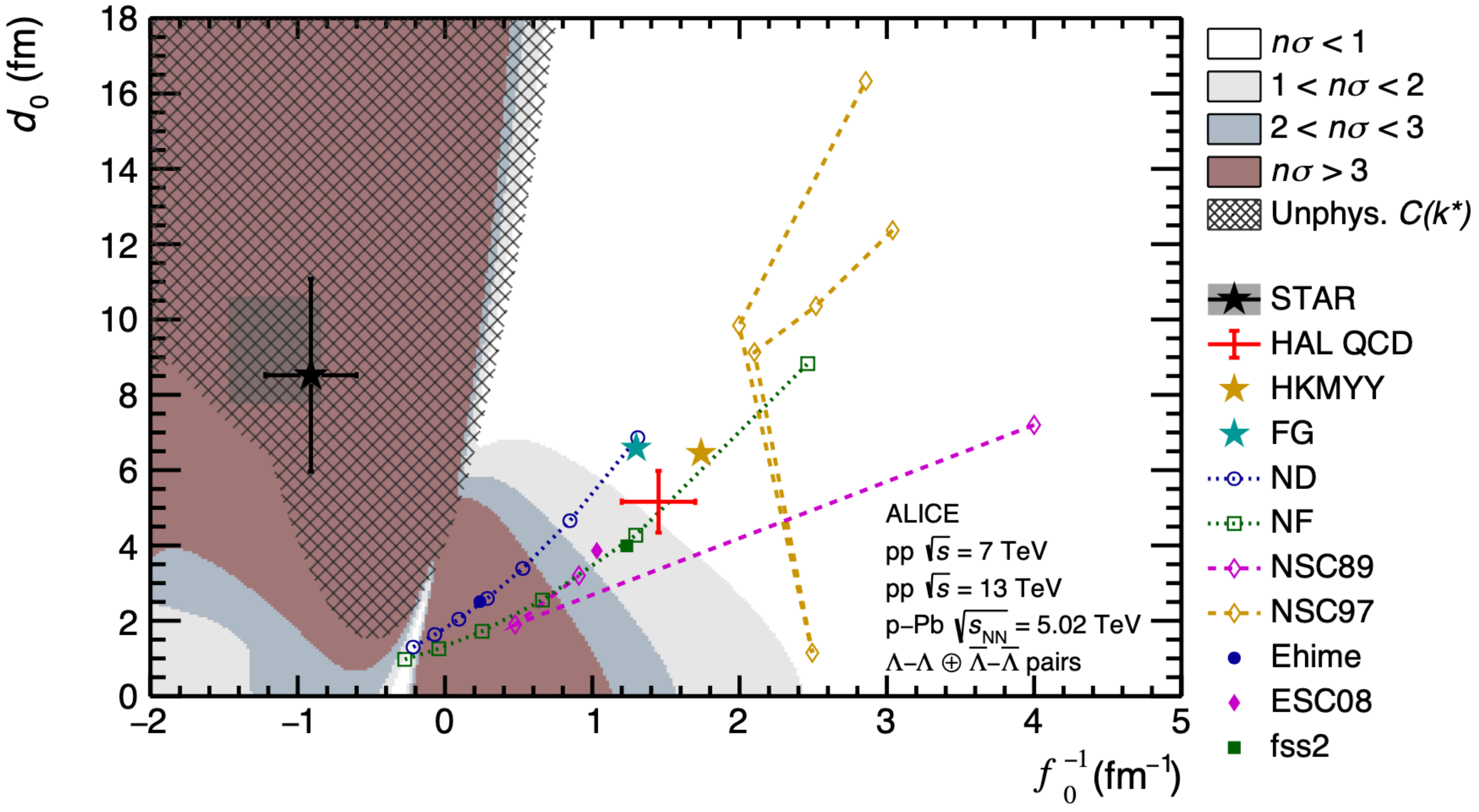

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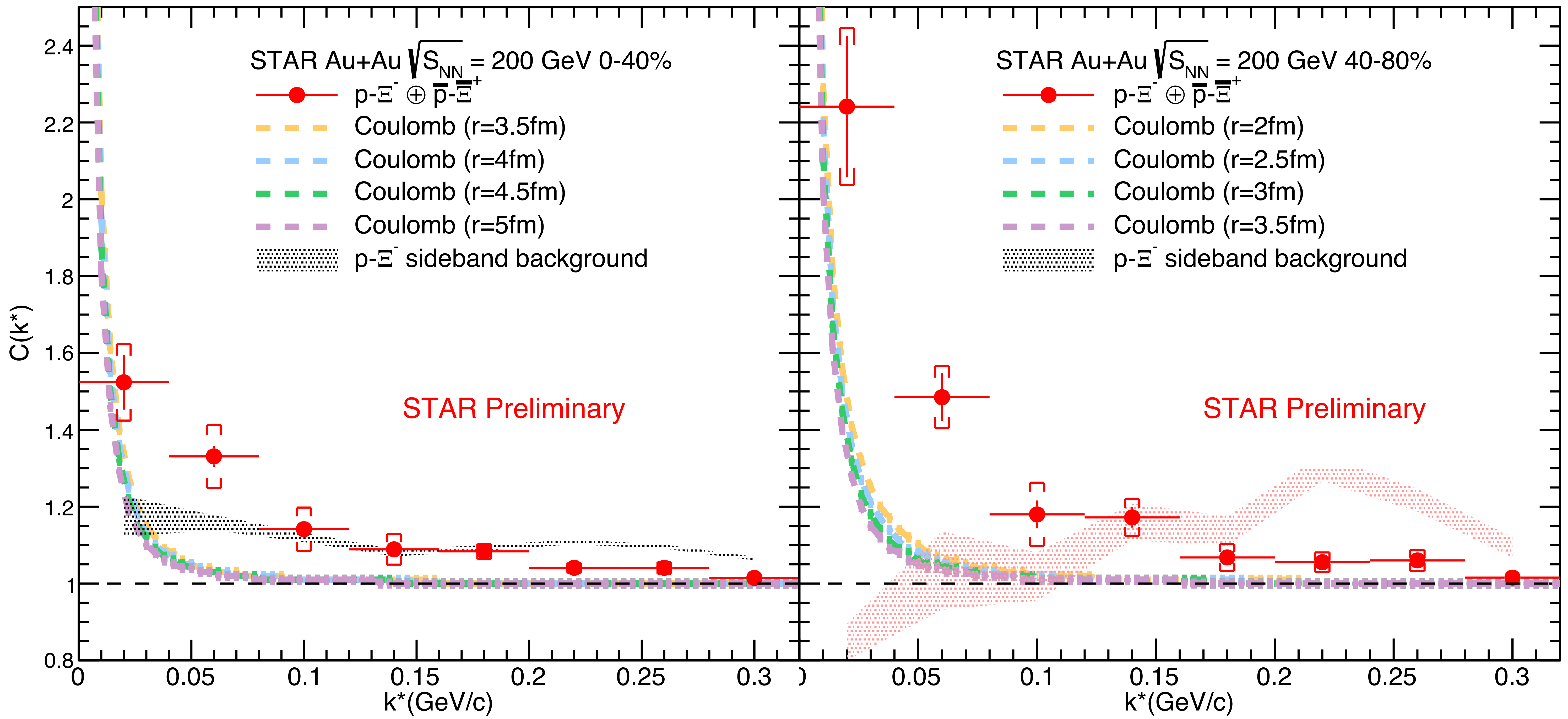
⇒ Parameterisation with Lednicky-Lyuboshitz model, strong interaction parameter (f_0 and d_0) are extracted

⇒ Larger statistics datasets at RHIC and LHC to yield a conclusive answer

LednickýR,LyuboshitzV.Sov.J.Nucl.Phys.35:770(1982)
STAR Coll, Phys.Rev.Lett, 114(2015) 022301
ALICE Coll, Phys.Lett.B 797 (2019) 134822

Proton-Ξ Correlation (|S| = 2)



⇒ Enhancement at low k* in both large (0-40%) and small (40-80%) system

⇒ p-Ξ CFs show deviation from Coulomb only —- Strong Interaction

⇒ No dip structure seen in data —- No bound state

EPJ Web of Conferences 259, 11015 (2022)
K.Sasaki, et al., Pos LATTICE2016, 116 (2017)
HAL QCD: Nucl. Phys. A967 (2017) 856-859

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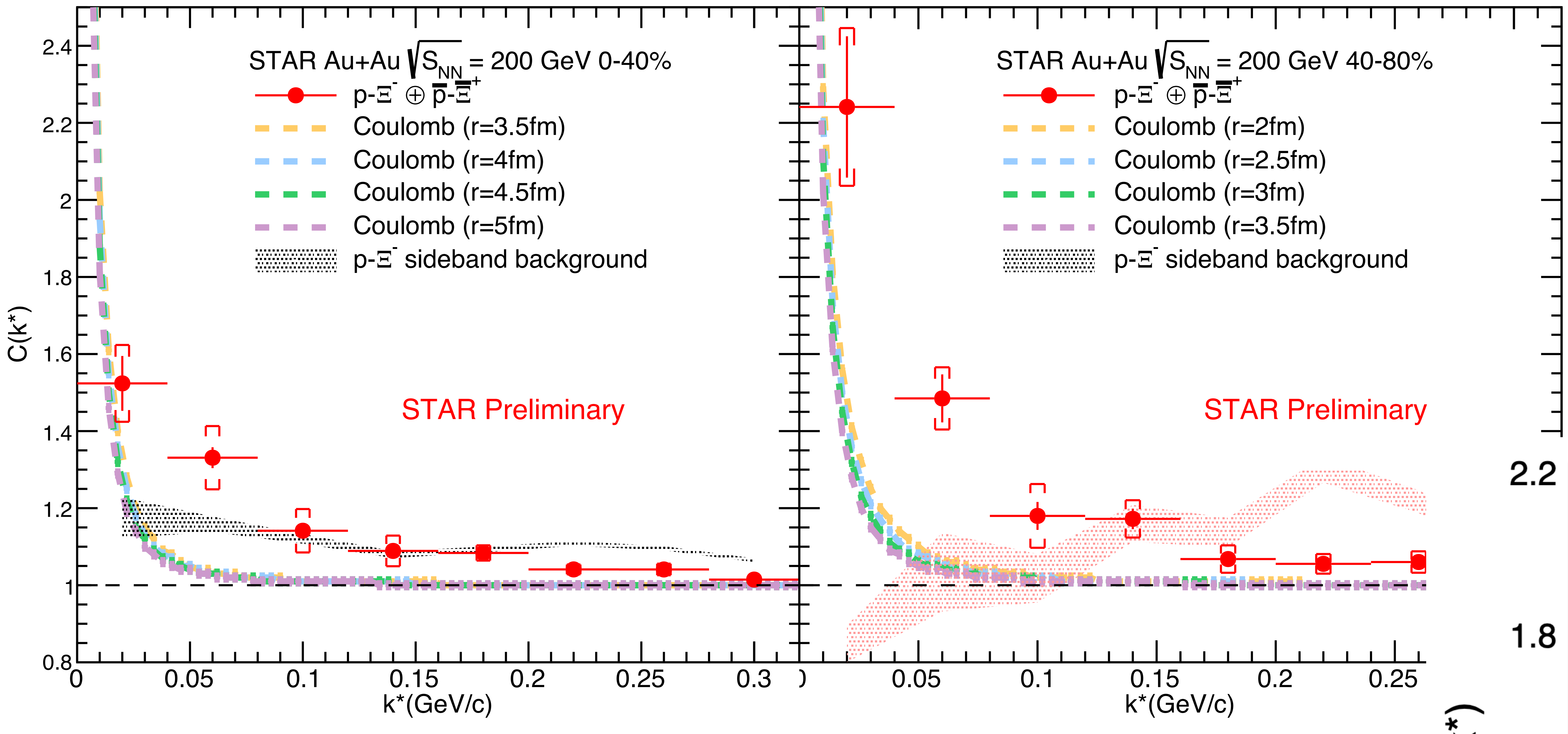
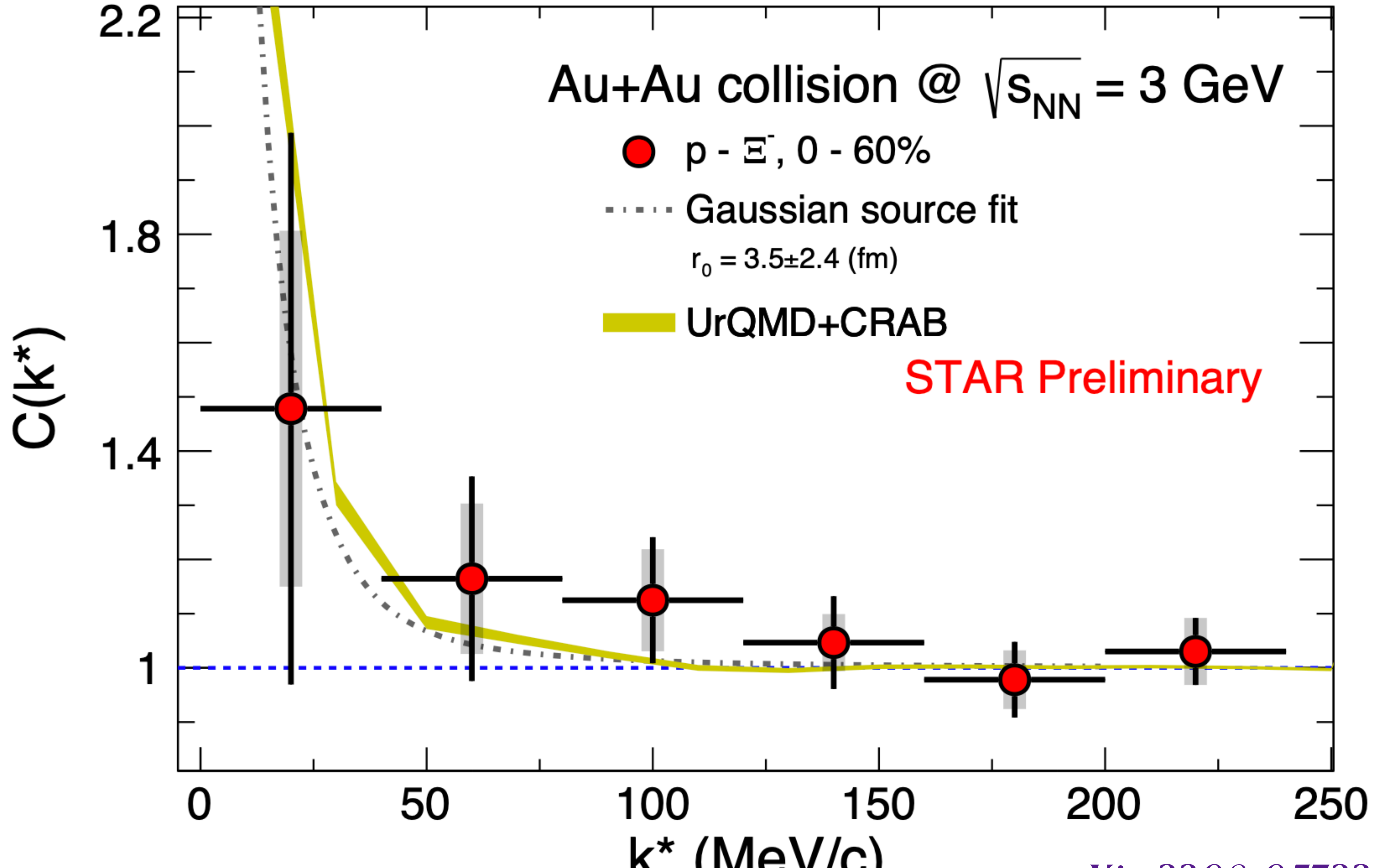




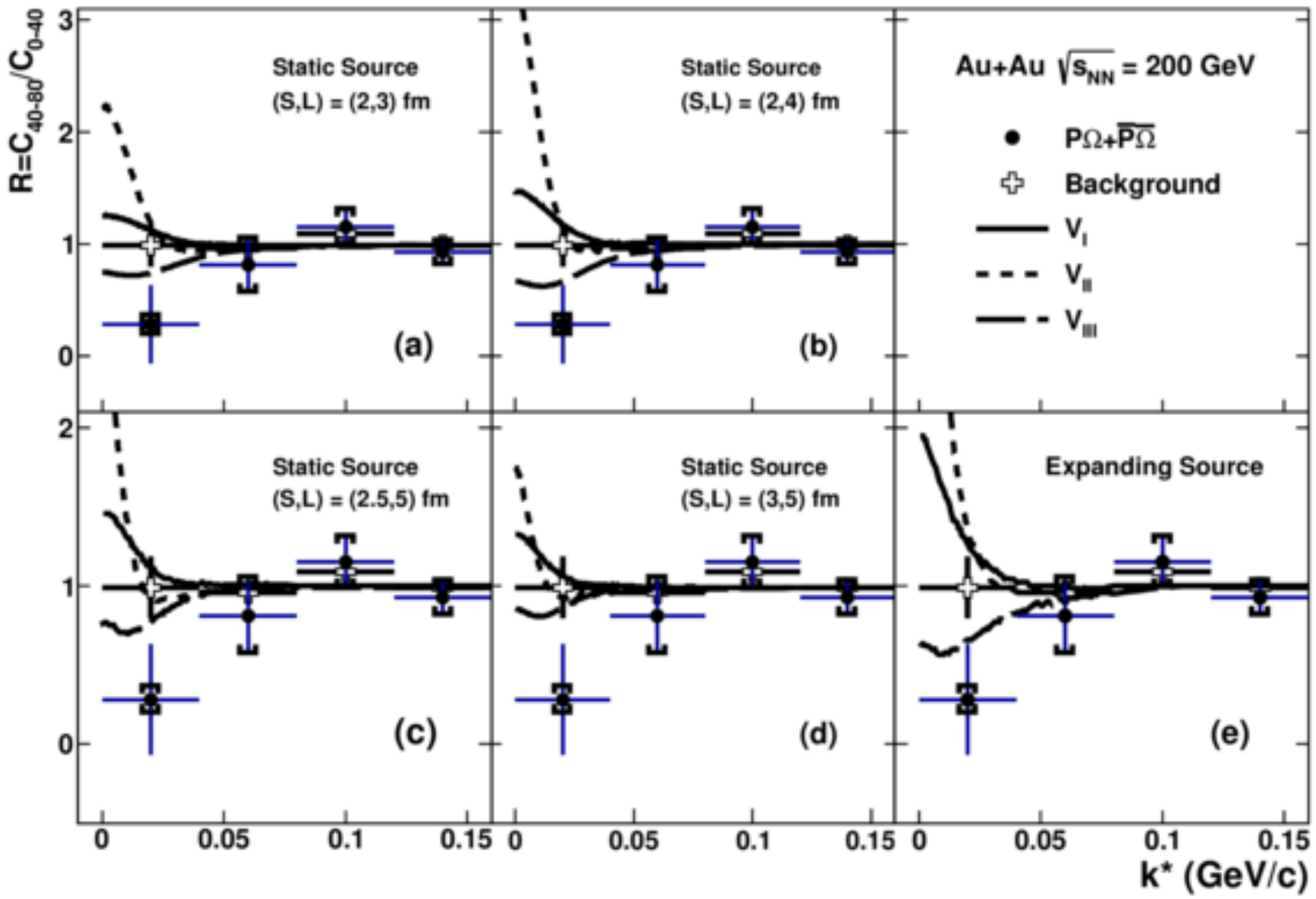
⇒ New results of p-Ξ CF at 3 GeV Au+Au collisions

⇒ Enhancement at low k* seen in data at 3 GeV

⇒ UrQMD + CRAB calculation is consistent with data (HAL QCD potential include)

arXiv:2208.05722

Proton-Ω Correlation (|S| = 3)



Spin-2 pOmega potentials	VI	VII	VIII
Binding energy E_B (MeV)	-	6.3	26.9
Scattering length a_0 (fm)	-1.12	5.79	1.29
Effective range r_eff (fm)	1.16	0.96	0.65
	No bound state	Shallow bound	Deep bound

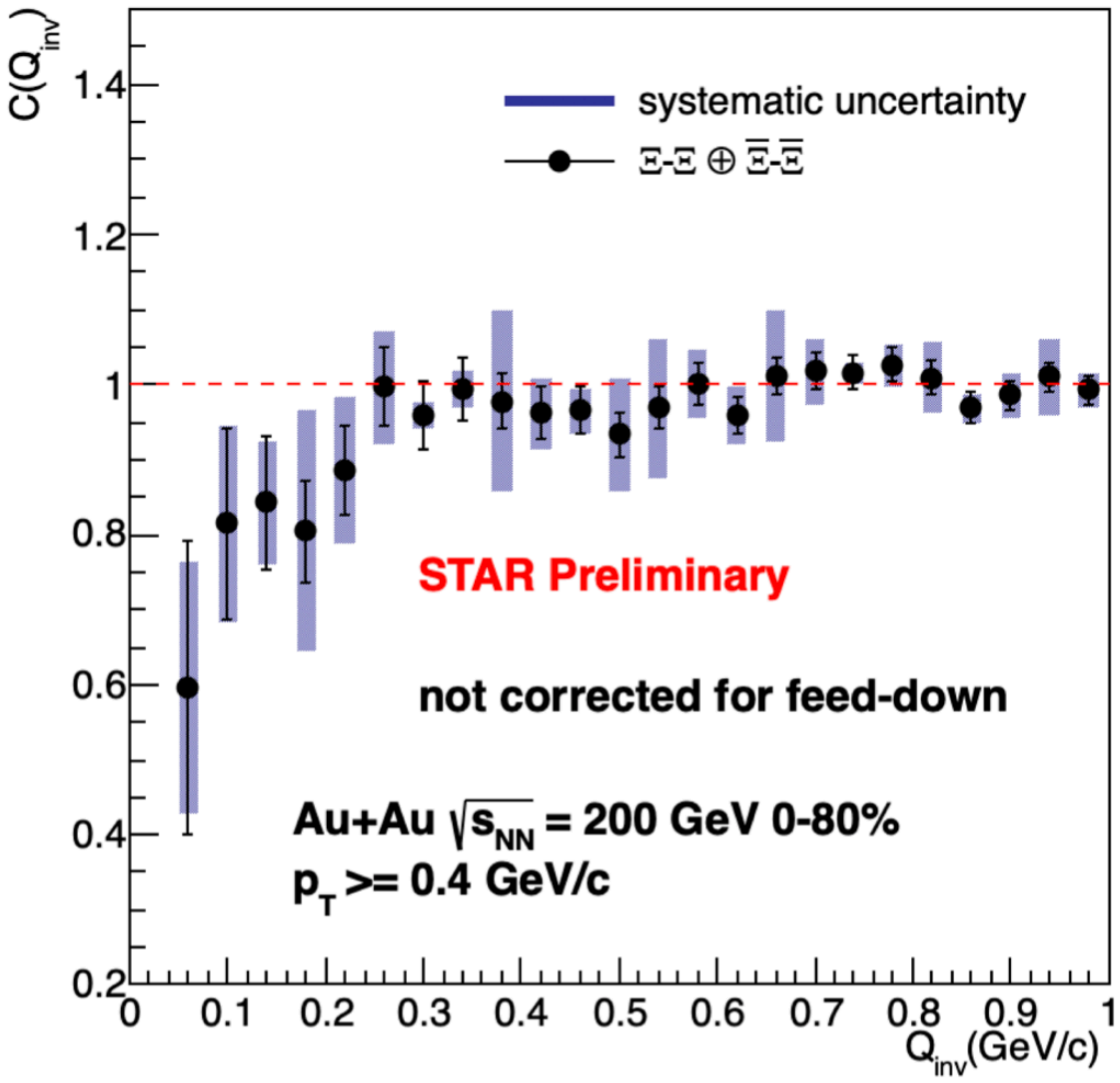
⇒ The ratio of CF for the small (40-80%) to large (0-40%) system is smaller than unity at low relative moment.

⇒ Measurement supports the existence of a deeply bound state decaying into the proton-Ω final state

- SS → Static source
- ES → Expanding source
- Background → Ω sideband is used
- Boxes → systematic uncertainty

STAR Coll, Phys.Lett.B 790 (2019) 490
Phys. Rev. C 94, 031901 (R) (2016)

Ξ-Ξ Correlation (|S| = 4)



- First measurement of Ξ-Ξ correlation in Au+Au collisions
- Lattice QCD/chiral EFT calculations indicate an attractive interaction, but not strong enough to form a bound state
- The result shows anti-correlation at Q_{inv} < 0.25 GeV/c.
  - Feed-down effect is not considered

EPJ Web of Conferences 259, 11015 (2022)
J. Haidenbauer et al., Eur. Phys. J. A 51: 17 (2015)
T,Doi et al., EPJ Web Conf. 175 (2018) 05009

Light Nuclei Correlations

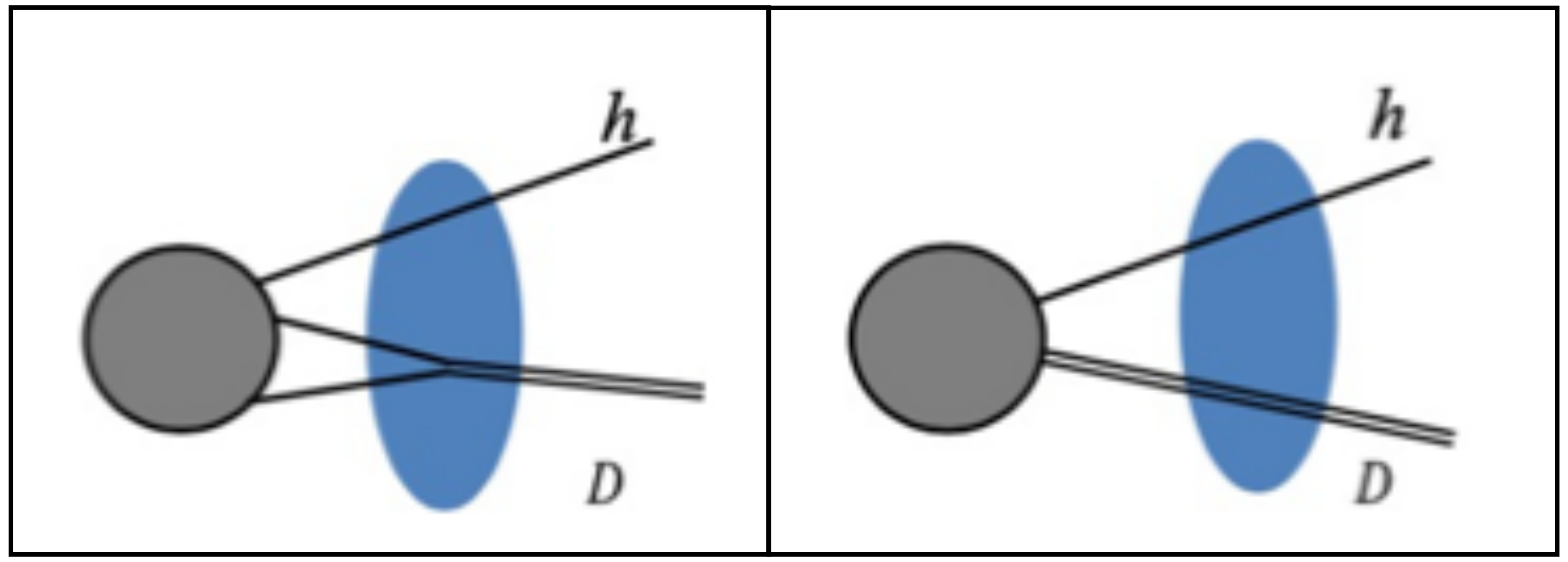
- Formation mechanism of light nuclei are under debate

  ⇒ Coalescence : final-state interaction

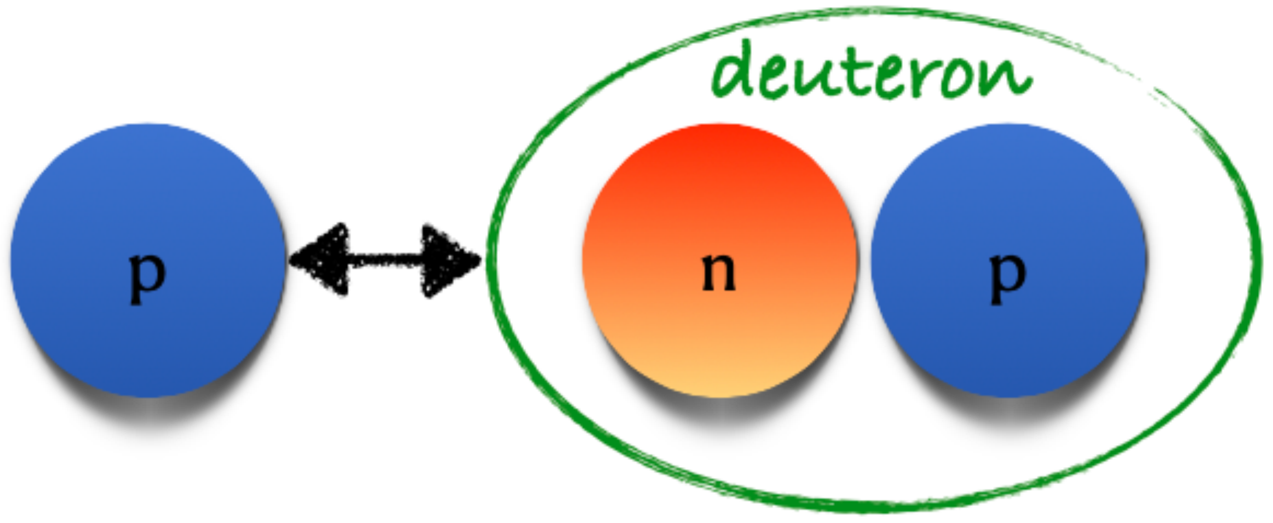
  ⇒ Thermal : produced directly from fireball

  ⇒ A systematic measurements of light nuclei femtoscopy may help to investigate

- Indirect approach of three-body and four-body interactions



Coalescence Direct production



J.Cleymans et al, Phys.Rev.C 74, 034903 (2006)
K. Blum et al, Phys.Rev.C 99, 04491 (2019)
St. Mrówczyński and P. Słoń, Acta Physica Polonica B 51, 1739 (2020)
St. Mrówczyński and P. Słoń, Physical Review C 104, 024909 (2021)

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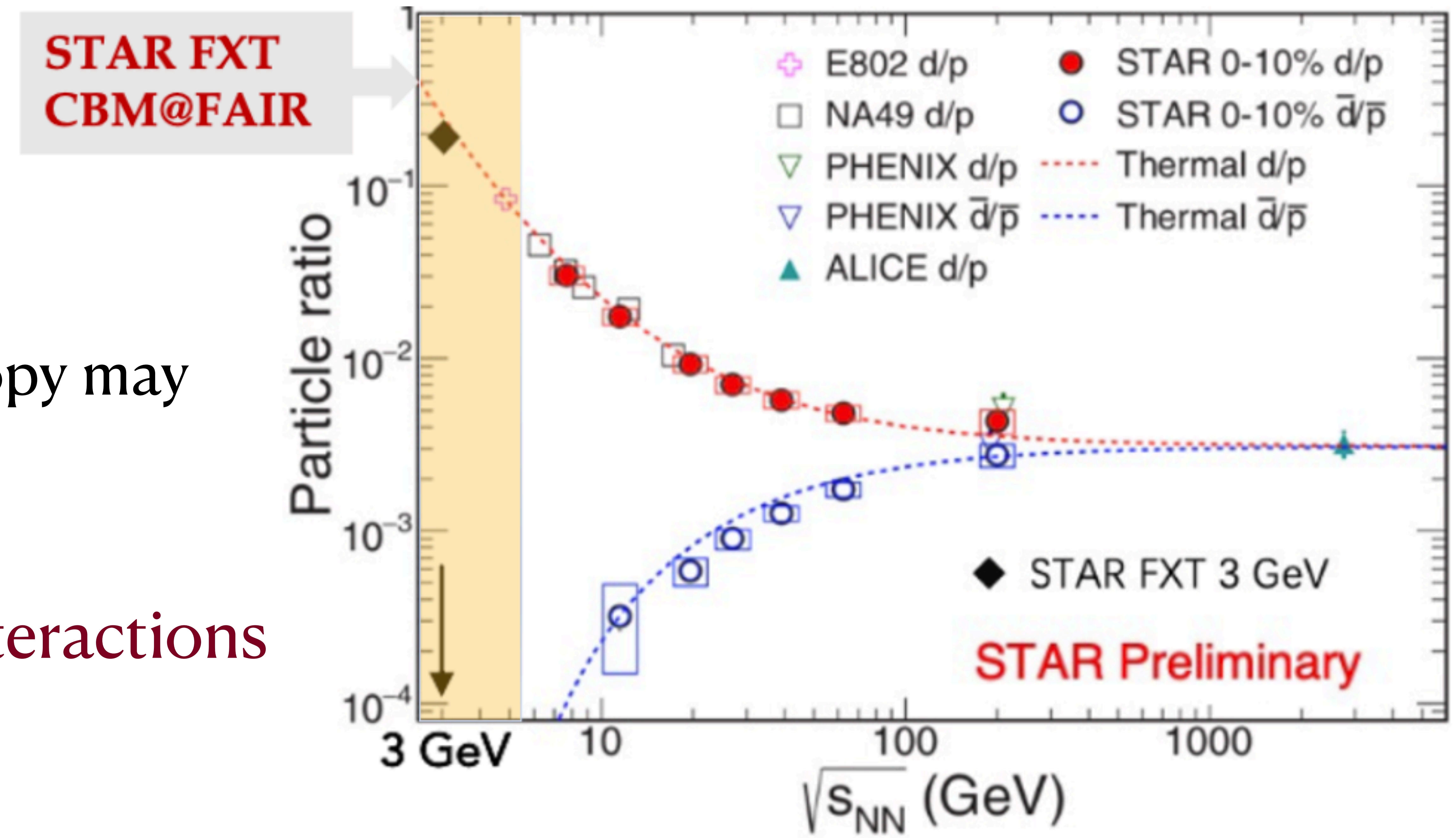


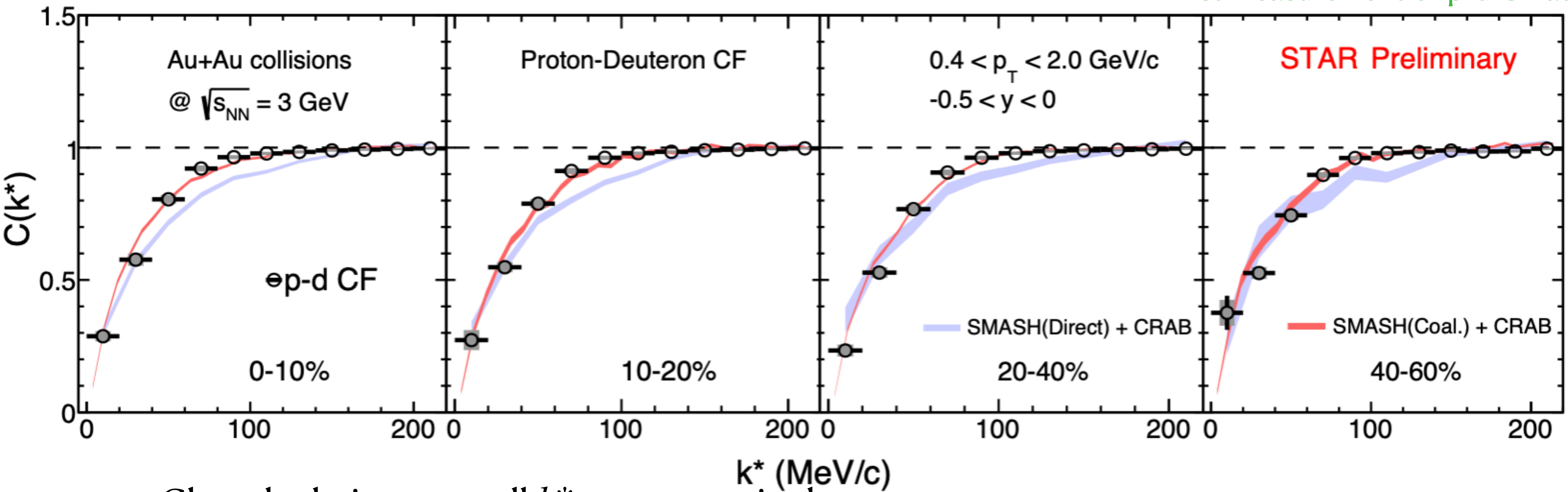
Large amount of light nuclei produced at 3 GeV, allowing precision measurements

In this talk: p-d and d-d correlation in Au+Au collisions

Phys.Rev.C 99, 064905 (2019)

Proton-Deuteron Femtoscopy

First measurement of p-d CF at STAR



⇒ Clear depletion at small k^* range seen in data

⇒ Compared with SMASH + Correlation After burner (CRAB) model

- Two deuteron formation mechanism: Direct (hadronic scattering) vs. Coal (Wigner fund.)
- CF calculated with coalescence of deuterons is in better agreement with data

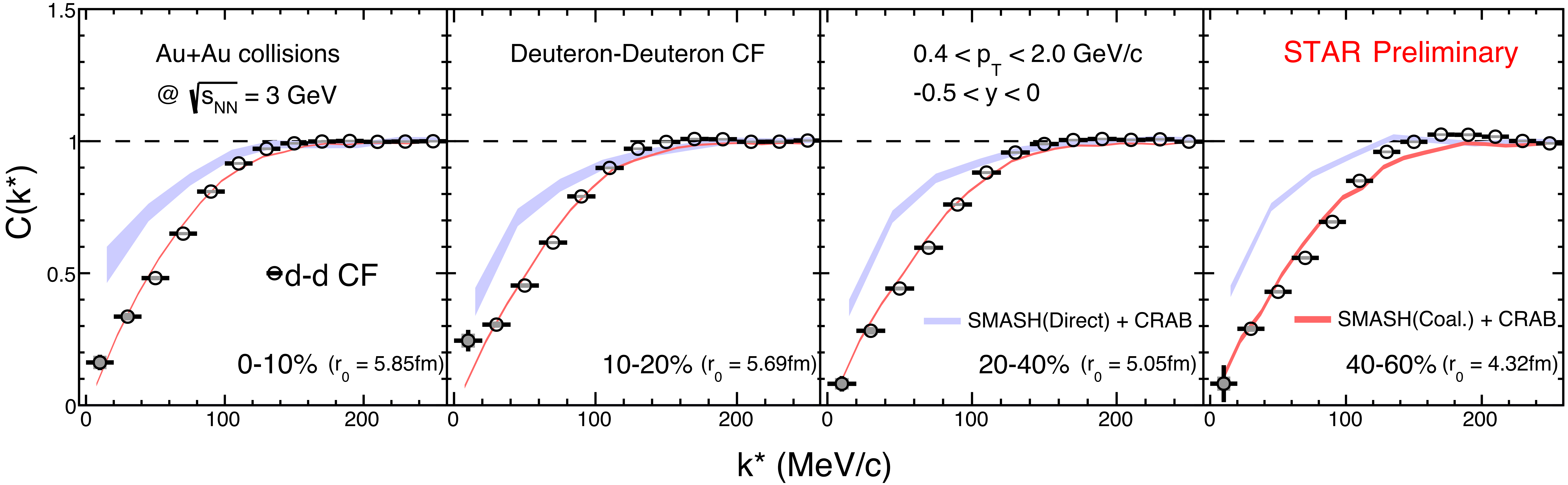
arXiv:2208.05722

SMASH: J. Weil et al. Phys.Rev.C 94 (2016) 5, 054905

Coalescence: W.Zhao et al. Phys. Rev. C.98 (2018) 5,054905

Deuteron-Deuteron Femtoscopy

First measurement of d-d CF at STAR



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Summary and Outlook

⇒ Femtoscopy measurements from heavy-ion collisions provides a unique tool to explore strong interactions and evolution dynamics.

⇒ Y-N and Y-Y interaction

- Constraints for L-L models and lattice QCD calculations
- High statistics during Run21, Run23 and Run25

⇒ Light Nuclei interaction

- First measurements of p-d and d-d correlation functions in STAR
- Deuterons are likely to be formed via Coalescence at 3 GeV

More precise femtoscopy results with large statistics in BES-II program coming soon !
(light nuclei, many body, exotica …)

Thank you for your attention !