Perspectives for quarkonium physics in CMS

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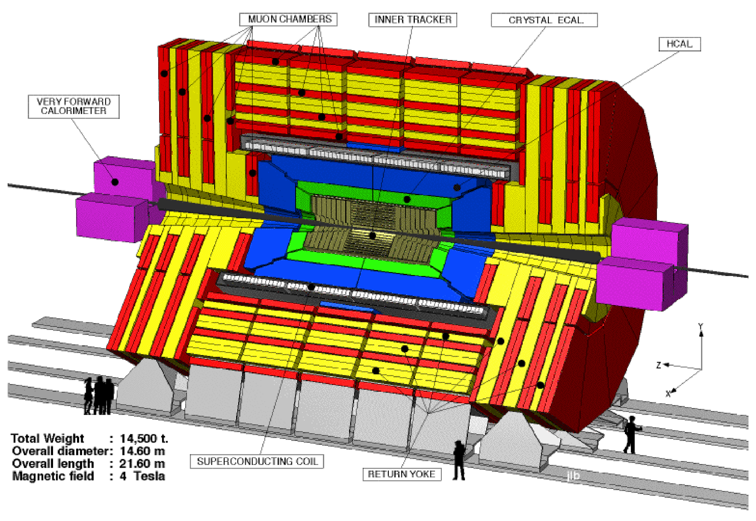
Abstract

We present Monte Carlo based studies which evaluate the perspectives of the CMS experiment for J/ψ and Υ measurements with the first data at LHC during the 2010 data taking. Some results from the 2010 runs are also presented.

The CMS Experiment

- The CMS Experiment [1] is one of the two general-purpose experiments at the proton-proton collider LHC at CERN.

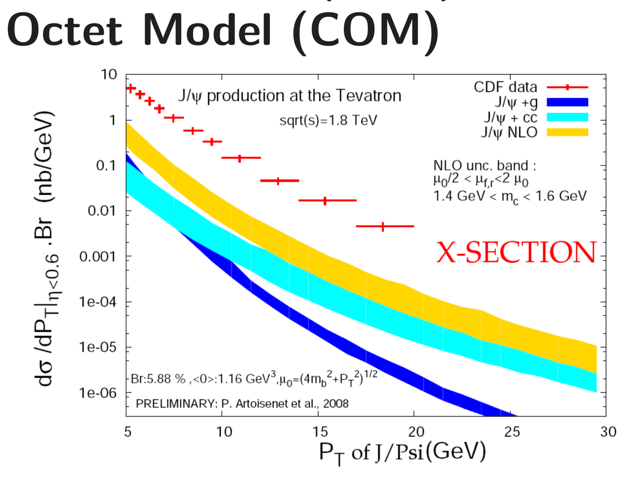


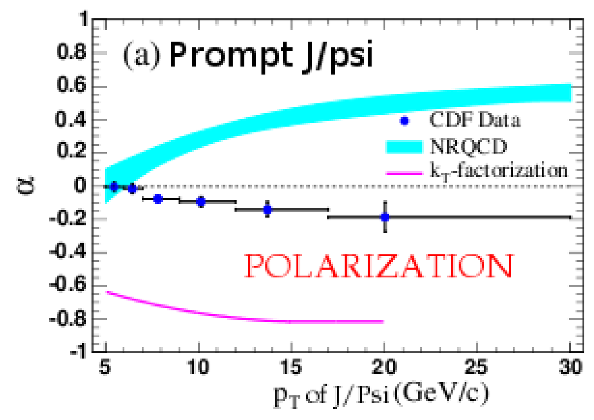
The CMS detector features:

- **Large rapidity coverage** ($|\eta| < 2.4$)
- **Excellent μ momentum resolution**:
  - matching between μ-chambers and the silicon tracker (only using the latter for momentum determination at low p_T)
  - strong solenoidal magnetic field (3.8 T)
- **Precise tracking**

Quarkonia production mechanisms

- Prompt (including feed down from $\chi_c/\psi(2S) \to J/\psi$ and $\chi_b \to \Upsilon$)
  - Several theoretical mechanisms contributing:
    - **Color Singlet Model (CSM)**: calculations now available at NNLO
    - **Color Octet Model (COM)**





  - No model can predict successfully both cross-section and polarization at Tevatron and at HERA
- As a decay product of a B-hadron ($B \to J/\psi + X$)

Determination of the J/ψ Cross-Section

- The J/ψ differential cross section times its branching ratio into two muons will be measured in the muon pseudorapidity region $|\eta| < 2.4$.
- It is based on the following expression:

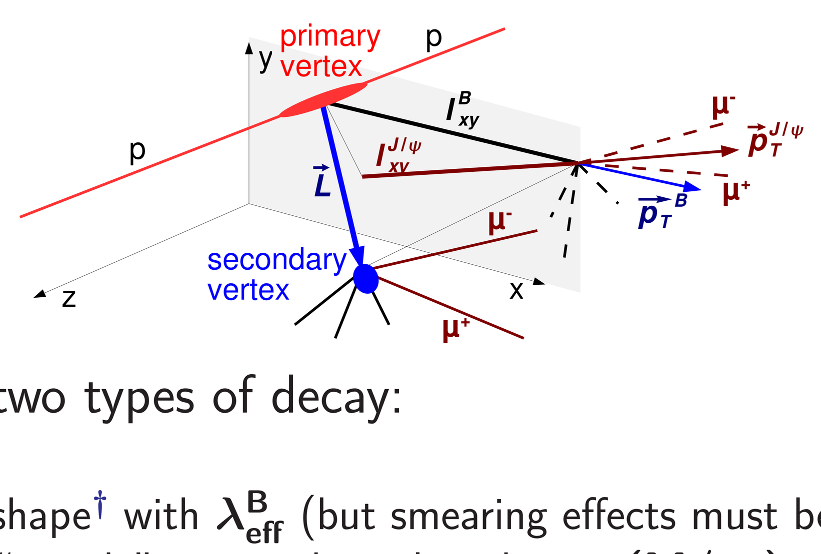
$$\frac{d\sigma(pp \to J/\Psi)}{dp_T} \times Br(J/\Psi \to \mu^+\mu^-) = \frac{N^{fit}_{J/\Psi}(p_T)}{\int \mathcal{L}dt \cdot \mathcal{A} \cdot \varepsilon \cdot \Delta p_T}$$

- where:
  - $N^{fit}_{J/\Psi} = (1 - f_b)N^{tot}_{J/\Psi}$ (prompt) or $f_b N^{tot}_{J/\Psi}$ (non prompt): number of reconstructed J/ψ's in a given p_T bin. Extracted from fit to invariant mass of the two reconstructed muons.
  - $L = \int \mathcal{L}dt$ integrated luminosity
  - $\mathcal{A}$ Detector geometrical and kinematical acceptance (from MC modeling)
  - $\varepsilon = \varepsilon_{trig} \cdot \varepsilon_{reco}$ trigger/reconstruction efficiency (correction evaluated from Monte Carlo simulation and data-driven methods)
  - Δp_T the p_T bin size

B-fraction extraction

- Using a 2D-fit to invariant mass and proper deacay length distributions:
  - Proper decay length calculated from decay length in the lab frame
  - Secondary vertex from a Kalman vertex fit to the two muon tracks

$$\ell^{J/\psi} = \frac{L^{J/\psi}_{xy} \cdot M_{J/\psi}}{p^{J/\psi}_T} \qquad L^{J/\psi}_{xy} = \frac{\vec{L} \cdot \vec{p}^{J/\psi}_T}{|\vec{p}^{J/\psi}_T|}$$

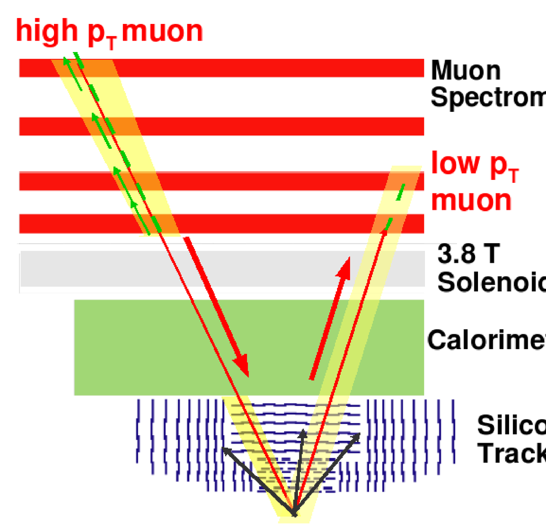


- This variable allows to discriminate the two types of decay:
  - For prompt events a δ function† is expected
  - For non-prompt events, it has an exponential shape† with λ^B_{eff} (but smearing effects must be considered since in this case we are using the "pseudo"-proper decay length, i.e. $(M/p_T)_{J/\psi}$ instead of $(M/p_T)_B$)
  - For background events a generic superposition of different contributions† (symmetric + asymmetric with effective lifetimes) is adopted

† = convoluted with a double-Gaussian resolution function

Muon reconstruction and handling of low p_T muons

- A reconstructed muon (**"global" muon**) in CMS is defined as a μ-chamber "seed", then matched to a track in the silicon tracker:
  - Curvature due to the B-field and material crossed limit the p_T acceptance
  - Problem with low-transverse momentum muons
- The idea of **tracker muons**:
  - Perform the reconstruction **inside out**, starting from a silicon track and searching for any possible compatible muon signal in the chambers
  - Tight selections on track-segment matching required to keep hadron background under control
  - Calorimeters can be also exploited to check compatibility with MIP energy deposits
  - Efficiency is enhanced by a large factor, especially at low p_T **(e.g. by a factor 2 at $p_T = 2.5$GeV/c)**

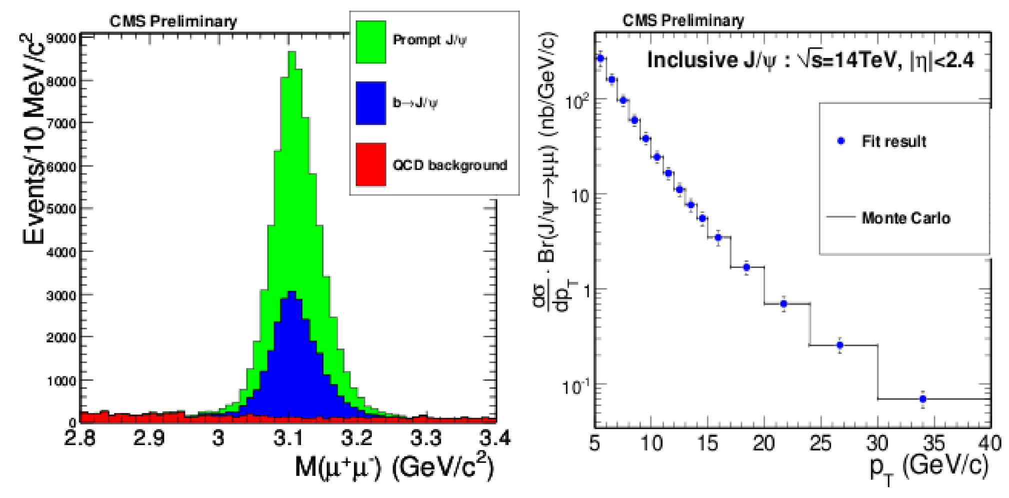


Expected results at $\sqrt{s} = 14$TeV (2007)

- Exercise using 3 pb^{-1} of integrated luminosity of $\sqrt{s} = 14$TeV MC data [2]:
  - Used only **"global muon"** pairs
  - Used a double-muon trigger with $p^{\mu}_T > 3$GeV/c

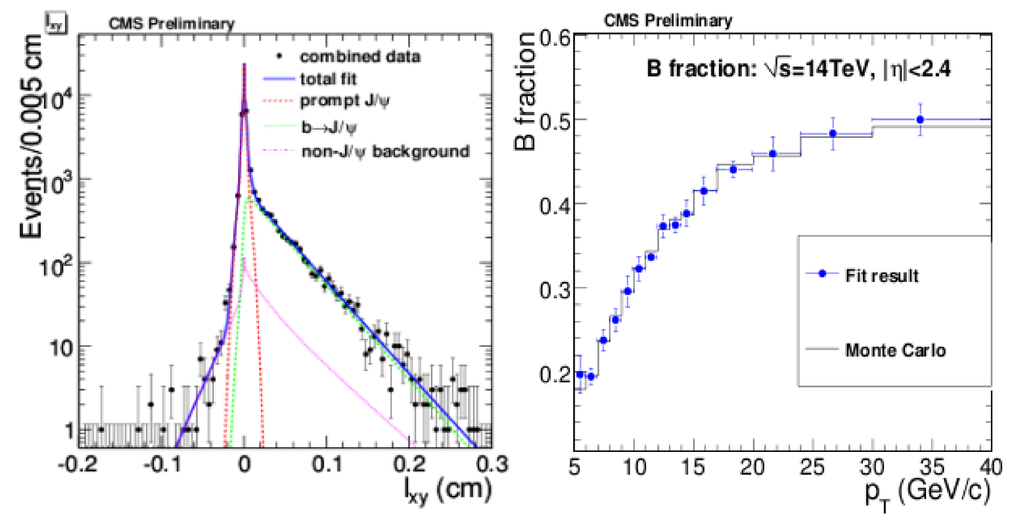
- **J/ψ yield fit results:**
  - 15 p_T bins: 5< p_T <40 GeV/c
  - 1 bin: $|\eta| < 2.4$
  - Resolution on invariant mass:

$$\begin{cases} \sigma^{barrel}_{M(\mu\mu)} \simeq 20 \text{ MeV}/c^2 \\ \sigma^{endcaps}_{M(\mu\mu)} \simeq 37 \text{ MeV}/c^2 \end{cases}$$



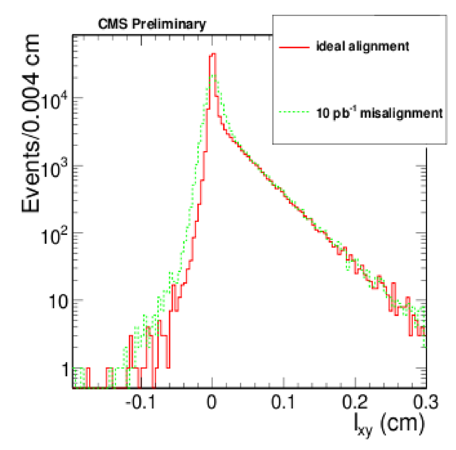
- **B fraction extraction:**
  - U.M.L. fit do data
  - No bias observed in the fitting technique
  - Stat. uncertainties on $N^{J/\psi}_{fit}$:

$$(\delta N/N)^{prompt}_{stat} \simeq 1.8\%\text{-}5\% \qquad (\delta N/N)^{b \to J/\psi}_{stat} \simeq 2\%\text{-}10\%$$



- **Analysis of systematic errors:**

Parameter affected	Source	$\Delta\sigma/\sigma$
Luminosity	Luminosity	$\simeq$ 10 %
Total Efficiency	J/ψ polarization	1.8 -7 %
Number of J/ψ	J/ψ mass fit	1.0 - 6.3 %
B fraction	Misalignment	0.7 - 3.5 %
Total sytematic uncertainty		**13-19 %**

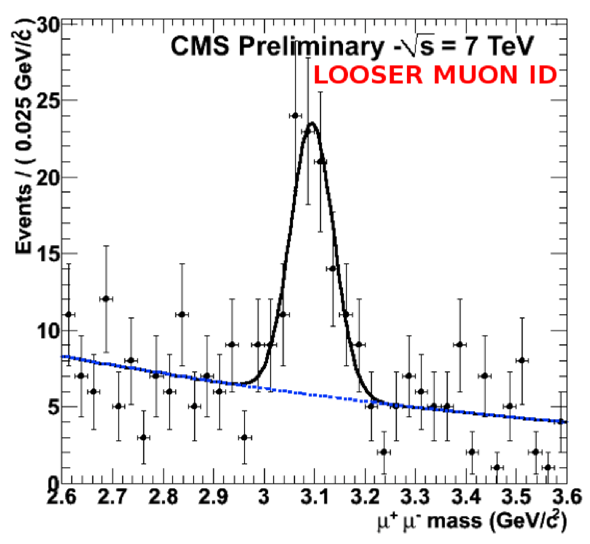


First results at $\sqrt{s} = 7$TeV (2010)

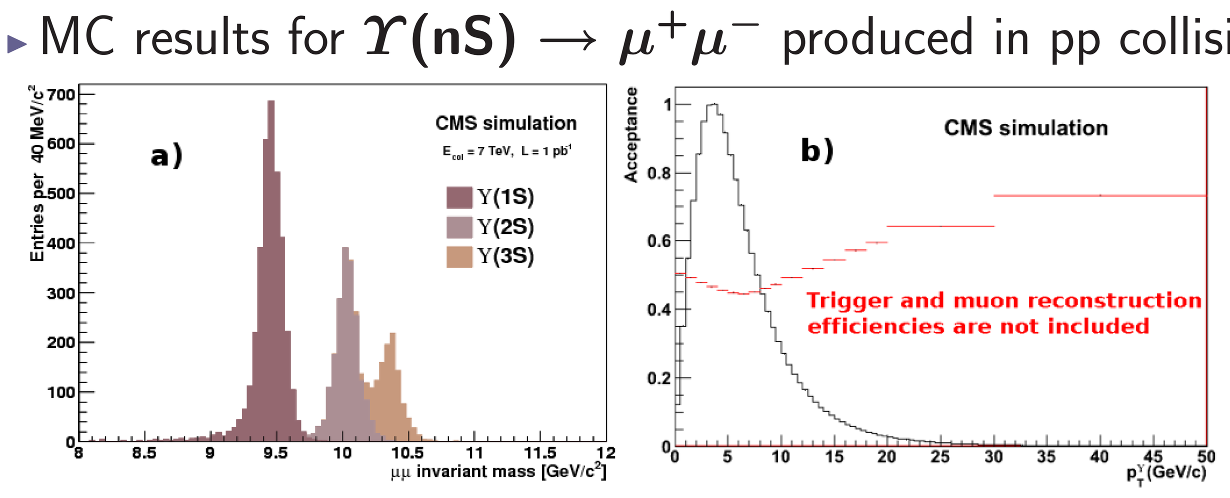
- In 2010 LHC has started to deliver high energy proton-proton collisions:
  - First CMS quarkonium analysis with 0.985 nb^{-1} at a c.o.m energy of 7 TeV
- Requirement of single-μ trigger at L1 (first level)
- A looser ("tracker"+"global") and a tighter ("global") selection is applied to the muon ID

Category	mass [MeV/c^2]	rms [MeV/c^2]	Signal events
Looser	3097 ± 7	42.5 ± 6.3	72 ± 12
Tighter	3094 ± 9	35.3 ± 6.8	24 ± 5

- As expected the yield of muon pairs is more than doubled using "tracker" muons



- MC results for $\Upsilon(nS) \to \mu^+\mu^-$ produced in pp collisions at 7 TeV



- Di-muon invariant mass for $\Upsilon(nS)$ signal (a)
- Expected p_T distribution and the CMS kinematic acceptance for the $\Upsilon(nS) \to \mu^+\mu^-$ process, with n=1,2,3 (b)

References

[1] CMS Collaboration, *Physics TDR vol. I.* (2006) CERN/LHCC 2006-001

[2] CMS Collaboration, *Physics Analysis Summary BPH-07-002* (2007)