# Search for the Lepton Flavour Violating decay $B^0_{(s)} \to \tau(\pi\pi\pi\nu)\mu$

Joan ARNAU ROMEU

*CPPM, Aix-Marseille Université CNRS/IN2P3, Marseille, France*




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# Goal

- The goal of the thesis is to perform the first search for the Lepton Flavour Violating (LFV) decay $B^0_{(s)} \to \tau\mu$ within the LHCb Experiment (CERN).

- Lepton Flavour is associated with the lepton family number (L), which is the quantum number representing the number of leptons plus the number of the anti-leptons of a given family.

| | $B^0_s$ | $\to$ | $\tau^-$ | + | $\mu^+$ |
|---|---|---|---|---|---|
| $L_\mu$ | 0 | = | 0 | + | -1 |
| $L_\tau$ | 0 | = | 1 | + | 0 |

# Motivation

- Lepton Flavour Violation (LFV) is heavily supressed in the Standard Model of Particle physics. LFV processes in charged lepton sector expected at $\mathcal{O}\left(10^{-54}\right)$.

  ☞ **Phys.Rev.Lett. 81 (1998) 156**

  ➔ Lepton Number is conserved.

- However, many models Beyond the Standard Model allow LVF at a measurable level.

  One can group them into:

  ➔ Supersymmetry theories (SUSY)

  ➔ Grand Unified Theories (GUT)

# LFV in theories Beyond the Standard Model

- Lepton Flavour Violation is allowed at one loop in SUSY.
- In the Pati-Salam model (GUT) Lepton Number is the 4th color.
  - ➔ Interaction between quarks and leptons due to leptoquarks.
- Some prediction of Beyond the Standard Model theories.

| | | |
|---|---|---|
| ➔ SUSY without R-parity: | $\mathcal{B}\left(B_s^0 \to \tau\mu\right) \sim 10^{-9}$ | ☞ hep-ph 9806359 |
| ➔ Leptoquark framework: | $\mathcal{B}\left(B_s^0 \to \tau\mu\right) \sim 10^{-8}$ | ☞ arxiv 1503.01084v1 |
| ➔ Generic $Z'$ models: | $\mathcal{B}\left(B_s^0 \to \tau\mu\right) \sim 10^{-7}$ | ☞ arxiv 1504.07928v2 |
| ➔ MSSM: | $\mathcal{B}\left(B_s^0 \to \tau\mu\right) \sim 10^{-6}$ | ☞ arxiv 1211.5168 |

# $B_{(s)} \to \tau\mu$ in experiments

- There is already an experimental upper limit for the $B^0$ channel measured by the *BaBar* collaboration.

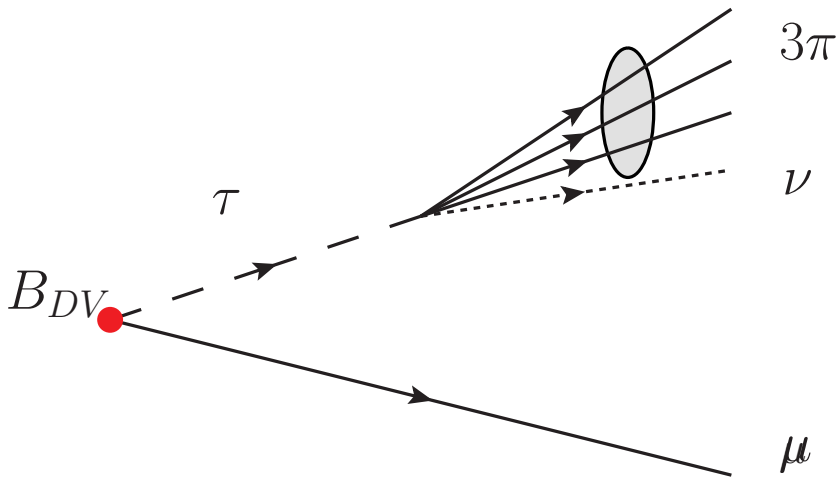
  ☞ **arxiv 0801.0697**

$$\mathcal{B}\left(B^0 \to \tau\mu\right)^{Babar}_{exp} < 2.2 \cdot 10^{-5} \qquad @\ 90\%\ \text{CL}$$

- There is no limit in the $B_s$ channel yet.
- Search of $B_{(s)} \to \tau\mu$ in LHCb starting.

# Search for $B \to \tau\mu$ in LHCb

- We study the case of $B^0_{(s)} \to \tau\mu$ where $\tau \to \pi\pi\pi\nu$.




- Reconstruction of the decay $B^0_{(s)} \to \tau(\pi\pi\pi\nu)\mu$.
  - ➔ 3 pions coming from a common displaced vertex.
  - ➔ Muon not pointing to the primary vertex.
- Using RUN I data so far.
- Expecting RUN II data for the end of the year.

# Analysis overview

- Branching ratio measurement:

$$\mathcal{B}\left(B^0_{(s)} \to \tau\mu\right) = \frac{N^{obs}_{sig}}{N_{norm}} \mathcal{B}\left(norm\right) \frac{\varepsilon_{norm}}{\varepsilon_{sig}}$$

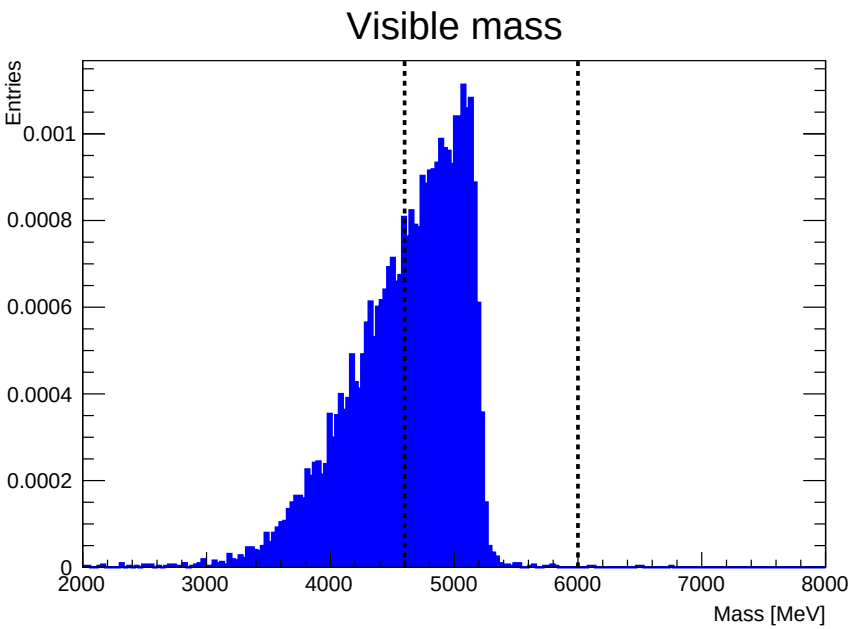
  Using as a normalization channel: $B \to D(K\pi\pi)\pi$.

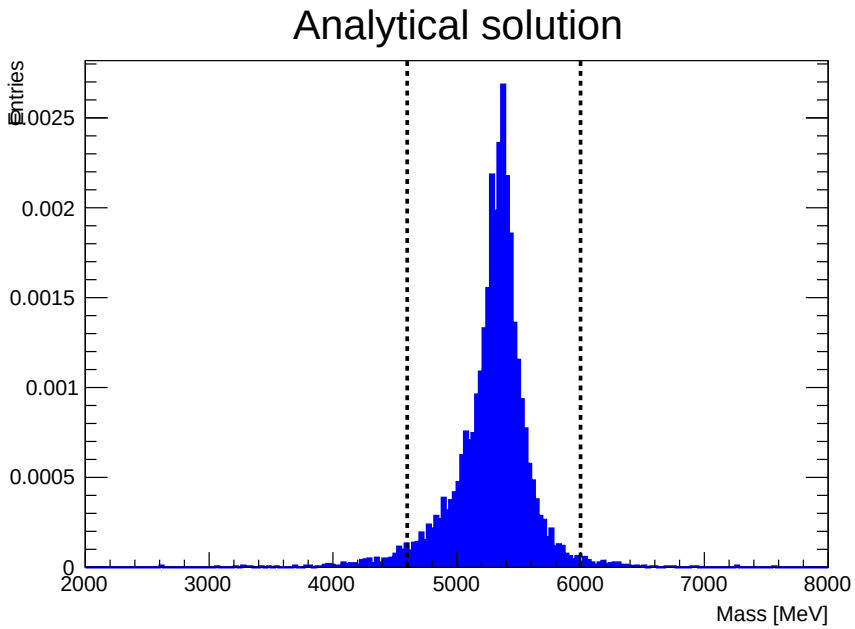
  - ➔ $\varepsilon_{sig}$ and $\varepsilon_{norm}$ will be extracted from simulation.
  - ➔ $N^{obs}_{sig}$ will be extracted from the fit of the mass distribution of the $B$ meson.

- Main challenges of $B \to \tau\mu$ in LHCb.
  - ➔ Signal reconstruction.
  - ➔ Background.

# Optimization of the B invariant mass reconstruction

- The neutrino is not detected.
- Work done: refine the $B$ mass reconstruction.
  - ➔ Neutrino momentum is constrained using vertexes positions and energy conservation in the $\tau$ decay vertex.



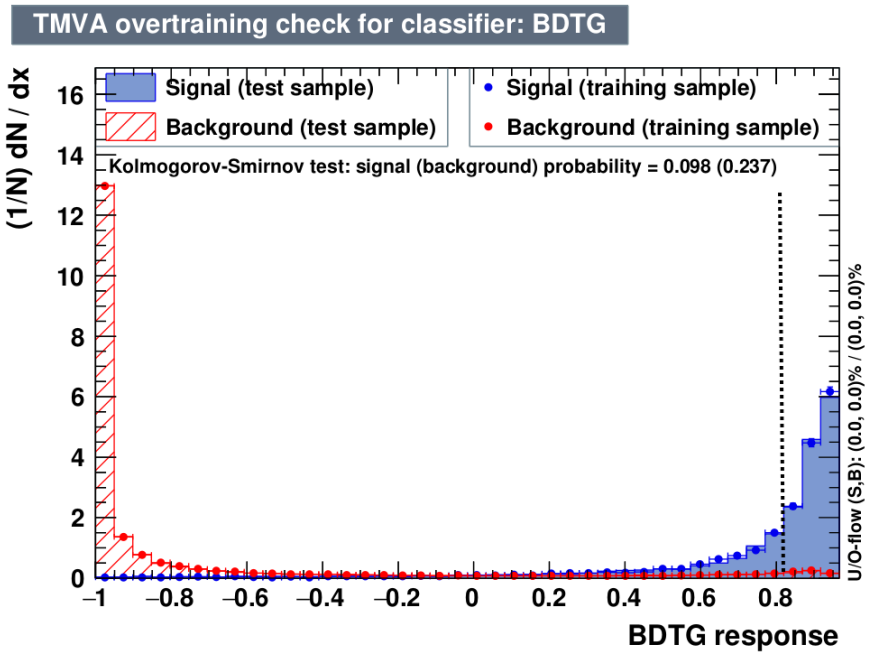

- Selecting a signal region in the $B$ reconstructed mass. This signal region will be blinded in the data.

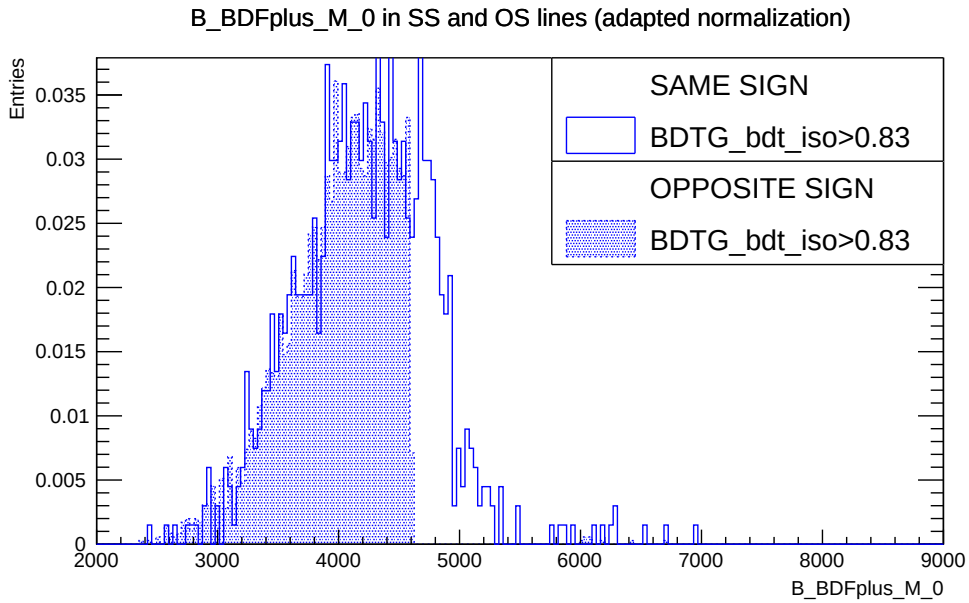
# Background suppression

- Huge background coming from B decays
  - ➔ Background modeling is a key issue.
- Using the DATA to model the background:
  - ➔ Same Sign DATA: contains the reconstruction of non-physical events $B_s \to \tau^+ \mu^+$.
  - ➔ Opposite Sign (Usual DATA) side-bands.
- Use of multivariate techniques: Boosted Decision Trees.
  - ➔ Using signal simulation as a template for the signal
  - ➔ Using Same Sign DATA as a template for the background
- For the variables used in the analysis the agreement between data and simulation have been checked.
- A BDT is be used as a first selection.
  - ➔ Remove the most obvious background.
  - ➔ Based on isolation variables.

# Signal Selection

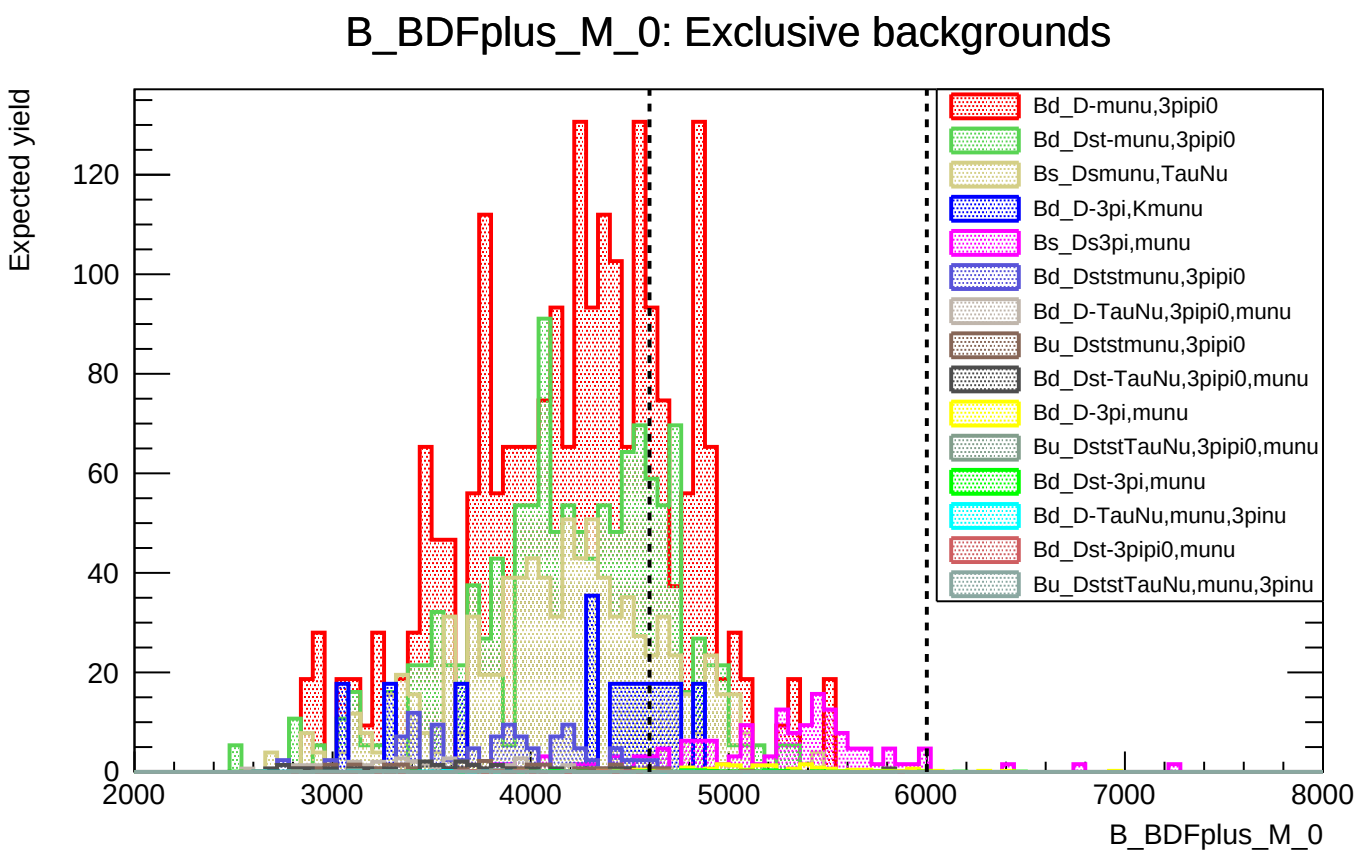
- BDT based on isolation variables.
- With the BDT variable, a first selection is made:
  - ➔ Keeping 60% of the signal.
  - ➔ Removing 97% of the background.

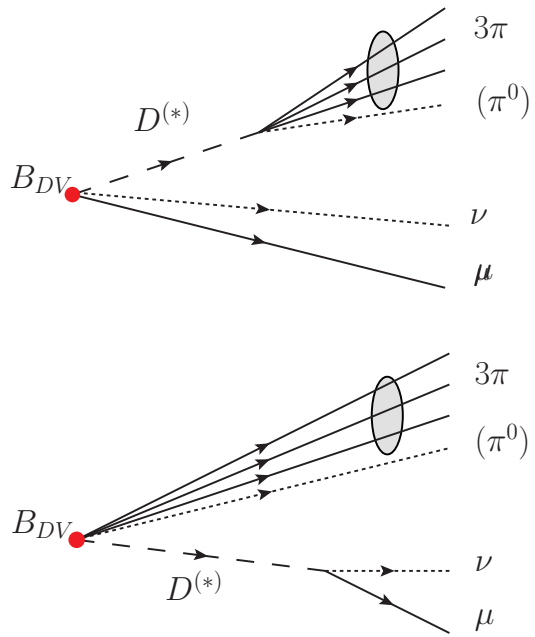


# Exclusive backgrounds simulation

- Background suppression crosscheck with some exclusive background modes.




- Currently working in a second selection to deal with these backgrounds.

# Ongoing work and next steps

## Ongoing work

- Optimization of a second selection to deal with the backgrounds.
- Exploring other ways of dealing with the backgrounds.

## Next steps

- Towards a fit on the B reconstructed mass.
- Systematic uncertainties study.

# Conclusions

- We are performing the first search in the $B_s \to \tau\mu$ channel.
- Work done:
  - ➔ Optimization of the $B$ mass reconstruction.
  - ➔ Check data simulation agreement.
  - ➔ Selection to remove the most obvious background
  - ➔ Optimizing the final selection.
- Expecting RUN II data for the end of the year!

# Backup slides

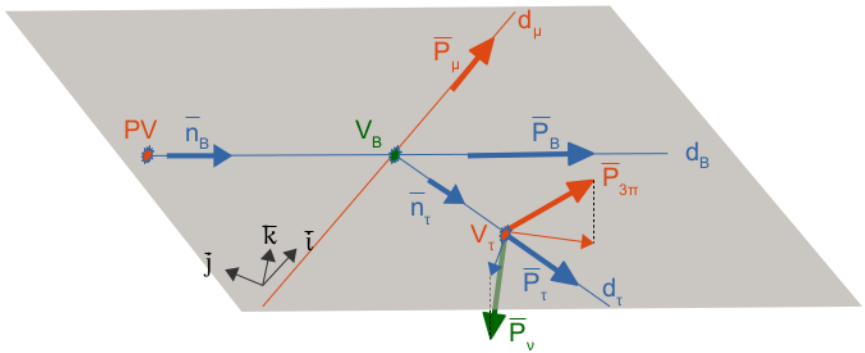
# Analytic reconstruction

## Measured magnitudes and system constrains

### Measured quantities:

- Primary Vertex coordinates
- Tau Decay Vertex coordinates
- Pion system 4-momentum
- Muon 4-momentum
- Muon Origin Vertex

### Process in the Decay Plane:




*Julien's!*

### Kinematic constrains in the Decay Plane:

- *B* Decay Vertex along the muon direction:
  $V_B \in d_\mu$
- *B* momentum in the $\vec{n}_B$ direction:
  $\vec{P}_B \wedge \vec{n}_B = 0$
- Tau momentum in the direction of Tau momentum:
  $\vec{P}_\tau \wedge \vec{n}_\tau = 0$
- Conservation of the 4-momentum in Tau Decay Vertex:
  $P_\tau^\alpha = P_{3\pi}^\alpha + P_\nu^\alpha$

Process kinetically closed.

- ⇛ *B* Decay Vertex.
- ⇛ Neutrino momentum.

$P_B^\alpha = P_{3\pi}^\alpha + P_\nu^\alpha + P_\mu^\alpha$

- ⇛ B invariant mass (two solutions).

# Isolation based BDT

- Use the most discriminating isolation variables to remove part of the background.
- Variables for the Isolation BDT:

| B candidate |
|---|
| SmallestDeltaChi2MassOneTrack |
| CDFIso_NEW |
| 0.50_cc_mult |
| 0.50_nc_sPT |

| Muon candidate |
|---|
| BDTiso3 |
| BDTiso1_1 |
| isolation_Giampi_nopi |
| 0.50_cc_mult |
| 0.50_nc_vPT |

| Tau candidate |
|---|
| BDTiso3 |
| BDTiso1_1 |
| SmallestDeltaChi2MassTwoTracks |
| iso2 |
| 0.50_cc_mult |
| 0.50_nc_sPT |

| Pions from Tau |
|---|
| $\sum$BDTiso3 |
| $\sum$BDTiso1_1 |

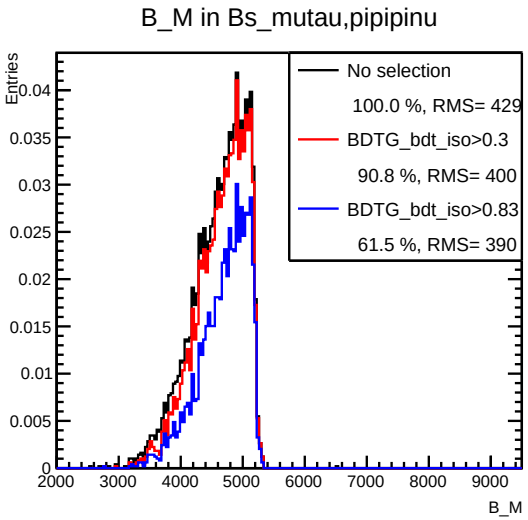
# B_M and B_⊕ outlook

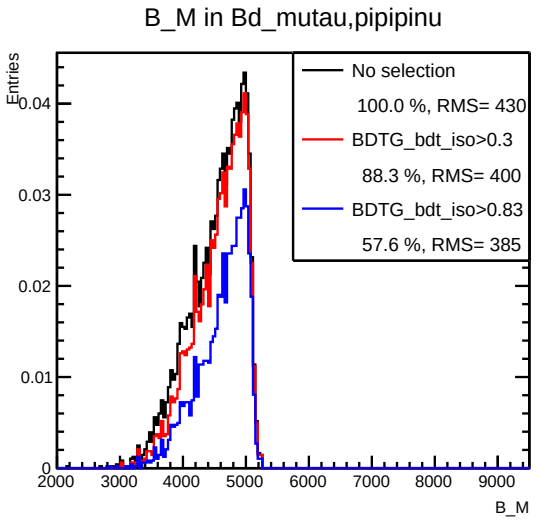
## $B_s$ MC signal

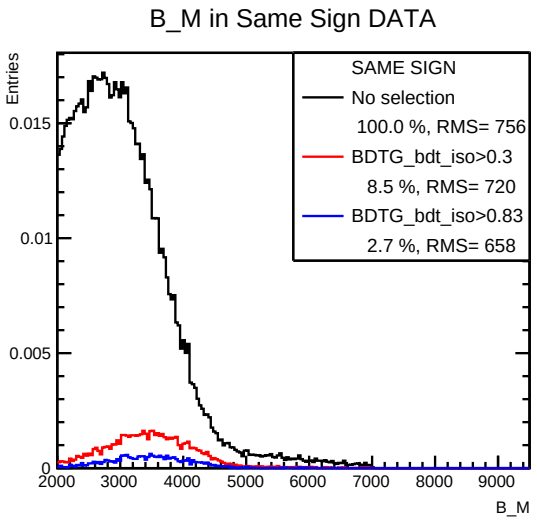
## $B_d$ MC signal

## SS DATA

B_M




B_⊕