Collectivity in small collision systems with ALICE

Katarína Křížková Gajdošová
(on behalf of the ALICE Collaboration)
Czech Technical University in Prague
Faculty of Nuclear Sciences and Physical Engineering

15.05.2019

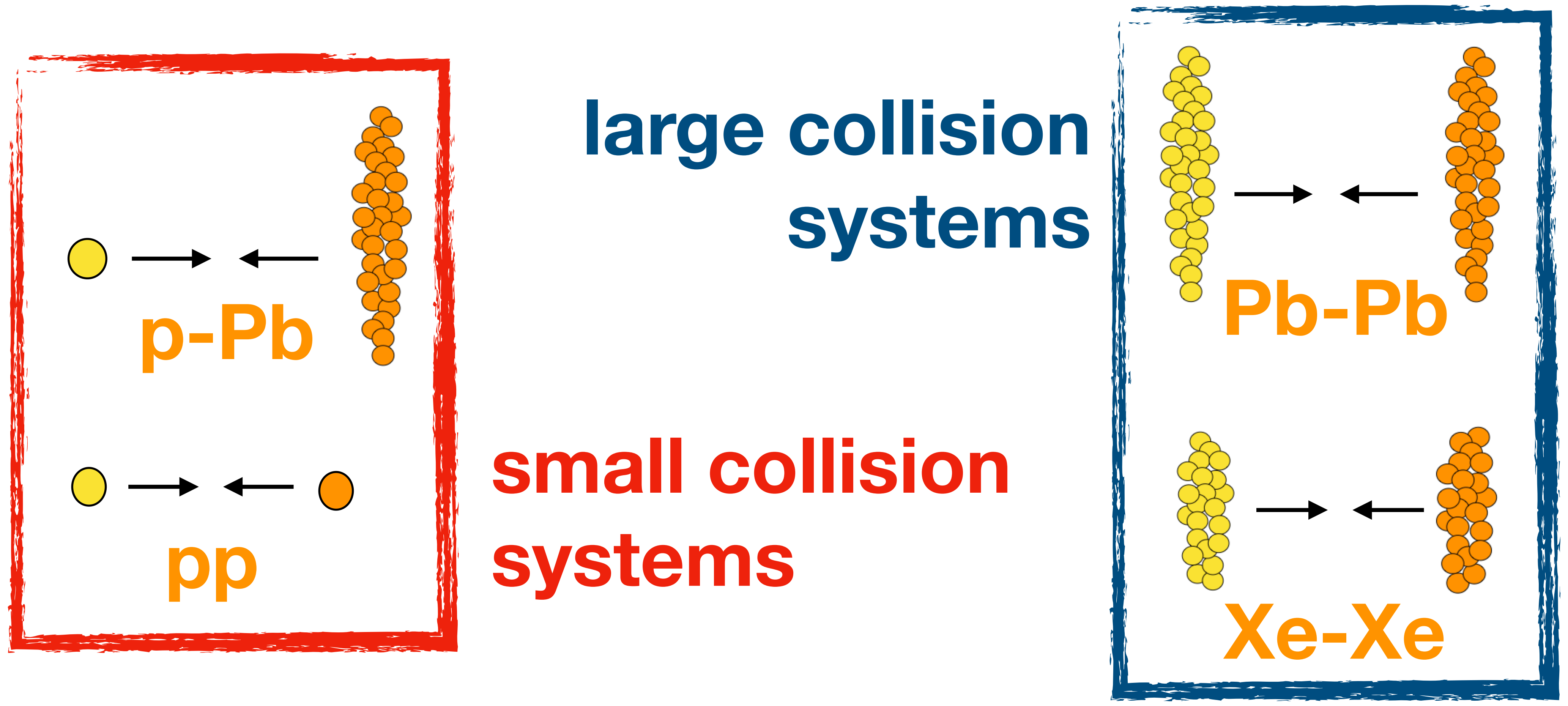
This talk is supported by the project Centre of Advanced Applied Sciences with the number: CZ.02.1.01/0.0/0.0/16-019/0000778. Project Centre of Advanced Applied Sciences is co-financed by European Union

EVROPSKÁ UNIE
Evropské strukturální a investiční fondy
Operační program Výzkum, vývoj a vzdělávání

MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

ALICE

Small and large collision systems



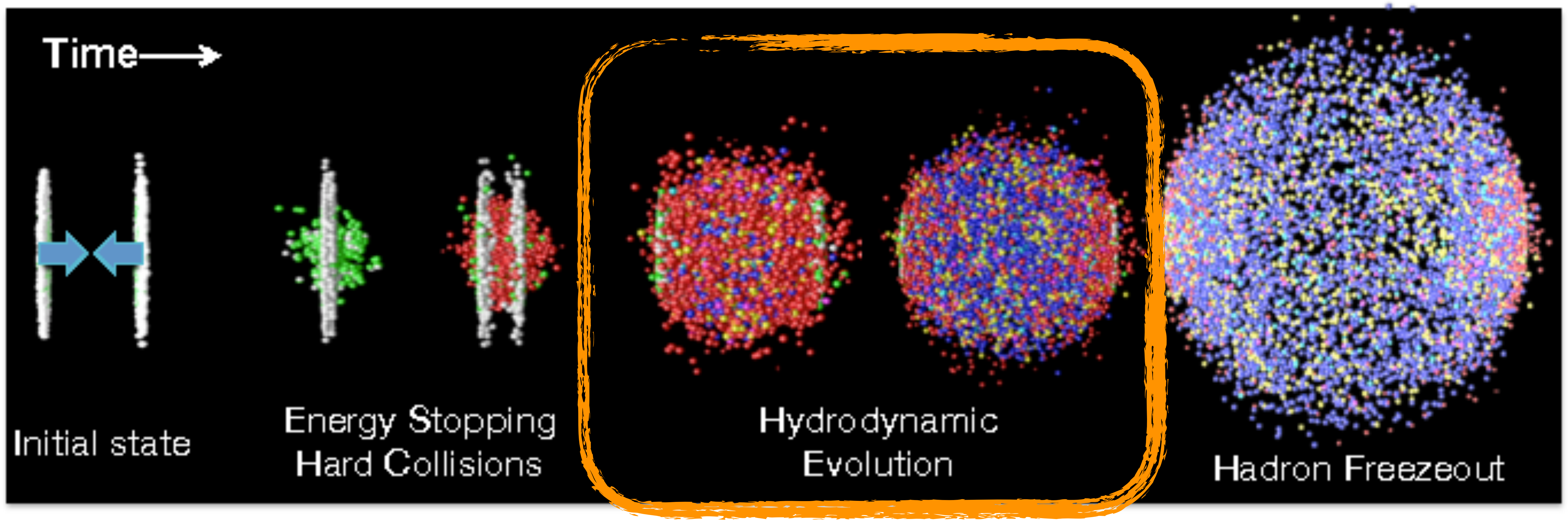
- QCD predicts a phase transition from a hadron gas to a strongly interacting deconfined medium (**Quark-Gluon Plasma**)
- High energy **heavy-ion collisions** (large systems) allow to produce this phase of matter
  - Study its properties (shear viscosity over entropy density, transport coefficients, …)

pp collisions

- Medium-free baseline for studies in heavy-ion collisions

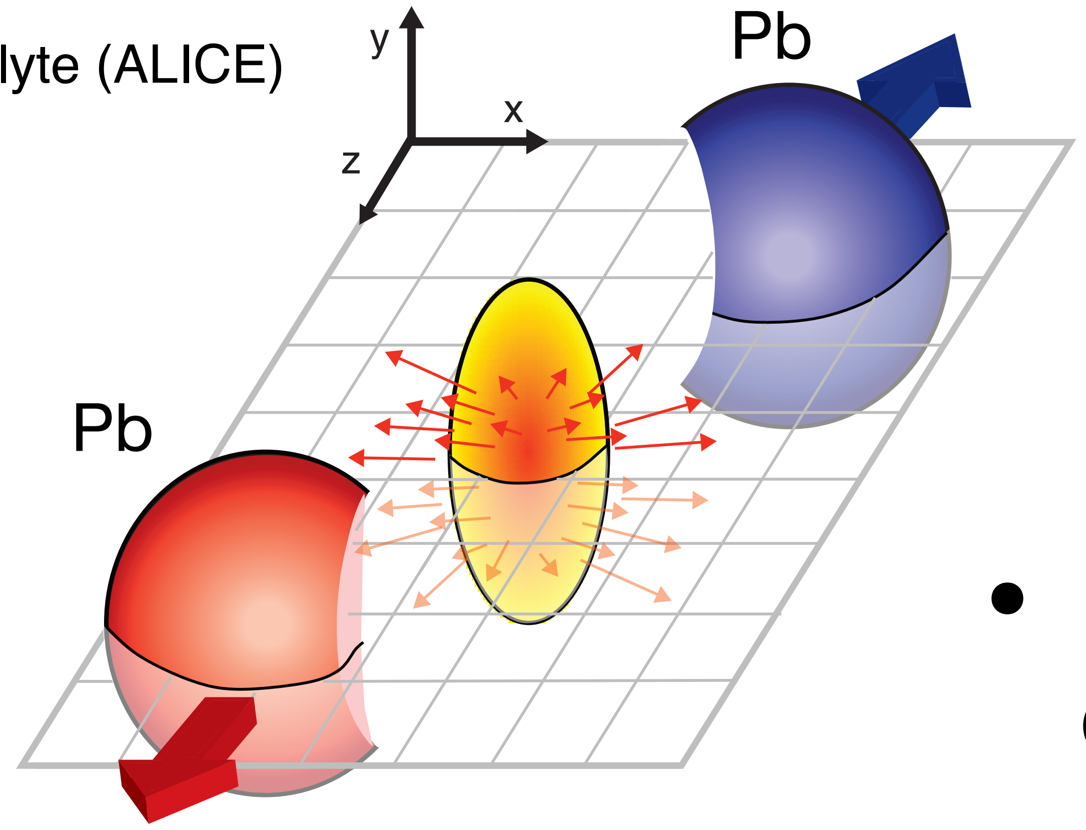
p-Pb collisions

- Access to Cold Nuclear Matter effects (CNM)

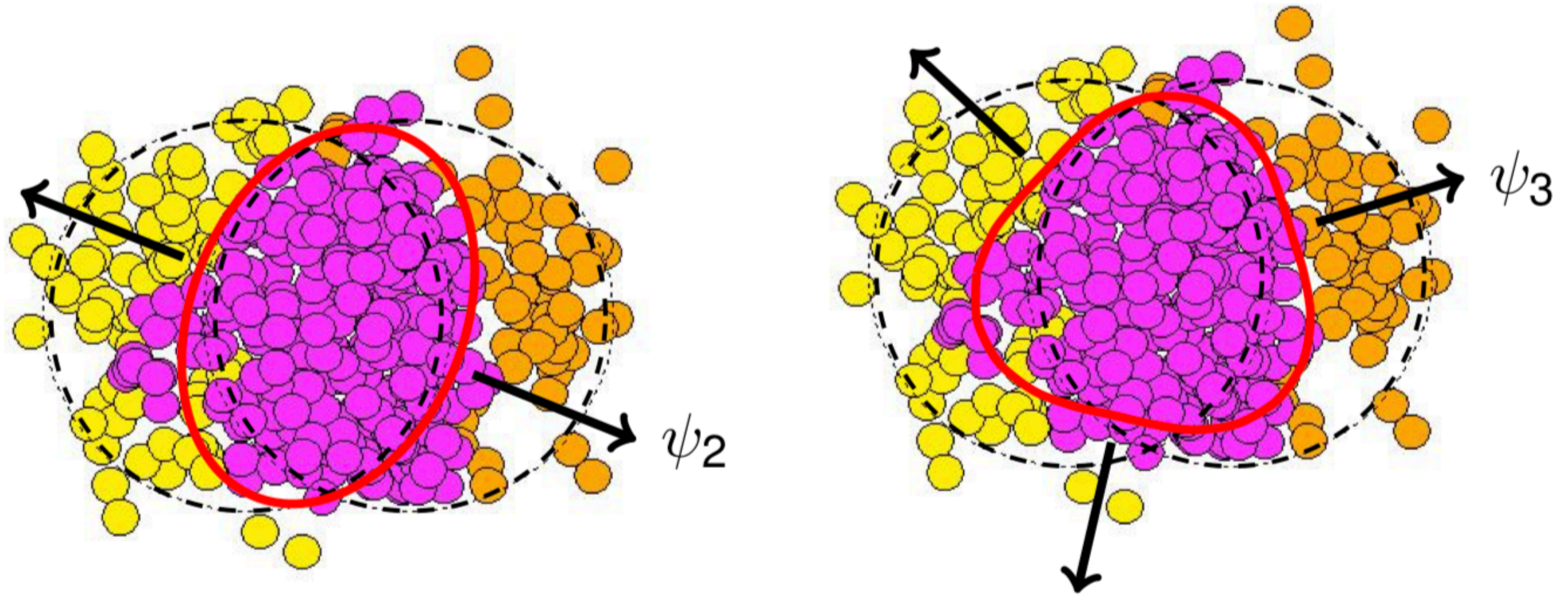


Heavy-ion collisions: what we want to measure?

credits: Boris Hippolyte (ALICE)



- Initial overlap geometry and its fluctuations is transferred into final momentum anisotropy via collective interactions in the QGP



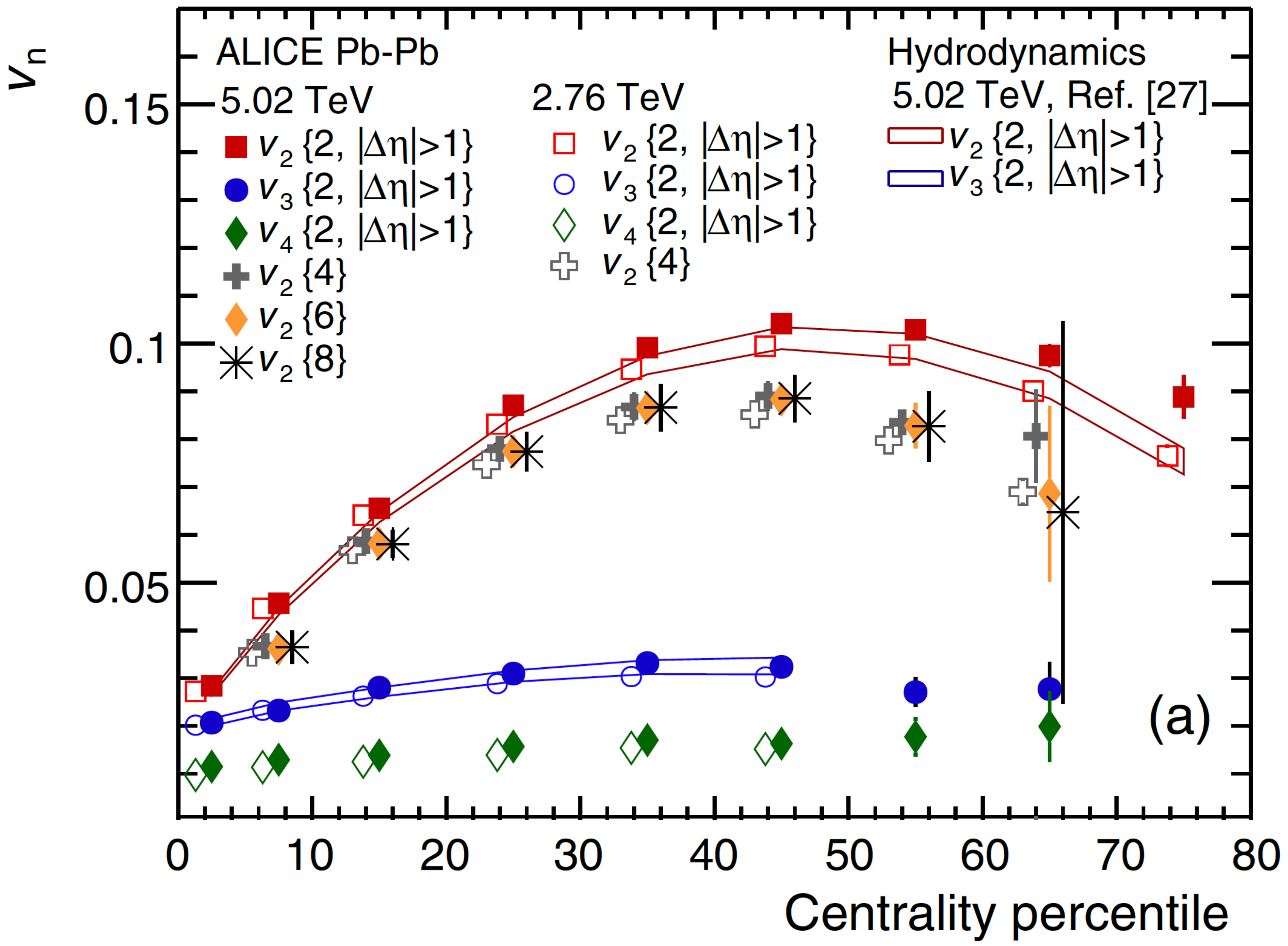
- Fourier expansion of the azimuthal distribution of emitted particles

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} \underline{v_n} \cos[\mathrm{n}\,(\varphi - \Psi_\mathrm{n})]$$

- **Flow coefficient**: correlation of particles with azimuthal angle φ with respect to a common symmetry plane Ψ_n

$$v_n = \langle \cos n\,(\varphi - \Psi_n) \rangle$$

- Measurements are described by **hydrodynamic calculations**



ALICE, PRL **116**, 132302 (2016)

Charged particles

How do we measure flow?

Bilandzic et al., PRC 83, 044913 (2011)
Bilandzic et al., PRC 89, 064904 (2014)

$$v_n = \langle \cos n\left(\varphi - \Psi_n\right)\rangle$$

- The symmetry plane Ψ_n is not known -> we use multi-particle correlations:

m-particle correlation

$$\langle\langle m\rangle\rangle_{n_1,\ldots,n_m}$$

Average over *m*-tuplets and events

$$\langle\langle 2\rangle\rangle_{n,-n} = \langle\langle\cos\left(n\varphi_1 - n\varphi_2\right)\rangle\rangle \approx \langle v_n^2\rangle$$

$$\langle\langle 4\rangle\rangle_{n,n,-n,-n} = \langle\langle\cos\left(n\varphi_1 + n\varphi_2 - n\varphi_3 - n\varphi_4\right)\rangle\rangle \approx \langle v_n^4\rangle$$

...

Charged particles

How do we measure flow?

Bilandzic et al., PRC 83, 044913 (2011)
Bilandzic et al., PRC 89, 064904 (2014)

$$v_n = \langle \cos n\left(\varphi - \Psi_n\right)\rangle$$

- The symmetry plane Ψ_n is not known -> we use multi-particle correlations:

m-particle correlation → **m-particle cumulant**

$$\langle\langle m\rangle\rangle_{n_1,\ldots,n_m} \longrightarrow c_n\{m\}$$

Average over *m*-tuplets and events

$$\langle\langle 2\rangle\rangle_{n,-n}$$

$$\langle\langle 4\rangle\rangle_{n,n,-n,-n}$$

...

$$c_n\{2\} = \langle\langle 2\rangle\rangle_{n,-n}$$

$$c_n\{4\} = \langle\langle 4\rangle\rangle_{n,n,-n,-n} - 2\cdot\langle\langle 2\rangle\rangle_{n,-n}^2$$

...

$$\langle\langle 2\rangle\rangle_{n,-n} = \langle\langle\cos\left(n\varphi_1 - n\varphi_2\right)\rangle\rangle \approx \langle v_n^2\rangle$$

$$\langle\langle 4\rangle\rangle_{n,n,-n,-n} = \langle\langle\cos\left(n\varphi_1 + n\varphi_2 - n\varphi_3 - n\varphi_4\right)\rangle\rangle \approx \langle v_n^4\rangle$$

Charged particles

How do we measure flow?

Bilandzic et al., PRC 83, 044913 (2011)
Bilandzic et al., PRC 89, 064904 (2014)

$$v_n = \langle \cos n\,(\varphi - \Psi_n) \rangle$$

- The symmetry plane Ψ_n is not known -> we use multi-particle correlations:

m-particle correlation → **m-particle cumulant** → **flow coefficient** (obtained from m-particle cumulant)

$$\langle\langle m \rangle\rangle_{n_1,\ldots,n_m} \longrightarrow c_n\{m\} \longrightarrow v_n\{m\}$$

Average over *m*-tuplets and events

m-particle correlation	m-particle cumulant	flow coefficient
$\langle\langle 2 \rangle\rangle_{n,-n}$	$c_n\{2\} = \langle\langle 2 \rangle\rangle_{n,-n}$	$v_n\{2\} = \sqrt{c_n\{2\}}$
$\langle\langle 4 \rangle\rangle_{n,n,-n,-n}$	$c_n\{4\} = \langle\langle 4 \rangle\rangle_{n,n,-n,-n} - 2 \cdot \langle\langle 2 \rangle\rangle_{n,-n}^2$	$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$
...	...	...

$$\langle\langle 2 \rangle\rangle_{n,-n} = \langle\langle \cos(n\varphi_1 - n\varphi_2) \rangle\rangle \approx \langle v_n^2 \rangle$$

$$\langle\langle 4 \rangle\rangle_{n,n,-n,-n} = \langle\langle \cos(n\varphi_1 + n\varphi_2 - n\varphi_3 - n\varphi_4) \rangle\rangle \approx \langle v_n^4 \rangle$$

Charged particles

How do we measure flow?

Bilandzic et al., PRC 83, 044913 (2011)
Bilandzic et al., PRC 89, 064904 (2014)

$$v_n = \langle \cos n\,(\varphi - \Psi_n) \rangle$$

- The symmetry plane Ψ_n is not known -> we use multi-particle correlations:

m-particle correlation		**m-particle cumulant**		**flow coefficient** obtained from m-particle cumulant
$\langle\langle m \rangle\rangle_{n_1,\ldots,n_m}$	→	$c_n\{m\}$	→	$v_n\{m\}$
$\langle\langle 2 \rangle\rangle_{n,-n}$		$c_n\{2\} = \langle\langle 2 \rangle\rangle_{n,-n}$		$v_n\{2\} = \sqrt{c_n\{2\}}$
$\langle\langle 4 \rangle\rangle_{n,n,-n,-n}$		$c_n\{4\} = \langle\langle 4 \rangle\rangle_{n,n,-n,-n} - 2 \cdot \langle\langle 2 \rangle\rangle_{n,-n}^2$		$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$
...		...		...

Average over *m*-tuplets and events

Symmetric Cumulant: $SC(m,n) = \langle v_n^2 \cdot v_m^2 \rangle - \langle v_n^2 \rangle \cdot \langle v_m^2 \rangle$

$$\langle\langle 2 \rangle\rangle_{n,-n} = \langle\langle \cos(n\varphi_1 - n\varphi_2) \rangle\rangle \approx \langle v_n^2 \rangle$$
$$\langle\langle 4 \rangle\rangle_{n,n,-n,-n} = \langle\langle \cos(n\varphi_1 + n\varphi_2 - n\varphi_3 - n\varphi_4) \rangle\rangle \approx \langle v_n^4 \rangle$$
$$\langle\langle 4 \rangle\rangle_{n,m,-n,-m} = \langle\langle \cos(n\varphi_1 + m\varphi_2 - n\varphi_3 - m\varphi_4) \rangle\rangle \approx \langle v_n^2 \cdot v_m^2 \rangle$$

How do we measure flow?

A) Two-particle differential cumulants

$$v_n\{2\}(p_{\mathrm{T}}) = \frac{d_n\{2\}(p_{\mathrm{T}})}{\sqrt{c_n\{2\}}} = \frac{\langle v_n(p_{\mathrm{T}}) \cdot v_n \rangle}{\sqrt{\langle v_n \cdot v_n \rangle}} \qquad (\mathrm{h}^{\pm},\ \pi^{\pm}, \mathrm{K}^{\pm},\ \mathrm{p}(\bar{\mathrm{p}}))$$

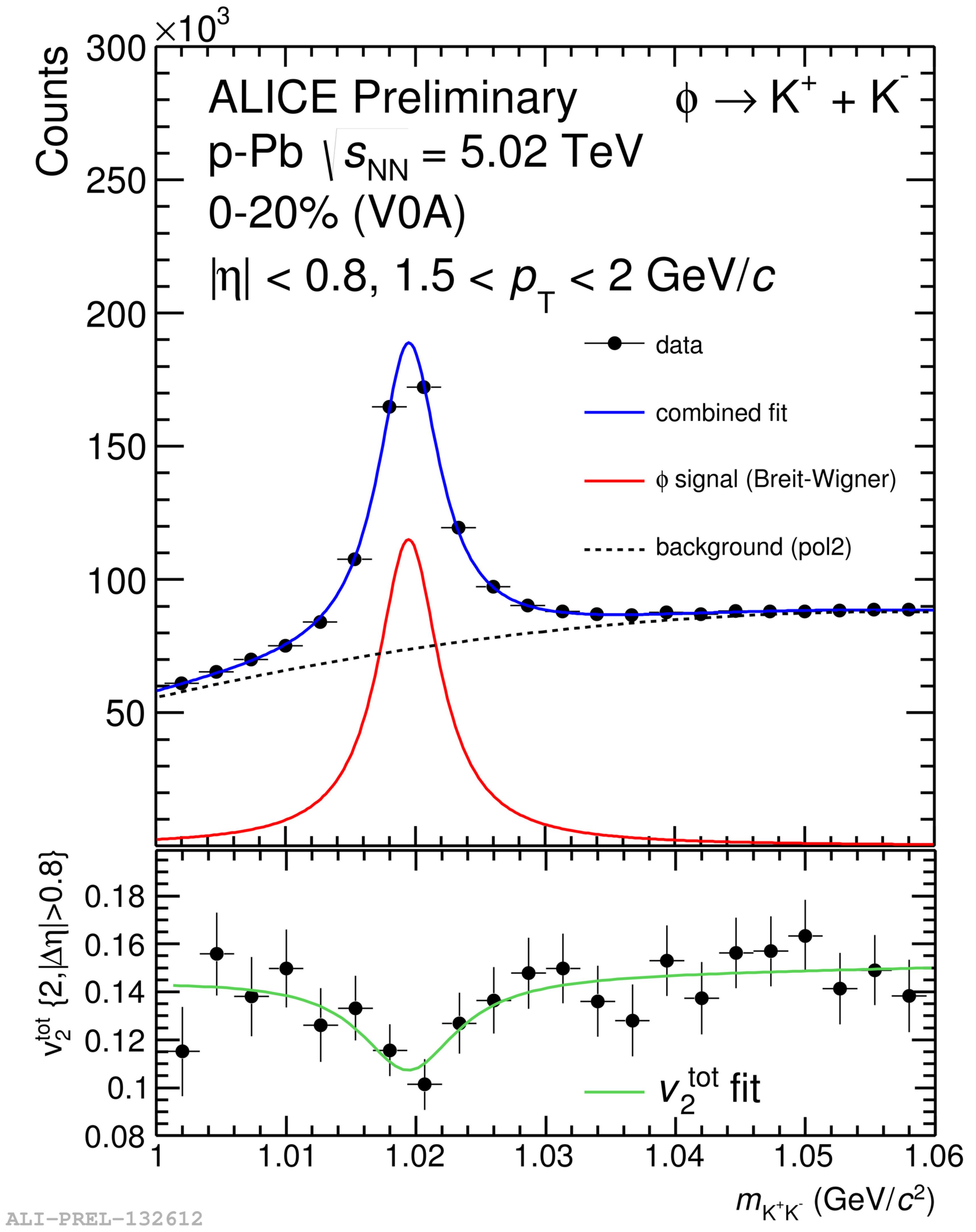
B) Invariant mass method

- Obtain the particle pair flow

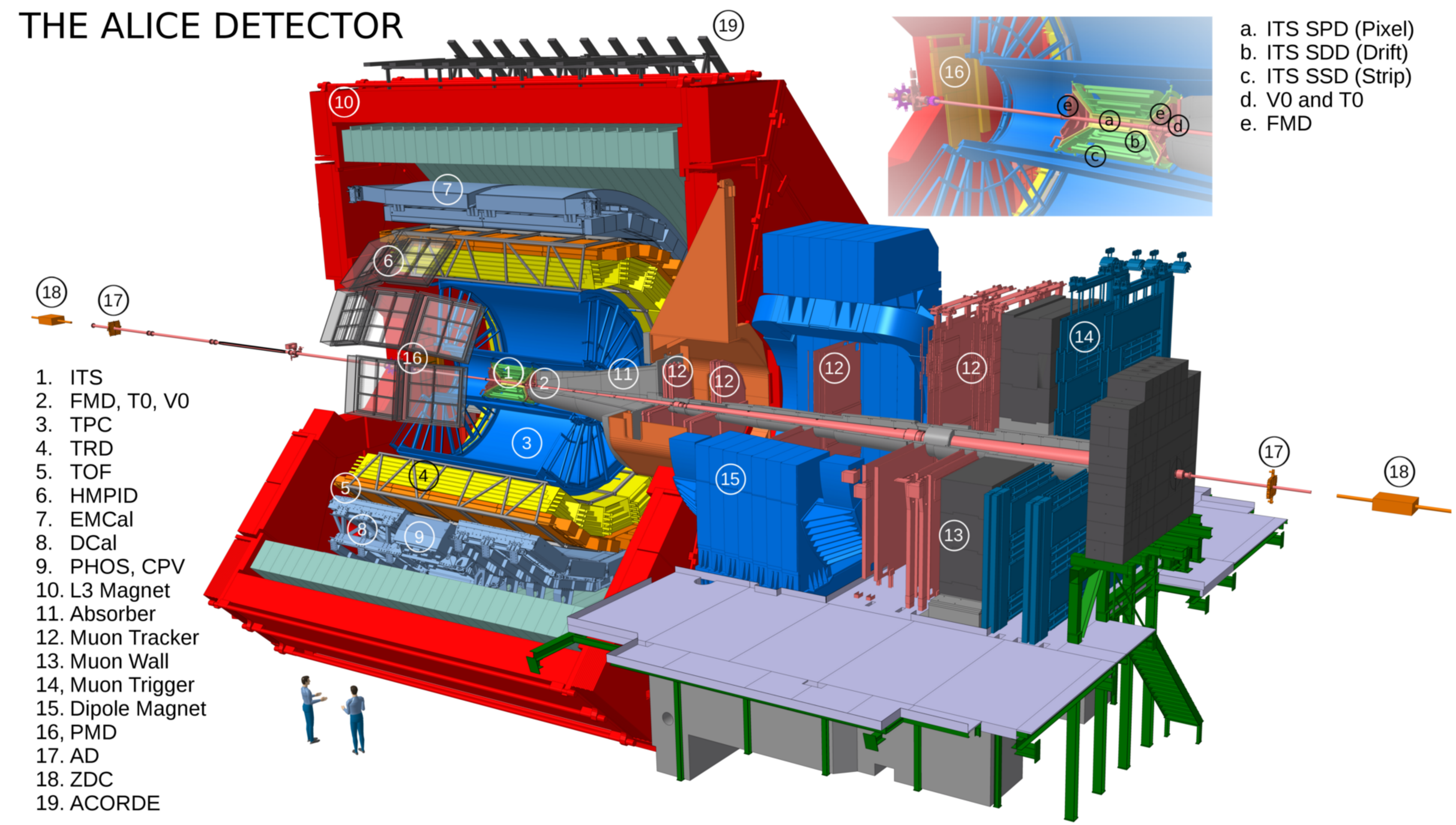
$$v_n^{\mathrm{tot}}\{2\}(p_{\mathrm{T}}, m_{\mathrm{inv}}) = \frac{d_n\{2\}(p_{\mathrm{T}}, m_{\mathrm{inv}})}{\sqrt{c_n\{2\}}} \qquad (\mathrm{K}^0_{\mathrm{S}}, \Lambda(\bar{\Lambda}), \phi)$$

- Extract the v_n from invariant mass method

$$v_n^{\mathrm{tot}}(m_{\mathrm{inv}}) = \frac{N^{\mathrm{sig}}(m_{\mathrm{inv}})}{N^{\mathrm{tot}}(m_{\mathrm{inv}})} \cdot v_n^{\mathrm{sig}} + \frac{N^{\mathrm{bg}}(m_{\mathrm{inv}})}{N^{\mathrm{tot}}(m_{\mathrm{inv}})} \cdot v_n^{\mathrm{bg}}(m_{\mathrm{inv}})$$



A Large Ion Collider Experiment



ALICE, JINST **3** S08002 (2008) ALICE, Int.J.Mod.Phys. **A29**, 1430044 (2014)

ALICE, JINST **5** P03003 (2010)

- **Inner Tracking System (ITS)**
  - trigger, tracking

ALICE, Nucl.Instrum.Meth. **A622**, 316 (2010)

- **Time Projection Chamber (TPC)**
  - tracking, particle identification

ALICE, Eur.Phys.J.Plus **128**, 44 (2013)

- **Time Of Flight (TOF)**
  - particle identification

- **V0** ALICE, JINST **8** P10016 (2013)
  - trigger
  - event multiplicity estimation

- **Data sets:**
  - Pb-Pb @ 5.02 TeV
  - Xe-Xe @ 5.44 TeV
  - p-Pb @ 5.02 TeV
  - pp @ 13 TeV

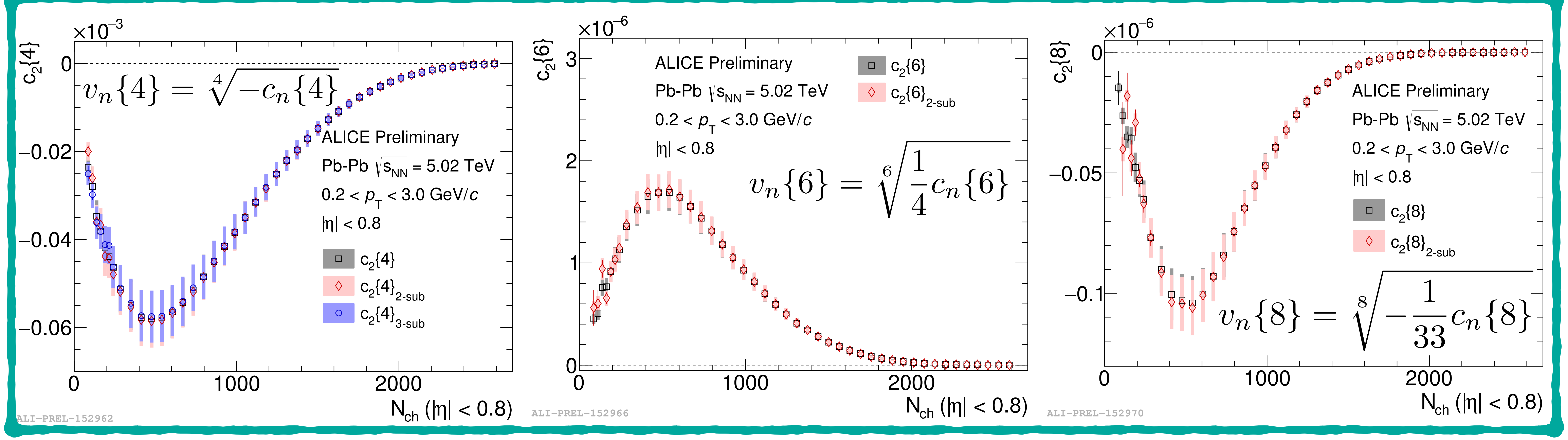
Collectivity in heavy-ion collisions

Charged particles

Experimental working definition:

Collectivity = long-range multi-particle correlations

$v_2\{m\} \sim v_2\{m\}_{sub}$



Collectivity in heavy-ion collisions

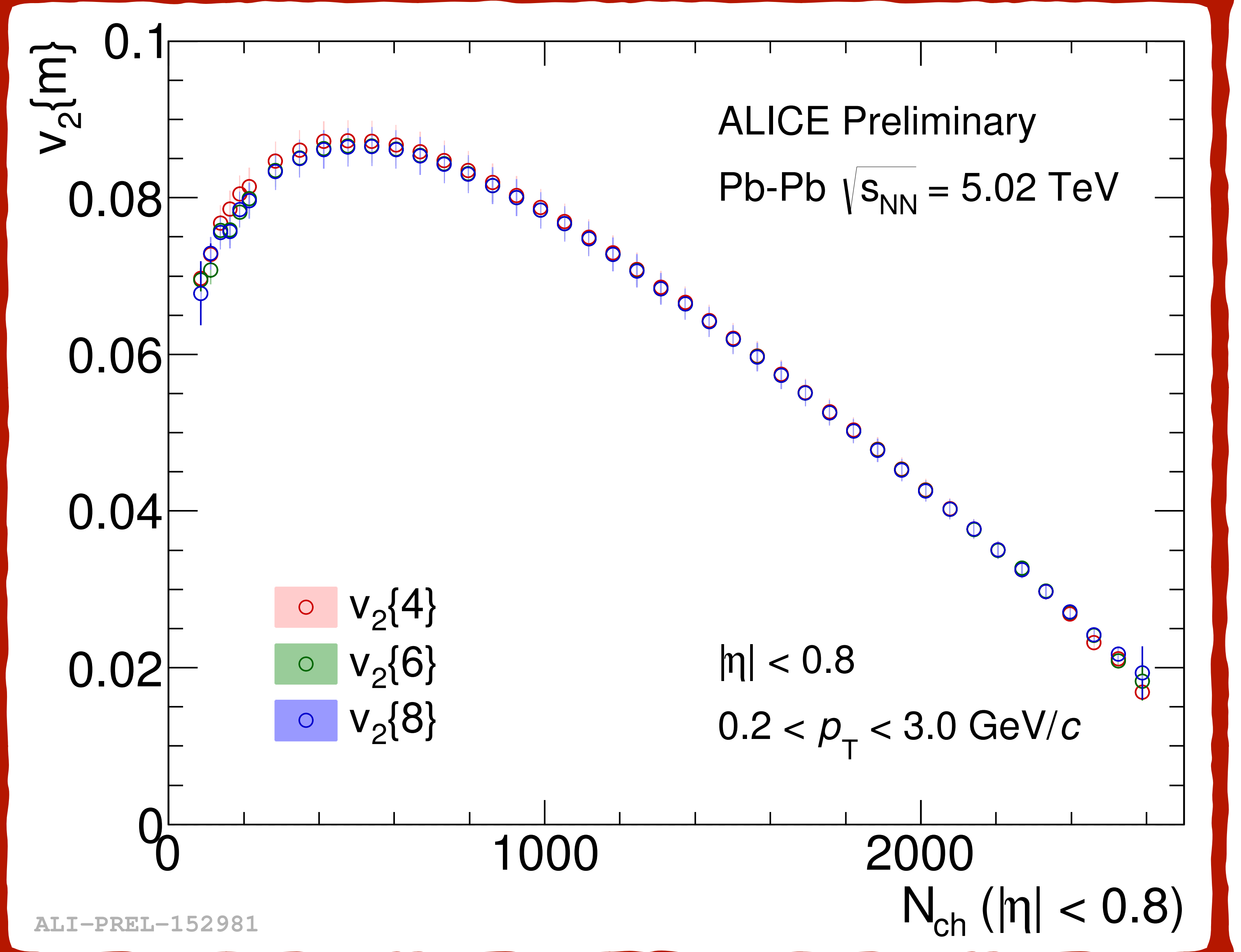
Charged particles

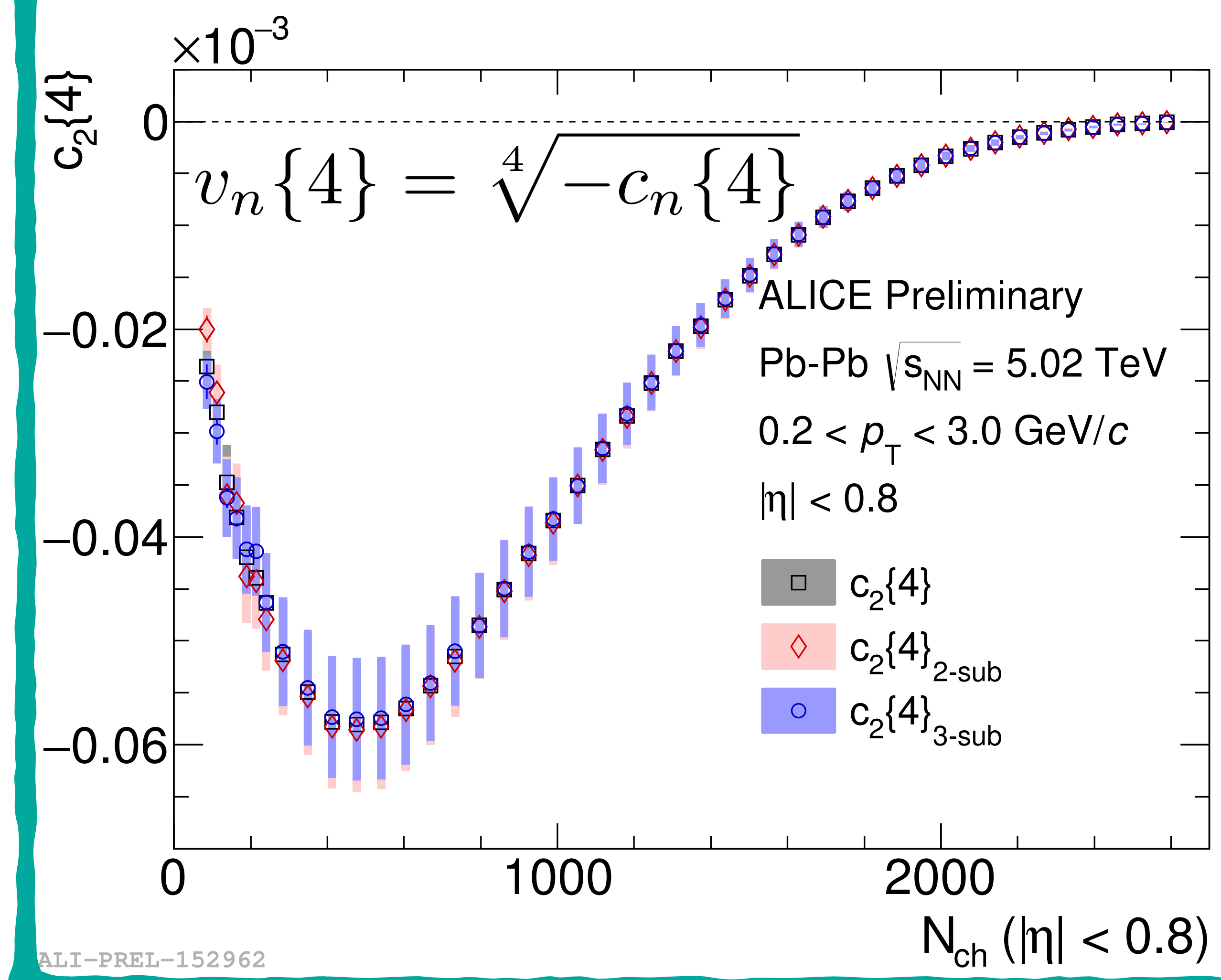
Experimental working definition:

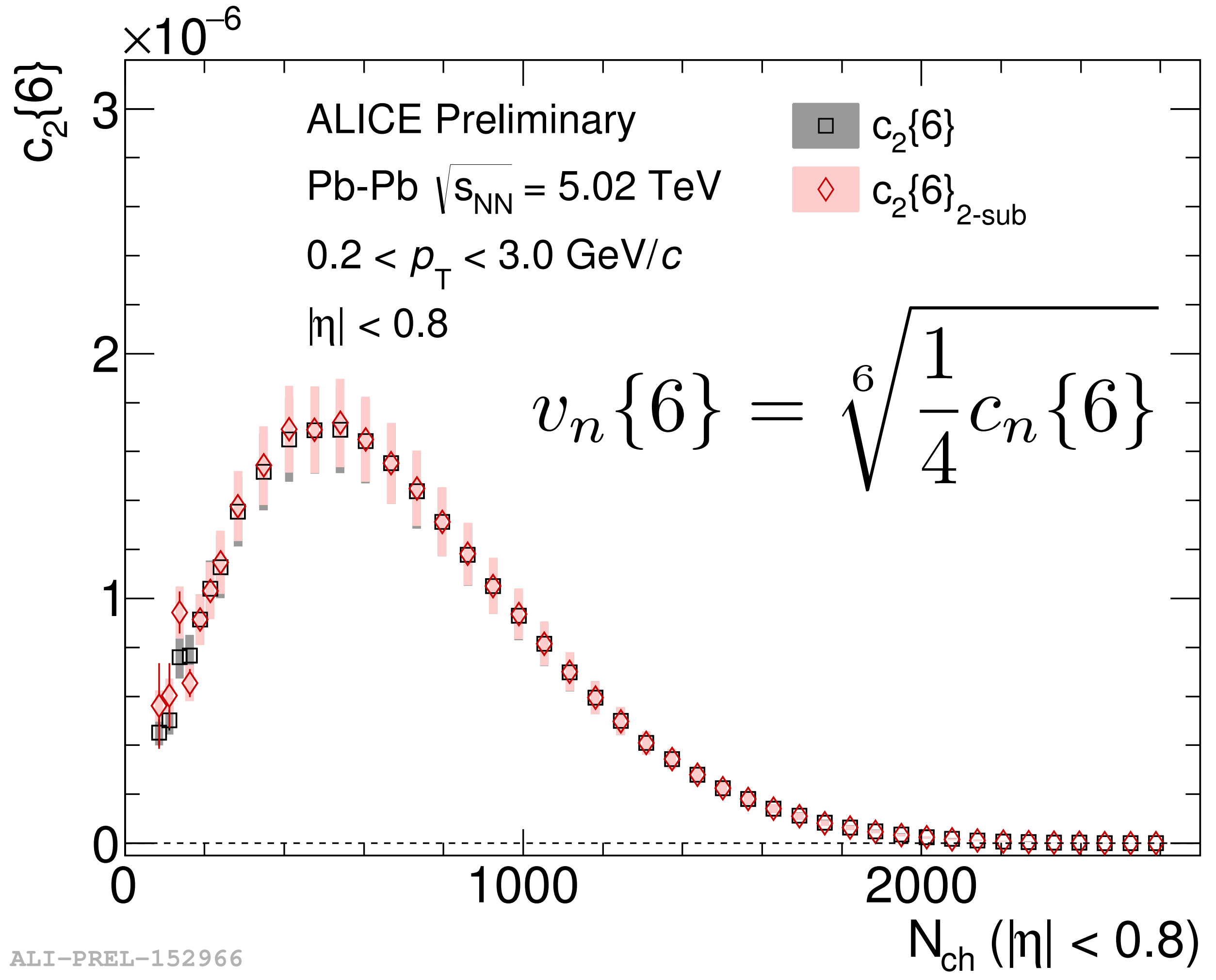
Collectivity = long-range multi-particle correlations

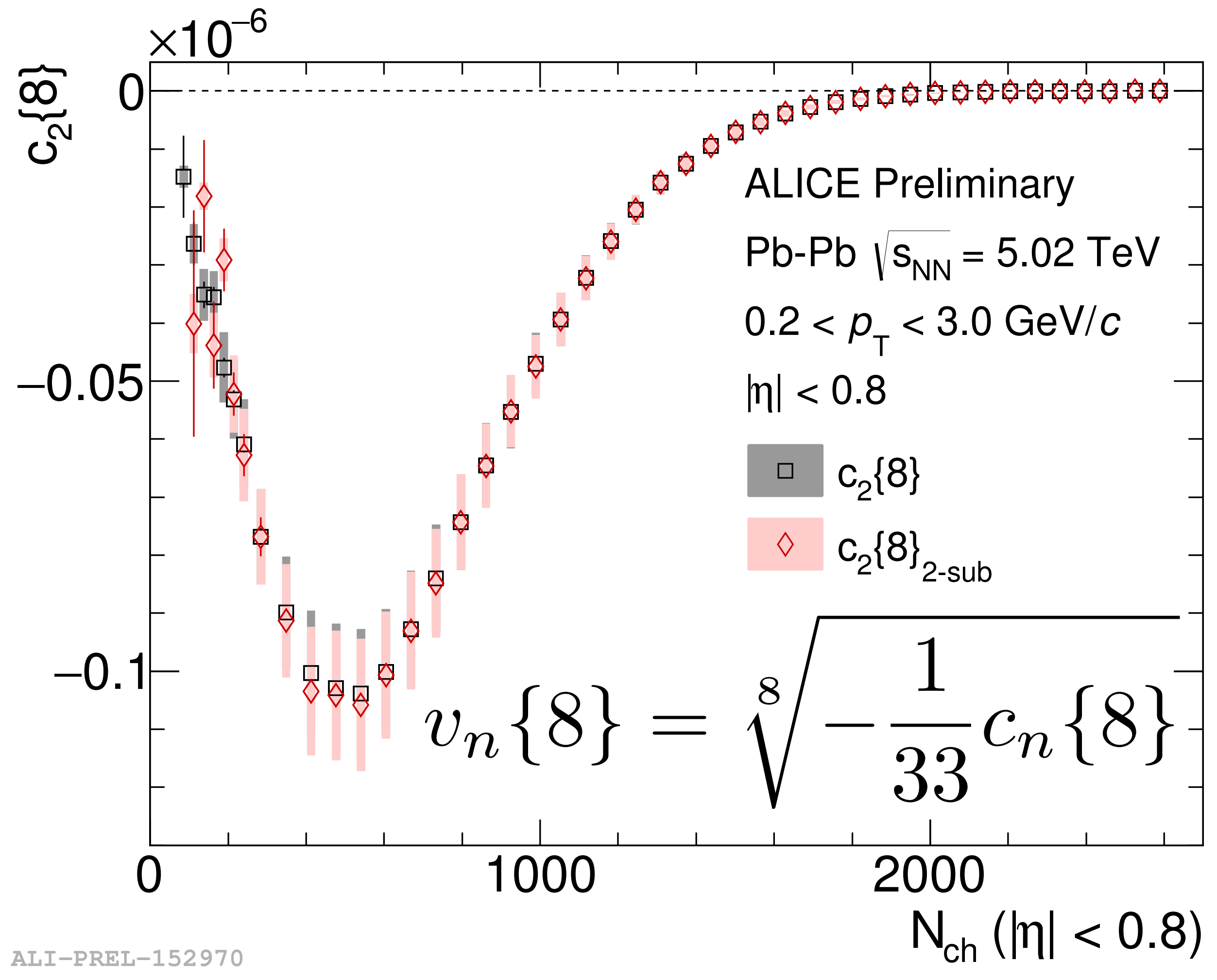
$v_2\{m\} \sim v_2\{m\}_{sub}$

$v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$





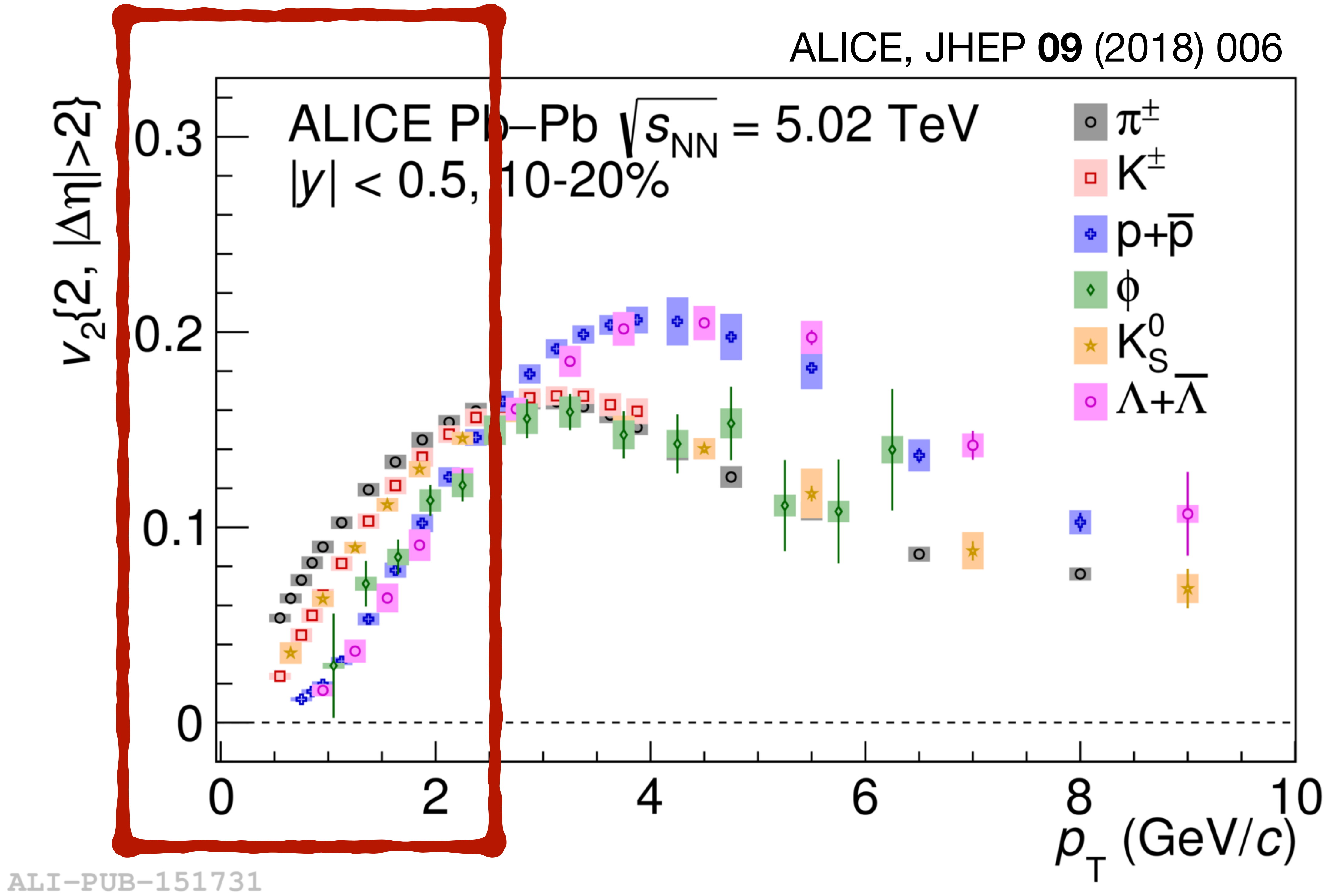




Collectivity in heavy-ion collisions

Identified particles

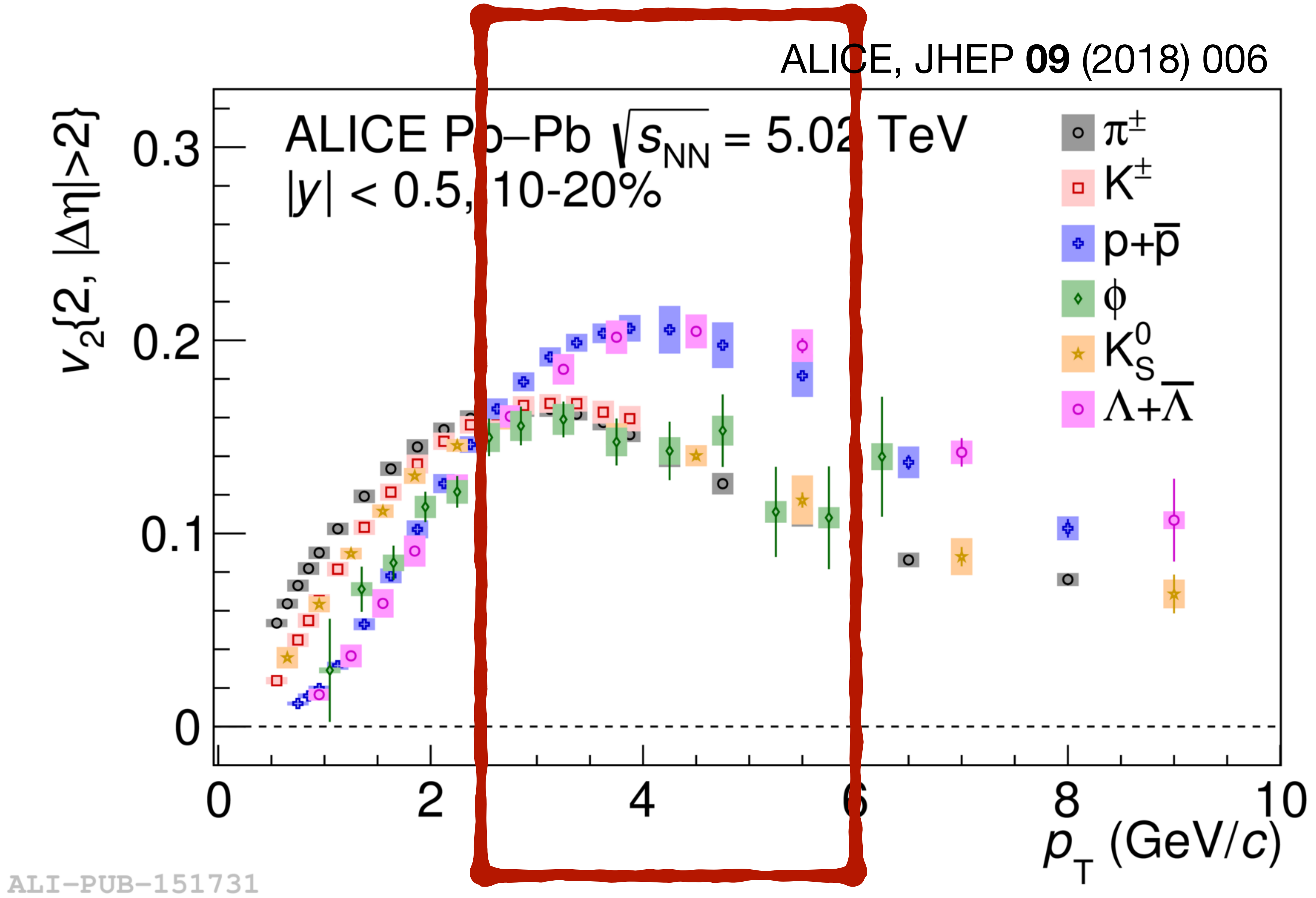
- **Mass ordering** (at low p_T)
  - Originates from hydrodynamic flow and hadron re-scattering in the hadronic phase



Collectivity in heavy-ion collisions

Identified particles

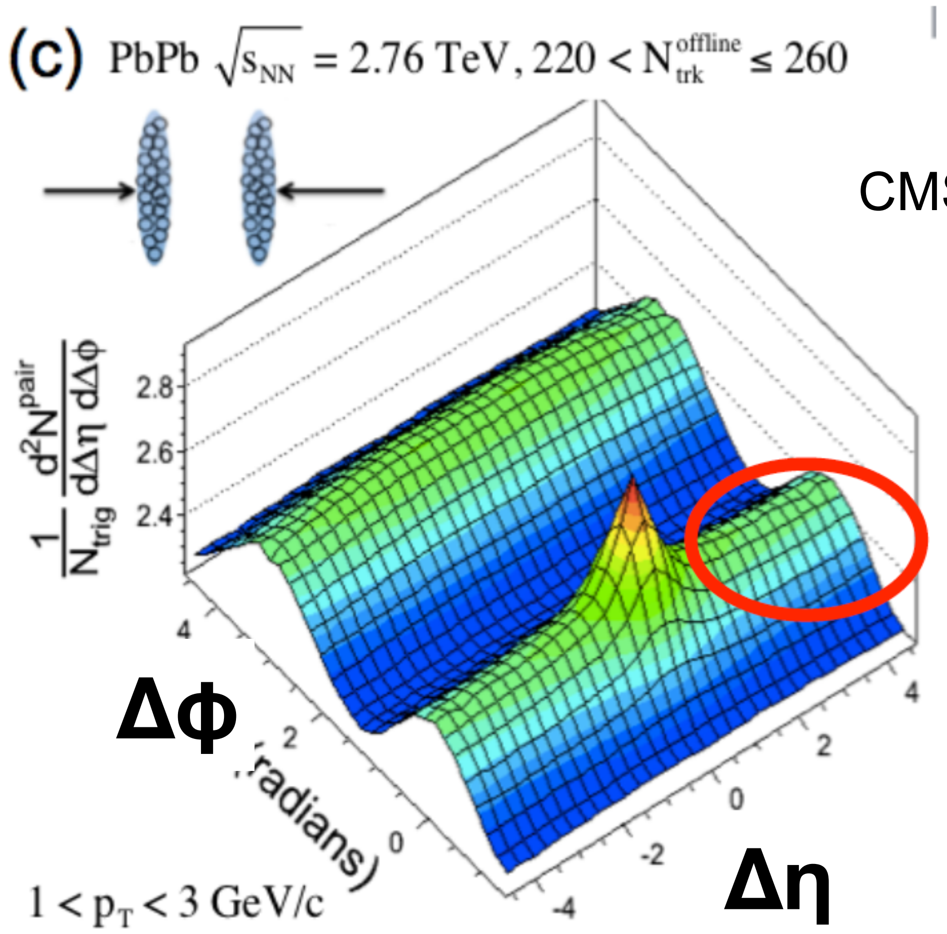
- **Mass ordering** (at low p_T)
  - Originates from hydrodynamic flow and hadron re-scattering in the hadronic phase
- **Baryon-meson grouping** (at intermediate p_T)
  - Originates from recombination or coalescence -> partonic collectivity



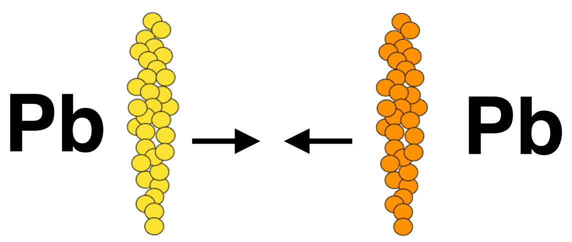
Collectivity in small systems ?

- Original understanding:
  - Large collision systems -> QGP

Flow:

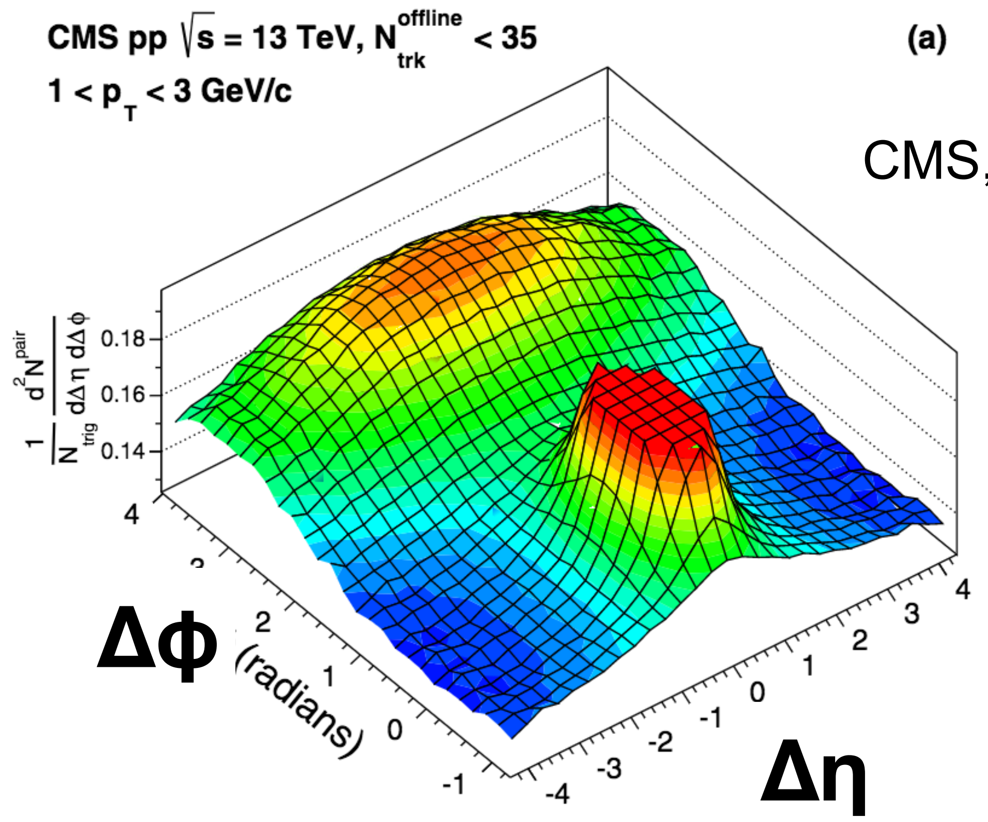


CMS, PLB 724 (2013) 213

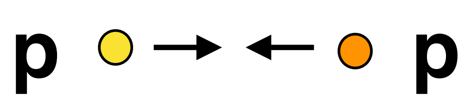


  - Small collision systems -> no QGP -> baseline & Cold Nuclear Matter (CNM)

No flow:



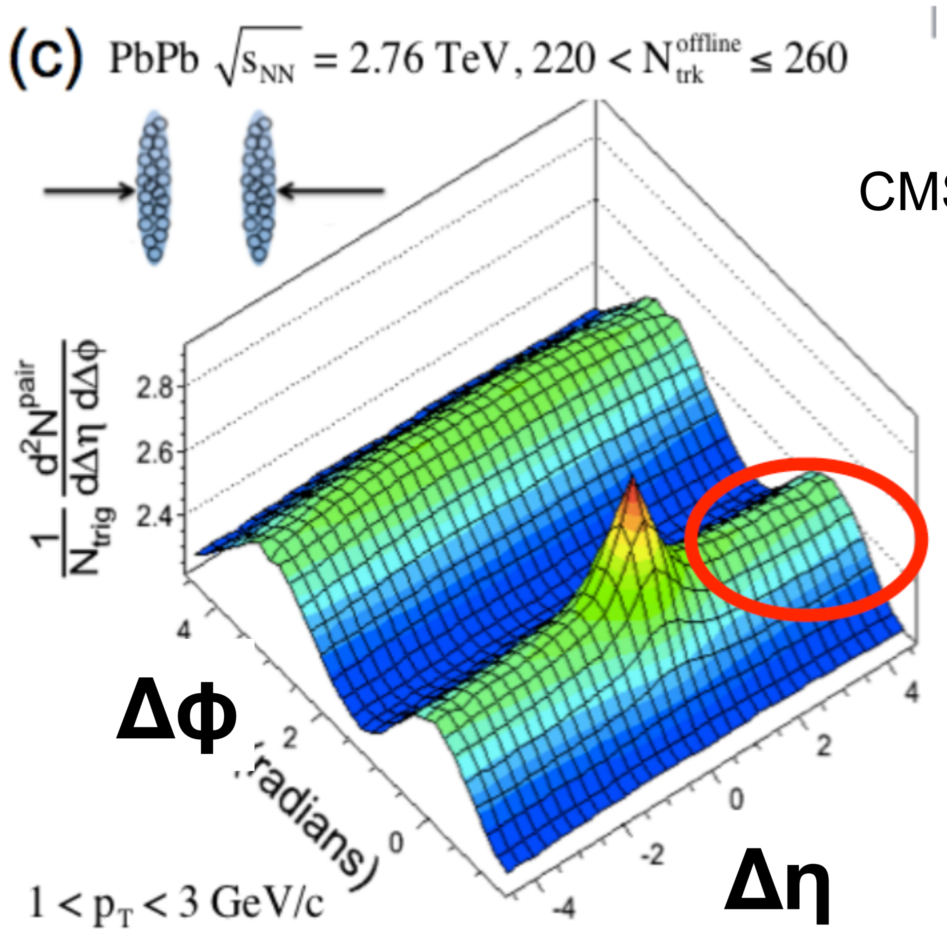
CMS, PRL 116, 172302 (2016)



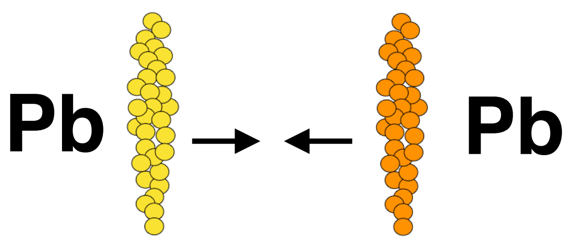
Collectivity in small systems ?

- Original understanding:
  - Large collision systems -> QGP

Flow:

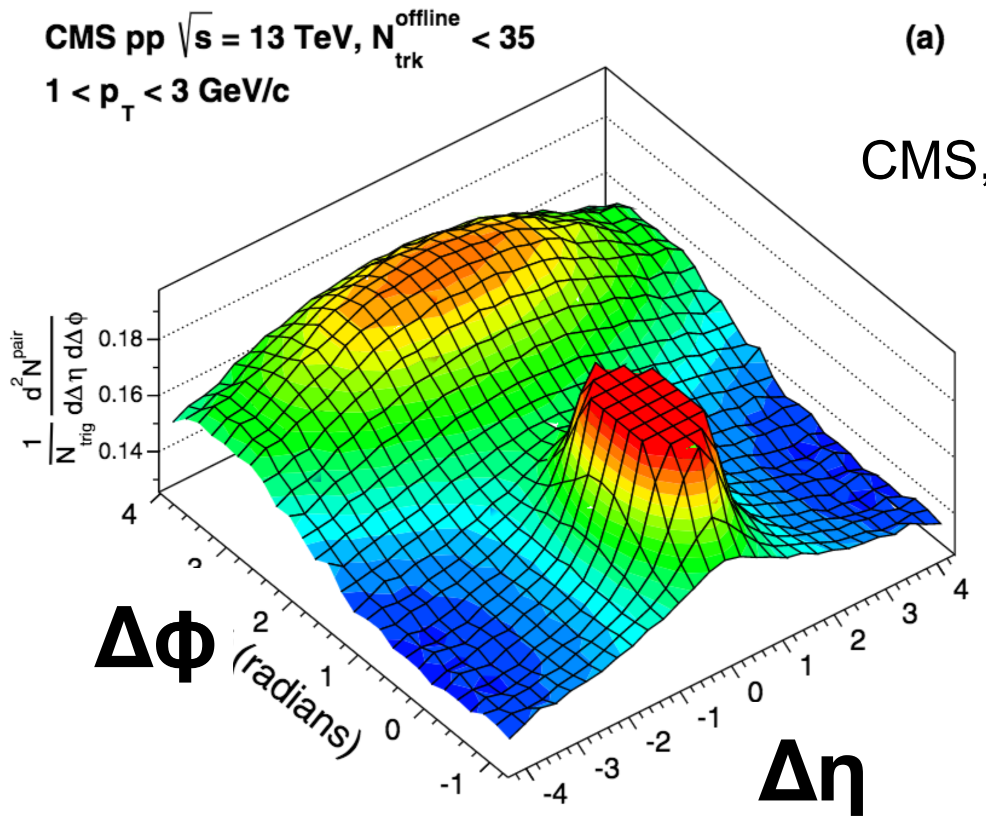


CMS, PLB 724 (2013) 213

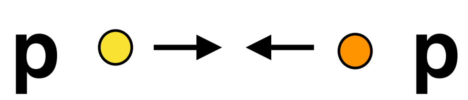


  - Small collision systems -> no QGP -> baseline & Cold Nuclear Matter (CNM)

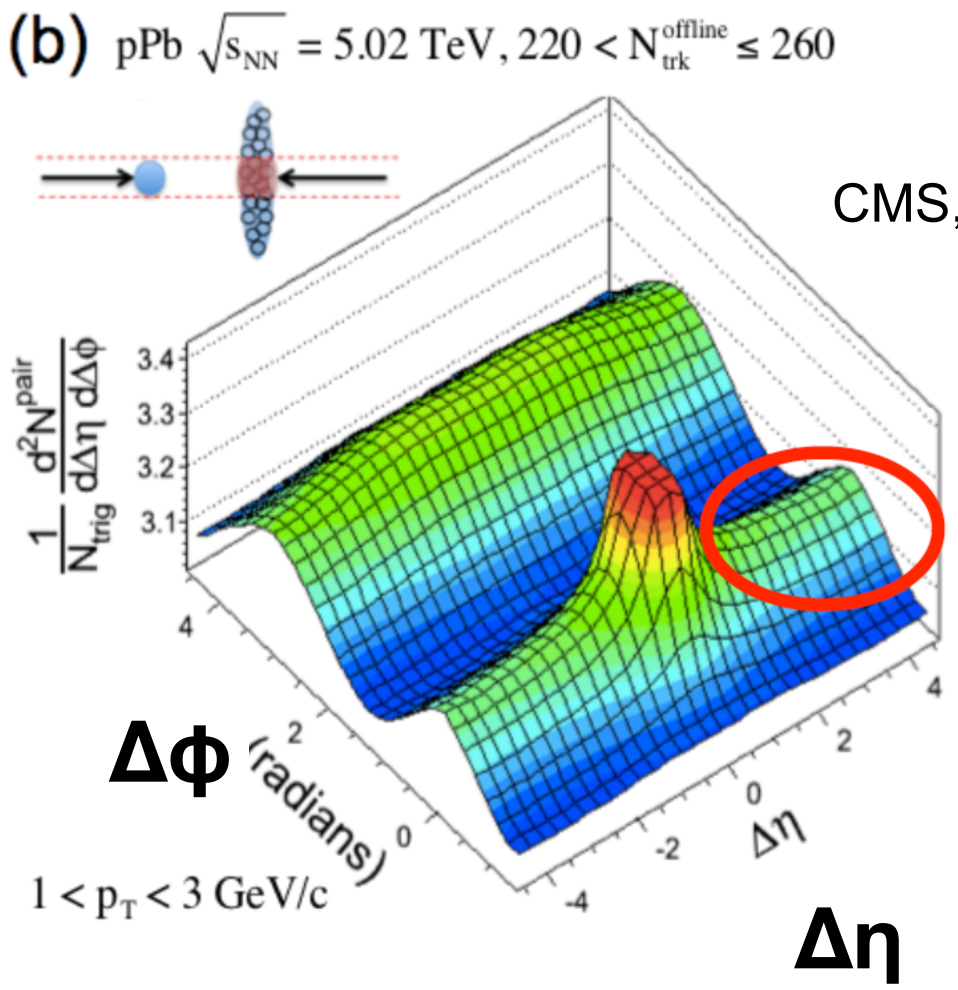
No flow:



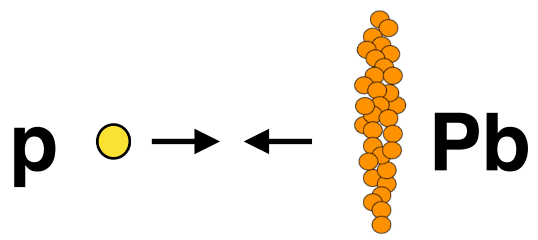
CMS, PRL 116, 172302 (2016)

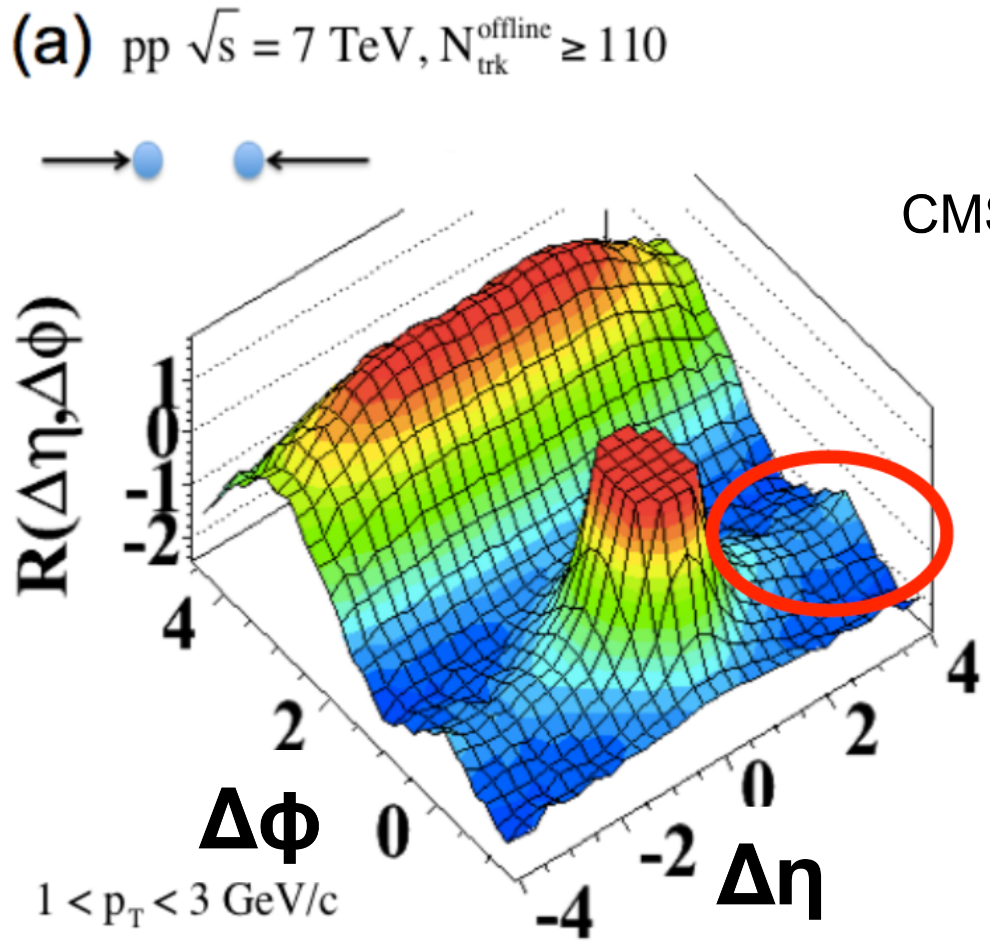


- Need for new understanding:
  - Large collision systems -> QGP
  - Small collision systems at high multiplicity -> ?

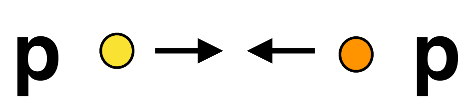


CMS, PLB 724 (2013) 213



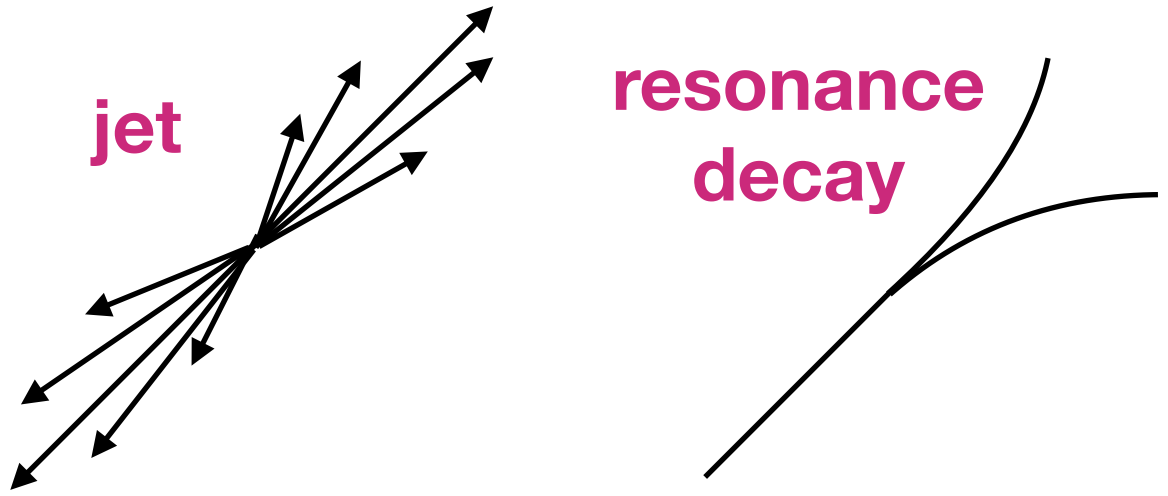


CMS, JHEP 09 (2010) 091



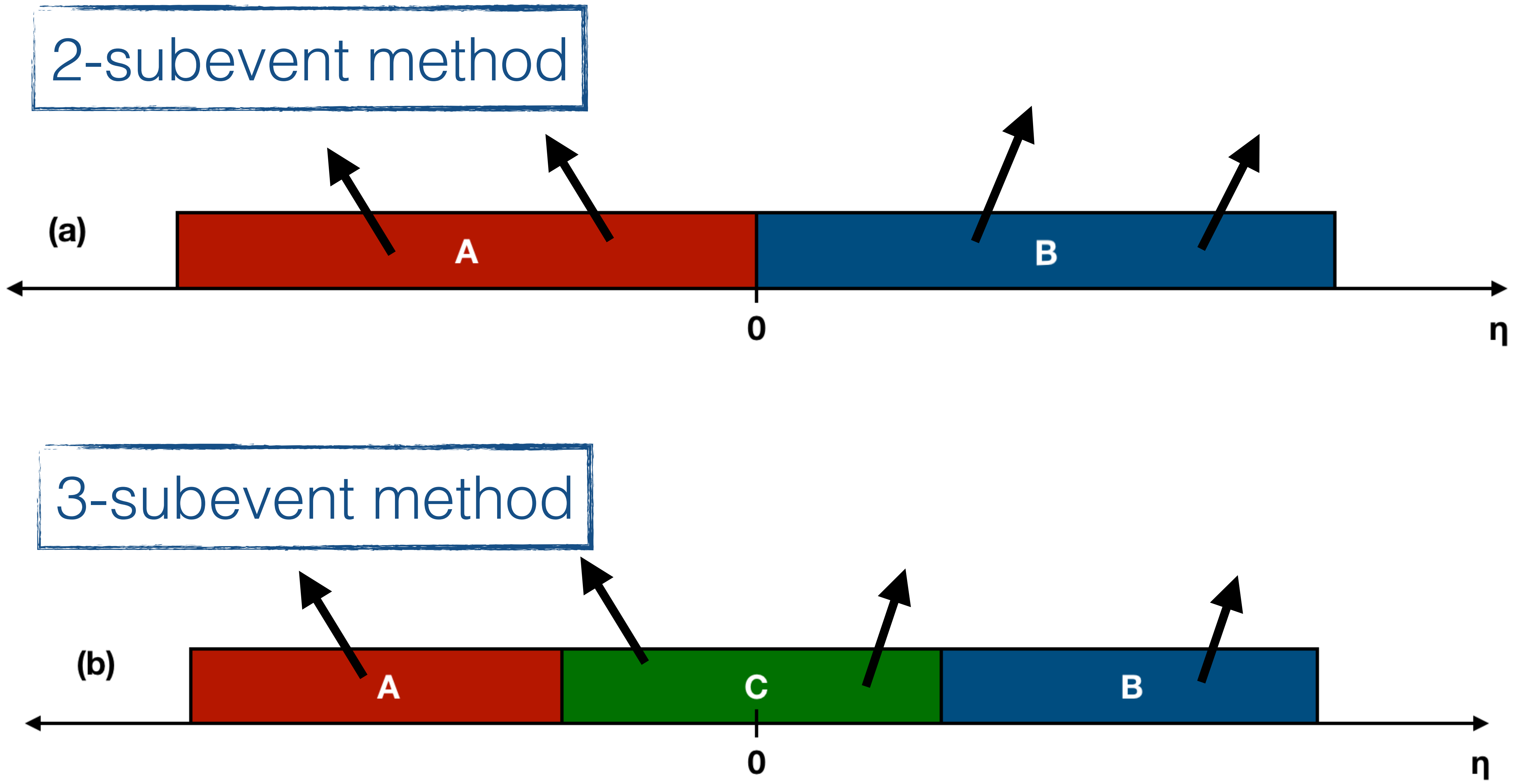
Non-flow effects - challenge in small collision systems

- **Non-flow**: correlations not associated with the common symmetry plane
  - Jets, resonance decays, …

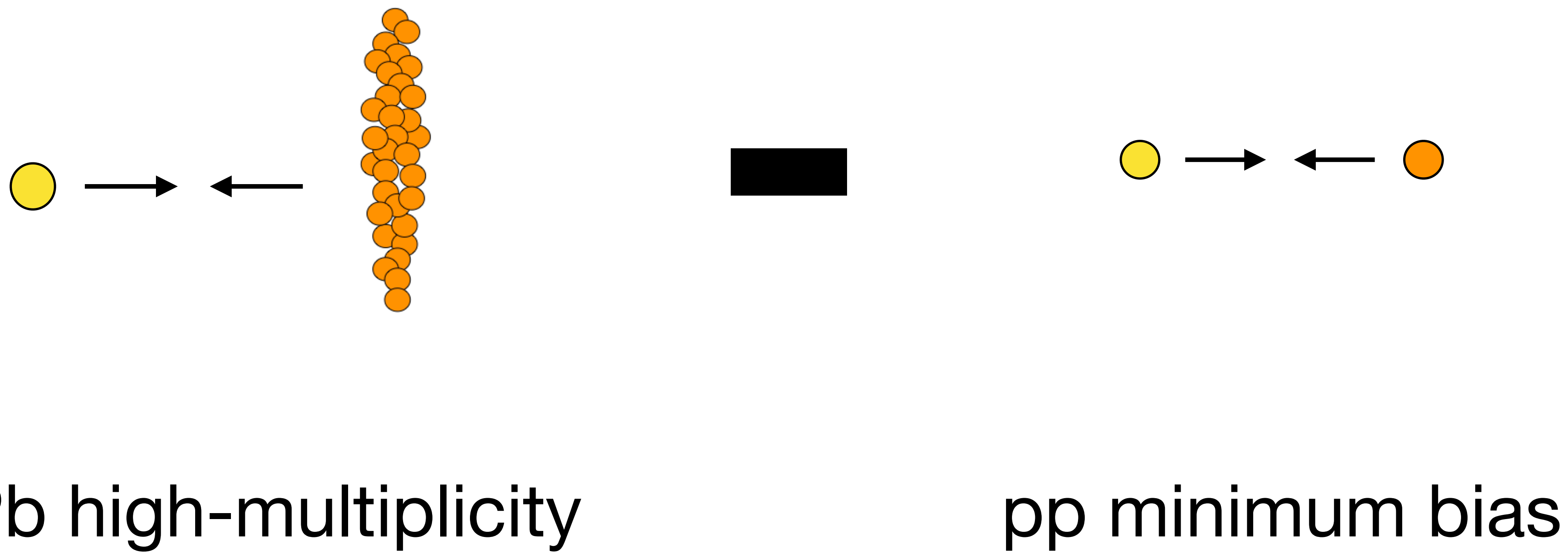


- **Subevent method**: suppresses non-flow effects in *m*-particle correlations
- Tested with PYTHIA calculations

J. Jia *et al.* PRC 96, 034906 (2017), P. Huo *et al.* PLB 777 (2018) 201

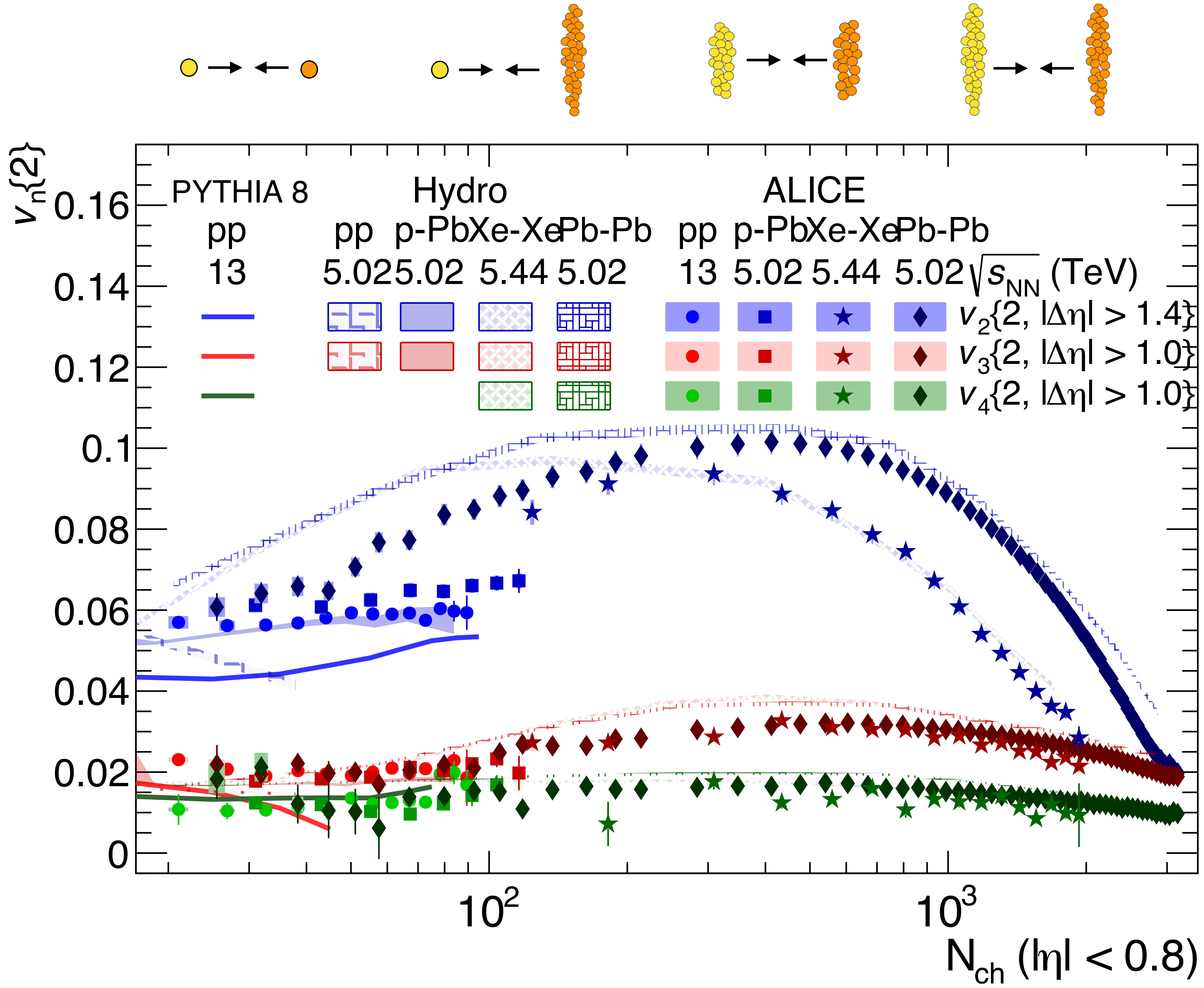


- **Subtraction method**: subtracts minimum-bias pp collisions (which are expected to be dominated by non-flow effects)



Flow coefficients $v_n\{2\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



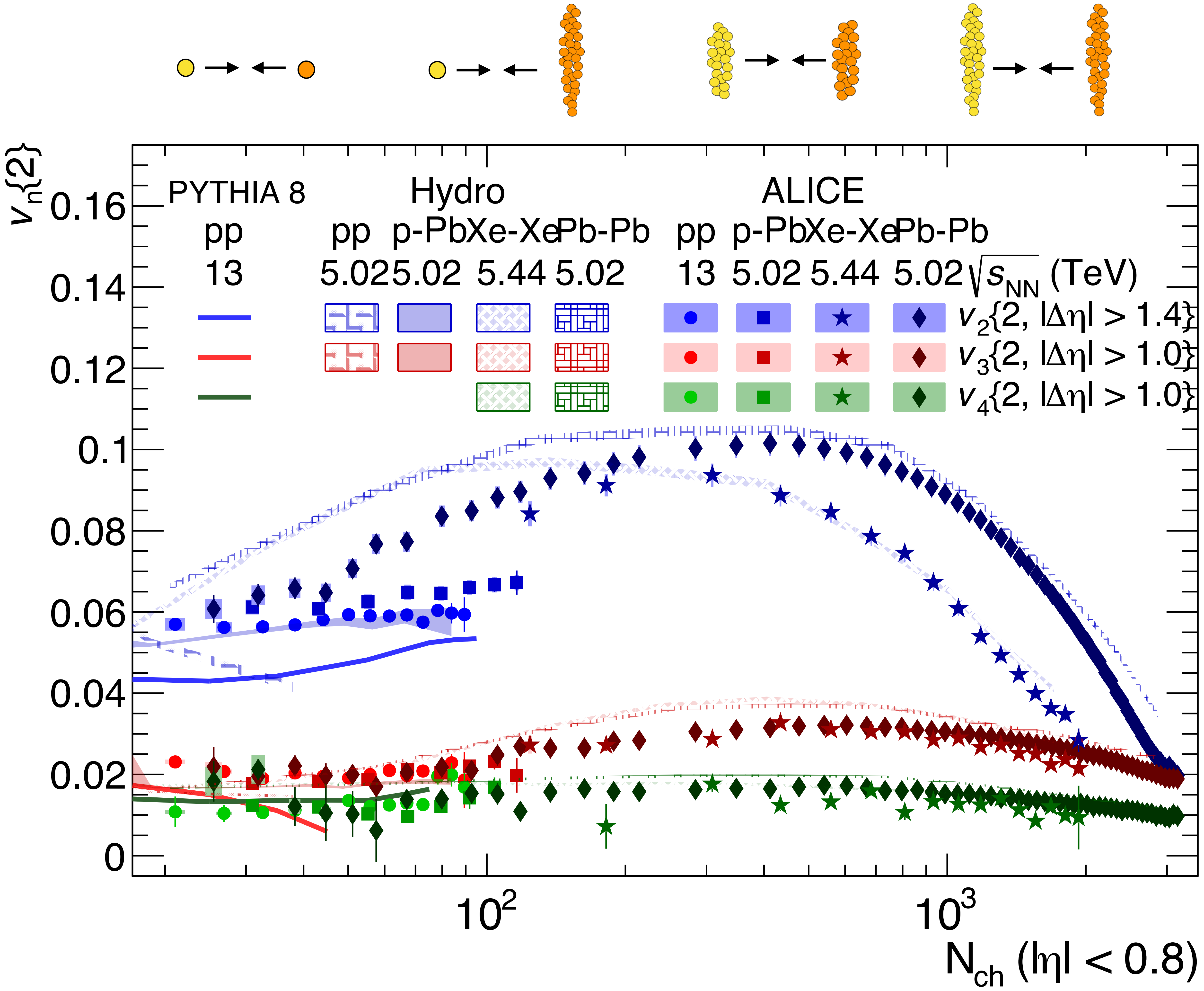
large collision systems

- Strong N_{ch} dependence of v_2
  - Reflecting the overlap geometry and strength of interactions
- Ordering **v_2** > **v_3** > **v_4**, except for very high N_{ch} (fluctuation dominant region)

Charged particles

Flow coefficients $v_n\{2\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



large collision systems

- Strong N_{ch} dependence of v_2
  - Reflecting the overlap geometry and strength of interactions
- Ordering $v_2 > v_3 > v_4$, except for very high N_{ch} (fluctuation dominant region)

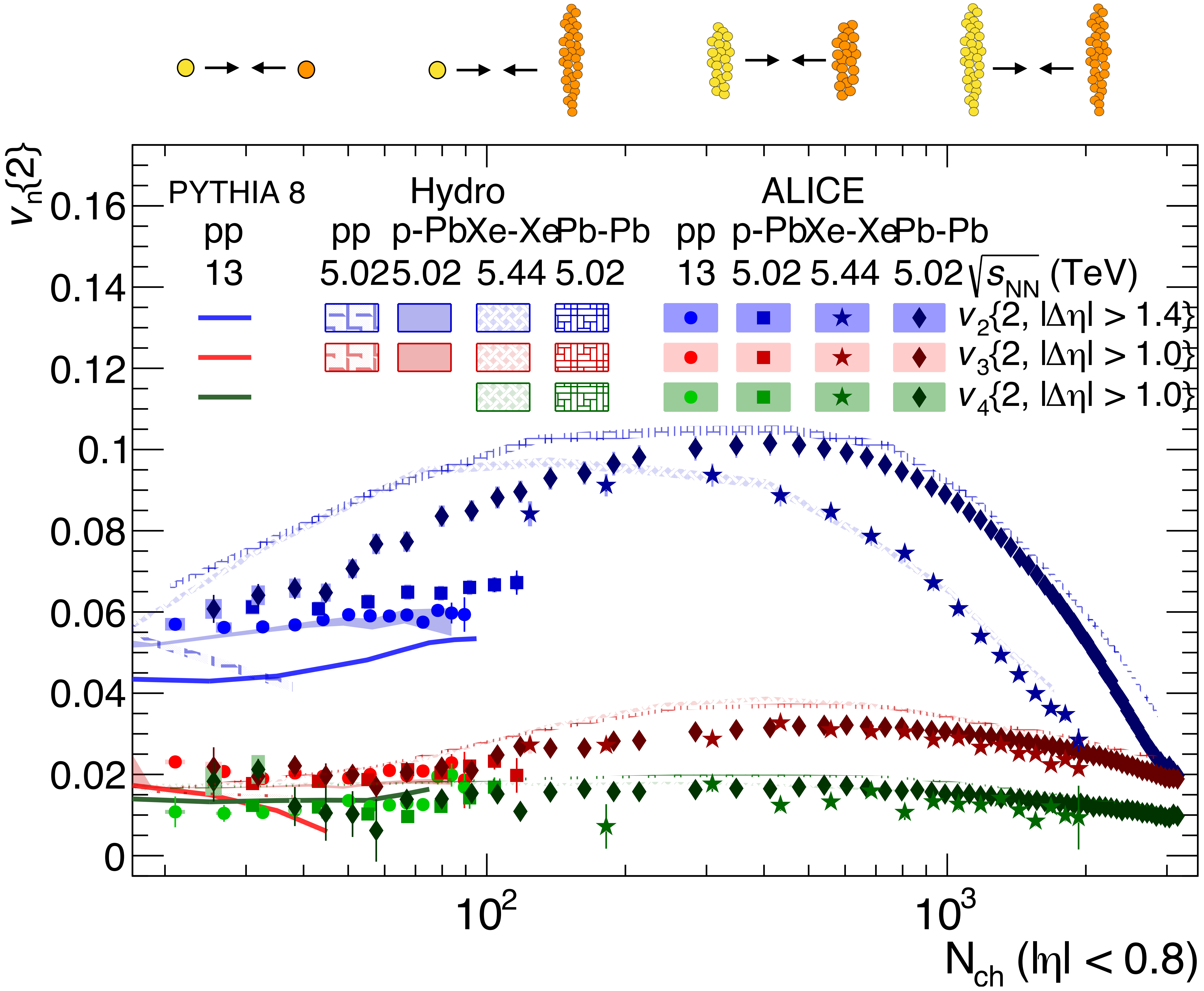
small collision systems

- At low N_{ch} v_n are compatible with large collision systems
- Weak v_n dependence on N_{ch} in pp and p-Pb collisions
- Ordering $v_2 > v_3 > v_4$

Flow coefficients $v_n\{2\}$

model comparison

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



PYTHIA 8.210 Monash 2013: Sjöstrand *et al.*, Comput.Phys.Commun. **191**, 159 (2015)

large collision systems

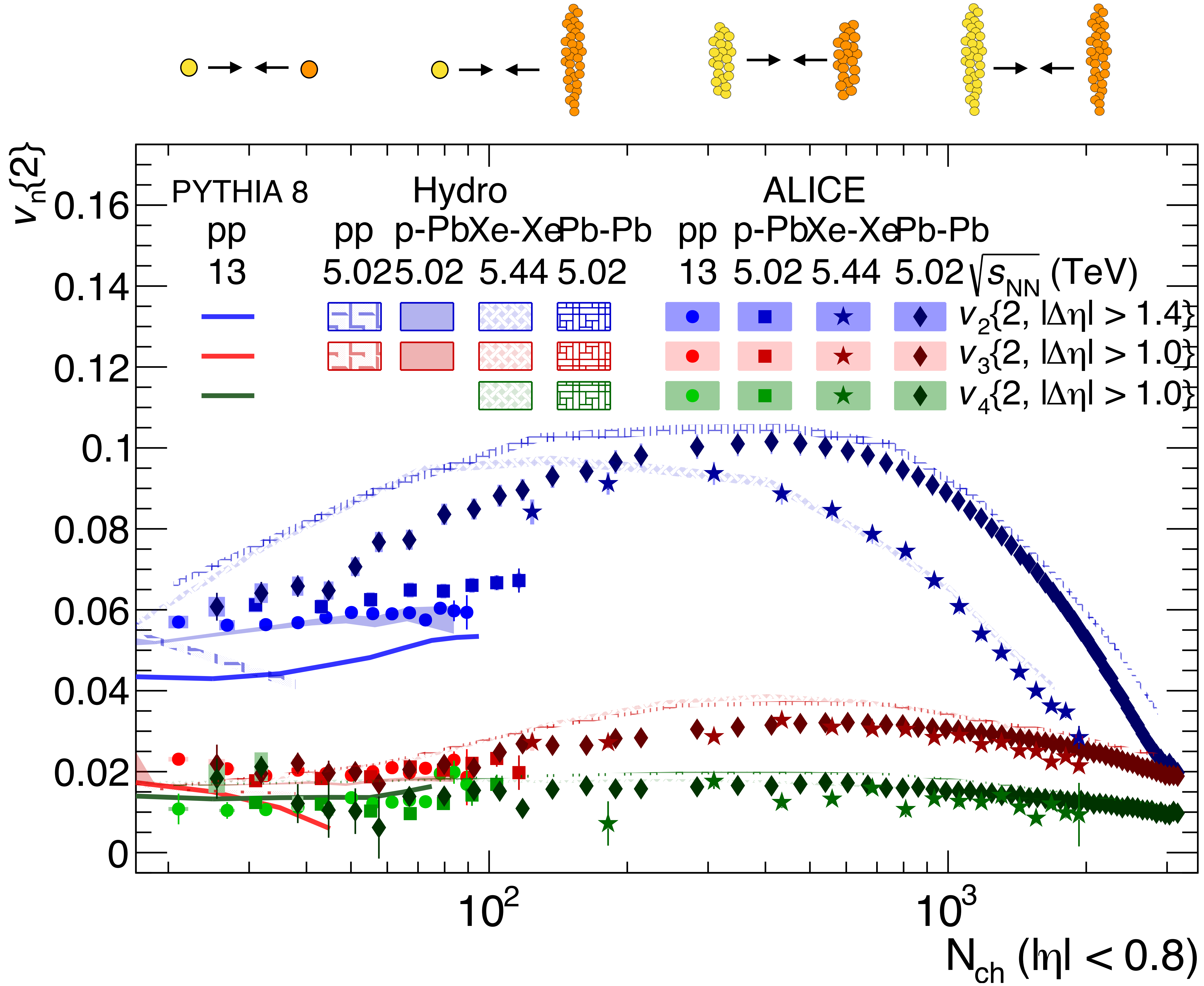
small collision systems

- Cannot be explained solely by non-flow (PYTHIA 8 model)

Flow coefficients $v_n\{2\}$

model comparison

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



large collision systems

- Hydrodynamic calculations:
  - Almost quantitative agreement with both Pb-Pb and Xe-Xe collisions
  - Largely overestimate v_2 at low N_{ch}

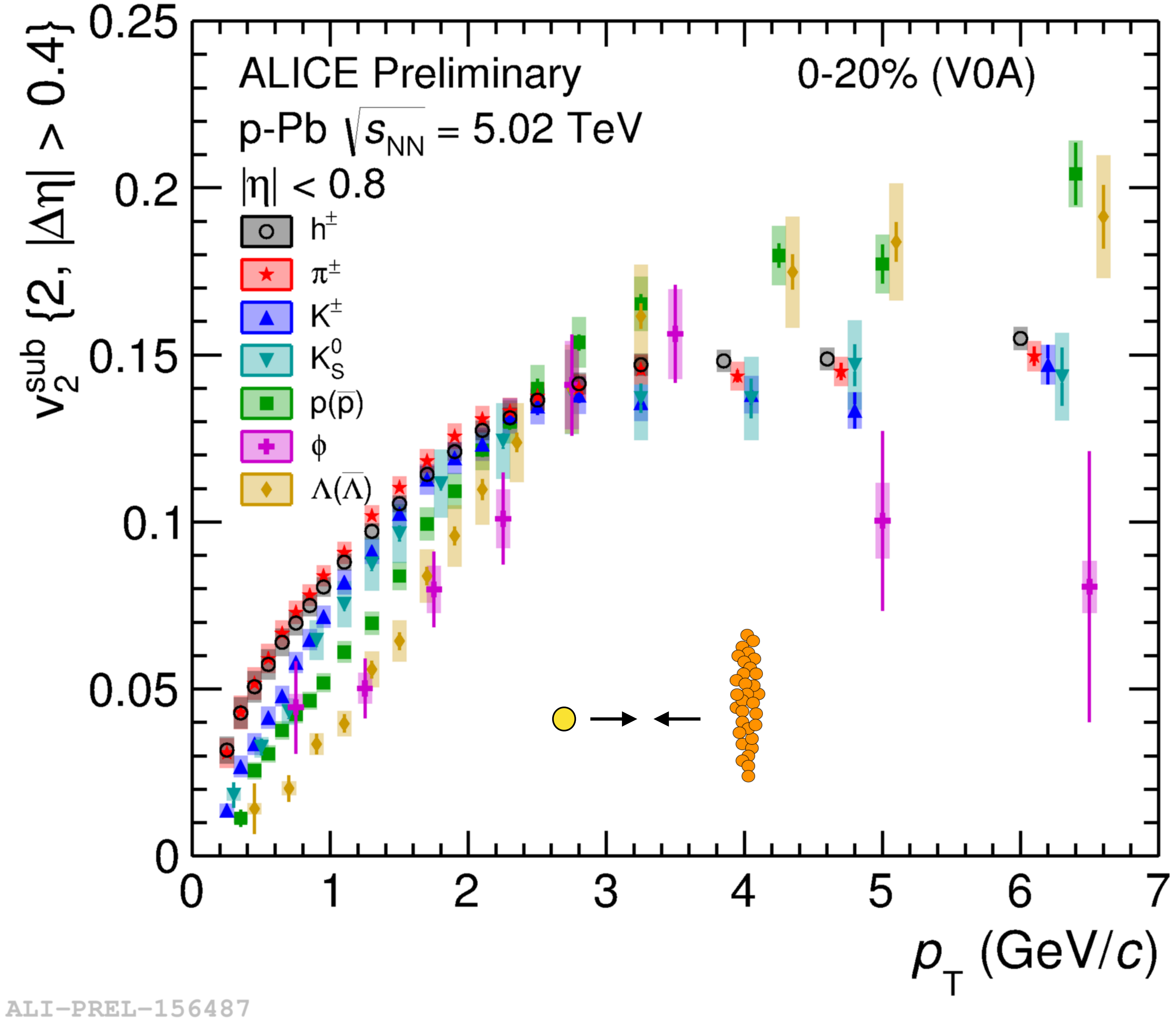
small collision systems

- Cannot be explained solely by non-flow (PYTHIA 8 model)
- Hydrodynamic calculations:
  - Almost quantitative agreement in p-Pb collisions
  - Model fails to describe pp collisions

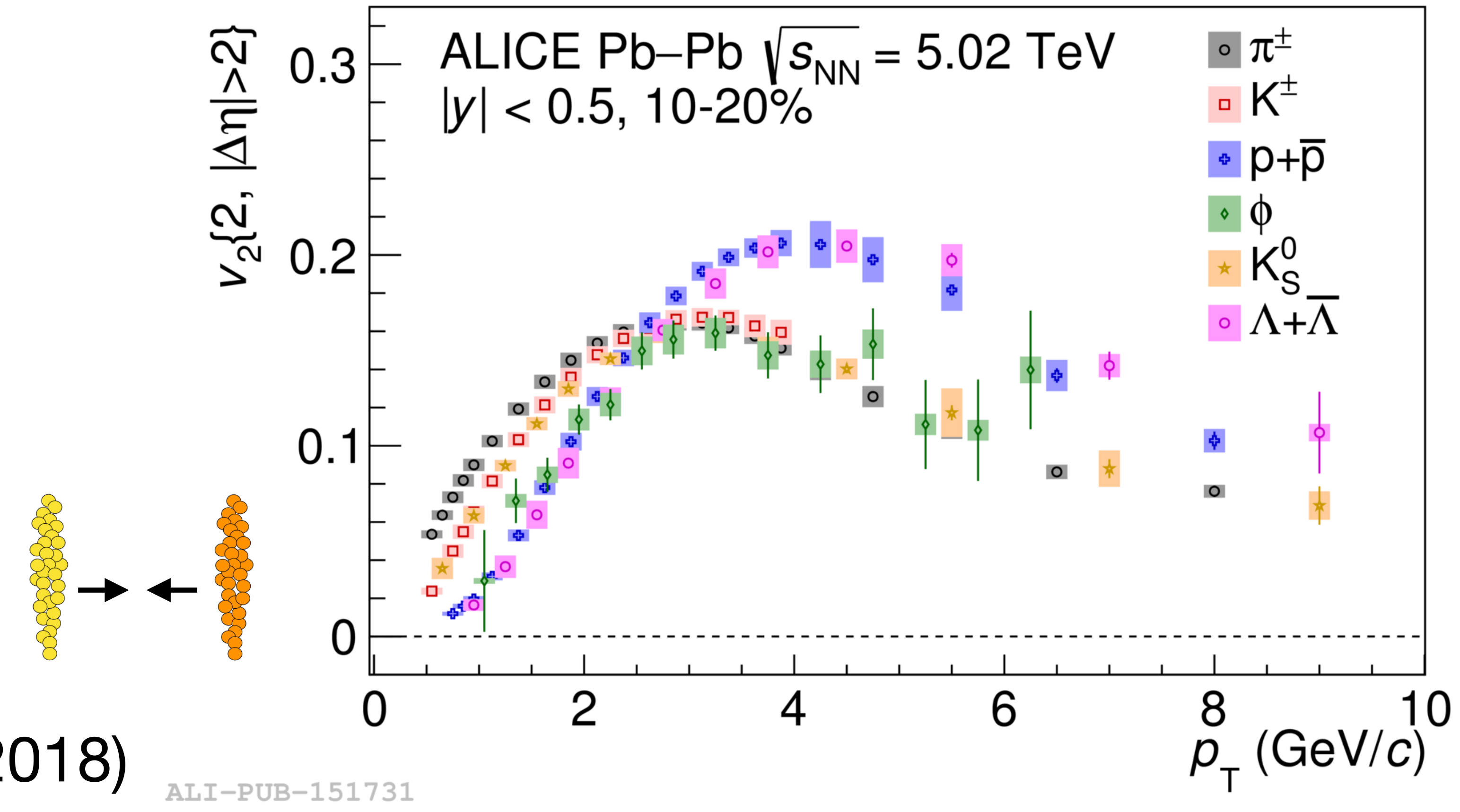
PYTHIA 8.210 Monash 2013: Sjöstrand *et al.*, Comput.Phys.Commun. **191**, 159 (2015)

IP-Glasma+MUSIC+UrQMD: Schenke *et al.* PRC**89**, 024901 (2014), Mäntysaari *et al*. PLB**772**, 681 (2017)

Flow coefficients $v_n\{2\}$



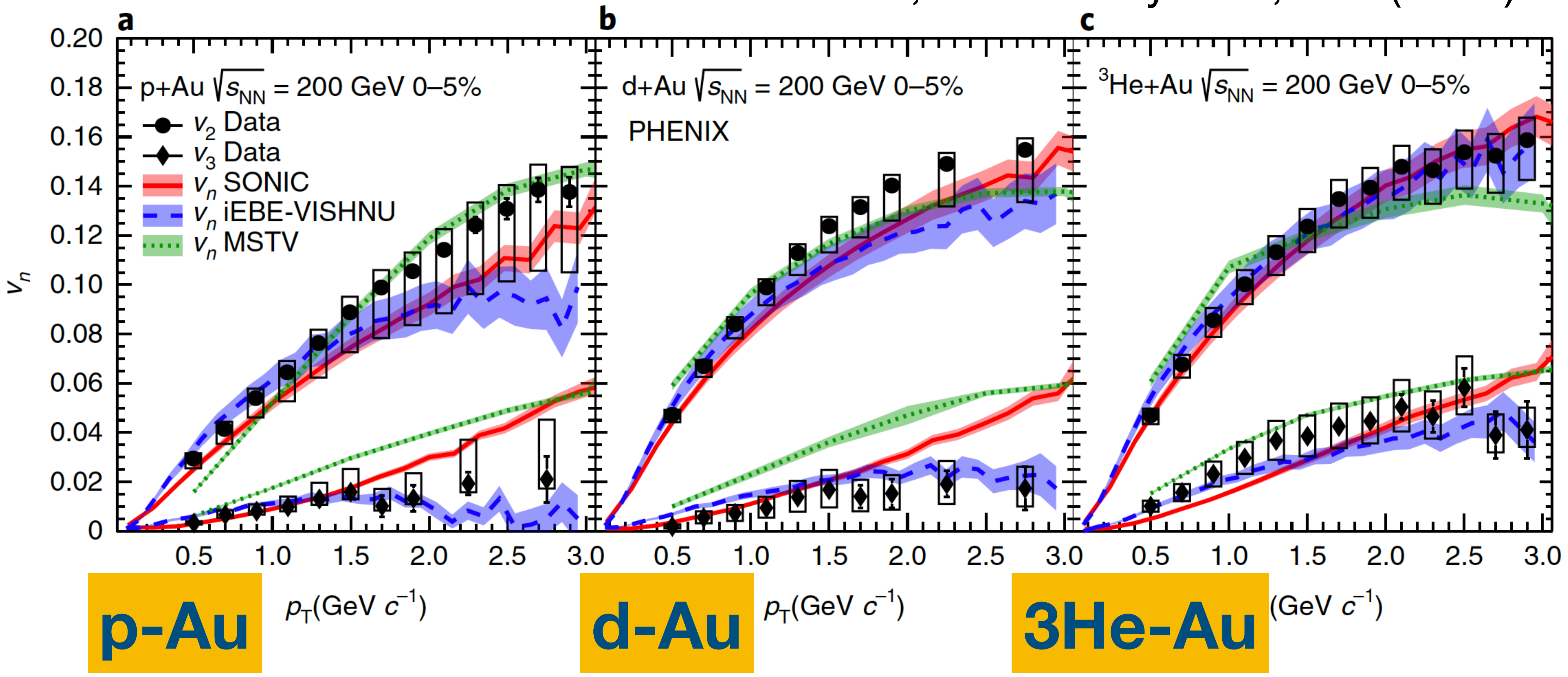
- Similar observations as in Pb-Pb measurements
  - Clear **mass ordering** at low p_T
  - Indication of **baryon/meson grouping** at intermediate p_T



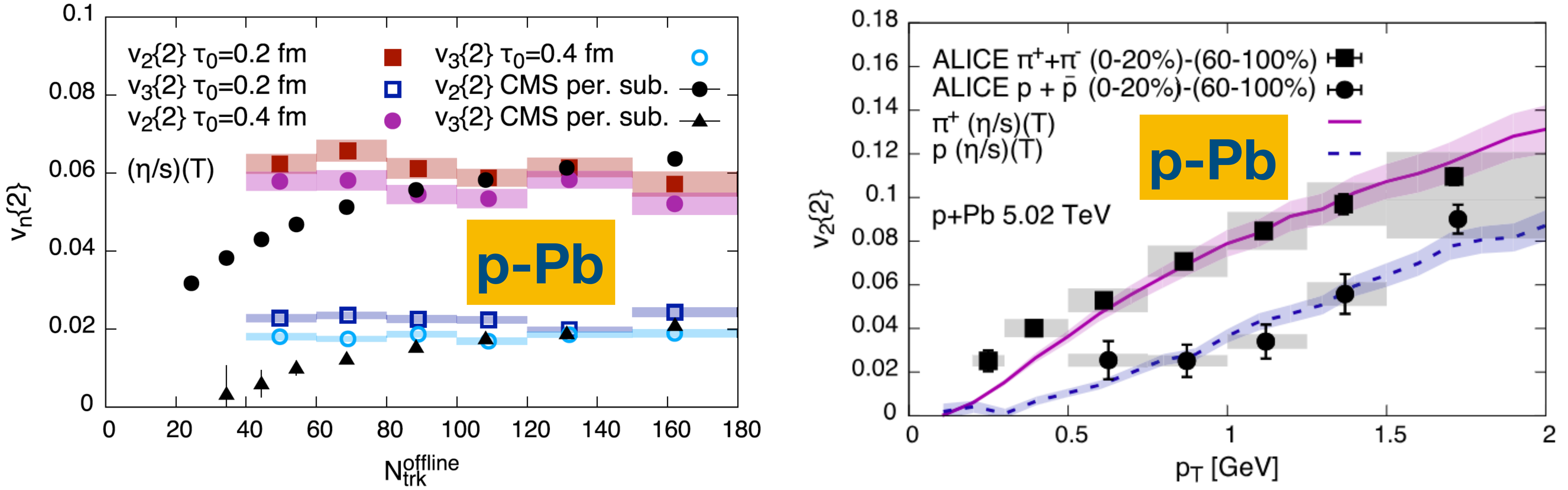
ALICE, JHEP09, 006 (2018)

Description by (some) other models two-particle correlations

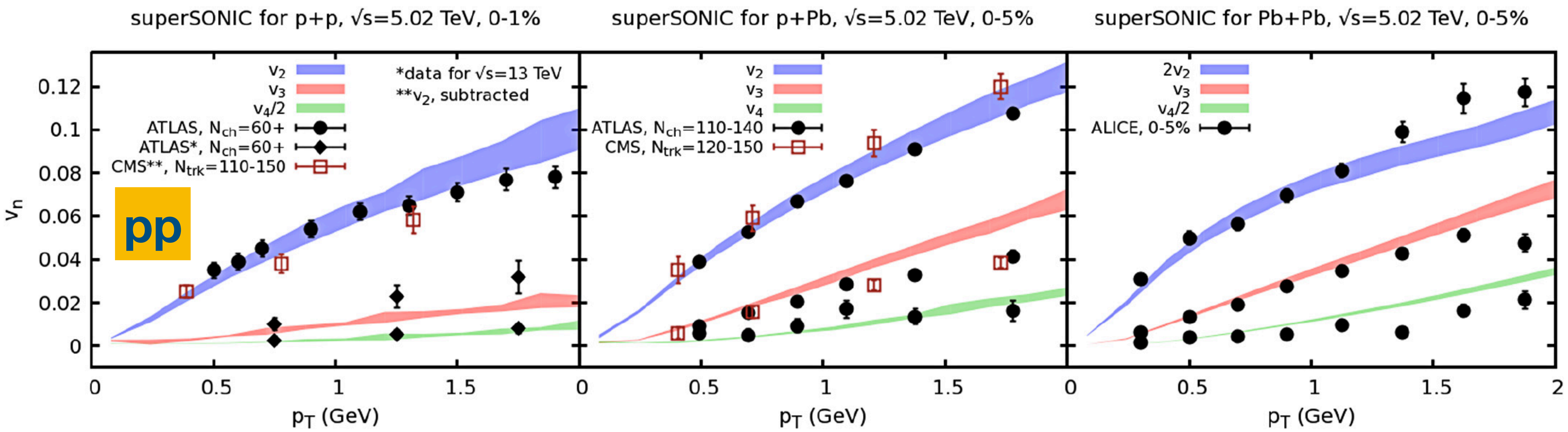
PHENIX, Nature Phys. 15, 214 (2019)



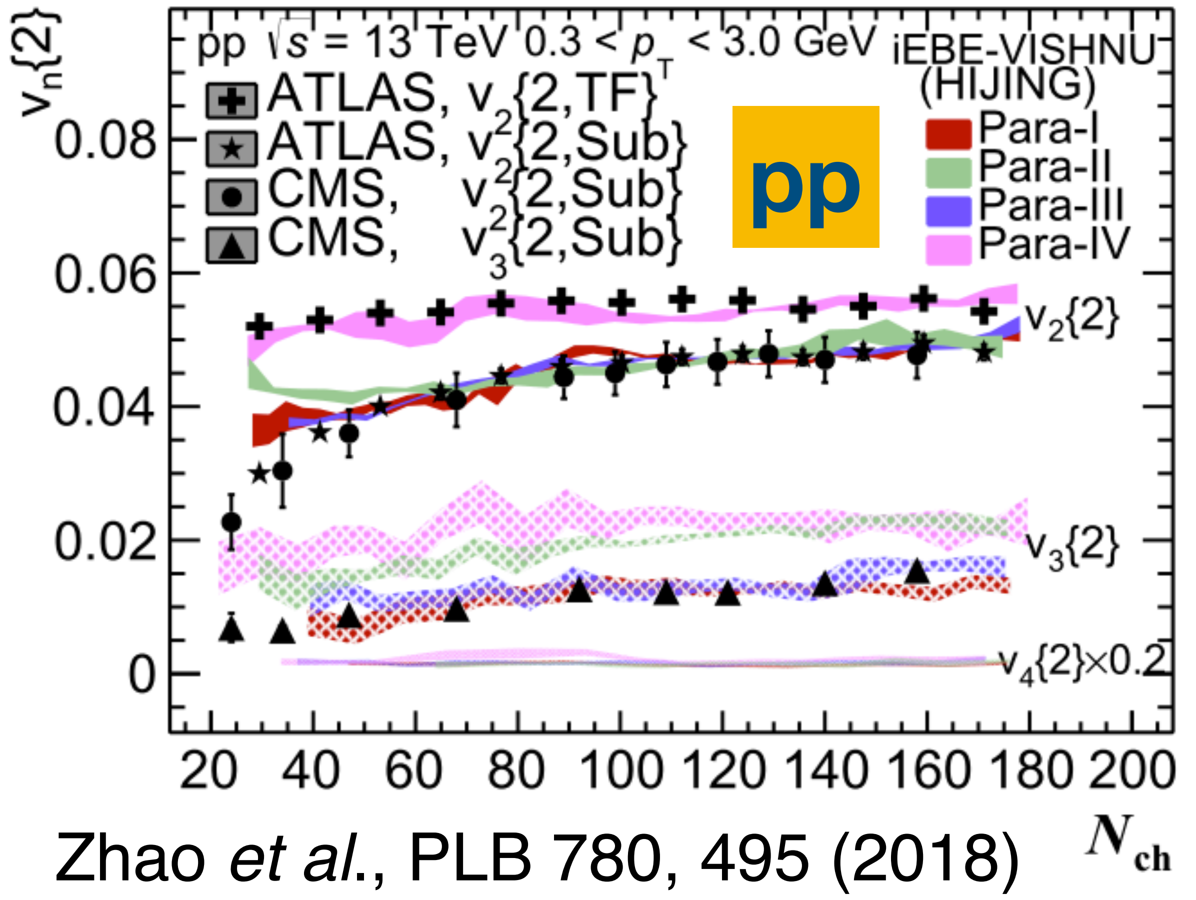
Mäntysaari *et al.*, PLB 772, 681 (2017)



- Hydrodynamics reproduces measurements of pA, dA, 3HeA collisions
- Some hydrodynamic models describe even measurements in pp collisions



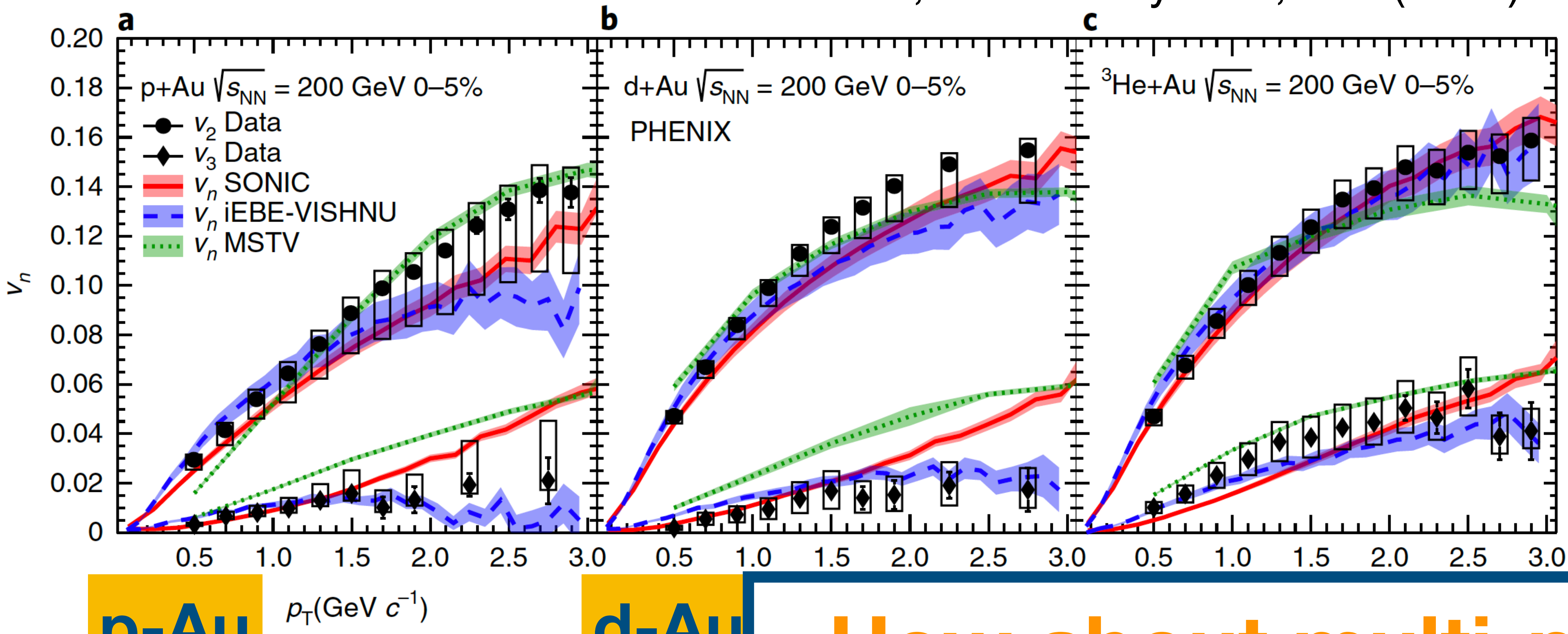
Weller, Romatschke, PLB 774, 351 (2017)



Zhao *et al.*, PLB 780, 495 (2018)

Description by (some) other models two-particle correlations

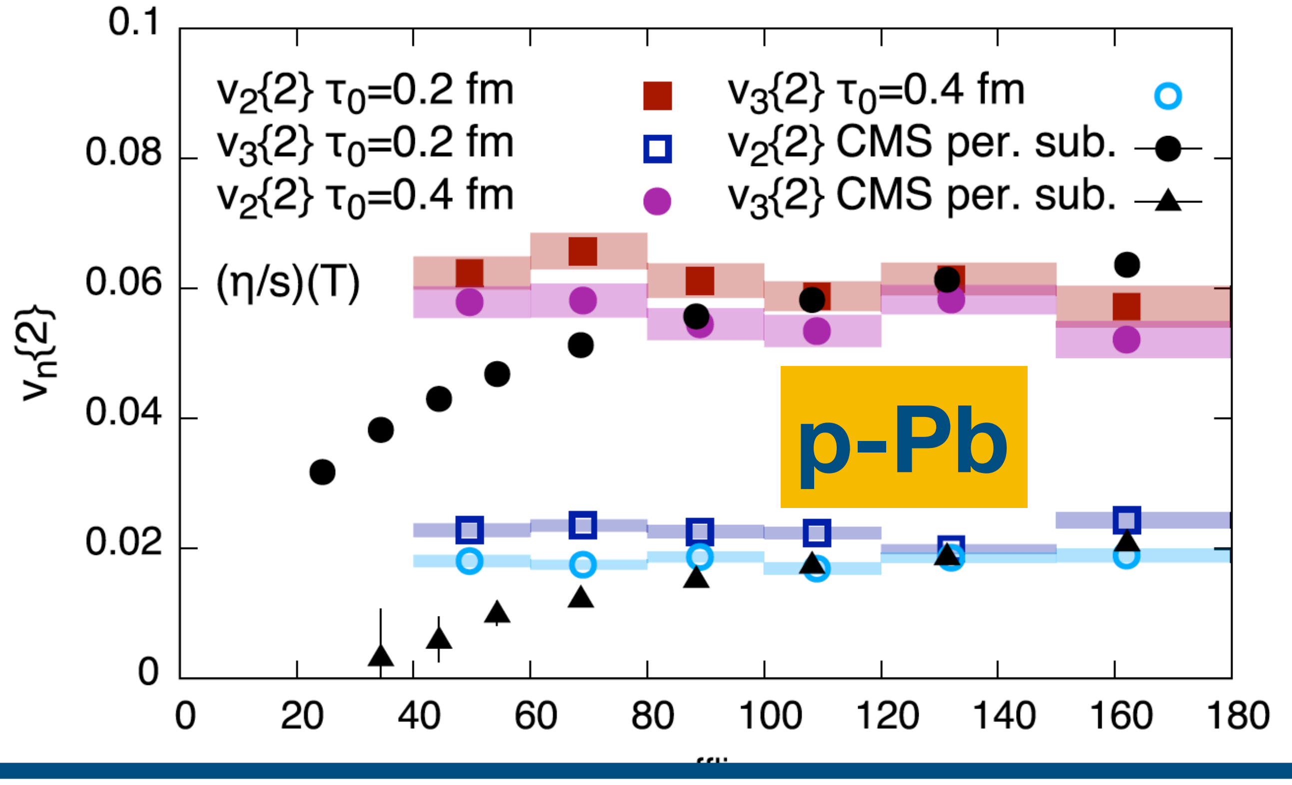
PHENIX, Nature Phys. 15, 214 (2019)



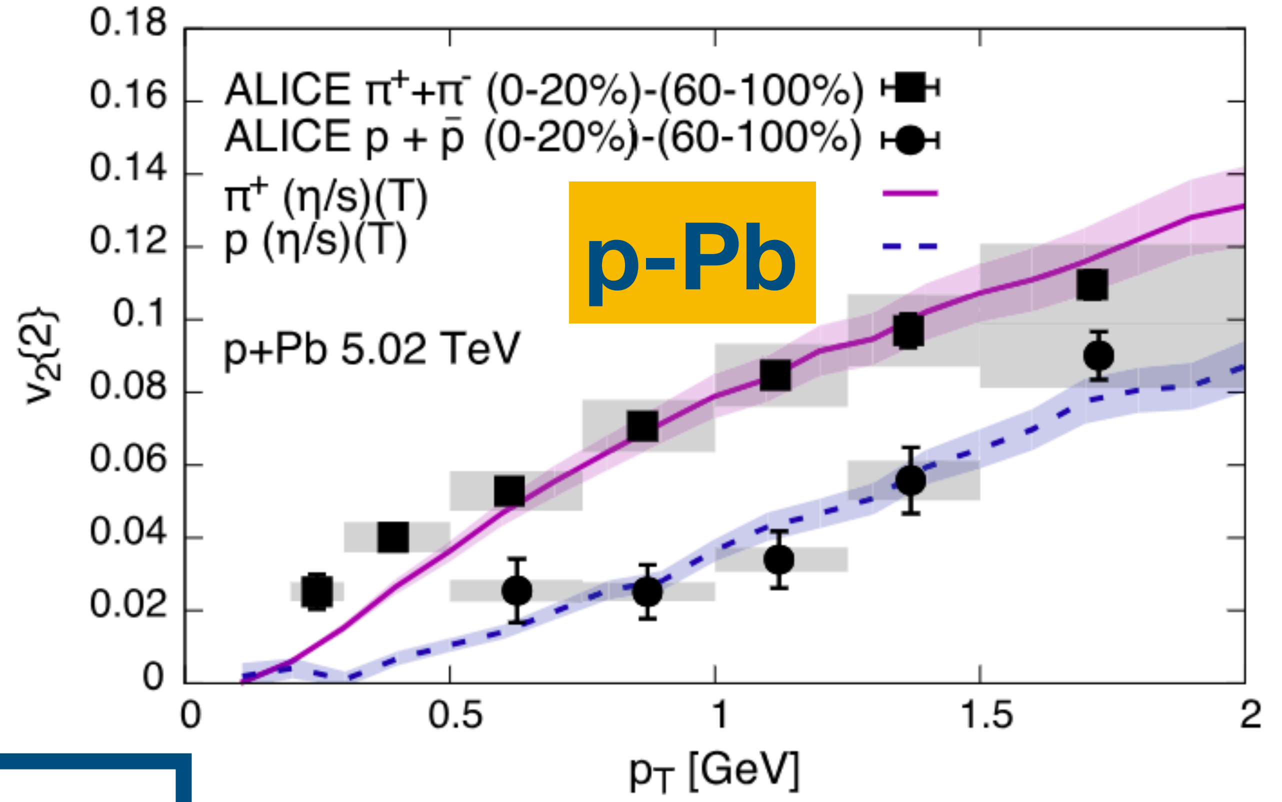
p-Au

d-Au

Mäntysaari *et al.*, PLB 772, 681 (2017)



p-Pb

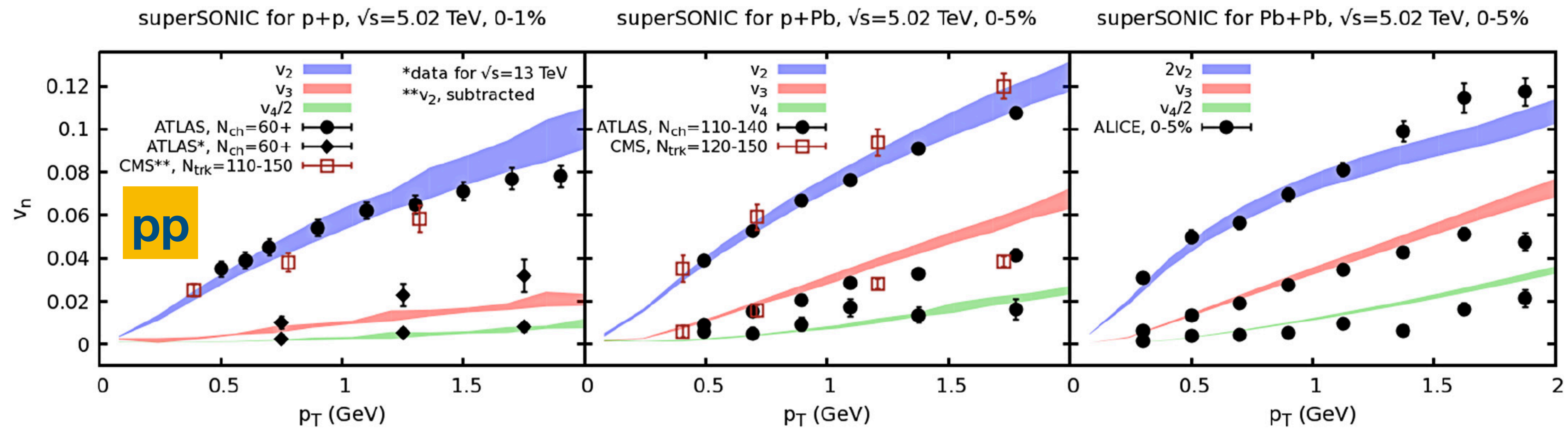


p-Pb

How about multi-particle correlations (m>2) ?

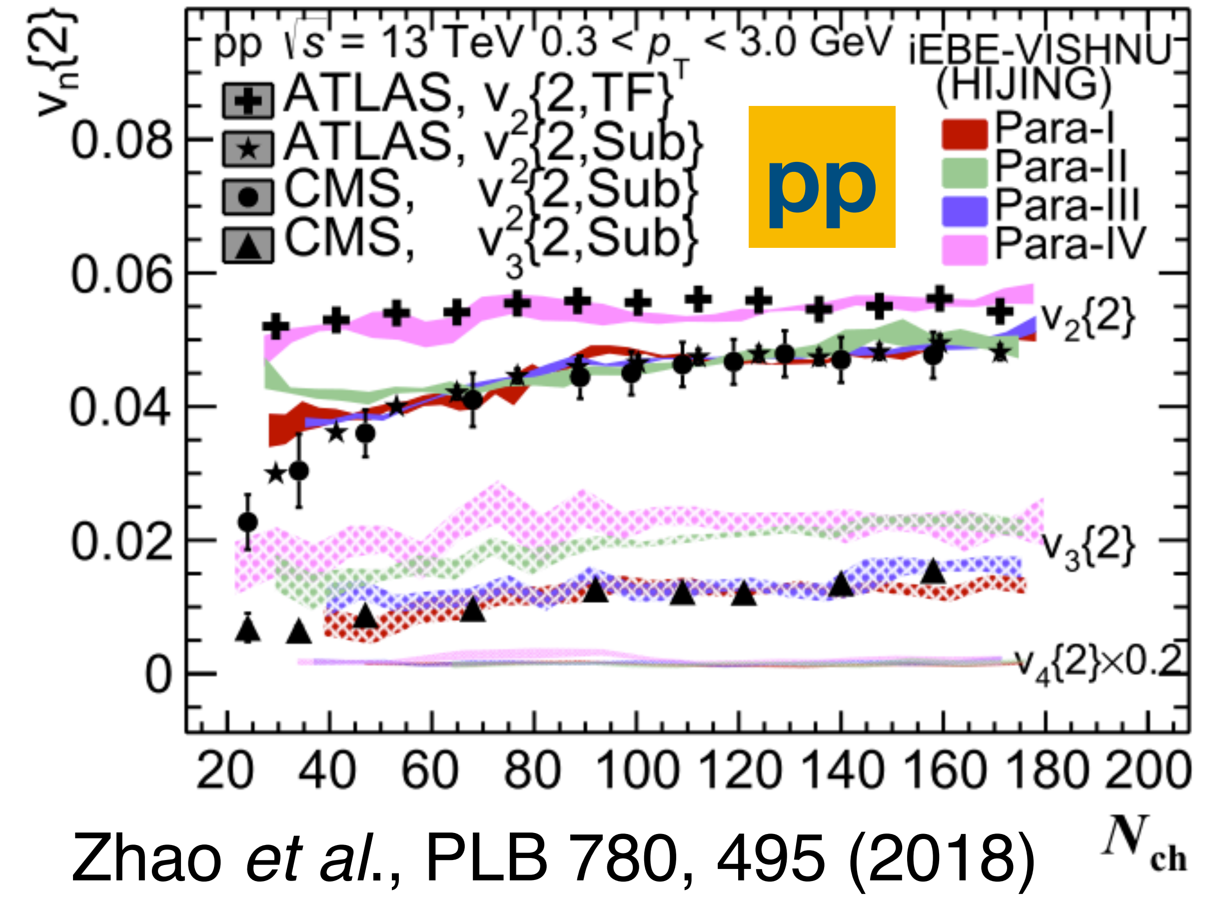
(Collectivity = long-range multi-particle correlations)

- Hydrodynamics rep... describe even measurements in pp collisions of pA, dA, 3HeA collisions



pp

Weller, Romatschke, PLB 774, 351 (2017)

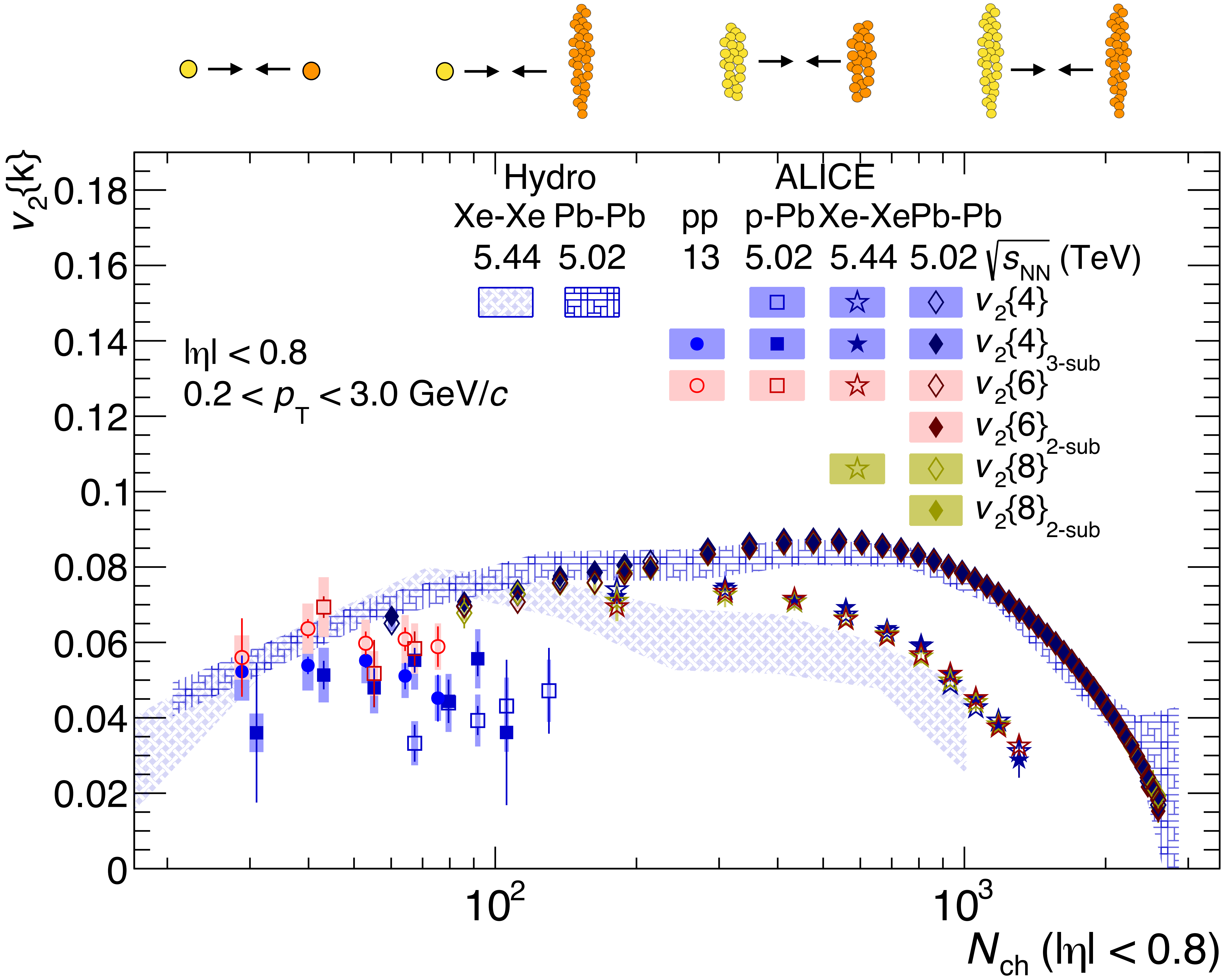


pp

Zhao *et al.*, PLB 780, 495 (2018)

Flow coefficients $v_n\{m\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



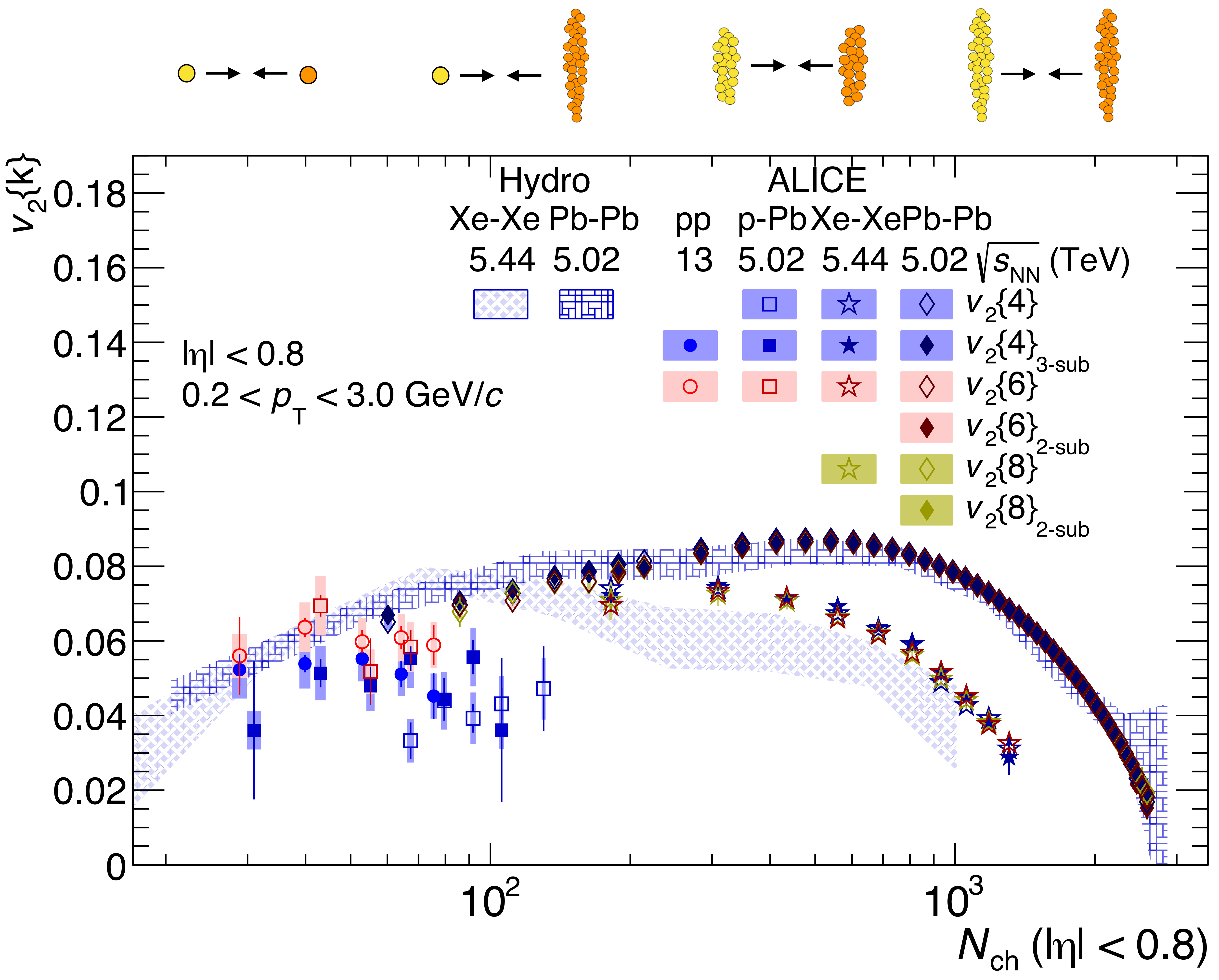
large collision systems

- $v_2\{m\} \sim v_2\{m\}_{sub}$ (long-range correlations)
- $v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$ (multi-particle correlations)

Charged particles

Flow coefficients $v_n\{m\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



large collision systems

- $v_2\{m\} \sim v_2\{m\}_{sub}$ (long-range correlations)
- $v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$ (multi-particle correlations)

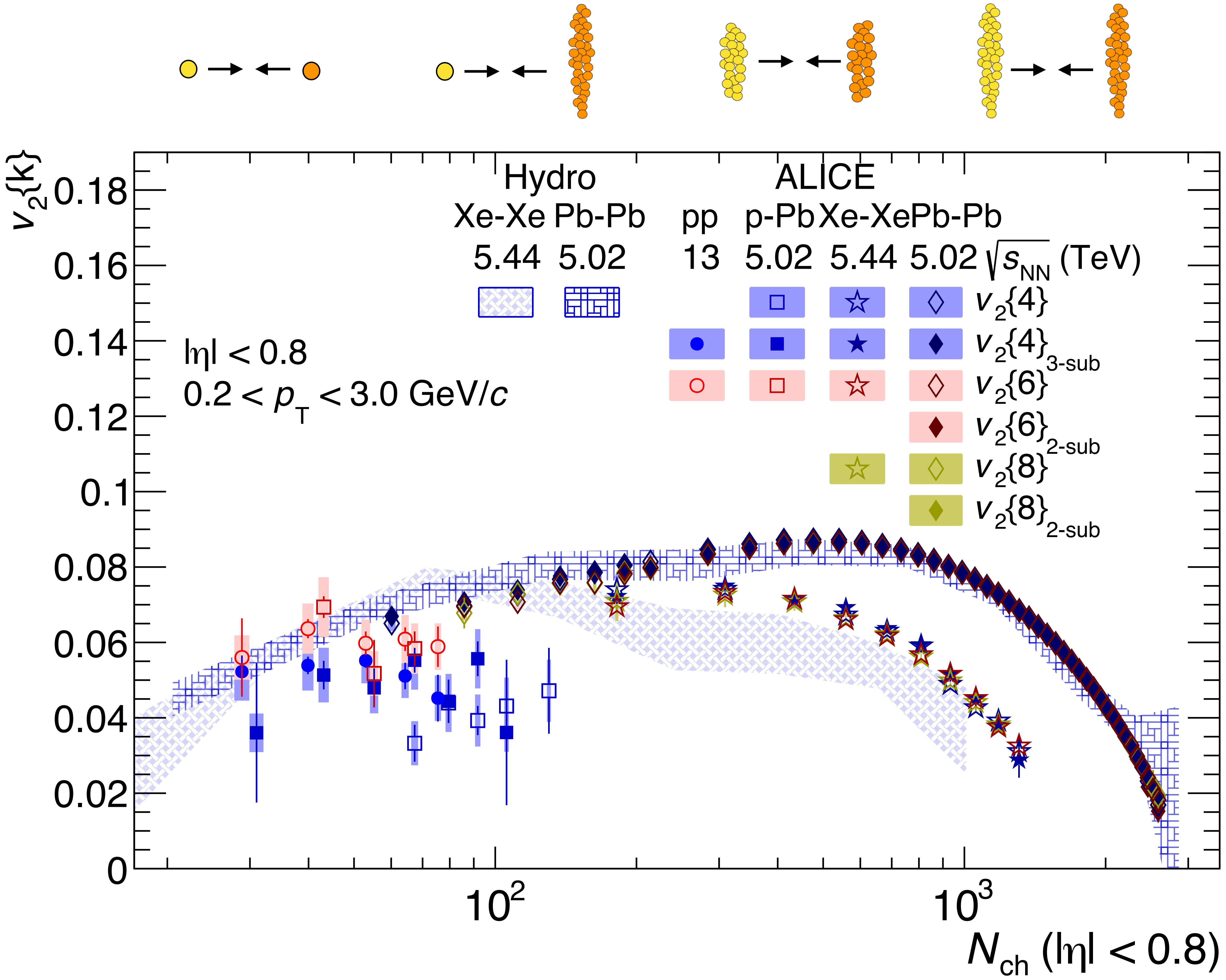
small collision systems

p-Pb collisions

- $v_2\{4\} < v_2\{4\}_{3\text{-sub}}$ after non-flow suppression
- Real values of $v_2\{4\}_{3\text{-sub}}$ obtained at lower N_{ch}
- Multi-particle correlations: $v_2\{4\}_{3\text{-sub}} \sim v_2\{6\}$

Flow coefficients $v_n\{m\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



large collision systems

- $v_2\{m\} \sim v_2\{m\}_{sub}$ (long-range correlations)
- $v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$ (multi-particle correlations)

small collision systems

p-Pb collisions

- $v_2\{4\} < v_2\{4\}_{3\text{-sub}}$ after non-flow suppression
- Real values of $v_2\{4\}_{3\text{-sub}}$ obtained at lower N_{ch}
- Multi-particle correlations: $v_2\{4\}_{3\text{-sub}} \sim v_2\{6\}$

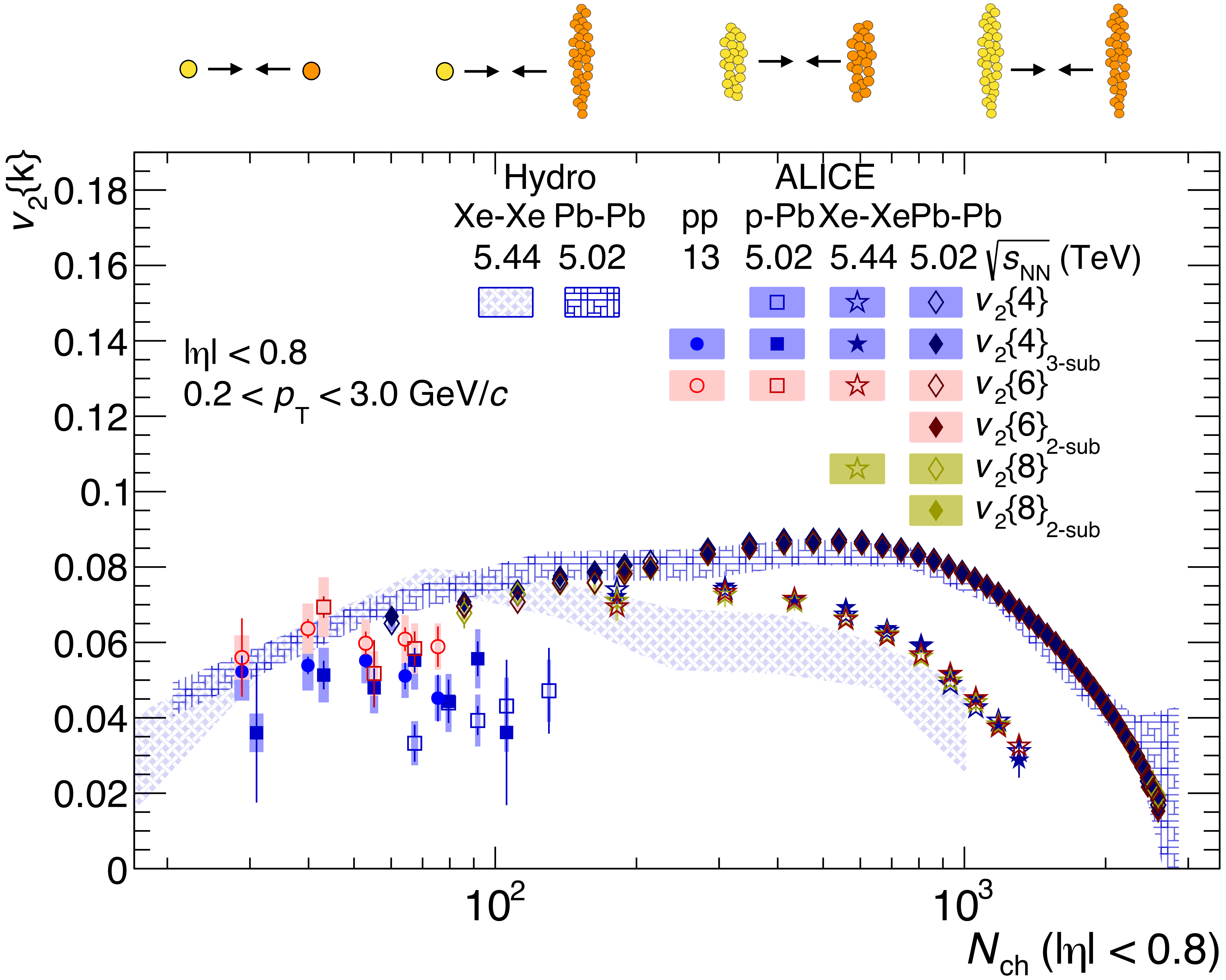
pp collisions

- Real values of $v_2\{4\}_{3\text{-sub}}$
  - Only possible with non-flow suppression!
- Multi-particle correlations: $v_2\{4\}_{3\text{-sub}} \sim v_2\{6\}$

Charged particles

Flow coefficients $v_n\{m\}$

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



large collision systems

- $v_2\{m\} \sim v_2\{m\}_{sub}$ (long-range correlations)
- $v_2\{4\} \sim v_2\{6\} \sim v_2\{8\}$ (multi-particle correlations)

small collision systems

p-Pb collisions

- $v_2\{4\} < v_2\{4\}_{3\text{-sub}}$ after non-flow suppression
- Real values of $v_2\{4\}_{3\text{-sub}}$ obtained at lower N_{ch}
- Multi-particle correlations: $v_2\{4\}_{3\text{-sub}} \sim v_2\{6\}$

pp collisions

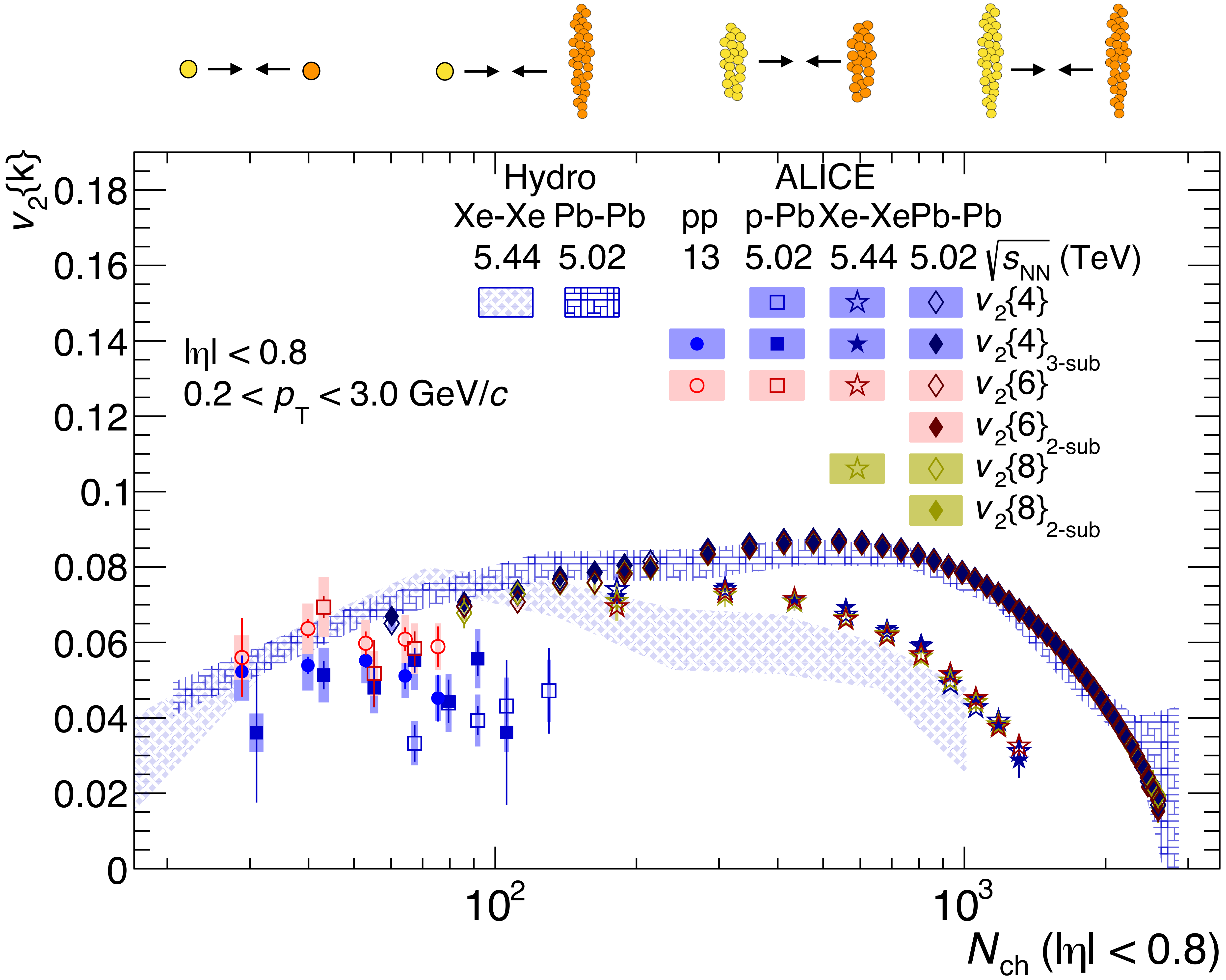
- Real values of $v_2\{4\}_{3\text{-sub}}$
  - Only possible with non-flow suppression!
- Multi-particle correlations: $v_2\{4\}_{3\text{-sub}} \sim v_2\{6\}$

Long-range multi-particle correlations observed in small collision systems!

Flow coefficients $v_n\{m\}$

model comparison

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



- Quantitative agreement with Pb-Pb data over the entire multiplicity range!
  - Note: $v_2\{2\}$ was overestimated by the model at low N_{ch}
- Underestimation of Xe-Xe data
  - Model is not tuned to different coll. system yet
- No hydrodynamic curves for small collision systems…

IP-Glasma+MUSIC+UrQMD:

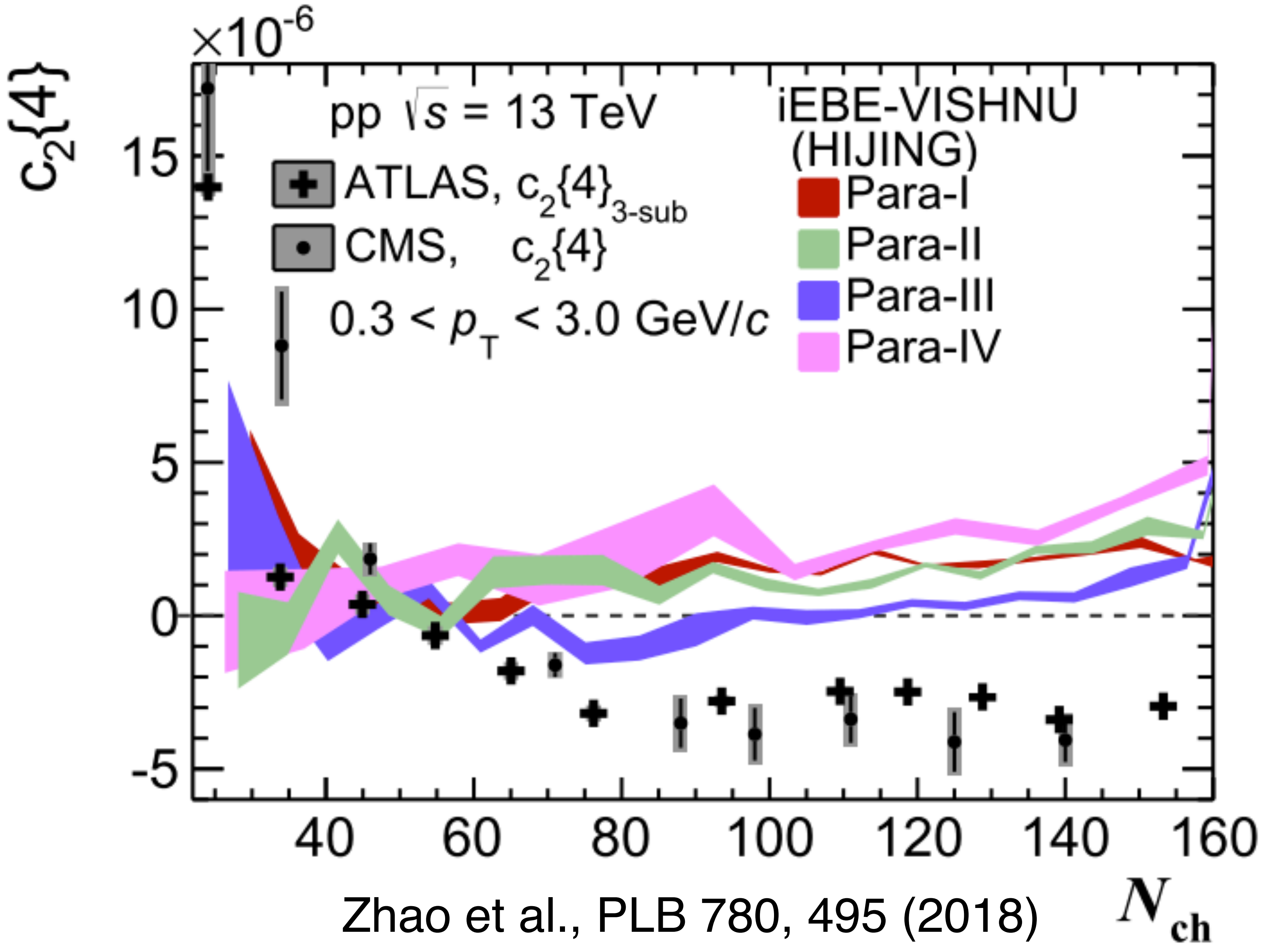
Schenke *et al.* PRC**89**, 024901 (2014), Mäntysaari *et al*. PLB**772**, 681 (2017)

…hydro does not show negative $c_2\{4\}$ in pp (yet?)

Charged particles

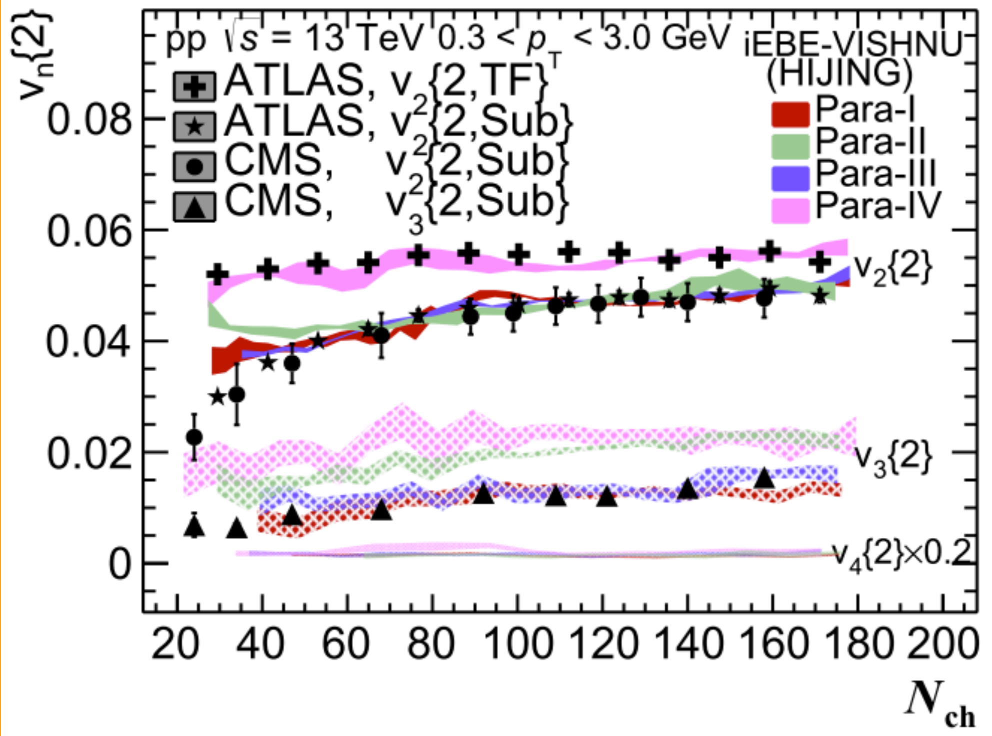
- There are not many model calculations of multi-particle cumulants on the market

- The $c_2\{4\}$ is not described by iEBE-VISHNU
- **Further investigation of initial conditions is necessary**



Zhao et al., PLB 780, 495 (2018)

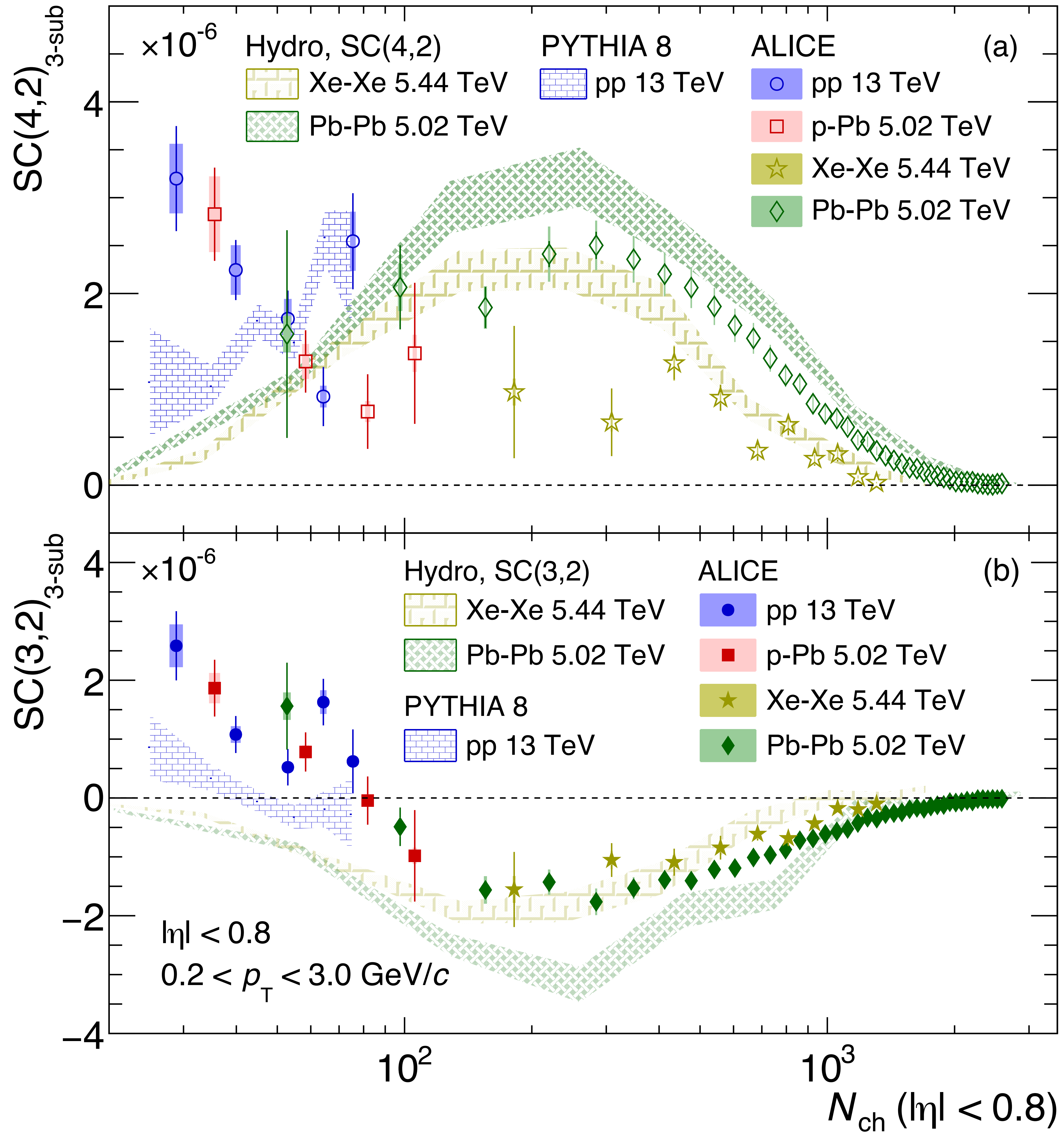
pp collisions



Charged particles

Symmetric cumulants

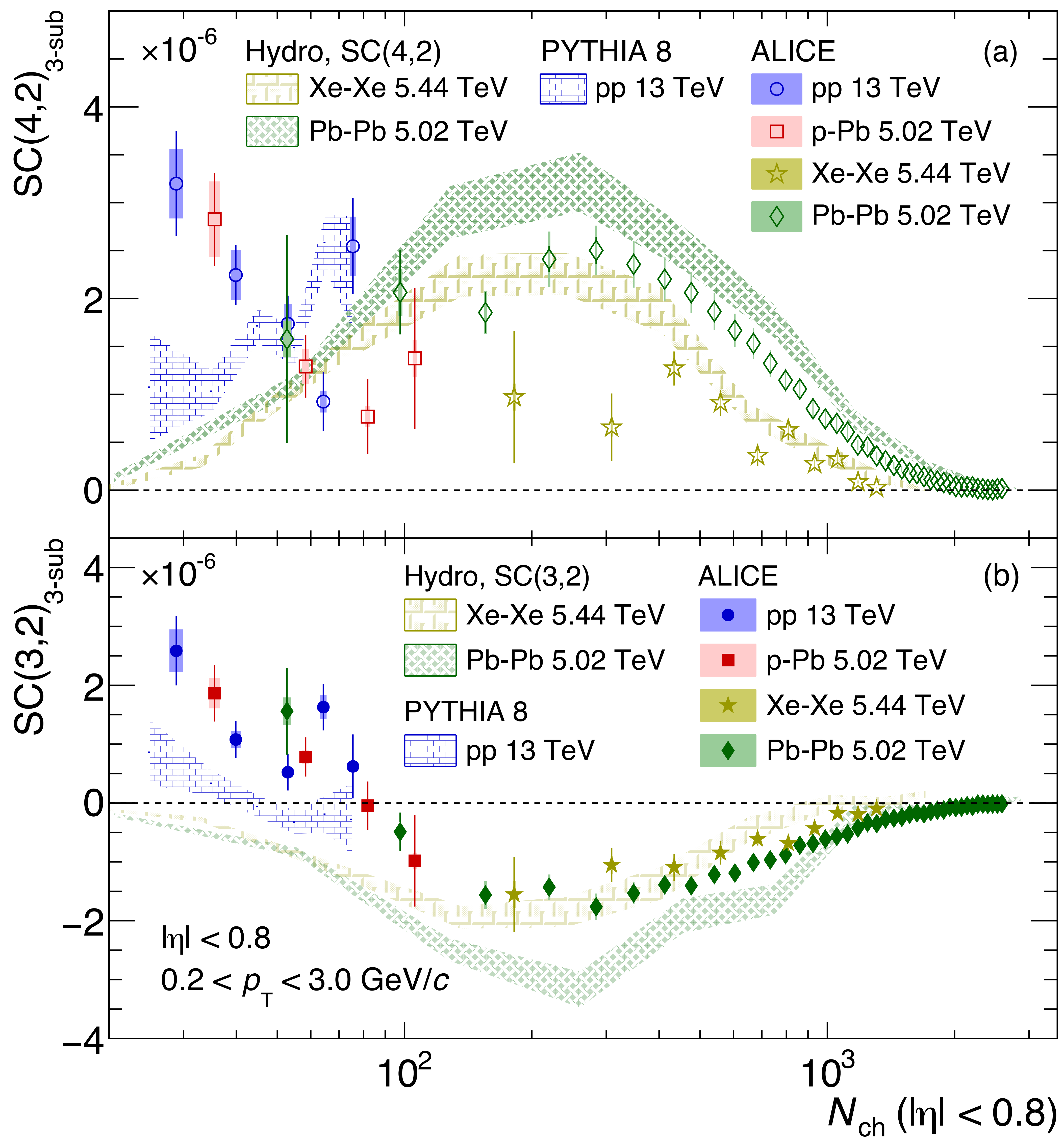
ALICE, arXiv:1903.01790 [nucl-ex] (2019)



- **Positive $SC(4,2)_{3\text{-sub}}$** observed in all collision systems
- **Negative $SC(3,2)_{3\text{-sub}}$** in Pb-Pb and Xe-Xe collisions at large multiplicities
- **Crossing** to a positive correlation in Pb-Pb collisions
  - Followed by small collision systems, too
  - Indication of a similar origin of the collectivity, or remaining non-flow ?

Symmetric cumulants

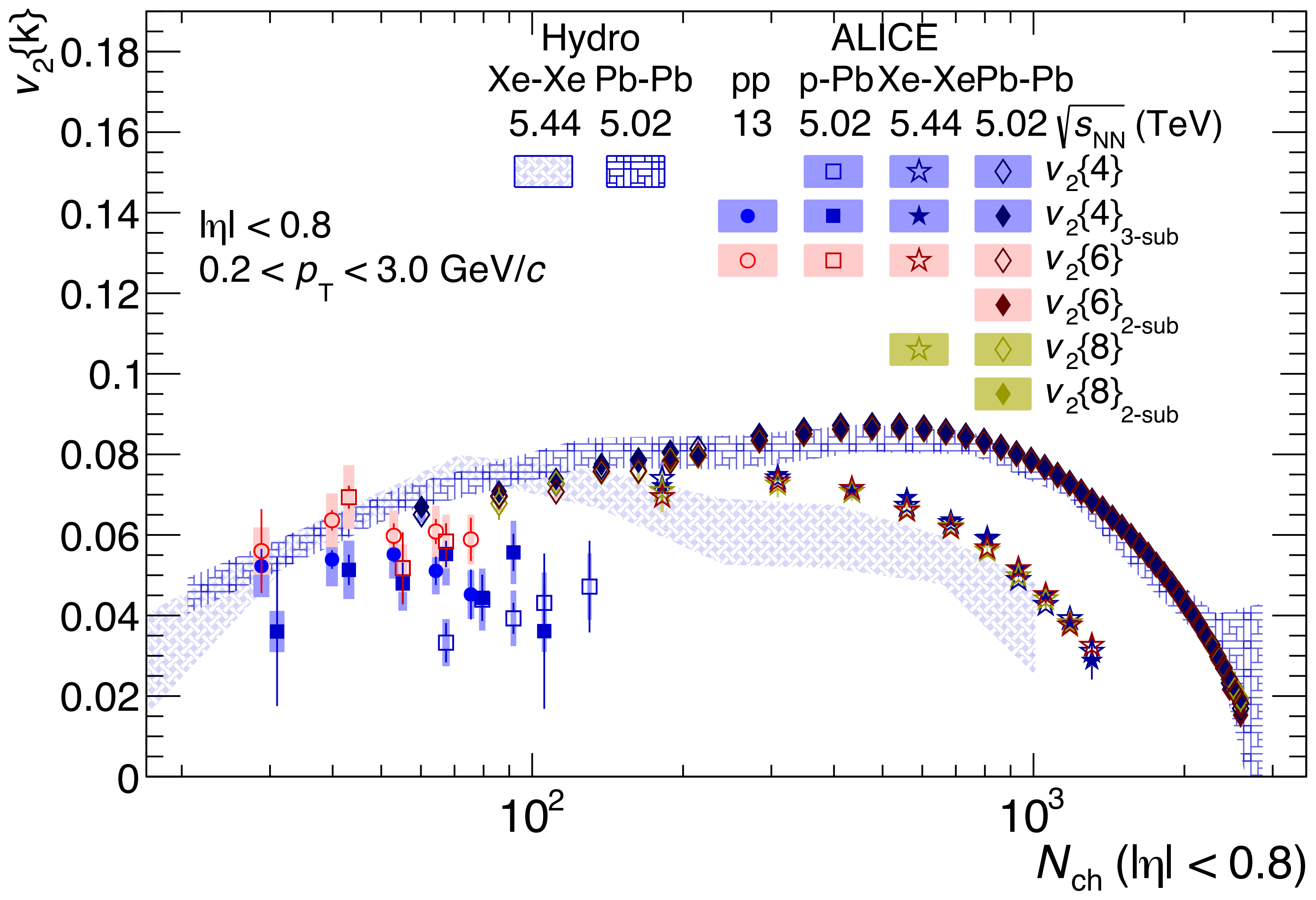
ALICE, arXiv:1903.01790 [nucl-ex] (2019)



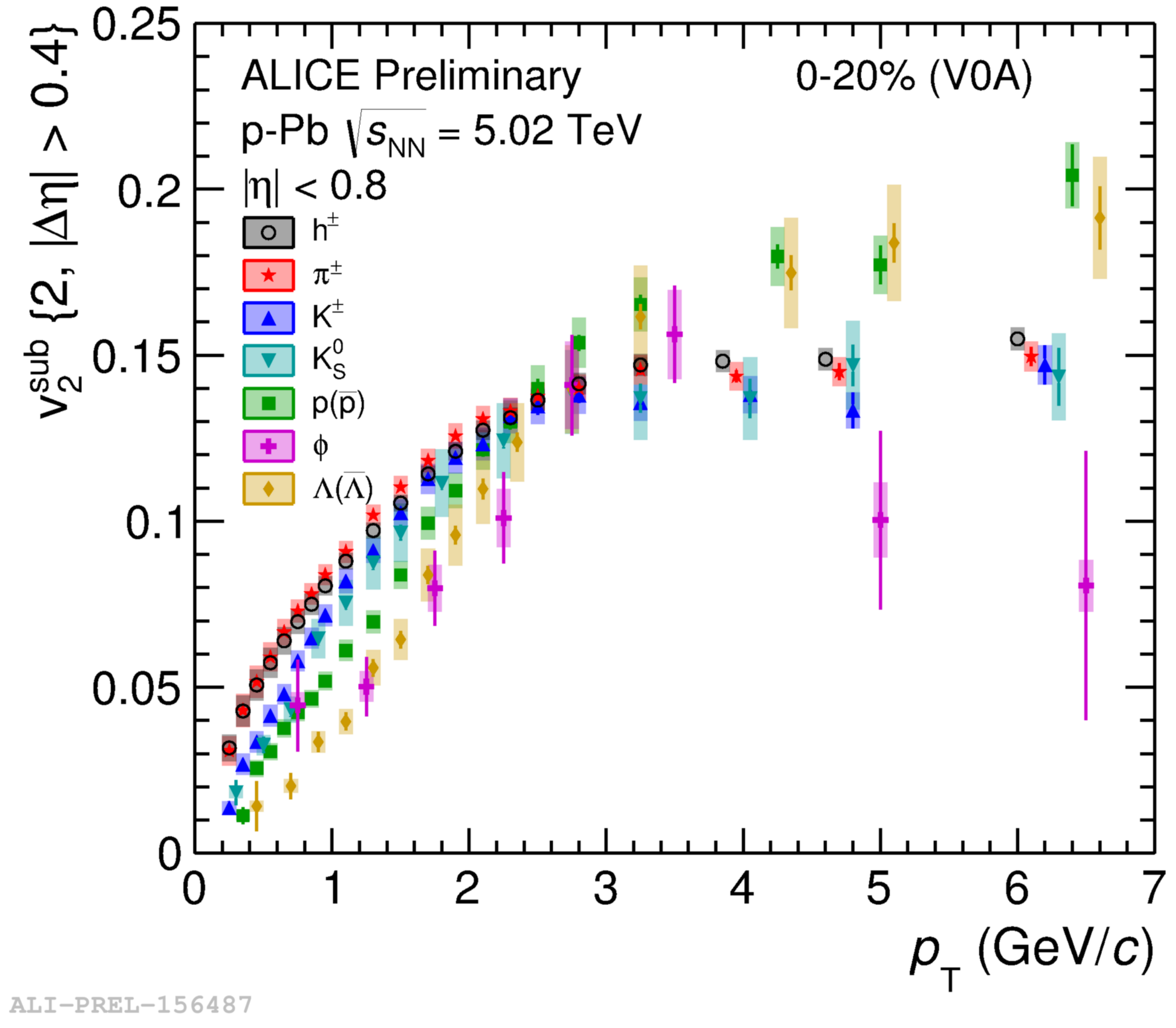
- **PYTHIA**
  - Does not reproduce the pp data, although the $SC(3,2)_{3\text{-sub}}$ reveals similar trend
- **IP-Glasma+MUSIC+UrQMD**
  - Qualitatively describes both Pb-Pb and Xe-Xe collisions, although the $SC(3,2)_{3\text{-sub}}$ remains negative at low N_{ch}

Summary

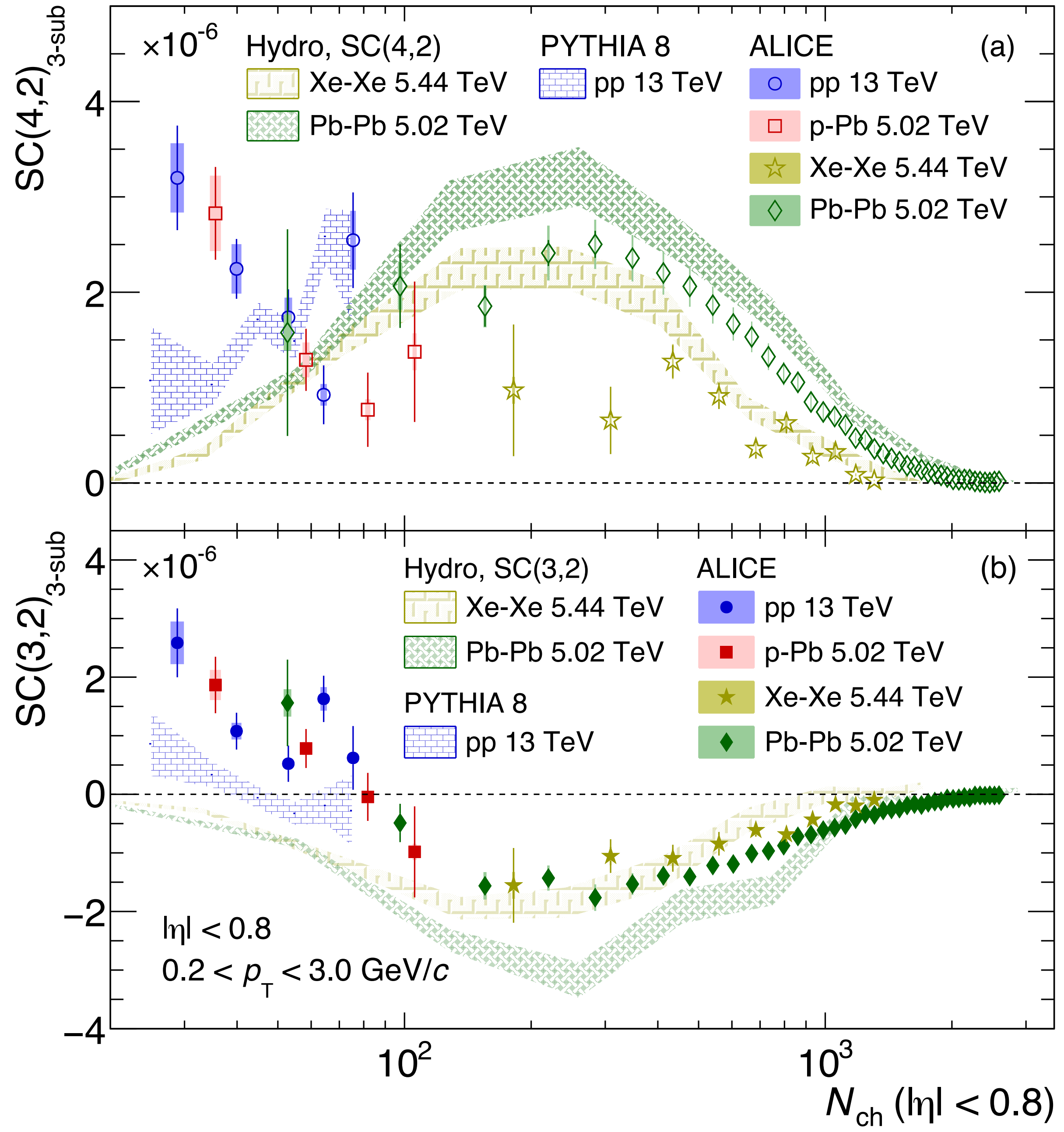
- **Collective phenomena observed** even in the smallest collision system
  - **$v_n\{m\}$**: long-range multi-particle correlations
  - **$v_2\{2\}(p_T)$**: mass ordering & baryon/meson grouping in p-Pb collisions
- **The origin of the collectivity** in small systems is yet to be understood
  - Initial state / final state / both initial and final state effects ?
  - **SC(m,n)**: the new ALICE data provide further constraints for model comparison



Charged particles



Identified particles

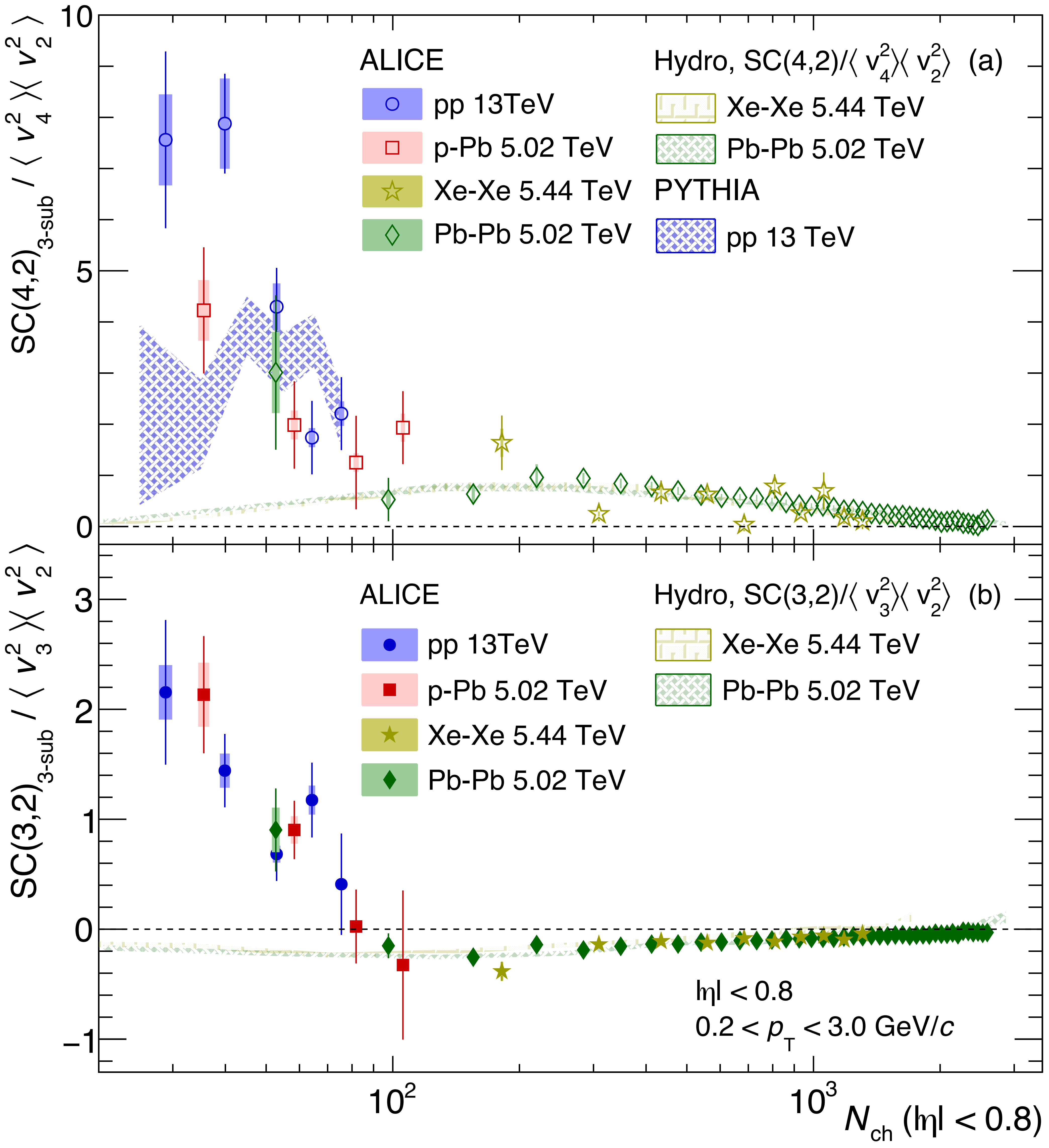


Backup

Normalised ratio

model comparison

ALICE, arXiv:1903.01790 [nucl-ex] (2019)



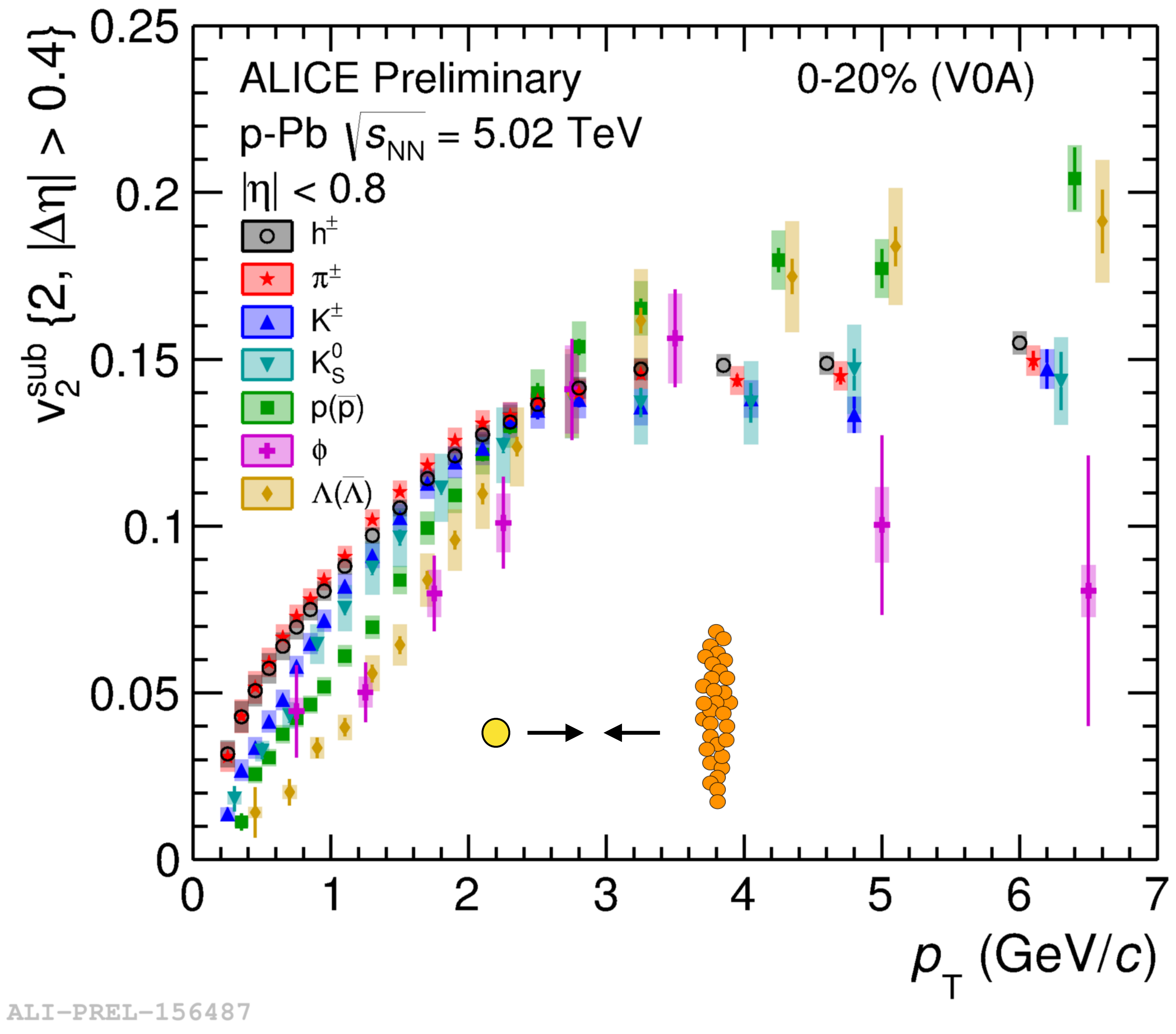
$$\frac{SC(m,n)_{3-\text{sub}}}{\langle v_n^2 \rangle \langle v_m^2 \rangle}$$

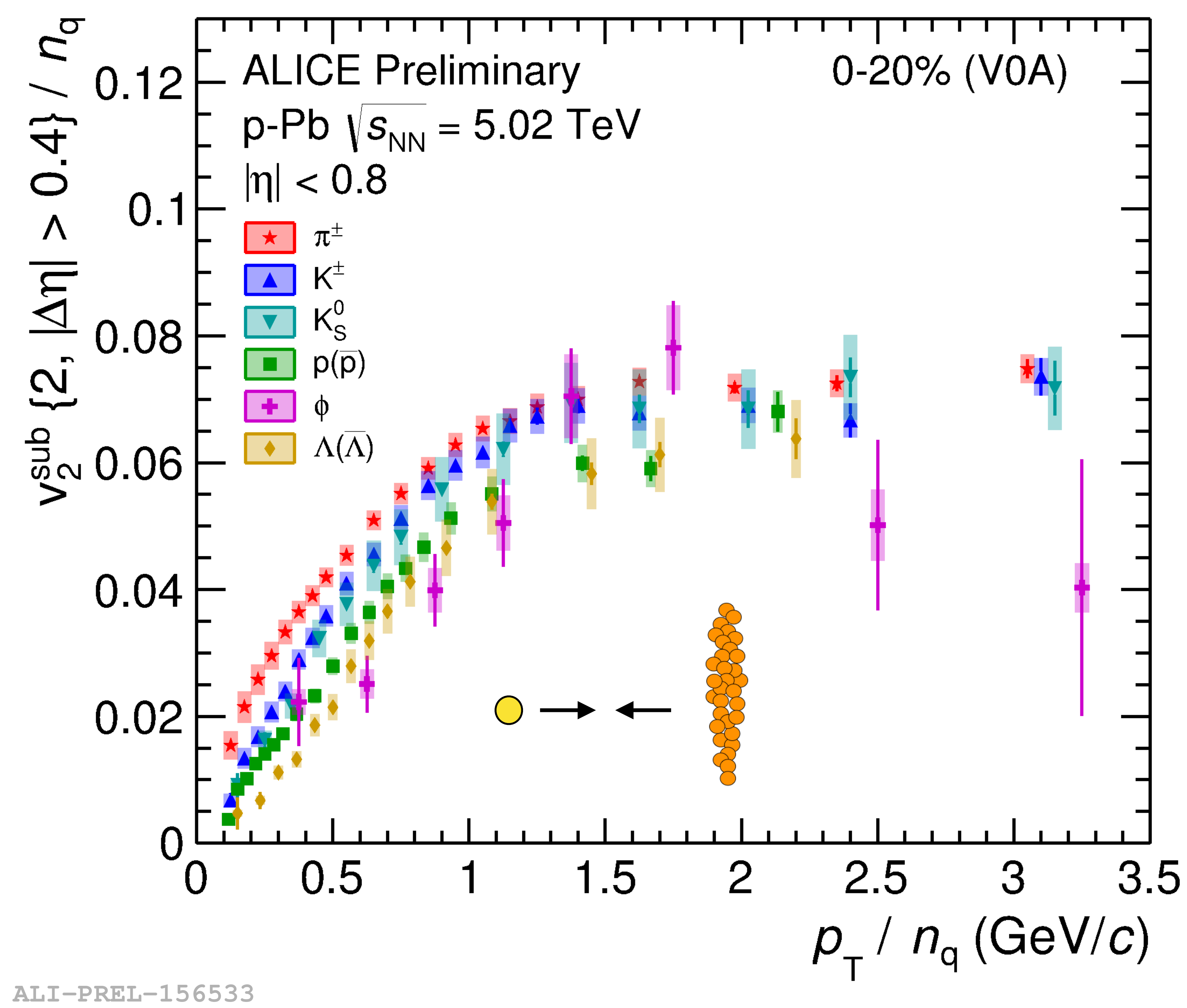
- The v_n and v_m are taken from $v_n\{2, |\Delta\eta|\}$
  - In the absence of non-flow, the ratio directly reflects correlations between flow coefficients

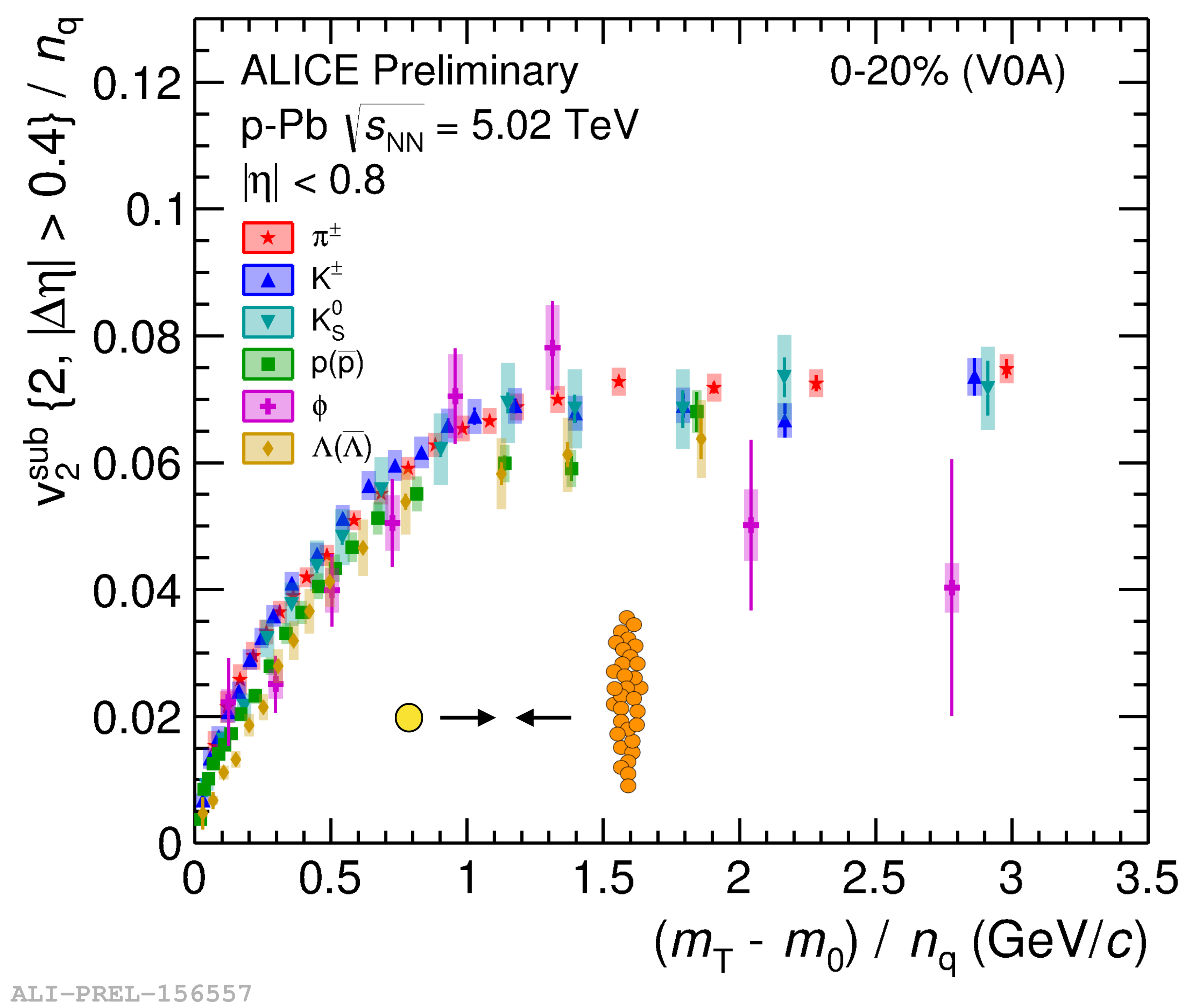
- Indication of similar correlation between different collision systems at the same N_{ch}
- Large increase of magnitude at N_{ch}<100

- IP-Glasma+MUSIC+UrQMD quantitatively describes large collision systems (except for low N_{ch})

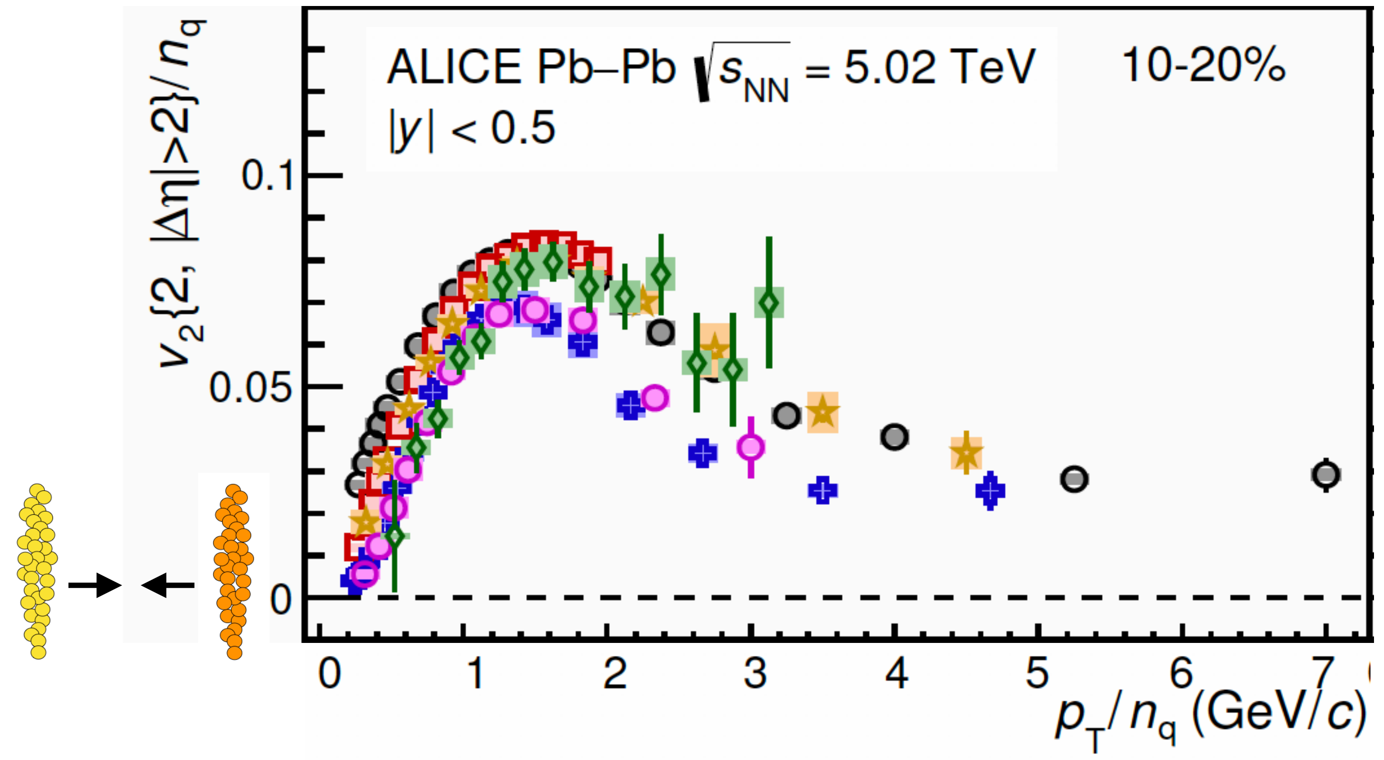
Flow coefficients $v_n\{2\}$





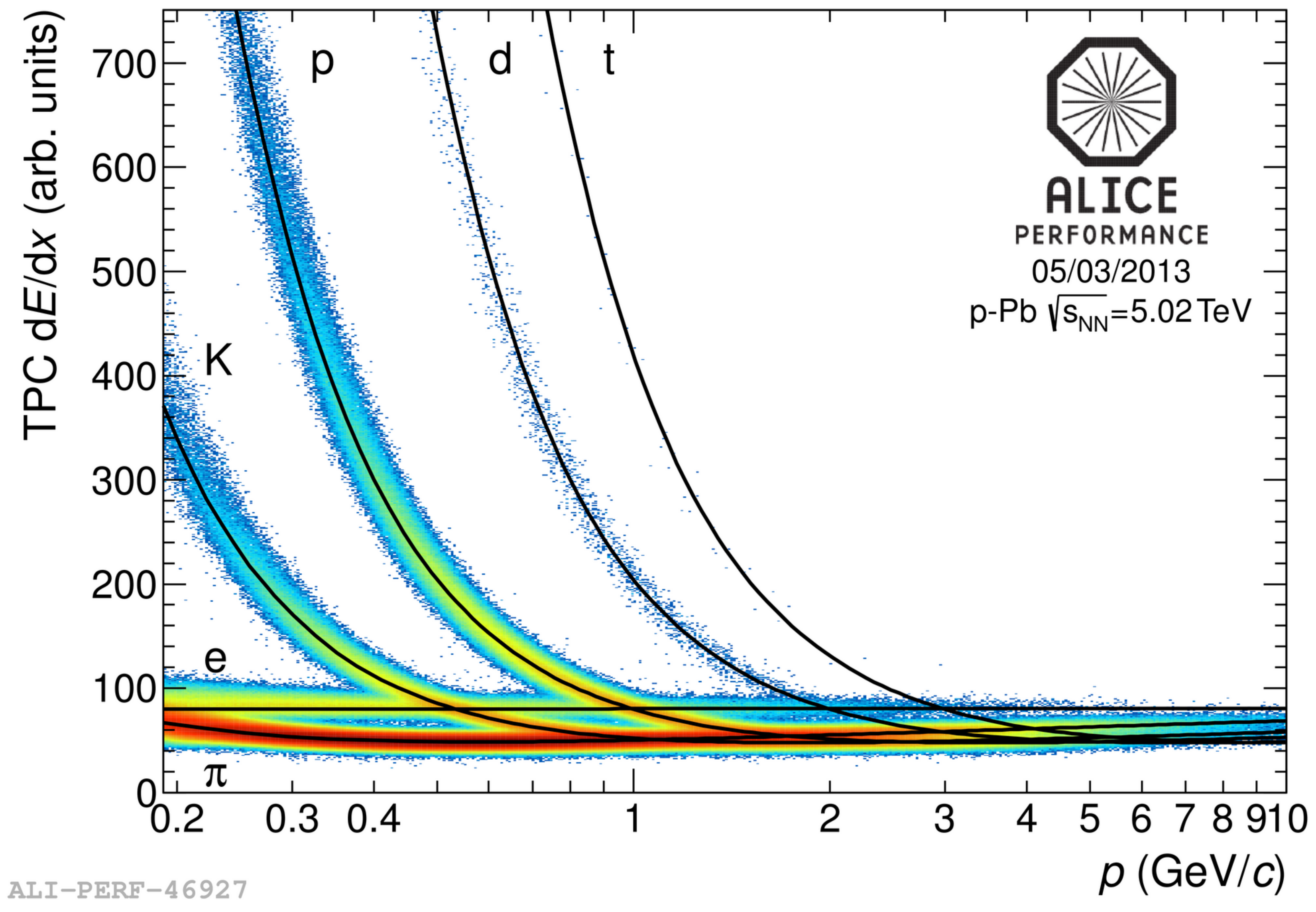


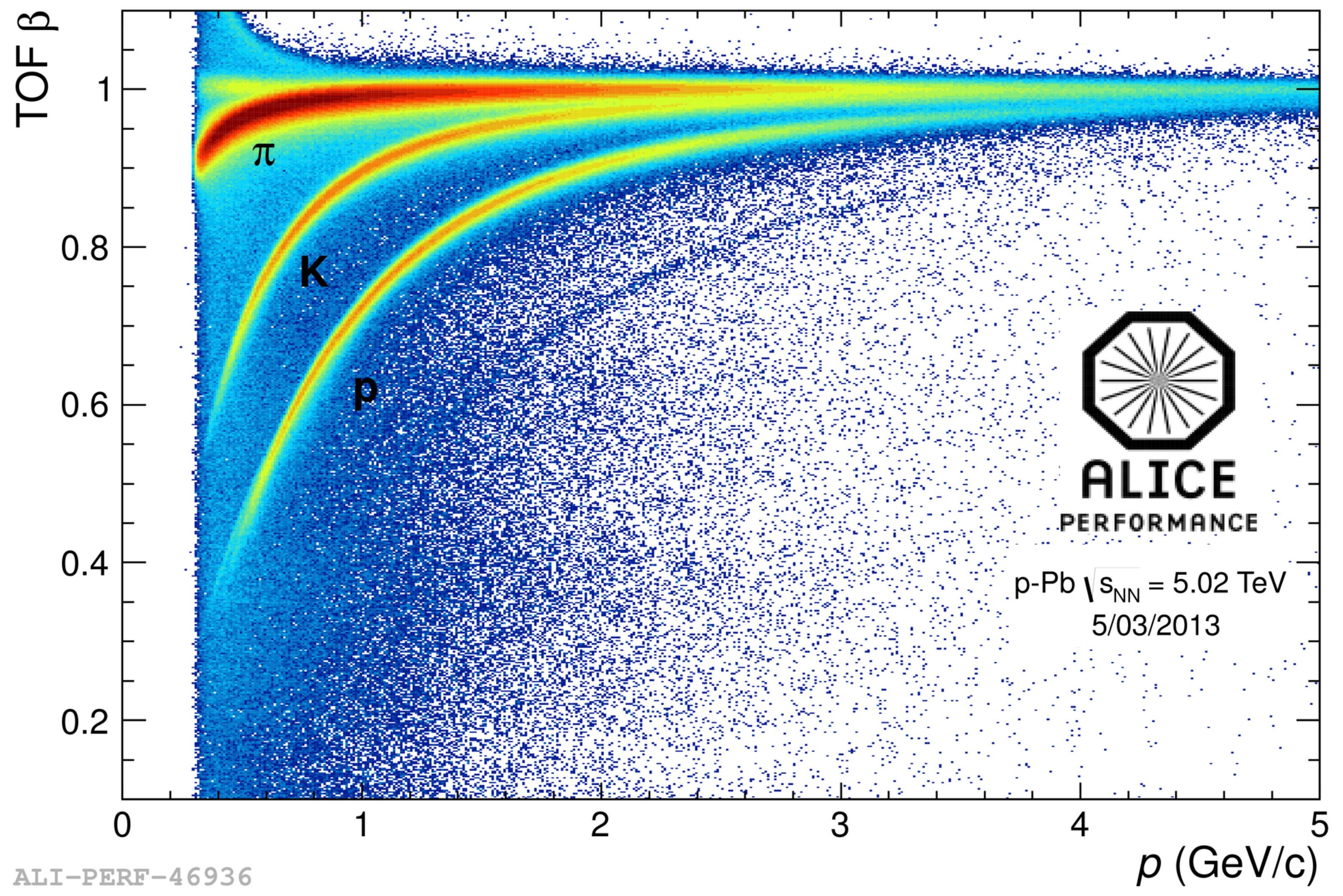
- Similar observations as in Pb-Pb measurements
  - Clear **mass ordering** at low p_T
  - Indication of **baryon/meson grouping** at intermediate p_T
  - Approximate NCQ/KE_T scaling: indication of partonic collectivity



ALICE, JHEP09, 006 (2018)

Particle identification & reconstruction

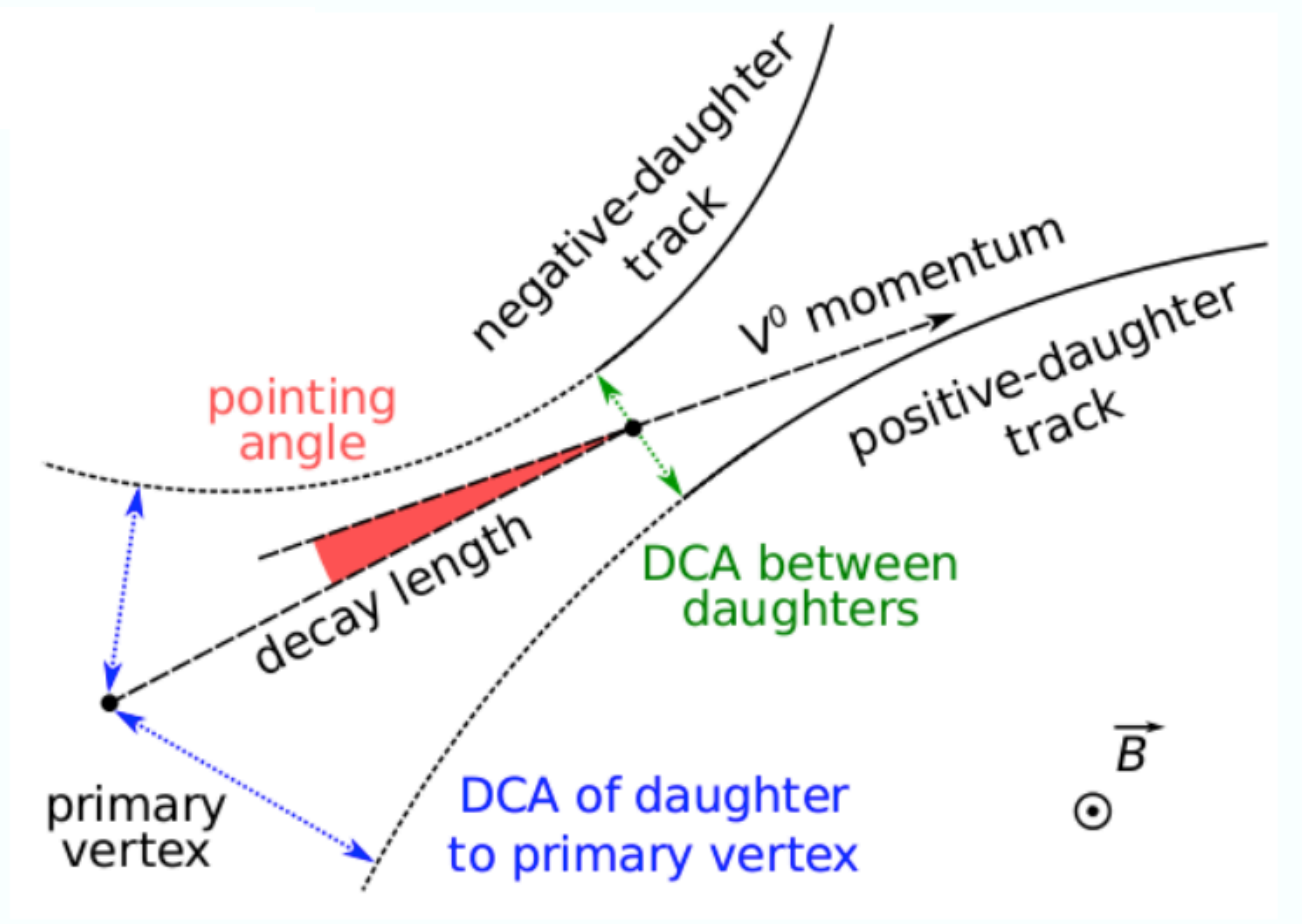




- Identification of π, K, p
  - Identification via energy loss dE/dx in TPC and time of flight in TOF
- Reconstruction of ϕ, K^0_S, Λ
  - Short-lived and no charge -> cannot be measured directly
  - Reconstruction via their decay products (which are identified via particle identification)

Hadronic decays

$$\phi \longrightarrow K^+ + K^-$$
$$K^0_S \longrightarrow \pi^+ + \pi^-$$
$$\Lambda \longrightarrow p + \pi^-$$
$$\bar{\Lambda} \longrightarrow \bar{p} + \pi^+$$

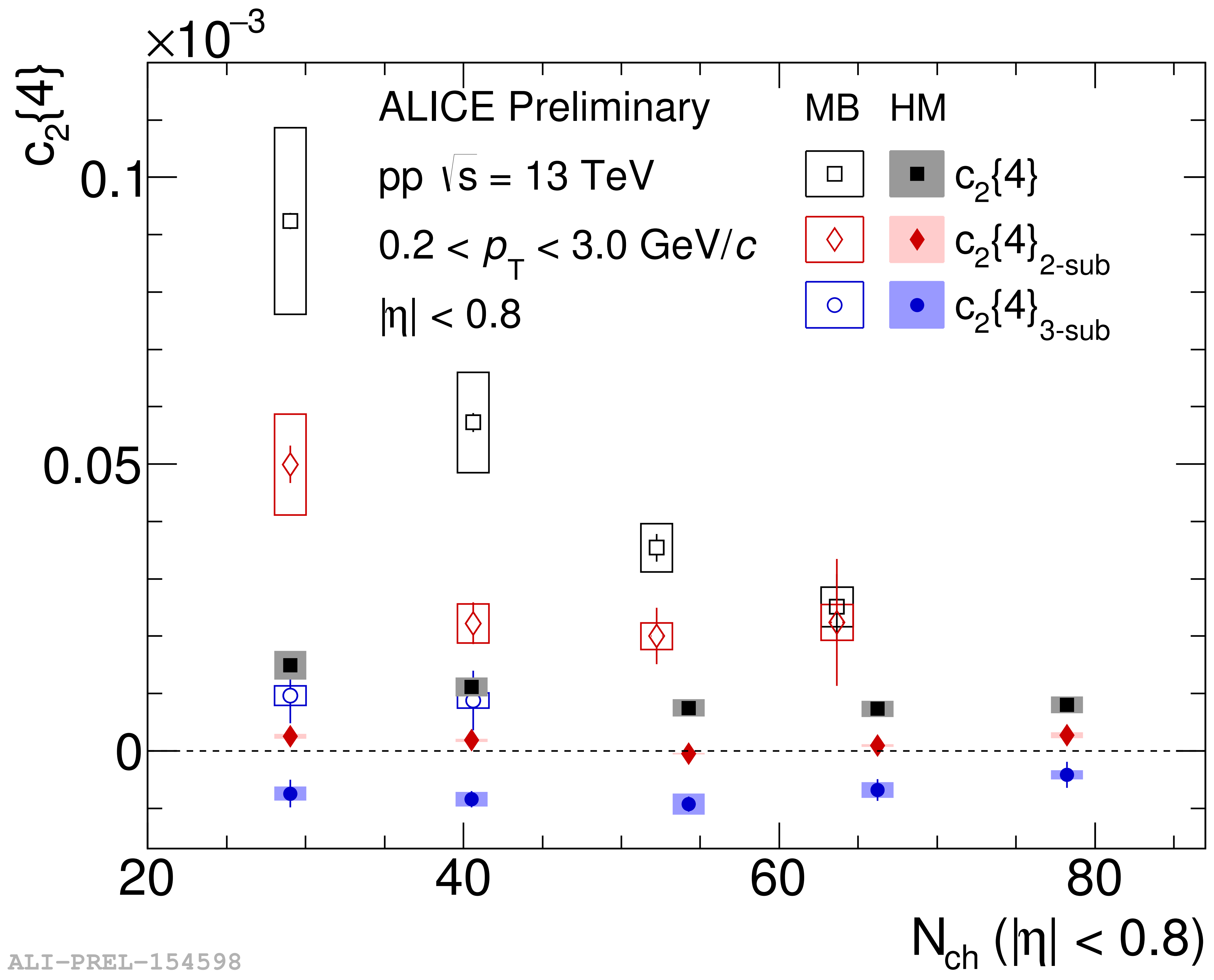


Trigger selection

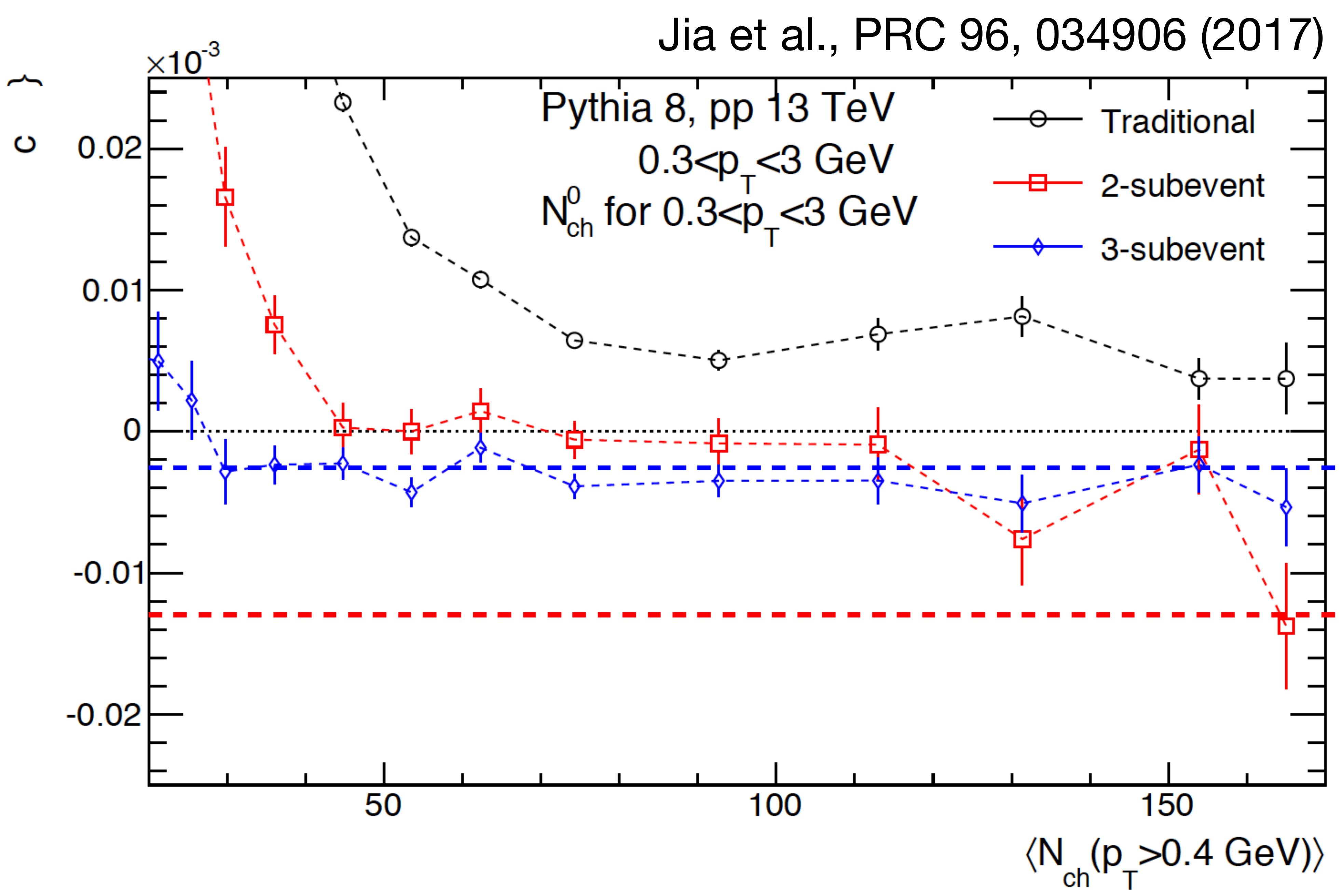
- Minimum-bias trigger:
  - Suppression of non-flow with subevent method
  - The sign of $c_2\{4\}$ remains positive
- High multiplicity trigger selection:

$$\frac{V0M}{\langle V0M \rangle} > 4$$

  - Additional event selection allows to obtain negative $c_2\{4\}_{3\text{-sub}}$

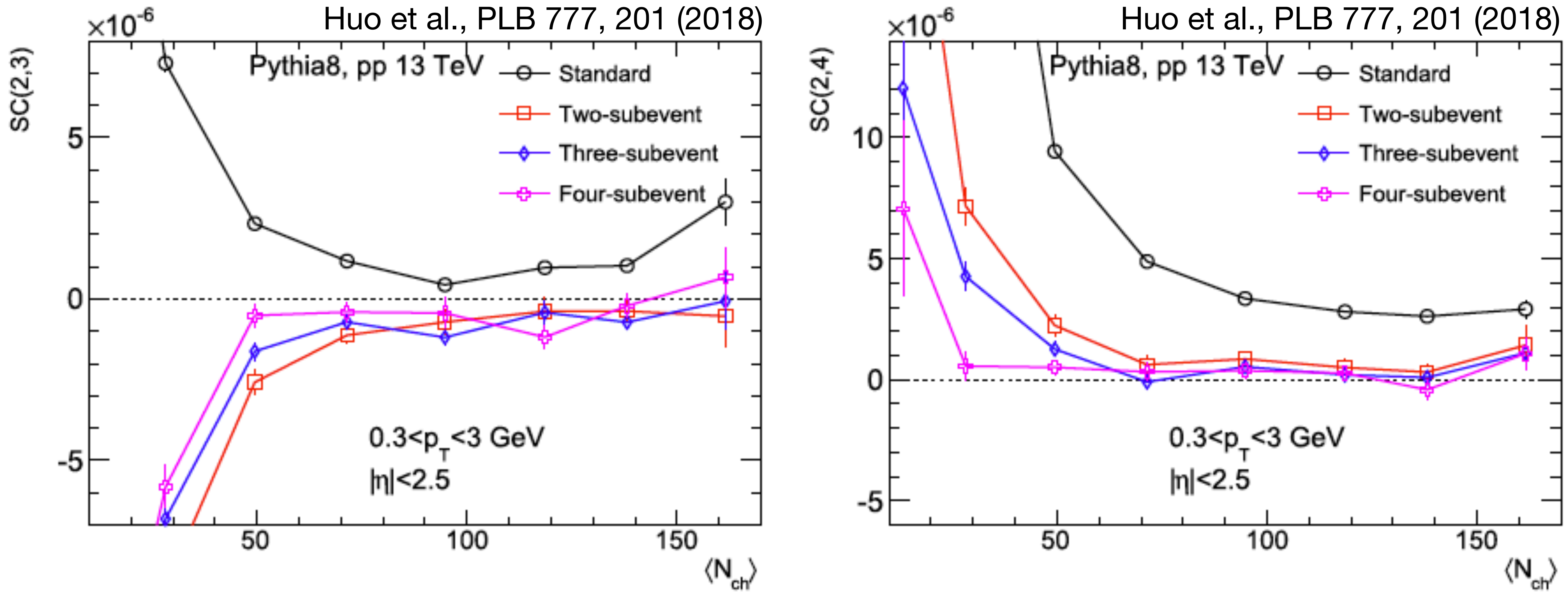


Testing the subevent method



- Clear decrease of the signal with the subevent method
  - PYTHIA = without flow -> $c_2\{4\}$ remains positive
- After injecting v_2 = 0.04
  - Only the 3-subevent method could reliably reproduce the signal

Subevent method in SC



- Subevent method tested in PYTHIA 8 (pp collisions) and HIJING (p-Pb collisions)
- Significant effect on the SC(m,n) measurements