Rare Decays Session Summary

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Heavy Quarks and Leptons 2012
Prague
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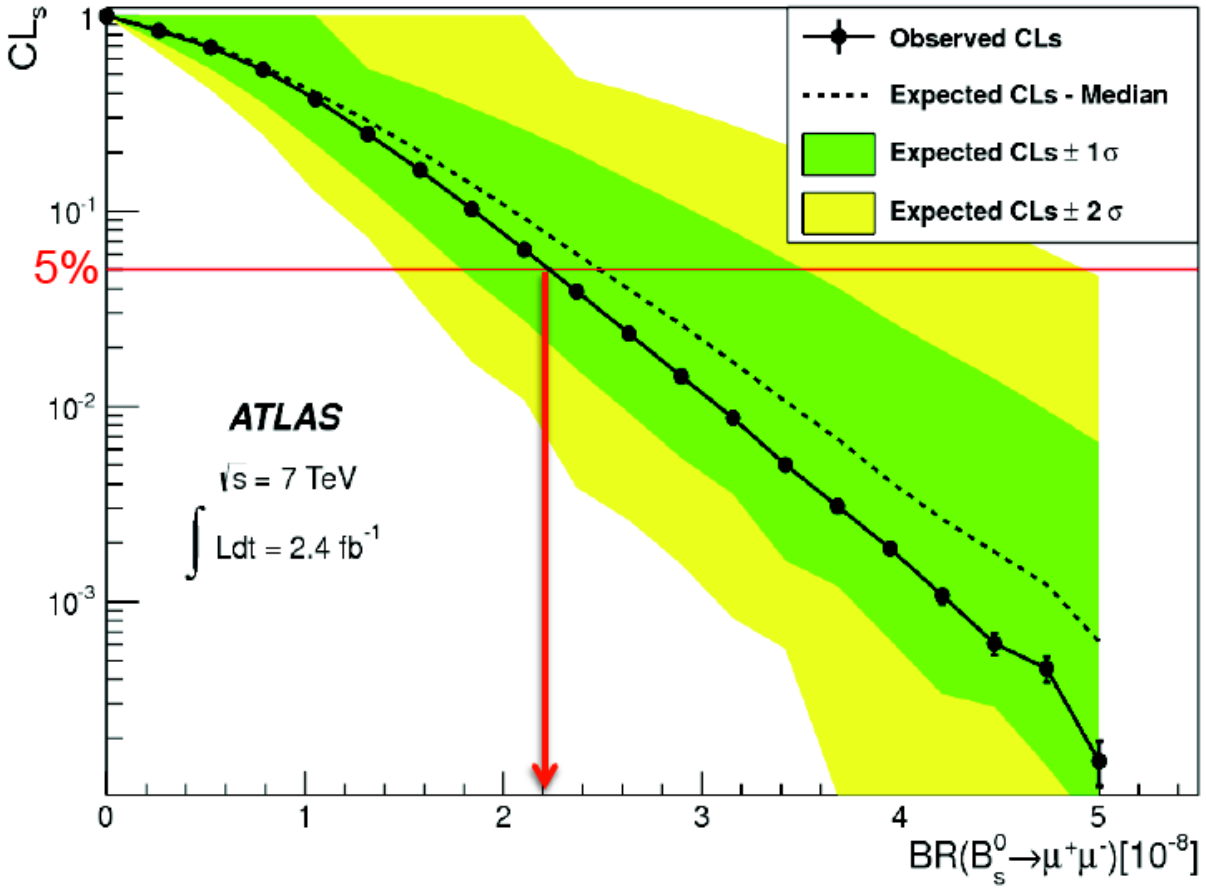
Topics discussed

Modes	**ATLAS**	**CMS**	**LHCb**	**BaBar**	**Belle**	**CDF**	**Theory**
Presenter	Ibragimov	Ronchese	Archilli	Wilson		Maestro	Bobeth
$B_{(s)} \to \mu^+\mu^-$	x	x	x			x	x
$B_{(s)} \to \mu^+\mu^-\mu^+\mu^-$			x				
$D^0 \to \mu^+\mu^-$			x				
$b \to s\, \mu^+\mu^-$			x	x	x	x	x
$B^+ \to \pi^+\mu^+\mu^-$			x				
$B^0 \to \nu\nu\ (\gamma)$				x	x		
LFV $B^+ \to h^+ \tau\, l$				(x)			
CLNV $B^+ \to X^-\, l^+\, l^+$				(x)	(x)		

Disclaimer: This table does not indicate which topics are being worked on.

Observed Limit

$B_s^0 \rightarrow \mu^+\mu^-$
Iskander Ibragimov, ATLAS



- Extracted with CLs method
- Use profiled likelihood ratio
- Likelihood for CLs is multi-bin:
  - three bins in muon $|\eta_{max}|$

⇒ Observed limit < 2.2×10^{-8} at 95% CL
⇒ Expected limit < 2.3×10^{-8} at 95% CL

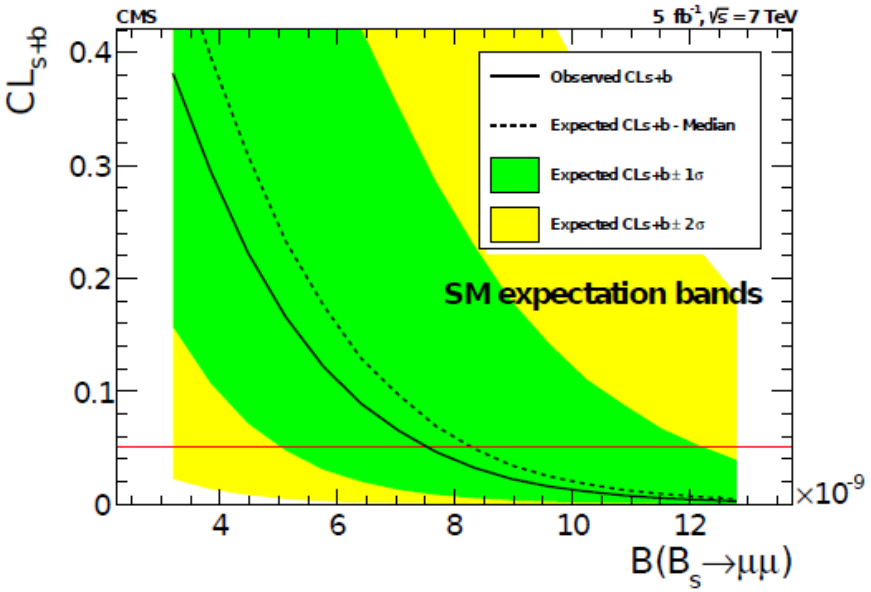
⇔ CDF: < 4.0×10^{-8} @ 95% CL (7 fb^{-1}) [arXiv:1107.2304]
⇔ CMS: < 0.77×10^{-8} @ 95% CL (5 fb^{-1}) [arXiv:1203.3976]
⇔ LHCb: < 0.45×10^{-8} @ 95% CL (1 fb^{-1}) [arXiv:1203.4493]

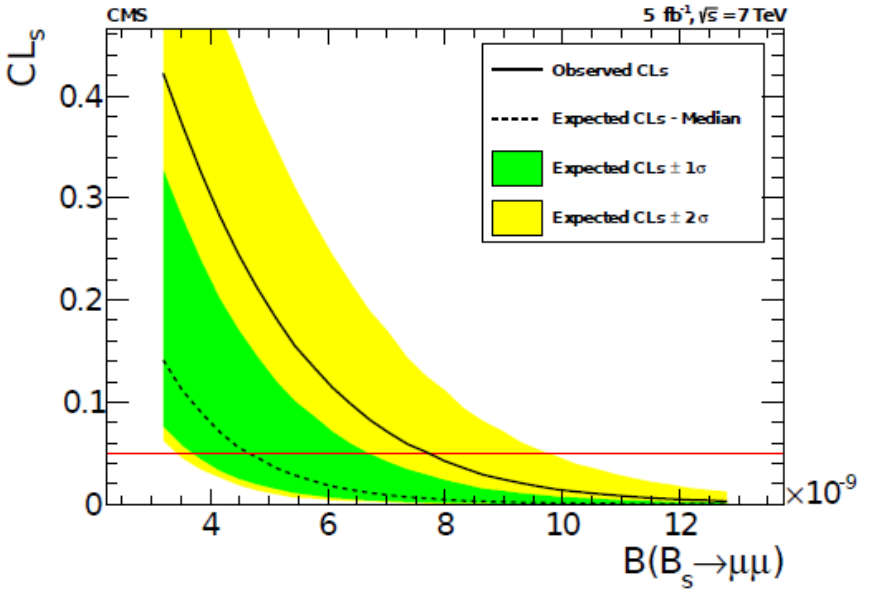
BR limit

$B_{(s)}^{0} \rightarrow \mu^{+}\mu^{-}$
Paolo Ronchese, CMS

	95% CL limit	*P*-value (BG only)	*P*-value (BG + SM signal)
$B_d^0 \rightarrow \mu^+\mu^-$	1.8×10^{-9}	0.24	0.86
$B_s^0 \rightarrow \mu^+\mu^-$	7.7×10^{-9}	0.11	0.71

BG-only *P*-value assumes freely-floating cross-feed





Expected limit: $BR(B_d^0 \rightarrow \mu^+\mu^-) < 1.6 \times 10^{-9}$
$BR(B_s^0 \rightarrow \mu^+\mu^-) < 8.4 \times 10^{-9}$

Upper limits evaluation

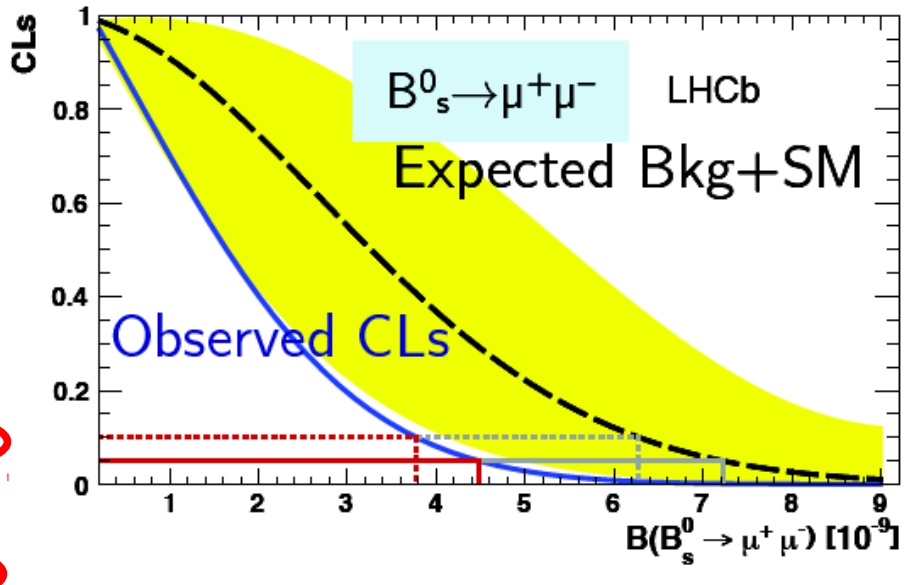
$B_{(s)}^{0} \to \mu^+\mu^-$
Flavio Archilli, LHCb

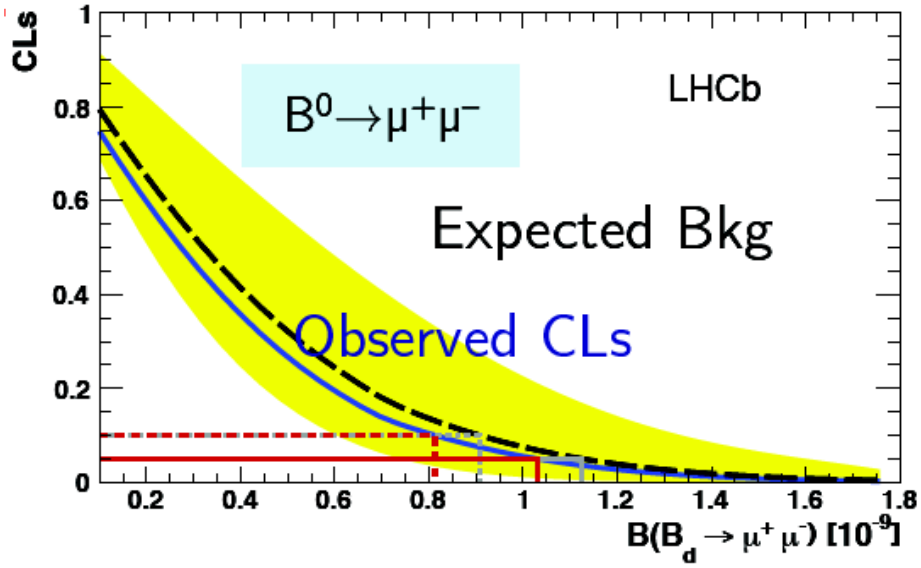
Last results with $1fb^{-1}$ data set:

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)]

Remark on $Br[B_s \to \mu^+\mu^-]$

Christoph Bobeth

So far theorists neglected mixing of B_s $\Rightarrow$ predict Br at $t = 0$: $Br[B_s(t=0) \to \bar{\mu}\mu]$

But with new measurements of $\Delta\Gamma_s$ (incl. sign) from LHCb and CDF, DØ

$\Rightarrow$ experiments actually measure time-integrated Br: [De Bruyn et al. arXiv:1204.1737]

$$Br[B_s \to \bar{\mu}\mu] \equiv \frac{1}{2}\int_0^\infty \mathrm{d}t \left(\Gamma[B_s(t) \to \bar{\mu}\mu] + \Gamma[\overline{B}_s(t) \to \bar{\mu}\mu]\right)$$

$$= \frac{1 + y_s \cdot \mathcal{A}_{\Delta\Gamma}}{1 - y_s^2} Br[B_s(t=0) \to \bar{\mu}\mu]$$

with (LHCb '11)

$$y_s = \frac{\Delta\Gamma_s}{2\Gamma_s} = 0.088 \pm 0.014$$

and

$\Rightarrow$ in SM $\quad \mathcal{A}_{\Delta\Gamma}|_{\mathrm{SM}} = +1$

$\Rightarrow$ beyond $\mathcal{A}_{\Delta\Gamma} \in [-1, +1]$ $\to$ depends on NP !!!

In SM for example

$$Br[B_s \to \bar{\mu}\mu]_{\mathrm{SM}} = (3.53 \pm 0.38) \times 10^{-9}$$

[Mahmoudi/Neshatpour/Orloff arXiv:1205.1845]

largest uncertainties from

$f_{B_s} = (234 \pm 10)\,\mathrm{MeV} \to 9\,\%$

$V_{ts} \to 5\,\%$

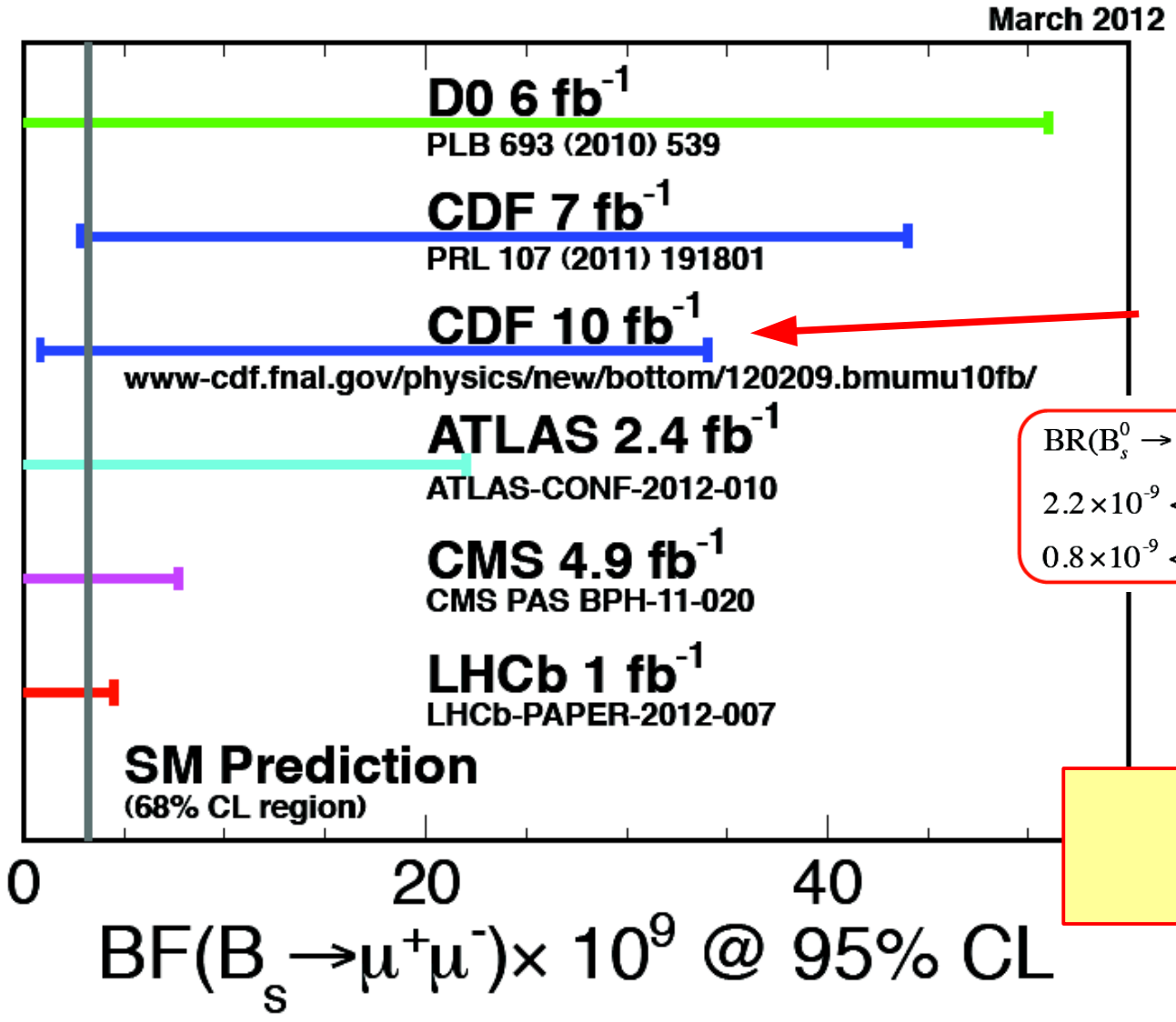
B_s lifetime $\to 2\,\%$

. . . or using precise ΔM_s measurement to substitute f_{B_s} (and assuming SM) [Buras hep-ph/0303060]

$$Br[B_s \to \bar{\mu}\mu]_{\mathrm{SM}} = \frac{(3.1 \pm 0.2) \times 10^{-9}}{0.91 \pm 0.01} = (3.4 \pm 0.2) \times 10^{-9}$$

[Buras/Girrbach arXiv:1204.5064]

$B_s^0 \to \mu^+\mu^-$ Experimental Status



Updated CDF analysis

$$BR(B_s^0 \to \mu^-\mu^+) = \left(1.3^{+0.9}_{-0.7}\right) \times 10^{-8}$$

$$2.2 \times 10^{-9} < BR(B_s^0 \to \mu^-\mu^+) < 3.0 \times 10^{-8} \ @ \ 90\% \ C.L.$$

$$0.8 \times 10^{-9} < BR(B_s^0 \to \mu^-\mu^+) < 3.4 \times 10^{-8} \ @ \ 95\% \ C.L.$$

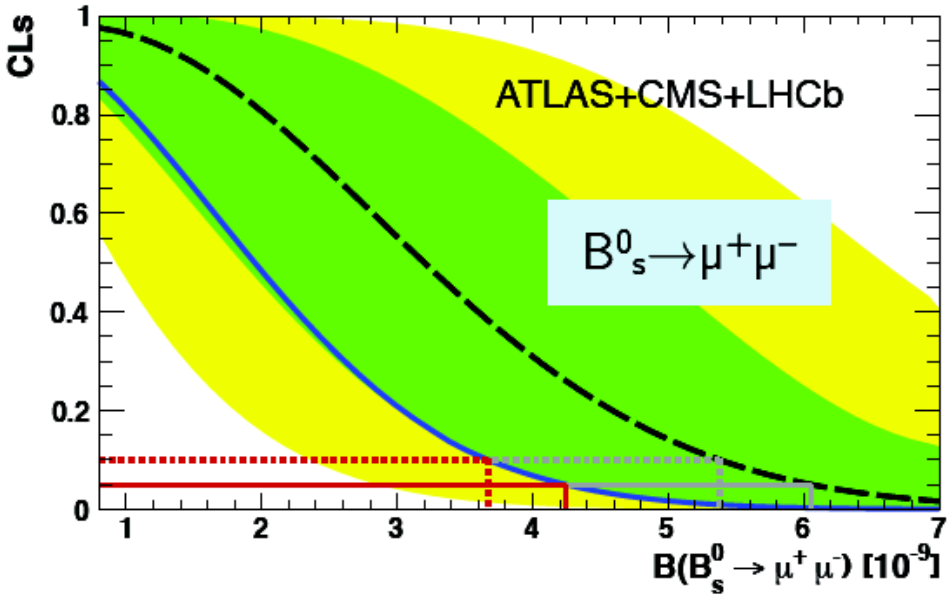
$B_{(s)}^0 \to \mu^+\mu^-$
Paolo Maestro

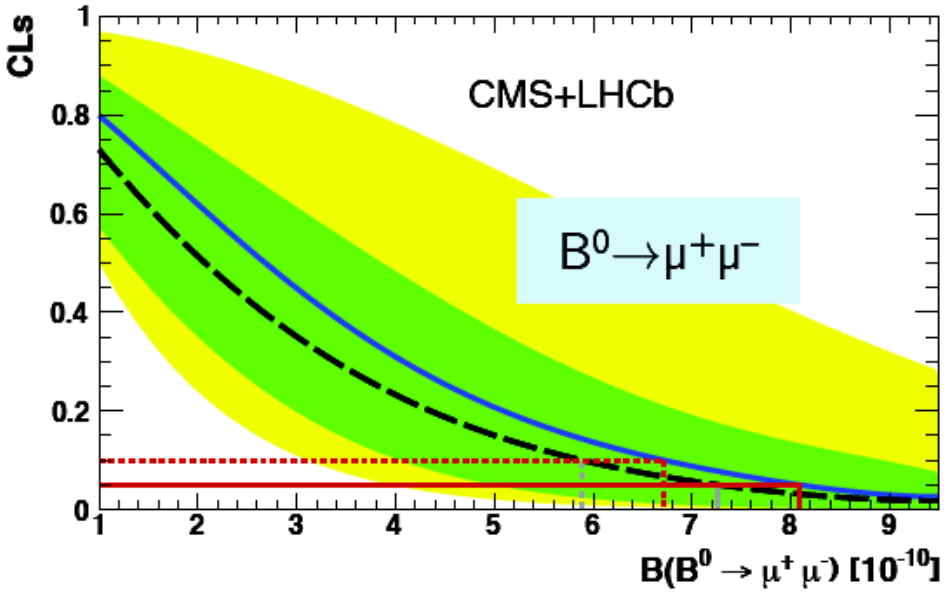
Combination with CMS and ATLAS

$B_{(s)}^{0} \rightarrow \mu^{+}\mu^{-}$
Flavio Archilli

ATLAS, CMS and LHCb results have been recently combined

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





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

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

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

$b \to s\, \mu^+\mu^-$

Paolo Maesto

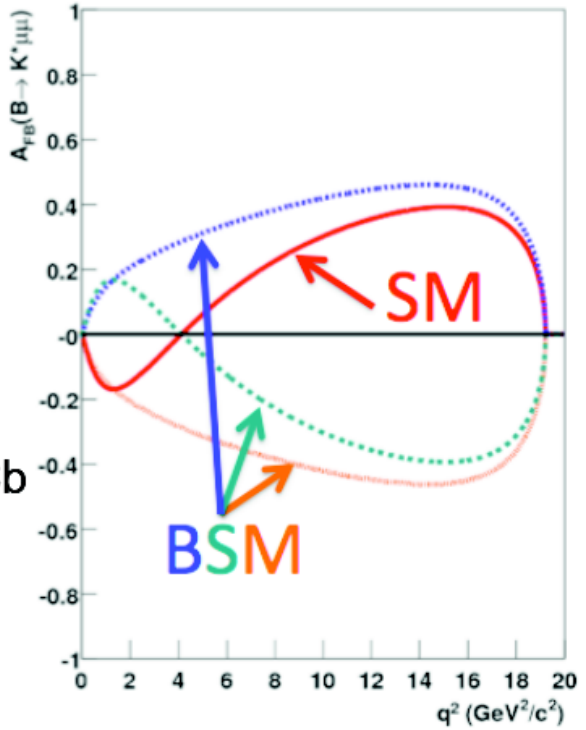
- $b \to s\, \mu^-\mu^+$ are rare FCNC decays, forbidden at tree level in SM.
  SM predicts very low rates BR~10^{-6}.

- Measure branching fractions is a good test for SM.

- **Forward-backward asymmetry** sensitive to BSM physics.
  A_{FB} in $B \to \mu\mu K^*$ decay: predictions exist for several new physics scenarios.

- Experimental status

$B^+ \to K^+ \mu^+\mu^-$	BaBar, Belle, CDF
$B^0 \to K^{*0} \mu^+\mu^-$	BaBar, Belle (2.7σ deviation for A_{FB}), CDF, LHCb
$B_s^0 \to \phi\, \mu^+\mu^-$	CDF, DØ, LHCb
$B^0 \to K_S\, \mu^+\mu^-$	Belle, CDF, LHCb
$B^+ \to K^{*+} \mu^+\mu^-$	BaBar, Belle, CDF, LHCb
$\Lambda_b^0 \to \Lambda\, \mu^+\mu^-$	CDF



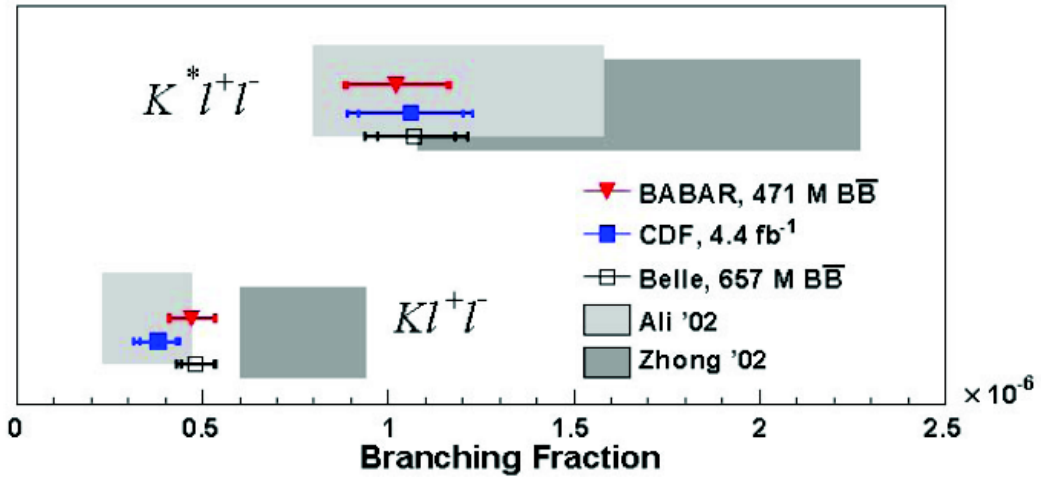
Fergus Wilson

Paolo Maesto

$B \to K^{(*)} l^+ l^-$ Branching Fractions

CDF II

$$\text{Predicted}\,(PRD66,034002(2002)):$$
$$B(B \to K l^+ l^-) = (3.5 \pm 1.2) \times 10^{-7}$$
$$B(B \to K^* l^+ l^-) = (11.9 \pm 3.9) \times 10^{-7}$$
$$\text{Measured}\,(arXiv:1204.3933):$$
$$B(B \to K l^+ l^-) = (4.7 \pm 0.6 \pm 0.2) \times 10^{-7}$$
$$B(B \to K^* l^+ l^-) = (10.2^{+1.4}_{-1.3} \pm 0.5) \times 10^{-7}$$



BaBar, 471M, arXiv:1204.3933 (submitted to PRD)
Belle, 657M, PRL 103, 171801 (2009)
CDF, 6.8fb-1, PRL 107, 201802 (2011)
LHCb, 0.37fb-1, PRL 108, 181806 (2012)

6.8 fb^{-1}

BR($B^+ \to K^+\mu^+\mu^-$) = [0.46 ± 0.04± 0.02]×10^{-6}

BR($B_s^0 \to \phi\mu^+\mu^-$) = [1.47 ± 0.24 ± 0.46]×10^{-6}

BR($B^0 \to K^{*0}\mu^+\mu^-$) = [1.02 ± 0.10 ± 0.06]×10^{-6}

BR($B^+ \to K^{*+}\mu^+\mu^-$) = [0.95 ± 0.32 ± 0.08]×10^{-6}

BR($B^0 \to K^0\mu^+\mu^-$) = [0.32 ± 0.10 ± 0.02]×10^{-6}

BR($\Lambda_b^0 \to \Lambda\mu^+\mu^-$) = [1.73 ± 0.42 ± 0.55]×10^{-6}

First observation

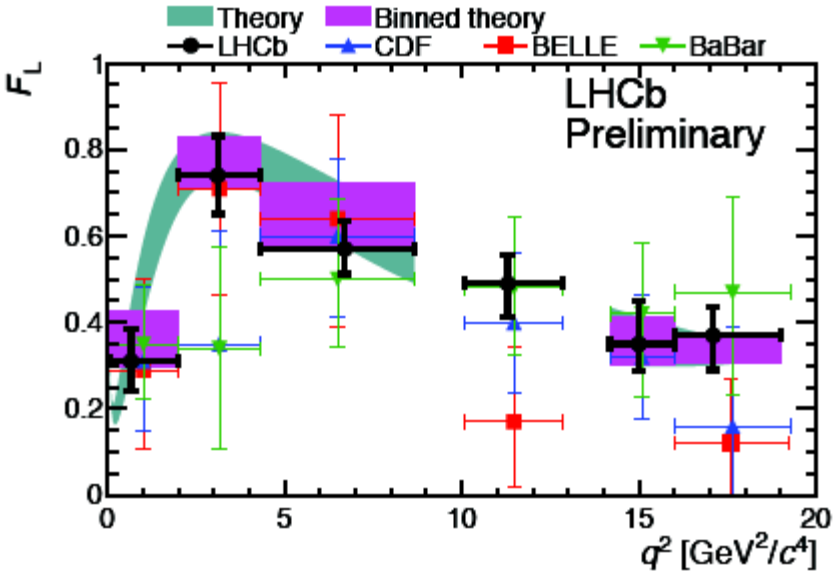
Angular Analysis: $B \to K^{*0} \mu^+\mu^-$

LHCb: 1 fb^{-1}

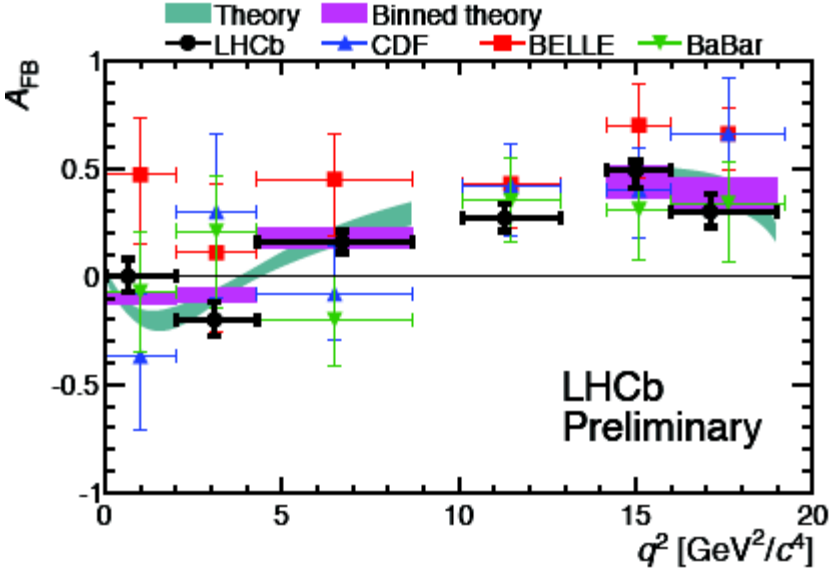
Flavio Archilli, LHCb
(also: F. Wilson)

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

F_L



A_{FB}



- A_{FB} zero crossing: $q^2_0 = 4.9^{+1.1}_{-1.3}$ GeV^2/c^4 (first measurement)
  [LHCb-CONF-2012-008]
- All consistent with SM, yet room for NP
  [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]

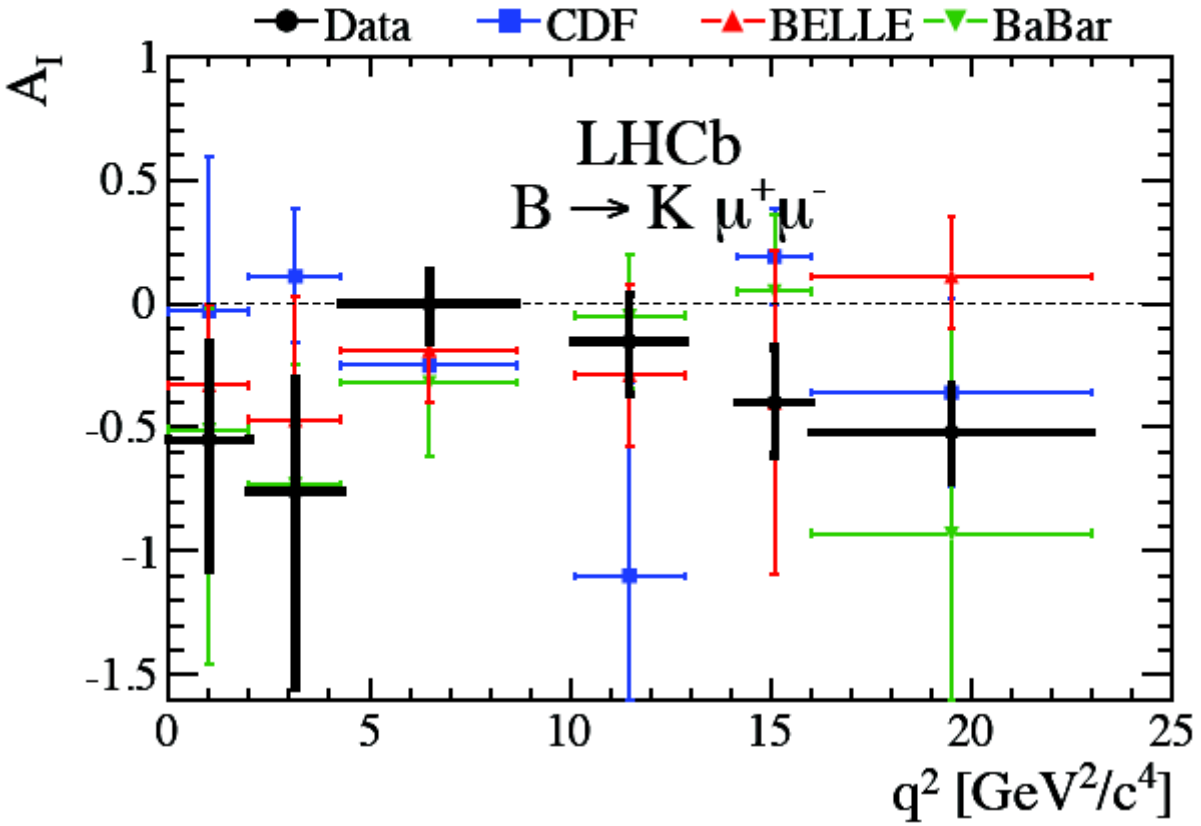
Isospin Asymmetry: B → $K^{(*)}$ $\mu^+\mu^-$

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

Flavio Archilli, LHCb
(also: F. Wilson)

LHCb: 1 fb^{-1}

[LHCb-Paper-2012-011]
[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]



- For B → K* $\mu^+\mu^-$ consistent with zero (SM prediction)
- For B → K $\mu^+\mu^-$ below zero; deviation 4.4 σ (integrated over q^2)
- BaBar/Belle: "consistent with SM predictions at 2.1 σ and 1.2 σ level respectively" [Wilson]

First observation: $B^+ \to \pi^+ \mu^+\mu^-$

SM prediction:

$BR(B^+ \to \pi^+\mu^+\mu^-) = (1.96 \pm 0.21)\times10^{-8}$

Prev. Exp.:

$BR(B^+ \to \pi^+\mu^+\mu^-) < 6.9\times10^{-8}$

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

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

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

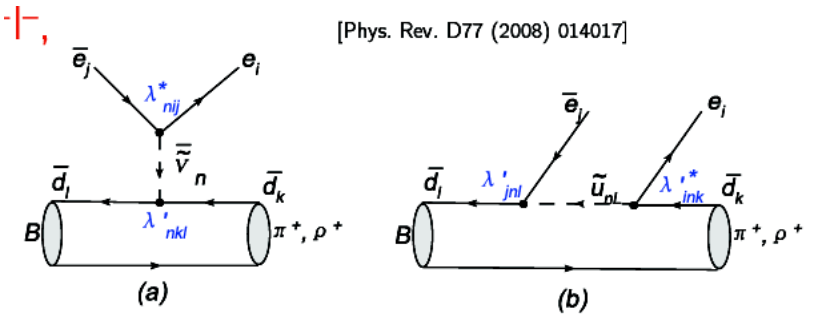
$J/\psi K^+$ decay used as normalization channel

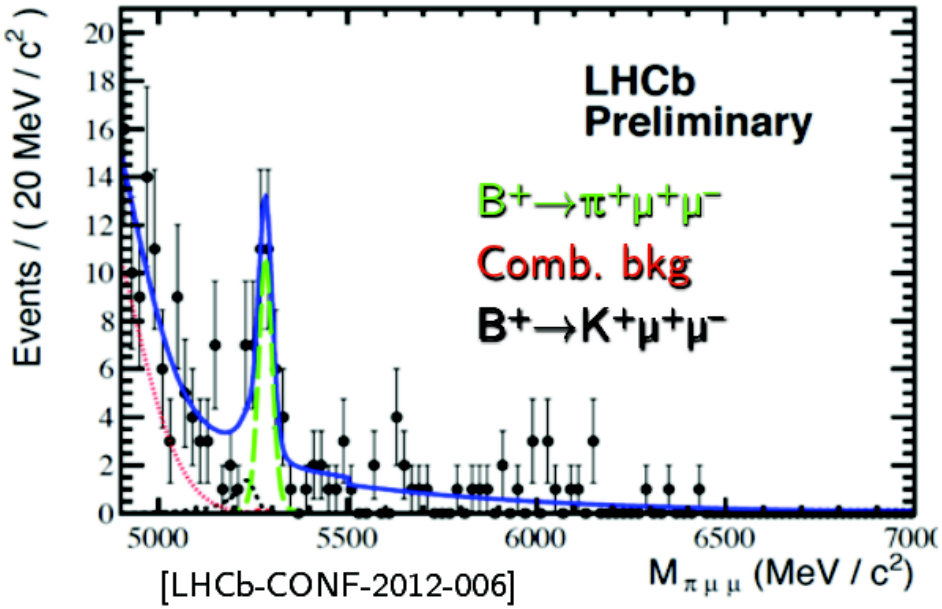
$BR(B^+ \to \pi^+\mu^+\mu^-) = (2.4 \pm 0.6_{stat} \pm 0.2_{syst})\times10^{-8}$

5.6σ excess

Nicely match with SM prediction

Rarest B decay ever observed

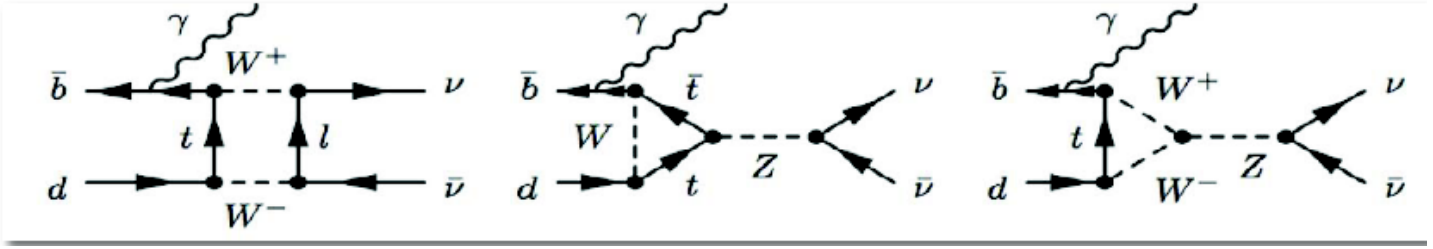




Flavio Archilli, LHCb

$B^0 \to \nu\bar{\nu}\ (\gamma)$

Fergus Wilson
BaBar/Belle



Standard Model
~ 10^{-9}

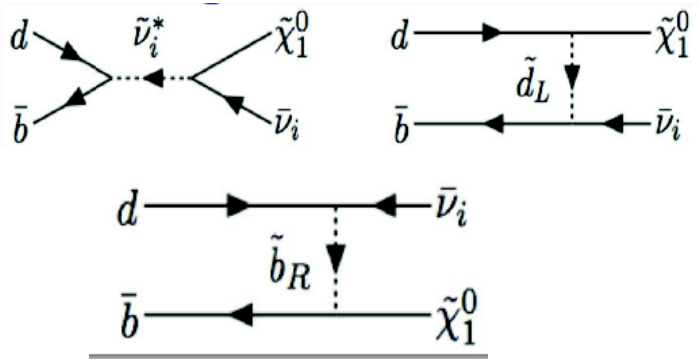
- Belle:

Mode	N_{sig}	N_{bkg}	$UL(90\%)$
$B^0 \to \text{invisible}$	9 ± 6	$\sim 100 \pm 23$	1.3×10^{-4}

- BaBar: new analysis

Mode	N_{sig}	N_{bkg}	$UL(90\%)$
$B^0 \to \text{invisible}$	-22 ± 9	334 ± 21	2.4×10^{-5}
$B^0 \to \text{invisible} + \gamma$	-3.1 ± 5.2	113 ± 12	1.7×10^{-5}

New Physics
~ 10^{-7} … 10^{-6}



Theory: Global Fit to Observables

Extension of EFT beyond the SM ...

Christoph Bobeth

$$\mathcal{L}_{\text{eff}}(\mu_b) = \mathcal{L}_{\text{QED}\times\text{QCD}}(u, d, s, c, b, e, \mu, \tau, ???)$$

$$+ \frac{4G_F}{\sqrt{2}} V_{\text{CKM}} \sum_{\text{SM}} (C_i + \Delta C_i)\mathcal{O}_i + \sum_{\text{NP}} C_j \mathcal{O}_j(???)$$

"Global Fit" = combination of $b \to s + (\gamma, \ell^+\ell^-)$ observables

Parameters of interest

$\vec{\theta} = (C_i)$

Nuisance parameters

1) process-specific

$\vec{\nu}$ FF's, decay const's, LCDA pmr's, sub-leading Λ/m_b, renorm. scales: $\mu_{b,0}$

2) general

quark masses, CKM, ...

Observables

1) observables

$O(\vec{\theta}, \vec{\nu})$

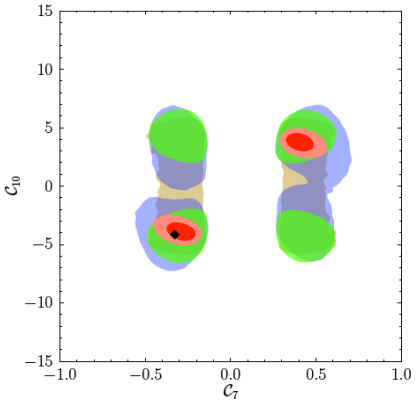
depend usually on sub-set of $\vec{\theta}$ and $\vec{\nu}$

2) experimental data for each observable

pdf$(O = o)$

$\Rightarrow$ probability distribution of values o

- Fit for Wilson coefficients
- O(5) observables
- O(30) nuisance parameters
- Results like:



Conclusions

Experiments:

- Real progress made in experimental results.
- LHC experiments are catching up;
  LHCb has a wealth of data.
- BR($B_s^0 \to \mu^+\mu^-$) < 4.2 10^{-9} @ 95% CL (ATLAS, CMS, LHCb)
  BR($B^0 \to \mu^+\mu^-$) < 8.1 10^{-10} (CMS, LHCb)
- CDF, BaBar and Belle improved their analyses.
- $b \to s\ \mu^+\mu^-$ is mostly consistent with Standard Model
- No clear sign of New Physics (yet).

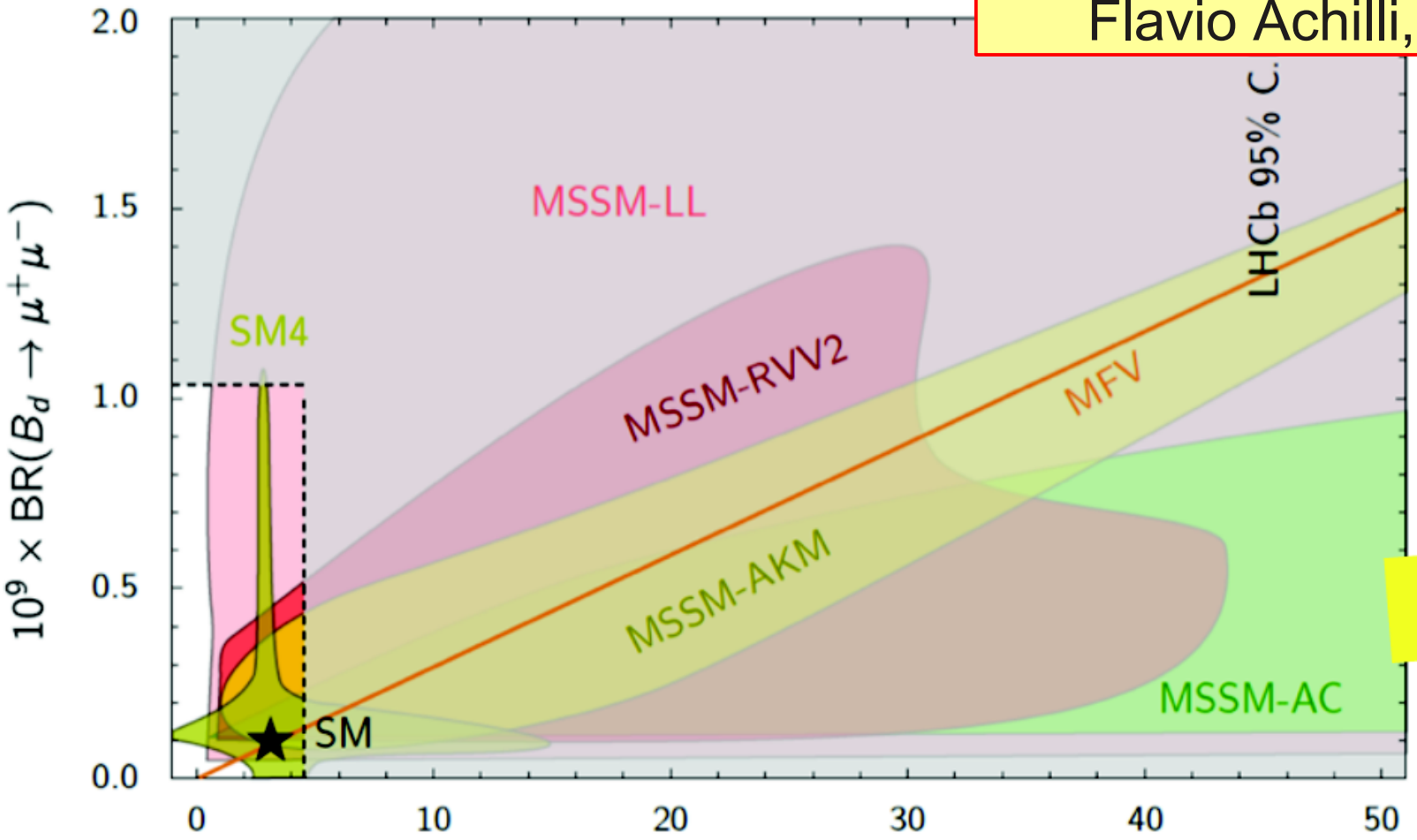
Theory:

- Interesting idea of using combination of all experimental observations in global fit for Wilson coefficients.

Supporting material

Impact of the latest LHCb limits

$B_{(s)}^{0} \rightarrow \mu^{+}\mu^{-}$
Flavio Achilli, LHCb



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	
$BR(B^0 \rightarrow \mu^+\mu^-)$	95% CL upper limit (10^{-9})	4.6	1.8		1.03	0.1±0.01
$BR(B^0 \rightarrow \mu^+\mu^-)$	95% CL upper limit (10^{-9})	31	7.7	22	4.5	3.2±0.2

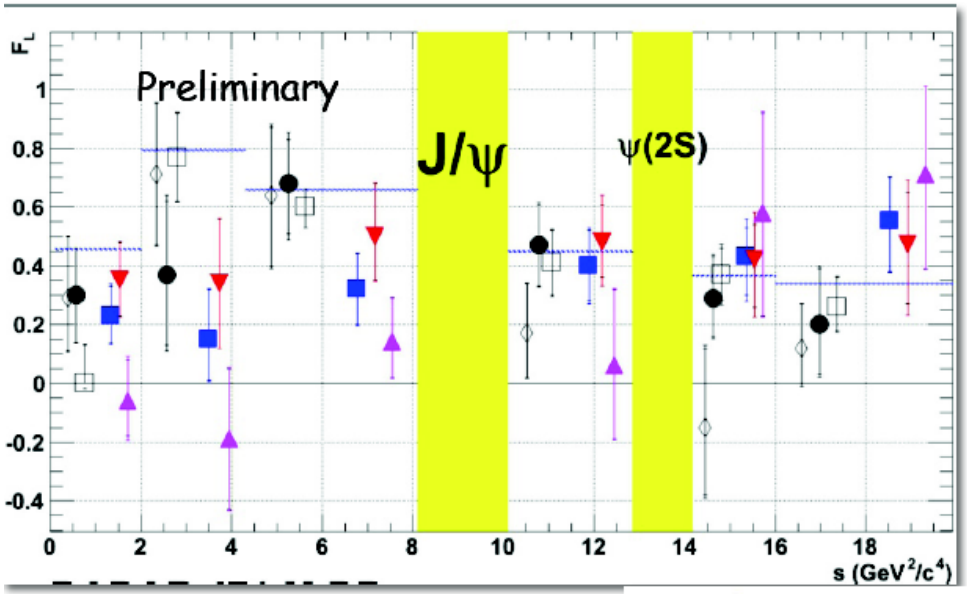
$B \to K^{(*)} l^+ l^-$ Angular Observables F_L and A_{FB}

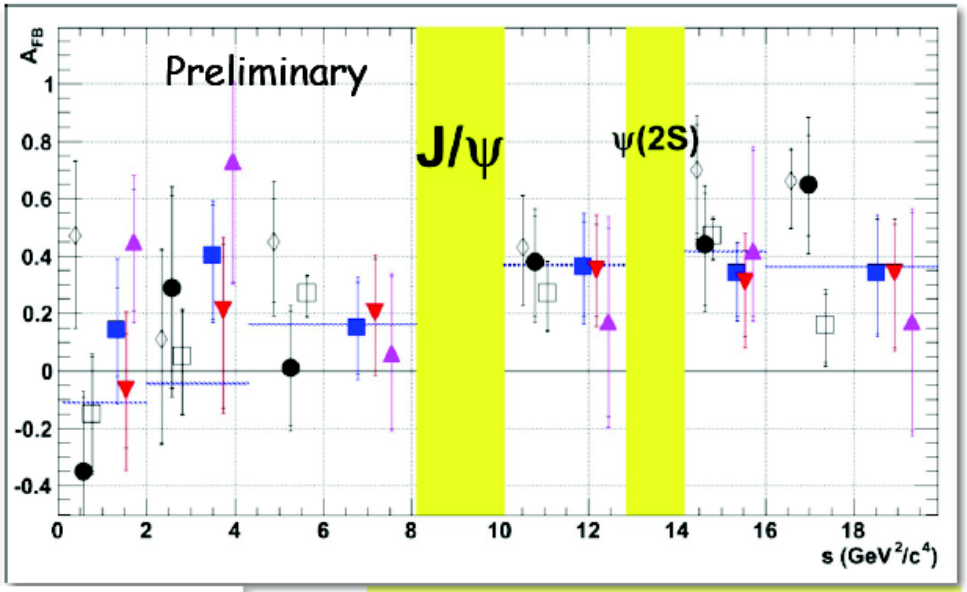
Longitudinal polarisation, F_L

$$\frac{1}{\Gamma(s)}\frac{d}{d\cos\theta_K} = \frac{3}{2}F_L(s)\cos^2\theta_K + \frac{3}{4}(1-F_L(s))(1-\cos^2\theta_K)$$

Forward Backward asymmetry, A_{FB}

$$\frac{1}{\Gamma(s)}\frac{d}{d\cos\theta_l} = \frac{3}{4}F_L(s)\cos^2\theta_l + \frac{3}{8}(1-F_L(s))(1+\cos^2\theta_l) + A_{FB}\cos\theta_l$$





$K^* l^+ l^-$ $K^{*0} l^+ l^-$ $K^{*+} l^+ l^-$
CDF Belle LHCb
Standard Model

BaBar, 471M, preliminary
Belle, 657M,PRL 103, 171801 (2009)
LHCb, 0.37fb-1, PRL 102, 181806 (2012)
CDF, 6.8fb-1, PRL 108, 081807 (2012)

- Most precise non-LHCb results so far
- Generally good agreement between SM and experiments
- Some deviation at low-s from SM

$B \to K^{(*)} l^+ l^-$ Isospin Asymmetries

Fergus Wilson

- Isospin Asymmetry:

$$A_I^{K^{(*)}} \equiv \frac{B(B^0 \to K^{(*)0} l^+ l^-) - r_\tau B(B^+ \to K^{(*)+} l^+ l^-)}{B(B^0 \to K^{(*)0} l^+ l^-) + r_\tau B(B^+ \to K^{(*)+} l^+ l^-)}$$

BaBar, 471M, arXiv:1204.3933
Belle, 657M, PRL 103, 171801 (2009)

- SM: ~ (0.5±2)% at low s, 6-13% over all s.
- Possible asymmetry below J/ψ.

BaBar :

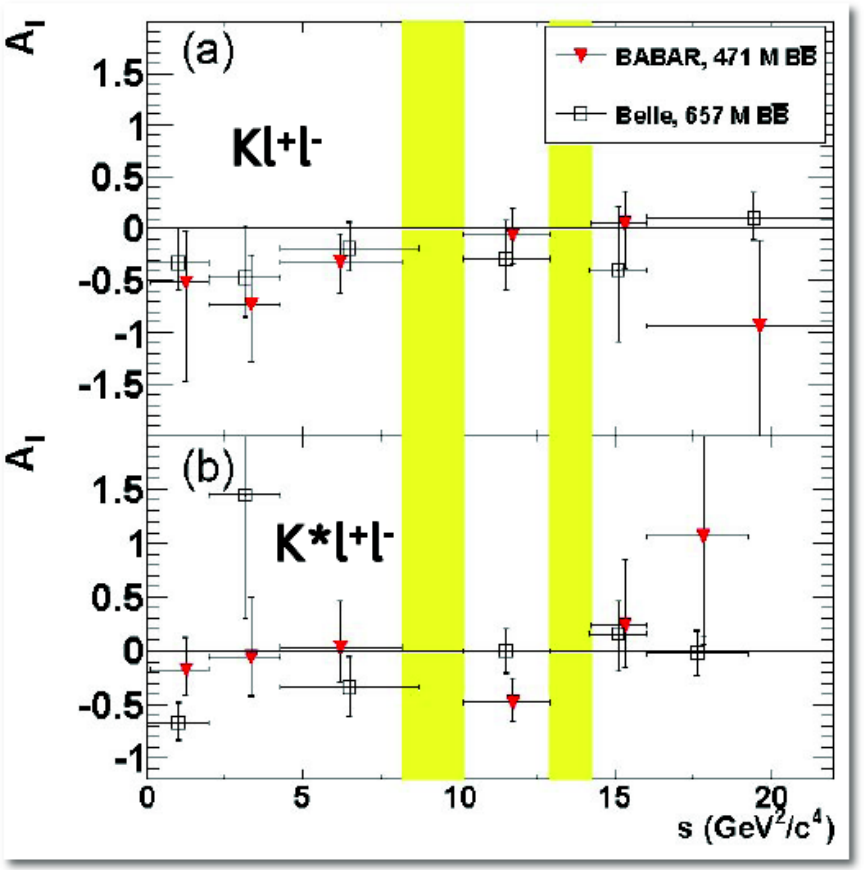
$$A_I^{low}(B \to K l^+ l^-) = -0.58^{+0.29}_{-0.37} \pm 0.02$$

$$A_I^{low}(B \to K^* l^+ l^-) = -0.25^{+0.20}_{-0.17} \pm 0.03$$

Belle :

$$A_I^{low}(B \to K l^+ l^-) = -0.31^{+0.17}_{-0..14} \pm 0.08$$

$$A_I^{low}(B \to K^* l^+ l^-) = -0.29 \pm 0.16 \pm 0.09$$



- Consistent with SM predictions at 2.1σ and 1.2σ level respectively.

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

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