ICPAQGP2010, Goa, 6-10/Dec/2010

J/ψ prompt and non-prompt cross sections in pp collisions at $\sqrt{s}$ = 7 TeV

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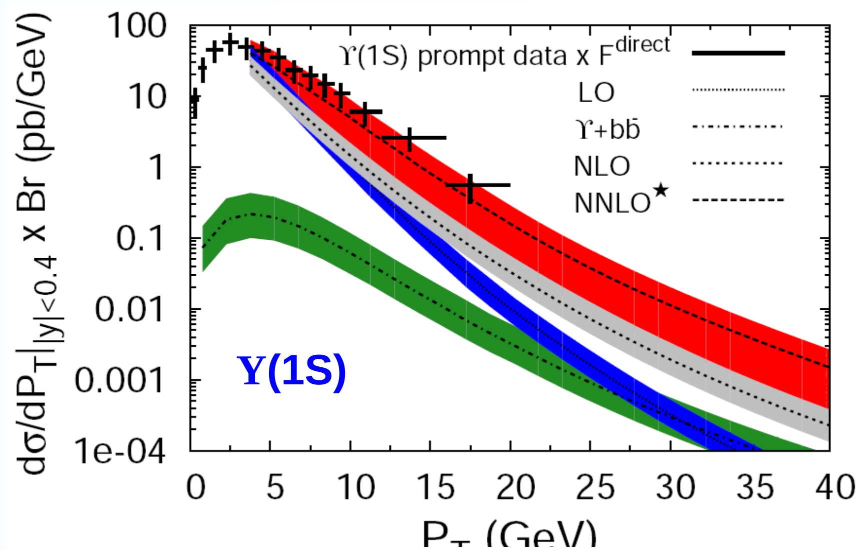
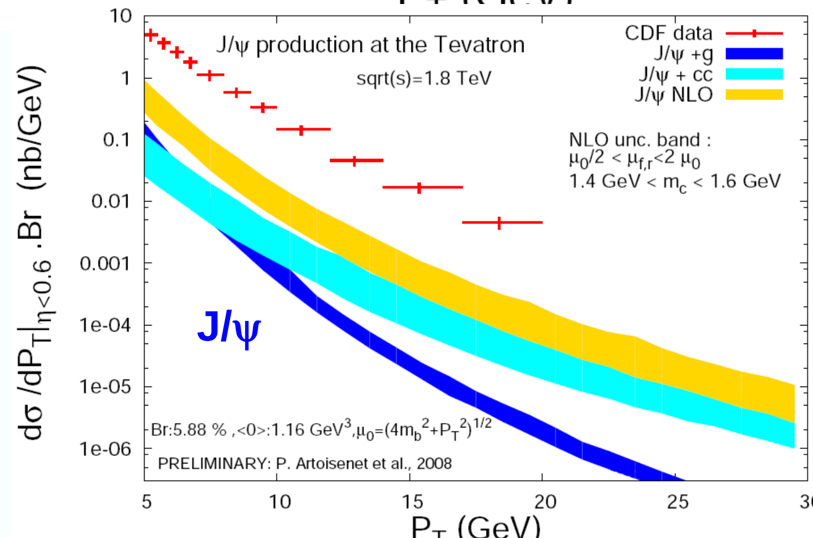
on behalf of the CMS collaboration

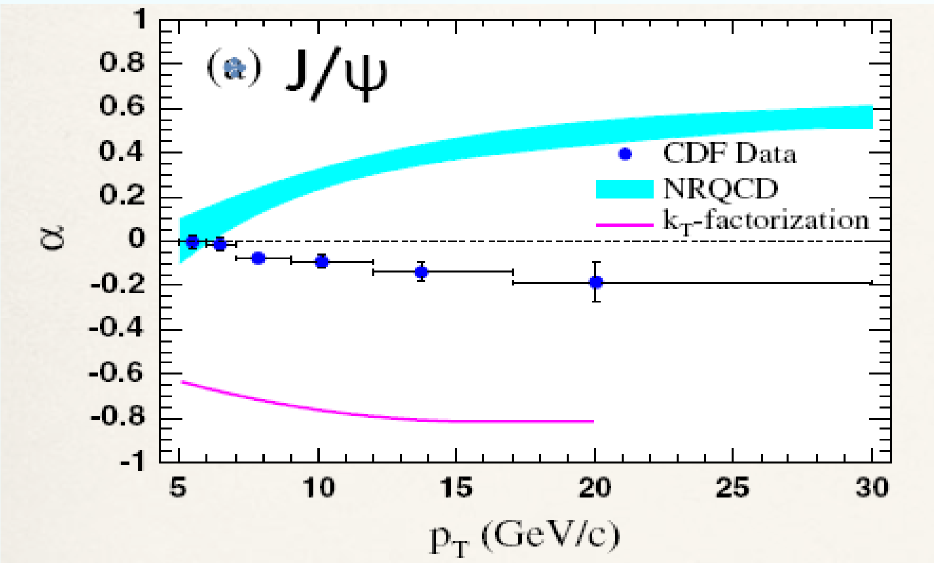
VI International Conference on Physics and Astrophysics of Quark Gluon Plasma, Goa, 6-10/12/2010

Physics motivations (I)

- **Prompt production:**
  - **Including feed-down from (χ_{cJ}, ψ' → J/ψ)**
- **Several theoretical mechanisms :**
  - **Color Singlet (new developments in recent years, NLO, NNLO…)**
  - **Color Octet in NRQCD**
- **No model predicting successfully both J/ψ cross-section and polarization at TeVatron.**





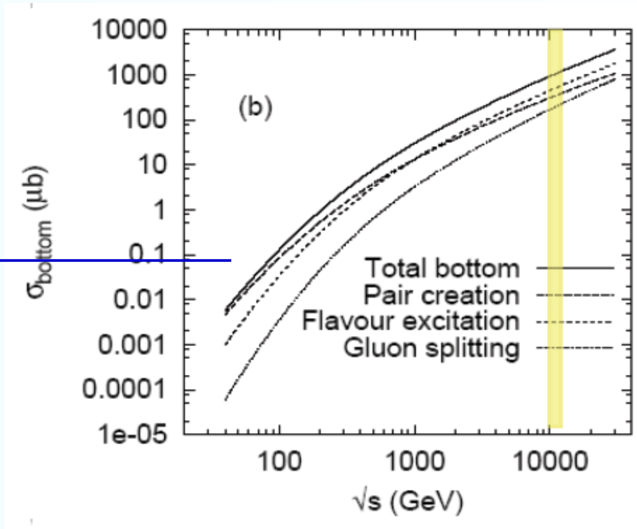


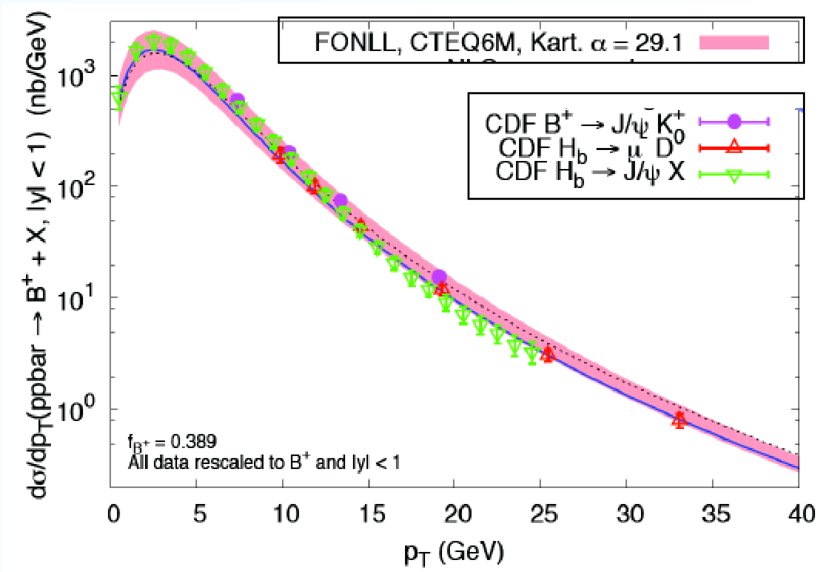
J.P. Lansberg
arXiv:0811.4005 [hep-ph]

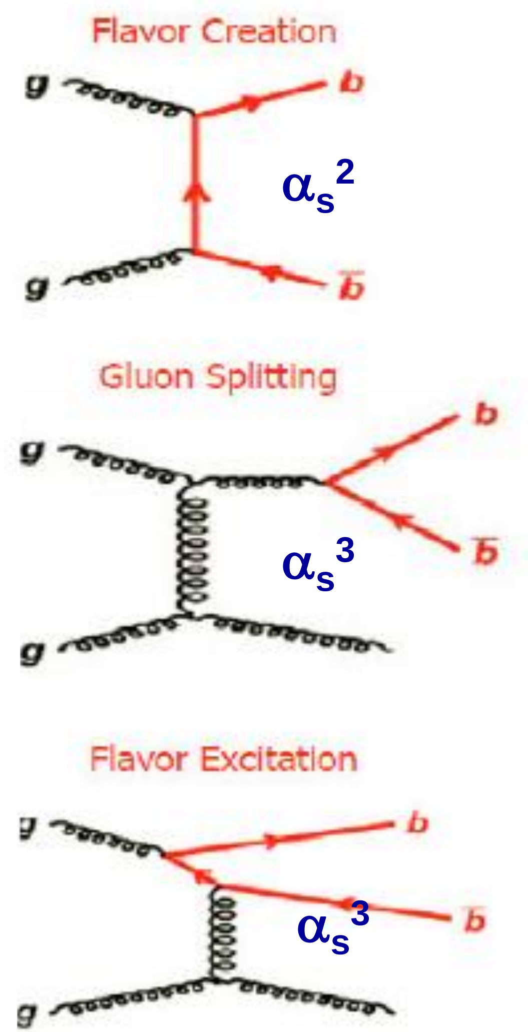
Physics motivations (II)

- $b\bar{b}$ cross-section:
  - LO: Flavor Creation
  - Large NLO contributions at LHC
    - Flavor Excitation
    - Gluon Splitting
- At TeVatron, good theory and data agreement:
  - FONLL approach
  - Improved b-fragmentation function (LEP $Z^0 \rightarrow$ bb data)

M . Cacciari et al.,
JHEP 0404, 068 (2004)

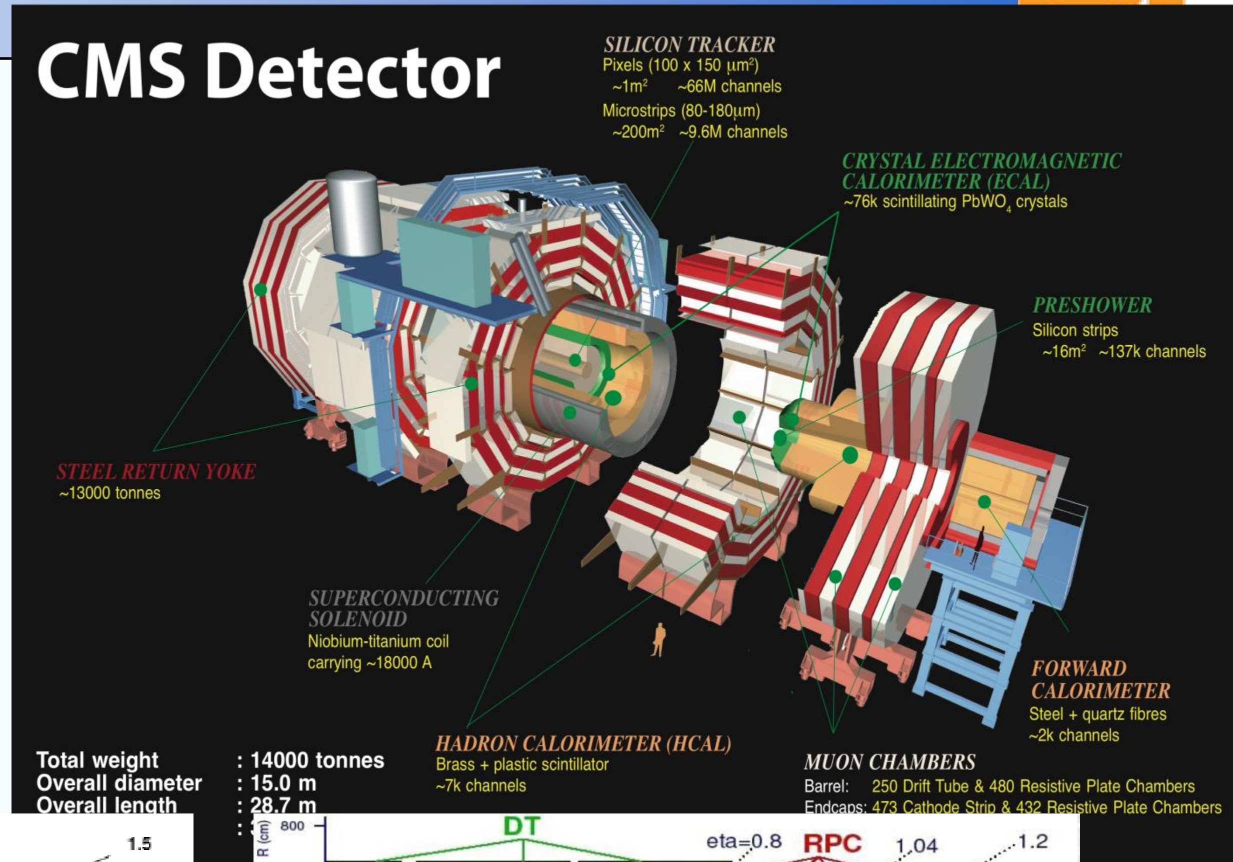


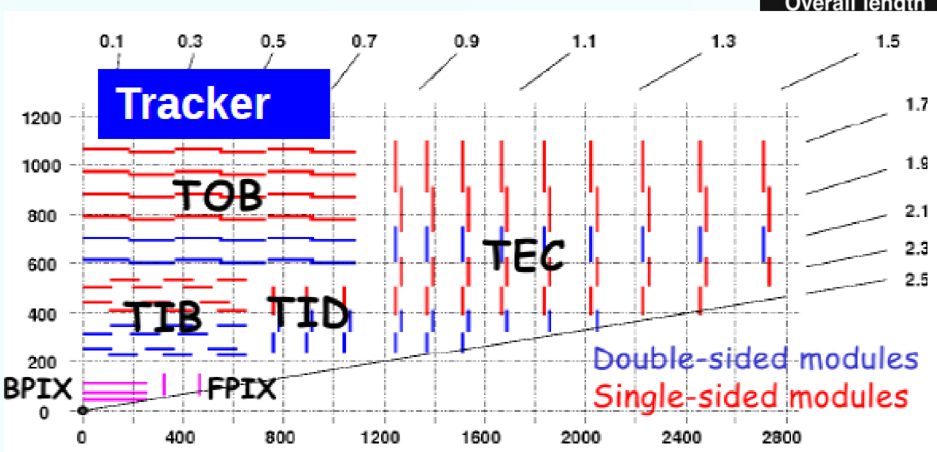


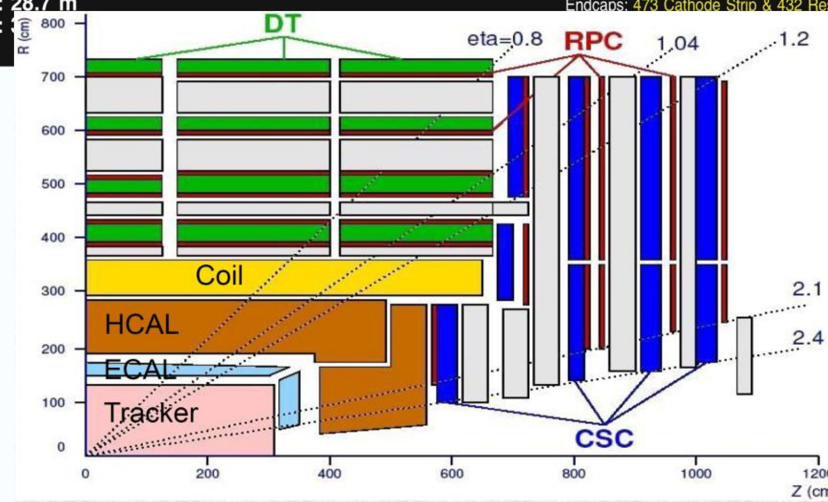


The CMS detector

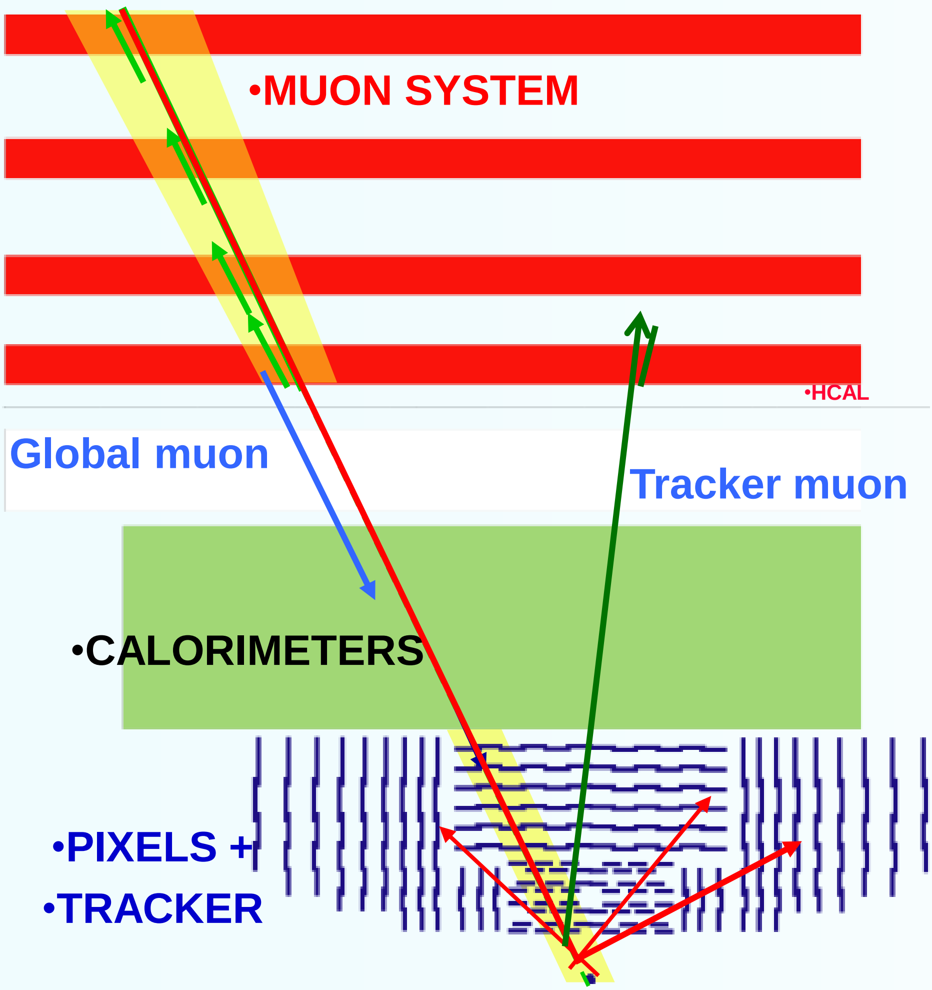
- **Tracker:**
  - **60M pixels**
  - **10M strips**
  - **coverage: |η| < 2.4**
- **Muon system:**
  - **Trigger detector**
  - **RPC+CSC, RPC+DT**







Muon reconstruction



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

Two muon identifications:

- **Global muon (outside-in):**
  - ***High purity***
  - ***Low efficiency for low momentum muon***
- **Tracker muon (inside-out):**
  - ***Fake muon level high***
  - ***Higher efficiency low momentum muon***

Muon triggers

- **Two trigger levels**

•L1: hardware

muon system and calorimeters only

↓

•HLT: software

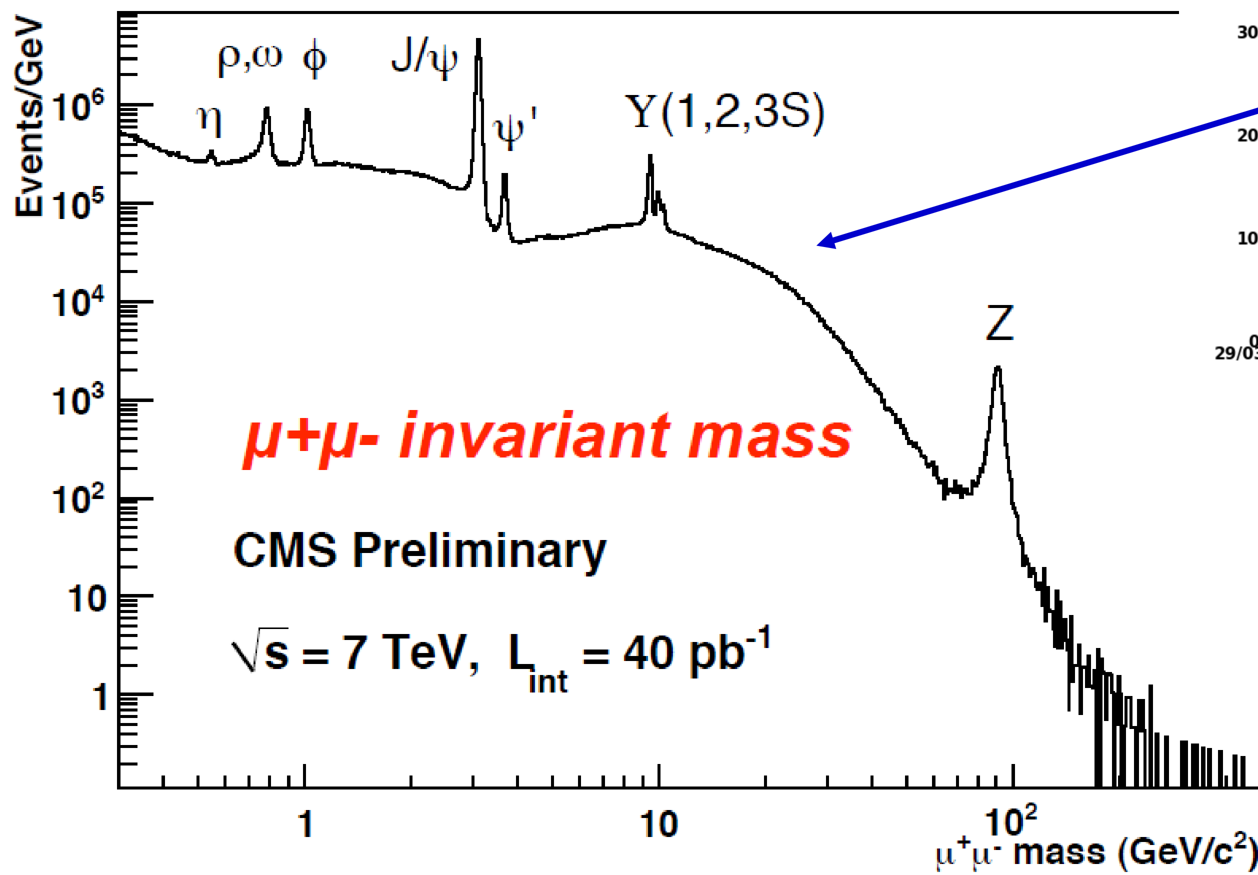
Matching of different sub-detectors.

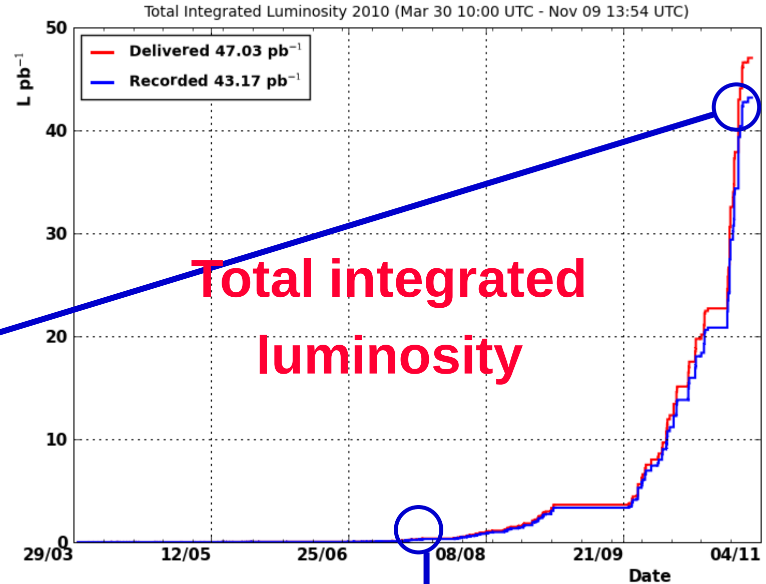
Fast local track reconstruction for muons

- **Trigger requirements changing with increasing luminosity:**
  - **Single muons:**
    - **$p_T > 3$ GeV threshold at the startup**
    - **Gradually increasing ($p_T > 7$ GeV at L ~ 10^{31} Hz cm^{-2})**
  - **Double muons:**
    - **L1 requirements only at the startup, no p_T threshold**

      •allowing us to go down to 0 quarkonium p_T in the forward region
    - **At L ~ 10^{31} Hz cm^{-2} new strategies adopted for quarkonia (combination of L1 and HLT muons, or HLT muon and track in specific invariant mass regions… etc.)**

The di-muon mass spectrum





Total integrated luminosity

- Used for the analyses shown here:

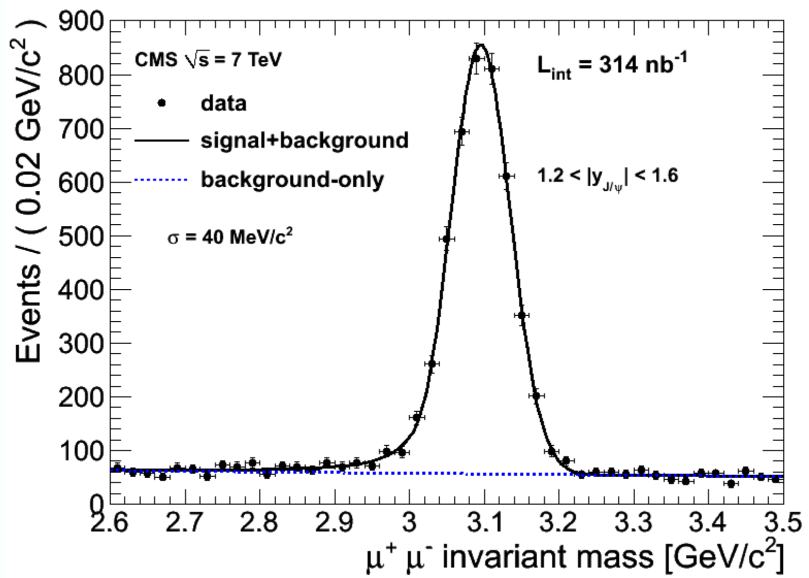
  Submitted to EPJC

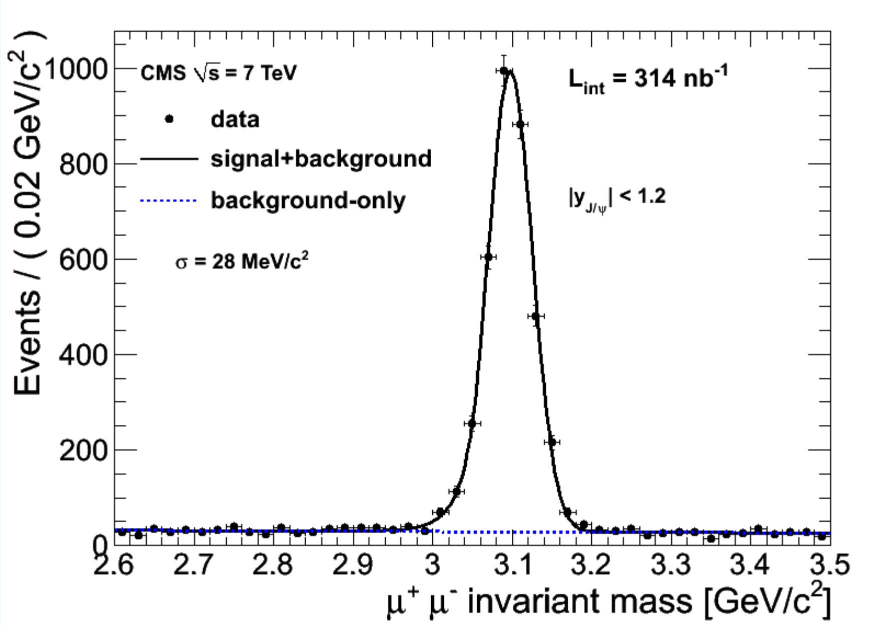
  arXiv:1011.4193

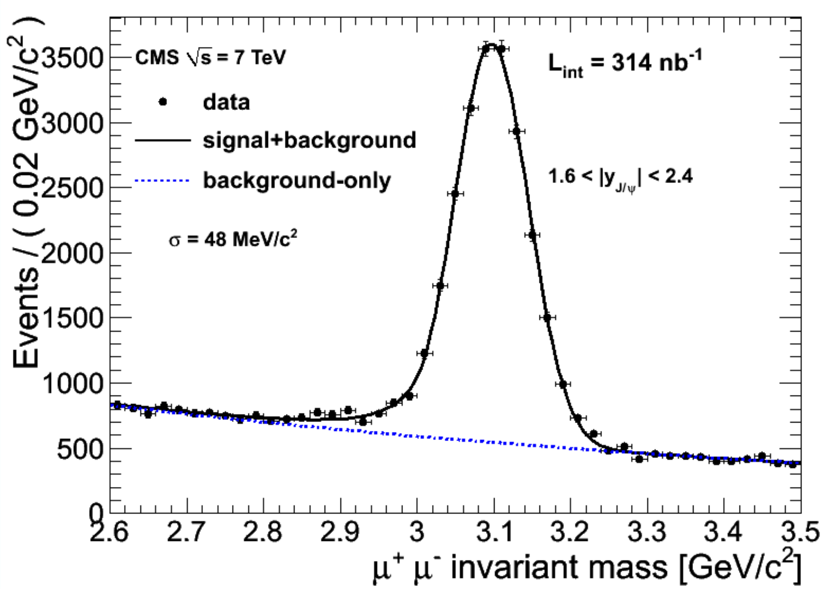
- Analysis with full 2010 statistics in progress.

J/ψ selection and yields

- **Selections:**
  - **Muons in acceptance window**
  - **Track quality (n_{hits}, n_{hits} in pixels, χ^2, $|d_{xy}|$, $|d_z|$)**
  - **Muon quality (global fit χ^2, track-muon segment angular matching)**
  - **Di-muon vertex probability**
- **~27000 events selected**







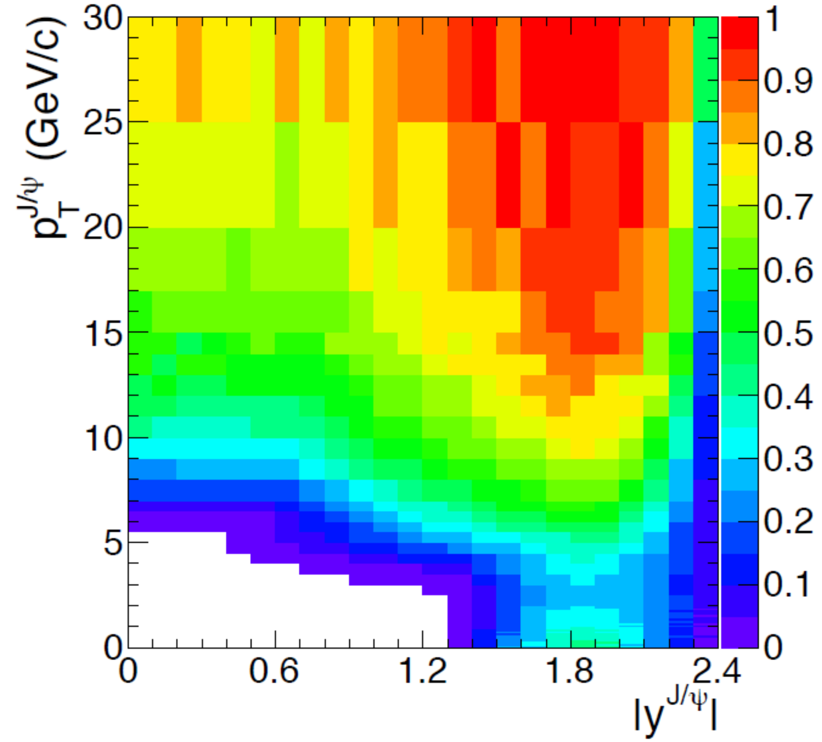
Acceptance

- **Acceptance is determined from MC:**

$$A(p_T, y, \lambda_\theta) = \frac{N_{det}(p_T, y, \lambda_\theta)}{N_{gen}(p_T, y, \lambda_\theta)}$$

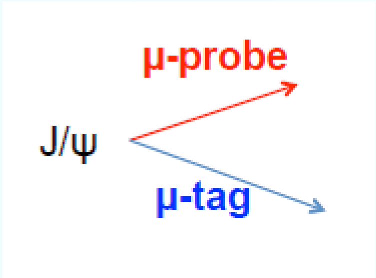
  - **Strongly dependent on polarization assumptions for the prompt component (polarization not well known)**
  - **Agreement to give result in 5 scenarios:**
    - **Isotropic**
    - **Extreme values of λ_θ (= $\pm$1) in the helicity frame (along the QQ momentum)**
    - **Extreme values of λ_θ (= $\pm$1) in the Collins-Soper frame (along the collision axis)**
- **Main systematic uncertainties coming from:**
  - **p_T smearing and calibration**
  - **uncertainty on final state radiation spectrum**

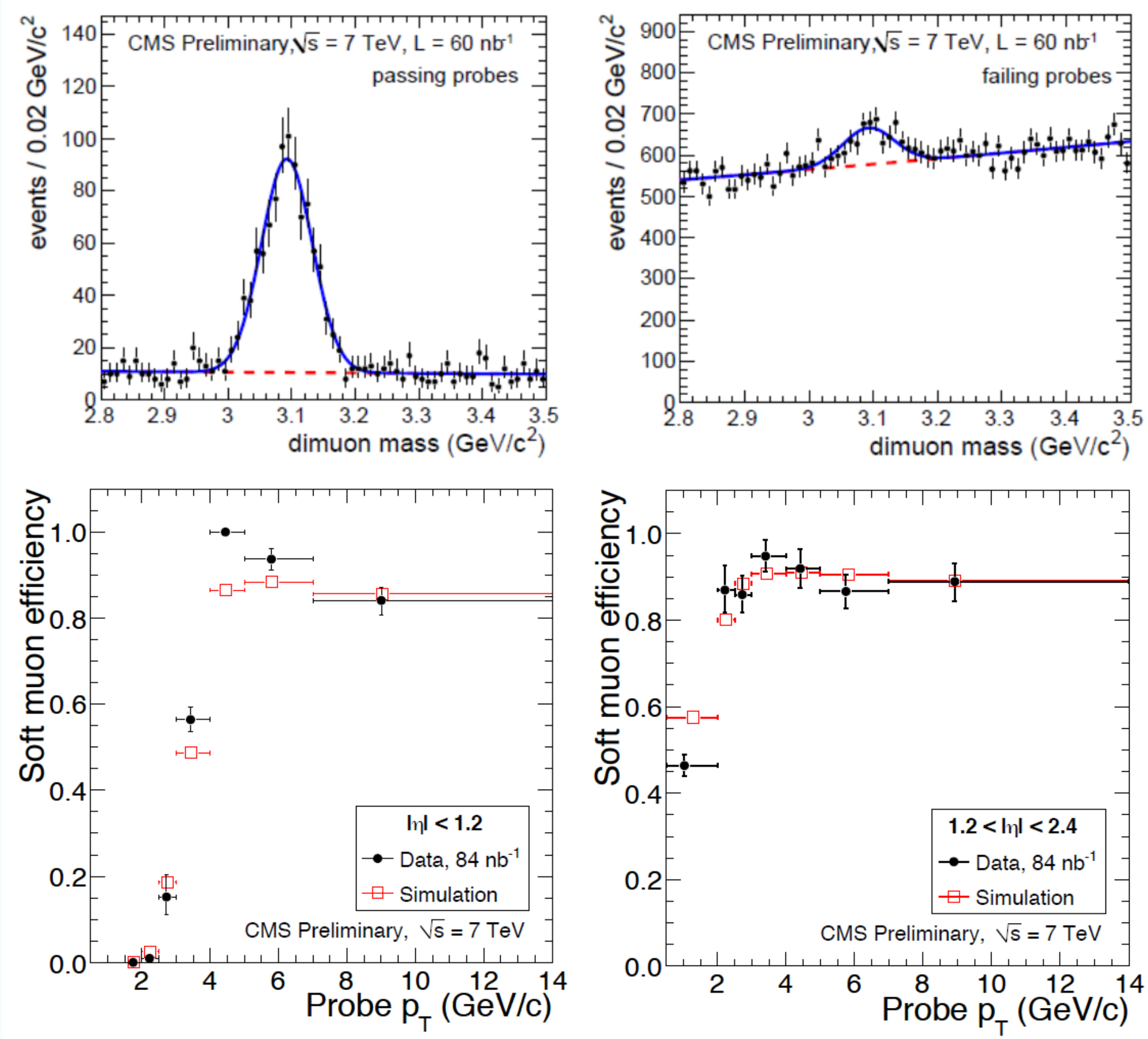
J/ψ acceptance in isotropic scenario



Muon efficiency using Tag&Probe

- **Muon efficiency from data: the “tag-and-probe” method:**
  - **Require one well-identified muon in the event (“tag”)**
  - **Another candidate muon, with looser criteria, is paired to it (“probe”)**
  - **Compare resonance yields for tag-probe pairs where the probes pass or fail a given selection.**



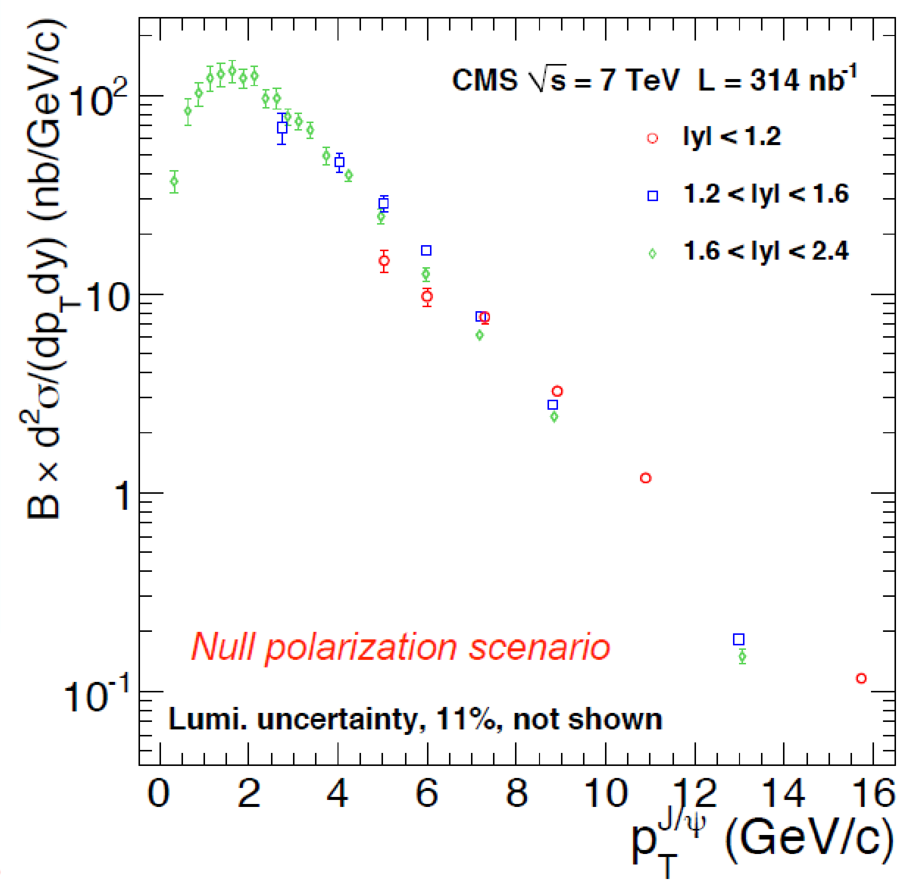


Inclusive J/ψ cross-section

$$\frac{d^2\sigma}{dp_T dy} \times B(J/\psi \to \mu\mu) = \frac{N_{\text{fit}} \left\langle \frac{1}{A \cdot \varepsilon} \right\rangle}{\int L dt \cdot \Delta p_T \cdot \Delta y}$$

$\langle A \cdot \varepsilon \rangle$ = average signal **acceptance/efficiency** in the bin *

- **Acceptance:** from MC simulation
- **Efficiency:** determined with tag and probe method from J/ψ events



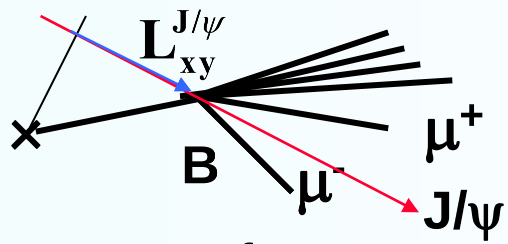
- **Systematic uncertainties**

Source	Relative error (%)		
	$\lvert y\rvert < 1.2$	$1.2 < \lvert y\rvert < 1.6$	$1.6 < \lvert y\rvert < 2.4$
FSR	0.8 – 2.5	0.3 – 1.6	0.0 – 0.9
p_T calibration and resolution	1.0 – 2.5	0.8 – 1.2	0.1 – 1.0
Kinematical distributions	0.3 – 0.8	0.6 – 2.6	0.9 – 3.1
b-hadron fraction and polarization	1.9 – 3.1	0.5 – 1.2	0.2 – 3.0
Muon efficiency	1.9 – 5.1	2.3 – 12.2	2.7 – 9.2
ρ factor	0.5 – 0.9	0.6 – 8.1	0.2 – 7.1
Fit function	0.6 – 1.1	0.4 – 5.3	0.3 – 8.8

$$\sigma(pp \to J/\psi + X) \cdot BR(J/\psi \to \mu^+\mu^-) = 97.5 \pm 1.5(\text{stat}) \pm 3.4(\text{syst}) \pm 10.7(\text{luminosity})\ \text{nb}$$

- **Measurement of prompt/non-prompt component with a 2D fit to mass and “pseudo”-proper decay length**

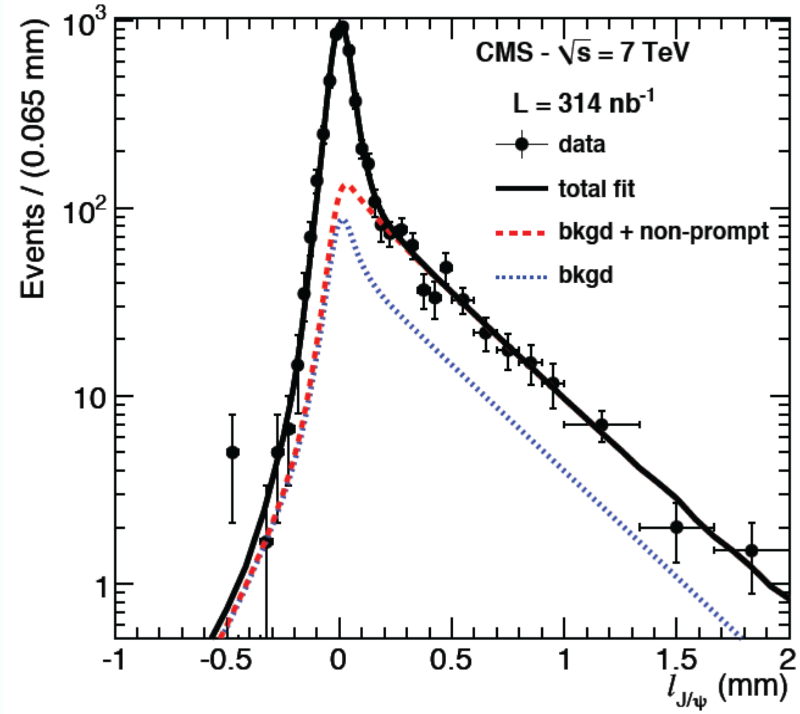
$$\ell_{xy} = \frac{L_{xy}^{J/\psi} \cdot M^{J/\psi}}{P_T^{J/\psi}}$$



$L_{xy}^{J/\psi}$ **is the transverse component of decay length in lab system**

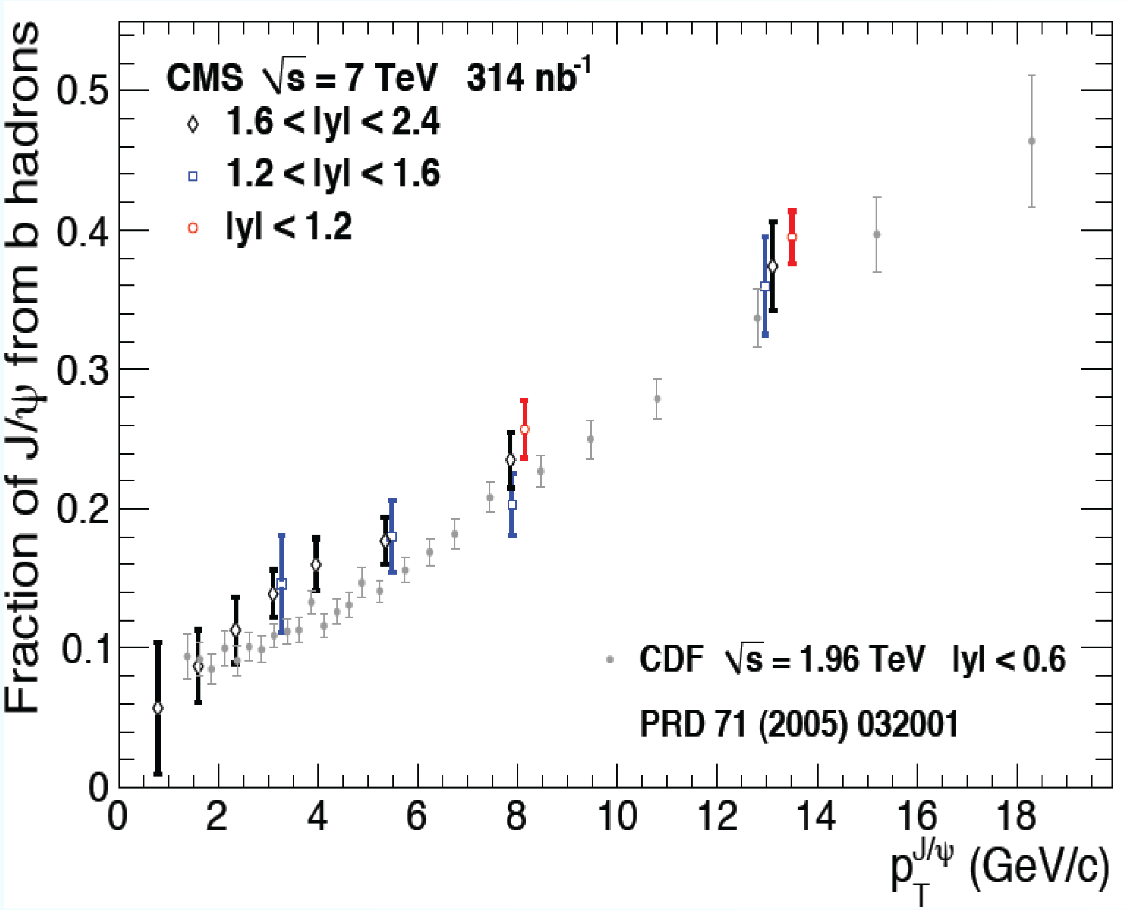
- **Decay length parameterization:**
  - **For prompt events, δ-function**
  - **For non-prompt events, MC templates**
  - **For background events a generic superposition of different contributions (symmetric + asymmetric with effective lifetimes)**

all convoluted with 3-Gaussian resolution



6.5<p_T<10 GeV/c, 1.6<|y|<2.4

Non-prompt fractions and systematics

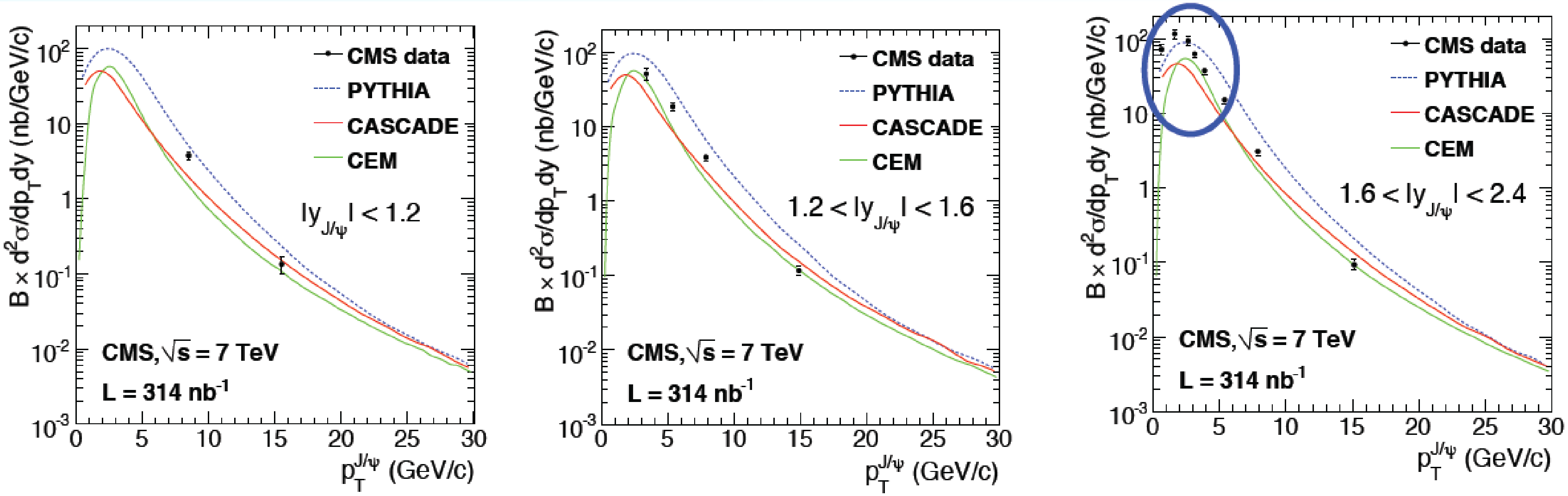


Systematics of the non-prompt fraction:

	$\lvert y\rvert < 1.2$	$1.2 < \lvert y\rvert < 1.6$	$1.6 < \lvert y\rvert < 2.4$
Tracker misalignment	0.5 – 0.7	0.9 – 4.6	0.7 – 9.1
b-lifetime model	0.0 – 0.1	0.5 – 4.8	0.5 – 11.2
Vertex estimation	0.3	1.0 – 12.3	0.9 – 65.8
Background fit	0.1 – 4.7	0.5 – 9.5	0.2 – 14.8
Resolution model	0.8 – 2.8	1.3 – 13.0	0.4 – 30.2
Efficiency	0.1 – 1.1	0.3 – 1.3	0.2 – 2.4

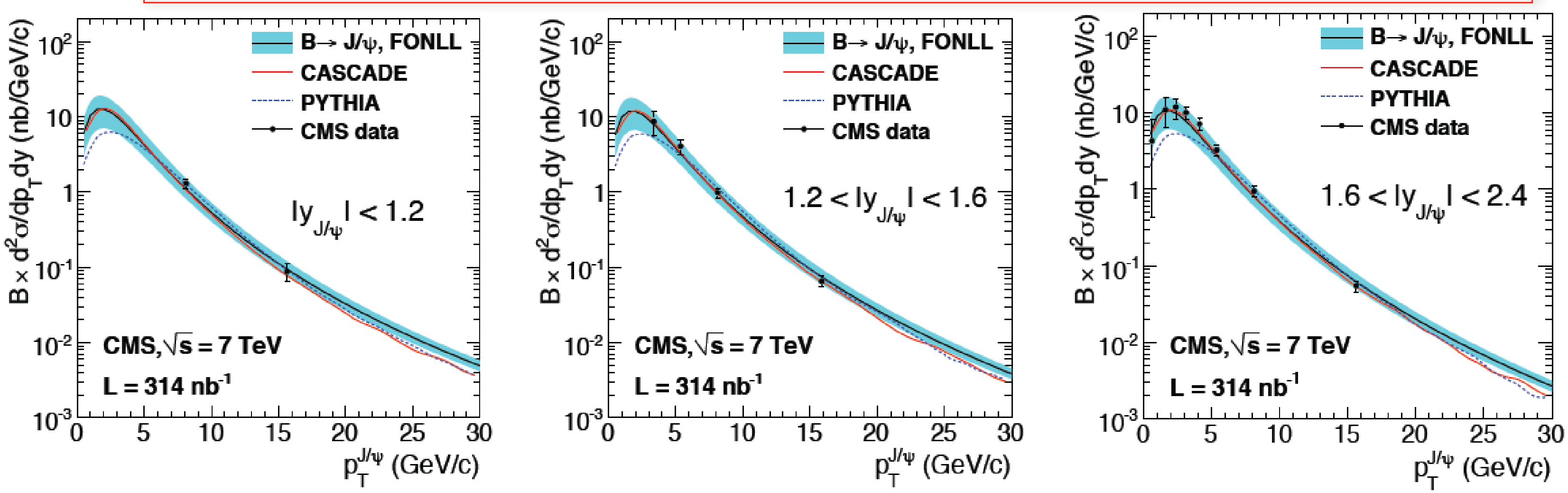
Comparison with theory

prompt



$$\sigma(pp \to J/\psi + X) \cdot BR(J/\psi \to \mu^+\mu^-) = 70.9 \pm 2.1(\text{stat}) \pm 3.0(\text{syst}) \pm 7.8(\text{luminosity})\ \text{nb}$$

non-prompt



$$\sigma(pp \to bX \to J/\psi X) \cdot BR(J/\psi \to \mu^+\mu^-) = 26.0 \pm 1.4\ (\text{stat}) \pm 1.6\ (\text{syst}) \pm 2.9\ (\text{luminosity})\ \text{nb}$$

Conclusion

- **Measurements of prompt and non-prompt J/ψ production cross sections have been presented, using data collected until Summer 2010 (314 nb^{-1}):**

> **•Prompt J/ψ, total and differential in p_T and |y|**
> **•Non-prompt J/ψ, total and differential in p_T and |y|**

  - **J/ψ analyses allow first theory tests to be performed from p_T =0 to ~30 GeV/c at 7 TeV.**
  - **Statistical accuracy of ~2%, but systematics ~12% limited by luminosity.**
  - **Good agreement with theory models for prompt J/ψ production.**

- **The proton LHC run has delivered ~43 pb^{-1} data, which amounts to >1 Million J/ψ decays to dimuons, more analyses in the pipeline:**
  - **J/ψ production polarizations in fine p_T-y bins**
  - **Ψ(2S) production and polarizations**
  - **χ_c and X(3872) production studies**

Thank you !

&

Backup slides.

Table 3: Differential inclusive cross sections and average p_T in the bin, for each prompt J/ψ polarization scenario considered: unpolarized ($\lambda_\theta = 0$), full longitudinal polarization ($\lambda_\theta = -1$) and full transverse polarization ($\lambda_\theta = +1$) in the Collins-Soper (CS) or the helicity (HX) frames [7]. For the unpolarized case, the first error is statistical and the second is systematic; for the others the total error is given.

$p_T^{J/\psi}$ (GeV/c)	$\langle p_T^{J/\psi} \rangle$ (GeV/c)	$\frac{d^2\sigma}{dp_T dy} \cdot$ BR(J/$\psi \to \mu^+\mu^-$) (nb/ GeV/c) $\lambda_\theta = 0$	$\lambda_\theta^{CS} = -1$	$\lambda_\theta^{CS} = +1$	$\lambda_\theta^{HX} = -1$	$\lambda_\theta^{HX} = +1$
			$\lvert y\rvert < 1.2$			
6.50 – 8.00	7.29	$7.63 \pm 0.30 \pm 0.97$	9.28 ± 1.20	6.99 ± 0.91	5.70 ± 0.74	9.14 ± 1.20
8.00 – 10.00	8.91	$3.23 \pm 0.11 \pm 0.38$	3.81 ± 0.47	3.00 ± 0.37	2.45 ± 0.30	3.85 ± 0.48
10.00 – 12.00	10.90	$1.18 \pm 0.05 \pm 0.14$	1.35 ± 0.17	1.10 ± 0.14	0.93 ± 0.12	1.37 ± 0.17
12.00 – 30.00	15.73	$0.116 \pm 0.005 \pm 0.013$	0.130 ± 0.016	0.110 ± 0.013	0.096 ± 0.012	0.129 ± 0.016
			$1.2 < \lvert y\rvert < 1.6$			
2.00 – 3.50	2.73	$68.8 \pm 6.3 \pm 13.0$	50.4 ± 9.9	84.6 ± 19.0	50.5 ± 9.9	84.5 ± 19.0
3.50 – 4.50	4.02	$46.1 \pm 2.7 \pm 6.5$	37.3 ± 5.7	52.8 ± 8.4	33.9 ± 5.2	56.4 ± 8.8
4.50 – 5.50	5.03	$28.6 \pm 1.3 \pm 3.9$	28.2 ± 4.1	28.7 ± 4.1	20.8 ± 3.0	35.0 ± 5.0
5.50 – 6.50	5.96	$16.5 \pm 0.8 \pm 2.0$	17.8 ± 2.3	16.0 ± 2.0	12.3 ± 1.6	20.1 ± 2.6
6.50 – 8.00	7.20	$7.64 \pm 0.30 \pm 0.87$	8.71 ± 1.10	7.19 ± 0.87	5.80 ± 0.71	9.19 ± 1.10
8.00 – 10.00	8.81	$2.76 \pm 0.14 \pm 0.32$	3.11 ± 0.39	2.62 ± 0.33	2.18 ± 0.27	3.24 ± 0.41
10.00 – 30.00	12.99	$0.182 \pm 0.010 \pm 0.021$	0.204 ± 0.026	0.173 ± 0.022	0.151 ± 0.019	0.202 ± 0.026
			$1.6 < \lvert y\rvert < 2.4$			
0.00 – 0.50	0.32	$36.8 \pm 2.2 \pm 6.0$	26.1 ± 4.5	46.5 ± 8.0	26.3 ± 4.5	45.6 ± 7.8
0.50 – 0.75	0.63	$83.2 \pm 4.5 \pm 15.3$	59.5 ± 11.3	105.1 ± 19.9	60.4 ± 11.6	103.2 ± 19.3
0.75 – 1.00	0.88	$102.3 \pm 5.0 \pm 16.9$	72.8 ± 13.3	128.9 ± 23.7	75.1 ± 13.4	125.0 ± 22.8
1.00 – 1.25	1.13	$121.9 \pm 5.3 \pm 21.1$	87.1 ± 14.8	152.4 ± 27.1	91.11 ± 18.2	146.2 ± 25.6
1.25 – 1.50	1.37	$127.7 \pm 5.6 \pm 21.6$	91.1 ± 15.6	160.1 ± 29.3	96.2 ± 17.7	152.9 ± 28.4
1.50 – 1.75	1.62	$132.5 \pm 5.3 \pm 21.9$	94.7 ± 15.8	165.9 ± 27.7	101.3 ± 16	157.8 ± 25.4
1.75 – 2.00	1.87	$121.9 \pm 6.2 \pm 17.9$	87.4 ± 13.6	152.1 ± 24.7	93.6 ± 14.9	143.9 ± 23.1
2.00 – 2.25	2.12	$125.2 \pm 6.1 \pm 18.7$	89.8 ± 13.9	156.3 ± 24.7	97.1 ± 14.9	147.3 ± 23.6
2.25 – 2.50	2.37	$96.3 \pm 4.2 \pm 14.1$	69.0 ± 10.2	120.5 ± 18.1	74.3 ± 11	114 ± 16.8
2.50 – 2.75	2.63	$96.4 \pm 7.7 \pm 13.0$	69.8 ± 11.1	119.3 ± 18.6	74.8 ± 11.8	113.2 ± 18.1
2.75 – 3.00	2.87	$77.9 \pm 3.7 \pm 10.7$	56.3 ± 8.0	96.4 ± 13.9	60.3 ± 8.5	91.6 ± 13.1
3.00 – 3.25	3.12	$73.7 \pm 3.5 \pm 10.0$	53.8 ± 7.7	91.2 ± 13.0	57.6 ± 8.3	86.5 ± 13.0
3.25 – 3.50	3.37	$66.7 \pm 3.2 \pm 8.8$	48.5 ± 6.9	82.8 ± 12.0	52.1 ± 7.3	78.3 ± 11.0
3.50 – 4.00	3.74	$49.6 \pm 1.7 \pm 7.1$	37.0 ± 5.5	60.6 ± 9.0	39.0 ± 5.8	58.3 ± 8.6
4.00 – 4.50	4.24	$39.7 \pm 1.4 \pm 5.0$	30.0 ± 4.0	47.3 ± 6.3	31.4 ± 4.2	46.0 ± 6.1
4.50 – 5.50	4.96	$24.5 \pm 0.7 \pm 3.3$	19.3 ± 2.6	28.7 ± 4.0	19.6 ± 2.7	28.2 ± 3.9
5.50 – 6.50	5.97	$12.6 \pm 0.4 \pm 1.7$	10.8 ± 1.4	14.0 ± 1.9	10.3 ± 1.4	14.3 ± 1.9
6.50 – 8.00	7.17	$6.20 \pm 0.24 \pm 0.74$	5.70 ± 0.72	6.61 ± 0.84	5.13 ± 0.65	6.94 ± 0.88
8.00 – 10.00	8.84	$2.41 \pm 0.11 \pm 0.28$	2.41 ± 0.31	2.44 ± 0.31	2.04 ± 0.26	2.64 ± 0.34
10.00 – 30.00	13.06	$0.149 \pm 0.008 \pm 0.019$	0.155 ± 0.021	0.148 ± 0.021	0.132 ± 0.019	0.161 ± 0.023

Table 6: Differential prompt J/ψ cross sections for each polarization scenario considered: unpolarized ($\lambda_\theta = 0$), full longitudinal polarization ($\lambda_\theta = -1$) and full transverse polarization ($\lambda_\theta = +1$) in the Collins-Soper (CS) or the Helicity (HX) frames [7]. For the unpolarized case, the first error is statistical and the second is systematic; for the others the total error is given.

p_T (GeV/c)	$BR(J/\psi \to \mu^+\mu^-) \cdot \frac{d^2\sigma_{prompt}}{dp_T dy}$ (nb/ GeV/c) $\lambda_\theta = 0$	$\lambda_\theta^{CS} = -1$	$\lambda_\theta^{CS} = +1$	$\lambda_\theta^{HX} = -1$	$\lambda_\theta^{HX} = +1$
			$\|y\| < 1.2$		
6.5 – 10.0	$3.76 \pm 0.13 \pm 0.47$	4.63 ± 0.60	3.45 ± 0.45	2.63 ± 0.34	4.79 ± 0.62
10.0 – 30.0	$0.134 \pm 0.033 \pm 0.016$	0.161 ± 0.044	0.123 ± 0.033	0.099 ± 0.026	0.164 ± 0.045
			$1.2 < \|y\| < 1.6$		
2.0 – 4.5	$50.6 \pm 3.6 \pm 8.4$	36.4 ± 6.5	63.6 ± 11.6	36.3 ± 6.5	63.1 ± 11.4
4.5 – 6.5	$18.4 \pm 0.7 \pm 2.4$	17.3 ± 2.3	19.1 ± 2.6	13.3 ± 1.8	22.7 ± 3.1
6.5 – 10.0	$3.85 \pm 0.15 \pm 0.44$	4.11 ± 0.49	3.74 ± 0.45	2.87 ± 0.34	4.67 ± 0.56
10.0 – 30.0	$0.116 \pm 0.009 \pm 0.014$	0.127 ± 0.018	0.111 ± 0.015	0.093 ± 0.013	0.133 ± 0.019
			$1.6 < \|y\| < 2.4$		
0.00 – 1.25	$71.9 \pm 2.4 \pm 11.2$	49.7 ± 7.9	92.5 ± 14.7	51.0 ± 8.1	90.3 ± 14.3
1.25 – 2.00	$116.2 \pm 3.5 \pm 16.8$	80.8 ± 11.9	149.1 ± 22.0	86.7 ± 12.8	140.7 ± 20.8
2.00 – 2.75	$93.7 \pm 3.4 \pm 12.4$	65.8 ± 9.1	118.8 ± 16.3	72.7 ± 10.0	110.3 ± 15.2
2.75 – 3.50	$62.6 \pm 2.0 \pm 7.9$	44.5 ± 5.7	78.8 ± 10.2	49.1 ± 6.4	72.7 ± 9.5
3.50 – 4.50	$37.4 \pm 1.1 \pm 4.9$	27.4 ± 3.7	45.7 ± 6.2	29.9 ± 4.1	42.8 ± 5.8
4.50 – 6.50	$15.2 \pm 0.4 \pm 2.0$	11.9 ± 1.6	18.0 ± 2.4	12.6 ± 1.7	17.1 ± 2.3
6.50 – 10.00	$3.08 \pm 0.11 \pm 0.37$	2.79 ± 0.35	3.36 ± 0.42	2.64 ± 0.33	3.37 ± 0.42
10.00 – 30.00	$0.093 \pm 0.007 \pm 0.012$	0.092 ± 0.014	0.096 ± 0.014	0.082 ± 0.012	0.100 ± 0.015