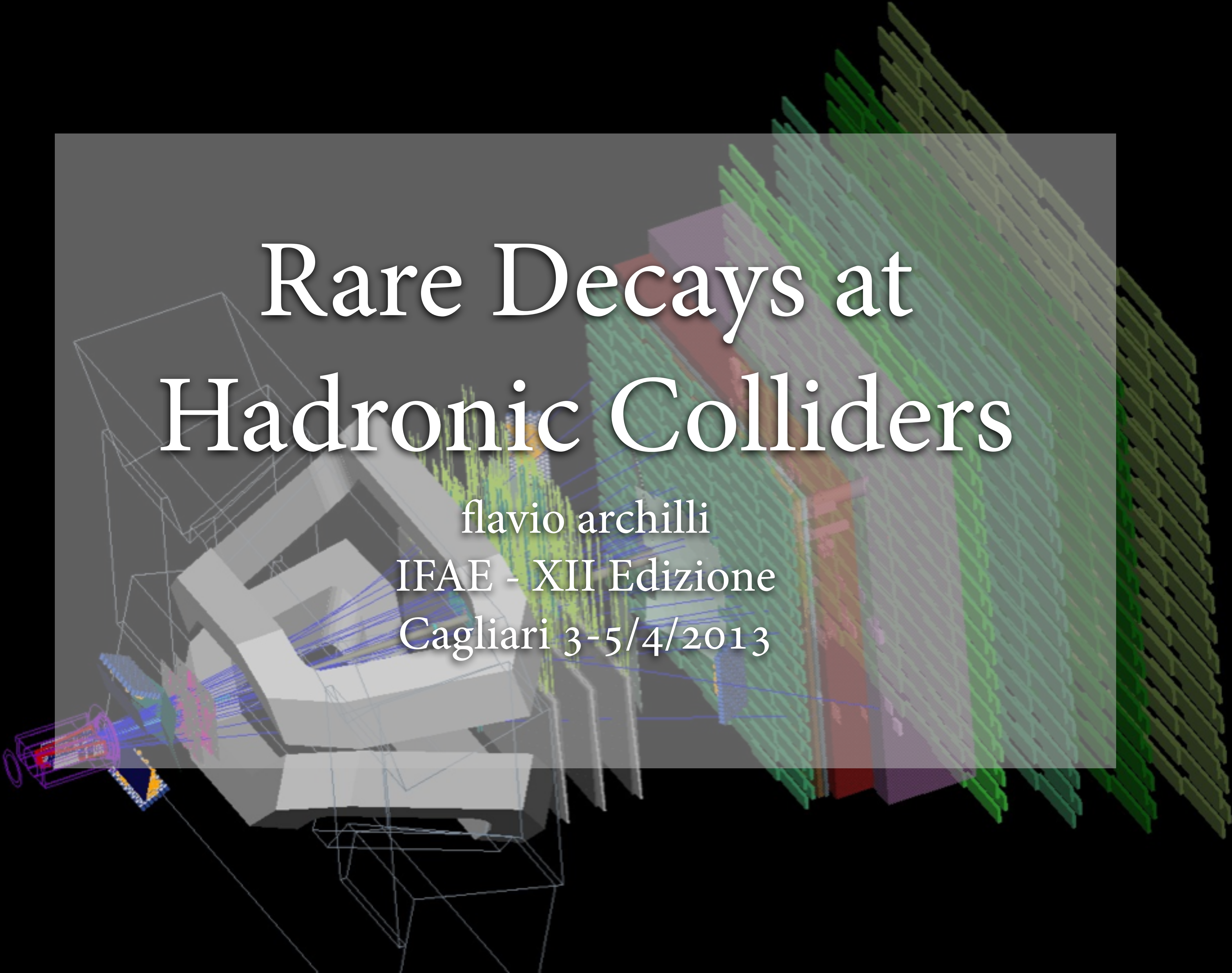
Rare Decays at Hadronic Colliders



flavio archilli

IFAE - XII Edizione

Cagliari 3-5/4/2013

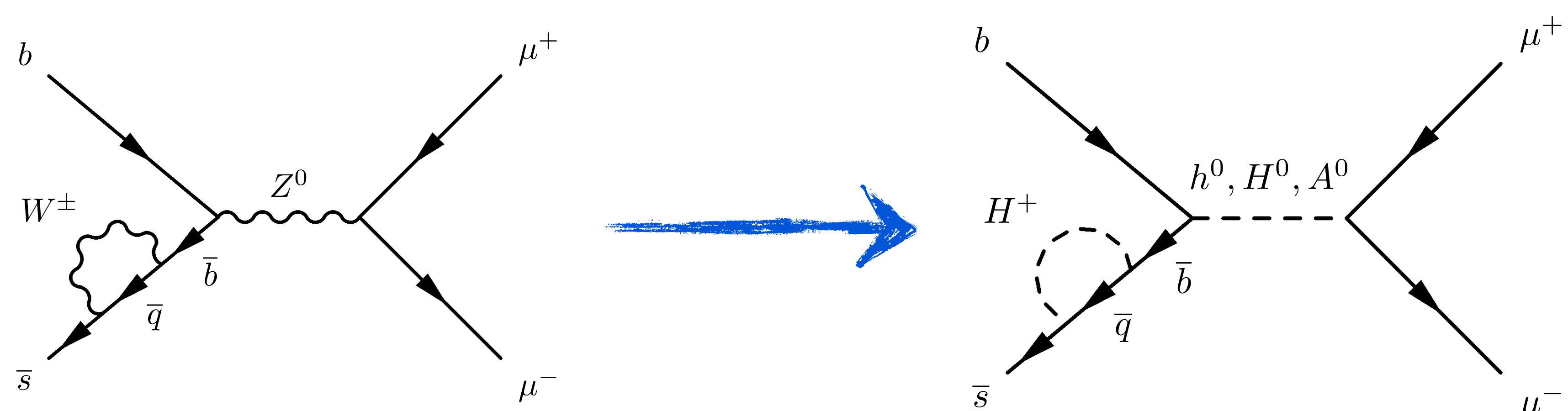
Introduction

➡If the energy of the particle collisions is high enough, we can discover NP detecting the production of **"real" new particles**.

➡If the precision of the measurements is high enough, we can discover NP due to the effect of **"virtual" new particles** in loops.

➡The effect of heavy (M>q^2) new particles does not decouple in **weak and Yukawa interactions**.

➡Therefore, **precision measurements of FCNC can reveal NP that may be well above the TeV scale**, or can provide key information on the couplings and phases of these new particles if they are visible at the TeV scale.



Overview

Highly suppressed in SM

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

$B^0_{(s)} \to 4\mu$

$D^0 \to \mu\mu$

$K_S \to \mu\mu$

...

BR/searches

$b \to s$ FCNC process

A_{CP} $B^0 \to K^{0*}\mu\mu$

A_{FB} $B^+ \to K^{+*}\mu\mu$

BR $B^+ \to \pi^+\mu\mu$

...

Comparison with the SM prediction

hints for New Physics

LFV

BR/searches $\tau \to \mu\mu\mu$

...

$B_s \to \mu\mu$ theory

FCNC process → very small branching fraction in SM:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)^{t=0} = (3.23 \pm 0.27) \cdot 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-)^{t=0} = (1.07 \pm 0.10) \cdot 10^{-10}$$

Buras et al., arXiv: 1208.0934

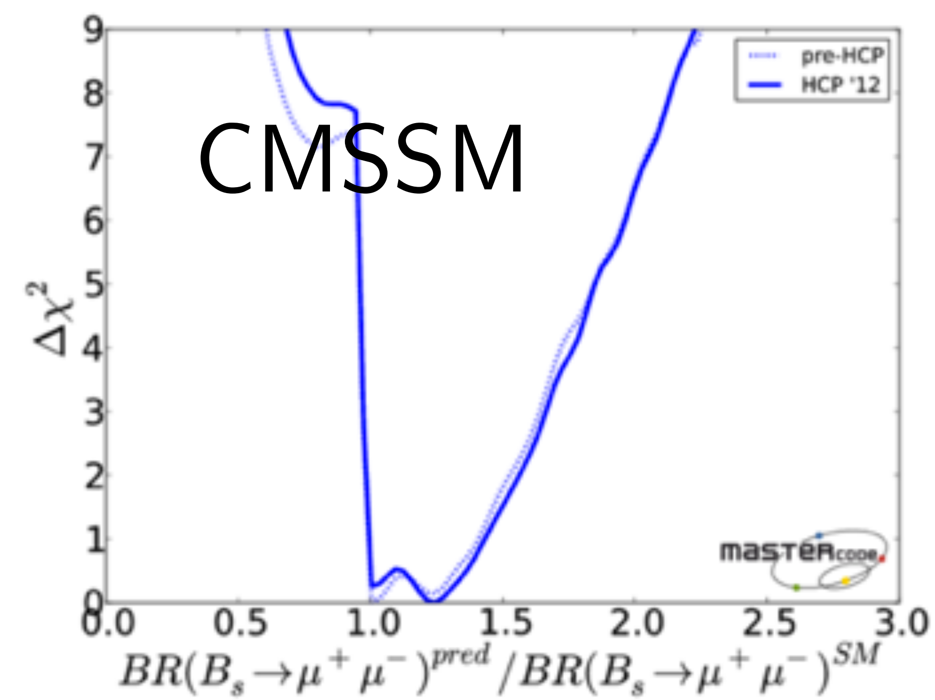
To compare with experiment need a time integrated branching fraction, taking into account the finite width of the B^0_s system:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)^{\langle t \rangle} = \frac{1}{1-y_s} \cdot \mathcal{B}(B_s^0 \to \mu^+\mu^-)^{t=0} = (3.54 \pm 0.30) \cdot 10^{-9}$$

De Bruyn et al., PRL 109, 041801 (2012)
uses LHCb-CONF-2012-002

Particularly sensitive to FCNC scalar currents and FCNC Z penguins.

NP enhancements of BR($B_s \to \mu^+\mu^-$) are constrained to be smaller or at the same level than the SM prediction. There still remains, however, room for a contribution from physics beyond the Standard Model.

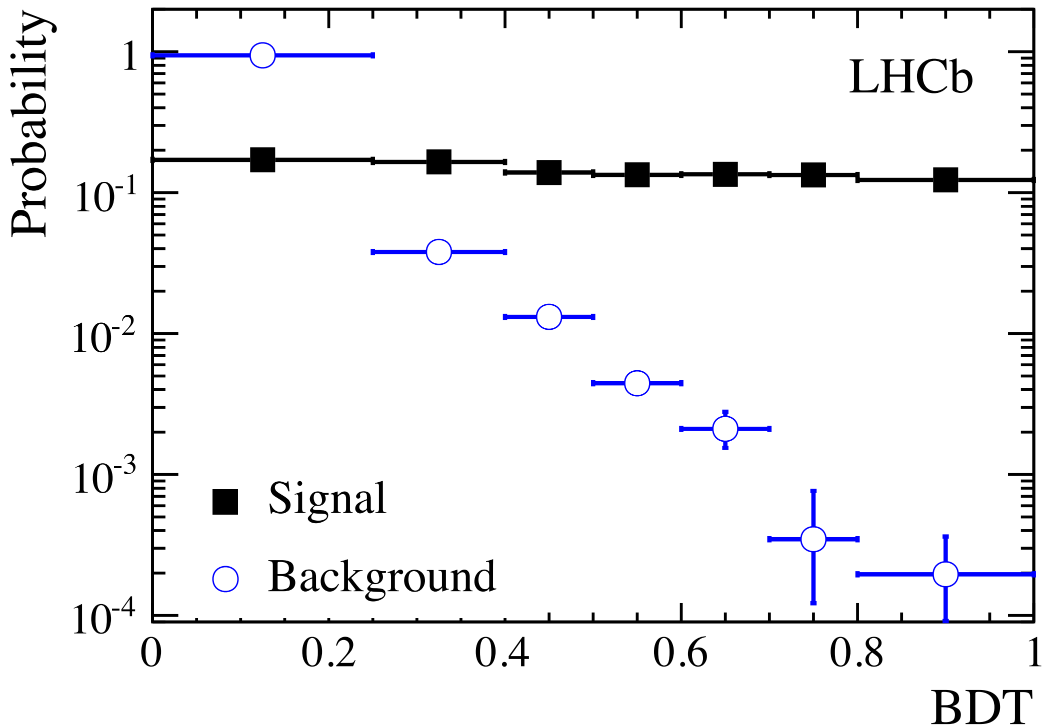


LHCb

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. 110, 021801 (2013)

Performed on full 2011 [@ 7 TeV] data (reanalyzed, with improved bkg evaluation), and 1.1 fb^{-1} of 2012 [@ 8 TeV] sample (~50% of available **statistics)**: 8 TeV data signal region kept blind until analysis completion.

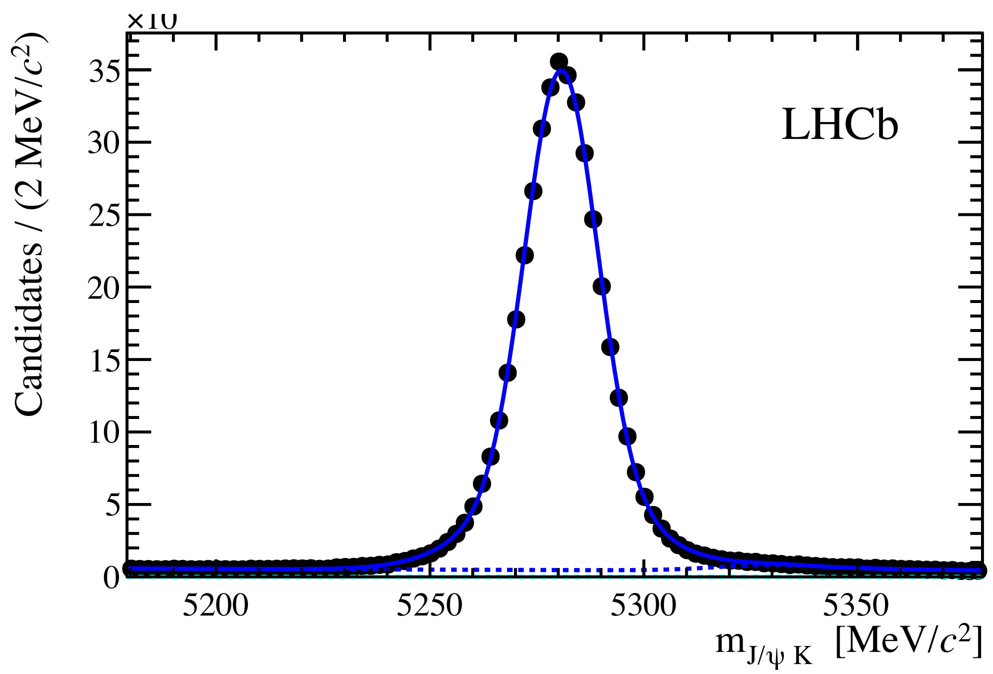
Assuming SM rates, after selection we expect in 7 TeV + 8 TeV data (1.0 + 1.1 fb^{-1}) ~11+13 $B^0_s \to \mu^+\mu^-$ and ~1.3+1.5 $B^0 \to \mu^+\mu^-$ **in sig. region** **($m(B^0_{(s)}) \pm 60$ MeV/c^2)**



- Signal/Background separation by invariant di-μ mass and a MVA classifier (BDT) including kinematic and topological information

BDT training on MC signal and bkg samples

BDT calibration for signal with exclusive $B^0_{(s)} \to h^+h'^-$ channels (h=π, K) and for background with IM sidebands



- Normalization with $B^\pm \to J/\psi K^\pm$ and $B^0 \to K^+\pi^-$

- Results provided in terms of:

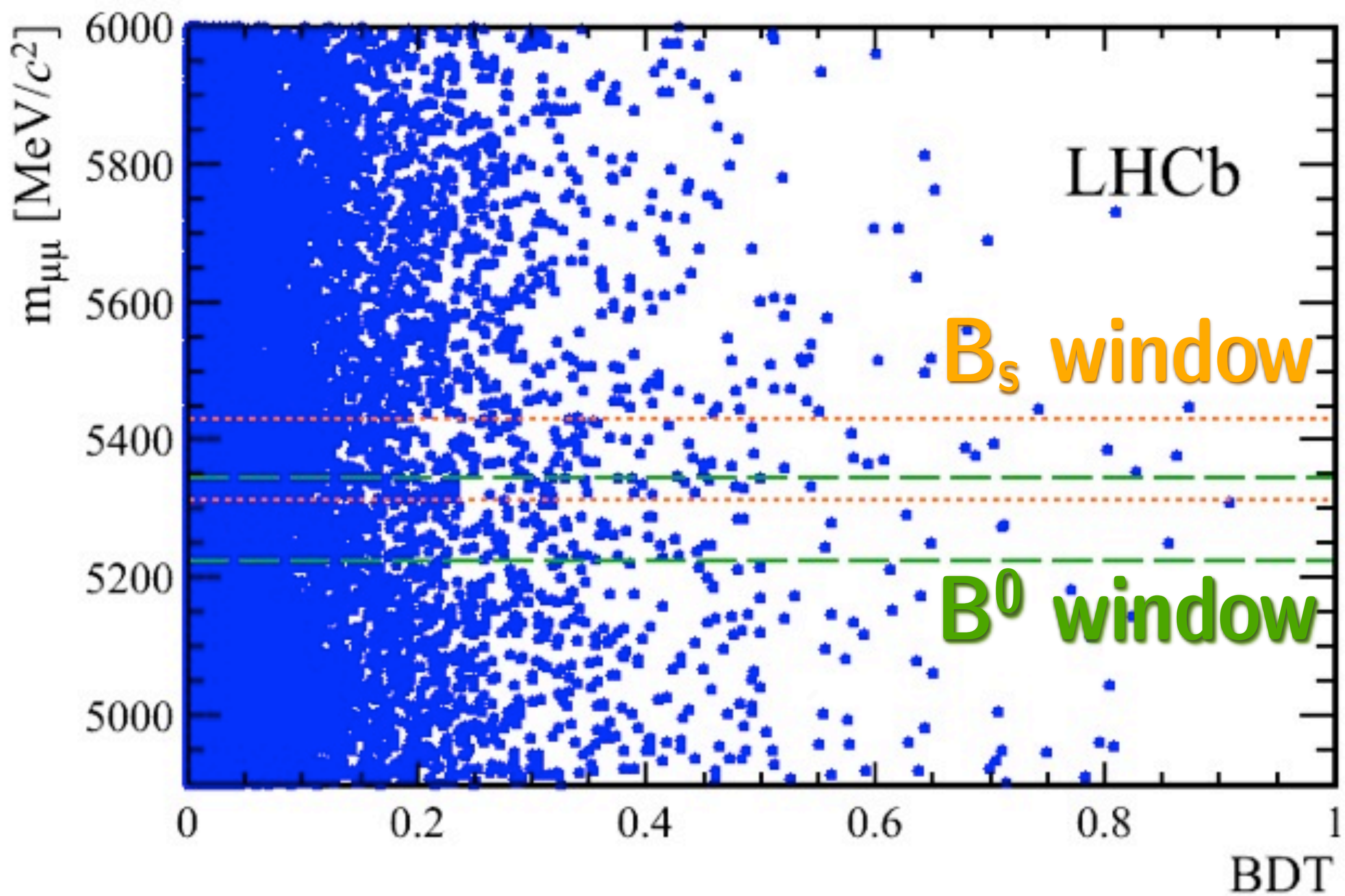
- Limit and significance with CLs method
- Unbinned maximum likelihood fit for BR

Open the box

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. 110, 021801 (2013)

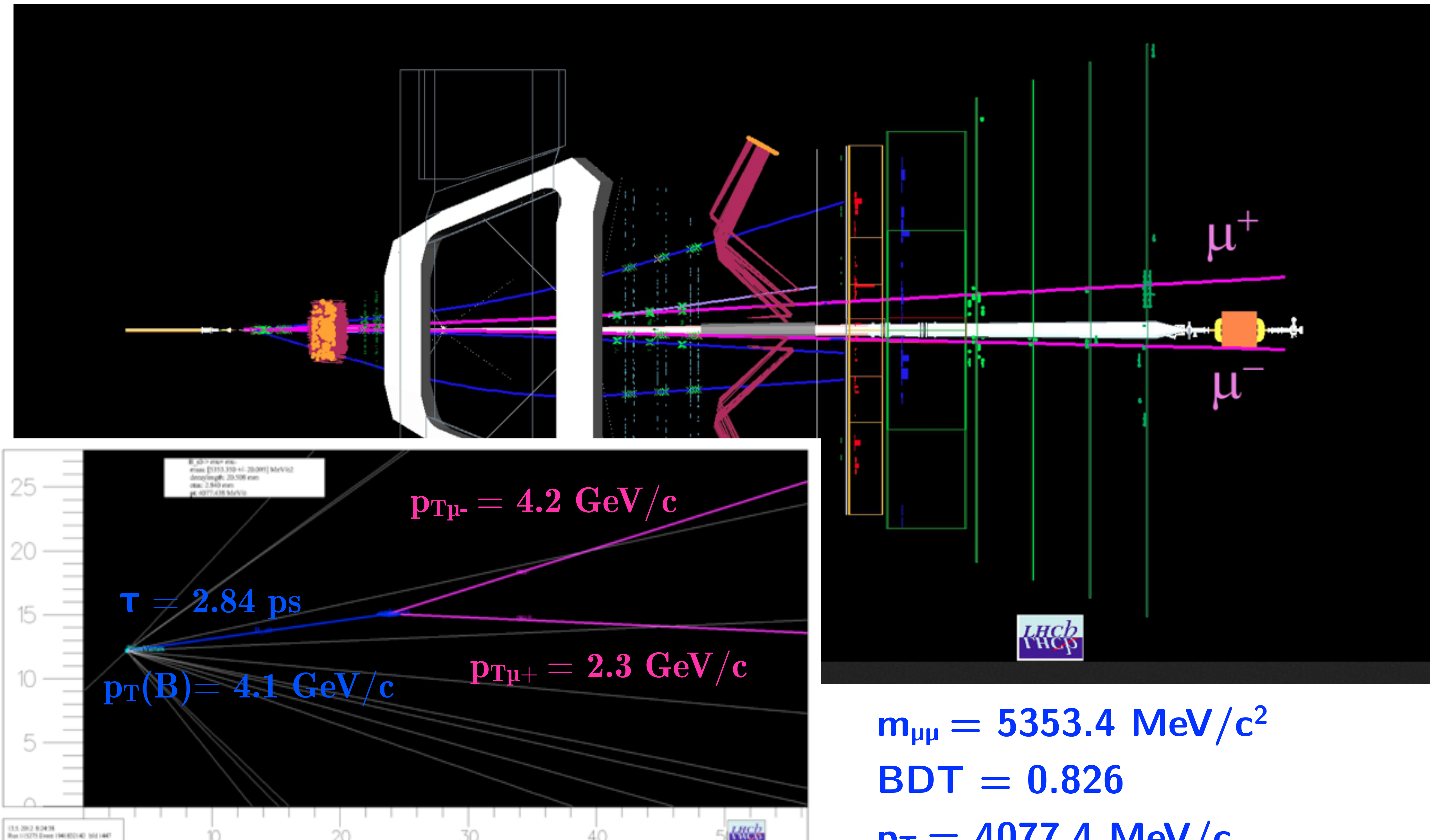
The main background source in the $B^0_{(s)} \to \mu^+\mu^-$ signal window, $m(B^0_{(s)})\pm60$ MeV/c^2, **is combinatorial from bb $\to \mu^+\mu^- X$, dominant a BDT<0.5**

Three dominant sources of excl. background which can bias the combinatoral background interpolation, **$B^0 \to \pi^-\mu^+\nu_\mu$ and $B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$**, or give a significant contribution in the signal mass window **$B^0_{(s)}\to h^+h'^-$ ($4.1^{+1.7}_{-0.8}$ events in B_S win.** and **$0.76^{+0.26}_{-0.18}$ events in B^0 win.**)



a candidate

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. 110, 021801 (2013)



$m_{\mu\mu}$ = 5353.4 MeV/c^2

BDT = 0.826

p_T = 4077.4 MeV/c

t = 2.84 ps

sensitivity

R. Aaij et al. (LHCb Collaboration)
Phys. Rev. Lett. 110, 021801 (2013)

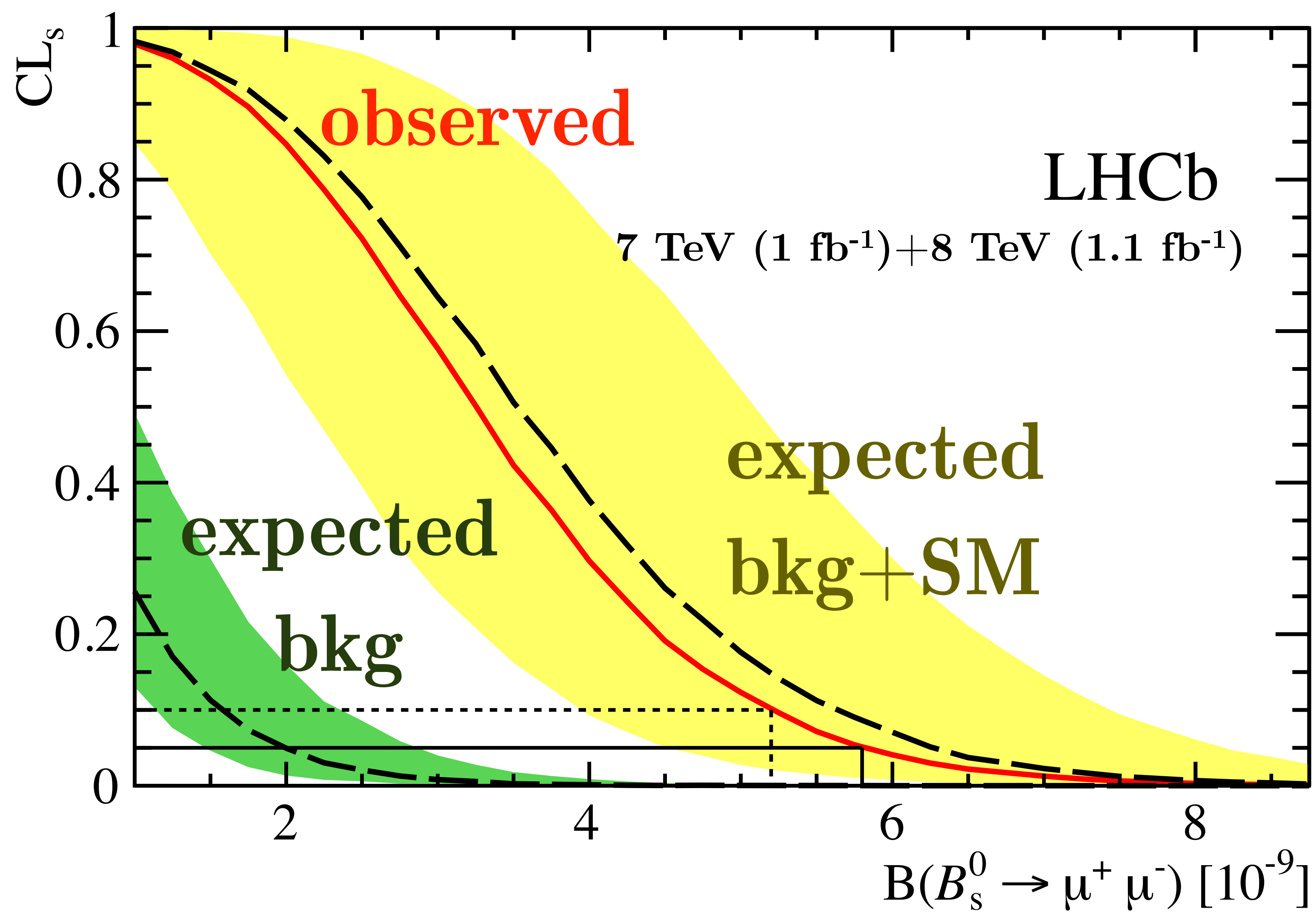
Use CLs method to evaluate compatibility with background only (CL_b) and signal + background hypotheses (CL_{s+b}); **the 95% CL upper limit is defined at $CL_s = CL_{s+b}/CL_b = 0.05$**

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

obs. BR limit < 9.4×10^{-10} at 95% CL

exp. BR limit < 7.1×10^{-10} at 95% CL

Compatibility with bkg only hypothesis:
p-value = $1-CL_b$ = 0.11



$B^0_s \to \mu^+\mu^-$:

bkg only p-value: 5.3×10^{-4}

(3.5 σ excess)

double-sided limit:

$1.1 \times 10^{-9} < B(B^0_s \to \mu^+\mu^-) < 6.4 \times 10^{-9}$ at 95% CL

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

Branching Fraction fit

- **Unbinned maximum likelihood fit** to the mass spectra
- Free parameters:
  - $BR(B^0_s \to \mu^+\mu^-)$, $BR(B^0 \to \mu^+\mu^-)$ and combinatorial background
  - The **signal yield** in each BDT bin is **constrained from $B^0_{(s)} \to h^+h'^-$ calibration**
  - The yields and pdf's for all of the relevant exclusive backgrounds are constrained to their expectations

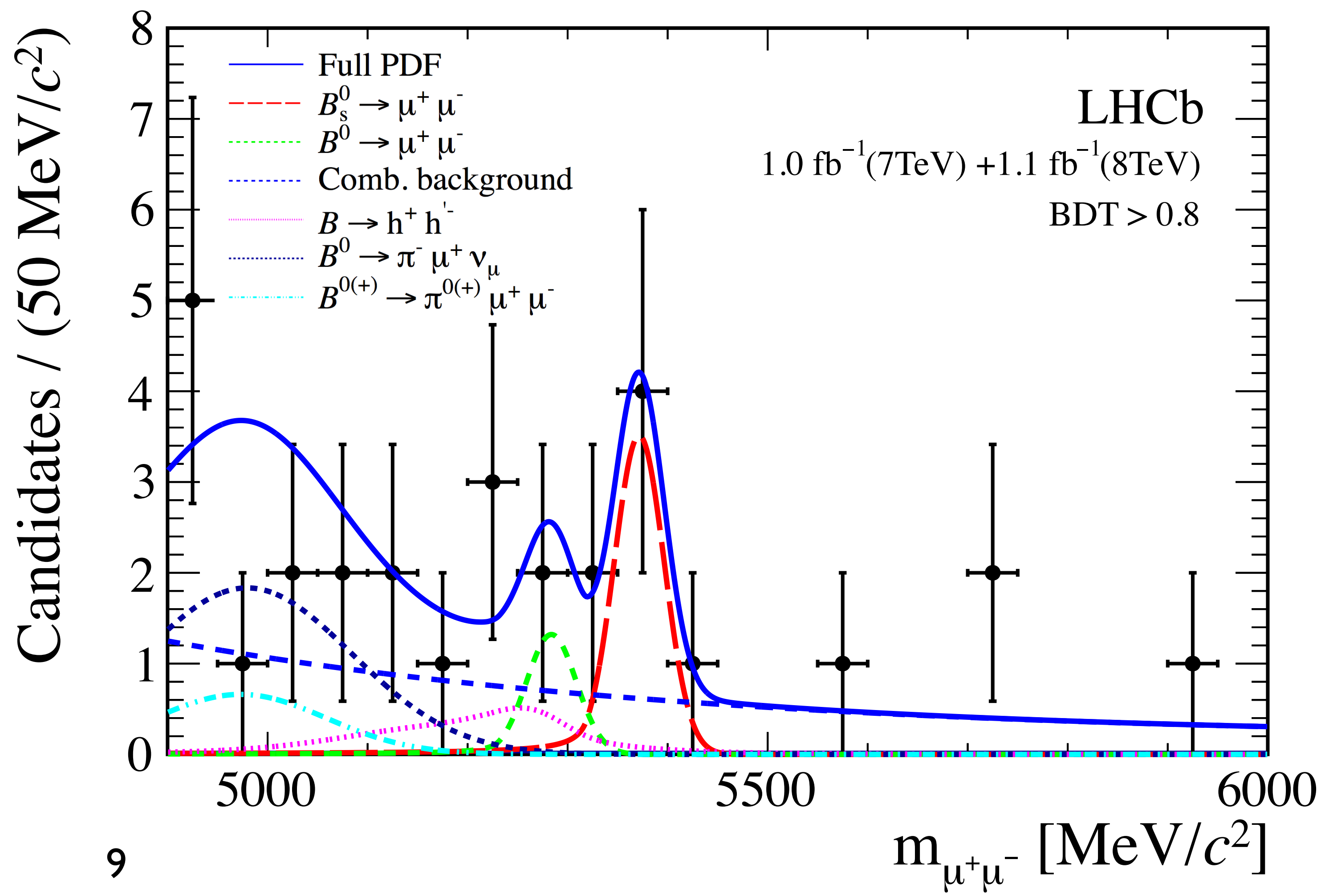
$BR(B^0_s \to \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}) \times 10^{-9}$

SM expectation

$(3.54 \pm 0.30) \times 10^{-9}$

$(3.2^{+1.4}_{-1.2}\ (\text{stat})\ ^{+0.5}_{-0.3}\ (\text{syst})) \times 10^{-9}$

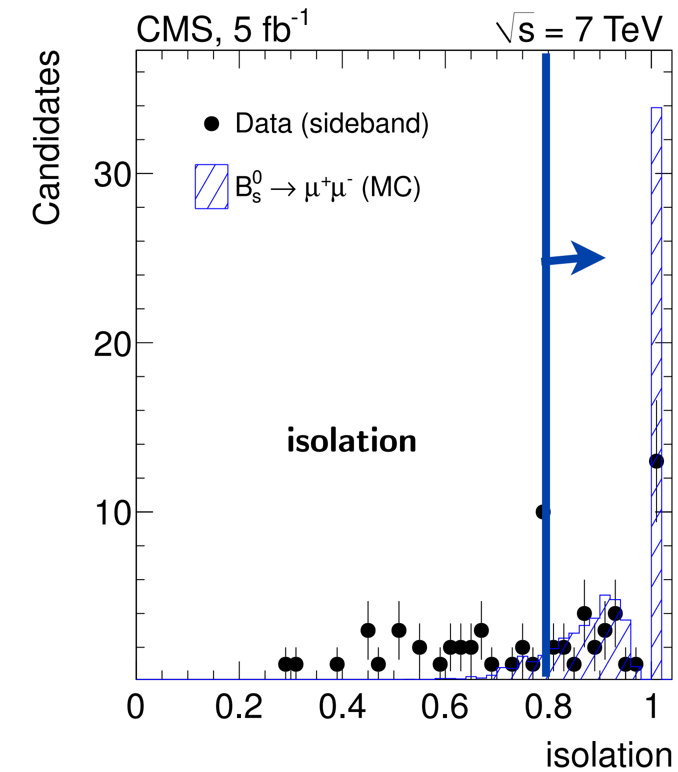
fully dominated by stat error



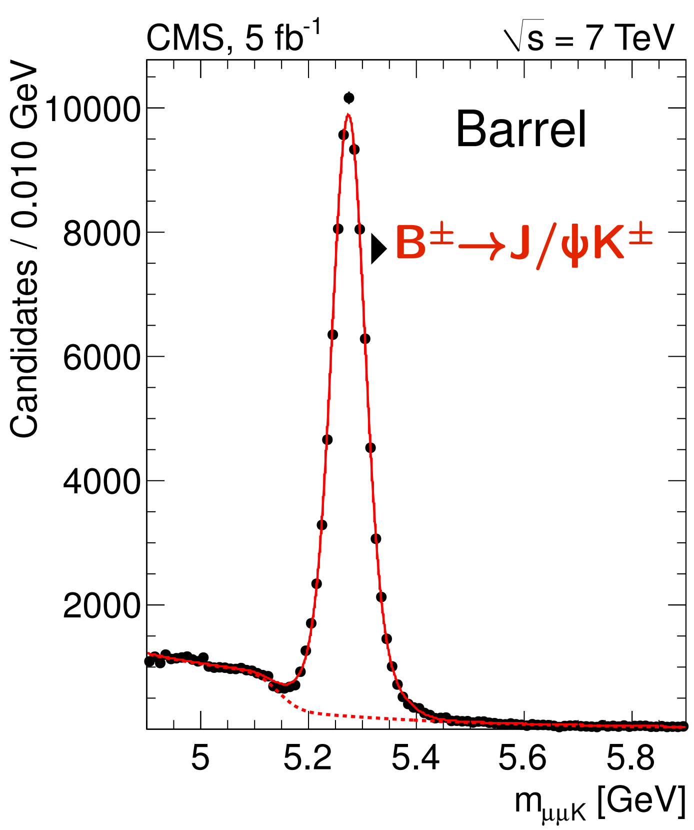
CMS

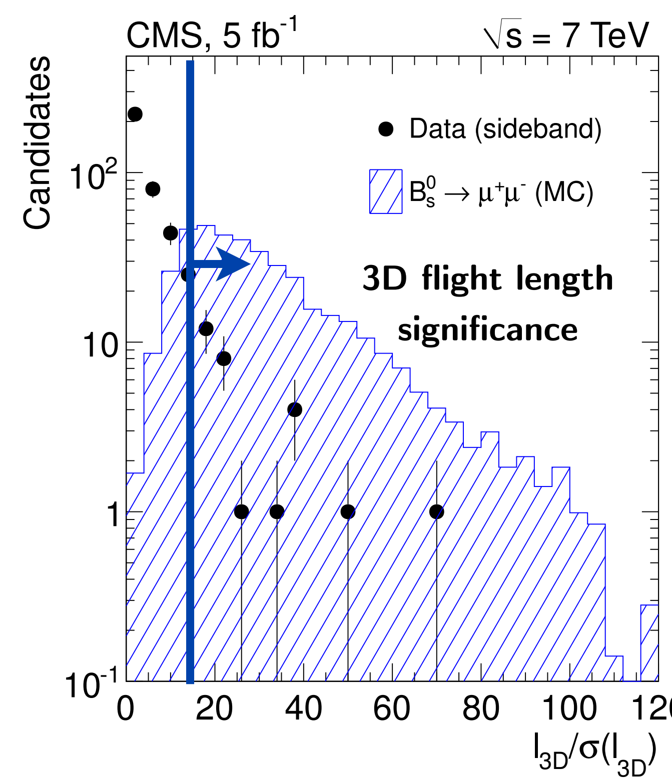
CMS: 2011 data 5 fb^{-1} [JHEP 04(2012), 033]

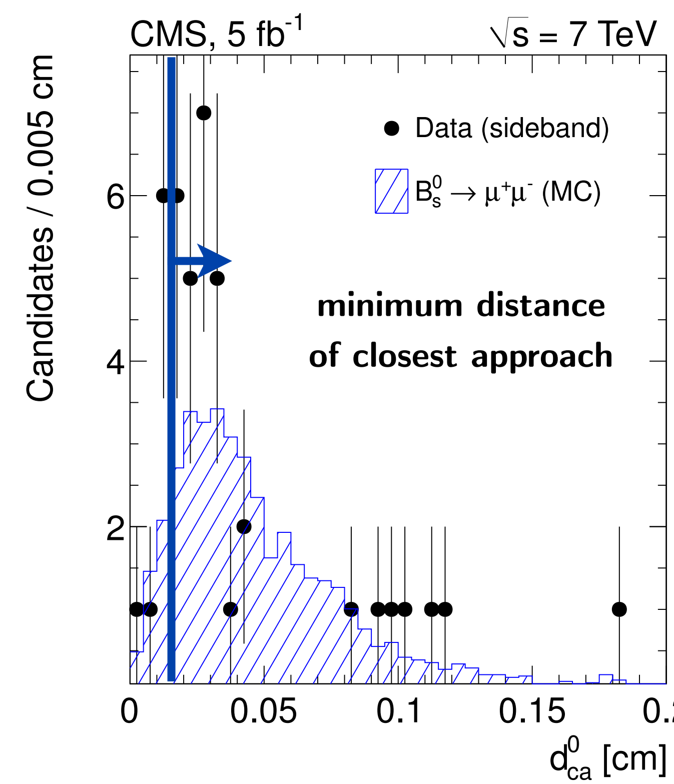
- CMS divide into 2 η regions corresponding to 2 different background conditions:
  - barrel: both tracks |η|<1.4
  - endcap: at least 1 track with |η|>1.4
- Mass resolution: 36 (86) MeV in barrel (endcap)



- **Cut-based analysis, optimized before the unblinding**
- $B^{\pm}\rightarrow J/\psi K^{\pm}$ used as normalization sample

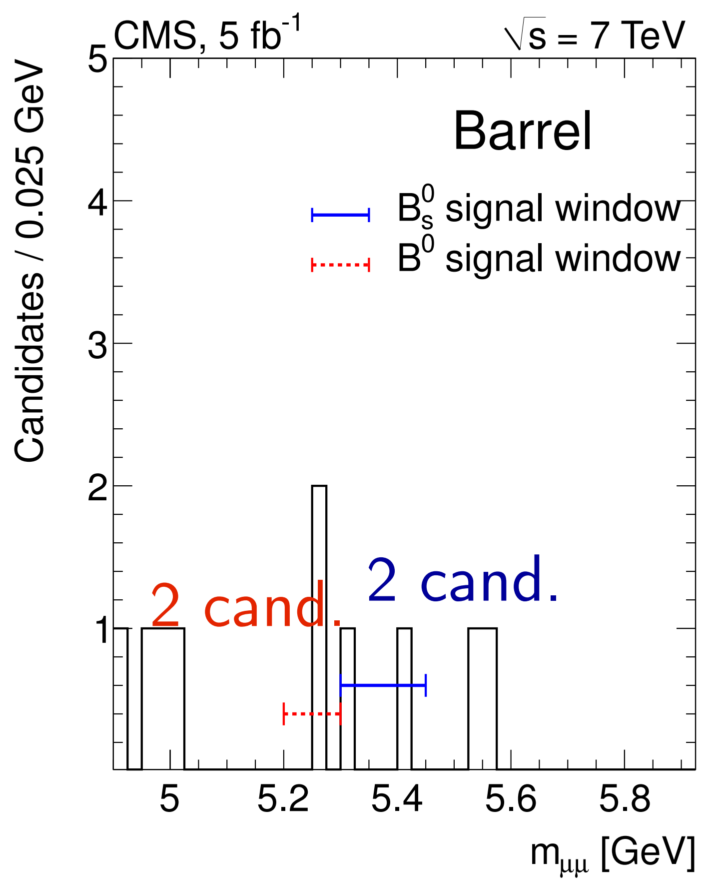


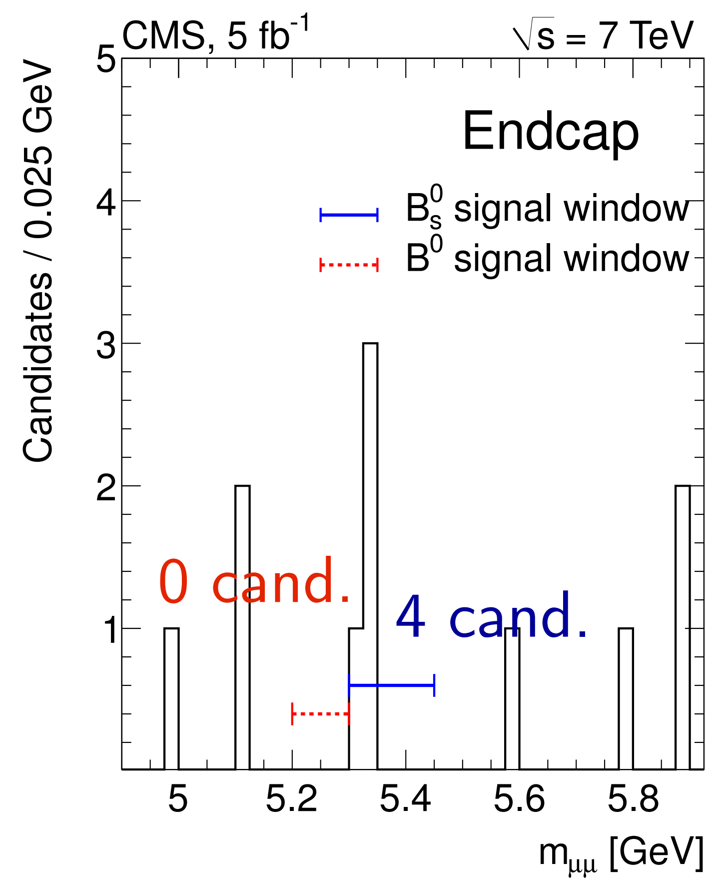




CMS results

CMS: 2011 data 5 fb^{-1} [JHEP 04(2012), 033]



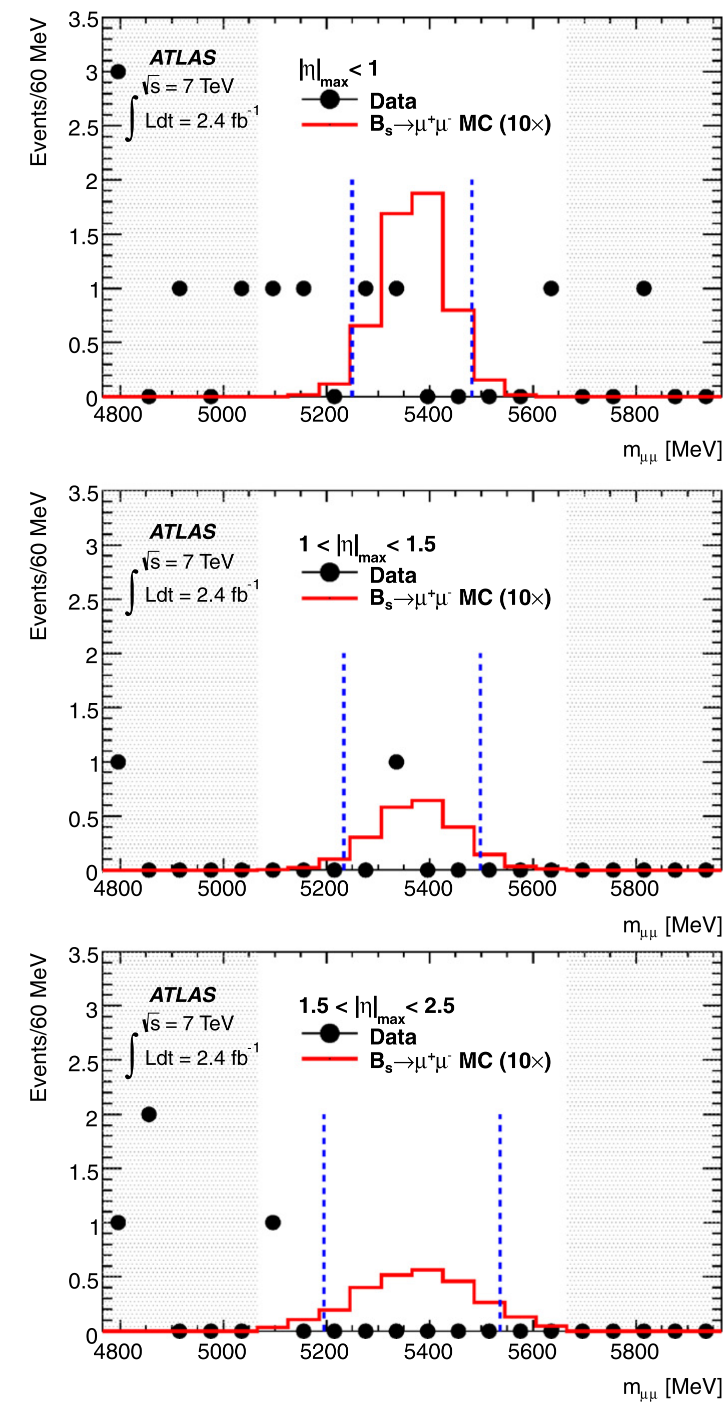


decay	Expected (95% CL)	Observed (95% CL)	Bkg-only p-value
B0→ μ+μ−	16×10^{-10}	18×10^{-10}	11% (1.2σ)
B0s→ μ+μ−	8.4×10^{-9}	7.7×10^{-9}	24% (0.7σ)

Atlas

ATLAS: 2011 data 2.4 fb^{-1} [PLB713(2012)387]

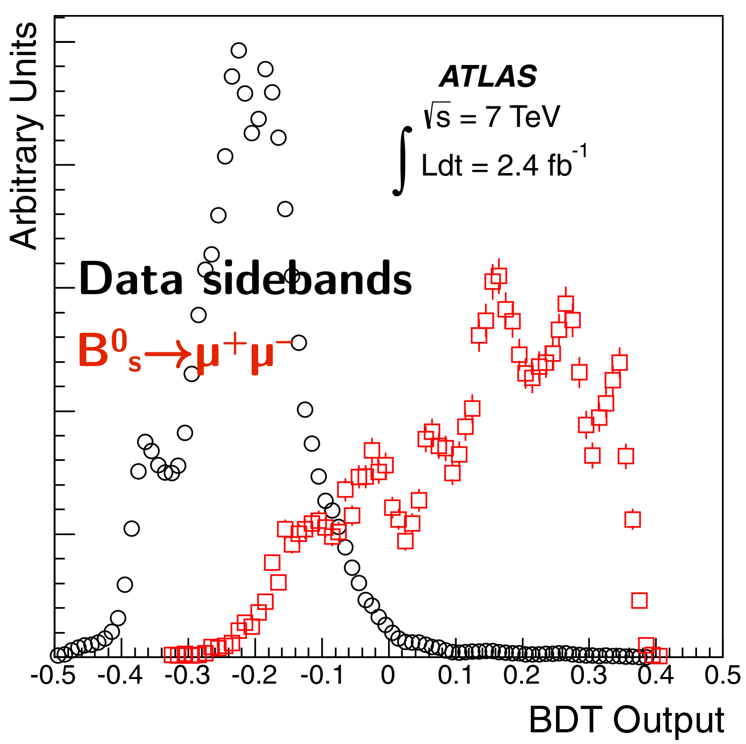
- Atlas divide the sample in 3 pseudo-rapidity (η) regions with different mass σ (mass windows ranging from 116-171 MeV/c^2)
- Multivariate classifier (BDT) is used for bkg/signal discrimination.
- The results normalized to $B^{\pm} \to J/\psi K^{\pm}$ (between 1100 and 4300 candidates) in order to reduce systematic uncertainties
- CLs method to evaluate the UL

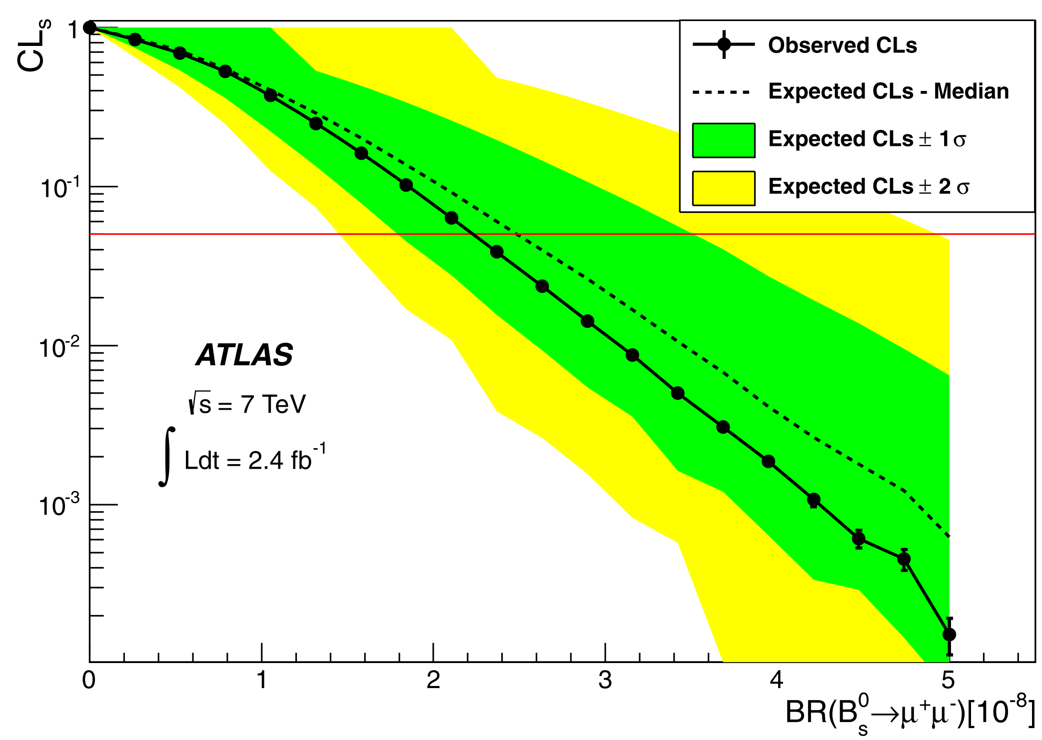


Atlas:

Expected: BR($B^0_s \to \mu^+\mu^-$) < 23 x 10^{-9} at 95% CL

Observed: BR($B^0_s \to \mu^+\mu^-$) < 22 x 10^{-9} at 95% CL

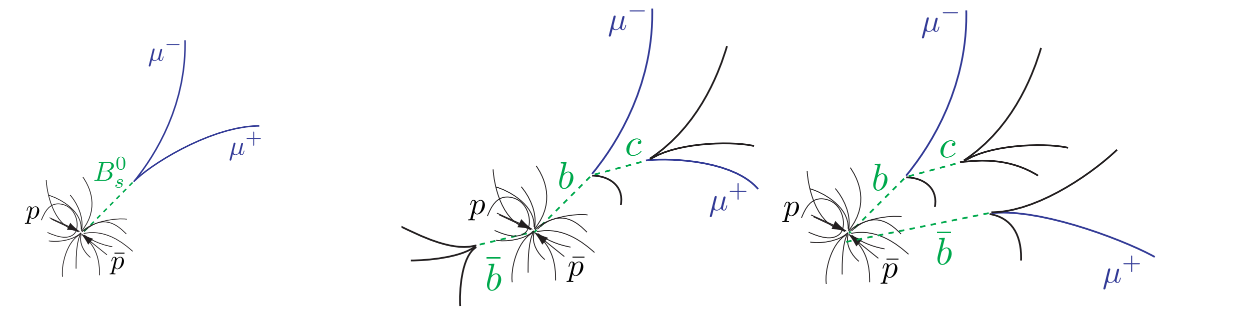




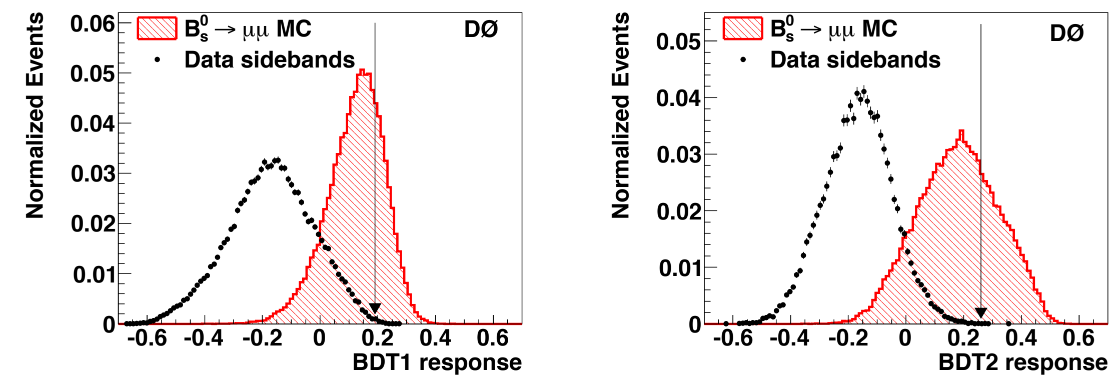
$B_s \to \mu\mu$ @ D0

D0: 10.4 fb^{-1} [http://arxiv.org/abs/1301.4507]

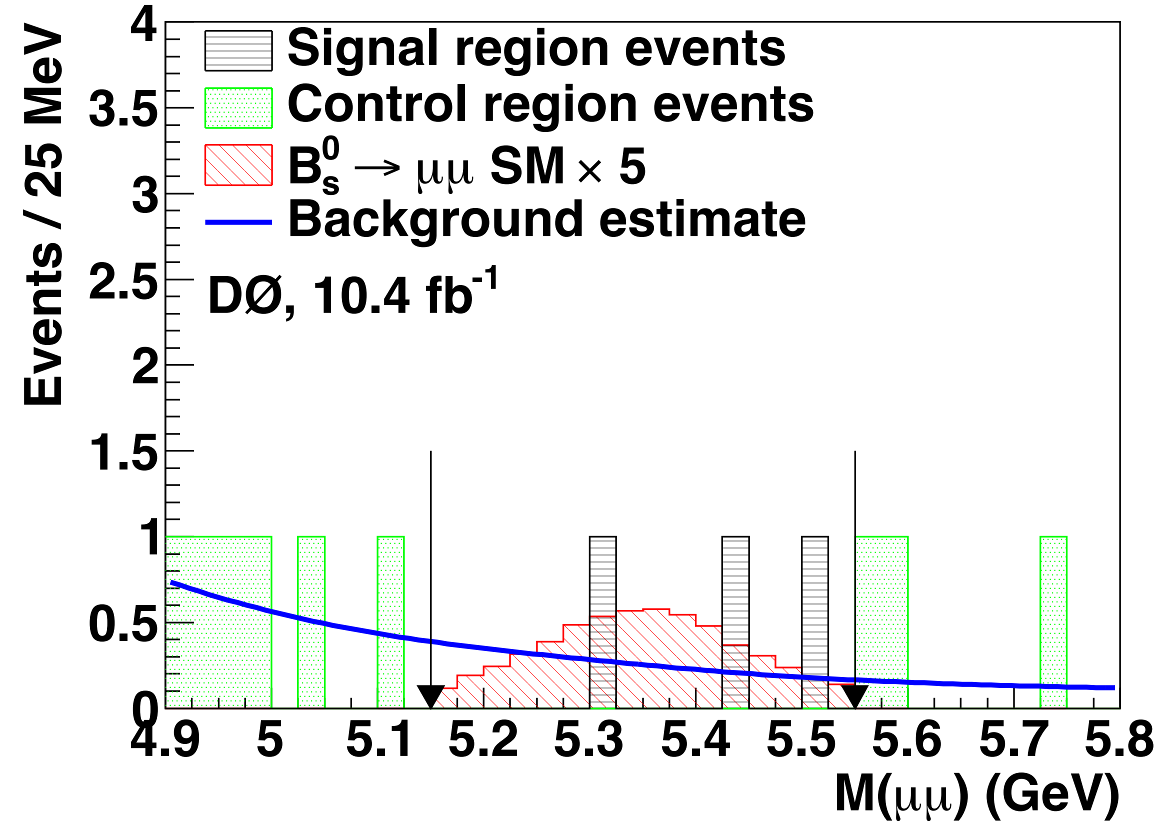
signal topology   sequential B decays   double semileptonic



- 2 different multivariate classifier (BDT) are used to increase the background reduction
- Determination of bkg from data SB fit
- The results normalized to $B^{\pm} \to J/\psi K^{\pm}$ in order to reduce systematic uncertainties.
- Signal/Bkg yields
  - -SM signal: 1.23 ± 0.13
  - -Bkg: 4.3 ± 1.6
  - -Exp. Limit $BR(B^0_s \to \mu^+\mu^-) < 23 \times 10^{-9}$ @95% CL



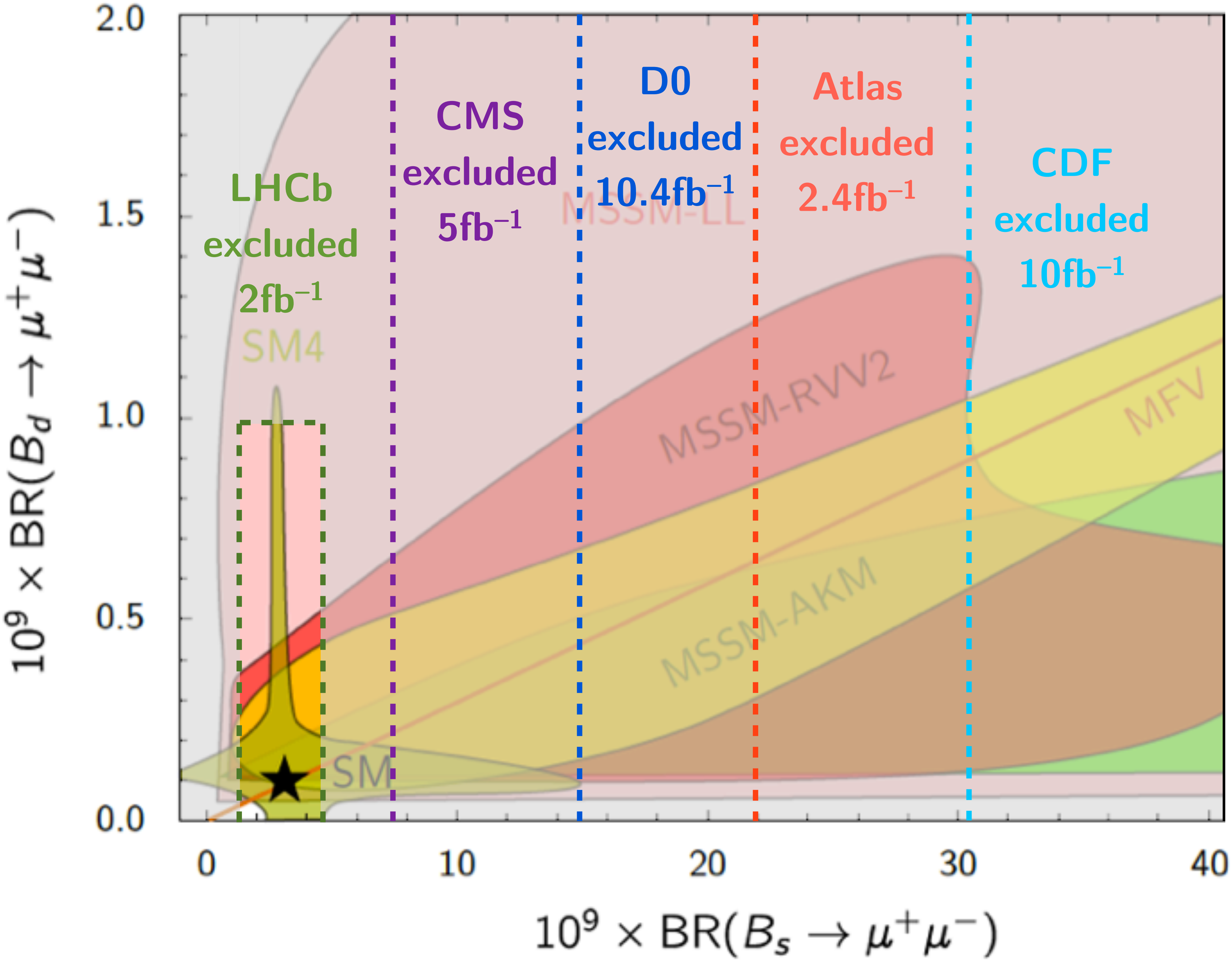
- **Observed 3 events:**
  $BR(B^0_s \to \mu^+\mu^-) < 15 \times 10^{-9}$ @95% CL



- To be compared with CDF single sided result:
  $BR(B^0_s \to \mu^+\mu^-) < 31 \times 10^{-9}$ @95% CL

http://www-cdf.fnal.gov/physics/new/bottom/120209.blessed-bmumu10fb/

Bs→μμ overview



CP asymmetry in $B^0 \to K^{0*}\mu\mu$

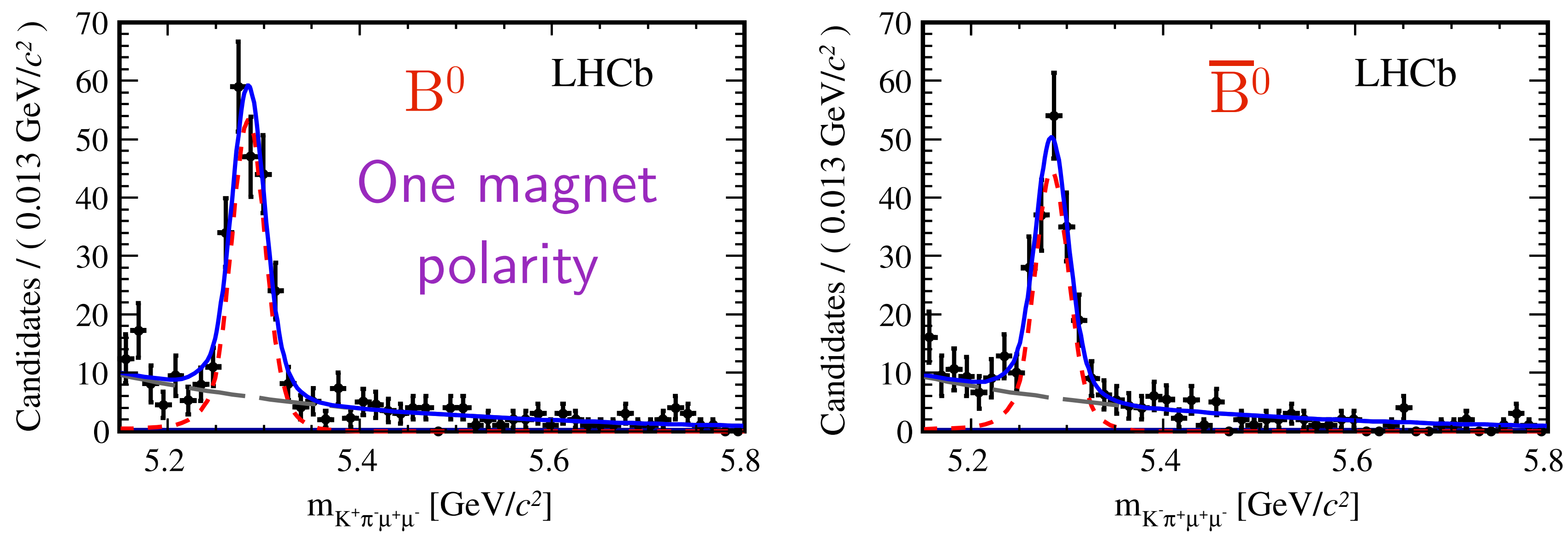
Phys.Rev.Lett 110, 031801 (2013)

CP asymmetry is predicted to be $O(10^{-3})$ in SM. Could be significantly enhanced in NP models (modifying the mixture of vector and axial vector components in the operator basis)

$$\mathcal{A}_{CP} = \frac{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\mu^+\mu^-) - \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}{\Gamma(\bar{B}^0 \to \bar{K}^{*0}\mu^+\mu^-) + \Gamma(B^0 \to K^{*0}\mu^+\mu^-)}$$

LHCb analysis based on $1\,fb^{-1}$ data recorded during 2011

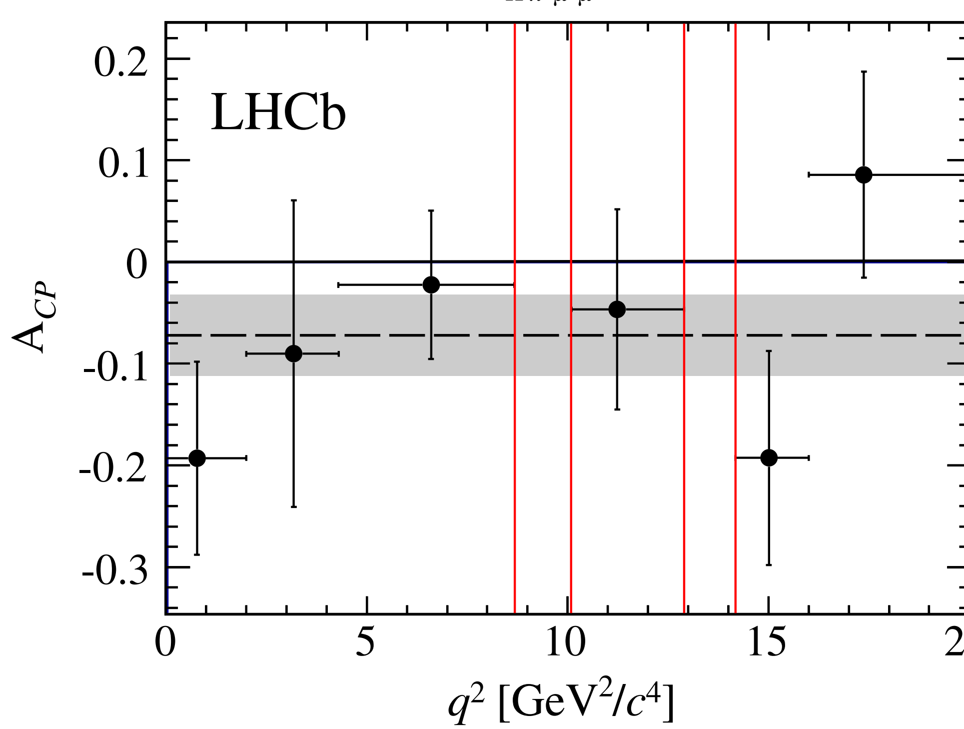
- self tagging from the kaon charge
- average data over two mag. pol.
- correct the observed asymmetry for production and detection asymmetry with $B^0 \to K^{0*} J/\psi$



- CP asym. extracted from simultaneous unbinned fit to the B^0 mass in $B^0 \to K^{0*} J/\psi$ and $B^0 \to K^{0*}\mu\mu$ in bins of q^2 (di-μ mass squared) and magnet polarity
- integrated result over q^2:

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\mu^+\mu^-) = -0.072 \pm 0.040 \pm 0.005$$

- consistent with SM 1.8σ
- most precise measurement to date

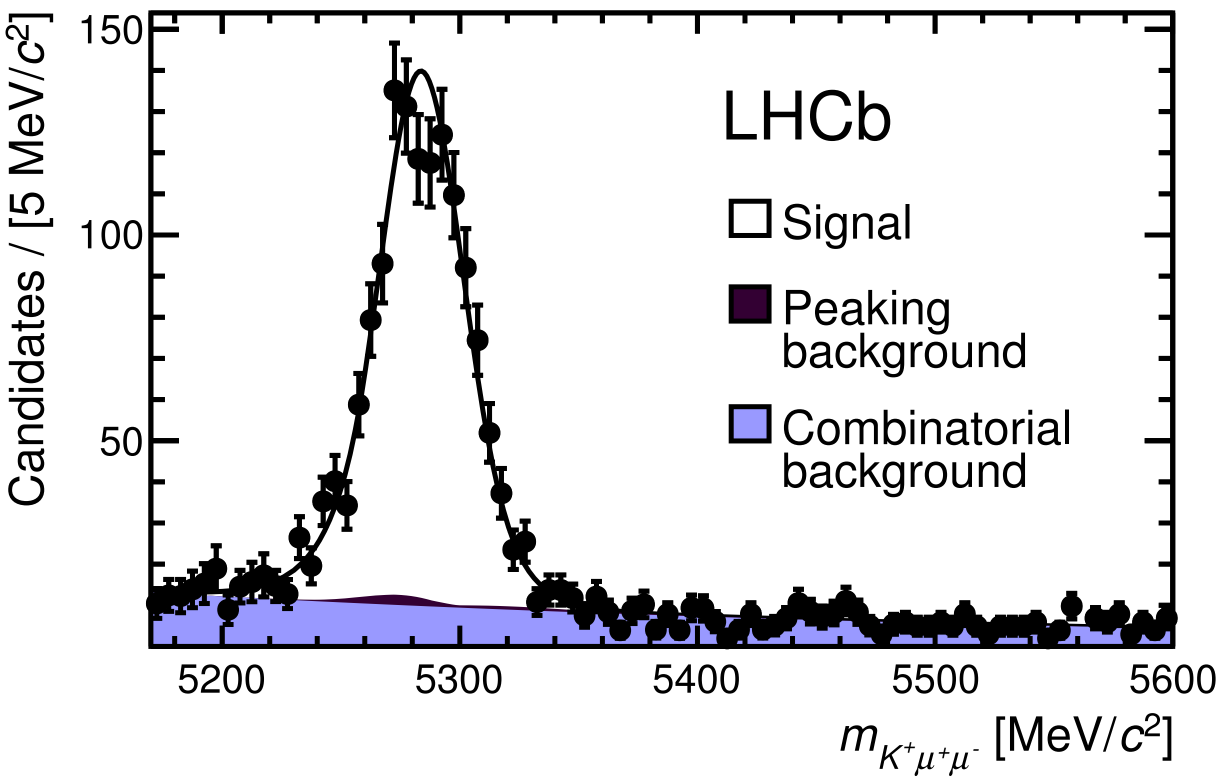


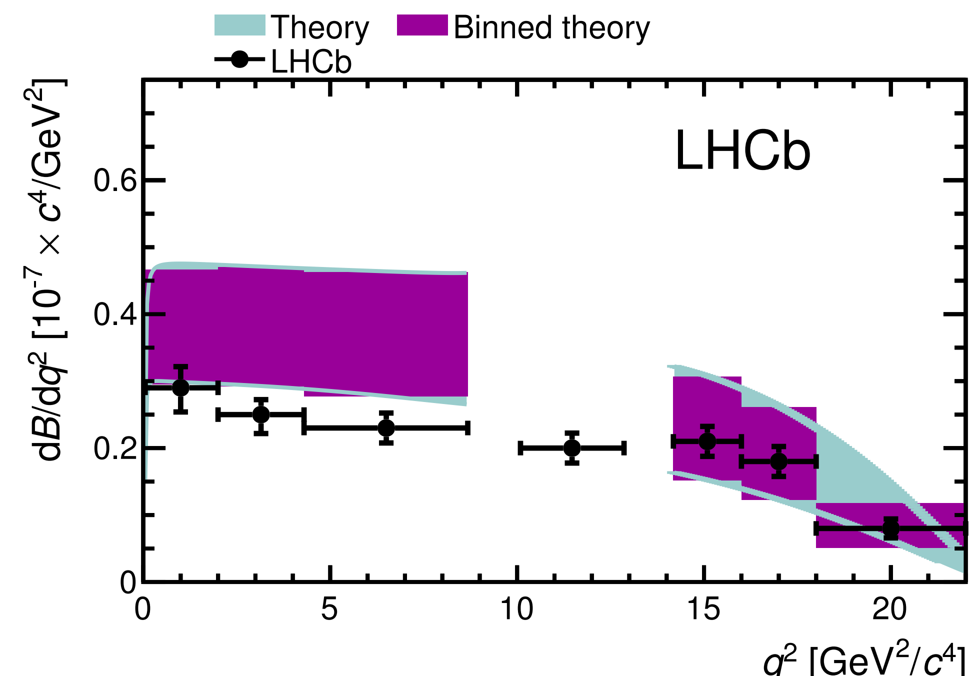
Differential BR($B^+ \to K^+\mu^+\mu^-$)

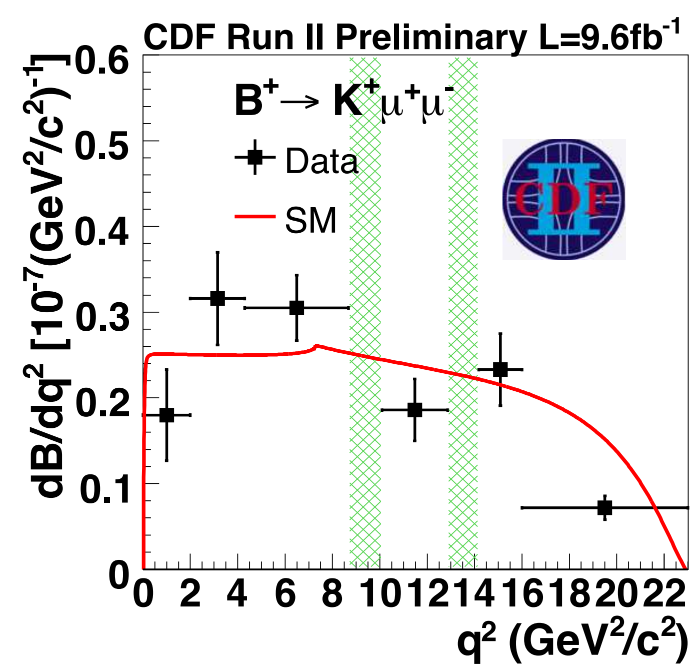
JHEP 02 (2013) 105

LHCb analysis based on 1fb^{-1} data recorded during 2011

- ~1200 $B^+ \to K^+\mu^+\mu^-$
- measurement in 7 q^2 bins ($0.05<q2<22$ GeV^2)
- $B^+ \to K^+J/\psi$ sample used for normalization, BDT training and signal shape







http://www-cdf.fnal.gov/physics/new/bottom/120628.blessed-b2smumu_96/public_b2smumu.pdf

- Results consistently below the SM in low q^2.
- Integrated BR in full q^2 range:

$$BR(B^+ \to K^+\mu^+\mu^-) = (4.36 \pm 0.15 \pm 0.18)\times 10^{-7}$$

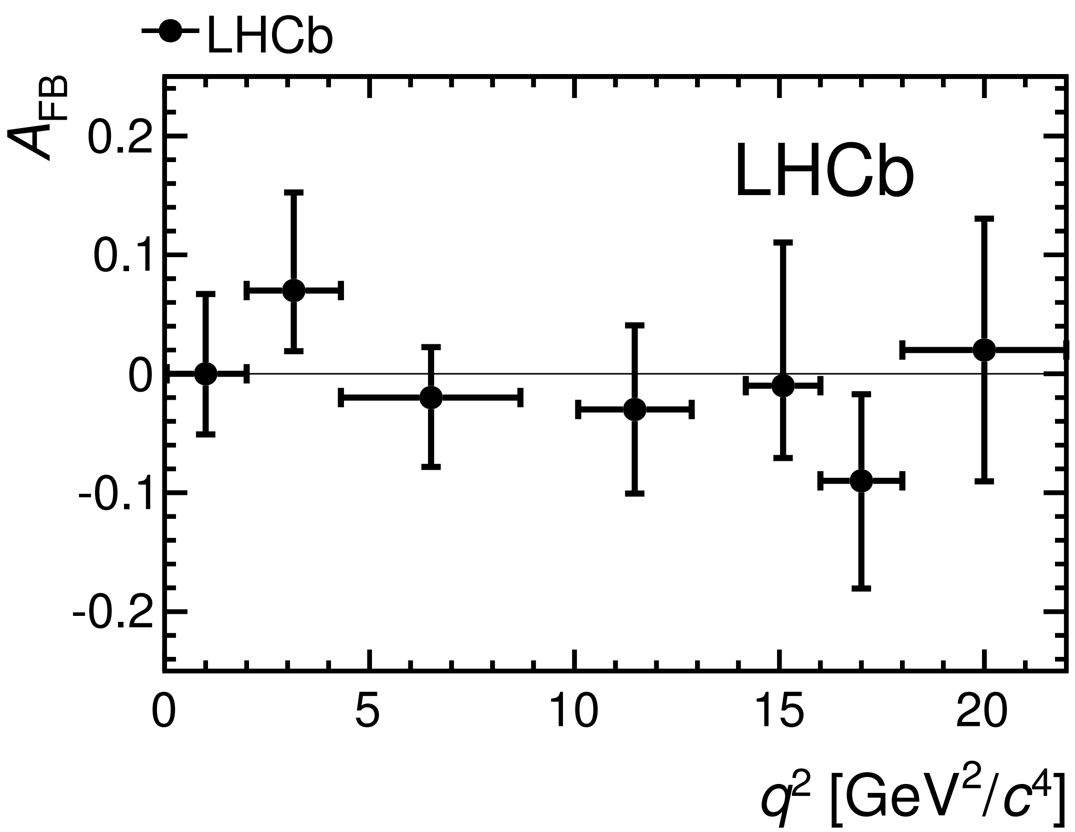
Angular analysis of $B^+ \to K^+ \mu^+ \mu^-$

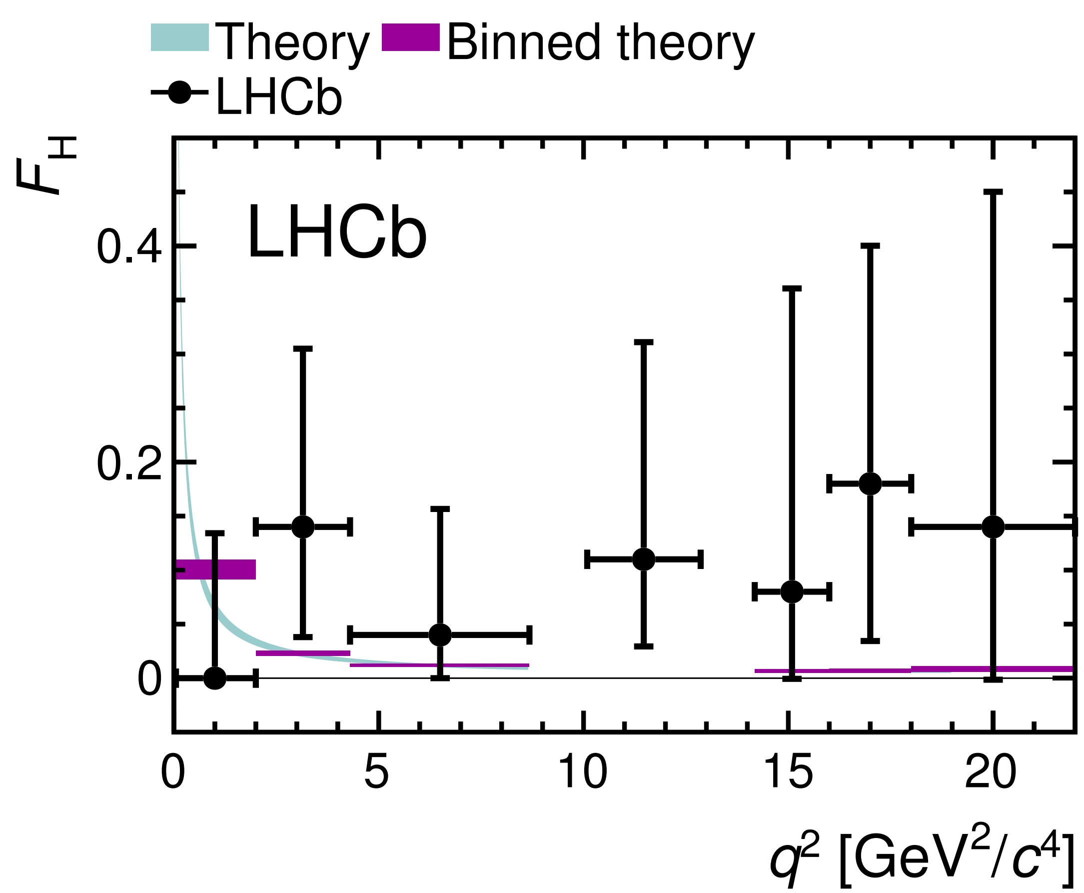
JHEP 02 (2013) 105

Differential decay rate:

$$\frac{1}{\Gamma}\frac{\mathrm{d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{\mathrm{d}\cos\theta_l} = \frac{3}{4}(1-F_{\mathrm{H}})(1-\cos^2\theta_l) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_l$$

- SM predictions fot $A_{FB} = 0$ and $F_H \sim 0$. Sensitive to NP scenarios with scalar and pseudoscalar or tensor-like couplings
- A_{FB} and F_H measured in the 7 bins of q^2 by likelihood fit in $m_{K\mu\mu}$ and $\cos_{\theta l}$





- Results consistent with the SM expectations

$B^{\pm} \to \pi^{\pm}\mu\mu$

JHEP 12 (2012) 125

In SM $b \to dl^+l^-$ transition even more suppressed by $|V_{td}|/|V_{ts}|$ with respect $b \to sl^+l^-$, never observed before. Could receive contribution from RPV terms in SUSY

SM prediction:

$BR(B^+ \to \pi^+\mu^+\mu^-) = (1.96 \pm 0.21) \times 10^{-8}$

Prev. Exp.:

$BR(B^+ \to \pi^+\mu^+\mu^-) < 6.9 \times 10^{-8}$

(Belle Phys. Rev. D77 (2008) 014017)

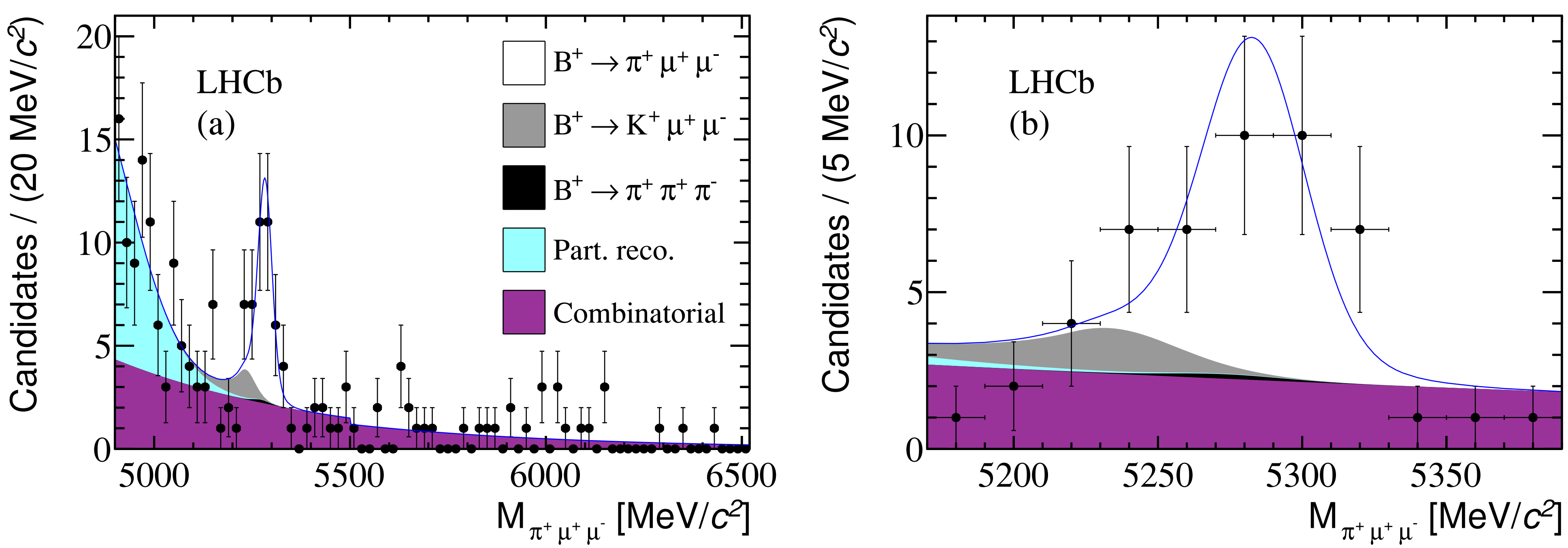
LHCb has seen this decay in $1 fb^{-1}$

Observed $25.3^{+6.7}_{-6.4}$ events

$BR(B^+ \to \pi^+\mu^+\mu^-) = (2.3 \pm 0.6_{stat} \pm 0.1_{syst}) \times 10^{-8}$

5.2σ excess

Nicely match with SM prediction



Interesting possibilities to search for light scalars in penguin B decays

Conclusions

▸**Tevatron opened the way to high precision Heavy Flavor physics at collider experiments, both through detector and trigger strategies and through advanced analysis techniques.**

▸**Heavy flavour physics at collider has been demonstrated to be fully competitive especially for hadronic modes and very rare decays.**

▸**Indirect approach to new physics in FCNC transitions fully exploited at hadron colliders:**

▸**$B_s \to \mu\mu$ evidence found at LHCb.**

▸**Agreement with the SM is excellent → large NP contribution ruled out in many cases.**

▸**The search has just started. Atlas CMS and LHCb have large amount of data to analyze and more will be collected in the next future.**

Spares

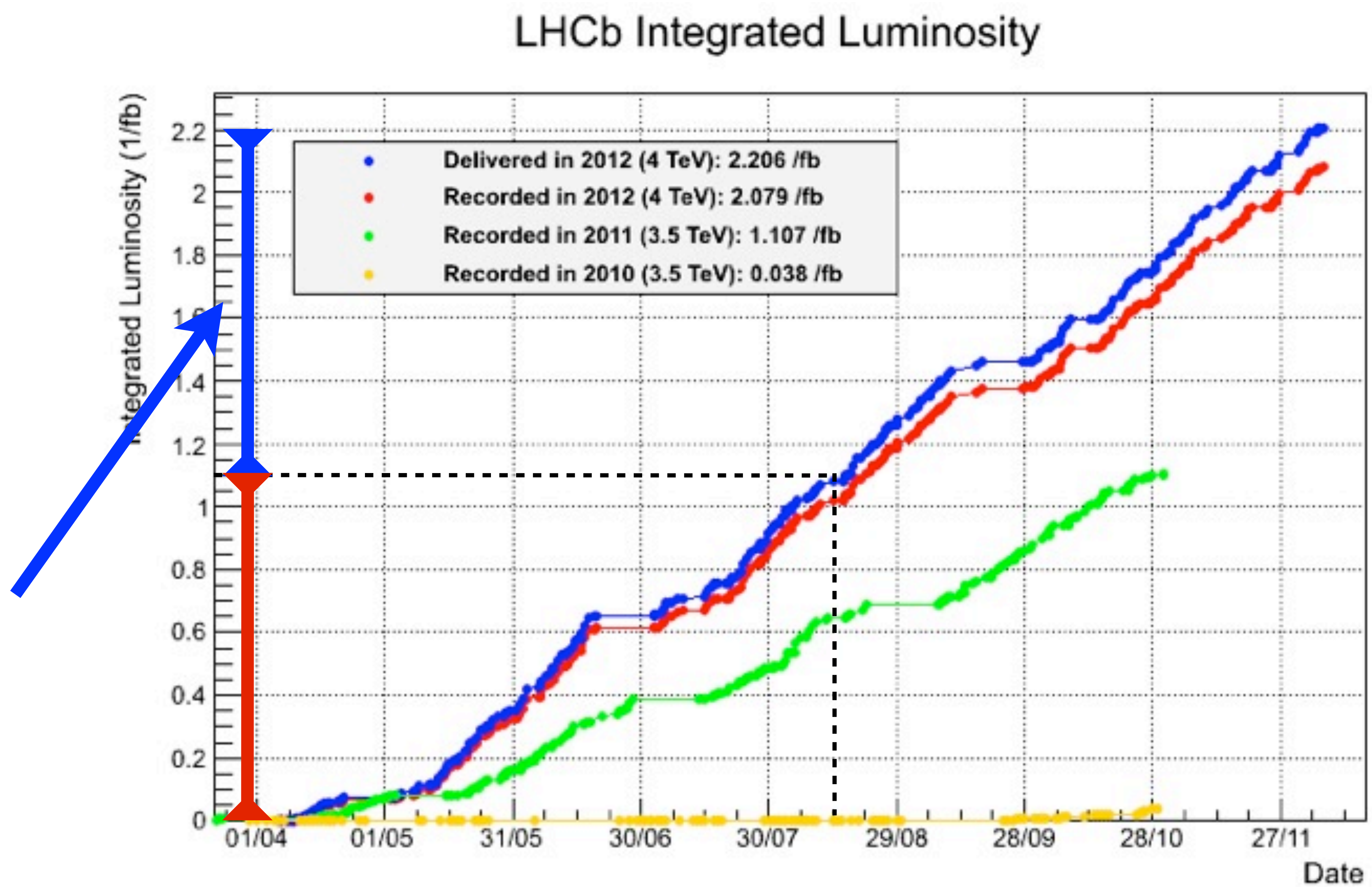
Datasets

The updated $B^0_{(s)} \to \mu^+\mu^-$ search uses the following datasets:

1.0 fb^{-1} at 7 TeV (2011) + 1.1 fb^{-1} at 8 TeV (2012)

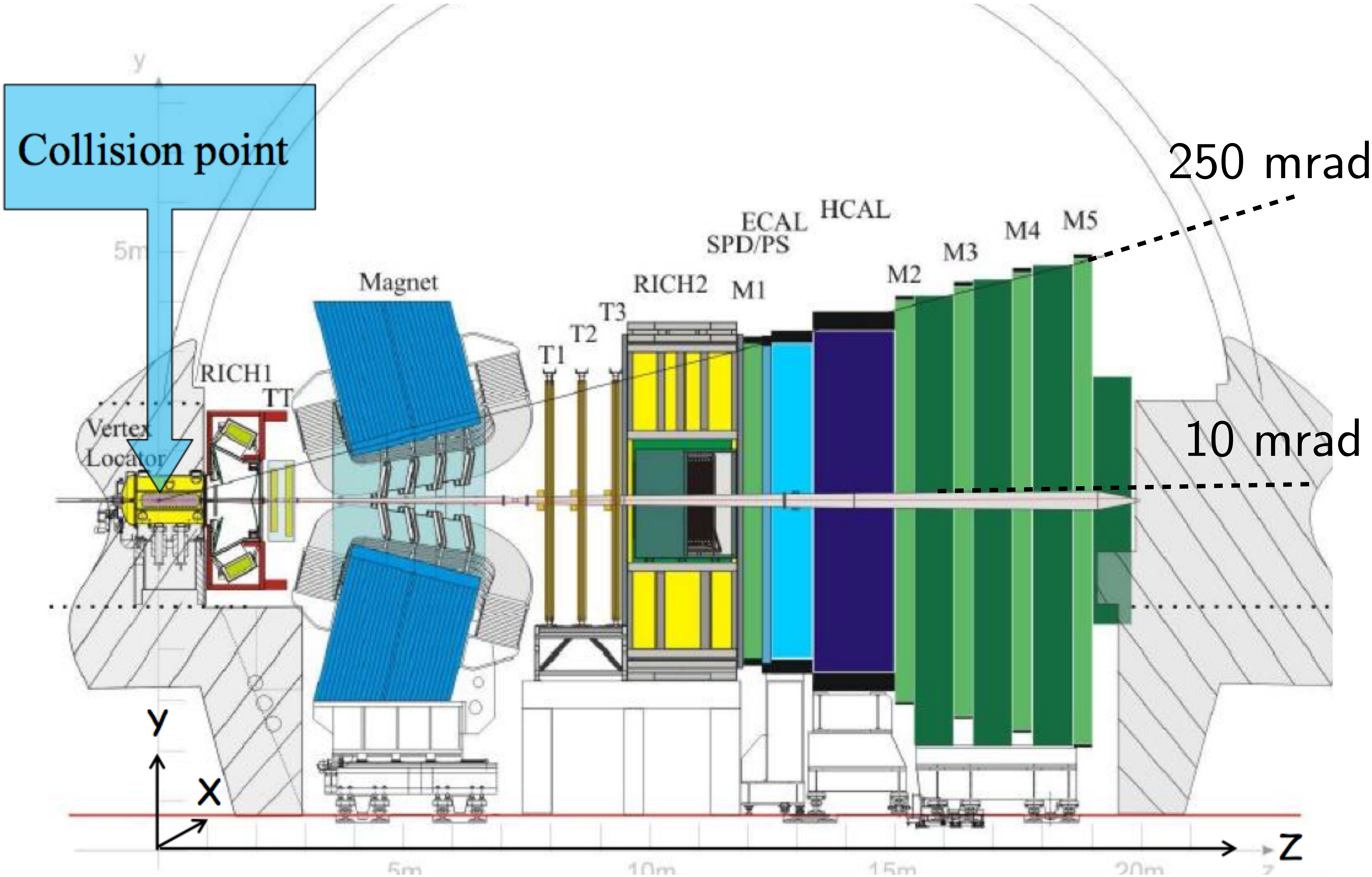
2012: another great year of data taking thanks to the performance of LHC!

additional 1.1 fb^{-1} to be analyzed



7 TeV data already published in PRL 108 (2012) 231801 **is reanalyzed** as part of the measurement presented here; <u>the result supersedes the previous publication</u>

LHCb detector



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

1) Managed to run the experiment at 4×10^{32} $cm^{-2}s^{-1}$ with 1262 colliding bunches (twice the design luminosity with half number of bunches)

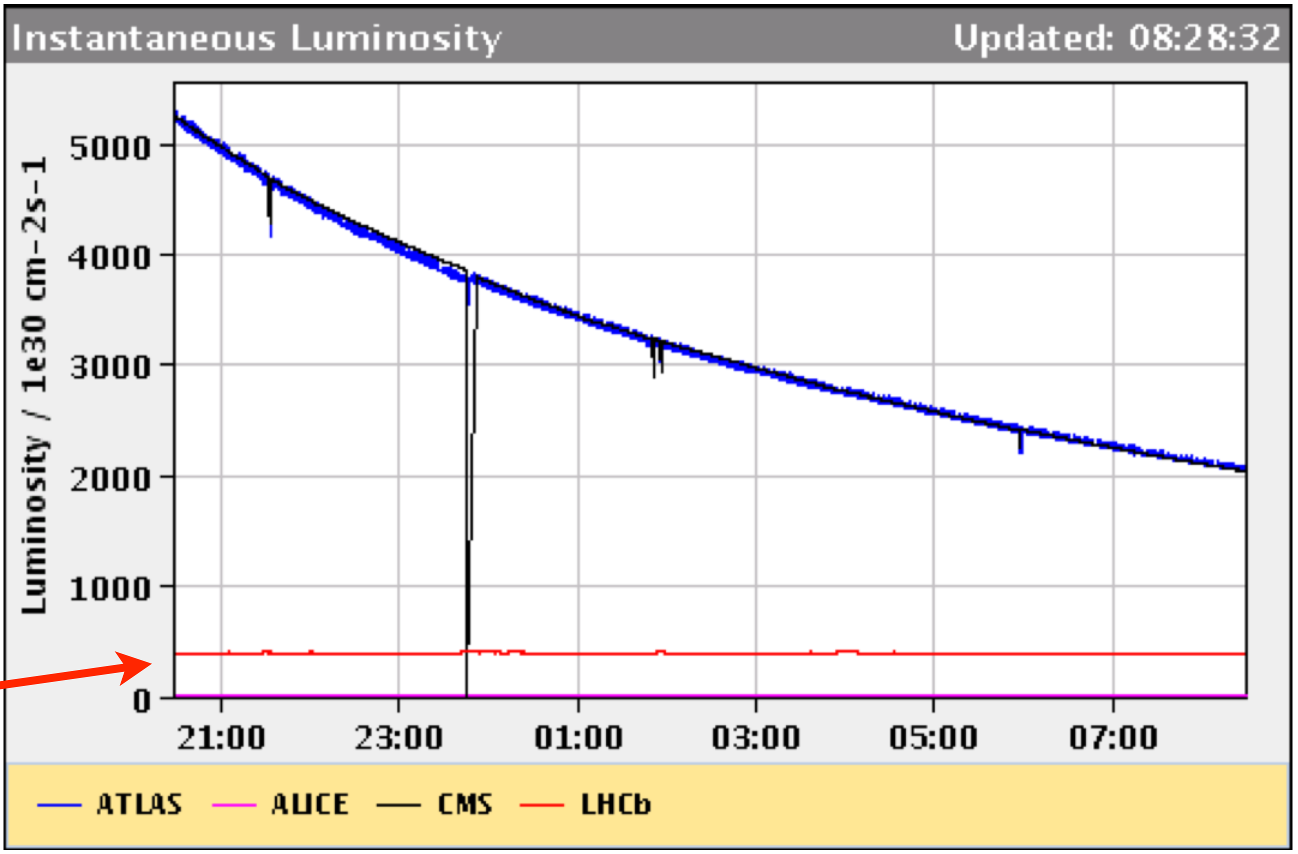
→ **4 times more collisions per crossing than design: $<\mu>_{8TeV}\sim1.7$**

→ higher occupancy in the detector

→ challenging for the trigger

2) Large acceptance, efficient muon trigger

- **acceptance × reconstruction efficiency for signal is ~10%**
- L0: single μ $p_T>1.76$ GeV/c, di-μ $\sqrt{(p_{T1} * p_{T2})}>1.6$GeV/c
- HLT: IP and invariant mass cuts
- **overall trigger efficiency ~90%**



LHCb instantaneous luminosity: leveling @ work!

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

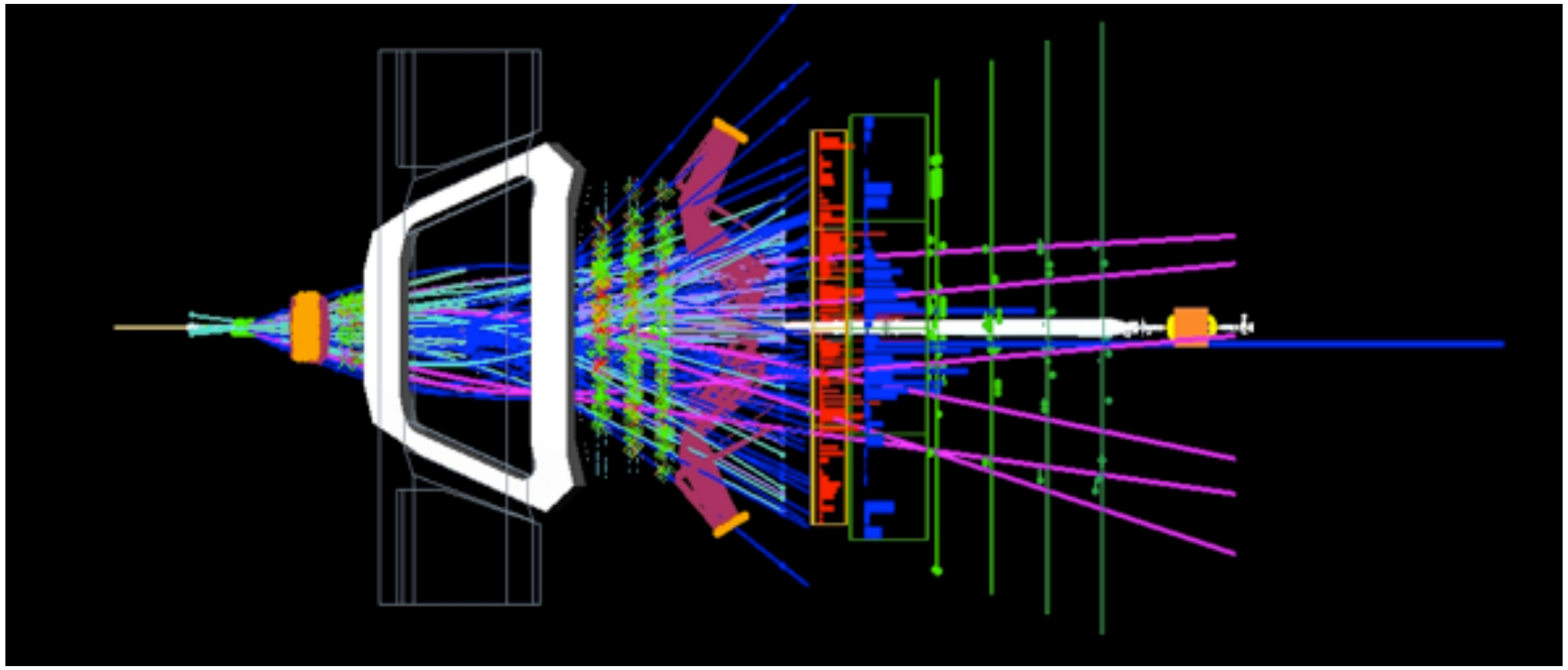
3) Background reduction:

- Very good momentum resolution : $\delta p/p \sim 0.4\% \rightarrow 0.6\%$ for p=(5-100) GeV/c
- Muon identification: matching between tracks reconstructed in the spectrometer and hits in the muon stations + moderate requirements on global PID likelihood (RICH+CALO+MUON):

for this analysis: $\varepsilon(\mu\rightarrow\mu)\sim 98\%$, $\varepsilon(\pi\rightarrow\mu)\sim 0.6\%$, $\varepsilon(K\rightarrow\mu)\sim 0.3\%$, $\varepsilon(p\rightarrow\mu)\sim 0.3\%$

4) Excellent vertex and IP resolution:

- to separate signals from background : $\sigma(IP)\sim 25$ μm @ p_T=2 GeV/c



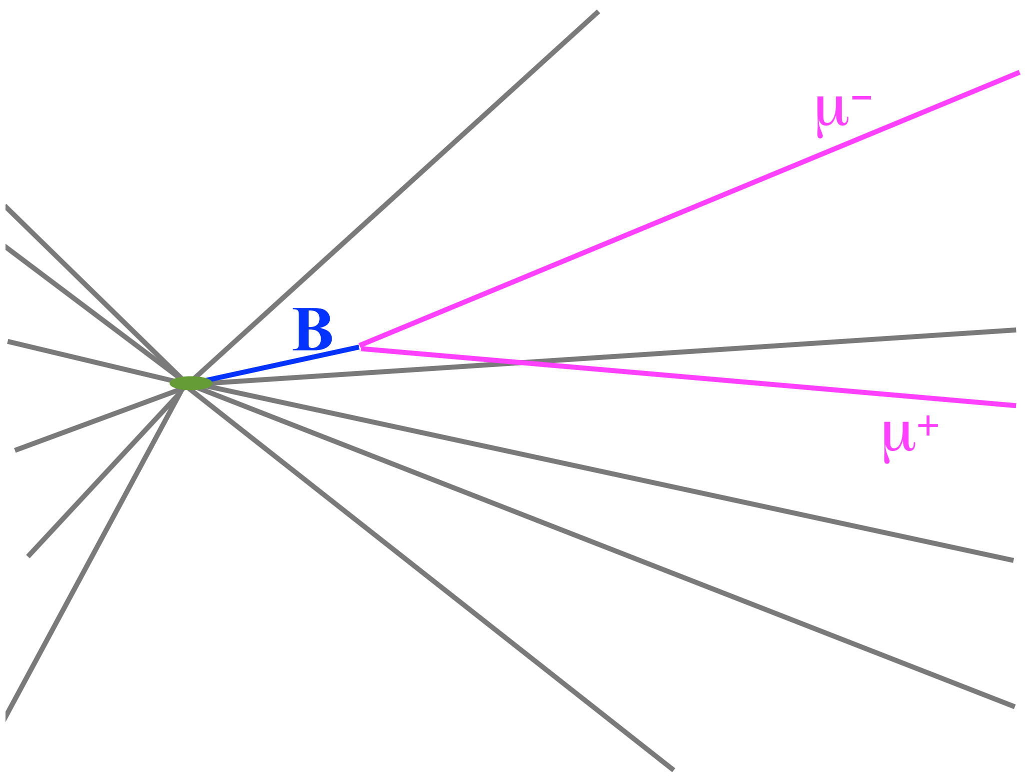
~1.7 pp interactions per Xing

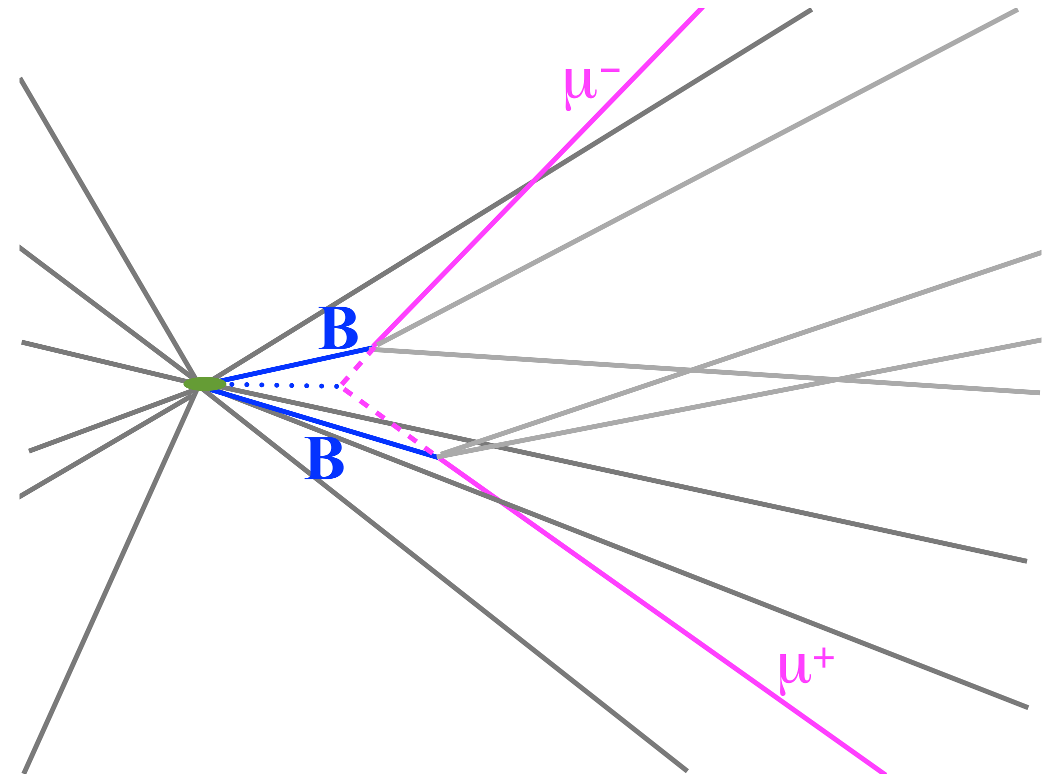
11+14 SM events expected in 1.0 fb^{-1} +1.1 fb^{-1}

Signal discrimination: BDT

signal: 2 muons from a single well reconstructed secondary vertex

dominant background: two real muons from $bb \to \mu^+\mu^- X$





Discrimination is achieved by a BDT with 9 input variables

B candidate:

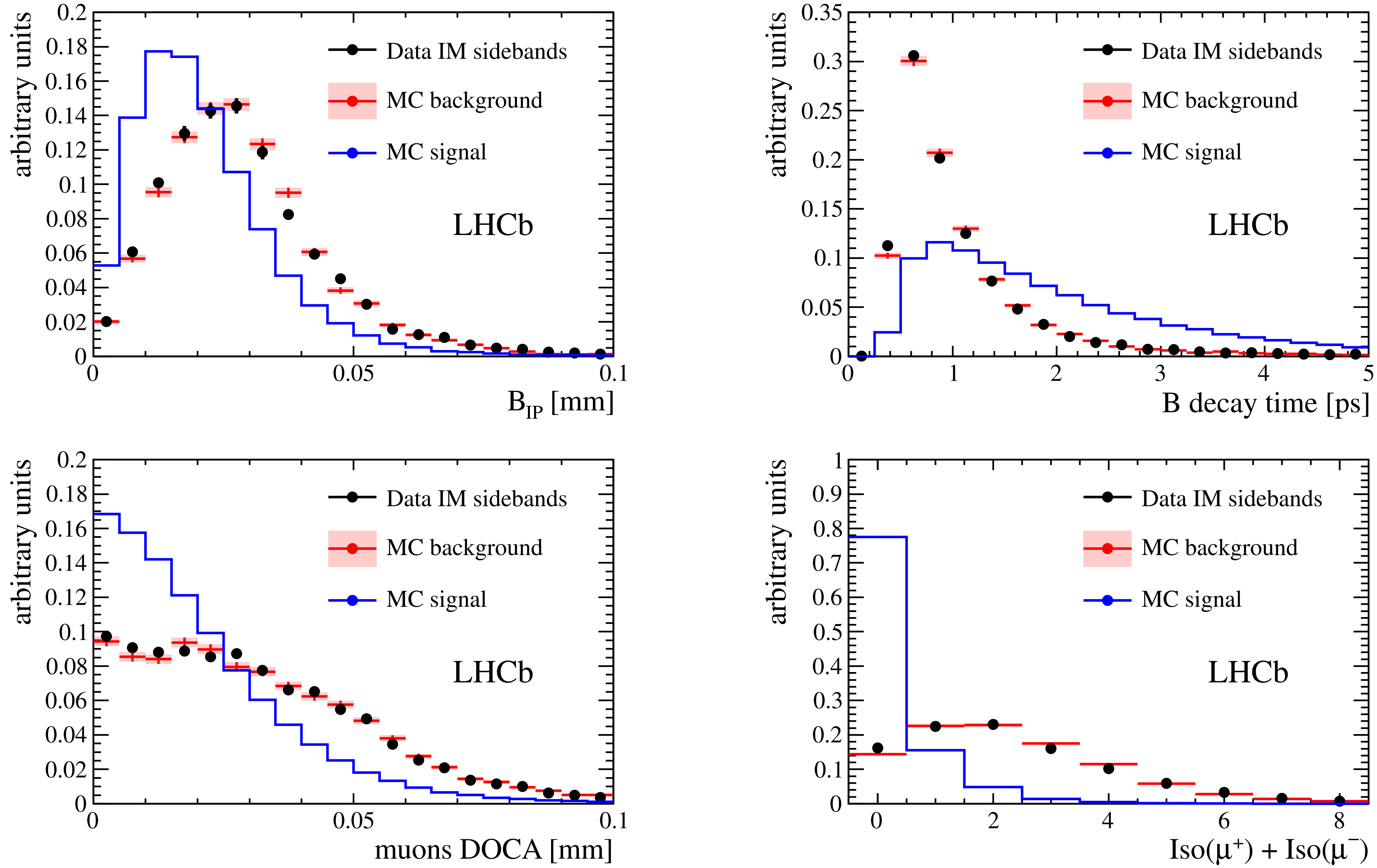
- proper time
- impact parameter
- transverse momentum
- B isolation

muons:

- min p_T
- min IP significance
- distance of closest approach
- muon isolation,
- cosP

this choice of variables avoids correlation with invariant mass

BDT variables



7 TeV data

Optimization and training on MC $B^0_s \to \mu^+\mu^-$ signal and $bb \to \mu^+\mu^- X$ background

Same definition of BDT is used for 7 TeV and 8 TeV data, since most of the input variables are in very good agreement (checked on $B^\pm \to J/\psi K^\pm$)

Normalization

$$\mathrm{BR} = \mathrm{BR}_{\mathrm{cal}} \times \frac{\epsilon_{\mathrm{cal}}^{\mathrm{REC}} \epsilon_{\mathrm{cal}}^{\mathrm{SEL|REC}}}{\epsilon_{\mathrm{sig}}^{\mathrm{REC}} \epsilon_{\mathrm{sig}}^{\mathrm{SEL|REC}}} \frac{\epsilon_{\mathrm{cal}}^{\mathrm{TRIG|SEL}}}{\epsilon_{\mathrm{sig}}^{\mathrm{TRIG|SEL}}} \times \frac{f_{\mathrm{cal}}}{f_{B_q^0}} \times \frac{N_{B_q^0 \to \mu^+\mu^-}}{N_{\mathrm{cal}}} = \alpha_{\mathrm{cal}} \times N_{B_q^0 \to \mu^+\mu^-}$$

Evaluated from MC, cross-checked with data

Measured on data

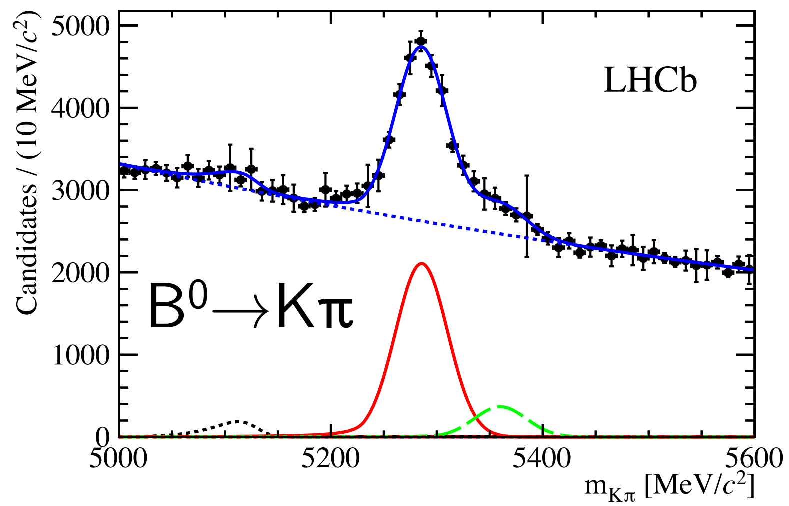
Ratio of probabilities for a b quark to hadronize to a given meson

Combined result at 7 TeV

$$f_s/f_d = 0.256 \pm 0.020$$

[PRD85 (2012) 032008]

[LHCb-PAPER-2012-037 submitted to JHEP]



$B^\pm \to J/\psi K^\pm$ and $B^0 \to K\pi$ channels give consistent results and averaged

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

8 TeV data

Assuming SM rates, after selection we expect in 7 TeV + 8 TeV data (1.0 + 1.1 fb^{-1}) ~11+13 $B^0_s \to \mu^+\mu^-$ and ~1.3+1.5 $B^0 \to \mu^+\mu^-$ **in signal region ($m(B^0_{(s)})$ ± 60 MeV/c^2)**

background estimation

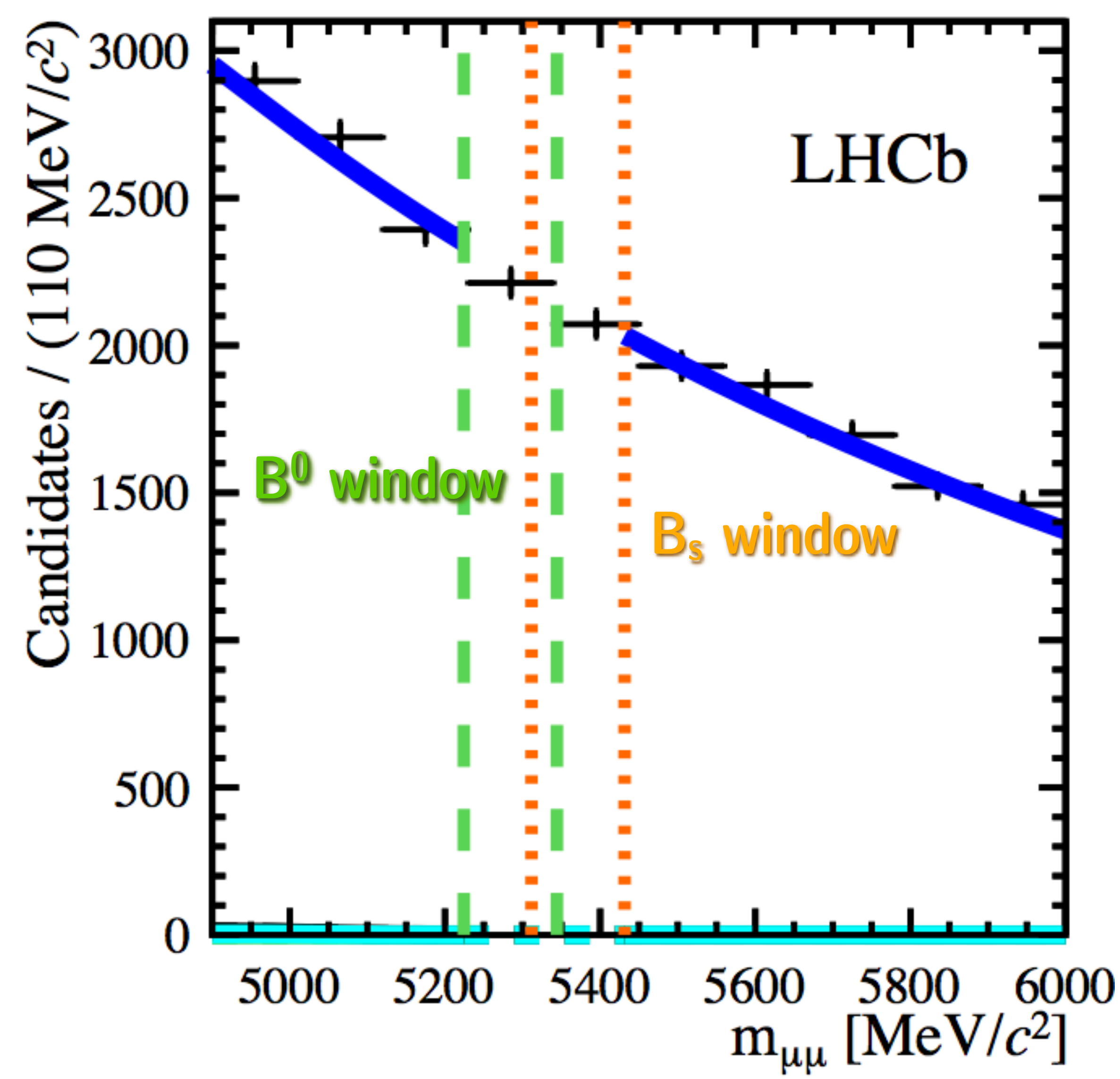
The main background source in the $B^0_{(s)} \to \mu^+\mu^-$ signal window, $m(B^0_{(s)}) \pm 60$ MeV/c^2, **is combinatorial from bb $\to \mu^+\mu^- X$**

For CLs computation, the expected background yield in the signal region is evaluated from a **fit to the mass sidebands**, for each BDT bin separately

An exponential shape is assumed

For BDT values <0.5 this is **by far the dominant bkg source** in the mass range [4900-6000] MeV/c^2

Three dominant sources of excl. background which can bias the combinatoral background interpolation, $B^0 \to \pi^-\mu^+\nu_\mu$ **and** $B^{+(0)} \to \pi^{+(0)}\mu^+\mu^-$, or give a significant contribution in the signal mass window $B^0_{(s)} \to h^+h'^-$ (**$4.1^{+1.7}_{-0.8}$ events in B_S win.** and **$0.76^{+0.26}_{-0.18}$ events in B^0 win.**)



$B_s \to 4\mu$

Bs→4μ in SM:

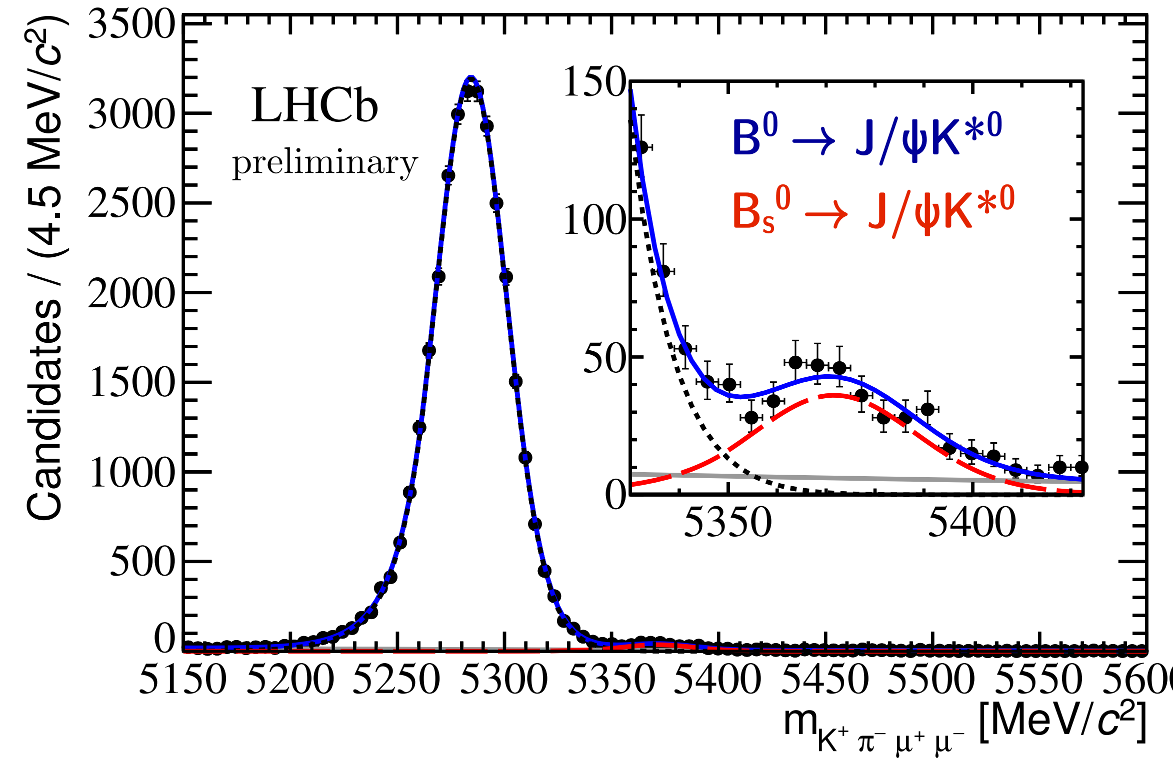
‣Resonant contribution $B_s \to J/\psi(\mu\mu)\phi(\mu\mu)$ which has a BR = $(2.3\pm0.9)\text{x}10^{-9}$

[Phys. Rev. D86 (2012) 010001]

‣Non resonant process with a virtual photon exchange BR~10^{-10}–10^{-11}

[D. Melikhov and N. Nikitin, Phys. Rev. D 70 (2004) 114028]

- **Possible enhances in NP scenarios (i.e. scalar–pseudoscalar sgoldstinos couple)**
- **Normalization on $B^0 \to J/\psi(\to\mu\mu)K^{*0}(\to K\pi)$**



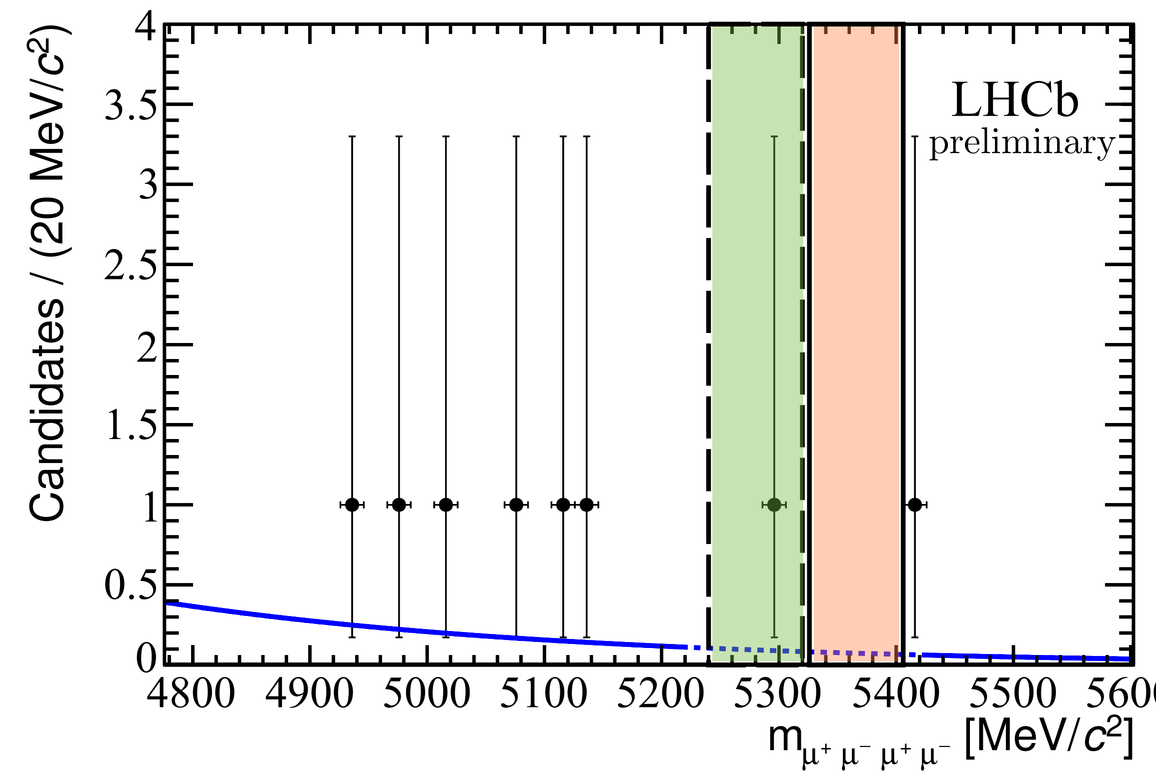
- **Result on 1 fb^{-1}: observed 1 event in B^0 window, 0 in B_s^0. Consistent with expected bkg.**
- [preliminary] Limits at 95(90)% C.L.:

‣**$BR(B_s^0 \to 4\mu) < 1.6\ (1.2) \cdot 10^{-8}$**

‣**$BR(B^0 \to 4\mu) < 6.6\ (5.3) \cdot 10^{-9}$**

Paper in preparation

First experimental limit to date



$K_S \to \mu\mu$

- The rare decays $K_S \to \mu^+\mu^-$ are a very useful source of information on the short-distance (box and penguin) structure of $\Delta S = 1$ FCNC transitions.
- SM prediction:

  $$\mathbf{BR(K_S \to \mu^+\mu^-) = (5.0 \pm 1.5) x 10^{-12}}$$

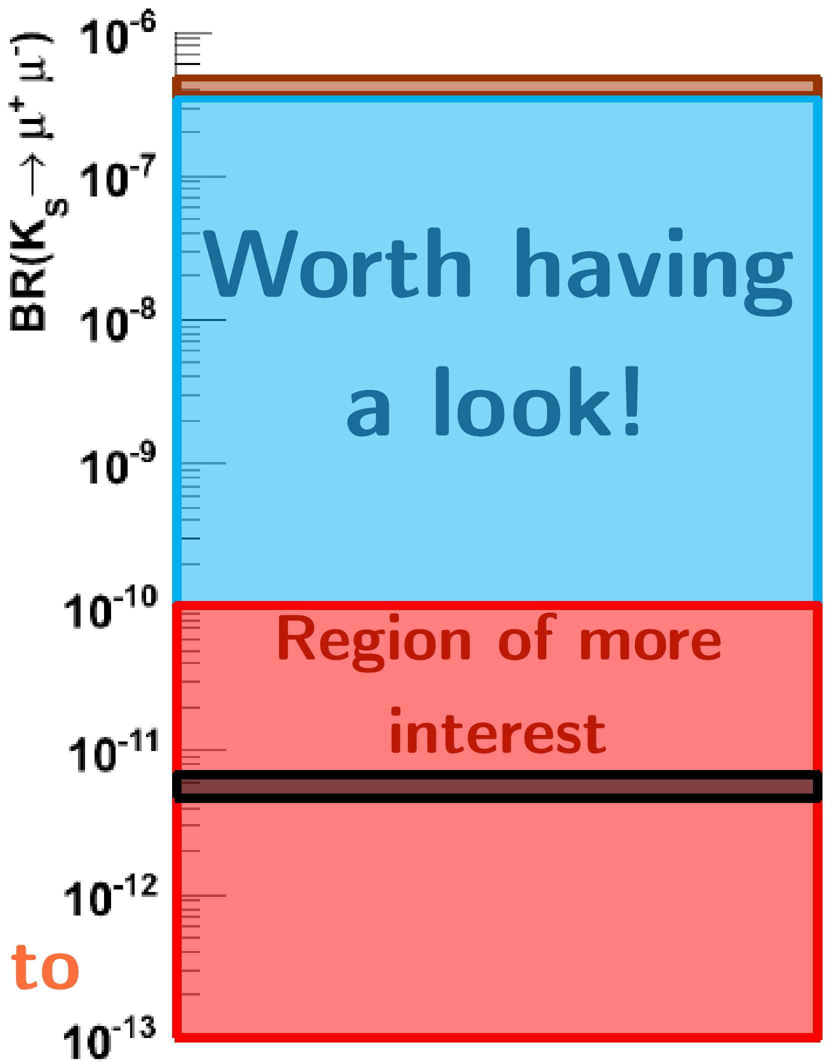
  [G. Ecker, A. Pich, Nuclear Physics B 366 (1991), G. Isidori, R. Unterdorfer, JHEP 0401 (2004)]

- Experimental status: **current limit from 1973**

  $$\mathbf{BR(K_S \to \mu^+\mu^-) < 3.2 \text{ x } 10^{-7} \text{ @ } 90\% \text{ of C.L.}}$$

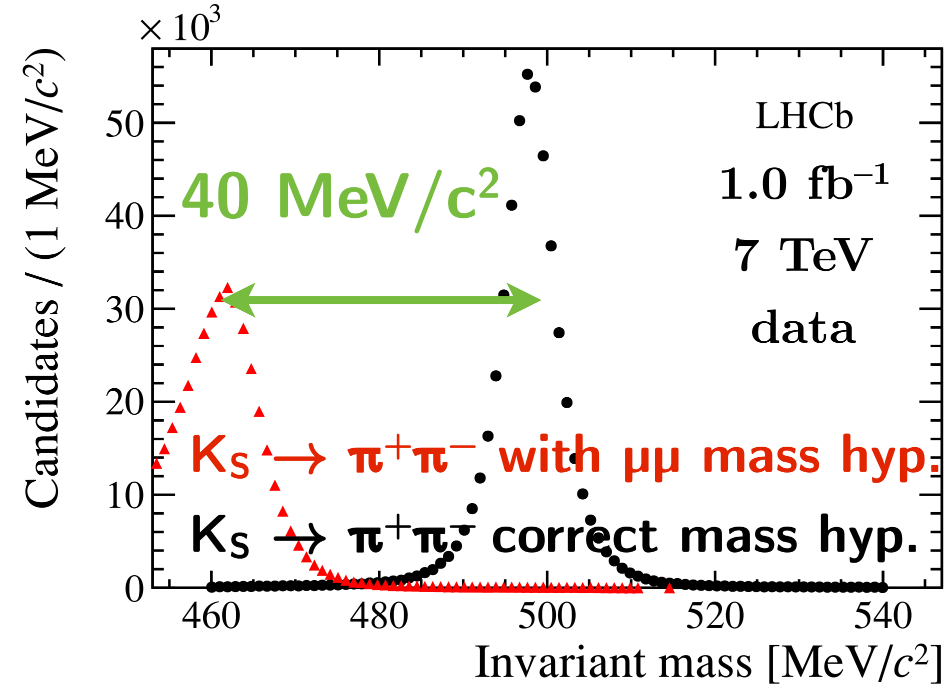
  [S. Gjesdal, J. Steinberger et al, Physics Letters B, 44 (1973)]

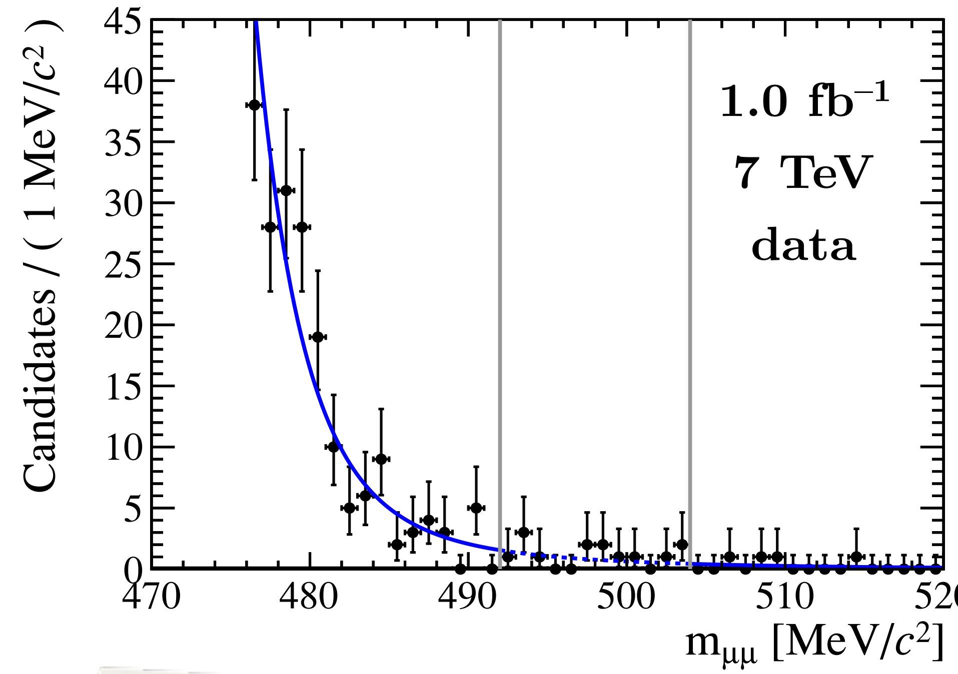
- **Comparison with $K_L \to \mu^+\mu^-$ can reveal effects due to new light scalars and bounds at 10^{-11} level constrain CP violating phase from $s \to d\ell\ell$ (E.g.: $K \to \pi\nu\nu$)**

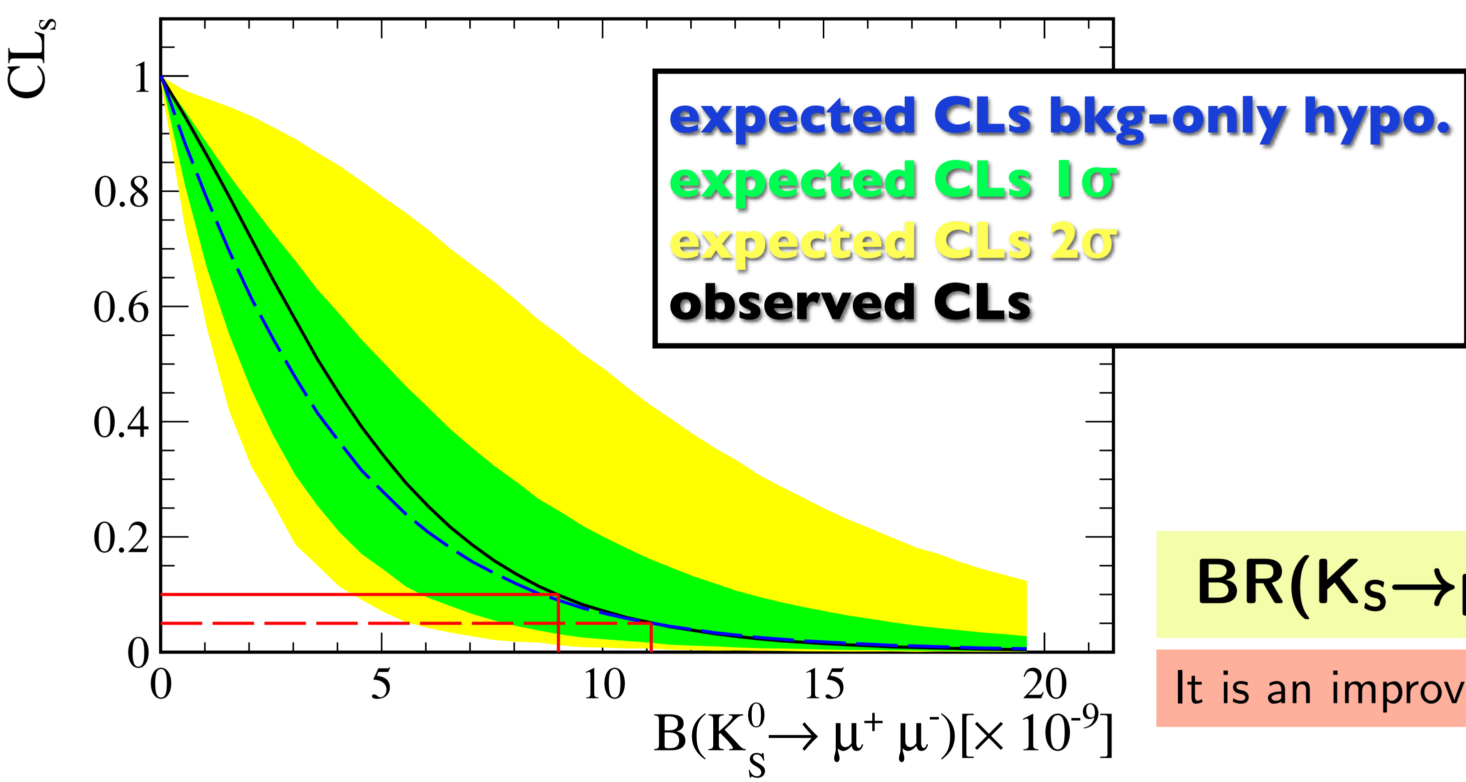


$K_S \to \mu\mu$

- Blind analysis on 1fb^{-1} of data collected during 2011 (~10^{13} K_S)
- LHCb **mass resolution exploited to discriminate $K_S \to \pi^+\pi^-$ with both pions misid as μ's**
- Main sources of bkg: **combinatorial & double misid $K_S \to \pi^+\pi^-$**
- $K_S \to \pi^+\pi^-$ used as normalization channel
- Limit is computed using the CLs (modified frequentist) approach [J. Phys. G28 (2002) 2693]







$BR(K_S \to \mu^+\mu^-) < 9(11) \times 10^{-9}$ @90%(95%) C.L.

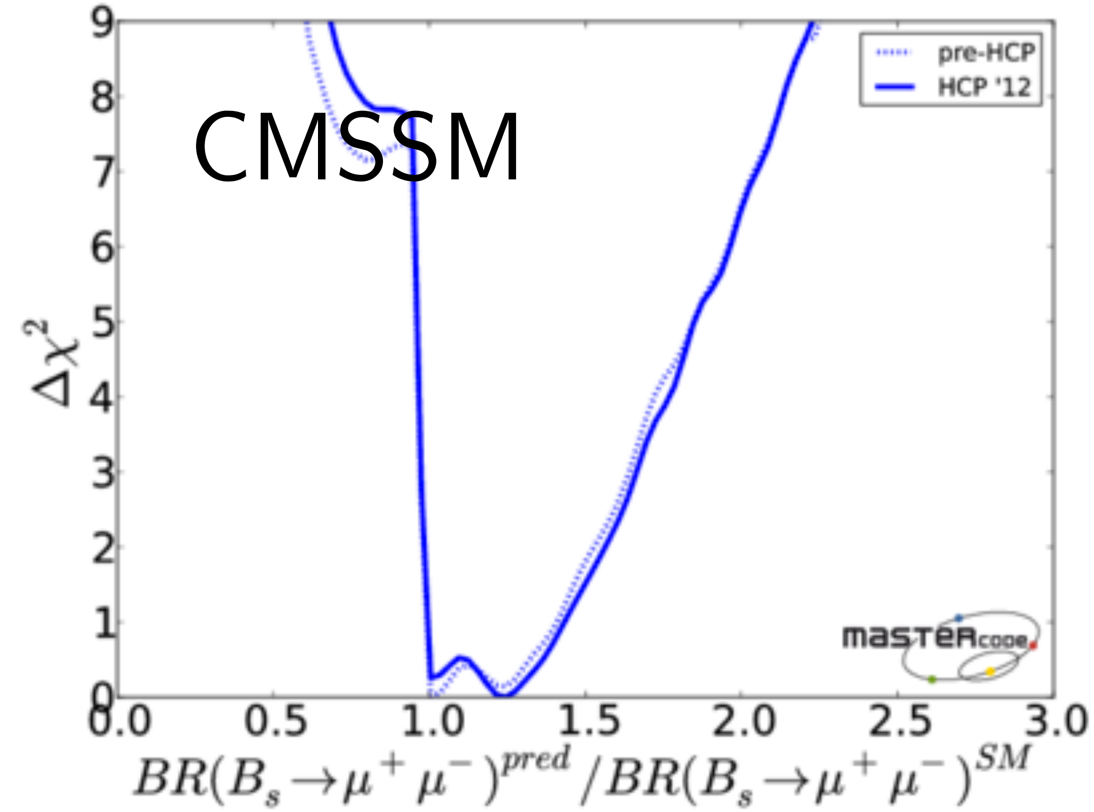
It is an improvement of a factor ~30 respect the previous best limit.

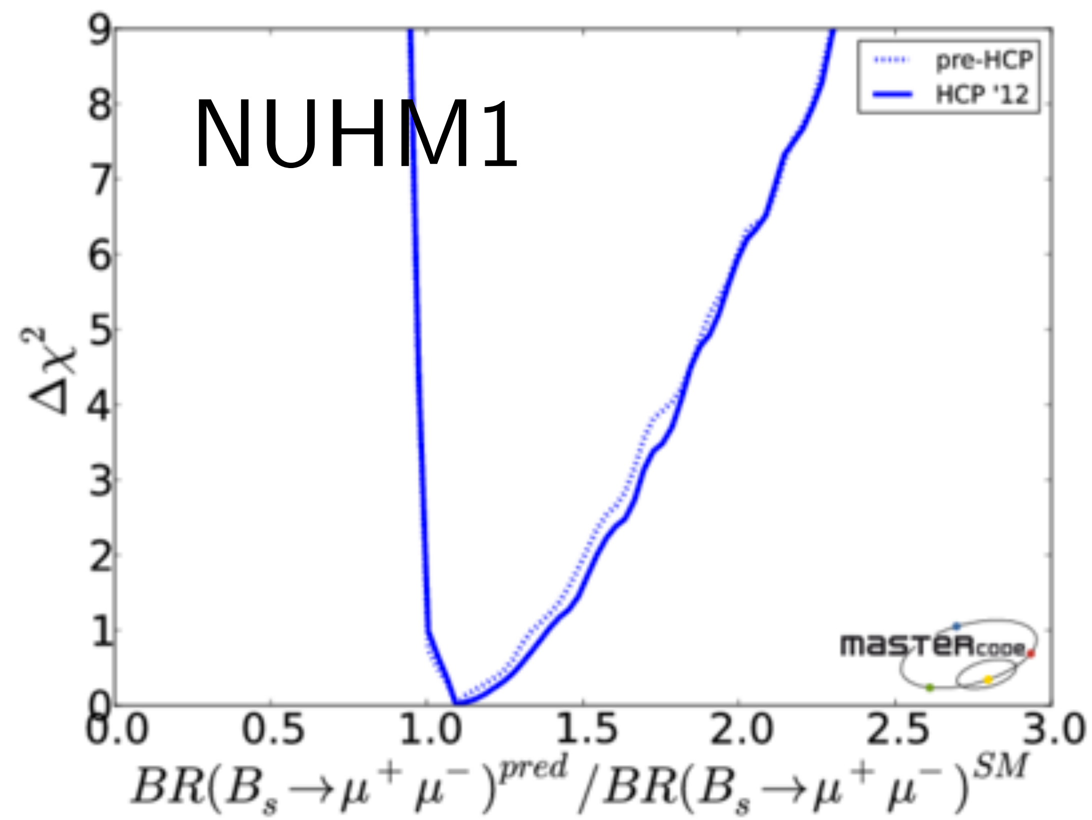
$B_s \to \mu\mu$ beyond the SM

Theoretically very clean source of information of Flavour Physics beyond the SM.

Useful to set a model-independent constraints on Wilson coefficients.

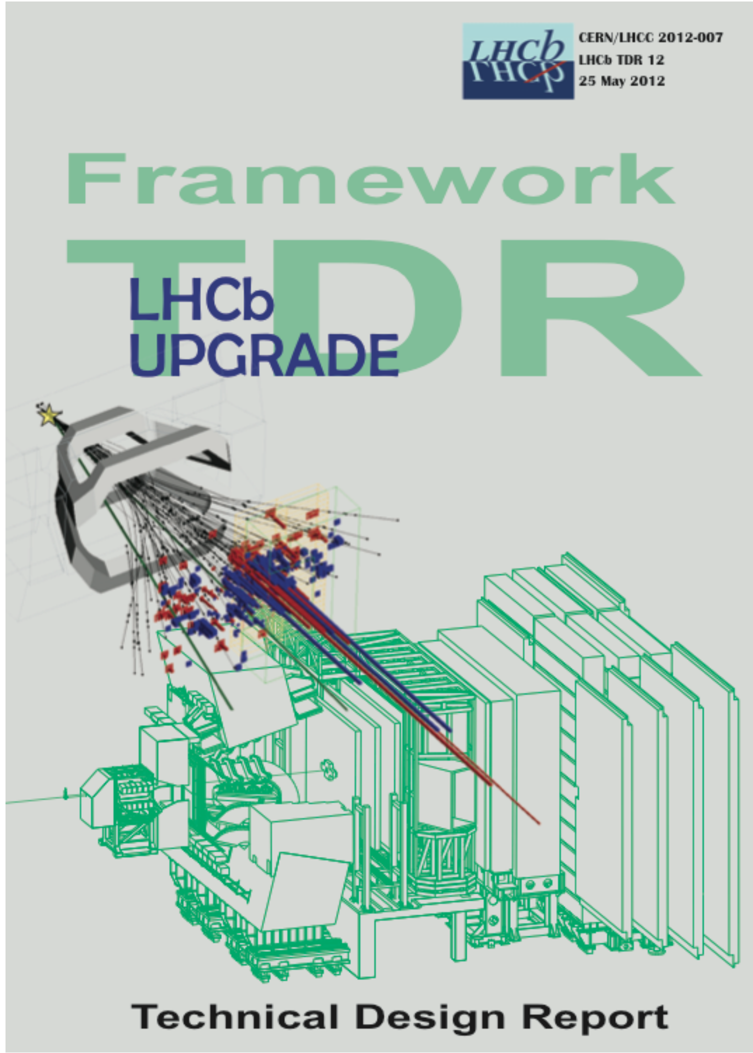
Particularly sensitive to FCNC scalar currents and FCNC Z penguins.





NP enhancements of $BR(B_s \to \mu^+\mu^-)$ are constrained to be smaller or at the same level than the SM prediction. There still remains, however, room for a contribution from physics beyond the Standard Model.

Glimpse on the Future



2012: LHCb Upgrade Framework TDR
http://cdsweb.cern.ch/record/1443882/files/LHCB-TDR-012.pdf

year	2011	2012	2015-2017	upgrade
$\sqrt{s}$	7	8	13	14
L_{int}	1	1.5(*)	4	50

(*) we actually collected 2!

The integrated statistics used in the uncertainty extrapolation for 2018 and the upgrade (2028) are respectively $L_{int} = 7\ fb^{-1}$ and $L_{int} = 50\ fb^{-1}$

Observable	Current precision	LHCb 2018	Upgrade ($50\,fb^{-1}$)	Theory uncertainty
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$

Extrapolation from 2011 Published analysis (1.5 10^{-9} precision) where the stat. uncertainty is scaled as $\sqrt{N}$.