Quarkonium Physics in CMS

Charm and bottom quark production at the LHC

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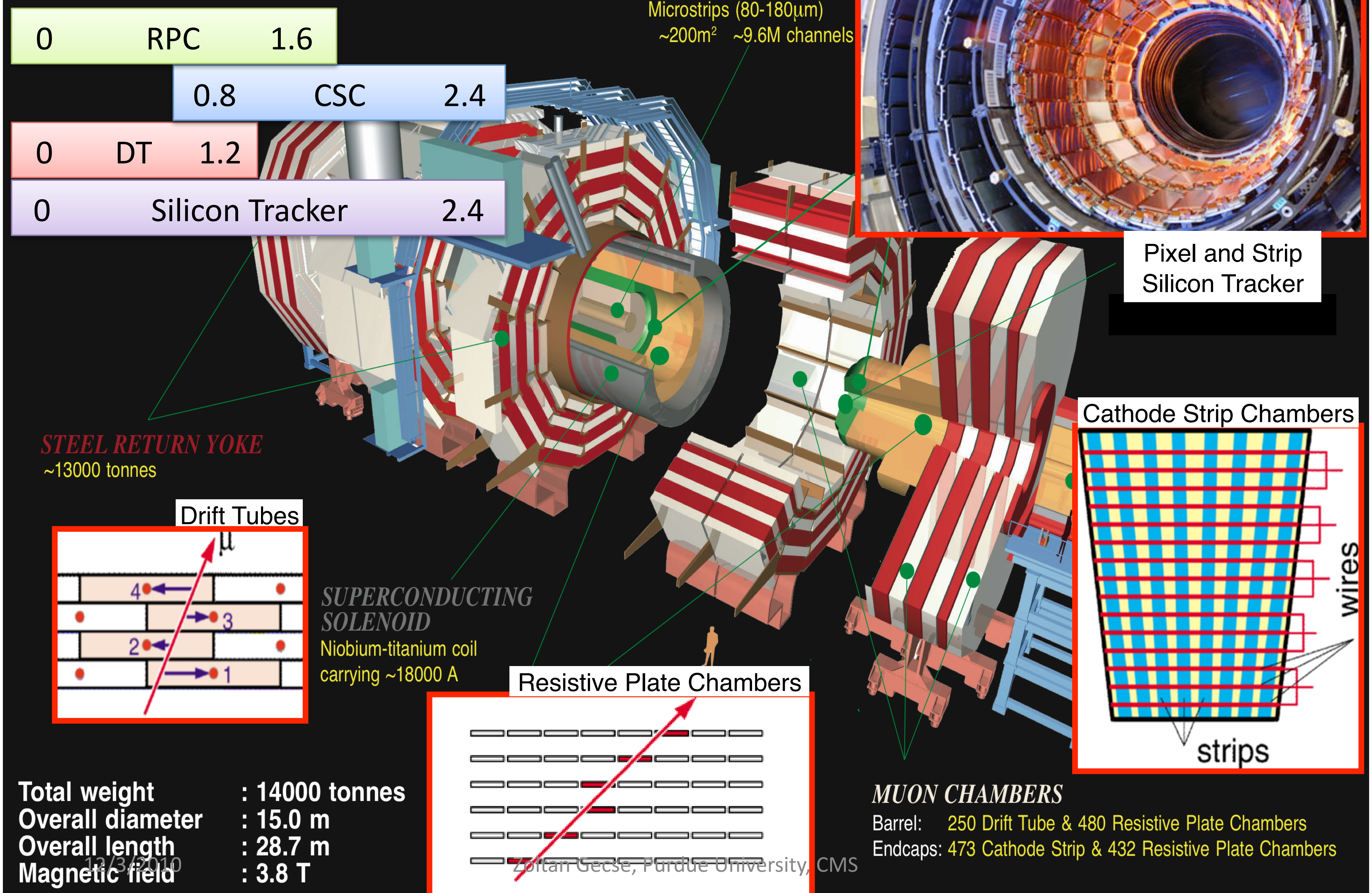
On behalf of the CMS Collaboration

Outline

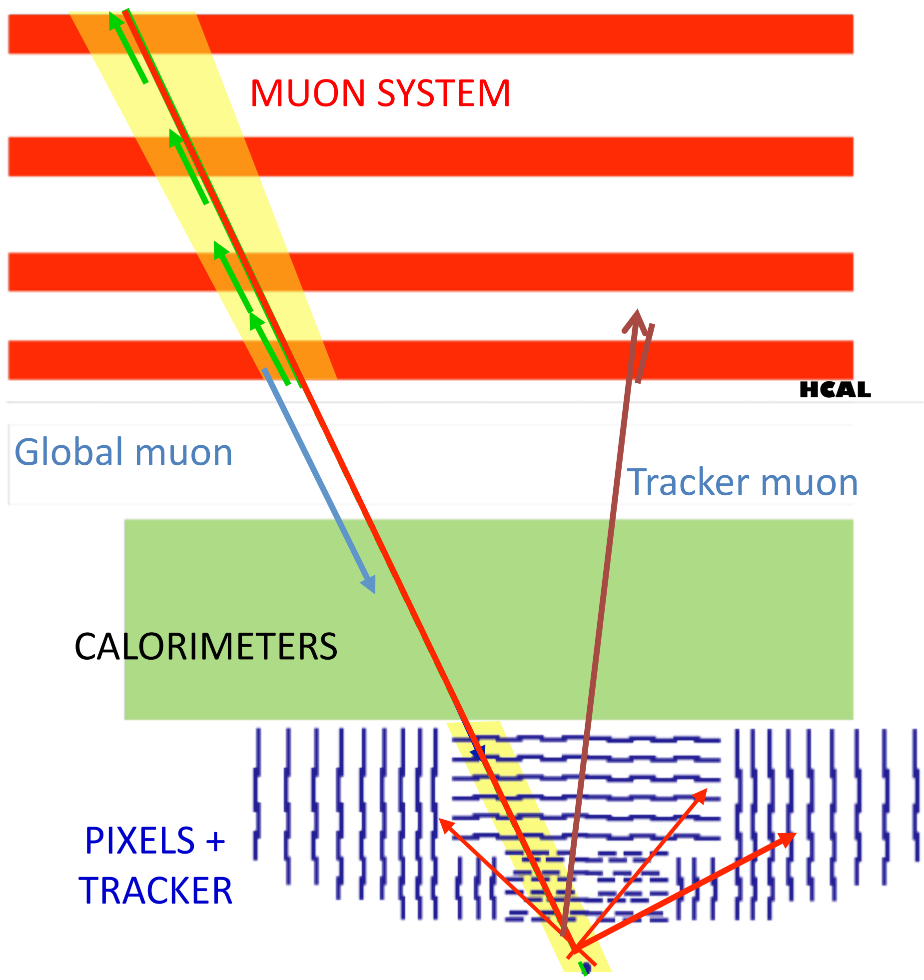
- The CMS Detector from Quarkonia Point of View
  - Detector subsystems
  - Muon Reconstruction
  - Muon Trigger
  - Tracking Performance
- The CMS Quarkonium Program
  - Current Results
  - Prospectives
- Conclusions

CMS Detector



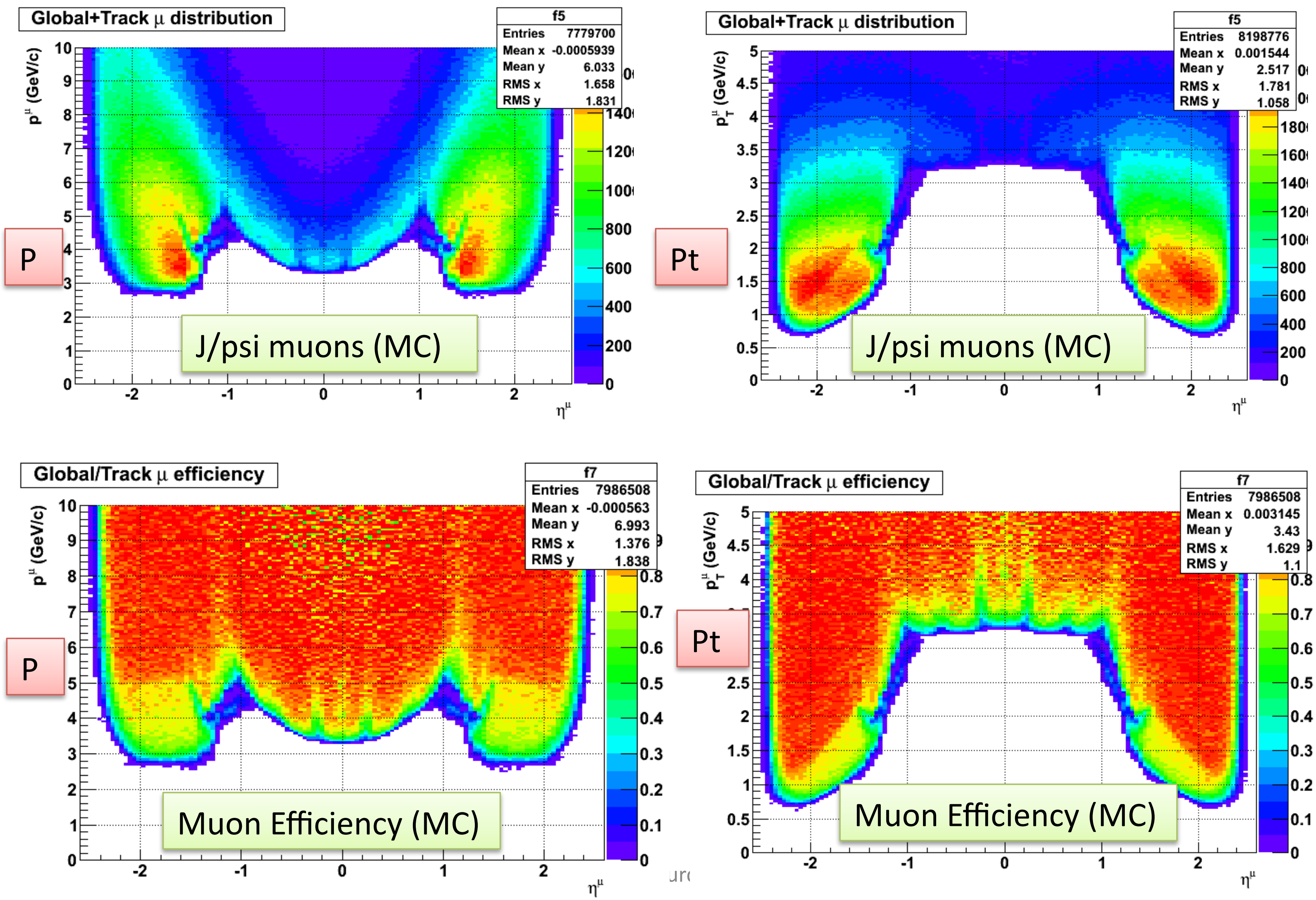
Total weight : 14000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

Muon Reconstructions

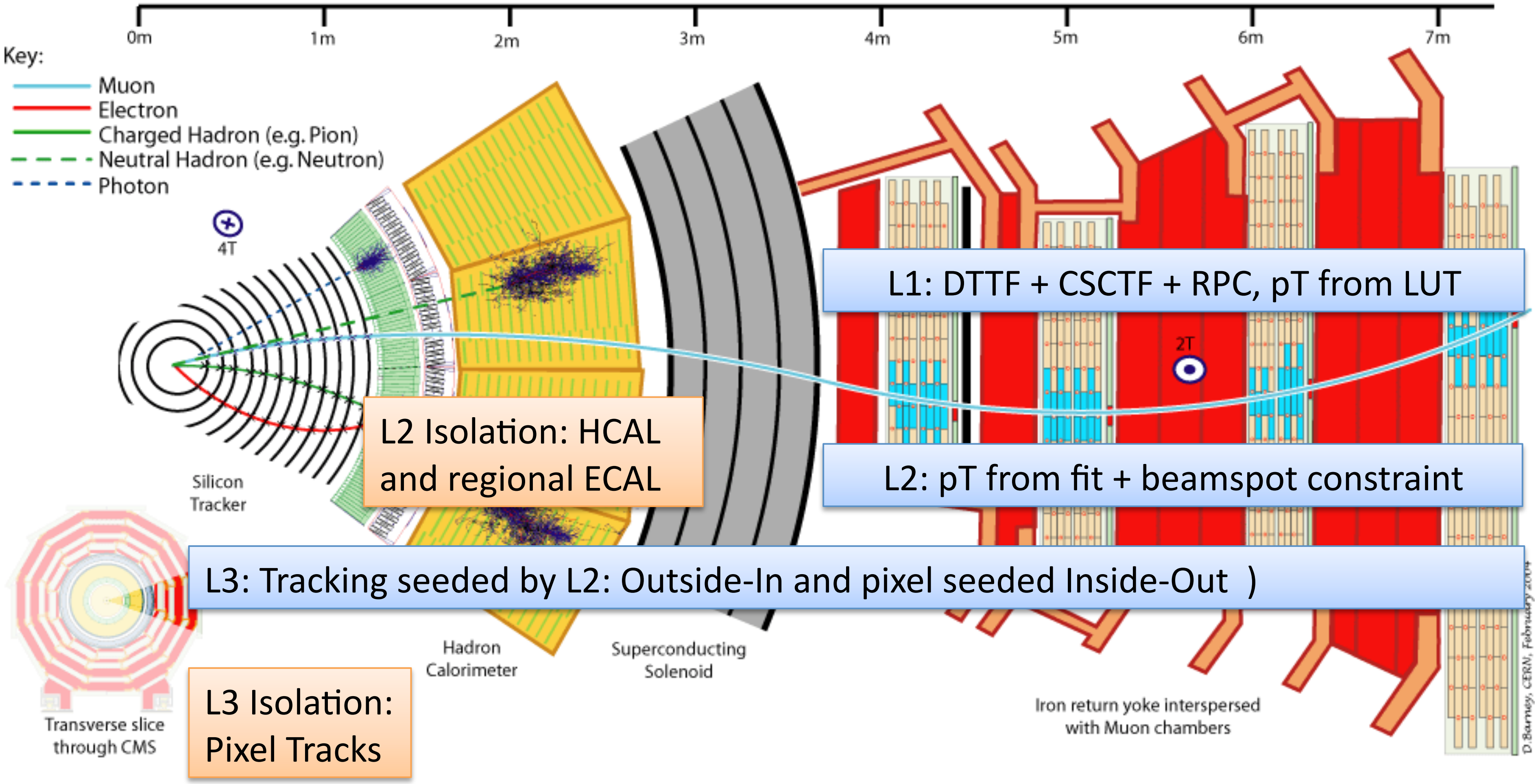


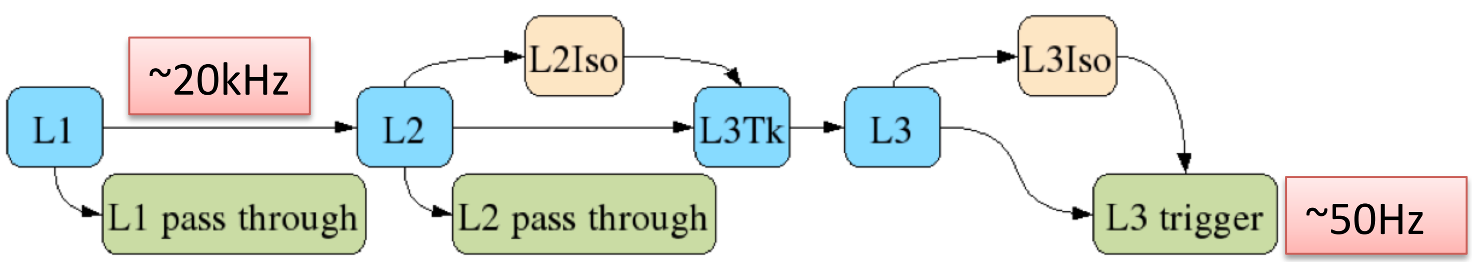
- Global Muons
  - Fit track in the Muon System
  - Fit track in the Silicon Tracker
  - Match and global refit
  - High purity
- Tracker Muons
  - Extrapolate inner tracks to the Muon System and find matching segments
  - Higher efficiency at low pT
  - Lower purity

Muon Kinematic Reach



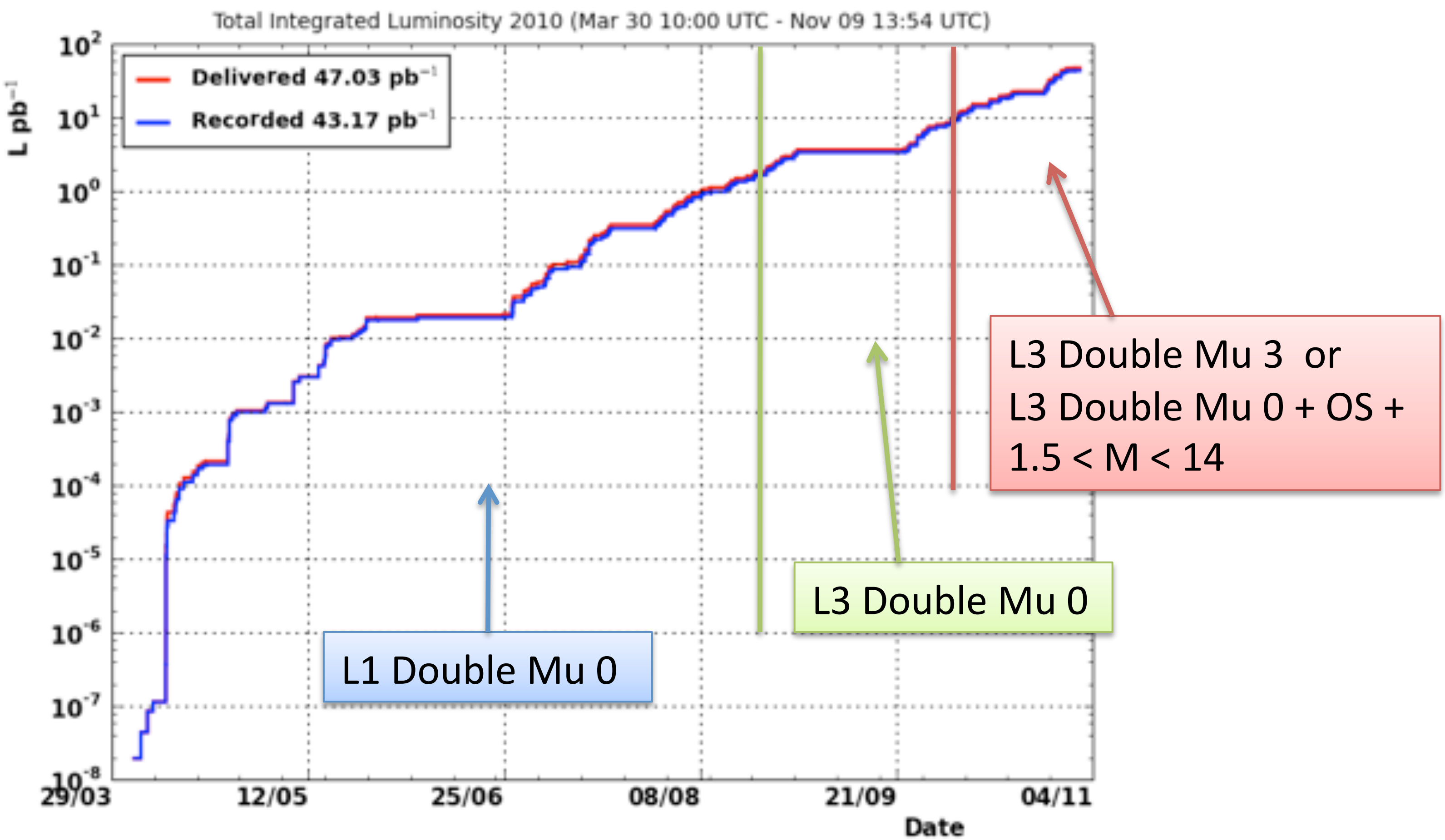
Muon Trigger



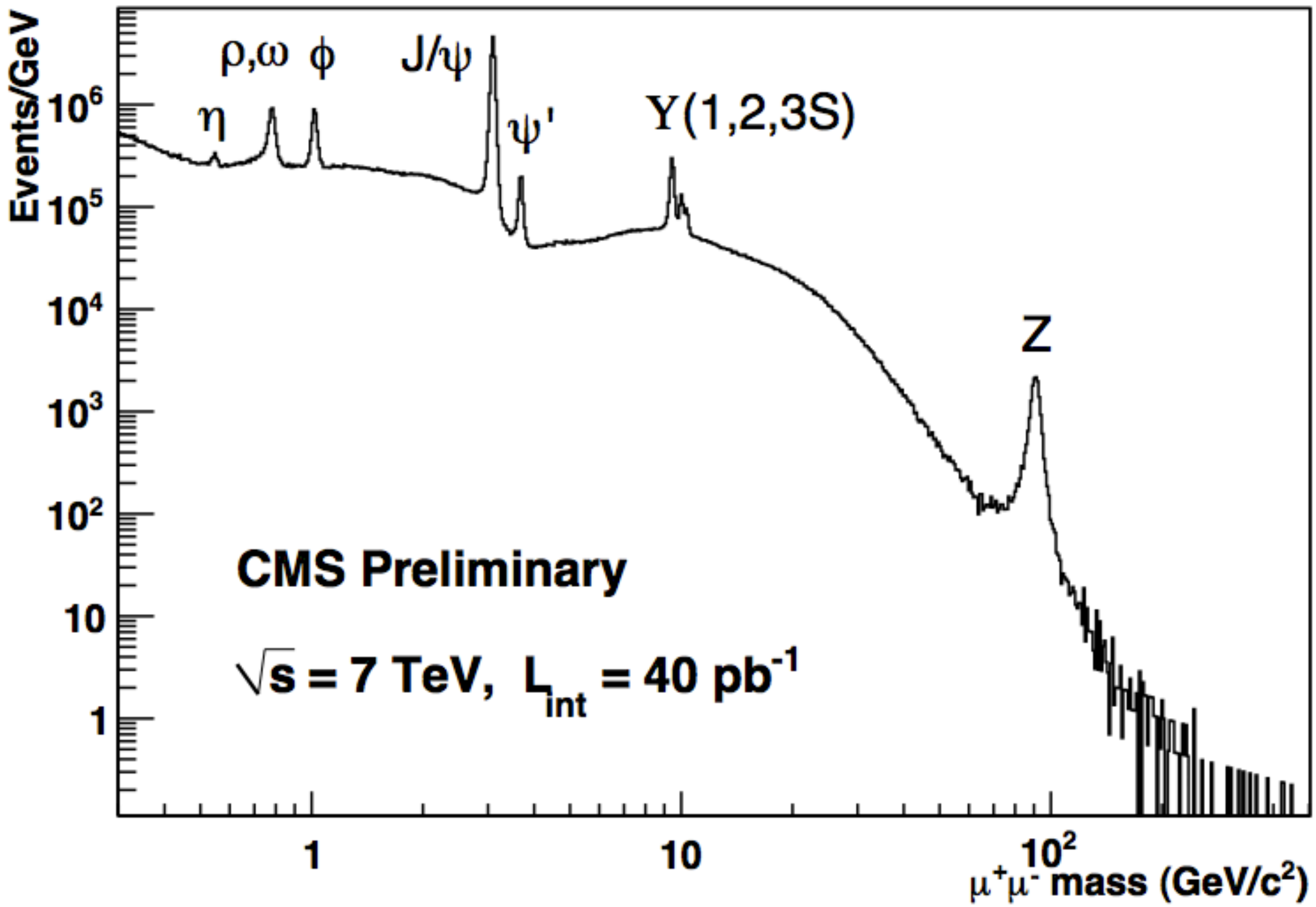


Trigger Strategy in 2010

CMS could manage trigger rates for quarkonia without pT thresholds

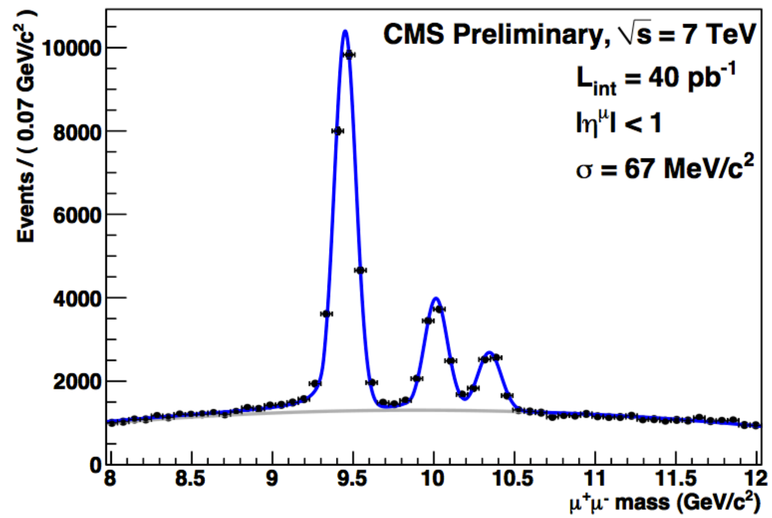


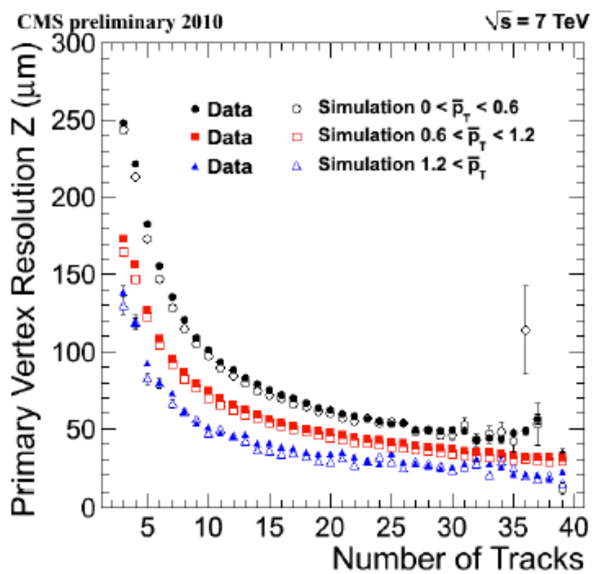
The Di-muon Mass Spectrum

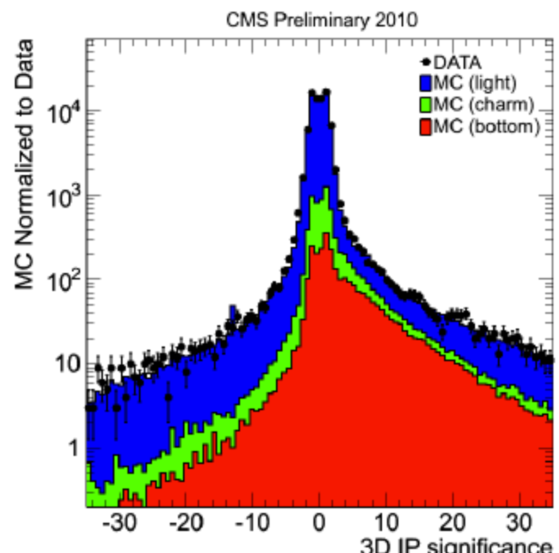


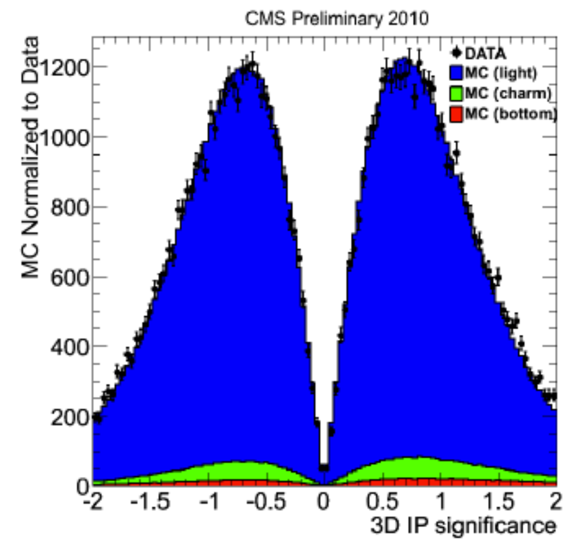
Mass and Vertex Resolutions

- Mass resolution 0.7—1.4 % of mass
- Tracker performance well understood
- Good agreement between MC and DATA





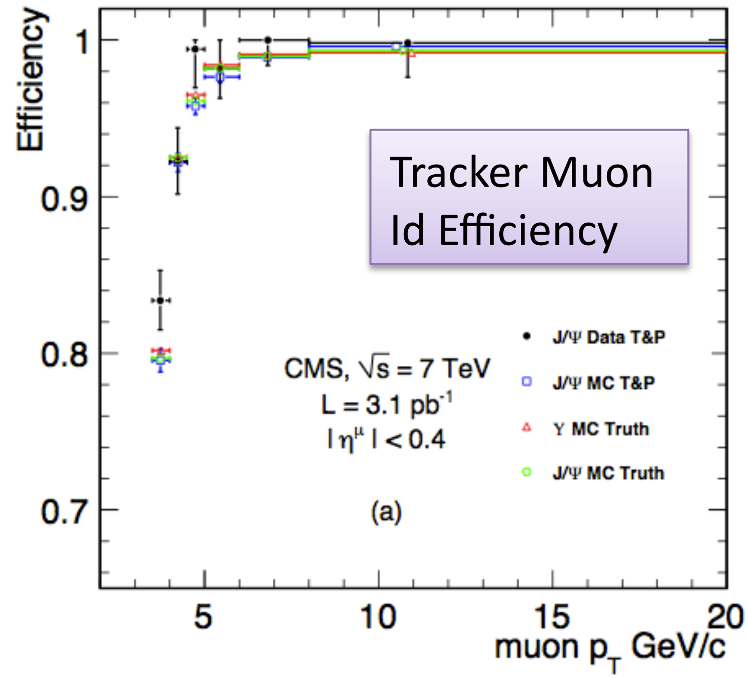


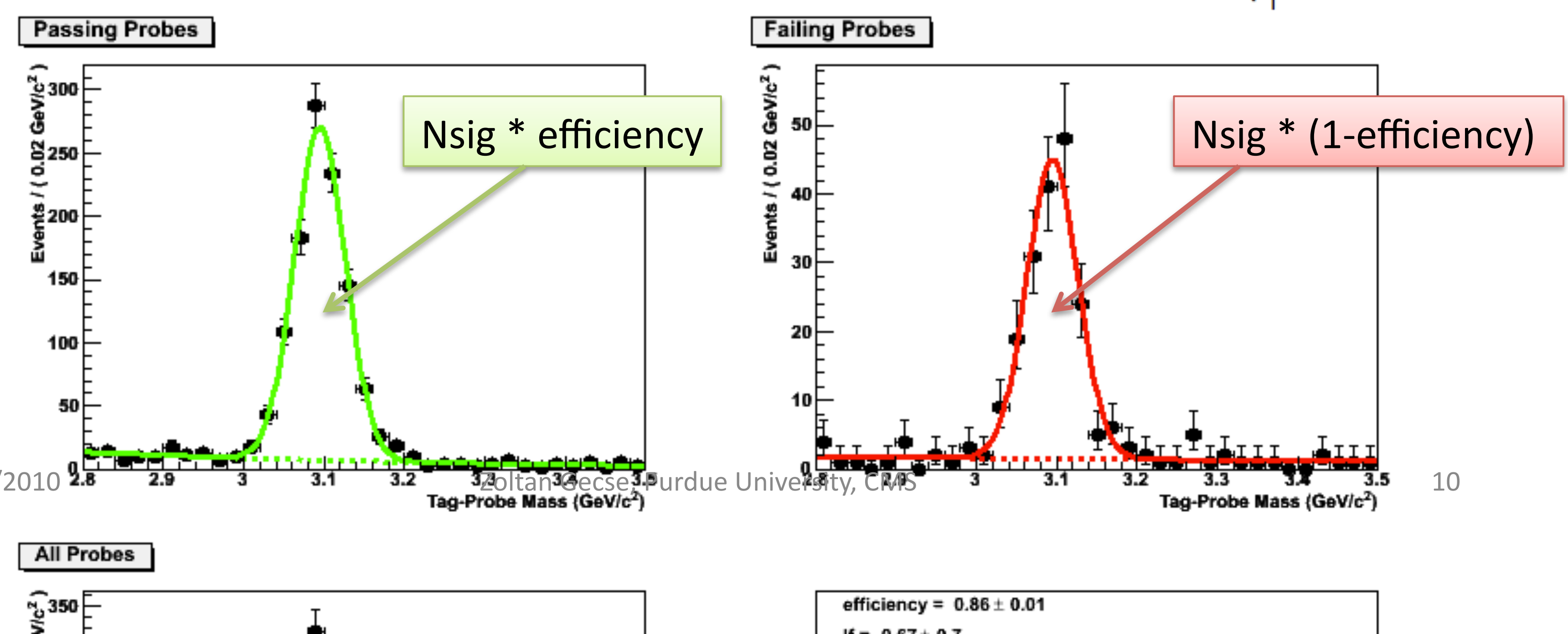


[CMS PAS BTV-10-001]

Data Driven Efficiency Measurements

- Use Tag and Probe method on J/psi for efficiency measurements in data
- Unbinned simultaneous fit to passing and failing tag-probe pair mass distributions
- Good agreement between DATA and MC simulation, efficiencies are independent from the used peak





CMS Quarkonium Program with Muons

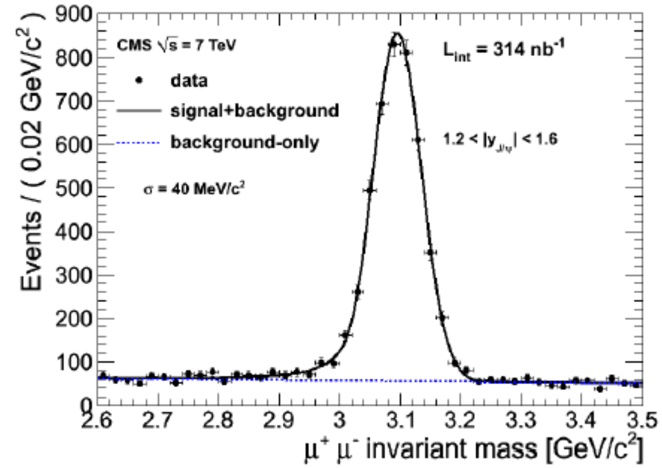
- J/psi (1S) and (2S)
  - Differential cross section, prompt and non-prompt
  - Polarization of prompt
  - Polarization of direct (with Chi_c tagging)
- Upsilon (1S), (2S) and (3S)
  - Differential cross section
  - Polarization inclusive
  - Polarization of direct (with Chi_b tagging)
- Chi_c, Chi_b and XYZ Exotics
  - Cross sections

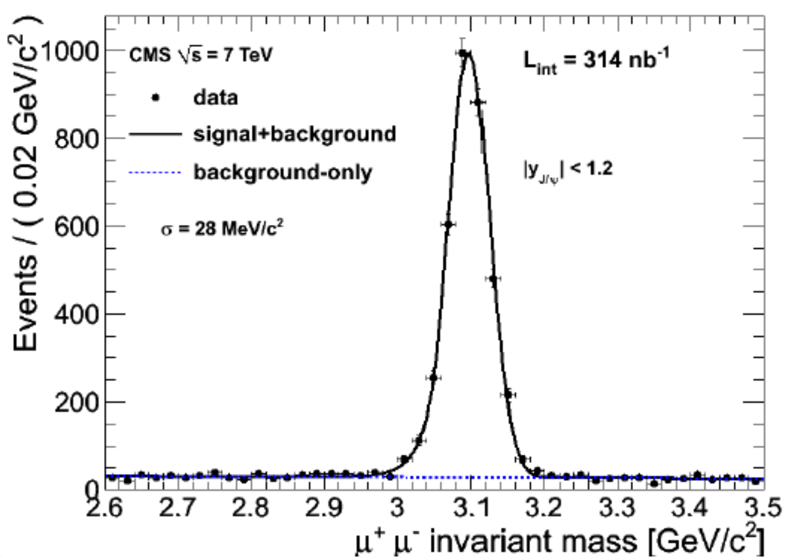
J/psi Cross Section Measurement

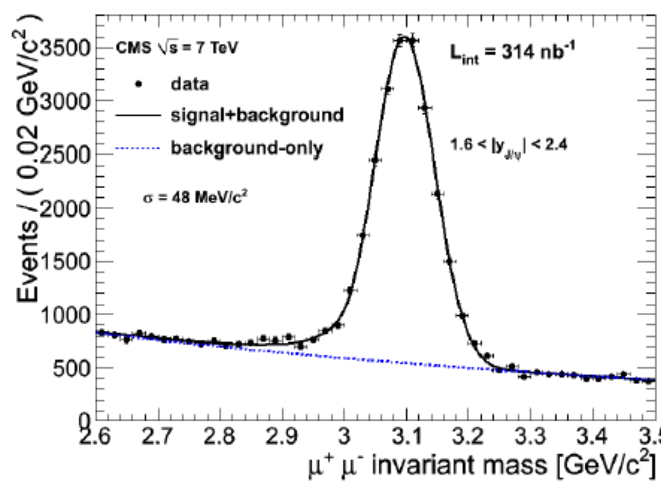
- **Muons well within acceptance window**
- **Track quality:**
  - number of hits in full tracker
  - number of hits in pixel layers
  - track fit χ^2
- **Muon quality:**
  - fit χ^2
  - track-muon matching
- **Di-muon vertex quality**
- **~27000 events selected**

CERN-PH-EP/2010-046
18 Nov. 2010

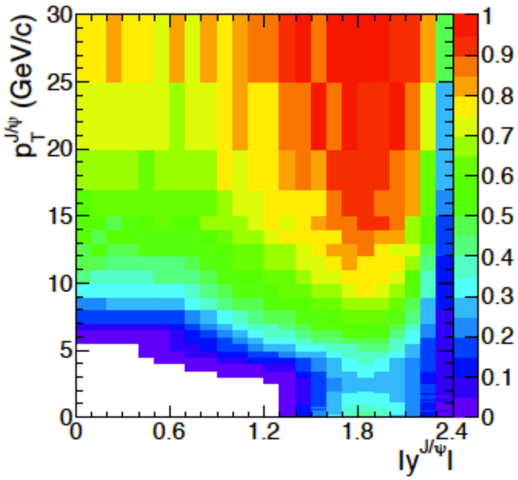
arXiv:1011.4193







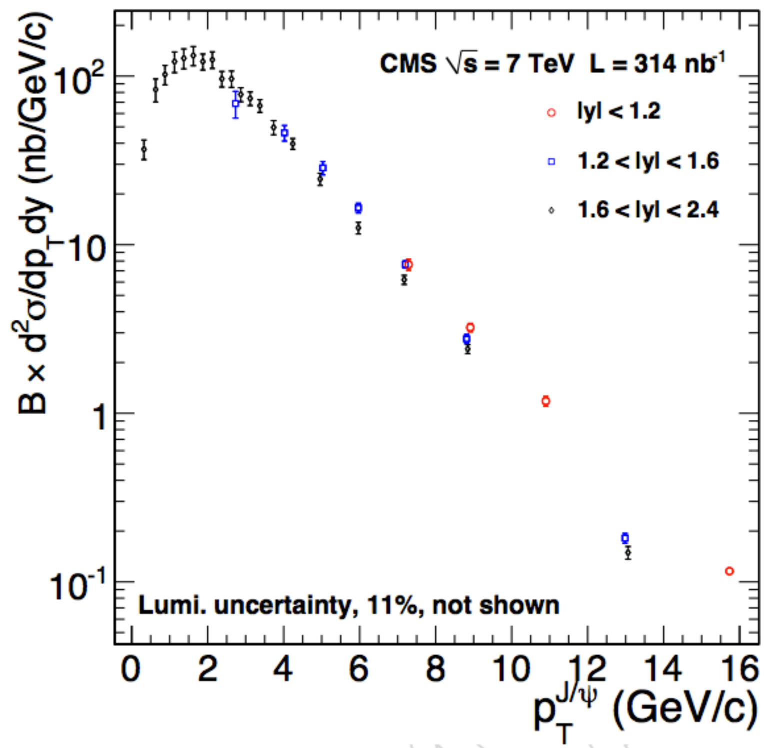
Inclusive J/psi Cross Section



- **The acceptance is calculated by MC and depends on the assumed polarization scenario:**
  - **isotropic**
  - **extreme values of λ_θ (= ±1) in the helicity frame (along the Q momentum)**
  - **extreme values of λ_θ (= ±1) in the Collins-Soper frame (along the collision axis)**
- **The efficiency is determined from data using a T&P approach**

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

Source	Relative error (%)		
	$\|y\| < 1.2$	$1.2 < \|y\| < 1.6$	$1.6 < \|y\| < 2.4$
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



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

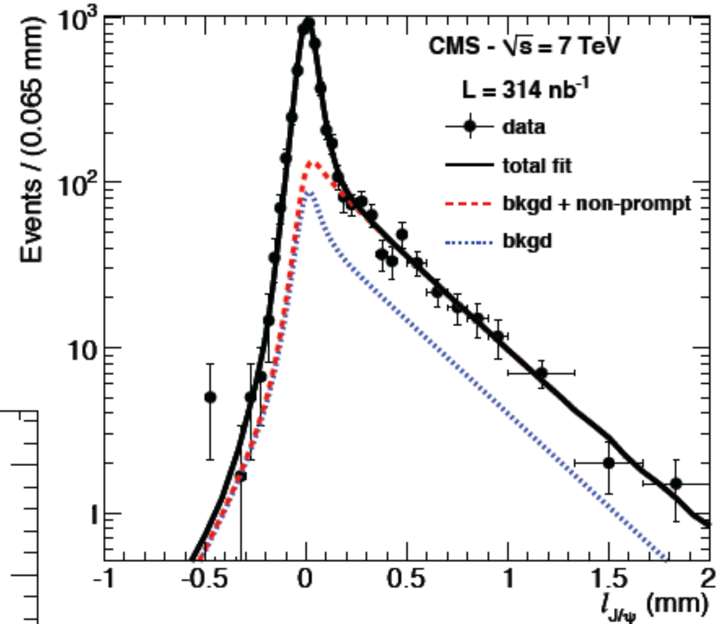
Non-prompt J/psi Fraction

Pseudo proper decay length

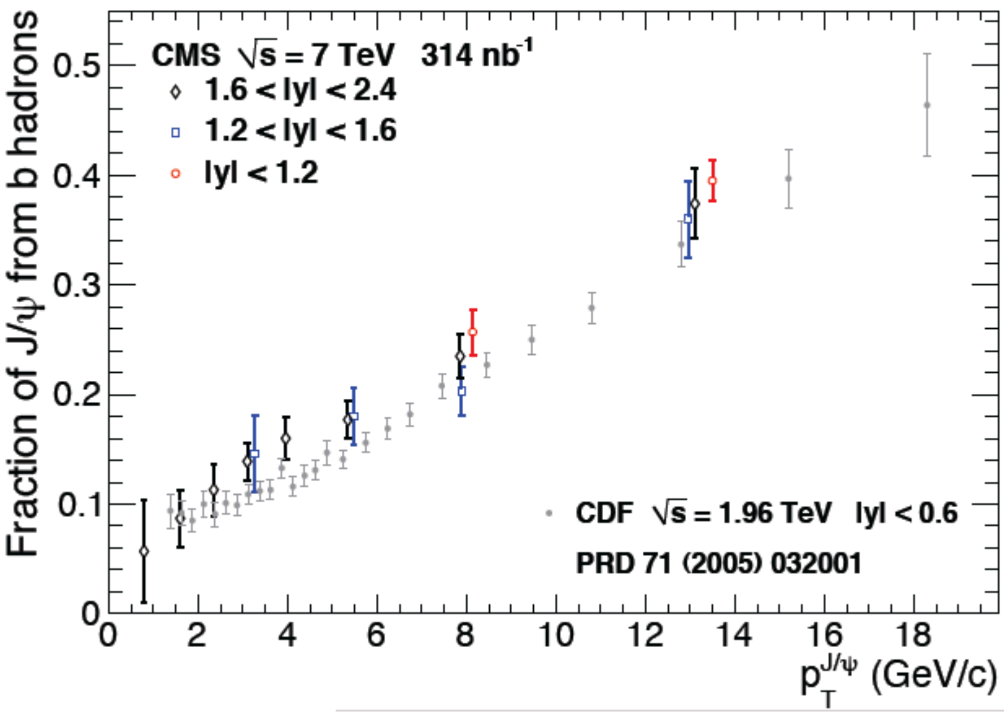
$$\ell_{J/\psi} = L_{xy} \cdot m_{J/\psi} / p_{\mathrm{T}} \qquad L_{xy} = \frac{\mathbf{u}^T \sigma^{-1} \mathbf{x}}{\mathbf{u}^T \sigma^{-1} \mathbf{u}}$$

- Decay length parameterization :
  - Prompt : δ-function
  - Non-prompt : MC templates

all convoluted with a 3-Gaussian resolution

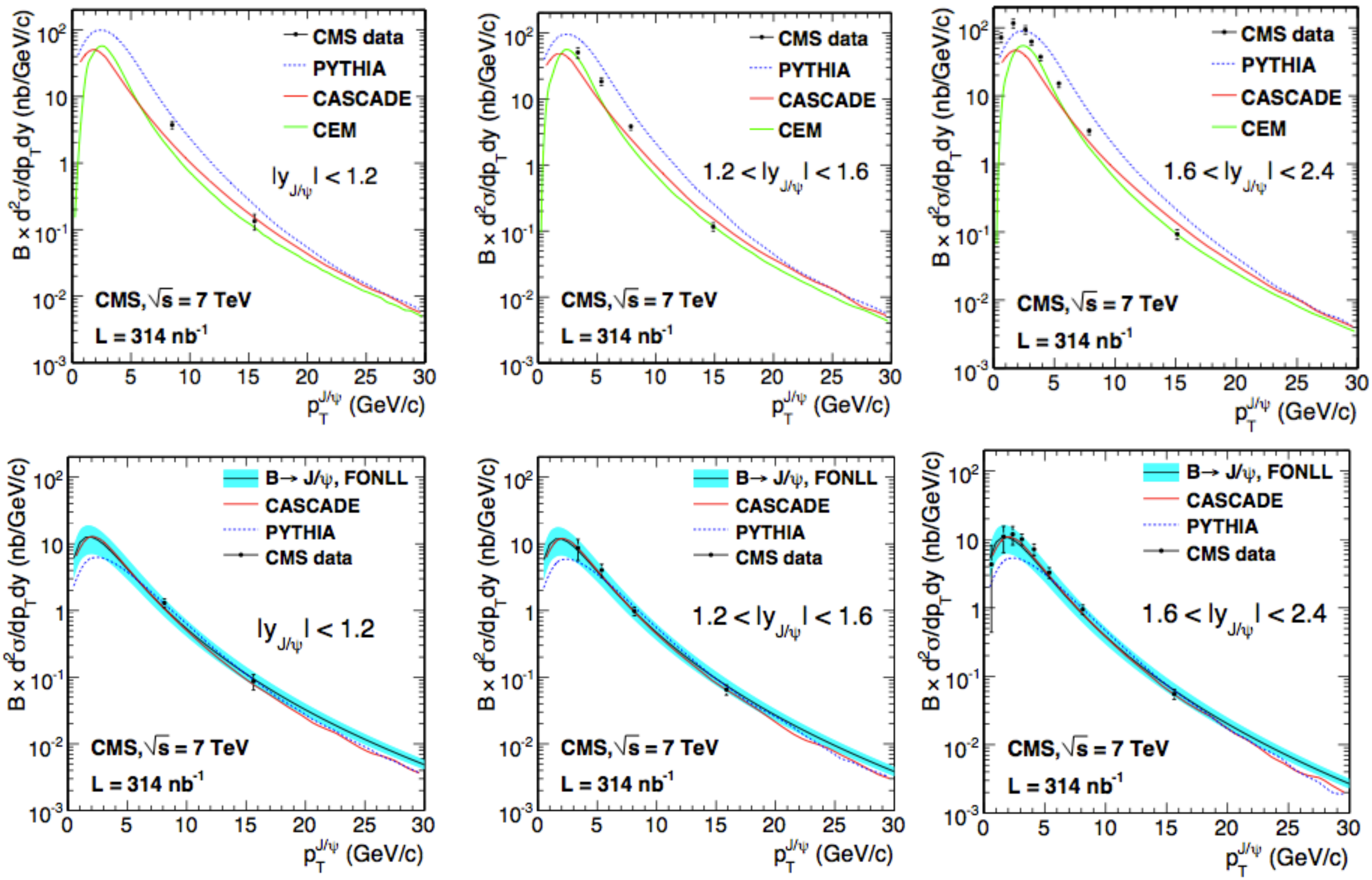


6.5<p_T<10 GeV/c, 1.6<|y|<2.4



	$\|y\| < 1.2$	$1.2 < \|y\| < 1.6$	$1.6 < \|y\| < 2.4$
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

Comparisons with Theory



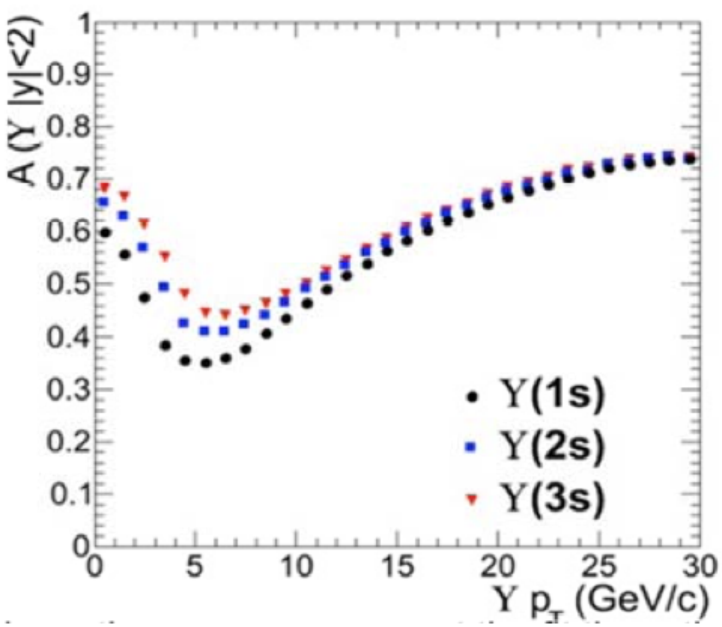
Upsilon Cross Section Measurement

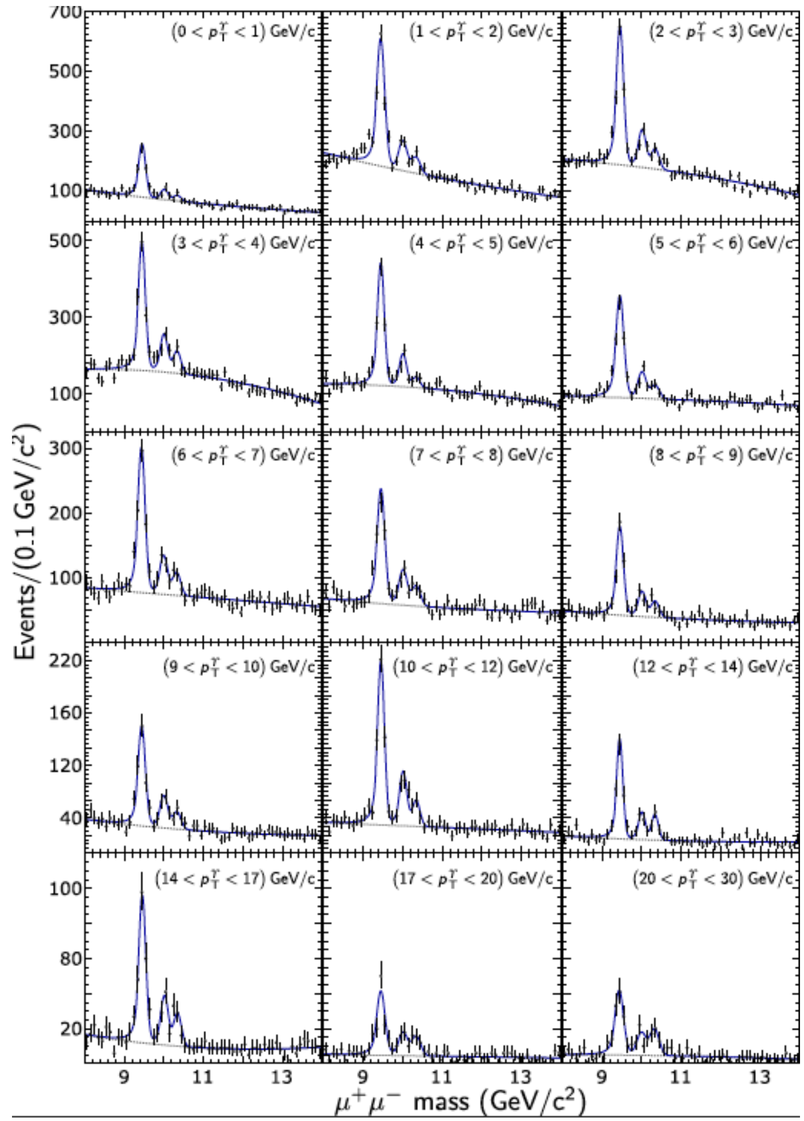
- 3.1/pb of data collected with L1 Double Mu 0 trigger
- Selection similar to J/psi but

pT>3.5GeV for |η| < 1.6

pT>2.5GeV for |η| > 1.6

- Good acceptance down to 0 pT of Upsilon
- Efficiencies from J/psi Tag and Probe
- Assume no polarization
- Full polarizations change acceptance by up to 20%



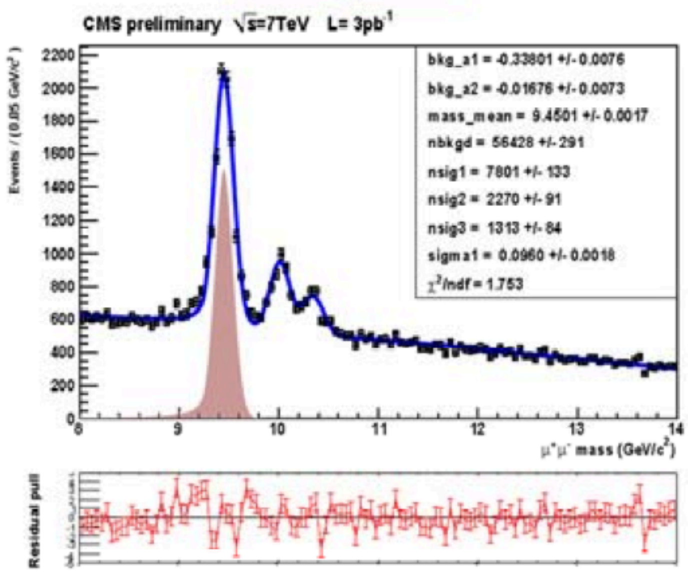


Signal Extraction

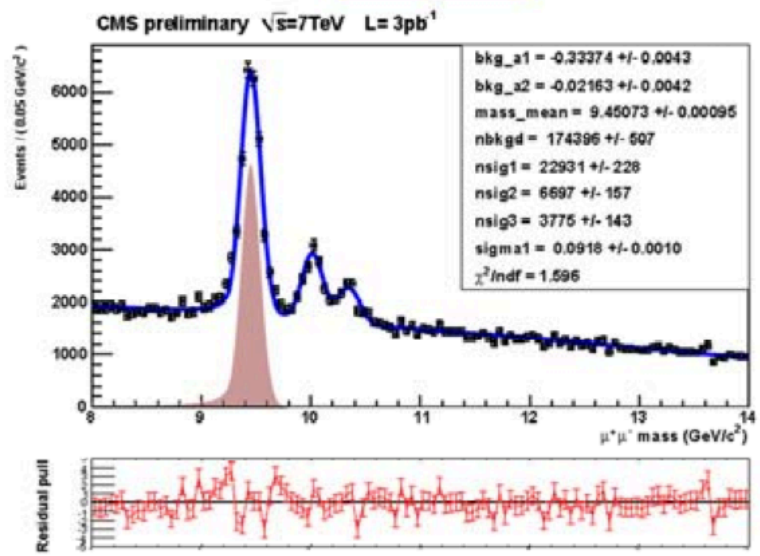
- Per-event weights to correct for efficiencies and acceptance
- Unbinned ML fit
- PDF: Common Crystal Ball resolution for the three peaks with mass differences fixed to PDG values
- 2nd order polynomial background

$$\frac{d^2\sigma\left(pp \to \Upsilon(\mathrm{nS})\right)}{dp_T\,dy} \cdot \mathcal{B}\left(\Upsilon(\mathrm{nS}) \to \mu^+\mu^-\right) = \frac{N^{\mathrm{fit}}_{\Upsilon(\mathrm{nS})}(p_T; \mathcal{A}, \varepsilon)}{\mathcal{L} \cdot \Delta p_T \cdot \Delta y}$$

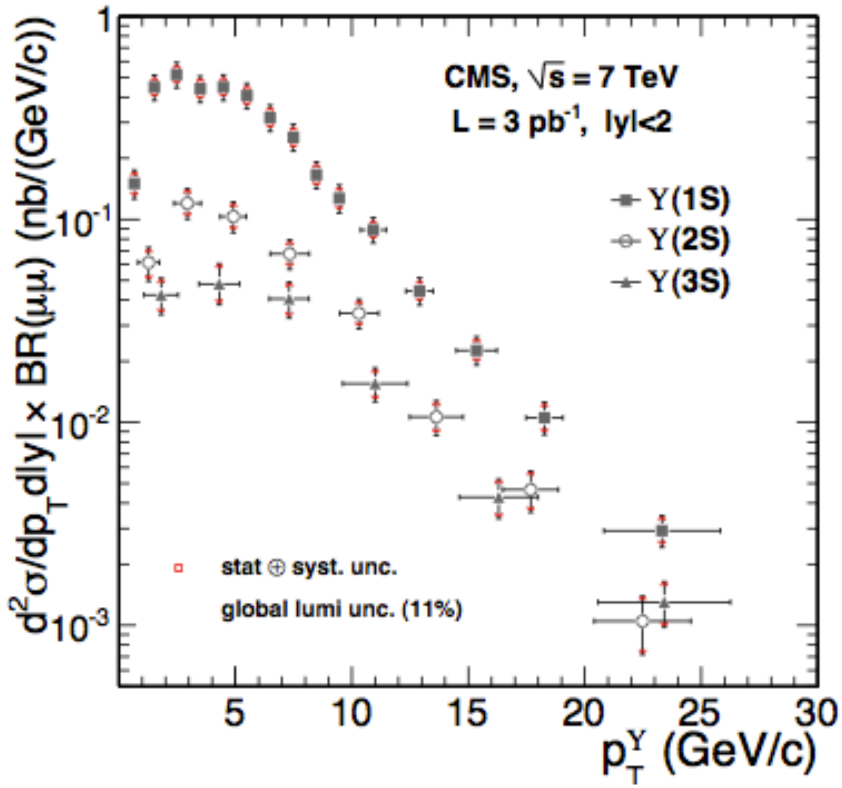
Unweighted

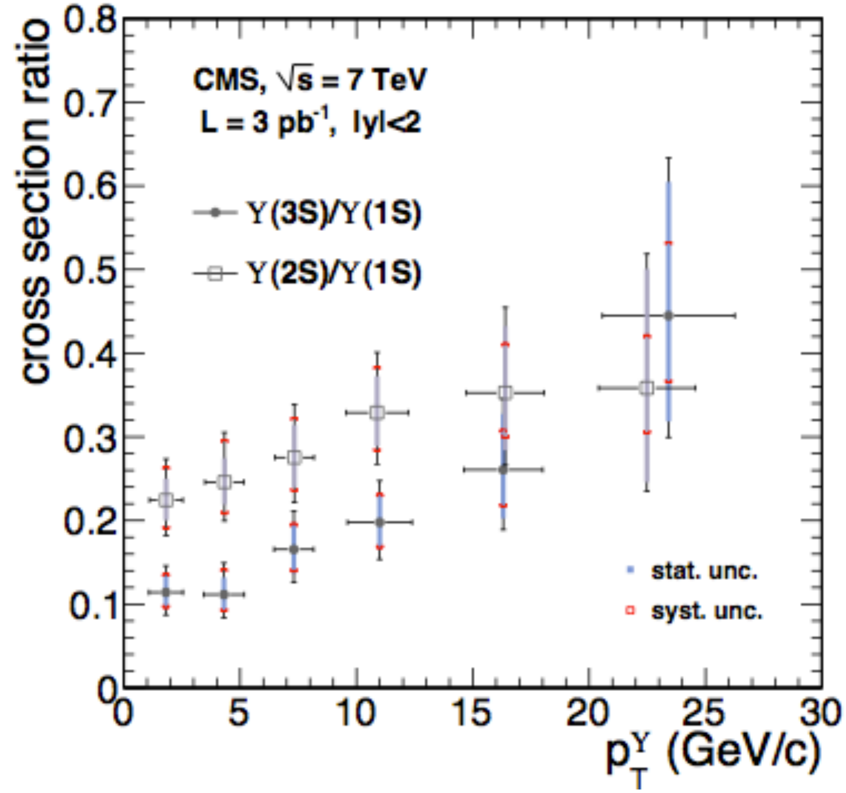


Weighted



Upsilon Cross Section Results





Syst. Errors: (%)

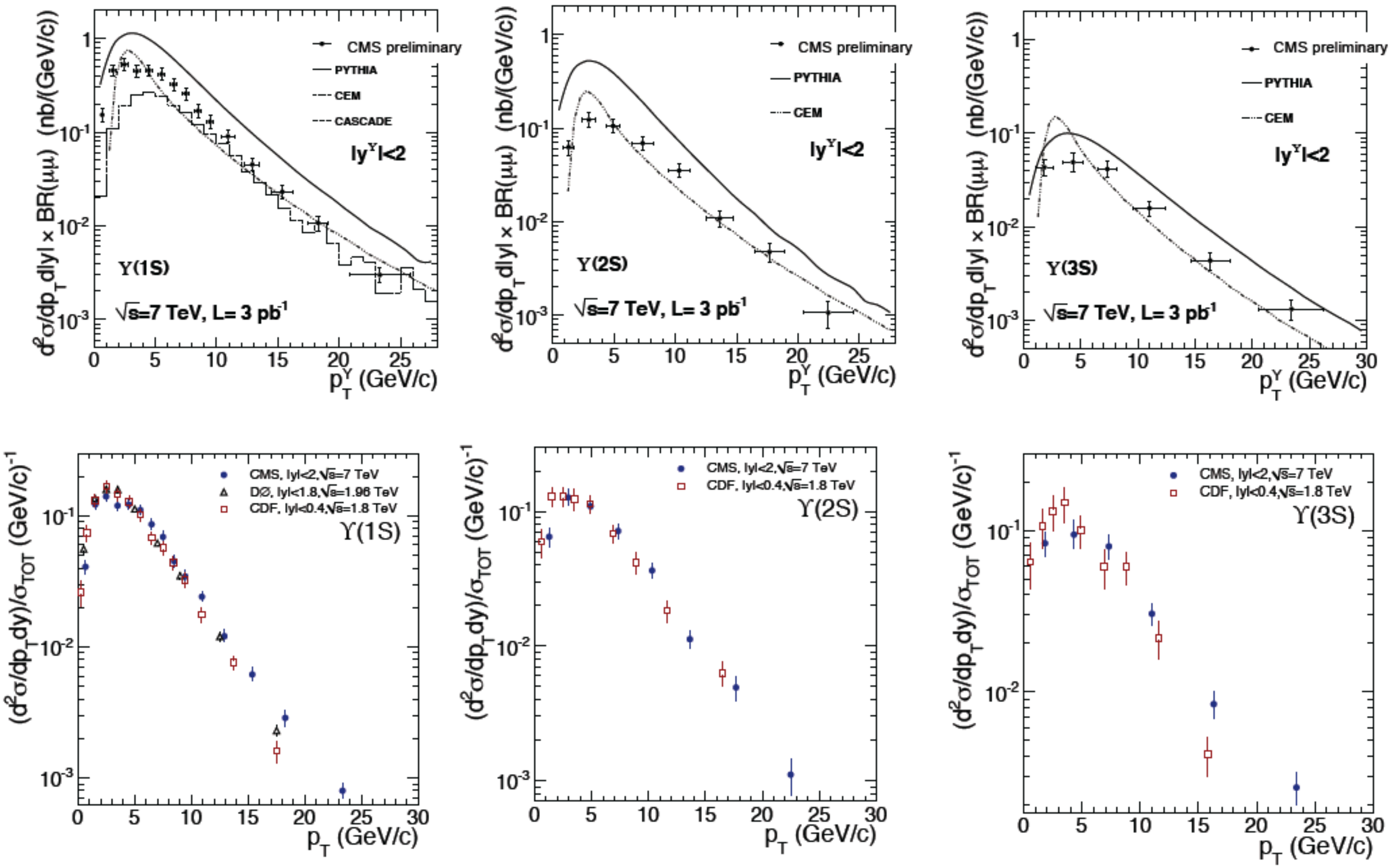
A	ε_{trk}	$\varepsilon_{trig,id}$	S_p	A_{p_T}	A_{vtx}	A_{fsr}	t&p	$\varepsilon_{J/\psi,\Upsilon}$	BG	add.
0.5 (0.5)	0.1 (0.1)	7.5 (4.6)	0.3 (0.3)	0.6	0.7	3.4	0.0	0.9	0.5	2.9

$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = (7.49 \pm 0.13(\text{stat.})^{+0.67}_{-0.49}(\text{syst.}) \pm 0.82(\text{lumi.}))\ \text{nb},$$

$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = (1.93 \pm 0.08(\text{stat.})^{+0.19}_{-0.14}(\text{syst.}) \pm 0.21(\text{lumi.}))\ \text{nb},$$

$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = (1.04 \pm 0.07(\text{stat.})^{+0.12}_{-0.09}(\text{syst.}) \pm 0.11(\text{lumi.}))\ \text{nb}.$$

Comparisons to Theory and Tevatron



Conclusions

- CMS has recorded ~40/pb of certified data
- More than 1M Psis and ~150K Upsilons
- Expect more precise quarkonium production cross section and polarization measurements
- Contribute to understanding of quarkonium hadro-production