XII. INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY

8-13 OCTOBER 2007

Laboratori Nazionali di Frascati (Rome)

Feasibility study of the B_c meson at CMS/LHC

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On behalf of the CMS collaboration

Outline

- Introduction
- Event generation
- Event selection
- Systematic errors
- Results
- Conclusions

Motivations

Goal: measure the mass and lifetime of the B_c-meson at CMS

Why studying the B_c meson at LHC?

- It's a unique meson! B^+_c meson is ground state of $b\bar{c}$.
  - Both quarks are heavy (similar to bottomonium and charmonium)
  - The two quarks have different flavours
- This implies unique properties in b production, mass and decay!
  - Only weak decays possible
  - Both b and c can participate
  - Lifetime measurable (smaller than B lifetime)
- Theoretical uncertainty on B_c properties are large (see next slide)

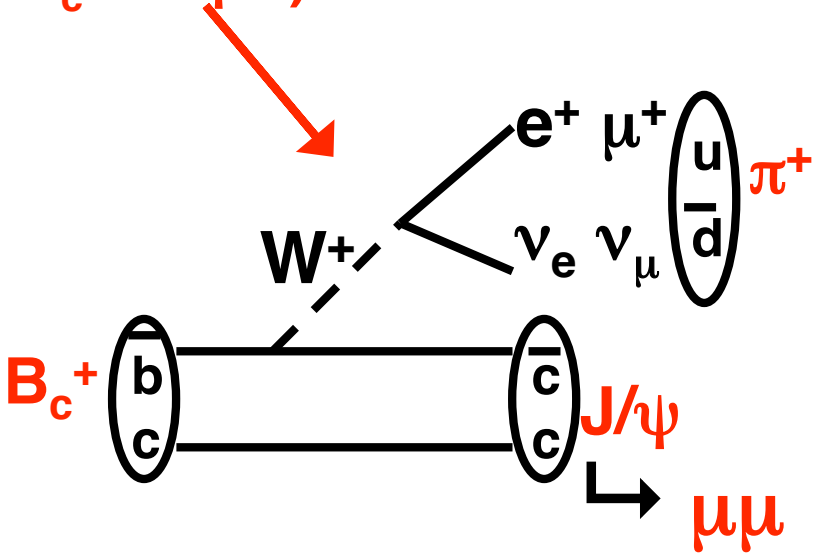
  ➡ interesting for experiments!

- Analysis possible with relatively early LHC data (1 fb^{-1})!

Production and decay at hadron colliders

- **B_c production:** e.g. via hard process $gg \to B_c\, b\, c$ — E.g:Chang&Wu,EPJC38,267
  - Many theoretical uncertainties! $\sigma(B_c) \sim 10^{-3}\sigma$(other B-mesons)
- **B_c mass:** theory M=6.24±0.05 GeV — See e.g: [Kwong,Rosner, PRD44, 212] [Eichten, Quigg, PRD49, 5845]
- **B_c decay:**
  - b-decay with c as spectator (here: $B_c \to J/\psi\, \pi$)
  - c-decay with b as spectator
  - annihilation decays $\bar{b}c \to \ell^+\nu, c\bar{s}, u\bar{s}$

B_c decay	theory prediction BR
$\Sigma \bar{b} \to \bar{c}$	20-25%
$\Sigma c \to s$	64-72%
$\Sigma B_c^+ \to c\bar{s}$	6.6-7.2%



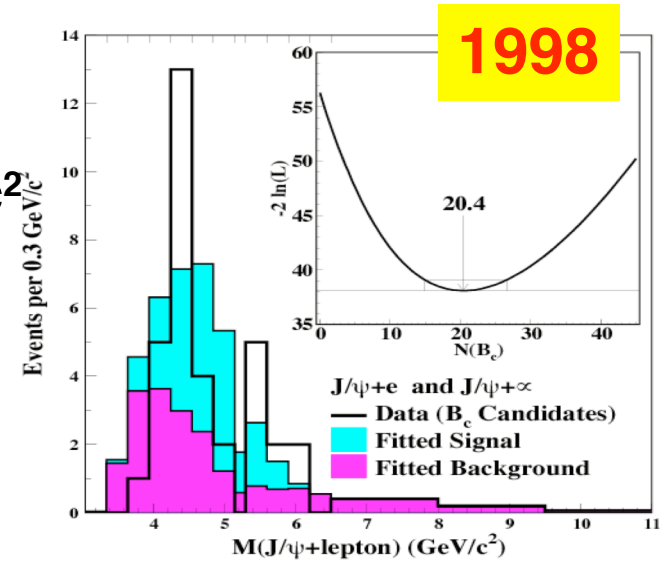
- **B_c lifetime:**

theory prediction τ: 0.48-0.55 ps — See e.g: V.V.Kiselev, hep-ph/0211021

The B_c-meson at the Tevatron

- 1998 CDF run I: observation of $B_c \to J/\psi\, l\, \nu$
  20 signal events (110 pb-1).

  PRL81:2432-2437,1998.
  - B_c mass:6.40±0.39(stat.)±0.13(syst.) GeV/c^2
  - B_c lifetime: $0.46^{+0.18}_{-0.16}$ (stat.) ± 0.03 (syst.) ps



- 2007: CDF run II, 2.2 fb^{-1}: 87 signal events!

  In channel $B_c \to J/\psi\, \pi$

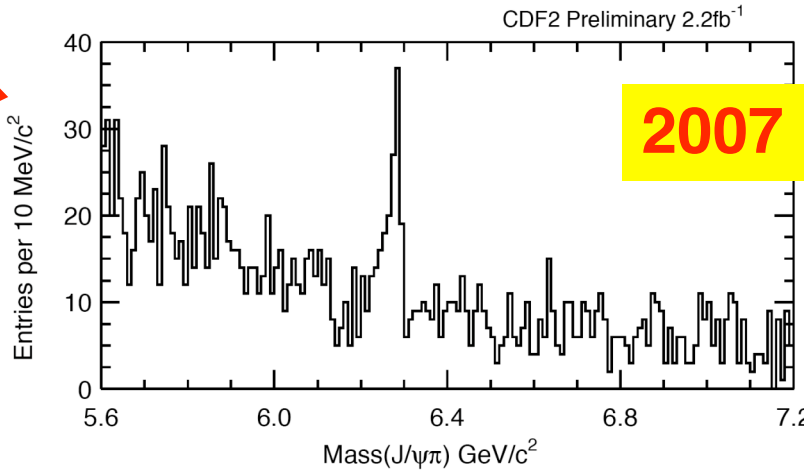
  CDF public note 07-07-12

  new
  - B_c mass: 6.2741±0.0032 (stat.)±0.0026(syst.) GeV/c^2

  Measurement of B_c lifetime in channel $B_c \to J/\psi\, e\, \nu$
  - B_c lifetime:

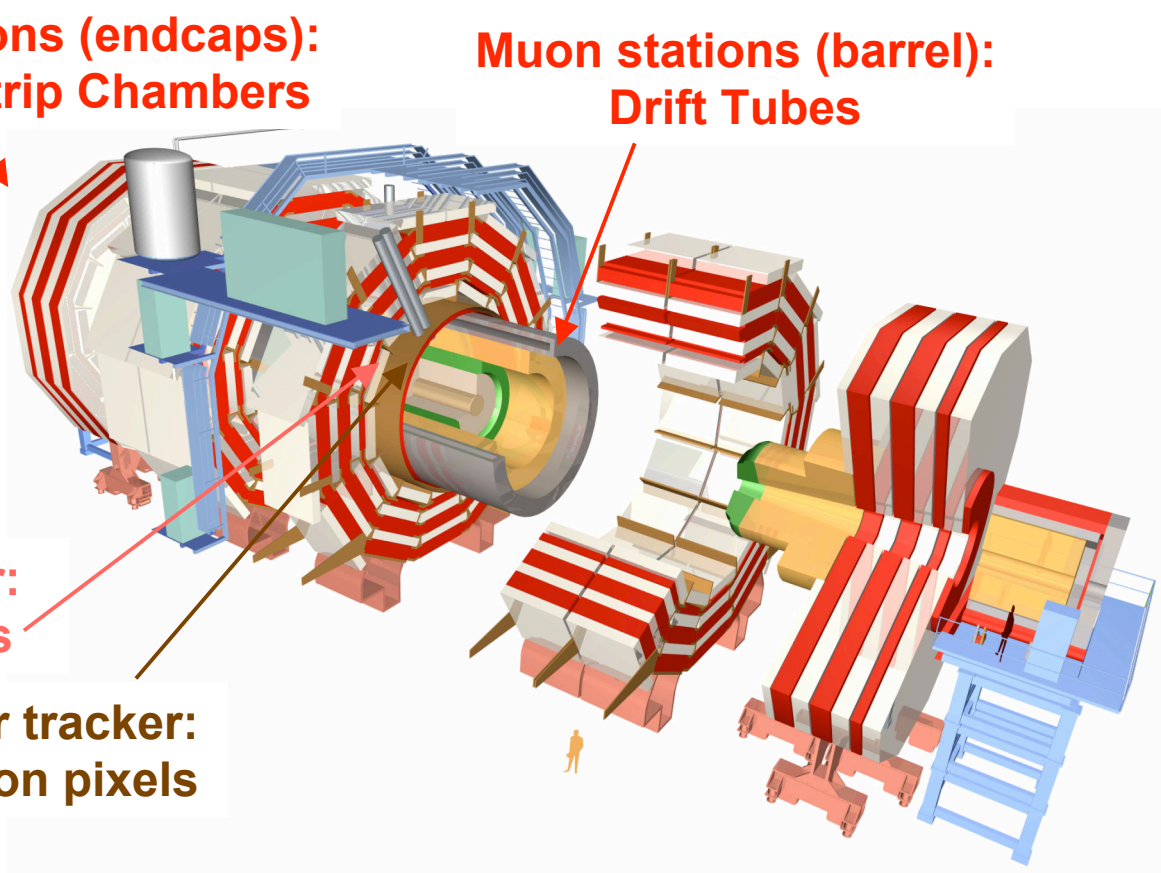
    PRL97,012002, 2006

    $0.463^{+0.073}_{-0.065}$ (stat.) ± 0.036 (syst.) ps



The B_c meson at CMS

- At LHC:
  - 20 times larger B_c production cross section than Tevatron!
  - Higher luminosity and √s!
  - Higher B_c P_T values!
- Hadron spectroscopy at CMS → plenary talk today Roberto Covarelli
- For Bc-meson:
  CMS has excellent
  muon system,
  tracker,
  large acceptance!



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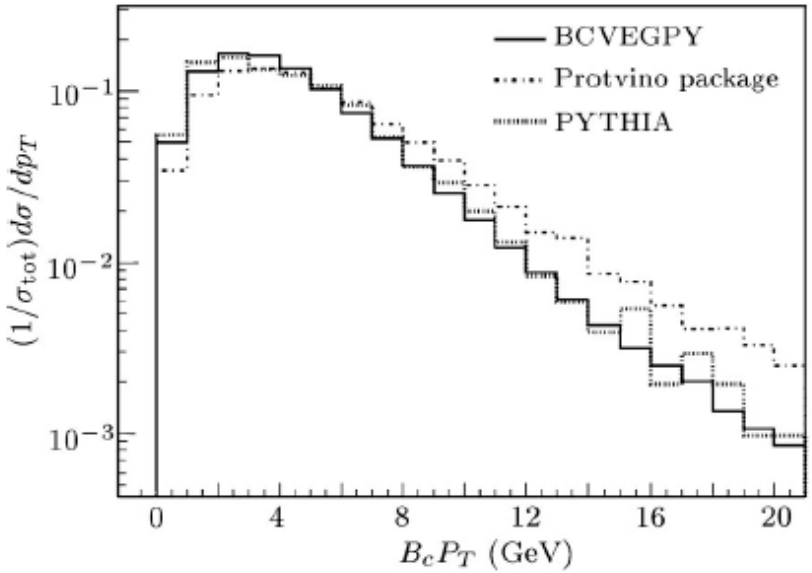
B_c event generation

Events $B_c \to J/\psi\,\pi$, $J/\psi \to \mu\mu$ generated with MC generator BCVEGPY

Chang&Wu, EPJC38:267,2004



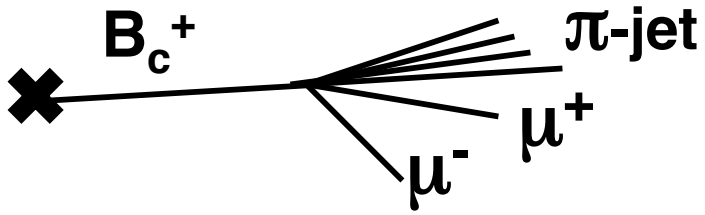
- **NB In agreement with PYTHIA, but much faster.**
- **With full and fast simulation**
  OSCAR_3_7_0, ORCA_8_7_3, FAMOS_1_3_2
- **Kinematical Cuts (simulating L1 and HLT):**

B_c	pT≥10GeV |η|≤2.0
μ	pT≥4GeV |η|≤2.2
π	pT≥2GeV |η|≤2.4

Particle	Decay channel	σ(pb)	Generated~ 30 fb-1
B_c	Bc→J/ψπ, J/ψ→μμ	1.781	5.2082(·10⁴)

Background event generation

- Event topology:



- Backgrounds:

1) Other b hadrons' decay include J/ψ
2) Prompt J/ψ
3) ccbar→μμx

4) bbbar →μμx
5) General QCD
6) W+jets, Z+jets

Fast and full simulation

channel	$\sigma \cdot Br.(pb)$	Nevents
B^0	70.3	740,000
B^+	70.7	740,000
B_s	14.8	190,000
Λ_b	19.4	200,000
prompt J/ψ	240.3	500,000
$c\bar{c} \rightarrow \mu^+\mu^- X$	1690	210,000

Full simulation In Pthat bins

bbbar →μμx	100000
QCD	950000
W+jets	880000
Z+jets	710000

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- Introduction
- Event generation
- Event selection
  - Selection procedure
  - Signal and background estimations
  - Kinematic fit on mass and lifetime
- Systematic errors
- Results

Event selection

- Step 0: trigger, not included in this study.
  - Future: displaced vertex trigger, add particle in vicinity of J/psi
    - ➢ L1: dimuon trigger, L2 inv mass cut, L3 secondary vertex

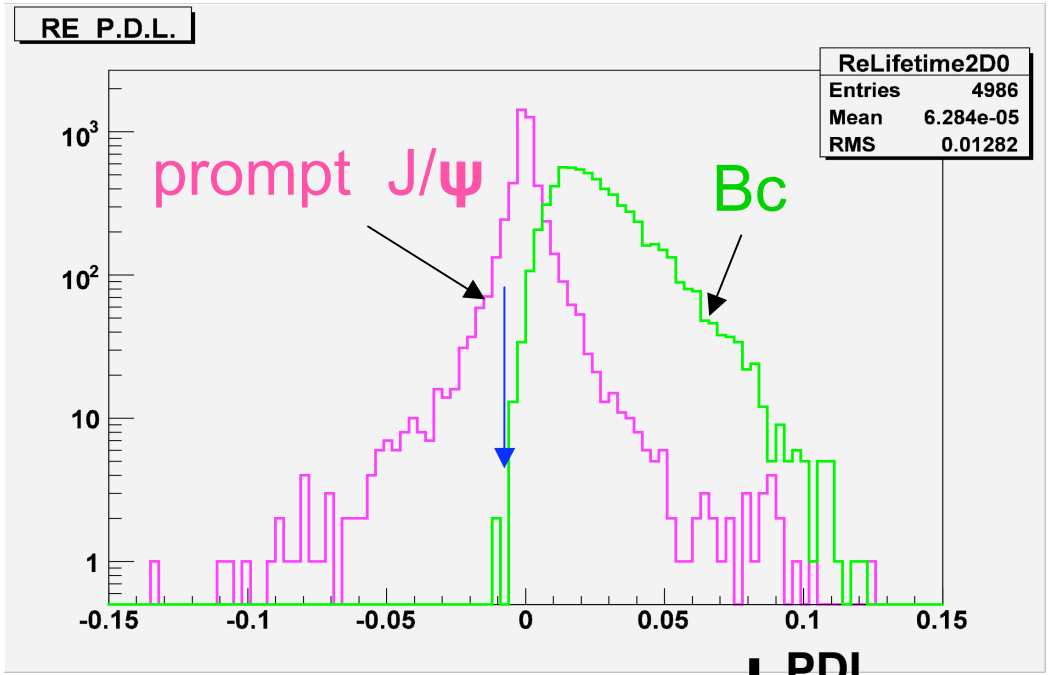
- Step 1: J/psi candidates
  - 2 muons $p_T \geq 4.0$ GeV , $|\eta| \leq 2.2$
  - muons share the same vertex
  - 2 muons have different charge
  - 2 muons' invariant mass around the J/Ψ(3.0,3.2)GeV

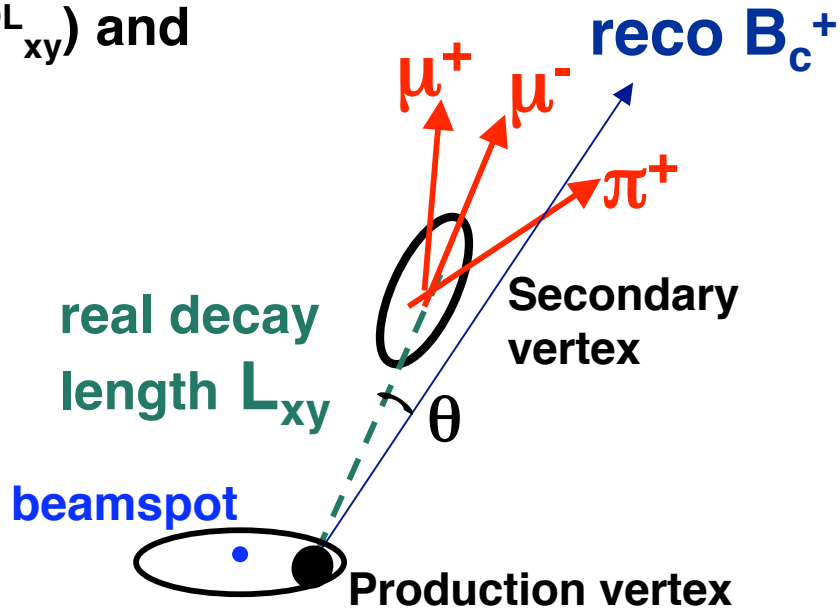
- Step 2: Pion candidates:
  - not identified as a lepton
  - $p_T \geq 2$ GeV ,$|\eta| \leq 2.4$
  - Share the same vertex with 2 muons (J/Ψ vertex)

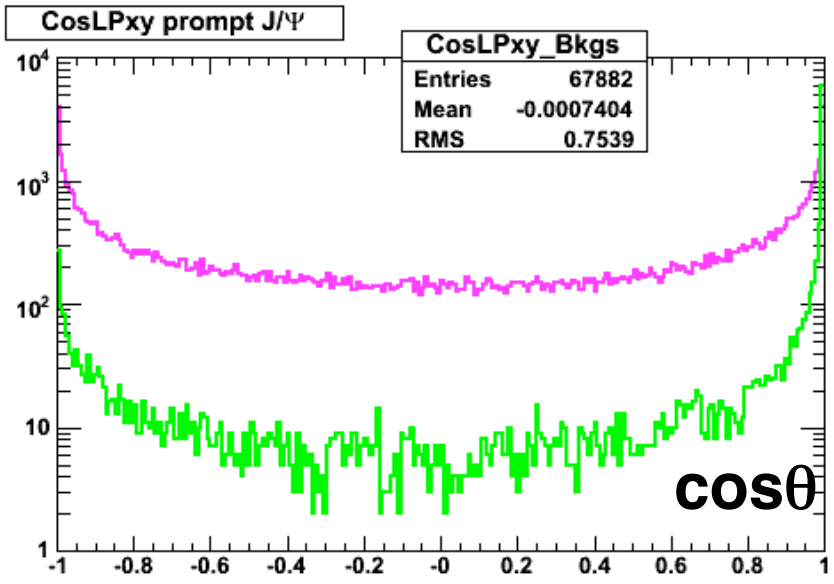
Event selection

- **Step 3: cut on proper decay length (L^{PDL}_{xy}) and significance (L^{PDL}_{xy}/σ_{xy}) to suppress prompt J/psi background**

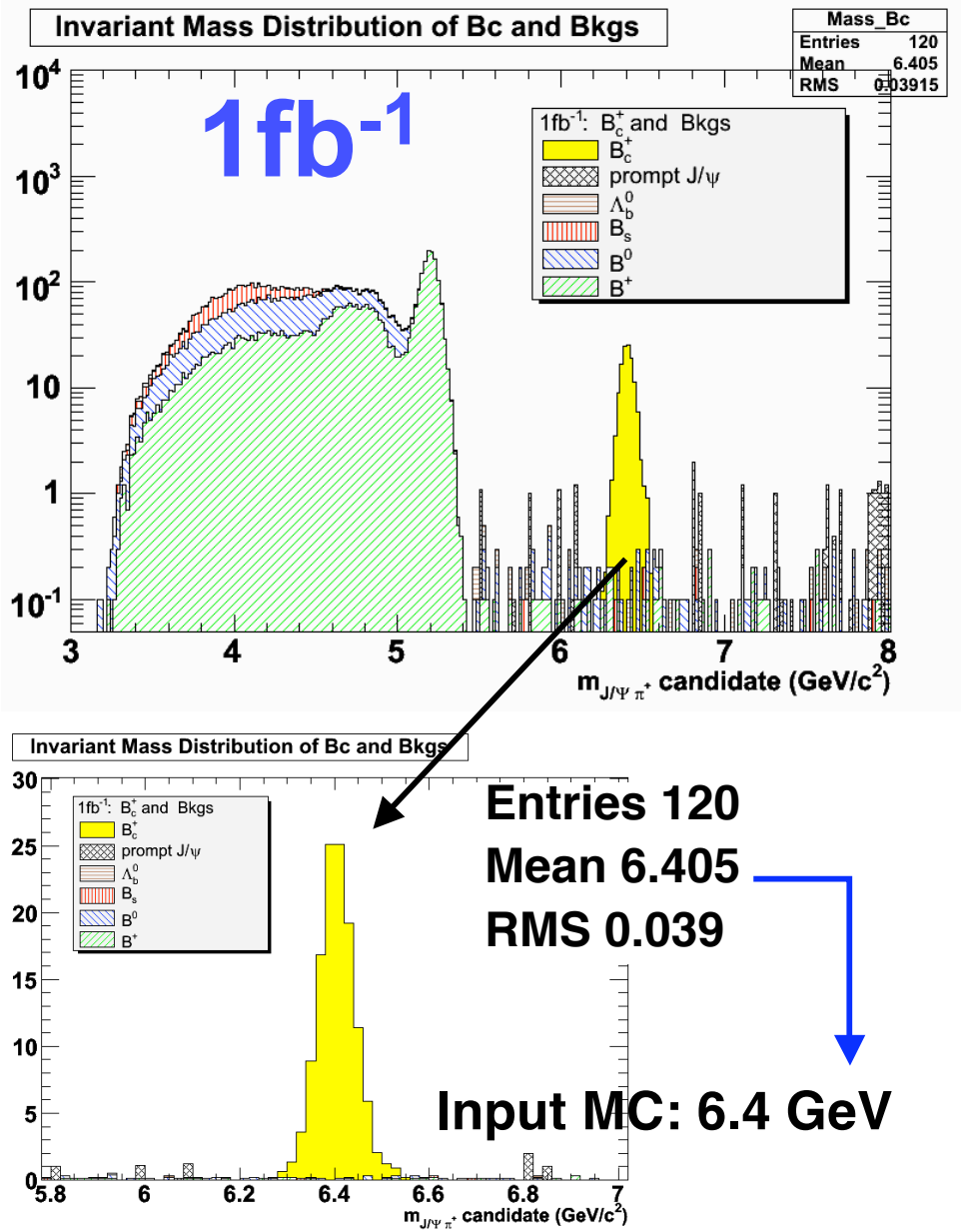
  $L^{PDL}_{xy}>60\mu m$
  $L_{xy}/\sigma_{xy}>2.5$
  $\cos\theta>0.8$







Event selection



- Step 4: invariant mass window cut: $M_{J/\psi\pi} \in [6.25, 6.55]$ GeV
- Summary of selection for B_c-events (~30 fb^{-1}):

Cuts and Selections	Cumulative Eff. (%)	Passed total 52082
Dimu and J/ψ	32.88	17127
Pion	15.07	7851
L^{PDL}_{xy}/σ_{xy} >2.5	7.07	3685
Cosθ>0.8	7.04	3666
L^{PDL}_{xy} >60μm	6.98	3637
Bc candidate (6.25,6.55)GeV	6.93	3608

Background estimation

- For b-decays, prompt J/psi's and ccbar→μμx: statistics high→ ok!
- W+jets, Z+jets, QCD: $L_{generated}$<1 fb^{-1}

➔ Determine selection efficiency step-by-step

1) Eff. to select two muons (step 1) ➡ ε(2μ)

2) Eff to reconstruct from 2 muons a J/ψ
[from ccbar→μμX sample]
➡ $\varepsilon(2\mu \to J/\psi)=(1.3\pm0.1)\times 10^{-3}$

3) Eff. for this J/ψ to pass final cuts (step 3,4)
[from prompt J/psi's, in mass[5,8] GeV]
➡ $\varepsilon(J/\psi_{pass})= (6.2\pm1.2)\times10^{-6}$

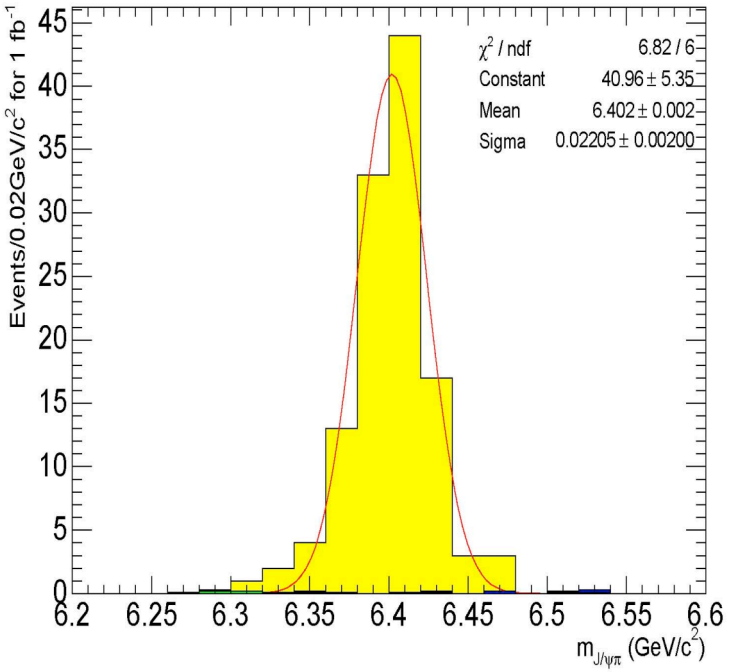
Total efficiency= $\varepsilon(2\mu)\cdot\varepsilon(2\mu \to J/\psi)\cdot\varepsilon(J/\psi_{pass})$

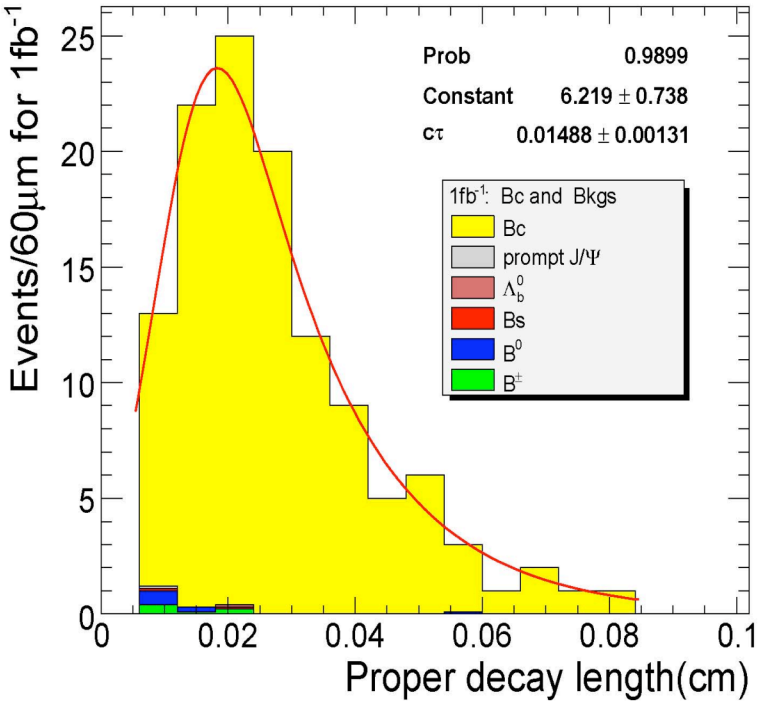
Summary of expected signal and background (~1 fb^{-1}):

signal B_c	120±11
total bg	2.6±0.4
B^+	0.7±0.2
B_s	0.1
B^0	0.8±0.3
Prompt J/ψ	0.1
QCD	0.7±0.1
Λ_b	0.1
ccbar	0.01
bbar	0.01

Mass and lifetime fit

- Kinematic fit Bc→J/ψπ, J/ψ→μμ: totally 3 tracks
  - 2 muon tracks: J/ψ mass constraint $M_{\mu\mu}$=3.096 GeV
  - all 3 tracks: from same vertex





$M(B_c)$: 6402 ± 2 MeV
Input MC:6400 MeV
Masswidth: 22 MeV

$c\tau(B_c)$:148.8 ± 13.1 μm
Input MC 150 μm
$\tau(B_c)$=0.0496 ± 0.044 ps

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Systematic uncertainties

- Misalignment
  1. muon and pion momentum scale uncertainty
  2. muon and pion momentum resolution deterioration
  3. vertex resolution deterioration
- Sensitivity to selection cuts
- MC statistics
- Theoretical uncertainty (B_c P_T-spectrum)
- Cuts sensitivity

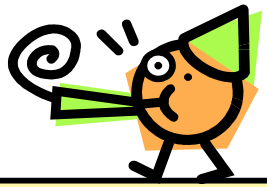
Summary (~1 fb^{-1}):

Source	B_c mass (MeV)	$B_c c\tau$ (μm)
mom scale	11	0.2
mom resolution	10	0.8
vertex uncertainty	-	2.4
Cuts sensitivity	0.1	0.2
MC statistics	-	0.1
Theoretical	-	1.5
Total	14.9	3.0

Result

	$\mathcal{L}$ (pb^{-1})	Signal Events	Mass (GeV/c^2)	Lifetime (ps)
CDF Run I $(B_c^{\pm} \to J/\psi l^{\pm}\nu_l)$	110	$20.4^{+6.2}_{-5.5}$	$6.4 \pm 0.39 \pm 0.13$	$0.46^{+0.18}_{-0.16} \pm 0.03$
D0 Run II $(B_c^{\pm} \to J/\psi \mu^{\pm}\nu)$	210	$95 \pm 12 \pm 11$	$5.95^{+0.14}_{-0.13} \pm 0.34$	$0.448^{+0.123}_{-0.096} \pm 0.121$
CDF Run II $(B_c^{\pm} \to J/\psi \pi^{\pm})$	360	14.6 ± 4.6	$6.2857 \pm 0.0053 \pm 0.0012$	
CDF Run II $(B_c^{+} \to J/\psi e^{+}\nu_e)$	360	238		$0.463^{+0.073}_{-0.065} \pm 0.036$
CDF Run $B_c \to J/\psi$	**2.2 fb^{-1}**	**87**	**M=6.2741±0.0032±0.0026.)**	

CMS AN 2006/079 CMS NOTE 2006/118
X.W. MENG, J.Q. TAO, G.M. CHEN



	L (fb^{-1})	Signal events	Precision of mass value (MeV)	Precision of lifetime (ps)
CMS $B_c \to J/\psi\pi$	1	120 ±11	2(fit)±15(syst)	0.044(fit)±0.010(syst)

Conclusions

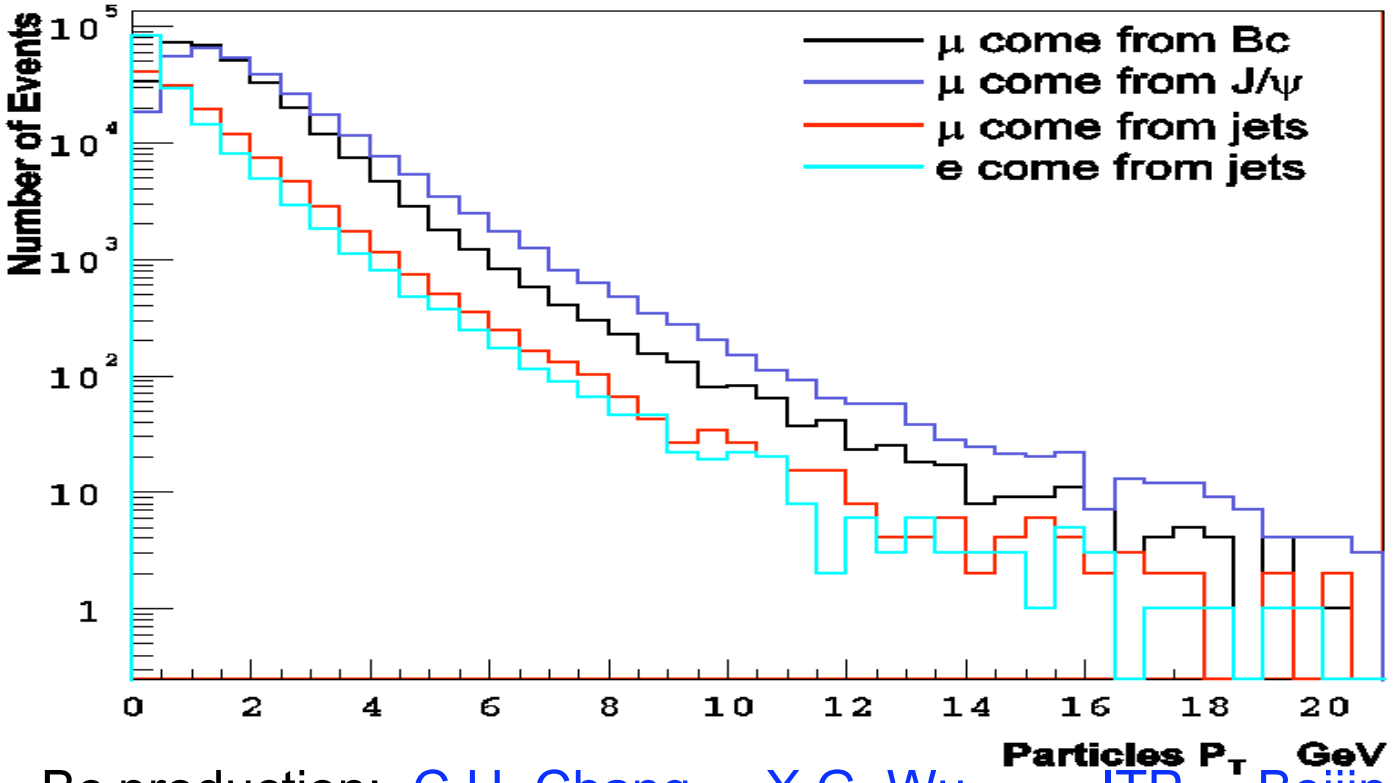
- With 1 fb-1 of data CMS can reconstruct 120 $B_c \rightarrow J/\psi\pi$ events
  - The precision on the mass (central value) is

    2 (fit)±15(syst) MeV
  - The precision on the lifetime is

    0.044(fit)±0.010(syst) ps
- The dominating systematic uncertainties are
  - For lifetime measurement: theoretical uncertainties
  - For mass measurement: momentum scale and resolution
- Improvents are foreseen when data come by using B->jpsi K as control sample

EXTRA SLIDES

Mc-generator: lepton P_T spectrum



Bc production: C.H. Chang X.G. Wu ITP Beijing

Bc decay and interface with OSCAR:

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