Quarkonium production in heavy ion collisions at the LHC

Francesco Bossù

Laboratoire de l’Accélérateur Linéaire, Orsay

Secondo incontro sulla fisica degli ioni pesanti a LHC
Torino, 10/10/2017
Why quarkonium in heavy ions (I)

- Matsui and Satz: screening in the $q\bar{q}$ potential, $J/\psi$ “melts” in the QGP.
- Different $q\bar{q}$ states may not form at different temperatures.

- At LHC, large charm (beauty) cross section: $\times 10$ ($\times 60$) more than at RHIC.
- About 100 $c\bar{c}$ pairs per PbPb collision.
- Possible statistical recombination of uncorrelated charm quarks.
- Charm may participate to collective motions of the medium.
Why quarkonium in heavy ions (II)

p-nucleus: just a control experiment?

- At LHC, heavy flavours allow one to reach of very small $x_B$.
- Density of gluons increases.
- Does collinear factorization still hold?
- Which other processes can intervene in quarkonium production?
- Coherent energy loss? Comovers?
- Small deconfined systems?

And what about pp collisions...
Textbook like plot for quarkonium suppression in PbPb!
Bottomonium in PbPb

CMS-HIN-16-023

- $R_{AA}(\Upsilon(1S)) \approx 0.4$, $R_{AA}(\Upsilon(2S)) \approx 0.1$, $\Upsilon(3S)$ not seen.
- Results at $\sqrt{s_{NN}} = 5$TeV and 2.67 TeV consistent within uncertainties.
- $y$-dependence: at 2.76TeV, forward rapidity $R_{AA}(\Upsilon(1S))$ lower than mid-rapidity. At 5TeV less tension.
- No $p_T$-dependence.
- $R_{AA}$ approaches unity in peripheral collisions.
• ALICE measurement at 2.76 TeV: striking difference with measurement at RHIC.
• $R_{AA}$ larger at low-$p_T$, compatible with $c\bar{c}$ recombination at later stages of the evolution.
Similar suppression at mid- and forward rapidities.

Compatible results at two energies. Better statistical precision with 5TeV data.

New results at 5TeV show of slightly larger $R_{AA}$ than 2.76TeV results for $2 < p_T < 6$GeV/c
CMS and ATLAS extend $J/\psi$ measurements at high $p_T$.

- Nonprompt fraction similar to pp, then similar $R_{AA}$ for prompt and nonprompt, but different mechanisms.
- 2.76TeV and 5TeV $R_{AA}$ results compatible also at medium/high $p_T$. 
Evidence of positive $v_2$ of J/$\psi$ at 2.67TeV.

Confirmation with better precision with 5TeV data.

Similar $v_2$ for J/$\psi$ and prompt charm mesons.

CMS data extend ALICE measurement at higher $p_T$. 
\( \psi(2S) \) production in PbPb: difficult measurement.

- Stronger suppression than \( J/\psi \).
- Also at intermediate/high \( p_T \).
\( \psi(2S) \) in PbPb

- Double ratio \([\psi(2S)/J/\psi]_{\text{PbPb}}/[\psi(2S)/J/\psi]_{\text{pp}}\): direct comparison of medium strength effects on \( J/\psi \) and \( \psi(2S) \).
- Puzzling enhancement observed by CMS at 2.76TeV, not seen by ALICE and not present in the 5TeV dataset.
- Double ratio compatible with zero at forward rapidity. Lower than unity also at high \( p_T \).
- Inclusive $J/\psi$ production in pPb@5 TeV
- Strong suppression at forward rapidity.
- At backward, $R_{pPb}$ compatible with unity.
- Suppression at low $p_T$, approaching unity at high $p_T$. 
Similar observations by LHCb and CMS for prompt J/$\psi$ production in pPb@5TeV.
Measurements of prompt and inclusive $J/\psi$ production in pPb@8.16TeV confirm of 5TeV results.

- Strong suppression at forward rapidity.
- At backward, $R_{pPb}$ compatible with unity, although interesting tensions with nPDF calculations.
- Suppression at low $p_T$, approaching unity at high $p_T$. 

\[ R_{pPb} \text{ (5TeV)} \]

\[ R_{pPb} \text{ (8.16TeV)} \]
Suppression of $\psi(2S)$ stronger than $J/\psi$.
Similar results already observed at RHIC.
Weak rapidity and momentum dependence.
pPb@5TeV sample is statistically limited.
Suppression of $\psi(2S)$ stronger than $J/\psi$. 
- New results at 8.16 TeV are compatible with 5TeV findings,.
- Small/No $p_T$ dependence.
Bottomonium in pPb

- $\Upsilon(1S)$ shows similar behaviour as $J/\psi$ within uncertainties.
- Exited states are suppressed (like $\psi(2S)$), but not as much as in PbPb.
- pPb run at 5TeV statistically limited. Waiting for 8.16TeV results.
Quarkonium production dependence on multiplicity.

Similar results observed in pp and pPb.

Forward-backward difference in high multiplicity events.

Suppression of exited bottomonium states depend on event multiplicity.
$v_2$ in pPb

- Correlations between hardons and $J/\psi$ in pPb collisions used to extract $v_2$.
- $p_T < 3$ GeV/c: no deviation from zero.
- $p_T > 3$ GeV/c: positive $v_2$.
- Similar strength at forward and backward rapidities and at the two energies.
- Overlay with PbPb central collisions shows similar $v_2$. 
Summary

**PbPb**

- Suppression of excited $\Upsilon$ states: iconic result for quarkonium suppression in QGP.
- Low-$p_T$ $J/\psi$: enhancement with respect to RHIC, regeneration of bound states.
- Non zero $v_2$ for inclusive $J/\psi$ over a large kinematic range.
- $\psi(2S)$ would benefit from larger samples.

**pPb**

- Quarkonia and heavy flavour hadrons allow one to test/constrain nPDF and gluon saturation.
- Stronger suppression of excited states: depends on event activity, but not much on kinematics.
- $J/\psi$ shows positive $v_2$ for $p_T > 3$ GeV/c.
Outlook

Still Run 2 will provide more PbPb data. Increase in statistics allows one to explore more differential measurements, in particular for exited states.

pPb data still to be fully exploited. More results are on the way, also possible measurements of $\chi_c$.

ALICE and LHCb will undergo major upgrades during LS2.

ALICE central barrel will run at 50kHz PbPb collisions.

ALICE muon arm will be equipped with a silicon tracker close to the interaction point: better resolution and measurements of $B \to J/\psi + X$

LHCb will have a better centrality reach in PbPb.