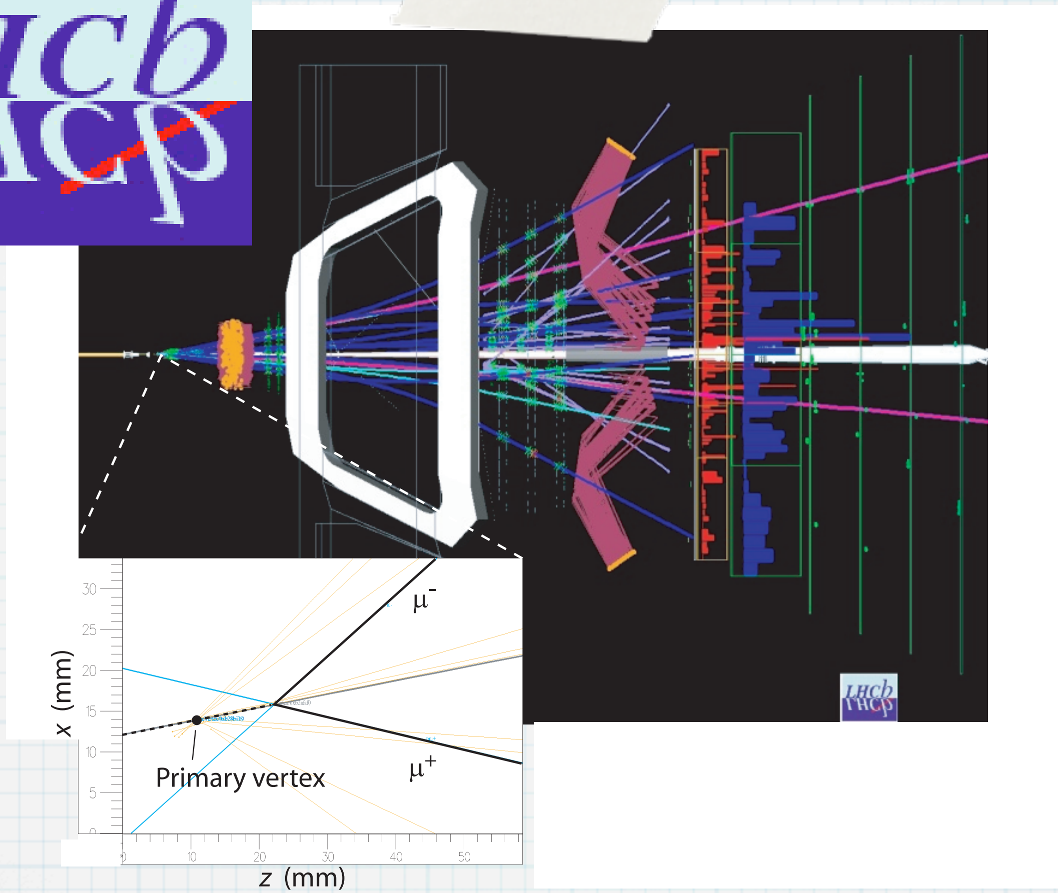

Rare decays in LHCb

XL International Meeting on Fundamental Physics, Benasque 2012

José Ángel Hernando Morata
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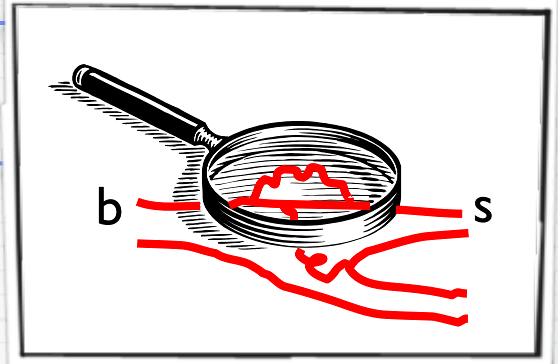
(on behalf of the LHCb collaboration)

27/05/2012

Introduction



- LHCb searches for NP
  - in FCNC with B (and D) decays, where new particles can enter in the loops and modify the SM prediction on some observables
- LHCb Rare Decays (RD) analyses:
  - Search for $B_{(s)} \to \mu\mu$ rare decays
    - Update with 1 fb^{-1} [LHCb-PAPER-2012-007]
  - Angular analysis of the $B \to K^* \mu\mu$ decay
    - Update with 1fb^{-1} [LHCb-CONF-2012-008]
    - Isospin Asymmetry $B \to K^{(*)} \mu\mu$ [LHCb-PAPER-2012-011]
    - Measurement of $\mathcal{B}(B_s \to \phi\mu\mu)/\mathcal{B}(B_s \to J/\psi\phi)$ [LHCb-CONF-2012-003]
  - Measurement of $\mathcal{B}(B_s \to \phi\gamma)/\mathcal{B}(B \to K^*\gamma)$ [LHCb-CONF-2012-004]

LHCb-CONF-2012-004

Measurement of $\mathcal{A}_{CP}$ B→K*γ

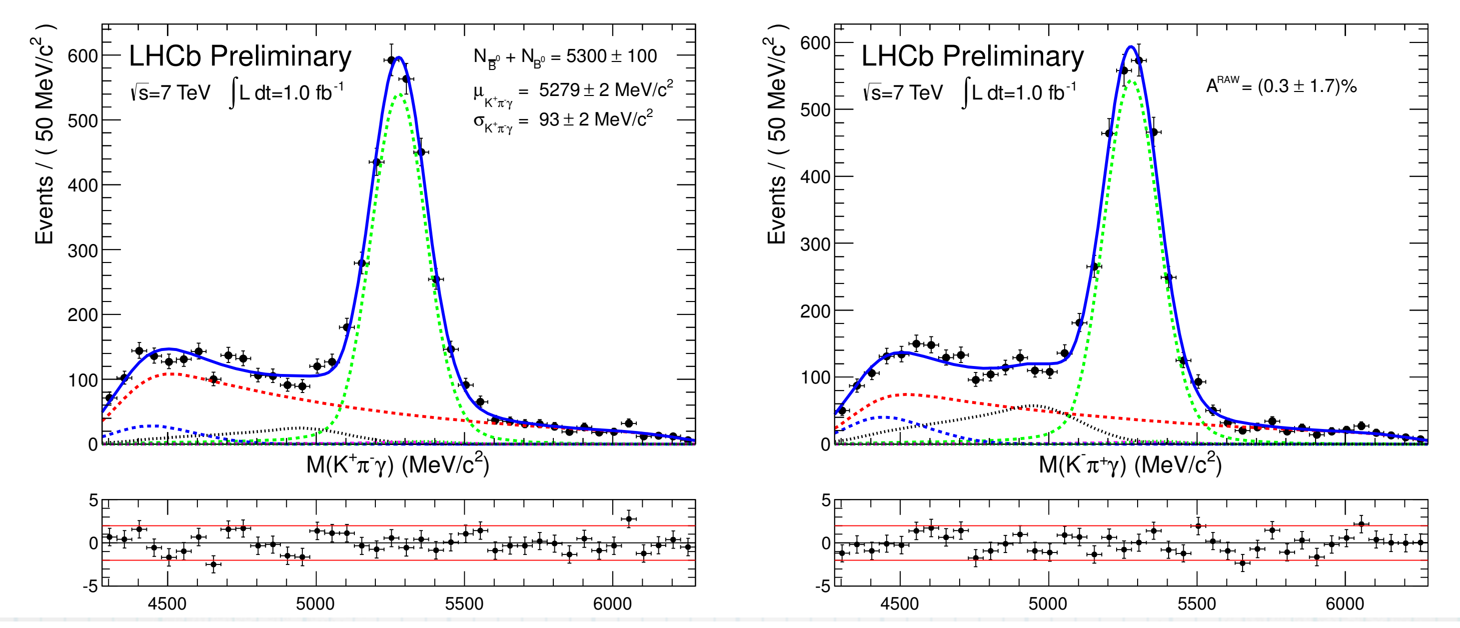
SM prediction:

$\mathcal{A}_{CP}$ = -0.0061±0.0043

[arXiv:0406055]

Experimental status:

	CLEOII	BABAR	Belle
$\mathcal{A}_{CP}$	$+0.08 \pm 0.13 \pm 0.03$	$-0.016 \pm 0.022 \pm 0.007$	$0.015 \pm 0.044 \pm 0.012$
	PRL 84 (2000)	PRL 103 (2009)	RD 68 (2004)



Correction by detector and production asymmetries:

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = \mathcal{A}^{\mathrm{RAW}}(B^0 \to K^{*0}\gamma) - \mathcal{A}_{\mathrm{D}}(K\pi) - \kappa\mathcal{A}_{\mathrm{P}}(B^0)$$

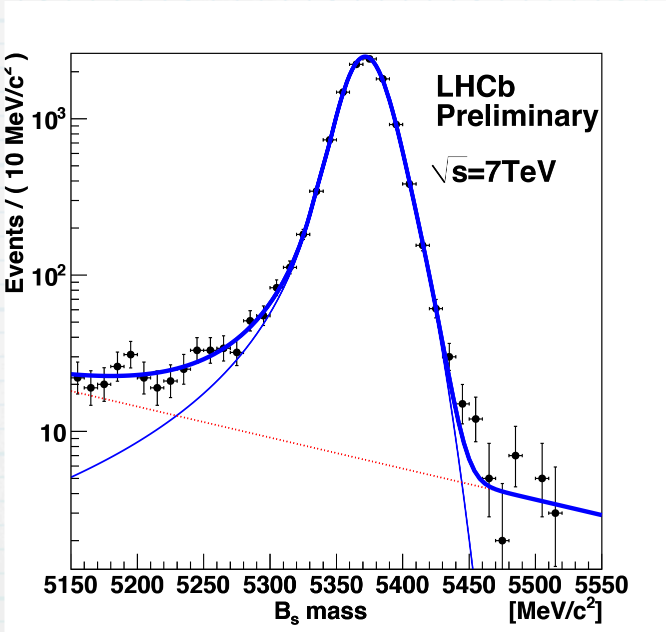
		correction	uncertainty
Background model	: $\Delta\mathcal{A}_{bkg}$	-0.002	±0.007
Detection	: $-\mathcal{A}_{\mathrm{D}}(K\pi)$	$+0.010$	±0.002
Magnet polarity	: $\Delta\mathcal{A}_{\mathcal{M}}$	$+0.001$	±0.002
B^0 production	: $-\kappa\mathcal{A}_{\mathrm{P}}(B^0)$	-0.004	±0.005
Total		$+0.005$	±0.009

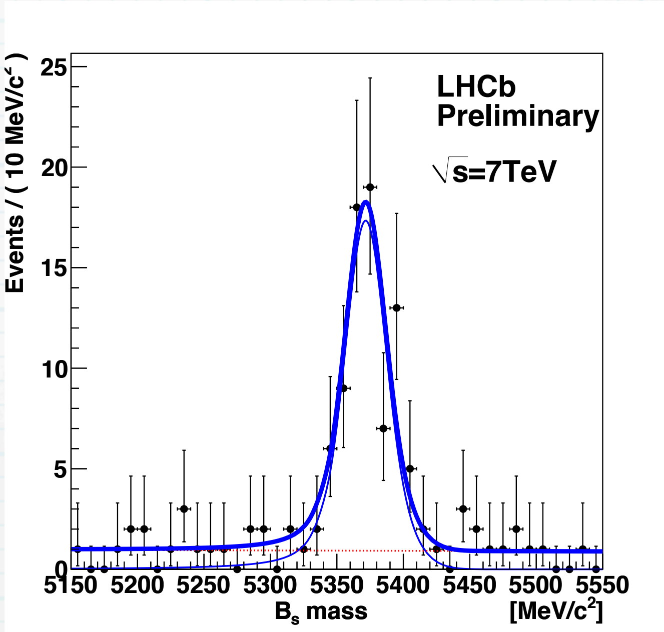
$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017(\mathrm{stat}) \pm 0.009(\mathrm{syst})$$

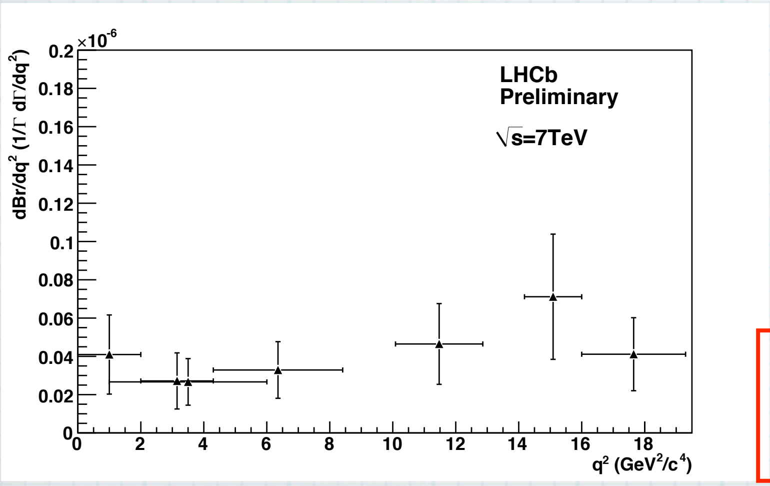
LHCb-CONF-2012-003

Measurement $B(B_s\to\phi\mu\mu)/B(B_s\to J/\psi\phi)$

Experimental status: $\frac{\mathcal{B}(B_s^0\to\phi\mu\mu)}{\mathcal{B}(B_s^0\to J/\psi\,\phi)} = (1.13\pm 0.19(\mathrm{stat})\pm 0.07(\mathrm{syst}))\times 10^{-3}(\mathrm{CDF})$ arXiv:1107.3753.







dB/dq² vs q²

$$\frac{N_{\phi\mu\mu}}{N_{J/\psi\,\phi}} = \frac{76.5\pm 9.5}{11073.5\pm 113.0} = (6.905\pm 0.863(\mathrm{stat})\pm 0.014(\mathrm{syst}))\times 10^{-3}$$

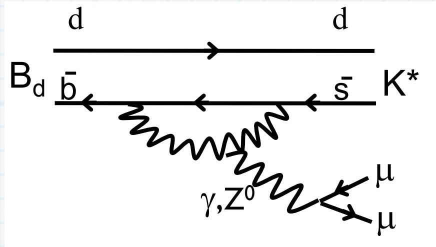
$$\frac{\mathcal{B}(B_s^0\to\phi\mu\mu)}{\mathcal{B}(B_s^0\to J/\psi\,\phi)} = \overset{\text{data}}{\frac{N_{\phi\mu\mu}}{N_{J/\psi\,\phi}}} \times \overset{\text{PDG}}{\frac{\mathcal{B}(J/\psi\to\mu^+\mu^-)}{1}} \times \overset{\text{MC}}{\frac{\varepsilon_{J/\psi\,\phi}}{\varepsilon_{\phi\mu\mu}}}$$

$$\frac{\mathcal{B}(B_s^0\to\phi\mu\mu)}{\mathcal{B}(B_s^0\to J/\psi\,\phi)} = (0.556\pm 0.069(\mathrm{stat})\pm 0.043(\mathrm{syst})\pm 0.006(\mathcal{B}))\times 10^{-3}$$

LHCb-CONF-2012-008

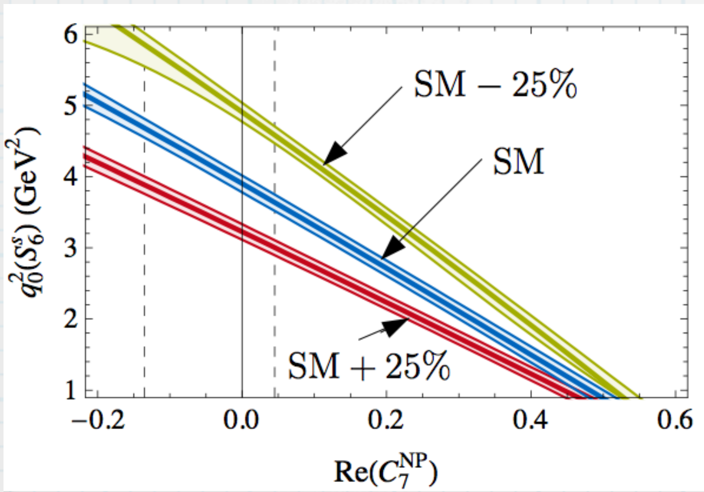
Angular analysis B→K*μμ

- In the SM, the γ/Z penguin introduces a forward/backward asymmetry (A_{FB}), with a well defined zero-crossing point
  - SM $q^2_0 = (4.-4.3)\ \mathrm{GeV}^2/c^2$
- This Asymmetry and other observables (F_L,S_3) can be altered by the presence of NP
  - Effective operators involved are: O_7,O_9,O_{10}
- Measured previously by BaBar, Belle and CDF with inconclusive results



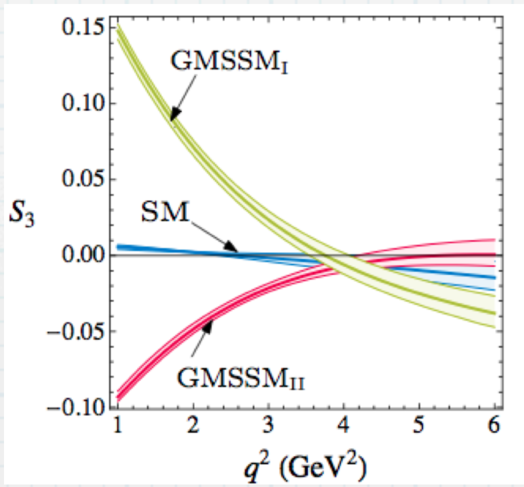
$$A_{FB}\left(s = m^2_{\mu^+\mu^-}\right) = \frac{N_F - N_B}{N_F + N_B}$$

See: F. Kruger, J. Matias PR D71(2005); J.Matias et al, JHEP, 1204:104,2012

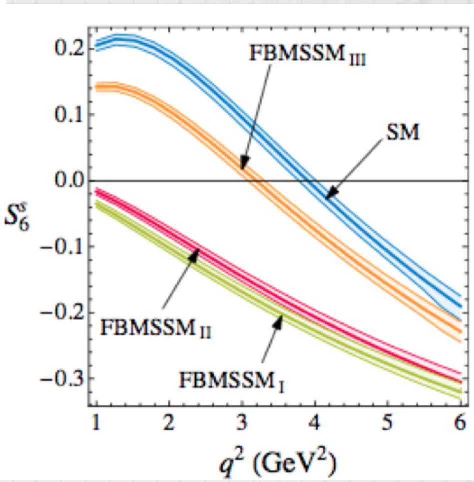


sensitivity to zero-crossing point

$S_3 = (1-F_L)\,A^2_T$



$S_6 = 4/3\ A_{FB}$

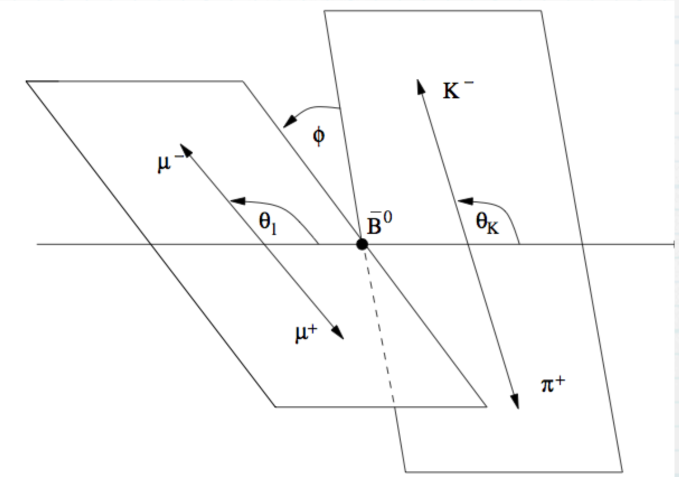


W. Altmannshofer et al, JHEP, 0901:019,2009

Angular analysis B→K*μμ

- The decay is described by 3 angles ($\theta_l,\theta_K,\varphi$) and the q^2 dimuon mass squared
  - Reduced expression of the angular distribution after φ folding:

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



- Thanks to a 3D fit in the angles (in bins of q^2) we access
  - F_L, the longitudinal polarization of K*
  - A_{FB}, the forward/backwark dimuon asymmetry
  - A_{Im} asymmetry
  - $S_3 = 1/2\,(1-F_L)\,A^2_T$

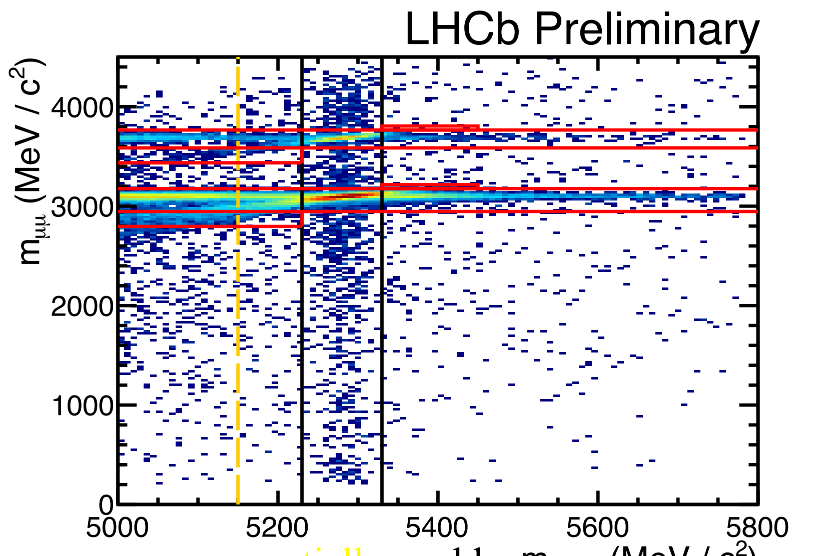
Angular analysis B→K*μμ

BDT using kinematic, vertex, track quality, IP and PID information

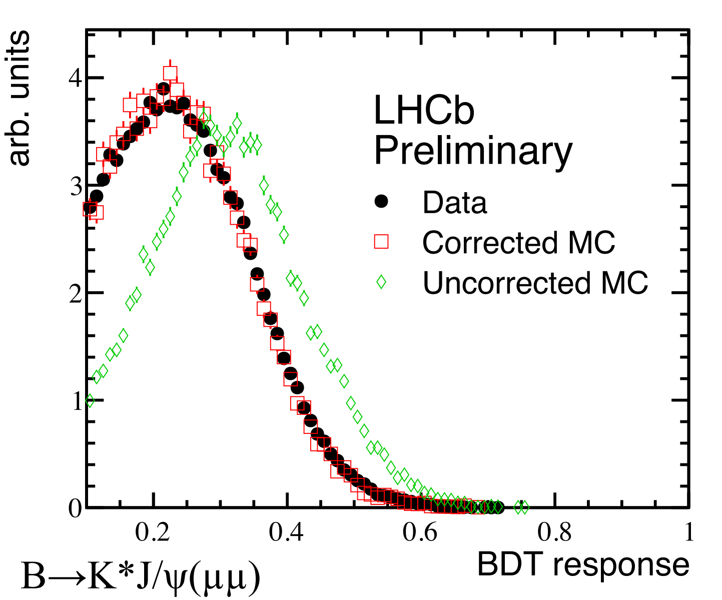
B→K*J/ψ(μμ): signal, B→K*μμ sidebands: bkg

Remove charmonium resonances and veto peaking bkg

B→K*J/ψ, Bs→ϕμμ



cc resonances, partially rec bkg



B→K*J/ψ(μμ)

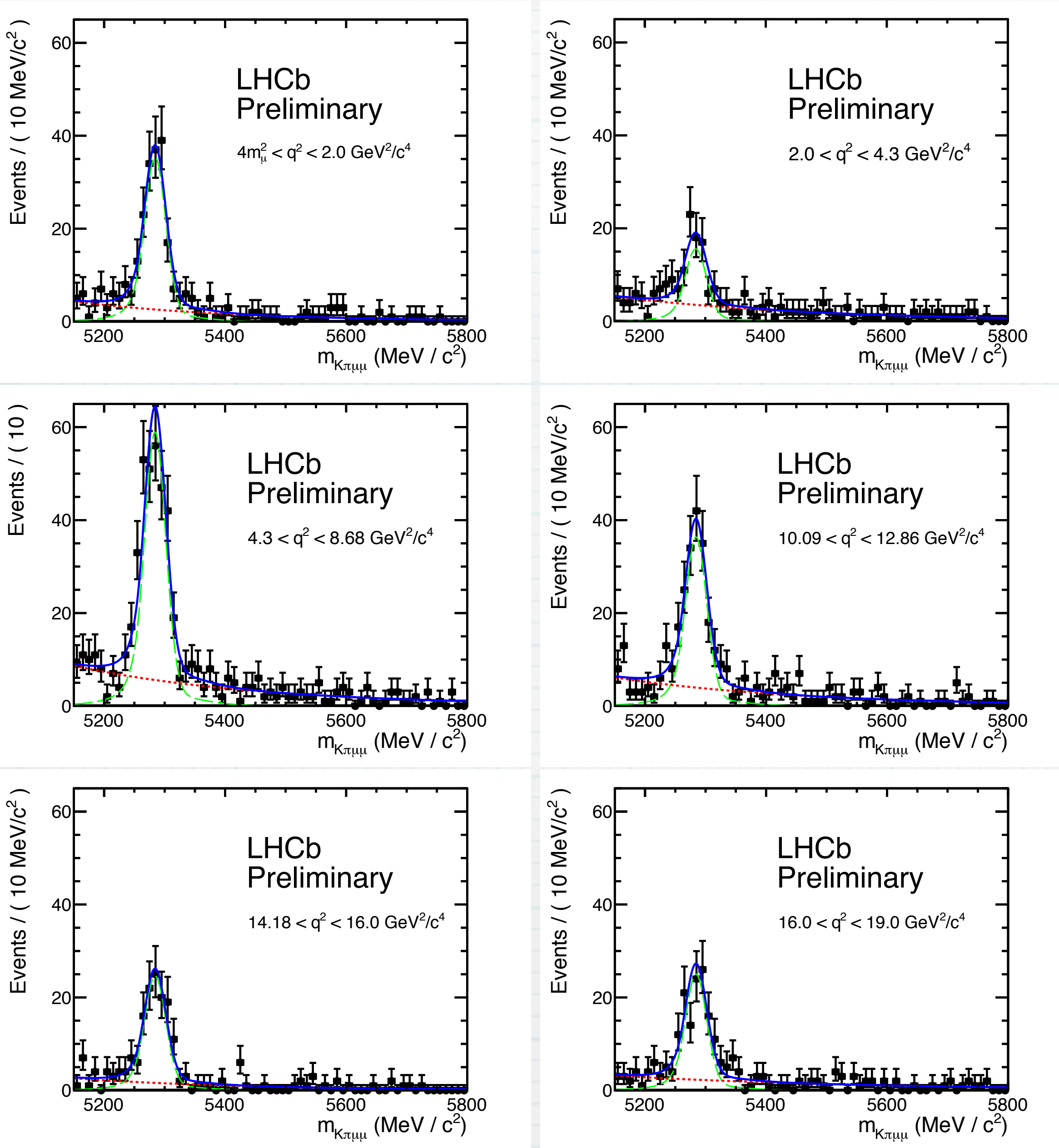
Tune MC for known discrepancies with data (IP)

verification with B→K*J/ψ

Use simulation to correct event-by-event as a function of the angles and q^2

BDT studied to keep acceptance in angles as flat as possible

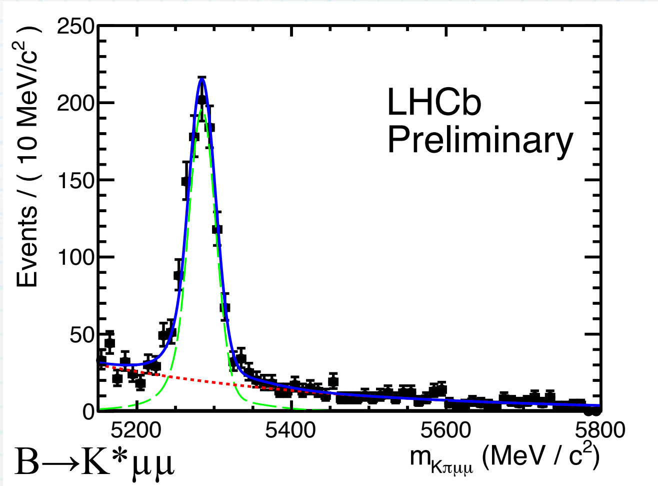
Angular analysis $B \to K^* \mu\mu$



S/B ~ 0.25

900±34 signal events

BaBar+Belle+CDF 600

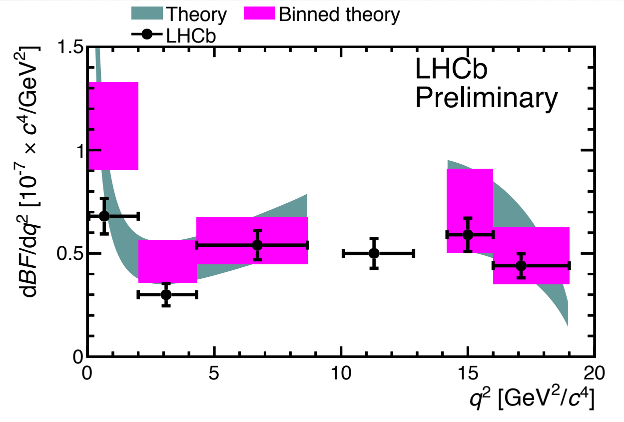


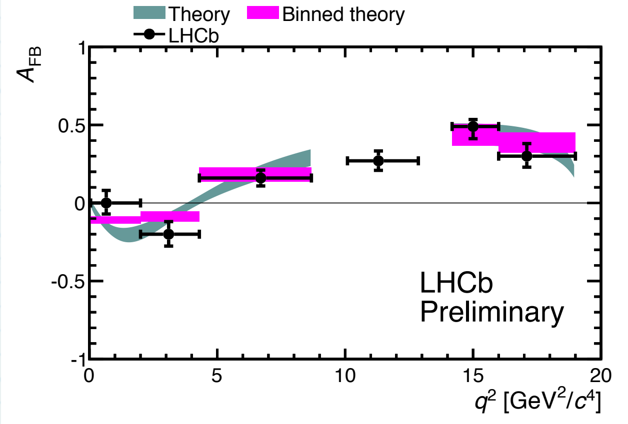
q^2 (GeV$^2/c^4$) range	Signal Yield	Background Yield
$4m_\mu^2 < q^2 < 2.00$	162.4 ± 14.2	27.7 ± 3.8
$2.00 < q^2 < 4.30$	71.4 ± 10.7	37.1 ± 4.1
$4.30 < q^2 < 8.68$	270.5 ± 18.8	58.8 ± 5.5
$10.09 < q^2 < 12.90$	167.0 ± 14.9	41.7 ± 4.5
$14.18 < q^2 < 16.00$	113.0 ± 11.7	17.1 ± 3.0
$16.00 < q^2 < 19.00$	115.0 ± 12.4	23.9 ± 3.6
$1.00 < q^2 < 6.00$	195.2 ± 16.9	75.8 ± 6.0
$4m_\mu^2 < q^2 < 19.00$	900.0 ± 34.4	206.2 ± 10.3

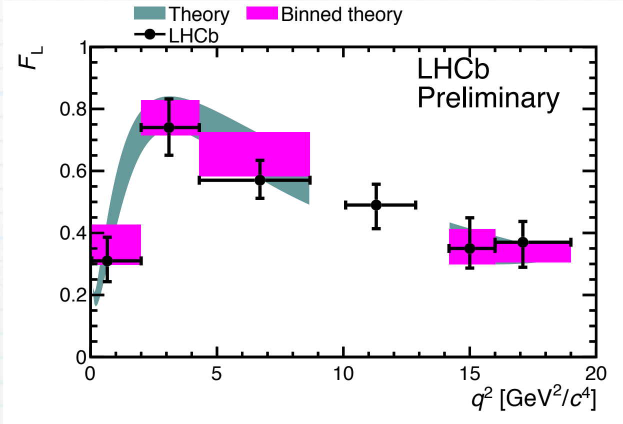
Angular analysis $B \to K^*\mu\mu$

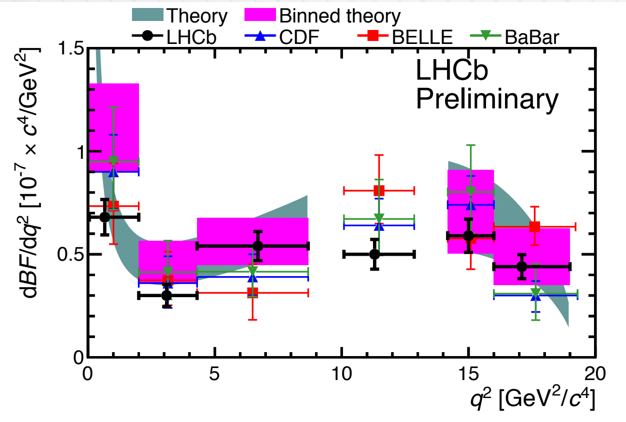
In agreement with SM!

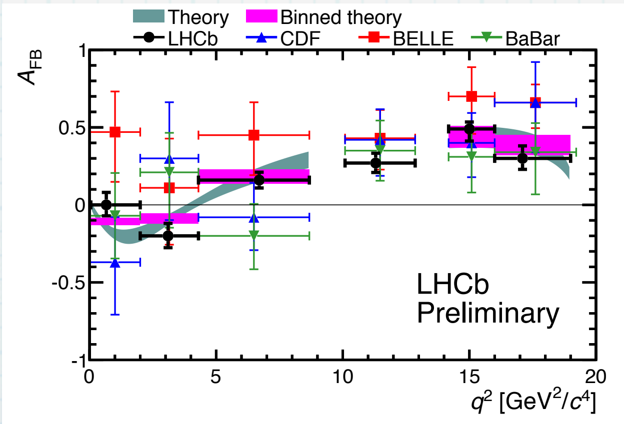
Differential B vs q^2 | A_{FB} | F_L

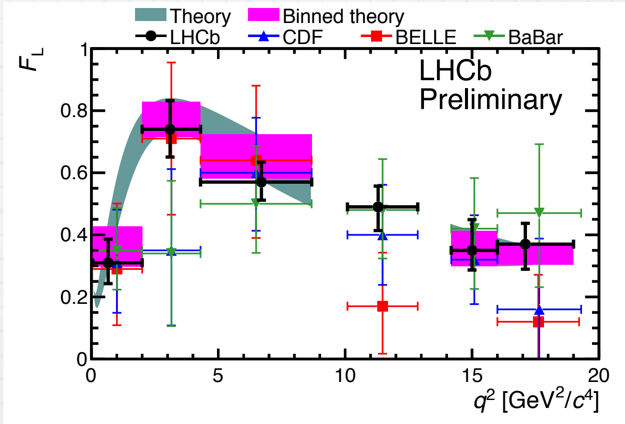








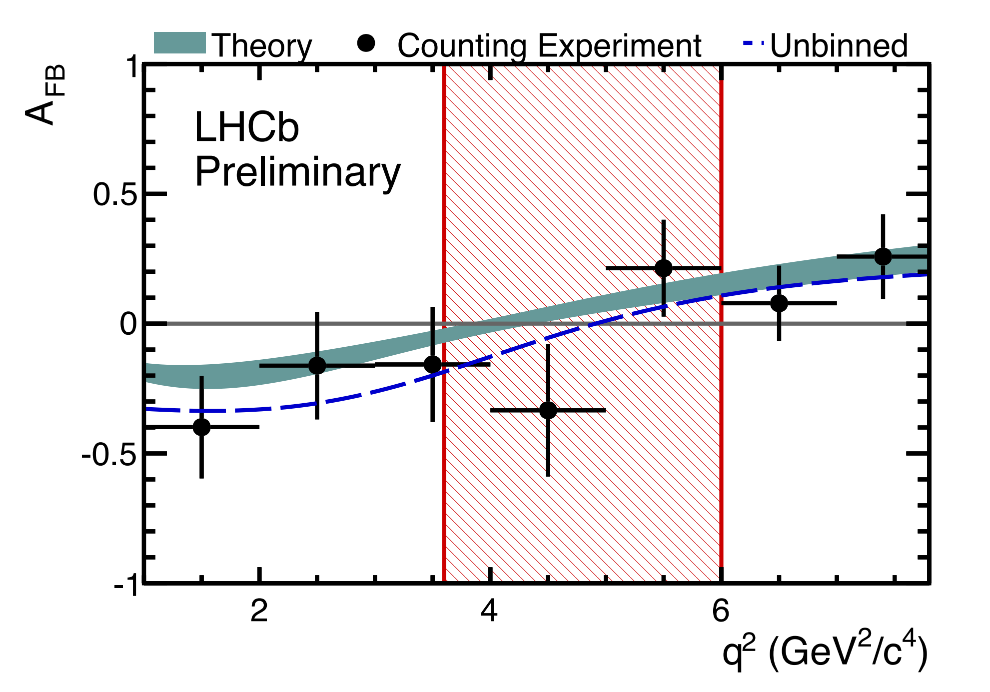


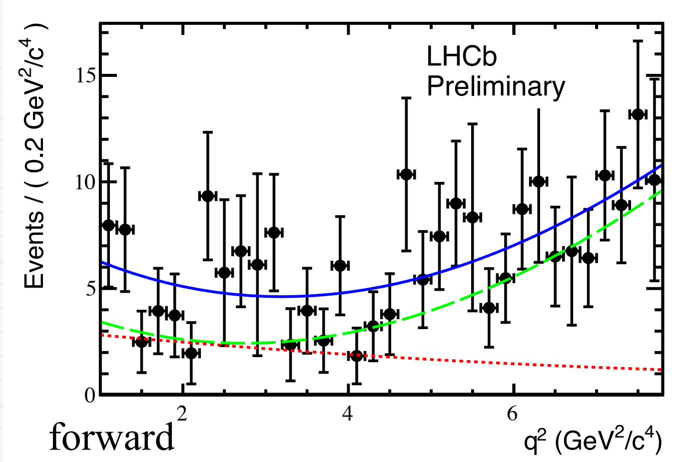


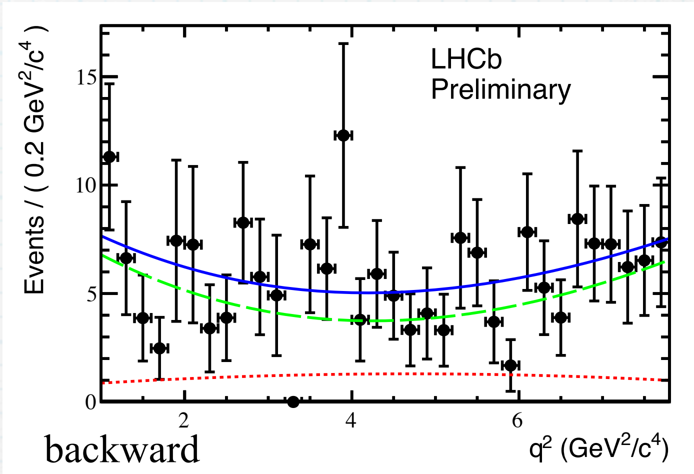
$$A_{FB} = -0.18^{+0.06+0.01}_{-0.06-0.02} \qquad (1 < q^2 < 6 GeV^2) \text{ LHCb}$$

Angular analysis B→K*μμ

A_{FB} vs q^2







$$q_0^2 = (4.9^{+1.1}_{-1.3})\ \mathrm{GeV}^2/c^4$$

Good agreement with SM!

- Results constrain NP scenarios but the statistical precision is still limited compared with theory prediction

Isospin Analysis $B\to K^{(*)}\mu\mu$

LHCb-PAPER-2012-011

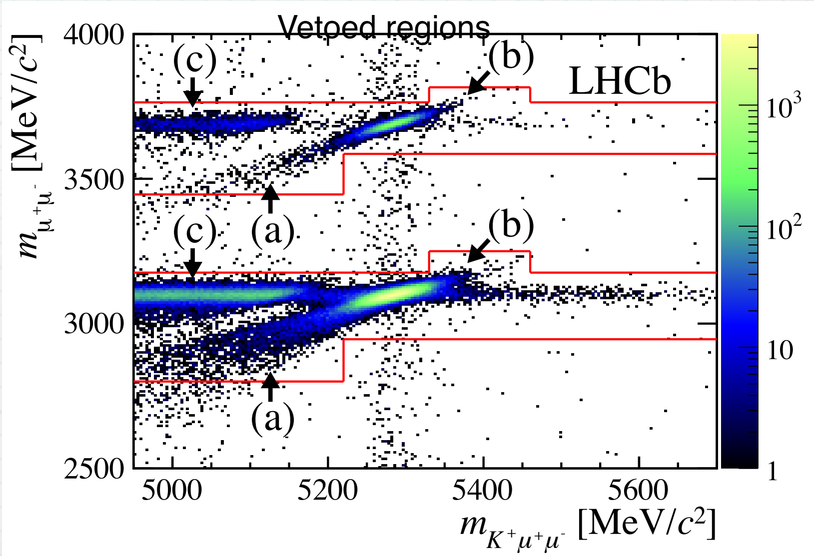
- Isospin asymmetry

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

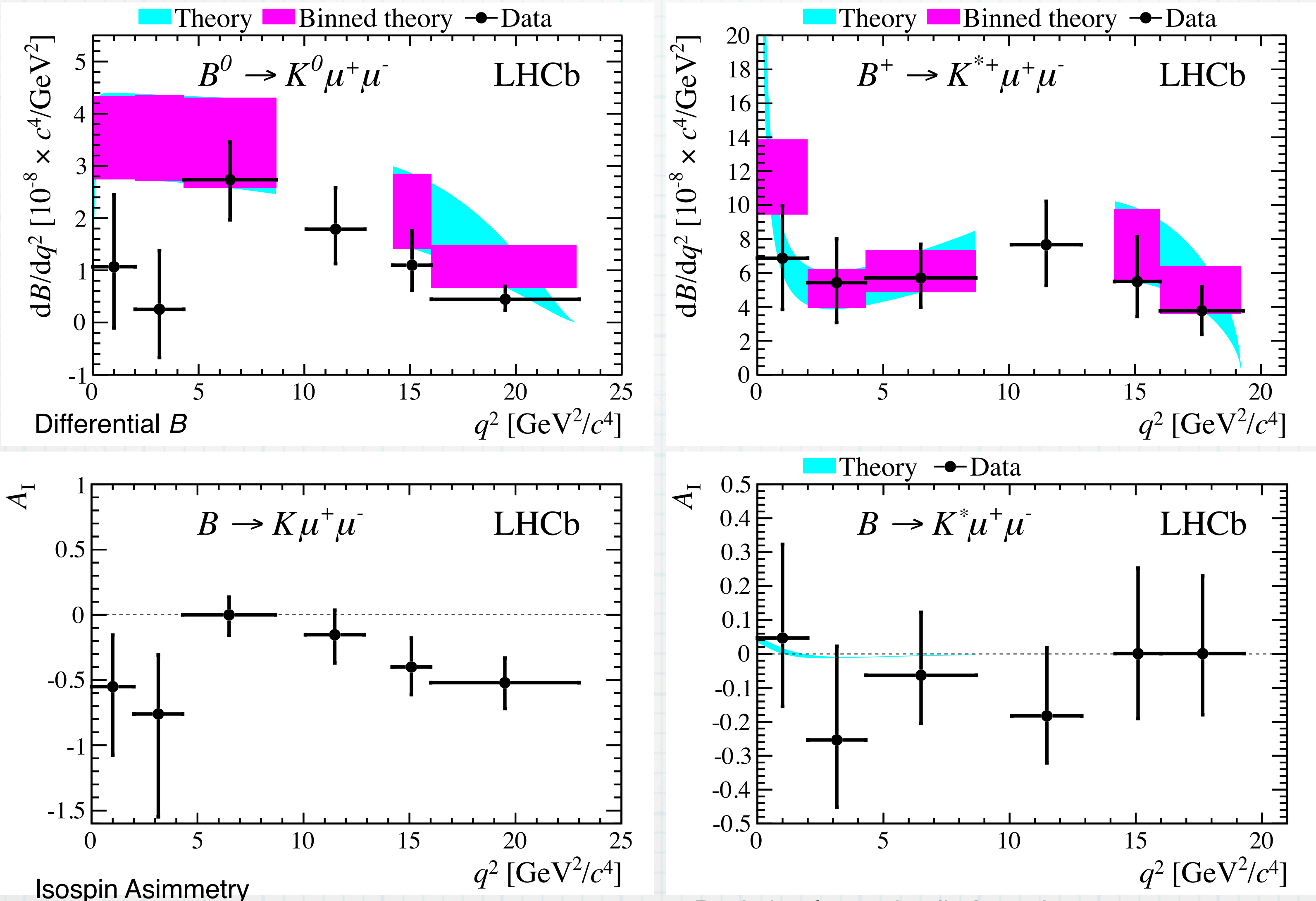
See: T.Feldmann and J.Matias, JHEP, 01 (2002) 074

- Measured by BaBar, Belle and CDF
  - $B\to K^*\mu\mu$ in agreement with SM
  - $B\to K\mu\mu$ some tension -deviated from zero-, dominated by $K_s\mu\mu$

- Measure differential *B*:
  - $B^+\to K^{*+}(K_s\pi_+)\mu\mu$, $B\to K^*\mu\mu$,
  - $B\to K\mu\mu$, $B^+\to K^+\mu\mu$
- Two tracking cathegories (long, downstream)
- Use as control channel $B\to K^*J/\psi(\mu\mu)$



Isospin Analysis $B \to K^{(*)}\mu\mu$



Deviation from 0 in all q^2 rate is 4.4 σ

In agreement with SM and with previous measurements!

Tension confirmed! but difficult to interpret

Search for the $B_{(s)} \to \mu\mu$ decay

LHCb-PAPER-2012-007

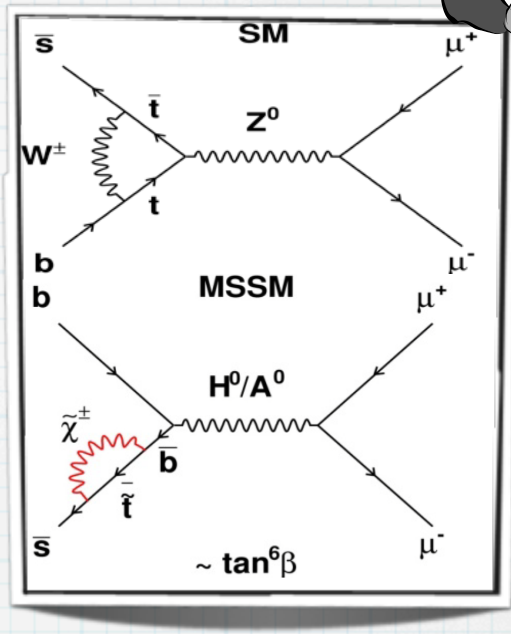
- SM prediction (FCNC, helicity suppressed)
  - SM $B(B_s \to \mu\mu) = (3.2 \pm 0.2)\ 10^{-9}$
  - SM $B(B \to \mu\mu) = (0.1 \pm 0.01)\ 10^{-9}$

arXiv:1005.5310
arXiv:1012.1447

- Branching ratio very sensitive to NP
- Current Status

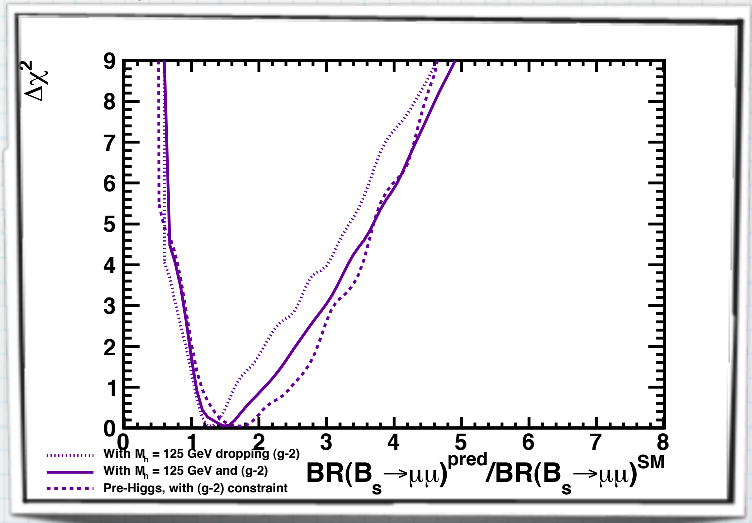
[0.37 fb^{-1} arXiv:1112.3515, PLB 707 (2012) 497-505]

  - LHCb limit:
    - $B(B_s \to \mu\mu) < 1.4\ 10^{-8}$ 95 % C.L (LHCb)
    - $B(B \to \mu\mu) < 3.2\ 10^{-9}$ 95 % C.L (LHCb)
  - CDF has an excess of events (10 fb^{-1}):
    - $B(B_s \to \mu\mu) = (1.0^{+0.8}_{-0.6})\ 10^{-8}$ (CDF)
  - $B(B_s \to \mu\mu) < 7.7\ 10^{-9}$ 95 % C.L (CMS)



NUHM

arXiv:1112.3564



$B_{(s)} \to \mu\mu$

Similar selection for signal and normalization channels:

$B^+ \to J/\psi(\mu\mu)K^+$, $B_s \to J/\psi(\mu\mu)\phi$, $B \to K\pi$

new! added a multi variate cut to the selection

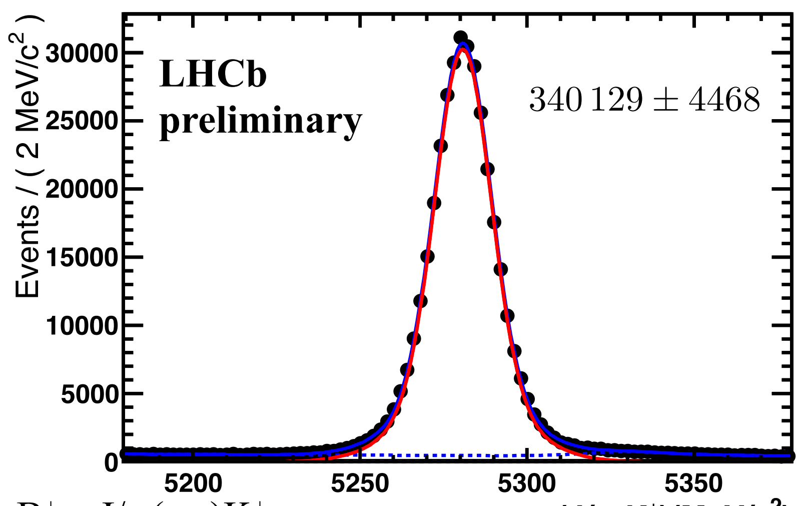
$$\mathcal{B} = \mathcal{B}_{\rm norm} \times \frac{\epsilon_{\rm norm}}{\epsilon_{\rm sig}} \times \frac{f_{\rm norm}}{f_{d(s)}} \times \frac{N_{B^0_{(s)} \to \mu^+\mu^-}}{N_{\rm norm}}$$
$$= \alpha^{\rm norm}_{B^0_{(s)} \to \mu^+\mu^-} \times N_{B^0_{(s)} \to \mu^+\mu^-},$$

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

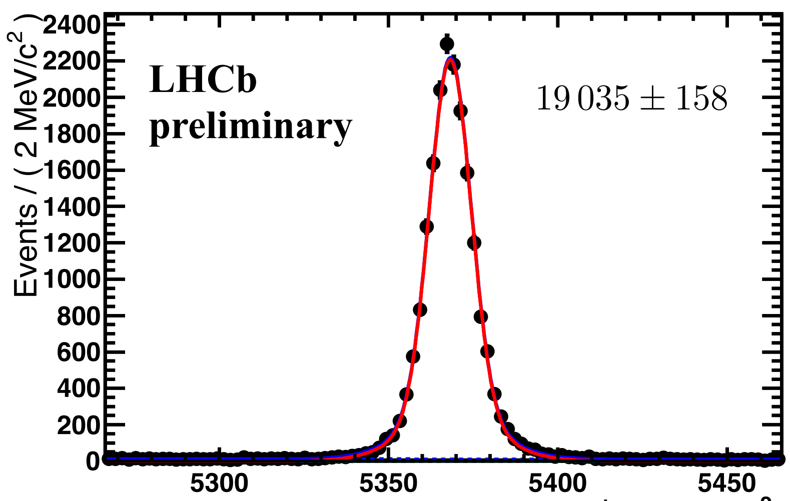
PRL 107 (2011) 211801, arXiv:1106.4435

$$\epsilon^{\rm TRIG|SEL}_{B^0_s \to \mu^+\mu^-} = (91.4 \pm 0.4_{\rm stat} \pm 3.9_{\rm syst})\%,$$

$$\alpha_{B^0_s \to \mu^+\mu^-} = (3.19 \pm 0.28) \times 10^{-10},$$
$$\alpha_{B^0 \to \mu^+\mu^-} = (8.38 \pm 0.39) \times 10^{-11},$$



$B^+ \to J/\psi(\mu\mu)K^+$ mass



$B_s \to J/\psi(\mu\mu)\phi$ mass

10 SM signal events in 17 k candidates [4.9, 6] GeV/c^2 mass window!

$B_{(s)} \to \mu\mu$

- **Background:**

  combinatorial background ($bb \to \mu\mu X$)

  $B \to hh'$ ($h \to \mu$ mis ID)

  new! tighter PID requirement (reduction ~1/6)

  $$\epsilon_{hh\to\mu\mu} = (1.52 \pm 0.07_{\rm stat} \pm 0.07_{\rm syst}) \times 10^{-5}.$$

  $\mu\mu$ from elastic diphoton production
  (PT(B)>500 MeV/c)

  Exclusive decays: (irrelevant!)

  $B_s \to \mu\mu\gamma$, $B^+ \to \pi^+\mu\mu$, $B_c^+ \to J/\psi\mu\nu$

- **A multivariate discriminant BDT:**

  kinematical and geometrical variables

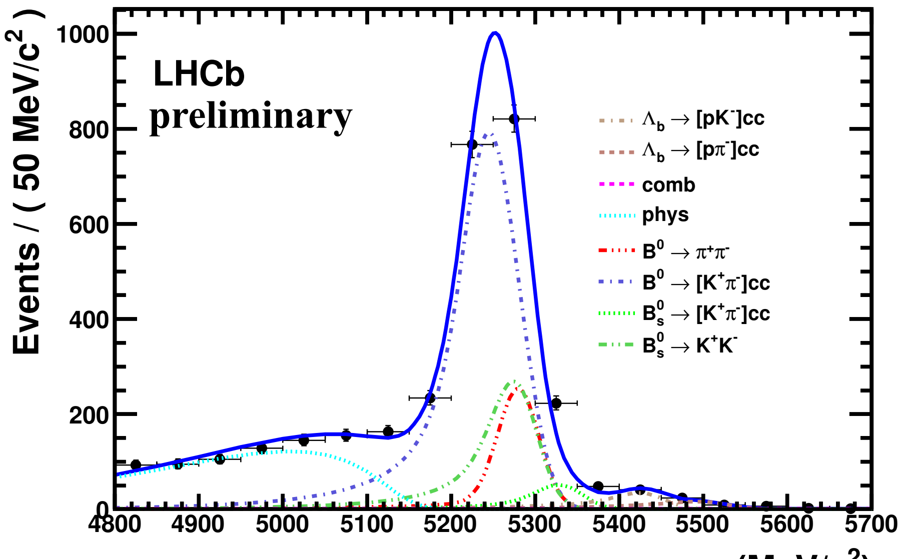
  signal uniformly distributed [0,1]

  trained with MC

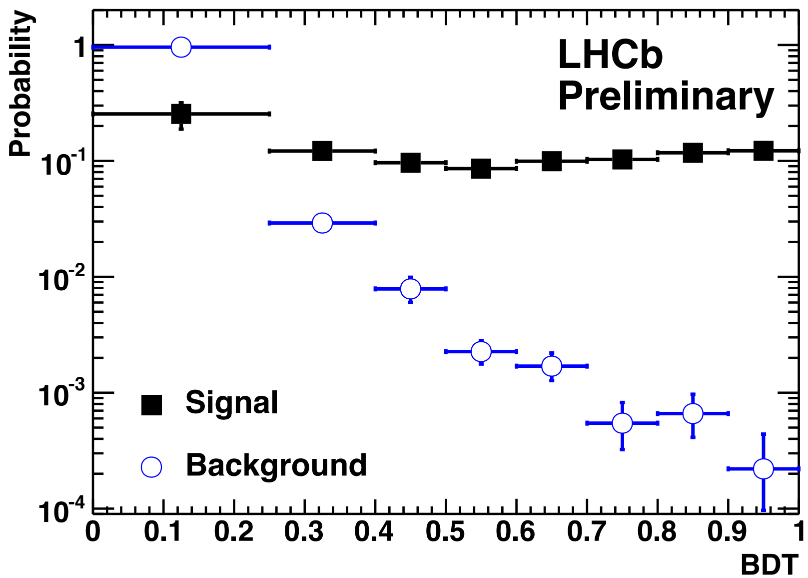
  estimated with data:

  signal $B \to hh$ trigger unbias

  background: $Bs \to \mu\mu$ sidebands



B→hh' mass, BDT [0.8,0.9]



$B_{(s)} \to \mu\mu$

- **Mass:**

signal: CB shape

central values $B \to hh$ fit

resolution: interpolation between $\mu\mu$ resonances J/ψ, $\Psi(2S)$, $\Upsilon(1S,2S,3S)$

bkg: exponential fit in bins of BDT

$$\sigma(B_s^0) = (24.8 \pm 0.3_{\text{stat}} \pm 0.7_{\text{syst}})\ \text{MeV}/c^2$$
$$\sigma(B^0) = (24.3 \pm 0.3_{\text{stat}} \pm 0.6_{\text{syst}})\ \text{MeV}/c^2$$

BDT *vs* Mass:

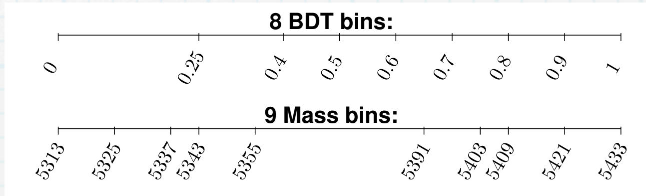
Divide BDT and mass plane in bins

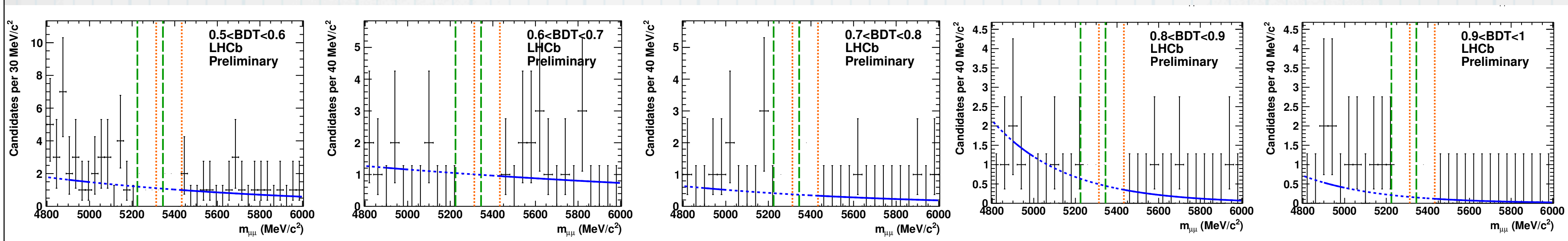
estimate number of background and signal (for each BR) events in each bin

Use CLs method!

$$Q = \frac{\mathcal{P}(d,s+b)}{\mathcal{P}(d,b)}$$

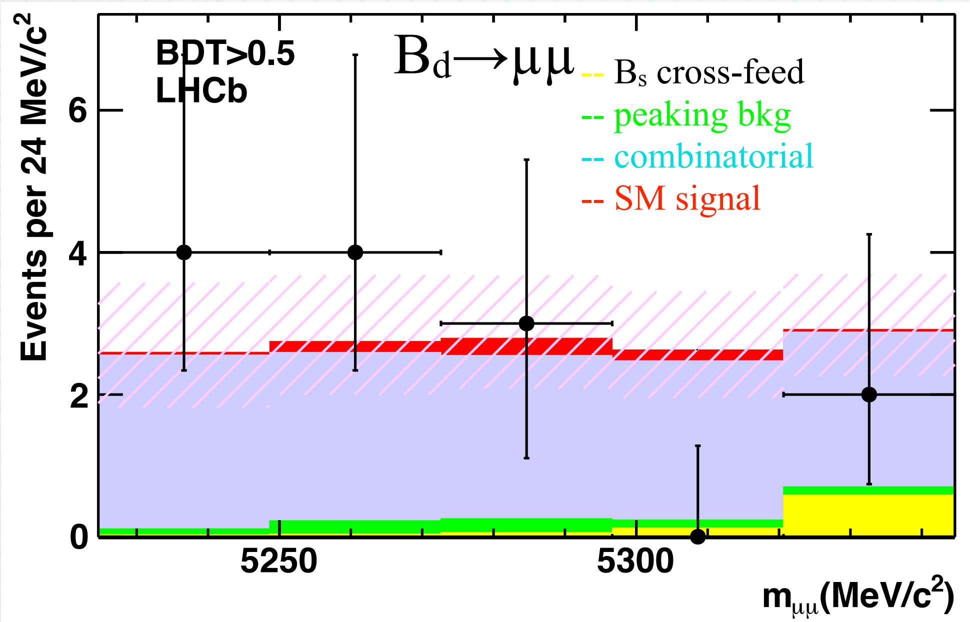
new! binning,optimized using MC toys!

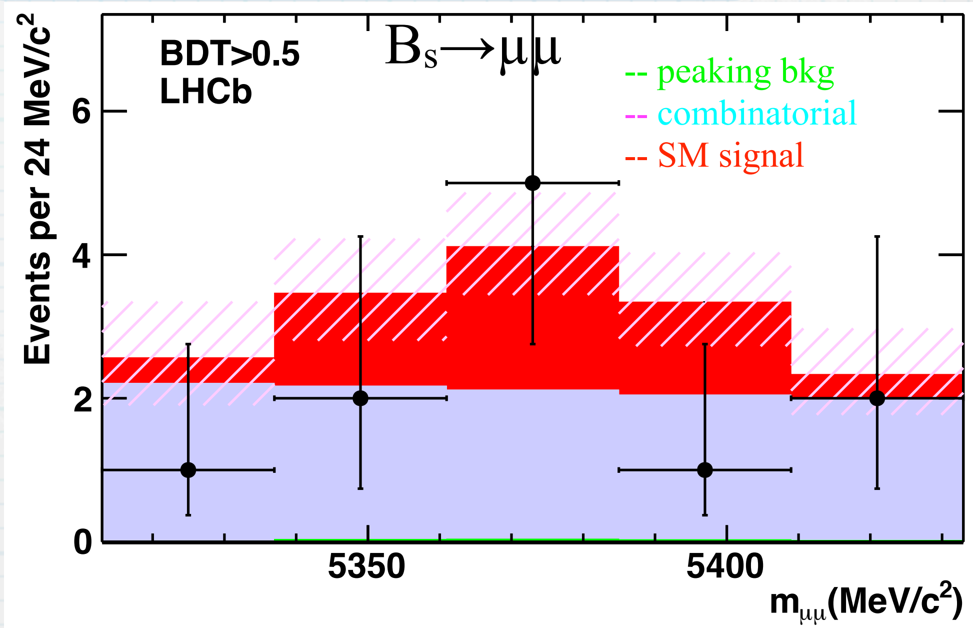




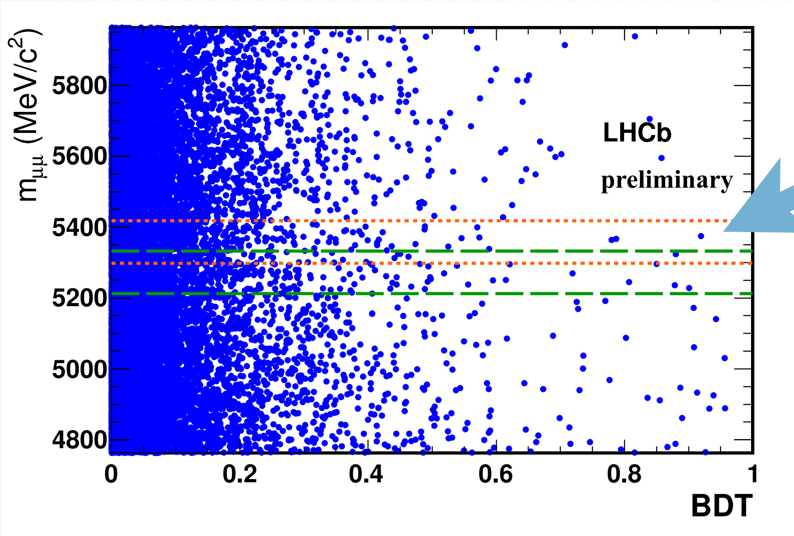
$B_{(s)} \to \mu\mu$

Mode	BDT bin	0.0 – 0.25	0.25 – 0.4	0.4 – 0.5	0.5 – 0.6	0.6 – 0.7	0.7 – 0.8	0.8 – 0.9	0.9 – 1.0
$B_s^0 \to \mu^+\mu^-$	Exp. comb. bkg	1889^{+38}_{-39}	57^{+11}_{-11}	$15.3^{+3.8}_{-3.8}$	$4.3^{+1.0}_{-1.0}$	$3.30^{+0.92}_{-0.85}$	$1.06^{+0.51}_{-0.46}$	$1.27^{+0.53}_{-0.52}$	$0.44^{+0.41}_{-0.24}$
	Exp. peak. bkg	$0.124^{+0.066}_{-0.049}$	$0.063^{+0.024}_{-0.018}$	$0.049^{+0.016}_{-0.012}$	$0.045^{+0.016}_{-0.012}$	$0.050^{+0.018}_{-0.013}$	$0.047^{+0.017}_{-0.013}$	$0.049^{+0.017}_{-0.013}$	$0.047^{+0.018}_{-0.014}$
	Exp. signal	$2.55^{+0.70}_{-0.74}$	$1.22^{+0.20}_{-0.19}$	$0.97^{+0.14}_{-0.13}$	$0.861^{+0.102}_{-0.088}$	$1.00^{+0.12}_{-0.10}$	$1.034^{+0.109}_{-0.095}$	$1.18^{+0.13}_{-0.11}$	$1.23^{+0.21}_{-0.21}$
	Observed	1818	39	12	6	1	2	1	1
$B^0 \to \mu^+\mu^-$	Exp. comb. bkg	2003^{+42}_{-43}	61^{+12}_{-11}	$16.6^{+4.3}_{-4.1}$	$4.7^{+1.3}_{-1.2}$	$3.52^{+1.13}_{-0.97}$	$1.11^{+0.71}_{-0.50}$	$1.62^{+0.76}_{-0.59}$	$0.54^{+0.53}_{-0.29}$
	Exp. peak. bkg	$0.71^{+0.36}_{-0.26}$	$0.355^{+0.146}_{-0.088}$	$0.279^{+0.110}_{-0.068}$	$0.249^{+0.099}_{-0.055}$	$0.280^{+0.109}_{-0.062}$	$0.264^{+0.103}_{-0.057}$	$0.275^{+0.108}_{-0.060}$	$0.267^{+0.106}_{-0.069}$
	Exp. cross-feed	$0.40^{+0.11}_{-0.12}$	$0.193^{+0.033}_{-0.030}$	$0.153^{+0.023}_{-0.021}$	$0.136^{+0.017}_{-0.015}$	$0.158^{+0.019}_{-0.017}$	$0.164^{+0.019}_{-0.017}$	$0.187^{+0.022}_{-0.020}$	$0.194^{+0.036}_{-0.033}$
	Exp. signal	$0.300^{+0.086}_{-0.090}$	$0.145^{+0.027}_{-0.024}$	$0.115^{+0.020}_{-0.017}$	$0.102^{+0.014}_{-0.013}$	$0.119^{+0.017}_{-0.015}$	$0.123^{+0.016}_{-0.015}$	$0.140^{+0.019}_{-0.017}$	$0.145^{+0.030}_{-0.026}$
	Observed	1904	50	20	5	2	1	4	1

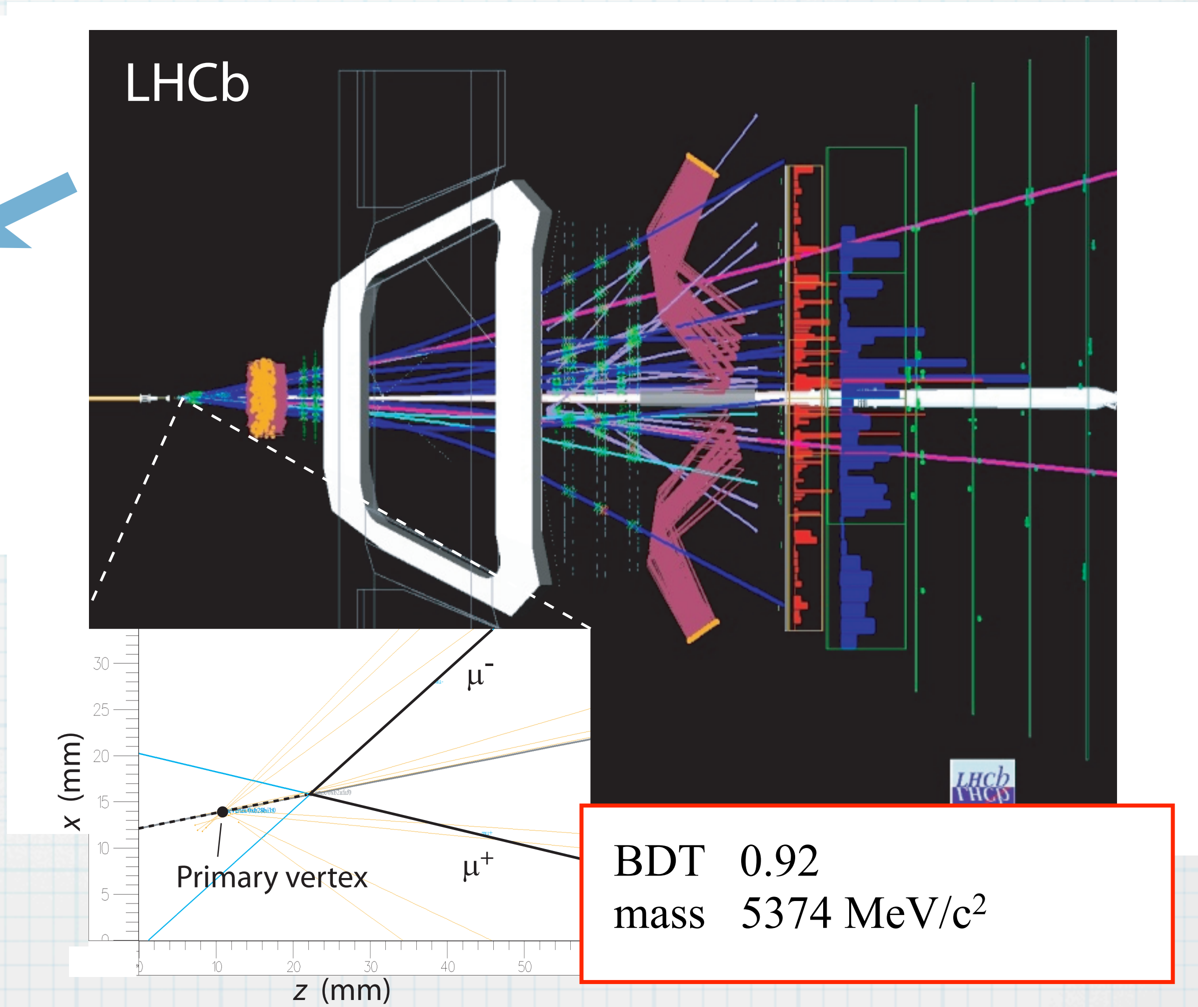




$B_{(s)} \rightarrow \mu\mu$



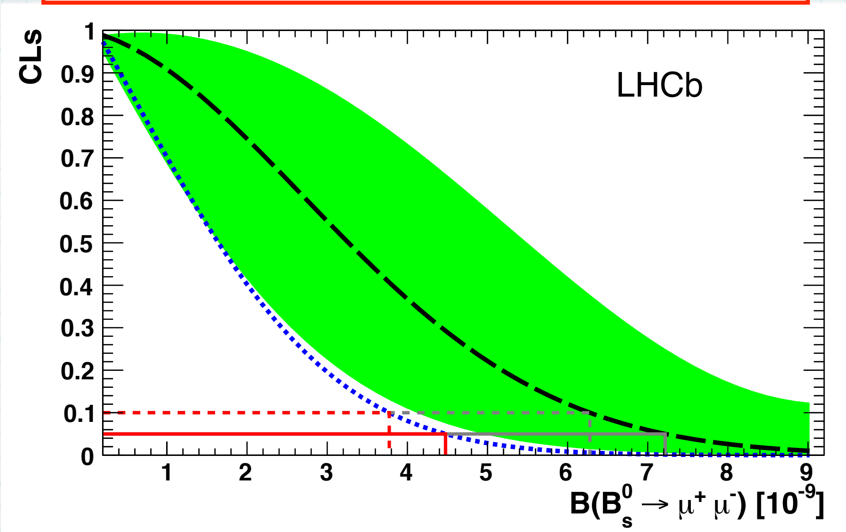
mass vs BDT data



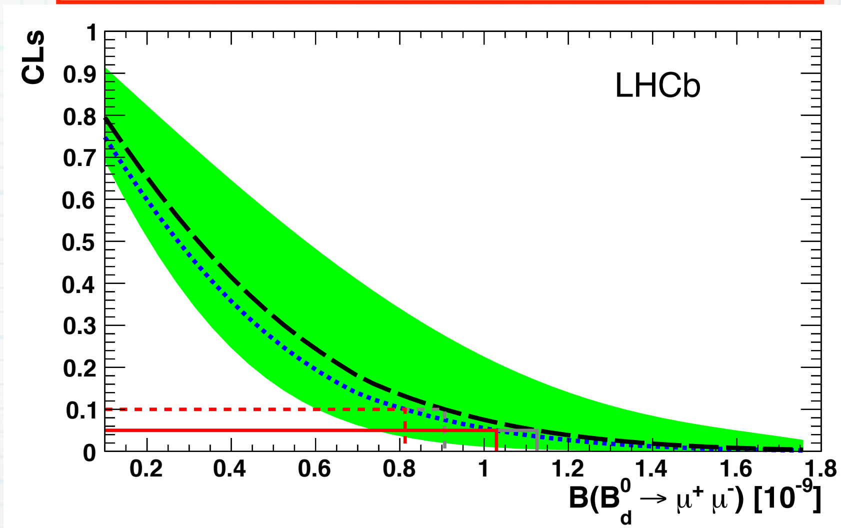
BDT 0.92
mass 5374 MeV/c^2

$B_{(s)} \to \mu\mu$

B(Bs→μμ) < 4.5 10^{-9} at 95% CL



B(B→μμ) < 10.3 10^{-10} at 95% CL



mode	limit	at 90 % C.L.	at 95 % C.L.
$B_s^0 \to \mu^+\mu^-$	expected bg+SM	6.3×10^{-9}	7.2×10^{-9}
	expected bg only	2.8×10^{-9}	3.4×10^{-9}
	observed	3.8×10^{-9}	4.5×10^{-9}
$B^0 \to \mu^+\mu^-$	expected	9.1×10^{-10}	11.3×10^{-10}
	observed	8.1×10^{-10}	10.3×10^{-10}

best limit!

1-CLb = 0.18

1-CLb =0.60

BR estimation:

simultaneous unbinned LL fit to the mass to the 8 BDT bins

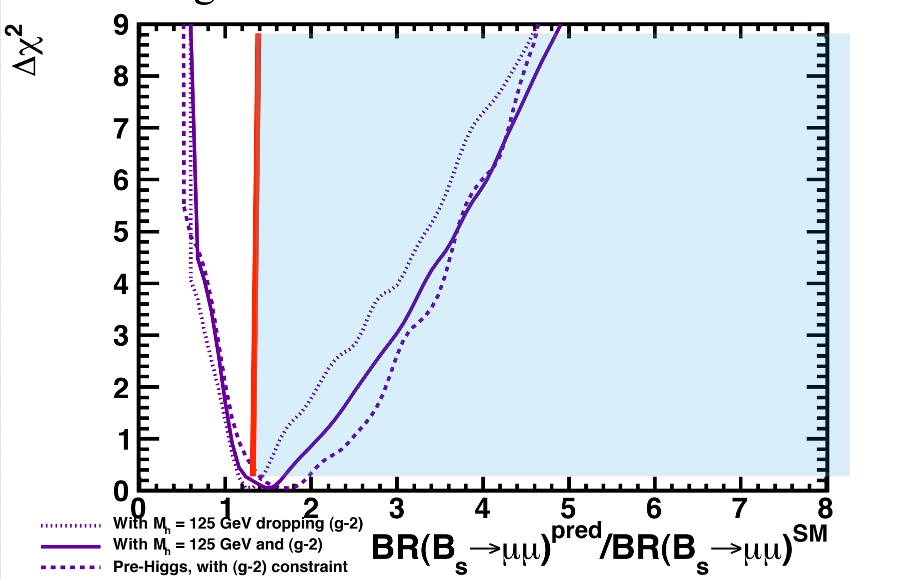
B(Bs→μμ) = $(0.8^{+1.8}_{-1.3})\ 10^{-9}$

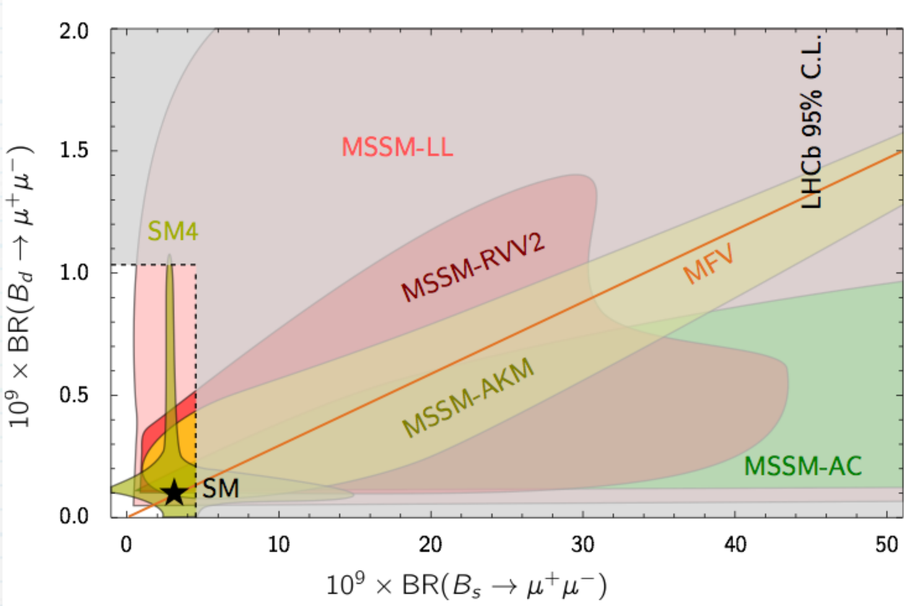
expected BR from minimum of the LL and error from ΔLL=0.5, coverage BR [0,SM] 82%

$B_{(s)} \to \mu\mu$

- Results strongly constrain NP scenarios
  - But some NP models predict lower B than the SM one

excluding in NUHM





exclusion of several NP models

See: D. Straub, EW Moriond, 2012

Conclusions

- LHC and LHCb performing beautifully
- LHCb has an intense program on RD searches:
  - Results with 1 fb^{-1}
    - $\mathcal{A}_{CP}$ with $B \to K^*\gamma$
    - $B(B_s \to \phi\mu\mu)/B(B_s \to J/\psi\phi)$
    - Update of $B \to K^*\mu\mu$ angular analysis
    - Measurement of Isospin Asymmetry
    - Update $B_{(s)} \to \mu\mu$
    - Other analysis not covered here: $B^+ \to \pi^+\mu\mu$, $B_{(s)} \to \mu\mu\mu\mu$, ...

$$\mathcal{A}_{CP}(B^0 \to K^{*0}\gamma) = 0.008 \pm 0.017(\mathrm{stat}) \pm 0.009(\mathrm{syst})$$

$$\frac{\mathcal{B}(B_s^0 \to \phi\mu\mu)}{\mathcal{B}(B_s^0 \to J/\psi\,\phi)} = (0.556 \pm 0.069(\mathrm{stat}) \pm 0.043(\mathrm{syst}) \pm 0.006(\mathcal{B})) \times 10^{-3}$$

$$q_0^2 = (4.9^{+1.1}_{-1.3})\ \mathrm{GeV}^2/c^4$$

$B(B_s \to \mu\mu) < 4.5\ 10^{-9}$ at 95% CL

$B(B \to \mu\mu) < 10.3\ 10^{-10}$ at 95% CL

- Everything in agreement with SM, no NP found (yet) in the key channels!
  - We still look for NP smallish effects...