Sorting of events according to their shapes

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Results shown here are worked out by
Renata Kopečná, **Jakub Cimerman**

2nd Workshop on simulations for NICA

16.4.2018

Motivation

- Each collision event evolves differently and has different final state
- Measured quantities are usually averaged over a large number of events
- Calculated quantities should be averaged over large number of events
- potential problems:
  - not enough events in the theoretical sample
  - different averaging procedure in theory and in experiment
  - in comparison of averages interesting information may get lost (e.g. critical fluctuations)
- Can we have a more exclusive approach to data analysis?

Anisotropic expansion

(only nuclear collisions and assume non-flow effects under control)

- generic effect: blue-shift
  $\Rightarrow$ more particles and higher p_t in direction of stronger transverse flow
- link between the observable spectrum and the expansion of the fireball
- expansion results from the pressure gradients
- anisotropic expansion $\Leftarrow$ anisotropic pressure gradients in initial conditions
- initial conditions evolved into final distribution—nothing added
- some contribution from hard partons depositing momentum during expansion

Mapping of ε_n's and v_n'n

- spatial anisotropy

$$\varepsilon_{m,n} e^{in\Psi_{m,n}} = \int r\, dr\, d\phi\, r^m e^{in\phi}\, \rho(r,\phi)$$

use $\varepsilon_n = \varepsilon_{n,n}$

- to a very good extent $\langle v_n \rangle = k \langle \varepsilon_n \rangle$
[F.G. Gardim *et al.*, Phys. Rev. C **85** (2012) 024908]

- also mapping between the values in individual events and between probability distributions
valid for various initial conditions and ideal as well as viscous hydro
[H. Niemi *et al.*, Phys. Rev. C **87** (2013) 54901]

Each event is different: selection of events

Each event undergoes different evolution

There is always averaging over others but the selected order event plane.

Various event shapes are averaged out!

Can we see non-averaged events?

An example:

- $R_o^2(\phi)$ for a fireball with both 2nd and 3rd order flow anisotropy
- varying angles between 2nd and 3rd event plane

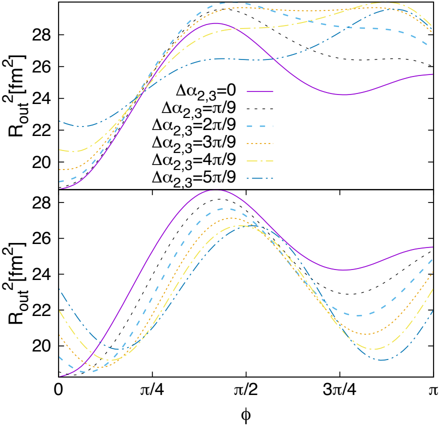


Figure: Sándor Lökös

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

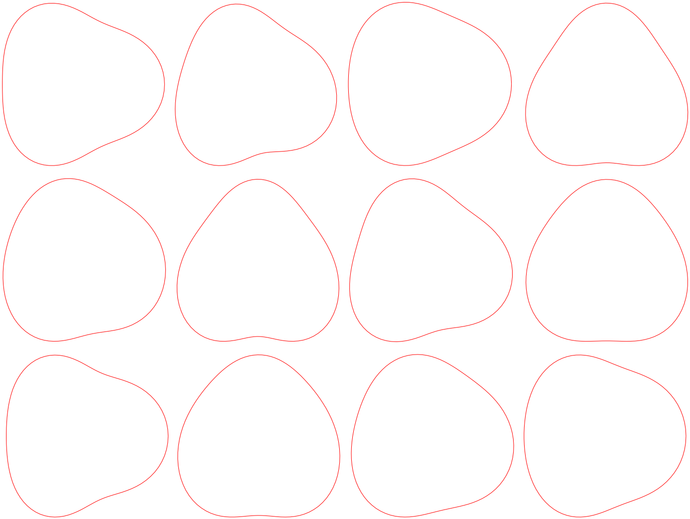
$$\vec{Q}_n = \left(\sum_{i=1}^{M} \cos(n\phi_i)\, , \sum_{i=1}^{M} \sin(n\phi_i) \right) \; ,$$

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

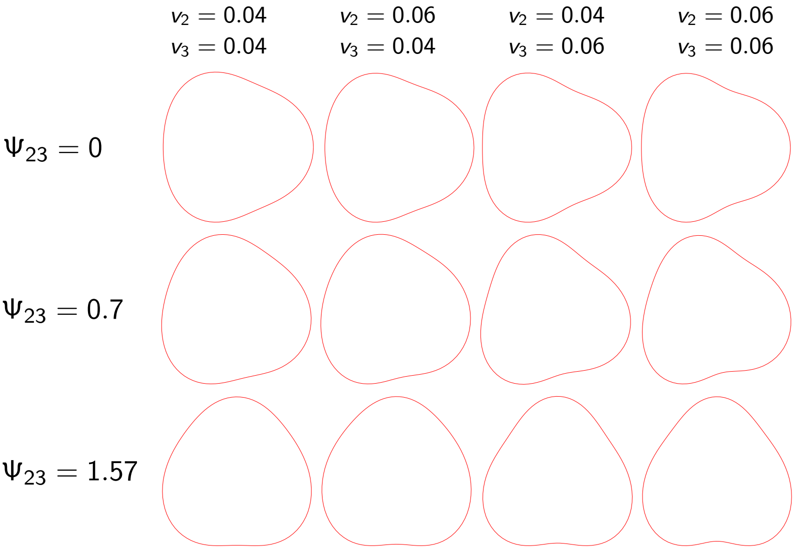
[J. Schukraft, A. Timmins, S. A. Voloshin, Phys. Lett. B 719 (2013) 394-398]

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

- 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.

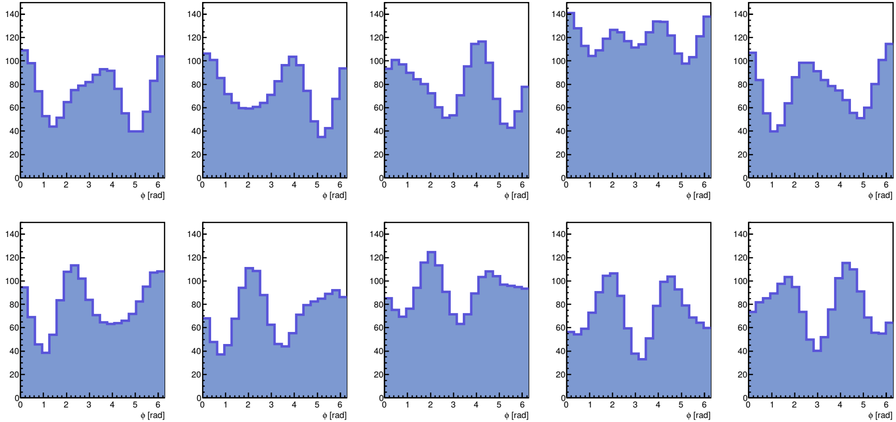
Event Shape Sorting: the algorithm

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.

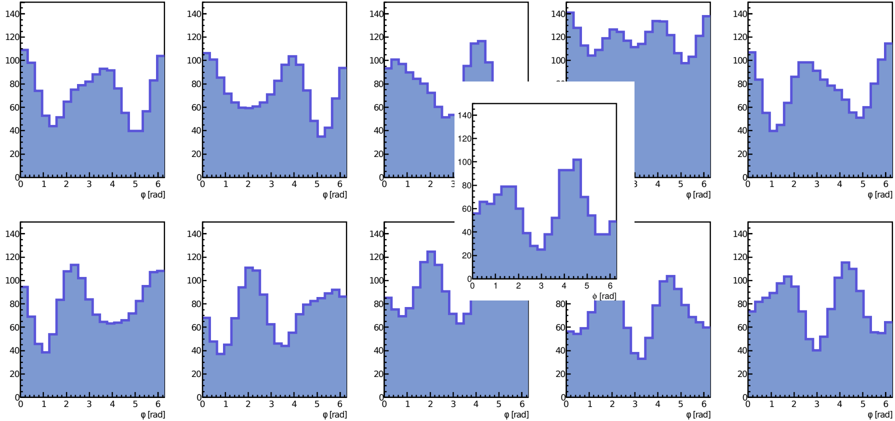
S. Lehmann, A.D. Jackson, B. Lautrup, arXiv:physics/0512238
S. Lehmann, A. D. Jackson and B. E. Lautrup, Scientometrics **76** (2008) 369 [physics/0701311 [physics.soc-ph]]

Assigning event to event bin



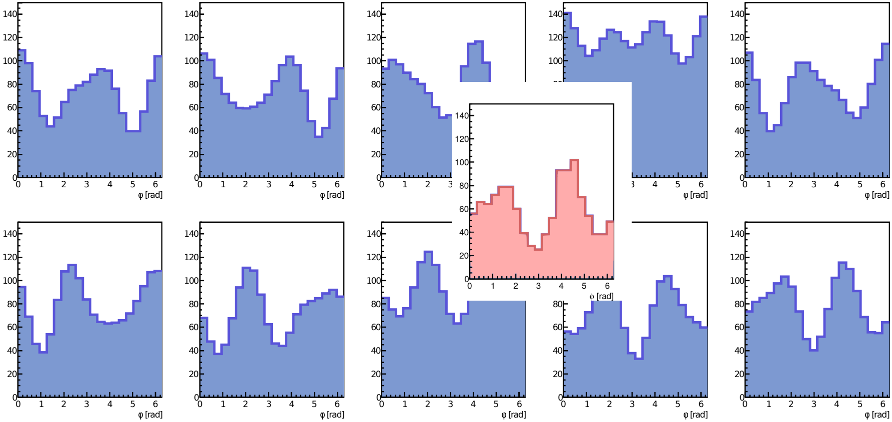
Assigning event to event bin

To which event bin is this event similar?



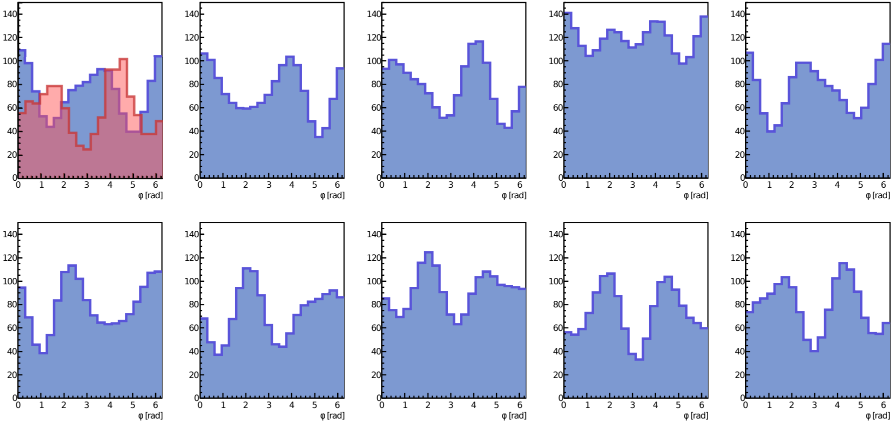
Assigning event to event bin

Calculate Bayesian probability that the event belong to each event bin



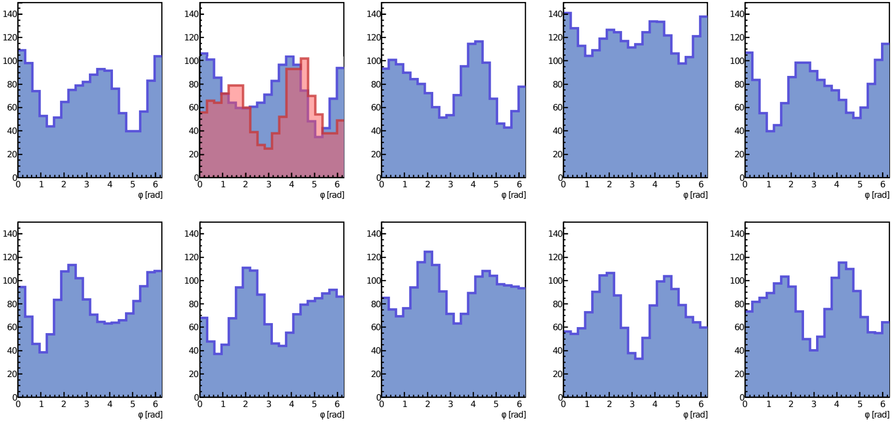
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 1



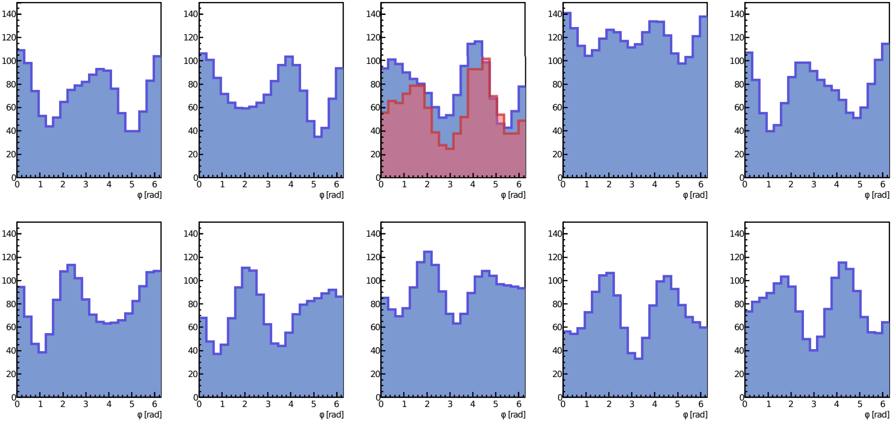
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 2



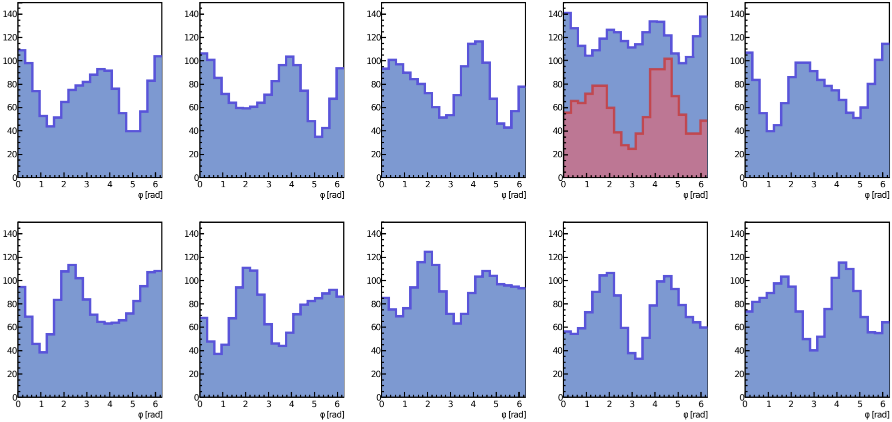
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 3



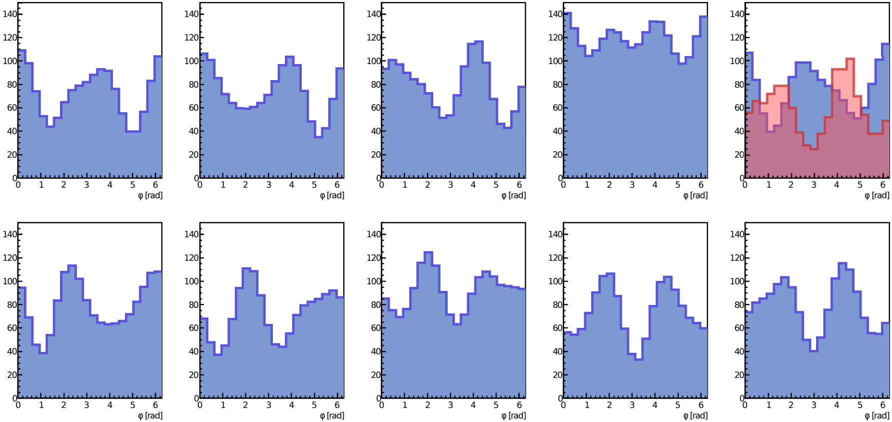
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 4



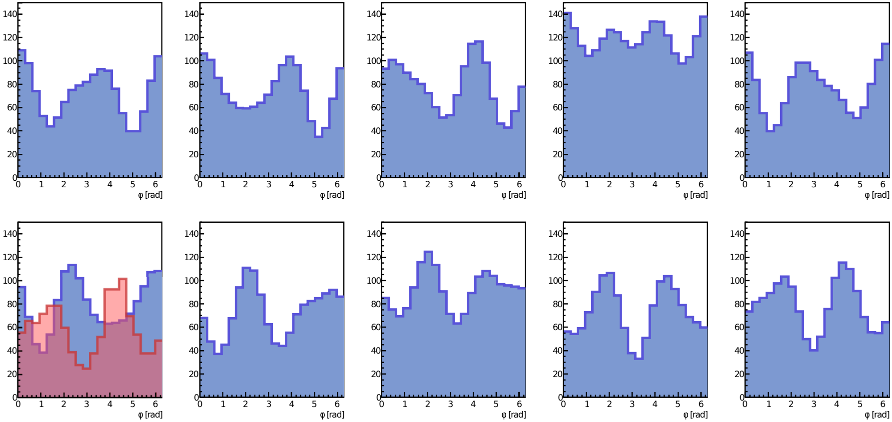
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 5



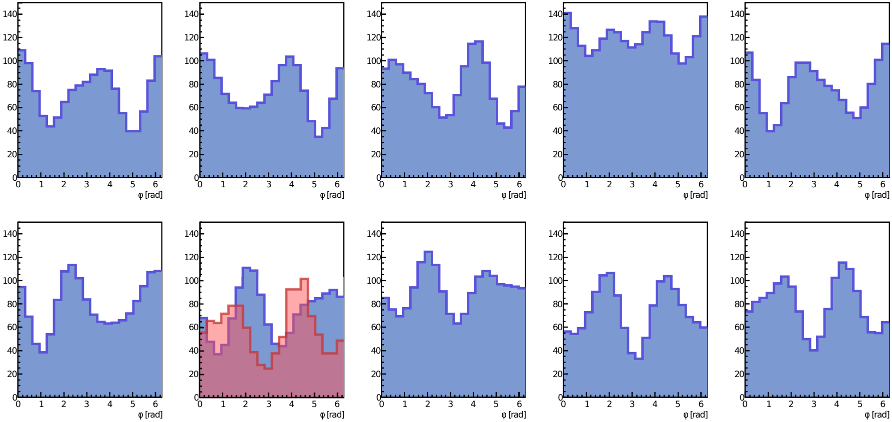
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 6



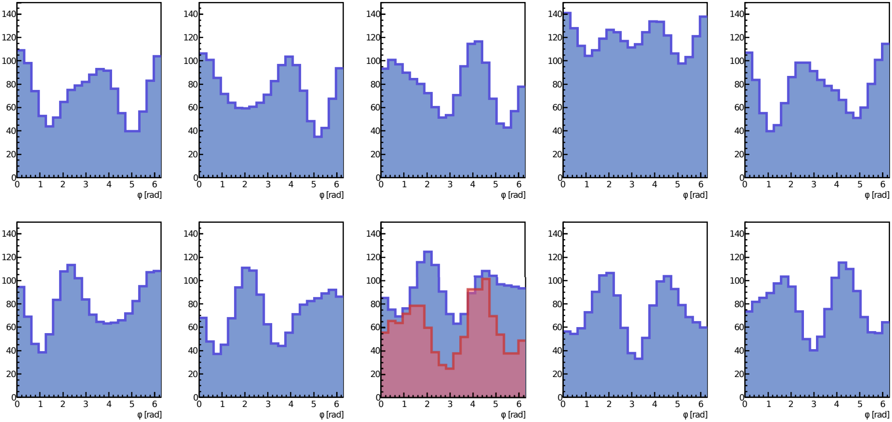
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 7



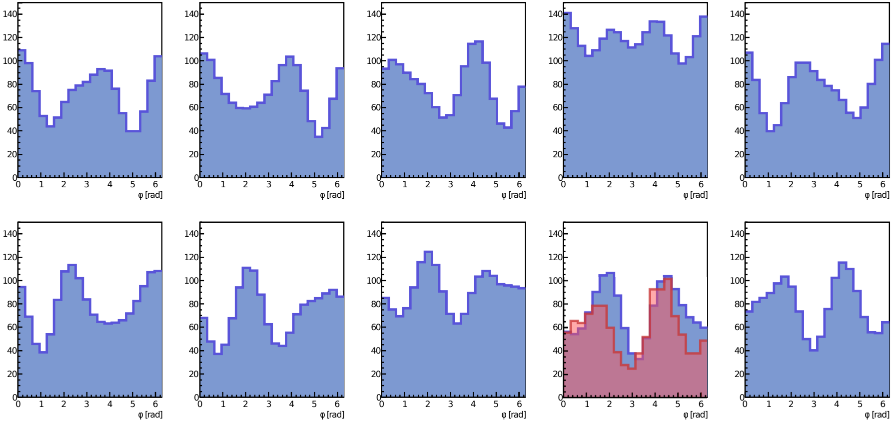
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 8



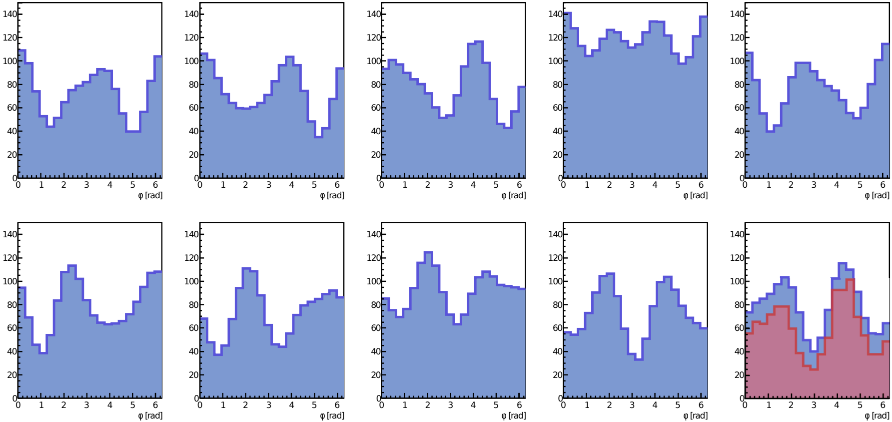
Assigning event to event bin

Calculate Bayesian probability that the event belong to event bin 9

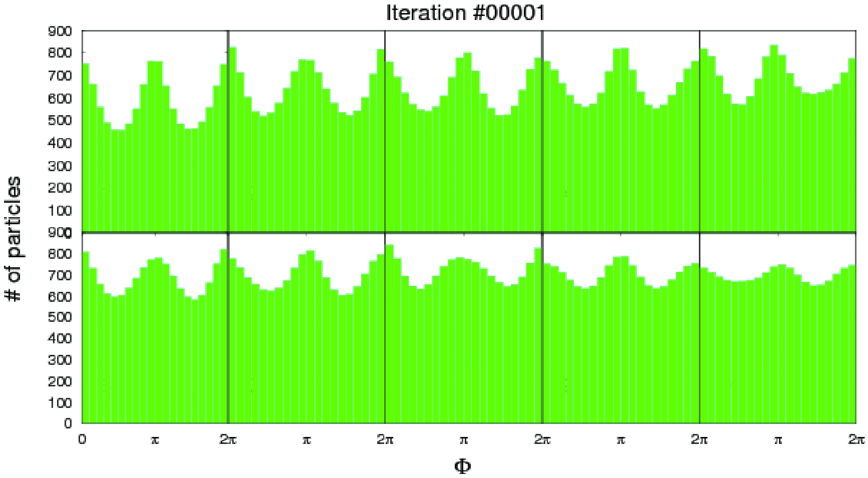


Assigning event to event bin

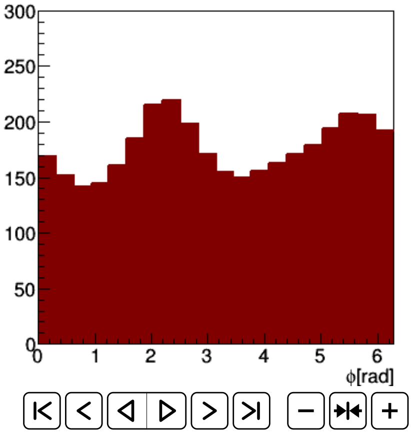
Calculate Bayesian probability that the event belong to event bin 10



Iterations of event bins



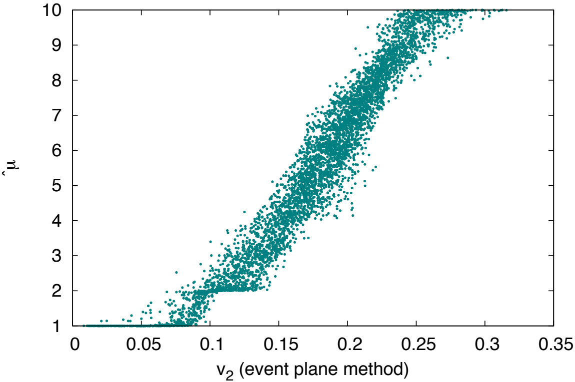
Sorted events: Gradual change of event shape



- 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

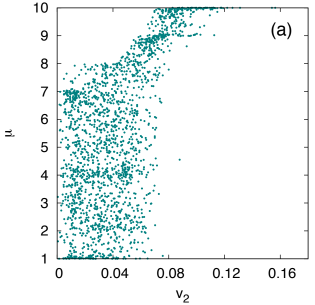
- in the toy model, azimuthal distribution of pions with only elliptic flow is generated
- correlation between v_2 and μ: 0.959
- v_2 is good sorting variable

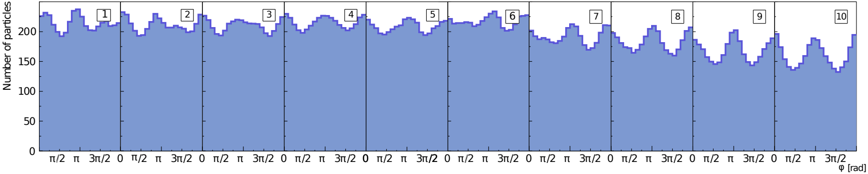


Sorted AMPT central events (LHC energy)

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.

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

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

Models which will be compared

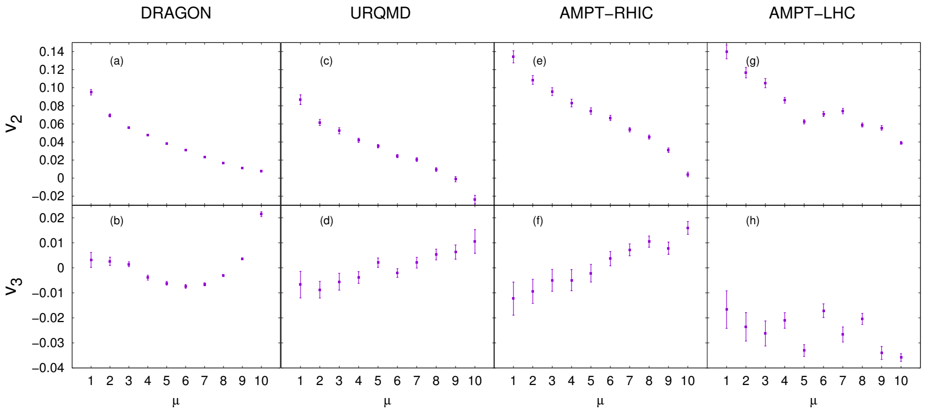
DRAGON 150 000 events by DRAGON with anisotropies $a_2, \rho_2 \in (-0.1; 0.1)$, $a_3, \rho_3 \in (-0.03; 0.03)$ (DRAGON is MC final state generator based on blast-wave model with included resonances)

UrQMD 100 000 events by UrQMD in AuAu collisions with energy $\sqrt{s_{NN}} = 200$ GeV, impact parameter $7 - 10$ fm

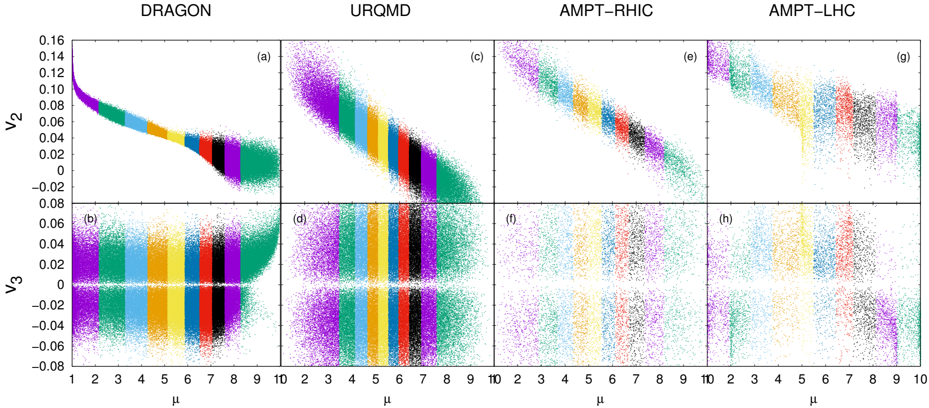
AMPT-RHIC 10 000 events by AMPT in AuAu collisions with energy $\sqrt{s_{NN}} = 200$ GeV, impact parameter $7 - 10$ fm

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

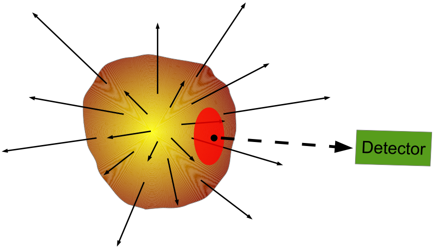
Correlation radii are parameters if the measured correlation function:

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

- 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

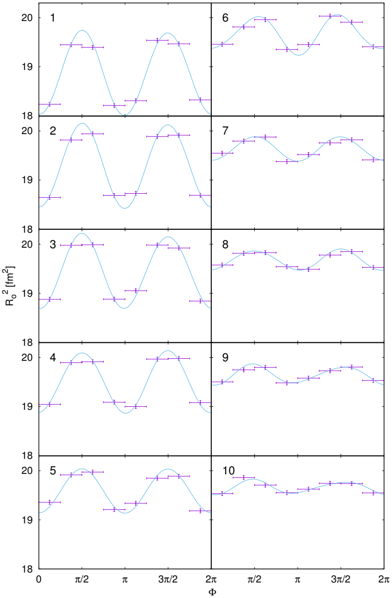
$$R_i^2(\phi) = R_{i,0}^2 + \sum_{n=1}^{\infty} R_{i,n}^2 \cos\left(n(\phi - \phi_n)\right)$$

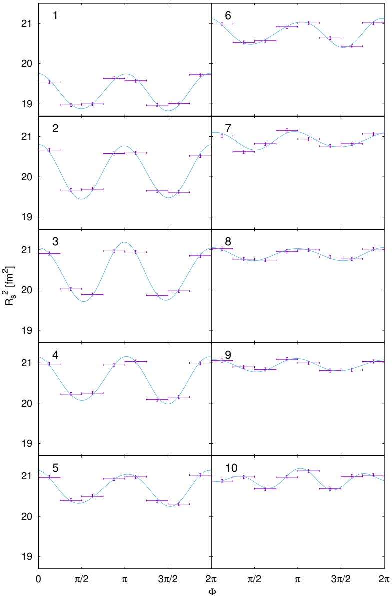
where $i = o, s, l$.

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

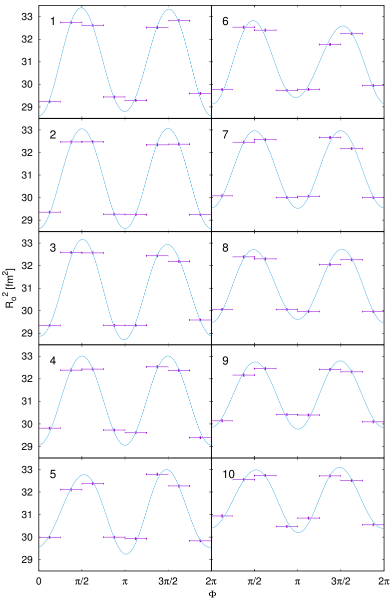
$$R_i^2(\phi) = R_{i,0}^2 \left(1 + \sum_{n=1}^{\infty} \frac{R_{i,n}^2}{R_{i,0}^2} \cos\left(n(\phi - \phi_n)\right)\right)$$

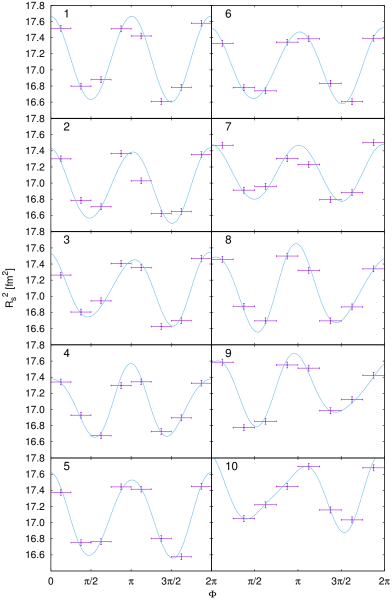
Correlation radii from DRAGON in different event bins



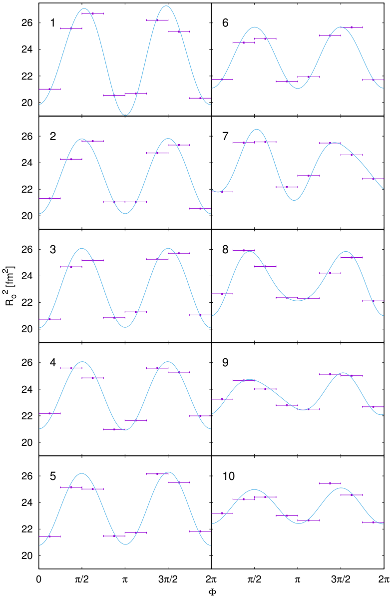


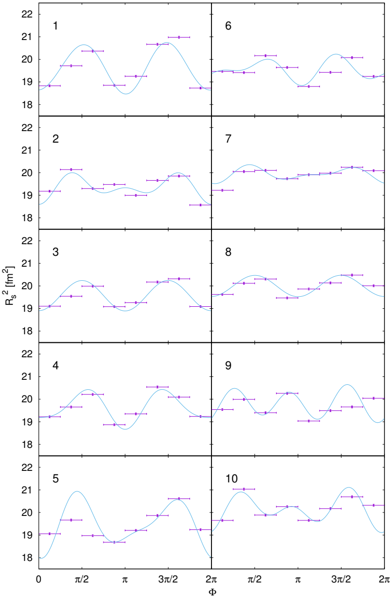
Correlation radii from UrQMD in different event bins



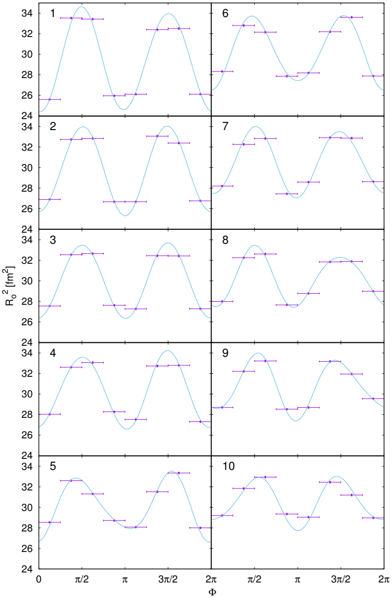


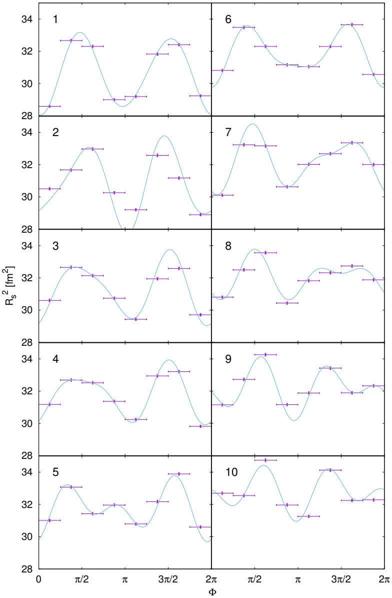
Correlation radii from AMPT-RHIC in different event bins



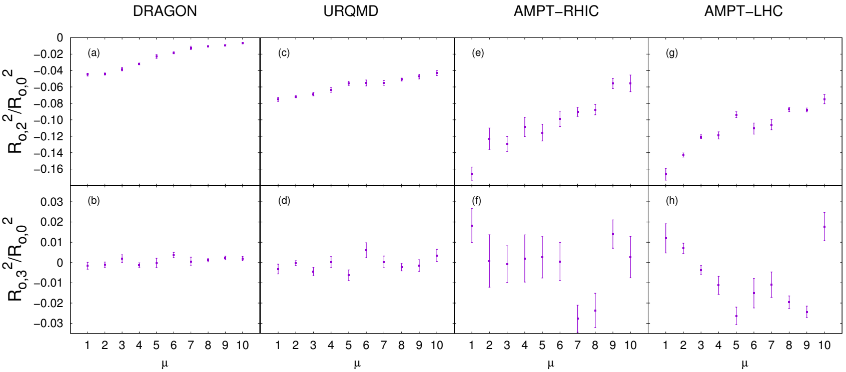


Correlation radii from AMPT-LHC in different event bins

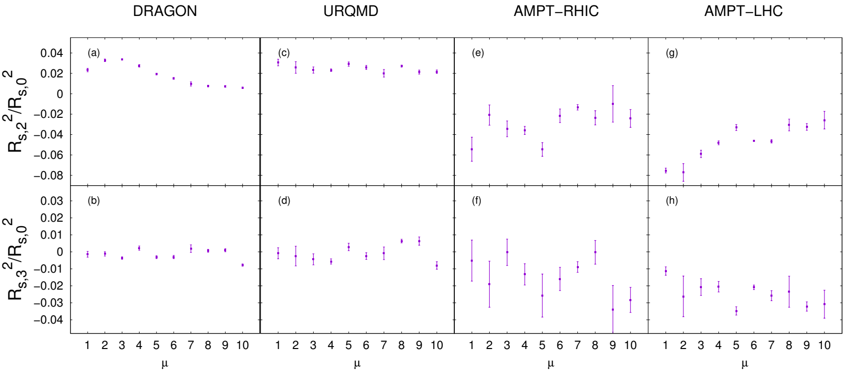


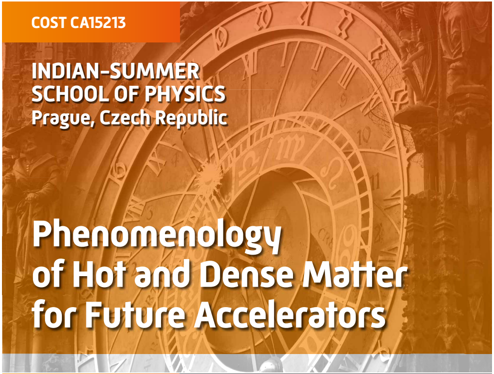


Oscillation amplitudes for R_o^2



Oscillation amplitudes for R_s^2





September 3–7, 2018

Registration deadline:
June 1, 2018

iss2018.fjfi.cvut.cz

Paul Romatschke:
Hydrodynamic evolution, flow, bulk properties

Nestor Armesto:
Hadron structure phenomenology

Konrad Tywoniuk:
Jet suppression and energy loss

Tuomas Lappi:
Initial stages of the collision, low-x physics

Mateusz Ploskon:
Overview of experimental results, EIC perspective

Chihiro Sasaki:
Theory of the deconfinement transition

Selected students from COST member states will be given a grant to cover expenses financed by the THOR COST action CA15213. Attendence is limitted to 45 participants.

Venue:
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University in Prague
Brehova 7, 11519 Prague 1

Organizers
Jan Cepila (chair), Boris Tomášik, Jesus Guillermo Contreras, Jaroslav Bielčík, Miroslav Myska, Jana Bielčíková, Jiří Mareš, Jiří Adam, Petr Bydžovský

FACULTY OF NUCLEAR SCIENCES AND PHYSICAL ENGINEERING CTU IN PRAGUE

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THOR

What is it good for?

- More selective comparison of data to theory.
- Looking for and selecting rare events.
- Construction of mixed-events background for correlation functions.
- Allows single-event femtoscopy?
- . . .

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