Quarkonia detection with the ALICE muon arm and low-x PDFs

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Outline

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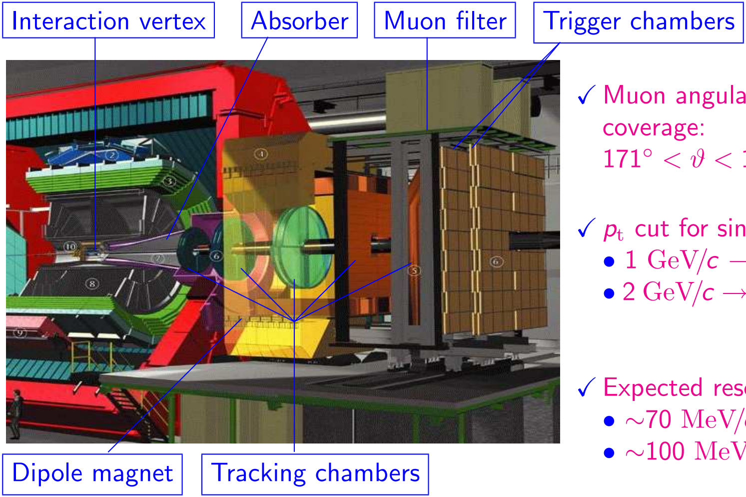
ALICE muon spectrometer



- ✓ Muon angular coverage: $171° < \vartheta < 178°$
- ✓ p_t cut for single Muon:
  - $1\ \mathrm{GeV}/c \rightarrow$ charmonia
  - $2\ \mathrm{GeV}/c \rightarrow$ bottomonia
- ✓ Expected resolutions:
  - $\sim 70\ \mathrm{MeV}/c^2 \rightarrow \mathrm{J}/\psi$
  - $\sim 100\ \mathrm{MeV}/c^2 \rightarrow \Upsilon$

Outline

Fast simulation

- Existing models foresee a large number of quarkonia produced in pp collisions at the LHC (order of $\sim 10^8$ in 10^7s for J/ψs decaying in muon pairs).
- Full Monte Carlo simulations require prohibitively long computing time.

$$\Downarrow$$

Fast simulation

- Parameterization of the whole spectrometer response at the single muon level.
- It can be divided in two phases:
  1. Particle generation from rapidity and transverse momentum distributions.
  2. Assignment of detection probability according to kinematic parameters of generated particle.

Heavy quarkonia: total cross sections

- "Prompt" total cross sections (σ) including:
  - direct production (σ_{dir})
  - feed-down from higher-mass quarkonia resonances

$\Rightarrow$

From Color Evaporation Model

	$\sigma \times$ BR$_{\mu^+\mu^-}$	σ_{dir}/σ
Υ	28 nb	0.52
J/ψ	3.18 μb	0.62

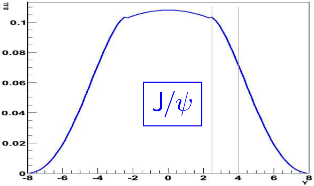
Caveat: CEM predictions in agreement with Tevatron data for Υ, but not for J/ψ (factor of $\sim$ 2 less) $\rightarrow$ "Conservative" approach.

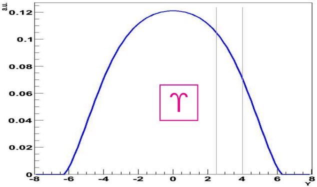
Only for J/ψ :

- "From B decay" cross section ($\sigma_{B \rightarrow J/\psi}$) obtained with PYTHIA:
  - $b\bar{b}$ pairs produced with $\sigma_{b\bar{b}} = 0.51$ mb (ALICE-INT-2003-019)
  - $B \rightarrow$ J/ψ forced (BR from PYTHIA, 1.16% on averge)
  - J/$\psi \rightarrow \mu^+\mu^-$ forced (BR from PDG, 5.88%)

Heavy quarkonia: prompt differential cross sections

- Rapidity (y) distributions for resonance → CEM

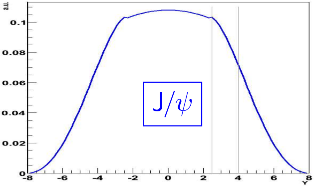


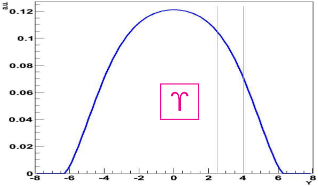


[1] A. Accardi et al., "Hard probes in Heavy Ion Collisions at the LHC: PDFs, Shadowing and pA Collisions"

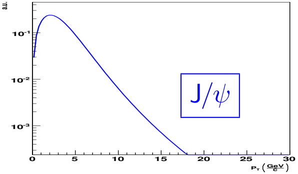
Heavy quarkonia: prompt differential cross sections

- Rapidity (y) distributions for resonance $\rightarrow$ CEM

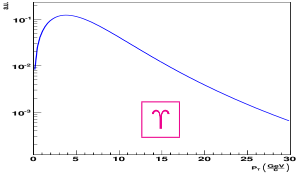




- p_t distributions for resonance $\rightarrow$ extrapolation of CDF data.
  - Fit of CDF p_t distribution @ 1.96 TeV
  - Extrapolation 1.96 $\rightarrow$ 14 TeV: $< p_\mathrm{t}^2 >$ dependence on $\sqrt{s}$ by CEM[1].



Results of extrapolations



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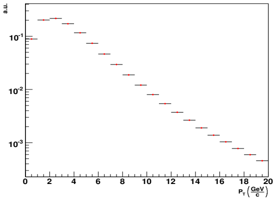
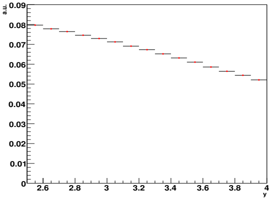
Heavy quarkonia: from B decay differential cross section

- J/ψ from B: p_t and y distributions from PYTHIA





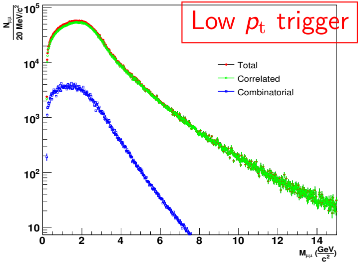
ALICE Muon Spectrometer is unable to distinguish J/ψ coming from B meson decays.

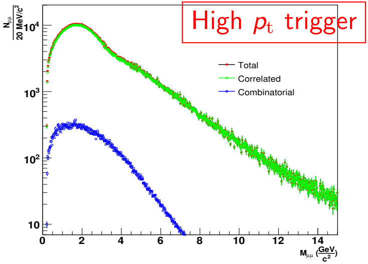
$\Downarrow$

Differential cross sections summed together with appropriate weight. No distinctions will be made in the following.

Background

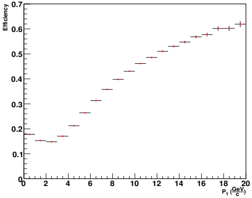
- Correlated (muon pairs from chain decays of $\mathrm{b\bar{b}}$ and $\mathrm{c\bar{c}}$)
  - Heavy hadrons produced with PYTHIA.
  - Semileptonic decay forced.
  - Unlike-sign muon pairs from decay chains of one $Q\bar{Q}$ pair selected.
- Combinatorial (muon pairs from uncorrelated decay of $\mathrm{b\bar{b}}$, $\mathrm{c\bar{c}}$, π, K)
  - Heavy hadrons like in correlated background.
  - π/K produced with PYTHIA. Semileptonic decay forced. Resulting muons weighted with the probability that π/K decay before reaching the Muon Spectrometer absorber.
  - Unlike-sign muon pairs from uncorrelated particles selected.



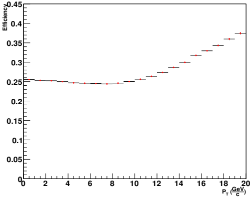


Quarkonia detection probabilities

- Computed with fast simulation (including geometrical acceptance, reconstruction and trigger efficiency)

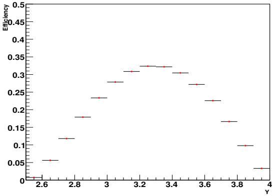


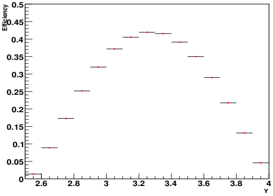
$\Leftarrow$ Normalized to $2.5 < y < 4.0$ $\Rightarrow$



J/ψ

Υ





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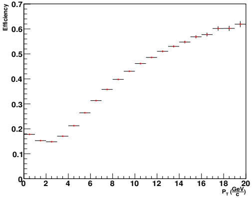

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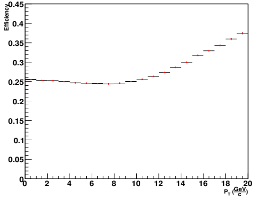
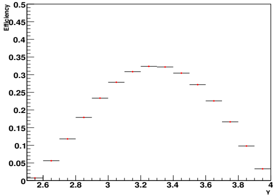
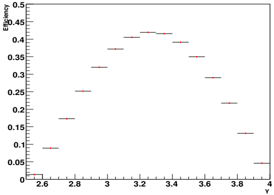


J/ψ 2.6% $\Longleftarrow$ Global detection probabilities (normalized to the whole phase space) $\Longrightarrow$ Υ 3.4%

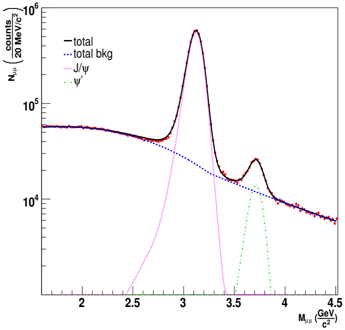


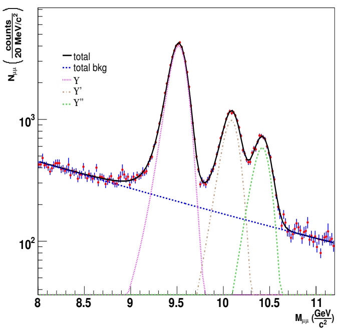


Expected rates

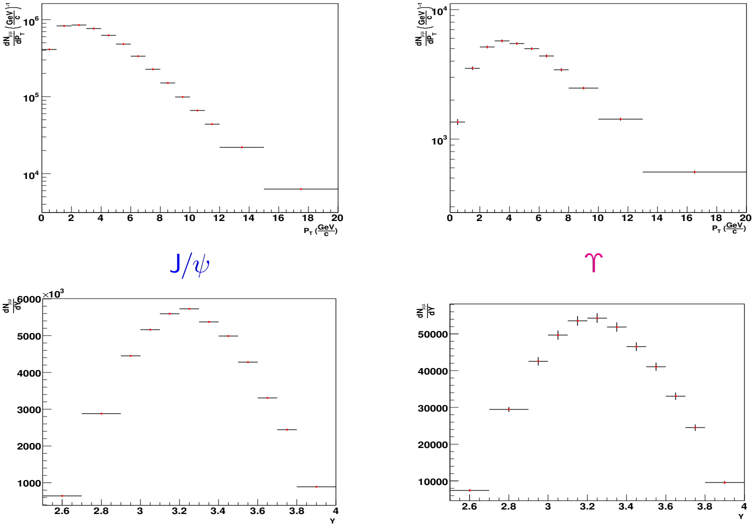
- Data taking scenario for pp run in ALICE IP:
  $\mathcal{L} = 5 \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$; $t = 10^7$ s
- Number of detected quarkonia: $\Longrightarrow$

Υ	48×10^3
Υ'	8.7×10^3
Υ''	5.3×10^3
J/ψ	5×10^6
ψ'	0.13×10^6

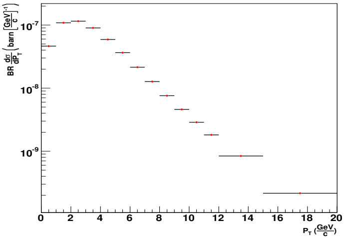


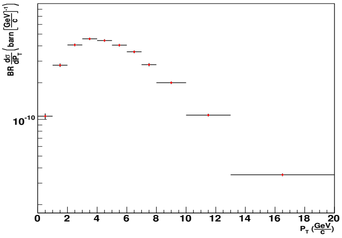


Expected yields vs. p_t and y

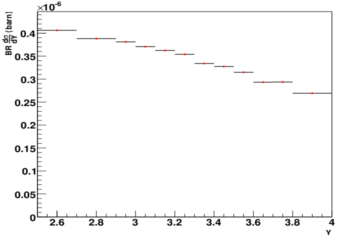


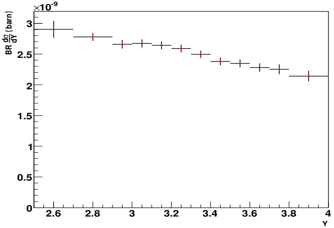
Distributions corrected for detection efficiency





J/ψ Υ

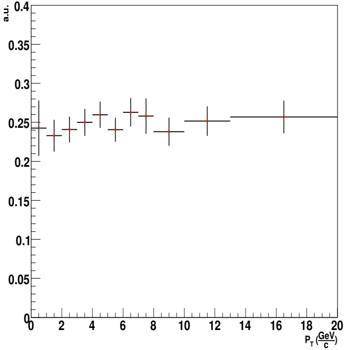




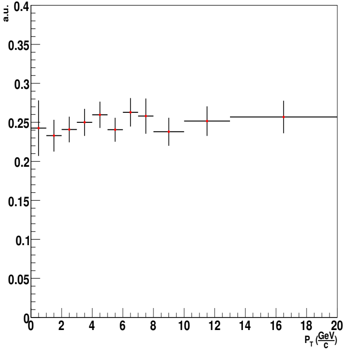
Ratio between bottomonia resonances

- No dependence of p_t distribution on quarkonia masses, as expected from input.

$\Upsilon(2S)/\Upsilon(1S)$



$\Upsilon(3S)/\Upsilon(1S)$



Conclusions

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- J/ψ and Υ yields for 10^7 s of pp data taking at 14 TeV have been evaluated.
- Muon Spectrometer able to resolve the higher-mass heavy quarkonia.
- Statistics good enough for measurements of p_{t} and y distributions, which can be further used for QCD studies of quarkonia production mechanism.

Revol scenario for November 2007

- $\mathcal{L} = 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- t = 20 shifts of 10 hours = 7.2×10^5 s

$\Rightarrow$

Υ	691
Υ'	125
Υ''	76
J/ψ	72000
ψ'	1872

A remarkable number of J/ψ available for physics studies since the first month.

Outline

Observables sensitive to PDFs at small x

For J/ψ production at 14 TeV: $y > 3 \Leftrightarrow x < 10^{-5}$. The rapidity window covered by the Muon Spectrometer is well suited.

$\sigma_{J/\psi}$ from CEM

$$\sigma_C^{CEM} = F_C \sum_{i,j} \int_{4m_Q^2}^{4m_H^2} \mathrm{d}\hat{s} \int \mathrm{d}x_1 \mathrm{d}x_2\, f_{i/A}(x_1, \mu^2) f_{j/B}(x_2, \mu^2) \hat{\sigma}_{ij}(\hat{s}) \delta(\hat{s} - x_1 x_2 s)$$

$$\Downarrow$$

In the CEM the J/ψ total cross section depends on PDFs, but not only

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$$\Downarrow$$

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$\mathrm{d}\sigma_{\mathrm{J}/\psi}/\mathrm{d}y$ from CEM

$$\frac{d\sigma_C^{CEM}}{dy} = \frac{F_C}{s} \sum_{i,j} \int_{4m_Q^2}^{4m_H^2} \mathrm{d}\hat{s}\, \hat{\sigma}_{ij}(\hat{s}) f_{i/A}\left(\sqrt{\frac{\hat{s}}{s}} e^{y}, \mu^2\right) f_{j/B}\left(\sqrt{\frac{\hat{s}}{s}} e^{-y}, \mu^2\right)$$

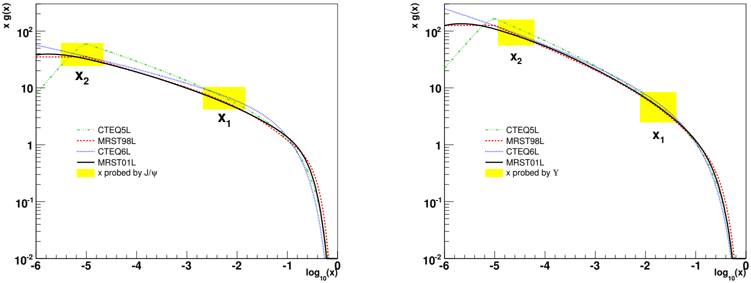
$$\Downarrow$$

In the CEM the shape of the J/ψ rapidity distr. at large rapidities depends heavily on gluon PDFs

PDF distributions

- LO calculations adopted

$\boxed{J/\psi}$ $\Longleftarrow$ Region explored by $(2.5 < y < 4)$ $\Longrightarrow$ $\boxed{\Upsilon}$



Rapidity distributions with different PDFs

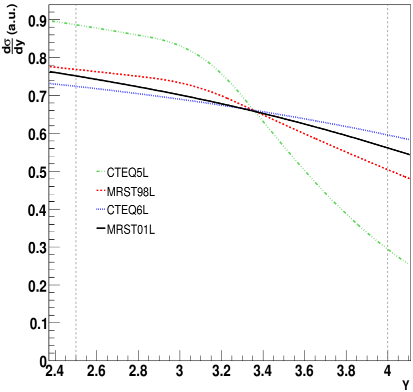
Integral in the rapidity acceptance $(2.5 < y < 4.0)$ is normalized to 1

Approximations

- Calculations LO
- *gg* contrib. dominant

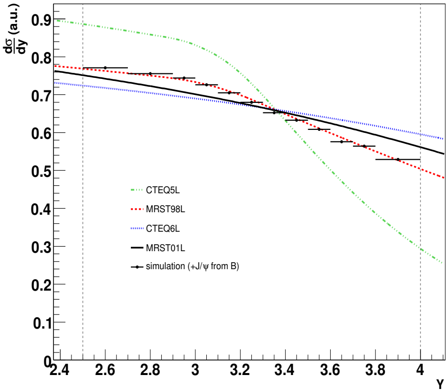
$$\Downarrow$$

$$\hat{\sigma}_{ij}(\hat{s}) = \hat{\sigma}_{gg}$$



Comparison with simulation

Small differences in shape between simulated data and MRST (LO) are due to the fact that the first include contribution of J/ψ from B decay

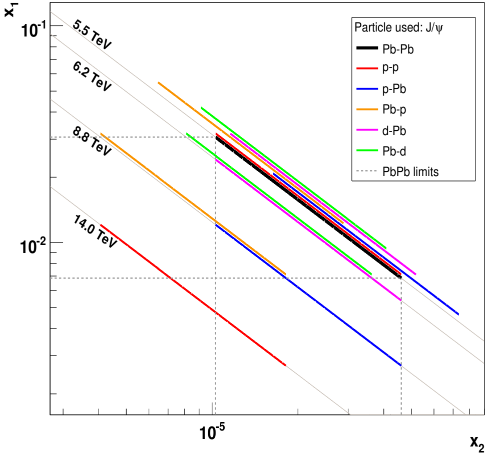


However the accuracy of data that will be taken in muon spectrometer seems good enough to...

...put some constraints on gluon distribution functions in the low x region

x regions explored with different collision systems

- pp collisions @ 14 TeV: high statistics but small overlap with x regions explored in Pb-Pb



- Stress on d-Pb @ 6.2 TeV

Conclusions and perspectives

Conclusions

- From a simple analysis (based on CEM and including some approximations) the shape of the rapidity distribution of prompt J/ψs in the rapidity region covered by the muon spectrometer seems to be sensitive to gluon distribution at low x.

Perspectives

- Extension of the study to p-Pb (Pb-p) and d-Pb (Pb-d)
- More sophisticated calculations based on NRQCD ???

Backup slides

Definitions

Rapidity: $y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$

Pseudorapidity: $\eta = -\ln\tan\frac{\vartheta}{2}$

Bjorken x: $x = \frac{Q^2}{2\mathbf{P}\cdot\mathbf{q}}$

Correlated background processes

DDprompt: $\mu^+ X_1 \leftarrow D(c) \qquad D(\bar{c}) \rightarrow X_2\, \mu^-$

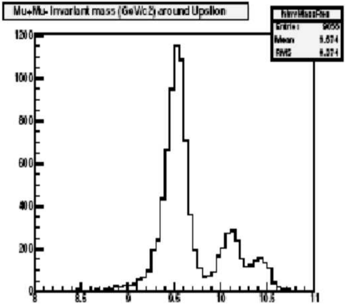
BBdiff: $\mu^+ X_1 \leftarrow B(\bar{b}) \qquad B(b) \rightarrow X_2\, \mu^-$

BDdiff: $\mu^+ X_1 \leftarrow B(\bar{b}) \qquad B(b) \rightarrow D(c)\, X_2$, $\quad D(c) \hookrightarrow X_3\, \mu^+$

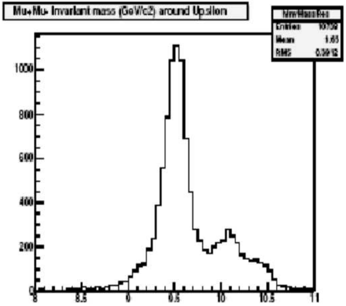
DDdiff: $X_1\, D(\bar{c}) \leftarrow B(\bar{b}) \qquad B(b) \rightarrow D(c)\, X_2$, $\quad \mu^- X_3 \hookleftarrow D(\bar{c})$, $\quad D(c) \hookrightarrow X_4\, \mu^+$

BDsame: $X_1\, X_2 \leftarrow B(\bar{b}) \qquad B(b) \rightarrow D(c)\, \mu^-$, $\quad D(c) \hookrightarrow X_3\, \mu^+$

Effects of chamber misalignment



0μm



100μm

E. Dumonteil, PhD. thesis