Charged-particle production in pp collisions at $\sqrt{s} = 13.6$ TeV and in Pb—Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV with ALICE

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On behalf of ALICE Collaboration

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Charged-particle multiplicity density ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$)

- Study interplay between soft and hard QCD

Nucleus-Nucleus (AA) collisions

- Direct relation to the energy density (ϵ) of QGP

$$\epsilon = \frac{\mathrm{d}E_{\mathrm{T}}/\mathrm{d}y}{\tau_0 \pi R^2} \sim \frac{3}{2} \langle m_{\mathrm{T}} \rangle \frac{\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta}{\tau_0 \pi R^2} > 1\mathrm{GeV/fm}^3$$

Proton-Proton (pp) collisions

- Reference data for nuclear effect
- Study Multiple Parton Interactions (MPIs) in high N_{ch} collisions

Proton-Nucleus (pA) collisions

- Discriminate beteween Final-State Radiation (FSR) in AA and Initial-State Radiation (ISR) of nuclei themselves

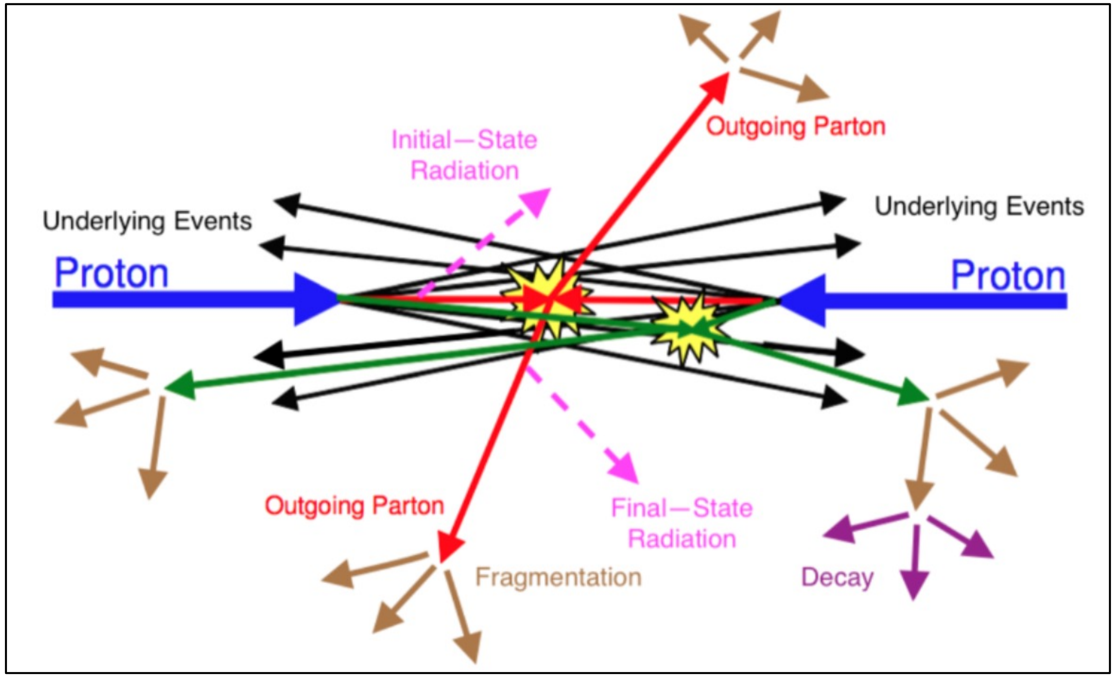
- Good index for system-size information
  - Continuous indicator of system-size information from pp to AA
- Good observable for detector calibrations
  - Well behaved and stable distribution following the power law as a function of collision energy

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in pp collisions

- At LHC energy → more contribution from hard processes
  - Multiple parton interactions (MPI): More than one hard scattering
  - Regulation of MPIs is connected to the QGP-like effect

- And additional soft processes
  - ISR+FSR
  - Color-connected beam remnant
  - Infrared MPIs (not primary)
  - Characteristics
    - $p_{\mathrm{T}} \sim$ few GeV
    - Non perturbative
    - Phenomenology
    - Modelling

EPJC 62 (2009) 237-242



$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in pp collisions

❑ MPIs in pp collisions

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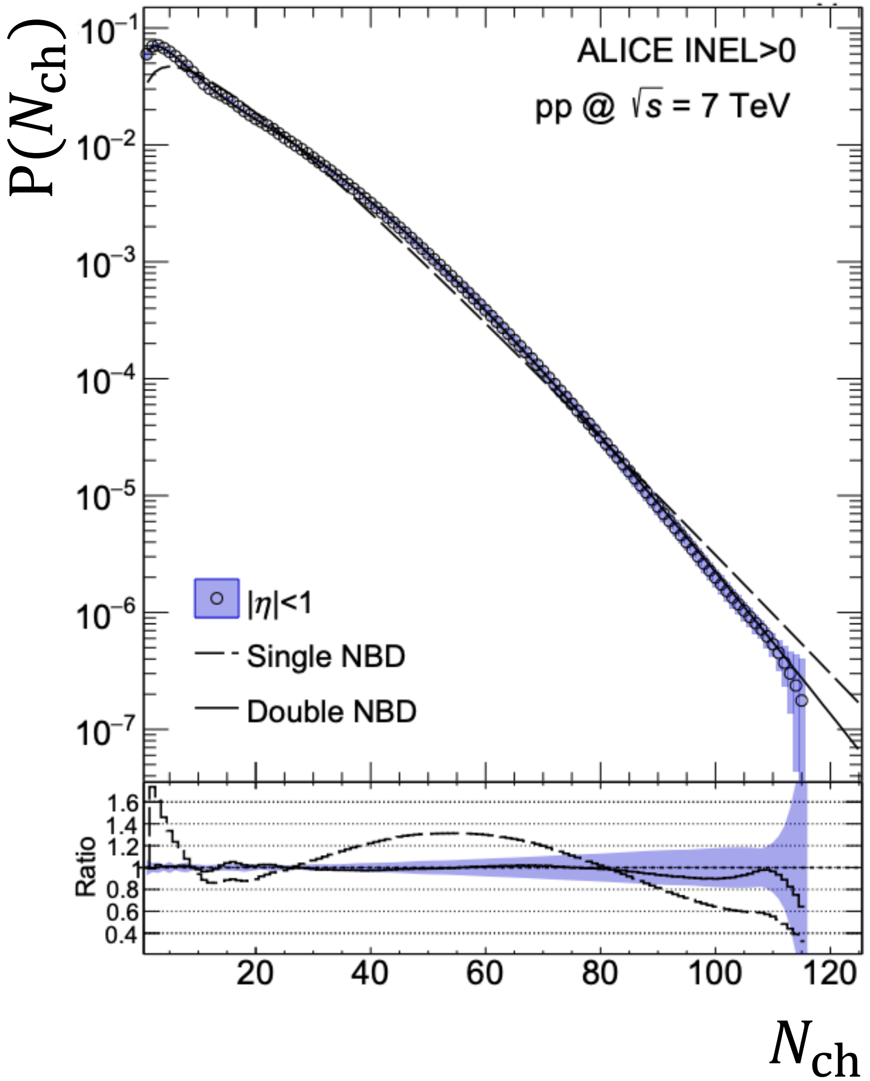


- **Single Negative Binomial Distribution (NBD) fit**
  - ✓ Traditional parametrisation of particle multiplicity (n)

$$P_{\mathrm{NBD}}\,(n, \langle n\rangle, k) = \frac{\Gamma(n+k)}{\Gamma(k)\Gamma(\mathrm{n}+1)}\left[\frac{\langle n\rangle}{\langle n\rangle + k}\right]^{n} \times \left[\frac{k}{\langle n\rangle + k}\right]^{k}$$

  - ✓ Single NBD fit does not explain the data well

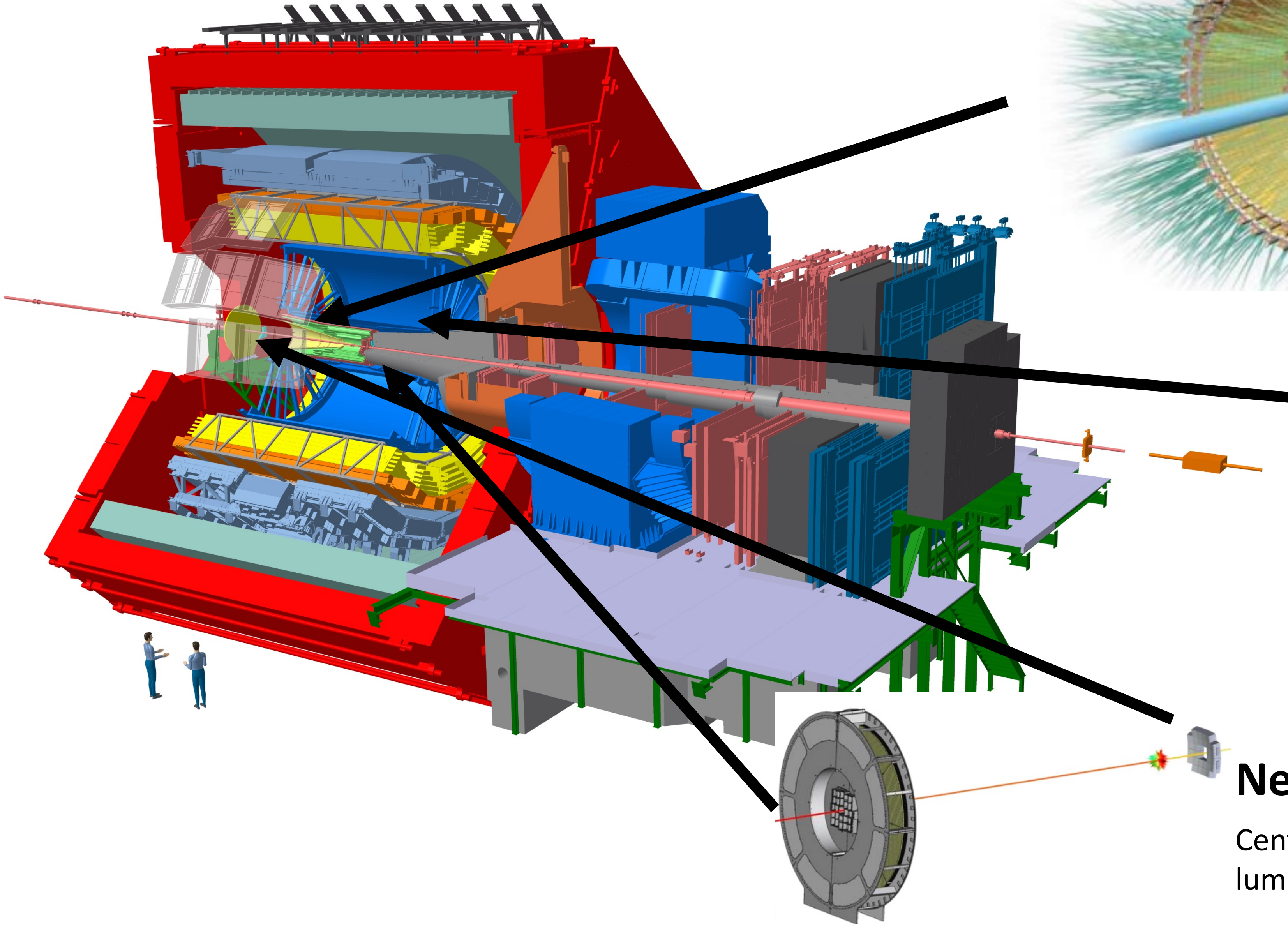
- **Double NBD fit**
  - ✓ Weighted sum of two NBD functions

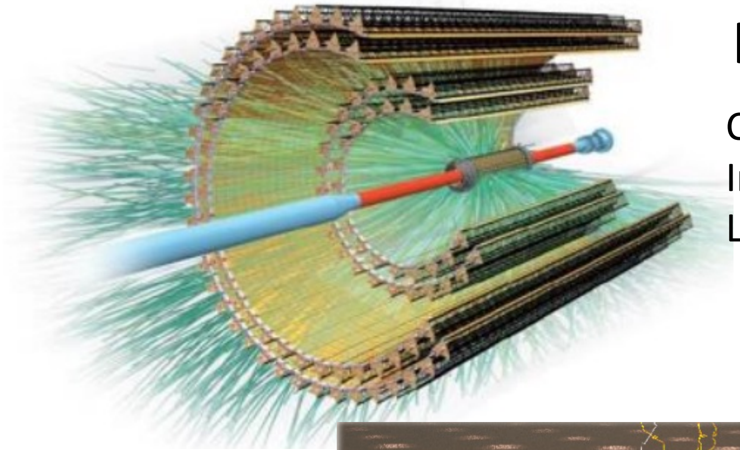
$$P_{\text{Double NBD}} = \lambda[\alpha P_{\mathrm{NBD}}\,(n, \langle n\rangle, k) + (1-\alpha) P_{\mathrm{NBD}}\,(n, \langle n\rangle, k)]$$

α: soft and MPIs (not primary), $1-\alpha$: hard scattering

  - ✓ Describes the LHC data better → Clear MPI contribution

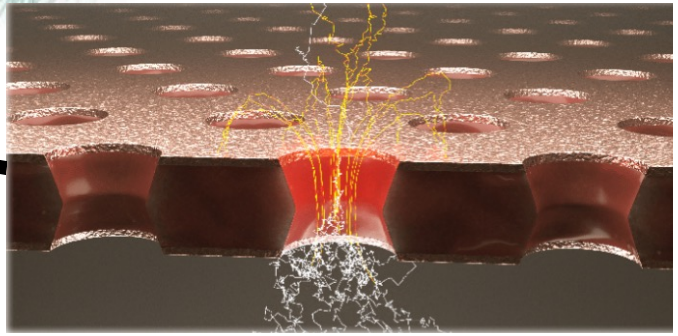
ALICE in RUN 3





ITS2

CMOS Pixel
Improved resolution
Less materisl, fast readout



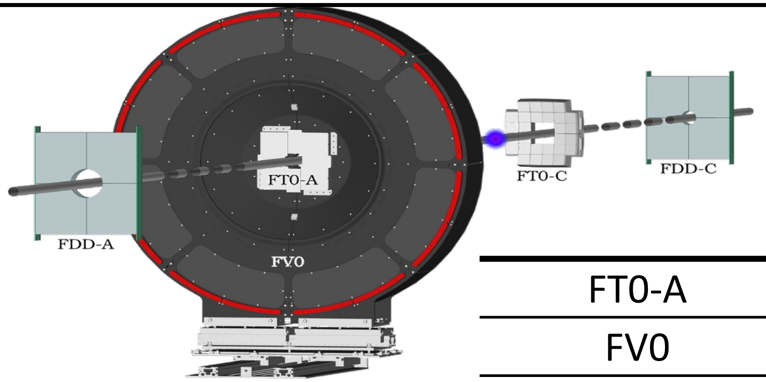
New TPC readout

Gas-Electron Multiplier
Faster and continuous readout

New Fast Interaction Trigger

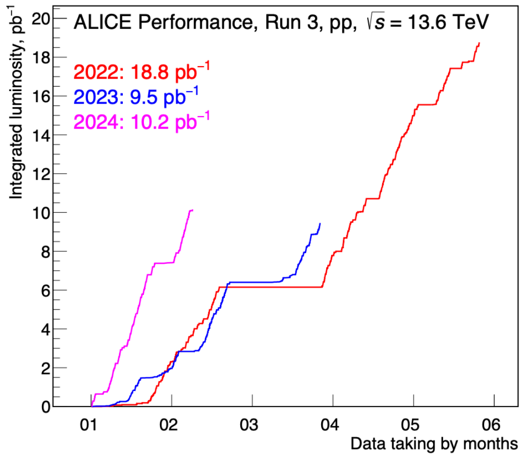
Centrality, event plane,
luminosity, and interaction time

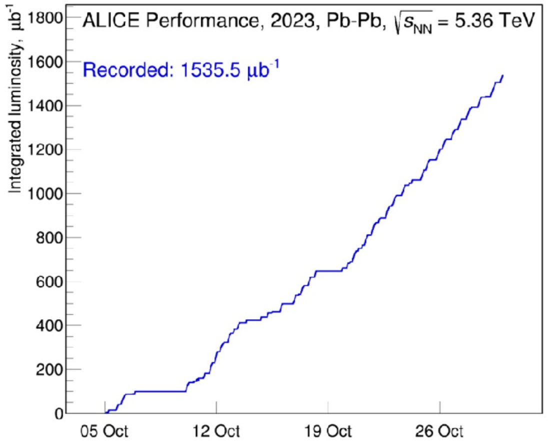
ALICE in RUN 3



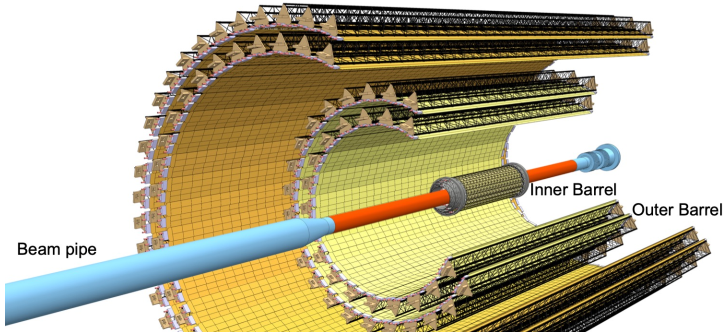
FIT

	Coverage
FT0-A	$3.5 \leq \eta \leq 4.9$
FV0	$2.2 \leq \eta \leq 5.1$
FT0-C	$-3.3 \leq \eta \leq -2.1$



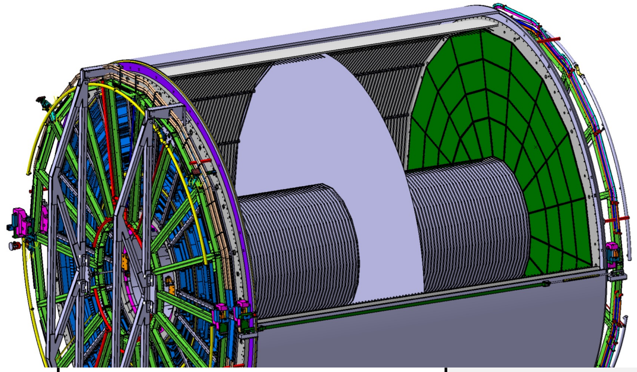


ITS



	RUN 2 (ITS 1)	**RUN 3 (ITS 2)**
Technology	pixel, strip, drift	**Monolithic active pixel sensors**
# of layers	6	**7**
Coverage	$\lvert\eta\rvert \leq 0.9$	$\lvert\eta\rvert \leq 1.3$
Material budget	$1.14\%\ X_0$	**Inner : $0.36\%\ X_0$** **Outer : $1.10\%\ X_0$**
Spatial resolution	$12 \times 100\ \mu m$	$5 \times 5\ \mu m$
Max rate (Pb−Pb)	1 kHz	**100 kHz (Pb−Pb)**

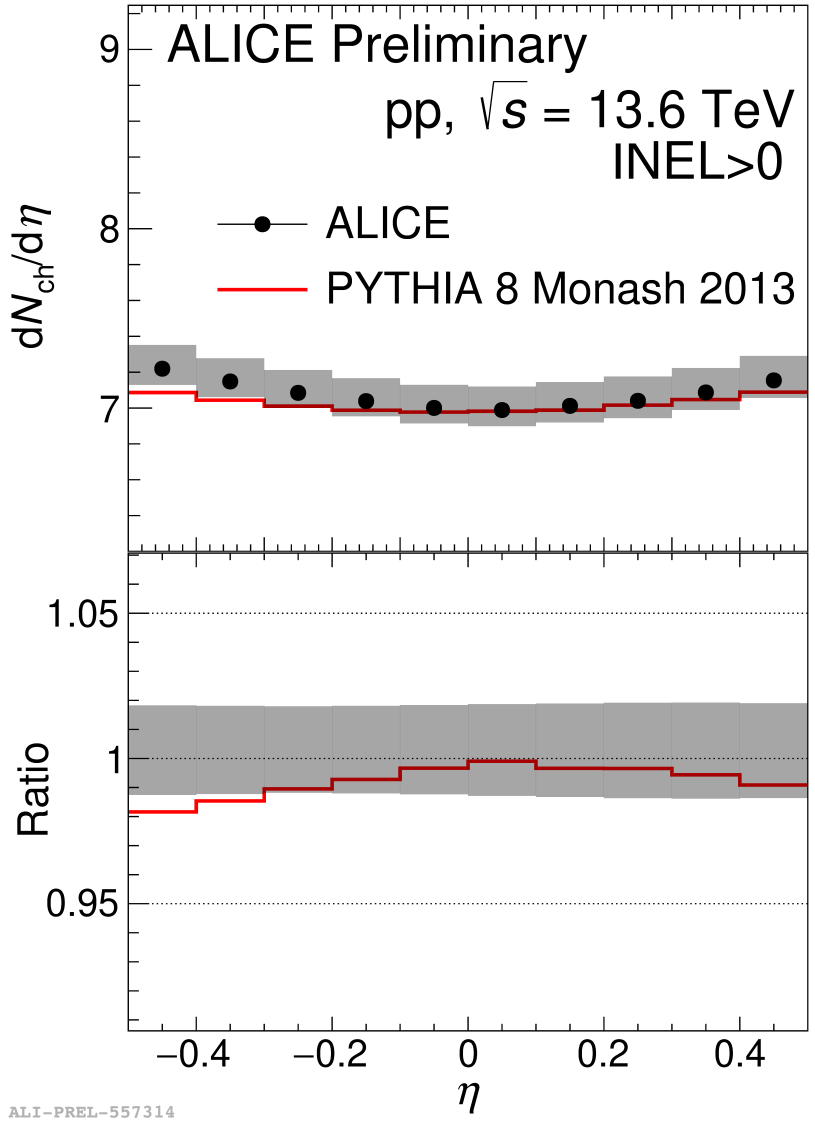
TPC



	Run 2	**Run 3**
Technology	MWPC (Multi wire proportional chamber)	**GEM**
Readout	few kHz	**50 kHz** **(continuous readout)**
Coverage	$\lvert\eta\rvert \leq 0.9$	

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in pp collisions

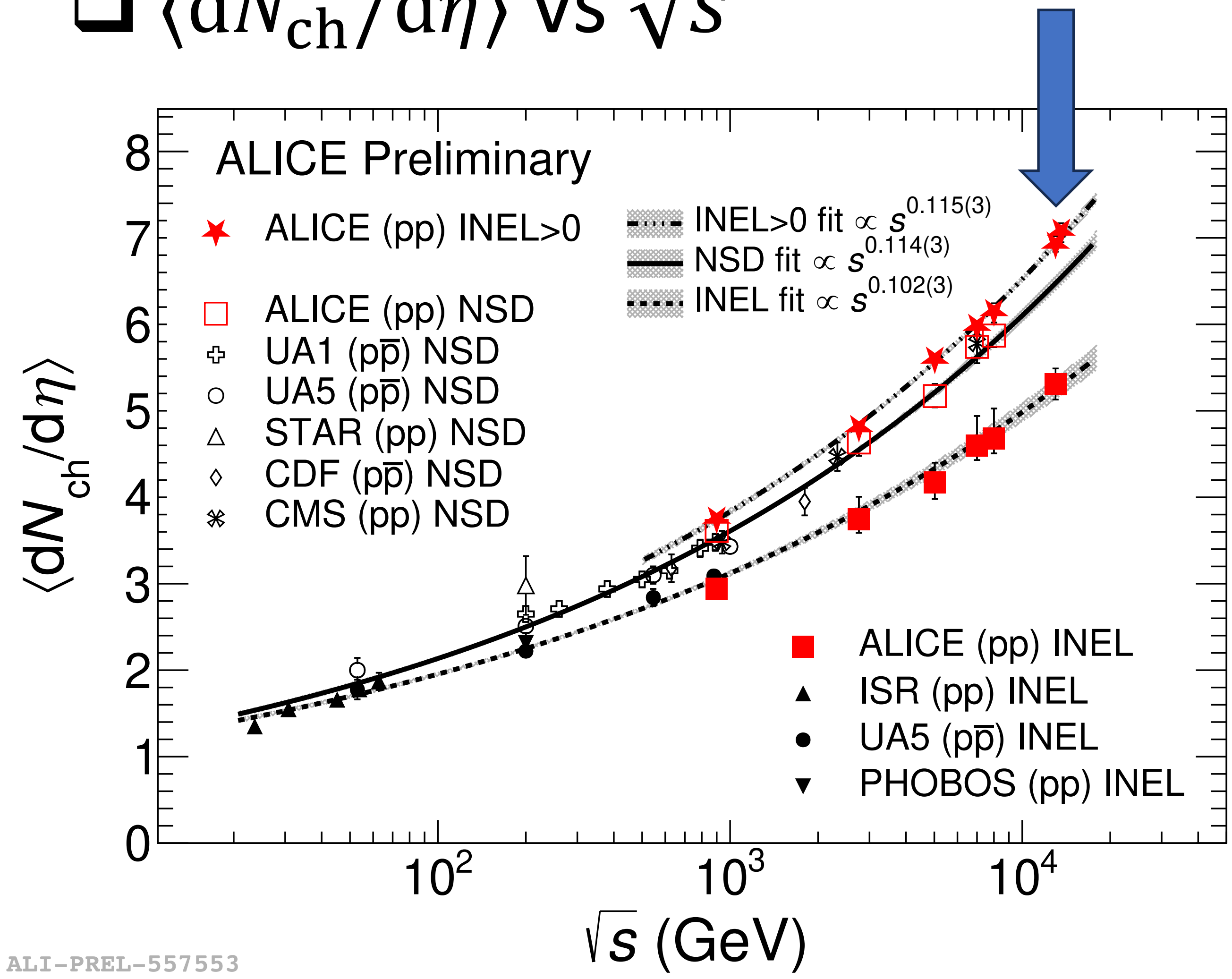
❑ $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distribution for INEL>0 events



- New ALICE setup works well in RUN 3
- INEL>0 events
  - ✓ Inelastic events having at least one charged particle in $|\eta| < 1$
  - ✓ Remove most diffraction events
  - ✓ Maximize model constraints by minimizing diffraction uncertainty
- PYTHIA 8 describes data well

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in pp collisions

❑ $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ vs $\sqrt{s}$



- $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ as a function of s

$$\left\langle \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta} \right\rangle \Bigg|_{\text{in mid}} \propto \frac{s^{\Delta}}{\sigma_{\mathrm{Int}}}$$

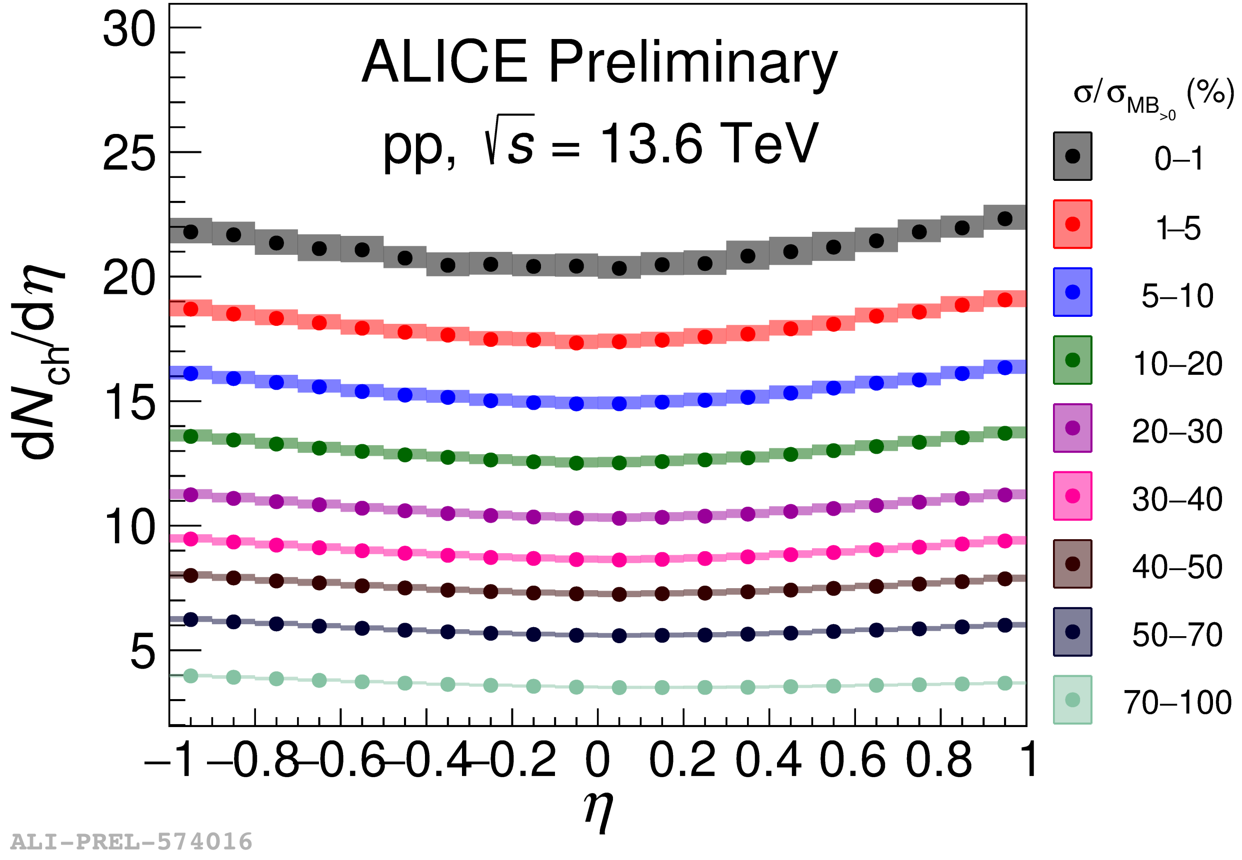
Δ: Pomeron trajectory intercept parameter

σ_{Int}: Interaction cross section

- $\left\langle \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta} \right\rangle \propto s^{a}$ expected in LHC energy
- 13.6 TeV data follow the power-law trend

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in pp collisions

❑ Multiplicity-dependent $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$



Multiplicity determination by signal sum of FT0-A and C

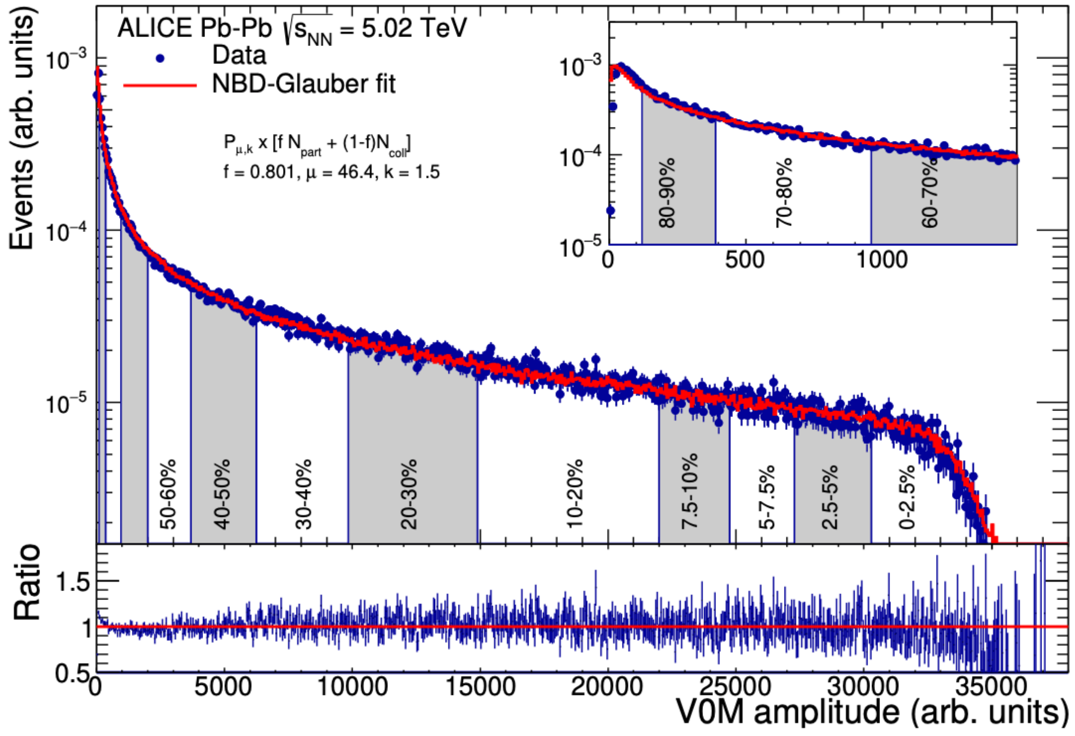
	Rapidity coverage
FT0-A	$3.5 \leq \eta \leq 4.9$
FT0-C	$-3.3 \leq \eta \leq -2.1$

- Fractional cross-section ($\sigma/\sigma_{\mathrm{MB}_{>0}}$)
  - ✓ $\sigma_{\mathrm{MB}_{>0}}$: Minimum-bias events having at least one track in $|\eta| < 1$
  - ✓ $\sigma_{\mathrm{MB}_{>0}}$ constituting 100%
  - ✓ Closer to 0% → higher the multiplicity of FT0-A and FT0-C
- $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ for the 0−1% is 7 times larger than one for the 70−100%
- **Important input** for other observables to study QGP-like effects

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in Pb—Pb collisions

❑ Centrality determination

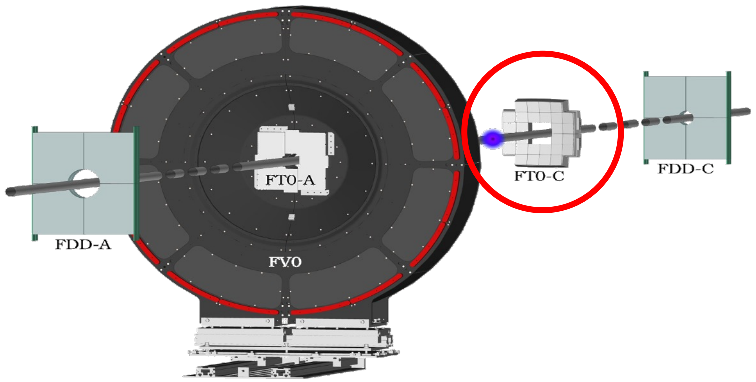
ALICE-PUBLIC-2018-011



RUN 2 example

➢ Centrality determined with the FT0-C

	Distance from IP	Rapidity coverage
FT0-C	-0.8 m	$-3.3 \leq \eta \leq -2.1$



➢ NBD Glauber fit coupled to a two component model

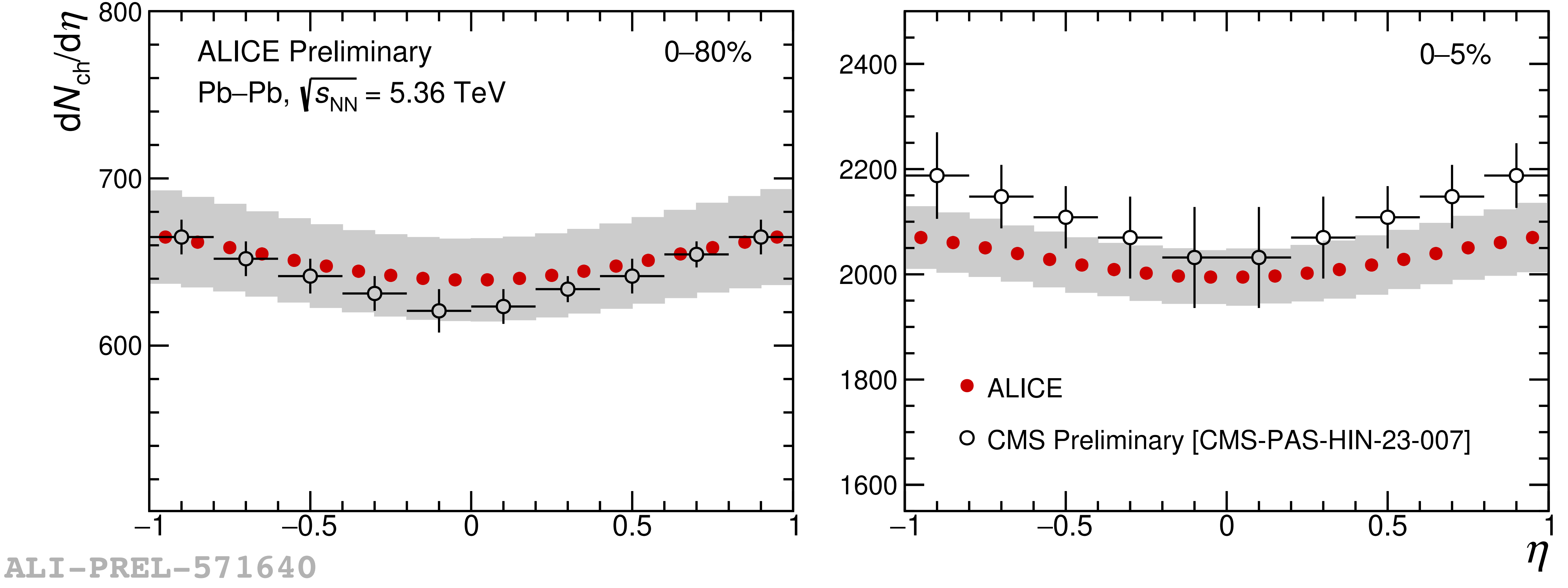
$$P_{\mathrm{NBD}}\,(n, \langle n \rangle, k) \times [f N_{\mathrm{part}} + (1-f) N_{\mathrm{coll}}]$$

N_{part}: The number of participants

N_{coll}: The number of binary collisions

$dN_{ch}/d\eta$ in Pb–Pb collisions

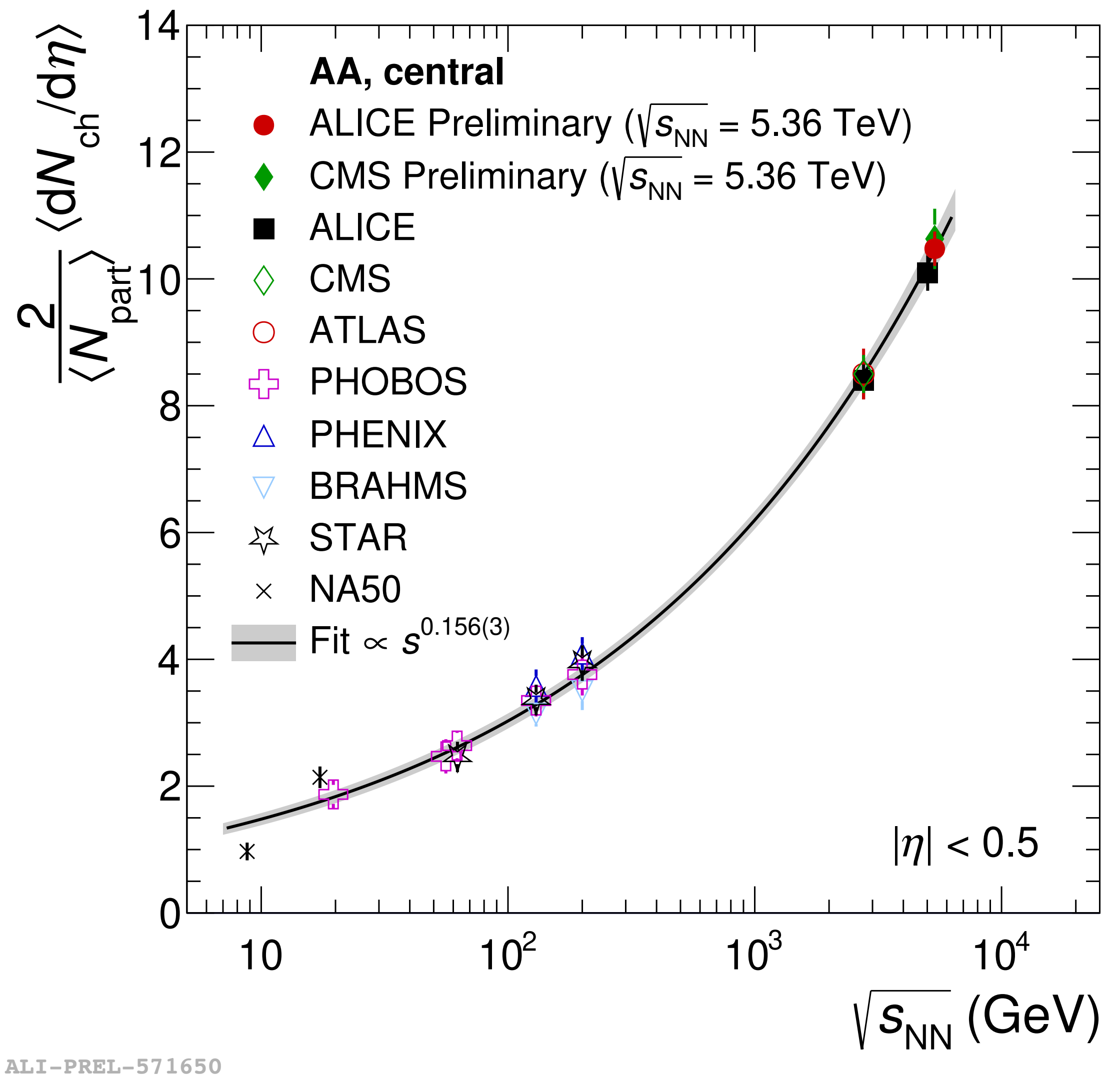
- ❑ $dN_{ch}/d\eta$ for the 0–80% and 0– 5% centralities



✓ Good agreement with the CMS preliminary results

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in Pb—Pb collisions

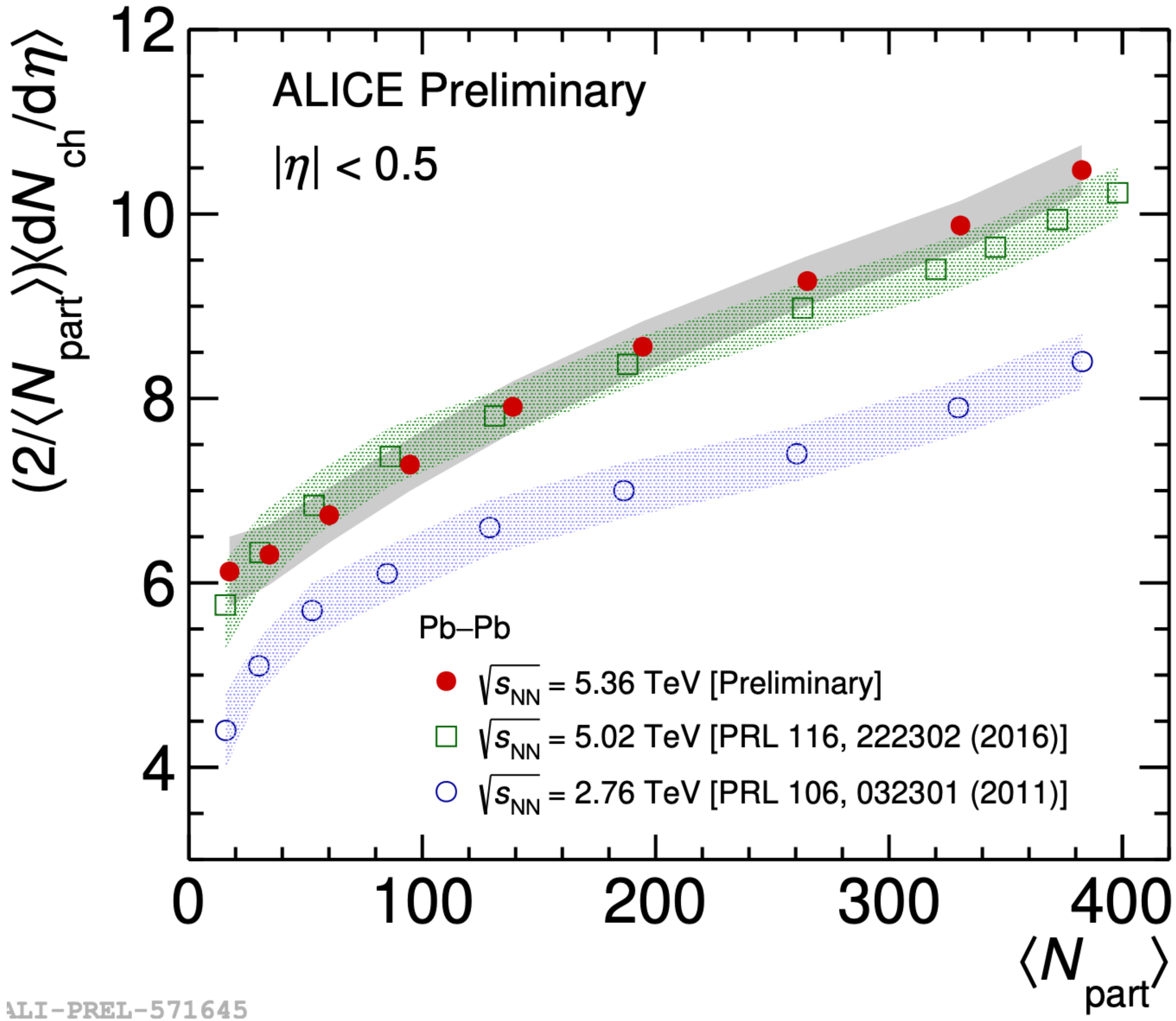
❑ $2/\langle N_{part}\rangle \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ vs $\sqrt{s_{\mathrm{NN}}}$



- ➢ $2/\langle N_{\mathrm{part}}\rangle\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ for the top 5% centrality
- ➢ One at 5.36 TeV in agreement with the trend
  - ✓ 2.76 TeV ALICE result: Phys. Rev. Lett. **106**, 032301
  - ✓ 5.02 TeV ALICE result: Phys. Rev. Lett. **116**, 222302
- ➢ A stronger rise w.r.t $\sqrt{s_{\mathrm{NN}}}$ than pp
  - ✓ $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ in pp $\propto s^{0.115(3)}$
  - ✓ $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ in Pb—Pb $\propto s^{0.156(3)}$

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in Pb−Pb collisions

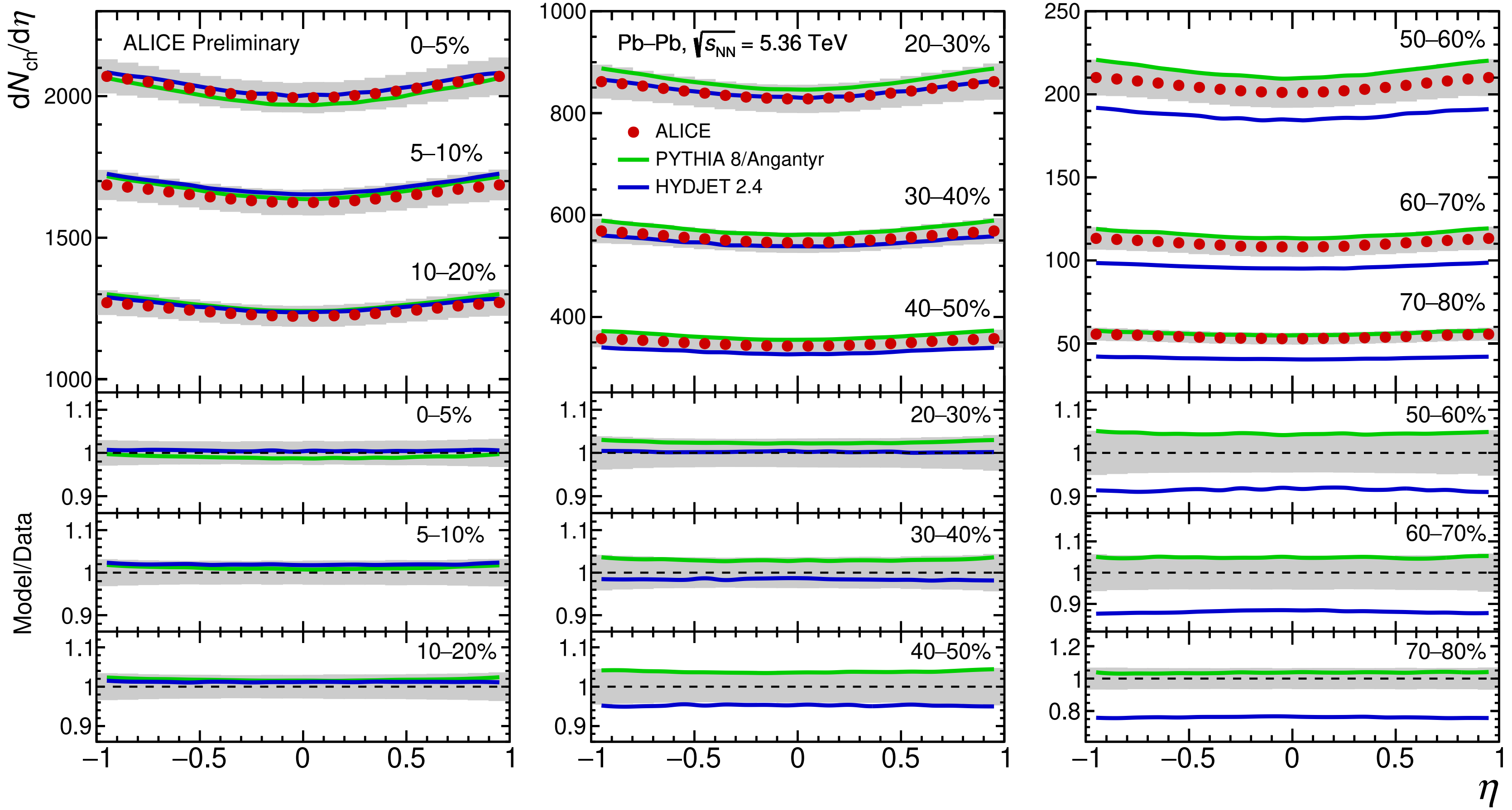
❑ $2/\langle N_{\mathrm{part}}\rangle \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ vs $\langle N_{\mathrm{part}}\rangle$



- ➢ New $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ vs $\langle N_{\mathrm{part}}\rangle$ at 5.36 TeV
  - ✓ Slightly higher than one at 5.02 TeV as expected
- ➢ $2/\langle N_{\mathrm{part}}\rangle \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ decreases
  - ✓ From $\sim$10 for the most central
  - ✓ To $\sim$6 for the most peripheral

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in Pb−Pb collisions

❑ Model comparison for $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$

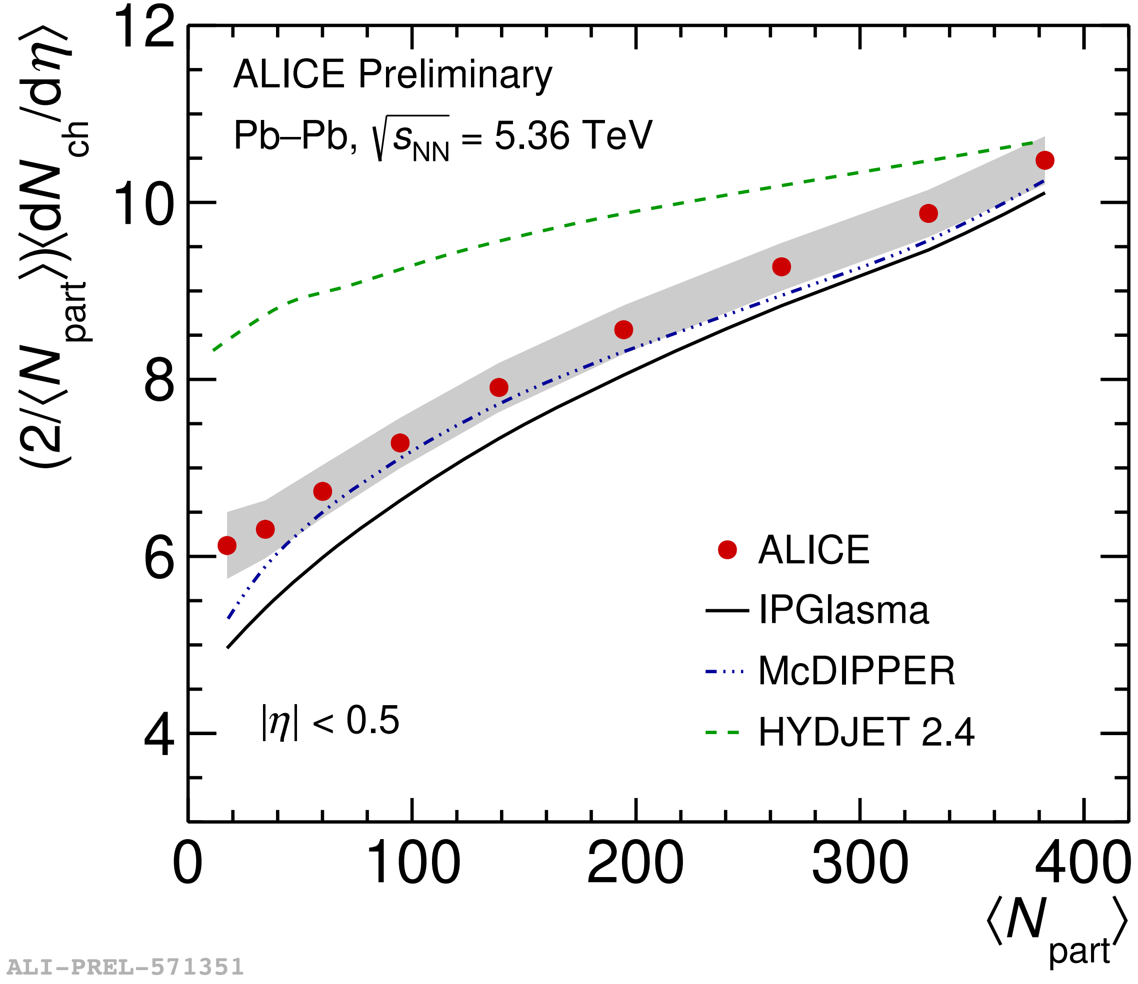


ALI-PREL-571341

- ➢ PYTHIA Angantyr: Extension of the PYTHIA, incorporating heavy-ion collisions
- ➢ HYDJET: Full evolution of heavy-ion collisions (jet interaction, QGP, hadronic phase)
- ➢ PYTHIA8 describes $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distributions well than HYDJET

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ in Pb−Pb collisions

❑ Model comparison for $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ vs $\langle N_{\mathrm{part}} \rangle$



- **IP Glasma**: Focusing on initial gluon field configuration and the early-time dynamics before thermalization
- **McDIPPER**: Saturation based model for the initial condition, then 3+1d medium evolution performed
- **IP Glasma** and **McDiPPER** underestimates the data slightly
- **HYDJET** overshooting much for lower $\langle N_{\mathrm{part}} \rangle$

Summary

- Charged-particle multiplicity density ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$) study
  - With a new experimental setup of ALICE
  - Validation of detector performance
- pp collisions at $\sqrt{s} = 13.6$ TeV
  - New minimum-bias result confirming RUN 3 detector's performance
  - Multiplicity-dependent results enable system-size dependent study for other observables
- Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV
  - Good agreement with the CMS preliminary results
  - $2/\langle N_{\mathrm{part}}\rangle \langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle$ vs $\sqrt{s_{\mathrm{NN}}}$ for the top 5% centrality in agreement with the previous AA power-law trend