Search for $B_s^0 \to \mu\mu$ and $B_d^0 \to \mu\mu$ at the CMS experiment

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Overview

Introduction

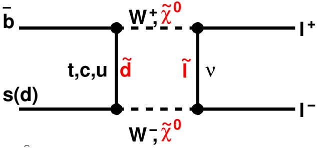
- Decay is highly suppressed in SM.
  - effective FCNC, helicity suppressed.
  - SM expectation

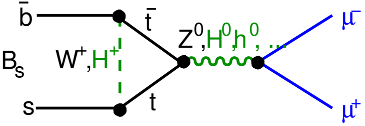
$$\mathcal{B}(B_s^0 \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B_d^0 \to \mu\mu) = (1.0 \pm 0.1) \times 10^{-10}$$

- CMS can constrain BSM directly and indirectly
  - MSSM: $\mathcal{B} \propto (\tan\beta)^6$
  - Cabibbo-enhancement ($|V_{ts}| > |V_{td}|$) of $B_s^0 \to \mu\mu$ over $B_d^0 \to \mu\mu$ only in MFV models.
  - $\mathcal{B}$ could also be smaller than SM prediction.

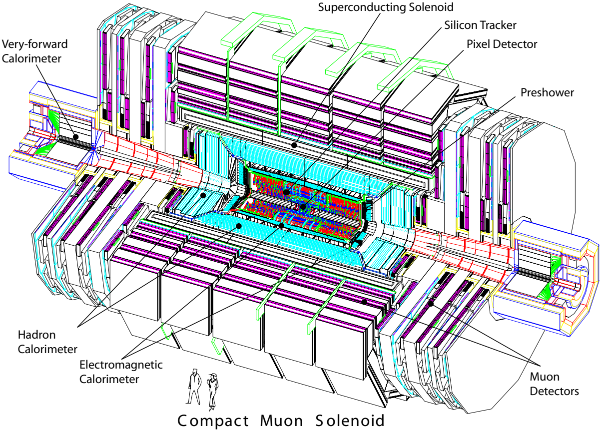
→ Constraints on parameter region

→ Sensitivity to extended Higgs boson sectors





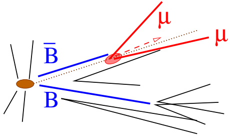
CMS Detector



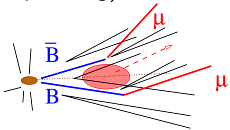
Component	Characteristics	resolutions
Pixel	3/2 Si layers	$\delta_z \approx 20\ \mu\mathrm{m}$, $\delta_\phi \approx 10\ \mu\mathrm{m}$
Tracker	10/12 Si strips	$\delta(p_\perp)/p_\perp \approx 1\%$
ECAL	$\mathrm{PbWO_4}$	$\delta E/E \approx 3\%/\sqrt{E} \oplus 0.5\%$
HCAL (B)	Brass / Sc, $> 7.2\lambda$	$\delta E/E \approx 100\sqrt{E}\%$
HCAL (F)	Fe/Quartz	$\delta(slashE_T) \approx 0.98\sqrt{\sum E_T}$
Magnet	3.8 T solenoid	
Muons	DT / CSC + RPC	$\delta(p_\perp)/p_\perp \approx 10\%(\mathrm{STA})$

Analysis overview

- Signal signature
  - two muons from one decay vertex
  - dimuon mass around $m_{B_s^0} = (5.3663 \pm 0.0006)\ \mathrm{GeV}$



- Background composition
  - two independent semileptonic B decays
  - one semileptonic (B) decay and one misidentified hadron
  - rare single B decays (peaking and non-peaking)
- Most powerful variables
  - Isolation of B candidate
  - good vertex fit
  - small pointing angle
  - high flight length significance ℓ_{3d}/σ_{3d}
  - d_{ca} of closest track near SV



Analysis methodology

- Measure the branching fraction $B^0_{s(d)} \to \mu\mu$

$$\mathcal{B}(B^0_s \to \mu\mu) = \frac{N(B^0_s \to \mu\mu)}{N(B^0_s)} = \frac{N(B^0_s \to \mu\mu)}{f_s \sigma_b \mathcal{L}} = \frac{N^{\mathrm{obs}}(B^0_s \to \mu\mu)}{\varepsilon^{B^0_s} f_s \sigma_b \mathcal{L}}$$

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- Replace $\sigma_b \mathcal{L}$ using a well measured branching fraction with similar signal topology

Analysis methodology

- Measure the branching fraction $B^0_{s(d)} \rightarrow \mu\mu$ using a normalization channel

$$\mathcal{B}(B^0_s \rightarrow \mu\mu; 95\% C.L.) = \frac{N(n_{obs}, n_B)}{N(B^{\pm} \rightarrow J/\psi K^{\pm})} \frac{f_u}{f_s} \frac{\varepsilon^{B^{\pm}}}{\varepsilon^{B^0_s}} \mathcal{B}(B^{\pm} \rightarrow J/\psi(\mu^+\mu^-)K^{\pm})$$

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- $B^{\pm} \rightarrow J/\psi K^{\pm}$ has similar decay topology and is well measured.

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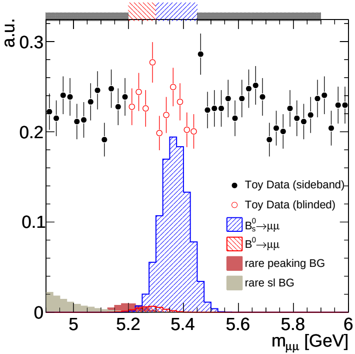
- $B^\pm \to J/\psi K^\pm$ has similar decay topology and is well measured.
- Systematics on efficiencies affect the signal and normalization channel in similar way, hence should largely cancel.

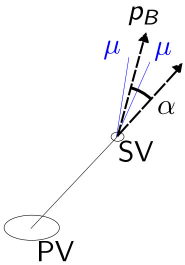
Event selection

- Vertexing pairs of muons and fill in histogram
- Blind analysis: Everything of the analysis was set before looking at the number of entries in the signal region.
  - ⇒ No signal candidates were reconstructed in the mass range $5.2\,\mathrm{GeV} < m_{\mu\mu} < 5.45\,\mathrm{GeV}$
    - Avoid bias
    - Avoid overtuning
    - Tradition in field
- Sideband was used to study the background in data.



Candidate variables

- pointing angle $\alpha(\vec{P}_B, \vec{SV} - \vec{PV})$.



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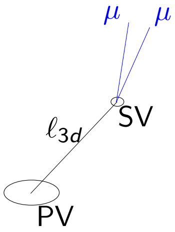
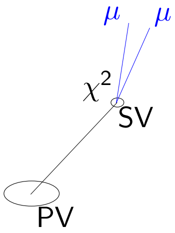
- flight length in three-dimensional space (ℓ_{3d}) and its error (σ_{3d}).



Candidate variables

- pointing angle $\alpha(\vec{P}_B, \vec{SV} - \vec{PV})$.
- flight length in three-dimensional space (ℓ_{3d}) and its error (σ_{3d}).
- χ^2 of secondary vertex fit.



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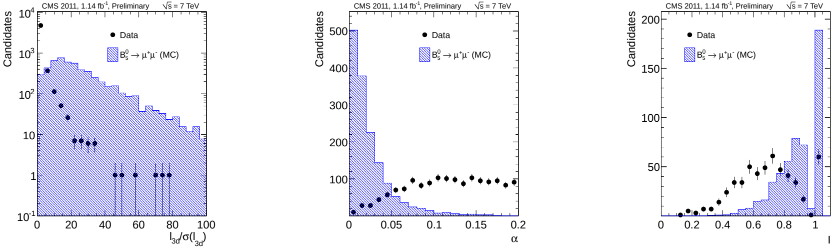
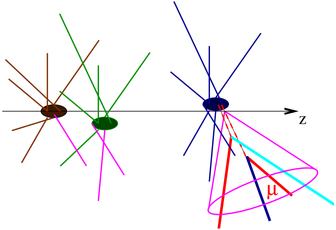
- pointing angle $\alpha(\vec{P}_B, \vec{SV} - \vec{PV})$.
- flight length in three-dimensional space (ℓ_{3d}) and its error (σ_{3d}).
- χ^2 of secondary vertex fit.
- Isolation (see next slide).



Isolation

- Isolation (I) defined as



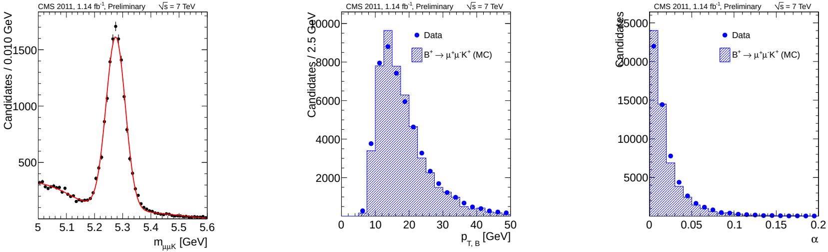
$$I = \frac{p_\perp(B_s^0)}{p_\perp(B_s^0) + \sum_{\mathrm{trk}} p_\perp},$$

where the sum over tracks in cone around $\vec{p}_B$ with track

  - not part of the B_s^0 candidate
  - from same PV as the B_s^0 candidate or close to secondary vertex.

Normalization channel: $B^{\pm} \to J/\psi(\mu^+\mu^-)K^{\pm}$

- Combine two muons with a track to form candidates.
- Compare MC simulation with data.

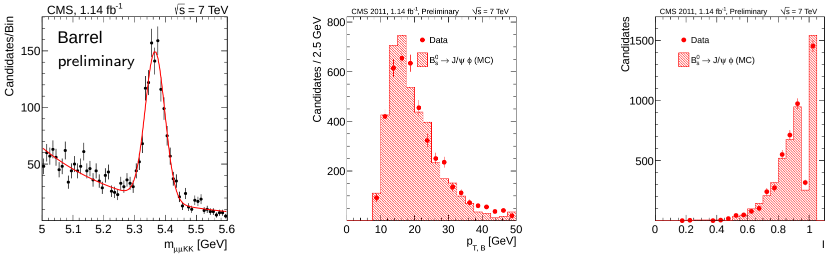


Control Sample: $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$

- Recall master formula

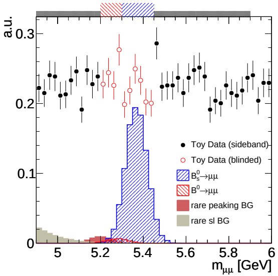
$$\mathcal{B}(B_s^0 \to \mu\mu; 95\% C.L.) = \frac{N(n_{obs}, n_B)}{N(B^\pm \to J/\psi K^\pm)} \frac{f_u}{f_s} \frac{\varepsilon^{B^\pm}}{\varepsilon^{B_s^0}} \mathcal{B}(B^\pm \to J/\psi(\mu^+\mu^-)K^\pm)$$

- Measure $B_s^0 \to J/\psi\phi$ to validate exclusive B_s^0 decay.



Background estimation

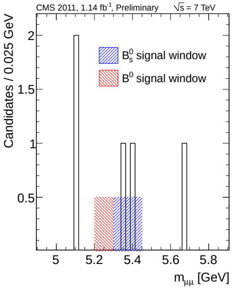
- Background in signal window estimated from sidebands by linear interpolation.
- Investigate shape of background (by loosening cuts) and get uncertainty for linear interpolation.

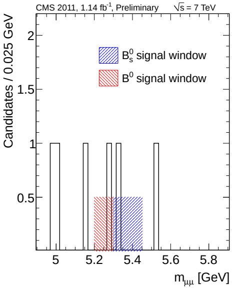


$B \to \mu\mu$ results

Expectations and observations

Variable	$B_s^0 \to \mu\mu$ Barrel	$B_d^0 \to \mu\mu$ Barrel	$B_s^0 \to \mu\mu$ Endcap	$B_d^0 \to \mu\mu$Endcap
$N_{\rm signal}^{\rm exp}$	0.80 ± 0.16	0.065 ± 0.011	0.36 ± 0.16	0.025 ± 0.004
$N_{\rm bg}^{\rm exp}$	0.60 ± 0.35	0.40 ± 0.23	0.80 ± 0.40	0.53 ± 0.27
$N_{\rm peak}^{\rm exp}$	0.071 ± 0.020	0.245 ± 0.056	0.044 ± 0.011	0.158 ± 0.039
$N_{\rm s+b}^{\rm exp}$	1.471 ± 0.385	0.71 ± 0.24	1.204 ± 0.431	0.713 ± 0.273
$N_{\rm obs}$	2	0	1	1





Upper limits

- SM values

$$\mathcal{B}(B_s^0 \to \mu\mu) = (3.2 \pm 0.2) \times 10^{-9}$$
$$\mathcal{B}(B_d^0 \to \mu\mu) = (1.0 \pm 0.1) \times 10^{-10}$$

- upper limits with $\mathrm{CL_s}$

$$\mathcal{B}(B_s^0 \to \mu\mu) \quad < \quad 1.9 \times 10^{-8} \quad (95\%\,\mathrm{C.L.})$$
$$\mathcal{B}(B_d^0 \to \mu\mu) \quad < \quad 4.6 \times 10^{-9} \quad (95\%\,\mathrm{C.L.})$$

- Expected upper limits for our measurement of $B_s^0 \to \mu\mu$

$$\text{bkg only:} \quad (1.45^{+0.52}_{-0.48}) \times 10^{-8}$$
$$\text{SM:} \quad (1.88^{+0.67}_{-0.77}) \times 10^{-8}$$

- p values for background only

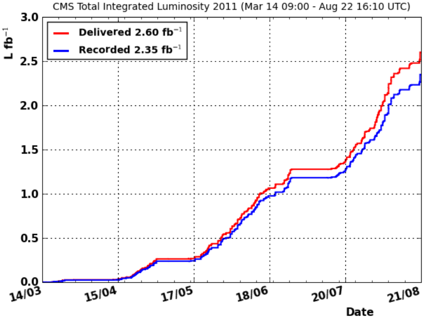
$$B_s^0 \to \mu\mu : 0.11 (= 1.20\sigma) \qquad B_d^0 \to \mu\mu : 0.40 (= 0.27\sigma)$$

- CMS+LHCb combination

$$\mathcal{B}(B_s^0 \to \mu\mu) < 1.1 \times 10^{-8}$$

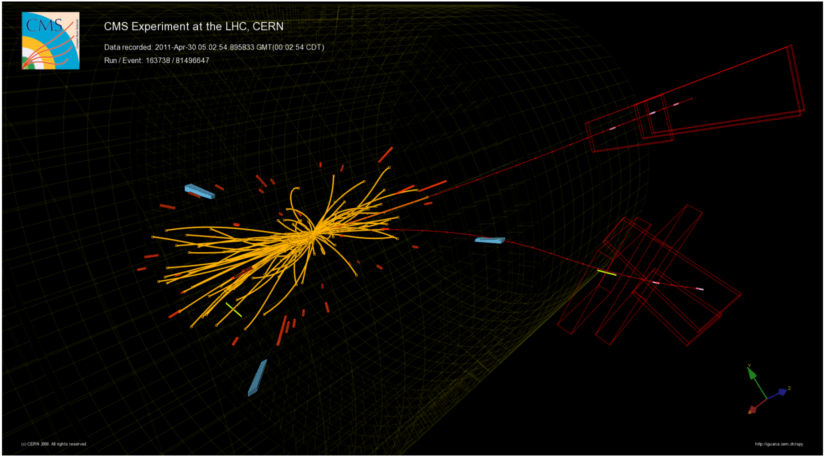
Outlook

- Luminosity increases



- More advanced analysis. Switch from 'Cut & Count' to MVA.
- Improvements within analysis

Candidate


CMS Experiment at the LHC, CERN
Data recorded: 2011-Apr-30 05:02:54.895833 GMT(00:02:54 CDT)
Run / Event: 163738 / 81496647
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