Femtoscopy studies on Kaon-proton with ALICE

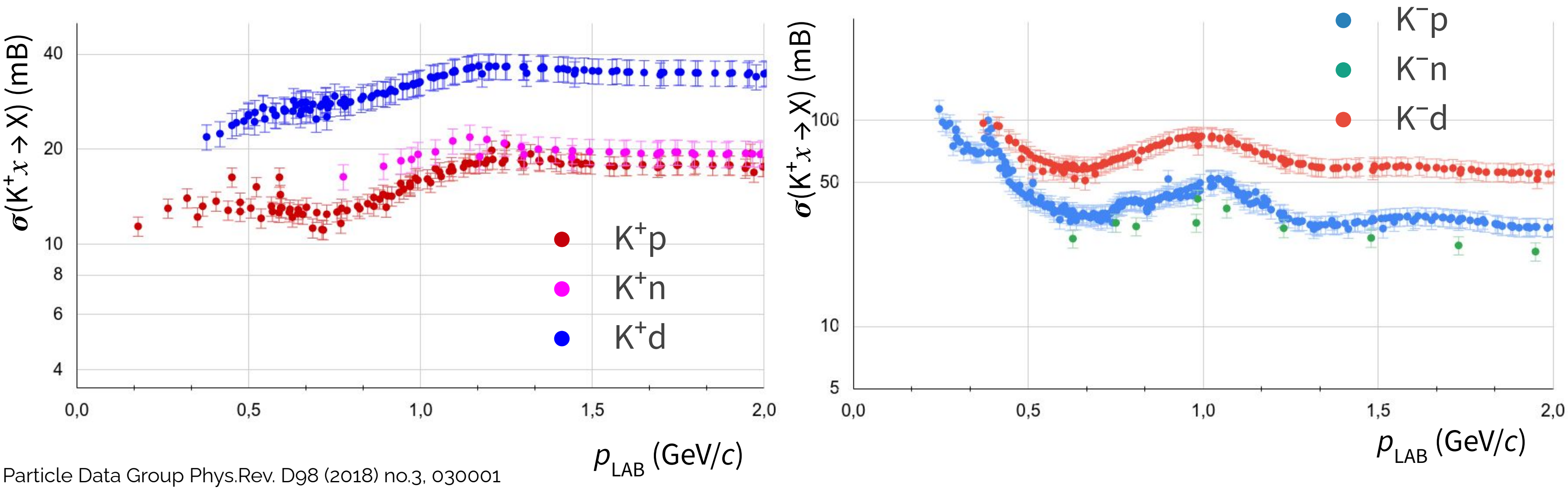
Ramona Lea
University of Brescia and INFN Pavia

ramona.lea@cern.ch

EXOTICO: EXOTIC ATOMS MEET NUCLEAR COLLISIONS

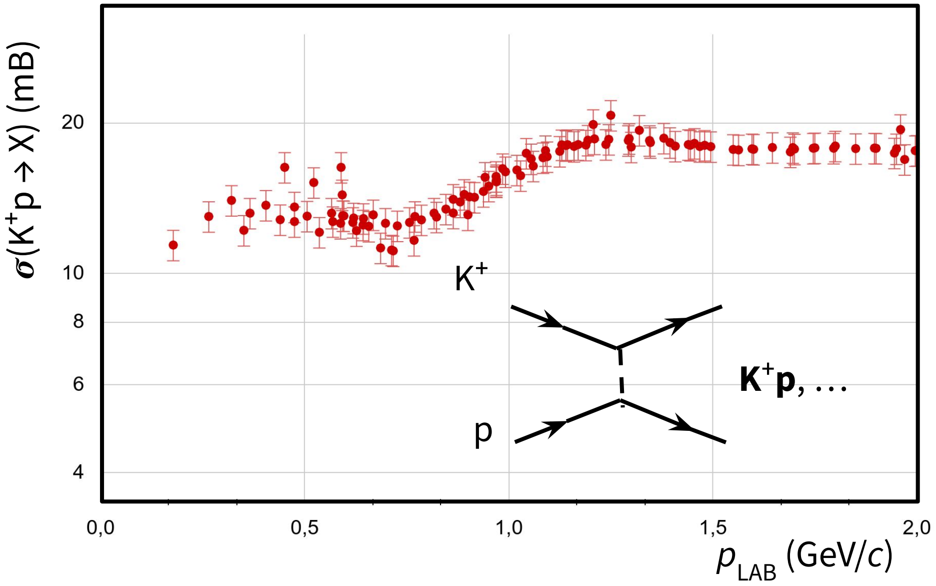
KN and $\bar{K}$N interactions and how to study them

- Kaon (K) nucleon (N) and anti-Kaon nucleon ($\bar{K}$N) interactions are fundamental for the study of low-energy QCD
  - K = $K^+ (u\bar{s})$, $K^0(d\bar{s})$; $\bar{K} = K^-(s\bar{u})$, $\bar{K}^0 (s\bar{d})$
- Traditionally, these interactions are studied by <u>scattering experiments</u> at low energies
  - few experimental measurements with big uncertainties and not at low-energy p_{lab}< 50 MeV/c



Particle Data Group Phys.Rev. D98 (2018) no.3, 030001

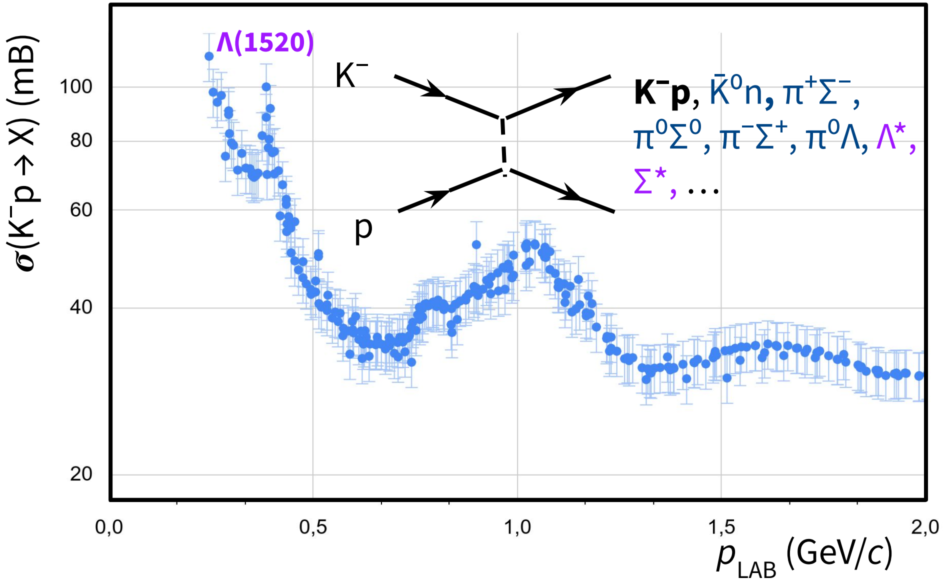
K^+p interaction

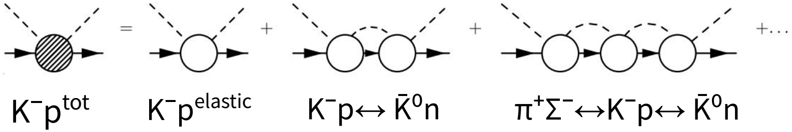


- **K^+p interaction**
  - Repulsive (due to Coulomb and strong interactions)
  - No coupled channels
  - No resonances
    - well known [1]

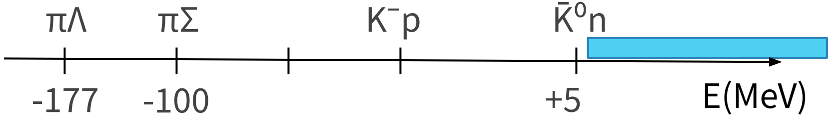
[1] K. Aoki and D. Jido, PTEP 2019 no. 1, (2019) 013D01 (arXiv:1806.00925 [nucl-th])

K⁻p interaction

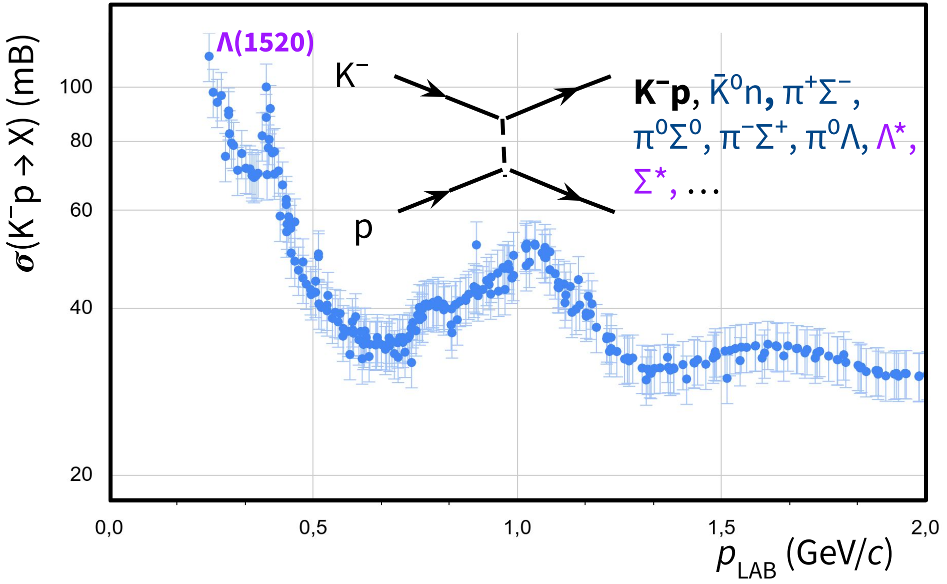




- **K⁻p interaction**
  - deeply attractive
  - several **resonances**
  - several **coupled channels** ($\bar{K}^0n$, $\pi^+\Sigma^-$, $\pi^0\Sigma^0$, $\pi^-\Sigma^+$, $\pi^0\Lambda$)
    - systems close to the K⁻p threshold and with the same quantum numbers



K^-p interaction



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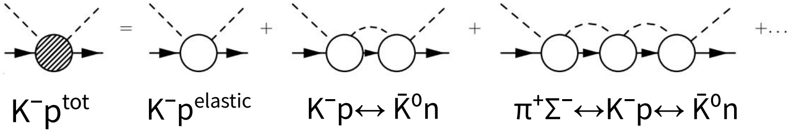
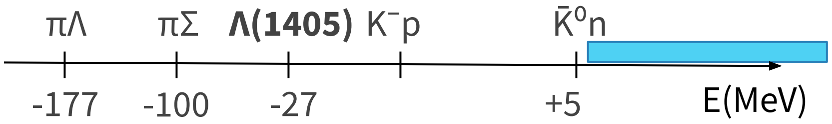
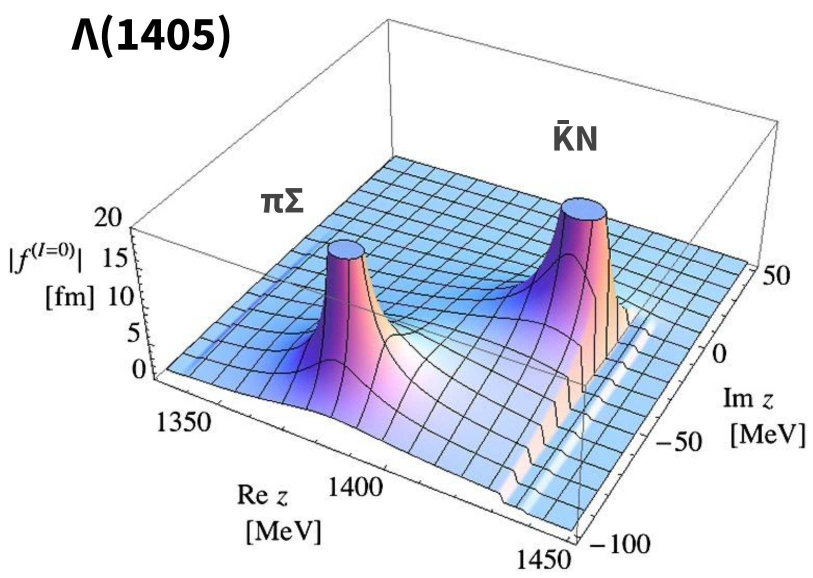
  - several **resonances**
  - several **coupled channels** ($\bar{K}^0n$, $\pi^+\Sigma^-$, $\pi^0\Sigma^0$, $\pi^-\Sigma^+$, $\pi^0\Lambda$)
    - systems close to the K^-p threshold and with the same quantum numbers
    - $\bar{K}N \leftrightarrow \pi\Sigma$ dynamics leads to the formation of the **Λ(1405)**, ~27 MeV below K^-p threshold

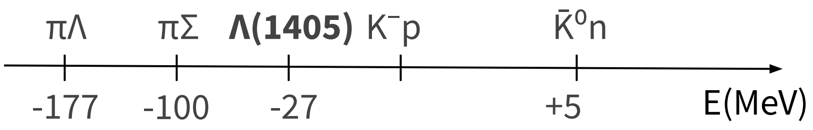




K^-p interaction and Λ(1405)

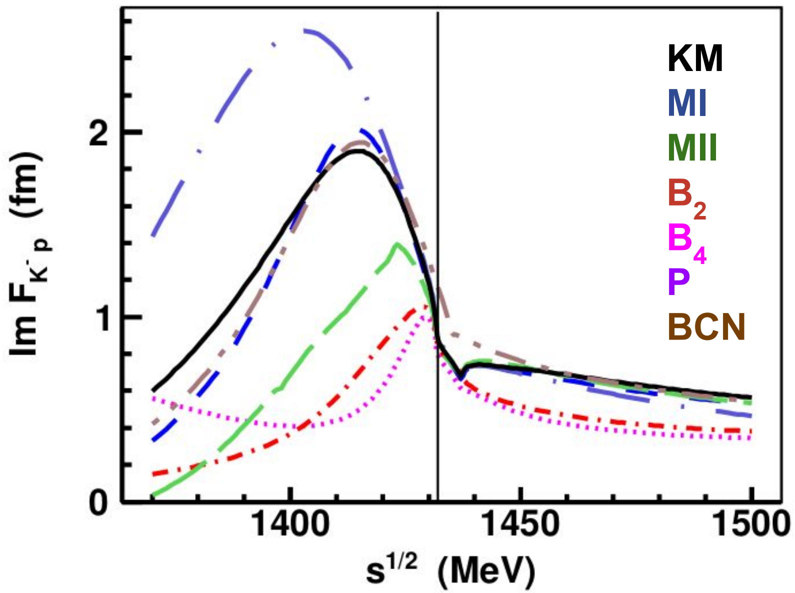


- Nature of Λ(1405): dynamically generated resonance
  - Models based on below-threshold extrapolations
    - positions of pole are model dependent (relative contributions not measured experimentally)



Y. Kamiya et al., NPA 954 (2016) 41-57
T. Hyodo et al., PPNP 67 (2012)
U. Meißner and T. Hyodo: PDG review (2020) (Section 83)

$K^{-}p$ interaction and Λ(1405)



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    - state-of-the-art chiral models (χEFT) are in agreement above threshold
    - large discrepancies in the region below threshold

A. Cieplý et al., arxiv:2001.08621

- KM Y. Ikeda, et al., NPA 881 (2012) 98
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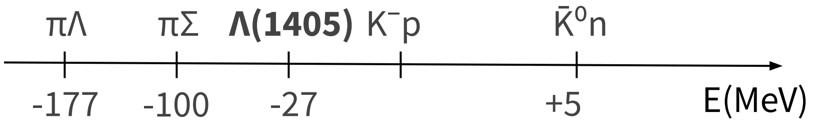

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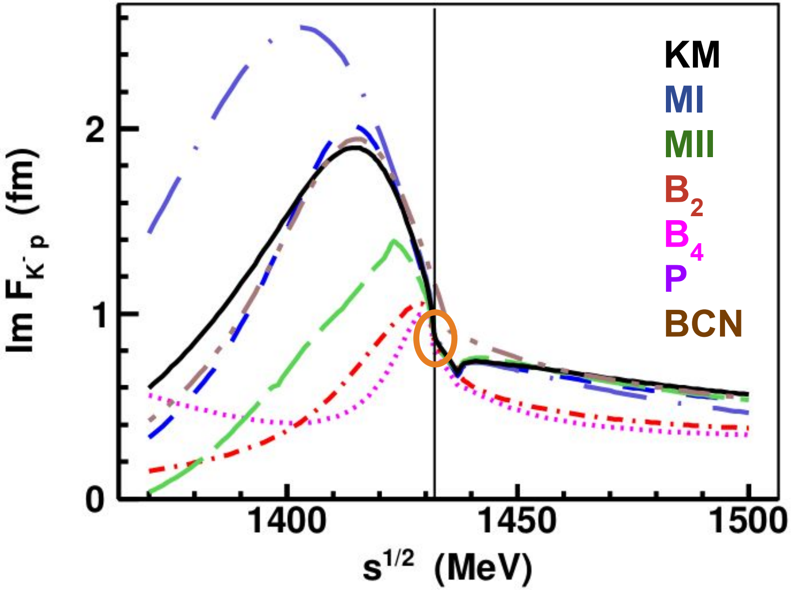

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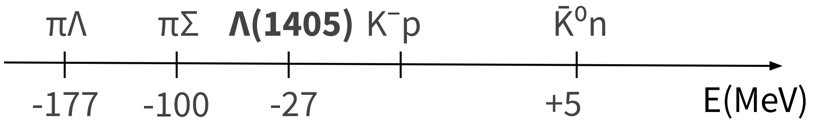
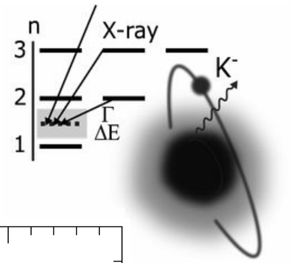
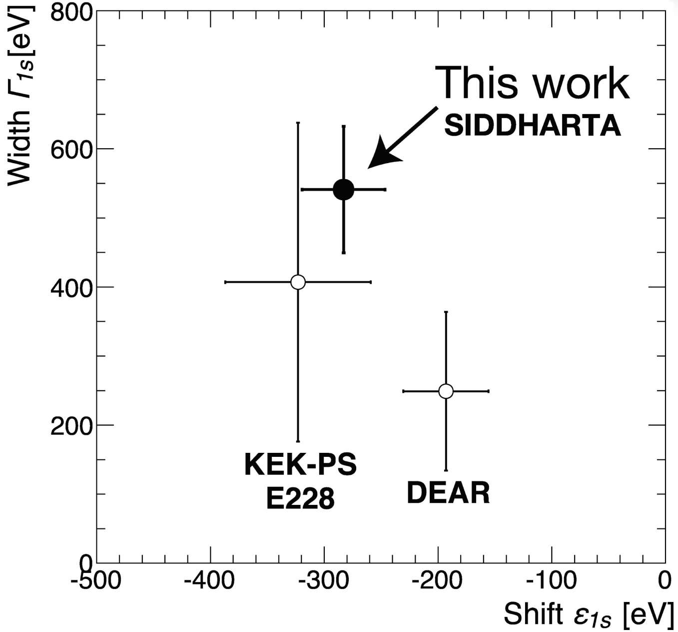


K^-p interaction and $\Lambda(1405)$





[1] SIDDHARTA Collaboration PLB704 (2011) 113

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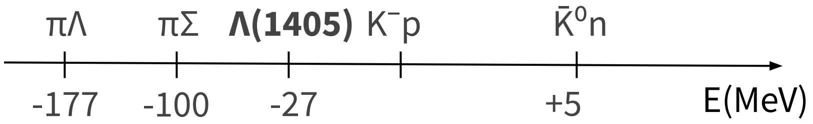
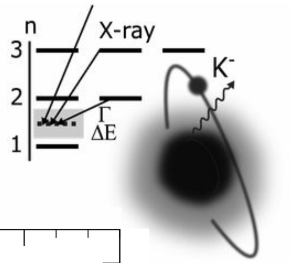
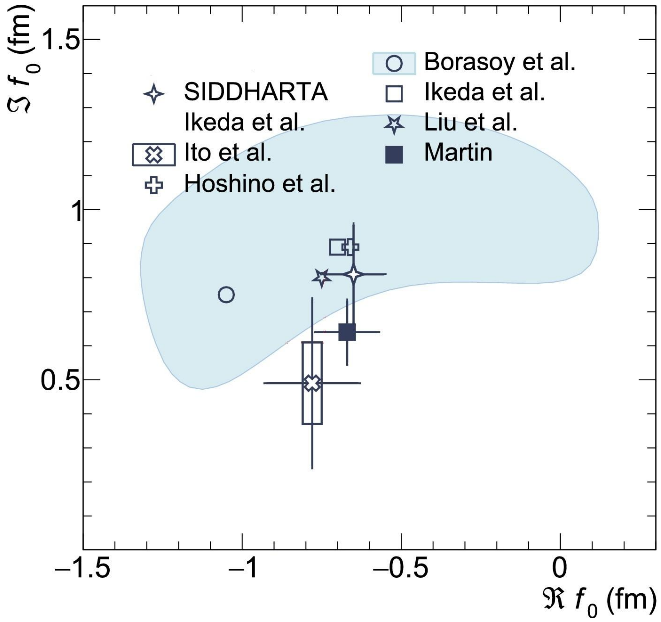
    - constraint at threshold by SIDDARTHA measurement [1] of kaonic hydrogen 1s level shift and width



K⁻p interaction and Λ(1405)





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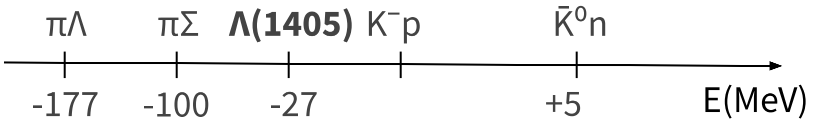
      - scattering length



[1] SIDDHARTA Collaboration PLB704 (2011) 113

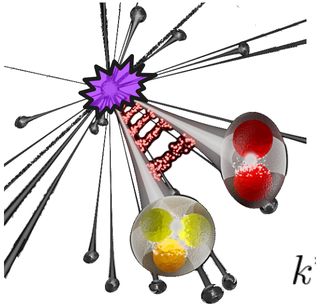
KN and $\bar{K}$N interactions : the game changer

Two-particle momentum correlation measured with ALICE at the LHC

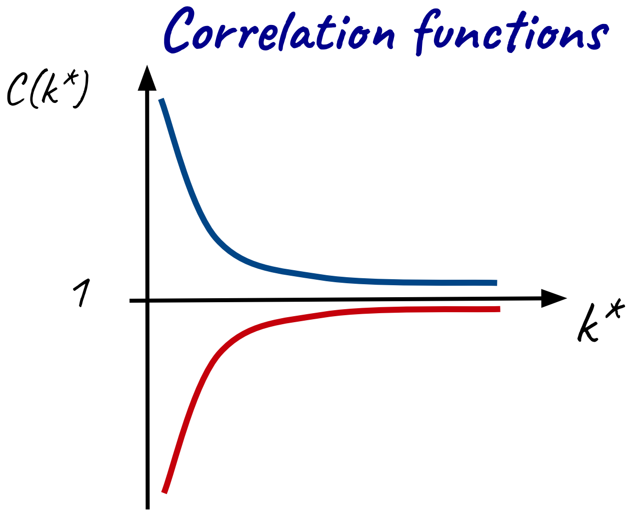
- **KN** and **$\bar{K}$N** interaction
  - ALICE Collaboration PRL 124 (2020) 9, 092301
  - ALICE Collaboration PLB 822 (2021) 136708
  - ALICE Collaboration arXiv: 2205.15176 (Accepted by EPJC)

- **and other interactions:**
  - pp, pΛ, ΛΛ: ALICE Collaboration PRC 99(2019)
  - ΛΛ: ALICE Collaboration PLB 797 (2019) 134822
  - pΞ: ALICE Collaboration PRL 123 (2019) 134822
  - pΣ^0:ALICE Collaboration PLB 805 (2020) 135419
  - pΩ: ALICE Collaboration Nature 588 (2020) 232-238
  - pϕ: ALICE Collaboration PRL 127 (2021) 172301
  - B-$\bar{B}$:ALICE Collaboration PLB B 829 (2022) 137060
  - pΛ: ALICE Collaboration arXiv:2104.04427
  - pD: ALICE Collaboration arXiv:2201.05352
  - ΛΞ: ALICE Collaboration arXiv:2204.10258
  - ppp and ppΛ: ALICE Collaboration arXiv:2206.03344

Two-particle momentum correlation...

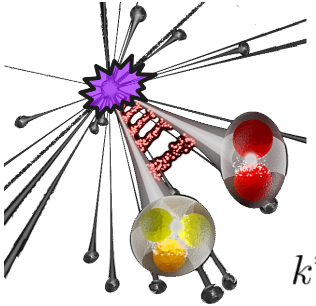


$$k^* = \frac{|\vec{p}_1^{\,*} - \vec{p}_2^{\,*}|}{2}$$



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

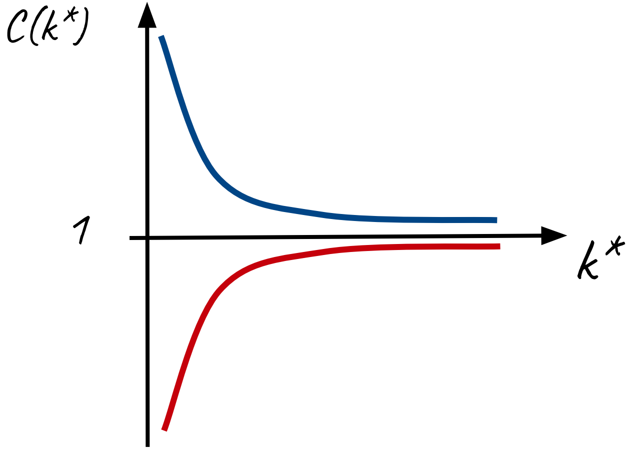
Two-particle momentum correlation...



$$k^* = \frac{|\vec{p}_1^{\,*} - \vec{p}_2^{\,*}|}{2}$$

Emission source $S(\vec{r}^{\,*})$

Correlation functions



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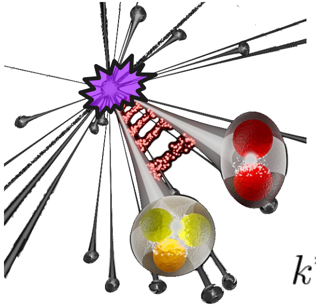
Two-particle momentum correlation…



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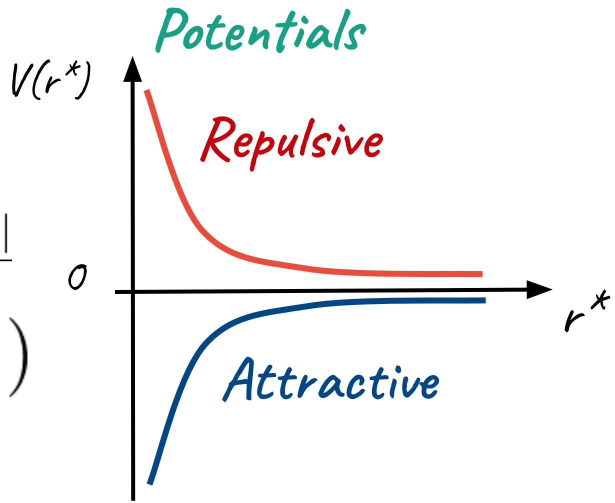
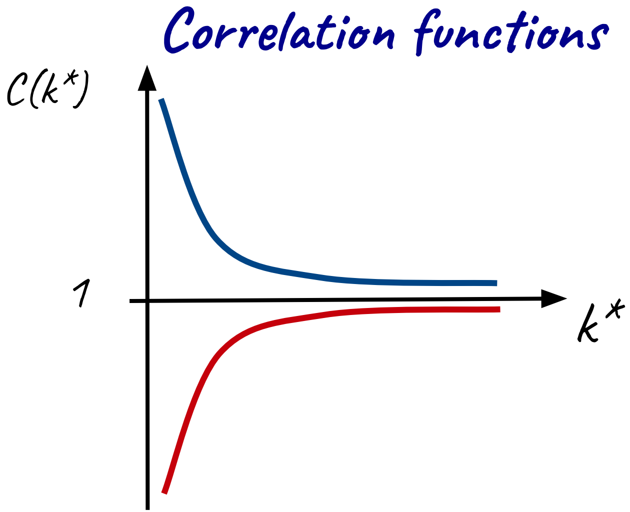
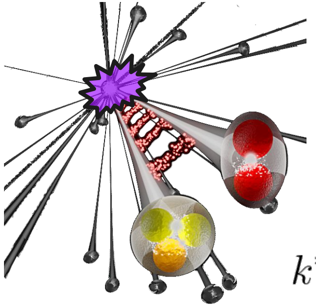




Two-particle wave function

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

Two-particle momentum correlation…



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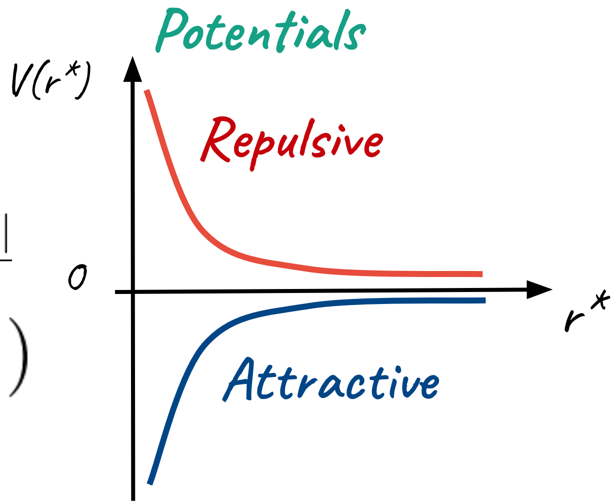
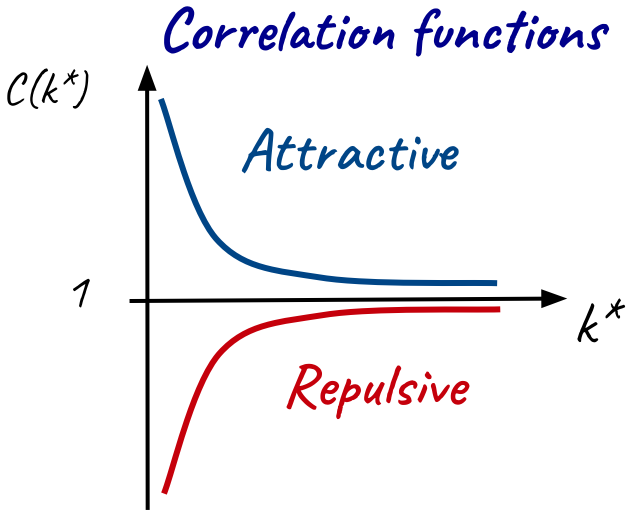
Emission source $S(\vec{r}^{\,*})$





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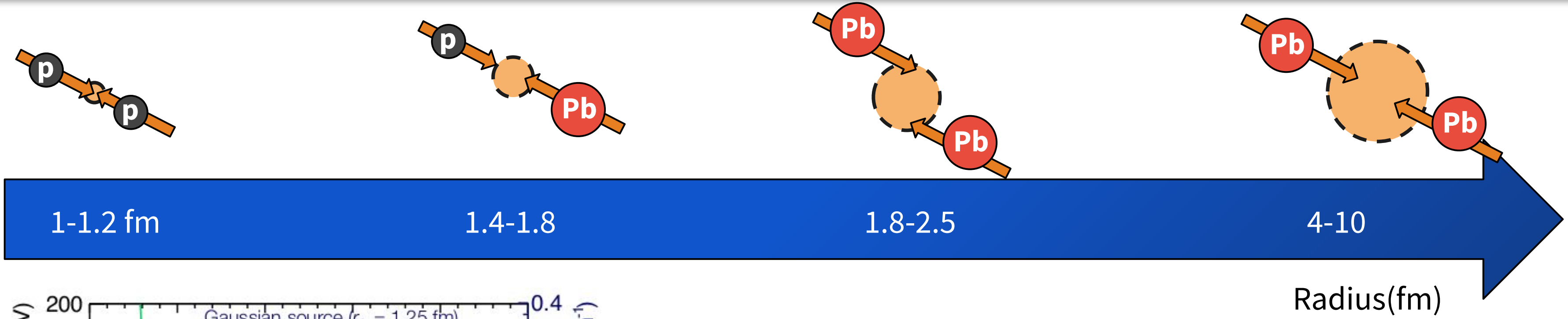
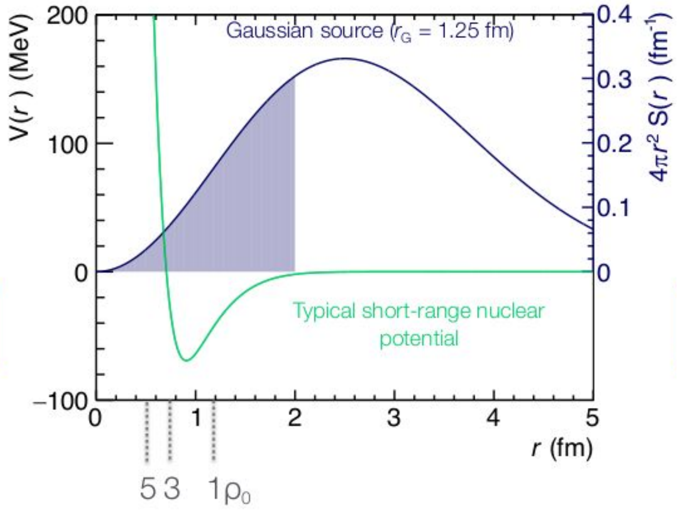
⇒ Measure $C(k^*)$ → fixing the source $S(\vec{r}^{\,*})$, study the interaction

… from small to large systems





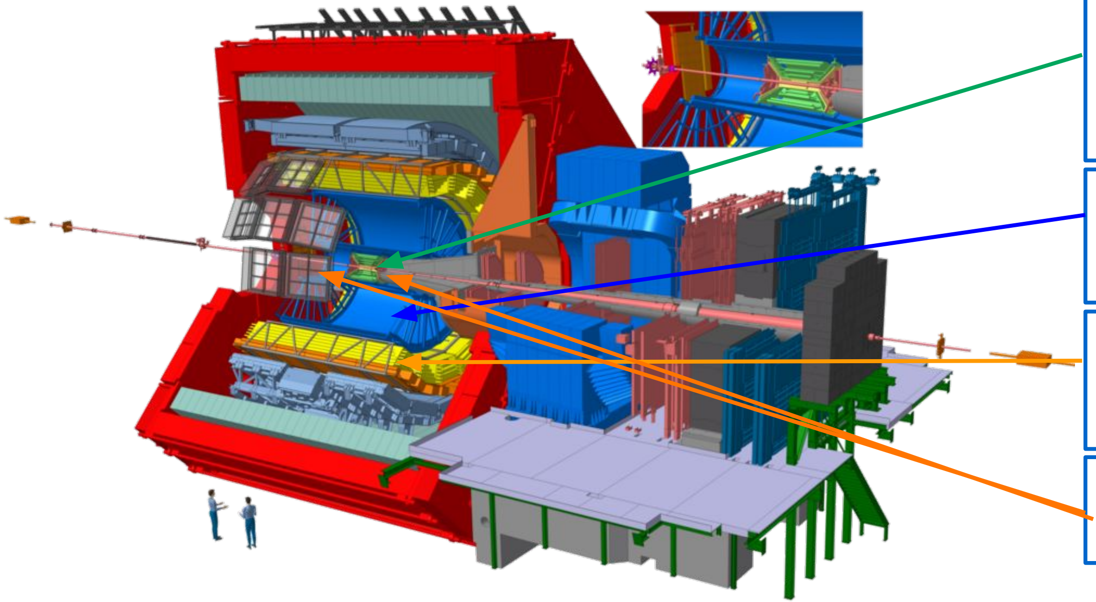
- By changing the colliding system it is possible to probe interaction distances ranging from ~1 fm up to ~10 fm

KN and $\bar{K}$N interactions : the game changer

Two-particle momentum correlation measured with **ALICE** at the LHC

ALICE

ALICE particle identification capabilities are unique. Almost all known techniques are exploited: specific energy loss (dE/dx), time of flight, transition radiation, Cherenkov radiation, calorimetry and decay topology (V0, cascade).



Inner Tracking System (ITS) :

- Primary vertex
- Tracking
- Particle identification via dE/dx

Time Projection Chamber (TPC):

- Global tracking
- Particle identification via dE/dx

Time Of Flight (TOF):

- Particle identification via velocity measurement

V0 (A-C): Trigger, beam-gas event rejection, centrality, multiplicity classes

ALICE Collaboration Int. J. Mod. Phys. A 29 (2014) 1430044

Analysis Details

- Protons and Kaons are identified combining the TPC + TOF informations (3σ cut)
  - Pure sample (~ 99% purity) of Kaons and Protons in the considered p_T interval
    - Kaons : $0.15 < p_T < 1.4$ GeV/c
    - Protons: $0.40 < p_T < 3.0$ GeV/c
- Data Sample:
  - pp collisions $\sqrt{s}$ =13 TeV (~1.0×10^9 MB events)
  - p–Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV (~8.0×10^8 MB event in 0–100%) → 3 centrality intervals
  - Pb–Pb collisions $\sqrt{s_{NN}}$ = 5.02 TeV (~1.6×10^9 MB events in 0–90%) → 9 centrality intervals

[1] ALICE Collaboration,Eur. Phys. J. C 72 (2012), 2124

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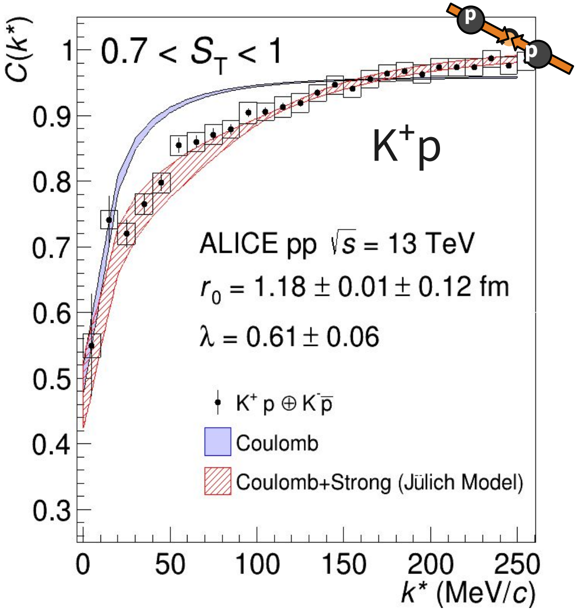
Two-particle momentum correlation measured with ALICE at the LHC



- The Coulomb-only potential is not able to describe K^+p interaction and the introduction of the strong potential is needed to fit the data:
  - CFs are sensitive to the strong interaction

ALICE Collaboration PRL 124 (2020) 9, 092301
Fit: CATS D. L. Mihaylov et al., EPJ C78 (2018) 5, 394)

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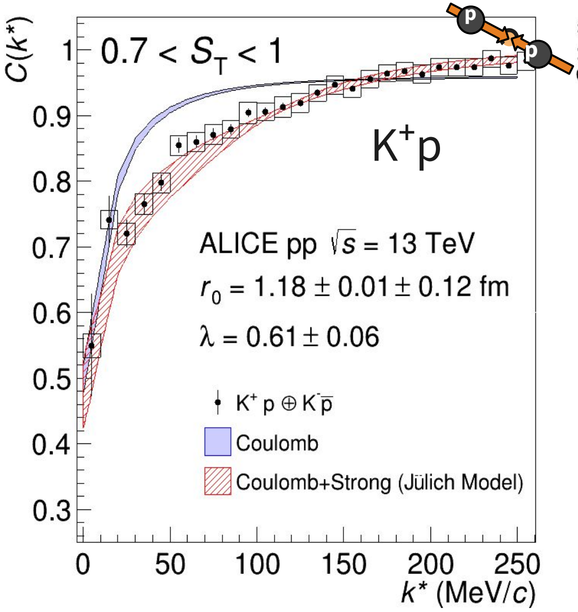

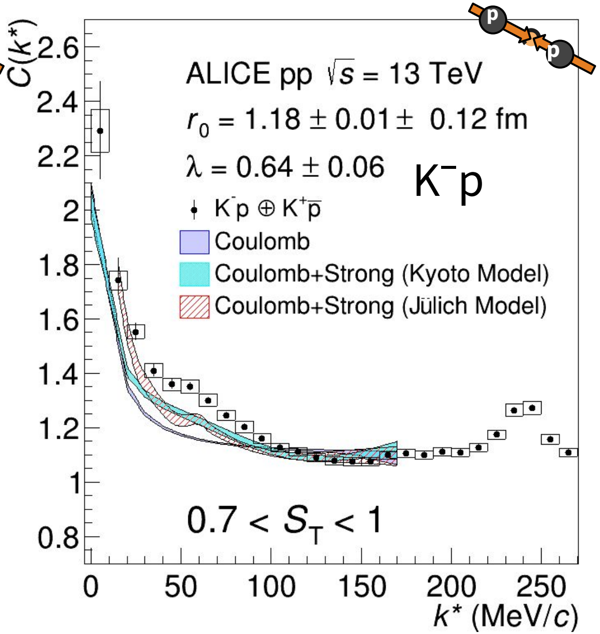

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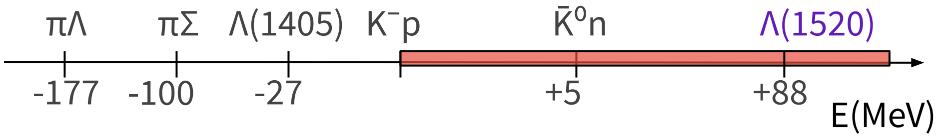

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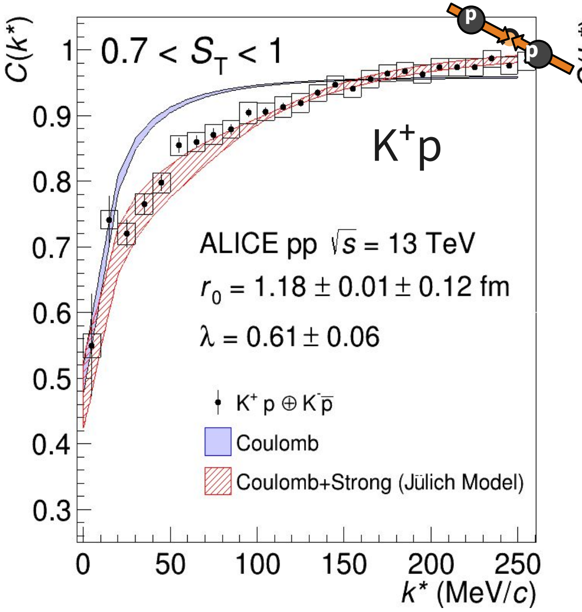

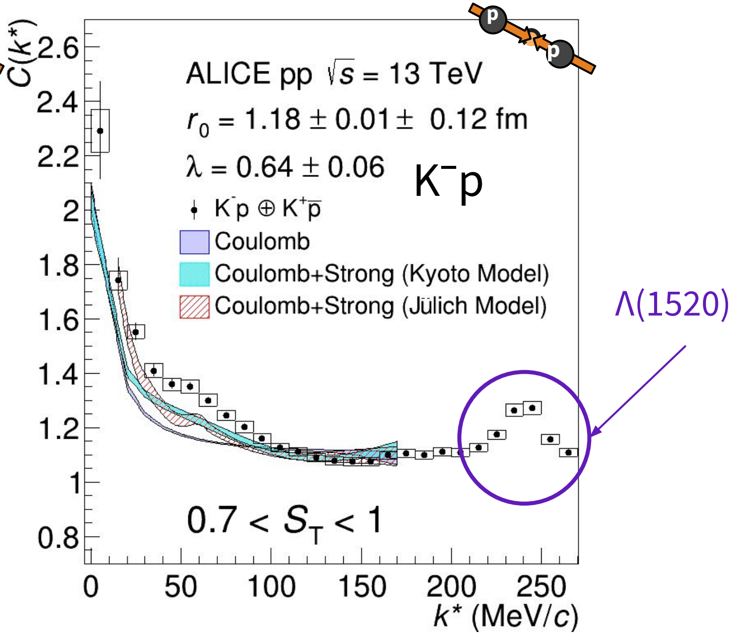

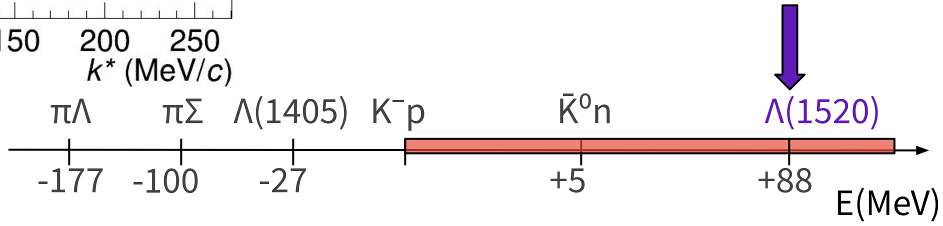

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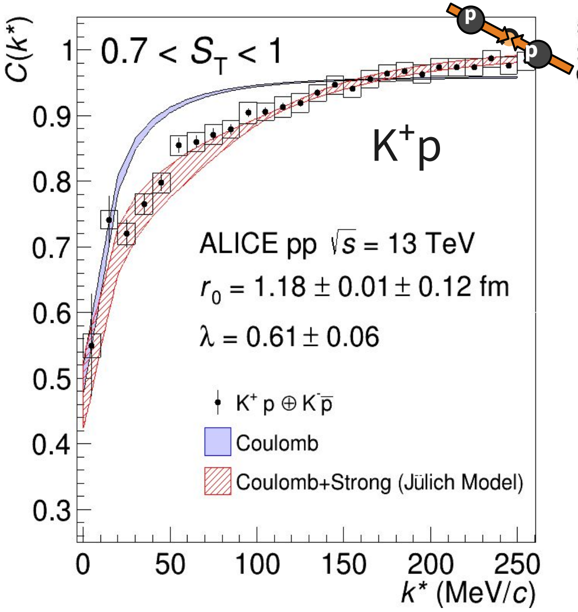

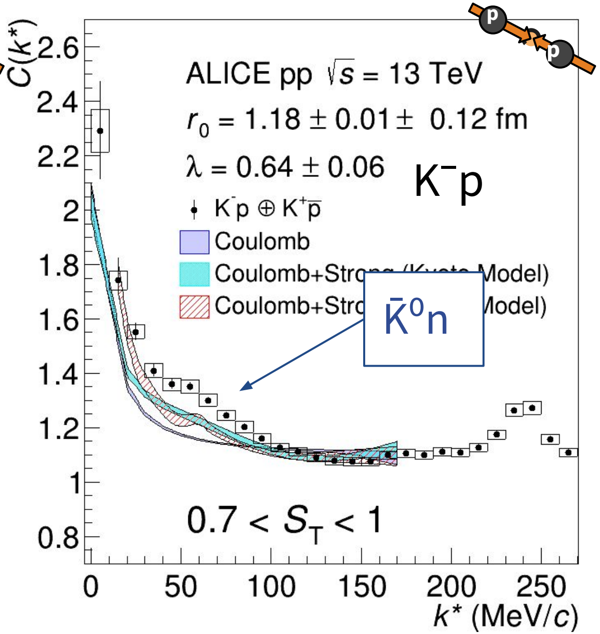

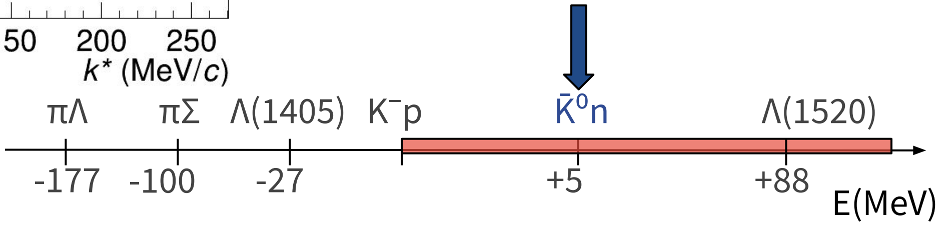

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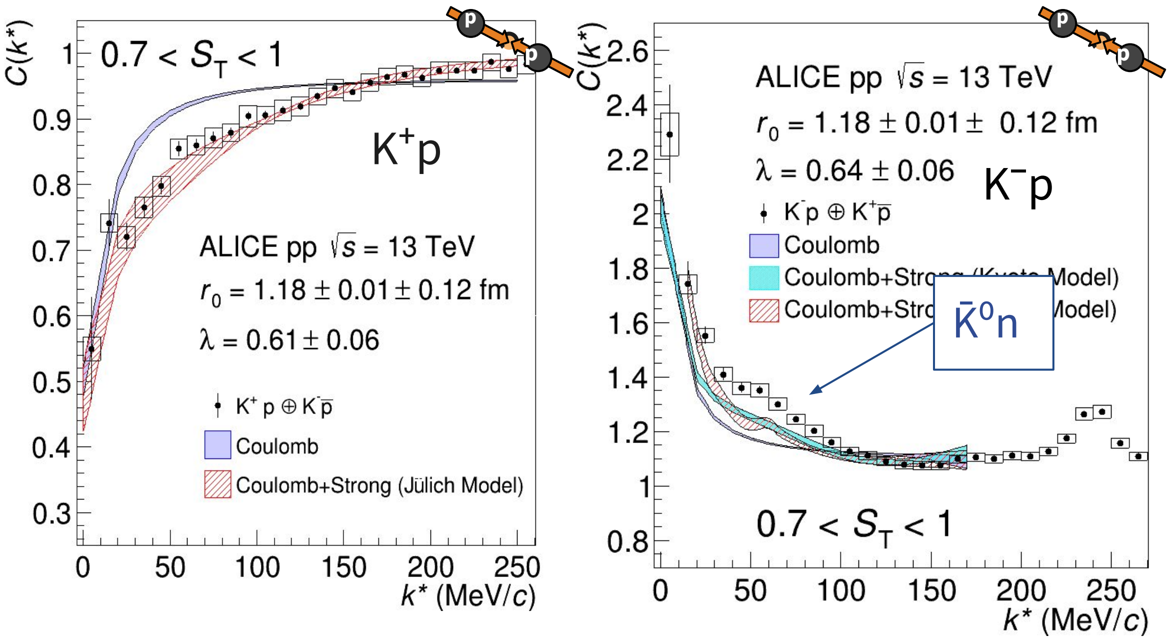

- First experimental evidence for the opening of the $\bar{K}^0$n channel
- New constraints for low-energy QCD chiral models

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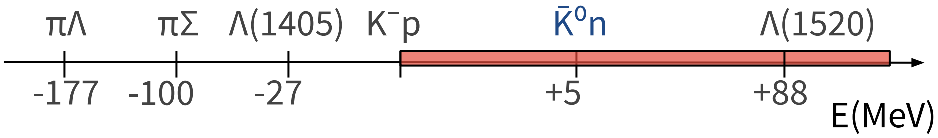

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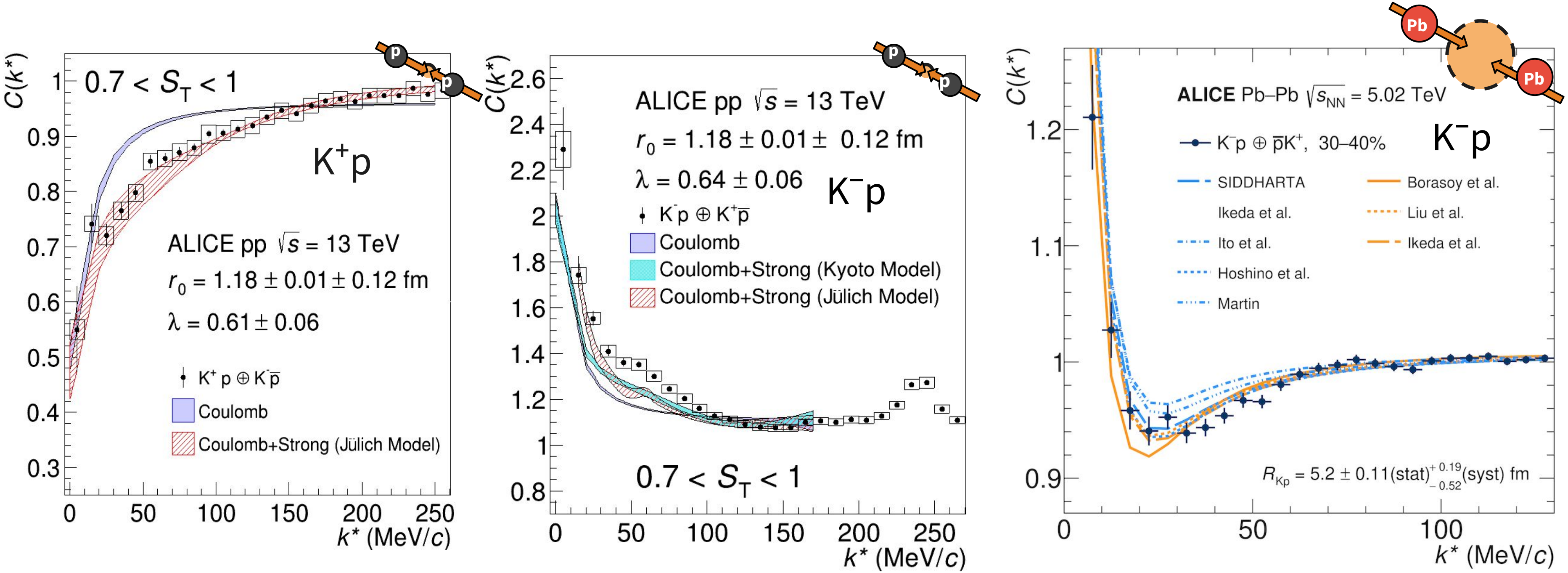
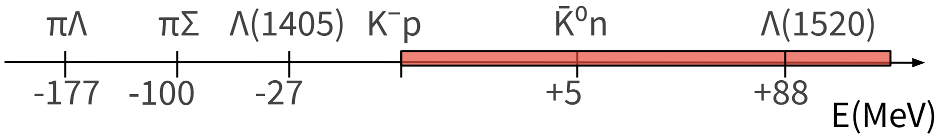




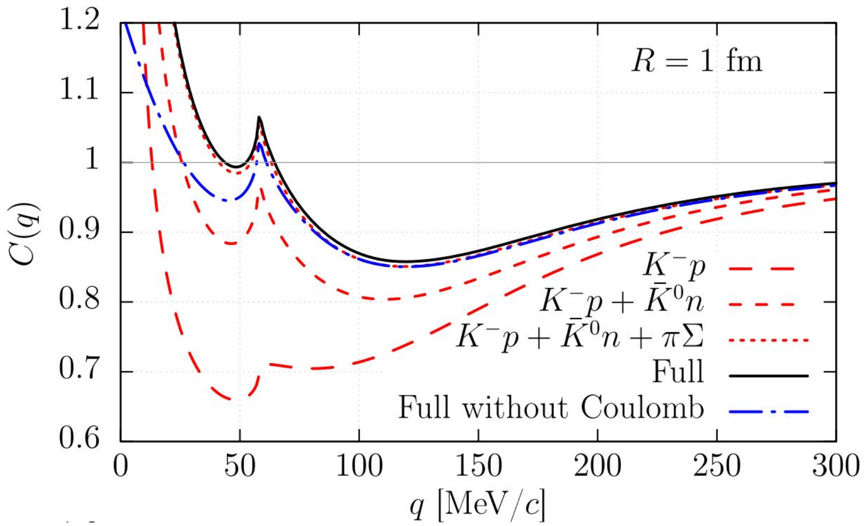
ALICE Collaboration PRL 124 (2020) 9, 092301
Fit: CATS D. L. Mihaylov et al., EPJ C78 (2018) 5, 394
ALICE Collaboration PLB 822 (2021) 136708

K^-p interaction: improved chiral model

Koonin-Pratt formula for coupled channels (CC)

$$C_{\mathrm{K^-p}}(k^*) = \int d^3\vec{r}^{\,*} S_{\mathrm{K^-p}}(\vec{r}^{\,*}) \left|\psi_{\mathrm{K^-p}}(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2 + \sum_j \omega_j \int d^3\vec{r}^{\,*} S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2$$

$j = \bar{K}^0 n,\ \pi^0\Sigma^0, \pi^+\Sigma^-, \pi^-\Sigma^+, \pi^0\Lambda$



- Coupled channel are short-range features of the strong interaction
  - the shape and strength of the correlation function are modified at small distances
- Improved Kyoto chiral model to describe CC potential V_j
- Conversion weights (ω_j)
  - control CC contribution
  - depend on primary yield and kinematics

R. Lednicky, et. al. Phys. At. Nucl. 61 (1998)
J. Haidenbauer NPA 981 (2018)
Y. Kamiya et al., PRL 124 (2020) 132501, arXiv:1911.01041

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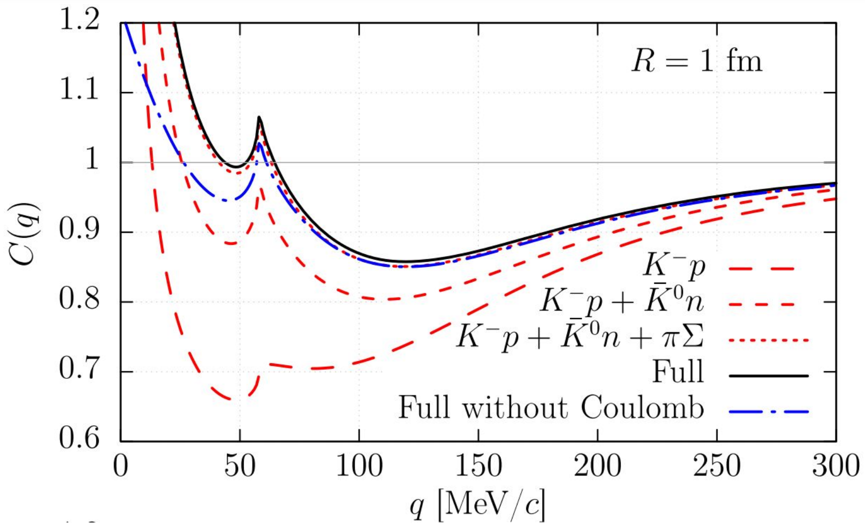
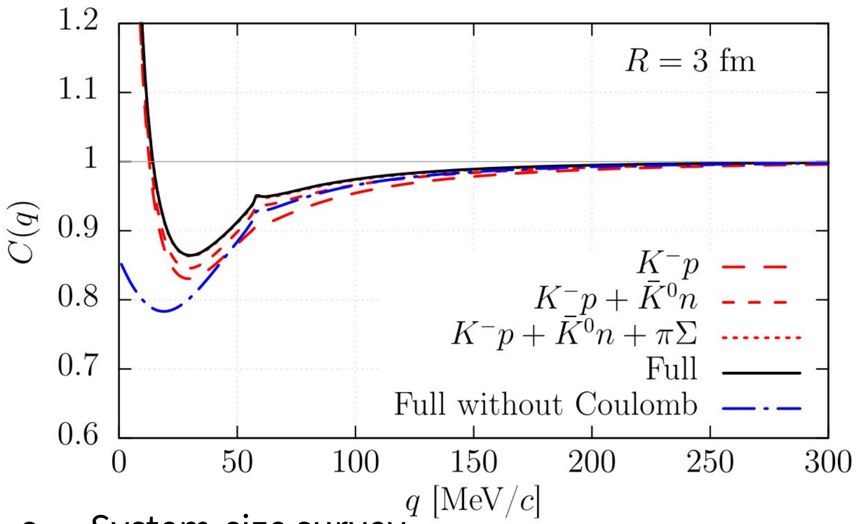


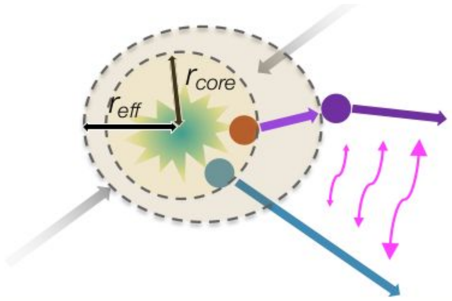


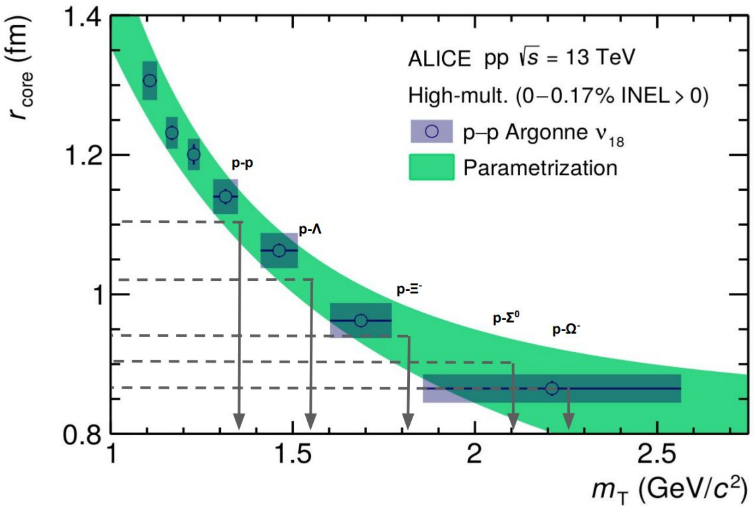
- System-size survey
  - For large radii contribution from CC gets negligible → elastic scattering

R. Lednický, et. al. Phys. At. Nucl. 61 (1998)
J. Haidenbauer NPA 981 (2018)
Y. Kamiya et al., PRL 124 (2020) 132501, arXiv:1911.01041

The emitting source in small colliding systems

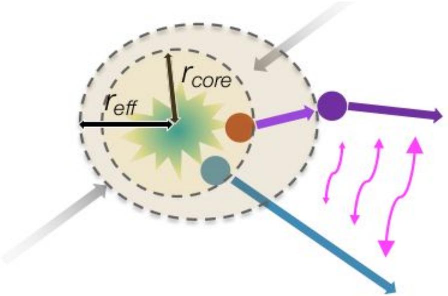
- Data-driven analysis on p–p and p–Λ pairs
  - Possible presence of collective effects → m_T scaling of the core radius
  - Contribution of strongly decaying resonances with cτ ~1 fm (*)
- Common universal core source for baryons





ALICE Collaboration PLB 811 (2020) 135849

The emitting source in small colliding systems



- Data-driven analysis on p–p and p–Λ pairs
  - Possible presence of collective effects → m_T scaling of the core radius
  - Contribution of strongly decaying resonances with cτ ~1 fm (*)
- Common universal core source for baryons

- What about meson-baryon pairs?
  - K^+p interaction is well known → extract r_{core} for Kp pairs
    - For small systems:
      - build effective sources for Kp($\bar{K}^0$n) and one for πΣ(πΛ) pairs using different resonances

ALICE Collaboration arXiv: 2205.15176

Kp emitting source

$$C(k^*) = \int S(\vec{r}^{\,*}) \left|\psi_{\mathrm{K+p}}(\vec{k}^*, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*}$$

Kp emitting source

$$C(k^*) = \int S(\vec{r}^{\,*}) \left| \psi_{\mathrm{K^+p}}(\vec{k}^*, \vec{r}^{\,*}) \right|^2 d^3\vec{r}^{\,*}$$

Potential based on the scattering amplitude in chiral SU(3) dynamics [1,2]

[1] K. Aoki and D. Jido, PTEP 2019 no. 1, (2019) 013D01
[2] K. Miyahara, et al, PRC 98 no. 2, (2018) 025201

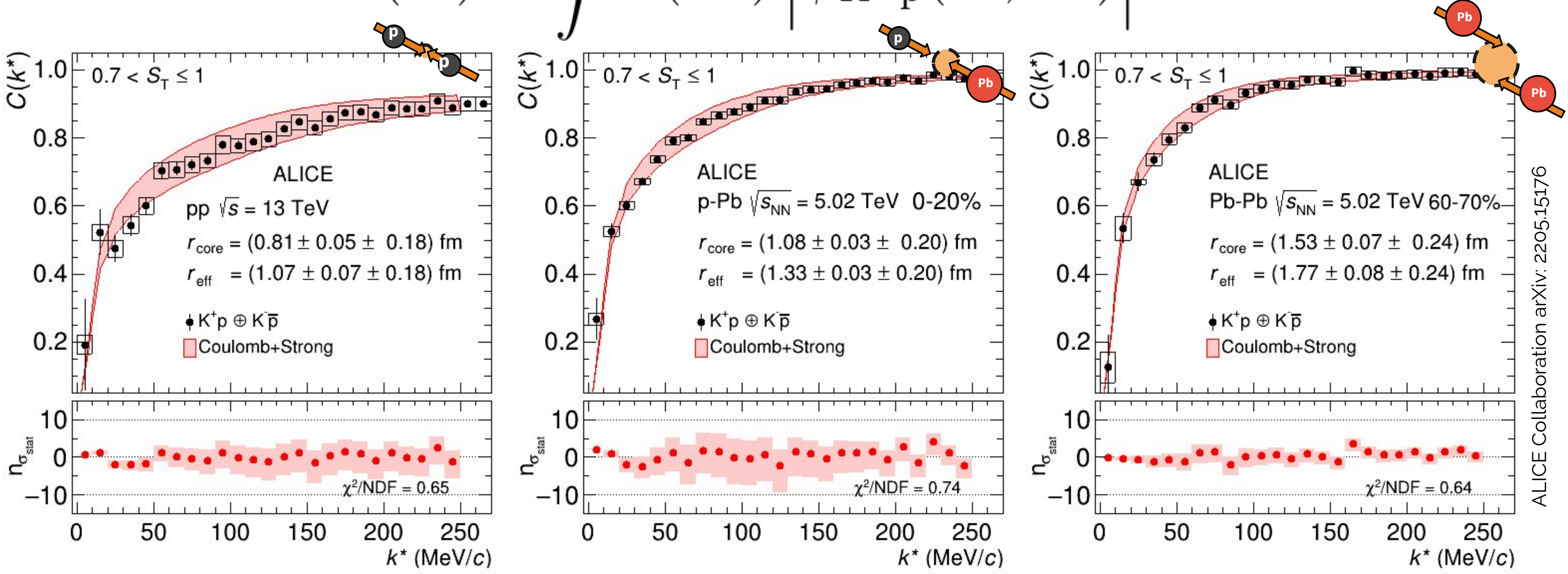
Kp emitting source

$$C(k^*) = \int S(\vec{r}^{\,*}) \left| \psi_{\mathrm{K^+p}}(\vec{k}^*, \vec{r}^{\,*}) \right|^2 d^3\vec{r}^{\,*}$$

Gaussian core + effects of short-lived resonances via a dedicated Monte Carlo procedure

Kp emitting source

$$C(k^*) = \int S(\vec{r}^{\,*}) \left|\psi_{\mathrm{K^+p}}(\vec{k}^*, \vec{r}^{\,*})\right|^2 d^3\vec{r}^{\,*}$$

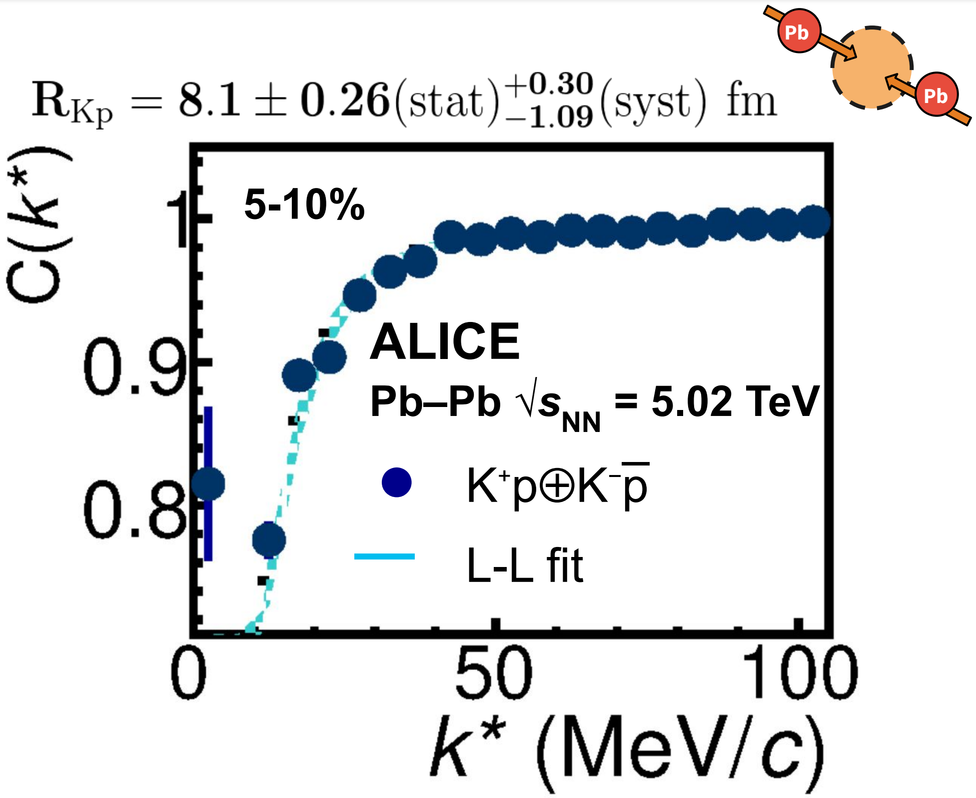


ALICE Collaboration arXiv: 2205.15176

The data are well reproduced by the assumed K^+p interaction and different r_{core} are extracted

Fit: CATS D. L. Mihaylov et al., EPJ C78 (2018) 5, 394

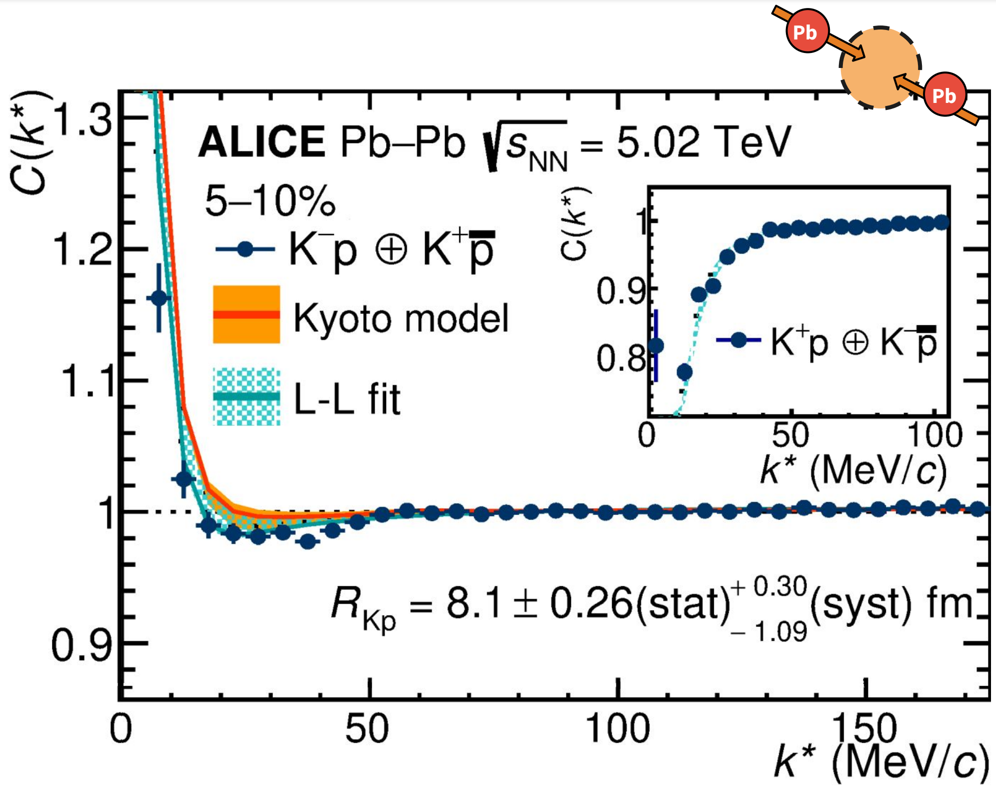
Kp emitting source in large systems



- $K^{+}p$ used to extract source size
  - Gaussian source
  - Lednický-Lyuboshitz (LL) fit to extract r_{eff}

ALICE collaboration PLB 822 (2021) 136708

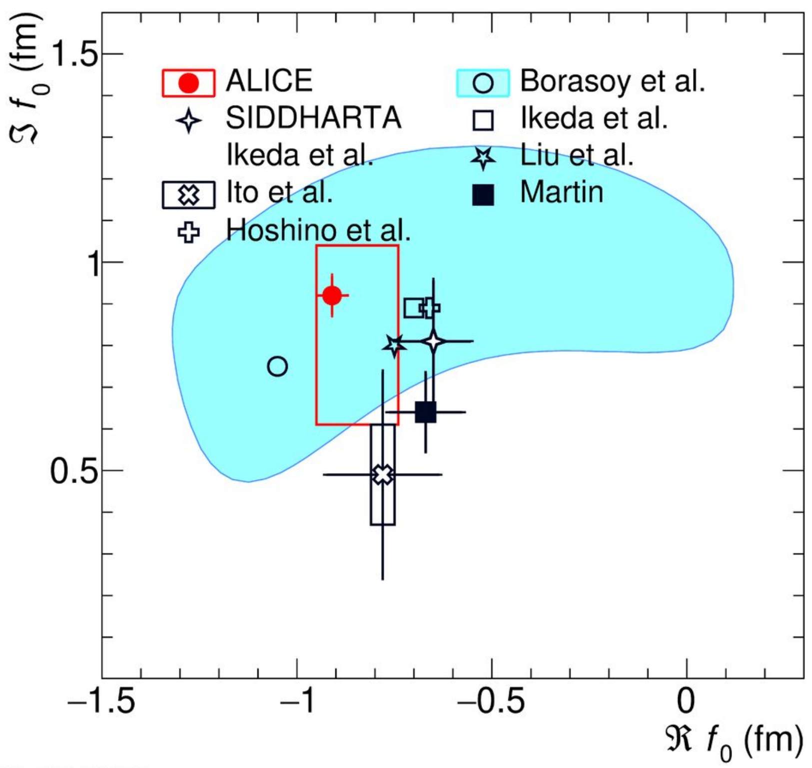
K^-p in large systems



- K^+p used to extract source size
  - Gaussian source
  - Lednický-Lyuboshitz (LL) fit to extract r_{eff}
- Large system: no coupled channels (as in Kyoto model)
- Use Lednický-Lyuboshitz (LL) fit to extract $\Re f_0$ and $\Im f_0$

ALICE collaboration PLB 822 (2021) 136708

K^-p in large systems



ALI-PUB-500325

ALICE collaboration PLB 822 (2021) 136708

- K^+p used to extract source size
  - Gaussian source
  - Lednický-Lyuboshitz (LL) fit to extract r_{eff}
- Large system: no coupled channels (as in Kyoto model)
- Use Lednický-Lyuboshitz (LL) fit to extract $\Re f_0$ and $\Im f_0$
- $\Re f_0$ and $\Im f_0$ in agreement with available data and calculations
  - Alternative to exotic atoms and scattering experiments!

K^-p from small to large systems

$$C_{\mathrm{K^-p}}(k^*) = \int d^3\vec{r}^{\,*} S_{\mathrm{K^-p}}(\vec{r}^{\,*}) \left|\psi_{\mathrm{K^-p}}(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2 + \sum_j \omega_j \int d^3\vec{r}^{\,*} S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2$$

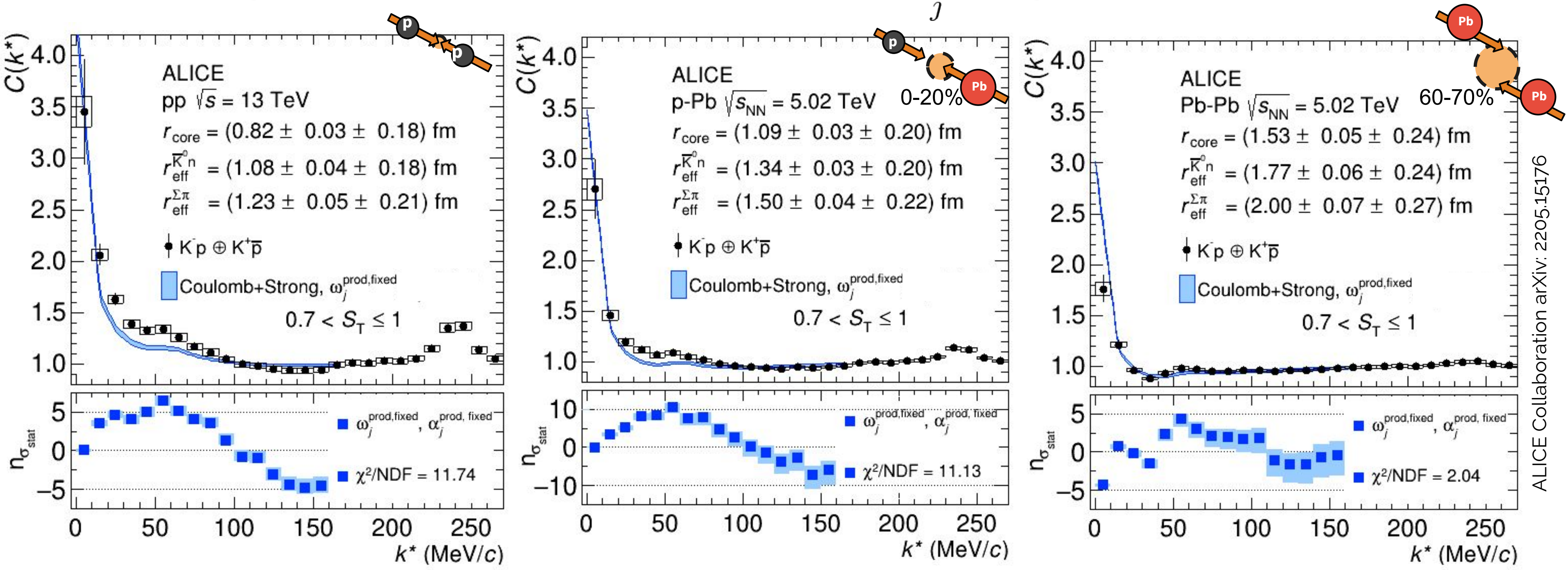
Each coupled channel is accounted in the ω_j weights

- primary production yields fixed from thermal model (Thermal-FIST) [1]
- estimate amount of pairs in kinematic region sensitive to final state interactions
- distribute particles according to blast-wave model [2,3,4]
- normalize to expected yield of K^-p

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

K^-p from small to large systems

$$C_{K^-p}(k^*) = \int d^3\vec{r}^{\,*} S_{K^-p}(\vec{r}^{\,*}) \left|\psi_{K^-p}(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2 + \sum_j \omega_j \int d^3\vec{r}^{\,*} S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2$$



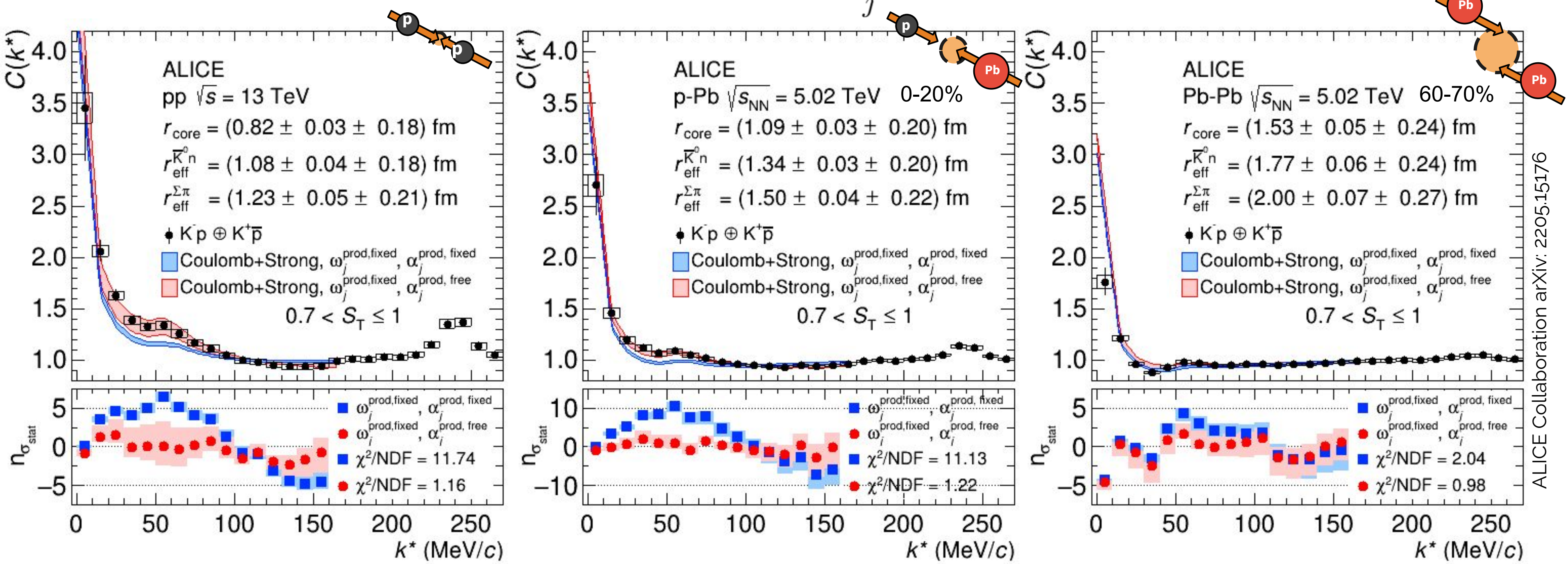
State-of-the art Kyoto Model is not able to describe the data from small to large source size

K^-p from small to large systems

$$C_{K^-p}(k^*) = \int d^3\vec{r}^{\,*} S_{K^-p}(\vec{r}^{\,*}) \left|\psi_{K^-p}(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2 + \sum_j \omega_j^{prod} \cdot \alpha_j \int d^3\vec{r}^{\,*} S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*}, \vec{r}^{\,*})\right|^2$$

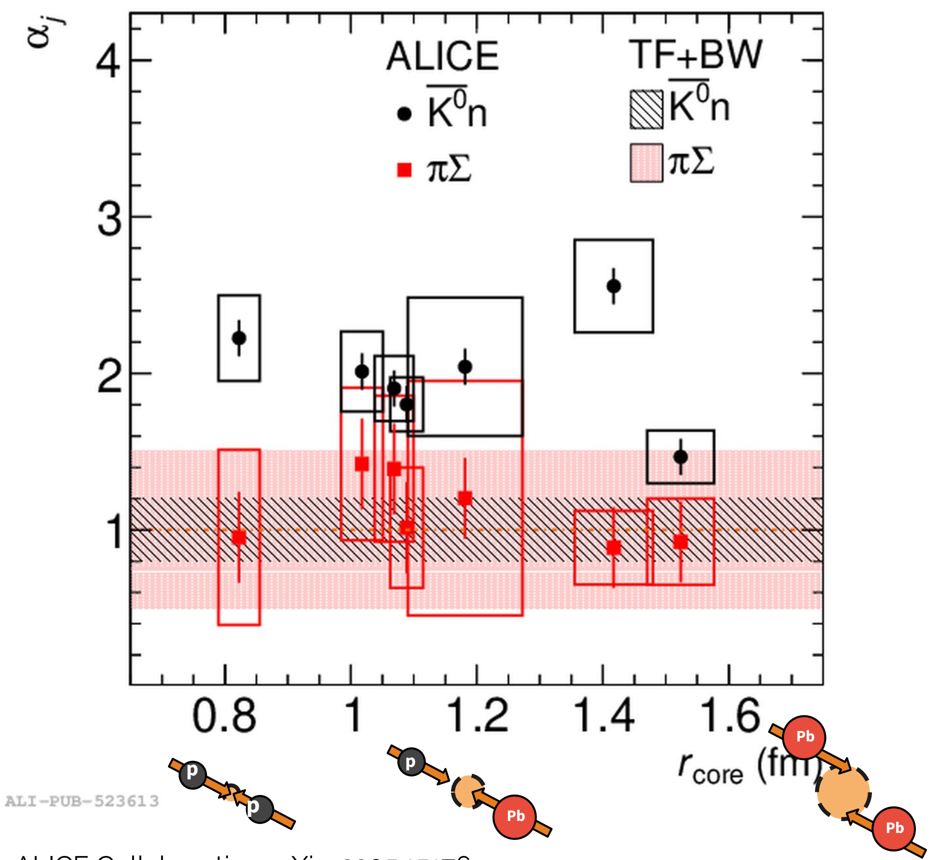
K⁻p from small to large systems

$$C_{\mathrm{K^-p}}(k^*) = \int d^3\vec{r}^{\,*} S_{\mathrm{K^-p}}(\vec{r}^{\,*}) \left|\psi_{\mathrm{K^-p}}(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2 + \sum_j \omega_j^{prod} \cdot \alpha_j \int d^3\vec{r}^{\,*} S_j(\vec{r}^{\,*}) \left|\psi_j(\vec{k}^{\,*},\vec{r}^{\,*})\right|^2$$



A correction factor α_j is introduced to quantify the model-to-data deviation

K^-p from small to large systems



ALICE Collaboration arXiv: 2205.15176

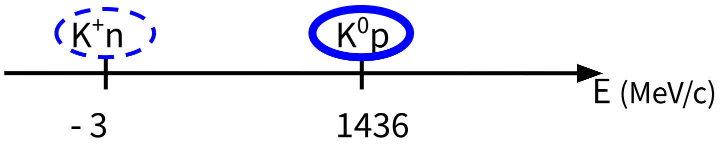
- Unique constraint and direct access to $K^-p \leftrightarrow \bar{K}^0n$ and $K^-p \leftrightarrow \pi\Sigma$ dynamics
- $\alpha_{\bar{K}^0-n}$ deviates from unity:
  - $K^-p \leftrightarrow \bar{K}^0n$ currently implemented in Kyoto χEFT is too weak
  - fine tuning of Kyoto χEFT is needed and data from hadron-hadron collisions have to be taken into account

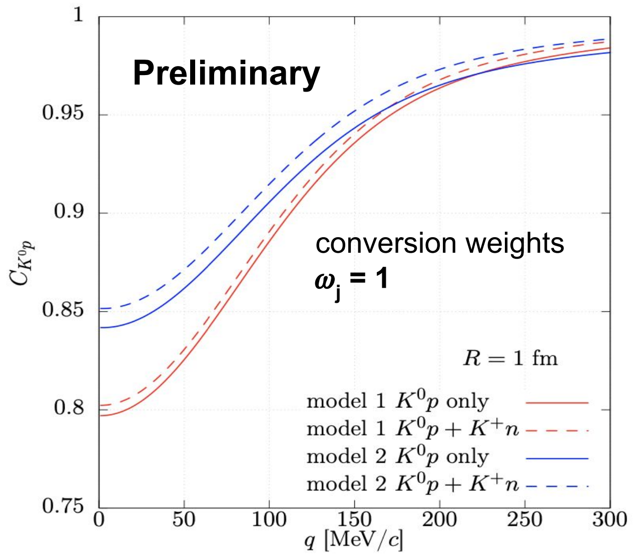
Accessing KN and $\bar{K}$N interaction with K°

- K^0_s –p system is a combination of strong eigenstates

$$|K^0_s p\rangle = \frac{1}{\sqrt{2}}\left[|K^0 p\rangle - |\bar{K}^0 p\rangle\right] \Rightarrow C_{K^0_s p} = \frac{1}{2}\left[C_{K^0 p} + C_{\bar{K}^0 p}\right]$$

- Weak strong repulsion
- 1 CC below threshold: K^+n
  - predicted to be a weak coupling
- Calculations from **A**oki-**J**ido χEFT model for KN[1]





Courtesy of Y. Kamiya

[1] K. Aoki and D. Jido, PTEP 2019, 013D01 (2019), 1806.00925.

Accessing KN and K̄N interaction with K⁰

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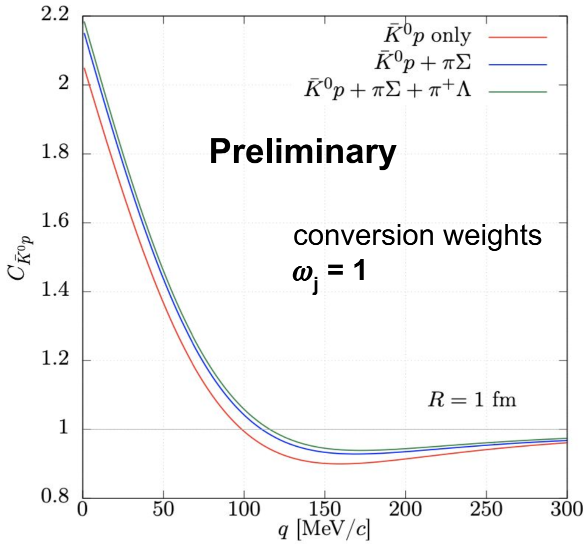
$$|K^0_s p\rangle = \frac{1}{\sqrt{2}}\left[|K^0 p\rangle - |\bar{K}^0 p\rangle\right] \Rightarrow C_{K^0_s p} = \frac{1}{2}\left[C_{K^0 p} + C_{\bar{K}^0 p}\right]$$

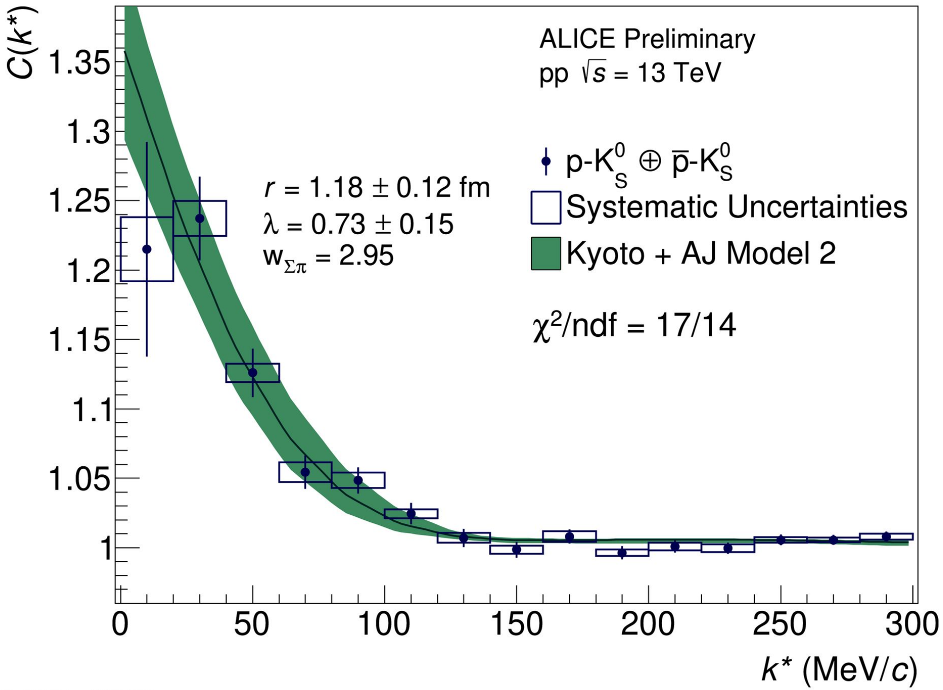
- Moderate attraction
- 3 CC below threshold: $\pi^0\Sigma^+$, $\pi^+\Sigma^0$, $\pi^+\Lambda$
  - large $\pi\Sigma$ coupling (as in K^-–p)
- Calculations from **Kyoto** χEFT model for KN̄ used for K^-p [1,2]



Courtesy of Y. Kamiya

[1] K. Miyahara, et al., PRC98, 025201 (2018), arXiv: 1804.08269
[2] Y.Kamiya, et al., PRL124 (2020) 132501

K^0_S–p interaction



- Gaussian source function with r_{eff}=1.18±0.12 fm [1]
- $K^0p(\bar{p})$ and $\bar{K}^0(\bar{p})$ ψ with CC provided by Kyoto χEFT
- Conversions weights ω_{ij} = 1 for K^0p, K^+n, and $\pi^+\Lambda$; $\omega_{\Sigma\pi}$ = 2.95 [2]

- **Model describes data within 2σ between 0 and 300 MeV/*c***
  - State-of-the-art theory well describes the experimental data
    - Small caveat: source not (yet) studied in details

[1] ALICE Collaboration, PRL 124, 092301 (2020)
[2] Y.Kamiya, et al., PRL 124 132501 (2020)

Conclusions and outlook

- Momentum correlation technique applied to data collected at the LHC in different collision systems
    - Unique way to access KN and $\bar{K}N$ interaction: New constraints for low-energy QCD chiral models
        - First experimental access to coupled channels dynamics ($K^-p \leftrightarrow \bar{K}^0n$, $K^-p \leftrightarrow \pi\Sigma$, $K^-p \leftrightarrow \pi\Lambda$)
        - Data-model tension in description of K^-p interaction:
            - $K^-p \leftrightarrow \bar{K}^0n$ currently implemented in state-of-the-art Kyoto χEFT is too weak
        - $K_s^0p(\bar{p})$ unique way to access the I=0 component of the KN interaction
- More studies in reach with large statistics in LHC Run 3 & 4
    - Unique way to access coupled channels dynamics in the meson-baryon sector: open a new era in the charm sector!

Backup

Accessing KN and $\bar{K}$N interaction with K^0

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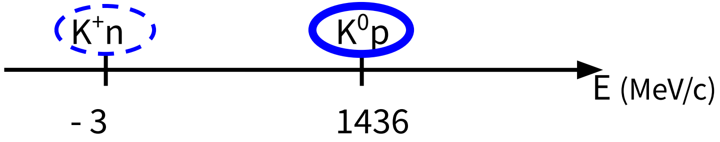

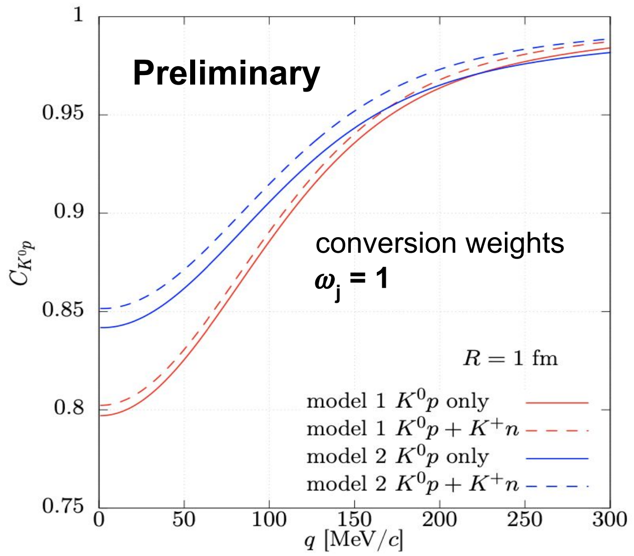

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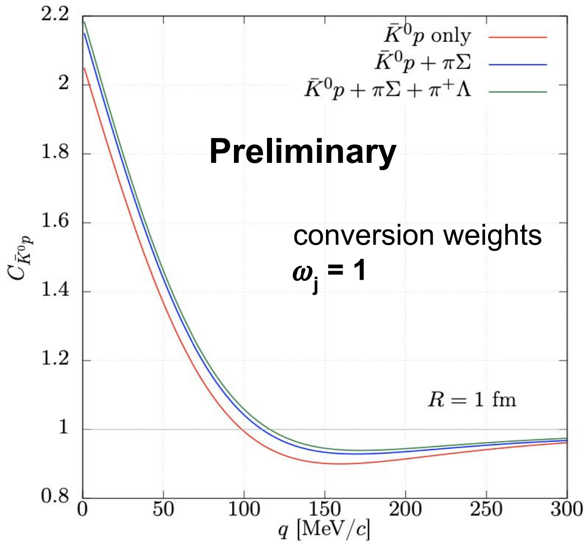

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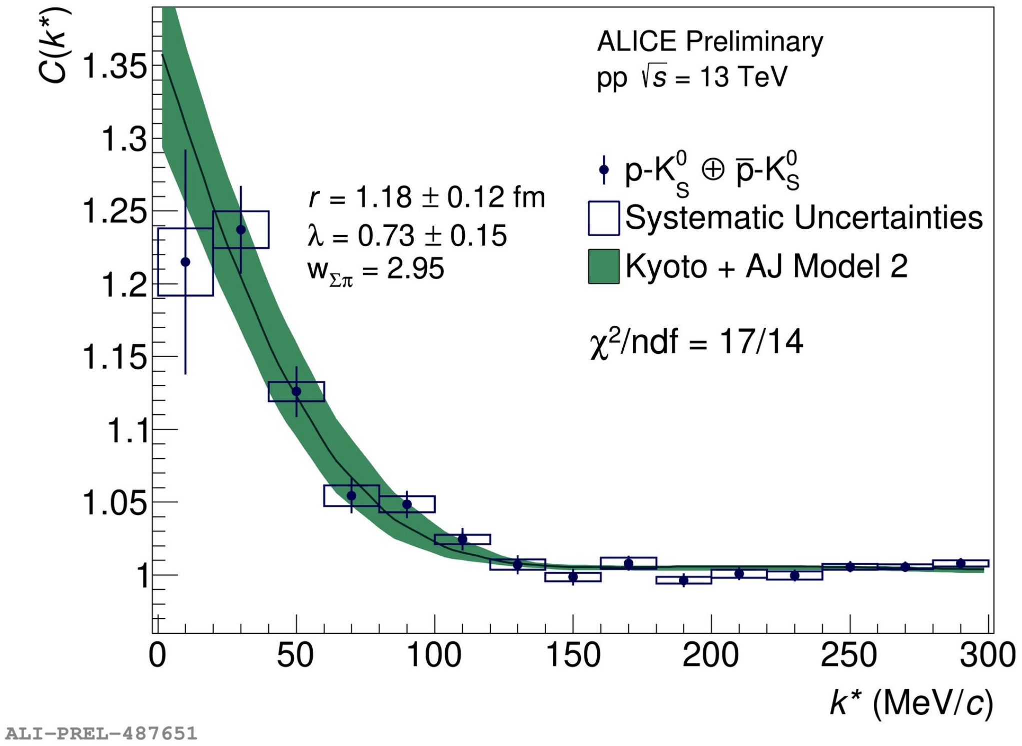
K^0_S–p interaction



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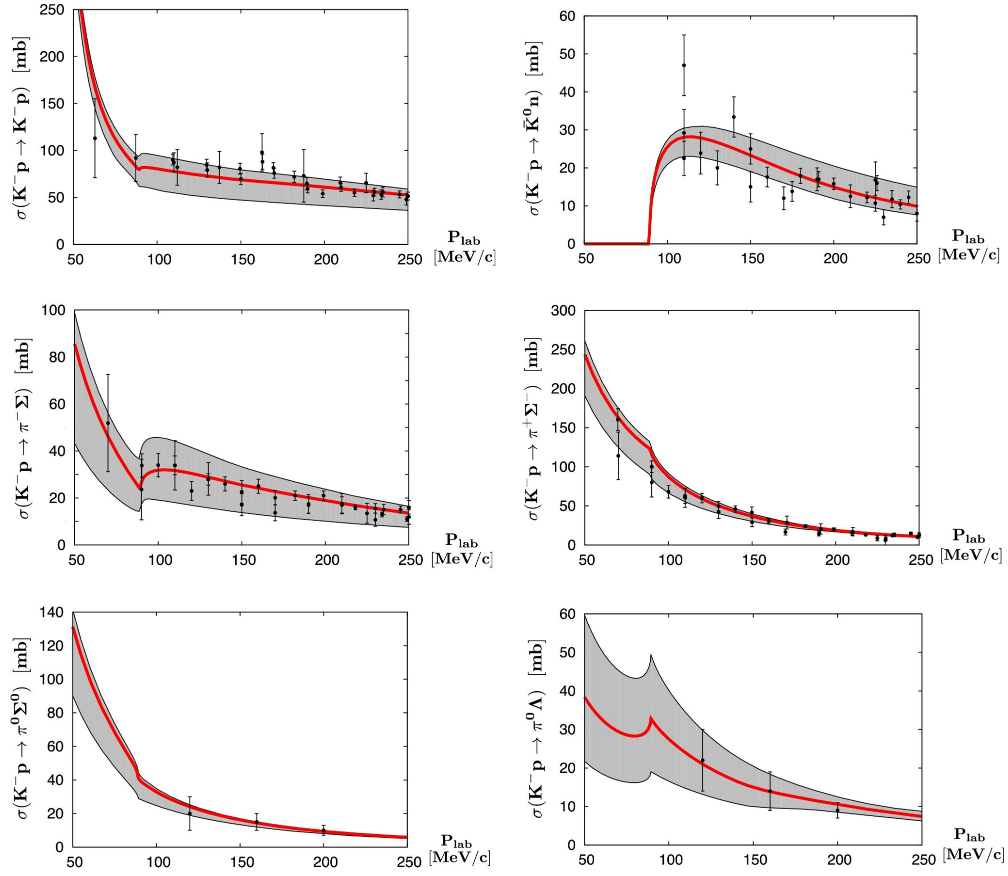
[2] Y.Kamiya, et al., PRL 124 132501 (2020)

Best fit of K⁻p observables: cross section data



Y. Ikeda et al., PLB Volume 706, (2011),63-67

$\bar{K}N$ scattering lengths

- Deser-type relation connects shift ε_{1s} and width Γ_{1s} to the real and imaginary part of a_{K^-p} and a_{K^-d}:

$$\varepsilon + \frac{i\Gamma}{2} = 2\alpha^3\mu^2 a_{K^-p} = 412\,\tfrac{eV}{fm}\,a_{K^-p}$$

done by SIDDHARTA

$$\varepsilon + \frac{i\Gamma}{2} = 2\alpha^3\mu^2 a_{K^-d} = 601\,\tfrac{eV}{fm}\,a_{K^-d}$$

aim of SIDDHARTA-2

- one can obtain the isospin dependent antikaon-nucleon scattering lengths

$$a_{K^-p} = \frac{a_0(I=0) + a_1(I=1)}{2}$$

$$a_{K^-d} = \frac{1}{2}\frac{m_N + m_K}{m_N + \frac{m_K}{2}}(3a_1 + a_0) + C$$

➢ Fundamental inputs of low-energy QCD effective field theories

Resonances used for πΣ(Λ) source (π)

- For modeling the source every resonance with a $c\tau > 8$ fm is taken out and the yields properly renormalized. These resonance are used to determine the decay-kinematics with EPOS.

Primordial fraction	Resonance fractions			
	$c\tau < 1$ fm	$1 < c\tau < 2$ fm	$2 < c\tau < 5$ fm	$c\tau > 5$ fm
28 %	15 %	35 %	10 %	12 %

$\langle m(\pi)\rangle = 1124$ MeV/c^2

$\langle c\tau(\pi)\rangle = 1.5$ fm

Resonance	ρ^0	ρ^+	ω	$K(892)^{**}$
Yield (in %)	9.01	8.71	7.67	2.29

Only resonances which contribute more then 2% to total yield are shown

Resonances used for $\pi\Sigma(\Lambda)$ source ($\Sigma\Lambda$)

- For modeling the source every resonance with a $c\tau > 8$ fm is taken out and the yields properly renormalized. These resonance are used to determine the decay-kinematics with EPOS.

Primordial fraction	Resonance fractions			
	$c\tau < 1$ fm	$1 < c\tau < 2$ fm	$2 < c\tau < 5$ fm	$c\tau > 5$ fm
26 %	0 %	5 %	5 %	64 %

$<m(\Sigma)> = 1463$ MeV/c^2

$<c\tau(\Sigma)> = 4.7$ fm

Resonance	Σ^0	Σ^{*0}	Σ^{*+}	Σ^{*-}
Yield (in %)	27	12	12	12

Only resonances which contribute more then 2% to total yield are shown

Contributions to the experimental correlation function

- Fit of the $C(k^*) = C_{data}(k^*)/C_{baseline}(k^*)$ to obtain the parameters of the strong interaction between K^0_S and p(p̄) is performed with the function:

$$C(k^*) = \left[1 + \lambda_{genuine} \left(C_{FSI}(k^*) - 1 \right) + \sum_{i,j} \lambda_{ij} \left(C_{ij}(k^*) - 1 \right) \right] \cdot Norm$$

- $\lambda_{genuine}$: Fraction of identified and primary particles, used as $C_{FSI}(k^*)$ weight
- $C_{FSI}(k^*) - 1$: Final-state interactions contribution
- $\sum_{i,j} \lambda_{ij} \left(C_{ij}(k^*) - 1 \right)$: Contribution linked to the presence of misidentified particles
- $Norm$: Normalization

$$\sum_{i,j} \lambda_{ij} \left(C_{ij}(k^*) - 1 \right) = \lambda_{\tilde{K}} \left(C_{\tilde{K}}(k^*) - 1 \right) + \lambda_{\tilde{p}(\tilde{\bar{p}})} \left(C_{\tilde{p}(\tilde{\bar{p}})}(k^*) - 1 \right)$$

K^0_S–p correlation function fit with Lednický-Lyuboshitz

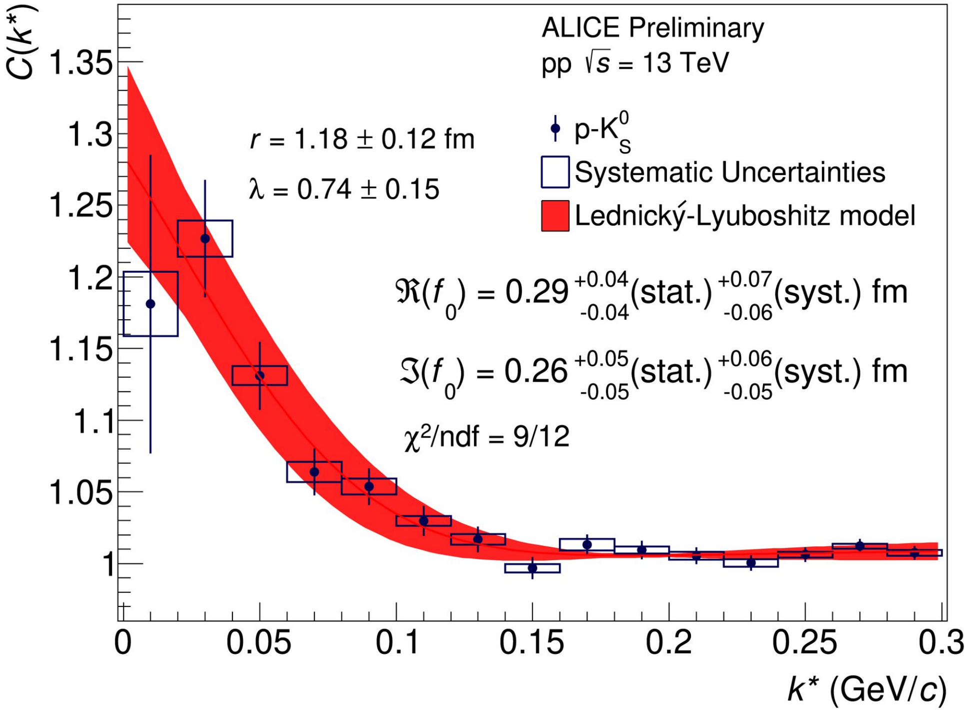
$$C_{FSI}(k^*) = \sum_S \rho_S \left[\frac{1}{2} \left| \frac{f(k^*)}{R} \right|^2 \left(1 - \frac{d_0}{2\sqrt{\pi} R} \right) + \frac{2\Re f(k^*)}{\sqrt{\pi} R} F_1(2k^* R) - \frac{\Im f(k^*)}{R} F_2(2k^* R) \right]$$

$$C_{Lednicky}(k^*) = 1 + C_{FSI}(k^*)$$

Scattering amplitude:

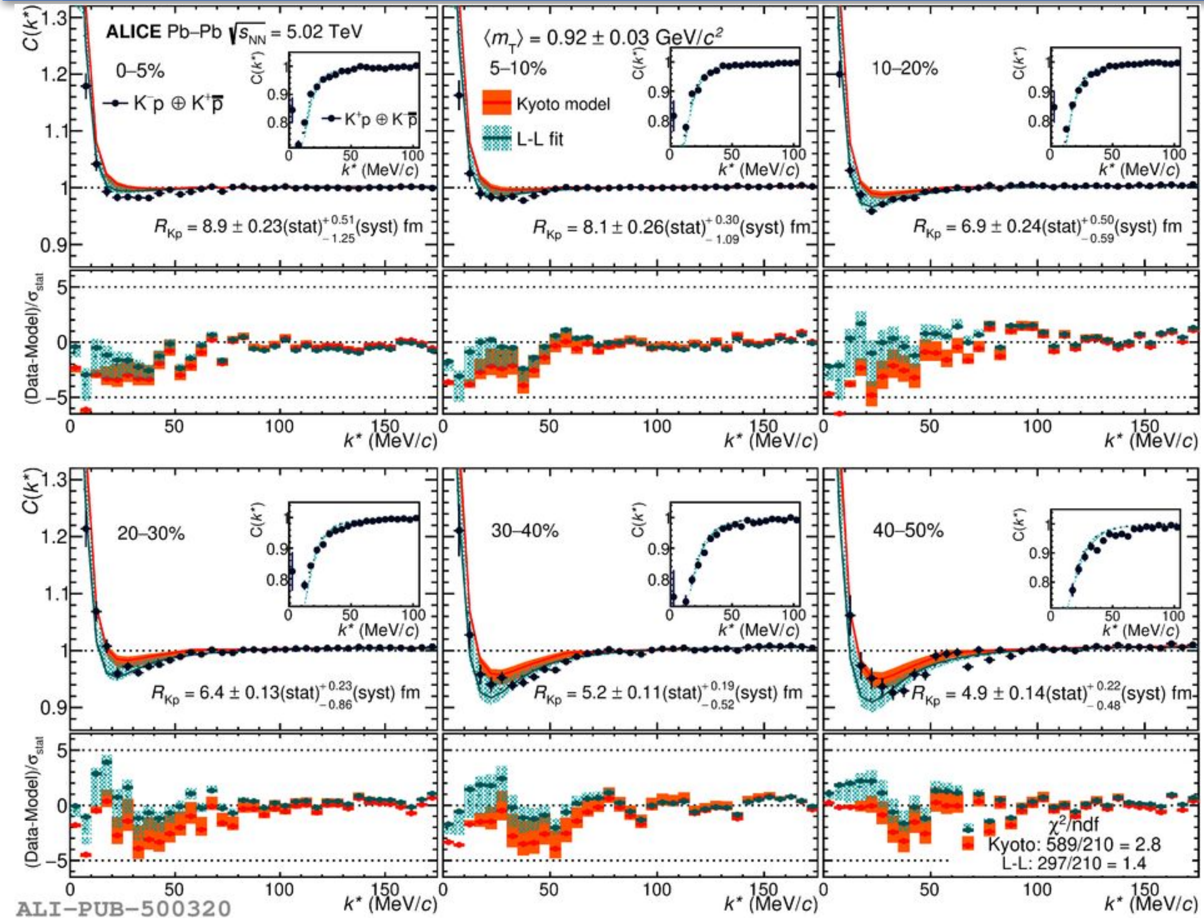
$$f(k^*) = \left(\frac{1}{f_0} + \frac{1}{2} d_0 k^{*2} - i k^* \right)^{-1}$$

- f_0 scattering length, d_0 effective range of interaction
  - $\Re f_0, \Im f_0$ estimated parameters
- **$\Re f_0$ >0 : attractive interaction**
- **$\Im f_0$ ≠0 : presence of annihilation processes**



ALI-PREL-487626

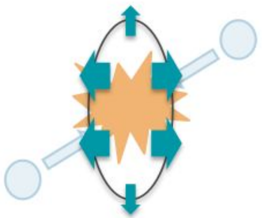
Kaon-proton in Pb–Pb



- No K^0n structure
- Simultaneous description (and fit) of the correlation functions for 6 centralities (0-50%) with two parameters and 6 radii
- Radii constrained from K^+p

Small Sources: Collective Effects and Strong Resonances

Elliptic flow



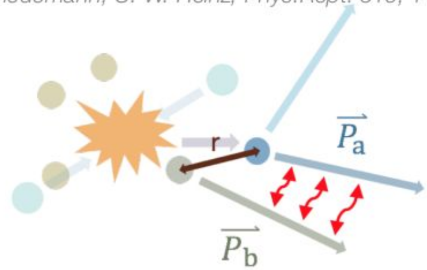
Anisotropic pressure gradients within the source

Radial flow

- Expanding source with constant velocity
- Different effect on different masses

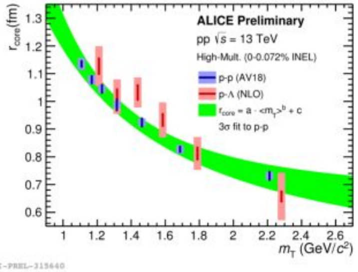
Strong decays of broad resonances

U. A. Wiedemann, U. W. Heinz, Phys.Rept. 319, 145-230 (1999)



- Resonances with $c\tau \sim r_0 \sim 1$ fm (Δ^*, N^*, Σ^*) introduce an exponential tail to the source
- Different for each particle species

Core Radius



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Strong decays of specific resonances

Kaon-proton interaction - Large systems

Lednický-Lyuboshitz model

$$C(\mathbf{k}^*) = \frac{\int S(\mathbf{r}^*,\mathbf{k}^*)|\psi(\mathbf{r}^*,\mathbf{k}^*)|^2}{\int S(\mathbf{r}^*,\mathbf{k}^*)} \mathrm{d}^4 r^*$$

$$|\psi(r^*, k^*)| = \sqrt{A_C(\eta)} \left[exp(-ik^* r^*) F(-i\eta, 1, i\xi) + f_c(k^*) \frac{G}{r^*} \right]$$

$$f_c(k^*) = \left(\frac{1}{f_0} + \frac{d_0 \cdot k^{*2}}{2} - \frac{-2h(k^* a_c)}{s_c} - ik^* A_C(k^*) \right)^{-1}$$

- Numerically solvable (strong+Coulomb)
- **3 parameters:** $\Re f_0$, $\Im f_0$ and source r define the correlation function.
- $d_0 = 0$ (zero effective range approx.)