First Evidence of $B_s^0 \to \mu^+\mu^-$

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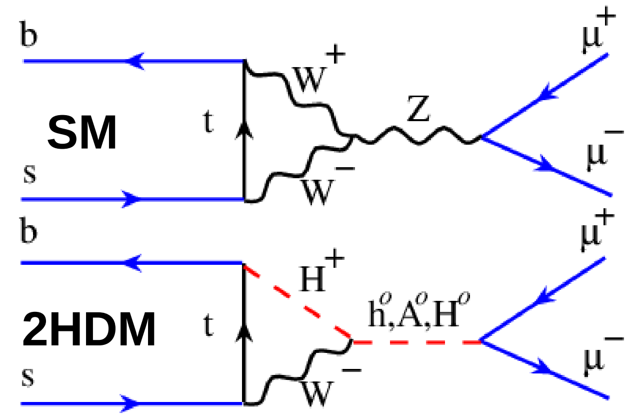
Motivations to search for $B^0_{(s)} \to \mu^+\mu^-$

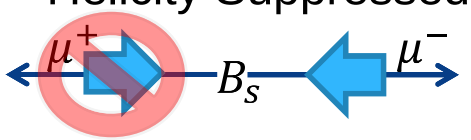
Why $B^0_{(s)} \to \mu^+\mu^-$?



- Testing SM in the loops:
  - Flavour Changing Neutral Current
  - No tree diagram, only higher orders

- Possible new particles in the loops

Helicity Suppressed



- Precise SM prediction:

$$\boxed{\begin{aligned} \boldsymbol{B(B^0_s \to \mu^+\mu^-)_{SM}} &= \boldsymbol{(3.23 \pm 0.27) \times 10^{-9}} \\ \boldsymbol{B(B^0 \to \mu^+\mu^-)_{SM}} &= \boldsymbol{(1.07 \pm 0.10) \times 10^{-10}} \end{aligned}}$$

Buras et al., arXiv:1208.0934

A good place to look for Physics Beyond SM

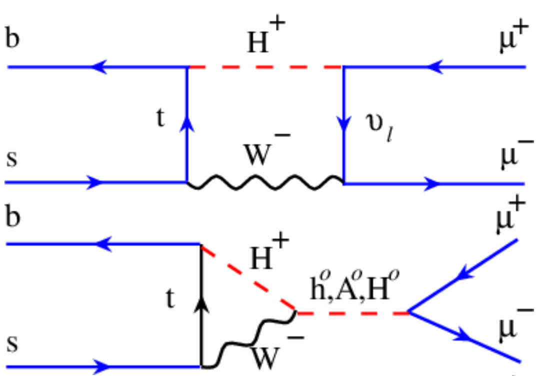
$B^0_{(s)} \to \mu^+\mu^-$ phenomenology

Model independent expression of the Branching Ratio:

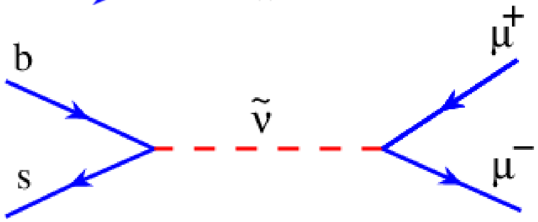
$$B(B^0_s \to \mu^+\mu^-) \propto 1 - \frac{4m_\mu^2}{m_{B_s}{}^2}|C_s - C'_s|^2 + \left|(C_P - C'_P) + 2\frac{m_\mu}{m_{B_s}}(C_{10} - C'_{10})\right|^2$$

In MSSM: $c_{S,P}^{MSSM\,2} \propto \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_A^4}$

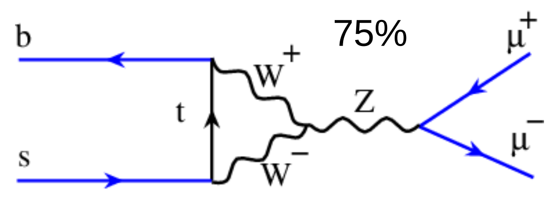
2HDM:

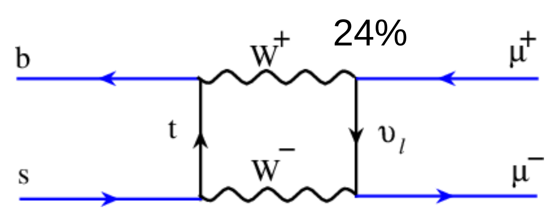


RPV:



SM contributions:



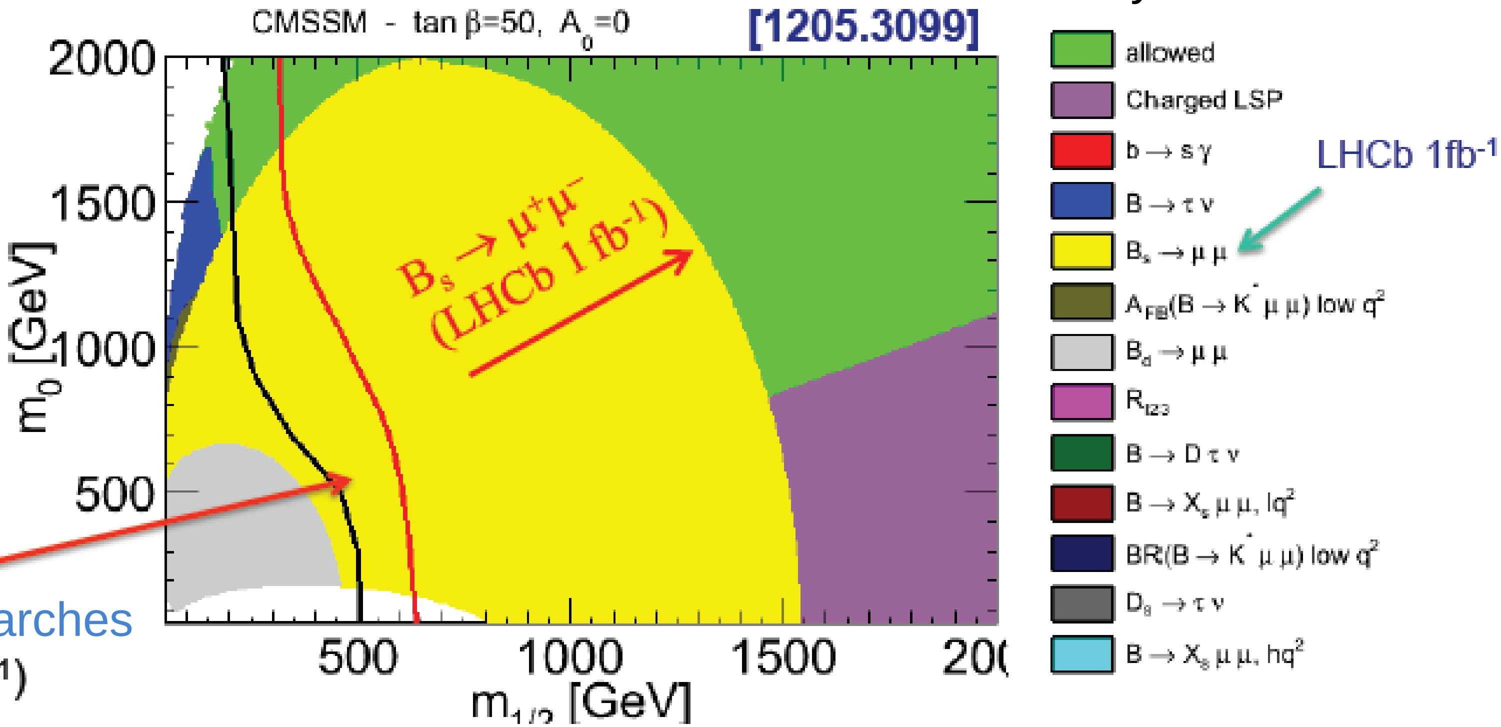


Constrains from $B_s^0 \to \mu^+\mu^-$

(NUHM1 similar)

F. Mahmoudi, [1205.3099]

May 2012



CMS Direct Searches

4.4fb-1 (1.1fb-1)

Experimental Picture

Experimental Observable

- Neutral B_s^0 mesons oscillate:

$$\langle \Gamma(B_s^0(t) \to f)\rangle \equiv R_H^f e^{-\Gamma_H^s t} + R_L^f e^{-\Gamma_L^s t}$$

- Experimental observable is the time integrated BR:

$$B(B_s^0 \to f)_{\mathrm{exp}} \equiv \frac{1}{2}\int_0^\infty \langle \Gamma(B_s^0(t) \to f)\rangle dt$$

- Theoretical definition for the prediction:

$$B(B_s^0 \to f)_{\mathrm{theo}} \equiv \frac{\tau_{B_s^0}}{2} \langle \Gamma(B_s^0(t) \to f)\rangle \Big|_{t=0}$$

- Time integrated prediction:

$$B(B_s^0 \to \mu^+\mu^-)_{\mathrm{exp}}^{\mathrm{SM}} = (3.54 \pm 0.30) \times 10^{-9}$$

De Bruyn et al., PRL 109, 041801 (2012), uses $\Delta\Gamma_s$ from LHCb-CONF-2012-002

Historical Picture

- The story begins in 1984 at CLEO:

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1

Two-body decays of *B* mesons

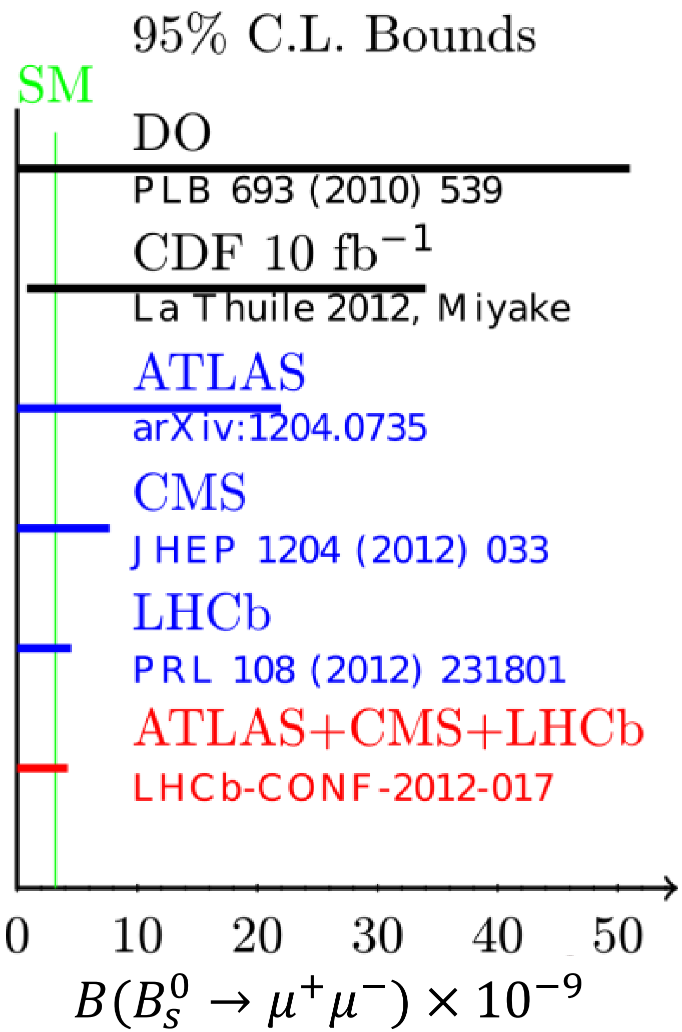
B. Search for exclusive $\bar{B}^0$ decays into two charged leptons

Our search for the $\pi^+\pi^-$ final state is not sensitive to the mass of the final-state particles, provided that they are light, since the mass enters only in the energy constraint. Therefore, the upper limit of 0.05% applies for any final-state particles with a pion mass or less. When the final-state particles are leptons the limits are improved by using the lepton identification capabilities of the CLEO detector.[14] For the decay $\bar{B}^0 \rightarrow \mu^+\mu^-$, we improve our limit by requiring that both muons penetrate the iron and produce signals in drift chambers. We find no such events. After correcting for detection efficiency (33%), we set an upper limit of 0.02% at 90% confidence for this decay. We im-

- Since then:

CLEO, ARGUS, UA1, Belle, BaBar, D0, CDF, ATLAS, CMS, LHCb

Experimental Status



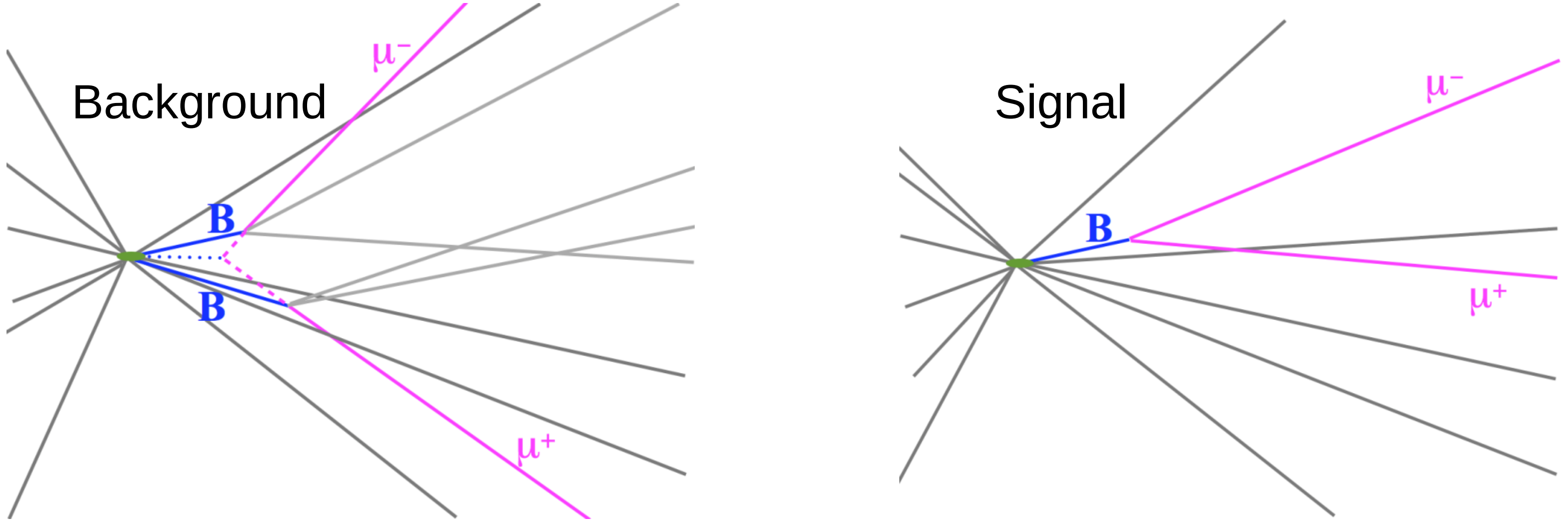
June 2012

- LHCb Results:
  $B(B^0 \to \mu^+\mu^-) < 1.0 \times 10^{-9}$
  $B(B_s^0 \to \mu^+\mu^-) < 4.5 \times 10^{-9}$
- Significant NP enhancements ruled out for $B(B_s^0 \to \mu^+\mu^-)$
- Road map now:
  - Constrain $B(B^0 \to \mu^+\mu^-)$
  - Measure $B(B_s^0 \to \mu^+\mu^-)$

Two key points to look for $B^0_{(s)} \to \mu^+\mu^-$:

1. Production of B mesons: (x-section and trigger)
2. Separation Signal/Background (detector performance)

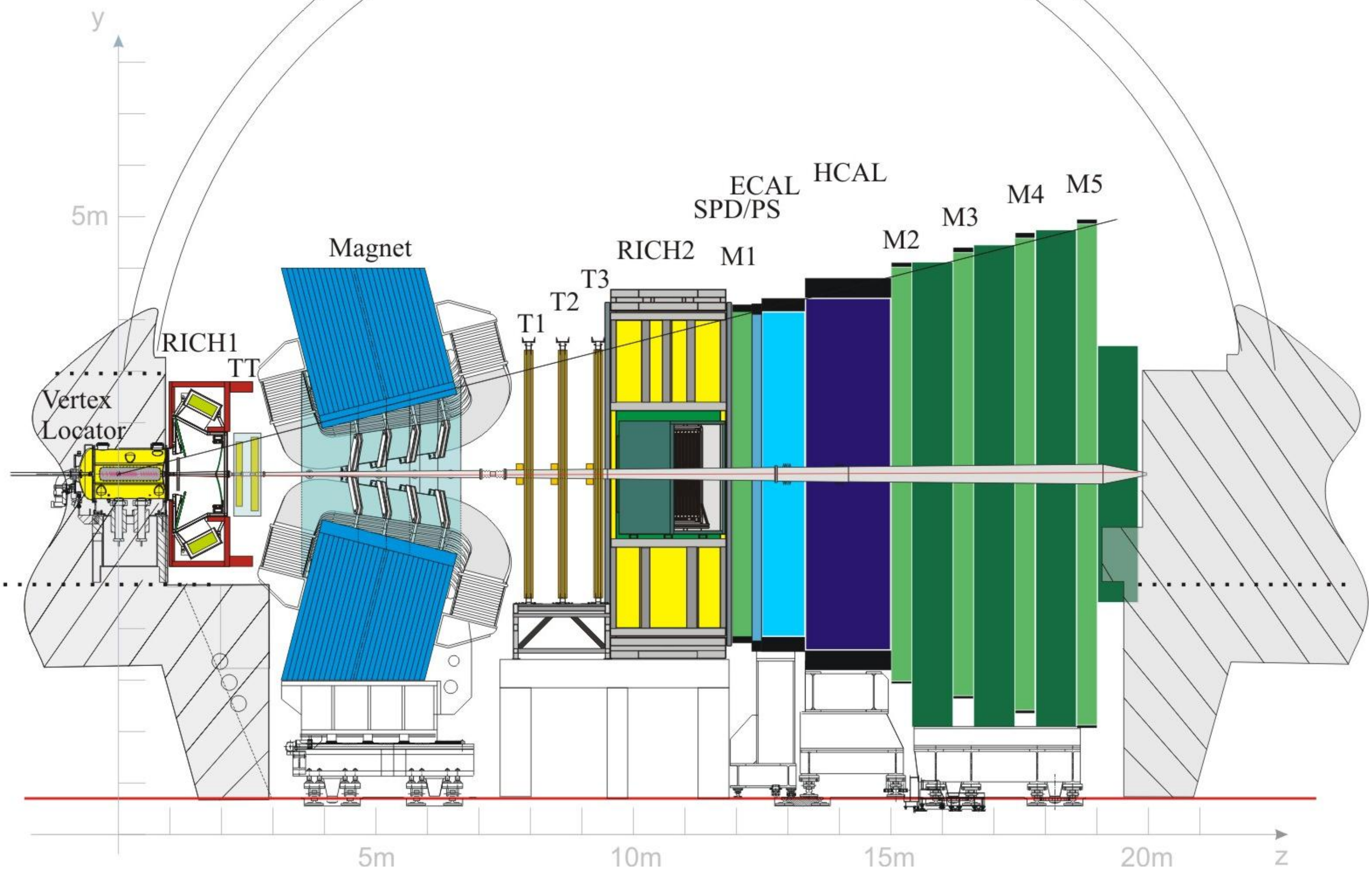
- Combinatorial background: $b\bar{b} \to \mu\mu X$



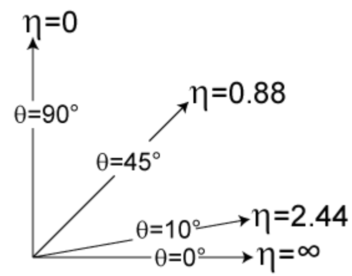
- Physical Backgrounds:

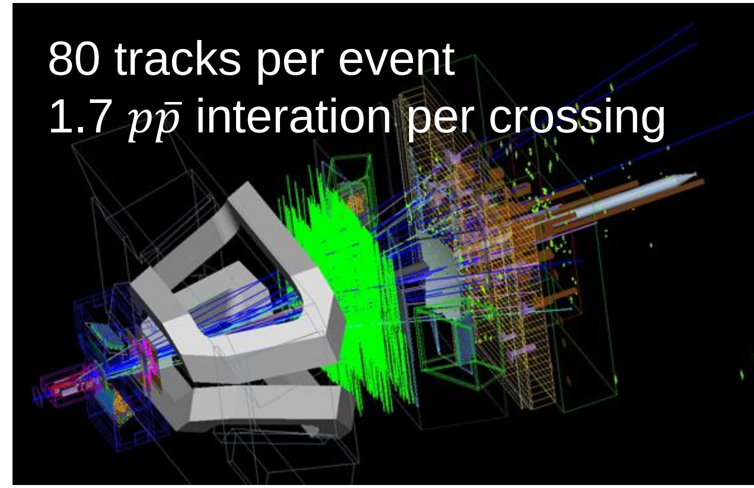
e.g. $B \to K\pi, KK, \pi\pi$ where K, π decay in flight to μ

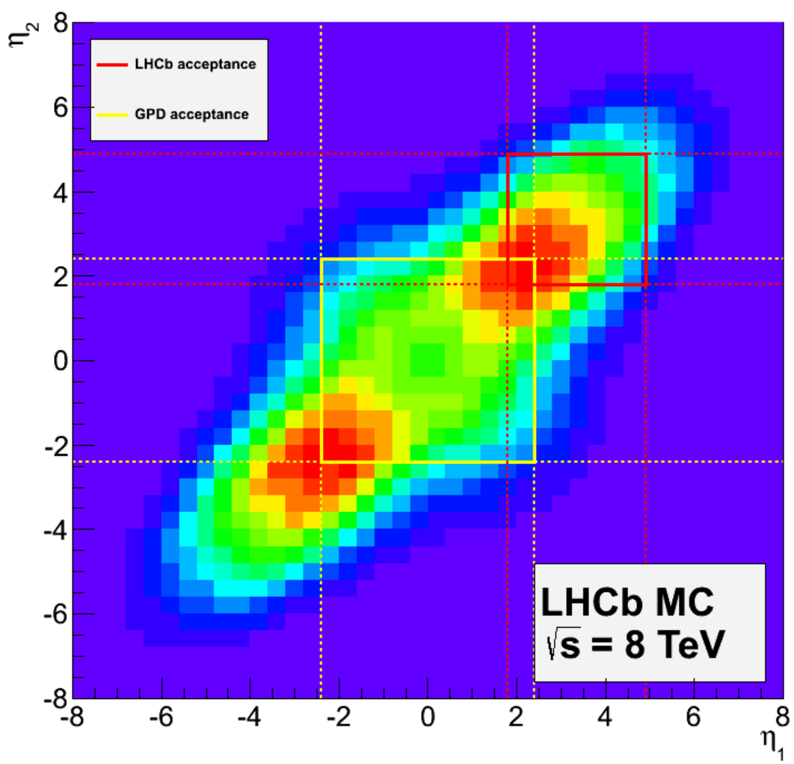
Searching for $B^0_{(s)} \to \mu^+\mu^-$ at **LHCb**



- The LHCb detector:
  - Single arm forward spectrometer
  - Acceptance: $2 < \eta < 6$







- Key Point 1: Production of B mesons: b quarks are produced forward

Exp.	Accept.	X-section	$b\bar{b}$ pairs
CDF	$\|\eta\| < 1$	$6.3 \pm 0.6\ \mu b$	$\sim 1 \times 10^{9}$
ATLAS CMS	$\|\eta\| < 2.2$	$75 \pm 17\ \mu b$	$\sim 4 \times 10^{11}$
LHCb	$2 < \eta < 6$	$94 \pm 8\ \mu b$	$\sim 9 \times 10^{10}$

arXiv: 1207.4287v2

LHCb Trigger for $B^0_{(s)} \to \mu^+\mu^-$

Sig. candidates triggered by the μ-lines:

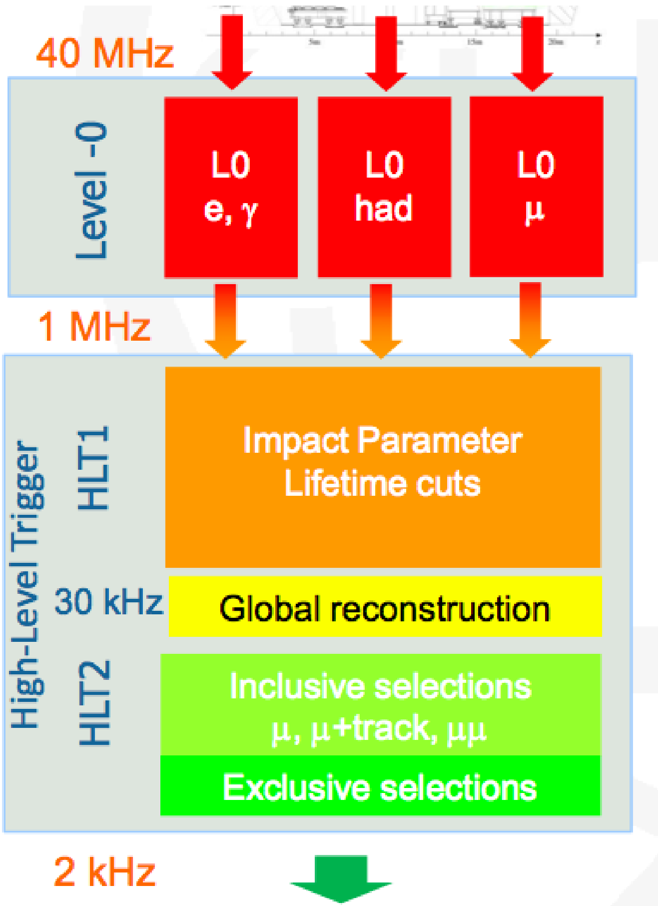
- Single muon

L0 requires 1 muon with $p_T > 1.76\ \mathrm{GeV/c^2}$
HLT require IP and mass cut

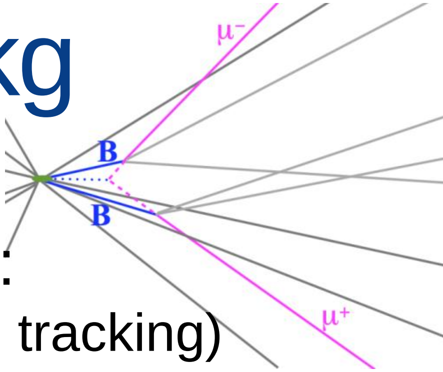
- Di-muons

L0 requires di-muons with $\sqrt{p_{T,1}p_{T,2}} > 1.6\,\mathrm{GeV/c^2}$
HLT require IP and mass cut

Overall: 90% of the sig. candidates pass the trigger



Key Point 2: Separation Sig/Bkg



Sig Separated form Combinatorial Bkg thanks to:

- excellent mass and momentum resolution (magnet, tracking)

$\frac{\delta p}{p} \sim 0.4 \to 0.6\%$ for $p = 5 \to 500\ GeV/c$

$\Delta m_{\mu\mu} \sim 25\mathrm{MeV/c^2}$ (2 [3-4] times better than CMS [ATLAS])

- excellent secondary vertex resolution: (high boost and tracking)

B average flight distance $10\ mm$

$\sigma_{IP} = 25\mu m$ at $p_t = 2\mathrm{GeV/c}$

Sig Separated form Physical Bkg thanks to:

- particle identification information (RICH – muons chambers)

$$\epsilon(\mu \to \mu) \sim 98\%$$
$$\epsilon(\pi \to \mu) \sim 0.6\%$$
$$\epsilon(K \to \mu) \sim 0.3\%$$
$$\epsilon(p \to \mu) \sim 0.3\%$$

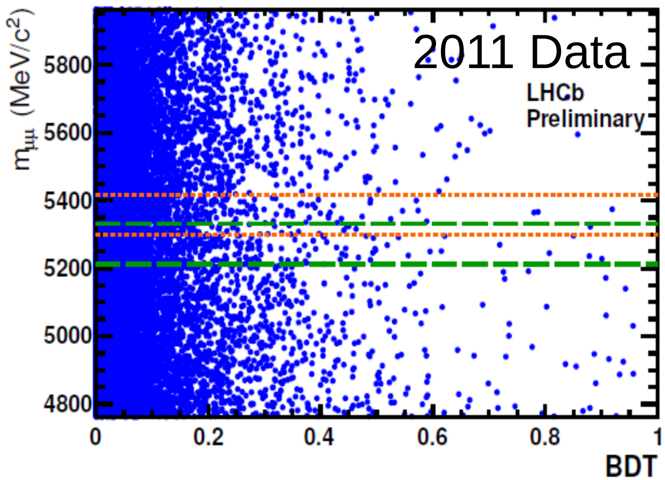
LHCb Analysis

Overview of the Analysis

Strategy:

1. Loose selection
2. Classify events in a 2D binned plane
   - $m_{\mu\mu}$ x BDT combining topological information

and derive expectations for sig and bkg



   - need control channels

   $B \to hh'$ and $B^+ \to J/\psi K^+$

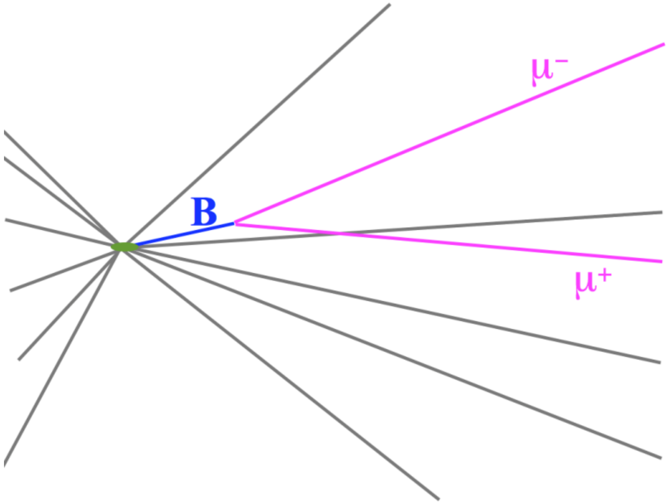
3. Extract Limit and BR

Data Set:

$1.0\ \mathrm{fb}^{-1} + 1.1\ \mathrm{fb}^{-1}$ collected in 2011 and 2012 at 7 and 8 TeV

Blind analysis: all choices are made without looking at the signal region

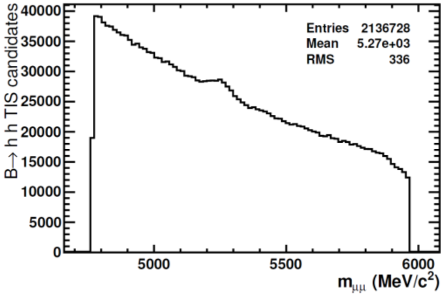
Selection



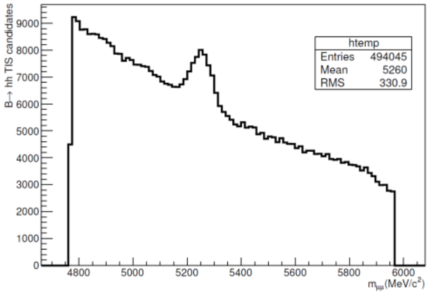
- Selection should be:
  - very efficient for the signal
  - similar for signal and control channels
- Initial Selection requires:
  - good tracks with a large impact parameter
  - good and displaced secondary vertex pointing to the primary vertex
- Tighten initial selection to reduce combinatorial Bkg:
  - cut on a output of a MVA combining information about the candidate topology

80% background rejection for 92% signal efficiency.

$B \to hh'$ after Initial Selection

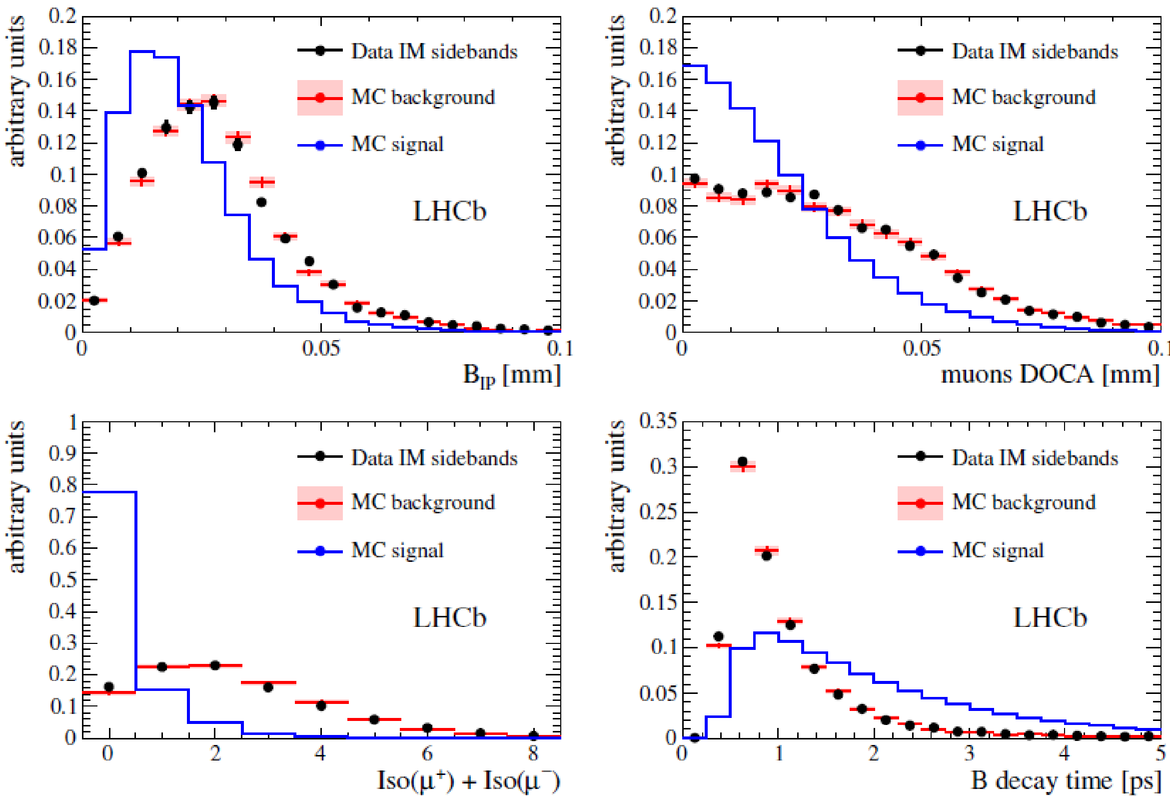


$B \to hh'$ after Tight Selection



Classification - BDT

- Boosted Decision Tree
- Inputs : 9 inputs variables uncorrelated with $m_{\mu\mu}$
- Trained and tested on MC signal and $b\bar{b} \to \mu\mu X$

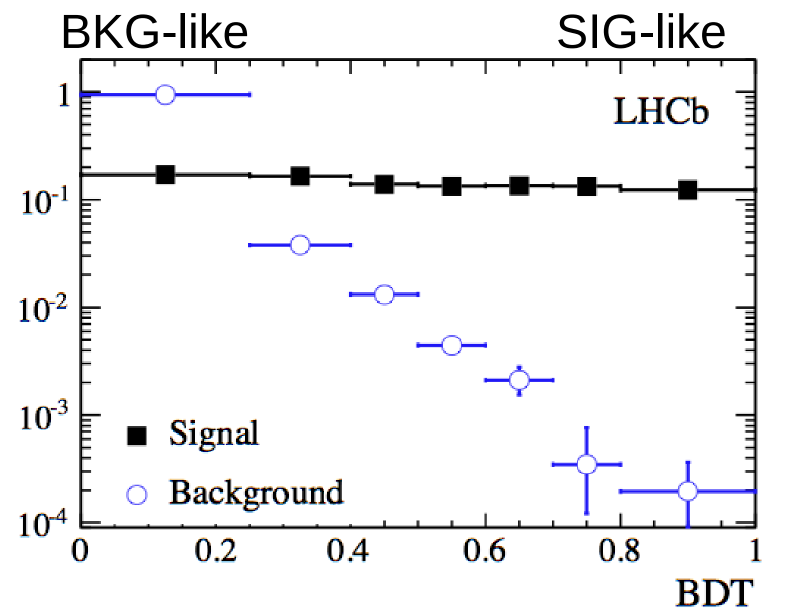


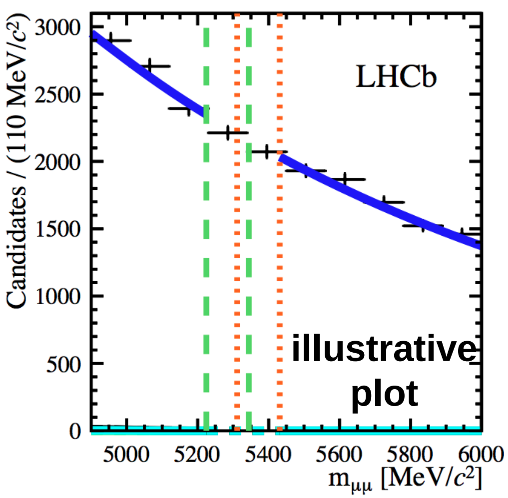
B candidate:
- proper time
- impact parameter
- transverse momentum
- B isolation

muons:
- min p_T
- min IP significance
- dist. of closest approach
- muon isolation,
- polarisation angle

Classification - BDT

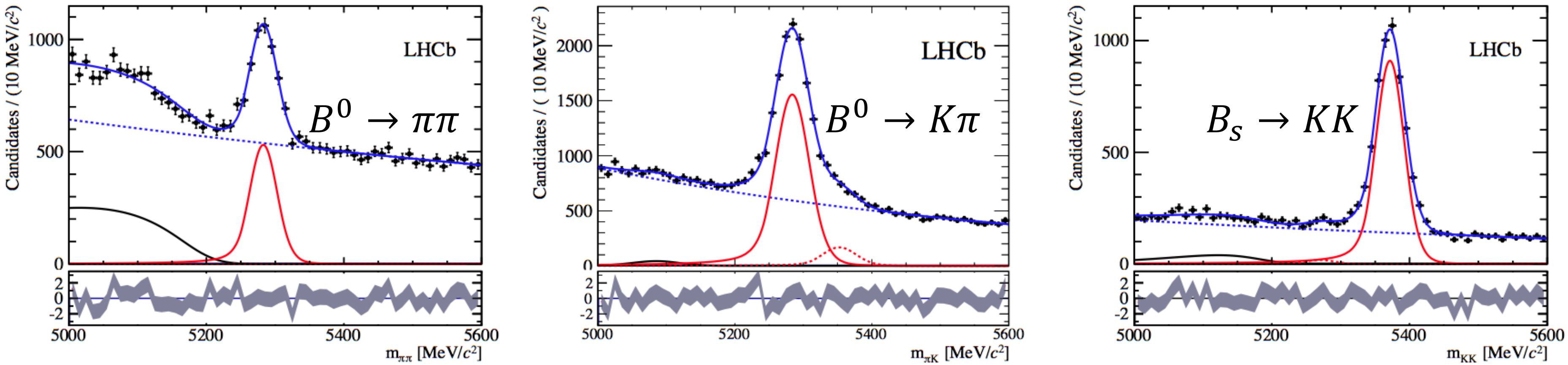
- Flat for signal by design
- Sig line shape calibrated on data using an unbiased $B \to hh'$ sample (same topology as sig)
- Combinatorial Bkg derived from data by interpolating from the mass side-bands





Sig Mass PDF - Mean

- Signal Crystal Ball Shape
- Mean taken form $B^0 \to \pi\pi, K\pi$ and $B_s \to KK$



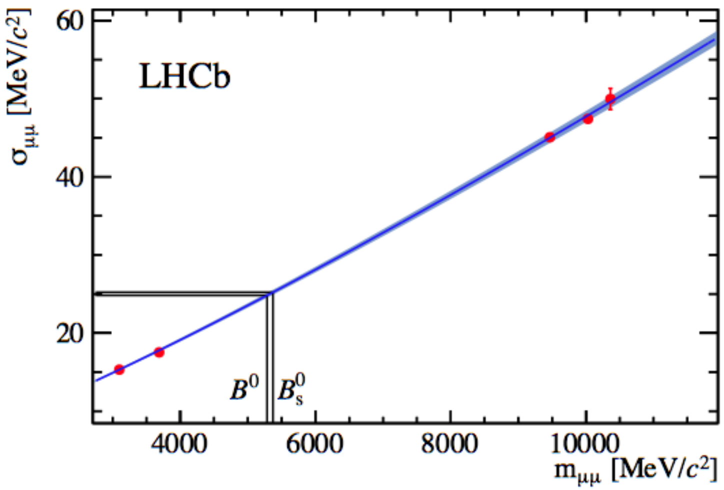
m_{B^0}	$(5284.36 \pm 0.26_{\text{stat}} \pm 0.13_{\text{syst}})$ MeV$/c^2$
$m_{B^0_s}$	$(5371.55 \pm 0.41_{\text{stat}} \pm 0.16_{\text{syst}})$ MeV$/c^2$

- The two modes are resolved: $m_{B_s} - m_{B_d} \sim 87\ MeV \sim 3.5\sigma_{B^0}$

Sig Mass PDF - Resolution

- $m_{\mu\mu}$ resolution depends on the invariant mass central value:

Interpolate the resolution of the resonances:
J/ψ , $\psi(2S)$, $\Upsilon(1S, 2S, 3S)$



- Averaging with the resolution obtained form the $B \to hh'$ fits:

$$\sigma_{B^0} = (24.63 \pm 0.13_{\rm stat} \pm 0.36_{\rm syst})\ {\rm MeV}/c^2$$
$$\sigma_{B^0_s} = (25.04 \pm 0.18_{\rm stat} \pm 0.36_{\rm syst})\ {\rm MeV}/c^2$$

Normalisation

- Number of signal events corresponding to a B :

$$N_{B^0_{(s)}\to\mu^+\mu^-} \propto B(B^0_{(s)} \to \mu^+\mu^-) \times N_{B_s}$$

- N_{B_s} cannot be obtained directly and precisely at hadron collider
- Need to normalise to a channel of known Br:

$$N_{B_s} \propto \frac{N_{B^+\to J/\psi K^+}}{B(B^+ \to J/\psi K^+)} \times \frac{f_s}{f_d} \qquad N_{B_s} \propto \frac{N_{B^0\to K\pi}}{B(B^0 \to K\pi)} \times \frac{f_s}{f_d}$$

- Correcting for efficiencies: $\boldsymbol{N_{B^0_{(s)}\to\mu^+\mu^-}} =$

$$\boldsymbol{B(B^0_{(s)} \to \mu^+\mu^-) \times \frac{N_{norm}}{B_{norm}} \frac{\epsilon^{REC}_{sig}\epsilon^{SEL,REC}_{sig}}{\epsilon^{REC}_{norm}\epsilon^{SEL,REC}_{norm}} \frac{\epsilon^{TRIG,SEL}_{sig}}{\epsilon^{TRIG,SEL}_{norm}} \frac{f_{B^0_{(s)}}}{f_{norm}} = \frac{B(B^0_{(s)} \to \mu^+\mu^-)}{\alpha_{norm}}}$$

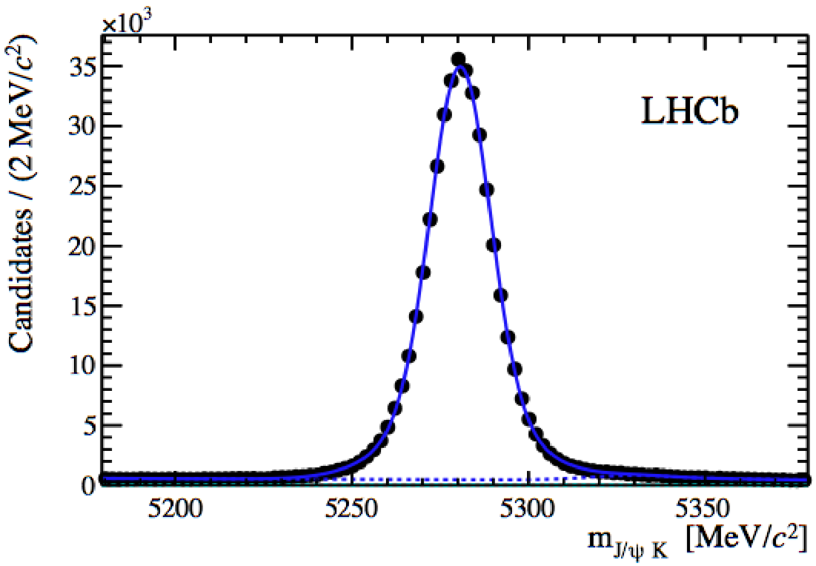
Extracted from Data

Evaluated from MC, x-checked with data

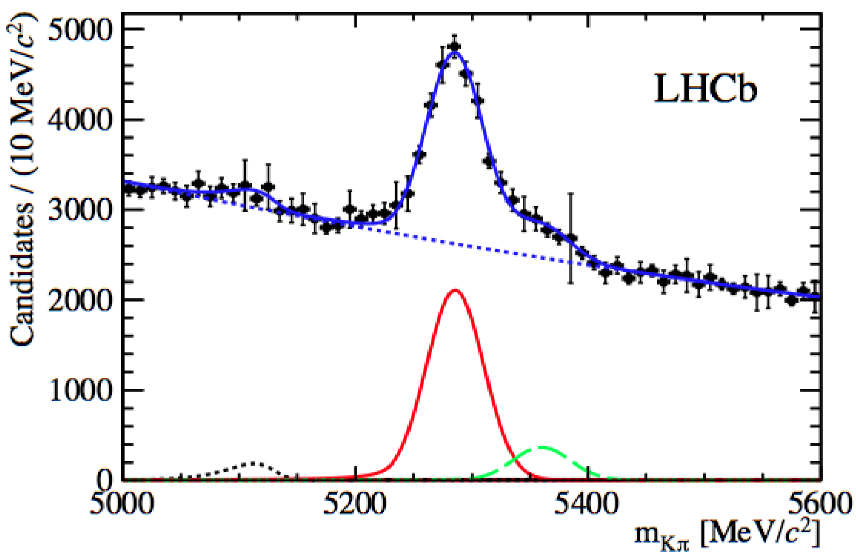
Measured on data

Ratio of prob for a b quark to hadronise into a $\boldsymbol{B^0_{(s)}}$ or into the norm. init. state

$B^+ \to J/\psi K^+$



$B^0 \to K\pi$



- Use f_s/f_d measured at LHCb PRD85 (2012) 032008 and LHCb-PAPER-2012-037
- Weighted average of the 2 channels:

$$\alpha_{B_s^0\to\mu^+\mu^-} = (2.80 \pm 0.25) \times 10^{-10}$$
$$\alpha_{B^0\to\mu^+\mu^-} = (7.16 \pm 0.34) \times 10^{-11}$$

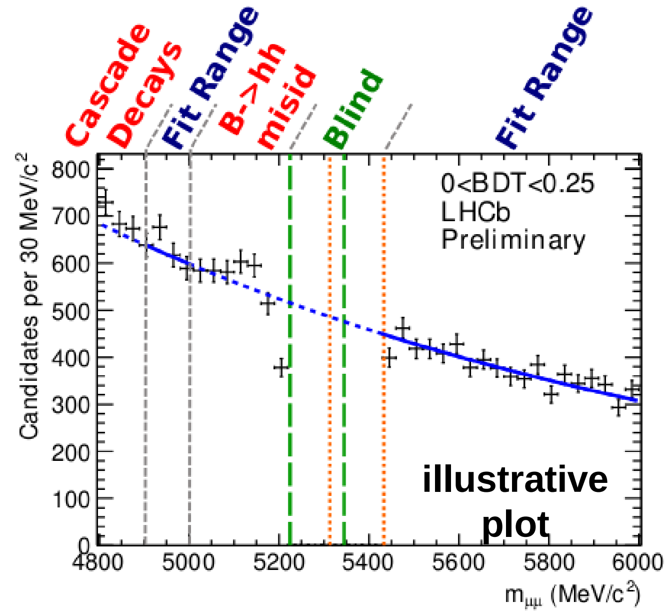
SM expectations 2012+2011 in the mass windows:
13 + 11 $B_s^0 \to \mu^+\mu^-$ and 1.5 + 1.3 $B^0 \to \mu^+\mu^-$

Combinatorial Background

- **2011 strategy**

Exponential interpolation from the mass side-bands:

$[4900 - 5000] \cup [5432 - 6000]\ \mathrm{MeV}/c^2$



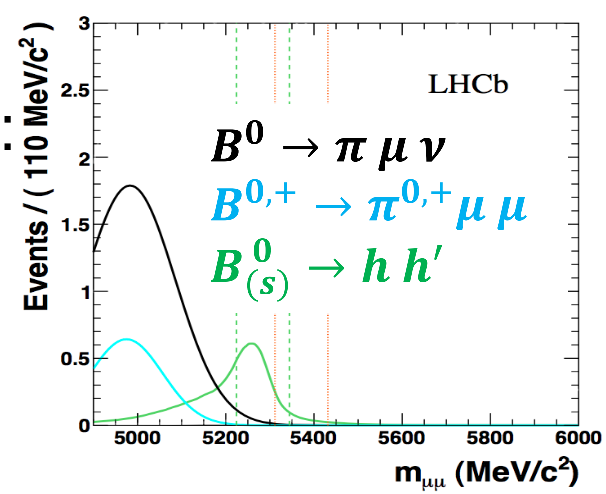
- **2012 refinement**

Study additional background sources:

$B^0 \to \pi\,\mu\,\nu$ and $B^{0,+} \to \pi^{0,+}\mu\,\mu$

➢Yields for $[4900 - 6000]\mathrm{MeV}/c^2$, BDT>0.8:

$B^0 \to \pi\,\mu\,\nu$	4.04 ± 0.28
$B^{0,+} \to \pi^{0,+}\mu\,\mu$	1.32 ± 0.39
$B^0_{(s)} \to h\,h'$	1.37 ± 0.11



Combinatorial Background Interpolation

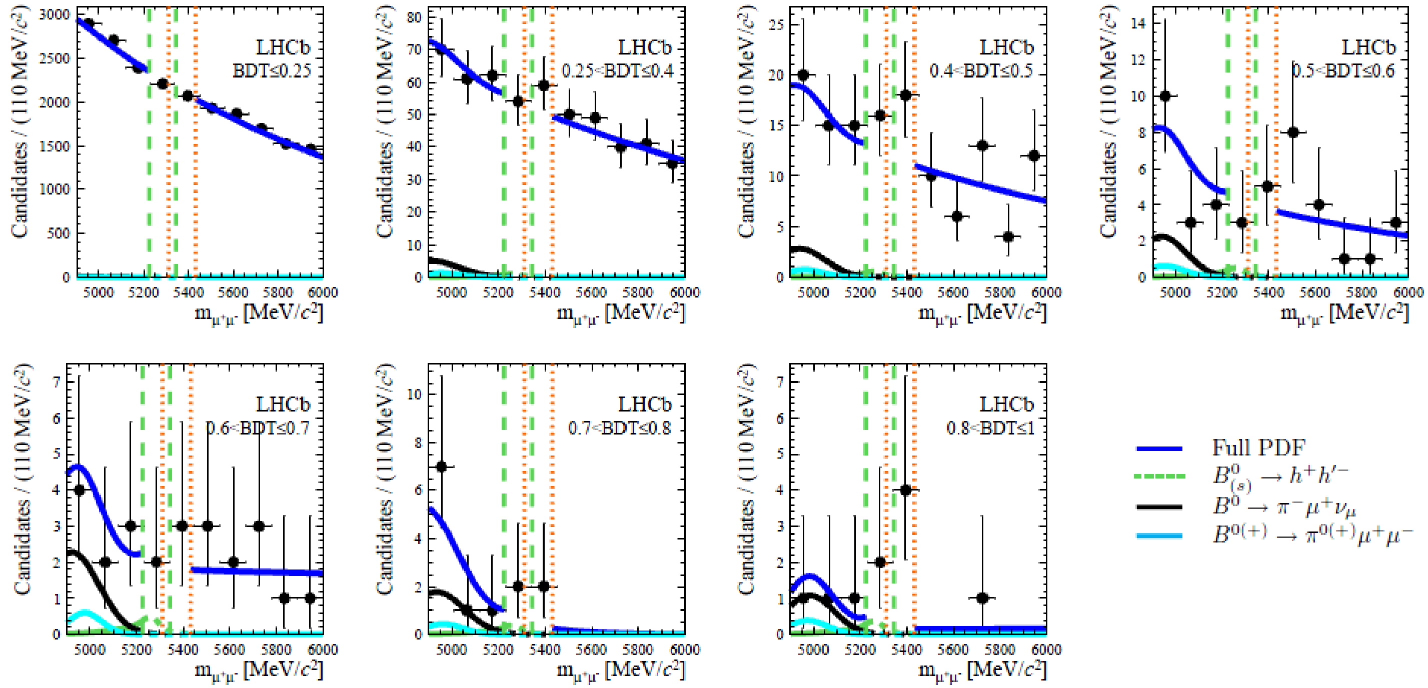
- Fit the mass side-bands with an exponential and separate PDFs for $B^0_{(s)} \to h\,h'$, $B^0 \to \pi\,\mu\,\nu$ and $B^{0,+} \to \pi^{0,+}\mu\,\mu$

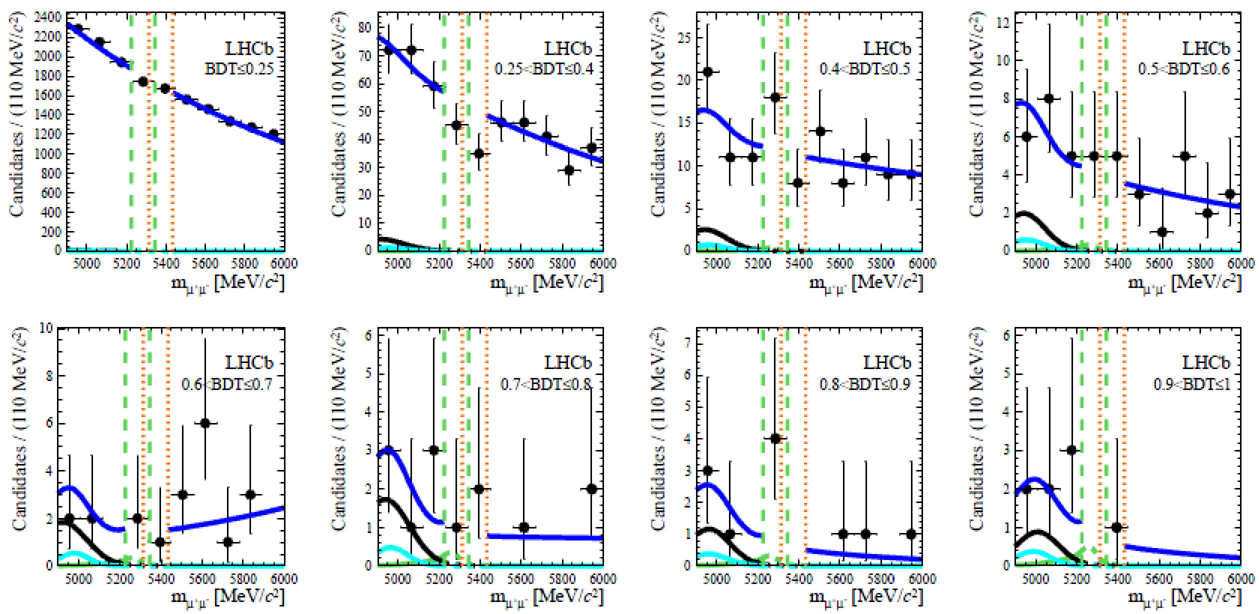
- PDF determination of Exclusive Bkg:
  - Derive misId probability $\pi, K \to \mu$ on data in p and p_T bins
  - Apply these propabilities to large MC samples
  - Mass and BDT PDF extracted from the weighted MC sample
  - Normalisation to $B^+ \to J/\psi K^+$

- Other backgrounds studied; all negligible:

$$B^0_s \to K\,\mu\,\nu, \qquad \Lambda_b \to p\,\mu\,\nu, \qquad B_c \to J\psi(\mu\mu)\,\mu\,\nu$$

2012


LHCb
BDT≤0.25
0.25<BDT≤0.4
0.4<BDT≤0.5
0.5<BDT≤0.6
0.6<BDT≤0.7
0.7<BDT≤0.8
0.8<BDT≤1
Candidates / (110 MeV/c^2)
$m_{\mu^+\mu^-}$ [MeV/c^2]
Full PDF
$B^0_{(s)} \to h^+h'^-$
$B^0 \to \pi^-\mu^+\nu_\mu$
$B^{0(+)} \to \pi^{0(+)}\mu^+\mu^-$

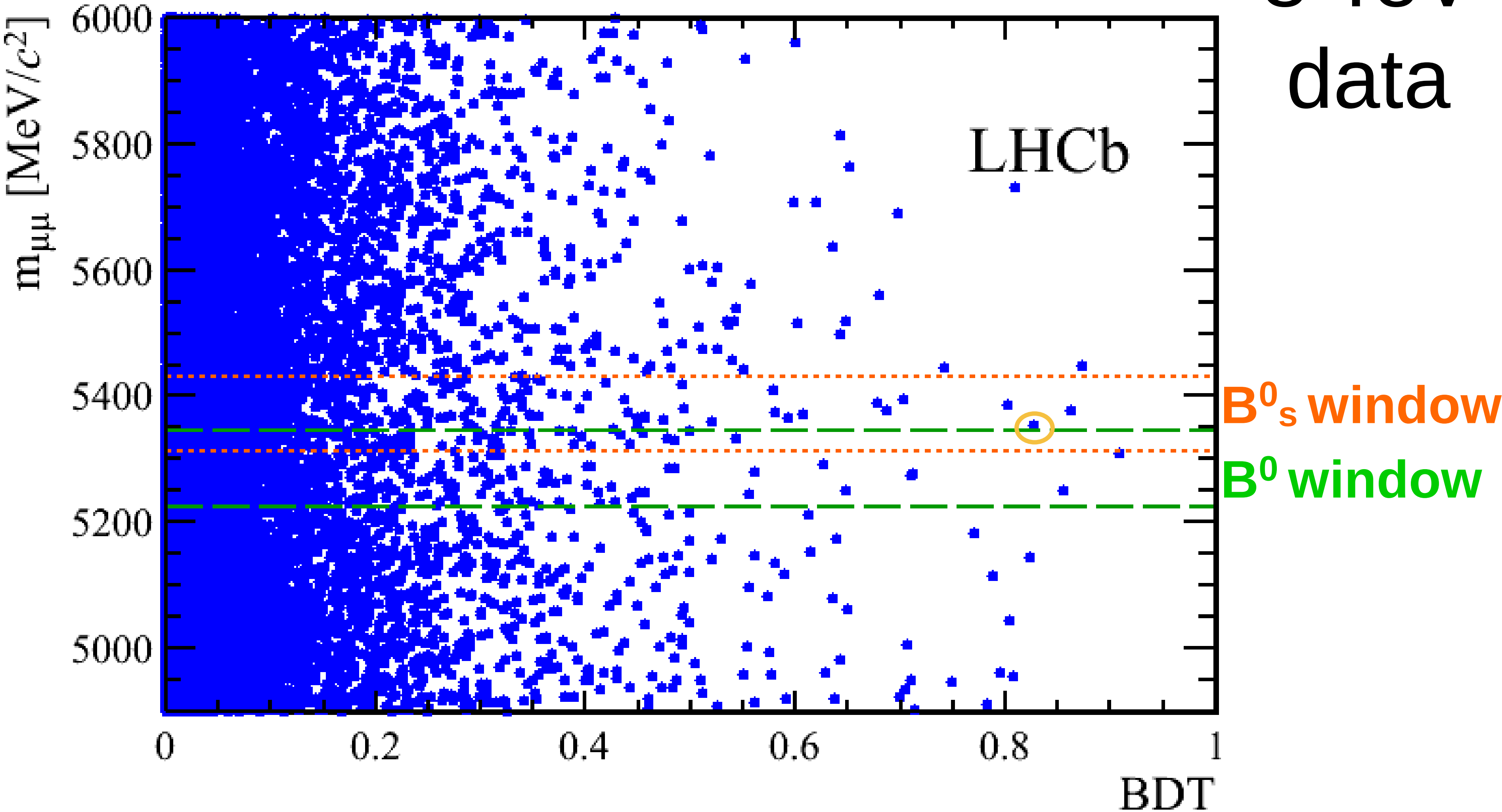

LHCb
BDT≤0.25
0.25<BDT≤0.4
0.4<BDT≤0.5
0.5<BDT≤0.6
0.6<BDT≤0.7
0.7<BDT≤0.8
0.8<BDT≤0.9
0.9<BDT≤1
Candidates / (110 MeV/c^2)
$m_{\mu^+\mu^-}$ [MeV/c^2]

2011

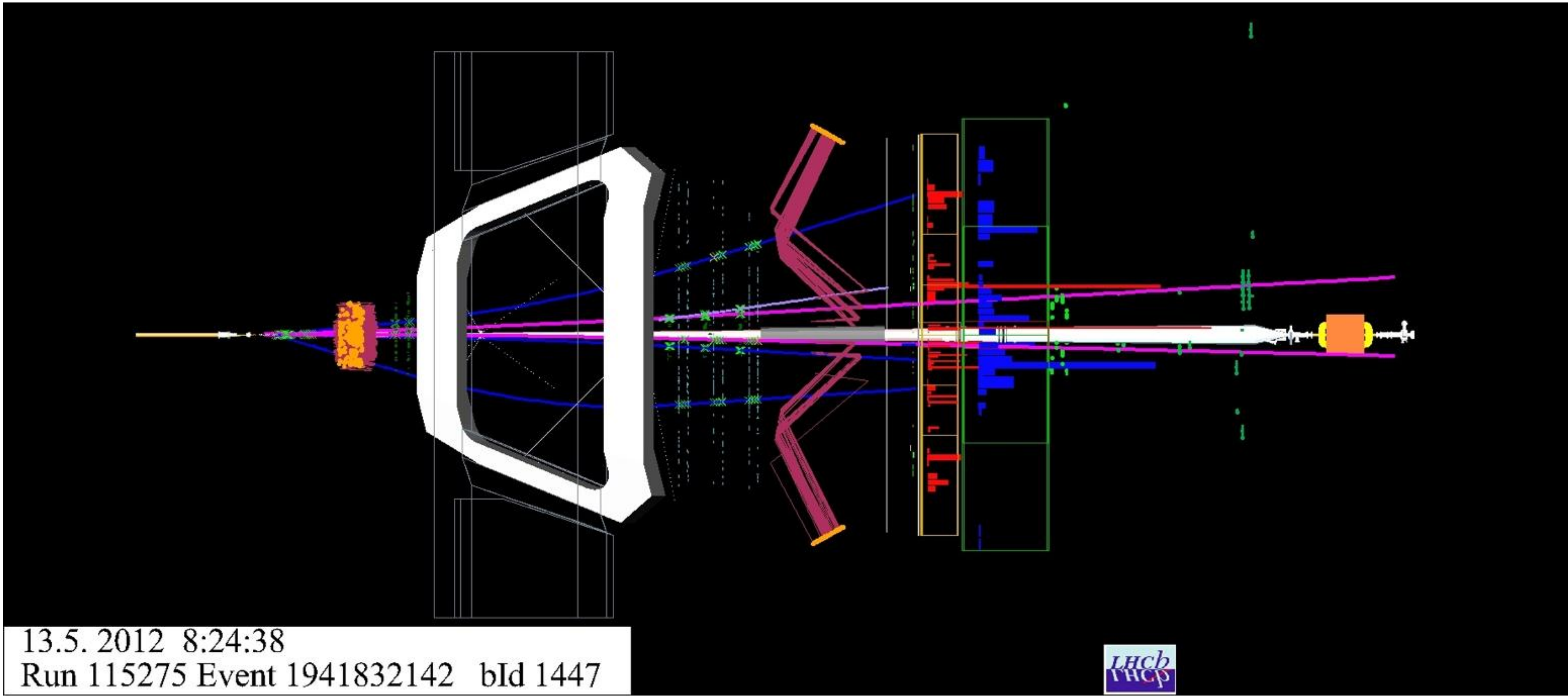
Results

Mass-BDT plane

2012
8 TeV
data



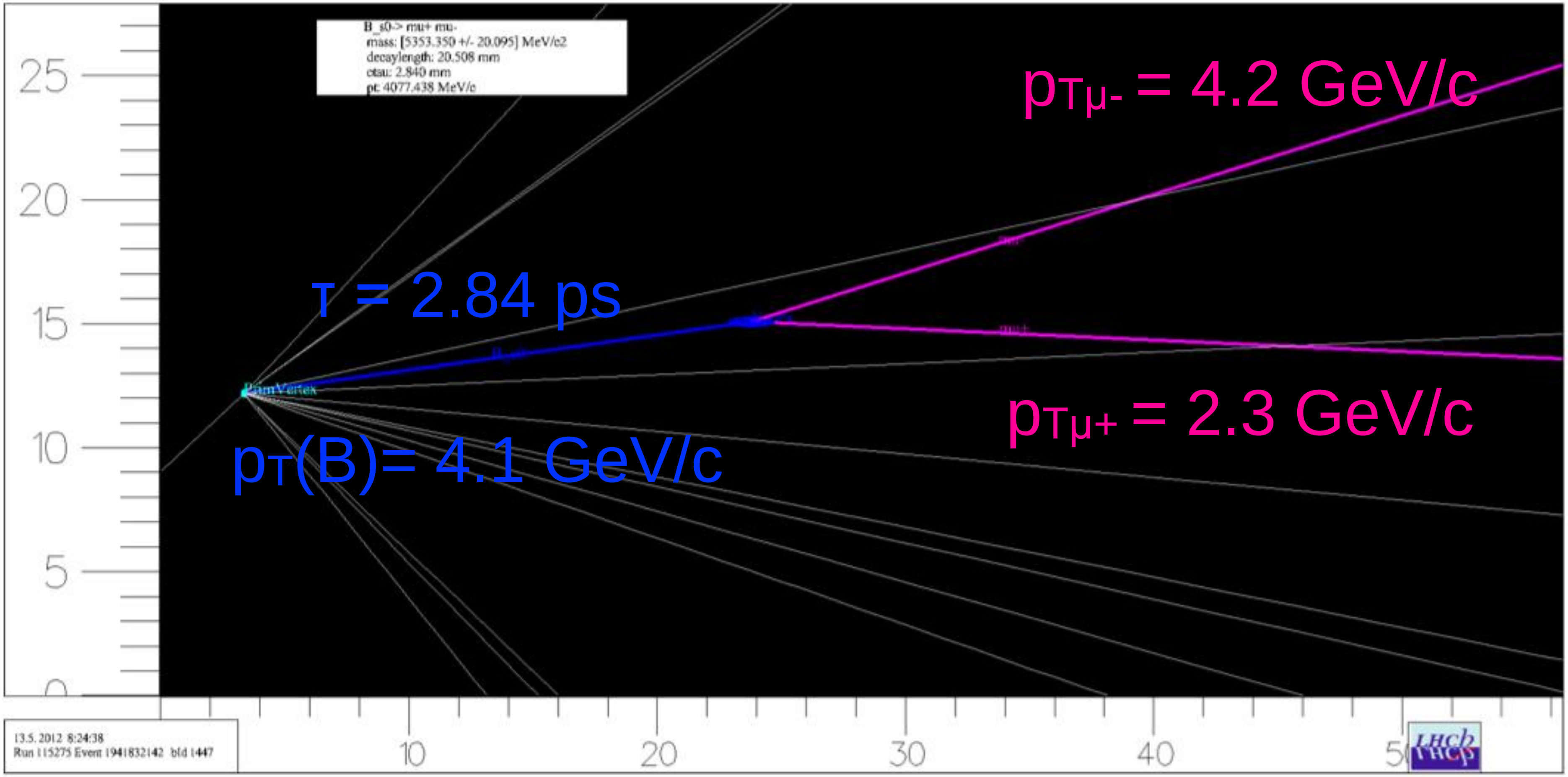
$B_s^0 \rightarrow \mu^+\mu^-$ Candidate



B candidate: $m_{\mu\mu}$ = 5353.4 MeV/c^2 BDT = 0.826

p_T = 4077.4 MeV/c τ = 2.84 ps

muons: $p_{T\mu^+}$ = 2329.5 MeV/c $p_{T\mu^-}$ = 4179.4 MeV/c


B_s0-> mu+ mu-
mass: [5353.350 +/- 20.095] MeV/c2
decaylength: 20.508 mm
ctau: 2.840 mm
pt: 4077.438 MeV/c
$p_{T\mu-}$ = 4.2 GeV/c
τ = 2.84 ps
PrimVertex
$p_T(B)$= 4.1 GeV/c
$p_{T\mu+}$ = 2.3 GeV/c
25
20
15
10
5
0
10
20
30
40
50
13.5. 2012 8:24:38
Run 115275 Event 1941832142 bld 1447
LHCb

CLs method

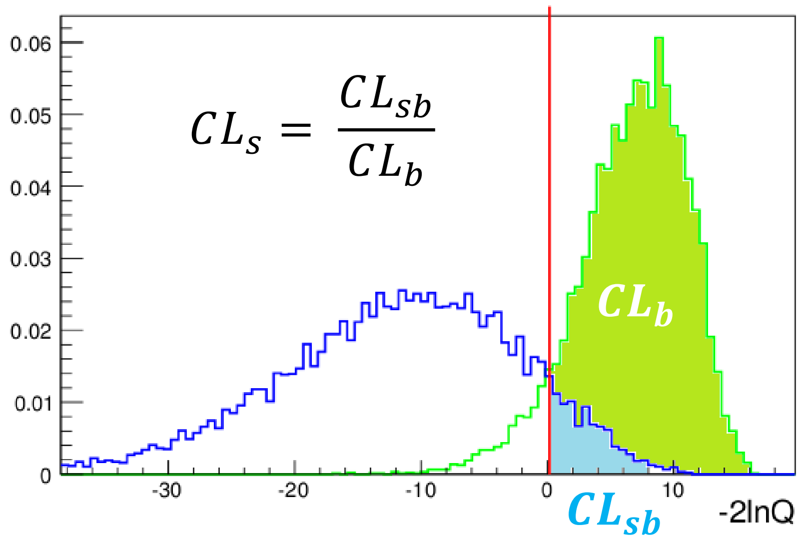
- Idea: compare observed data with expectations
- Define a test statistic for this comparison:

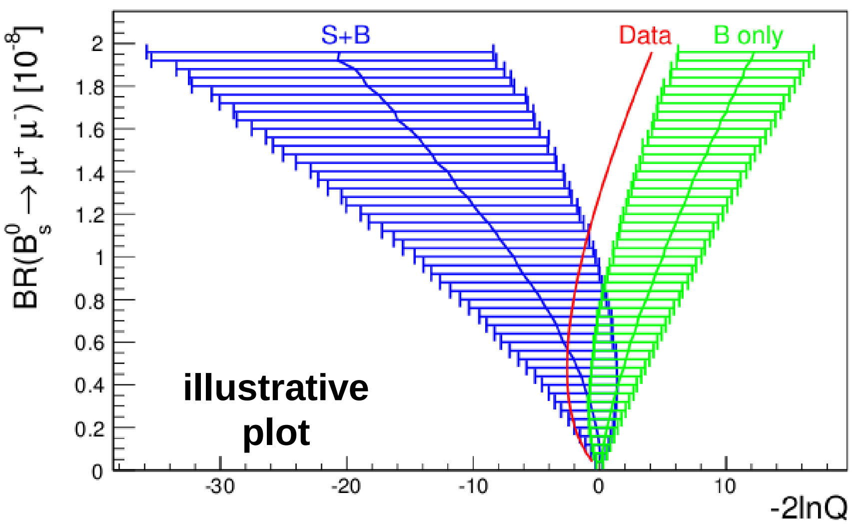
Signal $-2lnQ$ Background

- Calibrate this test statistic with pseudo-experiment

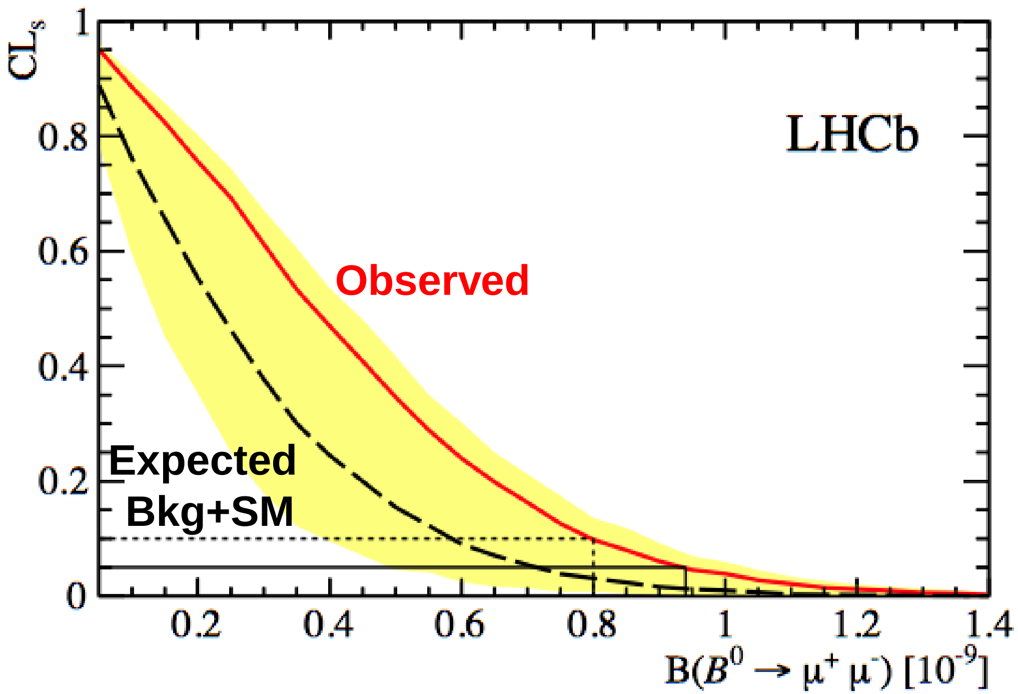
if Br was such then $\begin{matrix} \boldsymbol{Bkg\ Only} \\ \boldsymbol{Sig+Bkg} \end{matrix}$ *would give* $-2\ln Q$ *of* $\begin{matrix} \boldsymbol{such} \\ \boldsymbol{such} \end{matrix}$

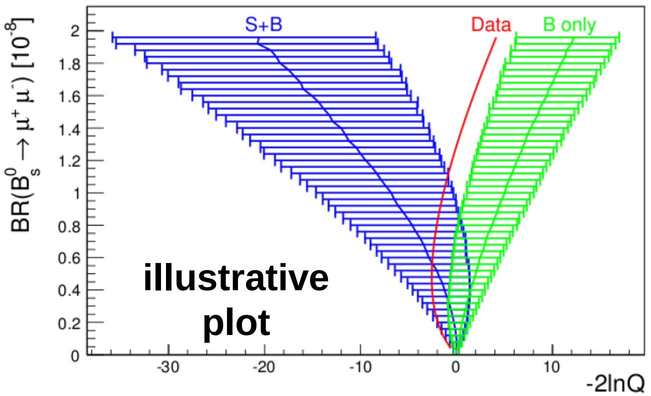
- Compute the $-2lnQ$ of the observed data





$B^0 \to \mu^+\mu^-$ upper limits 2011-2012





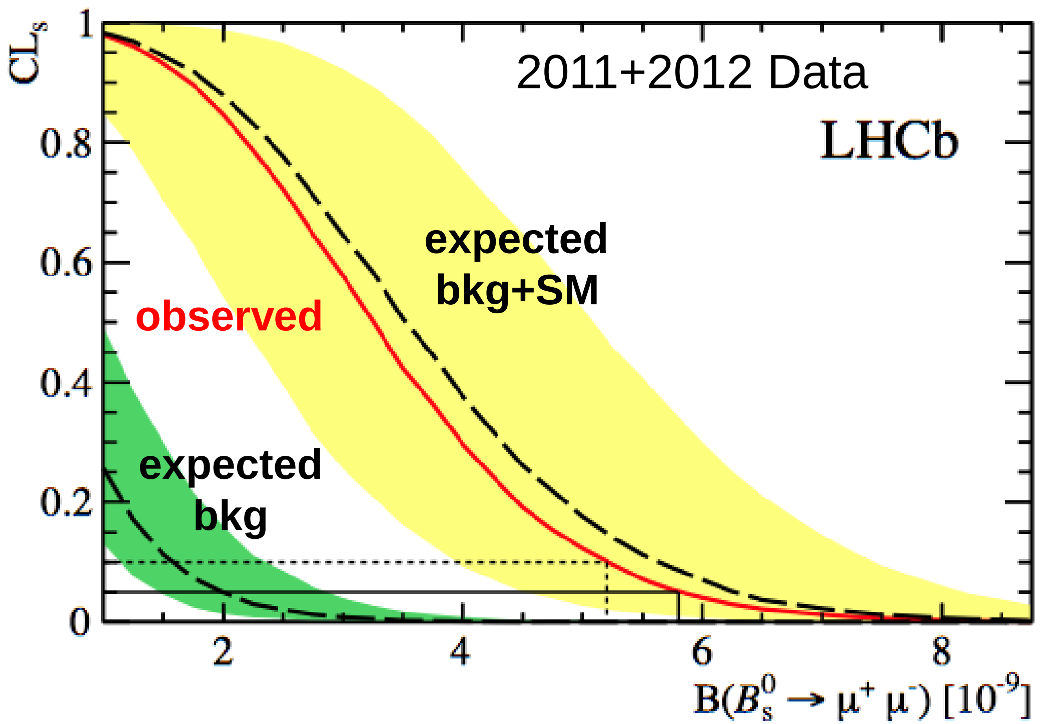
Compatibility with bkg only hypothesis:
p-value = $1\text{-}CL_b$ = 11%

Obs. limit: $B(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$ at 95% CL

Exp. limit: $B(B^0 \to \mu^+\mu^-) < 7.1 \times 10^{-10}$ at 95% CL

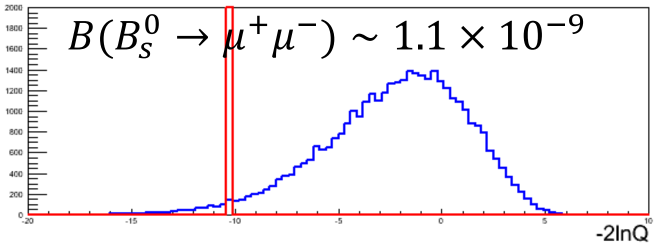
$B_s^0 \to \mu^+\mu^-$ sensitivity 2011-2012

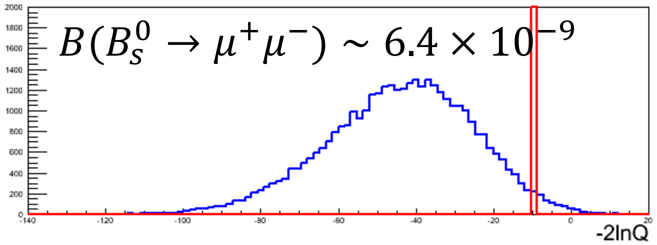
Good separation between the 2 expectations



Bkg only p-value:
5.3×10^{-4}
3.5 σ excess

FIRST EVIDENCE





Double-sided limit at 95% CL :

$$1.1 \times 10^{-9} < B(B_s^0 \to \mu^+\mu^-) < 6.4 \times 10^{-9}$$

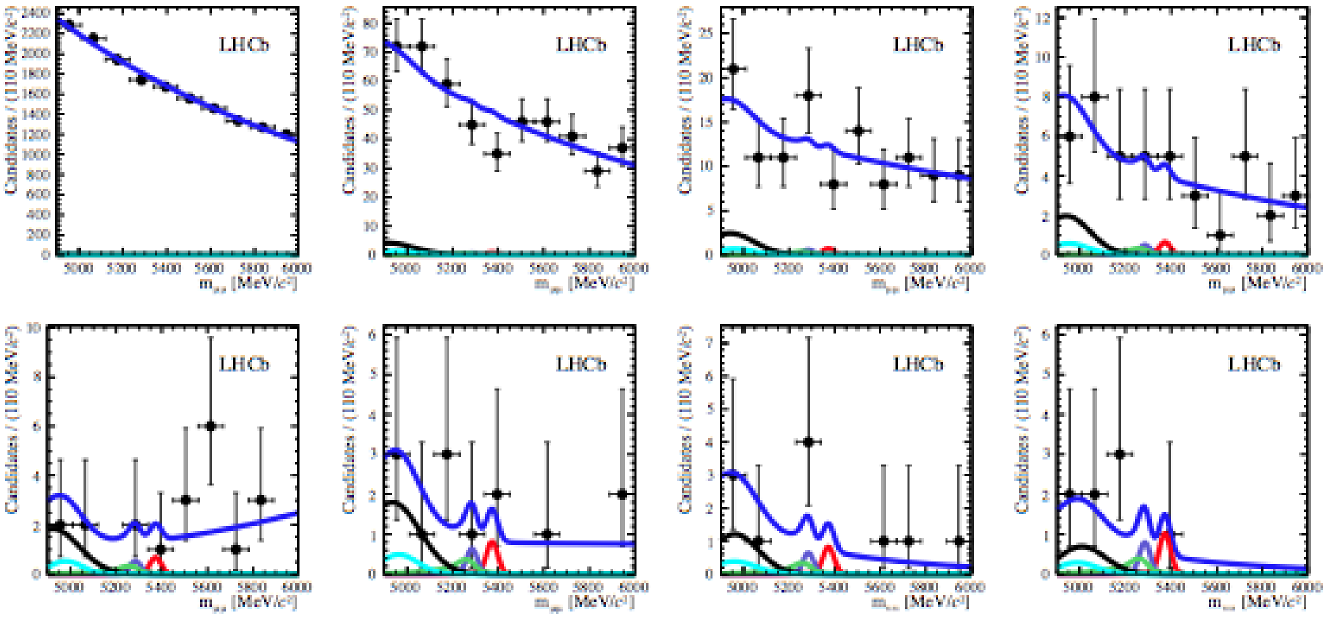
where the lower and upper limits are evaluated at:
$CL_{s+b} = 0.975$ and $CL_{s+b} = 0.025$

Branching Ratio Fit

- Unbinned maximum likelihood fit of the $m_{\mu\mu}$ distribution in the 2012 and 2011 BDT bins.
- $B(B_s^0 \to \mu^+\mu^-)$ and $\mathrm{B}(B^0 \to \mu^+\mu^-)$ are free and fit simultaneously
- Combinatorial bkg is free
- All other parameters (e.g. m_{B_s}, σ_{B_s}, exclusive bkg…) are gaussian constrained to their expectations

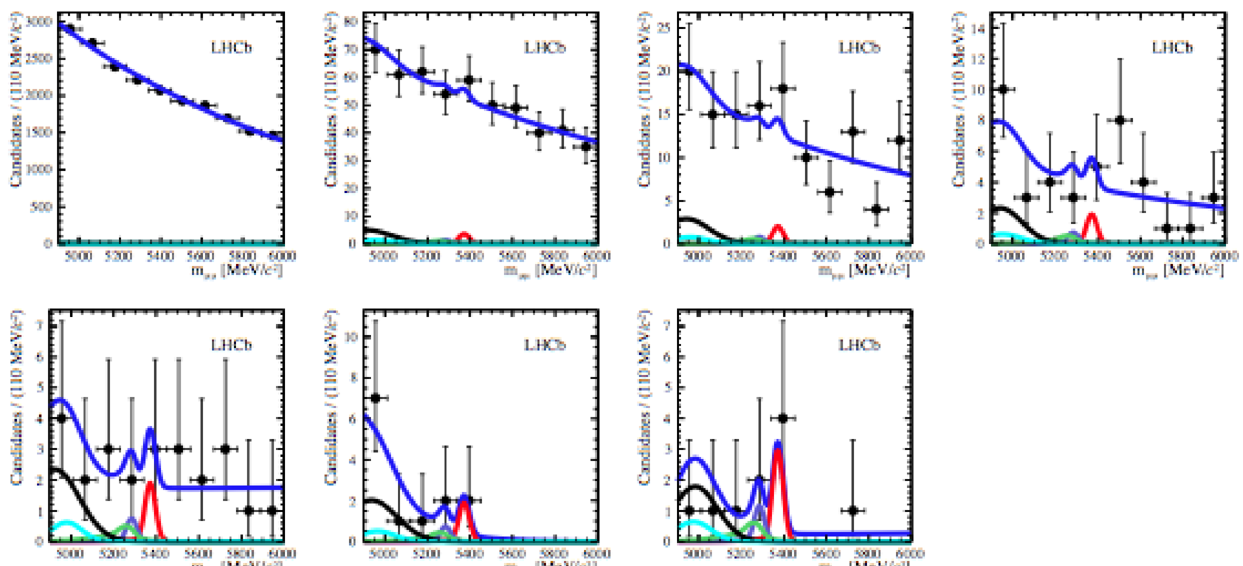
- An additional systematics is added to account for the hypotheses made on the combinatorial bkg shape (exponential vs double-exponential)

Fit projections



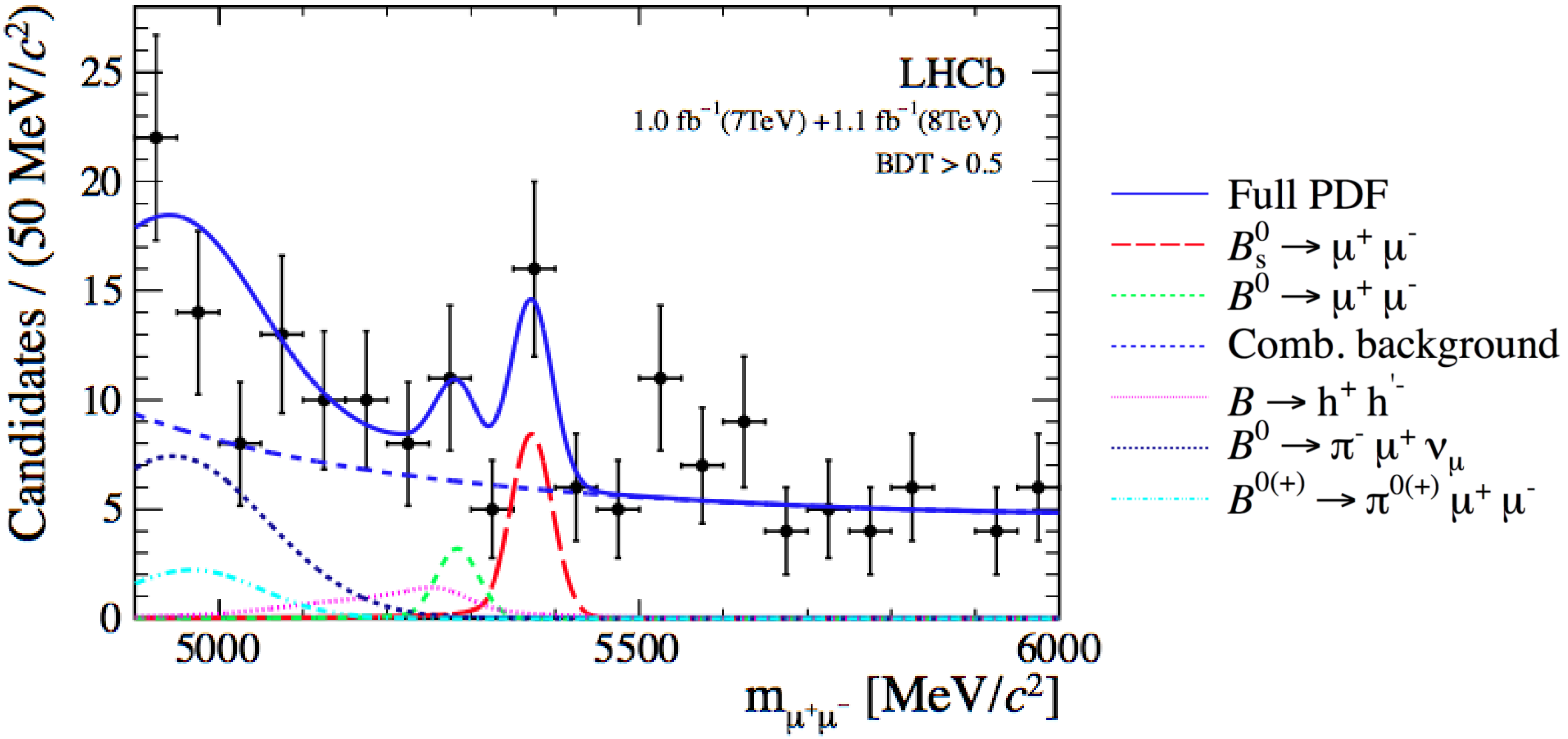
2011
7 TeV data, 1.0 fb^{-1}
8 BDT bins

$B^0_s \to \mu^+\mu^-$
$B^0 \to \mu^+\mu^-$
$B^0_{(s)} \to h^+h'^-$
$B^0 \to \pi^-\mu^+\nu_\mu$
$B^{\pm,0} \to \pi^{\pm,0}\mu^+\mu^-$
total

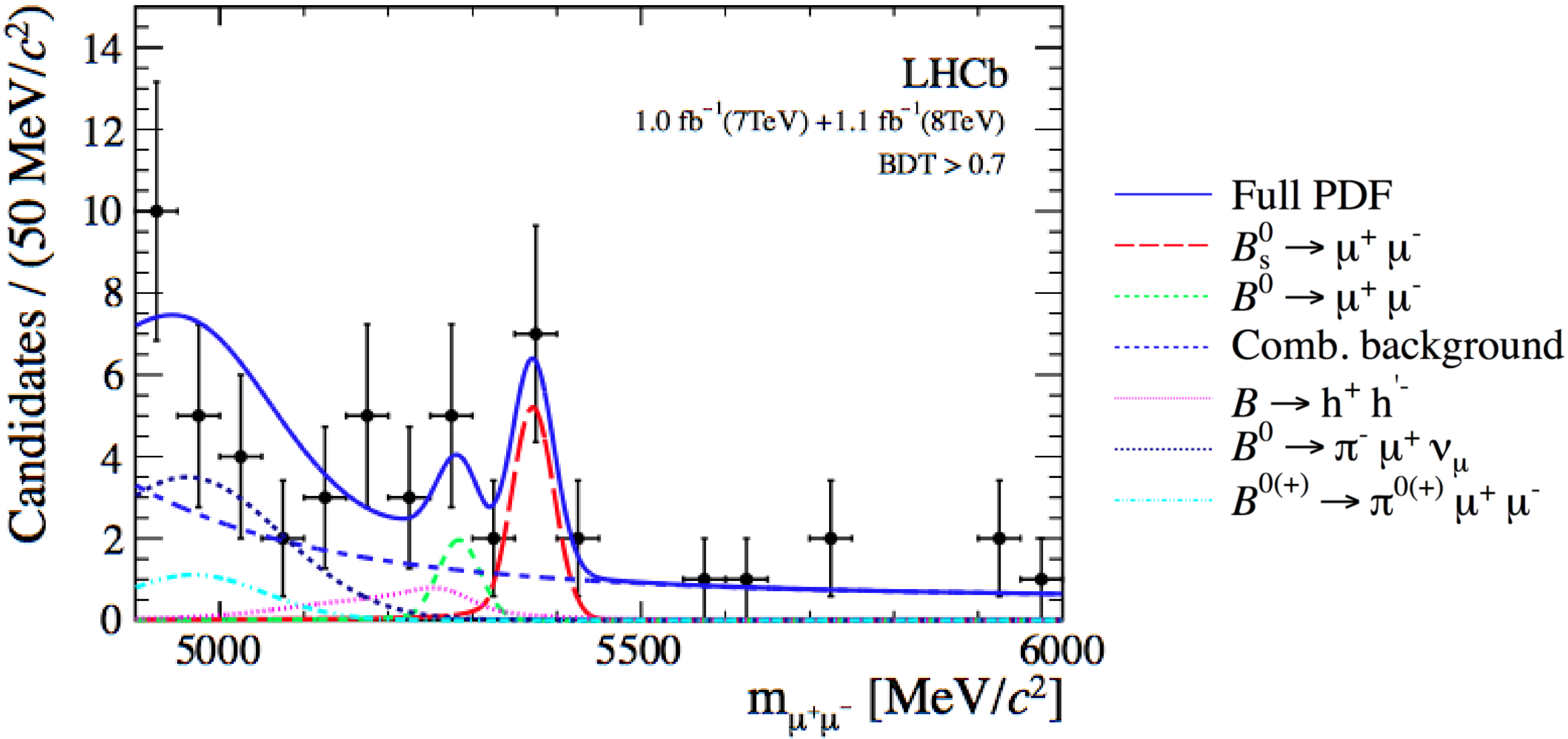


2012
8 TeV data, 1.1 fb^{-1}
7 BDT bins

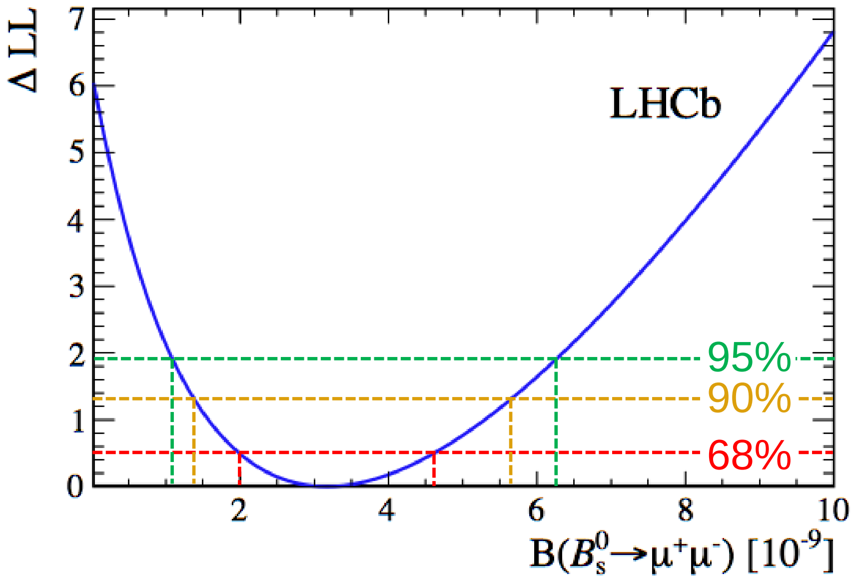
In the Signal Region BDT>0.5



In the Signal Region BDT>0.7



Fit Results 2011+2012



Profile Likelihood:

All parameters except $B(B_s^0 \to \mu^+\mu^-)$ are floated within their errors.

$$\boldsymbol{B(B_s^0 \to \mu^+\mu^-) = \left(3.2^{+1.5}_{-1.2}\right) \times 10^{-9}}$$

Value in agreement with SM prediction:

$$B(B_s^0 \to \mu^+\mu^-)_{SM} = (3.54 \pm 0.30) \times 10^{-9}$$

Nota: 95% interval in perfect agreement with the one provided by the $\mathrm{CL_s}$ method

Conclusions

- $B^0_{(s)} \to \mu^+\mu^-$ are very powerful tests of the SM

Harvest of the LHCb analysis of the data collected in 2012 and 2011:

- Contrains on $B^0 \to \mu^+\mu^-$:

$$\boldsymbol{B(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}}$$

- First evidence of $B^0_s \to \mu^+\mu^-$:

p-value: $\boldsymbol{5.3 \times 10^{-4}}$

$\boldsymbol{3.5\sigma}$

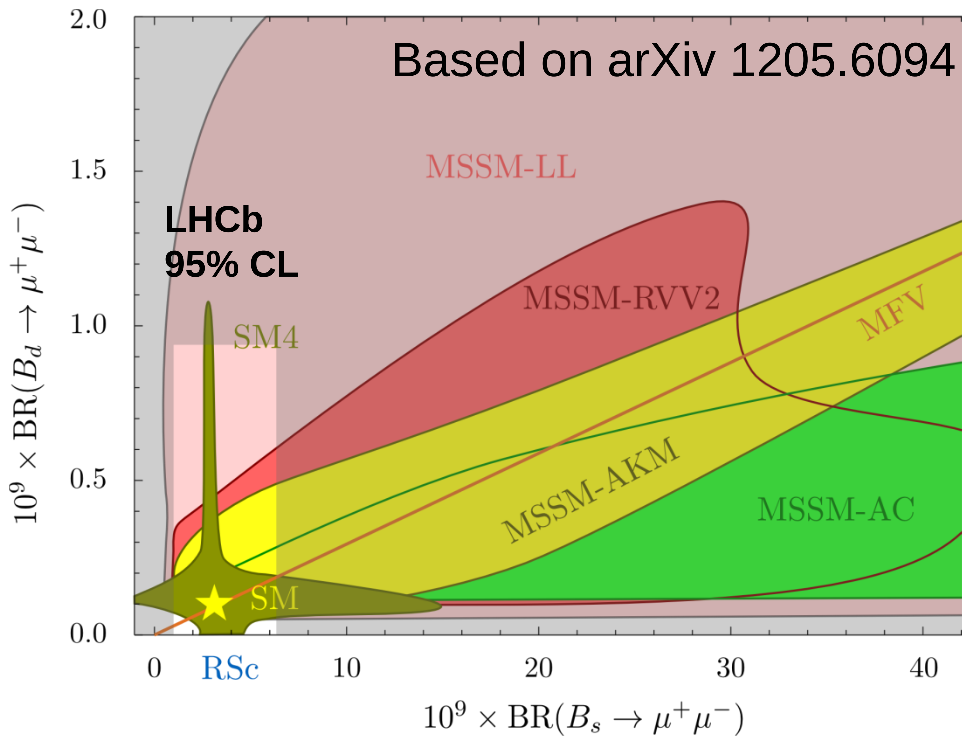
- BR measurement:

$$\boldsymbol{B\left(B^0_s \to \mu^+\mu^-\right) = 3.2^{+1.5}_{-1.2} \times 10^{-9}}$$

Paper submitted at PRL, arXiv: 1211.2674

Impact of the results

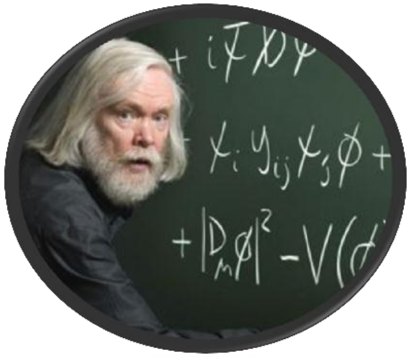
- Hard time for SuperSymmetry…



- But SUSY never dies **;-)**

The observation is "quite consistent with supersymmetry. In fact, it was actually expected in (some) supersymmetric models. I certainly won't lose any sleep over the result."

J. Ellis interviewed by BBC



BBC NEWS SCIENCE

Spares

Fit Statistical Error

Fix all the nuisance parameters to their expectations, subtract the error in quadrature with the errors obtained when all parameters are floating:

$$\boldsymbol{B}\left(\boldsymbol{B}_s^0 \to \boldsymbol{\mu}^+\boldsymbol{\mu}^-\right) = \mathbf{3.2}^{+1.4}_{-1.2}(\mathbf{stat})^{+0.5}_{-0.3}(\mathbf{syst}) \times \mathbf{10}^{-9}$$

fully dominated by stat error

Comparison 2012-2011

- 2011, 7 TeV (1 fb^{-1})

$$B(B_s^0 \rightarrow \mu^+\mu^-) = 1.4^{+1.7}_{-1.3} \times 10^{-9}$$

p-value 0.11

- 2012, 8 TeV (1.1 fb^{-1}):

$$B(B_s^0 \rightarrow \mu^+\mu^-) = 5.1^{+2.4}_{-1.9} \times 10^{-9}$$

p-value 9×10^{-4}

results from 7 TeV and 8 TeV are compatible at ~1.5σ

Exclusive Background Effect on 2011

New Analysis:

- $B_s^0 \to \mu^+\mu^-$
  - bkg only p-value: 0.11
  - UL = 5.1×10^{-9}, 95% CL
- $B^0 \to \mu^+\mu^-$
  - bkg only p-value: 0.19
  - UL = 13×10^{-10} , 95% CL

Published Analysis

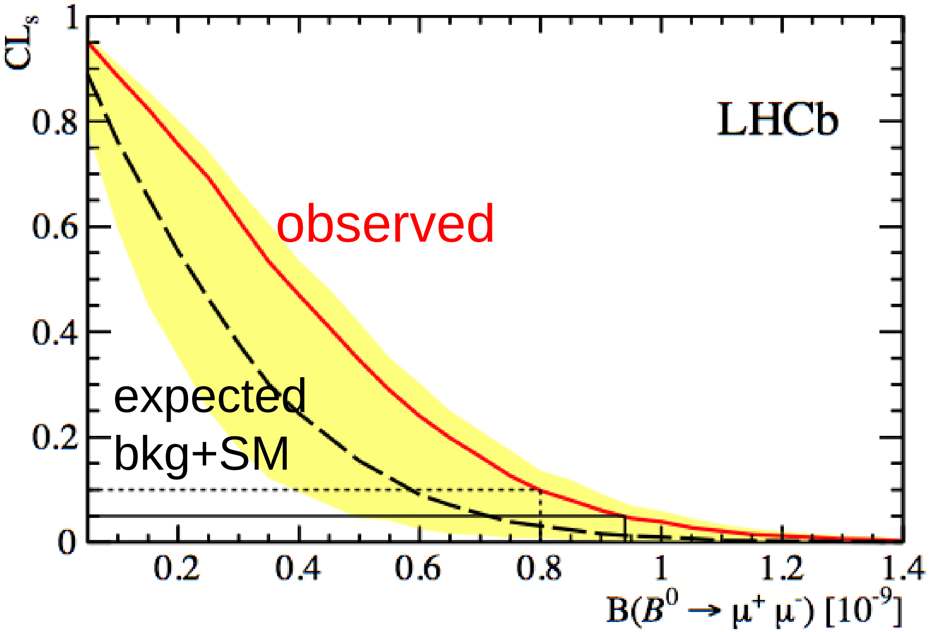
- $B_s^0 \to \mu^+\mu^-$
  - bkg only p-value: 0.18
  - UL = 4.5×10^{-9}, 95% CL
- $B^0 \to \mu^+\mu^-$
  - bkg only p-value: 0.60
  - UL = 10.3×10^{-10}, 95% CL

$B^0 \to \mu^+\mu^-$: limits and sensitivity

7 TeV (1 fb^{-1})+ 8 TeV (1.1 fb^{-1}):

$$B(B^0 \to \mu^+\mu^-) < 9.4 \times 10^{-10}$$

bkg only p-value (1-CL_b): 0.11
(corresponds to ~1.5σ excess)



UL are quoted at 95%CL

	Expected UL (SM+bkg)	Observed UL	Observed 1-CLb
7 TeV	6.0 x 10^{-10}	13.0 x 10^{-10} *	0,19 *
8 TeV	10.5 x 10^{-10}	12.5 x 10^{-10}	0,16
7TeV + 8TeV	7.1 x 10^{-10}	9.4 x 10^{-10}	0,11

*published results:
UL = 10.3 x 10^{-10}
1-CLb = 0.60

Some projections

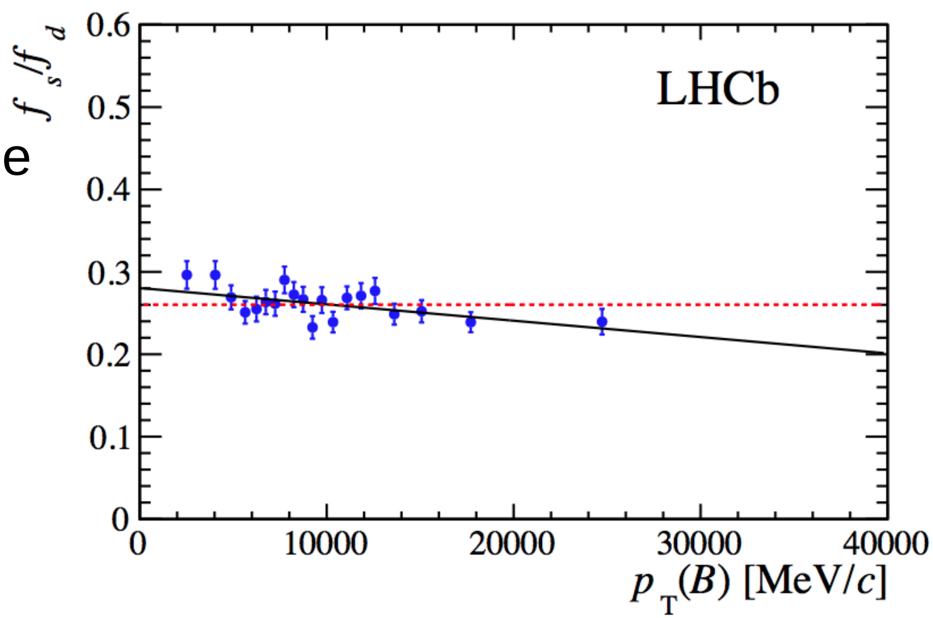
- From LHCB-TDR-012:

Obs.	End 2018	LHCb upgrade $50fb^{-1}$
$B(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	0.15×10^{-9}
$\frac{B(\mathrm{B_s^0} \to \mu^+\mu^-)}{B(\mathrm{B^0} \to \mu^+\mu^-)}$	100%	35%

Hadronisation Probablility f_s/f_d

- f_s/f_d is measured at LHCb by comparing abundances of:
  - $B_s^0 \to D_s^- \pi^+$, $B^0 \to D^- K^+$ and $B^0 \to D^- \pi^+$ arXiv:111.2357 aka PRD85 032008 (2012)
  - $B_s^0 \to D_s^- \mu^+ X$ and $B^0 \to D^- \mu^+ X$ LHCb-paper-2012-037 in preparation
- at 7 TeV: $f_s/f_d = 0.256 \pm 0.020$

- p_T dependency small enough to be negligible
- $\sqrt{s}$ dependency checked with $B^+ \to J/\psi K^+$ and $B_s^0 \to J/\psi \phi$: stable within 1σ



Exclusive Backgrounds : $B_s^0 \to K^+ \mu^- \bar{\nu}_\mu$ and $B^0 \to \pi^+ \mu^- \bar{\nu}_\mu$

- $B_s^0 \to K^+ \mu^- \bar{\nu}_\mu$ contribution is found negligible
- Accounted in the fit as a systematics
- Lower contribution from $B_s^0 \to K^+ \mu^- \bar{\nu}_\mu$ explained by:
  - $f_s/f_d = 0.26$
  - $B(B_s^0 \to K^+ \mu^- \bar{\nu}_\mu)/B(B^0 \to \pi^+ \mu^- \bar{\nu}_\mu) = 0.88$
  - $\epsilon_{K\to\mu}/\epsilon_{\pi\to\mu} = 0.28$ (RICH efficiency and $B(K^- \to \mu^- \bar{\nu}_\mu)/B(\pi^- \to \mu^- \bar{\nu}_\mu)$)

	2011	2012
$B^0 \to \pi^-\mu^+\nu_\mu$	3.51 ± 0.25	4.04 ± 0.28
$B^0_{(s)} \to h^+h'^-$ misID	0.91 ± 0.12	1.37 ± 0.11
$B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$	1.12 ± 0.35	1.32 ± 0.39
$\Lambda_b^0 \to p\mu^-\nu$	0.29 ± 0.17	0.50 ± 0.29
$B_s^0 \to K^-\mu^+\nu_\mu$	0.33 ± 0.13	0.46 ± 0.19
$B_c^+ \to J/\psi\mu^+\nu$	0.29 ± 0.33	0.34 ± 0.39

Yields for $[4900 - 6000]\mathrm{MeV}/c^2$, BDT>0.8

BDT Variables

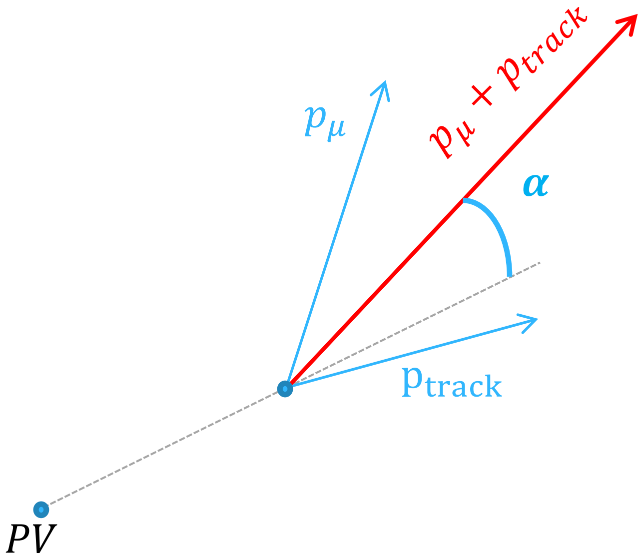
Muon isolation: number of other tracks with which the muon can make a good vertex

Other tracks requierement:

- Long track
- Impact Param Significance with PV > 3

Vertex requirement:

- Angle track-muon<0.27rad
- Distance of Closest Approach < 130 µm
- Distance to PV: 0.5cm<d<4cm
- Distance to SV: -0.15cm<d<30cm
- $\frac{|\vec{p_\mu}+\vec{p_{track}}| \sin\alpha}{|\vec{p_\mu}+\vec{p_{track}}| \sin\alpha + p_{T,\mu} + p_{T,track}} < 0.6$



BDT Variables

Polarisation Angle:

angle between the muon momentum in the B rest frame and the vector perpendicular to the B momentum and the beam axis

B Isolation:

$$I = \frac{p_{T,B}}{p_{T,B} + \sum_{tracks} p_{T,track}}$$

sum running on the tracks such that $\delta\eta^2 + \delta\phi^2 < 1.0$

MVA Selection Variables

- B Candidate
  - impact parameter*
  - impact parameter χ^2
  - χ^2 of the vertex
  - pointing angle
  - distance of closest approach*
- Muons
  - min IP

*common with BDT