


Universiteit Utrecht

# Machine Learning for $B_{(s)} \rightarrow \mu\mu$ decays

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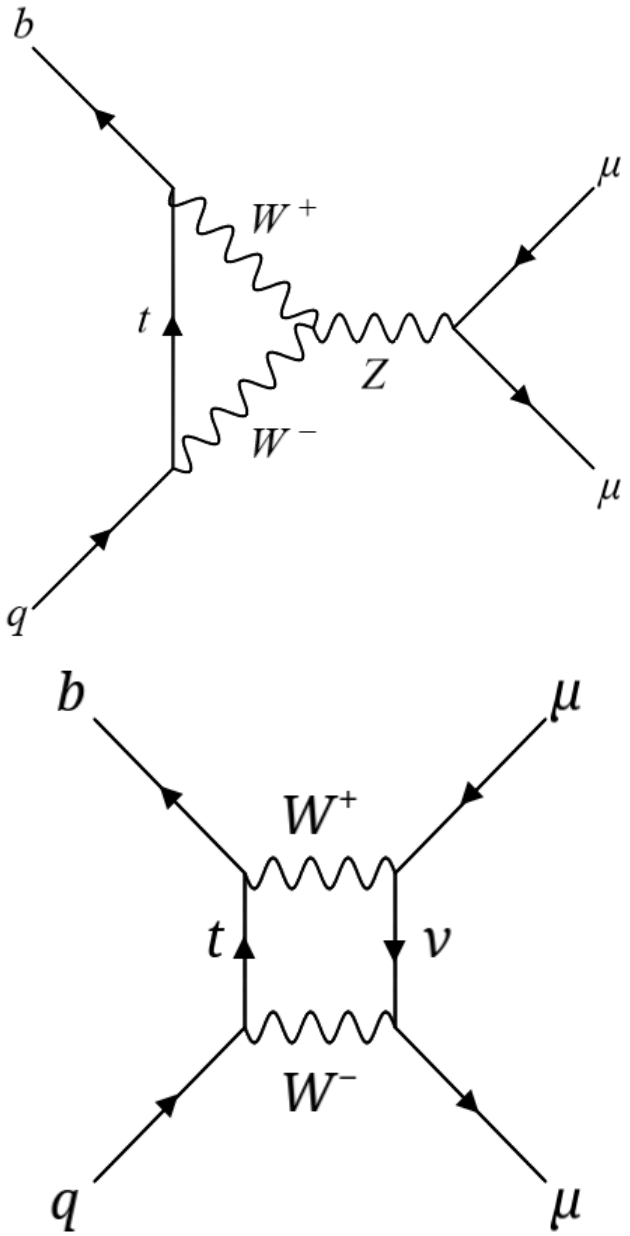
# Motivation

Rare decay with decay rate:

- $(3.67 \pm 0.17) \times 10^{-9}$ for $B_s \rightarrow \mu\mu$ [1]
- $(1.06 \pm 0.09) \times 10^{-10}$ for $B \rightarrow \mu\mu$ [2]

- Suppressed via GIM mechanism
- Helicity suppressed

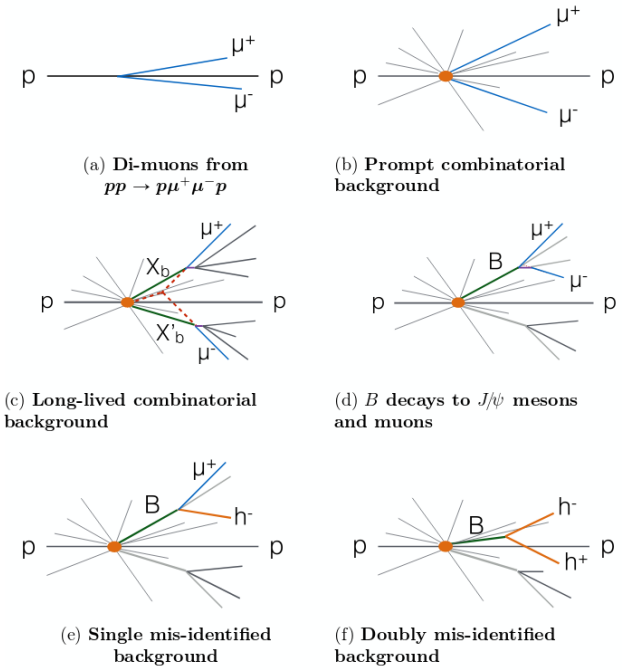
- $B_s$ decay has been observed
- Goal is B decay and more $B_s$ events
- Sensitive to beyond standard model physics




[1]: Phys. Rev. Lett. 120, 011801 (2018), [2]: Phys. Rev. Lett.112(2014) 101801

# Background

- Single mis-identified background at low mass
- Double mis-identified background peaking around 5250 MeV
- Constant combinatorial background
  - Short-lived
  - Long-lived




(a) Di-muons from $pp \to p\mu^+\mu^- p$

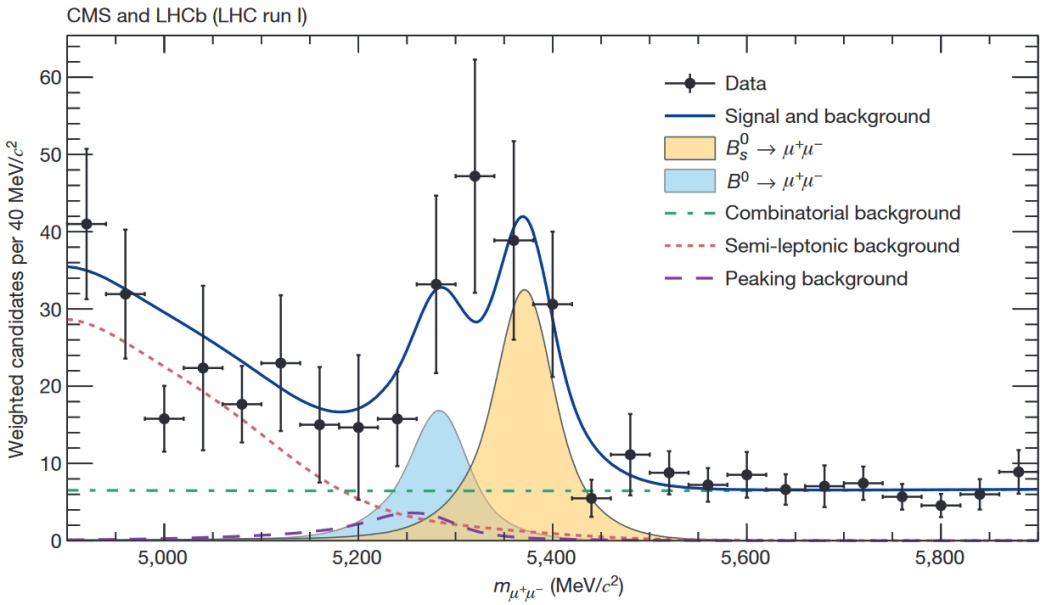
(b) Prompt combinatorial background

(c) Long-lived combinatorial background

(d) $B$ decays to $J/\psi$ mesons and muons

(e) Single mis-identified background

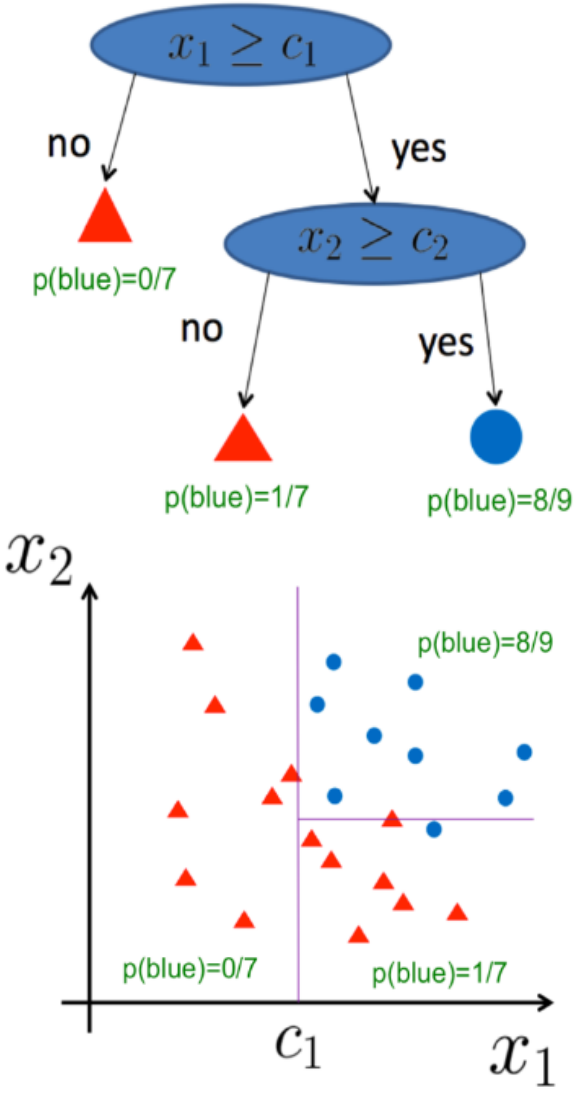
(f) Doubly mis-identified background




[3]: Nature 522, 68–72 (04 June 2015)

# Data analysis

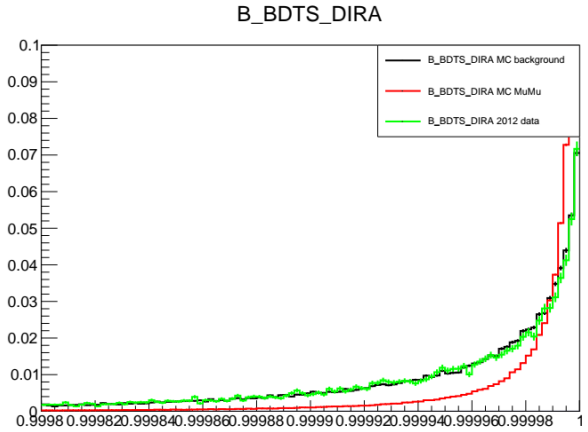
1) Fiducial cut is applied
    a) Targets shortlived background
2) Boosted decision tree (BDTS) removes 60% of combinatorial background and 5% of signal
    a) Needs well separating variables
    b) Focus of this project is training new BDTS
3) Second BDT classifies into bins with different signal to background ratio
    a) No further data rejected
    b) Recently optimised



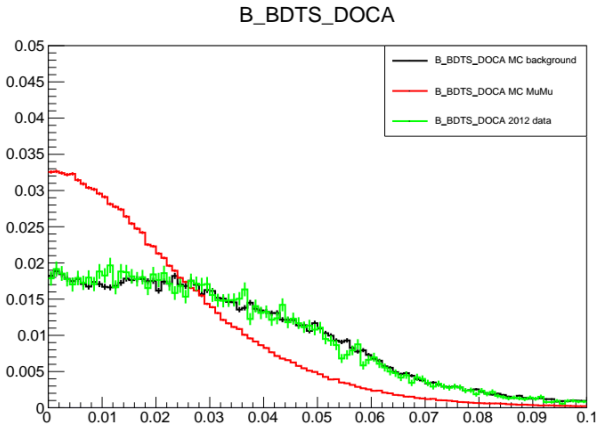
# Current BDTS variables

Data used:

- MC signal data in 2012 condition
- MC combinatorial background data in 2012 condition
  - $b\bar{b} \rightarrow \mu\mu X$
- 2012 sideband data
  - m> 5450 MeV

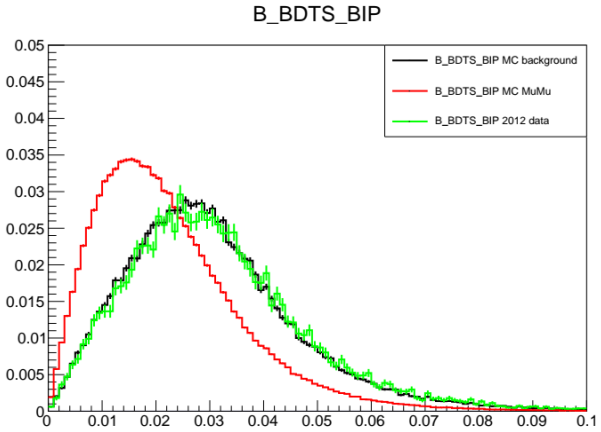



Angle between B and vertices

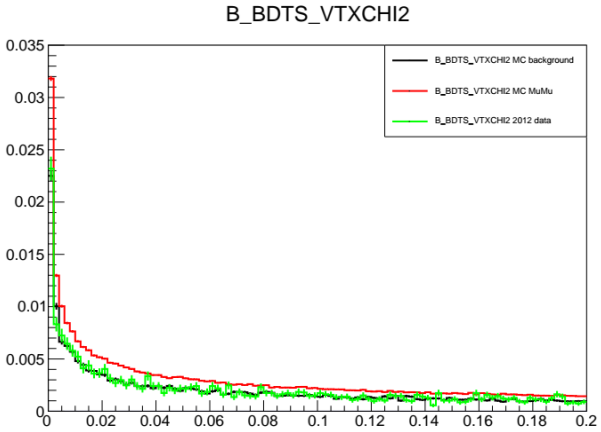



Distance of closest approach between muons

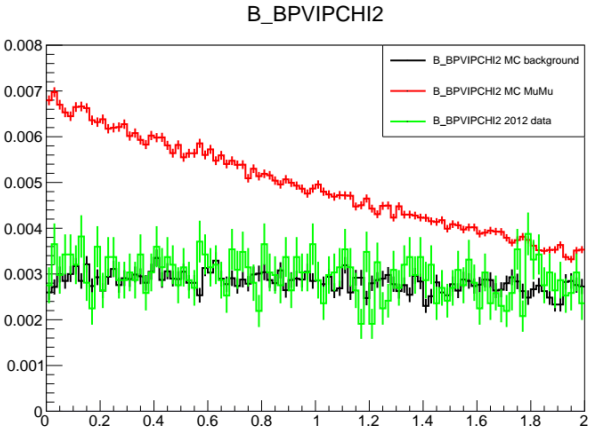
# Current BDTS variables



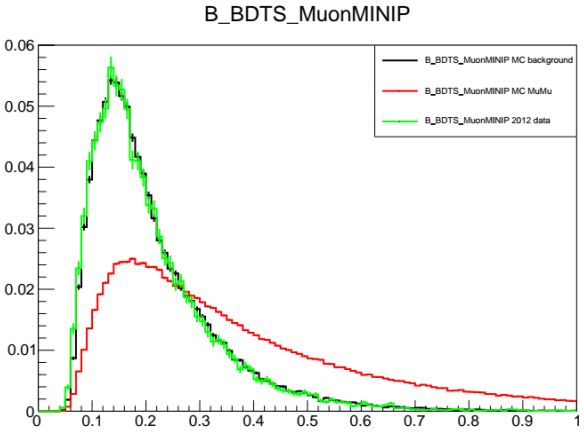

B impact parameter




Secondary vertex $\chi^2$ distribution




B impact parameter $\chi^2$ distribution

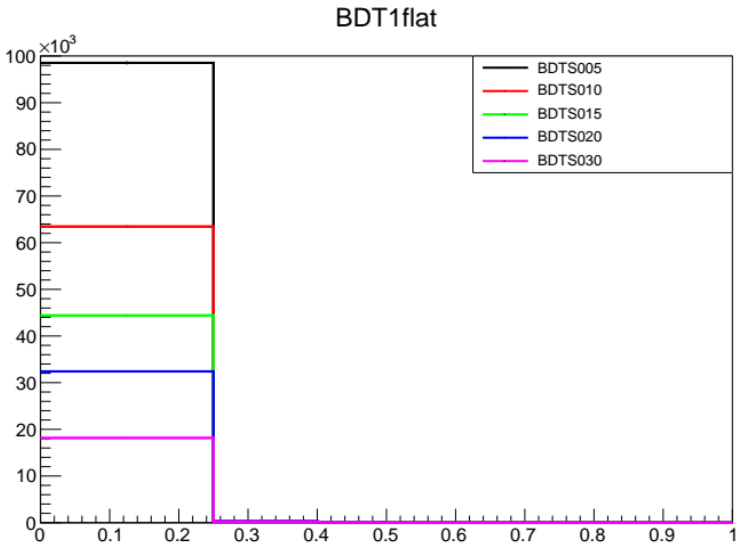



Minimum impact parameter of muons w.r.t. primary vertex

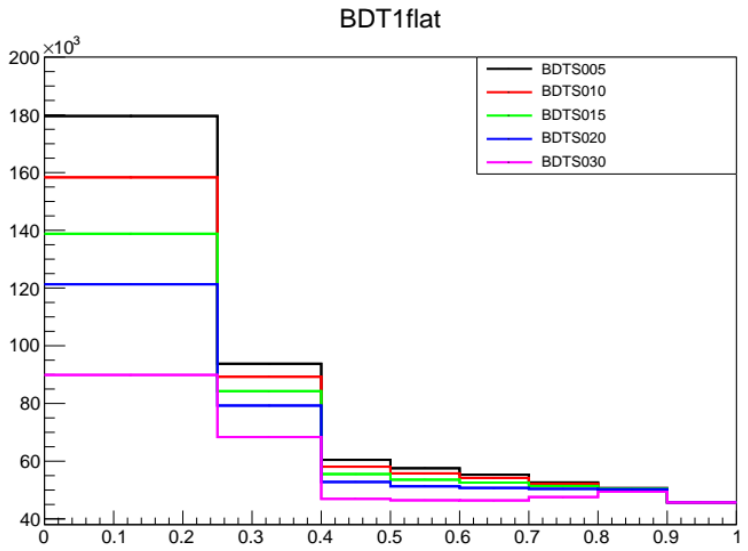
# Changing the BDTS cut

| BDTS cut value | 0.05 | 0.1 | 0.15 | 0.2 | 0.3 |
|---|---|---|---|---|---|
| MC background | 1.0 | 0.645 | 0.453 | 0.331 | 0.187 |
| 2012 data | 1.0 | 0.644 | 0.449 | 0.327 | 0.181 |
| MC signal | 1.0 | 0.947 | 0.894 | 0.842 | 0.740 |

Remaining data with different cut values of the BDTS




MC background BDT bins

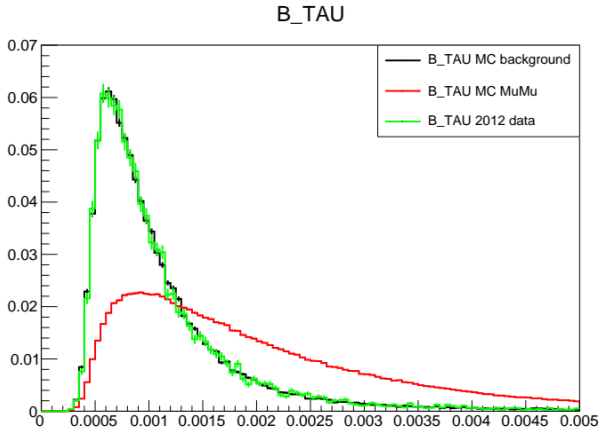



MC signal BDT bins

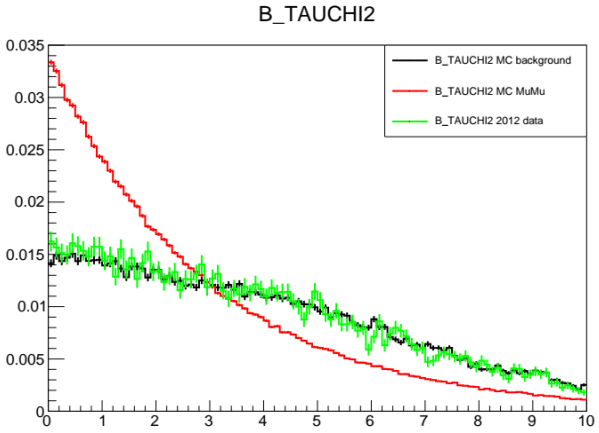
# New BDTS variables

Next step is training a new BDTS

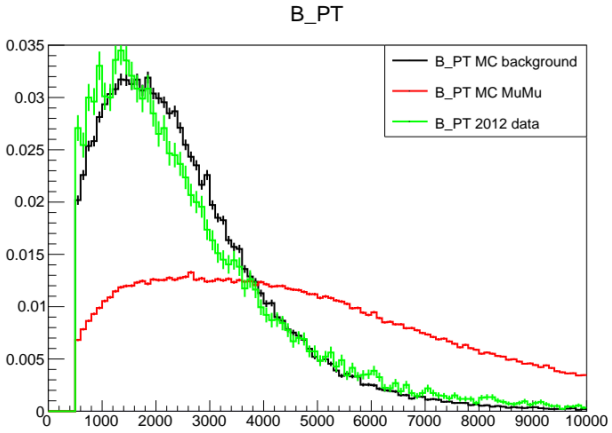
- Use discarded BDT variables
- Identify new separating variables
- Use scikit-learn BDT software




B candidate lifetime




$\chi^2$ distribution of lifetime




B candidate transverse momentum

# Summary

- $B_{(s)} \rightarrow \mu\mu$ is sensitive to beyond standard model physics
- Machine learning is used to reduce background for $B_{(s)} \rightarrow \mu\mu$ decays
- High mass sideband data is shown to be representative of combinatorial background
- Higher cut values of the BDTS seem useful in reducing background
- Next step will be training a new BDT using new variables

Questions?