Latest Results on Quarkonia from CMS

Catherine Silvestre
on the behalf of the CMS collaboration

First ReteQuarkonii Workshop (RQW 2010)

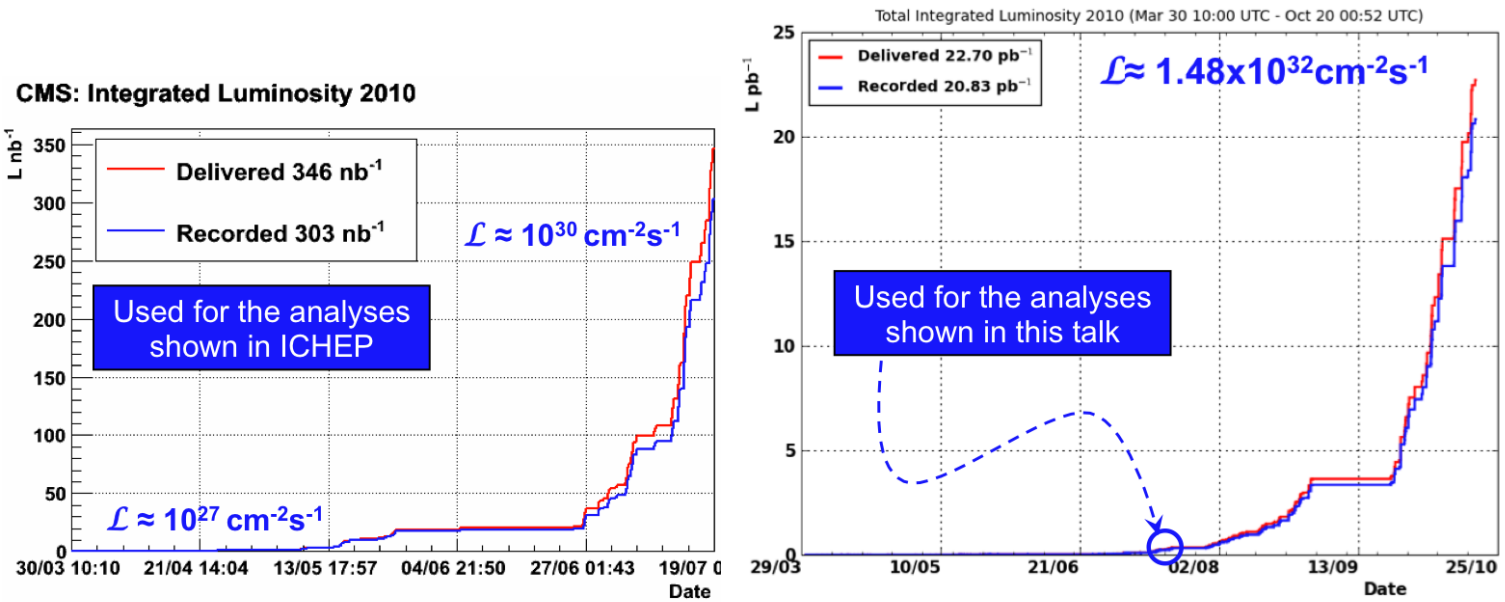
22 October 2010
Nantes (France)

1. The CMS Experiment
   - Detector
   - Muon Reconstruction
2. J/ψ
   - Cross-Section
   - Mass Spectra
3. $B \to J/\psi$
   - Non-Prompt J/ψ
   - B Hadron Decay Feed Down
   - Exclusive J/ψ Cross-Section
4. Υ
   - Mass Spectra
   - Cross-Section
5. Heavy Ion Run
   - First Measurement
   - Trigger Strategy
6. Summary and Prospects

CMS @ the LHC

Luminosity in p+p

- CMS expects to integrate around 40 pb^{-1} by the end of the 2010 p+p run with an overall data taking efficiency better than 91%. Now recording ~ 3.5 pb^{-1}/good fill.
- LHC instantaneous p+p luminosity already reached 10^{32} $cm^{-2}s^{-1}$
  - CMS trigger paths frequently upgraded to keep a tolerable rate
  - Low p_T dimuon triggers in 2010 optimized for J/ψ and Υ physics



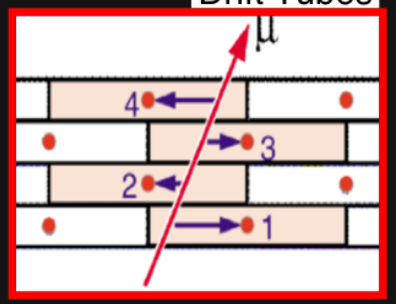
CMS Detector

SILICON TRACKER
Pixels (100 x 150 μm²)
~1m² ~66M channels
Microstrips (80-180μm)
~200m² ~9.6M channels

Pixel and Strip Silicon Tracker

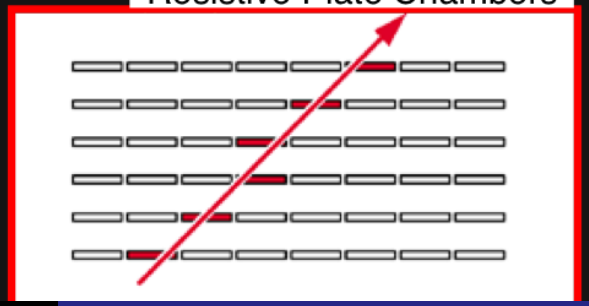
STEEL RETURN YOKE
~13000 tonnes

Drift Tubes

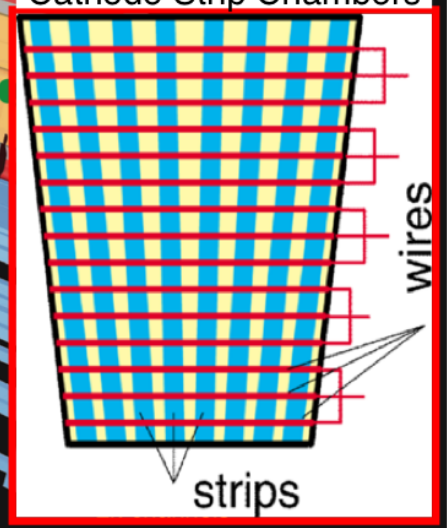


SUPERCONDUCTING SOLENOID
Niobium-titanium coil
carrying ~18000 A

Resistive Plate Chambers



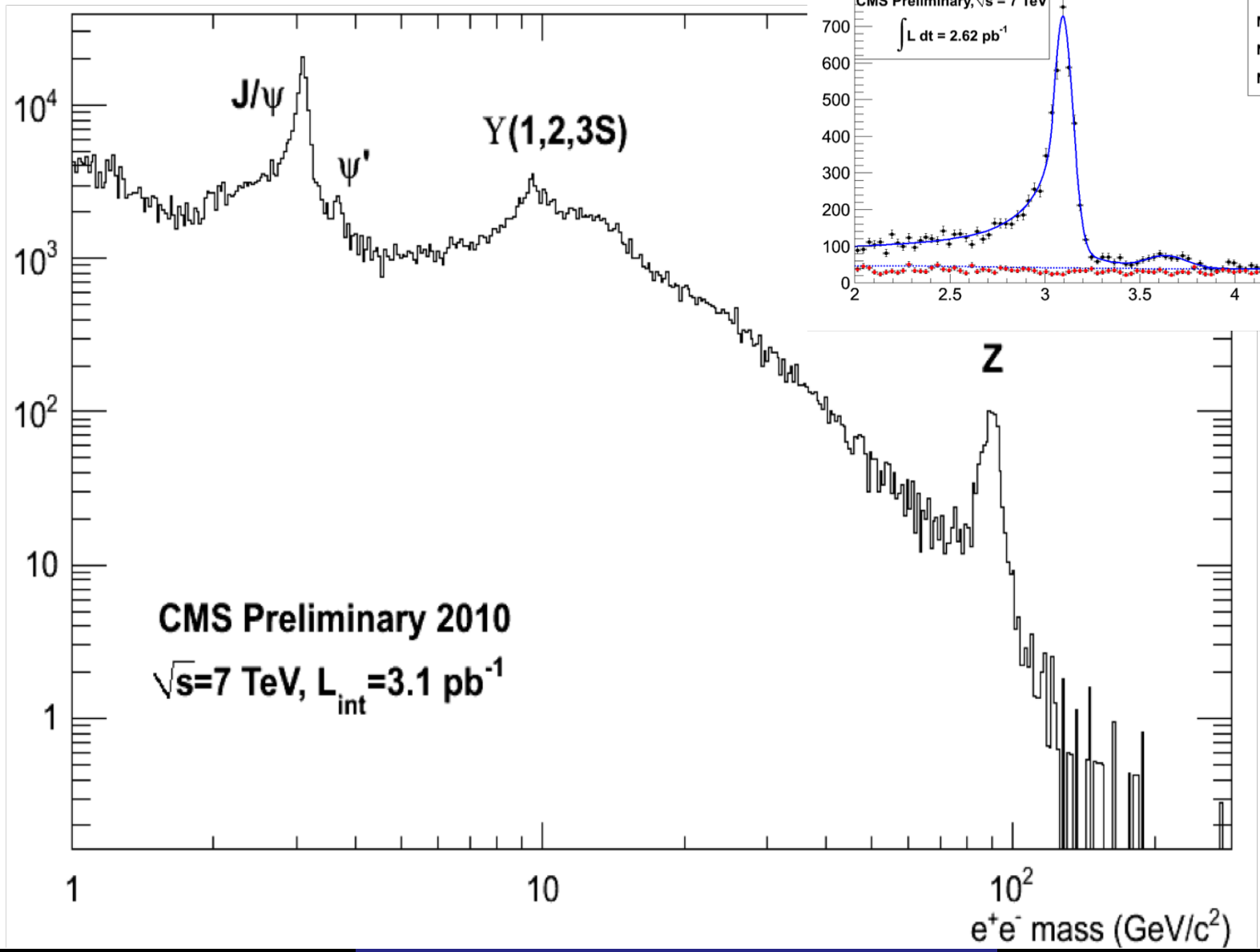
Cathode Strip Chambers



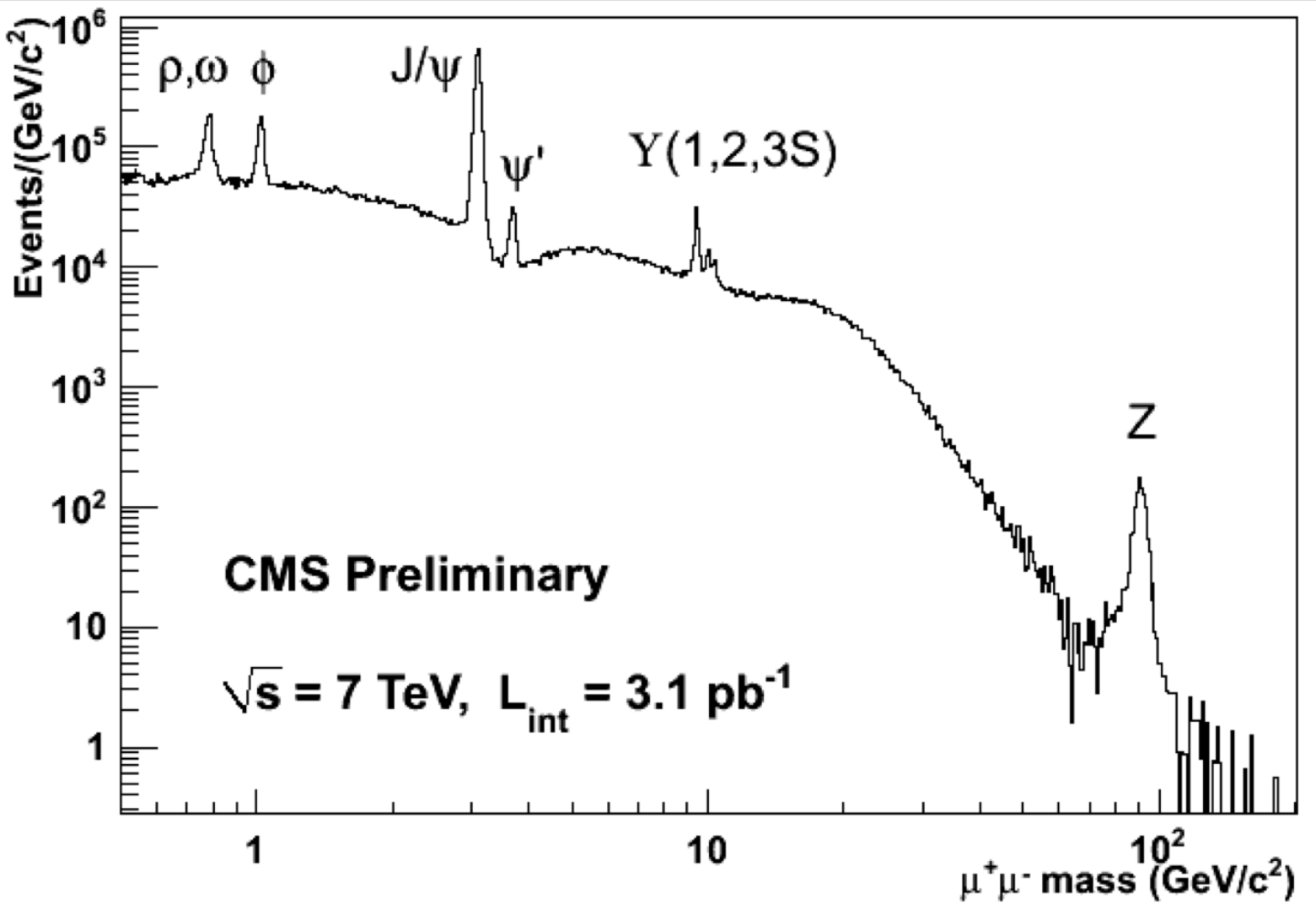
Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

MUON CHAMBERS
Barrel: 250 Drift Tube & 480 Resistive Plate Chambers
Endcaps: 473 Cathode Strip & 432 Resistive Plate Chambers

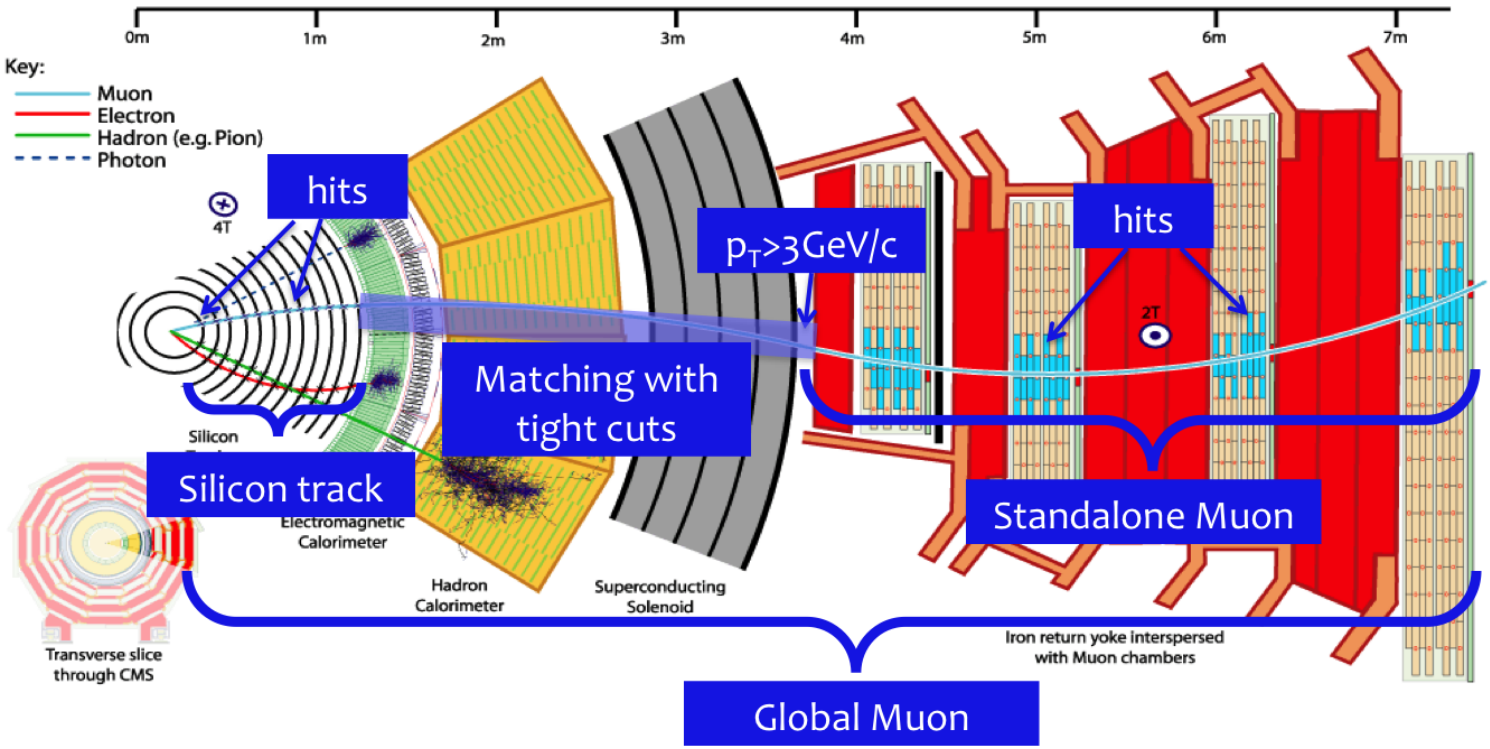
Di-Electrons



The Compact (di-)Muon Solenoid Experiment



Muon Reconstruction



Good muon momentum resolution

- Tight matching between the tracks in the muon chambers and in the silicon tracker
- Strong solenoidal magnetic field (3.8T)
- Large rapidity coverage ($|\eta| < 2.4$)

$$p_T = 100 \text{ GeV}, \sigma_p^\mu \sim 1\%$$
$$p_T = 1 \text{ TeV}, \sigma_p^\mu \sim 10\%$$

Ideal to measure dimuons

- Excellent dimuon mass resolution: varies as a function of η due to increasing material and of the different lever arm a track has above $\eta \sim 1.6$

$$|\eta| < 2.2, \sigma_{mass}(J/\psi) \approx 40 \text{ MeV}$$
$$|\eta| \approx 0, \sigma_{mass}(J/\psi) \approx 20 \text{ MeV}$$

Cross-Section Determination in p+p

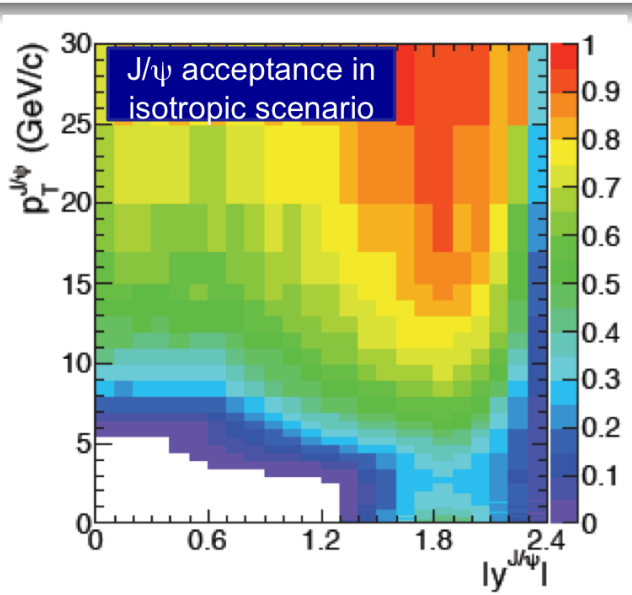
$$\frac{d^2\sigma}{dp_T dy}(Q\bar{Q}) \cdot \mathrm{BR}(Q\bar{Q} \to \mu^+\mu^-) = \frac{N_{Q\bar{Q}}}{\int \mathcal{L}dt \cdot A \cdot \epsilon_{trigger} \cdot \epsilon_{reco} \cdot \Delta p_T \cdot \Delta y}$$

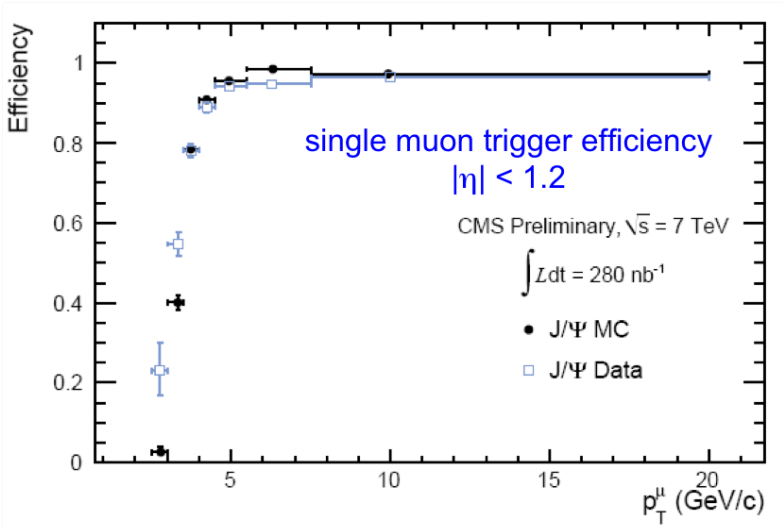
Acceptance calculated by MC and depends on the assumed polarization scenario:

- isotropic
- extreme values of λ_θ $(= \pm 1)$ in the helicity frame (along the Q momentum)
- extreme values of λ_θ $(= \pm 1)$ in the Collins-Soper frame (along the collision axis)

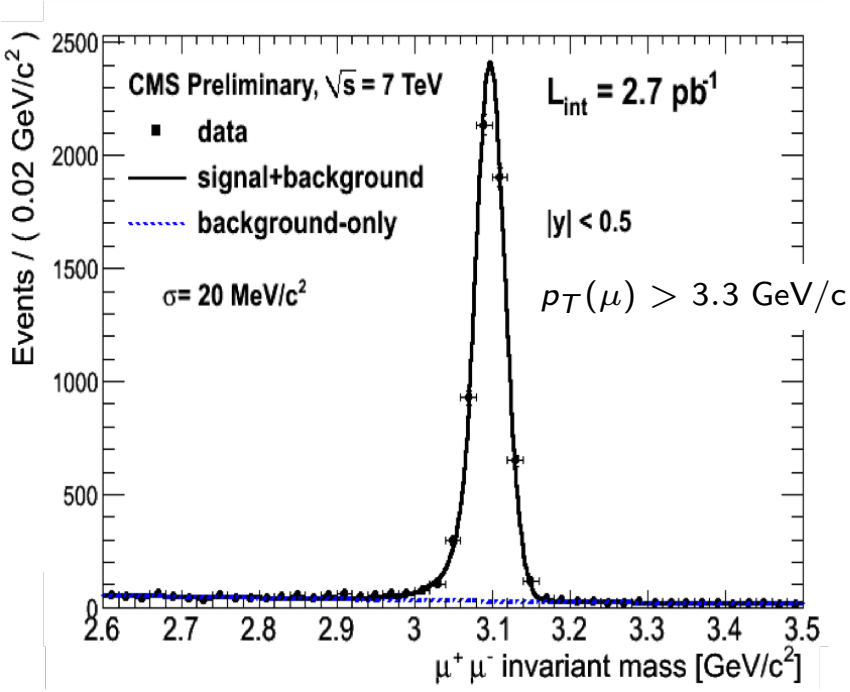
Efficiency determined with a data-driven (tag-and-probe) method

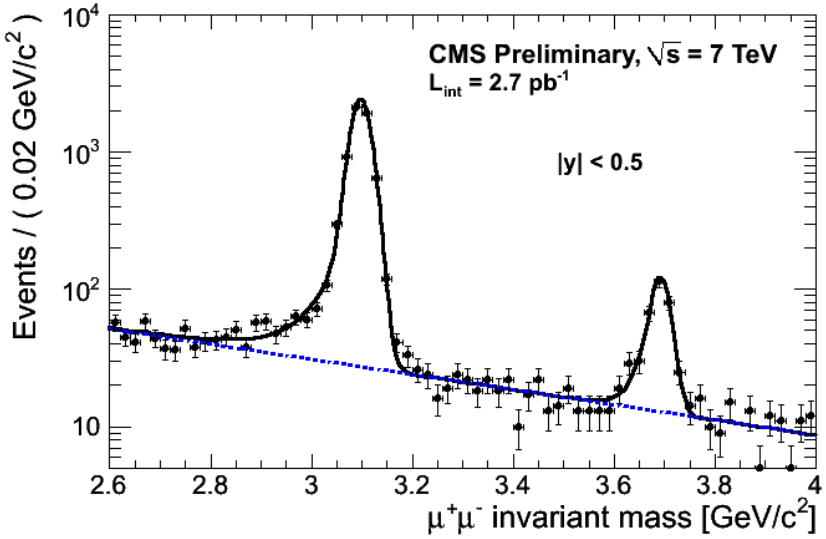
- take a well-identified muon in the event (tag)
- take another candidate muon, with looser criteria (probe)
- efficiency = fraction of all tag-probe pairs where the probes pass a given selection





$J/\psi \rightarrow \mu^+\mu^-$ in p+p at 7 TeV





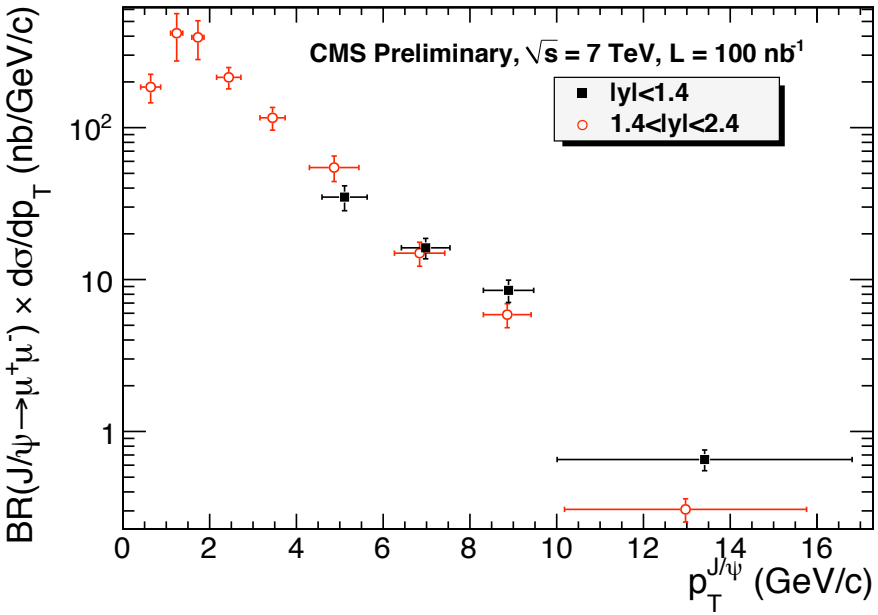
Excellent tracking performance

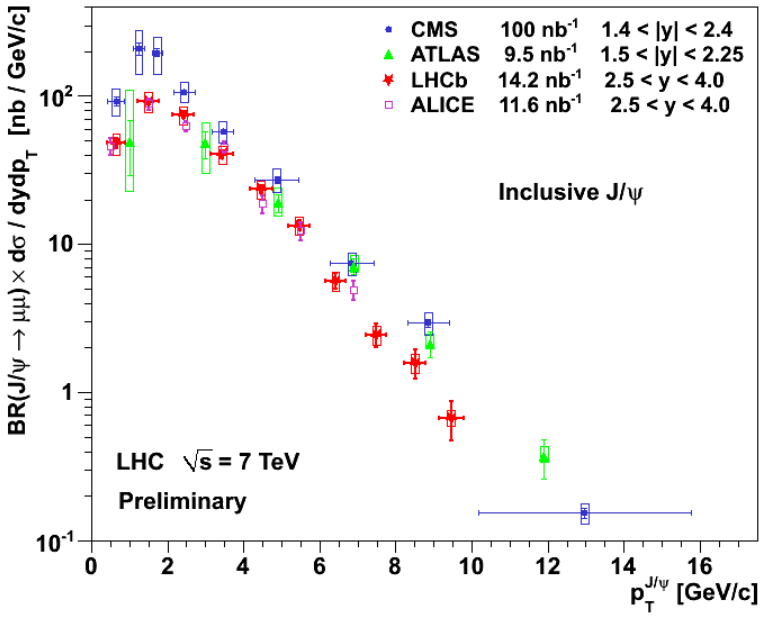
- B=3.8T
- Tracking resolution: $0.015\% p_T \oplus 0.5\%$
- CMS will collect unprescaled low p_T dimuon triggers up to the end of the p+p run

J/ψ Inclusive Cross-Section in p+p

From first 100 nb^{-1}

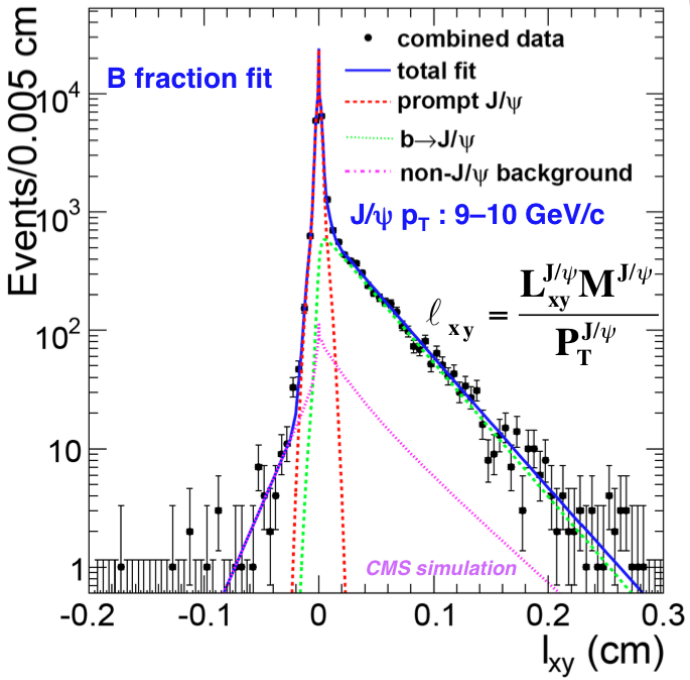
- Measured vs. p_T at mid and forward rapidity
- Assuming no polarization, for $p_T > 4$ and $|y| < 2.4$:
  $\sigma(pp \to J/\psi + X) \cdot BR(J/\psi \to \mu^+\mu^-) = 289.1 \pm 16.7(stat) \pm 60.1(syst)$ nb
- Selection : Vertexing prob. of $\mu^+\mu^- > 0.1\%$, high quality tracks associated to the muon segments : cuts on n_{hits}, χ^2, $|dxy|$, $|dz|$

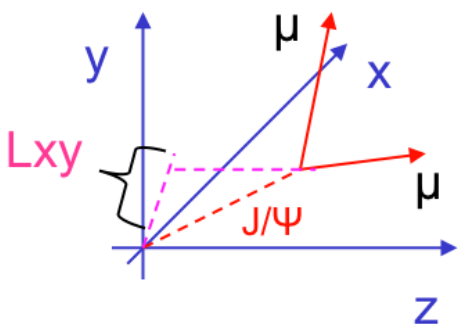


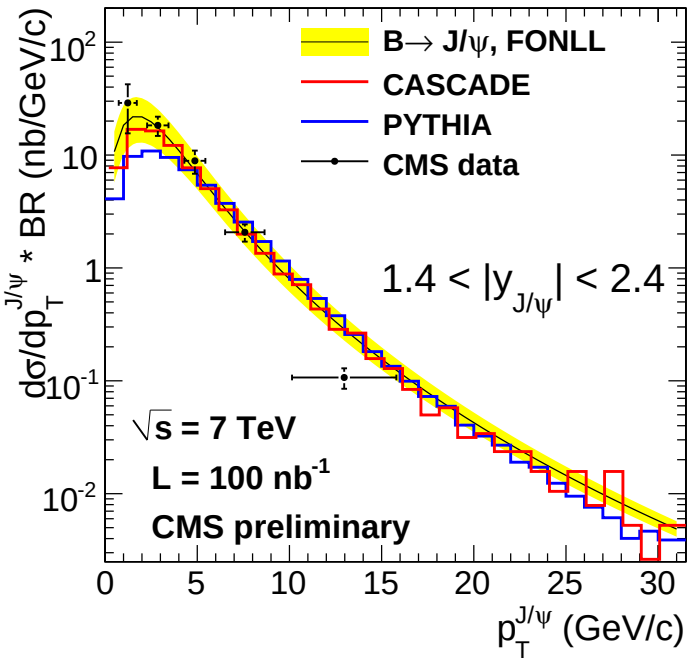


Prompt and Non-Prompt J/ψ

- Thanks to its very good tracking performance, CMS measures the distance between the interaction vertex and the dimuon vertex with a resolution around 50 micron
- The prompt and non-prompt components are obtained from a 2D fit to the dimuon mass and pseudo-proper decay length $l_{J/\psi} = L_{xy} \cdot m_{J/\psi}/p_T$
- Decay length parameterization: prompt (δ-function) and non-prompt (MC templates) convoluted with a 3-Gaussian resolution
- $\sigma(pp \to b \to J/\psi X) \cdot B(J/\psi \to \mu^+\mu^-) = 56.1 \pm 5.5(\text{stat}) \pm 7.2(\text{syst})$ nb

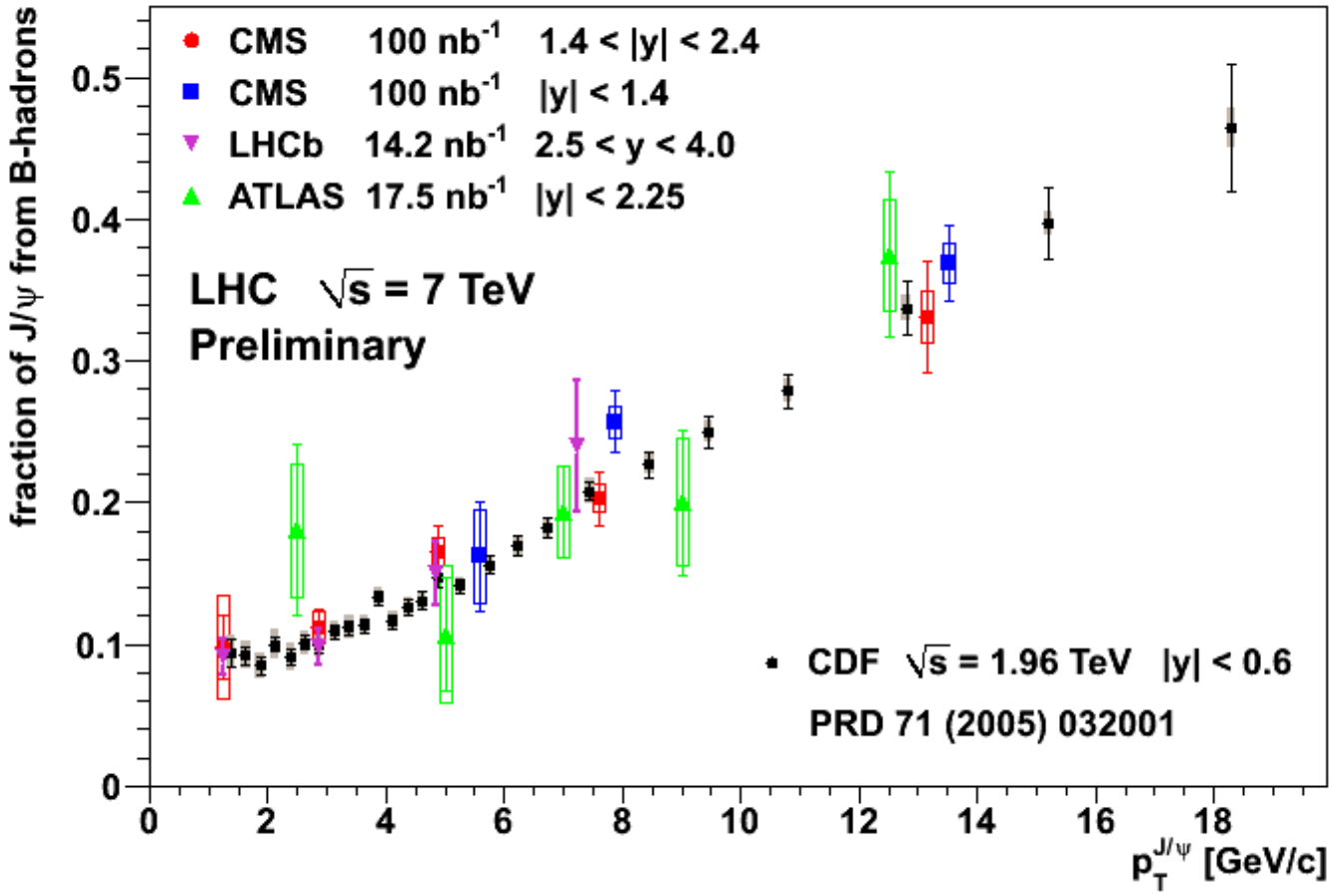






B Hadron Decay Feed Down

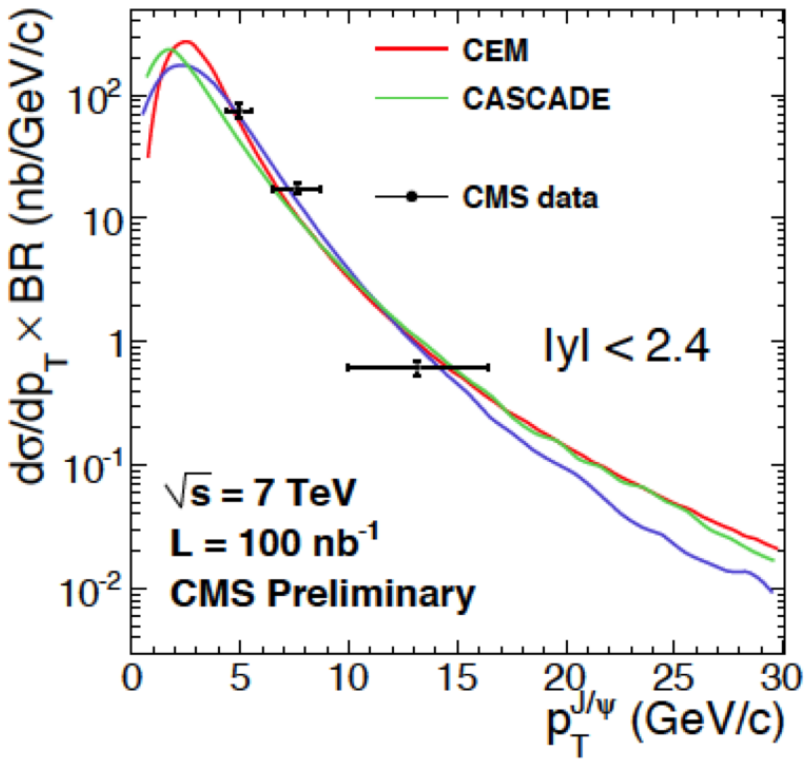
- The B fraction is not very sensitive to the J/ψ rapidity
- Nor to the collision energy (above 2 TeV)

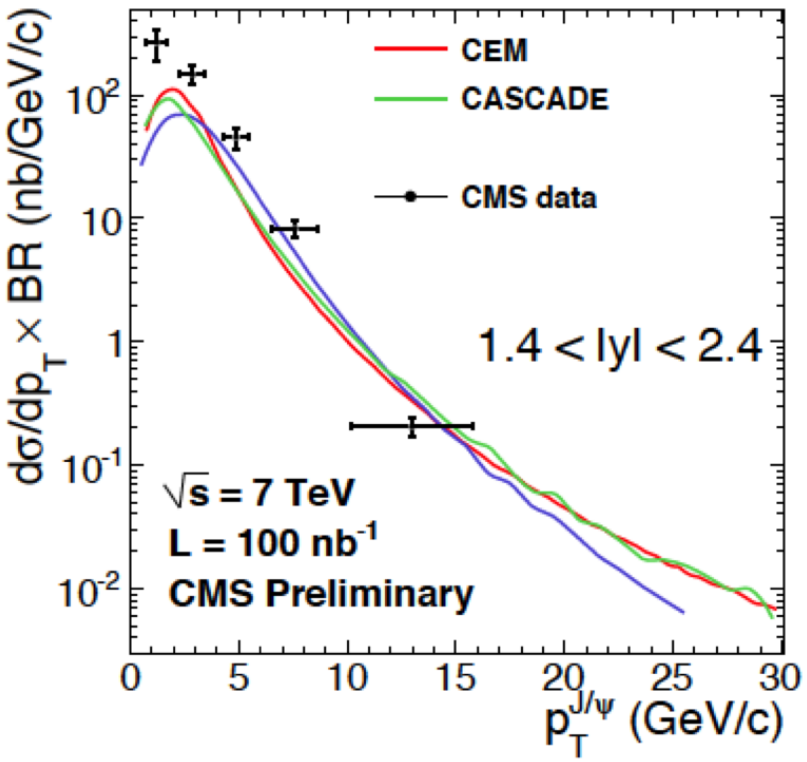


Prompt J/ψ Cross-Section

From first 100 nb^{-1}

- The J/ψ prompt cross section has been measured vs. p_T at mid and forward rapidity
- Assuming no polarization, for $p_T > 4$ and $|y| < 2.4$:
  $\sigma(pp \to J/\psi + X) \cdot \mathrm{BR}(J/\psi \to \mu^+\mu^-) = 289.1 \pm 16.7 \pm 60.1$ nb

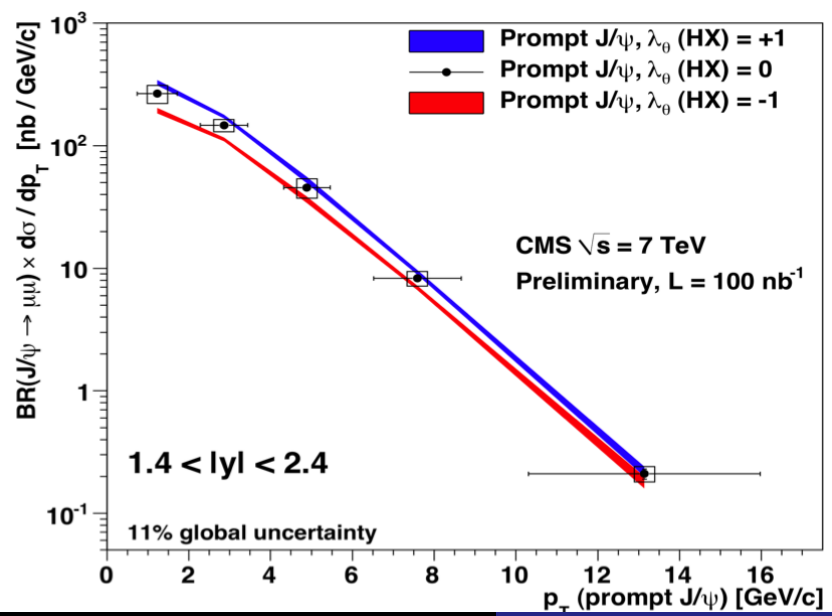


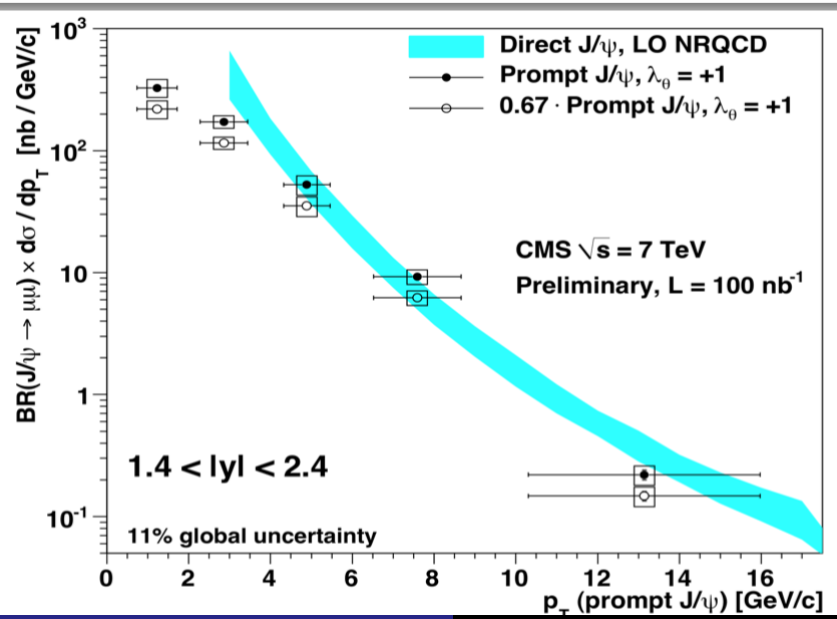


Prompt J/ψ Cross-Section

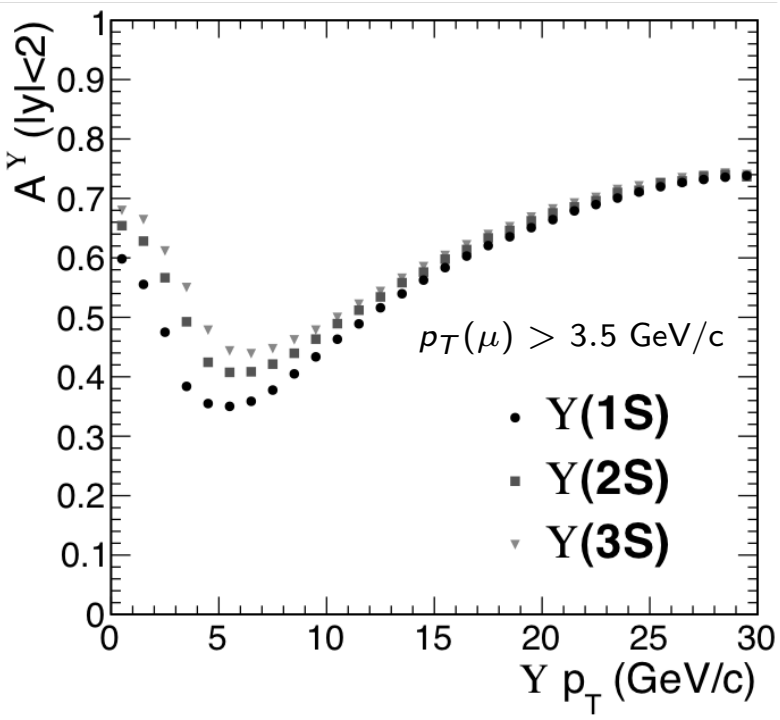
Effect of polarization

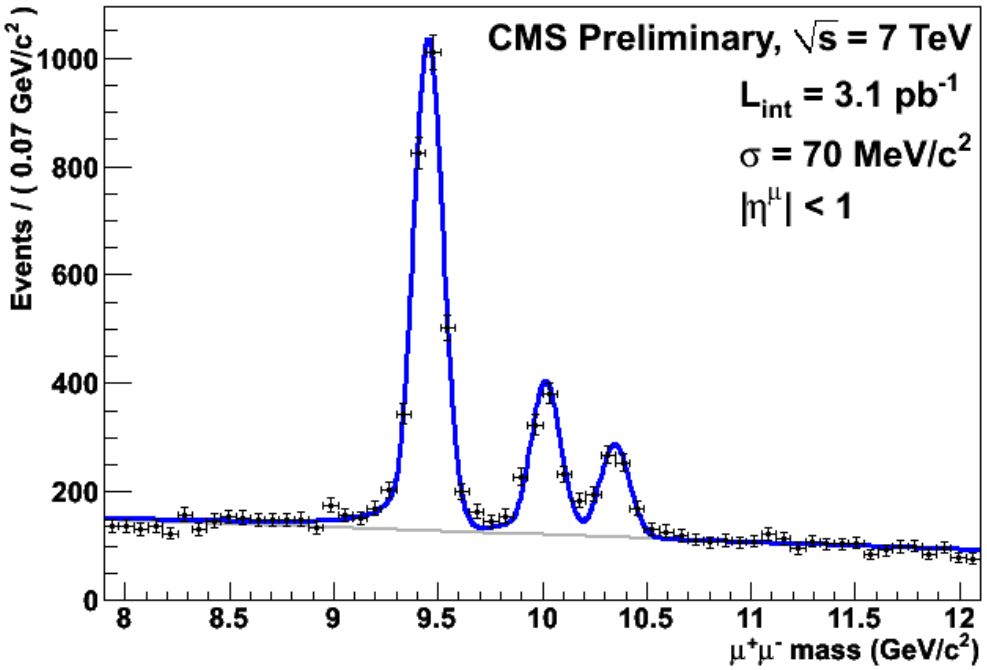
- The measured J/ψ cross-section depends on the assumed polarization
  - NRQCD predicts transverse polarization, growing with p_T
  - CSM predicts longitudinal polarization, flat with p_T
  - CEM calculations, so far, do not address polarization issues
- NRQCD & CSM curves only include the direct cross sections while the data includes feed-down terms from ψ and χ_c decays (around 33%)
- No (reliable) predictions for the ψ', χ_{c1} and χ_{c2} differential cross-sections or polarization, which are likely to change with $p_T \Rightarrow$ data-driven field





$\Upsilon \rightarrow \mu^+\mu^-$ in p+p at 7 TeV



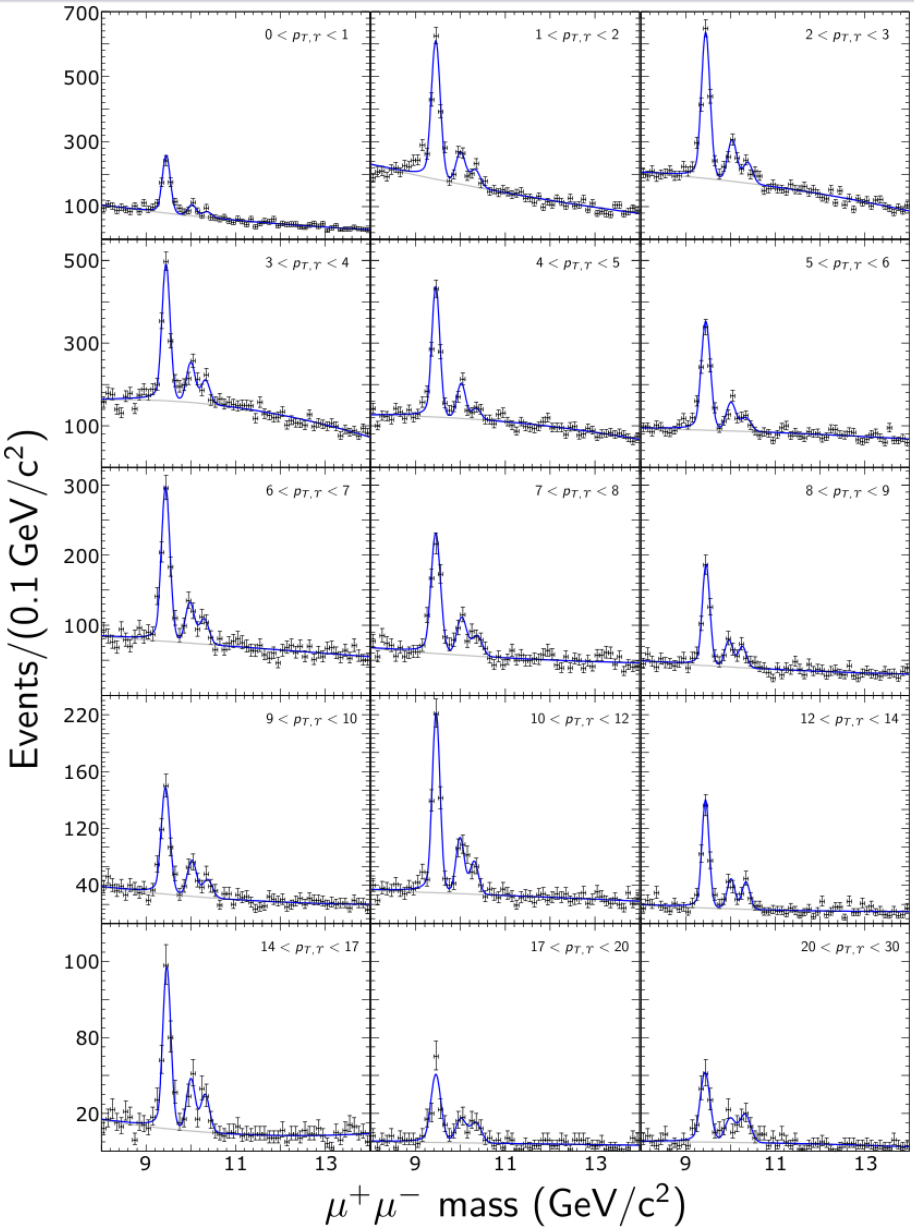


Performance

- CMS has a very good acceptance for Υ dimuons, even at very low p_T
- The mass distribution is $\sim$ 100 MeV integrating over full rapidity ($|y| < 2.4$) and $\sim$ 70 MeV in the barrel ($|\eta(\mu)| < 1$, for each of the two muons)

$\Upsilon \rightarrow \mu^+\mu^-$ in p+p at 7 TeV

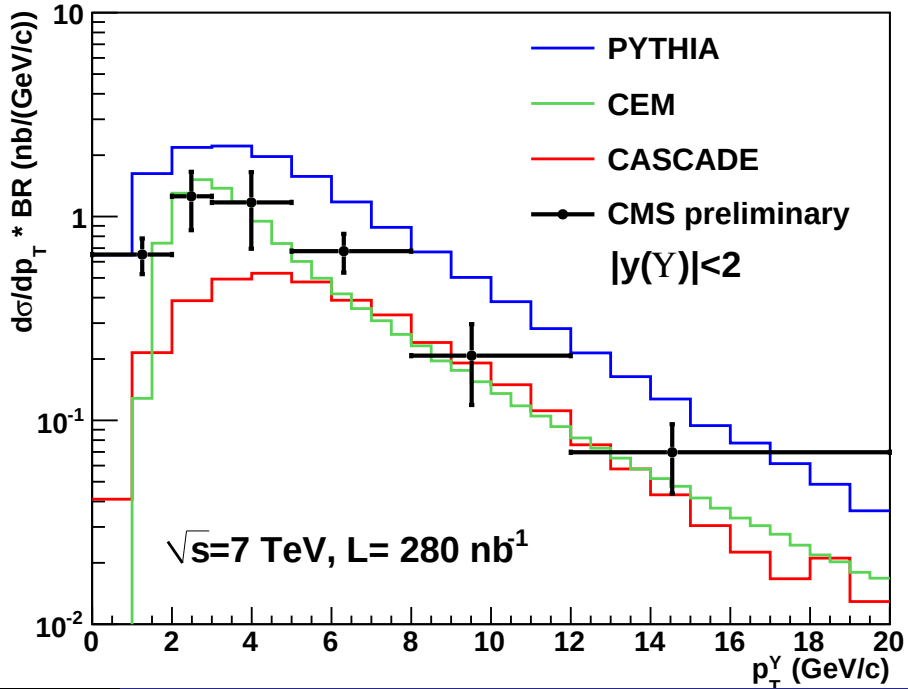
- 15 bins in p_T
- Disentangling Υ states even at $p_T = 30$ GeV/c !



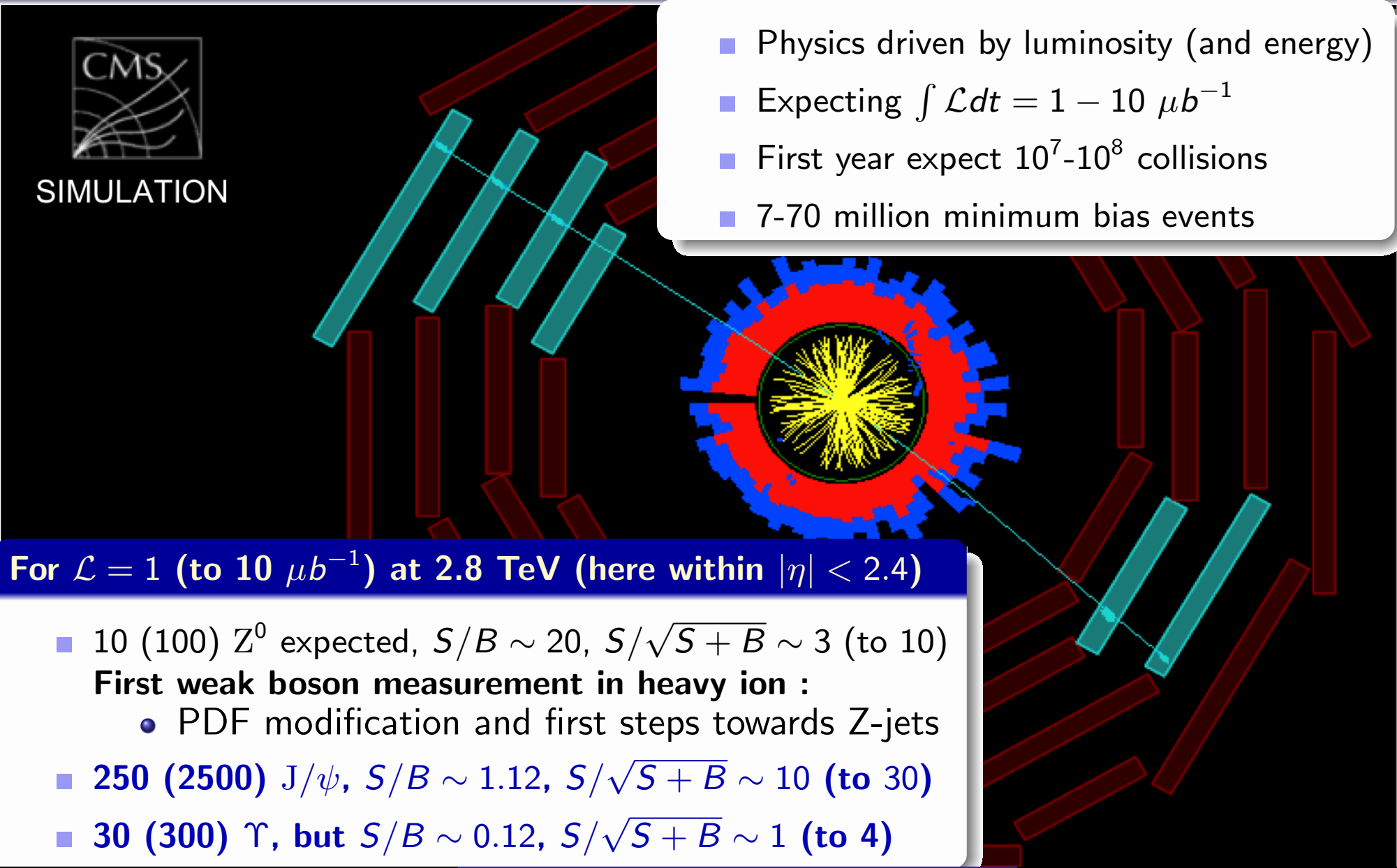
ϒ Cross-Section in p+p

From first 280 nb^{-1}

- Muons well within acceptance window ($|y| < 2.0$)
- Similar quality selection as J/ψ
- The ϒ (1S) differential cross section has been measured vs. p_T
- Integrated over $|y| < 2.0$ (value assuming no polarization):
  $\sigma(\Upsilon(1S))\cdot BR(\Upsilon(1S) \to \mu^+\mu^-) = 8.3\pm0.5(stat)\pm0.9(syst)\pm1.0(lumi)$ nb



First Measurements in Heavy Ions



- Physics driven by luminosity (and energy)
- Expecting $\int \mathcal{L}dt = 1 - 10\ \mu b^{-1}$
- First year expect 10^7-10^8 collisions
- 7-70 million minimum bias events

For $\mathcal{L} = 1$ (to 10 μb^{-1}) at 2.8 TeV (here within $|\eta| < 2.4$)

- 10 (100) Z^0 expected, $S/B \sim 20$, $S/\sqrt{S+B} \sim 3$ (to 10)
  First weak boson measurement in heavy ion :
  - PDF modification and first steps towards Z-jets
- **250 (2500)** J/ψ**,** $S/B \sim 1.12$**,** $S/\sqrt{S+B} \sim 10$ **(to** 30**)**
- **30 (300)** Υ**, but** $S/B \sim 0.12$**,** $S/\sqrt{S+B} \sim 1$ **(to 4)**

Triggers

Strategy

Finalizing triggering scheme, customized trigger menu both at L1 and at High Level Trigger (HLT)

- Expect up to 50-140 Hz collisions. Maximum disk writing limit is 150 Hz (200 Hz with no Tier-0 transfers)
- Aim to record all collisions
- Preparing HLT trigger menus to deal with possible luminosity scenarios
- Arranging data streams, alignment and calibration etc.
- Optimize data streams for HI physics plans

Summary and Prospects

In p+p

- Already spectacular quarkonia results with the CMS detector
- Expecting to have collected enough statistics by the end of the p+p run (around 2.5 M J/ψ and 100 000 Υ (1S)) to study much more :
  - J/ψ and Υ polarization, in several p_T and y bins
  - χ_c over J/ψ cross-section ratio, using calorimeter-seeded photons
  - χ_{c1} over χ_{c2} cross-section ratio, using tracker-seeded photon conversions

In HI

- We have been making steady progress on preparations
- The accelerator schedule and expected performance is quite uncertain, we are being conservative in our expectations
- We expect to collect non-zero-suppressed p+p data, this will provide important input to preparations
- Plans for calibrations, trigger, computing have been settled
- We are ready to collect and analyze first heavy ion data from LHC

The CMS physics results can be found in https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults