

# ToyFlow MC tool for FIT

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# Introductions

Heidi Rytkönen

- PhD. student

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- PhD. student

Sami Räsänen

- Senior researcher

# Motivation

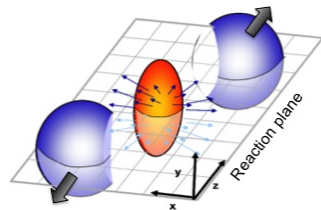
- The particle azimuthal distribution is not isotropic.
- It is customary to expand it in a Fourier series:

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

where

$$v_n = \langle \cos[n(\phi_i - \psi_{\text{RP}})] \rangle$$

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



## Event plane

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

$$\mathbf{Q}_n = w_i e^{in\psi_n} \quad (1)$$

where  $w_i$  are the weights and optimally  $w_i \approx v_n(p_T, y) \propto p_T$ , 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

$$v_n^{\text{obs}} = \langle \cos [n (\phi_i - \psi_n)] \rangle$$

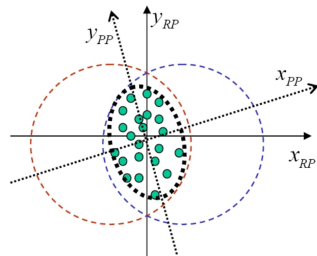


Figure: From  
arXiv:0809.2949v2

# Event plane

A resolution parameter is defined

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

so that

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

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

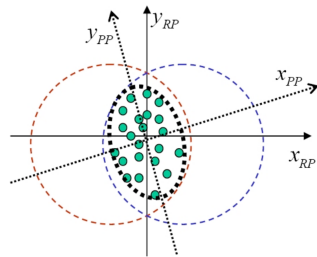


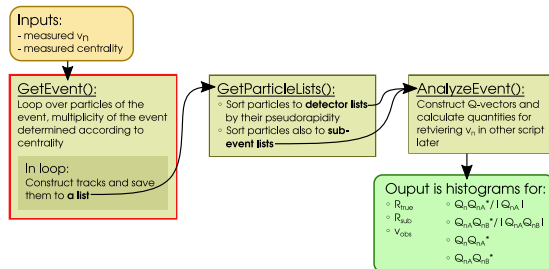
Figure: From  
arXiv:0809.2949v2

# Toy Monte Carlo

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

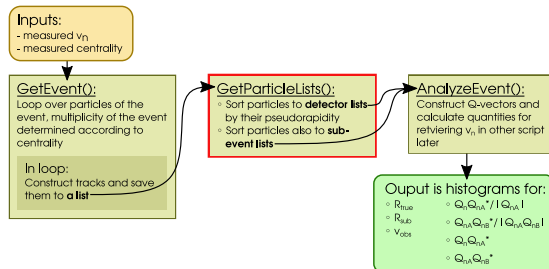
# How the event is formed

- Event multiplicity taken from data according to centrality
- Then for each particle in the event
  - $\phi$  is taken from the Fourier series
  - $\eta$  is taken from multiplicity distribution



# How the event is formed

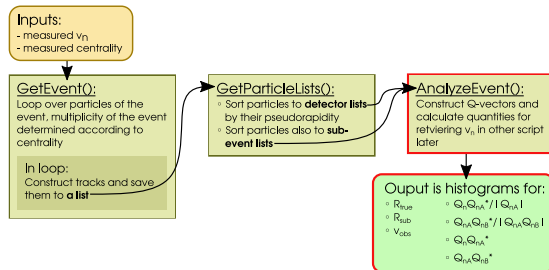
- Particles in full event are divided into detector specific lists according to pseudorapidity
  - Detectors are TPC, FT0-A, FT0-C and FV0
- Particles are also divided into two sub events





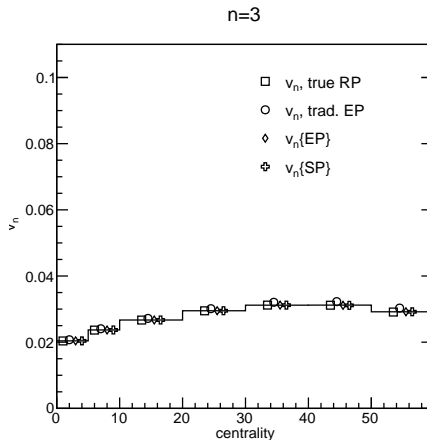
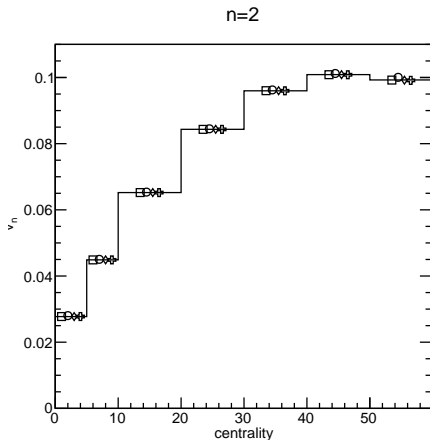
# How the event is formed

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

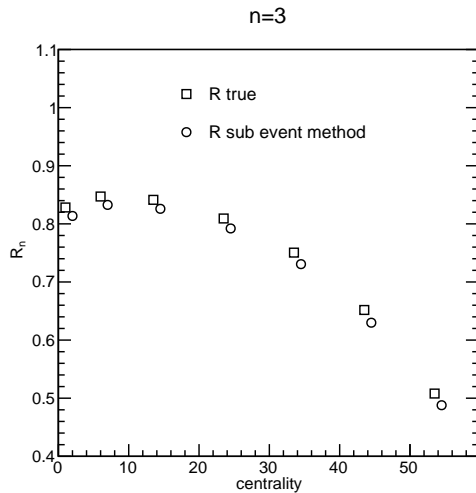
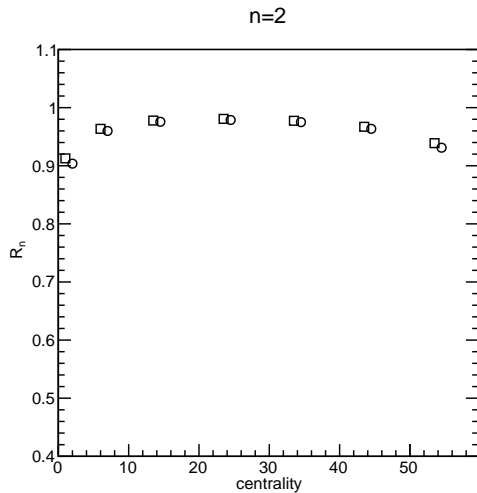


# Validating

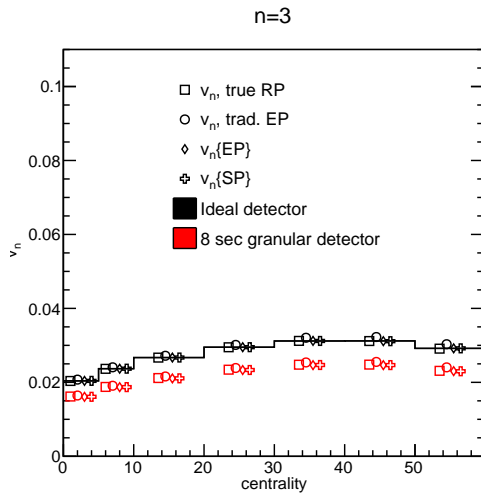
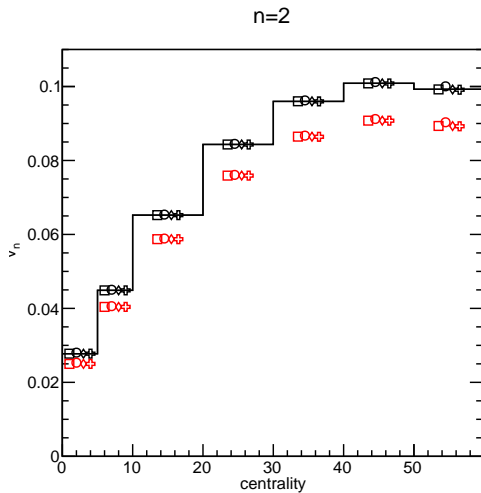
- In ideal situation the code produces the flow coefficients  $v_2$  and  $v_3$  well



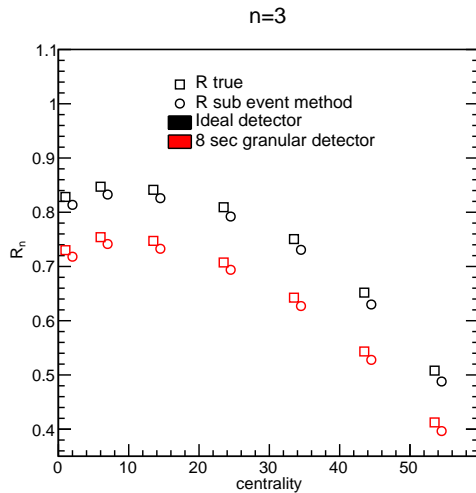
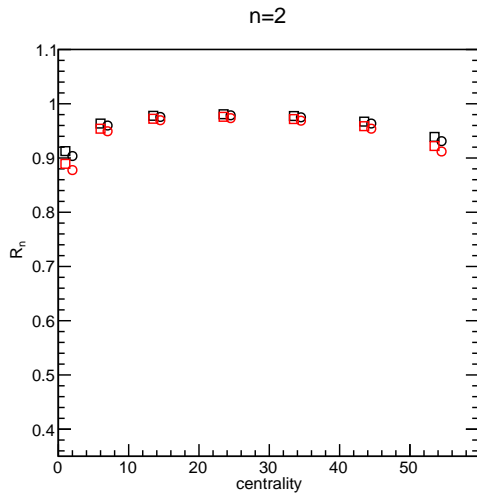
## Validating (if needed)



# Validating



## 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.

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.

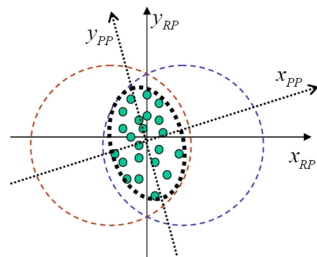


Figure: From  
arXiv:0809.2949v2

# Event plane

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

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

and then  $\chi_{sub}$  can be solved iteratively from the previous page equation.

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

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

and

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

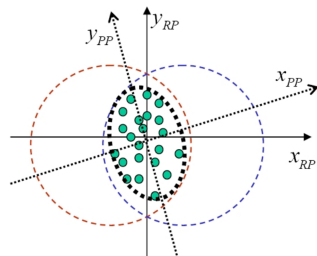


Figure: From  
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# Event plane

- Summary table:

Table: Is possible to use.

	Simulation	Data
$\Psi_{RP}$	x	
$\Psi_n$	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  $R_{n,true}$ .

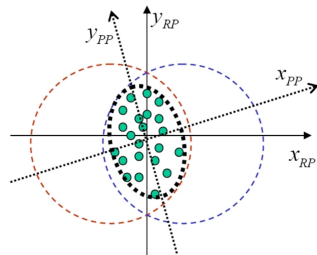


Figure: From  
arXiv:0809.2949v2

## Event Plane (Scalar Product) method

- Another way to calculate  $v_n$ :

$$\left\langle \mathbf{Q}_n \frac{\mathbf{Q}_{n,A}^*}{|\mathbf{Q}_{n,A}|} \right\rangle = \left\langle \mathbf{Q}_n e^{-in\psi_n} \right\rangle \left\langle \frac{\mathbf{Q}_{n,A}}{|\mathbf{Q}_{n,A}|} e^{-in\psi_n} \right\rangle^* = v_n R_{n,A}$$

where the last equality is valid when  $\mathbf{Q}_n$  and  $\mathbf{Q}_{n,A}$  are uncorrelated, except for the common  $\psi_n$ .

- For two subevents with equal multiplicities

$$\left\langle \frac{\mathbf{Q}_{n,A}}{|\mathbf{Q}_{n,A}|} \frac{\mathbf{Q}_{n,B}^*}{|\mathbf{Q}_{n,B}|} \right\rangle = \left\langle \frac{\mathbf{Q}_{n,A}}{|\mathbf{Q}_{n,A}|} e^{-in\psi_n} \right\rangle \left\langle \frac{\mathbf{Q}_{n,B}}{|\mathbf{Q}_{n,B}|} e^{-in\psi_n} \right\rangle^* = \left| \left\langle \frac{\mathbf{Q}_{n,A}}{|\mathbf{Q}_{n,A}|} e^{-in\psi_n} \right\rangle \right|^2 = R_{n,A}^2$$

- 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

$$v_n \{EP\} = \left\langle \mathbf{Q}_n \frac{\mathbf{Q}_{n,A}^*}{|\mathbf{Q}_{n,A}|} \right\rangle / \sqrt{\left\langle \frac{\mathbf{Q}_{n,A}}{|\mathbf{Q}_{n,A}|} \frac{\mathbf{Q}_{n,B}^*}{|\mathbf{Q}_{n,B}|} \right\rangle}.$$

- 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.