

# CMS B-physics program

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# Outline

- ▶ Introduction: motivations for B Physics study in CMS
- ▶ CMS detector: key subsystems
- ▶ Trigger strategy: L1 trigger and HLT
- ▶ Physics channels: approved studies
- ▶ Conclusions

# Motivations

- ▶ Physics:
  - ▶  $b\bar{b}$  x-section at 14(10?) TeV
  - ▶ NP search in decay rate: mainly  $B_s^0 \rightarrow \mu^+ \mu^-$ ,  $B_s^0 \rightarrow \gamma \mu^+ \mu^-$
  - ▶ NP search in  $\mathcal{A}_{FB}$ ,  $\mathcal{A}_{CP}$ ,  $M_{\mu^+ \mu^-}$ ,  $P_{L(T)}$ :  $B \rightarrow X_s \mu^+ \mu^-$  and  $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$
- ▶ Detector:
  - ▶ (di-)muon low  $p_T$  trigger, precise vertex detector, efficient tracker system
  - ▶ B and onia decays provide excellent calibration
- ▶ Collider:
  - ▶ at low luminosity phase no Higgs, but already plenty of  $b\bar{b}$
  - ▶ at high luminosity, thanks to efficient (di)-muon trigger, continue B Physics

# The CMS Detector

## ► The Compact Muon Solenoid

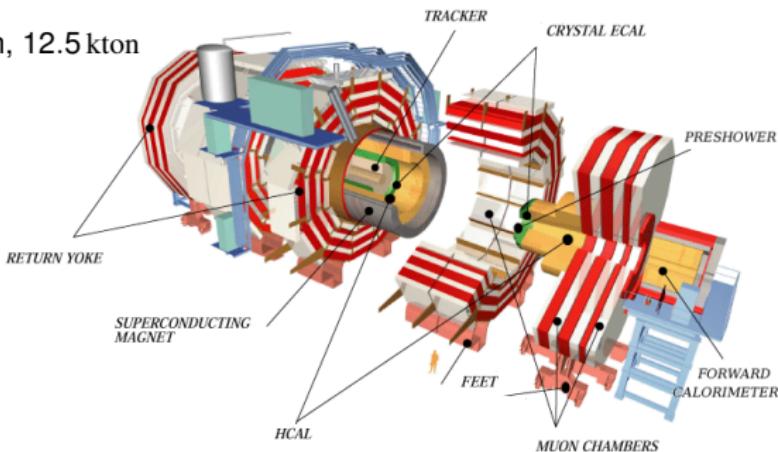
- Length 22 m , diameter 15 m, 12.5 kton
- Magnetic field 3.8Tesla

## ► Muon system

- DT, CSC, RPC
- $p_{\perp} > 3 \text{ GeV}/c$

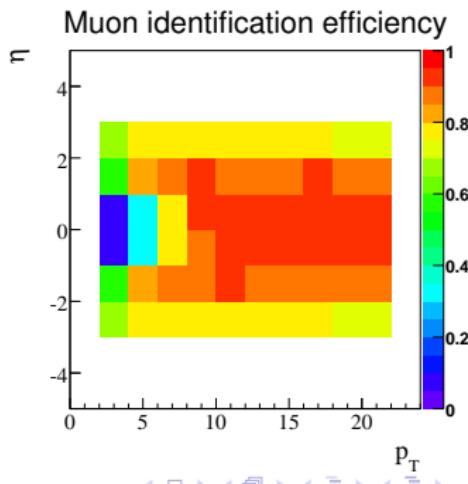
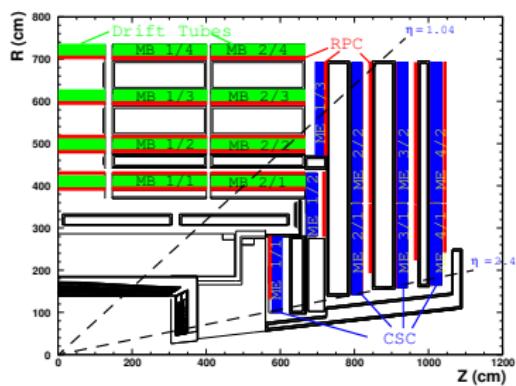
## ► All-silicon tracker ( $220 \text{ m}^2$ )

- $|\eta| < 2.5$
- pixel: 3 layers, 2 disks,  $100 \times 150 \mu\text{m}^2$  pixels
- strip tracker: 10 layers, 9 disks



# The CMS Muon System

- ▶ Three types of gaseous particle detectors for muon identification
  - Drift Tubes (DT) in the central barrel region: **position and momentum measurements**
  - Cathode Strip Chambers (CSC) in the endcap region: **position and momentum measurements**
  - Resistive Parallel Plate Chambers (RPC) in both the barrel and endcaps: **fast information for the Level-1 trigger**



# The CMS Tracker

## ► All-silicon tracker

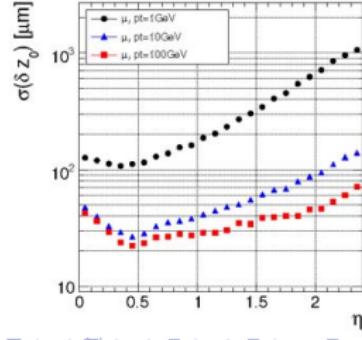
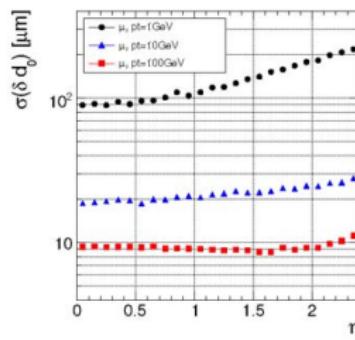
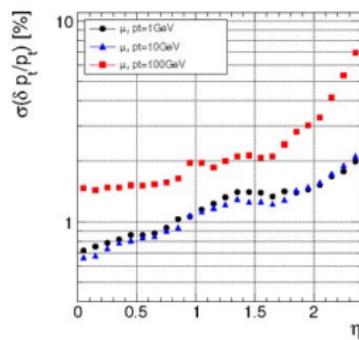
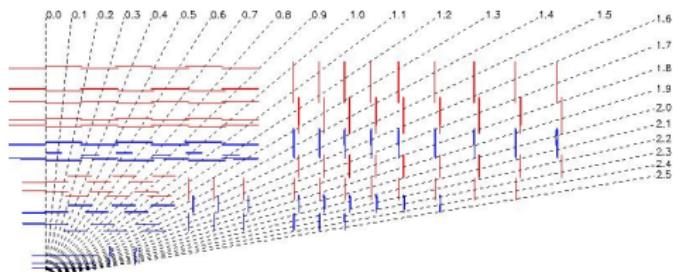
- few measurement layers
- but very precise:  $50/500 \mu\text{m}$  in  $(r - \phi)/z$

## ► Silicon Strip Detector

- 10÷14 points

## ► Pixel Detector

- hit resolution:  $10/17 \mu\text{m}$  in  $(r - \phi)/z$



# The CMS Trigger Strategy

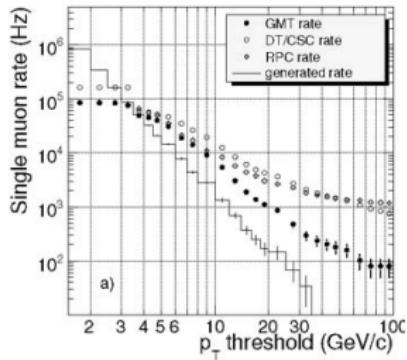
## ► Level 1 Triggers

- muons and calorimeters,  
Latency:  $3.2\mu s$ ,  
 $40 \text{ MHz} \rightarrow 100 \text{ kHz}$

## ► High-level Triggers (HLT)

- fast (local) reconstruction,  
 $100\text{kHz} \rightarrow 100\text{Hz}$

Single muon

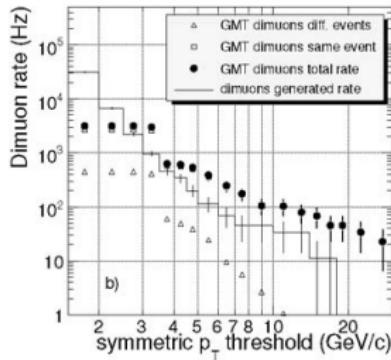


a)

## ► B-physics triggers

- **Level 1**: single- or di-muon trigger  
 $1\mu$ :  $p_T > 7(14) \text{ GeV}/c$ ,  
 $2\mu$ :  $p_T > 3(7) \text{ GeV}/c$
- **HLT**: exclusive and inclusive b/c triggers at  $\sim 5\text{Hz}$   
partial reconstruction,  
displaced di-muons

Di-muon



b)

# LHC start-up and CMS objectives

## ► 2008 - 10TeV Collision:

- Engineering Run →  $10 \div 100 \text{ pb}^{-1}$
- Nominal luminosity ( $10^{28} \rightarrow 10^{32}$ )  $\text{cm}^{-2}\text{s}^{-1}$ ,  $\text{bx}=75 - 25 \text{ ns}$
- Low luminosity detector commissioned, calibration and alignment

## ► 2009 - 14TeV Collision:

- Physics Run →  $1 \div 5 \text{ fb}^{-1}$
- Nominal luminosity ( $10^{32} \rightarrow 10^{33}$ )  $\text{cm}^{-2}\text{s}^{-1}$ ,  $\text{bx}=25 \text{ ns}$
- Detector calibrated and aligned, physics data taking

## ► Beauty related

- $\sigma_{b\bar{b}} \sim 500 \mu\text{b}$ ,  $N_{b\bar{b}} = 5 \times 10^{11} / \text{fb}^{-1}$
- L1 trigger:
  - 2 $\mu$ :  $p_\perp = 3 \text{ GeV}/c$ ;
  - 1 $\mu$   $p_\perp = 3, 5 \text{ GeV}/c$  - prescaled,  $p_\perp > 7 \text{ GeV}/c$  unprescaled till  $10^{32}$

# Heavy Flavor Menu

## ► Past

- $B_d \rightarrow \pi^\pm \pi^\mp$  and  $B_s \rightarrow K^\pm K^\mp$ : CP violation, angles  $\alpha$  and  $\gamma$
- $B_d \rightarrow J/\Psi K_s \rightarrow \mu^+ \mu^- \pi^+ \pi^-$ : CP violation, angle  $\beta$ , NP(?)
- $B_s - \bar{B}_s$  mixing in  $B_s \rightarrow D_s^- \pi^+ \rightarrow K^- K^+ \pi^- \pi^+$

## ► Present

- Inclusive b production: differential x-sections
- $B_s \rightarrow J/\Psi \phi \rightarrow \mu^+ \mu^- K^+ K^-$ : measurement of  $\Delta \Gamma_s$
- $B^0 \rightarrow \mu^+ \mu^-$ : FCNC rare decay, possible hint for NP
- $B_c^\pm \rightarrow J/\Psi \pi^\pm \rightarrow \mu^+ \mu^- \pi^\pm$ : mass and lifetime of  $B_c$
- Quarkonium studies ( $J/\Psi, \Upsilon \rightarrow \mu^+ \mu^-$ )

## ► Future (ongoing or planned analysis topics)

- $B^\pm \rightarrow J/\Psi K^\pm \rightarrow \mu^+ \mu^- K^\pm$ : measurement of  $\sigma_{b\bar{b}}$  (14 TeV)
- $B \rightarrow \mu + X$ : lifetime measurements, early 'engineering physics'
- $J/\Psi$  vs  $\mu$ :  $b\bar{b}$  correlation studies,  $b\bar{b}$  production mechanisms
- $B \rightarrow (\phi, K^*, K_s) \mu^+ \mu^-$ ,  $\Lambda_b \rightarrow \Lambda \mu^+ \mu^-$ : search for NP
- $B_s \rightarrow \mu^+ \mu^- \gamma$ ;  $\tau^+ \mu^-$ : search for NP
- $\tau \rightarrow 3\mu$ : lepton flavor violation

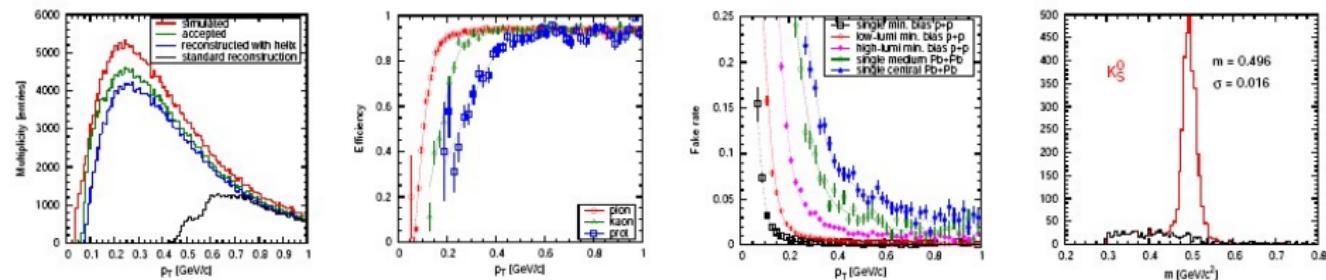
# $B_d \rightarrow J/\Psi K_s$ and low $p_\perp$ reconstruction

- Precision of  $\sin 2\beta$

- 2000: CMS planned  $\delta(\sin 2\beta)_{CMS} = 0.015_{stat}$  in  $10 \text{ fb}^{-1}$  ( $p_{\perp \pi} > 0.7 \text{ GeV}/c$ )
- 2008: HFAG quoted  $\delta(\sin 2\beta)_{exp} = 0.025(0.022)_{stat}$
- 2009: Can we contribute to  $\sin 2\beta$  measurement?

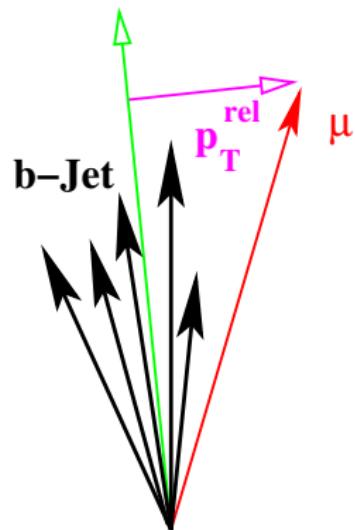
- New method for low  $p_\perp > 0.2 \text{ GeV}/c$  hadron reconstruction

- only silicon pixel hits used (3 layers), simple helix
- good efficiency, high resolution and negligible fake rate (proved by full simulation)



# Inclusive b production

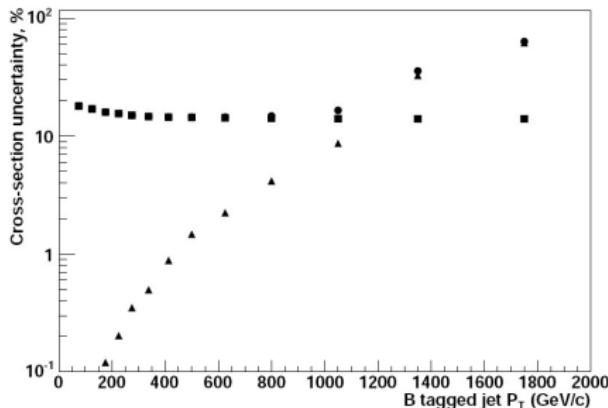
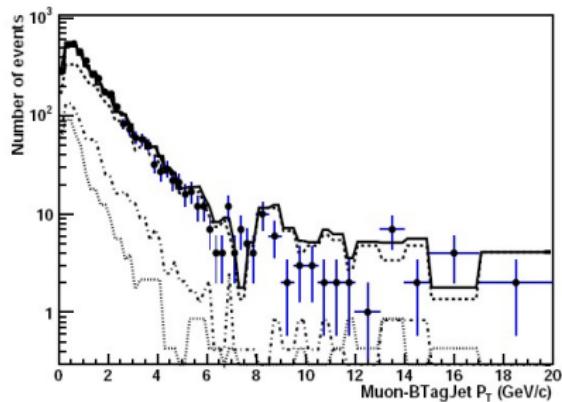
- ▶ Measure differential b-jet x-section:  $d\sigma/dp_{\perp}$  and  $d\sigma/d\eta$
- ▶ Key issue is data purity
  - select jets with muon inside (b-jet candidates)
  - fit data with MC shapes of muon transverse momentum with respect to jet axis
- ▶ Trigger
  - L1: single muon with  $p_{\perp} > 19 \text{ GeV}/c$
  - HLT: muon + b-jet of  $E_T > 50 \text{ GeV}$
- ▶ Off-line Analysis
  - b-jet tagging with CSV (secondary vertex based) algorithm
  - take most energetic b-jet in event as B-particle candidate
  - apply muon tag (muon in b-jet)
- ▶ 1.6M b-events collected @  $1 \text{ fb}^{-1}$



# Inclusive b production

muon  $p_{\perp}$  spectrum fit:  
b (dash), c (dot-dash), uds (dot)

x-section uncertainties:  
stat ( $\blacktriangle$ ), sys ( $\blacksquare$ ), total ( $\bullet$ )



Dominant source of systematic is JEC.

20% measurement up to  $p_{\perp}(B)=1.2$  TeV with  $10\text{ fb}^{-1}$

# $B_s \rightarrow J/\Psi \phi$

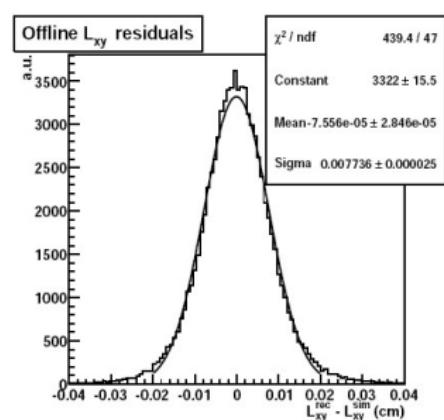
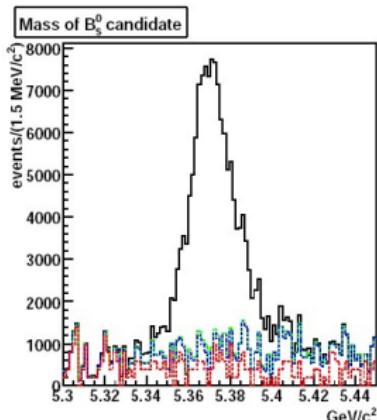
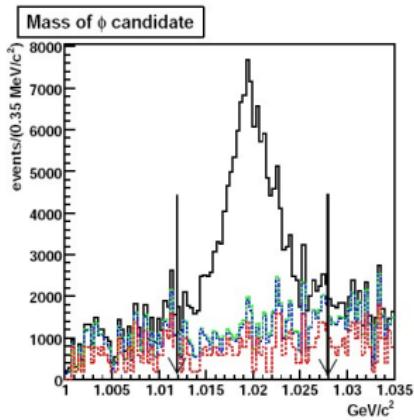
- ▶ Study properties of  $B_s$  system
  - width and mass difference of two weak eigenstates:  $\Delta\Gamma_s$ ,  $\Delta m_s$
  - height of the Unitarity Triangle ( $\eta$ ) and possible hint for NP:  
 $\phi_{CKM} = 2\lambda^2\eta \sim 0.03_{SM}$
- ▶ Trigger
  - L1: di-muon with  $p_\perp > 3 \text{ GeV}$
  - HLT 1: partial ( $\sim 6$  hits) track reconstruction
  - HLT 2:  $J/\Psi$  and vertexes reconstruction
  - HLT 3: kinematic ( $p_\perp$ , mass) and topological ( $L_{xy}$ ,  $\Delta\alpha$  etc) selections
  - HLT 4:  $\phi$  and  $B_s$  reconstruction and corresponding selections
- ▶ Off-line Analysis
  - almost the same as HLT but with complete information
  - angular analysis to measure  $\Delta\Gamma_s$
- ▶ Results
  - $\sim 10k$  events collected @  $1.3 \text{ fb}^{-1}$
  - Rel. errors on  $\bar{\Gamma}_s$ ,  $\Delta\Gamma_s$ ,  $\Delta\Gamma_s/\bar{\Gamma}_s$  are 3.4%, 19%, 20%

# $B_s \rightarrow J/\Psi \phi$

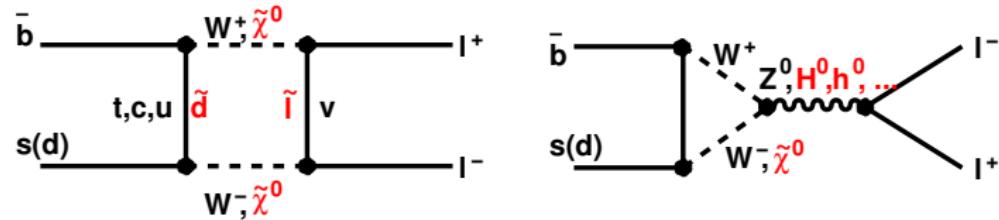
$$\Delta m_\phi \sim 3 \text{ MeV}/c^2$$

$$\Delta m_{B_s} \sim 14 \text{ MeV}/c^2$$

$$\sigma_{sv} \sim 77 \mu\text{m}$$

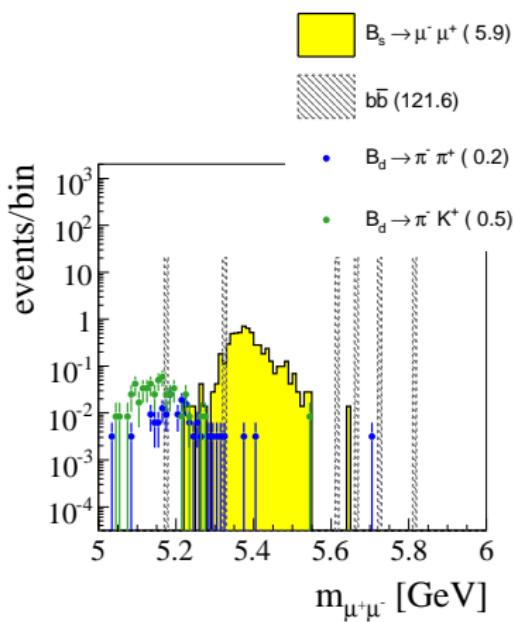
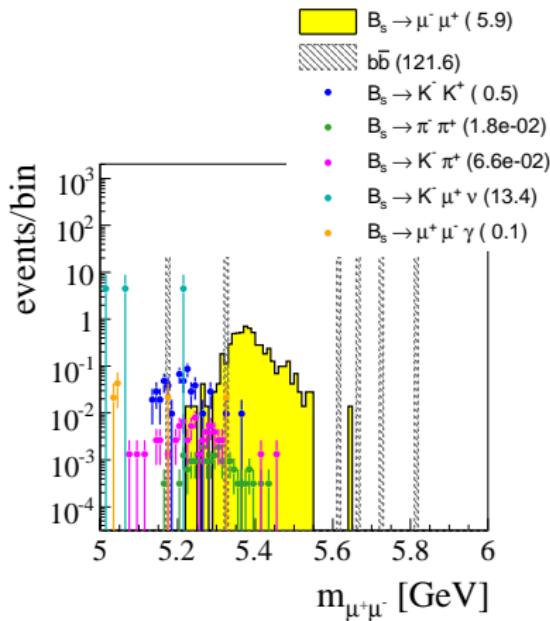


$$B_s^0 \rightarrow \mu^+ \mu^-$$



- ▶ Highly suppressed in SM:  $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.42 \pm 0.54) \times 10^{-9}$
- ▶ Sensitive to NP:
  - New particles contribute in decay diagrams
  - MSSM:  $\mathcal{B} \propto (\tan \beta)^6$  or 2HDM:  $\mathcal{B} \propto (\tan \beta)^4$
  - Constraints on masses ( $m_0$ ,  $m_{1/2}$  etc) and  $\tan \beta$
- ▶ Current best limit (Tevatron,  $2 \text{ fb}^{-1}$ ):
  - D0:  $\mathcal{B} \leq 9.3 \times 10^{-8}$  at 95% C.L.
  - CDF:  $\mathcal{B} \leq 5.8 \times 10^{-8}$  at 95% C.L.

## Rare background after selections ( $10 \text{ fb}^{-1}$ )



$$B_s^0 \rightarrow \mu^+ \mu^-$$

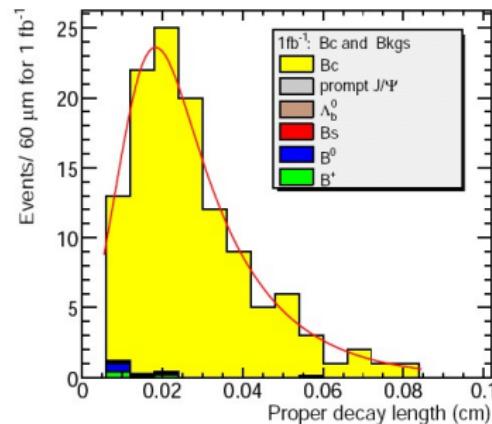
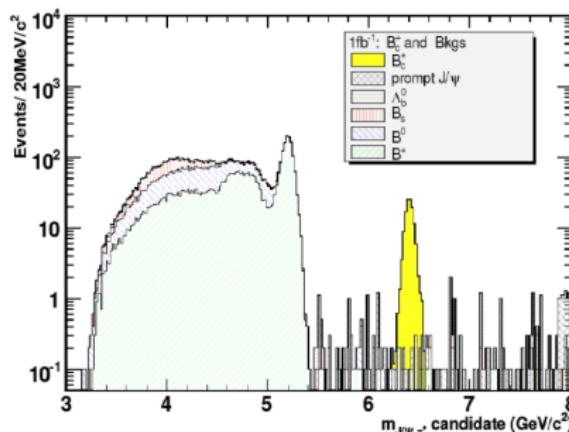
- ▶ Results for  $10 \text{ fb}^{-1}$
- ▶ Signal:  $\varepsilon_S = 0.019 \pm 0.002_{\text{stat}}, n_S = 6.1 \pm 0.6_{\text{stat}} \pm 1.5_{\text{sys}}$
- ▶ Background:  $\varepsilon = 2.6 \times 10^{-7}, n_B = (13.8 + 0.3)_{-14.1}^{+22.3}$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) \leq \frac{N(n_{\text{obs}}, n_B, n_S)}{\varepsilon_{\text{gen}} \varepsilon_{\text{total}} N_{B_s}} \leq 1.4 \times 10^{-8} \text{ (90% C.L.)}$$

\* Details of the study see in talk of C.Eggel on May 28

► Measure mass and life time of  $B_c$  in decay

- 120  $J/\Psi \pi^\pm$  selected in  $1\text{ fb}^{-1}$
- mass resolution  $15\text{ MeV}/c^2$  ( $M(B_c) \sim 6.4\text{ GeV}/c^2$ )
- lifetime error  $45\text{ fs}$  ( $\tau(B_c) \sim 460\text{ fs}$ )



# Conclusions and Outlook

## Conclusions

- ▶ While designed for high- $p_{\perp}$  physics, CMS has broad heavy flavor program
- ▶ Main features allow this program:
  - ▶ high  $b\bar{b}$  event rate even at low ( $10^{32} - 10^{33}$ ) initial luminosity
  - ▶ efficient low  $p_{\perp}$  di-muon trigger
  - ▶ excellent tracking: momentum, mass, vertex resolution

## Outlook

- ▶ More heavy flavor topics may come soon
- ▶ First results are expected in 2009