XXIV QUARK MATTER DARMSTADT 2014

Signatures of collective behavior in small collision systems

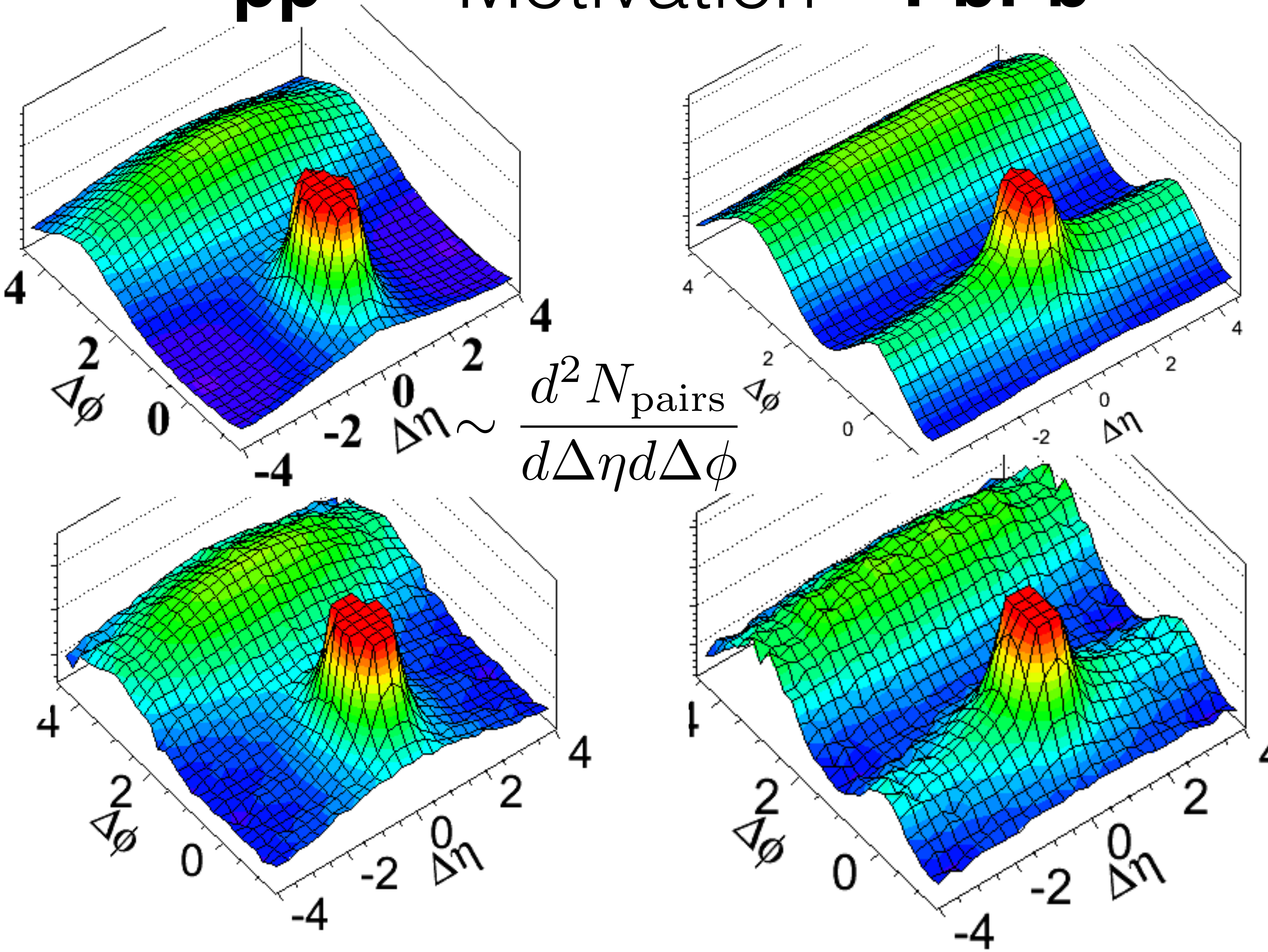
I. Kozlov, M. Luzum, G. Denicol, S. Jeon, C. Gale (1405.3976)

McGill, LBNL

Motivation

pp **PbPb**

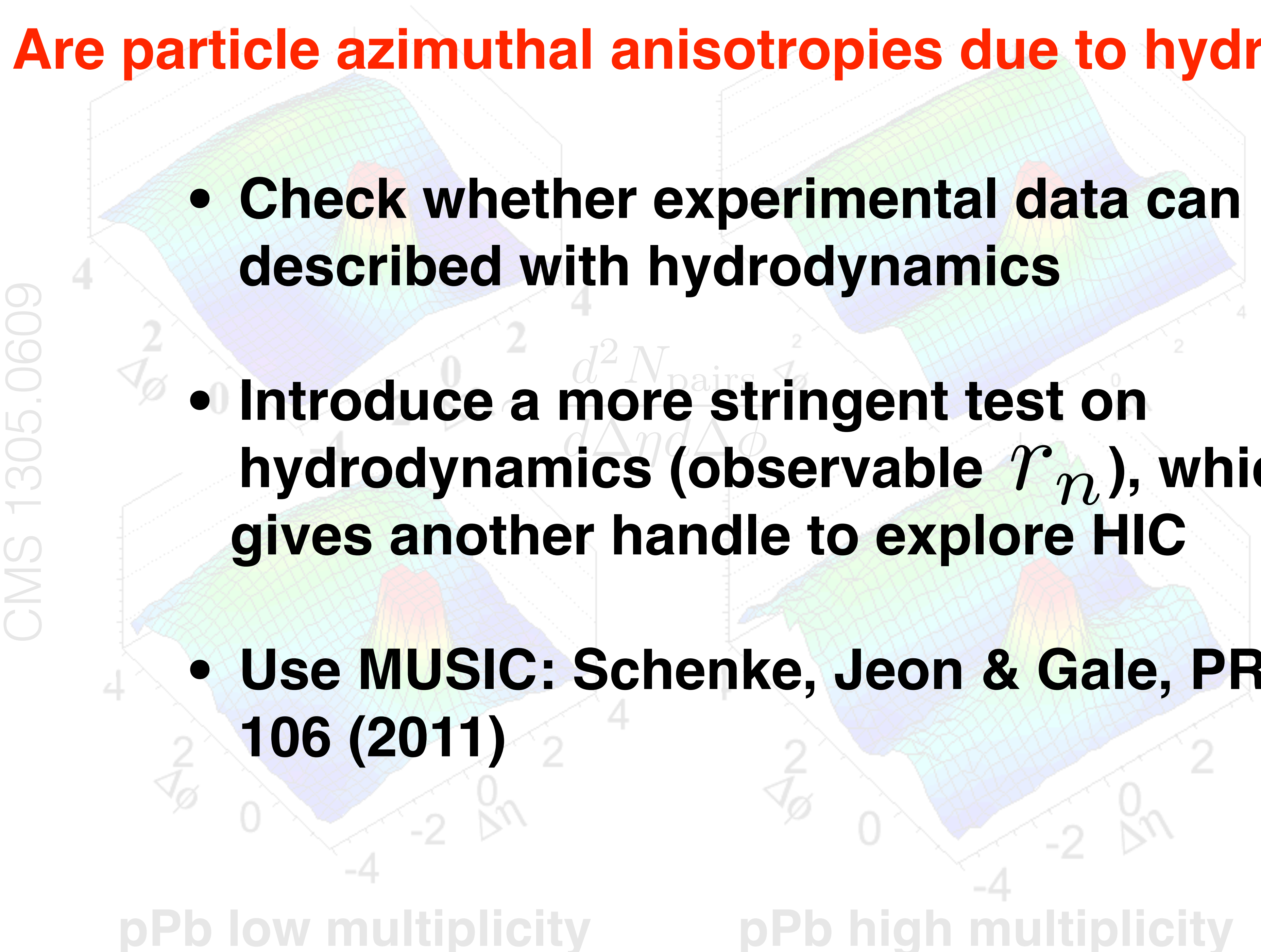
CMS 1305.0609



$$\sim \frac{d^2 N_{\rm pairs}}{d\Delta\eta d\Delta\phi}$$

pPb low multiplicity **pPb high multiplicity**

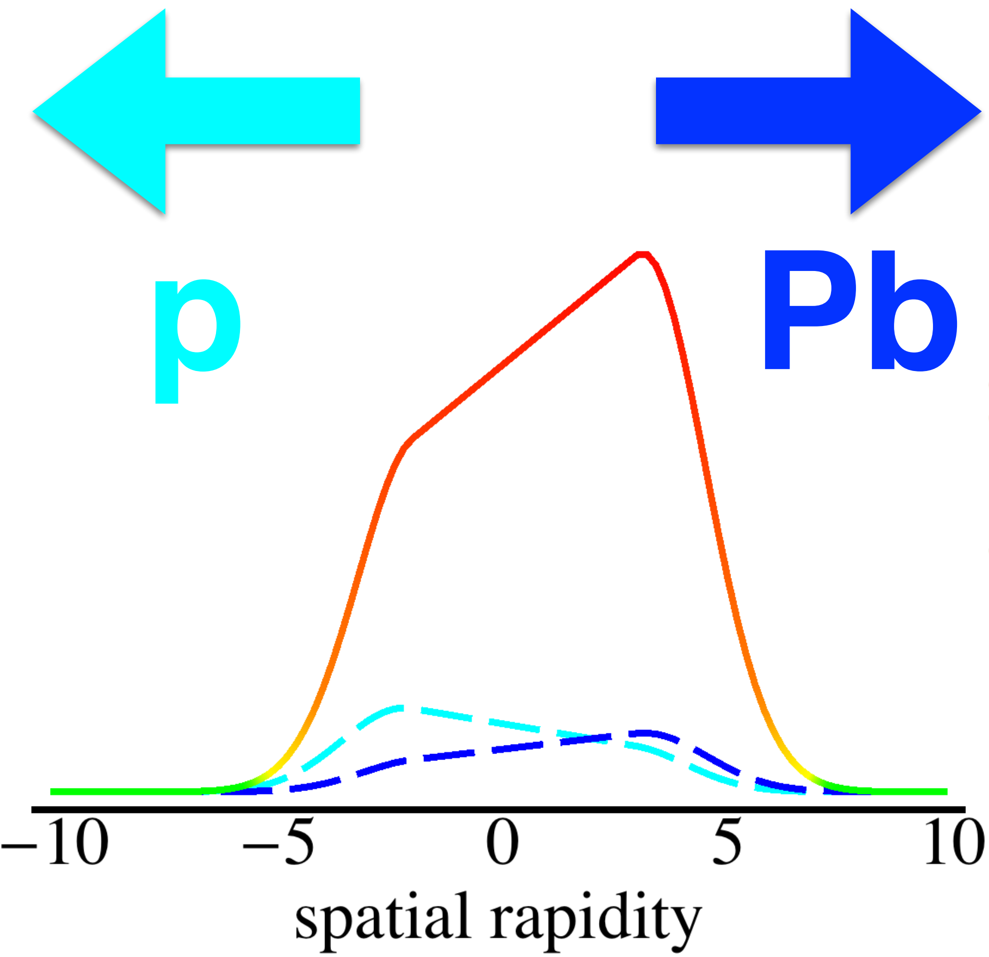
Are particle azimuthal anisotropies due to hydro?



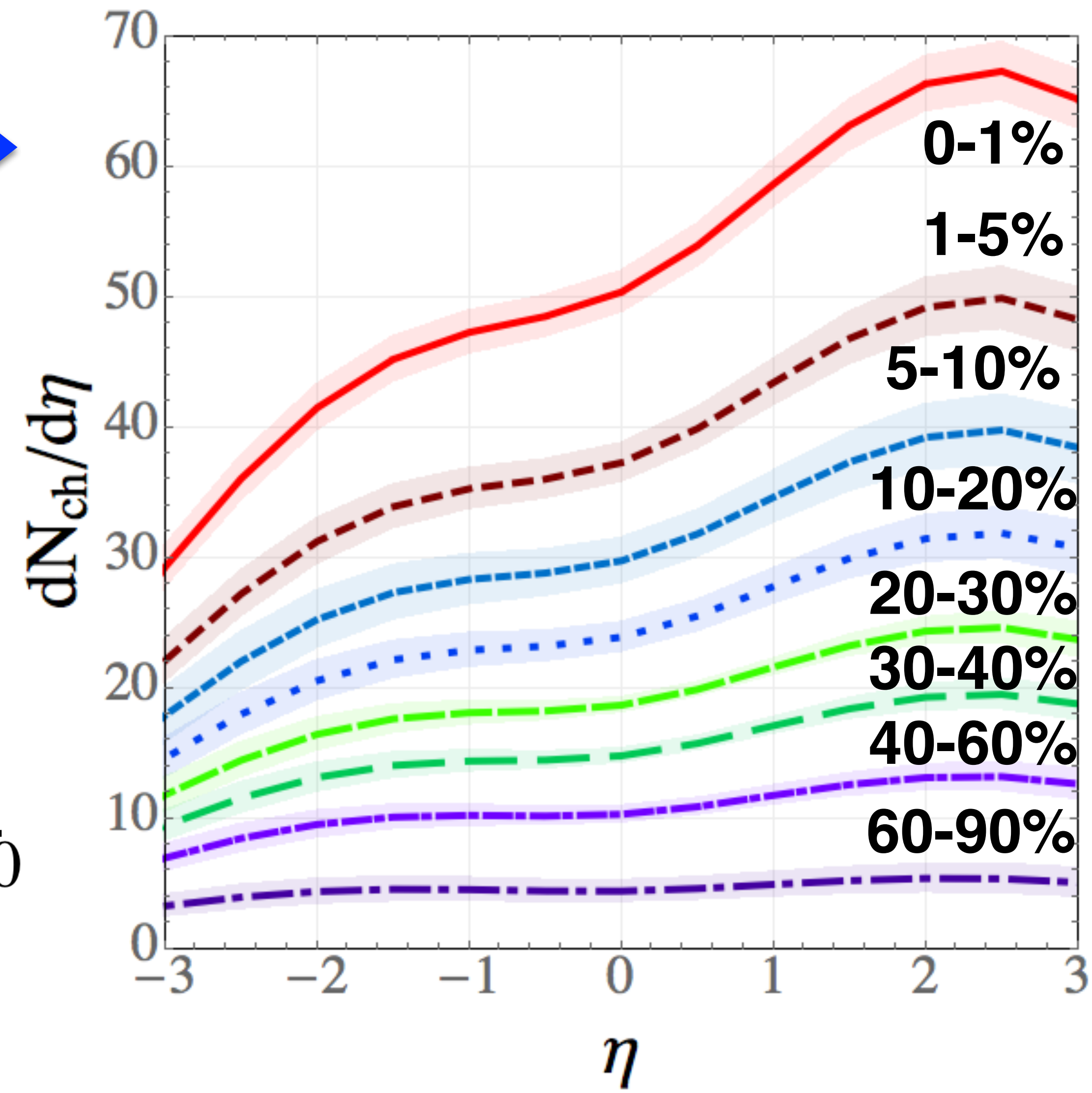
- Check whether experimental data can be described with hydrodynamics
- Introduce a more stringent test on hydrodynamics (observable r_n), which gives another handle to explore HIC
- Use MUSIC: Schenke, Jeon & Gale, PRL 106 (2011)

Glauber + rapidity distribution

initial entropy profile → final multiplicity profile

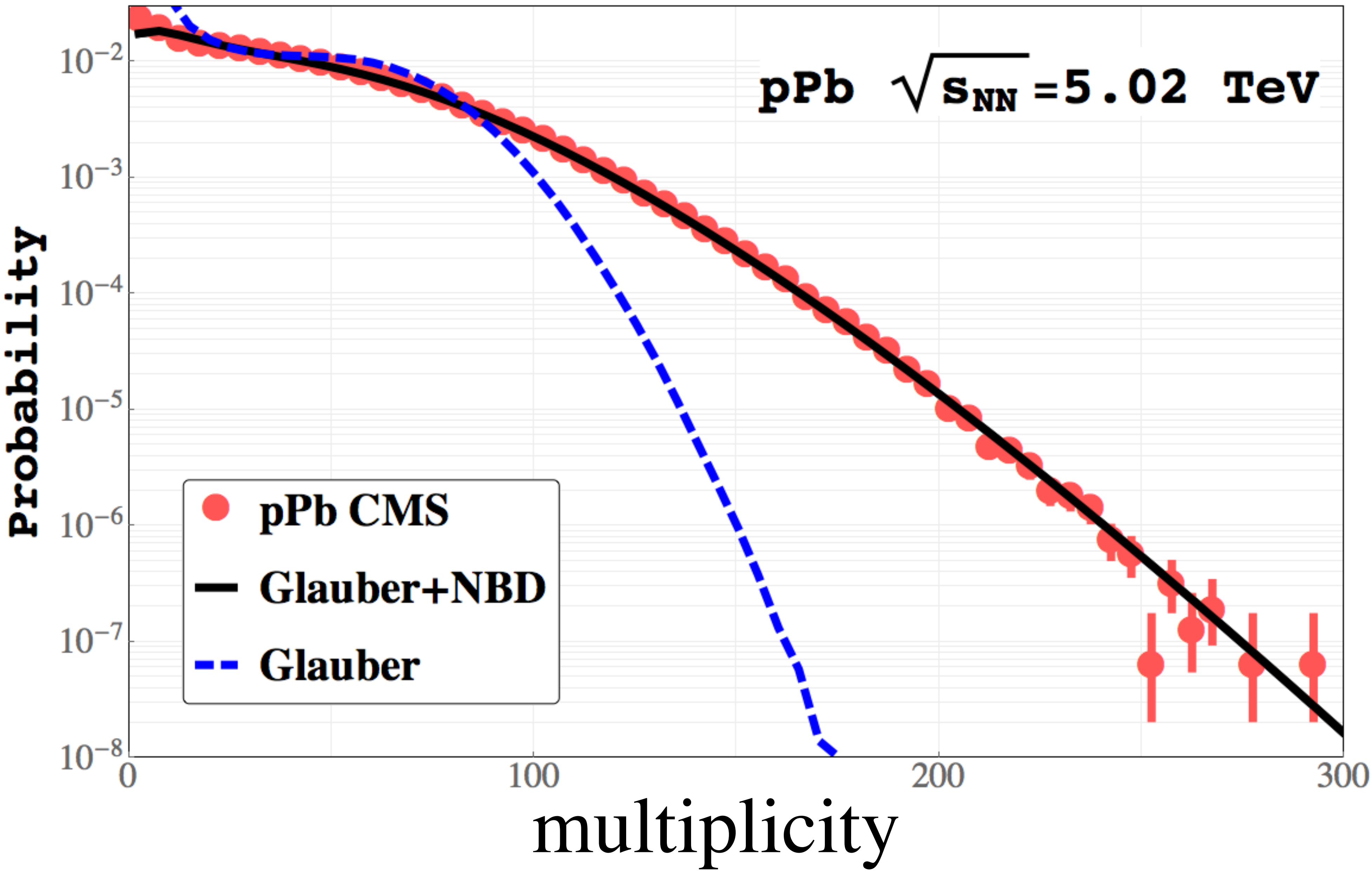


Bozek, Wyskiel 1002.4999



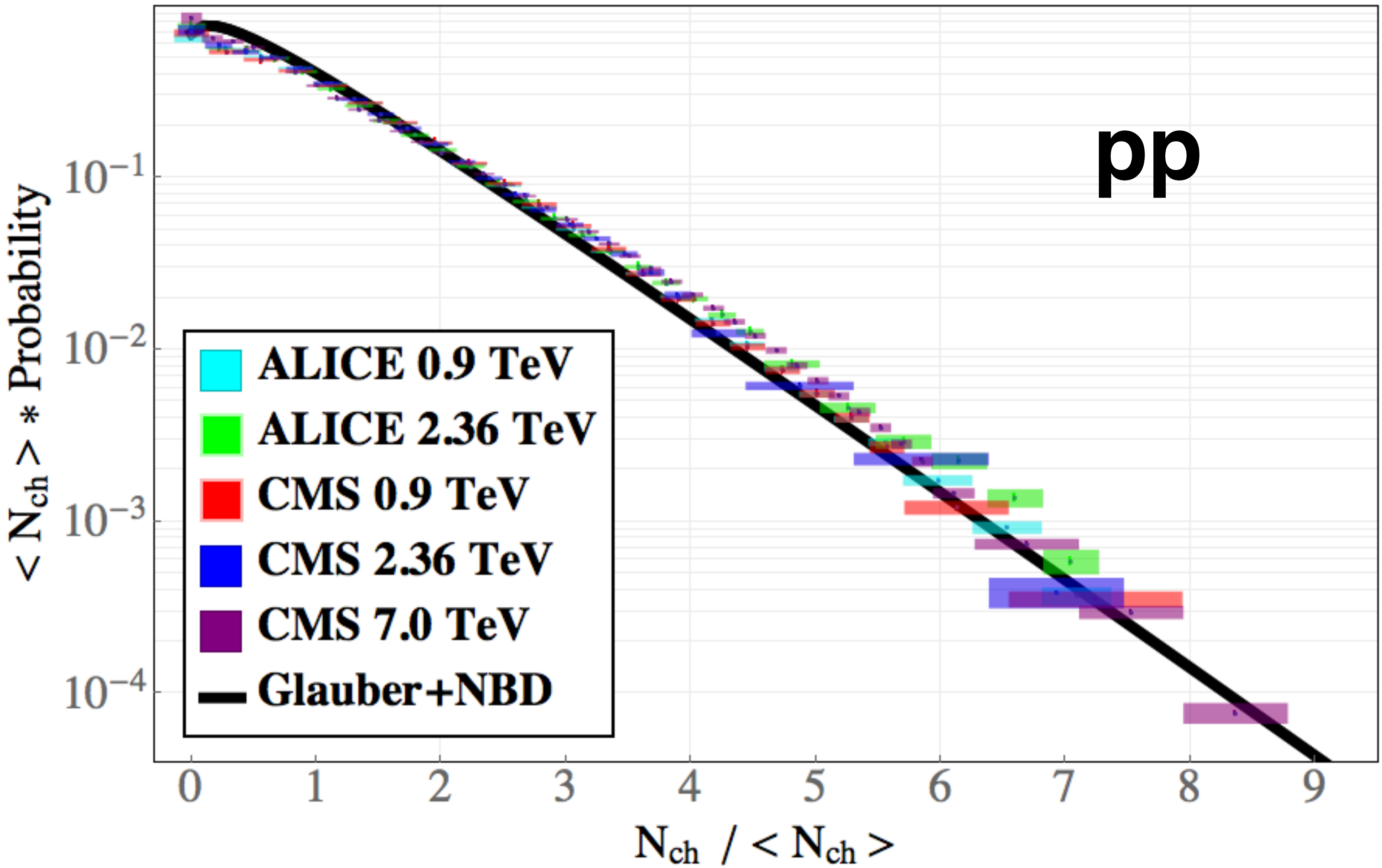
McGill, LBNL 1405.3976

Glauber+NBD



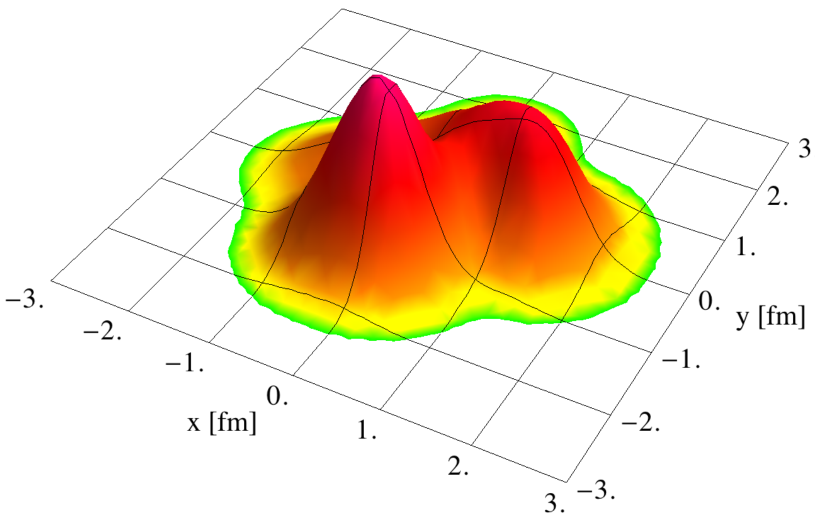
CMS twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13002

pp multiplicity with **Glauber+**NBD

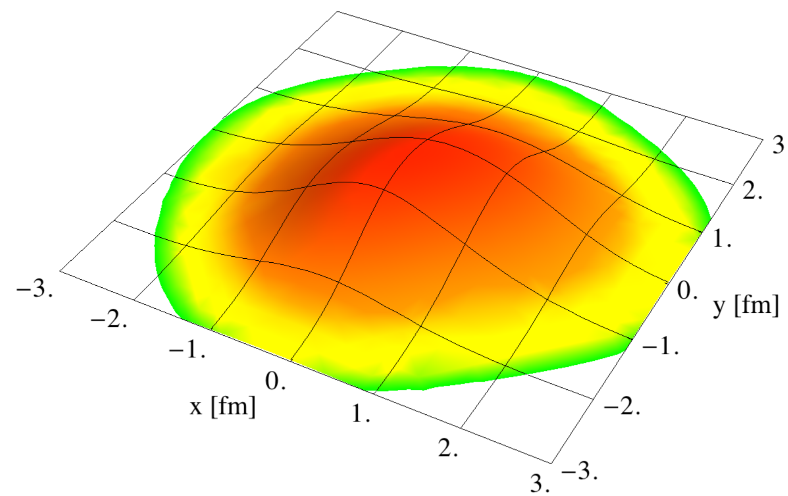


Transverse granularity

$\sigma = 0.40$ fm



$\sigma = 0.80$ fm



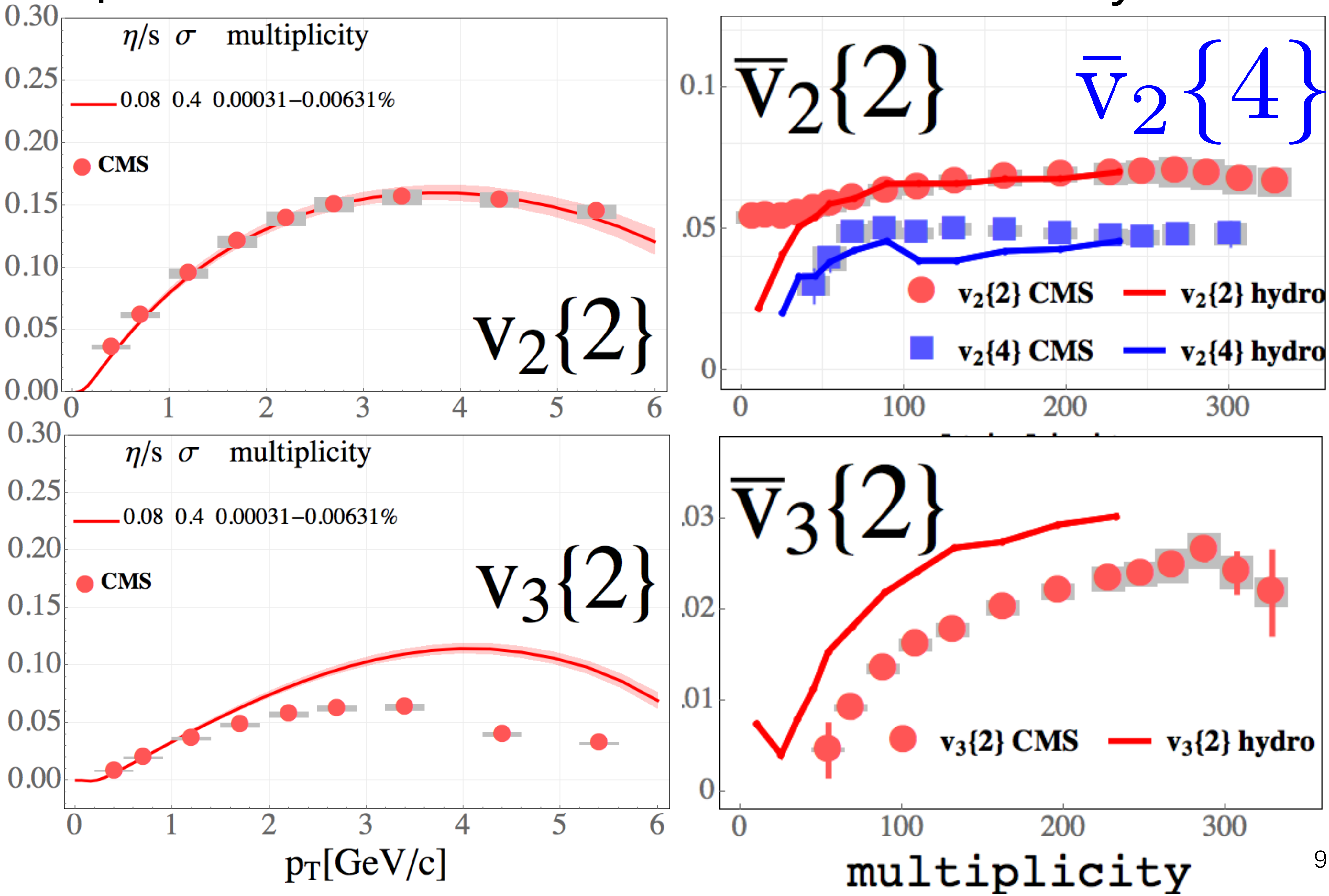
Compare with hydro; start with:

$$\sigma = 0.4\text{fm} \quad \eta/s = 0.08$$

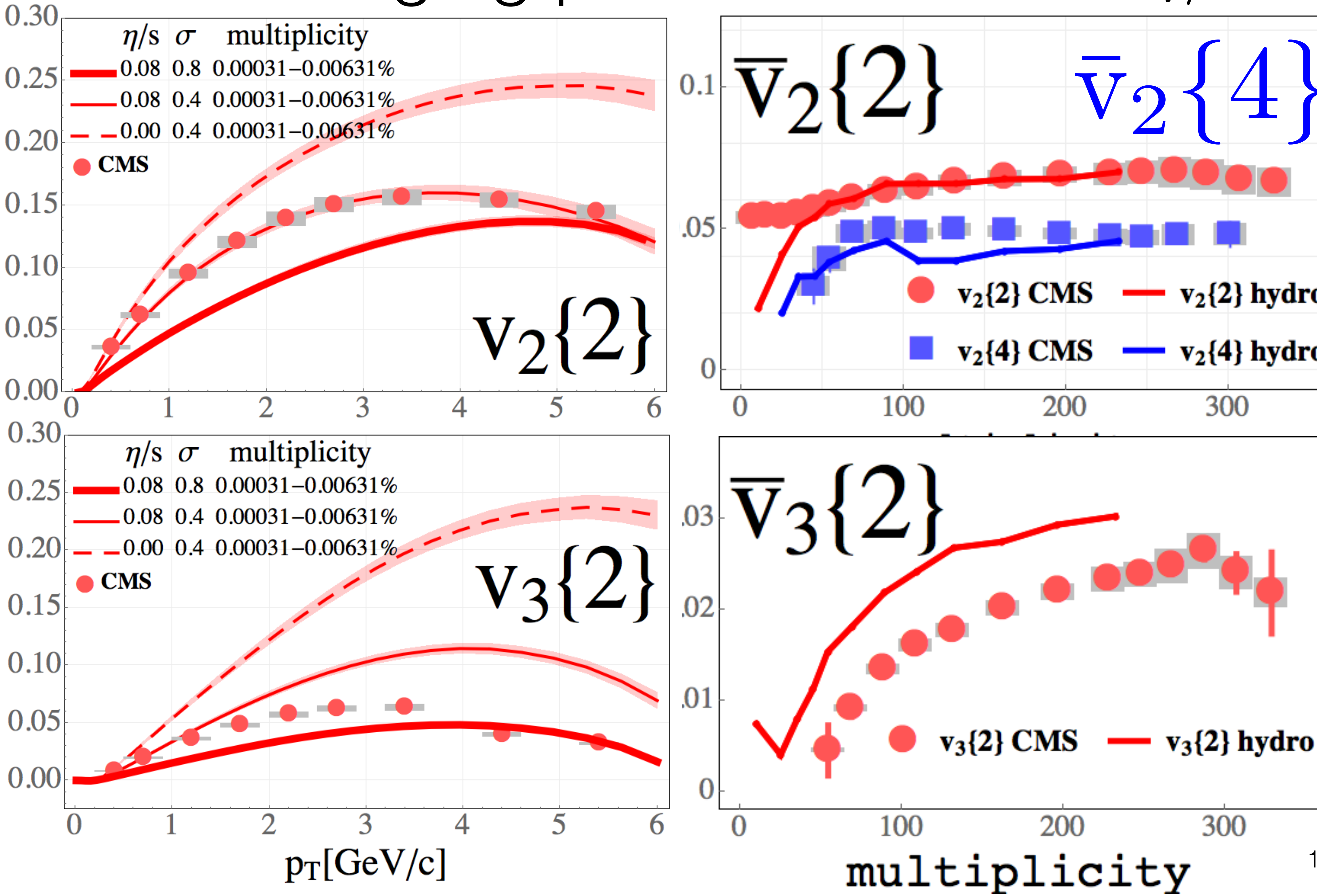
Comparing hydro calculations to existing pA data

CMS 1211.0989   McGill, LBNL 1405.3976

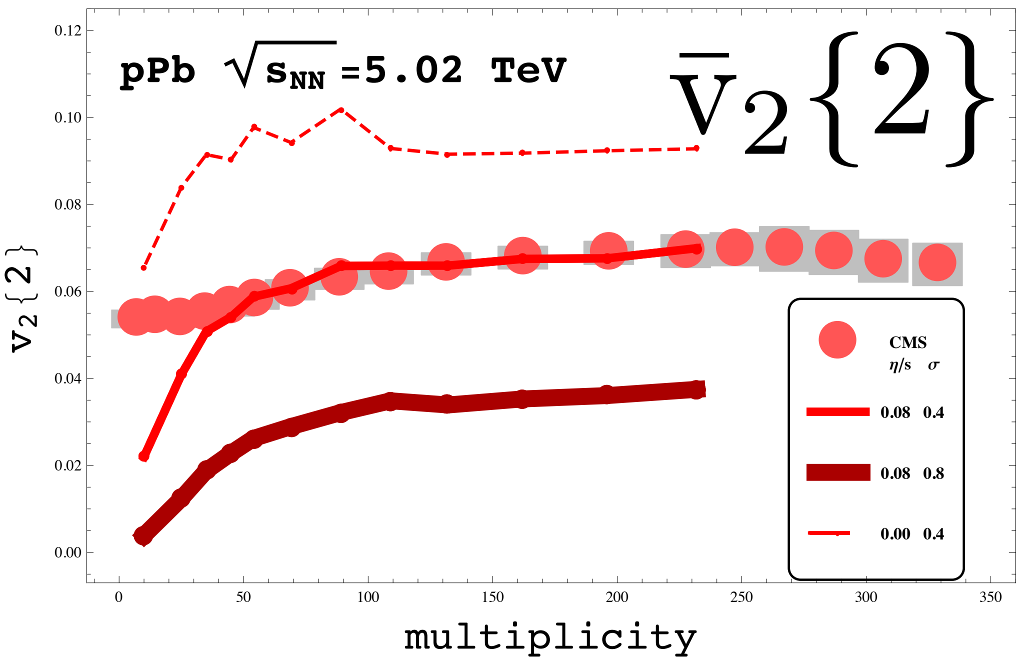
pPb flow observables: CMS & hydro

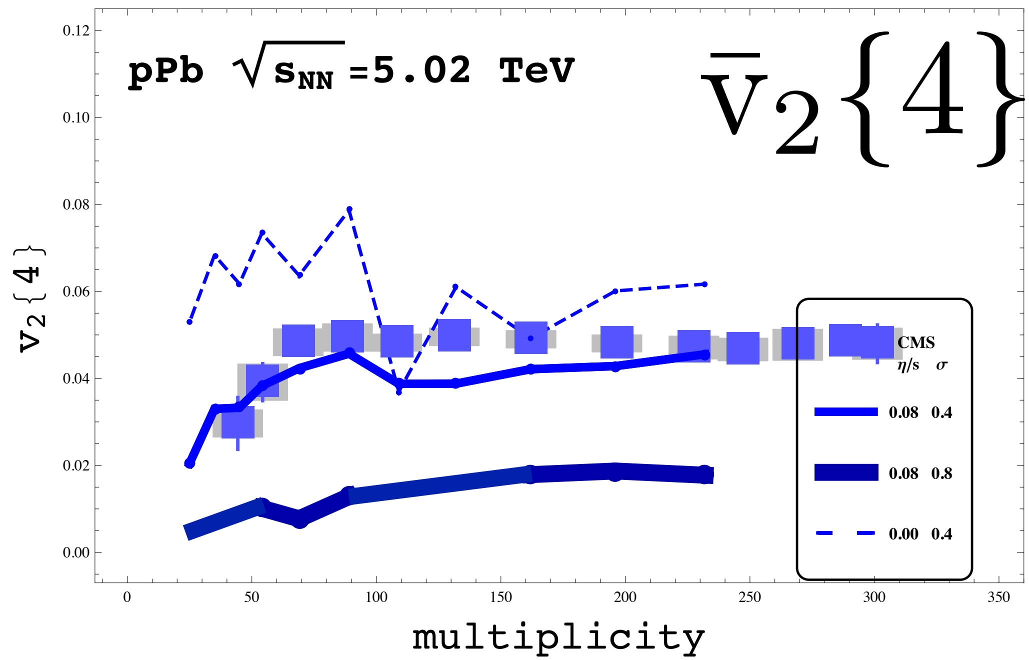


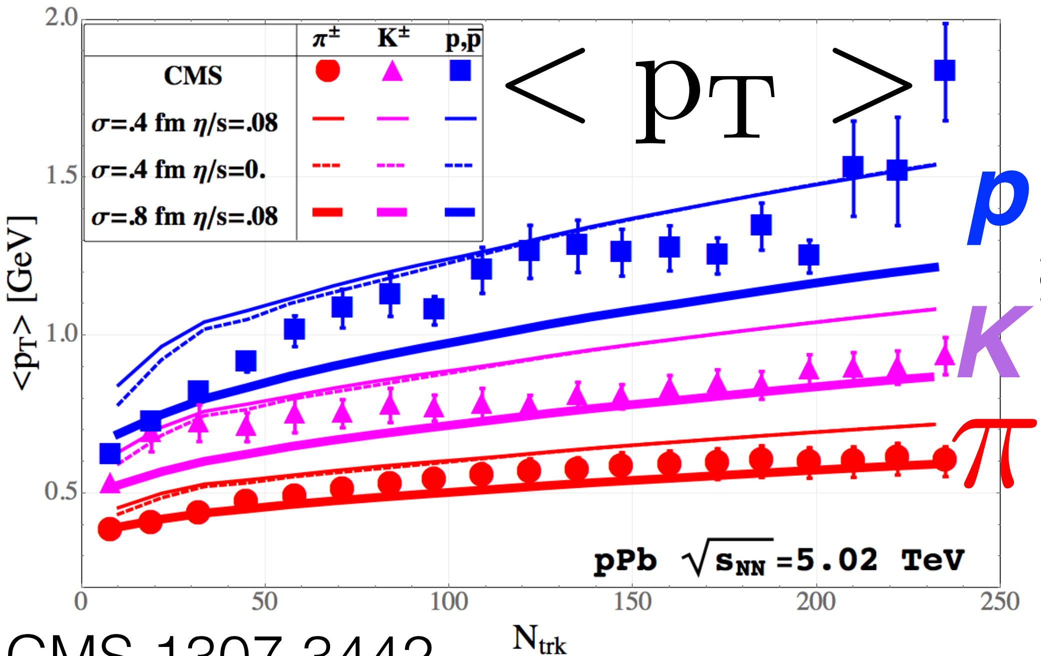
Changing parameters σ and η/s

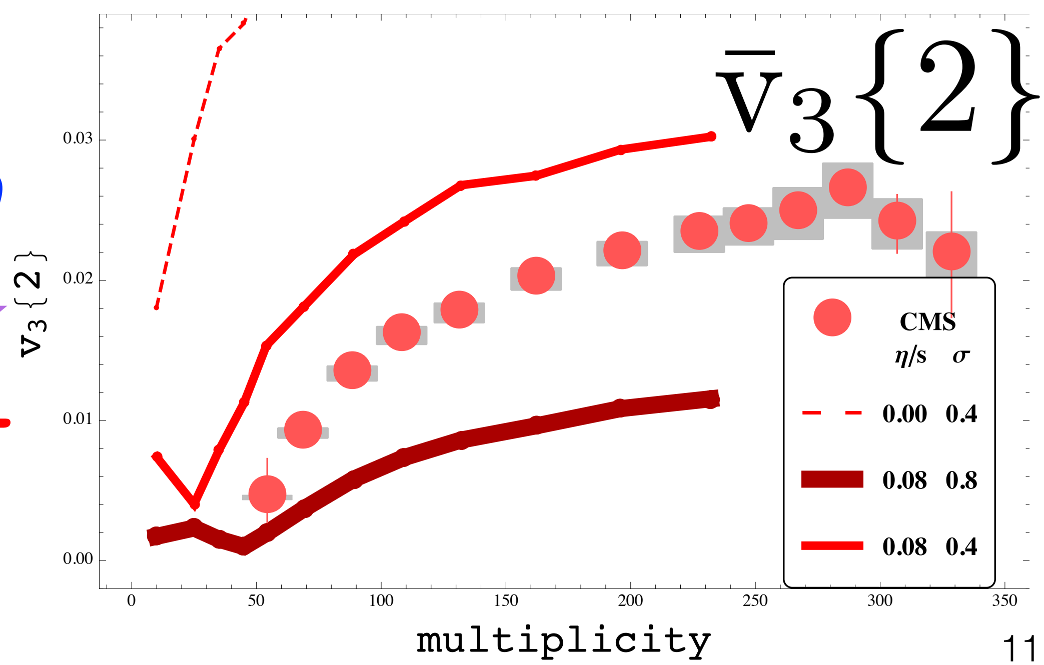


Flow observables dependence on σ and η/s





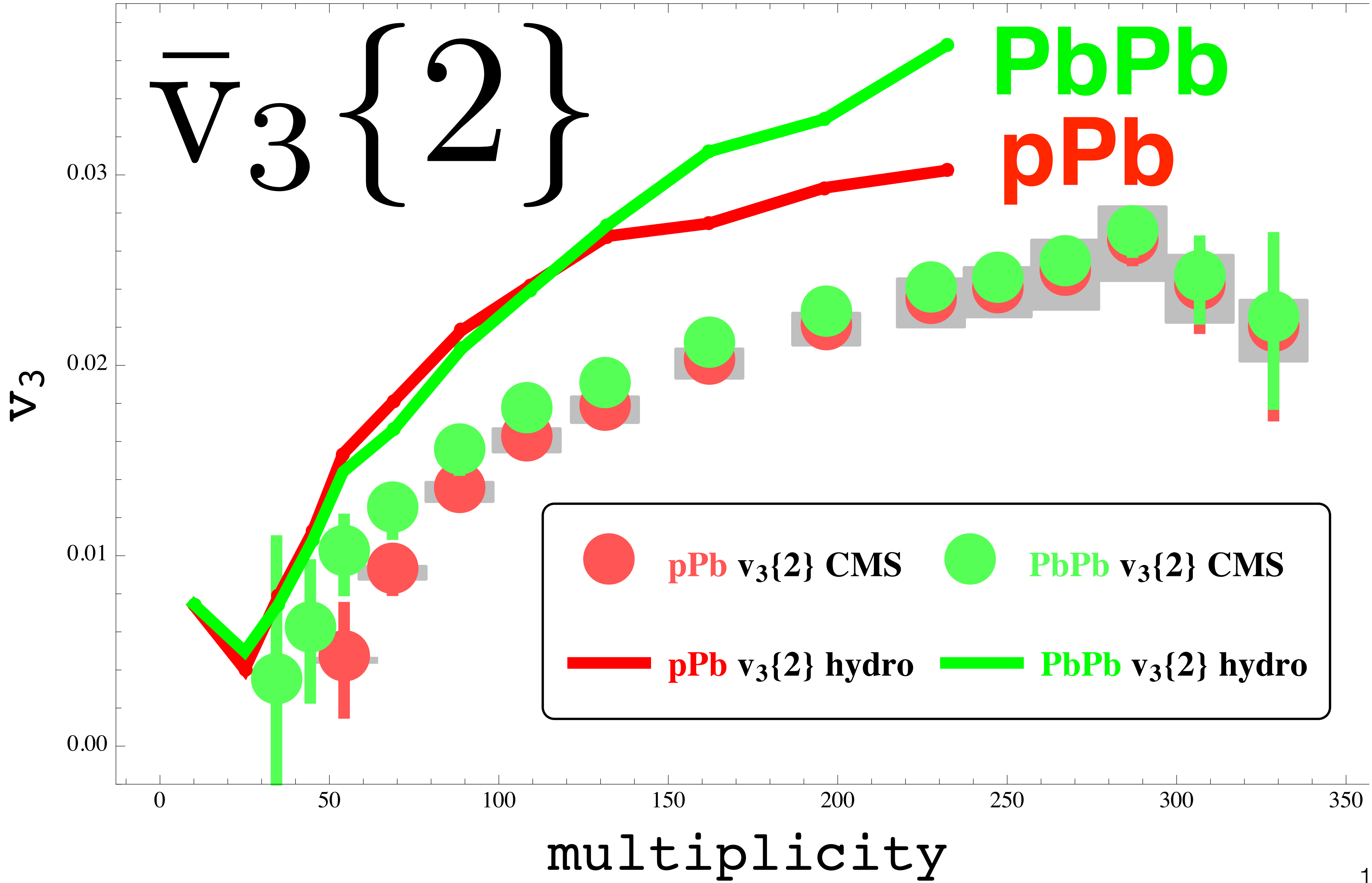




CMS 1307.3442

CMS 1211.0989   McGill, LBNL 1405.3976

CMS finding in hydro



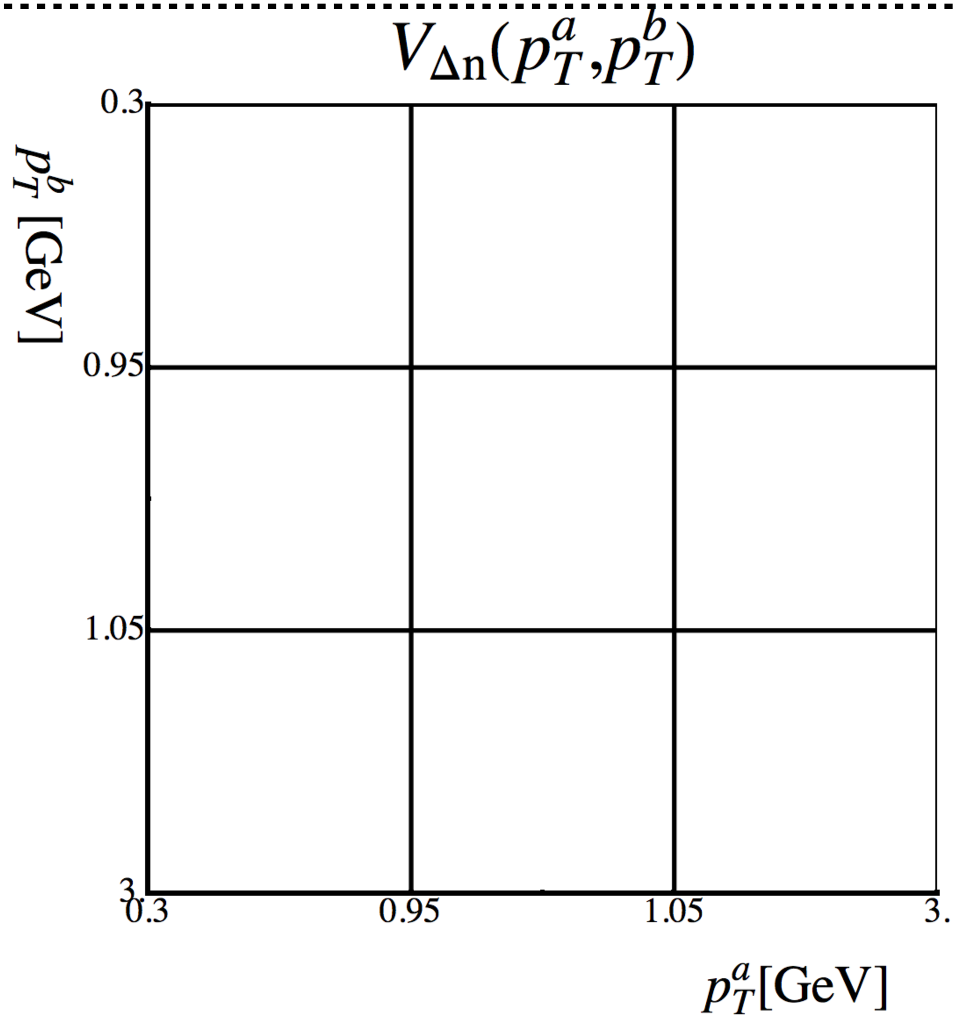
All two-particle correlation observables

theory:

$$\frac{2\pi}{N}\frac{dN}{d\phi^a} = 1 + 2\sum_{n=1}^{\infty} v_n(p_T^a)\cos n(\phi^a - \Psi_n)$$

experiment:

$$V_{n\Delta}(p_T^a, p_T^b) \equiv \langle\overline{\cos n(\phi^a - \phi^b)}\rangle$$



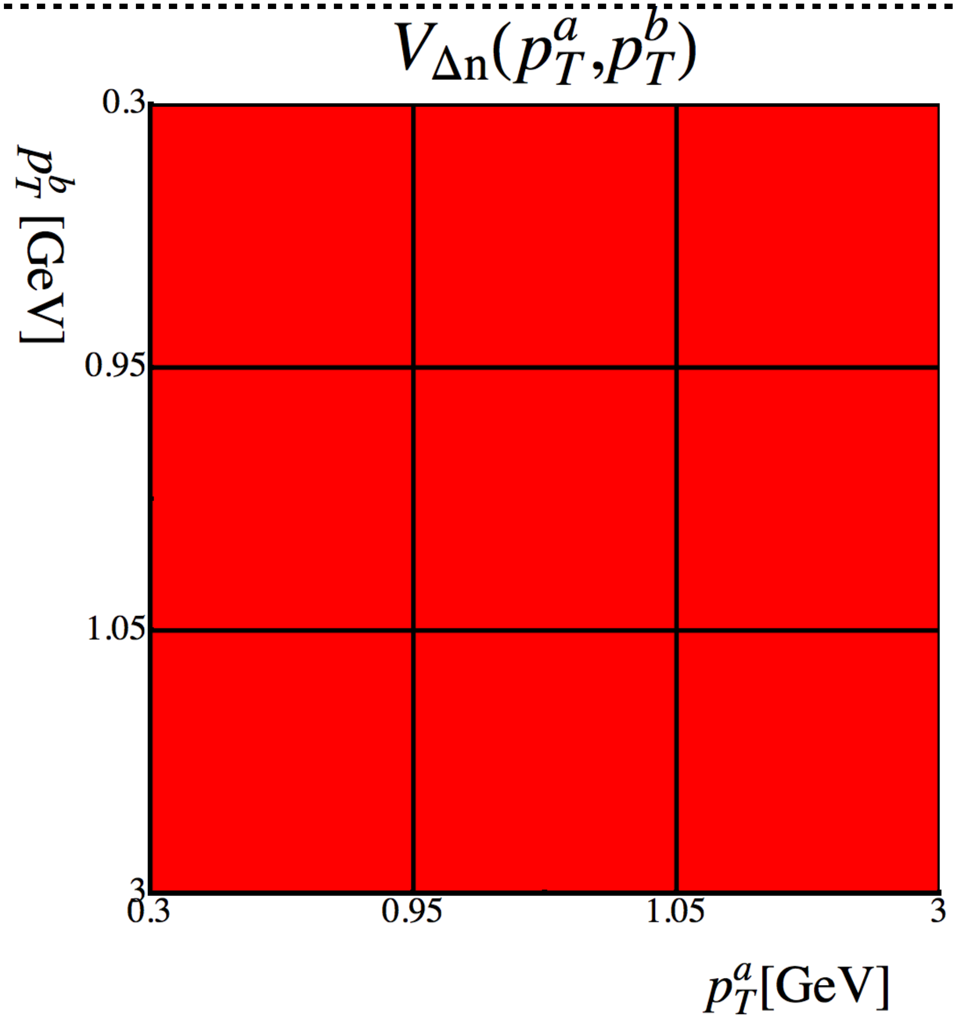
All two-particle correlation observables

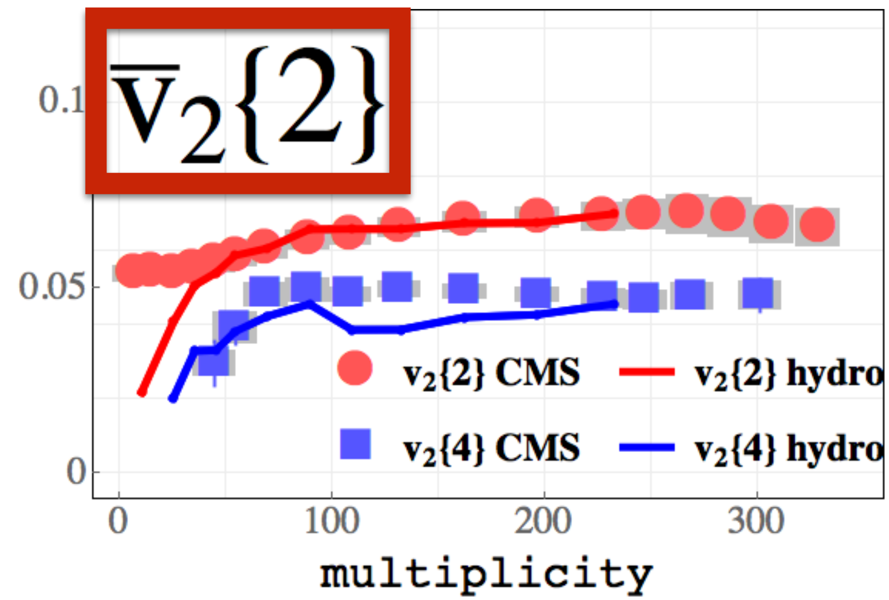
theory:

$$\frac{2\pi}{N}\frac{dN}{d\phi^a} = 1 + 2\sum_{n=1}^{\infty} v_n(p_T^a)\cos n(\phi^a - \Psi_n)$$

experiment:

$$V_{n\Delta}(p_T^a, p_T^b) \equiv \langle\overline{\cos n(\phi^a - \phi^b)}\rangle$$





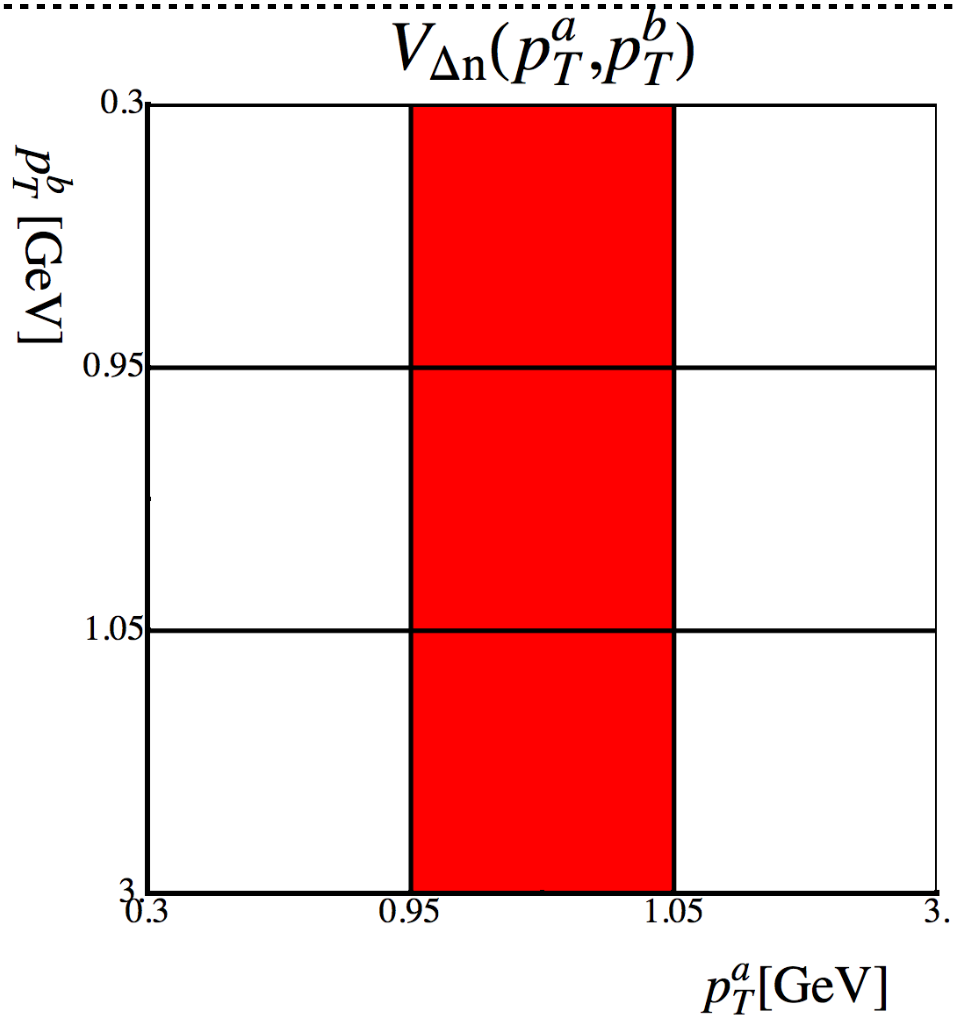
All two-particle correlation observables

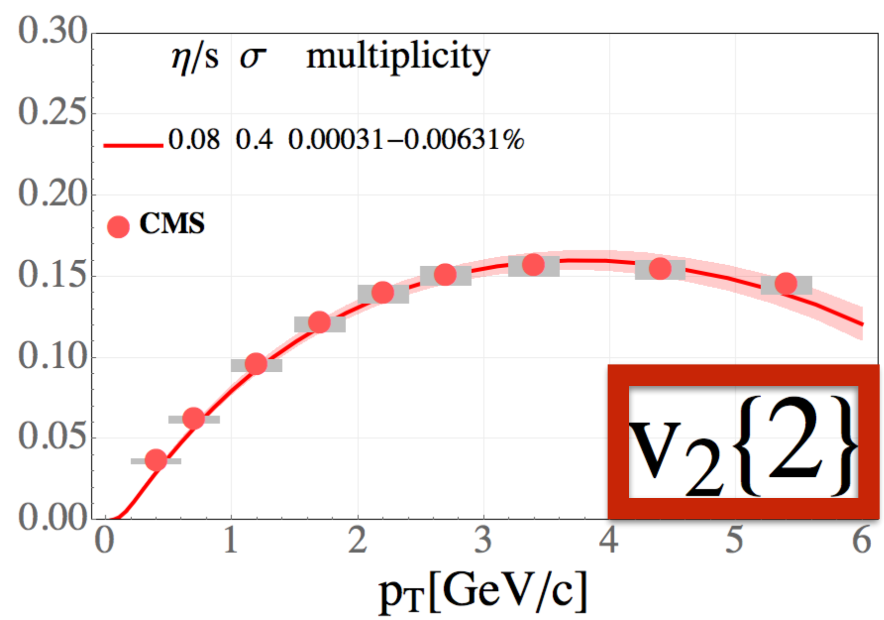
theory:

$$\frac{2\pi}{N}\frac{dN}{d\phi^a} = 1 + 2\sum_{n=1}^{\infty} v_n(p_T^a)\cos n(\phi^a - \Psi_n)$$

experiment:

$$V_{n\Delta}(p_T^a, p_T^b) \equiv \langle\overline{\cos n(\phi^a - \phi^b)}\rangle$$





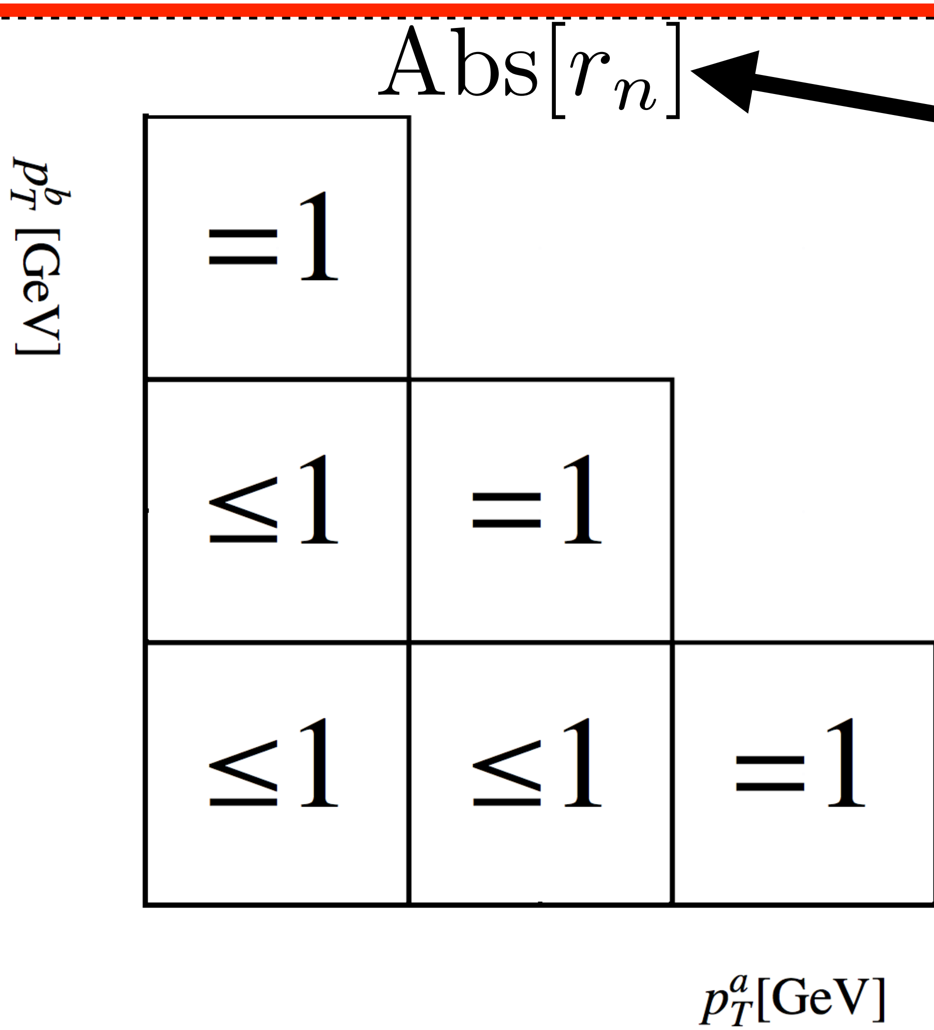
Two-particle correlation in hydro

theory:

$$\frac{2\pi}{N}\frac{dN}{d\phi^a} = 1 + 2\sum_{n=1}^{\infty} v_n(p_T^a)\cos n(\phi^a - \Psi_n)$$

experiment:

$$V_{n\Delta}(p_T^a, p_T^b) \equiv \langle \overline{\cos n(\phi^a - \phi^b)} \rangle$$



$$r_n \equiv \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a)V_{n\Delta}(p_T^b, p_T^b)}}$$

hydro:

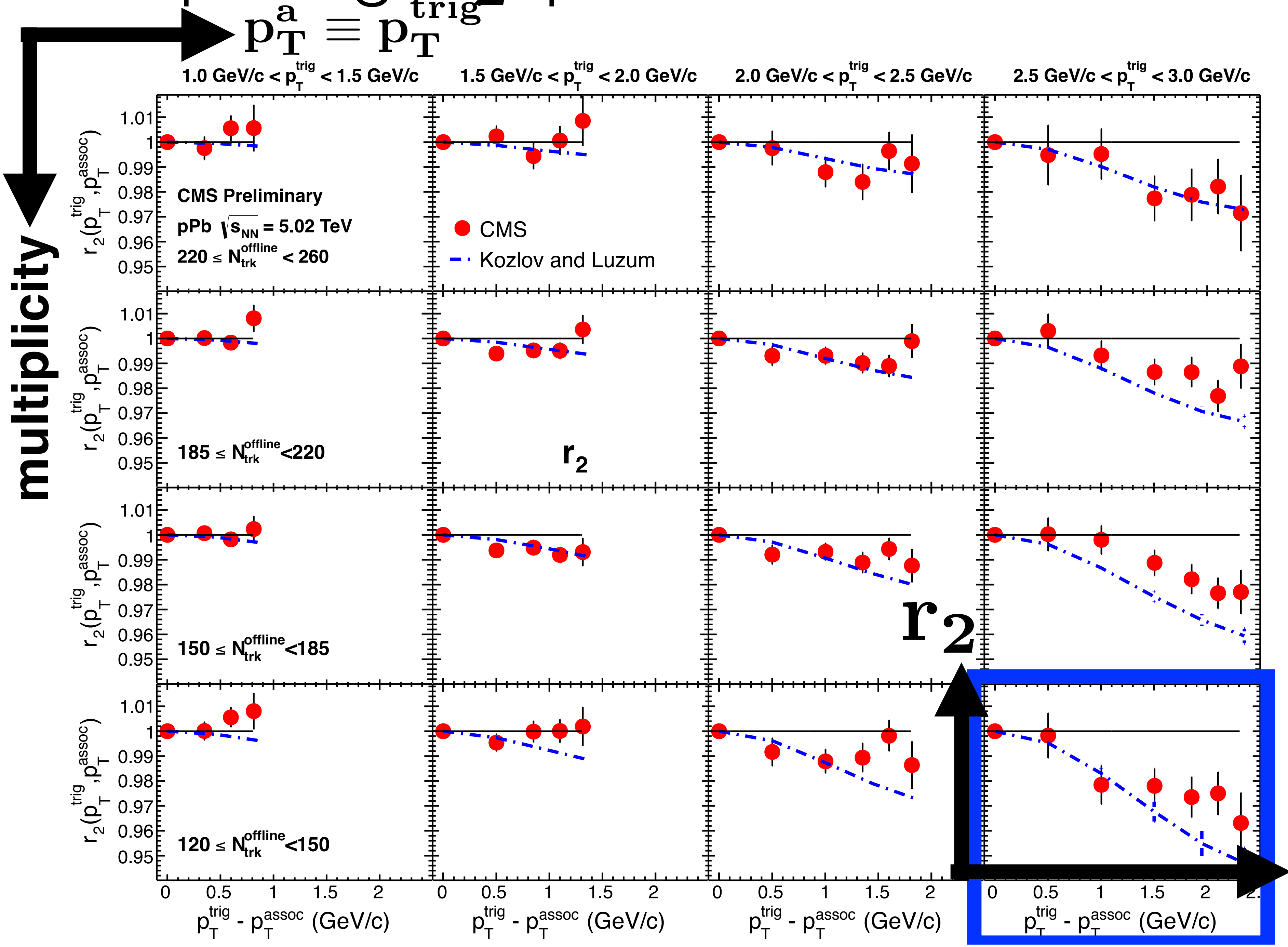
$$\frac{dN_{pairs}}{d^3p^a d^3p^b} \overset{(\text{flow})}{=} \frac{dN}{d^3p^a} \times \frac{dN}{d^3p^b}$$

$$V_{n\Delta}(p_T^a, p_T^a) \geq 0$$

$$V_{n\Delta}(p_T^a, p_T^b)^2 \leq V_{n\Delta}(p_T^a, p_T^a)V_{n\Delta}(p_T^b, p_T^b)$$

Gardim, Grassi, Luzum, Ollitrault 1211.0989

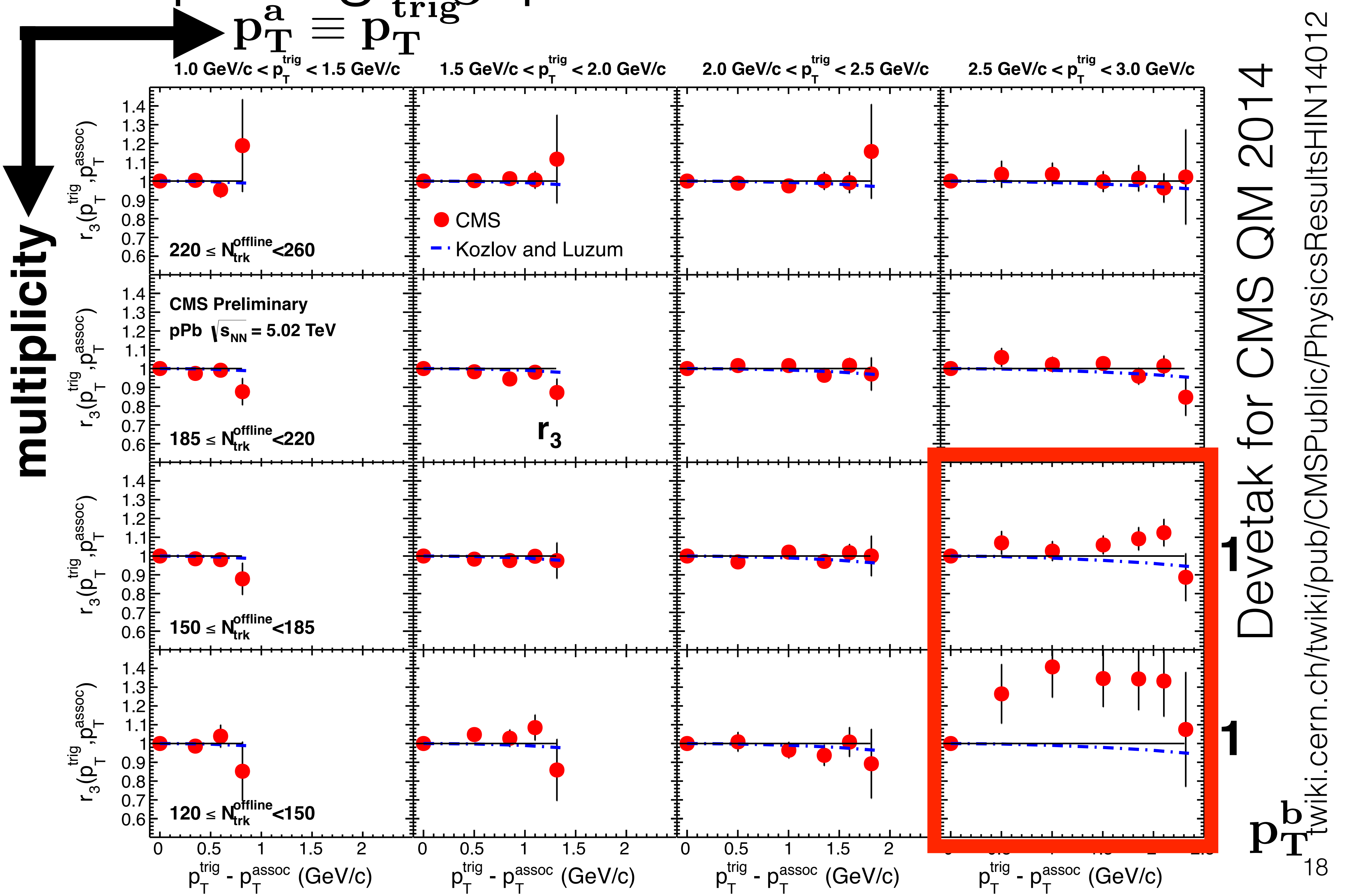
Comparing r_2 predictions to CMS data



Devetak for CMS QM 2014

twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsHIN14012

Comparing r_3 predictions to CMS data

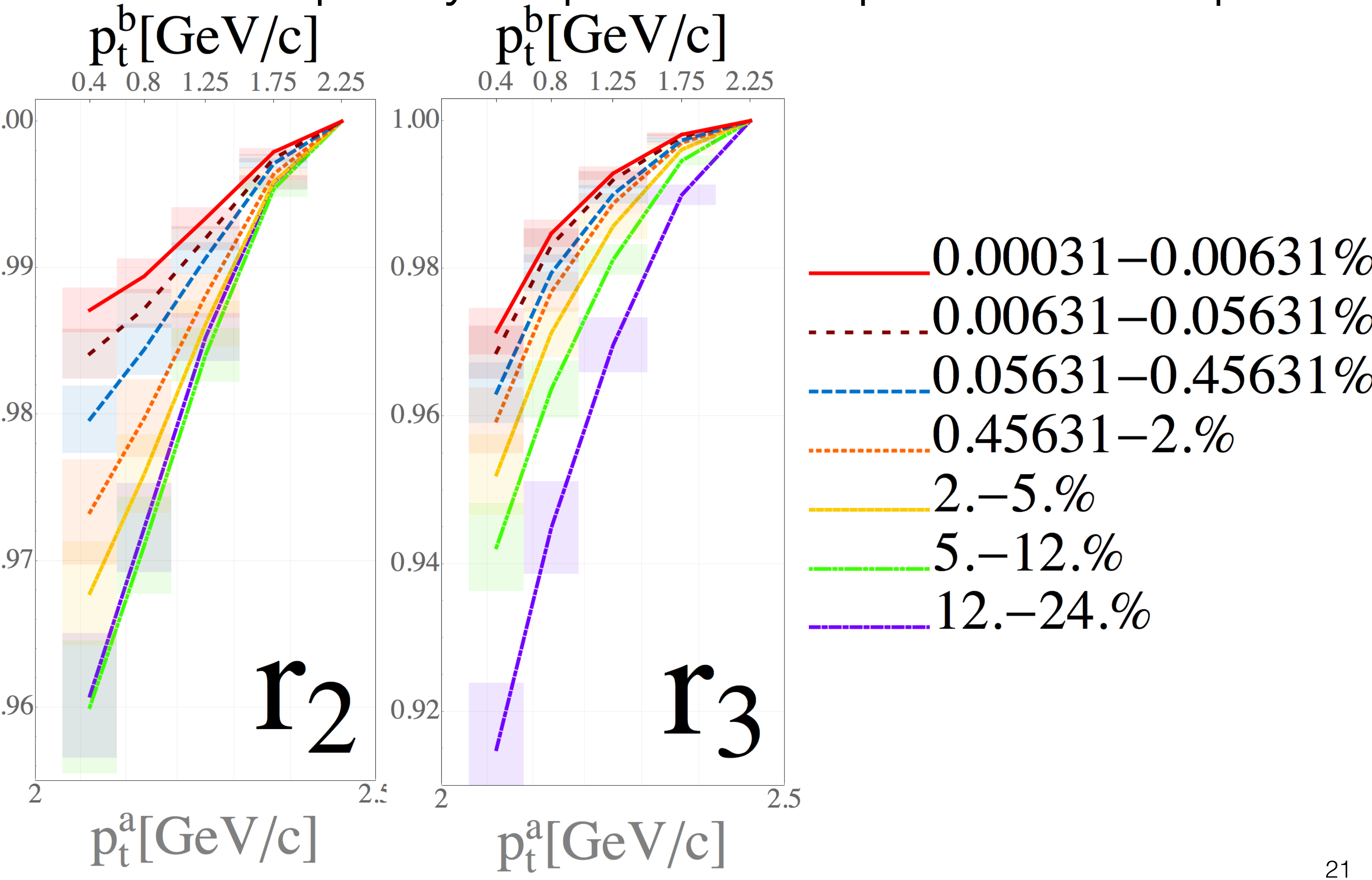


Section conclusions

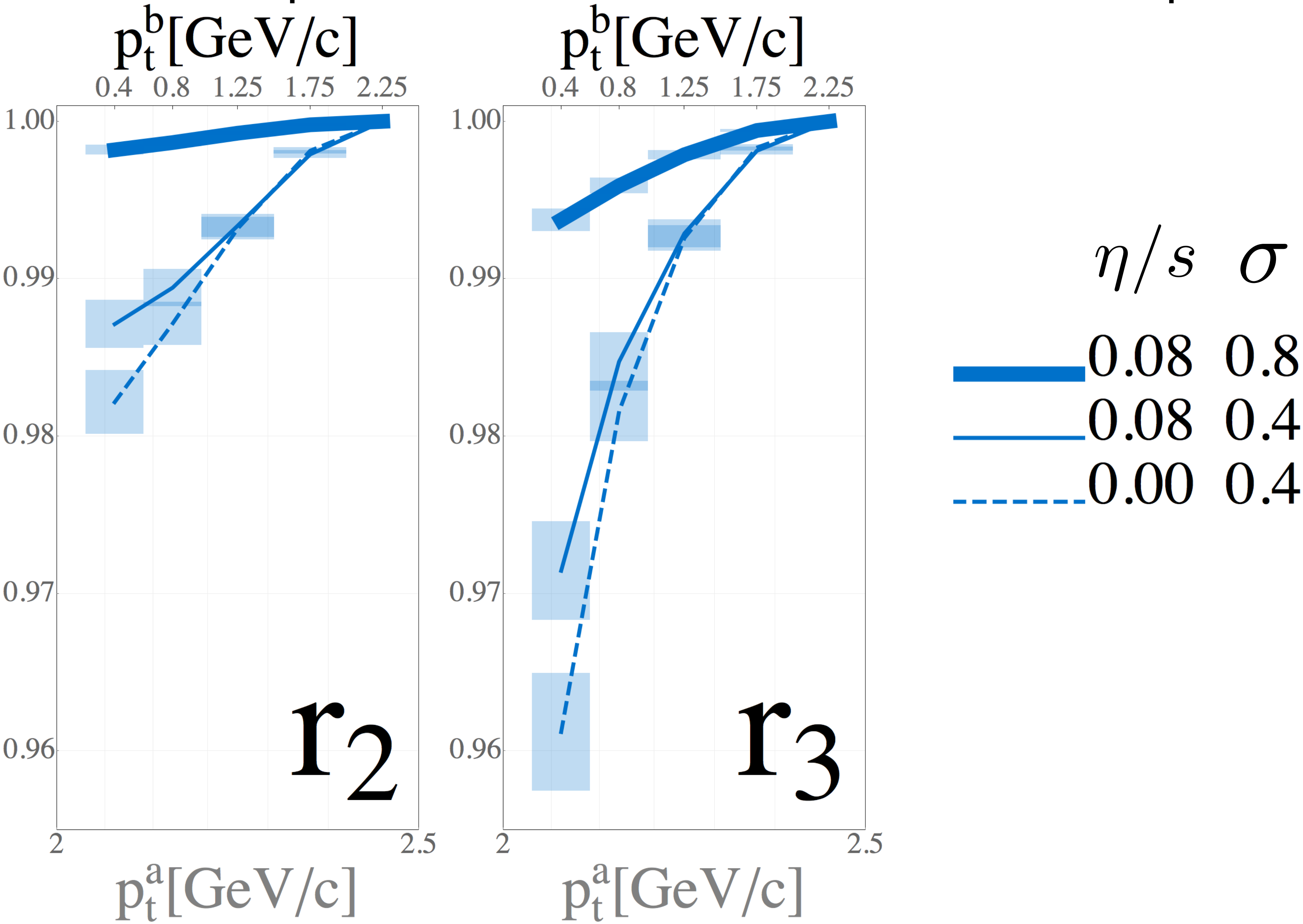
- Hydrodynamics can reasonably describe a wide range of flow observables for pPb system at high multiplicity $v_2\{2\}, v_3\{2\}, v_2\{4\}$ and r_n

Another handle to study HIC

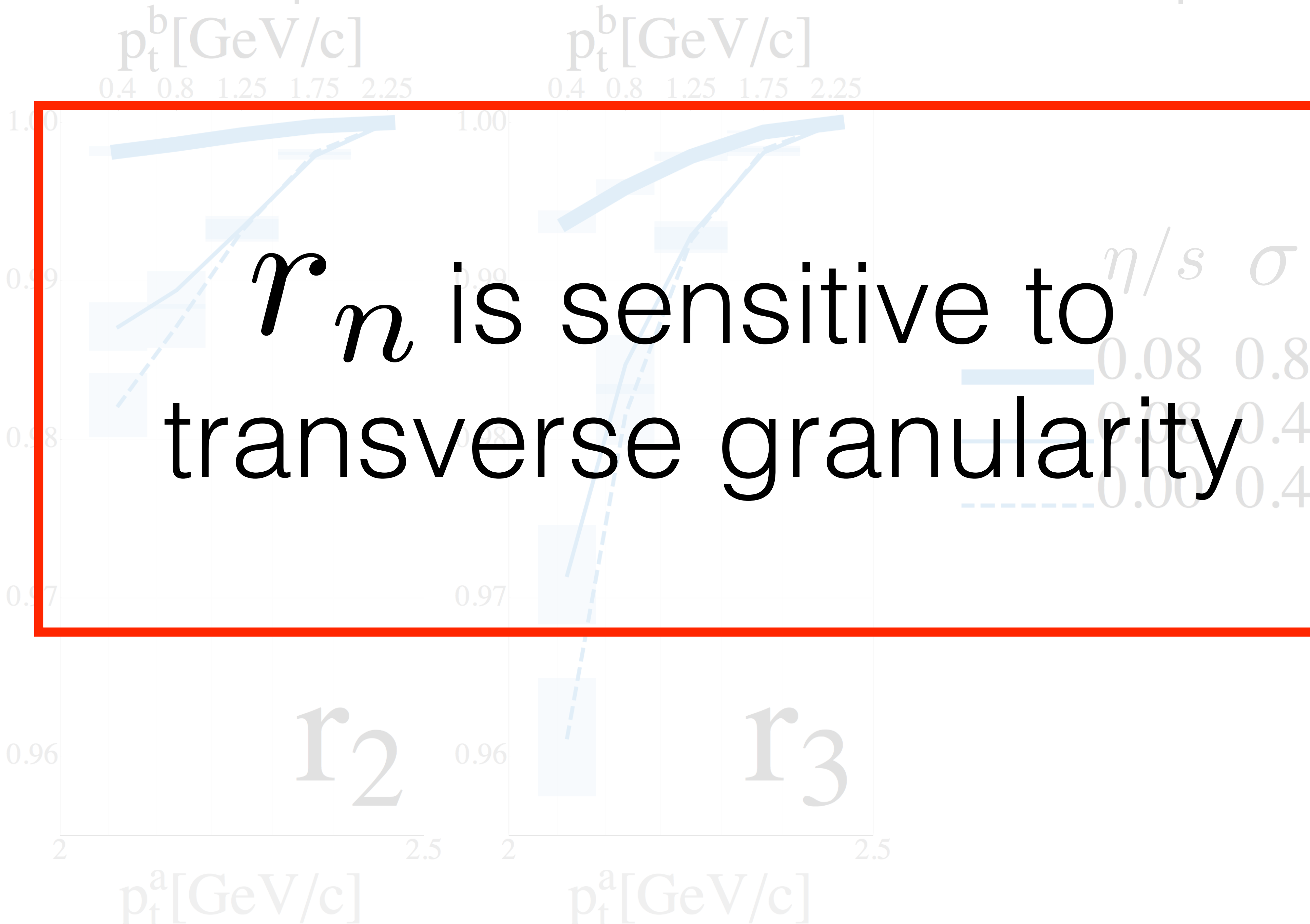
multiplicity dependence prediction in pPb



r_n dependence on σ and η/s in pPb

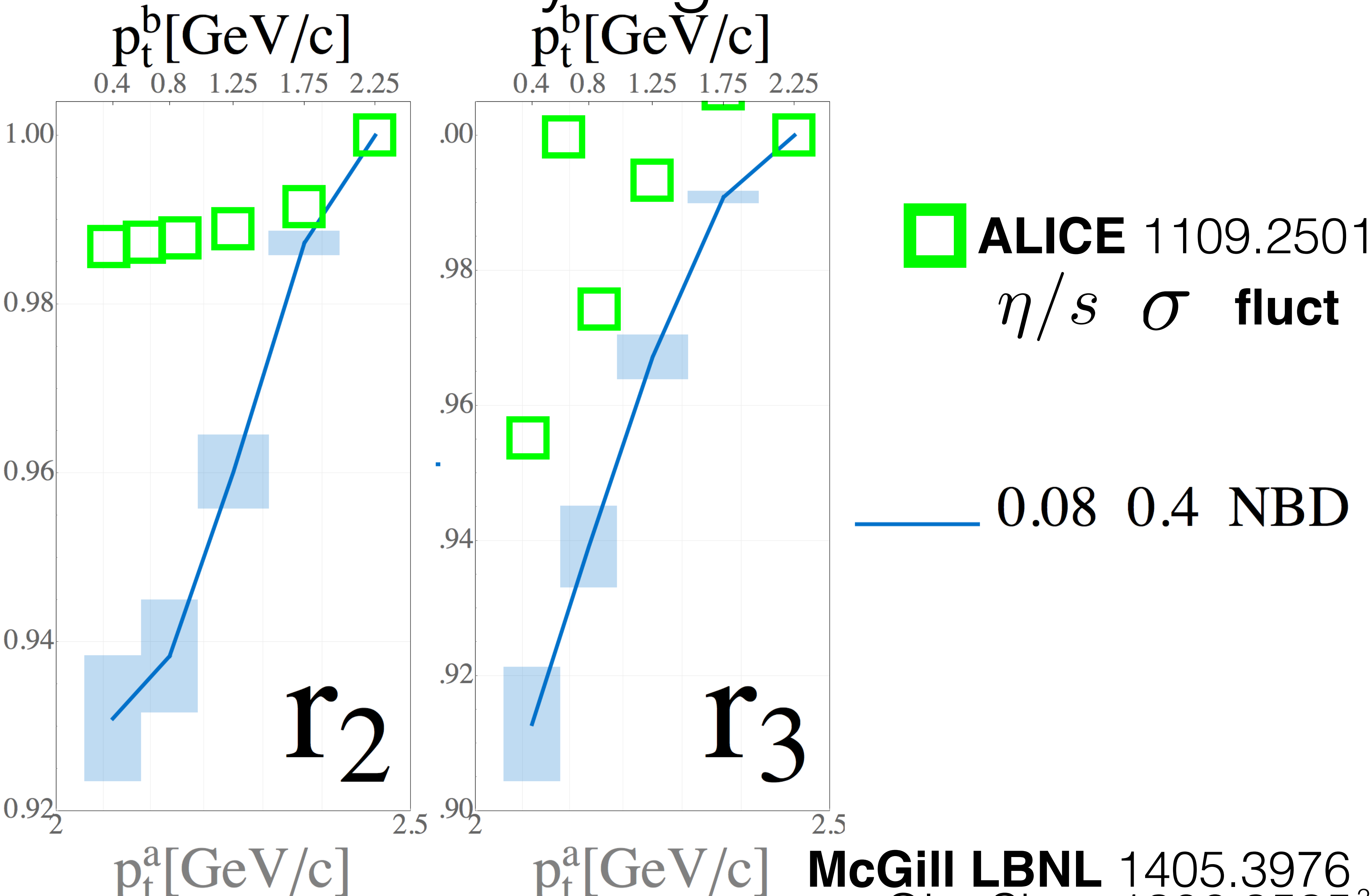


r_n dependence on σ and η/s in pPb



r_n is sensitive to transverse granularity

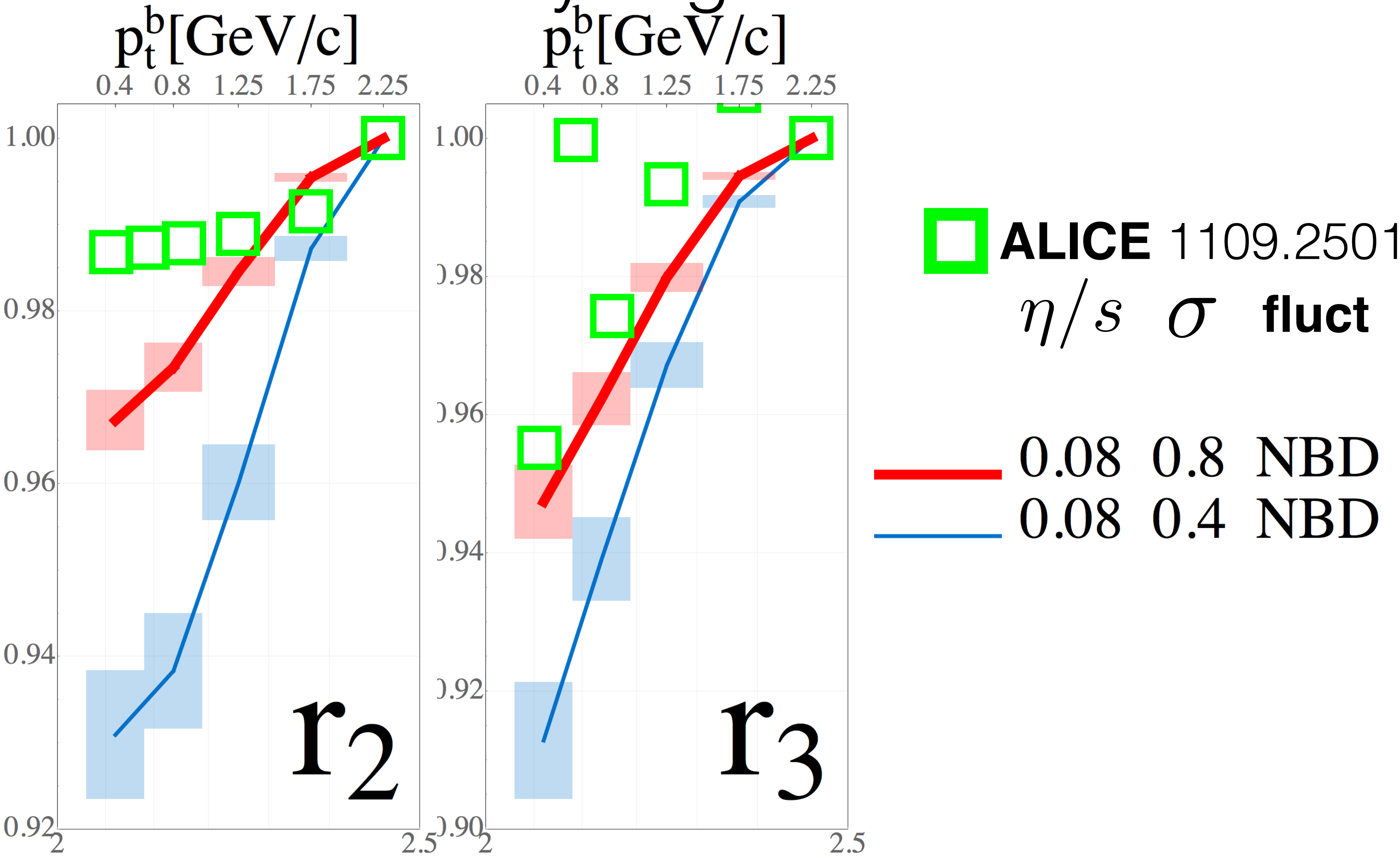
Reanalyzing PbPb data



McGill LBNL 1405.3976

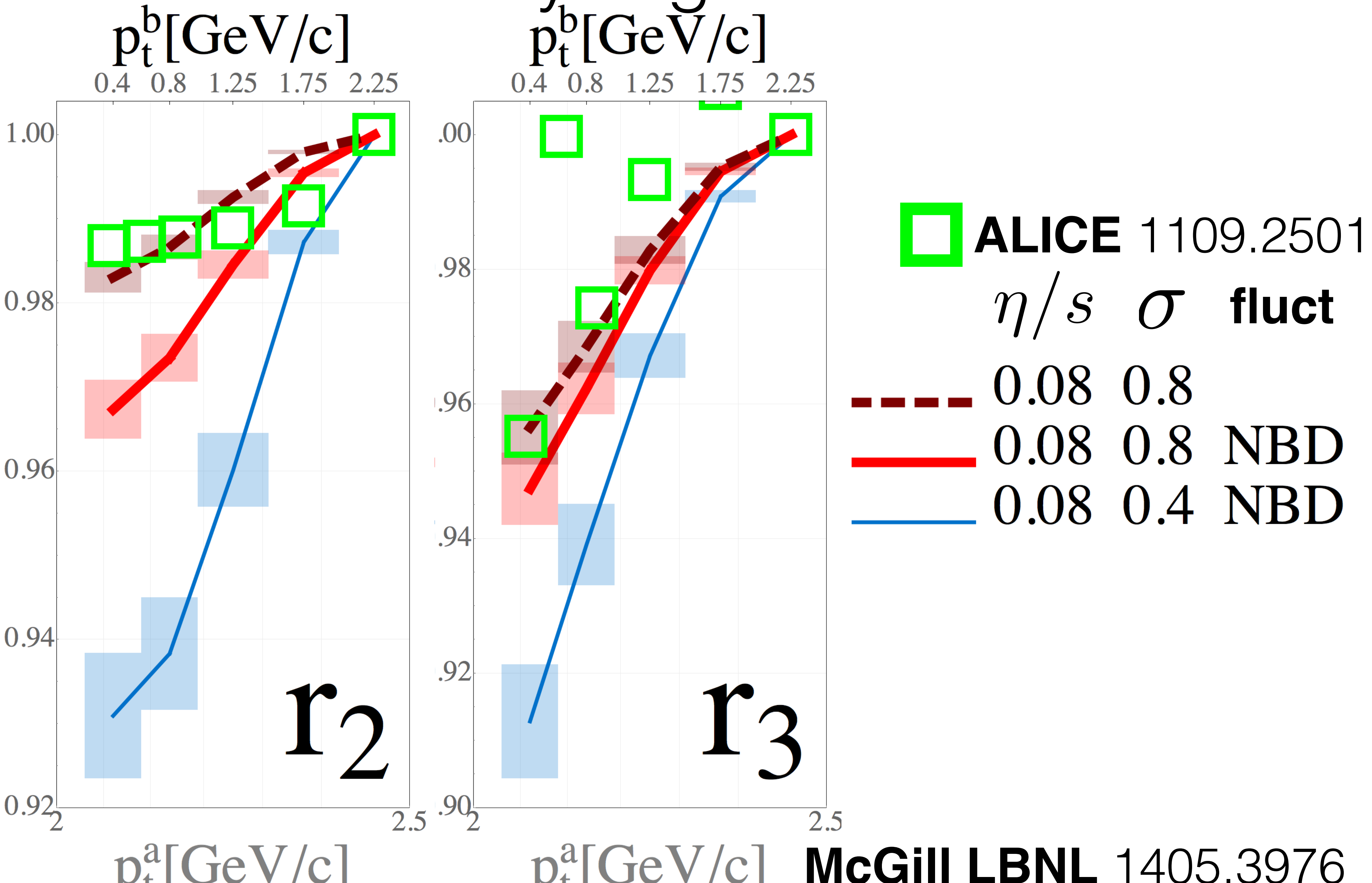
Heinz, Qiu, Shen 1302.3535

Reanalyzing PbPb data



McGill LBNL 1405.3976
Heinz, Qiu, Shen 1302.3535

Reanalyzing PbPb data



McGill LBNL 1405.3976

Heinz, Qiu, Shen 1302.3535

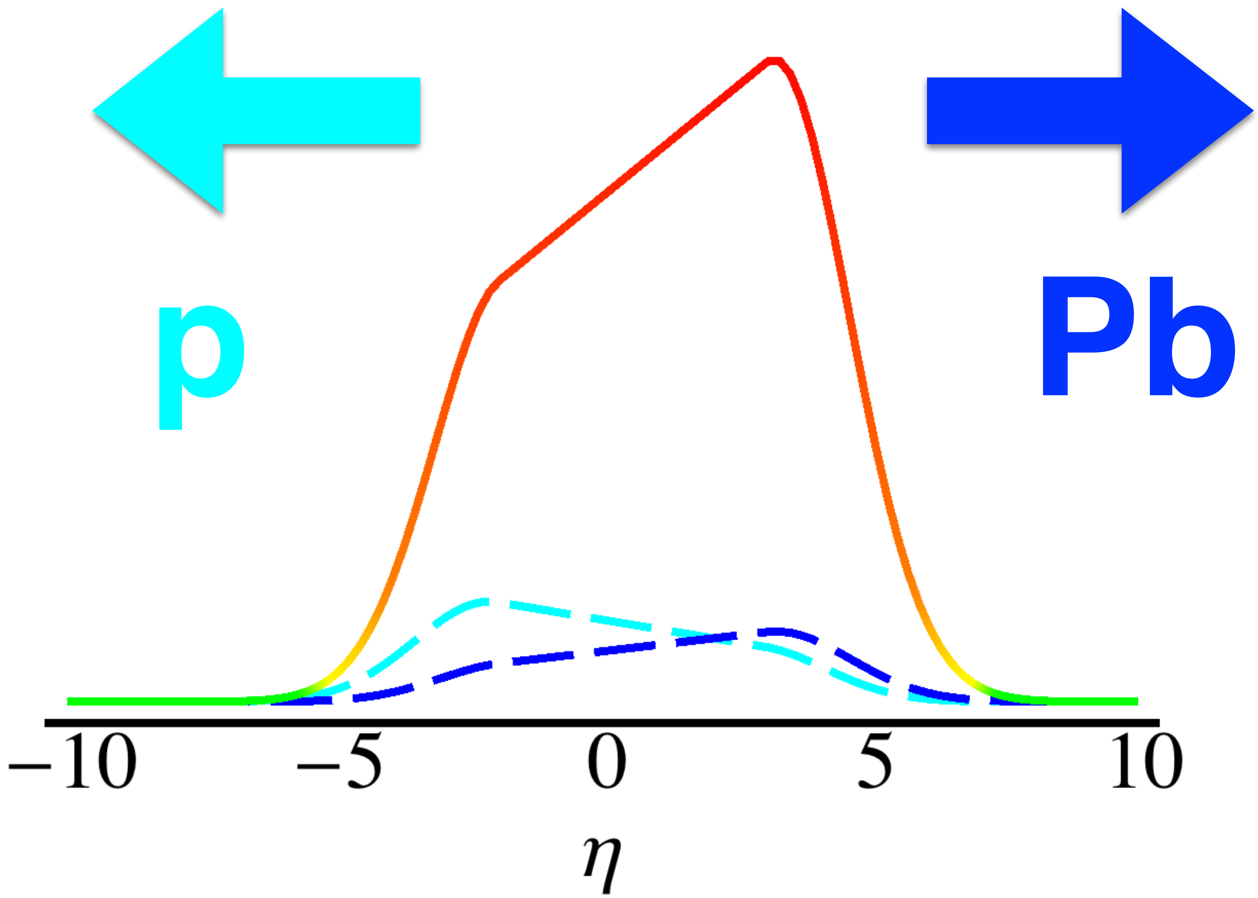
Conclusion

- Hydrodynamics can reasonably describe a wide range of flow observables for pPb system at high multiplicity $v_2\{2\}, v_3\{2\}, v_2\{4\}$ and r_n

- r_n predictions provide another handle to explore HIC
    - it tells us where hydro breaks down
    - a way to probe initial conditions (granularity)
    - a way to study differences between pA and AA

Backup

Initial conditions: longitudinal profile

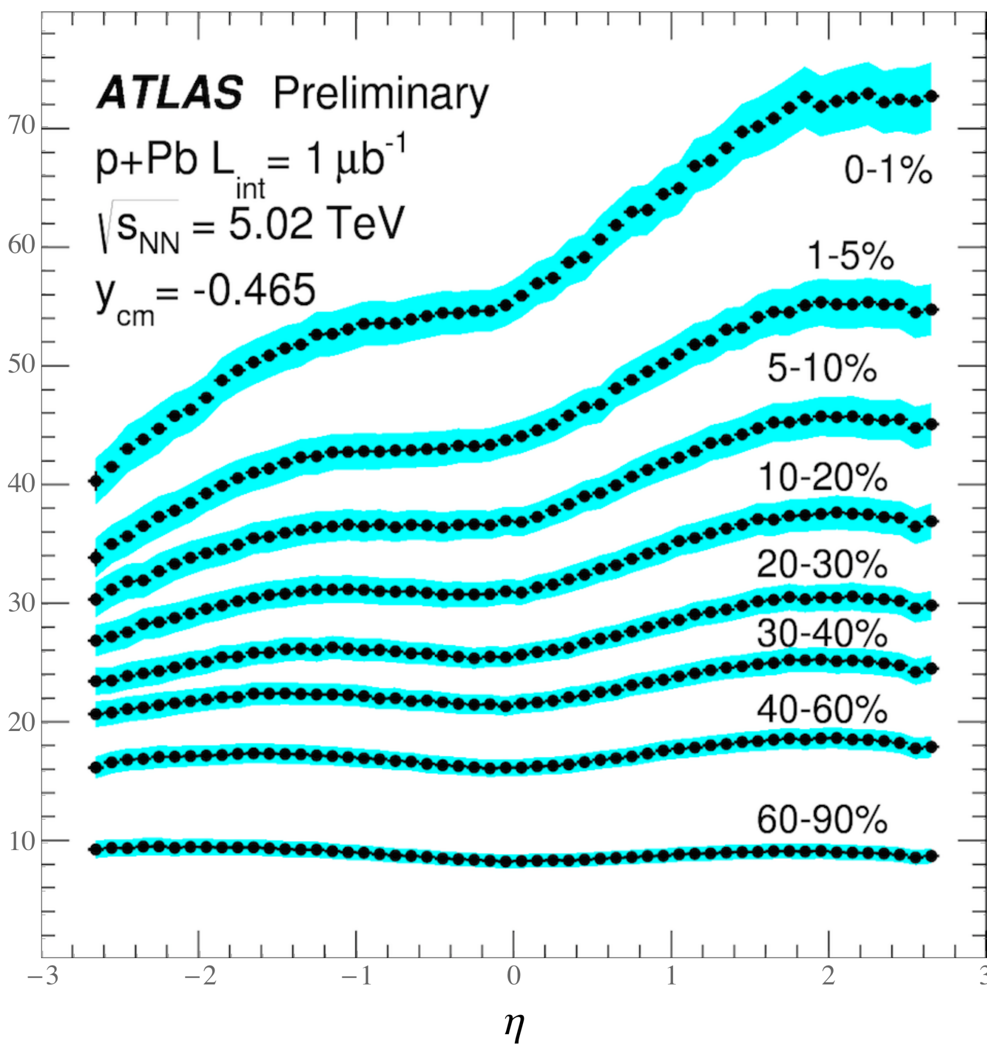


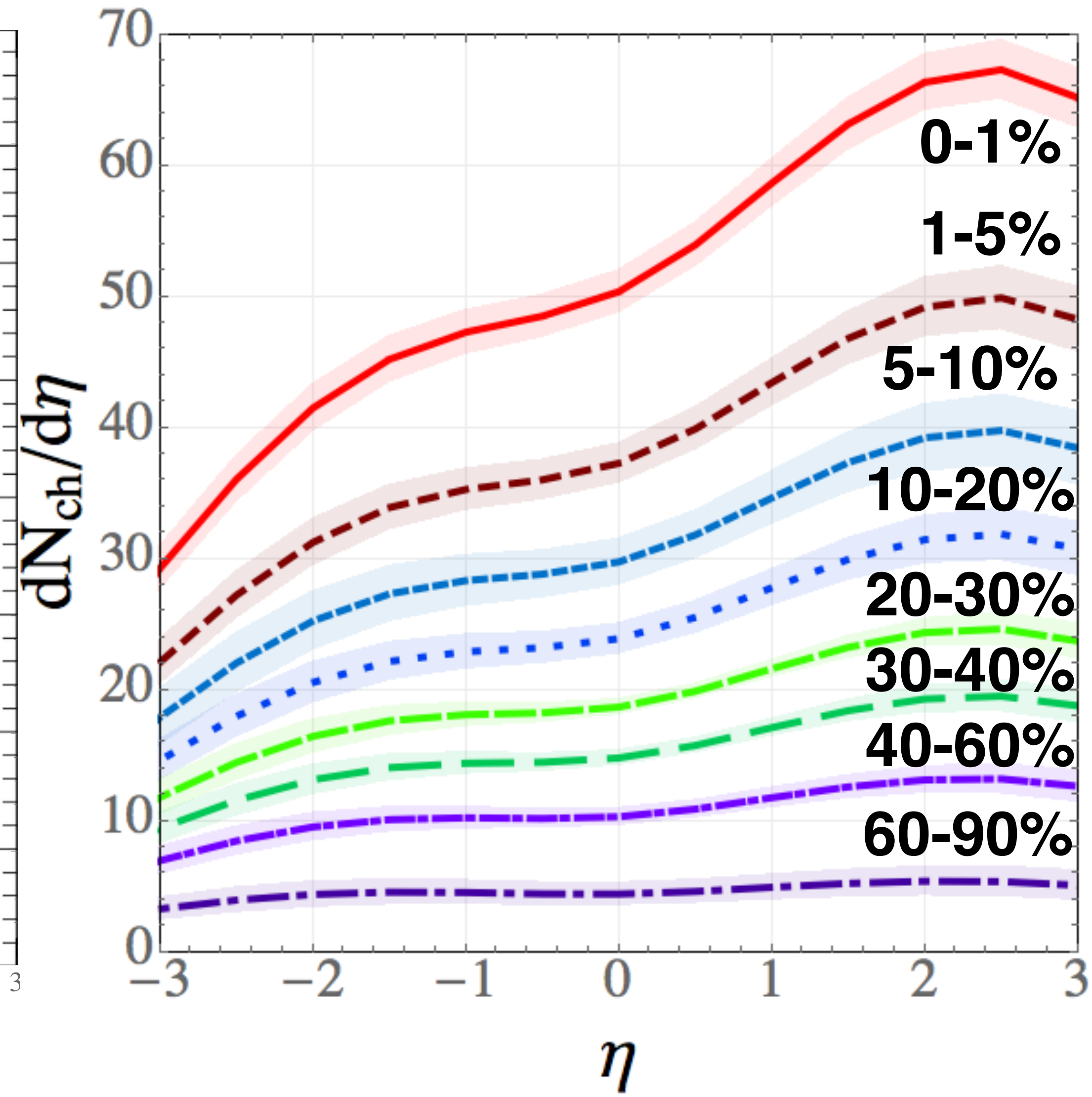
$$\left(1 \pm \frac{\eta}{y_{\mathrm{beam}}}\right) \exp\left(-\frac{(|\eta|-\eta_0)^2}{2\sigma_\eta^2}\theta(|\eta|-\eta_0)\right)$$

Bozek, Wyskiel 1002.4999

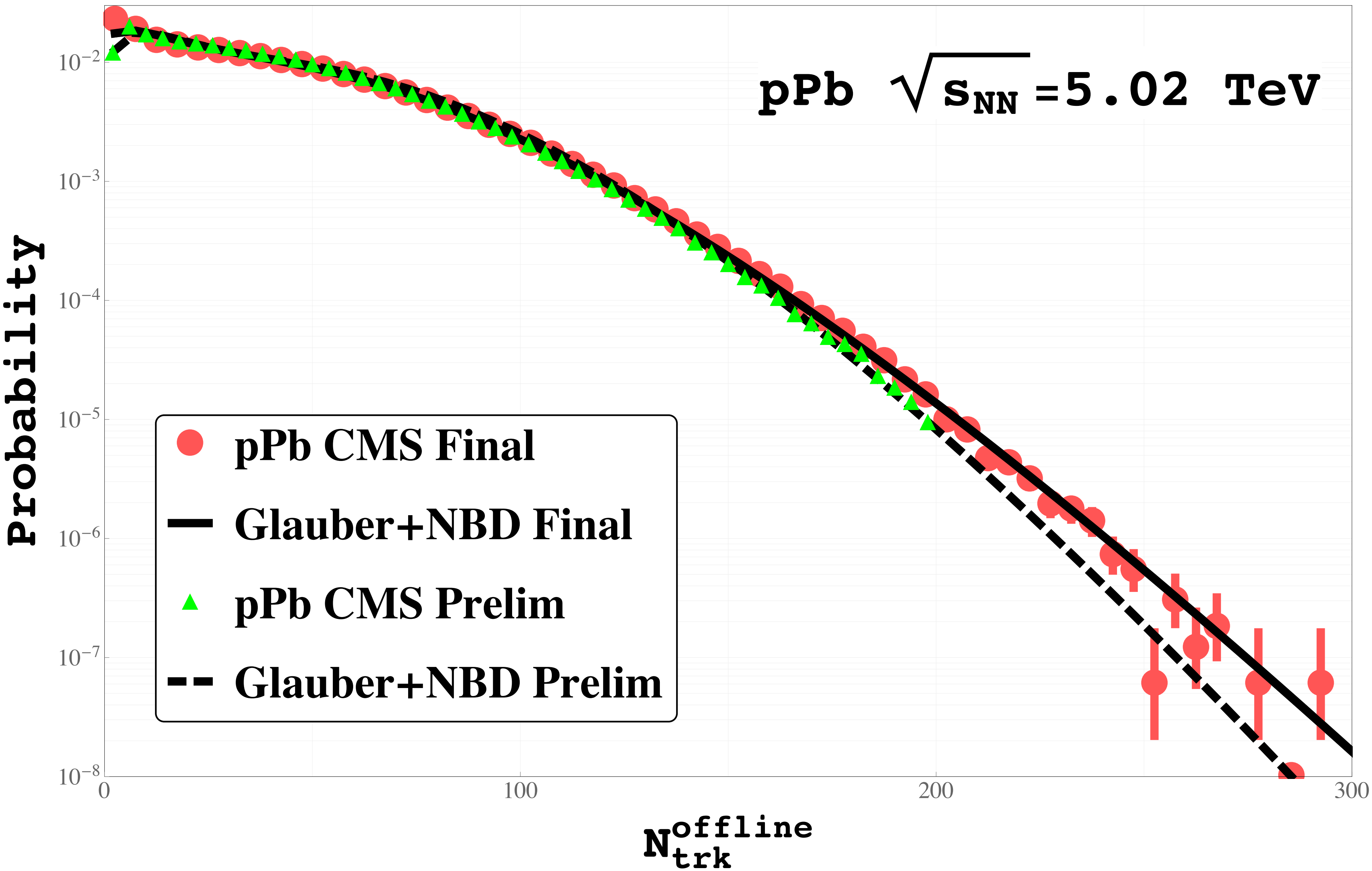
Pseudorapidity distribution

ATLAS arXiv/1403.5738



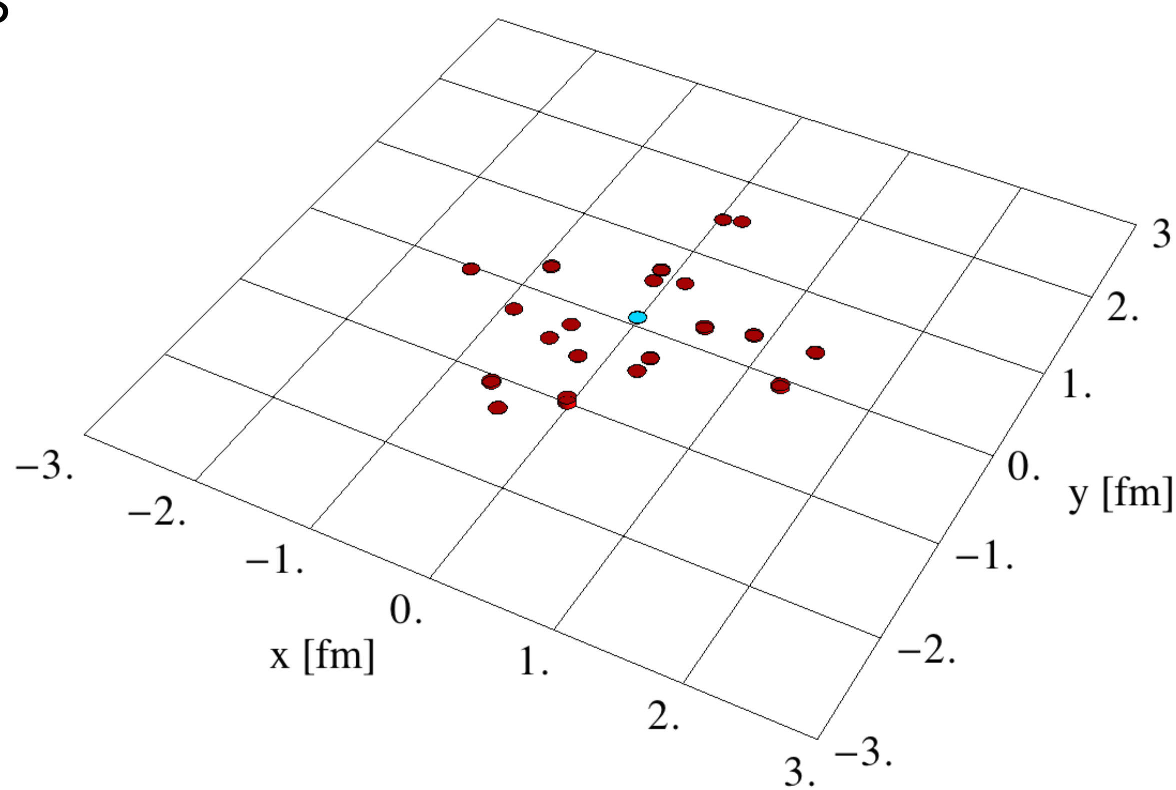


Initial conditions: Glauber+NBD



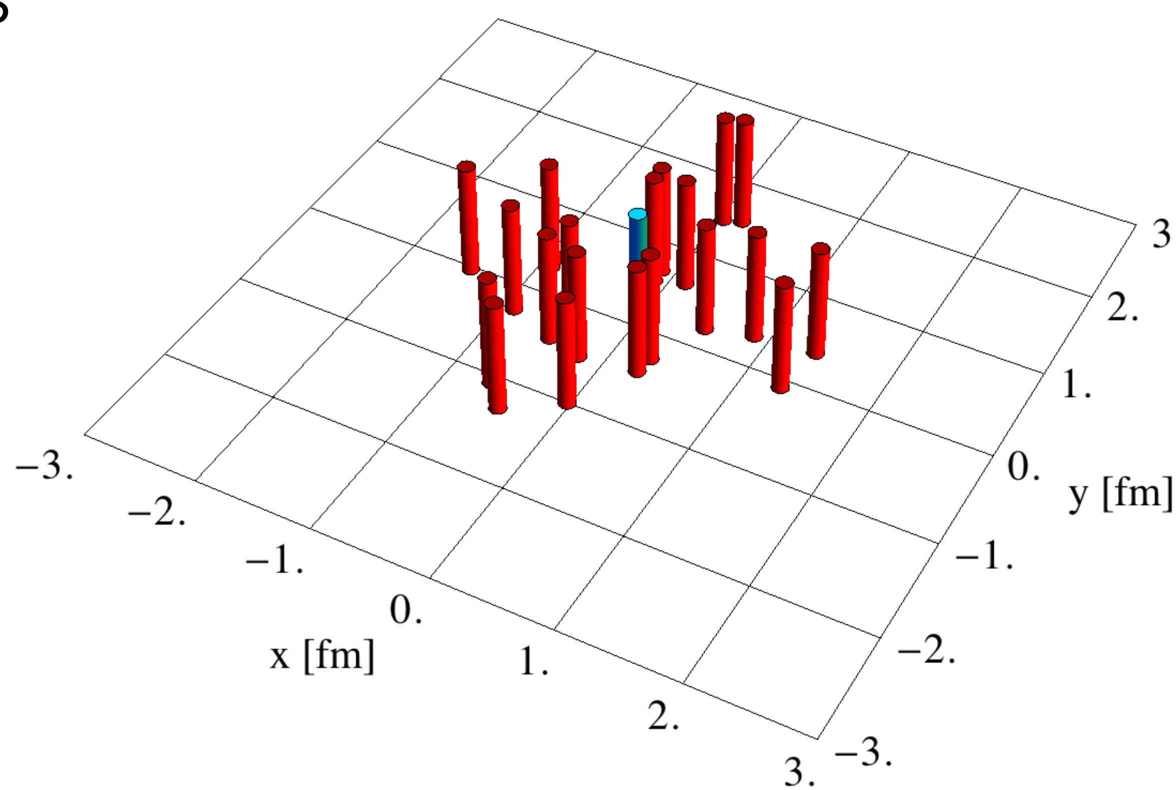
Initial conditions: Glauber

- sample participants



Initial conditions: Glauber

- sample participants
- add sources

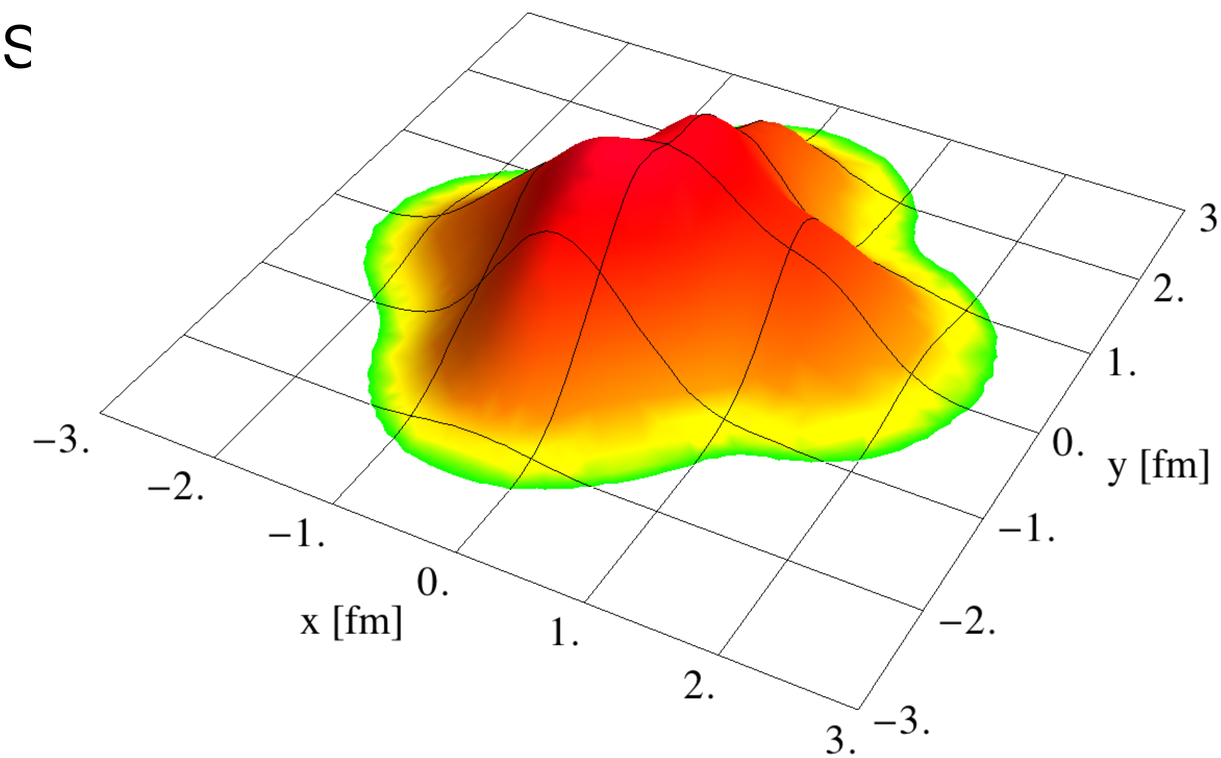


Initial conditions: Glauber

$$\sigma = 0.40 \text{ fm}$$

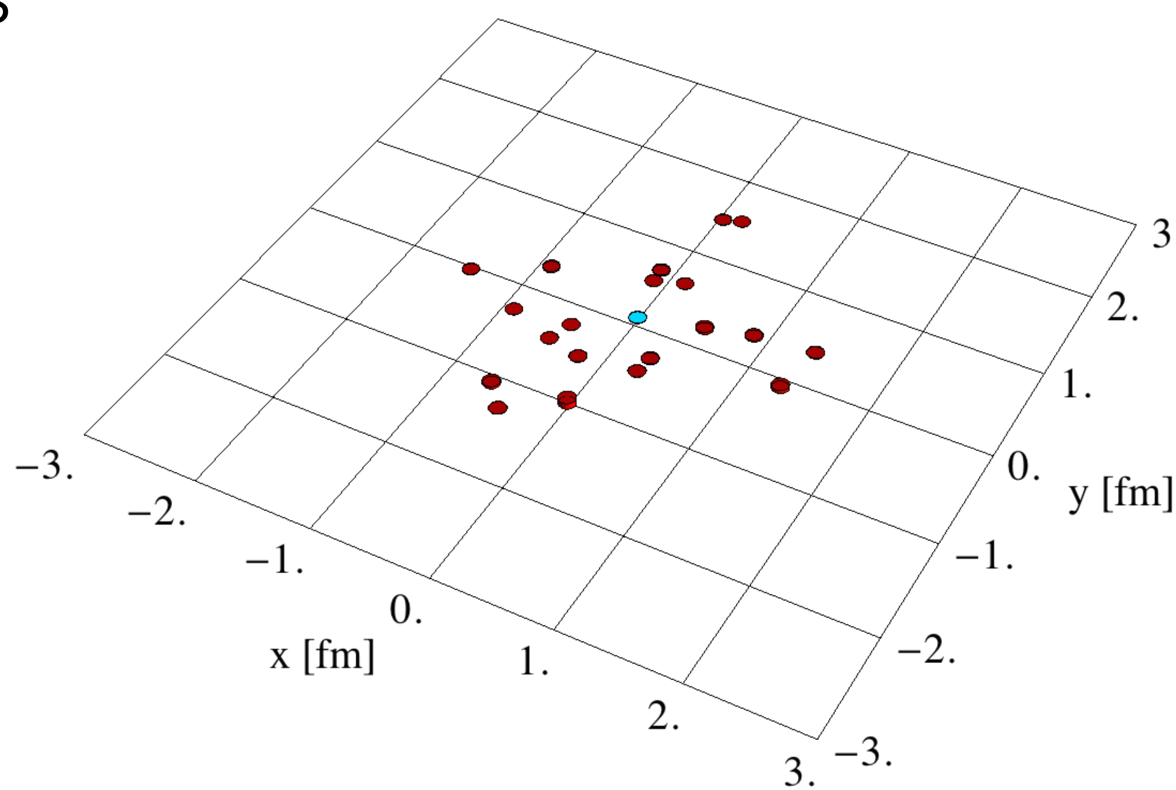
- sample participants
- add sources

- increase σ



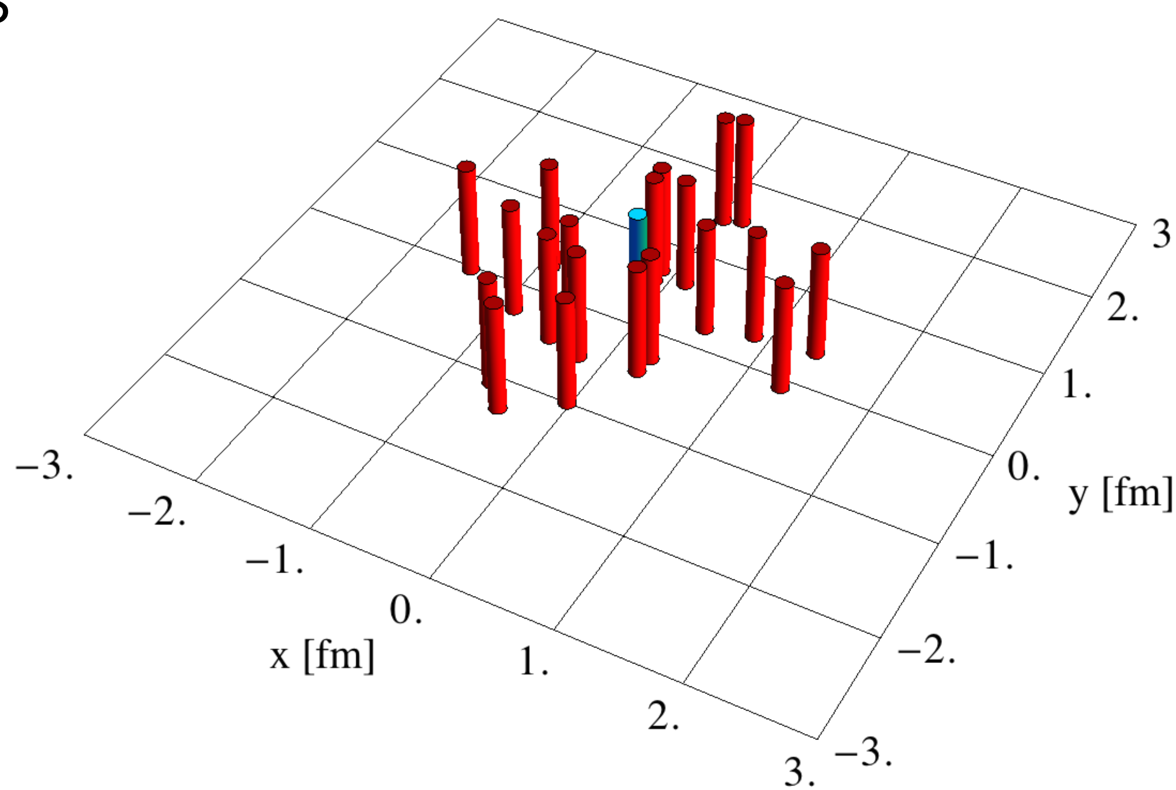
Initial conditions: Glauber+NBD

- sample participants



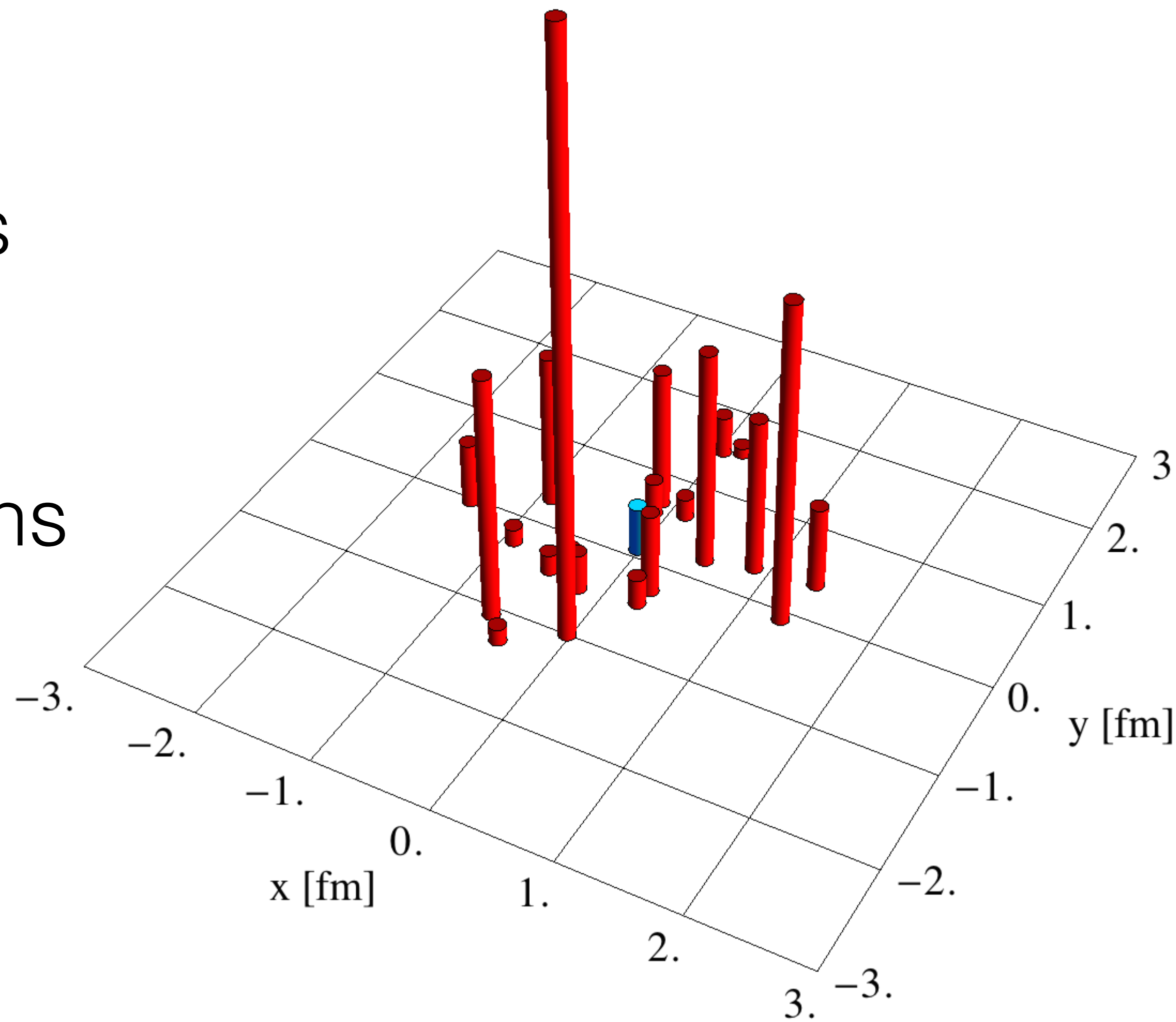
Initial conditions: Glauber+NBD

- sample participants
- add sources



Initial conditions: Glauber+NBD

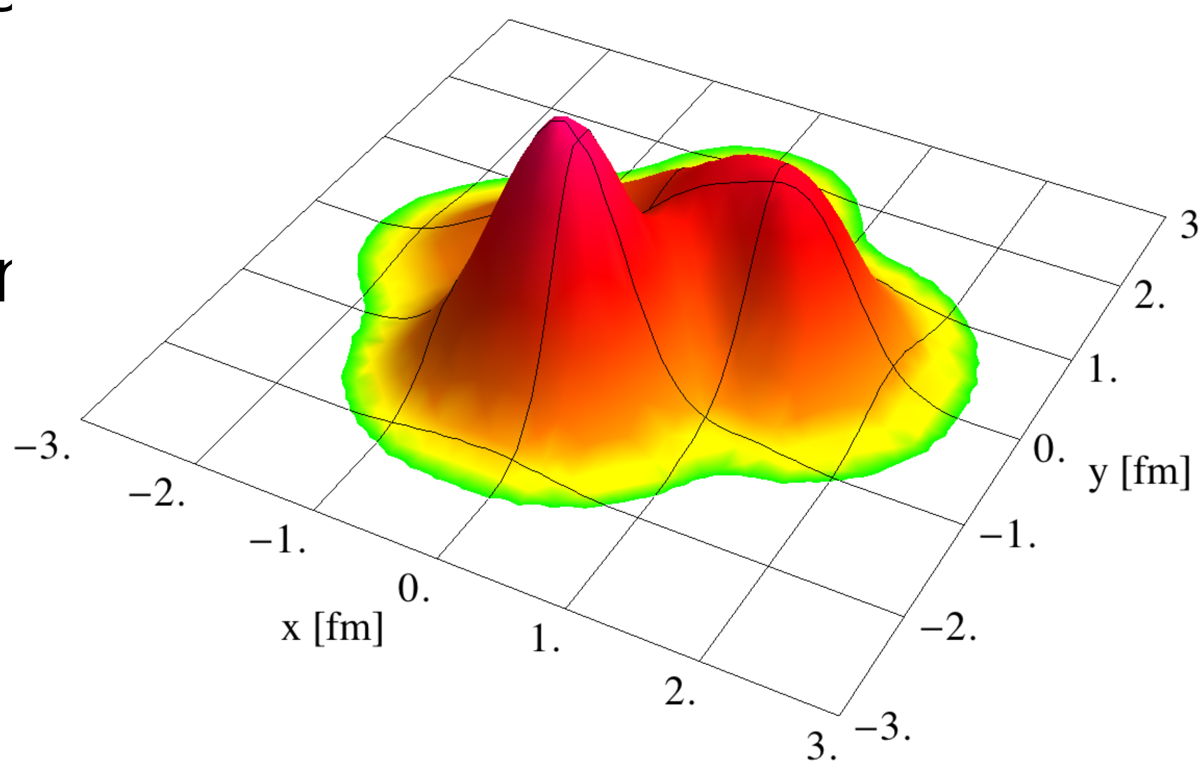
- sample participants
- add sources
- add NBD fluctuations



Initial conditions: Glauber+NBD

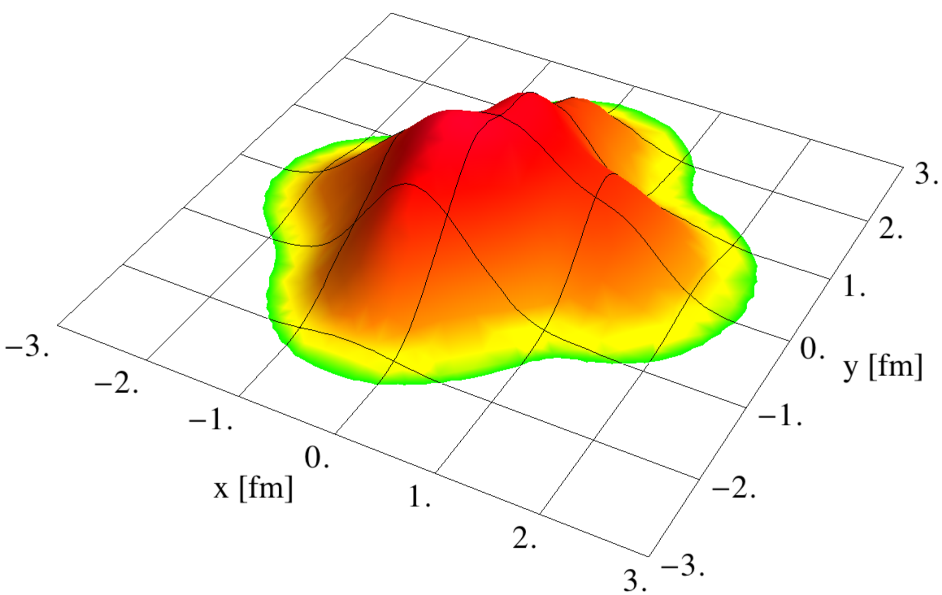
$$\sigma = 0.40 \text{ fm}$$

- sample participants
- add sources
- add NBD fluctuatior
- increase σ



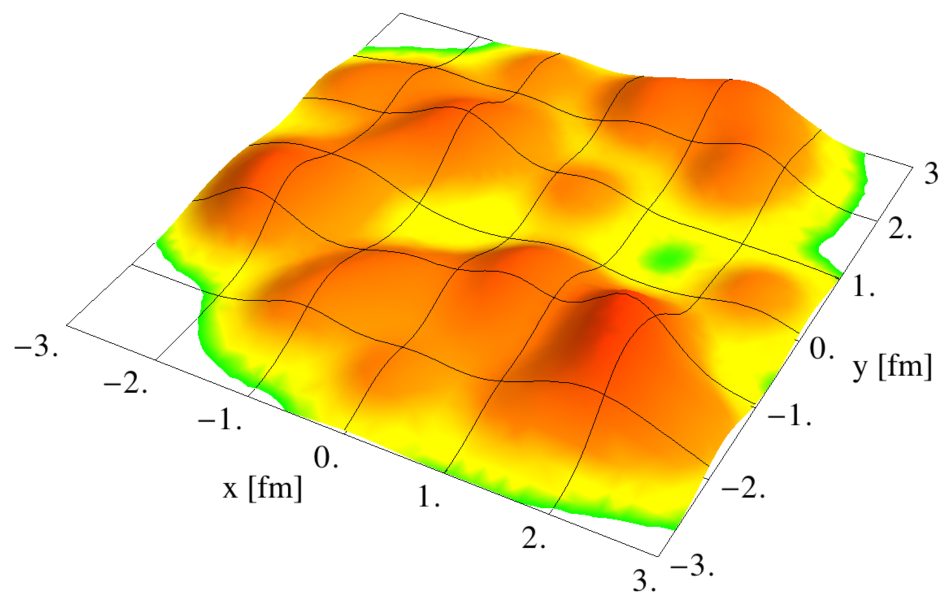
Initial conditions: Glauber

$\sigma = 0.40\ \text{fm}$



pPb

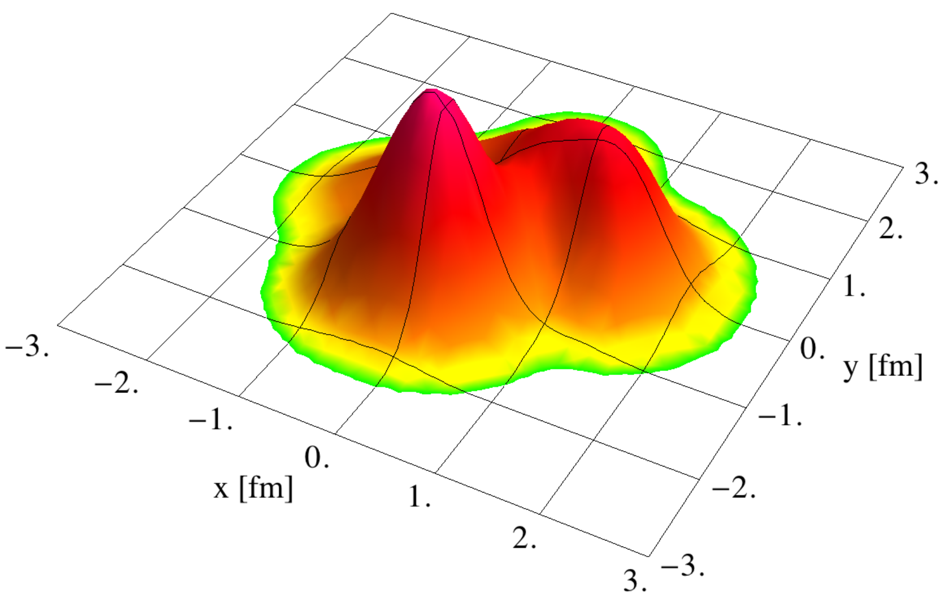
$\sigma = 0.40\ \text{fm}$



PbPb

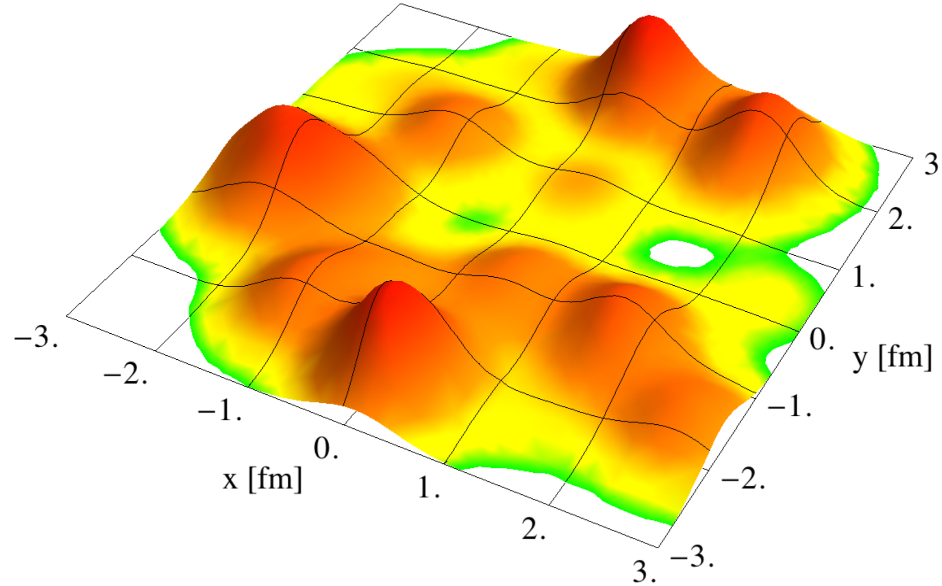
Initial conditions: Glauber+NBD

$\sigma = 0.40$ fm



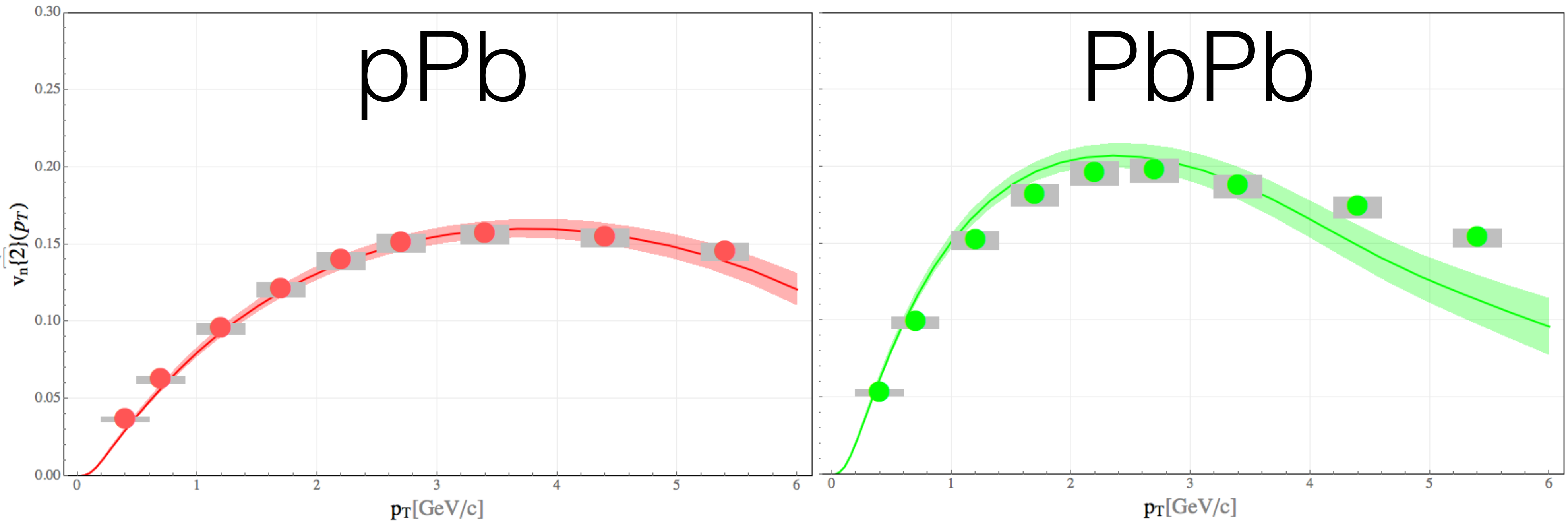
pPb

$\sigma = 0.40$ fm

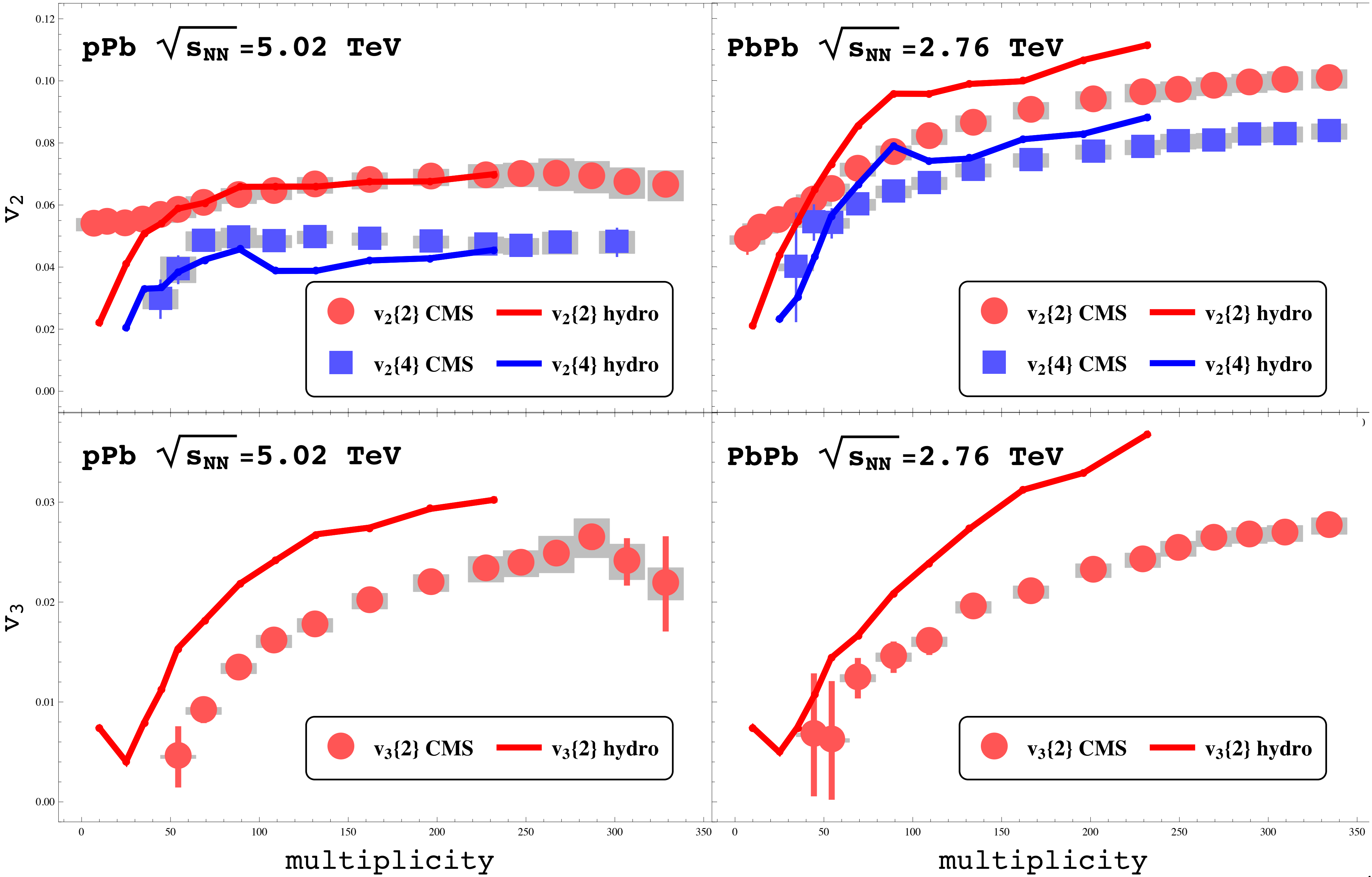


PbPb

Flow observables for pPb and PbPb



Flow observables for pPb and PbPb



experiment:

$$V_{n\Delta}(p_T^a, p_T^b) \equiv \langle \overline{\cos n(\phi^a - \phi^b)} \rangle$$

$$r_n \equiv \frac{V_{n\Delta}(p_T^a, p_T^b)}{\sqrt{V_{n\Delta}(p_T^a, p_T^a) V_{n\Delta}(p_T^b, p_T^b)}}$$

$$\frac{dN_{pairs}}{d^3p^a d^3p^b} \stackrel{\text{(flow)}}{=} \frac{dN}{d^3p^a} \times \frac{dN}{d^3p^b}$$

$$\langle \overline{e^{in(\phi^a - \phi^b)}} \rangle = \langle \overline{e^{in\phi^a}} \cdot \overline{e^{-in\phi^b}} \rangle$$

$$v_n^a e^{in\Psi_n^a} \equiv \overline{e^{in\phi^a}}$$

$$V_{n\Delta}^{ab}(p_T^a, p_T^b) = \langle v_n^a v_n^b e^{in(\Psi_n^a - \Psi_n^b)} \rangle$$

$$V_{n\Delta}(p_T^a, p_T^a) \geq 0$$

$$V_{n\Delta}(p_T^a, p_T^b)^2 \leq V_{n\Delta}(p_T^a, p_T^a) V_{n\Delta}(p_T^b, p_T^b)$$