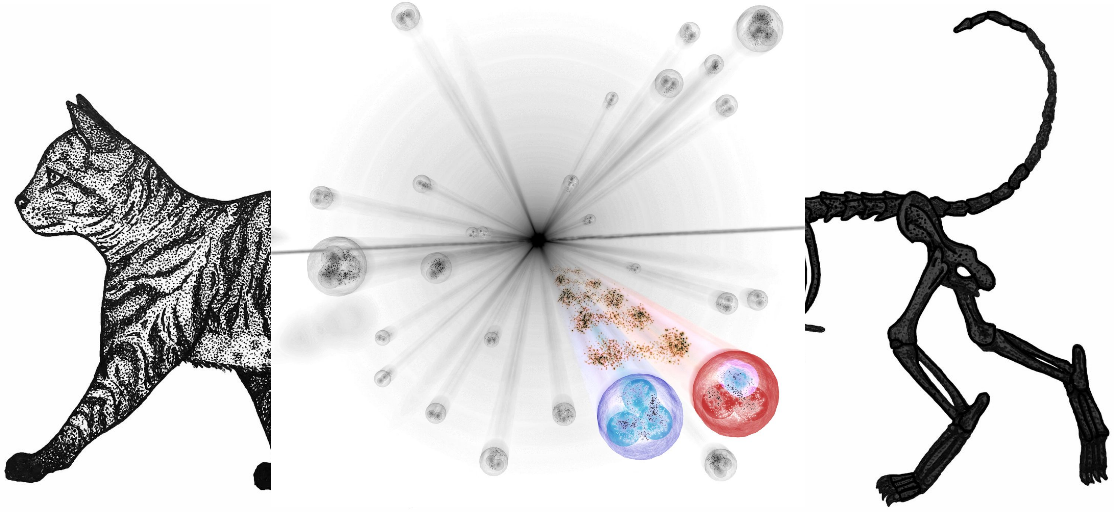
Sofia University St. Kliment Ohridski

Particle emitting source at the LHC

Dimitar Mihaylov

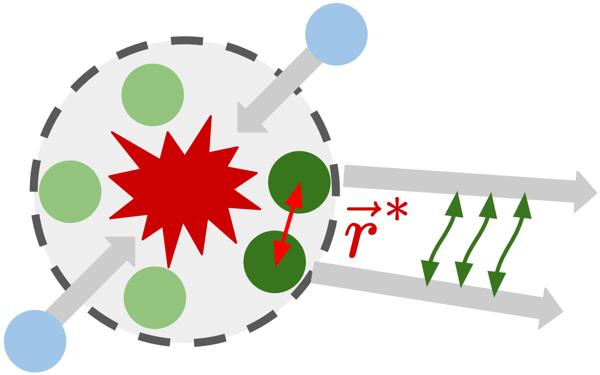


JENAA workshop, 20.08.2024

Femtoscopy @ LHC

Koonin-Pratt equation

[*Lisa et al.*
Ann.Rev.Nucl.Part.Sci.55:357-402, 2005]



two-particle relative momentum
*q = 2 · k**

$\Psi(\vec{k}^*, \vec{r}^*)$
two-particle wave function

$$C(k^*) = \frac{N_{\mathrm{SE}}(k^*)}{N_{\mathrm{ME}}(k^*)} = \int S(r^*) \left|\Psi(\vec{k}^*, \vec{r}^*)\right|^2 d^3r^* \xrightarrow{k^* \to \infty} 1$$

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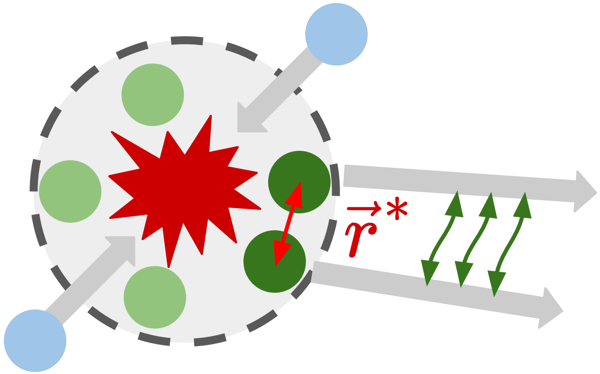

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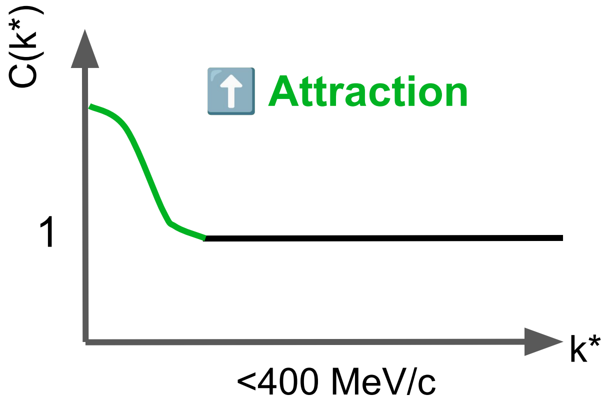

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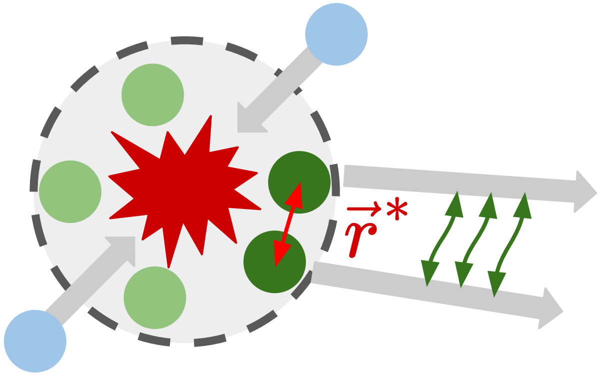

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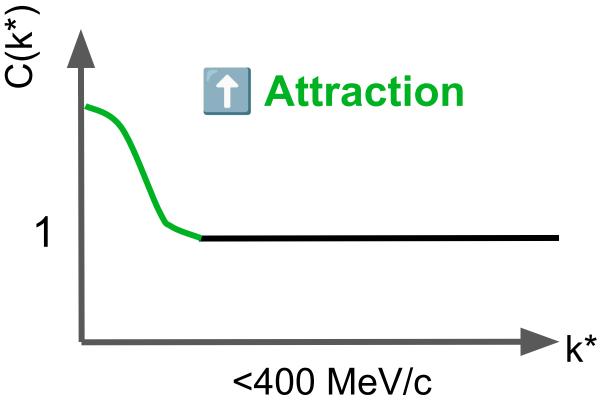

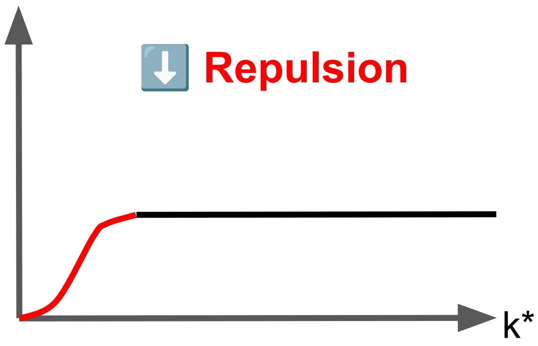

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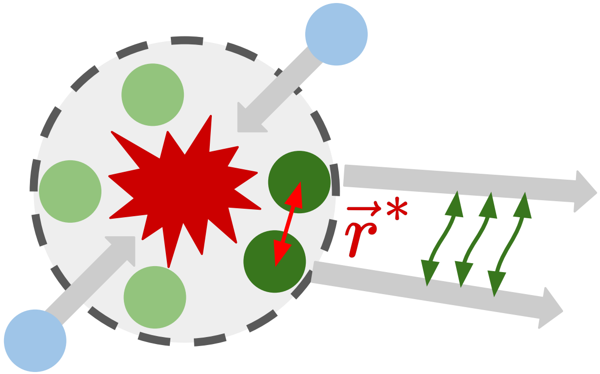

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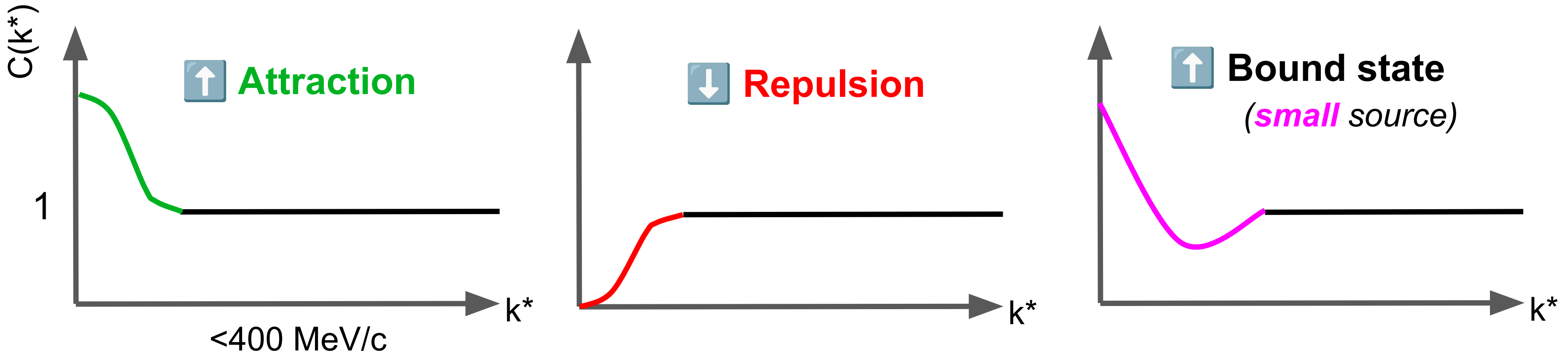
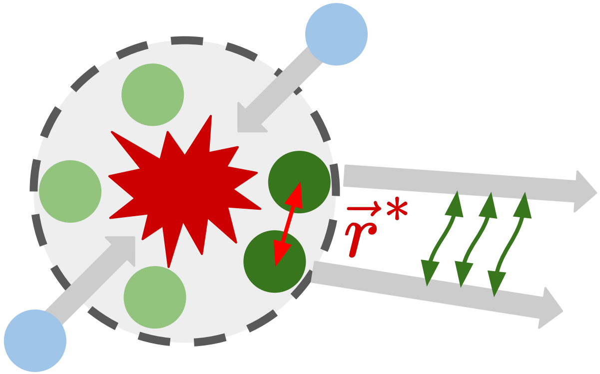


Femtoscopy @ LHC
-- ***Shallower*** *interaction*

[*Lisa et al.*
Ann.Rev.Nucl.Part.Sci.55:357-402, 2005]



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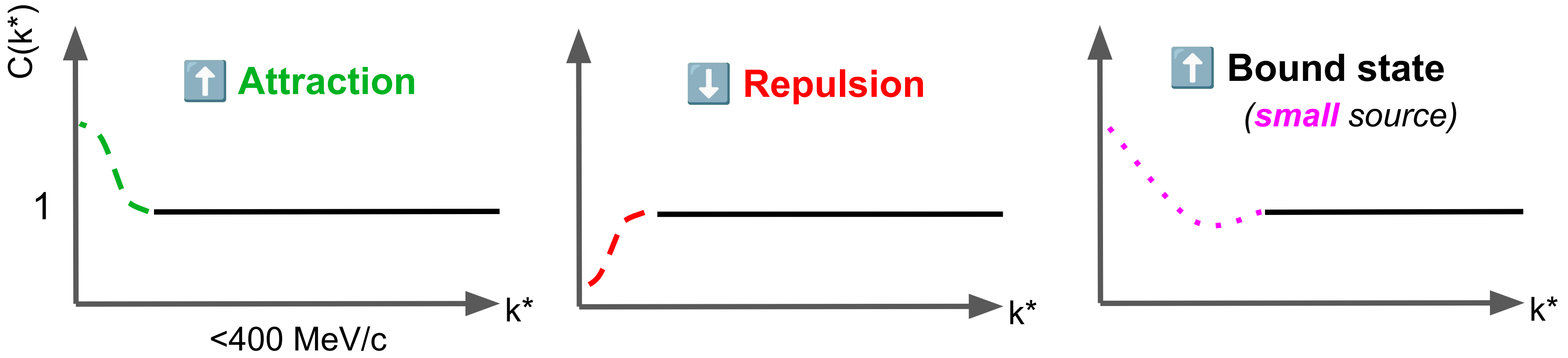
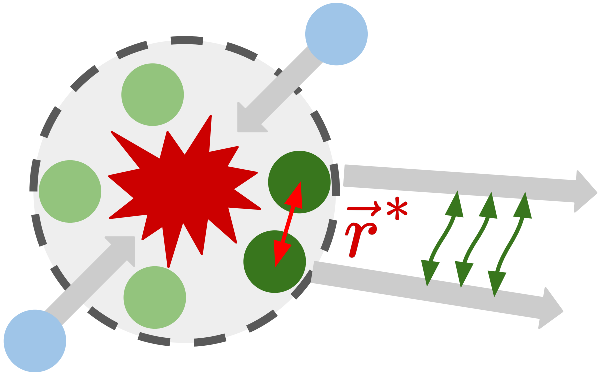


Femtoscopy @ LHC
-- ***Larger*** *source*

[*Lisa et al.*](#)
[Ann.Rev.Nucl.Part.Sci.55:357-402, 2005](#)



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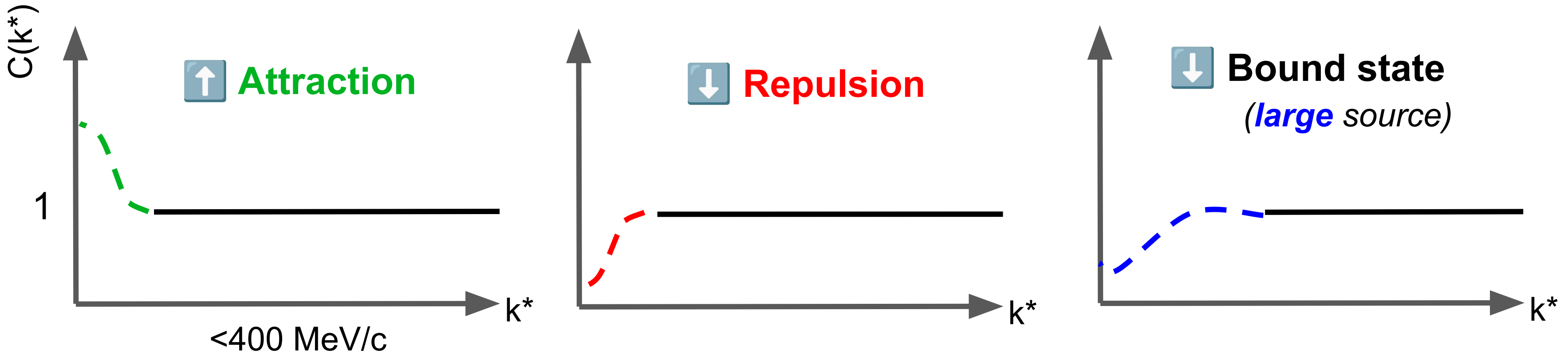
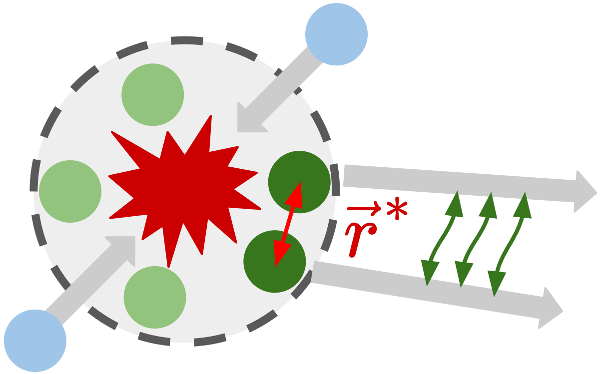


Menu

For today

[*Lisa et al.* Ann.Rev.Nucl.Part.Sci.55:357-402, 2005]



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A common source in small systems?

Menu

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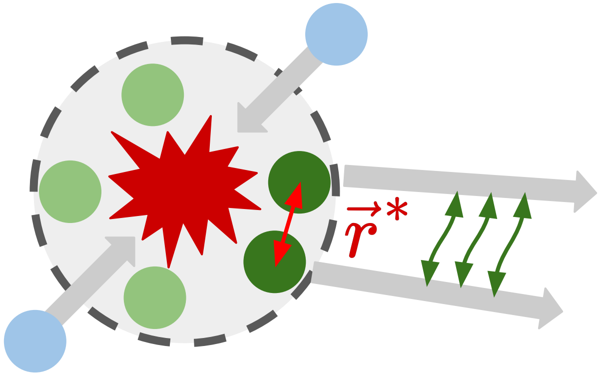

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A common source in small systems?

Future plans and links to coalescence

Femtoscopy @ LHC

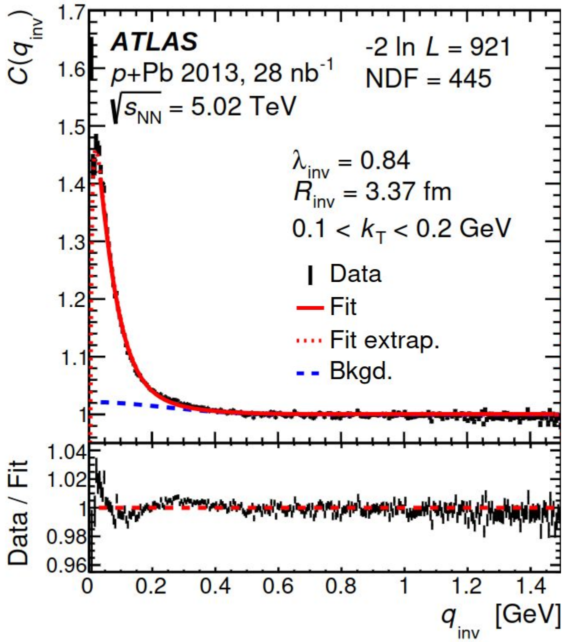
ππ correlations

ATLAS EXPERIMENT

p-Pb collisions @ 5.02 TeV

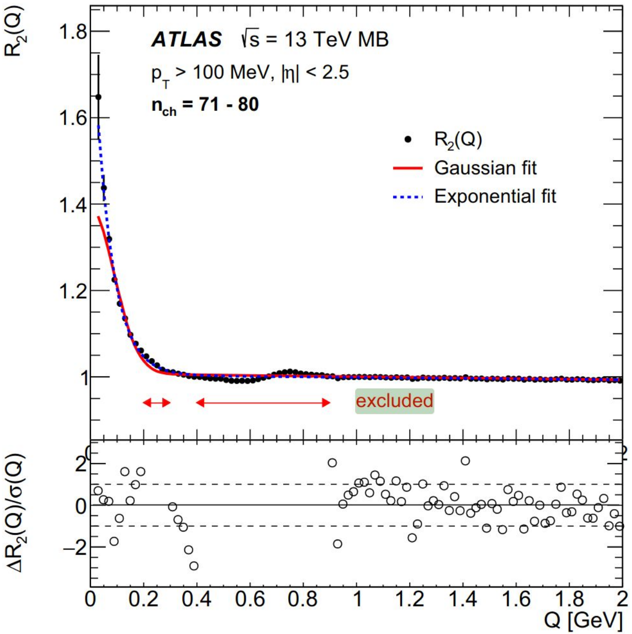
20-30% centrality

PRC 96 (2017) 6, 064908



pp collisions @ 13 TeV

EPJC 82 (2022) 7, 608



- ππ correlations well described by a Cauchy source (exp. correlation) in small coll. systems
- Also measured by *CMS* JHEP 03 (2020) 014 *LHCb* *JHEP 12 (2017) 025*
- The non-Gaussian profile (in small systems) may be related to production from resonances

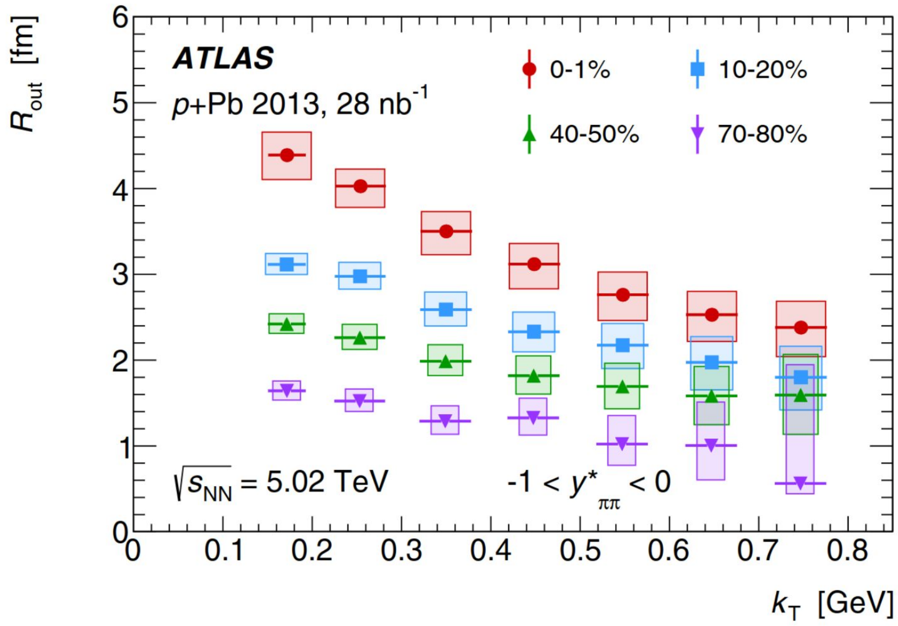
Femtoscopy @ LHC

Emission source

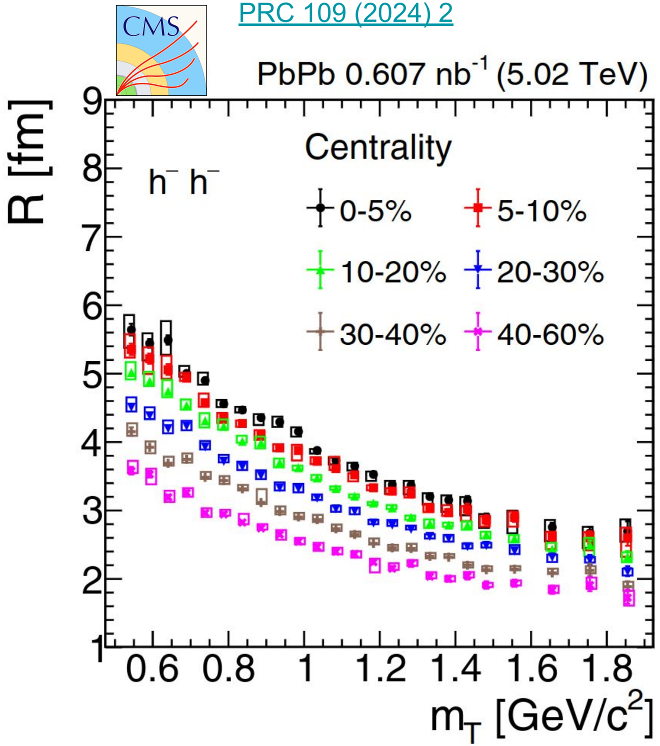
- k_T (m_T) scaling observed in p-Pb and Pb-Pb collision and associated with collectivity

p-Pb collisions @ 5.02 TeV

PRC 96 (2017) 6, 064908

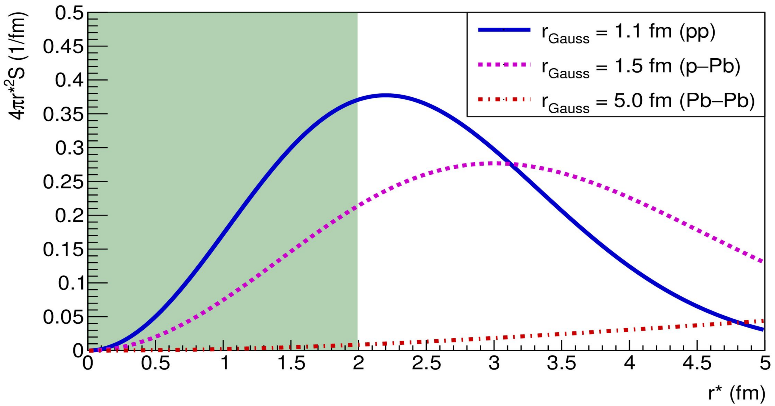


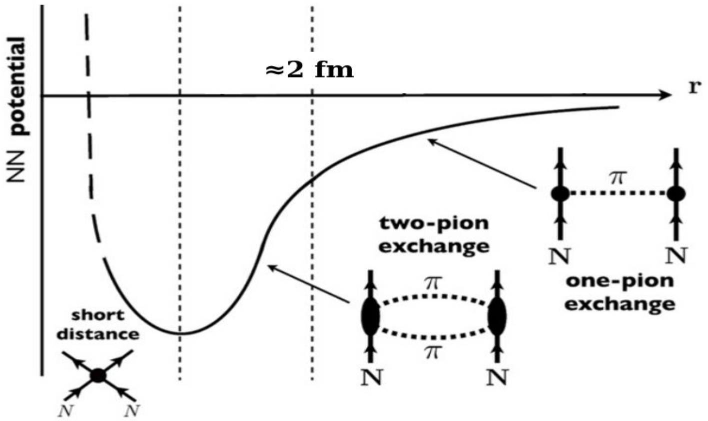
PRC 109 (2024) 2



The emission source

Advantages of small collision systems





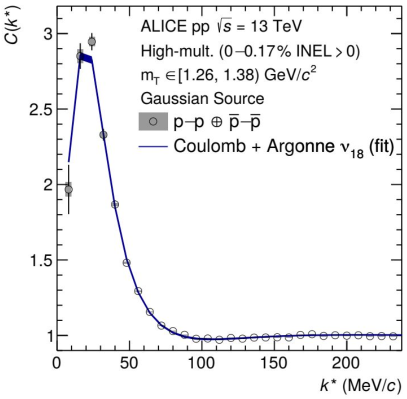
$$C(k^*) = \int S(r^*) \left| \Psi(\vec{k}^*, \vec{r}^*) \right|^2 d^3 r^*$$

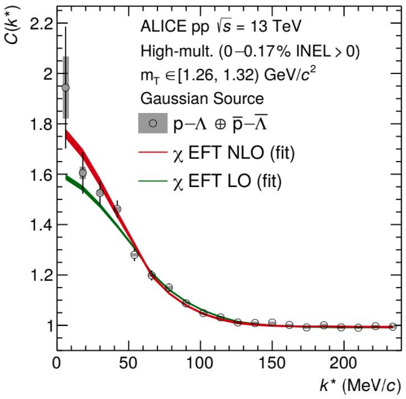
Measure Fix Study

- Enhanced sensitivity in **small collision systems (pp)**.
- **Common emission source for all hadrons?**

The emission source

pp and pΛ correlations

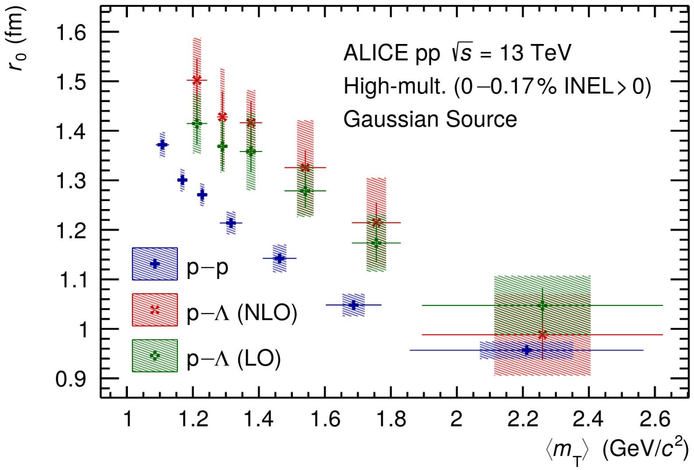


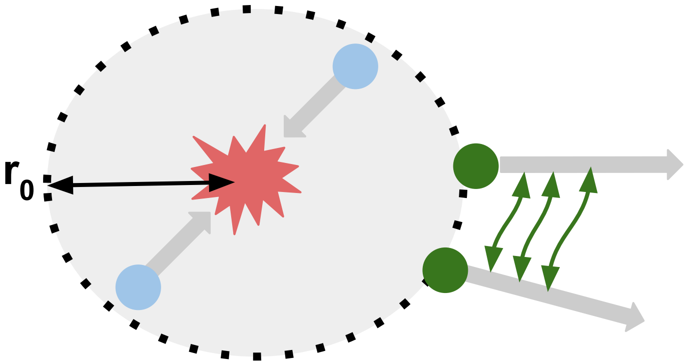


$$C(k^*) = \int S(r^*) \left|\Psi(\vec{k}^*, \vec{r}^*)\right|^2 d^3 r^*$$

Measure Fix Study

- Enhanced sensitivity in **small collision systems (pp)**.
- **Common emission source for light/strange baryons?**

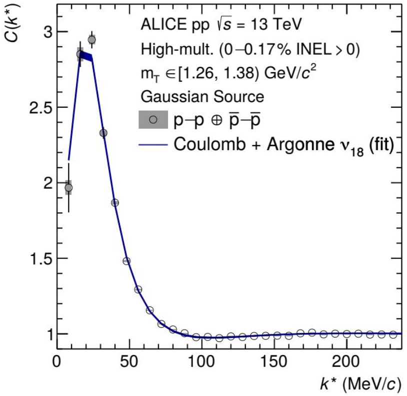


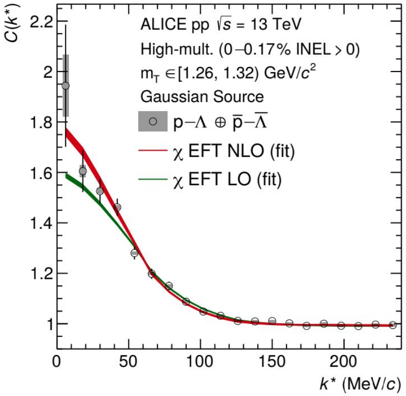


ALICE Coll. *Phys.Lett.B 811 (2020) 135849*

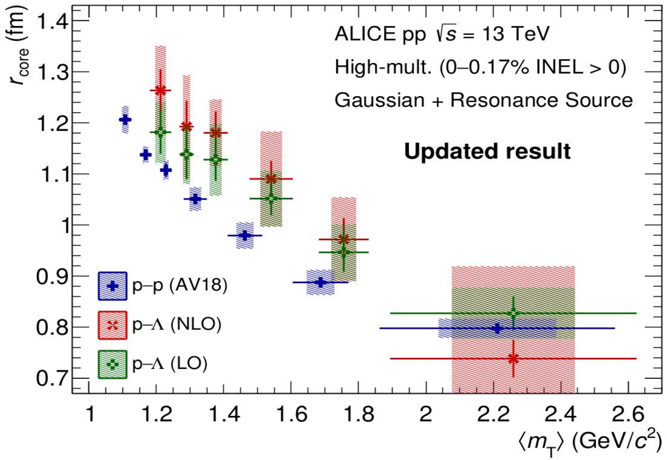
The emission source

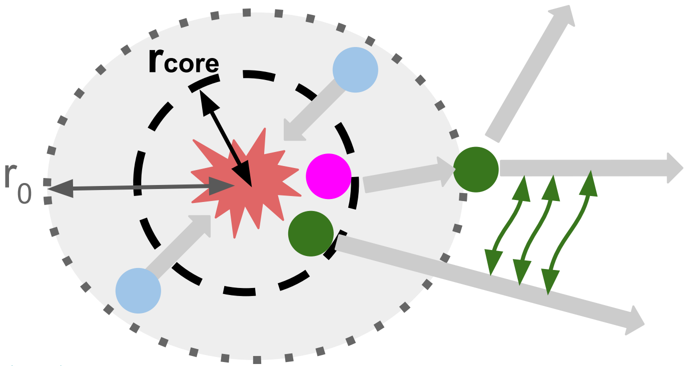
The resonances source model (RSM)





- Particle production through **decays of short lived resonances** (cτ~fm) increases effective source size.
- According to the statistical hadronization model, c.a. ⅔ of the protons and Lambdas stem from decays.
- The **pp correlation** can be used to **evaluate S(r*)**, based on the known interaction.
- The same source can be used to **study the final state interaction** for **ANY** other **baryon-baryon** pair.



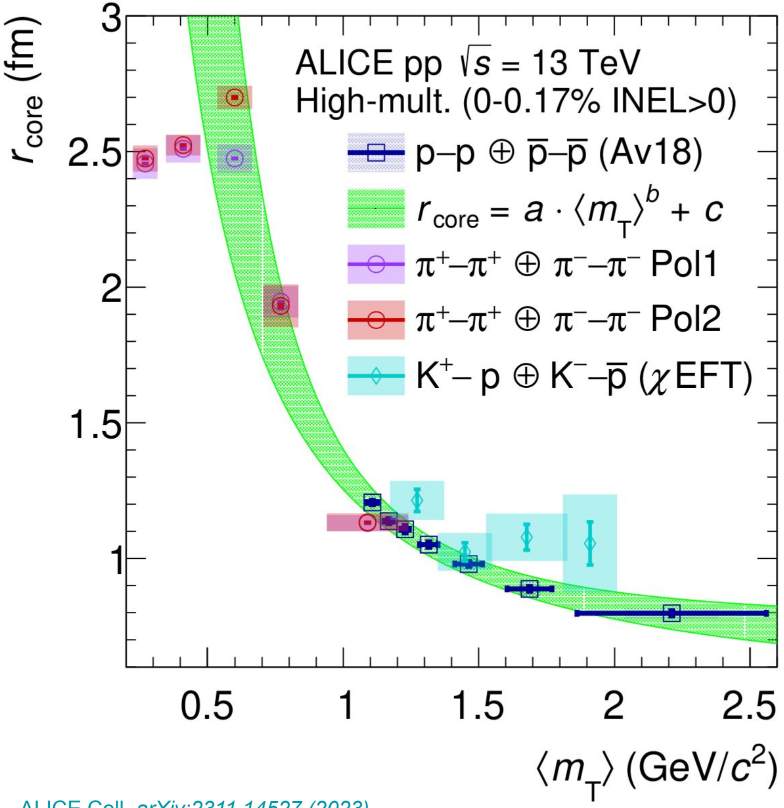


ALICE Coll. *Phys.Lett.B 811 (2020) 135849*

Update plot, new p-p points submitted as an erratum

Including ππ and pK correlations

Using the RSM

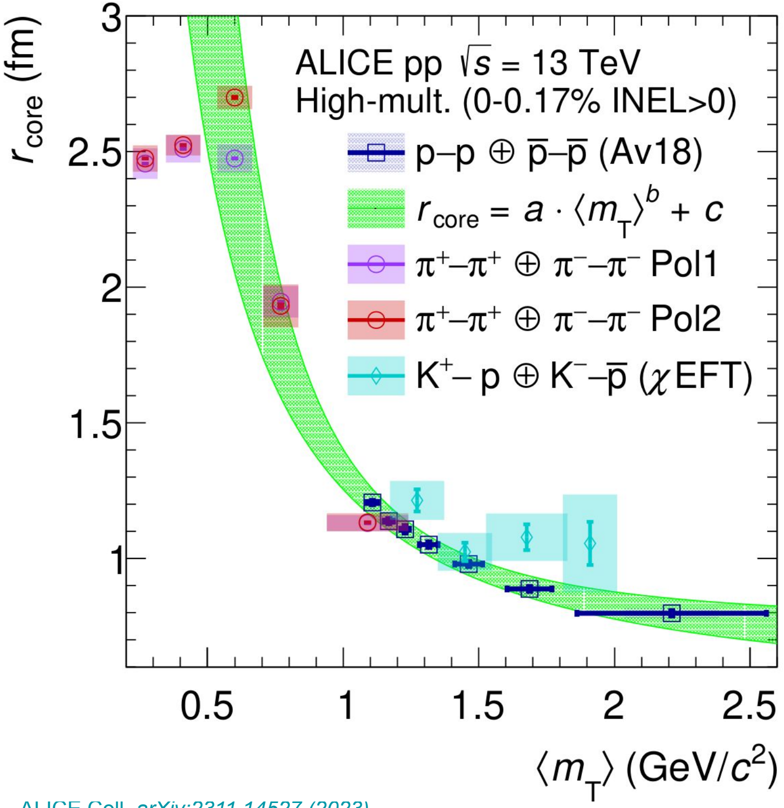


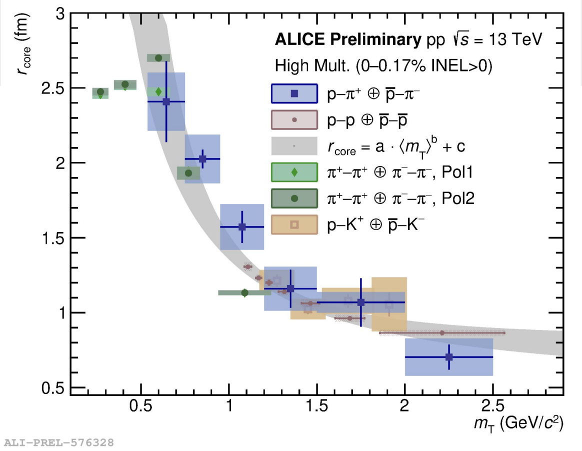
ALICE Coll. *arXiv:2311.14527 (2023)*

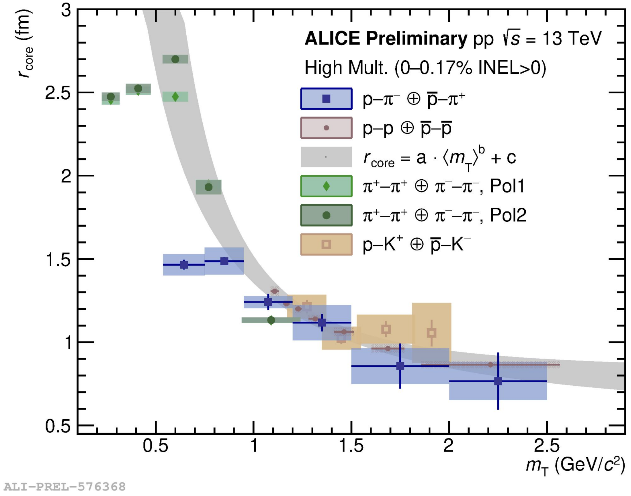
N.B. The plot is with update pp points

Including ππ and pK correlations, and even pπ

Using the RSM







Paper draft in preparation

ALICE Coll. *arXiv:2311.14527 (2023)*

N.B. The plot is with update pp points

Going beyond the RSM

Shortcomings of the RSM:

- No link to single particle properties.
- Applicable to two-body problems only.
- No space-momentum correlations and mT scaling.
- The geometry is fixed and model dependent.
- No notion of time. The equal time of emission is simply assumed.
- No Lorentz-boost effects.

The goal of the “Common Emission in CATS” (CECA) project is to address (effectively) these issues.

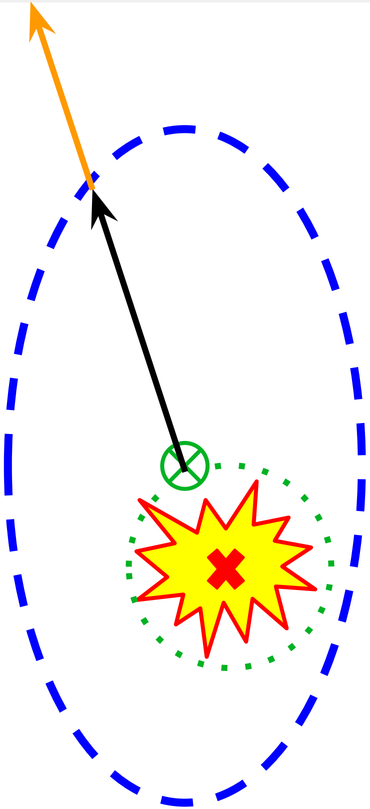
One source to rule them all

An improved source model: Common Emission in CAts (CECA)

Mihaylov and Gonzalez Gonzalez, *EPJC* 83 (2023) 7, 590

CECA

Single particle core source



- Initial random displacement point r_d
  The best fit reveals values of up to 0.3 fm*

- Hadronization scale
  A surface around r_d where the hadronization takes place
  N.B. Produces mT scaling, best value c.a. 3 fm*

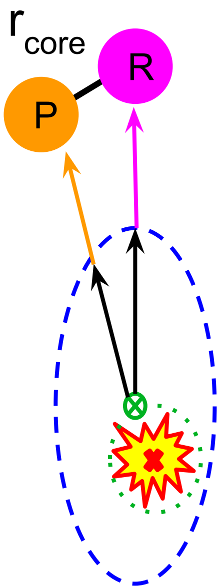
- Expansion time τ
  Further propagation of the particles before the start of FSI, e.g. scattering.
  This parameter is not necessarily common!
  The best values are 3-4 fm*

*) *The best values are based on the fits to pp and pΛ shown after few slides*

CECA

Resonances and N-particle sources

t = 0



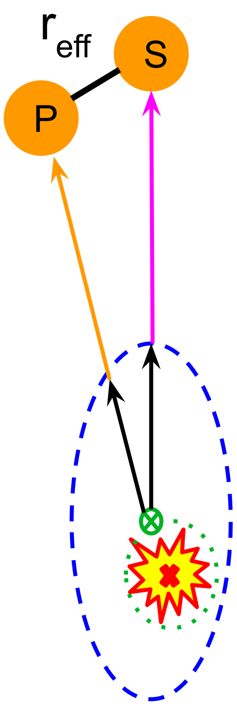
- CECA generates events of N particles, each emitted with a desired momentum distribution and spatial coordinates evaluated following the introduced rules and parameters

- Based on predefined probabilities, the particles can be primordials (P) or resonances (R)

CECA

Resonances and N-particle sources

t = decay time



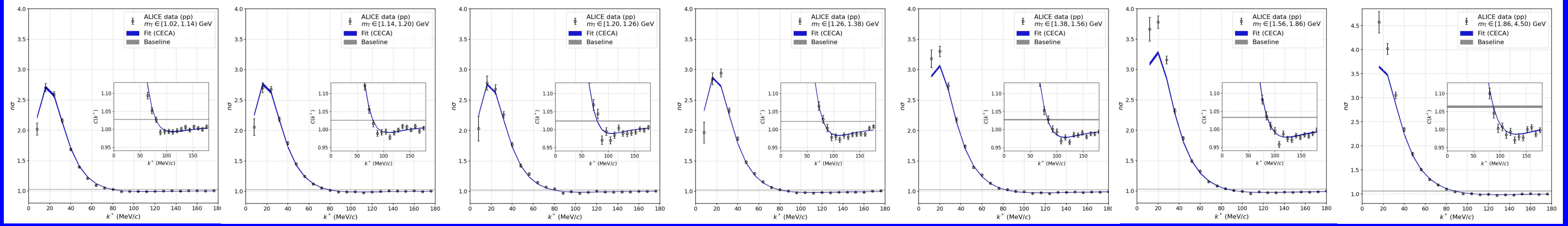
- CECA generates events of N particles, each emitted with a desired momentum distribution and spatial coordinates evaluated following the introduced rules and parameters

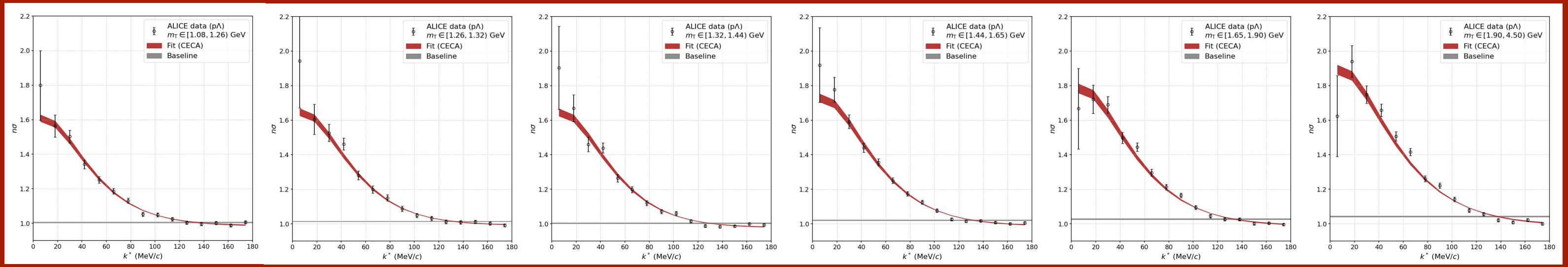
- Based on predefined probabilities, the particles can be primordials (P) or resonances (R)

- The pairs (or any N-tuplets) are build after the resonances have decayed into secondaries (S), and the time has been equalized.

CECA

Applied to pp and pΛ

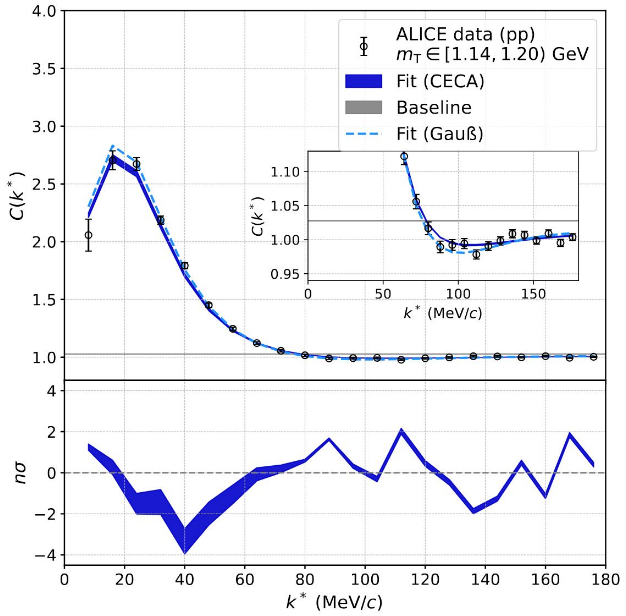


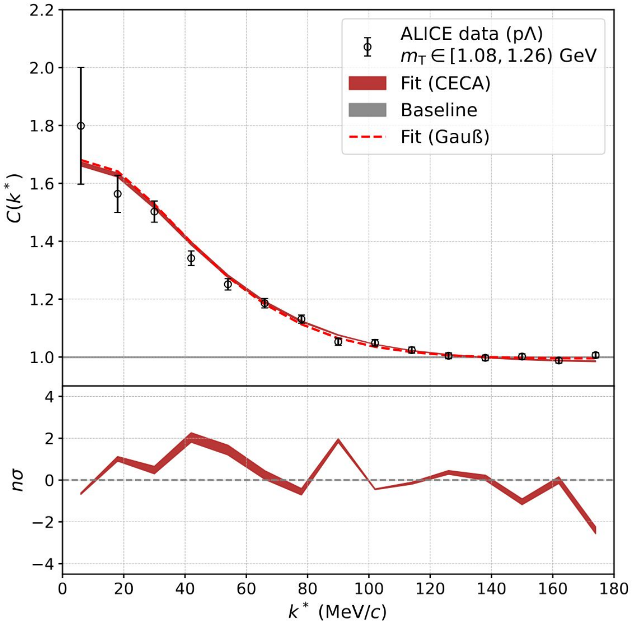


- pp interaction: fixed to the Argonne v18 potential Wiringa et al. *Phys. Rev. C, 51:38–51, 1995*
- pΛ interaction: Usmani potential, short-range repulsive core fitted Usmani et al. PRC, 29:684–687, 1984
- **A combined fit of the mT differential pp and pΛ correlations!**

CECA

Applied to pp and pΛ

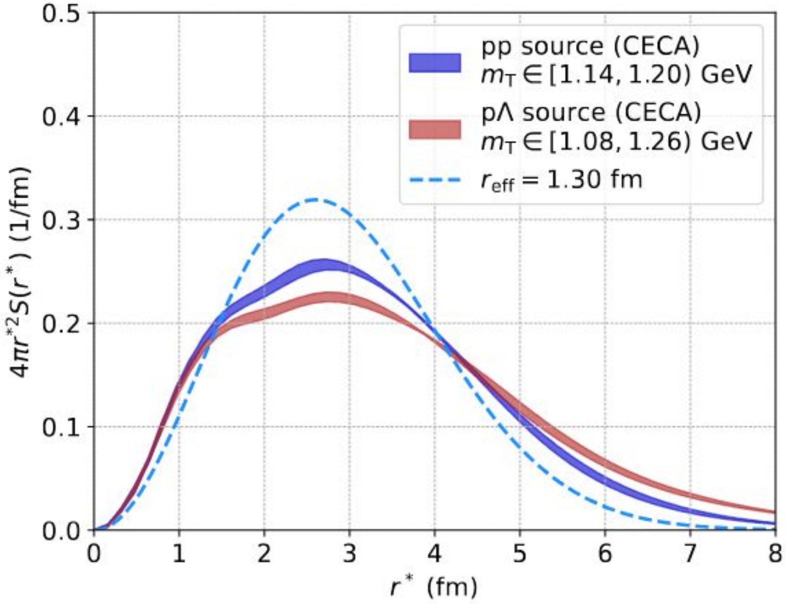


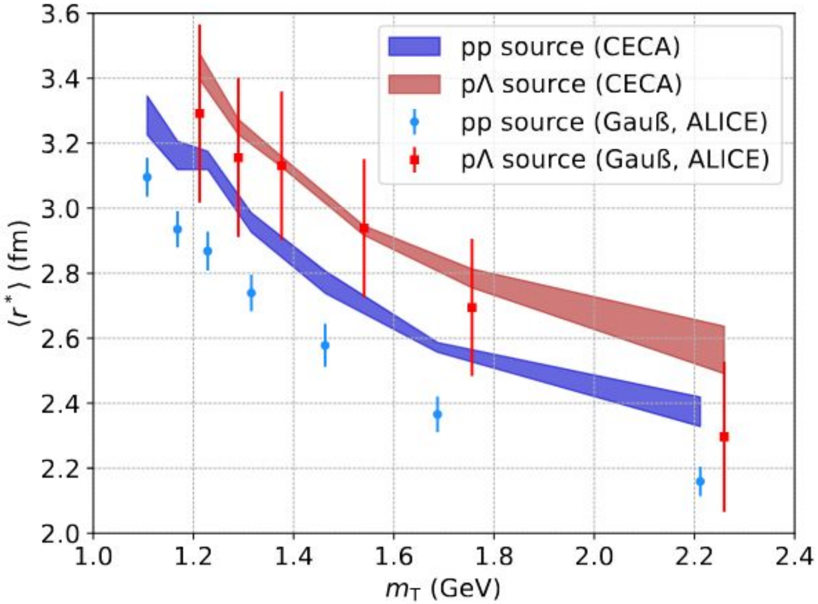


- Equally good description by the CECA fits, and a fit with an effective Gauß
- N.B. The Gaussian fits are performed independently for each correlation function

CECA

Applied to pp and pΛ





- The resulting sources are slightly non-Gaussian
- The mT scaling is generated by the model
  The "deviation" between CECA and Gauß fit is a manifestation of the importance of the source profile, as both sets of fits result in equally good description of the measured correlations

A step further: the equation of state

Details in the talk of Laura S.

Combining femtoscopy and scattering data on pΛ

- Conservative approach: refit the pΛ source
  Outcome: compatible results with pp
- Test different tunes of the Usmani potential to find out the allowed scattering parameters

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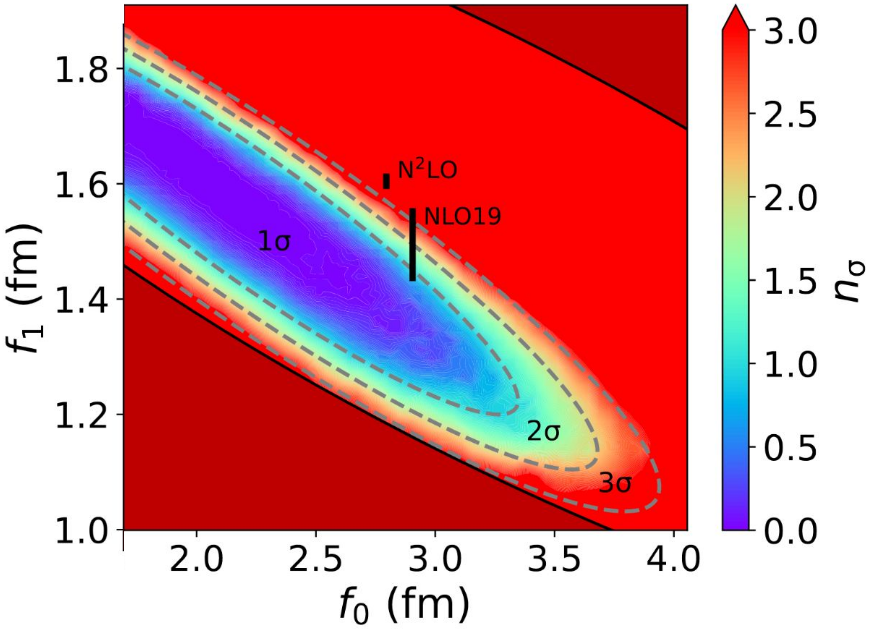

[Mihaylov, Haidenbauer and Mantovani Sarti; PLB 850 (2024) 138550]

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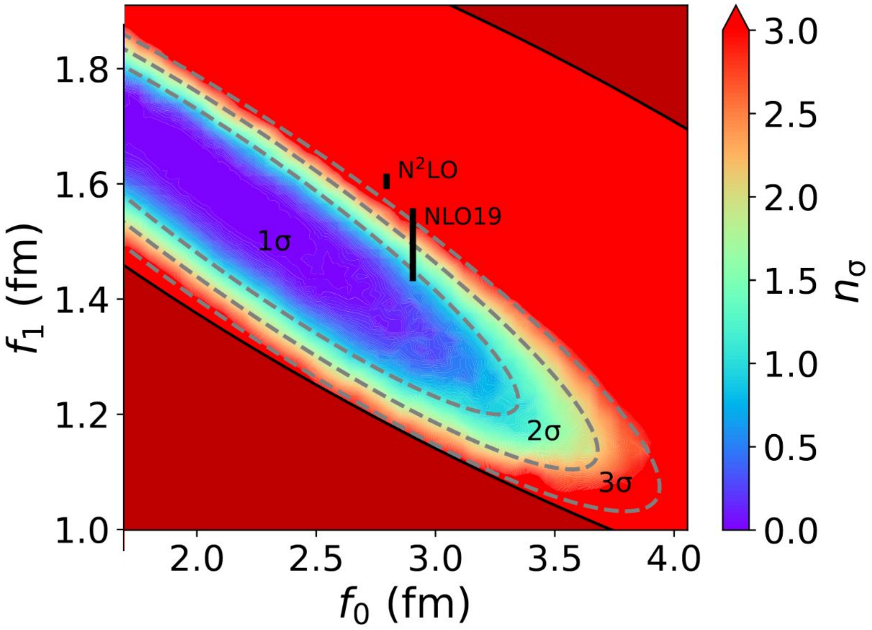
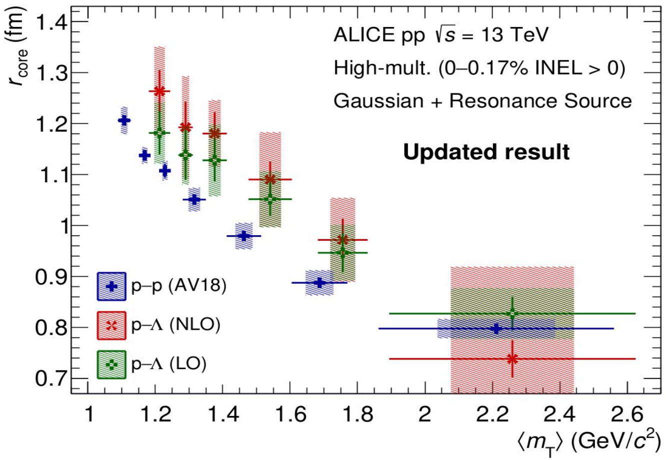


The slight tension is resolved



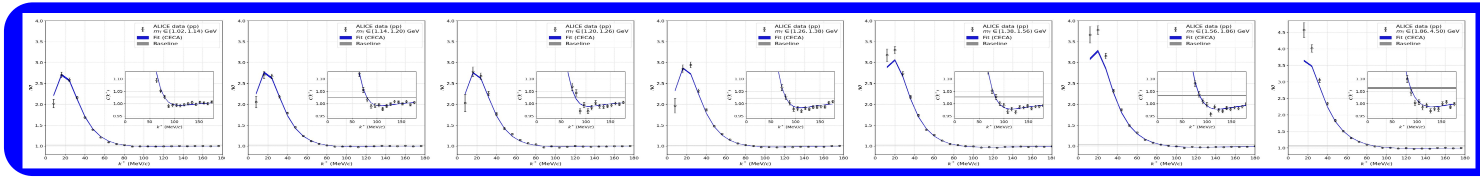
Mihaylov, Haidenbauer and Mantovani Sarti; PLB 850 (2024) 138550

Where to next?

Where to next?

Three-body source

Use CECA and 2-body correlations to obtain the source parameters

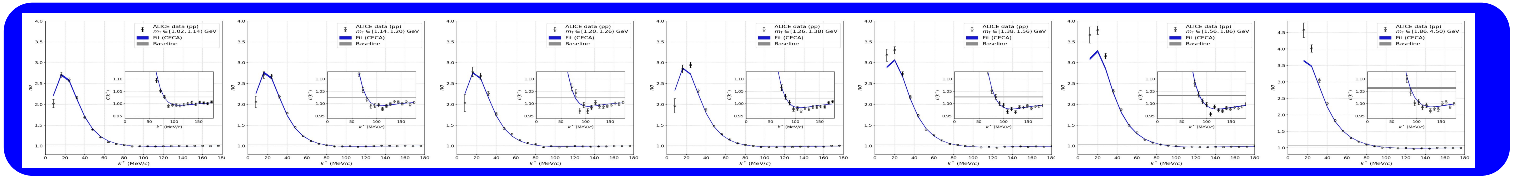


Where to next?

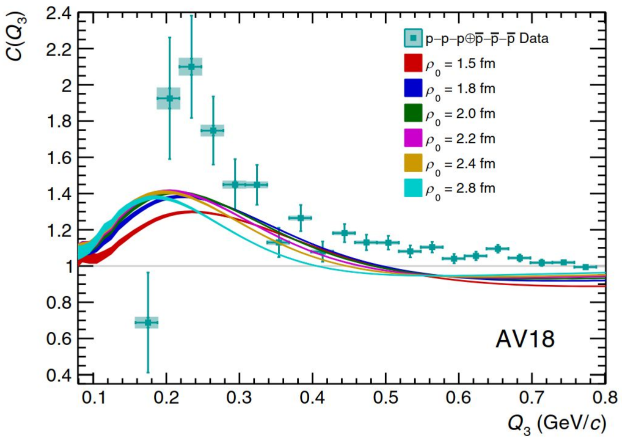
Three-body source

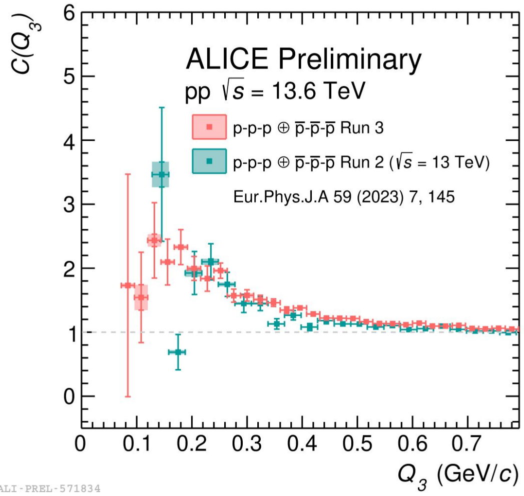
Details on the three-body studies @ 14:30 by Raffaele

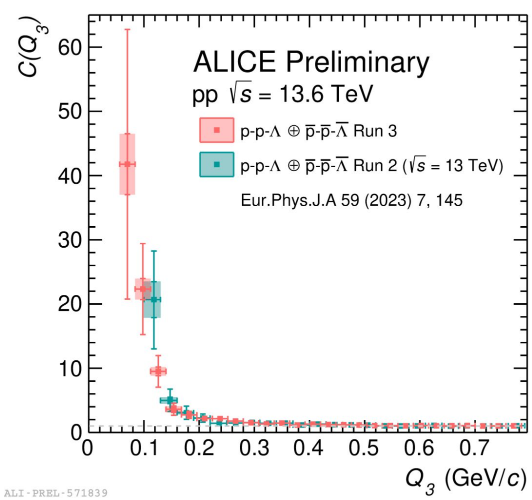
Use CECA and 2-body correlations to obtain the source parameters



Use CECA to obtain the 3-body source to make use of the calculations available for the 3-body interaction to interpret measured data



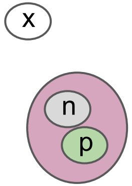




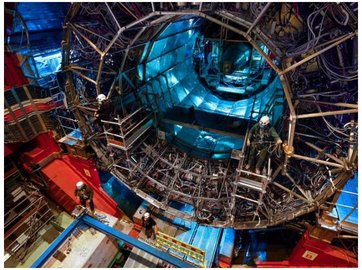
A. Kievsky et al. *PRC 109 (2024) 3, 034006*

Where to next?

The deuteron



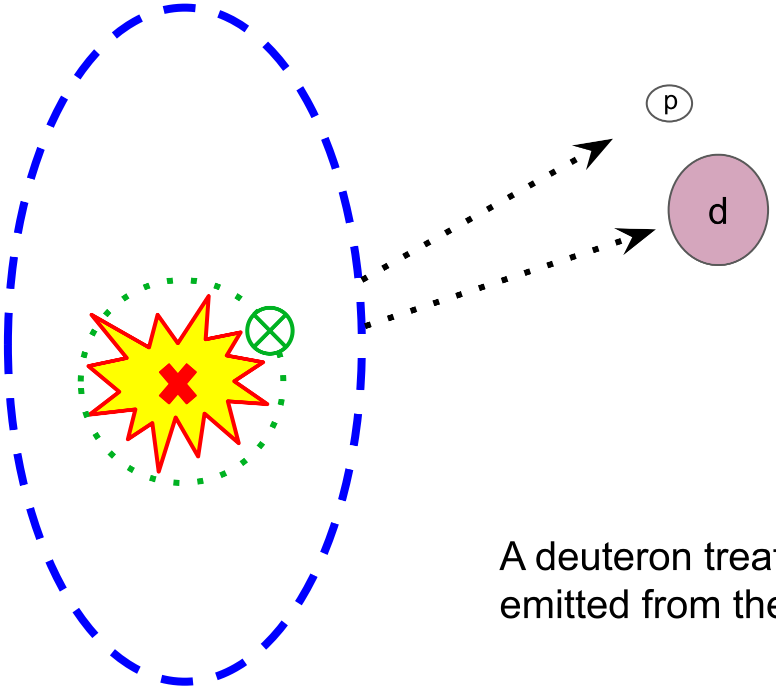
deuteron

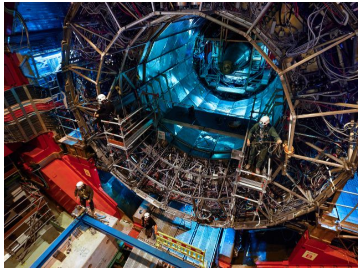


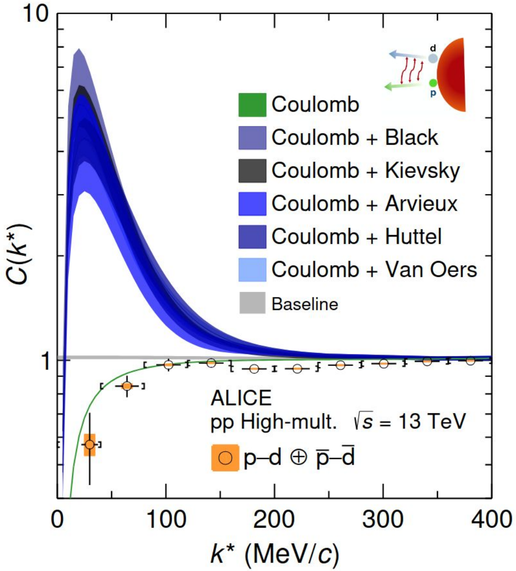
Where to next?

pd

Details on the three-body studies @ 14:30 by Raffaele







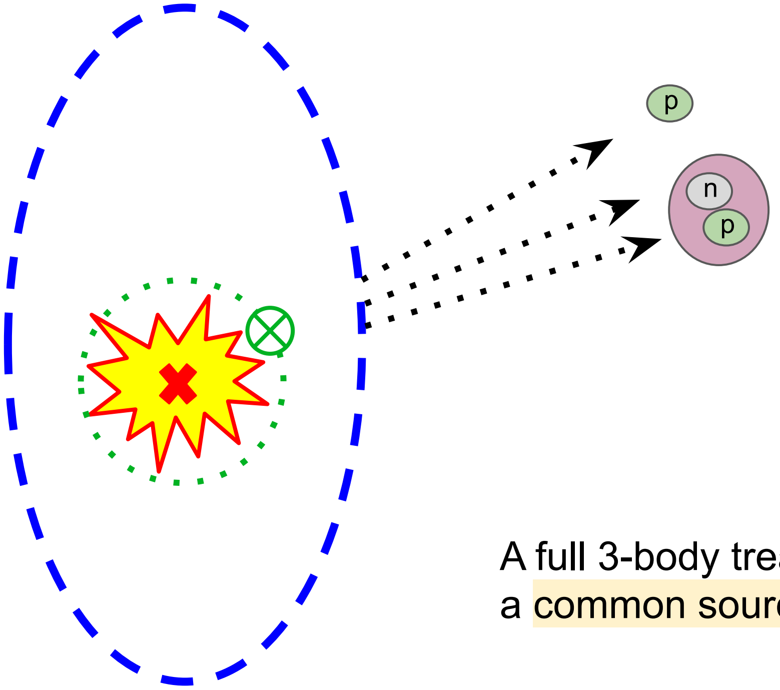
A deuteron treated as a single particle emitted from the source does **not** work

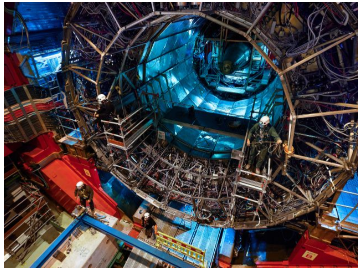
[ALICE Col, *arXiv: 2308.16120*]
Accepted by PRX

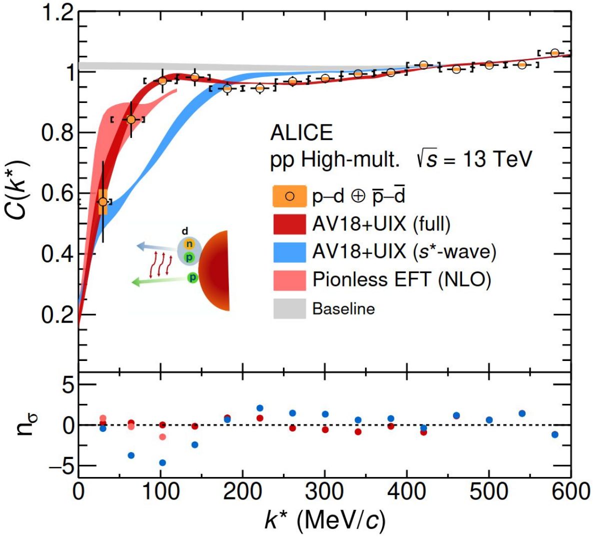
Where to next?

pd

Details on the three-body studies @ 14:30 by Raffaele





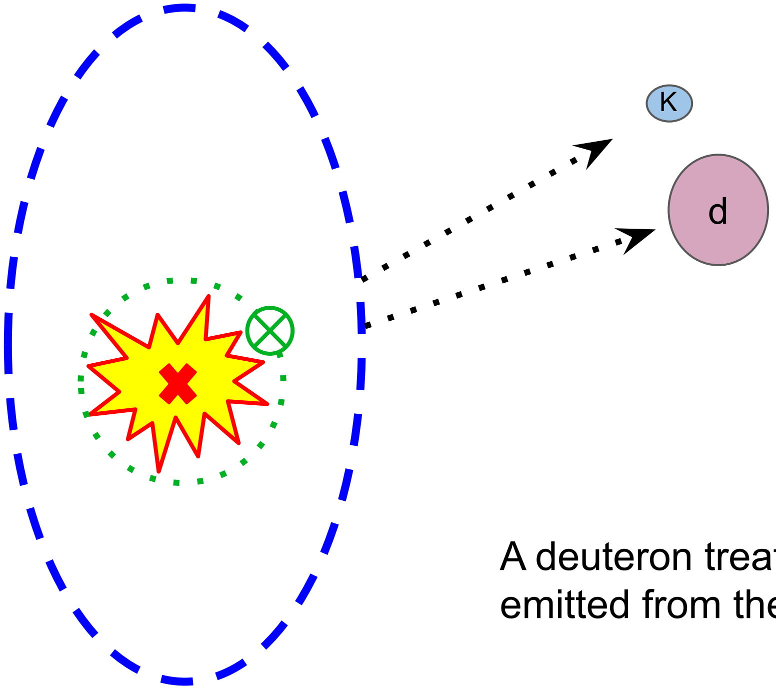


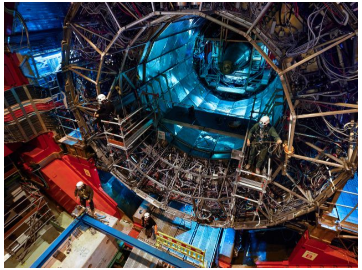
A full 3-body treatment with the p,p,n sharing a common source works fine

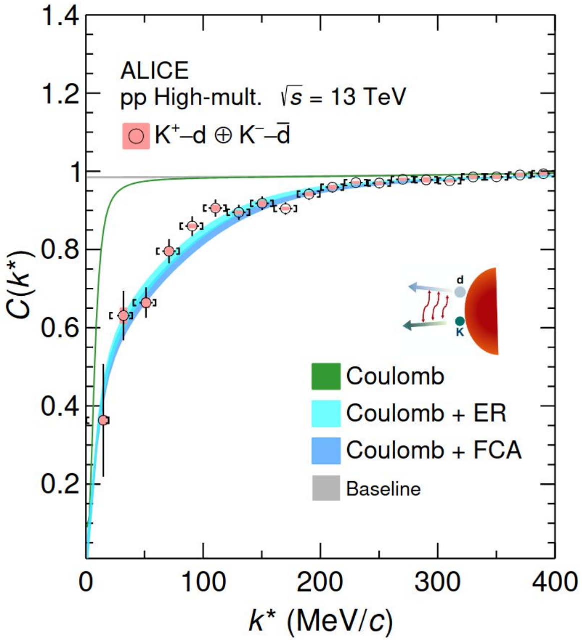
[ALICE Col, *arXiv: 2308.16120*](https://arxiv.org/abs/2308.16120)
Accepted by PRX

Where to next?

Kd





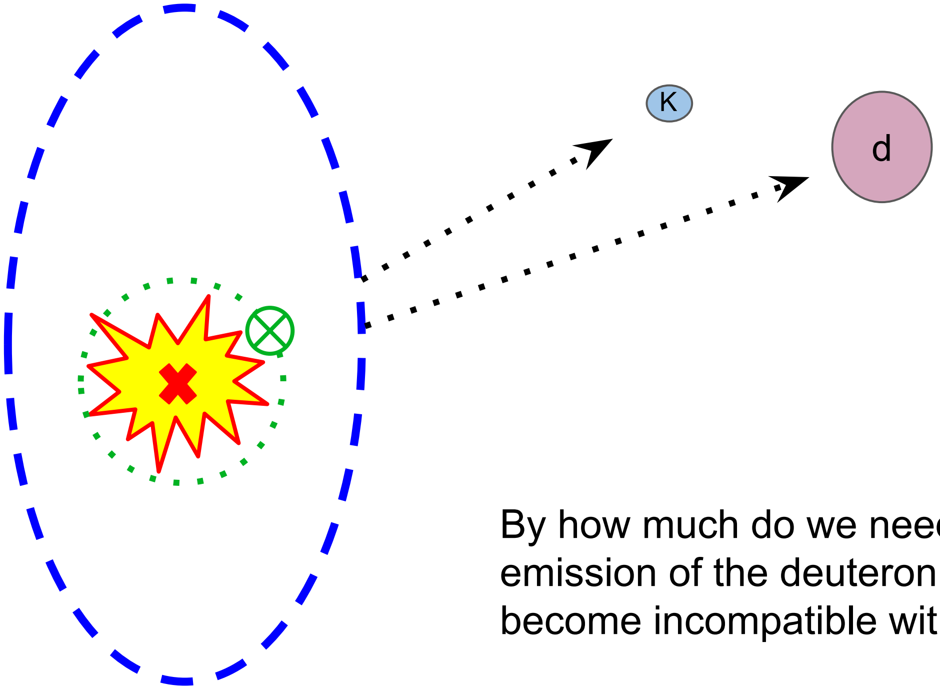


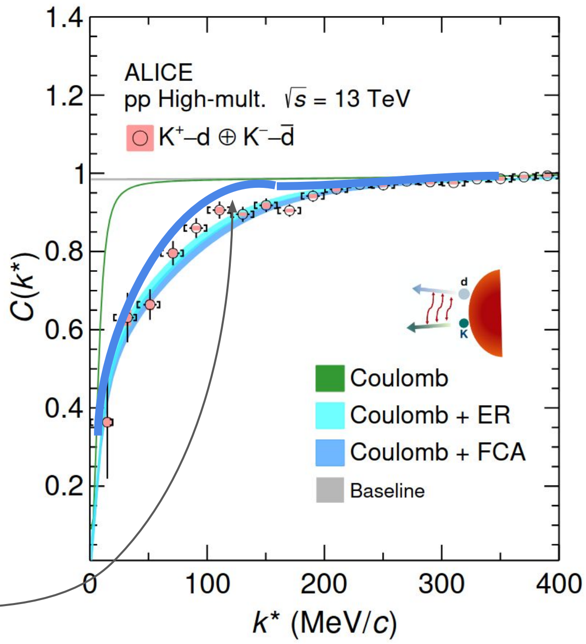
A deuteron treated as a single particle emitted from the common source **works.**

ALICE Col, *arXiv: 2308.16120*
Accepted by PRX

Where to next?

Kd: a toy study in the making





By how much do we need to delay the emission of the deuteron, before we become incompatible with the data?

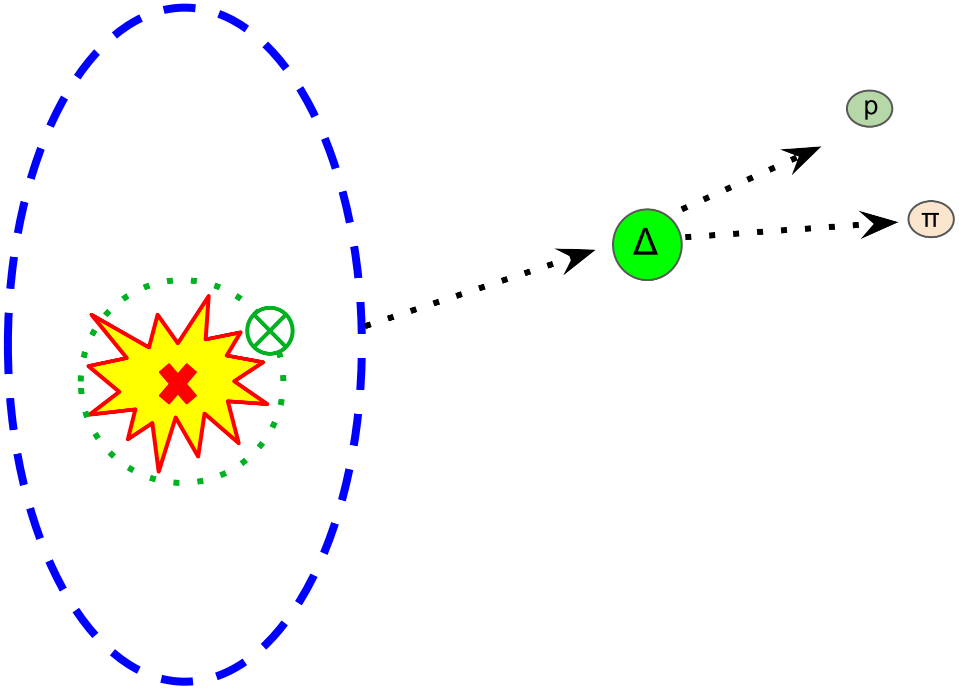
ALICE Col, *arXiv: 2308.16120*

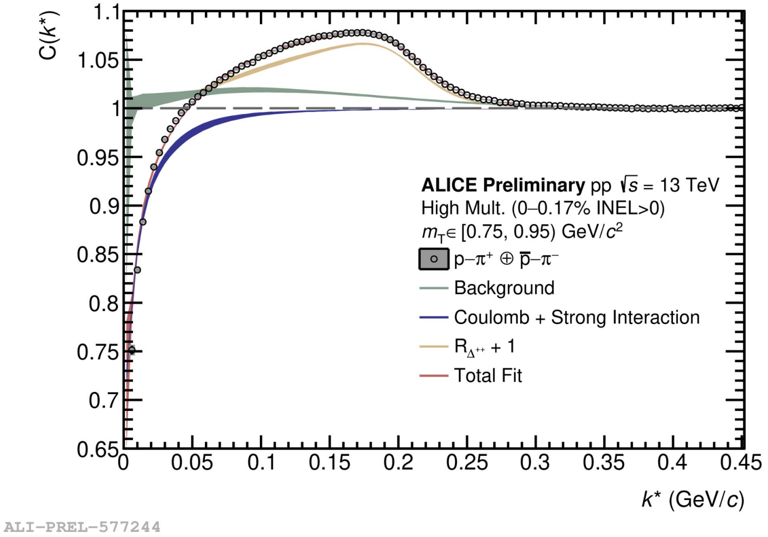
Accepted by PRX

A sneak peak

A signature of coalescence?

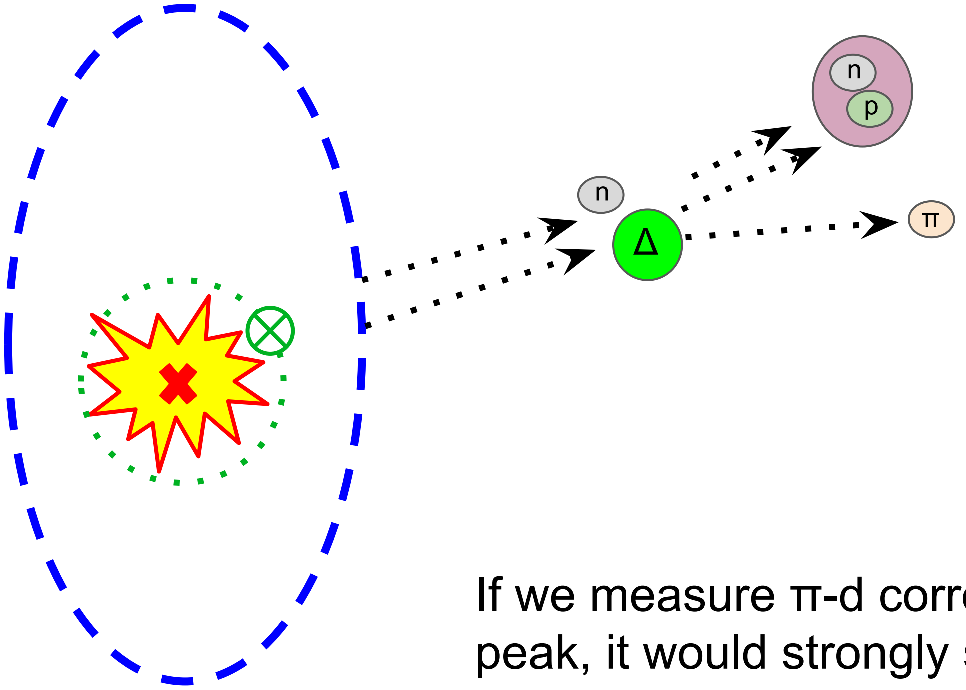
Paper draft in preparation

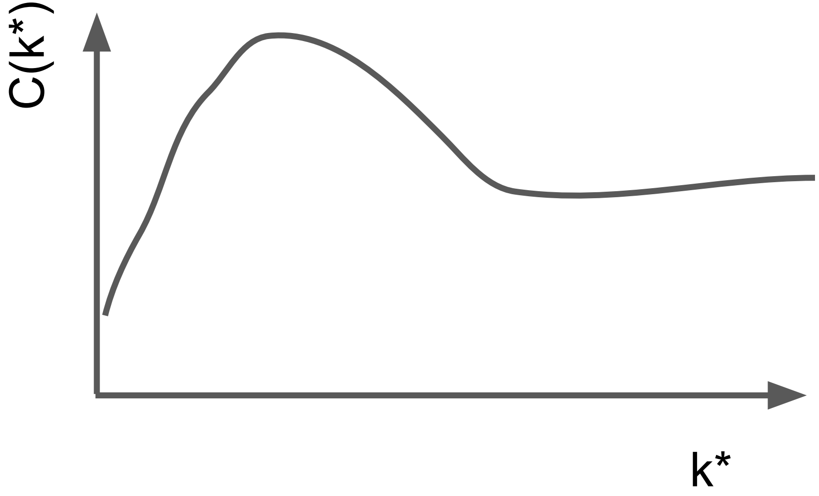




A sneak peak

A signature of coalescence?





If we measure π-d correlation function and see Δ-like peak, it would strongly suggest coalscence