Prospects in quarkonium studies at LHCb

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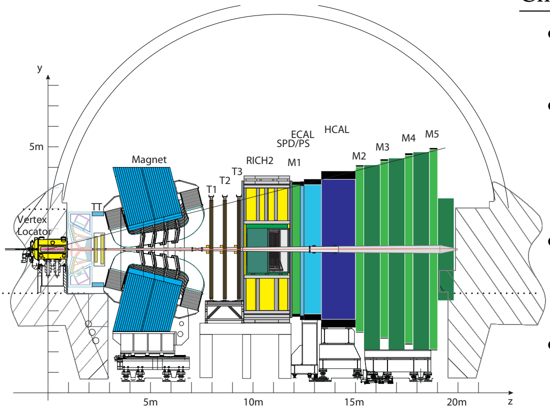
The LHCb experiment

Subdetectors: VErtex LOcator (VELO), Ring Imaging Cherenkov detectors (RICH1, RICH2), magnet, electromagnetic and hadron calorimeter (ECAL, HCAL), tracking system (TT, T1 to T3), muon system (M1 to M5).



Characteristics and performances

- Single-arm forward spectrometer
- Angular coverage: 10-300 mrad (bending plane), 10-250 mrad (non-bending plane)
- PV resolution: 40 μm (beam direction), 10 μm (perpendicular)
- MuonId: $\epsilon(\mu \rightarrow \mu) = 94\%$ $\epsilon(\pi \rightarrow \mu) = 3\%$
- Momentum resolution < 1%

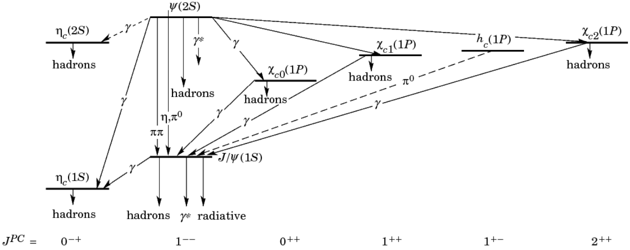
Quarkonium physics program at LHCb

1. Understanding quarkonium hadro-production mechanism
   - measurement of production cross section and polarization for J/ψ and $\psi(2S)$.
   - similar measurements for excited charmonium states χ_c and bottomonium state $\Upsilon(1S), \Upsilon(2S), \Upsilon(3S)$.
   - possibility for LHCb to explore a unique rapidity range $2 < \eta < 5$
2. Calibration of the apparatus, thanks to abundance of J/ψ also from the first collisions.
3. Studies of B physics: charmonium is present in the final states of many interesting B decay channels.
4. Exotic states: studies on $X(3872), Z(4430)^{\pm}$.

Charmonium hadro-production mechanism

Charmonium production is still not completly understood.
Contributions at high energy are

1. Prompt production in *pp* collisions.
2. Feed down from excited prompt charmonium states.

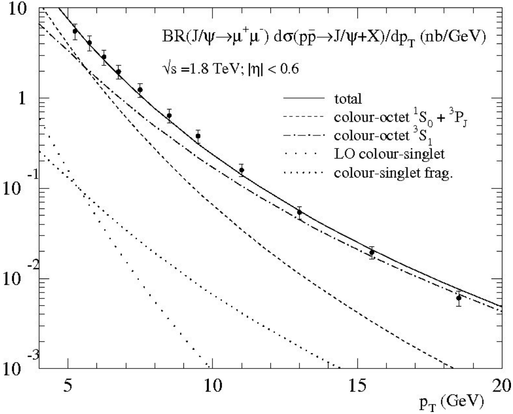


3. Production from b-hadrons decays, also through heavier charmonium states.

Prompt component production

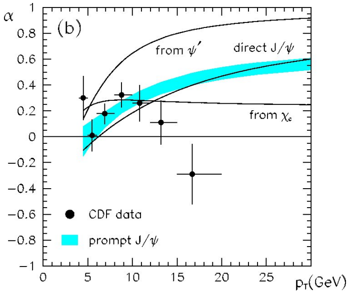
1. **Colour Singlet Model (CSM)**
   - production of $c\bar{c}$ on-shell pair.
   - binding the $c\bar{c}$ pair to form the meson, assuming colour and spin don't change. Since the physical state is colourless $c\bar{c}$ pair must be produced in colour singlet state.
2. **Colour Octet Model (COM)**: NRQCD approach. Charmonium production is possible also through colour octet states.

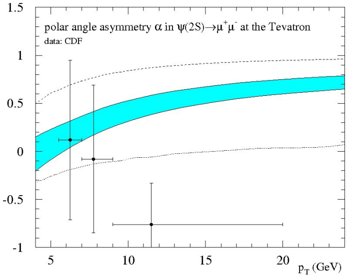
- J/ψ production cross section: experimental data underestimated by an order of magnitude by CSM but in agreement with COM prediction.
- Similar conclusion for $\psi(2S)$ production cross section.



Charmonium polarization

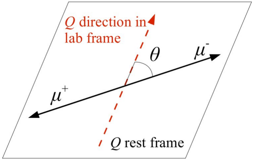
Charmonium polarization from polar angle asymmetry α





Angular distribution: $\frac{dN}{\cos\theta} = 1 + \alpha cos^2\theta$

- $\alpha = 0$ not polarized
- $\alpha > 0$ transverse polarization
- $\alpha < 0$ longitudinal polarization



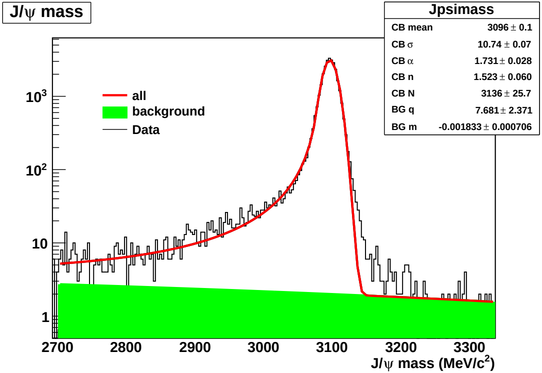
Colour Octet Model fails to predict charmonium polarization.

J/ψ production at LHCb

J/ψ production cross section expected at LHCb for $p_T < 7$ GeV, $3 < \eta(J/\psi) < 5$:

1. $\sigma_{prompt} \times \mathcal{B}(J/\psi \to \mu\mu) = (2597 \pm 12 \pm 24)$ nb
2. $\sigma_{from\ b} \times \mathcal{B}(J/\psi \to \mu\mu) = (161 \pm 4 \pm 2)$ nb
3. after L0 trigger **$1.3 \cdot 10^9$** J/ψ in 1 fb^{-1} at 14 TeV or **$0.65 \cdot 10^6$** in 1 pb^{-1} at 7 TeV (L0 $p_T^{muon} > 120$ MeV).
   Statistics allows to study cross section and polarization in p_T and η bins: statistical error $< 20\%$ in each bin for 1 pb^{-1}.

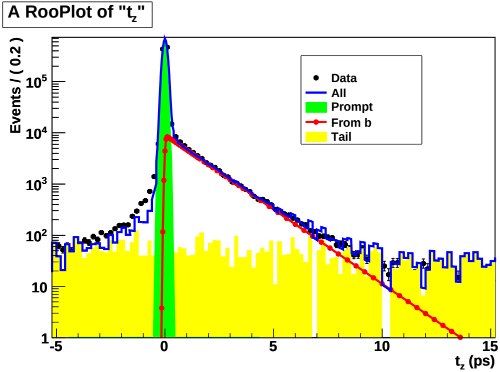
- Simulated, inclusive events at $\sqrt{s} = 14$ TeV
- $p_T > 1$ GeV, cut on vertex reconstruction quality, cut on muons track quality.
- Mass resolution 11 MeV/c^2



Disentangling prompt from delayed J/ψ

Pseudo proper time along beam direction: $t_z = \dfrac{(z_{J/\psi} - z_{PV}) m_{J/\psi}}{p_z}$

(approximation of b proper time)



Data sample: simulated, inclusive events, $\sqrt{s} = 14$ TeV

- Prompt component: gaussian shape (detector resolution) on 0 ps.
- Delayed component: exponential with $\tau_b = (1.495 \pm 0.008)$ ps (fit result), to be compared with b-hadron mixture decay time $\tau = (1.568 \pm 0.009)$ ps (PDG).
- Tail: wrong choice of primary vertex.

G. Sabatino, PhD thesis "Charmonium production at LHCb: measurement of the ψ' to J/ψ production ratio with the first data "

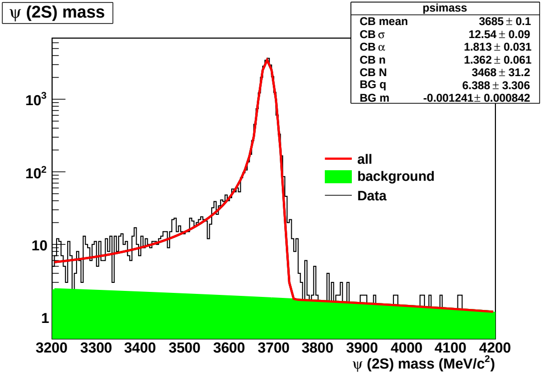
$\psi(2S)$ production at LHCb

$\psi(2S)$ production expected at LHCb for $p_T < 7$ GeV, $3 < \eta(\psi(2S)) < 5$:

1. Expected **$1.6 \cdot 10^4$** $\psi(2S)$ in 1 pb^{-1} at 7 TeV.
2. Separating prompt and delayed component to measure $\sigma(\psi(2S))/\sigma(J/\psi)$ production ratio as a function of p_T. Statistical error on $\sigma(\psi(2S)) \sim 20\%$ in each bin for 1 pb^{-1}.

- Simulated, inclusive events at $\sqrt{s} = 10$ TeV
- $p_T > 0.7$ GeV, cut on vertex reconstruction quality, cut on muons track quality.
- Mass resolution 12 MeV/c^2

G. Sabatino, PhD thesis "Charmonium production at LHCb: measurement of the ψ' to J/ψ production ratio with the first data "



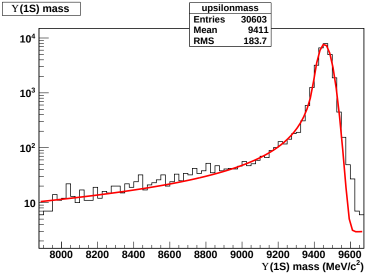
Heavier states detection

χ_c

- $\sim 30\%$ of J/ψ come from χ_c.
- Reconstructed from $\chi_c \to \gamma + J/\psi$ with γ detected in ECAL.
- Mass resolution 27 MeV/c^2.
- Production cross section and polarization measurements.

$\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$

- Reconstructed from $\Upsilon \to \mu^+\mu^-$.
- Expected $\sim 10^{-3}$ fraction of J/ψ.
- Mass resolution 37 MeV/c^2.
- Similar measurements as for χ_c.



$X(3872), Z(4430)^{\pm}$

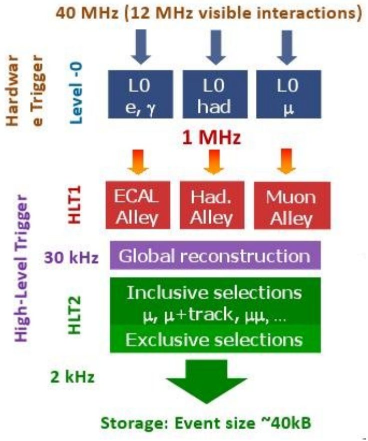
- Channels: 1800 events in $B^{\pm} \to X(3872)\,K^{\pm}$ channel and 6200 events in $B^0 \to Z(4430)^+(\to \psi(2S)\,\pi^+)\,K^-$ channel expected in 2 fb^{-1} at $\sqrt{s} = 14$ TeV
- try to disentangle $X(3872)$ J^{PC} quantum number: 1^{++} from 2^{-+}

Conclusion

- LHCb is able to explore a new rapidity range $2 < \eta < 5$ (LHCb acceptance) and high energy to measure J/ψ and $\psi(2S)$ production cross section and polarization.
- $\psi(2S)/J/\psi$ production ratio.
- Studies on other quarkonium states: χ_c, $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$. Measurement of cross section and polarization.
- Exotic states: $X(3872), Z(4430)^{\pm}$

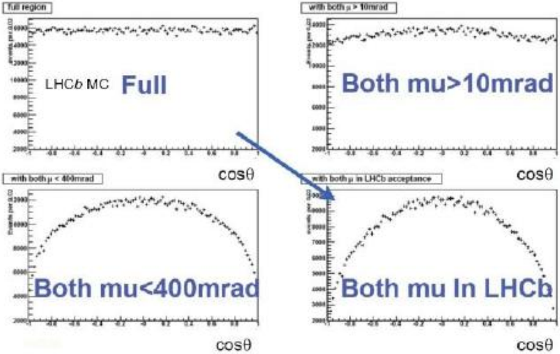
Back up slides

LHCb trigger: 2010 run

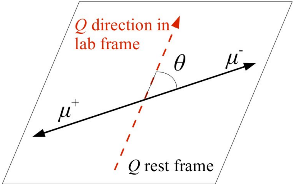


- L0+HLT1: 2 kHz
- HLT2: rate reduction 5-20

Effect of acceptance on polarization



Acceptance as function of polar angle θ



Large LHCb acceptance dependance on polarization.