Constraining the $\bar{\mathrm{K}}$N coupled channel dynamics using femtoscopic correlations with ALICE at the LHC

Maximilian Korwieser (Technische Universität München, E62) on behalf of ALICE

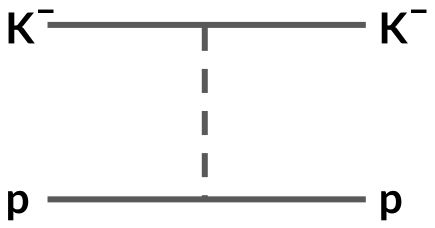
SQM22: Strange Quark Matter 2022

13 — 17 June 2022

Overview $\bar{K}N$ interaction

PDG review PRD 98 (2018)

- What is known so far …
  - use $K^{-}p$ as proxy for $\bar{K}N$
  - attractive strong interaction



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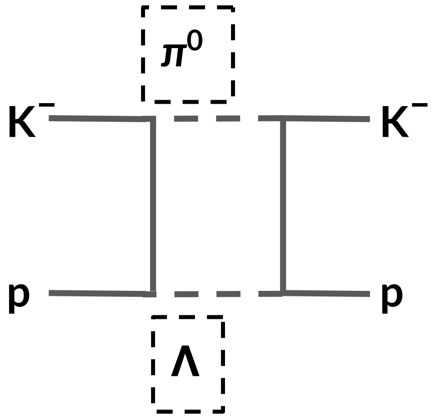

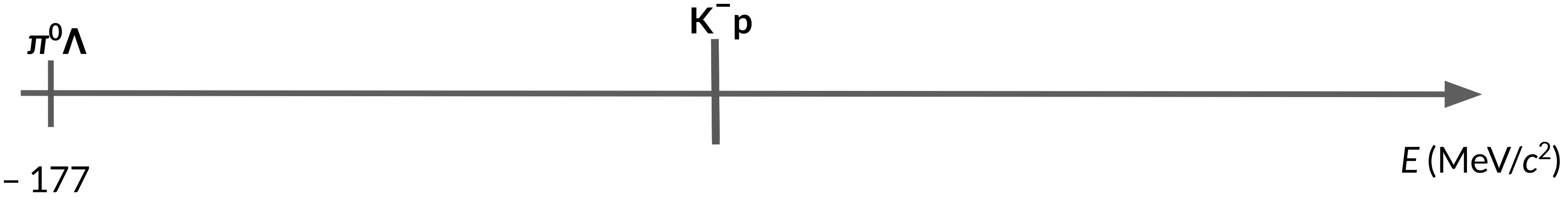

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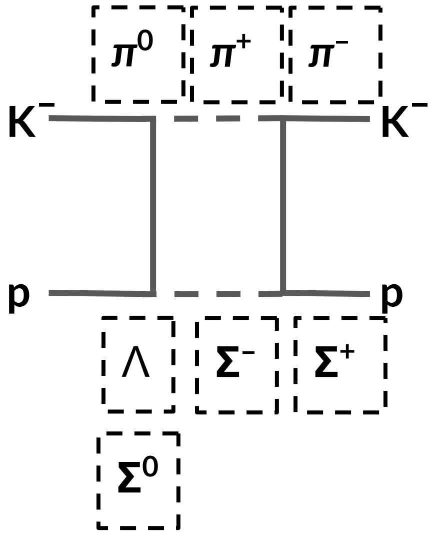
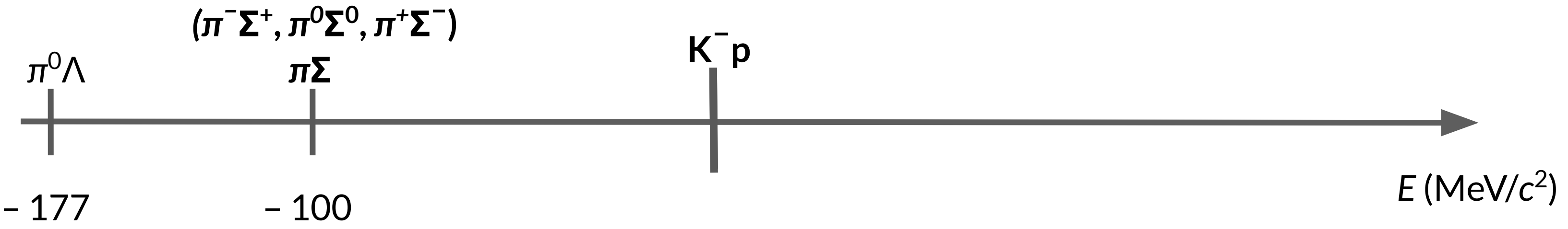
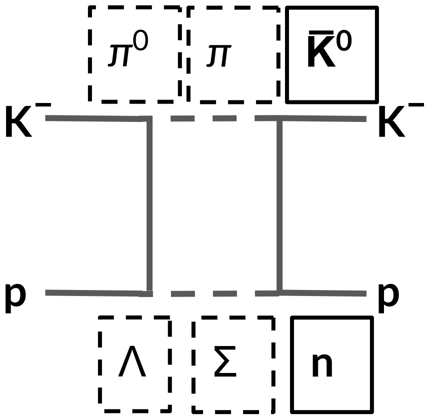
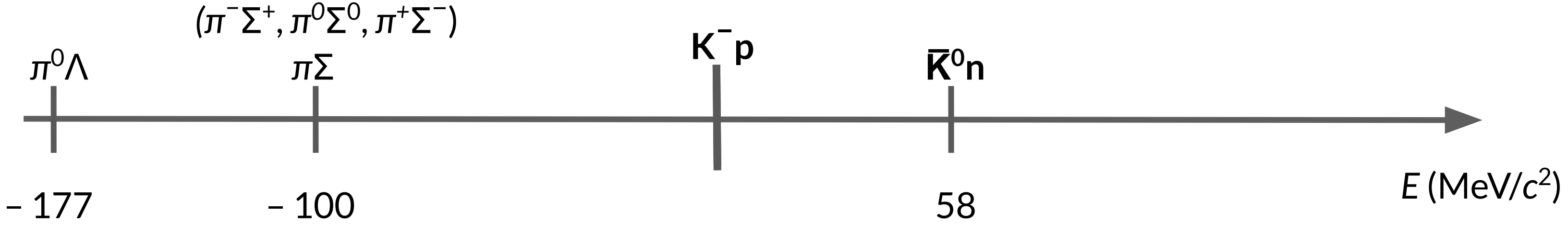




Overview $\bar{K}N$ interaction

- What is known so far …
  - use K^-p as proxy for $\bar{K}N$
  - attractive strong interaction
  - appearance of coupled channels
    - Conditions
      - Close in mass
      - Matching quantum numbers

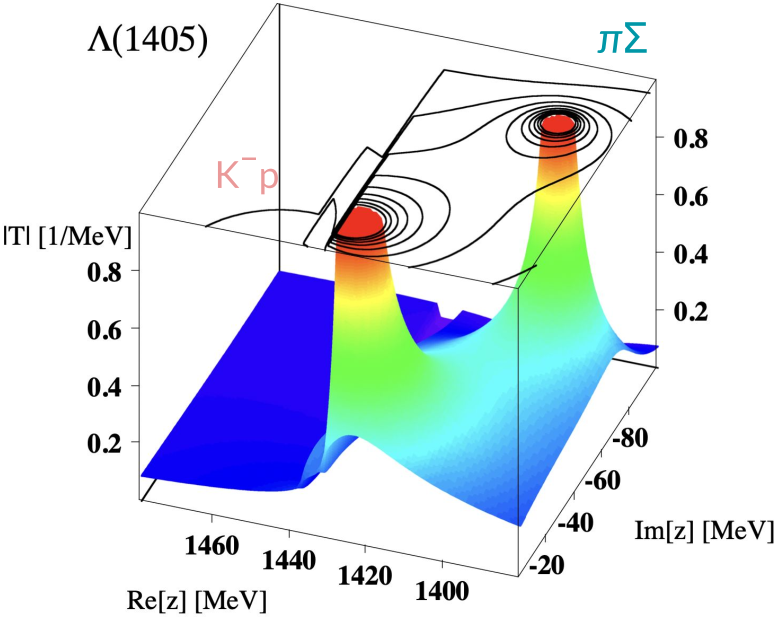


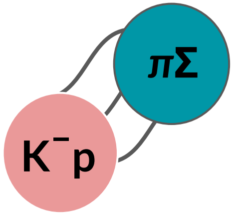


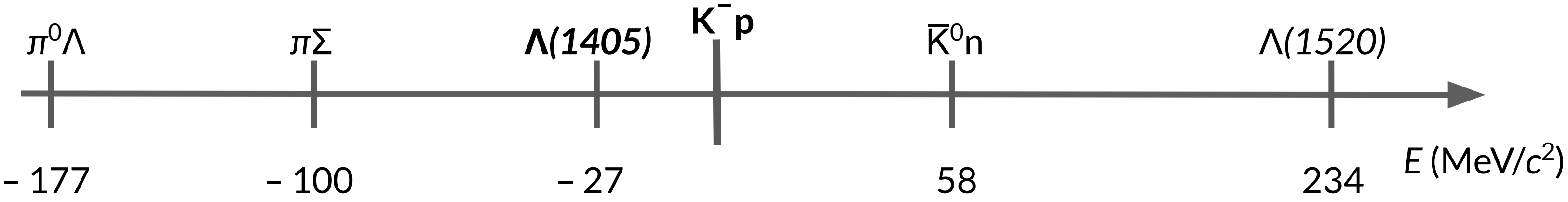
Overview $\bar{K}N$ interaction

- What is known so far …
  - use K^-p as proxy for $\bar{K}N$
  - attractive strong interaction
  - dynamic generation of Λ(1405)

T. Hyodo et al. PPNP 67 (2012)
U.Meißner et al. PDG review (2020)





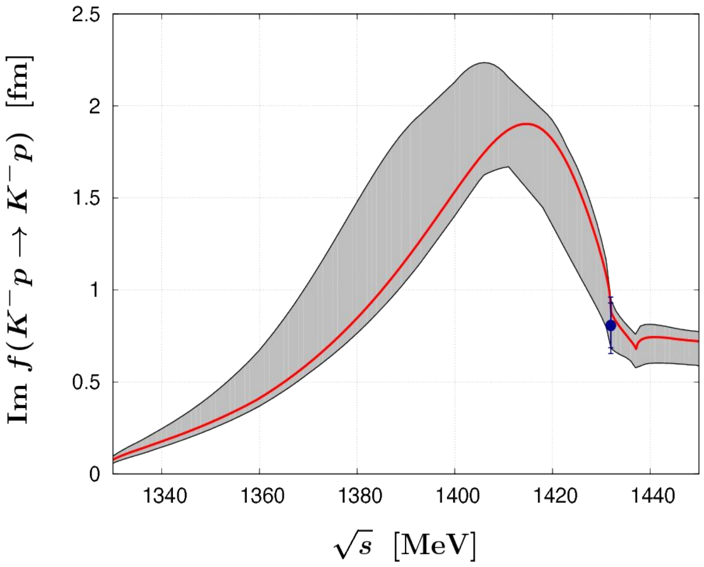


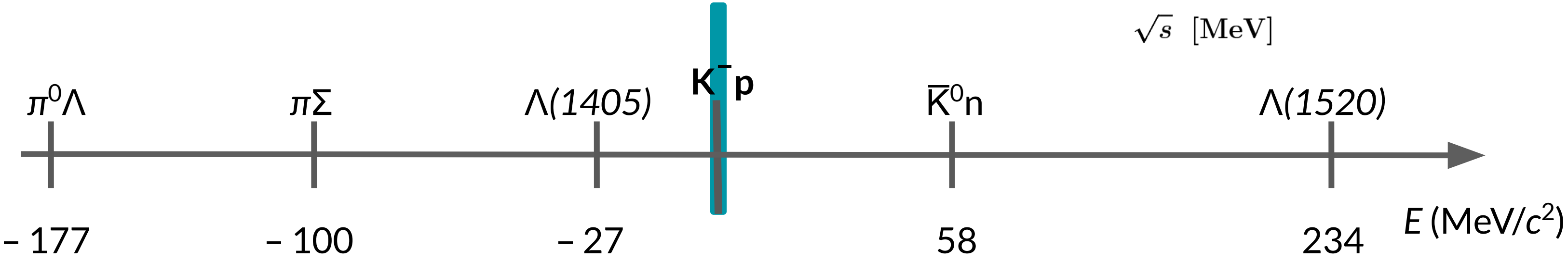
Overview $\overline{K}N$ interaction

- What is known so far …
  - attractive interaction
  - appearance of coupled channels
  - dynamic generation of Λ(1405)

- Experimental results
  - at threshold Kaonic atoms
  - above threshold scattering experiments

Y. Ikeda et al. NPA 881 (2012)
SIDDHARTA PLB 704 (2011)





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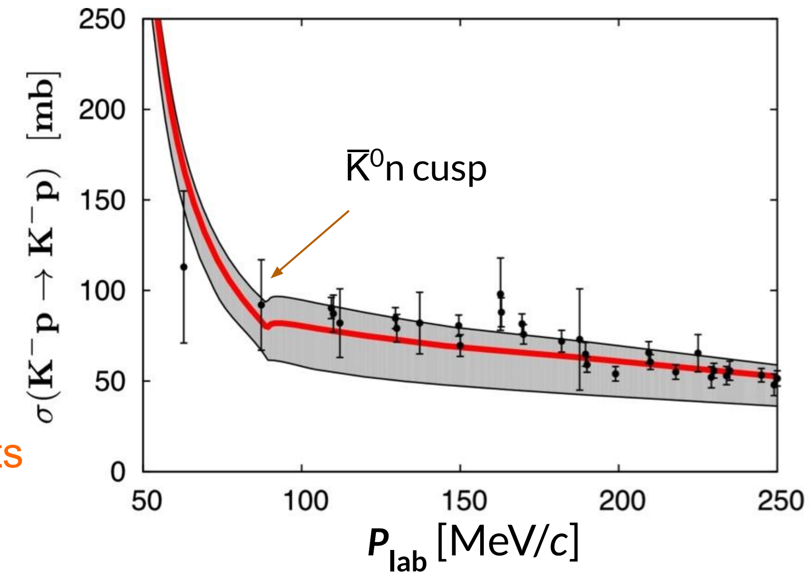
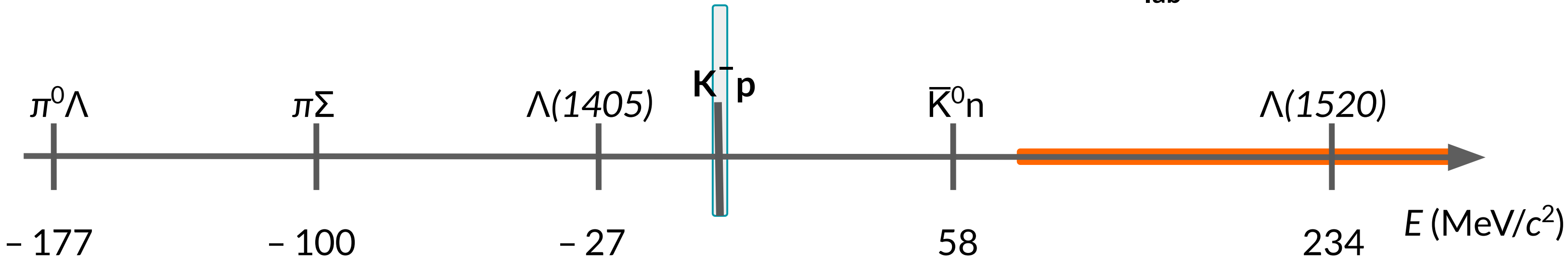
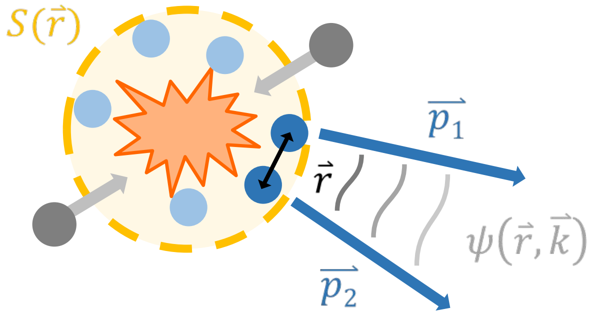
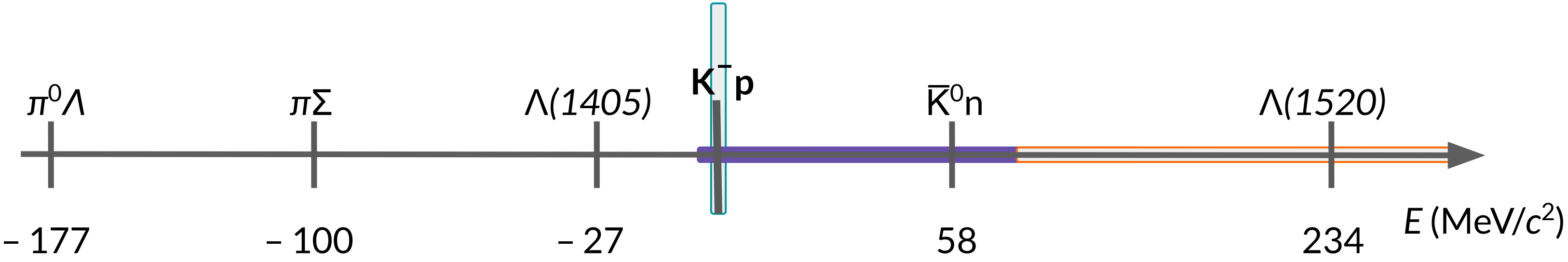




New access to $\overline{\text{K}}$N interaction

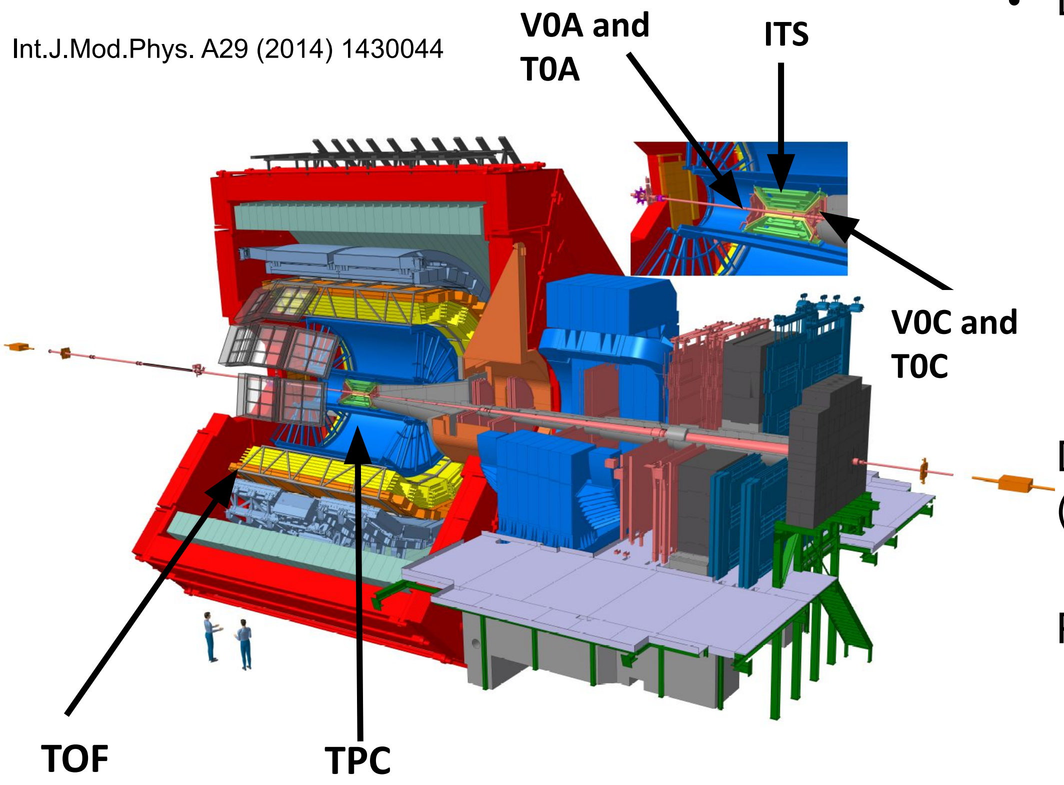
- Close to and at threshold enables
  - fixing low-energy constants in SU(3) χEFT
  - quantification of coupled-channel contribution
  - falsification of current models
- New approach: Analysis of momentum correlations
  - deliver high precision data
  - sensitivity to coupling parameters





Analysis with ALICE

Int.J.Mod.Phys. A29 (2014) 1430044



- Data sets (# evts)
  - **pp 13 TeV**
    (1000 M high mult.)
  - **p–Pb 5.02 TeV**
    (800 M **0–100%** mult. interval)
  - **Pb–Pb 5.02 TeV**
    (65 M **60–90%** cent. interval)

Direct detection of charged particles (protons, kaons) by TPC and TOF

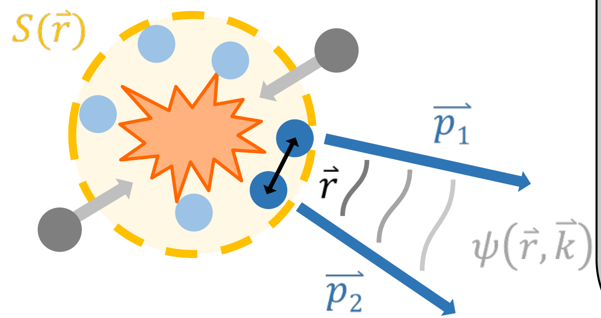
Purity of used particles **99%**

Basics of Femtoscopy

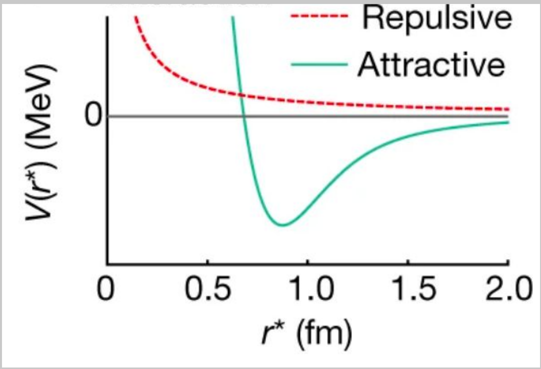
$$C(k^*) = \int S(\vec{r}^*) \left| \psi(\vec{k}^*, \vec{r}^*) \right|^2 d^3\vec{r}^* = \mathcal{N} \frac{N^{same}(k^*)}{N^{mixed}(k^*)}$$

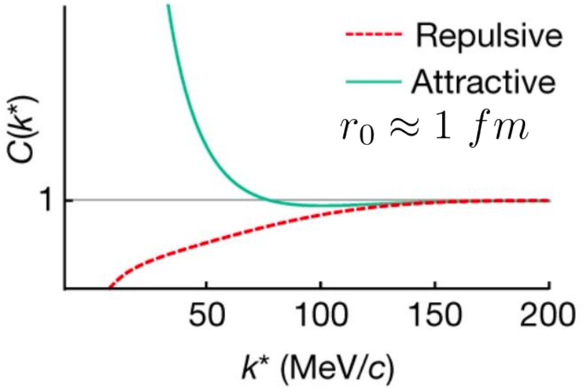
- > 1 attractive
- $= 1$ no int. (large k^*)
- < 1 repulsive

$$S(\vec{r}^*) = \frac{1}{(4\pi r_0^2)^{\frac{3}{2}}} \exp\left(-\frac{r^{*2}}{4r_0^2}\right)$$



Schrödinger Equation for relative wavefunction





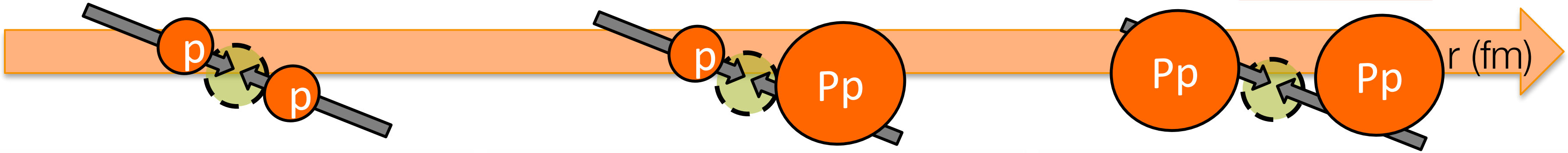
M. A. Lisa et al. Ann. Rev. NPS 55 (2005)
Nature 588 (2020)

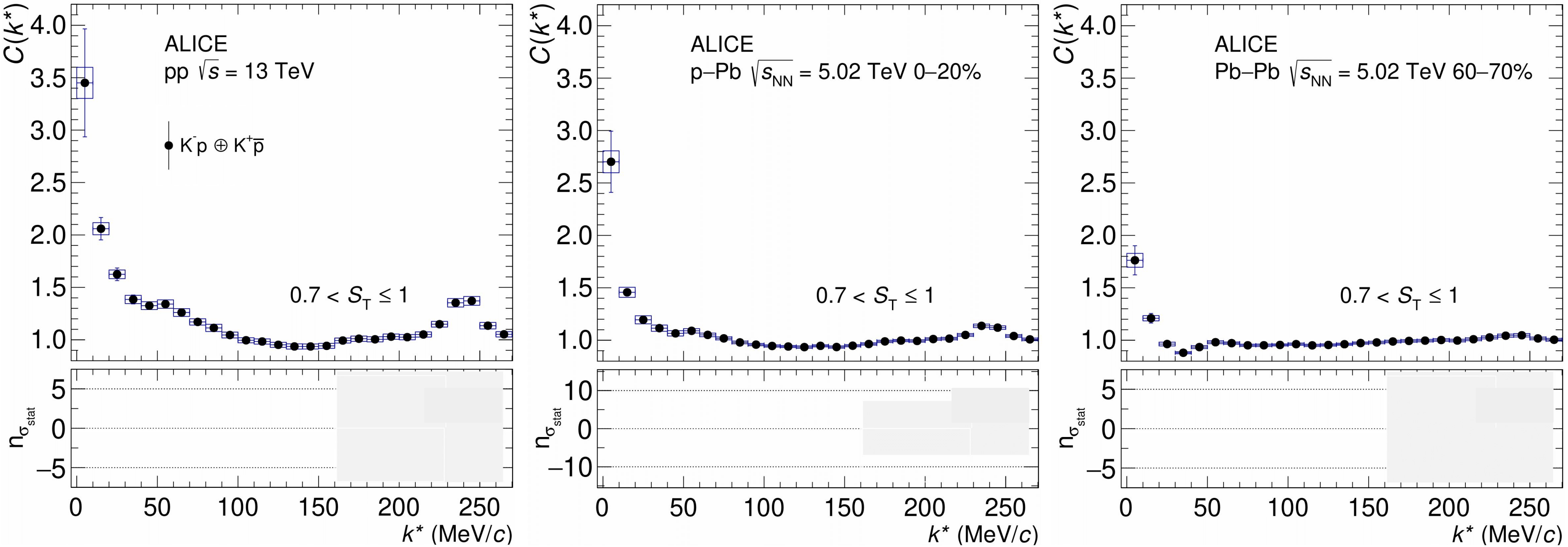
Relative momentum $k^* = \frac{1}{2} | \vec{p_1^*} - \vec{p_2^*} |$ and $\vec{p_1^*} + \vec{p_2^*} = 0$

Relative distance $\vec{r}^* = \vec{r}_1^* - \vec{r}_2^*$

Femtoscopics result

New!





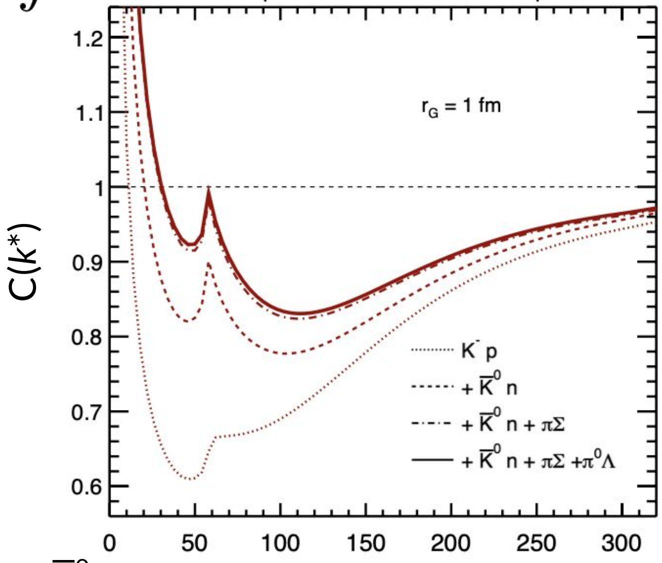
arXiv:2205.15176

Femtoscopy: Coupled Channels

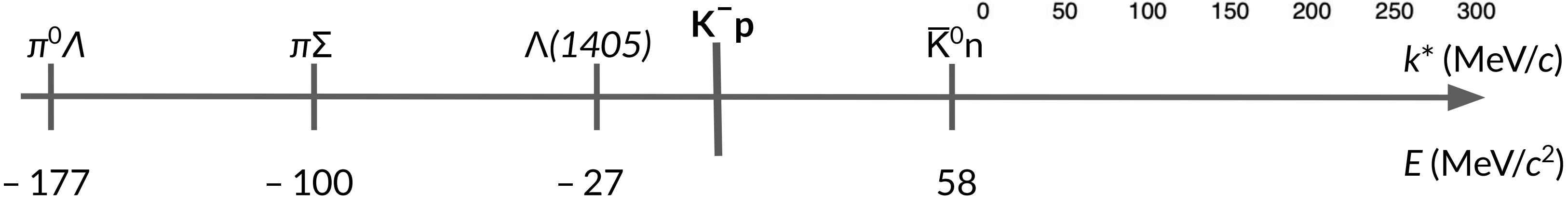
$$C(k^*) = \int S(\vec{r}^{\,*}) \left|\psi(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*} + \sum_j \omega_j \int S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*}$$

- Conversion weights (ω)
  - control CC contribution
  - depend on primary yield and kinematics

- System-size survey
  - study impact on correlation



J. Haidenbauer NPA 981 (2019)
Y. Kamiya et al. PRL 124 (2020)



Estimation of ω

$$C(k^*) = \int S(\vec{r}^{\,*}) \left|\psi(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*} + \sum_j \omega_j \int S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*}$$

- Calculation of expected primary yields
  - Thermal model (Thermal-FIST) [1]
    - for each collision system

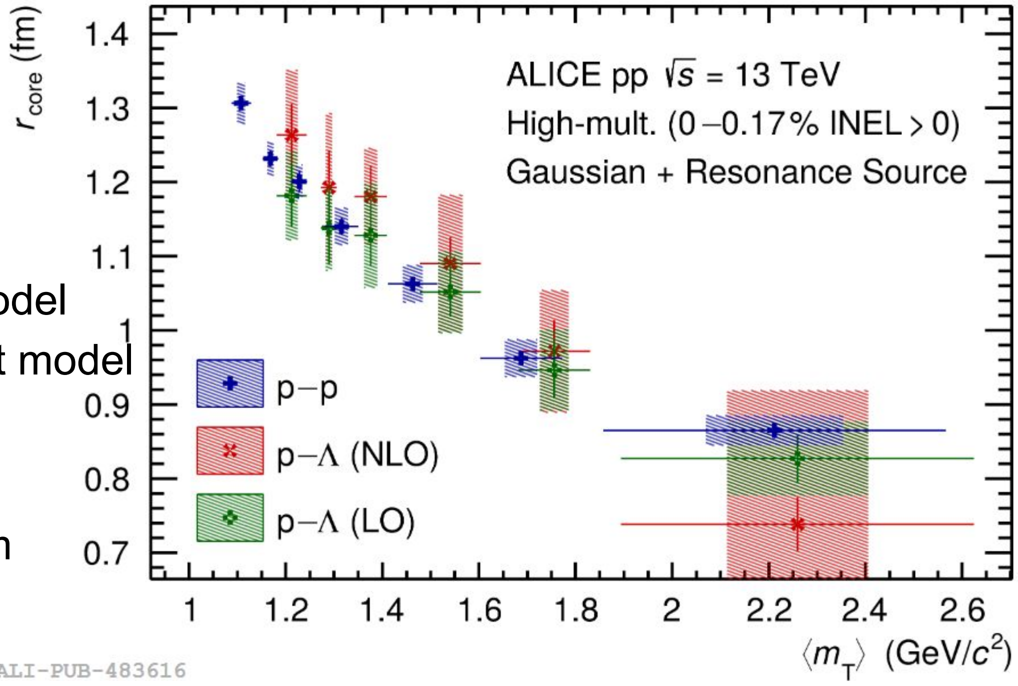
- Estimate amount of pairs in FSI sensitive kinematic region ($k^* < 200$ MeV/c)
  - Distribute particles according to Blast-wave (BW) model [2,3,4]
  - Normalize to expected yields

[1] V. Vovchenko et al. PRC 100 no. 5 (2019)
[2] E. Schnedermann et al. PRC 48 (1993)
[3] PLB 728 (2014)
[4] PRC 101 no. 4 (2020)

Pinning down the emitting source

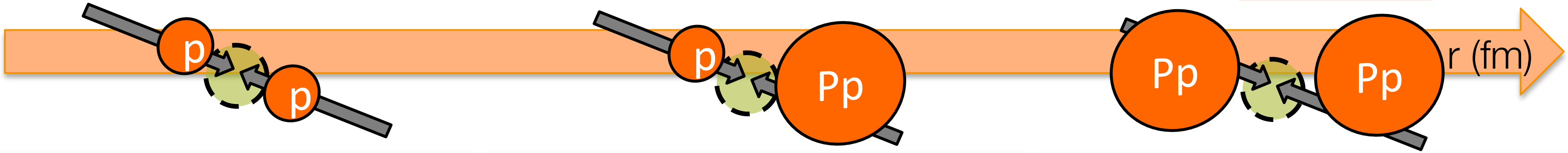
- Universal source ansatz
- Decompose source
  - Gaussian core source driven by thermal production
  - Exponential decays of particle-specific resonances
    - fractions from thermal model
    - kinematics from transport model
- Steps to generate the sources
  - Determine core by fitting $C(k^*)$ from K^+–p (same system and mult./cent. interval)
  - Use as input for K^-–p
  - Add for each channel resonance decays (Monte Carlo procedure)

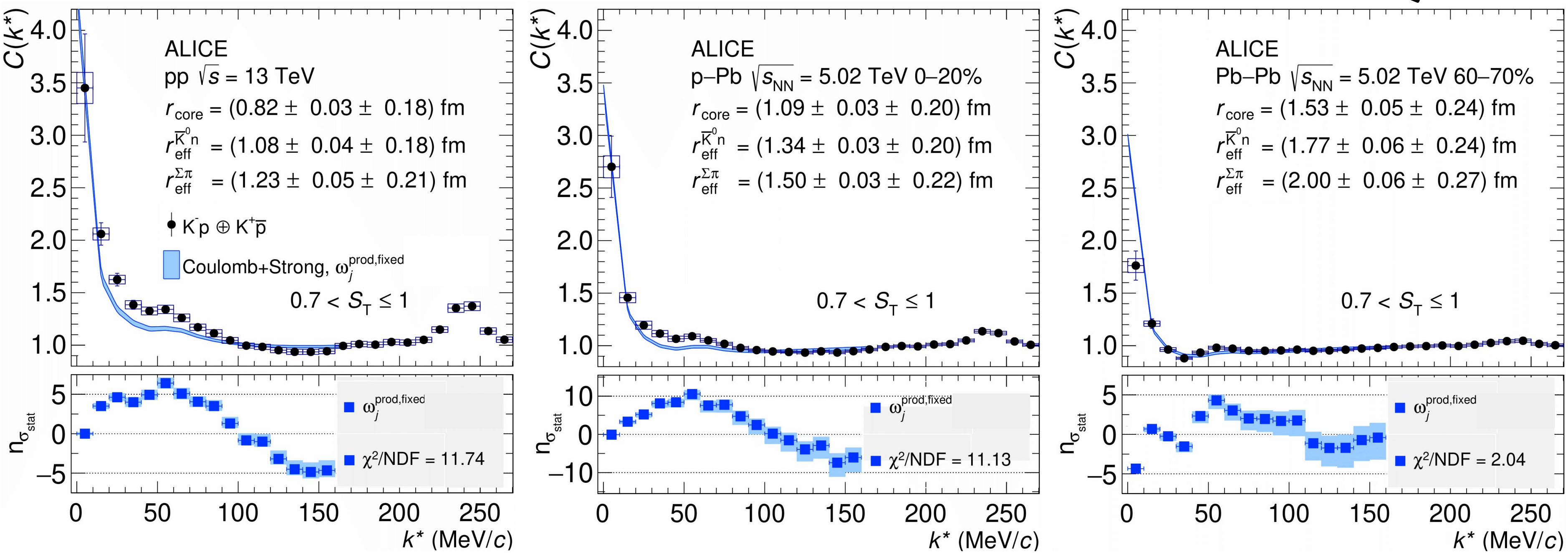
arXiv:2004.08018



Femtoscopics result

New!



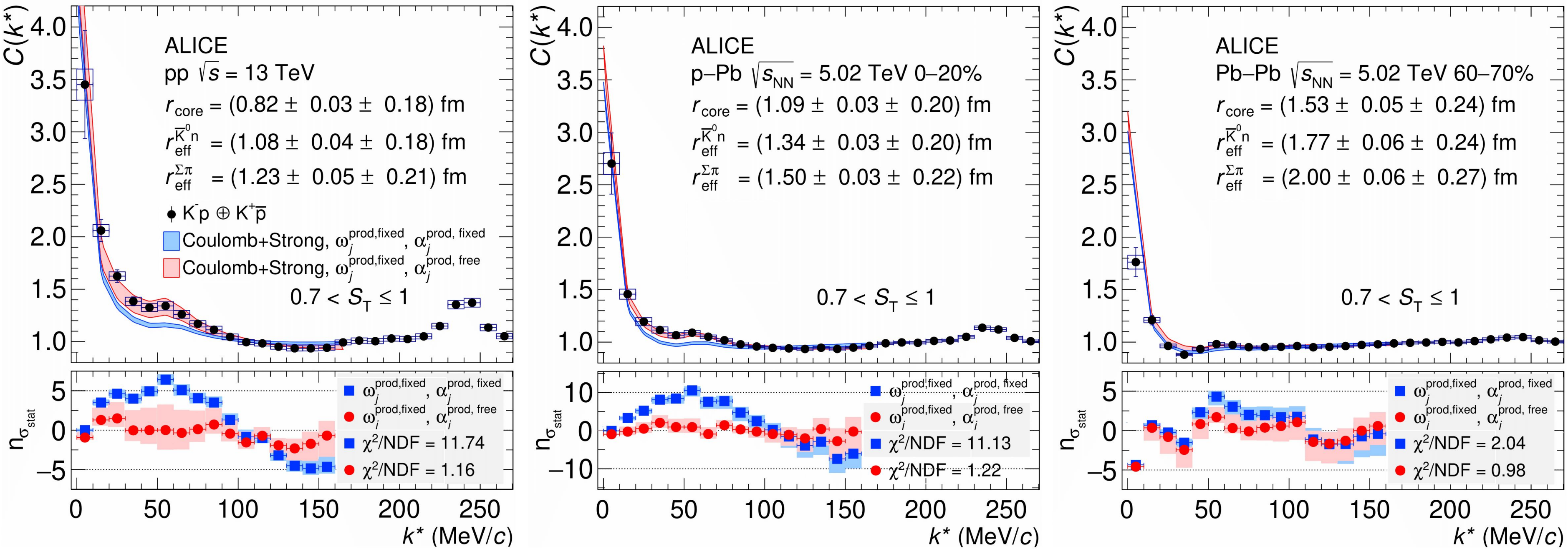


arXiv:2205.15176

Femtoscopics result (with scaling factor)

New!

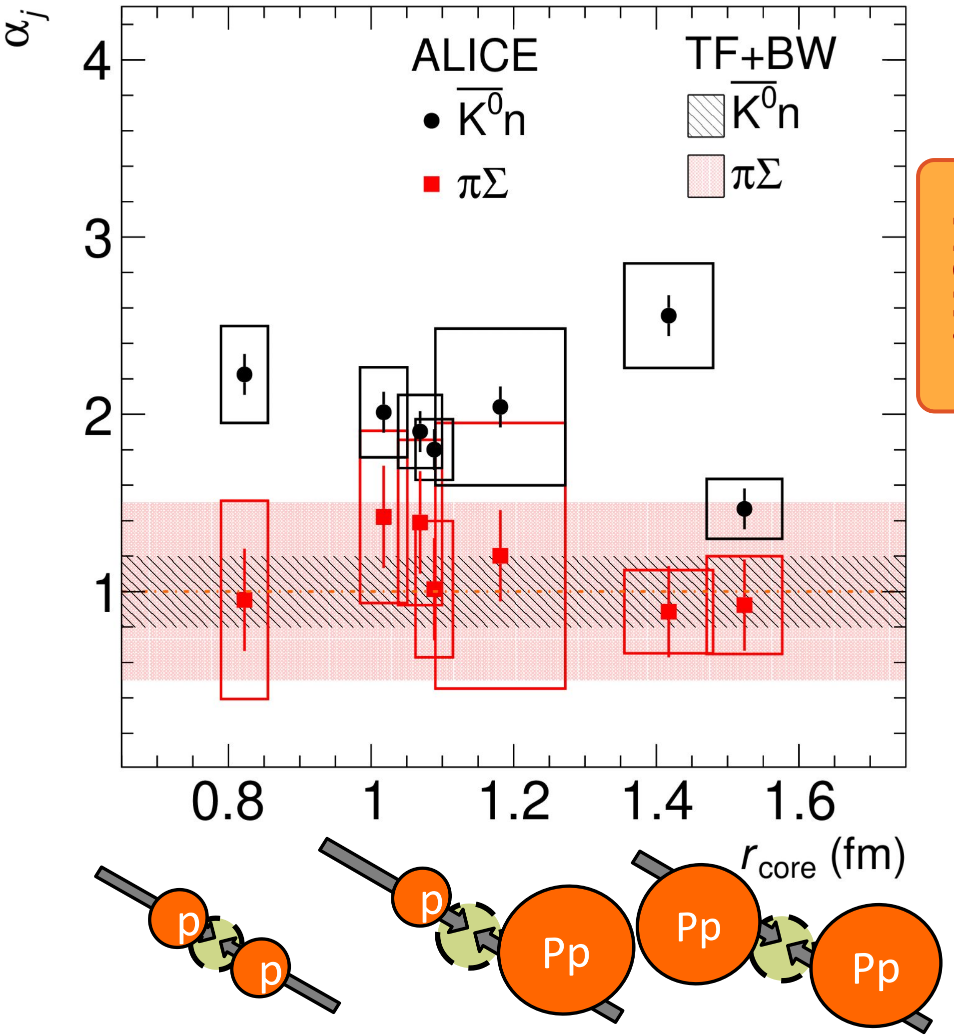
$$C(k^*) = \int S(\vec{r}^{\,*}) \left|\psi(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*} + \sum_j \alpha_j \cdot \omega_j \int S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*}$$



arXiv:2205.15176

Scaling factors

- Experimental results
  - improved data situation near threshold
  - hints at revising the coupling strengths in SU(3) χEFT
  - first experimental constraint of the $\overline{K}^0$–n channel



New!

arXiv:2205.15176

Summary & Outlook

- Measurement of the two-particle momentum correlation K^{-}–p
- High resolution of cusp structure K^{-}–p $\leftrightarrow$ $\overline{K}^{0}$–n
- Quality data available for model tuning (SU(3) χEFT)
- Kyoto model fits:
  - scaling factor needed to accomodate data
  - necessitates revision of coupling strengths

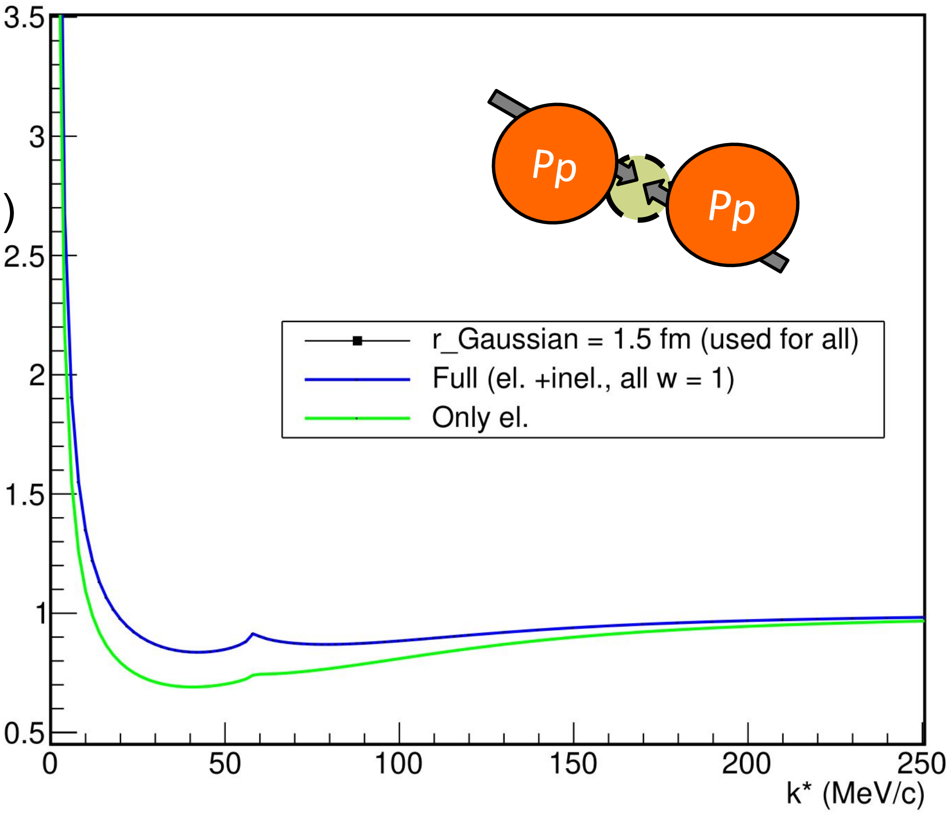
Back-up

Content

- CC for r_core = 1.5 fm (Pb-Pb peripheral)
- Femtoscopy: Information about the source

Last scaling bin

- Prediction SU(3) χEFT
  - Gaussian S(r*) (r0 = 1.5 fm) same for all channels
  - Weights at unity
  - Cusp still pronounced
    - non negligeable contribution predicted
    - difficult to resolve with current statistics

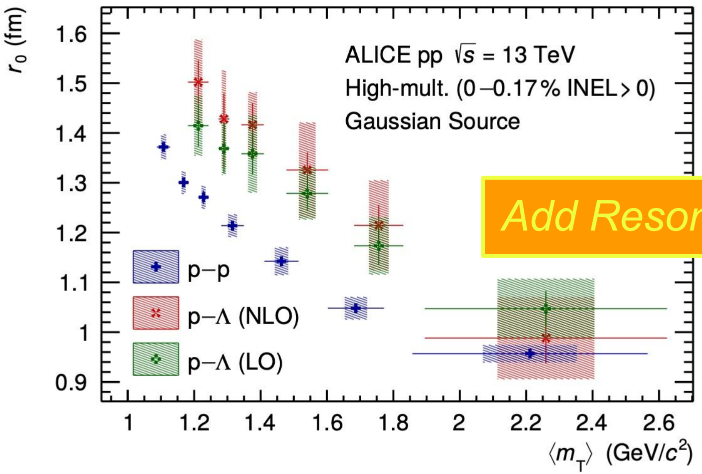


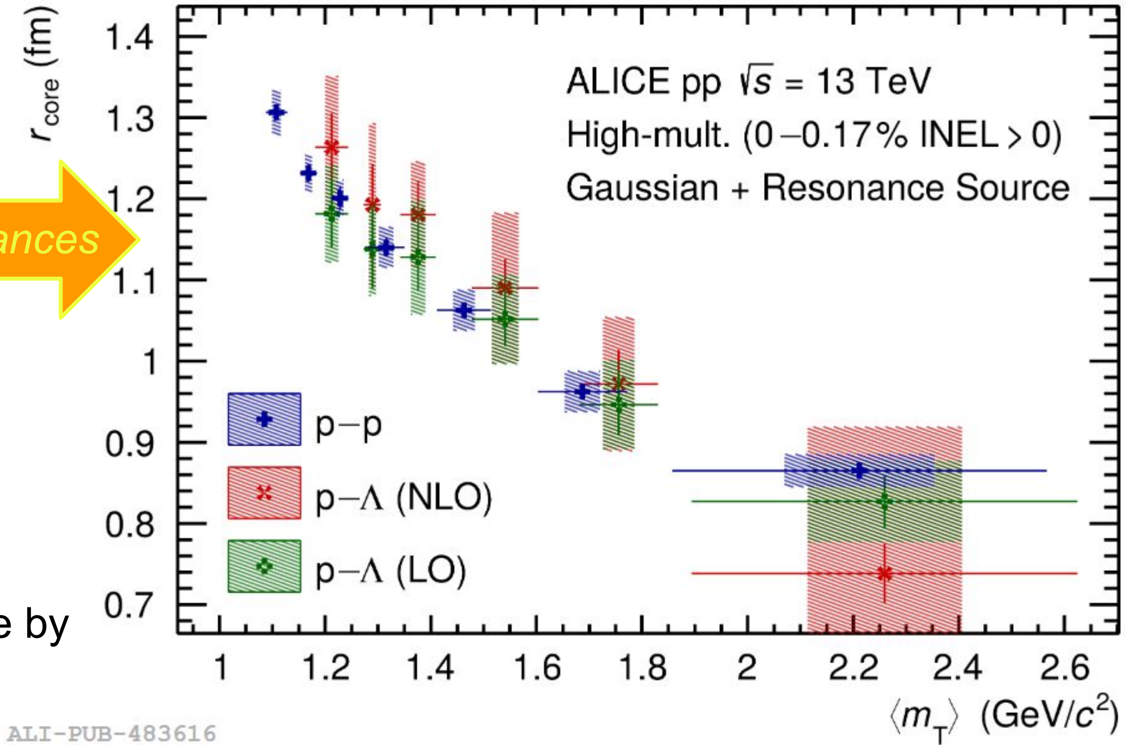
New!

arXiv:2205.15176

Femtoscopy: Source

ALICE Collab., *Physics Letters B*, 811 (2020) 135849

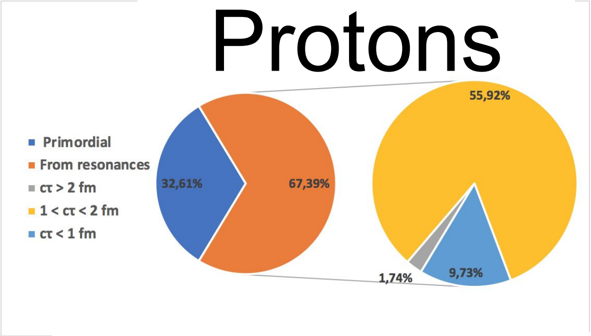


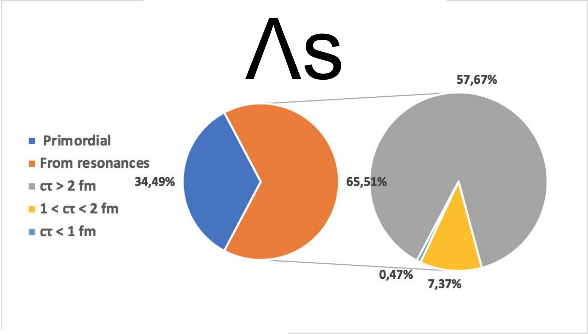


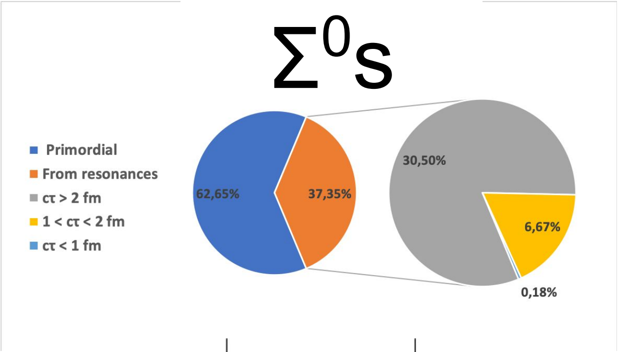
Source modifications

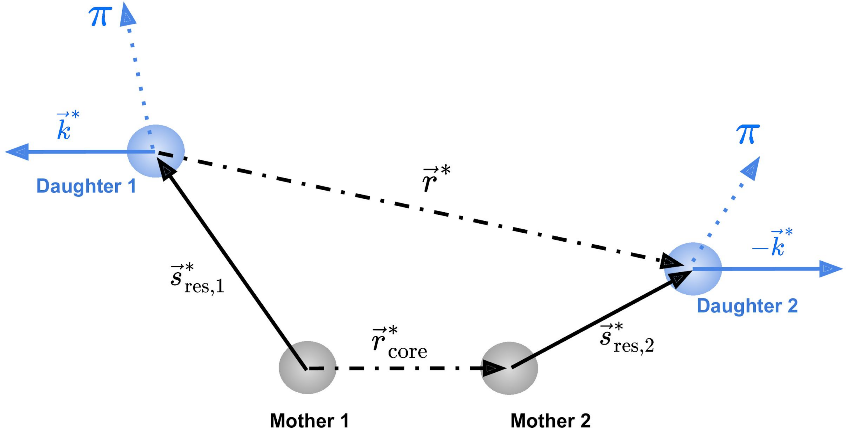
- Increase in apparent source size by short lived strongly-decaying resonances (e.g. Δ)

Femtoscopy: Source Resonances (example)









Particle	M_{res} [MeV]	τ_{res} [fm]
p	1361.52	1.65
Λ	1462.93	4.69
Σ^0	1581.73	4.28

$$s = \beta\gamma\tau_{\text{res}} = \frac{p_{\text{res}}}{M_{\text{res}}}\tau_{\text{res}}$$

$$E(r, M_{\text{res}}, \tau_{\text{res}}, p_{\text{res}}) = \frac{1}{s}\exp\left(-\frac{r}{s}\right)$$

Femtoscopy: Source

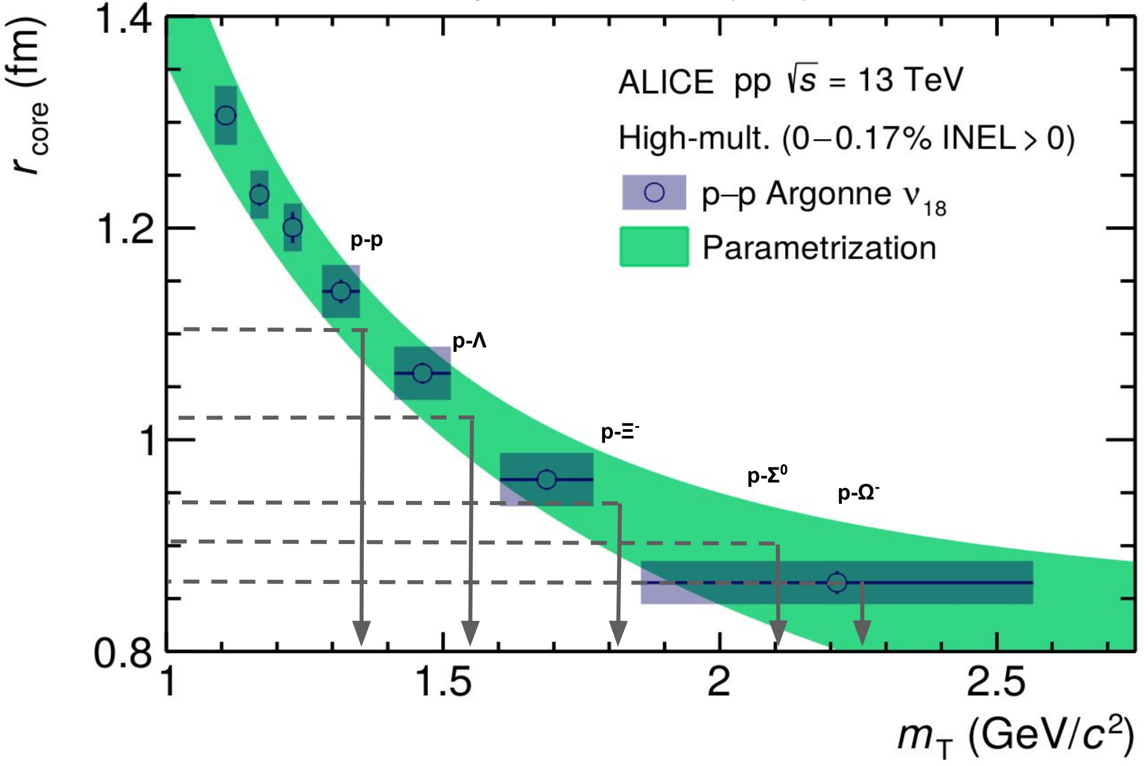
Universal source model

- r_{core} fixed for each pair based on $<m_T>$
- Particle-specific resonances are added to the core

Notice

- Small radii probe large densities

ALICE Collab., *Physics Letters B*, 811 (2020) 135849



Formula up-keep

$$S(r^*)=\frac{1}{(4\pi r_0^2)^{\frac{3}{2}}}\exp\left(-\frac{r^{*2}}{4r_0^2}\right)$$

$$C_{model}(k^*) = b(k^*)[\lambda_{p\Sigma^0}C_{p\Sigma^0}(k^*)+\lambda_{p(\gamma\Lambda))} C_{p(\gamma\Lambda))}(k^*)+\lambda_{ff}+\lambda_{\tilde{p}\Sigma^0}]$$

$$C_{model}(k^*) = (a+b\cdot k^*)[1+\lambda_{K-p}(C_{K-p}^{CC}(k^*)-1)+\sum_{ij}\lambda_{ij}(C_{ij}(k^*)-1)]$$

$$C(k^*) = \int S(\vec r^{\;*}) \left |\psi(\vec k^{\;*},\vec r^{\;*})\right |^2 d^3\vec r^{\;*} + \sum_{j} \alpha_{j}\cdot\omega_{j} \int S_{j}(\vec r^{\;*}) \left |\psi_{j}(\vec k^{\;*},\vec r^{\;*})\right | ^2 d^3\vec r^{\;*}$$

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