ToyFlow MC tool for FIT

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Introductions

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Motivation

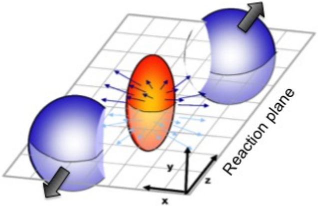
- The particle azimuthal distribution is not isotropic.
- It is customary to expand it in a Fourier series:

$$E\frac{\mathrm{d}^3N}{\mathrm{d}^3p} \propto 1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n\left(\phi - \Psi_{\mathrm{RP}}\right)\right)$$

where

$$v_n = \left\langle \cos\left[n\left(\phi_i - \Psi_{\mathrm{RP}}\right)\right]\right\rangle$$

and angled brackets mean an average over all particles in all events.



Event plane

- Problem: Ψ_{RP} is unknown when using real data.
- Define the event flow vector $\mathbf{Q_n} \in \mathbb{C}$:

$$\mathbf{Q}_n = w_i e^{in\Psi_n} \tag{1}$$

where w_i are the weights and optimally $w_i \approx v_n(p_{\mathrm{T}}, y) \propto p_{\mathrm{T}}$, with small p_{T}. Many times it is set $w_i = 1$ for all i.

$$\Psi_n = \frac{1}{n}\arctan\left(\frac{Q_{n,y}}{Q_{n,x}}\right)$$

- Now we have and now the observed v_n can be calculated using

$$v_n^{\mathrm{obs}} = \langle \cos\left[n\left(\phi_i - \Psi_n\right)\right]\rangle$$

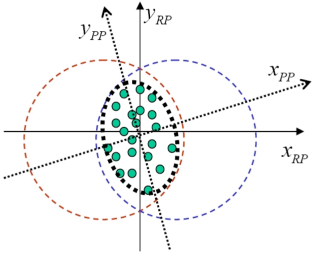


Figure: From arXiv:0809.2949v2

Event plane

A resolution parameter is defined

$$R_{n,true} = \langle \cos\left[n\left(\Psi_n - \Psi_{\mathrm{RP}}\right)\right]\rangle ,$$

so that

$$v_n = \frac{v_n^{\mathrm{obs}}}{R_{n,true}}.$$

The above definition of R_n can only be used with simulations as the Ψ_{RP} is unknown, but it can also be evaluated without the information of reaction plane by using subevents A and B.

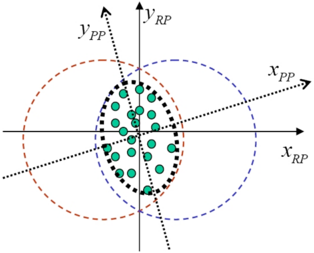


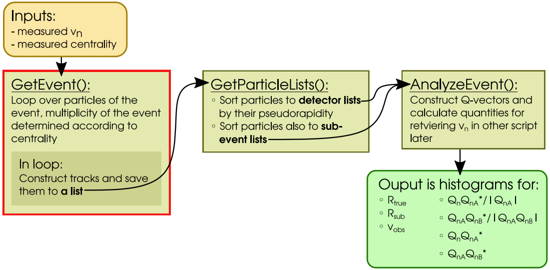
Figure: From arXiv:0809.2949v2

Toy Monte Carlo

- Toy MC to study the resolution parameter and flow coefficients
- Uses measured data for v_n and η-distribution from arXiv:1804.02944 and arXiv:1509.07299 respectively
- Code available at `https://github.com/hrytkone/ToyFlow`

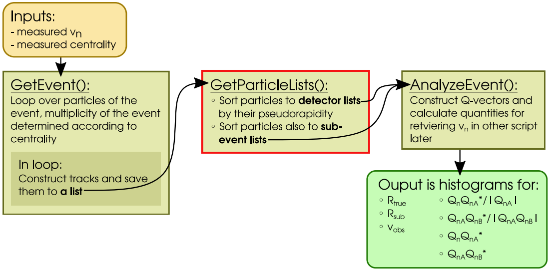
How the event is formed

- Event multiplicity taken from data according to centrality
- Then for each particle in the event
  - ϕ is taken from the Fourier series
  - η is taken from multiplicity distribution



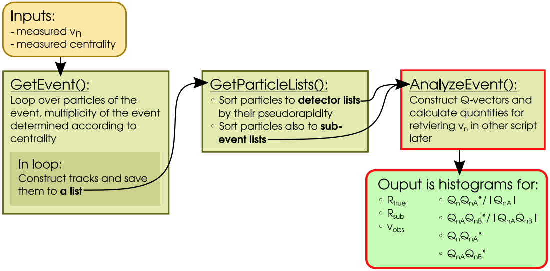
How the event is formed

- Particles in full event are divided into detector specific lists according to pseudorapidity
    - Detectors are TPC, FT0-A, FT0-C and FV0
- Particles are also divided into two sub events



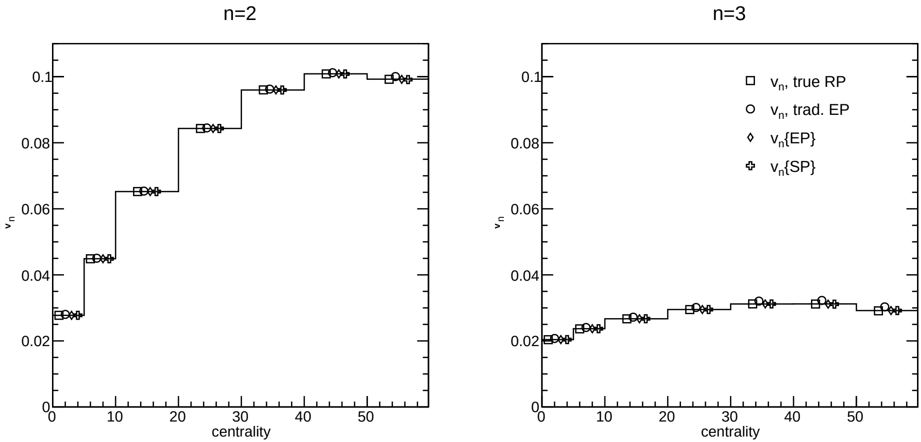
How the event is formed

- Q-vectors are then calculated
- Relevant information for retrieving the flow coefficients is saved to the histograms

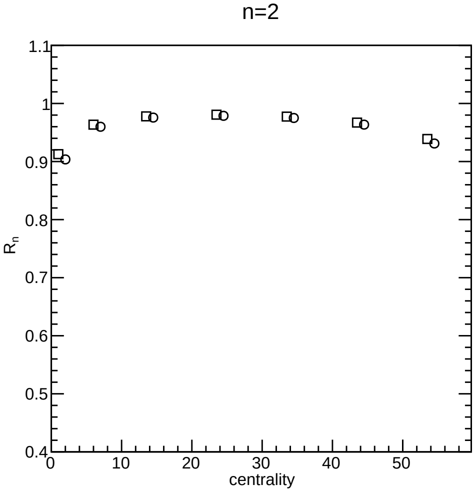


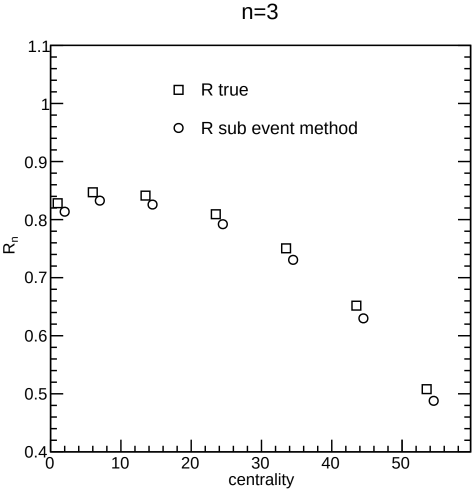
Validating

- In ideal situation the code produces the flow coefficients v_2 and v_3 well



Validating (if needed)





Simulations using FV0

- Ideal vs. gran
- Compare to Maciej: `https://indico.cern.ch/event/703569/contributions/2886293/attachments/1597688/2531598/2018.02.08-Slupecki-ToyFlow.pdf`

TODO

- TODO:
  - Subevent handling
    - In FIT?
  - Realistic geometry.
- In the future:
  - Realistic simulation of FIT.

The end

Thank you for listening

Questions?

Event plane

- R_n can also be written as

$$R_k(\chi) = \frac{\sqrt{\pi}}{2}\chi e^{-\frac{\chi^2}{2}}\left[I_{\frac{k-1}{2}}\left(\frac{\chi^2}{2}\right) + I_{\frac{k+1}{2}}\left(\frac{\chi^2}{2}\right)\right],$$

where I is the modified Bessel function and

$$\chi = v_n\sqrt{M}$$

where M is the multiplicity of the event. When comparing the same harmonic number correlation and event plane, $k = 1$ always.

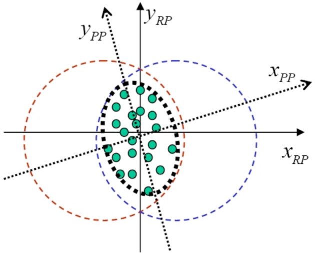


Figure: From arXiv:0809.2949v2

Event plane

- By splitting the event into two equal size independent sub-events

$$R_{n,sub} = \sqrt{\left\langle \cos\left[n\left(\Psi_n^{\mathrm{A}} - \Psi_n^{\mathrm{B}}\right)\right]\right\rangle},$$

  and then χ_{sub} can be solved iteratively from the previous page equation.

- Because $\chi \propto \sqrt{M}$, the full event $\chi = \sqrt{2}\,\chi_{\mathrm{sub}}$, and so finally full event resolution

$$R_n = R_{k=1}\left(\chi\right)$$

  and

$$v_n = \frac{v_n^{\mathrm{obs}}}{R_n}$$

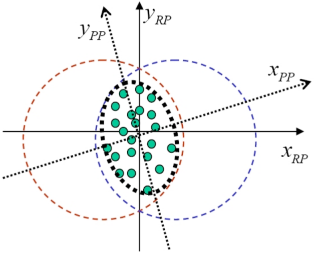


Figure: From arXiv:0809.2949v2

Event plane

- Summary table:

Table: Is possible to use.

	Simulation	Data
Ψ_{RP}	x	
Ψ_n	x	x
$R_{n,true}$	x	
R_n	x	x

- When using a simulation the methods can be validated by comparing to the true values of reaction plane and $R_{n,true}$.

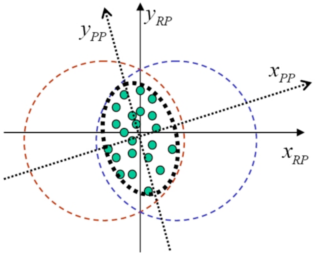


Figure: From arXiv:0809.2949v2

Event Plane (Scalar Product) method

- Another way to calculate v_n:

$$\left\langle \mathbf{Q_n} \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|}^* \right\rangle = \left\langle \mathbf{Q_n} e^{-in\Psi_n} \right\rangle \left\langle \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|} e^{-in\Psi_n} \right\rangle^* = v_n R_{n,\mathrm{A}}$$

  where the last equality is valid when $\mathbf{Q_n}$ and $\mathbf{Q_{n,A}}$ are uncorrelated, except for the common Ψ_n.
- For two subevents with equal multiplicities

$$\left\langle \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|} \frac{\mathbf{Q_{n,B}}}{|\mathbf{Q_{n,B}}|}^* \right\rangle = \left\langle \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|} e^{-in\Psi_n} \right\rangle \left\langle \frac{\mathbf{Q_{n,B}}}{|\mathbf{Q_{n,B}}|} e^{-in\Psi_n} \right\rangle^* = \left| \left\langle \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|} e^{-in\Psi_n} \right\rangle \right|^2 = R_{n,\mathrm{A}}^2$$

- The scalar product (SP) method uses the same equations but without the normalizations by the Q vector length.

Event Plane (Scalar Product) method

- Thus the v_n can be calculated using event-plane method by

$$v_n\{\mathrm{EP}\} = \left\langle \mathbf{Q_n} \frac{\mathbf{Q_{n,A}}^*}{|\mathbf{Q_{n,A}}|} \right\rangle \Bigg/ \sqrt{\left\langle \frac{\mathbf{Q_{n,A}}}{|\mathbf{Q_{n,A}}|} \frac{\mathbf{Q_{n,B}}^*}{|\mathbf{Q_{n,B}}|} \right\rangle}\,.$$

- This means that to calculate v_n, one does not necessarily need the event plane information explicitly. Only the flow vectors are necessary.
- By comparing the v_n from different methods, the validation is better.