proton-Kaon and proton-Omega interactions: bound states and coupled channels

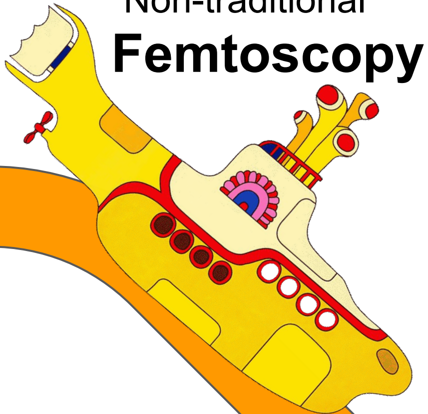
Otón Vázquez Doce (TUM)
for the ALICE Collaboration

STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics
ECT*, Trento
21-25 October 2019

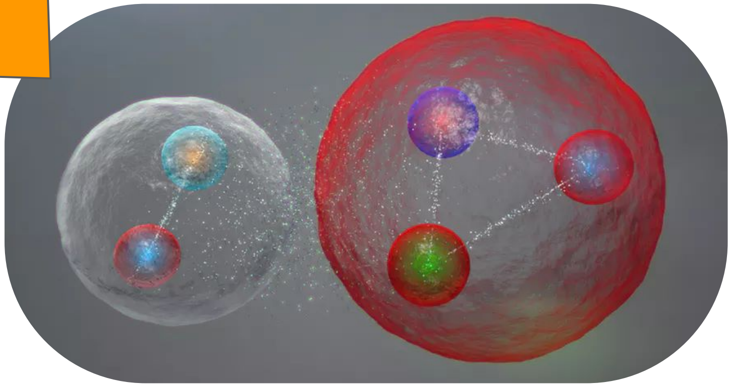
Outline

LHC: **High-energy physics**

“Non-traditional”
Femtoscopy

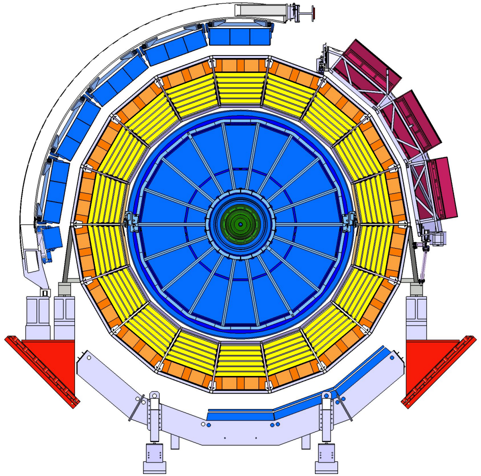


Hadron physics



Outline

ALICE experiment at the LHC



Used datasets:
- **pp** 13 TeV: 15·10^8 MB events
- **pp** 13 TeV: 15·10^8 High-Mult events
- **p-Pb** 5.02 TeV: 6.0·10^8 MB events

Tracking and PID:
- Inner Tracking System (**ITS**)
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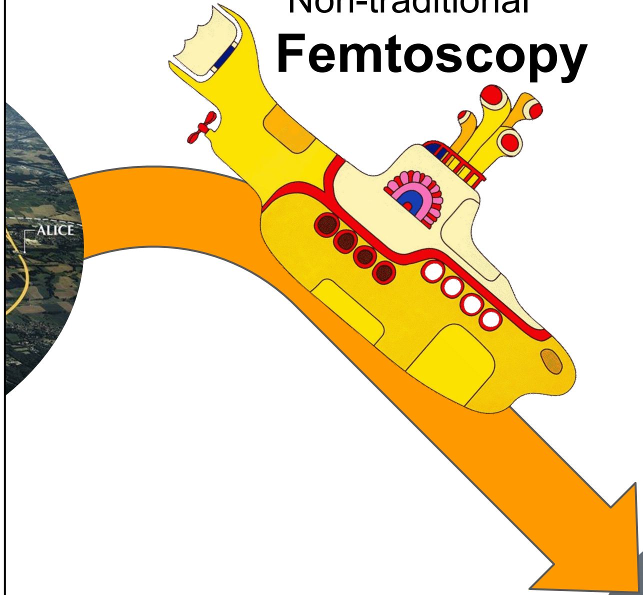

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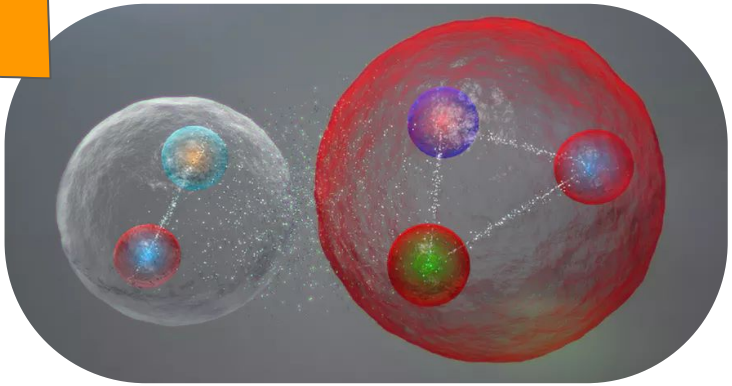

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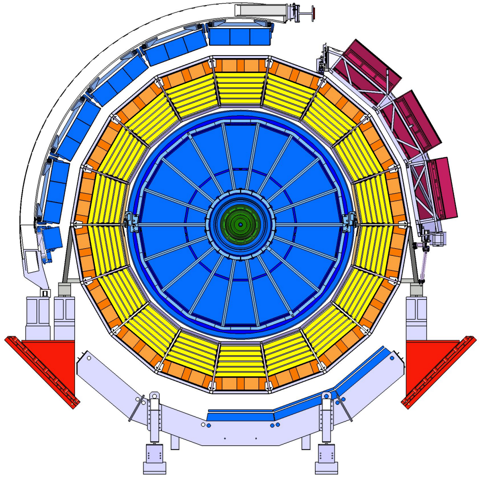

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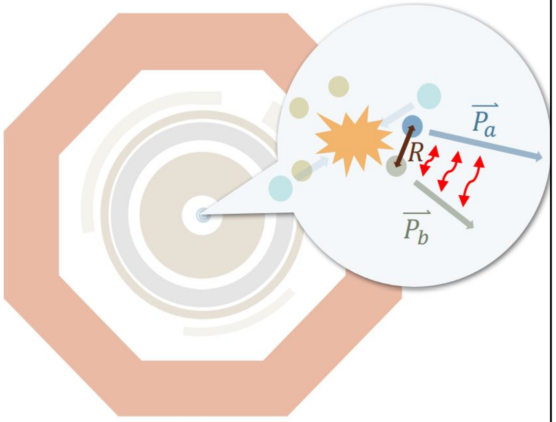
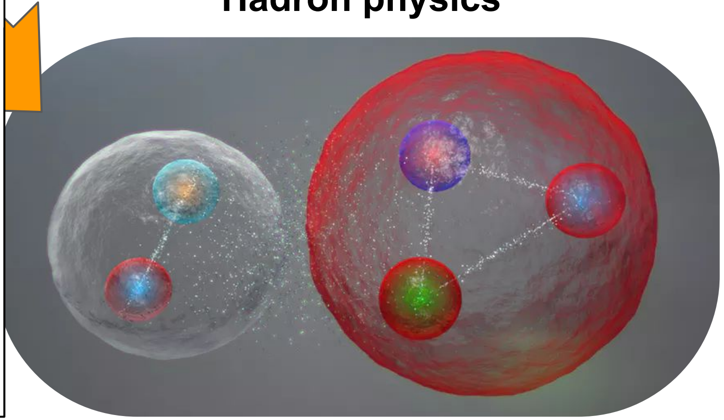


Study of hadron-hadron correlations of pairs from small sources:

p-p, **p-K$^{+/-}$**, p-Λ, Λ-Λ, p-Σ^0, p-Ξ^-, **p-Ω^-**

Reconstruction of hyperons
- $\Lambda \to p\pi$ (BR ~ 64%)
- $\Sigma^0 \to \Lambda\gamma$ (BR ~ 100%)
- $\Xi \to \Lambda\pi$ (BR ~ 100%)
- $\Omega \to \Lambda K$ (BR ~ 68%)

Hadron physics



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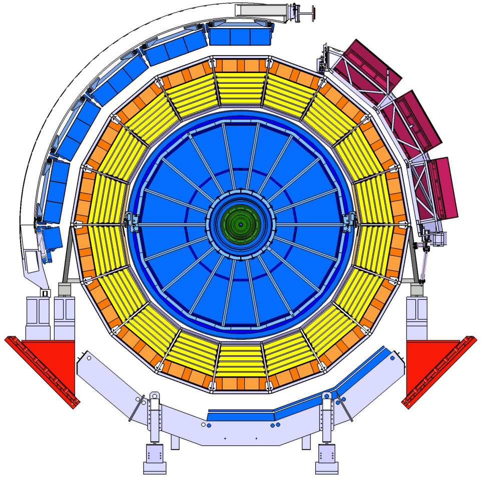

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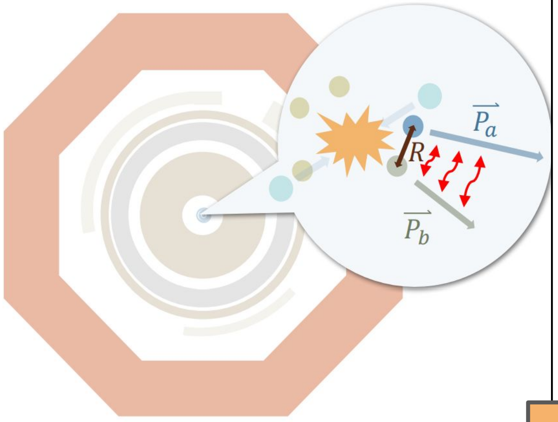

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Hadron physics

- Study the **interaction of hadrons with strange content**.
- Models are constrained by data with limited precision
- Experimental difficult with strange particle beams: Scattering data, hypernuclei, search for bound states, exotic atoms, etc.
- **Femtoscopy** with ALICE delivers **precise data** in the low momentum range region **not accessible with other approaches**

p-Ω^- femtoscopy

- Experimental **study on the interaction between a proton and a multi-strange baryon**

- Lattice QCD simulations predict an N-Ω interaction attractive at all distances
  → leading to the possible existence of a NΩ di-baryon

- No Ω beams, no hypernuclei…
  → for p-Ω interaction femtoscopy is the only experimental method!

p-K femtoscopy

- **Fundamental problem in the strangeness sector of hadron physics**

- Models are constrained by the (rather imprecise) scattering data above threshold and by SIDDHARTA data at threshold

- Extrapolations below threshold differs for models describing the scattering data.

Femtoscopy as a tool for studying h-h interactions

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Based on the correlation function $C(k^*) = \frac{P(\overrightarrow{p_a}, \overrightarrow{p_b})}{P(\overrightarrow{p_a})P(\overrightarrow{p_b})}$

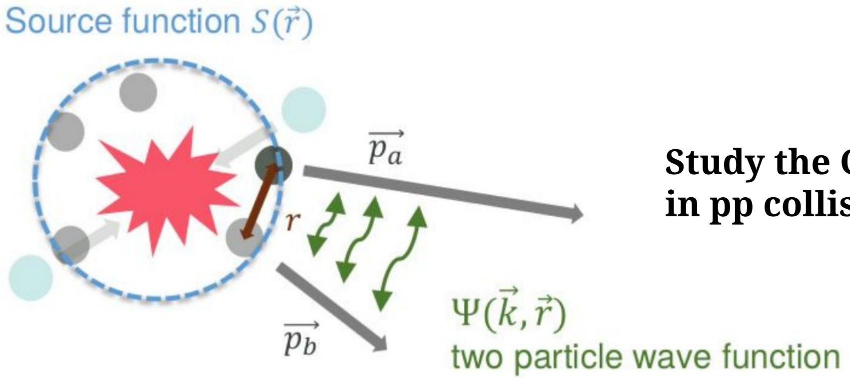
k* = reduced relative momentum with $\overrightarrow{p_a^*} + \overrightarrow{p_b^*} = 0$

Theoretically formulated: $C(k^*) = \int S(\vec{\boldsymbol{r}}, k)|\psi(\vec{\boldsymbol{r}}, k)|^2 \, d\vec{\boldsymbol{r}}$

Source

Relative wave function:
Sensitivity to the interaction potential

Theory



Study the C(k*) of hadron-hadron pairs
in pp collisions ⇒ small particle source (~1 fm)

Femtoscopy as a tool for studying h-h interactions

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Experimentally: $C(k^*) = \mathcal{N} \dfrac{N_{Same}(k^*)}{N_{Mixed}(k^*)}$

Generally, the experimental correlation function accounts for the genuine correlation and it is affected by residual correlations and finite momentum resolution.

Experiment

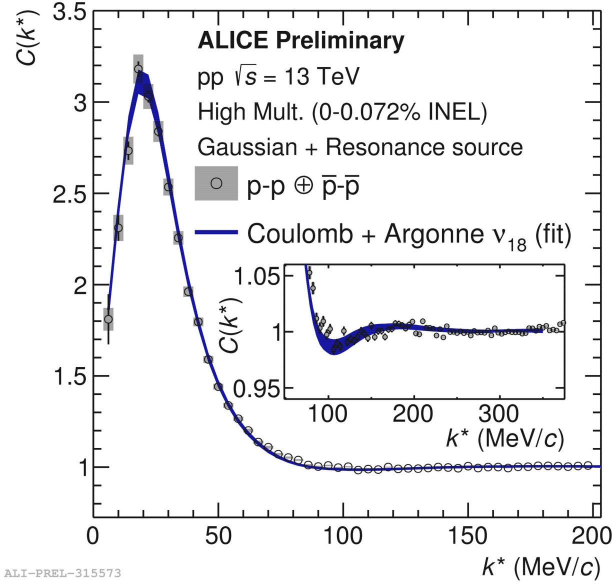
Setting the **source**

Ansatz: in small collision systems the source is similar for all baryon-baryon, baryon-meson pairs

The characteristics of the source are **determined from femtoscopic analysis of the p-p correlation:**
Assume a p-p known interaction → determination of the source size

- **Consider <m_T> dependence of the source** due to collective effects

- **Effect of strong short-lived resonances** computed for all hadrons



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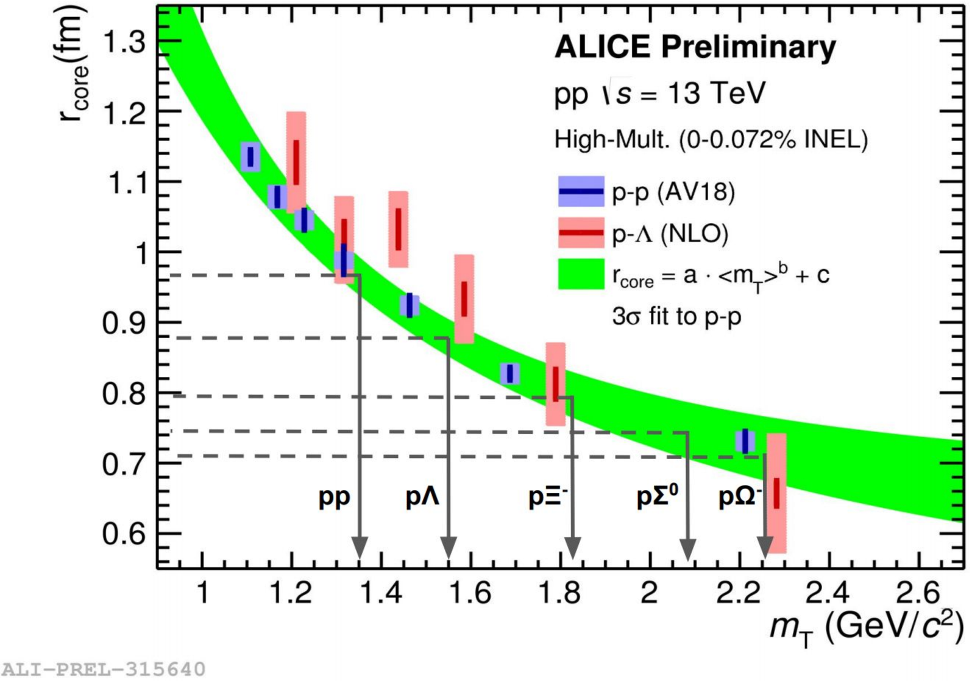


For p-Ω in pp High-Multiplicity events:

Parametrization with exponential law $r_{core} = a \cdot \langle m_T \rangle^b + c$

- Fit parameters: $a \in [\, 0.65 , 0.83 \,]$
  $b \in [\, -1.2 , -2.2 \,]$
  $c \in [\, 0.36 , 0.66 \,]$

The p-Ω^- source is **determined given the pair $\langle m_T \rangle$**:

p-Ω^-: $r_{core} = 0.73 \pm 0.05$ fm

For p-K in Minimum-Bias pp collisions:

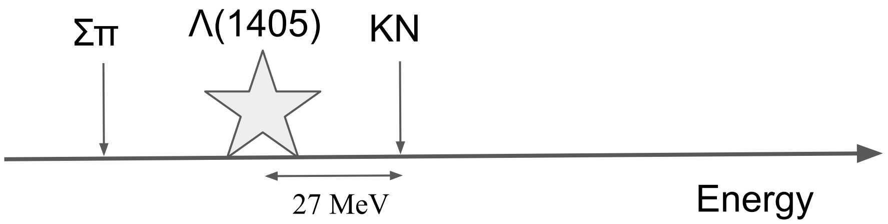
Gaussian source, with the radius fixed from the simultaneous fit to p-p, p-Λ and Λ-Λ femtoscopic data:

- $r_{7TeV} = r_{5TeV} = 1.13$ fm
- $r_{13TeV} = 1.18$ fm

ALICE Collaboration, Phys.Rev. C99 (2019) no.2, 024001,arXiv:1805.12455 [nucl-ex]

K-p femtoscopy: The KN interaction

- K^+p interaction is well established
- K^-p features a strong attraction
  - appearance of the Λ(1405) below threshold
  - Λ(1405): antiKN-Σπ molecular state



K-p femtoscopy: The KN interaction

- $K^{+}p$ interaction is well established
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- $K^{-}p$ scattering data and kaonic hydrogen data used to constrain the amplitude below threshold

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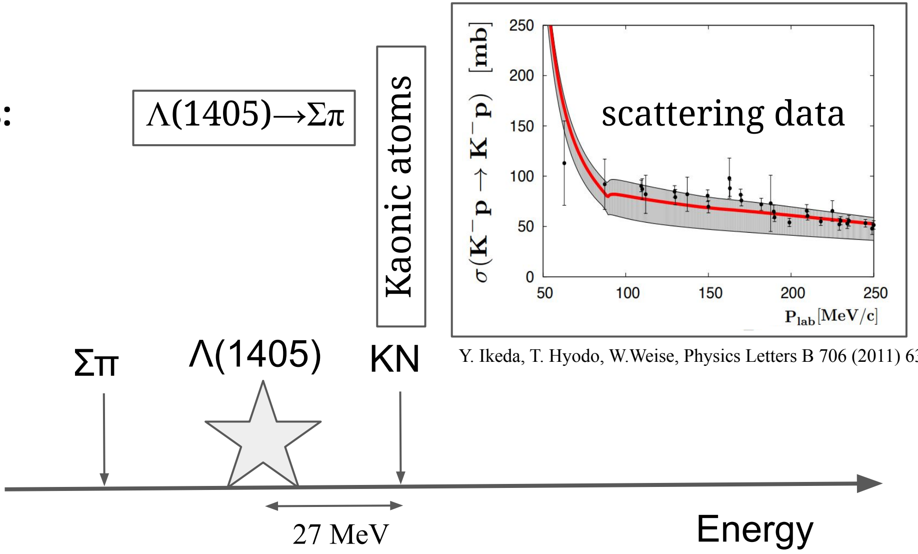

Y. Ikeda, T. Hyodo, W.Weise, Physics Letters B 706 (2011) 63

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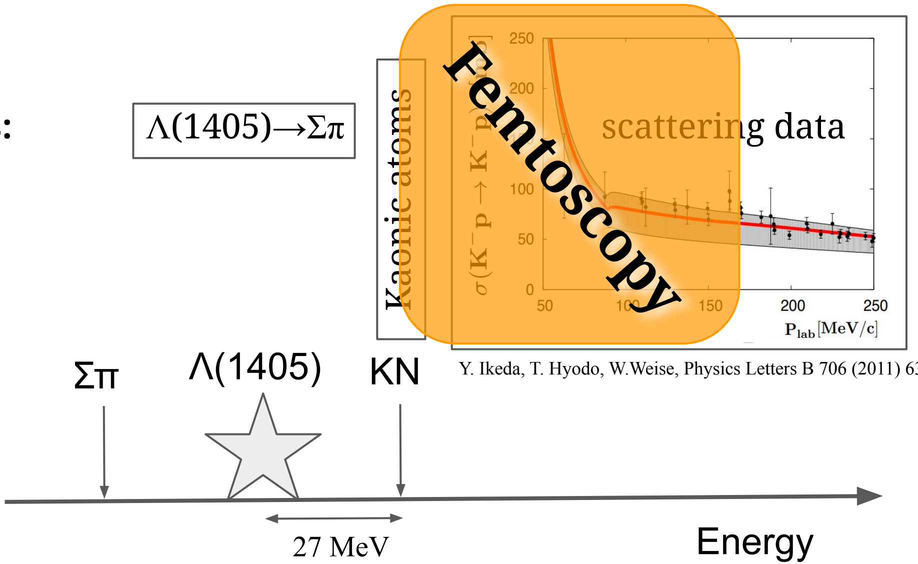

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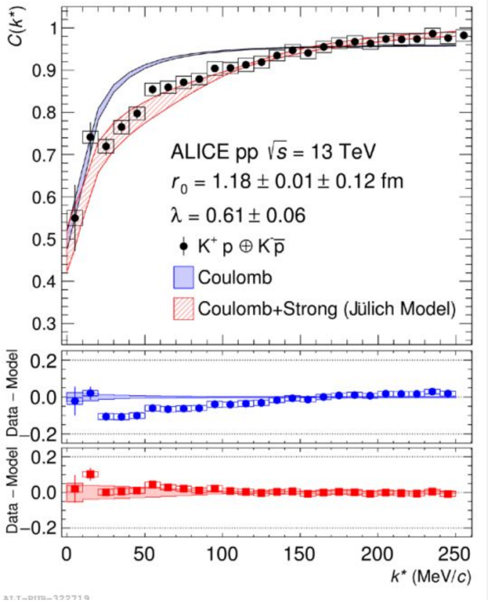
K-p femtoscopy in pp collisions

ALICE Collaboration, arXiv:1905.13470[nucl-ex]



- K^+p correlation used as a benchmark to study K^-p
- S_T > 0.7 selection removes mini-jet background

Jülich meson exchange model: Eur.Phys.J. A47 (2011) 18

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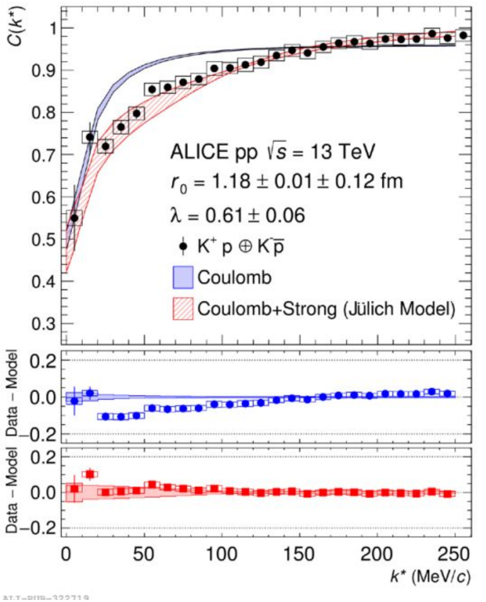

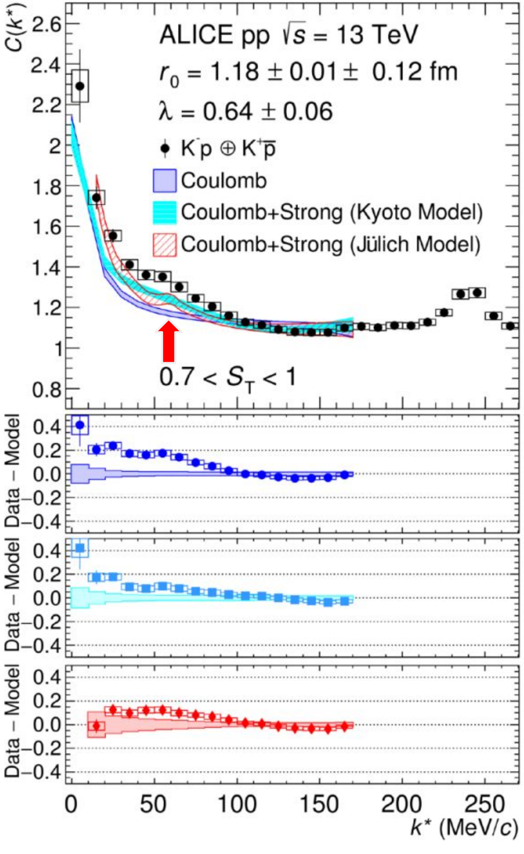

Kyoto Model: Phys. Rev. C93 no. 1, (2016) 015201
Jülich Model: Nucl. Phys. A981 (2019)

⇒ Bump close to the K^0n threshold→(58 MeV/c in CM frame)

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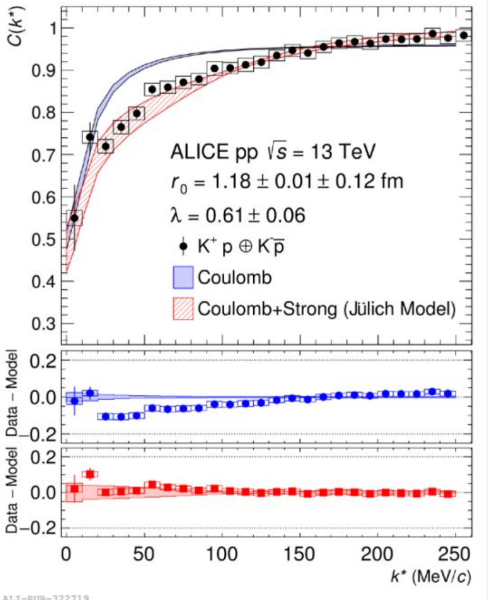

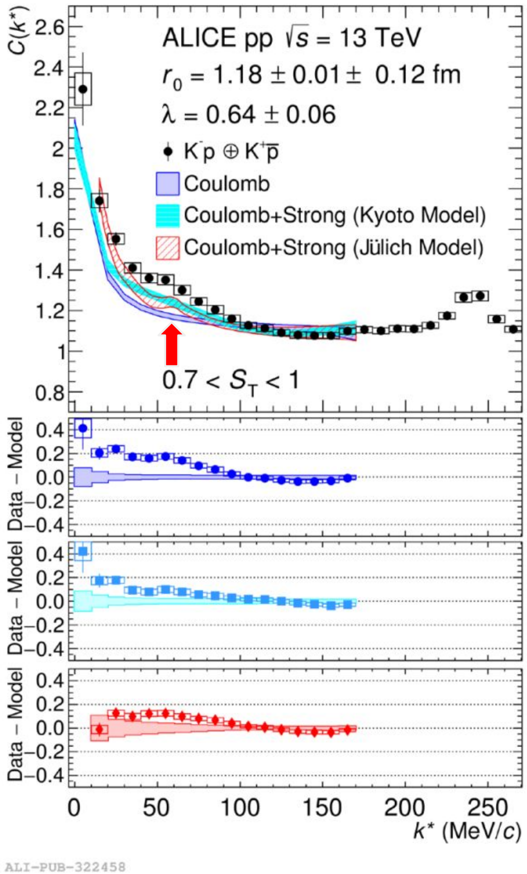

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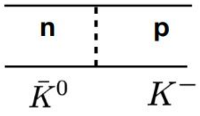
First experimental evidence of the opening of the K^0n isospin breaking channel

Coupled channel effect

$$M(K^-p) + 5\,\mathrm{MeV} = M(n\bar{K}^0)$$



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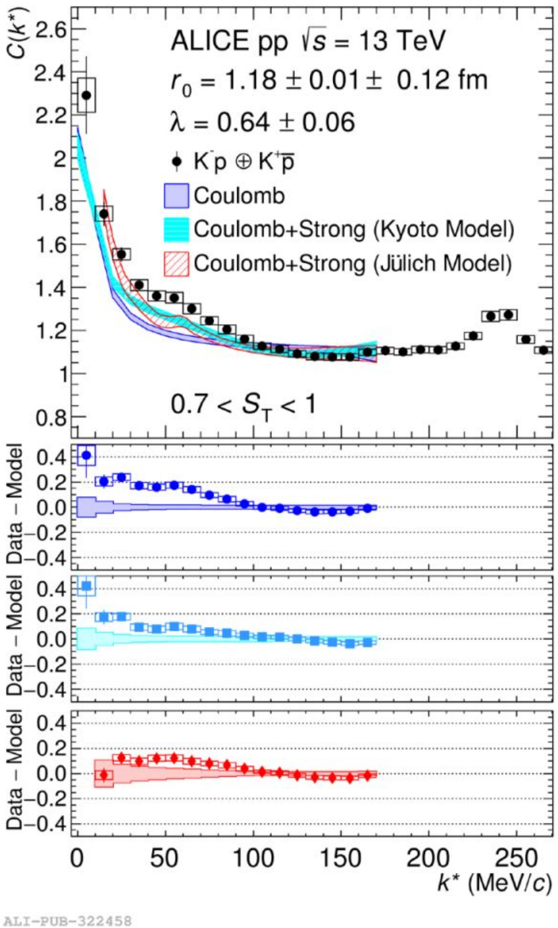

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Blue bands
Coulomb potential only

Light blue bands
Chiral Kyoto model with approximate boundary conditions:
- K^-–K^0 mass difference not considered (isospin averaged masses)
- Σπ and Λπ coupled channels neglected

Red bands
Jülich strong potential, meson exchange model
- Recently updated to reproduce the SIDDHARTA results at threshold
- Includes the K^-–K^0 mass difference and coupled channels (KN-πΣ-πΛ)

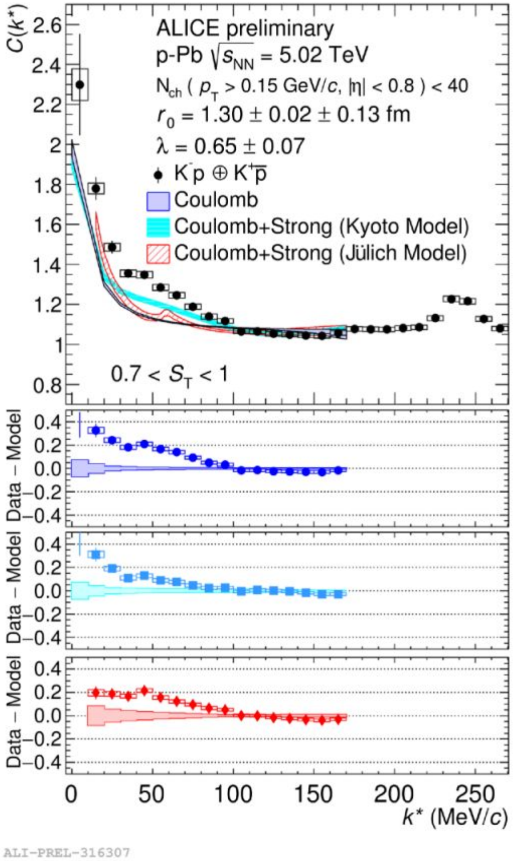
The correlation functions at low k* cannot be reproduced by any of the considered potentials

ALICE Collaboration, arXiv:1905.13470[nucl-ex]

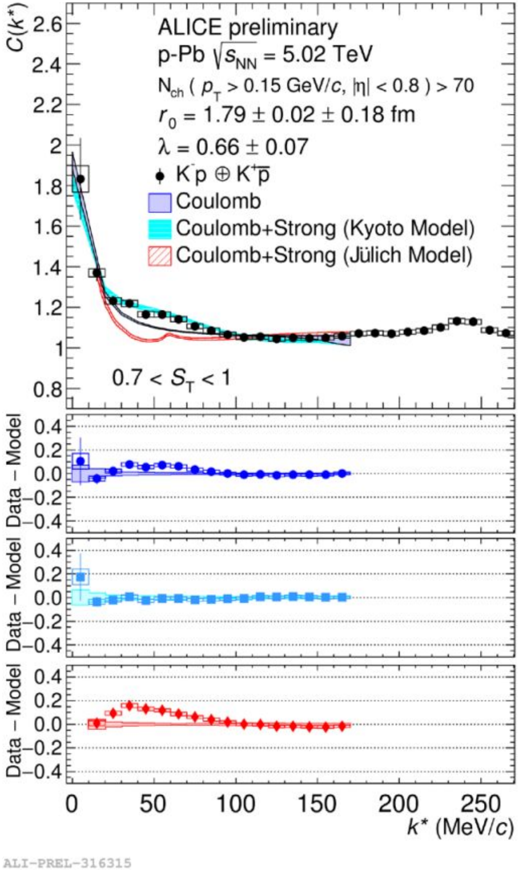
K-p femtoscopy in p-Pb collisions

K-p femtoscopy in p-Pb collisions

Low multiplicity (m<40)



High multiplicity (m>70)



- The results for lower multiplicity interval (smaller radius) are consistent and with pp results

- Different behavior of models:
  - Kyoto chiral model seems to describe the data quite well for large multiplicity
  - **Jülich** model describe the data worse w.r.t. the results obtained in pp collisions

⇒ **The present results represent a unique to tool to study Kp interaction**

Femtoscopic data constraints: Model tunning

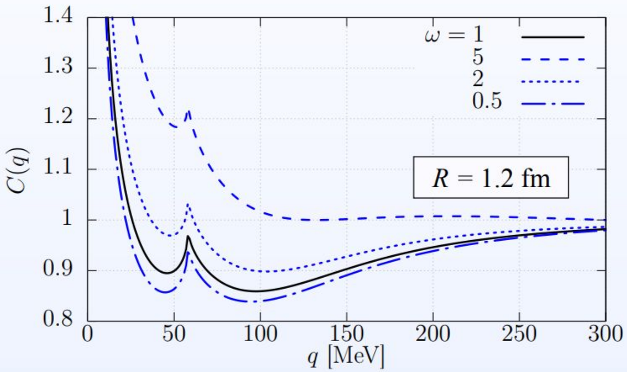
Y. Kamiya at FemTUM Workshop, Munich, October 2019

- Update of the Kyoto model: coupled-channel effect and interaction dependence

Channel weight dependence of $K^- p$ correlation

$$C_i(\mathbf{q}) = \int d^3\mathbf{r}\ S_i(\mathbf{r})\left[|\varphi^{C,\mathrm{full}}(\mathbf{r},\mathbf{q})|^2 - |j_0^C(qr)|^2 + |\chi_i^{C,(-)}(r,q)|^2\right] + \sum_{j\neq i}\omega_j \int d^3\mathbf{r}\ S_j(\mathbf{r})|\chi_j^{C,(-)}(r,q)|^2$$

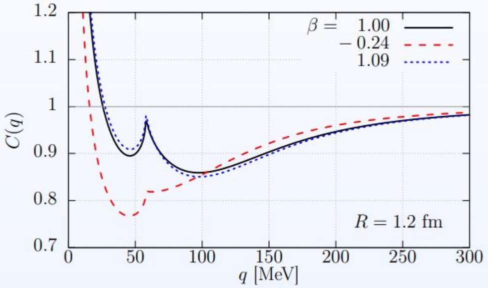
- Vary the source weight of the $\pi\Sigma$ channel:



- Increase $\omega_{\pi\Sigma}$ ==> • weaken dip at $q \sim 40$ MeV
  • weaken cusp

Interaction dependence of $\bar{K}N$ correlation

- $I=0$ $\bar{K}N$ interaction <== strongly constrained by the SIDDHARTA constraint
  M. Bazzi, et al., NPA 881 (2012)
- $I=1$ $\bar{K}N$ interaction is not well known ==> vary $V^{I=1}_{\bar{K}N-\bar{K}N} \to \beta V^{I=1}_{\bar{K}N-\bar{K}N}$
- SIDDHARTA constraint on $a_0^{K^-p}$ ==> Varied region of β as $-0.24 < \beta < 1.09$



β	$a_0^{K^-p}$ [fm]	$a_0^{\bar{K}N,I=1}$ [fm]
-0.24	0.75-i0.69	-0.07-i0.13
1.00	0.65-i0.91	0.61-i0.78
1.09	0.65-i0.96	0.64 -i0.95

$(a_0 \equiv -\mathscr{F}(E=E_{\mathrm{th}}))$

- For $\beta = -0.24$,
  - Remarkable suppression around $\bar{K}^0 n$ threshold ($q \simeq 58$ MeV)
  - Moderate cusp structure

$\boxed{I=1\ \bar{K}N \text{ interaction can be determined with the detailed analysis!}}$

p-Ω^- femtoscopy

Experimental **study on the interaction between a proton and a multi-strange baryon**

- Ω^- is a hyperon with quark content: sss

Use the most recent datasets to test recent models of the p-Ω interaction:

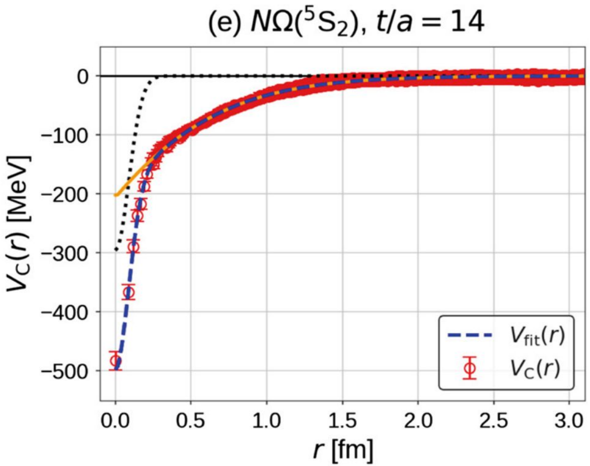
- Lattice QCD: HAL-QCD Collaboration
- Meson exchange (Sekihara model)

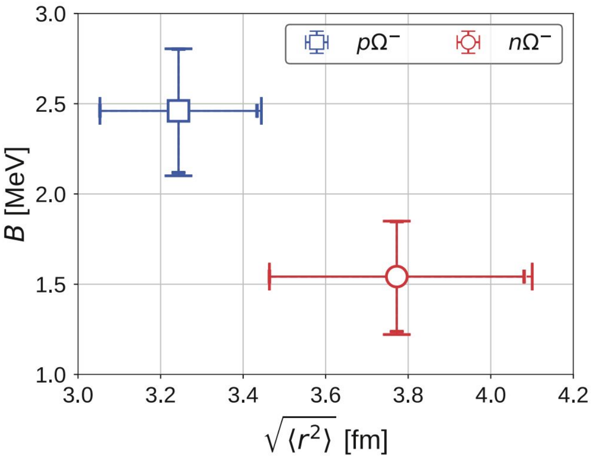
Lattice QCD prediction

In recent years calculations of baryon-baryon interactions became possible near the physical quark masses. Mainly due to development of advanced techniques such as the HAL QCD method.

Lattice QCD (**HAL Collaboration**) predicts **very attractive p-Ω⁻ interaction at all distances**
→ Open the door for a NΩ di-baryon

The NΩ system, with J=2, S=−3 would be a particularly interesting case since the Pauli blocking among valence quarks do not operate in this system ⇒ Absence of a repulsive core

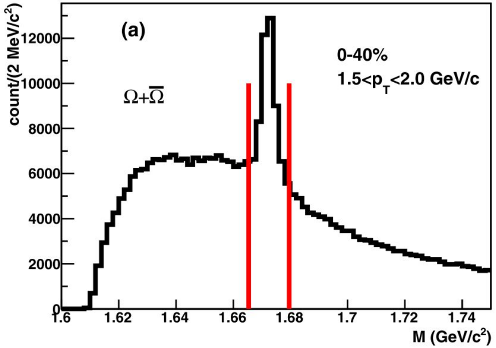




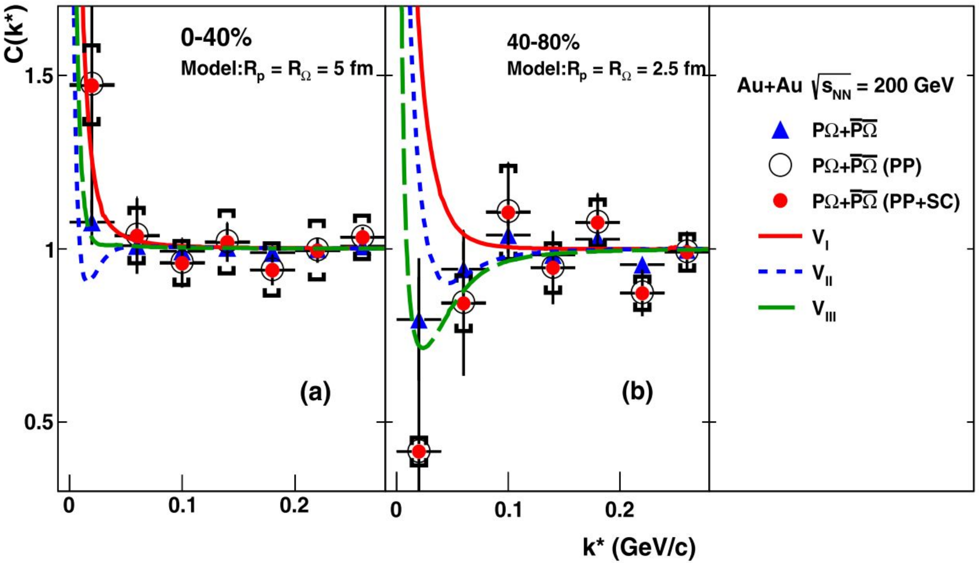
T. Iritani et al., Physics Letters B 792 (2019) 284–289

Previously available experimental data: STAR

- Study of the p-Ω^- correlation function in Au-Au collisions at $\sqrt{s_{NN}}$ = 200GeV STAR Collaboration. Phys. Lett. B790 (2019) 490-497
- Observable: ratio of the correlation function peripheral/central collisions.
- Comparison with Lattice QCD calculations (with large masses)



Omega purity between 0.2 and 0.7
Pair purity:
0-40%: 0.2
40-80%: 0.36



Lattice HAL-QCD potential with heavy quarks

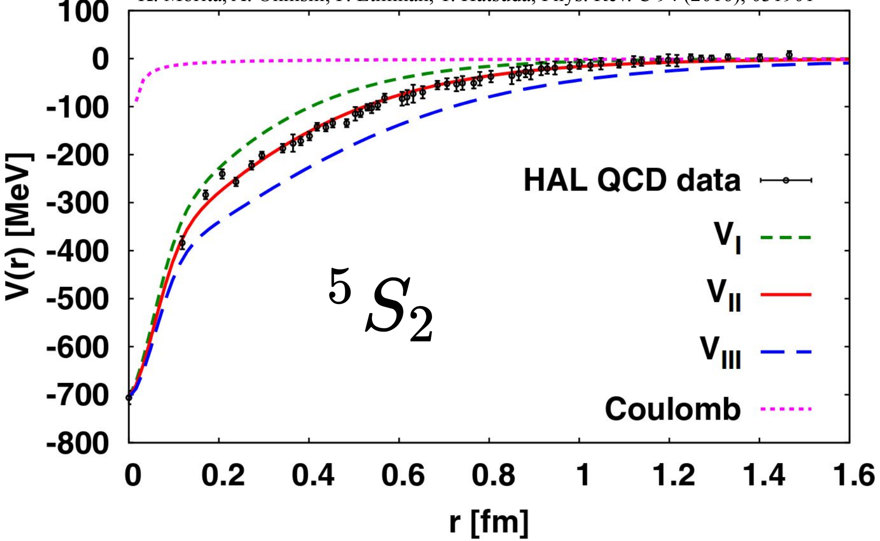
- Based on Lattice calculations with heavy quark masses F. Etminan et al.(HAL QCD Collaboration),Nucl. Phys. A928,89(2014)
  - $m_\pi = 875$ MeV/c^2
  - $m_K = 916$ MeV/c^2
- Used in the STAR pΩ analysis in Au-Au collisions at $\sqrt{s_{NN}} = 200$GeV
- Lattice calculations fitted by an attractive Gaussian core + an attractive tail, varying the range parameter at long distance (b_5)
  - **V_{II}**: best fit to Lattice calculations
  - **V_I / V_{III}**: weaker / stronger attraction

$$V(r) = b_1 e^{-b_2 r^2} + b_3(1 - e^{-b_4 r^2})(e^{-b_5 r}/r)^2$$

Binding energy ($\mathbf{E_b}$), scattering length ($\mathbf{a_0}$) and effective range ($\mathbf{r_{eff}}$) for the Spin-2 proton–Ω potentials [24].

Spin-2 pΩ potentials	V_I	V_{II}	V_{III}
$\mathbf{E_b}$ (MeV)	–	6.3	26.9
$\mathbf{a_0}$ (fm)	−1.12	5.79	1.29
$\mathbf{r_{eff}}$ (fm)	1.16	0.96	0.65

K. Morita, A. Ohnishi, F. Etminan, T. Hatsuda, Phys. Rev. C 94 (2016), 031901



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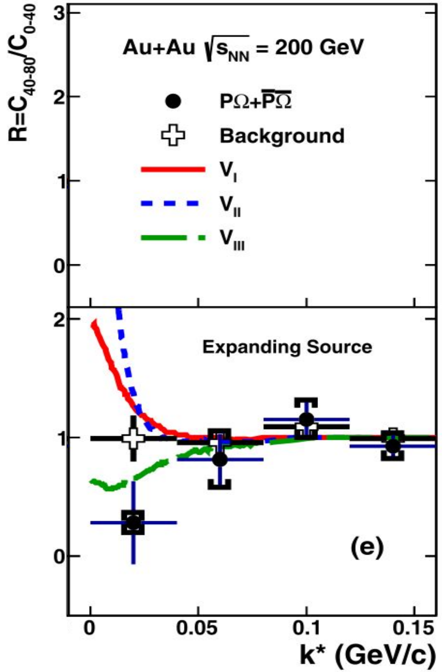

- Test different fits to Lattice QCD data (delivering **three different binding energies of the NΩ**):

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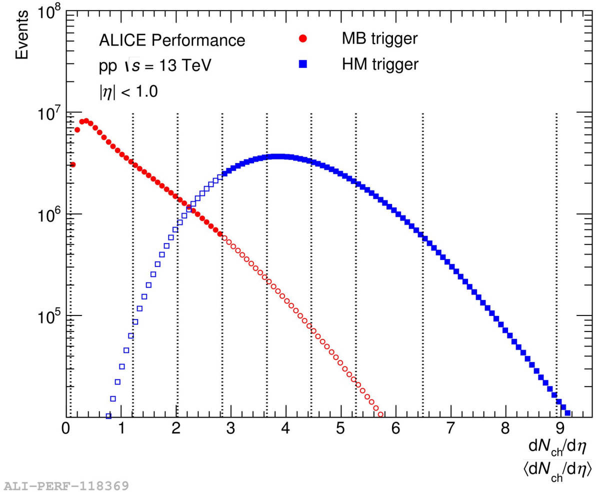
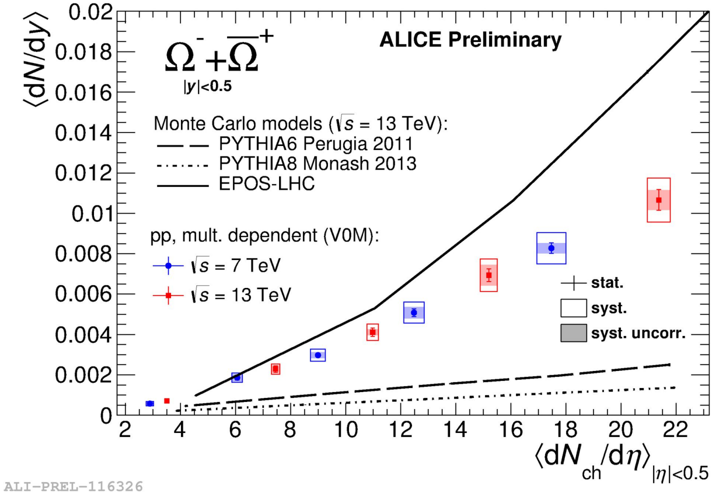
[24] K. Morita, A. Ohnishi, F. Etminan, T. Hatsuda, Phys. Rev. C 94 (2016), 031901

STAR data favor V_{III}, with $\mathbf{E_b}$ **= 27 MeV**

ALICE pp High Multiplicity data

- Analyzed 10^9 events data of ALICE Run2 (2016, 2017, 2018), pp collisions at $\sqrt{s}$ = 13 TeV
- **High multiplicity trigger**: 0.1% highest multiplicity with respect to Minimum Bias events (V0M, forward rapidities: $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$).
  - Increased yield of Ω baryon





Data analysis: Ω^- reconstruction

- Identified by its decay: $\Omega^- \rightarrow \Lambda K^- \rightarrow (p\pi^-)K^-$
- Total of 1.2×10^6 selected $(\Omega^- + \Omega^+)$ candidates:
  - 0.6×10^6 p-Ω^-⊕p-Ω^+ pairs
  - 11×10^3 pairs at k*<300 MeV/c
  - 700 pairs at k*<100 MeV/c
- Purity of the preliminary sample **75%**

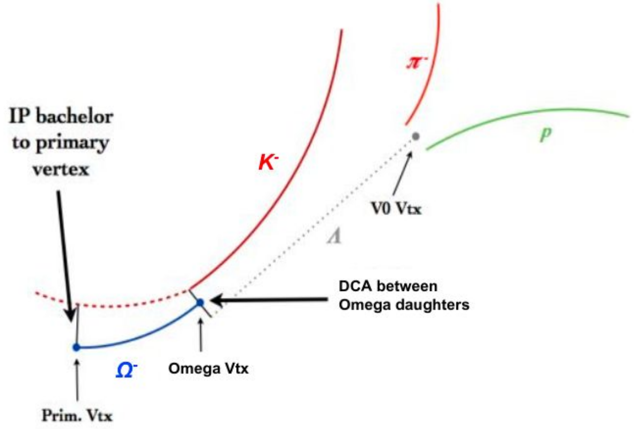
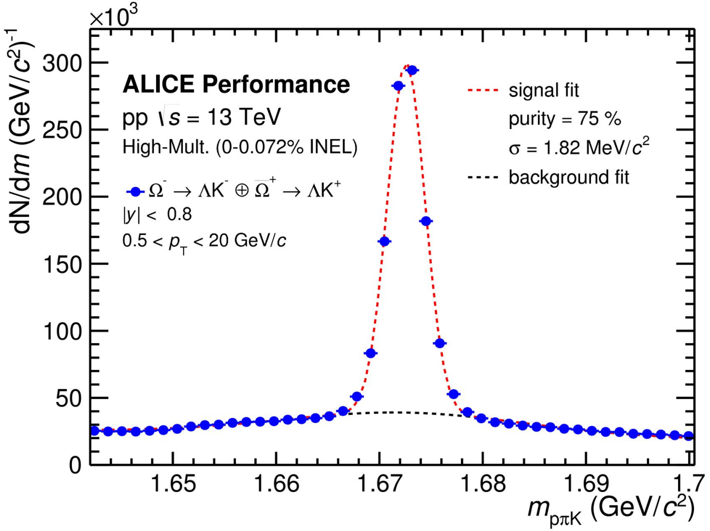
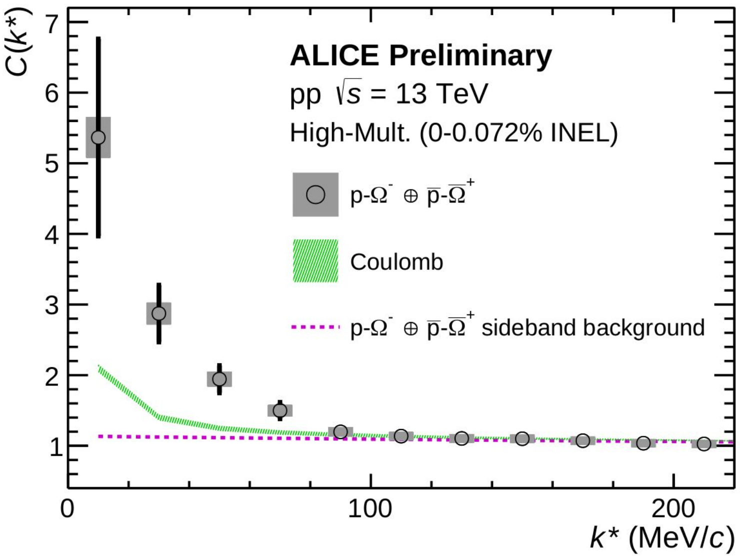


Fig. 2: Sketch of the Ω^- decay and identification.



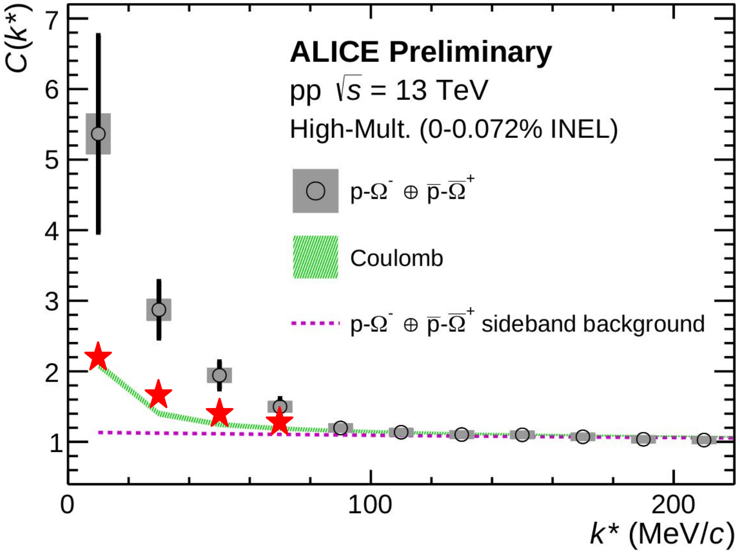
Results: p-Ω^- correlation function in pp HM



"Coulomb only" scenario discarded by ALICE data (> 6σ) showing the attractive character of the interaction

r_{source} = 0.73 fm (+resonances)
$\lambda_{genuine}$ = 0.62

Results: p-Ω^- correlation function in pp HM



"Coulomb only" scenario discarded by ALICE data (> 6σ) showing the attractive character of the interaction

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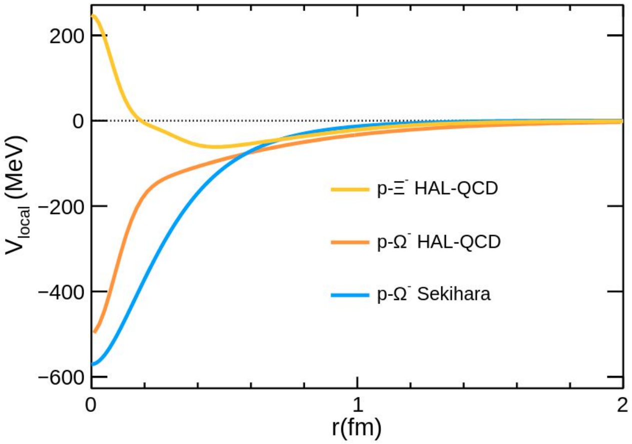
★ p-Xi correlation function



Comparison with models: p-Ω^- interaction potentials

- Lattice **HAL-QCD** potential with physical quark masses ($^5S_2$ channel)
  - m_π = 146 MeV/c^2
  - m_K = 525 MeV/c^2

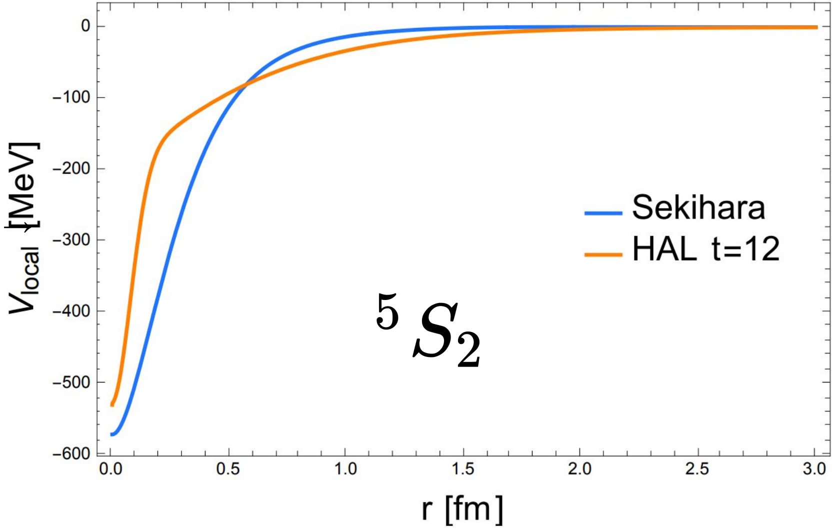
  T. Iritani et al., arXiv:1810.03416

- **Sekihara**: Meson-exchange model ($^5S_2$ channel)
  - Short range attractive interaction fitted to HAL-QCD scattering parameters
  - Includes inelastic channels (strong decays into XΞ) small contributions in the S-wave interaction

  T. Sekihara et al., Phys. Rev. C 98, 015205 (2018)

Model	pΩ^- binding energy (strong interaction only)
HAL-QCD	1.54 MeV
Sekihara	0.1 MeV

(+1 MeV with Coulomb)



→ Models provide so far only $^5S_2$ channel (weight ⅝)

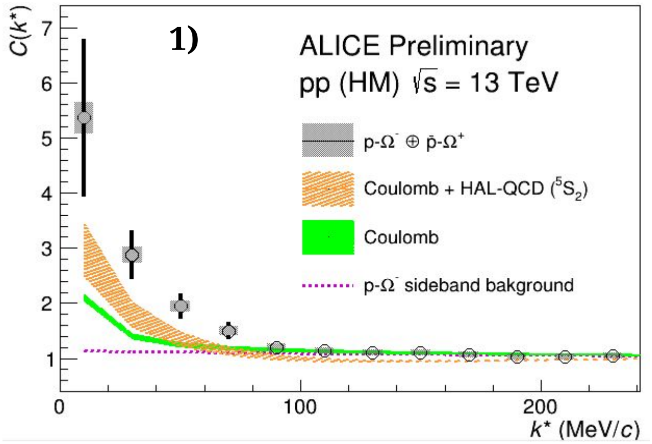
Model evaluation

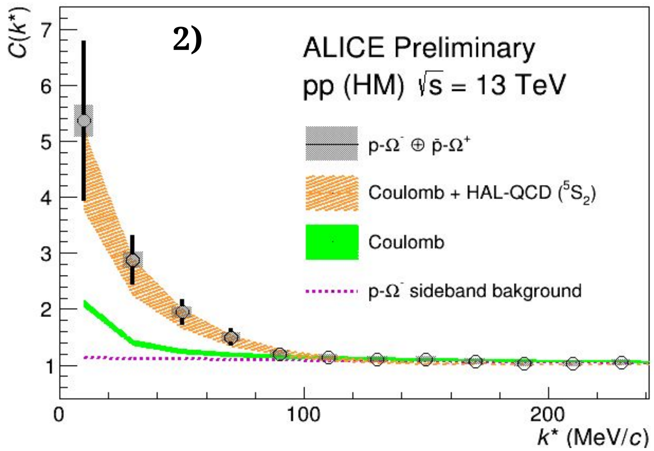
Calculations provide the potential shape for the $^5S_2$ channel (weight ⅝). **Currently, no model for the other channel in S-wave interaction, $^3S_1$ (weight ⅜)**. Requires coupled channel treatment.

Assume <u>two different (~extreme) scenarios</u>:

1.- Complete absorption for distances $r < r_0$. K. Morita, A. Ohnishi, F. Etminan, T. Hatsuda, Phys. Rev. C 94 (2016), 031901
$r_0 = 2$fm, chosen from the condition $|V(^5S_2)| < |V(\text{Coulomb})|$ for $r > r_0$

2.- Complete elastic with a similar attraction as $^5S_2$





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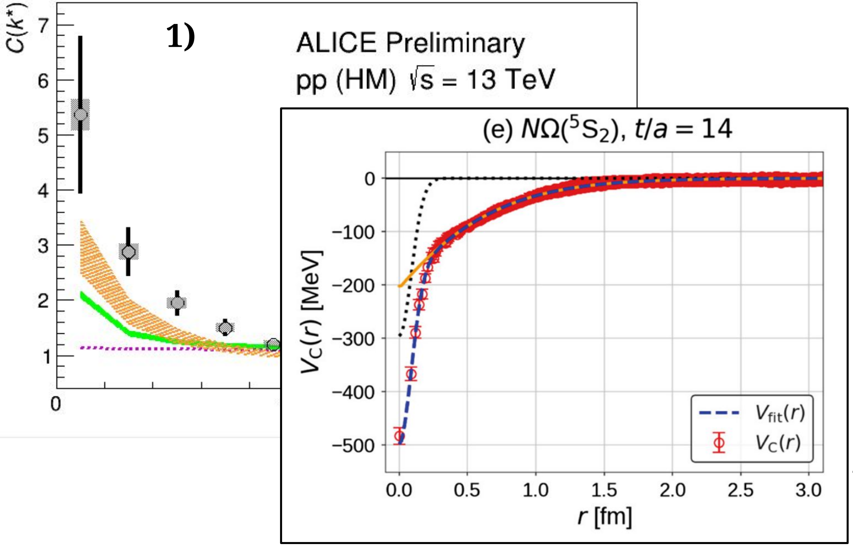
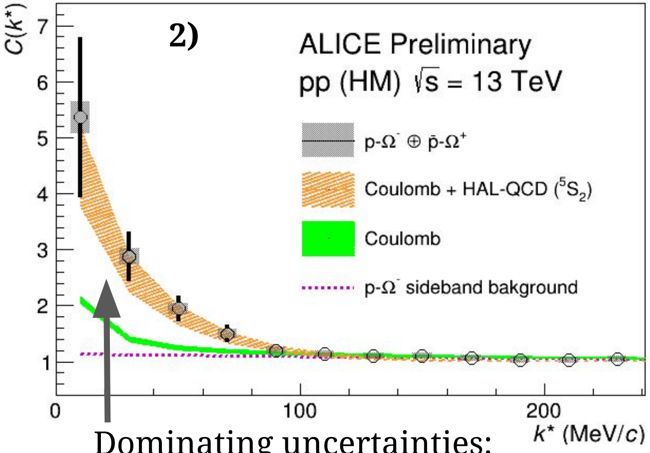
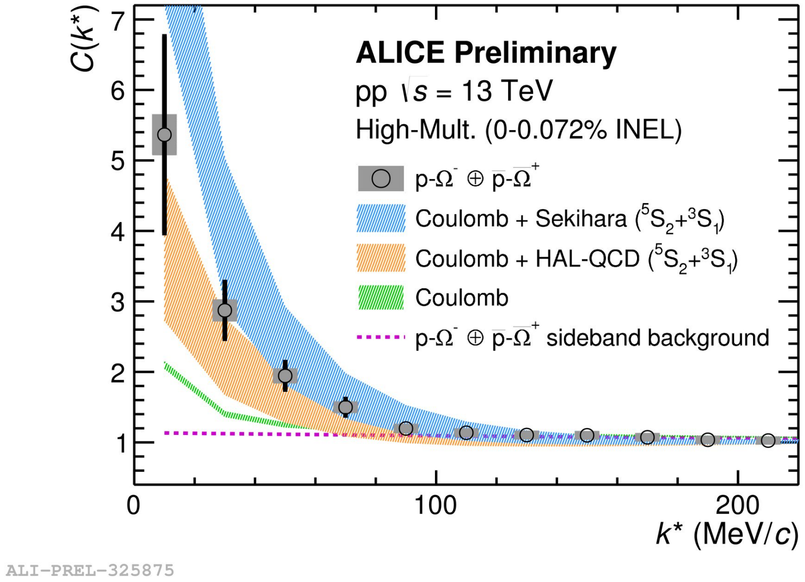




Dominating uncertainties:
- **Statistical uncertainty from Lattice**
- Determination of the radius

Results: p-Ω^- correlation function in pp HM



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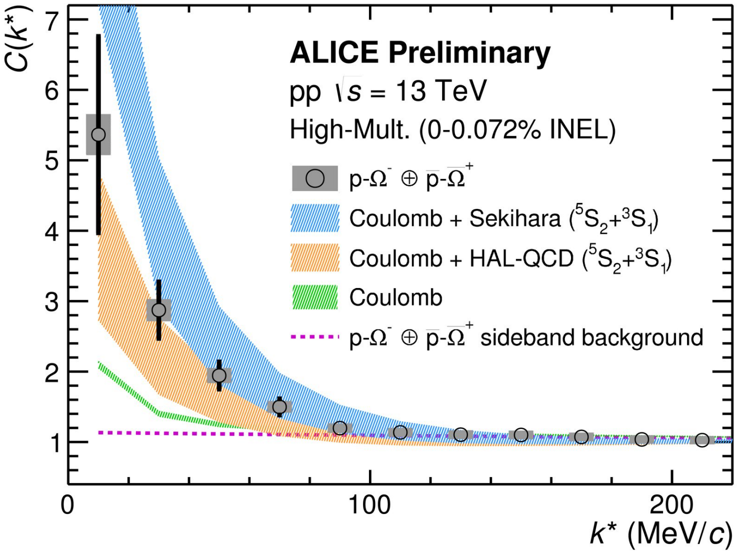
"Coulomb only" scenario discarded by ALICE data (> 6 σ) showing the attractive character of the interaction

Precision of ALICE data exceeds the theoretical predictions

Results: p-Ω^- correlation function in pp HM



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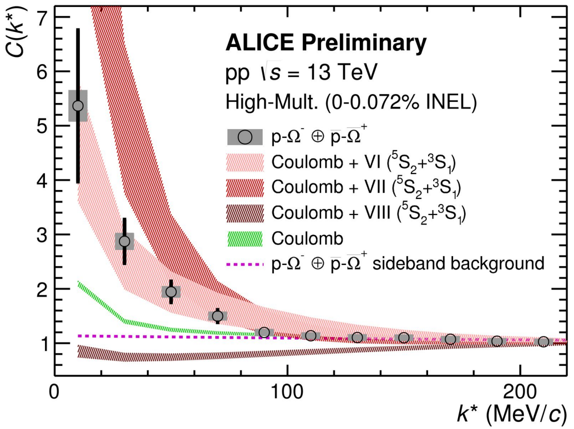
Precision of ALICE data exceeds the theoretical predictions

Comparison with the model favoured by STAR data
STAR Coll. Phys. Lett. B790 (2019) 490-497

V_{III}: Ad-hoc fit to previous HAL-QCD calculations with non-physical quark masses with pΩ dibaryon E_b = 27 MeV



Outlook

ALICE and the femtoscopy method deliver **precise data** to test hadron-hadron interactions at distances lower than 1 fm

The comparison of the ALICE data in small systems with the expectation from the models is **very sensitive to the shape of the strong potential**.

→ Femtoscopic data substitutes/complement the scattering data, hypernuclei and other approaches.

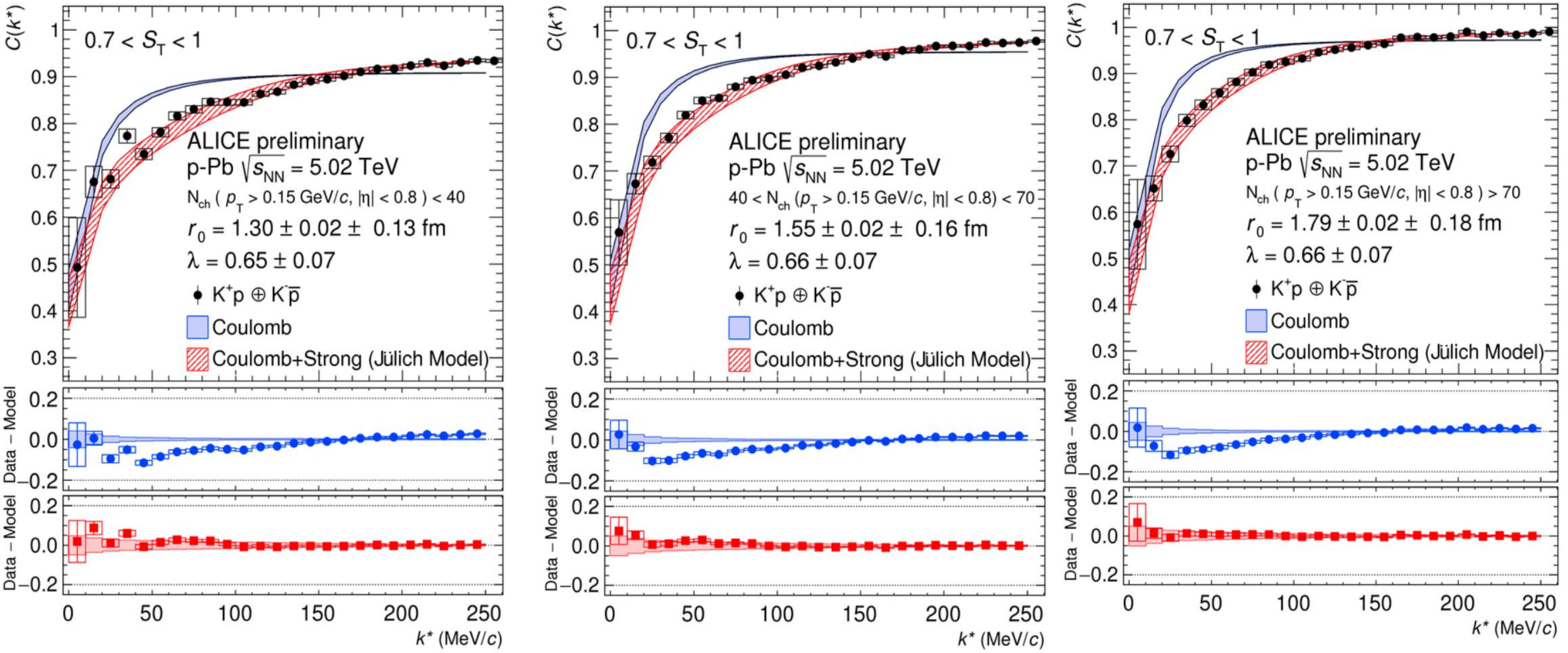
→ The precision in some of the studied channels exceed the model.

RUN3/4 will provide the possibility of carrying out new studies and investigate 3-body interactions.

THANK YOU!

K-p femtoscopy in p-Pb collisions

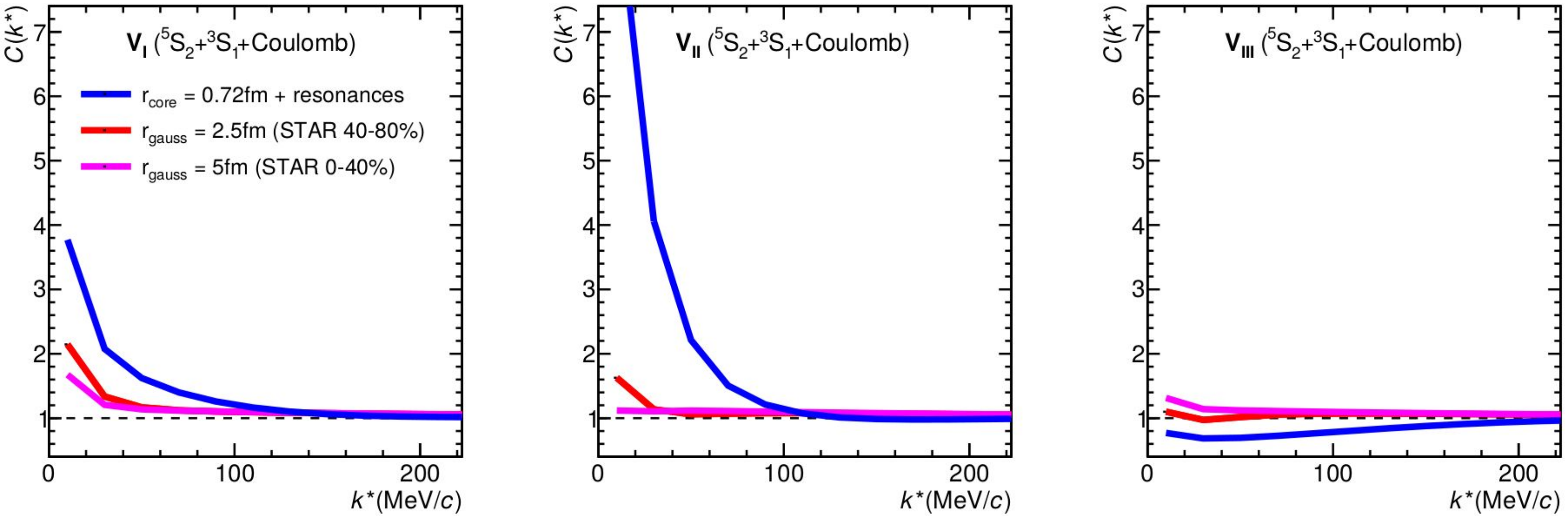
Low multiplicity (m<40) **High multiplicity (m>70)**



Sensitivity of ALICE and STAR data

- Expected correlation function from heavy quark Lattice QCD potentials
- **Smaller radius** source offers the ideal conditions to test the models
- **Better purity** of ALICE data increases the **sensitivity** of the test

purity 75% (ALICE)



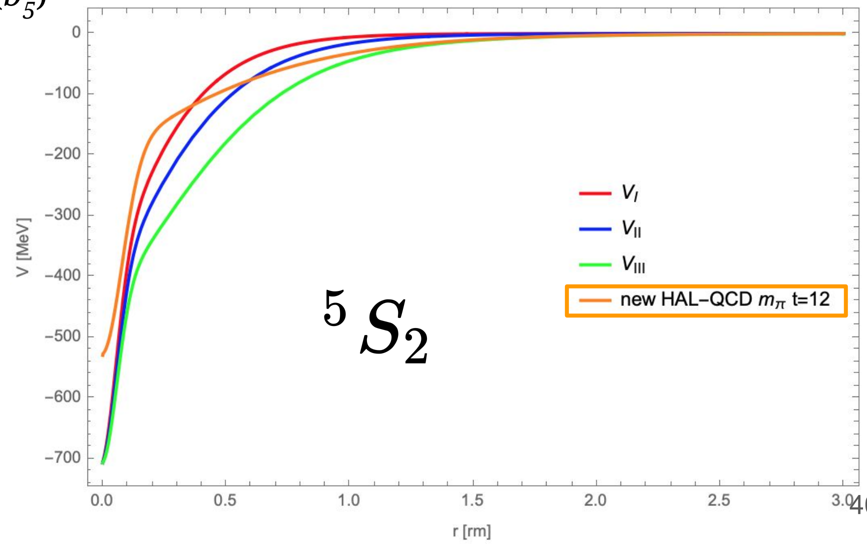
Lattice HAL-QCD potential with heavy quarks

- Based on Lattice calculations with heavy quark masses
  T. Etminan et al.(HAL QCD Collaboration),Nucl. Phys. A928,89(2014)
  - m_π = 875 MeV/c^2
  - m_K = 916 MeV/c^2
- Used in the STAR pΩ analysis in Au-Au collisions at $\sqrt{s_{NN}}$ = 200GeV
- Lattice calculations fitted by an attractive Gaussian core + an attractive tail, varying the range parameter at long distance (b_5)
  - **V$_{II}$**: best fit to Lattice calculations
  - **V$_I$** / **V$_{III}$**: weaker / stronger attraction

$$V(r) = b_1 e^{-b_2 r^2} + b_3(1 - e^{-b_4 r^2})(e^{-b_5 r}/r)^2$$

Binding energy ($\mathbf{E_b}$), scattering length ($\mathbf{a_0}$) and effective range ($\mathbf{r_{eff}}$) for the Spin-2 proton–Ω potentials [24].

Spin-2 pΩ potentials	V_I	V_{II}	V_{III}
$\mathbf{E_b}$ (MeV)	–	6.3	26.9
$\mathbf{a_0}$ (fm)	−1.12	5.79	1.29
$\mathbf{r_{eff}}$ (fm)	1.16	0.96	0.65



p-Ω^- ⊕ $\overline{\mathrm{p}}$-$\overline{\Omega}^+$ correlation function

- 0.6×10^6 p-Ω^-⊕$\overline{\mathrm{p}}$-$\overline{\Omega}^+$ pairs
- ~700 pairs at k* < 100 MeV/*c*
- Strong enhancement of the correlation function: the "**Coulomb only**" scenario is discarded by a χ^2 comparison to the data, n_σ~6
- λ parameters:

Pair	λ [%]
p–Ω^-	61.5
p_Λ–Ω^-	8.3
p_{Σ^+}–Ω^-	3.8
$\tilde{p}$–Ω^-	1.5
p–$\tilde{\Omega}^-$	20.5
p_Λ–$\tilde{\Omega}^-$	2.8
p_{Σ^+}–$\tilde{\Omega}^-$	1.3
$\tilde{p}$–$\tilde{\Omega}^-$	0.5

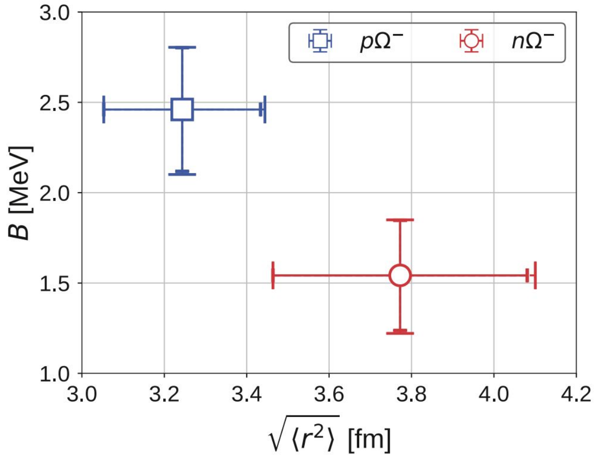
Lattice QCD prediction

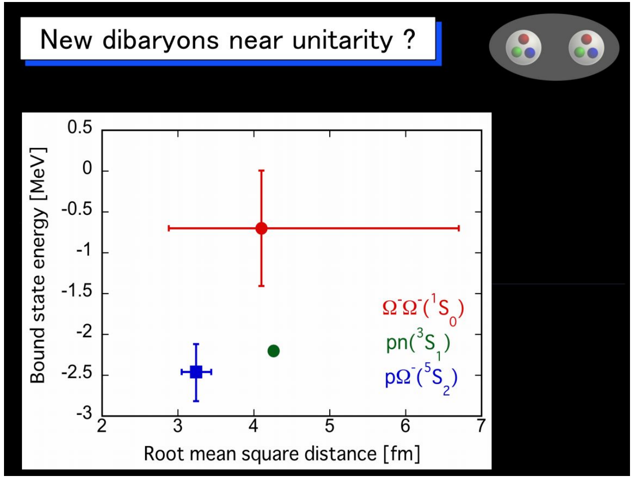
In recent years calculations of baryon-baryon interactions became possible near the physical quark masses. Mainly due to development of advanced techniques such as the HAL QCD method.

Lattice QCD (**HAL Collaboration**) predicts **very attractive p-Ω^- interaction at all distances**
→ Open the door for a NΩ di-baryon

The NΩ system, with J=2, S=−3 would be a particularly interesting case since the Pauli blocking among valence quarks do not operate in this system ⇒ Absence of a repulsive core

T. Iritani et al., Physics Letters B 792 (2019) 284–289

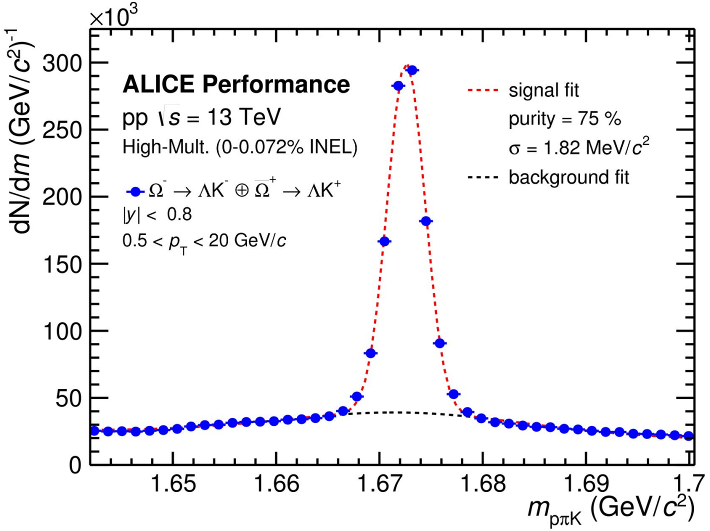




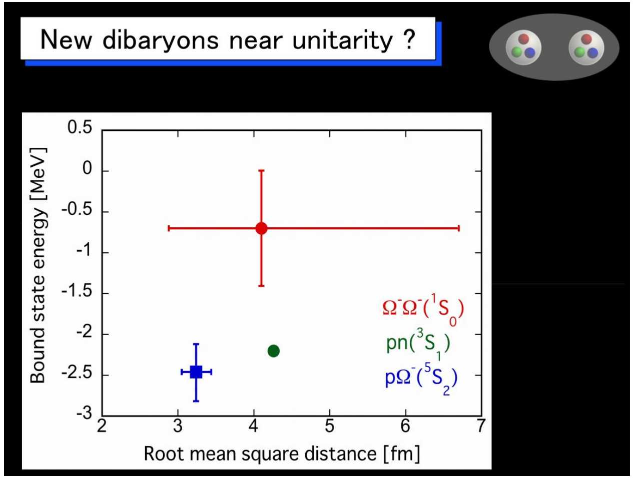
T. Hatsuda,
Strangeness in Quark Matter 2019, Bari.

Data analysis: Ω^- reconstruction

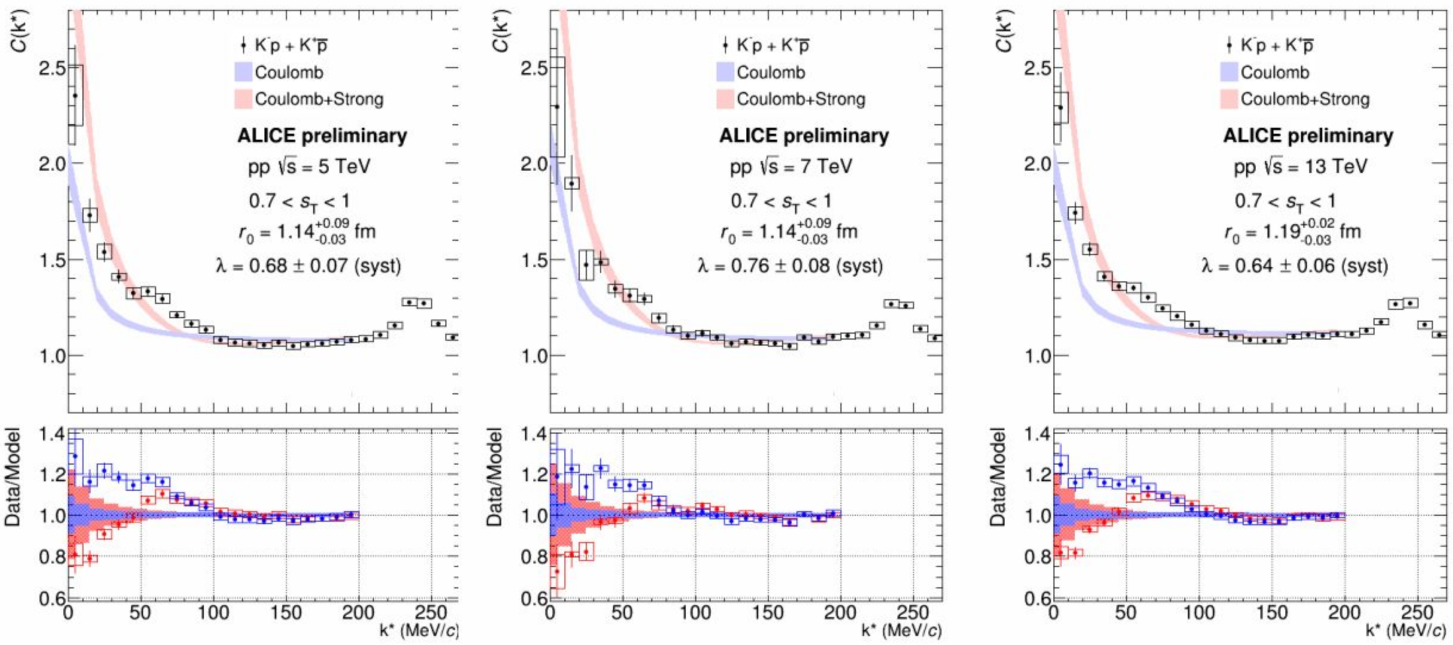
- Identified by its decay: $\Omega^- \to \Lambda K^- \to (p\pi^-)K^-$
- Total of 1.2×10^6 selected $(\Omega^- + \Omega^+)$ candidates:
  - **0.6×10^6** p-Ω-⊕p-Ω+ pairs → **304 ΩΩ pairs**
  - **11×10^3** pairs at k*<300 MeV/c → **3**
  - **700** pairs at k*<100 MeV/c → **0**
- Purity of the preliminary sample **75%**



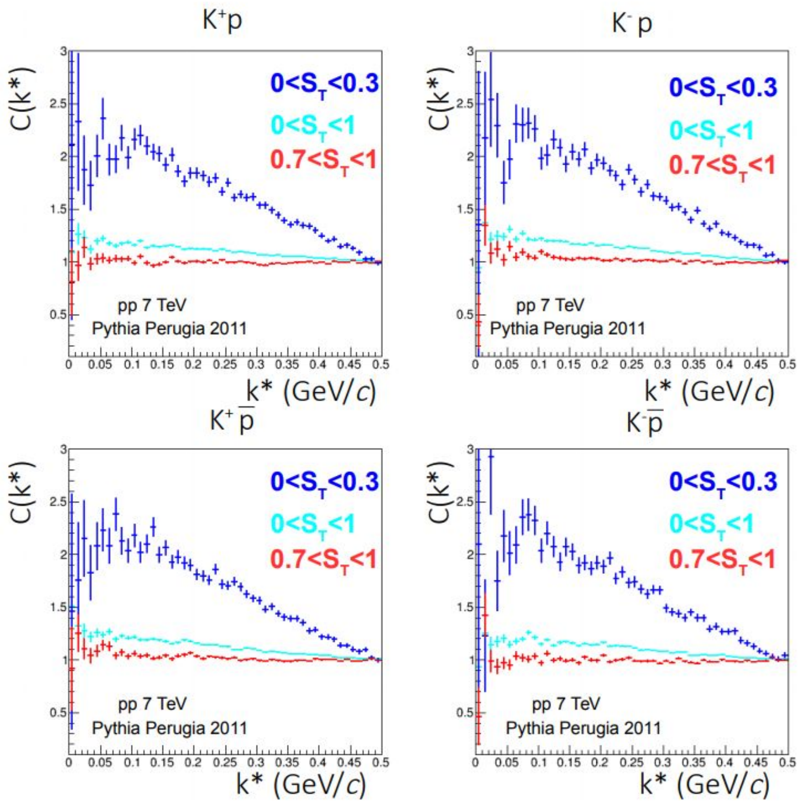
T. Hatsuda, Strangeness in Quark Matter 2019, Bari.



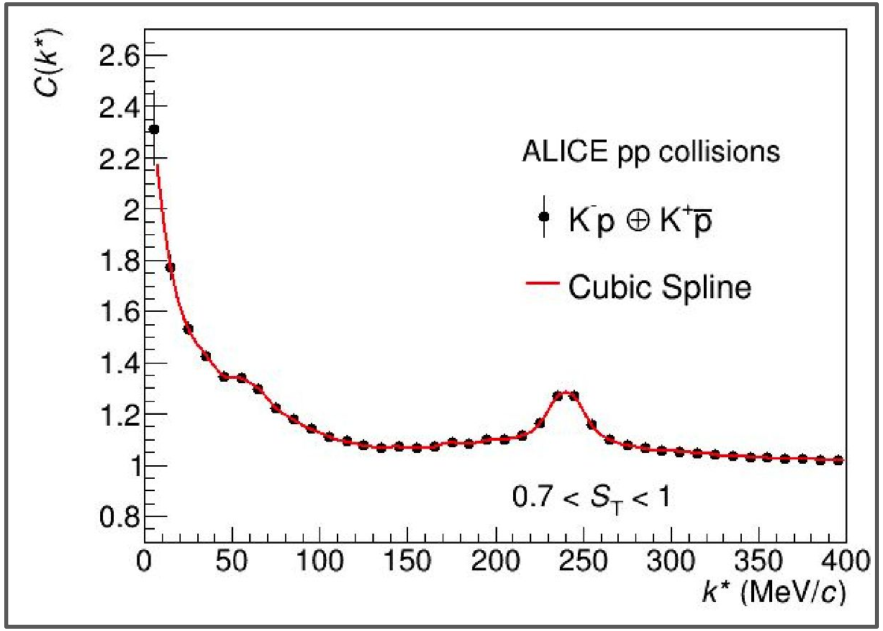
Updated results : K⁻p (Haidenbauer)



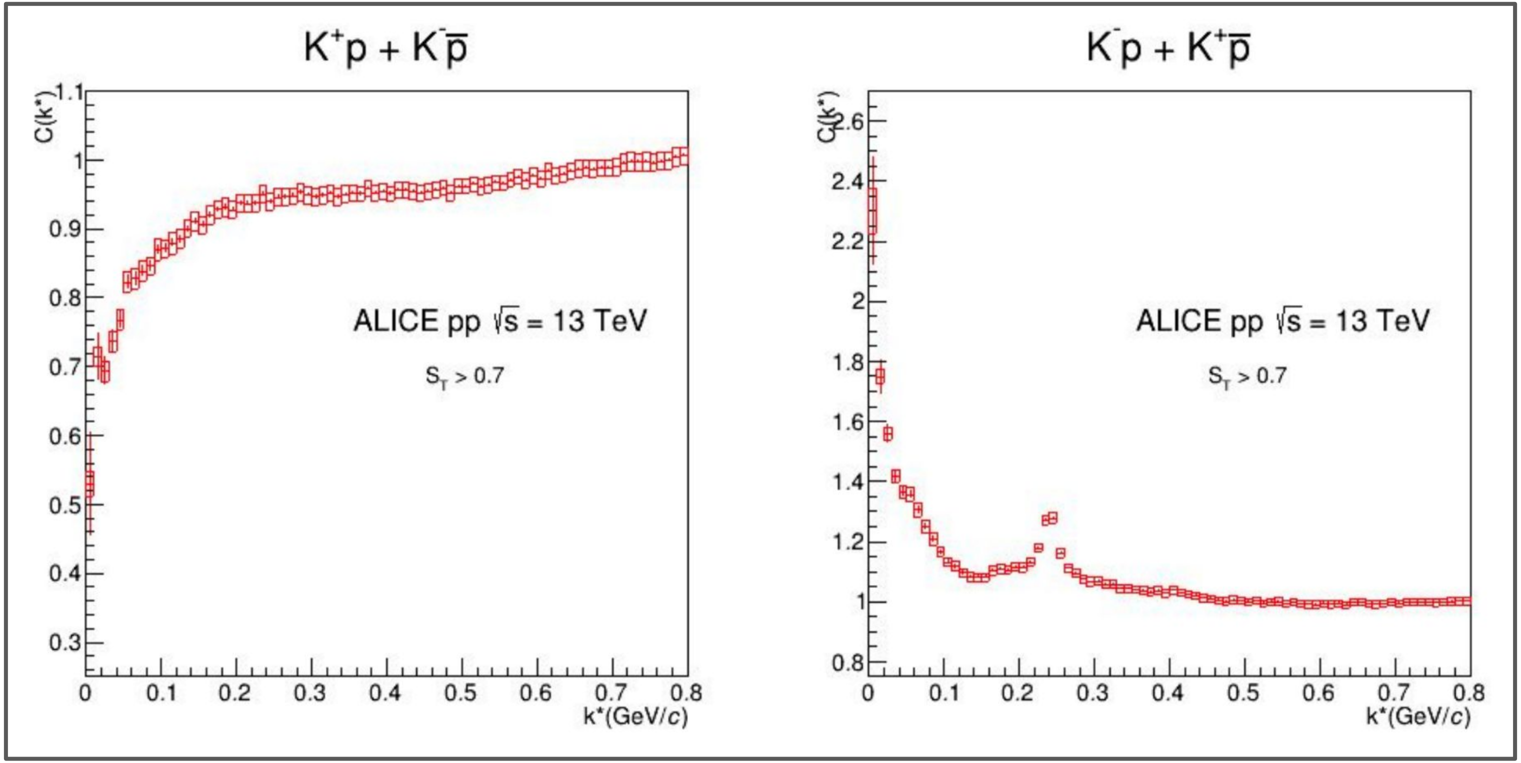
CF for different Sphericity- MC

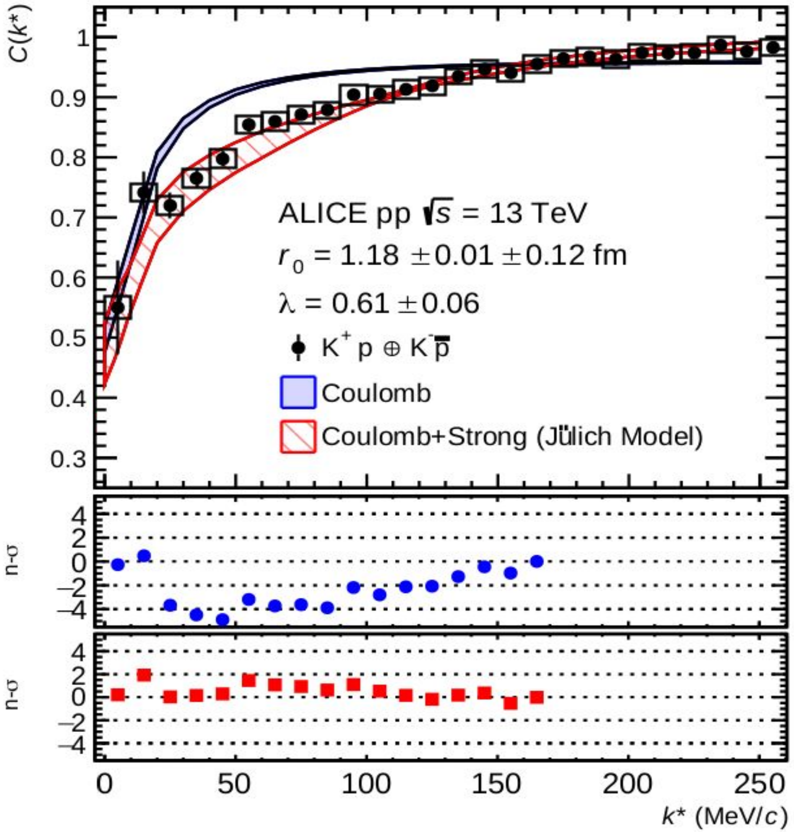


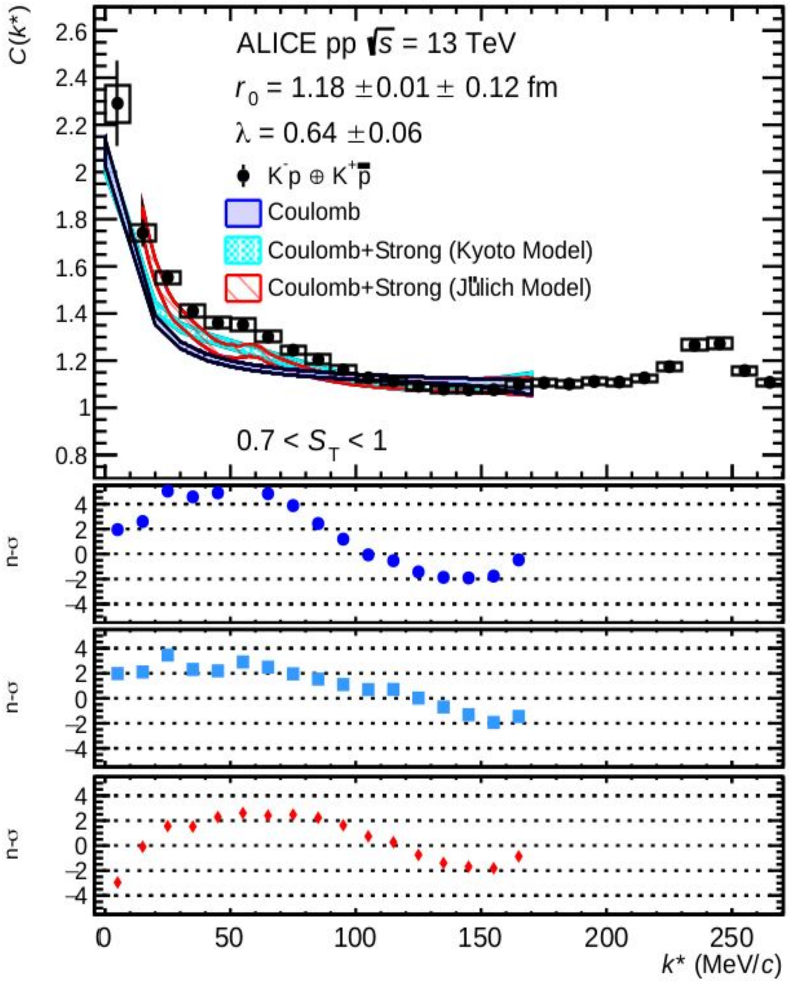
- Clear dependence on the sphericity for all charge combination considered
- Events with “large spericity” (0,7<s_T<1) have a flat behavior in the considered interval
- If only events with a large sphericity are considered, no Pythia-related function is needed to fit data



4.4σ has been observed, to be compared with a significance of 30σ for $\Lambda(1520)$.


$K^+p + K^-\overline{p}$
C(k*)
ALICE pp $\sqrt{s}$ = 13 TeV
$S_T > 0.7$
k*(GeV/c)
$K^-p + K^+\overline{p}$
C(k*)
ALICE pp $\sqrt{s}$ = 13 TeV
$S_T > 0.7$
k*(GeV/c)


ALICE pp √s = 13 TeV
r0 = 1.18 ±0.01 ±0.12 fm
λ = 0.61 ±0.06
K+p ⊕ K-p̄
Coulomb
Coulomb+Strong (Jülich Model)
C(k*)
n-σ
k* (MeV/c)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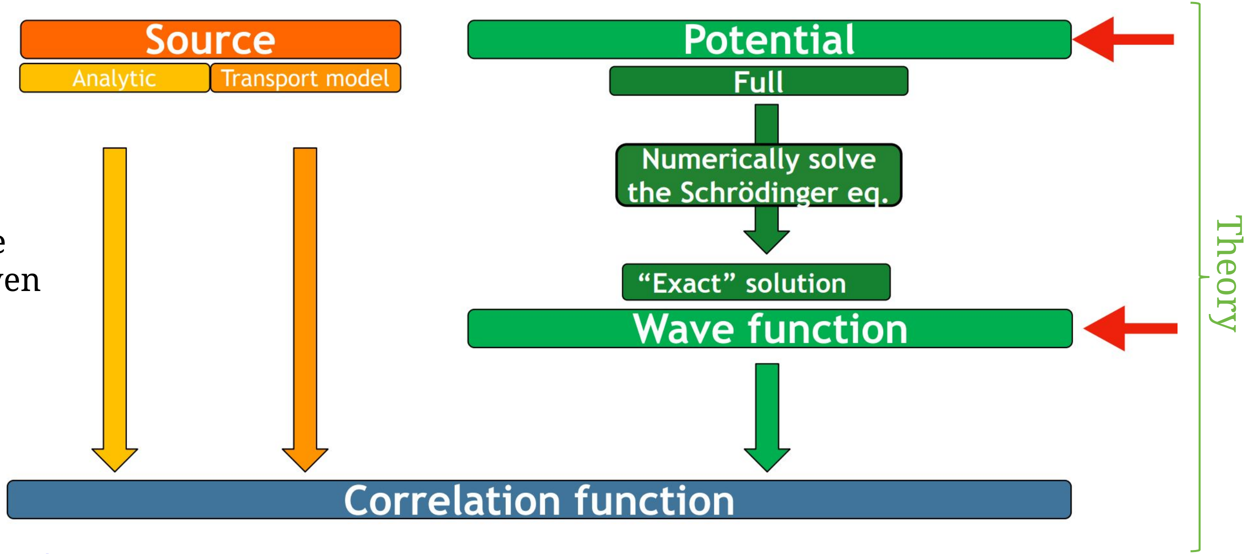
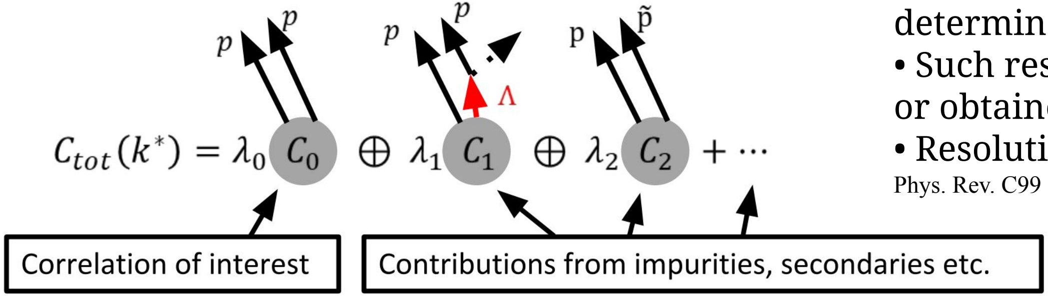
λ = 0.64 ±0.06
K-p ⊕ K+p̄
Coulomb
Coulomb+Strong (Kyoto Model)
Coulomb+Strong (Jülich Model)
0.7 < ST < 1
C(k*)
n-σ
k* (MeV/c)

CATS: Correlation Analysis Tool Using the Schrödinger Equation
D.L.Mihaylov et al. Eur.Phys.J. C78 (2018) no.5,394

Provides a exact solution computing the correlation function from the model given a local potential or wave function form.



Decomposition of the correlation function



- Purities and contributions from weak decays determined from fits to experimental data
- Such residual correlations modelled (weak decays) or obtained from data (impurities)
- Resolution effects applied to the fit function

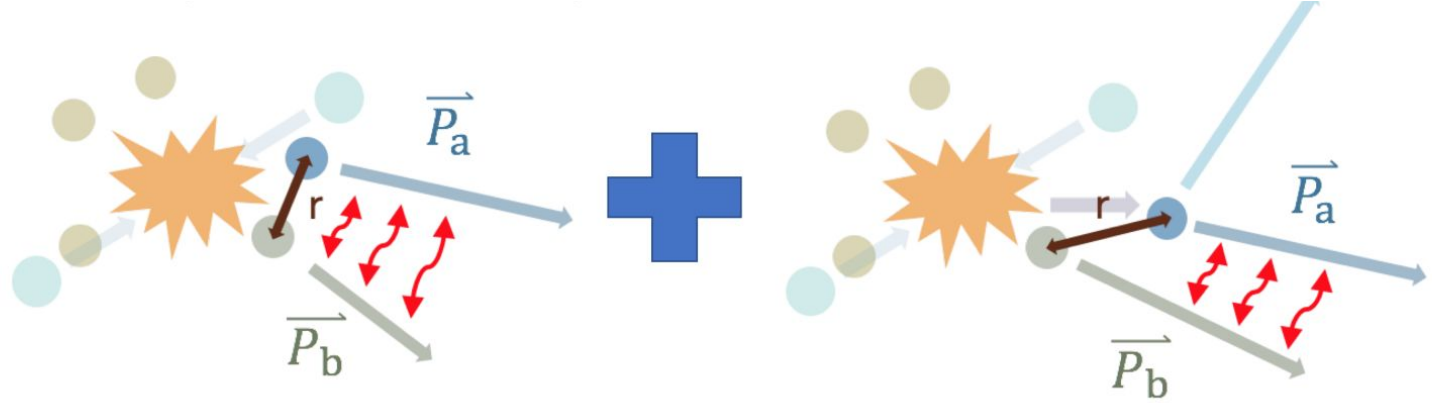
Phys. Rev. C99 (2019) no.2, 024001

Experiment

Effect of resonances in the source

Resonances with $c\tau >> r_0$
- Decrease of the correlation strength
- Taken into account by the λ **parameters**

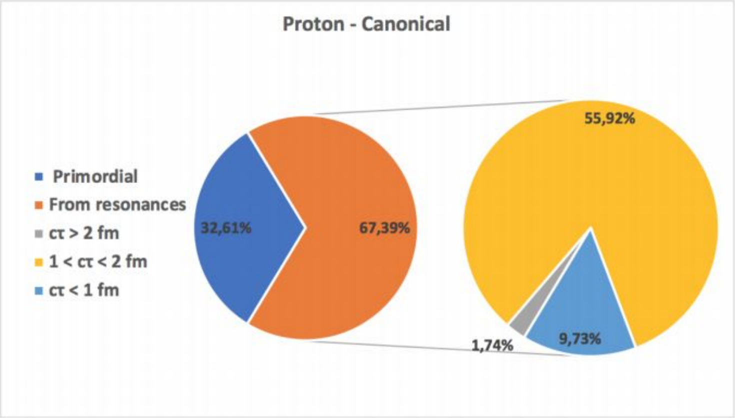
Resonances with $c\tau \sim r_0 \sim 1$ fm:
- Introduce an **exponential tale**
  - example: N*(Γ~150-200 MeV), Δ (Γ~150 MeV), etc
  - Specific exponential modulation to each pair due to different strong decaying resonances feeding to the different particle species

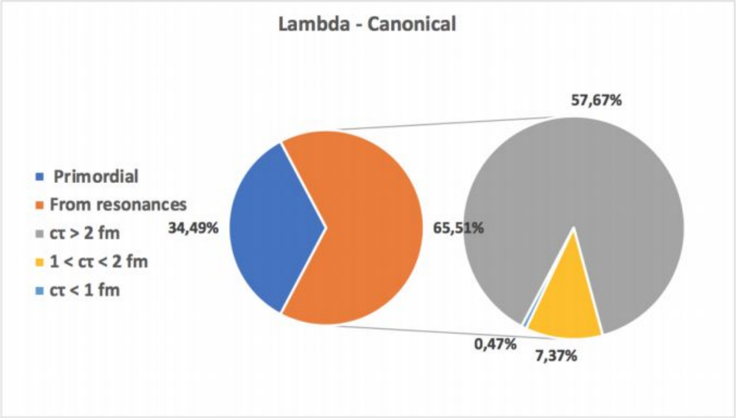


Details on resonances

Amount of resonances: Canonical approach of the statistical hadronization model (SHM)

- $T = 166$ MeV & $\gamma_s \sim 0.8$ (Private Comm Prof. F. Becattini, J. Phys. G38 (2011) 025002)





- For Ξ and no Ω contributions!
- Average mass and average cτ determined by the weighted average values of all resonances

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

Modelling the source including resonances

Gaussian Core

$$G(r, r_{core}) = \frac{2\sqrt{\pi}r^2}{r_{core}^3}\exp\left(\frac{r^2}{4r_{core}^2}\right)$$

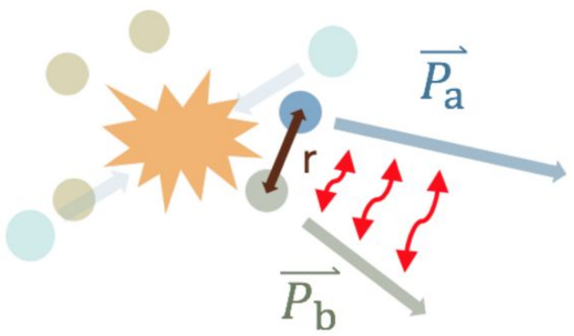
- Shared between particle pairs
- Scales as a function of m_T

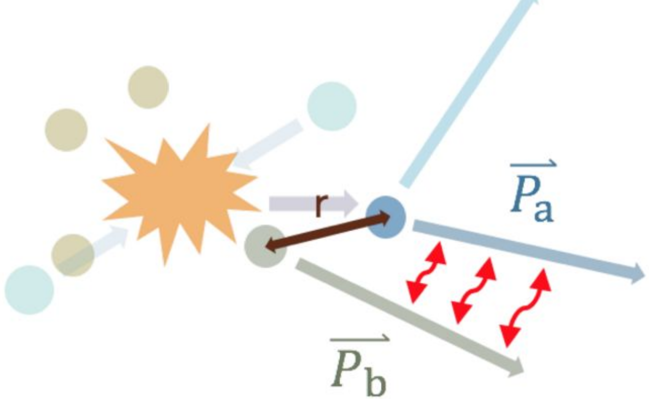
Exponential resonance tail

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

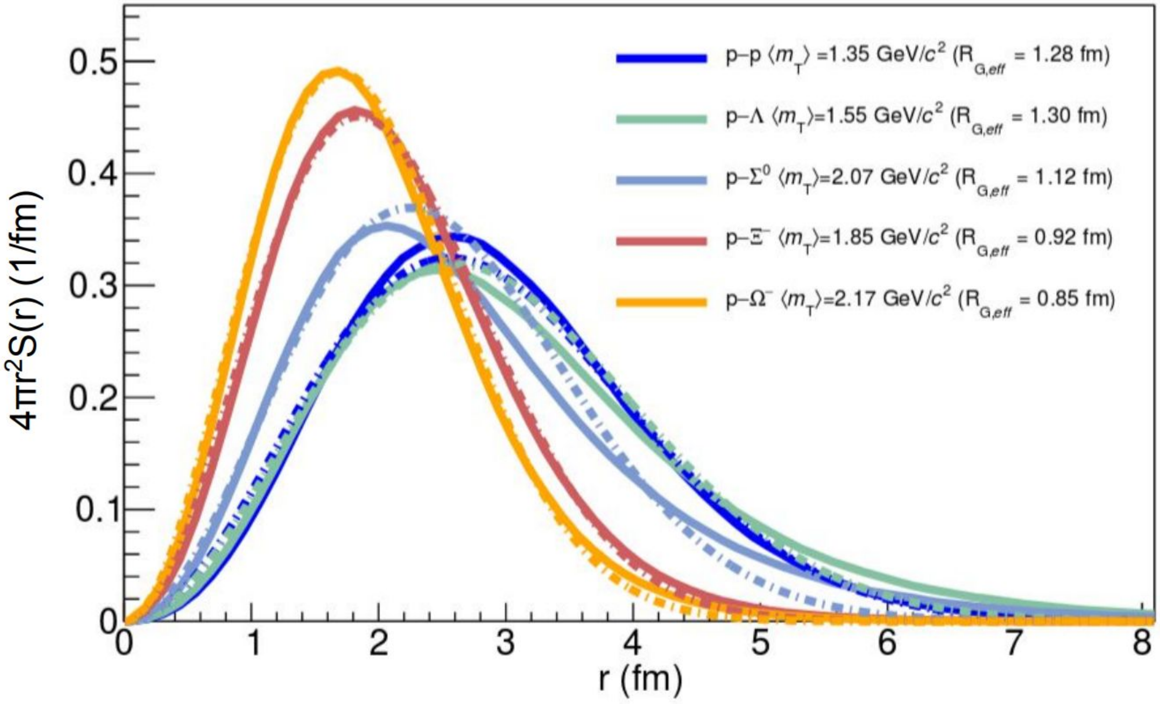
$$s = \beta\gamma\tau_{res} = \frac{p_{res}}{M_{res}}\tau_{res}$$

- Specific modulation of each pair





Gaussian core + resonances



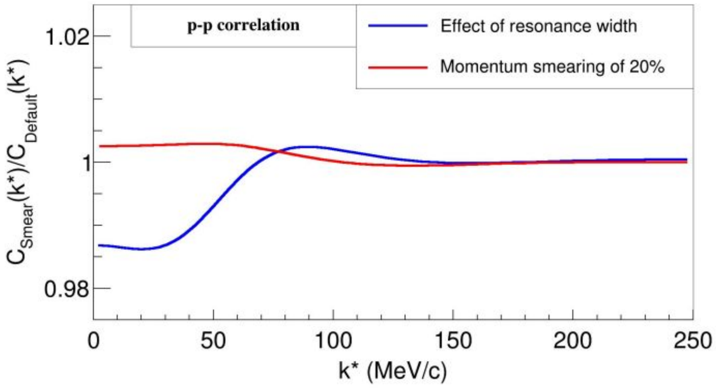
Solid line: Source distribution including the effect of resonances

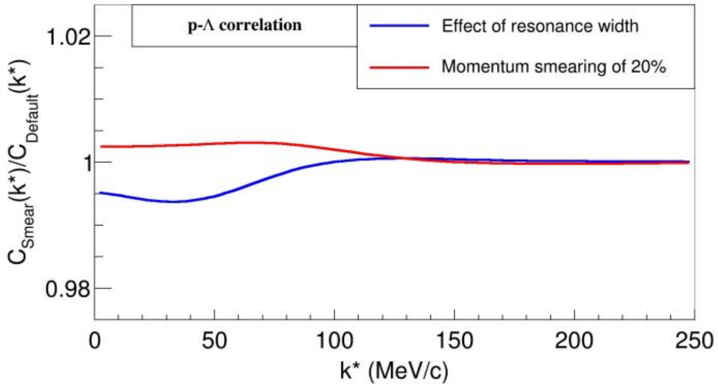
Dashed line: Fit with an effective Gaussian

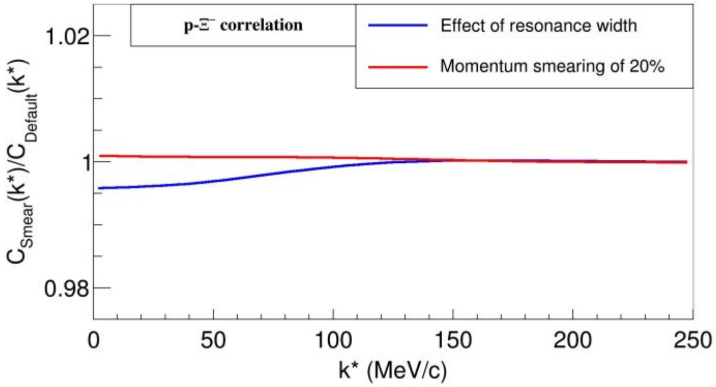
- Direct fit of the p-p correlation function yields similar radius

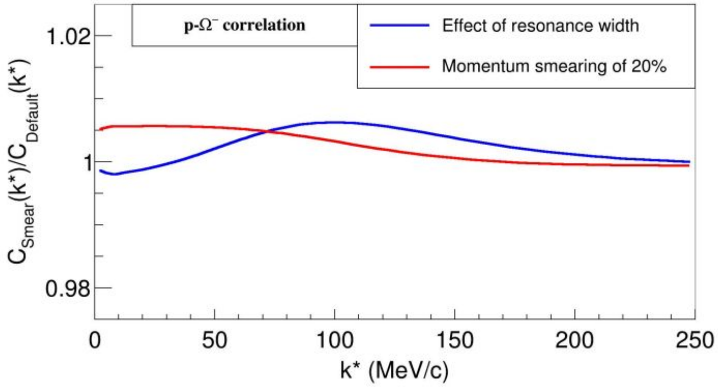
- Resonance contribution to Omega yield negligible.
- Modification of the gaussian core for p-Omega pairs coming only from resonances contribution to the proton yield

Effect on the source when smearing resonances









Setting the **source**

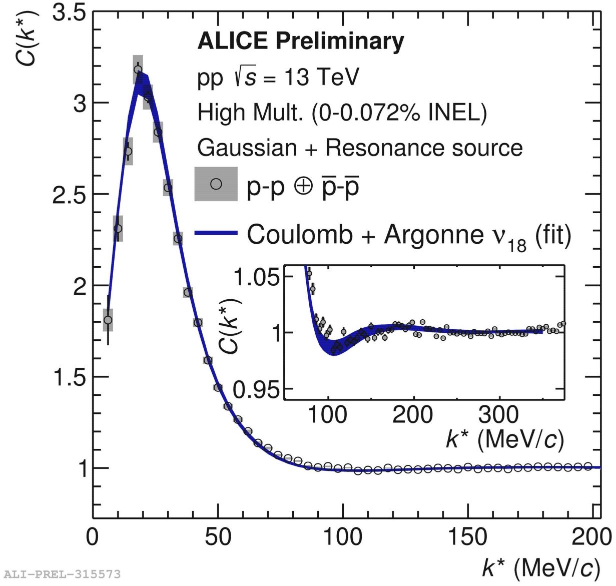
Ansatz: in small collision systems the source is similar for all baryon-baryon, baryon-meson pairs

The characteristics of the source are **determined from femtoscopic analysis of the p-p correlation**:
Assume a p-p known interaction → determination of the source size

- **Consider <m_T> dependence of the source due to collective effects:**
  - Femtoscopic p-p fits performed differentially in <m_T> bins
  - <m_T> dependence cross-checked with p-Λ analysis
- **Effect of strong short-lived resonances** computed for all hadrons
  - Statistical hadronization model in the canonical approach

Priv. comm. Prof. F. Becattini, J.Phys. G38 (2011) 025002

p-p femtoscopy



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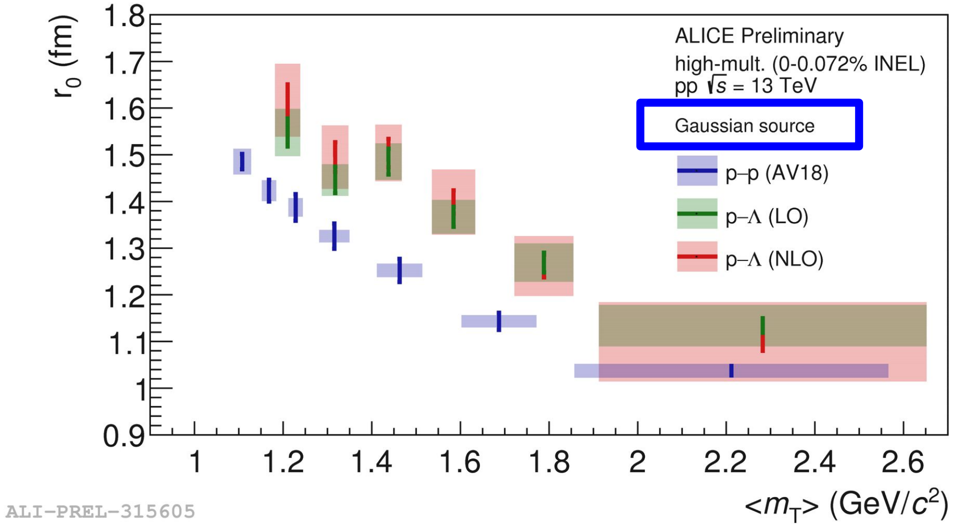
  - <m_T> dependence cross-checked with p-Λ analysis
- **Effect of strong short-lived resonances** computed for all hadrons

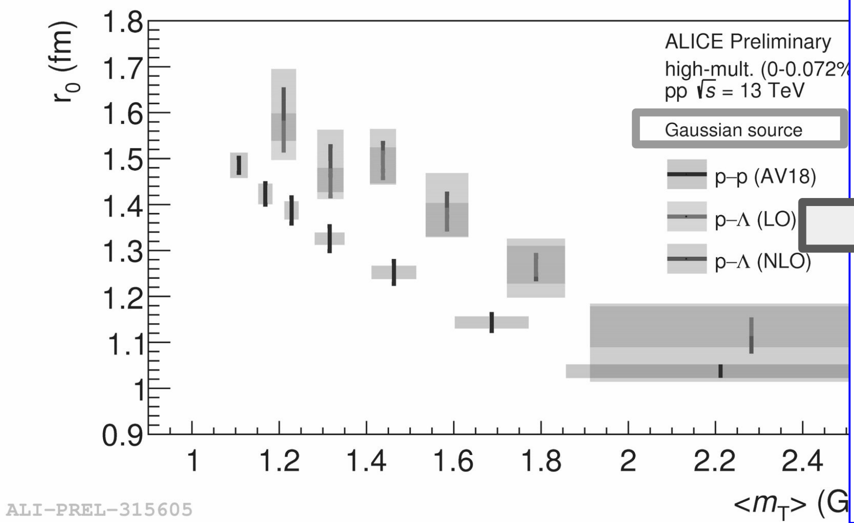


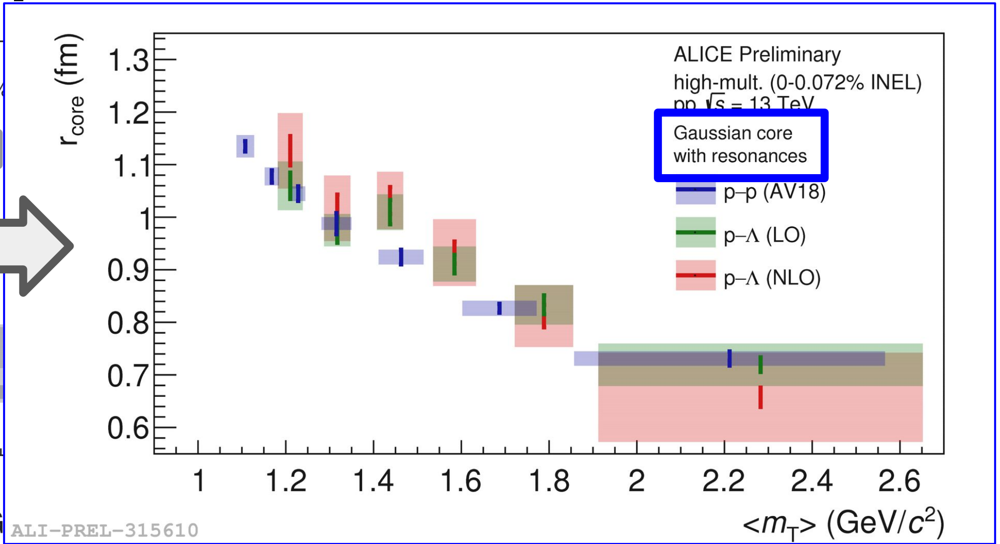
Setting the **source**

<u>Ansatz</u>: in small collision systems the source is similar for all baryon-baryon, baryon-meson pairs

The characteristics of the source are **determined from femtoscopic analysis of the p-p correlation**:
Assume a p-p known interaction → determination of the source size

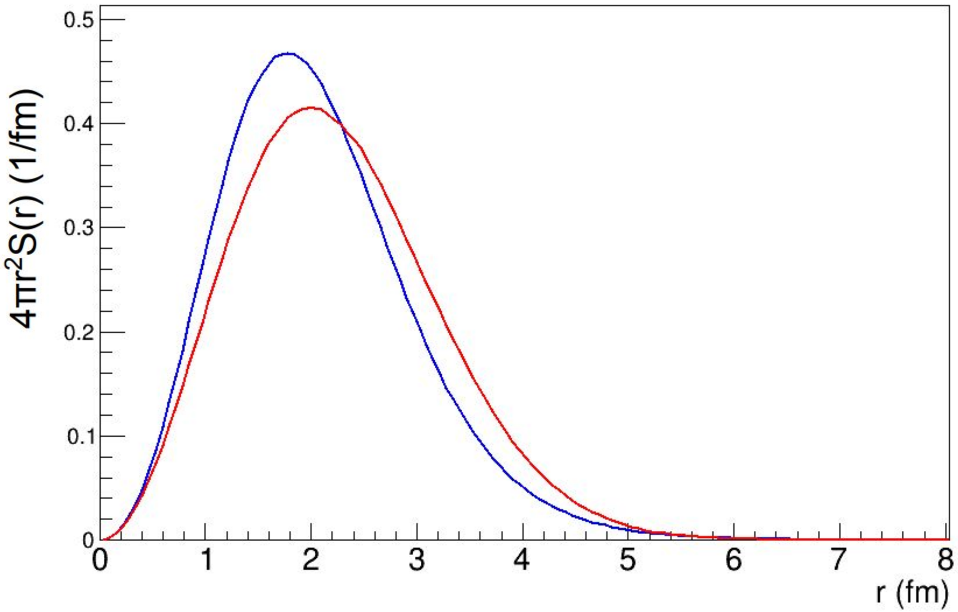
- **Consider <m$_T$> dependence of the source due to collective effects:**
  - Femtoscopic p-p fits performed differentially in <m$_T$> bins
  - <m_T> dependence cross-checked with p-Λ analysis
- **Effect of strong short-lived resonances** computed for all hadrons



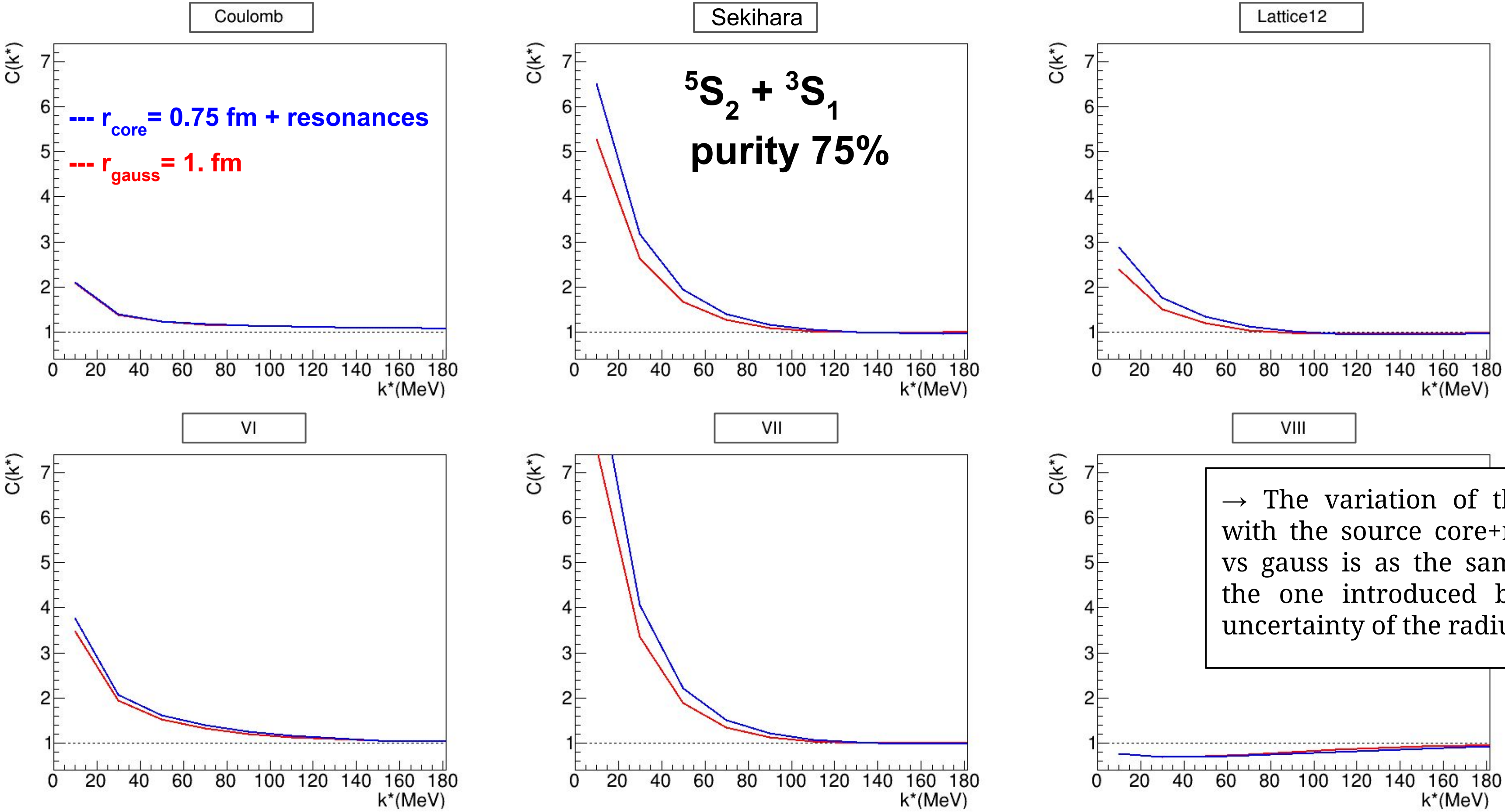


p-Ω^- Correlation function: source dependence

- Comparison of the C(k*) for the different models for different source assumptions
- Size of the source determined from p-p fitted radius vs $\langle m_T \rangle$
    - core gaussian source + resonances effects
    - pure gaussian source



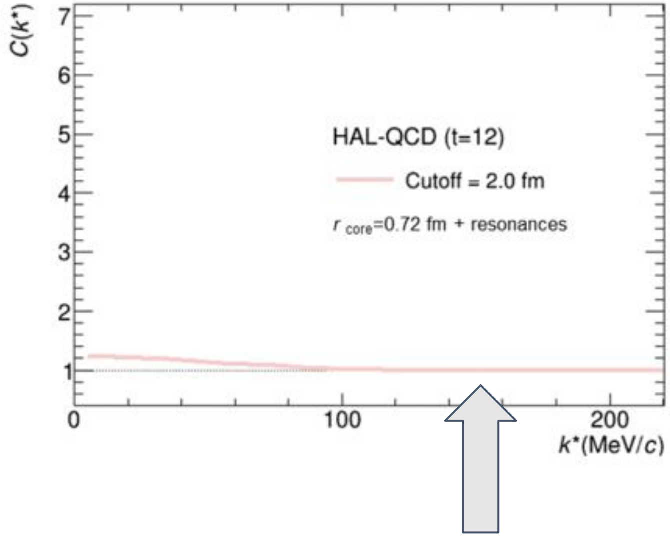
p-Ω^- Correlation function: source dependence



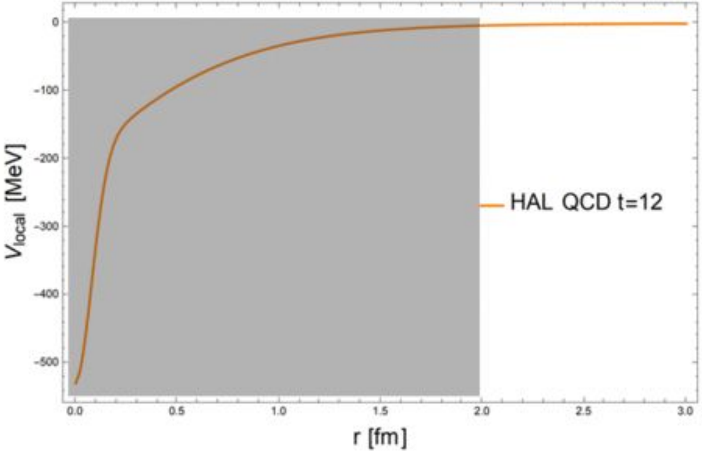
→ The variation of the models with the source core+resonances vs gauss is as the same level as the one introduced by the the uncertainty of the radius size

p-Ω^- Correlation function ($^5S_2$) with distance cutoff

- Correlation function from $^5S_2$ channel with cutoff in r (for $r < r_{\mathrm{cutoff}} \Rightarrow V = 0$)
- **HAL-QCD with physical quark masses (t=12): maximum of the $C(k^*)$ for $r_{\mathrm{cutoff}} = 0.5$ fm**



Precision of ALICE data ~5%



$^5S_2$

p-Ω^- Correlation function ($^5S_2$) with distance cutoff

- Correlation function from $^5S_2$ channel with cutoff in r (for $r < r_{\mathrm{cutoff}} \Rightarrow V = 0$)
- **HAL-QCD with physical quark masses (t=12): maximum of the $C(k^*)$ for r_{cutoff} = 0.5 f**
- For **VI potential (<u>no bound state</u>)** ***C*(*k**) always increases** with decreasing r_{cutoff}