Event shape analysis in ultrarelativistic nuclear collisions

Renata Kopečná
in collaboration with Boris Tomášik

Faculty of Nuclear Sciences and Physical Engineering
CTU in Prague

XI Workshop on Particle Correlations and Femtoscopy

6th of November, 2015

Outline

- Motivation
- Event shape engineering
- ESSTER
  - Toy Model Monte Carlo Generator
  - Event Shape Analysis
- Results

Motivation

- Every event undergoes different initial conditions, different fluctuations
- Fluctuations lost during summation
- Mixing really *similar* events
- Single event femtoscopy?
- Studying effects of the initial geometry
  - Sorting events according to different initial conditions
  - Centrality: problematic for small ranges
  - Differently sized and shaped nuclei
- What is a good observable for 'sorting' events?

Event Shape Engineering

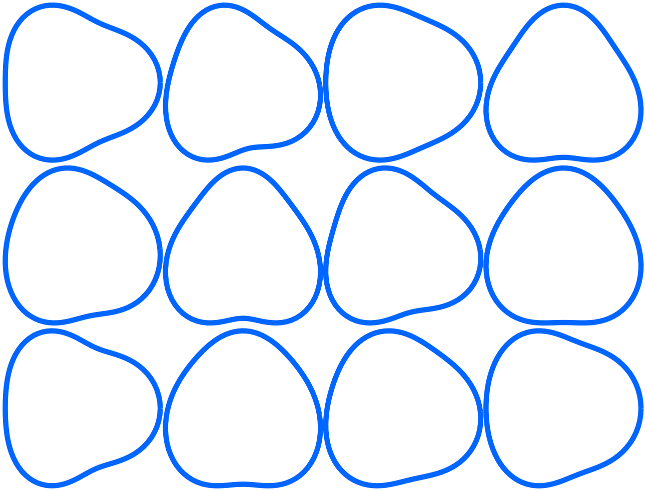
- Two subevents
  - Subevent *a*: event selection
  - Subevent *b*: physical analysis
- Helps avoiding nonphysical biases (nonflow effects)
- Information loss
- Event selection according to the magnitude of the ***reduced flow vector*** q_n

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

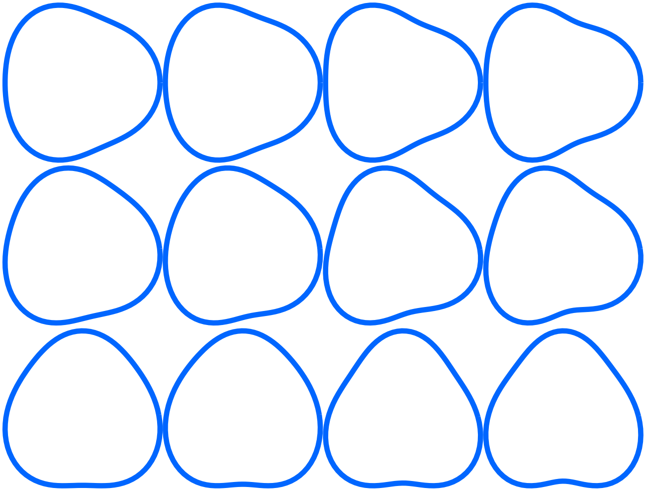
$$q_n = |\vec{Q}_n| / \sqrt{M} \, .$$

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

Ordering example

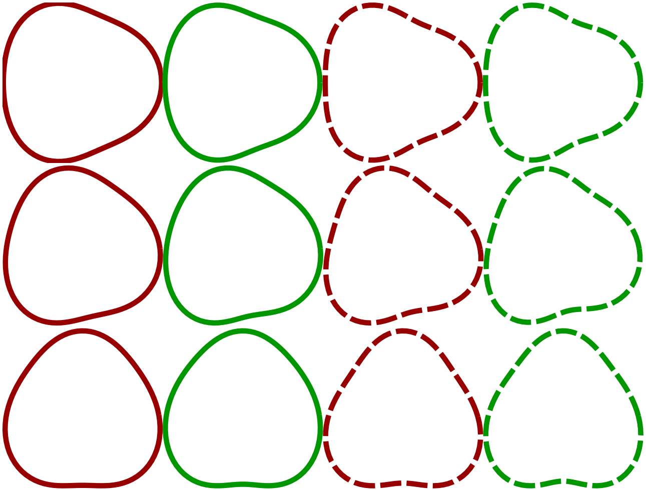


Ordering example



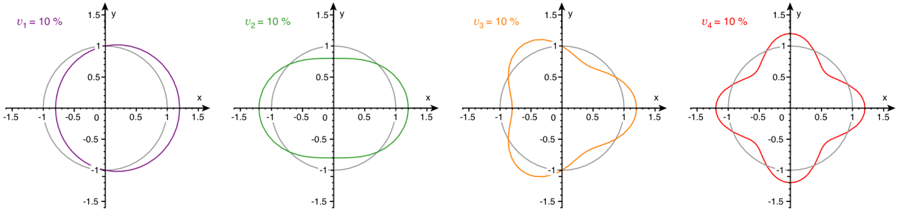
Ordering example

- Color: Same v_2
- Line/Dashed: Same v_3
- Row: Same Ψ_3



ESSTER (Event Shape SorTER)

- Toy Model MC generator
  - Azimuthal angle distribution $\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum_{n=1}^{\infty} 2v_n \cos[n(\phi - \Psi_n)]\right)$
  - $M \in (300, 3000)$
  - Flow multiplicity dependent: $v_n = a_n M^2 + b_n M + c_n$
    - Gaussian smearing
  - Ψ_n independent, uniform distribution
  - Generated 5000 events



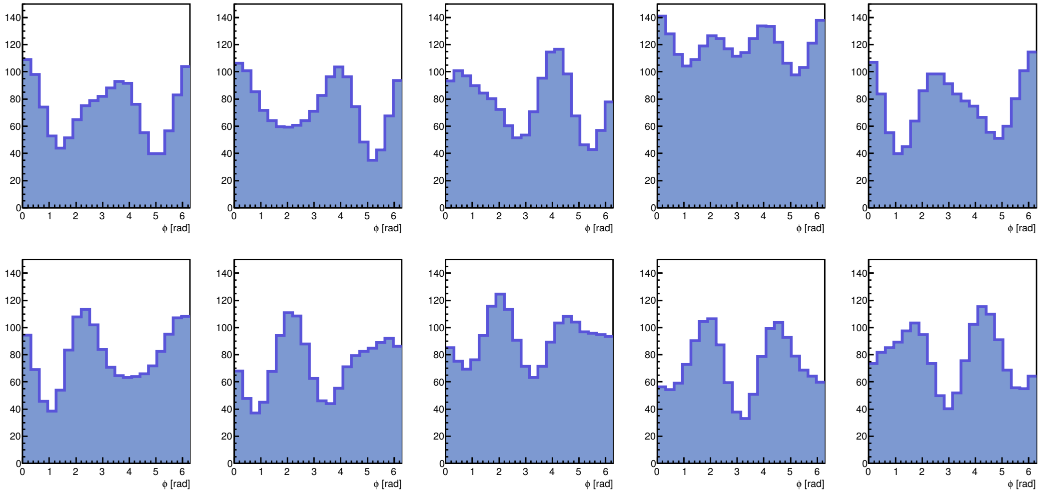
ESSTER (Event Shape SorTER)

- Event-Sorting
  - Order events according the similarity of the shape of their azimuthal angle histogram using Bayesian statistics
  - Dividing events into deciles according to a chosen variable
  - Final arrangement in the terms of $\hat{\mu}$ (1 - 10)

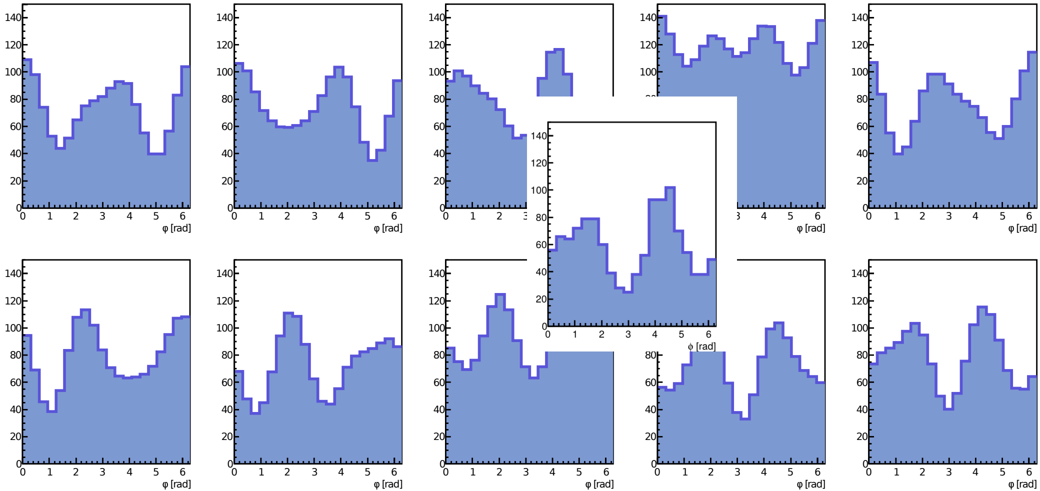
$$\hat{\mu} = \sum_{\mu} \mu P(\mu | \{n_i\})$$

  - Initial assignment error matrix
  - Correlation of $\hat{\mu}$ and several variables
  - How to initially *rotate* events?

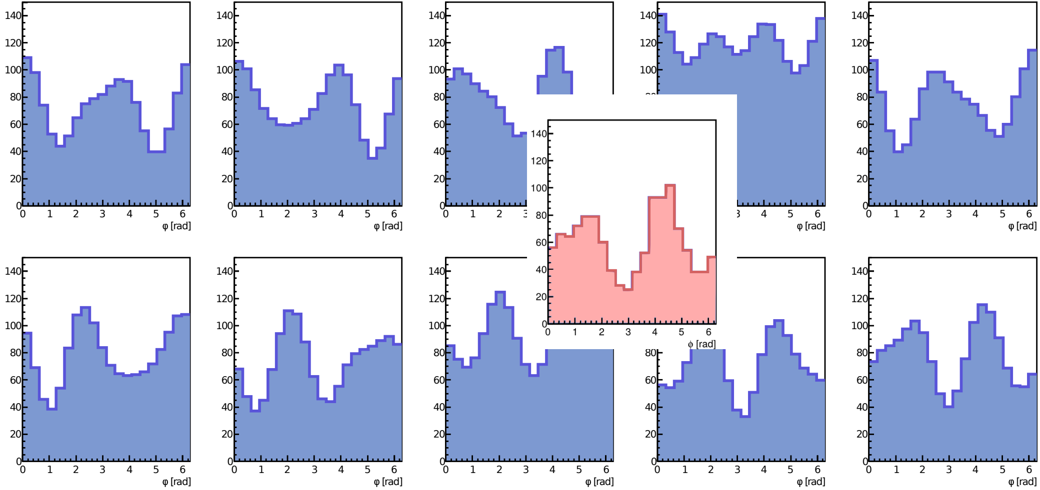
ESSTER: Assigning event to event bin



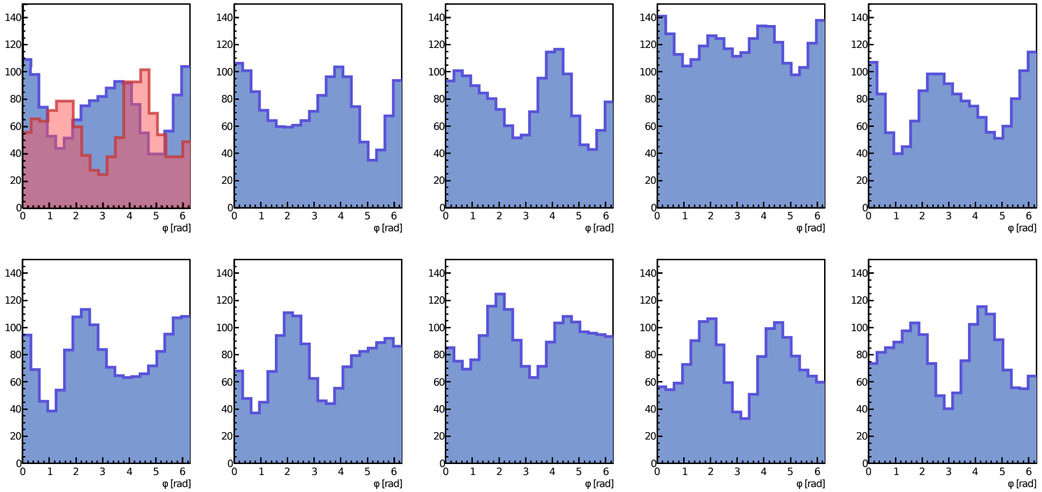
ESSTER: Assigning event to event bin



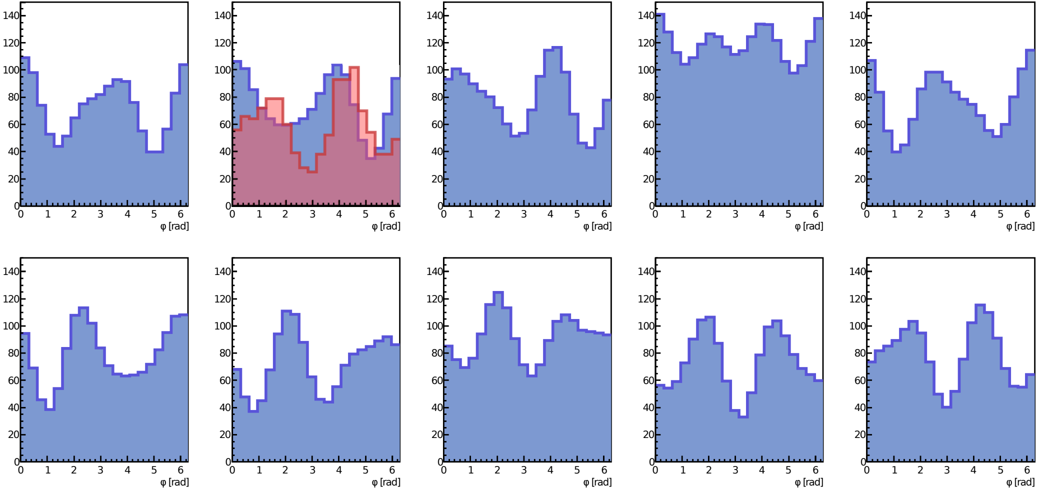
ESSTER: Assigning event to event bin



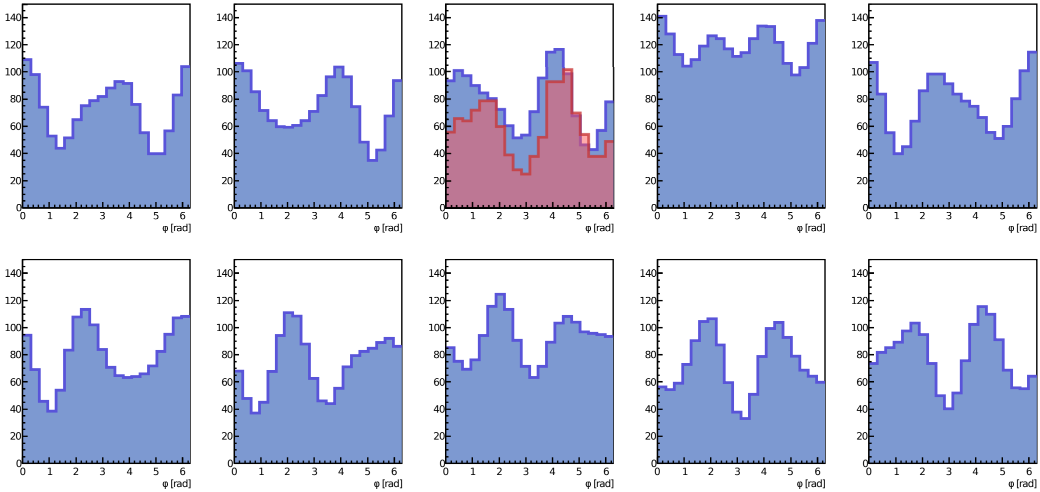
ESSTER: Assigning event to event bin



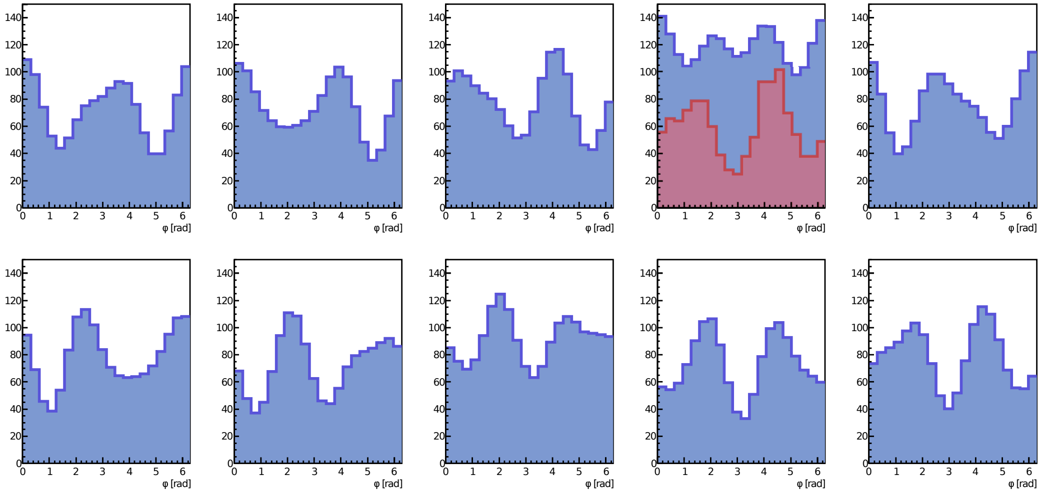
ESSTER: Assigning event to event bin



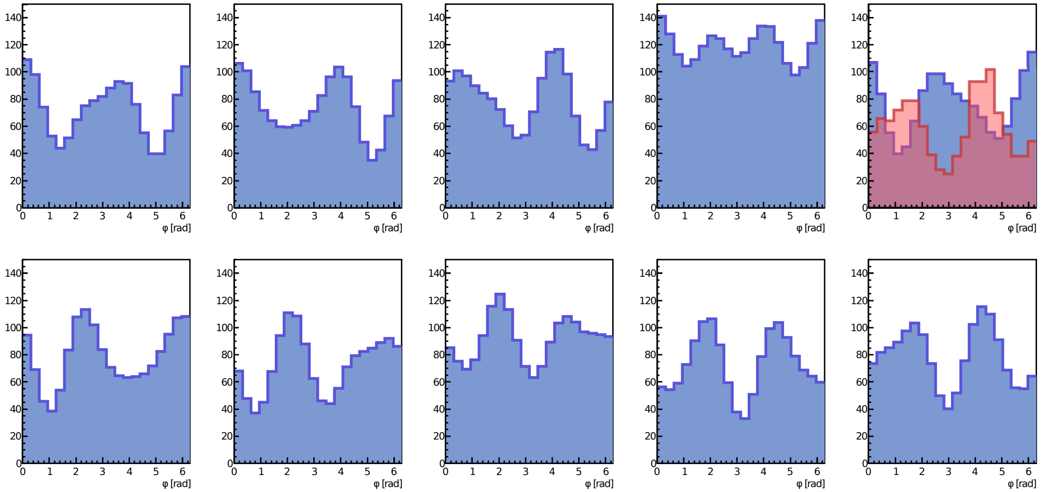
ESSTER: Assigning event to event bin



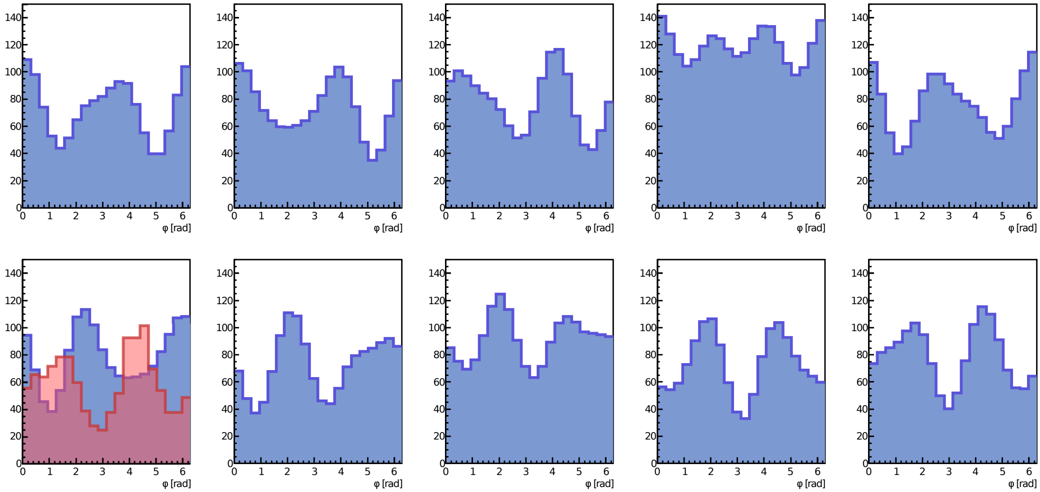
ESSTER: Assigning event to event bin



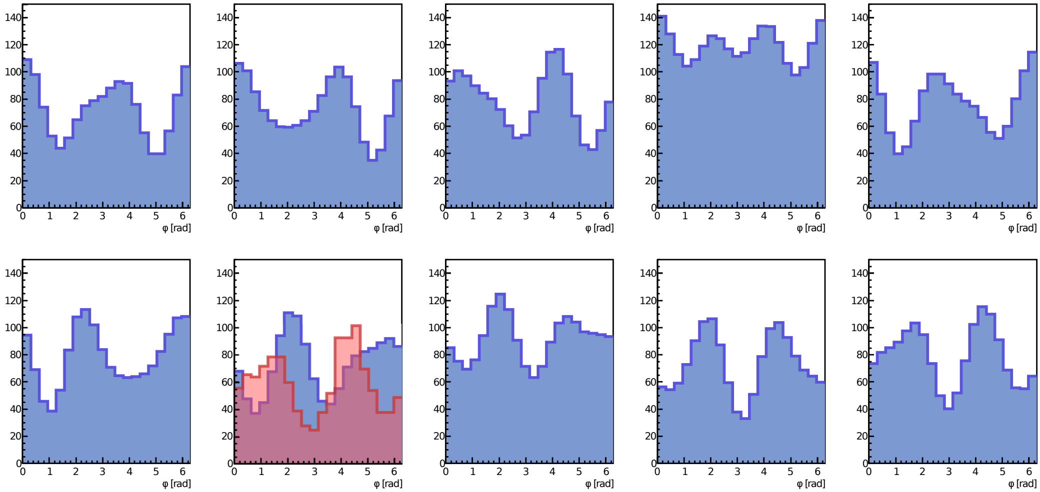
ESSTER: Assigning event to event bin



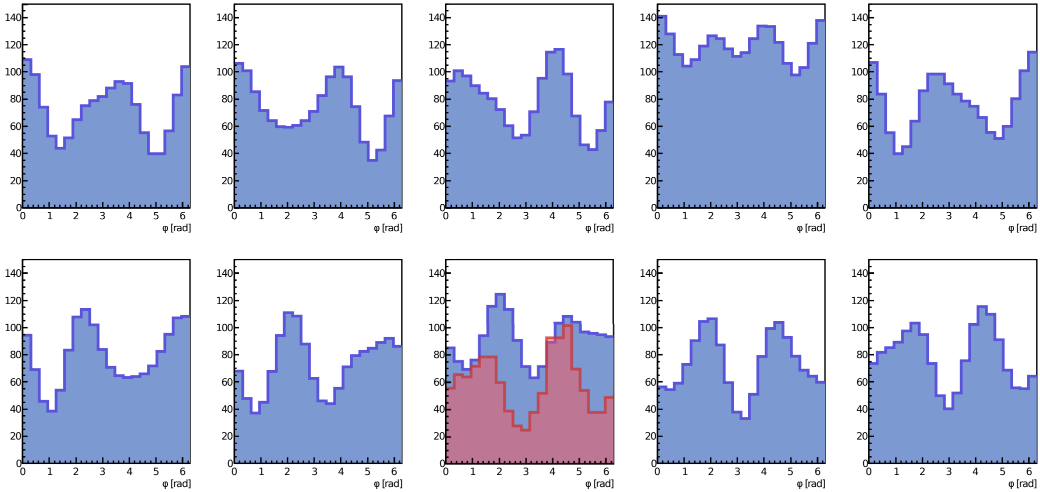
ESSTER: Assigning event to event bin



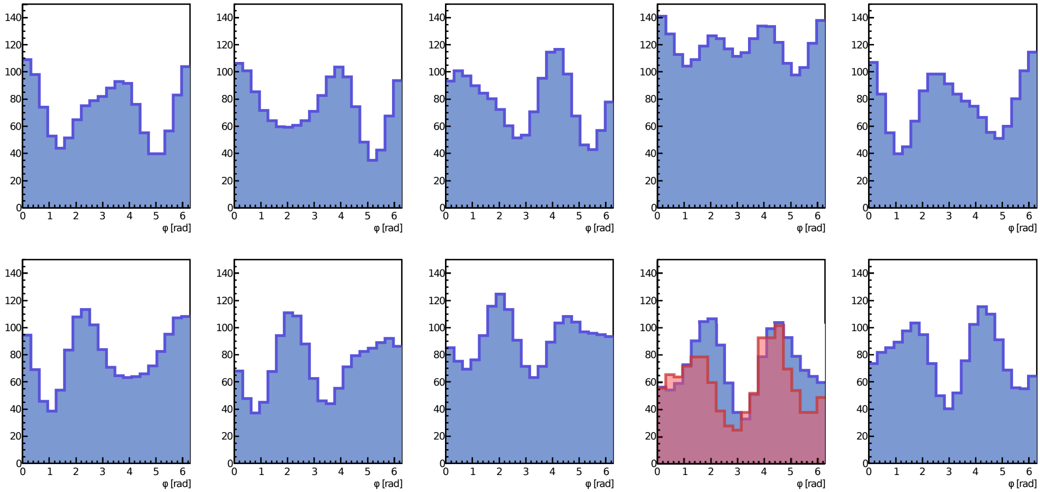
ESSTER: Assigning event to event bin



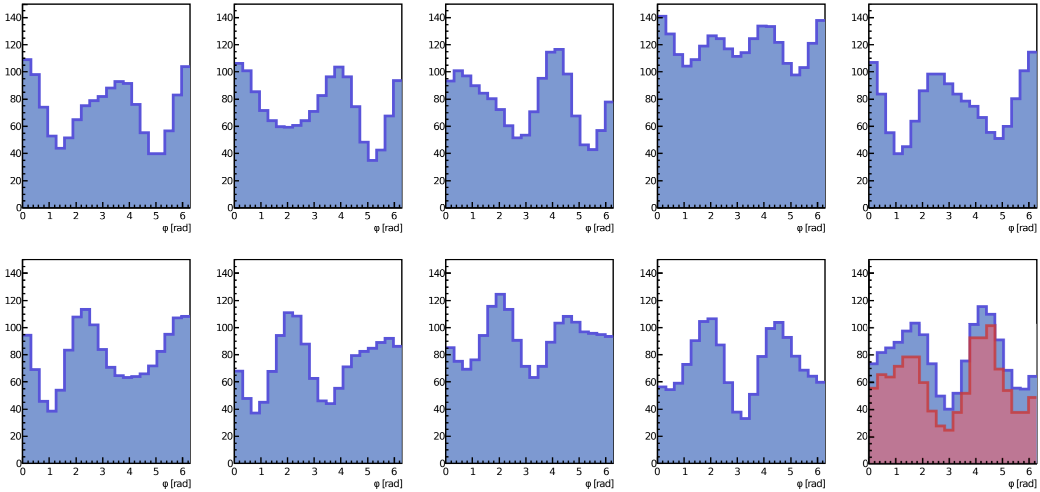
ESSTER: Assigning event to event bin



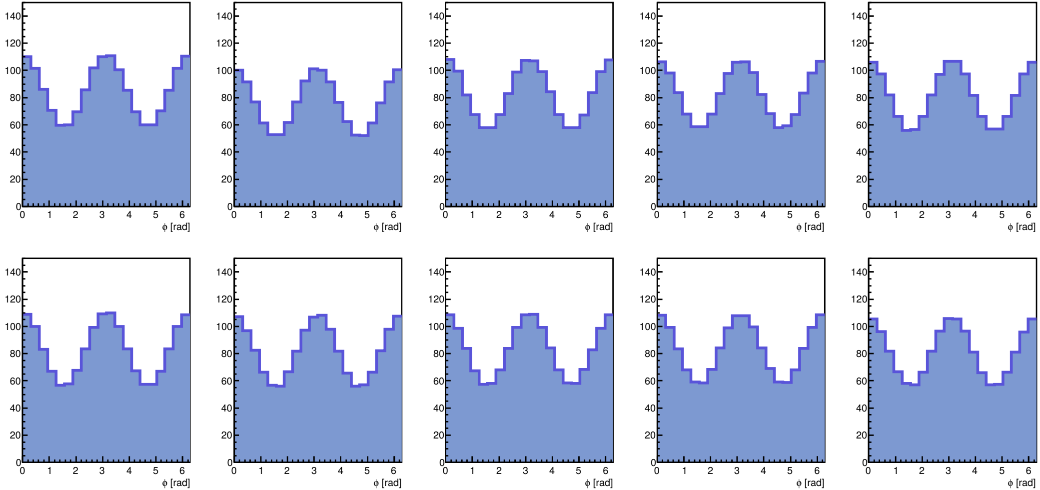
ESSTER: Assigning event to event bin



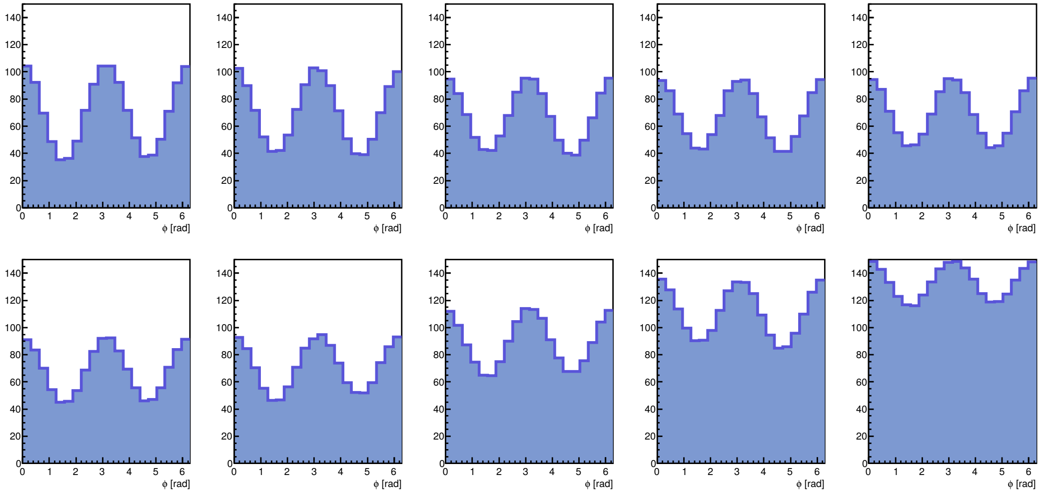
ESSTER: Assigning event to event bin



Average histograms, simple example with v_1 and v_2 only

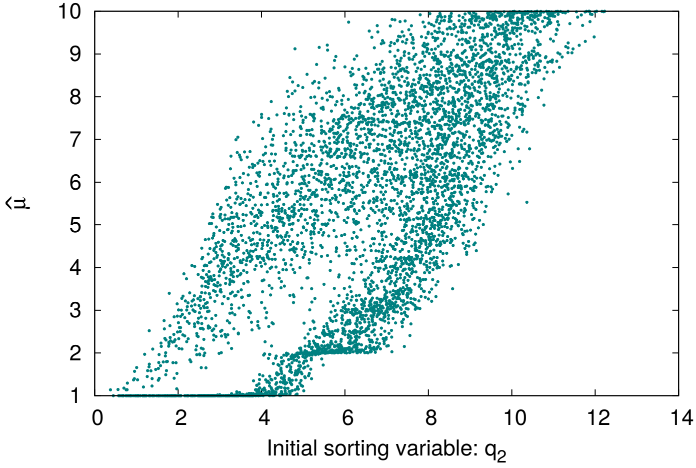


Average histograms, simple example after sorting



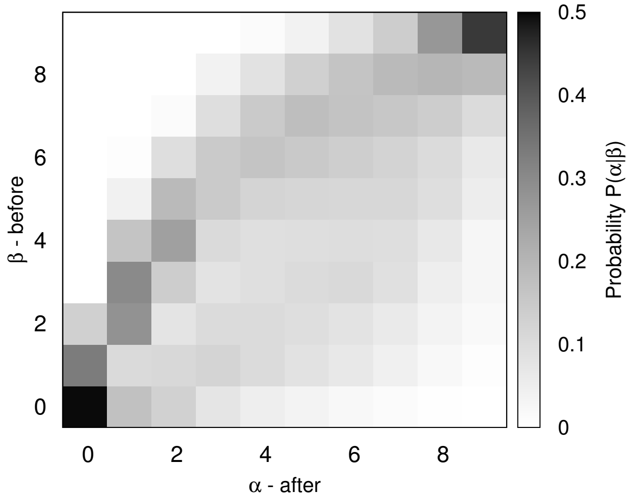
Simple example: comparison with q_2

- Initial rotation: Ψ_2
- Sort: q_2
- Each point represents one event
- Lines around integers: Distinct bins



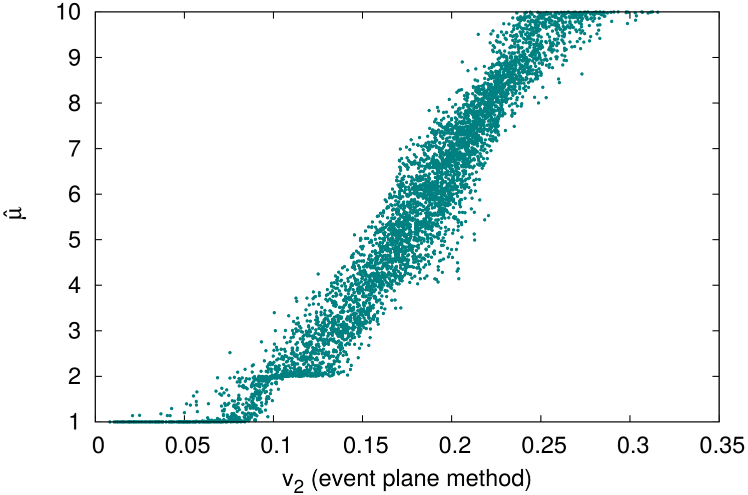
Simple example: Errors for initially q_2 sorted events

- Error of the 'original sorting variable' (in this case q_2) is the probability that event from bin β (*before*) should be in bin α (*after*)
- If the original sorting was good, we expect $\sim$ 1 around diagonal, $\sim$ 0 elsewhere.
- Not a diagonal
- Possible influence of quadratic dependence $v_2 = v_2(M^2)$
- Dark corners: finite number of bins



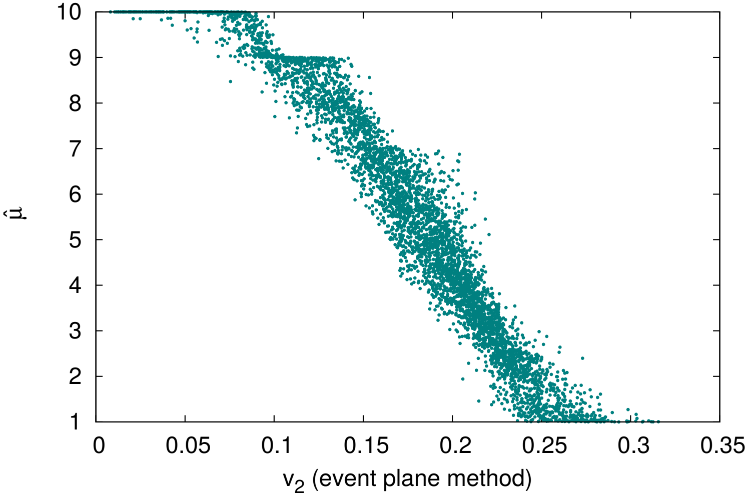
Simple example: Elliptic flow

- Correlation v_2 and $\hat{\mu}$: 0.959
- Obvious linear dependence
- v_2 might be a better measure than q_2



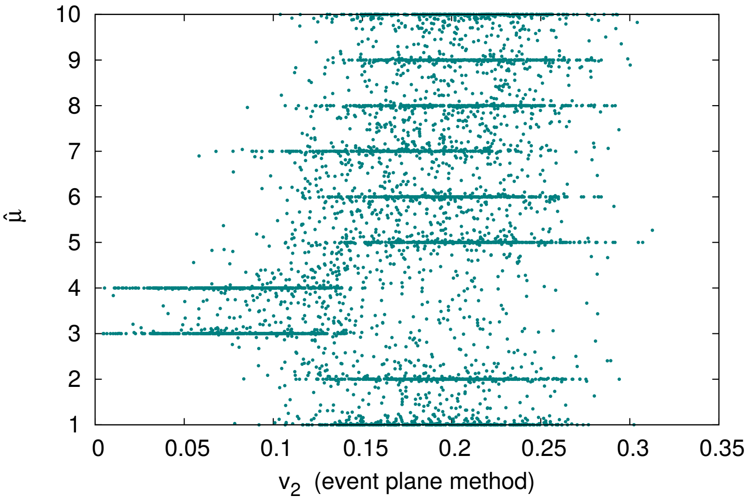
Simple example: Elliptic flow

- Correlation v_2 and $\hat{\mu}$: 0.959
- Obvious linear dependence
- v_2 might be a better measure than q_2
- Does not depend on initial sorting! (showing random initial assignment)

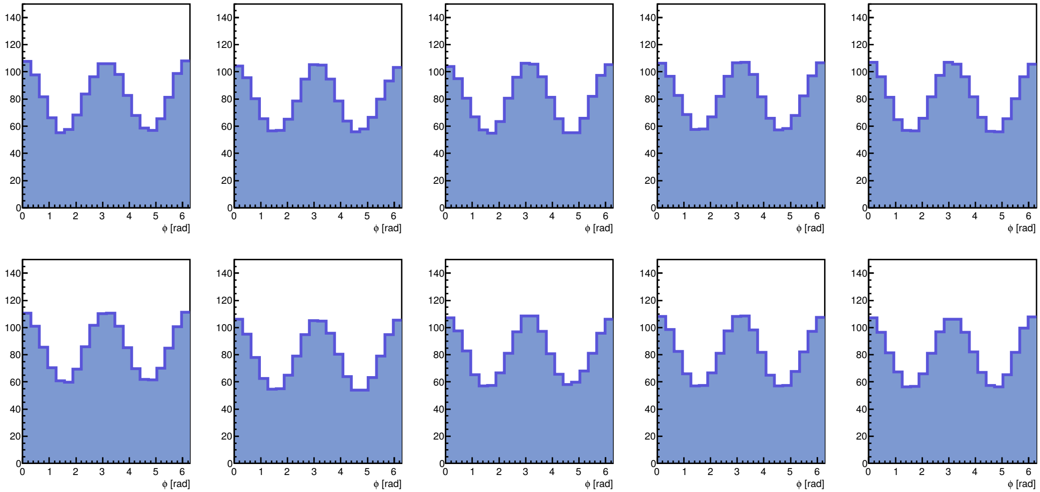


Advanced example: Flow up to v_5

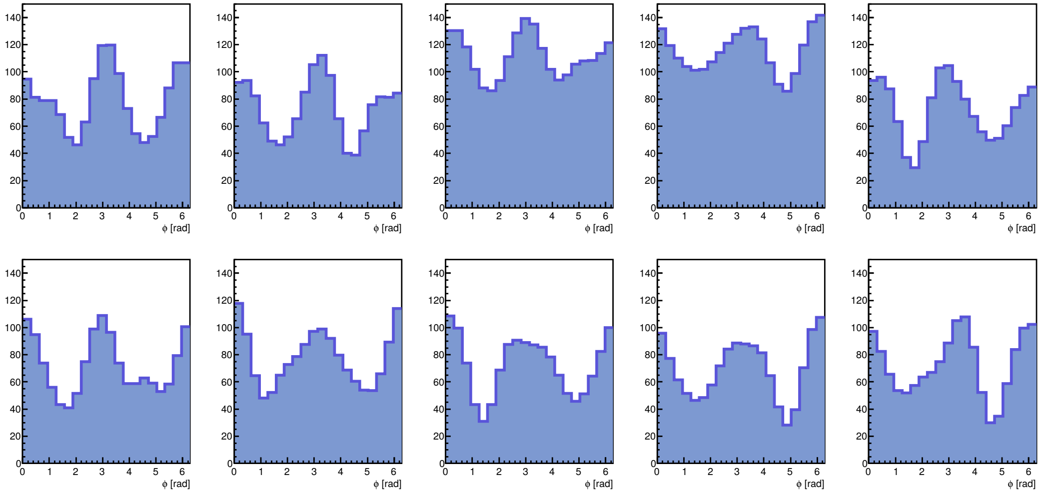
- Included flow up to v_5
- Initial rotation: Ψ_2
- Linear v_2 dependence lost
  - Interplay of other flow contributions



Advanced example: Average histograms before sorting

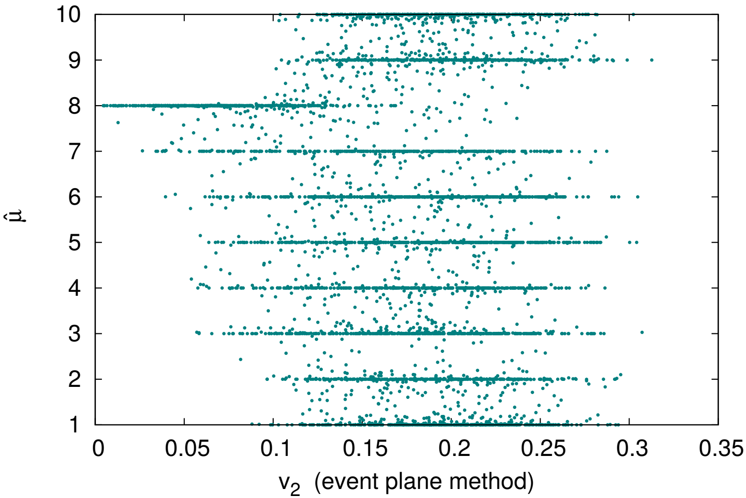


Advanced example: Average histograms after sorting

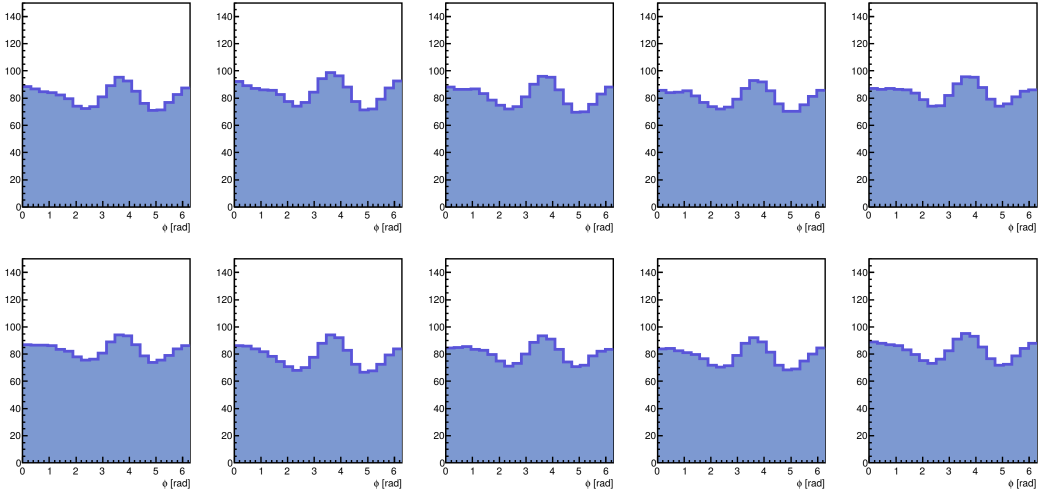


Rotation according to Ψ_2 and Ψ_3

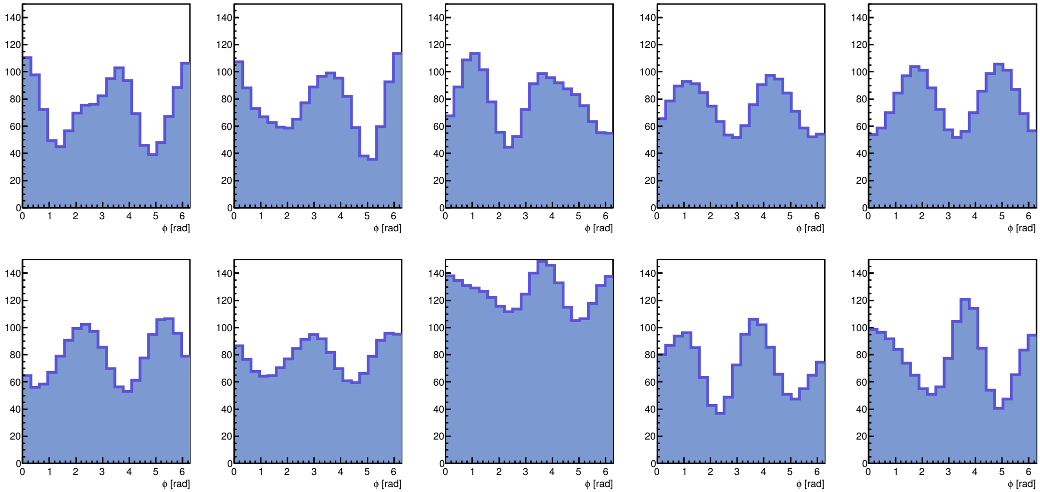
- Included flow up to v_5
- Initial rotation:
  - Angle bisector between Ψ_2 and Ψ_3
  - Ψ_2 less than $\pi/2$ counterclockwise from Ψ_3
  - Flip problem solved



Average histograms before sorting



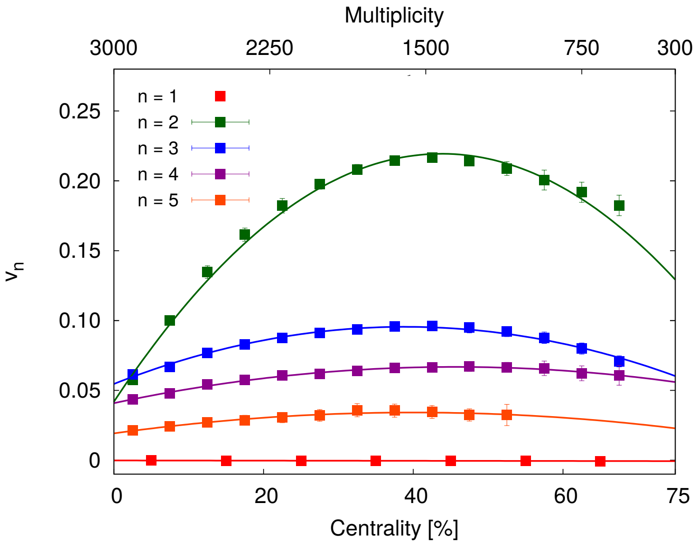
Average histograms after sorting



Conclusion & Outlook

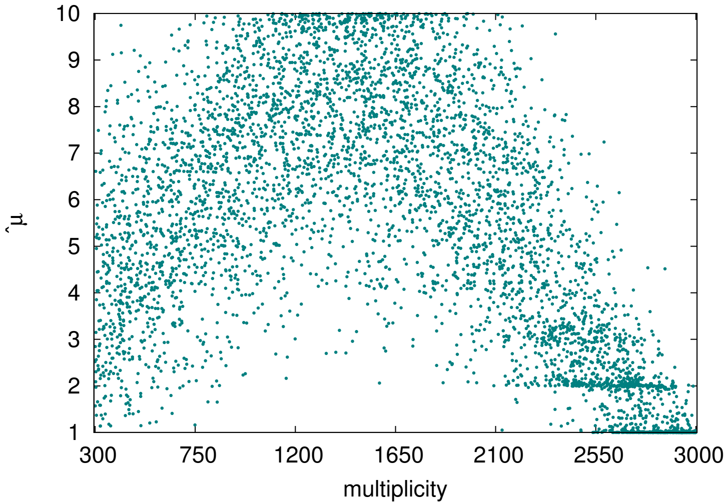
- ESSTER sorts events based on their similarity: appropriate sorting
- q_2 might not be a good measure to sort events
- v_2 might be a better measure than q_2
- **Femtoscopy**, U+U, Au+Co, He+Au collisions
- Further study of higher harmonics, histogram rotation, AMPT or other models, implementation improvement
- Renata Kopečná, Boris Tomášik: **Event shape sorting**
  arXiv: 1506.06776

Backup



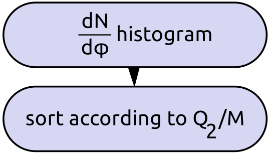
Multiplicity
3000
2250
1500
750
300
n = 1
n = 2
n = 3
n = 4
n = 5
0.25
0.20
0.15
0.10
0.05
0
v_n
0
20
40
60
75
Centrality [%]

- Does not depend on multiplicity, only *shape*!
- Follows v_2 distribution



Algorithm

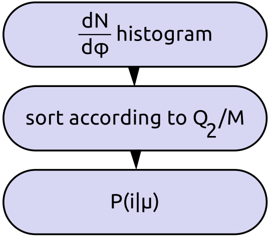
0) Histogram



- For every event make $\frac{dN}{d\phi}$ histogram
- Denoting bins as i
- Order events according to *something* (q_2) into deciles

Algorithm

1) Binning events



- Calculate the probability that particle is in i^{th} bin given the event is in event-bin μ:

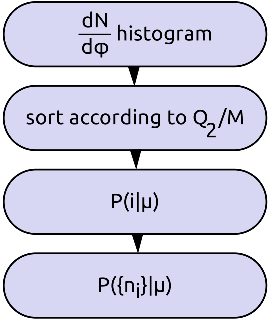
$$P(i|\mu) = \frac{\text{\# of particles in i}^{th}\text{ bin for all events in } \mu}{\text{\# of all particles in all events in } \mu}$$

Algorithm

2) Probability of event being in a bin

- Full description of any event α in μ is set of numbers $\{n_i\}$
  - Event α in μ is 'binned' according to $\frac{dN}{d\phi}$ as $\{n_1, \dots, n_i, \dots, n_{\#bin}\}$
- For each event we calculate the probability that event in bin μ will have $\frac{dN}{d\phi}$ histogram with n_i particles in each angle bin:

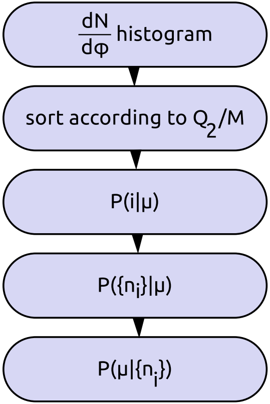
$$P(\{n_i\}|\mu) = N! \prod_i \frac{P(i|\mu)^{n_i}}{n_i!}$$



- We want to know the probability that an event with record $\{n_i\}$ belongs to the bin μ

$$P(\mu|\{n_i\}) = \frac{P(\{n_i\}|\mu)p(\mu)}{P(\{n_i\})} = \frac{P(\{n_i\}|\mu)p(\mu)}{\sum_{\mu'} P(\{n_i\}|\mu')p(\mu')}$$

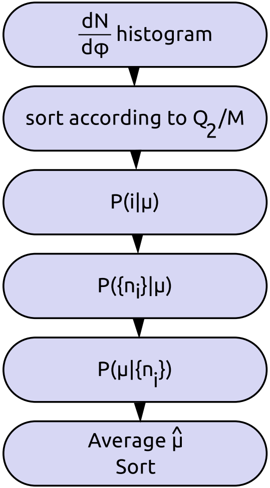
  - $p(\mu)$ is a *prior*; for deciles $p(\mu) = 1/10$
- This probability uses *all* data: fluctuations caused by 'rare' events are reduced



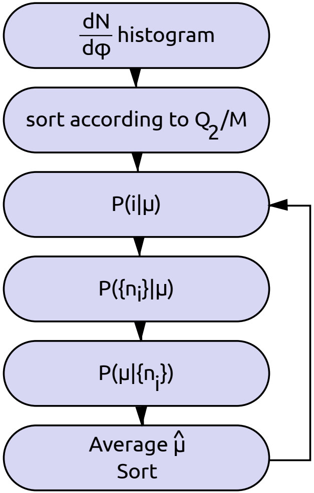
- For every event we calculate 'average bin number'

$$\hat{\mu} = \sum_{\mu} \mu P(\mu|\{n_i\})$$

- Sort according to $\hat{\mu}$



- Return to 1)
- Repeat until the μ bins remains unchanged



References

[1] S. Lehmann, A. D. Jackson, B. Lautrup: Measures and Mismeasures of Scientific Quality, Arxiv: physics/0512238

[2] R. Lednicky, Finite-size effects on two-particle production in continuous and discrete spectrum, Phys. Part. Nucl. 40 (2009) 307 [nucl-th/0501065].

[3] M. A. Lisa, S. Pratt, R. Soltz, U. Wiedemann, FEMTOSCOPY IN RELATIVISTIC HEAVY ION COLLISIONS: Two Decades of Progress, DOI: 10.1146/annurev.nucl.55.090704.151533.

[4] J. Schukraft, A. Timmins, S. Voloshin: Ultrarelativistic nuclear collisions: event. shape engineering, Phys. Lett. B 719 (2013) 394-398

[5] S. A. Voloshin, A. Poskanzer, R. Snellings, k Collective phenomena in non-central nuclear collisions. 2008. arxiv:0809.2949 *Relativistic Heavy Ion Physics, 23:293–333, 2010,* `http://dx.doi.org/10.1007/978-3-642-01539-7_10.`

[6] G. Aad et al. (ATLAS collaboration): Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{NN}}$=2.76 TeV lead-lead collisions with the ATLAS detector, Phys.Rev.C 86 (2012) 014907

References

[7] Press, S. James.: Subjective and Objective Bayesian Statistics: Principles, Models, and Applications, ISBN 9780470317945, Wiley 2009

[8] W. Press, S. Teukolsky, W. Vetterling, B. Flannery, Numerical Recipes 3rd Edition: The Art of Scientific Computing. Cambridge University Press, New York, NY, USA, 3 edition, 2007.

[9] G. Aad et al. (ATLAS collaboration): Measurement of the azimuthal anisotropy for charged particle production in at $\sqrt{s_{NN}}$ = 2.76 TeV lead-lead collisions with the ATLAS detector, Phys. Rev. C 86 (2012) 014907

[10] G. Eyyubova: Charged particle directed flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV measured with ALICE at the LHC, EPJ Web of Conferences 70 00075 (2014), DOI: 10.1051/epjconf/20147000075

[11] ROOT|A Data Analysis Framework, `http://root.cern.ch`, citation date: November 5, 2015

[12] LAPACK – Linear Algebra PACKage, `http://www.netlib.org/lapack/`, citation date: November 5, 2015