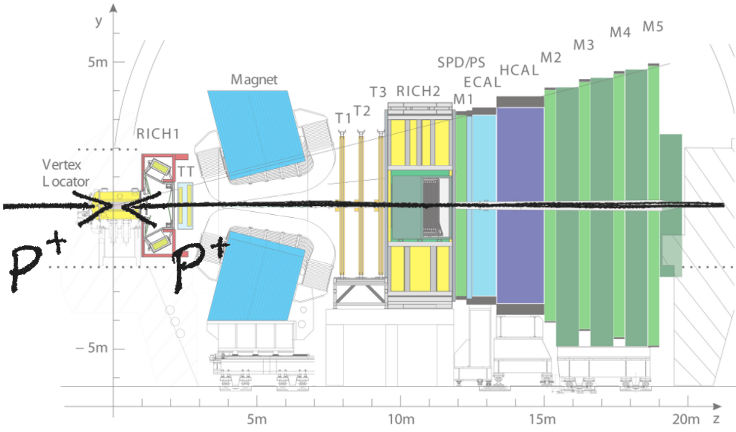
Search for $B^0_{(s)} \to \mu^+\mu^-$ at LHCb

$300\ \mathrm{pb}^{-1}$

Marc-Olivier Bettler, INFN Firenze
on behalf of the LHCb collaboration

LHCb

- ▷ Large $b\bar{b}$ cross section,
- ▷ Large acceptance for B decays,
- ▷ Very efficient muon trigger,
- ▷ Good particle ID, tracking and reconstruction.



LHCb published limits $\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-)$ on the 37 pb^{-1} of data from 2010

Phys. Lett. B699 330 (2011), [hep-ex/1103.2465]

We present here an update on 300 pb^{-1} collected in 3 months of 2011.

Assuming SM branching fractions and after selection, we expect in these data

3.2 $B^0_s \to \mu^+\mu^-$ events and 0.32 $B^0 \to \mu^+\mu^-$ events.

LHCb has 630 pb^{-1} on tape at the moment and expects to take $\sim 1\,\mathrm{fb}^{-1}$ this year.

Analysis Strategy

Selection

- ▷ **Muon** trigger
- ▷ **Soft selection**, similar to normalization channels
- ▷ **Blind** signal region $[M_{B^0} - 60\,\mathrm{MeV}/c^2, M_{B_s^0} + 60\,\mathrm{MeV}/c^2]$

Signal/background Discrimination

- ▷ **Boosted Decision Tree** combining topological and kinematic information
- ▷ **Invariant mass** of the muon pair

Data driven calibration through control channels to get signal and background expectations

Normalization to convert a number of observed events into a branching fraction using channels of known branching fractions

Observation/exclusion measurement confronting the experimental observation to signal and bacground expectations using the $\mathrm{CL_s}$ method in bins of mass and BDT. J. Phys. G28 (2002)

Boosted Decision Tree

Nine input variables such no correlation with mass:

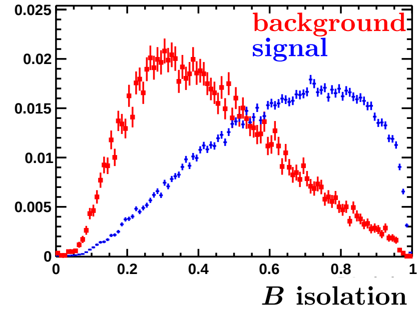
- B impact parameter, lifetime and p_{T}
- μ isolation, DOCA and minimal impact parameter

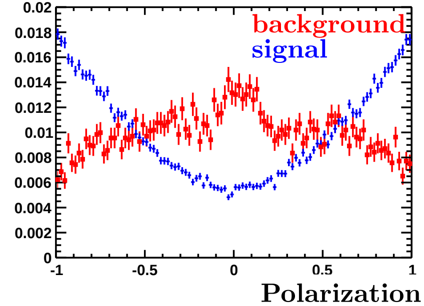
▶ B isolation

▶ Polarization variable

▶ minimum μ p_{T}

New variables

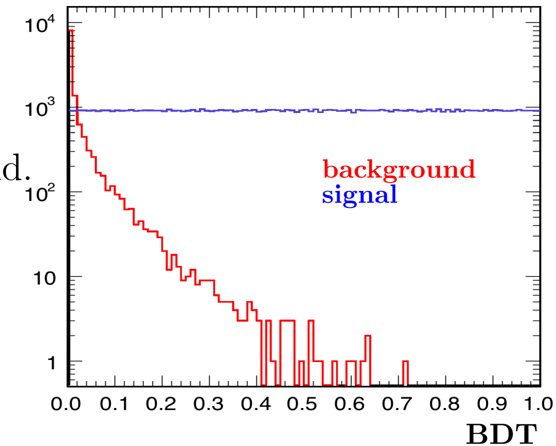




Trained on MC, with

▷ $B_s^0 \longrightarrow \mu^+\mu^-$ signal and

▷ $b\bar{b} \longrightarrow \mu\mu X$ background.



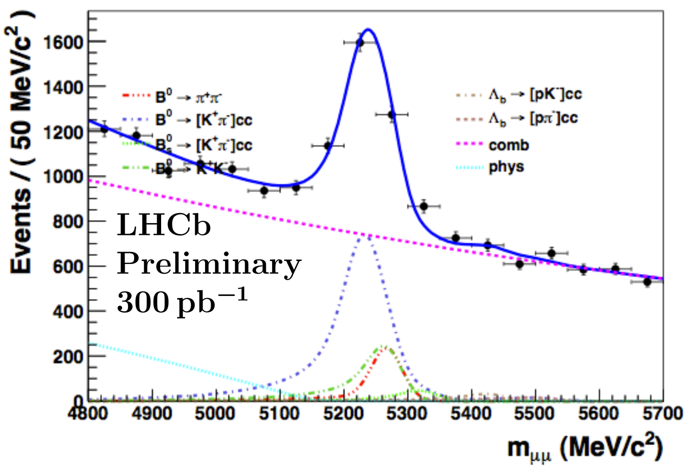
BDT Calibration

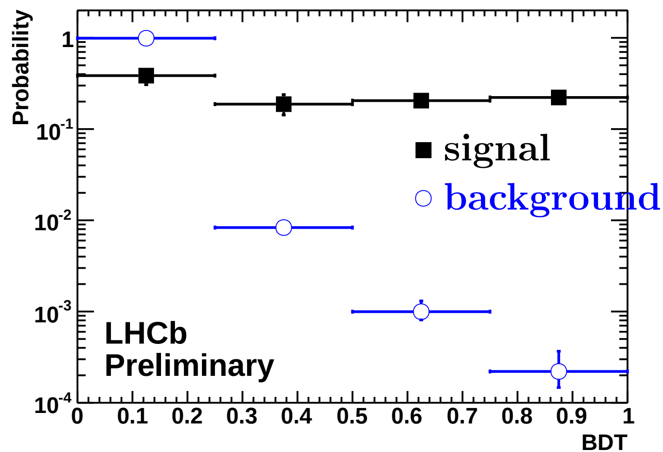
The BDT response is calibrated on data using:

▷ $\boldsymbol{B^0_{(s)} \to h^+h^-}$ events for the signal

- same topology as $B^0_s \to \mu^+\mu^-$
- triggered very differently ▷ use of candidates that did not contribute to the trigger decision to avoid bias.

▷ events in the **mass sidebands** for the background.





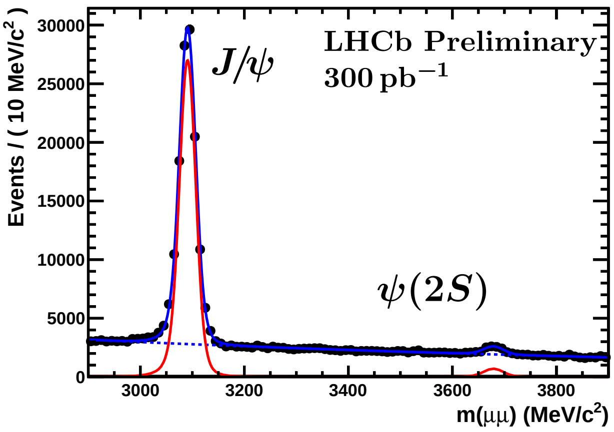
Signal Invariant Mass

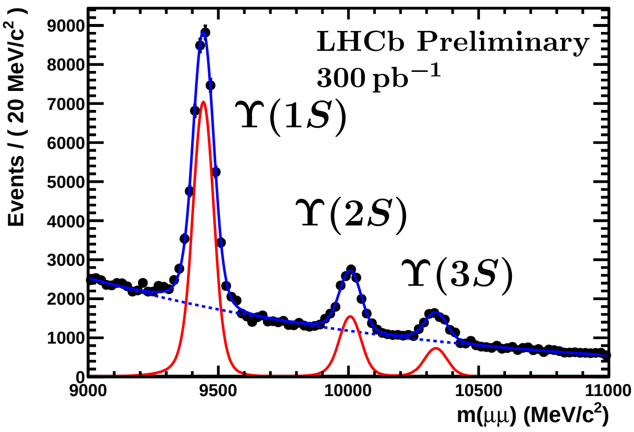
The Invariant mass is modeled with a Crystal Ball.

- The **means** ot the Gaussian are obtained from $B_s^0 \to K^+K^-$ and $B^0 \to K^+\pi^-$
- The **width** of the Gaussian is obtained from data the interpolation between the mass resolution of dimuon resonances (J/ψ, $\psi(2S)$ and Υ's) cross-checked with inclusive/exclusive fits of $B_{(s)}^0 \to h^+h^-$.

$\boldsymbol{\sigma = 24.6 \pm 0.2 \pm 1.0\,\mathrm{MeV}/c^2}$

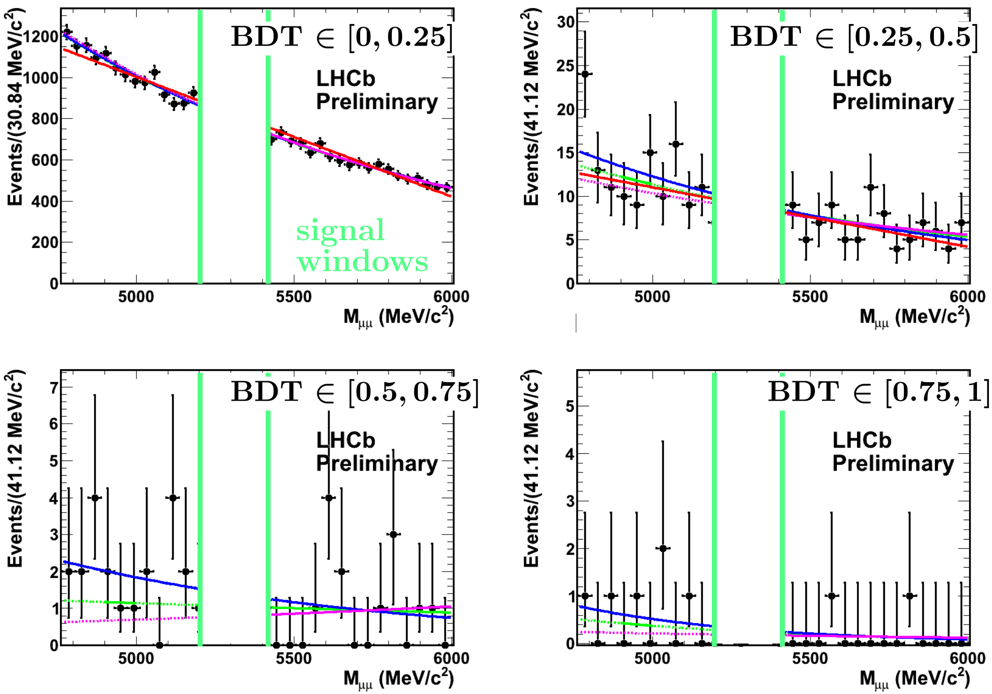
The search windows are defined as $\pm 60\,\mathrm{MeV}/c^2$ around each $B_{(s)}^0$ mass.





Background expectations

The combinatorial background expectation is extracted from a fit to the mass sidebands in bins of BDT.
Systematics are evaluated using different fit models and fit ranges.

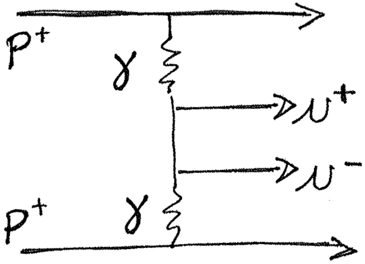


Other Backgrounds

The dominant background is composed of real muons from $b\bar{b} \to \mu\mu X$ events.
The other sources of background stem from:

- $pp \to p\mu^+\mu^- p$ processes.
  - ▷ Isolated muons,
  - ▷ Dimuon mass possibly high,
  - ▷ Very low p_{T} ▶ Very efficiently anti-selected requiring $p_{\mathrm{T}}(\mathrm{dimuon}) > 500\,\mathrm{MeV}/c$

LHCb-CONF-2011-022



- $B^0_{(s)} \to h^+h^-$ processes were the two final states are misidentified as muons
  - ▷ The misid probability is obtained from control channels and reweighted to the B kinematics
  - ▷ The distribution of the misidentified $B^0_{(s)} \to h^+h^-$ in bins of mass is evaluated from reweighted MC.

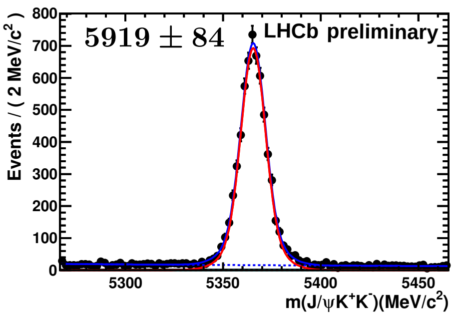
Normalization

$$\mathcal{B}_{\rm sig} = \mathcal{B}_{\rm norm} \times \frac{\epsilon^{\rm REC}_{\rm norm}\,\epsilon^{\rm SEL|REC}_{\rm norm}\ \ \epsilon^{\rm TRIG|SEL}_{\rm norm}}{\epsilon^{\rm REC}_{\rm sig}\,\epsilon^{\rm SEL|REC}_{\rm sig}\ \ \epsilon^{\rm TRIG|SEL}_{\rm sig}} \times \frac{f_{\rm norm}}{f_{\rm sig}} \times \frac{N_{\rm sig}}{N_{\rm norm}} = \alpha \times N_{\rm sig}$$

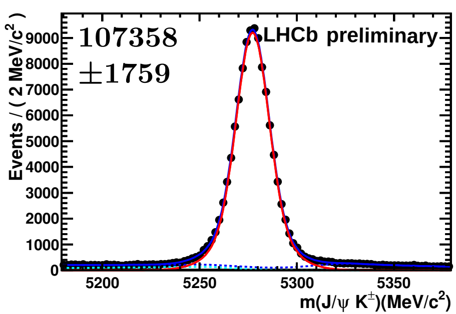
Evaluated on MC, cross-checked on data — Measured on data — new measurement by LHCb

Three complementary normalization channels are used:

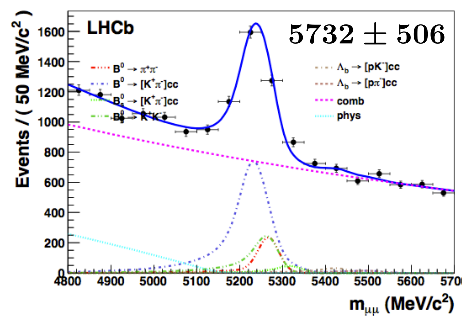
$B^0_s \to J/\psi\phi$



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



$B^0 \to K^+\pi^-$



$$\alpha_{B^0_s\to\mu^+\mu^-} = (9.84 \pm 0.91) \times 10^{-10}\,,$$

$$\alpha_{B^0\to\mu^+\mu^-} = (2.89 \pm 0.15) \times 10^{-10}\,.$$

f_s/f_d at LHCb

See Stefania Ricciardi's talk

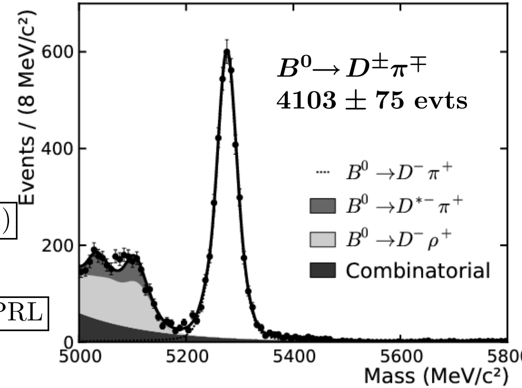
f_s/f_d is now measured at LHCb:

- in hadronic decays, via the relative yields of $B^0 \to D^\pm K^\mp$ or $B^0 \to D^\pm \pi^\mp$ to $B_s^0 \to D_s^\pm \pi^\mp$.

  Phys. Rev. D83,014017 (2011)

  $$f_s/f_d = 0.253 \pm 0.017^{\text{stat}} \pm 0.017^{\text{syst}} \pm 0.020^{\text{theo}}$$

  LHCB-PAPER-2011-006, submitt. to PRL



- and in semileptonic decays:

  $$\frac{f_s}{f_u + f_d} = 0.134 \pm 0.004^{+0.011}_{-0.010}$$

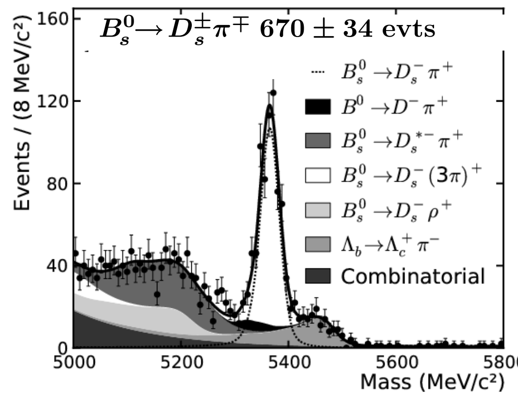
  LHCb-CONF-2011-028

- the combination of the two measurements

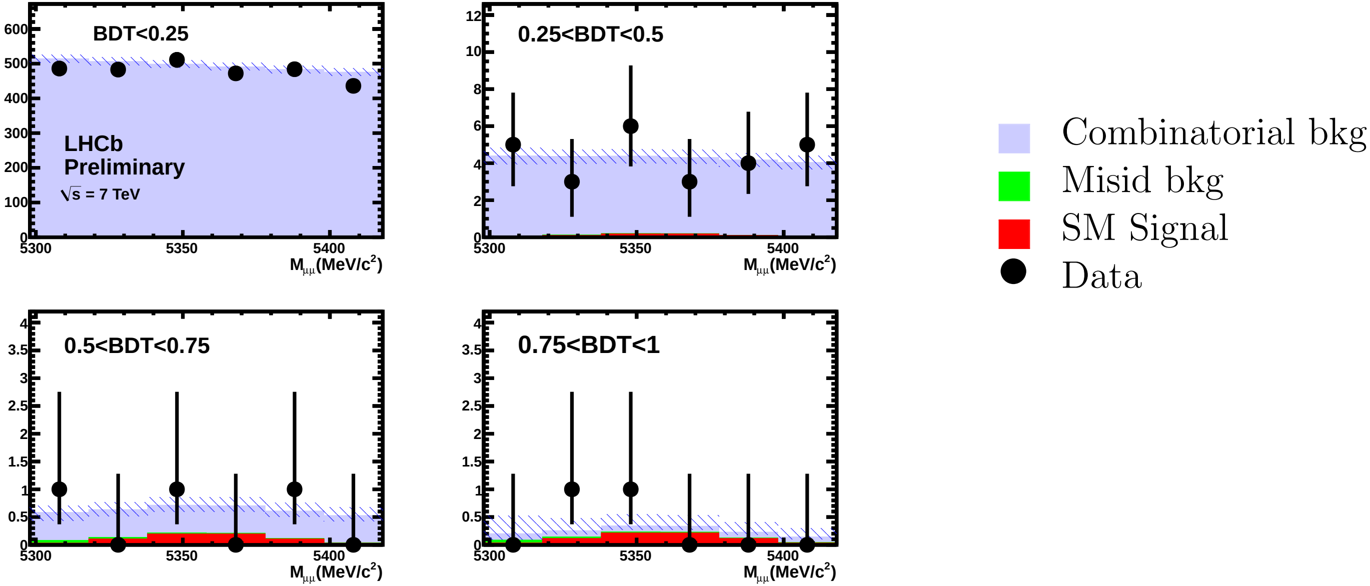
  $$f_s/f_d = 0.267^{+0.021}_{-0.020}$$

  LHCb-CONF-2011-034

  was used in the normalization.

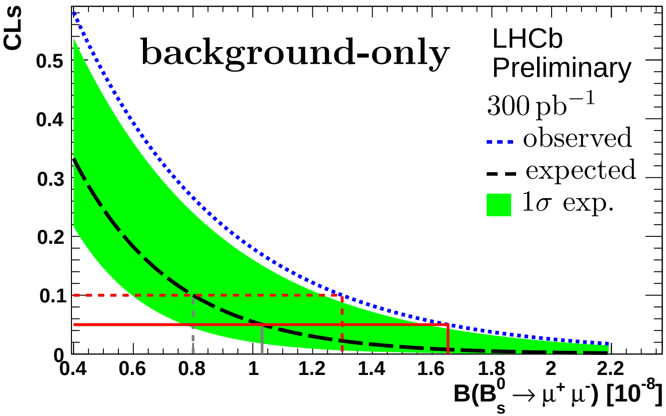


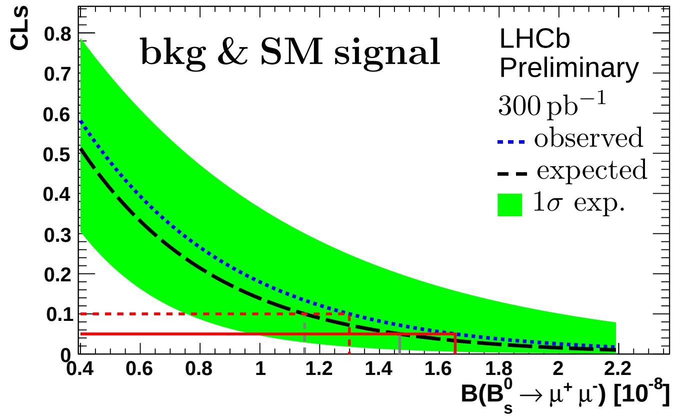
In the $B_s^0 \to \mu^+\mu^-$ search region



Preliminary	BDT bin			
	[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
Comb. bkg exp.	2969 ± 68	25 ± 2.5	2.89 ± 0.89	0.66 ± 0.40
SM signal exp.	1.26 ± 0.13	0.61 ± 0.06	0.67 ± 0.07	0.72 ± 0.07
Observed	2872	26	3	2

Limit on $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$



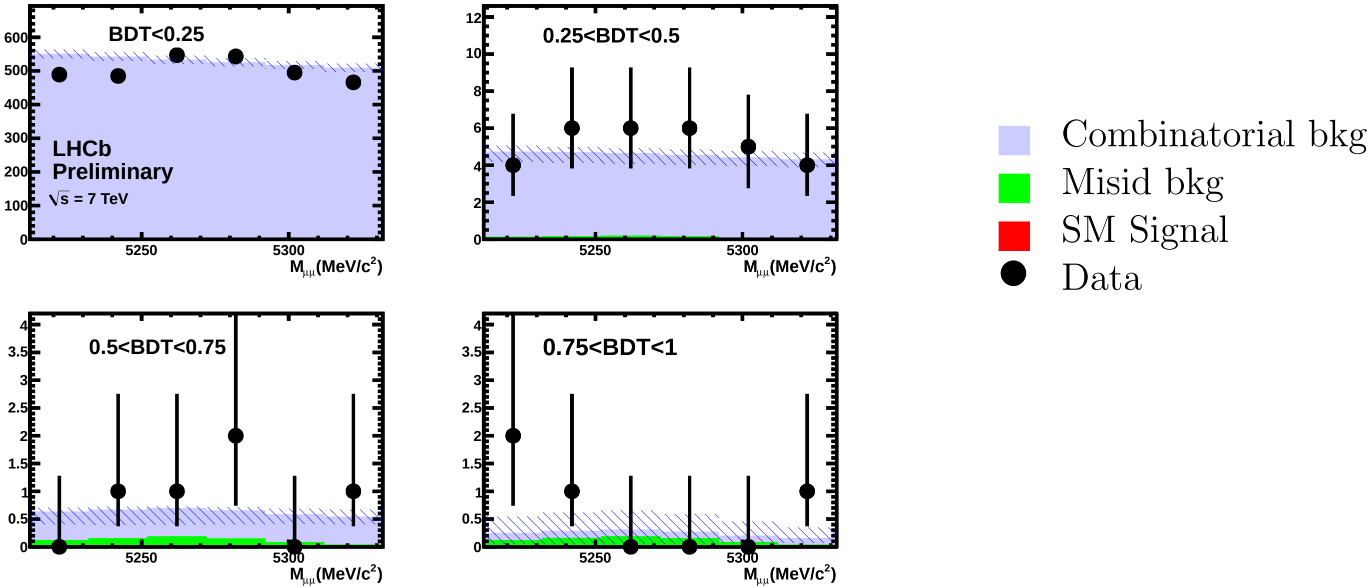


Preliminary results from $300\,\mathrm{pb}^{-1}$ of data collected in 2011:

$$\boldsymbol{\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.6 \quad (1.3) \times 10^{-8}} \textbf{ at 95\% (90\%) C.L.}$$

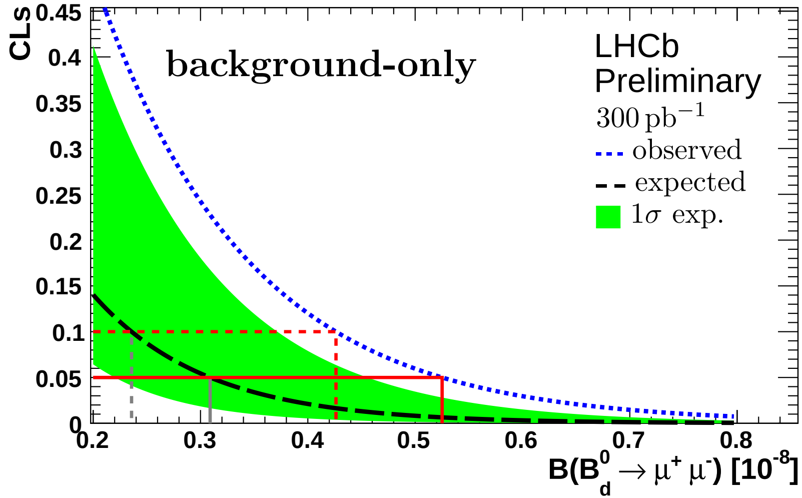
expected limit, bkg-only	$<$	1.0	$(0.8) \times 10^{-8}$
expected limit, bkg&SM	$<$	1.5	$(1.2) \times 10^{-8}$

In the $B^0 \to \mu^+\mu^-$ search region



Preliminary	BDT bin			
	[0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
Comb. bkg exp.	3176 ± 69	26.6 ± 2.5	3.1 ± 0.9	0.74 ± 0.40
MisID exp.	$0.6^{+0.4}_{-0.3}$	$0.6^{+0.4}_{-0.3}$	$0.6^{+0.4}_{-0.3}$	$0.6^{+0.4}_{-0.3}$
Observed	3025	31	5	4

Limit on $\mathcal{B}(B^0 \to \mu^+\mu^-)$

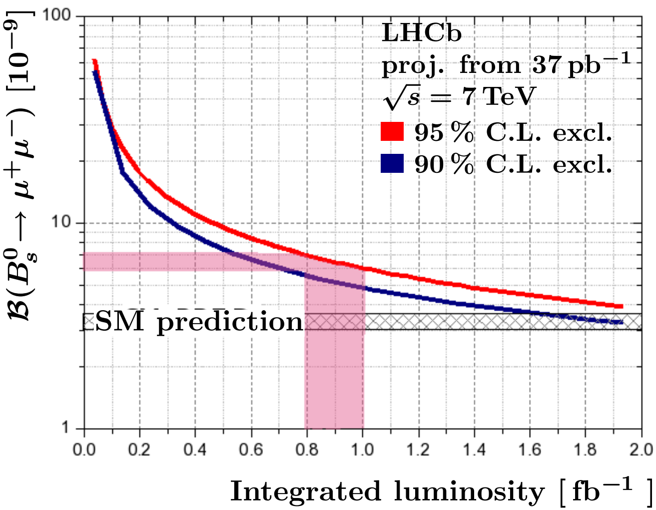


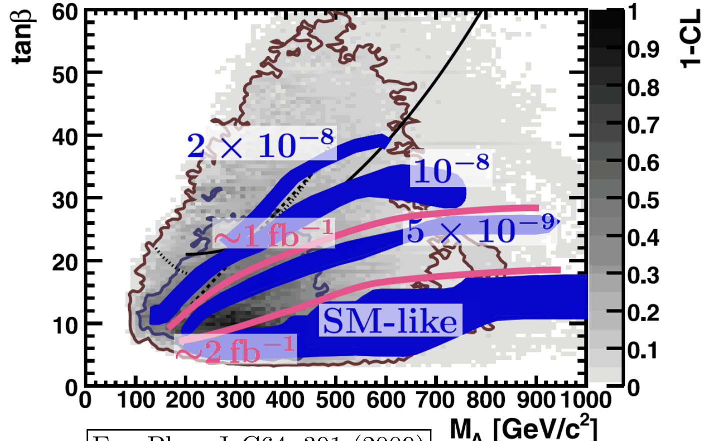
Preliminary results from $300\,\mathrm{pb}^{-1}$ of data collected in 2011:

$$\boldsymbol{\mathcal{B}(B^0 \to \mu^+\mu^-) \ < 5.2 \ \ (4.2) \times 10^{-9} \ \text{ at } 95\,\% \ (90\,\%) \text{ C.L.}}$$

expected limit, bkg-only $< \ 3.1 \qquad (2.4) \times 10^{-9}$

Extrapolation based on the $37\,\mathrm{pb}^{-1}$ collected in 2010 and analysed with the 2010-analysis. This can be considered rather conservative.





Eur. Phys. J. C64, 391 (2009)

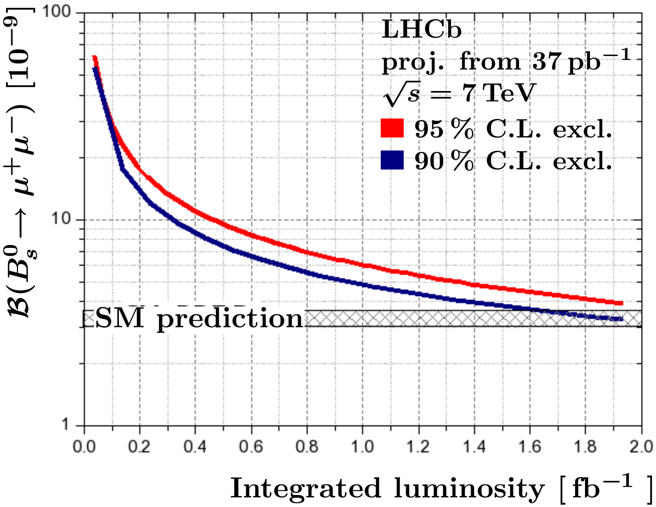
SuperIso: Comput. Phys. Comm. 180, 1718 (2009)

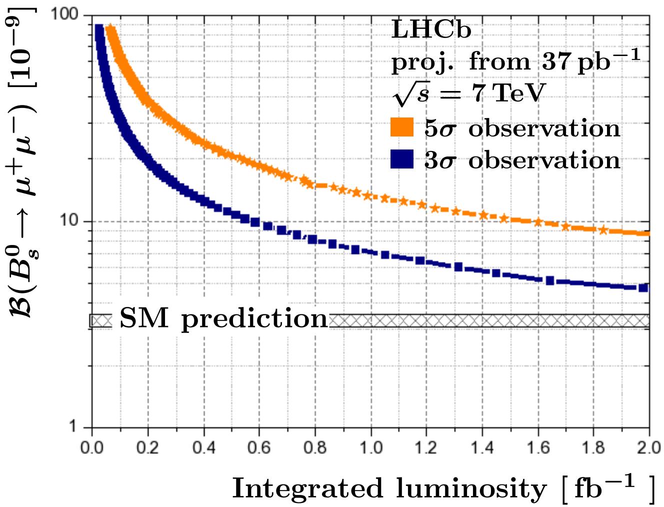
SoftSUSY: Comput. Phys. Comm. 143, 305 (2002)

The $\sim 1\,\mathrm{fb}^{-1}$ expected at the end of 2011 allow a considerable constraint on MSSM.

Prospects

Extrapolation based on the 37 pb^{-1} collected in 2010 and analysed with the 2010-analysis. This can be considered rather conservative.





Conclusions

- LHCb presents a preliminary result with $300\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 7\,\mathrm{TeV}$
  LHCb-CONF-2011-037

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.6\ (1.3) \times 10^{-8} \text{ at } 95\,\%\ (90\,\%) \text{ C.L.}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 5.2\ (4.2) \times 10^{-9} \text{ at } 95\,\%\ (90\,\%) \text{ C.L.}$$

- Combining with our previous result on $37\,\mathrm{pb}^{-1}$:
  Phys. Lett. B699 330 (2011)

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.5\ (1.2) \times 10^{-8} \text{ at } 95\,\%\ (90\,\%) \text{ C.L.}$$

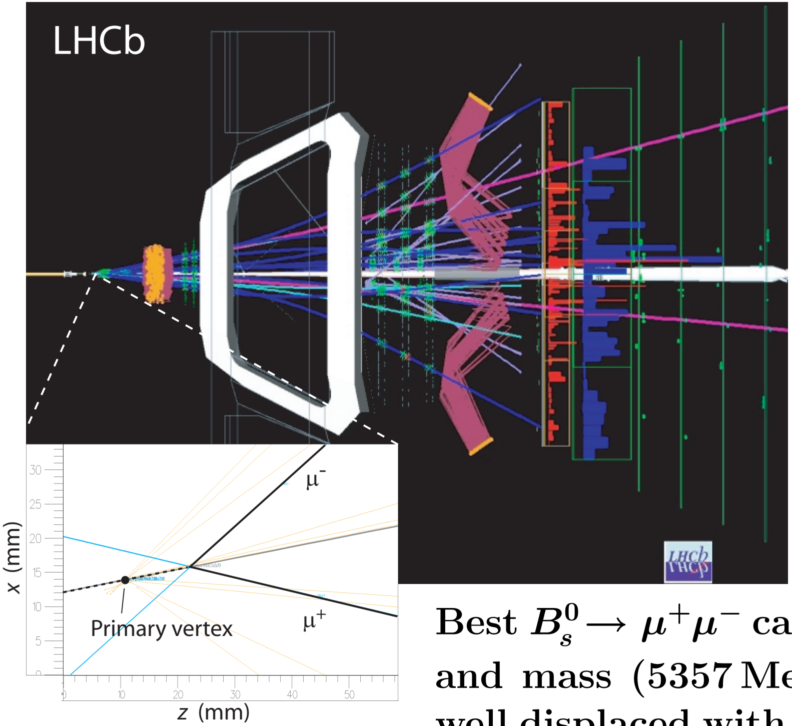
- And combining further with CMS result:
  LHCb-CONF-2011-047
  CERN-PH-EP-2011-120, sub. to PRL

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 1.1\ (0.9) \times 10^{-8} \text{ at } 95\,\%\ (90\,\%) \text{ C.L.}$$

- The excess seen by CDF is not confirmed.
  hep-ex/1107.2304

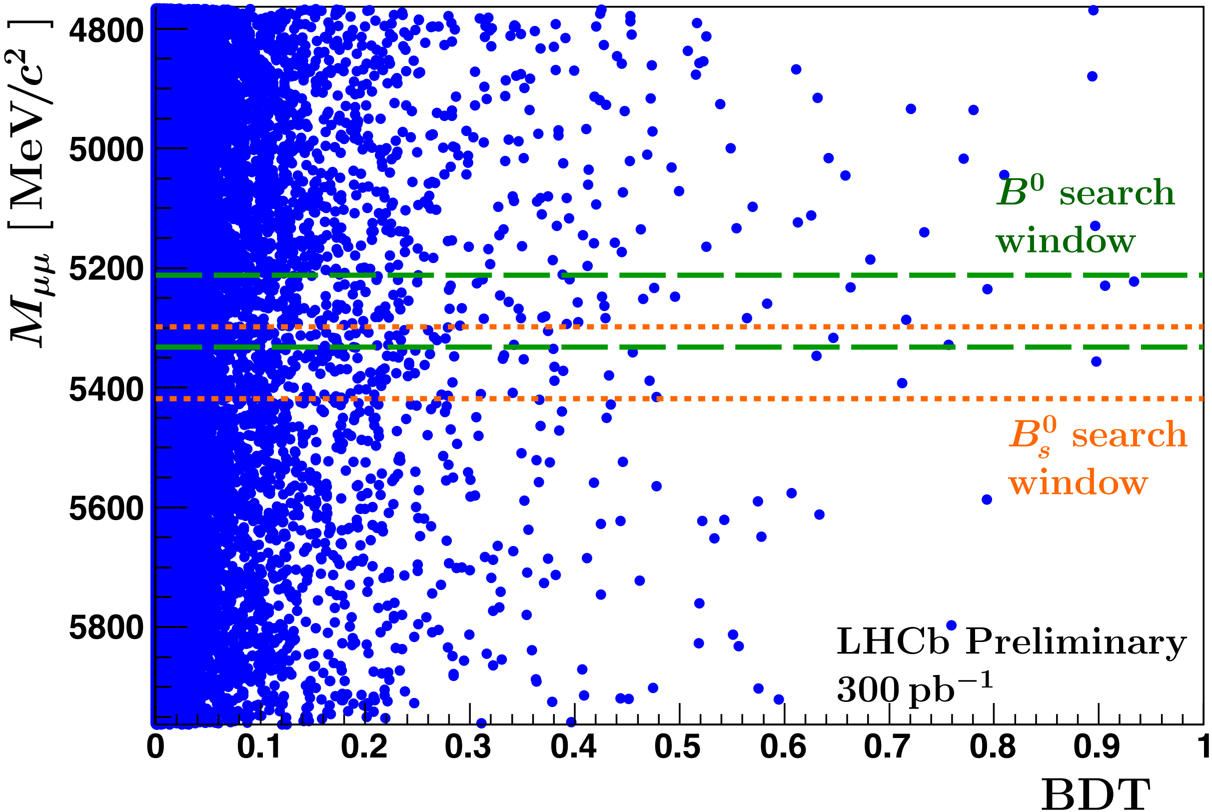
Backup Material

Nice candidate



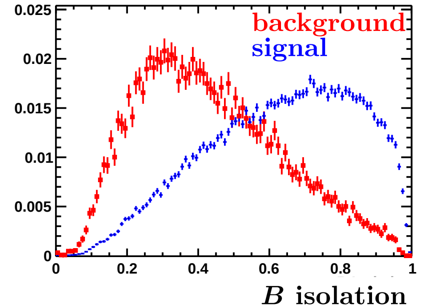
Best $B_s^0 \rightarrow \mu^+\mu^-$ candidate in terms of BDT (0.9) and mass ($5357\,\mathrm{MeV}/c^2$). The muons' vertex is well displaced with respect to the primary vertex ($l = 115\,\mathrm{mm}$). The B momentum is $58.16\,\mathrm{GeV}/c$, its transverse momentum is $3.5\,\mathrm{GeV}/c$ and its lifetime is $3.52\,\mathrm{ps}$.

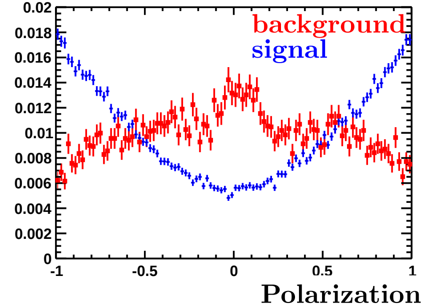
Observed distribution

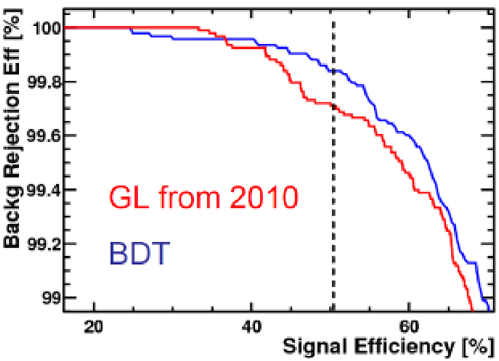


New Variables, BDT *vs* GL

- B isolation $= p_T(B)/p_T(B) + \sum_{\text{tracks}} p_T(\text{tracks})$ for tracks such that $\sqrt{\delta\eta^2 + \delta\phi^2} < 1.0$.
- Polarization variable $= \frac{(p_{y,\mu} \times p_{x,B}) - (p_{x,\mu} \times p_{y,B})}{2 \times p_{T,B} \times M_B}$ with μ is the muon with minimum p_T. Cosine of the angle between the muon momentum in the B rest frame and the vector perpendicular to the B momentum and the beam axis.







Our previous result was obtained using another MultiVariate tool: the GL. With additional variables, the best discrimination power was obtained using a BDT. Trained and tested on MC.

Normalization uncertainties

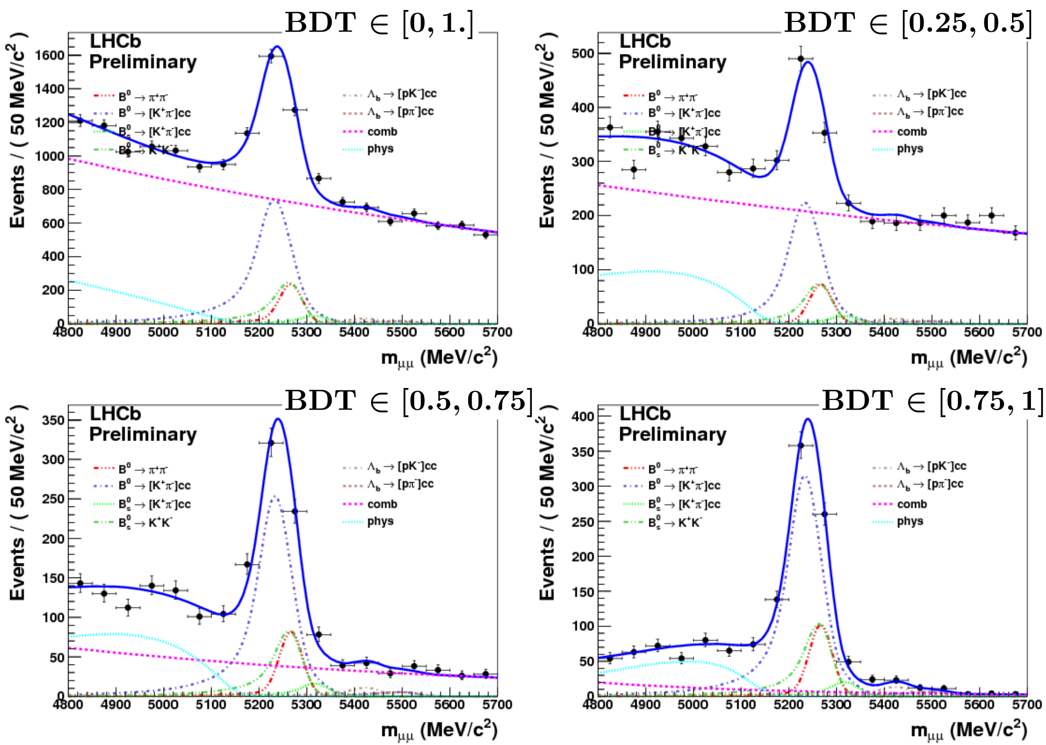
	$\mathcal{B}$ $(\times 10^{-5})$	$\frac{\epsilon_{\rm cal}^{\rm REC}\epsilon_{\rm cal}^{\rm SEL\|REC}}{\epsilon_{\rm sig}^{\rm REC}\epsilon_{\rm sig}^{\rm SEL\|REC}}$	$\frac{\epsilon_{\rm cal}^{\rm TRIG\|SEL}}{\epsilon_{\rm sig}^{\rm TRIG\|SEL}}$	N_{cal}	$\alpha^{cal}_{B_d\to\mu^+\mu^-}$ $(\times 10^{-10})$	$\alpha^{cal}_{B_s\to\mu^+\mu^-}$ $(\times 10^{-9})$
$B^+\to J/\psi K^+$	6.01 ± 0.21	0.48 ± 0.02	0.95 ± 0.01	107358 ± 1759	2.58 ± 0.16	0.966 ± 0.096
$B^0_s\to J/\psi\phi$	3.4 ± 0.9	0.23 ± 0.02	0.95 ± 0.01	5919 ± 84	3.39 ± 0.98	1.27 ± 0.35
$B^0\to K^+\pi^-$	1.94 ± 0.06	0.86 ± 0.03	0.051 ± 0.01	5732 ± 506	2.47 ± 0.57	0.92 ± 0.22

Summary of the factors and their uncertainties needed to calculate the normalization factors ($\alpha_{B^0_{(s)}\to\mu^+\mu^-}$) for the three normalization channels considered. The trigger efficiency and number of $B^0\to K^+\pi^-$ candidates correspond to TIS events only.

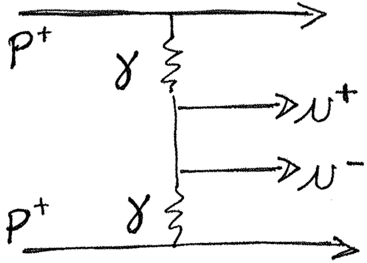
$B^+\to J/\psi K^+$	$B^0_s\to J/\psi\phi$	$B^0\to K^+\pi^-$
$\mathcal{B}=6.01\times10^{-5}\pm3.5\,\%$	$\mathcal{B}=3.4\times10^{-5}\pm26\,\%$	$\mathcal{B}=1.94\times10^{-5}\pm3.1\,\%$
trigger and PID similar to signal channel	trigger and PID similar to signal channel	different trigger: use $B^0_{(s)}\to h^+h^-$ candidates that did not contribute to trigger decision
+1 track wrt signal: error on tracking ϵ dominates in ϵ ratio	+2 tracks wrt signal: error on tracking ϵ dominates in ϵ ratio	topology identical to signal
f_s/f_d dominates overall	$\mathcal{B}$ dominates overall	f_s/f_d, trigger uncertainty

BDT Calibration

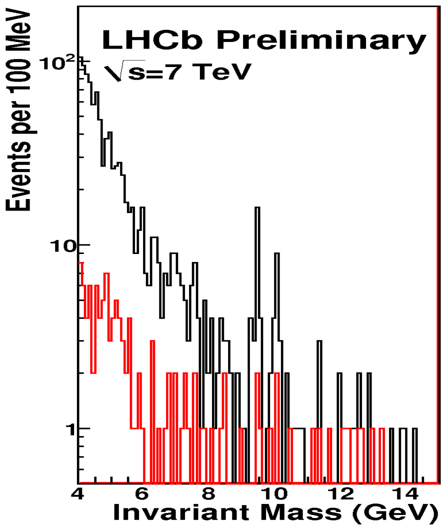
Full fit to the invariant mass distributions of $B^0_{(s)} \to h^+h^-$ candidates in the $\pi\pi$ mass hypothesis for the whole sample (top left) and for the samples in the bin 2,3,4 of the BDT (top right, bottom left, bottom right).



Diphoton Background



Topology look like signal when associated with another PV in the event.
Dimuon mass covers B mass range.
But very low p_{T}, can be anti-selected very efficiently with a p_{T} cut at 500 MeV (98.2 % eff. on signal).



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