Measurement of exclusive B-hadron production at 7 TeV with the CMS experiment

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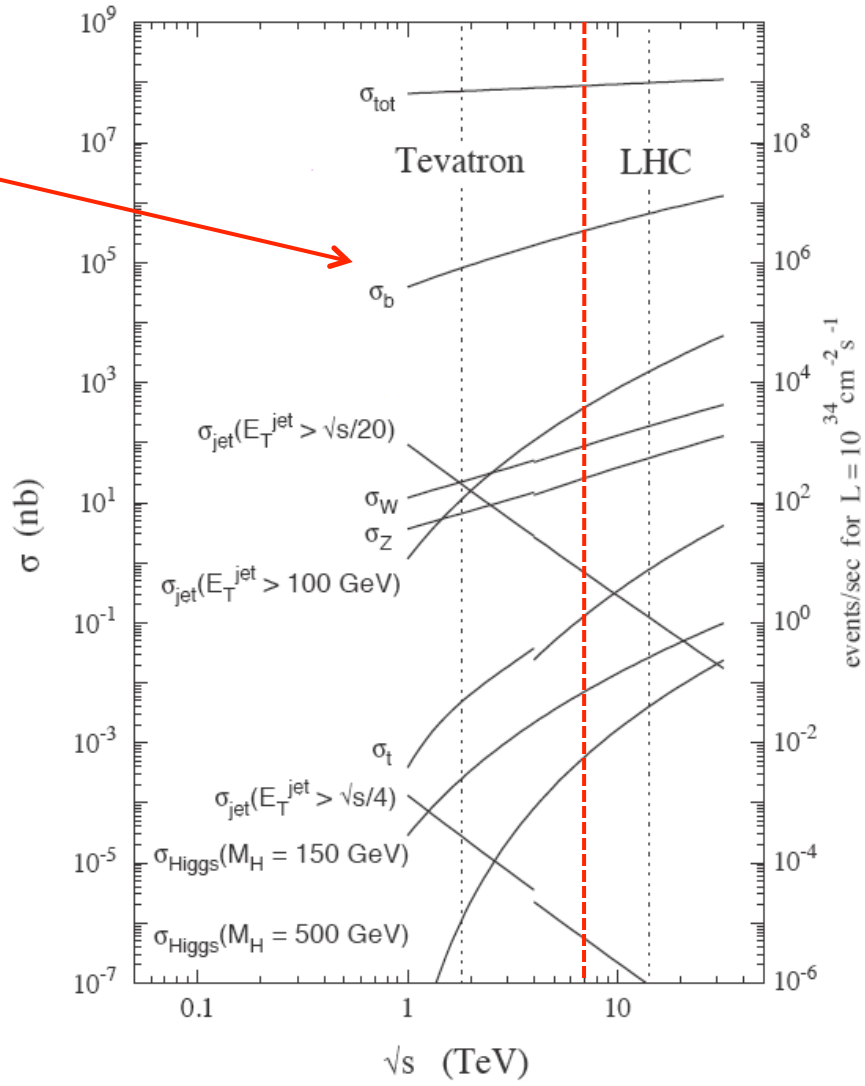
Contents

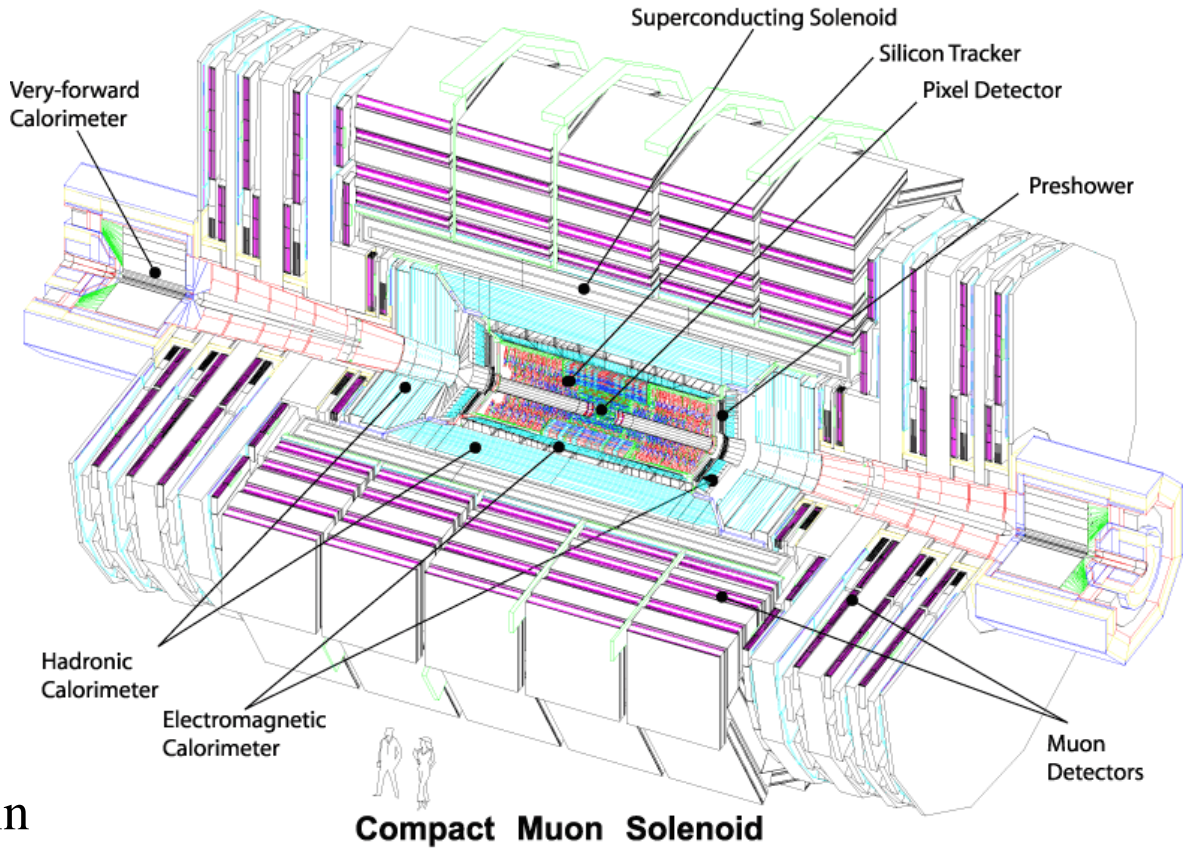
- Introduction
- The CMS detector
- Common to all: J/Ψ reconstruction
- $B^0 \rightarrow J/\Psi\ K_s(\pi^+\ \pi^-)$
- $B^+ \rightarrow J/\Psi\ K^+$
- $B^0_s \rightarrow J/\Psi\ \phi\ (K^+\ K^-)$
- Conclusion / Outlook

Introduction

- Early measurement possible due to large cross section
- Measurement at new energy allows tests of perturbative QCD and MC generators
- Improves understanding of b backgrounds for physics searches like Higgs, SUSY and other exotic physics
- Improves understanding of the detector, especially tracking and muon reconstruction



pp collisions @ a CM energy of 7 TeV/c^2
Data taken in 2010 with the CMS detector at the LHC



Main detector components for these analyses:
•Silicon tracker for $|\eta| < 2.5$ in a magnetic field of 3.8 T.
•Muon detector for $|\eta| < 2.4$

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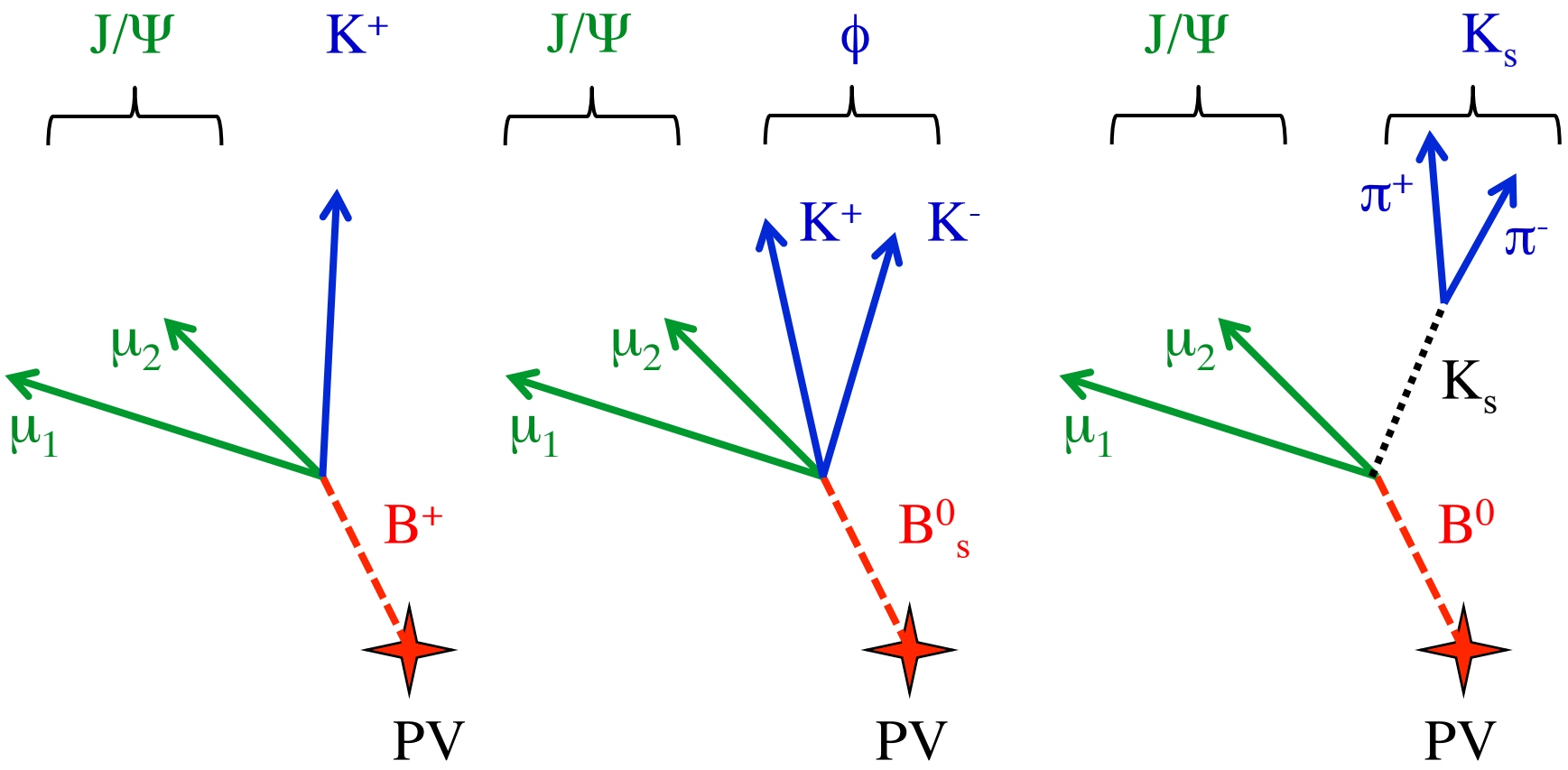
Exclusive B decays



Exclusive B decays

- Goal: measuring differential production cross-section in bins of p_T and y of the B mesons
- Strategy:
  - Build J/Ψ candidates from muons
  - Combine with 1 (2) tracks from same vertex to form B^+ (B^0_s) candidates or with 2 tracks from new vertex consistent with K_s mass for B^0 candidates
  - Kinematic fit with mass and vertex constraints
  - Extract signal yields from unbinned 2 dimensional maximum likelihood fit in variables m_B and ct with shape parameters determined from data as far as possible
- We don't distinguish between a neutral B meson and its charge conjugate.

J/Ψ reconstruction

Common to all 3 analyses:

- Trigger: Di-muon, without explicit p^{μ}_{T} cut
- Muon selection:

$$|\eta^{\mu}| < 1.3 \quad , \qquad p^{\mu}_{T} > 3.3 \text{ GeV/c}$$

$$1.3 < |\eta^{\mu}| < 2.2 \quad , \qquad p^{\mu} > 2.9 \text{ GeV/c}$$

$$2.2 < |\eta^{\mu}| < 2.4 \quad , \qquad p^{\mu}_{T} > 0.8 \text{ GeV/c}$$

- J/Ψ reconstruction:

  Oppositely charged muons fitted to common vertex

  Muons matched to trigger objects

  $|m_{\mu\mu} - m_{J/\Psi,PDG}| < 150 \text{ MeV/c}^2$

Efficiency for J/Ψ

$$\varepsilon_{J/\Psi} = \varepsilon_{\mu_1} \cdot \varepsilon_{\mu_2} \cdot \mathrm{corr}$$

where $\varepsilon_{\mu i}$ are the single muon efficiencies and **corr** is a correction factor for di-muon correlation effects, determined from simulation

The single muon efficiencies can be factorized as

$$\varepsilon_{\mu_i} = \varepsilon_{\mu_i\ \mathrm{trigger}} \cdot \varepsilon_{\mu_i\ \mathrm{ID}} \cdot \varepsilon_{\mu_i\ \mathrm{tracking}}$$

and each term is measured independently from data using a tag & probe method

Efficiency determined for each bin in p_T and y of the corresponding signal B meson.

$B^0 \rightarrow J/\Psi\,(\mu^+\,\mu^-)\,K_s(\pi^+\,\pi^-)$

- Accepted by PRL, preprint arXiv:1104.2892
- Integrated luminosity: $39.6 \pm 1.6\ pb^{-1}$
- Selection and reconstruction:
  - J/Ψ candidate from above
  - K_s candidate:
    - 2 oppositely charged tracks ($\geq$6 hits, $\chi^2/dof < 5$, $d_0 > 0.5\sigma$)
    - Vertex fit ($\chi^2 < 7$, transverse distance from beamline $> 5\sigma$)
    - $478\ MeV/c^2 < M_{Ks} < 518\ MeV/c^2$
  - B^0 candidate:
    - Kinematic fit with constraints on $M_{J/\Psi}$ and M_{Ks}
    - $4.9\ GeV/c^2 < M_{B0} < 5.7\ GeV/c^2$
    - B^0 decay vertex probability > 1%.
- Total number of events after selection: 23174

$B^0 \rightarrow J/\Psi\,(\mu^+\,\mu^-)\,K_s(\pi^+\,\pi^-)$

Backgrounds and probability density functions in m_B and ct
All shape parameters are extracted from data, except for the peaking background and the PDF for the signal m_B, which are taken from MC

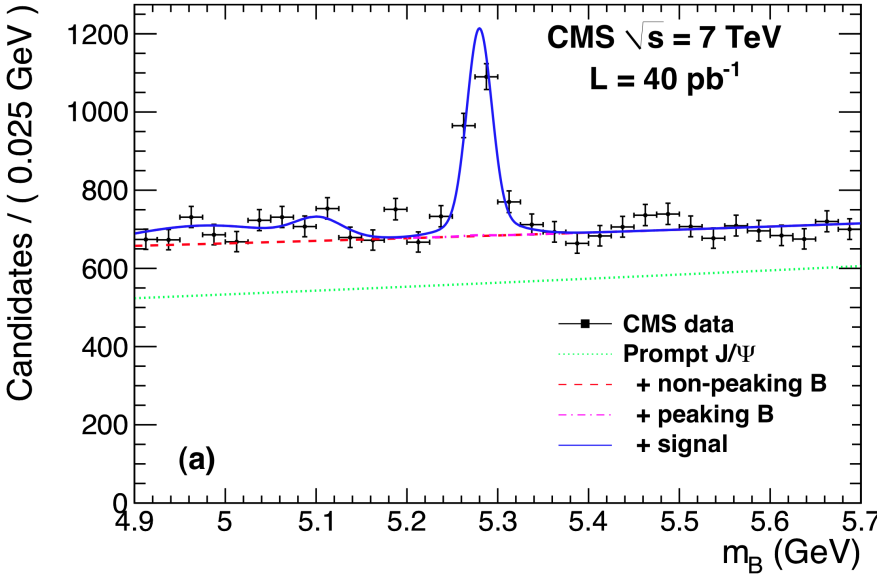
Component	P.D.F. for m_B	P.D.F. for ct
Signal	Sum of 2 Gaussians	R ⊗ Exponential
Peaking B Like $B^0 \rightarrow J/\Psi\ K^*(892)$	Sum of 3 Gaussians	R ⊗ Exponential
Prompt J/Ψ	Exponential	R
Combinatorial BB	Exponential	R ⊗ (sum of 2 exponentials)

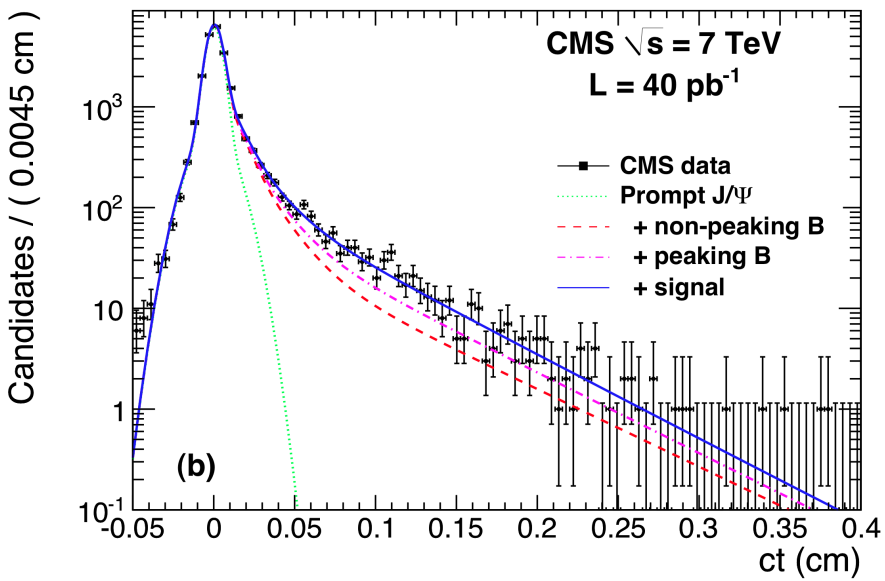
where R is a common resolution function = sum of two Gaussians

$B^0 \rightarrow J/\Psi\,(\mu^+\,\mu^-)\,K_s(\pi^+\,\pi^-)$

2D unbinned maximum likelihood fit: data driven fit procedure in 3 steps

1. High mass side band fit in m_B and ct to determine effective lifetime of combinatorial background
2. Full mass range fit to determine signal lifetime
3. Extract yields from full fit in bins of p^B_T and $|y_B|$ with (effective) lifetimes fixed from above.

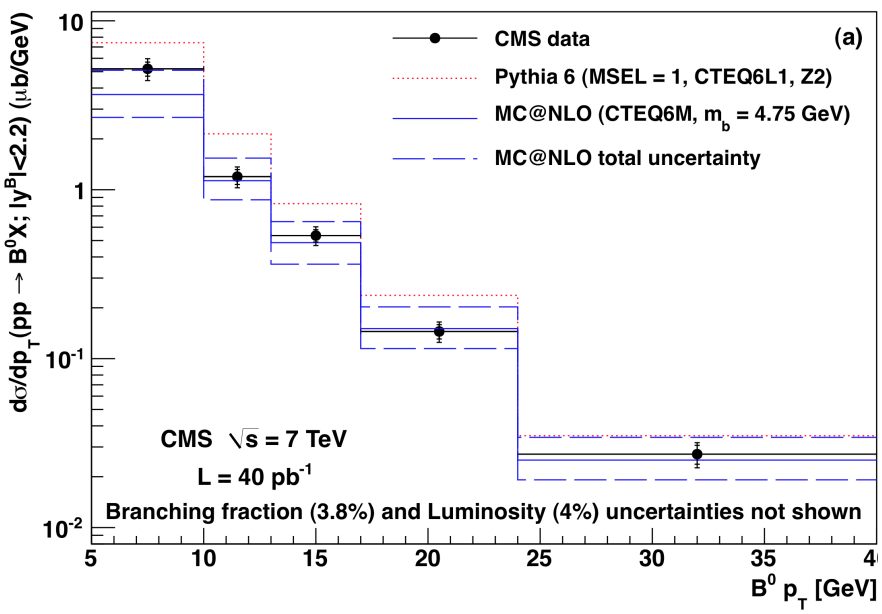


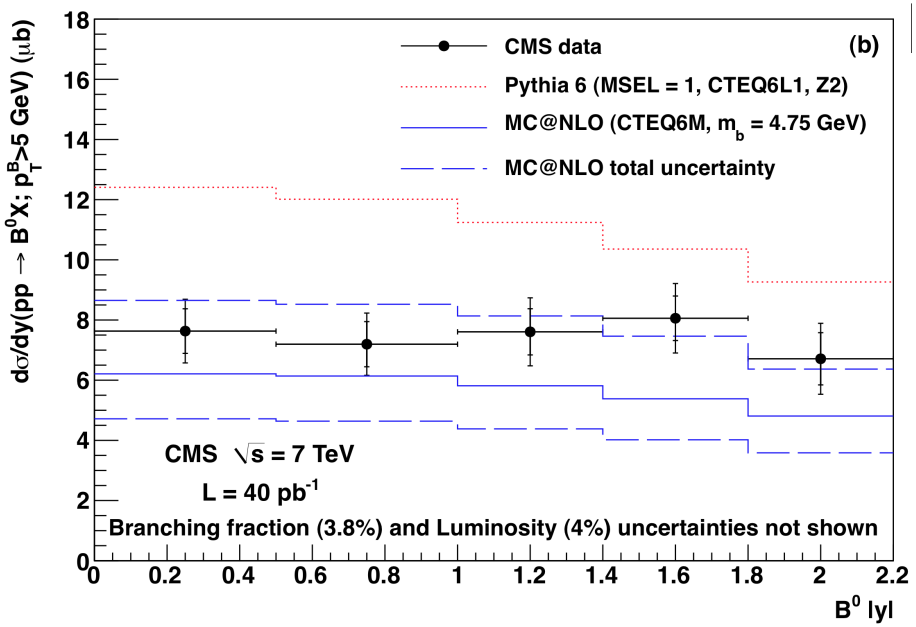


Systematic uncertainties

Contribution	**Value**
PDF parameters and potential fit bias	4 – 7 %
Effect of final state radiation on signal mass shape	1 %
Trigger efficiency	2 – 3 %
Muon identification	1 %
Muon tracking efficiency	1 %
K_s selection	5 %
B^0 selection	3 %
Acceptance	2 – 3%
Di-muon correlation	1 – 5 %
Mismeasurement of p^B_T and y^B	1 %
Kinematic reweighting	3 – 5 %
Total uncorrelated error	10 - 12 %
Branching fractions	3.8 %
Luminosity	4 %

$B^0 \rightarrow J/\Psi\,(\mu^+\,\mu^-)\,K_s(\pi^+\,\pi^-)$





Total cross section for $p_T(B^0) > 5$ GeV/c and $|y_{B0}| < 2.2$:

$$\sigma(pp \rightarrow B^0\,X) = 33.2 \pm 2.5(\text{stat}) \pm 3.5(\text{syst})\,\mu\text{b}$$

Prediction from MC@NLO $= 25^{+9.6}_{-6.2}\,\mu$b

$B^+ \rightarrow J/\Psi(\mu^+ \mu^-) K^+$

- Phys. Rev. Lett. 106, 112001 (2011), arXiv:1101.0131
- Integrated luminosity: 5.8 pb^{-1}
- Selection and reconstruction:
  - J/Ψ candidate from above
  - B^+ candidate:
    - Combine with track (≥4 hits, χ^2/ndof < 5) with kaon mass hypothesis and $p_T > 0.9$ GeV/c
    - Kinematic fit with constraint on $M_{J/\Psi}$
    - 4.95 GeV/c^2 < m_{B+} < 5.55 GeV/c^2
    - B+ decay vertex probability > 0.1%. Choose candidate with highest p_T
- Total number of events after selection: 35406

$B^+ \rightarrow J/\Psi(\mu^+ \mu^-) K^+$

Backgrounds and probability density functions in m_B and ct

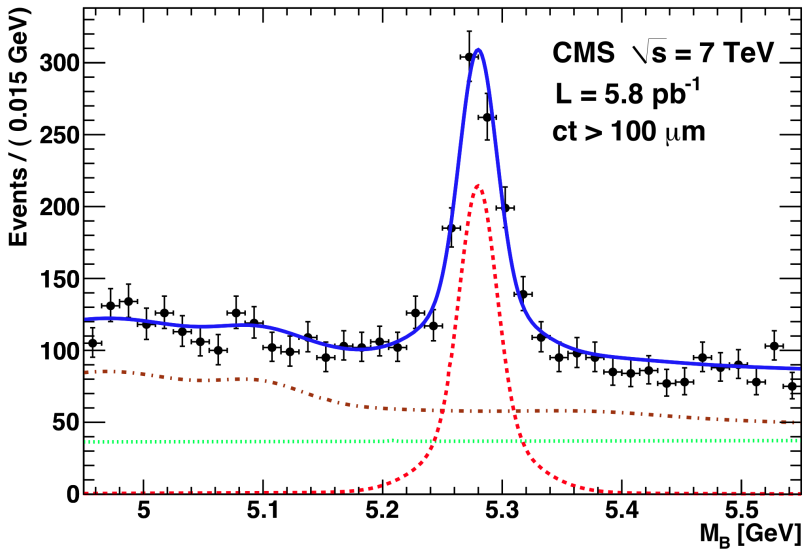
Component	P.D.F. for m_B	P.D.F. for ct
Signal	Sum of 3 Gaussians	R ⊗ Exponential
$J/\Psi\ \pi$ Cabbibo suppressed	Sum of 2 Gaussians	R ⊗ Exponential
Peaking B Mainly $B^0 \rightarrow J/\Psi\ K^*$, $B^0 \rightarrow \chi_c X$	Sum of 2 Gaussians + exponential	R ⊗ Exponential
Prompt J/Ψ	Exponential	R
Combinatorial BB	Exponential	R ⊗ (sum of 2 exponentials)

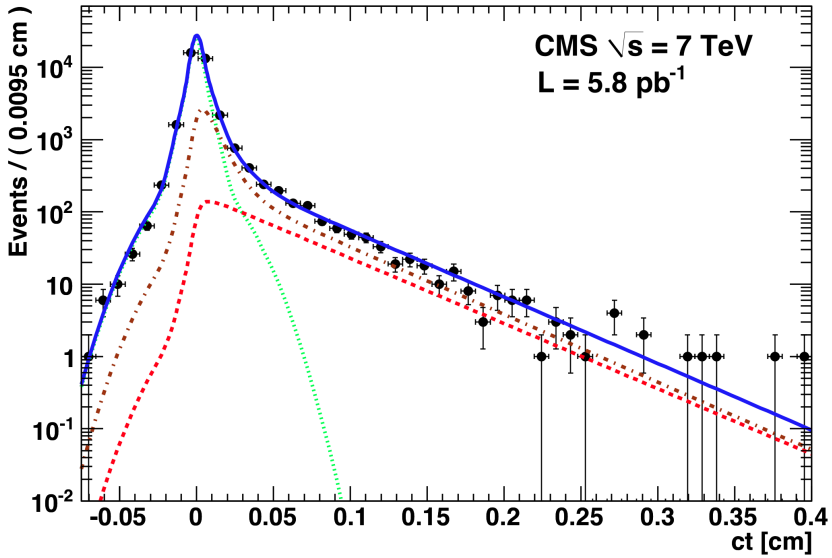
where R is a common resolution function = sum of two or three Gaussians

$B^+ \rightarrow J/\Psi(\mu^+ \mu^-) K^+$

2D unbinned maximum likelihood fit: data driven fit procedure in 3 steps

1. High mass side-band fit in ct to determine effective lifetime of combinatorial background.
2. Same fit in bins of p_T and |y| but with ct fixed from above to determine resolution function
3. Extract yields from full fit with m_B PDFs for signal, $J/\Psi\ \pi$ and peaking background from MC, ct parameters from above

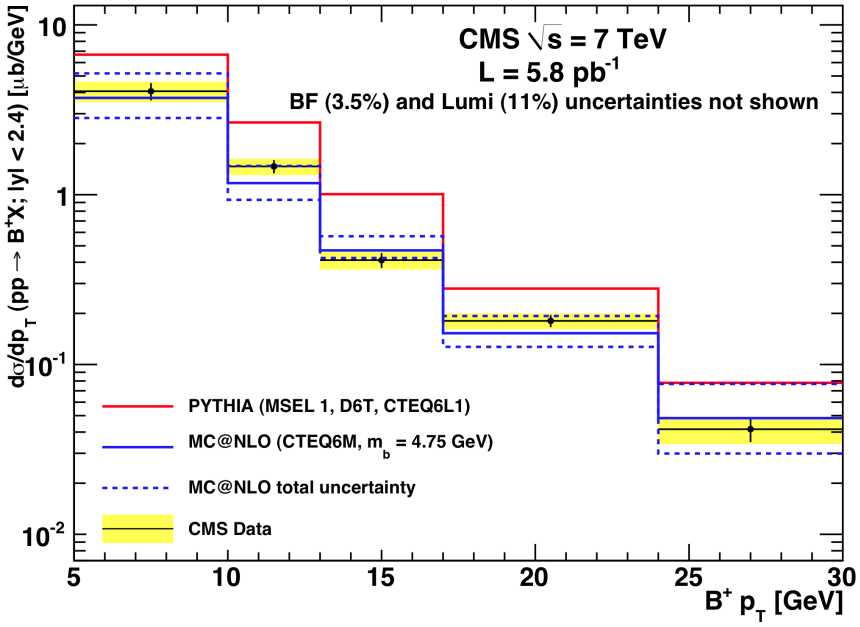


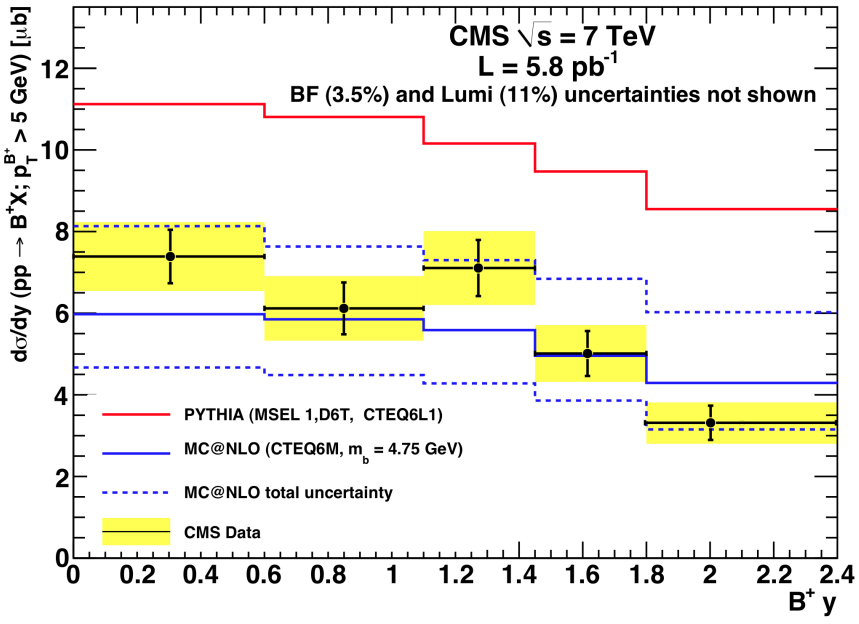


Systematic uncertainties

Contribution	**Value**
PDF parameters and potential fit bias	2 – 5 %
ct resolution function	1 – 2 %
Effect of final state radiation on signal mass shape	< 1 %
Trigger efficiency	2 %
Muon identification	1 %
Tracking efficiency for muon and hadron	1 - 4 %
B^+ momentum spectrum	1 - 4 %
Efficiency of vertexing	1.5 %
Misalignment	2 %
Total uncorrelated errors	6 - 10 %
Branching fractions	3.5 %
Luminosity	11 %

$B^+ \rightarrow J/\Psi(\mu^+ \mu^-) K^+$





Total cross section for $p_T(B^+) > 5$ GeV/c and $|y_{B+}| < 2.4$:

$$\sigma(pp \rightarrow B^+X) = 28.1 \pm 2.4(\text{stat}) \pm 2.0(\text{syst}) \pm 1.1(\text{lumi})\ \mu\text{b}$$

Prediction from MC@NLO $= 25.5^{+9.2}_{-5.7}\ \mu$b

$B^0_s \rightarrow J/\Psi(\mu^+ \mu^-)\ \phi(K^+ K^-)$

- Approved result
- Integrated luminosity: $39.6 \pm 1.6\ pb^{-1}$
- Selection and reconstruction:
  - J/Ψ candidate from above with $p_T > 0.5$ GeV/c
  - ϕ candidate:

    2 oppositely charged tracks (≥5 hits, χ^2/dof < 5) with kaon mass hypothesis, $p_T > 0.7$ GeV/c

    $1009\ MeV/c^2 < M_\phi < 1029\ MeV/c^2$
  - B_s^0 candidate:
    - Kinematic fit with constraint on $M_{J/\Psi}$
    - B_s^0 decay vertex probability > 2%. Choose candidate with highest probability
    - 8 GeV/c < p_T < 50 GeV/c, $|y_B| < 2.4$
    - $5.20\ GeV/c^2 < M_{Bs} < 5.65$ GeV/c2
- Total number of events after selection: 6200

$B^0_s \rightarrow J/\Psi(\mu^+ \mu^-)\ \phi(K^+ K^-)$

Backgrounds and probability density functions in m_B and ct

Component	P.D.F. for m_B	P.D.F. for ct
Signal	Sum of 2 Gaussians	R ⊗ exponential
Non-prompt J/Ψ Misreconstructed B decays to J/Ψ and higher mass K- mesons	Second order polynomial	R ⊗ (sum of 2 exponentials)
Prompt J/Ψ	First order polynomial	R

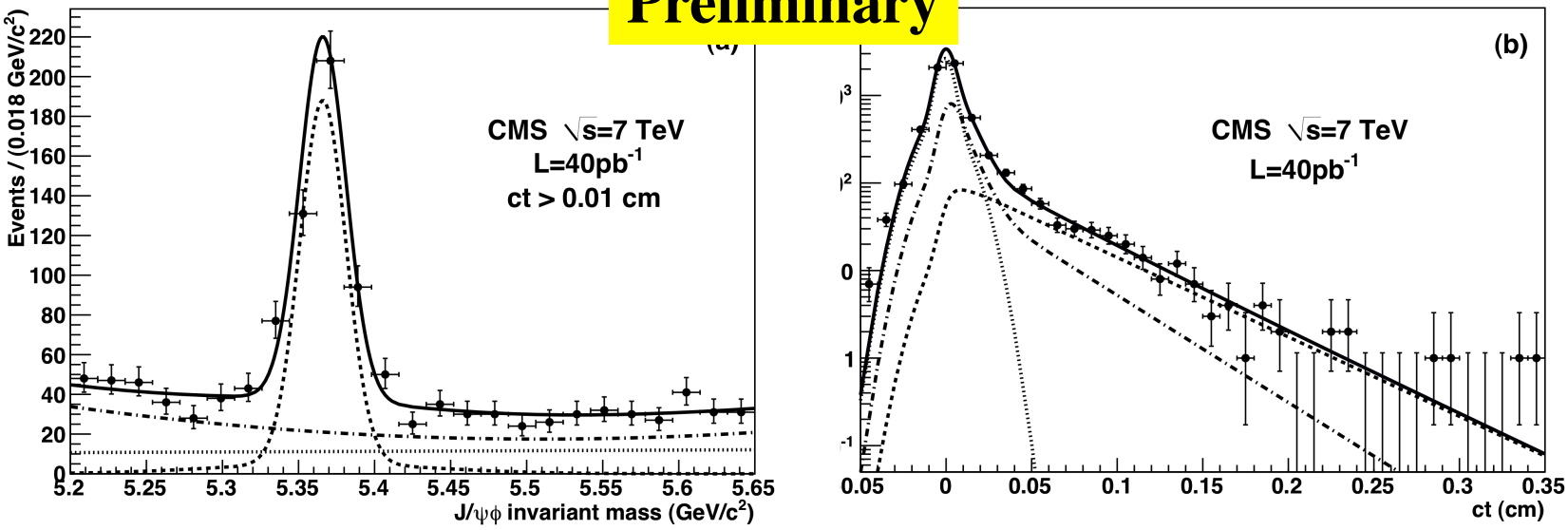
where R is a common resolution function = sum of two Gaussians

$B^0_s \rightarrow J/\Psi(\mu^+ \mu^-)\, \phi(K^+ K^-)$

2D unbinned maximum likelihood fit: data driven fit procedure in 3 steps

1. Mass side-band fit in ct to determine effective lifetime of combinatorial background.
2. Same fit in bins of p_T and |y| but with ct fixed from above to determine resolution function
3. Extract yields from full fit with m_B PDF for signal from MC, ct parameters from above

Preliminary



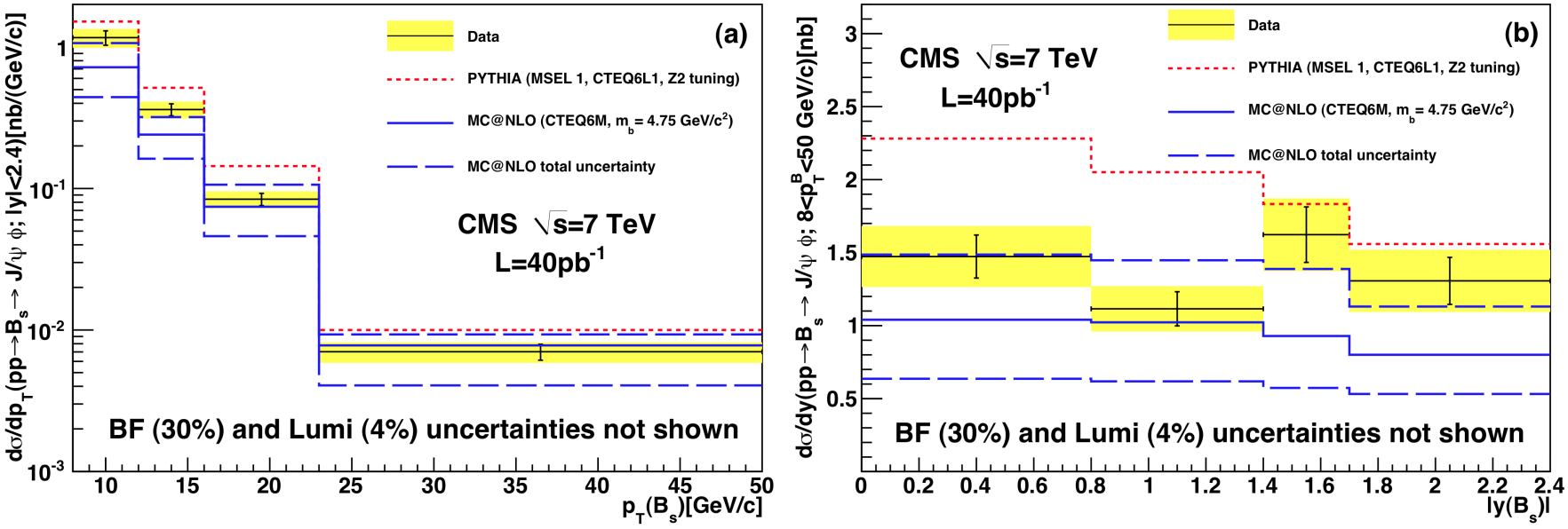
Systematic uncertainties

Preliminary

Contribution	**Value**
PDF parameters and potential fit bias	2 – 4 %
Muon efficiency (trigger + ID + tracking)	3 - 5 %
Tracking efficiency for hadron pair, including misalignment	9 %
B^0_s momentum spectrum	2 - 3 %
Reconstruction efficiency	3 %
Total uncorrelated error	9 - 12 %
Branching fractions	1.4 %
Luminosity	4 %

$B^0_s \rightarrow J/\Psi(\mu^+ \mu^-)\, \phi(K^+ K^-)$

Preliminary



Total cross section for 8 GeV/c < $p_T(B^0_s)$ < 50 GeV/c and $|y_{Bs}| < 2.4$:

$$\sigma(pp \rightarrow B^0_s \rightarrow J/\Psi\ \phi) = 6.9 \pm 0.6(\text{stat}) \pm 0.6(\text{syst})\ \text{nb}$$

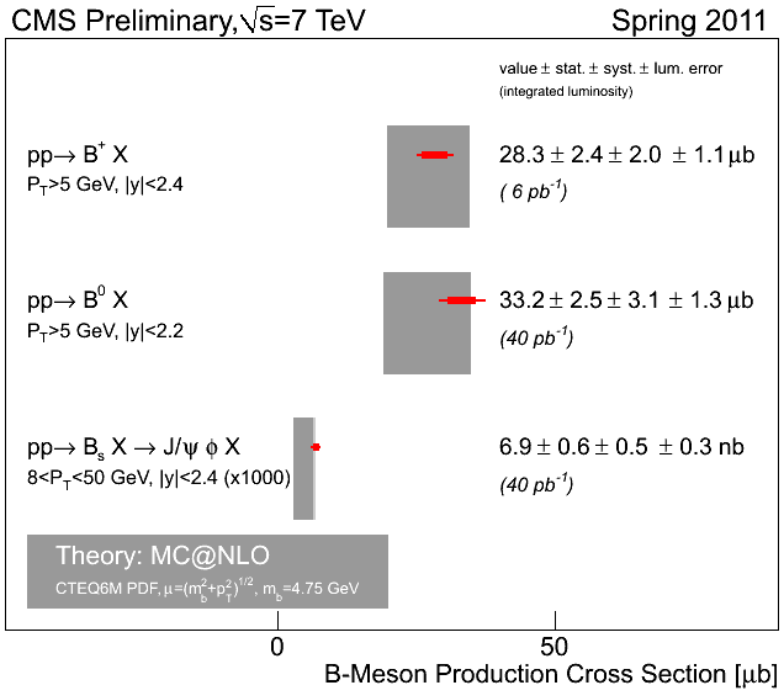
Prediction from MC@NLO $= 4.6^{+1.9}_{-1.7}$ nb

Conclusion

- First measurements of total and differential cross sections for B^+, B^0 and B_s^0 at the LHC

- Good agreement with predictions from MC@NLO

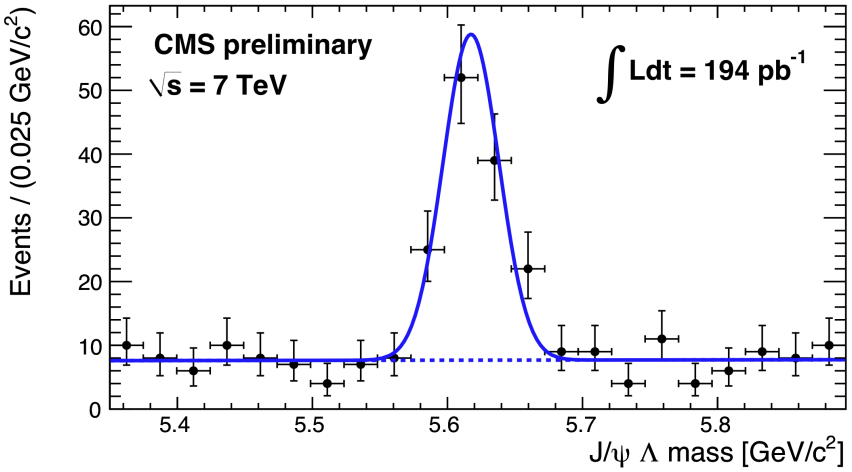
- Results show the great performance of the CMS detector



Outlook

Coming soon:

$\Lambda_b \rightarrow J/\Psi\ (\mu^+\ \mu^-)\ \Lambda^0(p\ \pi)$
Differential cross section and lifetime measurement
Using data taken in 2010-2011



$$\mu_{\text{Gauss}} = 5.617 \pm 0.003\ \text{GeV}/c^2$$
$$\sigma_{\text{Gauss}} = 0.021 \pm 0.002\ \text{GeV}/c^2$$
$$N_{\text{signal}} = 106 \pm 12$$
$$N_{\text{background}} = 32 \pm 3$$
$$S/\sqrt{S+B} = 9.0 \pm 1.1$$
$$S/B = 3.3 \pm 0.5$$