Towards Quarkonium Physics in CMS

Yu Zheng
Purdue Univeristy
on behalf of B Physics analysis Group in CMS

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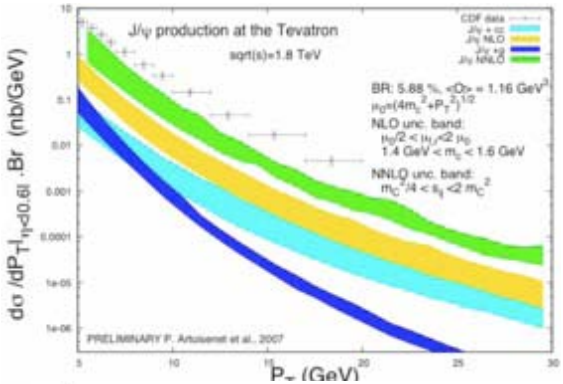
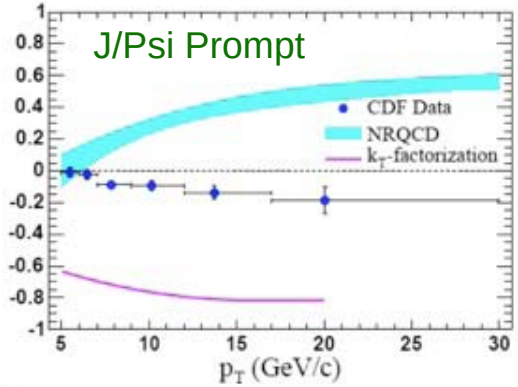
Outline

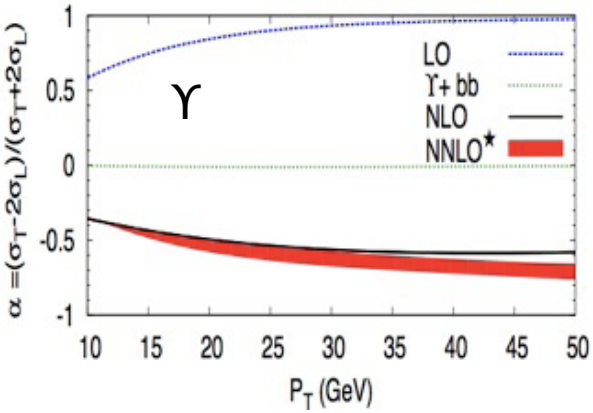
- Motivation
- CMS Detector
- Muon Reconstruction
- Early heavy-flavor physics measurements at 7 TeV
  - The $J/\psi \rightarrow \mu^+\mu^-$ cross-section
  - The $\Upsilon(nS) \rightarrow \mu^+\mu^-$ cross-section
- First data: J/Ψ peaks and $\Upsilon \rightarrow \mu\mu$ event!
- Summary

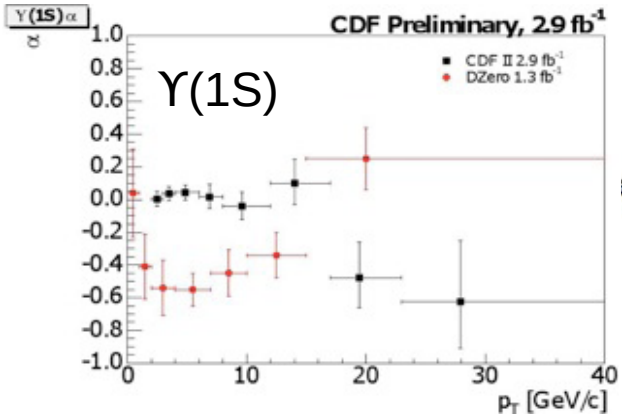
The Quarkonia Puzzle

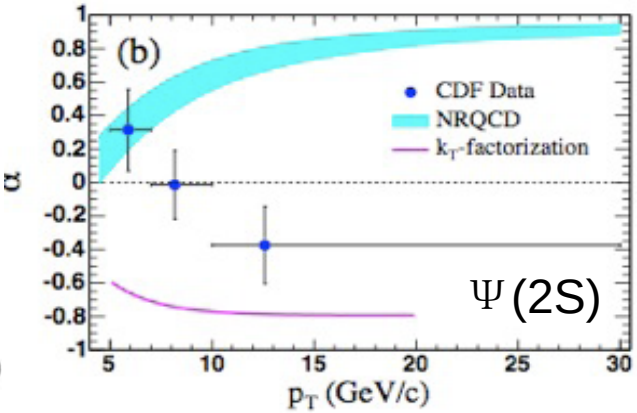
- Prompt production:
  - Direct
  - Indirect: feed-down from χ_{cJ}, $\psi' \rightarrow J/\psi$ and $\chi_{bJ} \rightarrow \Upsilon$
- Several theoretical mechanisms contributing:
  - Color Singlet (calculation now available at NNLO)
  - Color Octet in the NRQCD formalism
- No model predicting successfully both cross-section and polarization at TeVatron





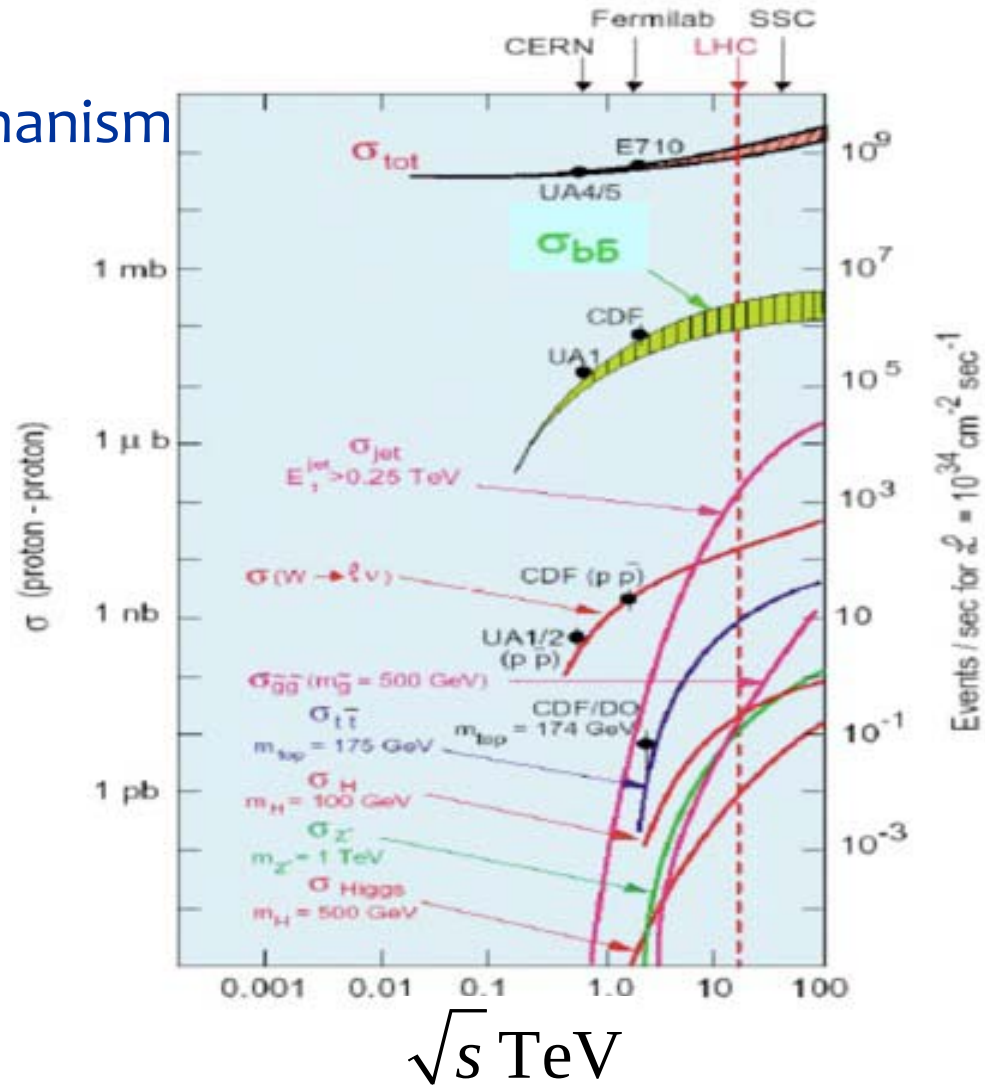




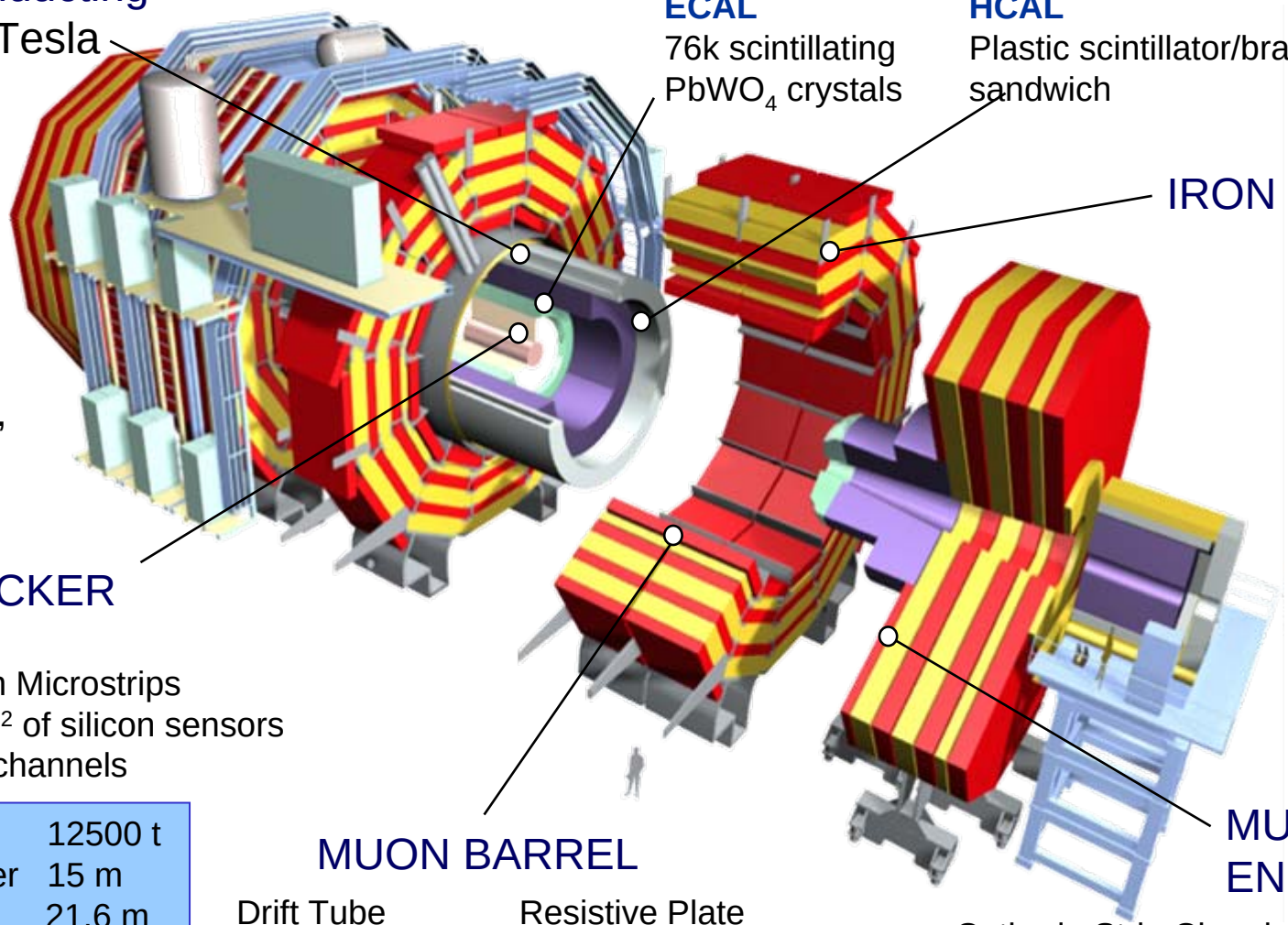


Why Quarkonia in Early LHC data?

- Theoretical Motivation
  - Quarkonia production mechanism at hadron colliders not yet understood
- LHC provides:
  - New energy scale!
  - Large p_T reach
  - Early measurements
  - Detector Calibration



Compact Muon Solenoid



Superconducting Coil, 3.8 Tesla

CALORIMETERS

ECAL
76k scintillating $PbWO_4$ crystals

HCAL
Plastic scintillator/brass sandwich

IRON YOKE

38 Nations,
182 Institutions,
2900 scientists

TRACKER

Pixels
Silicon Microstrips
210 m^2 of silicon sensors
9.6M channels

Total weight	12500 t
Overall diameter	15 m
Overall length	21.6 m

MUON BARREL

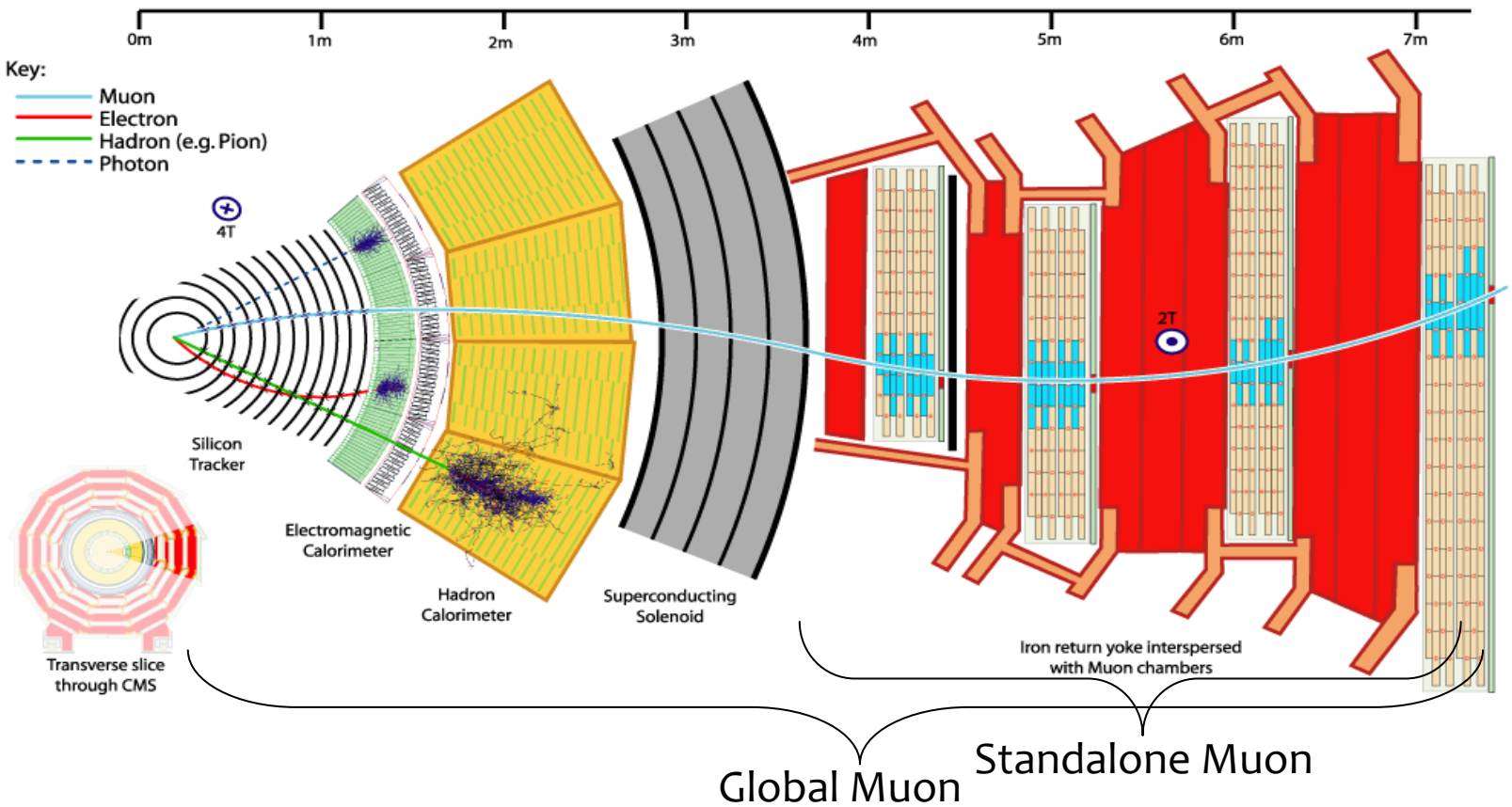
Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Muon Reconstruction



Low p_T muons might not traverse more than one instrumented muon layer because of the B-field (mid-rapidity) or material thickness (forward).

Tracker muon reconstruction starts from a silicon track and search for a compatible muon signal (even in one instrumented layer.) Tight quality cuts are applied on the track-segment match.

CMS Quarkonia Program

- Two analyses targeting early data
  - Inclusive total and differential production cross section of J/ψ in the di-muon channel
    - $O(0.1\ pb^{-1})$: Total cross section (prompt J/ψ + b-hadron not distinguishable), possibly differential in coarse p_T binning
    - $O(1\ pb^{-1})$: Differential cross section in finer p_T / rapidity binning, separation of prompt J/ψ + b-hadron, [measurement of $\sigma(\psi')/\sigma(J/\psi)$]
  - Measurement of the inclusive Upsilon production cross section in the di-muon channel
    - $O(0.1\text{-}1\ pb^{-1})$: Differential cross section in p_T, measurement of $[\sigma(\Upsilon(2S)) + \sigma(\Upsilon(3S))] / \sigma(\Upsilon(1S))$
- Other important analyses which need more statistics:
  - Quarkonium polarization
  - χ_{cJ} production using $\chi_{cJ} \rightarrow J/\psi\ \gamma$ …

On to Measuring cross section

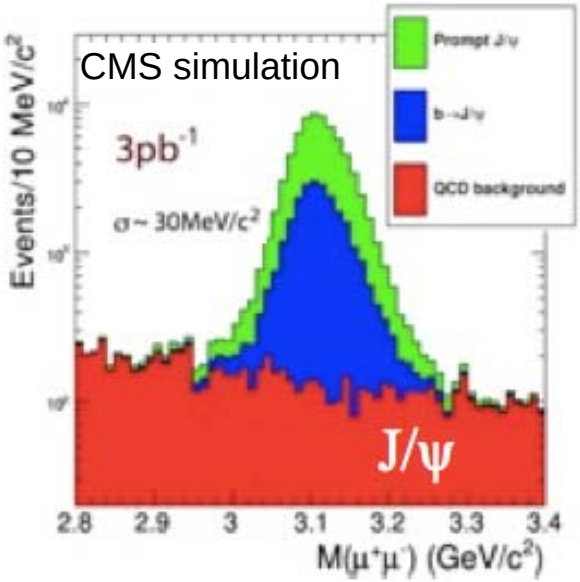
$$\frac{d^2\sigma}{dp_T dy}(Q\bar{Q}) \cdot BR(Q\bar{Q} \to \mu^+\mu^-) = \frac{N_{Q\bar{Q}}}{\int Ldt \cdot A \cdot \varepsilon_{trigger} \cdot \varepsilon_{reco} \cdot \Delta p_T \cdot \Delta y}$$

- $N_{Q\bar{Q}}$ = the number of reconstructed QQbar in a given p_T bin obtained from a fit to the mass spectrum
- $\int Ldt$ = integrated luminosity
- A = signal acceptance and efficiency (from MC modeling)
- $\varepsilon_{trigger} \cdot \varepsilon_{reco}$ = trigger/reconstruction efficiency MC/data correction (to be determined with "tag-and-probe" method)
- $\Delta p_T \cdot \Delta y$ = p_T / y bin size

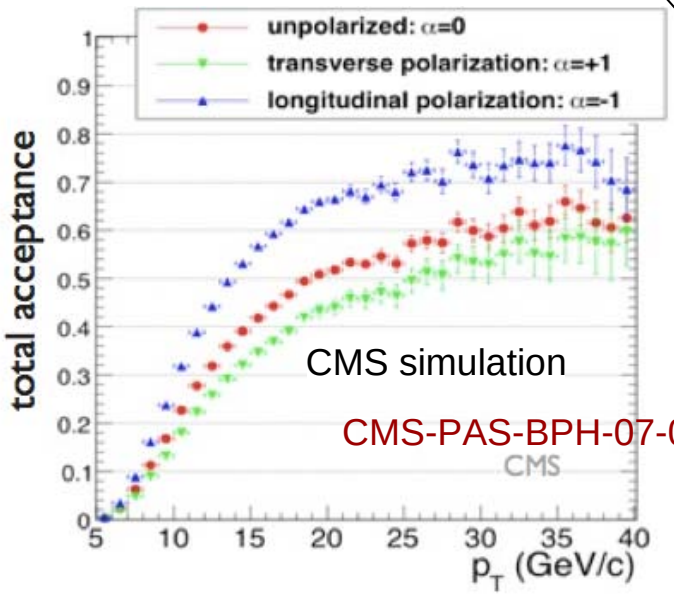
Measurement Ingredients

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

CMS-PAS-BPH-07-002



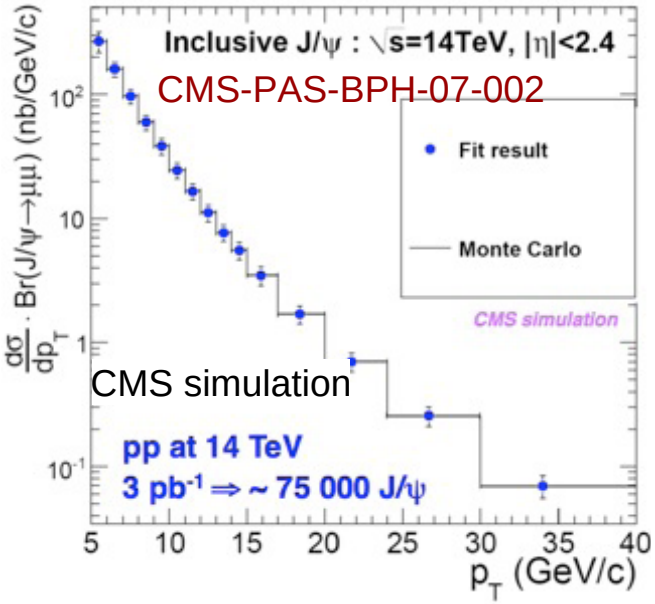
Acceptance is a strong function of the unknown production polarization



will be measured via a data-driven technique- "Tag and Probe"

J/Ψ Differential Cross Section

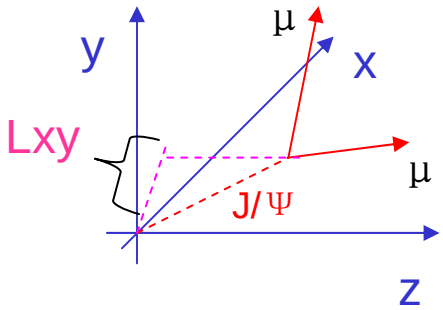
- Signal:
  - direct production (prompt)
  - from χ_c, ψ' decays (prompt)
  - from b hadron decays (non-prompt)

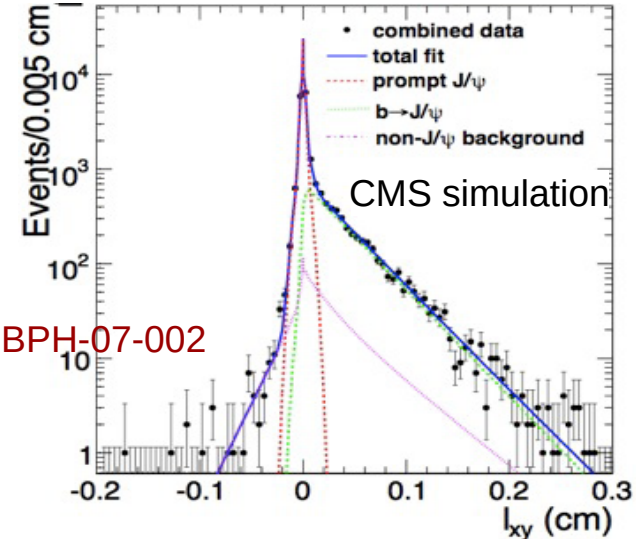


- measure inclusive, prompt, non-prompt production cross sections
- dominant systematics: Luminosity, Polarization, Fit
- competitive with Tevatron from first pb^{-1}
- probe cross section beyond 20 GeV/c after 3 pb-1 for the first time

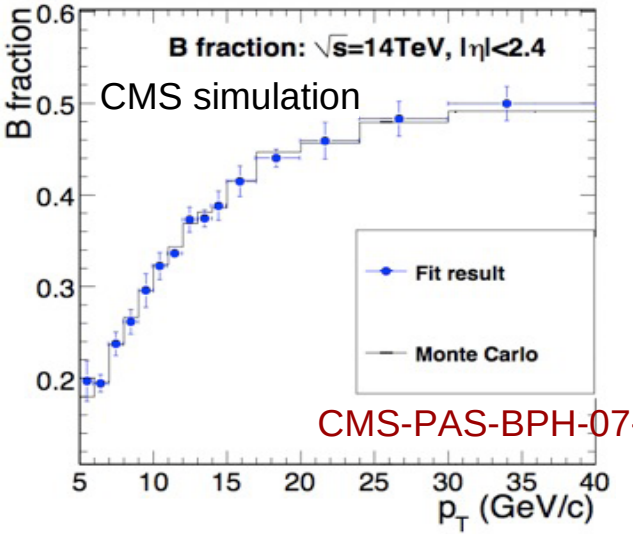
Disentangling Prompt and Non-prompt J/Ψ

- Based on pseudo-proper decay length $l_{xy} = \frac{L_{xy}^{J/\psi} M_{J/\psi}}{p_T^{J/\psi}}$
- yield determined from simultaneous likelihood fit to M and lxy in each p_T bin
  - signal PDF from MC convoluted with a double Gaussian resolution
  - background PDF fixed from MC sidebands
- Depending crucially on:
  - Pixel alignment
  - Beam-spot stability or PV resolution





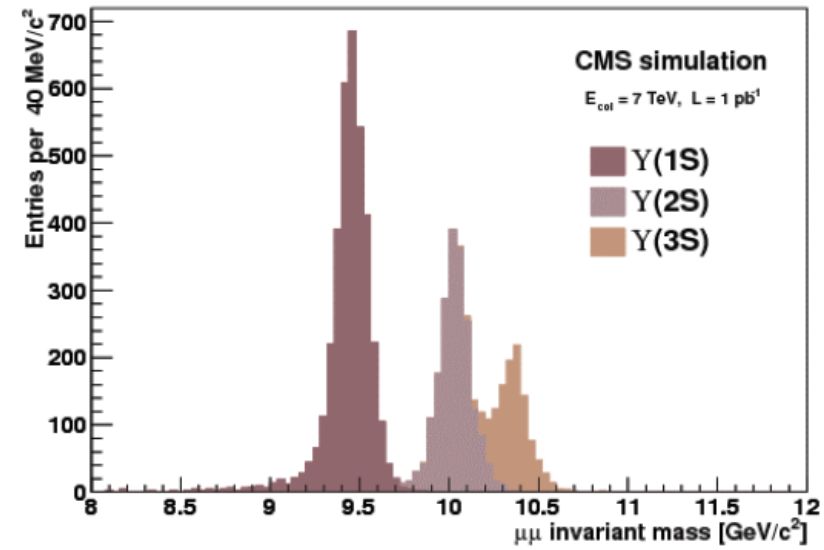
CMS-PAS-BPH-07-002

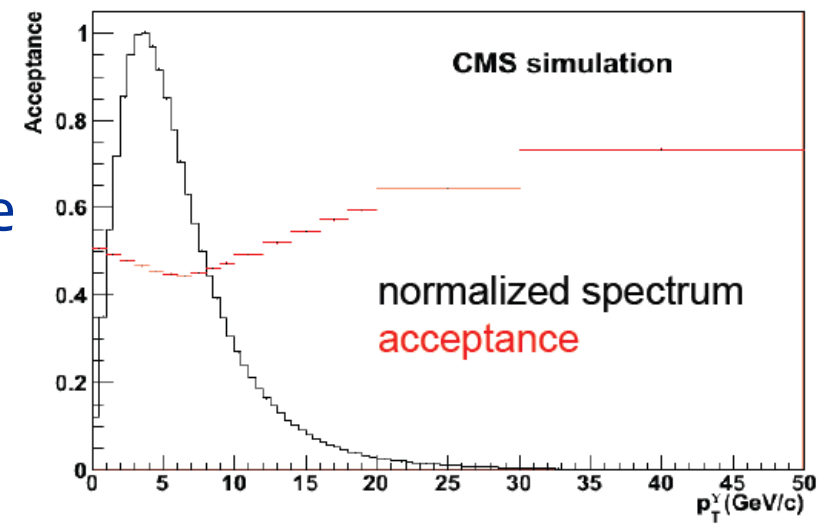


CMS-PAS-BPH-07-002

Y(ns) Cross Section

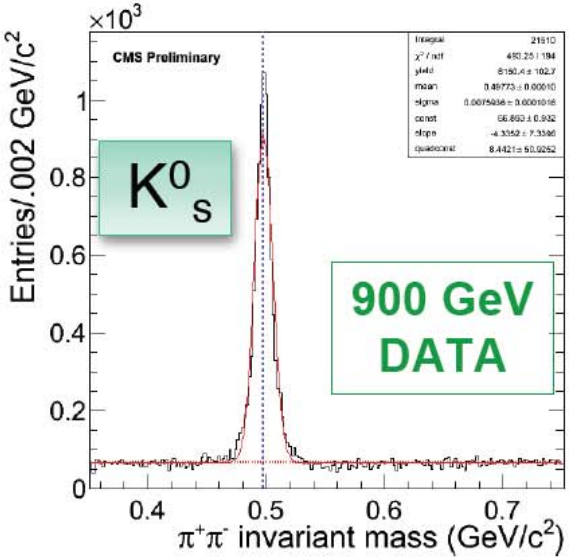
- The expected yield of reconstructed Y(ns) -> $\mu^+\mu^-$ in CMS is a few thousand per pb^{-1}
- The Plan is to have a result with o(1/pb)
  - first extension to 20-30 GeV in p_T, also $|y|>1.8$ -> add a new bin to the DØ results
  - Y(2S)+Y(3S) cross-section can be measured relative to Y(1S)
    - not affected by various systematic uncertainties



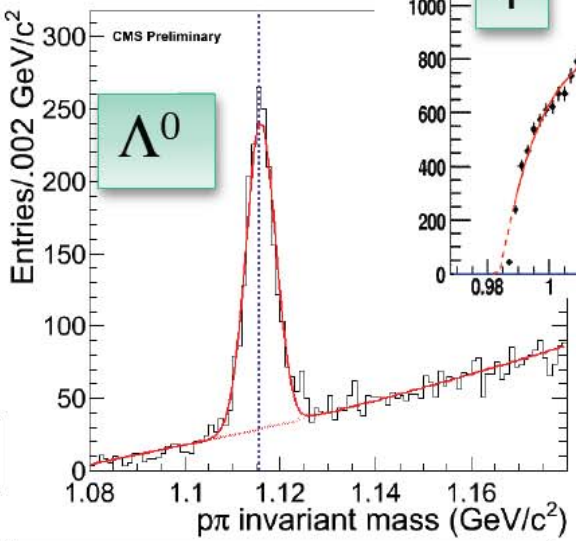


Light Mesons in Early 900GeV Collision

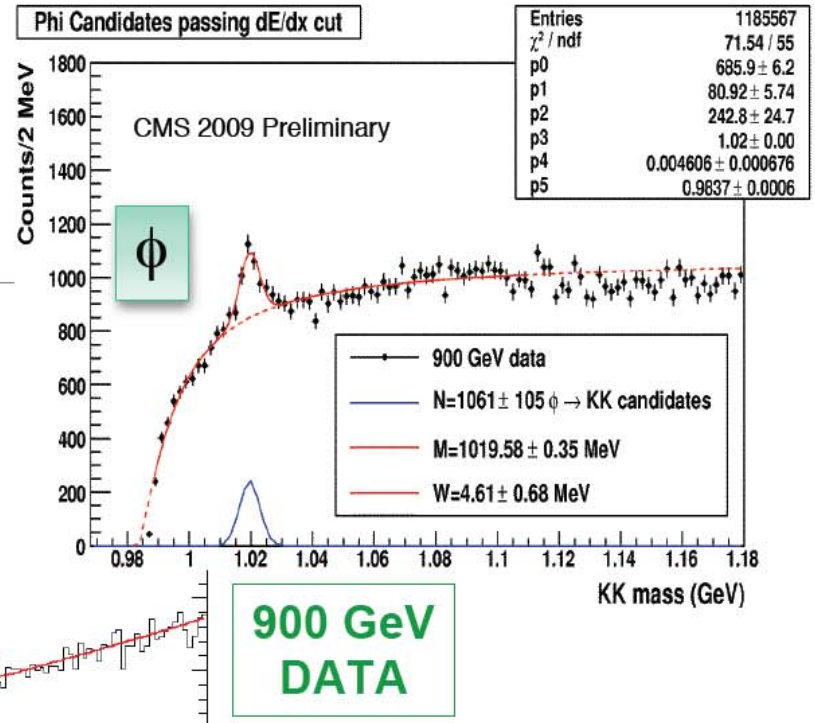
Real Data!!



M=497.7 MeV/c^2, σ=7.6 MeV/c^2

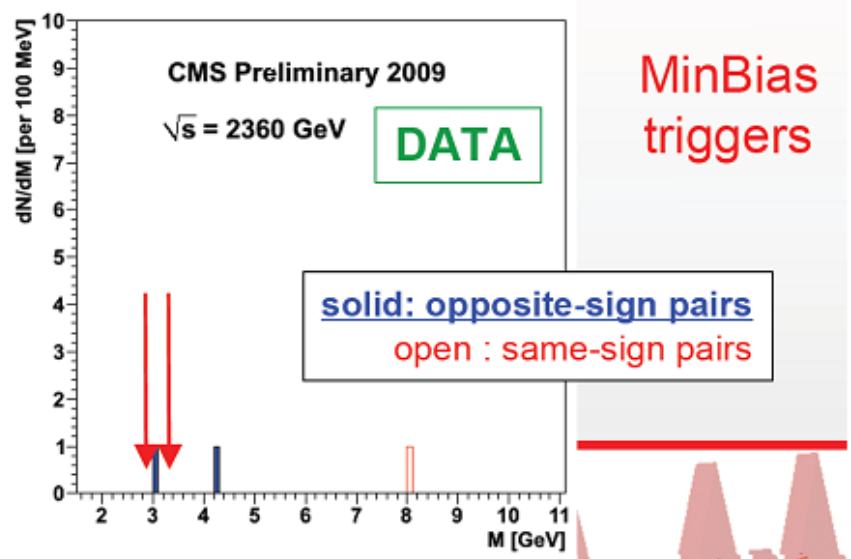


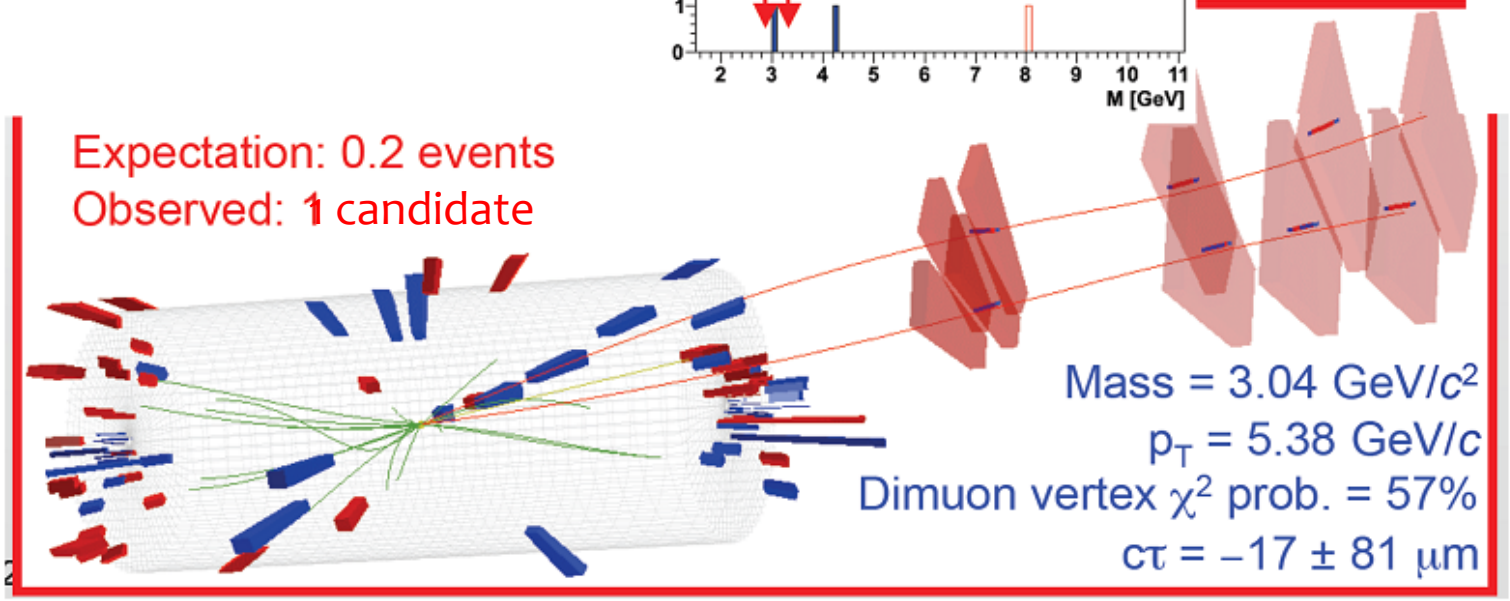
M=1.116 GeV/c^2, σ=3.1 MeV/c^2



J/Ψ Events in 2.36 TeV Collision

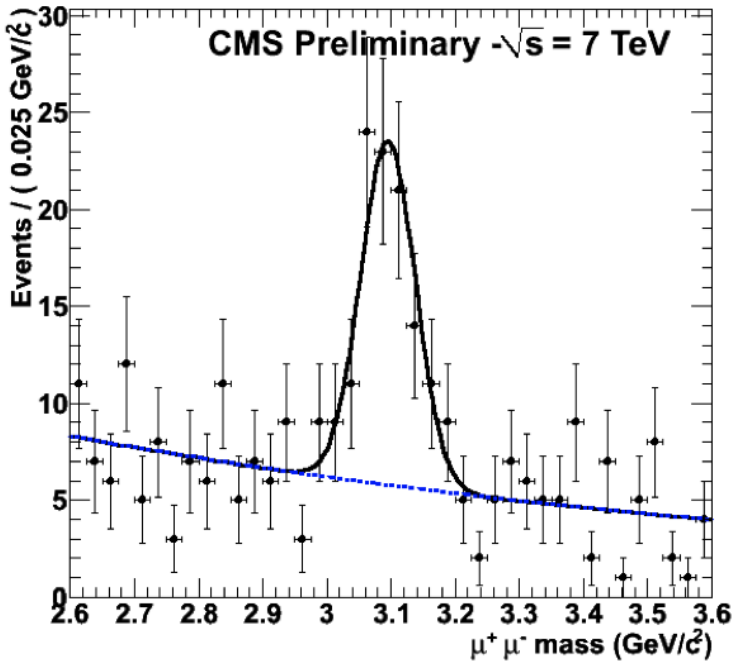
- 2.36 TeV Collisions
- MinBias trigger
- One J/Psi Candidate (0.2 expected)
- Very forward, μμ in endcap



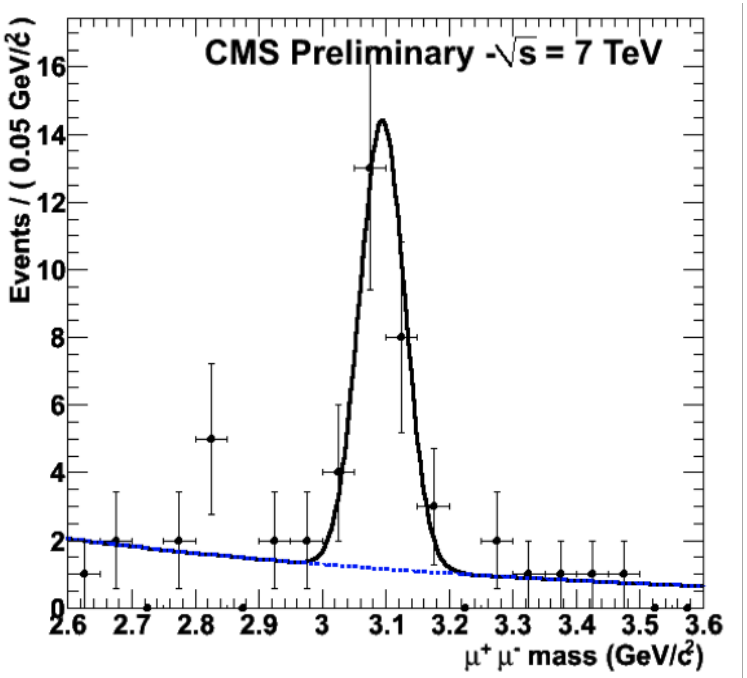


J/Ψ Yield in Early 7TeV Collisions

GLOBAL-GLOBAL + GLOBAL-TRACKER DI-MUONS



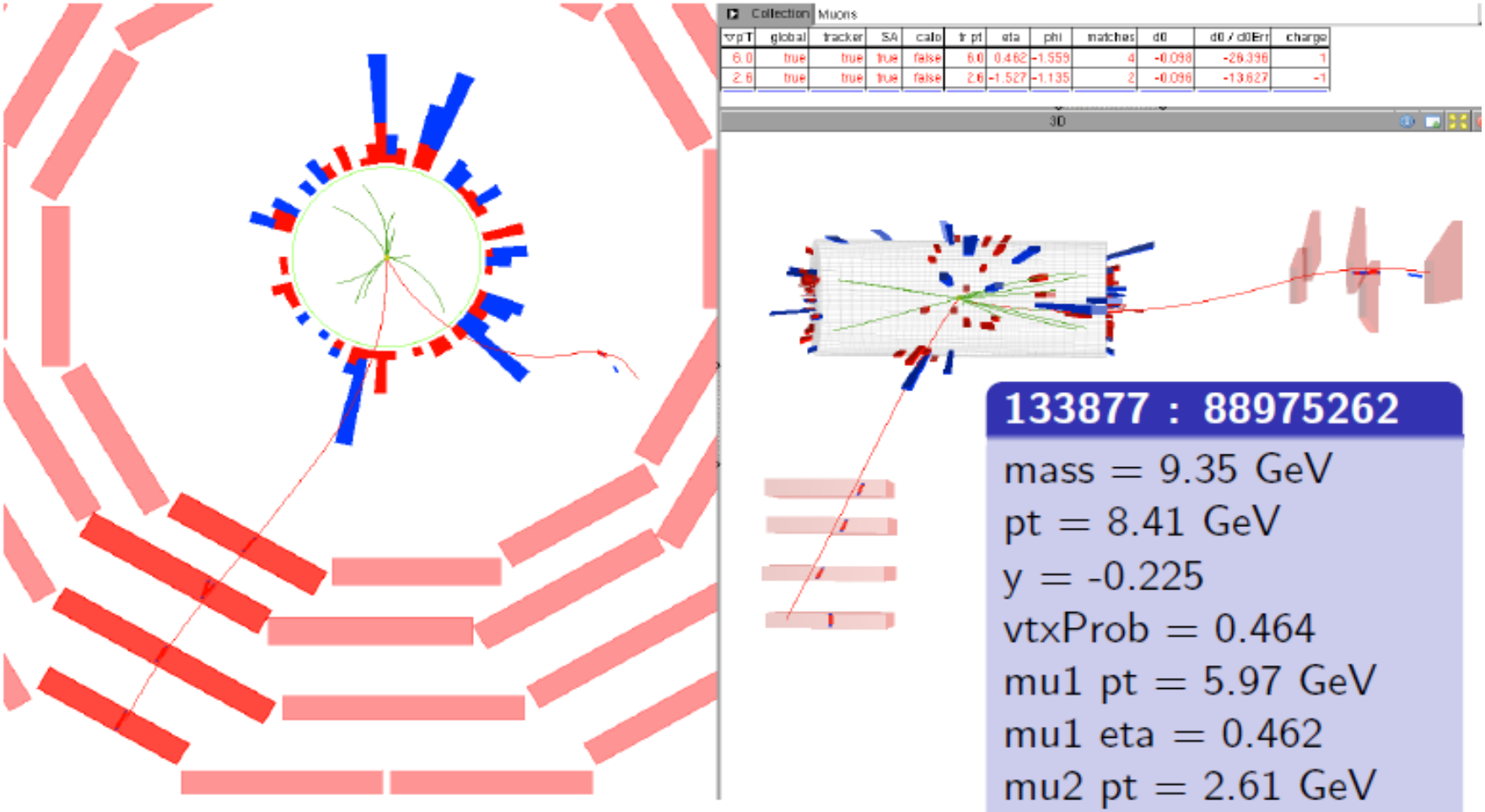
GLOBAL-GLOBAL DI-MUONS



Category	Mass (MeV/c^2)	RMS (MeV/c^2)	Signal
GG + GT	3095± 7	42.5±6.3	76± 12
GG	3094± 9	35.5±6.8	24± 5

Integrated luminosity: 0.985/nb

An Upsilon Candidate in Early 7TeV Collisions



▽pT	global	tracker	SA	calo	tr pt	eta	phi	matches	d0	d0 / d0Err	charge
6.0	true	true	true	false	6.0	0.462	-1.559	4	-0.098	-26.396	1
2.6	true	true	true	false	2.6	-1.527	-1.135	2	-0.096	-13.627	-1

133877 : 88975262

mass = 9.35 GeV
pt = 8.41 GeV
y = -0.225
vtxProb = 0.464
mu1 pt = 5.97 GeV
mu1 eta = 0.462
mu2 pt = 2.61 GeV
mu2 eta = -1.53

Summary

- J/Ψ and Υ(nS) cross-section measurements are the main targets for the CMS Quarkonium Program in early data.
- Feasibility:
  - Feasible with O(0.1 pb^{-1}): Measurement of the (not so) differential Υ and J/Ψ cross-section in p_T only. p_T-integrated prompt-non prompt J/Ψ separation may be possible
  - Feasible with O(1 pb^{-1}): Measurement of prompt-non prompt J/Ψ and Υ cross-sections differential in p_T, possibly in rapidity
- Stay tuned…..

Back up

Early B Physics Program

$\sim 0.1\mathrm{pb}^{-1}$

- Inclusive J/ψ differential cross section ($\sim$100nb)
  - b-hadron production cross section

$\sim 1\mathrm{pb}^{-1}$

- Υ(nS) differential cross section ($\sim$10nb)

$\mathcal{L}_{\mathrm{int}}$

$\sim 10\mathrm{pb}^{-1}$

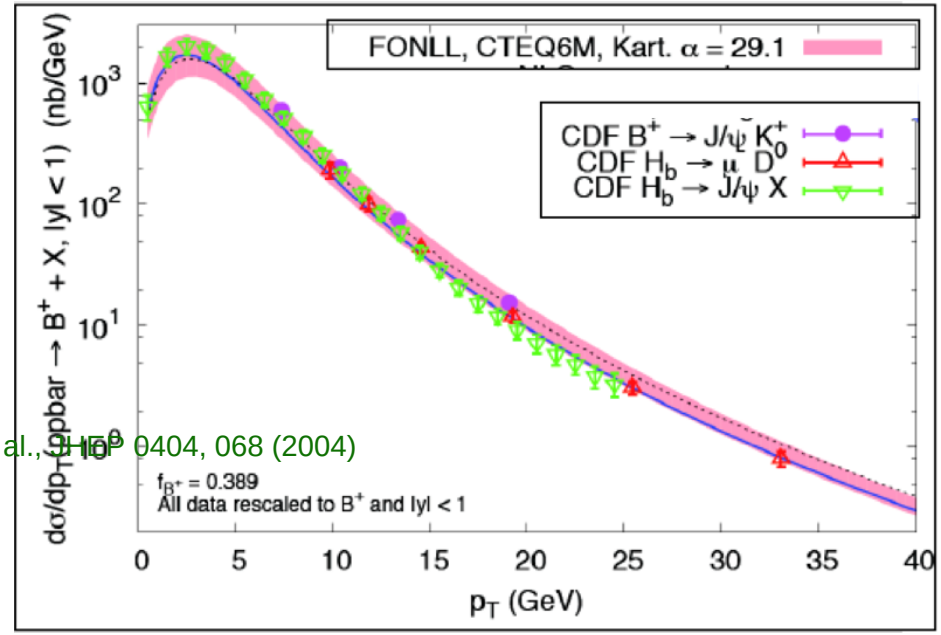
$\sim 100\mathrm{pb}^{-1}$

- $b\bar{b}$ correlations
- Quarkonia polarization

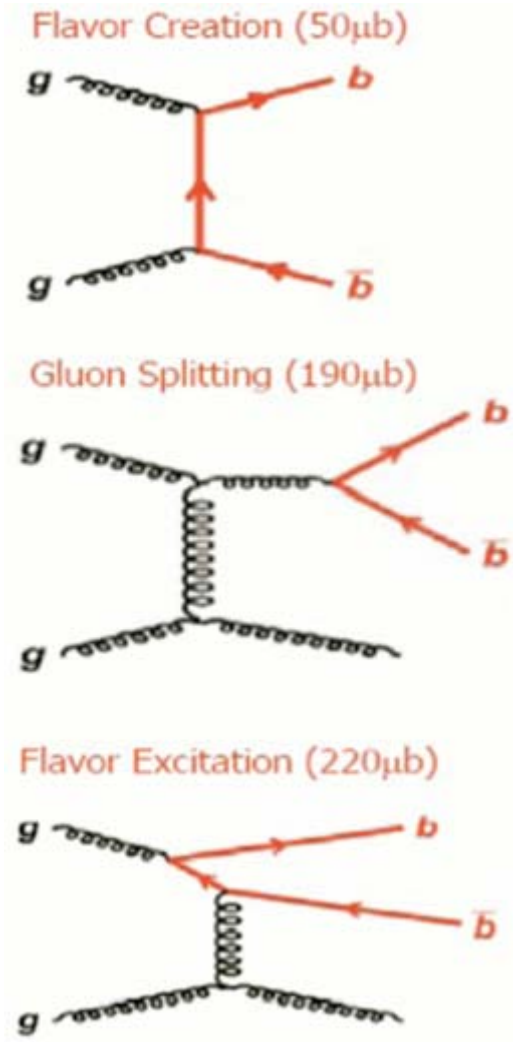
All early analyses use muons in the final state

bb Production Mechanism

- goal of study: test of NLO QCD, production topology, tune Monte Carlo generators for more realistic estimations of bb background for NP searches
- At TeVatron good theory-data agreement:
  - FONLL approach
  - Improved b- fragmentation function (LEP Zo → bb data)



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



bb correlations

- Use $b\bar{b} \rightarrow J/\Psi(\rightarrow \mu^+\mu^-)X + \mu^{\pm}X$
- $\Delta\phi = \phi_{J/\psi} - \phi_{\mu}$ is a highly discriminating quantity between production mechanisms
- signal yield measured in $\Delta\varphi$ bins, via a simultaneous Likelihood fit to J/ψ mass, L_{xy}, IP_{μ}
  - $\Delta\phi_{bb}$ distribution obtained via unfolding
- dominant systematics to cross section:
  - luminosity, tracking and trigger efficiency
- for $\int Ldt \sim 50\ pb^{-1}$
  - 15-25% uncertainty in each $\Delta\varphi$ bin
  - 10% for integrated $\sigma(pp \rightarrow bbX)$