Event by event fluctuations of the source shape: implications for the Levy shape and Event Shape Sorting

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Results shown here are worked out by
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Motivation

- Each collision event evolves differently and has different final state
- Measured quantities are usually averaged over a large number of events

- **Part 1: Influence on the shape of the correlation function**

- **Part 2: Can we have a more exclusive selection of events?**

Part 1: Correlation function from event averaging

see also:

A. Białas, Nucl. Phys. A 525 (1991) 345-360

C. Plumberg, U. Heinz, Phys. Rev. C 92 (2015) 044906 and add. 92 (2015) 049901

Non-Gaussian measured $C(q)$ is fitted with Levy stable distribution

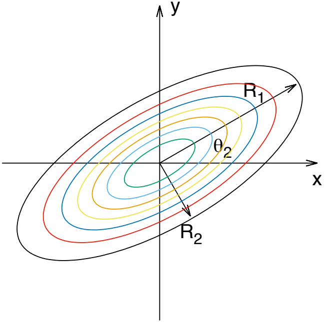
$$C(q) - 1 = \exp(-|Rq|^{\alpha})$$

- (HBT) correlation function is characteristic for each source (event)
- the sizes of the sources and their orientation fluctuate
- the **measured** correlation function results from a weighted average of correlation functions from each event
- observed shape of the correlation function results from:
  - shapes of the individual sources
  - distribution of sizes and orientations (event plane angles)

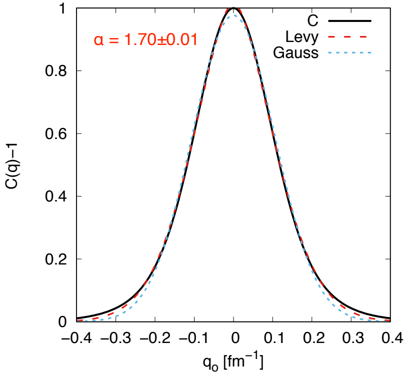
Can we get Levy-shaped correlation function from averaging?

Exercise 1: Levy-shaped $C(q)$ from Gaussian sources

Toy model: elliptic Gaussian source



Averaged correlation function



Averaging $C(q)$'s over:

- R_1 and R_2 distributed like in optical Glauber model
- θ_2 distributed uniformly

Extension of the blast-wave model to higher orders

The emission function:

$$S(x,p)d^4x = \frac{m_t \cosh(Y-\eta)}{(2\pi)^3} d\eta\, rdr\, d\varphi \frac{\tau\, d\tau}{\sqrt{2\pi\Delta\tau^2}} \times \exp\left(-\frac{(\tau-\tau_0)^2}{2\Delta\tau^2}\right) \exp\left(-\frac{p^\mu u_\mu}{T}\right) \Theta(1-\bar{r})$$

Transverse size

$$\bar{r} = \frac{r}{R(\varphi)} \qquad R(\varphi) = R_0 \left(1 - \sum_{n=2}^{\infty} a_n \cos\left(n(\varphi - \varphi_n)\right)\right)$$

Transverse expansion goes into u_μ, parametrized by transverse rapidity

$$\rho(\bar{r},\varphi) = \bar{r}\rho_0 \left(1 + \sum_{n=2}^{\infty} 2\rho_n \cos\left(n(\varphi-\varphi_n)\right)\right)$$

Exercise 2: Levy-shaped $C(q)$ from blast-wave sources

The model: blast-wave emission function with 2nd order anisotropy.

$$R_0 = 7\,\mathrm{fm},\ T = 120\,\mathrm{MeV},\ \rho_0 = 0.8$$

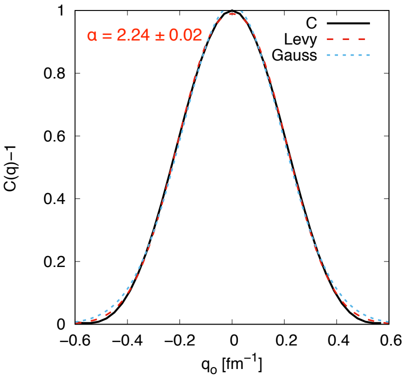
anisotropy parameters (flow and spatial)

$$\rho_2 = a_2 = 0.2$$

Averaging $C(q)$'s over:

- θ_2 distributed uniformly
- p_t from 0 to 1 GeV

Averaged correlation function



Conclusion: Levy shapes

- The averaging of the correlation functions over many events may have an influence on the shape of the measured correlation function.
- The exact value of the Levy parameter depends on details of the source shape and the distribution of the source paramaters.

Part 2: Event Shape Sorting and femtoscopy

- try to avoid extensive averaging over very different events by identifying events with similar distribution of final state hadrons and taking averages over them only
- useful for data analyses of observables which depend on fireball shape
  - jet quenching
  - jet shapes
  - anisotropic flow of heavy flavors
  - azimuthal dependence of correlation radii
  - ...
- useful for the comparison with theoretical simulations
  - hydrodynamic simulations with specific geometry
  - identification of rare events

Event Shape Engineering

- Two subevents
  - Subevent *a*: event selection
  - Subevent *b*: physical analysis
- Helps avoiding nonphysical biases (nonflow effects)
- Information loss
- Event selection according to the magnitude of the **reduced flow vector** q_n

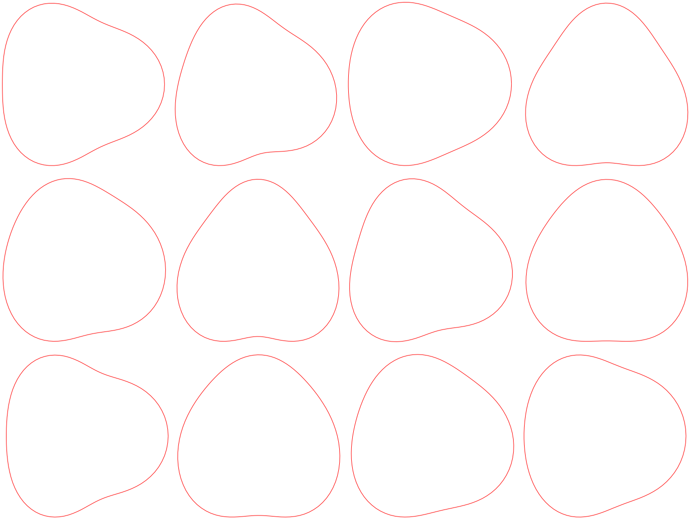
$$\vec{Q}_n = \left(\sum_{i=1}^{M} \cos(n\phi_i) \, , \sum_{i=1}^{M} \sin(n\phi_i) \right) \, ,$$

$$q_n = |\vec{Q}_n| / \sqrt{M} \, .$$

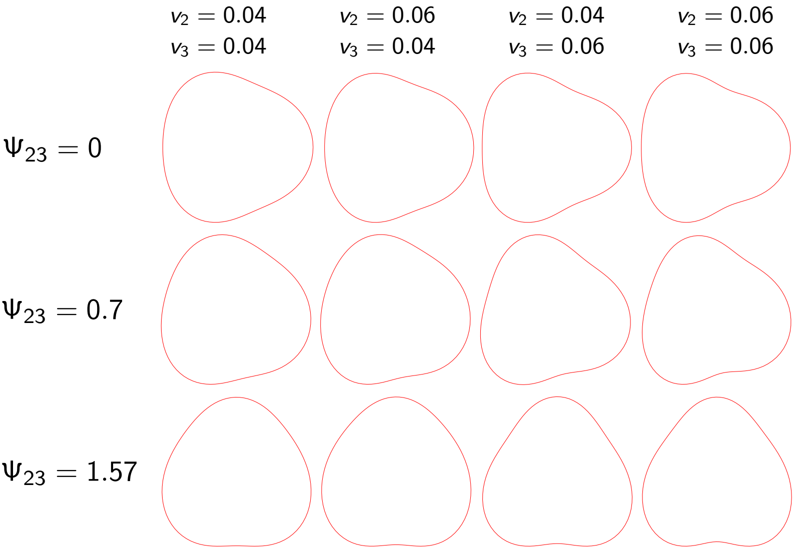
[J. Schukraft, A. Timmins, S. A. Voloshin, Phys. Lett. B 719 (2013) 394-398]

Event shapes

How to do Event Shape Engineering among these shapes. . . ?



. . . ordered


$v_2 = 0.04$
$v_3 = 0.04$
$v_2 = 0.06$
$v_3 = 0.04$
$v_2 = 0.04$
$v_3 = 0.06$
$v_2 = 0.06$
$v_3 = 0.06$
$\Psi_{23} = 0$
$\Psi_{23} = 0.7$
$\Psi_{23} = 1.57$

Event Shape Sorting

- iteratively sorts events in such a way, that events with similar histograms (in azimuthal angle, e.g.) end up close to each other
- divides the totality of events into (customarily 10) event bins
- no need to specify a sorting variable, unlike Event Shape Engineering
  [J. Schukraft, A. Timmins, S. A. Voloshin, Phys. Lett. B 719 (2013) 394-398]

Algorithm based on:

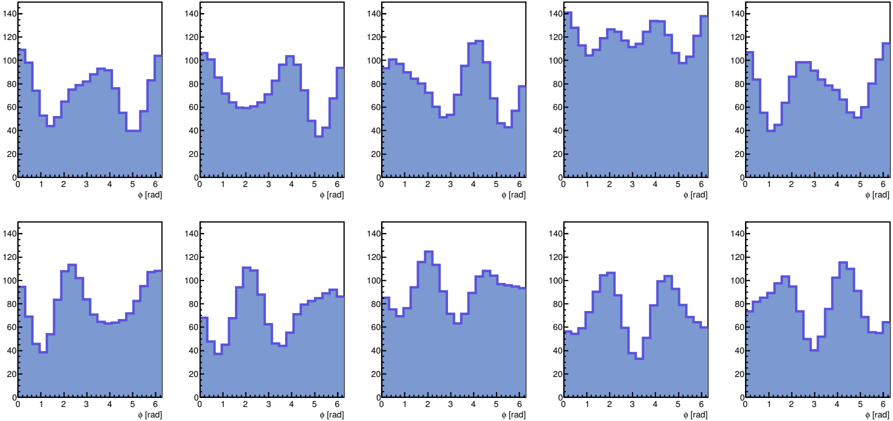
S. Lehmann, A.D. Jackson, B. Lautrup, arXiv:physics/0512238

S. Lehmann, A. D. Jackson and B. E. Lautrup, Scientometrics **76** (2008) 369 [physics/0701311 [physics.soc-ph]]

Published in

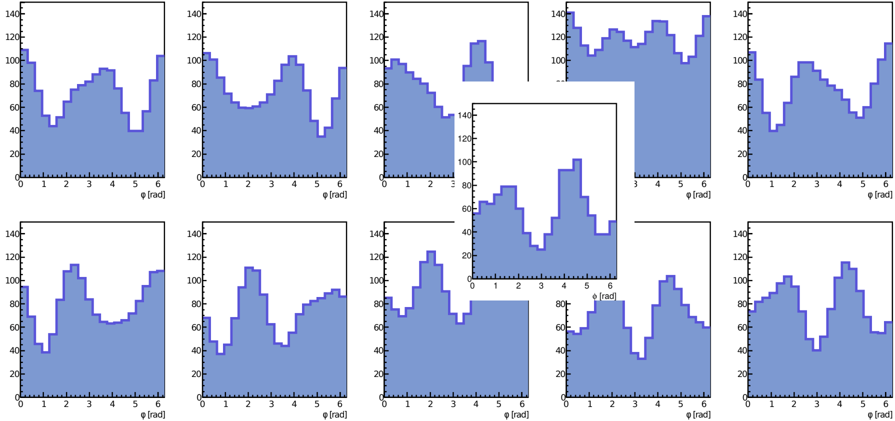
R. Kopečná, B. Tomášik: Eur. Phys. J. A **52** (2016) 115.

Assigning event to event bin



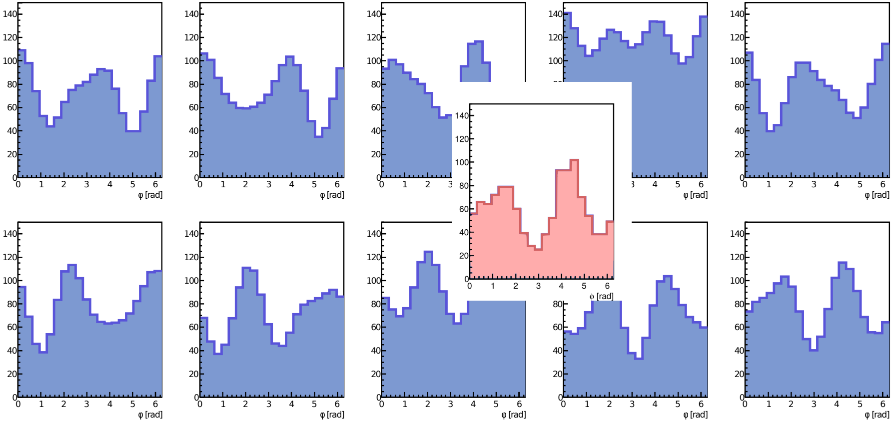
Assigning event to event bin

To which event bin is this event similar?



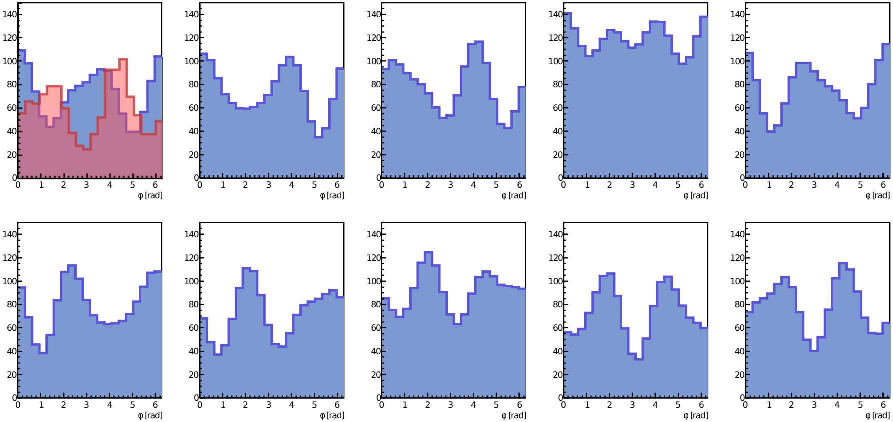
Assigning event to event bin

Calculate Bayesian probability that the event belong to each event bin



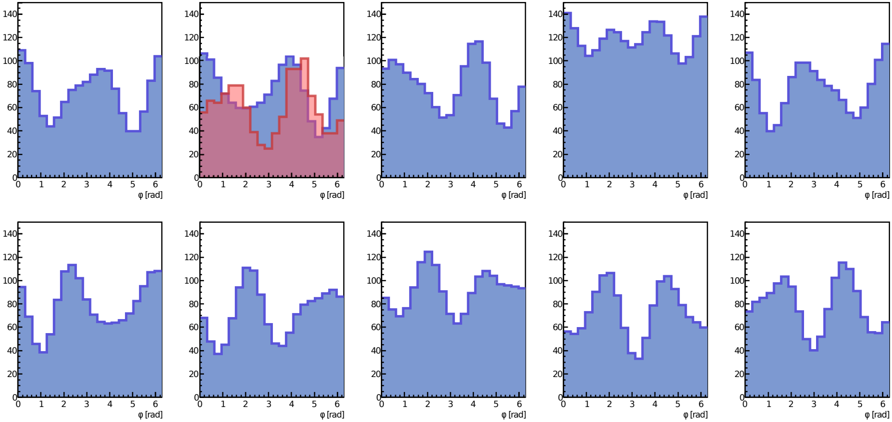
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 1



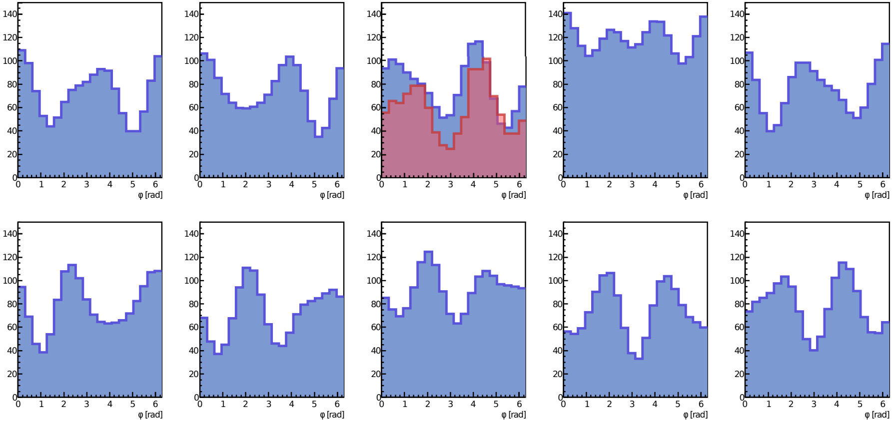
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 2



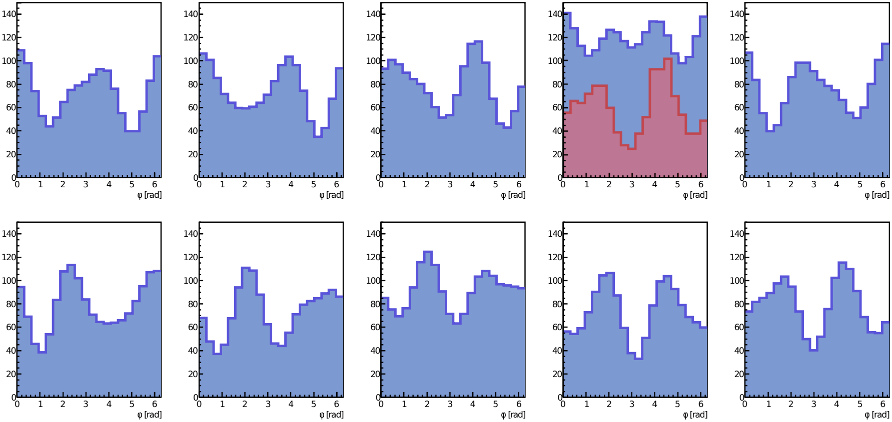
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 3



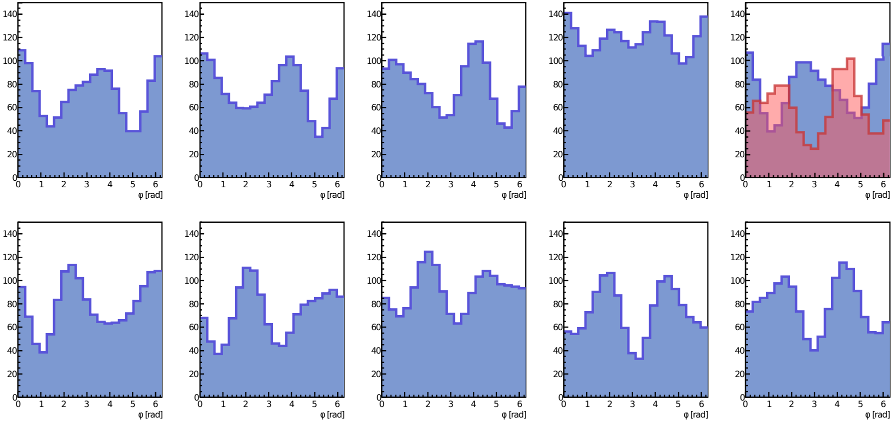
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 4



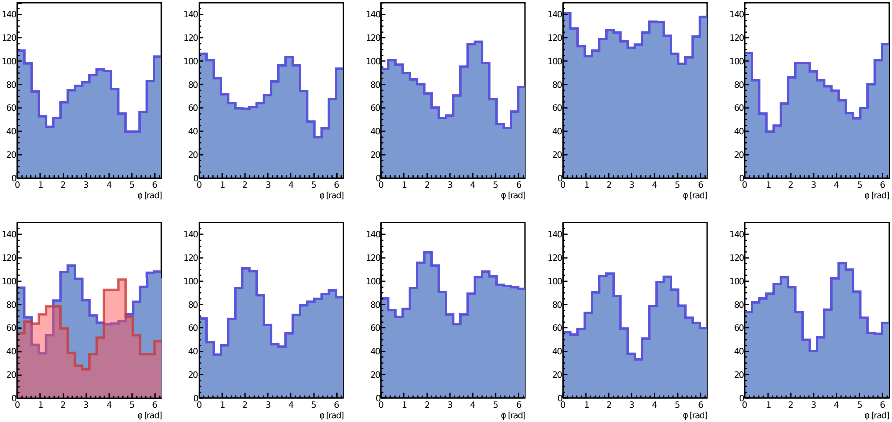
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 5



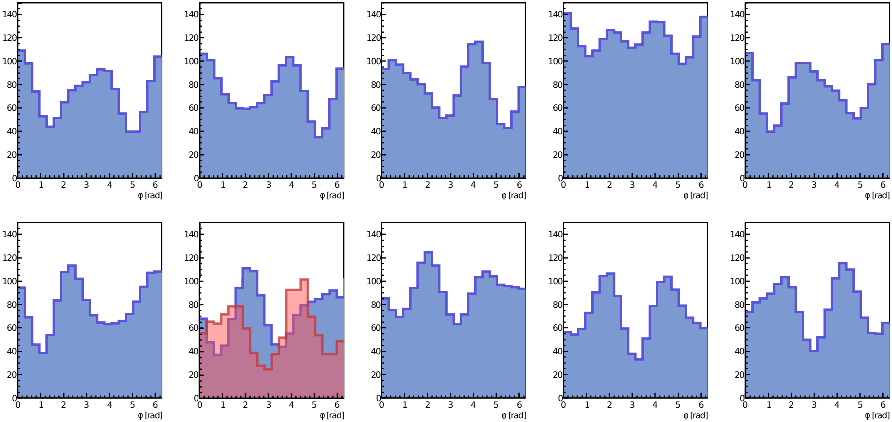
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 6



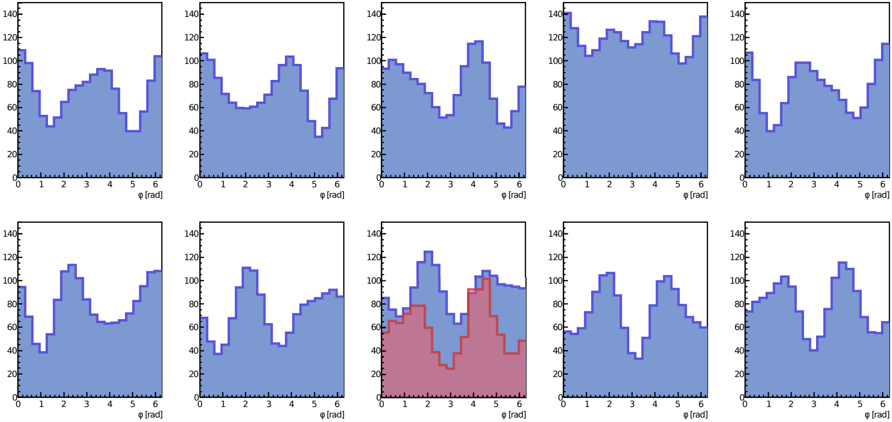
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 7



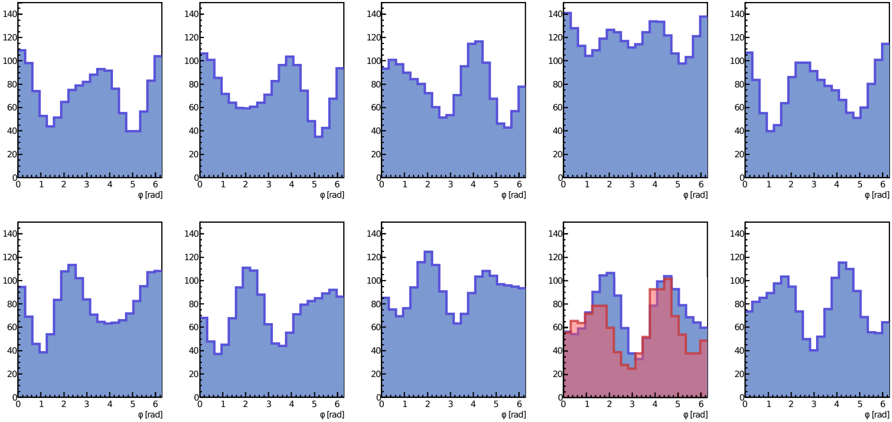
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 8



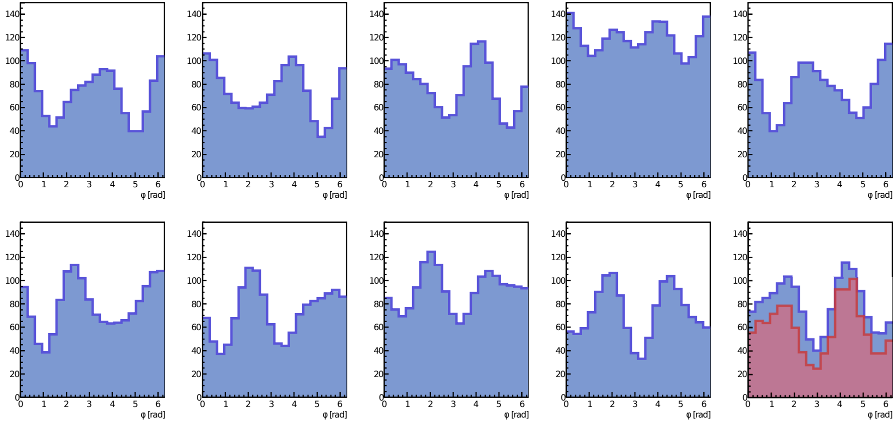
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 9

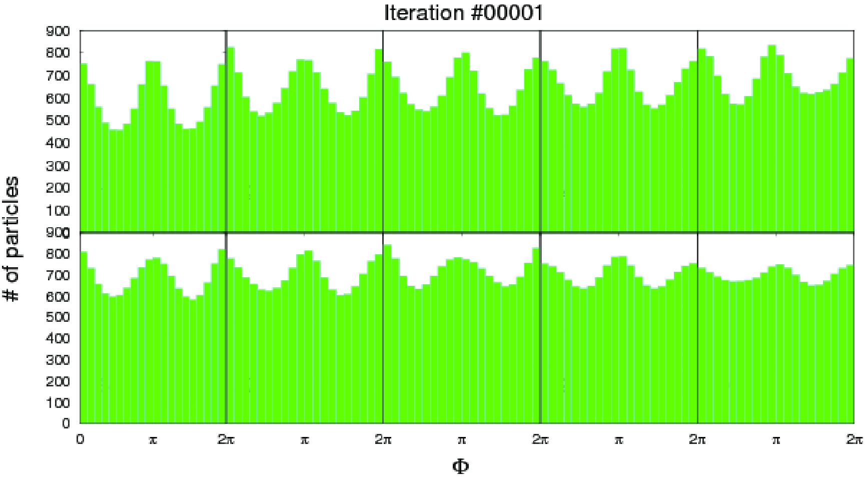


Assigning event to event bin

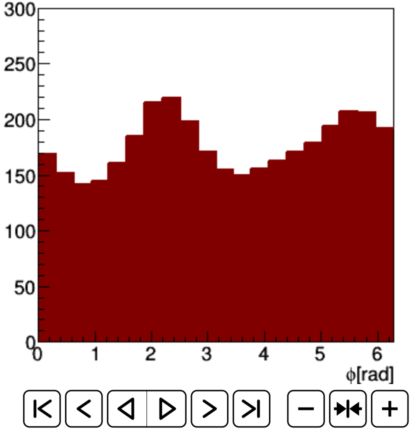
Calculate Bayesian probability that the event belong to event bin 10



Iterations of event bins



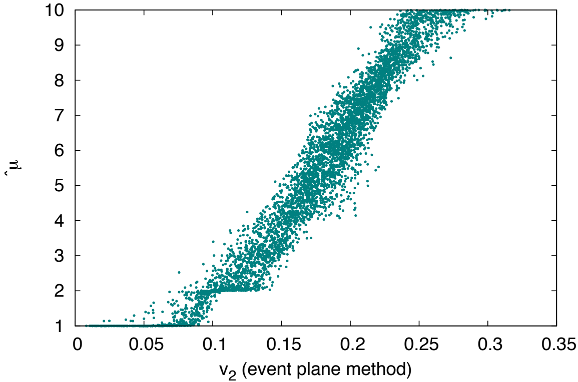
Sorted events: Gradual change of event shape



- 2000 events, AMPT centrality 0–20%, $\sqrt{s_{NN}} = 2.76$ TeV
- each frame averaged over 50 events and shifted by 10 events wrt previous frame
- change of colour = change of event bin

Toy model: only elliptic flow

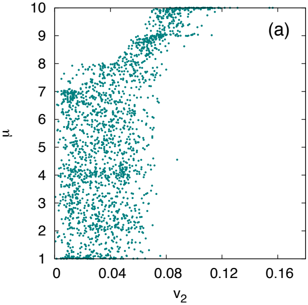
- in the toy model, azimuthal distribution of pions with only elliptic flow is generated
- correlation between v_2 and μ: 0.959
- v_2 is good sorting variable

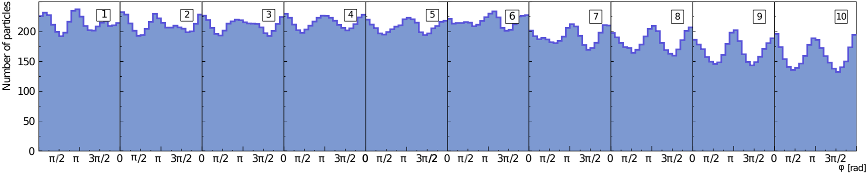


Sorted AMPT central events (LHC energy)

Event shape sorting goes beyond characterisation of events according to single variable (e.g. v_2 or q_2)

- simulated 2000 central 0–20% events from AMPT for $\sqrt{s_{NN}} = 2.76$ TeV
- correlation between sorting variable μ and elliptic flow v_2





R. Kopečná, B. Tomášik: Eur. Phys. J. A **52** (2016) 115.

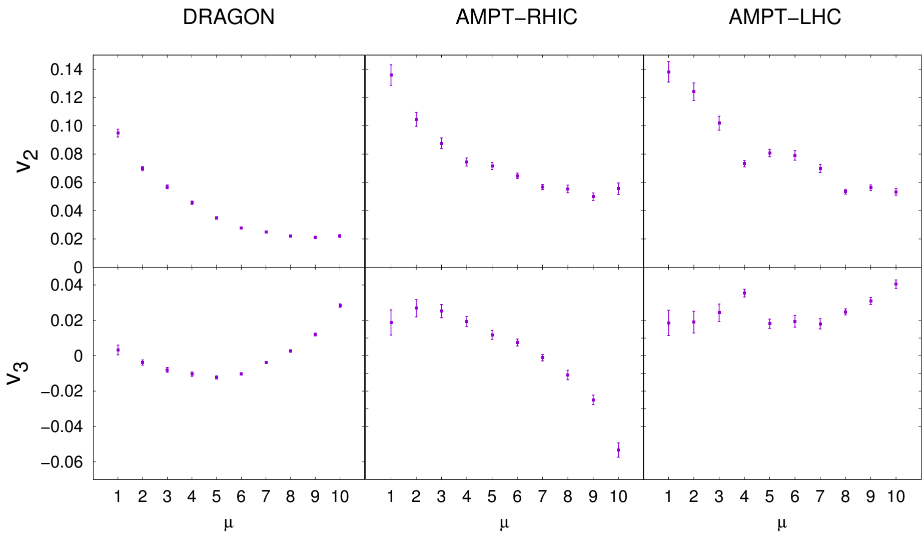
Models which will be compared

DRAGON 150 000 events by DRAGON with anisotropies $a_2, \rho_2 \in (-0.1; 0.1)$, $a_3, \rho_3 \in (-0.03; 0.03)$ (DRAGON is MC final state generator based on blast-wave model with included resonances)

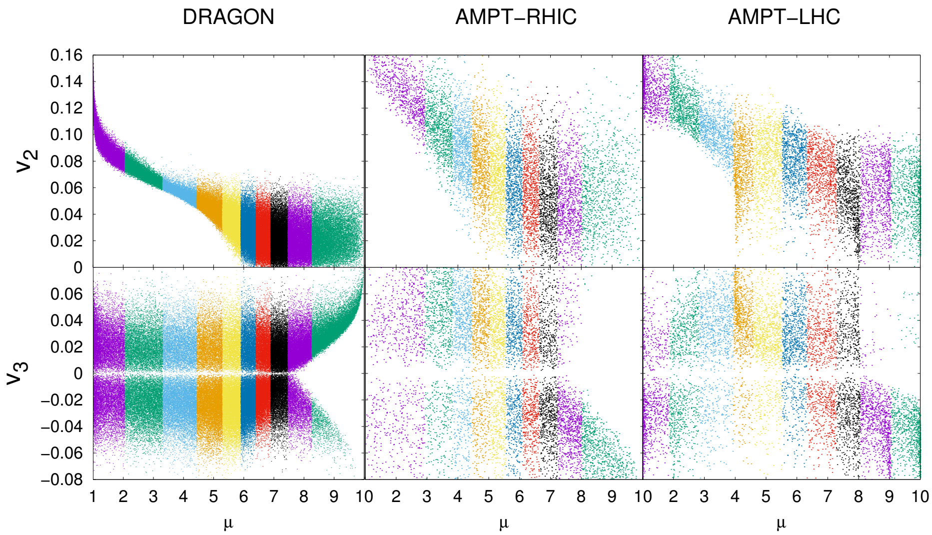
AMPT-RHIC 10 000 events by AMPT in AuAu collisions with energy $\sqrt{s_{NN}} = 200$ GeV, impact parameter $7 - 10$ fm

AMPT-LHC 10 000 events by AMPT in PbPb collisions with energy $\sqrt{s_{NN}} = 2760$ GeV, impact parameter $7 - 10$ fm

Anisotropic flow in similar events



Anisotropic flow in similar events



Femtoscopy: trivia

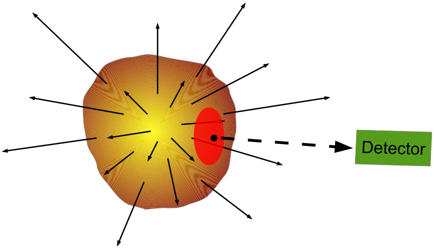
Correlation radii are parameters of the measured correlation function:

$$C(q,K) - 1 = \exp\left(-R_o^2(K)q_o^2 - R_s^2(K)q_s^2 - R_l^2(K)q_l^2\right)$$

- K: average pair momentum, q: relative pair momentum
- no cross terms at midrapidity at high energies
- out-side-long coordinate frame

out	perpendicular to beam, along K_t
long	beam direction
side	perpendicular to out and long

The correlation radii measure the sizes of the homogeneity regions



Azimuthal dependence of correlation radii

Correlation radii are customarily decomposed into Fourier series

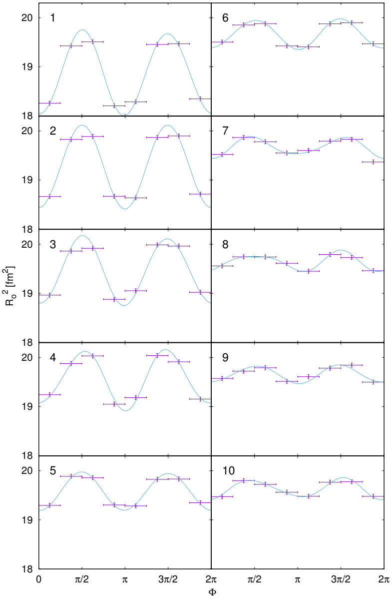
$$R_i^2(\phi) = R_{i,0}^2 + \sum_{n=1}^{\infty} R_{i,n}^2 \cos\left(n(\phi - \phi_n)\right)$$

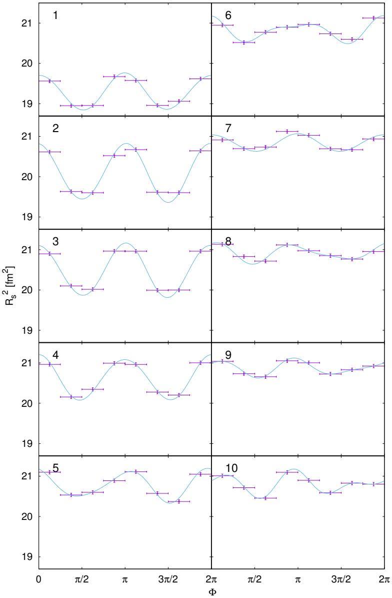
where $i = o, s, l$.

Real effect of oscillations: amplitudes divided by 0th term allow to scale out the absolute sizes

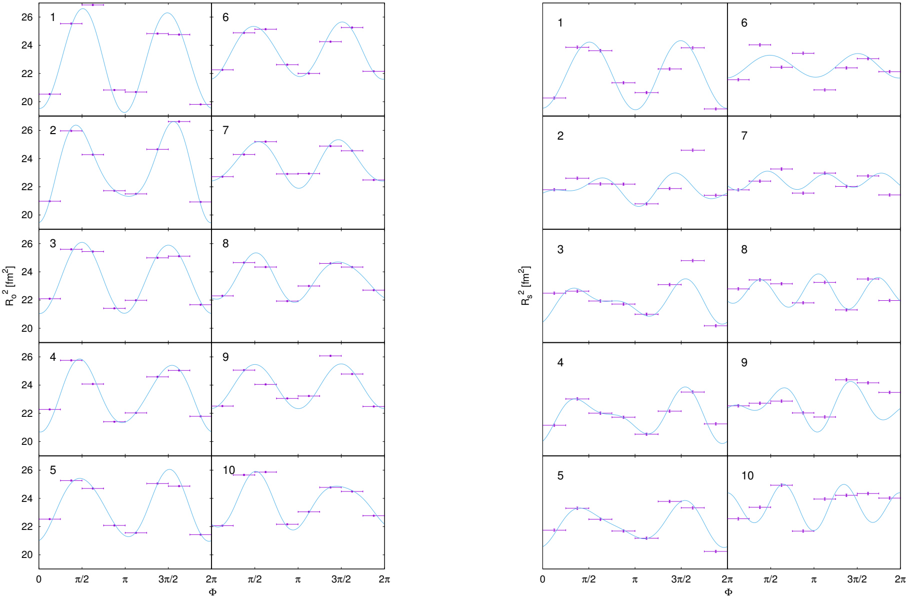
$$R_i^2(\phi) = R_{i,0}^2 \left(1 + \sum_{n=1}^{\infty} \frac{R_{i,n}^2}{R_{i,0}^2} \cos\left(n(\phi - \phi_n)\right)\right)$$

Correlation radii from DRAGON in different event bins

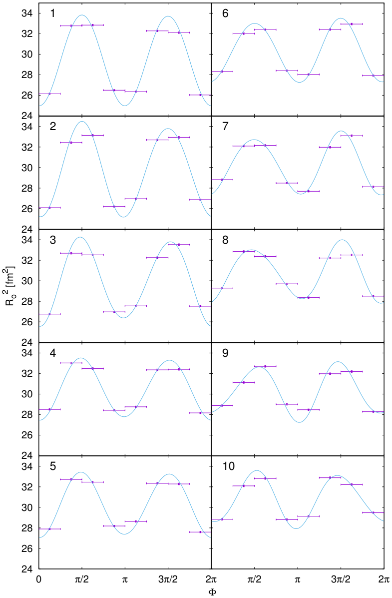


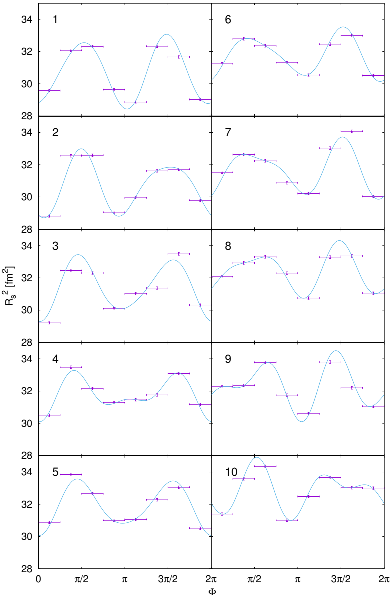


Correlation radii from AMPT-RHIC in different event bins

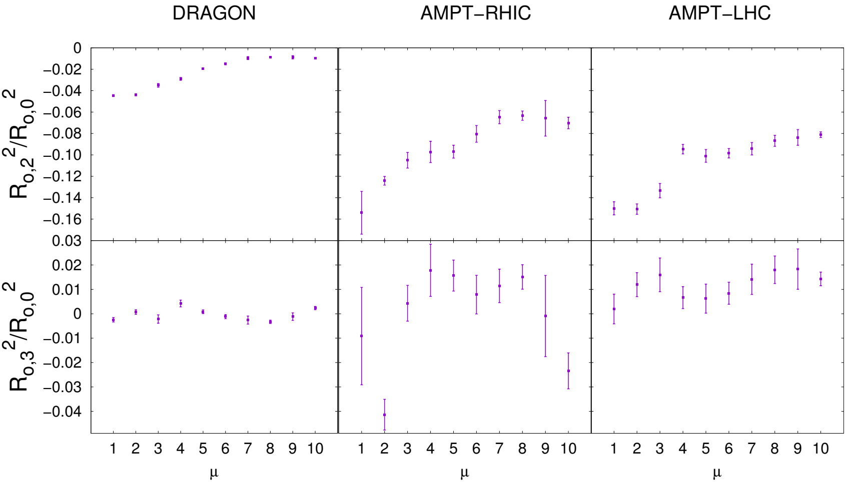


Correlation radii from AMPT-LHC in different event bins

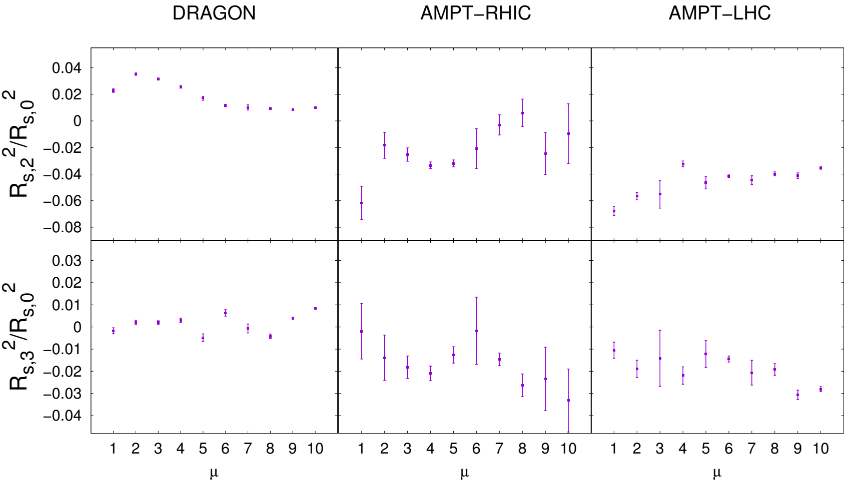




Oscillation amplitudes for R_o^2



Oscillation amplitudes for R_s^2



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THOR

What is it good for?

- More selective comparison of data to theory.
- Better insight into the dynamics of evolution and freeze-out.
- Looking for and selecting rare events.
- Construction of mixed-events background for correlation functions.
- Better selection of the environment for other processes, e.g. jet quenching.
- ...

Published in
R. Kopečná, B. Tomášik: Eur. Phys. J. A **52** (2016) 115.
J. Cimerman, B. Tomášik: in preparation.

BACKUP SLIDES

Event Shape Sorting: the algorithm

We will sort events according to their histograms in azimuthal angle.

1. (Rotate the events appropriately)
2. Sort your events as you wish
3. Divide sorted events into quantiles (we'll do deciles)
4. Determine average histograms in each quantiles
5. For each event i calculate Bayesian probability $P(i|\mu)$ that it belongs to quantile μ
6. For each event calculate average $\bar{\mu} = \sum_\mu \mu P(i|\mu)$
7. Sort events according to their values of $\bar{\mu}$
8. If order of events changed, return to 3. Otherwise sorting converged.

S. Lehmann, A.D. Jackson, B. Lautrup, arXiv:physics/0512238
S. Lehmann, A. D. Jackson and B. E. Lautrup, Scientometrics **76** (2008) 369 [physics/0701311 [physics.soc-ph]]