p_T dependent event-plane angle: A further step in understanding initial state fluctuations in PbPb and pPb collisions

WPCF 2014: Xth Workshop on Particle Correlations and Femtoscopy

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CMS Collaboration

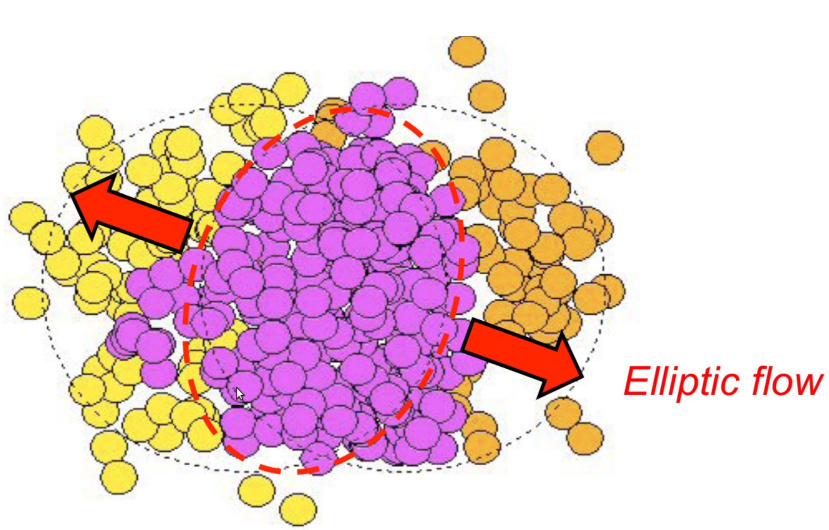
Motivation

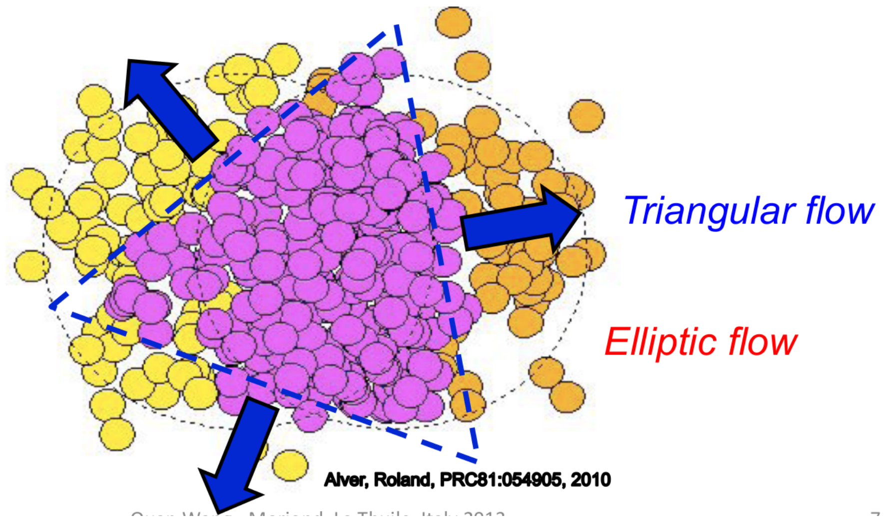
- **Single particle distribution**

$$\frac{dN}{d\phi} \sim 1 + \underbrace{2v_2 \cos[2(\phi - \Psi_2)]}_{\text{eliptic flow}} + \underbrace{2v_3 \cos[3(\phi - \Psi_3)]}_{\text{triangular flow}} + ..$$

$$\boxed{v_n = \langle cos[n(\phi - \Psi_n)] \rangle}$$

Two particle correlations: $\frac{dN}{d\Delta\phi} \sim 1 + 2V_{2\Delta} \cos 2\Delta\phi + 2V_{3\Delta} \cos 3\Delta\phi$





Asymmetric pressure gradients

Initial state fluctuations

Motivation

- **Connect $V_{n\Delta}$ and v_n:**

$$V_{n\Delta}(p_{T_1}, p_{T_2}) = \langle v_n(p_{T_1}) v_n(p_{T_2}) \times \cos[n(\Psi_n(p_{T_1}) - \Psi_n(p_{T_2}))]\rangle$$

$\neq 1$

initial state fluctuations $\rightarrow \Psi_n(p_T) \rightarrow$ factorization breaking

- $\Psi_n(p_T)$ **determined by final-state particles**
- $\Psi_n(p_T)$ **fluctuates from event to event**

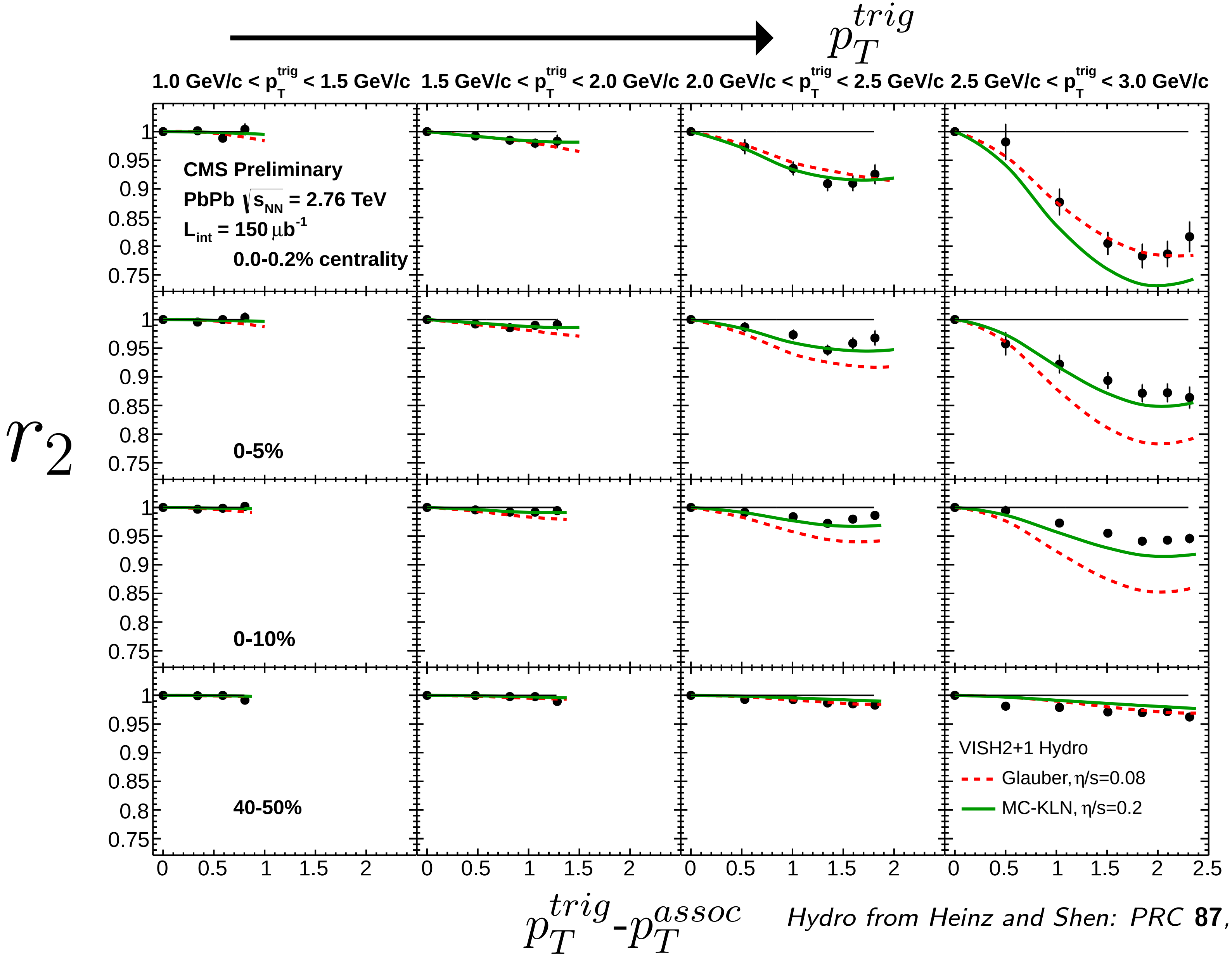
Papers on the subject:

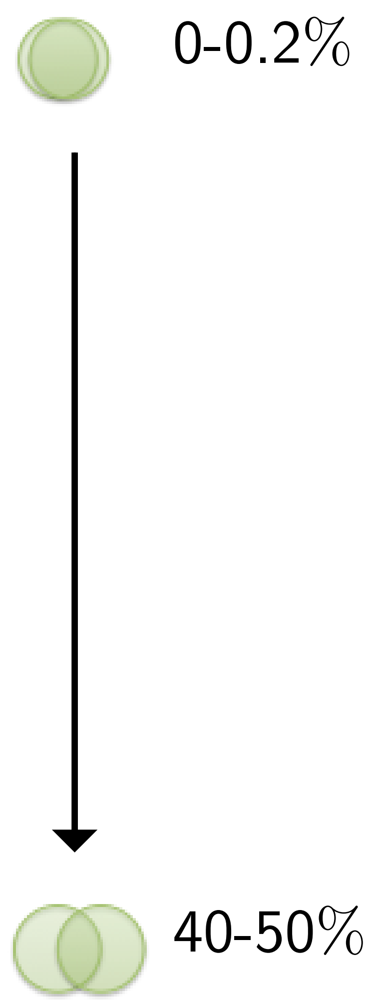
- **Ollitrault et. al.**, Phys. Rev. C **87**, 031901(2013) and **U. W. Heinz et. al.**, Phys. Rev. C **87**, 034913 (2013)
- **CMS collaboration**: Studies of azimuthal dihadron correlations in ultra-central PbPb collisions at $\sqrt{s_{NN}} = 2.76 TeV$, JHEP **1402** (2014)088

Motivation

$$r_n = \frac{V_{n\Delta}(p_{T_1}, p_{T_2})}{\sqrt{V_{n\Delta}(p_{T_1}, p_{T_1}) V_{n\Delta}(p_{T_2}, p_{T_2})}}$$

$$r_n = \begin{cases} 1 & \text{factorization} \\ < 1 & \text{factorization breaking} \end{cases}$$





Hydro from Heinz and Shen: PRC **87***,034913(2013)*

Motivation

Theory: $\boxed{V_{n\Delta} = \langle \cos(n\Delta\phi) \rangle}$, $\Delta\phi = \phi_1 - \phi_2$

Experiment: $\boxed{V_{n\Delta} = \langle\langle \cos(n\Delta\phi) \rangle\rangle_S - \langle\langle \cos(n\Delta\phi) \rangle\rangle_B}$, $|\Delta\eta| > 2$

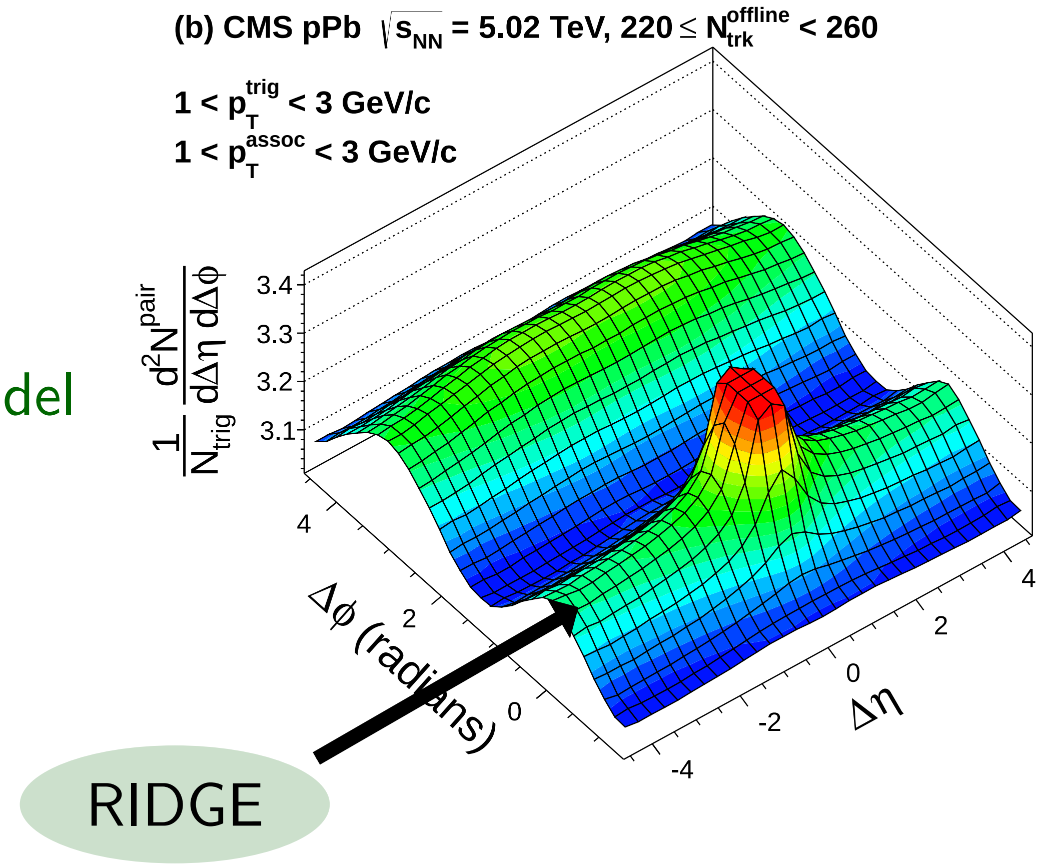
- $\langle\langle ... \rangle\rangle_B$ remove effect from non-uniform detector acceptance

- **Long range correlation in pPb!**
- **Initial state fluctuations?**
- **Expect large effect as in UCC PbPb?**

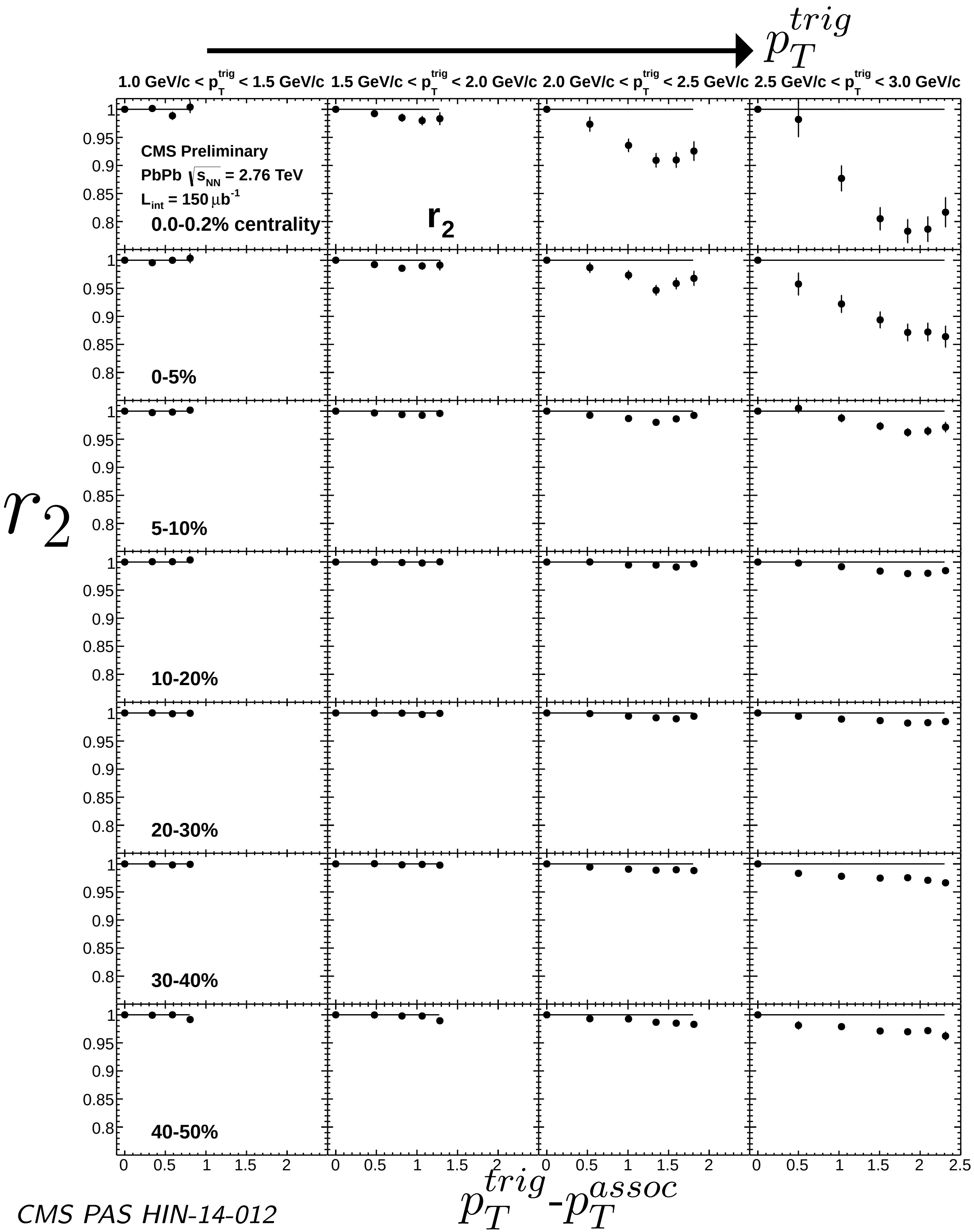
Look at hydro model predictions

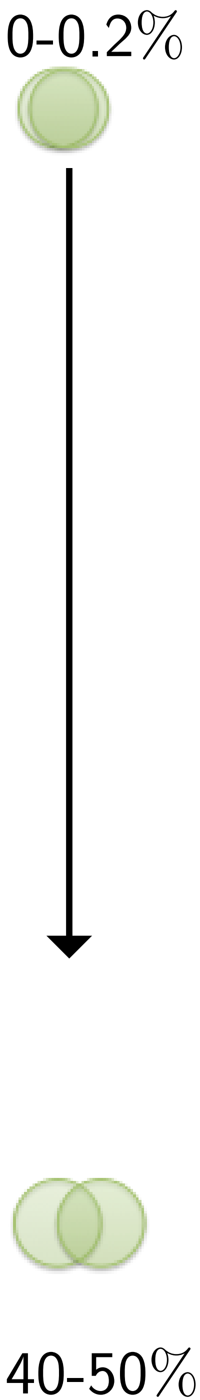
- Kozlov et. al. [arXiv:1405.3976] model
- Heinz-Shen VISH2+1: PRC **87**, 034913 (2013) model

Constrain initial condition and η/s



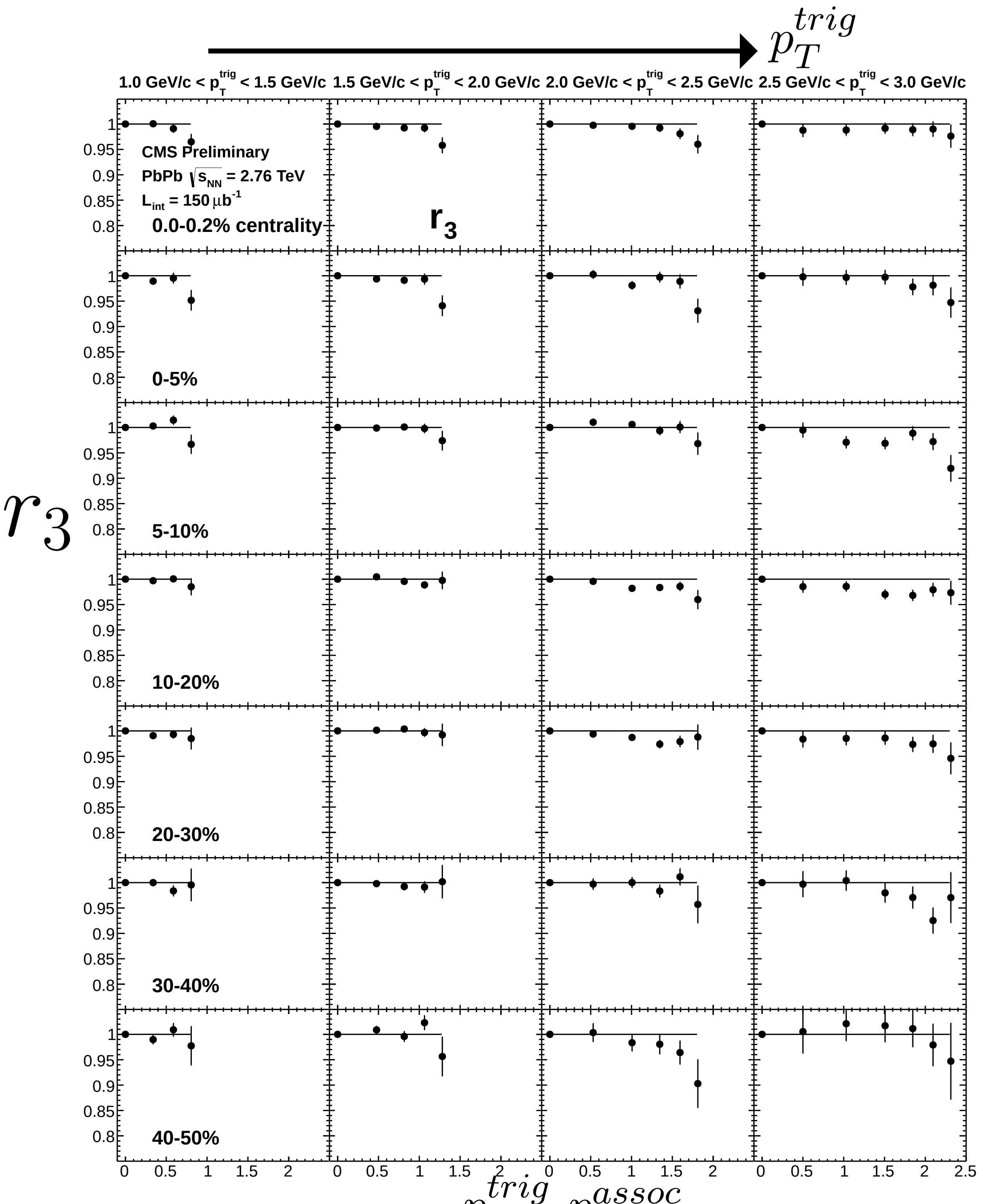
PbPb RESULTS

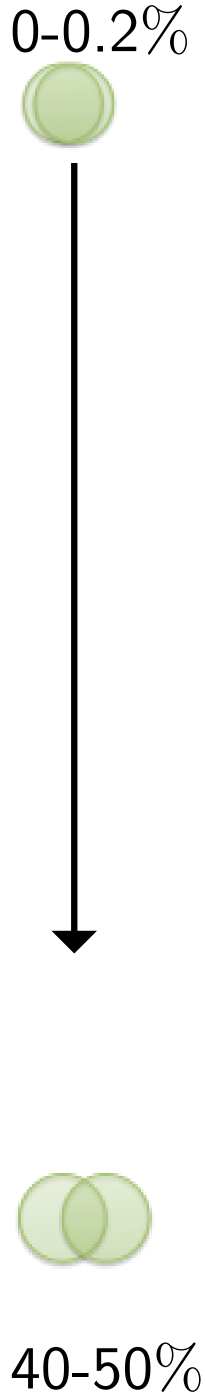




- The effect increases with rise of p_T^{trig} and $p_T^{trig} - p_T^{assoc}$
- Approaching the central collisions, the effect dramatically increases achieving over 20%
- For semi-central collisions, the effect achieves only a size of $2 - 3\%$

CMS PAS HIN-14-012

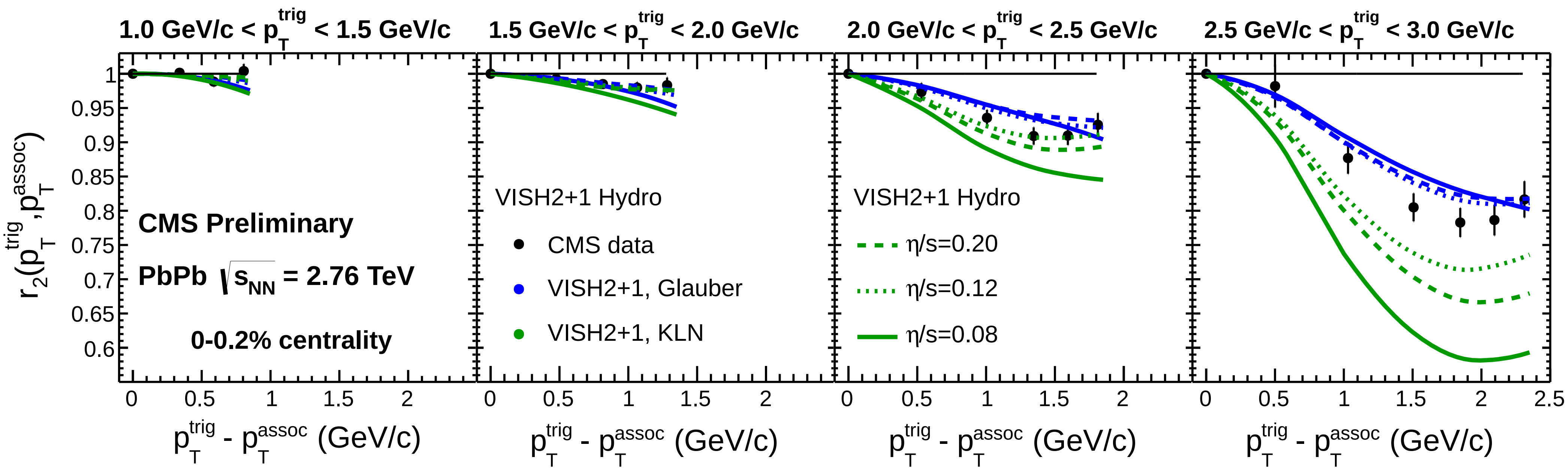




- Factorization holds better for V_3
- Breaking visible only for the highest $p_T^{trig} - p_T^{assoc}$
- Practically independent of centrality

CMS PAS HIN-14-012

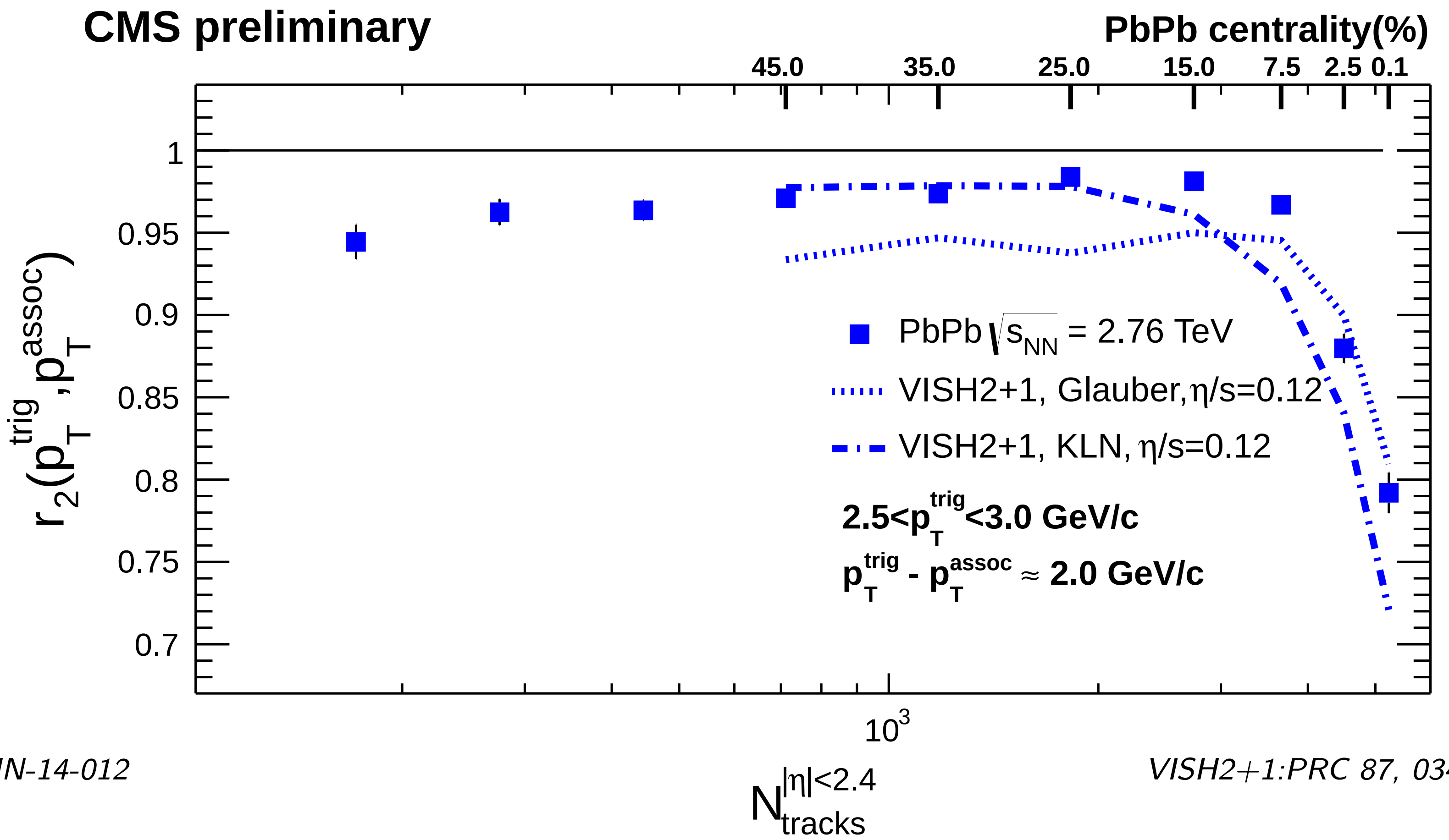
r_2 comparison with VISH2+1 for ultra-central collisions



CMS PAS HIN-14-012 *VISH2+1:PRC 87, 034913 (2013)*

- The VISH2+1 model qualitatively gives a good description of CMS data for both Glb and KLN initial conditions
- Very roughly, both initial conditions are closest to the exp. data for η/s=0.12

r_2 multiplicity dependence

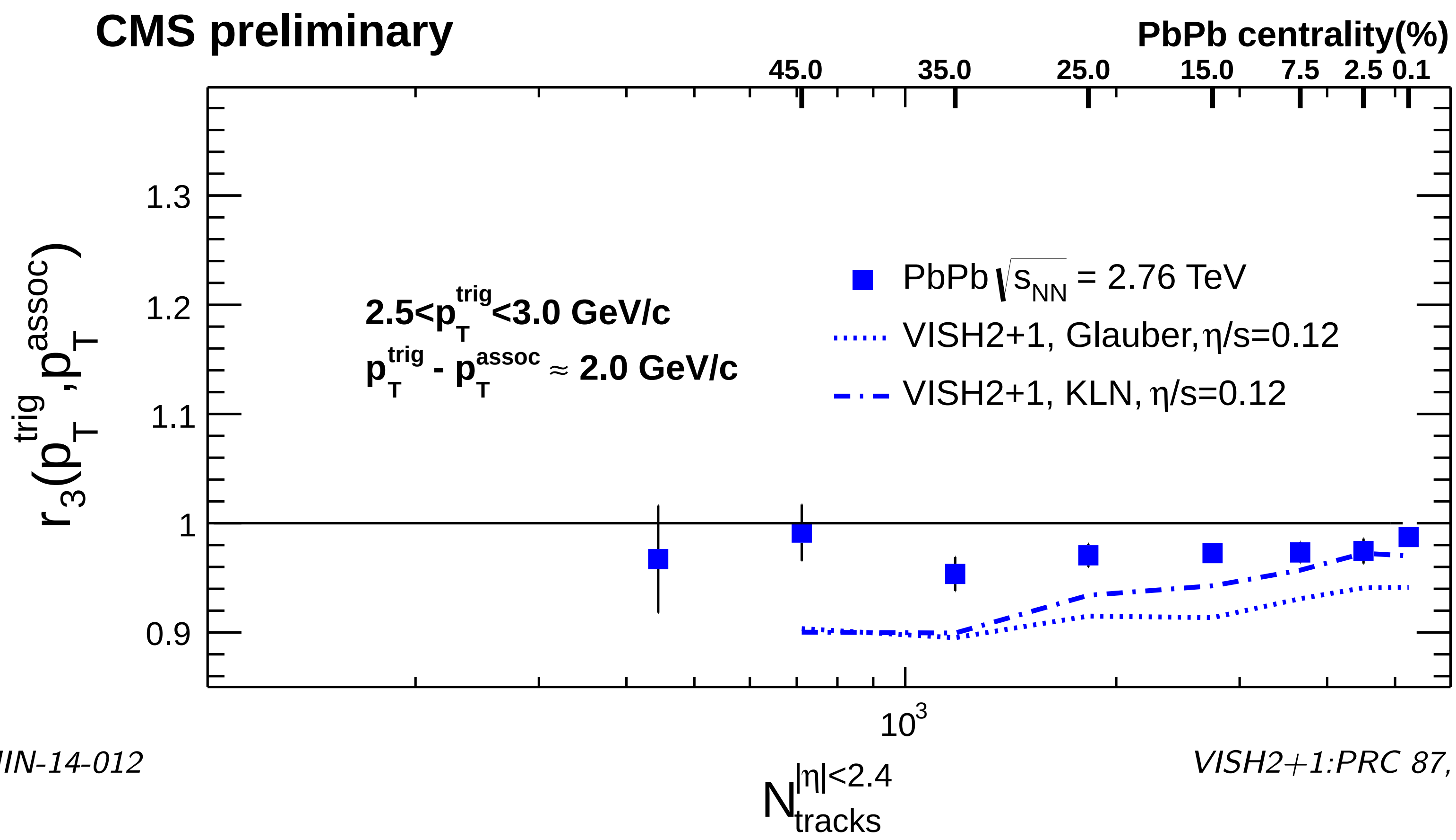


CMS PAS HIN-14-012

VISH2+1:PRC 87, 034913 (2013)

- The effect increases dramatically as the collisions become more central than 0-5%
- For the smaller centralities (>5%), the effect is on the level of few percent, and is nearly independent of centrality
- Both initial conditions, qualitatively describe CMS data

r_3 multiplicity dependence



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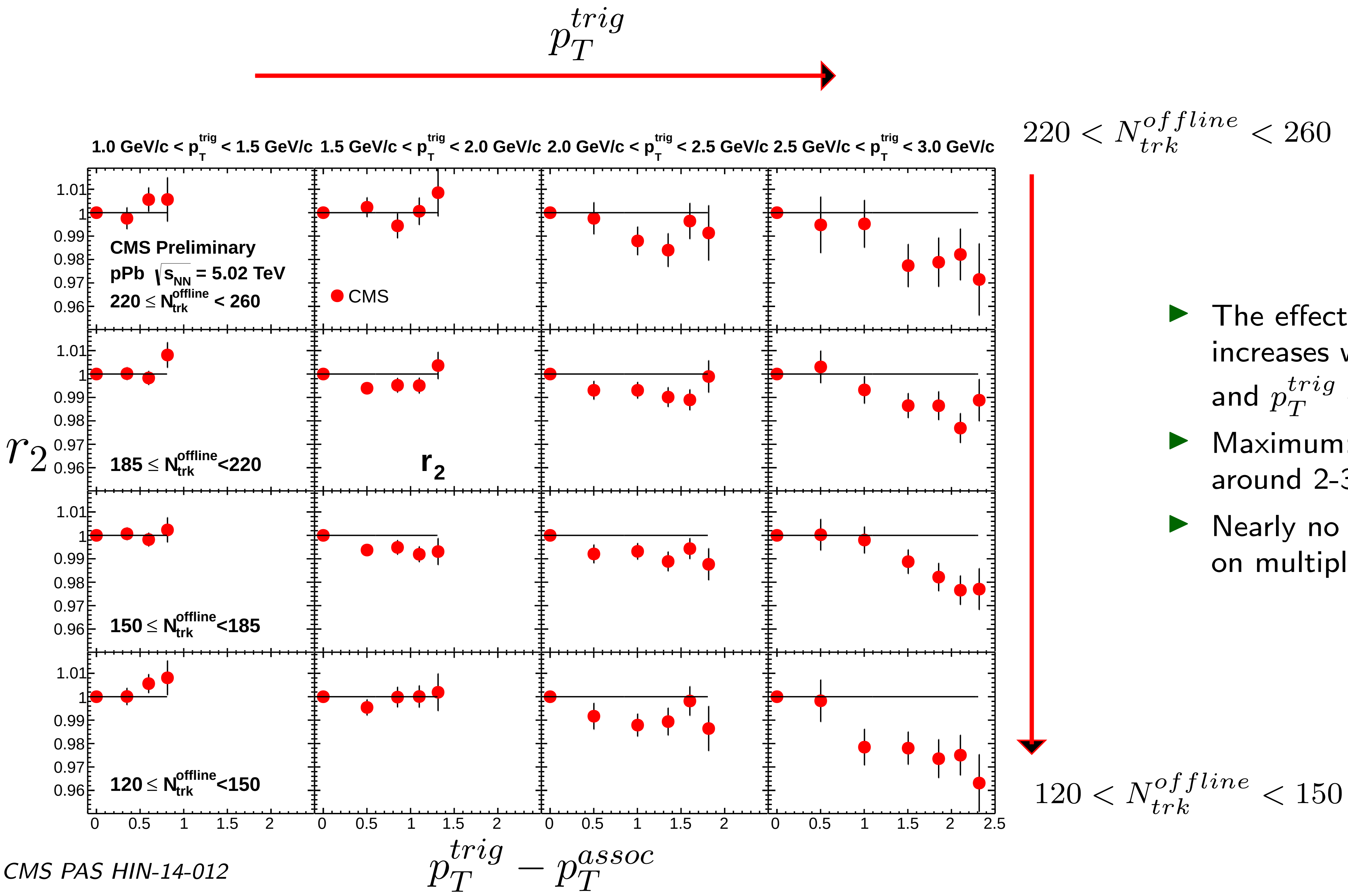
VISH2+1:PRC 87, 034913 (2013)

- No strong centrality dependence
- VISH2+1 qualitatively describes r_3

pPb RESULTS

r_2 from high-multiplicity pPb



- The effect increases with p_T^{trig} and $p_T^{trig} - p_T^{assoc}$
- Maximum: around 2-3%
- Nearly no dependence on multiplicity

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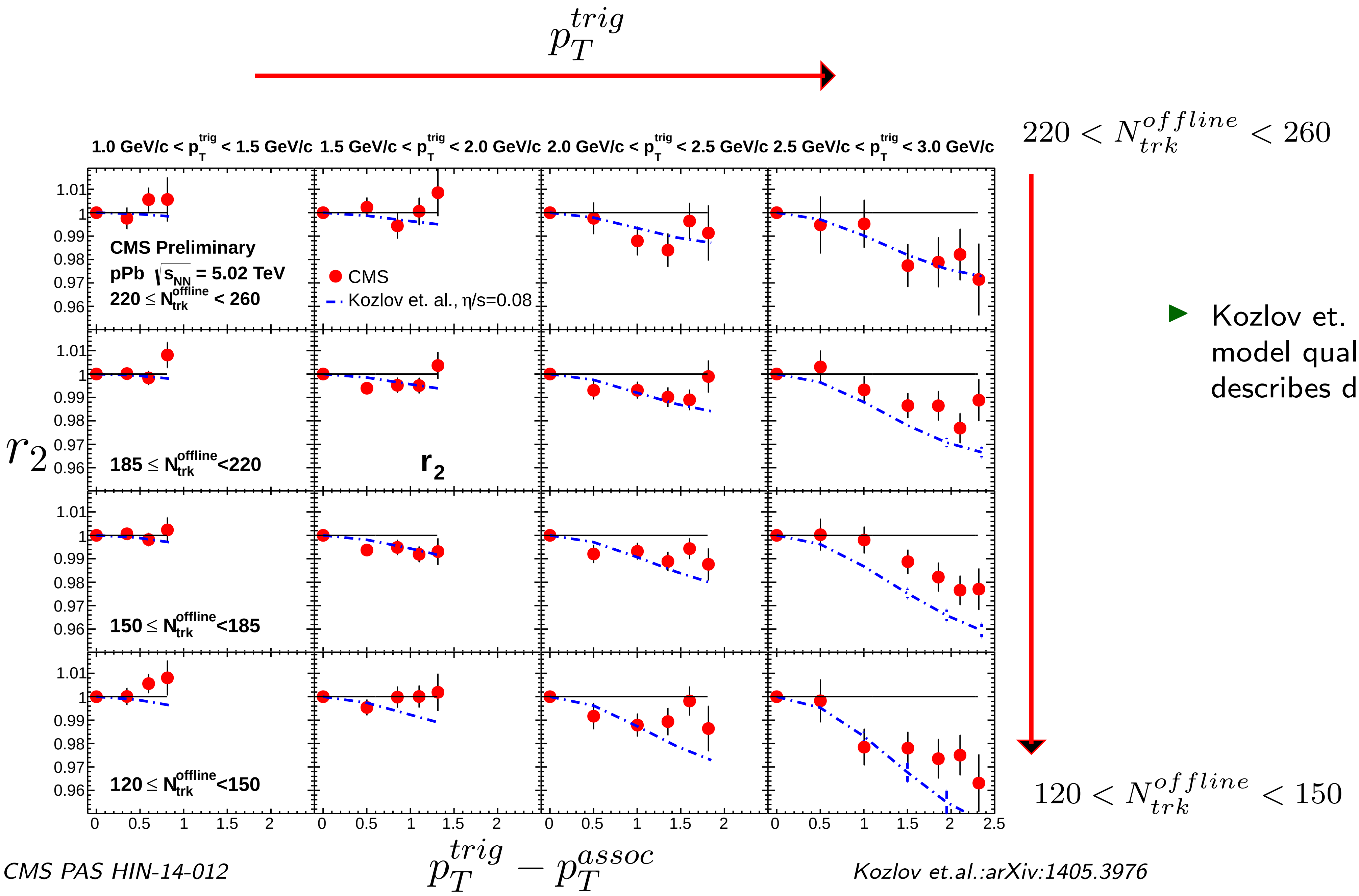
Comparison: r_2 from high-multiplicity pPb with Kozlov et. al. hydro model



- Kozlov et. al. hydro model qualitatively describes data

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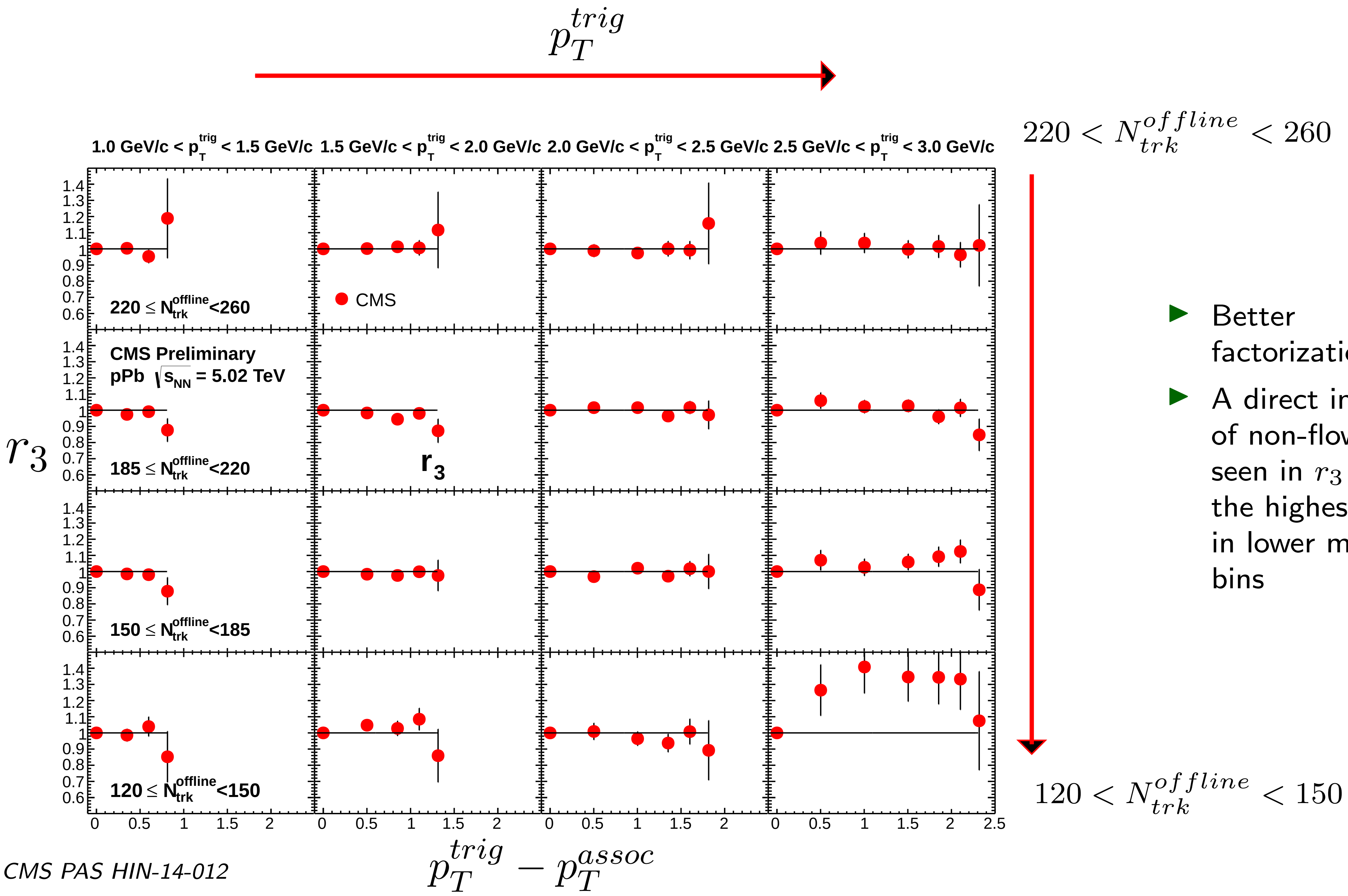
Kozlov et.al.:arXiv:1405.3976

r_3 from high-multiplicity pPb



- Better factorization for v_3
- A direct indication of non-flow effect seen in r_3 for the highest p_T^{trig} in lower multiplicity bins

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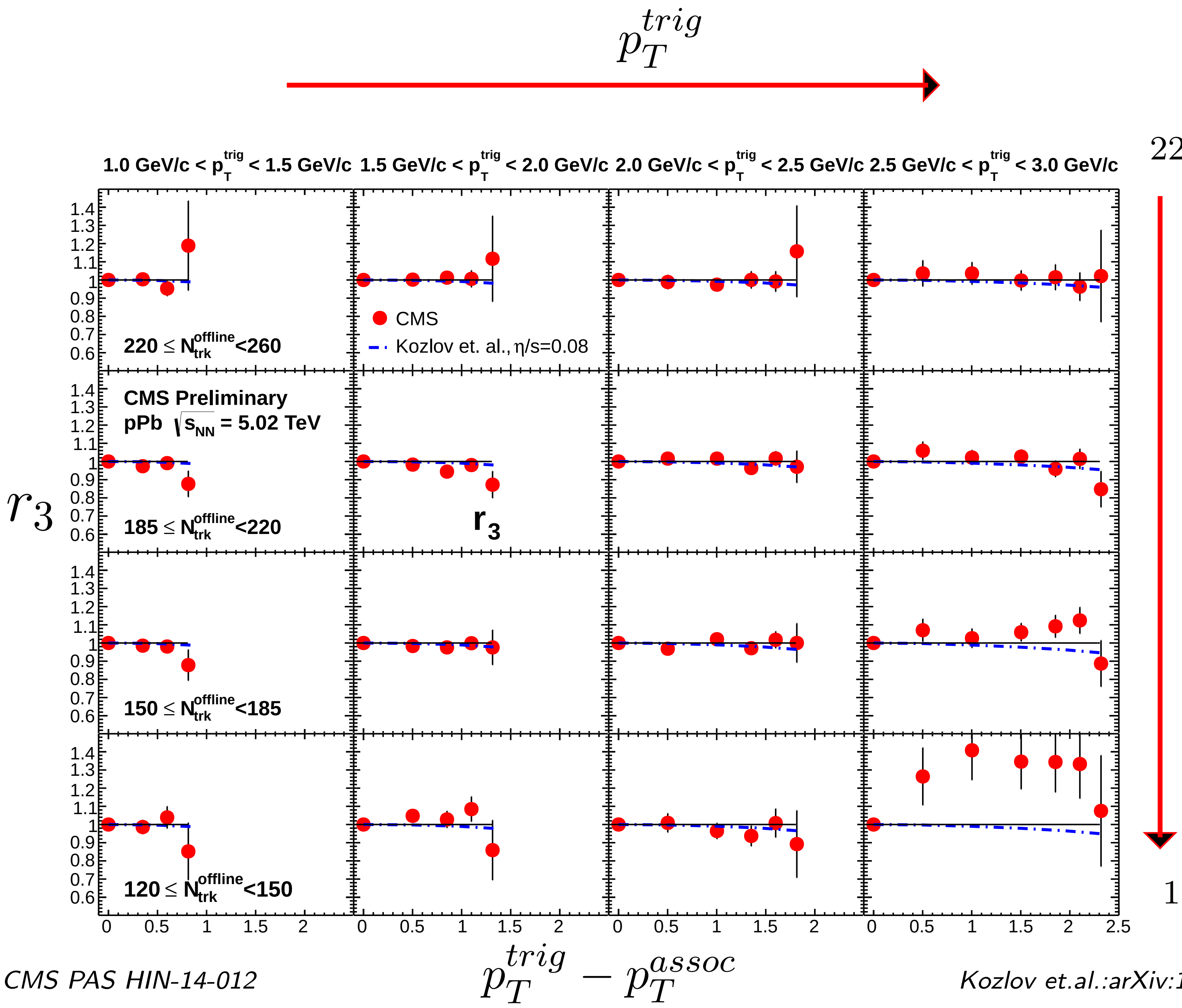
Comparison: r_3 from high-multiplicity pPb with Kozlov et. al . hydro model

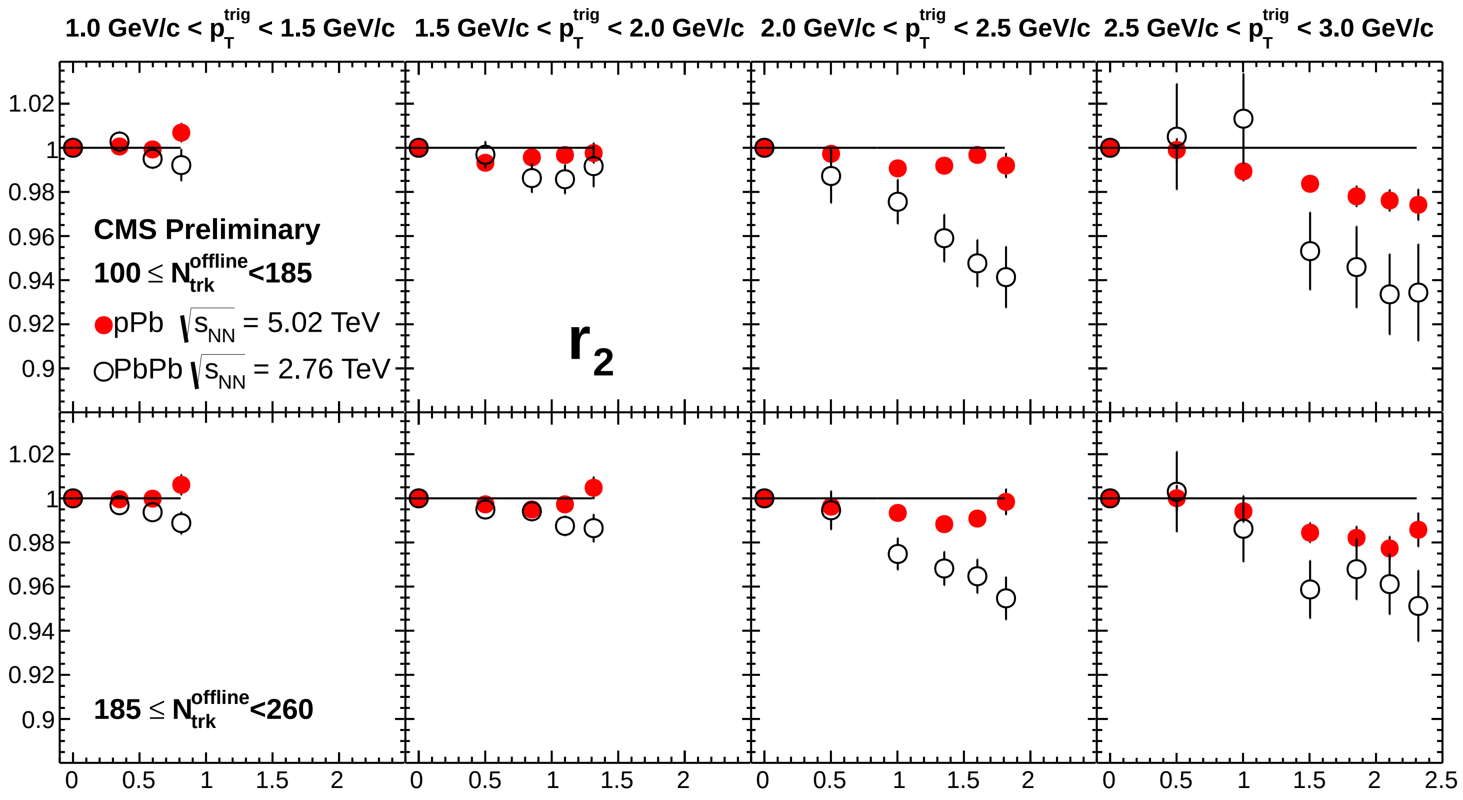


- Kozlov et. al. model qualitatively describes data except in lower multiplicity bins

CMS PAS HIN-14-012

Kozlov et.al.:arXiv:1405.3976

r_2 comparison between high-multiplicity pPb and peripheral PbPb collisions



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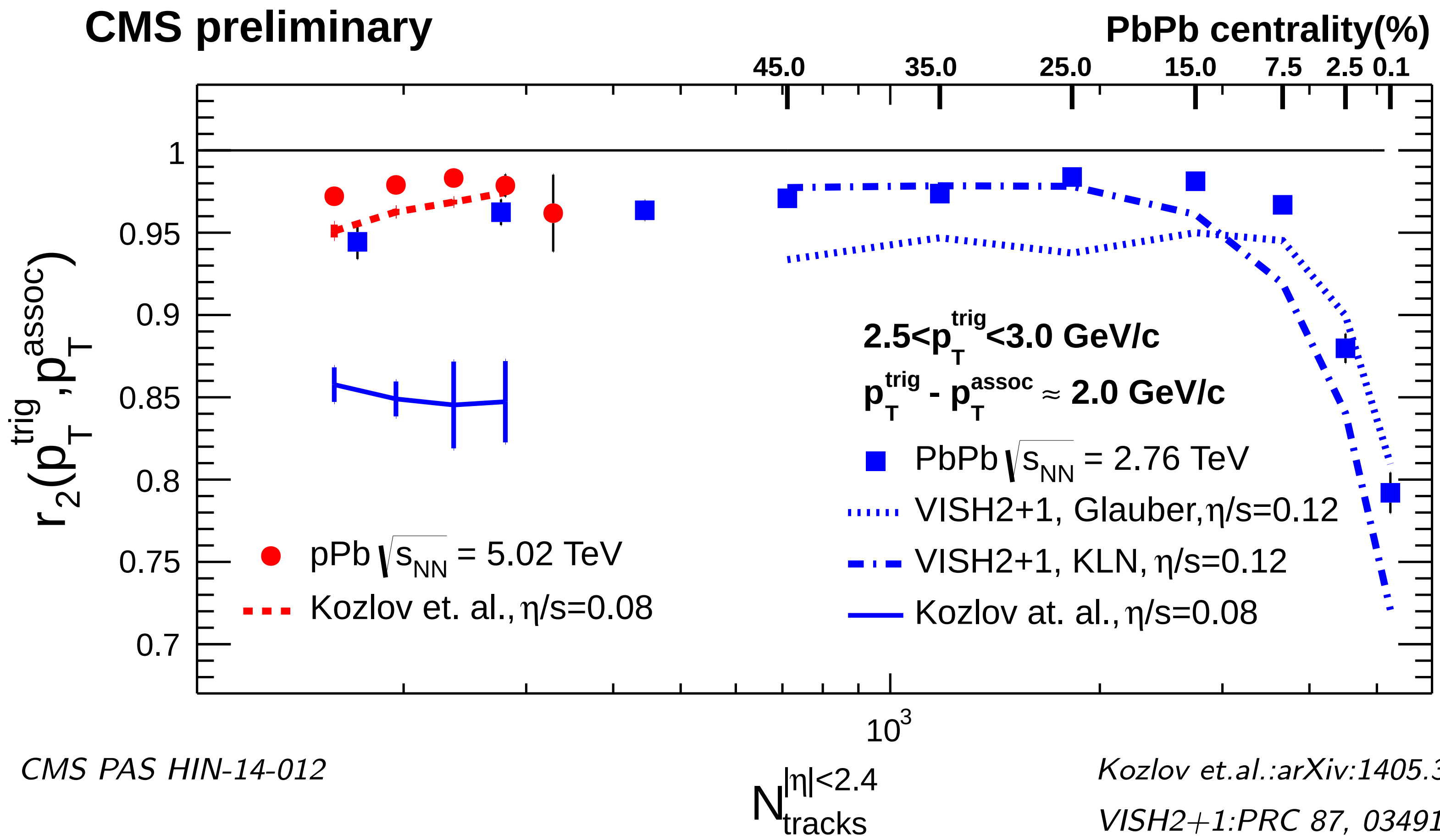
- The r_2 in peripheral PbPb is somewhat stronger w.r.t. high-multiplicity pPb
- The statistics in PbPb is $\approx$ 4 times smaller w.r.t. pPb
- The overall effect is small, on the level of 3- 5%
- The effect is very similar for both analyzed multiplicity intervals

r_2 multiplicity dependence



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VISH2+1:PRC 87, 034913 (2013)

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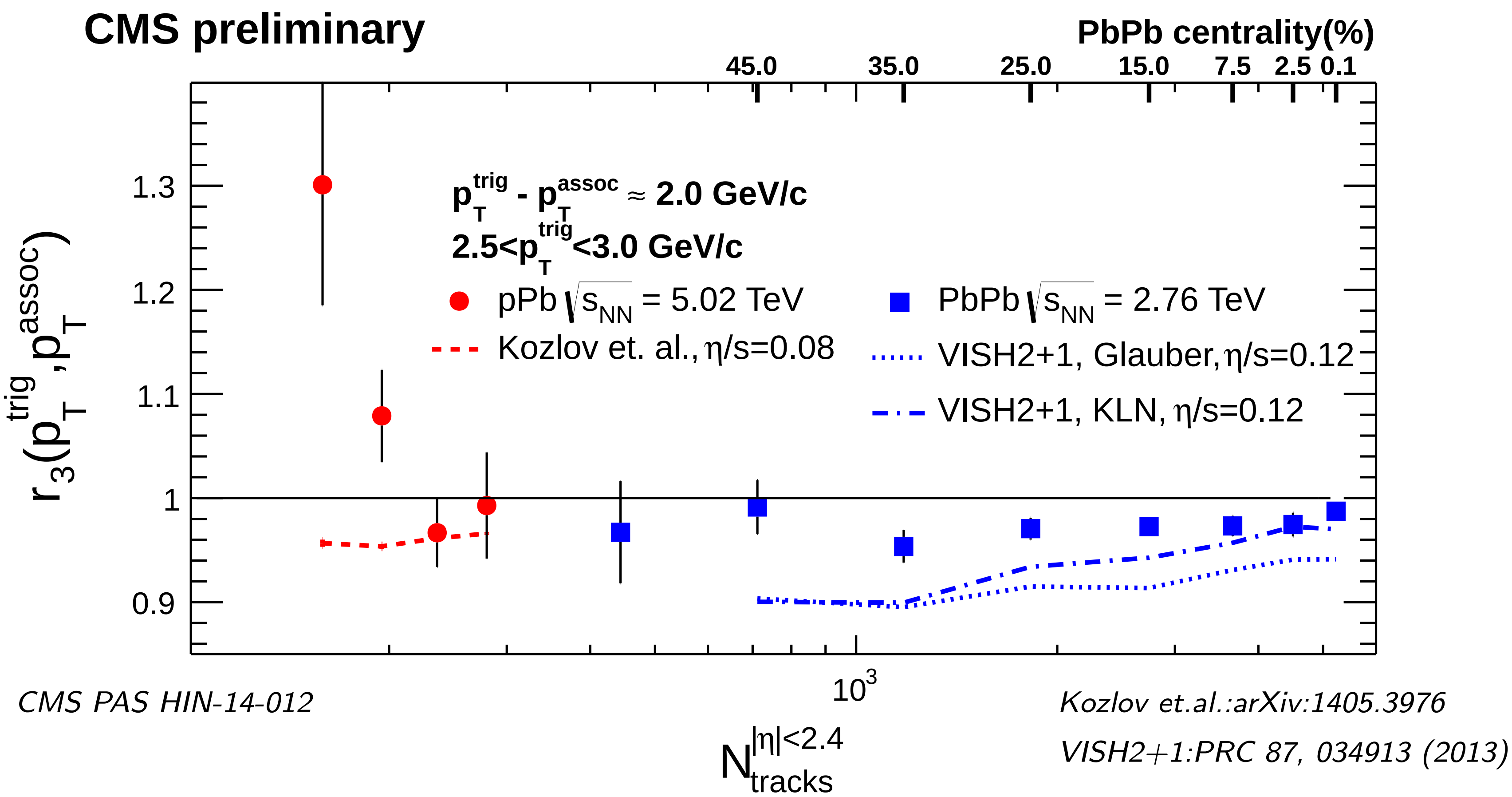
- For the smaller centralities (>5%), r_2 is on the level of few percent, and is nearly independent of centrality
- Both hydro models, qualitatively describe CMS data

r_3 multiplicity dependence



- Compared to PbPb, there is strong dependence from centrality in pPb
- A non-flow effect seen in pPb for the highest p_T^{trig} in lower multiplicities
- VISH2+1 qualitatively describes r_3 in PbPb
- Kozlov et. al. hydro qualitatively describes r_3 for the highest multiplicities in pPb, but fails for lower multiplicities

Summary

- CMS measured factorization breaking of two-particle correlations in PbPb and pPb
- Strong effect in ultra-central PbPb
- 2-3$\%$ in pPb, comparable to PbPb at similar multiplicity
- Qualitatively or even semi-quantitatively consistent with hydro with p_T dependent event plane angle induced by initial-state fluctuations