Multi-particle correlations in p-Pb and Pb-Pb collisions at the LHC

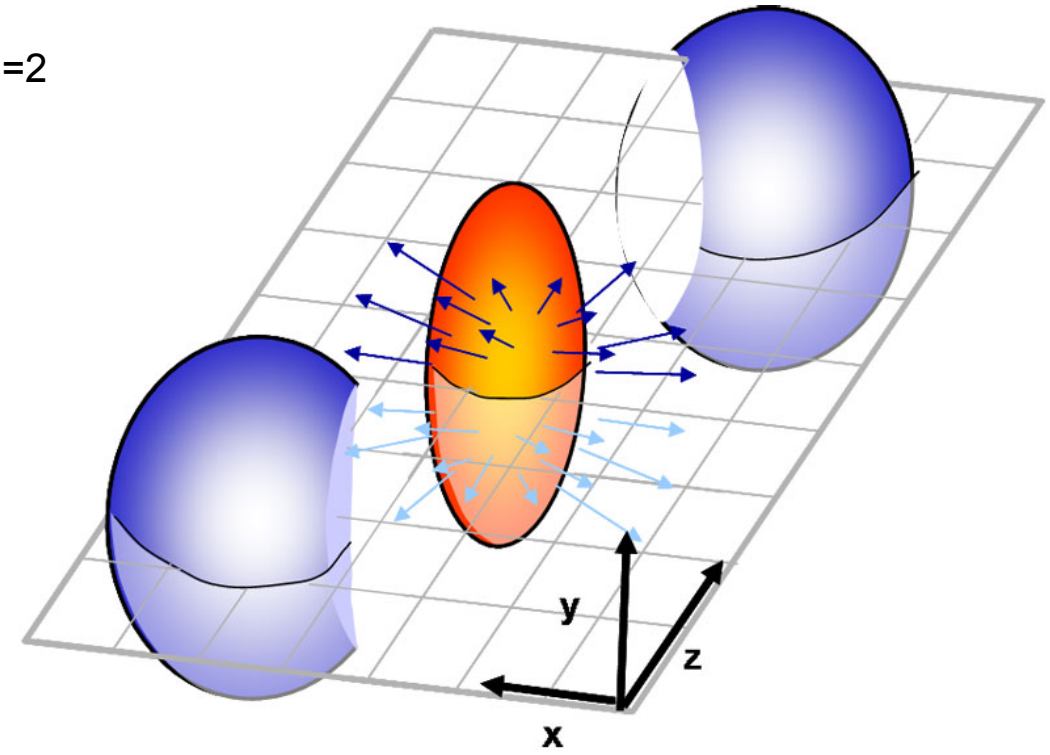
Anthony Timmins for the ALICE Collaboration

1. Flow fluctuations and multi-particle correlations
2. Analysis details
3. Second order cumulants and flow coefficients in Pb-Pb and p-Pb collisions
4. Third order cumulants and flow coefficients in Pb-Pb and p-Pb
5. Summary

Phys. Rev. C 90 (2014) 054901

Multi-particle correlations and moments

n=2



$$v_n = \langle \cos[n(\varphi - \psi_n)] \rangle$$

- Anisotropic flow v_n of **order n** can be measured from **m particle correlations**
- **Advantage:** No need to measure the reaction plane
- If m=2 (two particle correlation)
  - Correlation measurement $\langle \cos [n(\varphi_1-\varphi_2)] \rangle = \langle v_n^2 \rangle$
- If m=4 (four particle correlation)
  - Correlation measurement $\langle \cos [n(\varphi_1+\varphi_2-\varphi_3-\varphi_4)] \rangle = \langle v_n^4 \rangle$
- For convenience, we denote $\langle v_n^m \rangle$ as $\langle m \rangle$

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Cumulants and flow coefficients

- Cumulants formed from v_n moments
  - Isolate true m particle correlations

$$c_n\{2\} = \langle\langle 2\rangle\rangle$$
$$c_n\{4\} = \langle\langle 4\rangle\rangle - 2\langle\langle 2\rangle\rangle^2$$
$$c_n\{6\} = \langle\langle 6\rangle\rangle - 9\langle\langle 4\rangle\rangle\langle\langle 2\rangle\rangle + 12\langle\langle 2\rangle\rangle^3$$

- Flow coefficients formed from cumulants

$$v_n\{2\} = \sqrt{c_n\{2\}}$$
$$v_n\{4\} = \sqrt[4]{-c_n\{4\}}$$
$$v_n\{6\} = \sqrt[6]{\frac{1}{4}c_n\{6\}}$$

- Methods have different sensitivity to flow fluctuations

$$v_n\{2\} \approx \langle v_n\rangle + \sigma_n^2/(2\langle v_n\rangle)$$
$$v_n\{4,6\} \approx \langle v_n\rangle - \sigma_n^2/(2\langle v_n\rangle)$$

- If **non-flow dominates**, naively expected to scale with Multiplicity (M) as:

$$c_n\{m\} \propto \frac{1}{M^{m-1}}$$

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Flow coefficients and flow fluctuations

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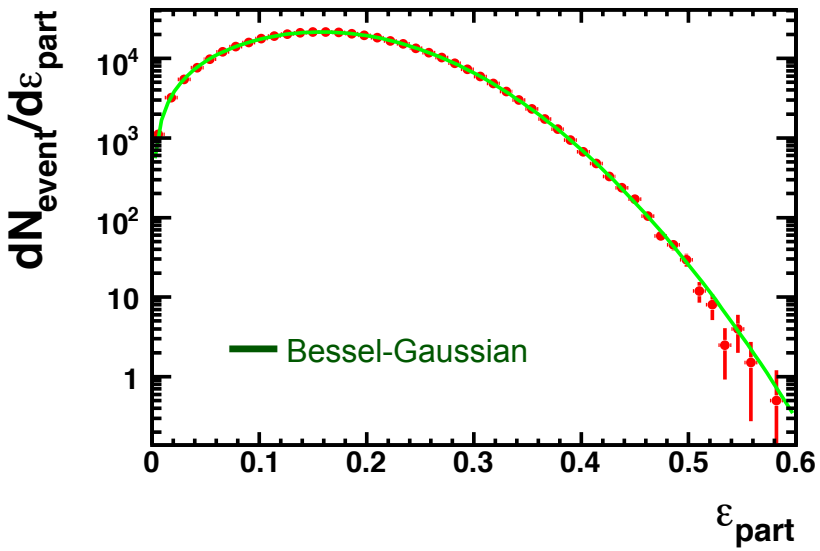
- If $v_n \propto \varepsilon_n$ (eccentricity)
  - Originally proposed distribution of ε_n and v_n Bessel Gaussian

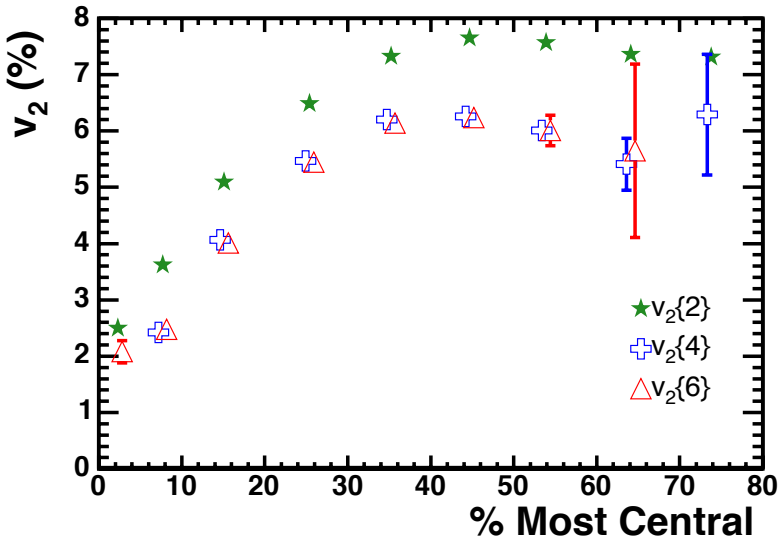
Phys. Lett. B 659 (2008) 537-541



- Bessel-Gaussian assumes:
  - Large number of sources form eccentricity
  - 1D projection of Gaussian ε_x and ε_y distributions

- Consequence: $v_2\{4\}=v_2\{6\}$
  - First observed by NA49
  - Then by STAR with better precision

Phys. Rev. C72 (2005) 014904



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Analysis details

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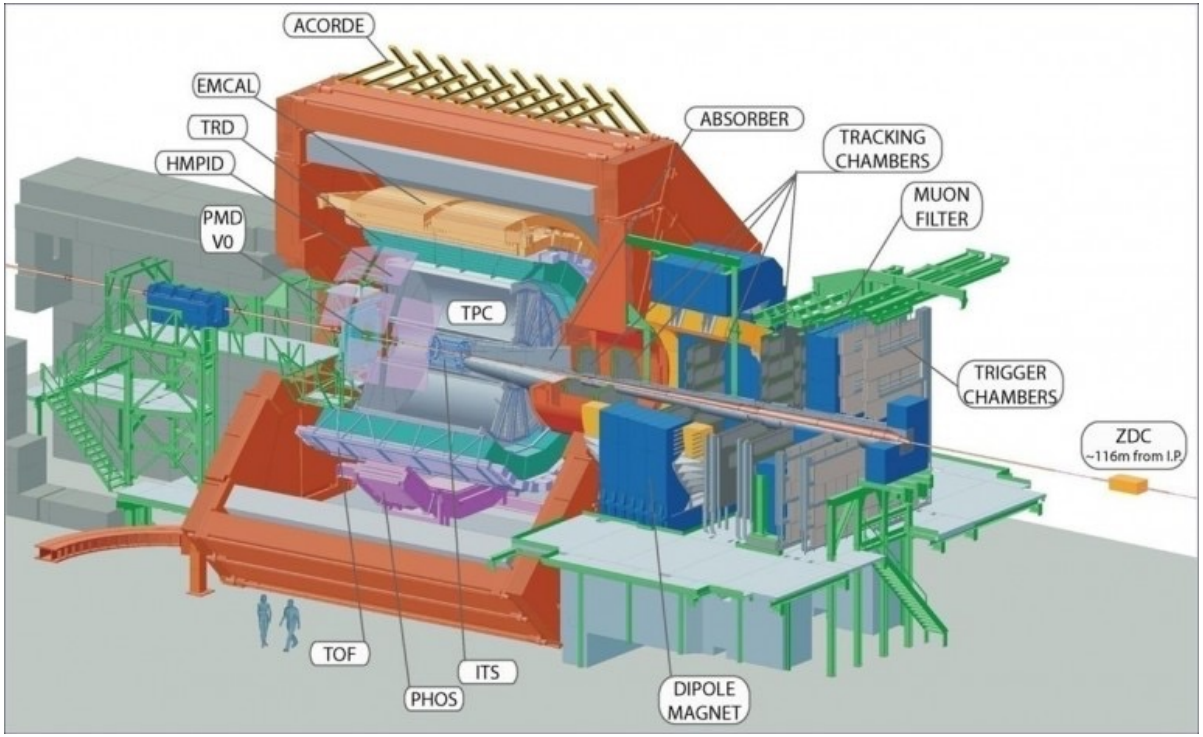
- Minbias triggering (p-Pb and Pb-Pb) based on V0s (forward detectors).
- High multiplicity trigger (p-Pb) uses ITS (Inner Tracking System) hits
- Tracking uses TPC and ITS
- Integrated $h^{\pm}$ c_n and v_n
  - $0.2 < p_T < 3$ GeV/c $|\eta_{lab}| < 1$
  - N_{ch} uses same cuts, corrected for efficiency



System	Collision energy	No. of minbias events	No. of high mult events
p-Pb	**$\sqrt{s_{NN}}$ = 5.02 TeV**	**110 M**	**1.4M**
Pb-Pb	**$\sqrt{s_{NN}}$ = 2.76 TeV**	**12 M**	**0**

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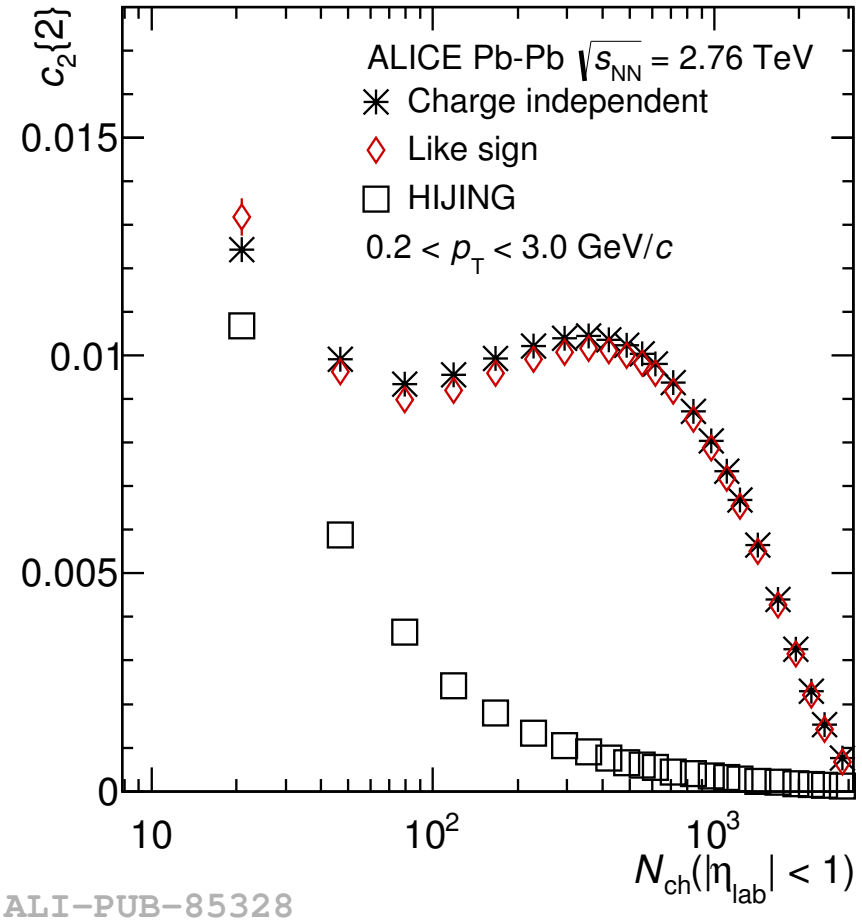
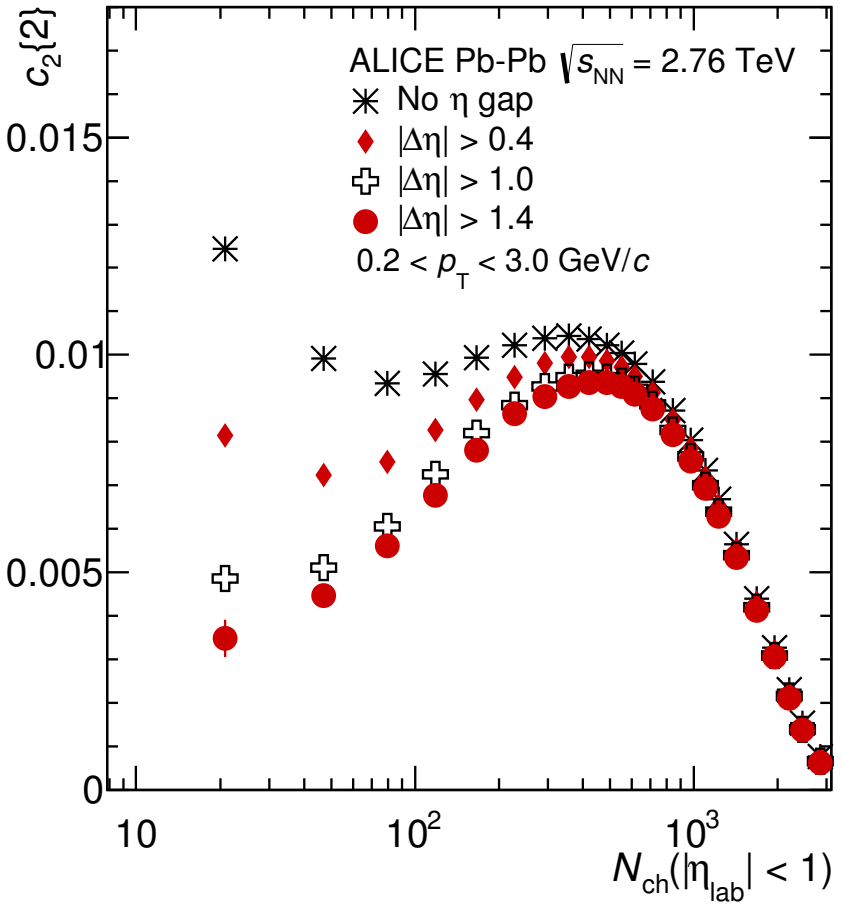
Second order two particle cumulants in Pb-Pb





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- Data show bump at N_{ch} ~200. Transition from non-flow → flow.
  - HIJING falls with N_{ch}.
  - Bigger dependence on |Δη| gap at low N_{ch}.

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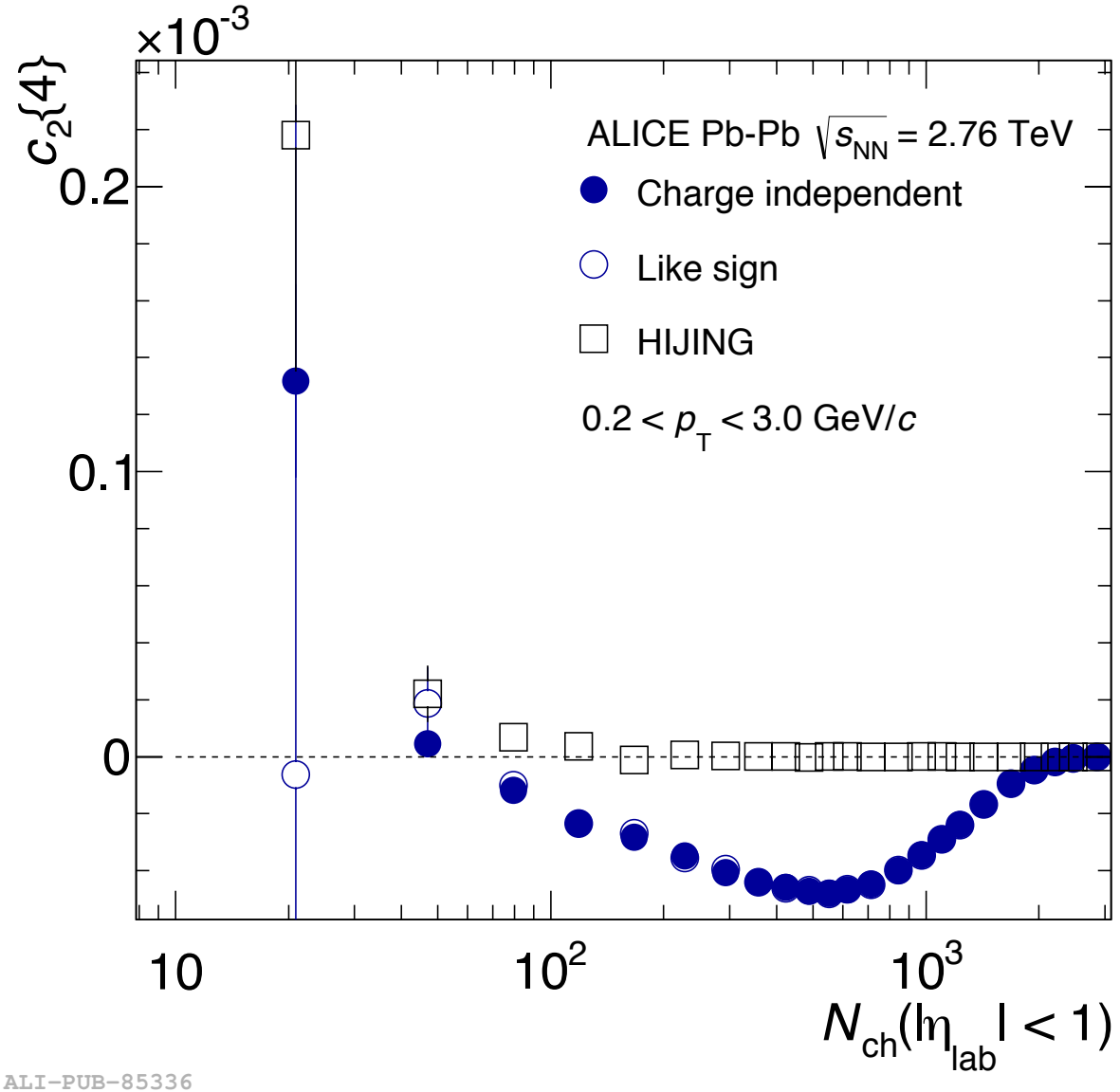
Second order four particle cumulants in Pb-Pb

- Four particle cumulant changes sign in Pb-Pb
  - Negative $c_2\{4\}$→ Real $v_2\{4\}$
- Occurs at N_{ch} ~80
- HIJING~0 at N_{ch} > 200
  - Not the case for the two particle cumulant
  - Shows complete suppression of non-flow



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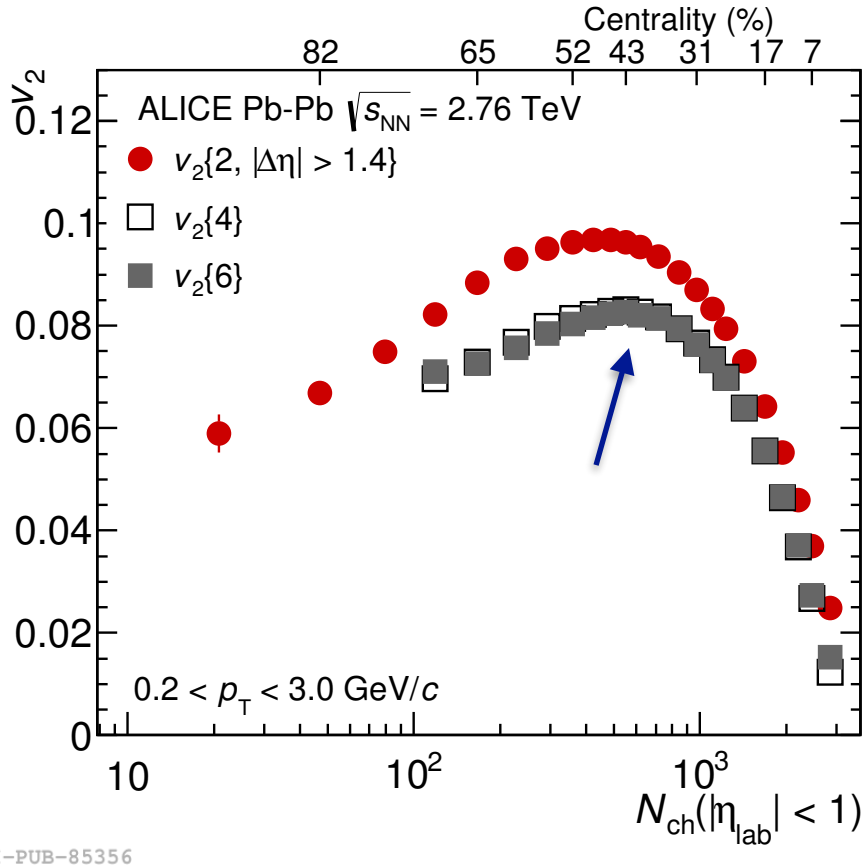
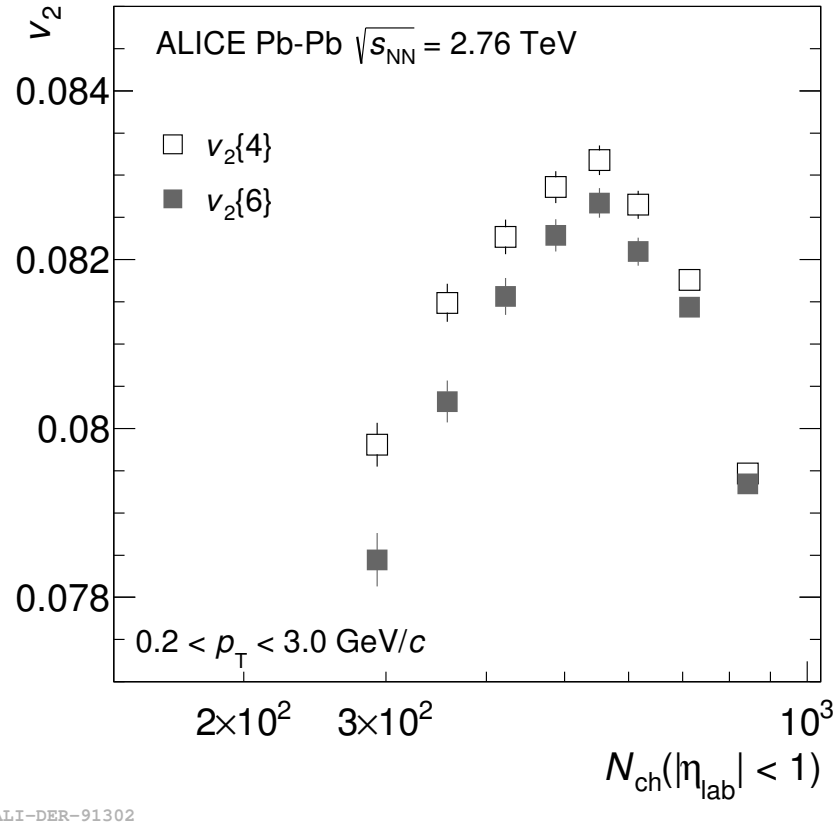
Second order flow coefficients in Pb-Pb

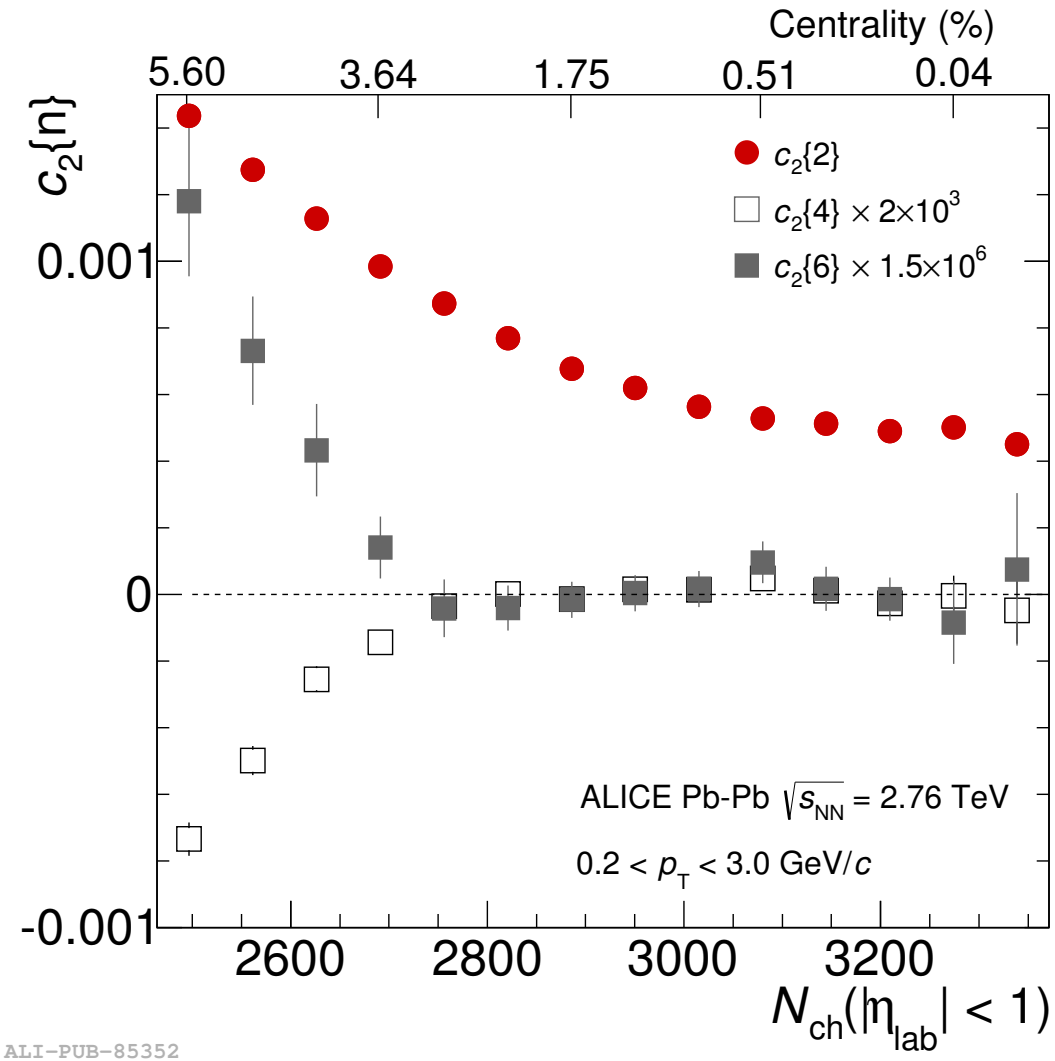


Zoom in



- $v_2\{4\}$ not exactly equal to $v_2\{6\}$ at the LHC
  - ✓ Indication of "Elliptic Power" fluctuations (arXiv:1408.0921)
  - ✓ Will be investigated further in run 2

Second order cumulants in very central Pb-Pb



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- Very central Pb-Pb collisions have higher order cumulants of zero.
- Multi-particle flow correlations gone??
  - ✓ No!
- v_2 fluctuations likely follow:

$$f(v_2) = \frac{v_2}{\sigma^2_{v_2}} \exp\left[\frac{-v_2^2}{\sigma^2_{v_2}}\right]$$

- Valid for large numbers of sources and b~0 fm.

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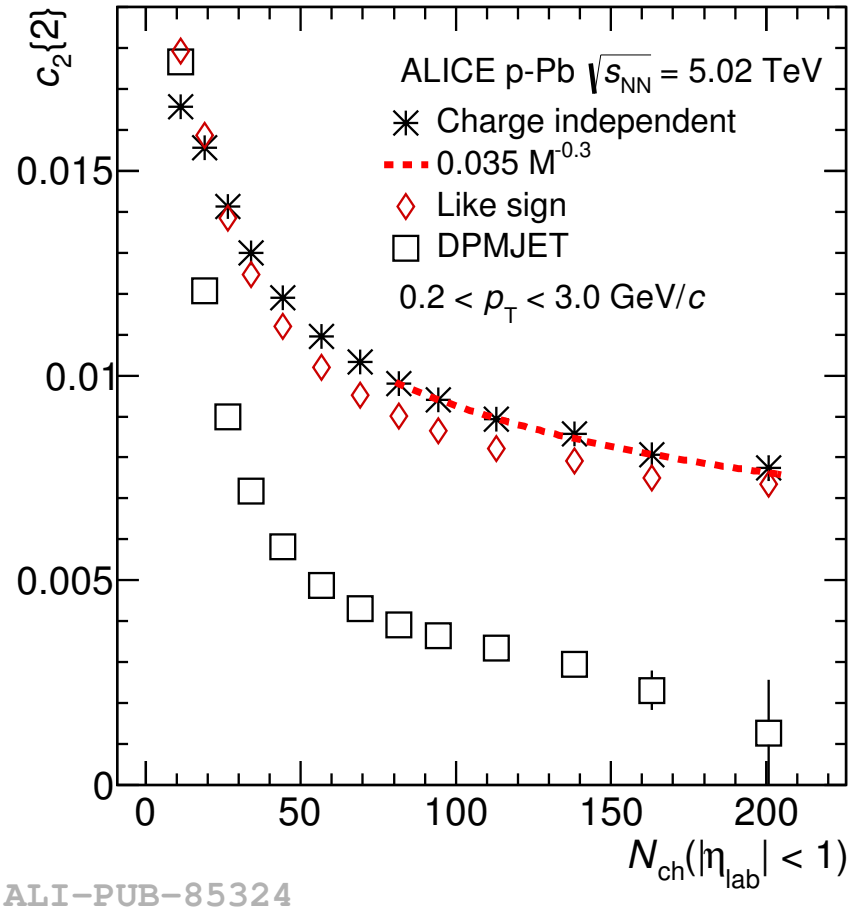
Second order two particle cumulants in p-Pb



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Non-flow $\Rightarrow$ $c_n\{m\} \propto \frac{1}{M^{m-1}}$

- Two particle correlations can be used to investigate multi-particle correlations
  - ✓ Decrease when non-flow dominates
  - ✓ Increase can be explained by emergence of global correlations

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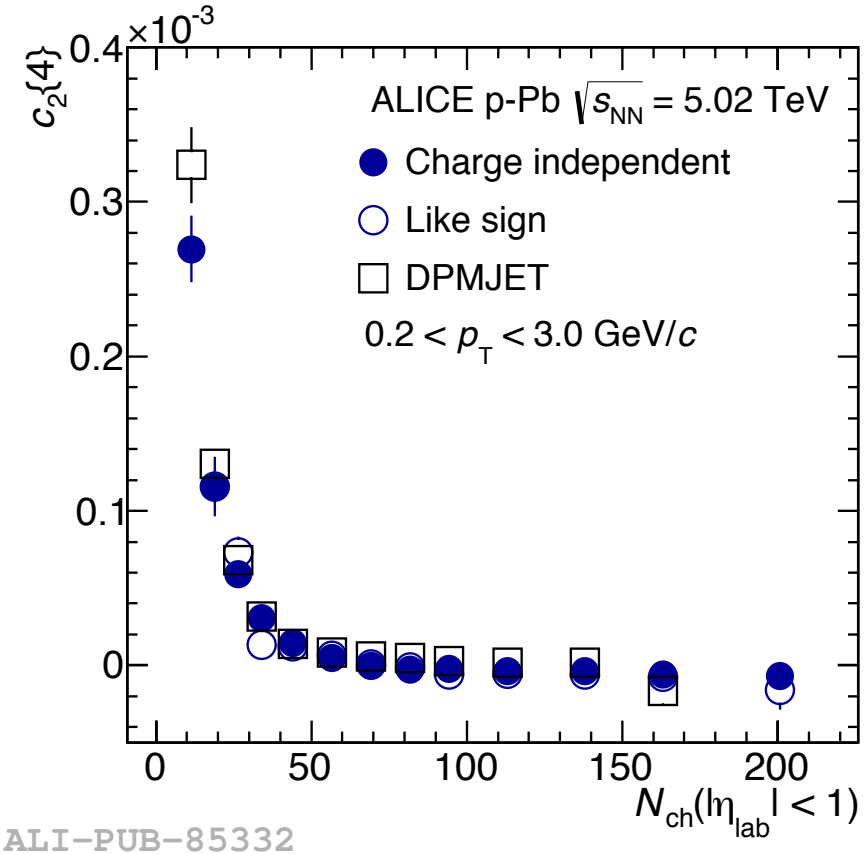
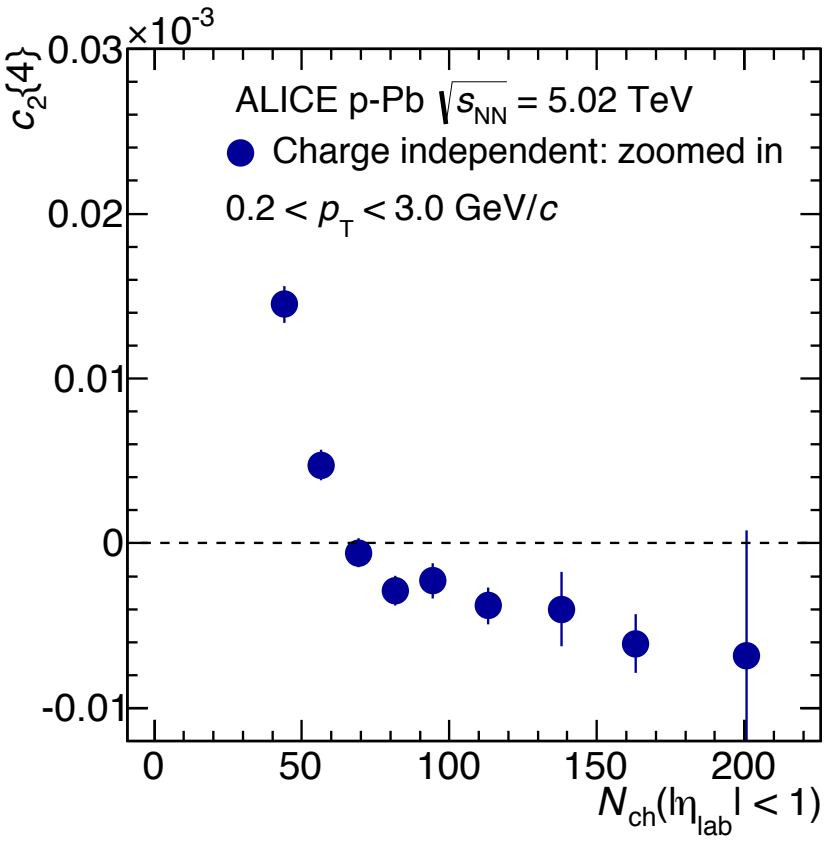
Second order four particle cumulants in p-Pb





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- Change of sign also occurs in p-Pb
  - Further evidence of multi-particle correlations
  - Change of sign can be described in CGC (arXiv:1410.4844)
  - Disconnected → connected diagrams

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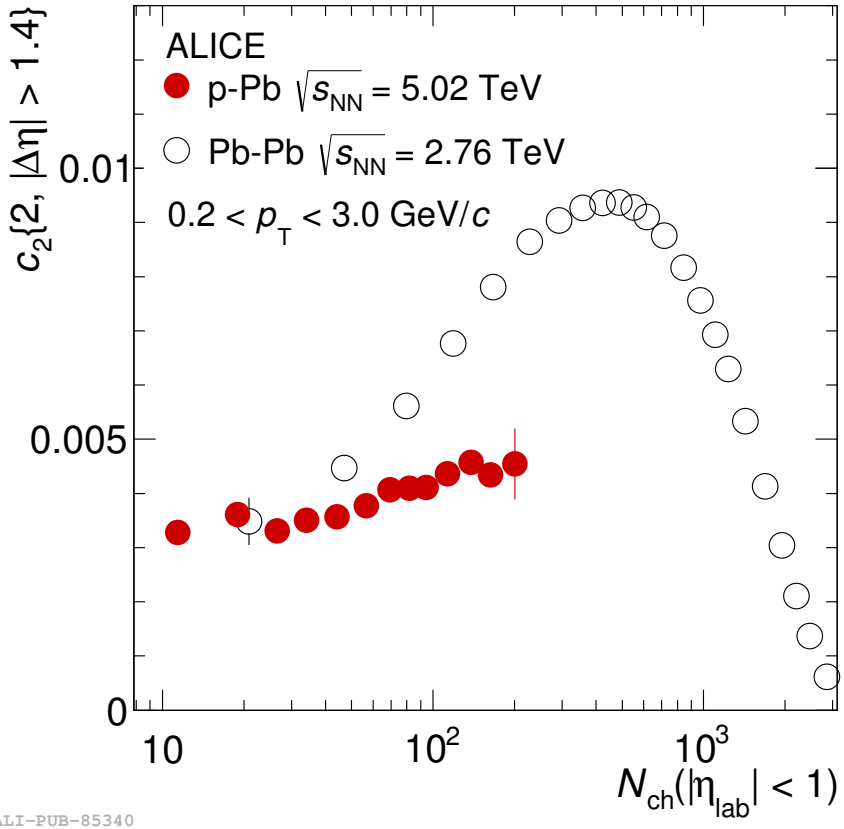
Second order comparison of Pb-Pb and p-Pb



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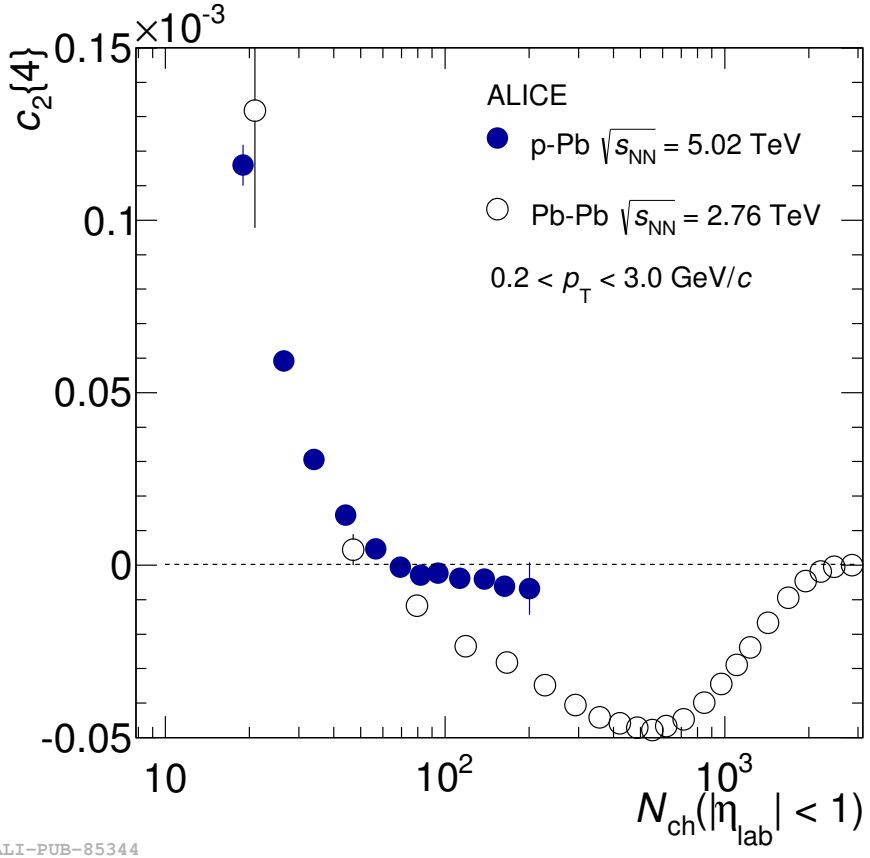

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- Magnitude of Pb-Pb $c_2\{2\}$ and $c_2\{4\}$ values bigger at same N_{ch}
  - ε_2 (Pb-Pb) driven by geometry & fluctuations.
  - ε_2 (p-Pb) by just fluctuations?

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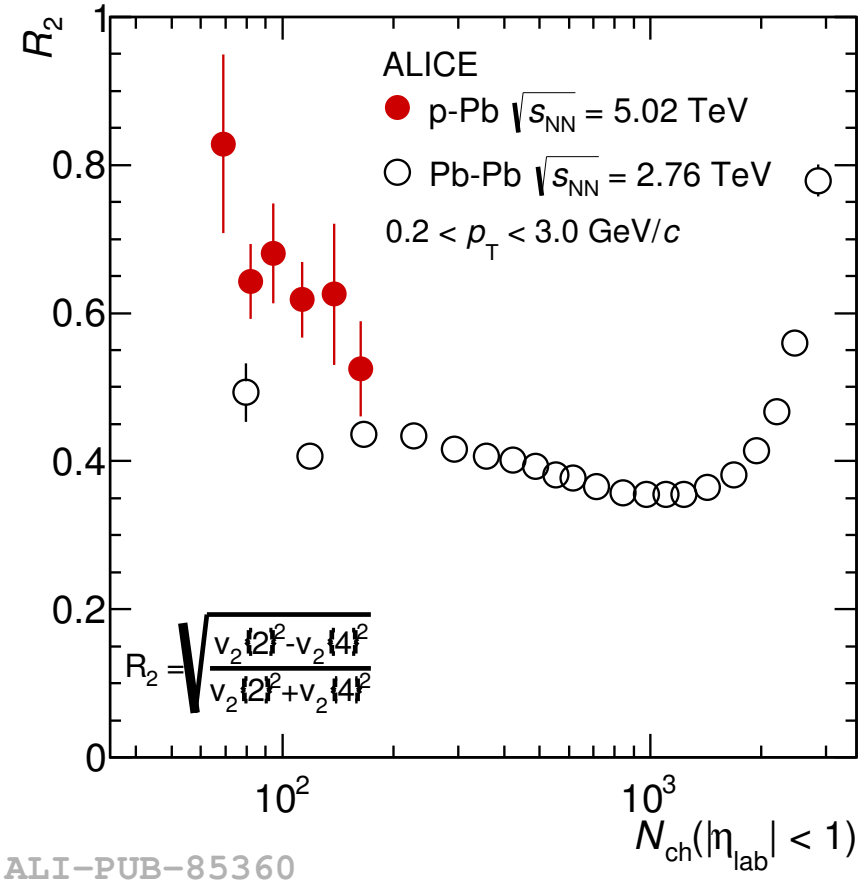
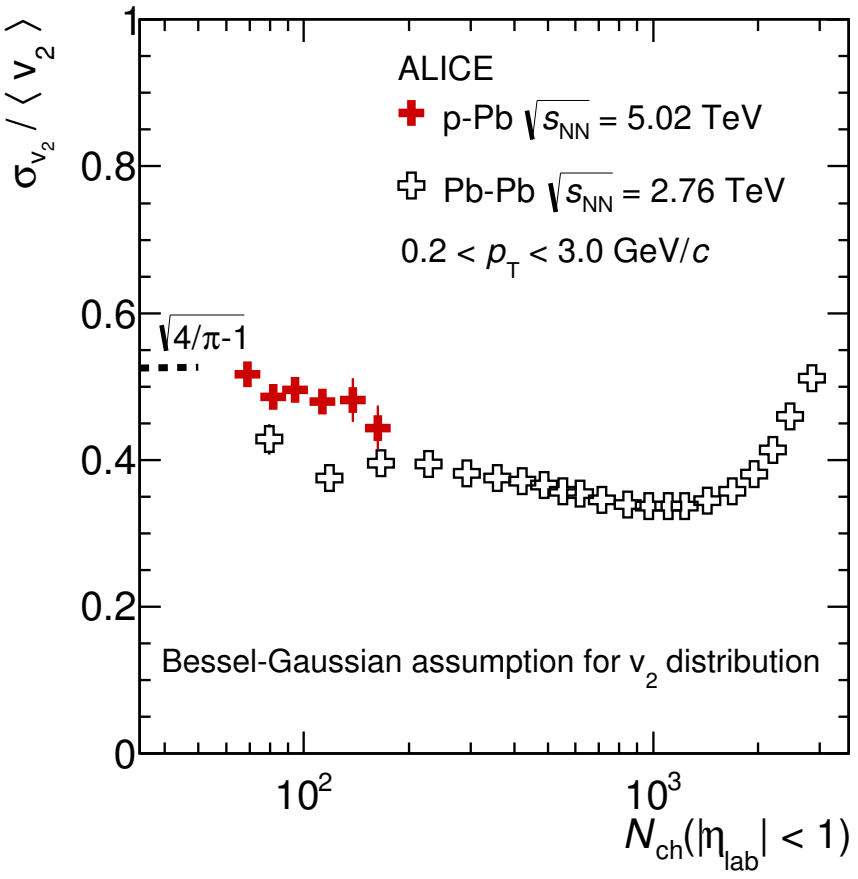
Second order comparison of Pb-Pb and p-Pb





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- Two measures of fluctuation strength which approximate $\sigma_{vn}/\langle v_n \rangle$
  - Both indicate fluctuations maybe higher in p-Pb
  - Contributions from residual non-flow should not be discounted

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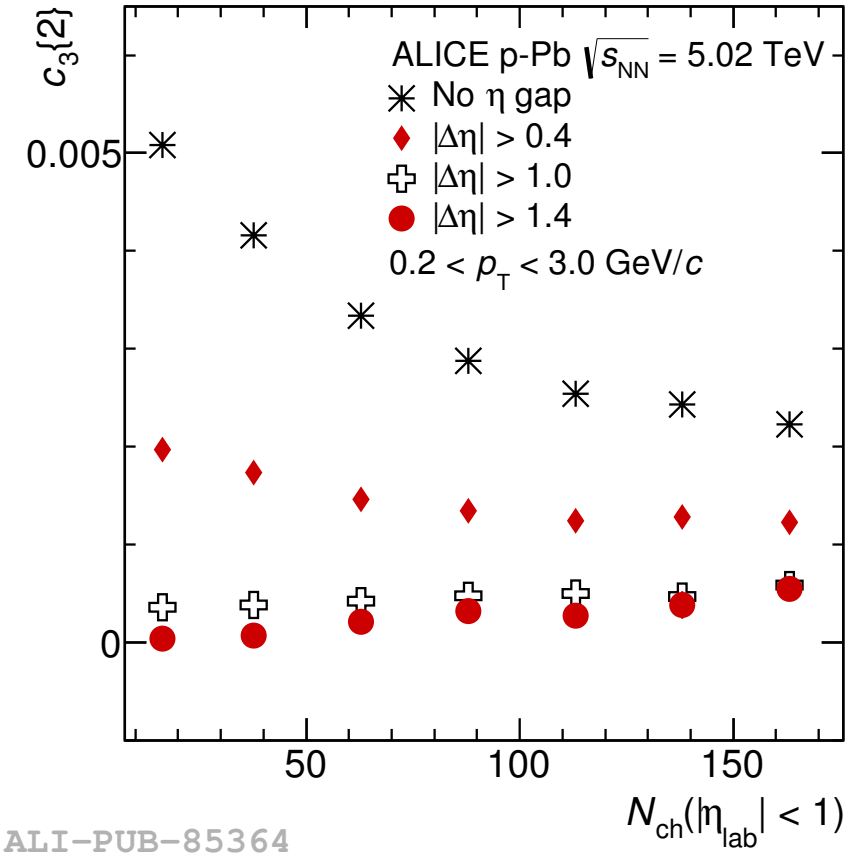
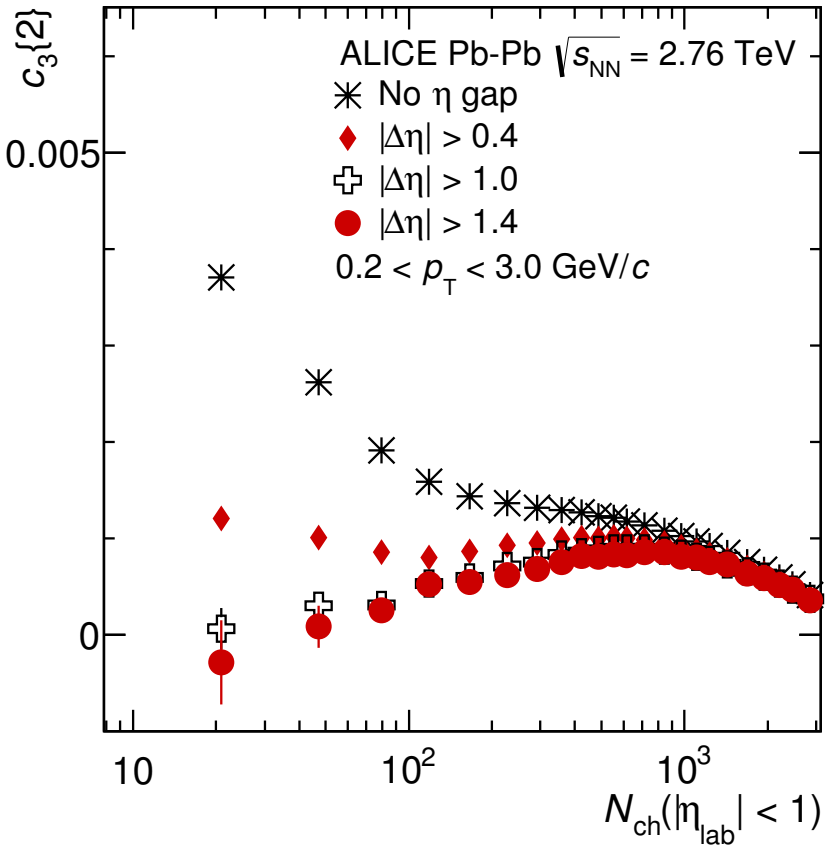
Third order cumulants in p-Pb and Pb-Pb





ALI-PUB-85364

- Large dependence on Δη gap for $c_3\{2\}$ in p-Pb. Increases with N_{ch} for large Δη
- Convergence at large N_{ch} for Pb-Pb. Expected if triangular flow dominates.

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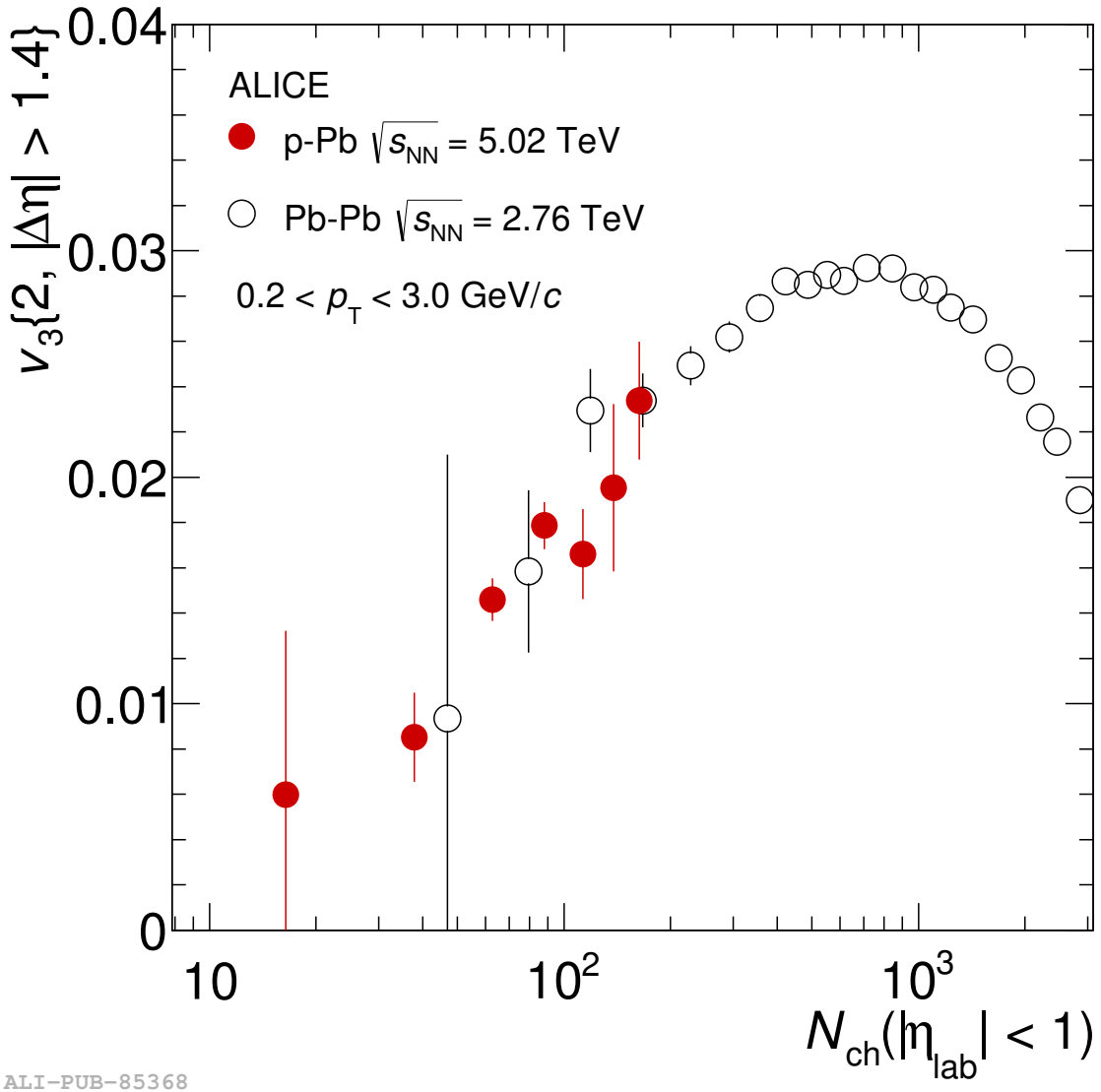
Third order flow coefficients in p-Pb and Pb-Pb

- $v_3\{2\}$ in p-Pb consistent with Pb-Pb at same N_{ch}
  - In contrast to $v_2\{2\}$…
- Implies $\varepsilon_3(\text{p-Pb})_{\text{RMS}} \sim \varepsilon_3(\text{Pb-Pb})_{\text{RMS}}$
- Both driven by fluctuations?
  - More theoretical studies in (Phys. Rev. C 90 2014 054903)



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Summary

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- **Second order flow in Pb-Pb**
  - Changing behaviour in cumulants from low to high N_{ch} → Development of elliptic flow
  - Indication of non Bessel Gaussian fluctuations in Pb-Pb
  - Higher order cumulants become zero for very central collisions

- **Second order cumulants in p-Pb collisions**
  - $c_2\{2\}$ rises in p-Pb with N_{ch} for large $|\Delta\eta|$. Naively inconsistent with non-flow.
  - $c_4\{2\}$ in p-Pb transitions from pos. to neg. values. $v_2\{4\}$ becomes real.
    - ➡ Both point to collective behaviour in p-Pb collisions
  - $c_2\{m\}$ higher in Pb-Pb compared to p-Pb at same N_{ch}.
    - ➡ Contribution to Pb-Pb ε_2 from overlap geometry

- **Third order cumulants and flow coefficients in p-Pb and Pb-Pb**
  - $c_3\{2\}$ rises in p-Pb with N_{ch} for large $|\Delta\eta|$.
  - $v_3\{2\}$ in p-Pb and Pb-Pb very similar at same N_{ch}. Indicates both ε_3's driven by fluctuations

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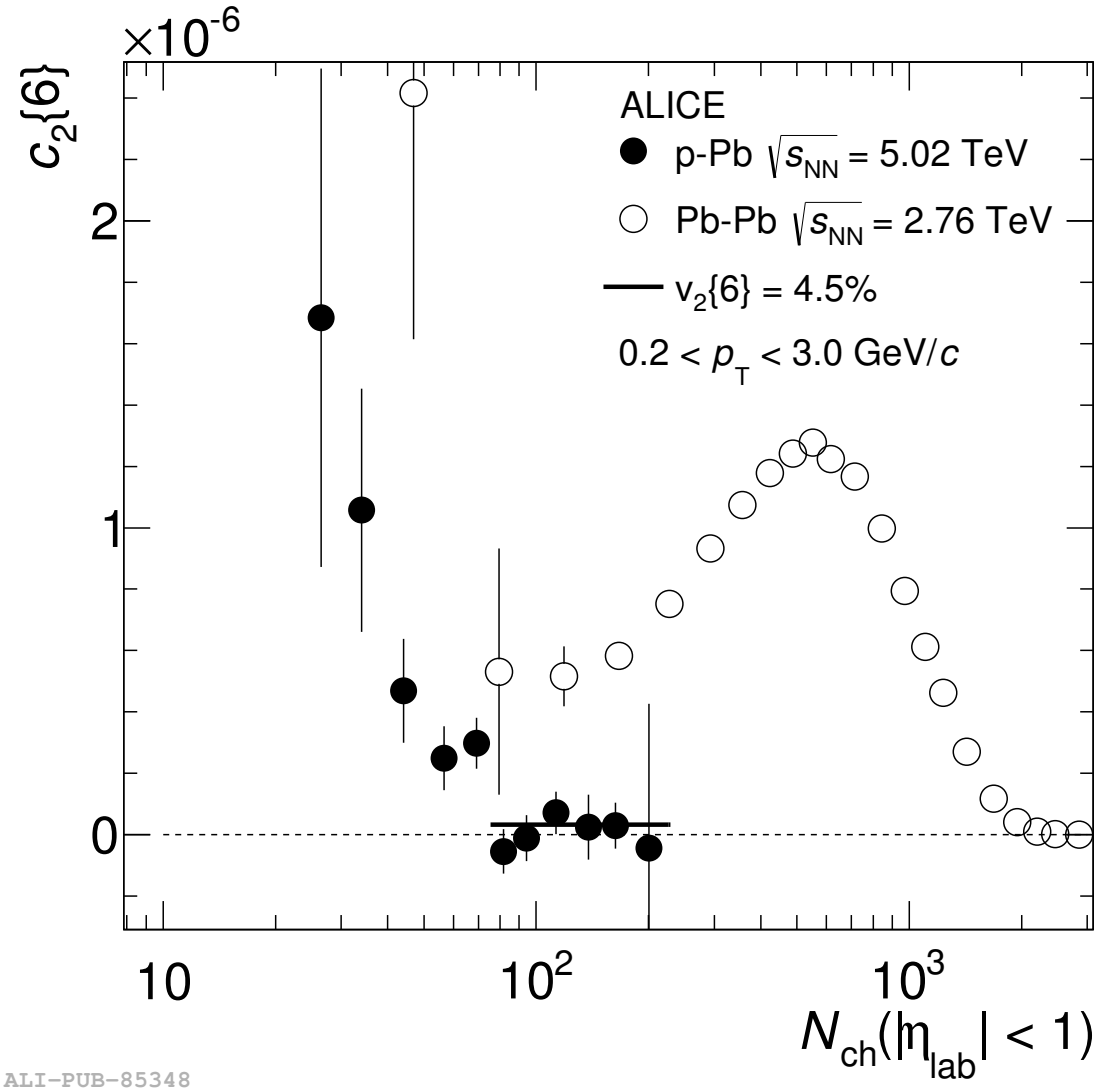
Back-up



ALI-PUB-85348