Elliptic flow of D mesons in Pb-Pb collision for ALICE

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Introduction

We want to verify the possibility at ALICE to discriminate between different elliptic flow models.
So we want to develop a method to introduce an elliptic flow in a (isotropic) Montecarlo Generator. Characteristics:

- has to be very fast
- has to use different values for v2
- manages D mesons differently from other particles

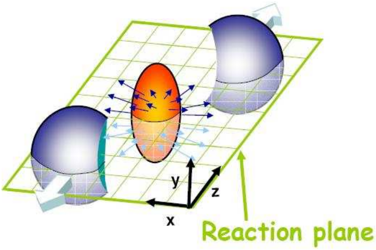
Introduction (2)

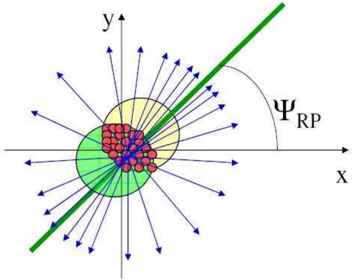
2 ways to generate ellitpic flow:

1. Build up a full hydrodinamical simulation to generate elliptic flow.
   - More precise, possible predictions
   - takes a lot of time and work
2. Generates expected particles from standard generators (PYTHIA+HIJING). Then change particles momenta distribution to introduce ellitpic flow.

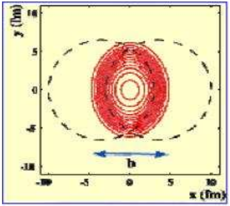
The Elliptic Flow (1)

When 2 nucleus collides with impact parameter $b \neq 0$ at high energy, interaction region is not isotropic. Thus, if the system thermalize, there are different pressures on x and y axis that force an anisotropy on momenta distribution.





The Elliptic Flow (2)



If we expand with Fourier the azimuthal particles distribution we get

$$\frac{d^3N}{p_t dp_t dy d\phi} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}(1+2v_1 cos(\phi-\Psi)+2v_2 cos[2(\phi-\Psi)]+...)$$

- 0^{th} : Radial flow
- 1^{st} : Direct flow
- 2^{nd} : Elliptic flow

$$v_n = \frac{\int d\phi cos(n\phi)\frac{dN}{d\phi}}{\int d\phi \frac{dN}{d\phi}} =< cos(n\phi) >$$

The Elliptic Flow (3)

At midrapidity, for geometrical reasons, all the terms v_n with odd n are very low.
So if it's true that $v_2 \gg v_4 \gg v_6$ we get

$$\frac{2\pi}{N_0}\frac{dN}{d\phi} = 1 + 2v_2 cos[2(\phi - \Psi)]$$

where v_2 is called *elliptic flow* and is possible to calculate it as mean value of $cos[2(\phi - \Psi)]$

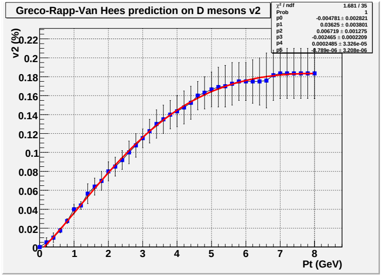
Input of v_2 (1)

A lot of different models of v_2 are going to be tested at LHC. It has to be very easy to add any new trend of v2 in the tool.
I'm working on:

- Langevin hydrodynamics. (V. Greco, H. Van Hees, R. Rapp)
- Ideal hydrodynamic models. (J. Y. Ollitrault)
- Covariant transport model. (D. Molnar)
- CGC + hydro + cascade models. (T. Hirano, M. Nardi)
- agnostic extrapolation of v2 from RHIC points.
- a model based on angular momentum conservation. (Becattini)

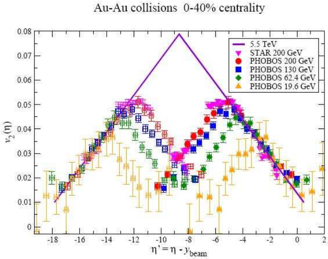
Models of v_2 (1) - Langevin

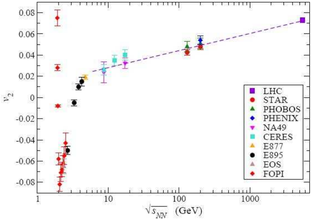
The default value of v_2 used for D mesons is taken from the Langevin model with a coalescence-fragmentation hadronization.



Modelli di v_2 (2) - Extrapolations from RHIC

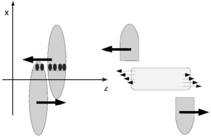
There are some universal trends (scaling dof N_{ch}/N_{ch}^{pp} with $< N_{part} >$, scaling of $< N_{ch} > / < N_{part} >$ with $ln^2\sqrt{s}$) that allow us to build expected pseudorapidityh distribution.
We can use it to extend $v_2(\eta)$ from RHIC to LHC.





This way pions are expected to have an ellitpic flow between 7% and 8%.

Models of v_2 (3) - Angular momentum



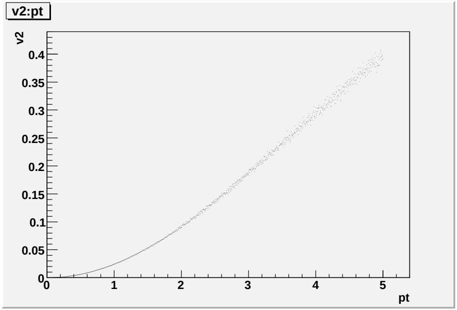
Bjorken hypotheses implies $\frac{\partial v_z}{\partial x_i} \approx 0$ but these hypotheses doesn't allow angular momentum global conservation. If we don't make it we find out that

$$\epsilon_0 \gamma_0^3 \frac{\partial u_i}{\partial t} \Big|_{t=0} = -\frac{1}{4} \frac{\partial \epsilon \gamma^2}{\partial x_i} \Big|_{t=0} + \frac{1}{4} 2 \epsilon_0 \gamma_0^4 v_{z0} \frac{\partial v_{z0}}{\partial x_i} \Big|_{t=0}$$

- First term: spatial anisotropy (standard)
- Second term: new term due to angular momentum conservation

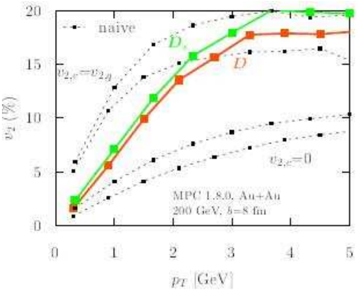
Models of v_2 (4) - Angular momentum

It's not trivial getting from the equation before to an analytical expression for v_2. If we use a spinning rigid sphere (not realistic) we have this result



Models of v_2 (5) - Covariant transport

The system is made of 3 massless quarks (u, d, s) and 1 massive (c). It evolves through 2 body into 2 body collisions (both elastic and inelastic).
Hadronization is made thorugh coalescence.
Not all the processes are taken itno account $\Rightarrow$ Overestimates x-sections.



Test values

in order to be able to test the program, we're at the moment using the following settings for v_2:

- a constant v_2 of 0.07 for kaons and pions (expected midrapidity value).
- a constant v_2 of 0.05 for protons.
- a p_T dependent value of v_2 for D mesons based on a coalescence-fragmentation scheme (Van Hees - Greco - Rapp).

The tool

The tool works in sequential steps:

1. Generation of the particles via cocktail (HIJING + PYTHIA) of generators.
    - Heavy quarks switched off in HIJING, they are generated by PYTHIA. The number of $c\bar{c}$ couples reproduces pQCD next to leading order calculations for Pb-Pb (MNR).
    - The generation is isotropic.
2. Reading of the Kinematics: are selected pions, kaons, protons and D mesons.
    - We throw away particles coming from D decays.
    - Kinematic cuts (pseudorapidity, decay region...)
3. Introduction of the elliptic flow $\Leftarrow$
4. Decay of the D mesons $\Leftarrow$

Introduction of the elliptic flow (1)

The standard method (used also in the afterburner class of Aliroot) to introduce elliptic flow in a set of isotropically generated particles is (Poskanzer - Voloshin)

arXiv:nucl-ex/9805001v2 24 Jun 1998

Methods for analyzing anisotropic flow in relativistic nuclear collisions

A. M. Poskanzer[1] and S. A. Voloshin[2]*

V. SIMPLE WAY TO INTRODUCE FLOW IN A MONTE-CARLO EVENT GENERATOR

Sometimes in order to investigate different detector effects or the reliability of the method, one needs to introduce anisotropic flow into a Monte-Carlo event generator. It can be done by changing the azimuthal angle of each particle (and consequently changing the density in the azimuthal angle space)

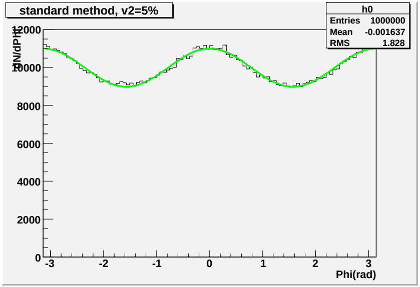
$$\phi \to \phi' = \phi + \Delta\phi, \quad (34)$$

where

$$\Delta\phi = \sum_n \frac{-2}{n} \tilde{v_n} \sin(n(\phi - \psi_0)), \quad (35)$$

Introduction of the elliptic flow (2)

for v2 higher than 5% our distribution is not following the expected $\frac{dN}{d\phi'} = 1 + 2v_2 cos(2\phi')$ (Fourier expansion).



green: expected trend and higher armonics; black: simulation result.

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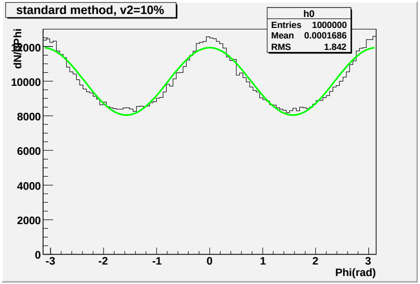

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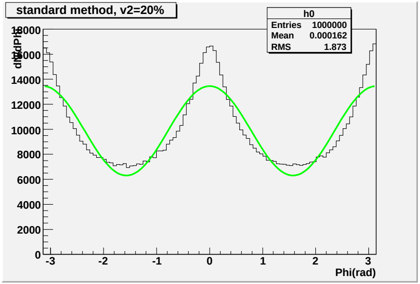

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Introduction of the elliptic flow (3)

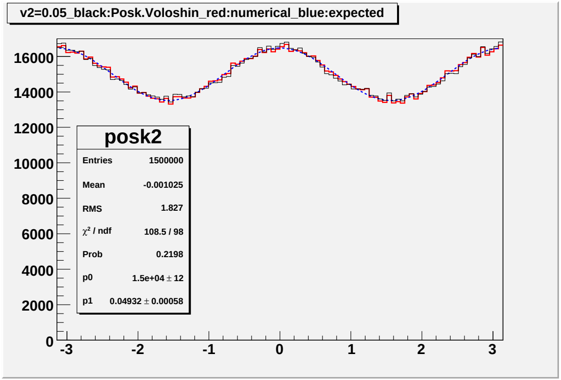
We start from isotropic distributions $\Rightarrow \frac{dN}{d\phi} = K$ and we want to get a distribution like $\frac{dN}{d\phi'} = 1 + 2v_2 cos(2\phi')$

$$K = \frac{dN}{d\phi} = \frac{dN}{d\phi'}\frac{d\phi'}{d\phi} = [1 + 2v_2 cos(2\phi')]\frac{d\phi'}{d\phi}$$

so, very easily

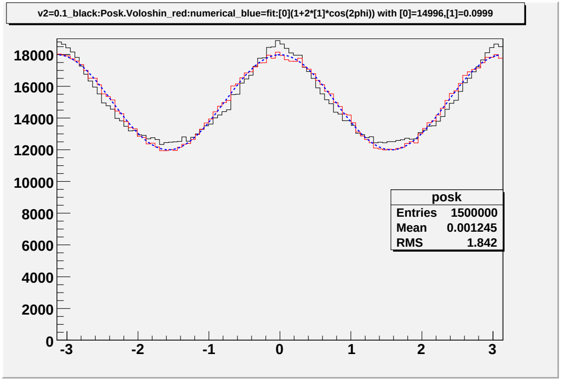
$$\phi' = \phi - v_2 sin(2\phi')$$

which is the same of the Poskanzer-Voloshin equation $\phi' = \phi - v_2 sin(2\phi)$ only in the approximation of low v_2 $(\phi' \sim \phi)$.we can solve the correct equation above using Newton roots method, and we get...



Blue: expected trend; Red: Simulation result; Black: Poskanzer-Voloshin simulation result.

Introduction of the elliptic flow (4)



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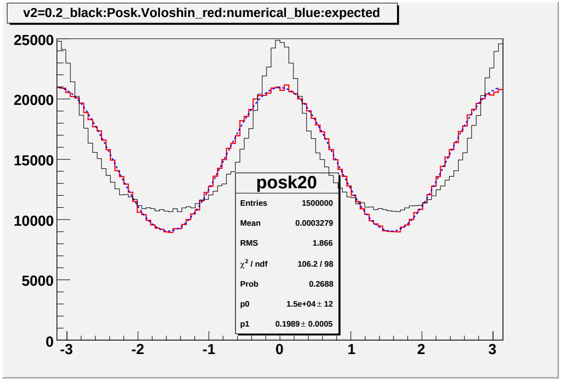

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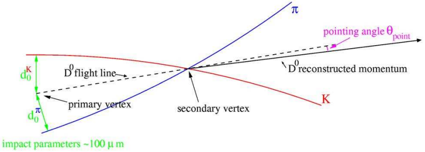
Decayer (1)

The decayer is the last step of the process. We need to decay only D mesons, all the other decays were already made by PYTHIA. We force the D mesons to decay in the (golden) channels:

- $D^0 \longrightarrow K^+ \ \pi^-$
- $D^+ \longrightarrow K^- \ \pi^+ \ \pi^+$
- $D_s^+ \longrightarrow K^- \ K^+ \ \pi^+$



Decayer (2)

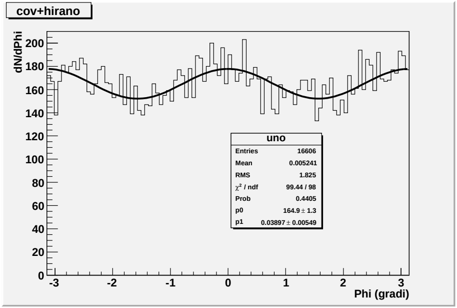
The 2-body decay is made generating a isotropic decay in the CM rest frame and then boosting in the lab frame.

The 3-body decay is made using 2 subsequential 2-body decay ($D \rightarrow 1 + 23 \rightarrow 2 + 3$).

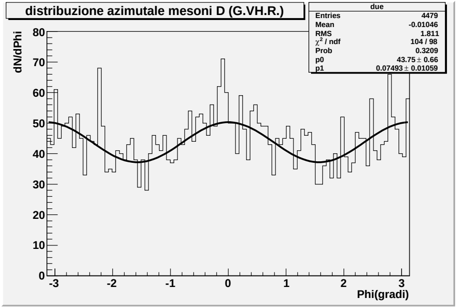
Matrix element corrections and phase space weights are calculated as in PYTHIA decayer.

Resonance decays are taken in account with theyr relative probability.

Results (1)

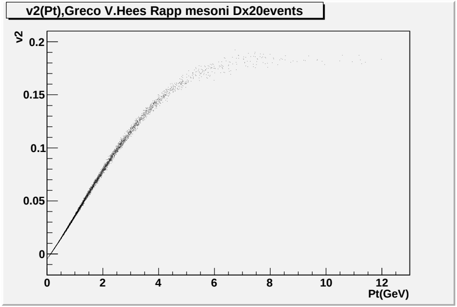


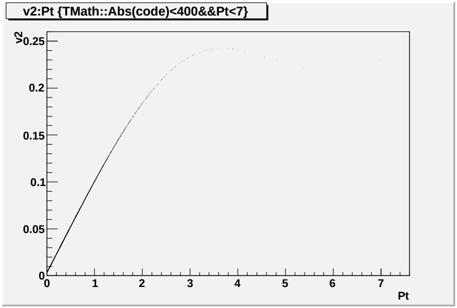
Pions azimuthal distribution in 1 mid-central Pb-Pb event(CGC+hydro for $p_t < 3$ GeV, covariant transport elsewhere)



D mesons azimuthal distribution in 20 mid-central Pb-Pb events.(Langevin hydro)

Results (2)

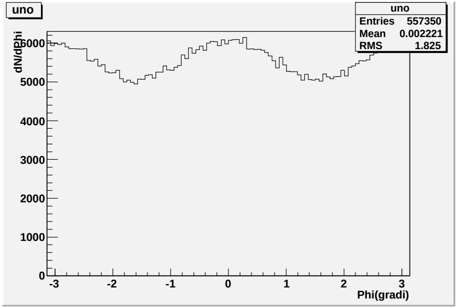


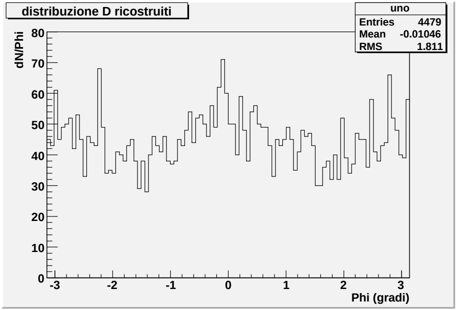


$v_2(p_t)$ for D mesons in 20 smidcentral Pb-Pb events (Langevin hydro)

$v_2(p_t)$ for pions in 1 midcentral Pb-Pb event (covariant transport)

Results (3)





azimuthal distribution of particels after decayer

azimuthal distribution of reconstructed D mesons

Conclusions

Is this method fast? Does it use too much memory?

- Time to run a 1 event Pb-Pb generation (PYTHIA + HIJING, ITS switched off) on standard machine: $\approx$ 5 minutes
- Time to run afterburner and decayer on standard machine: $\approx$ 2 minutes and a half.
- Space on disk used by all the files created by the generator: 6,3 Mb
- Space on disk used by the files created by this tool: 8 Mb