Signatures of collective behavior in small collision systems

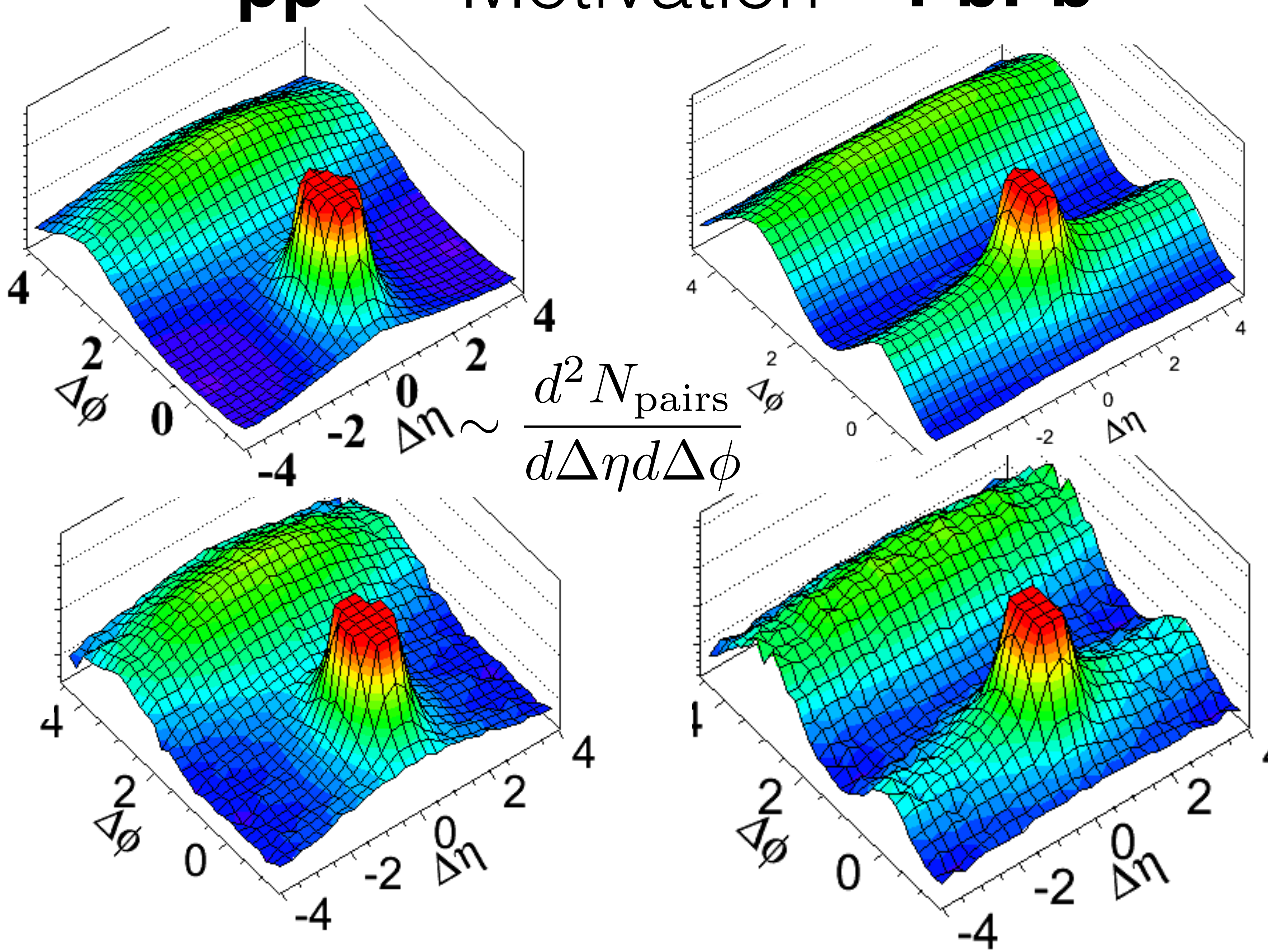
Igor Kozlov

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

JET Summer School (Davis, CA), June 21, 2014

Motivation

pp **PbPb**



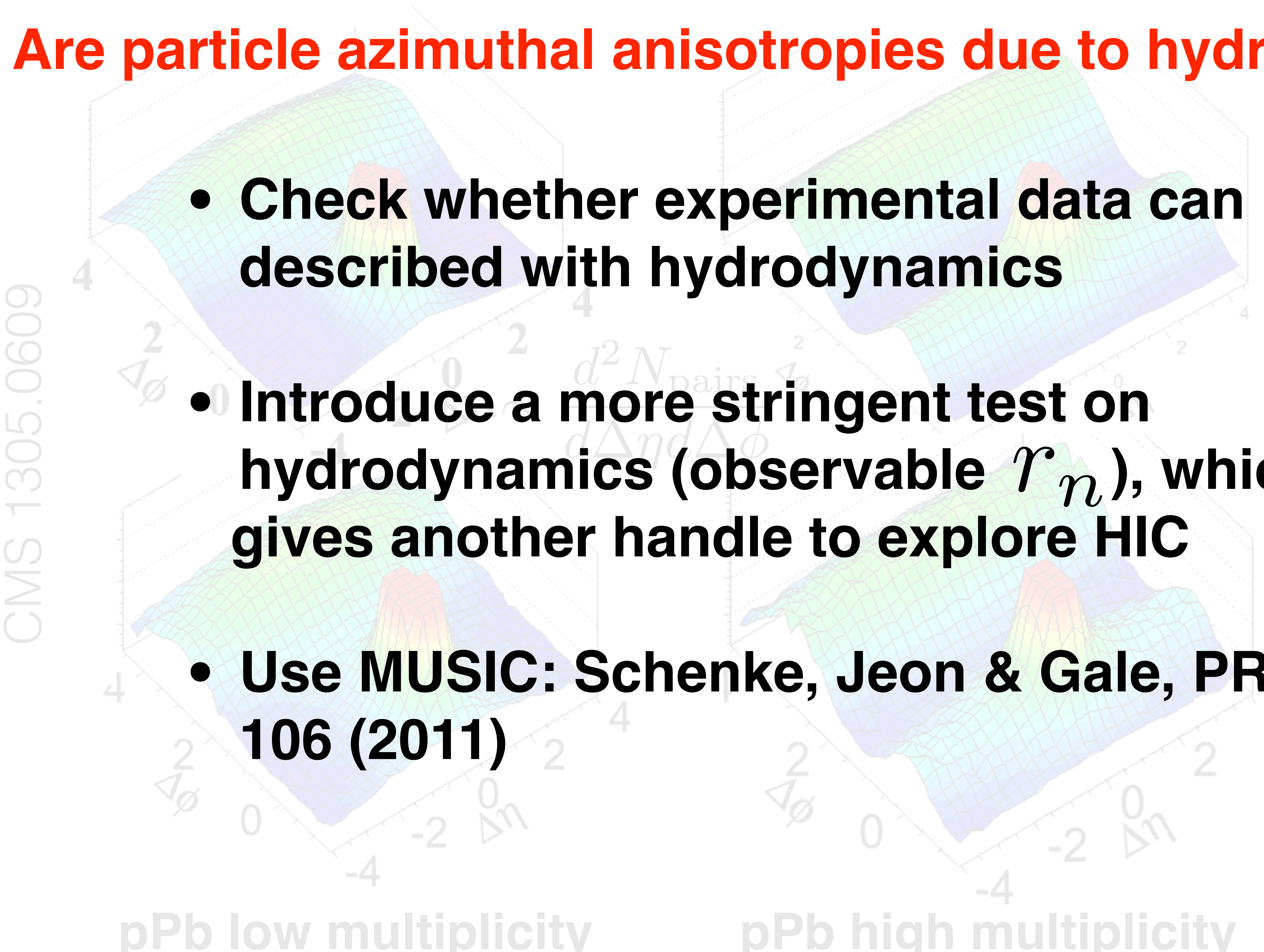
$$\sim \frac{d^2 N_{\rm pairs}}{d\Delta\eta d\Delta\phi}$$

CMS 1305.0609

pPb low multiplicity **pPb high multiplicity**

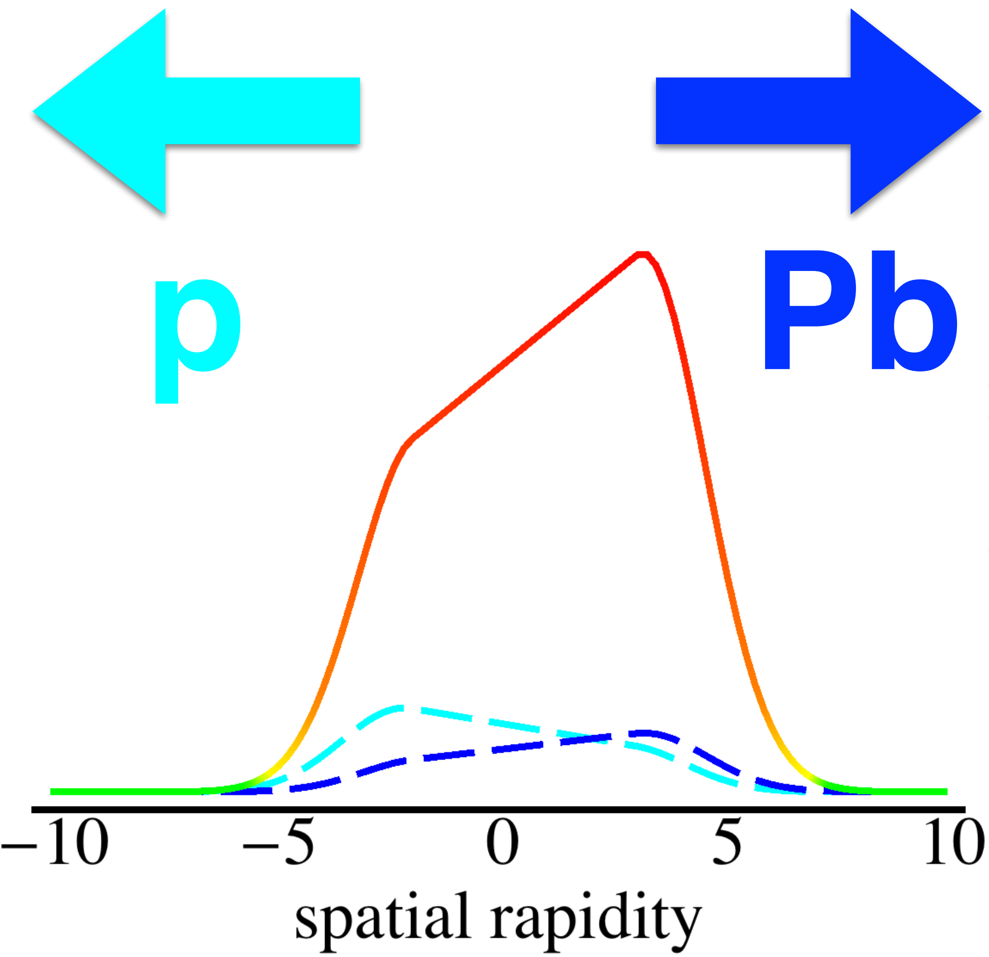
Are particle azimuthal anisotropies due to hydro?

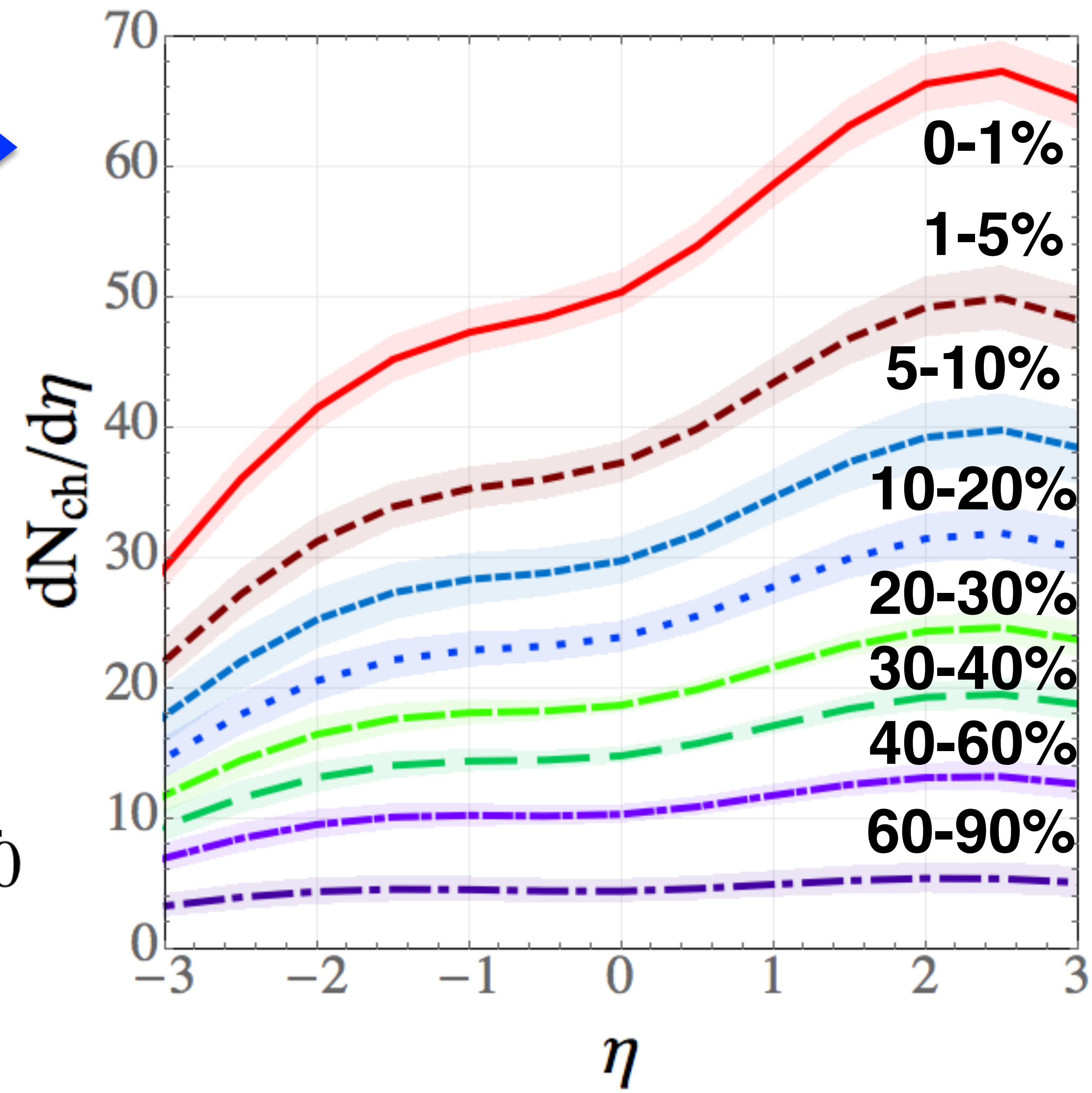
- **Check whether experimental data can be described with hydrodynamics**
- **Introduce a more stringent test on hydrodynamics (observable r_n), which gives another handle to explore HIC**
- **Use MUSIC: Schenke, Jeon & Gale, PRL 106 (2011)**



Glauber + rapidity distribution

initial entropy profile → final multiplicity profile

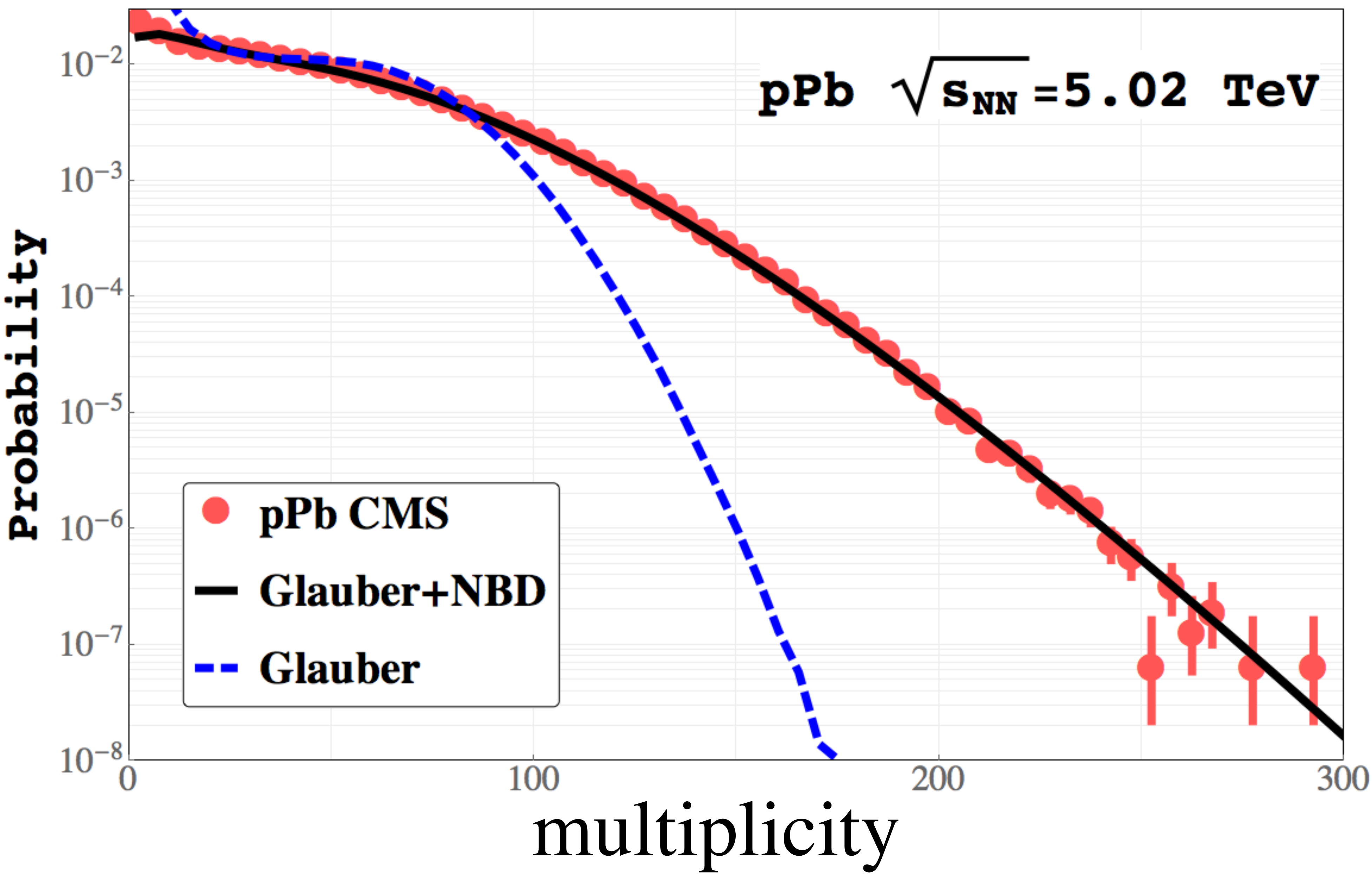




Bozek, Wyskiel 1002.4999

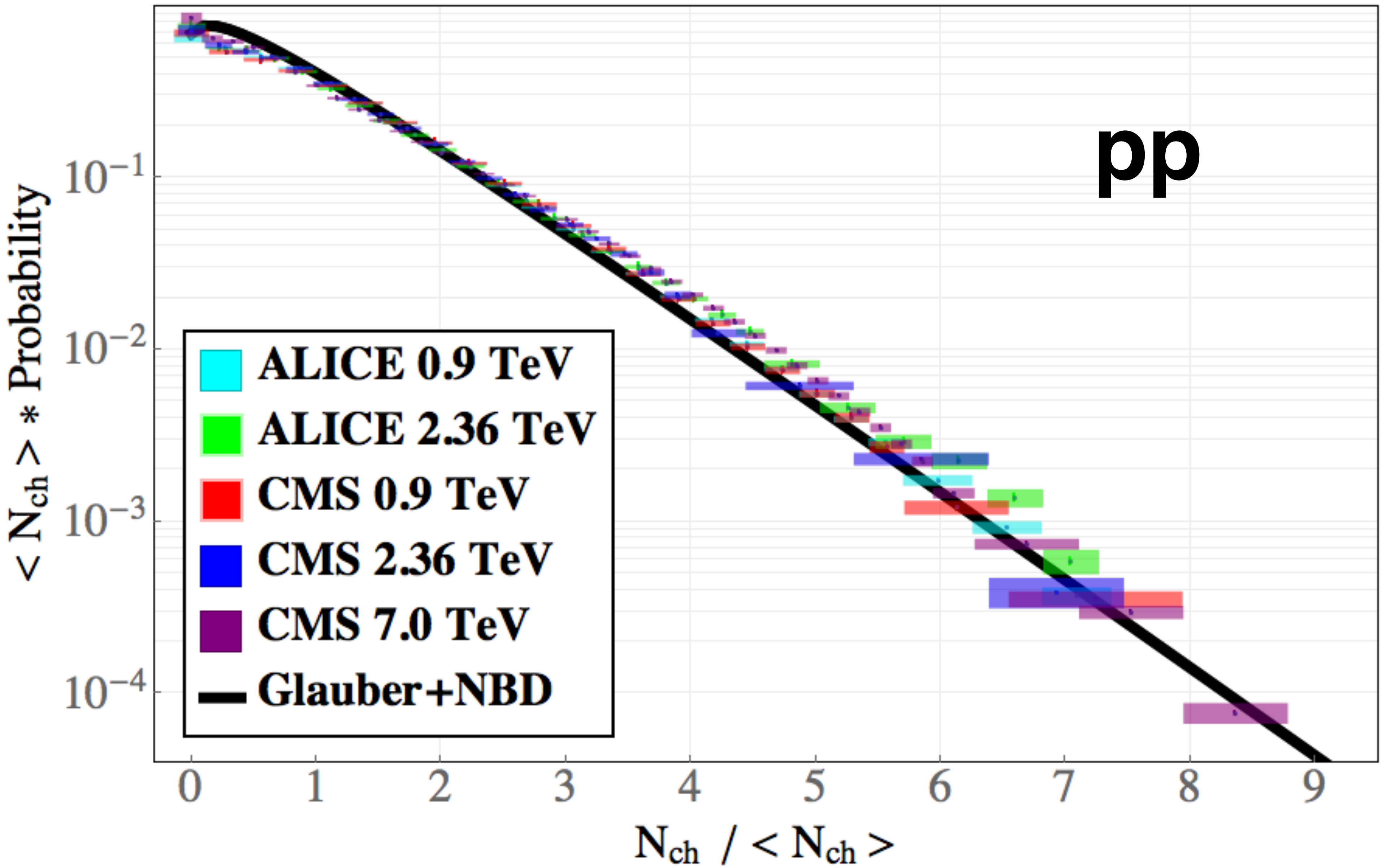
McGill, LBNL 1405.3976

Glauber+NBD



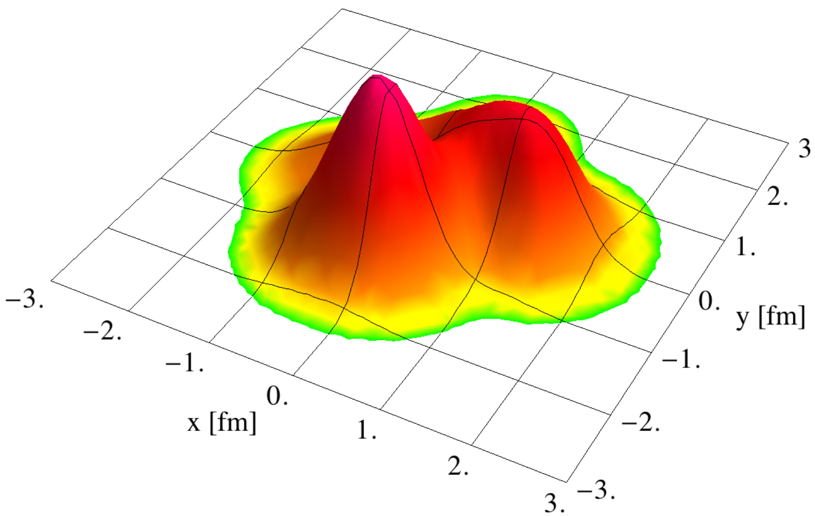
CMS twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13002

pp multiplicity with **Glauber+**NBD

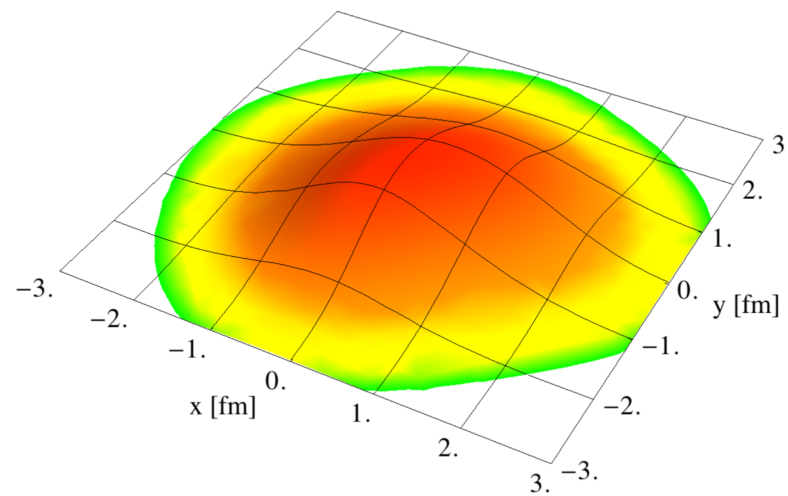


Transverse granularity

$\sigma = 0.40$ fm



$\sigma = 0.80$ fm



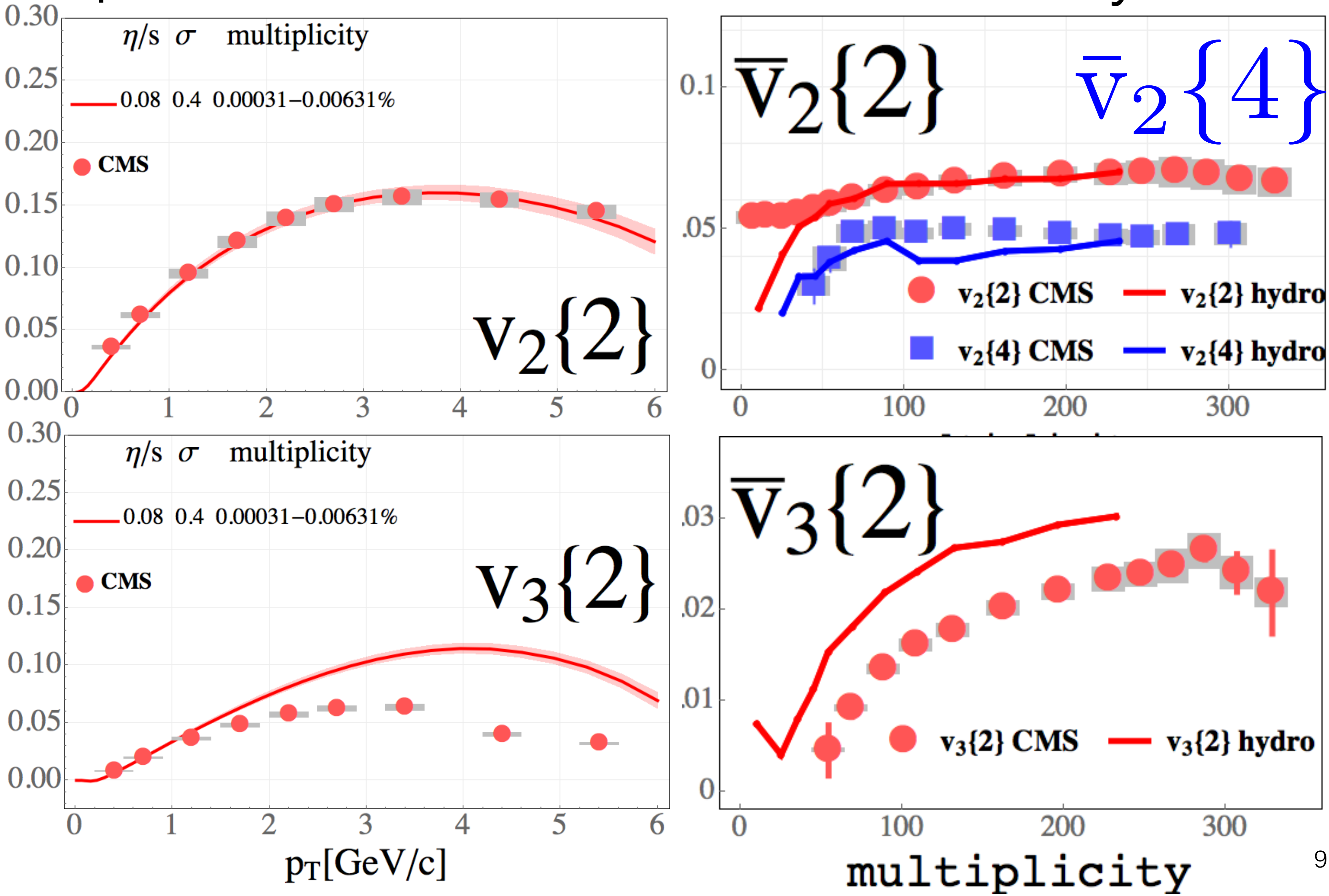
Compare with hydro; start with:

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

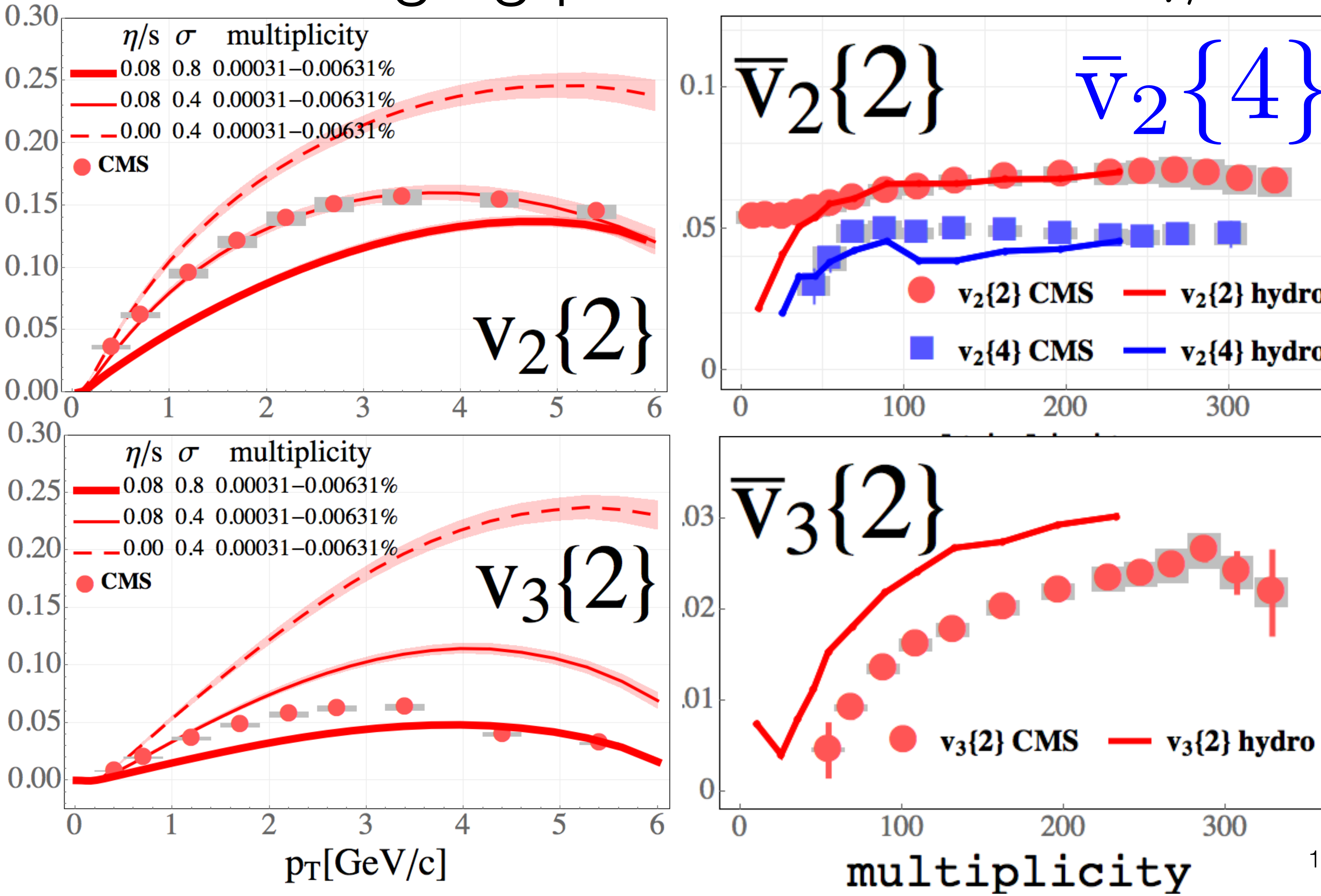
Comparing hydro calculations to existing pA data

CMS 1211.0989 McGill, LBNL 1405.3976

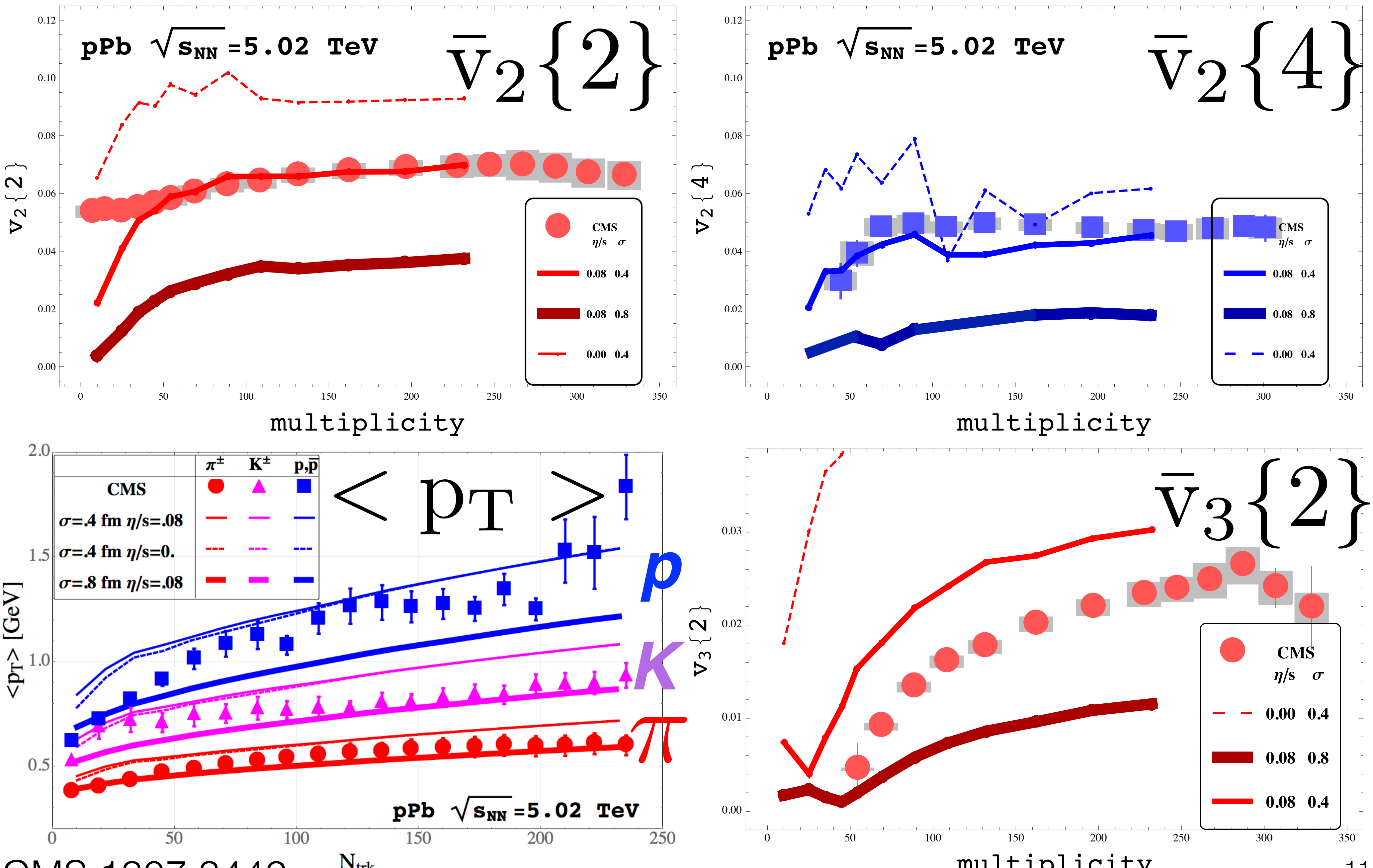
pPb flow observables: CMS & hydro



Changing parameters σ and η/s



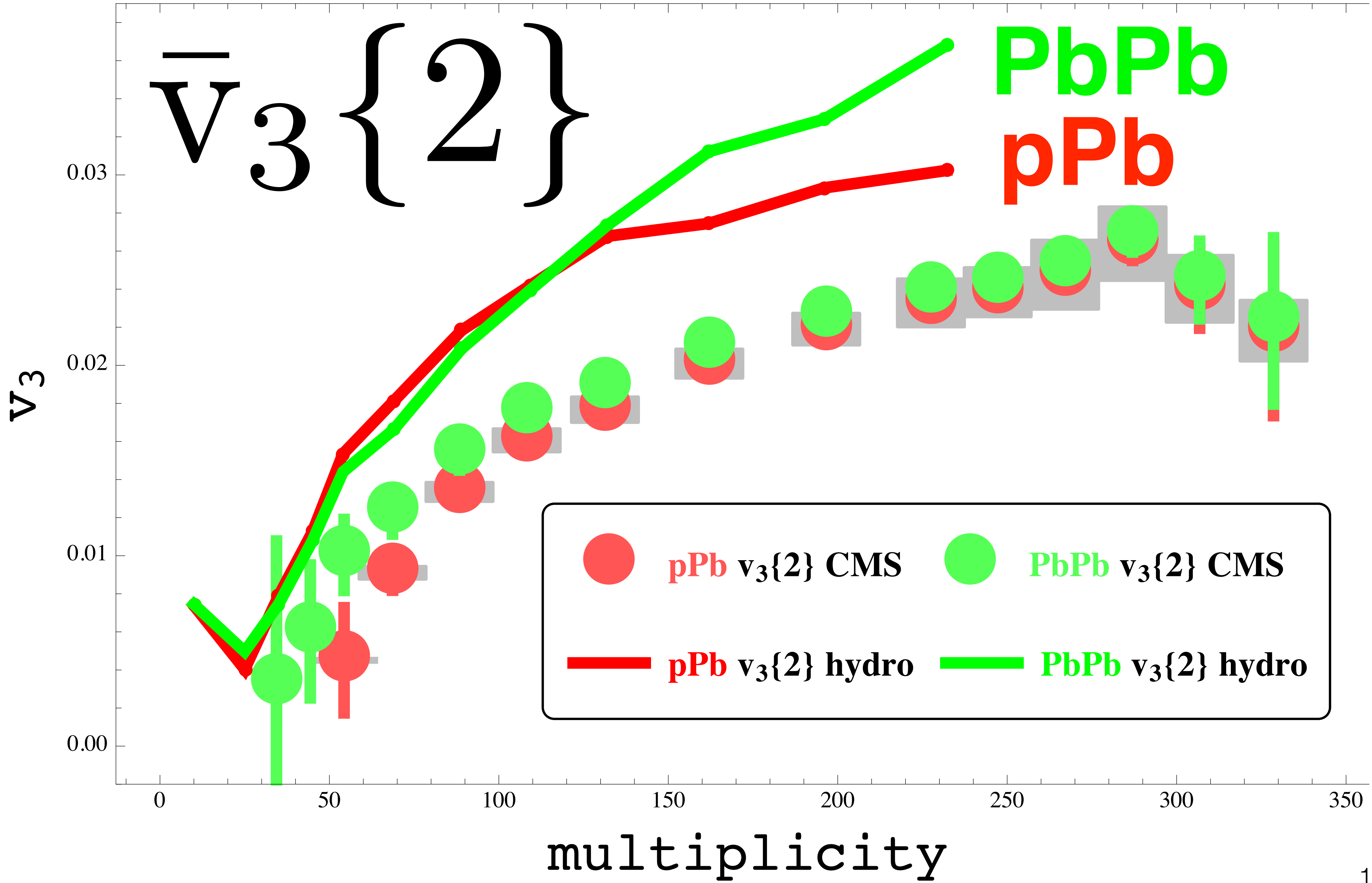
Flow observables dependence on σ and η/s



CMS 1307.3442

CMS 1211.0989 McGill, LBNL 1405.3976

CMS finding in hydro



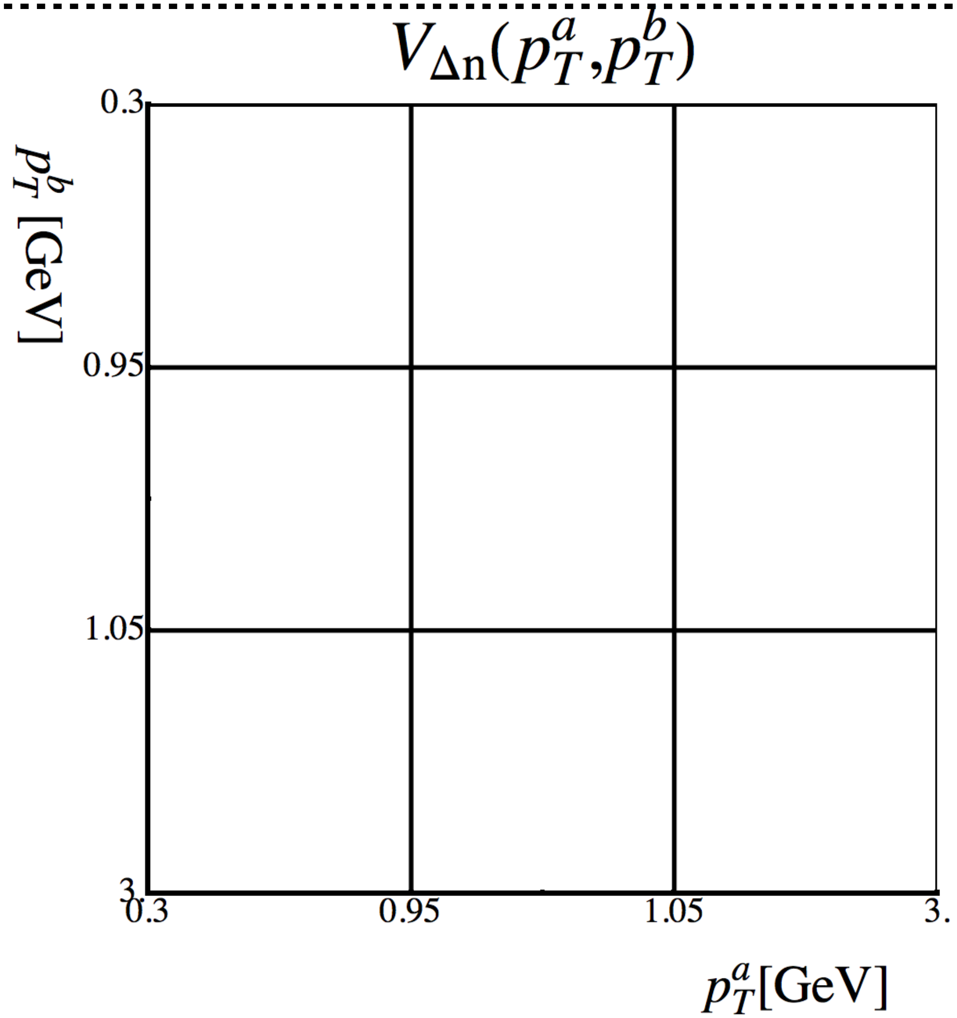
All two-particle correlation observables

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:

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



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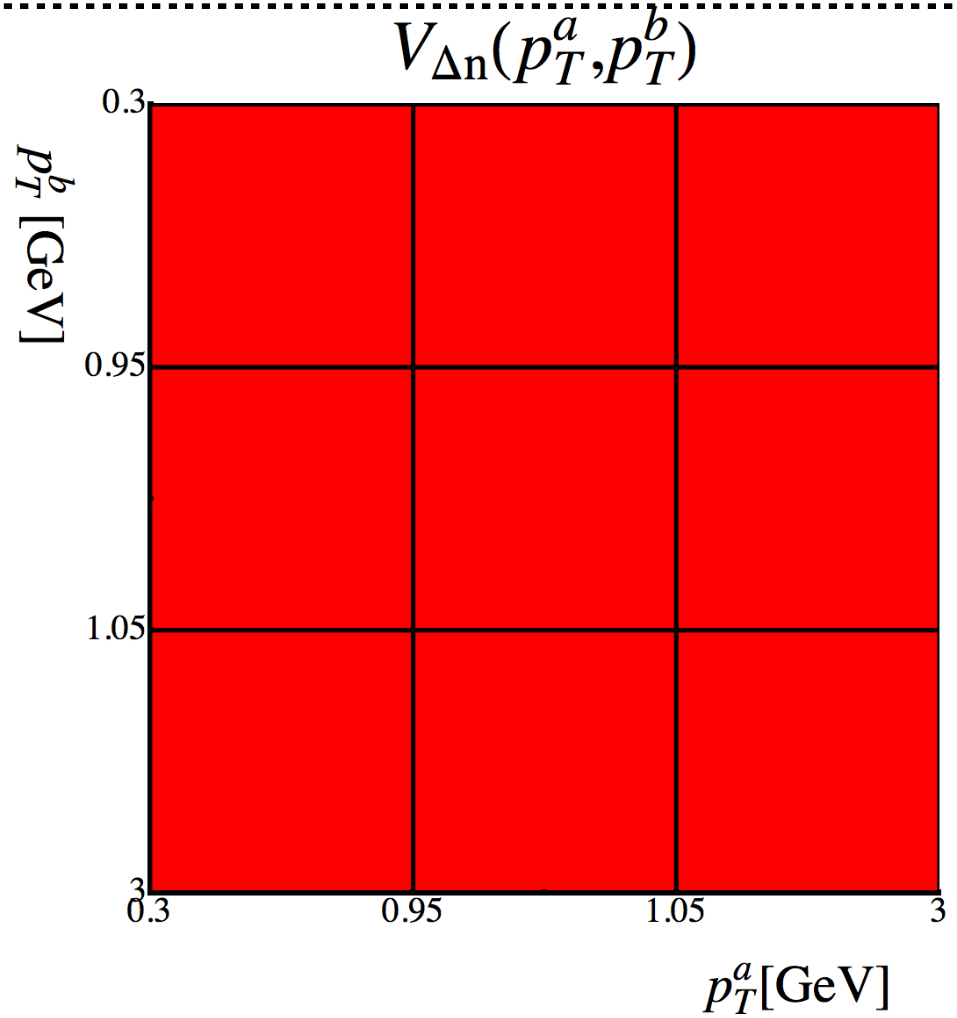

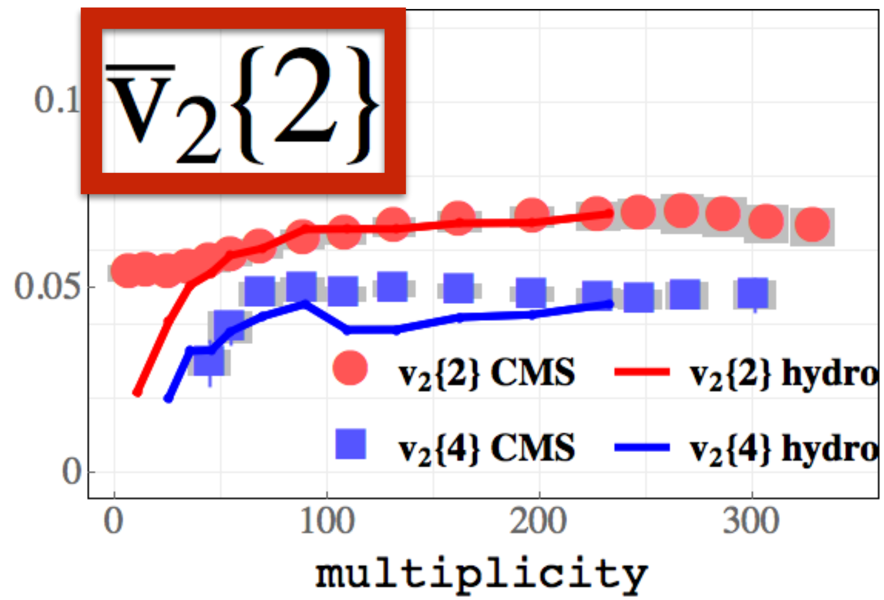

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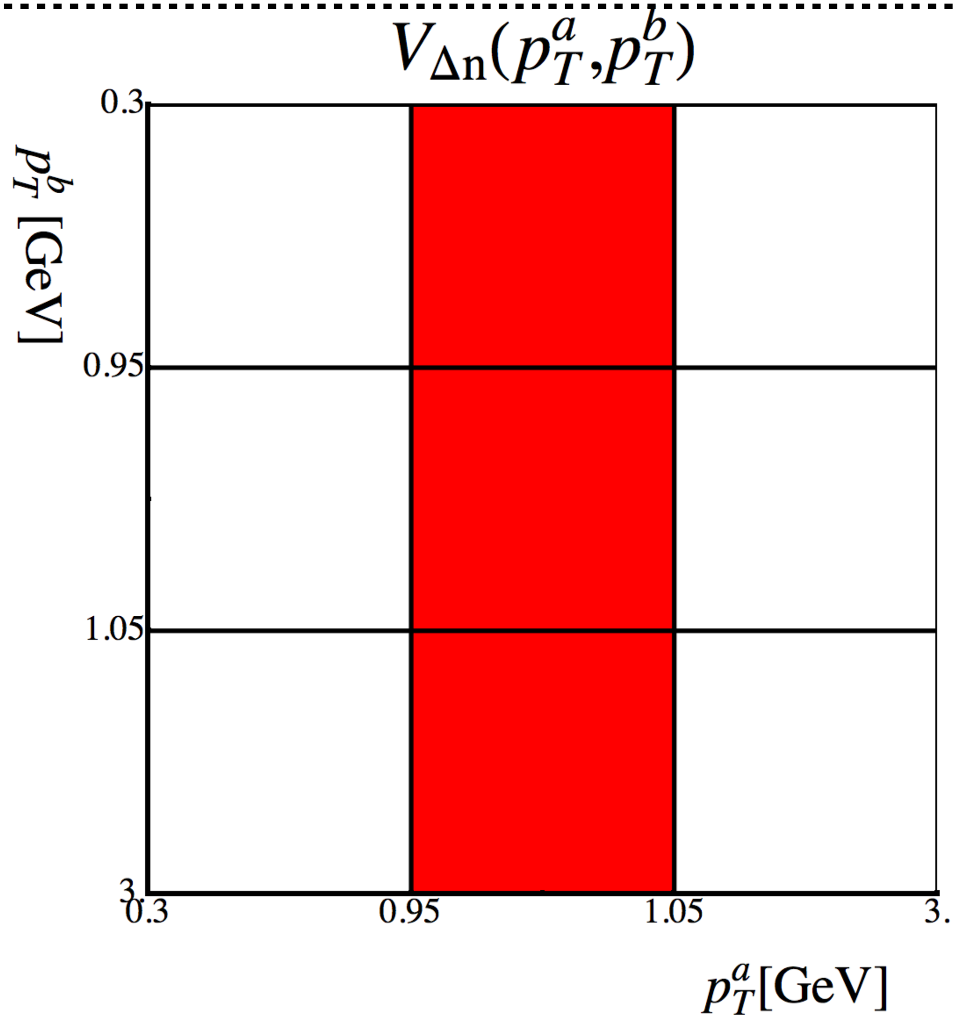
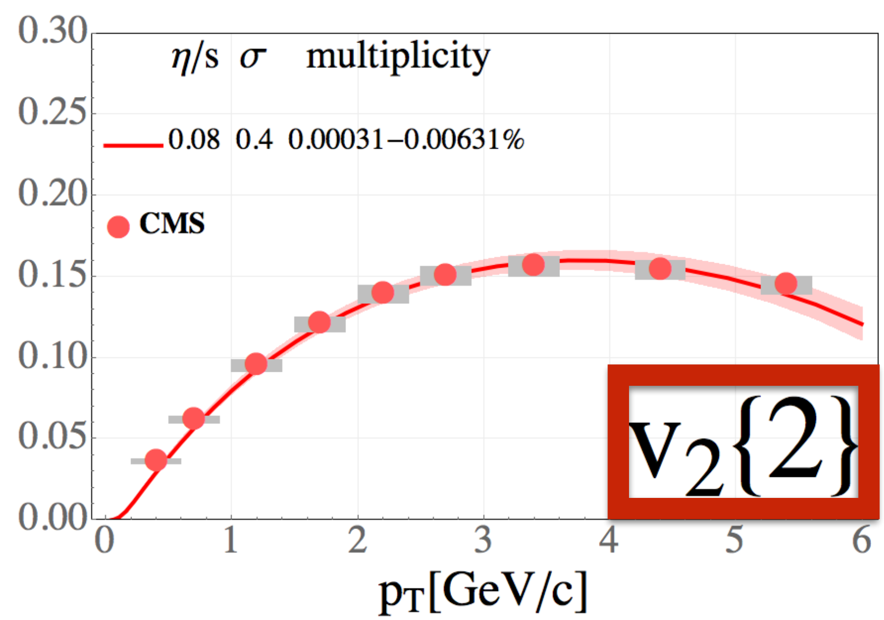




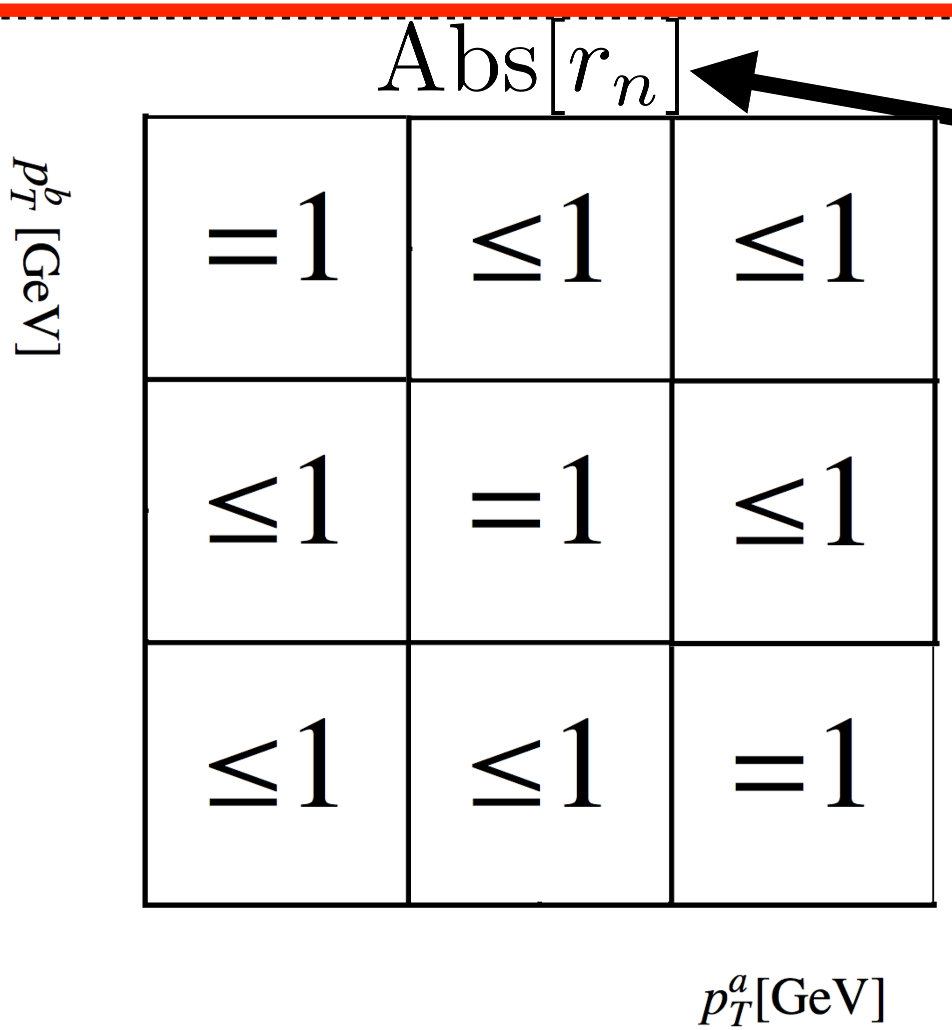
Two-particle correlation in hydro

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:

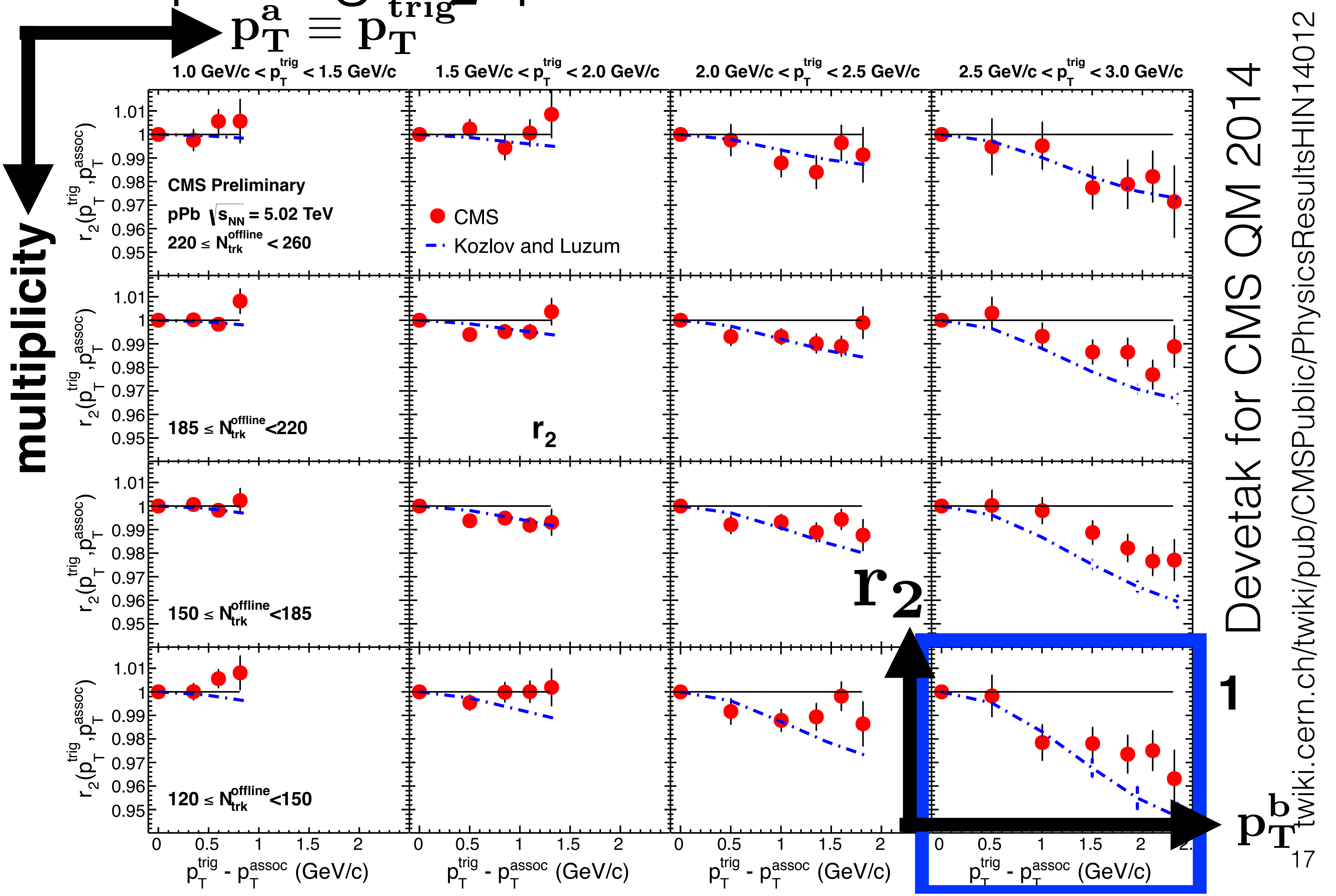
$$\frac{dN_{pairs}}{d^3p^a d^3p^b} \overset{\text{(flow)}}{=} \frac{dN}{d^3p^a} \times \frac{dN}{d^3p^b}$$

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

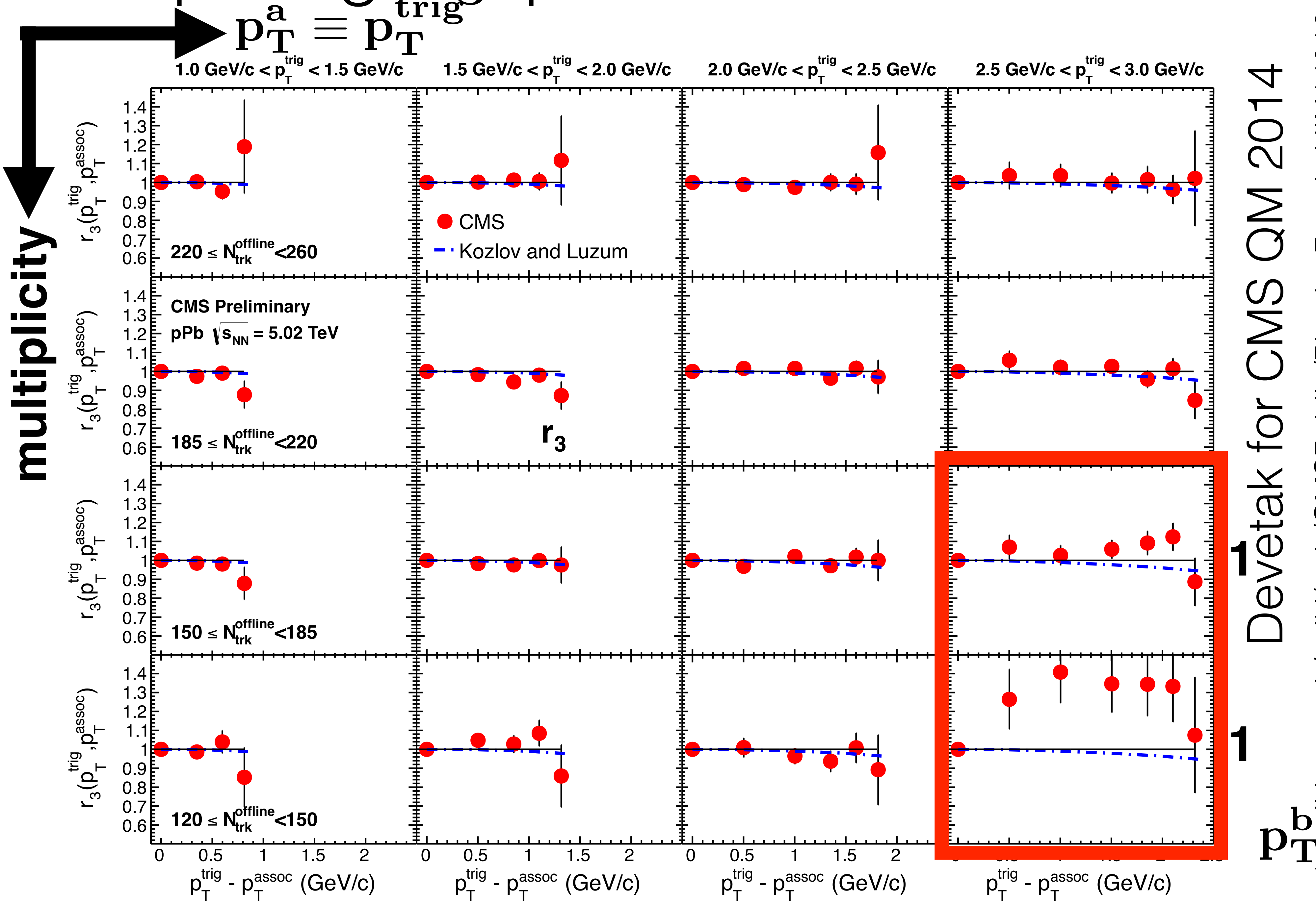
$$V_{n\Delta}(p_T^a, p_T^b)^2 \leq V_{n\Delta}(p_T^a, p_T^a)V_{n\Delta}(p_T^b, p_T^b)$$

Gardim, Grassi, Luzum, Ollitrault 1211.0989

Comparing r_2 predictions to CMS data



Comparing r_3 predictions to CMS data



Devetak for CMS QM 2014

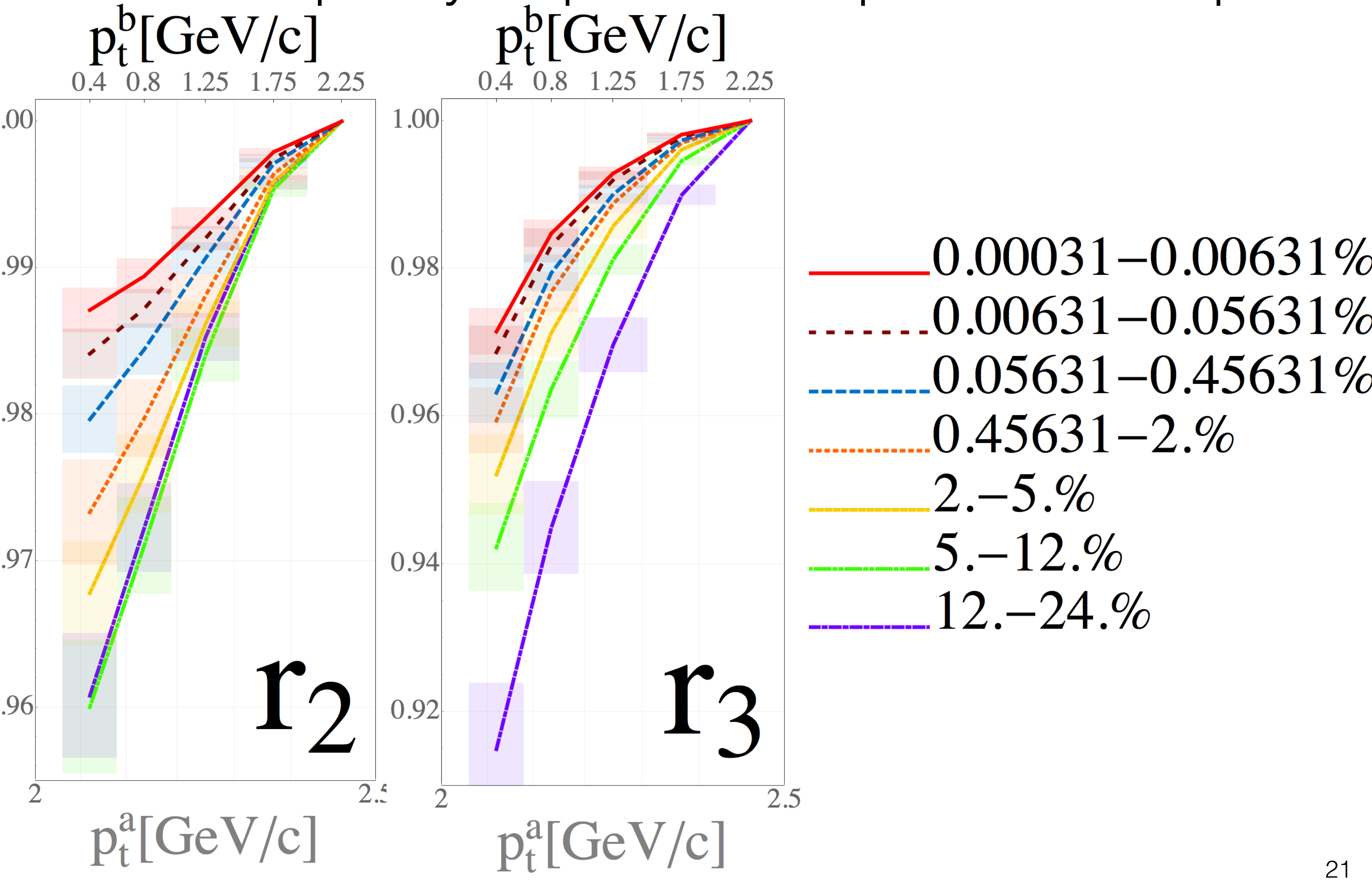
twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsHIN14012

Section conclusions

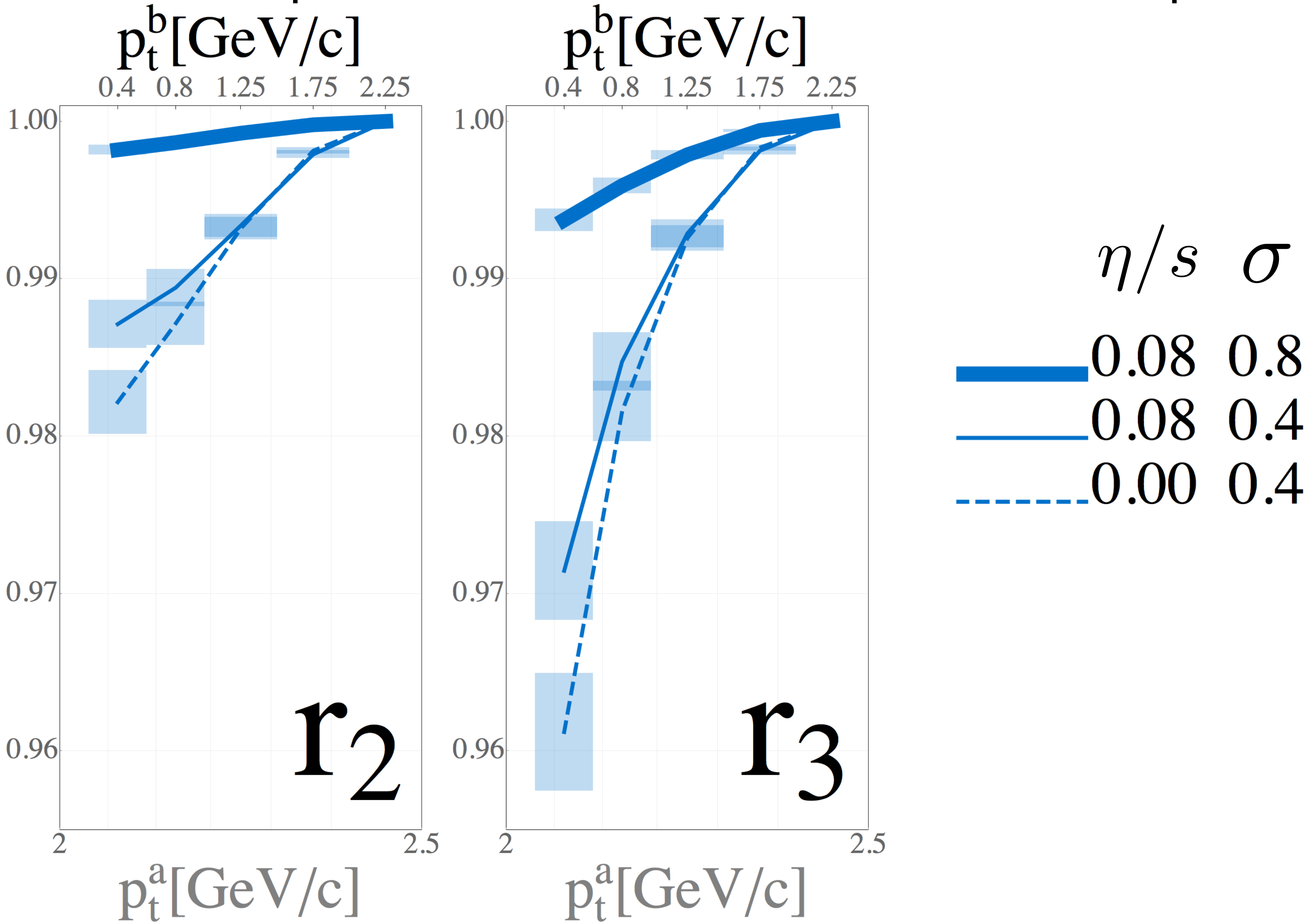
- Hydrodynamics can reasonably describe a wide range of flow observables for pPb system at high multiplicity $v_2\{2\}, v_3\{2\}, v_2\{4\}$ and r_n

Another handle to study HIC

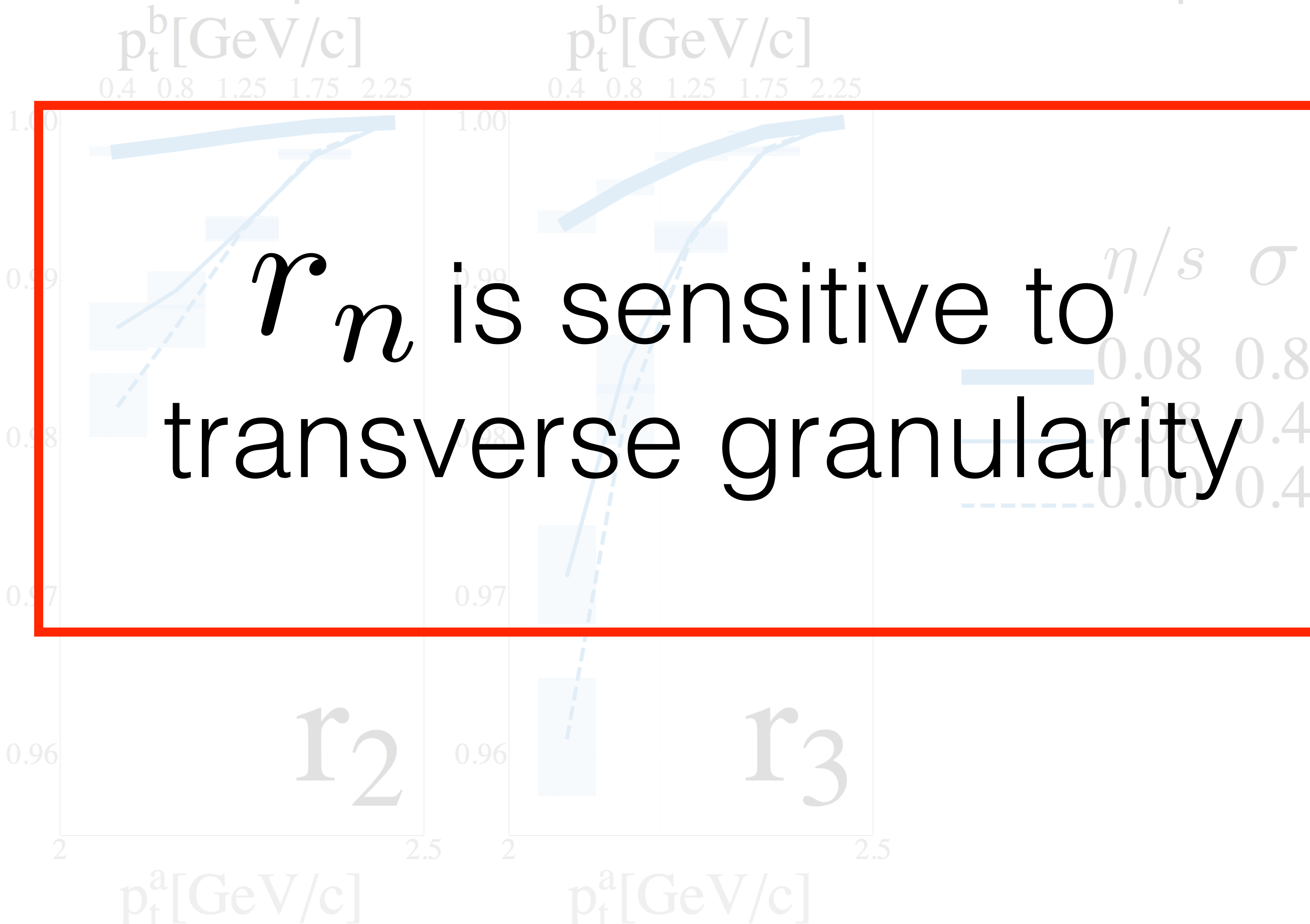
multiplicity dependence prediction in pPb



r_n dependence on σ and η/s in pPb

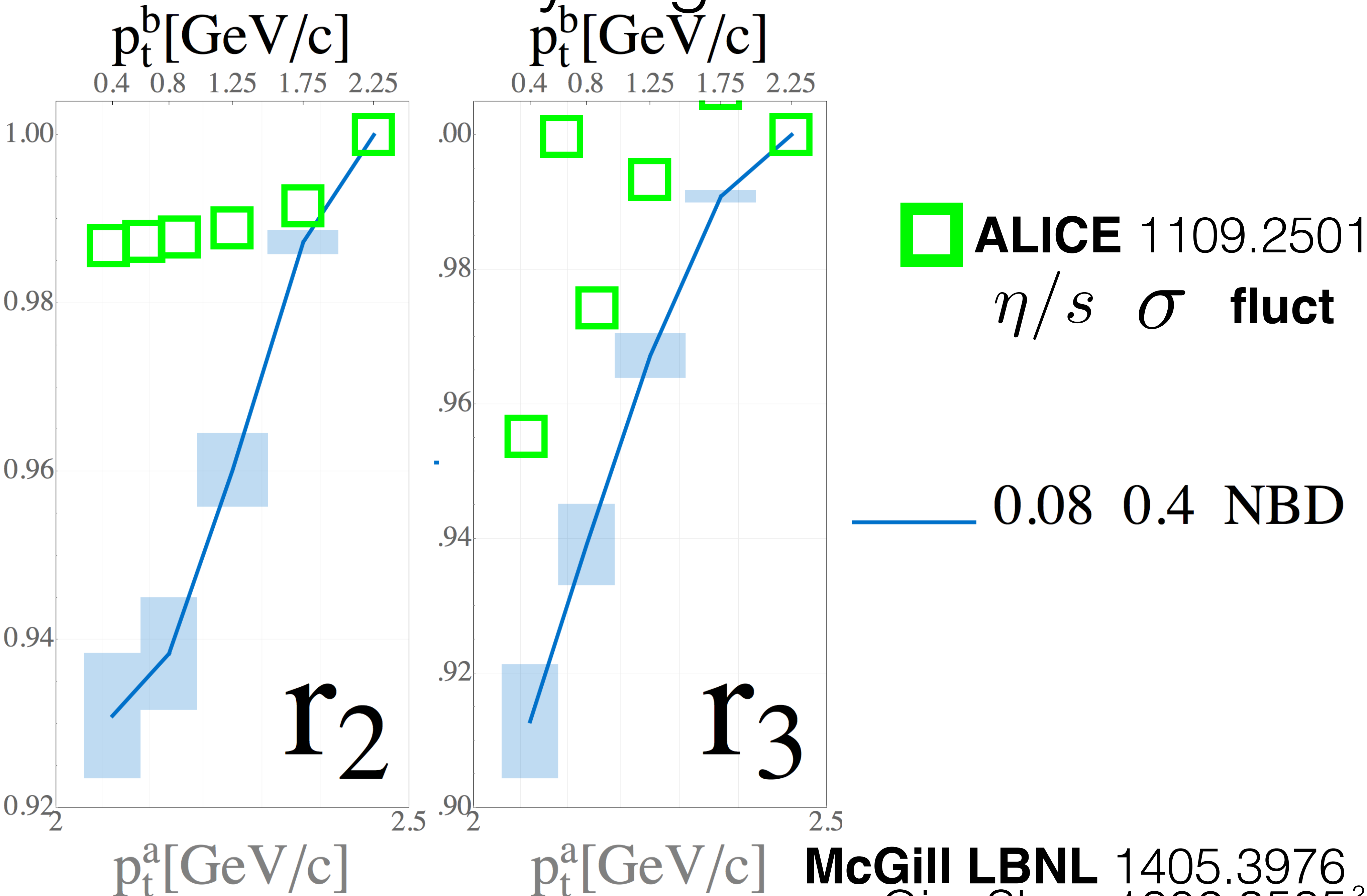


r_n dependence on σ and η/s in pPb



r_n is sensitive to transverse granularity

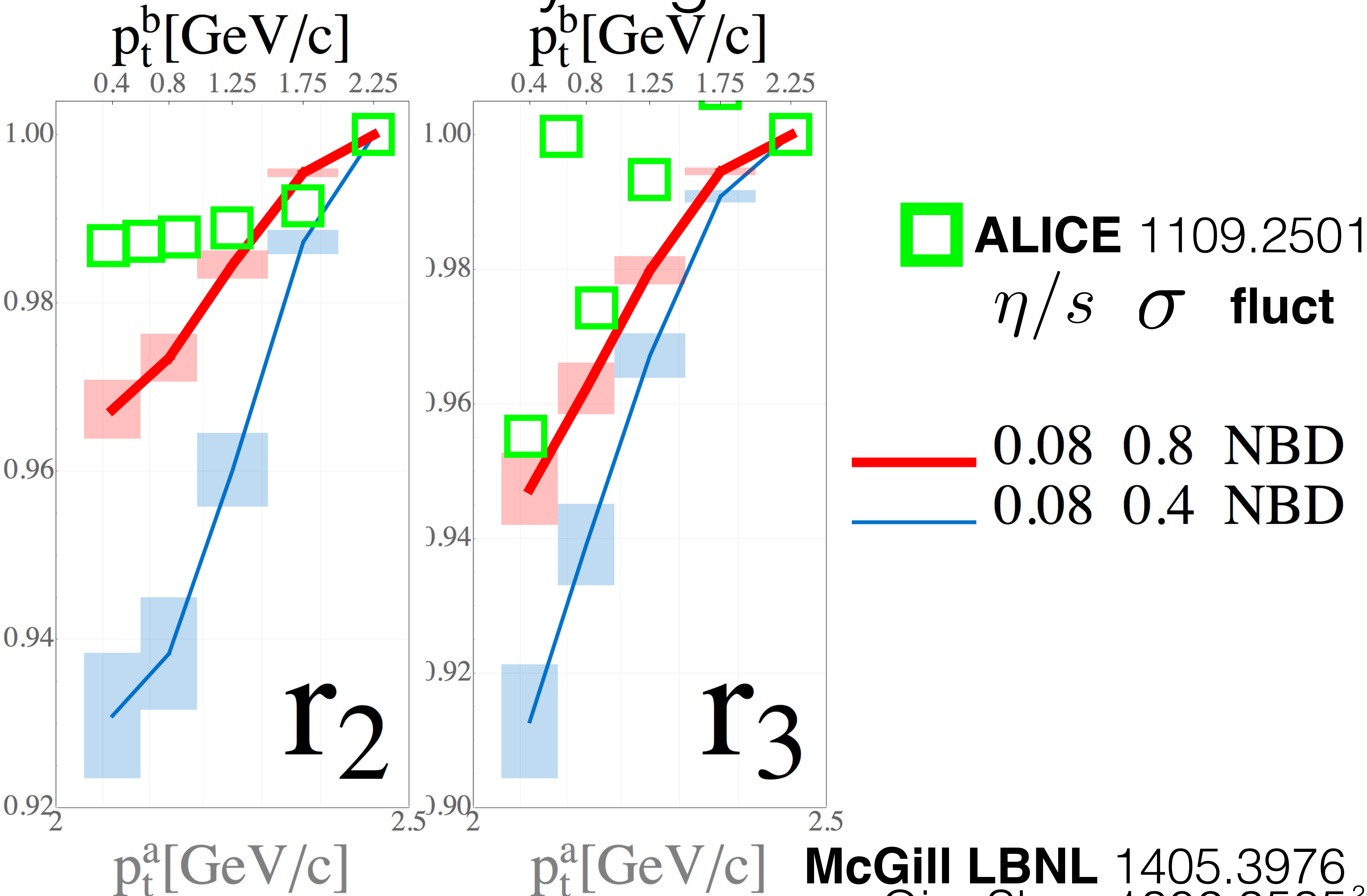
Reanalyzing PbPb data



McGill LBNL 1405.3976

Heinz, Qiu, Shen 1302.3535

Reanalyzing PbPb data



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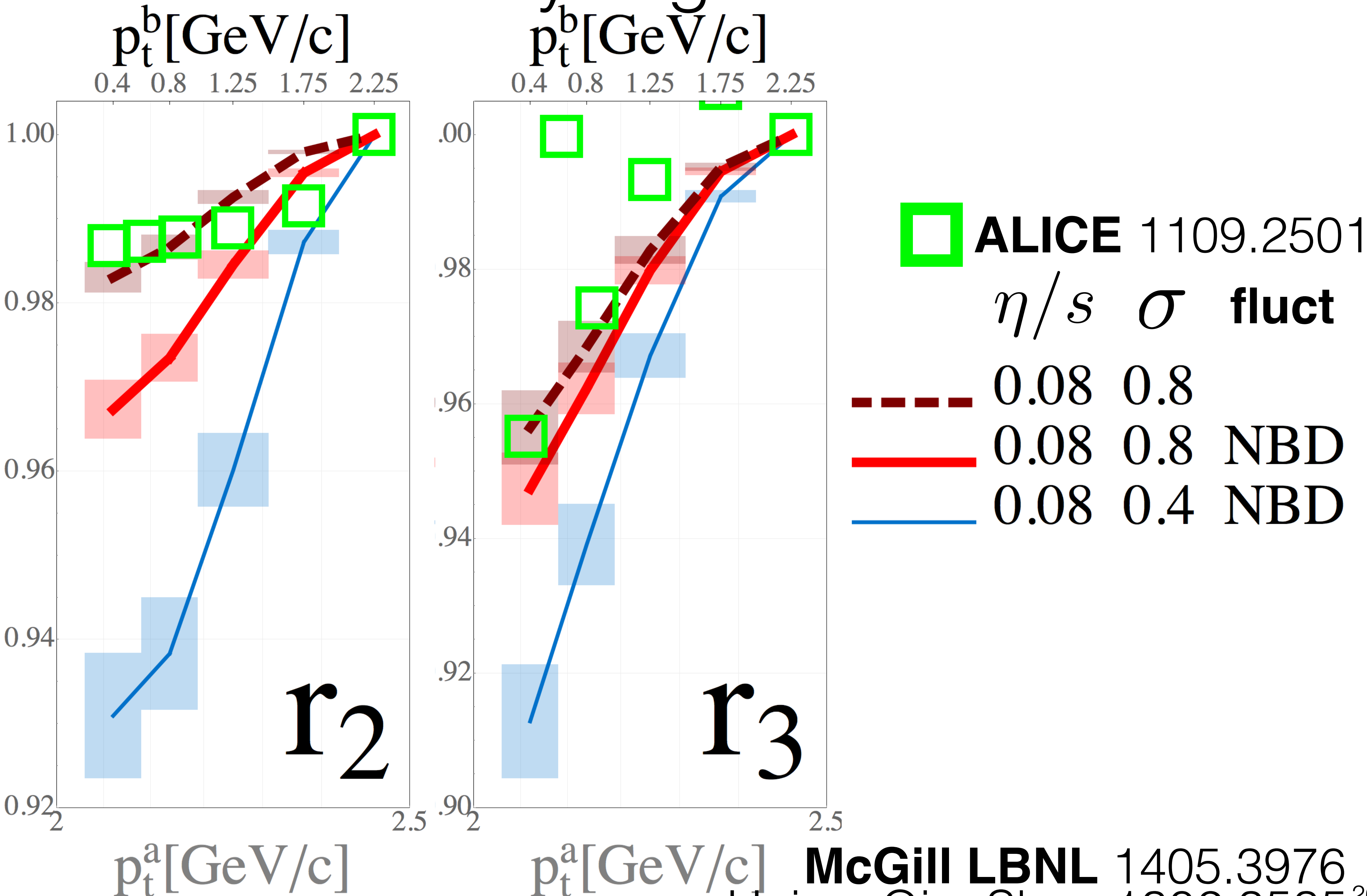


McGill LBNL 1405.3976
Heinz, Qiu, Shen 1302.3535

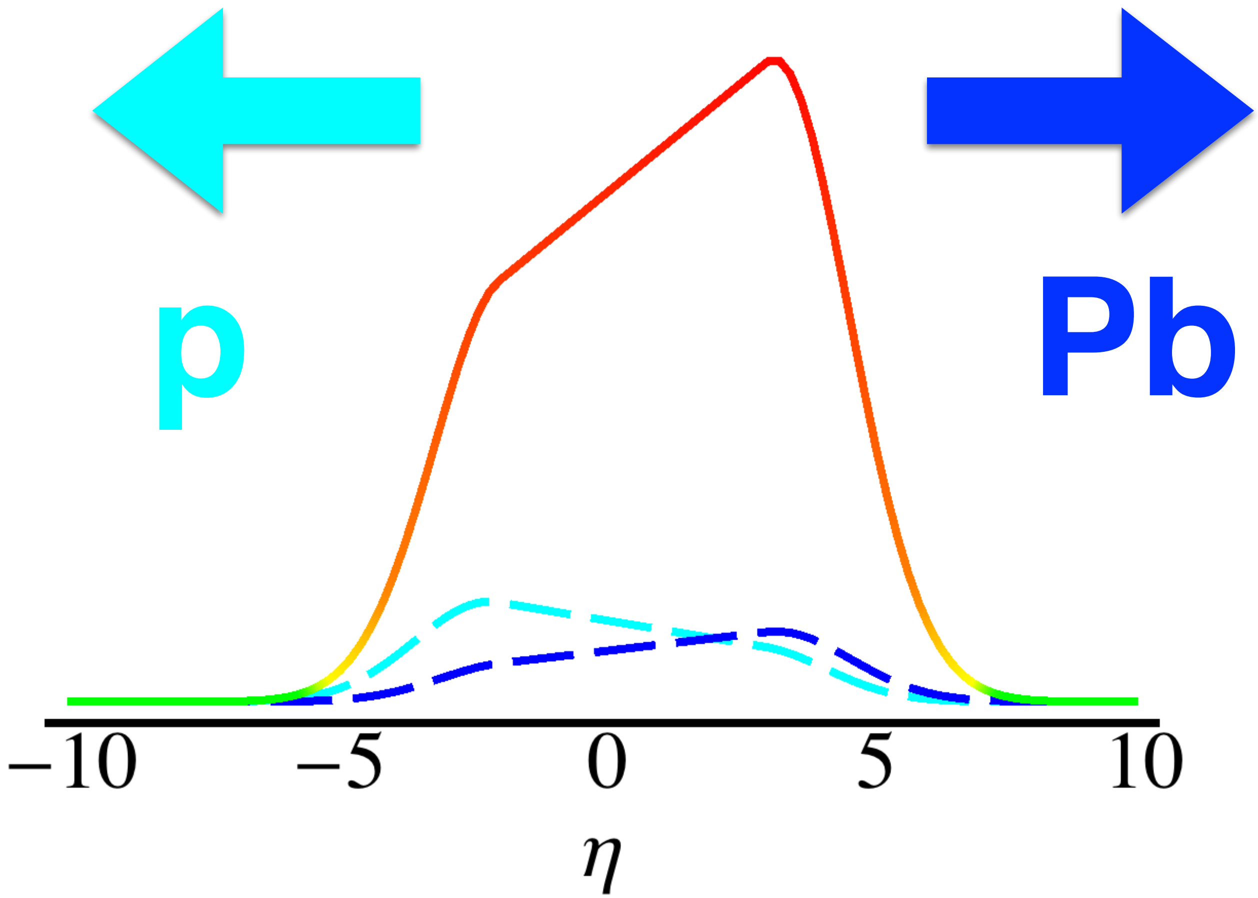
Conclusion

- 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

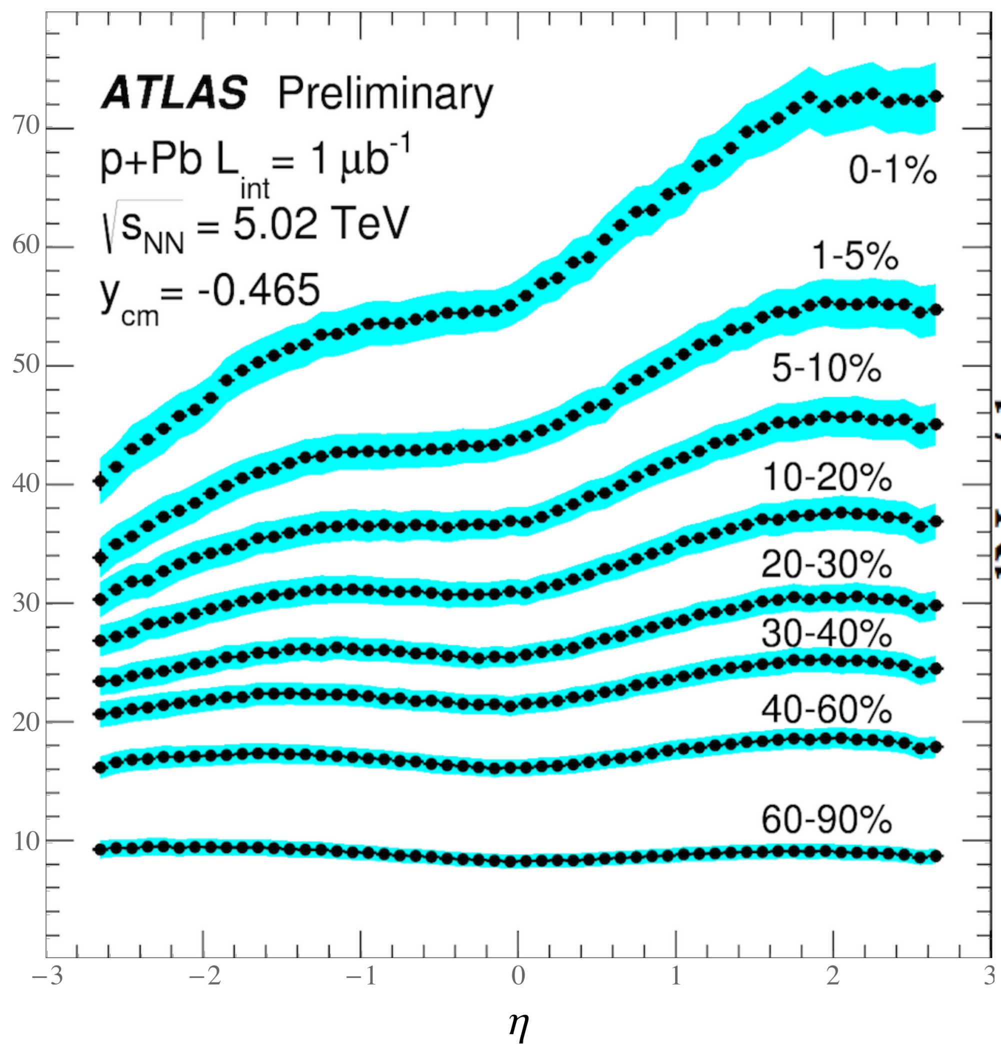


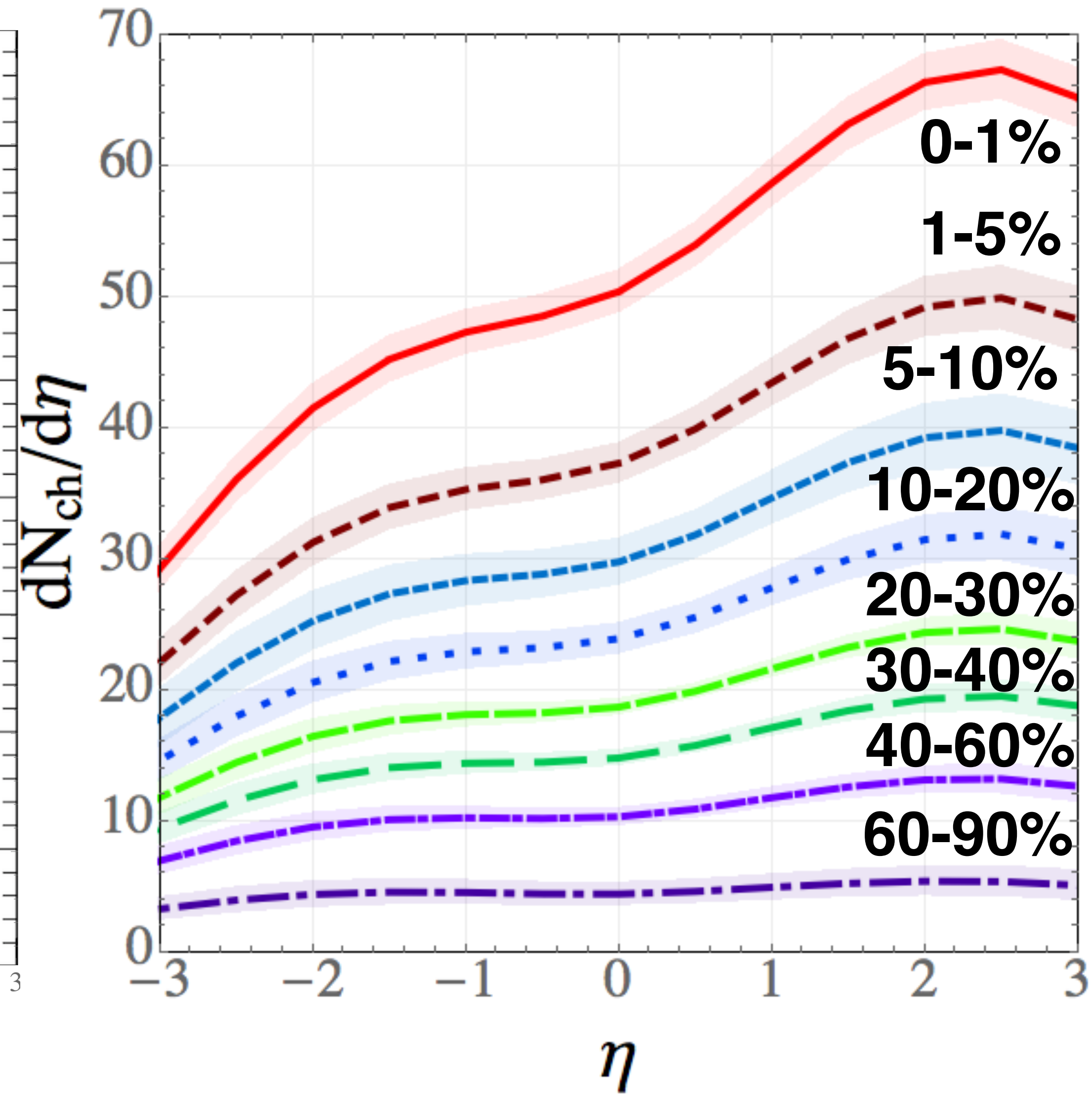
$$\left(1 \pm \frac{\eta}{y_{\mathrm{beam}}}\right) \exp\left(-\frac{(|\eta|-\eta_0)^2}{2\sigma_\eta^2}\theta(|\eta|-\eta_0)\right)$$

Bozek, Wyskiel 1002.4999

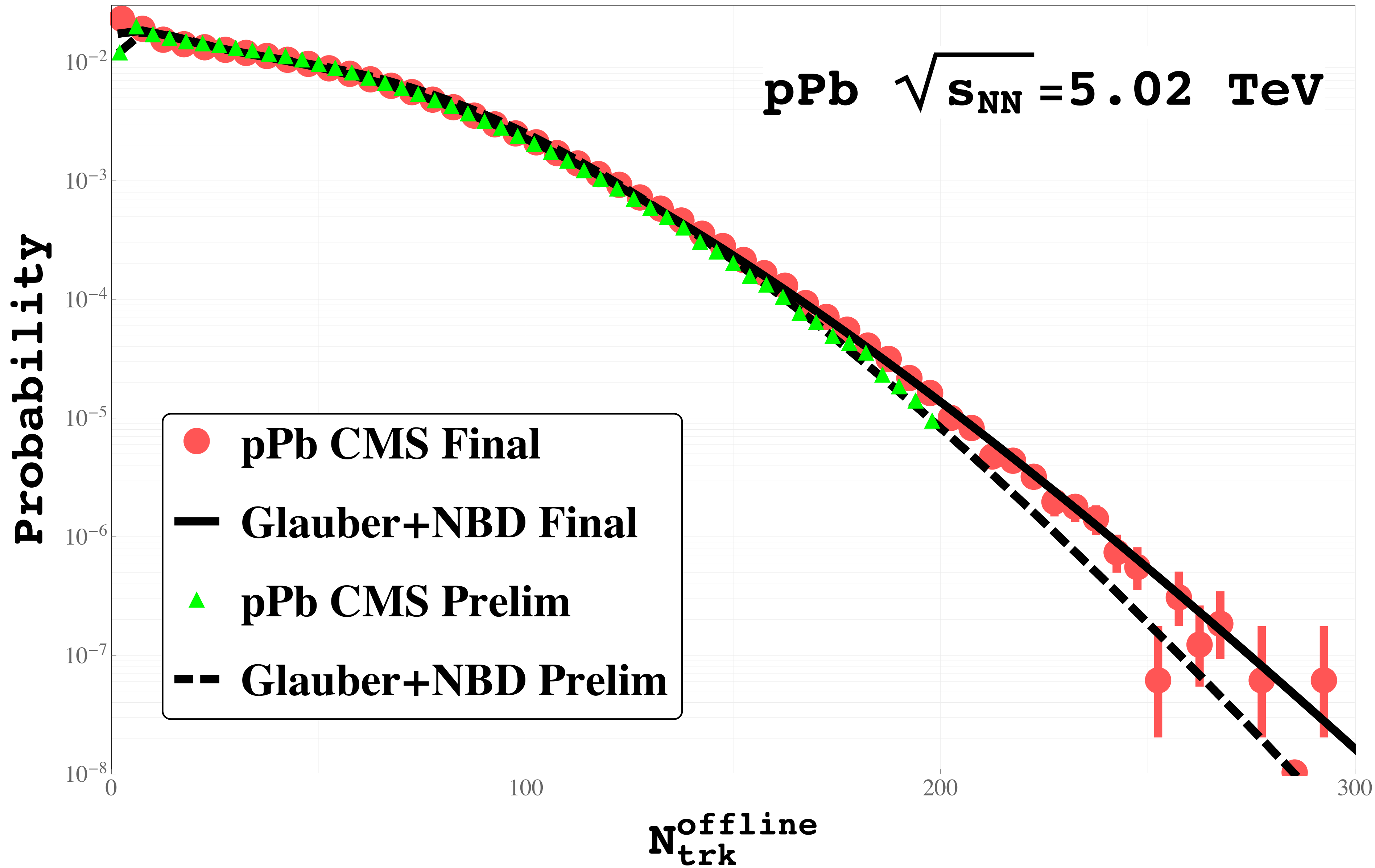
Pseudorapidity distribution

ATLAS arXiv/1403.5738



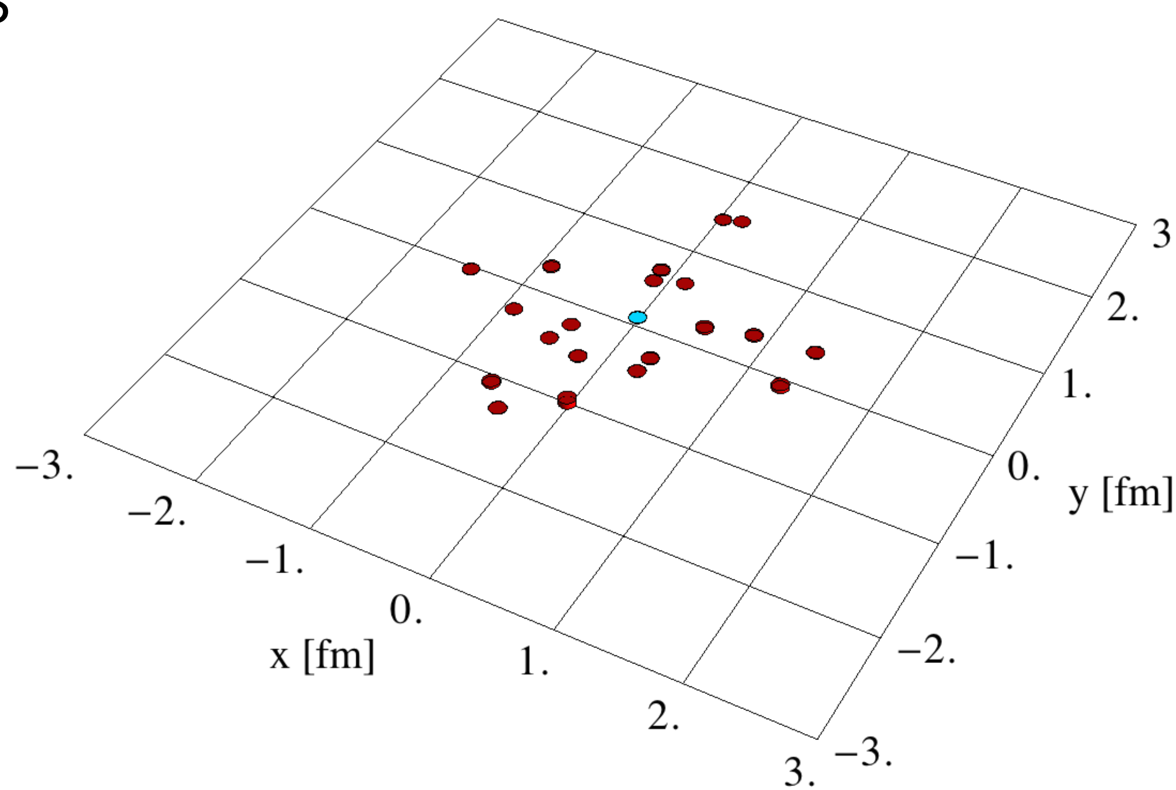


Initial conditions: Glauber+NBD



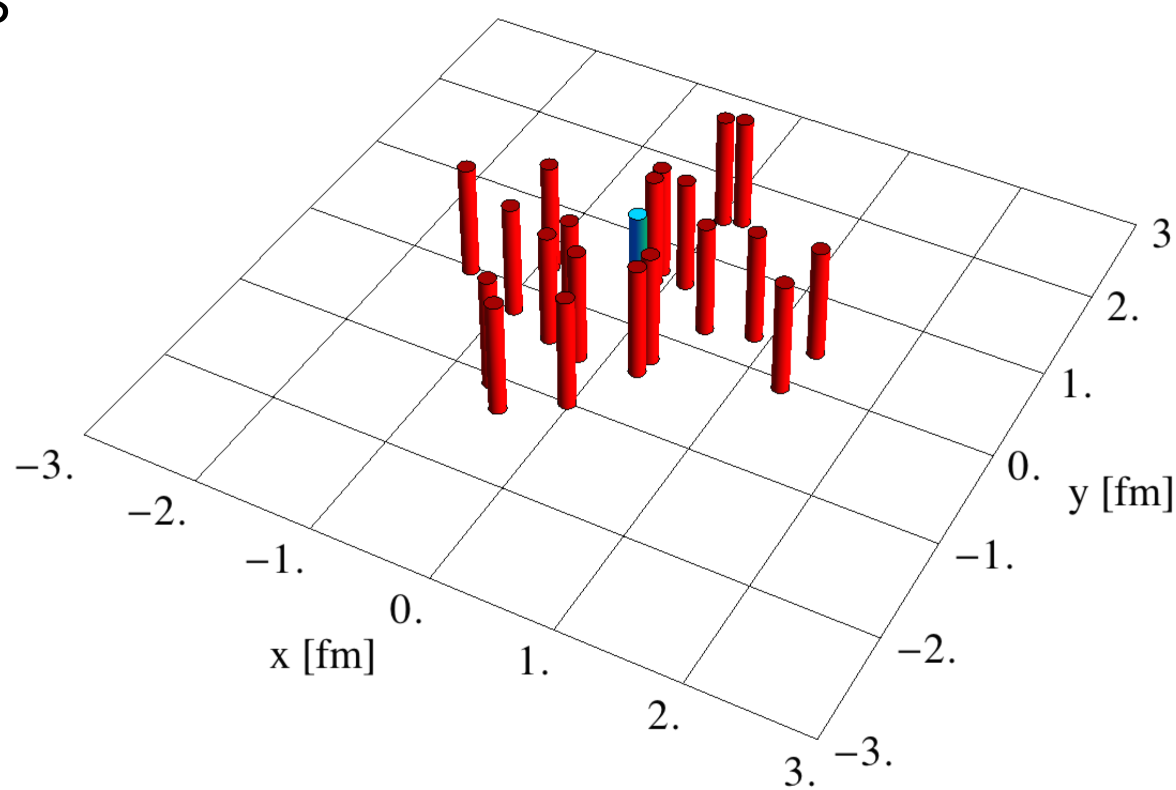
Initial conditions: Glauber

- sample participants



Initial conditions: Glauber

- sample participants
- add sources

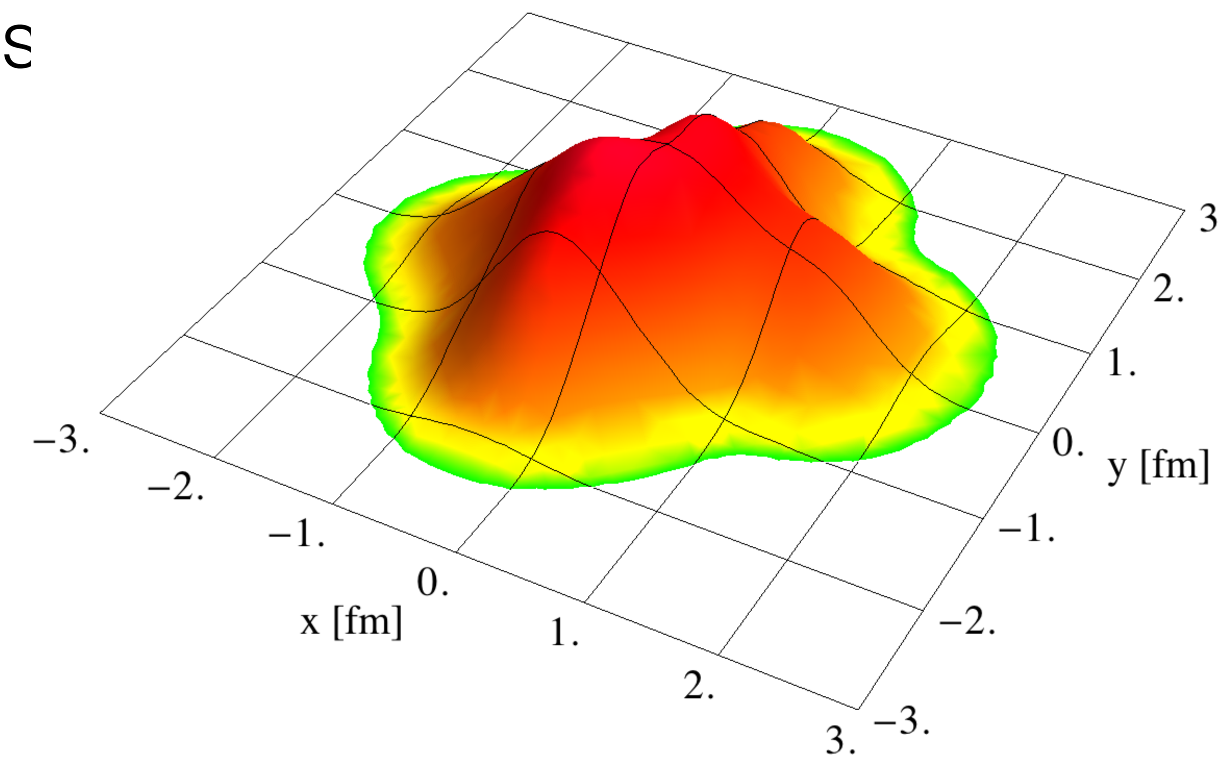


Initial conditions: Glauber

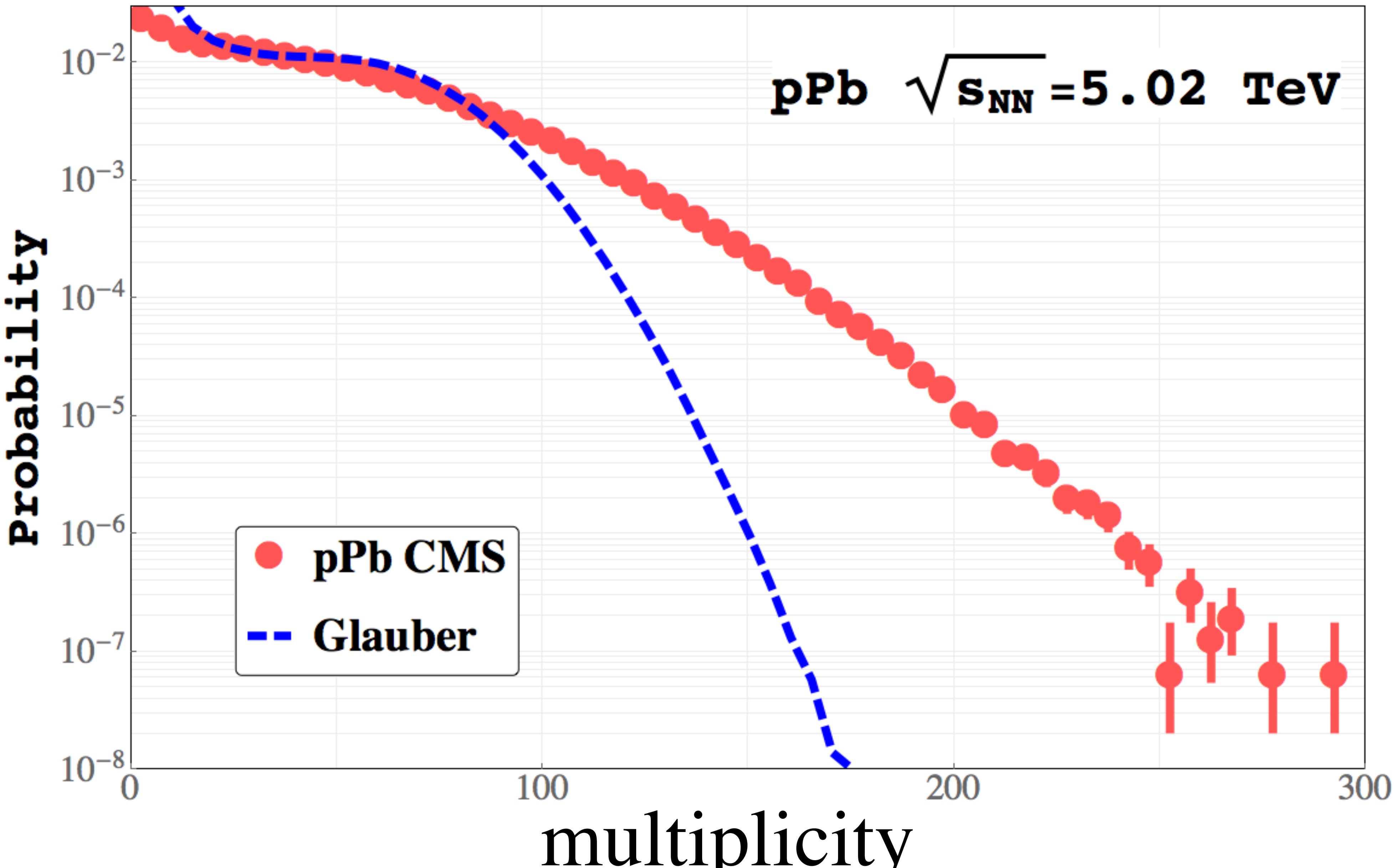
$$\sigma = 0.40 \text{ fm}$$

- sample participants
- add sources

- increase σ



Glauber+NBD



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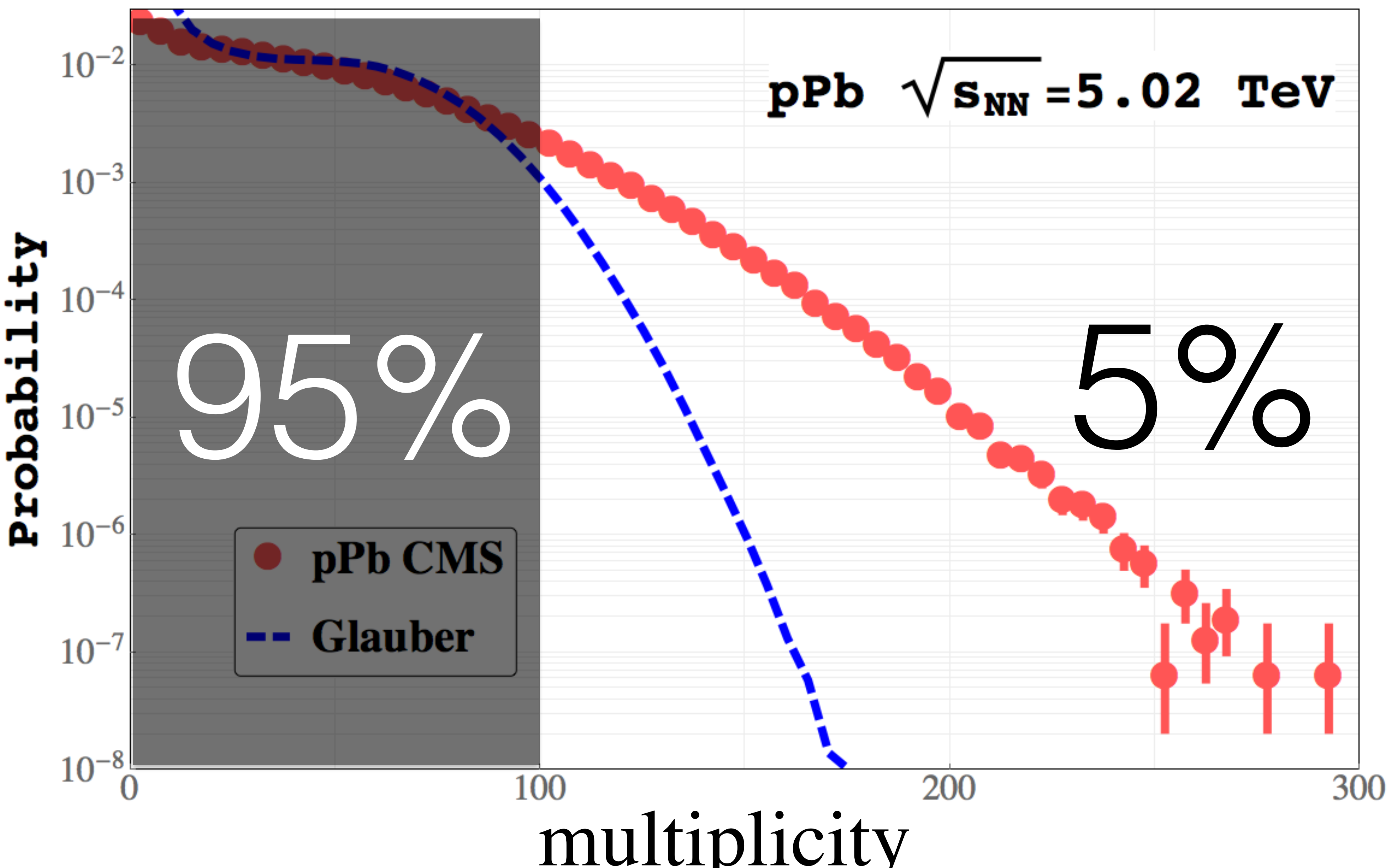
Glauber+NBD



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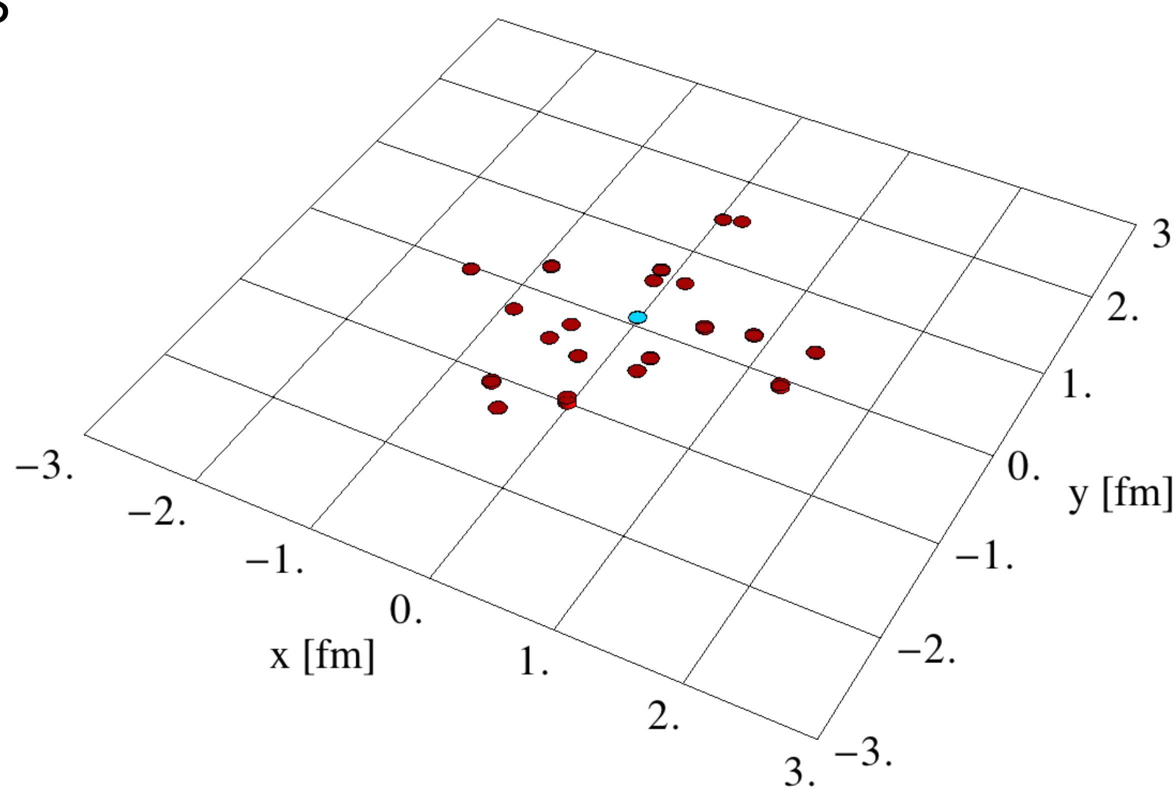

Initial conditions: Glauber+NBD

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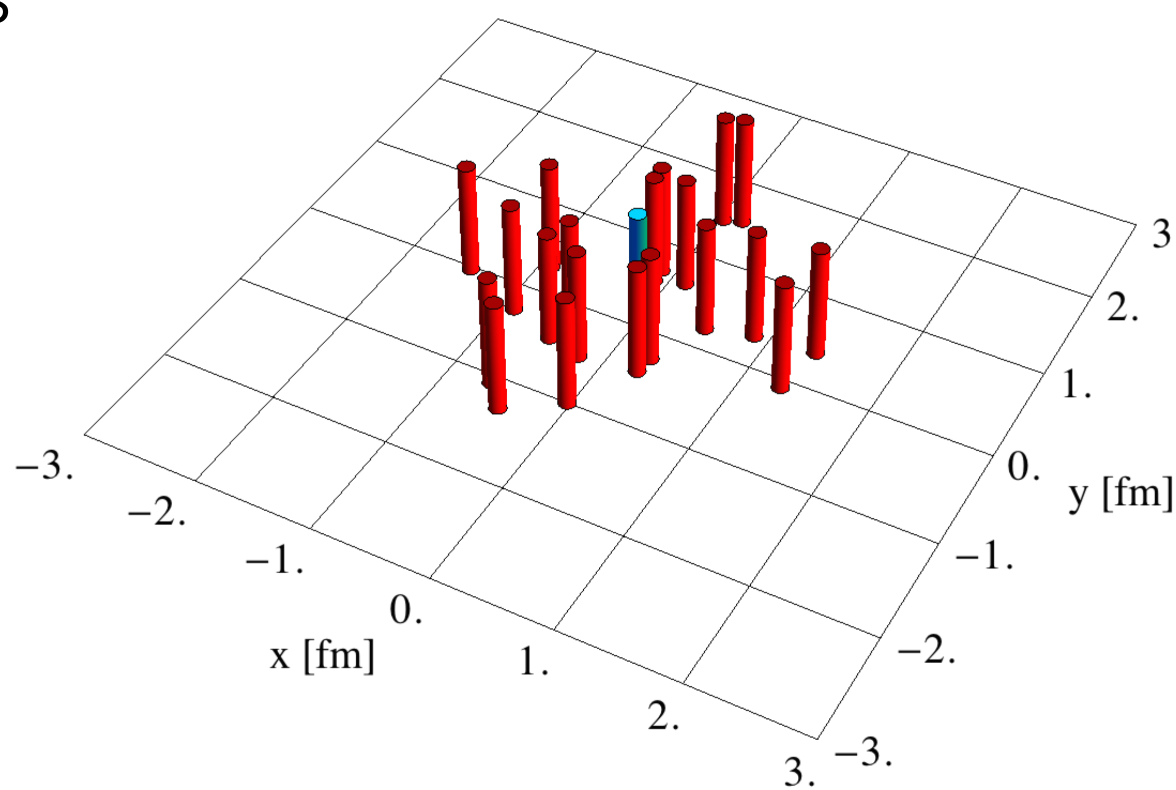
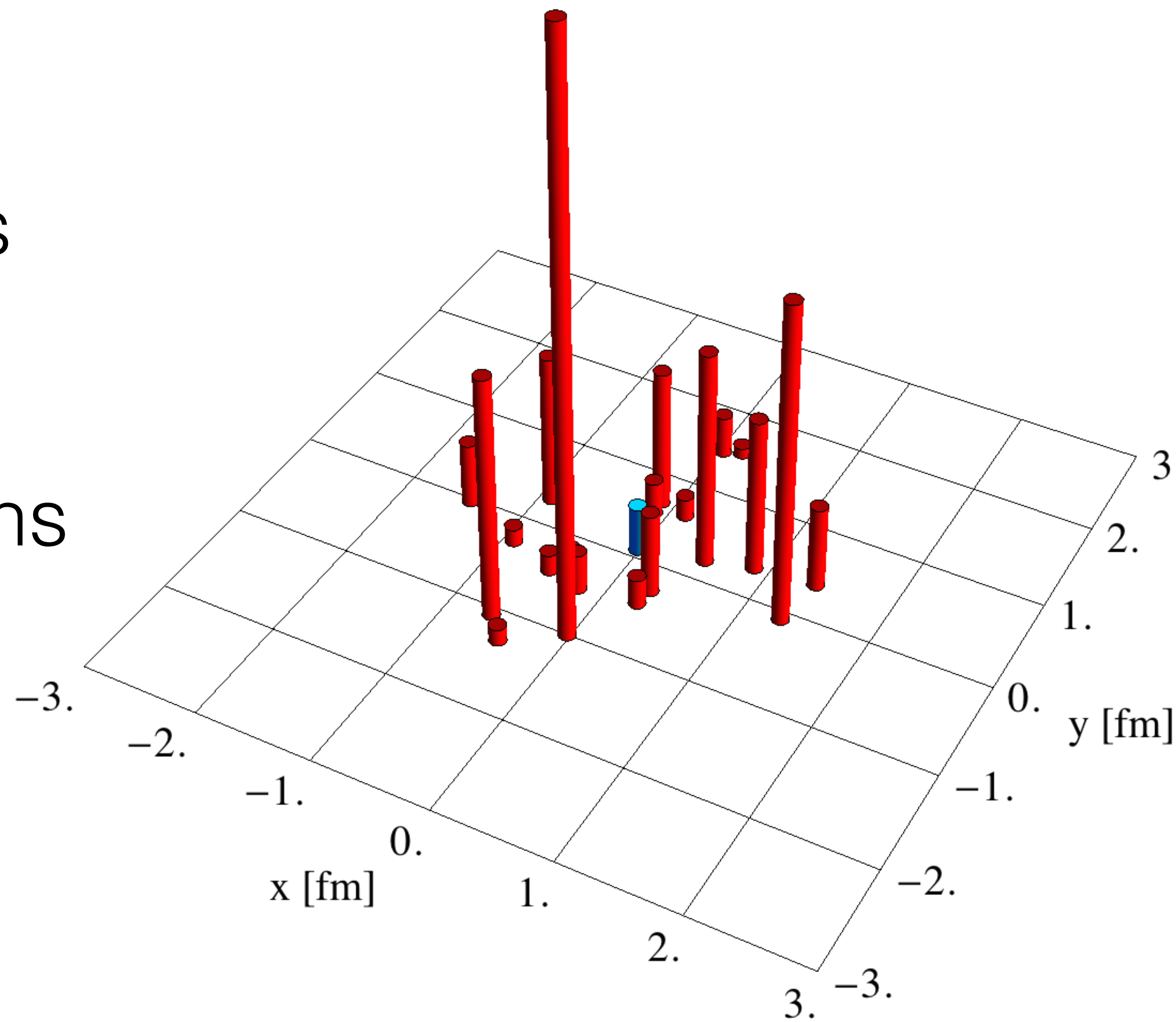


Initial conditions: Glauber+NBD

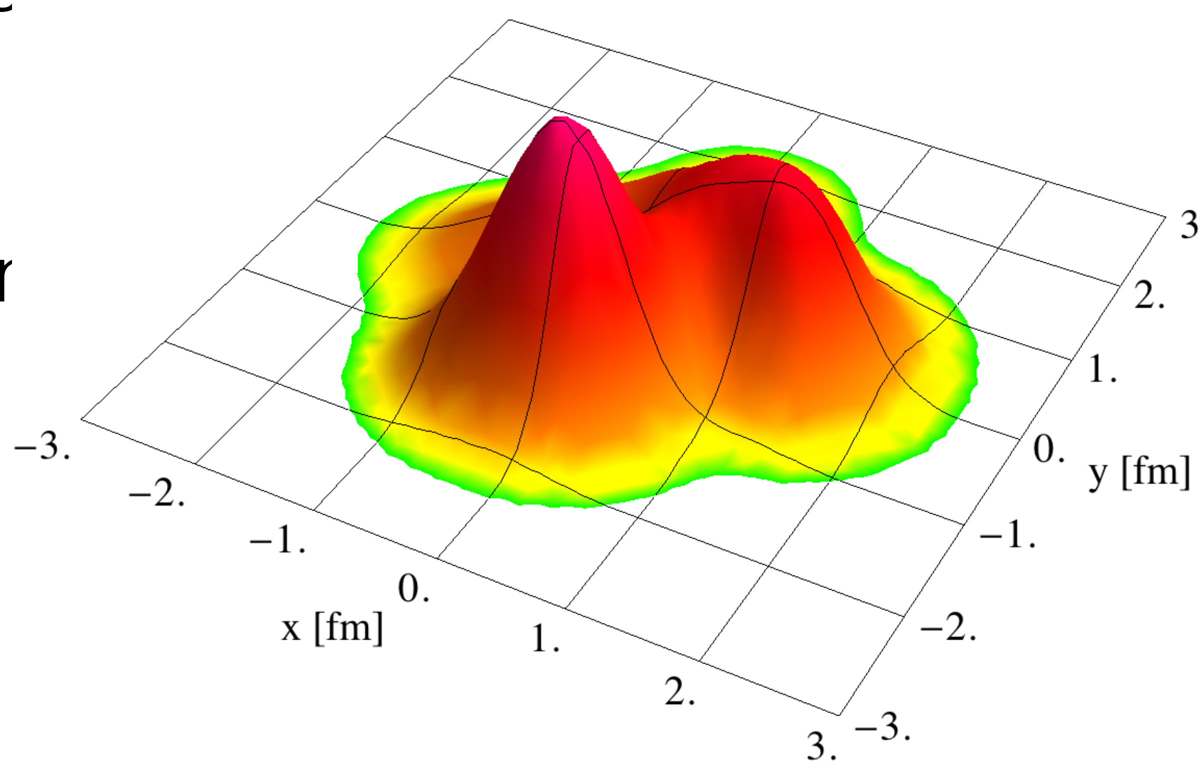
- sample participants
- add sources
- add NBD fluctuations



Initial conditions: Glauber+NBD

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

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



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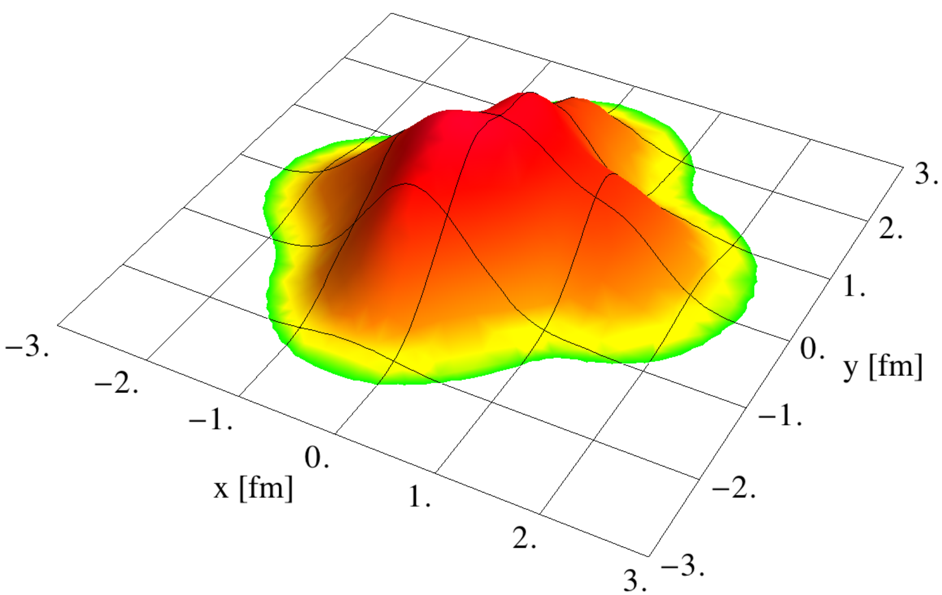
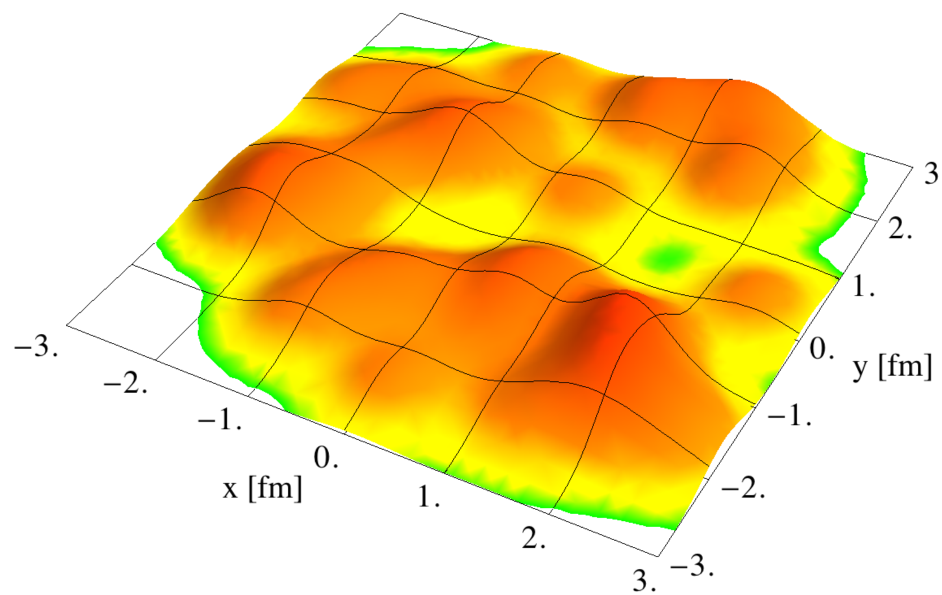


pPb

$\sigma = 0.40$ fm



PbPb

Initial conditions: Glauber+NBD

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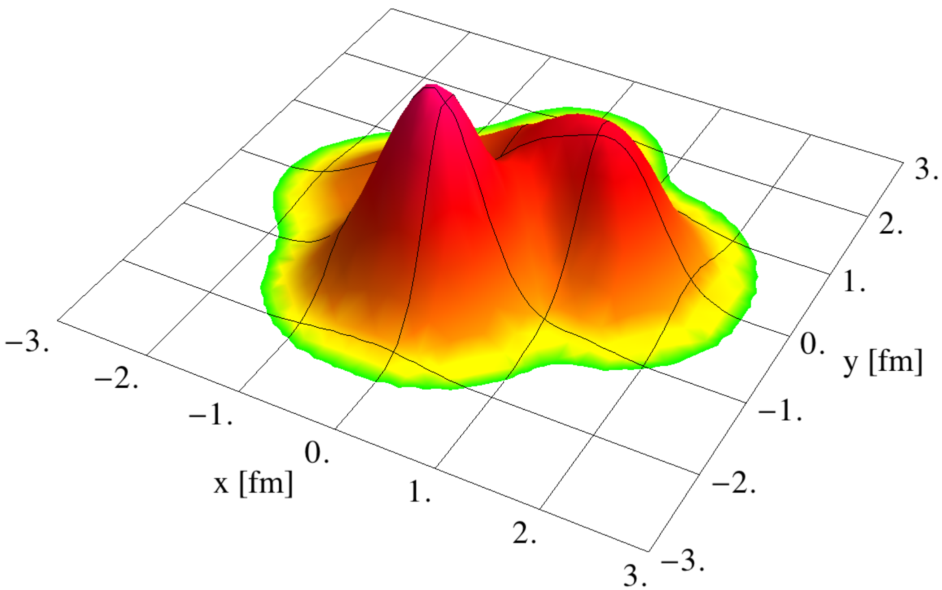

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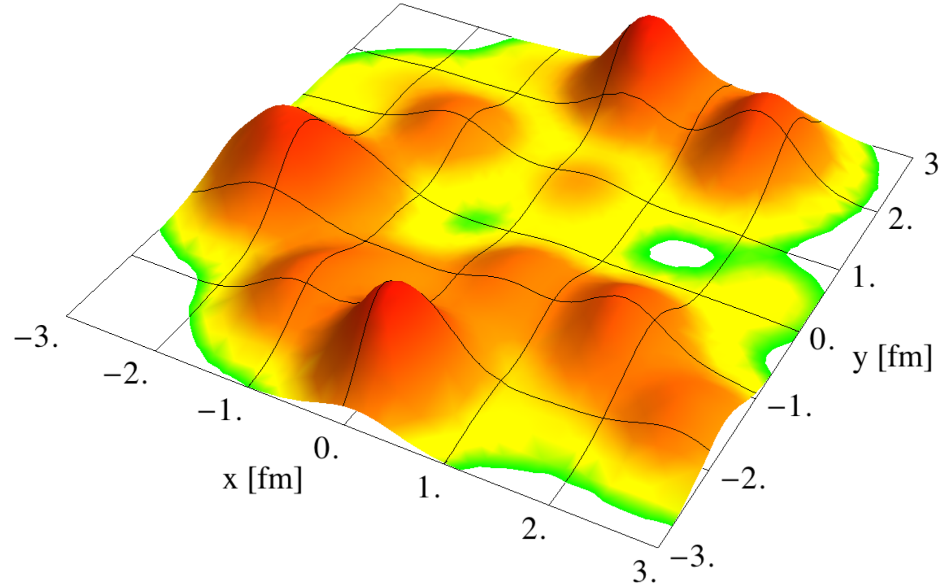
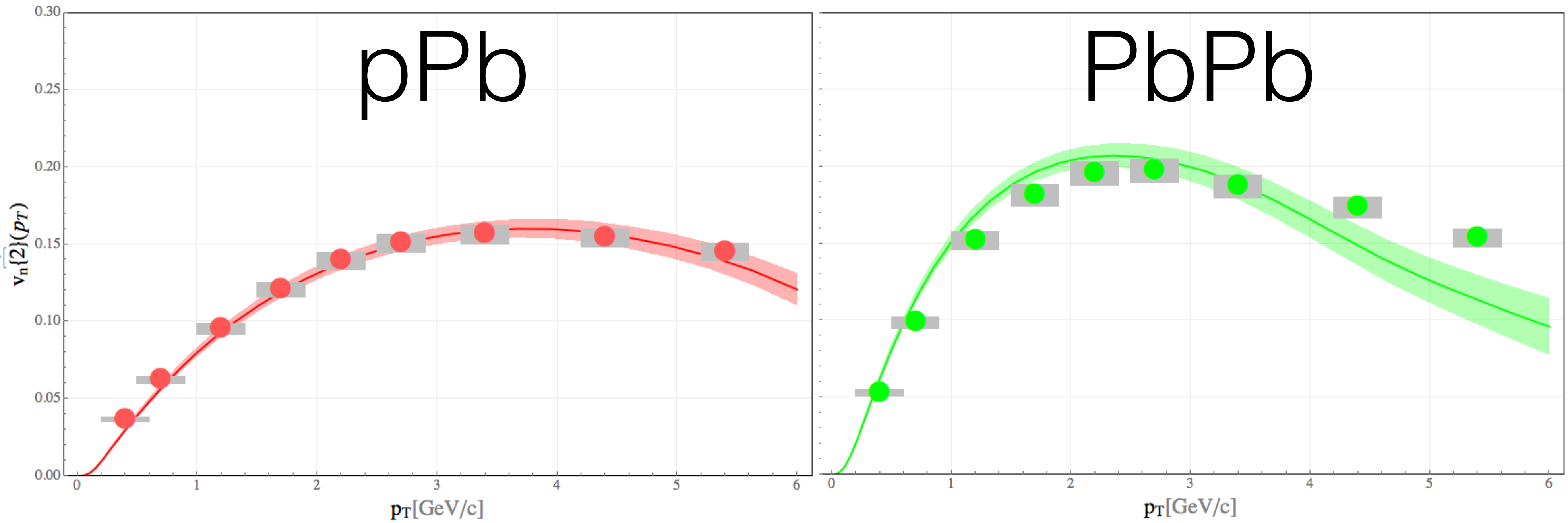
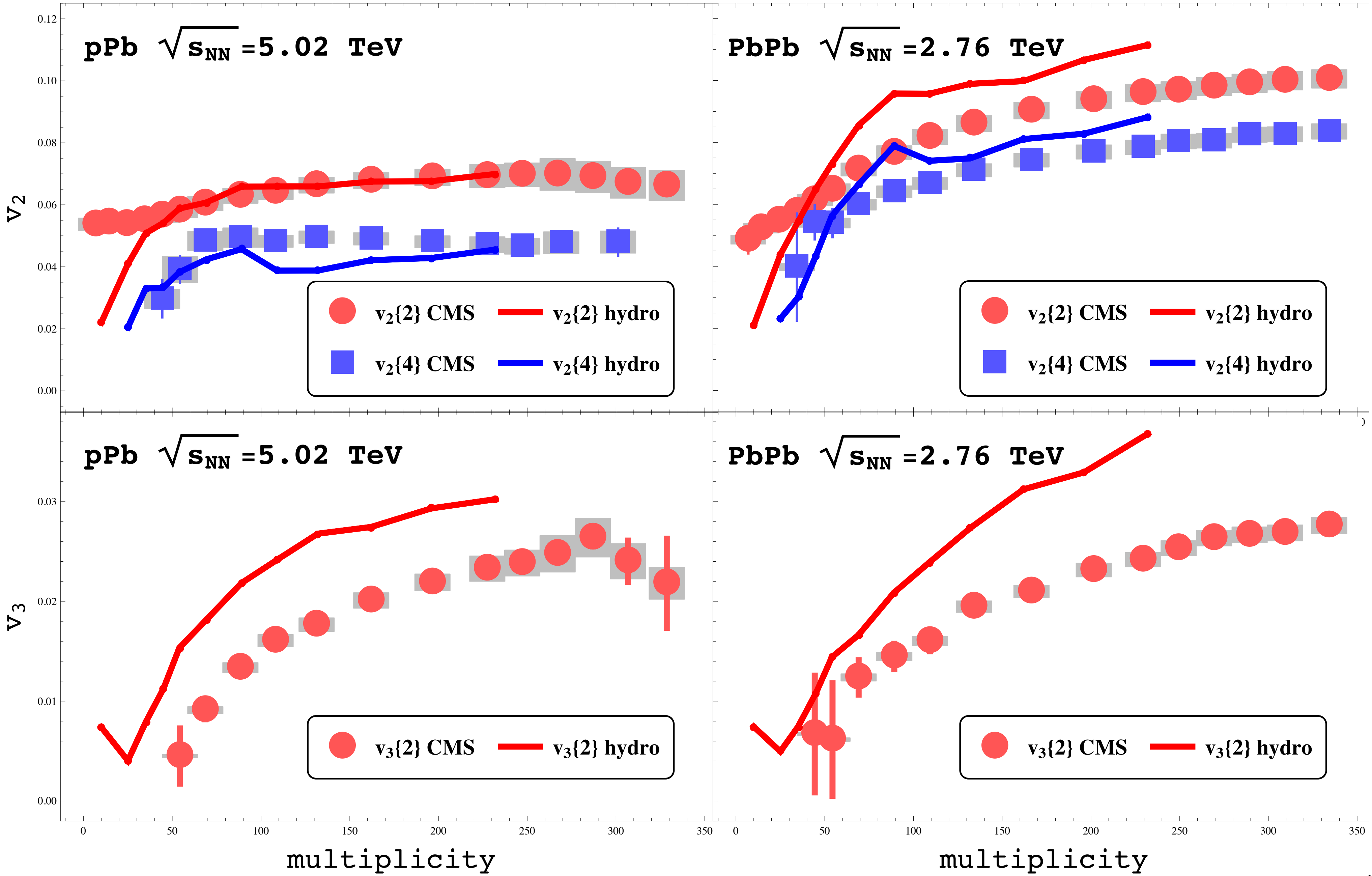


PbPb

Flow observables for pPb and PbPb



Flow observables for pPb and PbPb



experiment:

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

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

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

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

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

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

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

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