ALICE physics results summary

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ALICE publications in 2013

- **15** physics **papers** already published by ALICE in 2013
  - **Journals**: 7 on PLB, 5 on PRL, 2 on EPJC, 1 on PRD
  - plus … **8** papers submitted to arXiv (3 of them already accepted for publication)

- **System**: 6 papers on p-Pb, 10 on Pb-Pb, 7 on pp results

- **Italian contribution**: 8 of them had at least one italian member of the paper committee
### Cite summary (from InSPIRE)

already 40 citations for a p-Pb paper
ALICE at SQM conference

- Most relevant conference about physics with heavy ion collisions in 2013
- 32 ALICE talks + 3 posters
  - 8 talks with new results from the p-Pb run
  - 8 talks with Italian speaker
... in the next slides

- A selection of results from few analyses that were recently published or that produced recently new preliminary results
- DISCLAIMER: the selection is strongly biased towards
  - Analyses with a significant contribution from Italian groups
  - New results from the p-Pb run
p-Pb run in Jan-Feb 2013

- **3 weeks** of data taking with p-Pb collisions
  - About 30 nb\(^{-1}\) delivered to ALICE, ATLAS and CMS and few nb\(^{-1}\) to LHCb
  - Beam reversal (p-Pb and Pb-p) for about 1/2 of statistics (relevant for ALICE and LHCb)

- **Motivations**
  - **Benchmark for AA collision** for hard processes to disentangle initial state (cold nuclear matter) effects
  - Nuclear PDFs at **small-x** (shadowing/saturation/Color Glass Condensate)
Collective expansion

- Bulk matter created in high-energy heavy-ion collisions can be described in terms of **hydrodynamics**
  - The initial hot and dense partonic matter rapidly expands and cools down
  - **Collective flow** develops
  - Phase transition to hadron gas when critical temperature is reached

- This results in:
  - Dependence of the shape of the $p_T$ distribution on the particle mass
    - Described with a common kinetic freeze-out temperature $T_{\text{kin}}$ and a collective average expansion velocity $<\beta_T>$
  - Azimuthal anisotropic flow patterns as a consequence of anisotropic spatial distribution of the colliding nucleons

- **Open question**: are there final state dense matter effects in $p$-A at the LHC?
Identified particle spectra in p-Pb

- $p_T$ spectra measured for $\pi^\pm$, $K^\pm$, $K^0_s$, $p$, $\Lambda$ in $0<y_{\text{cms}}<0.5$ for 7 multiplicity intervals
- Clear evolution with multiplicity: $p_T$ distributions become harder with increasing multiplicity
Baryon/meson: p-Pb vs. Pb-Pb

- Evolution of $p/\pi$ and $\Lambda/K^0_s$ ratios vs. $p_T$ reminiscent of what observed in Pb-Pb (enhancement at intermediate $p_T$)
- Pb-Pb results commonly understood in terms of collective flow and hadronization via quark recombination
- The magnitude of the effect differs significantly between p-Pb and Pb-Pb
Constrain theoretical models

- **Models:**
  - **Blast-wave fit** = locally thermalized medium expanding with collective flow velocity
  - **EPOS LHC** = full event generator including hydrodynamical evolution
  - **Kracow** = 3+1 viscous hydrodynamics (works at low $p_T$)
  - **DPMJET** = PHOJET pp + nuclei via Glauber-Grybov approach

- Models including hydrodynamics give a better description of the spectra

ALICE, arXiv:1307.6796
**In-medium energy loss**

- Partons produced in high $Q^2$ processes (high $p_T$, large mass) lose energy traversing the medium
- Modification of the momentum distribution of hadrons/jets $\rightarrow$ **suppression of yield at high $p_T$**
  - Observable: **nuclear modification factor**:
    \[
    R_{AA} = \frac{dN^{AA}/dp_T}{N_{coll}dN^{pp}/dp_T}
    \]

- Open questions
  - How much of this suppression is due to **initial state** (cold nuclear matter) effects $\rightarrow$ **check with p-Pb**
  - Is the expected hierarchy $\Delta E(g) > \Delta E(u,d,s) > \Delta E(c) > \Delta E(b)$ there? $\rightarrow$ check with heavy flavours
Charged particle $R_{AA}$ and $R_{pA}$

- Charged particle spectra strongly modified in Pb-Pb collisions
  - Large suppression of yield of charged particles in a wide $p_T$ range
  - Maximum suppression at $p_T \sim 6-7$ GeV/c
- Results from p-Pb confirm that it comes from a final state effect (parton in-medium energy loss)
D-meson nuclear modification

Large suppression of D meson yield at high $p_T$ → substantial in-medium energy loss of c quarks

Small effect expected from nuclear PDFs for $p_T > 5$ GeV/c → p-Pb as control experiment
D mesons in p-Pb

- D-meson nuclear modification factor in p-Pb
  \[ R_{pA} = \frac{d \sigma^{pA}/dp_T}{A \cdot d \sigma^{pp}/dp_T} \]

- $R_{pPb}$ is compatible with unity and well described by predictions from pQCD + EPS09 nuclear PDFs

- Cold nuclear matter effects are small

- Suppression measured in Pb-Pb is due to charm quark in-medium energy loss
Charm vs. Beauty energy loss

- $R_{AA}$ of prompt D (ALICE) vs. non-prompt $J/\psi$ from B decays (CMS)
  - $p_T$ interval of D mesons chosen to match the $p_T$ range of parent B
  - Caveat: slightly different $y$ range (but $y$ dependence of $R_{AA}$ is small)
- Goal: test the expectation: $R_{AA}(D) < R_{AA}(B)$
- Indication of larger energy loss of charm quarks than beauty quarks
Quarkonia as a QGP thermometer

- In the QGP, quarkonia with radius $>\text{Debye screening length}$ are expected to melt due to colour screening of the $q\bar{q}$ potential.
  - Quarkonia states melt above a given temperature, depending on their binding energy → sequential suppression pattern
  - Melting sequence of quarkonia as QGP thermometer
    - Matsui, Satz, PLB178 (1986) 416; Digal et al., PRD64 (2001) 094015

- Also expected: $J/\psi$ production from $c\bar{c}$ (re)combination in the deconfined medium or at hadronization
  - (Re)combination contribution larger at LHC $\sqrt{s}$
    - Braun-Munzinger, Stachel, PLB 490 (2000) 196

- Plus other effects:
  - Feed-down from higher quarkonium states
  - Cold nuclear matter effects (also in p-A)
J/ψ suppression vs. (re)combination

→ Flat J/ψ $R_{AA}$ vs. centrality
→ Less suppression at LHC with respect to RHIC energy

In (re)combination models
→ 50% of low-$p_T$ J/ψ produced via (re)combination
→ at high $p_T$ negligible contribution from recombination

→ qualitatively as expected in a scenario with J/ψ (re)combination
**J/ψ in p-Pb**

- **$R_{pPb}$ for inclusive $J/\psi$ vs. $y$**
  - Fraction of $J/\psi$ from B decays is small (<10%)
  - p-Pb and Pb-p collisions to cover forward and backward rapidity regions
    - Bjorken $x$ values probed for nucleons in the Pb nucleus
      - p-Pb: $1.8 \cdot 10^{-5} < x < 8.1 \cdot 10^{-5}$
      - Pb-p: $1.2 \cdot 10^{-2} < x < 5.3 \cdot 10^{-2}$
    - similar to those for Pb-Pb
  - **Color Glass Condensate calculations disfavoured by the data**

ALICE, arXiv:1308.6726
\( \Upsilon \) in Pb-Pb and p-Pb

- Similar suppression in Pb-Pb for \( \Upsilon \) and J/\( \psi \) within uncertainties
- Less regeneration for \( \Upsilon \) (b quarks less abundant)
- Feed-down from \( \Upsilon(2S) \), \( \Upsilon(3S) \) and \( \chi_b \) is \( \sim50\% \)

- Compatible nuclear modification factor of \( \Upsilon \) and J/\( \psi \) in p-Pb
- Shadowing models describe within uncertainties both J/\( \psi \) and \( \Upsilon \) \( R_{pPb} \)
Conclusions

- Many results already published from the p-Pb run + several preliminary results from p-Pb shown in conferences
  - **p-Pb** as control experiment: first assessment of cold nuclear matter effects → important for the interpretation of nuclear modification factors measured in Pb-Pb
  - **p-Pb** revealed many **interesting** and novel aspects **per se**, such as parton saturation, hints of collective behaviour in high multiplicity events
- Analysis of the **Pb-Pb** samples collected in 2010 and 2011 are continuing with more differential measurements
  - e.g. first measurement of D meson elliptic flow just published on PRL
- Preparation of Run II about to start
- … plus a lot of effort on the performance studies for the ALICE upgrades
Backup
Twin ridge structure in p-Pb

**High multiplicity**
- \(2 < p_{\text{T}_{\text{Twin}}} < 4 \text{ GeV/c}\)
- \(1 < p_{\text{T}_{\text{assoc}}} < 2 \text{ GeV/c}\)

\(\text{p-Pb} | s_{\text{NN}} = 5.02 \text{ TeV}\)
- 0-20%

**Low multiplicity**
- \(2 < p_{\text{T}_{\text{Twin}}} < 4 \text{ GeV/c}\)
- \(1 < p_{\text{T}_{\text{assoc}}} < 2 \text{ GeV/c}\)

\(\text{p-Pb} | s_{\text{NN}} = 5.02 \text{ TeV}\)
- 60-100%

**High - Low**
- \(2 < p_{\text{T}_{\text{Twin}}} < 4 \text{ GeV/c}\)
- \(1 < p_{\text{T}_{\text{assoc}}} < 2 \text{ GeV/c}\)

\(\text{p-Pb} | s_{\text{NN}} = 5.02 \text{ TeV}\)
- (0-20%) - (60-100%)

**Similar observations in Pb-Pb are ascribed to collective effects**
** in Pb-Pb ALICE vs. CMS

- ** suppression at forward rapidity in ALICE is similar to that measured at mid-rapidity by CMS

- No strong rapidity dependence of ** $R_{AA}$ within the large range probed by ALICE and CMS
**p-Pb: global event properties (1)**

- **Pseudorapidity distribution of charged particles**

- **Model predictions:**
  - Saturation models are too steep with $\eta_{\text{lab}}$
  - pQCD models (HIJING, DPMJET) reproduce better the data
    - Where shadowing is included, significant (~30%) reduction of the yield
p-Pb: global event properties (2)

- Average $p_T$ of charged particles vs. multiplicity
- Three different $\sqrt{s}$ for pp, p-Pb and Pb-Pb, but $\sqrt{s}$ dependence expected to be weak
- Much stronger increase of $\langle p_T \rangle$ in p-Pb than in Pb-Pb
- p-Pb follows pp up to $N_{ch} \sim 14-15$