SEARCH FOR THE RARE DECAY $B_s^0 \rightarrow \mu^+\mu^-$

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Young Scientist Forum

Rencontres de Moriond - EW

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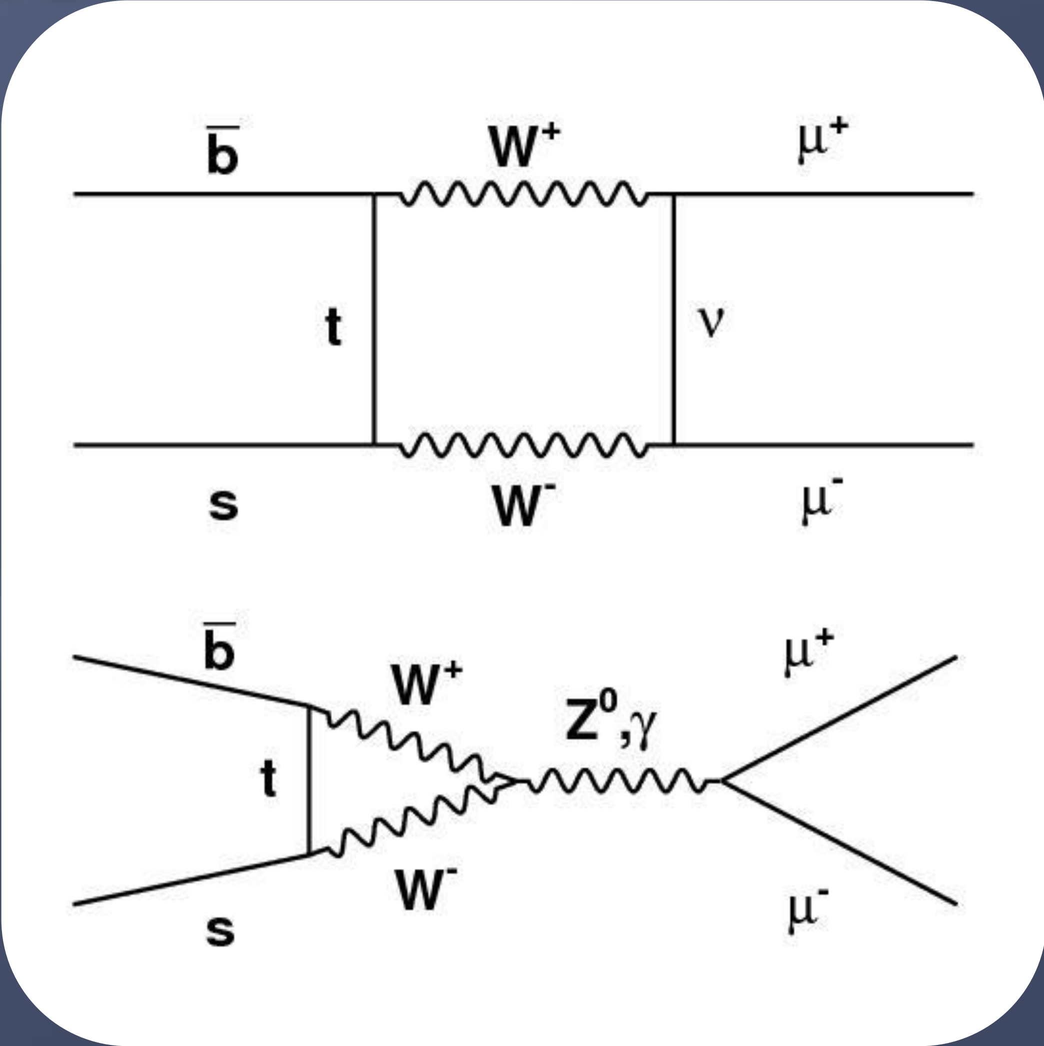
Standard Model

- Flavor changing neutral current restricted
- Helicity suppressed
- $BR(B^0_s \rightarrow \mu^+\mu^-) =$
  - $(3.2 \pm 0.2)\ x10^{-9}$
  - $(3.5 \pm 0.2)\ x10^{-9}$ (lifetime corrected)*



*A. J. Buras et al.,
Eur. Phys. J. C72, 2172 (2012).

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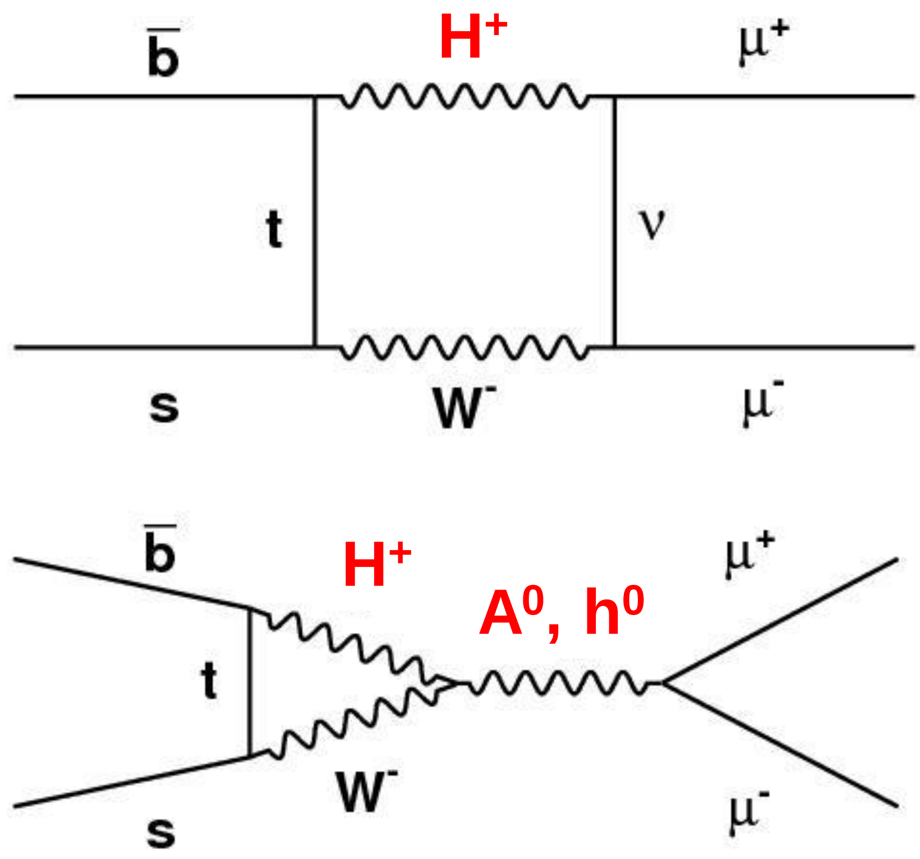
- Can have enhancement or suppression of BR with BSM physics



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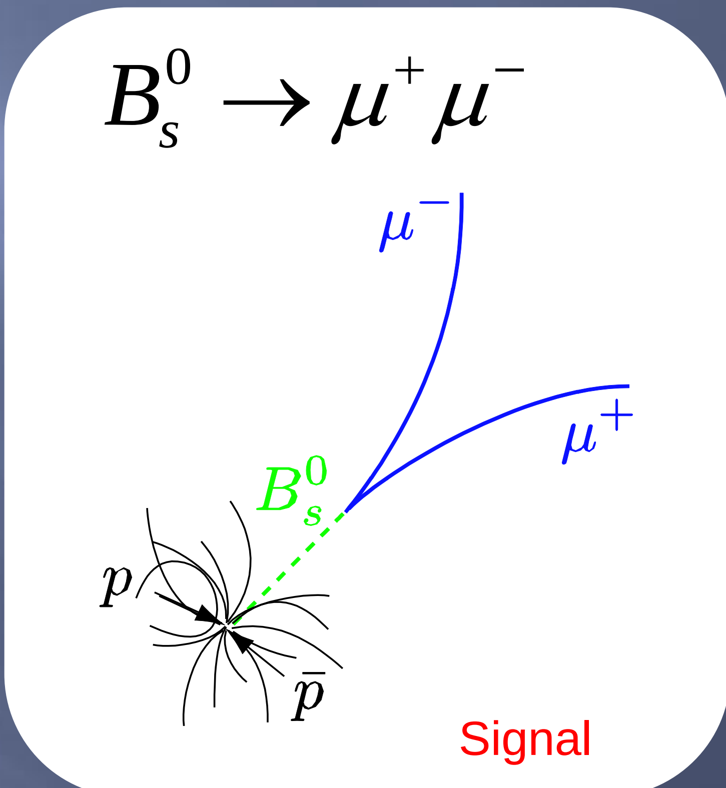
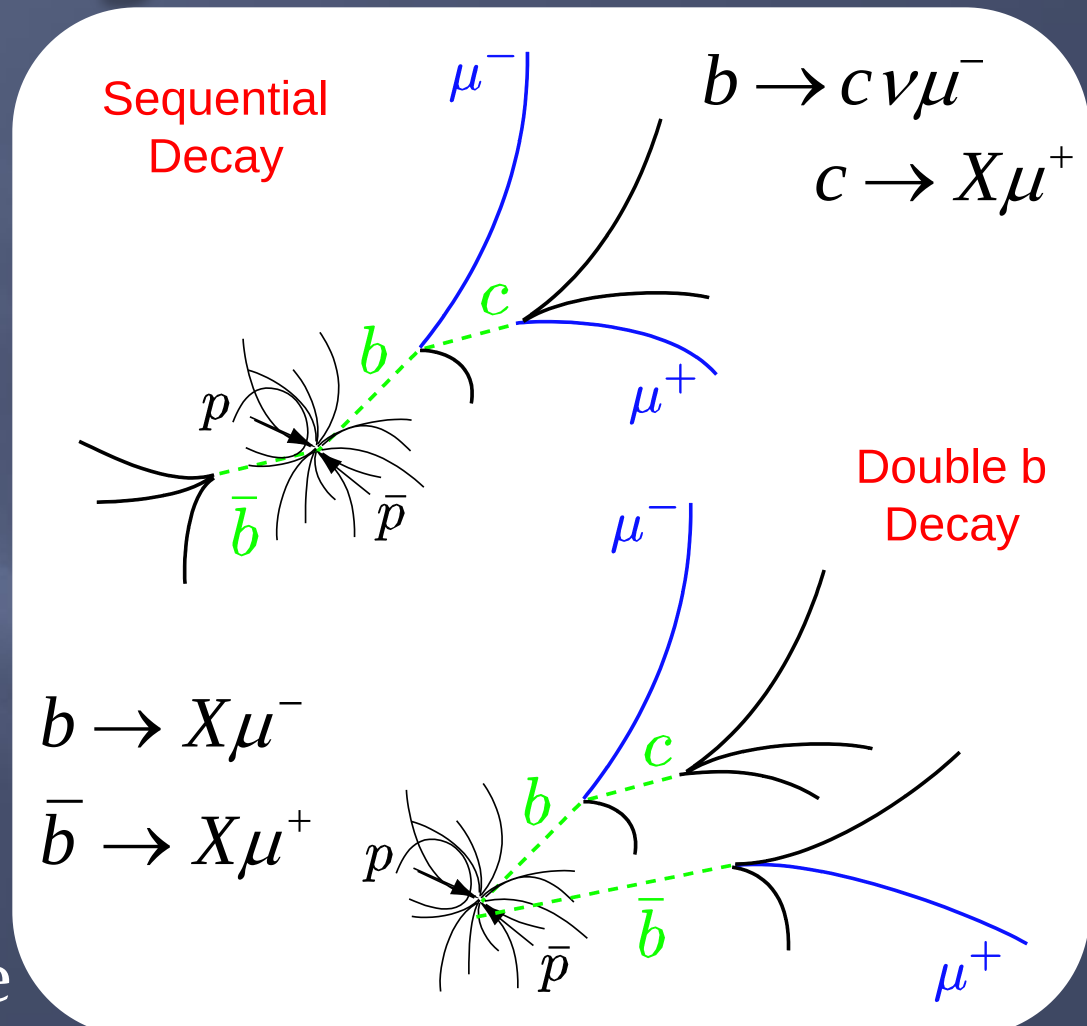
Signal vs Background

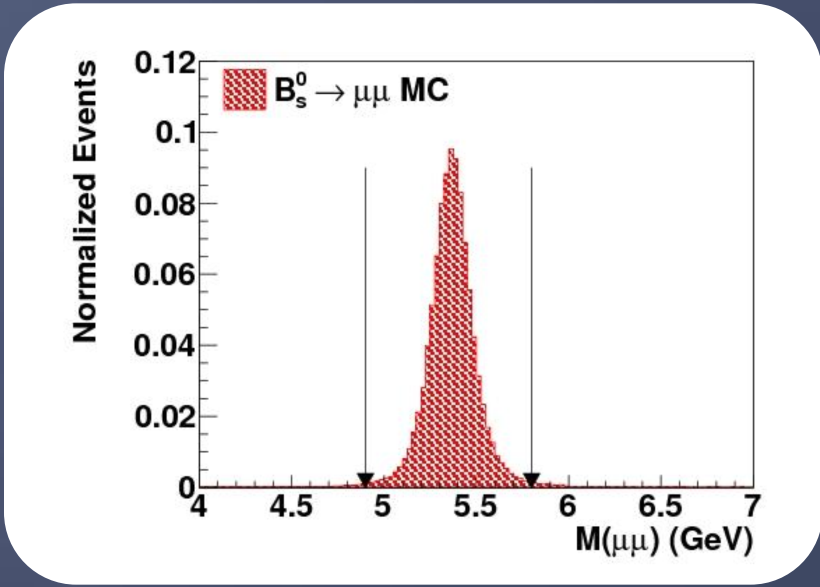
Thanks to B. Casey for figures!





- Dimuon final state

Mass resolution σ = 125 MeV



Analysis Outline

- Blinded analysis
  - Dimuon mass: 4.0 – 7.0 GeV
  - Blinded: 4.9 – 5.8 GeV
- Normalization mode
  - $B^{\pm} \to J/\Psi K^{\pm}$ with $J/\Psi \to \mu^+\mu^-$
- New variables to fight the backgrounds
- BDT
  - Use data sidebands as background for training
- Optimize cuts
- Estimate signal and background, then limits
- Results

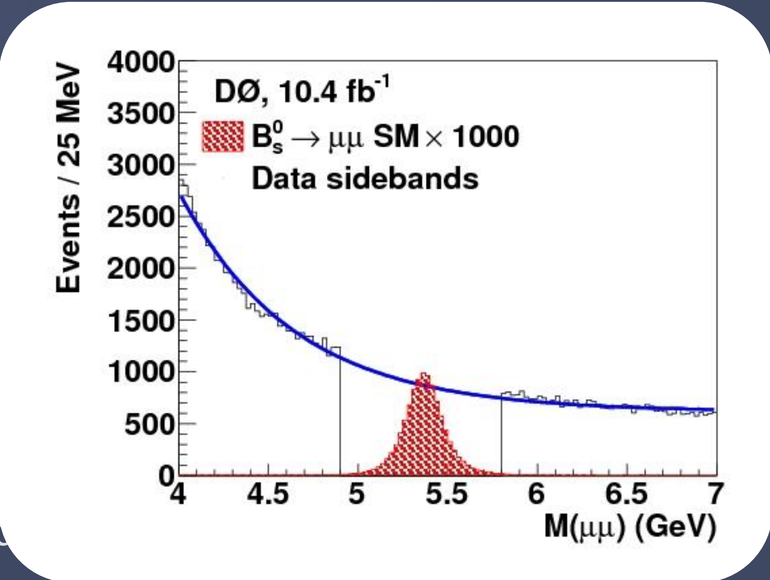
Single Event Sensitivity

$$SES = \frac{1}{N(B^{\pm})} \times \frac{\varepsilon(B^{\pm})}{\varepsilon(B_s^0)} \times \frac{f(b \to B^{\pm})}{f(b \to B_s^0)} \times BR(B^{\pm} \to J/\psi K^{\pm}, J/\psi \to \mu^+\mu^-)$$

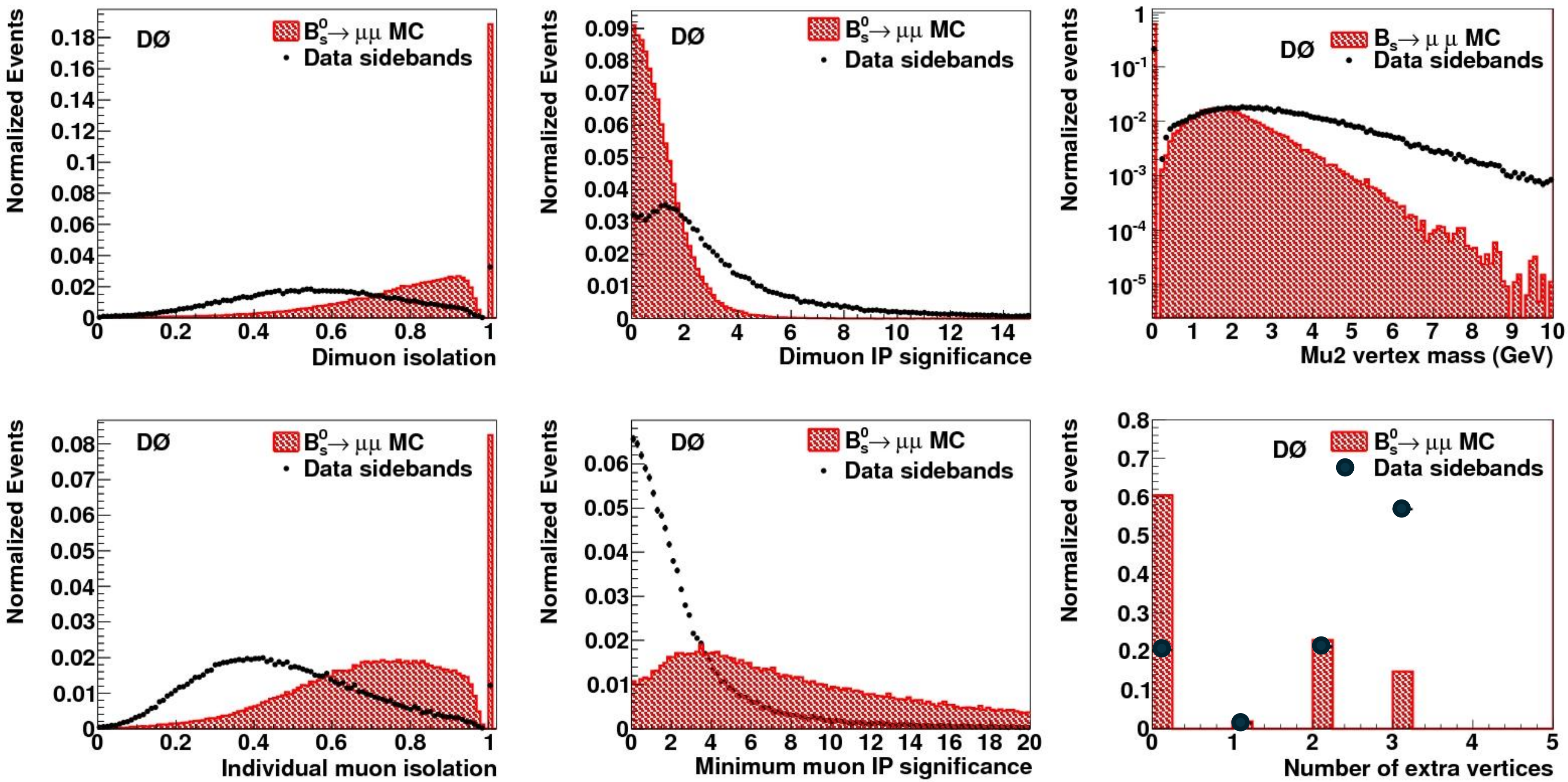
- The single event sensitivity (SES) is the branching ratio at which you expect 1 event in your data sample
- The SES gives us the number of expected B_s events in the data
- Expect 10.4 ± 1.1 $B_s \to \mu^+\mu^-$ events in the blinded region of the data (before BDT cuts)

Optimizing the BDT(s)

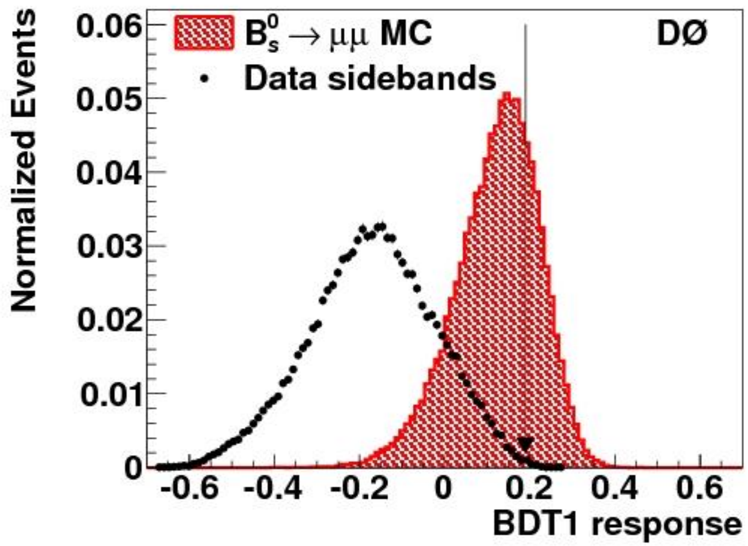
- Use a boosted decision tree (BDT) multivariate technique
  - Data sidebands are used as background
  - B_s MC is used as signal
- Make additional requirements before BDT training
  - Cosine of 2D pointing angle > 0.95
  - Cosine of 3D pointing angle > 0.90
  - Dimuon p_T > 5 GeV
- Use 2 different BDTs to discriminate against the 2 types backgrounds
  - Sequential decay
  - Double b decay
- 30 variables

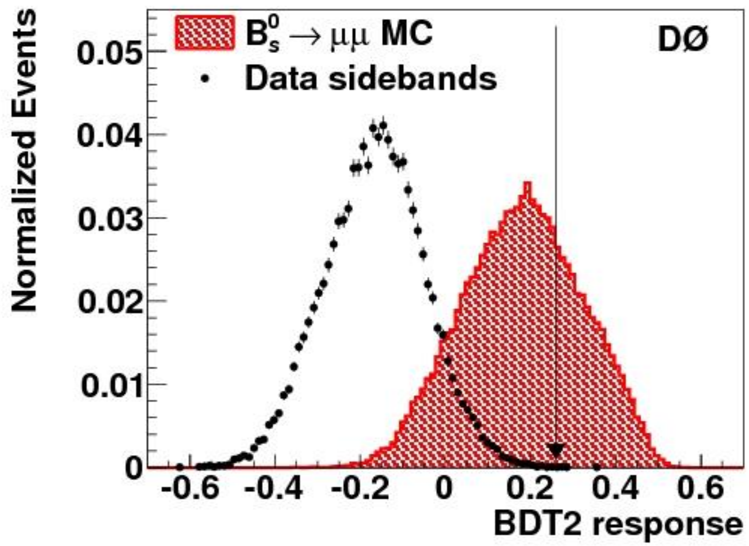


BDT Variables



BDT Response

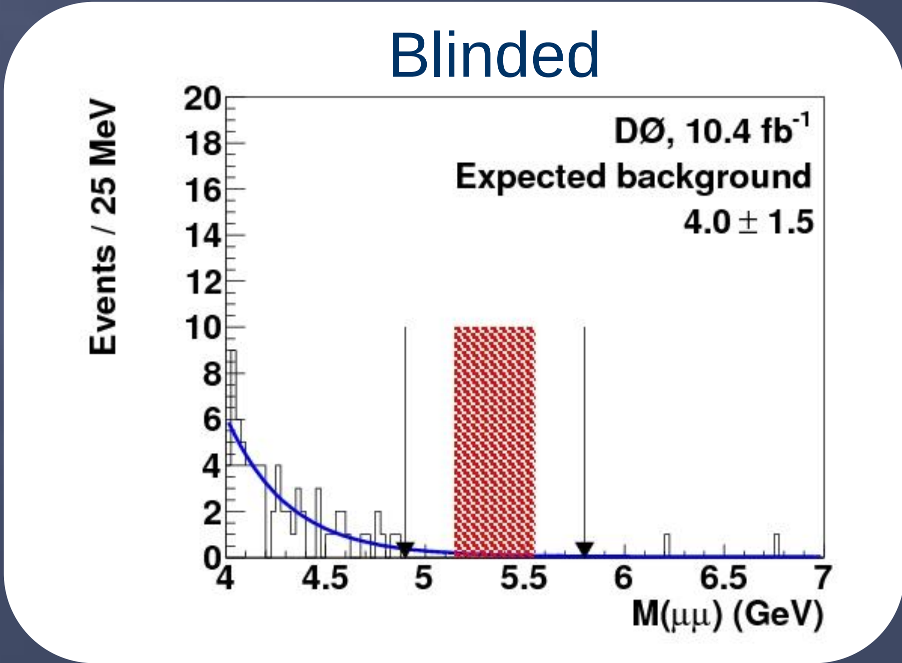




- BDT 1
- Sequential decay
- BDT 2
- Double b decay
- Coarse cuts optimization, maximize $S/\sqrt{(S+B)}$
- Final cuts optimize the expected limit

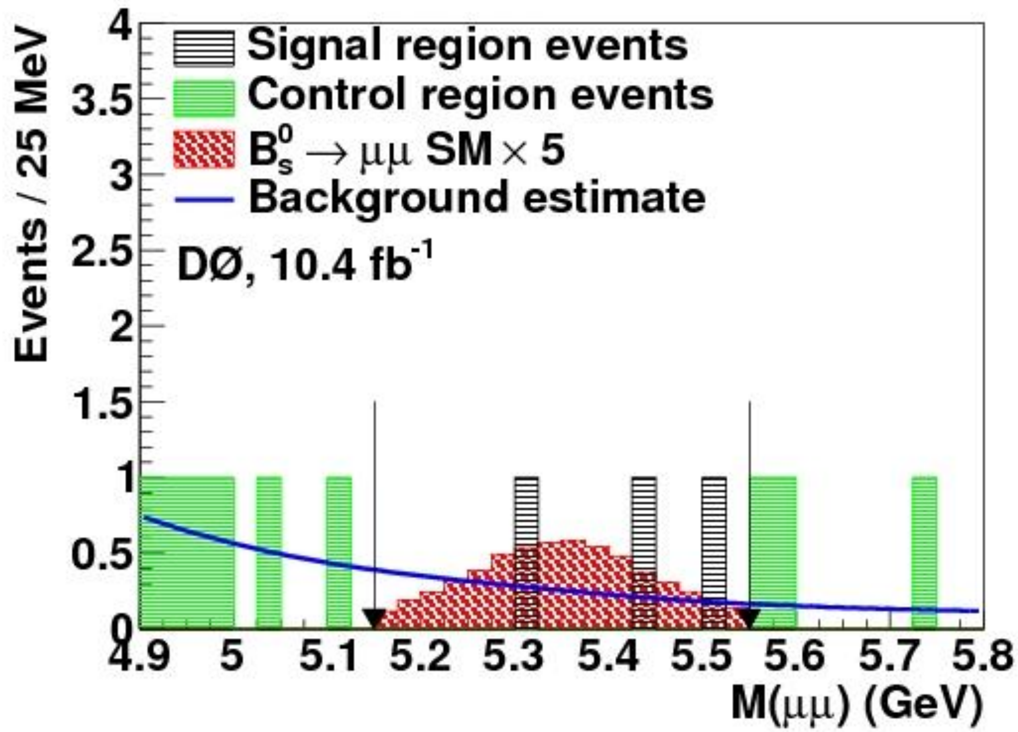
Expected Signal and Background

- Total Expected Background of 4.3 ± 1.6
  - 4.0 ± 1.5 ± 0.6 dimuon background events
  - 0.3 ± 0.1 $B_s \rightarrow KK$ peaking background events
- Expected SM Signal 1.23 ± 0.13
- Expected 95% C.L. upper limit on the branching ratio $BR(B_s \rightarrow \mu^+\mu^-) < 23 \times 10^{-9}$ using modified frequentist method*



*T. Junk, Nucl. Instrum. and Meth. in Phys. Res. A 434, 435 (1995).

Result

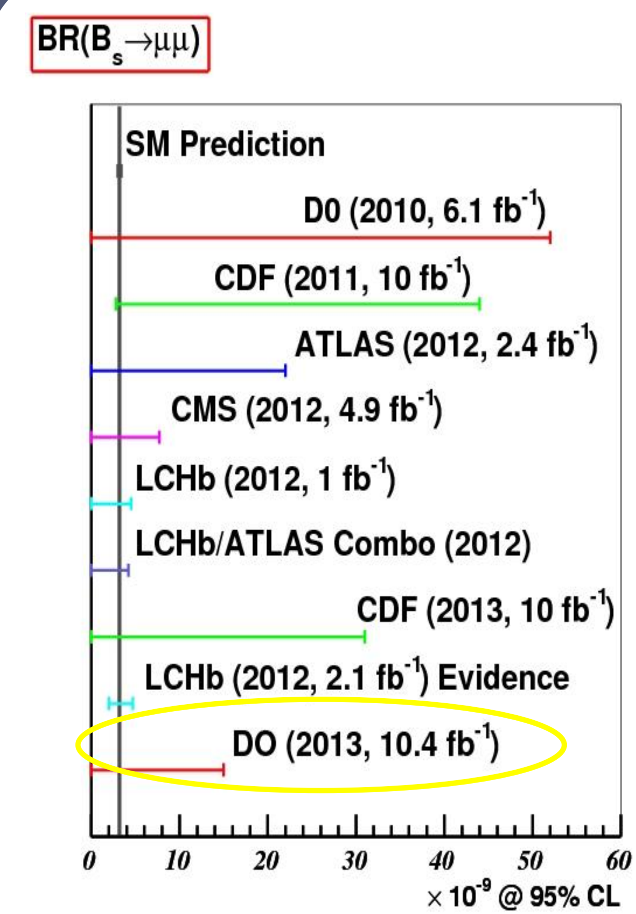


- Expected
  - SM Signal: 1.23 ± 0.13
  - Background: 4.3 ± 1.6
  - Limit: $BR(B_s \to \mu^+\mu^-)$ = $23\text{x}10^{-9}$
- Observed 3 events in the signal region setting a 95% C.L. limit on the branching fraction of

$$\mathrm{BR}(B_s^0 \to \mu^+\mu^-) < 15 \times 10^{-9}$$

Summary

- Searched for the decay of $B_s \to \mu^+\mu^-$
- Set a limit on the branching ratio of 15 x 10^{-9}
- Improved upon previous D0 results by a factor of 3.4 and a factor of 1.7 better than the $\sqrt{\mathcal{L}}$
  - Created new variables to distinguish signal from background
  - Used separate BDTs for the different types of backgrounds
- Best observed Tevatron limit

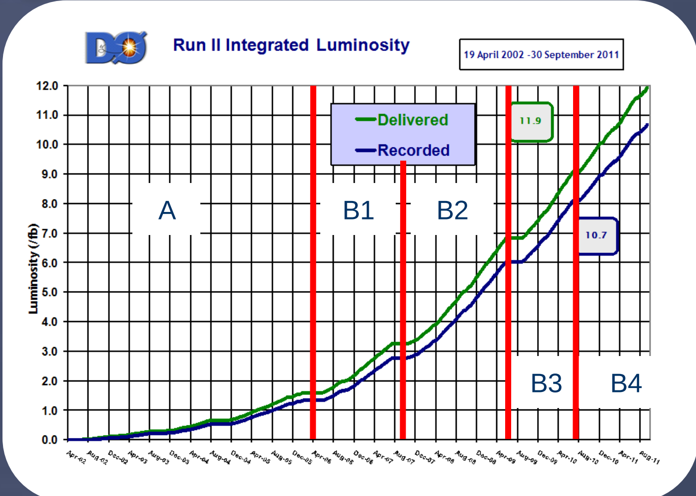


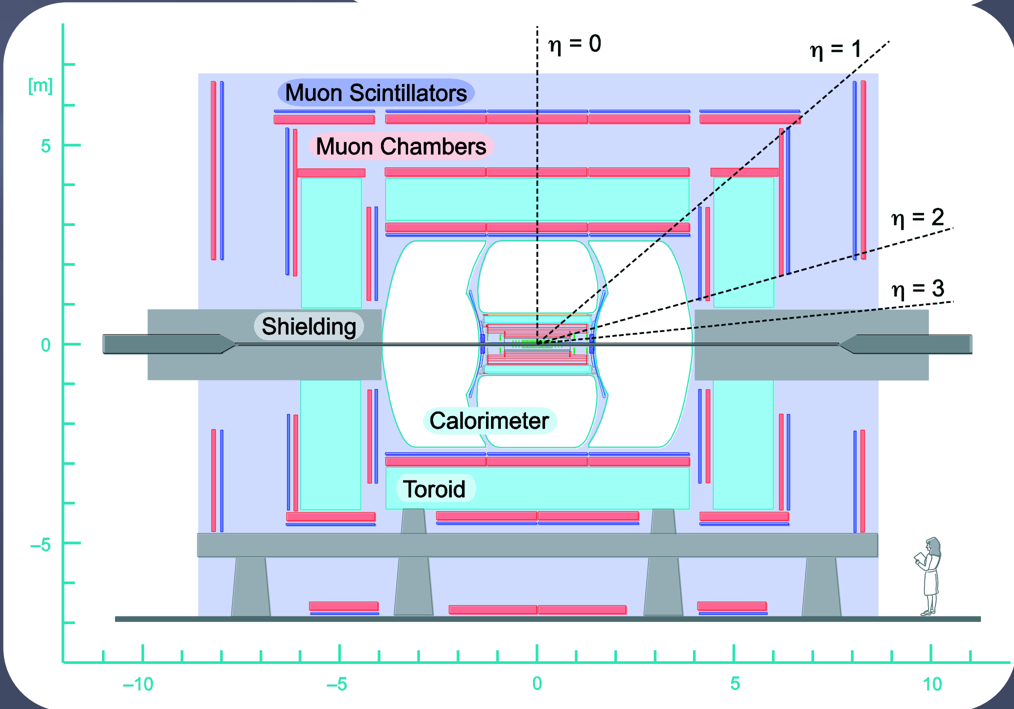
Thanks!

Backup

D0 Detector and Data

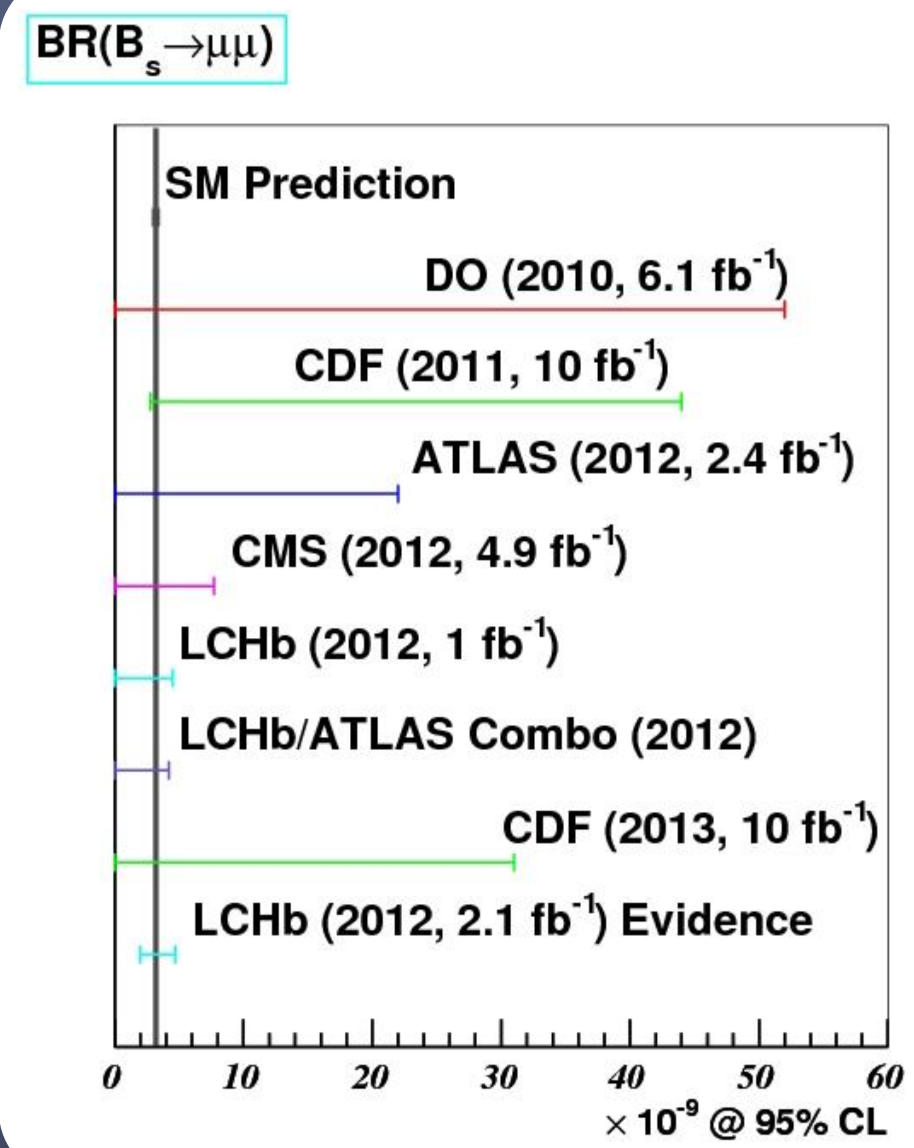
- p-pbar interactions
  - 10.4 fb^{-1}
- Silicon Microstrip Tracker
- Central Fiber Tracker
- Calorimeter
- Muon System
  - Coverage up to $|\eta| = 2$





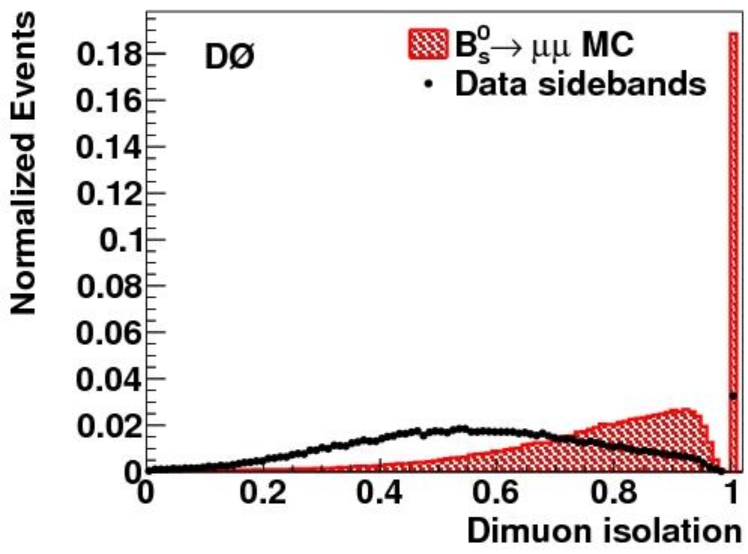
Current Experimental Situation

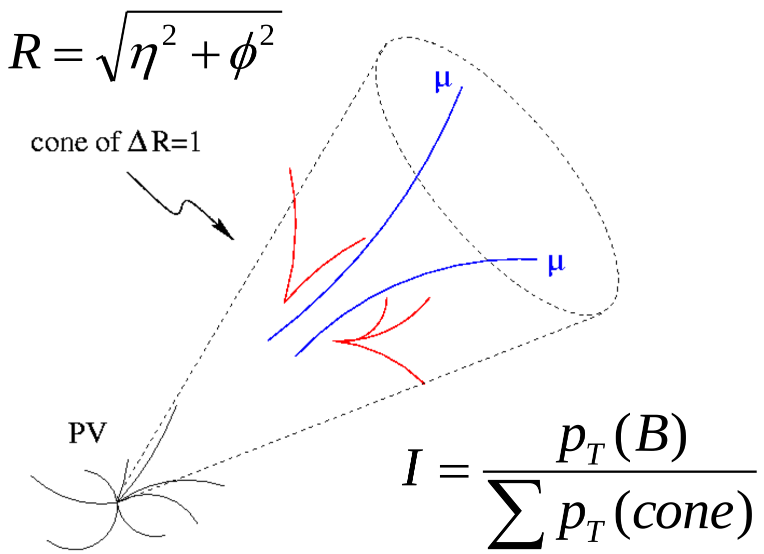
- LCHb:
  - Evidence
  - BR($B^0_s \rightarrow \mu^+\mu^-$) = $3.2^{+1.5}_{-1.2} \times 10^{-8}$
- CDF:
  - ". . . . we measure $B(B^0_s \rightarrow \mu^+\mu^-) = 1.3^{+0.9}_{-0.7} \times 10^{-8}$ and the following bounds are set, . . . $0.8 \times 10^{-9} < B(B^0_s \rightarrow \mu^+\mu^-) < 3.4 \times 10^{-8}$ at . . . 95% C.L., respectively. "



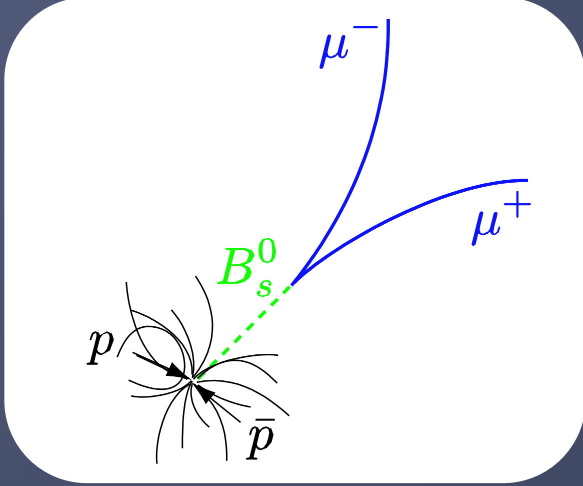
Isolation

- Tracker based isolation
- Dimuon
- Individual muons





Event Selection



- Inclusive trigger strategy
- 2 oppositely charged muons
- Muon must have at least 2 hits in SMT and CFT and a match in the muon system
- Muon p_T >1.5 GeV and $|\eta|<2$
- B p_T < 20 GeV
- B vertex χ^2/dof<14
- B decay length significance >3
- Additionally in the normalization mode
  - $K^{\pm}$ must have p_T >1.0 GeV and $|\eta|<2$

SES = (3.36 ± 0.29) x10^{-10}

$$SES = \frac{1}{N(B^{\pm})} \times \frac{\varepsilon(B^{\pm})}{\varepsilon(B_s^0)} \times \frac{f(b \to B^{\pm})}{f(b \to B_s^0)} \times BR(B^{\pm} \to J/\psi K^{\pm}, J/\psi \to \mu^+\mu^-)$$

- Number of $B^{\pm}$
  - (87.4 ± 3.0) x10^3
- Efficiency of finding $B^{\pm}$ and B_s
  - (13.0 ± 0.5) %
- Fragmentation ratio
  - HFAG 2012
  - 1/(0.263 ± 0.017)
- Branching ratio
  - PDG
  - (6.01 ± 0.21) x10^{-5}

Expect 10.4 ± 1.1 $B_s \to \mu^+\mu^-$ events in the blinded region of the data (before BDT cuts)

Optimizing the BDT(s)

- Make additional requirements before BDT training
  - Cosine of 2D pointing angle > 0.95
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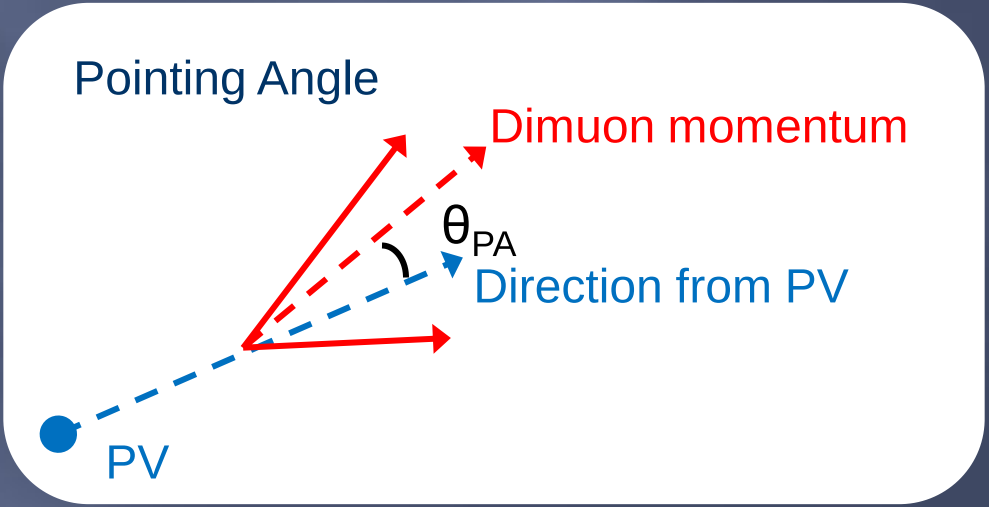
  - Dimuon p_T > 5 GeV



Cuts reduce background by 96% and keep 78% signal.

Other Backgrounds

- $B_s \to KK$ peaking background
  - K decays in flight after the tracker faking a good muon
  - $K \to \mu$ fake rate determined from $B \to \mu D^0 X$ with $D^0 \to K\pi$
  - Other $B_s \to hh$ contributions found to be negligible due to low fake rate and lower branching fractions
- $B_d \to \mu\mu$
  - Mass resolution not sensitive enough to distinguish B_d from B_s, but assume negligible B_d contribution
  - SM $BR(B_d \to \mu\mu) = (1.1 \pm 0.1) \times 10^{-10}$

BDT Variables

- $ptmumu$: p_T of the dimuon system.
- $cxymumu$: Cosine of the dimuon pointing angle, calculated using information only in the transverse plane.
- $c3dmumu$: Cosine of the dimuon pointing angle using 3D information.
- $lxymumu$: Dimuon decay length, calculated using information only in the transverse plane.
- $l3dmumu$: Dimuon decay length using 3D information.
- $sigxymumu$: Dimuon decay length significance.
- $ip1mumu$: Dimuon impact parameter, calculated using information only in the transverse plane.
- $ipsig1mumu$: Dimuon impact parameter significance.
- $chi2mumu$: χ^2 of the dimuon vertex.
- $ptxysqmumu$: Square of the dimuon momentum component perpendicular to the line from the primary vertex to the dimuon vertex, calculated in the transverse plane.
- $pt3dsqmumu$: Same as $ptxysqmumu$ excepted calculated using 3D information.
- iso: Standard isolation variable $I=p_T(\mu \mu)$/[$p_T(cone)$+$p_T(\mu \mu)]$ in R~=~1 cone.
- $isomu1$: Same as iso, but defined with respect to the leading muon rather than the dimuon direction.
- $isomu2$: Isolation defined with respect to the trailing muon direction.
- $isosum$: Sum of the individual muon isolation. $isomu1+isomu2$
- $ptmu1$: p_T of the leading muon.
- $ptmu2$: p_T of the trailing muon.
- $ip1mu1$: Leading muon impact parameter.
- $ip1mu2$: Trailing muon impact parameter.
- $ipsig1mu1$: Leading muon impact parameter significance.
- $ipsig1mu2$: Trailing muon impact parameter significance.
- $deltaphi$: Difference in azimuthal angles between the two muons.
- $ipsigless$: Smaller of the two impact parameters of the two muons.
- $cxyNew$: Cosine of the pointing angle. %need to look up
- $mTer$: Invariant mass of the tracks associated with an additional vertex that does not include either muon.
- $mTermu1$: Invariant mass of the tracks associated with an additional vertex that includes the leading muon.
- $mTermu2$: Invariant mass of the tracks associated with an additional vertex that includes the trailing muon.
- $chi2mu1iso$: χ^2 of the vertex of tracks with the leading muon.
- $chi2mu2iso$: χ^2 of the vertex of tracks with the trailing muon.
- $cxymu2iso$: Cosine of the pointing angle for the vertex of tracks with the trailing muon.