Hadron spectroscopy and hadron-hadron interactions

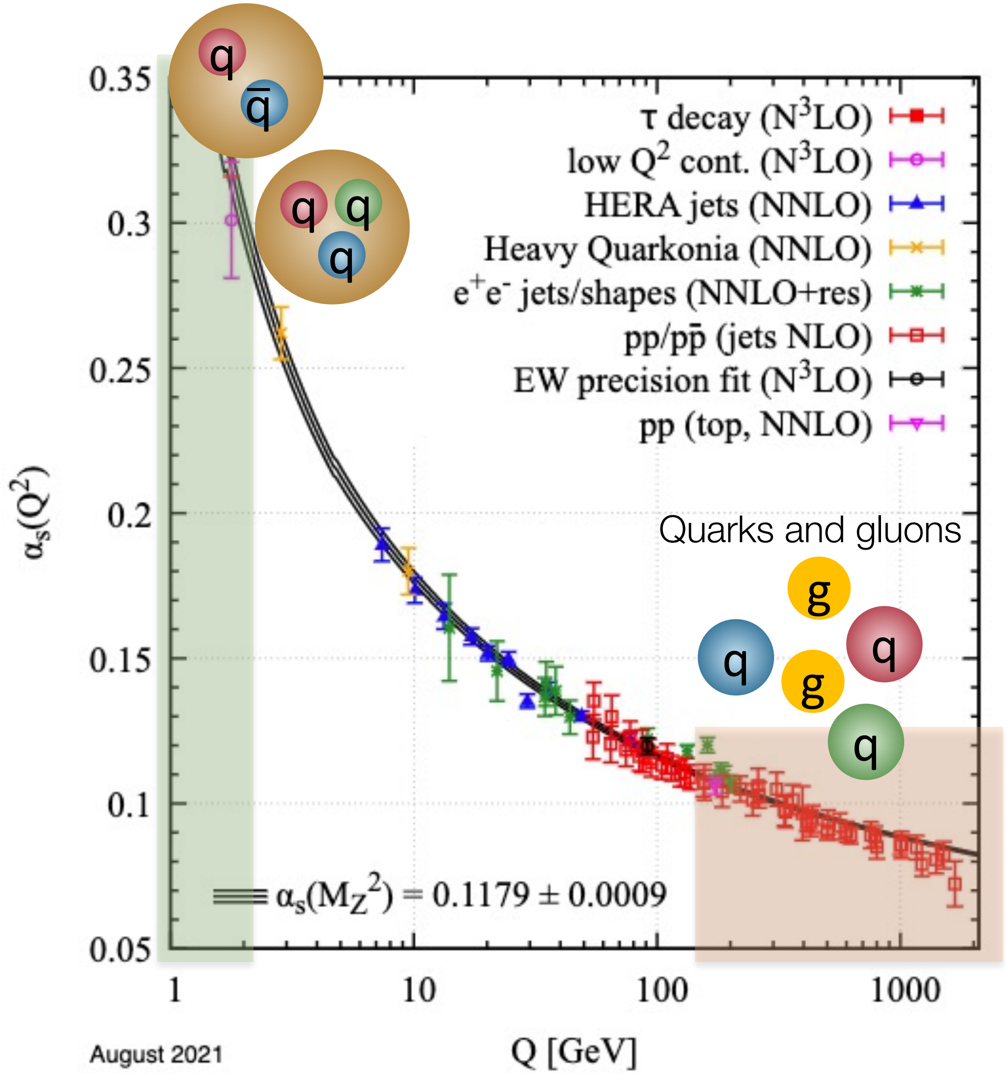
V. Mantovani Sarti (TUM) on behalf of the LHC experiments

LHCP, May 21-26 2023 Belgrade

valentina.mantovani.sarti@cern.ch

Strong interaction between hadrons

Mesons and baryons



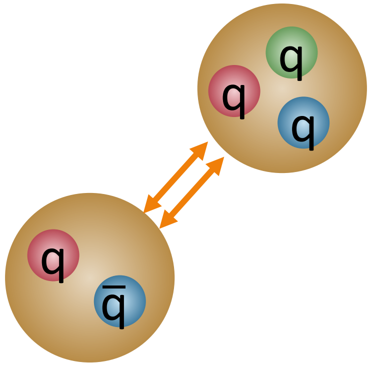
PDG, Prog.Theor.Exp.Phys 2022, 083C01(2022)

- Understanding how QCD evolves from high-energy to low-energy regime

How do hadrons emerge?

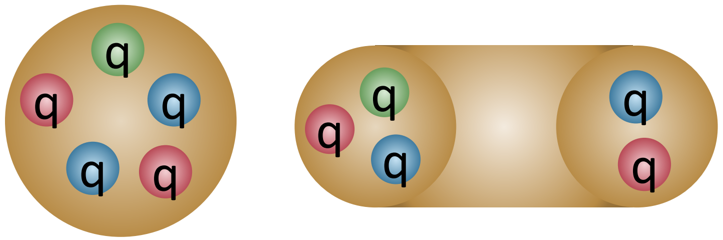
How do hadrons interact?

2-body and many-body interactions



How is the QCD spectrum organized?

Bound states/resonances
Conventional and exotic states



Need for experimental data

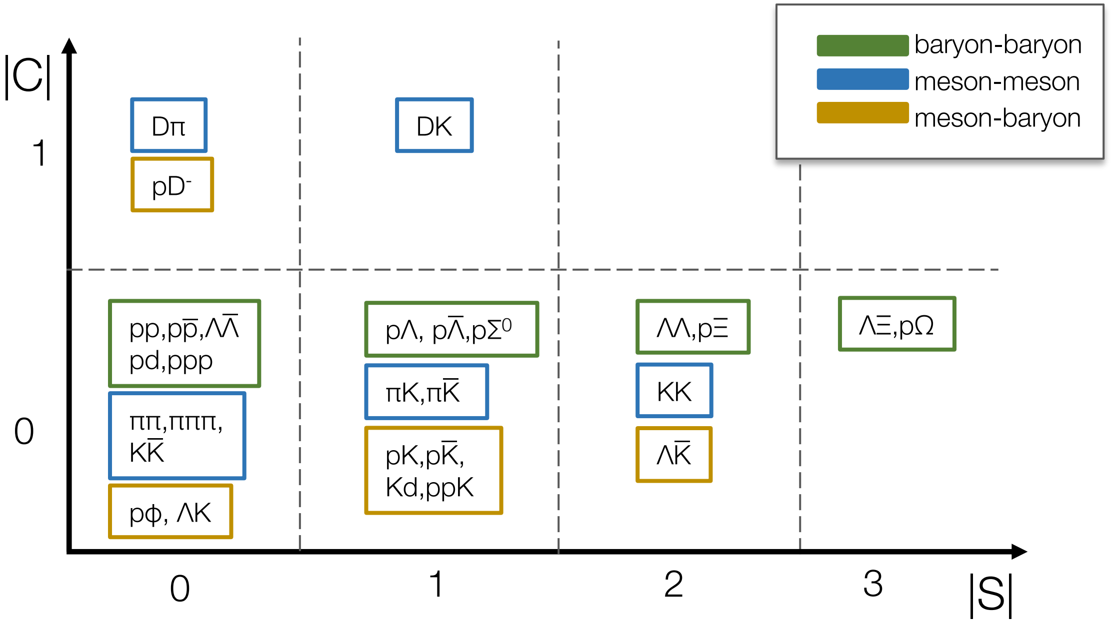
Spectroscopy and femtoscopy at LHC

ALICE · ATLAS EXPERIMENT · CMS · LHCb

Correlations

ALICE major player in the study of hadronic interactions, contributing also in investigations on the emitting source

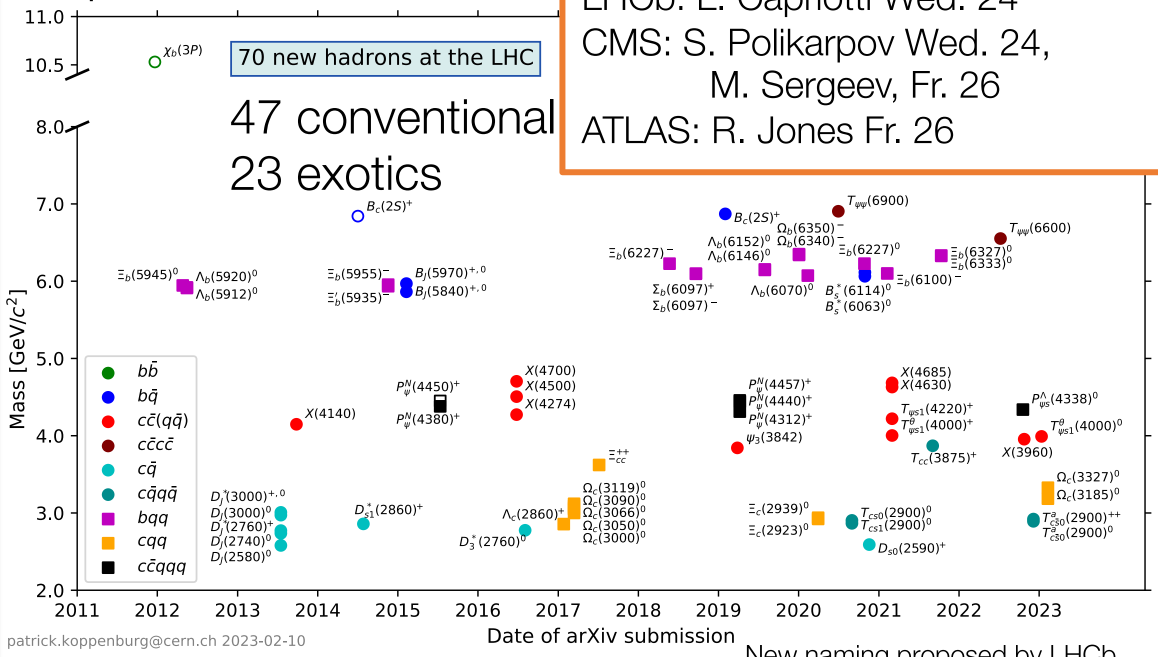
CMS and **ATLAS** providing significant input to source size and interaction studies



Spectroscopy

LHCb major player in the exotic and conventional spectroscopy sectors thanks to the dedicated design

CMS and **ATLAS** largely contributing to beauty and quarkonium sectors



LHCb: L. Capriotti Wed. 24
CMS: S. Polikarpov Wed. 24,
M. Sergeev, Fr. 26
ATLAS: R. Jones Fr. 26

https://www.nikhef.nl/~pkoppenb/particles.html

New naming proposed by LHCb
arXiv:2206.1523

Outline

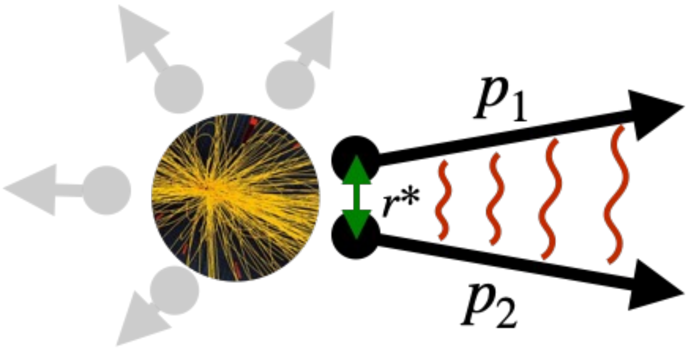
Focus on **strange** and **charm** sector:

- Correlations measurements for
  - Interactions of Λ baryons with protons and K^-
  - First results for correlations with charmed D mesons

- Highlights in the exotic spectroscopy
  - first pentaquark with strange content $P_{\psi s}^{\Lambda}(4338)$ in $B^- \to J/\Psi \Lambda \bar{p}$
  - new tetraquark states $T_{c\bar{s}0}^{a}(2900)^{++,0}$ in $B \to \bar{D} D_S^+ \pi$

Correlations with strange and charm hadrons

The femtoscopy technique at the LHC

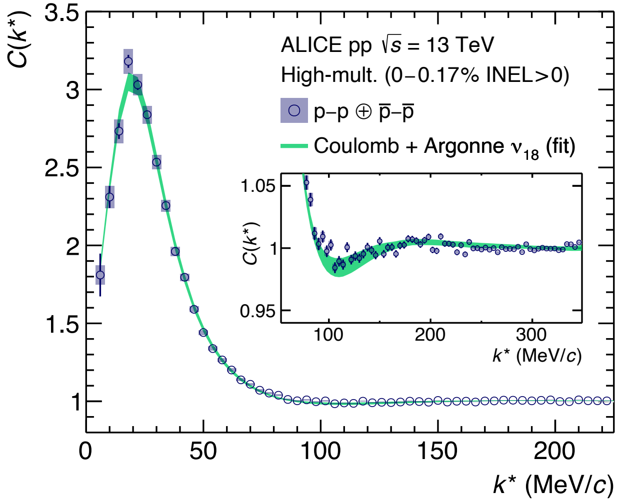


- Access to the **short-range dynamics** between hadrons[1,2]:

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

ALICE measurements shown today in
high-multiplicity pp collisions at 13 TeV
→ **Emitting source anchored to p-p correlation data** [3]
→ Interparticle distances ~1-2 fm in pp collisions

Two-particle wave function[4]
→ Profile of $C(k^*)$ vs nature of the interaction



$$C(k^*) \begin{cases} > 1 & \text{Attractive} \\ < 1 & \text{Repulsive} \\ \gtrless 1 & \text{Bound state} \end{cases}$$

[1] M.Lisa, S. Pratt et al, Ann.Rev.Nucl.Part.Sci. 55 (2005), 357-402
[2] L. Fabbietti, VMS and O. Vazquez Doce ARNPS 71 (2021), 377-402
[3] ALICE coll., PLB, 811 (2020), 135849
[4] D. Mihaylov et al., EPJC 78 (2018), 5, 394

The ΛN interaction in neutron stars

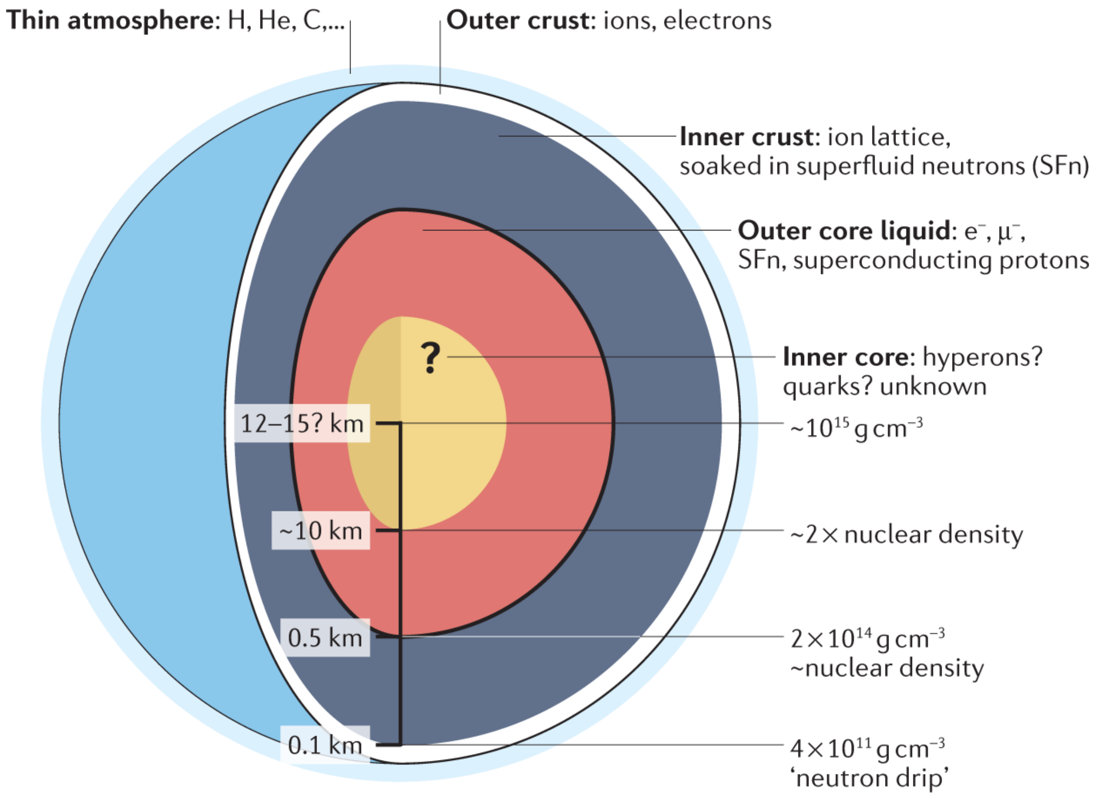
- Constraining the ΛN interaction in vacuum

  → How Λ hyperons behave at finite density?
  → Are there hyperons inside neutron stars?

- High density in the core of neutron stars

  → Production of hyperons as Λ at $\rho \sim 2\text{-}3\rho_0$ and softening of the equation of state
  → Incompatibility with astrophysical measurements of $M_{NS} \gtrsim 2\ M_\odot$
  → Long-standing **hyperon puzzle**

High-precision data on 2-body hyperon-nucleon interaction



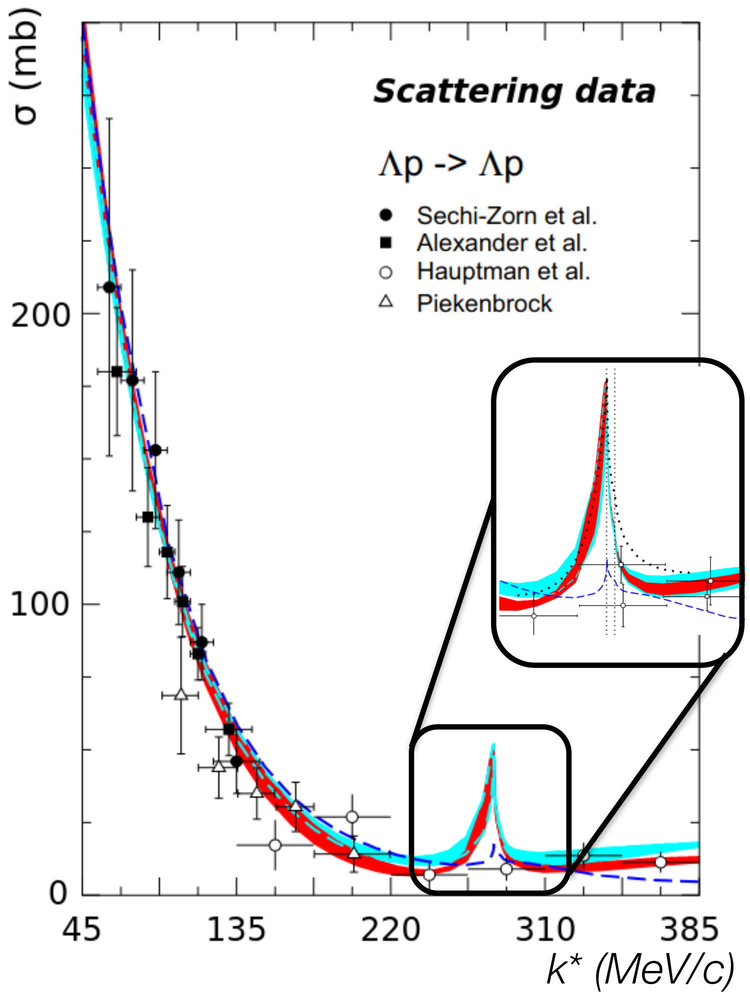
Nature Reviews Physics 4 (2022)
Figure adapted from NICER

The pΛ interaction so far…

- Mainly investigated with **scattering data**
  → High-precision results by CLAS at large momenta[1]
  → Large uncertainties at low momenta and not available down to threshold

- Cusp structure at ΣN opening
  → Coupling ΛN-ΣN driving the behaviour of Λ at finite ρ [2,3]
  → State-of-art chiral potentials with different ΛN-ΣN strength[3,4]

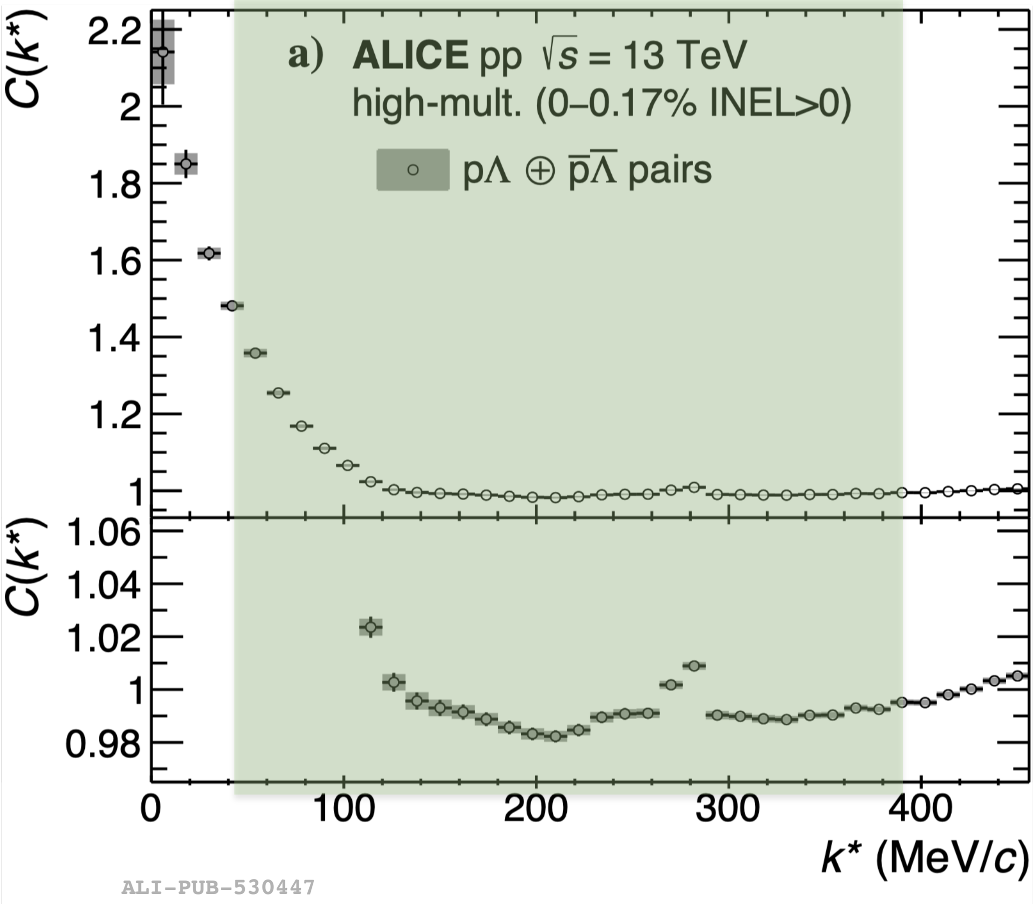
High-precision data on ΛN interaction



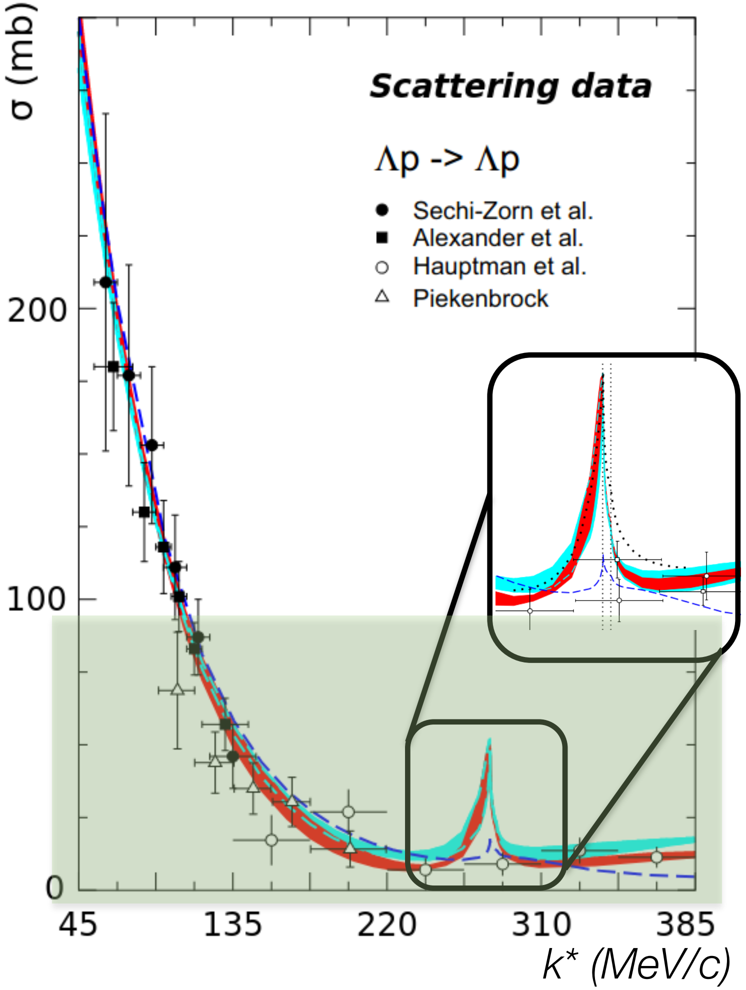
[1] CLAS coll.PRL 127 (2021), 27, 27230
[2] D. Gerstung et al. Eur.Phys.J.A 56 (2020), 6, 175
[3] NLO19: J.Haidenbauer, U. Meiβner, EPJA 56 (2020), 3, 91
[4] NLO13: J.Haidenbauer, N.Kaiser et al., NPA 915, 24 (2013)

The pΛ interaction in the femtoscopy era

ALICE coll. PLB 833 (2022), 137272



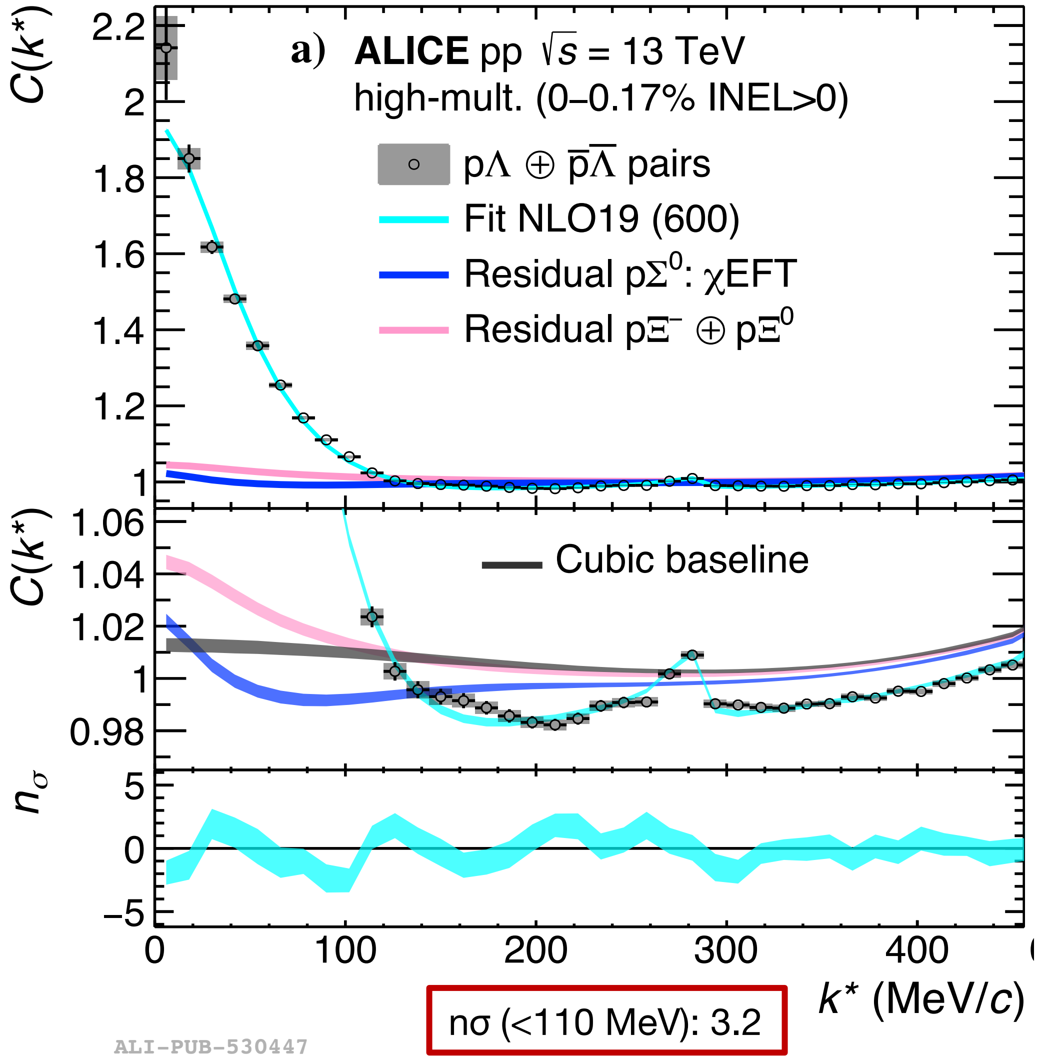
- Measurement down to **zero momentum**
- Factor 20 improved precision (<1%)
- First experimental evidence of ΣN opening in 2-body channel



[3] NLO19: J.Haidenbauer, U. Meiβner, EPJA 56 (2020), 3, 91
[4] NLO13: J.Haidenbauer, N.Kaiser et al., NPA 915, 24 (2013)

The pΛ interaction in the femtoscopy era

ALICE coll. PLB 833 (2022), 137272



nσ (<110 MeV): 3.2

- New scenario for pΛ interaction
  → **Weaker ΛN-ΣN coupling favoured**, important for neutron stars[1]

- Most precise data on pΛ system at low momenta
  → Input for low energy effective models in the strange baryonic sector

- More pieces needed for the hyperon puzzle in LHC Run 3-4
  → $p\Sigma^{+,-}$ and Λd interactions
  → Three-particle ppp and ppΛ interactions[2]

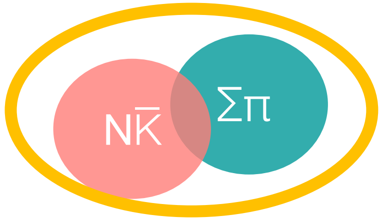
Talk by R. Del Grande
Wed. 24

[1] D. Gerstung et al. Eur.Phys.J.A 56 (2020), 6, 175
[2] ALICE coll. arXiv: 2206.03344

The interaction between kaons and Λ baryons

- **$K^{-}p$ correlations** measured by ALICE in different colliding systems[1]
  → Improve understanding on **Λ(1405) molecular state**[2]

Λ(1405)



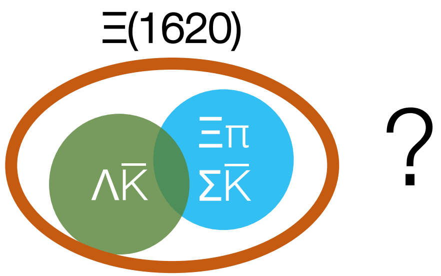
[1] ALICE coll. PRL 124 (2020) 9, 092301, PLB 822 (2021), 136708, EPJC 83 (2023), 4, 340
[2] M. Mai EPJ.ST 230 (2021), 6, 1593-1607

The interaction between kaons and Λ baryons

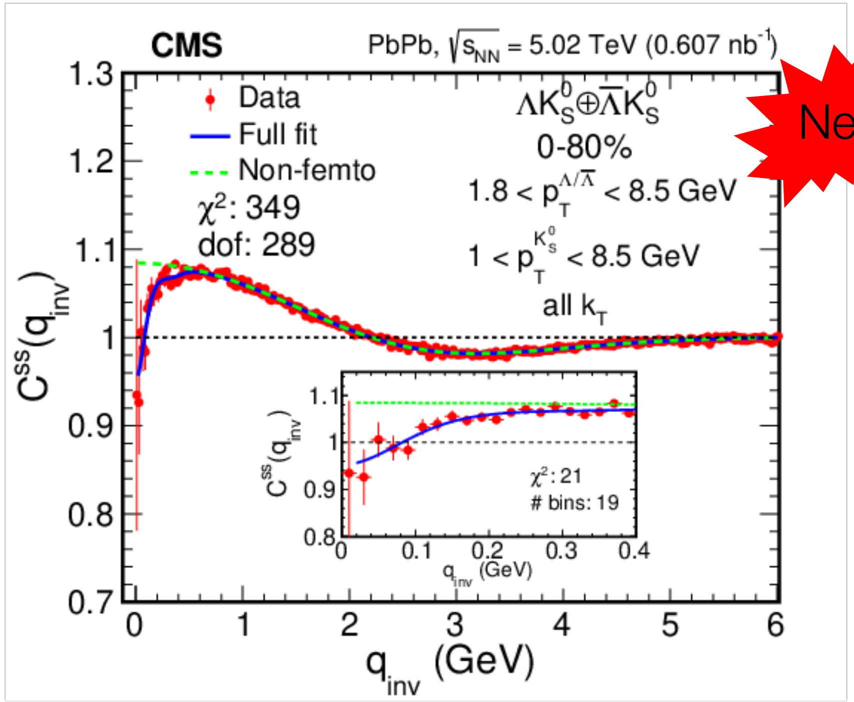
- **K^-p correlations** measured by ALICE in different colliding systems[1]
  → Improve understanding on **Λ(1405) molecular state**[2]

- Similar scenario in **$\Lambda\bar{K}$ interaction with Ξ(1620) state**?
  → Shed light on the nature of Ξ(1620), observed by Belle in $\Xi^-\pi^+$ decay[3]

- Measurements of $\Lambda K^{\pm}$ and ΛK^0_S in Pb-Pb collisions by **ALICE**[4] and **CMS**
  → **First measurement of scattering parameters**



CMS coll. arXiv: 2301.05290



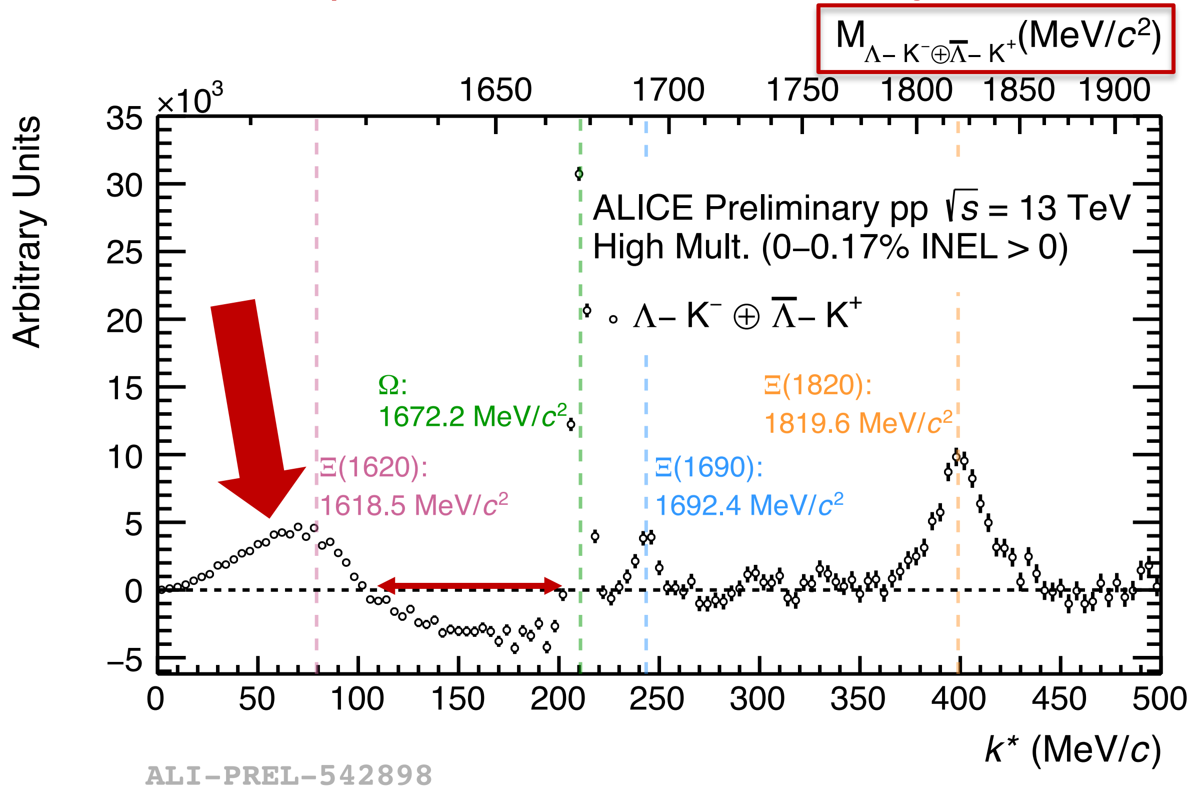
New

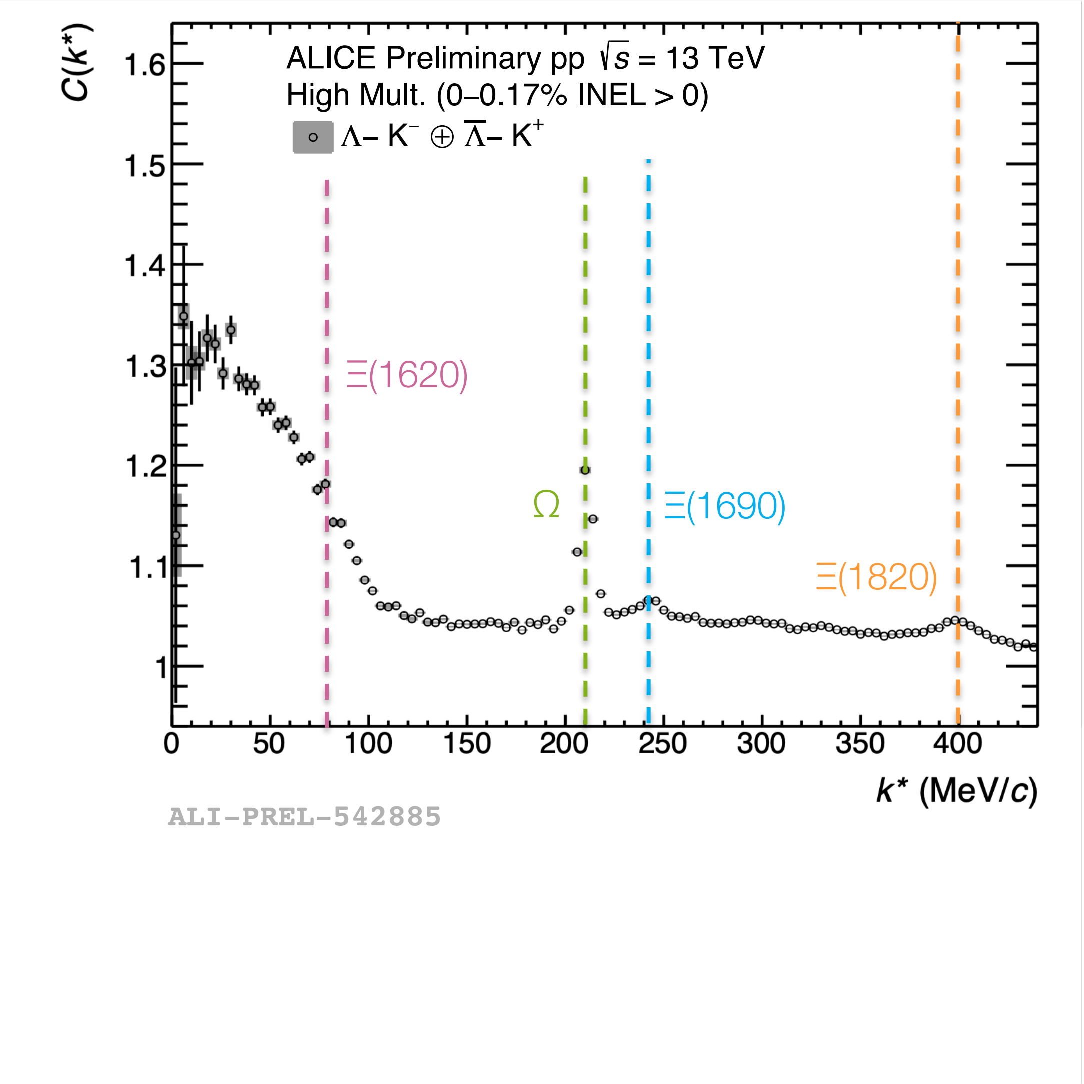
Extend the measurements of ΛK^- correlations in pp collisions

[1] ALICE coll. PRL 124 (2020) 9, 092301, PLB 822 (2021), 136708, EPJC 83 (2023), 4, 340
[2] M. Mai EPJ.ST 230 (2021), 6, 1593-1607
[3] Belle coll. PRL 122 (2019), 7, 07250
[4] ALICE coll. PRC 103 (2021), 5, 055201

The ΛK- correlation in pp collisions

- Several peak structures in the measured correlation
- Invariant mass from same and mixed event distributions used to build the correlation
  - Ξ(1620) just above the threshold
    → First experimental evidence of decay into ΛK^-



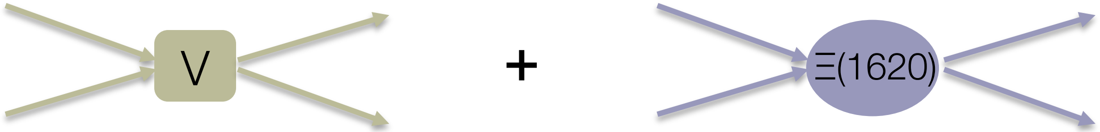


The ΛK⁻ correlation in pp collisions

- Data modeled with the Lednicky-Lyuboshits formula[1]

Non resonant

Resonant



Assuming the effective-range expansion

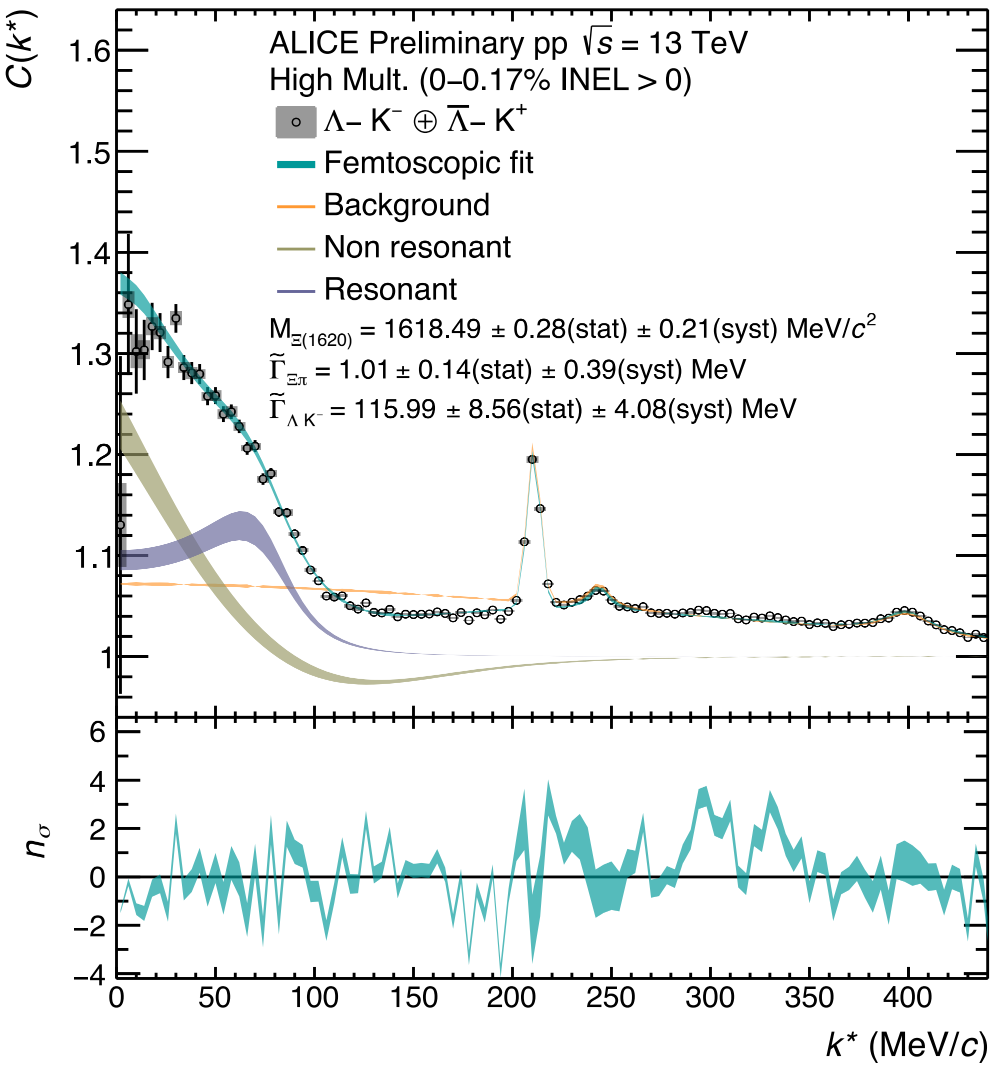
Assuming a Flattè-like amplitude[2] for Ξ(1620)

- **Ξ(1620) properties** and scattering parameters
  → Mass in agreement with Belle[3]

$$M_{\Xi(1620)} = 1618.49^{\pm 0.28(stat)}_{\pm 0.21(syst)}$$

  → Indication of a large coupling of Ξ(1620) to ΛK⁻
  → Non-resonant scattering parameters in agreement with ALICE Pb-Pb results[4]

- High-precision data to constrain effective chiral theories and to understand the Ξ(1620) nature[5,6]



ALI-PREL-542885

[1] R. Lednicky, V. Lyuboshits SJNP 35 (1982)
[2] F. Giacosa et al. EPJA 57 (2021), 12, 336
[3] Belle coll. PRL 122 (2019), 7, 07250
[4]ALICE coll. PRC 103 (2021)), 5, 055201
[5] A. Ramos et al. PRL 89 (2002), 252001
[6] A. Feijoo et al. PLB 841 (2023), 137927

Accessing the strong interaction with charm hadrons

ALICE

- First measurement of the genuine correlation between protons and D⁻ mesons
  → Important input in studies and searches for charm nuclear states[1]
- Comparison with available models
  → Indication of an attractive interaction
  → Compatible also with the formation of bound state

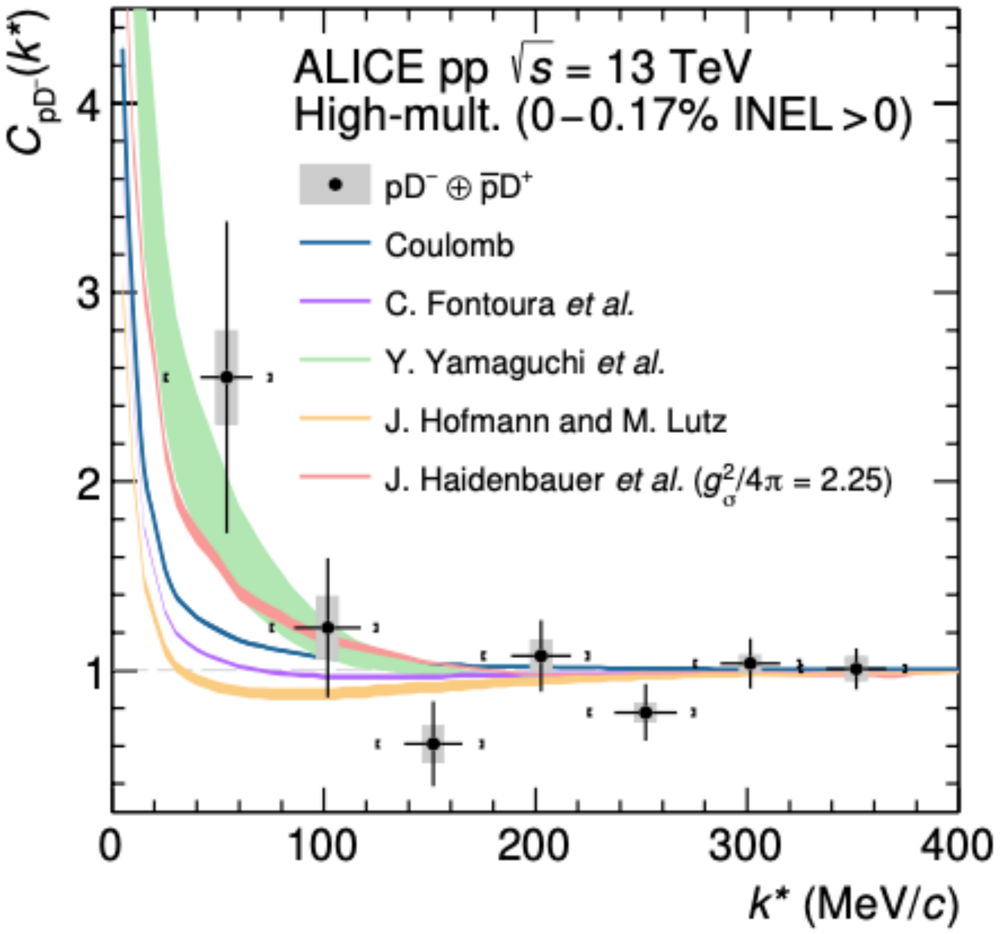
TABLE I. Scattering parameters of the different theoretical models for the N$\bar{D}$ interaction [22–25] and degree of consistency with the experimental data computed in the range $k^* < 200$ MeV/c.

Model	$f_0(I=0)$	$f_0(I=1)$	n_σ
Coulomb			(1.1–1.5)
Haidenbauer *et al.* [22] ($g_\sigma^2/4\pi = 2.25$)	0.67	0.04	(0.8–1.3)
Hofmann and Lutz [23]	−0.16	−0.26	(1.3–1.6)
Yamaguchi *et al.* [25]	−4.38	−0.07	(0.6–1.1)
Fontoura *et al.* [24]	0.16	−0.25	(1.1–1.5)

- New results on Dπ and DK correlations measured by ALICE

Talk by D. Battistini
Fr. 26

ALICE coll. PRD 106 (2022), 5, 052010



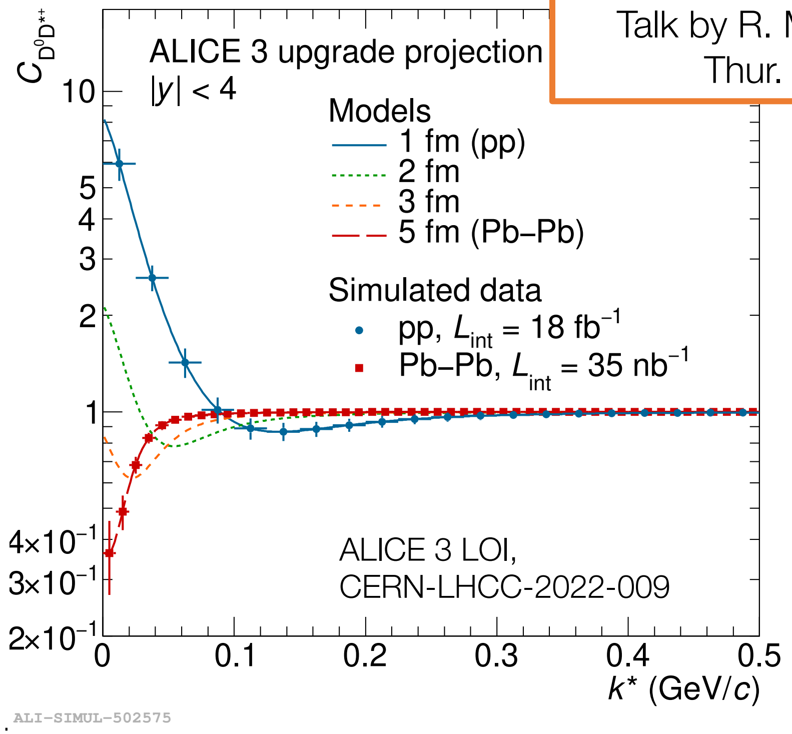
ALI-PUB-502166

[1] A. Hosaka et al. Prog. Part. Nucl. Phys. 96 (2017), 6, 062C01

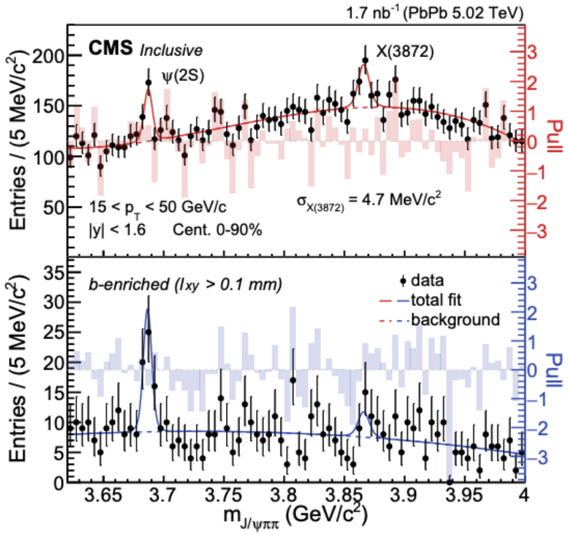
Correlations and exotic states for a charming future

- Exotic charm states as $\mathbf{T_{cc}^{+}}$ or $\boldsymbol{\chi_{c1}(3872)}$ investigated at LHCb and CMS
- Investigate its nature with ALICE 3 in Run 5 and Run 6 via DD* and D$\bar{\text{D}}$* correlations
  → **Complementarity** between spectroscopy and femtoscopy

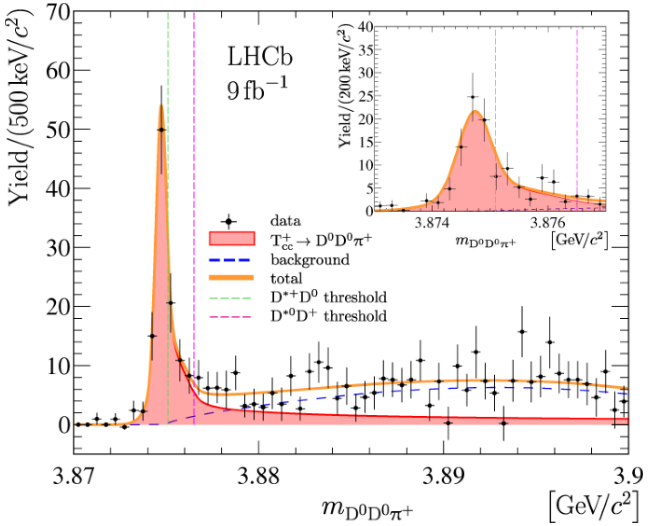
ALICE Upgrade
Talk by R. Münzner
Thur. 25



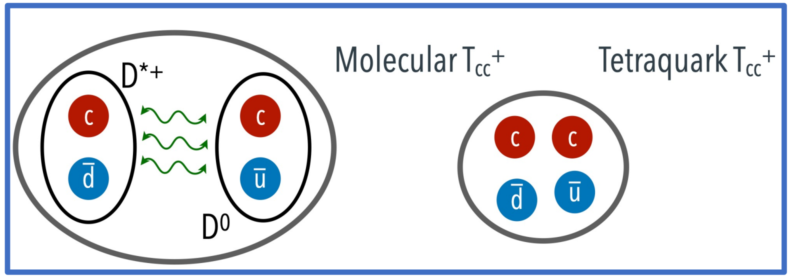
CMS. PRL 128 (2022) 032001



LHCb, Nature Physics 18 (2022)
LHCb, Nature Comm. 13 (2022)



- Interplay between source size and scattering length
  → Size-dependent modification on the C(k*) and insights into the nature of $\mathbf{T_{cc}^{+}}$



Exotic spectroscopy

Pentaquark states in J/Ψp and J/ΨΛ systems

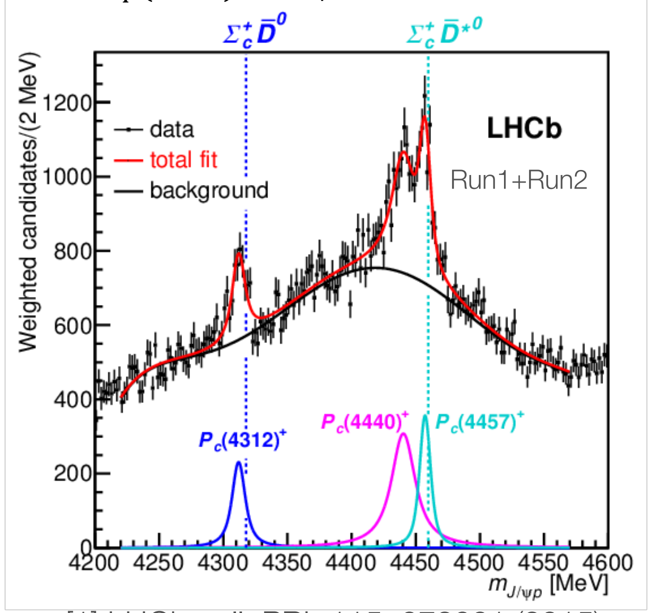
- Very active field of investigation
  - Close to meson-baryon thresholds
    → **Hadronic molecules? Or else?**
  - Need for further investigation!

$P_{\psi}^{N}\ (c\bar{c}uud)$

$P_{\psi s}^{\Lambda}\ (c\bar{c}uds)$

Pentaquarks in $\Lambda_b \to J/\Psi p K$[1]

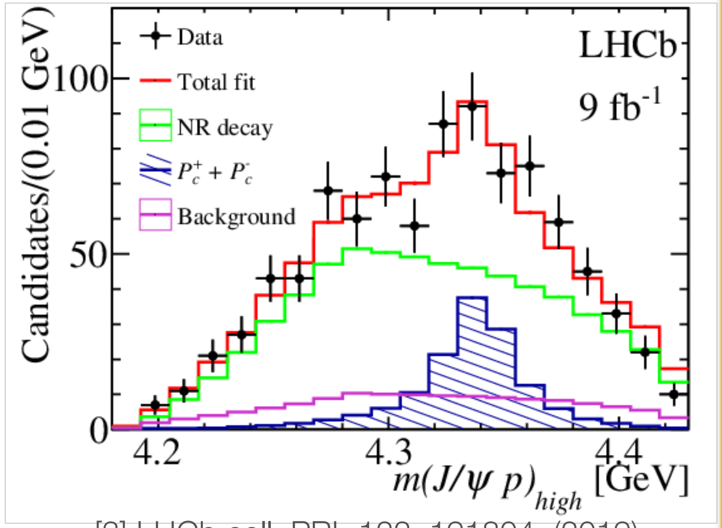
$P_{\psi}^{N}(4312)^{+}$ + 2 peaks at 4450 MeV[2]



[1] LHCb coll. PRL 115, 072001 (2015)
[2] LHCb coll. PRL 122, 222001 (2019)

Pentaquarks in $B_s \to J/\Psi p\bar{p}$[3,4]

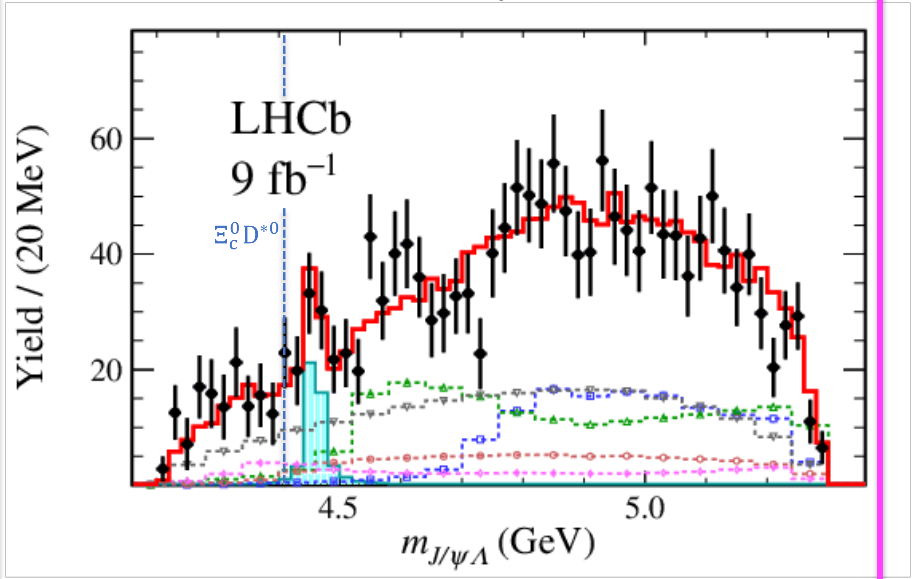
Evidence of $P_{\psi}^{N}(4337)^{+,-}$



[3] LHCb coll. PRL 122, 191804 (2019)
[4] LHCb col. PRL 128, 062001 (2022)

Pentaquarks in $\Xi_b^- \to J/\Psi \Lambda K^-$ [5]

Evidence of $P_{\psi s}^{\Lambda}(4459)$



[5] LHCb coll. Sci. Bull. 66, 1278-1287(2021)

Pentaquark states in J/Ψp and J/ΨΛ systems

- Very active field of investigation
  - Close to meson-baryon thresholds
    → **Hadronic molecules? Or else?**
  - Need for further investigation!

First observation of $\Lambda_b \to J/\Psi\Xi^- K^+$ at >5σ by CMS
→ Future searches for J/ΨΞ pentaquarks
[CMS preliminary public link]

New

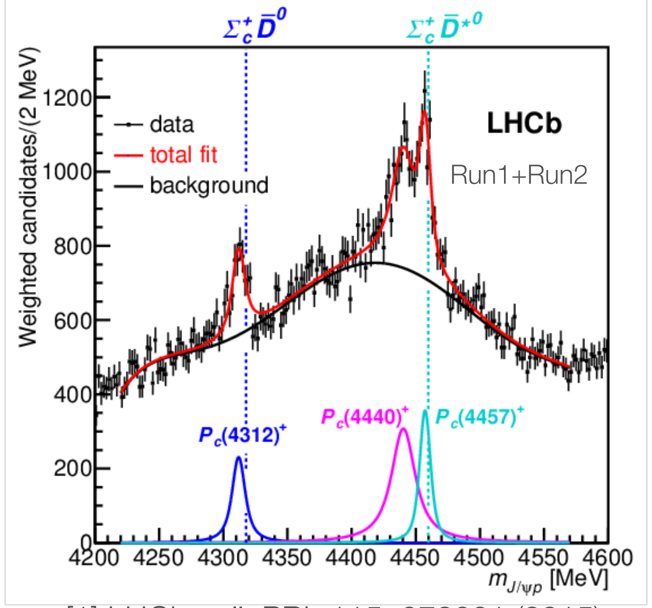
Talk by M. Sergeev
Fr. 26

P_ψ^N ($c\bar{c}uud$)

$P_{\psi s}^\Lambda$ ($c\bar{c}uds$)

Pentaquarks in $\Lambda_b \to J/\Psi pK$[1]

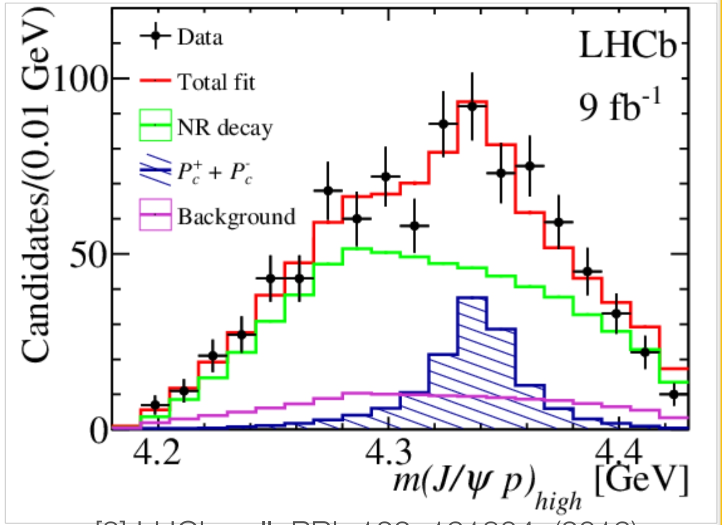
$P_\psi^N(4312)^+$ + 2 peaks at 4450 MeV[2]



[1] LHCb coll. PRL 115, 072001 (2015)
[2] LHCb coll. PRL 122, 222001 (2019)

Pentaquarks in $B_s \to J/\Psi p\bar{p}$[3,4]

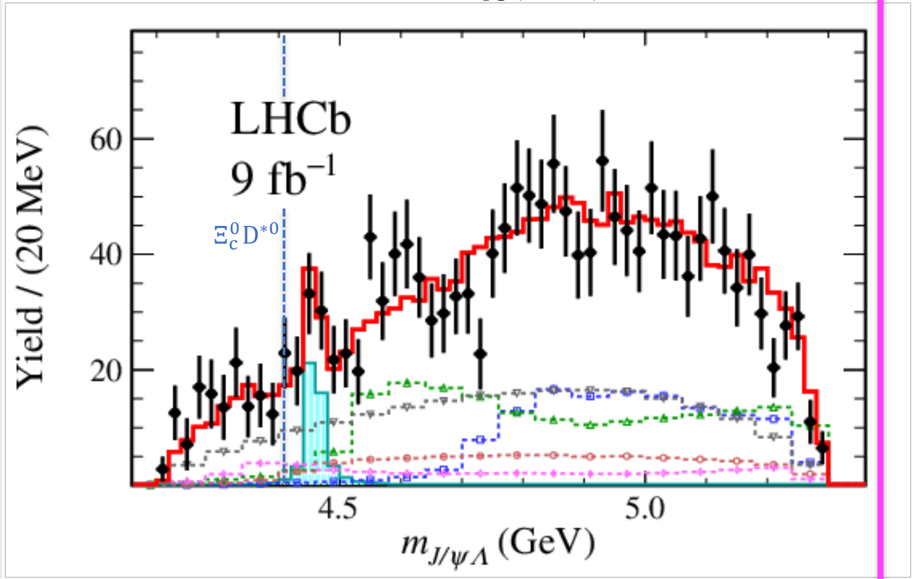
Evidence of $P_\psi^N(4337)^{+,-}$



[3] LHCb coll. PRL 122, 191804 (2019)
[4] LHCb col. PRL 128, 062001 (2022)

Pentaquarks in $\Xi_b^- \to J/\Psi\Lambda K^-$ [5]

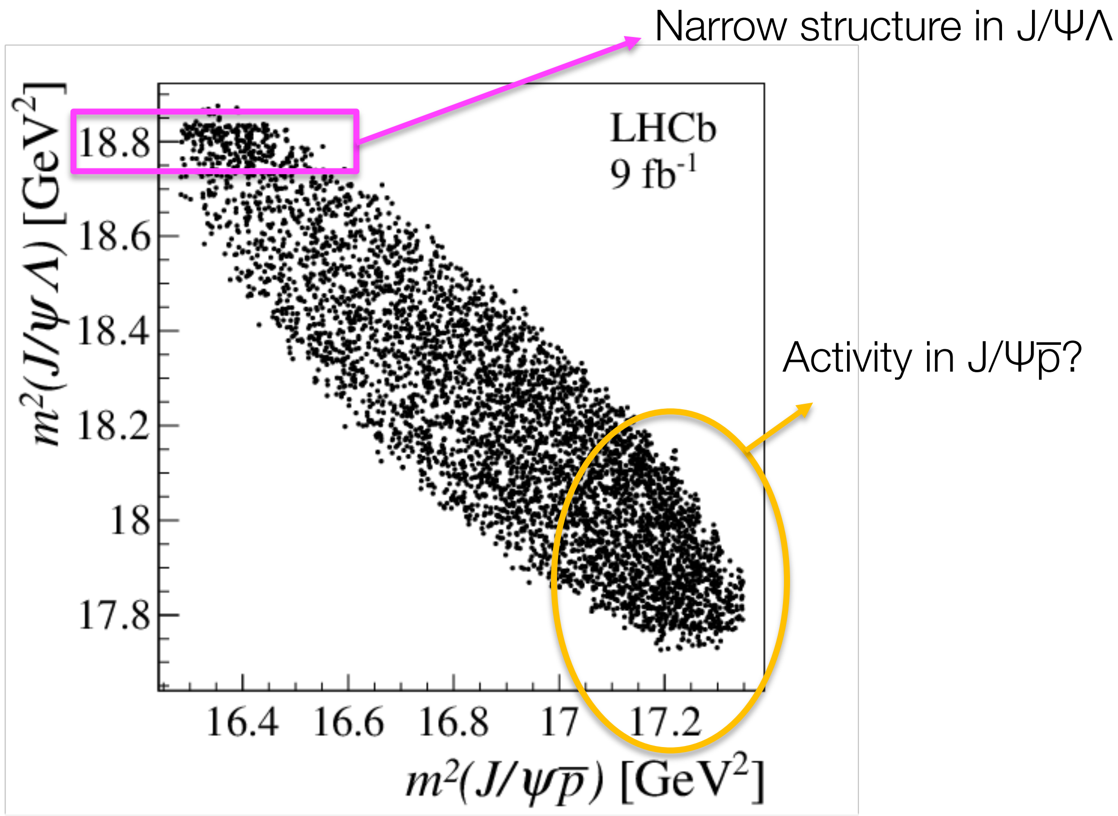
Evidence of $P_{\psi s}^\Lambda(4459)$



[5] LHCb coll. Sci. Bull. 66, 1278-1287(2021)

Looking for new pentaquarks in $B^- \to J/\Psi \Lambda \bar{p}$

New



LHCb-PAPER-2022-031,
arXiv:2210.10346

- Perfect environment to search for narrow resonances
  → Good invariant mass resolution
  → High signal purity (~93%)
  → **Simultaneous search** for $P^{\Lambda}_{\psi s}$ and $\bar{P}^{N^-}_{\psi}$

- Results from CMS in pp collisions at $\sqrt{s}$ = 8 TeV [1]
  → Inconsistency with phase-space only hypothesis

- Full analysis on **Run 1 and Run 2** performed

1. $J/\Psi\Lambda\bar{p}$ ⟶ non resonant $\Lambda\bar{p}$
2. $\Lambda J/\Psi\bar{p}$ ⟶ non resonant $J/\Psi\bar{p}$
3. $\bar{p}J/\Psi\Lambda$ ⟶ $P^{\Lambda}_{\psi s} \to J/\Psi\Lambda$

[1] CMS coll. JHEP 12 (2019), 100

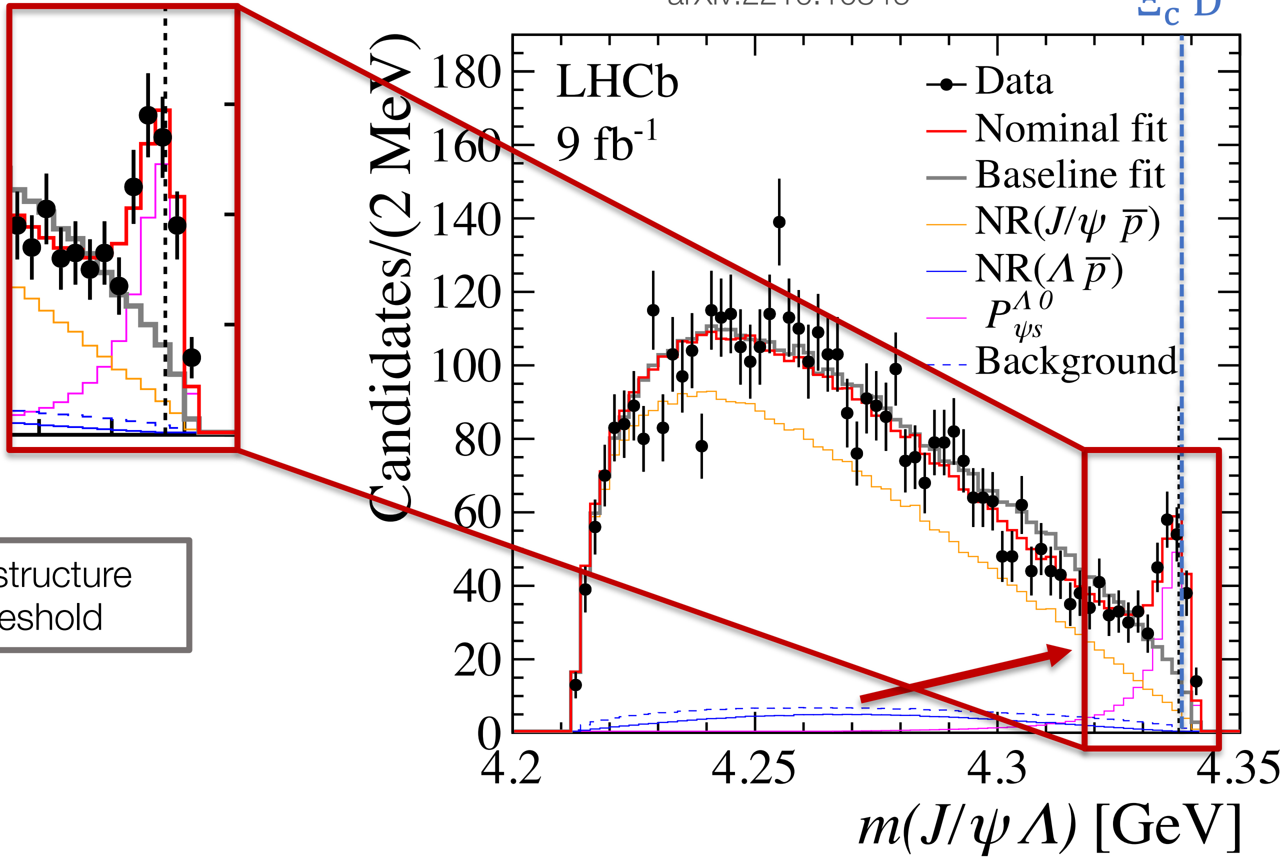
First pentaquark with strange content

New

$P^{\Lambda}_{\Psi s}(4338)$ at >10σ

$M_{P^{\Lambda}_{\Psi s}} = 4338.2 \pm 0.7 \pm 0.4$ MeV
$\Gamma_{P^{\Lambda}_{\Psi s}} = 7.0 \pm 1.2 \pm 1.3$ MeV
$J^P = 1/2^-$

LHCb-PAPER-2022-031,
arXiv:2210.10346



- Amplitude contributions
  - NR($\Lambda\bar{p}$)
  - NR($J/\Psi\bar{p}$)
  - $P^{\Lambda}_{\psi s}(J/\Psi\Lambda)$

  Baseline fit (NR($\Lambda\bar{p}$), NR($J/\Psi\bar{p}$)): Cannot reproduce structure close to $\Xi_c^+ D^-$ threshold

- Close to $\Xi_c^+ D^-$ production threshold
  → **Molecular state?**
- Similar mass to $P^N_\Psi(4337)$ in $B_s \to J/\Psi p\bar{p}$
  → **SU(3) multiplets?**

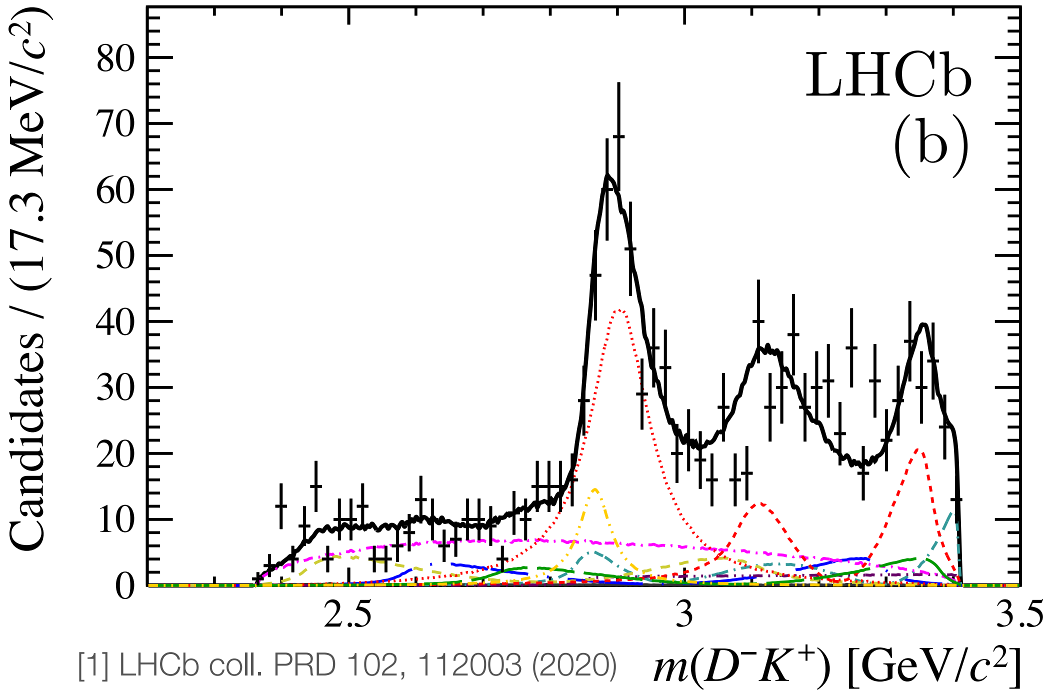
Open charm tetraquarks in DK systems

- States with four different quark types should be tetraquarks
  → Tetraquark states observed in D^-K^+ system [1]
  → Searching for $D_s^+\pi^\pm$ resonances: candidates for $(c\bar{s}u\bar{d})$ and $(c\bar{s}\bar{u}d)$ tetraquarks

$T_{cs0,1}$ $(cs\bar{u}\bar{d})$

Tetraquark in $B^+ \to D^+D^-K^+$ [1]

$T_{cs0,1}(2900)^0$



[1] LHCb coll. PRD 102, 112003 (2020)

Theoretical predictions of SU(3) flavour partners

$$T_{c\bar{s}0} \to D_s\pi$$

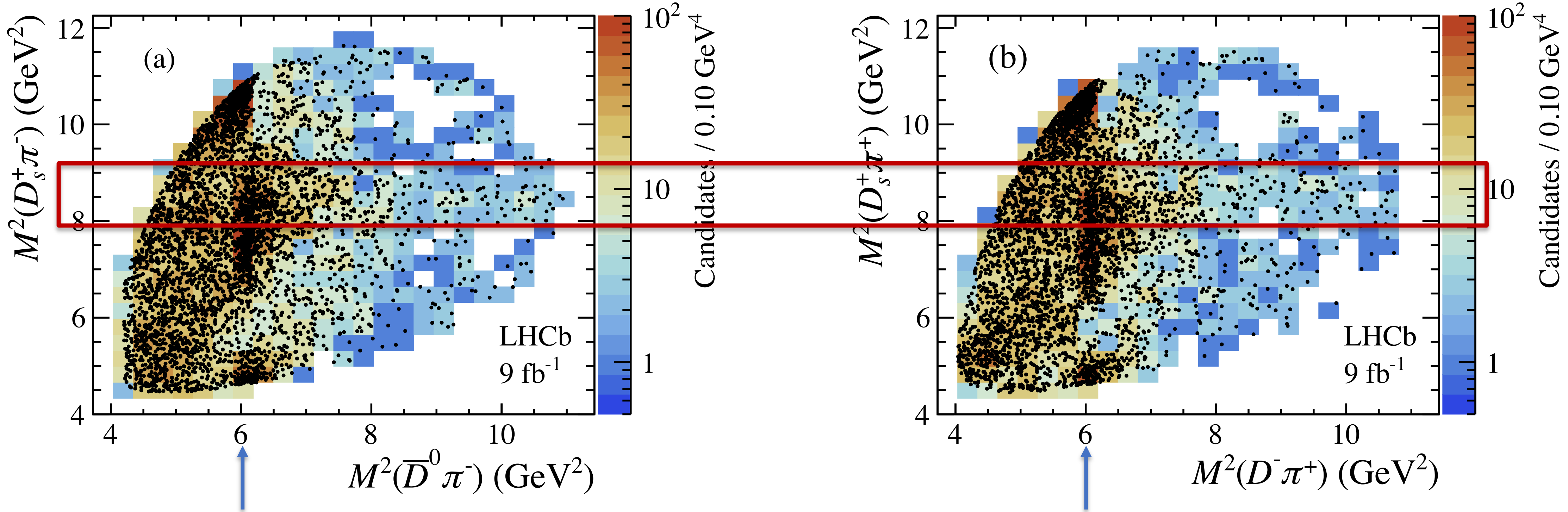
Search for possible tetraquarks in

$$B^0 \to \bar{D}^0 D_s^+\pi^-$$
$$B^+ \to D^- D_s^+\pi^+$$

New tetraquark states in $D_s\pi$ system

- Horizontal band at $M^2(D_s\pi)$~8.5 GeV^2 → new tetraquark candidates!
- Contributions from D^* resonances must be included
- Assuming isospin symmetry: fit with only D^* resonances and fit with $D_s\pi$ resonance added

$B^0 \to \overline{D}^0 D_s^+ \pi^-$ $B^+ \to D^- D_s^+ \pi^+$



$D_2^*(2460)$ $D_2^*(2460)$

LHCb-PAPER-2022-026,
arXiv:2212.02716

First observation of a doubly charged tetraquark

New

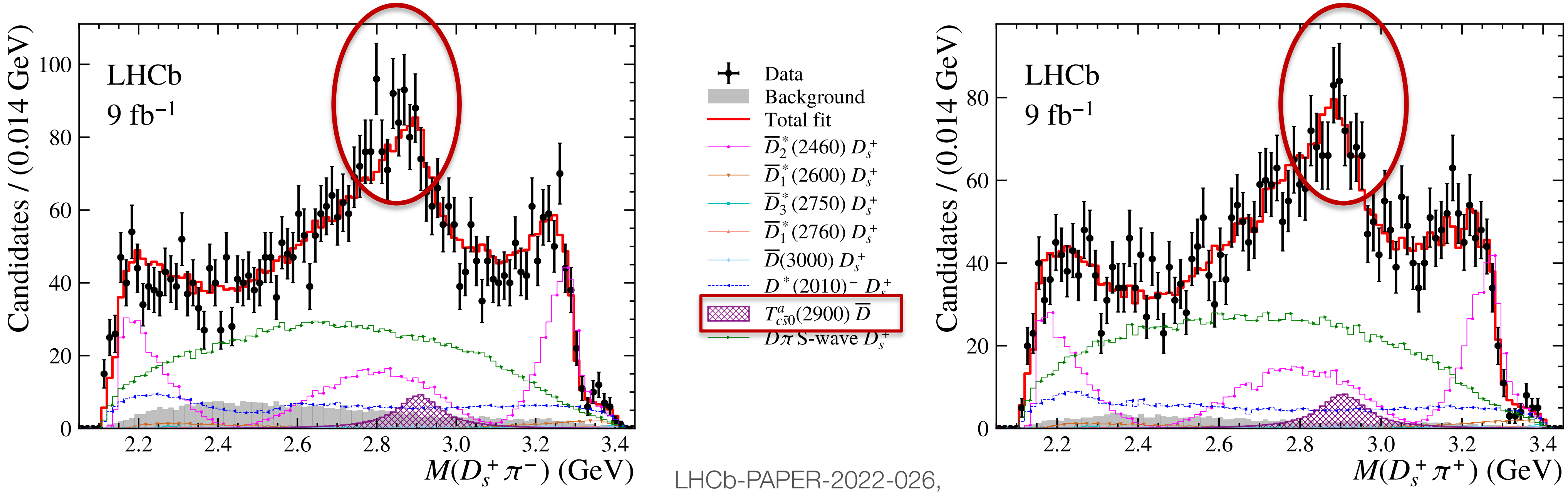
- $M(D_s^+\pi)$ well described by adding $T^a_{c\bar{s}0}(2900)^{++,0}$ at >9σ with $J^P = 0^+$

$$M_{T^a_{c\bar{s}0}(2900)^0} = 2.892 \pm 0.014 \pm 0.015\ \text{GeV}$$
$$\Gamma_{T^a_{c\bar{s}0}(2900)^0} = 0.119 \pm 0.026 \pm 0.013\ \text{GeV}$$

$$M_{T^a_{c\bar{s}0}(2900)^{++}} = 2.921 \pm 0.017 \pm 0.020\ \text{GeV}$$
$$\Gamma_{T^a_{c\bar{s}0}(2900)^{++}} = 0.137 \pm 0.032 \pm 0.017\ \text{GeV}$$

- Further investigations on its inner structure and relation to $T^a_{cs0}(2900)$, search for $T^a_{c\bar{s}0}(2900)^+ \to D_s^+\pi^0$

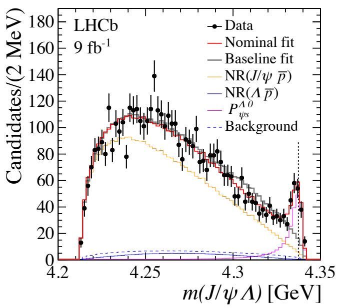
$B^0 \to \bar{D}^0 D_s^+ \pi^-$ $\qquad$ $B^+ \to D^- D_s^+ \pi^+$

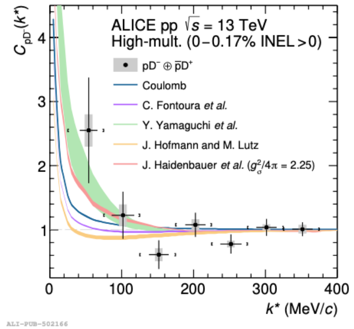


LHCb-PAPER-2022-026,
arXiv:2212.02716

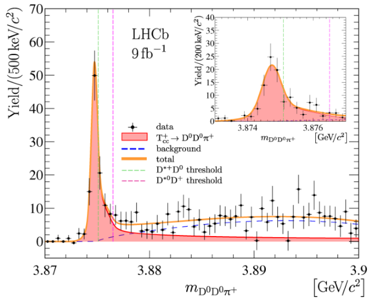
Conclusions and Outlooks

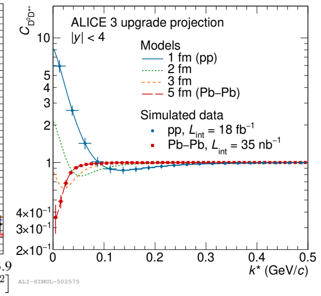
- Exciting results from spectroscopy and femtoscopy
  → Important experimental input in the effort to understand the many facets of QCD in strange and charm sector
  - Most precise pΛ, ΛK⁻ data at low momenta and first measurements of correlations with D mesons
  - First pentaquark with strange quark content and new open-charm tetraquarks observed





- On-going Run 3 and future Run 4
  → major upgrades in LHC experiments and increased statistics
  - Access to precise data on three-particle interactions and interactions with charm mesons
  - Access to states with lower production rate (exotics and conventional)



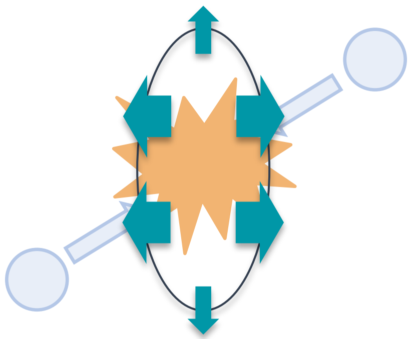


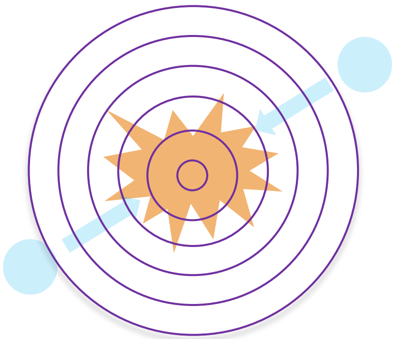
- Complementary studies with ALICE 3 in Run 5-6
  - investigate the T_{cc}^{+} structure with DD* correlations

Hadron spectroscopy at LHCb, L. Capriotti, Wed.24
b-hadron spectroscopy at CMS, S. Polikarpov Wed. 24
B decays and spectroscopy results from CMS, M. Sergeev Fr. 26
B decays and resonances in ATLAS, R. Jones Fr. 26
Three-particle femtoscopy at ALICE, R. Del Grande, Wed. 24
D-light hadron femtoscopy at ALICE, D. Battistini, Fr. 26

Additional slides

A source to rule them all





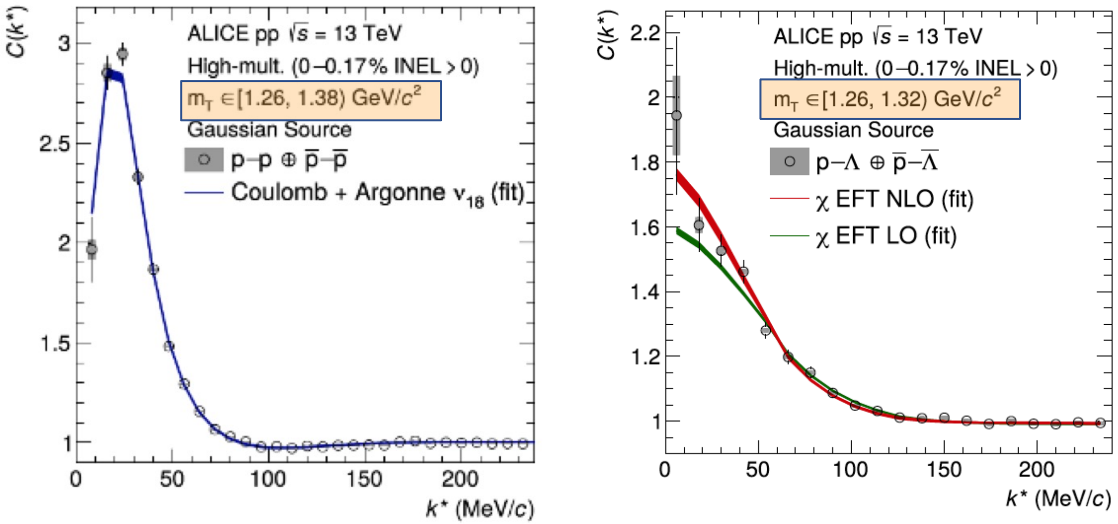
Anisotropic + pressure gradients Radial

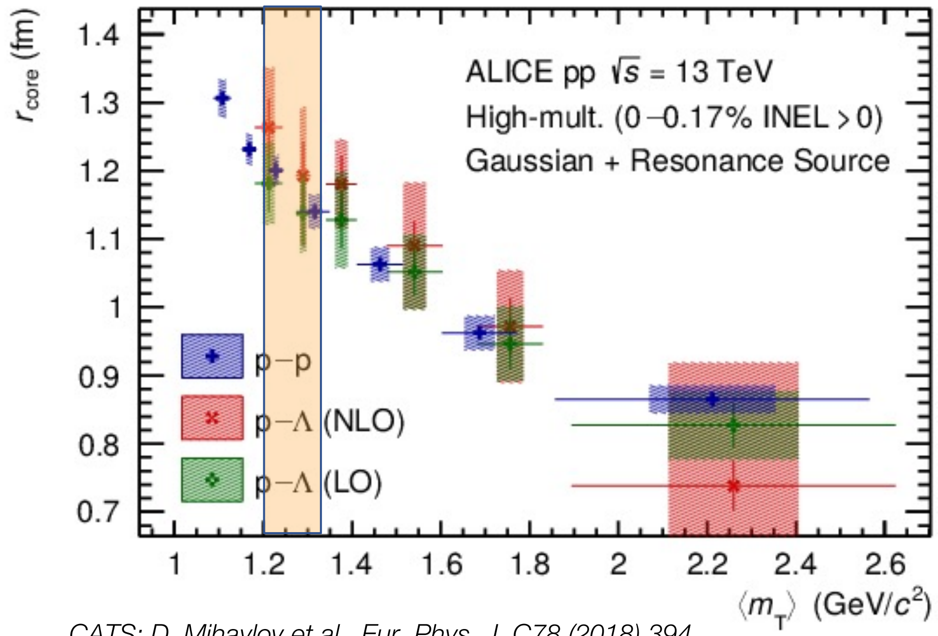
Different effect on different masses

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

$$S(r) = G(r, r_{core}(m_T)) = \frac{1}{(4\pi r_{core}^2)^{3/2}} \exp\left(-\frac{r^2}{4r_{core}^2}\right) \otimes \frac{1}{s} \exp\left(-\frac{r}{s}\right)$$

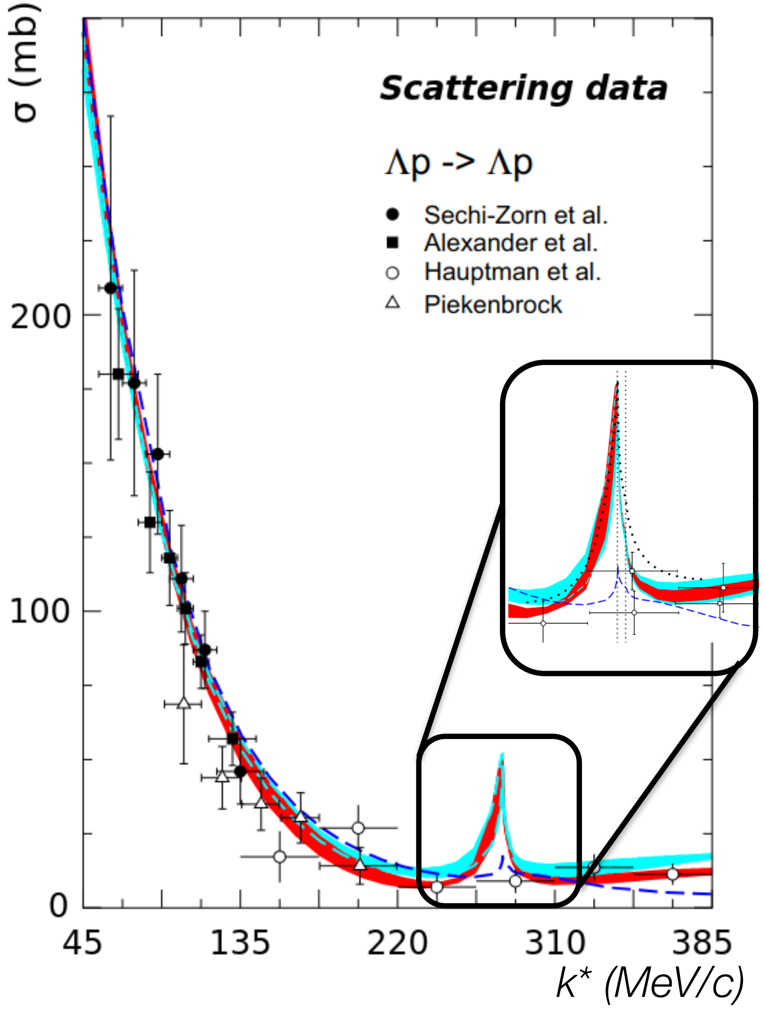
ALICE Coll., PLB, 811 (2020)





CATS: D. Mihaylov et al., Eur. Phys. J. C78 (2018) 394

The ΛN interaction and the role of ΣN coupling

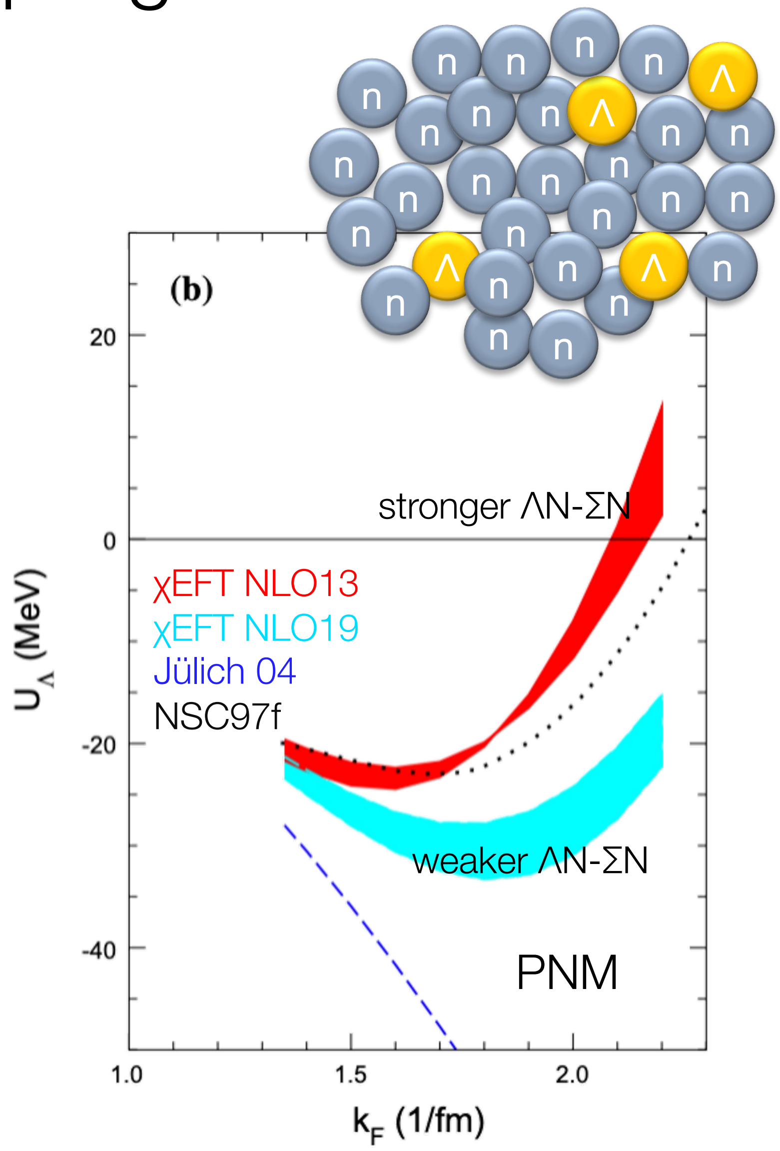


NLO13: J.Haidenbauer, N.Kaiser et al., NPA 915, 24 (2013)
NLO19: J.Haidenbauer, U. Meiβner, Eur.Phys.J.A 56 (2020)
(*)D. Gerstung et al. Eur.Phys.J.A 56 (2020) 6, 175

- ΣN coupling strength relevant for EoS

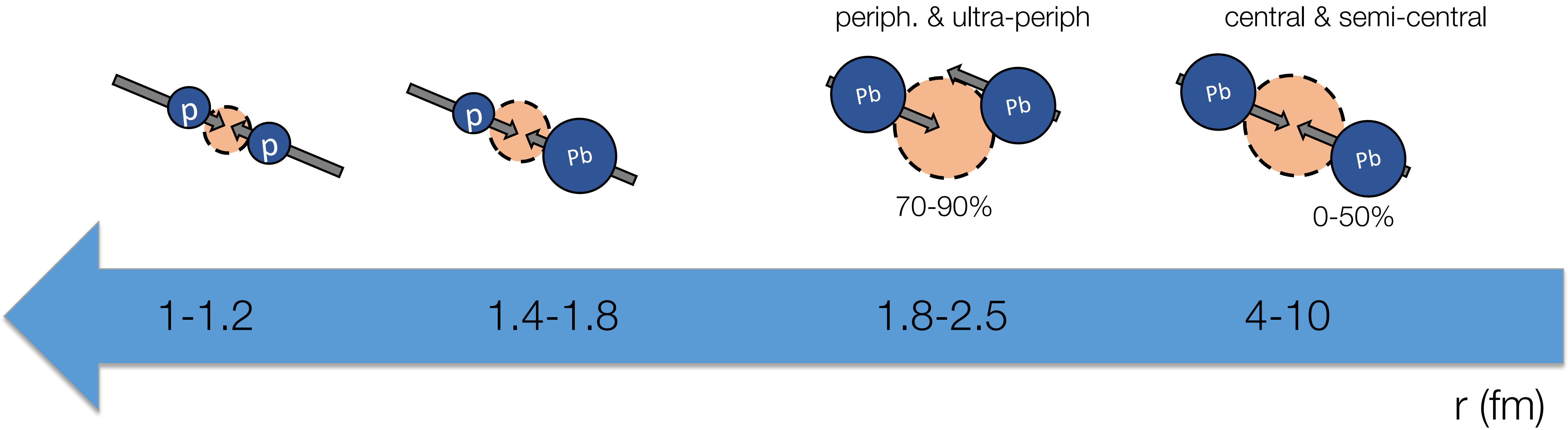
  →deeply affects the behaviour of Λ at finite density

  →implications for 3-body interactions(*)



Small vs large colliding systems

- By changing the colliding system we can probe distances ranging from 1 fm up to 10 fm
- Accessing the strong interaction → relative distances of ~1 fm → pp
- Small interparticle distance → doorway to studying large densities



Modeling of the correlation function

- Lednicky-Lyuboshits analytical formula
  - assuming a gaussian source
  - relies on the asymptotic behaviour of wf
    → scattering parameters as inputs, eff.

$$C_{\mathrm{LL}}(k^*) = 1 + \frac{1}{2}\left|\frac{f}{r_0}\right|^2 \left[1 - \frac{d_0}{2\sqrt{\pi} r_0}\right] + \frac{2\mathcal{R}[f]F_1(2k^* r_0)}{\sqrt{\pi} r_0} - \frac{\mathcal{I}[f]F_2(2k^* r_0)}{r_0}$$

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

  - might break down for small sources
    widely used in large colliding systems

R. Lednicky, V.L. Lyuboshits Sov. J. Nucl. Phys. 35 (1982)

- CATS framework
  - local potentials, wavefunctions, gaussian and beyond sources
  - relies on the exact wavefunction
    → behaviour at short-distances

$$\Psi_k(\vec{r}) = R_k(r) Y(\theta),$$

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

  - works for small and large sources

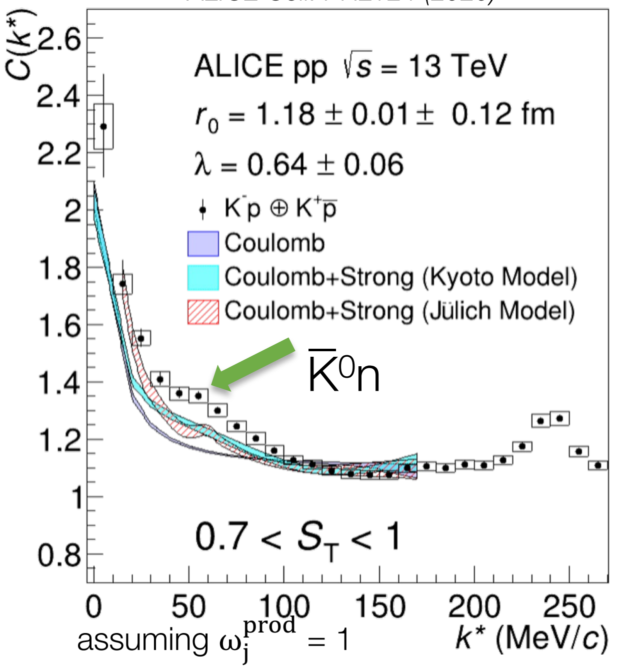
CATS Framework: D. Mihaylov et al., Eur. Phys. J. C78 (2018) 394

K⁻p femtoscopy: constraining the inelastic dynamics

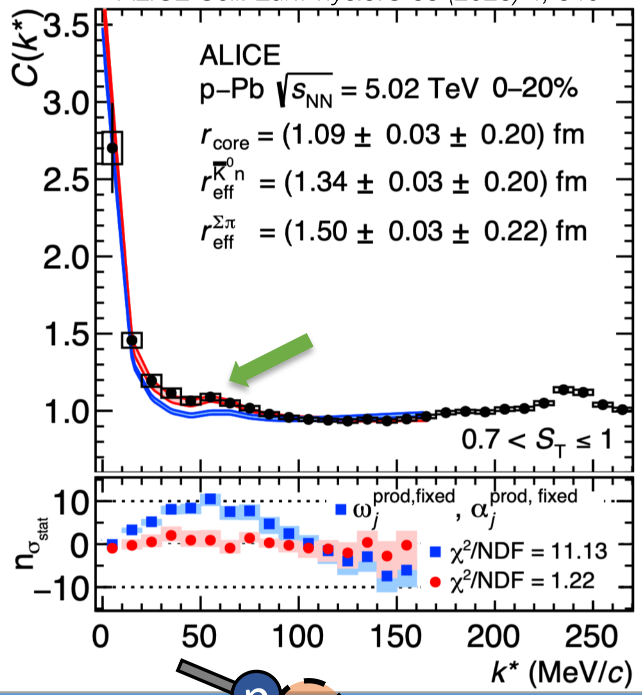
- Measurement in pp collisions
  → First experimental evidence of the opening of $\bar{K}^0$n channel (k*~ 60 MeV/*c*)
- Extending the measurements to p-Pb and Pb-Pb colliding system
  → Interplay source size and coupled-channel dynamics in the correlation
  → Constraints for coupling to $\bar{K}^0$n and Σπ
- Three- particle ppK± correlations and K^0_s p data available soon!

χEFT Kyoto model:
Ikeda et al. NPA 881 (2012), PLB706 (2011)
Kamiya et al. PRL 124 (2020)
Mihayara et al. PRC95 (2017)

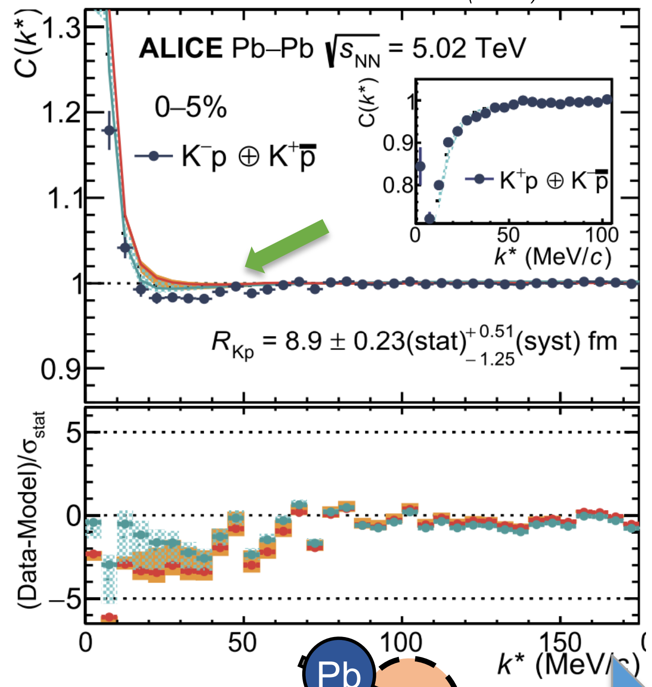
ALICE Coll. PRL124 (2020)

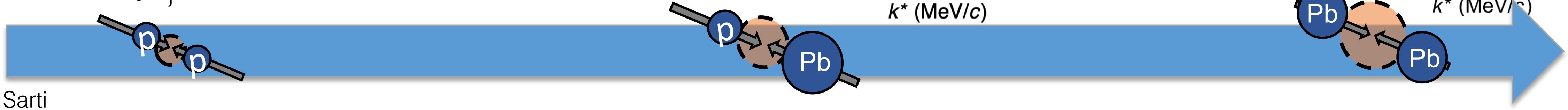


ALICE Coll. Eur.Phys.J.C 83 (2023) 4, 340

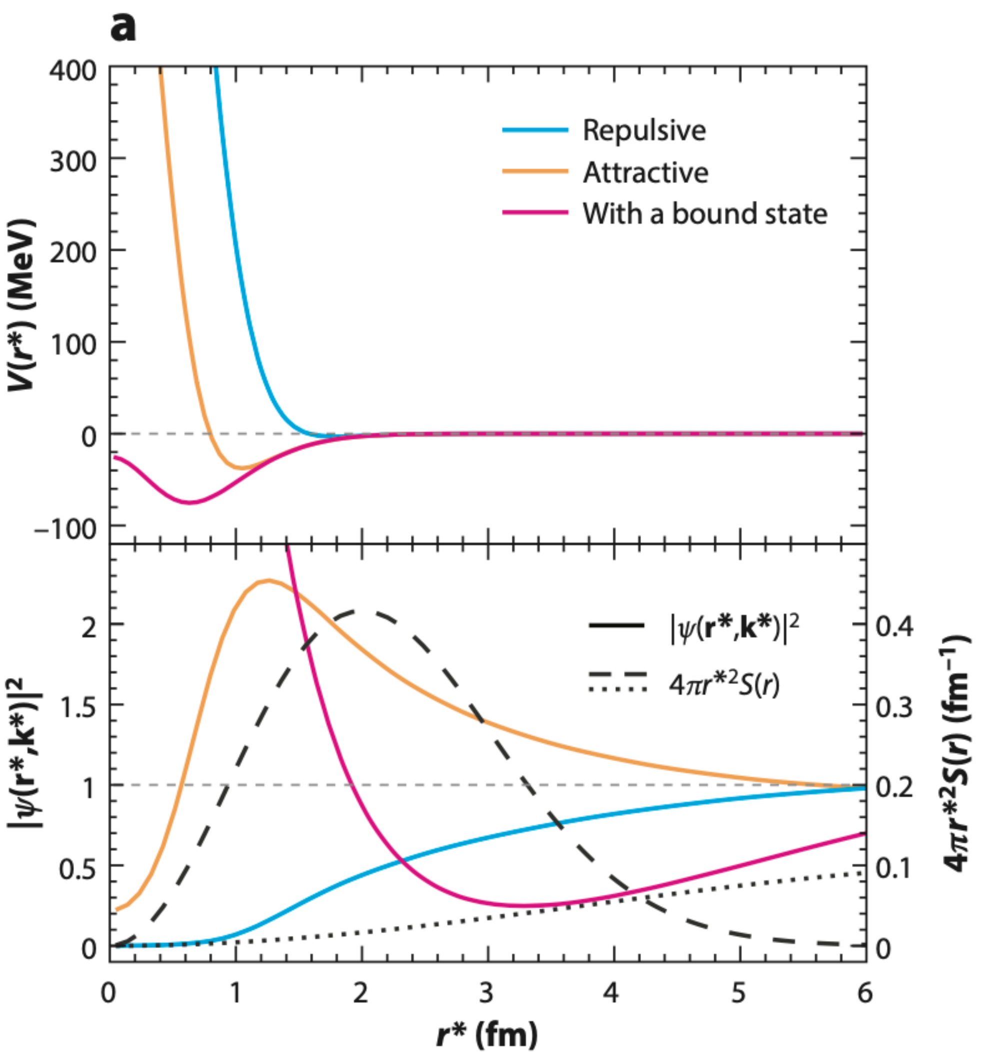


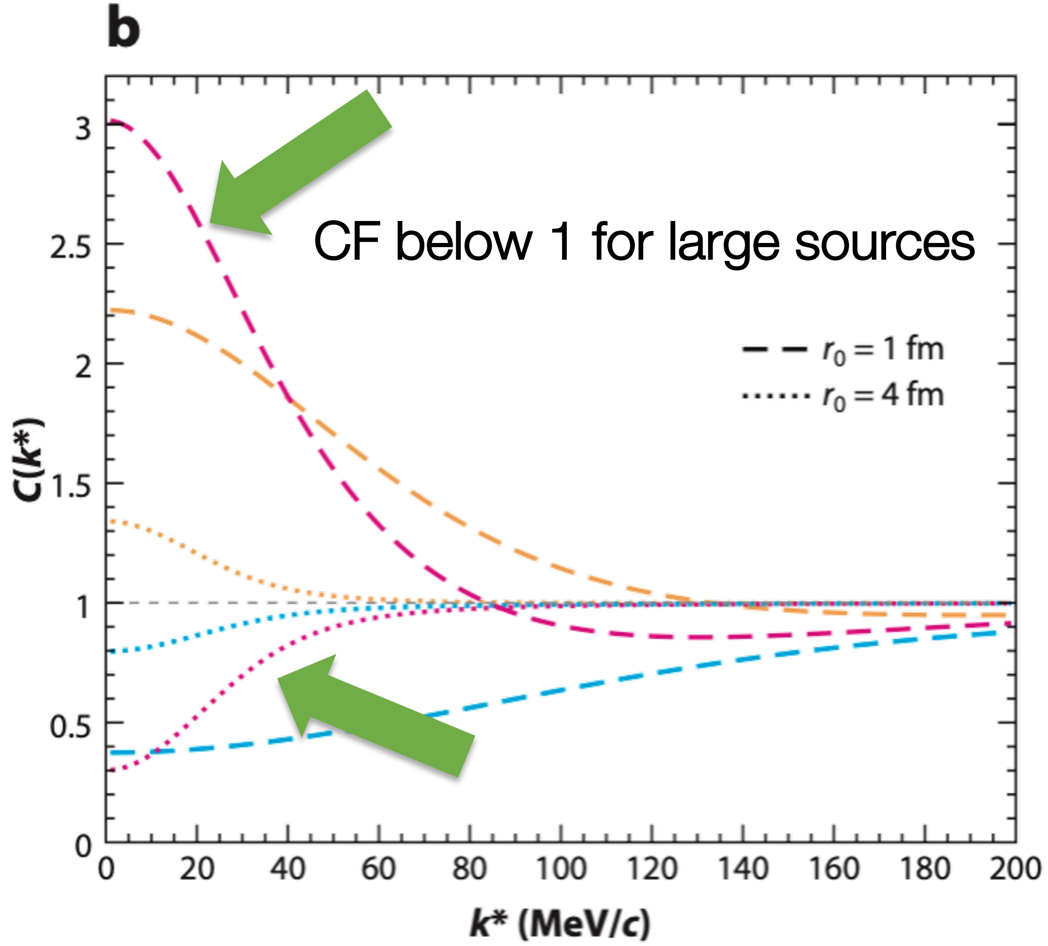
ALICE Coll. PLB 822 (2021)





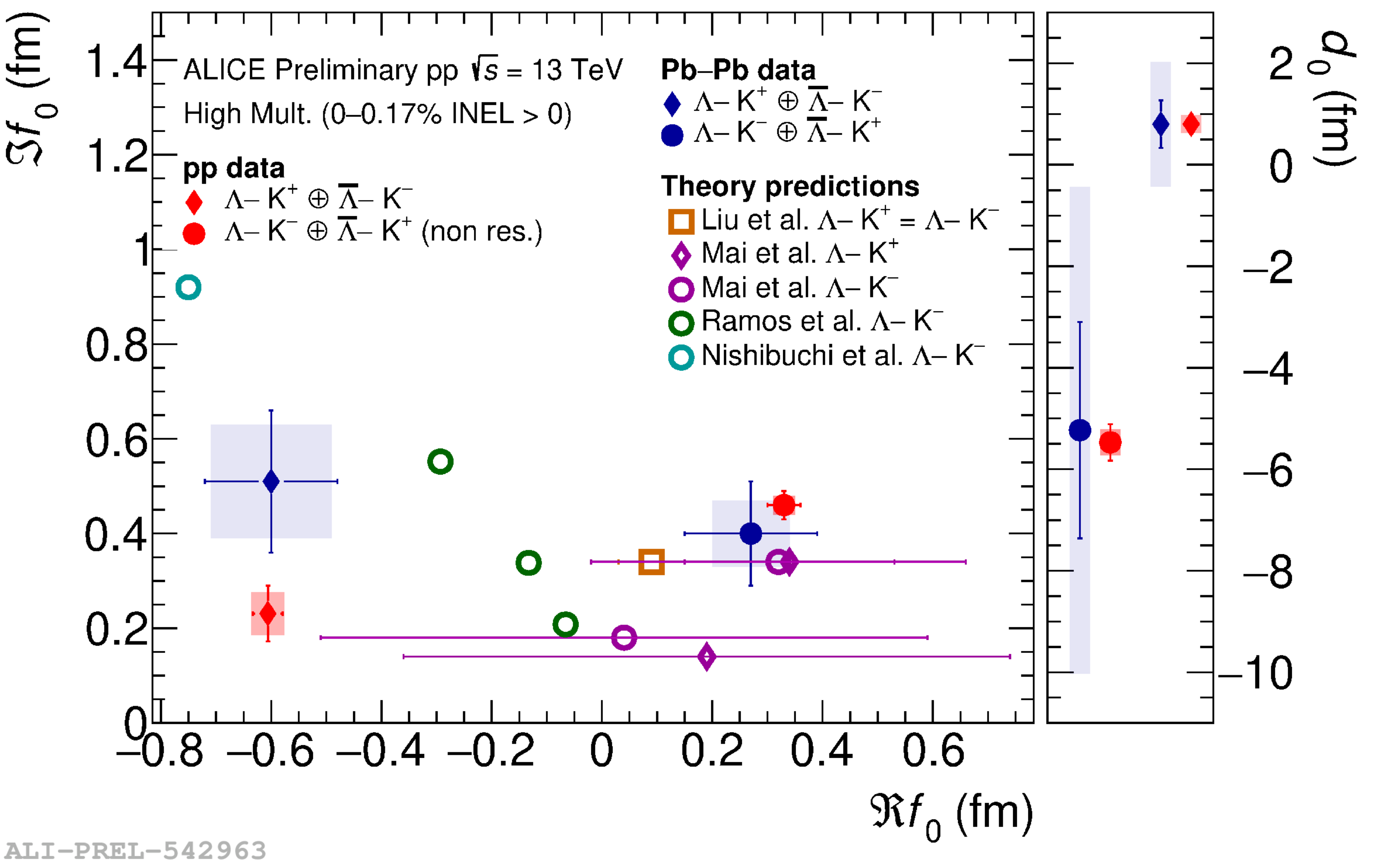
Study the strong interaction: bound states and correlations



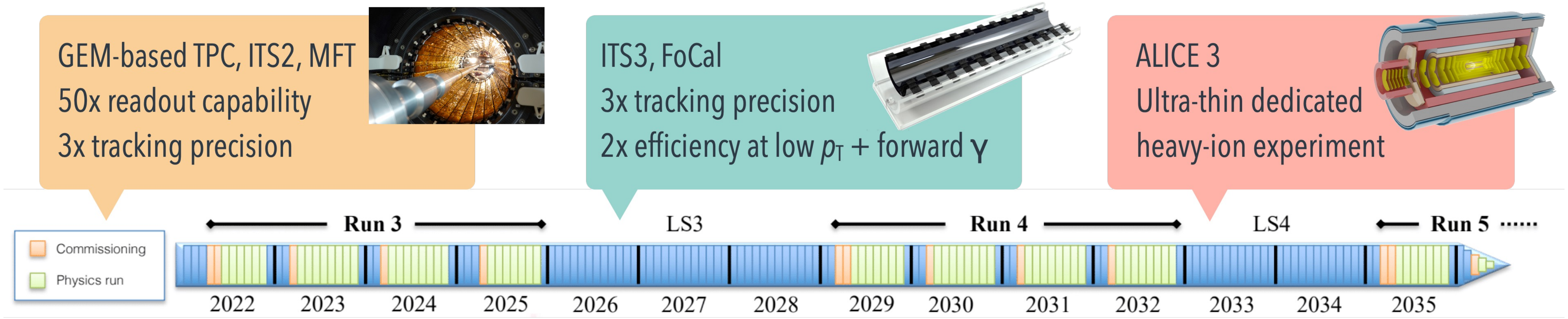


V.Mantovani Sarti, L. Fabbietti, O. Vazquez Doce Ann. Rev. NPS 71 (2022)

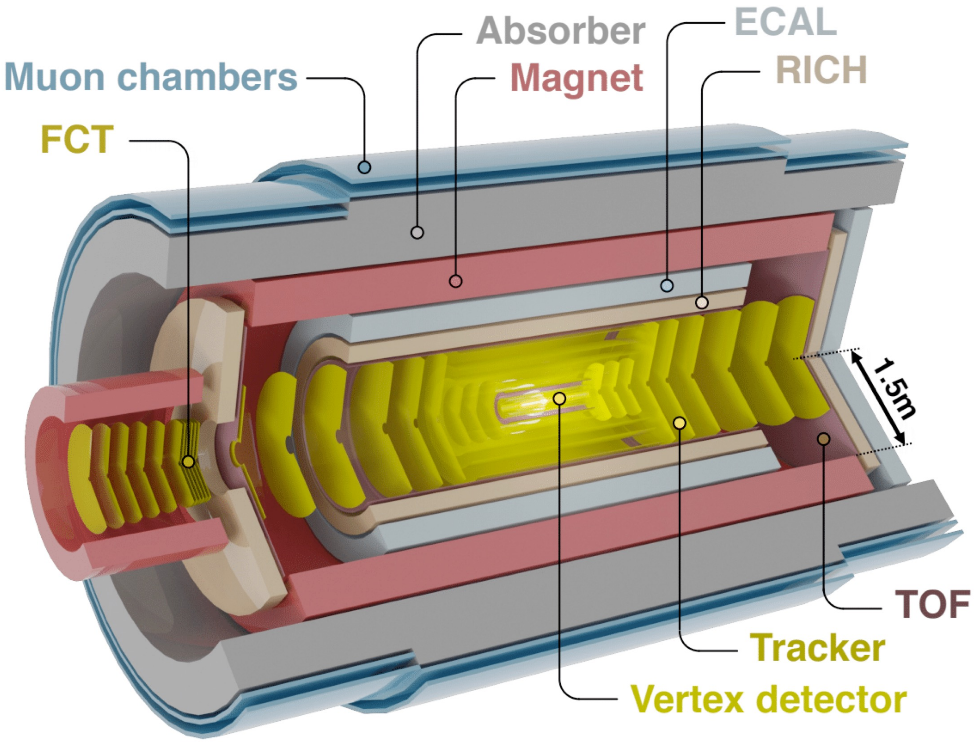
Scattering parameters for ΛK and Λ$\bar{K}$



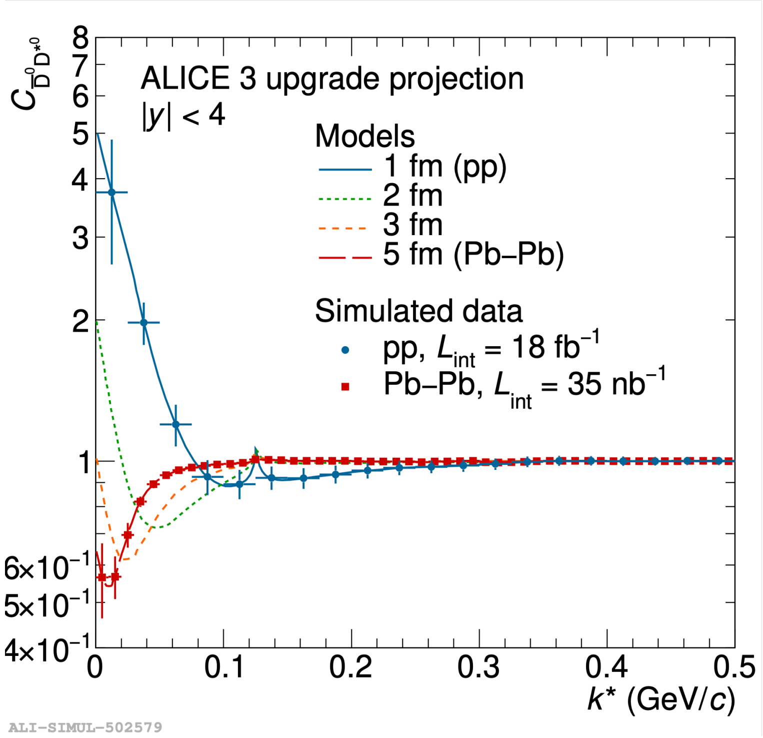
ALICE 3 detector

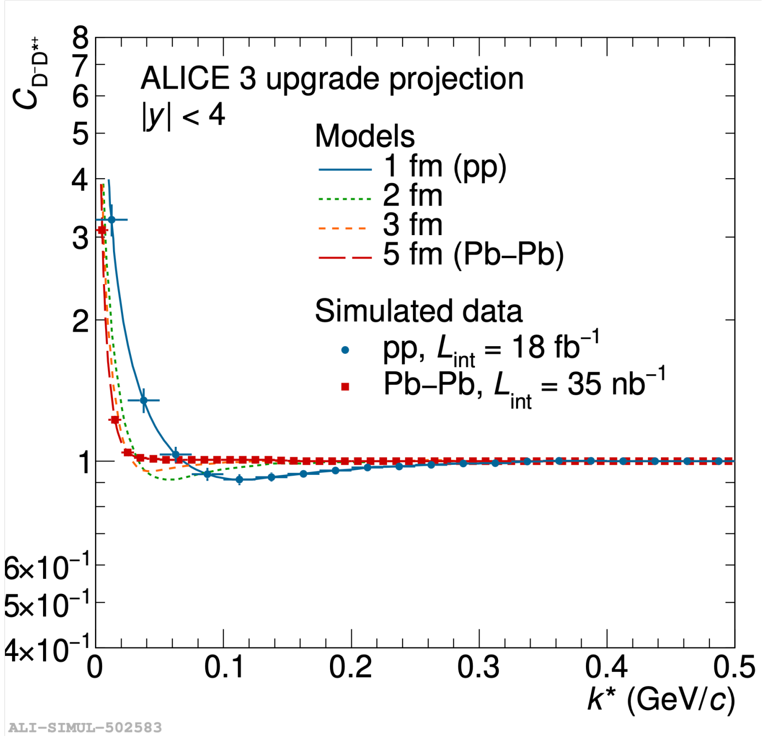


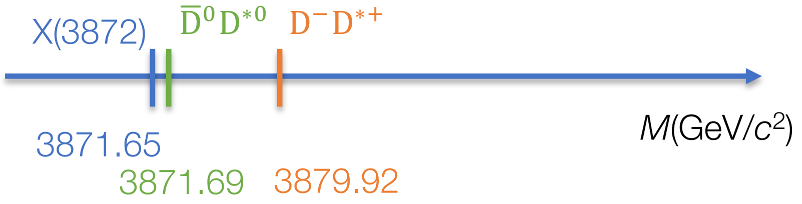
- Each upgrade improves
  1. Spatial resolution (improves reconstruction of weakly-decaying particles)
  2. Readout capability (improves integrated luminosity)
- Excellent pointing resolution (~10μm, p= 200 MeV/c) + large acceptance (|η| < 4)
  → secondary vertices and decay chains
  - All silicon tracker with σ_p/p ~1%
  - First tracking layer at 5 mm from primary vertex
- Excellent hadron and lepton PID
  - Silicon-based TOF and RICH
  - Muon chambers with absorber
- x5 more AA luminosity than Run 3&4 → DD* correlations!!



$D\bar{D}^*$ correlations







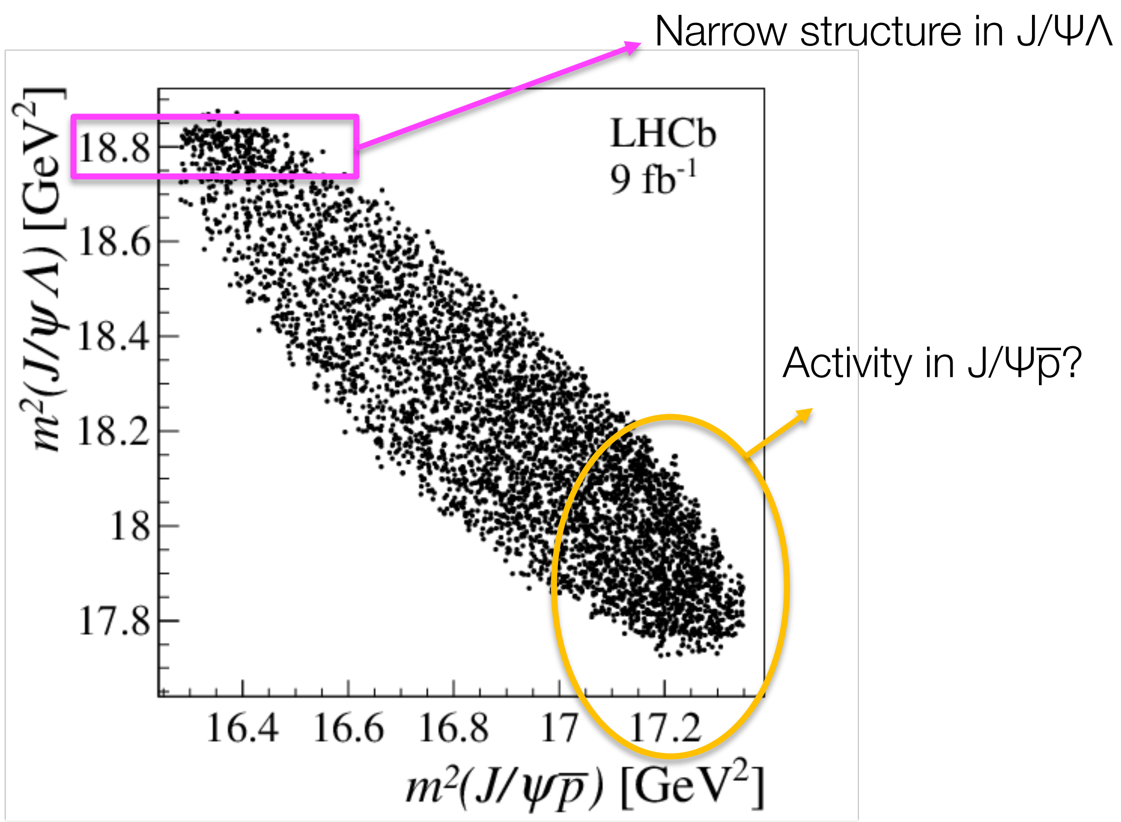
- Inversion of the correlation function not observed for D^-D^{*+} because the X(3872) is 'far' (148 MeV) from the mass threshold with respect to $\bar{D}^0 D^{*0}$ (~200 KeV).

Correlations function can confirm a molecular state scenario.

Looking for new pentaquarks in $B^- \to J/\Psi \Lambda \bar{p}$

New

LHCb-PAPER-2022-031,
arXiv:2210.10346



Simultaneous search for $P^{\Lambda}_{\psi s}$ and $\bar{P}^{N^-}_{\psi}$

- Perfect environment to search for narrow resonances
  → Good invariant mass resolution
  → high signal purity (~93%)
- Results from CMS in pp 8 TeV [1]
  → Inconsistency with phase-space only hypothesis
- Full amplitude analysis performed

1. $J/\Psi\Lambda\bar{p}$ → $K^* \to \Lambda\bar{p}$; non resonant $\Lambda\bar{p}$
2. $\Lambda J/\Psi\bar{p}$ → $\bar{P}^{N^-}_{\psi} \to J/\Psi\bar{p}$; non resonant $J/\Psi\bar{p}$
3. $\bar{p}J/\Psi\Lambda$ → $P^{\Lambda}_{\psi s} \to J/\Psi\Lambda$

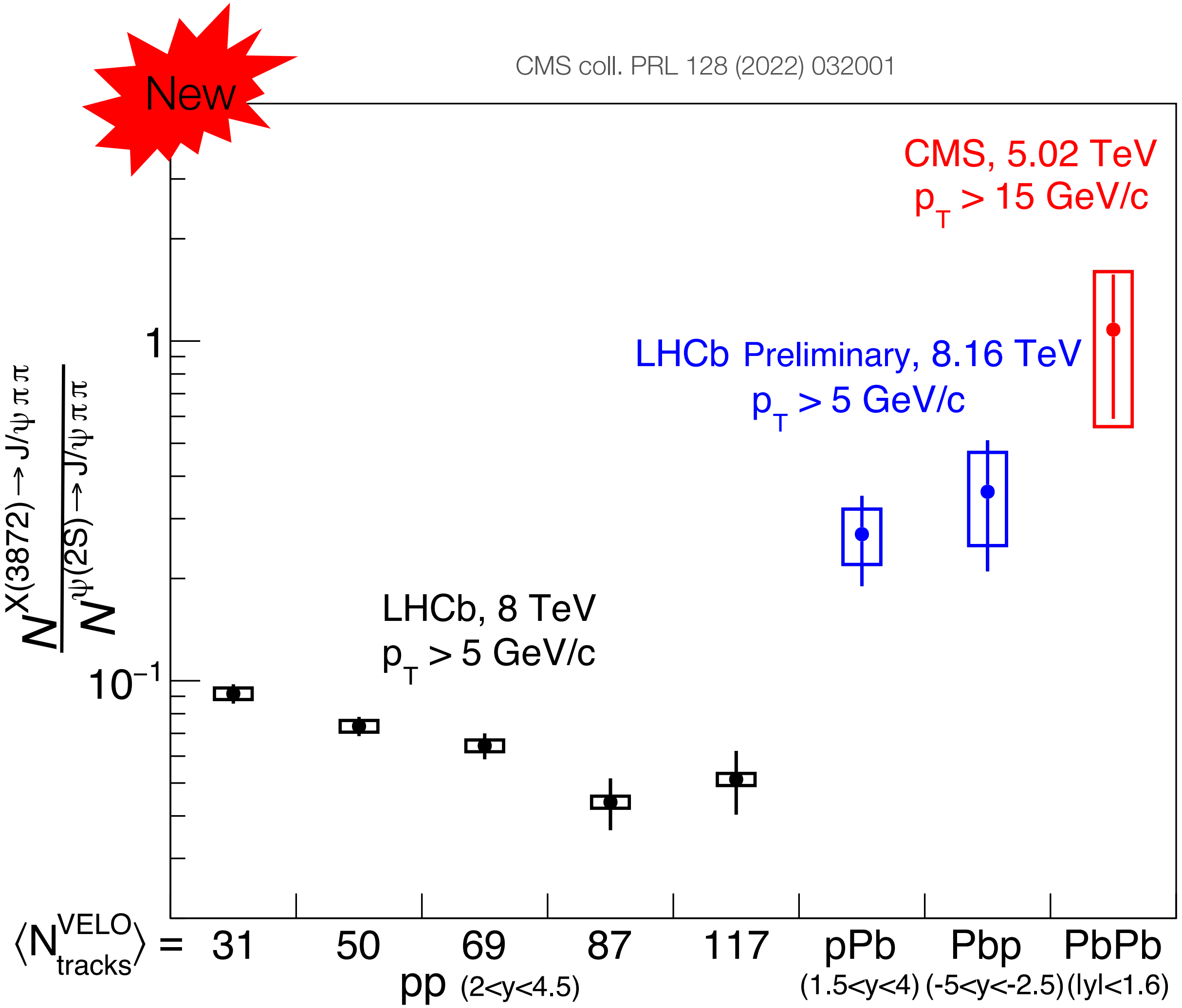
[1] CMS coll. JHEP 12 (2019)

Production of the X(3872) state at LHC

- Inner structure of X(3872) still elusive
- Studies on exotic states production
  → Dissociation: lower yield for molecular states, loosely bound
  → Recombination: higher yield for molecular states, larger object
- First evidence for X(3872) production in relativistic heavy ion collisions

$\rho_{Pb\text{-}Pb} = 1.08 \pm 0.49\,(\text{stat}) \pm 0.52\,(\text{syst}).$

- New important input for models!



Model with only K^* resonances

- No well-established resonances are expected to decay into the $J/\Psi\Lambda$ and $J/\Psi\bar{p}$ final states
- Excited K^* resonances decaying outside of the phase space of the $B^- \rightarrow J/\psi\Lambda p$ decay can contribute to the Λp channel
- Fit with
  - NR($p\bar{\Lambda}$)
  - $K^*_{2,3,4}$
  - resonant amplitudes does not reproduce the data distribution $\rightarrow \chi^2$/n.d.f. of 123.2/46

Resonance	Mass (MeV)	Natural width (MeV)	J^P
$K_4^*(2045)^+$	2045 ± 9	198 ± 30	4^+
$K_2^*(2250)^+$	2247 ± 17	180 ± 30	2^-
$K_3^*(2320)^+$	2324 ± 24	150 ± 30	3^+

PDG 2020

Even more strange pentaquark states in the future

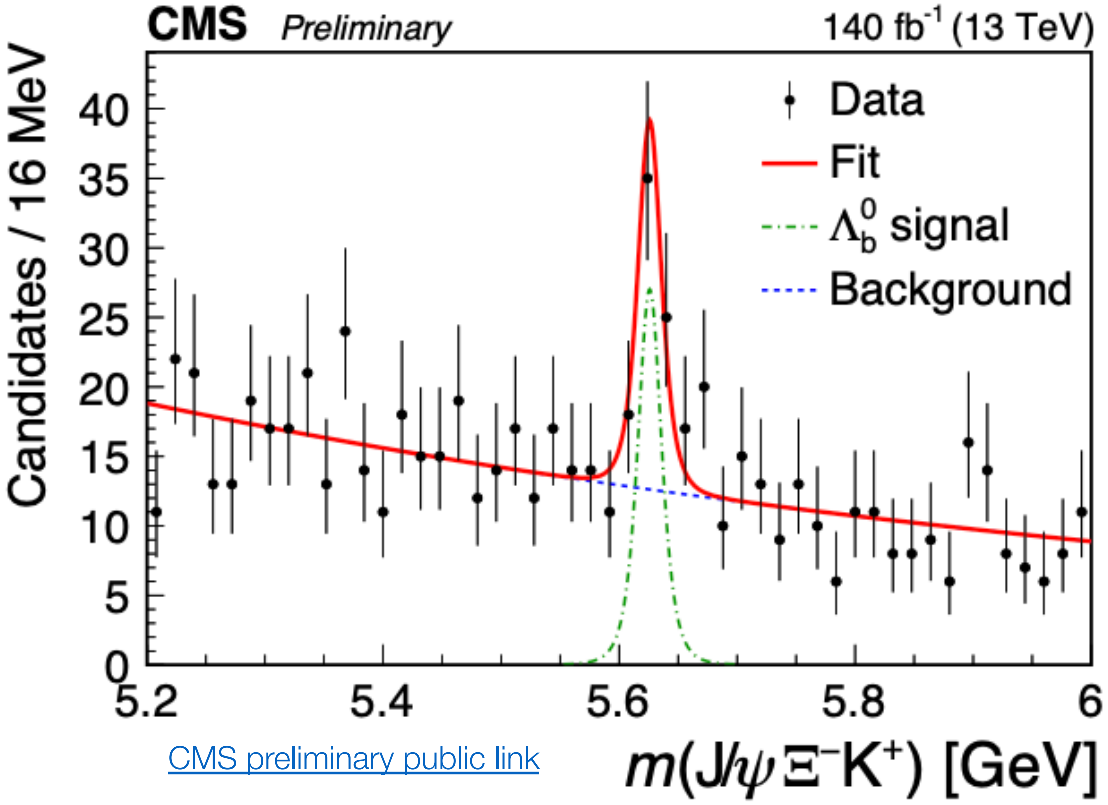
New

- Analysis on Run 2 data in pp collisions at $\sqrt{s}$=13 TeV

First observation of $\Lambda_b \rightarrow J/\Psi \Xi^- K^+$ at >5σ

$$\mathcal{R} \equiv \frac{\mathcal{B}(\Lambda_b^0 \to J/\psi \Xi^- K^+)}{\mathcal{B}(\Lambda_b^0 \to \psi(2S)\Lambda)} = [2.5 \pm 0.8\,(\text{stat}) \pm 0.9\,(\text{syst})]\%,$$

- Open prospects to search for $J/\Psi\Xi$ pentaquarks in the future!



CMS preliminary public link

Talk by M. Sergeev
Fr. 26

Fit with only D* resonances

New

LHCb-PAPER-2022-026,
arXiv:2212.02716

- Peaking structures in the $M(D_s^+\pi)$ distribution around 2.9 GeV² not reproduced with only D* resonances

$B^0 \to \overline{D}^0 D_s^+ \pi^-$ $B^+ \to D^- D_s^+ \pi^+$