Recent ALICE physics results

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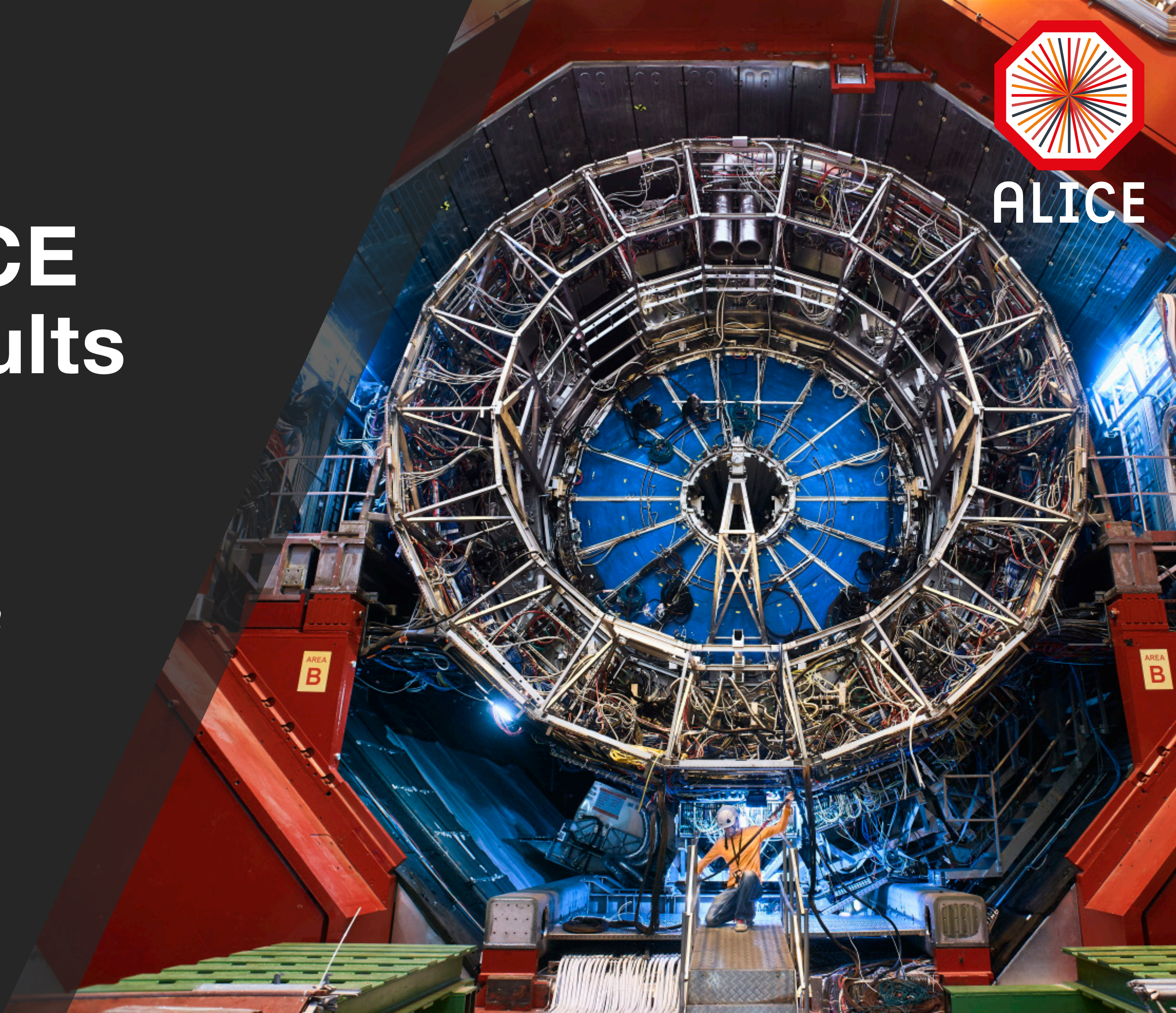
LNF, 15th July 2021



ALICE

ALMA MATER STUDIORUM
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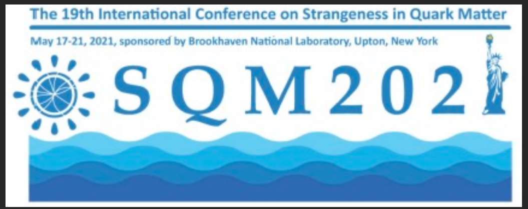
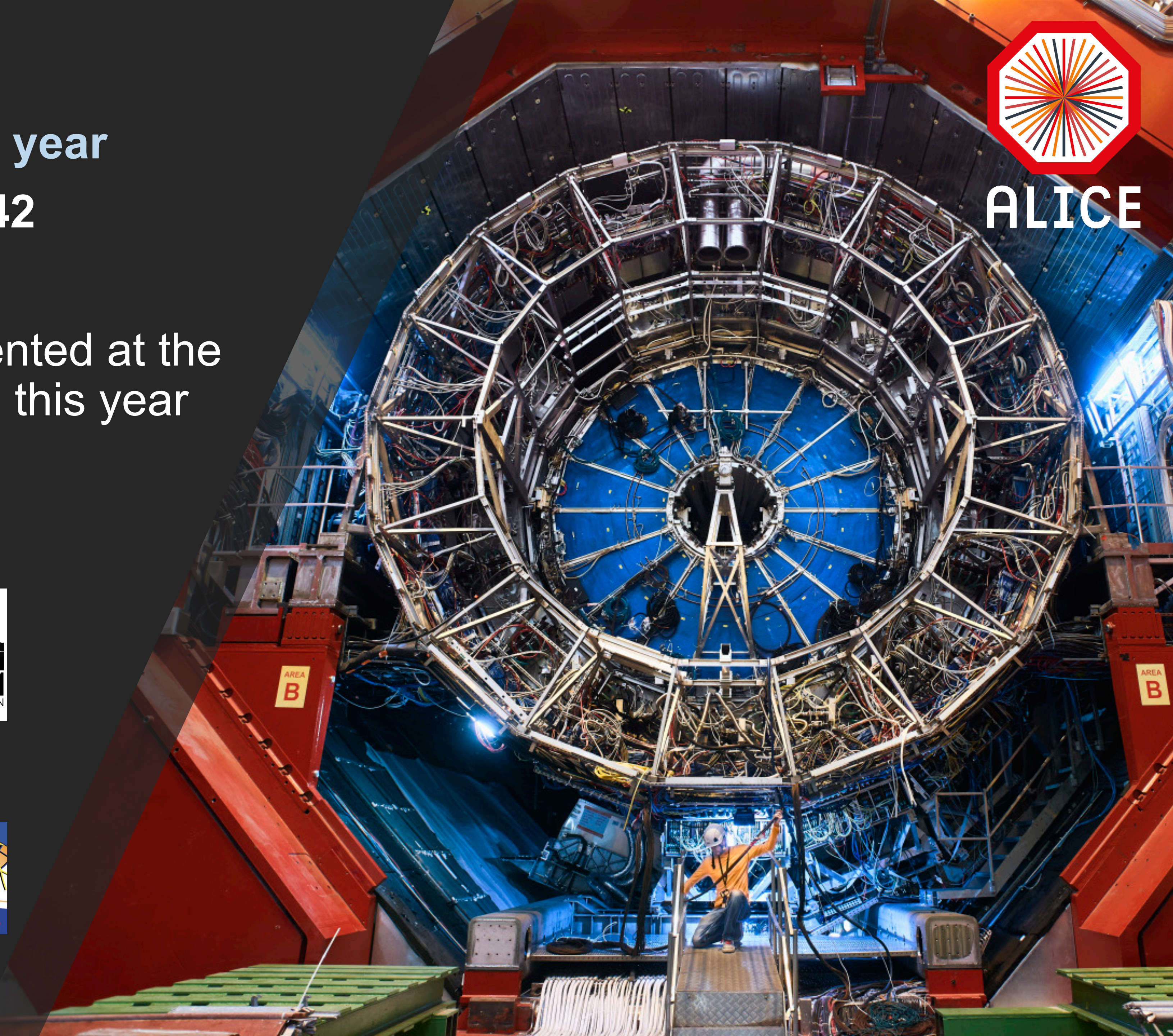
INFN
Istituto Nazionale di Fisica Nucleare

→ 30 new papers in the last year

Total numbers of papers: 342

New preliminary results presented at the major conferences of the field this year





A broad physics programme from AA to pp collisions

Properties and emergence of the QGP

- thermodynamic properties
- hydrodynamic and transport properties
- parton energy loss in medium

Nature of the initial state of heavy-ion collisions

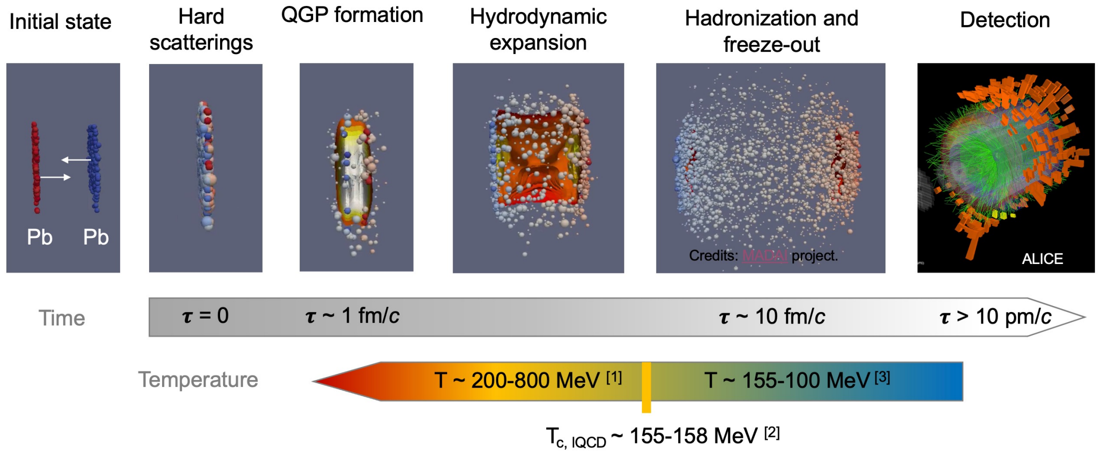
Hadronization in-medium vs in-vacuum

Formation of light nuclear clusters

Study of the strong interaction

- Effect of deconfinement on the strong force
- Nature of the hadron-hadron interaction

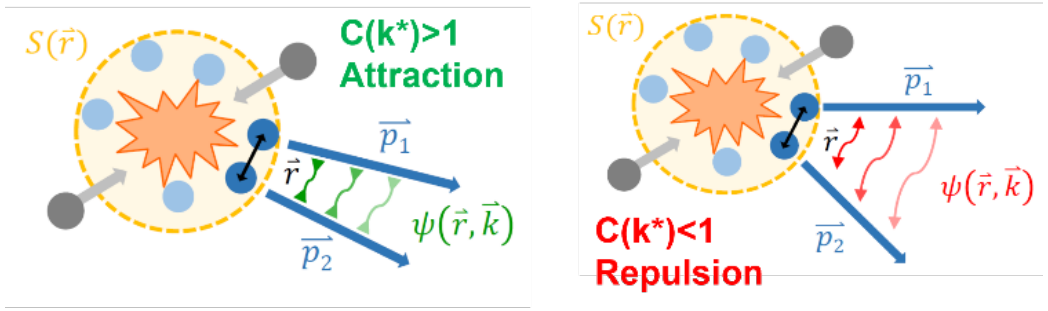
Evolution of heavy-ion collisions



No direct observation of the QGP is possible
→ rely on emerging particles as "probes"

[1] F. Gardim et al. Nature Phys. 16 (2020) 6, 615-619
[2] A. Bazavov et al., Phys. Lett. B 795 (2019)
[3] A. Andronic et al., Nature 561 (2018) 7723, 321-330

h-h interaction via correlation functions



Disclaimer:
a necessary selection of few highlights based on personal taste
Apologies to those that were not included!

For the full list of papers submitted in the last year check this link

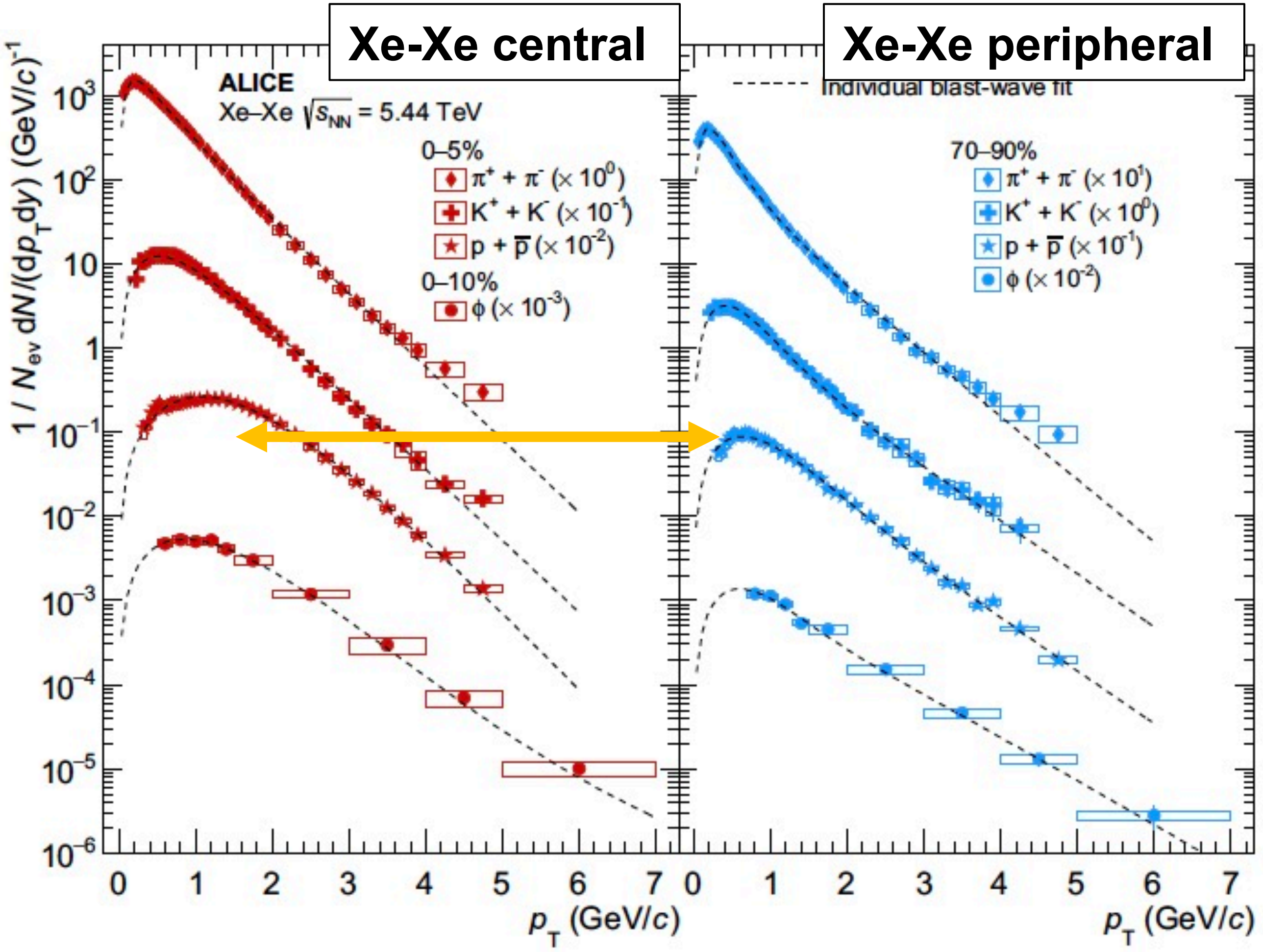
Focus of the day: new measurements in the light and heavy flavour sector contribute to constrain models of hadronization in-medium and in-vacuum and particle production mechanisms

Light flavour, strangeness and nuclei

Identified particle production in Xe-Xe collisions

- πKp most abundant species in the bulk
- meson/baryon ratio test fragmentation/recombination
- ϕ and p with similar mass receive similar push from radial flow
- Xe-Xe vs Pb-Pb: different eccentricity at the same multiplicity

Radial flow manifests itself in the hardening of the spectra with increasing centrality and particle mass



Eur.Phys.J.C 81 (2021) 7, 584

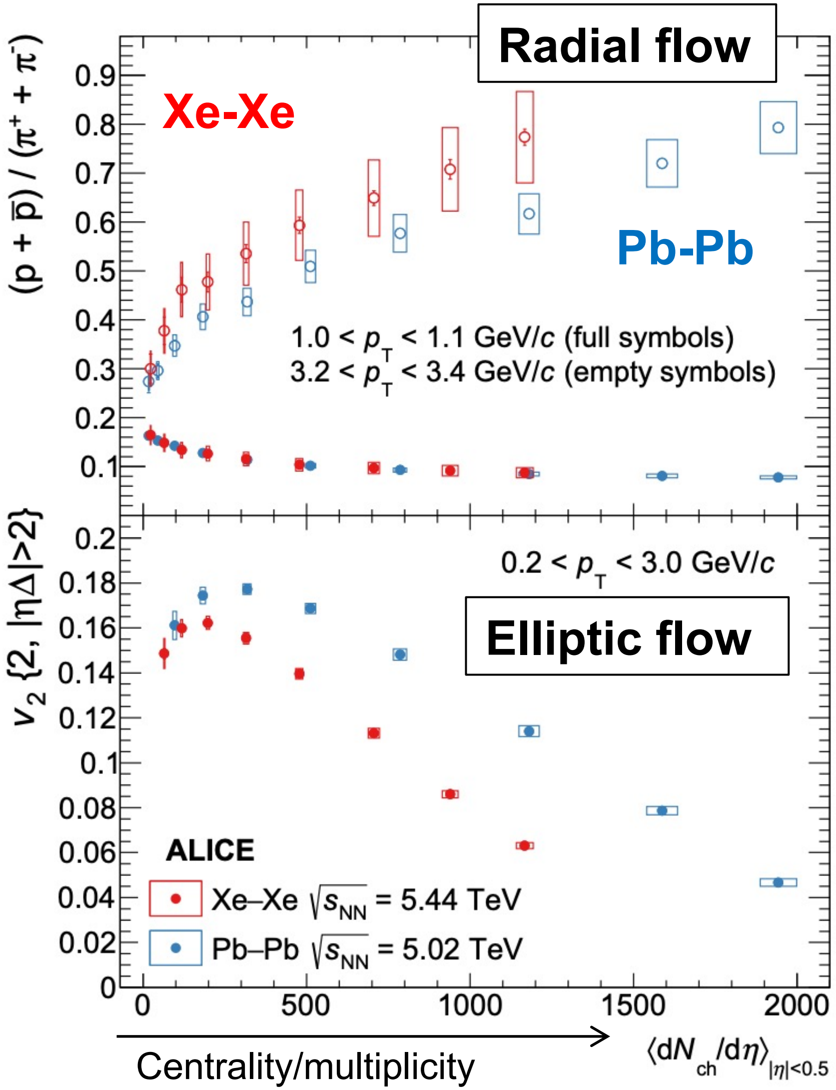
Radial and elliptic flow in AA collisions

- πKp most abundant species in the bulk
- meson/baryon ratio test fragmentation/recombination
- ϕ and p with similar mass receive similar push from radial flow
- Xe-Xe vs Pb-Pb: different eccentricity at the same multiplicity

Radial flow manifests itself in the hardening of the spectra with increasing centrality and particle mass → p/π increase at mid p_T

Radial flow depends only on final-state multiplicity (system size)

Elliptic flow depends also on the eccentricity (initial geometry)



Eur.Phys.J.C 81 (2021) 7, 584

Particle chemistry from low to high multiplicity

At a fixed final state-particle multiplicity, particle production is independent of collision energy and nuclear species / system

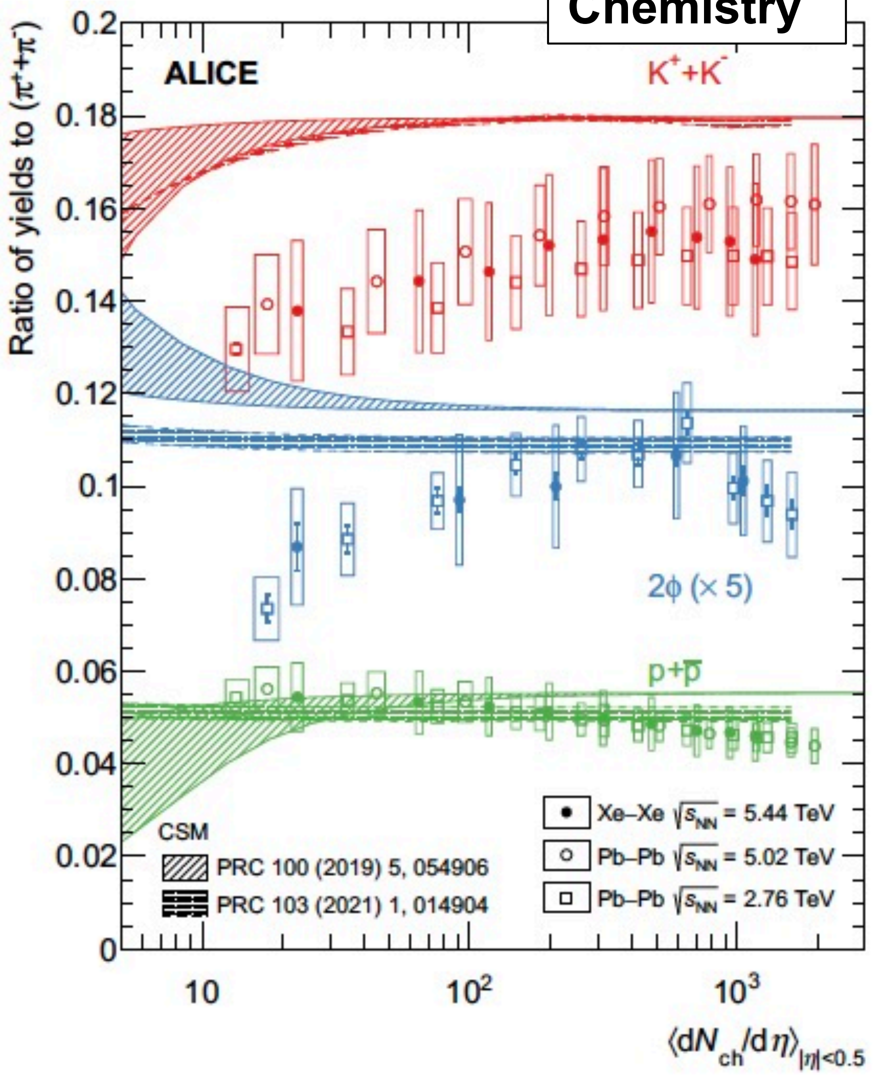
Final-state particle multiplicity confirmed as a good scaling observable for particle production

→ *stringent constraints to models of statistical hadronization*

→ *important result in view of the future physics programme with lighter ions*

ϕ meson production in small system still puzzling

Chemistry



Eur.Phys.J.C 81 (2021) 7, 584

Light flavour hadrons from small to large systems

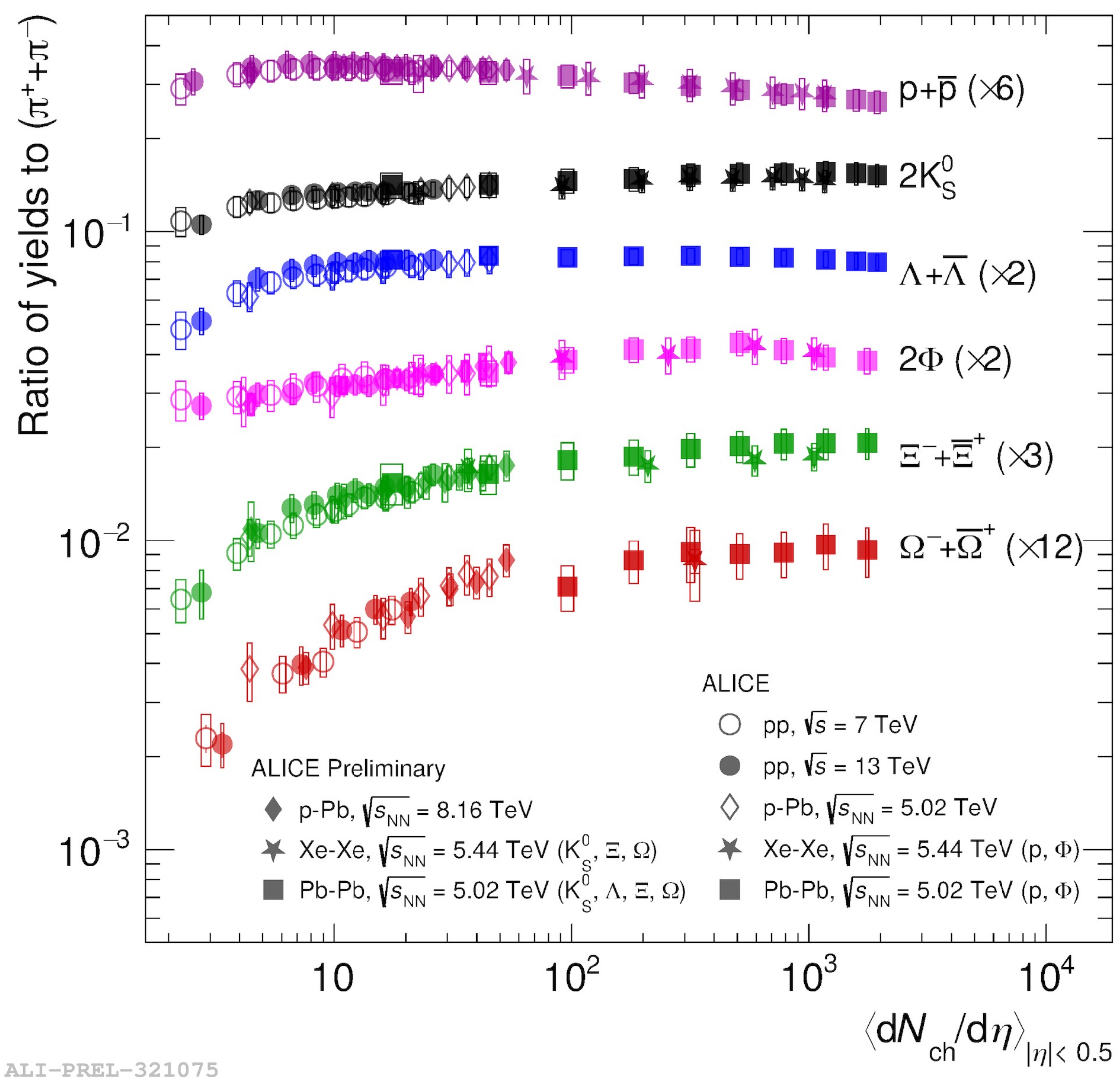
Production and particle ratios measured in all available collision systems and as a function of multiplicity for most species

A smooth evolution of particle chemistry and, in particular, an increase of strangeness production is observed from low to high multiplicity

Strangeness increase with multiplicity is still not understood

→ *since oct. 2020, effort in collaboration with model builders, a "PHENOmenal" initiative within ALICE*

→ *new studies with new observables*

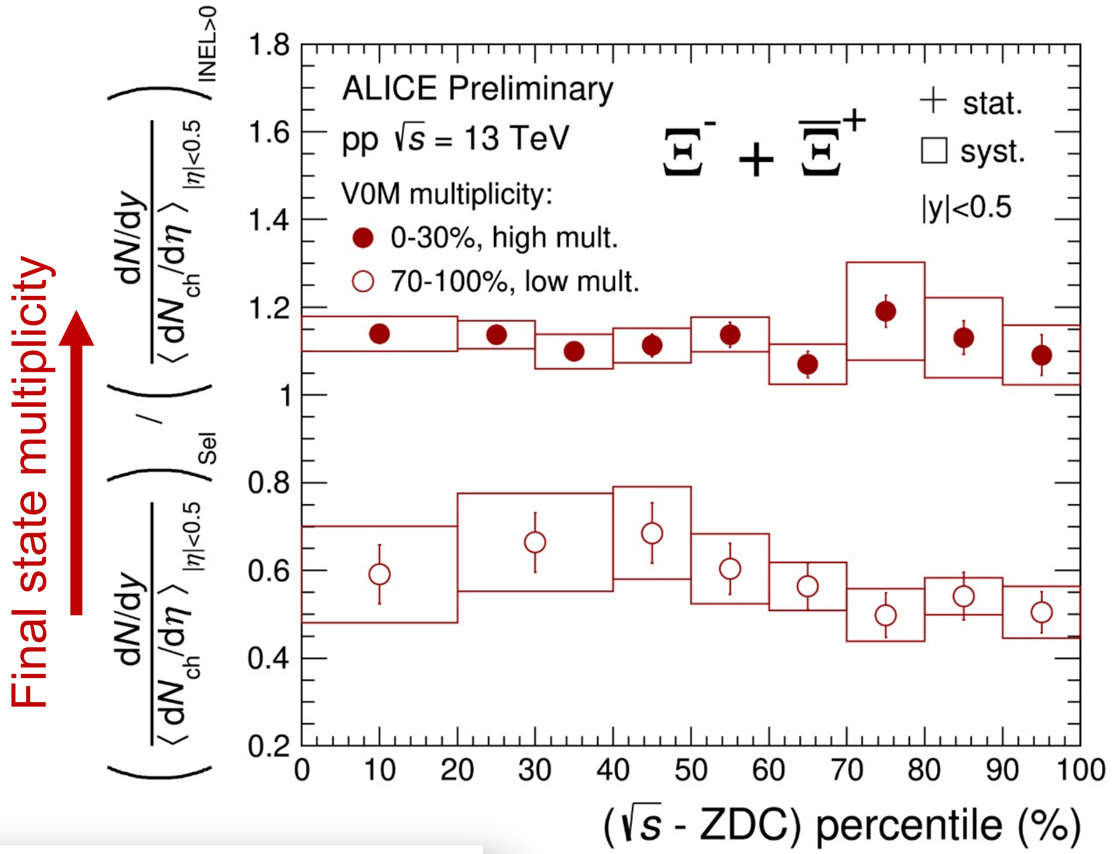


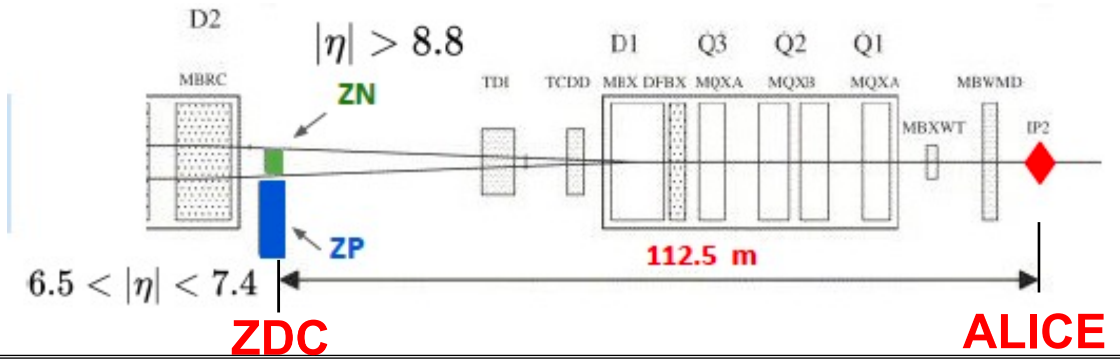
Strangeness vs effective energy and multiplicity

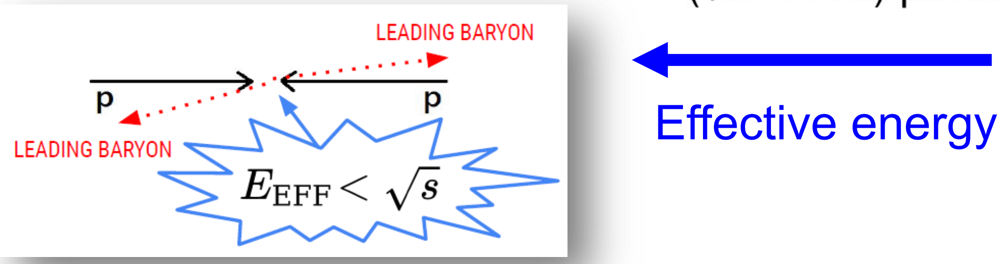
Effective energy: energy available for particle production in the initial phase of a pp collision

- Reduced with respect to the center of mass energy due to the *leading baryon effect*
- Estimated through the measurement of the energy of forward baryons with the **ZDC**
- Combined multiplicity and effective energy selections

The increase with multiplicity is not an initial state effect (effective energy), but more sensitive to the final state (multiplicity)





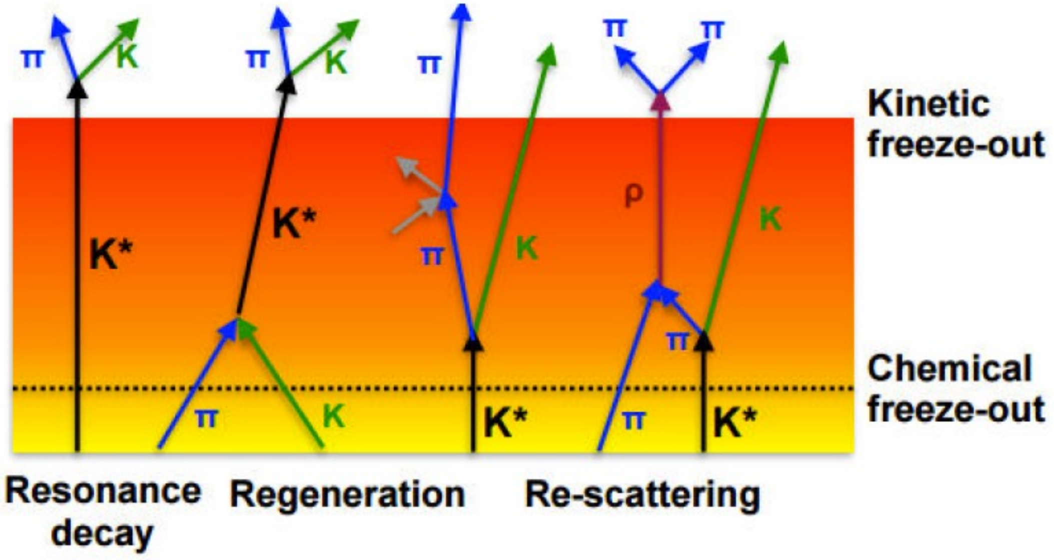


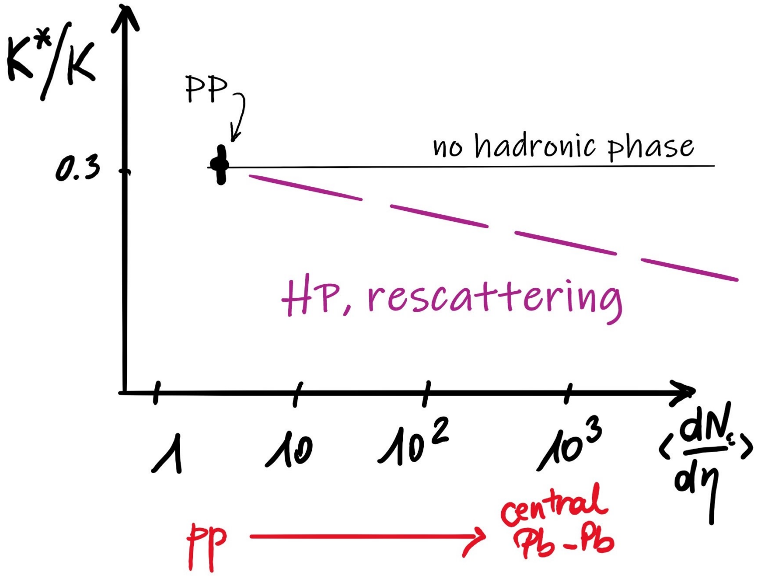
Resonances probe the hadronic medium

Resonances that decay with short lifetimes, O(1 -10 fm/c) are probes for the hadronic medium:

- lifetime of the hadronic phase ~ lifetime of resonances
- yields affected by interactions in the dense and hot hadron gas (regeneration and rescattering processes)
- feeddown affects long-lived hadron distributions

ρ(770)⁰	K(892)⁰	Σ(1385)±	Λ(1520)	Ξ(1530)⁰	Φ(1020)
cτ ~ 1.3 fm	4 fm	5.5 fm	12.5 fm	22 fm	46 fm
S = 0	S = 1	S = 1	S = 1	S = 2	S = 0





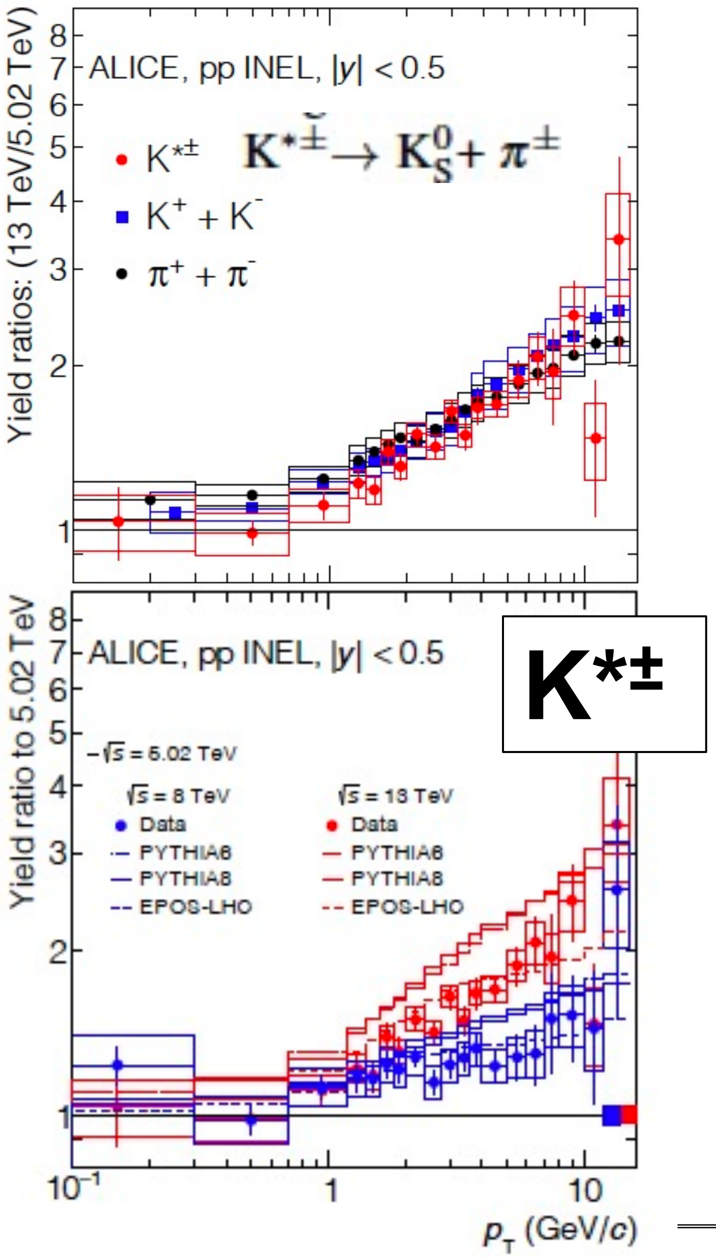
Energy dependence of K* and phi in pp

First measurements of $K^{*\pm} \rightarrow K^0_S\pi$ resonance in inelastic pp collisions at various energies

→ *demonstrated possibility to reduce systematic uncertainties on the K*/K ratio using topological reconstruction of the decay*

Phi meson measured as a function of rapidity in the dimuon channel (forward) and hadronic channel (midrapidity)

Excitation functions (ratio of p_T spectra energies) for resonant states are similar to those of ground-state hadrons



arXiv2105.00713, arXiv:2105.05760

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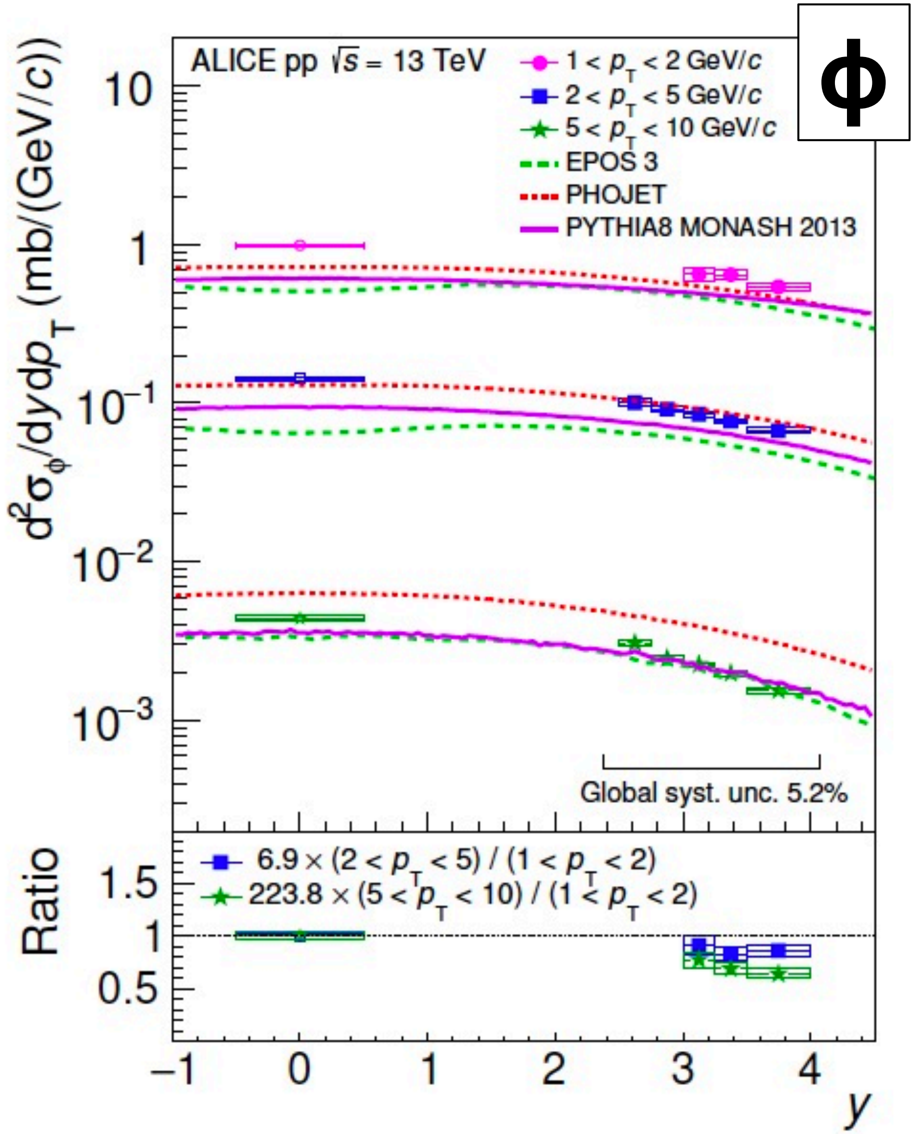
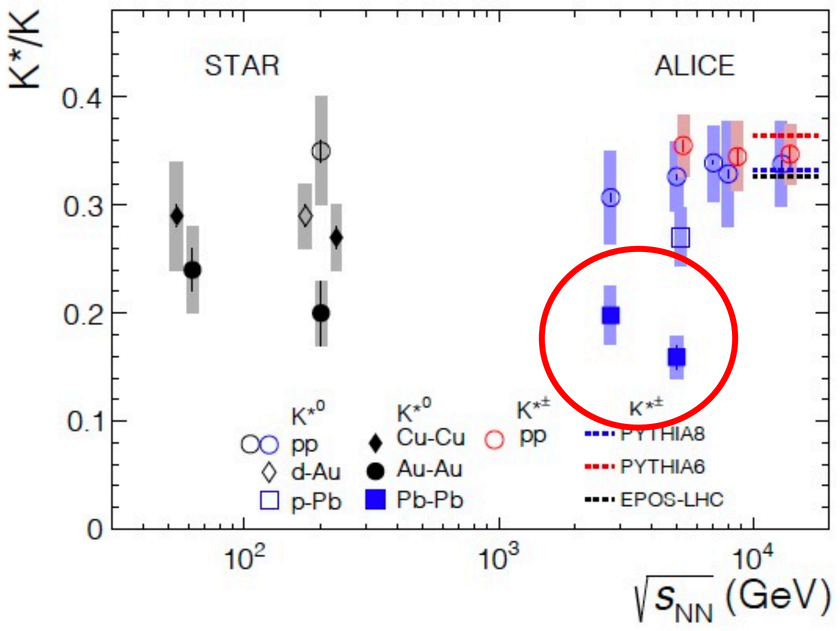
Excitation functions (ratio of p_T spectra energies) for resonant states are similar to those of ground-state hadrons

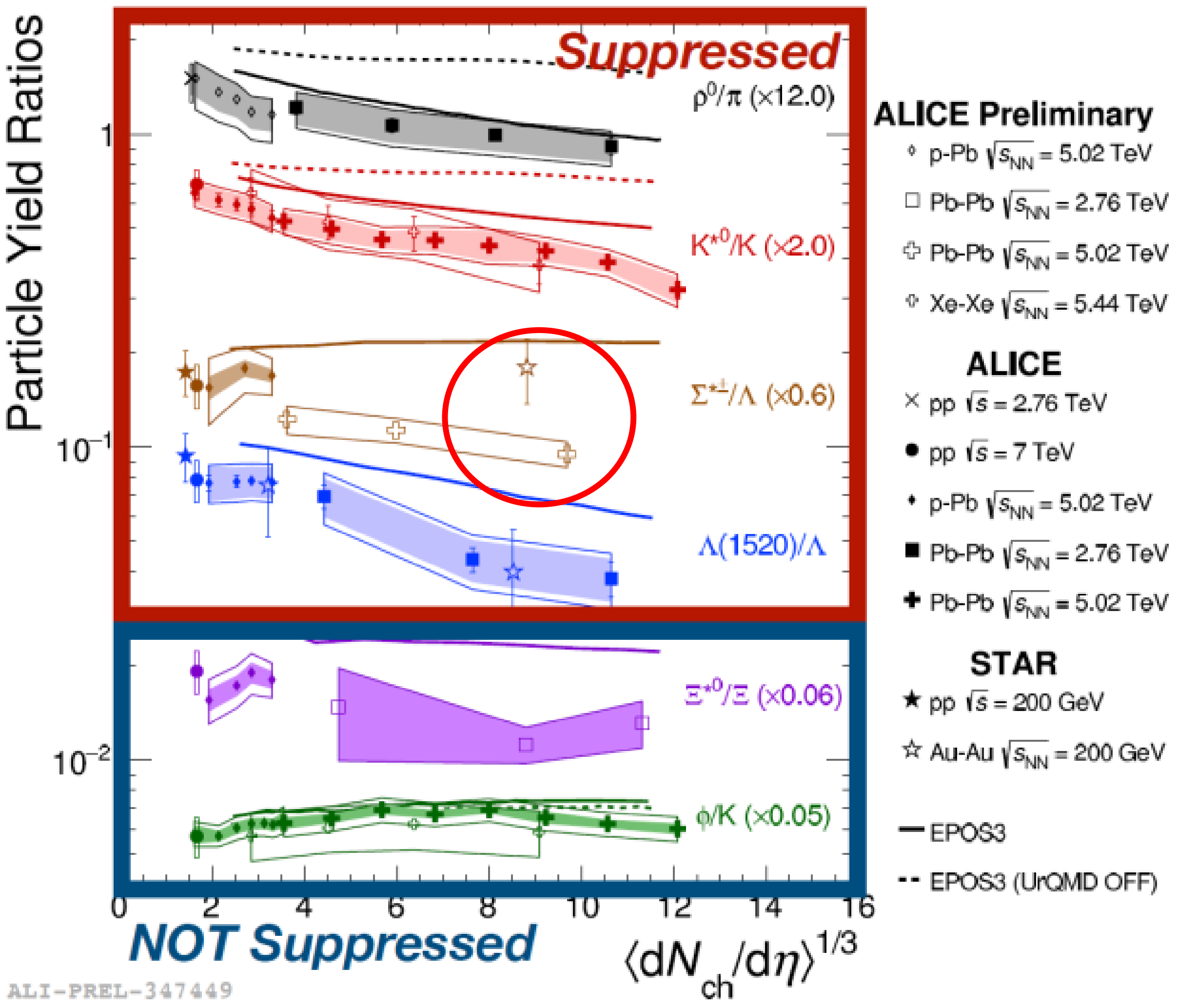
Model calculations are not able to reproduce the measured distributions in the full (p_T or rapidity) range



arXiv2105.00713, arXiv:2105.05760

Suppression of short-lived resonances in Pb-Pb





Suppression of short-lived resonances as $\rho(770)$, K(892)*, $\Lambda(1520)$*, $\Sigma(1385)$* in central AA collisions understood as due to the dominance of rescattering effects over regeneration in the hadronic phase

Unexpected suppression of Σ?*

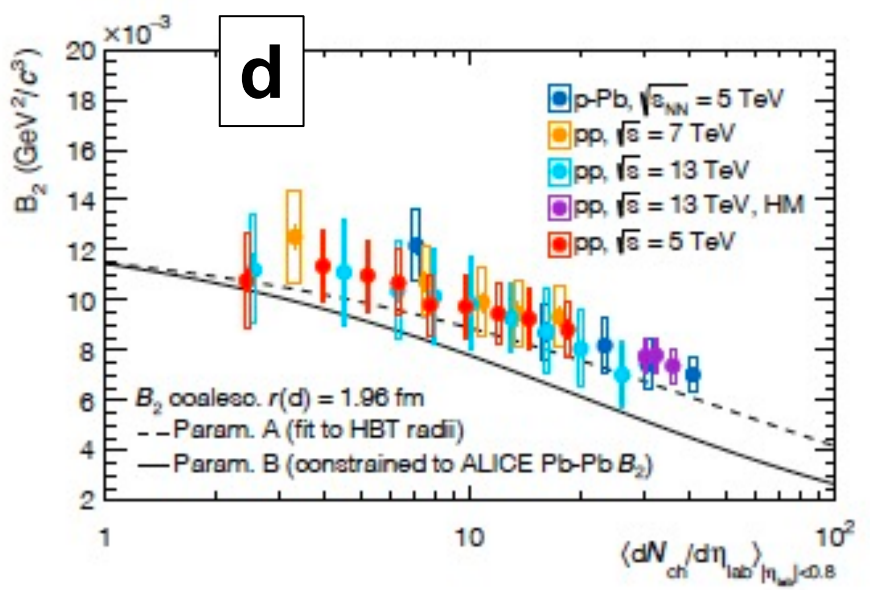
arXiv:2105.05760, arXiv:2106.13113

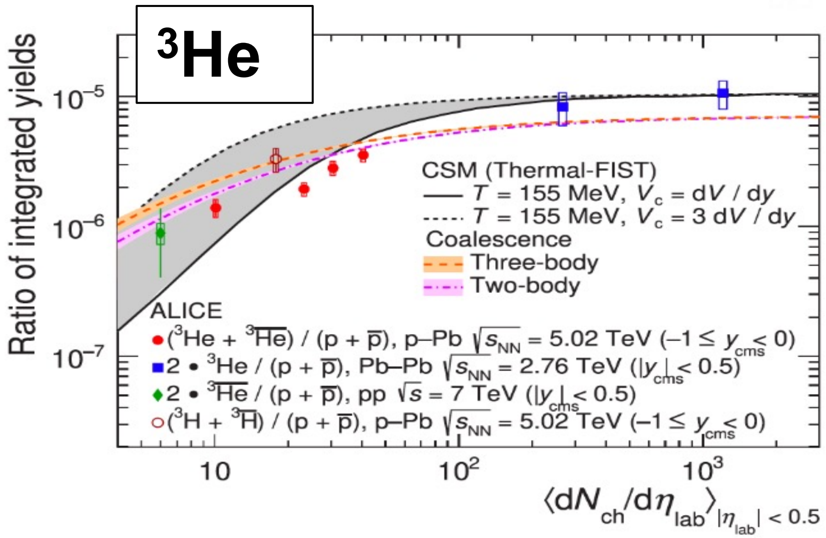
Production of nuclei and antinuclei

Measurements of light nuclei as a function of the system size from pp to Pb-Pb collisions are required to constrain production models

- Statistical hadronization
- Coalescence

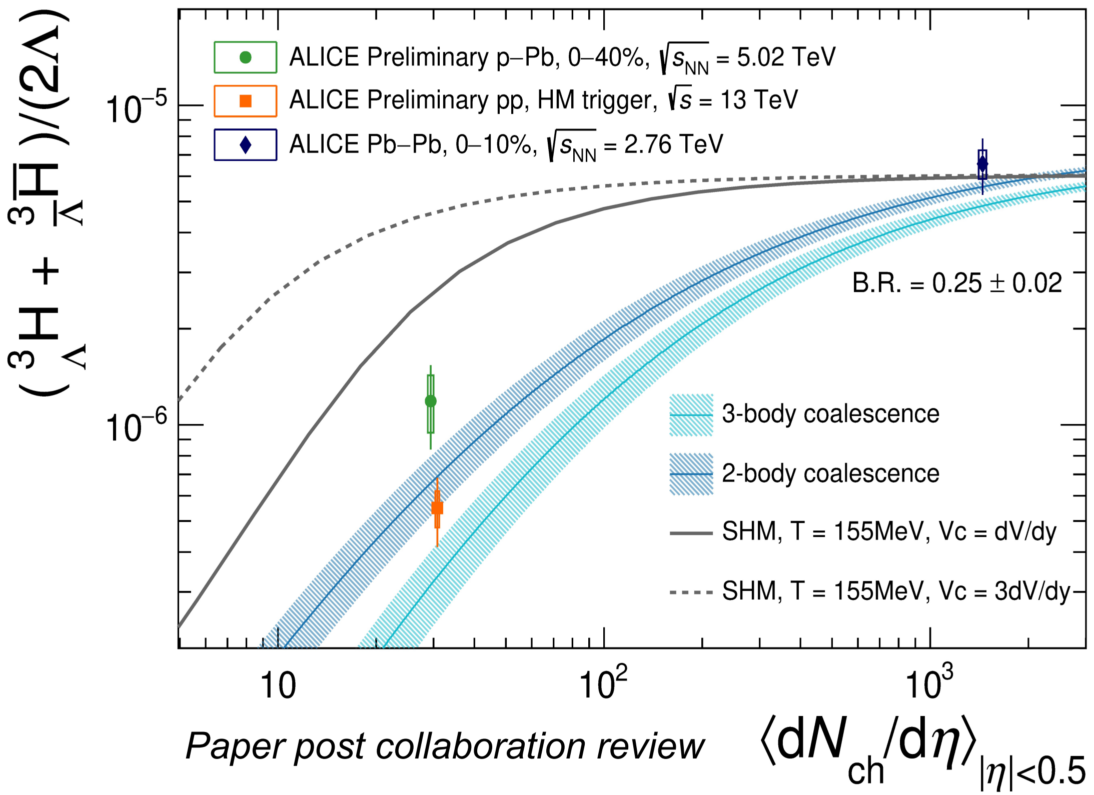
Address the puzzle of the survival of loosely bound states (E_B ~ 2 MeV) in the hot hadron gas (T ~ 150-100 MeV) produced in heavy ion collisions





Papers in collaboration review

Studying formation mechanism of hypertriton



Paper post collaboration review

First measurements of hypertriton production in pp and p-Pb collisions confronted with production models

Measurement in small systems impose tight constraints to production models

2-body coalescence is favoured in small systems

→ *opens the way for systematic and precise measurements as a function of multiplicity in Run 3*

→ *formation via coalescence to be studied further by investigating final state interactions via two-particle femtoscopic correlations*

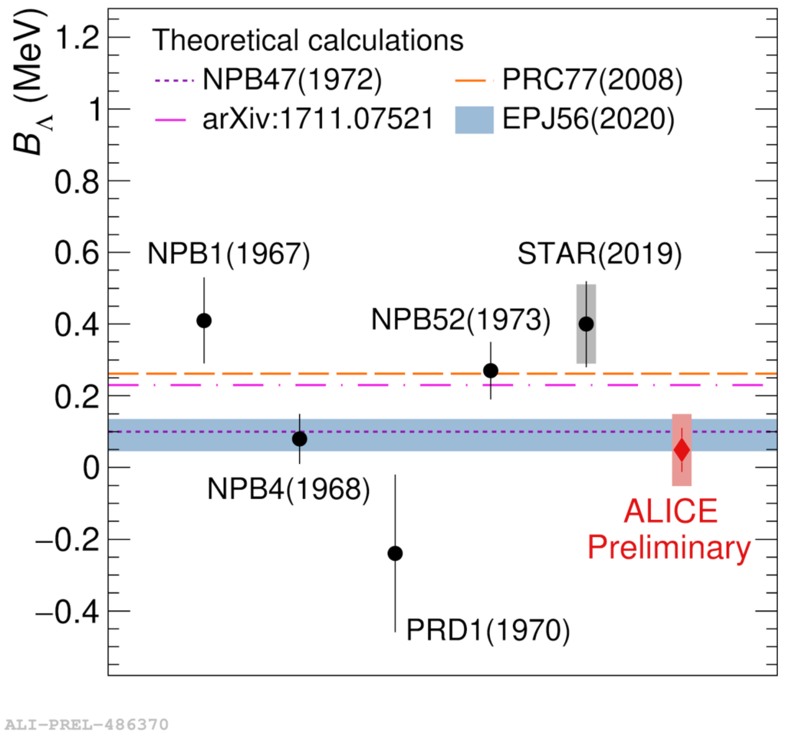
The hypertriton lifetime puzzle

Very precise measurements of mass and binding energy of $^{3}_{\Lambda}H$

→ *Machine Learning (BDTs) techniques applied to identify $^{3}_{\Lambda}H$ candidates in Pb–Pb*

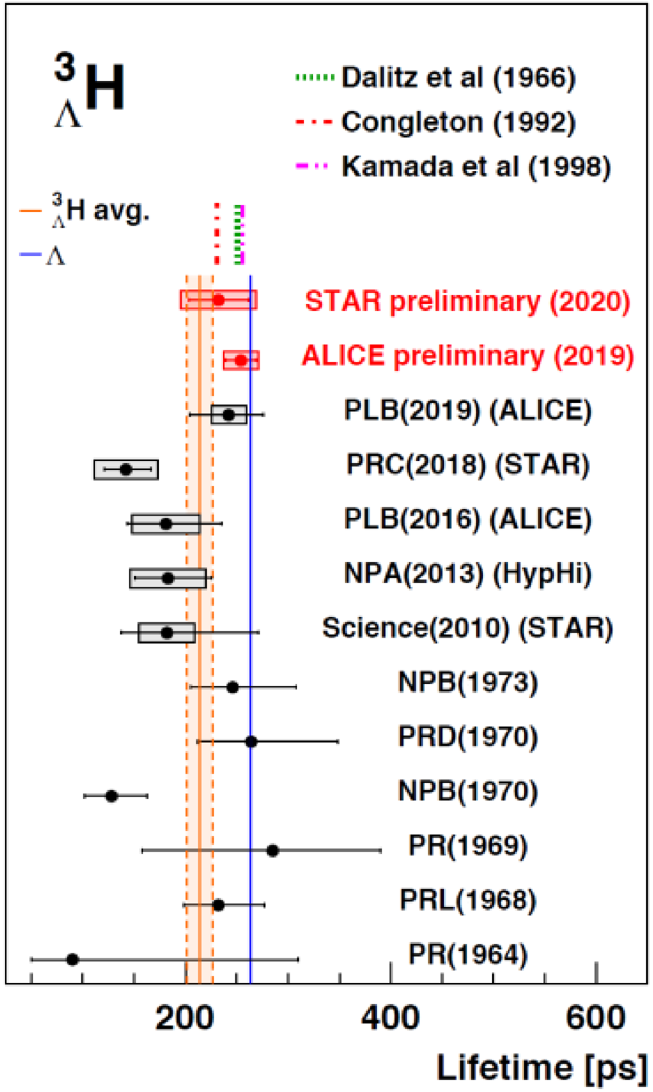
Binding energy compatible with 0 supports the hypothesis of a loosely bound state

Most precise measurement of $^{3}_{\Lambda}H$ lifetime favors a lifetime near the free-Λ lifetime



Current experimental average

$\tau_{3\Lambda H} = (81 \pm 5)\% \tau_{\Lambda}$



New precise results on the lifetime and Λ separation energy from ALICE make progress towards the resolution of the hypertriton lifetime puzzle

DARK UNIVERSE | FEATURE

CERN COURIER 30.10.2020

ALICE’s dark side

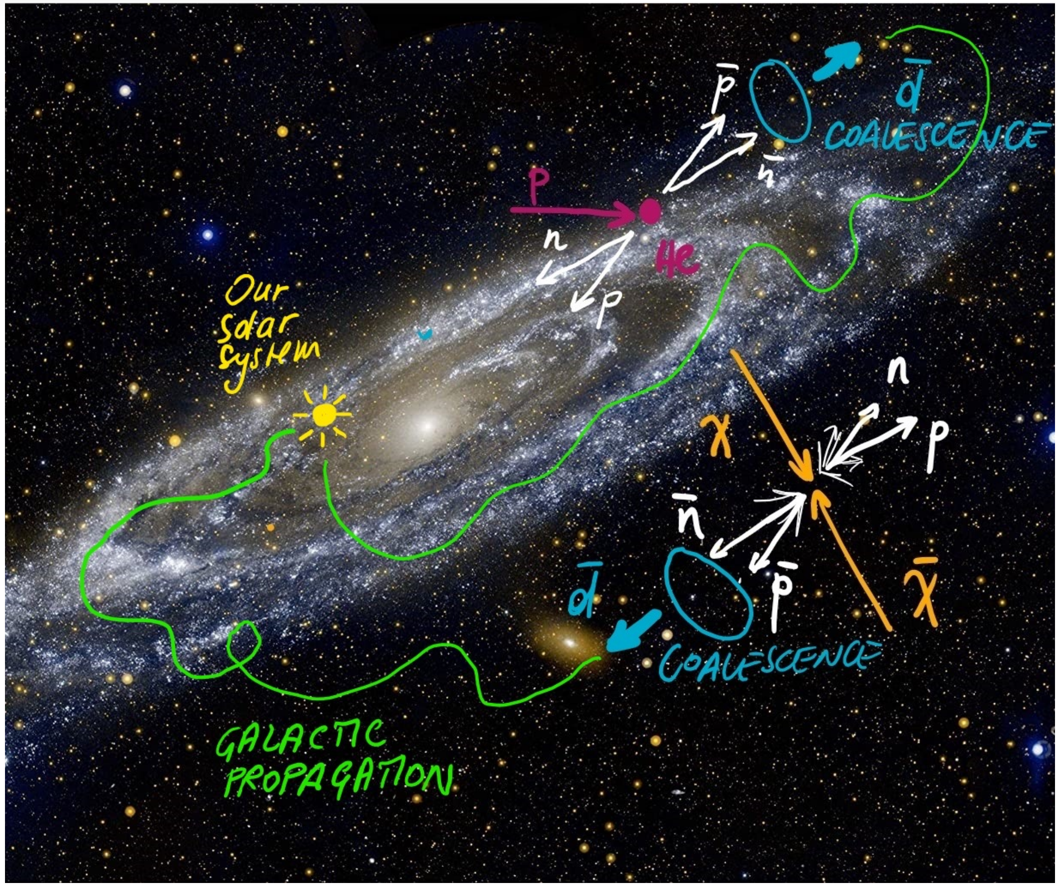
Precision measurements of the production and annihilation of light antinuclei are sharpening the search for dark matter.

If found in cosmic rays (AMS-02, GAPS), light antinuclei (antideuterons, antihelions) may be originated from interactions of

- dark matter (WIMP) particles
- primary CR with the galactic interstellar matter (pp, p-He…)

Ingredients needed to predict rates:

- antimatter cluster **formation mechanisms**
  → constrain with measurements in ALICE
- model of **cosmic ray propagation** in the Galaxy and the heliosphere
- **annihilation** cross section of antinuclei
  → measured with ALICE at low p_T

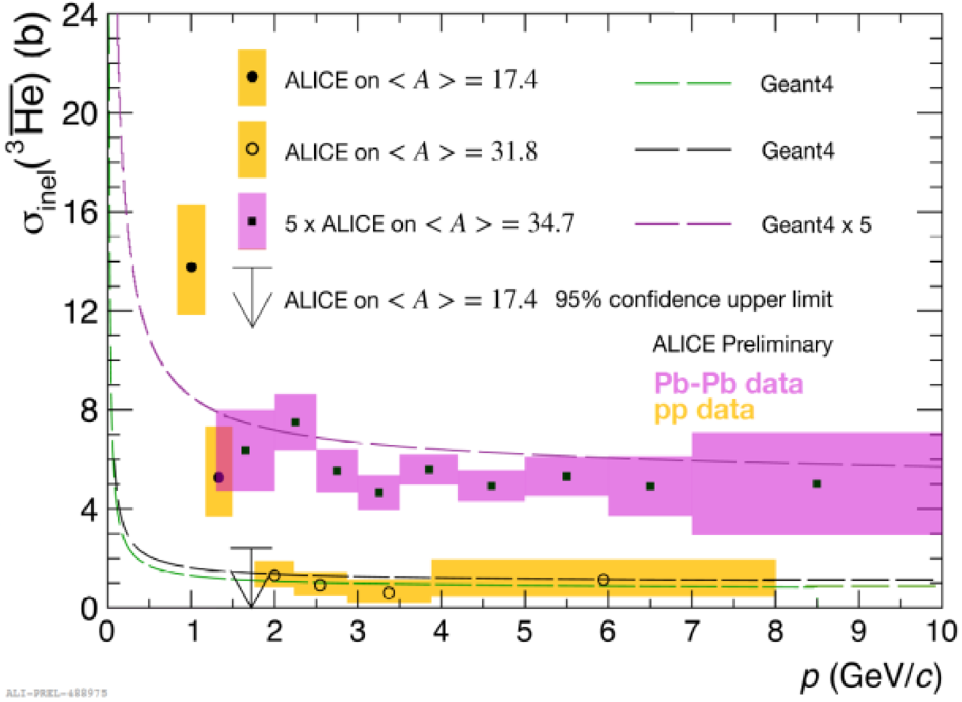


H2020-ERC-STG CosmicAntiNuclei@BO

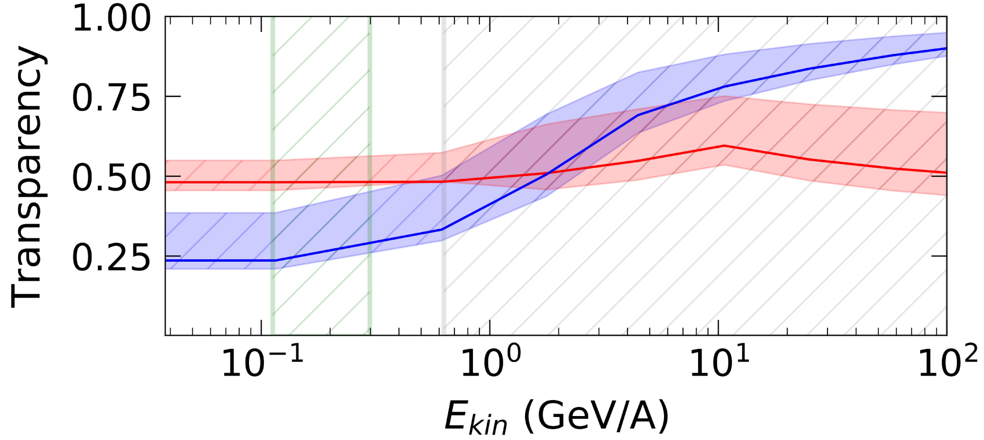
Inelastic cross section of anti-^{3}He

First measurement of the anti-^{3}He inelastic cross section using pp, Pb-Pb data and ALICE as a target

→ new information on interaction with the detector material (compare to Geant)



Application to the propagation of cosmic ray antinuclei through the Galaxy, show high transparency of the Galaxy to anti-^{3}He fluxes



→ *relevant to indirect dark matter searches with space-borne experiments as AMS-02, GAPS*

Heavy flavour sector

PD, TO
BA

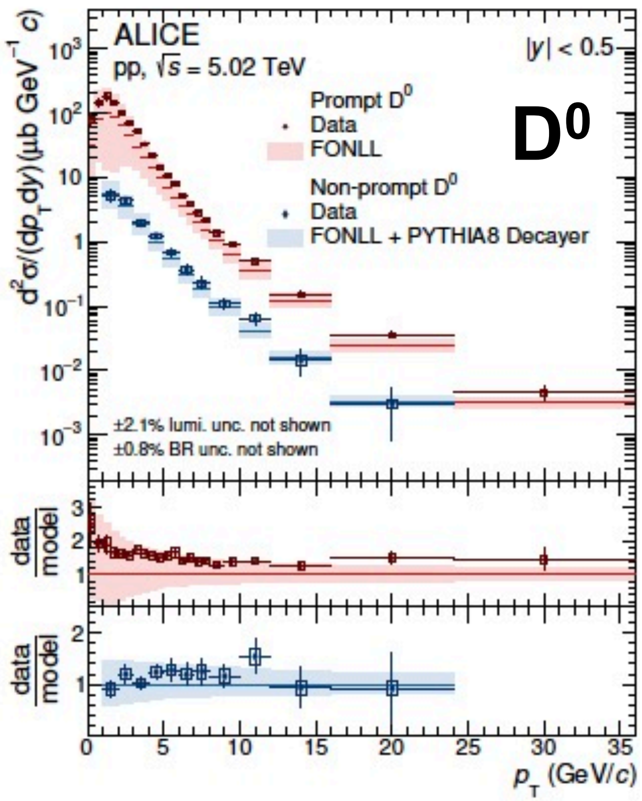
Production of D mesons from charm and beauty

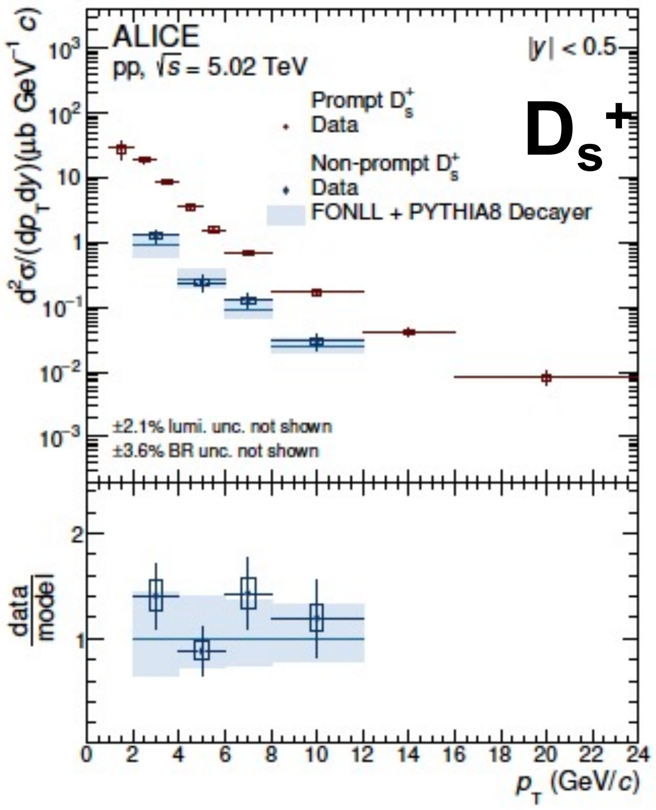
Measurements of prompt (from charm) and non-prompt (from beauty) D^0 and D^+, D_s^+ cross sections in pp collisions are used to study the fragmentation fractions (FF) of heavy quarks to mesons w/ and w/o strangeness

→ *extension of measurement to $p_T = 0$ important for testing pQCD calculations and as a reference for AA*

NLO pQCD calculations describe meson cross sections down to low p_T with extracted from e^+e^-

→ *D mesons also measured in correlation with charged hadrons in pp, p-Pb to investigate possible effects of cold nuclear matter on the FF (not observed)* [EPJC 80 (2020) 979]





arXiv:2102.13601

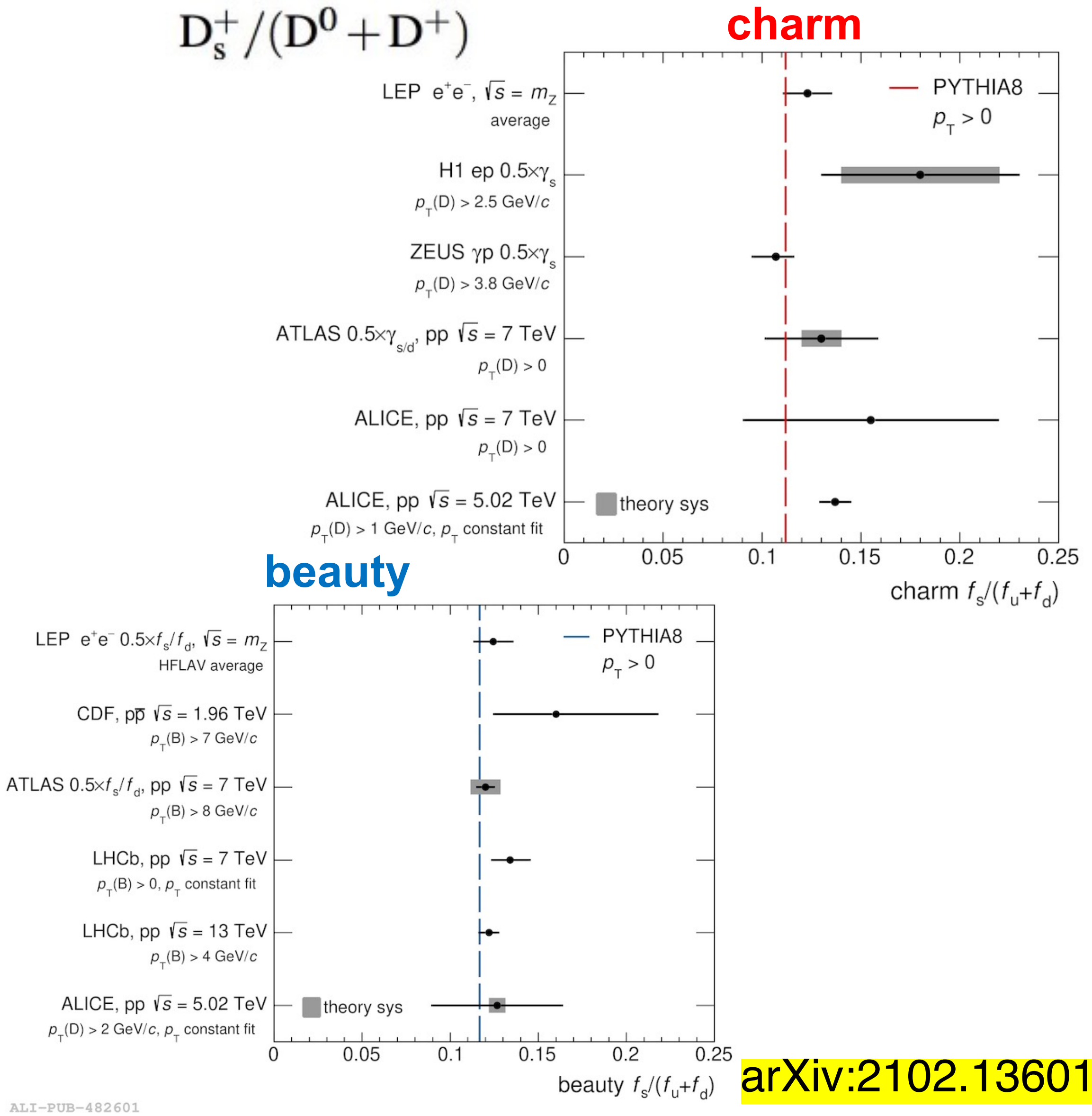
Charm and beauty fragmentation to mesons

Measurements of prompt (from charm) and non-prompt (from beauty) D^0 and D^+, D_s^+ cross sections in pp collisions are used to study the fragmentation fractions (FF) of heavy quarks to mesons w/ and w/o strangeness

→ *extension of measurement to $p_T = 0$ important for testing pQCD calculations and as a reference for AA*

NLO pQCD calculations describe meson cross sections down to low p_T with extracted from e^+e^-

FF consistent with previous measurements at other energies as well as in e^+e^-



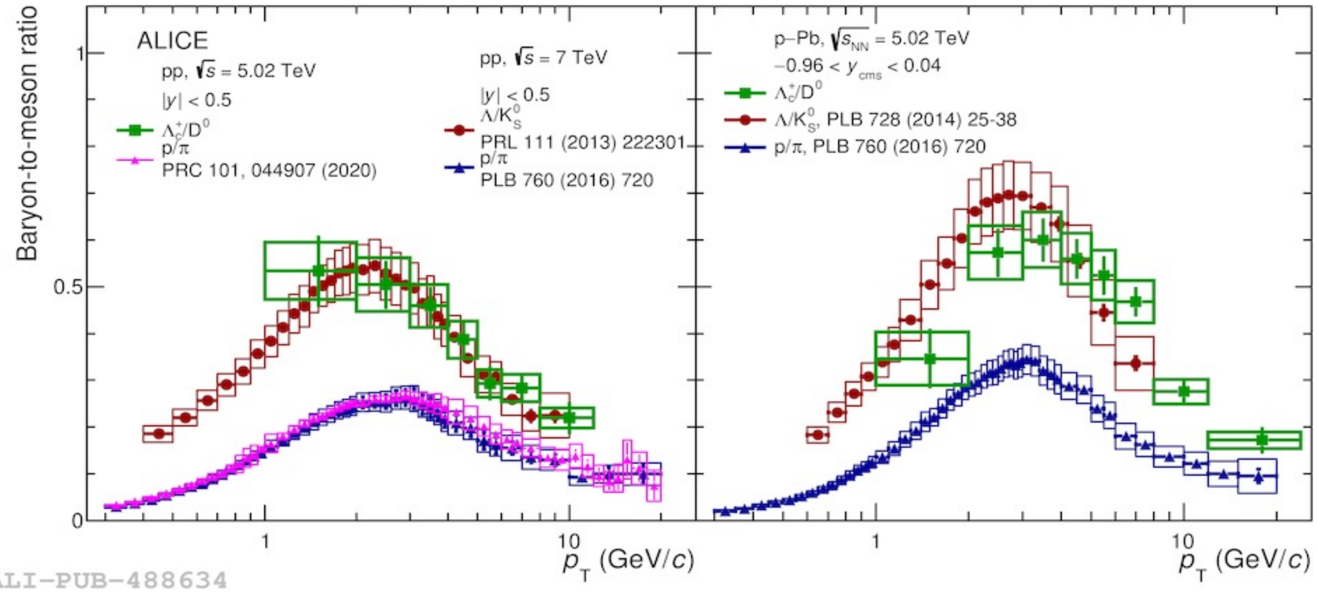
arXiv:2102.13601

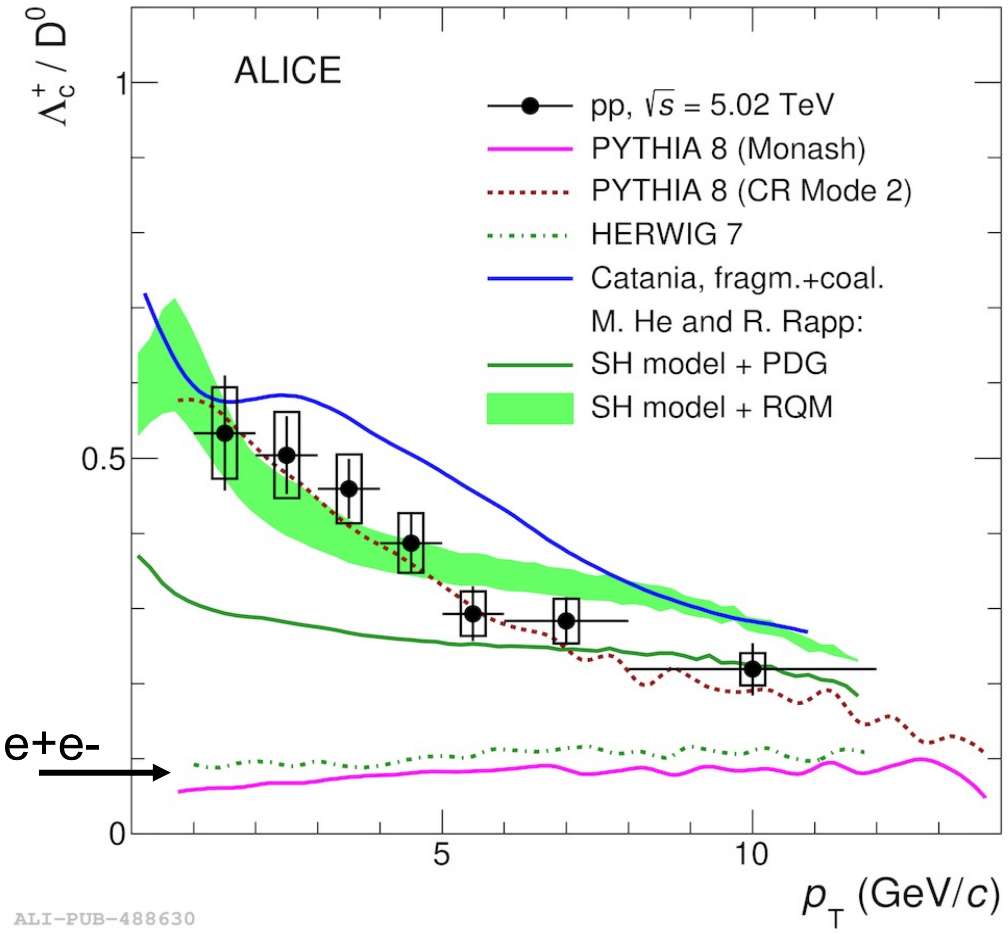
Charmed baryon production: Λ_c^+

Charmed baryon-to-meson ratio provide information on hadronization mechanisms and fragmentation

Λ_c^+/D^0 decreases with increasing momentum, similarly to the baryon/meson ratio in the light flavour sector

Predictions based on charm fragmentation processes measured in e^+e^- and e^-p significantly underestimate the data





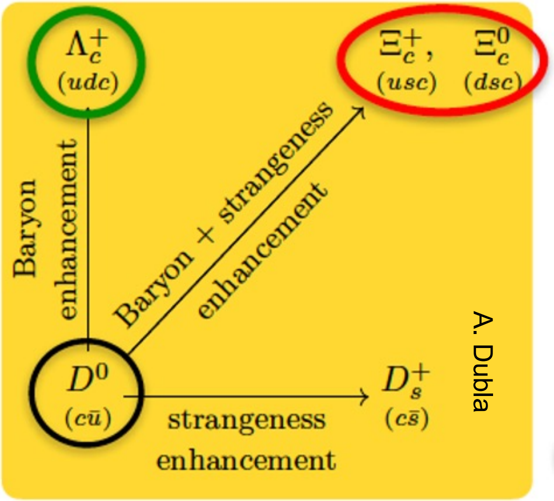
PYTHIA: JHEP 1508 (2015) 003 (new CR modes)
SHM+RQM: PLB 795 117-121 (2019) (additional charm states)
Catania: arXiv:2012.1200 (hadronization via coalescence)

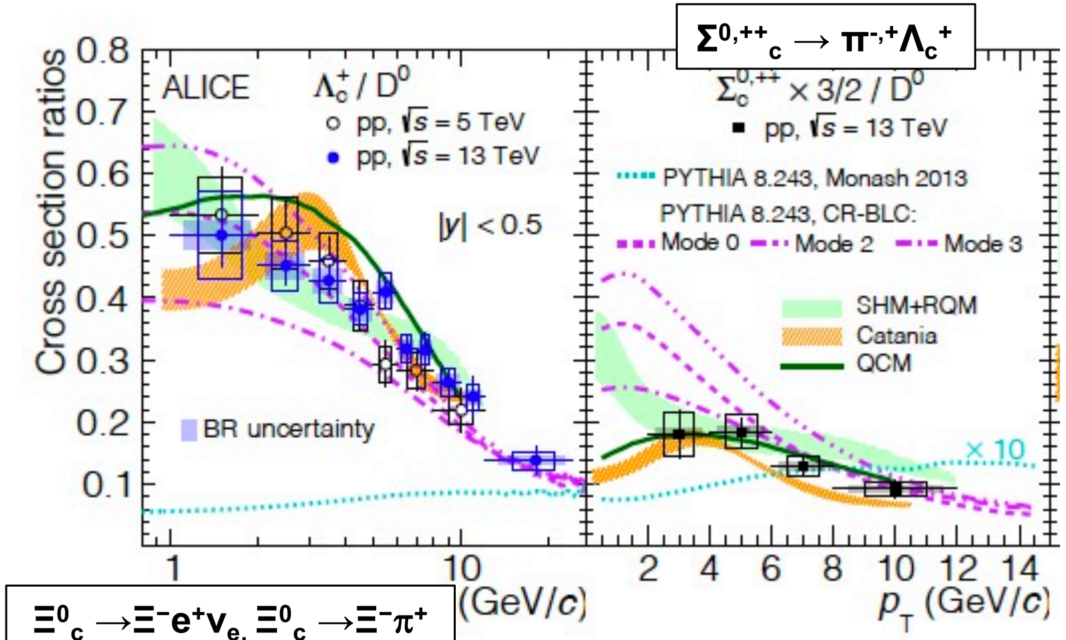
arXiv:2011.06078, arXiv:2011.06079

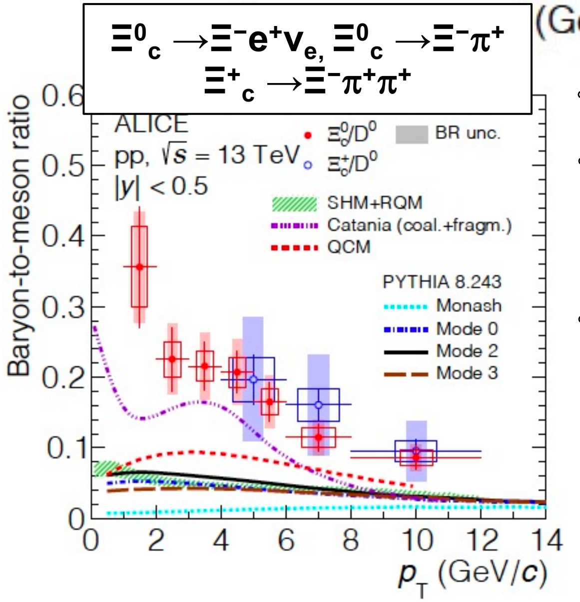
The family of charmed baryons gets bigger!

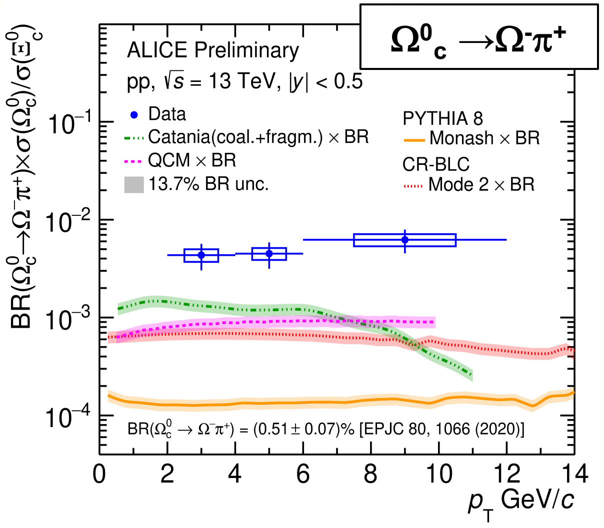
More charmed baryons now measured to test hadronization mechanisms (fragmentation, coalescence) further, starting from pp collisions, in comparison to models.

From success of the Catania model, a hint that charm hadronisation in pp collisions involves coalescence of charm quark with light quarks









arXiv:2105.05616, arXiv:2105.05187, arXiv:2106.082

New measurements of the charm cross section and FF

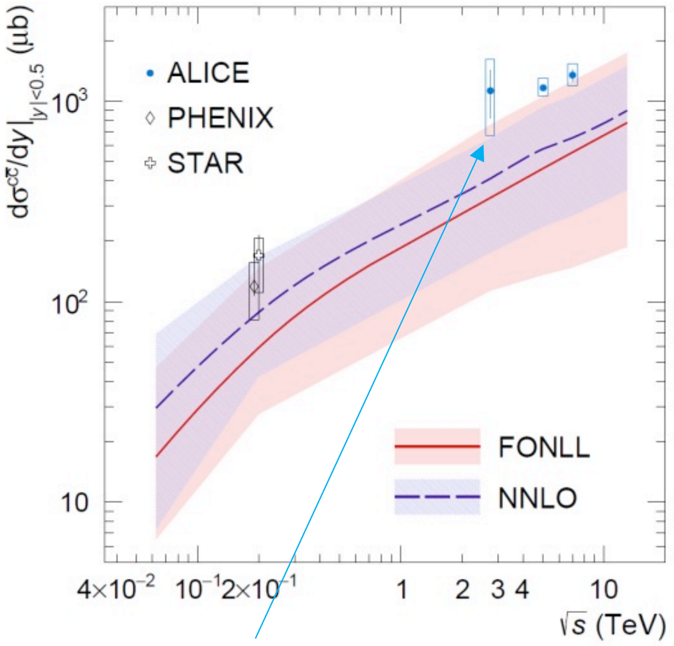
Fundamental input for the determination of the total charm cross section and charm FF

Evidence that universality (colliding-system independence) of parton-to-hadron fragmentation is broken

→ *Milestone measurements for studies of hadronization and in-jet production*

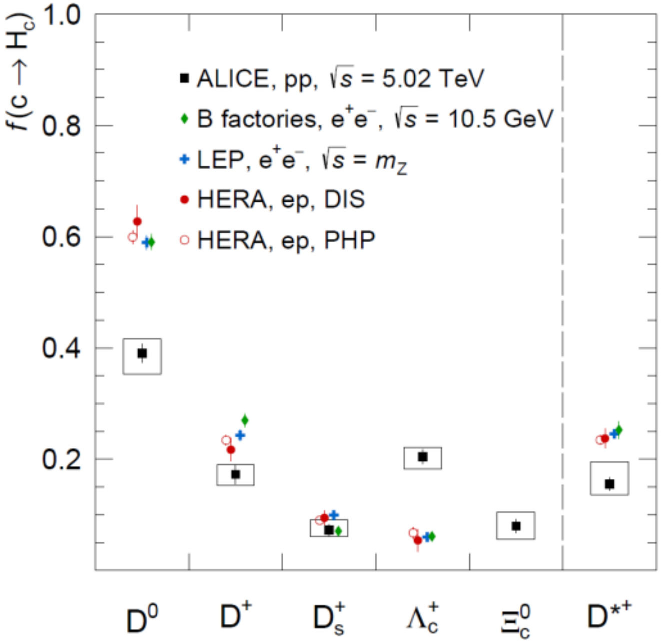
→ *Extend measurements to AA to test modified fragmentation in medium*

$d\sigma^{ccbar}/dy$



30-40% increase wrt D/FF from LEP

$f(c\to H_c)$



First measurement!

ALICE finds that charm hadronisation differs at the LHC

New measurements by the ALICE collaboration show that the way charm quarks form hadrons in proton-proton collisions differs significantly from expectations based on electron collider measurements

CERN Press release, June '21