

$B \rightarrow \mu^+ \mu^-$ decays at CMS

P. Ronchese - CMS collaboration

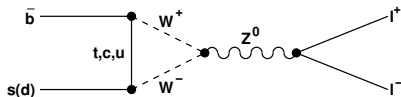
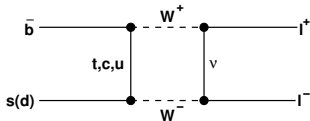
University and INFN Padova

XI International Conference on Heavy Quarks and Leptons
Prague, June 11-15, 2012



SM processes

$B \rightarrow \mu^+ \mu^-$ is a highly suppressed process in the SM:



- FCNC: only at higher order processes (box, penguin)
- Cabibbo suppressed: $|V_{ts(td)}|^2$
- Helicity suppressed: $(m_\mu/m_B)^2$
- Internal annihilation: $(f_B/m_B)^2$

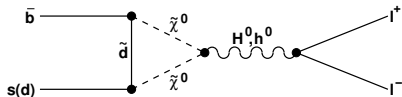
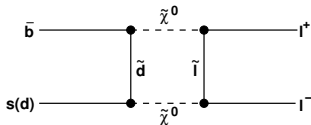
$$Br(B_d^0 \rightarrow \mu^+ \mu^-) = (1.0 \pm 0.1) \times 10^{-10}$$

$$Br(B_s^0 \rightarrow \mu^+ \mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$



Beyond-SM processes

In SM extensions new particles can contribute to the process



- Extended Higgs sector (2HDM): enhanced Br at high $\tan \beta$
- Higgs-mediated decays in MSSM:
 $Br(B_{(s,d)}^0 \rightarrow \mu^+ \mu^-) \propto \tan^6 \beta$
- Leptoquarks, NUHM models: enhanced BRs even at low $\tan \beta$
- MSSM with modified Minimal Flavor Violation: enhanced $R = Br(B_d)/Br(B_s)$

(Non) observation: bounds to parameters space



Data analysis

Dimuon events selected in pp collisions:

- $\sqrt{s} = 7\text{TeV}$, $\mathcal{L} = 5\text{fb}^{-1}$
- Trigger: L1 from muon detector only, HLT includes tracker information
- Muon identification: tracker & muon detector signal matched + additional cuts
- Secondary vertices reconstructed
- Background estimated in sidebands

$Br(B_{d,s}^0 \rightarrow \mu^+\mu^-)$ (limit) computed by comparison with a “normalization” process: $B^+ \rightarrow J/\psi K^+$ ($J/\psi \rightarrow \mu^+\mu^-$)

Systematic errors cancellation:

$b\bar{b}$ production, luminosity, acceptance, efficiency

Barrel (both muons with $|\eta| < 1.4$)
 Endcap (at least one muon with $|\eta| > 1.4$) } kept separate,
 then combined



Normalization

$$Br(B_{d,s}^0 \rightarrow \mu^+ \mu^-) = \frac{N_{\text{sig}}}{N_{\text{nrn}}} \frac{\epsilon_{\text{nrn}}}{\epsilon_{\text{sig}}} \frac{f_U}{f_{d,s}} Br(B^\pm \rightarrow J/\psi K^\pm \rightarrow \mu^+ \mu^- K^\pm)$$

- $N_{\text{sig}}, N_{\text{nrn}}$: background-subtracted event numbers
- $\epsilon_{\text{nrn}}, \epsilon_{\text{sig}}$: total trigger + reconstruction efficiencies for signal and normalization channels
- $f_U/f_{d,s}$: ratio of B^+ and $B_{d,s}^0$ production cross sections
 - $f_d/f_U = 1$
 - $f_s/f_U = 0.267 \pm 0.021$ from LHCb at $2 < \eta < 5$
- $Br(B^\pm \rightarrow J/\psi K^\pm \rightarrow \mu^+ \mu^- K^\pm) = (6.0 \pm 0.2) \times 10^{-5}$ (PDG)

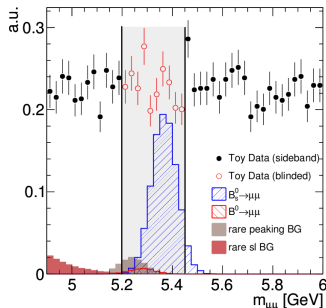
$Br(B_S^0 \rightarrow J/\psi \phi)$ ($J/\psi \rightarrow \mu^+ \mu^-$, $\phi \rightarrow K^+ K^-$)
computed in parallel as control



Blind analysis

The signal region ($5.20\text{GeV} < m_{\mu^+\mu^-} < 5.45\text{GeV}$) inspected only when all analysis details have been defined

- Selection cuts
- Trigger & selection efficiencies
- Background estimation
- Systematic uncertainties



Muon identification

Track segments in the silicon tracker and muon detector reconstructed and matched

- At least 2 segments in the muon system
- At least 10 hits in the tracker (at least 1 in pixels)
- Combined track $\chi^2/(\text{dof}) < 10$
- Impact parameter $d_{xy} < 0.2\text{cm}$

Signal/normalization efficiency, trigger+id.

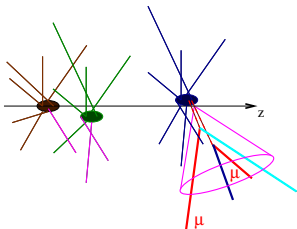
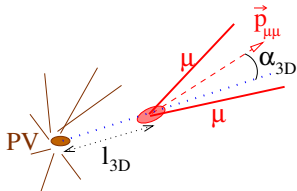
- Evaluation from MC
- Tag & probe method, both for data and MC, in J/ψ events
- Difference $\epsilon_{\text{data}} - \epsilon_{\text{MC}}$ included in the systematic error

$$\epsilon_{\mu} = 71\%(\text{barrel}), 85\%(\text{endcap})$$



Vertices analysis

- Opposite-charge muon pairs fitted to a common vertex
- Muons combined to form a B candidate



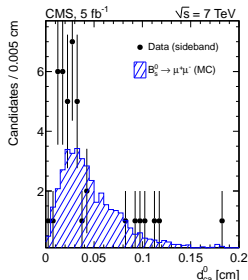
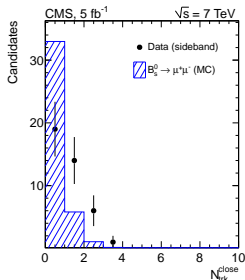
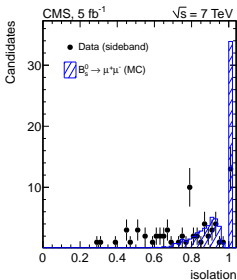
$\bar{N} = 8$ pp collisions per BX

Primary vertex chosen as the nearest, along the beams axis, to the B candidate to remove pileup



Isolation

- $I = \frac{p_T(B)}{p_T(B) + \sum_{\text{trk}} p_T}$, with the sum running over all tracks with
 - $\Delta R = \sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.7$
 - $p_T > 0.9\text{GeV}$
 - Consistent with coming from primary or B vertex
- N_{close} : number of tracks with $p_T > 0.5\text{GeV}$ and $d_{\text{ca}} < 0.03\text{cm}$ to B vertex
- d_{ca}^0 : minimum distance to B vertex for all tracks



Final selection

variable		barrel	endcap	unit
$p_{T\mu 1}$	>	4.5	4.5	GeV
$p_{T\mu 2}$	>	4.0	4.2	GeV
$p_{T\mu\mu}$	>	6.5	8.5	GeV
δ_{3D}	<	0.008	0.008	cm
$\delta_{3D}/\sigma(\delta_{3D})$	<	2	2	
α	<	0.05	0.03	rad
$\chi^2/\text{d.o.f.}$	<	2.2	1.8	
$\ell_{3D}/\sigma(\ell_{3D})$	>	13	15	
l	>	0.8	0.8	
d_{ca}	>	0.015	0.015	cm
N_{close}	<	2	2	

$$\epsilon_{\text{sig}}(B_{d,s}^0 \rightarrow \mu^+ \mu^-) = \begin{cases} (29 \pm 2) \times 10^{-4} & \text{barrel} \\ (16 \pm 2) \times 10^{-4} & \text{endcap} \end{cases}$$

$$\epsilon_{\text{nrn}}(B^\pm \rightarrow J/\psi K^\pm) = \begin{cases} (110 \pm 9) \times 10^{-5} & \text{barrel} \\ (32 \pm 4) \times 10^{-5} & \text{endcap} \end{cases}$$

Efficiency estimated in MC and data (sidebands):
difference included in the systematic error

Normalization and control samples

Similar (not identical) selections:

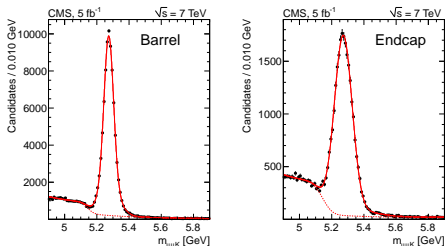
- Different $\mu^+ \mu^-$ mass range
- 1 or 2 additional tracks assumed to be kaon(s)



Normalization

Invariant mass distributions fit

- a double-gaussian for the signal
- a step function for background
(partly reconstructed decays, e.g. $B^\pm \rightarrow J/\psi K^*$)



$$N_{\text{norm}} = \begin{cases} (82.7 \pm 4.2) \times 10^3 & (\text{barrel}) \\ (23.8 \pm 1.2) \times 10^3 & (\text{endcap}) \end{cases}$$

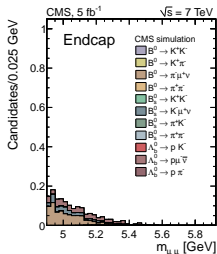
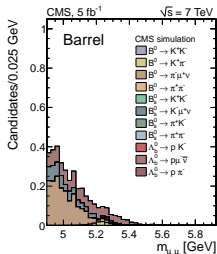


Background

- misidentified B decays (from simulation)
 - $B \rightarrow h_1 h_2$ decays, with h_1, h_2 hadrons misidentified as muons
 - $B \rightarrow h \mu \nu$ decays, with h misidentified as a muon
- combinatorial (from sidebands)

$$\Pi_{(\pi, K) \rightarrow \mu} = (0.10 \pm 0.02)\% \text{ (from } D^0 \rightarrow K^+ \pi^- \text{),}$$

$$\Pi_{p \rightarrow \mu} = (0.05 \pm 0.01)\% \text{ (from } \Lambda \rightarrow p \pi^- \text{)}$$



$$N_{\text{Bmis}}(B_d^0 \rightarrow \mu^+ \mu^-) = \begin{cases} 0.33 \pm 0.07 \text{ (barrel)} \\ 0.15 \pm 0.03 \text{ (endcap)} \end{cases}$$

$$N_{\text{Bmis}}(B_s^0 \rightarrow \mu^+ \mu^-) = \begin{cases} 0.18 \pm 0.06 \text{ (barrel)} \\ 0.08 \pm 0.02 \text{ (endcap)} \end{cases}$$

$$N_{\text{Comb}}(B_d^0 \rightarrow \mu^+ \mu^-) = \begin{cases} 0.40 \pm 0.34 \text{ (barrel)} \\ 0.76 \pm 0.35 \text{ (endcap)} \end{cases}$$

$$N_{\text{Comb}}(B_s^0 \rightarrow \mu^+ \mu^-) = \begin{cases} 0.59 \pm 0.50 \text{ (barrel)} \\ 1.14 \pm 0.53 \text{ (endcap)} \end{cases}$$



Systematic errors - physics

	barrel(%)	endcap(%)
Acceptance: evaluated for different production mechanisms (GGF, FEX, GSP)	3.5	5.0
Production ratio of u and s quarks: f_s/f_u from LHCb	8.0	8.0
Misidentified B decays: cross-section, br.ratios and misid. probabilities	20.0	20.0



Systematic errors - experiment

	barrel(%)	endcap(%)
Trigger efficiency: different p_T cuts, data-MC difference		
	3.0	6.0
Muon id. efficiency	4.0	4.0
Data-MC difference in analysis efficiency:		
signal	3.0	3.0
normalization	4.0	4.0
K tracking efficiency (normalization)	4.0	4.0
Mass resolution: from J/ψ and $\Upsilon(1S)$	3.0	3.0
Normalization fit: different functions for signal and background		
	5.0	5.0
Combinatorial background	4.0	4.0



Control analysis

$$Br (B_s^0 \rightarrow J/\psi \phi) (J/\psi \rightarrow \mu^+ \mu^-, \phi \rightarrow K^+ K^-)$$

computed as a cross-check:

Same selection with an additional kaon

Result compatible with world average

$$BR = (3.8 \pm 1.2) \times 10^{-5}$$

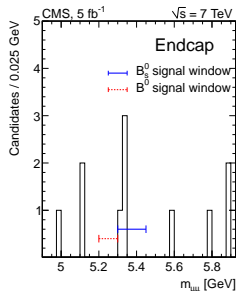
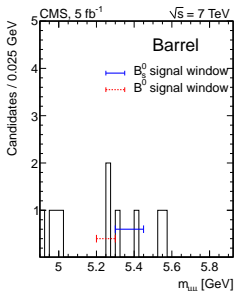
for both barrel and endcap

- Correct acceptance and efficiency calculations
- Vertices analysis robustness
- Selection biases
- f_s/f_u



Results

	$B_d^0 \rightarrow \mu^+ \mu^-$ 5.20 GeV < $m_{\mu^+ \mu^-}$ < 5.30 GeV		$B_s^0 \rightarrow \mu^+ \mu^-$ 5.30 GeV < $m_{\mu^+ \mu^-}$ < 5.45 GeV	
	Barrel	Endcap	Barrel	Endcap
Signal	0.24 ± 0.02	0.10 ± 0.01	2.70 ± 0.41	1.23 ± 0.18
B background	0.33 ± 0.07	0.15 ± 0.03	0.18 ± 0.06	0.08 ± 0.02
Combinatorial background	0.40 ± 0.34	0.76 ± 0.35	0.59 ± 0.50	1.14 ± 0.53
Sum	0.97 ± 0.35	1.01 ± 0.35	3.47 ± 0.65	2.45 ± 0.56
Observed	2	0	2	4



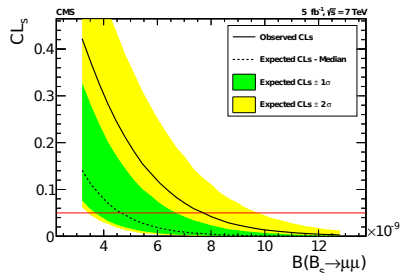
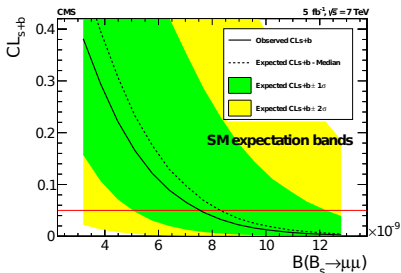
No excess observed \Rightarrow compute a limit



BR limit

	95% CL limit	P -value (BG only)	P -value (BG + SM signal)
$B_d^0 \rightarrow \mu^+ \mu^-$	1.8×10^{-9}	0.24	0.86
$B_s^0 \rightarrow \mu^+ \mu^-$	7.7×10^{-9}	0.11	0.71

BG-only P -value assumes freely-floating cross-feed



Expected limit: $BR(B_d^0 \rightarrow \mu^+ \mu^-) < 1.6 \times 10^{-9}$
 $BR(B_s^0 \rightarrow \mu^+ \mu^-) < 8.4 \times 10^{-9}$



Conclusions

- Search for $B_{d,s}^0 \rightarrow \mu^+ \mu^-$ decays has been performed
- pp collisions at $\sqrt{s} = 7\text{TeV}$ data have been analyzed, corresponding to an integrated luminosity $\mathcal{L} = 5\text{fb}^{-1}$
- No excess was observed
- A 95% CL limit

$$Br \left(B_d^0 \rightarrow \mu^+ \mu^- \right) < 1.8 \times 10^{-9}$$

$$Br \left(B_s^0 \rightarrow \mu^+ \mu^- \right) < 7.7 \times 10^{-9}$$

has been set

