Recent soft-physics results in ALICE

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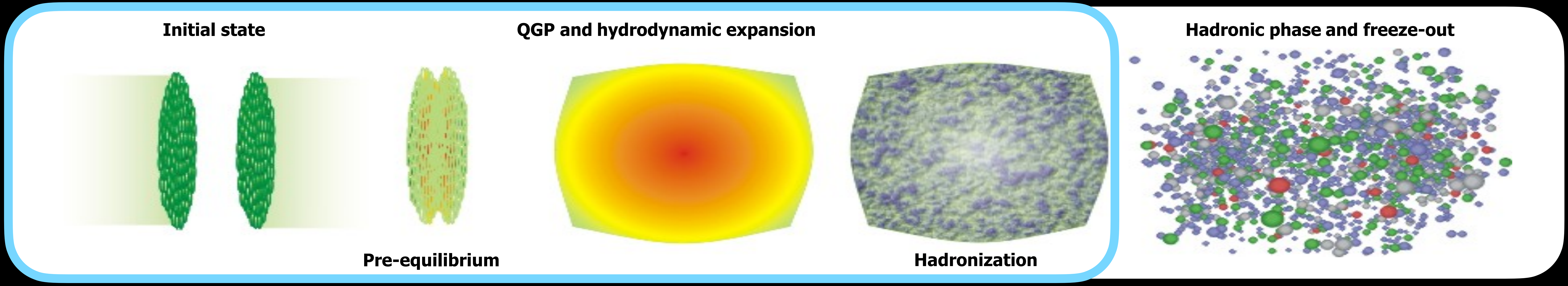
Lund University, Sweden

Lake Louise Winter Institute, 2022

ALICE

Relativistic Heavy-Ion Collisions

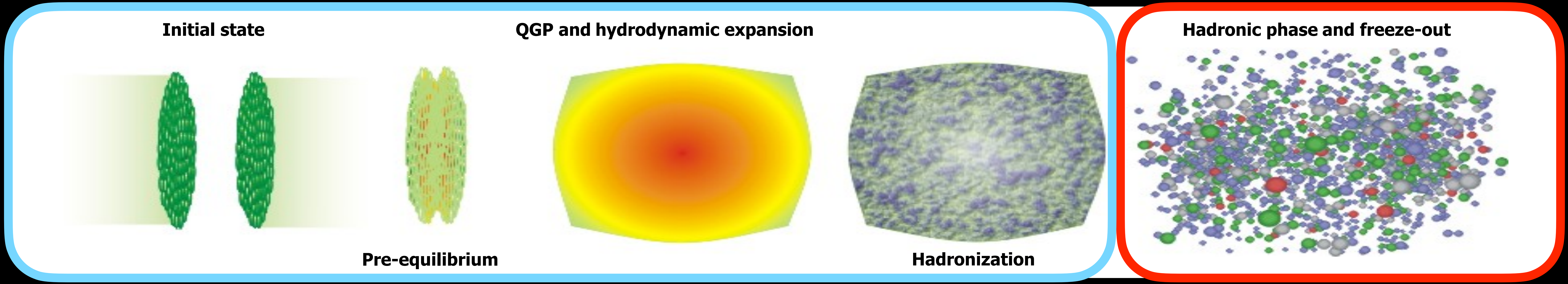
- Non-perturbative QCD processes lead to quark-gluon plasma (QGP) production, evolution, and hadronization, all in < 10^{-22} second



Relativistic Heavy-Ion Collisions

- Non-perturbative QCD processes lead to quark-gluon plasma (QGP) production, evolution, and hadronization, all in < 10^{-22} second
- Measurement: particles produced at the final stage of QGP evolution

⇛ Heavy-ion research: infer properties of initial state and QGP from measured particles

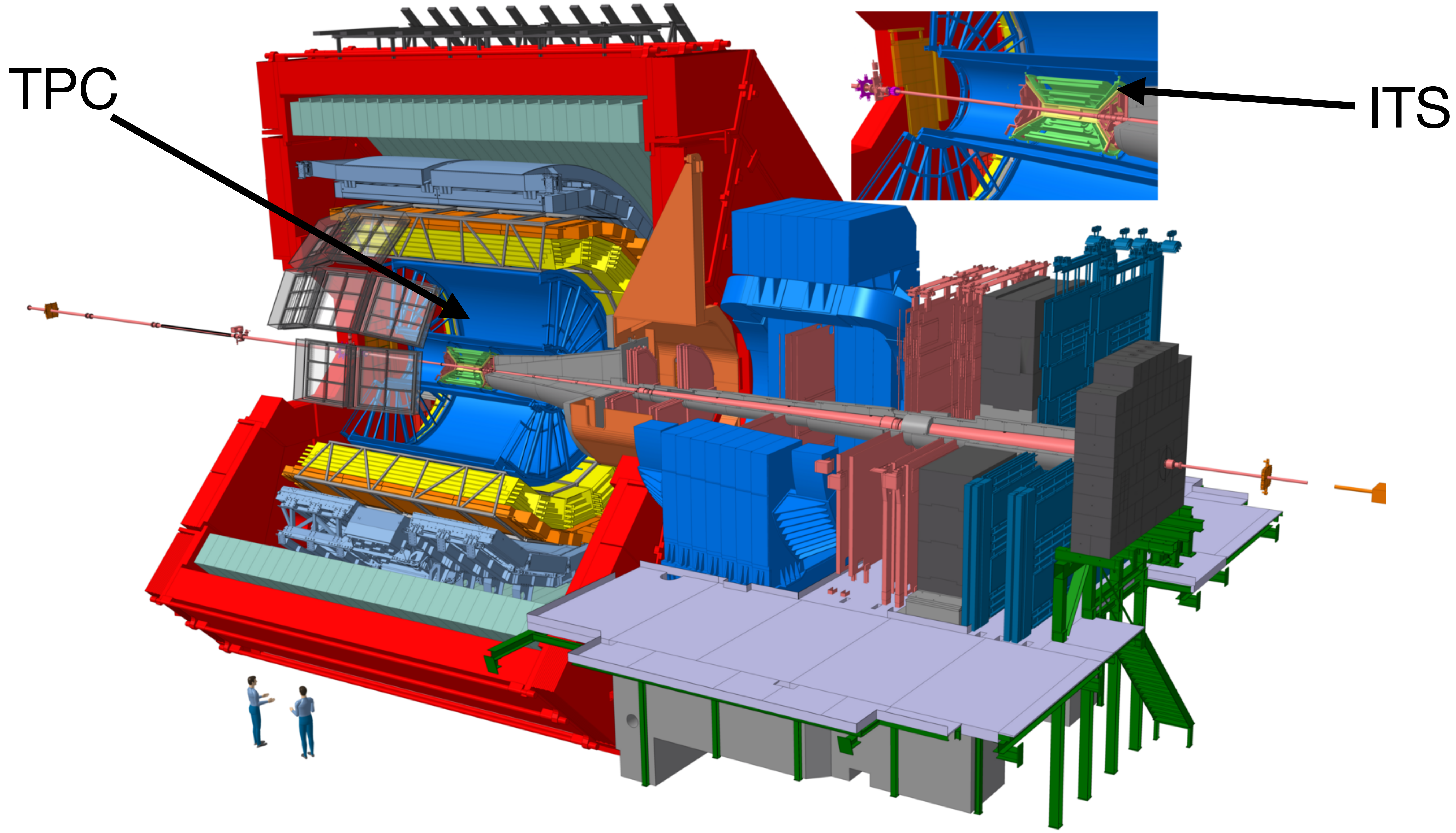


The ALICE detector

in Run 1 & 2

Run 1 & 2 ITS:
~ 10^7 channels

Run 1 & 2 TPC: MWPC readout
~1 kHz (Pb—Pb)

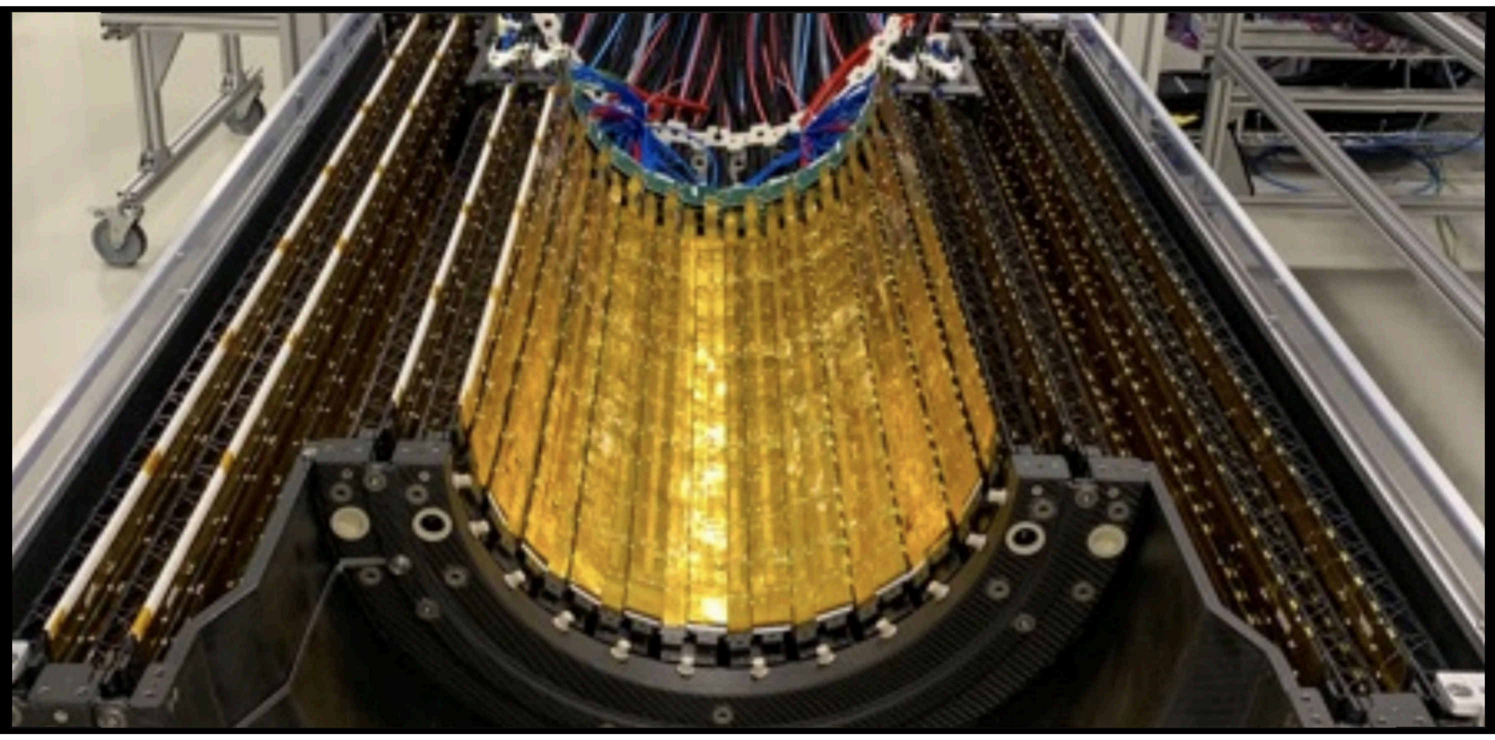


The ALICE detector

in Run 3

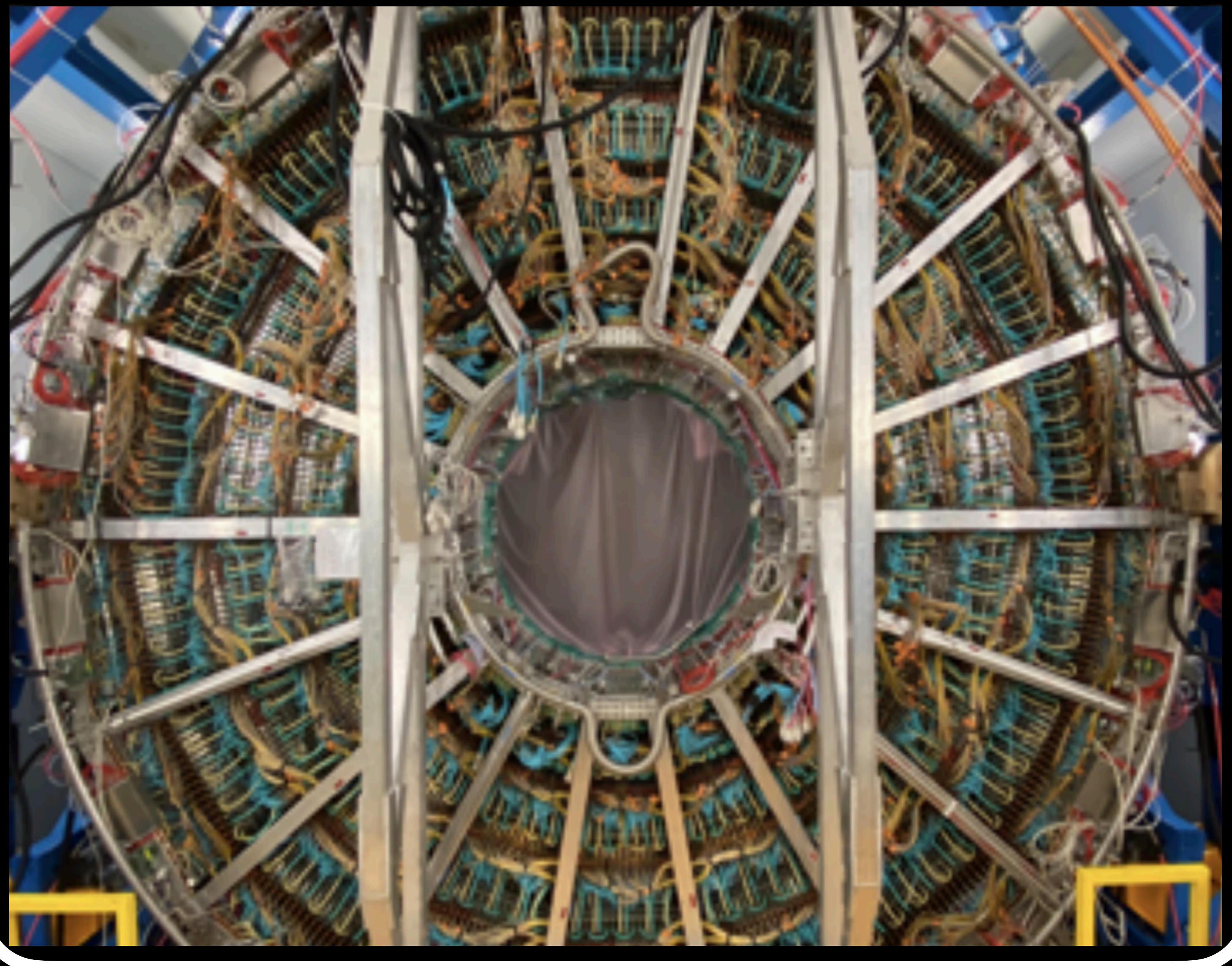
Run 1 & 2 ITS:
~ **10^7 channels**

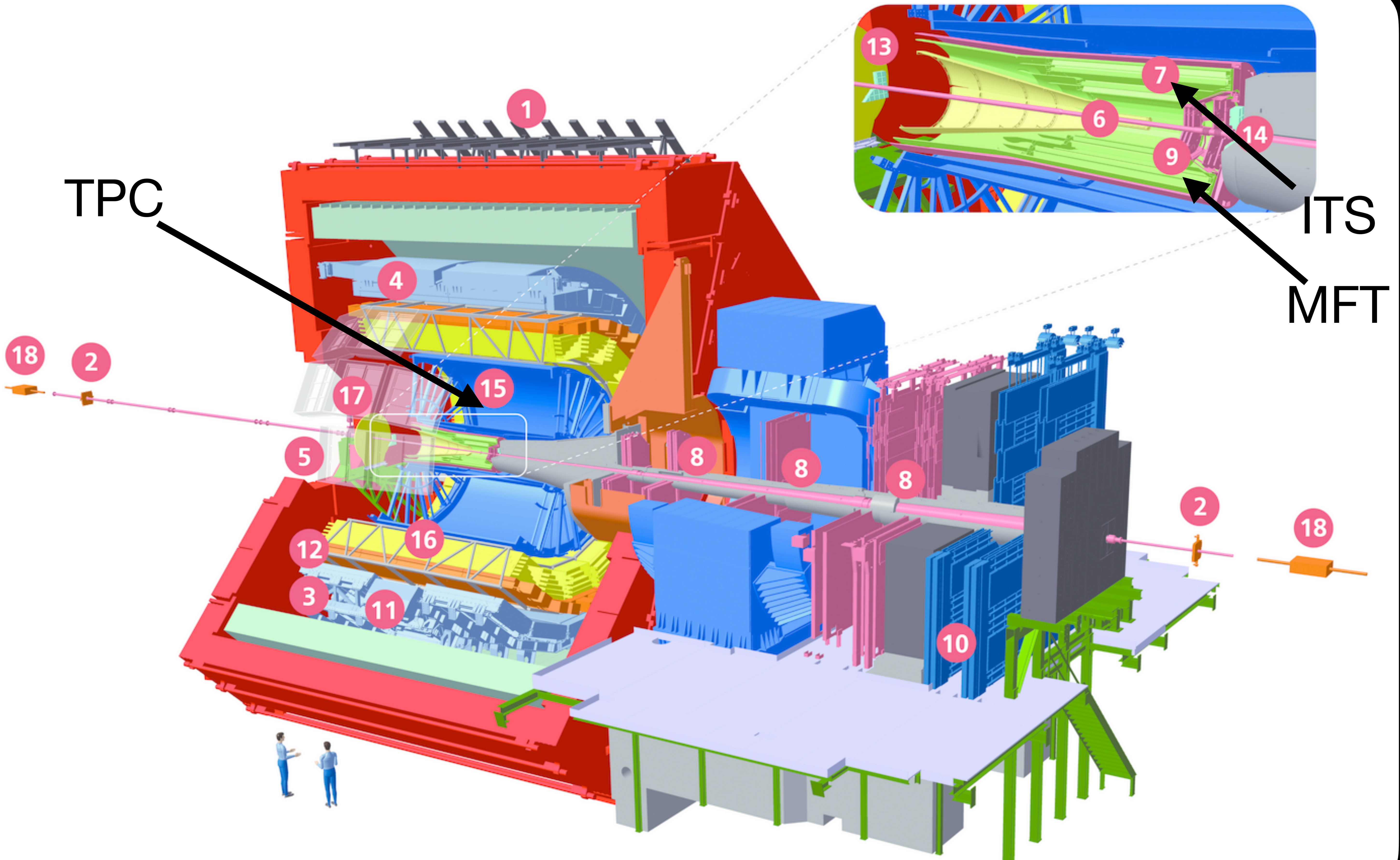
Run 3 ITS2 & MFT:
13×10^9 pixels



Run 1 & 2 TPC: MWPC readout
~1 kHz (Pb—Pb)

Run 3 TPC: GEM readout
~50 kHz (Pb—Pb)





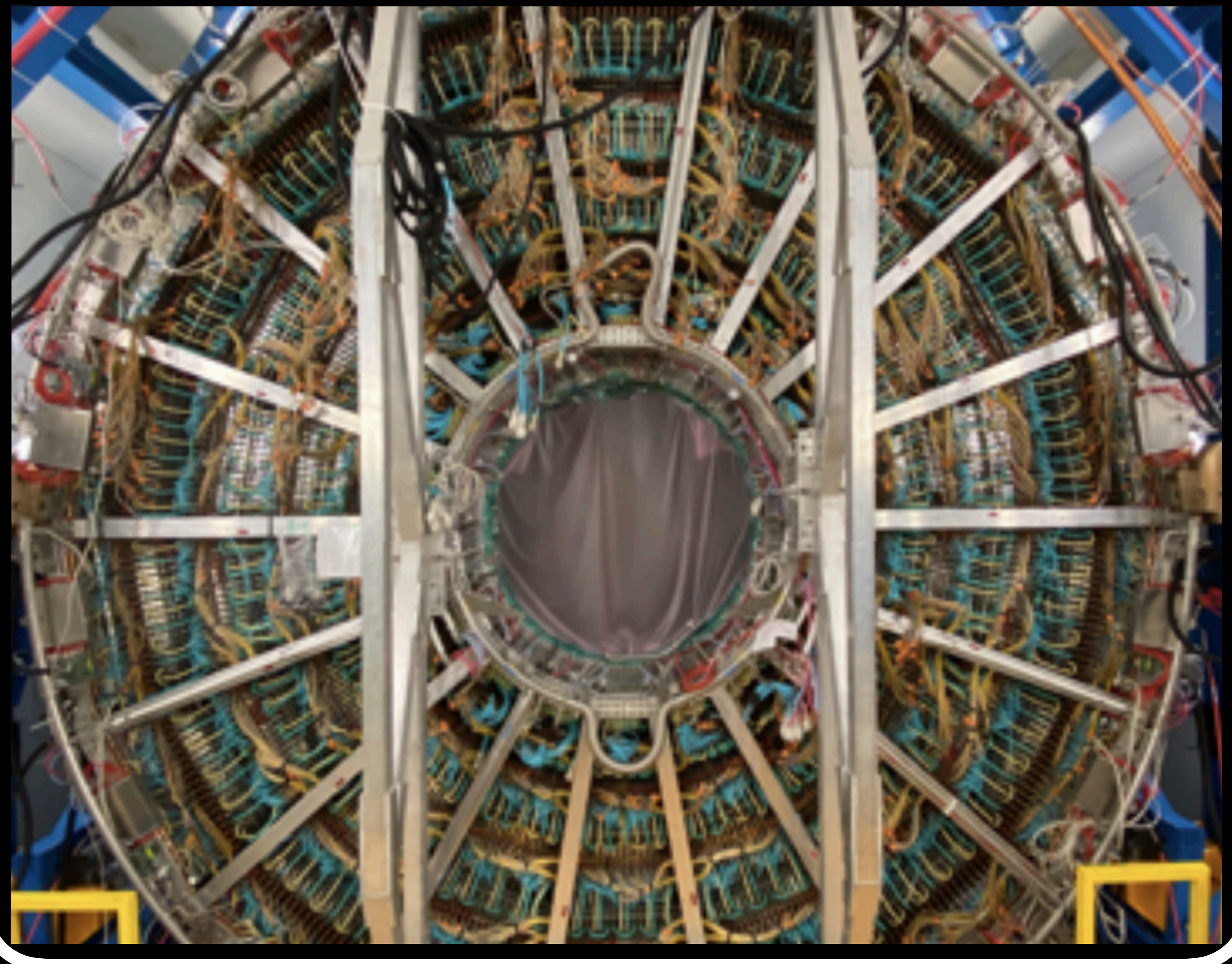
The ALICE detector

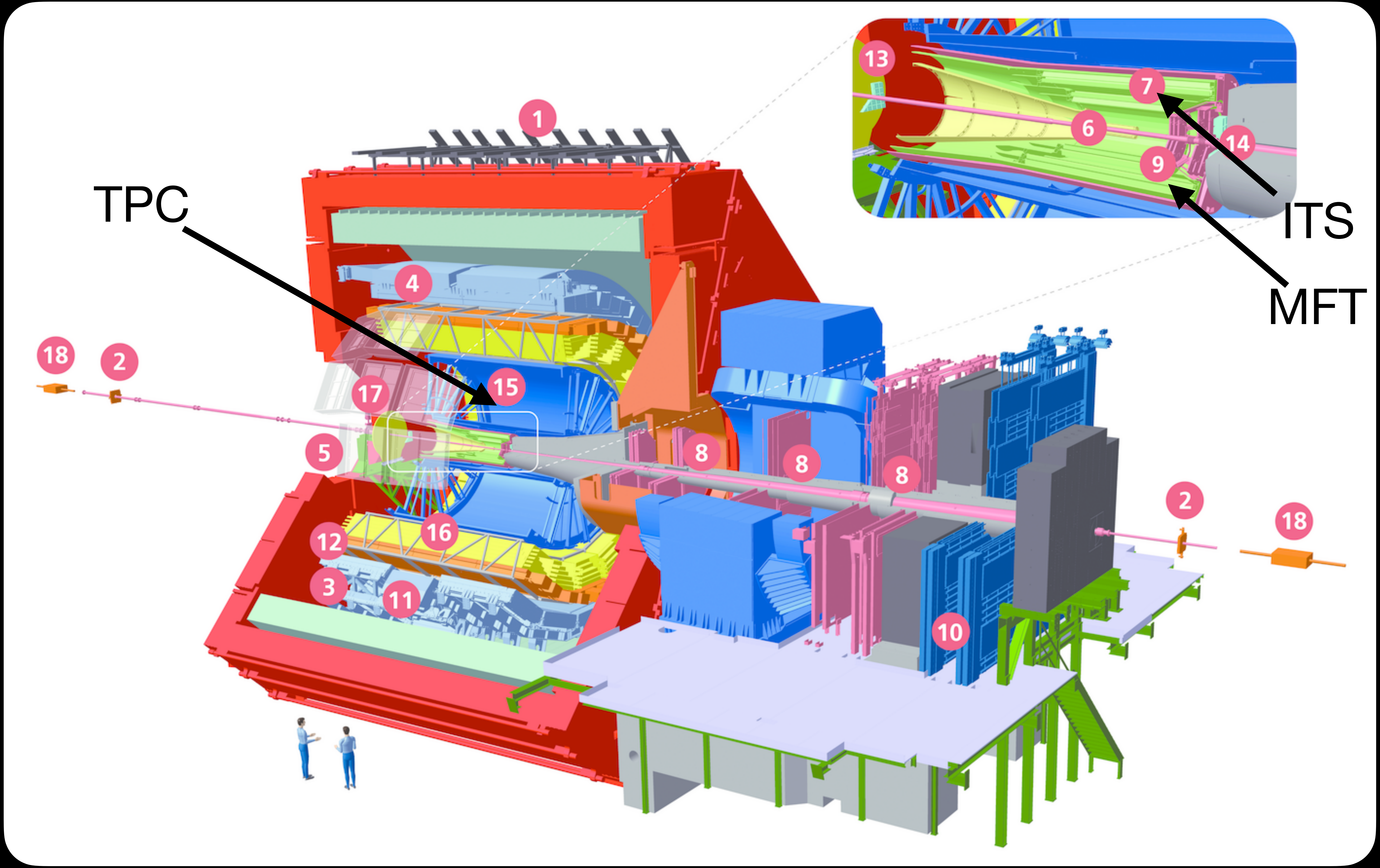
in Run 3

- New trigger detector (FIT)
- Readout upgrade in several detectors
  - Continuous readout
- Combined Online-Offline system (O^2)

Run 1 & 2 TPC: MWPC readout
~1 kHz (Pb—Pb)

Run 3 TPC: GEM readout
~50 kHz (Pb—Pb)



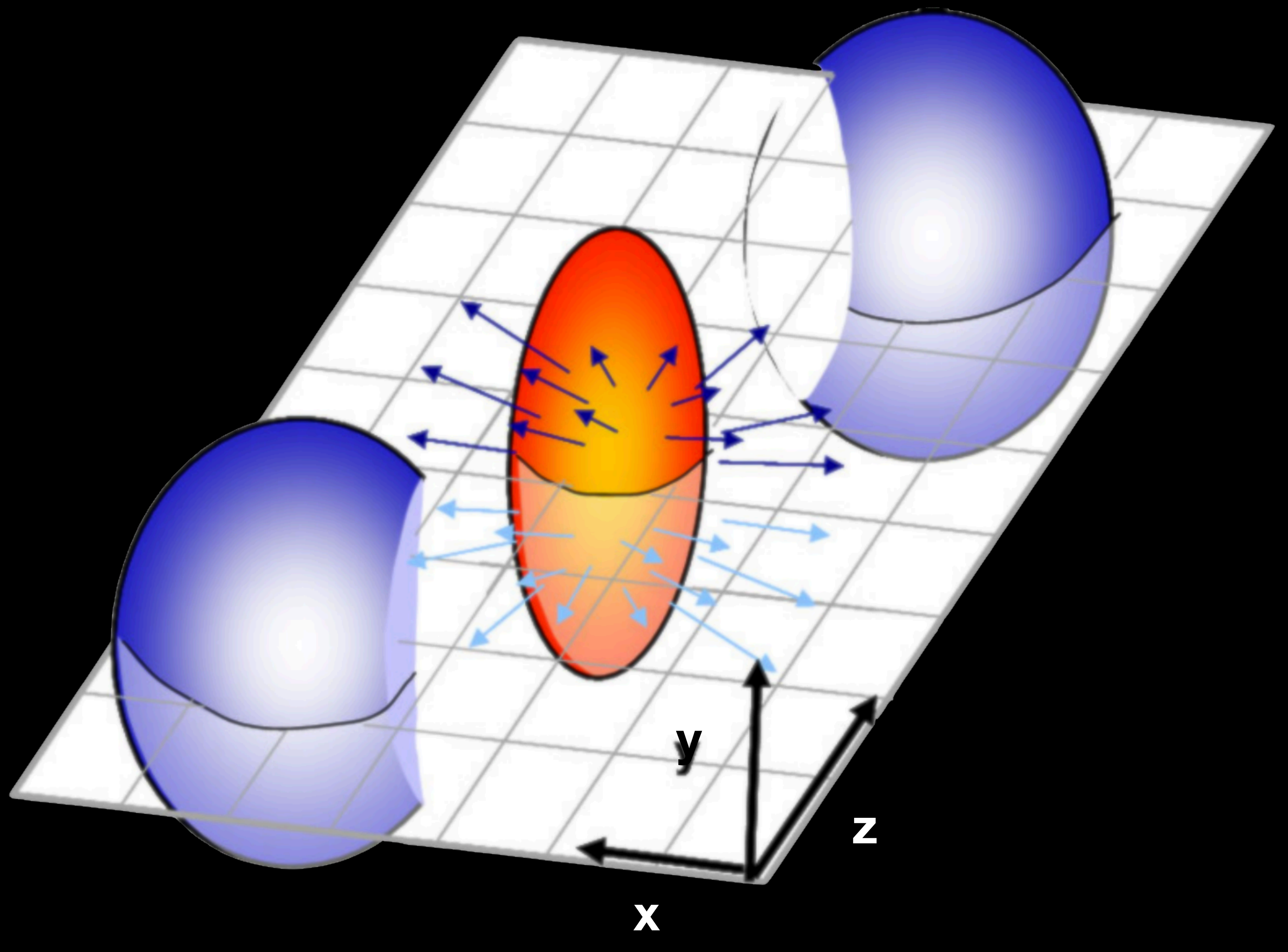


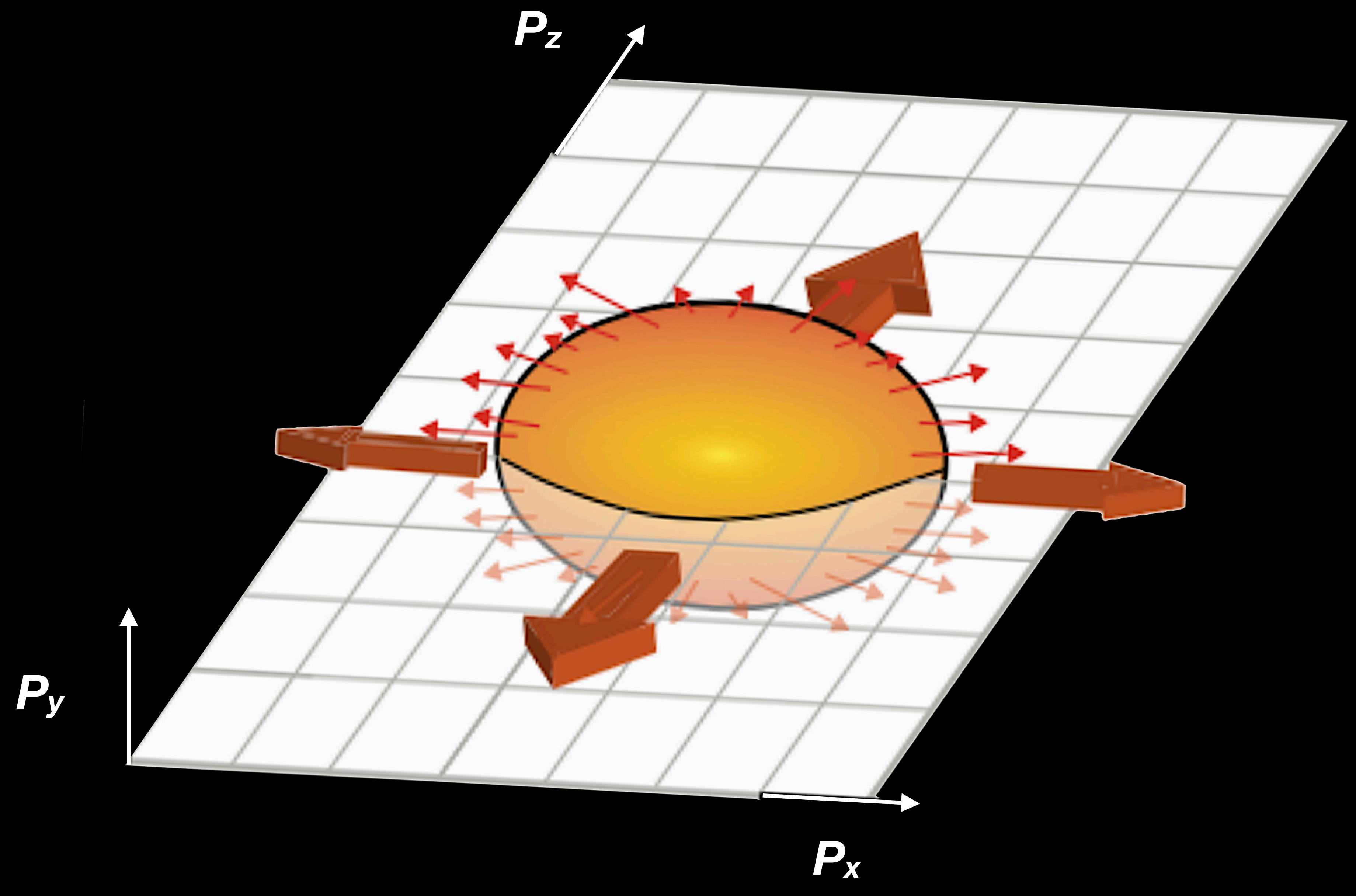
From collision to particle production

Overlap between colliding nuclei:
⇛ Initial state, geometry & its fluctuations

Hydrodynamical expansion of QGP:
⇛ Radial and anisotropic flow, sensitive to initial state and properties of QGP

Freeze-out and hadronization:
⇛ Bulk particle production in a thermalised medium, sensitive to fireball volume and temperature

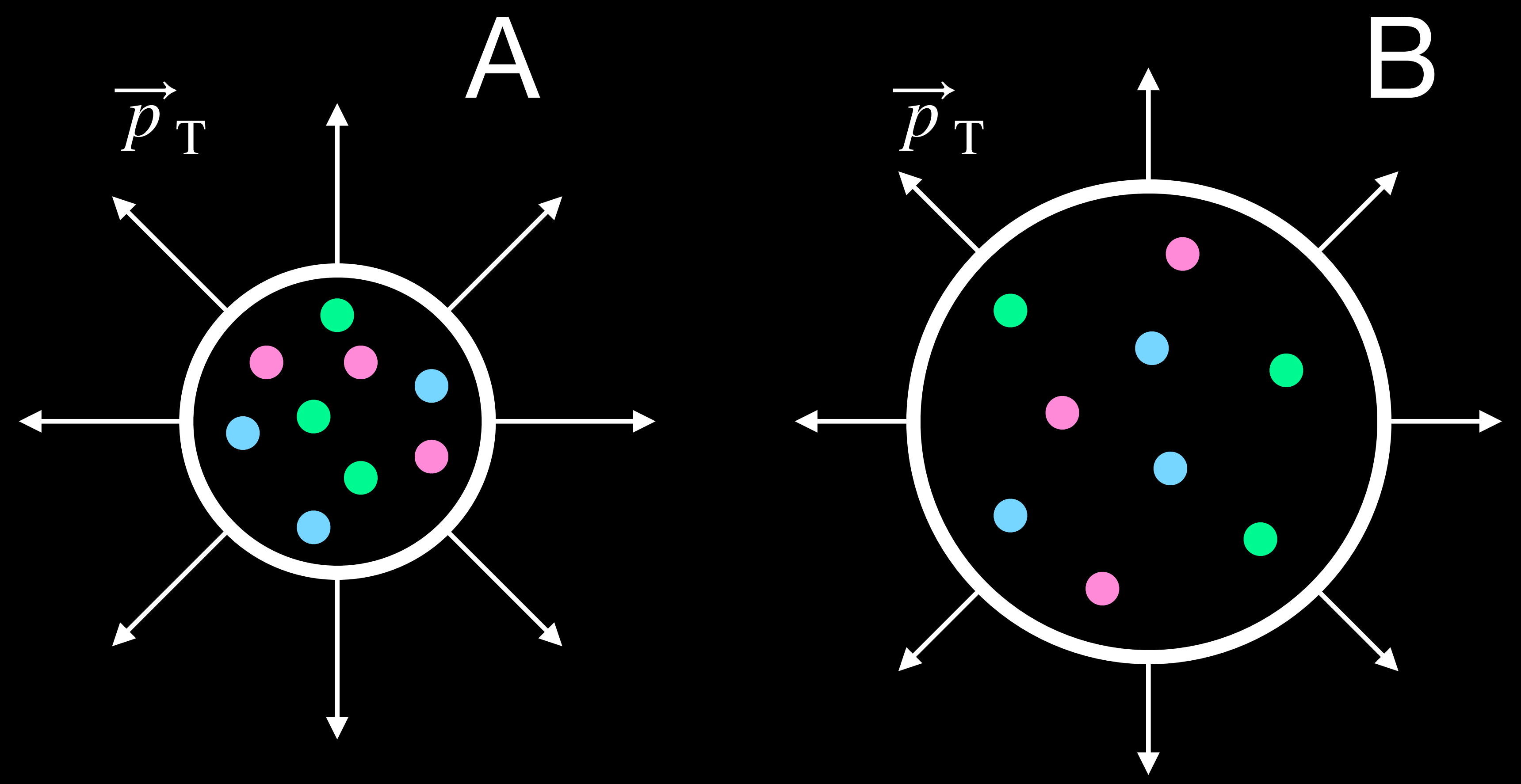




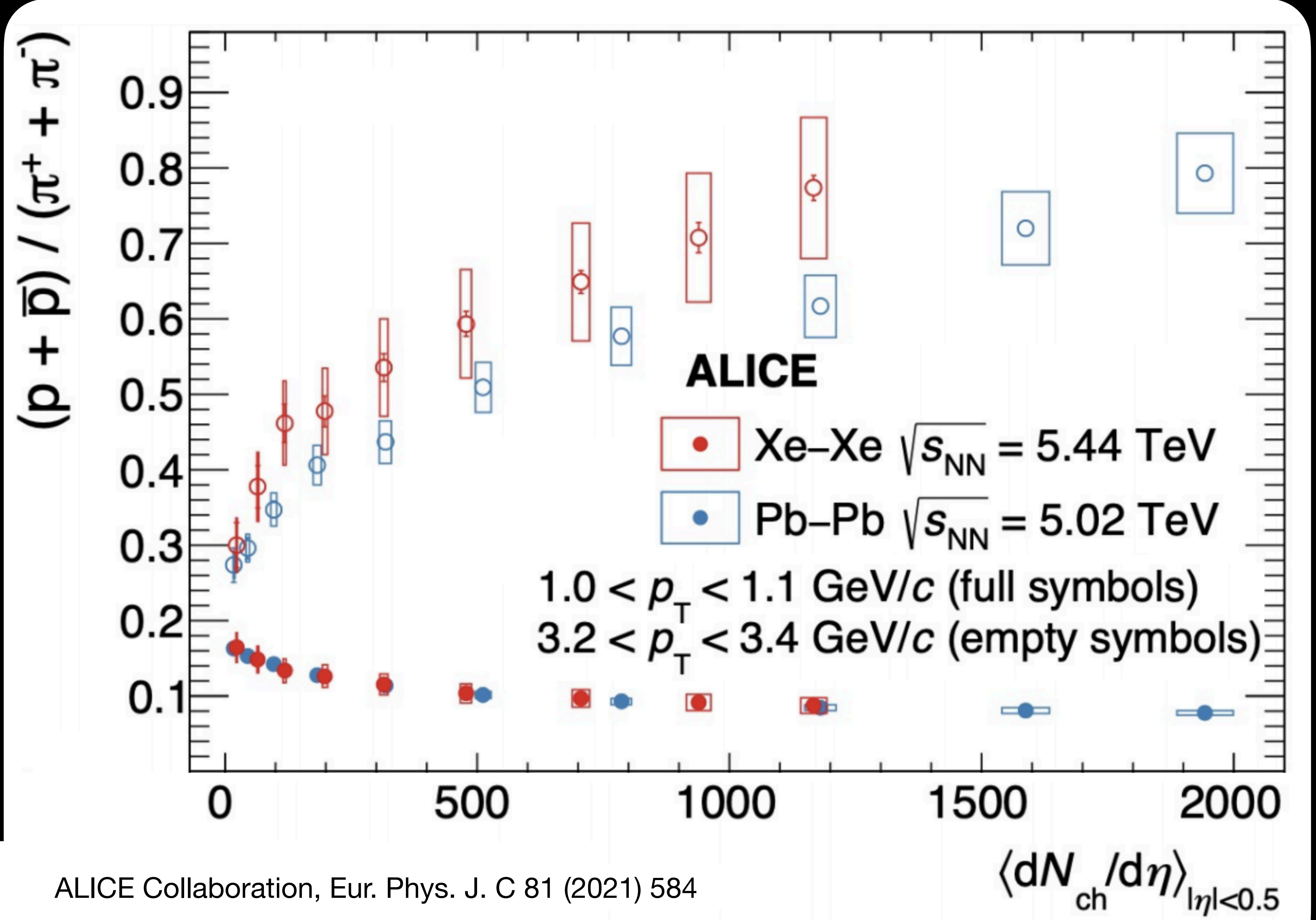
Radial vs. elliptic flow in heavy-ion collisions

p_T - differential p/π ratio:

- Multiplicity-depedent “boost” of the ratio towards higher p_T
  - ⇛ Dominantly driven by $\langle dN_{ch}/d\eta \rangle$, slightly larger in Xe—Xe than in Pb—Pb, but comparable
  - ⇛ Smaller volume → larger mean p_T



$$S_A = S_B, \quad R_A < R_B \implies T_A > T_B \implies \langle p_T \rangle_A > \langle p_T \rangle_B$$



ALICE Collaboration, Eur. Phys. J. C 81 (2021) 584

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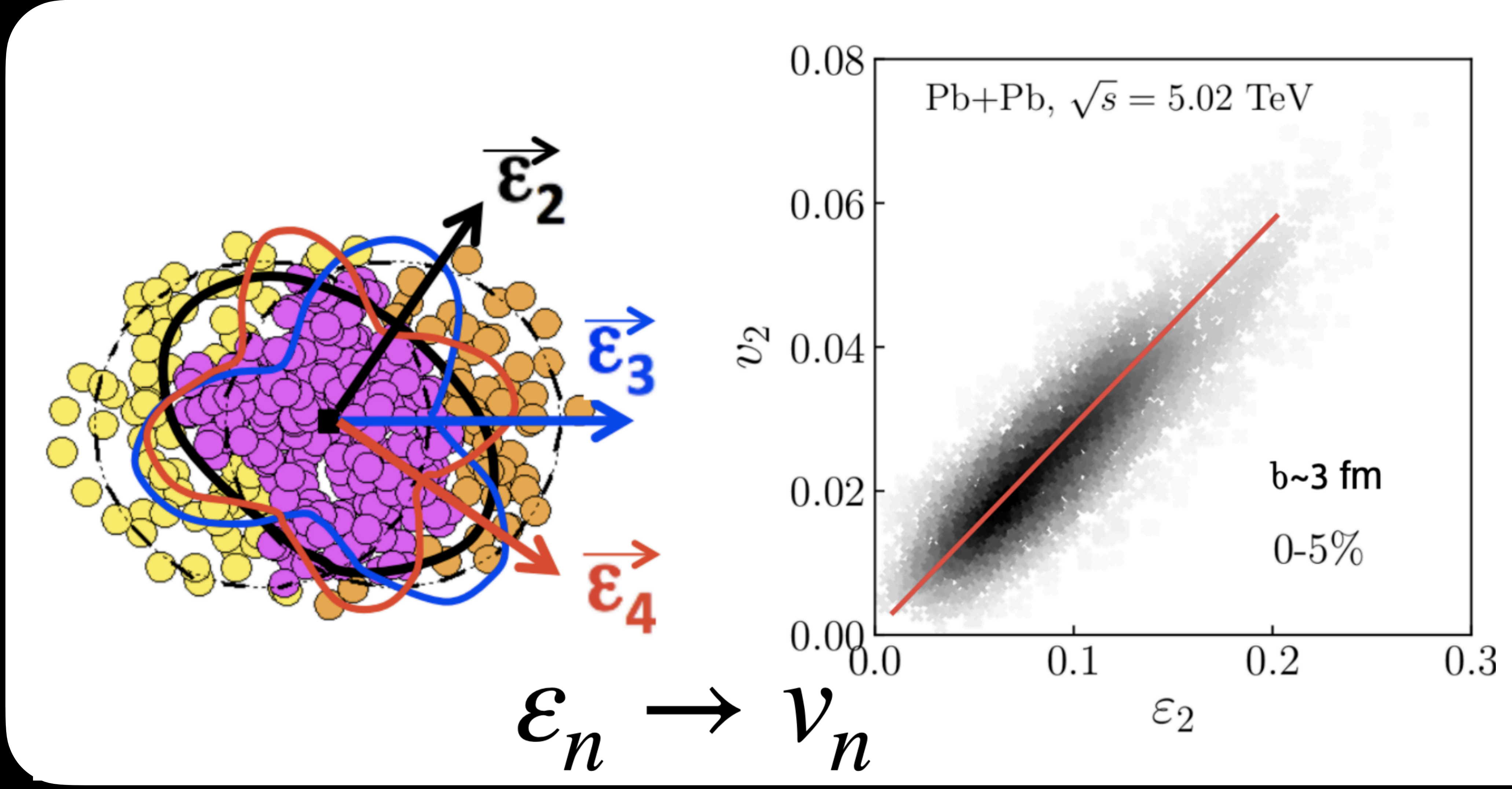
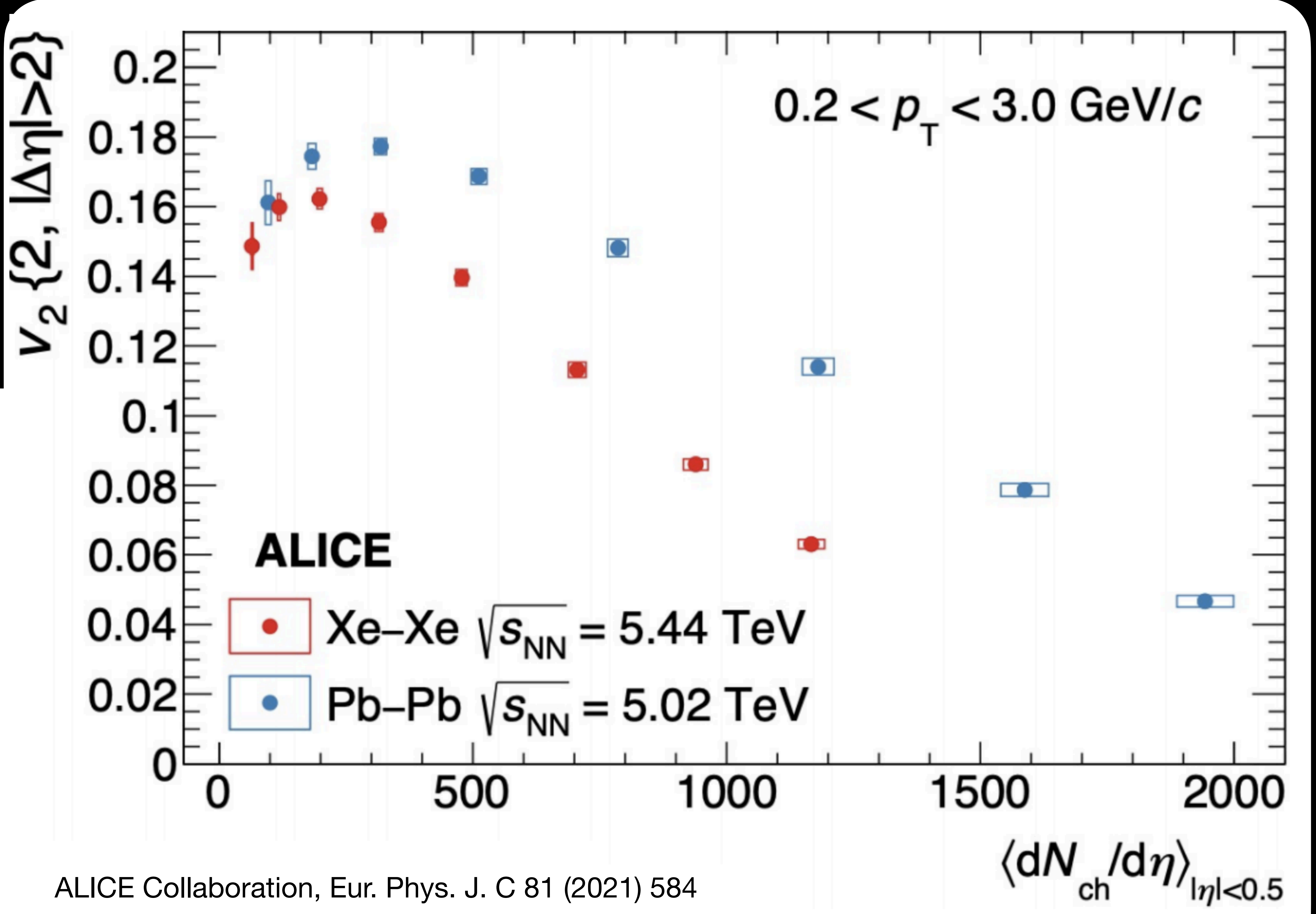
v_2 in Pb—Pb and Xe—Xe collisions:

- Significantly larger in Pb—Pb even at comparable $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle$ ⇒ Sensitive to initial geometry





ALICE Collaboration, Eur. Phys. J. C 81 (2021) 584

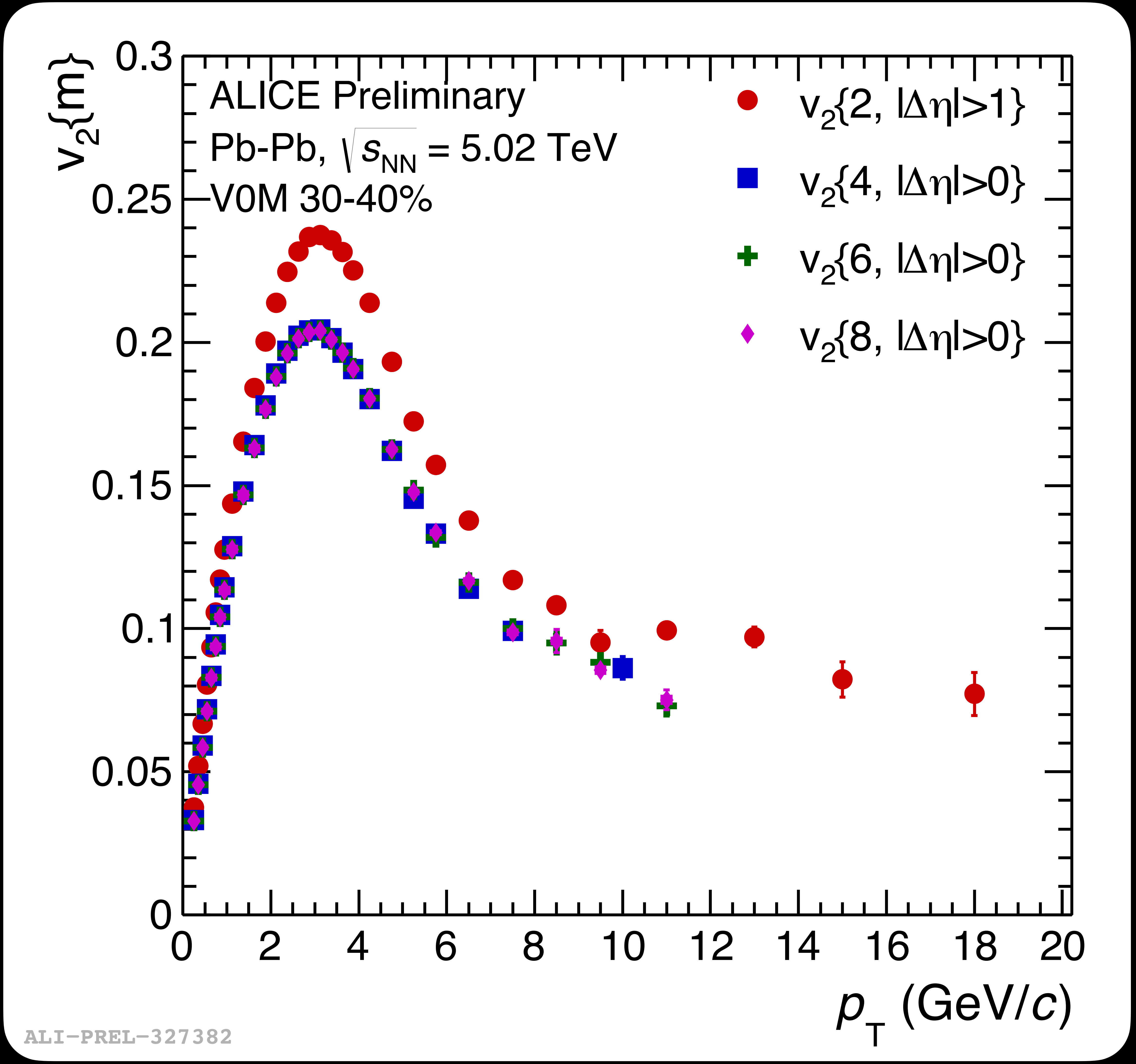
Flow measurements in Pb—Pb collisions

Measure v_2 using *m*-particle correlations

- Different *m*'s probe different moments of underlying v_2 PDF

  ⇛ $v_2\{2\} > v_2\{4,6,8\}$ due to different contributions from flow fluctuations

  ⇛ Can study the behaviour of underlying PDF



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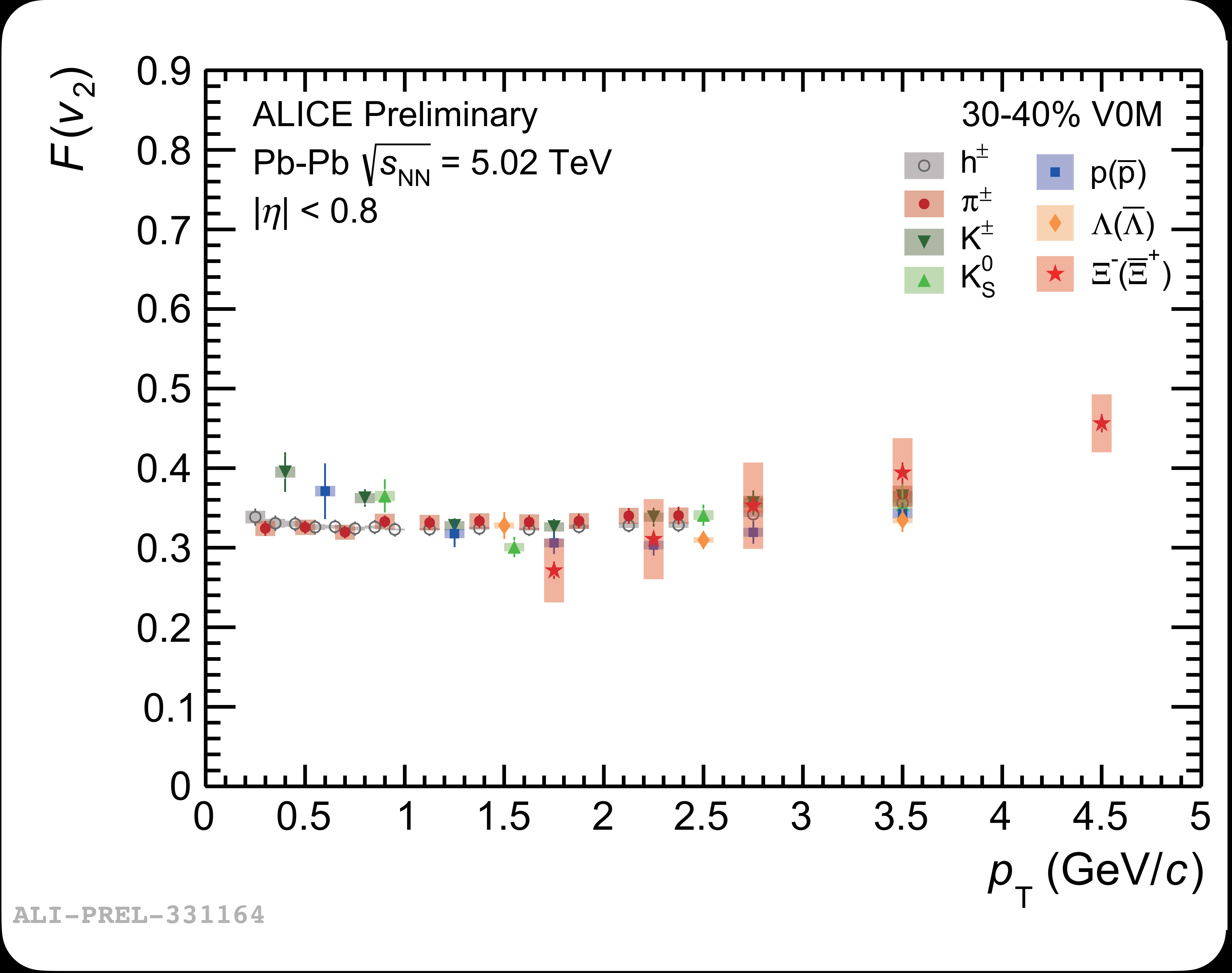
- Second moment constant up to moderate p_T, independent of species

$$F(v_2) = \frac{\sigma(v_2)}{v_2}$$



Flow measurements in Pb—Pb collisions

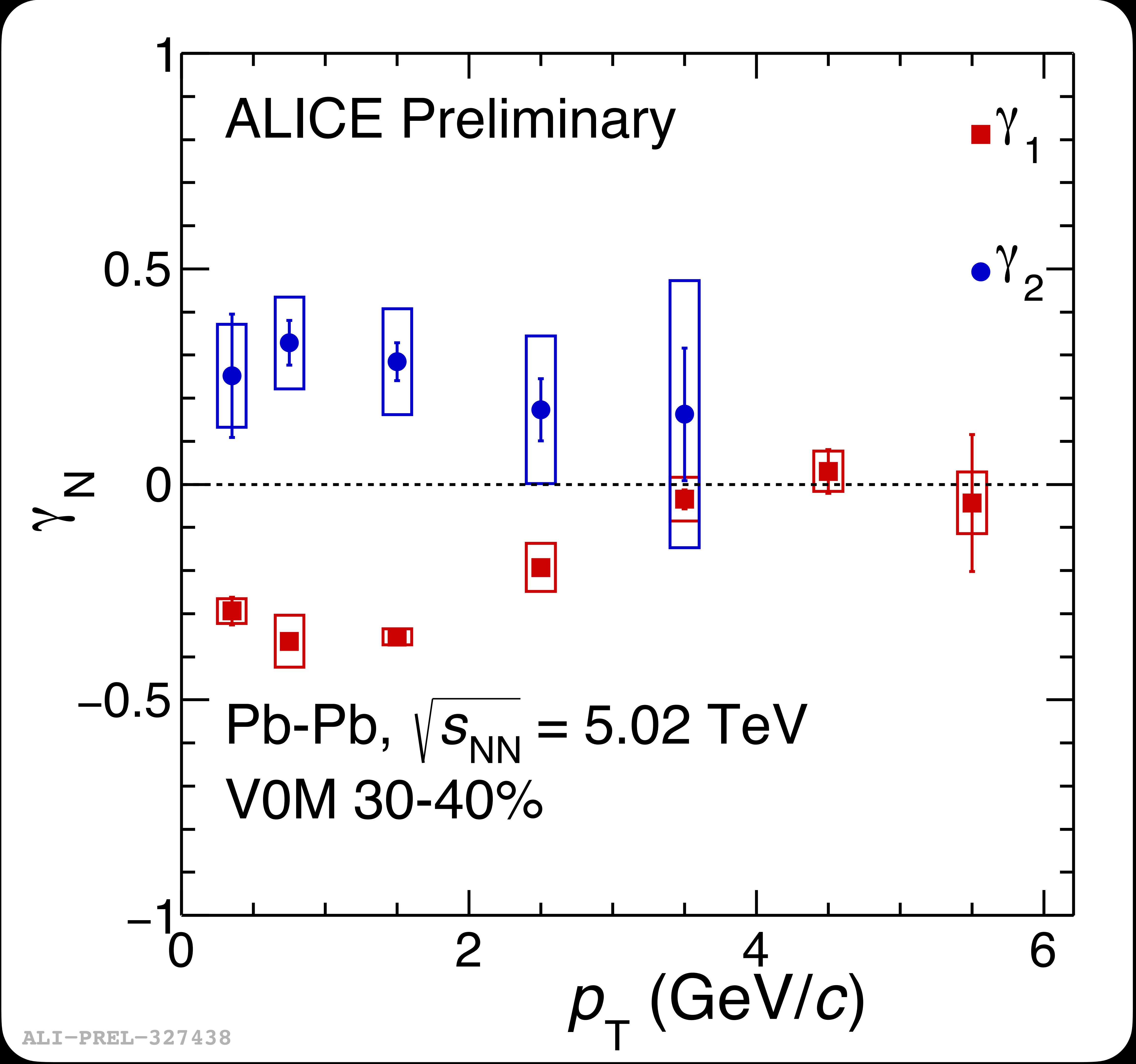
Measure v_2 using m-particle correlations

- Different m's probe different moments of underlying v_2 PDF

  ⇛ $v_2\{2\} > v_2\{4,6,8\}$ due to different contributions from flow fluctuations

  ⇛ Can study the behaviour of underlying PDF
- Second moment constant up to moderate p_T, independent of species
- Skewness (γ_1) and kurtosis (γ_2): clear p_T dependence:

  ⇛ Initial geometry → v_2, which is later modified by the evolution of QGP



Correlation between v_2 and $[p_\mathrm{T}]$

- Shape of the fireball: anisotropic flow, $\varepsilon_n \rightarrow v_n$
- Size of the fireball: radial flow, $[p_\mathrm{T}]$, $1/R \rightarrow [p_\mathrm{T}]$
- Initial state: geometry and fluctuations of shape and size
- Final state: correlation between v_n and $[p_\mathrm{T}]$

Study with Pearson correlation coefficient:

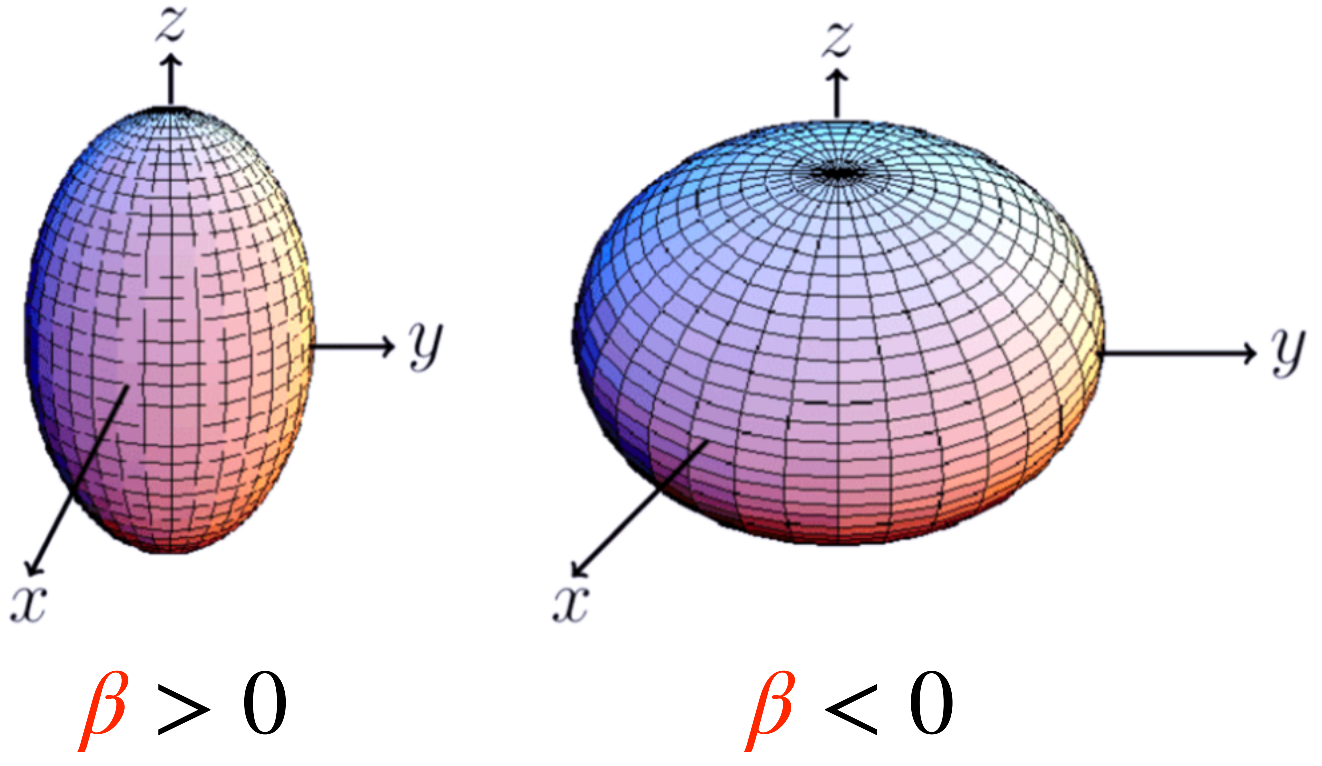
$$\rho_n \equiv \rho\left(v_n^2, [p_\mathrm{T}]\right) = \frac{\mathrm{cov}\left(v_n^2, [p_\mathrm{T}]\right)}{\sqrt{\mathrm{var}\left(v_n^2\right)}\sqrt{\mathrm{var}\left([p_\mathrm{T}]\right)}}$$

For deformed nuclei:

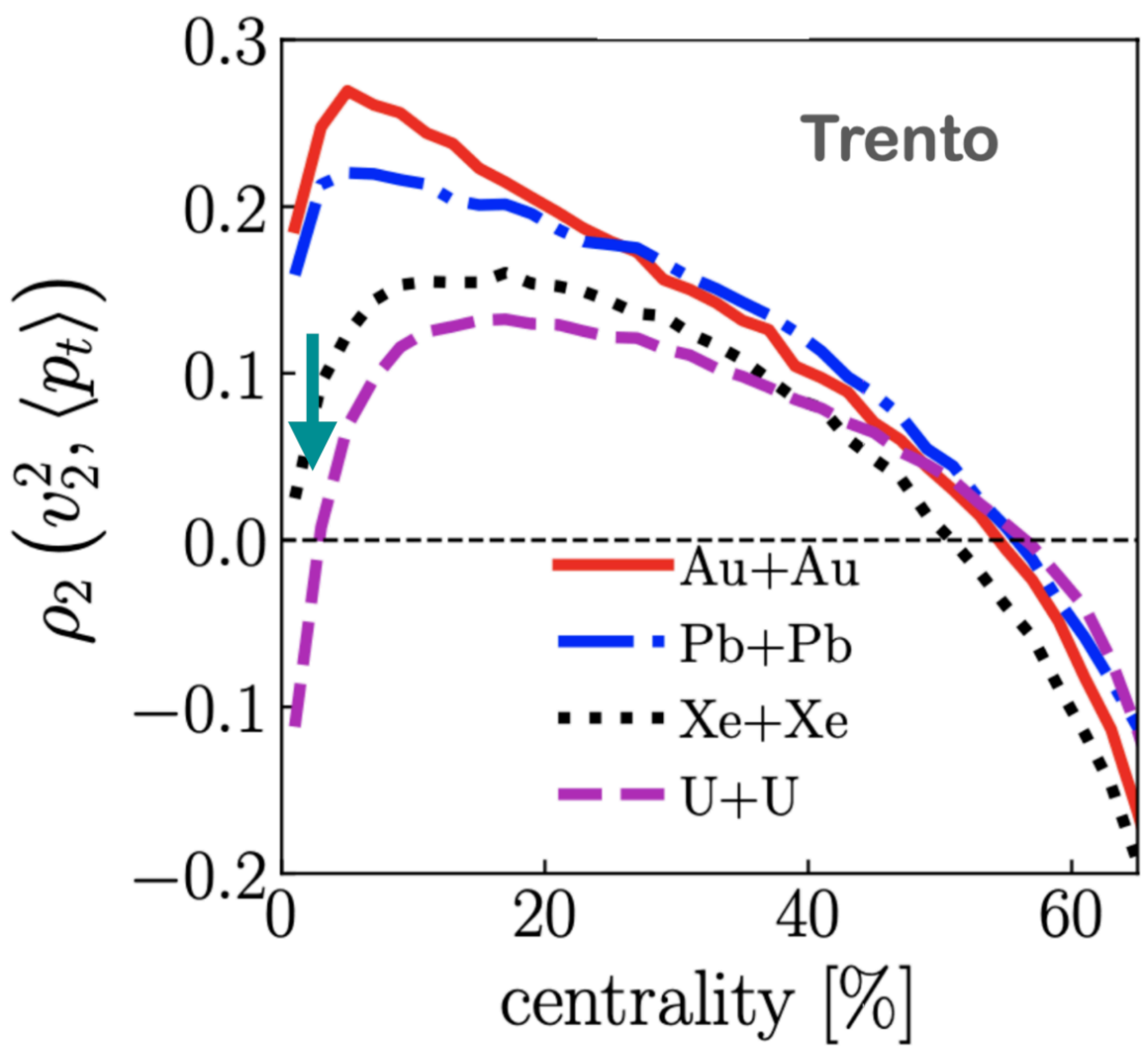
- Significantly smaller ρ_2 in central Xe—Xe compared to Pb—Pb

⇛ Deformation β reduces ρ_2

$$D_{WS}(r) = \frac{D_0}{1 + e^{\left(r - R_0\left(1+\beta Y_{20}\right)\right)/a}}$$



Pb—Pb: $\beta \approx 0$
Xe—Xe: $\beta \approx 0.16$



G. Giacalone, Phys. Rev. C 102, 024901 (2020)

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Probing initial state:

- Low multiplicity: geometry → initial momentum correlations

  ⇛ Change of slope → presence of color glass condensate (CGC)?

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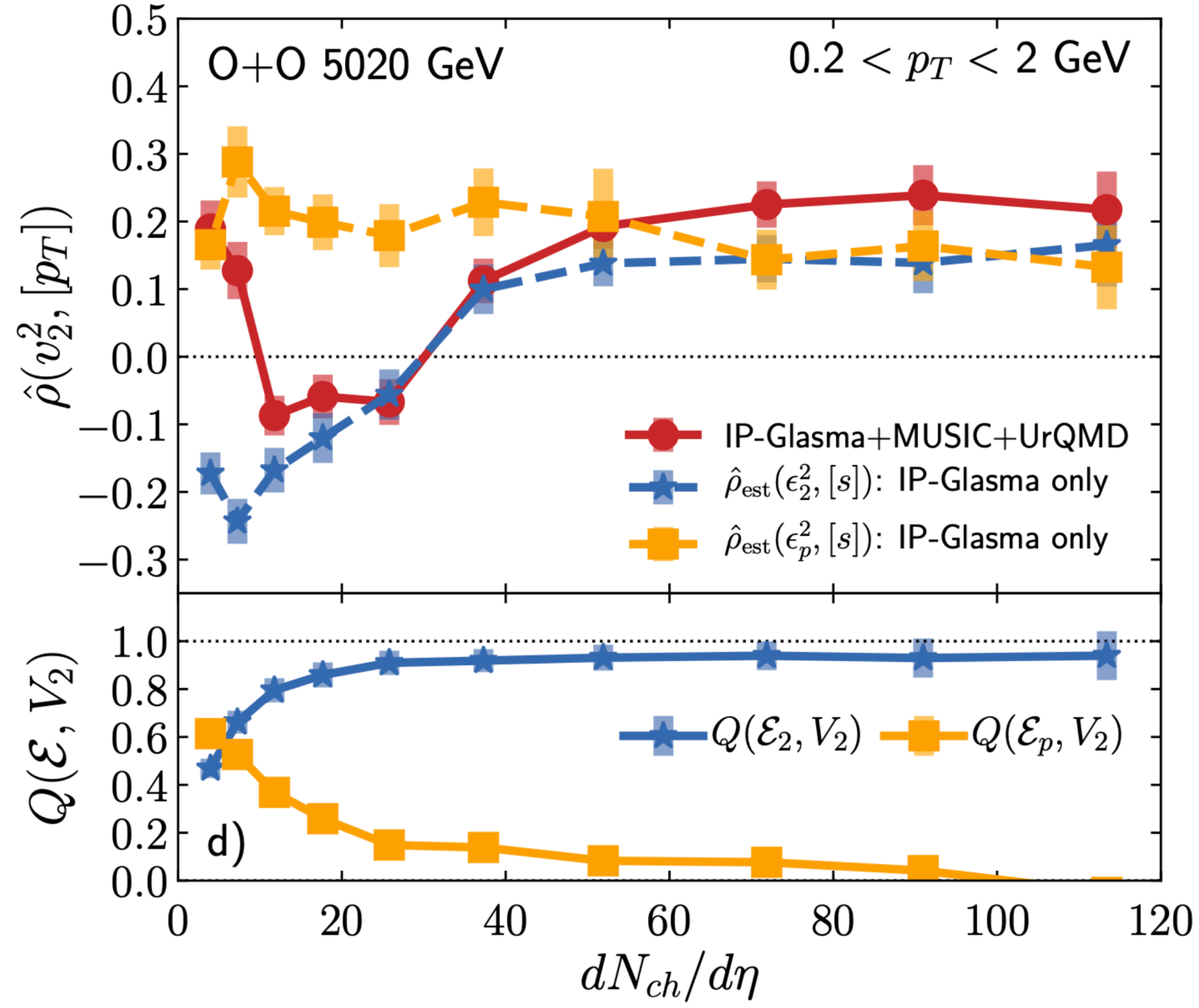
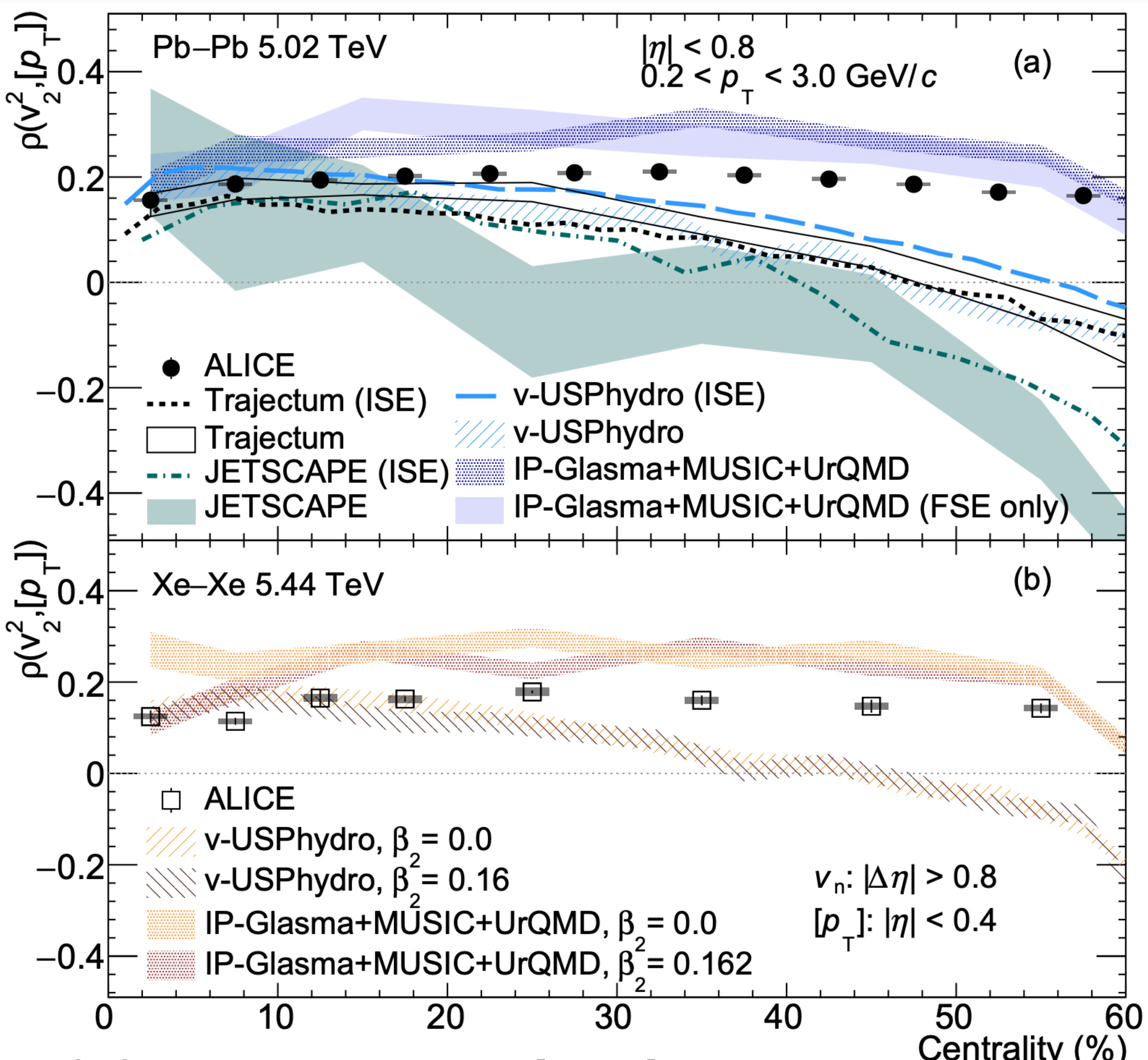


G. Giacalone, Phys. Rev. Lett. 125, 192301 (2020)

ρ_2 in Pb—Pb and Xe—Xe

- ρ_2 slightly larger in Pb—Pb compared to Xe—Xe
- Comparison to models:
  — Below 20% centrality, all models do good
  — More peripheral → best described by models with IP-Glasma

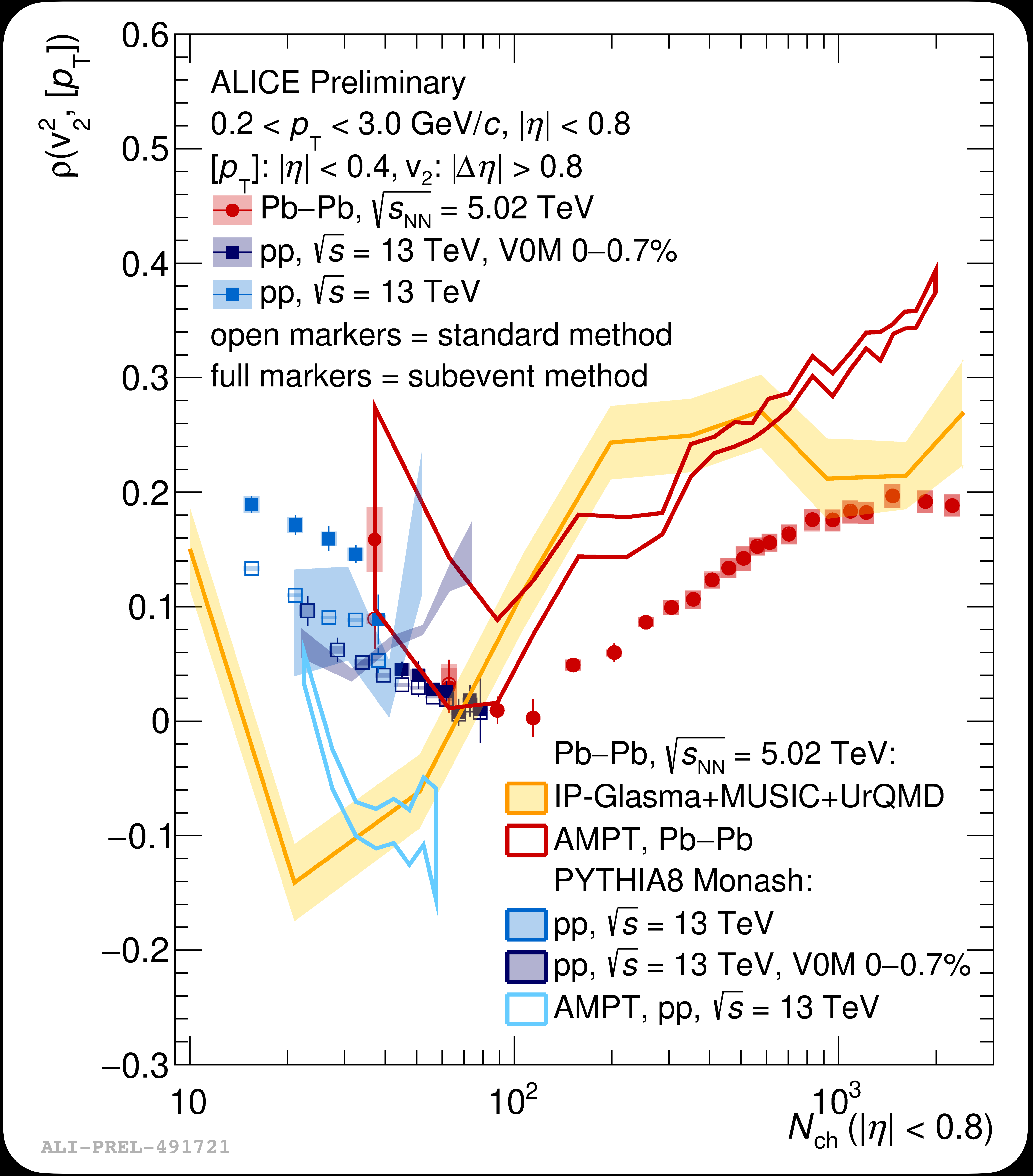
- Xe—Xe:
  — β = 0.162 gives better description in most central collisions, similar to β = 0 in more peripheral



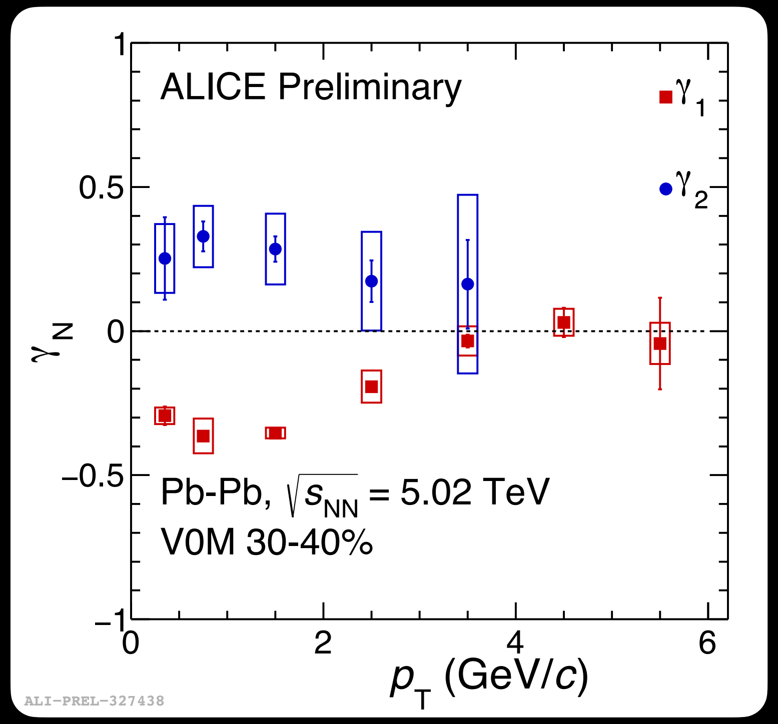
ALICE Collaboration, arXiv:2111.06106 [nucl-ex]

ρ_2 in Pb—Pb and low multiplicity

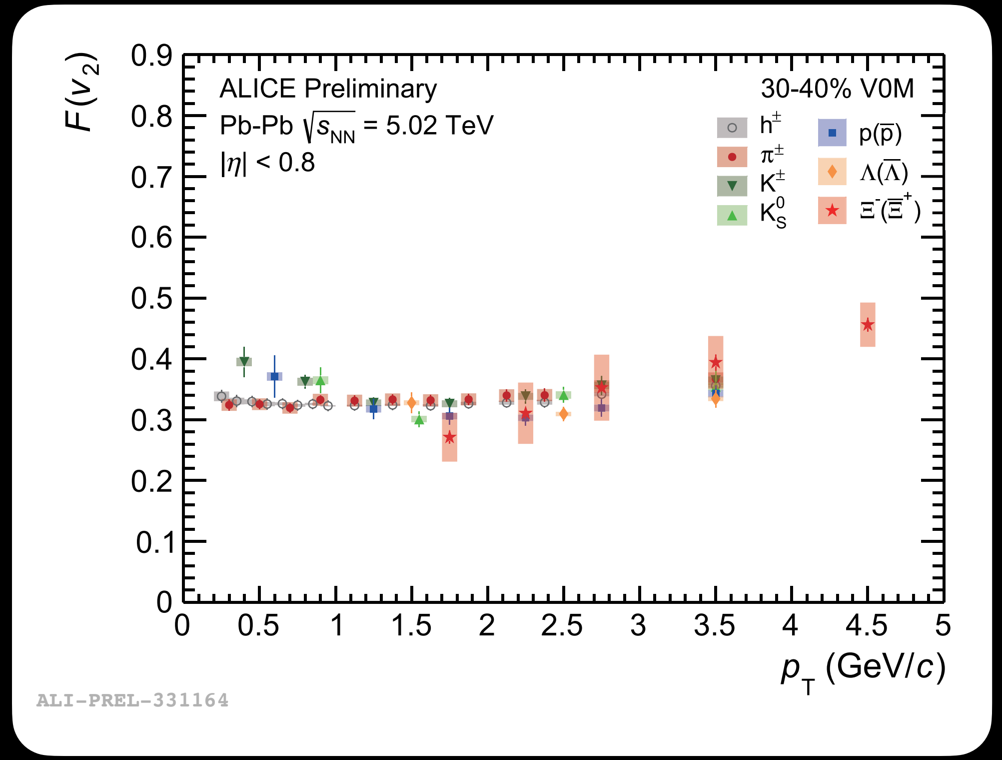
- ρ_2 in Pb—Pb decreasing with decreasing N_{ch} down to around $N_{ch} \sim 100$ particles
  ⇛ More pronounced geometry in smaller system
- Signs of increase at very low N_{ch}
  ⇛ Signs of initial state or other effects?
  ⇛ Answer will be provided by OO in Run 3!
- IP-Glasma+MUSIC+UrQMD predicts a steeper fall
- Change of slope not unique to CGC models



Summary

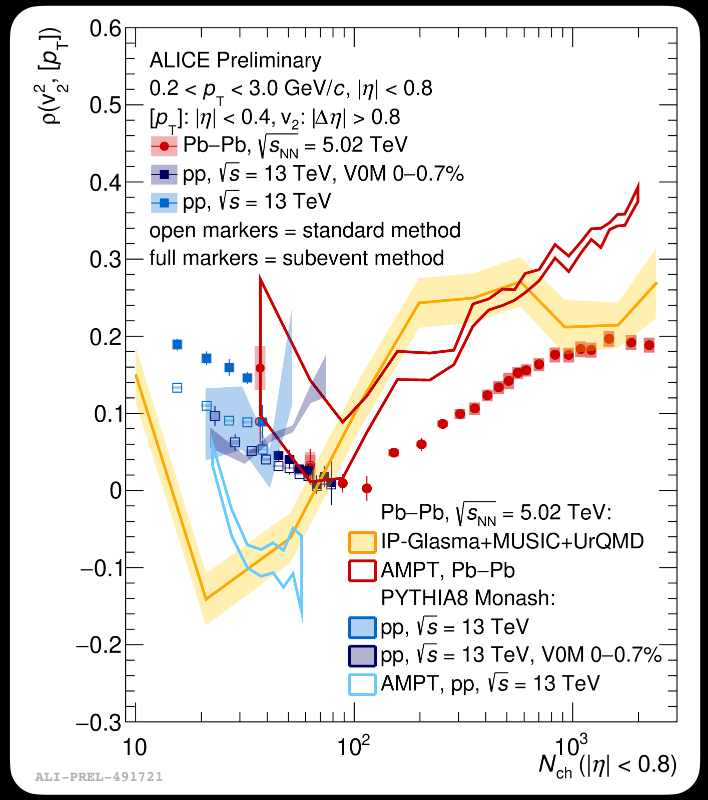


- Precision flow measurements provide new input to study the properties of the quark-gluon plasma



- The PDF of v_2:
  - Sensitive to collision geometry ⇨ important to initial state models
  - Evolution of PDF with p_T ⇨ test for hydrodynamical models

- v_2 fluctuations independent of particle species



- Correlation between v_2 and $\left[p_{\mathrm{T}}\right]$:
  - ρ_2 better described by models with CGC
  - Slope change of ρ_2 not unique to CGC models

Backup

Backup

p_T-differential $v_2\{6,8\}/v_2\{4\}$ ratios

- Around 2% difference between $v_2\{4\}$ and $v_2\{6,8\}$ at low p_T
- Further splitting between $v_2\{6\}$ and $v_2\{8\}$, smaller than 1%

⇛ Underlying PDF of v_2 shows evolution with p_T, becomes consistent with Bessel-Gaussian at around $p_T = 3.5\ \mathrm{GeV}/c$