

Introduction

The measurement of the $\Upsilon(1S)$ production cross-section with the LHCb detector is presented, as a function of the $\Upsilon(1S)$ transverse momentum and rapidity. First observation of double J/ψ production is also reported together with a first measurement of the cross-section.

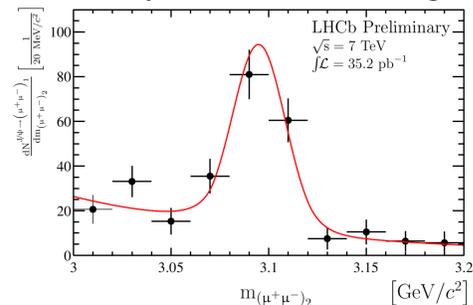
Double J/ψ production

Selection

- Muons tracks well reconstructed and identified $\chi^2_{tr} < 5$, $\Delta \log \mathcal{L}^{\mu-h} > 0$
- Muon tracks $p_T > 650$ MeV/c
- Opposite sign muons ($\mu^+\mu^-$) originated from well reconstructed common vertex and with invariant mass within [3.0; 3.2] GeV/c²
- Muons pairs ($\mu^+\mu^-$)₁ ($\mu^+\mu^-$)₂ originated from well reconstructed common vertex compatible with primary vertex

Invariant mass distribution

- Double Crystal Ball function for signal, exponential for background.



Signal events:

- $N_{J/\psi J/\psi} = 139.6 \pm 17.8$
- In the signal window both J/ψ $p_T < 10$ GeV/c and $y \in [2; 4.5]$ $N_{J/\psi J/\psi} = 136.7 \pm 17.5$

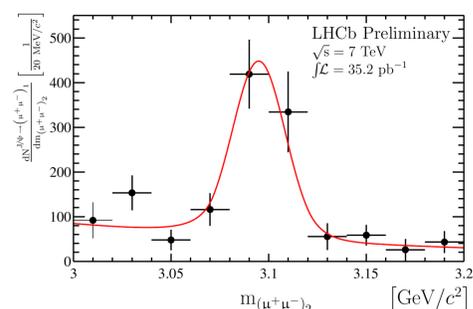
Efficiency calculation

Total efficiency calculated event per event

$$\varepsilon_{J/\psi J/\psi}^{tot} = \varepsilon_{J/\psi J/\psi}^{sel\&reco\&acc} \times \varepsilon_{J/\psi J/\psi}^{\mu ID} \times \varepsilon_{J/\psi J/\psi}^{trg}$$

- $\varepsilon_{J/\psi J/\psi}^{sel\&reco\&acc} = \varepsilon_{J/\psi}^{sel\&reco\&acc} \times \varepsilon_{J/\psi}^{sel\&reco\&acc}$ selection, reconstruction acceptance efficiency estimated from MC.
- $\varepsilon_{J/\psi J/\psi}^{\mu ID} = (\varepsilon_{1\mu}^{\mu ID})^4 = (91.0 \pm 0.1)\%$ muon identification efficiency, from data.
- $\varepsilon_{J/\psi J/\psi}^{trg} = 1 - (1 - \varepsilon_{J/\psi 1}^{trg/TOS}) (1 - \varepsilon_{J/\psi 2}^{trg/TOS})$ trigger efficiency, from data.

Efficiency corrected distribution



- Efficiency correction: weight each event with $\omega = (\varepsilon_{J/\psi J/\psi}^{tot})^{-1}$
- $J/\psi \rightarrow (\mu^+\mu^-)$ ₁ events efficiency corrected distribution in bins of $(\mu^+\mu^-)$ ₂ pair.

Signal events

$$N_{J/\psi J/\psi}^{corr} = 667.1 \pm 127.0$$

Systematic error

$\delta\omega$ varying ω by 1σ	3%
Effects on trigger efficiency	8%
$J/\psi J/\psi$ vertex discrepancy data/MC	3%
Global Events Cuts	2%
Tracking	$4 \times 4\%$
Muon identification	$2 \times 1.1\%$

Cross section determination

With $\mathcal{L} = 35.2 \pm 0.35$ pb⁻¹

$$\sigma_{J/\psi J/\psi} = \frac{N_{J/\psi J/\psi}^{corr}}{\mathcal{L} \mathcal{B}_{\mu^+\mu^-}^2} = (5.6 \pm 1.1 \pm 0.5|_{eff} \pm 0.9|_{track} \pm 0.6|_{\mathcal{L}}) \text{ nb}$$

Measurements with both J/ψ $p_T < 10$ GeV/c and $y \in [2; 4.5]$

- Theory/Color Singlet: 4.15 nb

$\Upsilon(1S)$ production

Upsilon production cross section

$\Upsilon(1S)$ production cross section from $\Upsilon \rightarrow \mu^+\mu^-$ decays

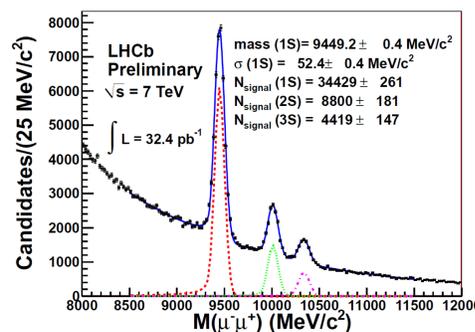
$$\sigma = \frac{N(\Upsilon(1S) \rightarrow \mu^+\mu^-)}{L \times \varepsilon \times Br(\Upsilon(1S) \rightarrow \mu^+\mu^-)}$$

- Number of signal events N : extracted from the fit to the invariant mass distribution.
- Total efficiency ε .
- Luminosity: $L = (32.4 \pm 0.3)$ pb⁻¹.

Event Selection:

- muon track reconstructed in VELO and tracker with good χ^2
- muon $p_T > 1$ GeV/c
- good vertex reconstruction
- mass window [8.5; 11.5] GeV/c²

Number of $\Upsilon \rightarrow \mu^+\mu^-$ events determination

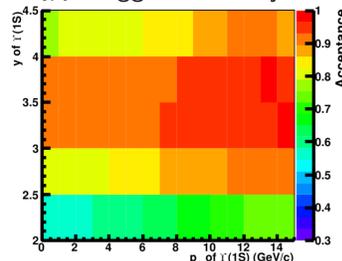


- Triple Crystal Ball function for signal, exponential for background
- Resolution $\Upsilon(1S)$ $\sigma(1S) = 52.4 \pm 0.4$ MeV/c²
- Resolution $\Upsilon(2S)$ and $\Upsilon(3S)$ fixed to $\sigma(1S)$ scaled by ratios of $\Upsilon(2S)$ and $\Upsilon(3S)$ masses to $\Upsilon(1S)$ mass.

Efficiency determination

$$\varepsilon = A \times \varepsilon_{rec} \times \varepsilon_{tri}$$

- ε_{tri} : trigger efficiency from data.



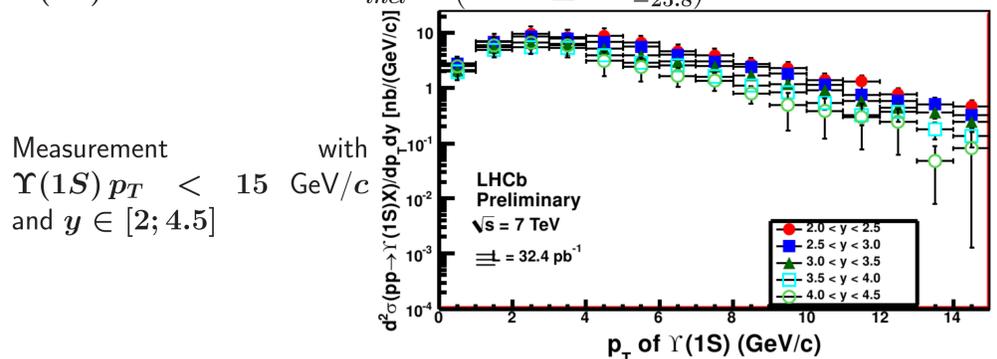
ε_{rec} : MC simulation

A: MC simulation

ε_{tri} : trigger efficiency estimated from data

$\Upsilon(1S)$ differential cross section

$\Upsilon(1S)$ total cross section: $\sigma_{incl} = (108.3 \pm 0.7^{+30.9}_{-25.8})$ nb



Measurement with $\Upsilon(1S)$ $p_T < 15$ GeV/c and $y \in [2; 4.5]$

Systematic error

Unknown $\Upsilon(1S)$ polarization	17%
Trigger efficiency	16%
Tracking efficiency discrepancy data/MC	4% per track
Luminosity	10%