Rare heavy flavour decays at LHCb

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on behalf of the LHCb collaboration

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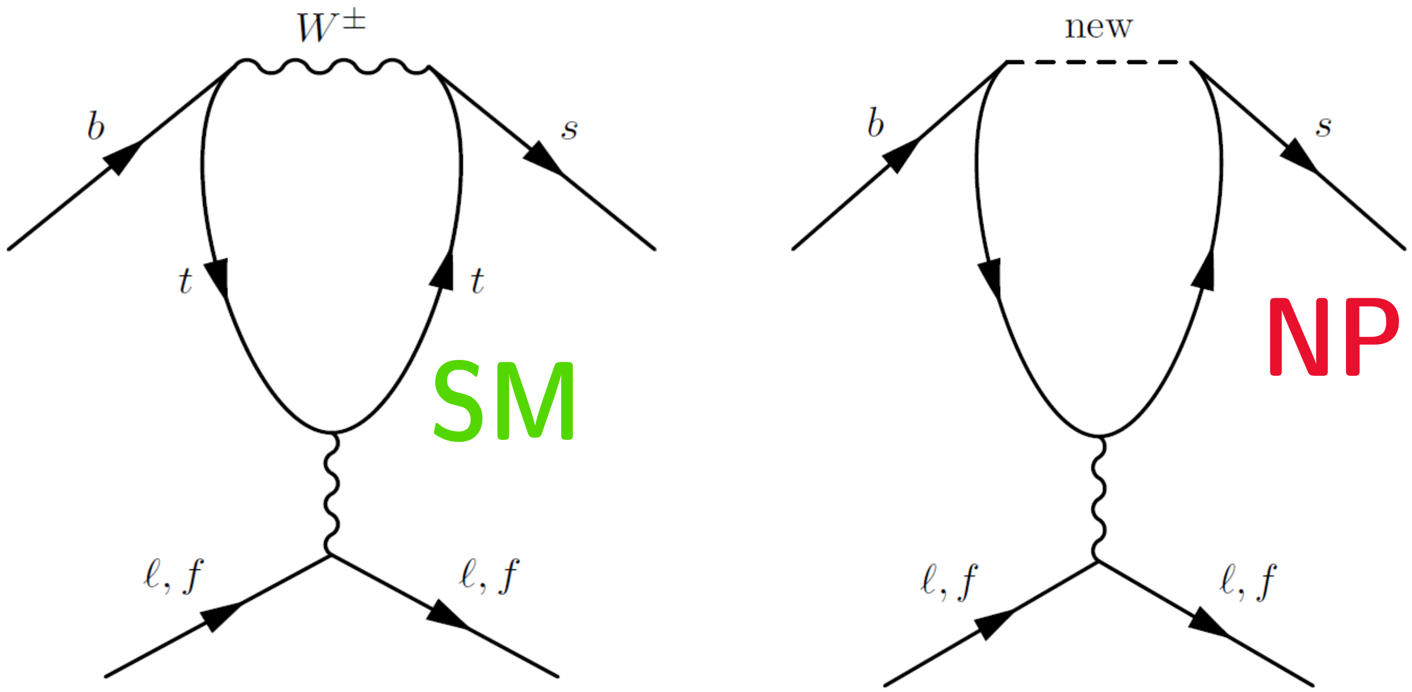
Istituto Nazionale di Fisica Nucleare

Introduction

- FCNC process prohibited at the tree level in the SM
- Rare B and D decays can access to NP through new virtual particles entering in the loop
- Indirect search:
  - Branching fractions
  - Angular distributions
  - Asymmetries



- Hadronic weak decays studied in terms of effective Hamiltonian of local operator O_i

$$H_{eff} \propto \sum_i \mathcal{C}_i \mathcal{O}_i$$

i=1,2	Tree
i=3-6,8	Gluon Penguin
i=7	Photon penguin
i=9,10	Electroweak penguin
i=S	Higgs (scalar) penguin
i=P	Pseudoscalar penguin

- NP could modify C_i short distance Wilson coefficient

Outline

- Rare leptonic decays:
  - $B_{d,s} \to \mu^+\mu^-$
  - $D^0 \to \mu^+\mu^-$
  - $B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$
- Rare semi-leptonic decays:
  - $B^0 \to K^{*0}\,\mu^+\mu^-$ (angular analysis)
  - $B \to K^{(*)}\,\mu^+\mu^-$ (isospin asymmetry)
  - $B^+ \to \pi^+\mu^+\mu^-$

$B_{d,s} \to \mu^+\mu^-$: theory

$B_{d,s} \to \mu^+\mu^-$ is the best way for LHCb to constrain the parameters of the extended Higgs sector in MSSM, fully complementary to direct searches

Double suppressed decay: helicity and FCNC

↳ very small BR in SM and well predicted:

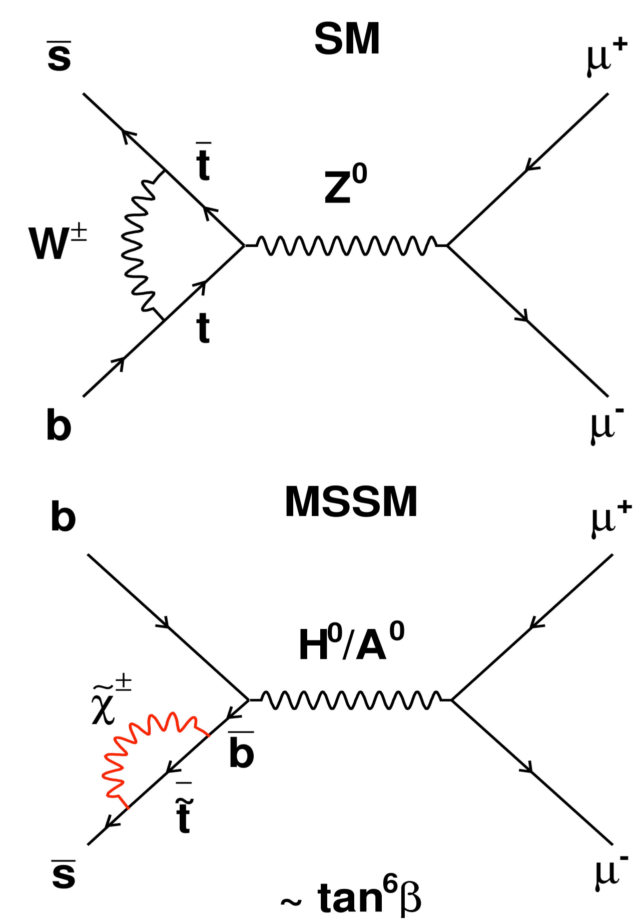
$BR(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$

$BR(B_d \to \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$

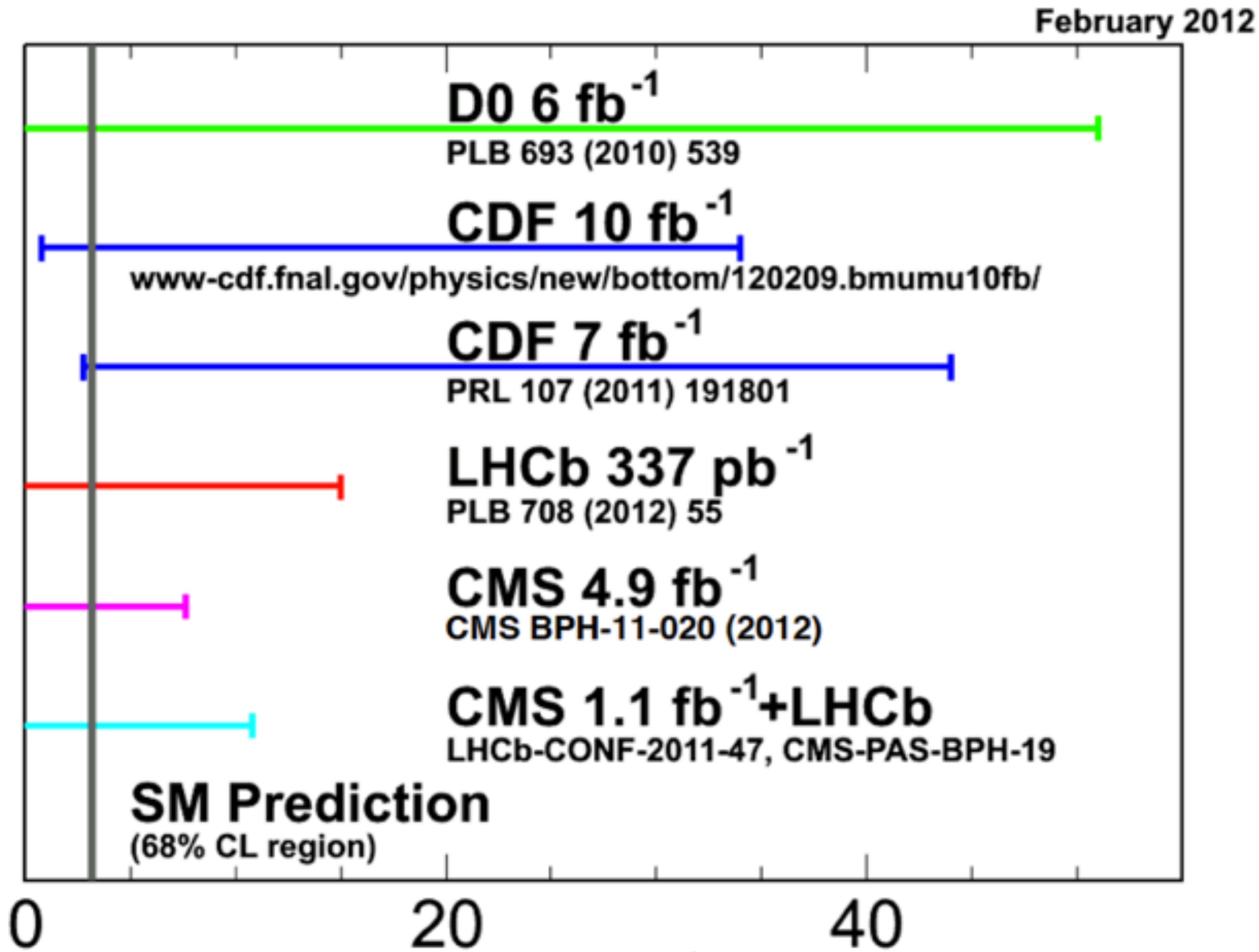
[A. Buras *et al.*, JHEP 1010 (2010)]

↳ sensitive to NP effects in scalar/pseudoscalar Higgs sector (C_S, C_P): in MSSM large tanß approximation

$BR(B_{d,s} \to \mu^+\mu^-) \propto \tan^6\beta / M^4_A$



$B^0_s \to \mu^+\mu^-$: experimental status (Feb. 2012)



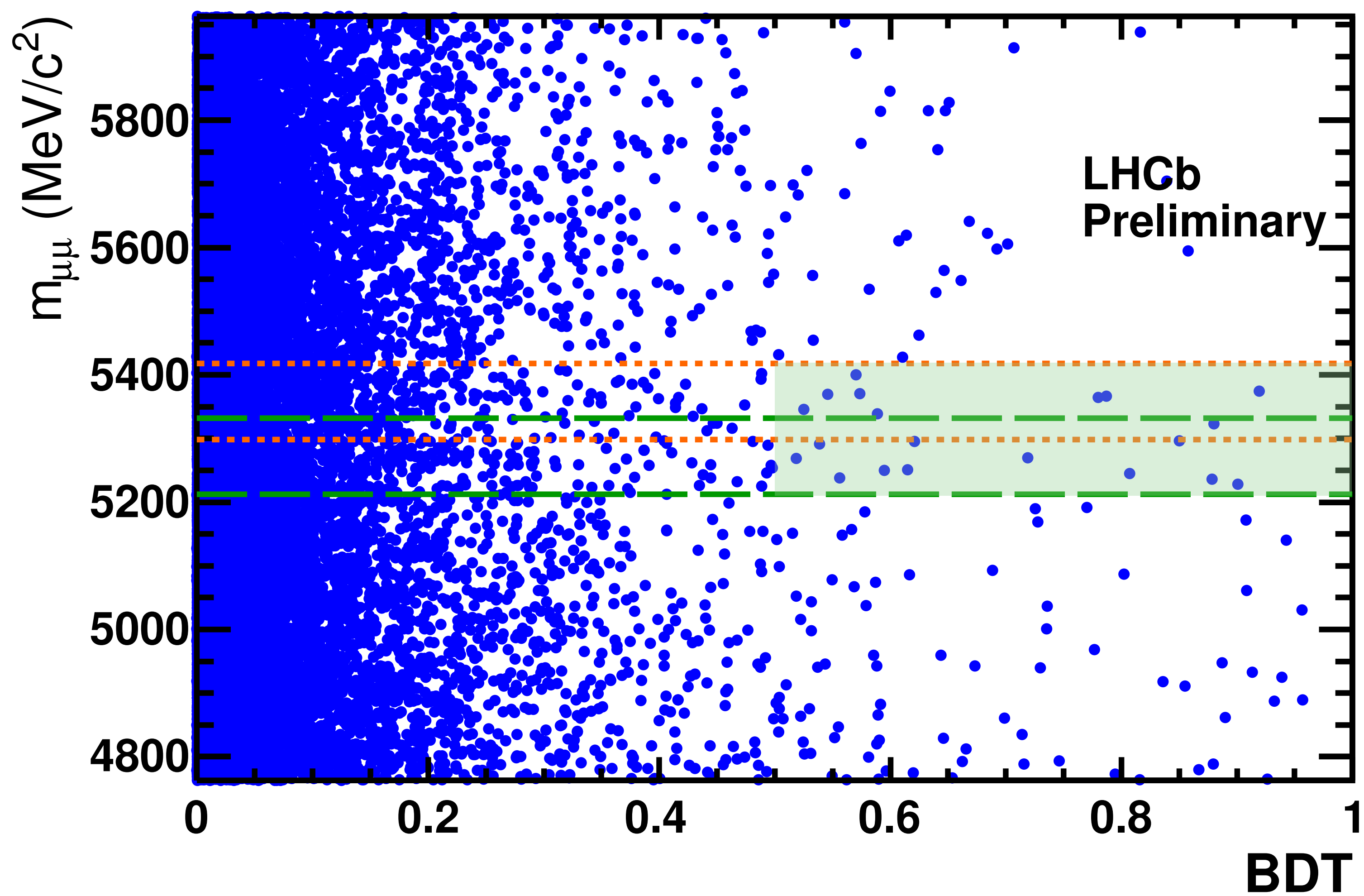
$BR(B \to \mu^+\mu^-) \times 10^9$ @ 95% CL

[H. Miyake, La Thuile, 29 Feb 2012]

Analysis strategy

[Phys. Rev. Lett. 108, 231801 (2012)]

- Blind analysis on $1fb^{-1}$ of data collected during 2011
- A MVA classifier (BDT) based on kinematic and geometrical variables used to increase S/B separation
- Events are studied in a 2D binned plane ($m_{\mu\mu}$,BDT).
- For each bin the expected signal and background yields have been computed



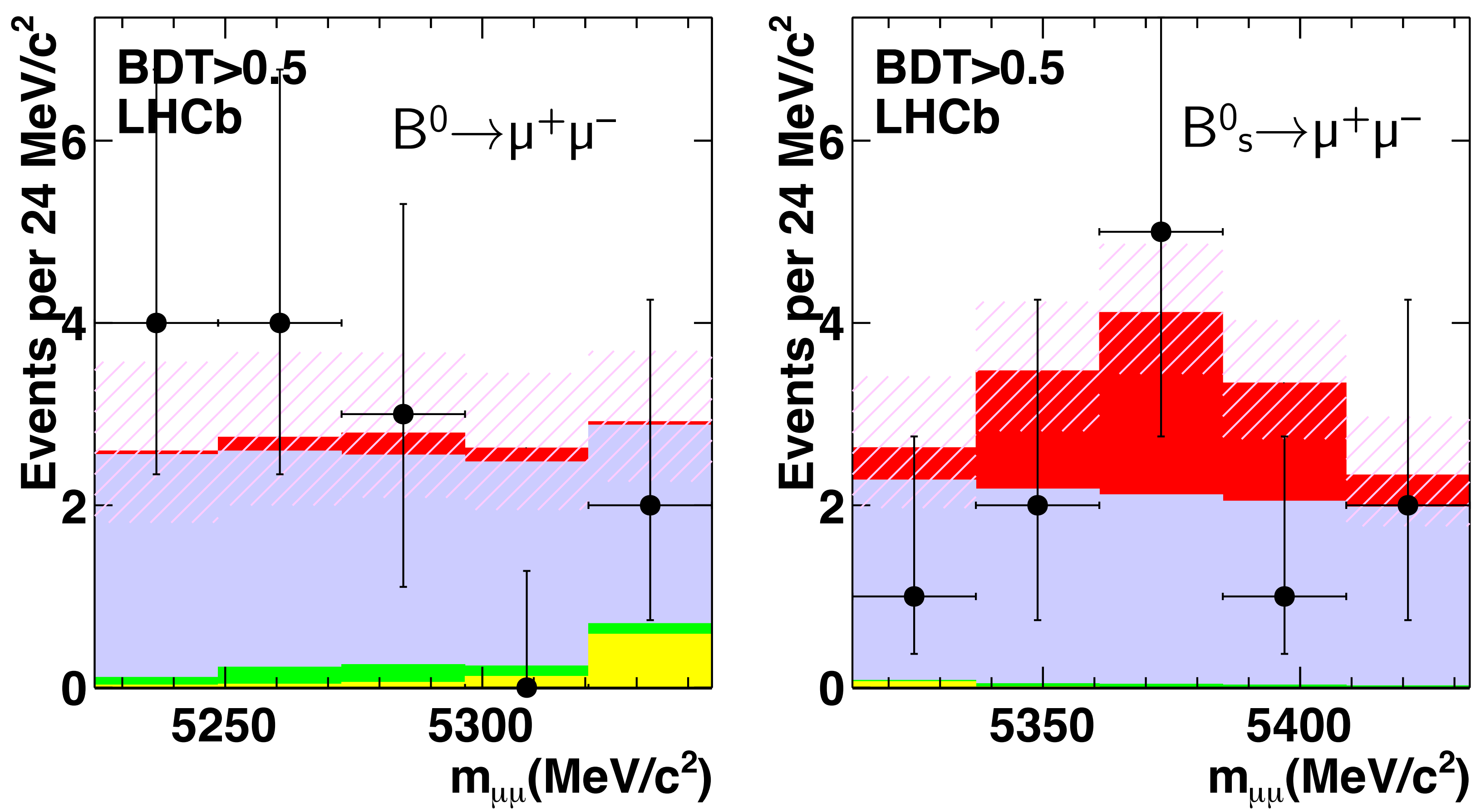
- Data driven calibration
- The CLs (=CLs+b/CLb, modified frequentist approach) is evaluated and used for the upper limit extraction.

$B_{d,s} \to \mu^+\mu^-$: mass distribution

- Background, dominated by $bb \to \mu\mu X$ component, well understood
- Bs $\to \mu\mu$ slowly emerging (?), not significant excess
- yields compatible with SM model expectations

[Phys. Rev. Lett. 108, 231801 (2012)]

Black dots data
$B^0_{(s)} \to \mu^+\mu^-$ SM signal
combinatorial background
$B^0_{(s)} \to h^+h'^-$ (peaking) background
$B^0 \leftrightarrow B^0_s$ cross feed



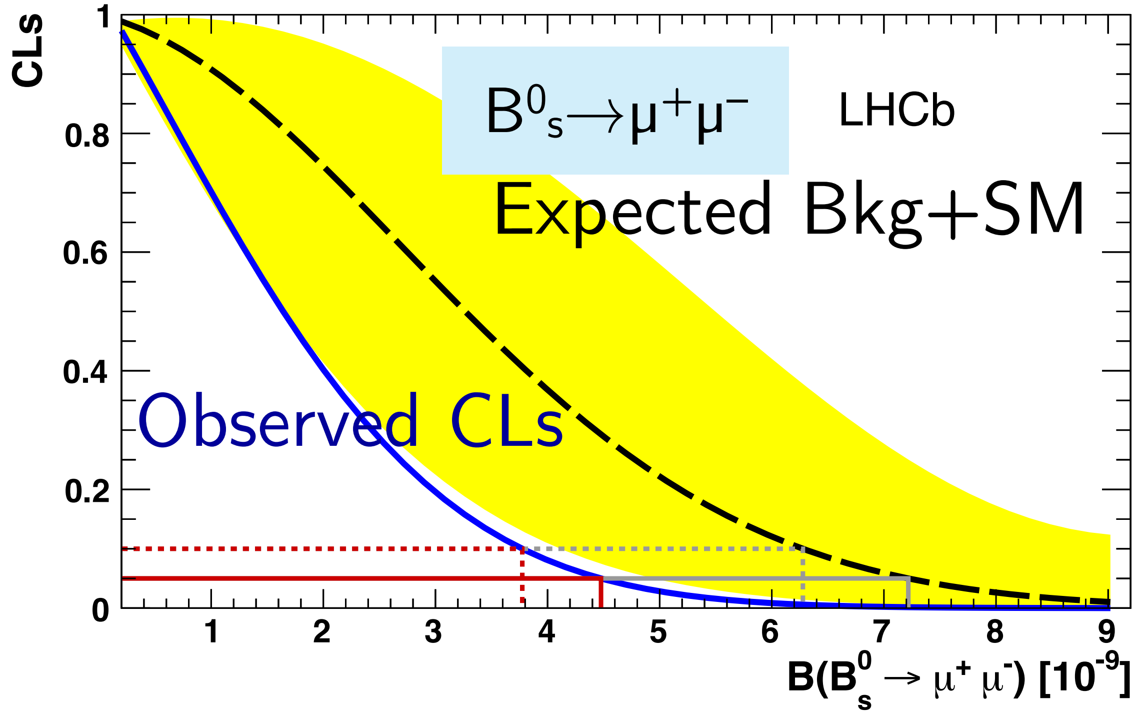
Upper limits evaluation

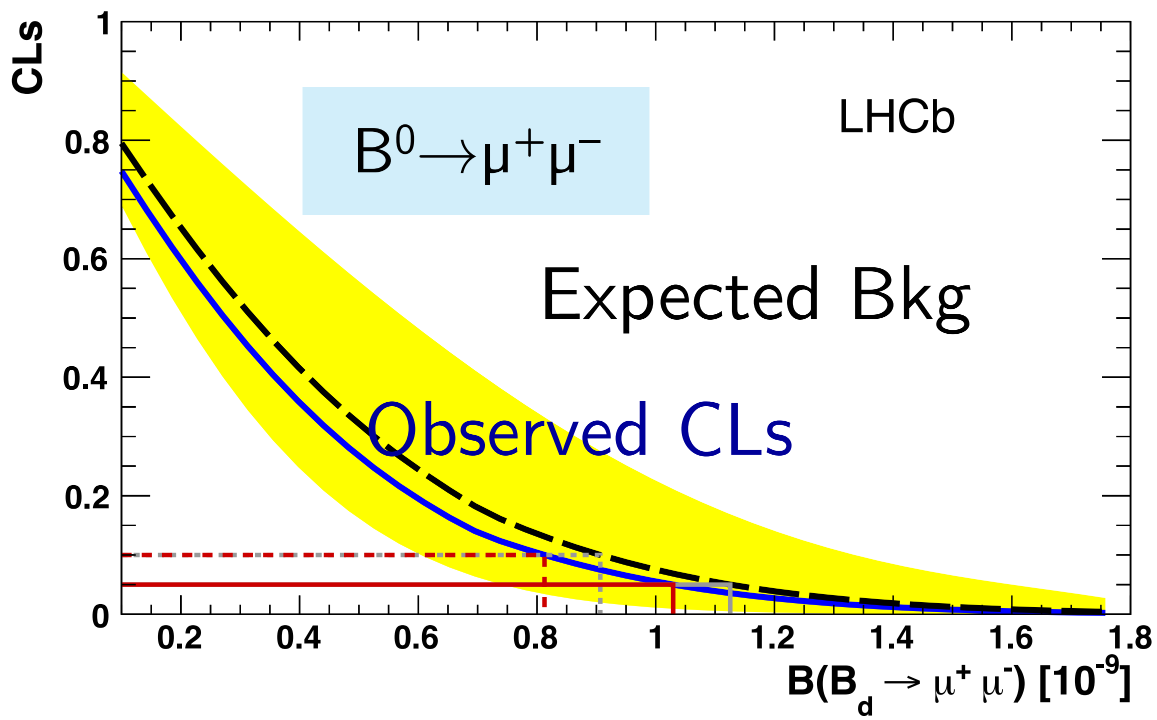
Last results with 1fb^{-1} data set:

Mode	Limit	at 90 % CL	at 95 % CL
$B_s^0 \to \mu^+\mu^-$	Exp. bkg+SM	6.3×10^{-9}	7.2×10^{-9}
	Exp. bkg	2.8×10^{-9}	3.4×10^{-9}
	Observed	3.8×10^{-9}	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	Exp. bkg	0.91×10^{-9}	1.1×10^{-9}
	Observed	0.81×10^{-9}	1.0×10^{-9}

A fit to the BR is also performed using a profile likelihood method:

$B(B^0_s \to \mu^+\mu^-) = (0.8^{+1.8}_{-1.3})\ 10^{-9}$



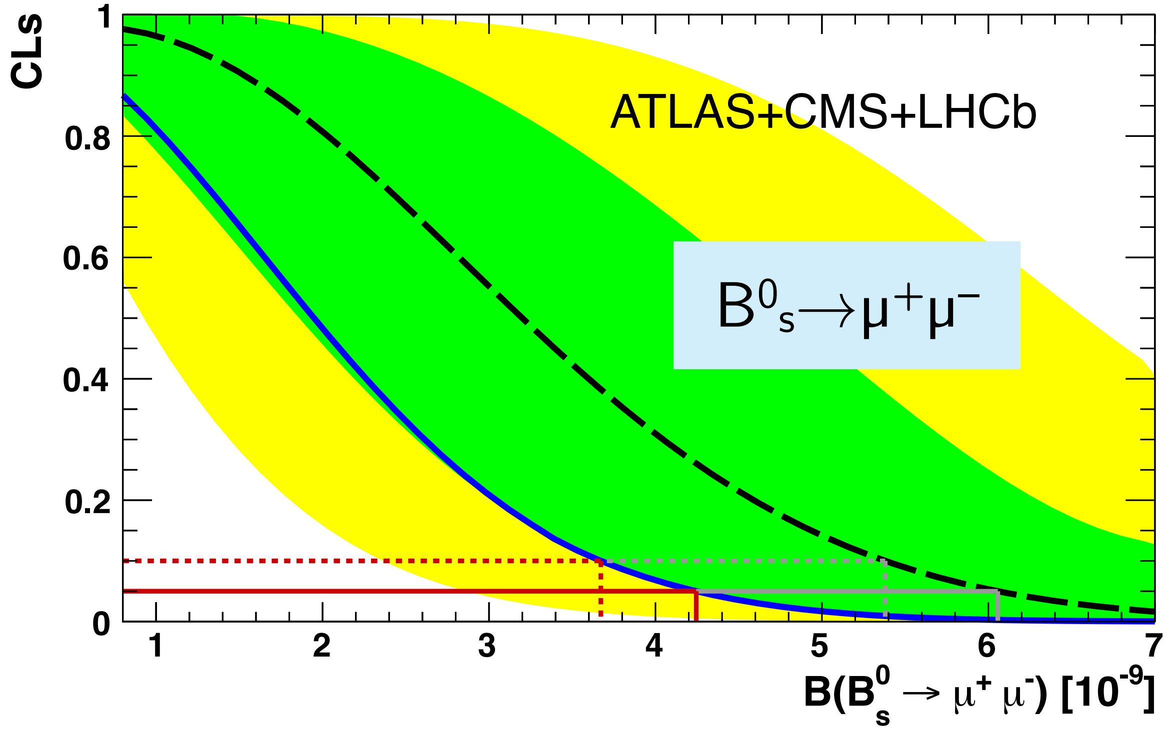


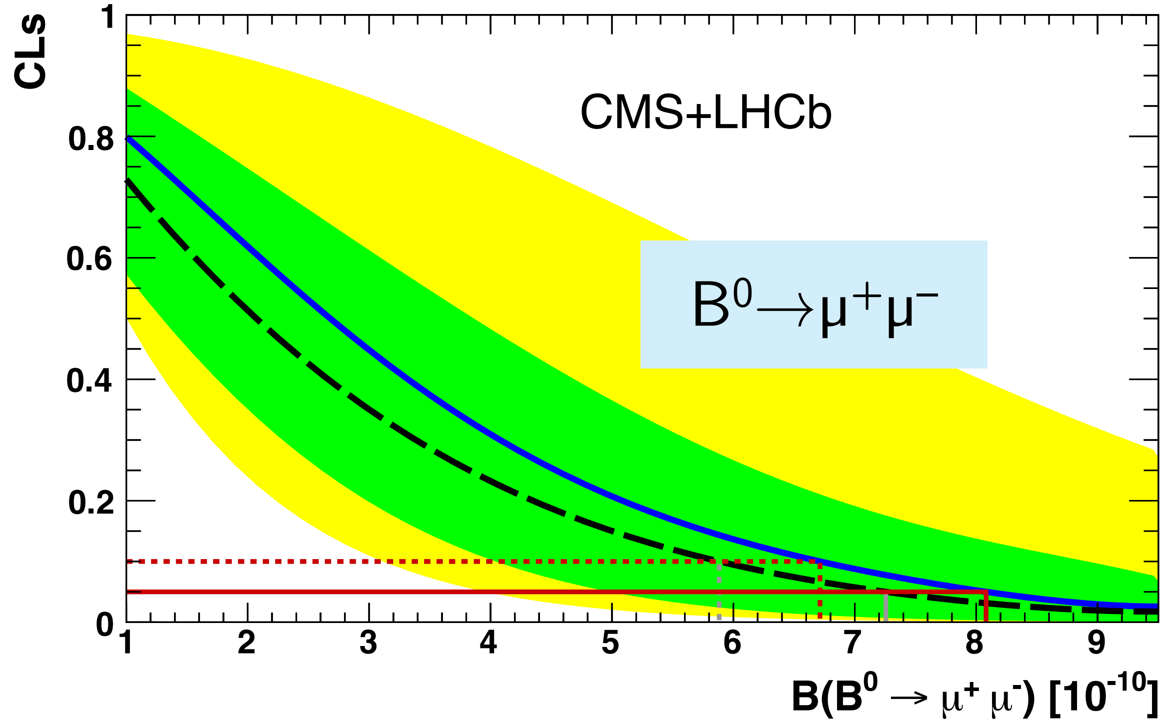
[Phys. Rev. Lett. 108, 231801 (2012)]

Combination with CMS and ATLAS

ATLAS, CMS and LHCb results have been recently combined

[arXiv:1204.0735, JHEP 1204(2012) 033, PRL 108,231801(2012),LHCb-CONF-2012-017]



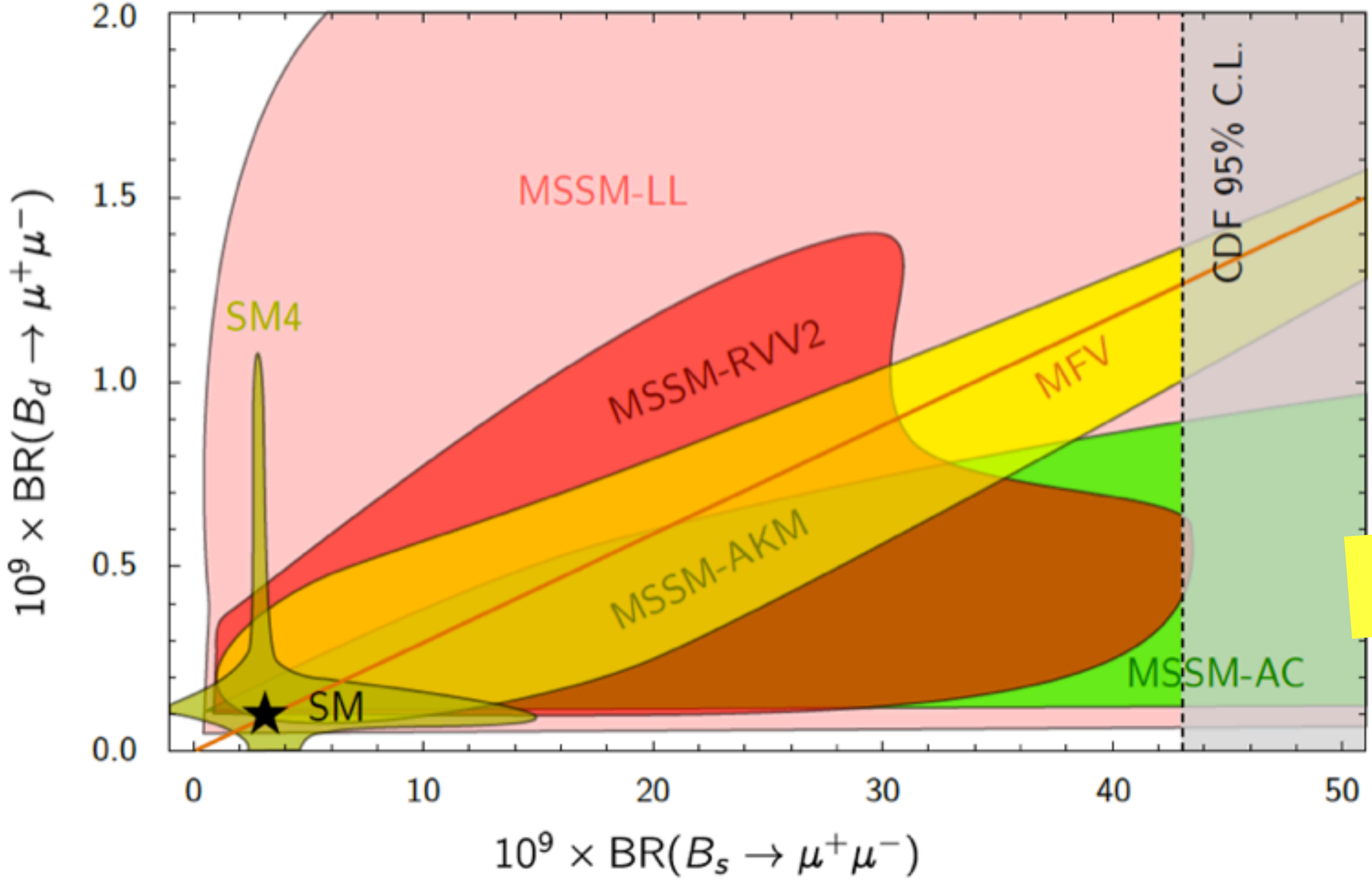


$$BR(B_s \to \mu^+\mu^-) < 4.2\text{x}10^{-9} \text{ @95\% C.L.}$$

- Excess over background at ~2σ level (1-CL_b (p-value)=5%)
- Compatible with SM at 1σ (1-CL_{s+b}=84%)

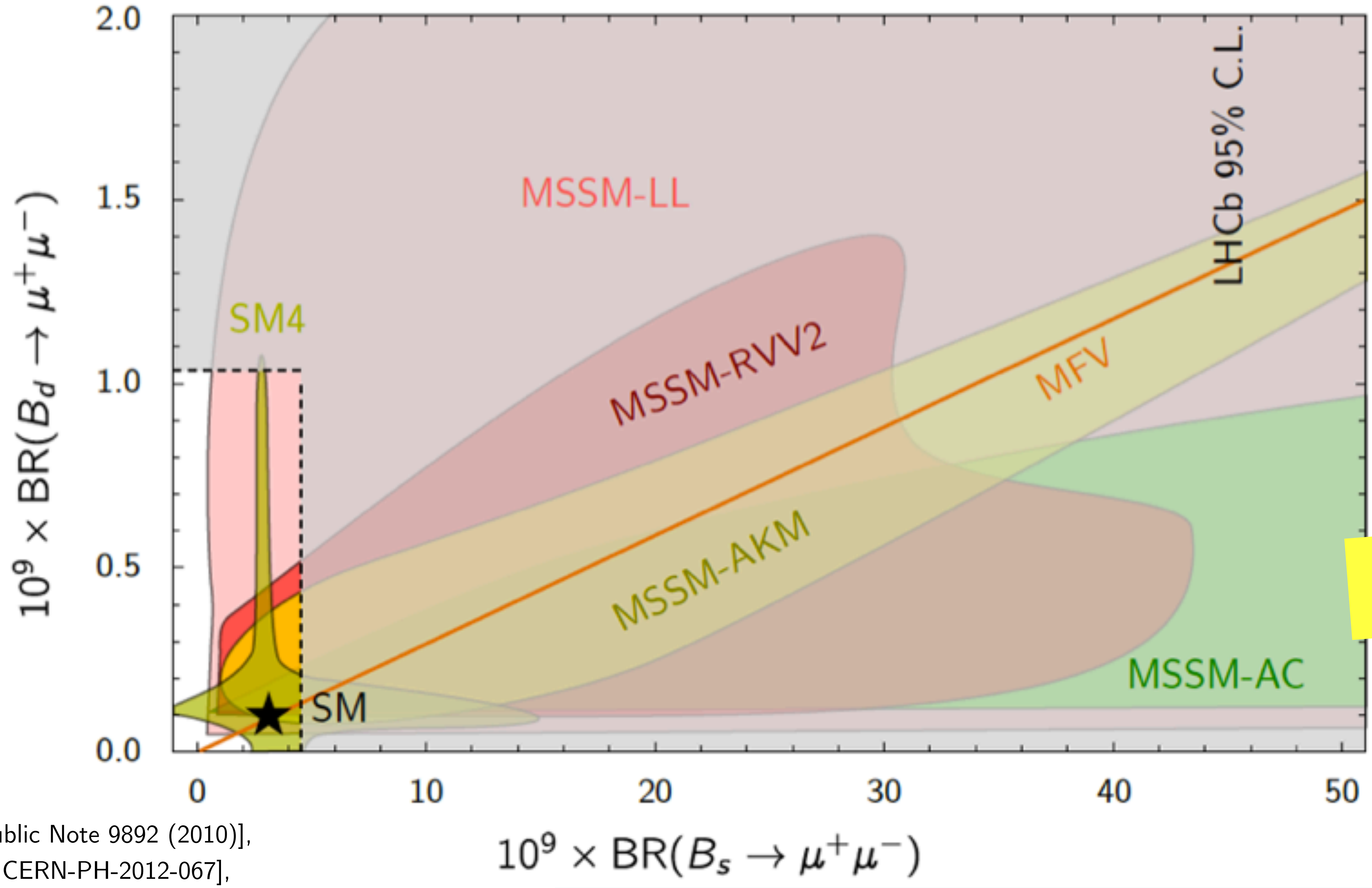
$$BR(B^0 \to \mu^+\mu^-) < 0.81\text{x}10^{-9} \text{ @95\% C.L.}$$

Impact of BR($B^0_s \to \mu^+\mu^-$) on some NP models



From D. Straub
@Moriond E.W.

Impact of the latest LHCb limits

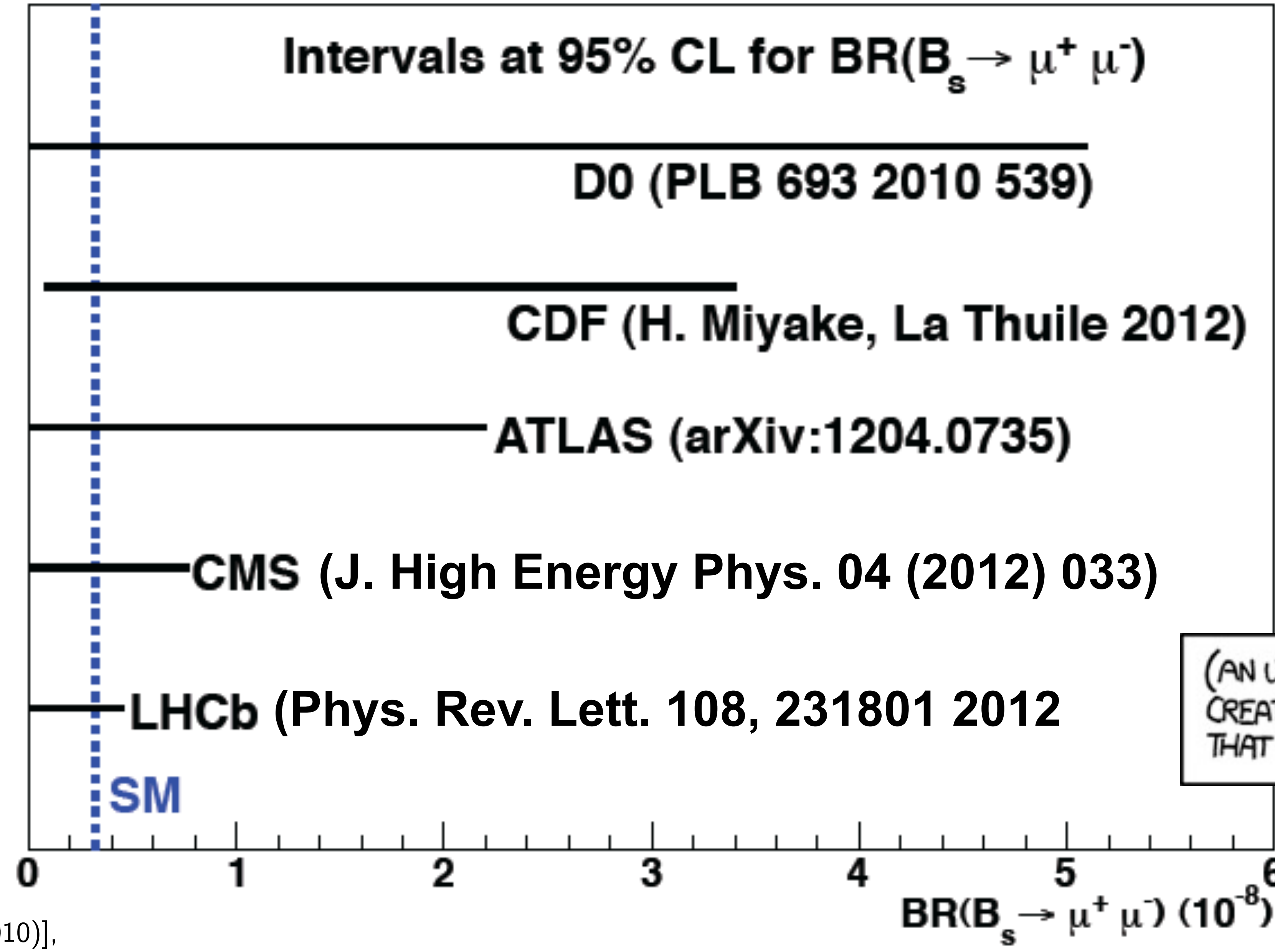


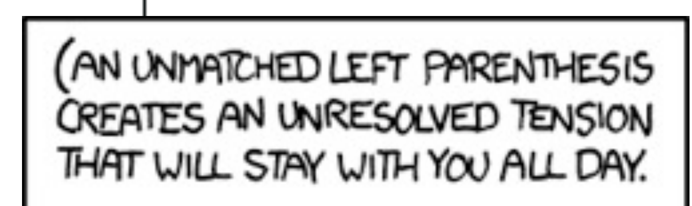
From D. Straub
@Moriond E.W.

[CDF, Public Note 9892 (2010)],
[ATLAS, CERN-PH-2012-067],
[CMS, BPH-11-020 (2012)]

		CDF	CMS	ATLAS	LHCB	SM
	luminosity (fb^{-1})	10	4.9	2.9	1	
$BR(B^0 \to \mu^+\mu^-)$	95% CL upper limit (10^{-9})	4.6	1.8		1.03	0.1±0.01
$BR(B^0 \to \mu^+\mu^-)$	95% CL upper limit (10^{-9})	31	7.7	22	4.5	3.2±0.2

Experimental status





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$D^0 \to \mu^+\mu^-$: motivation and analysis

- $D^0 \to \mu^+\mu^-$ is suppressed in SM because FCNC and GIM mechanism.
- Its BF is dominated by the long distance contribution due $\gamma\gamma$ intermediate state which set the SM prediction bounds:

$10^{-13} < B(D^0 \to \mu^+\mu^-) < 6 \times 10^{-11}$ [G. Burdman et al., PR D66 (2002)]

- Enhancement in NP models (e.g. BR~10^{-9} in RPV-SUSY tree level transition)

[E. Golowich et al., PR D 79, 114030 (2009)]

- Current best experimental limit from Belle:

$B(D^0 \to \mu^+\mu^-) < 1.4 \times 10^{-7}$ @90% C.L. [Phys. Rev. D81 239 (2010) 091102]

- LHCb analysis performed 0.9 fb^{-1} using D^{*+} tagged sample selecting $D^{*+} \to D^0(\to \mu^+\mu^-)\pi^+$.

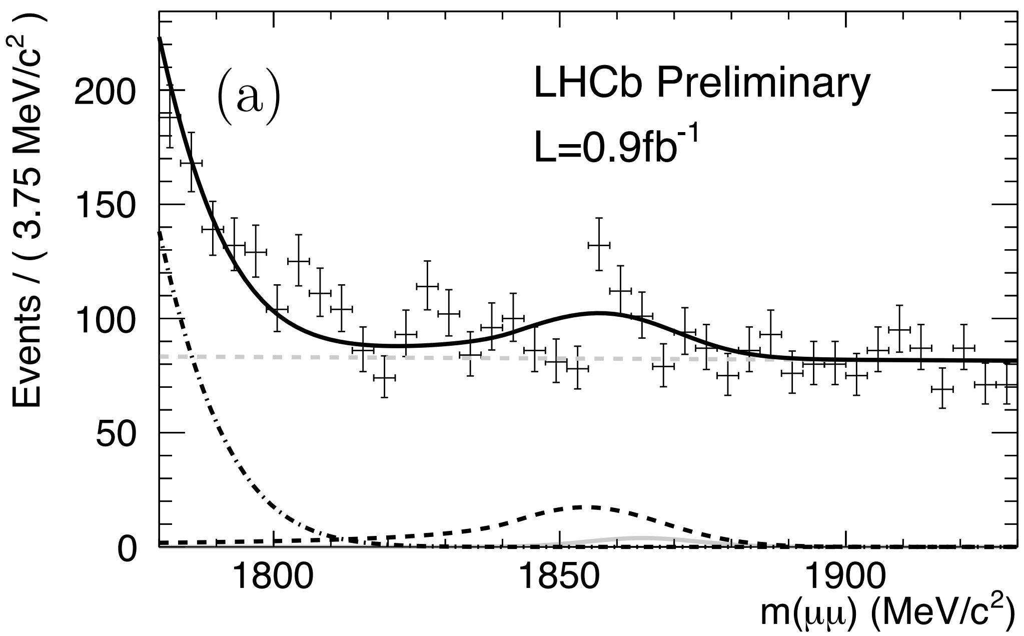
- MVA classifier used to reduce main bkg sources due to combinatorial from b and c hadron decays

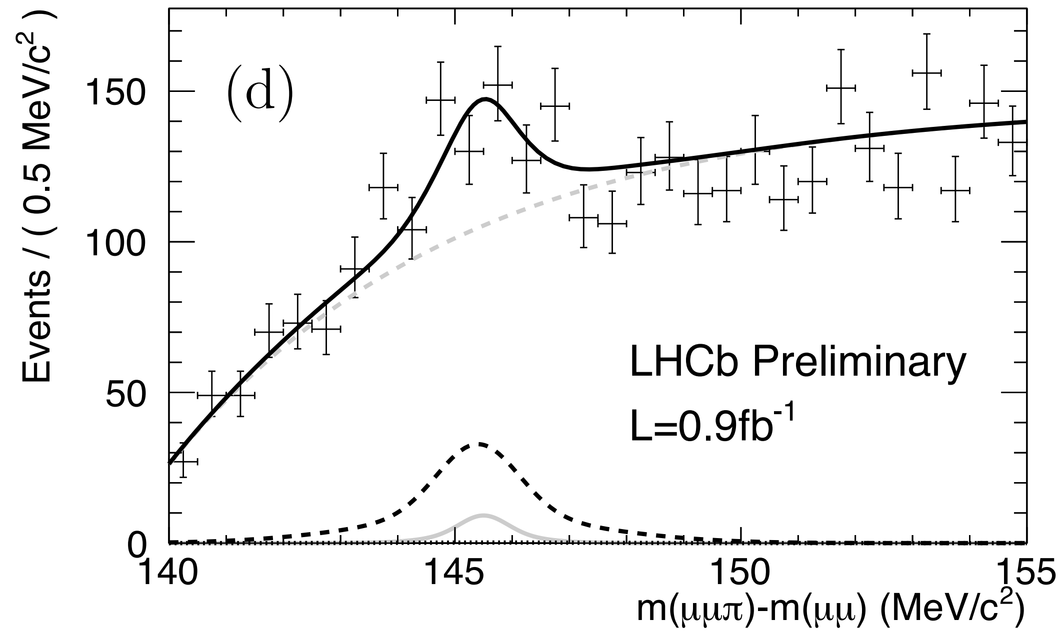
[LHCB-CONF-2012-005]

- $D^0 \to \pi^+\pi^-$ used as normalization channel:

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}} \frac{\varepsilon_{\pi\pi}}{\varepsilon_{\mu\mu}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-) = \alpha \cdot N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}$$

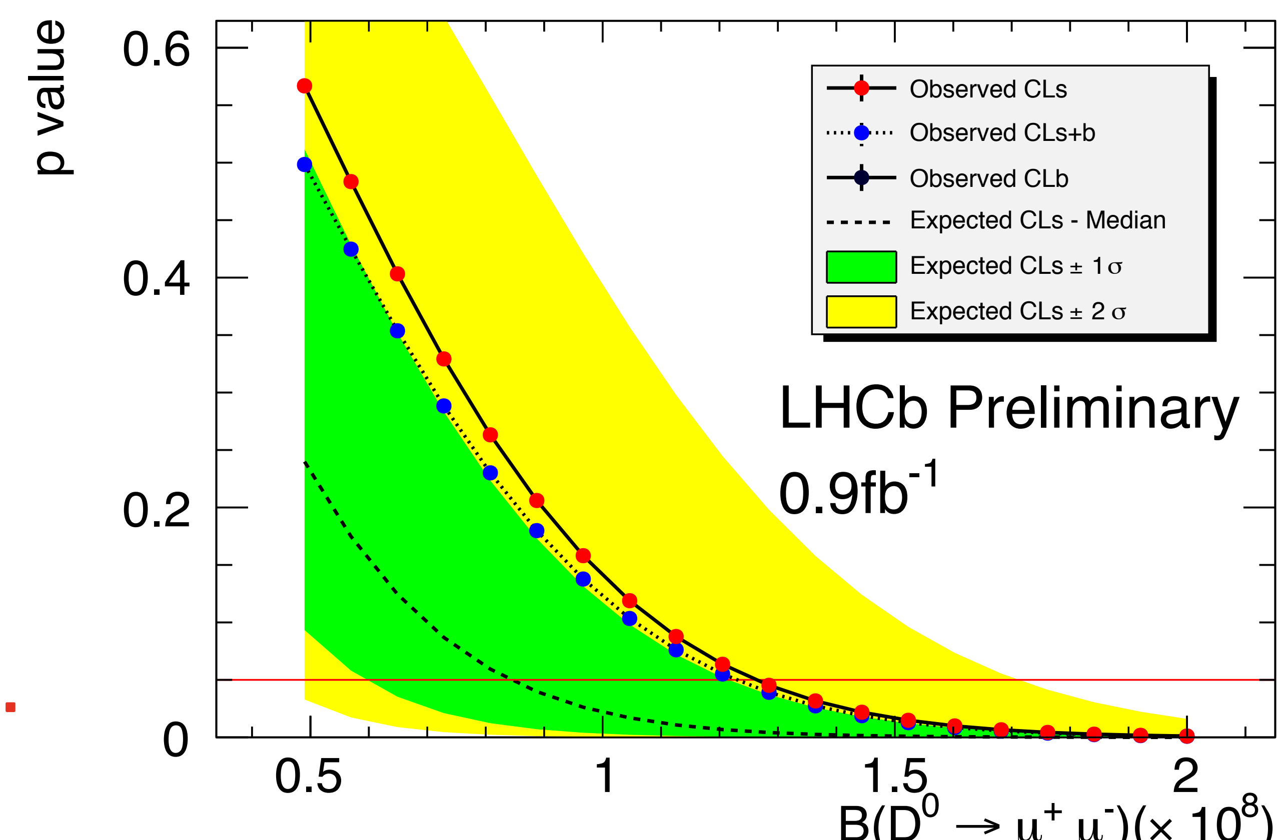
Results





[LHCB-CONF-2012-005]

dashed light grey: combinatorial bkg
dashed dark grey: $D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$
light gray: signal



yields is extracted from a 2D fit on IM and $\Delta M(D^{*+}\text{-}D^0)$

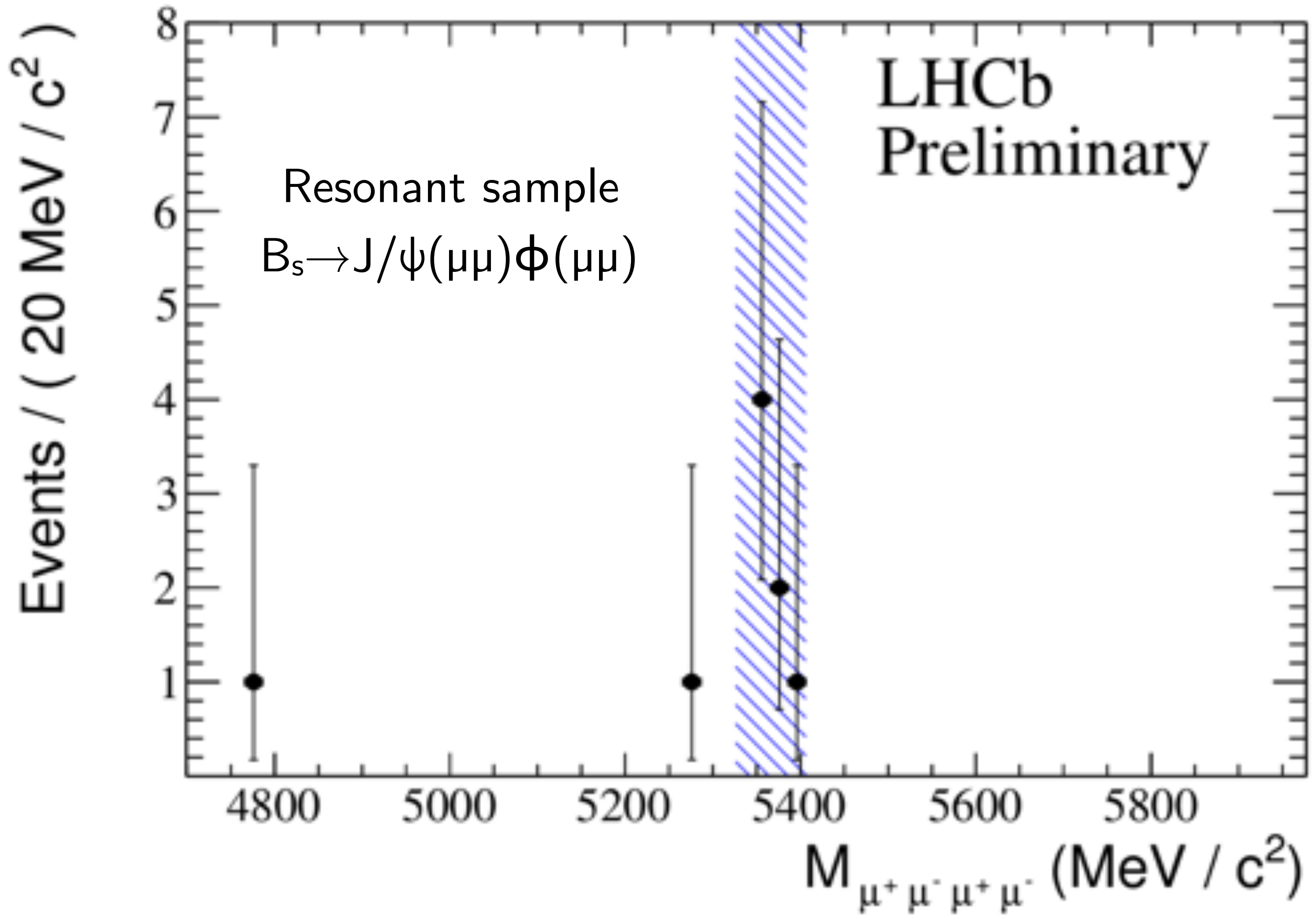
Preliminary result:

$BR(D^0 \to \mu^+\mu^-) < 1.3\times10^{-8}$ @95%C.L.

$B_{d,s} \to \mu^+\mu^-\mu^+\mu^-$: motivation and analysis

- Strongly suppressed in the SM (FCNC)
- Large contribution from $B_s \to J/\psi(\mu\mu)\phi(\mu\mu)$ which has a BR = $(2.3\pm0.9)\times10^{-9}$
- Non resonant process also can occur in SM with a virtual photon exchange BR$\sim10^{-10}$–10^{-11} **[Phys. Rev. D 70, 114028 (2004)]**
- Possible enhances in NP scenarios (i.e. scalar–pseudoscalar sgoldstinos couple)

[LHCB-CONF-2012-010]

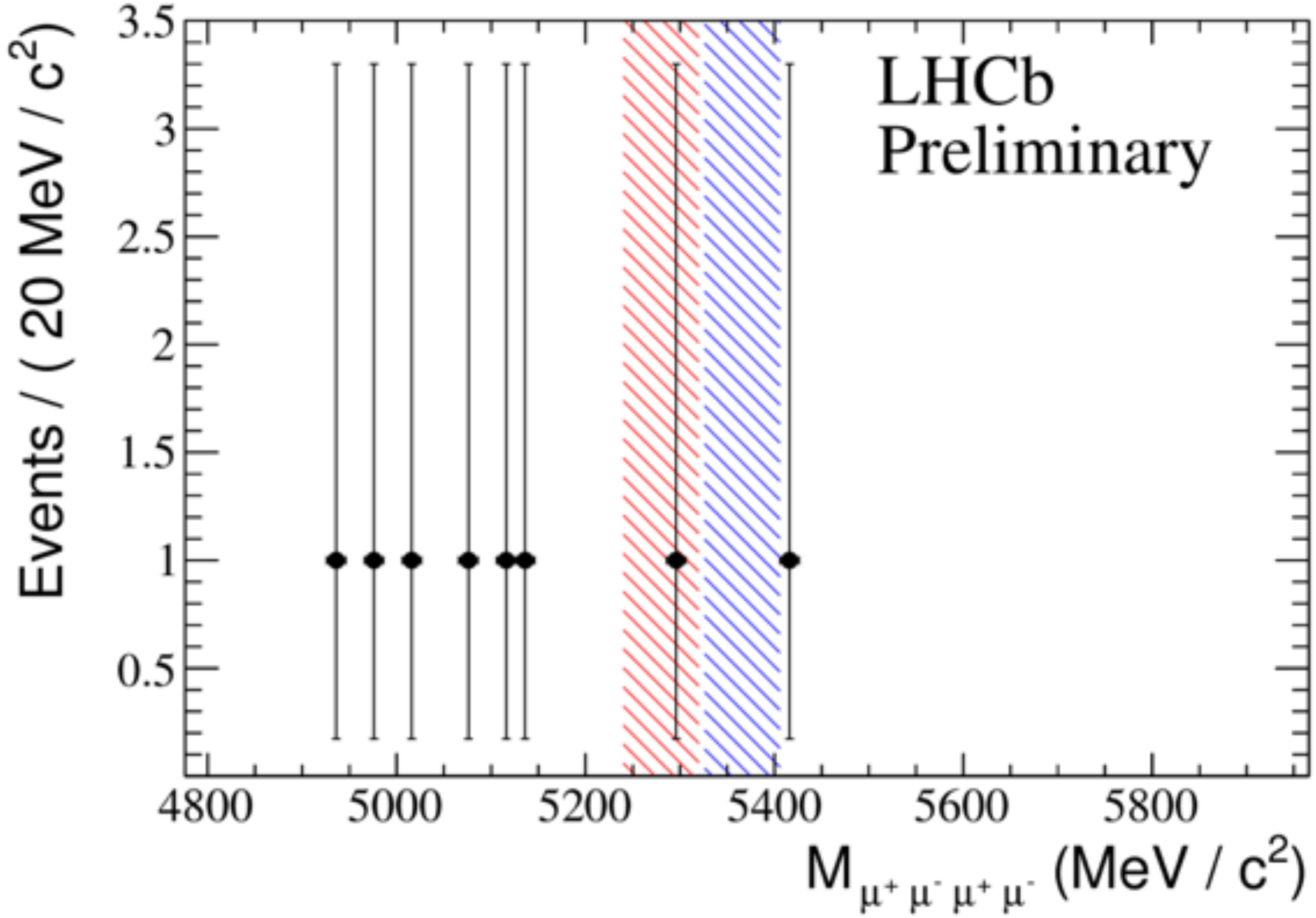


- Cut based analysis on 1fb^{-1} data sample:
  - Resonant sample used for selection optimization
  - PID, separation between B vertex and primary vertices, B vertex quality, veto on ϕ mass
  - BR evaluated normalizing on $B^0 \to J/\psi(\mu^+\mu^-)K^{*0}(K^+\pi^-)$

Results

[LHCB-CONF-2012-010]

Signal region	Expected bkg	Observed
B_d	$0.30^{+0.22}_{-0.20}$	1
B_s	$0.38^{+0.23}_{-0.17}$	0



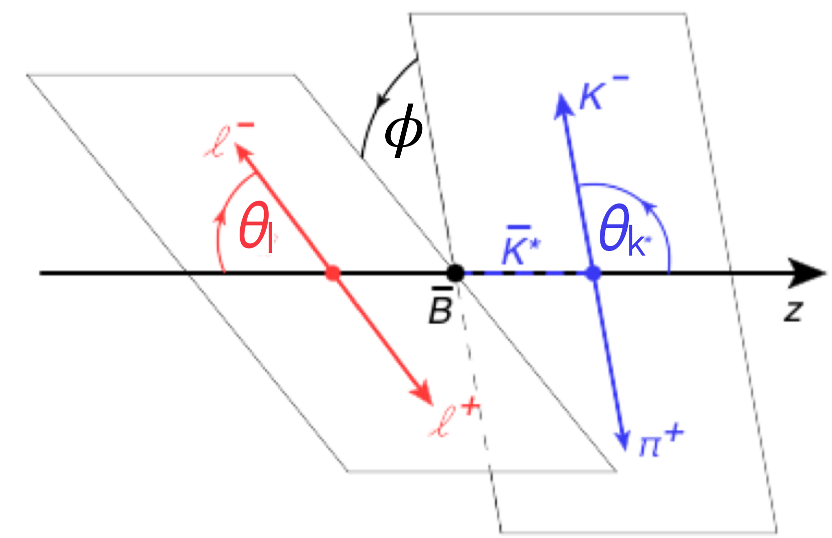
$BR(B_s \to \mu^+\mu^-\mu^+\mu^-) < 1.30 \times 10^{-8}$ @95% C.L.

$BR(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 0.54 \times 10^{-8}$ @95% C.L.

$B \to K^{*0}\mu^+\mu^-$

[LHCb-CONF-2012-008]

$B \to K^{*0}\mu^+\mu^-$ differential decay distribution can be described with 3 angles (θ_l, θ_k, ϕ) and dimuon mass q^2 Parametrized in terms of 4 angular observable (folding ϕ angle) F_L, A_{FB}, S_3 and A_{Im} ← theoretically clean observables, sensitive to NP contribution to C_7, C_9 and C_{10}



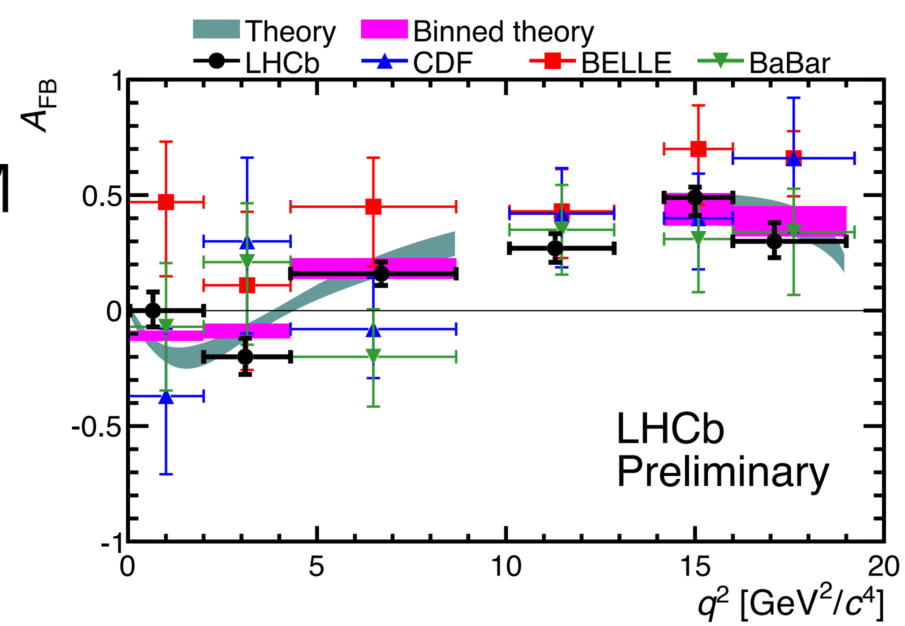
$$\frac{1}{\Gamma}\frac{d^4\Gamma}{d\cos\theta_\ell\, d\cos\theta_K\, d\hat{\phi}\, dq^2} = \frac{9}{16\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) + F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell-1) + S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell + A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi}\Big]$$

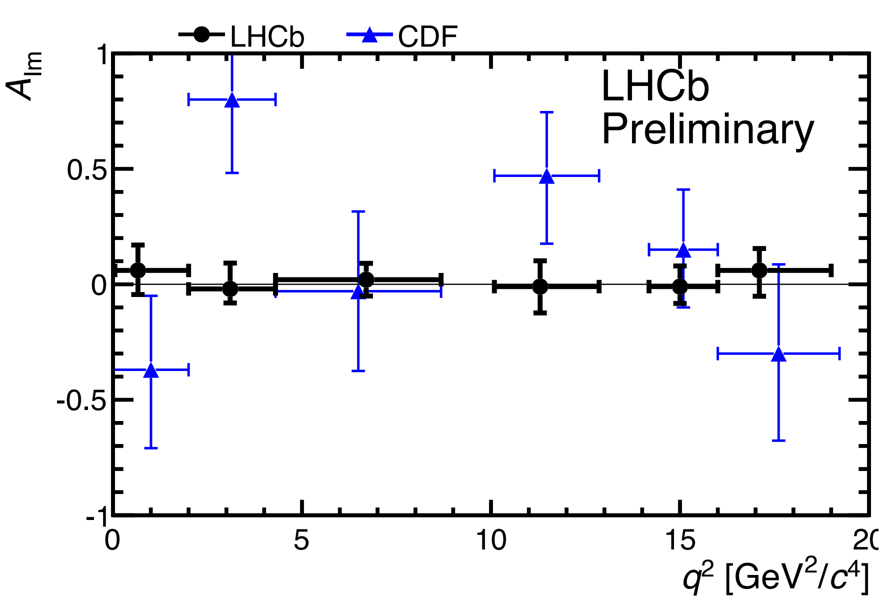
- F_L fraction of K^{*0} longitudinal polarization
- A_{FB} forward backward asymmetry
- $S_3 \propto A_T^2(1\text{-}F_L)$ with A_T = asymmetry in K^{*0} transverse plane
- A_{Im} a T-odd CP asymmetry

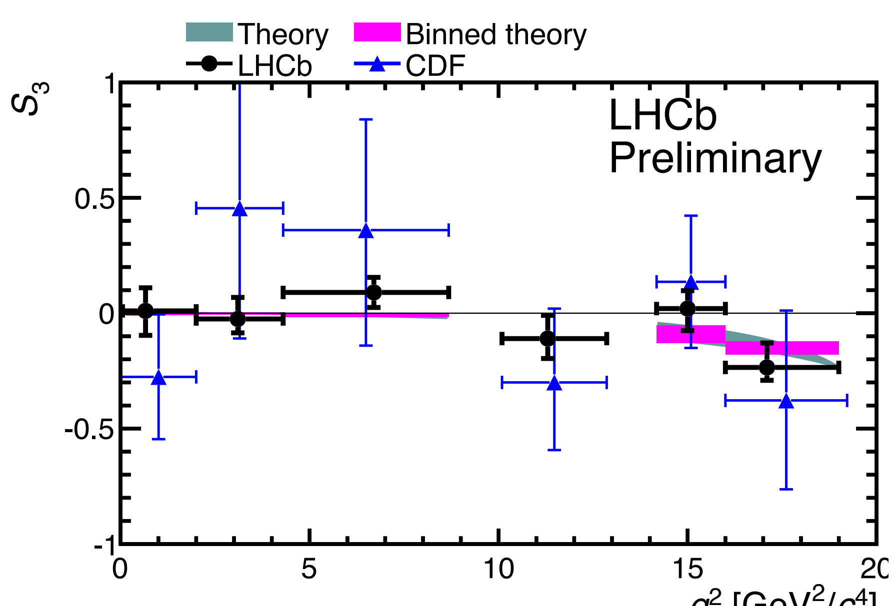
Angular analysis: A_{FB}, F_L, A_{Im} and S_3

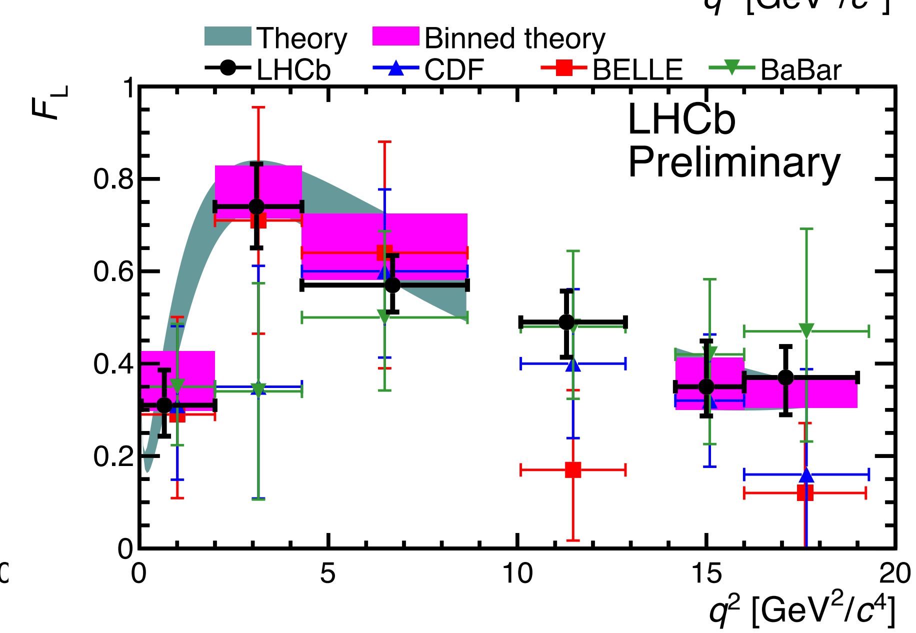
- ➡ Used $1fb^{-1}$ data, observed 900±34 events (more than Babar+Belle+CDF) splitted in 6 q^2 bins
- ➡ 4D simultaneous fit to 3 angles and mass for the extraction of A_{FB}, F_L, S_3 and A_{Im}
- ➡ 68% confidence intervals estimated 1D profile likelihood
- ➡ T-odd CP asymmetry A_{Im} expected to be $O(10^{-3})$ in SM
- ➡ Most precise measurements up-to-date consistent with the SM prediction [C. Bobeth et al., JHEP 07 (2011) 067]
- ➡ Still room for NP contribution

Babar: S. Akar, Lake Louise 2012
Belle: Phys. Rev. Lett. 103, 171801 (2009)
CDF: Phys. Rev. Lett. 108, 081807 (2012)
LHCb: LHCb-CONF-2012-008





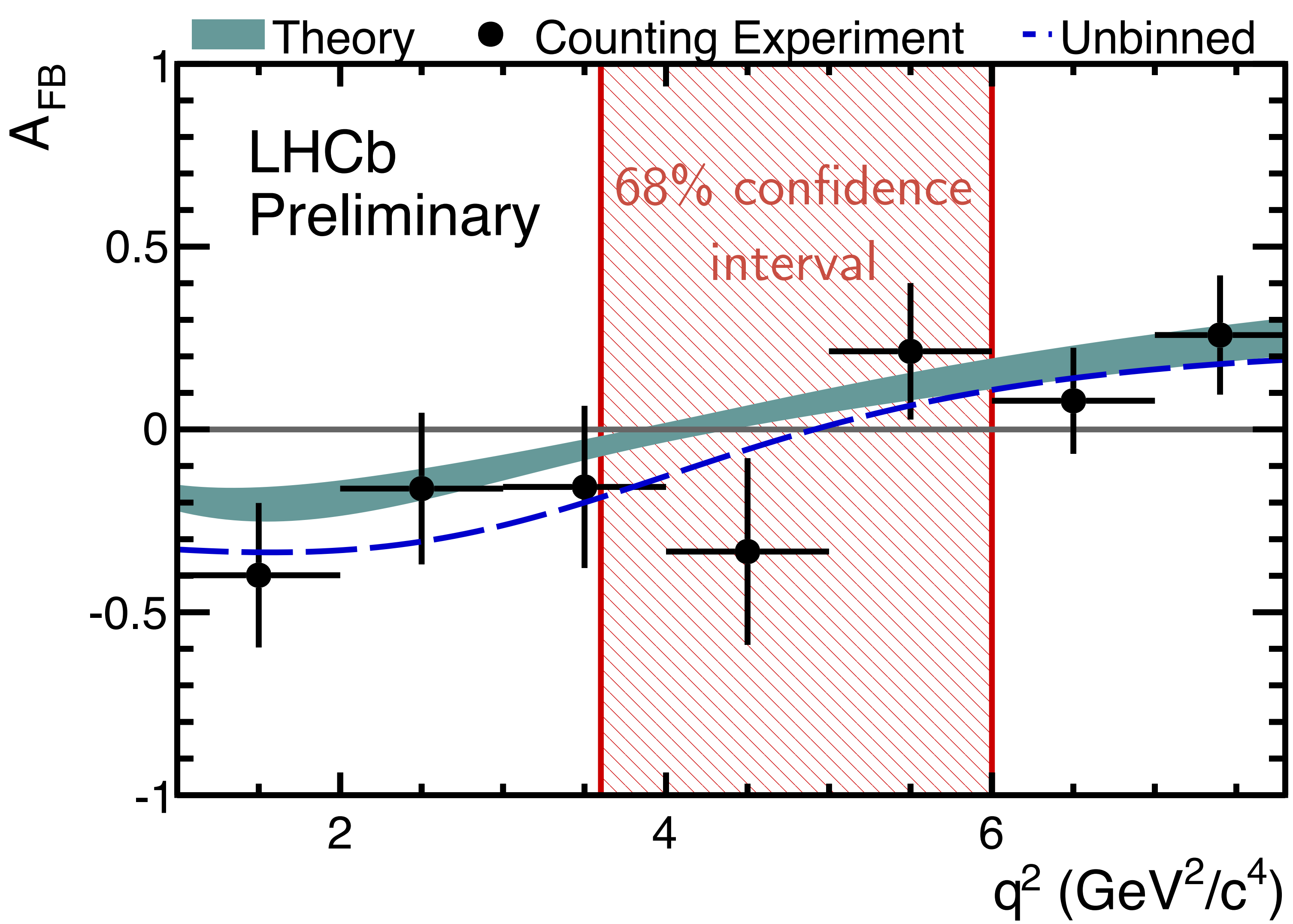




$A_{FB}(q^2)$ zero crossing angle

[LHCb-CONF-2012-008]

- A_{FB} zero-crossing point (q^2_0) for dimuon system well defined in the SM
- q^2_0 has been extracted from 2D fit of IM,q^2



world first measurement:

$q^2_0 = 4.9^{+1.1}_{-1.3}$ GeV^2/c^4

consistent with SM predictions which range from 4 to 4.3 GeV^2/c^4

[C. Bobeth et al., JHEP 07 (2011) 067;

M. Beneke et al., Eur. Phys. J. C41 (2005) 173;

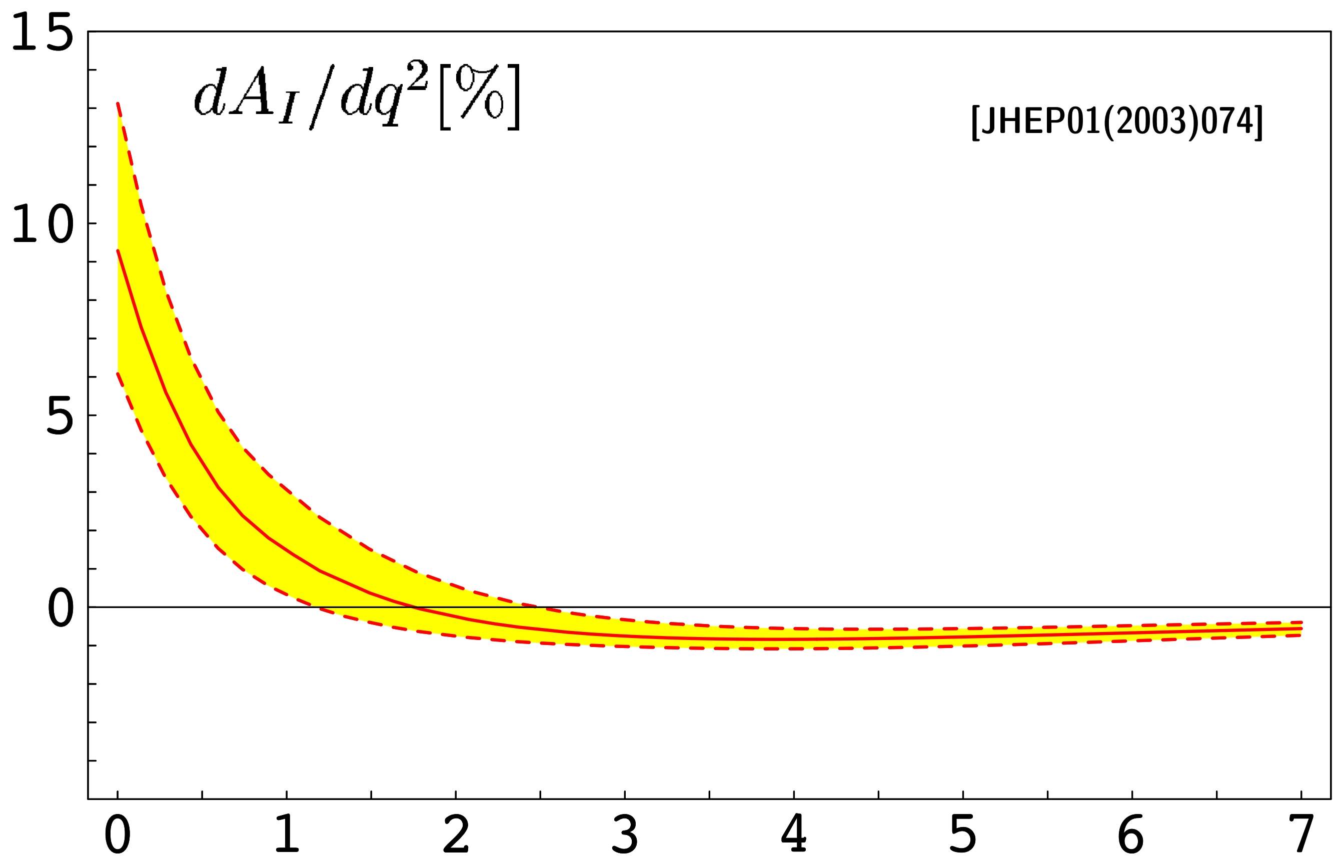
A. Ali et al., Eur. Phys. J. C47 (2006) 625]

Isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$

The isospin asymmetry defined as follow:

$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$$

can precisely measured better than the BFs



Expected $A_I \sim 0$ in the SM (O(10%) at $q^2 \to 0$ for $B \to K^{(*)}\mu^+\mu^-$)

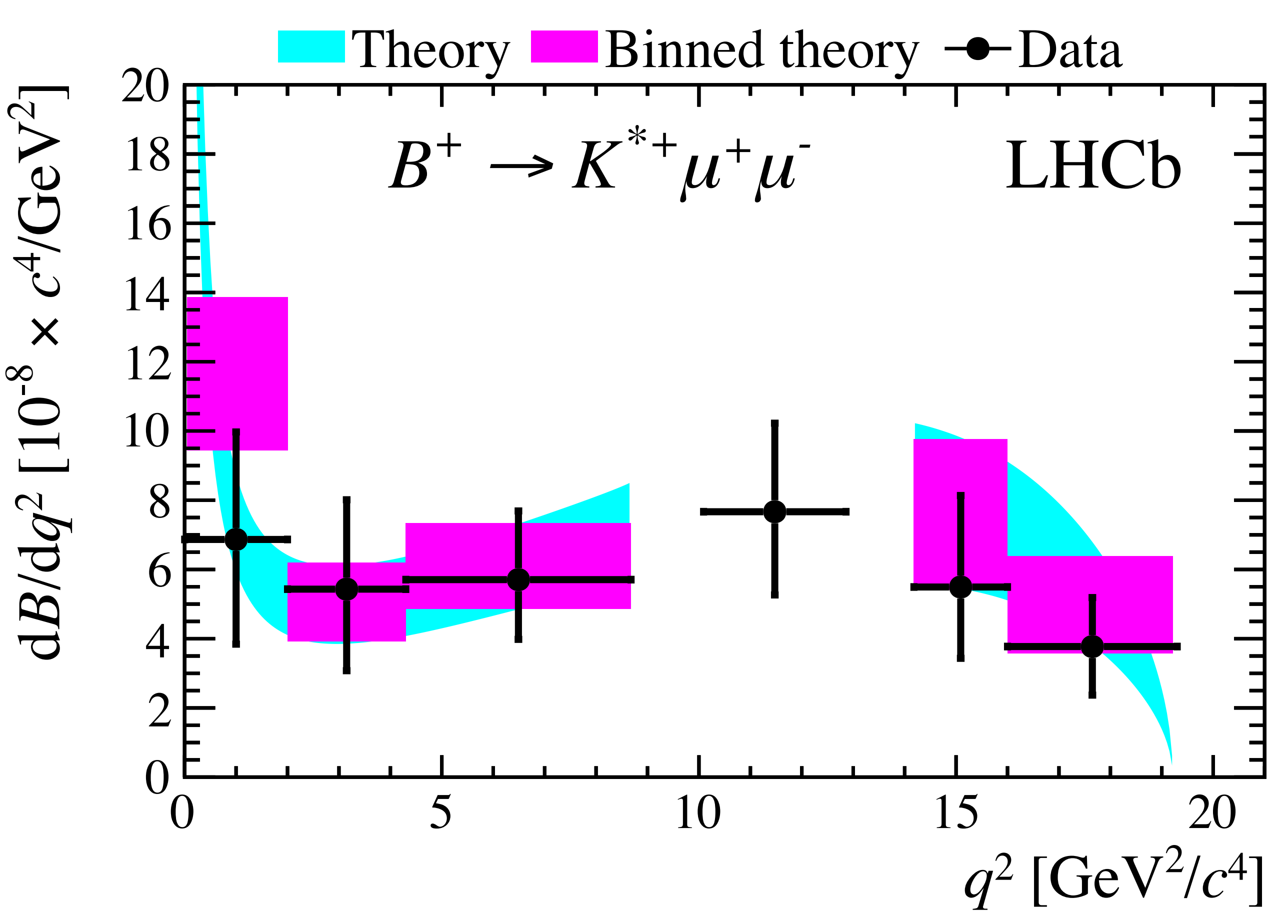
Analysis based on $1 fb^{-1}$

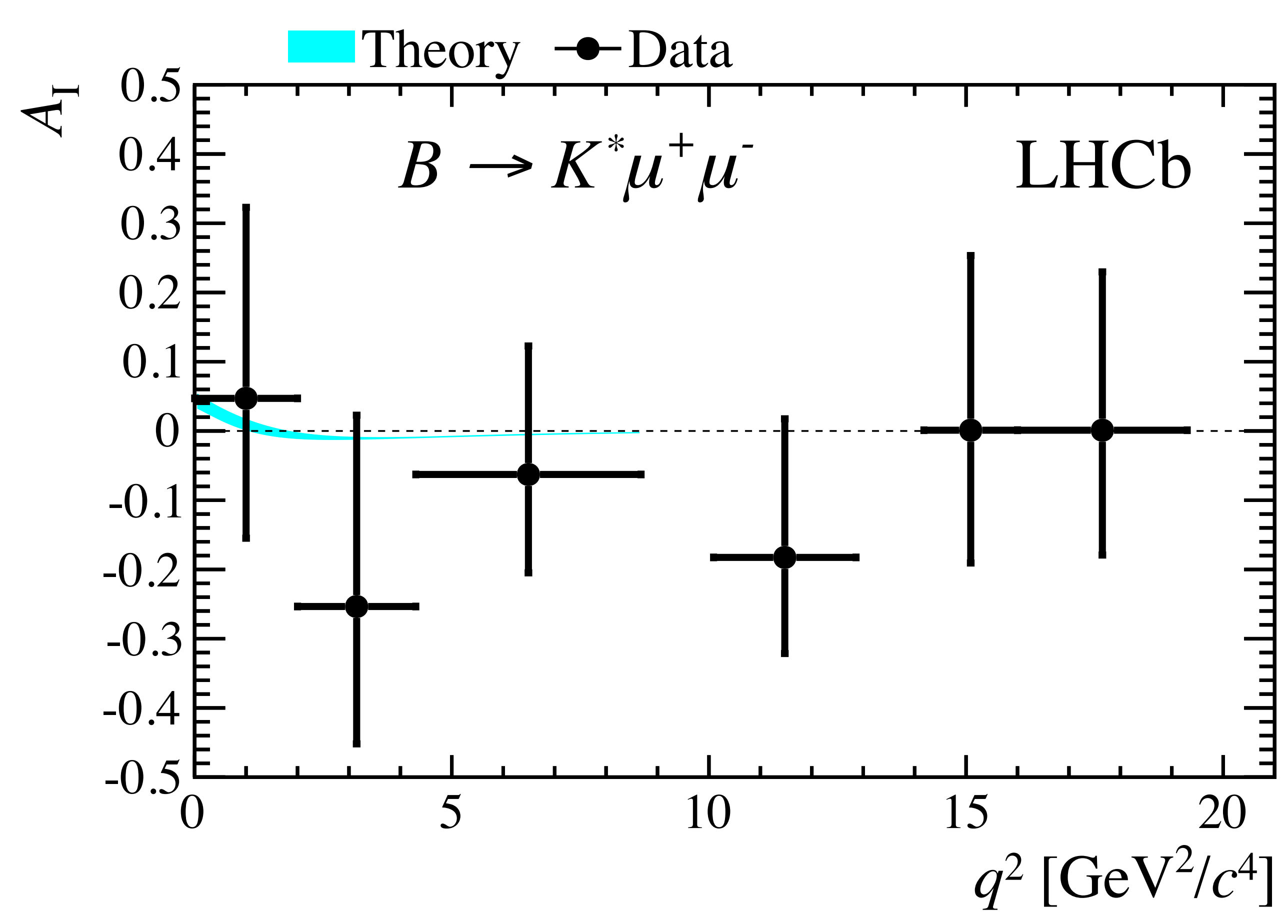
q^2

$B \to K^* \mu^+ \mu^-$ results

[LHCB-PAPER-2012-011]

- Differential BR measured
- A_I for the $B \to K^* \mu^+ \mu^-$ is consistent with zero, as predicted by the SM



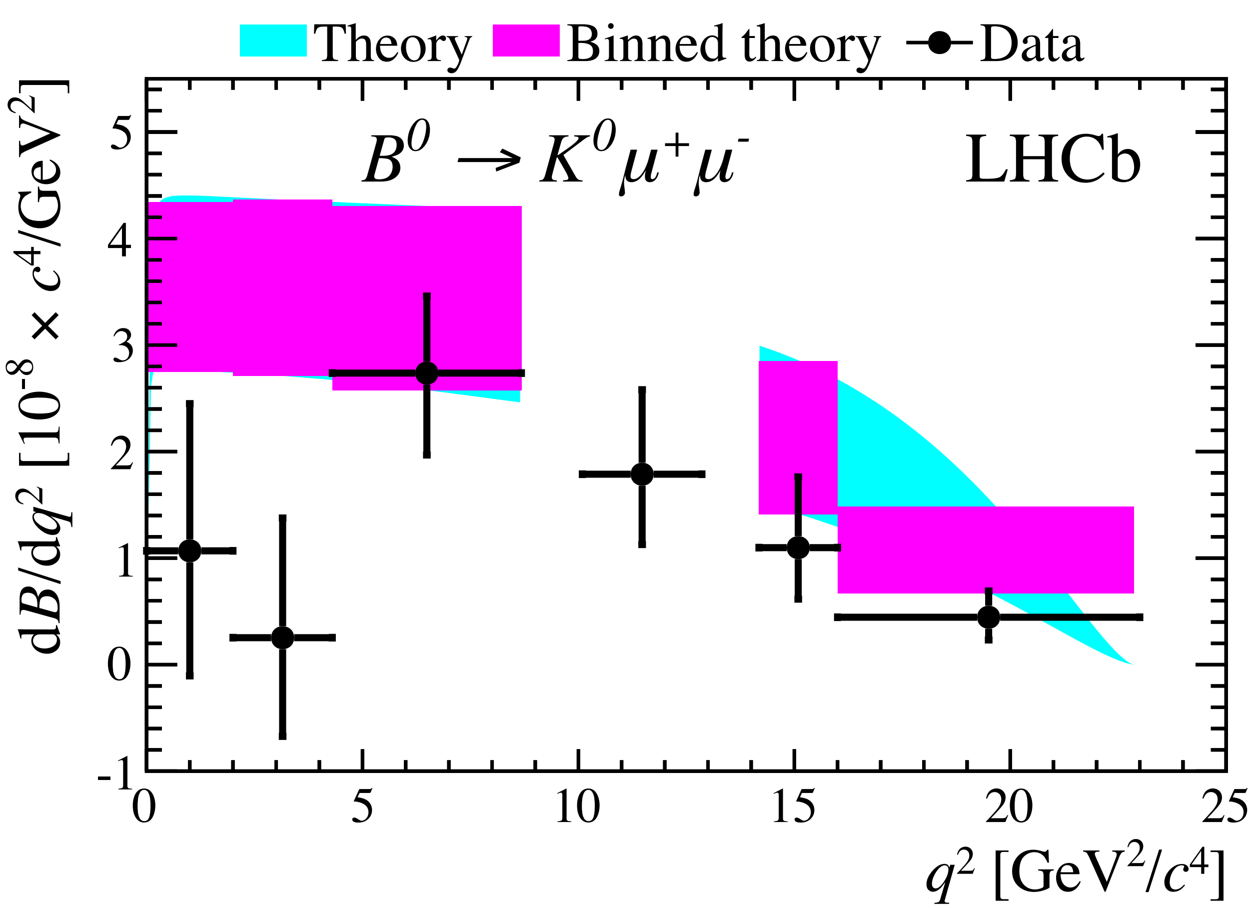


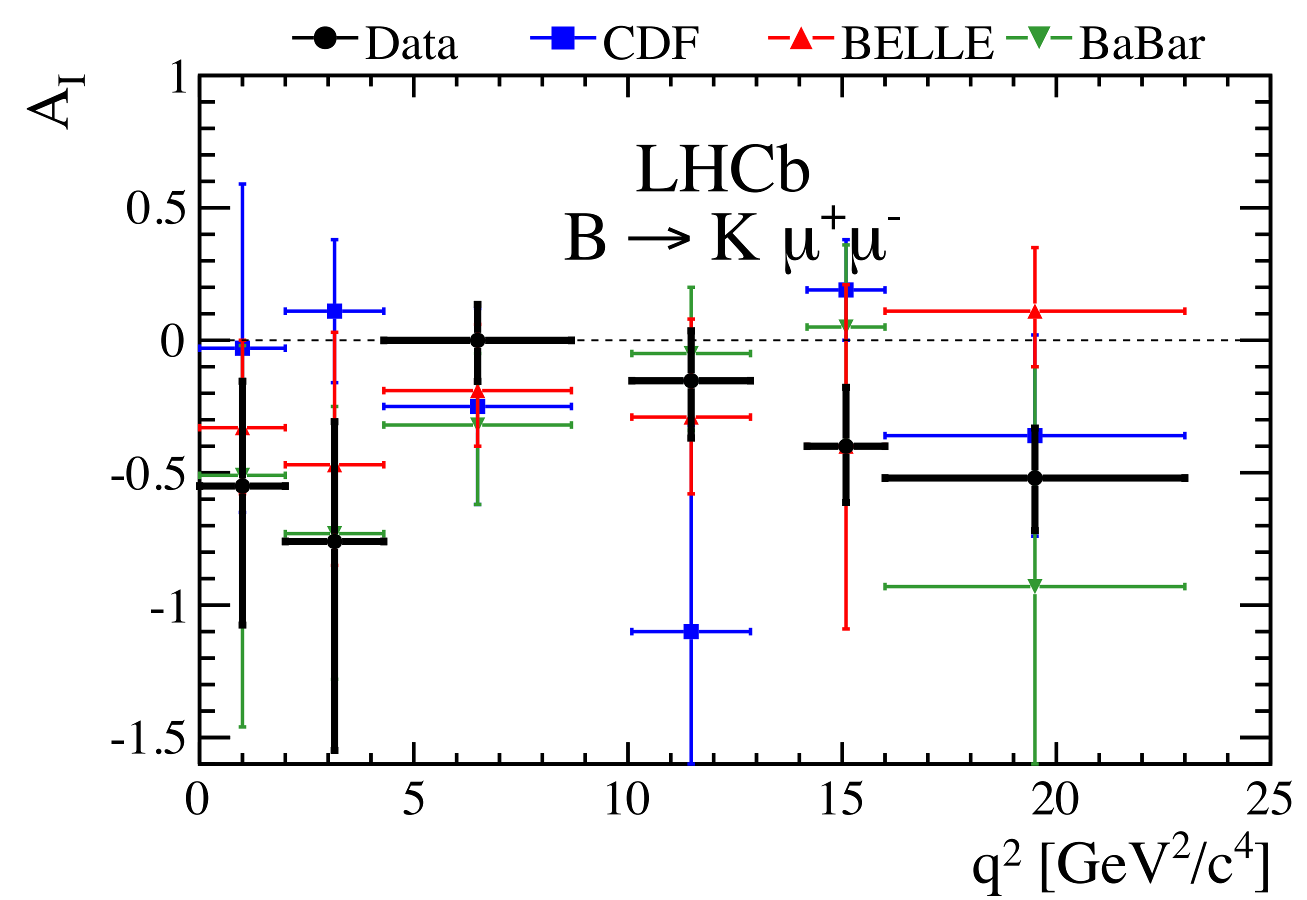
$B \to K\mu^+\mu^-$ results

[LHCB-PAPER-2012-011]

- Observed a deficit of $B^0 \to K^0\mu^+\mu^-$ where SM is well predicted
- A_I for the $B \to K\mu^+\mu^-$ below the SM prediction
- Deviation from zero integrated across q^2 4.4σ (ignoring small correlation of errors between each q^2 bin)
- All the previous measurements of A_I are negative

[BABAR: B. Aubert et al., submitted to Phys. Rev. D, arXiv:1204.3933]
[Belle: J.-T. Wei et al. Phys. Rev. Lett. 103 (2009) 171801, arXiv:0804.4770]
[CDF: Phys.Rev.Lett. 107 (2011) 201802, arXiv:1204.3933]

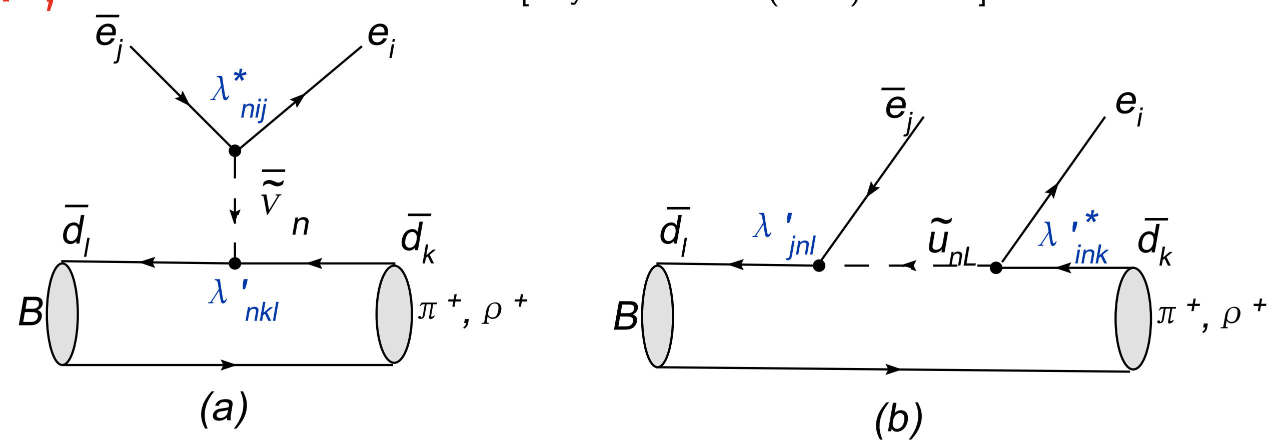




$B^+ \to \pi^+ \mu^+ \mu^-$

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

[Phys. Rev. D77 (2008) 014017]



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

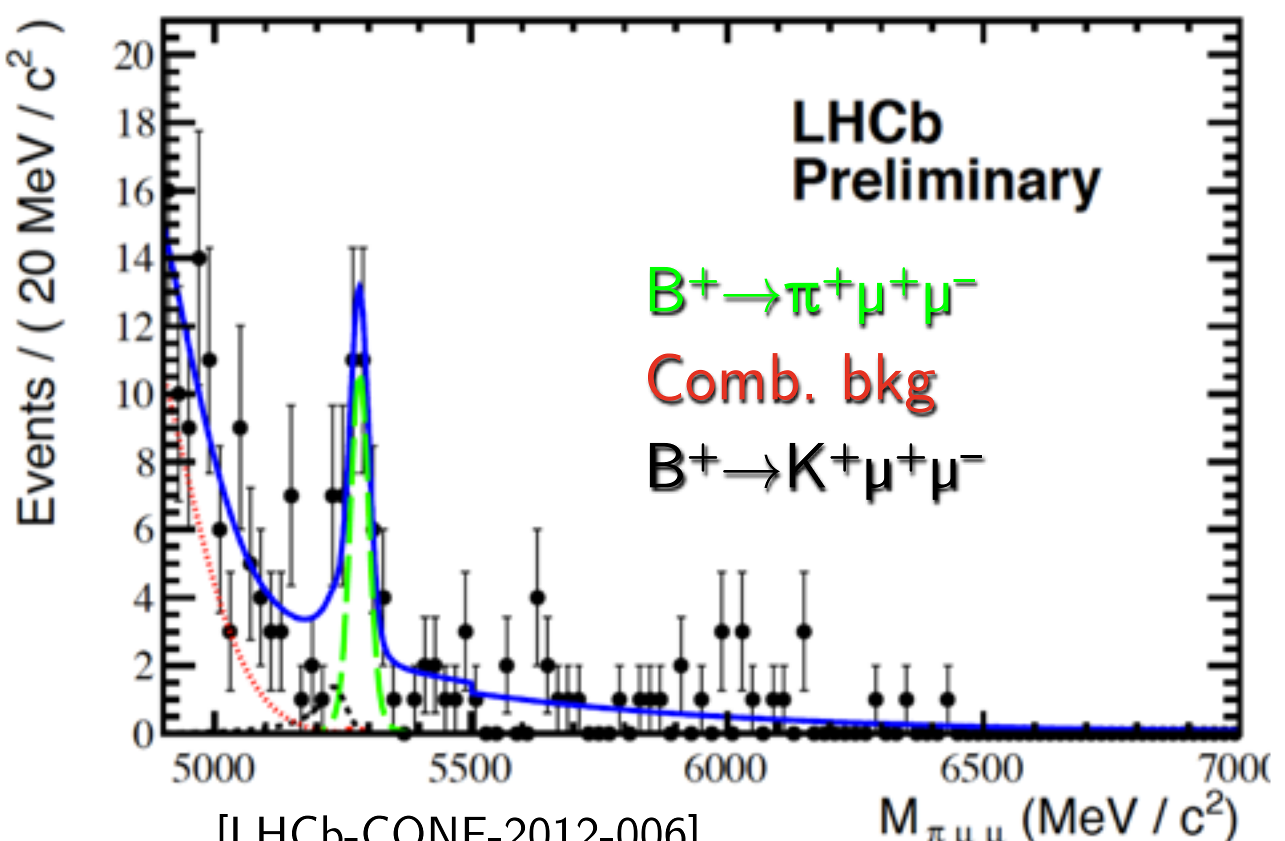
$J/\psi K^+$ decay used as normalization channel

$BR(B^+ \to \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6_{stat} \pm 0.2_{syst}) \times 10^{-8}$

5.6σ excess

Nicely match with SM prediction

Rarest B decay ever observed



[LHCb-CONF-2012-006]

Conclusions

- LHCb has demonstrated its power in many flavour physics topics: CPV studies with b and c hadrons, rare B and D decays, and others

- Current results on $BR(B_{d,s}\to\mu^+\mu^-)$ put severe constraints to NP approaching the SM prediction; brand new LHC combination presented
- World best limits for $BR(D^0\to\mu^+\mu^-)$ and $BR(B_{d,s}\to\mu^+\mu^-\mu^+\mu^-)$

- LHCb have obtained the most precise measurement of the angular observables in $B\to K^{*0}\mu^+\mu^-$, all of them agree with the SM
- Isospin-asymmetry in $B\to K^{(*)}\mu^+\mu^-$ decays: 4.4σ deviation from 0 (~SM) for the $B\to K\mu^+\mu^-$ observed.
- First observation of $B^+\to\pi^+\mu^+\mu^-$

- Expected to double the data statistics in 2012, many improvements are foreseen, stay tuned!