Purely leptonic $b - c$ decays @ LHC(b)

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Introduction

Purely leptonic $B_{(s)}^{0,\pm}$ decays:

- A unique laboratory to detect new dynamics
- Theoretically clean: only one hadronic non-perturbative input $f_B$
- Helicity suppression: $\mathcal{B}(\text{decay}) \propto m_\ell$

### Charged currents

- $B^{\pm} \to \ell^\pm \nu_\ell$
- Missing energy
- Clean environment

### SM FCNC

- $B_{(s)}^0 \to \ell^\pm \ell^\mp$
- Very rare (and missing energy for $\ell = \tau$)
- High statistic & clean environment

### LFV

- $B_{(s)}^0 \to \ell^\pm \ell',\mp$
- Very rare (and missing energy for $\ell = \tau$)
- High statistic & clean environment

LHC experiments focused on $B_{(s)}^0 \to \ell\ell^{(r)}$

None of these modes observed before the LHC

Main observables are branching ratios $\mathcal{B}$

... plus a plethora of angular observables & ratios of $\mathcal{B}$ sensitive to MFV & LFU departures
$B_{(s)} \rightarrow \ell \ell$ observables

\[ \mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{tq}^* \frac{e^2}{16\pi^2} \left\{ C_{10}^{(t)} (\bar{b} \gamma^\mu P_{L(R)} q_d) (\bar{\ell} \gamma_\mu \gamma^5 \ell) + C_{P}^{(t)} m_b (\bar{b} P_{L(R)} q_d) (\bar{\ell} \gamma^5 \ell) + C_{S}^{(t)} m_b (\bar{b} P_{L(R)} q_d) (\bar{\ell} \ell) \right\} \]

- The expression for the CP-averaged $B$ at $t = 0$ is
  \[ \beta_\ell \equiv 1 - 4 \frac{m_\ell^2}{M_{B_q}^2} \]

In the SM:
- $C_{S,P}^{(t)}, C_{10} \approx 0$
- helicity suppression

NP scenarios:
- $C_{S,P}^{(t)}, C_{10} \neq 0$, $C_{10} = C_{10}^{\text{SM}} + \delta C_{10}^{\text{NP}}$
- No helicity suppression

- one hadronic input ($f_{B_q} = 227.7 \pm 4.5$ MeV) [FLAG, '13]
- $\mathcal{B}$ constrains only the differences $C_i - C_i'$
- $\mathcal{B}$ can be enhanced or suppressed wrt to the SM prediction

In SM only $B_{q,H}^0 \rightarrow \ell^+ \ell^-$

\[ \mathcal{A}_{\Delta \Gamma} \equiv \frac{R_{H}^{\ell\ell} - R_{L}^{\ell\ell}}{R_{H}^{\ell\ell} - R_{L}^{\ell\ell}} = 1 \]

with $\Gamma(B_{H,L}^0(t) \rightarrow \ell \ell) \equiv R_{H,L}^{\ell\ell} e^{-\Gamma_{H,L} t}$

- $\mathcal{A}_{\Delta \Gamma}$ measurable through
  \[ \tau_{\ell\ell} = \frac{\tau_B}{1 - y_s^2} \left[ \frac{1 + 2 \mathcal{A}_{\Delta \Gamma} y_s + y_s^2}{1 + \mathcal{A}_{\Delta \Gamma} y_s} \right] \]

being

\[ y_s \equiv \frac{\Gamma_H - \Gamma_L}{\Gamma_H + \Gamma_L} = 0.061 \pm 0.006 \]
$B_{(s)}^0 \to \ell\ell$ SM predictions

SM predictions [Bobeth et al., PRL 112(2014)101801]:

\[ \mathcal{BR}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10} \]
\[ \mathcal{BR}(B_s^0 \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9} \]
\[ \mathcal{BR}(B^0 \to \tau^+\tau^-) = (2.22 \pm 0.19) \times 10^{-8} \]
\[ \mathcal{BR}(B_s^0 \to \tau^+\tau^-) = (7.73 \pm 0.49) \times 10^{-7} \]

$b$-$c$ hadron leptonic decays searches with Run 1 data

- $D^0 \to \mu\mu$ [LHCb, arXiv:1305.5059]
- $B_{(s)}^0 \to e^+\mu^-$ [LHCb, PRL 111 (2013) 141801]
- $B_{(s)}^0 \to \mu^+\mu^-\mu^+\mu^-$ [LHCb, PRL 110, 211801 (2013)]

$B_{(s)}^0 \to \mu\mu$ milestones

- first evidence $B_s^0 \to \mu\mu$ [LHCb, PRL 110, 021801 (2013)]
- first observation $B_s^0 \to \mu\mu$
- first evidence $B^0 \to \mu\mu$ [LHCb & CMS, Nature 522 (2015) 68]

Recent activities in $B_{(s)}^0 \to \ell\ell$

- search for $D^0 \to e^+\mu^+$ [LHCb, Phys. Lett. B754 (2016) 167]
- search for $B_{(s)}^0 \to \mu\mu$ [ATLAS, EPJ C76 (2016) 513]
- update $B_{(s)}^0 \to \mu\mu$
- first search $B_s^0 \to \tau\tau$ [LHCb "17] Today
$B_{(s)}^0 \rightarrow \mu^+ \mu^- - \text{Run 1 & 2}$ - [LHCb, arXiv:1703.05747, submitted to PRL]

The strategy is unchanged with respect to previous LHCb analyses

$$\mathcal{B}(B_q^0 \rightarrow \mu^+ \mu^-) = \frac{1}{\epsilon} \frac{\mathcal{N}_{B_q^0 \rightarrow \mu^+ \mu^-}^{\text{obs}}}{\mathcal{N}_{B_q}^{\text{tot}}}$$

Dataset: $4.4 \, fb^{-1}$ ($1+2+1.4 \, fb^{-1}$ @ 7,8,13 TeV)

Analysis flow

- candidates reconstruction
- selection
- $m_{\mu\mu} \otimes$ geometry classification
- normalization
- signal yield extraction and conversion to $\mathcal{B}$

Normalization channels

- same topology: $B^0 \rightarrow K^+ \pi^-$
- 2 $\mu$ from one vertex: $B^+ \rightarrow J/\psi(\rightarrow \mu^+ \mu^-)K^+$

Main improvements:

- Particle Identification ($\pi, K \rightarrow \mu$ misID)
- MVA classification
Candidates reconstruction

- pair of $\mu^\pm$
- $0.25 < p_T < 40$ GeV & $p < 500$ GeV
- large Impact Parameter (IP) wrt PV
- good quality vertex well displaced PV
- tight $\mu$ ID requirements

- $m_{\mu\mu} \in [4900, 6000]$ GeV
- veto on $m_{\mu\mu^*} \in [m_{J/\psi} \pm 30]$ MeV,
  $\mu^*$ any other $\mu$ track in the event
- loose cut on MVA output with kinematic & geometrical inputs

Drop of 50% misID $B^0 \rightarrow hh' \left(h^{(r)} = K, \pi\right)$ for 90% signal efficiency

Total selected candidates for $B$ measurement: 78241
Background

the most abundant source of noise are random combinations of \( \mu \) tracks from \( b \)-hadron decays in the same event.

Discrimination achieved through a BDT classifier

- **Inputs**
  - pointing related variables
  - vertex quality
  - isolation variables

Combinatorial background candidate

Correlation with \( m_{\mu\mu} \sim 3\% \)

\(~50\%\) less combinatorial bkg in BDT \( >0.25 \) wrt previous LHCb analyses
Two categories

- with misID $K, \pi \rightarrow \mu$
  - $B^{0}_{(s)} \rightarrow hh^{(l)}$, $B^{0}_{(s)} \rightarrow h\mu^{+}\nu_{\mu}$, $\Lambda_{b}^{0} \rightarrow p\mu^{-}\bar{\nu}_{\mu}$

- with 2 $\mu$ from same vertex
  - $B_{c}^{+} \rightarrow J/\psi(\rightarrow \mu\mu)\mu^{+}\nu_{\mu}$, $B_{c}^{0(+)} \rightarrow \pi^{0,+}(\mu^{+}\mu^{-})$

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<thead>
<tr>
<th>mode</th>
<th>yield in BDT $&gt;0.5$</th>
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<tbody>
<tr>
<td>$B^{0}_{(s)} \rightarrow hh^{(l)}$</td>
<td>2.9 ± 0.3</td>
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<tr>
<td>$B_{c}^{+} \rightarrow J/\psi\mu^{+}\nu_{\mu}$</td>
<td>1.2 ± 0.2</td>
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<tr>
<td>$\Lambda_{b}^{0} \rightarrow p\mu^{-}\bar{\nu}_{\mu}$</td>
<td>0.7 ± 0.2</td>
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<tr>
<td>$B^{0}<em>{(s)} \rightarrow h\mu^{+}\nu</em>{\mu}$</td>
<td>0.8 ± 0.06</td>
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**Signal PDF**

- BDT from $B^{0} \rightarrow K^{+}\pi^{-}$ in data
- $m_{\mu\mu}$ Crystal Ball:
  - power-law tail exponent and transition point from simulations
  - resolution from interpolation of $\mu\mu$ resonances: $\sigma_{\mu\mu} = 23$ MeV

**Combinatorial background**

- BDT from $m_{\mu\mu}$ sidebands
- $m_{\mu\mu}$ extrapolated from $m_{\mu\mu}$ sidebands

**b-hadron decays**

$B^{0}_{(s)} \rightarrow h\mu^{+}\nu_{\mu}$ & BDT from simulation

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A. Mordâ (INFN Padova) Purely leptonic b - c meson decays © LHC(b)
Normalization

\[ \mathcal{B}(B^0_{(s)} \rightarrow \mu^+ \mu^-) = \frac{\mathcal{B}_{\text{norm}}}{N_{\text{norm}}} \cdot \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \cdot \frac{f_{\text{norm}}}{f_{d(s)}} \cdot N_{\text{sig}} \equiv \alpha_{B^0_{(s)}}^{\text{norm}} \cdot N_{\text{sig}}^{d(s)} \]

- yield of normalization channel events
- total efficiencies
  - trigger: data driven method
  - acceptance, reconstruction, selection: using simulation
  - tracking, PID: on data through control channels
- hadronization factor
  - measured by LHCb [LHCb JHEP 04 (2013) 001], LHCb-CONF-2013-011

\[ N_{\text{norm}} \text{ for } B^+ \rightarrow J/\psi K^+: (1964.2 \pm 1.5) \cdot 10^3 \]

\[ \alpha_{B^0_s}^{\text{norm}} = (5.7 \pm 0.4) \cdot 10^{-11}, \quad \alpha_{B^0}^{\text{norm}} = (1.60 \pm 0.04) \cdot 10^{-11} \]
Results

No evidence for $B^0 \rightarrow \mu^+ \mu^- \Rightarrow$ Upper Limit @ 95%

$$\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 3.4 \cdot 10^{-10}$$

7.8σ excess for $B_s^0 \rightarrow \mu^+ \mu^-$. First single experiment observation

$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = 3.0 \pm 0.6^{+0.3}_{-0.2} \cdot 10^{-9}$$
The strategy:

- Selection of $B^0_s \rightarrow \mu^+\mu^-$ candidates
- Evaluation of bias due to reconstruction & selection: acceptance function
- sPlot technique to statistically separate signal & background
- Fit to signal decay time distribution

$B^0_s \rightarrow \mu^+\mu^-$ selection

- Similar requirements of $B$ measurement, except
- Reduced $m_{\mu\mu}$ ([5320, 6000] MeV) range ⇒ remove $B^0$ & exclusive decays
- Looser PID requirements ⇒ increase of the statistics
- Cut on BDT output $> 0.55$

42 candidates in selected sample
\( \tau_{\mu\mu} \) measurement

- Mass fit
  - only \( B_s^0 \rightarrow \mu^+\mu^- \) & combinatorial
  - same parametrization used for \( B \) measurement
  - correlation between \( m_{\mu\mu} \) & \( \tau_{\mu\mu} \leq 3\% \)

\[ \tau_{\mu\mu} = 2.04 \pm 0.44 \pm 0.05 \text{ ps} \]

\( \tau_{\mu\mu} \) consistent with \( A_{\Delta \Gamma} = 1(-1) @ 1.0(1.4) \sigma \)

"this result establishes the potential of the effective lifetime measurement in constraining New Physics scenarios with the datasets that LHCb is expected to collect in the coming years"
$B(s)_0 \to \tau^+\tau^- @ LHCb - Run 1$ [LHCb, arXiv:1703.02508, accepted in PRL]

Status before LHC

- $B(B_d^0 \to \tau^+\tau^-) < 4 \cdot 10^{-3} @ 90\% \text{ CL}$ by BaBar [PRL 96 (2006) 241802]
- $B(B_s^0 \to \tau^+\tau^-)$ only indirect constraints $\sim \%

Pioneering analysis at an hadron machine

Dataset: 3 $fb^{-1}$ (1+2 $fb^{-1}$ @ 7, 8 TeV)

exploits the $\tau^- \to \pi^+\pi^-\pi^-\nu_\tau$ final state

- only two undetected $\nu_\tau$
- $\tau^\pm$ decay vertexes reconstructible
- Non trivial Dalitz structure of $\pi^+\pi^-\pi^-$ system
- intermediate resonances: $\tau^- \to a_1^- (\to \rho^0 (\to \pi^+\pi^-)\pi^-)\nu_\tau$
- $B(\tau \to \pi^+\pi^-\pi^-\nu_\tau) = (9.31 \pm 0.05)\%$

Analysis strategy:

- Reconstruction & selection
- Extraction of signal yield
- Use of $B^0 \to D^+D_s^-$ as normalization & control channel
- Computation of Upper Limit (UL)

Signal modeled with simulated events

Data-driven techniques to describe the background sources
Candidate reconstruction & Dalitz plane structure

Candidate reconstruction similar for signal and normalization mode:

\[ \pi^\pm \] requirements
- Particle Identification,
- track quality,
- Impact Parameter wrt primary vertexes

\[ \tau^\pm \] reconstruction
- 3 tracks forming a good vertex

\[ B_s^0 \] reconstruction
- pair of \( \tau^\pm \)
- requirements on transverse momentum of \( B, \tau \text{ and } \pi \)

Dalitz plane used as handle to deal with huge amount of background (from \( b \rightarrow c \) transitions)

Signal Region (SR)
Control Region (CR)
Signal Depleted Region (SDR)

LHCb simulation

signal region \( m_{\pi^+ \pi^-} \in [0.615, 0.935] \text{ GeV} \)

optimized for \( B_s^0 \rightarrow \tau \tau \) sensitivity using pseudoexperiments

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Candidates selection & classification

Requirement on reconstructed $B^0_{(s)}$ candidates:

- Dalitz plane selection
- charged tracks & neutral clusters isolations
- variables from analytic reconstruction [CERN-THESIS-2015-264]
- output of a Neural Network (NN) classifier combining kinematic, topology, & isolation variables

- efficiency of $B^0_{(s)}$ the selection (including geometrical acceptance): $2.2(2.4) \times 10^{-5}$
- expected number of events in SM: 0.02
- fraction of selected candidates in regions:

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<th>CR</th>
<th>SDR</th>
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<tr>
<td>$B^0_{(s)} \rightarrow \tau\tau$ MC</td>
<td>16 %</td>
<td>58 %</td>
<td>13 %</td>
</tr>
<tr>
<td>Data</td>
<td>7 %</td>
<td>47 %</td>
<td>37 %</td>
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14700 candidates selected in data SR

Discriminating variable

- output of a NN with 29 input variables
- trained on signal simulated events, and data from SDR
- output flat in $[0,1]$ by design for signal MC
- NN range divided in 10 bins
- $[0.7,1.0]$ not investigated till the fit strategy is fixed
Fit model

- The NN distribution is fitted to extract the signal yield

- Fit model given by:

\[ \mathcal{N}_{\text{data}}^{\text{SR}} = s \cdot \hat{\mathcal{N}}_{\text{MC}}^{\text{SR}} + f_b \cdot \left( \mathcal{N}_{\text{data}}^{\text{CR}} - s \cdot \frac{\varepsilon_{\text{CR}}^{\text{SR}}}{\varepsilon_{\text{SR}}^{\text{SR}}} \cdot \hat{\mathcal{N}}_{\text{MC}}^{\text{CR}} \right) \]

- signal yield
- scaling factor for background template
- correction for presence of signal candidates in CR \((\varepsilon_{\text{SR}^{\text{CR}}}) \text{ signal efficiency in SR(CR)}\)

- NN templates \(\mathcal{N}_{\text{MC, data}}^{\text{SR, CR}}\) are taken
  - from simulation for \(B_s^0 \to \tau \bar{\tau}\)
  - from data CR for background

- Reliability of background NN template extrapolation from the CR to SR checked on
  - data for NN background dominated bin
  - generic \(b \bar{b}\) sample
  - specific simulated background modes (e.g. \(B^0 \to D^- \pi^+ \pi^- \pi^+, D^- \to K^0 \pi^+ \pi^- \pi^-, B_s^0 \to D_s^- (\to \tau \bar{\nu}_\tau) \pi^+ \pi^- \pi^+)\)
Main sources of systematic uncertainties

- for signal:
  ▶ mismodel of NN input variables in the simulation
  ▶ NN shape computed after re-weighting
  ▶ differences in NN shape wrt the nominal are assigned as systematics

- for background
  ▶ extrapolation from the CR to SR
  ▶ gaussian constraint on bin yield
  ▶ range from difference of NN shape in control region subsamples

The signal yield is found being

\[ s = -23 \pm 63 \text{(stat)} \pm 31 \text{(syst)} \]
Normalization

The measured signal yield is converted into a value of the branching fraction using the $B^0 \rightarrow D^- D_s^+$ normalization mode

$$\mathcal{B}(B_s^0 \rightarrow \tau\tau) = \alpha_s \cdot s$$

with

$$\alpha_{s,d} = \frac{1}{N_{D^- D_s^+}^{obs}} \cdot \frac{\epsilon \cdot f_d}{f_s} \cdot \frac{\mathcal{B}(B^0 \rightarrow D^- D_s^+) \cdot \mathcal{B}(D^- D_s^+ \rightarrow \text{final states})}{[\mathcal{B}(\tau \rightarrow 3\pi\nu_{\tau})]^2}$$

- **from fit**: $10629 \pm 114$
- **measured by LHCb**
- **from simulation**
- **known**

$$\alpha_s = (4.07 \pm 0.70) \times 10^{-5}, \quad \alpha_d = (1.16 \pm 0.19) \times 10^{-5}$$
Results

No evidence for signal is found

Computation of the 90%(95%) upper limit using the $CL_s$ method

- Assuming no signal from $B^0$, the **first experimental UL for the $B_s^0$** is

\[
\mathcal{B}(B_s^0 \rightarrow \tau^+\tau^-) = 5.2(6.8) \cdot 10^{-3}
\]

- Assuming no signal from $B_s^0$, the **world best UL for the $B^0$** is

\[
\mathcal{B}(B^0 \rightarrow \tau^+\tau^-) = 1.6(2.1) \cdot 10^{-3}
\]
Conclusions

• Purely leptonic decays are a theoretically clean laboratory to look for new degrees of freedom

• Offer a wide range of observables in addition to $B$
  ▶ effective lifetime sensitive to different contributions of mass eigenstates
  ▶ angular distributions (for $\tau$ final states) sensitive to $\ell$ polarization (left/right handed currents)
  ▶ ratio of $B$ sensitive to MFV or LFU departures

• LHC experiment main target have been searches in FCNC with $\mu$
  ▶ large statistics sample
  ▶ excellent detectors performances with $\mu$
  ▶ golden mode is $B_{(s)}^0 \rightarrow \mu^+ \mu^-$

• First single experiment observation of $B_{s}^0 \rightarrow \mu^+ \mu^-$ from LHCb
  ▶ evidence for $B_{s}^0 \rightarrow \mu^+ \mu^- @ 7.8 \sigma$
  ▶ waiting for $B^0 \rightarrow \mu^+ \mu^-$
  ▶ first measurement of $\tau_{\mu\mu}$
  ▶ no significant deviations from SM are observed

• First search of $B_{(s)}^0 \rightarrow \tau^+ \tau^-$ from LHCb
  ▶ First upper limit on $B_{s}^0 \rightarrow \tau^+ \tau^-$
  ▶ World best Upper limit in $B^0 \rightarrow \tau^+ \tau^-$
  ▶ LHCb can deal with $\tau$
  ▶ relevant the interplay with Belle 2
Backup
$B \rightarrow \tau \tau$ signal simulation

- $pp$ collision: PYTHIA
- hadron decay: EvtGen
- final state radiation: PHOTOS
- interaction with detector: GEANT4

Effect of CLEO model:
- 20% higher efficiency:
- different intermediates resonances
- lower limit
- no impact on NN distribution

- $\tau \rightarrow 3\pi^{\pm} \nu_{\tau}$ resonance chiral lagrangian
- TAUOLA with BaBar results
- $\tau \rightarrow \pi^{-} \pi^{0} \pi^{0} \nu_{\tau}$ from CLEO
NN input variables

selection NN: 8 variables

- $\tau^\pm$ mass & decay time
- $\pi^\pm$ isolation
- $B^0$ neutral isolation
- one variable from analytic reconstruction method

classification NN: 29 variables

- kinematic & geometrical
- $\pi^\pm$ isolation
- $B^0$ neutral isolation
- 8 variables from analytic reconstruction method
Normalization factor

Uncertainties on normalization factor
- $B^0 \rightarrow D^- D_s^{+}$ fit model
  - Signal: Hypatia → 2 gaussians with same mean and power law
  - combinatorial: exponential → second order Chebychev
  - exclusive: add $B^0_S \rightarrow D^- D_s^{*+}$ & $B^0 \rightarrow a_1(1260)^- D_s^{*+}$
  - relative uncertainty on $\alpha_s$ from $N_{D^- D_s^+}^{obs}$: 1.7 %
- external inputs
  - branching ratios
  - hadronization factor: accounts for 17% of total uncertainty on $\alpha_s$
- finite size of simulated samples
- uncertainty from correction to simulation
  - control channels: $J/\psi \rightarrow \mu^+ \mu^-$ & $D^0 \rightarrow K^- \pi^+$
  - corrections to tracking, PID, hardware
  - trigger efficiencies
- relative uncertainties on $\alpha_s$ from these two sources: 2.9 %

All the errors are added in quadrature to give

$$\alpha_s = (4.07 \pm 0.7) \cdot 10^{-5}$$
Main sources of systematic uncertainties

For signal:

- mismodel of NN input variables in the simulation
  ▶ check distributions on $B^0 \rightarrow D^- D_s^+$ control sample in data
  ▶ retrain NN with corrected input variable distributions
  ▶ difference in NN output shape assigned as systematic

- $\tau \rightarrow 3\pi \nu_\tau$ decay model in simulation
  ▶ checked using simulated data with a different $\tau$ decay model
  ▶ can affect both the selection efficiencies and the signal template shape
  ▶ negligible effect on the NN output shape
  ▶ 20% effect on the efficiency → assigned as systematic
$B \rightarrow \mu\mu$ BDT input variables

BDT selection
- $B^0_{(s)}$ candidate direction
- $B^0_{(s)}$ impact parameter wrt its PV
- separation between $\mu^\pm$ tracks and IP wrt any PV
- separation between $\mu^\pm$ tracks and IP wrt any PV

isolation variables function of distance between the $\mu$ & other tracks

proximity quantified by a MVA output with inputs:
- angular and spatial separation between $\mu$ & other track
- signed distance between $\mu$ track and $B$ candidate PD
- kinematic and impact parameter information of $\mu$ track

BDT classification
- $\mu$ isolation
- $\min \chi^2$ of $\mu^\pm$ wrt $B$ candidate PV
- $\hat{p}_B \cdot \hat{r}_B$ pointing
- $B$ vertex fit $\chi^2$ and IP$\chi^2$
\( \frac{f_s}{f_b} \) measurement LHCb

\( \frac{f_s}{f_b} \) @ 7 TeV measured by LHCb

\[
\frac{f_s}{f_b} = 0.259 \pm 0.015
\]

- stability @ 8 & 13 TeV evaluated looking at variation of ratio of \( B_s^0 \to J/\psi \phi \) & \( B^+ \to J/\psi K^+ \)

- effect of increase in \( \sqrt{s} \)
  - negligible for 8 TeV
  - scaling factor of 1.068 ± 0.046 applied for 13 TeV
$B \to \mu\mu$ Fit details

- Run 1 & 2 each divided into 5 BDT BDT bins $[0.0, 0.25, 0.4, 0.5, 0.6]$
- $B(B_0^0 \to \mu\mu$ determined through a simultaneous fit to $m_{\mu\mu}$ in $5 \times 2$ BDT bins
- free parameters:
  - $B(B(s) \to \mu\mu$
  - parameters of Crystal Ball constrained to their expectation within their errors
- combinatorial: common shape in BDT bins of a dataset, free yield
- exclusives:
  - included as separate components in the fit
  - total and single BDT bin gaussianly constrained to their expectations
  - mass shape from simulations for each BDT bin

Dependence on $A_{\Delta\Gamma}$
- affects selection efficiency & BDT output
- Fit done assuming the SM value $A_{\Delta\Gamma} = 1$
- model dependence evaluated repeating the fit with $A_{\Delta\Gamma} = 0, -1$
- manifests an increase of $B(B_0^s \to \mu\mu$ wrt SM of 4.6% & 10.9%
- dependence approximately linear in the physical region
\( \tau_{\mu\mu} \) acceptance function

- variation of trigger and selection efficiency with decay time corrected by introducing and acceptance function
- acceptance function determined through simulated events, weighted to match properties observed in data
- Validation of simulation through control channel \( B^0 \rightarrow K^+ \pi^- \)

\[
\tau_{K\pi} = 1.52 \pm 0.03 \text{(stat)}
\]

in agreement with world average

- statistical uncertainty on \( \tau_{K\pi} \) assigned as systematic due to use of simulation to determine acceptance function
\[ B^0_{(s)} \rightarrow e^\pm \mu^\mp \] [PRL 111 (2013) 141801]

Strategy à la \( B^0_{(s)} \rightarrow \mu\mu \)

- Dataset: 1 fb\(^{-1}\) collected in 2011 at \( \sqrt{(s)} = 7 \text{ TeV} \)
- \( B^0 \rightarrow K\pi \) as normalization channel
- Events classification in \( m_{e\mu} \)-BDT plane

No excess over background is seen \( \Rightarrow \) upper limit on \( BR(B^0_{(s)} \rightarrow e\mu) \) is obtained using the \( CL_s \) method

\[ B^0_s \rightarrow e\mu, \text{ background-only expectation} \]

\[ BR(B^0_s \rightarrow e\mu) < 1.1(1.4) \cdot 10^{-8} @ 90(95)\% \text{ CL} \]

\[ BR(B^0 \rightarrow e\mu) < 2.8(3.7) \cdot 10^{-9} @ 90(95)\% \text{ CL} \]

\( \sim 20 \text{ times more stringent than previous limits} \)