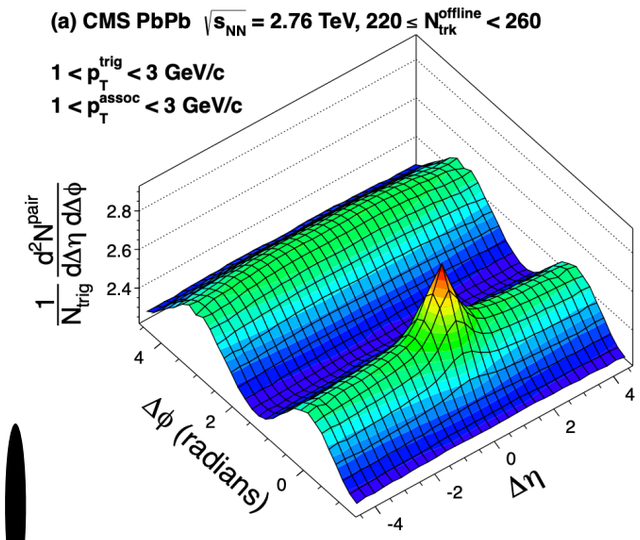
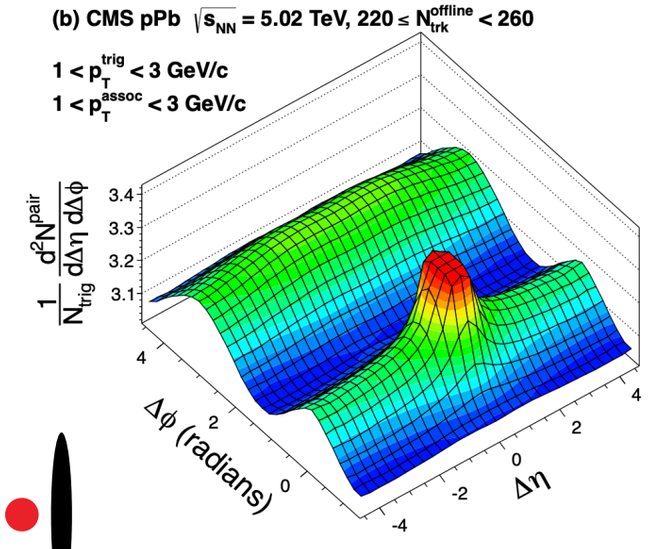
Probing particle production and transport in small collision systems with ALICE

Lucia Anna Tarasovičová
On behalf of ALICE Collaboration
Pavol Jozef Šafárik University, Košice
WPCF, 07.11.2023

From large to small systems



Phys. Lett. B 724 (2013) 213



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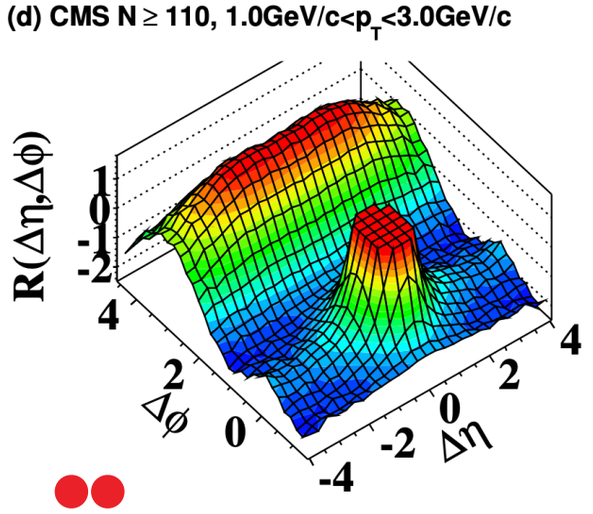
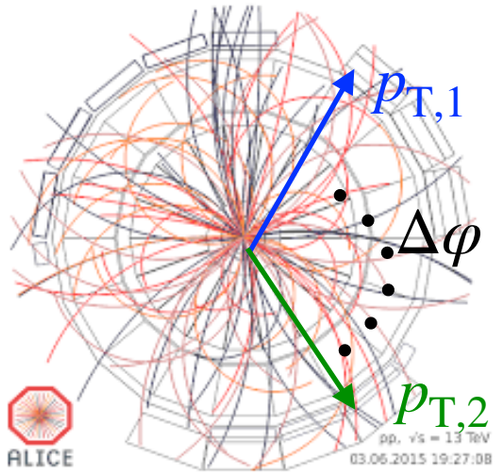


JHEP 1009:091,2010

- In Pb—Pb collisions
  - long-range ridge as manifestation of QGP anisotropic collective expansion
- Ridge visible also in p—Pb and pp collisions
  - origin?

Normalised two-particle cumulant

Soft particles $p_{\mathrm{T}} < 2$ GeV/c



Like sign pairs (+ +) (- -)

Unlike sign pairs (+ -)

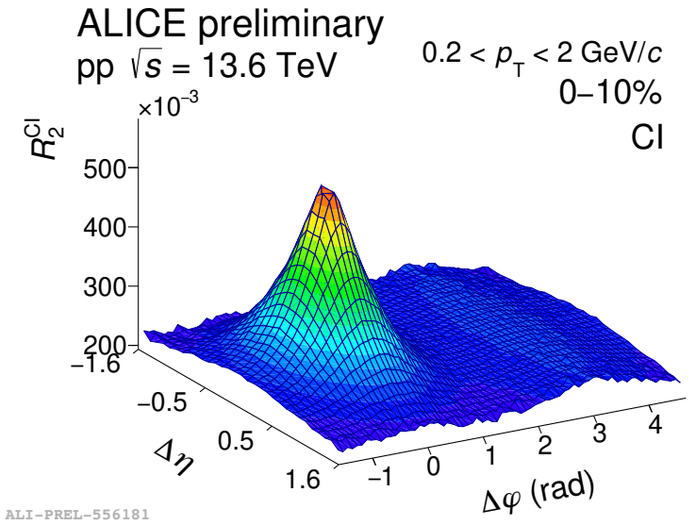
$$R_2^{\alpha\beta} = \frac{\rho_2^{\alpha\beta}}{\rho_1^{\alpha}\rho_1^{\beta}} - 1 \qquad \rho_2 = \frac{\mathrm{d}^2N}{\mathrm{d}\Delta\varphi\mathrm{d}\Delta\eta} \qquad \rho_1 = \frac{\mathrm{d}^2N}{\mathrm{d}\varphi\mathrm{d}\eta}$$

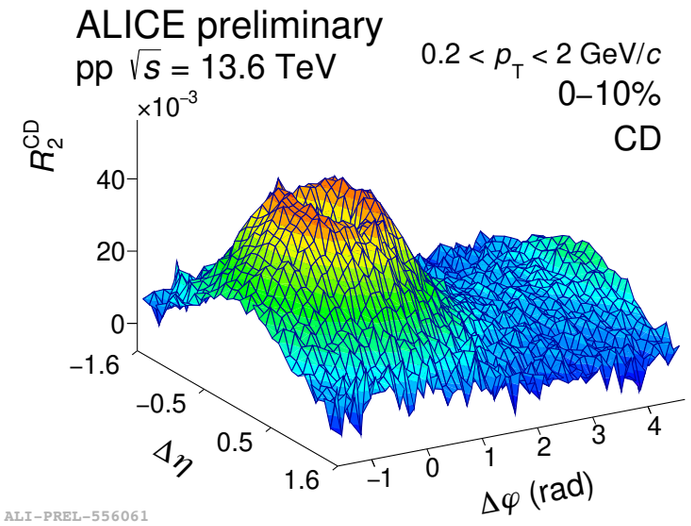
- Charge independent (CI):
  - sensitive to collective behaviour

$$R_2^{CI} = \frac{1}{2}(R_2^{US} + R_2^{LS})$$

- Charge dependent (CD):
  - influenced by charge conservation

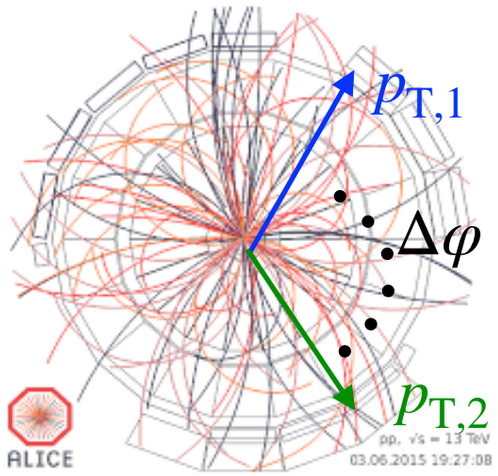
$$R_2^{CD} = \frac{1}{2}(R_2^{US} - R_2^{LS})$$





Balance function

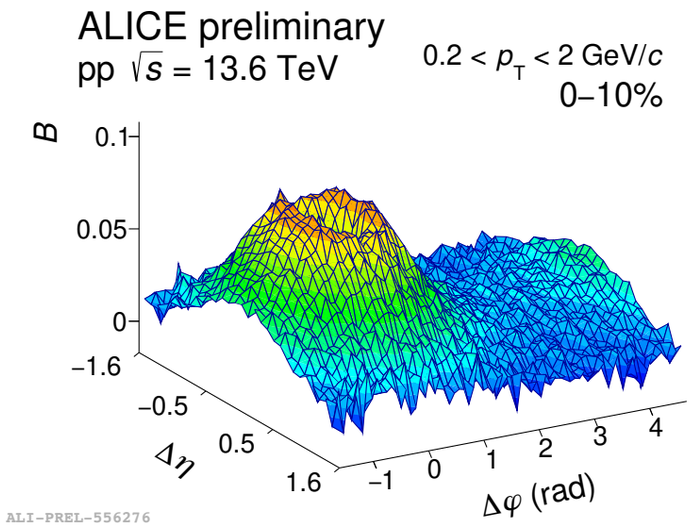
Soft particles $p_{\mathrm{T}} < 2$ GeV/c

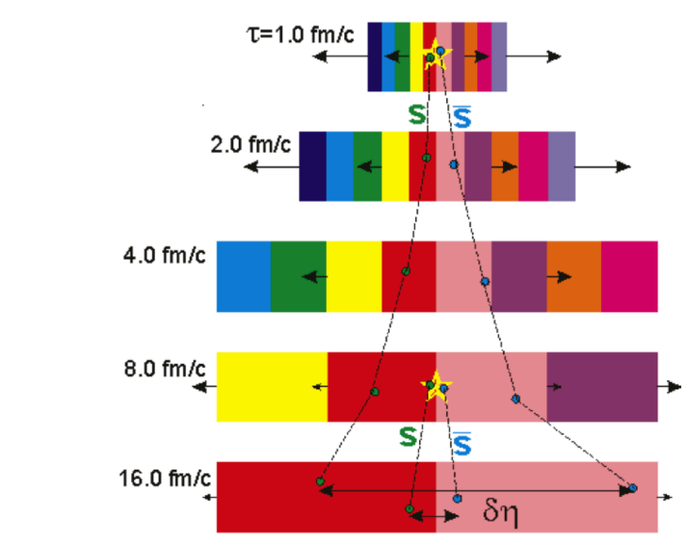


Like sign pairs (+ +) (- -)

Unlike sign pairs (+ -)

- Measure of balancing charges
- Giving insight on charged-particle production and transportation mechanisms
- Sensitive to:
  - delayed hadronisation
  - two-states quark production
  - diffusivity of light quarks
  - charge susceptibility of QGP

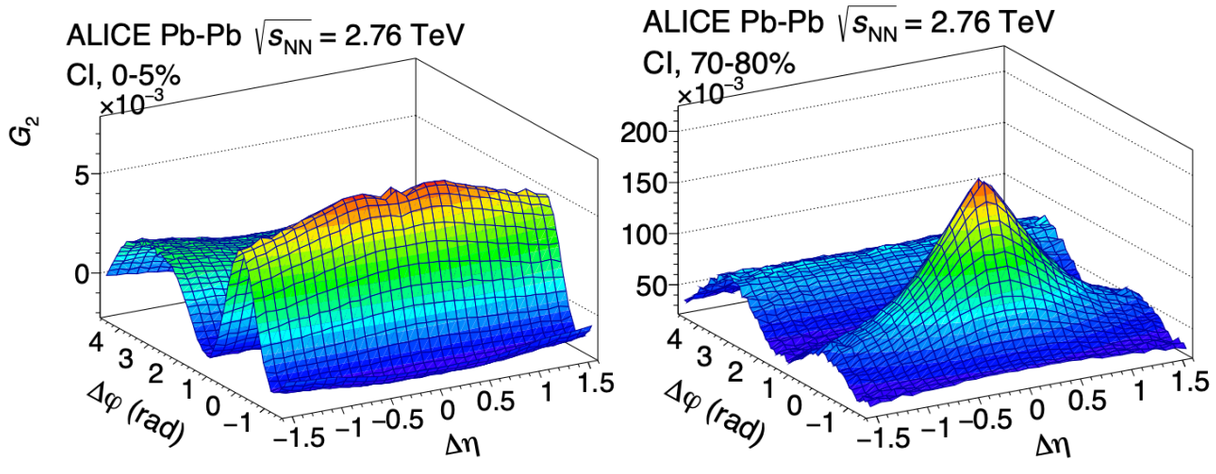




$$B^{\alpha\beta} = \frac{1}{2}\left\{ \rho_1^{\beta^-} \left[R_2^{\alpha^+\beta^-} - R_2^{\alpha^-\beta^-} \right] + \rho_1^{\beta^+} \left[R_2^{\alpha^-\beta^+} - R_2^{\alpha^+\beta^+} \right] \right\}$$

Correlations in Pb—Pb collisions

PLB 804 (2020) 135375



- Transverse momentum correlator

$$G_2 = \frac{1}{\langle p_{\mathrm{T},1}\rangle\langle p_{\mathrm{T},2}\rangle}\left[\frac{\int_\Omega p_{\mathrm{T},1}p_{\mathrm{T},2}\rho_2(p_1,p_2)\mathrm{d}p_{\mathrm{T},1}\mathrm{d}p_{\mathrm{T},2}}{\int_\Omega \rho_1(p_1)\mathrm{d}p_{\mathrm{T},1}\int_\Omega \rho_2(\mathrm{p}_2)\mathrm{d}p_{\mathrm{T},2}} - \langle p_{\mathrm{T},1}\rangle\langle p_{\mathrm{T},2}\rangle\right]$$

- Sensitive to:
  - momentum current correlations
  - specific shear viscosity, η/s

Correlations in Pb—Pb collisions

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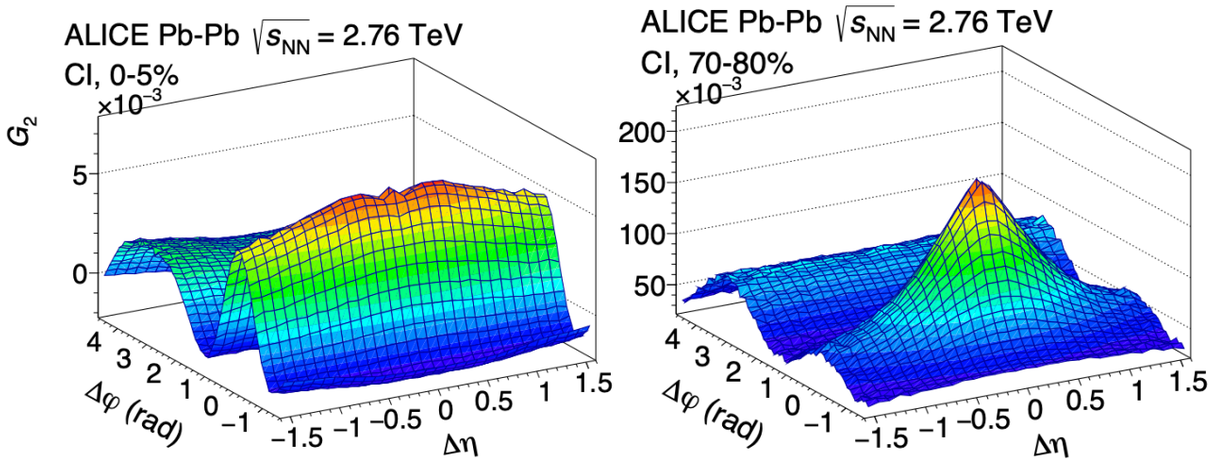
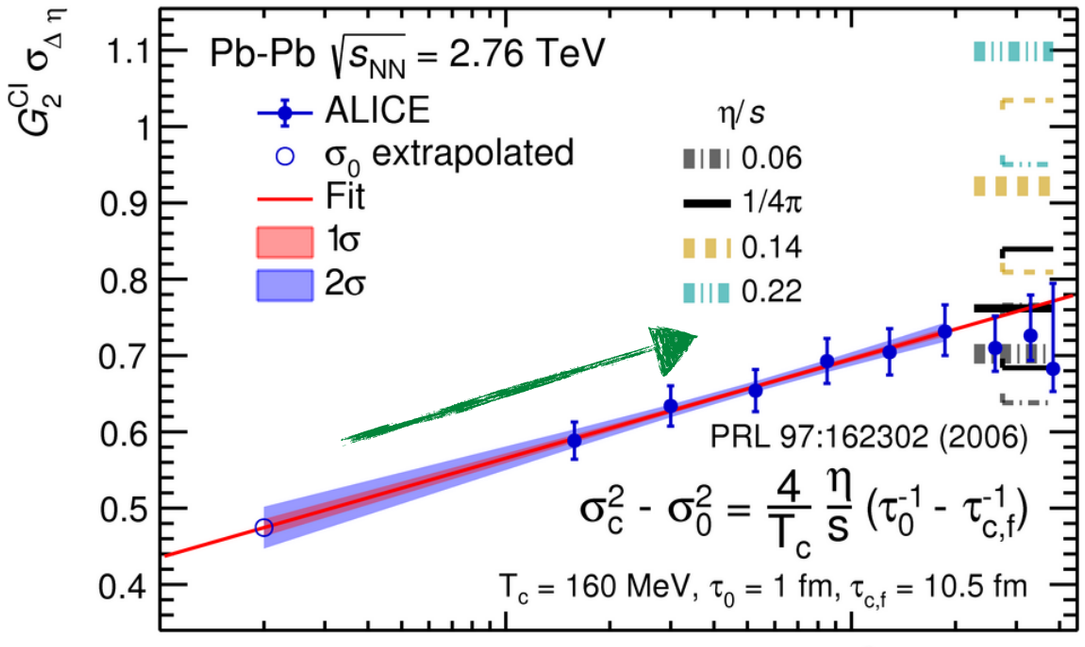




- Transverse momentum correlator

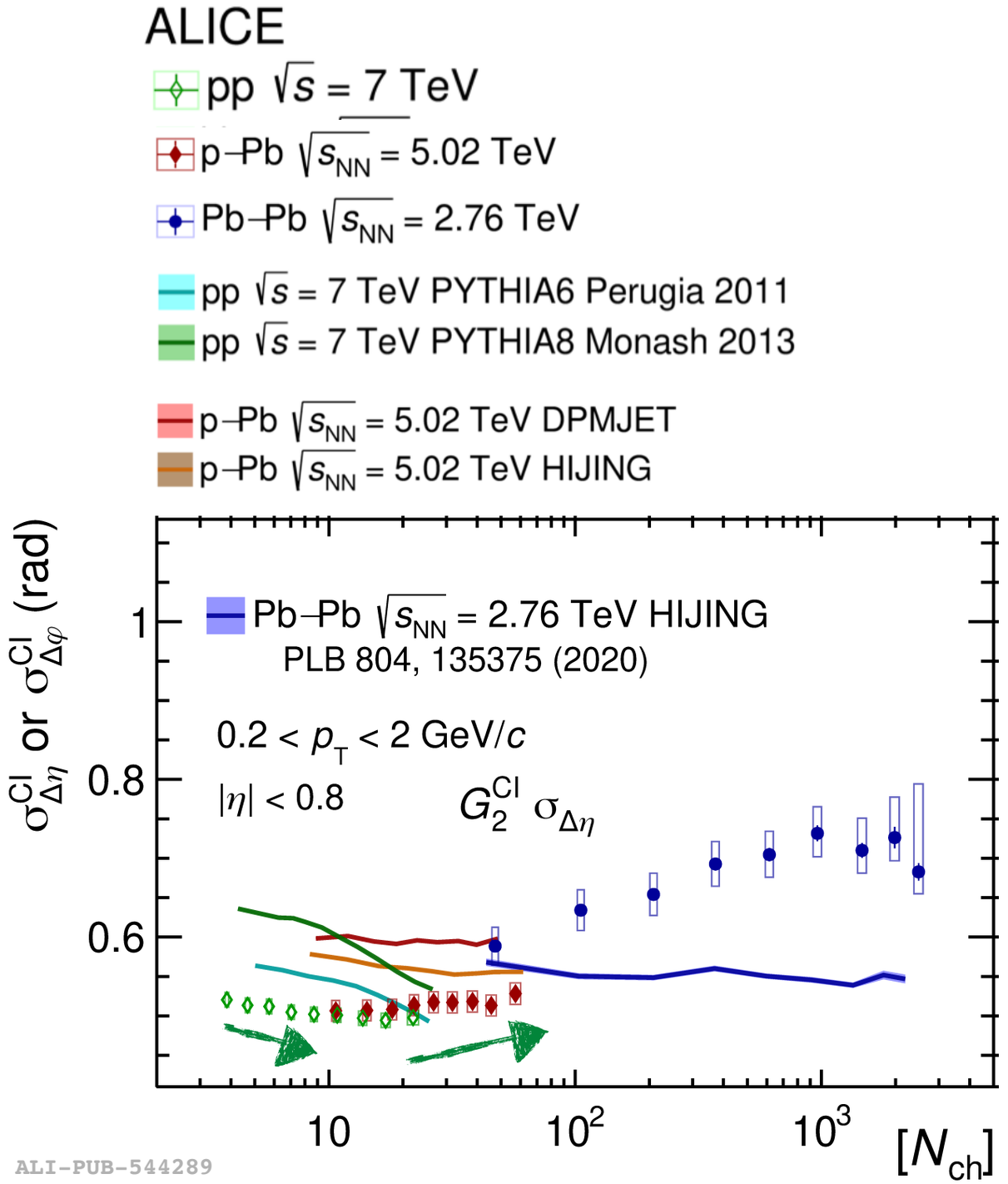
$$G_2 = \frac{1}{\langle p_{T,1}\rangle\langle p_{T,2}\rangle}\left[\frac{\int_\Omega p_{T,1}p_{T,2}\rho_2(p_1,p_2)dp_{T,1}dp_{T,2}}{\int_\Omega \rho_1(p_1)dp_{T,1}\int_\Omega \rho_2(p_2)dp_{T,2}} - \langle p_{T,1}\rangle\langle p_{T,2}\rangle\right]$$

- Sensitive to:
  - momentum current correlations
  - specific shear viscosity, η/s
- Observations:
  - longitudinal **broadening** of CI with centrality
  - **small values of η/s favoured** - close to the KSS limit $1/4\pi$

Phys.Rev.Lett. 94 (2005) 111601

System evolution

- Could reveal presence of viscous forces in small systems
- Observations:
  - longitudinal broadening with multiplicity in **Pb—Pb** collisions
  - **pp** - slight decrease, **p—Pb** slight increase
    - **too small for viscous forces to equilibrate the system?**



Phys. Rev. C 107 (2023) 054617

System evolution

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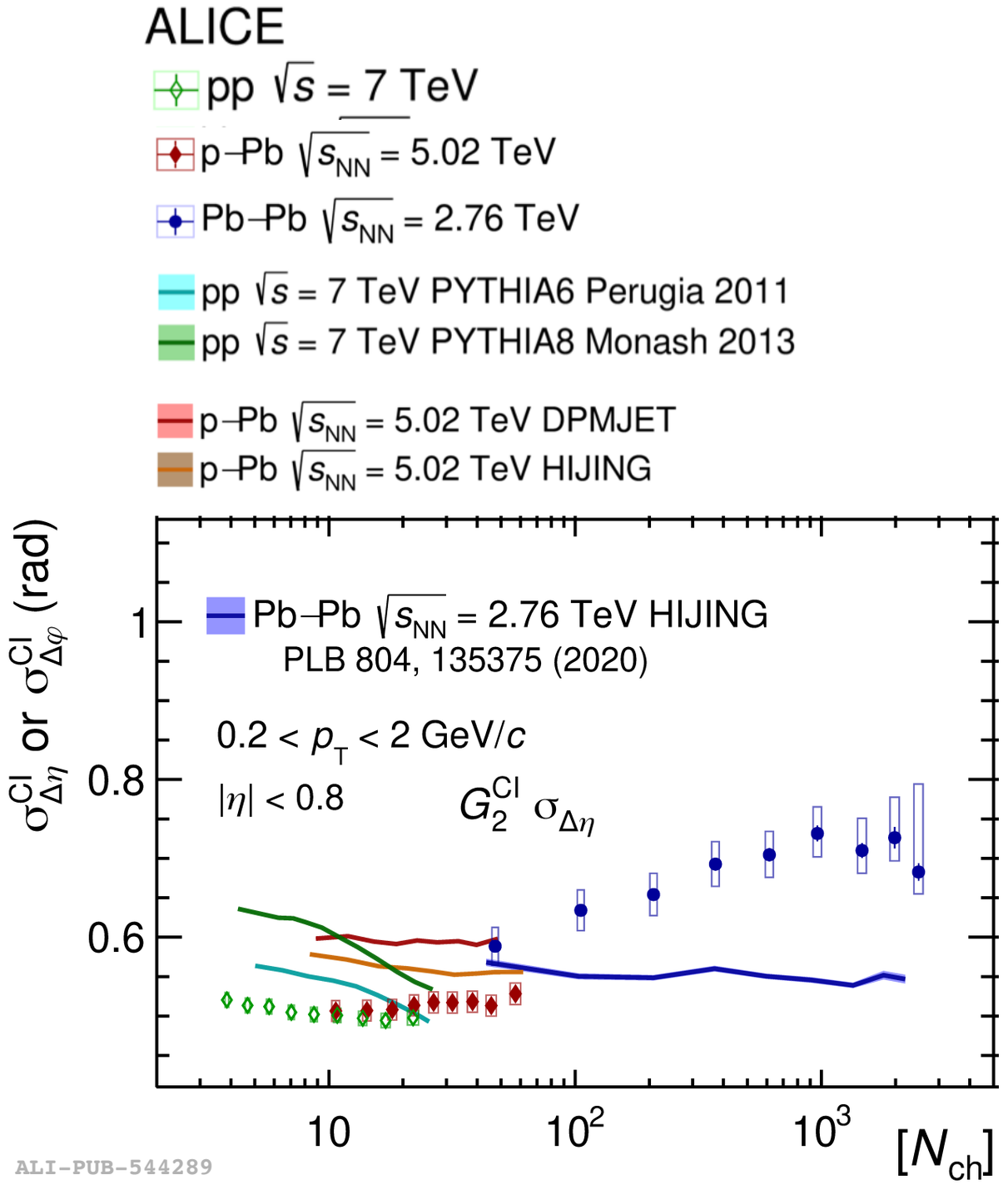
- Observations:
  - longitudinal broadening with multiplicity in **Pb—Pb** collisions
  - **pp** - slight decrease, **p—Pb** slight increase
    - **too small for viscous forces to equilibrate the system?**
  - models without collective effects do not describe data



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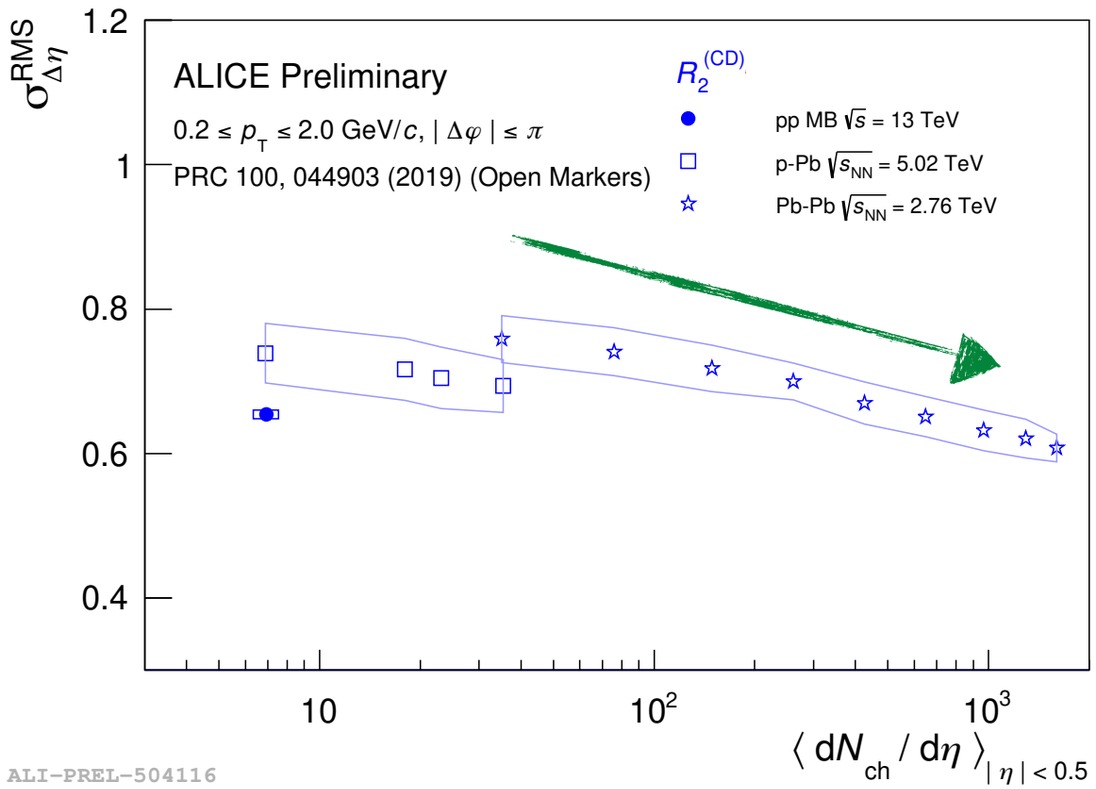
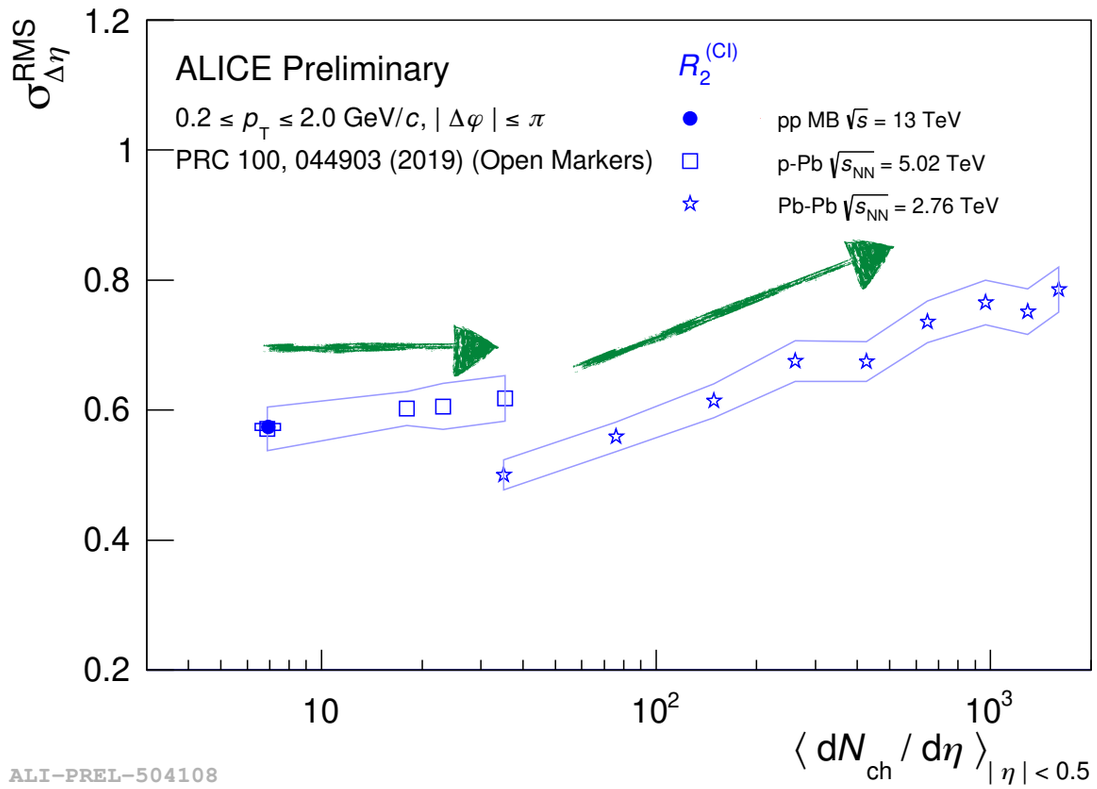
System evolution R_2

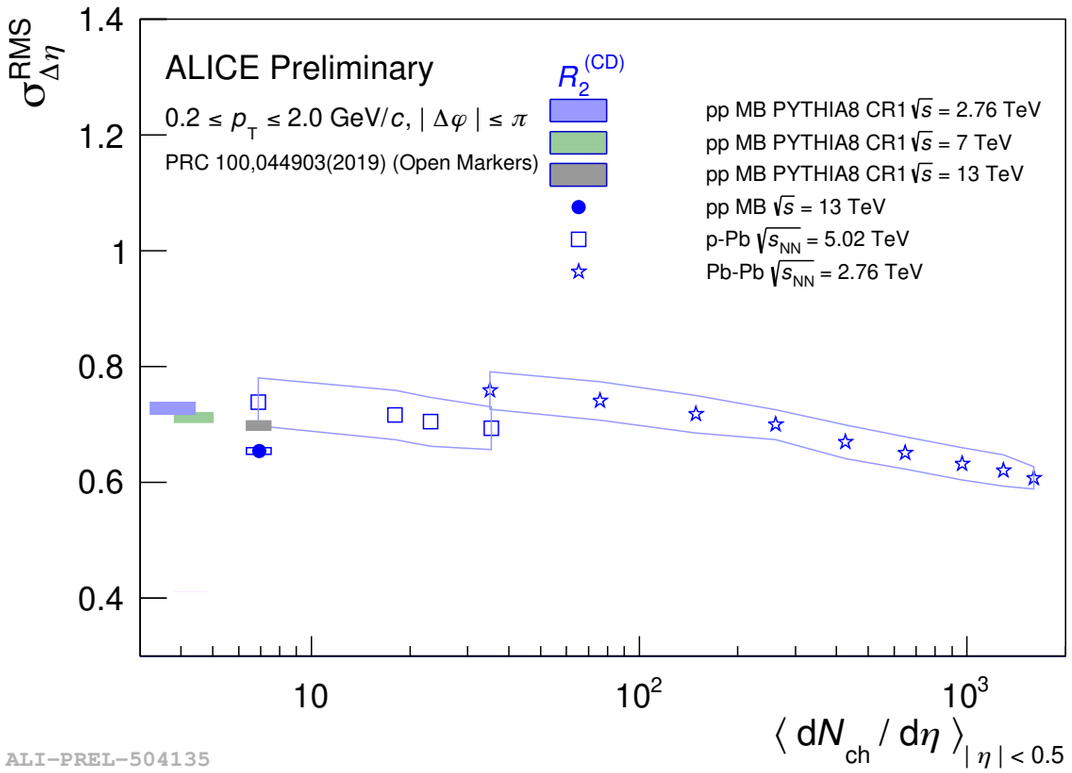


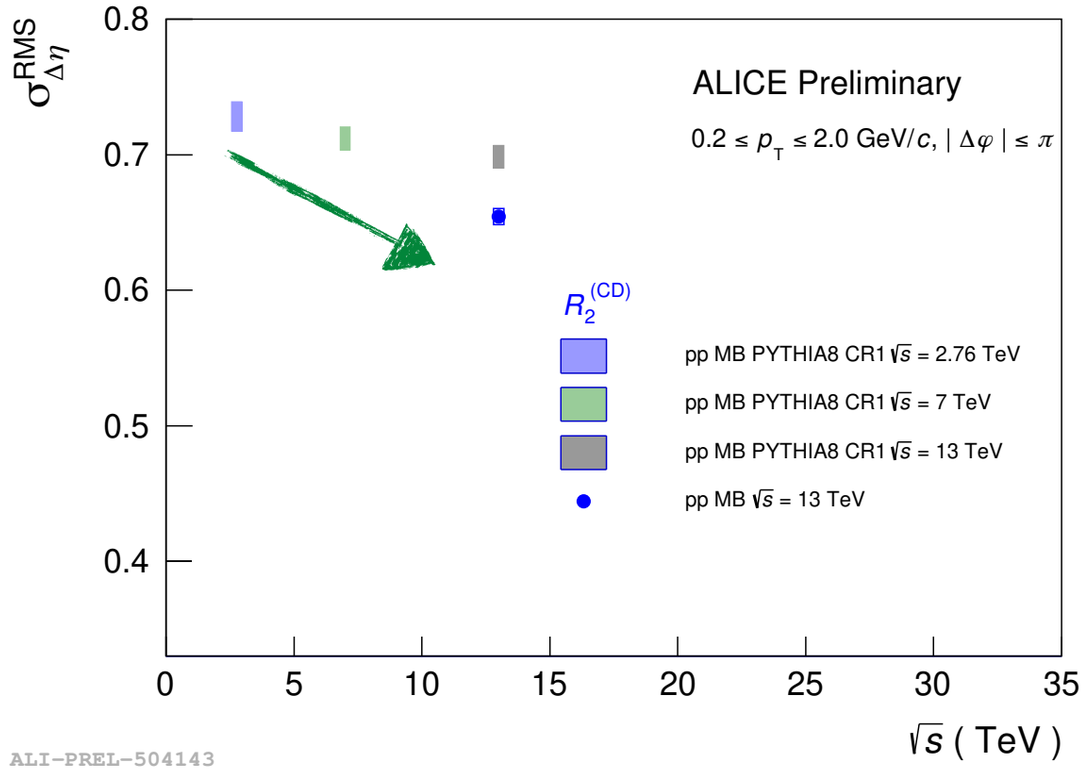


- CD sensitive to, radial flow, diffusion and pair creation processes
- **Narrowing** - presence of strong radial flow and two-stage emission
- pp result - significantly smaller:
  - slightly different extraction
  - collision energy

- CI measure of average correlation strength between all charged particles
- **Different dependencies** (Pb—Pb, p—Pb) - diffusion processes, more significant in longer-lived systems
- pp result consistent with p—Pb

Collision energy evolution R_2



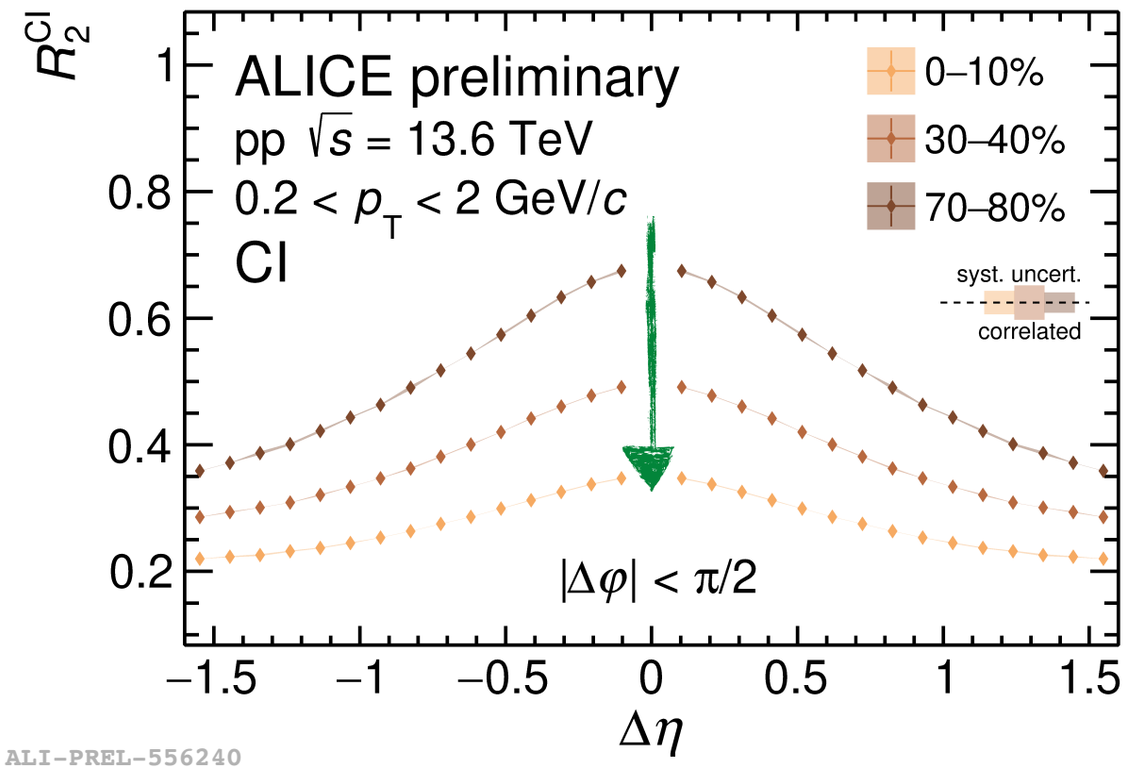


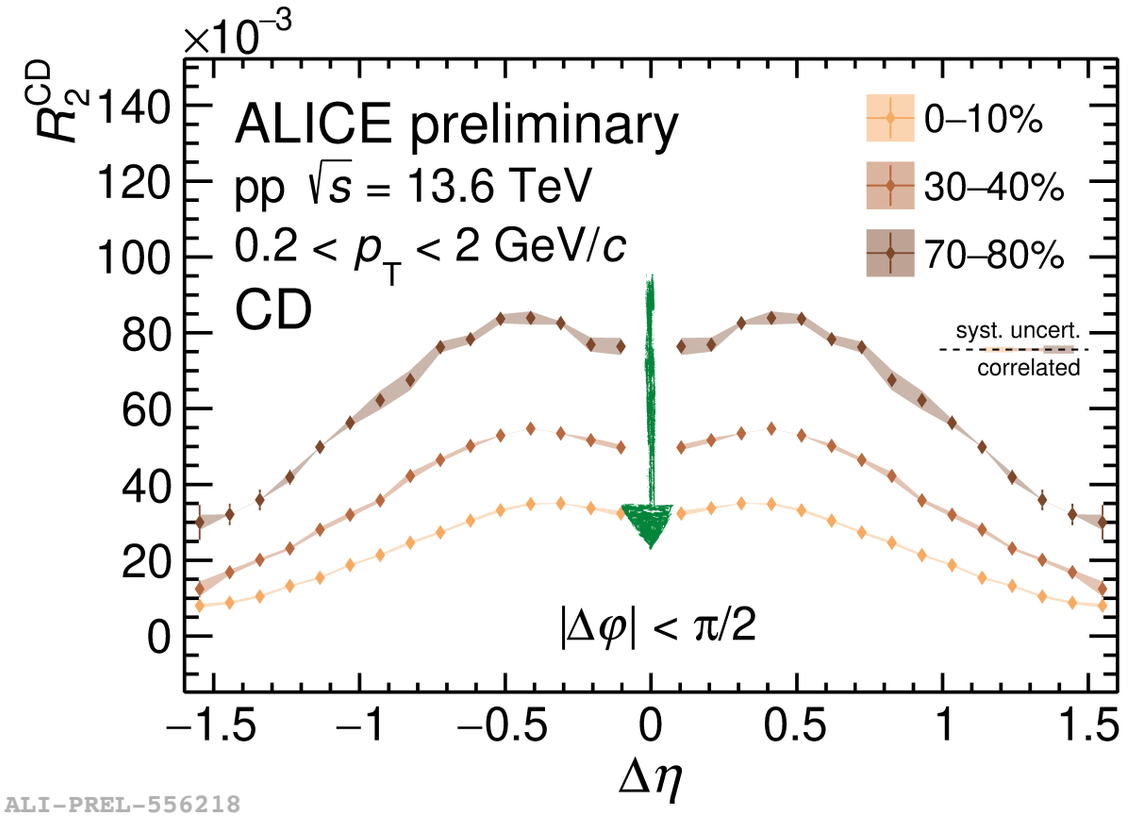
- pp result - significantly smaller:
  - slightly different extraction
  - collision energy

- PYTHIA study:
  - **decreasing** trend with collision energy

More differential study of pp collisions necessary!

R_2 at the top LHC energy

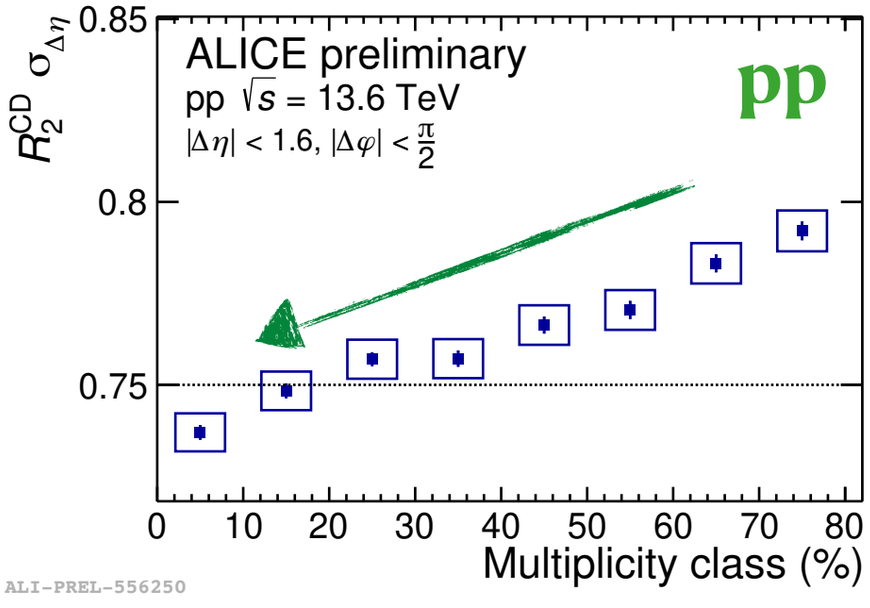


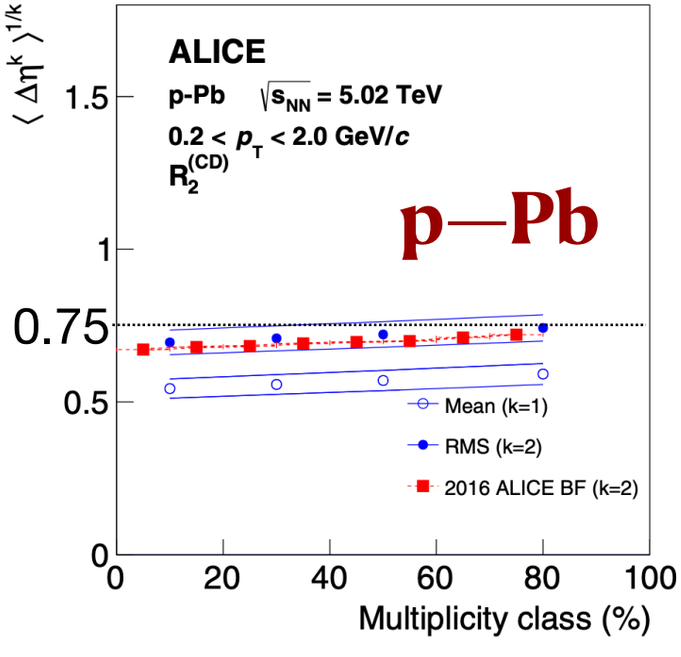


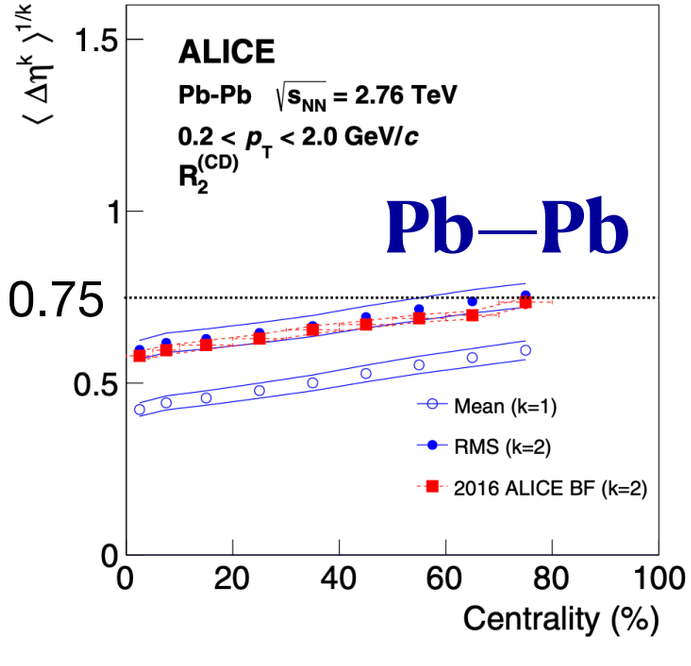
- Increase of statistics:
  - multiplicity differential study
  - smaller uncertainties

- **Decrease** of amplitude with increasing multiplicity:
  - based on the definition
  - scales as $1/\langle N \rangle$

R_2 - multiplicity evolution



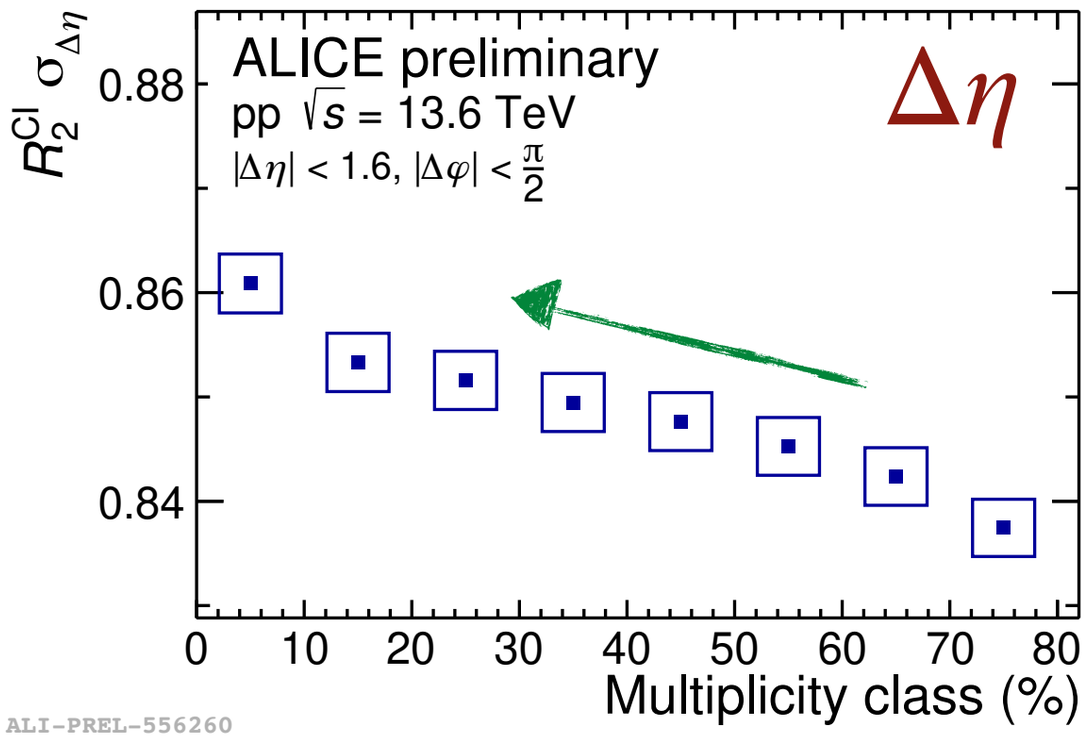


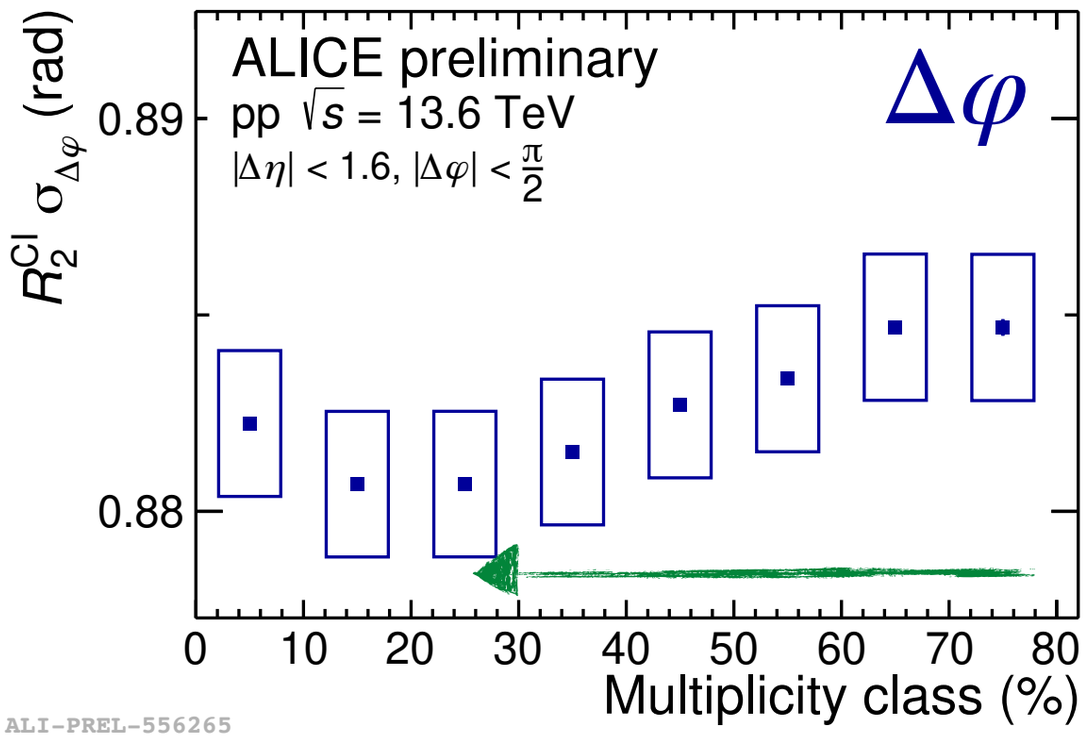


Phys. Rev. C 100, 044903 (2019)

- **Narrowing** also in pp collisions:
  - presence of radial flow in pp collisions, consistent with $\langle p_{\mathrm{T}} \rangle$ increase
  - values at the largest pp multiplicities **consistent** with low multiplicity p—Pb and peripheral Pb—Pb

R_2 - multiplicity evolution

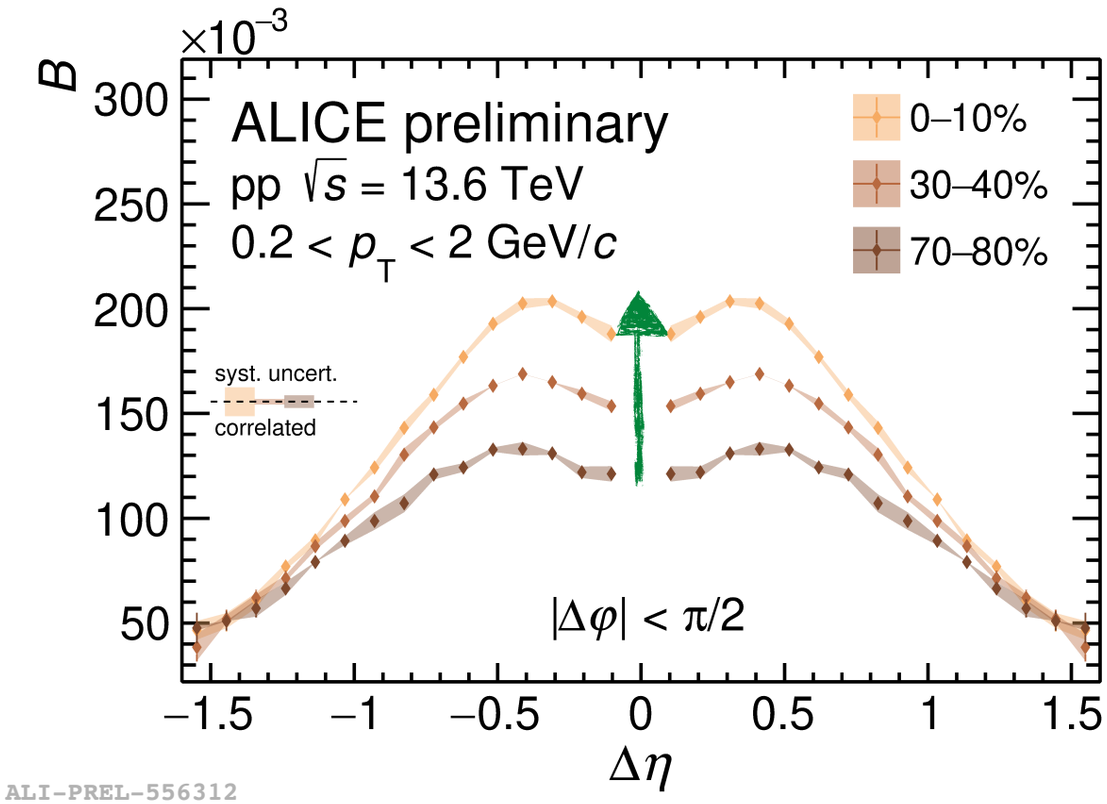


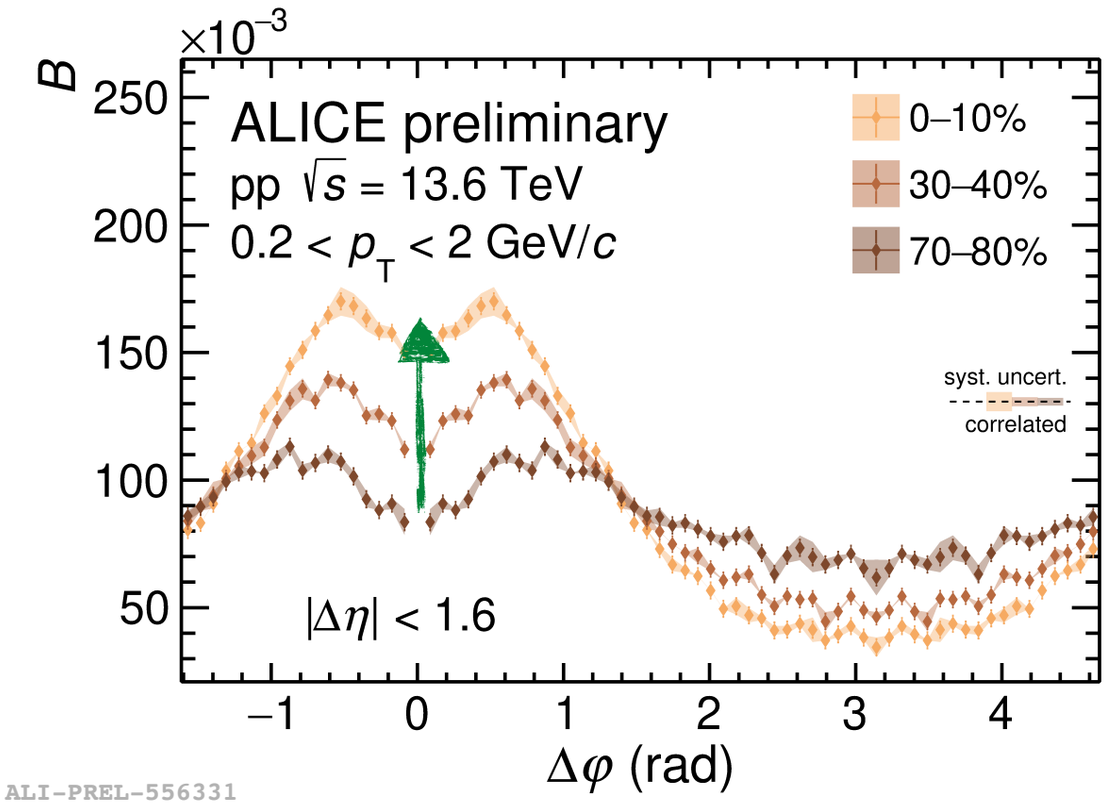


- **Broadening** in longitudinal direction:
  - in Pb—Pb connected with diffusion processes in QGP
- **Rather flat** in azimuthal direction:
  - in contrast to the diffusivity scenario

No clear explanation found yet!

BF at the top LHC energy

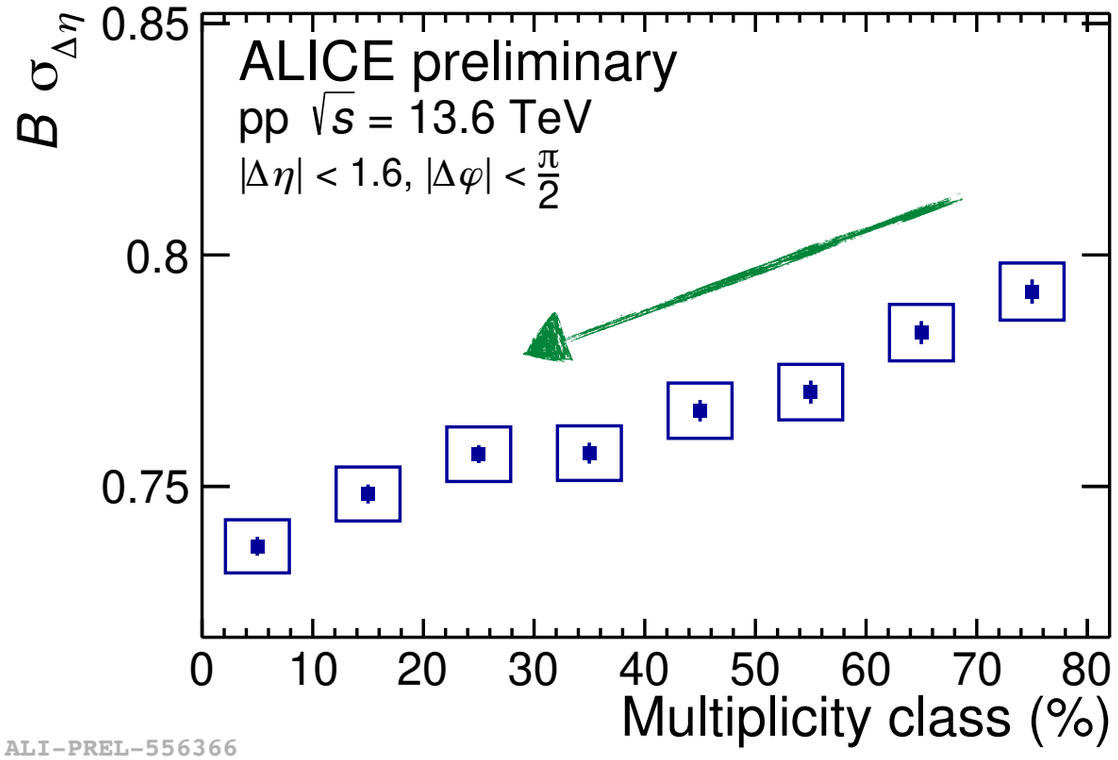


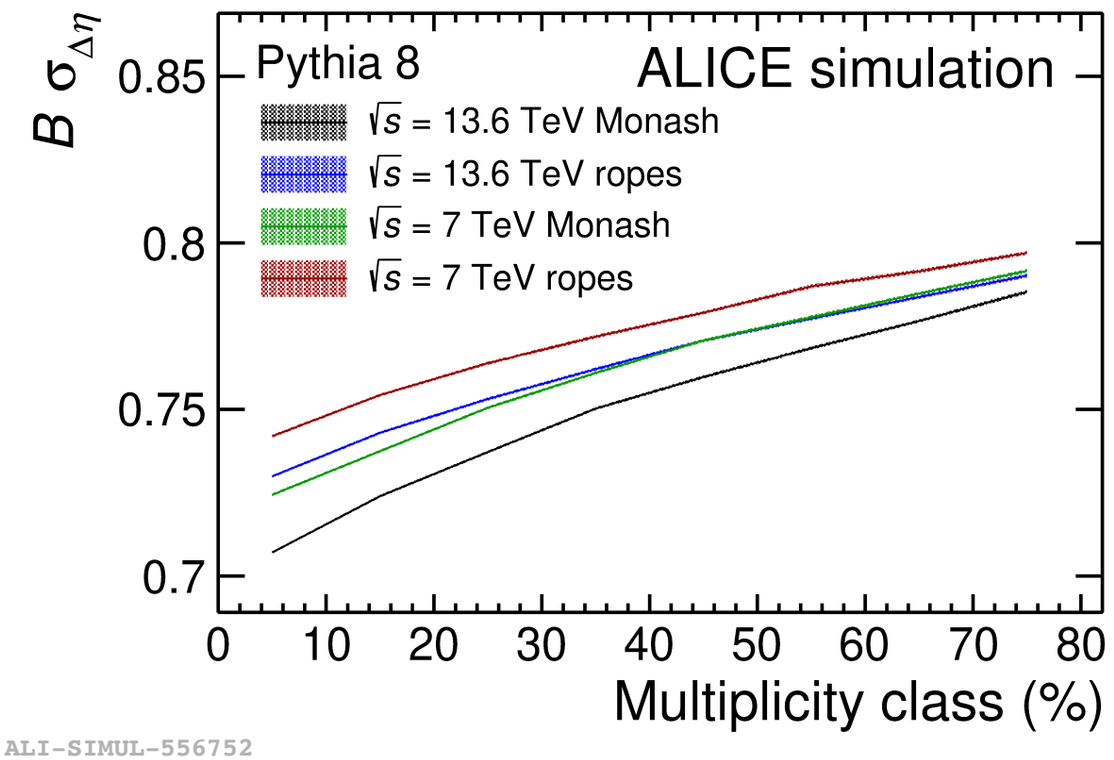


First time measurement at 13.6 TeV!

- **Increase** of amplitude with increasing multiplicity:
  - no dependence on $\langle N \rangle$
  - driven by balancing charges

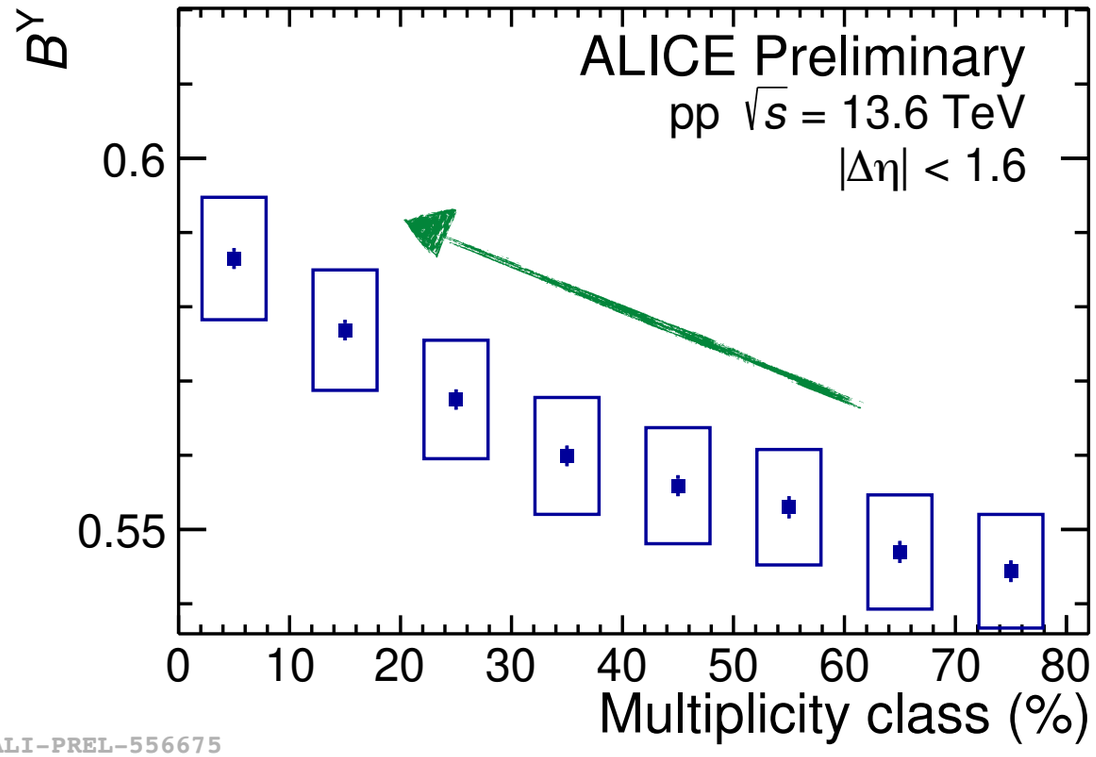
Balance Function - multiplicity evolution

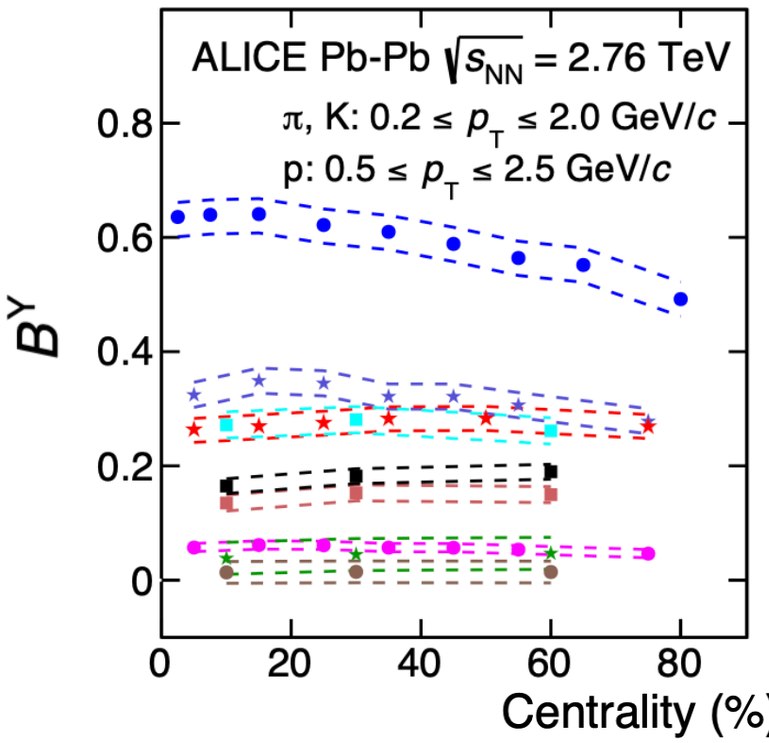




- **Narrowing** of the Balance Function:
  - consistent with the narrowing of R_2^{CD}
  - in Pb—Pb connected with radial flow and two-stage particle production
  - PYTHIA8 qualitatively reproduces the narrowing without collective effects

Integral of Balance Function





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- **Increase** of the Balance Function integral:
  - in higher multiplicities, higher probability of having balanced charges within the acceptance
  - in Pb—Pb, only pions increasing
  - models needed for more precise interpretation

Conclusions

- Correlation measurements - powerful tool to study collective effects in small systems
- First R_2 and Balance Function measurements at the top LHC energy
- Narrowing of the CD correlator in pp:
  - In agreement with peripheral p—Pb
  - Hint of presence of radial flow
- Narrowing of the BF in pp:
  - In Pb—Pb interpreted with two-stage particle production
  - In agreement with PYTHIA8 predictions
- More Run 3 data to come!

Thank you for your attention!

Questions