

Probing the transverse size of initial inhomogeneities with flow observables

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Work done in collaboration with:

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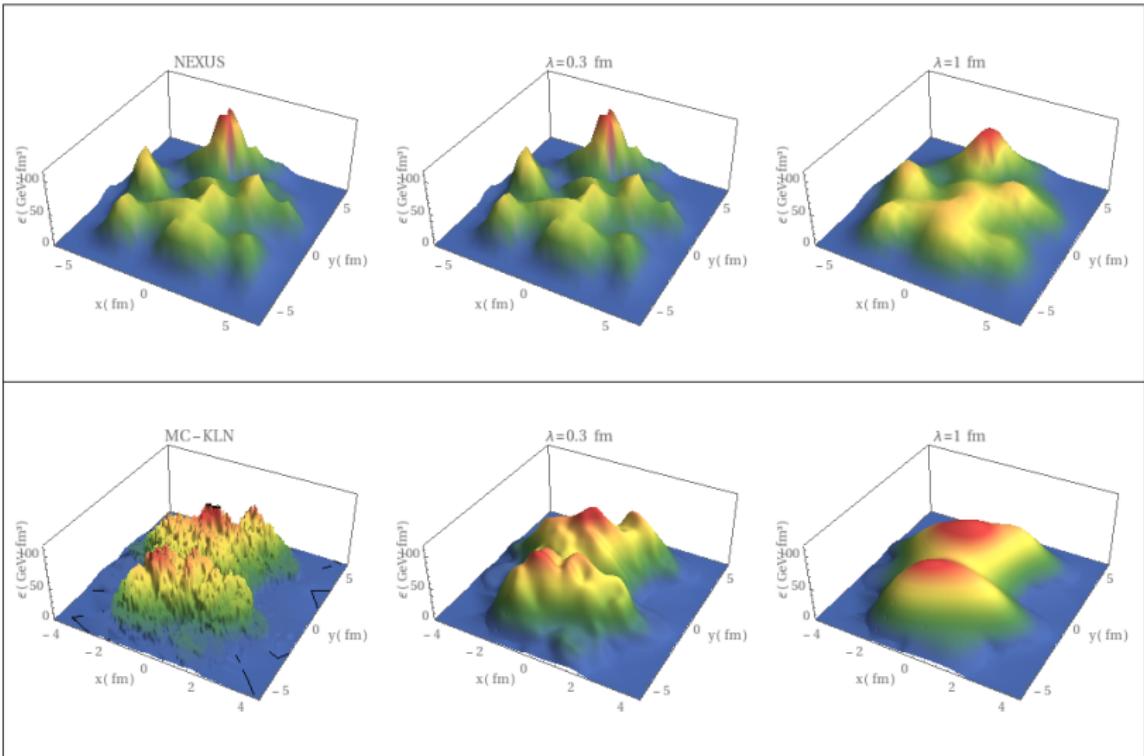
J.Noronha-Hostler (State University of New Jersey-USA).

Based on arXiv:1712.03912, to appear in Phys. Rev. C.

Objective in words

- ▶ Open question: disantangle effects from initial conditions and medium properties.
- ▶ Models of initial conditions have different physics content
⇒ different predictions for hot spot sizes.
- ▶ Question: are these sizes reflected in observables?
- ▶ Method: vary size of hot spots maintaining global properties fixed.

Objective in picture



Observe 1) the different scales for NeXus and MC-KLN
2) how they are smoothed maintaining overall shape
Does this change predictions?

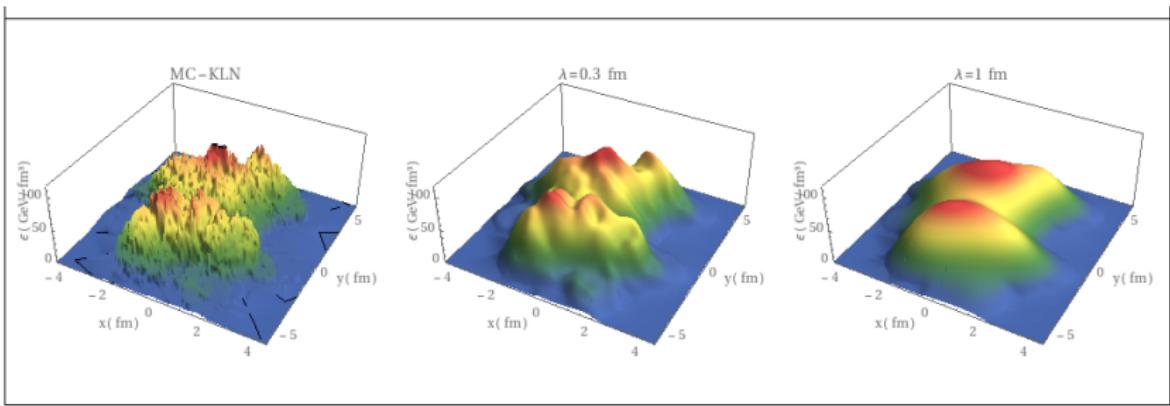
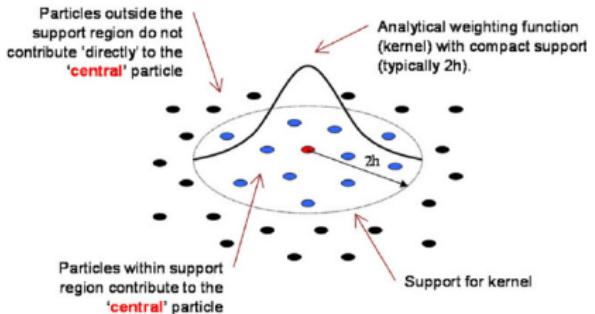
Method

Smoothing of initial conditions

[J.Noronha-Hostler, J.Noronha & M.Gyulassy Phys. Rev. C 93 (2016) 024909]

$$\epsilon(\tau_0, \vec{r}; \lambda) \sim \sum_{\alpha=1}^N \epsilon(\tau_0, \vec{r}_\alpha) W\left(\frac{|\vec{r}-\vec{r}_\alpha|}{\lambda}; \lambda\right)$$

W normalized cubic spline, zero if $|\vec{r}| > 2\lambda$.



Decomposition of initial conditions [Teaney & Yan PRC83 (2011) 064904]

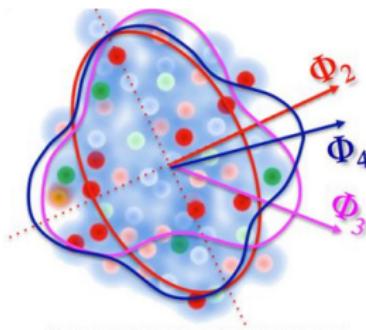
$$\epsilon(\tau_0, \vec{r}) \xrightarrow[\text{transf.}]{\text{Fourier}} \epsilon(\vec{k}) \xrightarrow[\text{fct}]{\text{generating}} \epsilon(\vec{k}) = e^{W(\vec{k})}$$

$$\text{with } W(\vec{k}) = \sum_{m=0}^{\infty} \sum_{n=-\infty}^{\infty} W_{n,m} k^m e^{-in\phi_k}$$

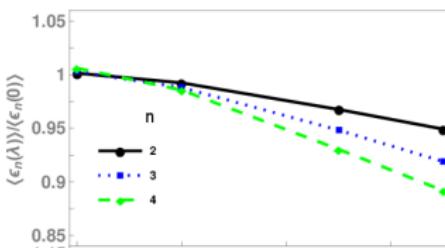
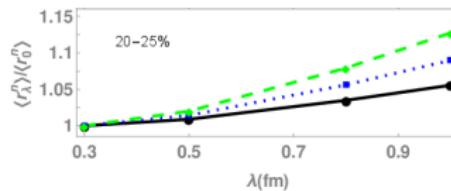
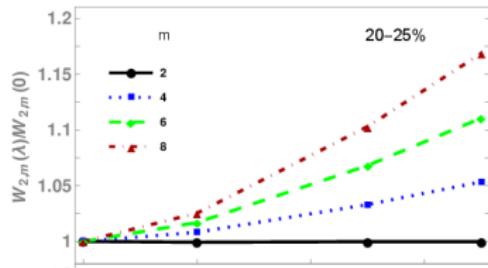
$n \rightarrow$ rotational properties, *large m* \leftrightarrow *small structures*

Connection with eccentricities:

$$\epsilon_n \propto \frac{W_{n,n}}{\langle r^n \rangle}.$$



Quantifying the effect of smoothing



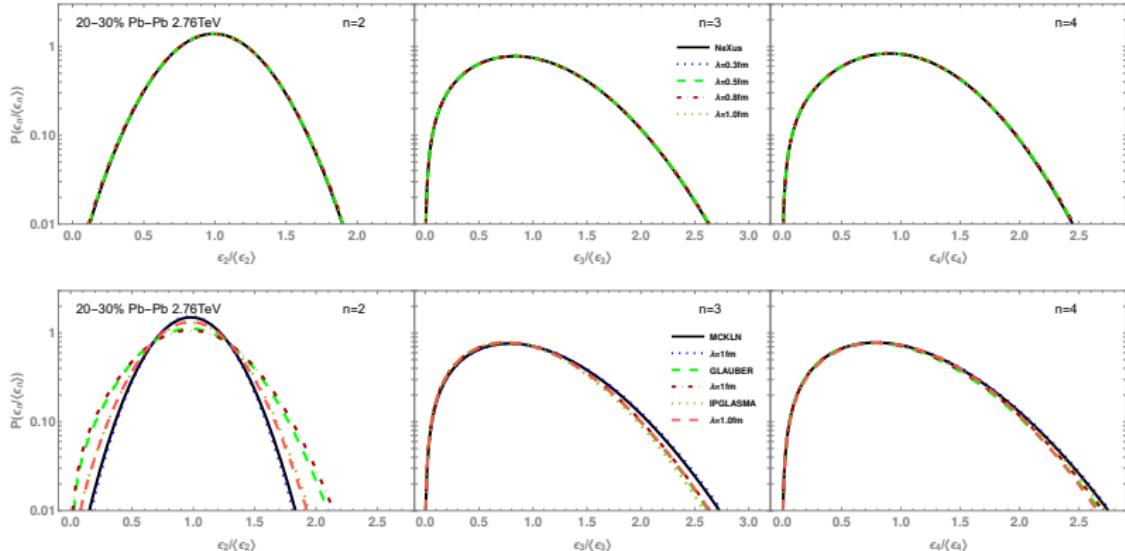
With $\lambda \nearrow$:

1. $W_{n,n} \sim cst, W_{n,m} \nearrow$
2. $\langle r^n \rangle \nearrow$
 $\Rightarrow \epsilon_n \searrow$ by $n \times 2.5\%$ (NeXus).
 \Rightarrow Look for effects larger than this.

Results

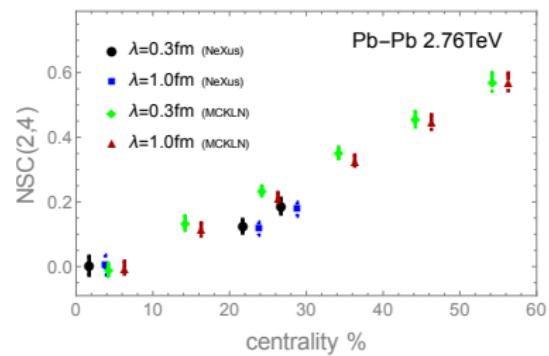
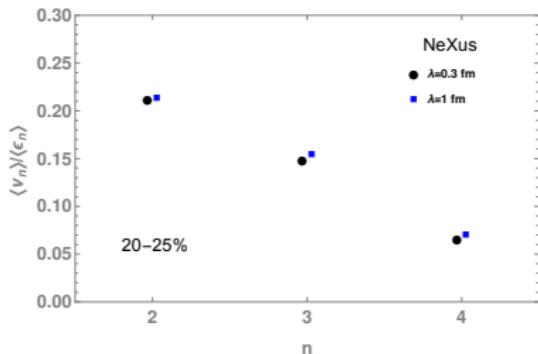
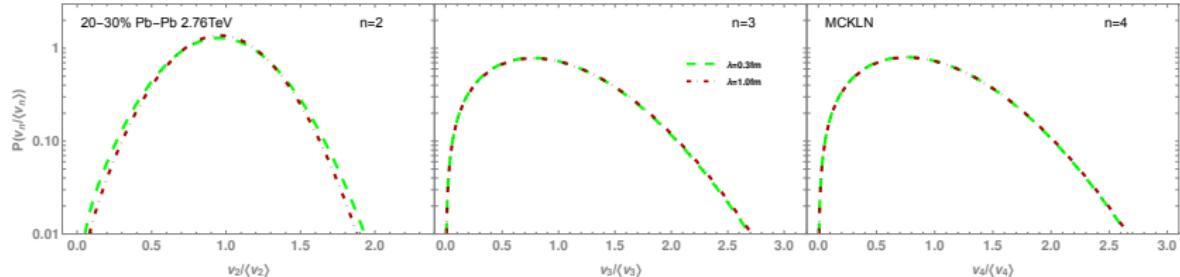
Integrated observables

4 models of initial conditions:
no effect of smoothing on $P(\epsilon_n / \langle \epsilon_n \rangle)$.



Comparison 3+1 NeXSPheRIO with ATLAS data: see poster by L. Barbosa

No effect of smoothing on integrated flow variables

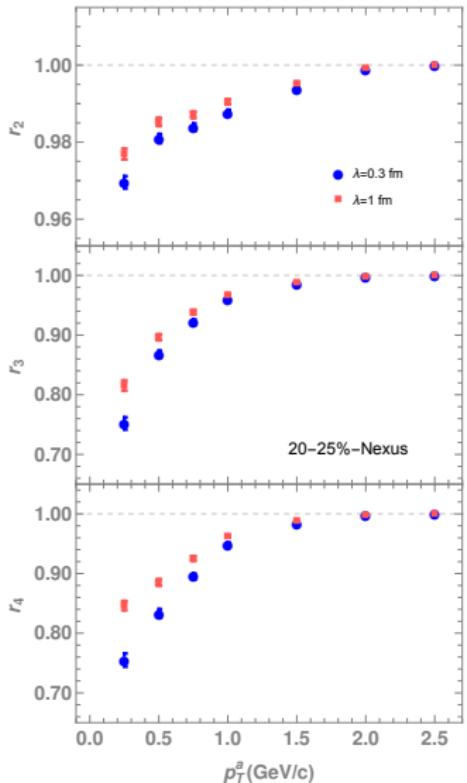


$$NSC(n, m) = \frac{\langle v_n^2 v_m^2 \rangle - \langle v_n^2 \rangle \langle v_m^2 \rangle}{\langle v_n^2 \rangle \langle v_m^2 \rangle}$$

Results

Differential observables

15-20 % difference in factorization breaking ratio



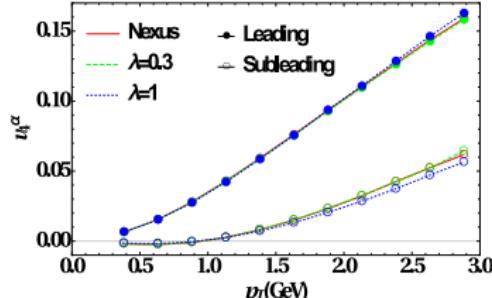
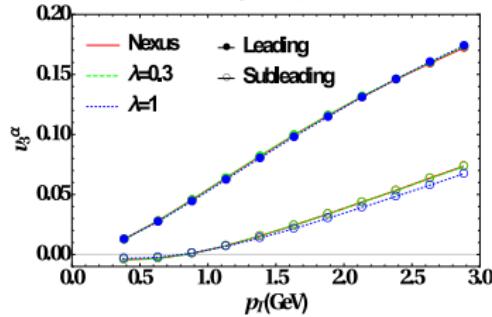
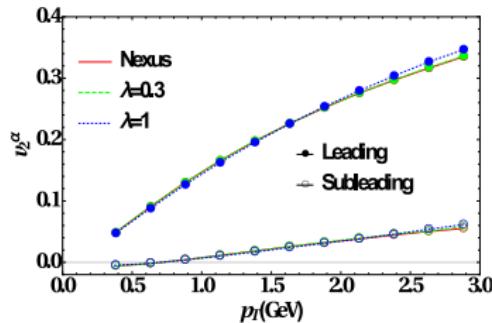
$$r_n(p_1, p_2) = \frac{V_{n\Delta}(p_1, p_2)}{\sqrt{V_{n\Delta}(p_1, p_1)V_{n\Delta}(p_2, p_2)}}$$
$$= \frac{< v_n(p_1)v_n(p_2) \cos n(\Psi(p_1) - \Psi(p_2)) >}{\sqrt{< v_n(p_1)^2 >< v_n(p_2)^2 >}}$$

[F. Gardim, FG, M.Luzum, J.-Y. Ollitrault PRC87 (2012)
031901(R)]

$2.5 \text{ GeV} < p_T^b < 3.0 \text{ GeV}$

Similar results for MC-KLN.

Difference in sub-leading component in PCA



Expand covariance matrix of two-particle correlation using real orthogonal eigenvectors $V_n^{(\alpha)}(p_T)$

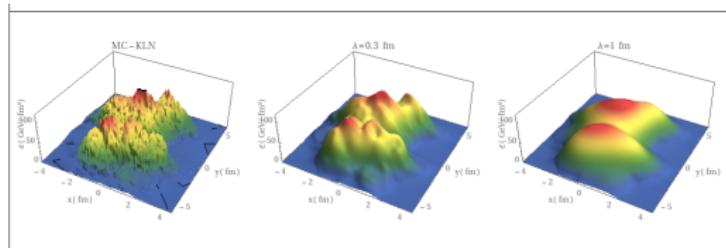
[R.S. Bhalerao, J.-Y. Ollitrault, S. Pal and D. Teaney
PRL 14 (2015) 152301]

1. Leading component (largest eigenvalue): $V_n^{(1)}(p_T) \propto v_n(p_T)$
⇒ no dependence on smoothing expected
2. Sub-leading component (together w. leading): approximate r_n ⇒ dependence on smoothing expected

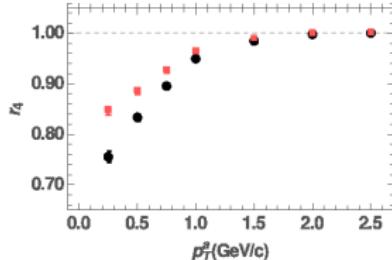
Comparison of 3+1 NeXSPheRIO with CMS data: see poster by P. Ishida

Conclusion

- Method to smoothen initial conditions maintaining global properties (e.g. ϵ_n) fixed.



- 4 models of initial conditions considered: MC-Glauber, MC-KLN, IP-Glasma, NeXus.
- Most flow observables considered are insensitive to increase in the smoothing length except r_n and sub-leading component



- r_n not very sensitive to viscosity = good probe of hot spot size.

EXTRA SLIDES

Smoothing: cubic spline

$$\epsilon(\tau_0, \vec{r}; \lambda) = \sum_{\alpha=1}^N \epsilon(\tau_0, \vec{r}_\alpha) W\left(\frac{|\vec{r} - \vec{r}_\alpha|}{\lambda}; \lambda\right)$$

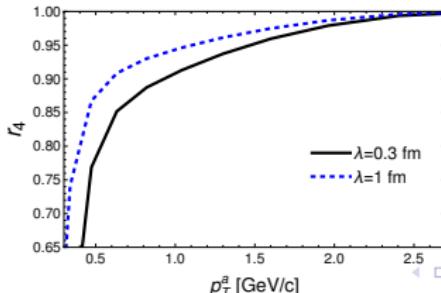
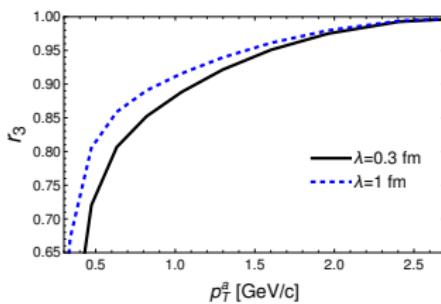
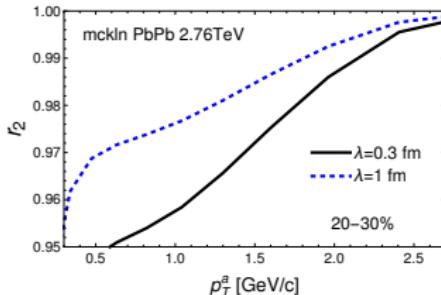
with W cubic spline: (note $\int W d\vec{r} = 1$)

$$W\left(\frac{|\vec{r}|}{\lambda}; \lambda\right) = \frac{10}{7\pi\lambda^2} f\left(\frac{|\vec{r}|}{\lambda}\right)$$

and

$$f(\xi) = \begin{cases} 1 - \frac{3}{2}\xi^2 + \frac{3}{4}\xi^3 & \text{if } 0 \leq \xi < 1 \\ \frac{1}{4}(2 - \xi)^3 & \text{if } 1 \leq \xi \leq 2 \\ 0 & \text{if } \xi > 2 \end{cases}$$

r_n for MC-KLN



Event plane correlations

