$J/\psi \rightarrow \mu\mu$ Cross Section Measurement

A Feasibility Study in Early Data

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On behalf of CMS collaboration

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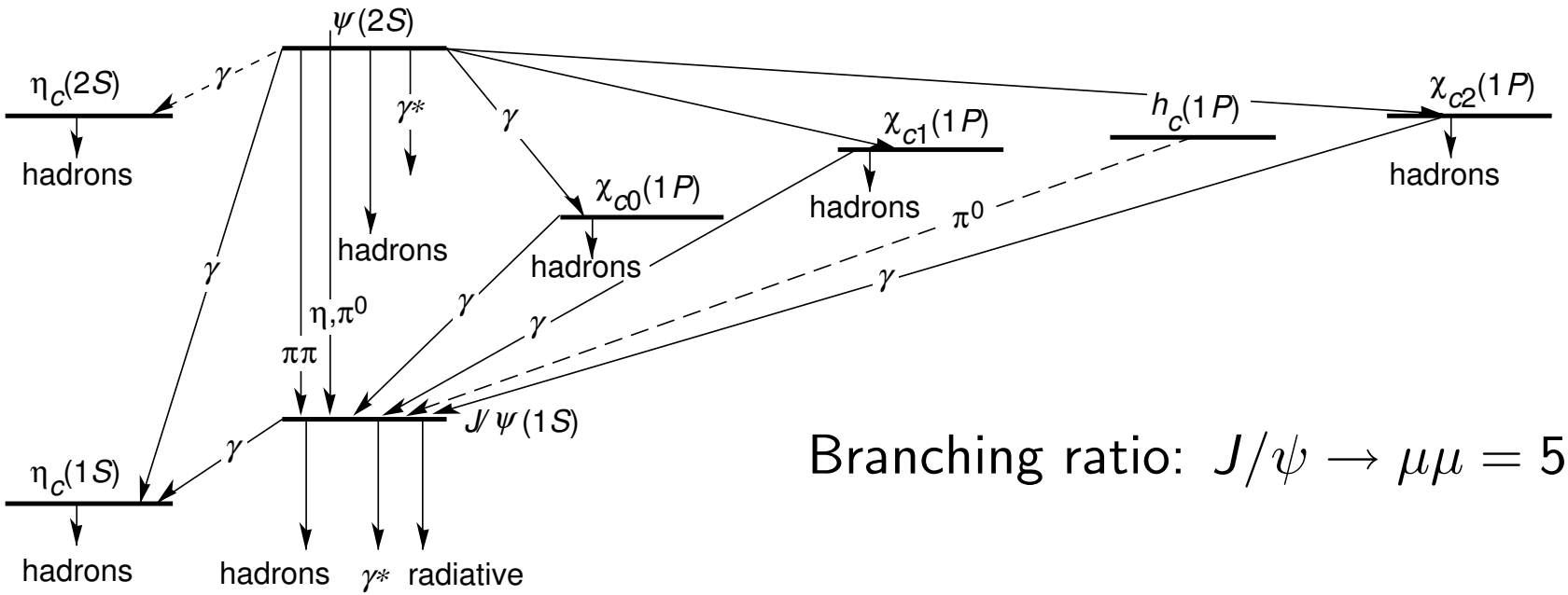
Workshop on Physics Opportunities with the First LHC Data
Berkeley, May 6, 2009

Outline

Production Types of J/ψ

1st step	2nd step	3rd step	Prod. type
	$c\bar{c} \to J/\psi$	–	Prompt,Direct
$p\bar{p} \to c\bar{c} + X$	$c\bar{c} \to \chi_c$	$\chi_c \to J/\psi + \gamma$	Prompt,Indirect
	$c\bar{c} \to \psi'$	$\psi' \to J/\psi + X$	Prompt,Indirect
$p\bar{p} \to \bar{b}c + X$	$c\bar{c} \to J/\psi$	–	Non-prompt
$\bar{b}c \to \bar{c}c + l^- + \nu_l$	$c\bar{c} \to \chi_c$	$\chi_c \to J/\psi + \gamma$	Non-prompt

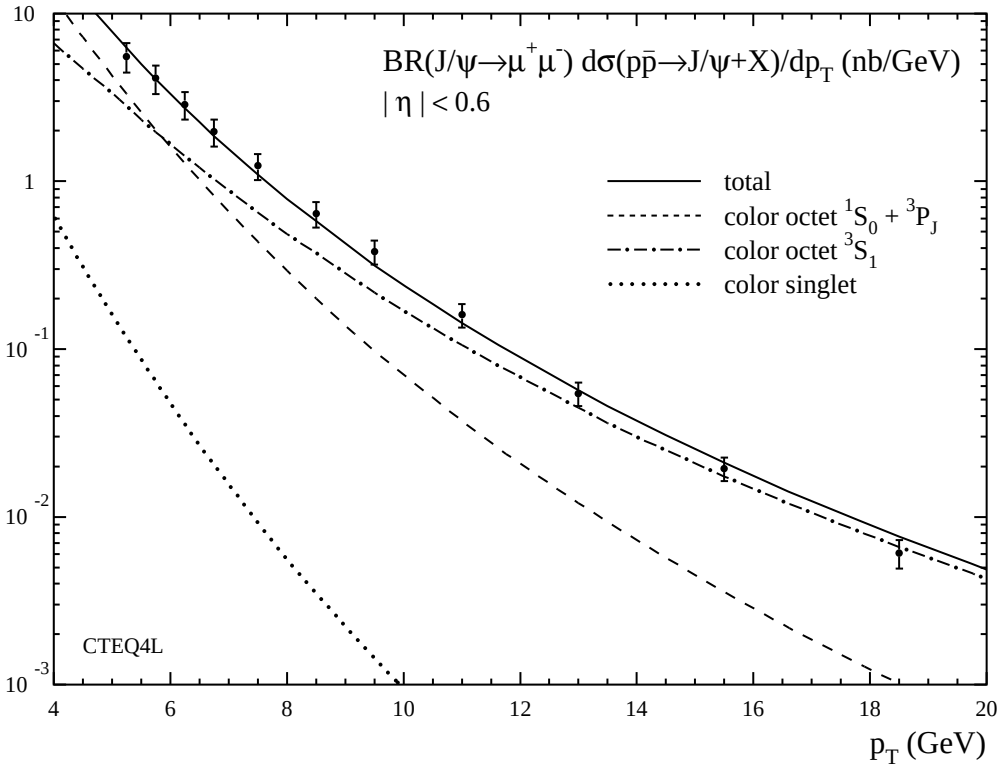


Branching ratio: $J/\psi \to \mu\mu = 5.88\%$

J^{PC} = 0^{-+} 1^{--} 0^{++} 1^{++} 1^{+-} 2^{++}

Measurements at Hadron Colliders

Color Octet Model of Non-relativistic QCD fits CDF cross-section measurement well



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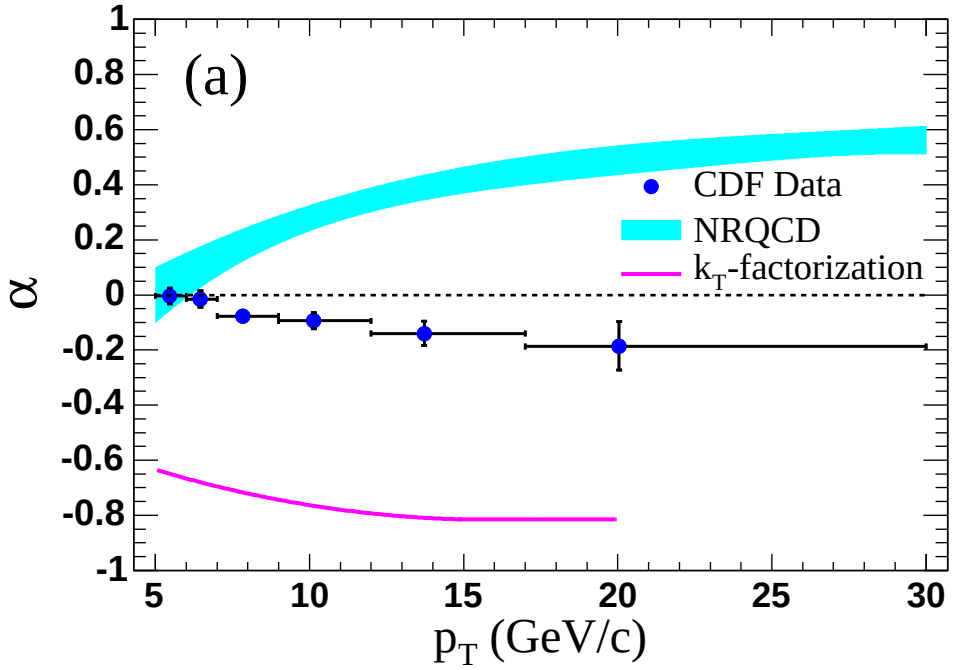
Non-relativistic QCD predictions are in disagreement with the CDF polarization measurement



Phys.Rev.Lett.99:132001,2007

Review: Int. J. Mod. Phys. A, Vol. 21, Nos. 19 & 20 (2006) 3857-3915

Motivations

1. Production mechanism of J/ψ is not well understood
   - LHC with high luminosity and large p_T J/ψs has the potential to discriminate between the theoretical models
2. Large cross section of J/ψ production allows its measurement in early data at a new energy scale of 10TeV
3. J/ψs are important for calibration and alignment of the detector

Monte Carlo Samples, $\sqrt{s} = 14$GeV

Signal Samples:

- Prompt J/ψ
  - Leading Order, Color Singlet and Octet Mechanisms
  - No polarization
  - 2 muons with $p_T > 2.0$GeV and $|\eta| < 2.5$ gen. filter
- Non-prompt J/ψ
  - QCD $2 \rightarrow 2$, B-hadron decays
  - 2 muons with $p_T > 2.0$GeV and $|\eta| < 2.5$ gen. filter

Background Samples:

- Muon enriched QCD
  - QCD $2 \rightarrow 2$, heavy flavor quark decays
  - Decays in flight
  - 1 muon with $p_T > 2.5$GeV and $|\eta| < 2.5$ gen. filter
- Drell-Yan
  - 2 muons with $p_T > 2.0$GeV and $|\eta| < 2.5$ gen. filter

Full GEANT simulation, CMSSW reconstruction software

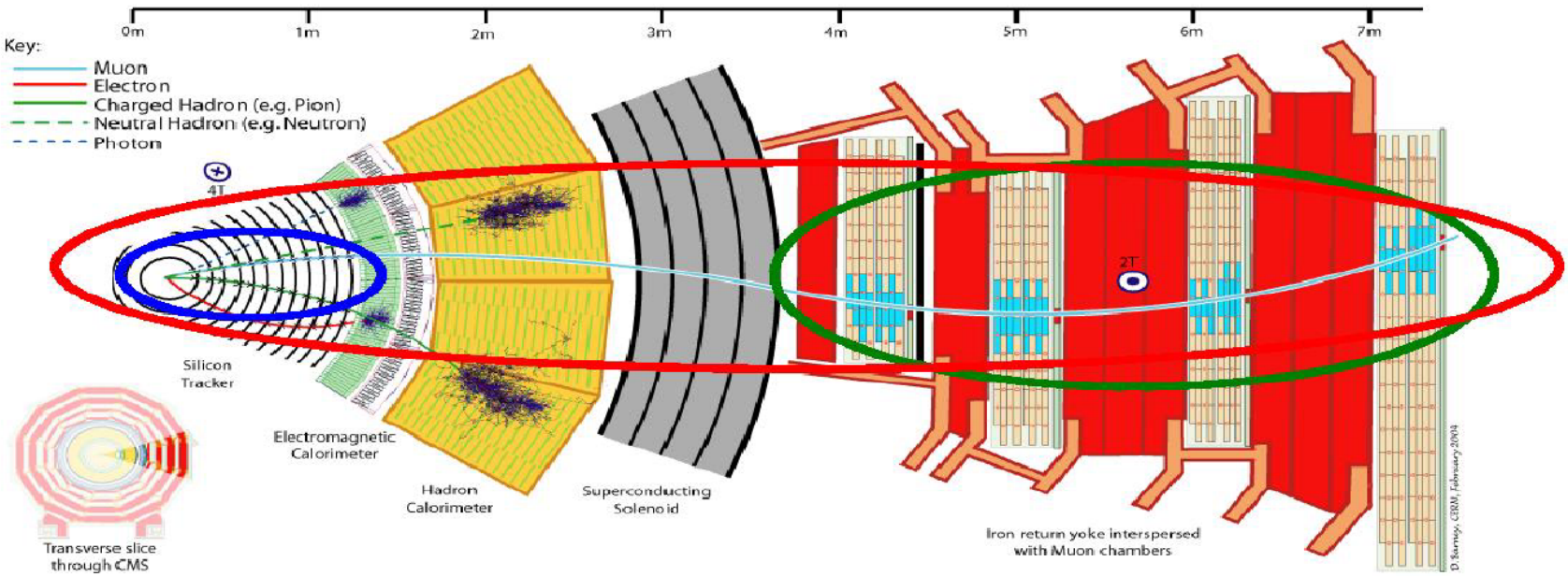
J/ψ Trigger

- Level1 Trigger (L1):
  - L1 muon objects are based on muon chamber information only
  - requires 2 L1 muons with $p_T > 3\text{GeV}$
- High Level Trigger (HLT):
  - HLT muon objects confirm L1 muons and add silicon tracker information to improve p_T resolution
  - requires 2 HLT muons with $p_T > 3\text{GeV}$
  - opposite charge
  - and $2.8\text{GeV} < \text{invariant mass} < 3.4\text{GeV}$
- Rates assume instantaneous luminosity of $10^{32}\text{cm}^{-2}\text{s}^{-1}$
- Number of events normalized to 3pb^{-1} of data

	Trigger rate (Hz)	Number of events
Prompt J/ψ	1.92	58K
B-decay J/ψ	0.85	26K
QCD background	0.40	12K

Muon Reconstruction

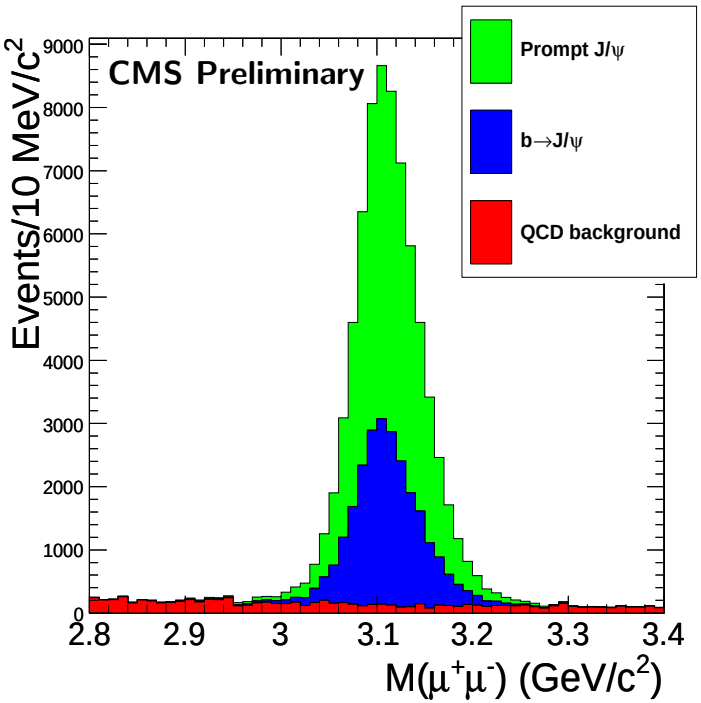
- Global Muons combine Stand Alone Muons in the muon system with matched Tracker Tracks in the tracking system
- Reconstruction efficiency for $p_T > 7$GeV and $|\eta| < 2.4$ is about 95%
- Momentum resolution is at percent level

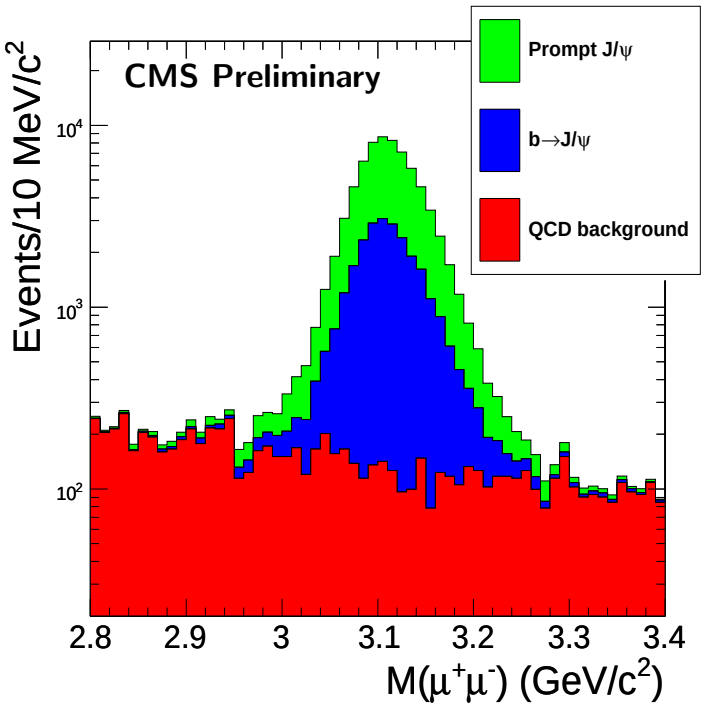


Tracker Track **Global Muon** **Stand Alone Muon**

Dimuon Spectrum

- Event Selection:
  - Two Global Muons with $p_T > 3$GeV and opposite charge
  - Muons required to come from a common vertex
- Drell-Yan is less than 1% of QCD background (omitted)
- Two fake muon background is estimated to be ∼10% of QCD background (systematic uncertainty)





Differential Cross Section Measurement

$$\left.\frac{d\sigma\left(J/\psi\right)}{dp_T}\right|_{|\eta|<2.4} Br\left(J/\psi \to \mu^+\mu^-\right) = \frac{N^{fit}_{J/\psi}}{\int \mathcal{L}dt \cdot A \cdot \lambda^{corr}_{trig} \cdot \lambda^{corr}_{reco} \cdot \Delta p_T}$$

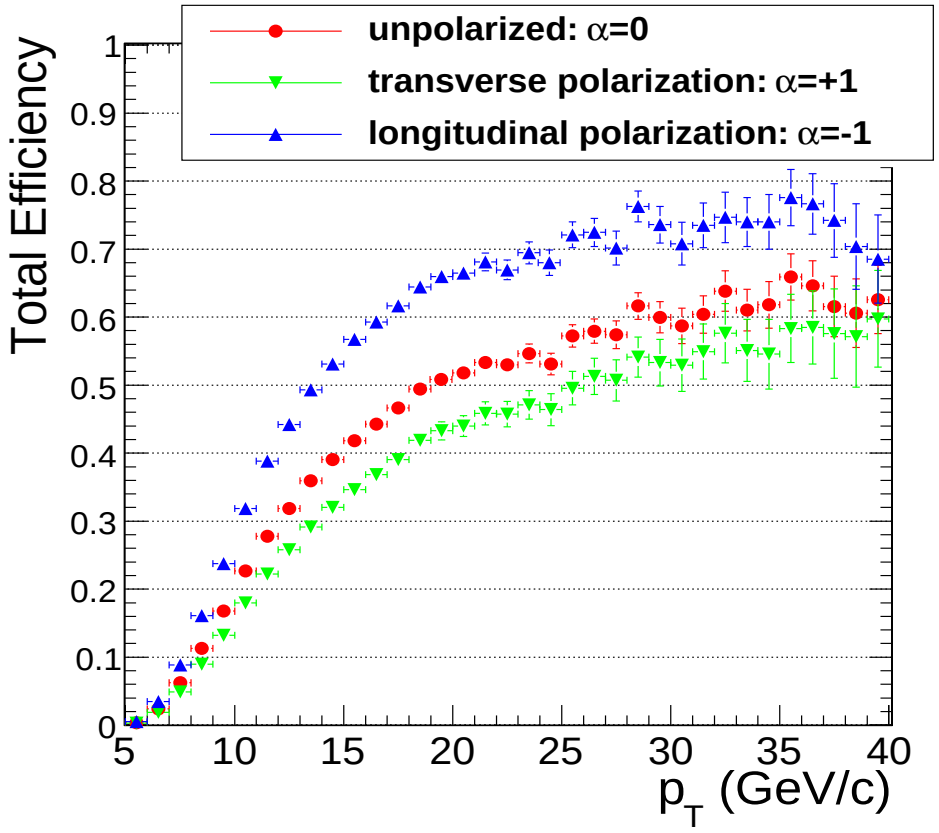
- N^{fit}_{Υ} – Number of reconstructed J/ψs in a given p_T bin as obtained from the mass fit using double Gaussian signal and linear background
- $A(p_T^{J/\psi})$ – Total efficiency of triggering and reconstructing J/ψ events including finite acceptance of the detector, measured in MC
- λ^{corr} – correction factors to the trigger and reconstruction efficiencies measured using Tag and Probe method in data and MC
- $\int \mathcal{L}dt$ – integrated luminosity
- Δp_T – J/ψ p_T bin size

Total Reconstruction Efficiency

Total reconstruction efficiency combines

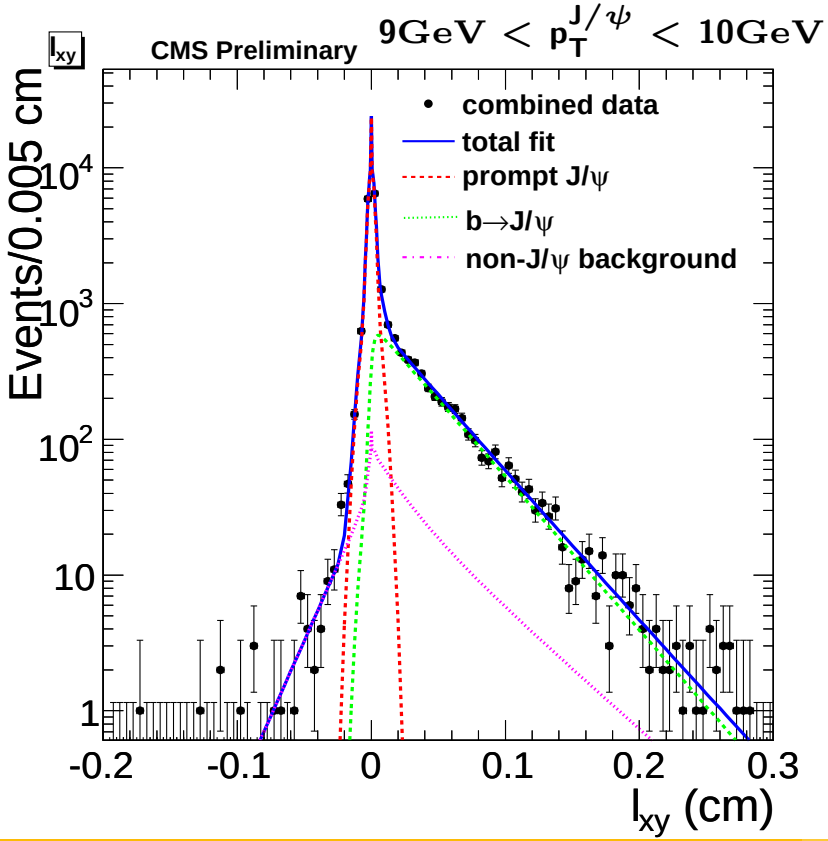
- Detector acceptance
- Trigger efficiency
- Reconstruction efficiency

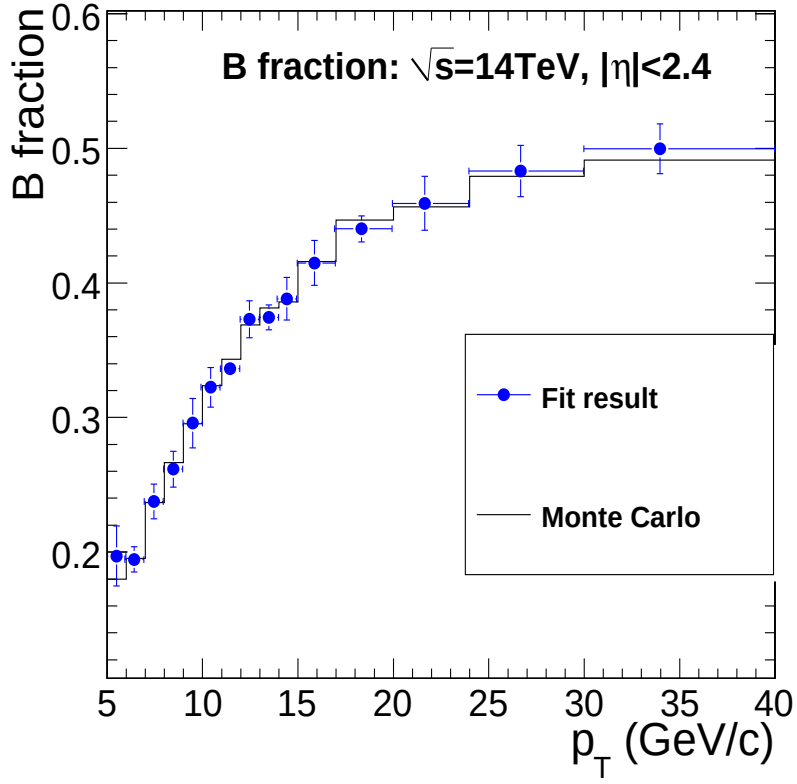
Detector acceptance depends on polarization (systematics)



Disentangling Prompt and Non-prompt J/ψ

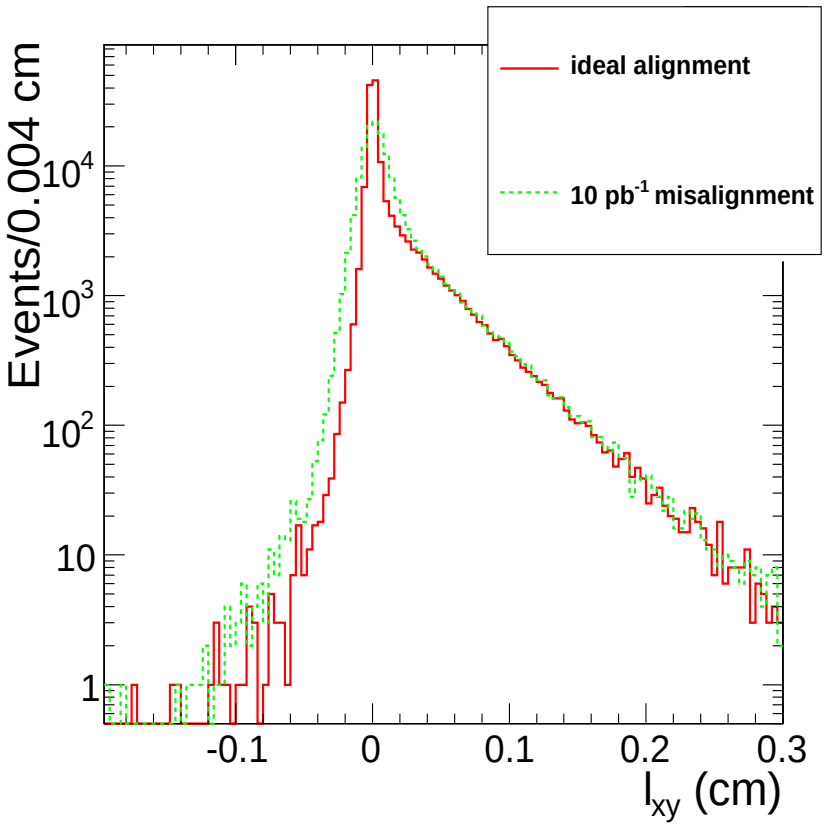
- Based on pseudo-proper decay time of B-hadrons $l_{xy} = \frac{L_{xy}^{J/\psi} M_{J/\psi}}{p_T^{J/\psi}}$
- Unbinned maximum likelihood fit simultaneously to mass and pseudo-proper decay time in each $p_T^{J/\psi}$ bin
- Signal PDFs from MC convoluted with a resolution function





Effects of Misalignment

- Samples are reconstructed with different alignment scenarios
- Relative difference in B-hadron fractions is 4% (plot)
- J/ψ mass resolution averaged over all $p_T^{J/\psi}$ range is shown in table



Alignment after	J/ψ mass resolution
$10\mathrm{pb}^{-1}$	34.2 MeV
$100\mathrm{pb}^{-1}$	30.5 MeV
ideal	29.5 MeV

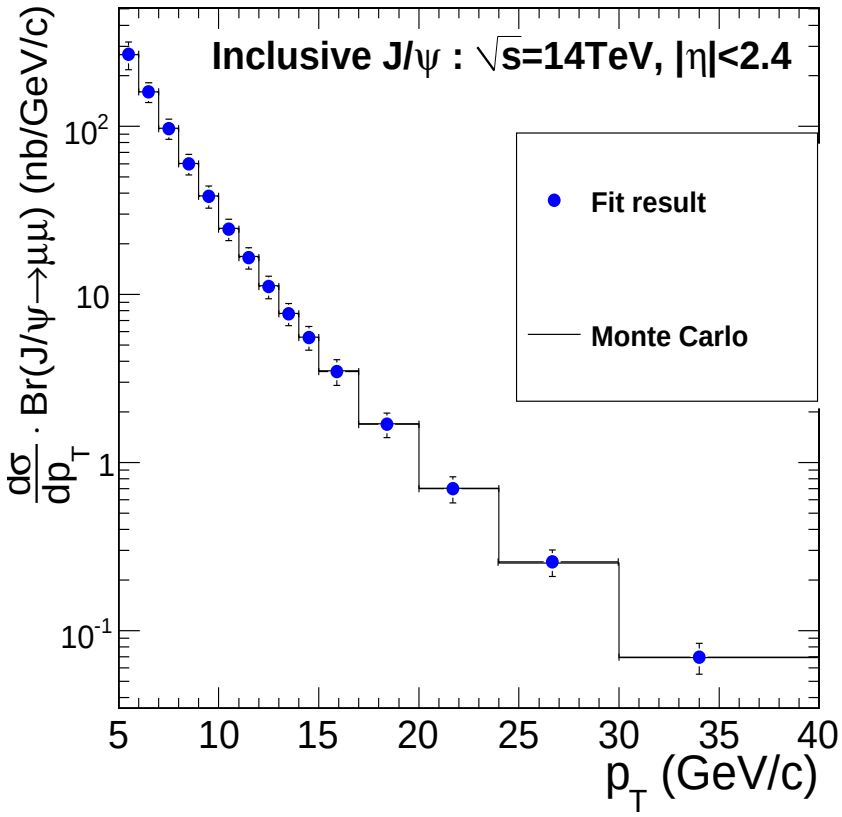
Sources of Systematic Uncertainties

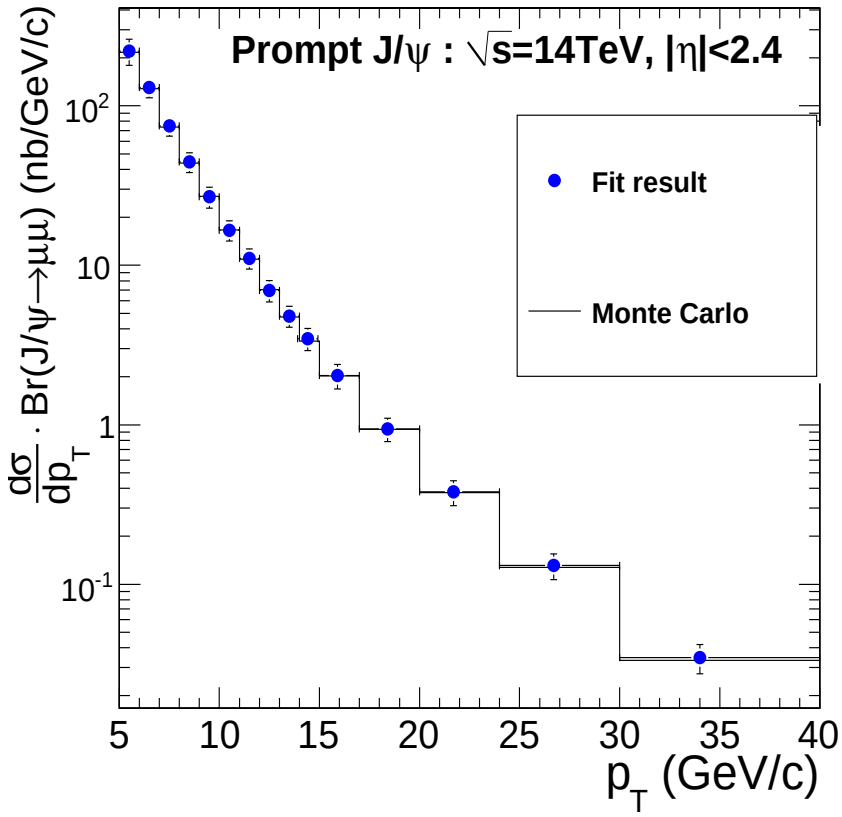
Parameter affected	Source	$\Delta\sigma/\sigma$
Luminosity	Luminosity	$\sim$10 %
Number of J/ψ	J/ψ mass fit	1.0 - 6.3 %
Number of J/ψ	Momentum scale	$\sim$1%
Total efficiency	J/ψ polarization	1.8 - 7.0%
Total efficiency	$p_T^{J/\psi}$ binning	0.1 - 10 %
Total efficiency	MC statistics	0.5 - 1.7 %
λ_{reco}	Non-perfect detector simulation	$\sim$5%
λ_{trig}	Non-perfect detector simulation	$\sim$5%
B fraction	l_{xy} resolution model	0 - 1.9 %
B fraction	B-hadron lifetime model	0.01 - 0.05 %
B fraction	Background	0.1 - 3.0 %
B fraction	Misalignment	0.7 - 3.5 %
	Total systematics $p_T^{J/\psi} \in (5,6)$GeV	13 %
	Total systematics $p_T^{J/\psi} > 20$GeV	19 %

Uncertainties evaluated in each $p_T^{J/\psi}$ bin

Results

- Results of inclusive and prompt cross section measurement
- Include systematic and statistical uncertainties
- Integrated luminosity of $3\mathrm{pb}^{-1}$





Summary

- We studied the feasibility of the J/ψ cross section measurement at CMS
- Prompt and non-prompt components are separated making use of large B-hadron lifetime
- Measurement with $3\mathrm{pb}^{-1}$ of data is dominated by systematic uncertainties ($\sim 15\%$)
- Measurement is feasible in early LHC data!