Properties of the matter created in heavy ion collisions
results from the PHOBOS experiment at RHIC

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Outline

The PHOBOS detector - a brief description
Evidences for creation of a new state of nuclear matter
Particle production in heavy ion collisions - recent results
  • correlations with a high $p_T$ trigger particle
  • two particle correlations - particle production in clusters
Predictions for LHC
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Properties of the matter created in heavy ion collisions ...

PHOBOS detector - trigger system & TOF

- Trigger counter
- Time of flight detector (TOF)
- Beam

HEP 2009
Kraków, Poland
Spectrometer:

two arms
16 layers of silicon sensors
2 Tesla magnetic field

\[ 0 < \eta < 2 \]

\( p_T \) from 30 MeV/c (reconstructed)
PHOBOS detector - multiplicity detector

Multiplicity detector:
- octagon and 6 rings
- single layer of silicon sensors
- no magnetic field

$|\eta| < 5.4$
$p_T$ from 7-35 MeV/c
Production of particles with high transverse momentum is strongly suppressed in central Au+Au collisions. This effect is caused by strong interactions of partons traversing the dense matter created in the A+A collisions.

\[
R_{AA} = \frac{\sigma^{inel}_{pp} \frac{d^2 N_{AA}}{dp_T d \eta}}{N_{coll} \frac{d^2 \sigma_{pp}}{dp_T d \eta}}
\]
Large elliptic flow

Geometrical anisotropy of the interaction area is reflected in the momenta of produced particles.

Elliptic flow is close to results of calculations in hydrodynamical models for a perfect fluid.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{v2_vs_Npart}
\caption{\textbf{Flow}}
\end{figure}
Very low $p_T$ particles production

No anomalous enhancement in production of particles with very low $p_T$ (expected for weakly interacting quark-gluon plasma).

Parameterization fitted at higher $p_T$ and extrapolated to low $p_T$
Correlations with a high $p_T$ trigger particle

**Question:** what happens to partons stopped in the dense matter in central Au+Au collisions

**Trigger particle:**
- measured in spectrometer
- $p_T > 2.5$ GeV/c

**Other particles:**
- measured in a single layer of octagon, or first layer of vertex detector or spectrometer
- $p_T > 7-35$ MeV/c
Correlations with a high $p_T$ trigger particle

PHOBOS Au+Au 200 GeV

$p_T^{\text{trig}} > 2.5 \text{ GeV/c}$

$p_T^{\text{assoc}} > 7 - 35 \text{ MeV/c ($\pi^\pm$)}$

\[
\frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{ch}}}{d\Delta\phi \; d\Delta\eta}
\]

PHOBOS Au+Au central 0-30%
Correlations with a high $p_T$ particle

More quantitative analysis and comparisons

**Au+Au (PHOBOS)**

\[ \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{ch}}}{d\Delta \phi \, d\Delta \eta} \]

**p+p (PYTHIA)**

\[ \frac{1}{N_{\text{trig}}} \frac{d^2N_{\text{ch}}}{d\Delta \phi \, d\Delta \eta} \]

dependence on $\Delta \eta$

dependence on $\Delta \phi$

PHOBOS Experiment
New state of matter
Recent results
Predictions for LHC
Near-side correlations with a high $p_T$ particle

Near-side correlations, $\Delta \phi \approx 0^\circ$: Au+Au @ 200 GeV, 0-30%

PHOBOS Experiment

New state of matter

Recent results

Predictions for LHC

Near-side, $|\Delta \phi| < 1.0$

- Au+Au 0-30% (PHOBOS)
- p+p (PYTHIA v6.325)
- $v_2$ uncertainty
- ZYAM uncertainty

Long-range ridge yield

PHOBOS
arXiv: 0903.2311 [nucl-ex]
Near-side correlations with a high $p_T$ particle

Near-side correlations, $\Delta \phi \approx 0^\circ$: Au+Au @ 200 GeV, 0-30%

The same additional yield

PHOBOS

arXiv: 0903.2311 [nucl-ex]
Correlations with a high $p_T$ particle

Dependence on $\Delta \phi$ in selected $\Delta \eta$ ranges

short range: $|\Delta \eta| < 1$

long range: $-4 < \Delta \eta < -2$

Centrality dependence

PHOBOS
arXiv: 0903.2311 [nucl-ex]
Correlations with a high $p_T$ particle

Near-side and away-side $\Delta \phi$: subtraction of p+p yields

-4 < $\Delta \eta$ < -2

$|\Delta \eta| < 1$

PHOBOS

arXiv:0903.281

Recent results

Predictions for LHC
After subtraction of p+p yield ...

The near side ridge extends to at least $|\Delta \eta| \approx 4$
It disappears for peripheral Au+Au collisions at $N_{\text{part}} < 80$

The additional yield in Au+Au collisions (in excess of that in p+p) decreases for peripheral collisions

NEAR side: $\Delta \phi \approx 0^\circ$
  - short-range minus PYTHIA
  - long-range (PYTHIA≈0)

AWAY side: $\Delta \phi \approx 180^\circ$
  - short-range
  - long-range
  - both minus PYTHIA

PHOBOS
arXiv: 0903.2311 [nucl-ex]
Two-particle correlations

Correlations measured as a function of $\Delta \phi$ and $\Delta \eta$ in the very wide pseudorapidity interval $|\eta| < 3$

p+p@200GeV  Cu+Cu@200GeV  Au+Au@200GeV

PHOBOS
arXiv: 0812.1172 [nucl-ex] (Cu+Cu, Au+Au)
Possible explanation of correlations:
production of intermediate objects (clusters) which decay into particles

Cluster model & two-particle correlations

PHOBOS p+p@200GeV

Cluster model

A cluster of lamps
Cluster parameters can be extracted from the data using correlation function integrated over $\Delta \phi$

$k_{\text{eff}}$ - effective cluster size

$\delta$ - RMS of the two particle distance in $\eta$ characterizing cluster width

Parameters are obtained by fitting the function:

$$R(\Delta \eta) = (k_{\text{eff}} - 1) \left( \frac{G(\Delta \eta)}{B(\Delta \eta)} - 1 \right)$$

where:

$$G(\Delta \eta) \approx \exp \left( \frac{-\Delta \eta^2}{4 \delta^2} \right)$$

$$B(\Delta \eta) = \text{background}$$

Note: even if particles from very wide range ($|\eta| < 3$) are used, acceptance corrections are large.
Two-particle correlations & cluster model

Multiplicity of the clusters is large (up to 6 charged particles - more than for known resonances)

Cluster width exceeds that for isotropic decay at rest

Cluster parameters are similar for p+p and central Au+Au collisions, maximal difference is observed for semi-peripheral collisions

Note: acceptance corrections were applied
Centrality expressed by the fractional cross-section allows to compare similar geometry of the collisions.

**Cluster parameters scale with fractional cross-section**

### Note:
acceptance corrections were applied
Extrapolations to LHC energies

In the collider experiments the laboratory frame coincides with the center of mass of the nuclei. In this frame energy dependence of many observables is complicated.

Alternatively, the rest frame of one of the nuclei involved in the collision may be used.

After transformation to the rest frame of one of the nuclei, the “extended longitudinal scaling” of pseudorapidity distributions of charged particles density $dN/d\eta$ and the elliptic flow are observed.
Extrapolations to LHC energies: $dN/d\eta$

PHOBOS data 19.6-200 GeV
PRL 91 (2003) 052303

Extrapolation of PHOBOS data based on extended longitudinal scaling allows to obtain prediction for $dN/d\eta$ at 5.5 TeV

Transformation to the rest frame of one of the nuclei:
$y' = y - y_{beam}$
and, approximately:
$\eta' = \eta - y_{beam}$

Extrapolations to LHC energies: elliptic flow

PHOBOS data 19.6-200 GeV
PRL 91 (2003) 052303

Similar extrapolation of $v_2$ measured by PHOBOS gives predictions for elliptic flow distribution at 5.5 TeV

Transformation to the rest frame of one of the nuclei:
$y' = y - y_{beam}$
and, approximately:
$\eta' = \eta - y_{beam}$

PHOBOS experiment contributed to the discovery of the new phase of nuclear matter (sQGP) and studied its properties using unique features of the detector: very large angular acceptance and reconstruction of low $p_T$ particles.

Recent analysis of particle production reveals strong long-range correlations with a high $p_T$ trigger particle and emission of particles in large clusters.

Extended longitudinal scaling (limiting fragmentation) allows to give reliable predictions for heavy ion collisions at LHC.
Welcome to Kraków

Krzysztof Woźniak
Properties of the matter created in heavy ion collisions...
Two-particle correlations & cluster model

Importance of acceptance corrections

Uncorrected results for the same events analyzed in different $\eta$ ranges

\[ R(\Delta \eta) \]

$|\eta| < 3$

$K_c = 2.87$

$\delta = 0.84$

$|\eta| < 1$

$K_c = 1.29$

$\delta = 0.45$