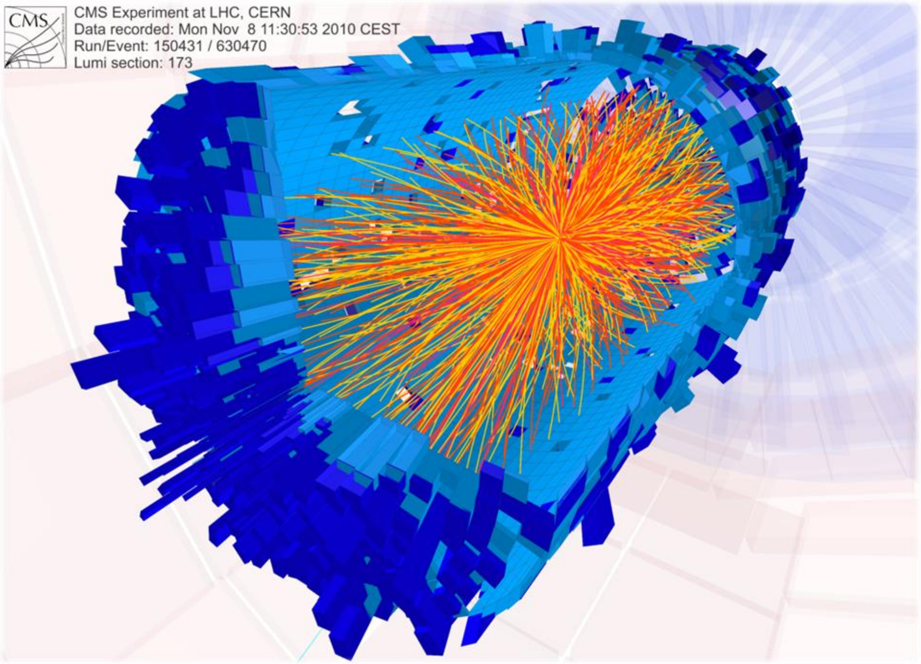
Quarkonia production in p+p & heavy-ion collisions in CMS



Ji Hyun Kim(Korea University)

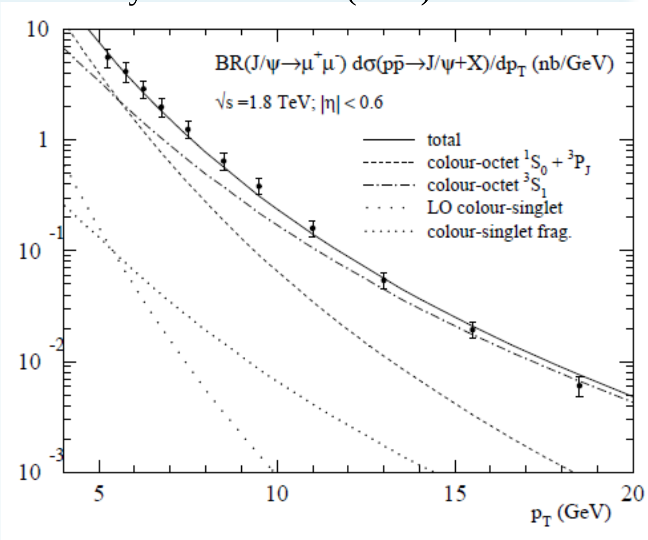
Outline

- Physics Motivation
- CMS Detector
- First p+p run at LHC in 2010
- Quarkonia Production in p+p collisions
- First heavy-ion run at LHC in 2010
- Quarkonia Production in Pb+Pb collisions
- Summary

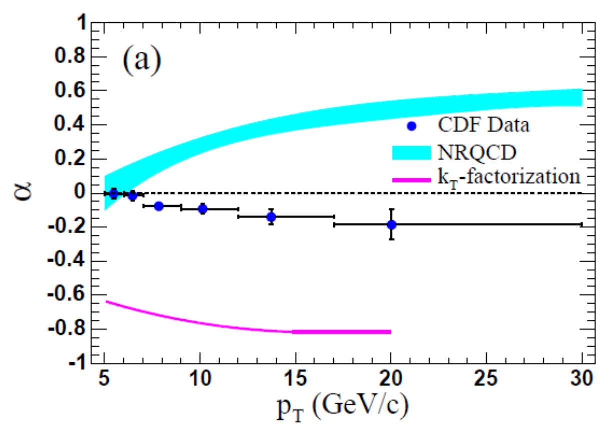
Theoretical Motivation

- Quarkonium Production Mechanism
  - The J/ψ production is :
    - prompt : direct & indirect from prompt ψ(2S), χ_c
    - non-prompt J/ψ from B-hadrons decay
- Some theoretical models for J/ψ production:
  - CSM, COM, CEM, etc.
- Prompt J/ψ Puzzles:
  - COM can explain the CDF cross section, but not polarization.
  - Despite recent theory progress, no satisfactory model fits cross section and polarization.

F. Abe et al. [CDF Collaboration], Phys. Rev. Lett. **79** (1997) 572.



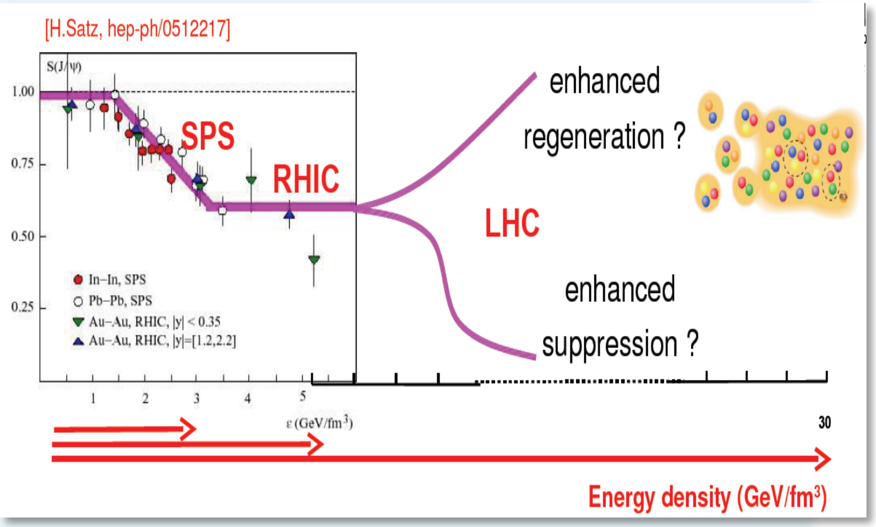
Prompt J/ψ polarization



Quarkonia Suppression in HI collisions

- Good candidates to probe the QGP
  - Large masses and (dominantly) produced at the early stage of the collision, via hard-scattering of gluons.
  - Strongly bound (small radius) and weakly coupled to light mesons.
  - J/ψ should be anomalously suppressed in heavy ion collisions due to color screening if Quark Gluon Plasma was formed.

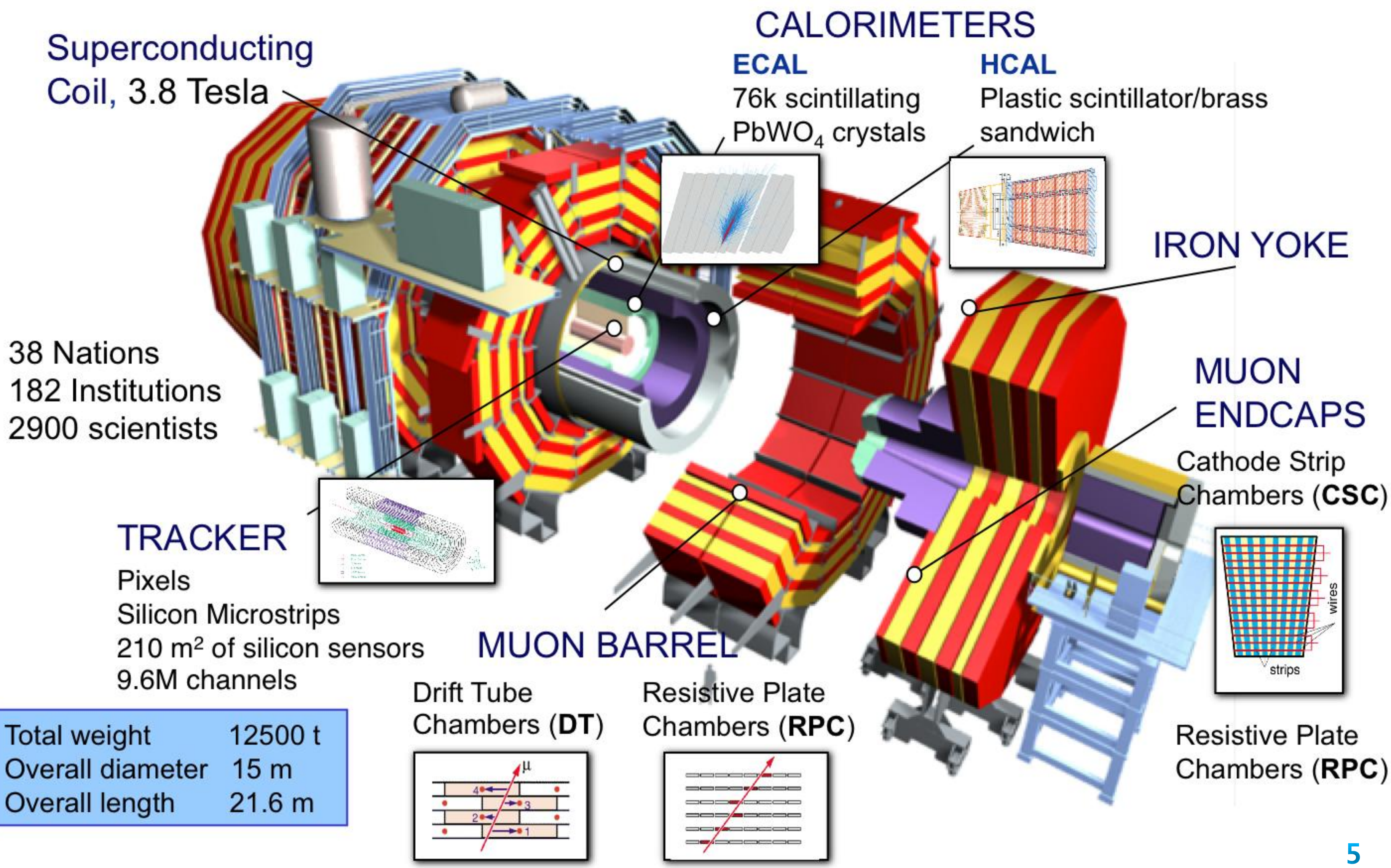
T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416.



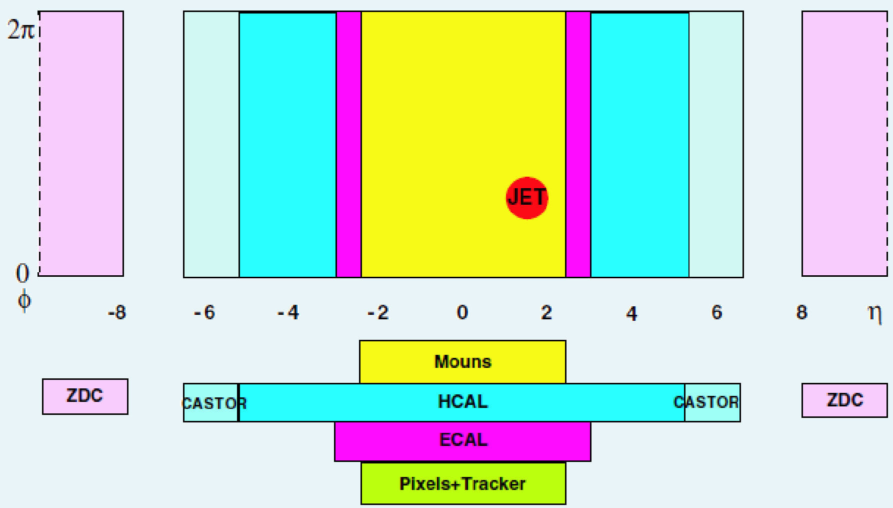
- Regeneration at the LHC?
- Possible to study ϒ

New energy scale & Large p_T reach!!

CMS(Compact Muon Solenoid)



Excellent Capabilities of CMS

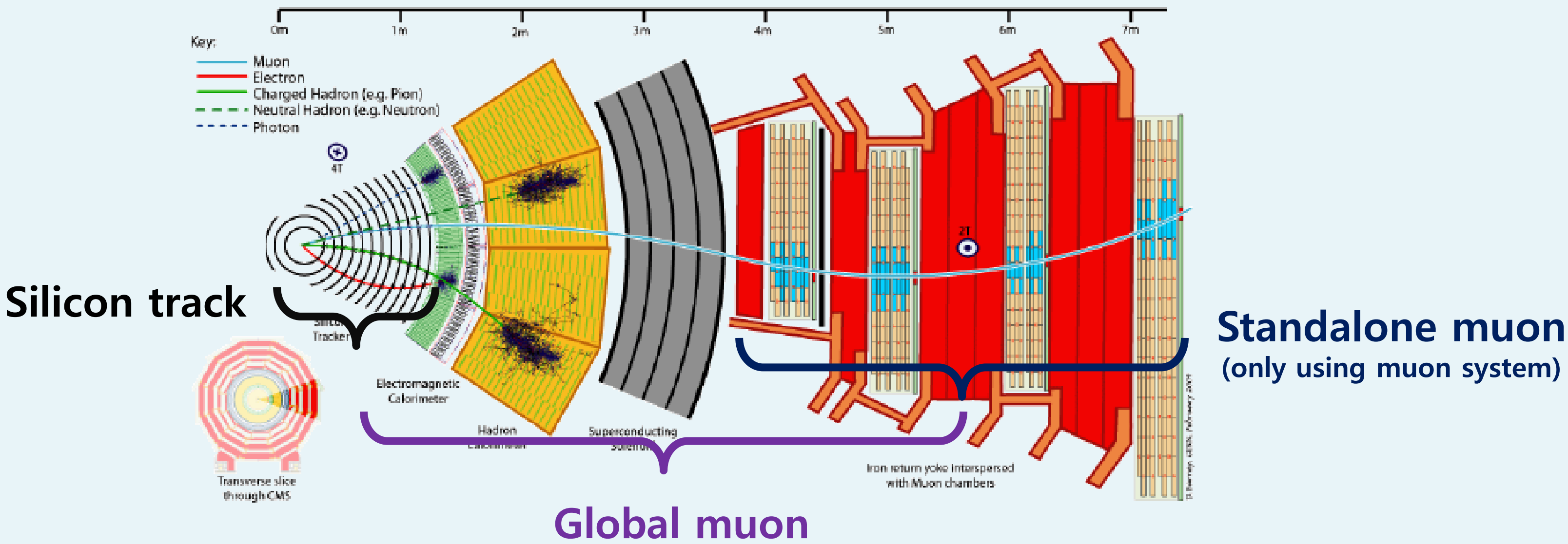


- Calorimeters
  - High resolution and segmentation
  - Hermetic coverage up to $|\eta|<5$
  - $-5.2<\eta<-6.6$ with CASTOR
  - Zero Degree Calorimeter, $|\eta|>8.3$

- Silicon Tracker
  - Good efficiency & purity for $p_T > 1$ GeV.
  - Pixel occupancy < 2% at $dN_{ch}/d\eta \sim 3500$.
  - $\sigma_p^{\mu} \sim 1\%$ at $p_T < 100$ GeV.
  - Good low-p_T acceptance using pixels.

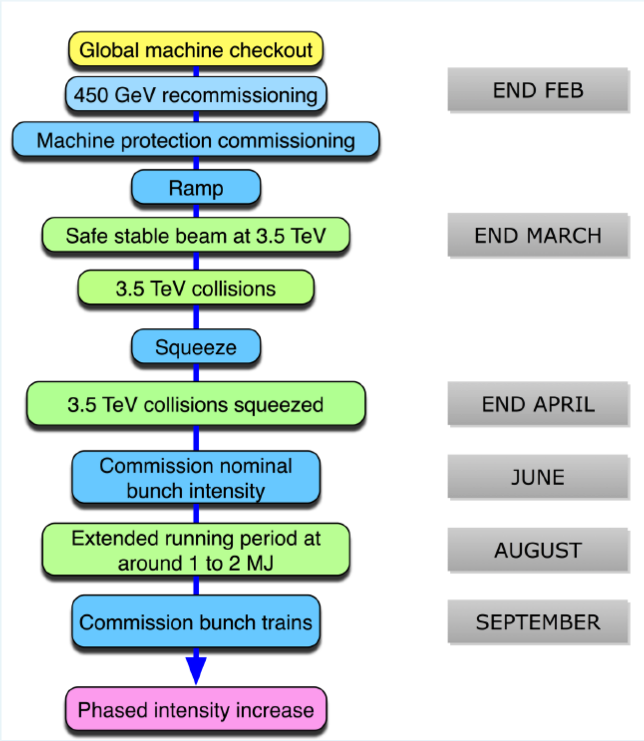
- DAQ and Trigger
  - High rate capability for A+A, p+A, p+p
  - High Level Trigger: real time HI event reconstruction

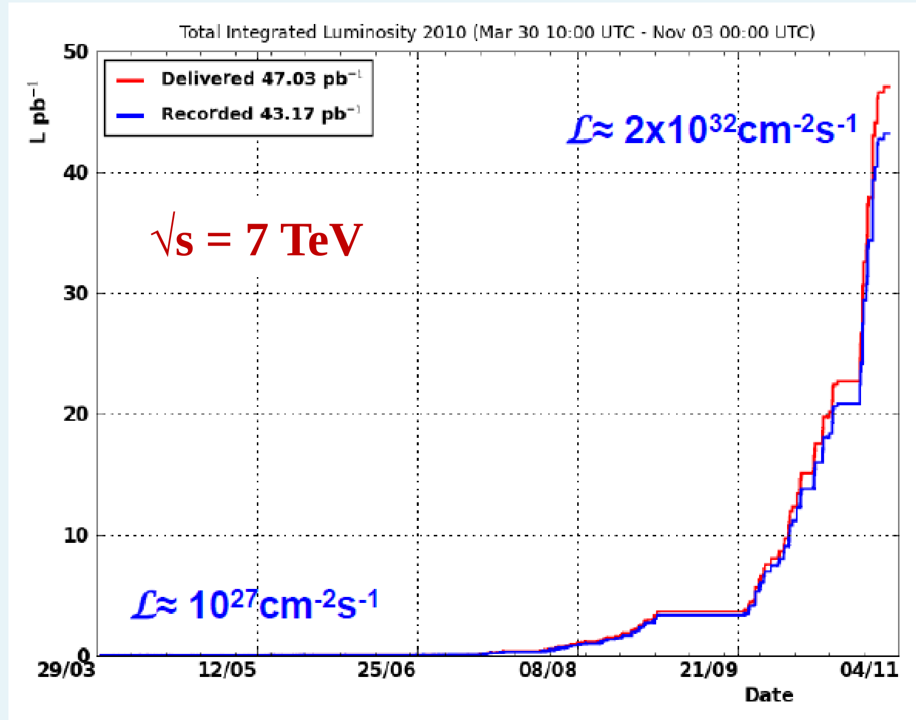
CMS Muon Reconstruction



- Global muon is built by matching silicon track and standalone with tight cuts.
- Strong magnetic field (3.8T), Large rapidity coverage ($|\eta|< 2.4$).
- Good muon momentum resolution:
  $\sigma_p^\mu \sim 1\%$ at $p_T=100$ GeV , $\sigma_p^\mu \sim 10\%$ at $p_T=1$ TeV.
- Excellent dimuon mass resolution: $\sigma_m \sim 100$ MeV at the Υ mass in $|\eta|< 2$.

First p+p collisions at LHC

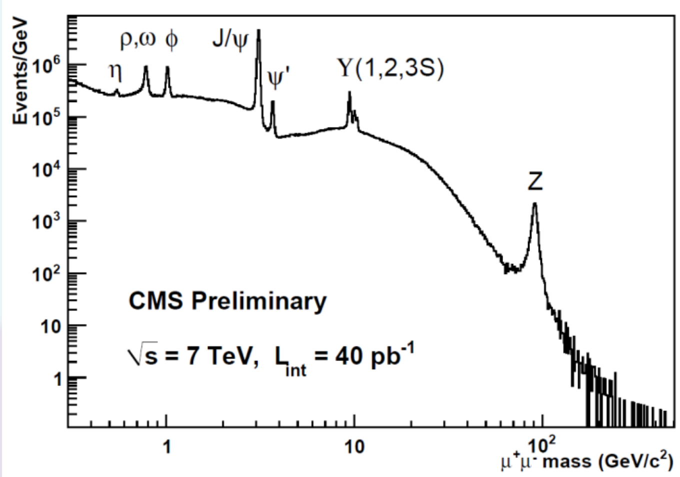




- About $47pb^{-1}$ delivered by LHC and $\sim 43pb^{-1}$ of data collected by CMS. Overall data taking efficiency ~92%.
- Excellent performance in coping with more than 5 order of magnitude increase in instantaneous luminosity.

Quarkonia in p+p collisions

- Baseline measurement of heavy-ion.
- Investigating production mechanism and polarization puzzle.



Cross-section Formula

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

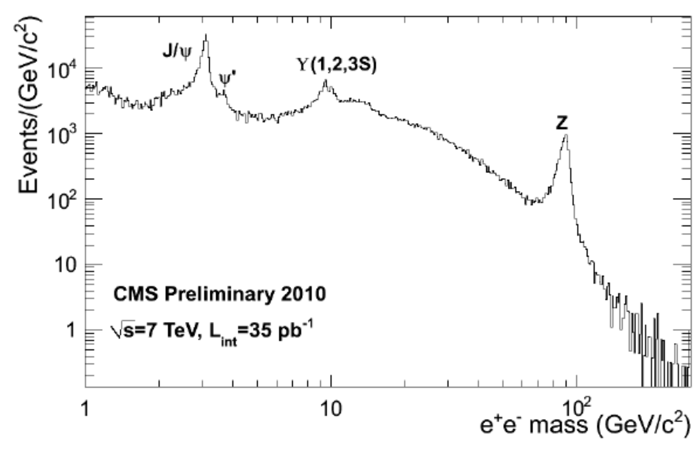
$N_{Q\bar{Q}}$: signal yield in a given p_T, y bin from fitting to the reconstructed dimuon invariant mass spectrum

∫Ldt : integrated luminosity

A : J/ψ, ϒ geometrical and kinematical acceptance (MC)

$\varepsilon_{trigger}$, ε_{reco} : trigger and reconstruction efficiency by Tag and Probe method (Data-driven)

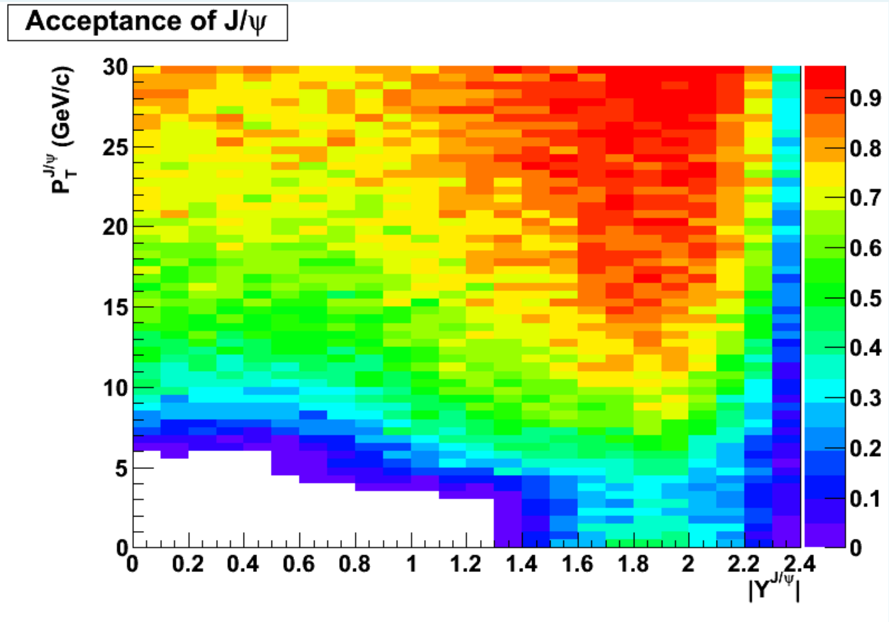
Δp_T, Δy : p_T, y bin size



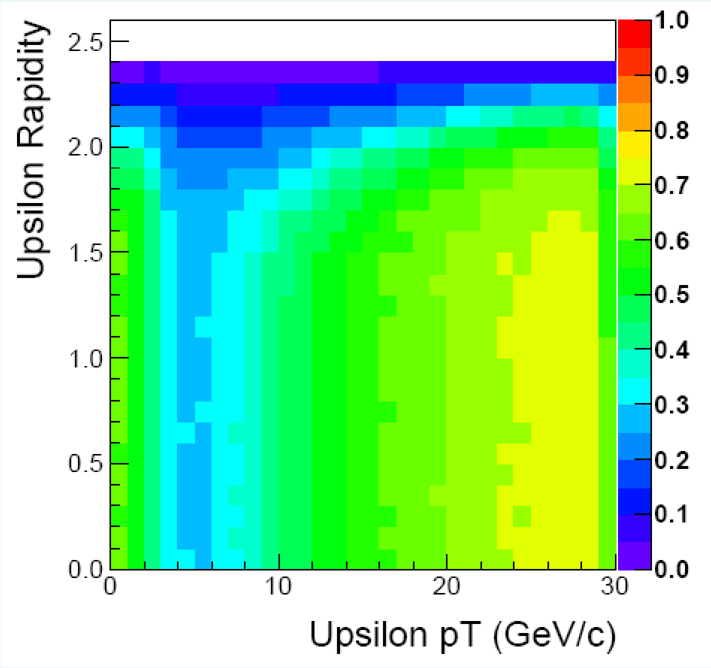
J/ψ & Υ Acceptance

- single-muon delectability > 10%.
- Non-polarization scenario.

$$A(p_T, y) = \frac{N_{dec}(p_T, y)}{N_{gen}(p_T, y)}$$



$$|\eta_\mu| < 1.3 \rightarrow p_T^\mu > 3.3 \text{ GeV}/c,$$
$$1.3 \leq |\eta_\mu| < 2.2 \rightarrow p^\mu > 2.9 \text{ GeV}/c,$$
$$2.2 \leq |\eta_\mu| < 2.4 \rightarrow p_T^\mu > 0.8 \text{ GeV}/c$$



$$p_T^\mu > 3.5 \text{ GeV}/c \quad \text{if} \quad |\eta^\mu| < 1.6$$
$$p_T^\mu > 2.5 \text{ GeV}/c \quad \text{if} \quad 1.6 < |\eta^\mu| < 2.4$$

Muon Efficiencies by T&P

$$\epsilon_{total}(\mu) = \epsilon_{trig|id} \cdot \epsilon_{id|track} \cdot \epsilon_{track|accepted} \equiv \epsilon_{trig} \cdot \epsilon_{id} \cdot \epsilon_{track}$$

$$\epsilon_{total}(J/\psi) = \epsilon_{total}(\mu^{+}) \cdot \epsilon_{total}(\mu^{-}) \cdot \epsilon_{vertex}$$

- Tag & Probe Method
  - Well established data-driven approach to measure particle efficiencies.
  - Use of a well-known two decay products of the resonance(e.g. J/ψ, Υ, Z).
  - Tag: Object that passed a set of very tight selection criteria.
  - Probe: Selected by pairing with tags such that invariant mass of the combination is consistent with that of resonance.
  - Passing Probe: Subset of probes that pass the more restrictive selection for the efficiency being measured.

$$\varepsilon = \frac{p_{pass}}{p_{all}}$$

P_{pass} : # of probes passing the selection criteria

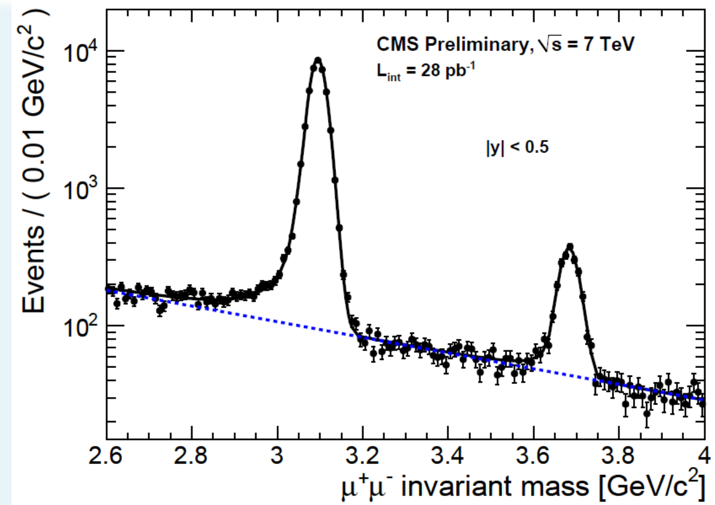
P_{all} : total # of probes

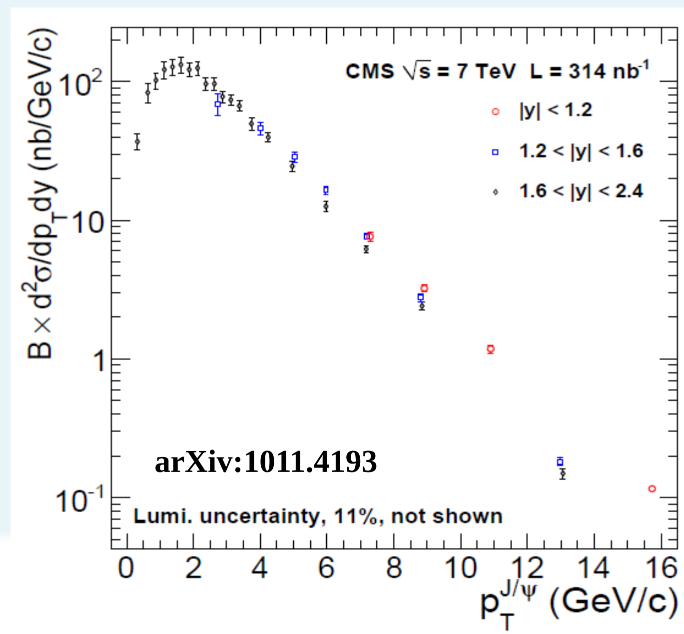
Inclusive J/ψ Production in p+p

- Selection
  - Vertexing prob. of μ+μ- >0.1%
  - High quality track associated to the muon segments: cut on n_{hits}, χ^2, |dxy|, |dz|
- Yield extraction: Unbinned ML fit to invariant mass
  - Crystal Ball + exponential
- Mass resolution
  - ~ 28 MeV/c² (|η|<1.2)
  - ~ 40 MeV/c² (1.2<|η|<1.6)
  - ~ 48 MeV/c² (1.6<|η|<2.4)
- Total cross-section

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

= (97.5 ± 1.5(stat) ± 3.4(syst) ± 10.7(lumi) nb



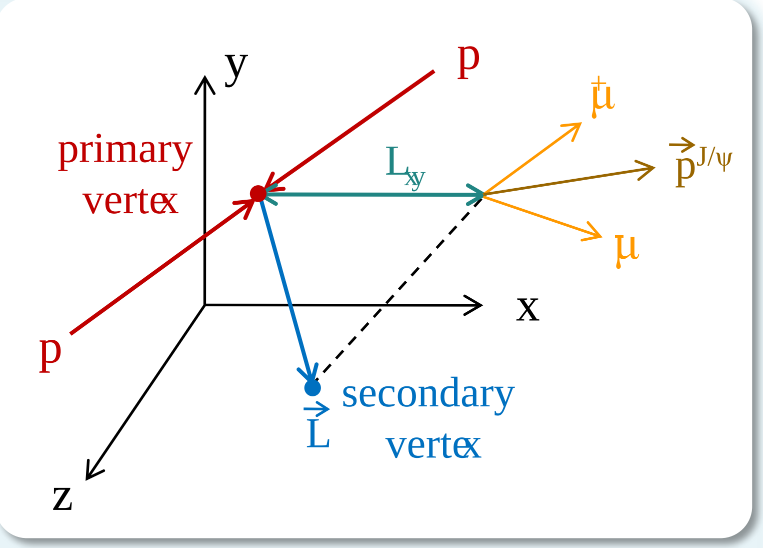


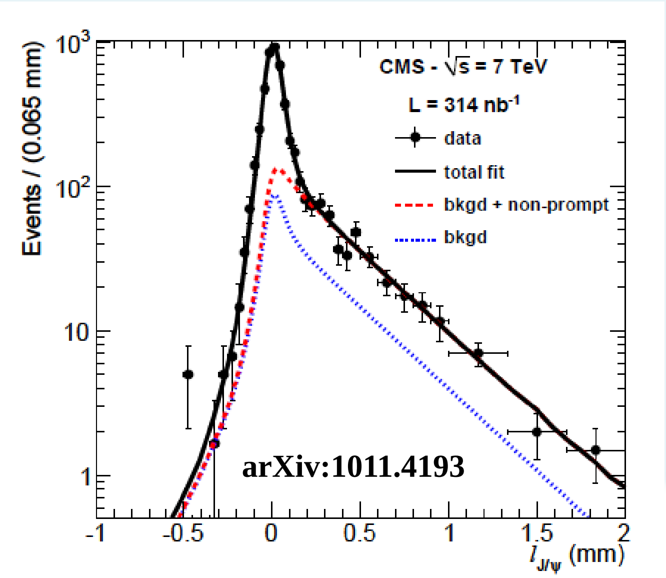
Fraction of J/ψ from B-hadron decay

- J/ψ pseudo-proper decay length

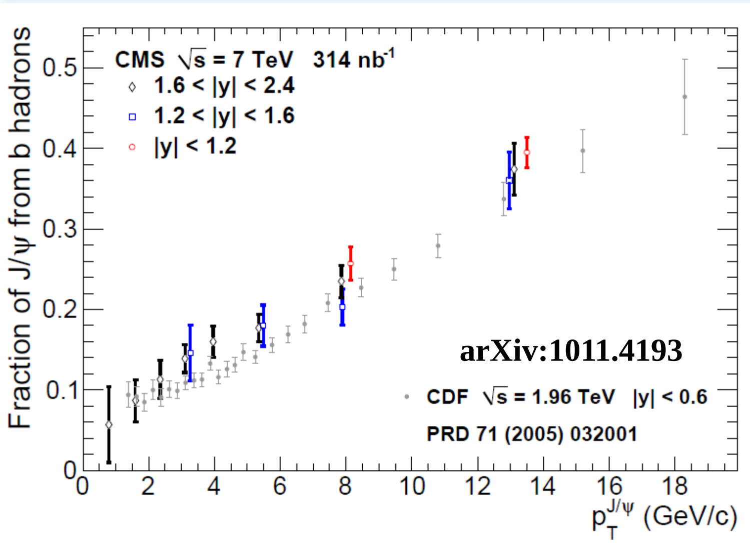
$$l_{xy}(J/\psi) = L_{xy}(J/\psi) \cdot \frac{M(J/\psi)}{p_T(J/\psi)}$$

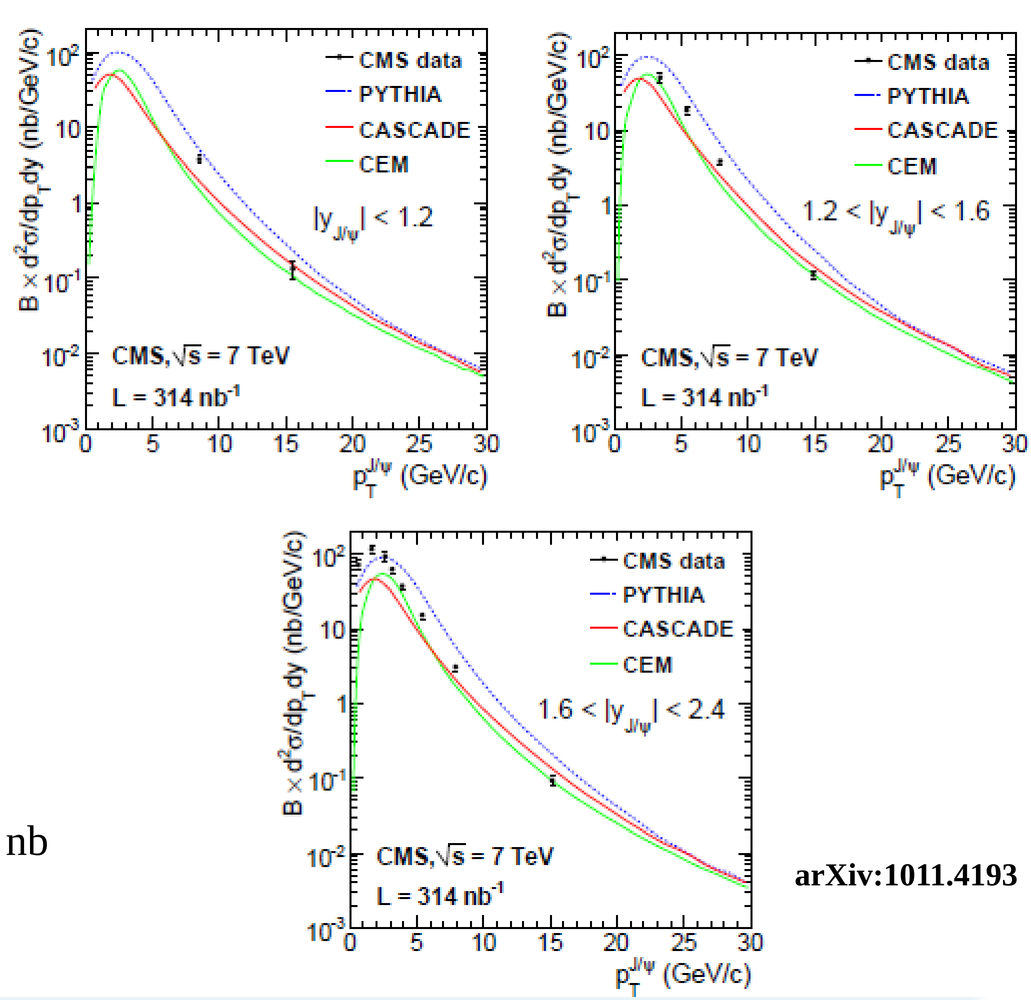
  - Prompt J/ψs decay immediately at the primary vertex while B-hadrons have relatively long lifetimes and decay at the secondary vertex.
  - Measure non-prompt contributions by a 2D unbinned ML fit to invariant mss and pseudo proper-decay length.





Prompt J/ψ Cross Section in p+p



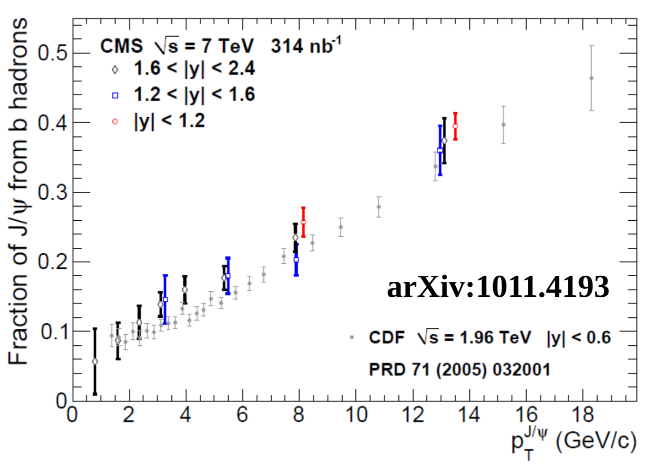


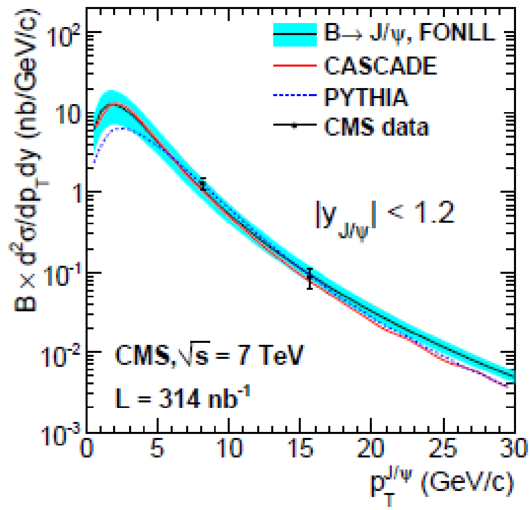
- Total cross-section

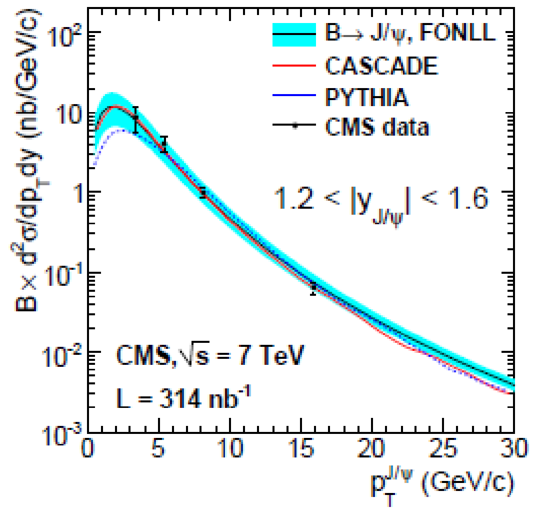
$$BR(J/\psi \to \mu^+\mu^-)\cdot\sigma(pp \to prompt\ J/\psi)$$

= (70.9 ± 2.1(stat) ± 3.0(syst) ± 7.8(lumi)) nb

Non-prompt J/ψ in p+p



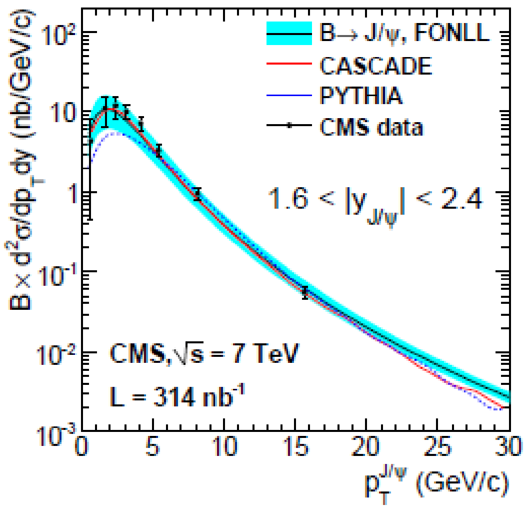




- Total cross-section

$$BR(J/\psi \rightarrow \mu^+\mu^-)\cdot\sigma(pp \rightarrow bX \rightarrow J/\psi\ X')$$

$$= (26.0 \pm 1.4(\text{stat}) \pm 1.6(\text{syst}) \pm 2.9(\text{lumi})\ \text{nb}$$



arXiv:1011.4193

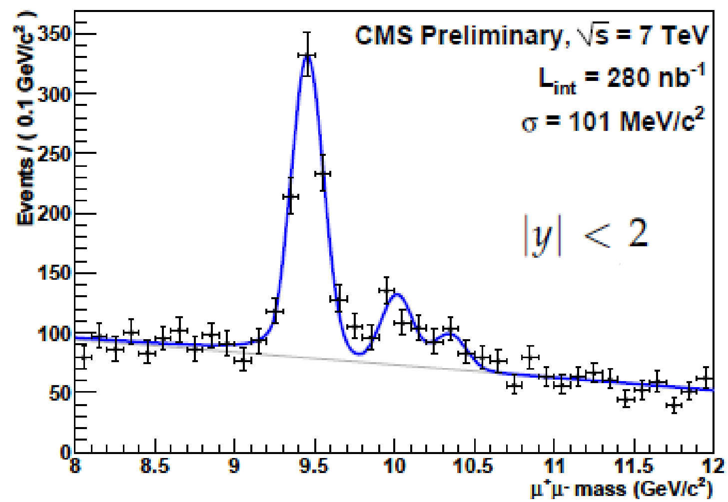
Υ Production in p+p

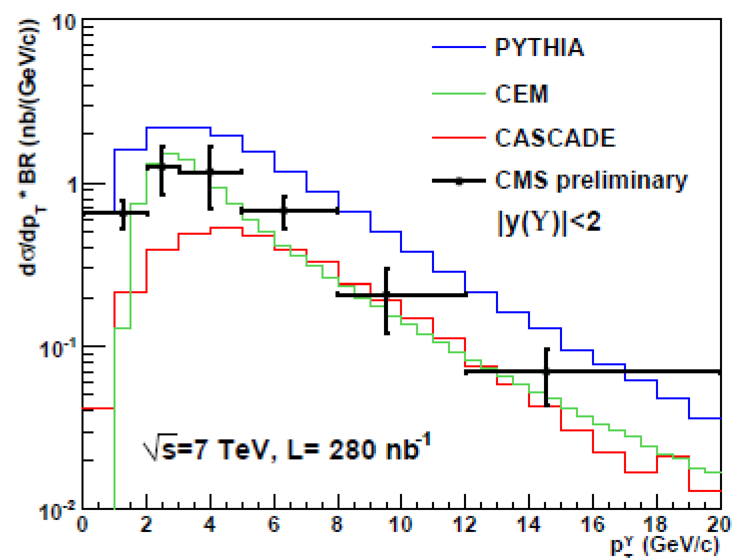
- Selection
  - similar to the J/ψ selection
  - $|y(\Upsilon)|<2.0$
- Yield extraction: Unbinned ML fit to invariant mass
  - Crystal Ball + linear background
- Mass resolution
  - ~ 100 MeV/c² ($|\eta|<2.4$)
  - ~ 67 MeV/c² ($|\eta|<1.0$)
- Total Cross-section

$$\sigma(pp \to \Upsilon(1S) + X) \cdot BR(\Upsilon(1S) \to \mu^+\mu^-)$$

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

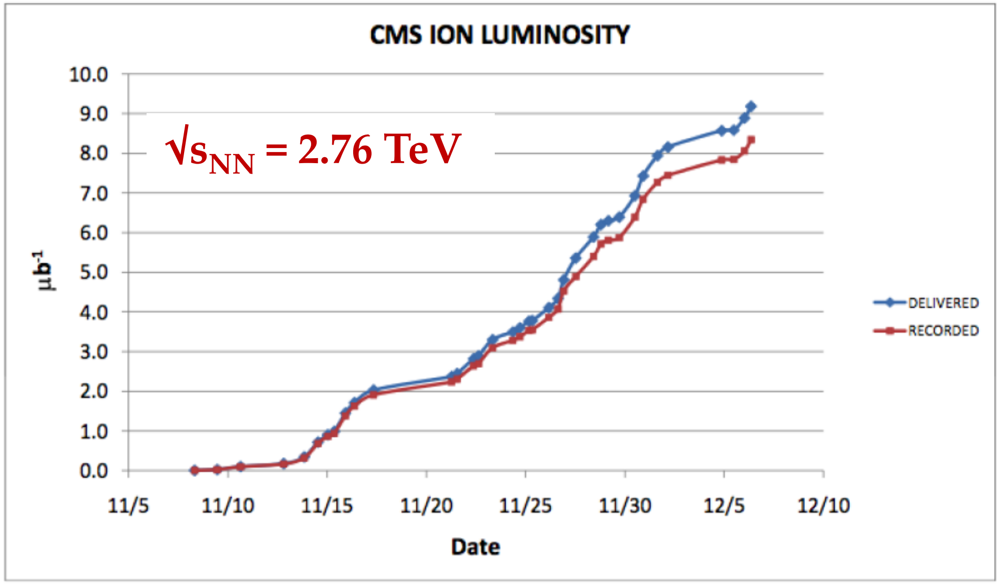
CMS PAS BPH-10-003





CMS PAS BPH-10-003

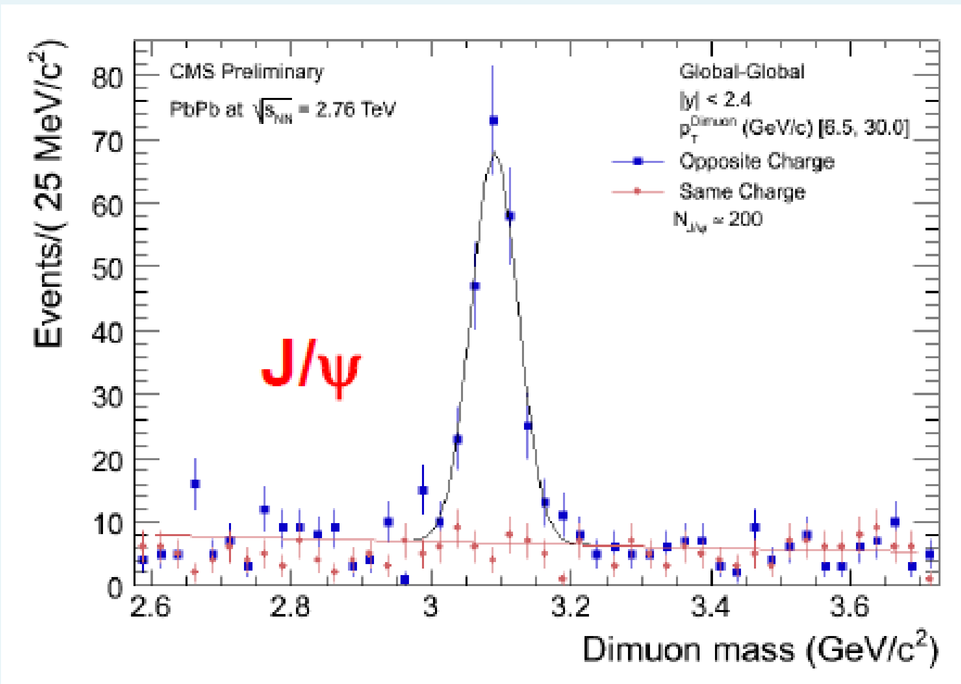
First Heavy-ion collisions at LHC



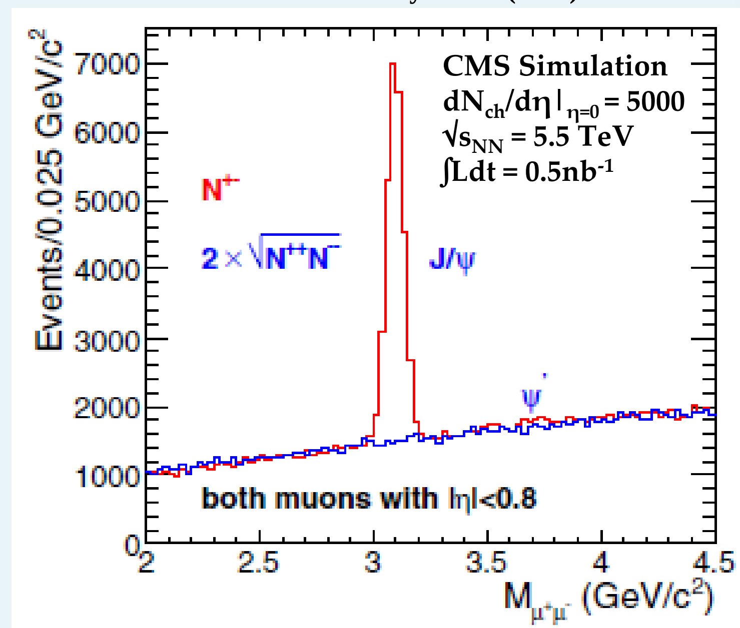
		Early (2010/11)
$\sqrt{s_{NN}}$ (per colliding nucleon pair)	TeV	2.76
Number of bunches		62
Bunch spacing	ns	1350
β^*	m	$2 \rightarrow 3.5$
Pb ions/bunch		7×10^7
Transverse norm. emittance	µm	1.5
Initial Luminosity (L_0)	$cm^{-2}s^{-1}$	$(1.25 \rightarrow 0.7)\ 10^{25}$
Stored energy (*W*)	MJ	0.2
Luminosity half life (1,2,3 expts.)	h	τ_{IBS}=7-30

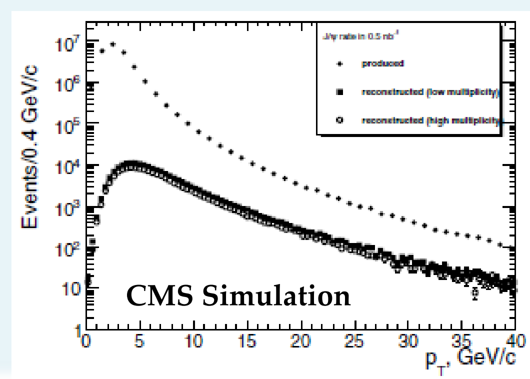
- LHC runs 1 month/year for A-A collisions, initially Pb-Pb, later p-Pb,...
- Even at initial half-nominal energy, LHC is the energy frontier for nuclear collisions a factor of 13.7 (later up to 28) beyond RHIC.
- About 9.2µb^{-1} delivered by LHC and ~8.3µb^{-1} of data collected by CMS. Overall data taking efficiency > 90%.

J/ψ in Pb+Pb collisions



J. Phys. G 34 (2007) 2307-2455

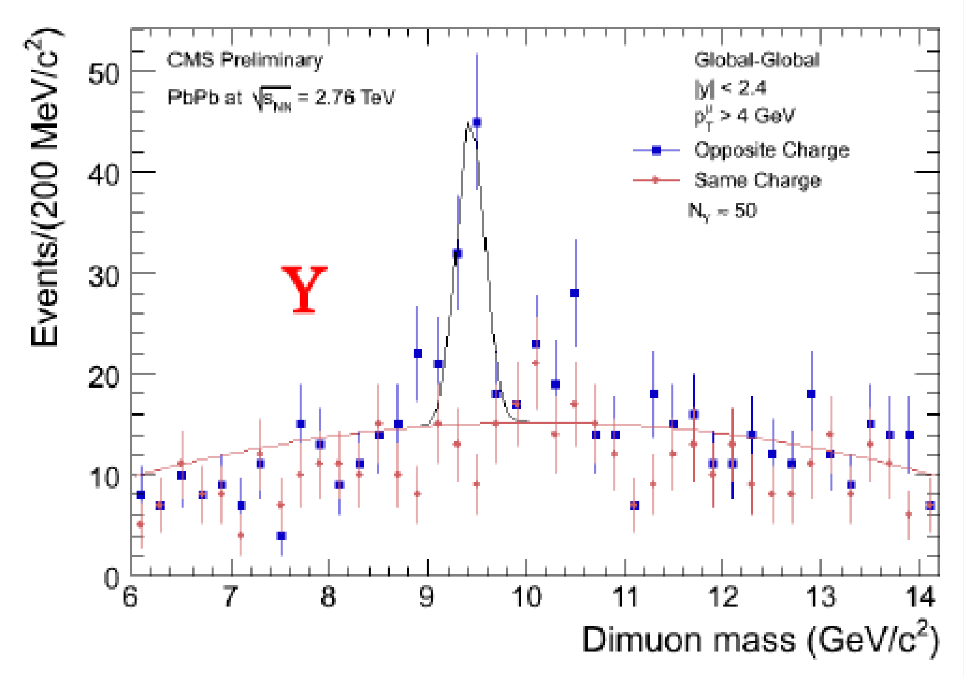




high p_T reach

J. Phys. G 34 (2007) 2307-2455

Υ in Pb+Pb collisions



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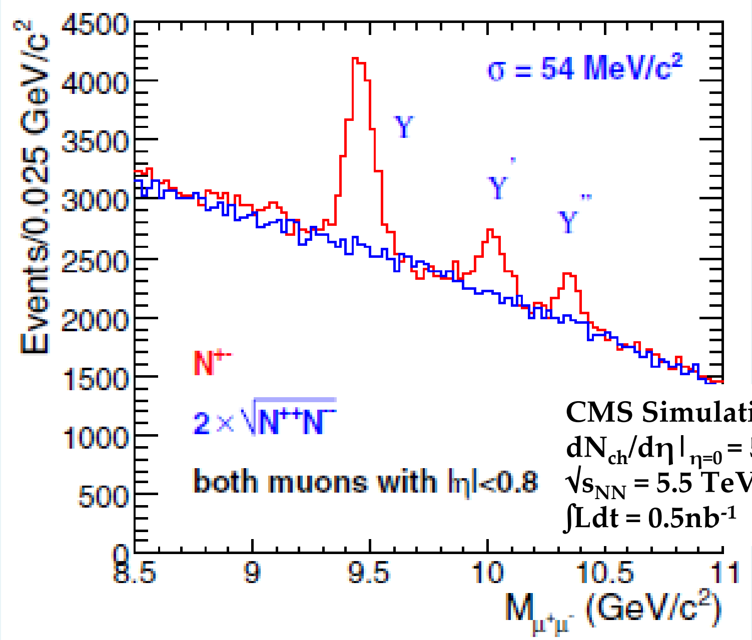
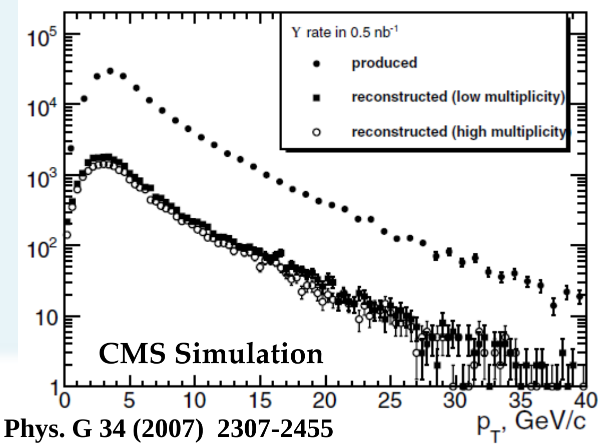


CMS Simulation
$dN_{ch}/d\eta|_{\eta=0}$ = 5000
$\sqrt{s_{NN}}$ = 5.5 TeV
$\int Ldt$ = 0.5nb^{-1}



J. Phys. G 34 (2007) 2307-2455

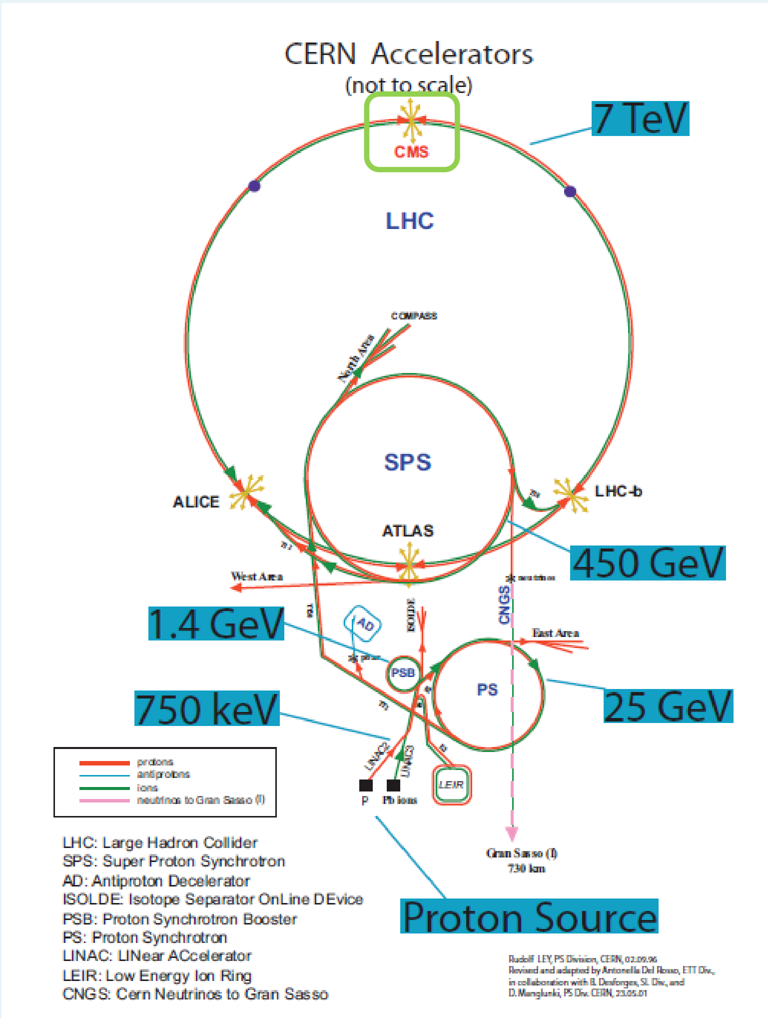
high p_T reach

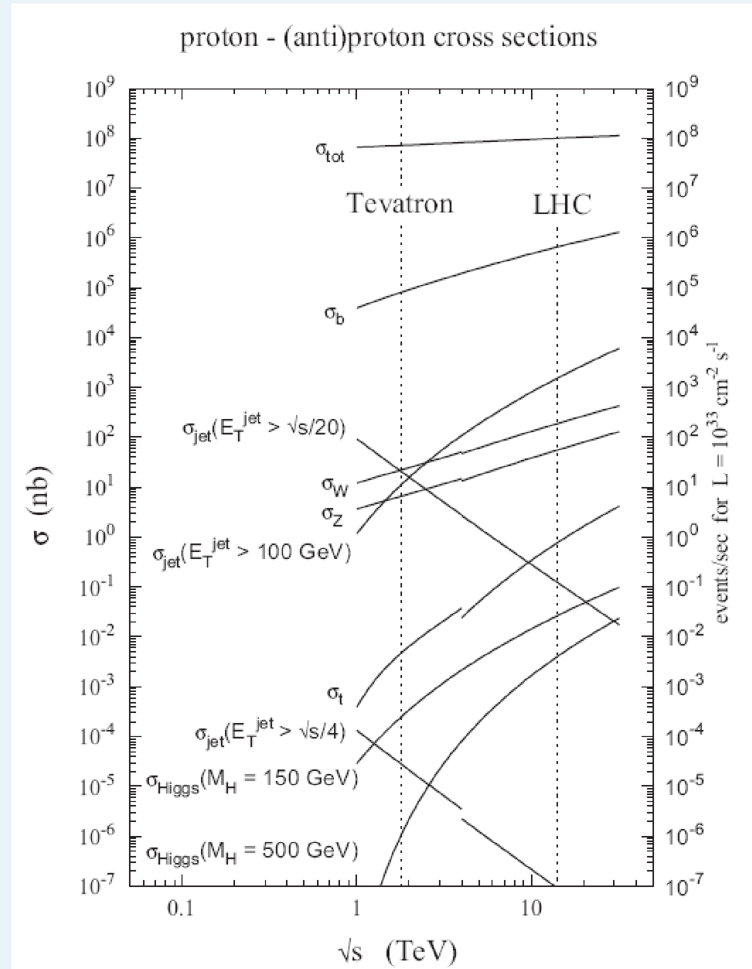
Summary

- pp and heavy-ion collisions at LHC in 2010 were started and operated successfully.
- CMS did quite well : Excellent status of the detector and of the operations and excellent physics results.
- J/ψ and Υ productions in p+p are well matched with theoretical model and published.
- Quarkonia analysis in heavy-ion collisions are actively ongoing now.
- We will see new physics soon!

Backup

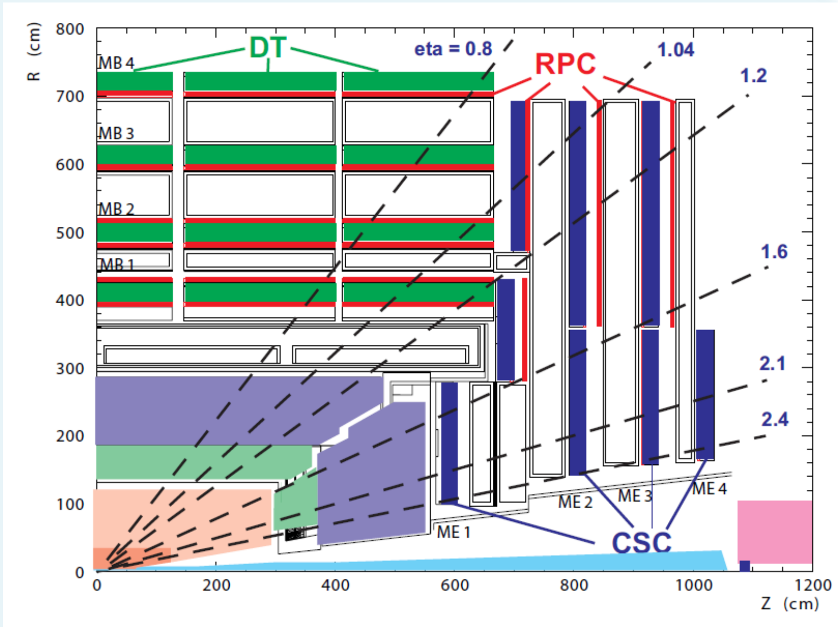
LHC(Large Hadron Collider)

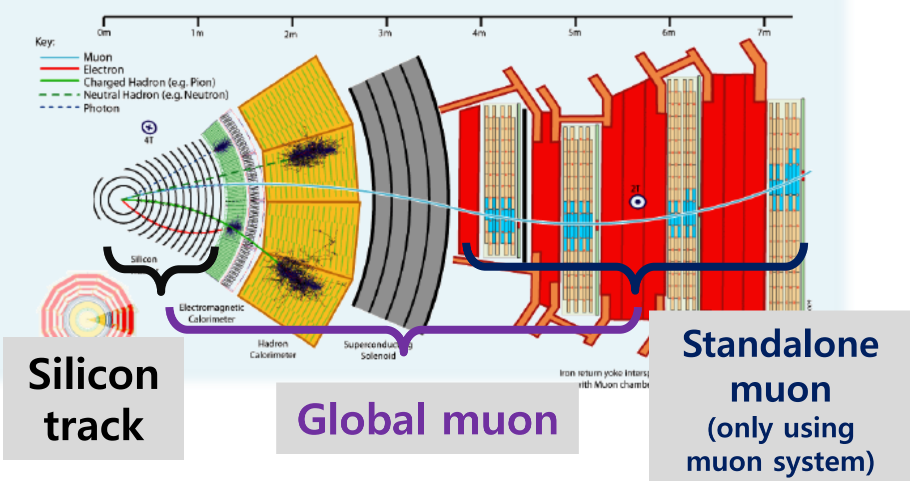




Muon System

- Three gaseous detectors:
  - Barrel: DT, RPC
  - Endcaps : CSC, RPC
- Strong magnetic field (3.8T), Large rapidity coverage ($|\eta|< 2.4$).
- Good muon momentum resolution:
  - σ_p^{μ}~1% at p_T=100 GeV , σ_p^{μ}~10% at p_T=1 TeV
- Excellent dimuon mass resolution: σ_m ~ 50 MeV at the J/ψ mass in the endcap.





Quarkonia in Pb+Pb collisions

- Dimuon trigger strategy
  - Basically attempt to record all collisions.
  - Optimizing HLT menu to select necessary events.
    - HLTL1DoubleMuOpen : physics trigger
    - Single Muon trigger : efficiency calculation by T&P
- Reconstructing muons in a dense environment.
  - p+p reconstruction algorithm modified because of heavy consumption of CPU(memory and time).
    - Tracks inside-out based on 3 pixel seeds instead of pairs.
    - Regional matching standalone muon and tracker track.