

Study of $B_s^0 \rightarrow \mu^+ \mu^-$ in CMS

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for the CMS collaboration

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- Introduction
- The CMS Experiment
- Analysis

Introduction

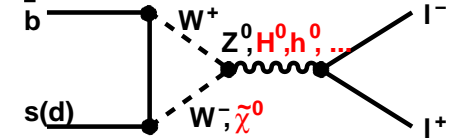
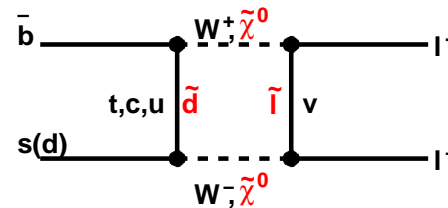
- Decays **highly suppressed** in Standard Model (Buras, 2003)

- ▷ effective FCNC

- ▷ helicity suppression

- ▷ $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.42 \pm 0.54) \times 10^{-9}$

- ▷ $\mathcal{B}(B_d^0 \rightarrow \mu^+ \mu^-) = (1.00 \pm 0.14) \times 10^{-10}$



- **Sensitivity to new physics**

- ▷ 2HDM: $\mathcal{B} \propto (\tan \beta)^4, m_{H^+}$; MSSM: $\mathcal{B} \propto (\tan \beta)^6$

- ‘Measurement’ of $\tan \beta$ (Kane, *et al.* ph/0310042)

- $B_s^0 \rightarrow \mu^+ \mu^-$ Cabibbo-favored over $B_d^0 \rightarrow \mu^+ \mu^-$

- ▷ not true for non-minimal flavor violation

- ▷ mass resolution critical!

- This decay channel

- ▷ not B physics, but a **search for ‘new physics’**

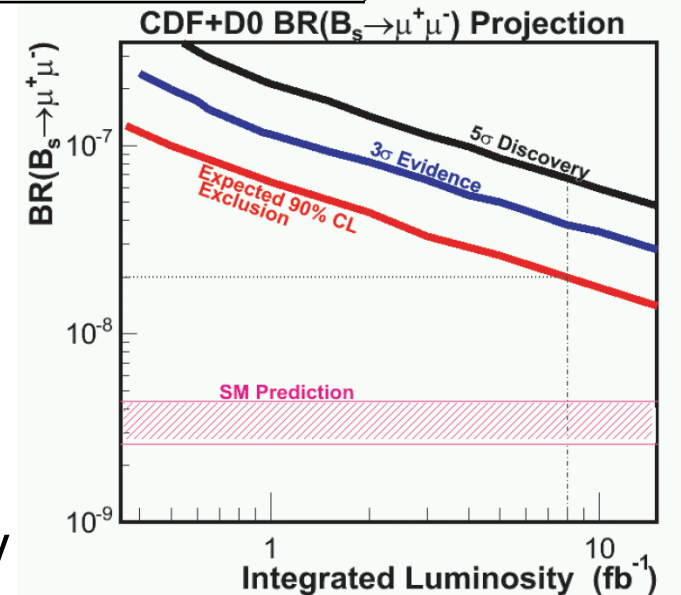
- ▷ well suited for **early CMS data** (with pixel detector)

State-of-the-art (before ICHEP06)

- All decay channels beyond the reach of experiments:

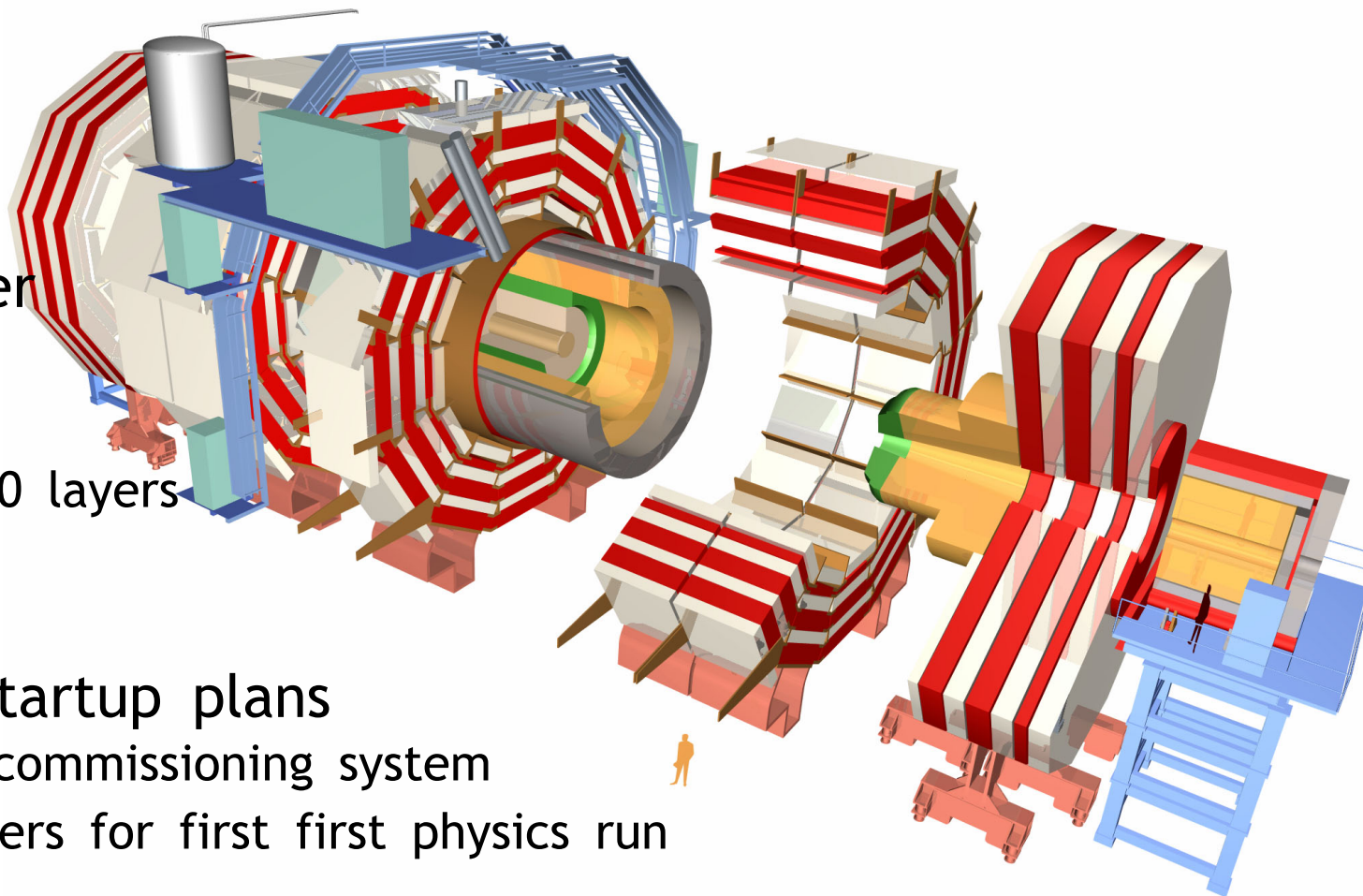
Mode	$B_s^0 \rightarrow \mu^+ \mu^-$	$B_d^0 \rightarrow \mu^+ \mu^-$	Reference
SM Expect.	3.5×10^{-9}	1.0×10^{-10}	Buras, 2003
CLEO	-	6.1×10^{-7}	PRD62, 091102
BELLE	-	1.6×10^{-7}	PRD68, 111101
CDF	5.8×10^{-7}	1.5×10^{-7}	PRL93, 032001
D0	4.1×10^{-7}	-	PRL94, 071802
BABAR	-	0.61×10^{-7}	PRL94, 221803
CDF	1.5×10^{-7}	0.39×10^{-7}	PRL95, 221805 + Err.
CDF	0.8×10^{-7}	0.23×10^{-7}	CDF public note 8176

- B -factories search also for
 - $B^0 \rightarrow e^+ e^-$
 - $B^0 \rightarrow e^\pm \mu^\mp$
- SM branching ratio is very low:
 - $b\bar{b}$ cross section at LHC $\sim 10\times$ larger than at Tevatron
 - Events can be triggered at high luminosity



The CMS Experiment

- The Compact Muon Solenoid
 - ▷ Length 22 m, diameter 15 m, 14 kton
 - ▷ Magnetic field 4 T
- Muon system
 - ▷ DT, CSC, RPC
 - ▷ $p_{\perp} > 3 \text{ GeV}$
- All-silicon tracker
 - ▷ $|\eta| < 2.5$
 - ▷ pixel: 3 layers
 - ▷ strip tracker: 10 layers
- Pixel detector startup plans
 - ▷ 2007: minimal commissioning system
 - ▷ 2008: three layers for first physics run



The CMS Tracker

- All-silicon tracker configuration

- ▷ Few measurement layers
- ▷ Very precise measurements

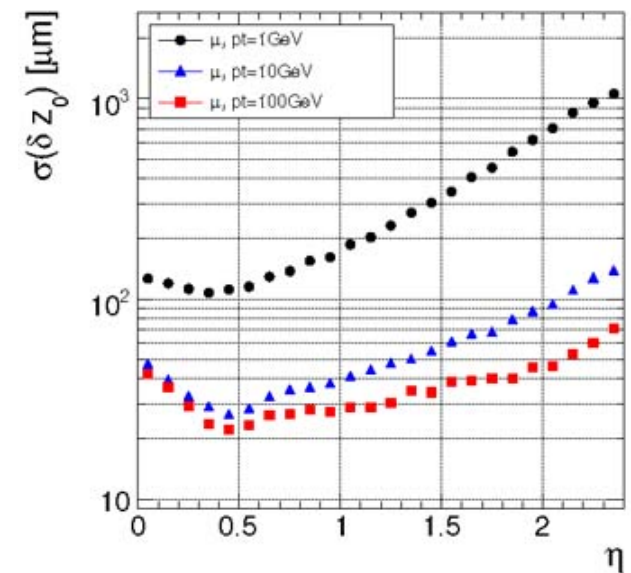
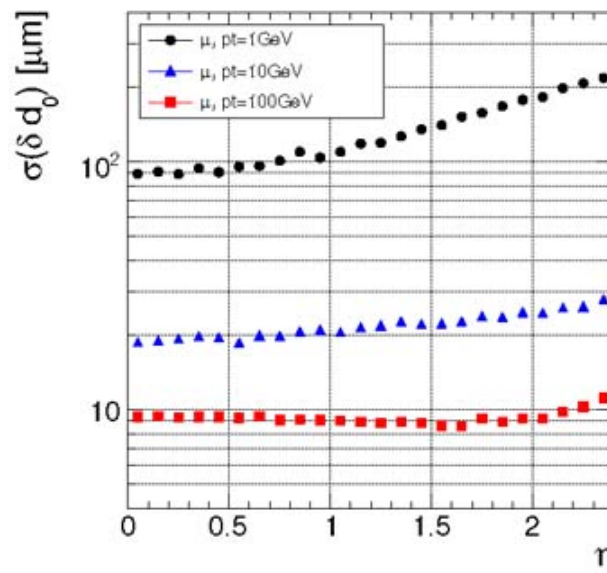
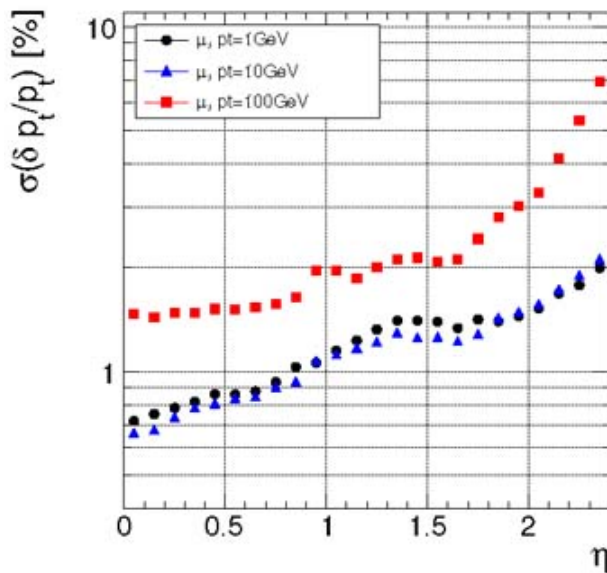
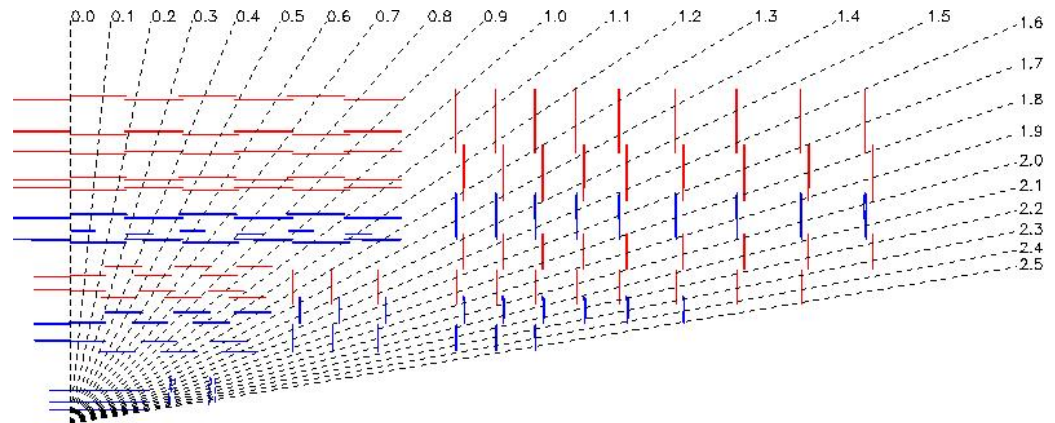
- Pixel Detector

- ▷ hit resolution: 10-15 μm

- Silicon Strip Detector

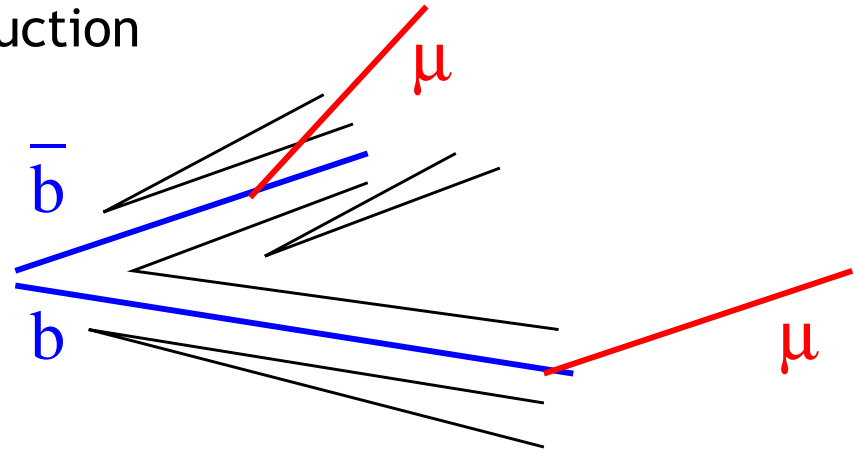
- ▷ 10-14 points

- Resolution:



Overview

- Search for a very rare decay
 - ▷ Clean experimental signature
 - Efficiency and background reduction
- b -hadrons produced in
 - ▷ gluon splitting
 - ▷ flavor excitation
 - ▷ gluon-gluon fusion
- Background composition
 - ▷ two independent semileptonic B decays (mostly from gluon splitting)
 - ▷ rare single B decays
- Background reduction in analysis
 - ▷ 2 final state muons consistent with **one** decay vertex
 - ▷ large (transverse) flight length
 - ▷ isolation of dimuon system



Event Samples

- Full MC simulation study for $\mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
 - ▷ Including 5 pile-up events
- Signal MC sample
 - ▷ 20k signal events
 - ▷ Minimum bias QCD events
- Background MC sample
 - ▷ 15k background events
 - ▷ Minimum bias QCD events
 - ▷ 2 muons on generator level,
 $p_{\perp} > 3 \text{ GeV}$, $|\eta| < 2.4$, $0.3 < \Delta R(\mu\mu) < 1.2$
- Rare decays with PYTHIA (phasespace)
 - ▷ $B_d \rightarrow \pi^0 \mu^+ \mu^-$
 - ▷ $B^+ \rightarrow \mu^+ \mu^- \mu^+ \nu_{\mu}$

for first studies (with full simulation)

Trigger Strategy

- CMS has two-level trigger architecture

- Level 1

- ▷ muons and calorimeters

Latency: $3.2 \mu\text{s}$

40 MHz \rightarrow 100 kHz

- High-level trigger (HLT)

- ▷ fast (local) reconstruction

100 kHz \rightarrow 100 Hz

- B -physics triggers

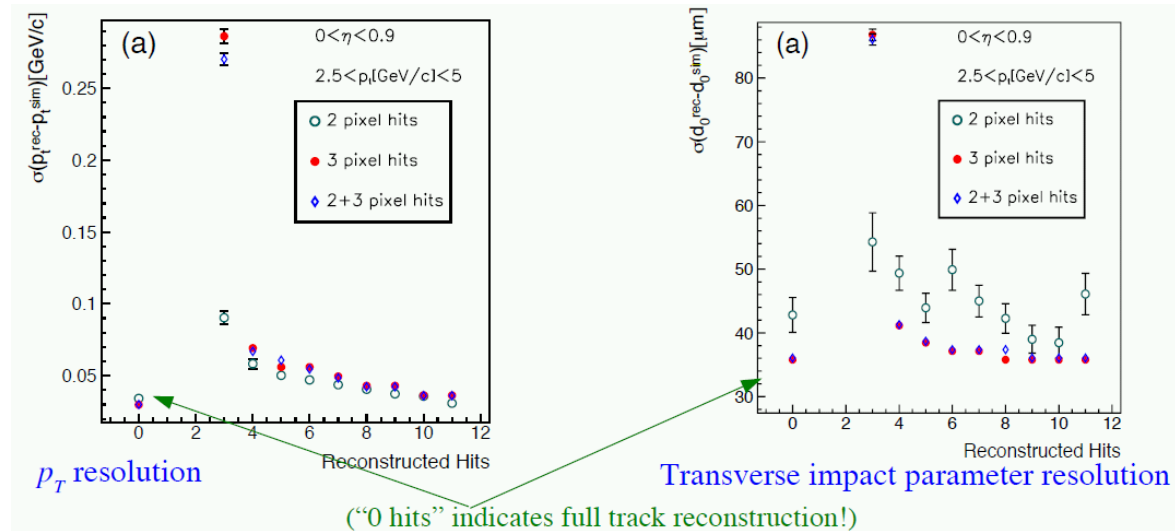
- ▷ Level 1: single- or di-muon trigger

single-muon: $p_{\perp} > 14 \text{ GeV}$

di-muons: $p_{\perp} > 3 \text{ GeV}$

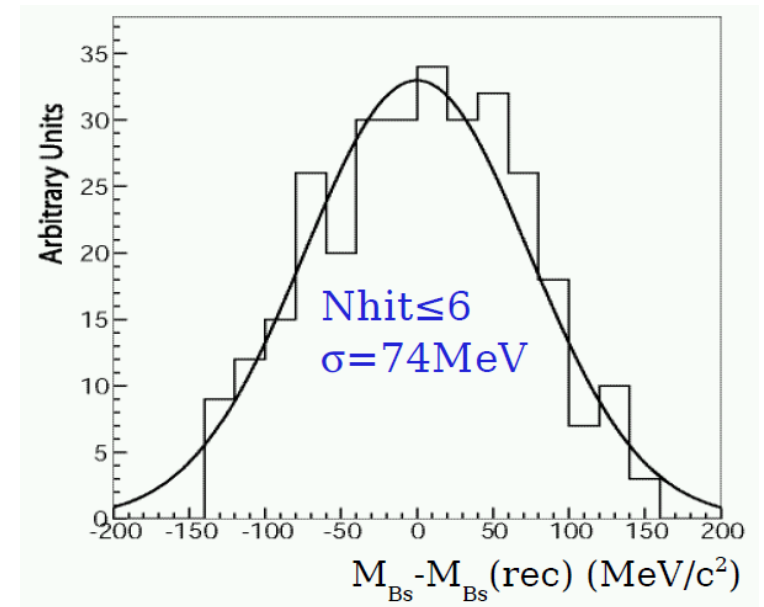
- ▷ HLT: exclusive and inclusive b, c triggers at $\sim 5 \text{ Hz}$

exclusive B decays: partial (local) reconstruction



High-level trigger selection study

- Primary vertex reconstruction with pixel detector
 - ▷ use three most probable vertices
 - Regional track reconstruction in cones around L1-muon candidates
 - ▷ partial reconstruction using ≤ 6 hits
 - ▷ $p_{\perp} > 4 \text{ GeV}$
 - Track pairs
 - ▷ mass windows for signal (and background)
 - ▷ (un)like sign charge
 - Vertex fit
 - ▷ $\chi^2 < 20$
 - ▷ Decay flight length $l_{3d} > 150 \mu\text{m}$
- ⇒ HLT accept rate $< 1.7 \text{ Hz}$



Analysis: Variables

- Decay flight length significance l_{xy}/σ_{xy}
 - ▷ transverse plane: $l_{xy}/\sigma_{xy} > 18$
- Muon separation in $\eta\phi$:

$$\Delta R(\mu\mu) = \sqrt{(\eta_{\mu_1} - \eta_{\mu_2})^2 + (\phi_{\mu_1} - \phi_{\mu_2})^2}$$

- ▷ $0.3 < \Delta R(\mu\mu) < 1.2$

- Isolation of muon pair

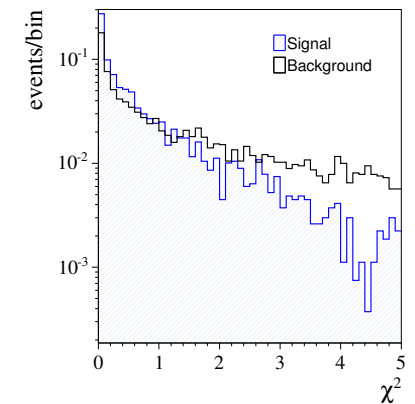
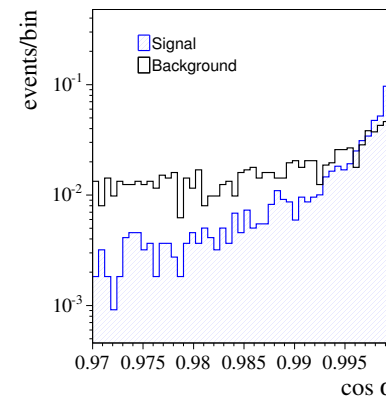
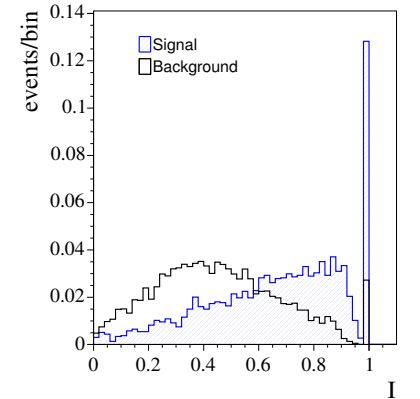
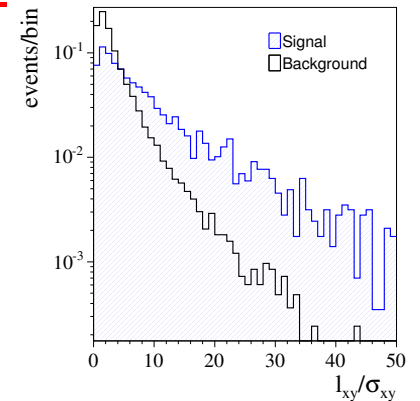
$$I = \frac{p_{\perp}(B_s)}{p_{\perp}(B_s) + \sum_{trk} |p_{\perp}|}$$

tracks in cone with $r = \sqrt{\eta^2 + \phi^2} < 1.0$
and $p_{\perp} > 0.9 \text{ GeV}$

- ▷ $I > 0.85$

- Secondary vertex

- ▷ Pointing angle: $\cos(\alpha) > 0.995$
- ▷ vertex fit $\chi^2 < 1$



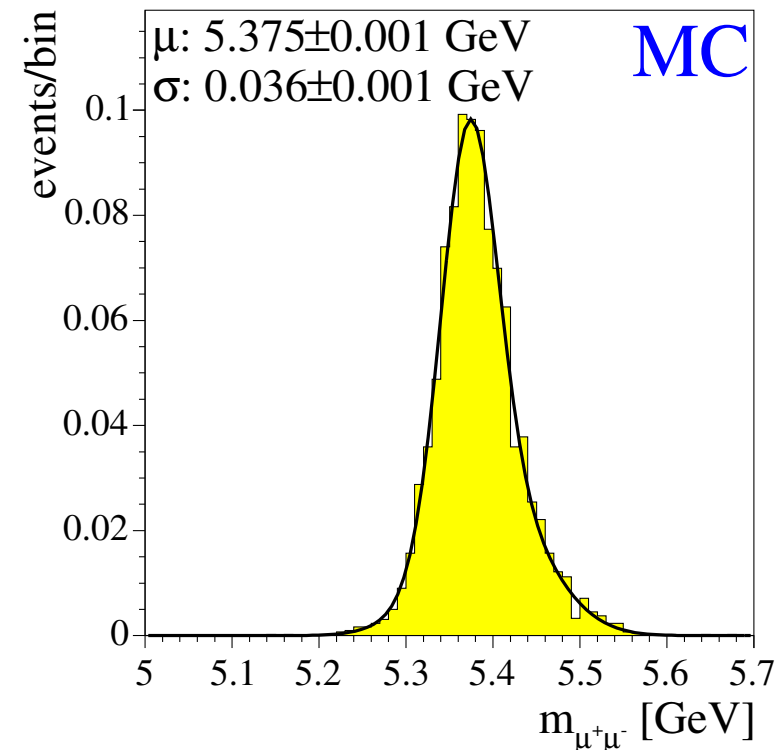
Mass Reconstruction

- Fit with two Gaussians

Gaussian	Narrow	Wide
Mean	5372.5 ± 1.3	5398.8 ± 3.3
Sigma	32.1 ± 1.4	60.2 ± 2.4
Normalization	0.08	0.03

(statistical errors only)

- Good mass resolution
 - ▷ essential against rare B decays
 - ▷ $\sim 2\sigma$ separation to B_d
- Impact of tracker misalignment on mass resolution
 - ▷ 2 alignment scenarios
 - short-term $\sim 20\%$
 - long-term $\sim 10\%$



Results

- Signal selection efficiency $\varepsilon = 0.019 \pm 0.002_{stat}$
where the efficiency $\varepsilon = \varepsilon_{cuts} \varepsilon_I \varepsilon_{\chi^2}$ is factorized
 - ▷ In 10 fb^{-1} : $N_S = 6.1 \pm 0.1$ signal events
- Background rejection $\eta = 2.6 \times 10^{-7}$
 - ▷ In 10 fb^{-1} : $N_B = 13.8^{+22.0}_{-13.8}$ background events
(one remaining background event in $5 < m_{\mu\mu} < 6 \text{ GeV}$)
- Extract upper limit with Bayesian procedure (CDF)

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

including statistical and systematic error

Systematics

- Systematics have minor impact compared to statistical error
 - ▷ with current background MC sample
- Determination of efficiency with factorizing cuts
 - ▷ 15%
- Tracker misalignment (decay flight significance, χ^2 , $\cos \alpha$)
 - ▷ 10% for signal efficiency, 50% for background
- L1 trigger efficiency
 - ▷ 10%
- Particle identification
 - ▷ muon ID and hadron mis-ID
- Tracking
 - ▷ efficiency: isolation veto
- Normalization
 - ▷ 15%, a la CDF and D0

Summary:

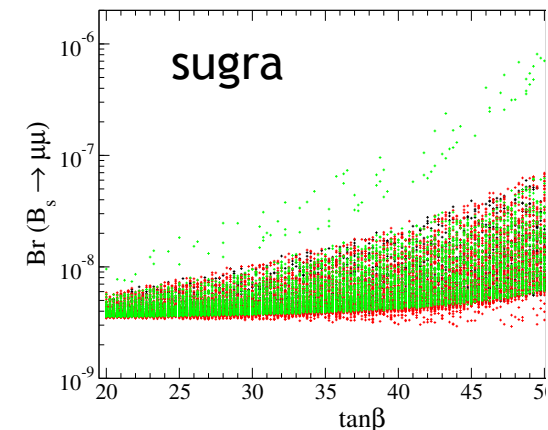
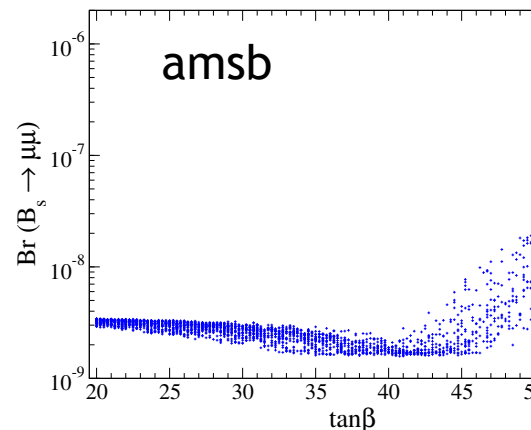
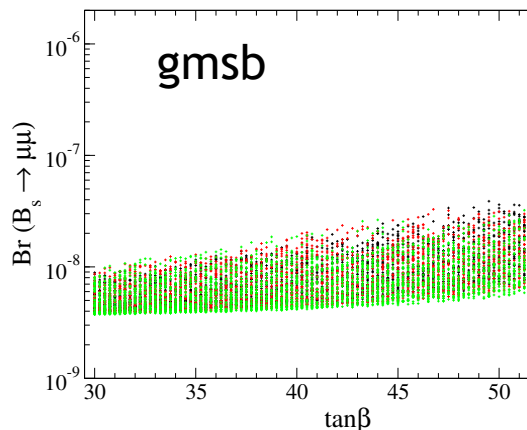
$$\Delta(\varepsilon) : 24\%$$

$$\Delta(n_B) : 50\%$$

$$\Delta(N_{B_s}) : 15\%$$

Conclusions

- First CMS update on search for $B_s^0 \rightarrow \mu^+ \mu^-$ since 1999
 - ▷ Full reconstruction with pileup for $2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$
- Expected upper limit in 10 fb^{-1} : $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) \leq 1.4 \times 10^{-8}$
 - ▷ study limited by size of background MC sample
 - ▷ good mass resolution
- Outlook
 - ▷ include rare B decays
 - ▷ full analysis: likelihood selection and normalization sample



(from hep-ph/0310042)