Recent Heavy-Ion Results with the ALICE Detector

Jörn Putschke
On behalf of the ALICE Collaboration
The ALICE Experiment

LHC Heavy-Ion running

- Two heavy-ion runs at the LHC so far:
  - in 2010 – commissioning and the first data taking
  - in 2011 – already above nominal instant luminosity!
- p–Pb run moved to beginning of 2013
  - jan-mar 2013 - 30 nb^(-1) (for rare-probe statistics equivalent to ~0.15 nb^(-1) of Pb–Pb)
- Followed in 2013 by Long Shutdown–1 (LS1) year

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The ALICE Experiment

Adam Kisiel (WUT)

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Energy and integrated luminosity:

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The QGP at the LHC


PLB 696, 328 (2011)

Hotter, denser (x2.5), bigger (x2) and longer lifetime (30%) as compared to RHIC!
Focus on hard probes:
Before we can utilize hard probes/jets (and their modifications/tomography) to probe the medium in heavy-ion collisions we first have to establish that:

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   Comparison of pQCD calculations with p-p measurements
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2) **Control experiment:**
   Measure initial state/Cold Nuclear Matter (CNM) effects;
   Probe the “cold medium” via p-Pb collisions (compare to p-p)
Nuclear Modification ($R_{AA}$) in p-Pb Collisions

$$R_{AA}(p_T) = \frac{Yield(A + A)}{Yield(p + p) \times \langle N_{coll} \rangle}$$

Average number of p-p collision in A-A collision

**Strong suppression in central Pb-Pb collisions**

**$R_{pPb}$ (minbias) consistent with unity in p-Pb collisions**

No “Effect”:
- $R < 1$ at small momenta - production from thermal bath
- $R = 1$ at higher momenta where hard processes dominate

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**Theory Meets Experiment 2013, 10-12 June 2013, Warsaw, Poland**

Adam Kisiel (WUT)

arXiv:1210.4520 [nucl-ex]

PRL, 110, 082302 (2013)
Charged Jet $R_{AA}$ in $p$-Pb Collisions

Jet $R_{pPb}$ (minbias) consistent with unity in $p$-Pb collisions
Heavy-flavor $R_{AA}$ in p-Pb Collisions

Heavy-flavor $R_{pPb}$ (minbias) at mid-rapidity consistent with unity in p-Pb collisions (within uncertainties)
J/ψ and Υ $R_{AA}$ in p-Pb Collisions

**J/ψ $R_{pPb}$:**
- Described by shadowing
- CGC overestimates the suppression at large $y$

**Υ $R_{pPb}$:**
- Consistent with J/ψ (weaker $y$ dep.)
- Shadowing alone seems to underestimate the suppression
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Jets

Michael L. Knichel
Moriond 2012

• single particles observables depend on fragmentation function
• full jet reconstruction (~parton energy) and jet $R_{AA}$ is the most obvious to study parton energy loss

jets in ALICE are coming soon:
• EMCal was fully installed in 2011 run
• dedicated jet trigger
• underlying event and background subtraction has been studied
• background fluctuations are important in Pb-Pb!

Hard Probes in Pb-Pb Collisions (a small selection ...)

Jet in EMCal (Pb-Pb)
Nuclear Modification in Pb-Pb Collisions

No suppression of hadron yields in p-Pb
No suppression of direct photons, W, Z^0
Strong suppression of hadron yields and in Jet R_{AA} in central Pb-Pb collisions

→ Energy loss of colored probes in the QGP at the LHC is a final-state effect!
Ratio of jet x-section $R=0.2/R=0.3$ is sensitive to broadening in the jet structure:

Pb-Pb jet structure consistent with vacuum jets; no jet broadening (within $R=0.3$) observed!
Similar $R_{AA}$ for pions, kaons and protons at high-$p_T$
Proton/pion ratio at high-$p_T$ consistent with vacuum
→ Particle composition unmodified in Pb-Pb collisions!
“Jet PID” in Pb-Pb Collisions

A closer look via two particle $\Delta \eta \times \Delta \Phi$ correlations; Isolate jet-like and bulk-like region:

- $p/\pi$ in bulk region consistent with inclusive ratio
- $p/\pi$ in jet consistent with vacuum
D and B $R_{AA}$ vs. centrality

First clear indication of mass dependent partonic energy loss in heavy-ion collisions!

Bottom less suppressed than charm and light flavor!

J/ψ from bottom decay (CMS) $B <p_T> \sim 11$ GeV

Charm Meson $D <p_T> \sim 10$ GeV
Hard Probes Summary:

The energy loss of colored probes in the QGP at the LHC is unambiguously a final-state effect!

The hard core of the jet, after energy loss, seems to fragment vacuum like:
No broadening or change in PID is observed!

For the first time:
Mass dependent partonic energy loss is observed (bottom loses less energy than charm and light quarks)

Observations are (qualitatively) consistent with a pQCD-type energy loss picture in which a significant amount of energy loss happens at early times with the “lost” energy thermalized in the medium and the leading parton fragmenting vacuum like!
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Concerning hard probes!

BUT: Surprise concerning the “bulk” properties in high multiplicity p-Pb collisions: The twin ridge structure!

Just a quick look ...
Fourier Decomposition of the twin Ridges

$p$-Pb: 0-20%-60-100%

**Initial state:**
- Color glass condensate?

**Final state:**
- Multiparton interactions?
- Collective effects?

- Second harmonic larger than third harmonic
- Higher harmonics negligible
- Increasing with $p_T$
- Depending on centrality

**The double ridge**

$|\Delta \phi| < \pi/3$
$|\Delta \phi - \pi| < \pi/3$

**Remaining $\Delta \phi$ projections to $\Delta \eta$**

**Projections to $\Delta \phi$**

**Fit allows to extract $v_n$ coefficient**

- Excess in the correlation yield between the two multiplicity event classes

**Associate vs. Trigger**

$\Delta \phi = \phi_{\text{Trigger}} - \phi_{\text{Assoc.}}$

**$v_2 > v_3$ in central $p$-Pb collision**

$v_n$ increasing with $p_T$

Centrality dependence visible

**Theory Meets Experiment 2013, 10-12 June 2013, Warsaw, Poland**

Joern Putschke, ISMD 2013
PID $v_2$ in p-Pb and Pb-Pb Collisions

**Similar features of $v_2(p_T)$ in p-Pb and PbPb collisions observed:**

**Mass ordering at low-$p_T$**
(in Pb-Pb attributed to hydro behavior)

**Proton $v_2 >$ pion $v_2$ for $p_T > 2$ GeV**
(constituent quark scaling in p-Pb!?)
Similar trend in p-Pb and p-p collisions compared to Pb-Pb collisions as function of \( dN_{ch}/d\eta \) (although smaller in p-Pb)
The control experiment p-Pb revealed surprising results in high-multiplicity p-Pb collision:

Mass ordering of $v_2$ at low-$p_T$ is observed, as well as similar trends in particle ratios as function of $dN_{ch}/d\eta$!

Are we seeing hydrodynamical behavior in p-Pb collision or is it the CGC!?