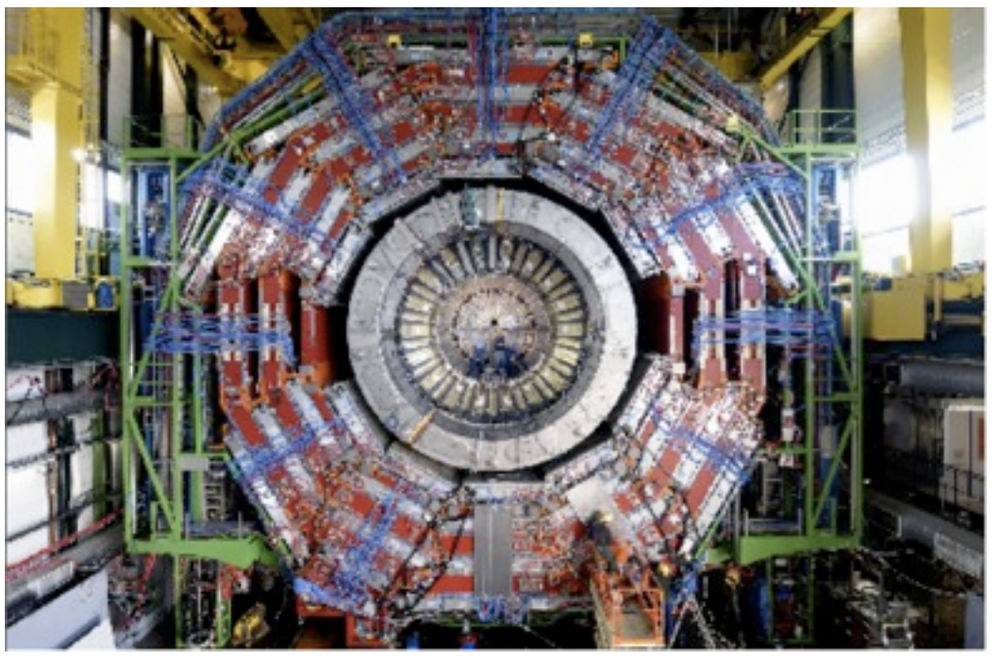
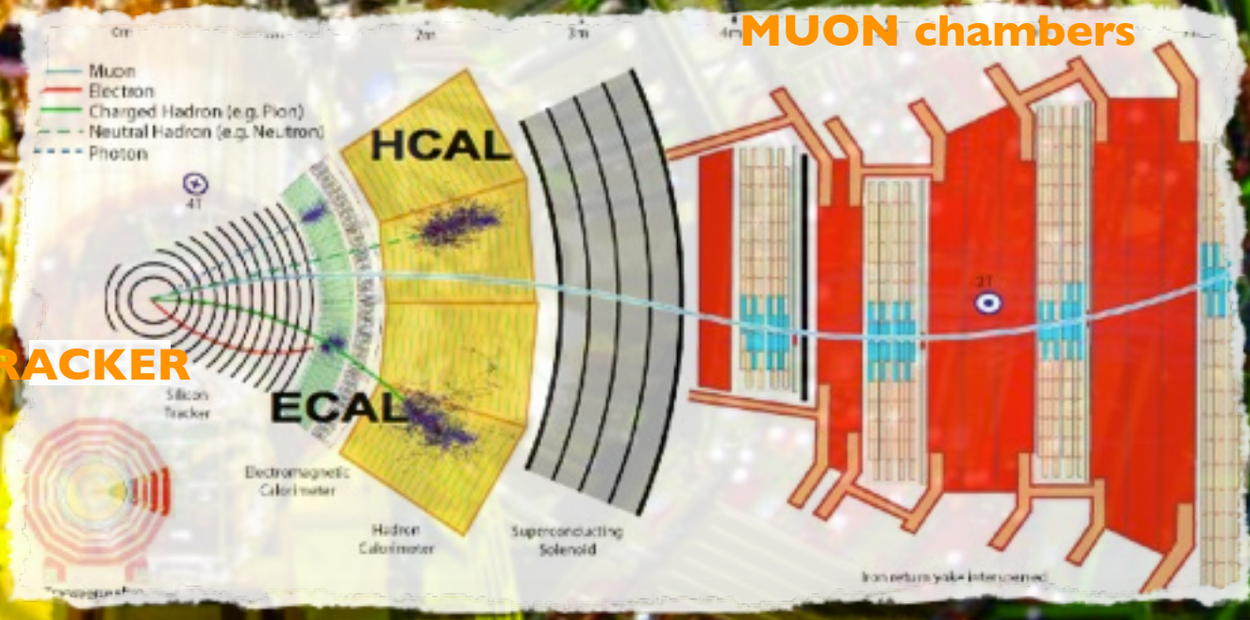


Measurement of the J/ψ, Υ, and b hadron production in pp collisions at $\sqrt{s}$=7 TeV with the CMS experiment

Nuno Leonardo
(Purdue University)
On Behalf of the CMS Collaboration

ICHEP 2010, June 22

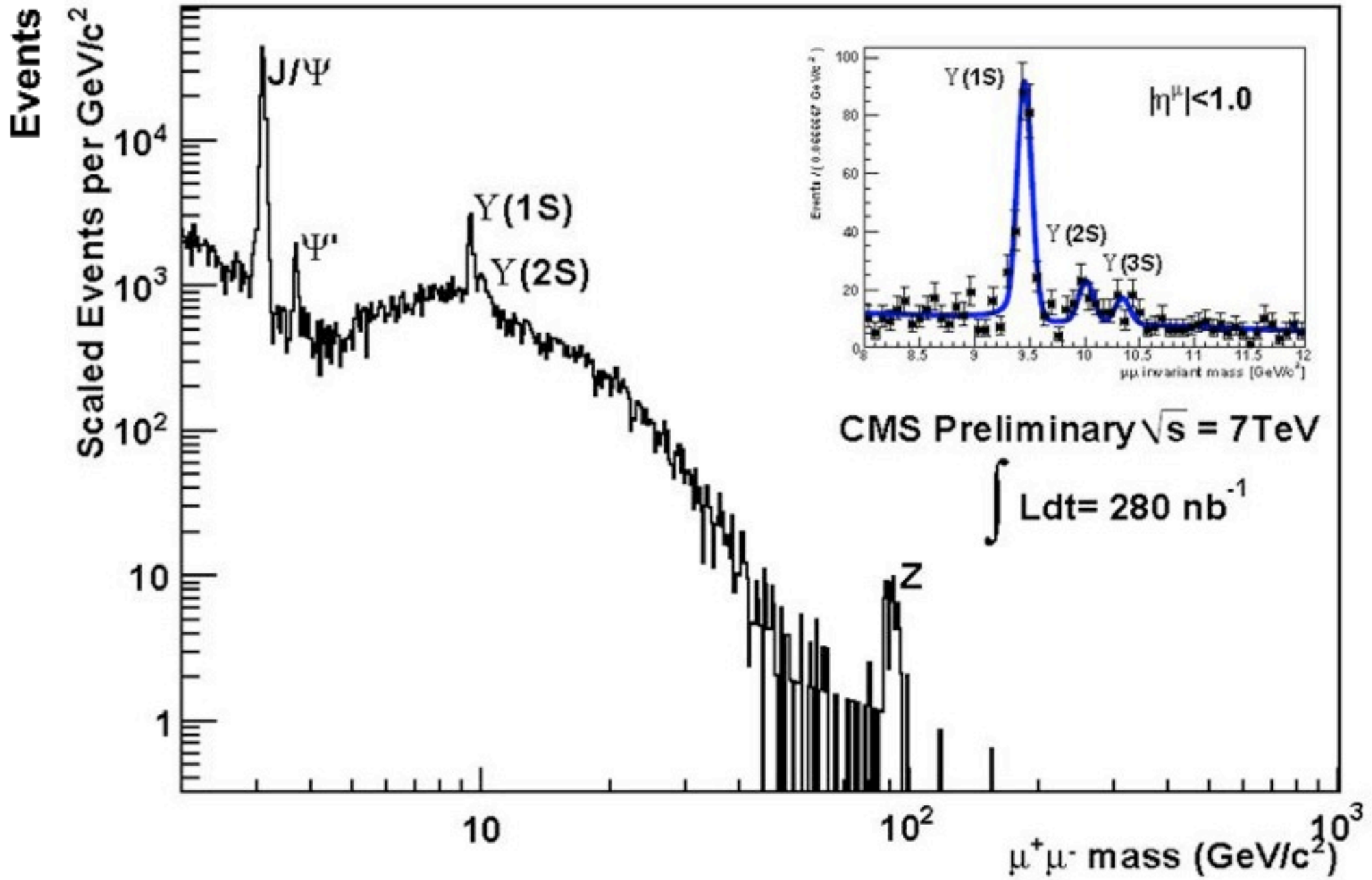
the CMS detector



MUON chambers

TRACKER

the dimuon spectrum



total data available for physics at CMS has been analyzed

outline

First measurements at 7 TeV

- Inclusive J/ψ cross section and non-prompt fraction
- $\Upsilon(nS)$ cross sections and ratio

Perspectives

- First fully reconstructed B decays

BPH-PAS 10-002

Jpsi prompt and non-prompt cross section in pp collisions at $\sqrt{s}$=7TeV

BPH-PAS 10-003

Upsilon production cross section in pp collisions at $\sqrt{s}$=7TeV

EWK-PAS 10-004

Measurement of CMS luminosity

MUO-PAS 10-002

Performance of muon identification in pp collisions at $\sqrt{s}$=7TeV

TRK-PAS 10-002

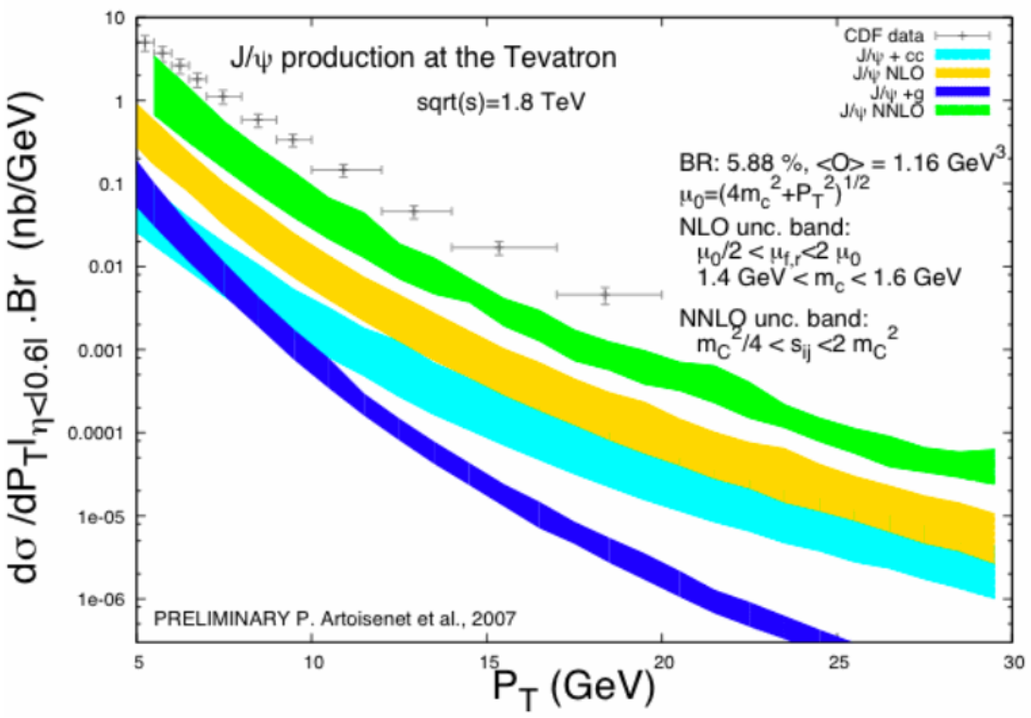
Measurement of tracking efficiency

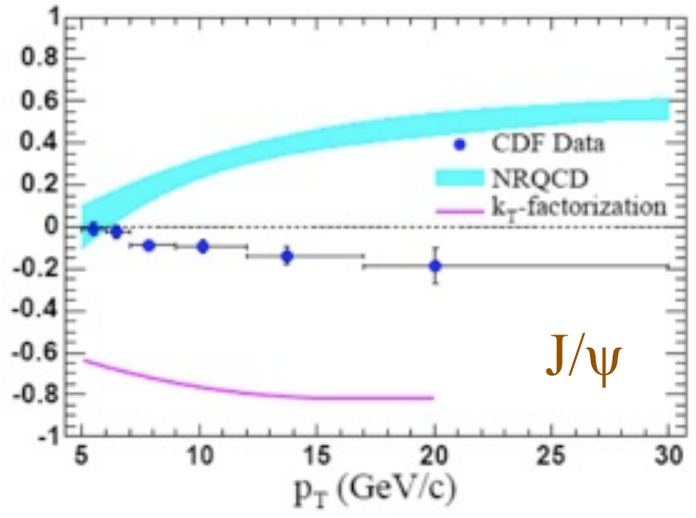
TRK-PAS 10-004

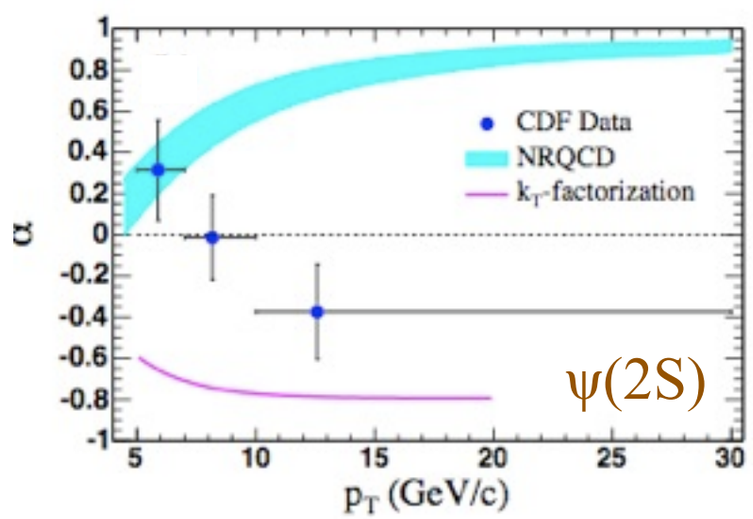
Measurement of momentum scale and resolution using low mass resonances and cosmic-ray muons

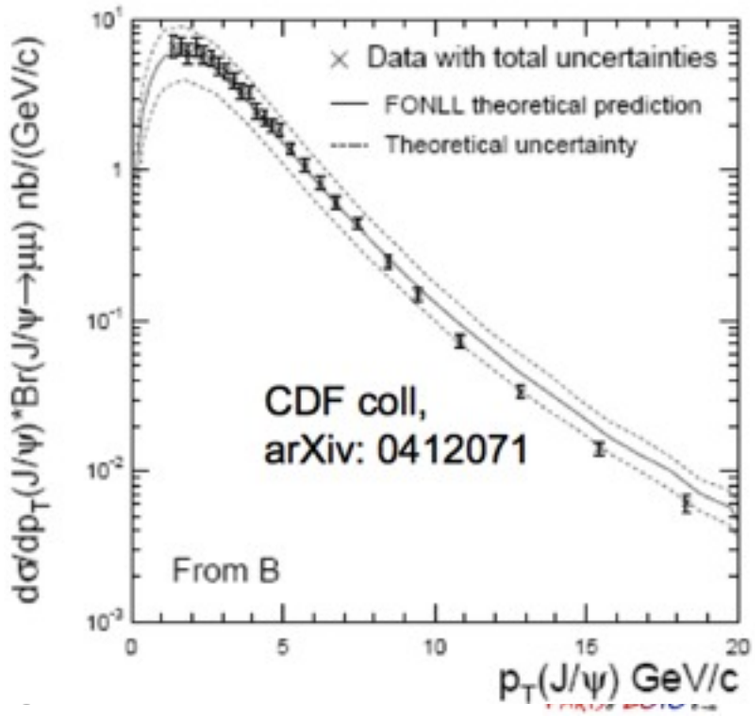
the onia puzzle

- no model explains cross section and polarization simultaneously
- many models on the market
  - Color Singlet Model: LO, NLO, NNLO
  - Color Octet Mechanism: NRQCD... many more
- measurement of J/ψ and ϒ cross sections and polarization at the LHC desirable
- probe high p_T region not accessible at previous experiments









muon trigger @ cms

Level 1 Trigger
Hardware based
Muons and Calorimeters

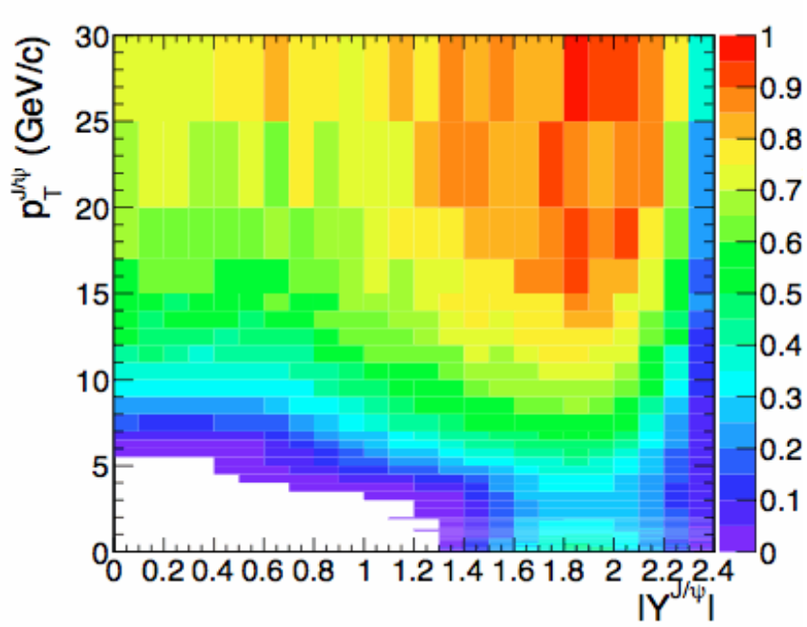
High Level Trigger (L2,L3)
Software based
Fast (local) reconstruction
in the tracker included

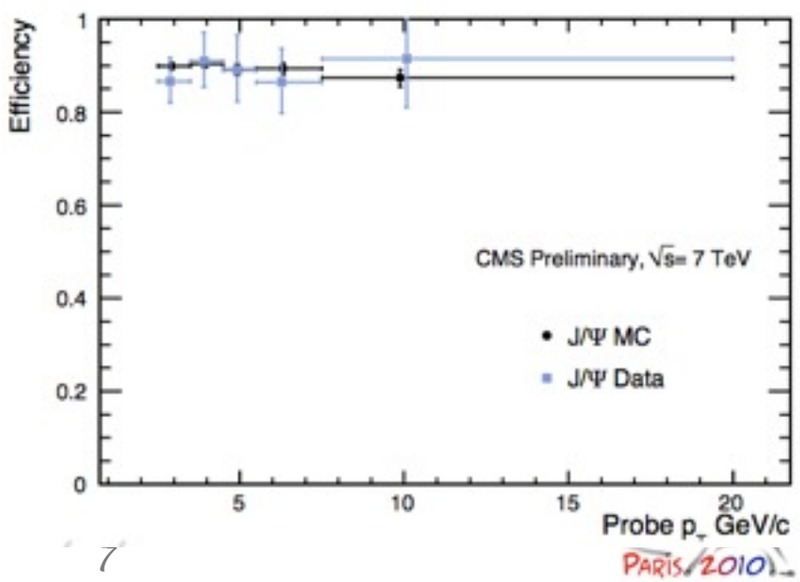
- trigger menu adapting to rapidly evolving instantaneous luminosity
- dimuon paths
  - startup: L1 and HLT triggers, acceptance down to 0 p_T in forward region
  - L>1E30: several HLT paths turn on, combination of L1 and HLT objects, or HLT + track (in loose J/ψ mass window), unprescaled up to few 1E31
- single muon paths
  - L1 and HLT: one muon with p_T> x GeV/c (x=3,5, etc lowest threshold still unprescaled)
- demonstrated ability to collect muons at low p_T, including in the central region

cross section overview

$$\frac{d^2\sigma}{dp_T dy}(pp \to Q\bar{Q}X) \times \mathcal{B}(Q\bar{Q} \to \mu^+\mu^-) = \frac{N_{Q\bar{Q}}}{\int Ldt \cdot A \cdot \epsilon_{trigger} \cdot \epsilon_{reco} \cdot \Delta p_T \Delta y}$$

- N_{QQ} = signal yield in a given p_T,y bin from a 1-d fit to the $\mu\mu$ invariant mass distribution
- $\int Ldt$ = integrated lumi, uncertainty $\mathcal{O}(10\%)$
- A = J/ψ, Υ geometrical and kinematical acceptance (MC)
  - Strongly dependent on production polarization
- $\varepsilon_{trigger}$, ε_{reco} = trigger and reconstruction efficiencies, data driven through Tag and Probe (T&P) method



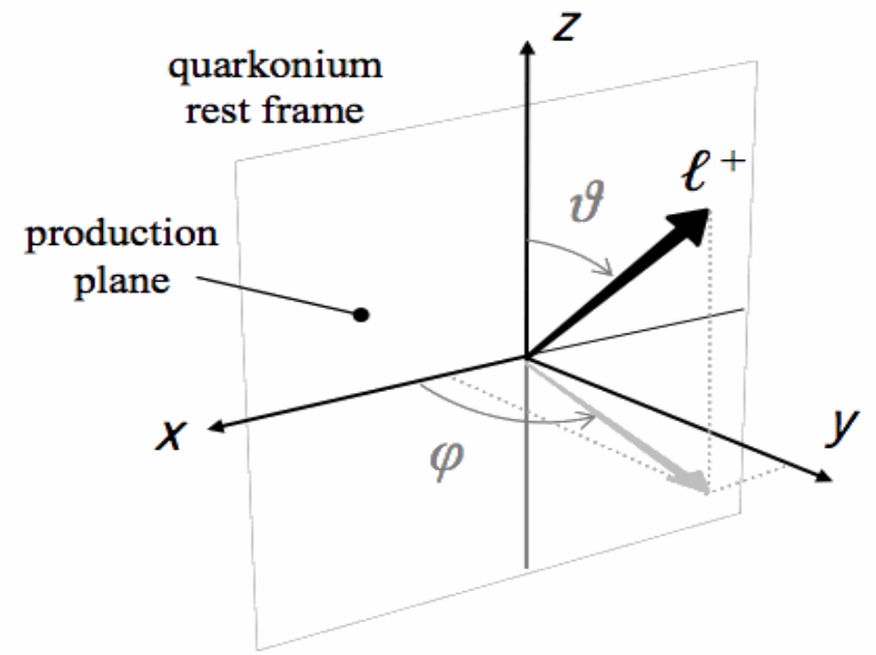


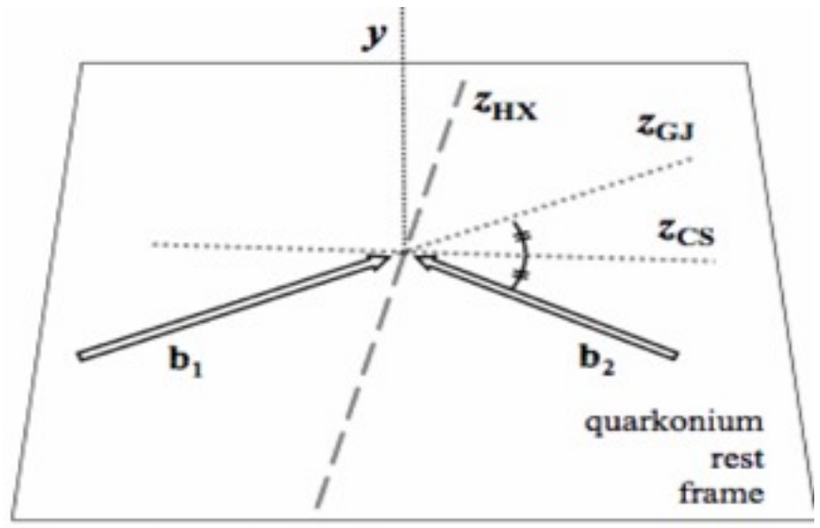
J/ψ and Υ polarization

- acceptance dependent on onia polarization

$$W(\cos\theta,\phi) = \frac{3}{2(3+\lambda_\theta)} \cdot (1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi)$$

- the observed polarization depends on
  - the reconstructed dimuon kinematics (p_T, η)
  - the frame: CS (along the collision direction), HX (along the onia momentum)
- non-prompt
  - use EvtGen; two body decays: B-factory measurements, multibody decays: pure phase space
- LHC-wide agreement to use isotropic for central value, cross section measured for different polarization scenarios



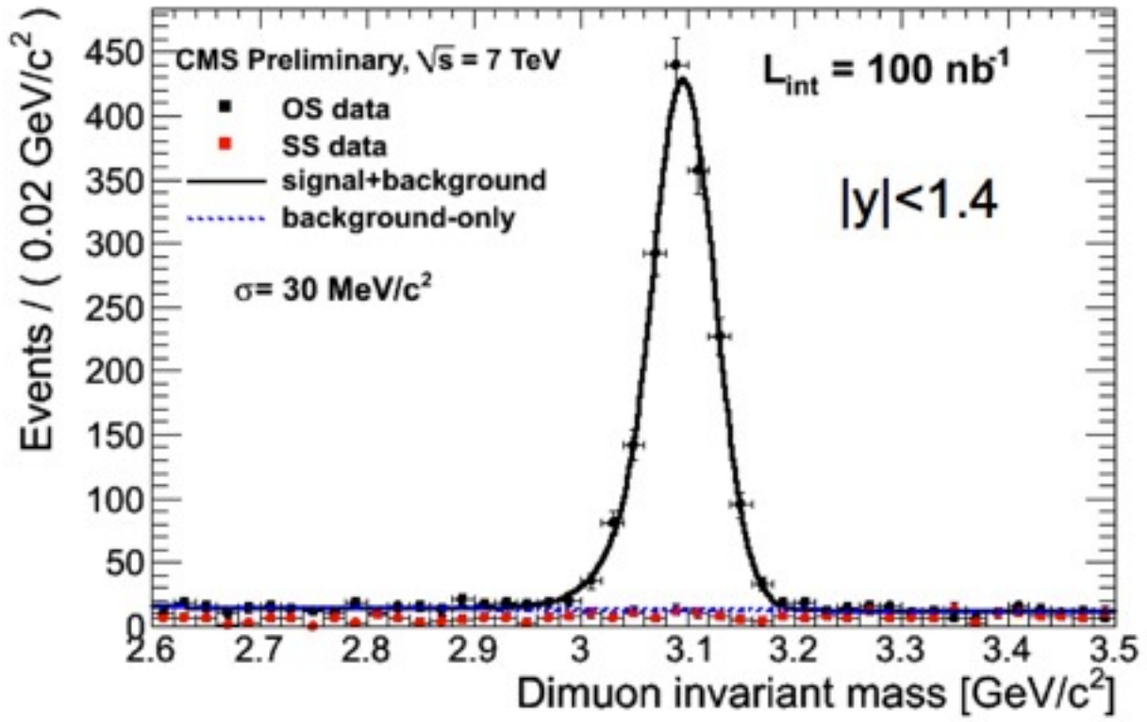


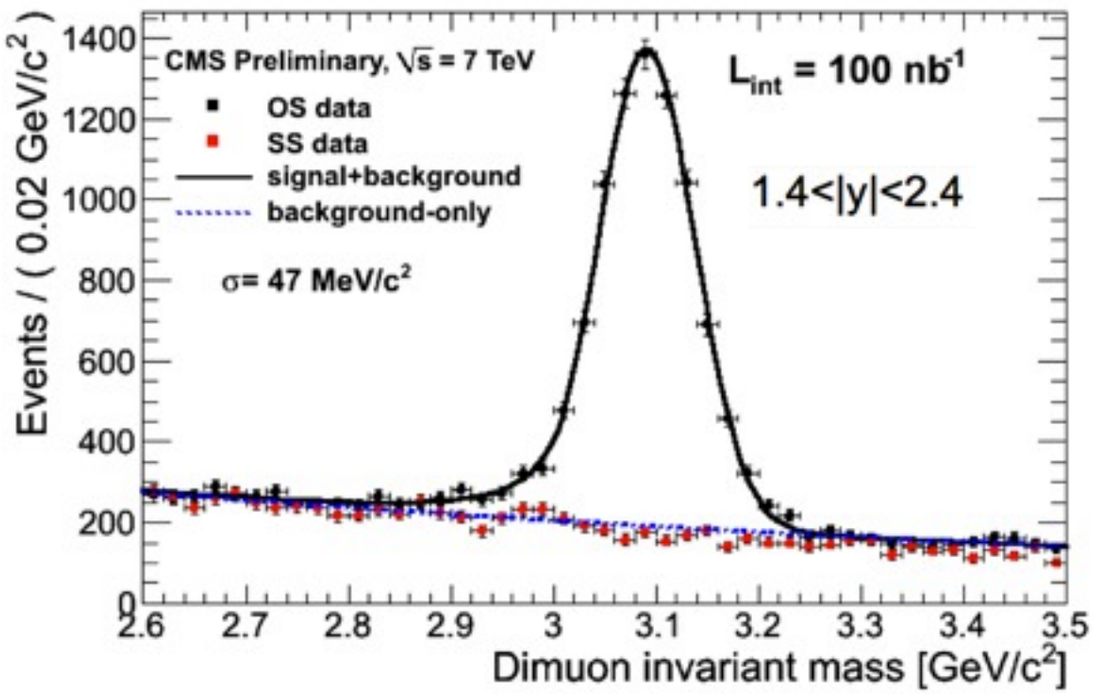
J/ψ selection and yield

- Selection
  - Vertexing of opposite sign dimuon combinations (prob>0.1%)
  - High quality track associated to the muon segments: cut on n_{hits}, χ^2, |dxy|,|dz|
  - muon acceptance cuts:

$$\begin{aligned} |\eta^\mu| &< 1.3 \quad p_T^\mu > 3.3 \text{ GeV}/c \\ 1.3 < |\eta^\mu| &< 2.2 \quad p^\mu > 2.9 \text{ GeV}/c \\ 2.2 < |\eta^\mu| &< 2.4 \quad p_T^\mu > 0.8 \text{ GeV}/c \end{aligned}$$

- Yield extraction: Unbinned ML fit to invariant mass: Crystal Ball + exponential





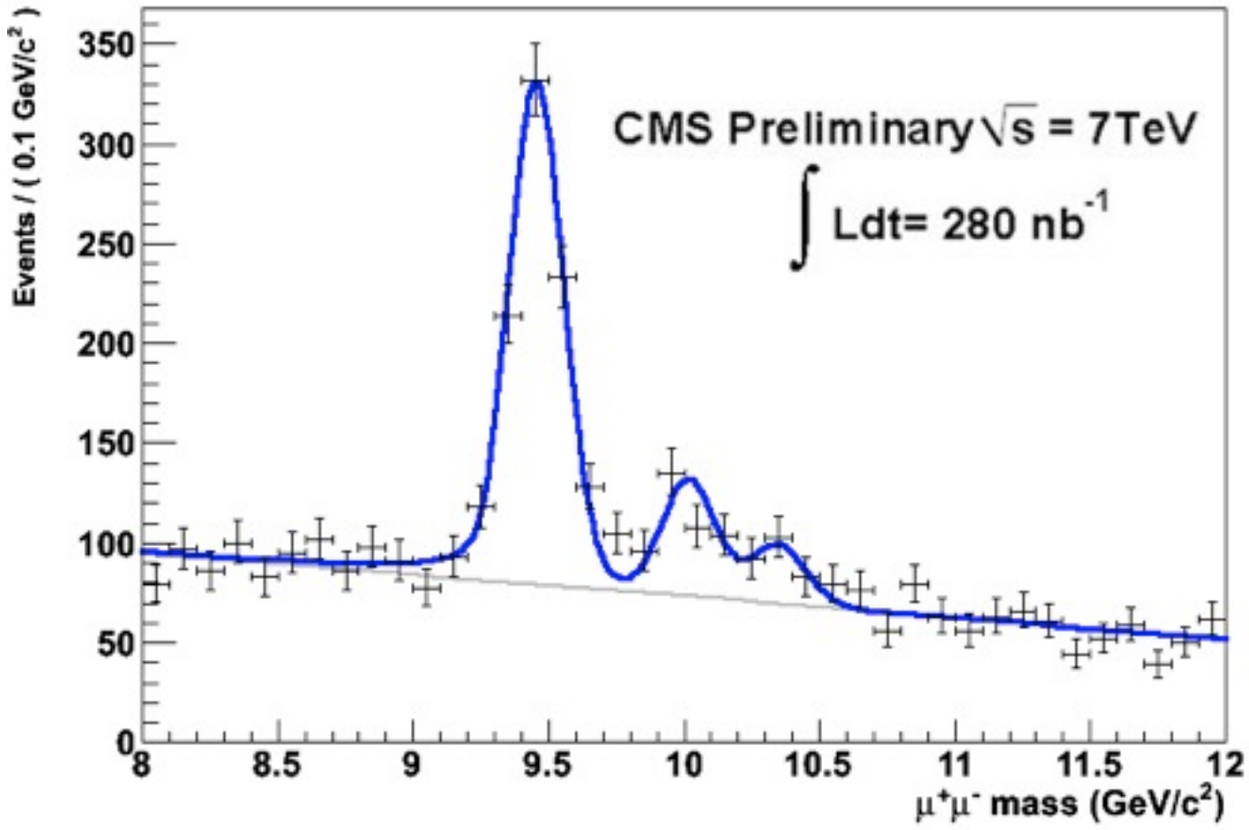
Υ selection and yield

- Selection similar to the Jpsi
  - muon acceptance cuts

$$|\eta| < 1.6,\ p_T > 3.5\ \text{GeV}/c$$
$$1.6 < |\eta| < 2.4,\ p_T > 2.5\ \text{GeV}/c$$

  - Restrict to |y(Υ)|<2.0

- Yield extraction: Unbinned ML fit to invariant mass: signal Crystal Ball + linear background
  - Core Resolution common to Υ(nS) n=1,2,3, Υ(1S) mean floated, Δm(Υ(2,3S)-Υ(1S)) fixed to PDG



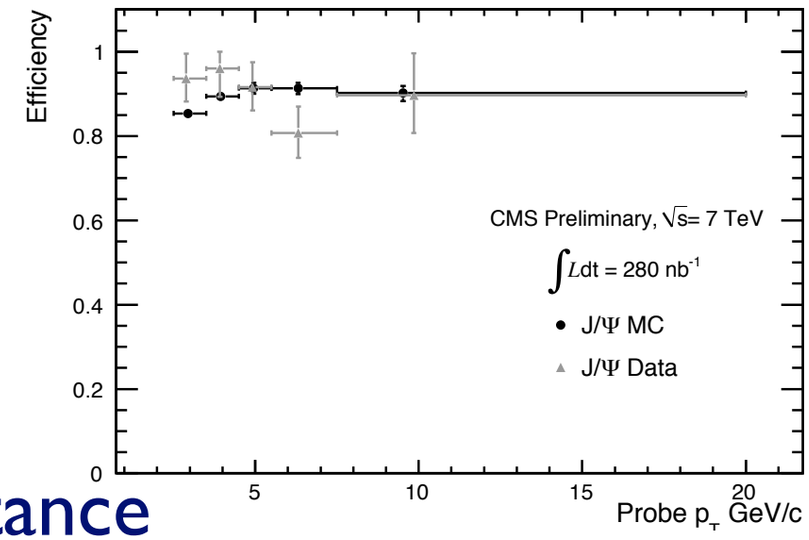
N(Υ1(1S)) = 678 ± 37

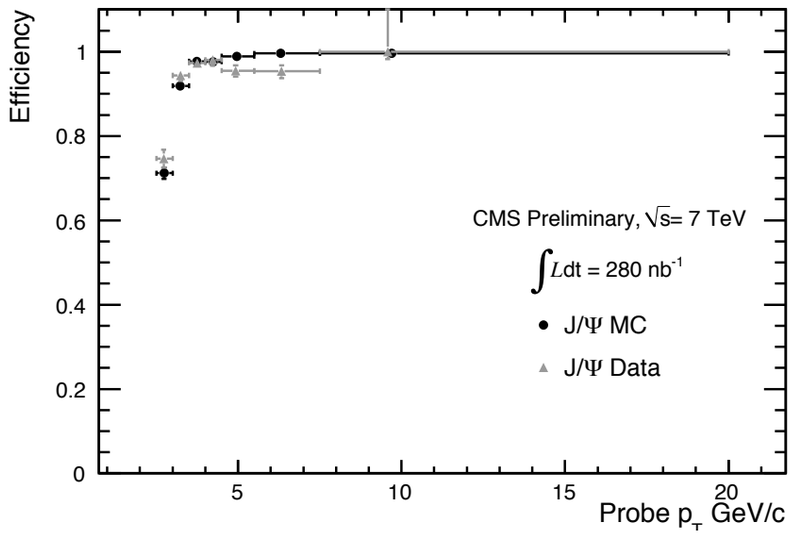
Mass resolution
~100 MeV/c (|η|<2.4)
~ 67 MeV/c (|η|<1.0)

systematic uncertainties

- common to large extent between J/ψ and ϒ analyses
- Efficiency
  - T&P using J/ψ, binning effects and factorization assumption using MC

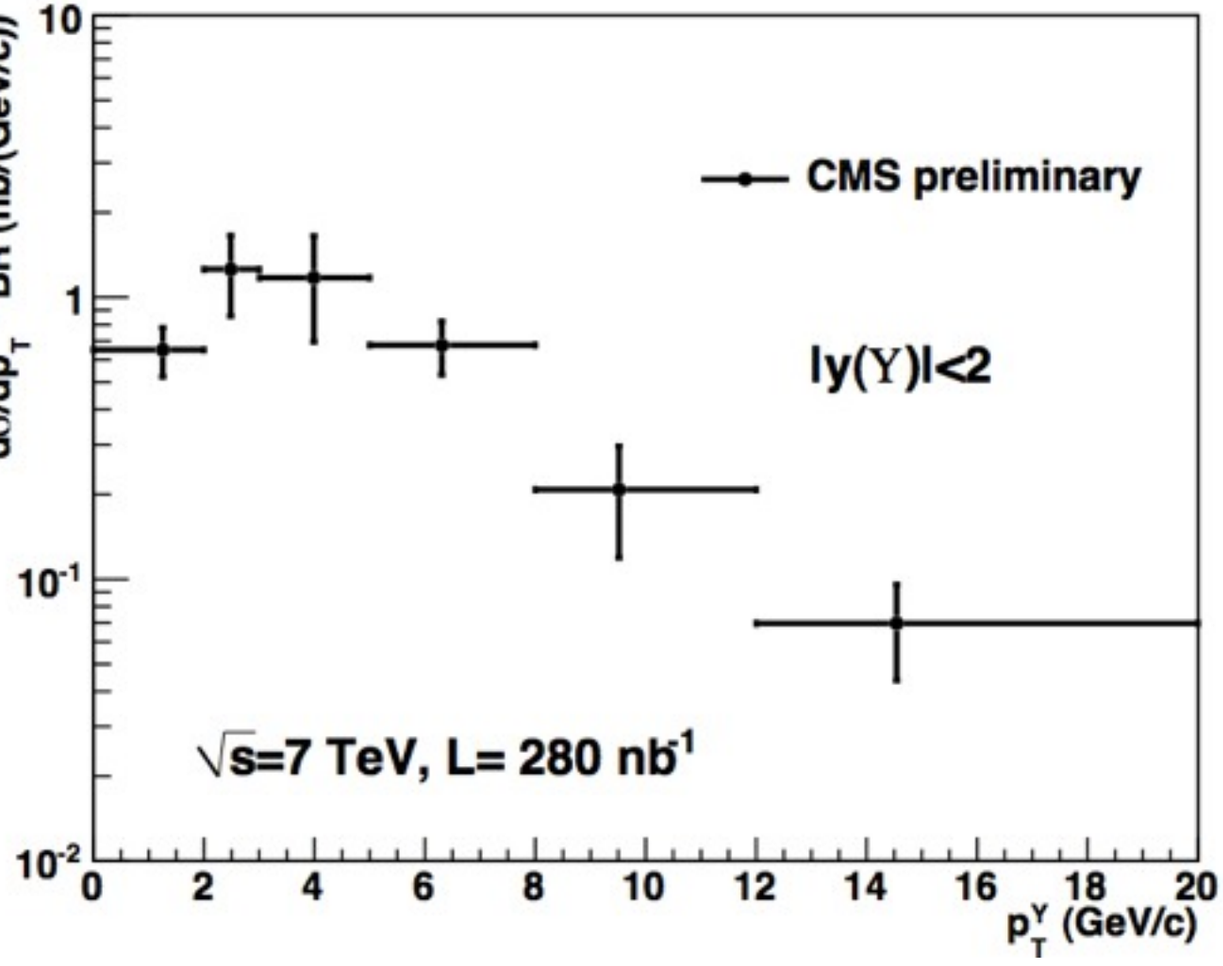
$$\varepsilon(\text{total}) = \varepsilon(\text{trig}|\text{id}) \times \varepsilon(\text{id}|\text{track}) \times \varepsilon(\text{track}|\text{accepted}) \equiv \varepsilon_{\text{trig}} \times \varepsilon_{\text{id}} \times \varepsilon_{\text{track}}$$





- Acceptance
  - p_T spectrum shape, FSR, b-fraction, momentum scale and resolution, beam spot position, material effects
- Yield extraction
  - validated with toy MC studies, effect of modified PDF
- b fraction fit
  - residual misalignment, pseudo proper time PDF, resolution function

Υ differential cross section

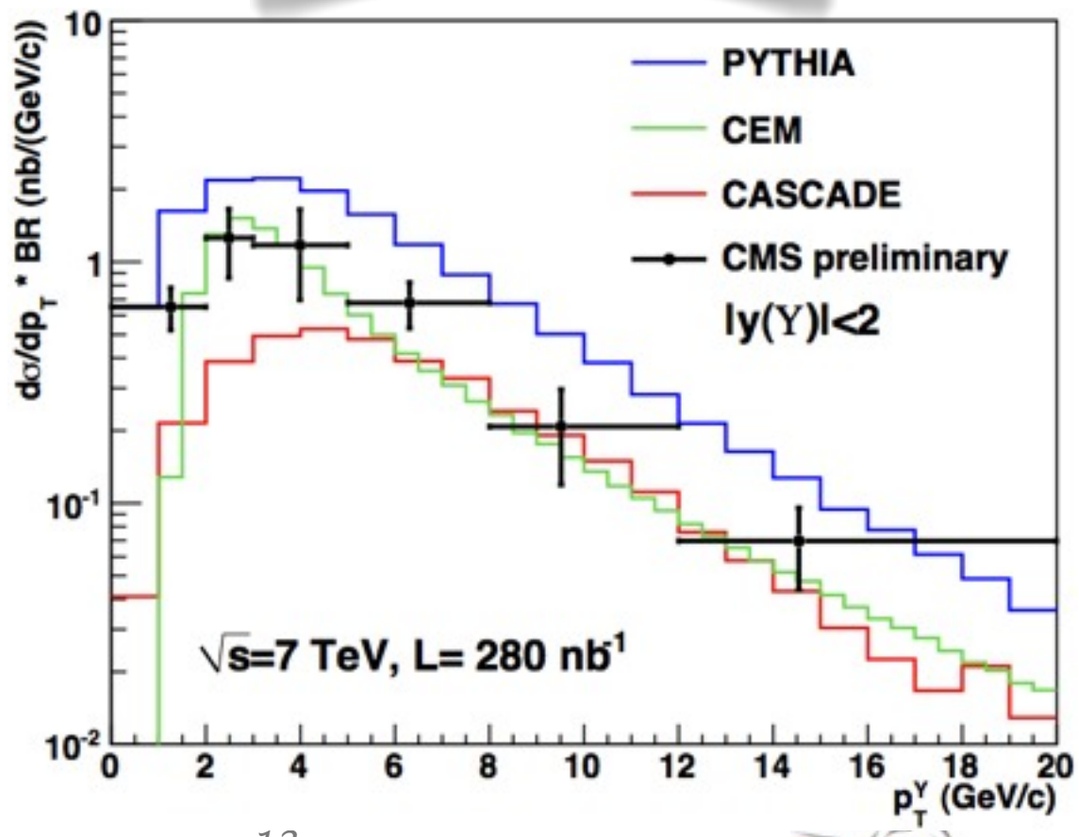


$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) =$$

$$8.3 \pm (0.5)_{\text{stat.}} \pm (0.9)_{\text{lumi.}} \pm (1.0)_{\text{syst.}} \text{ nb}$$

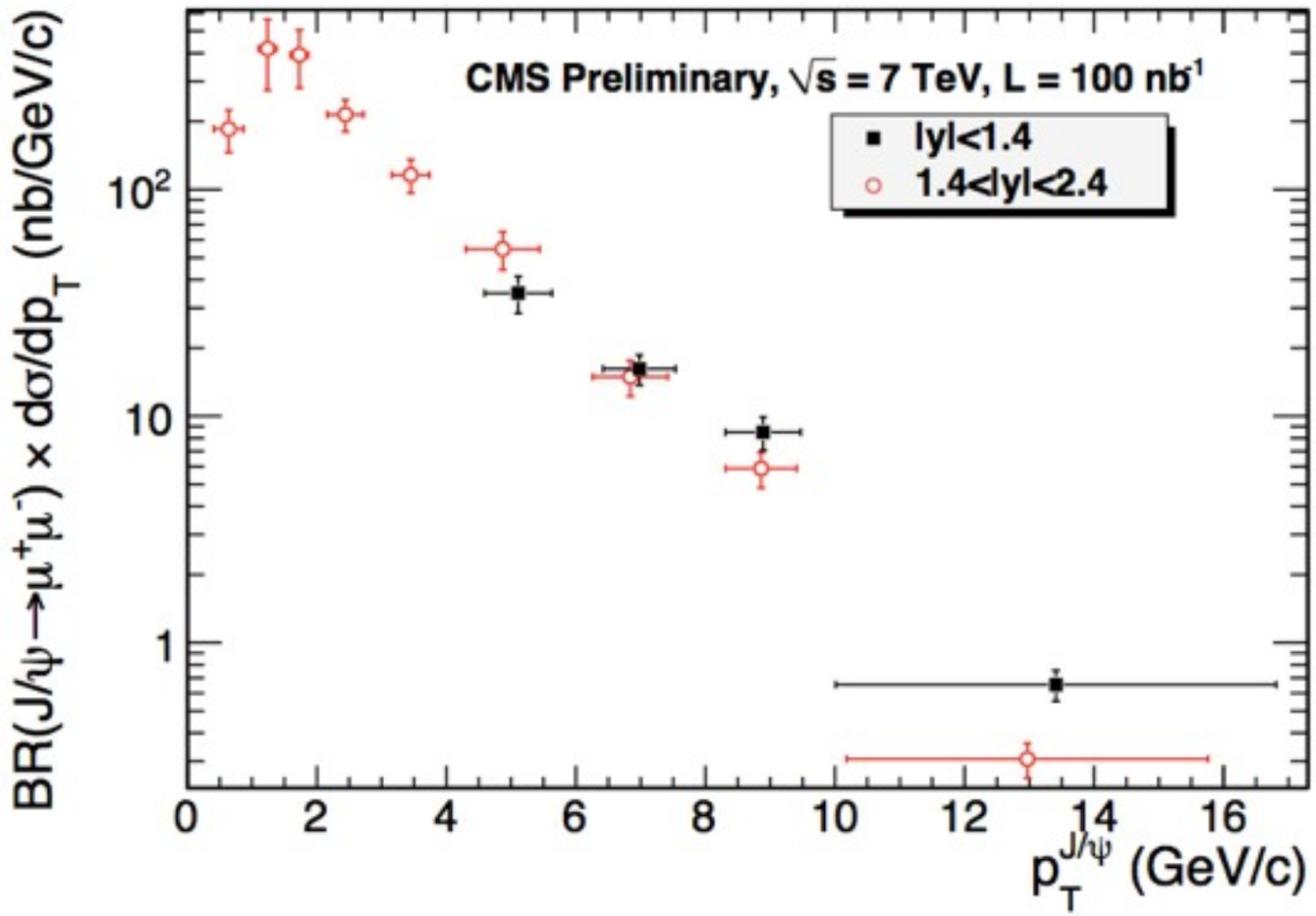
$\Upsilon(2S) + \Upsilon(3S)$ to $\Upsilon(1S)$ ratio

$$0.44 \pm 0.06 \pm 0.05$$



- assuming fully T or L polarizations leads to changes in the cross section by about 20%

J/ψ differential cross section



$$BR(J/\psi \to \mu^+\mu^-) \cdot \sigma(pp \to J/\psi + X) =$$

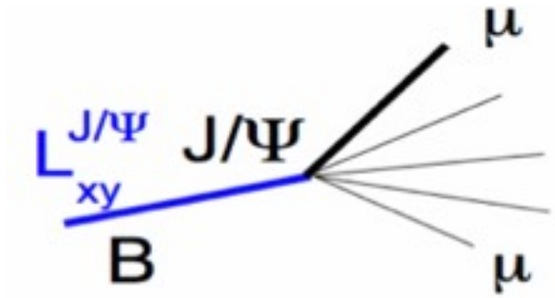
$$(289.1 \pm 16.7(\text{stat}) \pm 60.1(\text{syst}))\ \text{nb}$$

(measured for $4<p_T<30$ GeV, $|y|<2.4$)

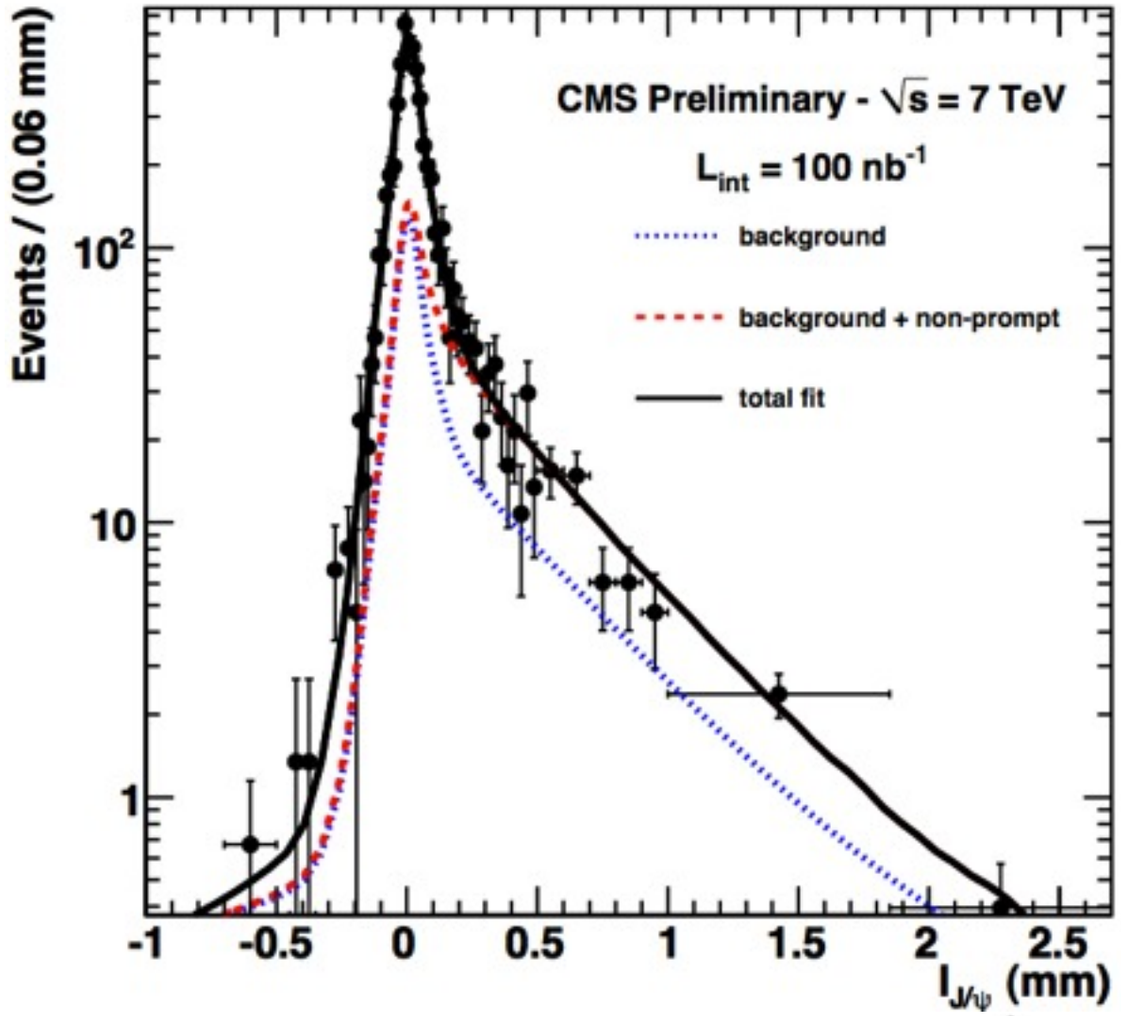
- largest source of systematic uncertainty: statistical error from T&P on efficiency determination

prompt J/ψ and $b \to J/\psi X$

- measure prompt and non-prompt contributions by a 2-d unbinned LH fit to invariant mass and pseudo proper-decay length



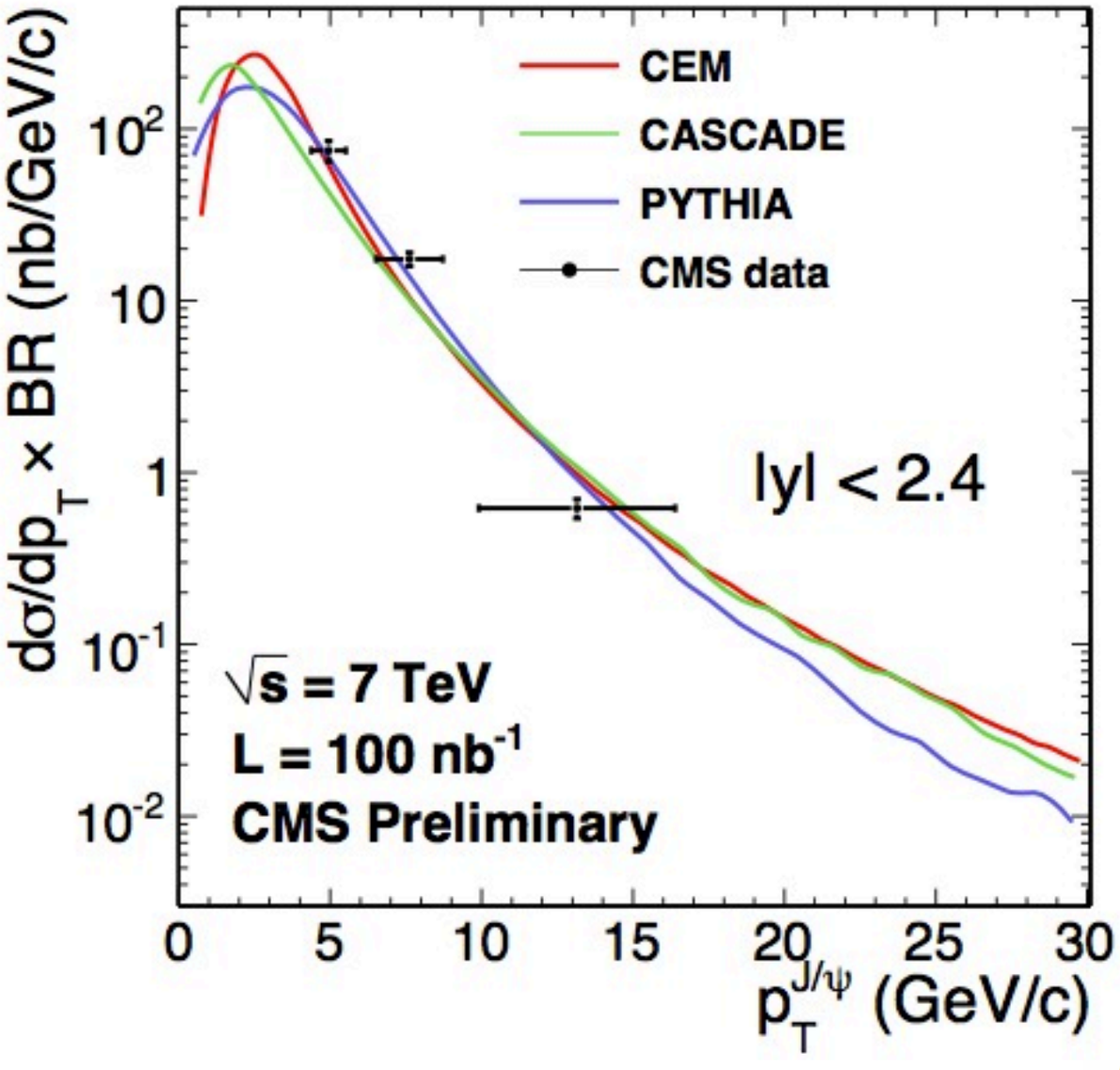
$$\ell_{xy} = \frac{L_{xy}^{J/\Psi} \cdot M^{J/\Psi}}{p_T^{J/\Psi}}$$



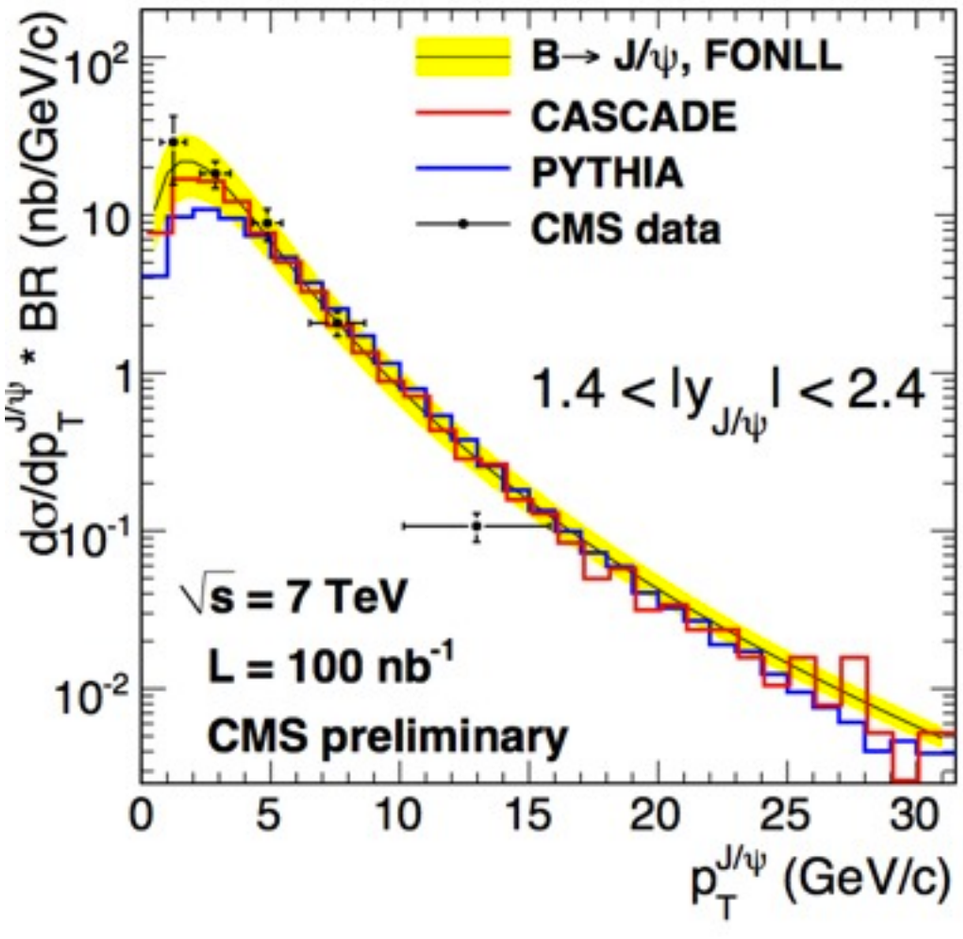
- pure resolution function (three gaussian) to parameterize l_{xy} for prompt decays, convolution with exponential for non-prompt

prompt J/ψ and $b \to J/\psi X$

prompt



non prompt

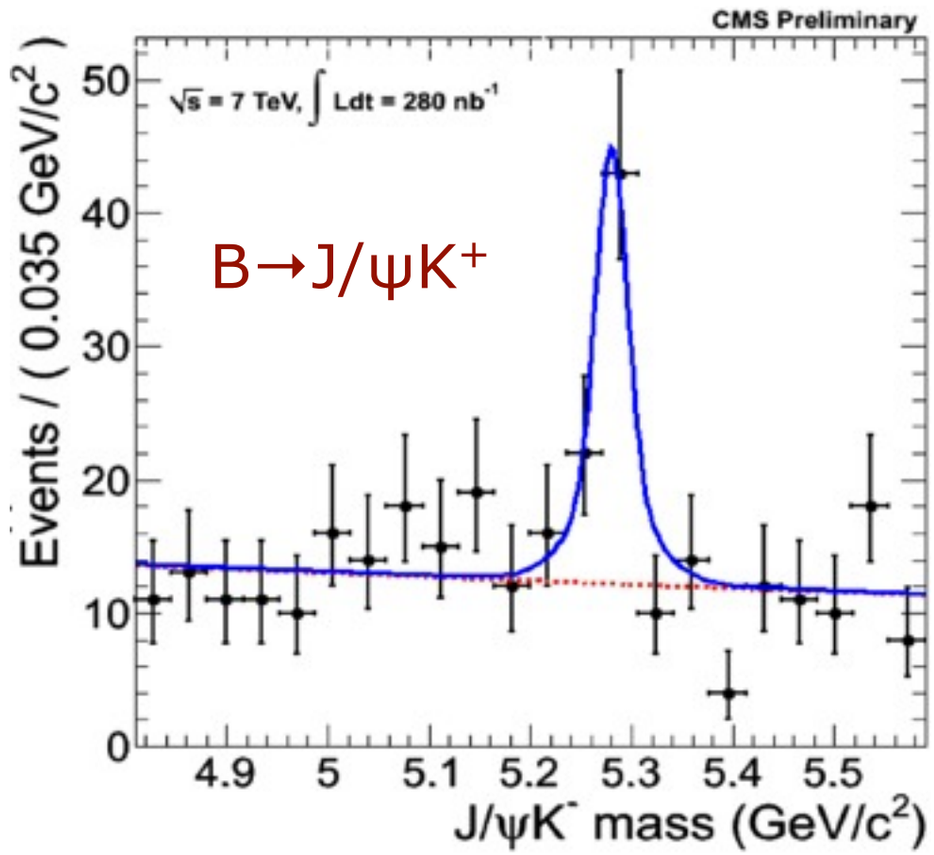


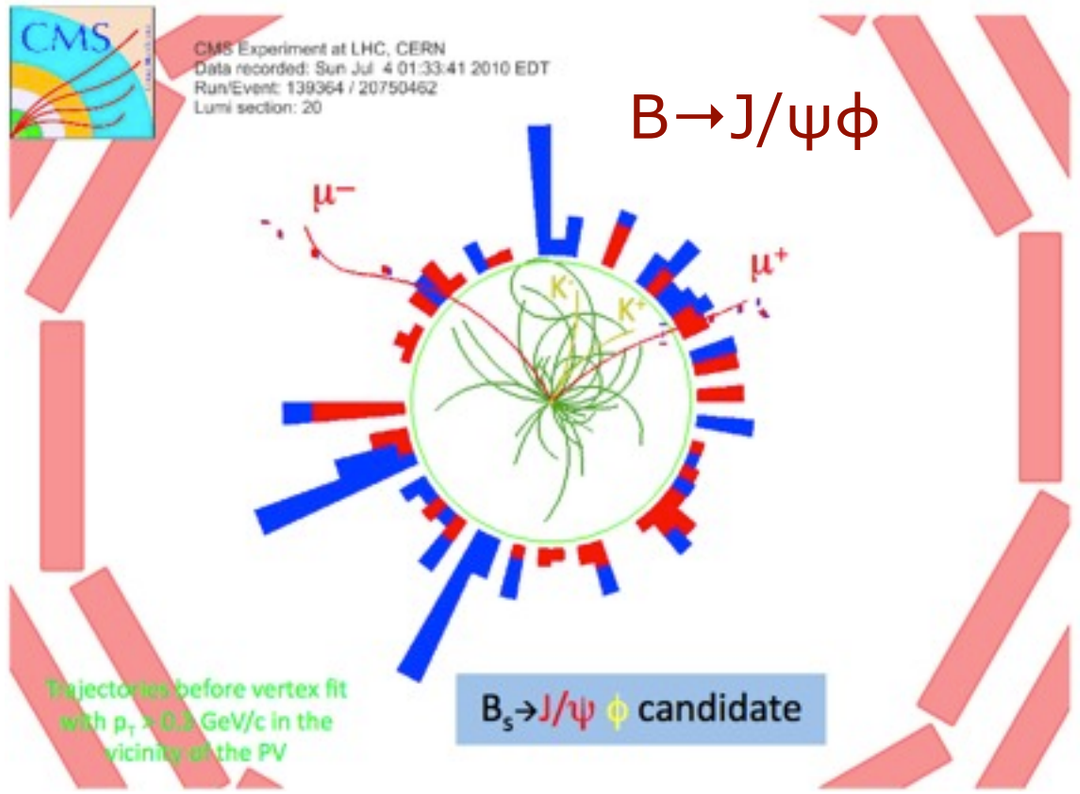
$$\mathcal{B}(J/\psi \to \mu^+\mu^-)\cdot$$

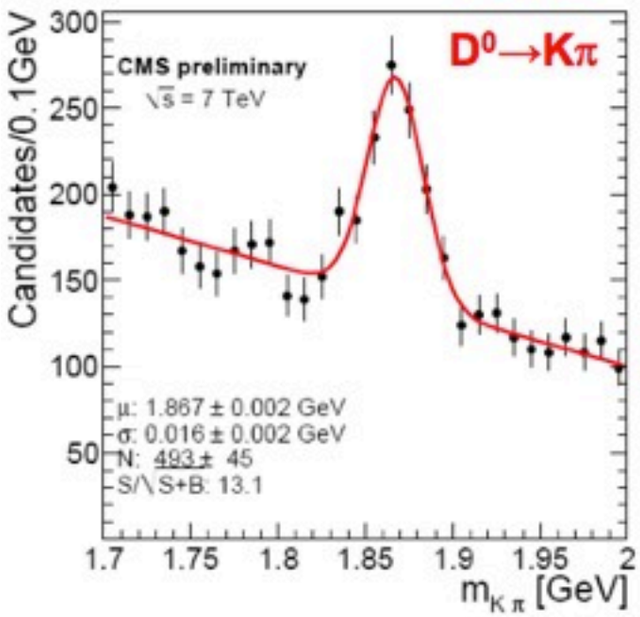
$$\sigma(pp \to bX \to J/\psi X', p_T > 4\mathrm{GeV}/c, |y| < 2.4) =$$

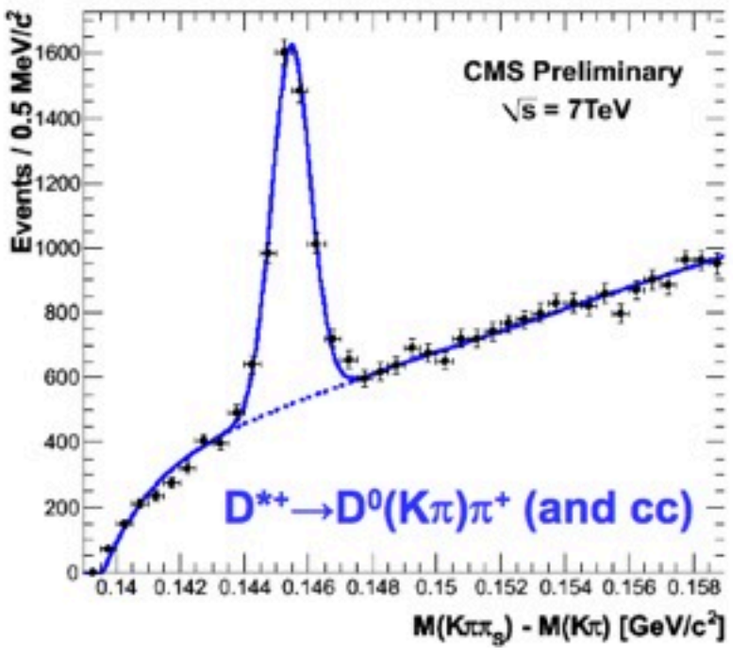
$$56.1 \pm 5.5(\mathrm{stat}) \pm 7.2(\mathrm{syst})\ \mathrm{nb}$$

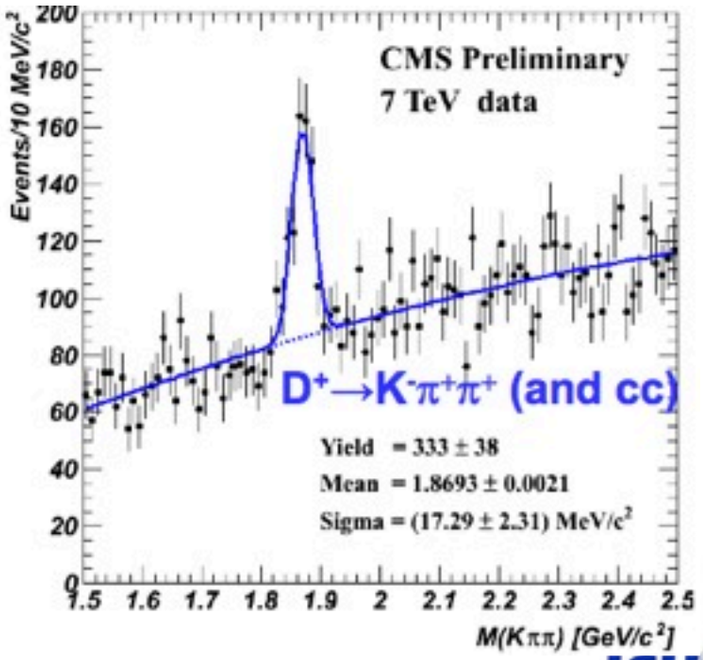
exclusive beauty and open charm











ICHEP PARIS 2010

evolving heavy flavor menu

$\int L.dt$

- detector performance
  - alignment, tracker, trigger with J/ψ, Υ

$\mathcal{O}(nb^{-1})$

- cross section for bottom, charm and quarkonia
- inclusive J/ψ, exclusive *B* decays containing J/ψ
- quarkonia studies: polarization, production mechanisms

$\mathcal{O}(pb^{-1})$

- *bb* production, and correlations: $J/\psi+\mu$, μ+jet, jet+jet
- lifetime and properties of *b* hadrons: B_u, B_d, B_s, B_c, Λ_b
- B_s oscillations, CP violation

$\mathcal{O}(fb^{-1})$

- FCNC rare decays, eg $B\to\mu\mu$, $\mu\mu K^{(*)}$, $\mu\mu\Phi$, $\mu\mu\gamma$

conclusions

- **presented first CMS onia measurements from LHC 2010 Run at 7 TeV**
  - differential cross section for J/ψ and ϒ
  - ϒ(2S+3S)/ϒ(1S) ratio
  - b fraction production using non prompt J/ψ
- proof of excellent performance of LHC and CMS
- some measurements already systematics limited, but large improvements expected from fast rise of integrated luminosity and improved understanding of the detector
- rich heavy flavor program at CMS just started
- *stay tuned!*

J/ψ systematics

(relative uncertainties on the corrected yields)

$p_T^{J/\psi}$ (GeV/c)	Statistics	FSR	p_T calibration	B-frac.	non-prompt polar.	Muon effic.	ρ	Fit function
				$\lvert y\rvert < 1.4$				
4 – 6	7.2	2.0	3.1	0.1	0.0	11.1	4.6	6.1
6 – 8	5.2	2.0	2.4	0.2	0.1	7.0	7.0	0.2
8 – 10	5.3	1.6	1.4	0.3	0.1	9.9	7.1	0.6
10 – 30	4.7	0.9	0.7	0.4	0.2	10.8	1.2	1.0
				$1.4 < \lvert y\rvert < 2.4$				
0 – 1	6.4	0.8	0.3	0.1	0.0	10.5	12.6	6.5
1 – 1.5	9.5	0.7	0.3	0.0	0.0	11.4	28.2	8.3
1.5 – 2	6.1	0.4	0.5	0.0	0.0	11.2	22.7	6.1
2 – 3	4.3	0.2	0.9	0.0	0.0	10.0	5.6	2.4
3 – 4	3.9	0.6	0.7	0.1	0.0	9.7	5.9	6.8
4 – 6	5.6	0.8	0.5	0.1	0.0	10.6	9.3	5.7
6 – 8	4.3	0.6	0.4	0.1	0.0	9.4	6.8	8.3
8 – 10	5.8	0.5	0.2	0.2	0.1	13.1	4.2	1.0
10 – 30	7.8	0.2	0.2	0.2	0.1	11.8	0.6	2.1

Υ systematics

(relative uncertainties on the corrected yields)

Δp_T	$\mathcal{A}^\Upsilon$	ε_{muid}	ε_{trig}	ε_{trk}	FSR	$S\ p_T$	T	TJ/ψ	PDF	Σ
Υ(1S)										
0-2	0.5	9.5	3.4	0.6	3.5	0.2	2.1	2.0	0.4	11.1
2-3	0.5	10.0	3.5	0.6	4.1	0.6	2.1	1.4	0.4	11.7
3-5	0.6	10.0	0.5	0.6	3.7	0.5	2.0	1.3	0.4	11.0
5-8	0.6	11.0	6.2	0.6	3.2	0.6	1.8	2.0	0.4	13.3
8-12	0.6	10.3	6.5	0.6	2.6	0.8	2.2	2.9	0.4	13.1
12-20	0.4	13.3	14.0	0.7	2.3	1.6	2.2	4.3	0.4	20.1
0-20	0.6	10.4	5.1	0.6	3.4	0.5	2.0	2.0	0.4	12.5