Unveiling the strong interaction among hadrons at the LHC

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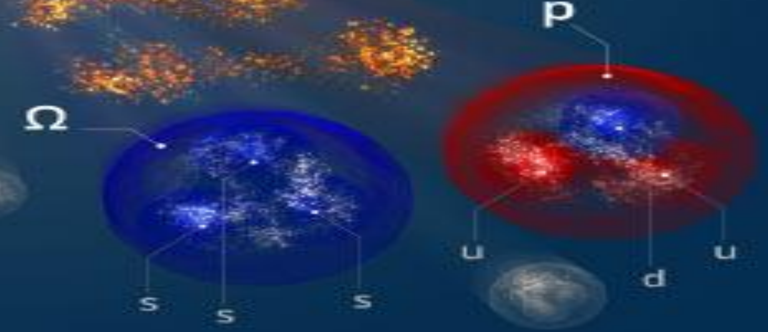

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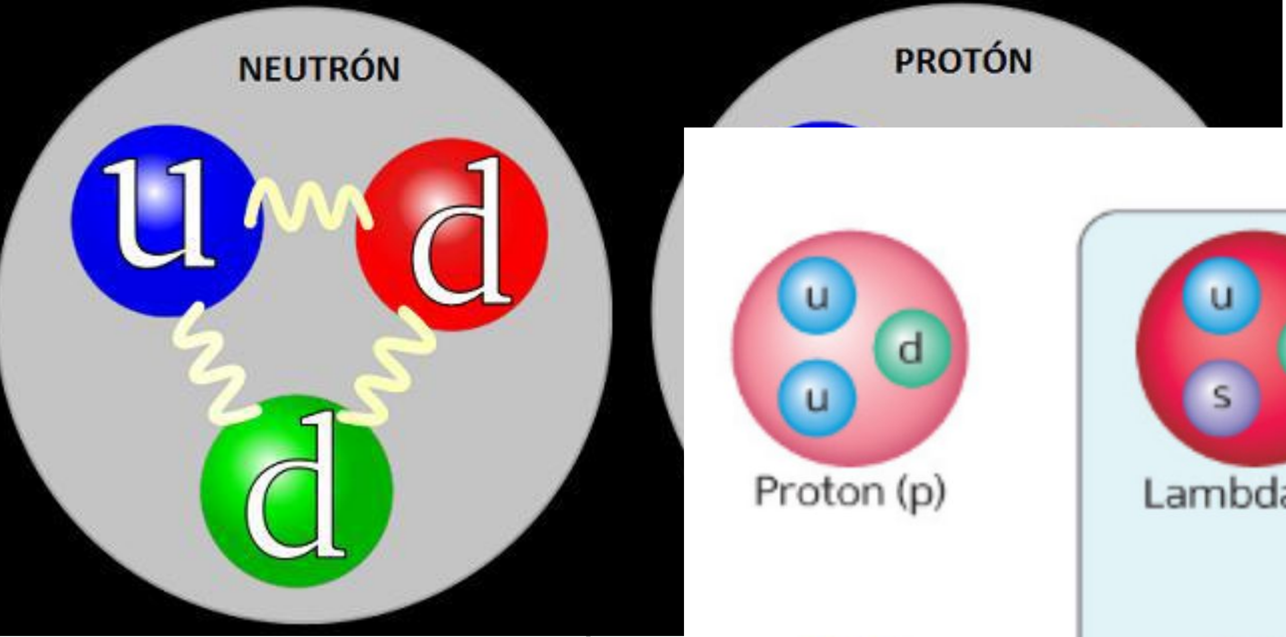
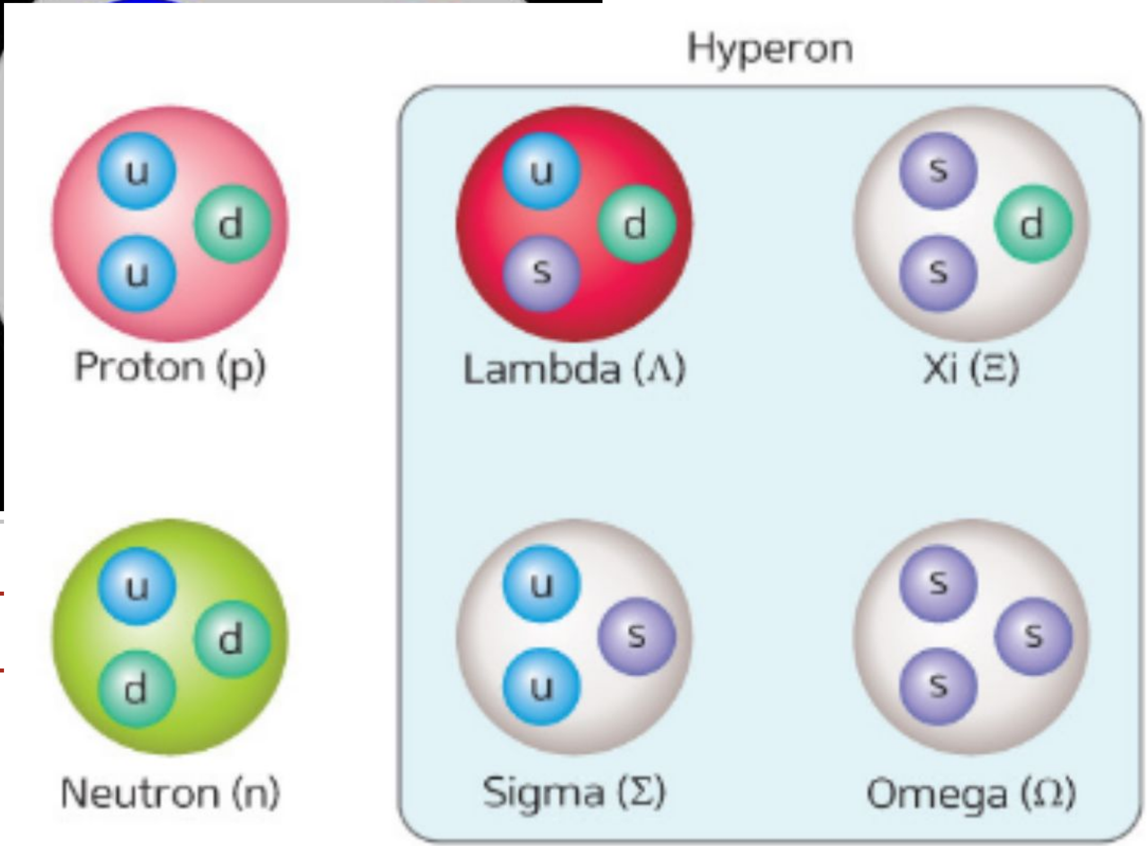
4. Summary

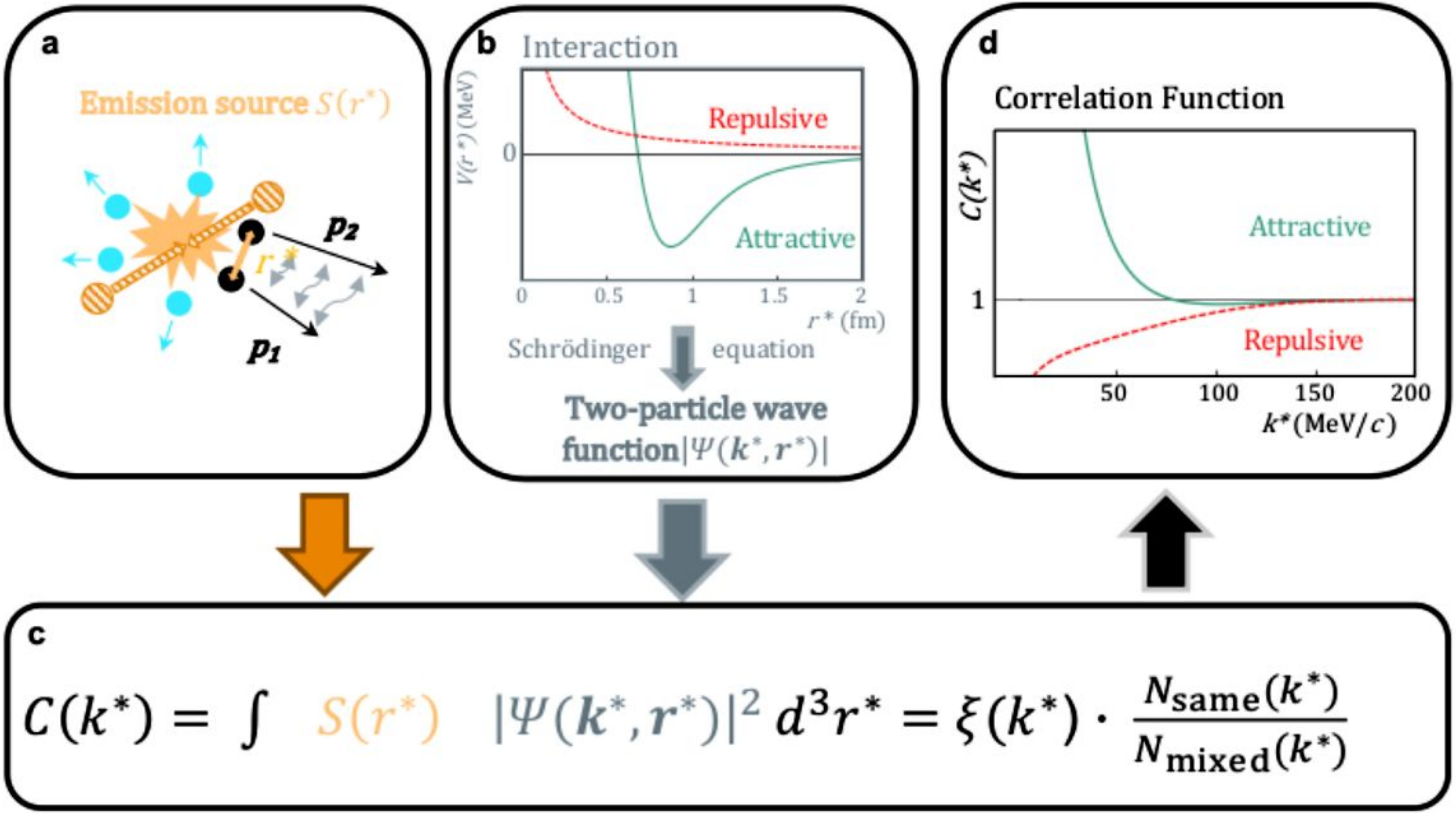
STANDARD MODEL OF ELEMENTARY PARTICLES


NEUTRÓN
u
d
d
PROTÓN


Hyperon
u
u
d
Proton (p)
u
d
s
Lambda (Λ)
s
d
s
Xi (Ξ)
u
d
d
Neutron (n)
u
s
u
Sigma (Σ)
s
s
s
Omega (Ω)

Hyperon

- One of the current challenges in nuclear physics is to calculate the **strong interaction among hadrons** starting from first principles.
- Perturbative techniques are used to calculate strong-interaction phenomena in high-energy collisions with a level of precision of a few percent. For baryon–baryon interactions at low energy such techniques cannot be employed;
- however,**numerical solutions on a finite space-time lattice** have been used to calculate scattering parameters among nucleons and the properties of light nuclei.


a
Emission source $S(r^*)$
p_2
p_1
r^*
b
Interaction
$V(r^*)$ (MeV)
0
Repulsive
Attractive
0
0.5
1
1.5
2
r^* (fm)
Schrödinger equation
Two-particle wave function $|\Psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|$
d
Correlation Function
$C(k^*)$
Attractive
1
Repulsive
50
100
150
200
k^*(MeV/c)
c
$C(k^*) = \int S(r^*) \; |\Psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2 \, d^3r^* = \xi(k^*) \cdot \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$

Methods

1. Particle Identification
2. Determination of the Source Size
3. Corrections of the Correlation Function

1. Particle Identification

For the identification and momentum measurement of charged particles, the following ALICE detectors are used:

1. Inner Tracking System(ITS),
2. Time Projection Chamber(TPC) and
3. Time Of Flight(TOF) detectors of ALICE

All three detectors are located inside a solenoid magnetic field(0.5 T) leading to a bending of the trajectories of charged particles. The measurement of the curvature is used is used to reconstruct the particle momenta.

(continuation)

- Baryons $\boldsymbol{\Xi}$ and $\boldsymbol{\Omega}$ are detected through their weak decays,

$\boldsymbol{\Xi^- \to \Lambda + \pi^-}$

$\boldsymbol{\Omega^- \to \Lambda + K^-}$

- Both decays are followed by a second decay of the unstable $\boldsymbol{\Lambda}$ hyperon,

$\boldsymbol{\Lambda \to p + \pi^-}$

As consequence, $\boldsymbol{\pi^-}$, $\boldsymbol{K^-}$ and protons have to be detected and then combined to search for $\boldsymbol{\Xi}^-$ and Ω^- candidates

2. Determination of the Source Size

The source size (particle-emitting source) r* is found from the widths of the Gaussian distribution *S(r)*, on the basis of the results of the analysis of the p-p correlation function in pp collisions at $\sqrt{s} = 13\ TeV$.

Assuming a common source for all baryons, its size was studied as a function of the transverse mass (m_T) of the baryon-baryon pair,

$$r_{core} = a.\ m_T^{\ b} + c$$

In these collisions, Ξ^- and Ω^- baryons are produced mostly as primary particles, but about ⅔ of the protons originate from the decay of short-lived resonances with a lifetime of a few *fm* per *c*.

3. Corrections of the Correlation Function

The $\boldsymbol{\xi}$ (k*) accounts for the normalization of the k* distribution from the mixed-events for effects produced by finite momentum resolution and for the influence of residual correlations.

The $N_{mixed}(k^*)$ has to be scaled down because nr of $pairs_{mixed(k)} > pairs_{same(k^*)}$. The normalization parameter $\mathcal{N}$ is chosen such that $C(k^*) = 1$, *for* $500 < k^* < 800$ *MeV/c*

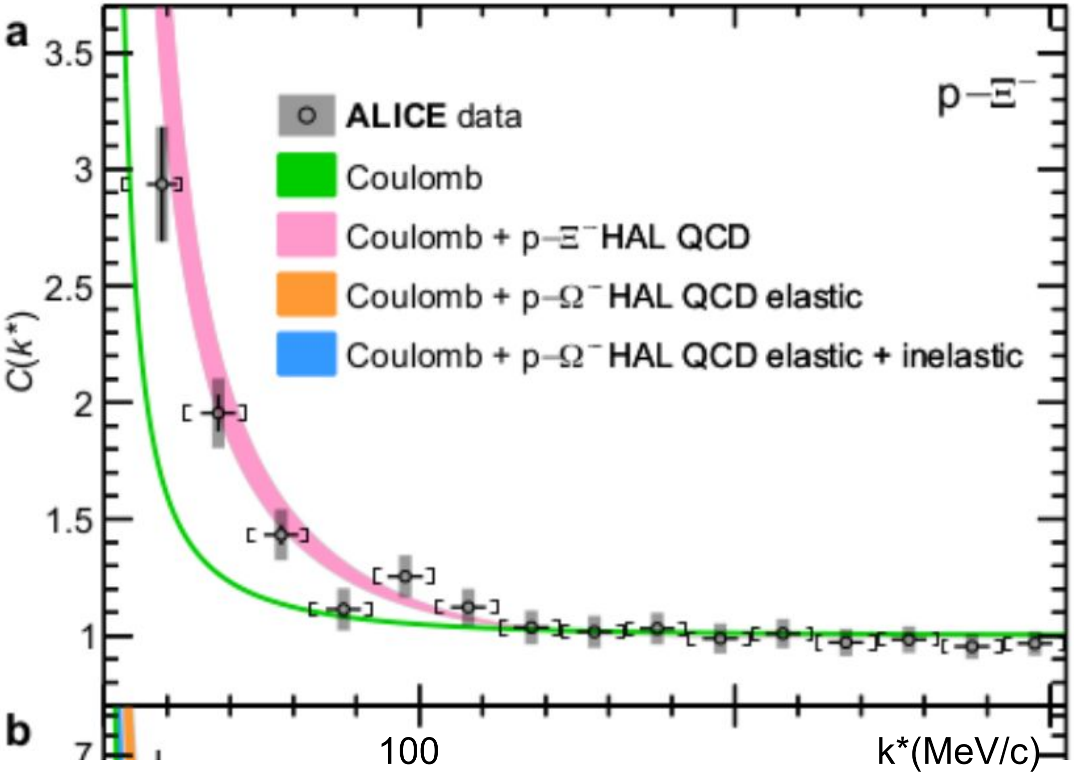
Comparison of the *p-Ξ* and *p-Ω* interactions

In the next next slide, experimental correlations functions is presented along with theoretical predictions, shown as coloured bands. Assuming:

- source-size values of 1.02 ± 0.05 fm for the *p-Ξ* system and 0.95±0.06 fm for the *p-Ω*
- The average m_T of the *p-Ξ* and *p-Ω* pairs are *1.9 GeV/c* and *2.2 GeV/c*, respectively.

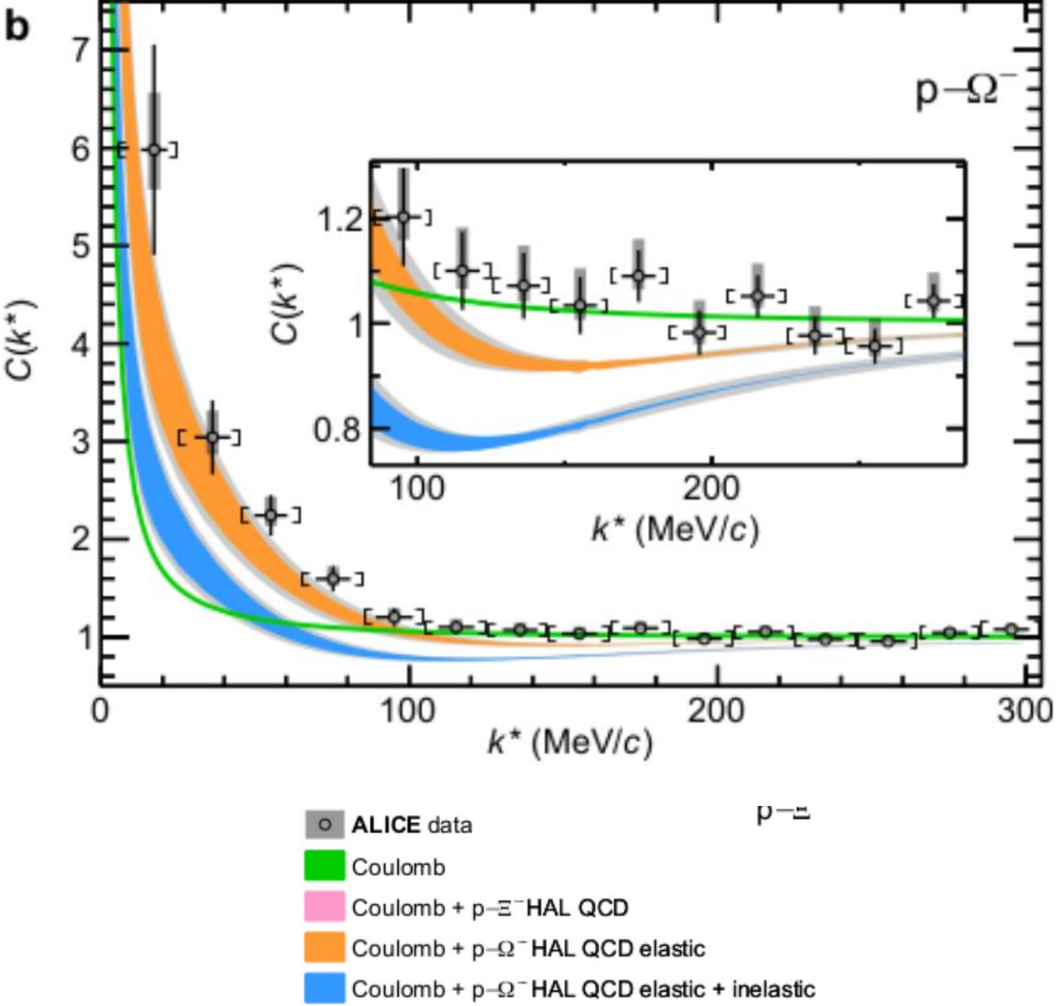
p-Ξ⁻

- *C(k*) > 1* implies the presence of an attractive interaction
- For opposite-charge pairs we have Coulomb attractive interaction
- Marching of experimental data with calculations from first principles by HAL QCD

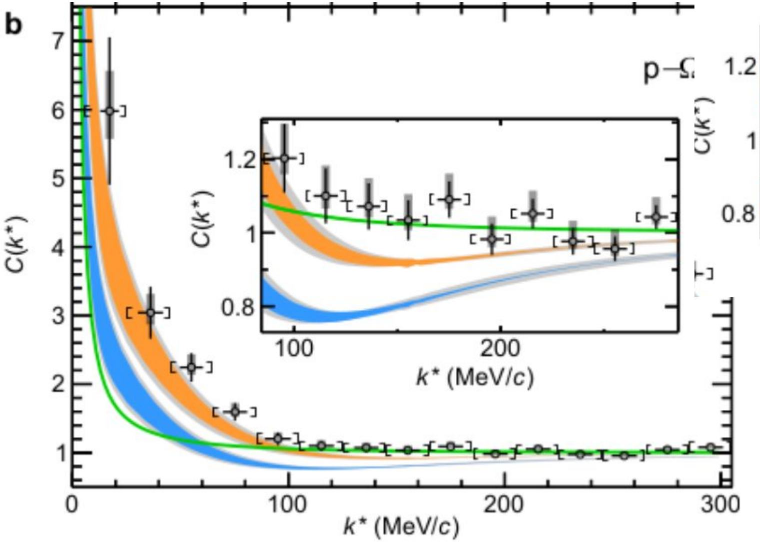


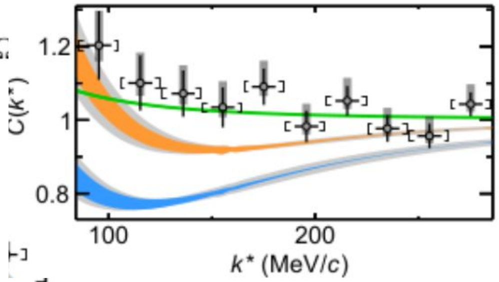
p-Ω⁻

strangeness-rearrangement processes may occur (*pΩ→ΞΛ, ΞΣ*) and may affect *p-Ω* interaction and *C(k*)* depending on the relative orientation of the total spin. Since J_p=½ and the $J_Ω$ = *3/2* and **the total *J* = 2 or *J=1.***



The inset of the previous plot shows that in the region (of k*) between (100 - 300)MeV the data are consistent with unity and do not follow either of the two theoretical predictions.





state J =2

The J =2 state cannot couple to the strangeness-rearrangement processes mentioned behind, except through D-wave processes, which are strongly suppressed.

State J =1

Two limiting cases can be discussed in the absence of measurements of the $p\Omega \rightarrow \Xi\Lambda$, $\Xi\Sigma$ cross sections:

First case: assumes that the effect of the inelastic channels is negligible for both configurations and that the radial behaviour of the interaction is driven by elastic processes, following the lattice QCD potential. This results in a prediction, shown by the **orange curve** that is close to the data in the low k* region.

State J =1

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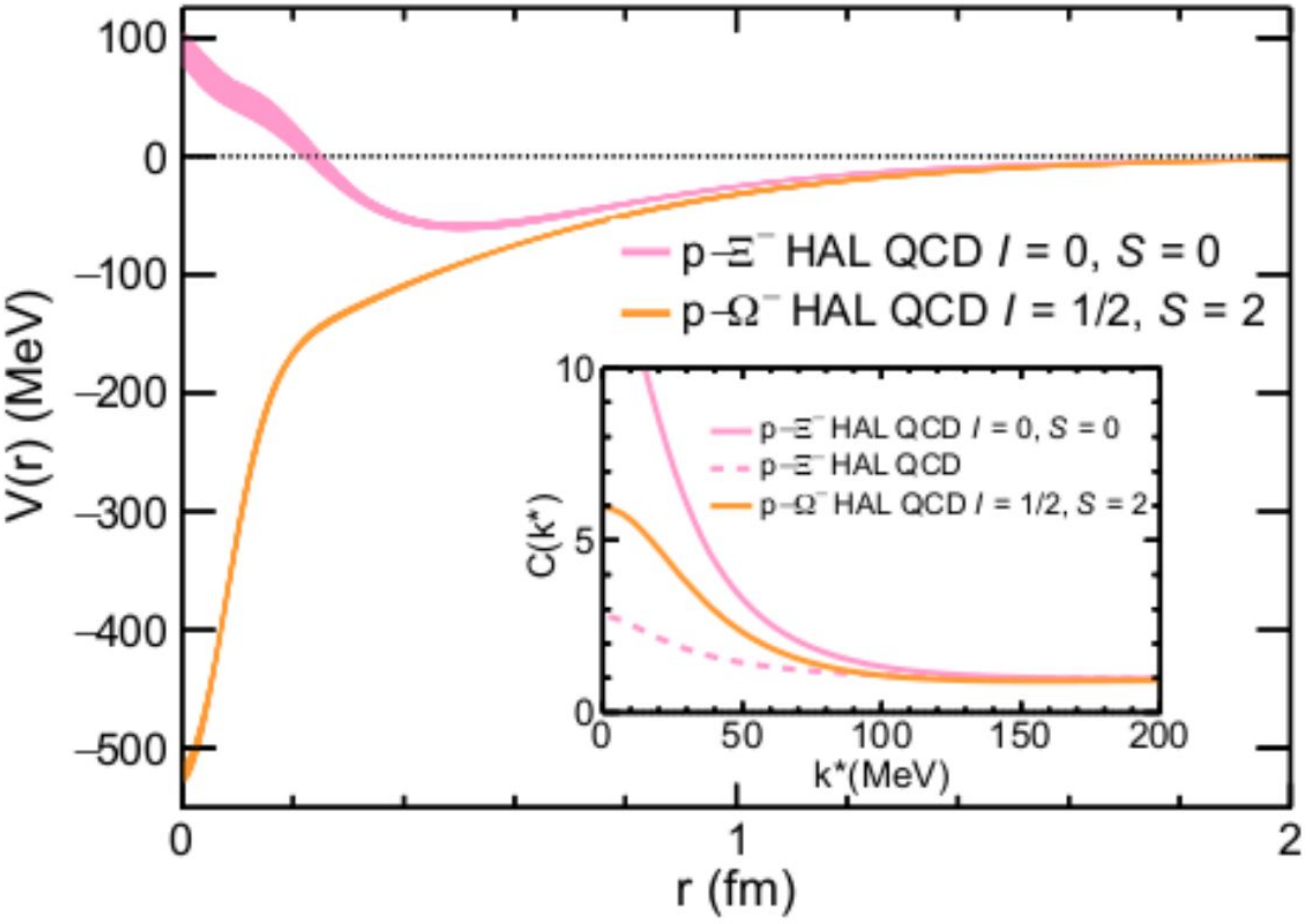
First case: assumes that the effect of the inelastic channels is negligible for both configurations and that the radial behaviour of the interaction is driven by elastic processes, following the lattice QCD potential. This results in a prediction, shown by the orange curve(late plot) that is close to the data in the low k* region.

Second limiting case: the J=1 configration is completely dominated by strangeness-rearrangement processes(**blue curve**). This curve clearly deviates from the data.

Both theoretical calculations predict the existence of a p-Ω bound state with a binding energy of 2.5 MeV/c, because pairs that form a bound state are lost to their correlation yield.

Interaction potentials

Despite the fact that the strong ***p-Ω⁻*** potential is more attractive than the ***p-Ξ⁻***(*I=0, S=0*), the resulting *C(k*)* is lower due to bound state in the ***p-Ω⁻***.



Summary

- hyperon-proton interaction can be studied in detail in pp collisions at $\sqrt{s}$ = 13 TeV at the LHC
- the comparison of the measured correlation functions shows that the ***p-Ω^-*** signal is up to a factor two larger than the ***p-Ξ^-*** signal
- For the ***p-Ω^-*** interaction, the inelastic channels are not yet accounted for quantitatively within the lattice QCD calculations
- The depletion in the correlation function that is visible in the calculations around *k* =150 MeV/c,* owing to the presence of a ***p-Ω^-*** bound state, is not observed in the measured correlation.

Obrigado

khanimambo

thank you