Rare decays at LHCb

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on behalf of the LHCb collaboration

BEACH 2012, Witchita, Kansas
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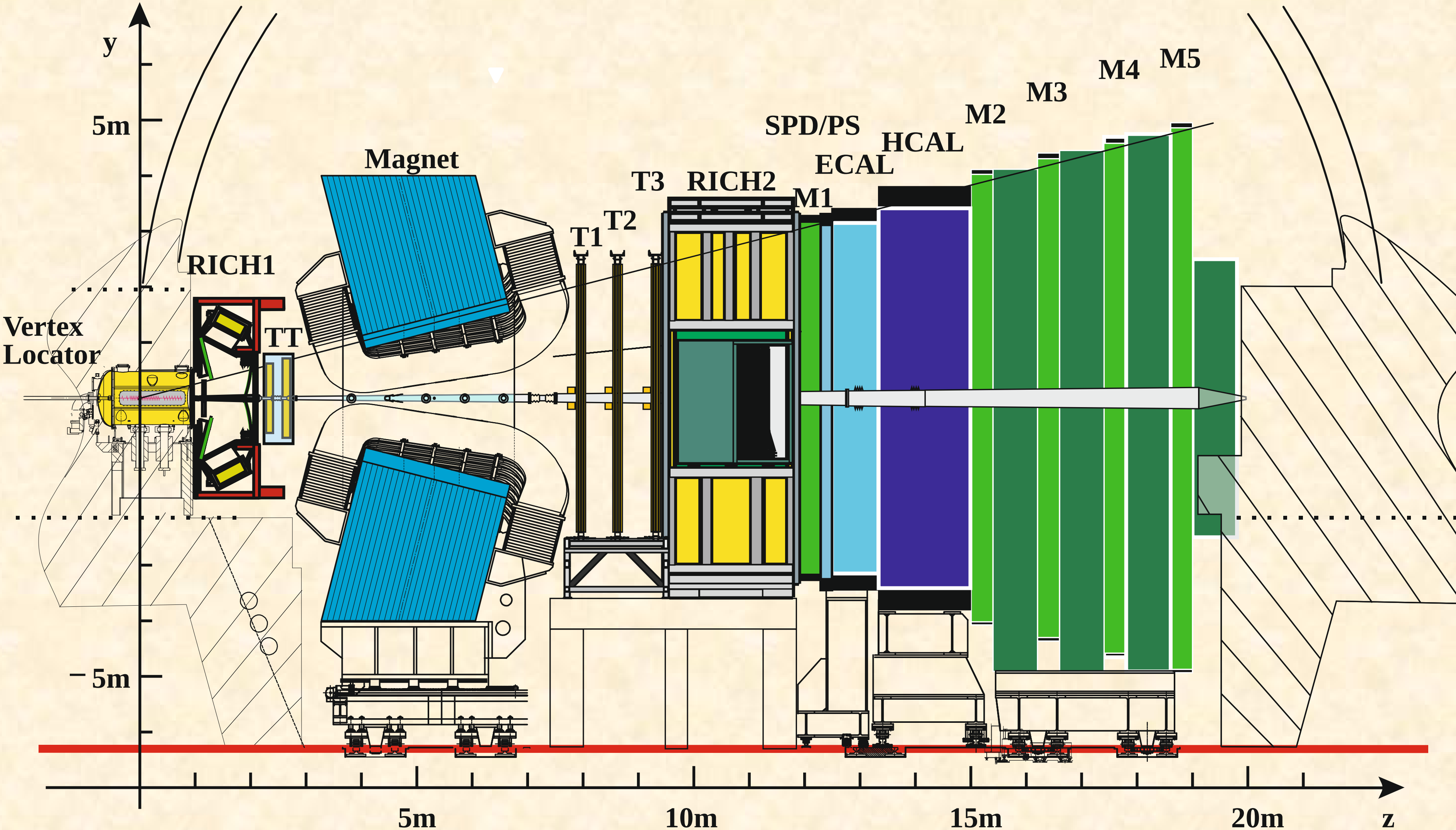
The LHCb detector



Rare decays at LHCb

- Results are presented for

$$B^0_{(s)} \to \mu^+\mu^-$$
$$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$$
$$\tau^- \to \mu^-\mu^+\mu^-$$
$$D^0 \to \mu^+\mu^-$$
$$B \to K^{(*)}\mu^+\mu^-$$

- All results presented are on 1 fb^{-1} at $\sqrt{s} = 7$ TeV data collected in 2011
  - Except $\tau^- \to \mu^-\mu^+\mu^-$ which used 0.9 fb^{-1}

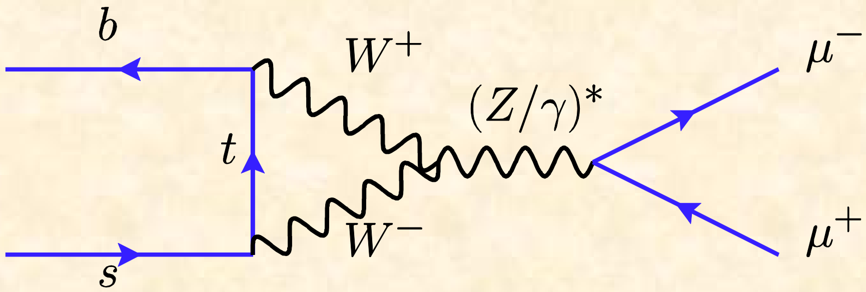
$B^0_{(s)} \to \mu^+\mu^-$ expectation

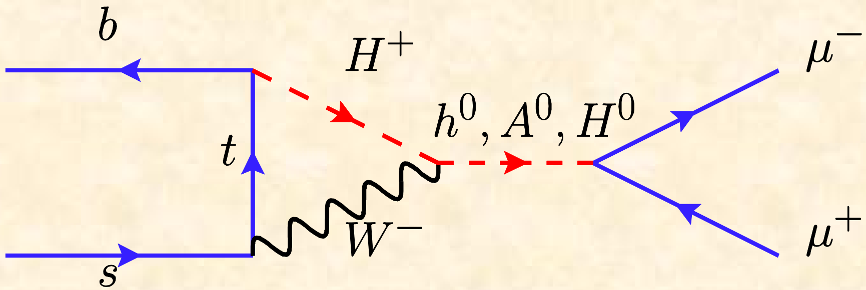
In the standard model:

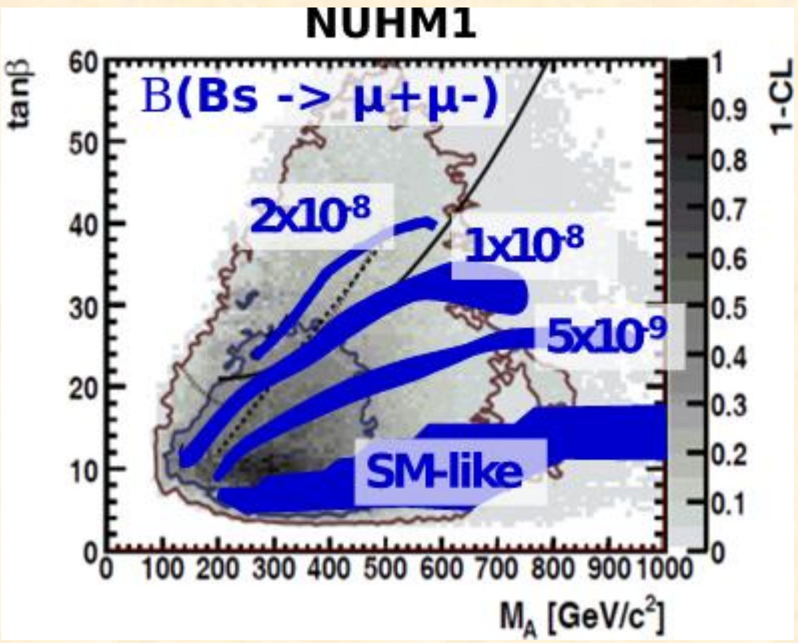
$$Br(B^0_s \to \mu\mu) = (3.2 \pm 0.2) \cdot 10^{-9}$$
$$Br(B^0 \to \mu\mu) = (0.10 \pm 0.01) \cdot 10^{-9}$$

JHEP 1010 (2010) 009,arXiv:1005.5310

Note: time integrated values, estimates at t=0 (above) must be increased by 10% to match measured values; arXiv:1204.1735v3





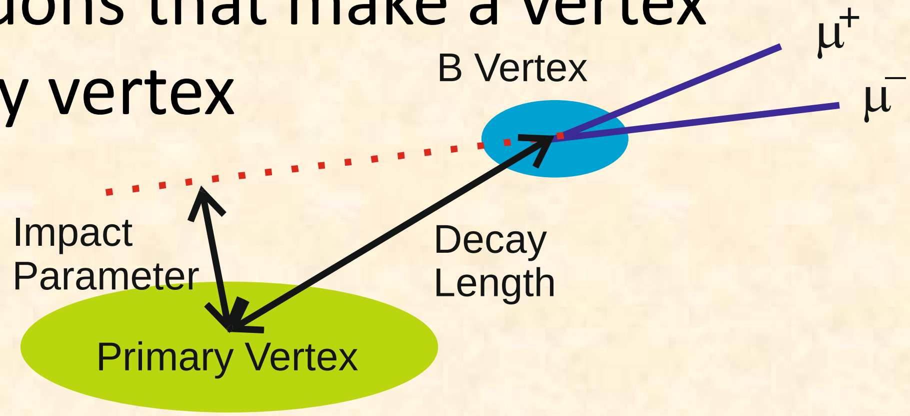


Expectation for branching ratio in a common non-universal Higgs mass

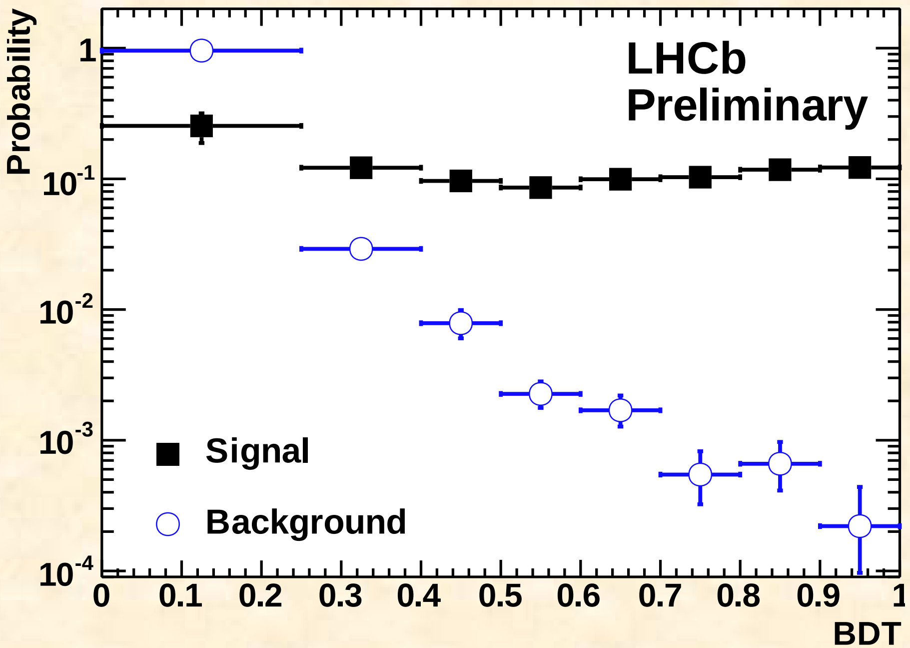
Modified from arXiv:0907.5568

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

- Two tracks identified as muons that make a vertex separated from the primary vertex
- Use an MVA to reduce backgrounds:
  - A boosted decision tree with 9 variables based on the topology of the event

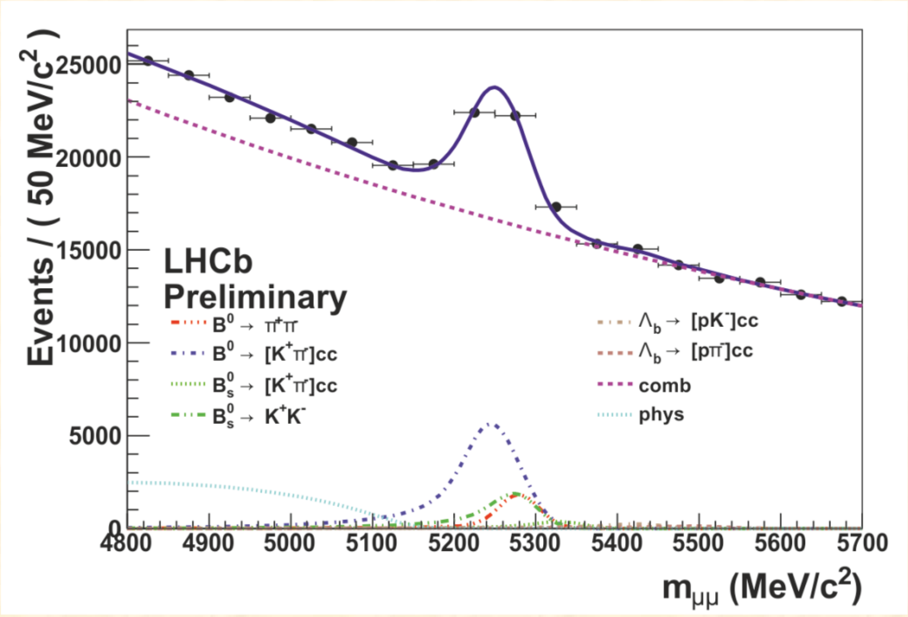


- Use MC to train the BDT and use the decay $B^0_{(s)} \to h^+h'^+$ and sidebands to calibrate

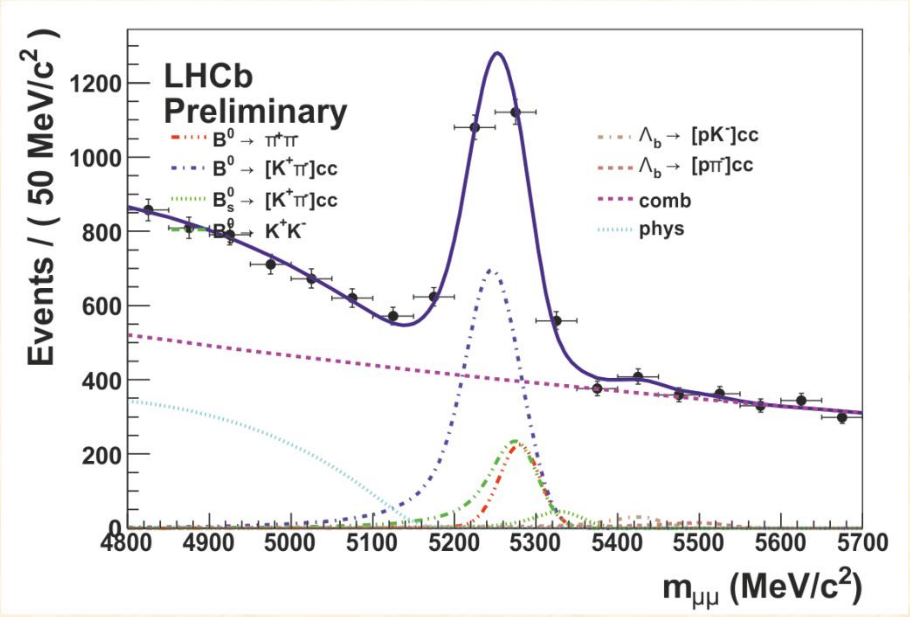


Backgrounds to selection

- Peaking backgrounds are from $B^0_{(s)} \to h^+h'^-$
  Non-peaking from $bb \to \mu^+\mu^- X$
  and combinatorial muon candidates



All BDT output, muon ID not applied



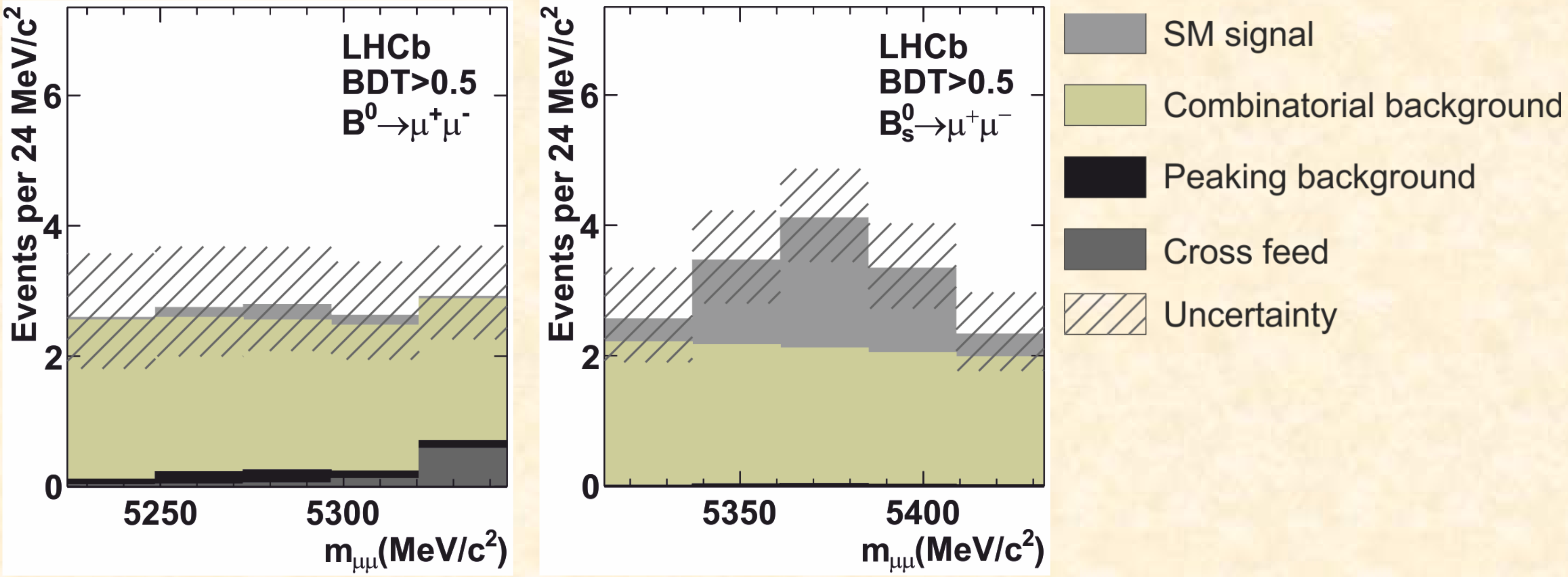
0.25<BDT<0.4, muon ID not applied

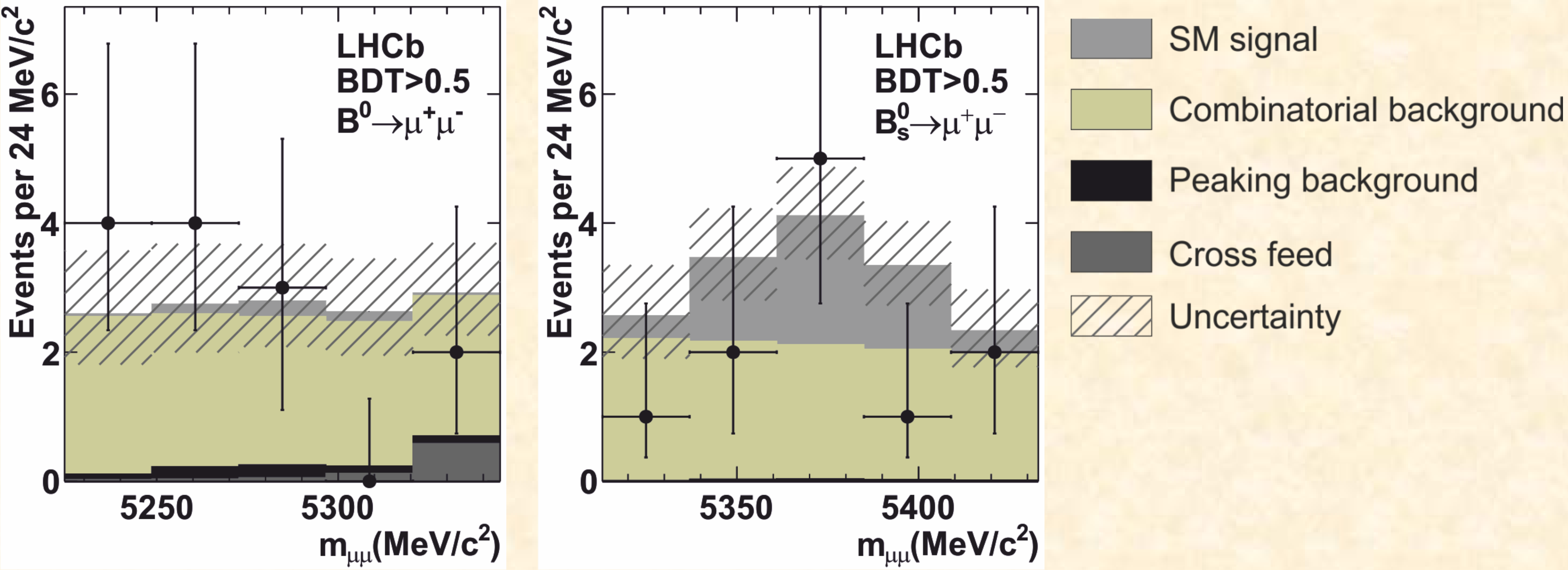
Signal events, normalisation and limits

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

- The normalisation channel is $B^- \to J/\psi K^-$
- Use data driven methods to get the efficiencies
- $\frac{f_s}{f_d}$ measured at LHCb PRD85 (2012) 032008, arXiv:1111.2357

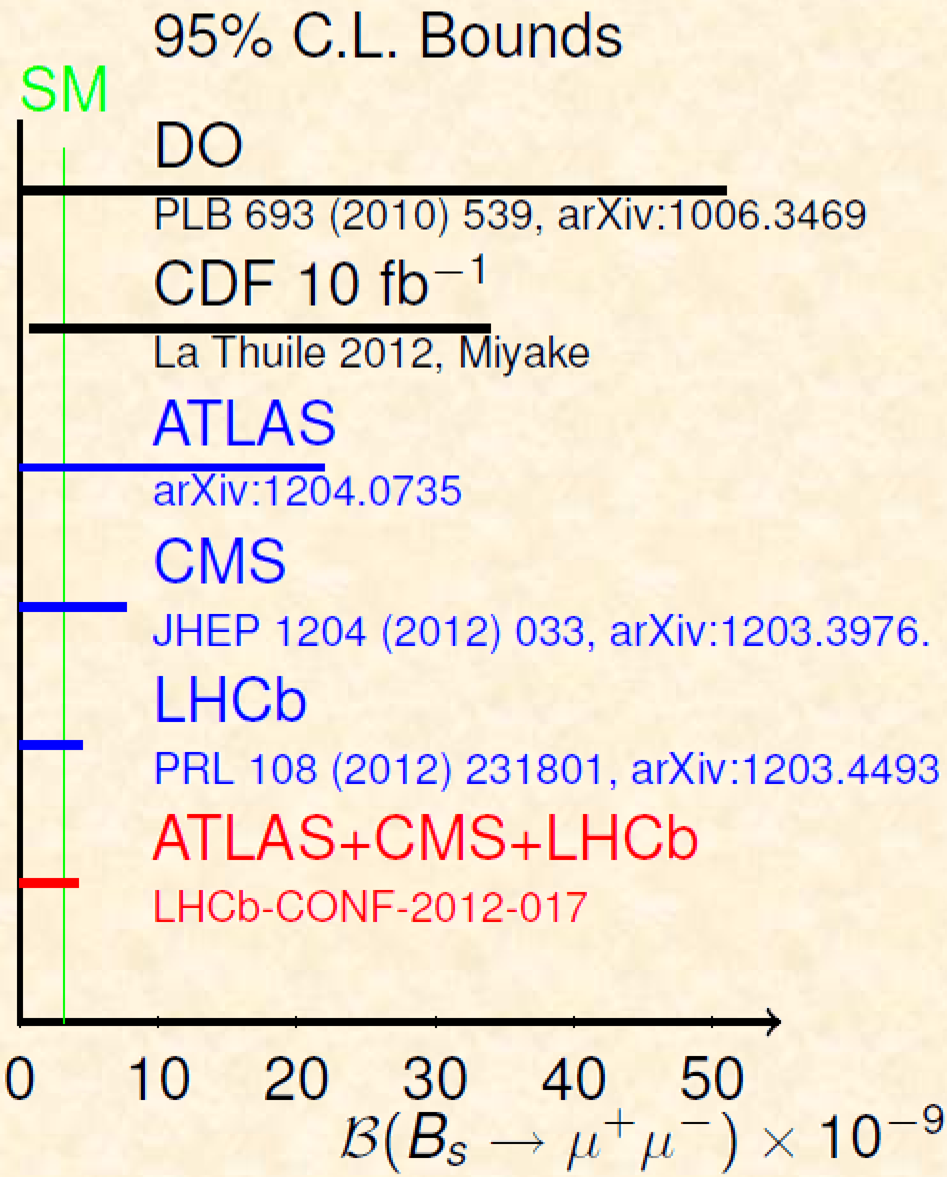
Expectation in 1.0 fb^{-1}





- Limits are set on the branching ratios at 95% CL
  - $B^0 \to \mu\mu$ 1.0 x 10^{-9} (expected 1.1 x 10^{-9} Bkg only)
  - $B_s^0 \to \mu\mu$ 4.5 x 10^{-9} (expected 7.2 x 10^{-9} SM + Bkg)
- Compatible with SM +Bkg within 1σ
  - p-value (1-CL_b) = 18%

Reference: PRL 108 (2012) 231801, arXiv:1203.4493



LHCb-CONF-2012-017

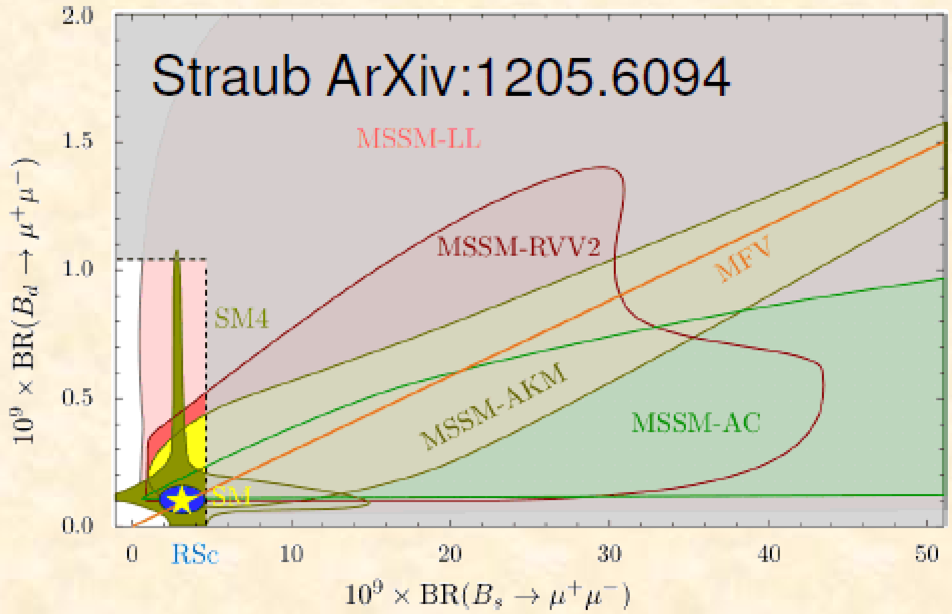
Upper Limits (95%C.L.):

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.2 \times 10^{-9}$$

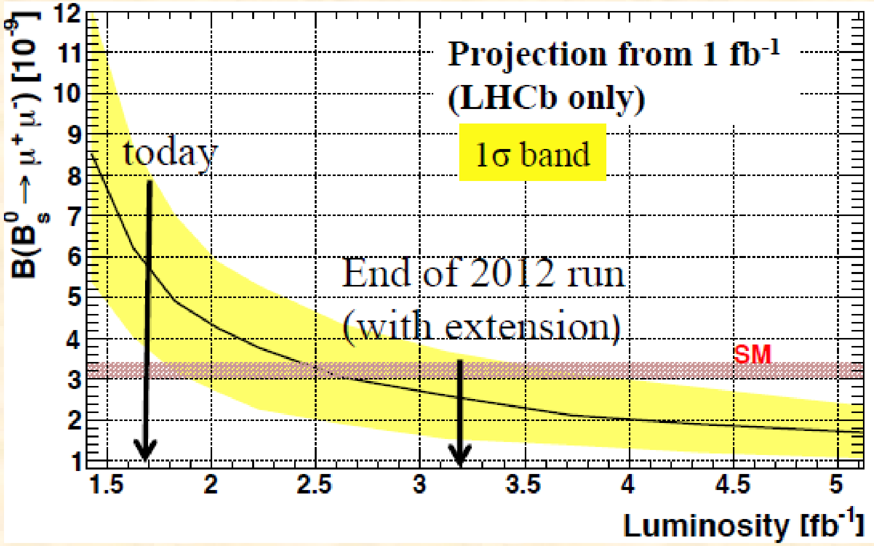
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.1 \times 10^{-10}$$

Preliminary limit combination

Limits on super-symmetric models



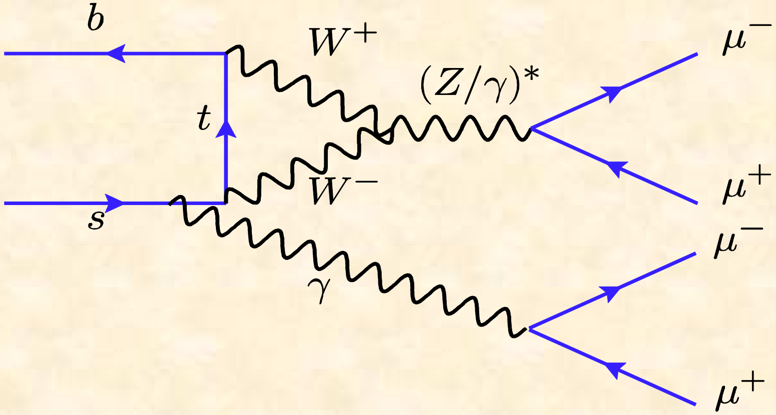
Prospects for a 3σ observation of the SM branching ratio:



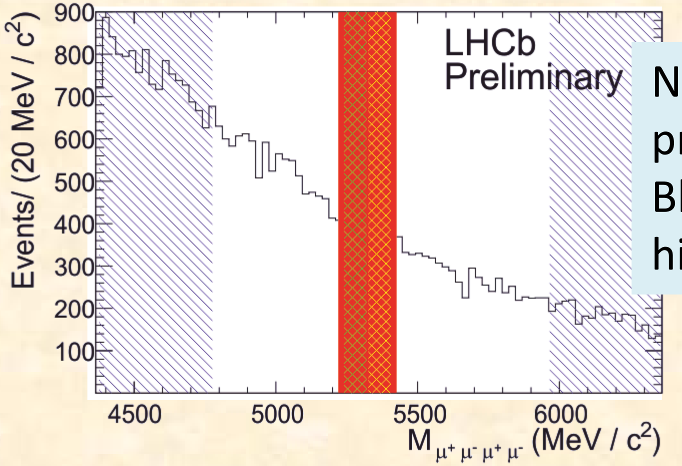
$B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-$

- Motivations
  - PDG : $\mathcal{B}(B^0_s \to J/\psi\phi \to \mu^+\mu^-\mu^+\mu^-) = (2.3 \pm 0.8) \times 10^{-8}$
  - Other SM : $\mathcal{B}\left(B^0_{(s)} \to \mu^+\mu^-\mu^+\mu^-\right) < 10^{-10}$

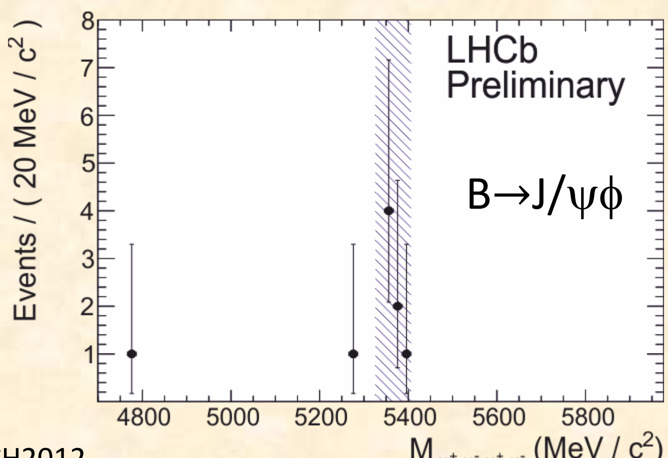
Phys. Rev. D 70, 114028, (2004)



- Method : cut-and-count
  - Use resonant decays to optimise the selection
  - Use good secondary vertex reconstruction and muon ID
  - Normalise to $B^0_s \to J/\psi(\mu^+\mu^-)\overline{K}^*(K^+\pi^-)$

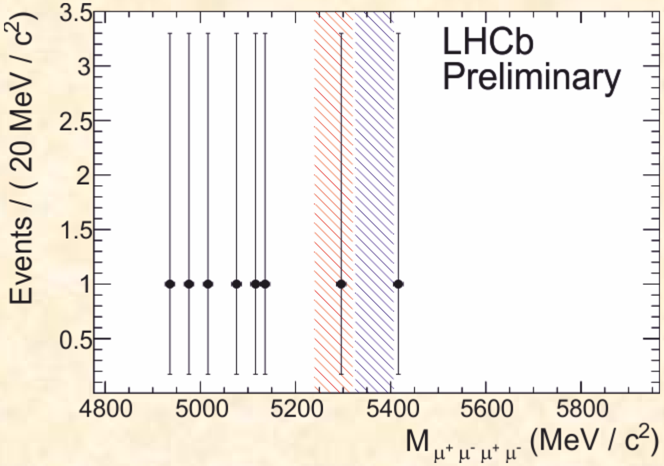


Non-resonant pre-selection Blinded region highlighted



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

- Results
  - Events that are non-resonant, compatible with background expectations



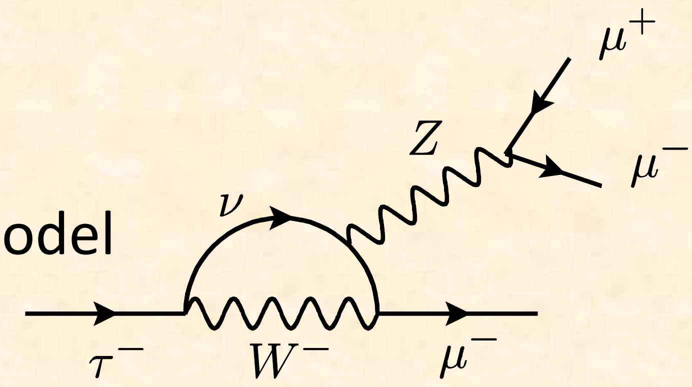
  - Preliminary limits are set in LHCb-CONF-2012-010

$$\mathcal{B}(B^0_s \to \mu^+\mu^-\mu^+\mu^-) < 1.3\times 10^{-8}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-\mu^+\mu^-) < 5.4\times 10^{-8}$$

First limits set on these modes

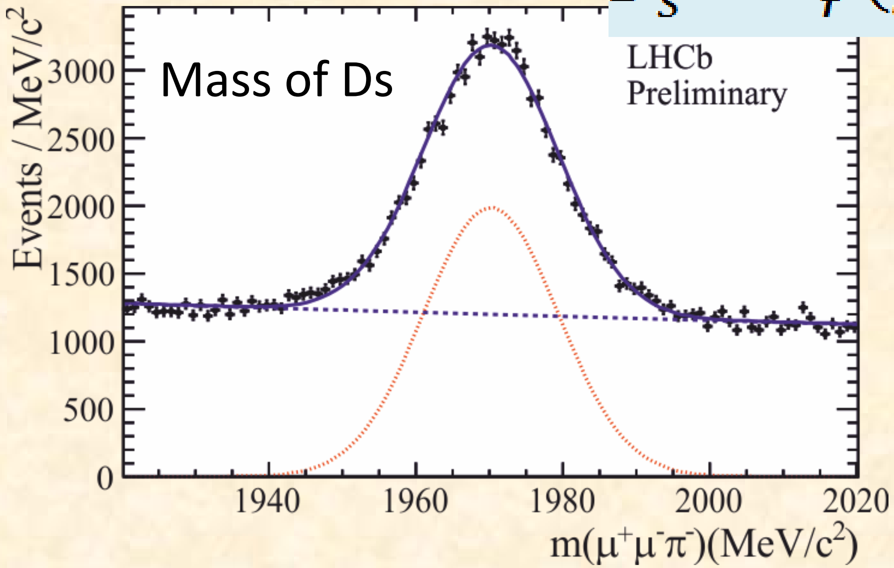
$\tau^- \to \mu^- \mu^+ \mu^-$

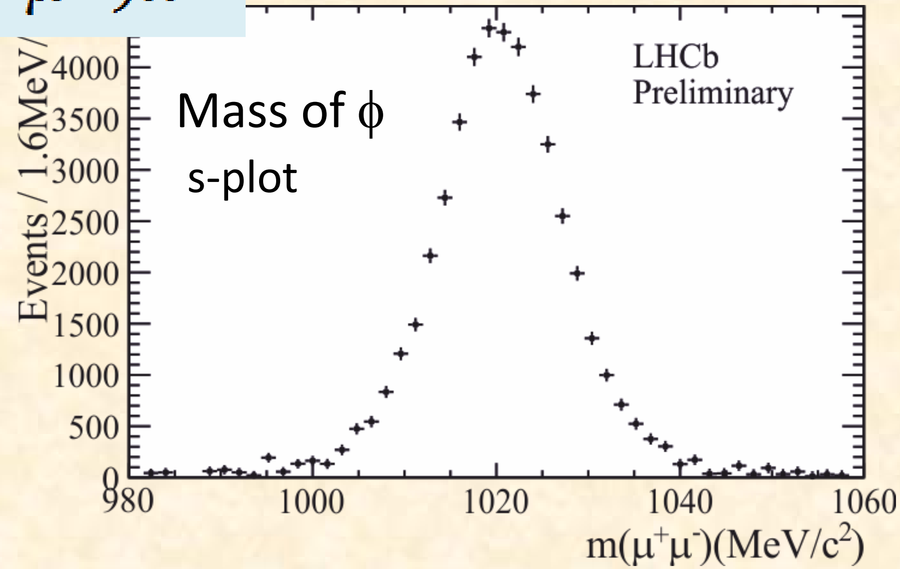
- Motivation
  - Evidence for lepton flavour violation
  - Highly suppressed in the standard model



    - An excess would indicate new physics
  - $D_s^- \to \phi(\mu^+\mu^-)\pi^-$ is used as a control channel and to normalise the branching ratio
- Analysis
  - Use two MVAs, then a fit to the τ and D_s^- masses
    - Do the tracks make a good secondary three track vertex?
    - Are the tracks good candidate muons or pions?

$D_s^- \to \phi(\mu^+\mu^-)\pi^-$



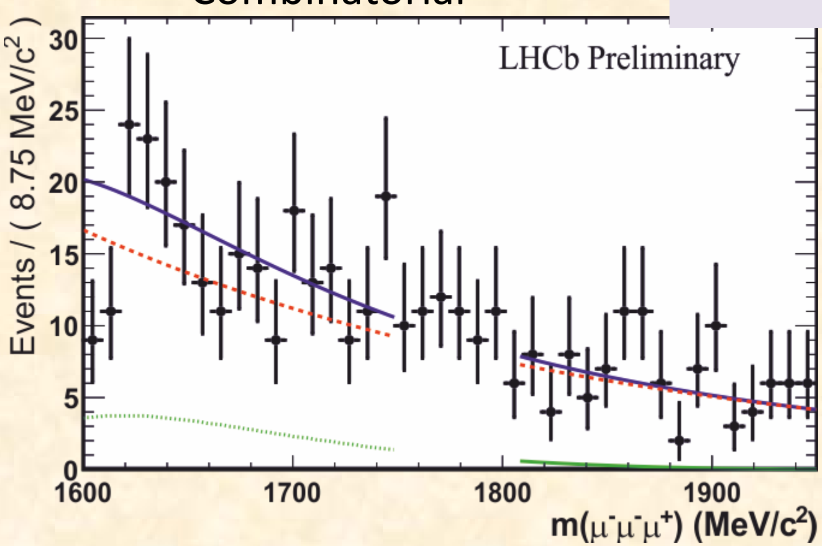


Total Bkg.

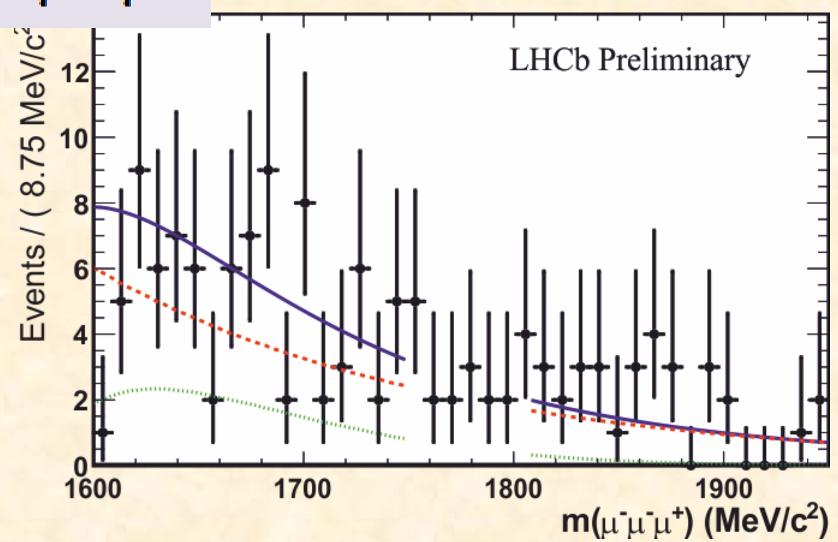
Combinatorial

$\tau^- \to \mu^-\mu^+\mu^-$

$D_s^- \to \eta(\mu^+\mu^-\gamma)\mu^-\bar{\nu}_\mu$

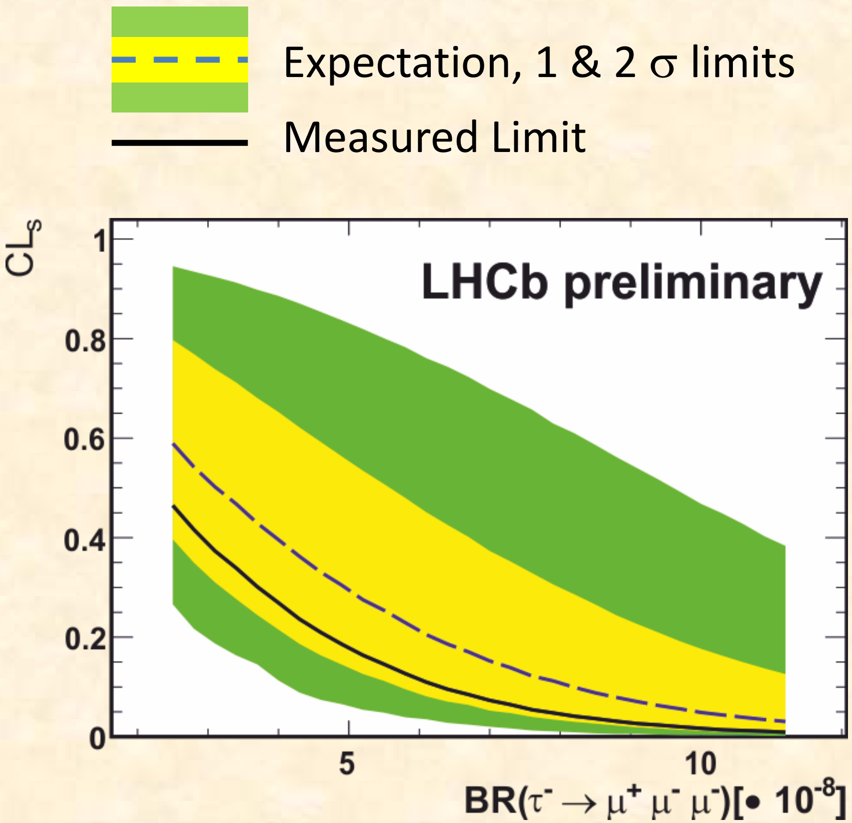


Highest signal fraction selection: 21%



Next highest selection: 11%

Limits on $\tau^- \rightarrow \mu^- \mu^+ \mu^-$



Using CL_S method the preliminary limits are

$$\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-) < 7.8(6.3) \times 10^{-8}$$

at 95% (90%) confidence level

LHCb-CONF-2012-015

World's best result was from Belle

PLB 687 (2010) 139, arXiv:1001.3221

$$\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-) < 2.1 \times 10^{-8} \text{ (90\% CL.)}$$

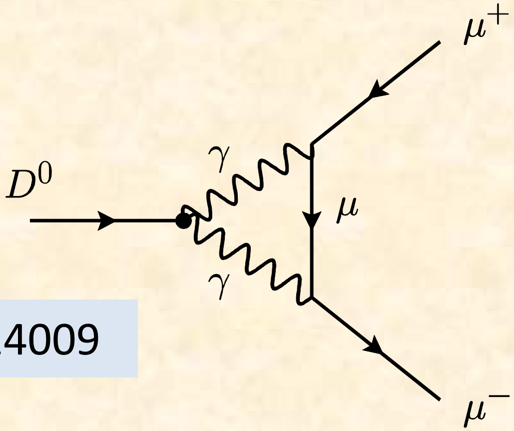
$D^0 \to \mu^+\mu^-$

Low SM expectation:

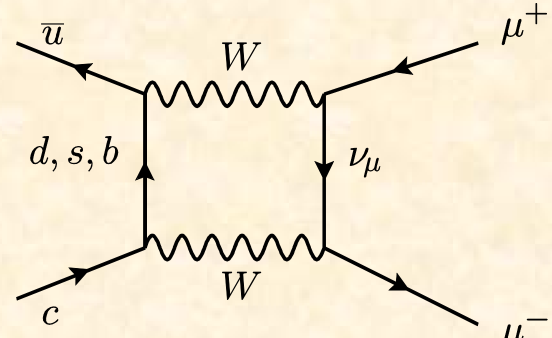
$$\mathcal{B}^{(\gamma\gamma)}(D^0 \to \mu^+\mu^-) \approx 2.7 \times 10^{-5} \cdot \mathcal{B}(D^0 \to \gamma\gamma)$$

$$\mathcal{B}^{SM}(D^0 \to \mu^+\mu^-) \geq 10^{-13}$$

Phys. Rev. D66 (2002) 014009



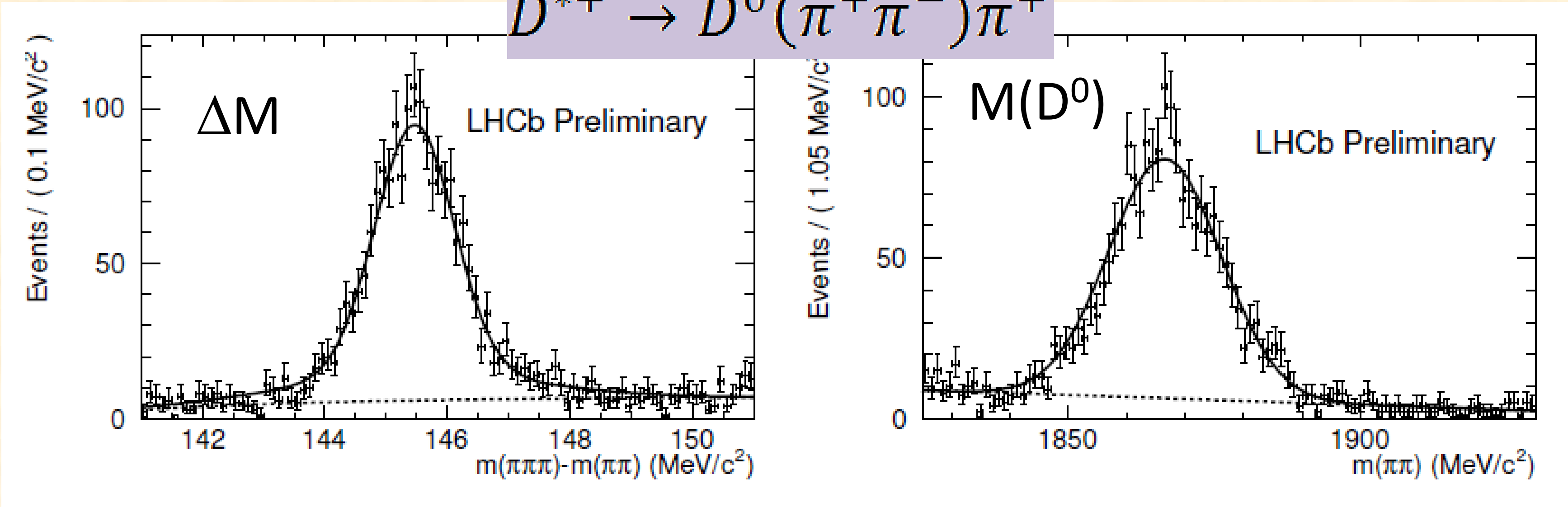
GIM mechanism suppresses the decay due to the lack of a heavy down quark



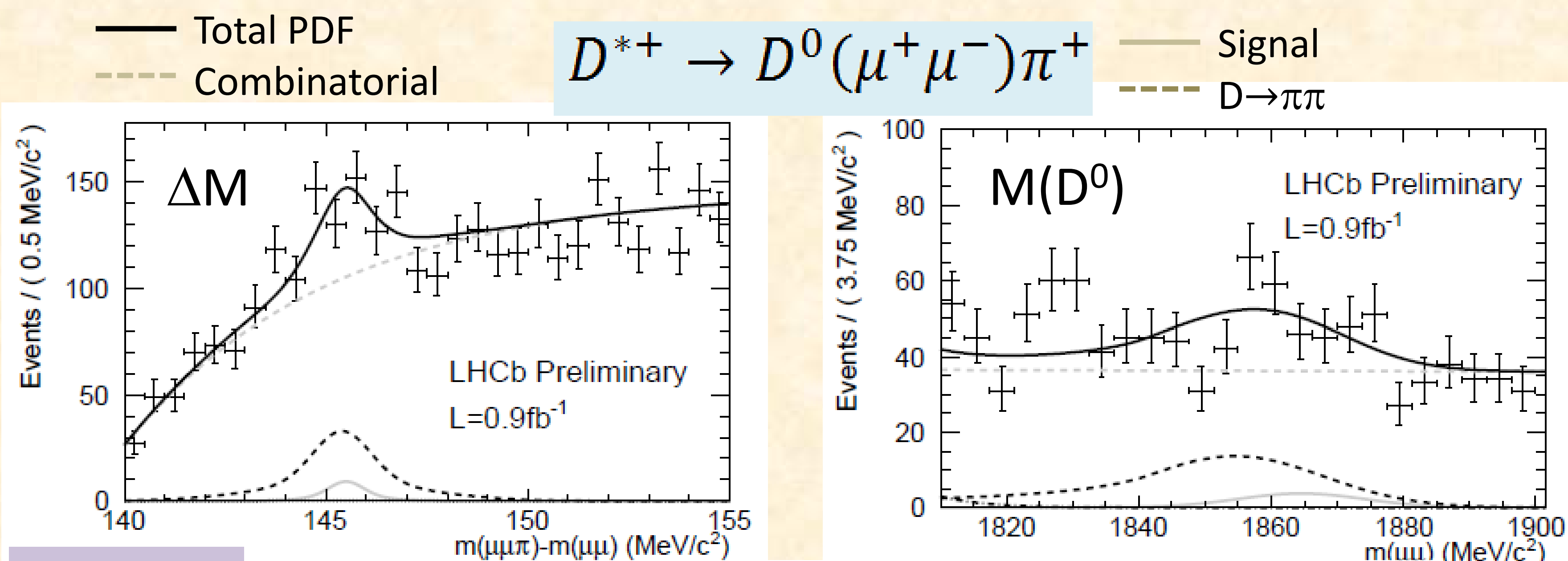
Use $D^{*+} \to D^0(\pi^+\pi^-)\pi^+$ as the control channel so:

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

$$D^{*+} \to D^0(\pi^+\pi^-)\pi^+$$



$$D^{*+} \to D^0(\mu^+\mu^-)\pi^+$$



Preliminary limits

$$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3\ (1.1) \cdot 10^{-8} \quad \text{at } 95\ (90)\%\text{CL}$$

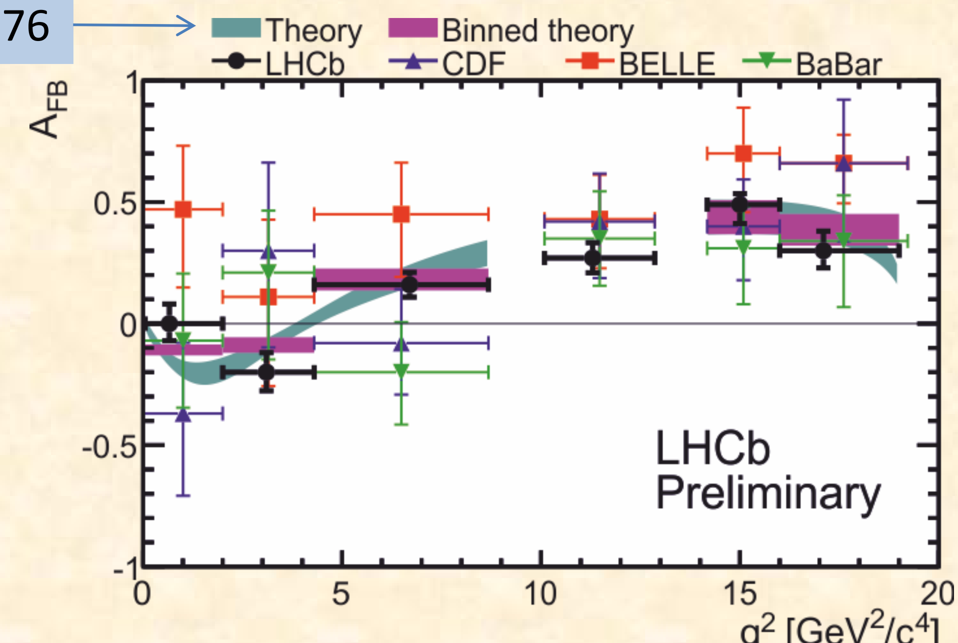
CERN-LHCb-CONF-2012-005

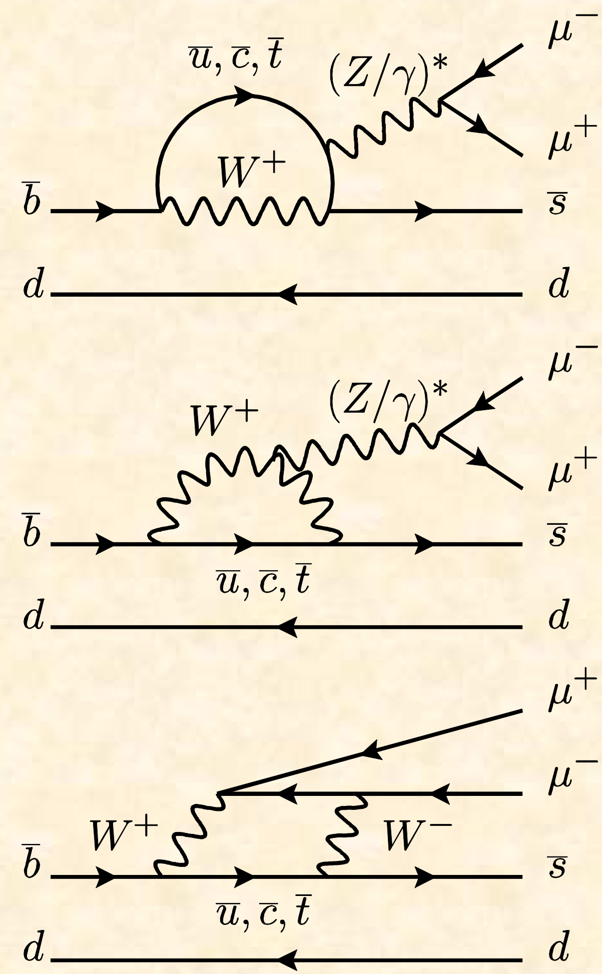
$B^0 \to K^{*0}\mu^+\mu^-$

Standard model decays have FCNC through electroweak loops.
Lots of angles to measure, most are sensitive to new physics in the loops

A good SM prediction for the zero point of A_{FB} for the muon system is at 4.0–4.3 GeV^2/c^4

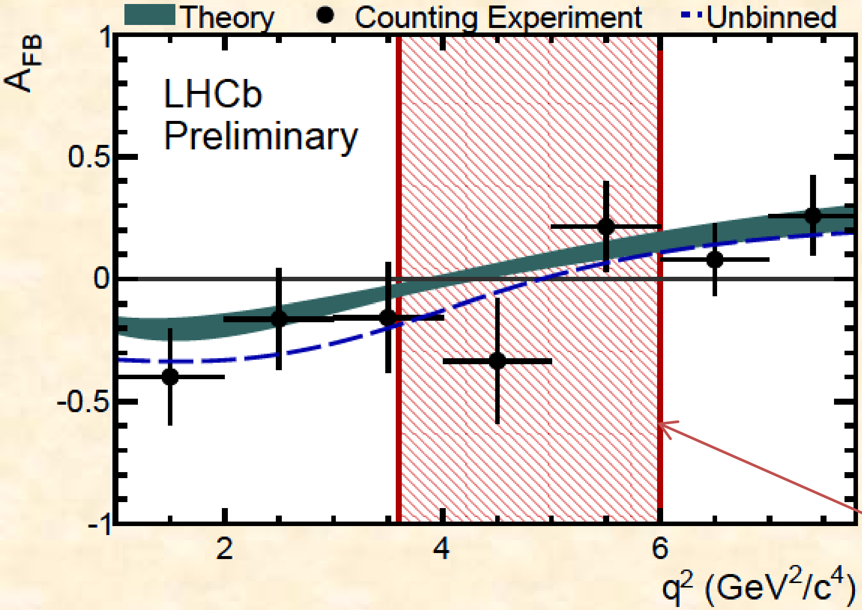
arXiv:1105.0376





CERN-LHCb-CONF-2012-008

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



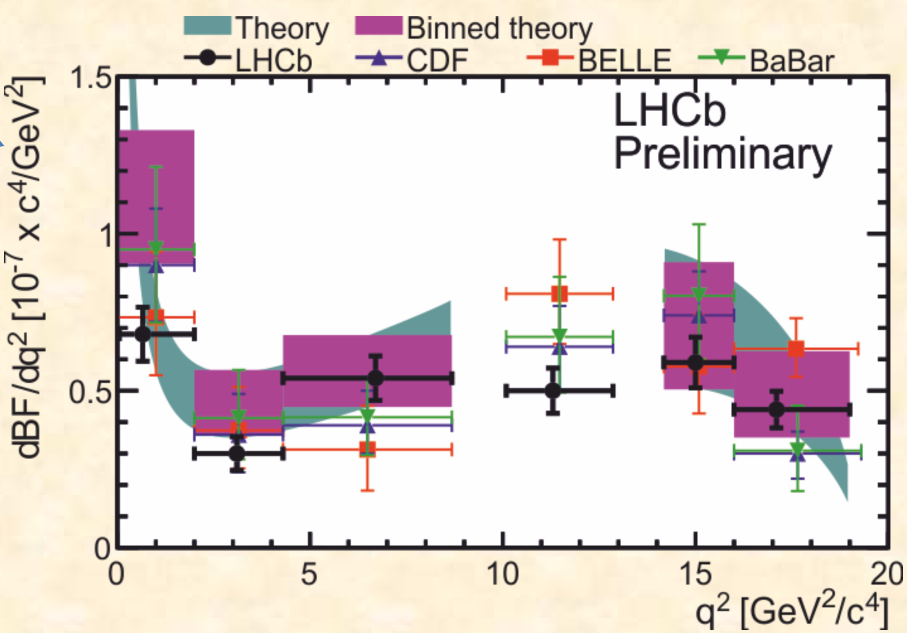
LHCb preliminary measurement is

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

the first measurement of the crossing point

68% CL for unbinned crossing point
Error bars on points are statistical only

Also look at the differential branching fraction normalised to $B^0 \to K^{*0} J/\psi$



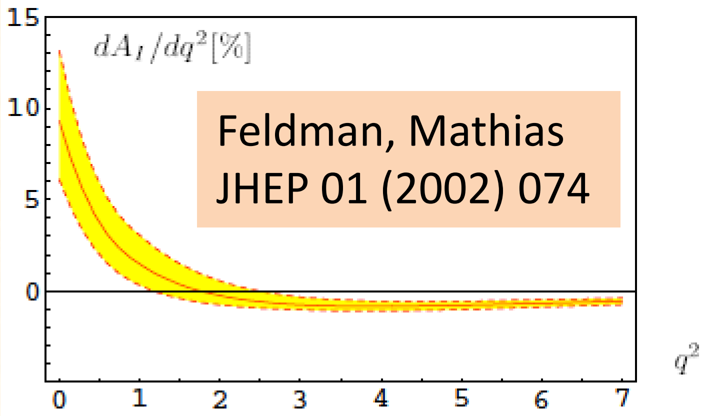
Another 3 parameters are also fitted
F_L, S_3 and S_9
Where theoretical predictions exist they are compatible with the SM

CERN-LHCb-CONF-2012-008

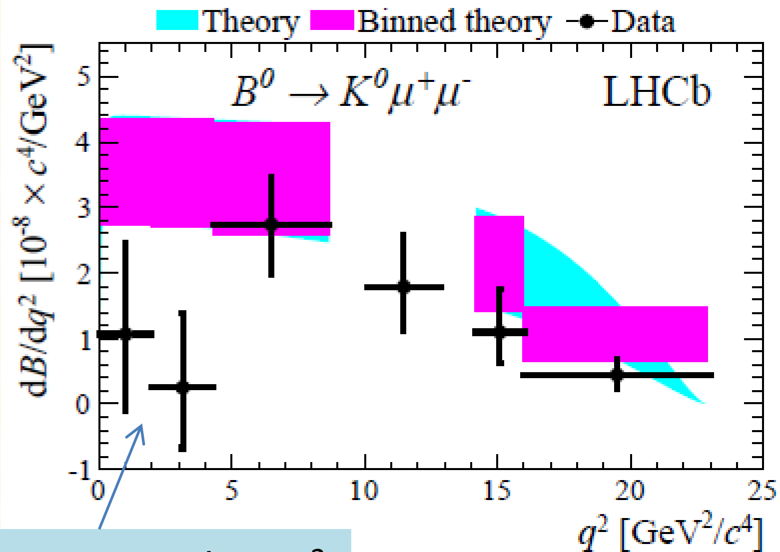
Isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$

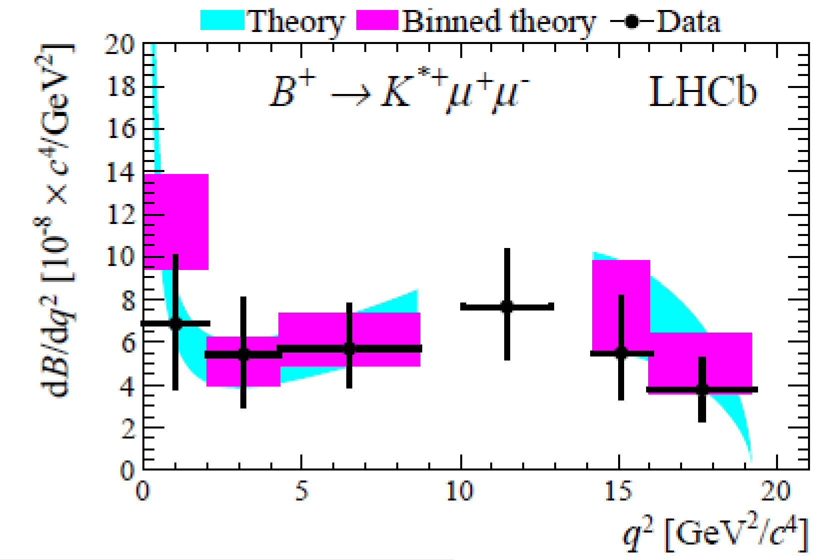
$$A_l = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \left(\frac{\tau_0}{\tau_+}\right)\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \left(\frac{\tau_0}{\tau_+}\right)\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$$

- A_l is the isospin asymmetry in the $B \to K^{(*)}\mu^+\mu^-$ system
- τ_0/τ_+ is the ratio of B^0 to B^+ lifetimes
- Expected to be O(1%) in the SM



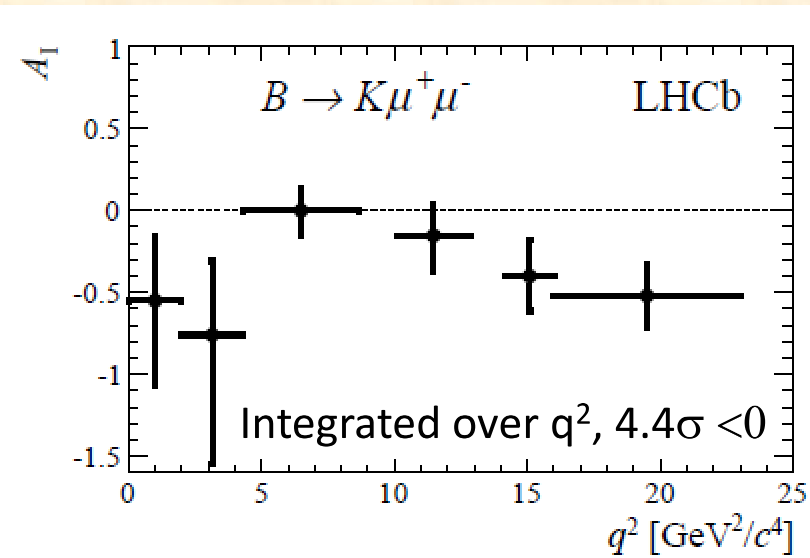
- For $B \to K^*\mu^+\mu^-$ the prediction is for positive at low q^2, dropping to small and negative as q^2 rises

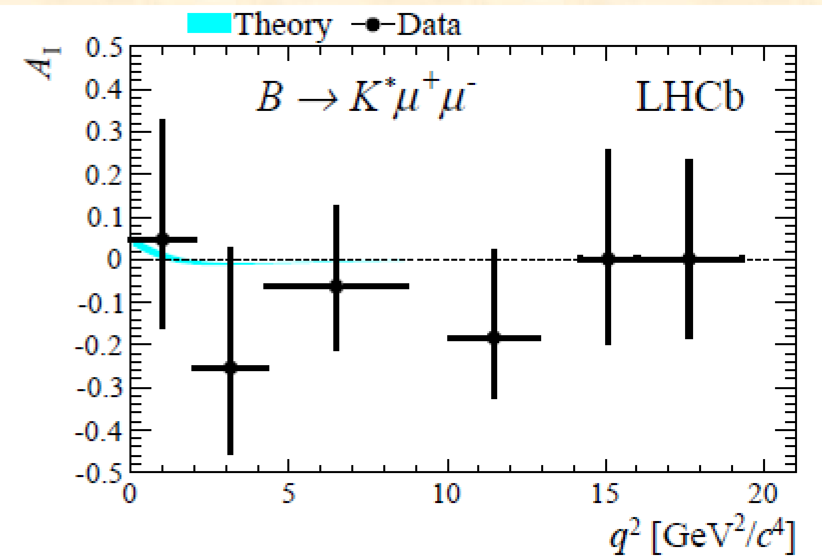




Deficit seen in at low q^2

Differential Branching ratio measurements





Isospin Asymmetry

LHCB-PAPER-2012-011, submitted to JHEP

Conclusion

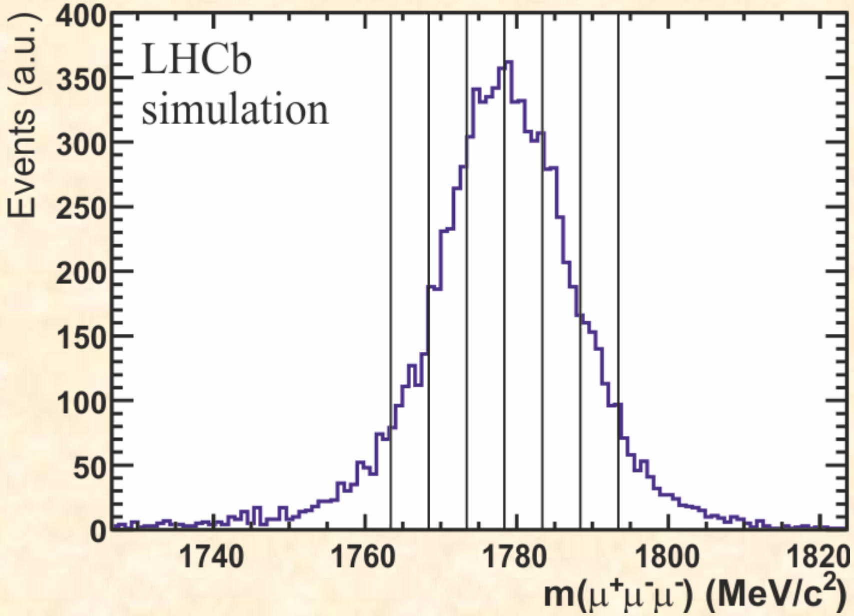
- New upper limits set on $B_{(s)}$ to two and four muons, τ to three muons and D to two muons ~1 fb^{-1} of LHCb data
- No evidence for enhancement in any of these decays
- Angular distributions of $B^0 \to K^{*0}\mu^+\mu^-$ were also tested, good agreement with SM
- Stringent limits placed on many models with new heavy particles
- Isospin 4.4σ low for $B \to K\mu^+\mu^-$, consistent with SM for $B \to K^*\mu^+\mu^-$
- Expect to increase collected luminosity to over 3.2 fb^{-1} by the end of 2012
  - Then we could confirm the SM branching ratio for $B_s^0 \to \mu^+\mu^-$

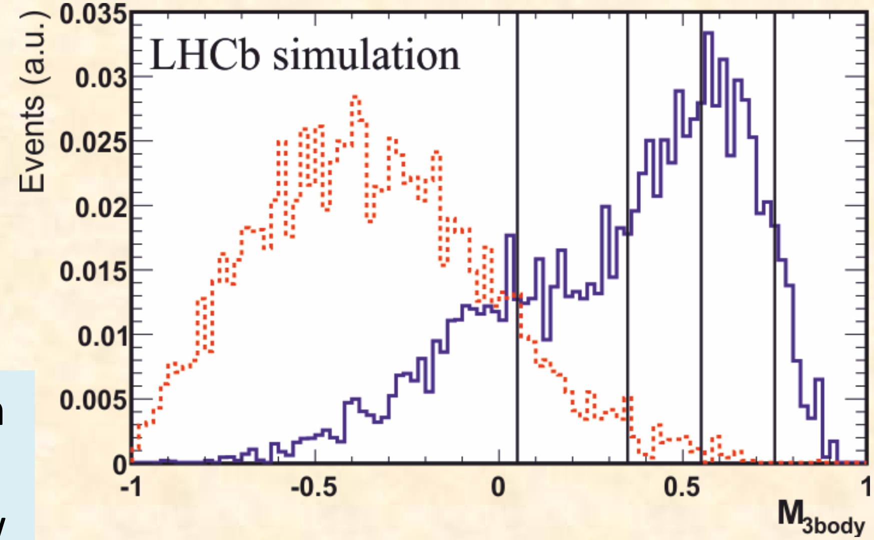
Backups

LHCb muon triggers

- Level-0 trigger runs at 40MHz and selects muons, electrons, photons and hadrons from the Muon detectors and Calorimeters
- Double muon decays are prioritised for rare decay searches
  - Single muon trigger : $p_T > 1.4$ GeV/c
  - Double muon trigger : $p_{T1} > 0.56$ GeV/c, $p_{T2} > 0.48$ GeV/c

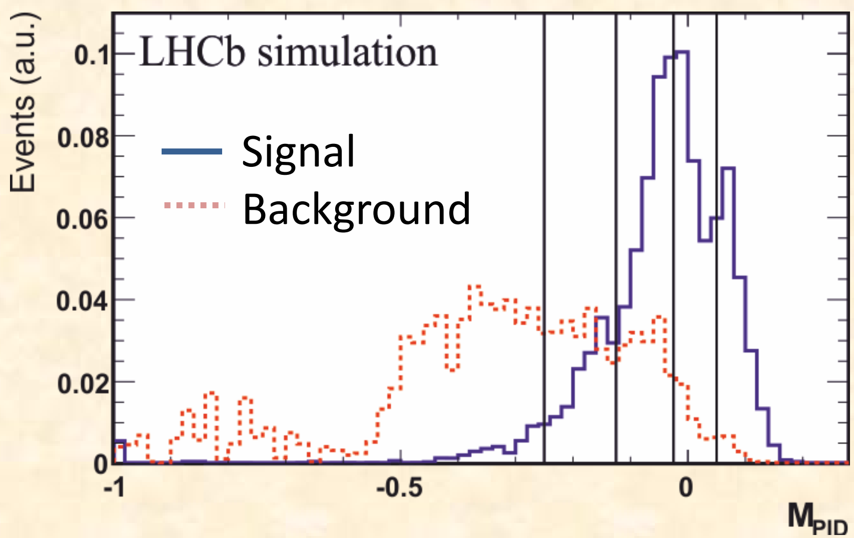
Simulated signal and backgrounds for $\tau^- \to \mu^-\mu^+\mu^-$

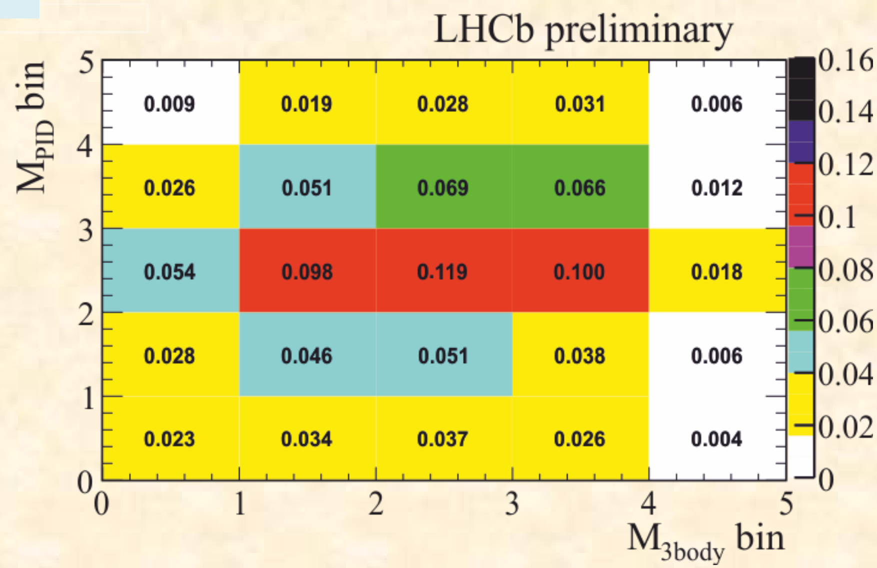




The M_3 and M_{PID} MVA variables are evaluated in the bins marked by the vertical lines

The correlations tuned to data are shown below





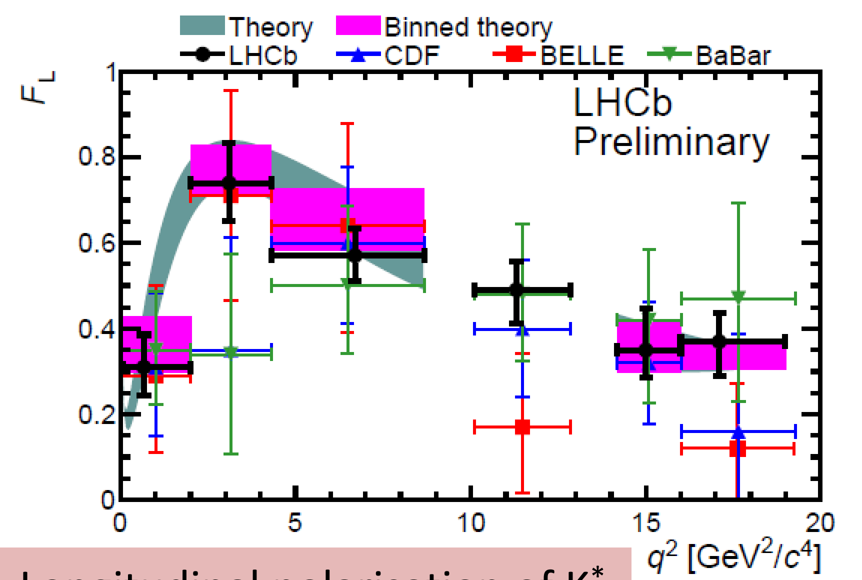
Angles in $B^0 \to K^{*0}\mu^+\mu^-$

Helicity angle of the kaon wrt the K* : θ_K
Helicity angle of the μ^+ wrt the B : θ_l
Angle between decay plane of di-muons and K* : ϕ (folded to $\hat{\phi} = \phi + \pi$ if $\phi < 0$)

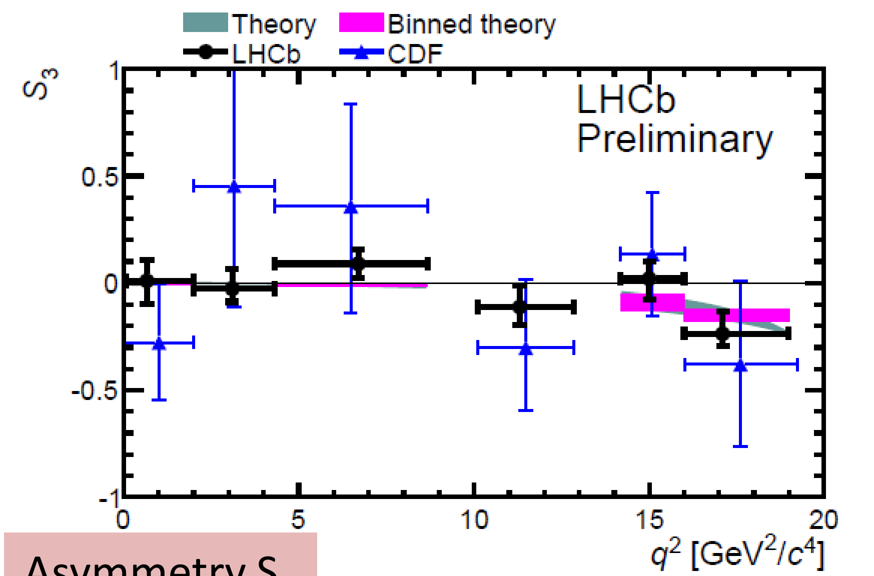
$$\frac{1}{\Gamma}\frac{d^4\Gamma}{d\cos\theta_\ell \, d\cos\theta_K \, d\hat{\phi} \, dq^2} = \frac{9}{16\pi}\Big[\boxed{F_L}\cos^2\theta_K + \frac{3}{4}(1-F_L)(1-\cos^2\theta_K) - F_L\cos^2\theta_K(2\cos^2\theta_\ell - 1) + \frac{1}{4}(1-F_L)(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) + \boxed{S_3}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} + \frac{4}{3}\boxed{A_{FB}}(1-\cos^2\theta_K)\cos\theta_\ell + \boxed{S_9}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \Big]$$

Angular analysis of three body system, the 4 parameters fitted are highlighted above

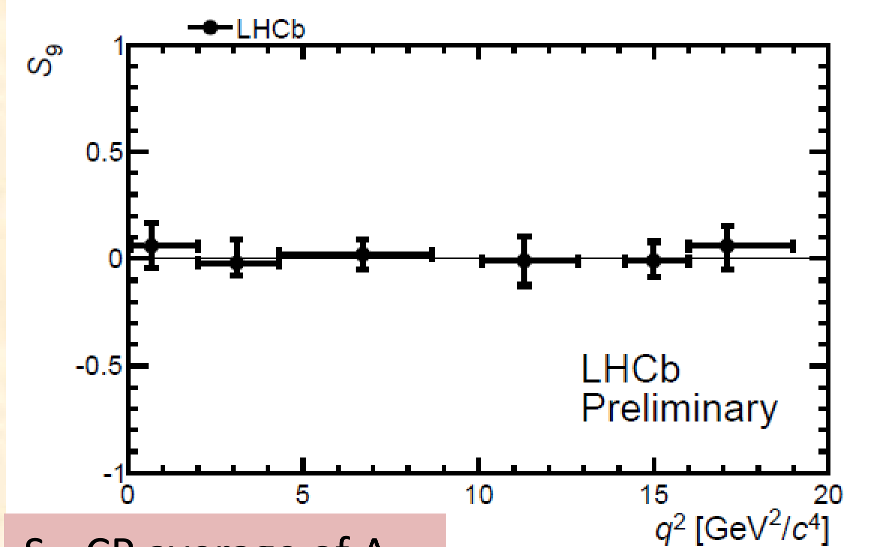
$B^0 \to K^{*0}\mu^+\mu^-$



Longitudinal polarisation of K^*



Asymmetry S_3



S_9, CP average of A_{Im}

CERN-LHCb-CONF-2012-008

Table 2: Partial branching fractions of $B^0 \to K^0\mu^+\mu^-$ and isospin asymmetries of $B \to K\mu^+\mu^-$ decays. The significance of the deviation of $A_{\rm I}$ from zero is shown in the last column. The errors include the statistical and systematic uncertainties.

q^2 range [GeV^2/c^4]	$d\mathcal{B}/dq^2[10^{-8}/\,\mathrm{GeV}^2/c^4]$	$A_{\rm I}$	$\sigma(A_{\rm I}=0)$
0.05 – 2.00	$1.1^{+1.4}_{-1.2}$	$-0.55^{+0.40}_{-0.56}$	1.5
2.00 – 4.30	$0.3^{+1.1}_{-0.9}$	$-0.76^{+0.45}_{-0.79}$	1.9
4.30 – 8.68	2.8 ± 0.7	$0.00^{+0.14}_{-0.15}$	0.1
10.09 – 12.86	$1.8^{+0.8}_{-0.7}$	$-0.15^{+0.19}_{-0.22}$	0.8
14.18 – 16.00	$1.1^{+0.7}_{-0.5}$	-0.40 ± 0.22	1.9
16.00 – 23.00	$0.5^{+0.3}_{-0.2}$	$-0.52^{+0.18}_{-0.22}$	3.0
1.00 – 6.00	$1.3^{+0.9}_{-0.7}$	$-0.35^{+0.23}_{-0.27}$	1.7

Table 3: Partial branching fractions of $B^+ \to K^{*+}\mu^+\mu^-$ and isospin asymmetries of $B \to K^*\mu^+\mu^-$ decays. The significance of the deviation of $A_{\rm I}$ from zero is shown in the last column. The errors include the statistical and systematic uncertainties.

q^2 range [GeV^2/c^4]	$d\mathcal{B}/dq^2[10^{-8}/\,\mathrm{GeV}^2/c^4]$	$A_{\rm I}$	$\sigma(A_{\rm I}=0)$
0.05 – 2.00	$7.0^{+3.1}_{-3.0}$	$0.05^{+0.27}_{-0.21}$	0.2
2.00 – 4.30	$5.4^{+2.6}_{-2.4}$	$-0.27^{+0.29}_{-0.18}$	0.9
4.30 – 8.68	$5.7^{+2.0}_{-1.7}$	$-0.06^{+0.19}_{-0.14}$	0.4
10.09 – 12.86	$7.7^{+2.6}_{-2.4}$	$-0.16^{+0.17}_{-0.16}$	0.9
14.18 – 16.00	$5.5^{+2.6}_{-2.1}$	$0.02^{+0.23}_{-0.21}$	0.1
16.00 – 19.30	3.8 ± 1.4	$0.02^{+0.21}_{-0.20}$	0.1
1.00 – 6.00	$5.8^{+1.8}_{-1.7}$	-0.15 ± 0.16	1.0