Soft QCD results from ALICE

The 8th annual Conference on Large Hadron Collider Physics

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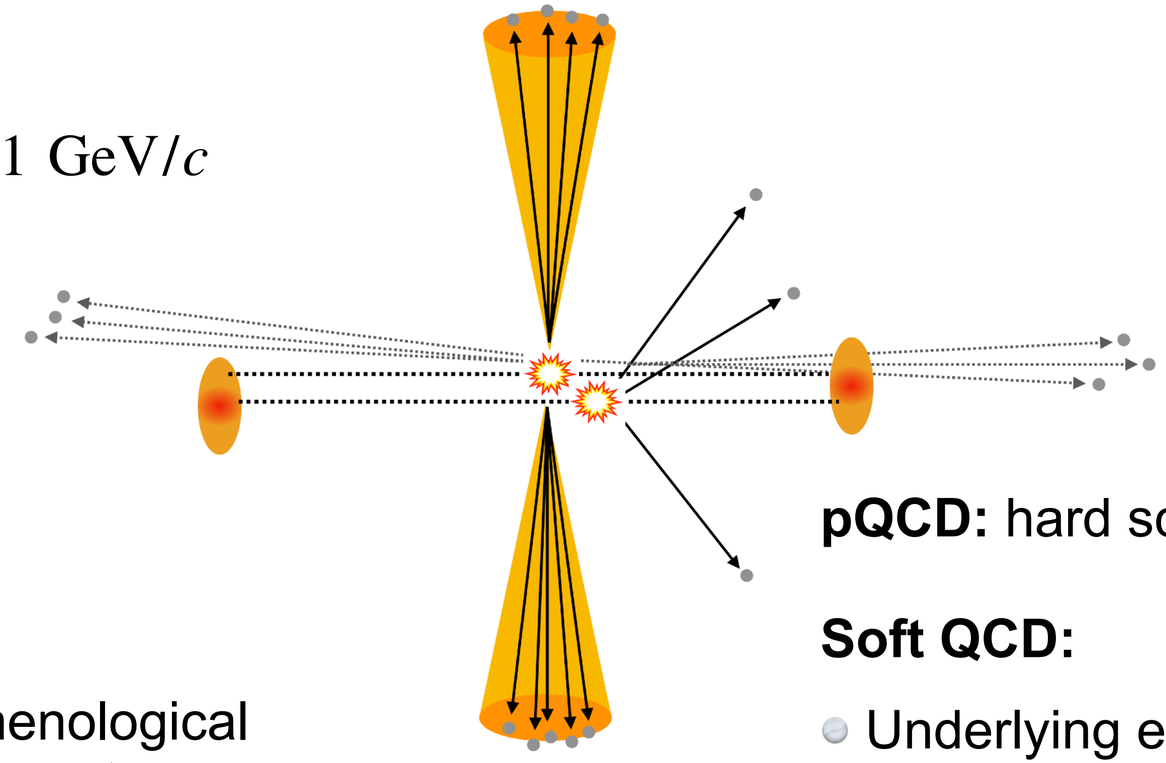
GSI Helmholtzzentrum für Schwerionenforschung GmbH

Introduction

High-energy hadronic collisions:

most of the interactions have $|\vec{q}| \lesssim 1\ \mathrm{GeV}/c$

⟶ **Non-perturbative QCD**



pQCD: hard scattering

Soft QCD:

- Underlying event
- Collective effects
- Multi-parton interactions
- Diffraction (beam remnants)
- Hadronization …

Description mostly based on phenomenological models implemented in MC event generators

- Soft QCD measurements fundamental for tuning the model parameters
- Improve our understanding of non-perturbative processes

Experimental apparatus

Detectors used in the measurements
shown in this presentation

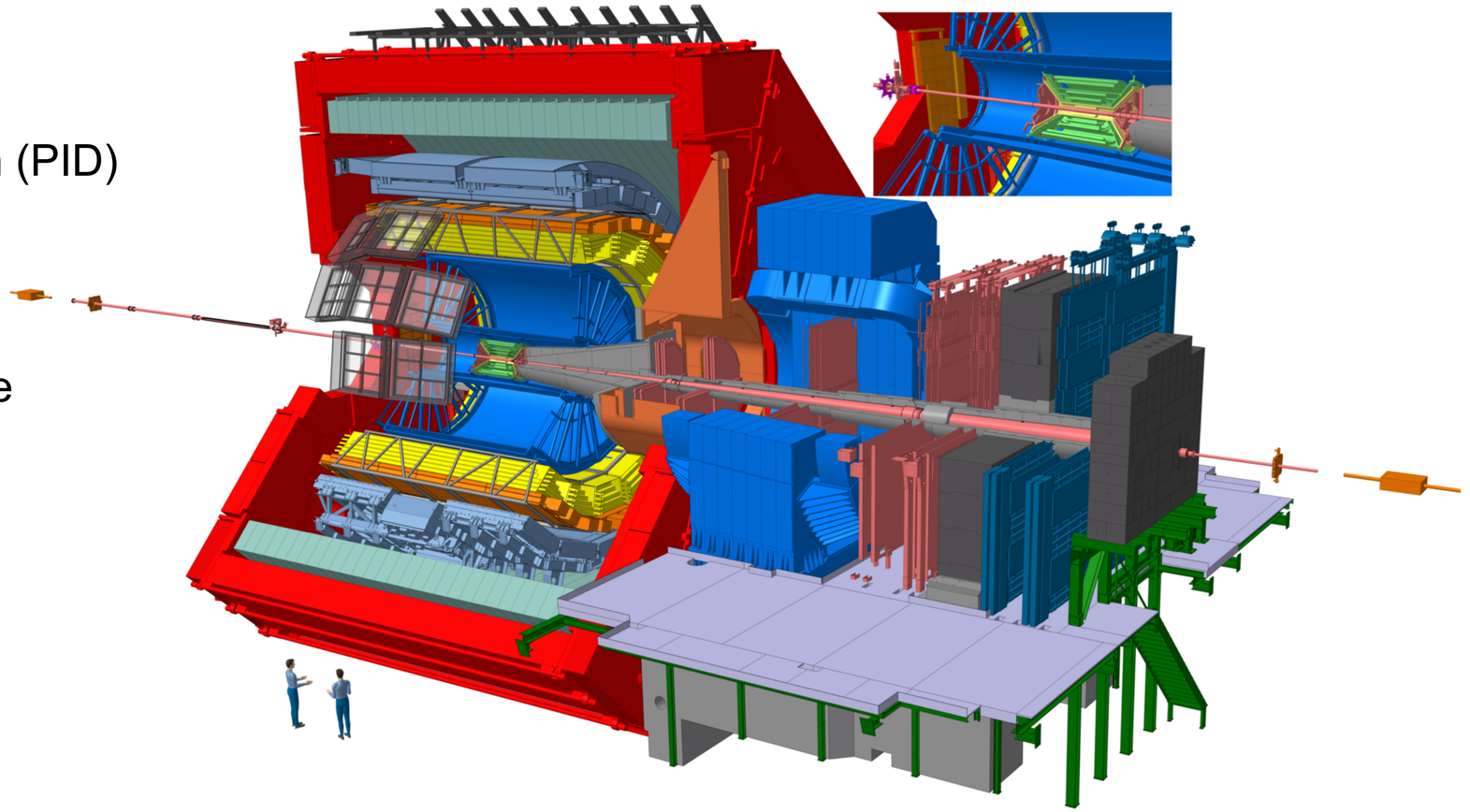
Inner Tracking System (ITS):
tracking, vertex and particle identification (PID)
via d*E*/d*x* in silicon

Time projection chamber (TPC):
tracking and PID via d*E*/d*x* in gas mixture

Time-Of-Flight (TOF):
PID via velocity (β) measurement

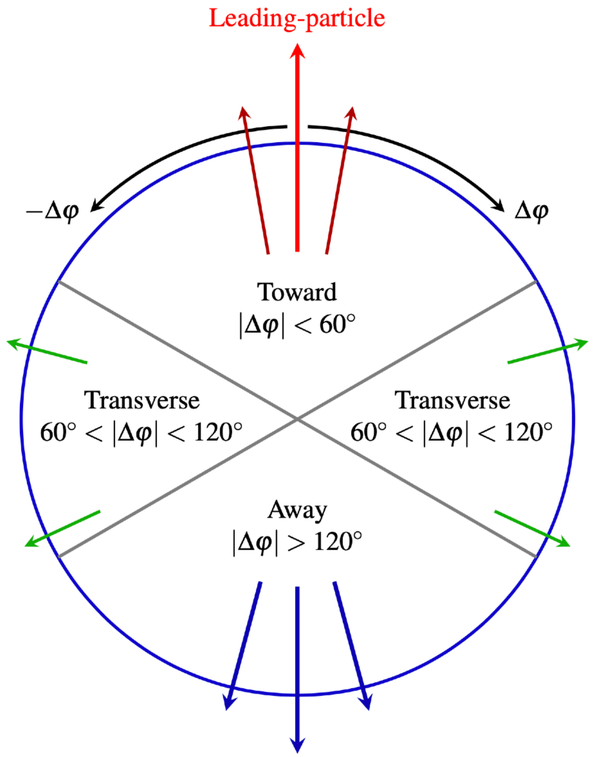
Forward detectors (V0, FMD):
trigger, multiplicity estimators

Muon spectrometer:
tracking of muons



The underlying event

Underlying event (UE) properties using method of the leading particle (with $p_{\mathrm{T}}^{\mathrm{max}}$)



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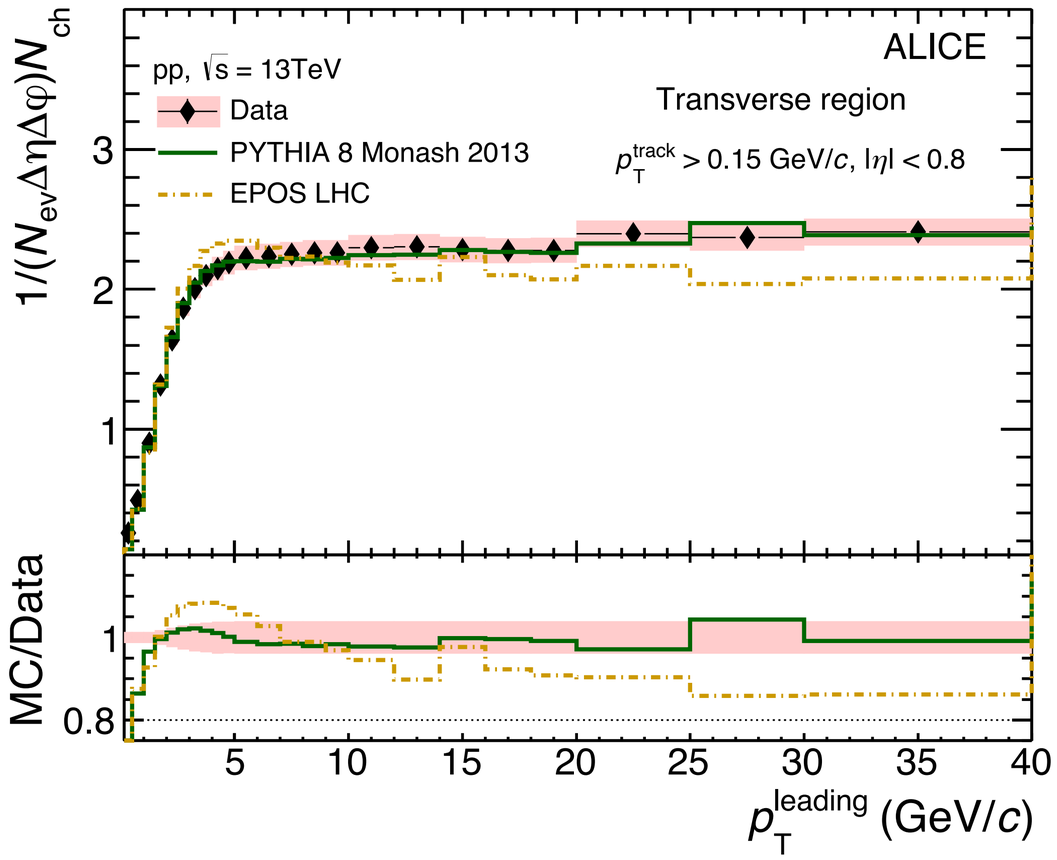

Steep rise in event activity followed by a change to a smaller slope for $p_{\mathrm{T}}^{\mathrm{leading}} > 5$ GeV/c

Trend qualitatively described by MC models (also for Toward and Away regions)

> Better agreement for PYTHIA 8

The underlying event

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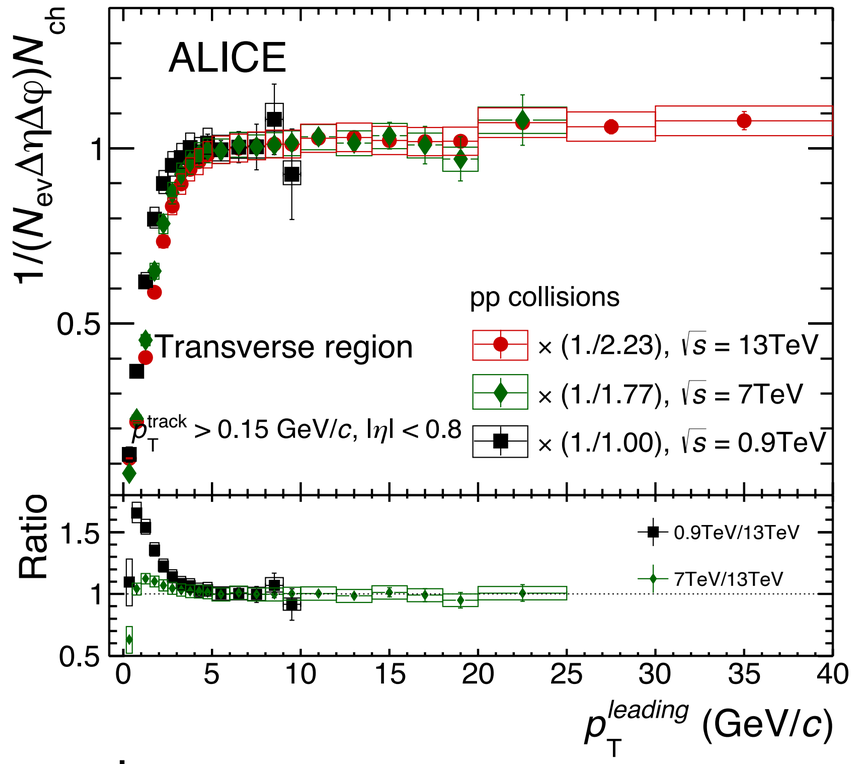

$\sqrt{s}$ - dependence:

- clear ordering among the three collision energies in the region of the rise
- N_{ch} densities consistent in the jet pedestal region within uncertainties

The underlying event

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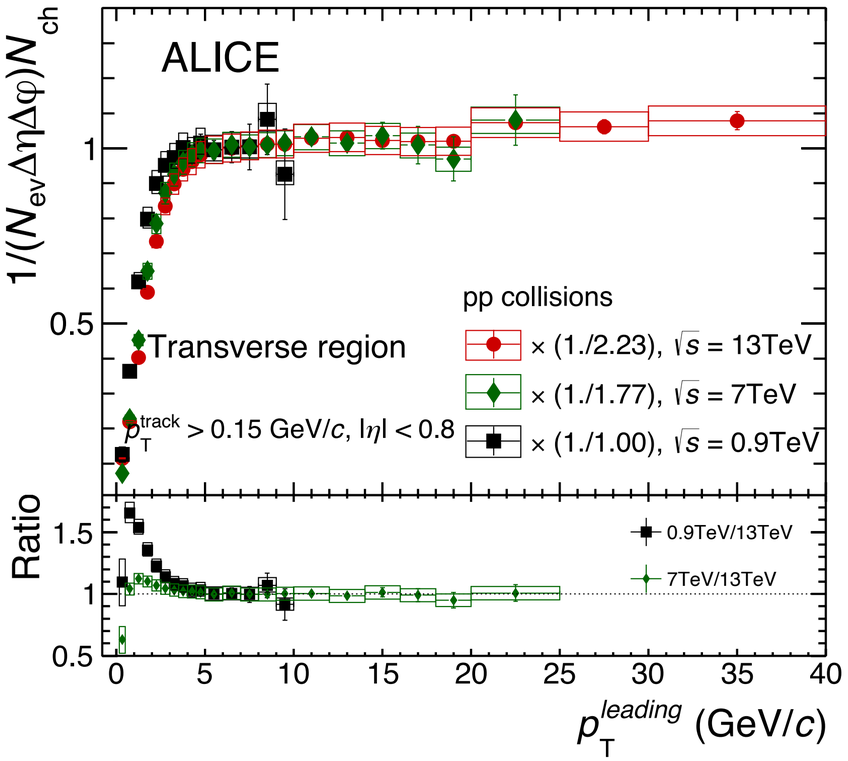
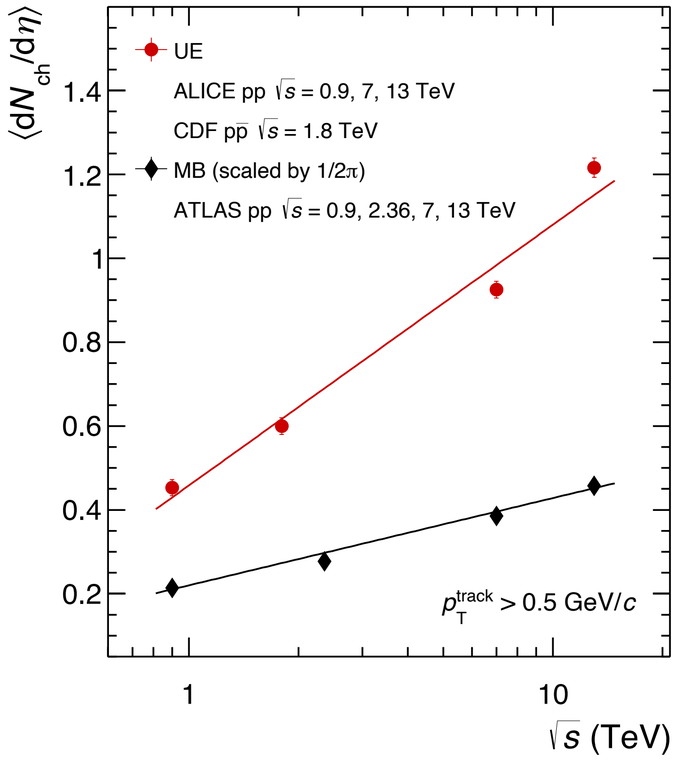




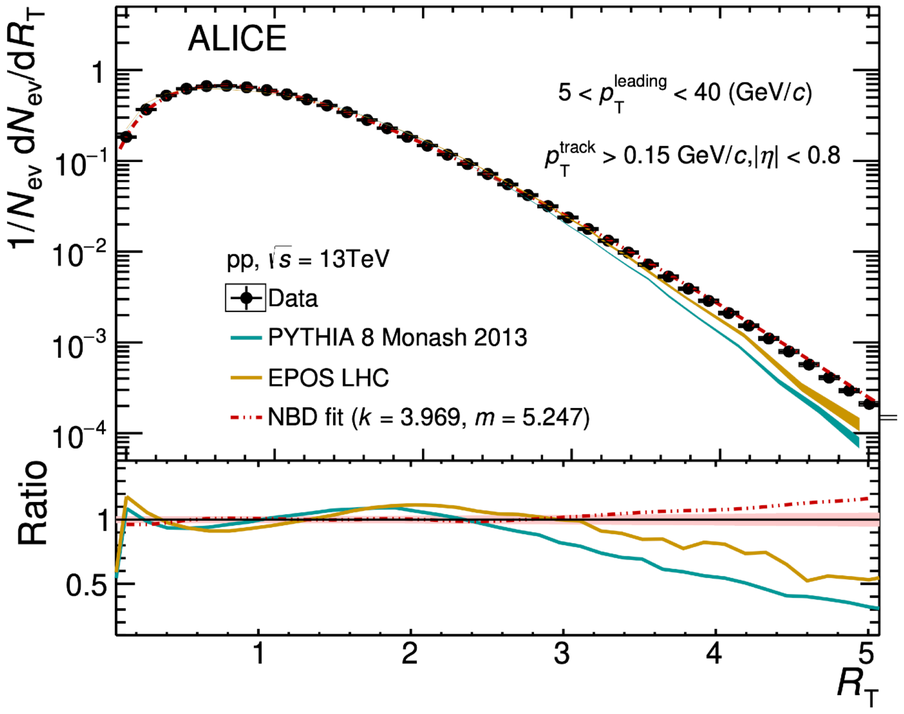
$< dN_{ch}/d\eta > \propto \log(\sqrt{s})$
for both UE and MB

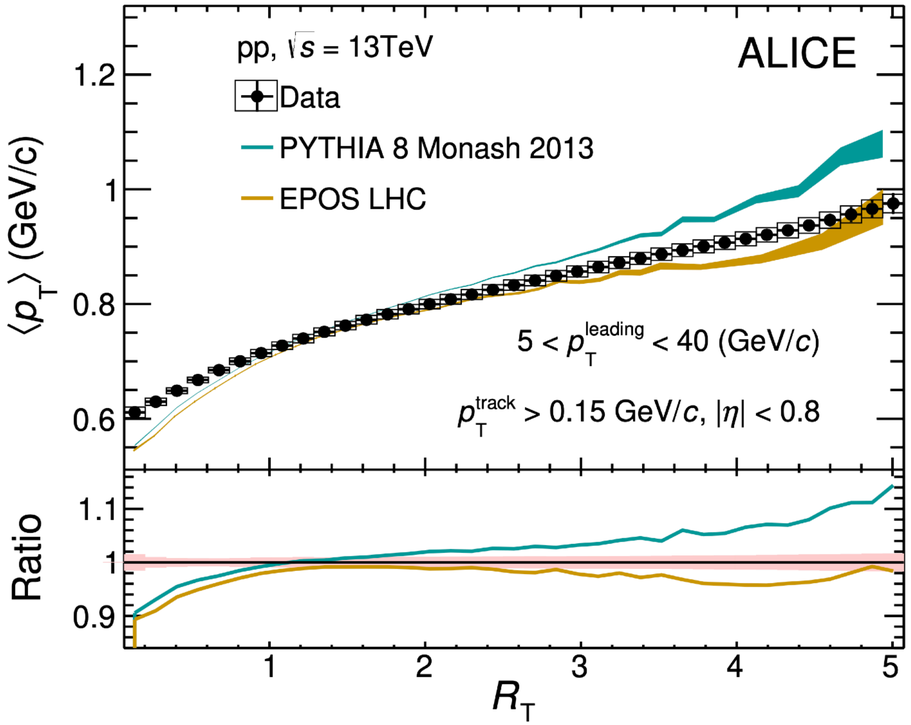
$\sqrt{s}$ - dependence:

- clear ordering among the three collision energies in the region of the rise
- N_{ch} densities consistent in the jet pedestal region within uncertainties

UE activity: factor ~2 larger than $dN_{ch}/d\eta$ in min. bias and stronger increase with $\sqrt{s}$

The underlying event





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$$R_T = \frac{N^T_{\text{inclusive}}}{< N^T_{\text{inclusive}} >}$$

Relative transverse UE activity: sensitivity to rare events with large or small transverse activity with respect to the event-averaged mean

- Good description of R_T distribution by PYTHIA 8 and EPOS LHC only for $R_T < 2.5$
- Deviations up to 10% in $<p_T>$ at extremes of R_T: opposite trend for the two models at high R_T

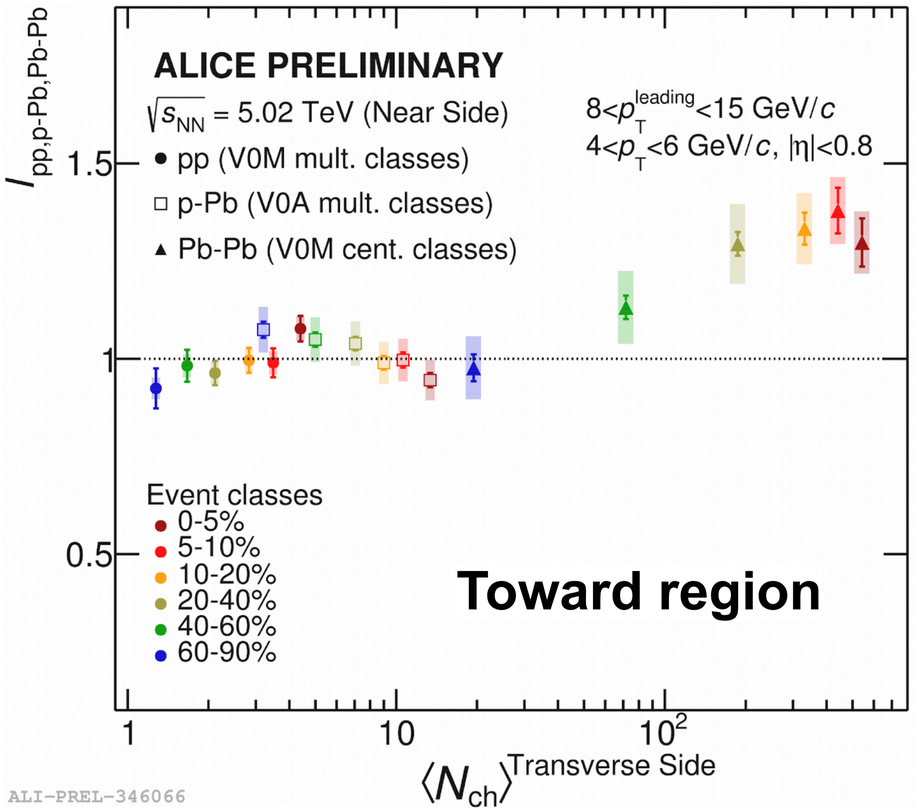
→ Data provides important constraints on the models

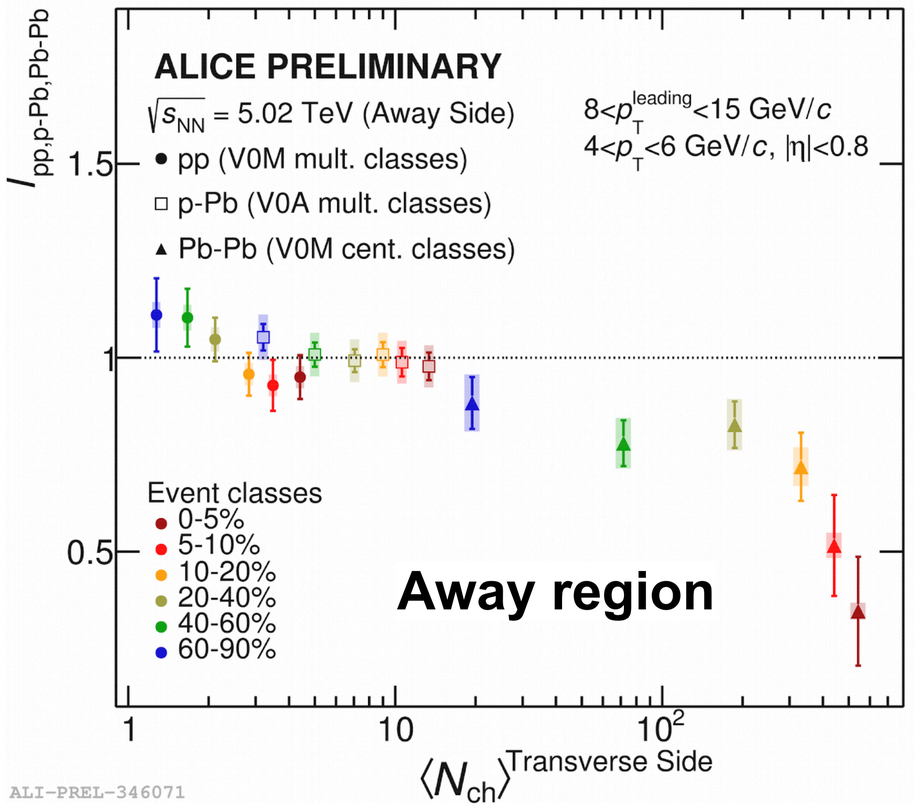
(No) energy loss in pp collisions

$$I_{\text{pp/pA/AA}} = \frac{Y_{\text{pp/pA/AA}}}{(Y_{\text{pp/pA/AA}})_{\text{min.bias}}}$$

Toward region (TR): $\Delta\varphi = |\varphi_{\text{leading}} - \varphi_{\text{associated}}| < 60^\circ$

Away region (AR): $\Delta\varphi = |\varphi_{\text{leading}} - \varphi_{\text{associated}}| > 120^\circ$





NEW

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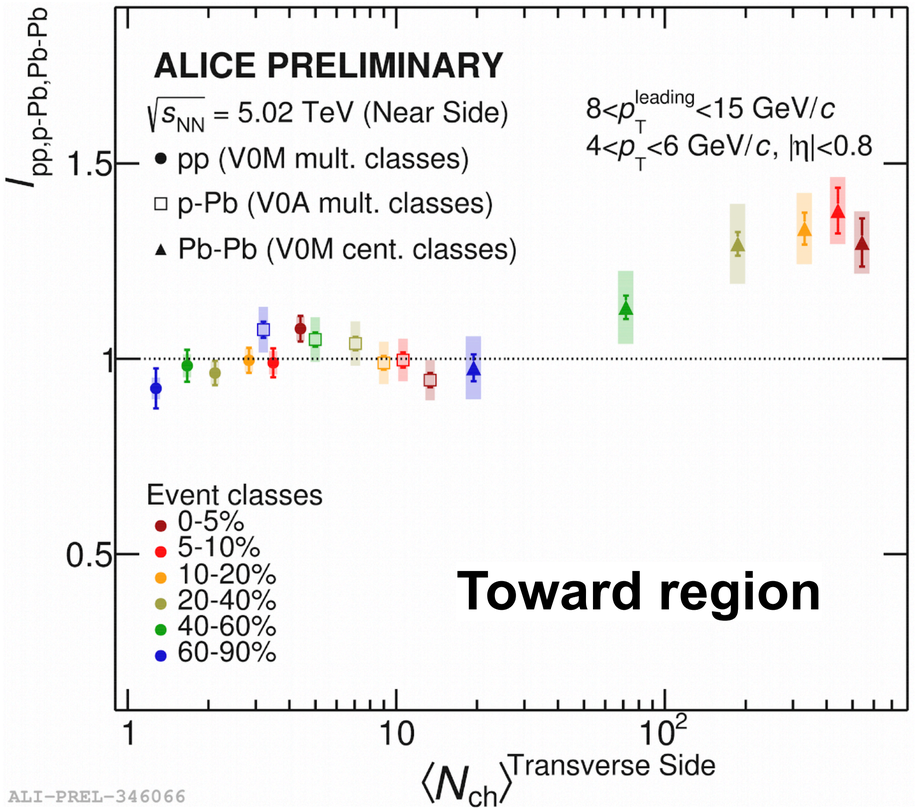

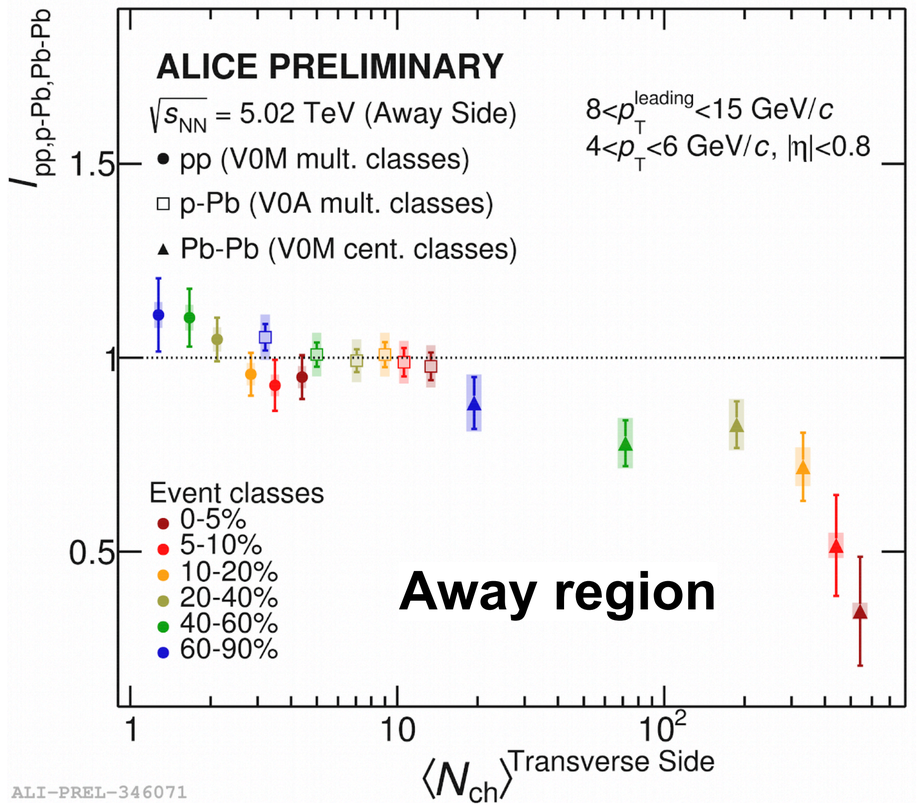

NEW

No **enhancement (suppression)** for **TR (AR)** in pp and p-Pb collisions

No hint of jet quenching in small systems in the measured multiplicity range

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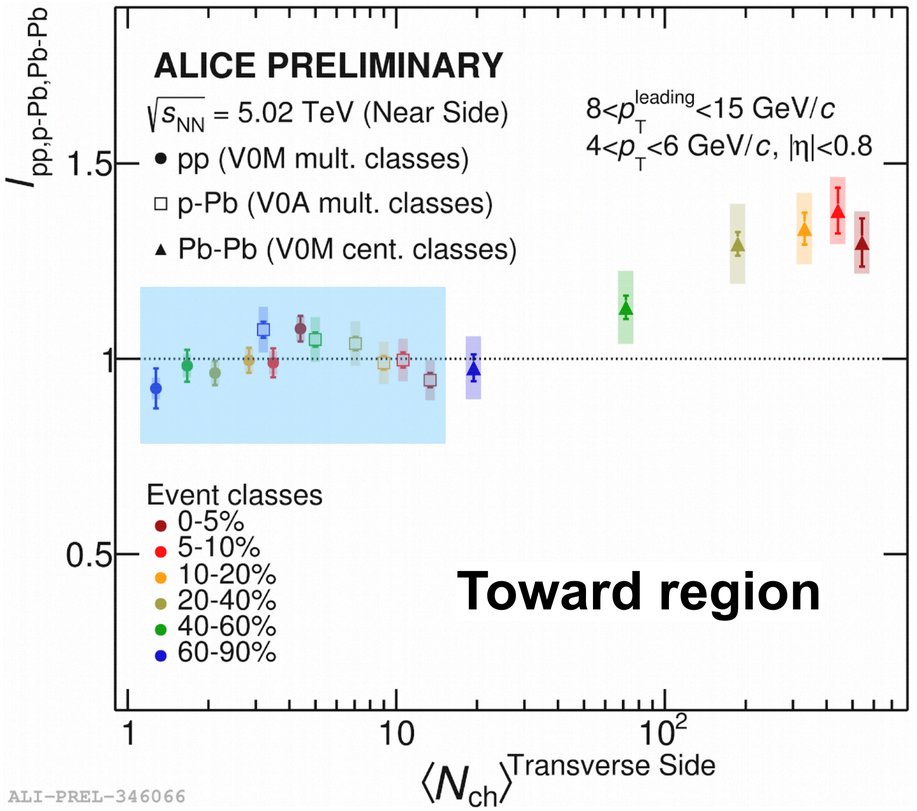

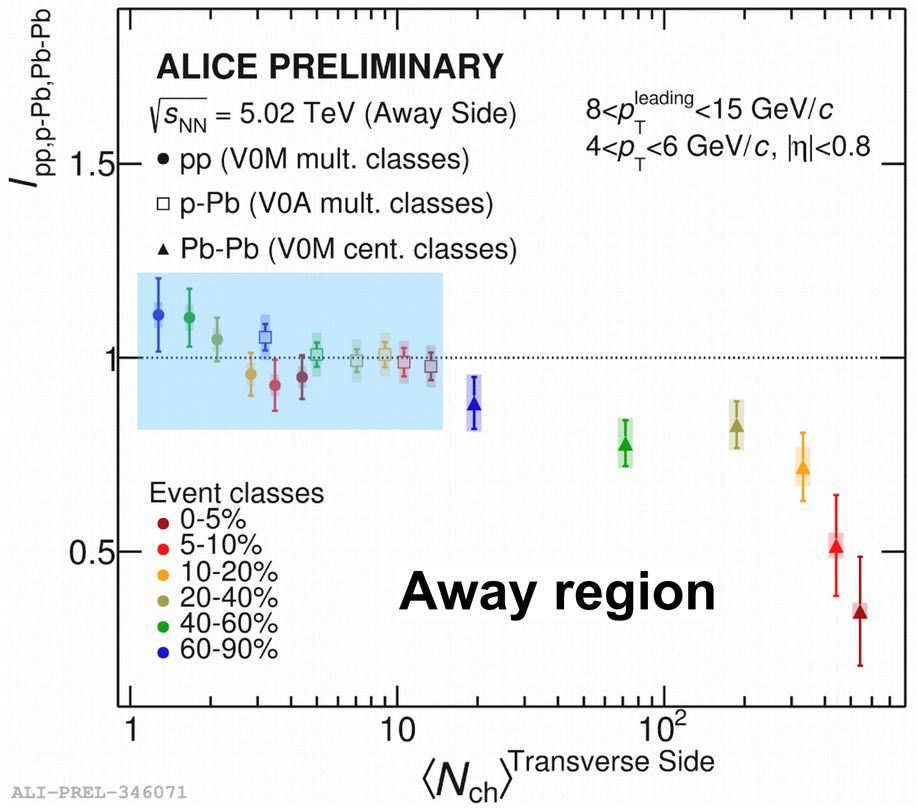

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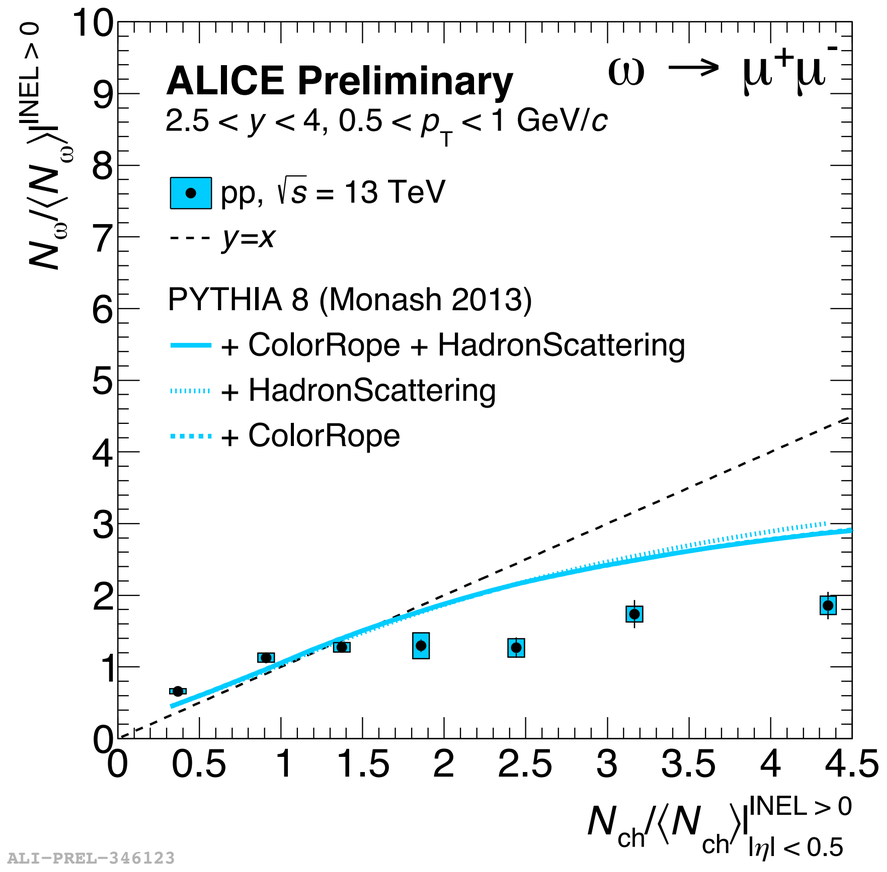
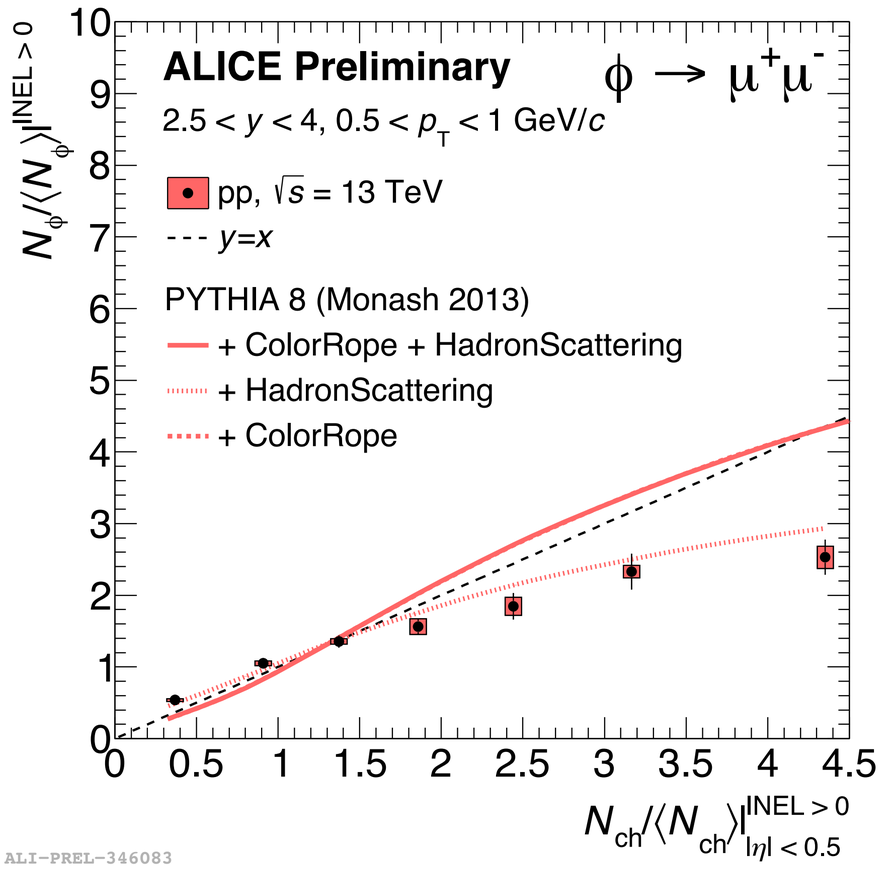
Particle production at forward rapidity





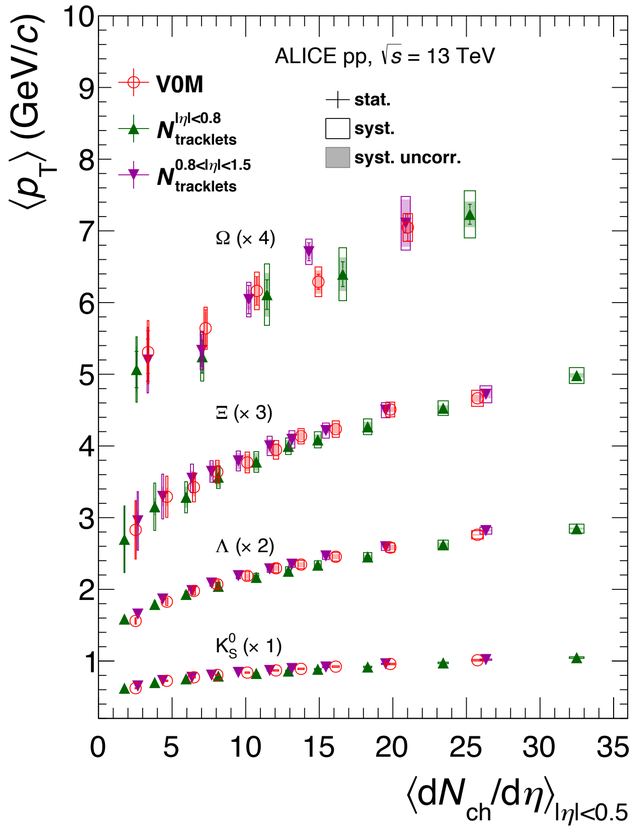
NEW

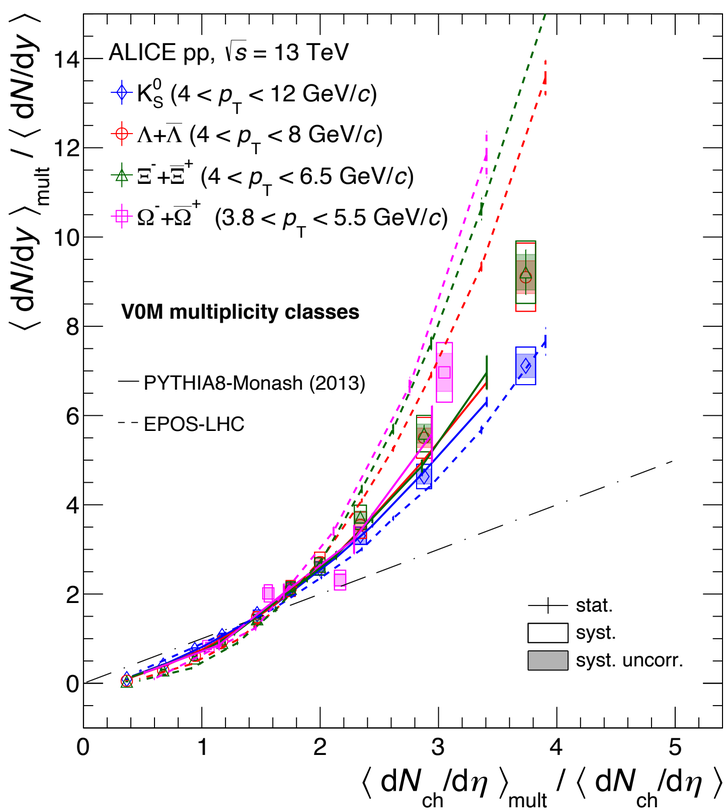
Low p_T region:

- Only PYTHIA 8 + scattering is consistent with ϕ measurement over full multiplicity interval
- All implementations overestimate data for ω at high multiplicity

High p_T region: Different versions of PYTHIA 8 consistent with the data (see backup)

(multi-)strange hadron production





Eur. Phys. J. C (2020) 80: 167

Increase of $\langle p_T \rangle$ with multiplicity more pronounced for heavier particles

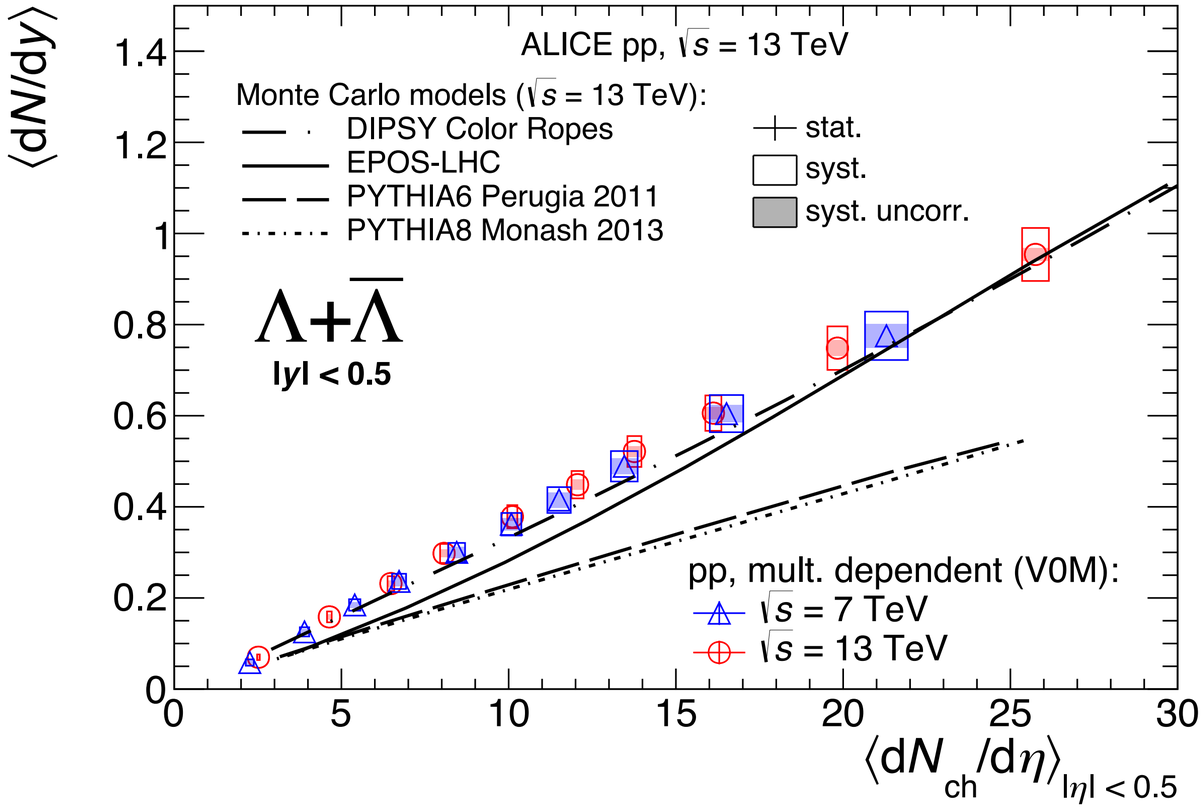
- well-known feature of Pb–Pb collisions (collective expansion)

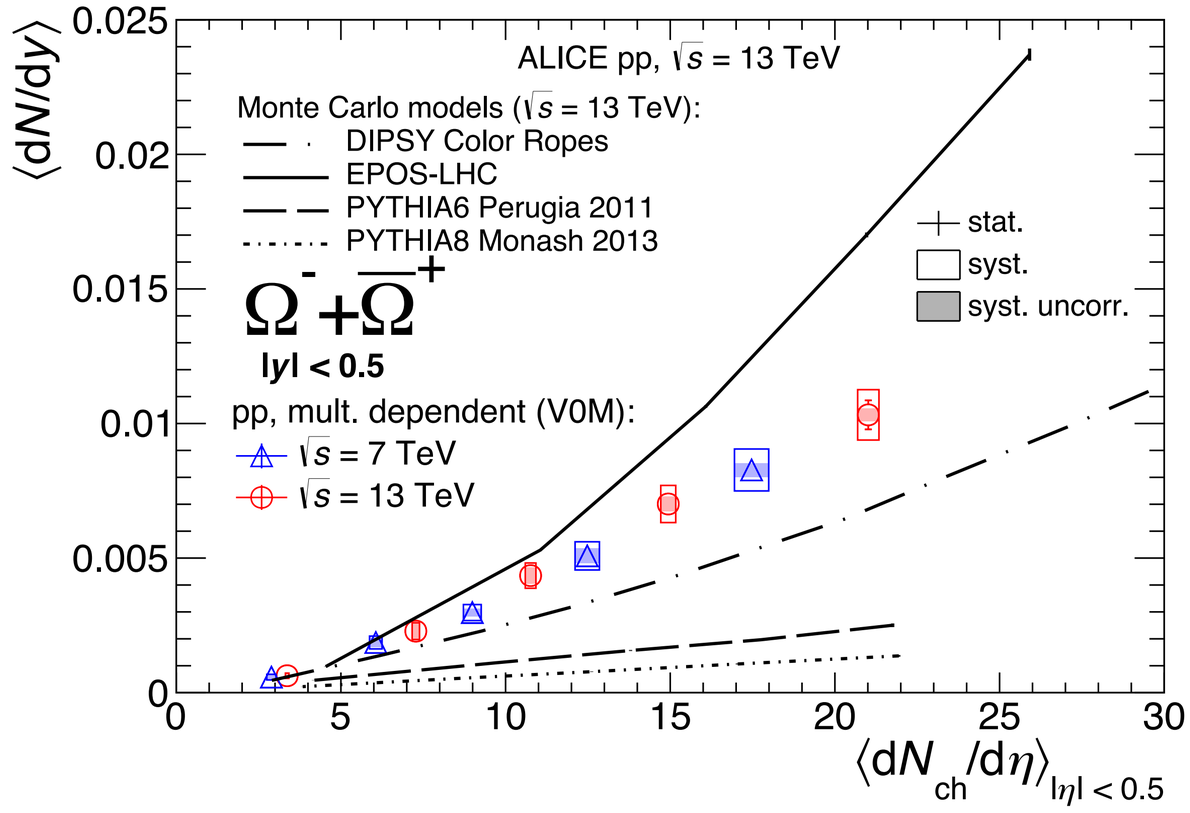
High-p_T yields of strange hadrons increases non linearly and faster than N_{ch}

- trend described by EPOS-LHC and PYTHIA 8 (color reconnection, hydro, MPIs)

(multi-)strange hadron production

Eur. Phys. J. C (2020) 80: 167



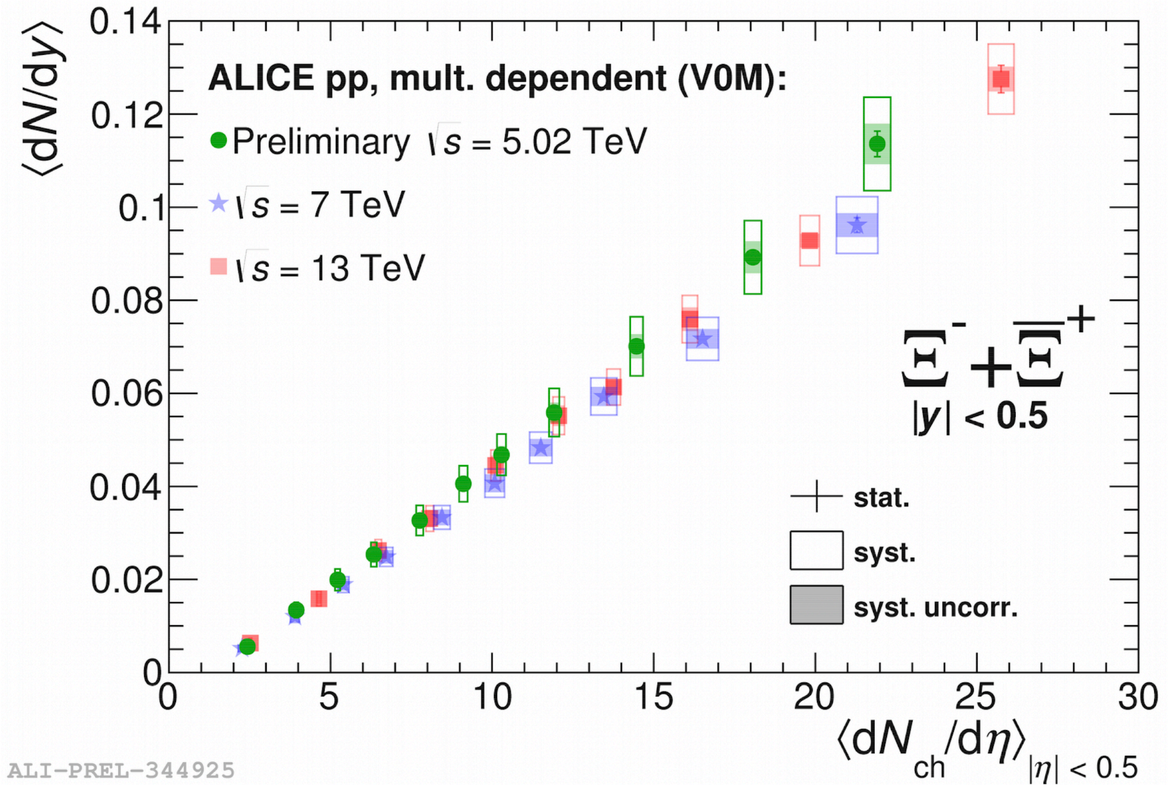


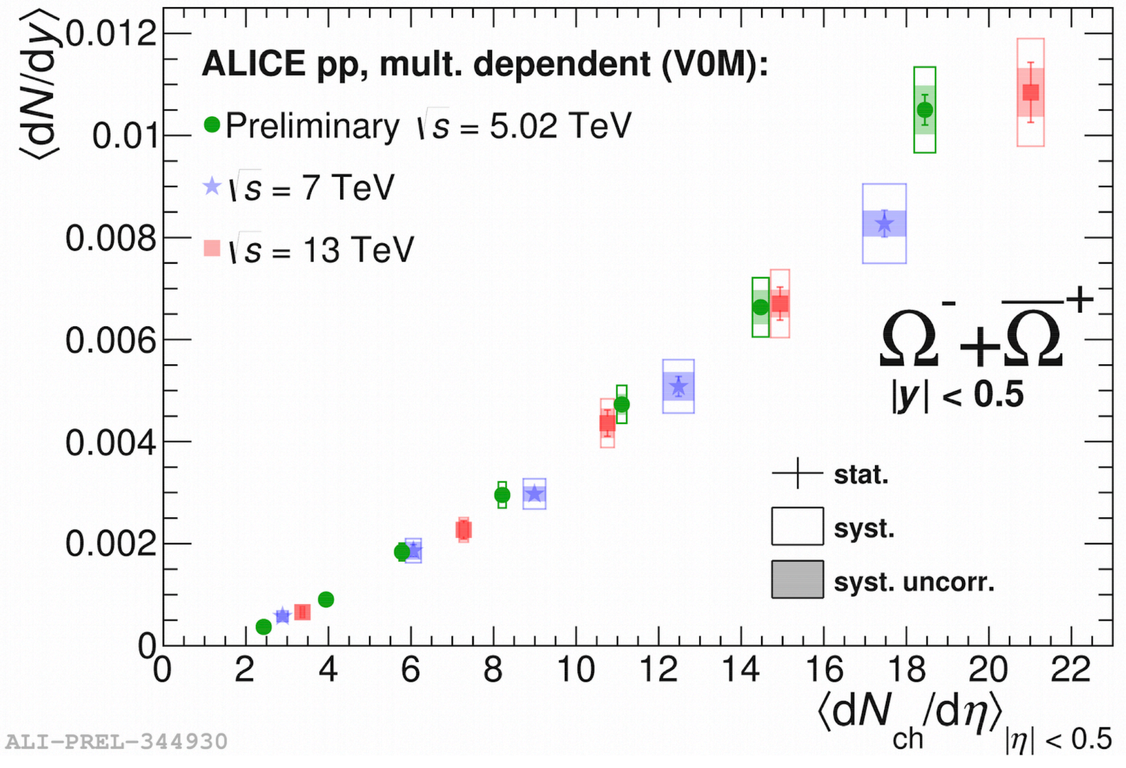
No consistent description of (multi-)strange hadron production vs. multiplicity

Origin of the **strangeness enhancement** vs. multiplicity
is still an open problem for the MC models

(multi-)strange hadron production

NEW

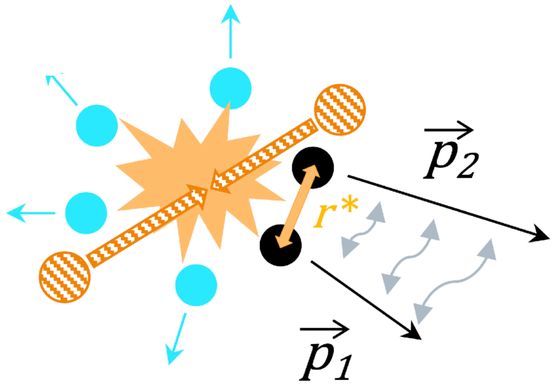




Multi-strange hadrons measured in pp collisions at $\sqrt{s}$ = 5.02 TeV complement and confirm existing measurements at higher energies

Higher “granularity” and slightly better precision

Hyperon-nucleon interaction



Emission source $S(r^*)$

Correlation function:

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

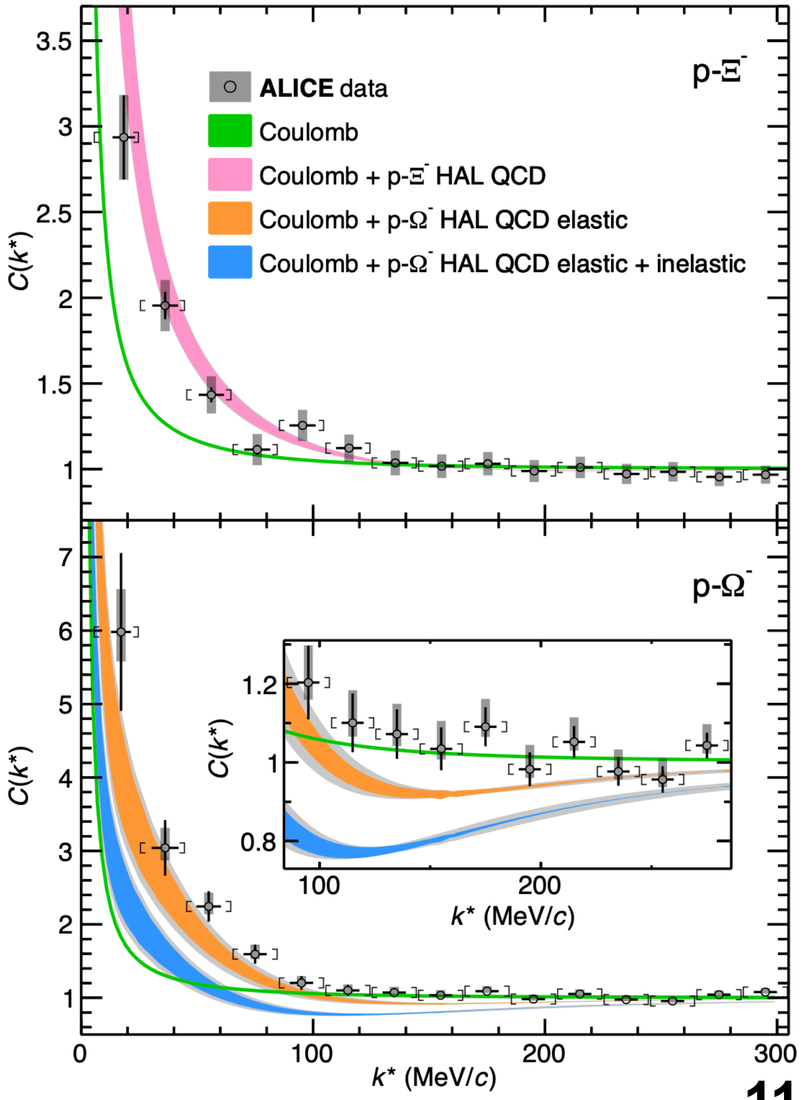
Emission source

Two-particle wave function

$$= \xi(k^*) \otimes \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

arXiv:2005.11495 [nucl-ex]
(Submitted to Nature)

NEW



p-Ω interaction stronger than p-Ξ as predicted by lattice QCD

p-Ξ interaction: data consistent with lattice QCD

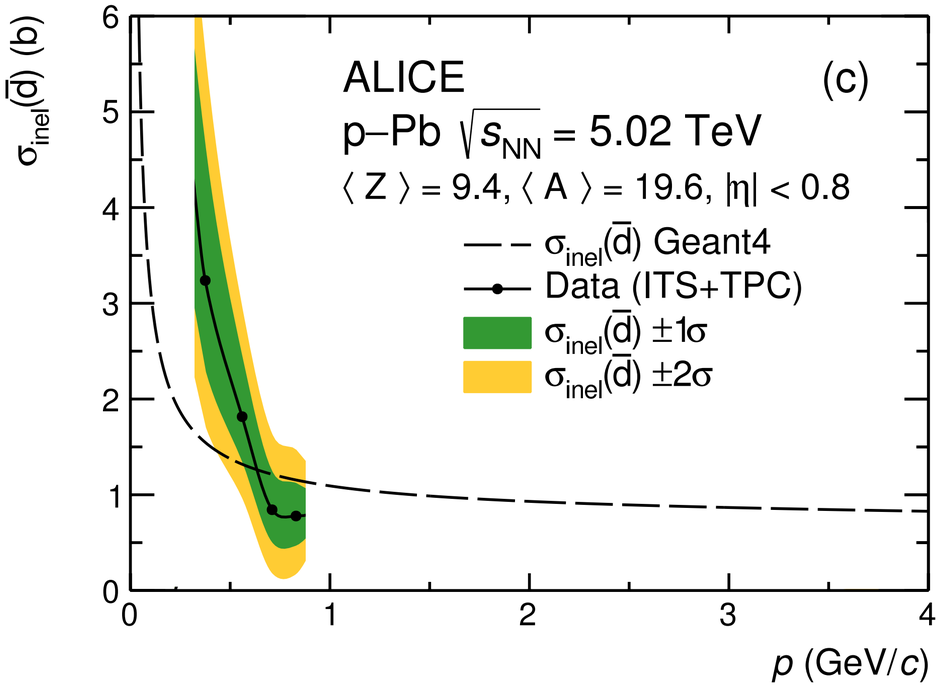
p-Ω interaction: data underestimated in 100 < k^* < 300 MeV/c

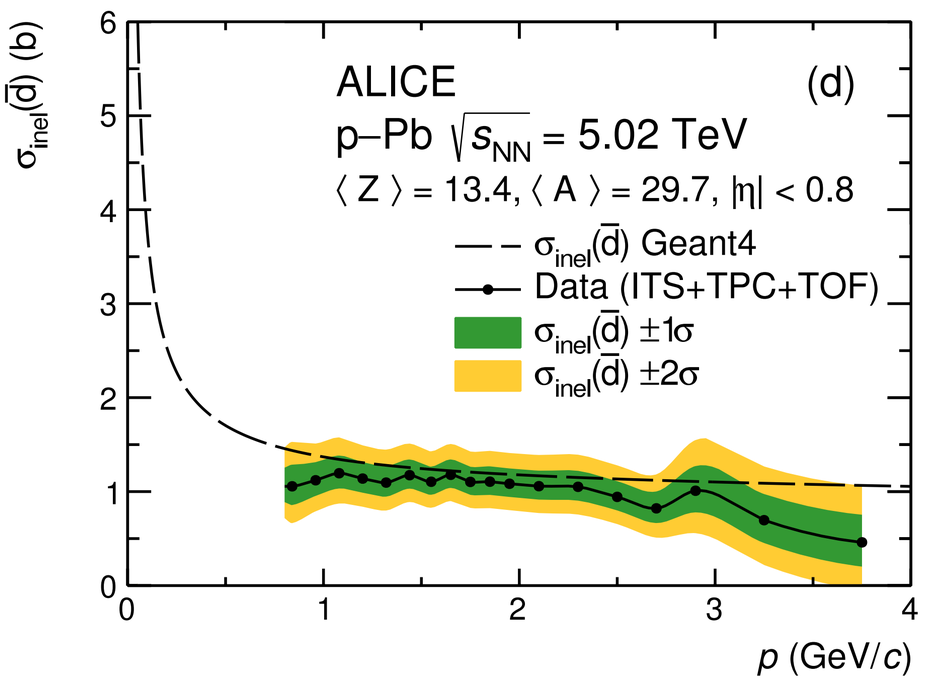
1. Inelastic interaction not accounted for quantitatively
2. Bound state p-Ω assumed (E_b = 2.5 MeV): depletion of C(k^*)

→ Further investigation in Run 3

Antimatter-matter inelastic interaction

arXiv:2005.11122 [nucl-ex] (Submitted to PRL)





NEW

First measurement of antideuteron σ_{inel} at low momentum

Method: 1. measurement of $\bar{d}/d$ and compare with same ratio in MC simulation
2. variation of σ_{inel} in MC to construct confidence bands

Data indicate rise starting from higher momentum compared to Glauber model (GEANT 4)
> origin of this effect under investigation (dedicated setup will be used in Run 3)

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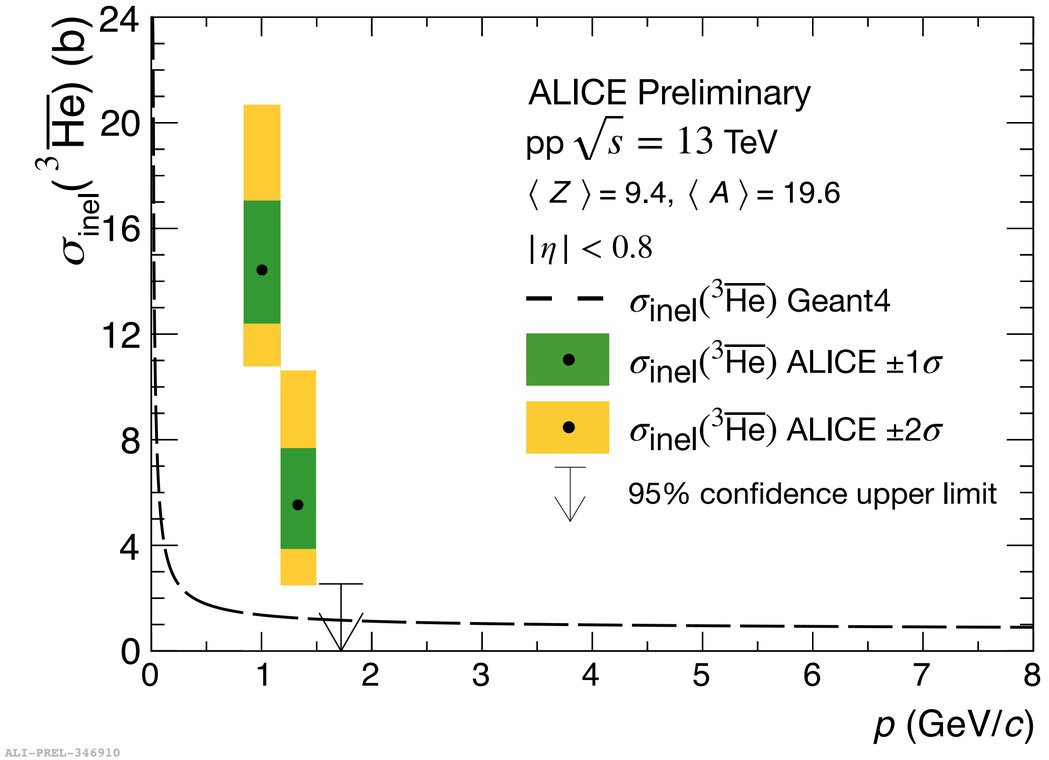

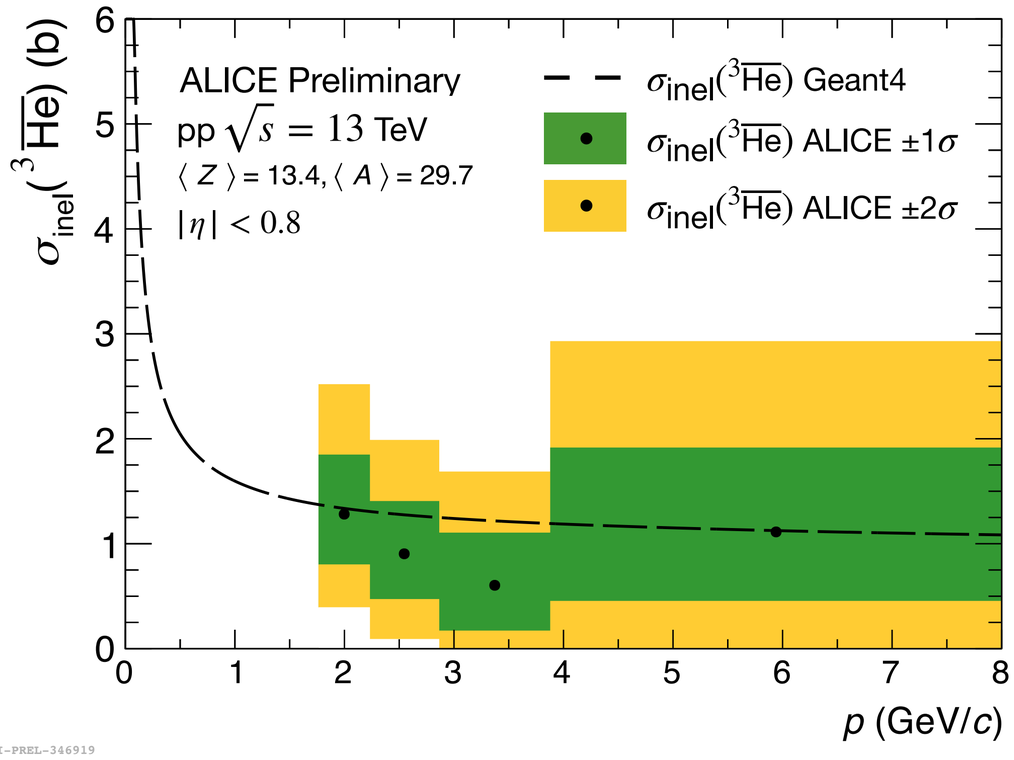

NEW

First measurement of anti-^{3}He σ_{inel} using same method

Significant deviation from Glauber model (GEANT 4) at low momentum
> Striking effect!

→ Essential input of these measurements for **dark matter searches**

Summary

Substantial contribution to characterization of **underlying event** properties in pp collisions at $\sqrt{s}$ = 13 TeV

Particle production at forward rapidity and multi-strange hadron measurements challenge the existing MC models

Experimental validation of lattice QCD calculations of **YN interaction via correlation** measurements: a new avenue for high-precision test of QCD at LHC has been opened

First measurements of light **anti-nuclei σ_{inel}** at low momentum

- Significant impact on indirect searches of dark matter

Discussion at the end of this session

Join Zoom Meeting: Link

Meeting ID: 781 8206 0928
Password: same as this session

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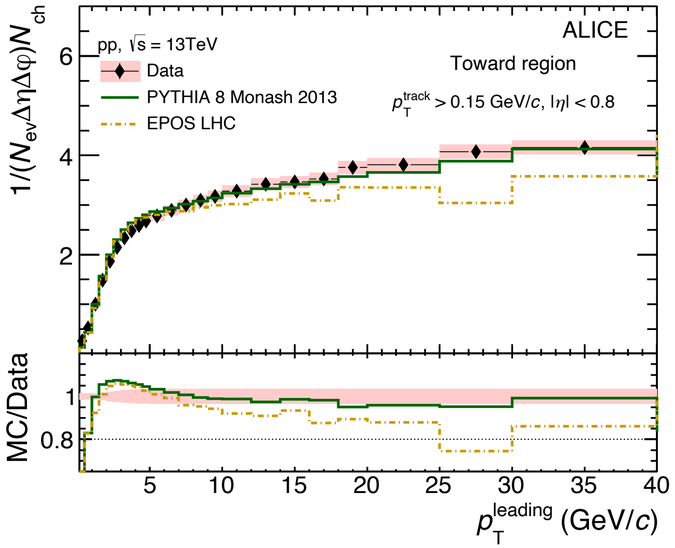
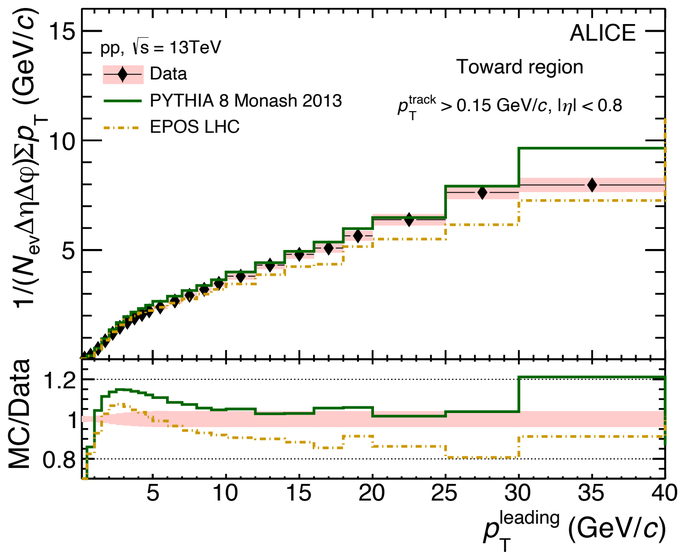
Thank you for your attention!

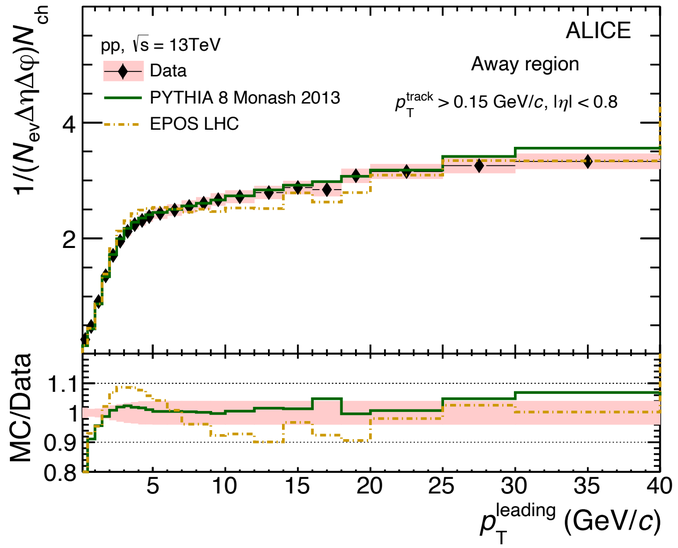
Backup slides

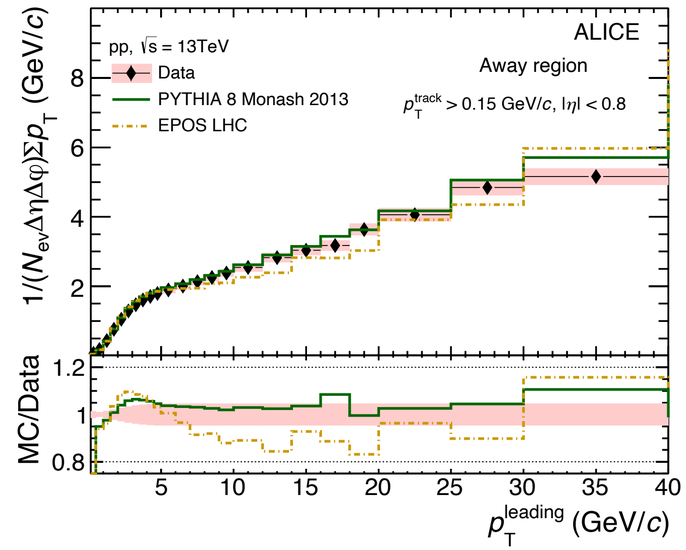
UE properties: Toward & Away regions

arXiv:1910.14400v1 [nucl-ex]



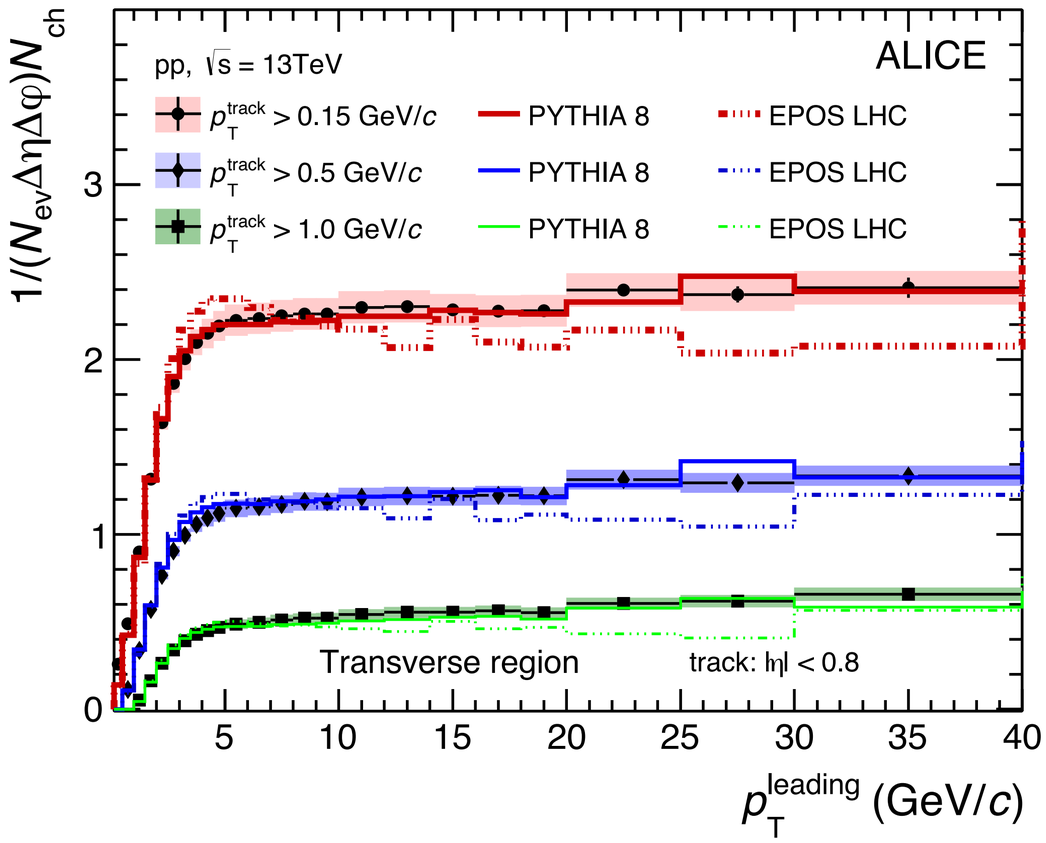






Trend qualitatively described by MC models for Toward and Away regions

The underlying event



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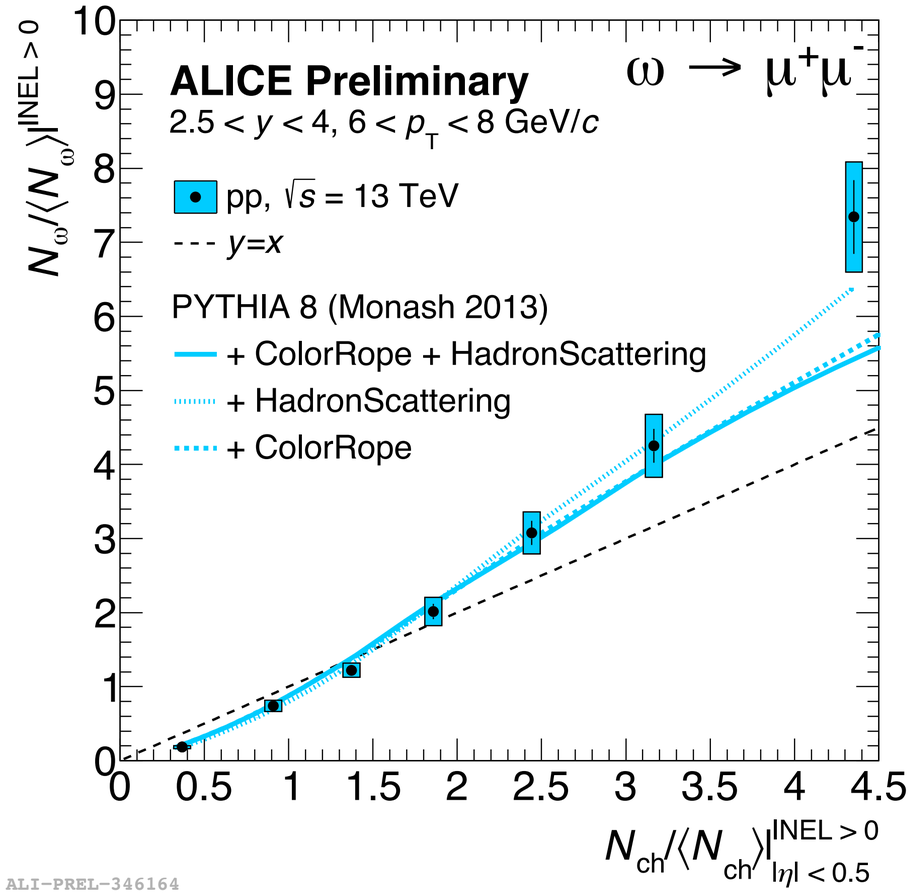
Effect of increasing the p_T threshold on the pedestal region ($p_T^{leading} > 5$ GeV/c) :

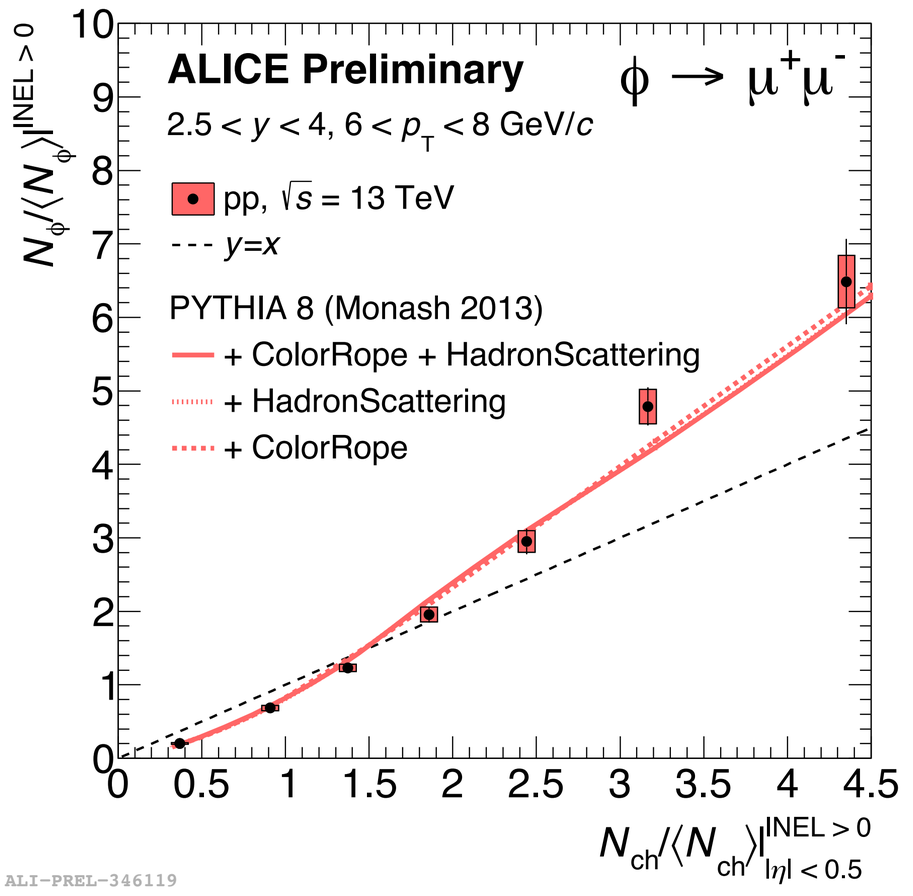
→ Lower N_{ch} density and increasing slope: larger contribution of hard processes

Highest sensitivity to the UE obtained using the lowest p_T threshold

- Excellent tracking capabilities of ALICE down to low p_T make this detector unique

Particle production at forward rapidity



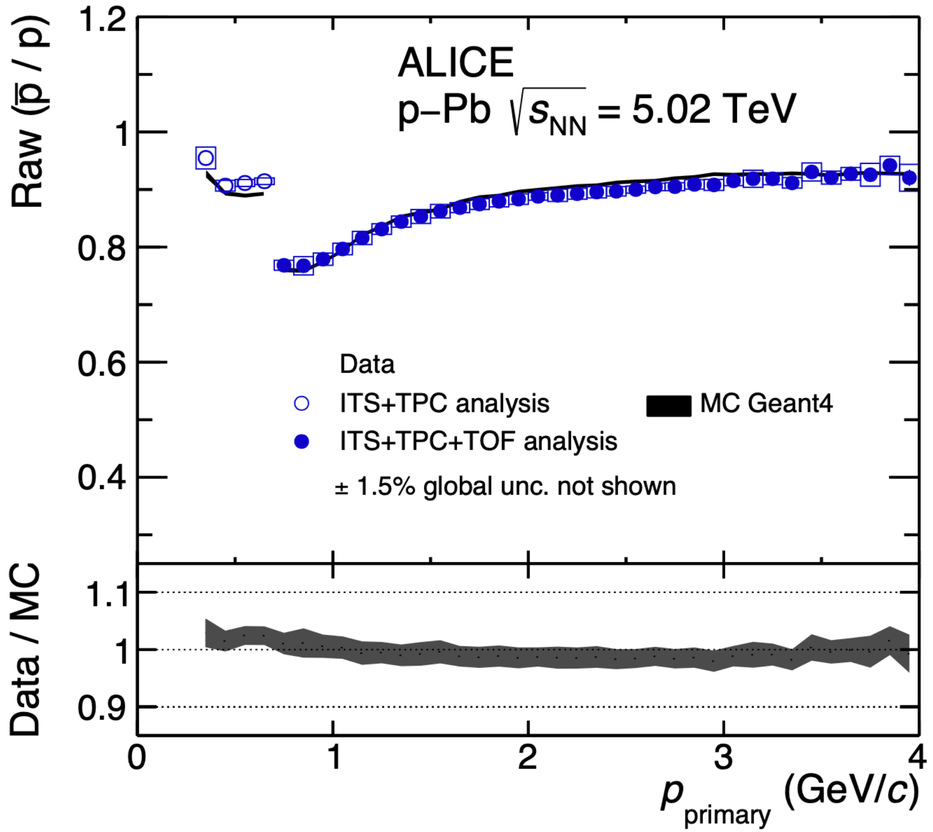


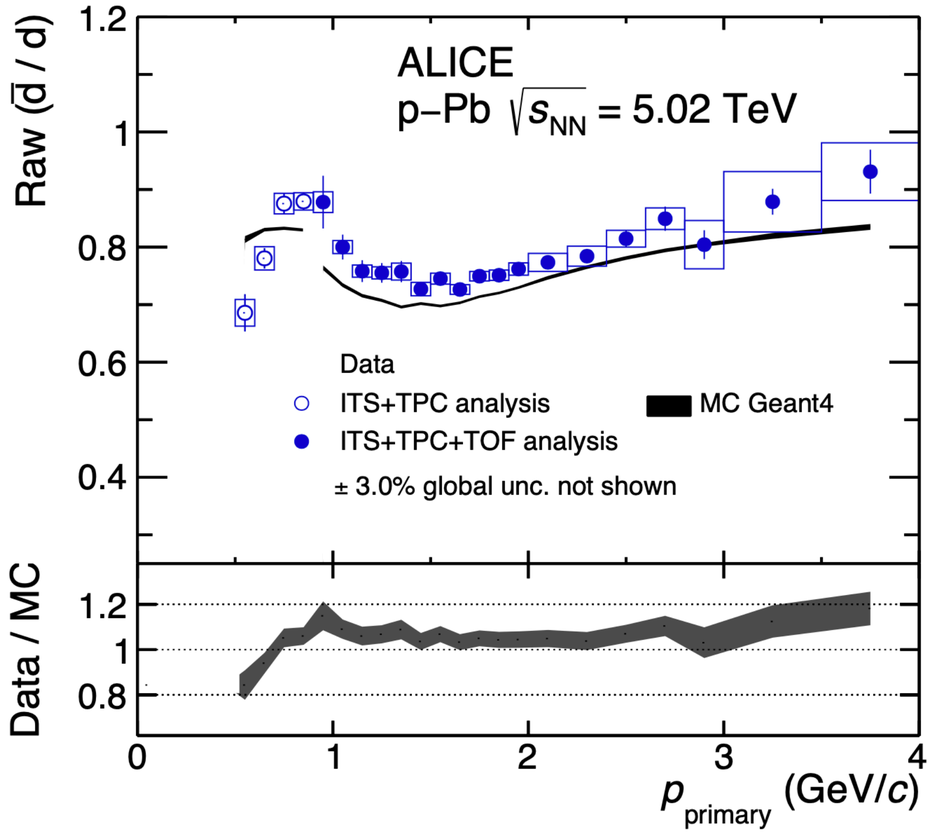
High p_T region:

- Different versions of PYTHIA 8 give similar predictions
- Consistent with the data over the measured multiplicity interval

$\bar{p}/p$ and $\bar{d}/d$ vs. GEANT 4

arXiv:2005.11122 [nucl-ex] (Submitted to PRL)



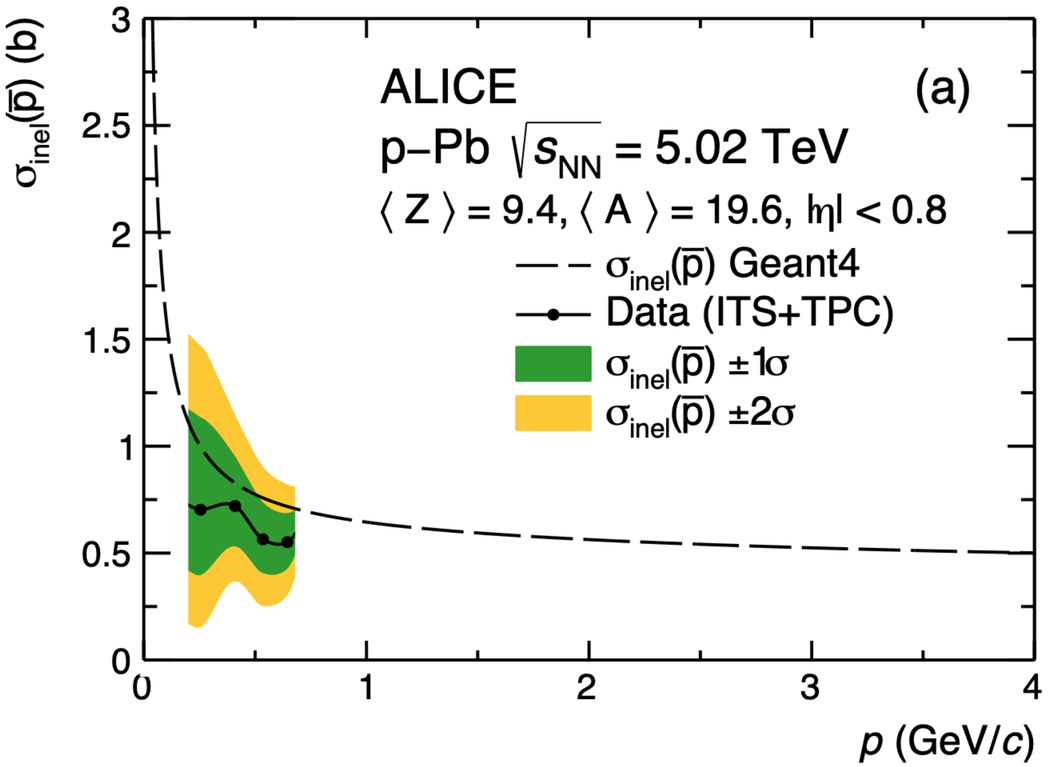


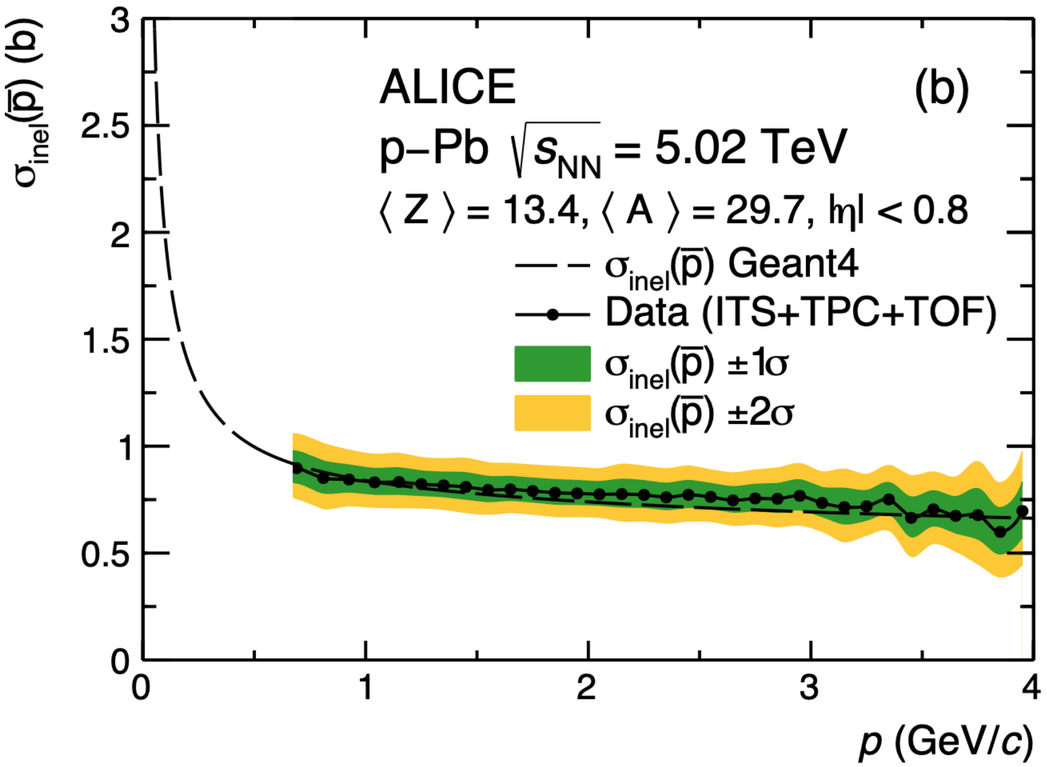
$\bar{p}/p$ and $\bar{d}/d$ ratios measured using ITS-TPC (at low momentum) and ITS-TPC-TOF (at high momentum)

- Antiproton measurement as a consistency check

Antiproton inelastic cross section

arXiv:2005.11122 [nucl-ex] (Submitted to PRL)



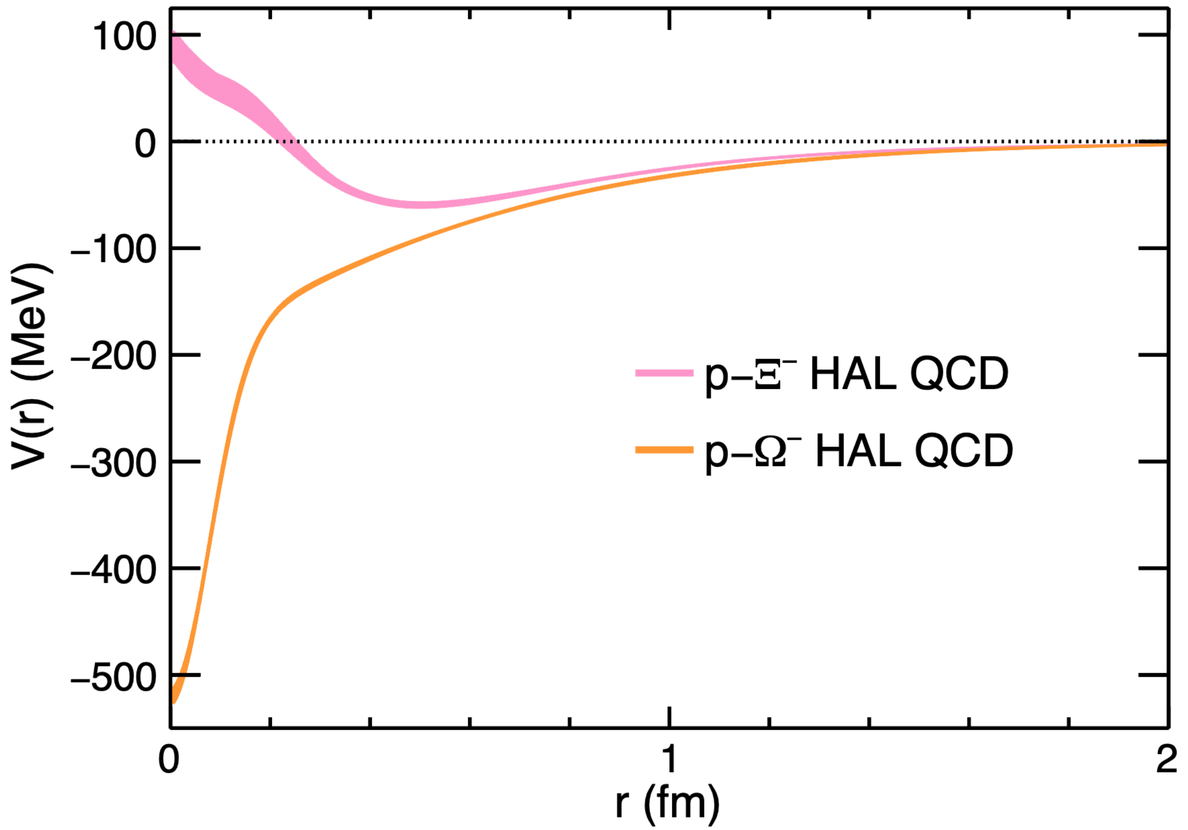


Antiproton σ_{inel} consistent with Glauber model (GEANT 4) over measured momentum range

GEANT 4 parametrization is based on existing measurements of antiproton annihilation on different targets

> this consistency check demonstrates the reliability of the antideuteron σ_{inel} measurement

Lattice QCD calculations of pY potential



arXiv:2005.11495 [nucl-ex]
(Submitted to Nature)

lattice QCD predicts stronger p-Ω attractive interaction compared to p-Ξ

Attractive interaction between p-Ω at low *r* is strong enough to accommodate a bound state (E_b = 2.5 MeV)