$B_s \rightarrow \mu^+\mu^-$ in LHCb

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- Motivation
- LHCb conditions
- Soft Bs $\rightarrow \mu\mu$ selection
- N-counting method
  Backgrounds
- Exclusion/discovery potential of LHCb
- Normalization effect
- mSUGRA examples
**Motivation: BR (B_s \rightarrow \mu\mu) sensitive to New Physics (NP)**

- Accurate SM prediction: $(3.4 \pm 0.5) \times 10^{-9}$ (*)
- Could be **enhanced** by $\tan^6 \beta$ (SUSY)
- CMSSM: Relation with *Muon Anomalous Magnetic Dipole Moment*
  \[ \alpha_{\mu} - \alpha_{\mu}(SM) \rightarrow \text{if } \tan \beta \sim 50 \]
  gaugino mass are in $\sim 400$ – $600$ GeV $\rightarrow$ BR(B_s $\rightarrow$ \mu\mu) $\sim 1-4 \times 10^{-8}$
- Sensitive to several other models

**LHCb conditions**

- $b$ produced at low angle
- $L \sim 2 - 5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
- $\sim 5 \times 10^{11} \text{ bb/fb}^{-1}$
- Trigger dedicated to select $b$ events (\(\sim 90\%\) for reconstructed $B_s \to \mu\mu$)
- Total efficiency on $B_s \to \mu\mu$ (detection + reconstruction + trigger + selection) $\sim 10 \%$

**The LHCb detector: single arm forward spectrometer: 15-300 mrad (1.9 < $\eta$ < 4.9)**
**LHCb conditions (II). Tracking & muon IDentification**

- Excellent tracking resolution

- Invariant Mass Resolution in BS peak $\sim 18$ MeV

$\rightarrow$ *Reduction of search window (less background)*

- LHCb muon ID variable(s): DLL($\mu - \pi$), DLL($\mu - K$)… Combines Muon System & Calorimeters info (& RICH for kaons) $\rightarrow$ *95% efficiency for 0.6% of missID pions* (hits in certain Field Of Interest (depending on p) in M.Chambers are required before use DLL)
**Bs → μμ Event Selection**

- Very soft cuts are applied in order to keep most of the signal events, but removing an important amount of background.

- ~ 400 K background events/fb⁻¹ expected after selection (and trigger) - and 35.4 Bs → μμ for SM BR.

- But most of these 400 K are not significant, (see next slides)

- **Cut** (arbitrary normalization)

- Mass window: 60 MeV
- Vertex Chi2 < 14
- B IPS < 6
- Z (SV – PV) > 0
- Pointing angle < 0.1 rad
- Hits in FOI’s of Muon Chambers

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**N-counting Experiment**

**Counting:** Take a variable (or a set of), make some cuts and look at the surviving events.

**N-Counting:** Do not cut in your set of variables, but make a counting bin-by-bin.

**Bs → μμ Analysis:** N-Counting in a 3D space, composed by:

- **Geometrical likelihood:** [0,1]
- **PID Likelihood:** [0,1]
  (Combines DLL(μπ) DLL(μK) of both ‘muons’)
- **Invariant Mass:** [-60, +60] around Bs peak

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Geometrical Variables

- lifetime
- muon Impact Parameter Significant (IPS)
- DOCA: distance between tracks making the vertex
- B Impact Parameter (IP) to PV
- Isolation: Idea: muons making fake Bs→μμ might came from another SV’s → For each muon; remove the other μ and look at the rest of the event: How many good - SV’s (forward, DOCA, pointing) can it make?

\[ \text{Red: signal} \]
\[ \text{Blue: bb inc.} \]
\[ \text{Black: } b \rightarrow \mu \]
\[ \text{Green: } Bc^+ \rightarrow J/\Psi \mu \nu \]

Discussion:
- \( n \) signal events with good isolation
- \( m \) background events with bad isolation

(arbitrary normalization)

<table>
<thead>
<tr>
<th>DOCA (mm)</th>
<th>lifetime (ps)</th>
<th>Bs IP (mm)</th>
<th>Isolation</th>
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Method for variable-combination

- For constructing Geometry & PID likelihoods, we have made some operations over the input variables. Trying to make them uncorrelated

- A very similar method is described by Dean Karlen, *Computers in Physics* Vol 12, N.4, Jul/Aug 1998

- The main idea:

\[
\chi^2_S = \sum S_i^2
\]

\[
\chi^2_B = \sum b_i^2
\]

\[
\chi^2 = \chi^2_S - \chi^2_B
\]

And made it uniform for signal (\(\rightarrow\) flat distribution)
\textbf{N-counting Experiment (II): Backgrounds}

- Geometry (GL) < 0.5 $\rightarrow$ large background
- $b\rightarrow\mu b\rightarrow\mu$ % in bb sample increases with geometry
  - identified as main source of background
  - < 210 evts/fb$^{-1}$ @ 90 $\%$ CL for GL > 0.5
**N-counting Experiment (II):**  
*B* → *h+h-* background

(after selection)

- At least one particle not from *B* → *hh* tree
- At least one hadron decays before T stations
- Rest of *B* → *hh*

→ Decays in flight degraded in mass and geometry
→ Wrong particle mass assignation causes also a mass degradation

→ Was shown that probability to misidentify a pion from *B* → ππ is ~ 0.6 %

→ ‘Survivors’ still fall in low PIDL values.

*B* → *hh* **NEGLIGIBLE** (~ 2 evts) in comparison to ~210 events/fb-1 from *b* → *μ* *b* → *μ*
**LHCb potential**

*Limit @ 90% CL*
No signal observed

No signal observed in 2008 $\rightarrow$ BR $\leq$ BR (SM)

~ end 2008

**LHCb sensitivity**
signal + background observed

~ end 2009
**Normalization**

- Using B+ $\to J/\Psi K^+$ and Bs $\to J/\Psi \Phi$

- Implies uncertainties of $\sim 14\%$ (due to uncertainty in b quark hadronization) in 1$^{\text{st}}$ case and $\sim 35\%$ in 2$^{\text{nd}}$ (due to uncertainty in Bs $\to J/\Psi \Phi$ BR)

- Uncertainties in the number of events for both normalization channels are completely negligible in comparison with those above
Some mSUGRA-implications examples

CMSSM parameter values chosen:

- $m_{1/2}$ in [0, 1400 GeV]
- $m_0$ in [0, 1400 GeV]
- $A_0 = 0$
- $\mu > 0$

Other constraints:
- $h_0 > 114$ GeV
- $m_W = 80.398 \pm 0.025$ GeV

Calculations using the program *SoftSUSY* from Ben Allanch (Cambridge); BR’s computed using program from Athanasios Dedes (Durham)
Exclusion

Only background observed in 2008 would indicate low $\tan\beta$ or/and high $m_0$ with low $m_{1/2}$.

Higgs mass constraint makes this region empty.

~ end 2008 if only background is observed.

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In case of $B_s \rightarrow \mu\mu$ Observation

mSUGRA Phase Space is strongly reduced as function of the BR seen (and its accuracy)

if $5\sigma$ in ~2009

$4.6 \times 10^{-9} < BR < 6 \times 10^{-9}$

Phase Space region compatible with $0.8 \times 10^{-8} < BR(B_s \rightarrow \mu\mu) < 1.2 \times 10^{-8}$

5$\sigma$ observation before end 2008 $\rightarrow$ BR $\sim 10^{-8}$
Backup Slides
Correlation for signal (very small for background)

- Signal independent Gaussian variables (for background)

→ Same procedure making a 2D Gaussian for Background
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