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Condições iniciais utilizando PYTHIA para simulações hidrodinâmicas

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CAMPINAS

2022

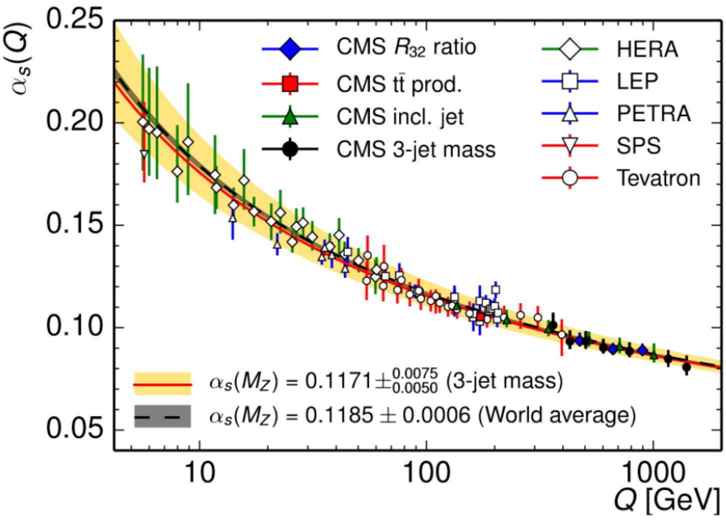
"It's the questions we can't answer that teach us the most. They teach us how to think. If you give a man an answer, all he gains is a little fact. But give him a question and he'll look for his own answers."

The Wise Man's Fear

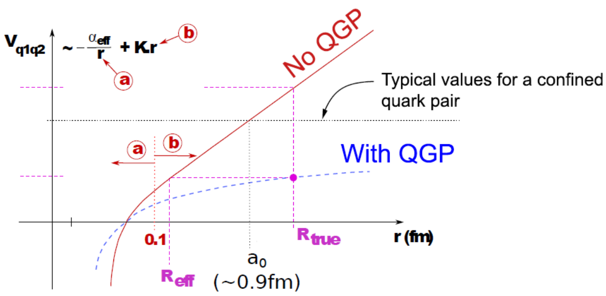
Palavras-chave

Keywords

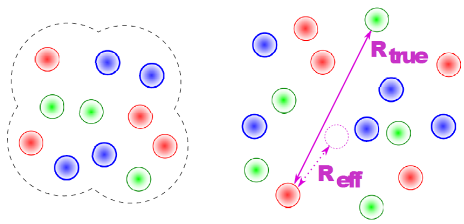
Big Bang



$\alpha_s(Q)$
0.25
0.20
0.15
0.10
0.05
10
100
1000
Q [GeV]
CMS R_{32} ratio
CMS $t\bar{t}$ prod.
CMS incl. jet
CMS 3-jet mass
HERA
LEP
PETRA
SPS
Tevatron
$\alpha_s(M_Z) = 0.1171^{+0.0075}_{-0.0050}$ (3-jet mass)
$\alpha_s(M_Z) = 0.1185 \pm 0.0006$ (World average)



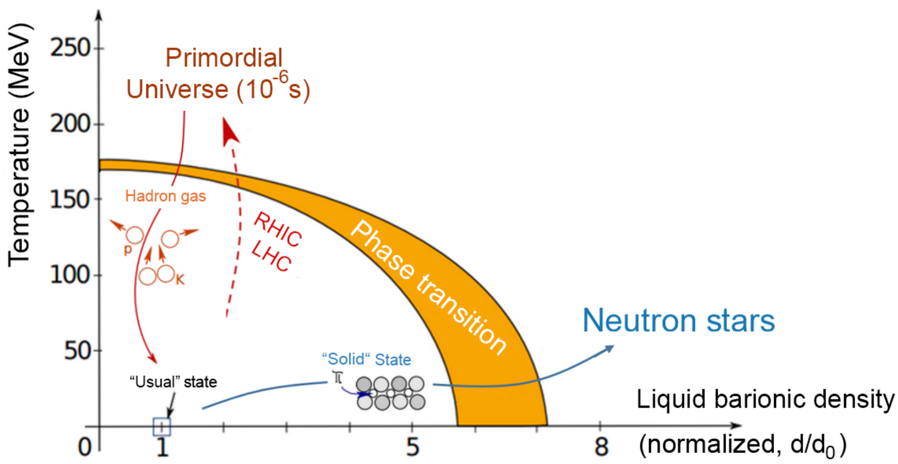
$V_{q1q2} \sim -\frac{\alpha_{eff}}{r} + K.r$
No QGP
Typical values for a confined quark pair
With QGP
0.1
R_{eff}
R_{true}
a_0 (~0.9fm)
r (fm)



R_{true}
R_{eff}

$$-\frac{\hbar}{\qquad}$$

$-$

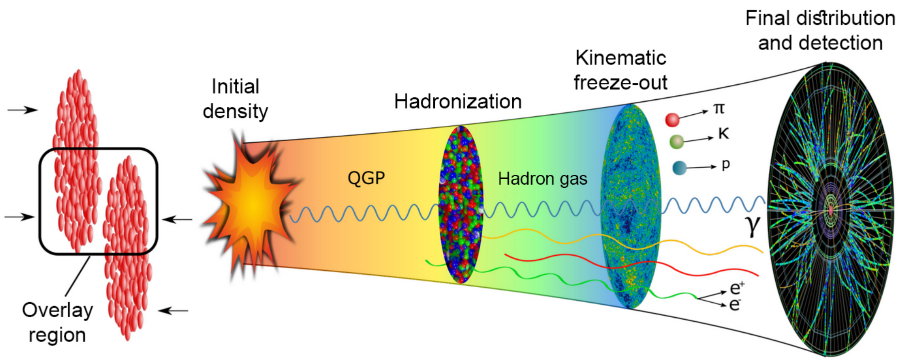


Non-zero elliptic flow

-

Particle production ratios

Transverse momentum spectra



Initial hard scattering

Thermalization

Hadronization

Chemical *Freeze-out*

Kinematic *Freeze-out*

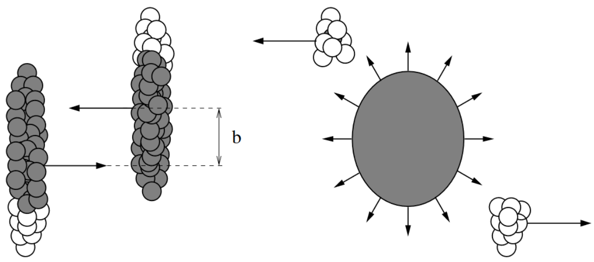
The energy of the collision

$\mathbf{p_i}$

p p p p

–

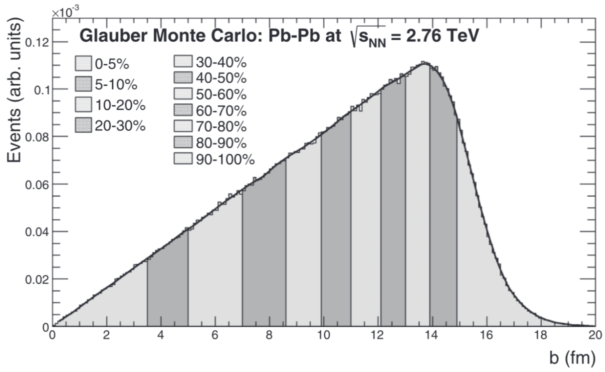
The collision's geometry

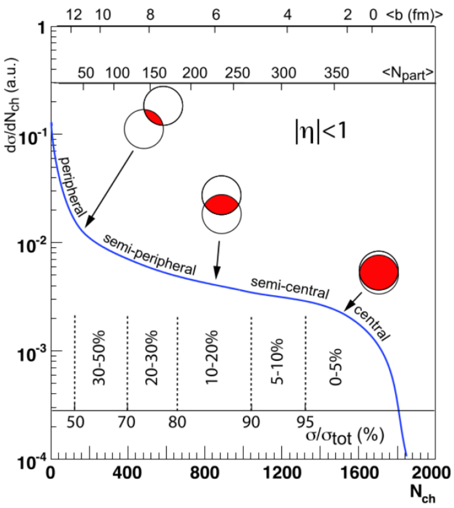


$$\frac{\overline{\quad}, \quad '}{\infty \; \overline{\quad}, \quad '}$$

–

Determining centrality





Kinematic variables

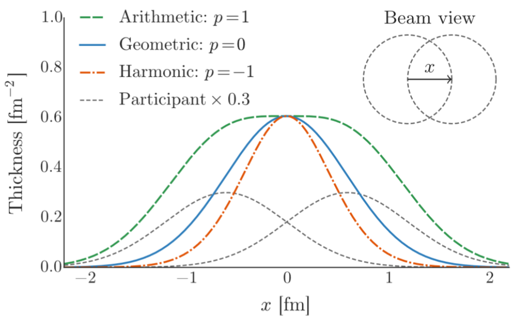
p

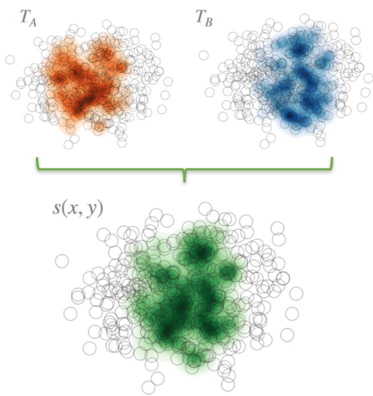
pseudorapidity

$$- \quad - \quad \frac{\mathbf{p}}{\mathbf{p}}$$

$$\frac{}{\mathbf{p}}$$

$$- \quad \frac{}{}$$

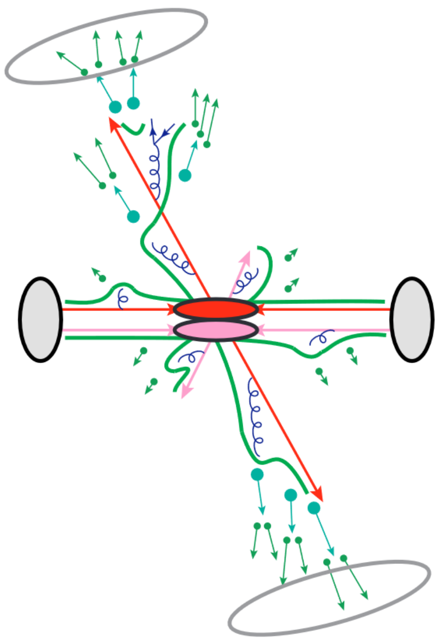

Arithmetic: $p = 1$
Geometric: $p = 0$
Harmonic: $p = -1$
Participant × 0.3
Beam view
x
Thickness [fm^{-2}]
x [fm]


T_A
T_B
$s(x, y)$

$_{part}$

$\mathbf{x}$

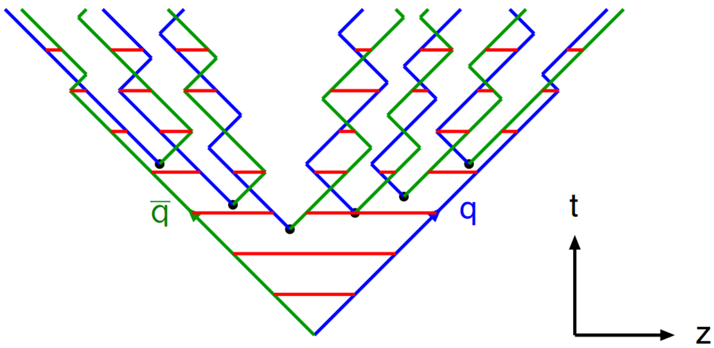
reduced



Hard processes

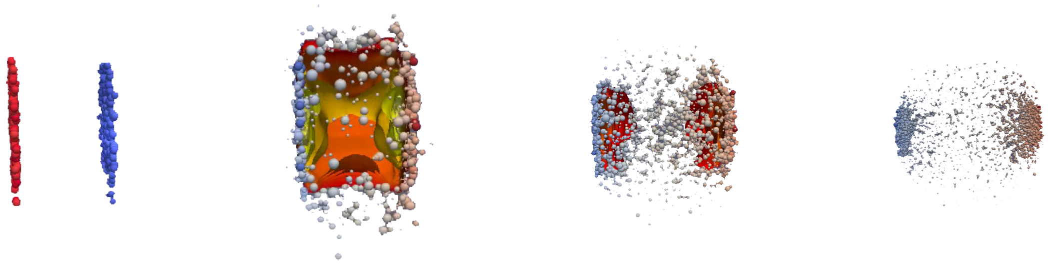
Soft processes

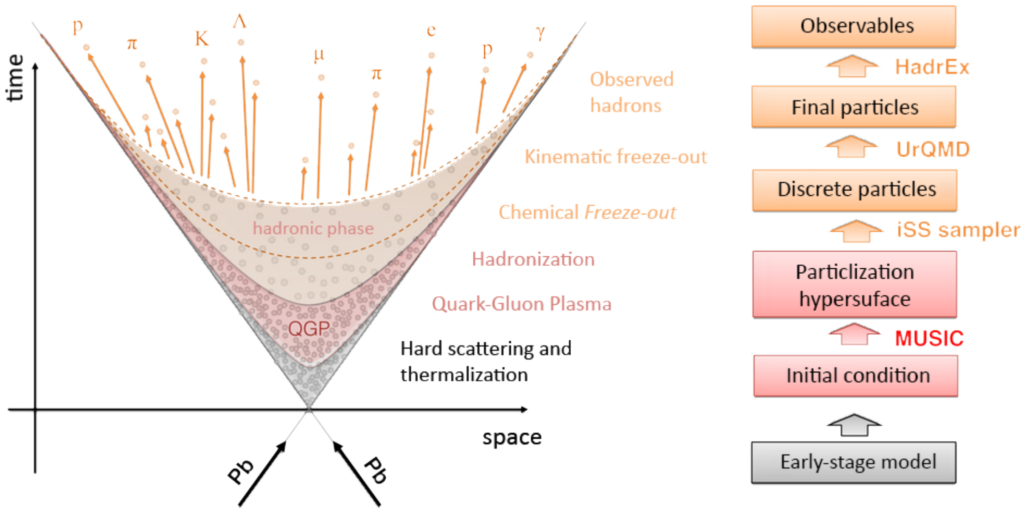
Hadronization



q̄
q
t
z

$\frac{r-2\sigma}{a}$





*The specific code to generate the EoS used in this project from this source was: `python3 eos.py --res-width-off --species=urqmd --Tmax 1.0 --write-bin eos_urqmd.bin --music_output_format`

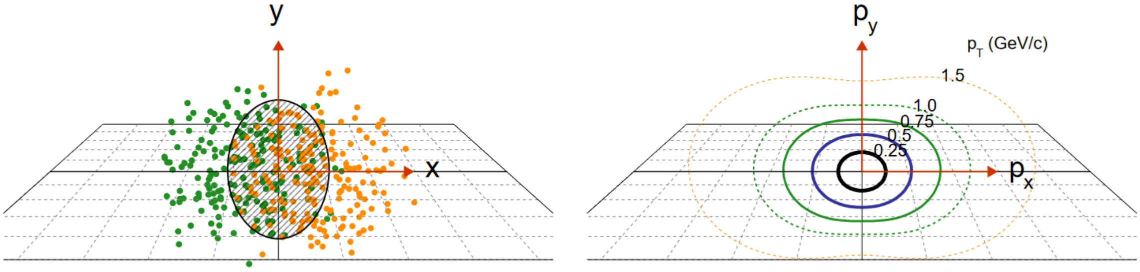
$\frac{3}{\quad 3} s$

-

-

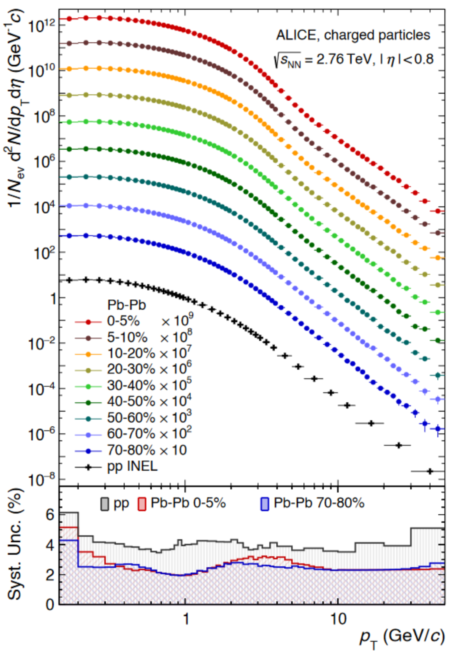
—

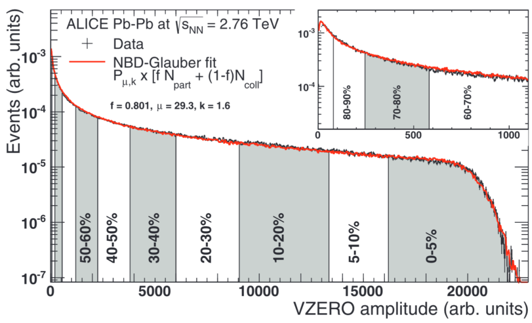
.OSCAR



∞

$\frac{3}{3}$


ALICE, charged particles
$\sqrt{s_{NN}}$ = 2.76 TeV, |η| < 0.8
$1/N_{ev}\, d^2N/dp_T d\eta$ (GeV^{-1}c)
Pb-Pb
0-5% × 10^9
5-10% × 10^8
10-20% × 10^7
20-30% × 10^6
30-40% × 10^5
40-50% × 10^4
50-60% × 10^3
60-70% × 10^2
70-80% × 10
pp INEL
Syst. Unc. (%)
pp
Pb-Pb 0-5%
Pb-Pb 70-80%
p_T (GeV/c)

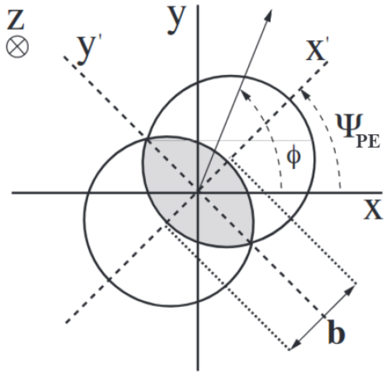

ALICE Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV
Data
NBD-Glauber fit
$P_{\mu,k}$ x [f N_{part} + (1-f)N_{coll}]
f = 0.801, μ = 29.3, k = 1.6
Events (arb. units)
VZERO amplitude (arb. units)
50-60%
40-50%
30-40%
20-30%
10-20%
5-10%
0-5%
80-90%
70-80%
60-70%

∞ ∞

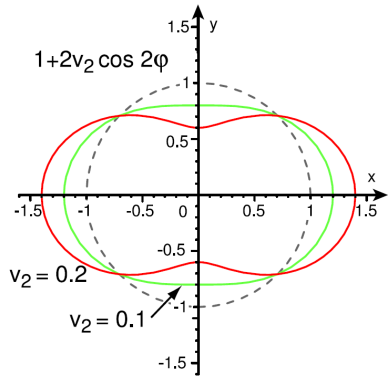
n $-$

$-\infty$

n



z
y
y'
x'
Ψ_{PE}
ϕ
x
b



$1+2v_2 \cos 2\varphi$
$v_2 = 0.2$
$v_2 = 0.1$
x
y

$i-\ j$ $'$ $i-\ j$

i

$*\ \ *$ $i\ \ j-\ k-\ l$

$'$

$$1-\ 2 \quad \overline{}' \quad i-\ j \quad \overline{}$$

$$1\ \ 2-\ 3-\ 4 \quad \overline{}' \quad i\ \ j-\ k-\ l$$

$$*\ \ *$$

$$1-\ 2 \quad \frac{\langle\ \rangle}{\langle\ \rangle}$$

$$1\ \ 2-\ 3-\ 4 \quad \frac{\langle\ \rangle}{\langle\ \rangle}$$

$\langle\ \rangle$ $\langle\ \rangle$

$\langle\ \rangle$

$\langle\ \rangle$

4

′ ′

′ ′ ′

^{p} $_{i}$

^{q} $_{i}$

Particle of Interest

Reference Flow Particle

′ ′

$$' \quad 1- \quad 2 \quad \frac{\quad}{\quad} \quad p \quad * \quad i- \quad j \quad \frac{*}{\quad}$$

$$' \quad 1 \quad 2- \quad 3- \quad 4 \quad \frac{\quad}{\quad} \quad p \quad i \quad j- \quad k- \quad l \quad * \quad * \quad *$$

$$* \quad * \quad * \quad * \quad * \quad * \quad * \quad *$$

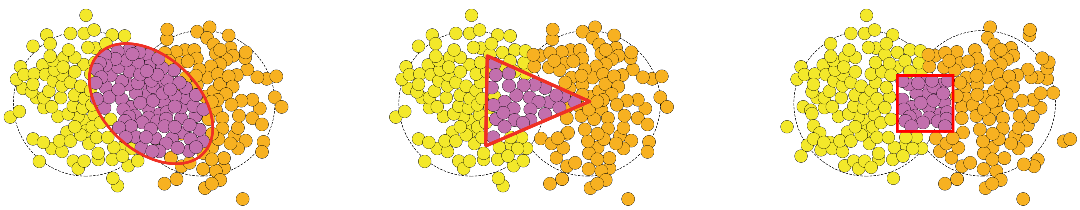
$$* \quad *$$

$$\langle \ ' \rangle$$

$$\langle \ ' \rangle$$

$$' \quad 1- \quad 2 \quad \frac{\langle \ ' \rangle \quad '}{\langle \ ' \rangle}$$

$$' \quad 1 \quad 2- \quad 3- \quad 4 \quad \frac{\langle \ ' \rangle \quad '}{\langle \ ' \rangle}$$



$$\mathbf{x}$$

$$\frac{\mathbf{k}}{\quad} \qquad \frac{\mathbf{x}}{\qquad \mathbf{x}}$$

$$\overline{\mathbf{k}}$$

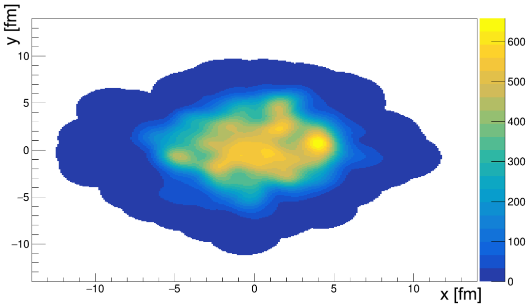
$$\frac{\mathbf{k}}{\quad} \quad \infty \quad \infty \quad -\infty \quad \frac{\quad}{\quad} \quad - \quad k$$

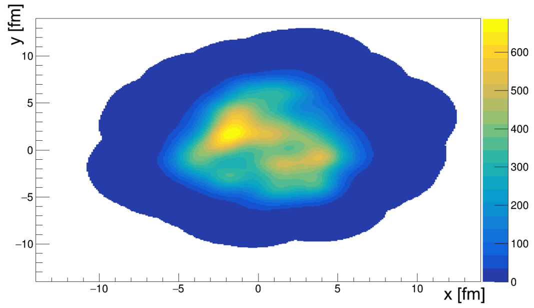
$$\frac{\qquad}{\frac{\quad}{\quad} \quad \frac{-}{\quad}} \qquad \frac{\mathbf{x}}{\quad \mathbf{x}}$$

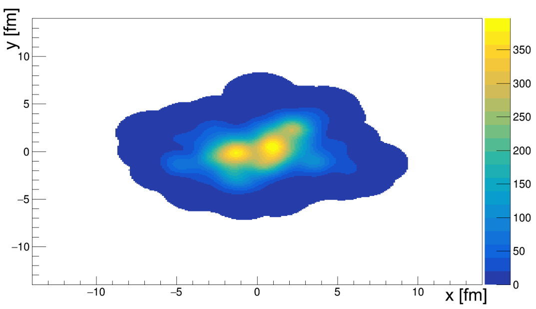
hotspots

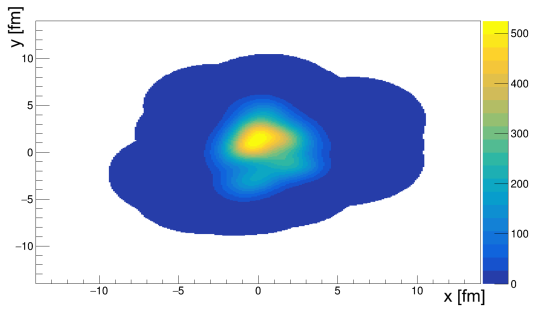
---

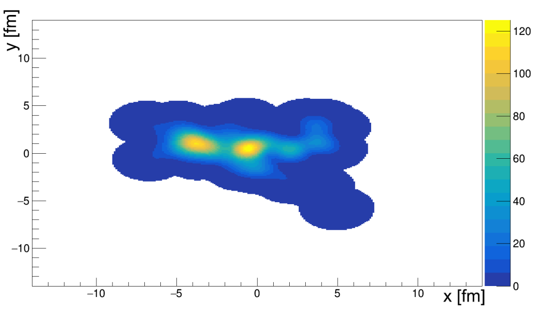
hotspots

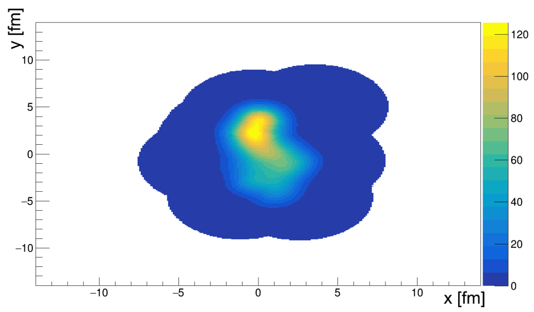

y [fm]
x [fm]
600
500
400
300
200
100
0

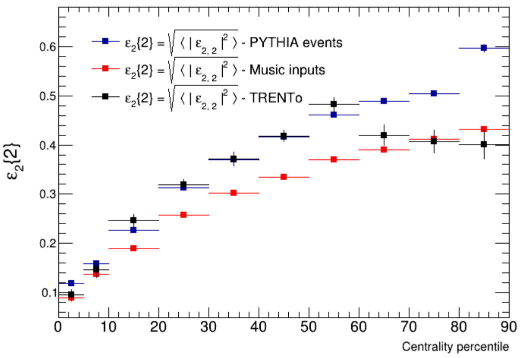

y [fm]
x [fm]
600
500
400
300
200
100
0


y [fm]
x [fm]
350
300
250
200
150
100
50
0

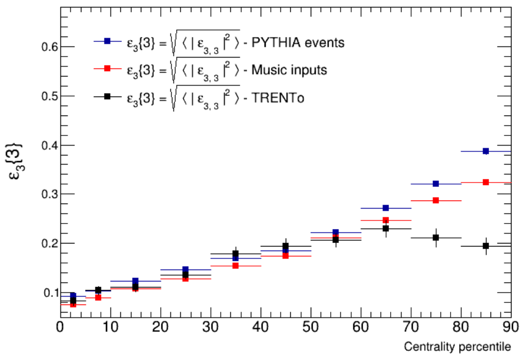

y [fm]
x [fm]
500
400
300
200
100
0


y [fm]
x [fm]
120
100
80
60
40
20
0

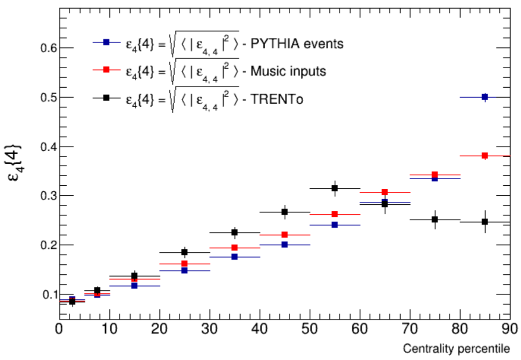

y [fm]
x [fm]
120
100
80
60
40
20
0



ε2{2} = √⟨|ε2,2|²⟩ - PYTHIA events
ε2{2} = √⟨|ε2,2|²⟩ - Music inputs
ε2{2} = √⟨|ε2,2|²⟩ - TRENTo
ε2{2}
Centrality percentile



ε3{3} = √⟨|ε3,3|²⟩ - PYTHIA events
ε3{3} = √⟨|ε3,3|²⟩ - Music inputs
ε3{3} = √⟨|ε3,3|²⟩ - TRENTo
ε3{3}
Centrality percentile



ε4{4} = √⟨|ε4,4|²⟩ - PYTHIA events
ε4{4} = √⟨|ε4,4|²⟩ - Music inputs
ε4{4} = √⟨|ε4,4|²⟩ - TRENTo
ε4{4}
Centrality percentile

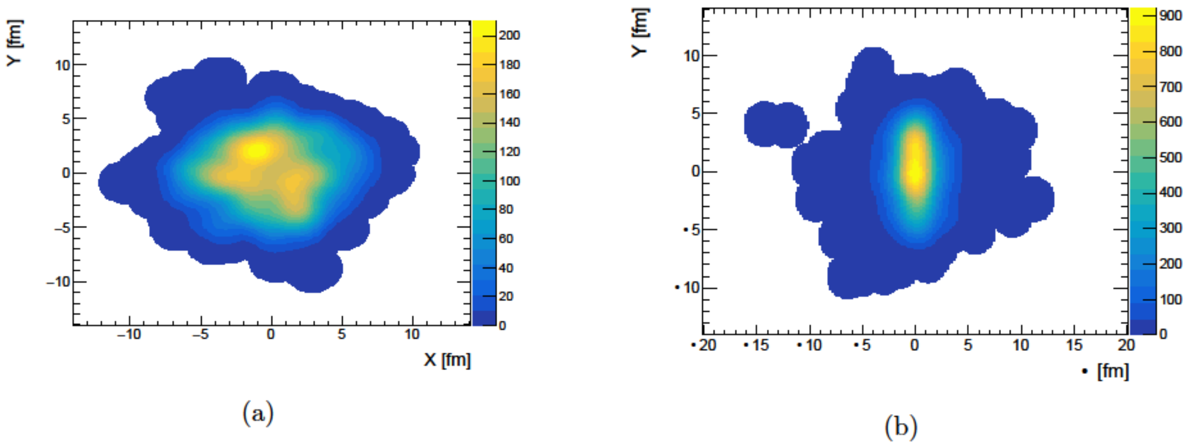


Figure 5.5: Projections of a three-dimensional initial condition produced using Eq. 2.6 and PYTHIA's events, for the range of 0-10% in centrality. (a) Projection in the XY plane and (b) In the XZ plane.

can see that the magnitude of the highest values of density are considerably larger than those from the XY projection, with also a tight spread in the Z direction.

5.1.2 Particle densities and momentum distribution

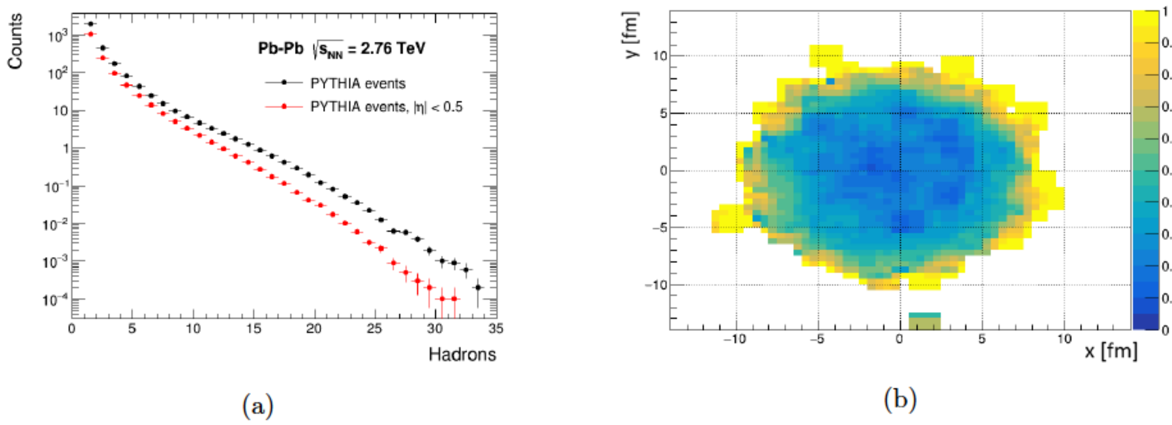
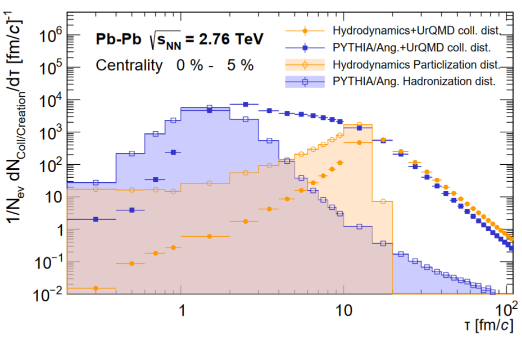


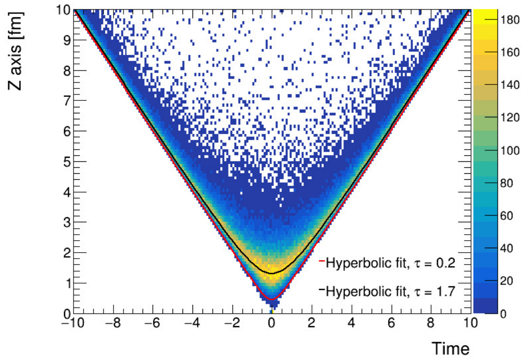
Figure 5.6: (a) Distribution of particles with respect to the density of the cell where they are located, with the two curves comparing particles generated with (in red) and without (in black) an acceptance window in $|\eta|$. (b) Ratio of the sum of the absolute values of the momenta and the absolute value of the vector sum of momenta at $\eta_s = 0$. The grid resolution for this result is 0.5 fm.

Another way of understanding the modeled distribution is to calculate the densities of hadrons in each cell and their momentum configuration. The results of this first study is given in Fig. 5.6 (a), showing the number of cells with a certain number of particles, in arbitrary units, where most of those having no more than 10 hadrons, which results in the initial conditions with grids of lower densities of particles.

For the momentum configuration, however, the procedure was to define the ratio between the



Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
Centrality 0 % - 5 %
Hydrodynamics+UrQMD coll. dist.
PYTHIA/Ang.+UrQMD coll. dist.
Hydrodynamics Particlization dist.
PYTHIA/Ang. Hadronization dist.
$1/N_{ev}\ dN_{Coll/Creation}/d\tau\ [fm/c]^{-1}$
τ [fm/c]



Z axis [fm]
Time
Hyperbolic fit, τ = 0.2
Hyperbolic fit, τ = 1.7

to the evolution of the particlization surface, allowing for a simple approximation for τ. From this equation, the hyperbola shown in this figure were drawn, using first $\tau = 0.2$ fm/c, the standard initialization time for a hydrodynamic simulation using TRENTo as the initial condition generator, and later $\tau = 1.7$ fm/c, as this value encompasses most of PYTHIA's hadrons, as both figures on Fig. 5.7 indicates.

5.2 Final state observables

5.2.1 Multiplicity and momentum distribution

As mentioned in Sec. 4.1, the simulated events can be characterized using the number of particles as functions of transverse momenta, collision's centrality and angular distribution. The multiplicities of charged particles, N_{ch}, are one of the initial consistency metrics for the given outputs of any simulation, when compared to particle detector's results. The next few figures will present those results for simulated particles given by 2D and 3D approaches for initial conditions in a hydrodynamic chain. Also, as discussed in 3.2.1, the computational costs of running 3D hydrodynamics is considerably larger than in the 2D approach, and for that reason the data sample of the former is smaller than the latter. This may induce higher fluctuations and uncertainties in the following three-dimensional results.

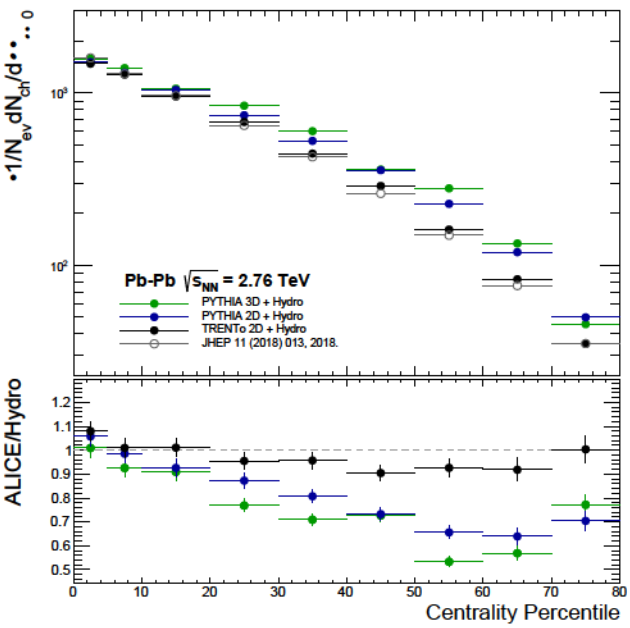
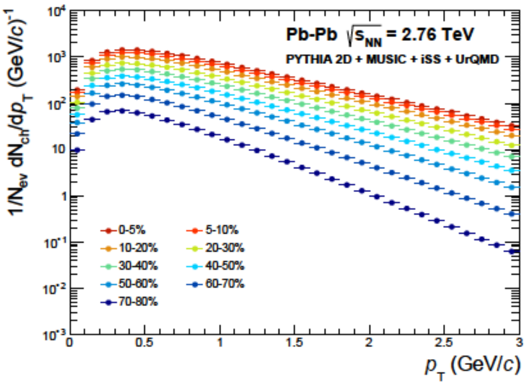
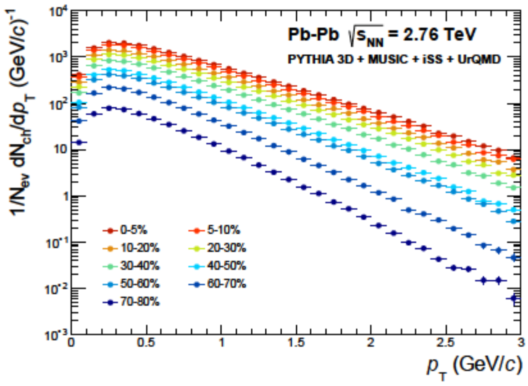


Figure 5.8: Charged particles for two and three dimensional simulations, with data from [59].

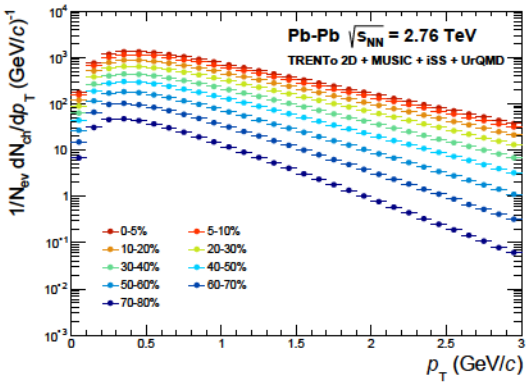
Fig. 5.8 shows the total number of charged particles, integrated in $0.2 < p_T < 5.0$ GeV/c, for



(a)



(b)



(c)

Figure 5.9: Transverse momenta spectra for hydrodynamic simulations for nine centrality classes using (a) two-dimensional and (b) three-dimensional PYTHIA initial conditions, and (c) TRENTo initial conditions.

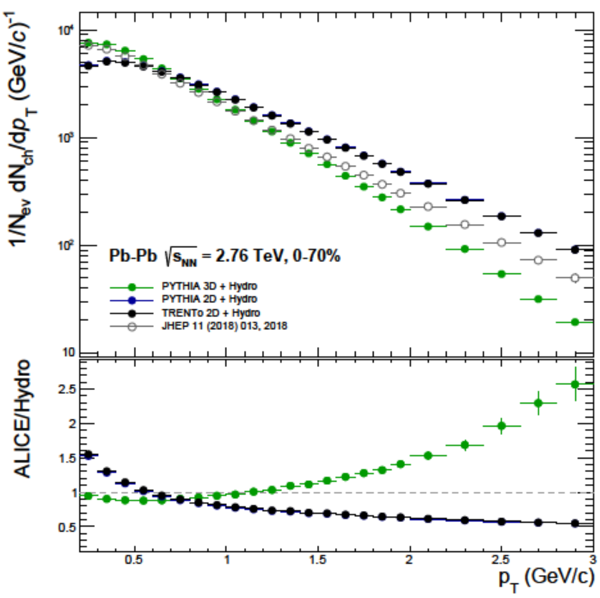
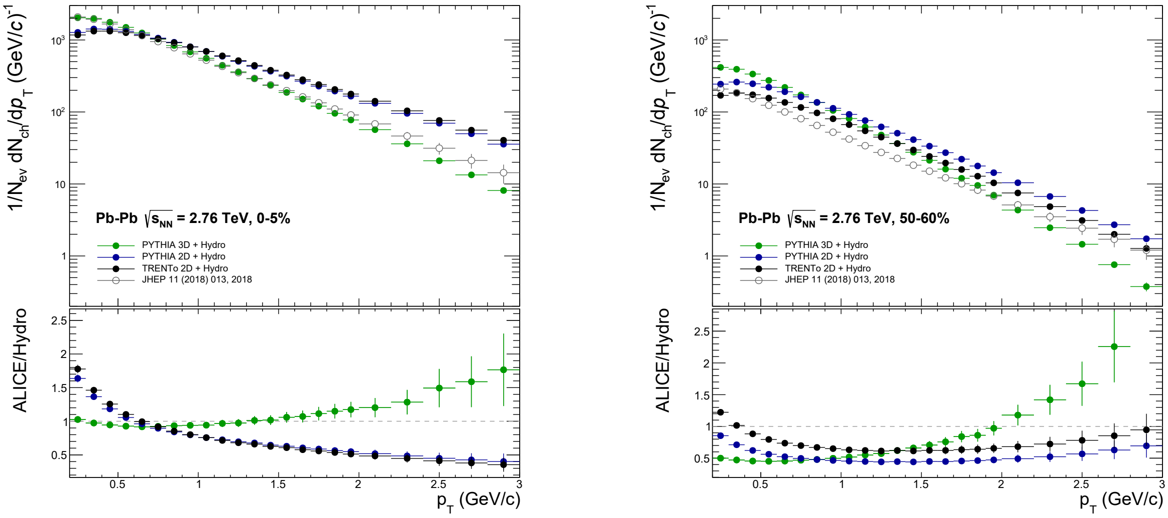
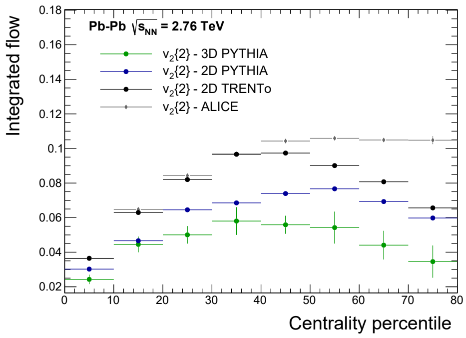
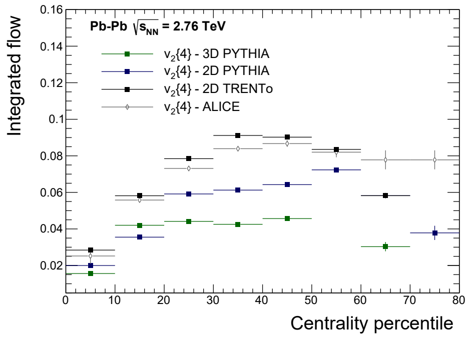
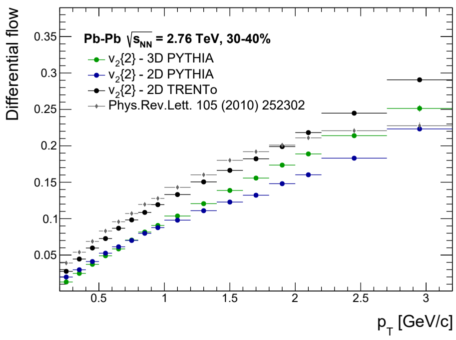


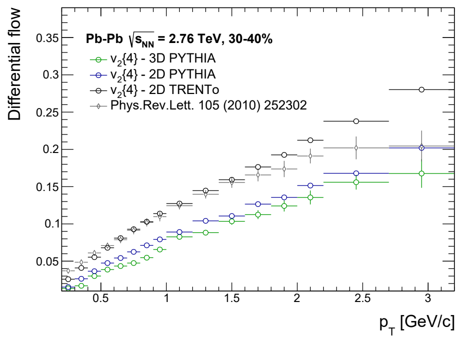
Figure 5.10: Comparison of PYTHIA and TRENTo results for p_T distribution integrated from 0 to 70% in centrality. Experimental data from [58].

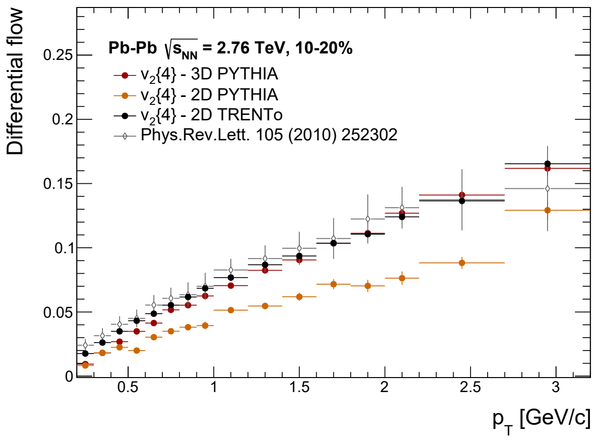

1/N_ev dN_ch/dp_T (GeV/c)^-1
Pb-Pb √s_NN = 2.76 TeV, 0-5%
PYTHIA 3D + Hydro
PYTHIA 2D + Hydro
TRENTo 2D + Hydro
JHEP 11 (2018) 013, 2018
ALICE/Hydro
p_T (GeV/c)
Pb-Pb √s_NN = 2.76 TeV, 50-60%
PYTHIA 3D + Hydro
PYTHIA 2D + Hydro
TRENTo 2D + Hydro
JHEP 11 (2018) 013, 2018
ALICE/Hydro
p_T (GeV/c)


Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$v_2\{2\}$ - 3D PYTHIA
$v_2\{2\}$ - 2D PYTHIA
$v_2\{2\}$ - 2D TRENTo
$v_2\{2\}$ - ALICE
Integrated flow
Centrality percentile

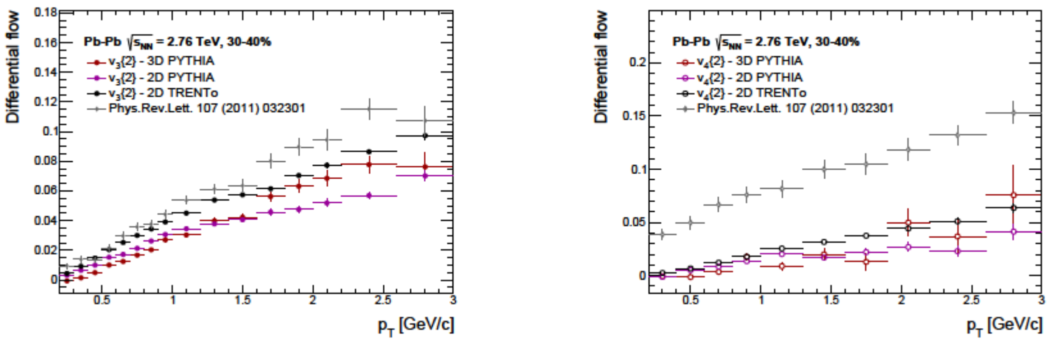

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$v_2\{4\}$ - 3D PYTHIA
$v_2\{4\}$ - 2D PYTHIA
$v_2\{4\}$ - 2D TRENTo
$v_2\{4\}$ - ALICE
Integrated flow
Centrality percentile


Differential flow
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV, 30-40%
$v_2\{2\}$ - 3D PYTHIA
$v_2\{2\}$ - 2D PYTHIA
$v_2\{2\}$ - 2D TRENTo
Phys.Rev.Lett. 105 (2010) 252302
p_T [GeV/c]


Differential flow
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV, 30-40%
$v_2\{4\}$ - 3D PYTHIA
$v_2\{4\}$ - 2D PYTHIA
$v_2\{4\}$ - 2D TRENTo
Phys.Rev.Lett. 105 (2010) 252302
p_T [GeV/c]



Differential flow
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV, 10-20%
$v_2\{4\}$ - 3D PYTHIA
$v_2\{4\}$ - 2D PYTHIA
$v_2\{4\}$ - 2D TRENTo
Phys.Rev.Lett. 105 (2010) 252302
0
0.05
0.1
0.15
0.2
0.25
0.5
1
1.5
2
2.5
3
p_T [GeV/c]



(a) (b)

Figure 5.15: Higher order anisotropy results for two and three-dimensional simulations. (a) triangular and (b) quadrangular flow, with experimental results from [64].

When compared, the approaches for hydrodynamics shows very distinct behaviors between themselves. While 2D TRENTo display results that are within uncertainty with data for $v_3\{2\}$ in low p_T ranges, 3D PYTHIA has a similar distribution to the former after $p_T = 1.5$ GeV. For Fig. 5.15 (b), it can be seen that none of the proposed methodologies describes data, that is, hydrodynamics does not produce large enough higher order anisotropy coefficients at v_4.

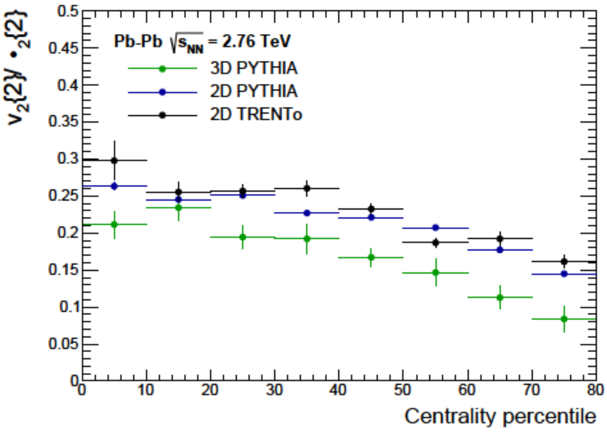


Figure 5.16: Ratio of elliptic flow to the eccentricity of a Pb+Pb collision for all approaches considered.

As for the impact of the geometry of the early stages of collision into the observed anisotropy of final particles that was discussed in Sec. 4.2.1. Fig. 5.16 shows the ratio of elliptic flow using two-particle correlations, $v_2\{2\}$, to the respective geometry of the original event calculated in first order, given by its eccentricity coefficient. This value can be interpreted as a response coefficient of hydrodynamics-based evolution, i.e. $v_2 = \alpha\varepsilon_2$. In this figure, it can be seen that the resulting ratios for each approach presents an almost constant behavior for central events, with a steady decrease in

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