ALICE
(A Large Ion Collider Experiment)
results at the LHC

B.V.Batyunya (JINR, VBLHEP)

Seminar, BLTP
Dubna, 19.02.2014
$p+p@14$ TeV (8 TeV now)
$Pb+Pb@5.5$ A TeV (2.76 A TeV)
Heavy Ion Collision

$t = -3 \text{ fm/c}$

$t = 0$

$t = 1 \text{ fm/c}$

$t = 5 \text{ fm/c}$

$t = 10 \text{ fm/c}$

$t = 40 \text{ fm/c}$

hard collisions

pre-equilibrium

QGP

hadron gas

freeze-out

Full QGP stage is reached if temperature and density is enough, otherwise in the pre-equilibrium stage the local clusters only with QGP inside are created by the percolation mechanism, i.e. the mixed phase (of partons and hadrons) appears.

The Lorentz-contraction makes the nuclei as two thin discs during 0.1 fm at RHIC. Parton density increases with overlapping of partons and creation of percolation clusters - the condensate of deconfined partons. The percolation condition is

\[ np = N\pi r^2 / \pi R^2 \cong 1.128 \]

where \( n \) is number of partons with size \( r \) (\( r \) is found from the uncertainty relation \( \pi r^2 \cong \pi / < k^2 T > \), \( kT \) - parton momentum), \( R \) is nuclear radius (\( R \gg r \))
A Large Ion Collider Experiment
European Organisation for Nuclear Research
ALICE Collaboration

> 1000 Members, > 100 Institutes, > 30 Countries
Length: 26 m, Height: 16 m, Weight: 10,000 tons
Display of high multiplicity events

in p-p at 7 TeV       in PbPb at 2.76 ATeV
ALICE Physics Teams

- Event characterization (multiplicity, centrality)
  - Particle species and spectra
  - Correlations
  - Resonance production
  - Jet physics
  - Photons
  - Dileptons
  - Heavy-quark and quarkonium production

- Physics of ultra-peripheral heavy ion collisions
- Contribution of ALICE to cosmic-ray physics
Observation of the anti nucleus using the TPC particle identification capability.

Ten events with the anti alpha particles were found (the first 25 ones have been identified in the STAR experiment).
Charged particles density for Pb-Pb at 2.76 TeV

\[ \frac{dN_{\text{ch}}}{d\eta} \sim 1600 \pm 76 \text{ (syst)} \]

\[ \varepsilon_B = \frac{1}{\pi R^2 \tau} (dE_T/dy) \], \( \tau \) – the formation time, \( R = 1.12A^{1/3} \text{ [fm]} \),

\[ \varepsilon_B \tau = 16 \text{ GeV/(fm}^2\text{c)}, \text{ factor 2.7 larger than RHIC value.} \]
Spectra

0-5% most central Pb-Pb

Hydrodynamic using the viscosity

Particle Ratios

Statistical model (Grand-canonical equation):
The nuclear modification factor $R_{AA}$ for charged particles

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA}) d^2N_{ch}^{AA} / d\eta d p_T}{\langle N_{coll} \rangle (1/N_{evt}^{PP}) d^2N_{ch}^{PP} / d\eta d p_T}$$

An evidence for stronger parton energy loss and larger medium density at LHC.

[ALICE, PL, B696 (2011) 30]
The low values of $R_{\text{PbPb}}$ in central collisions is not due an Initial-state nuclear effect but rather a consequence of hot matter created in A-A isions. The first results for the p-Pb at 5.02 TeV. Only some evidence for the Cronin effect ($R_{\text{pPb}}>1$) is seen (near 1.4 at RHIC).


Green points – ALICE data

[ALICE, PRL,110 (2013) 082302]
Quarkonia ($J/\psi, \psi', Y, Y', Y''$) suppression.

Predictions for influence of hot and dense hadronic matter, particularly of Quark-Gluon plasma (QGP):

-- Debye screening of the quark colour charge in the QGP stage,  
  or in the pre-QGP stage (mixed phase) with creation of the percolation  
  clusters in the parton percolation model.  

-- quarkonia dissociation by impact of gluons at the pre-resonance stage.  

-- an absorption by the interaction in the hot and dense nuclear matter.  
J/ψ suppression (the observation in SPS, NA-50, 1997)

Quarkonia suppression is considered, since a long time, as one of the most striking signatures for QGP formation in AA collisions.

Sequential quarkonia suppression:
- Information on the initial temperature of QGP...but many effects to be taken into account: cold nuclear matter, $\bar{c}c$ (re)combination

Puzzles from SPS and RHIC:
- RHIC: stronger suppression at forward rapidities
- SPS vs. RHIC: similar $R_{AA}$ pattern versus $\sqrt{s}$

LHC results can give decisive inputs, investigating the role of
- the large charm quark multiplicity
  $\sigma c\bar{c} (LHC) = 10 \times \sigma c\bar{c} (RHIC)$
- other quarkonia states (bottomonium)
The RAA in the ALICE is almost a factor of three larger than in the PHENIX for \( <N_{\text{part}} > \geq 180 \). The theoretical description is with an including of 50\% J/\( \psi \) regeneration component from deconfined charm quarks in the medium.

\[ \text{[ALICE, PRL, 109 (2012) 072301]} \]

The suppression \( (R_{pPb} < 1) \) is seen in the proton direction only. The well prediction is based on a nuclear shadowing scenario including a coherent parton energy loss. The \( R_{pPb} \) (\(~0.75\)) is larger than \( R_{PbPb} \) (\(~0.57\)), i.e. the suppression in Pb-Pb can't be ascribed to cold nuclear matter effect alone.

\[ \text{[ALICE, arXiv:1308.6726 (2013)]} \]
Motivation

Strange Hadrons:

- Strangeness enhancement → one of the predicted signatures of Quark Gluon Plasma formation.

  - Strangeness enhancement increases with strangeness content.
    $$\Omega(\text{sss}) > \Xi(\text{ssd}) > \Lambda(\text{sud})$$

Strange Resonances:

- Lifetime comparable to the lifetime of fireball → sensitive to the properties of the medium.

Re-scattering and regeneration:

- $$(K^*/K)_{AA}$$ and $$(K^*/K)_{pp}$$ → re-scattering / regeneration effects.
- $$(\phi/K)$$ independent of centrality → rules out $\phi$ production mainly through kaon coalescence.

The $\Xi(1530)$ resonance analysis in p-p collisions at 7 TeV (ALICE resonance group).

Very good peak of $\Xi(1530)^0$ is seen in ALICE analysis.

No evidence to the pentaquark (1.862) ($dss\bar{d}$)

The pentaquark (1.862) was detected in the NA49 experiment (SPS) with the mass $1.862 \pm 0.002$ GeV/c$^2$. 
Mass shifts at low $p_T$: up to 1.0% for $K^*$ is the same in pp and Pb-Pb, no medium effect but the detector methodical ones.

(up to 6.5% and 9% for $\rho^0$ in p-p and Au-Au of STAR).
Strangeness Enhancement with respect to pp collisions following the hierarchy based on the strangeness content of the particle.

- Enhancement decreases with increase in beam energy from SPS → RHIC → LHC.
**Femtoscopic correlations (HBT)**

**Formalism:**

Following to Haunbary Brown and Twiss (HBT) method for an estimation of star angle sizes G.I.Kopylov and M.I.Podgorecky suggested to study the space - time parameters of the sources emission of identical particles using the correlation function with Bose-Einstein interferometric effect:

\[ CF = 1 + (-1)^S \langle \cos q \Delta x \rangle, \text{ where } S = j^2, j - \text{spin} \]

4-vectors: \( q = p_1 - p_2, \Delta x = x_1 - x_2 \)

**In practice:**

\[
C(q) = 1 + \lambda \exp(-R^2 q^2) \\
CF = 1 + \lambda \exp(-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2)
\]

for 1D analysis

for 3D analysis

\( R \) – source radii, \( \lambda \) – the correlation strength parameter

Projections of the momentum difference \( q_l, q_o, q_s \) are used to the correspondence axis:

- \( l \) - ‘longitudinal’ (beam) direction
- \( o \) - ‘outward’ direction parallel to transverse pair velocity,
- \( s \) - ‘side-ward’ direction transverse to ‘longitudinal’ and ‘outward’
1D - femtoscoical analysis

\[ \text{CF}(q) = (1 - \lambda) + \lambda \cdot K(q) \cdot [1 + \exp(-R^2q^2)] \cdot D(q) \]

\( K(q) \) – Coulomb factor, \( D(q) \) – baseline from MC simulation.

-- The \( R_{\text{inv}} \) increases with increase of event multiplicity as expected in geometrical picture and decreases with \( m_T(k_T) \) increase according of collective flow effect predicted by Hydrodynamic (HKM) model (V.M. Shapoval, et al. PRC 88(2013)064904).

-- Such a behaviour is seen for p-p events at higher multiplicities and is the contrary one for the lowest multiplicity (ALICE, PRD, 87(2013)052016).

-- The emission source sizes of kaons and protons exhibit \( m_T \) scaling which is consistent with the Hydrodynamic model prediction.
3D - femtoskopical analysis for pairs of charged pions

The source volume \( (R_{out} R_{side} R_{long}) \) and the hadron formation time \( (\tau) \) obtained in ALICE 2 and 1.5 times larger respectively than at RHIC energy. [Phys. Lett. B696 (2011)328]

3D radii increase at LHC energy.

Azimuthal anisotropic flow

Fourier series of particle azimuth dependence:

\[ v_n = \langle \cos[n(\phi - \Psi_R)] \rangle \] - Fourier coefficients, \( \phi \) – azimuth, \( \Psi_R \) – reaction plane angle, \( n \) – a harmonic order [S. Voloshin, Y. Zhang, Z. Phys., C70 (1996) 665].

Triangular \( v_3 \): should be zero because smooth matter distribution but is not zero due to \( \text{ev-by-ev} \) fluctuations of the matter distribution.

---

Directed \( v_1 \)

Elliptic \( v_2 \)

---

Integrated elliptic flow at 20% centrality for the ALICE increase \(~30\%\) as compared with RHIC energy. [ALICE, PRL, 105 (2010) 252302]

---

The hydrodynamic models which incorporate viscous corrections do allow for such an increase of \( v_2 \) at the LHC energy. [H. Masui et al., NP, A830 (2009) 463c]
Flow dependence on the particle masses (F. Noferini, IX WPCF, Acireale, Italy, 2013)

The mass ordering: heavier mass $\rightarrow$ smaller $v_2$ at $p_T < 2.5$ GeV/c, is described by the hydrodynamic with shear viscosity parameter $(\eta/s)_{QGP} = 0.2$ ($\eta$ and $s$ are the viscosity and entropy density respectively). At $p_T > 2.5$ GeV/c $\varphi$ meson follows to the $\pi$ and $K^0_s$, i.e. quark coalescence prediction.

The Number of Quark (NQ) scaling for $v_i/n_q$ is within 15-20% at transverse kinetic energy smaller of 1 GeV.
Conclusions

– A lot of interesting results have been obtained in the ALICE for p-p p-Pb and Pb-Pb collisions at the LHC energies.
– Some new effects were found and have to be understood with the theoretical point of view as a signatures of very hot and dense nuclear matter.
– The QGP stage used in the theoretical model to understand most of the Pb-Pb results.
Thank you for your attention
Backup
It is expected in the QCD that $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$ because the gluon energy loss is larger than for the quark one (less colour charge). This effect has to be stronger in the QGP phase with a large number of deconfined heavy flavor quarks. The evidence of this effect is seen in the left side figures (not seen at the RHIC energy).
- 30,000 cores
- 70 computer centres (1T0, 5T1, 64T2)
- America, Europe, Africa and Asia

- Stable and smooth operation 24 x 7
- Operated according to the Computing Model