International Workshop on Multiple Partonic Interactions at the LHC
Perugia, 11th December 2018

Implications of MPI in ALICE multiplicity measurements

Valentina Zaccolo
University and INFN - Trieste

for the ALICE Collaboration

Introduction

At LHC high collision energy → significant contributions from hard processes

- pQCD precise calculations

Still particle production dominated by **soft-QCD** processes

***p_T* ~ few GeV**

- non perturbative phenomenology
- modelling

Introduction

At LHC high collision energy → significant contributions from hard processes

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Multiple parton interactions (MPI): more than one hard scattering

Still particle production dominated by **soft-QCD** processes

***p_T* ~ few GeV**

- non perturbative phenomenology
- modelling

Underlying Event

semi-hard + soft interactions

Soft processes

single, double and non-diffractive

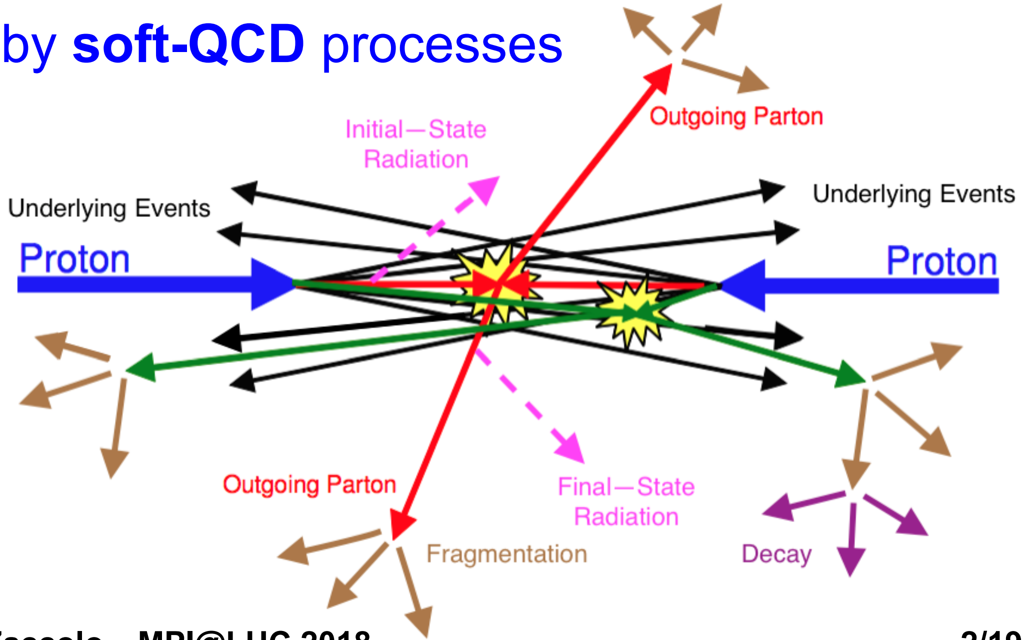


Figure adapted from
Eur.Phys.J. C62 (2009) 237-242

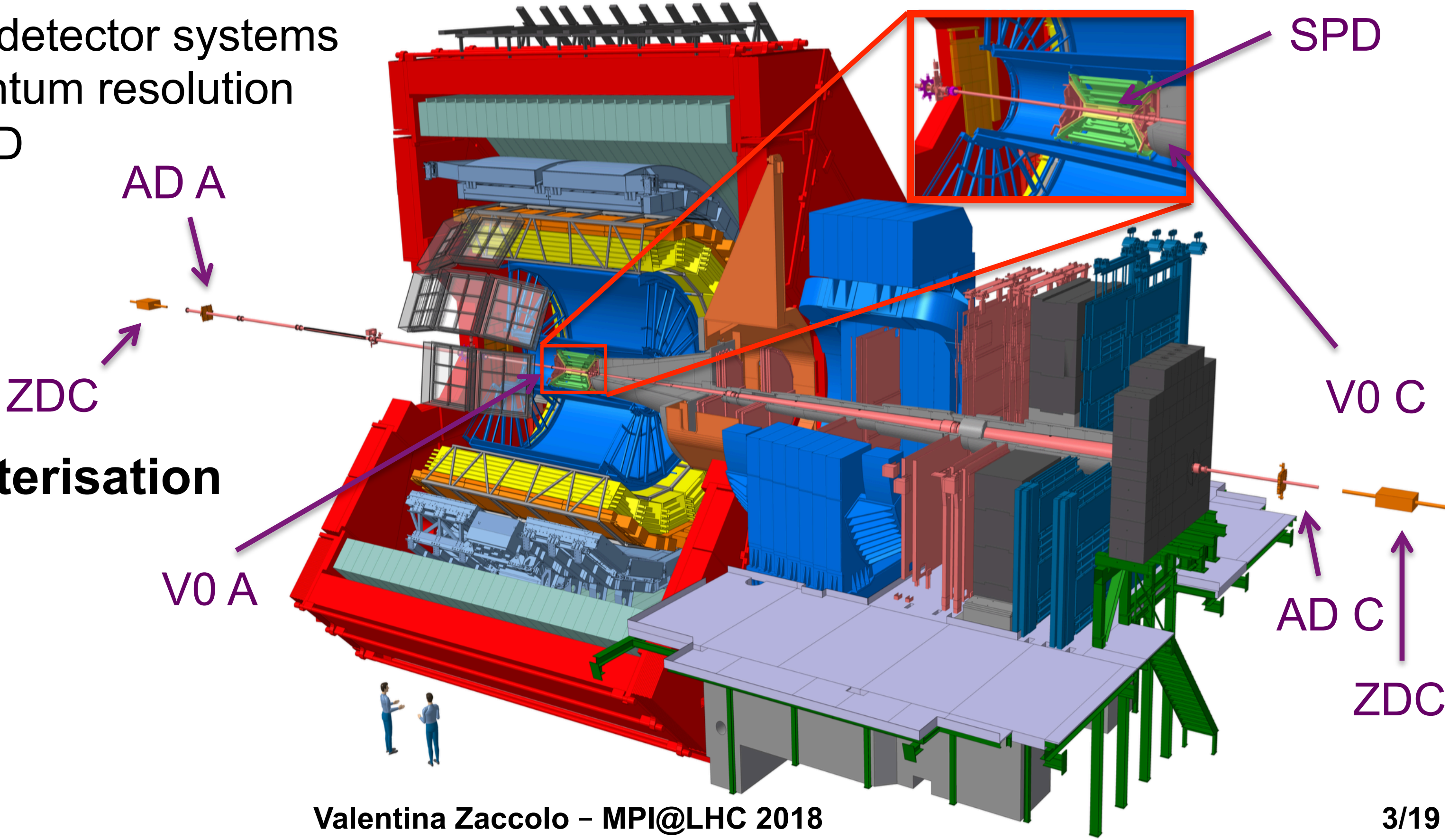
Detector

A Large Ion Collider Experiment

- 17 different detector systems
- high-momentum resolution
- excellent PID

solenoidal magnet: 0.5 T

Trigger and event characterisation detectors



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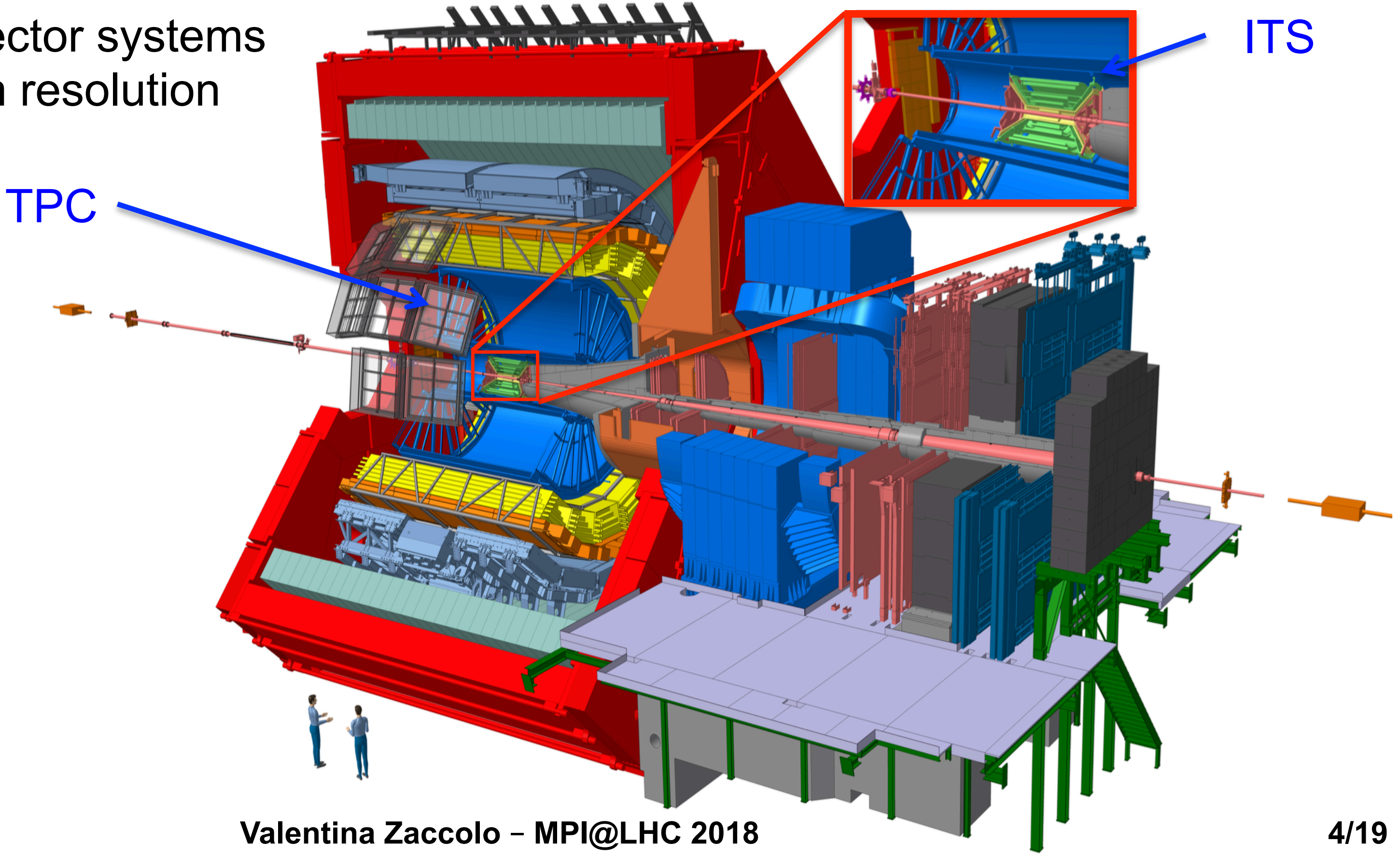
Data-taking detectors

Tracking



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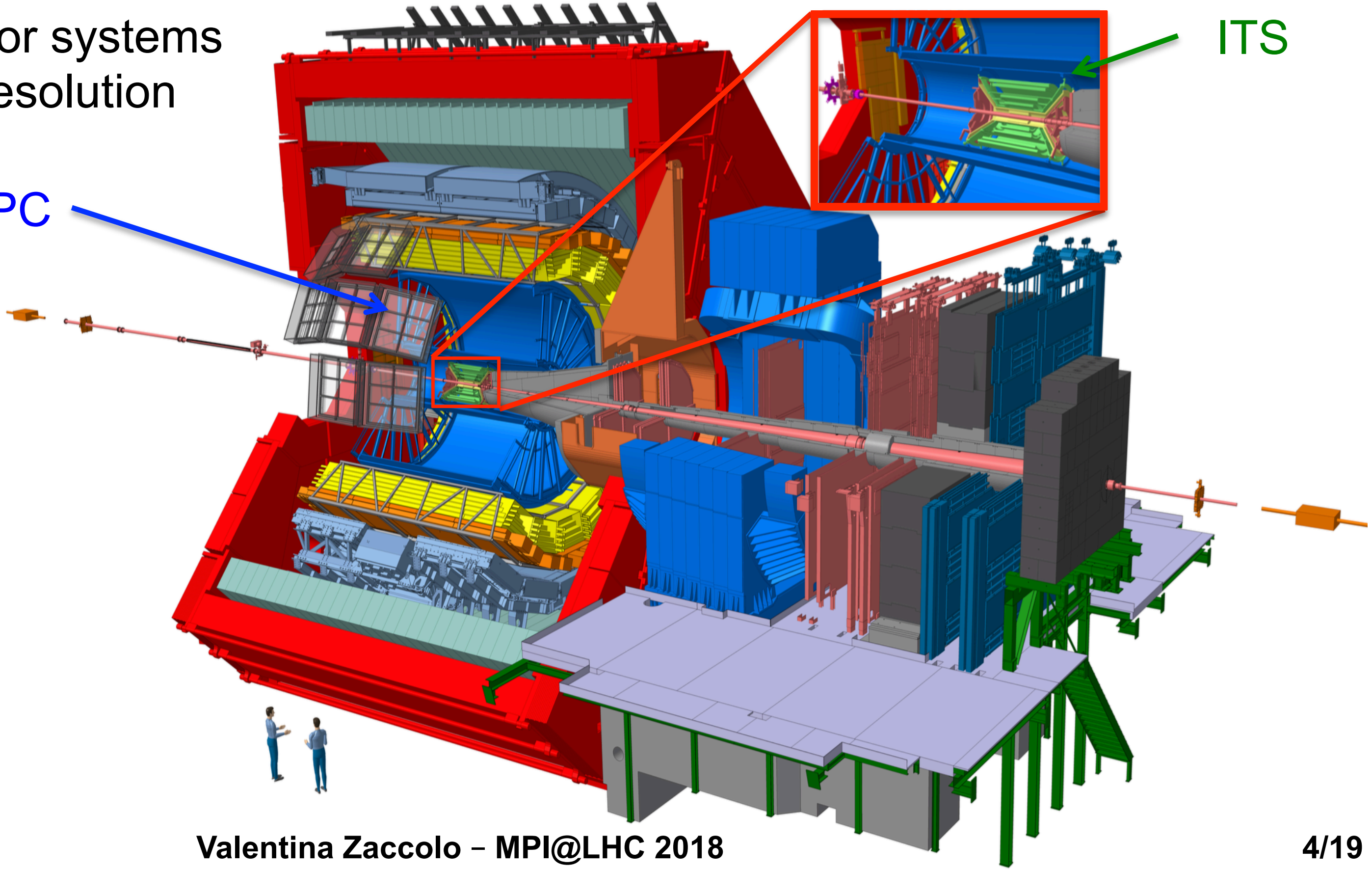
Vertexing



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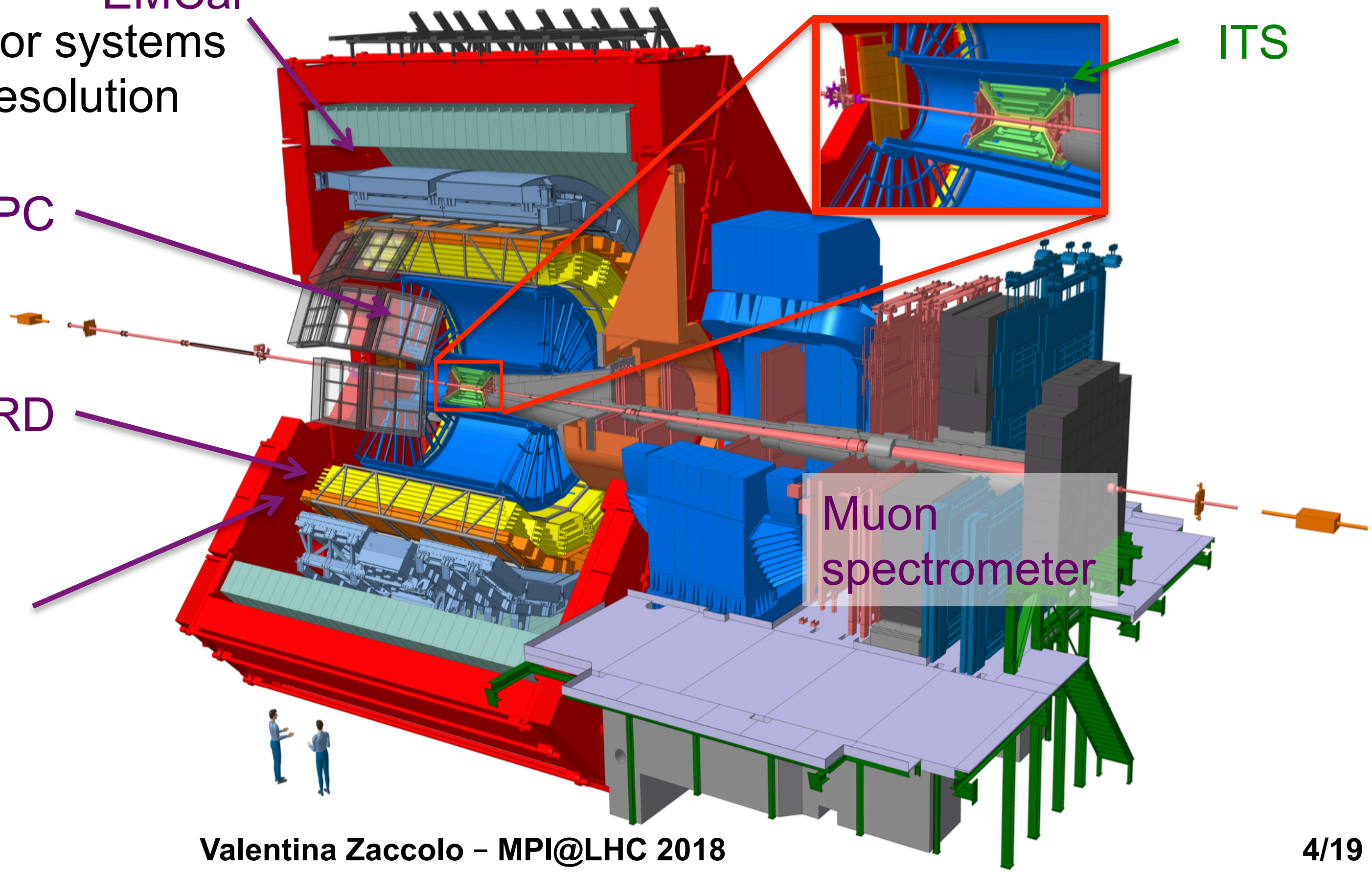
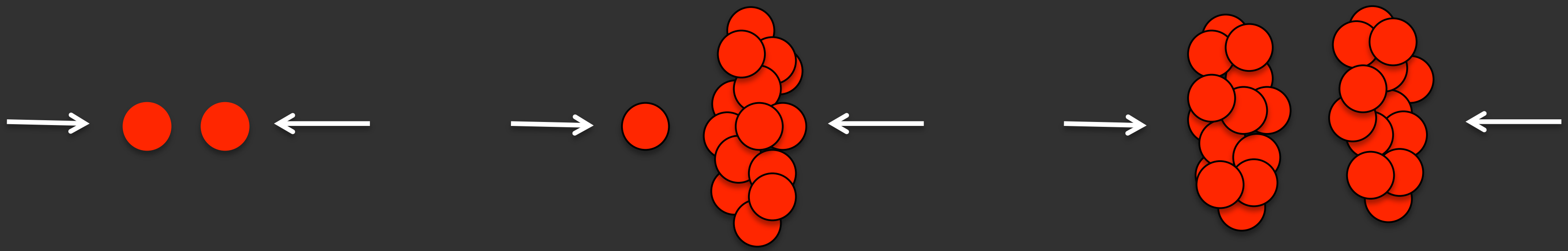
PID



Particle multiplicities



Soft and hard sector separation
Multiplicity distributions in pp

- Tuned generators for diffraction arXiv:0909.5156 [hep-ph]
- fit with Negative Binomial Distributions

single NBD fails

double NBD fits well

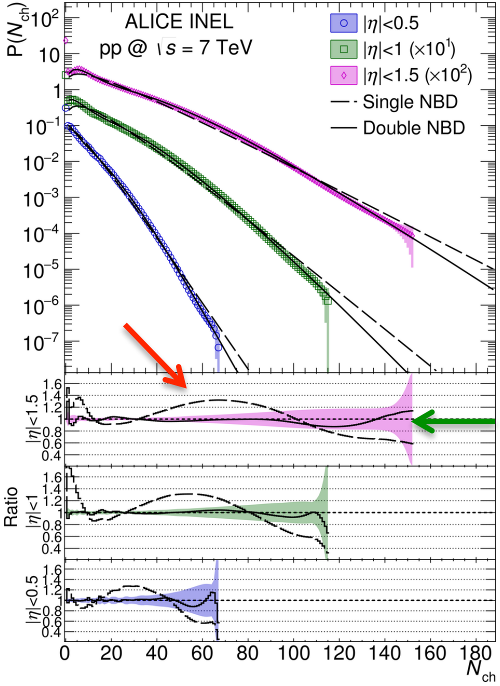
$$P(n) = \lambda[\alpha P_{\text{NBD}}(n, \langle n\rangle_1, k_1) + (1-\alpha) P_{\text{NBD}}(n, \langle n\rangle_2, k_2)]$$

α ~ soft

1-α ~ N_{MPI} ~ hard

higher energy → harder spectrum

wider rapidities → softer



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Eur. Phys. J. C 77 (2017) 33

Soft and hard sector separation

Multiplicity distributions in pp

- Tuned generators for diffraction
- fit with Negative Binomial Distributions

"IP-Glasma" initial conditions

evolution of the glasma gluon fields

Phys.Rev. C89 no. 2, (2014) 024901

Nucl.Phys. A945 (2016) 216-225

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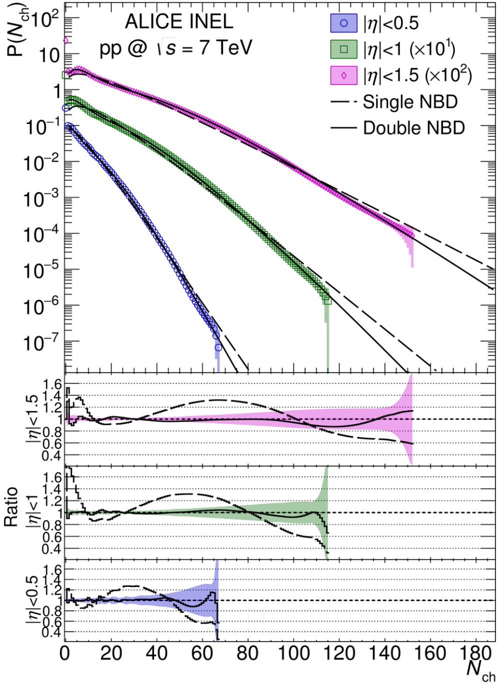

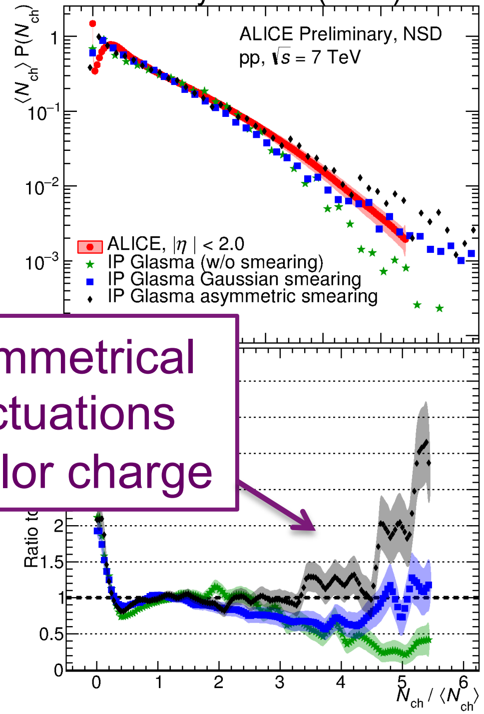

asymmetrical fluctuations of color charge

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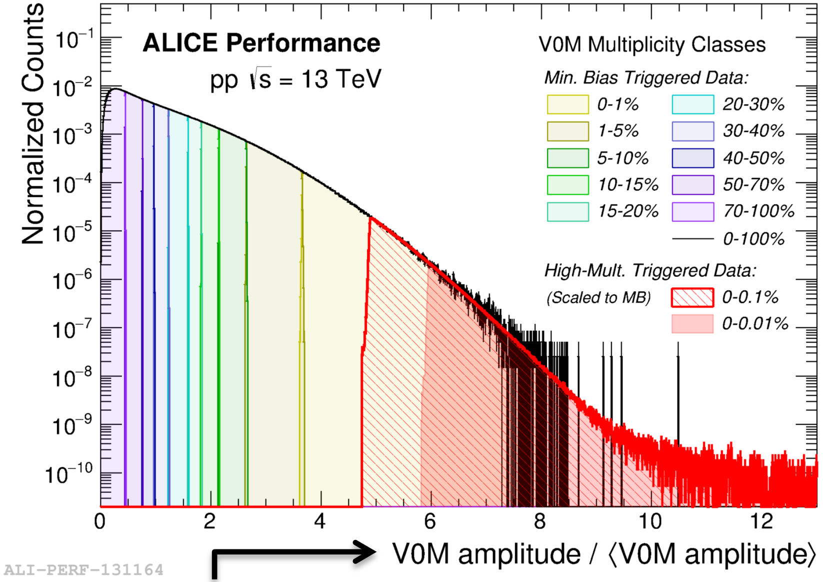
Eur. Phys. J. C 77 (2017) 33
Eur. Phys. J. C 77 (2017) 852

Tuning of models

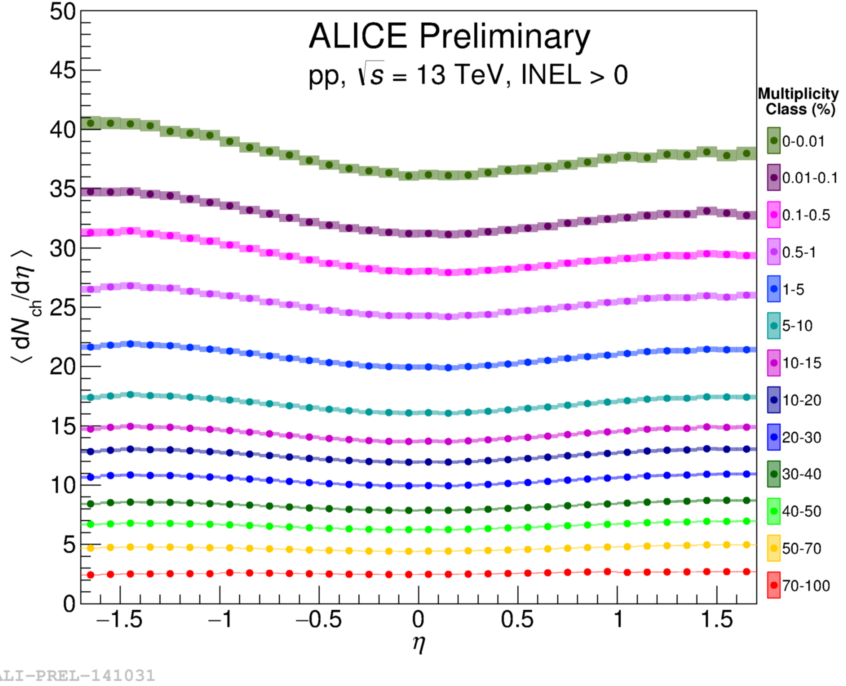
Multiplicity dependent studies at 13 TeV

Minimum-Bias measurements good performance of models

High-multiplicity triggered data collected during 2016 extend the multiplicity reach compared to Minimum Bias



Multiplicity in the forward region



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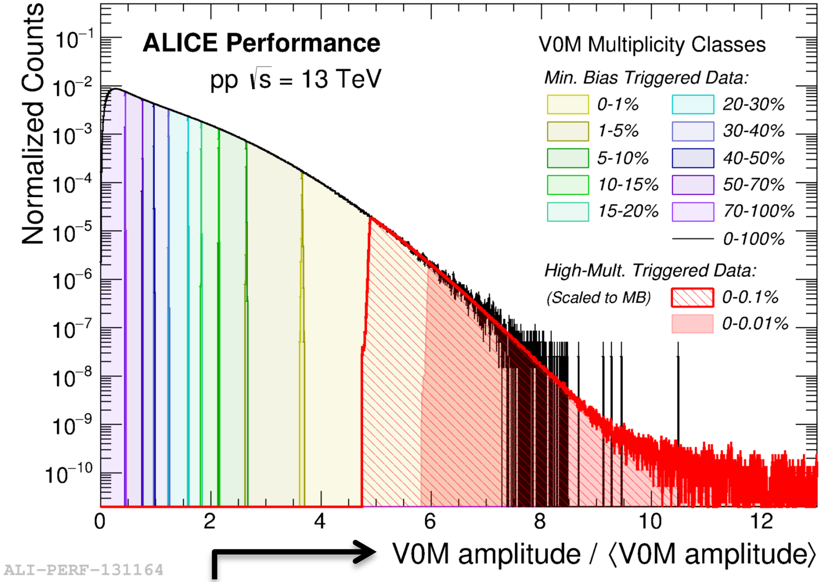

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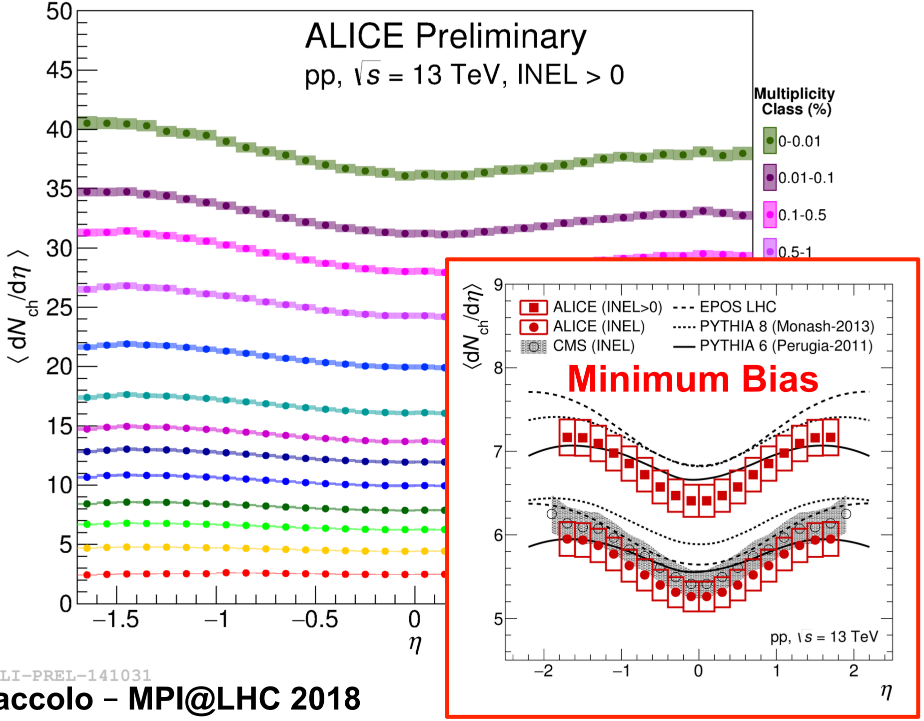

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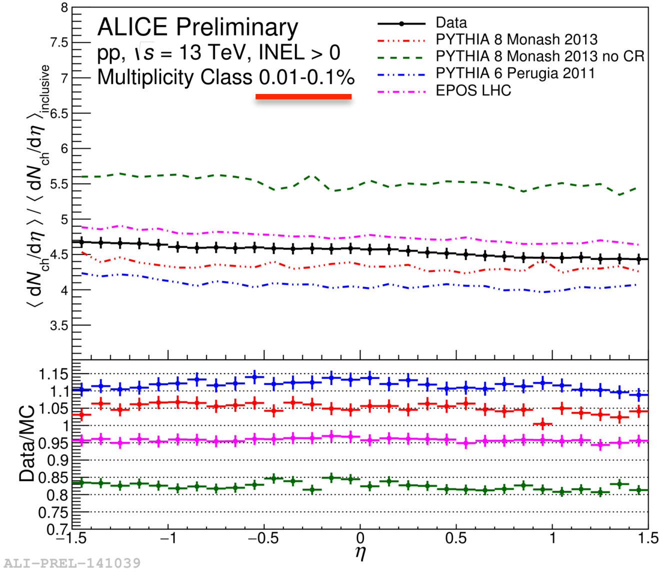
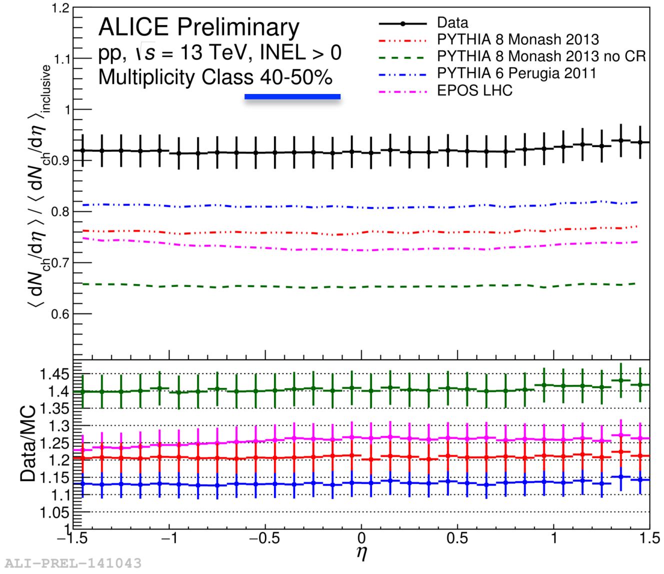
Phys. Lett. B 753 (2016) 319-329

Tuning of models

Multiplicity dependent studies at 13 TeV

At high multiplicity both EPOS LHC and Pythia 8 are close to data
At mid multiplicity Pythia 6 is closer → understimation of soft part for newer models?





- Colour reconnection is needed to get a good performance

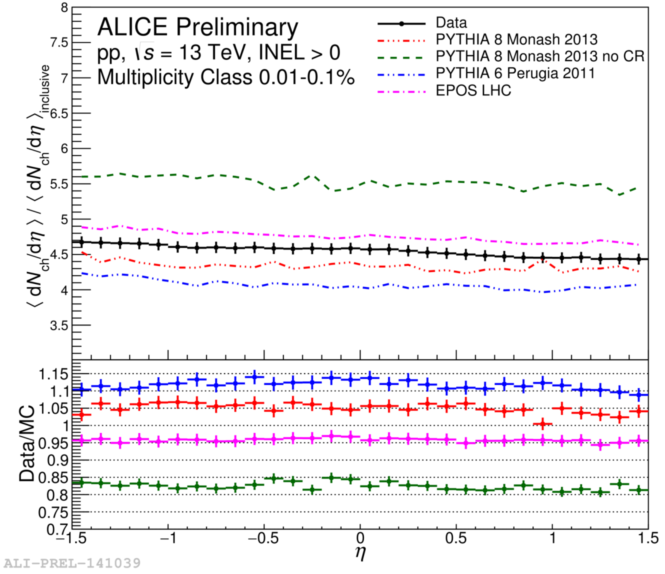
Tuning of models

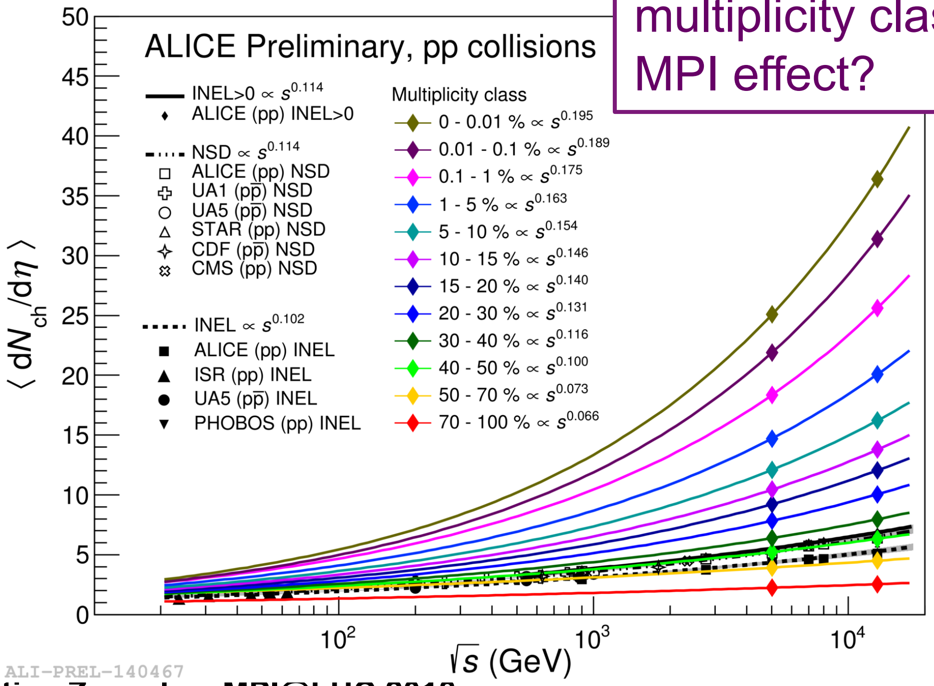
Multiplicity dependent studies at 13 TeV

At high multiplicity both EPOS LHC and Pythia 8 are close to data

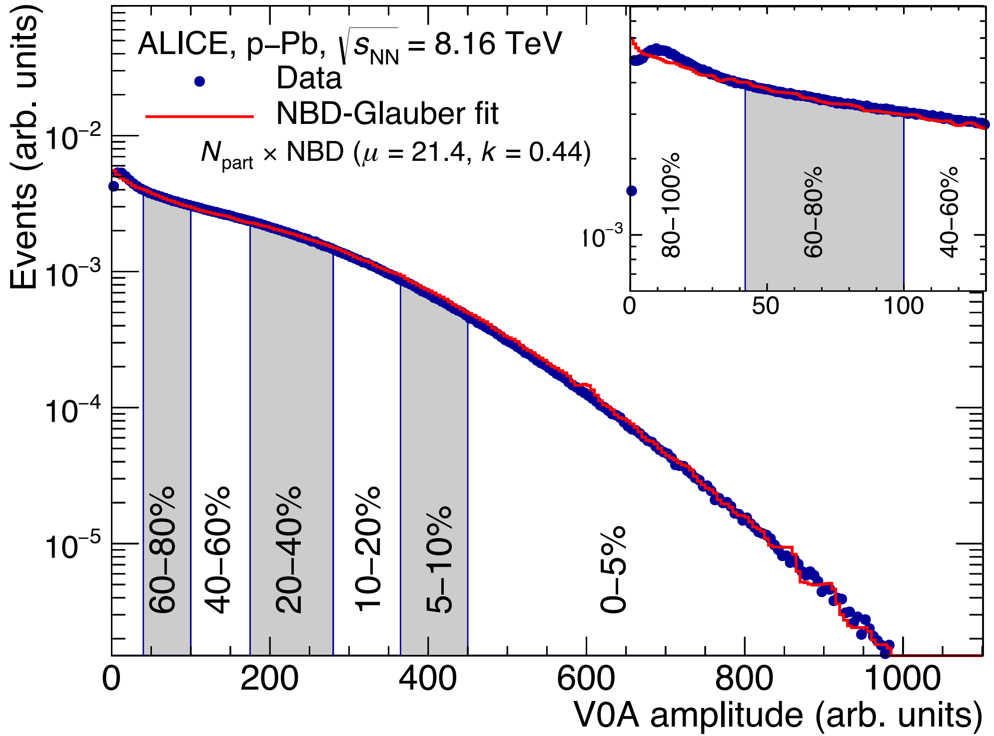
At mid multiplicity Pythia 6 is closer

Rise steeper for high multiplicity classes → MPI effect?





Centrality slicing effects
The Glauber-MC



1. Stocastically define nucleons position $\rho(r) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$
2. simulate sequence of independent nucleon-nucleon collisions
3. Glauber-MC + fit with NBD

M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Ann.Rev.Nucl.Part.Sci. 57 (2007) 205-243
C. Loizides, J. Kamin, and D. d'Enterria, Phys.Rev. C97 (2018) no.5, 054910
ALICE, arXiv: 1812.01312 [nucl-ex]

Centrality slicing effects

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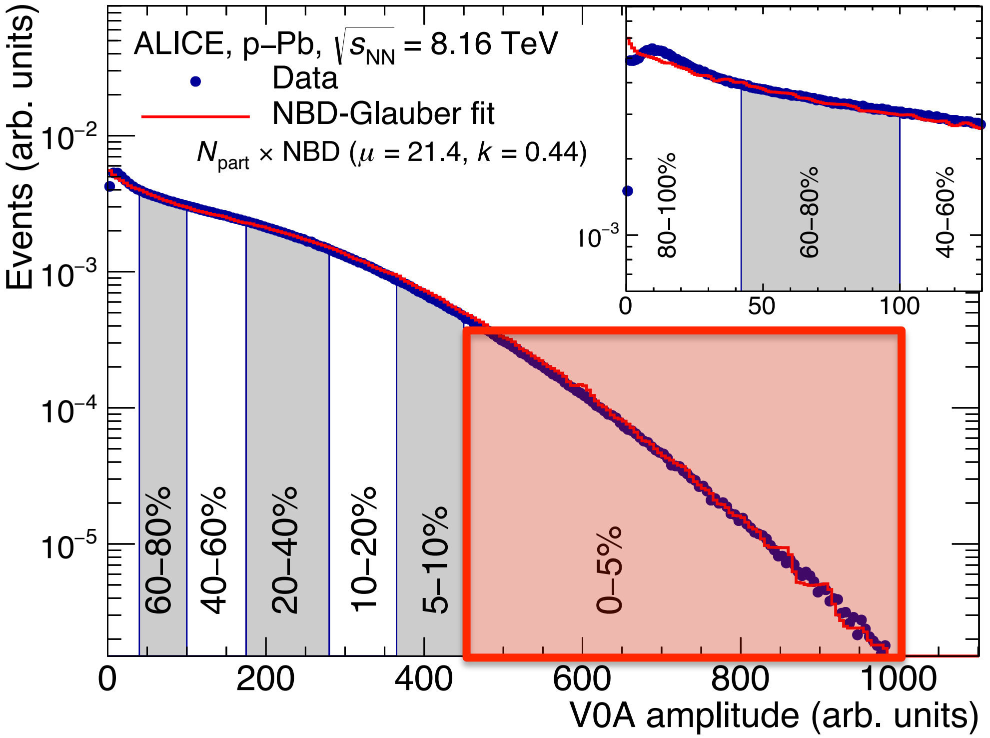

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2. simulate sequence of independent nucleon-nucleon collisions
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High-multiplicity selects:

- larger $\langle N_{part} \rangle$
- widely spread N_{coll}

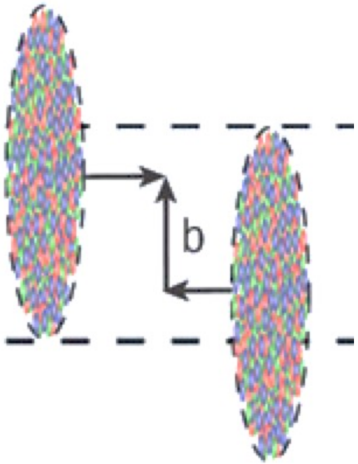
→ deviations from the scaling of hard processes with MPI

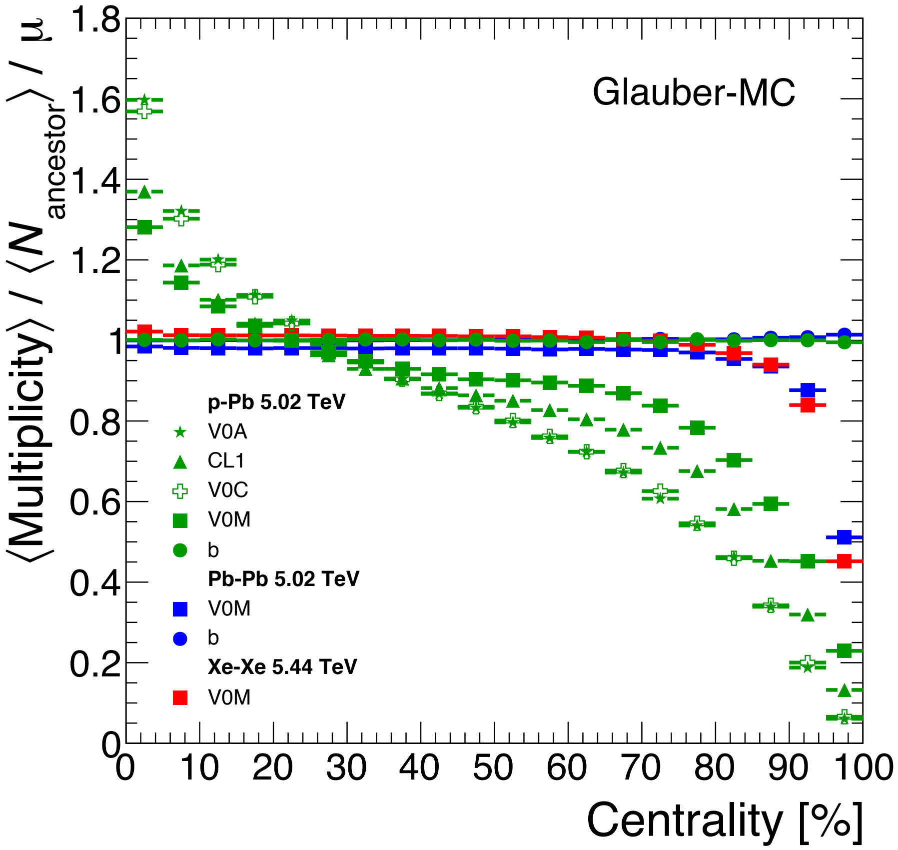
M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Ann.Rev.Nucl.Part.Sci. 57 (2007) 205-243
C. Loizides, J. Kamin, and D. d'Enterria, Phys.Rev. C97 (2018) no.5, 054910
ALICE, arXiv: 1812.01312 [nucl-ex]

Centrality slicing effects
Bias in *smallish* systems

- Multiplicity fluctuations
- few participants

→ dynamical bias in measuring the centrality classes relying on multiplicity





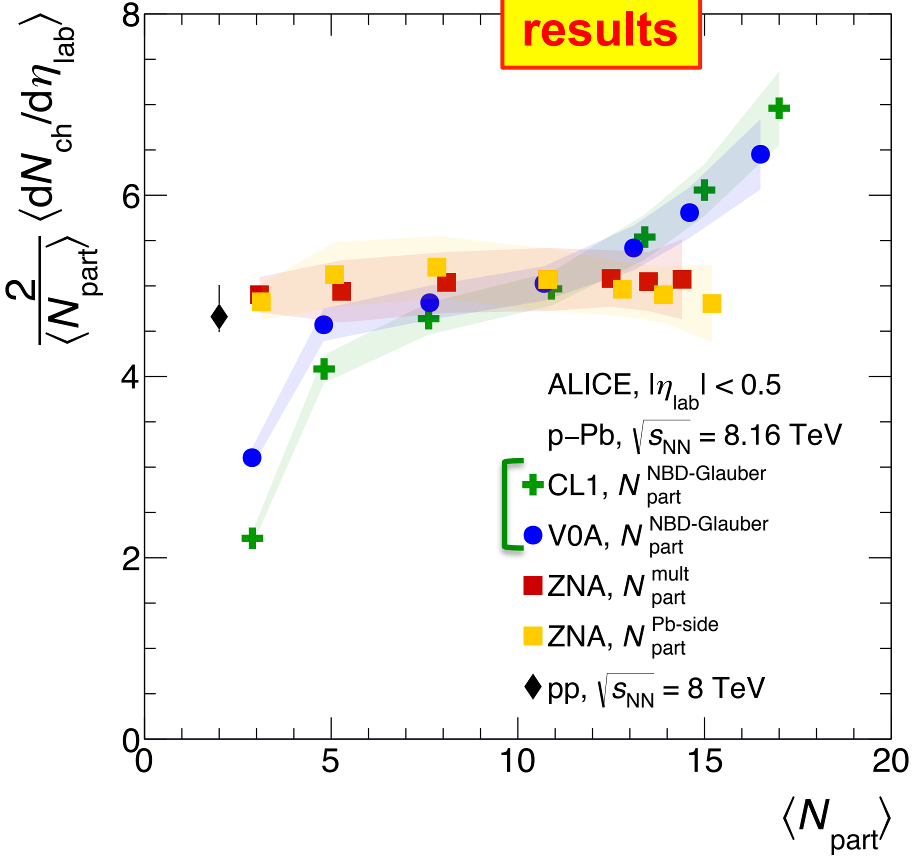
Centrality slicing effects

Bias in pA

New results

Collision centrality using ZDC-based estimator: energy deposited in the neutron calorimeter in the Pb fragmentation side

Multiplicity estimators:
→ bias (grow more than linearly)



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Centrality slicing effects

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Collision centrality using ZDC-based estimator: energy deposited in the neutron calorimeter in the Pb fragmentation side

Multiplicity estimators:

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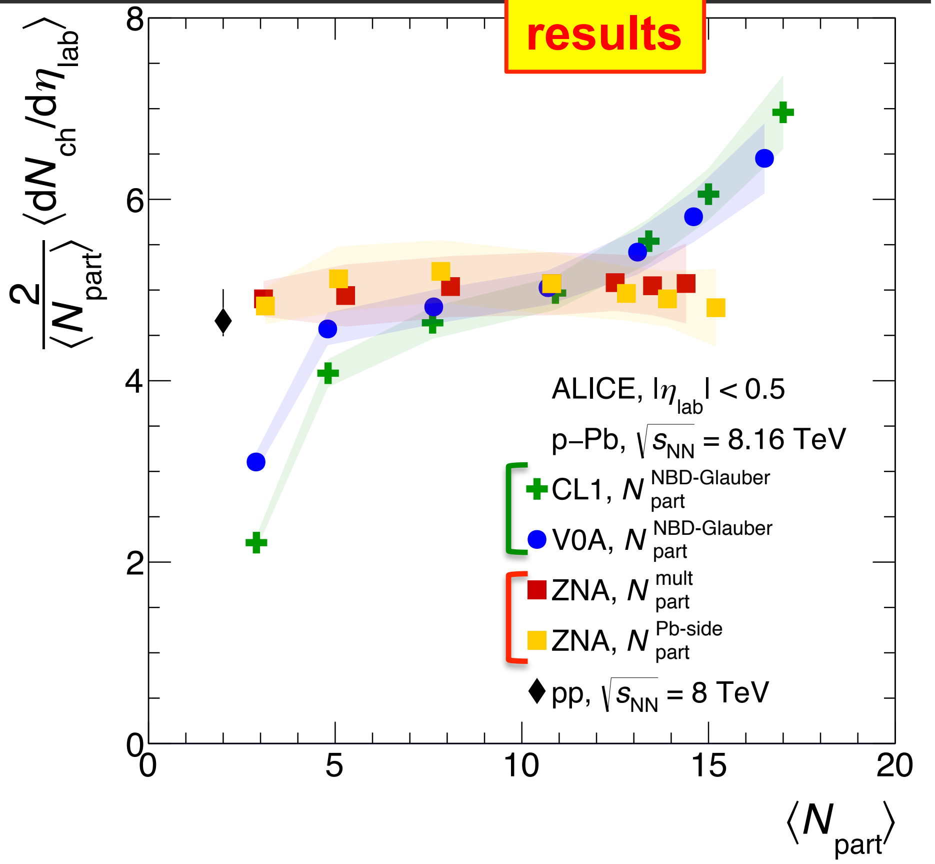
Hybrid

- ZNA + mid-mult α N_{part}
- ZNA + forward-signal α N_{coll}

→ nearly perfect scaling with N_{part}

→ convergence to pp point



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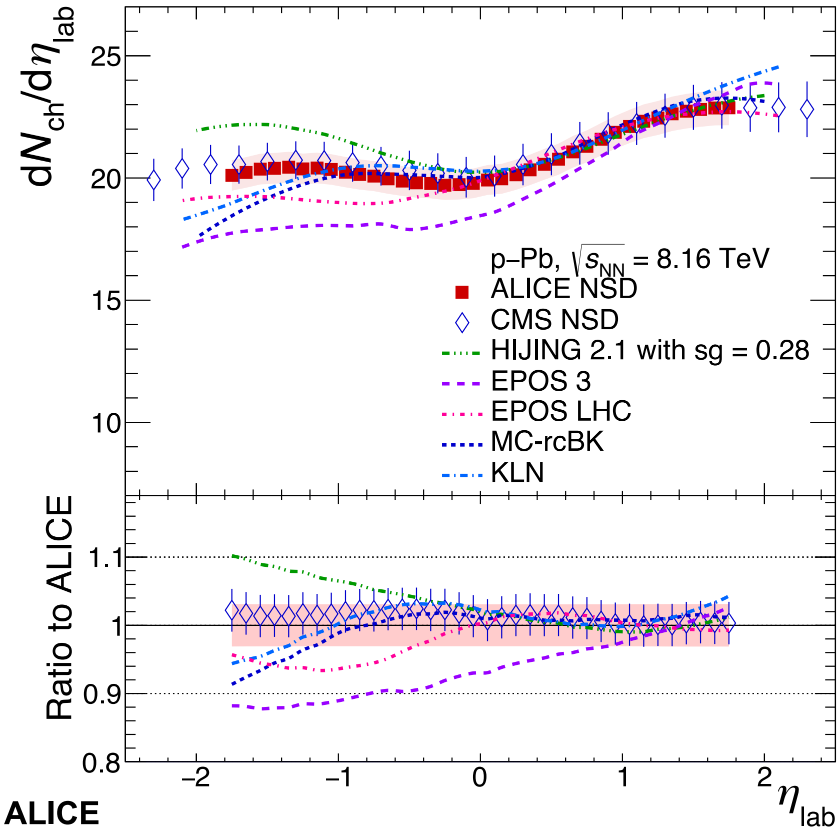
Tuning of models

Multiplicities in p-Pb at 8.16 TeV

New results



Asymmetry:
higher particle production for Pb-going side

good agreement Pb fragmentation
saturation-based models better job

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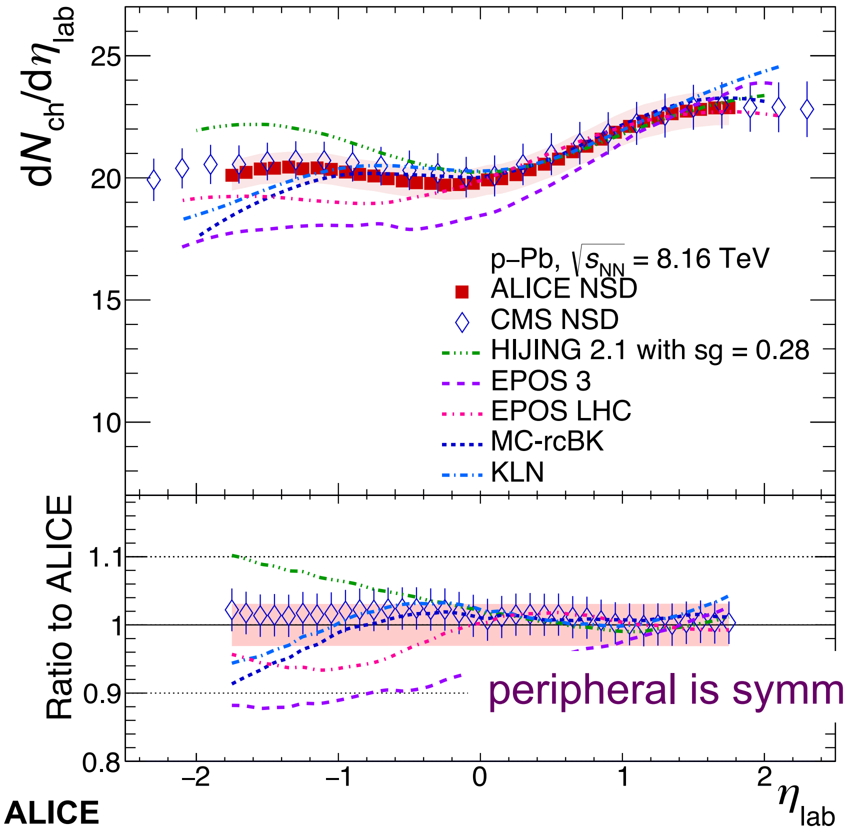
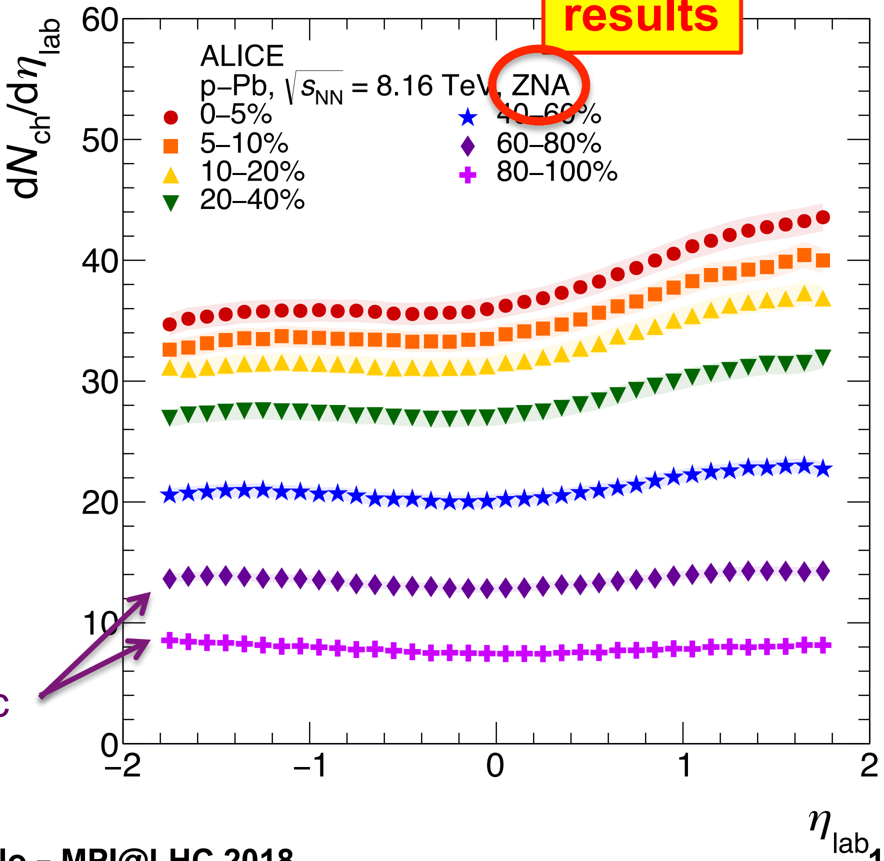
arXiv:1812.01312 [nucl-ex]

Implications of centrality slicing

Multiplicities in p-Pb at 8.16 TeV

New results





peripheral is symmetric

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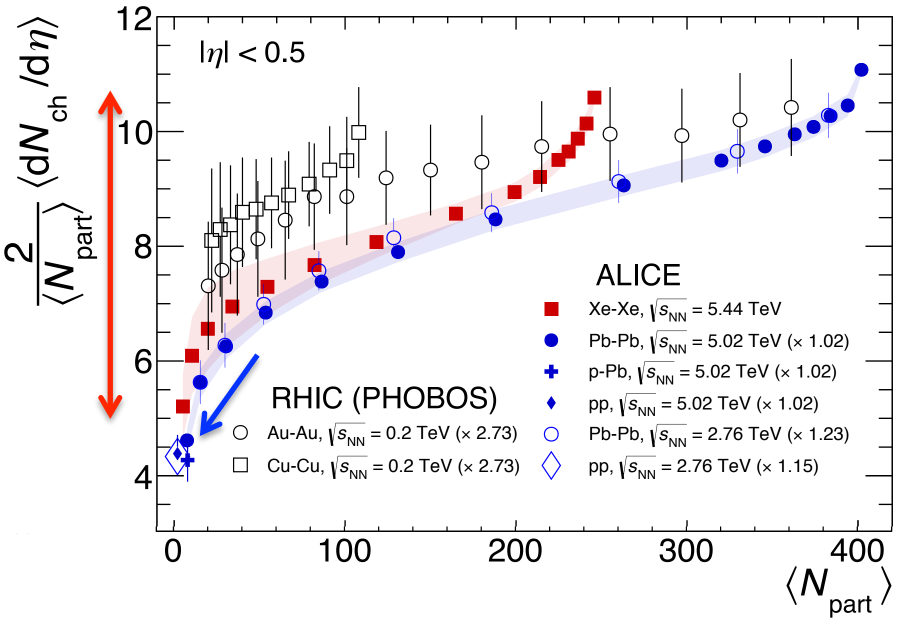
arXiv:1812.01312 [nucl-ex]

The *uptick* effect

Multiplicities in Xe-Xe and Pb-Pb



- Factor 2 rise from peripheral to central
- agreement with pp and p-Pb in peripheral

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Phys. Rev. Lett. 116 (2016) 222302
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The *uptick* effect
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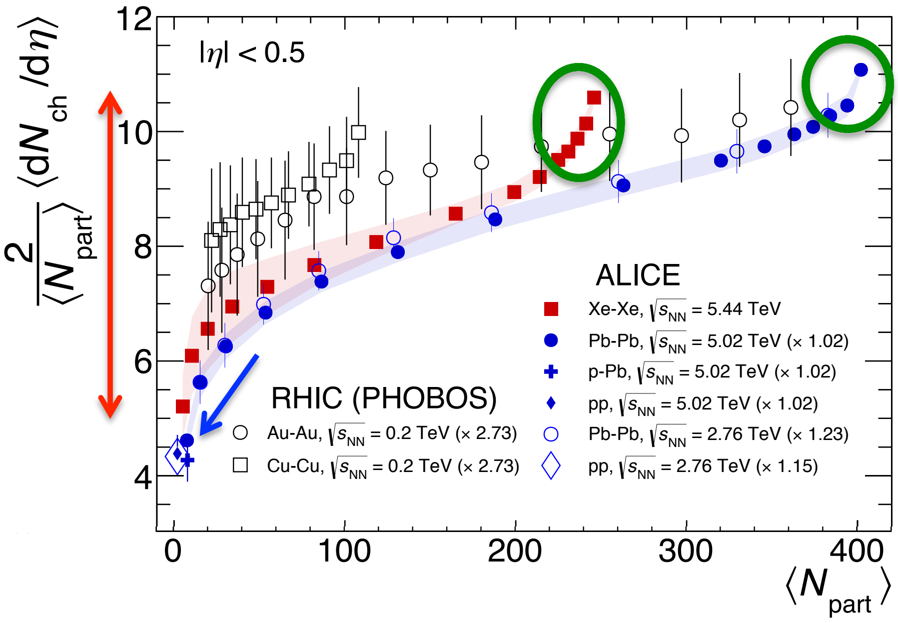

- Factor 2 rise from peripheral to central
- agreement with pp and p-Pb in peripheral
- the *uptick*:
  steeper rise: 5% (2%) most central events for Xe-Xe (Pb-Pb) collisions

ALICE
Phys. Rev. Lett. 116 (2016) 222302
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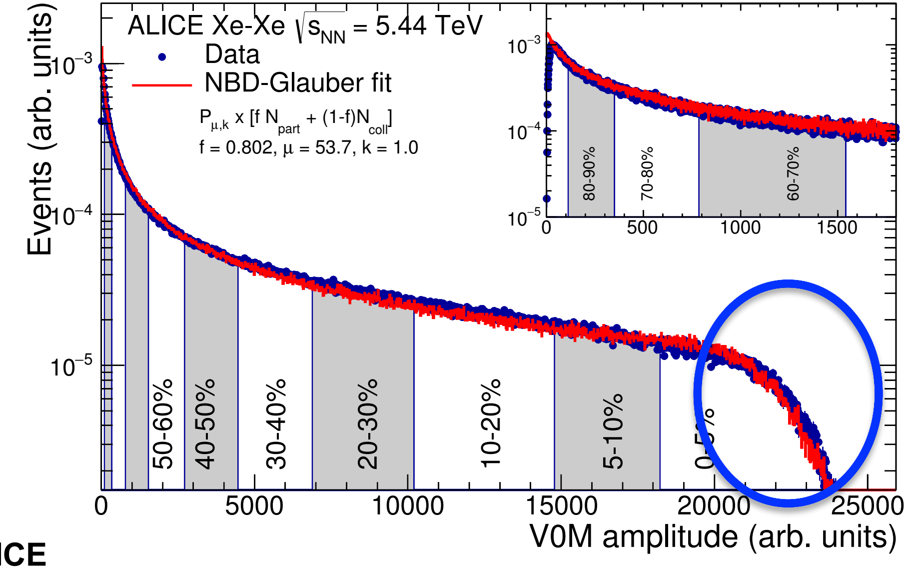
The *uptick* effect
Multiplicities in Xe-Xe and Pb-Pb

The *uptick* originates from:

1. multiplicity fluctuations in the tail of the Xe-Xe forward amplitude distribution



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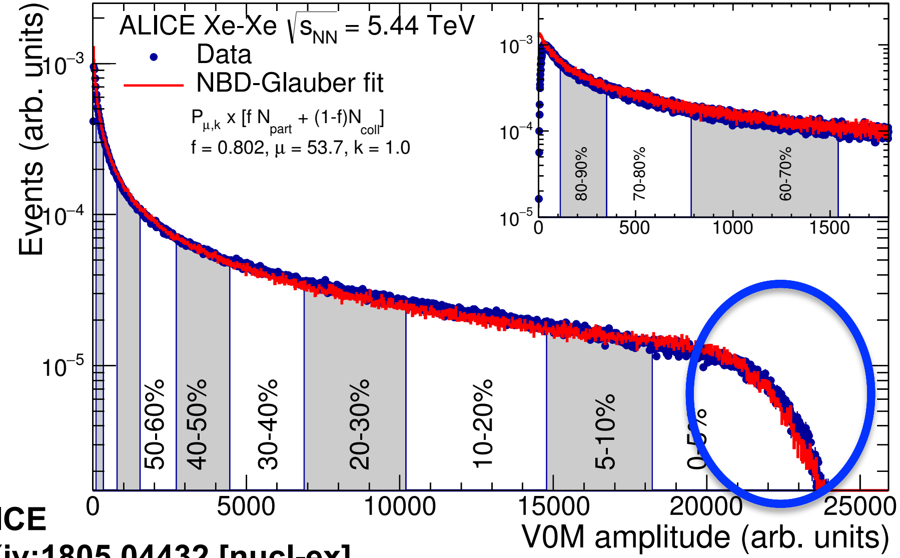
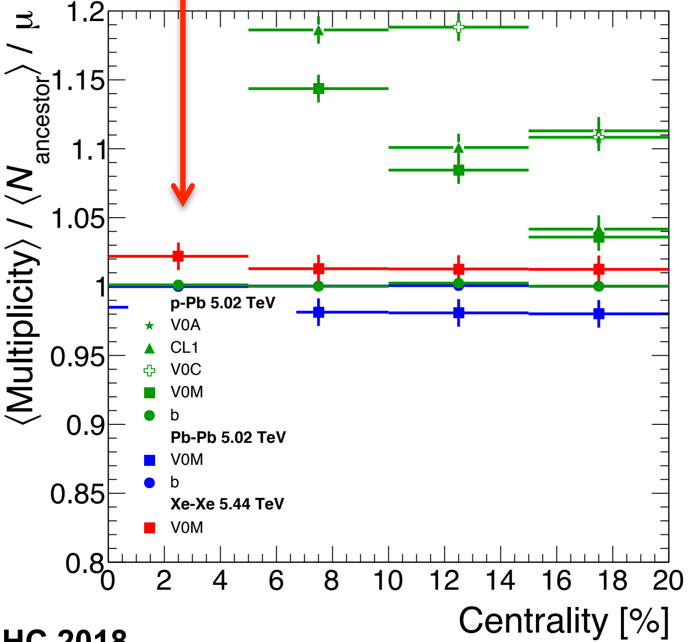
The *uptick* effect
Multiplicities in Xe-Xe and Pb-Pb

The *uptick* originates from:

1. multiplicity fluctuations in the tail of the Xe-Xe forward amplitude distribution
2. the Glauber-MC shows an *uptick* → due to multiplicity fluctuations at fixed number of ancestors (particle sources) α MPI





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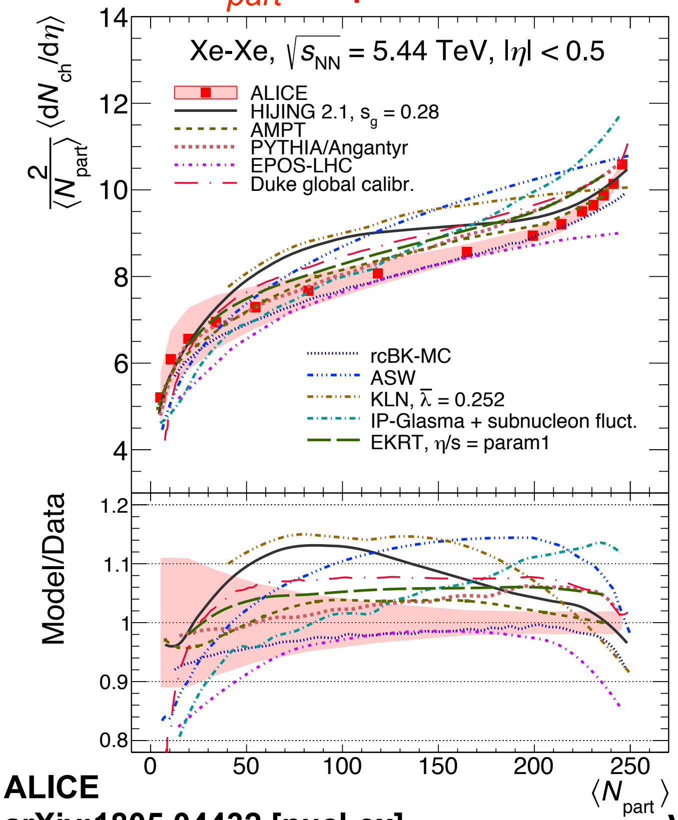
arXiv:1805.04432 [nucl-ex]
ALICE-PUBLIC-2018-003

Tuning of models

Multiplicities in Xe-Xe

N_{part}-dependence



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Almost all models reproduce the *uptick*

→ EPOS-LHC, ASW and KLN show a saturation behaviour

Tuning of models
Multiplicities in Xe-Xe

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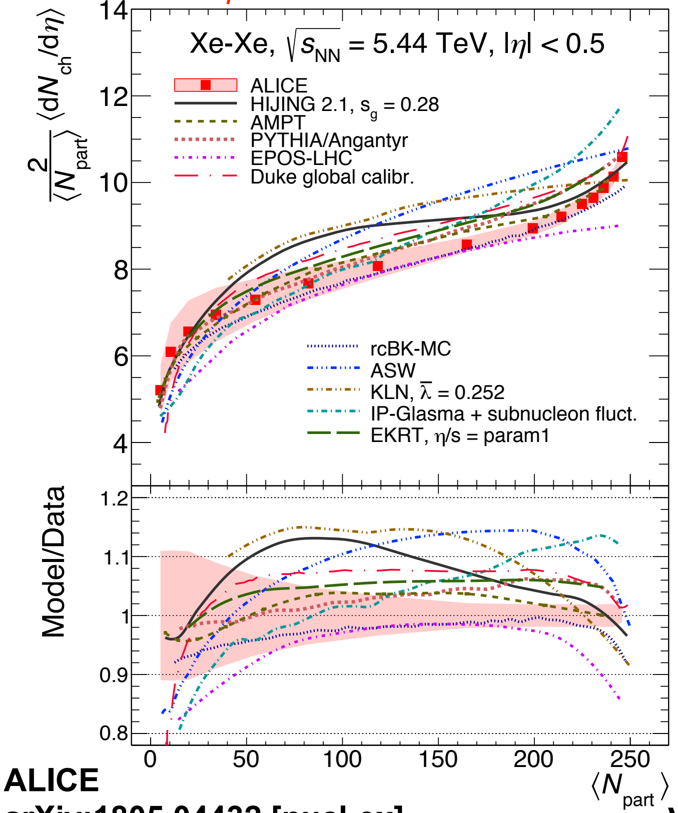
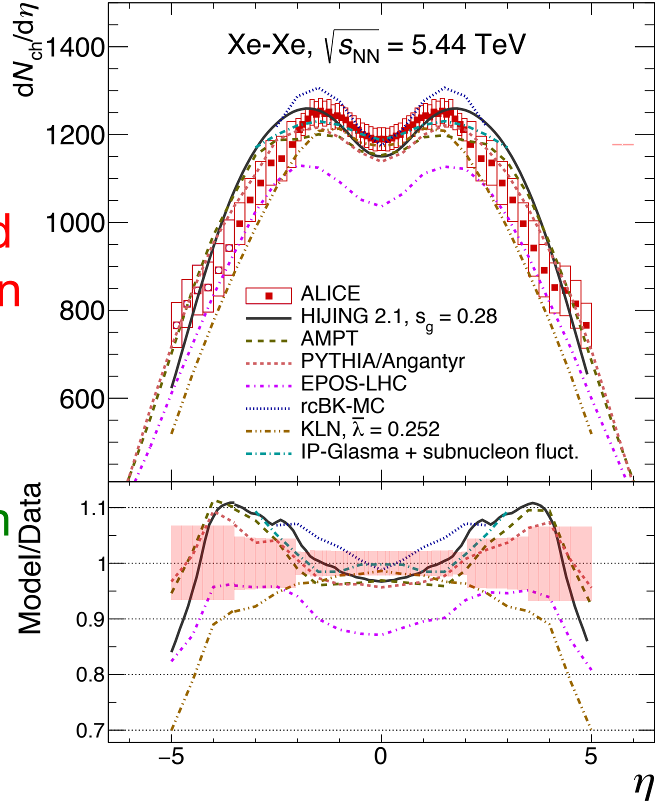


Almost all models reproduce the *uptick*

→ EPOS-LHC, ASW and KLN show a saturation behaviour

→ the shape of the η-dependent distribution is challenged

η-dependence



ALICE
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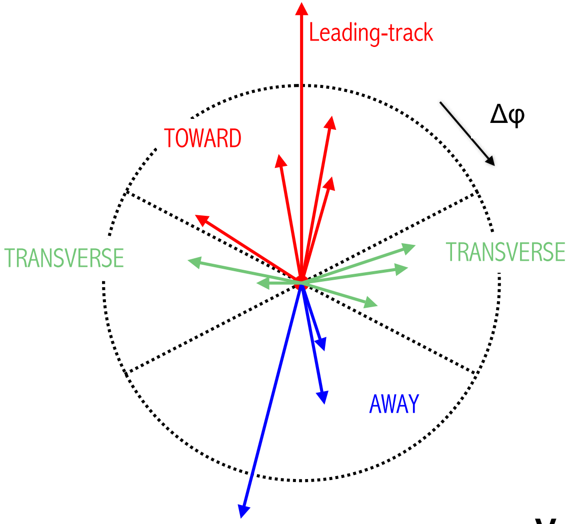
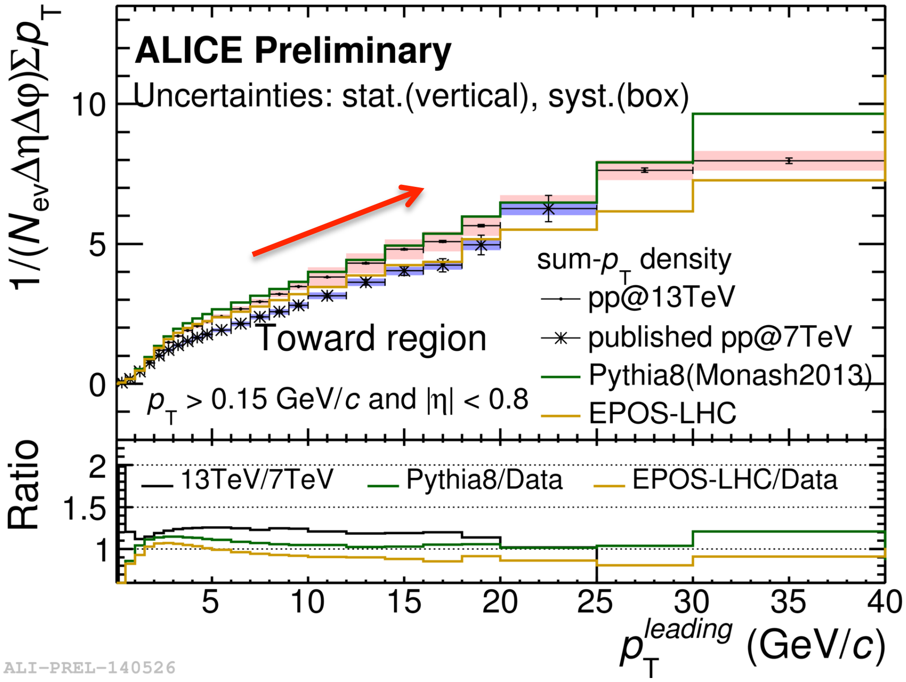
Underlying – Event distributions

Soft-hard processes separation
Underlying event in pp at 13 TeV

Summed p_T vs. $p_{T,LT}$

Toward and Away regions
collect fragmentation products
from hard scattering
→ increasing monotonically



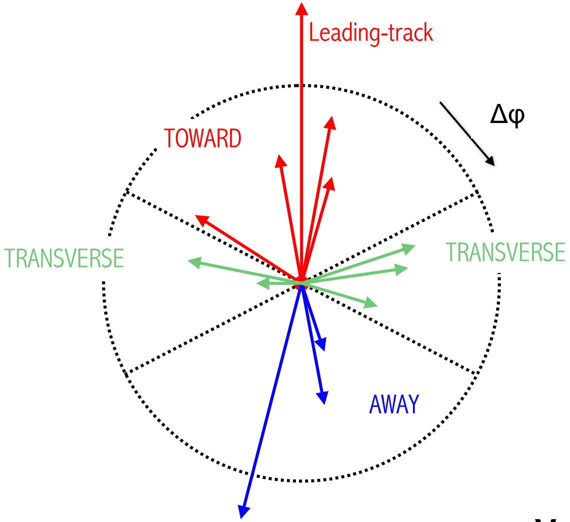


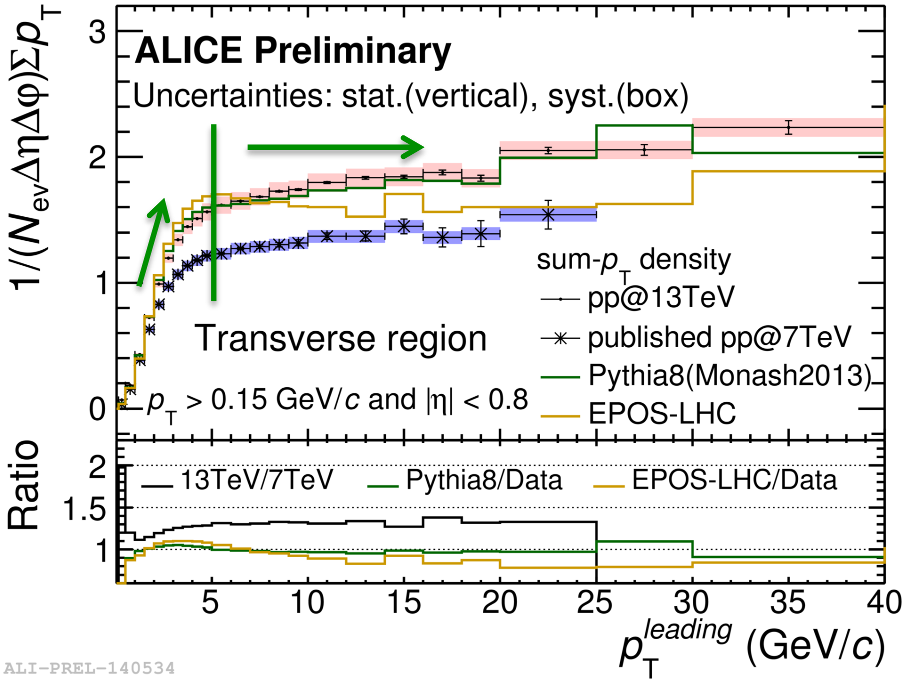
- Pythia 8 closer to the data for $p_{T,LT} > 10$ GeV/c
- EPOS LHC closer for $p_{T,LT} < 10$ GeV/c

Soft-hard processes separation
Underlying event in pp at 13 TeV

Summed p_T vs. $p_{T,LT}$

Transverse region
underlying event
→ first increases → **MPI increase**
→ flattens → **MPI saturation**





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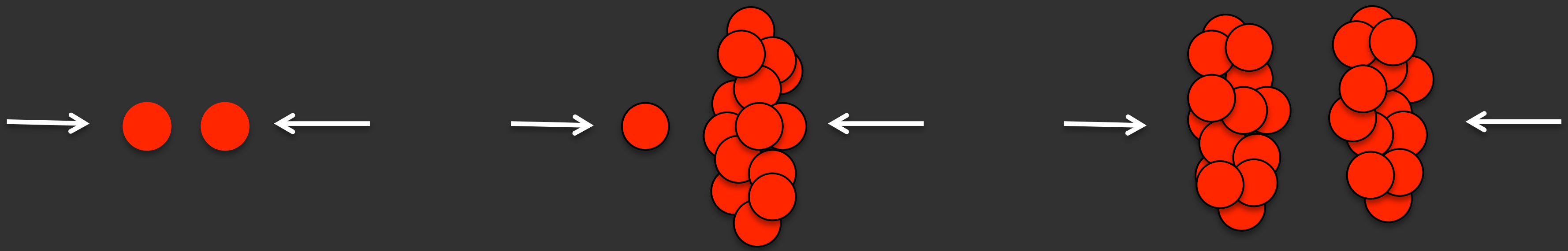
Multiplicity dependence studies



Tuning of models fails

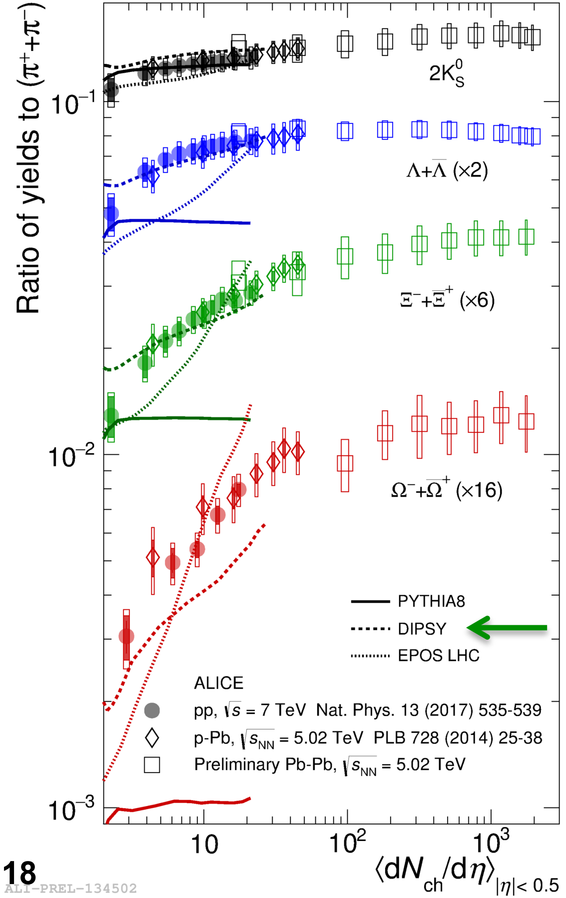
Strangeness production in pp, p-Pb and Pb-Pb

➢ Measurements of strange hadron production important tune for MC models

- enhanced strangeness production
- constant protons over pions

not reproduced simultaneously by all models

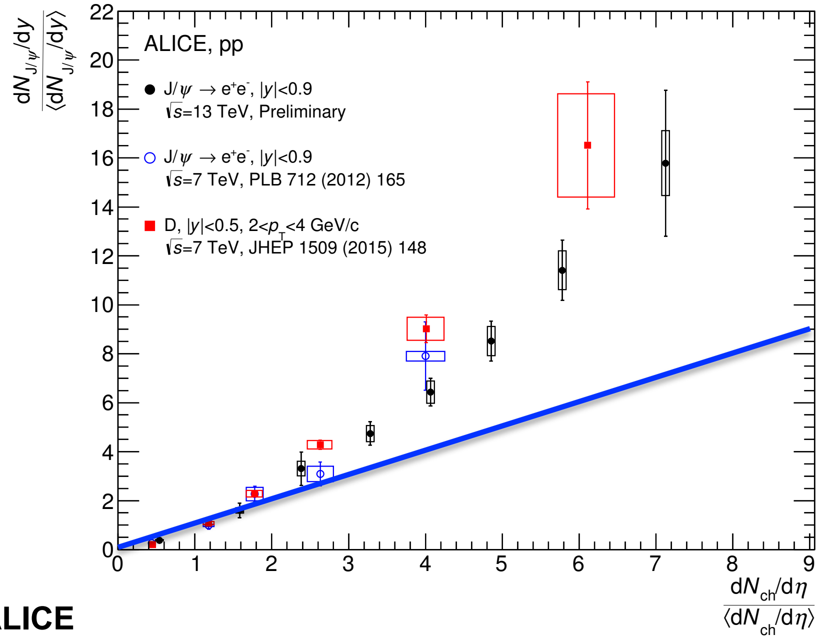
• DIPSY with color ropes does better



ALICE
Nature Physics 13 (2017) 535-539
PLB 728 (2014) 25-38

Multiplicity dependence studies
D and J/Ψ yields in pp and p-Pb

- Similar D meson and J/Ψ increase with multiplicity
- but faster than diagonal → effect of multiplicity saturation? Interplay between multiplicity fluctuations of individual PI and decreasing of MPI distribution? arXiv:1811.07744



ALICE
Phys.Lett. B712 (2012) 165-175
JHEP 1509 (2015) 148

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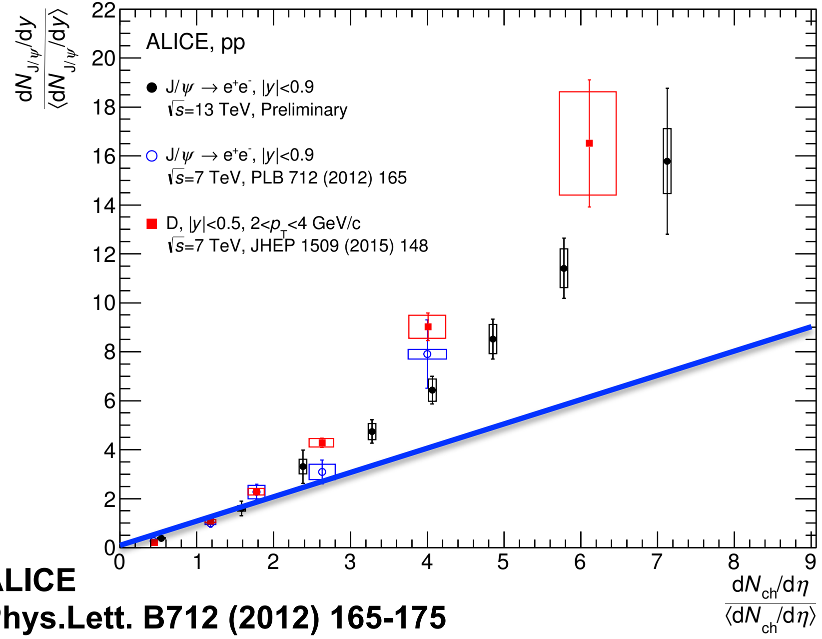
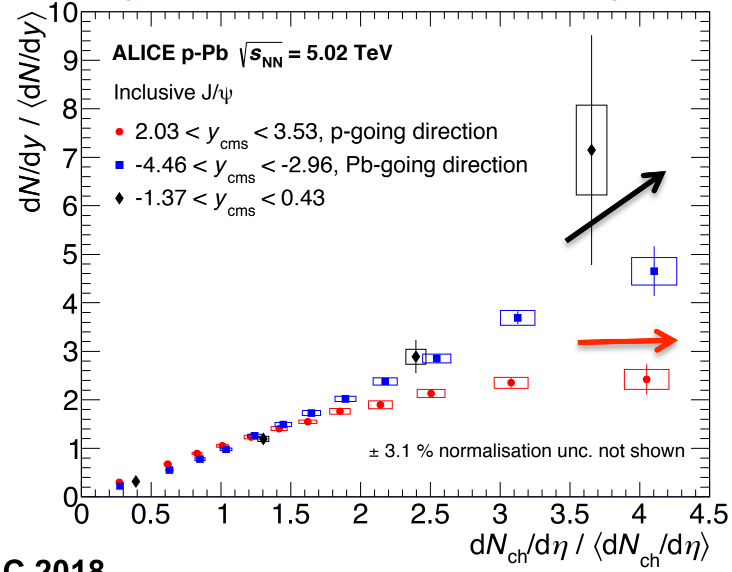


- MPI influences hard spectrum
- forward rapidity ~ saturation effect of y – axis



ALICE
Phys.Lett. B712 (2012) 165-175
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Phys.Lett. B776 (2018) 91-104

Summary and outlook

- ✓ Charged-particle multiplicity densities and the UE are quite well described by models → improvement needed for AA

- ✓ Multiplicity fluctuations at fixed number of ancestors/MPI influence pA and AA distributions as a function of centrality: *uptick* effect

- ✓ Saturation of N_{MPI} observed in several measurements? UE, D and J/Ψ yields

Effects of MPI fluctuations and saturation are visible in multiplicity measurements!

Summary and outlook

- ✓ Charged-particle multiplicity densities and the UE are quite well described by models → improvement needed for AA
- ✓ Multiplicity fluctuations at fixed number of ancestors/MPI influence pA and AA distributions as a function of centrality: *uptick* effect
- ✓ Saturation of N_{MPI} observed in several measurements? UE, D and J/Ψ yields

Can we further constrain soft QCD using the Underlying Event as a probe?
UE: semi-hard + soft interactions

- ➢ general idea: soft-QCD dynamics tested excluding the hard sector

Eur.Phys.J. C76 (2016) no.5, 299 and Phys.Rev. D96 (2017) no.11, 114019

Backup

Digression on Initial Conditions
Partons and Their Evolution

In Deep Inelastic Scattering: Bjorken-x

$$x \equiv \frac{Q^2}{2(P \cdot q)} = \frac{Q^2}{s + Q^2 - M^2}$$

Parton Area $1/Q^2$

1. Q^2-evolution Q^2 grows
2. *Y*-evolution *x* decreases at fixed *Q*^{2}

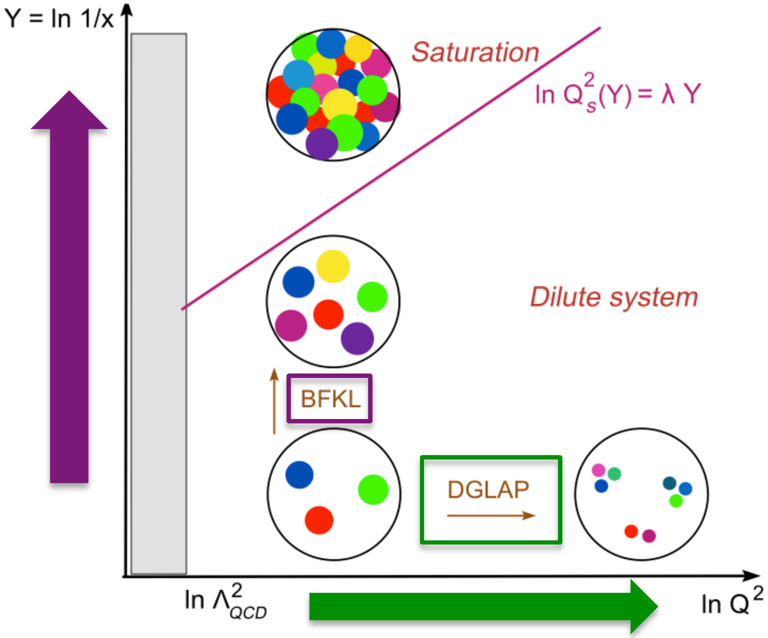
Gluon density: $xg(x, Q^2) \equiv x\frac{dN_g}{dx}$

occupation number increases

$$n(x, Q^2) \simeq xg(x, Q^2)/Q^2 R^2$$

formation of Color Glass Condensate

arXiv: hep-ph/0303204



Centrality: the Glauber-MC

1. Stocastically define nucleons position
   nuclear density funciton (Fermi's distribution)

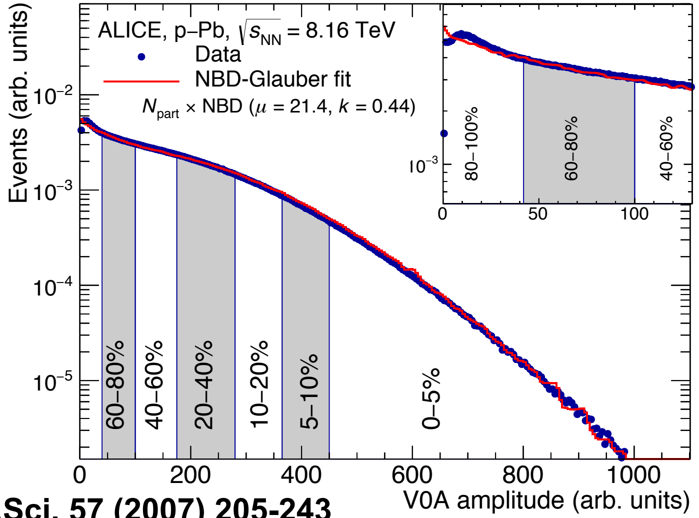
$$\rho(r) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

2. Simulate a nuclear collision
   - sequence of independent binary nucleon-nucleon collisions
   - eikonal approximation
   - same cross section for all collisions
   - hard sphere diameter

$$d < \sqrt{\sigma_{NN}^{inel}/\pi}.$$

3. Hadronic cross section
   Glauber-MC + fit with NBD → multiplicity distribution

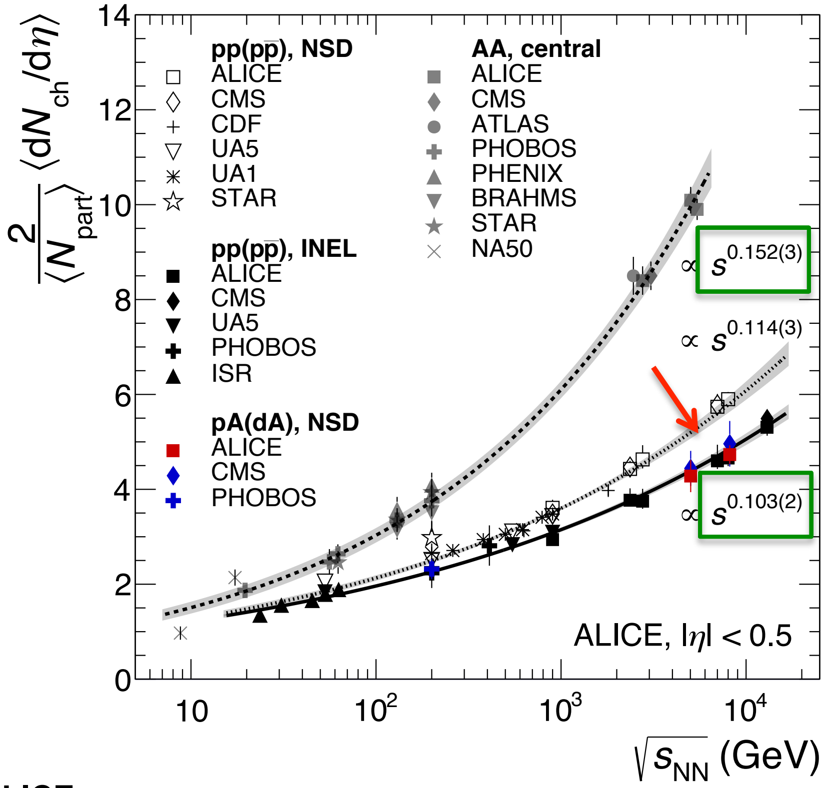
4. Anchor Point
   discrepancy point from data and simulation



M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, Ann.Rev.Nucl.Part.Sci. 57 (2007) 205-243
C. Loizides, J. Kamin, and D. d'Enterria, Phys.Rev. C97 (2018) no.5, 054910
ALICE, arXiv: 1812.01312 [nucl-ex]

How soft is p-Pb?

Multiplicities in p-Pb at 8.16 TeV



At midrapidity $|\eta|<0.5$

p-Pb fits with **INEL pp** points

Steeper rise for AA than for small systems

AA

pA and pp

ALICE
arXiv:1812.01312 [nucl-ex]