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Elliptic flow studies in heavy-ion collisions using the CMS detector

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Initial spatial anisotropy results in elliptic flow of finite particles. Azimuthal anisotropy of particles is a signature of thermalization.
Azimuthal distribution on RHIC

Ψ_R – azimuthal angle of the reaction plane

\[ \frac{dN}{d\phi}(\phi_p) = N_0 (1 + 2v_1 \cos(\phi_p - \Psi_R) + 2v_2 \cos 2(\phi_p - \Psi_R) + \ldots) \]

Elliptic flow \( v_2 = \langle \cos 2(\phi - \Psi_R) \rangle \)

\[ \phi = \tan^{-1}(p_y/p_x) \]

$v_2$ – current data and prediction for LHC

Simple extrapolation for LHC: $v_2 = 0.07$


Simple extrapolation gives slight increasing of $v_2$ for LHC energy (but a number of models predicts slight decreasing of $v_2$)
$v_2$ vs. $p_T$ – RHIC and LHC

MPC parton cascade of Molnar for RHIC and LHC, $b = 8$ fm.


Viscous hydrodynamical calculations for RHIC and LHC, minimum bias collisions.

Elliptic flow on LHC: experiments

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CMS experiment on the LHC

- Silicon Tracker
  $|\eta| < 2.4$

- Electromagnetic Calorimeter
  $|\eta| < 3.0$

- Hadron Calorimeter
  barrel and endcap
  $|\eta| < 3.0$
  with HF-calorimeter up to
  $|\eta| < 5.2$

- Muon Chambers
  $|\eta| < 2.4$

- + CASTOR detector
  $5.3 < |\eta| < 6.4$
- + Zero-degree calorimeter
- + TOTEM

Magnetic field: 3.8 Tesla
CMS experiment on the LHC

Tracker system:
- Silicon pixel layers (3 in barrel $|\eta| < 1.5$, 2 in endcap $1.5 < |\eta| < 2.4$)
- Silicon strips layers (10 in barrel $|\eta| < 1.5$, 12 in endcap $1.5 < |\eta| < 2.4$)

Calorimeter system:
- ECAL – electromagnetic (crystals of lead tungstate PbWO$_4$) $|\eta| < 3.0$
- HCAL – hadron (active plastic scintillator tiles interspersed between stainless steel and brass absorber plates) $|\eta| < 3.0$
- HF – hadron forward (steel absorbers and embedded radiation hard quartz fibers) $3.0 < |\eta| < 5.2$

- Excellent coverage:
  - Tracker
    $\sim$ 5 units of rapidity and $2\pi$
  - Calorimeter
    $> 10$ units of rapidity and $2\pi$

- Momentum resolution:
  $\sim 2\%$ of momentum resolution for tracks with $p_T < 100$ GeV/c
Physics proton-proton run on LHC will start in mid-November 2009
Two weeks heavy-ion run will be expected in the end of 2010

Expected LHC one week of 1-st year run for PbPb collisions at $\sim 4$ TeV
$L=10 \, \mu b^{-1}$ $\sim 70$M events

STAR (similar acceptance as CMS)
2000 year, first publications on Elliptic flow on RHIC:
$\sim 25$M events

Statistical reach at CMS will be better or comparable with the RHIC results

Elliptic flow – one of the priorities of the CMS heavy-ion group
for the first heavy-ion run on the LHC

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Reconstruction of the reaction plane in CMS

CMS Tracker

Reconstructed Tracks

\[
\tan(2\varphi_{\text{rec}}) = \frac{\sum \omega_i \sin 2\varphi_i}{\sum \omega_i \cos 2\varphi_i}
\]

\[
\omega_i = 1, p_T^i, (p_T^i)^2
\]

CMS Calorimeters

ECAL and HCAL

\[
\tan(2\varphi_{\text{rec}}) = \frac{\sum_{\text{towers}} \omega_{\text{tower}} \sin 2\varphi_{\text{tower}}}{\sum_{\text{towers}} \omega_{\text{tower}} \cos 2\varphi_{\text{tower}}}
\]

\[
\omega_{\text{tower}} = E_{\text{tower}}, E_T^{\text{tower}}
\]

HYDJET generator was used to simulate PbPb events at the LHC.


GEANT-based software was used to simulate CMS responses.

Sergey Petrushanko (CMS Collaboration), Elliptic Flow, Lomonosov 2009
Reaction plane in CMS with calorimeter
PbPb, b=9 fm

Azimuthal distribution of the reconstructed energy

Event plane resolution with ECAL: 0.37 radian

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$v_2$ vs. $p_T$ – CMS tracker, PbPb $b=9$ fm

Tracks with $p_T > 0.9$ GeV/c
- generated
- reconstructed
(by Event Plane method)

The uncertainties of the CMS Tracker detector is not higher than 3%

Methods of $v_2$ extraction
- $v_2\{EP\}$ in generated events
- original events
- Lee-Yang zeros method

Non-flow corrections

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$v_2$ vs. $\eta$ – CMS tracker
PbPb, $b=9$ fm

Tracks with $p_T > 0.9$ GeV/c

○ - generated
■ - reconstructed
(by Event Plane method)
✓ $v_2$ study at LHC energy can give important information about quark matter.

✓ Heavy-ion collisions are expected at the LHC in the end of 2010.

✓ CMS detector at the LHC is ready to study elliptic flow by different detector subsystems, in different pseudorapidity windows and by different methods.
BACK UP
Materials about elliptic flow at the CMS

G.Kh. Eyyubova, V.L. Korotkikh, I.P. Lokhtin, S.V. Petrushanko, L.I. Sarycheva, A.M. Snigirev (SINP MSU, Russia) & David Krofcheck (Auckland, NZ)

- CMS NOTE-2003/019, “Azimuthal Anisotropy and Jet Quenching in Heavy Ion Collisions with CMS Calorimetry”

- Chapter 4 “Elliptic Flow” in PTDR Addendum “High Density QCD with Heavy Ions”

- CMS AN-2007/004 “Azimuthal Anisotropy in Heavy Ions Collisions with CMS Tracker”

- Quark Matter 2008 Proceeding