First results from the ALICE experiment

Iouri Belikov (IPHC, Strasbourg)
for the ALICE collaboration
ALICE experiment at CERN LHC
- Motivation for doing the pp measurements
- Trigger, data samples and event classes

The first results:
- Multiplicity
- Charged particle spectra
- Baryon production
- Bose-Einstein correlations
- Identified particle spectra
- Jet and underlying event properties
- Heavy Flavour production

- published
- preliminary
- in preparation
The ALICE experiment

Detector configuration 2009/2010:

- ITS, TPC, TOF, HMPID, MUON, V0, T0, FMD, PMD, ZDC (100%)
- TRD (7/18)
- EMCAL (4/12)
- PHOS (3/5)

J. Schukraft
The main goal of the ALICE experiment: properties of strongly interacting matter (QGP) created in HE nucleus-nucleus collisions
- Necessity of the hadronic reference for the observables

Understanding the particle production in the new energy domain
- Comparison with models

Search for collective effects at the partonic level
- Multiplicity dependence of the measurement results
### Trigger and data samples

- **“Minimum bias” trigger**: at least one charged particle in 8 units of $\eta$ (All ALICE is read out)
  - SPD or V0A or V0C
- **“Single-muon trigger”** (MUON, SPD, V0, FMD, ZDC are read out)
  - MUON in coincidence with the “minimum bias”
- Both in coincidence with the BPTX beam pickup counters

### Available statistics:

- **2009 (0.9 and 2.36 TeV)**: ~0.5 M min. bias
- **2010 (0.9 and 7 TeV)**: ~250 M min. bias, (~8 M MUON trg)
**Event classes**

### 0.9 and 2.36 TeV

- INEL and NSD
- Use measured cross sections for diffractive processes
- Change MC generator fractions (SD/INEL, DD/INEL) so that they match these fractions
- Use Pythia and Phojet to assess effect of different kinematics of diffractive processes

**7 TeV**

- Diffraction is quite unknown
  - All events that have at least one charged primary particle in $|\eta|<1$ “INEL>0”
  - Minimizes model dependence

**Definitions**

- INEL: $MB_{\text{OR}} (\text{SPD or VZEROA or VZEROC})$ and offline background suppression
- NSD: $MB_{\text{AND}} (\text{VZEROA and VZEROC})$ and offline background suppression
- INEL>0: INEL and at least one charged primary particle in $|\eta| < 1$
Multiplicity measurements

- Multiplicity measured using tracklets in the two pixel layers (R ~ 4 and 7 cm)

- ALICE has published the **pseudorapidity density** and **multiplicity distribution** at 0.9, 2.36, and 7 TeV

---

**Graph**

![Graph showing dN/dη for various conditions.](image)
\( \frac{dN_{ch}}{d\eta} \) vs other experiments

- Consistent with UA5
  - (only 900 GeV)
- Consistent with CMS
  - (only NSD)
  - does not include charged leptons \( \rightarrow \sim 1.5\% \) difference

\[ \sqrt{s} = 0.9 \text{ TeV} \]

\[ \sqrt{s} = 2.36 \text{ TeV} \]
$dN_{ch}/d\eta \ vs \ \sqrt{s}$

Power law dependence fits well

Significantly larger increase from 0.9 to 7 TeV than in MCs

| Increase in $dN_{ch}/dh$ in $|\eta| < 1$ for INEL > 0 | $\sqrt{s}$ | ALICE (%) | MCs (%) |
|---------------------------------------------------|-------------|------------|
| $0.9 \rightarrow 2.36 \text{ TeV}$ | $23.3 \pm 0.4^{+1.1}_{-0.7}$ | $15 - 18$ |
| $0.9 \rightarrow 7 \text{ TeV}$ | $57.6 \pm 0.4^{+3.6}_{-1.8}$ | $33 - 48$ |
Multiplicity distributions

- Distributions in three $\eta$-regions
- Consistent with UA5 ($|\eta|<0.5$)
- Fits with one negative binomial work well in limited $\eta$-regions
  - clan-based model of production
- Difference between INEL and NSD in low-multiplicity region
Momentum spectra and PID

**TPC**

**ITS**

**TOF**

ALICE performance work in progress

Dec. 2009

~7% at 10 GeV/c

ALICE Performance

21 May 2010

pp @ 7 TeV

pp @ √s = 900 GeV (2009 data)

ITS standalone
$dN_{ch}/dp_T$ at 0.9 TeV

$\langle p_T \rangle_{\text{INEL}} = 0.483 \pm 0.001 \text{ (stat)} \pm 0.007 \text{ (syst.) GeV/c}$

$\langle p_T \rangle_{\text{NSD}} = 0.489 \pm 0.001 \pm 0.007 \text{ GeV/c}$
\( \frac{dN_{ch}}{dp_T} \) vs other experiments

- ALICE measures harder spectrum than CMS, ATLAS, UA1
  (narrower window at central rapidity)

\[ \text{arXiv:1007.0719} \]
<p><span>&lt;p_t&gt; vs multiplicity vs MC</span></p>

- **Perugia-0** (fails for multiplicity) describes well <span>&lt;p_t&gt;</span>, but only for <span>p_t &gt; 500 MeV/c</span> (ATLAS found agreement for <span>p_t &gt; 500 MeV/c</span>)

- **Phojet** (describes multiplicity) fails for <span>&lt;p_t&gt;</span>
Baryon number transport by a di-quark and/or a string junction

Valence quarks: Rossi and Veneziano, NPB123 (1977) 507
Gluonic field: Kopeliovich and Zakharov, ZPC43 (1989) 241

Proton identification with TPC dE/dx

Special care for secondary particle contamination and absorption corrections

\( p/\bar{p} \) at |y| < 0.5 and 0.45 < \( p_t \) < 1.05 GeV/c

\[
\frac{\bar{p}}{p} = \frac{1}{1 + C \cdot e^{(a_j - a_p)\Delta y}} \rightarrow \begin{cases} 
  a_j = 0.5 \ (\text{fixed}) \\
  a_p = 1.2 \ (\text{fixed}) \\
  C = 10.0 \pm 1.0 
\end{cases}
\]
$\bar{p}/p$ measurement vs MCs

- Data described well by PYTHIA ATLAS-CSC
- Other models (HIJING-B, PYTHIA Perugia-SOFT) underestimate the data
- Suppression of the baryon transport over large rapidity gaps
  
  (Accepted by PRL)

arXiv:1006.5432
Bose-Einstein correlations

- Assess the space-time evolution of the system that emits particles in pp collisions
- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference $q_{\text{inv}} = |p_1 - p_2|$, vs. event multiplicity and pair $k_t = |p_{t1} + p_{t2}|/2$
- Fit with a Gaussian

$$C(q_{\text{inv}}) = 1 + \lambda \exp(-q_{\text{inv}}^2 R^2)$$

0.9 TeV
arXiv:1007.0516
BEC vs other experiments

- Radius grows with $dN_{ch}/d\eta$
- No visible $k_t$ dependence
Identified spectra at 0.9 TeV

- Analysis in progress (spectra not fully corrected yet)
- Good agreement between the 3 detectors (ITS, TPC, TOF)
- Shows that detectors’ calibration/understanding is OK

⇒ M. Lopez Noriega
Strangeness at 0.9 and 7 TeV

ALICE Performance work in progress
minimim bias p+p (2009)
$\sqrt{s} = 900$ GeV

- $K_S^0$

0.2 < $p_t$ (GeV/c) < 3.0

ALICE Performance work in progress
minimim bias p+p (2009)
$\sqrt{s} = 900$ GeV

- $\Lambda$

0.5 < $p_t$ (GeV/c) < 3.5

ALICE data, p+p at 7 TeV (sel. runs 114783 - 115401 / GRID pass1) - 5.71 MeVevents

Counts per 2 MeV/c^2

ALICE Performance April 2010

$\Sigma^-$ candidates
($M_{\Sigma^-} = 1.3217$ GeV/c^2)

Gaussian+Pol1 Fit:
$\chi^2$/ndf = 98.97/40
$M_0 = 1.3214 \pm 0.0000$ GeV/c^2
$\sigma_m = 2.0 \pm 0.0$ MeV/c^2

ALICE Performance April 2010

$\Omega^-$ candidates
($M_{\Omega^-} = 1.6725$ GeV/c^2)

Gaussian+Pol1 Fit:
$\chi^2$/ndf = 43.71/45
$M_0 = 1.6722 \pm 0.0003$ GeV/c^2
$\sigma_m = 2.7 \pm 0.3$ MeV/c^2
Strange particle spectra at 0.9 TeV

- $K^\pm$, TPC+TOF PID
- $K^0_S$, V0 reconstruction
- $K^\pm \to \mu^\pm \nu$, kink reconstruction
- $\Lambda$ and anti-$\Lambda$, V0 reconstruction

Good internal consistency!
$\phi$ and $K^{*0}$ at 0.9 and 7 TeV

**pp 0.9 TeV**

$\phi \rightarrow K^+ K^-$

$0.7 < p_t < 1.0$ GeV/c

**pp 7 TeV**

$\phi \rightarrow K^+ K^-$

Kaon-Pion invariant-mass spectrum (like-sign background subtracted)

**pp 0.9 TeV**

$K^{*0}$

Fit parameters:

$K^{*0} \rightarrow K^+ \pi^-$

$m = 895.6 \pm 3.8$ MeV/c$^2$

$\Gamma = 66 \pm 13$ MeV/c$^2$

**pp 7 TeV**

$K^{*0}$

PDG parameters:

$m = 896.00 \pm 0.25$ MeV/c$^2$

$\Gamma = 50.3 \pm 0.6$ MeV/c$^2$
Prospects for $\pi^0$: conversions

- Electron ID in TPC
  - TRD to join soon
- Conversion reconstruction in TPC+ITS
  - also very important for material budget scan
- For $\pi^0$ and $\eta$: double conversion
Prospects for $\pi^0$: calorimeters

**EMCAL**

<table>
<thead>
<tr>
<th>$M_{\pi^0}$, 1.0&lt;p_T&lt;1.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{\pi^0}$, 2.0&lt;p_T&lt;2.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{\pi^0}$, 5.0&lt;p_T&lt;5.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$M_{\pi^0}$, 5.0&lt;p_T&lt;5.5 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image4" alt="Graph" /></td>
</tr>
</tbody>
</table>
Charged-track jets raw spectra 0.9 and 7 TeV

- $|\eta|<0.5$
- Four jets algos compared
- uncorrected

→ J. Rak
Underlying Event structure

- Event-by-event analysis:
  - Identify leading hadron
  - Define transverse regions
  - $\Sigma p_t$ in the two regions

- Region with larger energy (MAX) $\rightarrow$ sensitive to QCD final-state radiation

- Region with smaller energy (MIN) $\rightarrow$ sensitive to soft component (multiple interactions)
**Inclusive $\Delta \phi$ correlations wrt the leading track**

- For $p_t < 10 \text{ GeV/c}$, the data are less back-to-back-ish than MCs
$J/\psi \rightarrow \text{ee, } |\eta| < 0.9$

- e PID from TPC
- TRD and EMCAL calibration is ongoing

**ALICE Performance**
June 1st, 2010

- Counts [145 MeV/c^2]
- $N_{\text{signal}} = 59 \pm 9$
- Significance = $6.72 \pm 1.14$
- S/B = $3.22 \pm 1.62$
- Mass = $3.076 \pm 0.009$ GeV/c^2
- width = $0.51 \pm 0.10$ MeV/c^2

Acceptance to $p_t = 0$

\[ \Rightarrow \text{G. Bruno} \]
Forward $J/\psi \rightarrow \mu\mu$

- $J/\psi \rightarrow \mu\mu$, $-4<\eta<-2.5$

$\sigma_{J/\psi} = 94 \pm 4 \text{ MeV}/c^2$

Acceptance to $p_t=0$

$\rightarrow$ J. Castillo Castellanos
Charm: $D^0$, $D^+$, $D^{*+}$ at 7 TeV

Signal in the $p_T$ range 1–15 GeV/c

- compare to pQCD (FONLL) at 7 TeV

$D^0 \rightarrow K^-\pi^+$

**ALICE Performance 13/07/2010**

- Mean = $1.867 \pm 0.001$
- Sigma = $0.014 \pm 0.001$
- Significance (2 $\sigma$) $21.3 \pm 1.2$

**S** ($2\sigma$) $1486 \pm 82$

**B** ($2\sigma$) $3380 \pm 32$

$D^* \rightarrow D^0\pi^+$

**ALICE performance 15/07/2010**

- Mean = $(145.44 \pm 0.04)$ MeV/$c^2$
- Sigma = $(610 \pm 34)$ keV/$c^2$

- $S$ = $662 \pm 26$
- $B$ = $408 \pm 20$

$pp \sqrt{s} = 7$ TeV, $1.40 \times 10^8$ events, $p_T^{D^0} > 2$ GeV/c

$D^* \rightarrow K^-\pi^+\pi^+$

**ALICE Performance 13/07/2010**

- Mean = $1.870 \pm 0.001$
- Sigma = $0.013 \pm 0.001$

**S** ($2\sigma$) $508 \pm 30$

**B** ($2\sigma$) $273 \pm 8$
Heavy flavour from single leptons

- Electrons $|\eta|<0.9$
- TPC dE/dx, K and p rejection with TOF
- TRD and EMCAL will join soon
- Displacement selection

$\rightarrow$ R. Bailhache

- Muons $-4<\eta<-2.5$
- Light quark contribution subtracted with PYTHIA
- c & b to be separated by fitting based on pQCD shapes (in progress...)

**Graphs:**

- Single electron inclusive spectrum (uncorrected)
- p+p @ $\sqrt{s}=7$ TeV
  - 1.6 x 10^8 events
- uncorrected $p_t$ distribution

**Notes:**

ALICE Performance
14/07/2010
First physics results from ALICE

Particle multiplicity
- *increase from 0.9 to 7 TeV significantly larger (>20%) than predicted*

Momentum spectra
- $<p_t> \text{ vs } N_{ch}$ not described by any of the MCs

Anti-proton/proton ratio at midrapidity
- $pbar/p \text{ goes to 1 at 7 TeV } \rightarrow \text{ baryon number transfer suppressed over large } \Delta y$

Bose-Einstein correlations at 0.9 TeV
- *particle emitting source “size” increases with multiplicity*

Event topology
- *lower “jettiness” than expected in LHC collisions*

Promising performance for ID spectra, strangeness, charm, charmonium
The first paper at LHC


dN_{ch}/d\eta for |\eta| < 0.5

\begin{align*}
\text{data collected 23 Nov, paper submitted 28 Nov} \\
\text{284 events (~ 3.7 authors per event)}
\end{align*}
### Systematic uncertainties $dN_{ch}/d\eta$

<table>
<thead>
<tr>
<th>Systematic uncertainties in %</th>
<th>900 GeV</th>
<th>2.36 TeV</th>
<th>7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractions ND/DD/SD*</td>
<td>0.5</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>MC dependence</td>
<td>+0.8</td>
<td>+1.5</td>
<td>+2.8</td>
</tr>
<tr>
<td>Detector efficiency</td>
<td></td>
<td>±1.5</td>
<td></td>
</tr>
<tr>
<td>Particle composition**</td>
<td></td>
<td>±(0.5 - 1.0)</td>
<td></td>
</tr>
<tr>
<td>Material budget</td>
<td></td>
<td>negl.</td>
<td></td>
</tr>
<tr>
<td>$p_T$ spectrum</td>
<td></td>
<td>±0.5</td>
<td></td>
</tr>
<tr>
<td>SPD triggering efficiency</td>
<td></td>
<td>negl.</td>
<td></td>
</tr>
<tr>
<td>V0 triggering efficiency</td>
<td></td>
<td>negl.</td>
<td></td>
</tr>
<tr>
<td>Background</td>
<td></td>
<td>negl.</td>
<td></td>
</tr>
</tbody>
</table>

* Fractions changed at 0.9 and 2.36 TeV like in paper 2; at 7 TeV by 50%
** $\eta$-dependence
Unfolding using $\chi^2$-Minimization

$$\chi^2(U) = \sum_m \left( \frac{M_m - \sum_t R_{mt} U_t}{e_m} \right)^2 + \beta R(U)$$

- One free parameter per bin for unfolded spectrum $U_t$
- Regularization
  - Prefer constant locally
  - Prefer linear function locally
- Weight parameter $\beta$ needs to be tuned
  - $\chi^2/\text{ndf}$ not larger than 1
  - Keep bias low

V. Blobel, Yellow report, 1984
Phojet
- provides a good description at 900 GeV
- fails at 2.36 and 7 TeV

Pythia Atlas CSC
- fails at 0.9 TeV
- reasonably close at 2.36 and 7 TeV but deviations around 10-20

Pythia D6T and Perugia-0 far from the distribution at all energies
Charged particle $p_T$ spectrum

Track reconstruction in TPC ($\leq 160$ hits) + ITS ($\leq 6$ hits)
- $p_t$ measurement from TPC only (ITS-TPC alignment not final)
  - $(\sigma(p_T)/p_T)^2 \approx (0.01)^2 + (0.007p_T)^2 \%$

Track selection:
- $p_t > 150$ MeV/c, $|\eta| < 0.8$
- $n_{\text{hits,TPC}} > 70$, $\chi^2/\text{hits} < 4$ in TPC
- at least 2 matching hits in ITS
  - at least 1 in SPD
  - 4.7 on average
- cut on transverse impact parameter (7$\sigma$)

From MC, cross-checked with data:
- Efficiency 50-80%
- Secondary cont. 9-1%
Baryon number at midrapidity

- Valence quarks: Rossi and Veneziano, NPB123 (1977) 507
- Gluonic field: Kopeliovich and Zakharov, ZPC43 (1989) 241

Conventional approach - QGSM

Within QGSM one expects an asymmetry $\sim 0$ at LHC energies
- No BN transported at mid-rapidity from the fragmentation region

String Junction

BN transport even at large rapidity gaps (large energies).
- Veneziano: Probability exponentially suppressed ($a_J$: SJ intercept – model dependent)
- Kopeliovich: Probability constant with rapidity
Main selection: displaced-vertex topology

Example: $D^0 \rightarrow K^- \pi^+$
- good pointing of reconstructed $D$ momentum to the primary vertex
- pair of opposite-charge tracks with large impact parameters

Kaon ID in TPC+TOF helps rejecting background at low $p_t$

Impact parameters $\sim 100 \ \mu m$