Inclusive $J/\psi$ production at ALICE

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Daniel Tapia Takaki
IPN Orsay (CNRS) – Paris XI
Plan of this talk

- **Quarkonia production in p+p**
  - Physics motivation
  - ALICE detector and collected data
  - Data analysis
  - Comparison to theoretical models
- **What is next?**
  - Quarkonia production in Pb+Pb
  - Exclusive production, polarisation, ...
- **Summary**
Several models have been proposed to describe the Tevatron and RHIC data

- Colour Evaporation Model (CEM)
- Colour Octet Model (COM)
- Colour Singlet Model (CSM)

Mainly differ in the relative weight of the color singlet and color octet intermediate qq states that, once hadronised, will form the final observed resonance.
Polarisation of heavy quarkonia states

The models are not able to reproduce consistently the production cross section, the transverse momentum ($p_T$) distributions and the polarisation.

**Graph:**

- CDF RunII – $p\bar{p}$ at $\sqrt{s}=1.96$ TeV - $|y|<0.6$

\[ \frac{dN}{d\cos \theta} = A(1 + \lambda \cos^2 \theta) \]

- $\lambda > 0$ transverse
- $\lambda < 0$ longitudinal

**CEM:**
No predictions

**COM:**
Transverse polarisation at high $p_T$

**CSM:**
Longitudinal at high $p_T$
The ALICE experiment at the CERN LHC
The ALICE detector

Central barrel ($|\eta|<0.9$)
- Tracking: ITS+TPC+TRD
- PID: TPC+TRD+TOF
- Secondary vertexing: ITS

Muon spectrometer ($-4.0<\eta<-2.5$)
- Tracking: 10 CPC planes
- Muon PID: absorbers
- 5 L0 inputs from trigger chambers

- Using the central barrel: $J/\psi \rightarrow e^-e^+$ (BR = 5.94 %)
- With the muon spectrometer: $J/\psi \rightarrow \mu^-\mu^+$ (BR = 5.93 %)
ALICE 2010

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

*upgrade to the original setup
The ALICE Muon Spectrometer
The ALICE Muon Spectrometer

5 tracking stations (10 planes of MWPCs with bi-cathode pad readout): resolution $\approx 70\mu$m in the bending plane

2 Trigger Stations (4 planes of RPCs): fast response (~2ns)

Dipole Magnet ($|B_{dl}| = 3$Tm)

Iron wall (muon filter-7$\lambda_{int}$)

Front Absorber ($10\lambda_{int}$)

Beam shield

Hardware momentum cut:
$p^\mu = 4$ GeV/c
$(p_T^\mu > 0.5$GeV/c)
The ALICE Muon Spectrometer

I. Mass resolution for $\Upsilon < 100 \text{ MeV/c}^2 \rightarrow$ spatial resol. $< 100 \mu\text{m}$ along $y$ (bending direction)

II. Up to 500 hits/central Pb-Pb collision on the 1\textsuperscript{st} station (assuming $dN_{ch}/dy|_{y=0} = 8000$)

III. Trigger rate $< \sim 1 \text{ kHz}$ (DaQ bandwidth for muon)
   • $8 \text{ kHz}$ Pb-Pb collisions with $L = 10^{27} \text{ cm}^{-2}\text{s}^{-1}$
**Muon Tracking Chambers**

- 5 stations of two Cathode Pad Chambers ~ 100 m²
- $1.1 \times 10^6$ channels, smallest pads $4.2 \times 6.3$ mm$^2$ : occupancy < 5% (in Pb+Pb) → Read out at 1 kHz
- Chamber thickness ~ 3% X0
- Beam test results for the spatial resolution : 50 μm for a required resolution < 100 μm
- Measurement of detectors displacement with an accuracy < 50 μm (GMS)

St 3, 4 & 5 : 140 slats (max size 40x280 cm$^2$)  
St 1 & 2 : 16 quadrants

Collaboration  
France, India, Italy, Russia
**Trigger chambers**

- 72 RPCs located on 2 stations of 2 chambers
- “low resistivity” bakelite working in streamer mode or saturated avalanche (p-p)
- 2 mm single gap
- Time resol. < 2 ns
- 20992 readout strips (pitch 1, 2 and 4 cm; length 17 to 72 cm)

FEE : 2384 Front-End boards with 8 ch. ADULT ASIC read each 25 ns.

Decision electronics : 16 VME crates with 242 local trigger cards. Decision delay of 250 ns

- Trigger decision in < 700 ns
- Readout 140 μs
- Deliver 5 output signals/triggers, for single μ, like-sign and unlike-sign μ pairs above 2 p_⊥ thresholds (1 or 2 GeV/c)
Quarkonia measurements at ALICE

- in the central barrel in the $e^+e^-$ channel ($|y|<0.9$)
- in the forward spectrometer in the $\mu^+\mu^-$ channel ($2.5<y<4$)

3 sources of $J/\psi$

1) Direct production
2) Feed down from heavier $cc$ states
3) $J/\psi$ from $b$-hadron decay

\[\text{Prompt } J/\psi \quad \text{radiative decay } \chi_c \rightarrow J/\psi \gamma\]

- can be identified in the central barrel, good impact parameter resolution ($\sigma_{r_\phi} < 60 \mu m$ for $p_T>1 \text{ GeV/c}$)
- forward detection more difficult
  - $3$-muon events
  - $B$ cross section from single-$\mu$
  - Semileptonic decays of $B$ pairs

Preliminary ALICE results refer to inclusive $J/\psi$ production
First results from $p+p \sqrt{s_{NN}} = 7$ TeV
MB triggers during the p+p runs this year

<table>
<thead>
<tr>
<th>Minimum Bias Triggers</th>
<th>MB1</th>
<th>SPD or (V0A or V0C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MB3</td>
<td>SPD and (V0A and V0C)</td>
</tr>
</tbody>
</table>

Aat least 2 pixels in coincidence with beams

V0A  $\ 2.8 < \eta < 5.1$

V0C  $\ -1.7 < \eta < -3.7$

at least 1 charged particle in 8 rapidity units

Global Fast Or (GFO) is the trigger from the Silicon Pixel Detector (SPD)
$J/\psi \rightarrow \mu^+\mu^- : p+p @ \sqrt{s}=7 \ TeV \ sample$

**Data sample:**
Integrated luminosity = 13.6 nb$^{-1}$, corresponding to data collected between May and July 2010 (~ 10-15% of the 2010 total statistics)
Trigger: muon in the forward spectrometer, in coincidence with minimum bias interaction trigger

**Run Selection:**
Runs selected according to quality checks on the stability of the muon spectrometer tracking and trigger performances

**Event Selection:**
- at least one muon reconstructed in the tracking and trigger chambers satisfying the trigger algorithm
- at least one vertex reconstructed in the silicon pixel detector
cut on the track position at the end of the front absorber ($2^0<\theta_{\text{abs}}<9^0$)

rapidity window: $2.5<y<4$
transverse momentum window $0<p_T<8$ GeV/c (statistics)
**J/ψ → µ⁺µ⁻ : signal extraction**

The number of J/ψ is extracted from a fit to the invariant mass spectrum using

Crystal Ball shape for the signal (J/ψ and ψ')
Sum of two exponentials for the background

The available J/ψ statistics, used for the cross section determination is

\[ N_{J/\psi} = 1909 \pm 78 \]

S/B (2.9<M<3.3) ~ 2.4

With a suitable p_T cut (smaller background), also the ψ(2S) signal is visible, but with a much lower statistical significance
$J/\psi \rightarrow \mu^+ \mu^-$: Comparison to the MC

$J/\psi$ peak width well reproduced by MC:
- alignment
- data taking conditions
$J/\psi \rightarrow \mu^+ \mu^- : \text{acceptance } \times \text{efficiency}$

Data corrected for acceptance and efficiency

→ data somewhat softer than the MC

Generated MC distribution “CDF pp 7 TeV”

• $p_T$ extrapolated from CDF results, $y$ obtained from CEM calculations, no polarisation
\( J/\psi \rightarrow \mu^+\mu^- : \text{acceptance } \times \text{efficiency} \)

Based on simulations performed separately for each LHC period, in order to reproduce in a realistic way, the detector status

Input: realistic \( y \) and \( p_T \) \( J/\psi \) distributions

\( p_T \rightarrow \text{CDF extrapolation} \)

\( y \rightarrow \text{CEM calculation} \)

Study of differential distributions: 1D acceptance correction
$J/\psi \rightarrow e^+e^-$: $p+p \rightarrow J/\psi \rightarrow e^+e^-$: $p+p \at \sqrt{s}=7\ TeV\ sample$ and signal extraction

Analysis is based, for the moment, on a smaller data sample wrt to $J/\psi \rightarrow \mu^+\mu^-$ → $L=4.0\ nb^{-1}$ (~15% of 2010 stat.)

Track selection:

| $\eta^{e^+,e^-}|<0.88$ and $|y^{J/\psi}|<0.88$ |
| $p_T^{e^+,e^-}>1\ GeV/c$ |

TPC-based PID

$N_{J/\psi} = 123 \pm 15$
$J/\psi \rightarrow e^+e^- : \text{acceptance } \times \text{efficiency}$

As for the muon channel, $J/\psi$ reconstruction down to $p_T = 0$
J/ψ → µ⁺µ⁻: Luminosity normalisation

• To get an estimation of the luminosity we use the signal from the V0 (V0A and V0C in coincidence → V0and).

• Using a Van der Meer scan we get the Luminosity
  → \(\sigma_{V0\text{and}} = 62.3 \text{ mb} \) with 10% systematic

• With low intensity runs (to avoid large pile-up) we can extract the ratio V0and/CINT1B.

• CINT1B is our main MB trigger in pp. CINT1B = V0A or V0C or SMB (a pixel trigger)
  → \(\sigma_{\text{CINT1B}} = \sigma_{V0\text{and}} / (V0\text{and}/\text{CINT1B}) = 71.4 \text{ mb}\)

We use \(\sigma_{\text{CINT1B}}\) to normalize the cross section with the following formula (most of data come from single µ trigger):

\[
\sigma_{J/\psi} = \frac{N_{J/\psi|\text{single} \mu}}{Acc \times \varepsilon} \times \frac{1}{N_{\mu|\text{single} \mu}} \times \frac{N_{\mu|\text{CINT1B}}}{N_{\text{CINT1B}} \text{ (pile up corr)}} \times \sigma_{\text{CINT1B}}
\]
Cross section calculated as
\[
\sigma_{J/\psi} \left(2.5 < y < 4\right) = \frac{N_{J/\psi}}{Acc_{J/\psi} \times \varepsilon} \times \frac{1}{L}
\]

The ALICE results, integrated over y and \(p_T\), are:

\[
\sigma_{J/\psi} \left(-0.88 < y < 0.88\right) = 12.95 \pm 2.15 (\text{stat}) \pm 2.32 (\text{syst})^{+1.26}_{-2.55} (\text{syst.pol.}) \mu b
\]

\[
\sigma_{J/\psi} \left(2.5 < y < 4\right) = 7.25 \pm 0.29 (\text{stat}) \pm 0.98 (\text{syst})^{+0.87}_{-1.50} (\text{syst.pol.}) \mu b
\]

(polarisation-related errors calculated in the helicity frame)

Good agreement with the corresponding LHCb result obtained at forward rapidity (ICHEP2010)

\[
\sigma_{J/\psi} \left(2.5 < y < 4\right) = 7.65 \pm 0.19 (\text{stat}) \pm 1.10 (\text{syst})^{+0.87}_{-1.27} (\text{syst.pol.}) \mu b
\]
## Systematic errors

### Source of systematic error

<table>
<thead>
<tr>
<th>Source of systematic error</th>
<th>Muons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty on signal extraction</td>
<td>7.5 %</td>
<td>polarization</td>
</tr>
<tr>
<td>$p_T$ and $y$ shapes in the MC</td>
<td>2 %</td>
<td>$\lambda=-1$</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td>4 %</td>
<td>$\lambda=1$</td>
</tr>
<tr>
<td>Tracking efficiency</td>
<td>2 %</td>
<td>Helicity</td>
</tr>
<tr>
<td>Normalization</td>
<td>10 %</td>
<td>-21%</td>
</tr>
<tr>
<td><strong>Total systematic error</strong></td>
<td><strong>13.5 %</strong></td>
<td>+12%</td>
</tr>
</tbody>
</table>

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<tr>
<th>Source of systematic error</th>
<th>Electrons</th>
<th>polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics</td>
<td>&lt;1%</td>
<td>$\lambda=-1$</td>
</tr>
<tr>
<td>Track quality,$#$clusters TPC</td>
<td>10%</td>
<td>$\lambda=1$</td>
</tr>
<tr>
<td>PID cuts</td>
<td>10%</td>
<td>Helicity</td>
</tr>
<tr>
<td>Signal extraction range</td>
<td>4%</td>
<td>-20%</td>
</tr>
<tr>
<td>Normalization</td>
<td>10 %</td>
<td>+10%</td>
</tr>
<tr>
<td><strong>Total systematic error</strong></td>
<td><strong>18 %</strong></td>
<td>Collins-Soper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-25%</td>
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<td>+12%</td>
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</tbody>
</table>
Good agreement with the LHCb result in the same rapidity range
Other sources of point to point systematic errors
(signal extraction, acceptance input) vary between 3 and 10%
(not yet fully evaluated)
Differential cross section: 
\[ d\sigma_{J/\psi}/dy \ (p_T>0) \]

ALICE can measure the distribution of the inclusive J/ψ production in a wide rapidity range

\( p_T \) coverage extends to zero at both central and forward rapidities
Preliminary comparison(s)
Preliminary comparison(s)

Model calculations:
- J.P. Lansberg, arXiv:1006.2750

CMS: \( p_T \)-integrated cross section 1.6<\( y <2.4 \) from (arXiv:1011.4193)

ATLAS: \( d\sigma/dy \ 1.5< y < 2.25 \), ATLAS-CONF-2010-062

LHCb: \( d\sigma/dy \ 2.5< y < 4 \) from LHCb-CONF-2010-010
\( \sqrt{s}\)-dependence of inclusive \( J/\psi \)

- NLO calculation for \( cc \) by Mangano et al., normalized to the CDF point
- Same \( \sqrt{s}\)-dependence for the inclusive \( J/\psi \) cross section

\[ d\sigma_{J/\psi}/dy \text{ (\( \mu b \))} \]

- ALICE, \( |y|<0.88 \), preliminary
- CDF, \( |y|<0.6 \)
- PHENIX, \( |y|<0.35 \)

line: \( d\sigma_{\infty}/dy \), scaled to CDF data point
NLO (MNR), \( m_c=1.2 \text{ GeV} \), \( \mu_F = \mu_R = 2m_c \)
7th November 2010: moving from p-p to Pb-Pb (2.76 TeV)

Higher occupancy with respect to Pb-Pb
Re-tuning of reconstruction parameters
Quarkonia in heavy-ions

Quarkonia suppression was one of the main pieces of evidence for CERN's claim to have produced a QGP phase at SPS energies.

Different lattice calculations do not agree on whether the J/ψ is screened or not; measurements will have to tell!

Debye screening predicted to destroy J/ψ's in a QGP with other states "melting" at different temperatures due to different sizes or binding energies.
J/ψ Suppression

Colour screening in QGP: Screening radius < size of J/ψ \( (~0.5 \text{ fm}) \)

So cc bound state cannot survive in QGP. Seen at SPS energies

At LHC energies, colour screening could be strong enough to break-up \( \Upsilon \) (bb) or maybe just \( \Upsilon' \) or \( \Upsilon'' \).
**Terminology**

- **Collision Centrality**
  - Describes the overlap of two incoming ions at the point at which they collide.
  - The more central the collision, the greater number of participating nucleons ($N_{\text{part}}$ or $N_{\text{wound}}$).
  - Energy of system increases with collision centrality.

- **Multiplicity**
  - Number of charged particles produced in the collision.
Anomalous suppression of $J/\psi$ production at SPS and RHIC

Peripheral collisions exhibit a $J/\psi$ yield in agreement with the normal nuclear absorption pattern derived from pA collisions.

As the centrality of the collision increases → the $J/\psi$ yield decreases: anomalous $J/\psi$ suppression

Suppression patterns are surprisingly similar at SPS and RHIC!
Anomalous suppression of $J/\psi$ production at RHIC

$J/\psi$ Nuclear modification factor

$|y|<0.35$

$1.2<|y|<2.2$
The J/ψ Puzzle

- PHENIX J/ψ Suppression:
  - like SPS at mid-rapidity
  - stronger at forward rapidity with forw/mid ~0.6 saturation
  - <p_T^2> centrality indep.

Data - SPS, PHENIX, STAR, LHC...
Need high statistical & systematic accuracy

Sequential screening χ_c, ψ', J/ψ later

- lattice & dynamical screening J/ψ not destroyed?

- large gluon density destroys J/ψ's

Regeneration & destruction
- less suppression at mid-rapidity narrowong of p_T & γ
- J/ψ flow

Regeneration (in medium?)
- large charm cross section
- Charm dE/dx & flow

- configuration of ccbar state
- ~40% feeddown from χ_c, ψ' (uncertain fraction)
- CNM
- absorption d+Au constraint?
- shadowing or coherence
- CGC - less charm at forward rapidity
- comovers more mid-rapidity suppression

5/25/2009 Mike Leitch
$J/\psi$ production at LHC energies: regeneration/suppression?
The $J/\psi$ is not completely suppressed!
Expected final statistics for Pb run $\rightarrow O(10^3)$
Extract $R_{AA}$ in (some) centrality bins
Exclusive $J/\psi$ production in $p+p$

- Two tracks in otherwise an empty detector
The small-\(x\) regime

From RHIC to LHC

\[ x_{\text{min}} \downarrow \sim 10^{-2} \]
- factor 1/30 due to energy
- factor 1/3 larger rapidity

With \(J/\psi\) at rapidity 4

- Pb+Pb collisions \(x_{\text{min}} \sim 10^{-5}\)
- p+p collisions \(x_{\text{min}} \sim 3 \times 10^{-6}\)
Diffractive Physics
Today

ZDC  V0A
ADD

ZN  |η| > 8.7  ZP  |η| > 8.4

TPC  |η| < 0.9

ZEM  4.8 < η < 5.7

ZN  |η| > 8.7  ZP  |η| > 8.4

T0A  4.5 < η < 5.0

T0C  - 2.9 < η < -3.3

V0C  - 1.7 < η < -3.7

FMD  1.7 < η < 5.0  - 3.4 < η < -1.7

ADD  - 4.9 < η < -6.0
4 stations of scintillator detectors
Summary

• Preliminary results on inclusive J/$\psi$ production
  • Analysis in both electron and muon decay channels.
  • Integrated and differential cross sections
  • Comparison to theoretical models of quarkonia production

• Prospects of measuring J/$\psi$ production in Pb+Pb interactions, in exclusive p+p (Pb+Pb) reactions
Thanks,

Merry Christmas

and a happy new year

2011!
Additional slides
Quarkonia challenges at the LHC

- $J/\psi, \Upsilon \rightarrow \ell^+\ell^-$ measurements require $\mu^\pm, e^\pm$, secondary-vertex detectors
  - ATLAS/CMS within $-2.5 < \eta < 2.5$, full $\phi$
  - LHCb within $2 < \eta < 5$, full $\phi$

- Focus on dimuons at moderately high-$p_T$ (ATLAS/CMS), low-$p_T$ (LHCb)

- Dielectron channels accessible but more difficult: large $X_0/X$ in front of ECALs (ATLAS/CMS).

- Early measurements (low lumi, dedicated low-thresh. triggers):
  - ATLAS/CMS: $p+p$ & Pb-Pb studies
  - LHCb: $p+p$ studies only

B $\rightarrow J/\psi$ (20%) contribution

1-year pp 14 TeV (nominal Luminosity)
Heavy-ion collisions

The CGC provides a framework to describe nucleus-nucleus collisions up to a time of

\[ \tau \sim Q_s^{-1} \]
Small-$x$ physics and non-linear evolution

At low $x$, there must be a regime (at $q^2 < Q_s^2$) where partons overlap. Here, the increase in the number of small $x$ partons becomes limited by gluon fusion.

- **Saturation scale** $Q_s^2(x)$ to be determined experimentally.

This is the quantum evolution of the hadron wavefunction. Because the saturation momentum is larger in nuclei than it is in protons, it is more difficult to produce glue at small $x$. Therefore as one goes to smaller values of $x$, there should be fewer particles at small $x$ relative to the expectation from incoherent scattering.... L.M.
Parton Distribution Functions in nuclei

Is a free proton the same as a proton inside a nucleus?
No! Some “nuclear effects” modify the probabilities of finding partons of given x
when the proton is inside a nucleus.
The “EKS 98 model” (among others) provides the ratio between the PDFs in a
“proton of a nucleus of mass number A” and in a “free proton”

\[ R_i^A(x, Q^2) = \frac{f_i^A(x, Q^2)}{f_i^P(x, Q^2)} \]

“Shadowing” or “anti-shadowing”:
Decrease or increase of the parton’s density in the nucleus, in a certain
kinematic range…

For a given collision energy and a
given produced mass, the x values
depend on the rapidity range where
the measurement is made

(Shadowing means that some of the partons are obscured by virtue of having another parton in
front of them. For hard spheres, for example, this would result in a decrease of the scattering
cross section relative to what is expected from incoherent independent
scattering.)
Absorbeur composé de plusieurs matériaux

\[ R_{abs} : \text{distance entre la ligne faisceau et la trace au bord de l'absorbeur.} \]