$b \to s\ell^+\ell^-$ perspective from LHCb

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$b \to s(d)\mu^+\mu^-$

- Measure the decay rates, asymmetries and angular distributions of final state products
- Different final states sensitive to different combinations of Wilson coefficients
  - Allows for precise extraction of LH and RH Wilsons
  - $b \to d$ vs $b \to s$ allows to test Minimal Flavour Violation of new physics
- Observables built out of ratios of angular coefficients reduce theory uncertainties due to hadronic form factor

Operator $\mathcal{O}_i$	$B_{s(d)} \to X_{s(d)}\mu^+\mu^-$	$B_{s(d)} \to \mu^+\mu^-$	$B_{s(d)} \to X_{s(d)}\gamma$
$\mathcal{O}_7 \sim m_b(\bar{s}_L\sigma^{\mu\nu}b_R)F_{\mu\nu}$	✓		✓
$\mathcal{O}_9 \sim (\bar{s}_L\gamma^\mu b_L)(\bar{\ell}\gamma_\mu\ell)$	✓		
$\mathcal{O}_{10} \sim (\bar{s}_L\gamma^\mu b_L)(\bar{\ell}\gamma_5\gamma_\mu\ell)$	✓	✓	
$\mathcal{O}_{S,P} \sim (\bar{s}b)_{S,P}(\bar{\ell}\ell)_{S,P}$	(✓)	✓	

In SM $C_{S,P} \propto m_\ell m_b/m_W^2$

In SM chirality flipped $\mathcal{O}_i$ suppressed by m_s/m_b

Suite of LHCb measurements

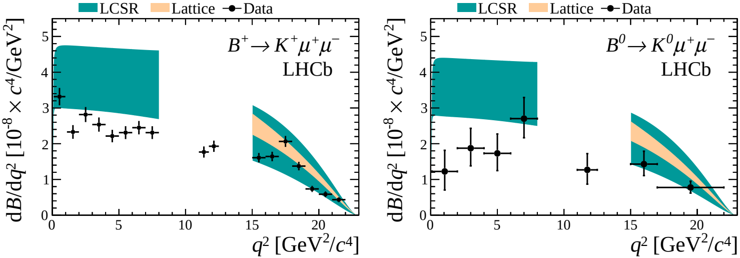
World's most precise measurements

channel	$\mathcal{L}^{int}$ (fb^{-1})	Publication
$d\mathcal{B}/dq^2$ $B \to K^{*+}\mu^+\mu^-$	3	[1403.8044]
$d\mathcal{B}/dq^2$ $B \to K^0\mu^+\mu^-$	3	[1403.8044]
$d\mathcal{B}/dq^2$ $B \to K^+\mu^+\mu^-$	3	[1403.8044]
$d\mathcal{B}/dq^2$ $B^0 \to K^{*0}\mu^+\mu^-$	1	[JHEP08(2013)131]
$d\mathcal{B}/dq^2$ $B_s^0 \to \phi\mu^+\mu^-$	1	[JHEP07(2013)084]
$d\mathcal{B}/dq^2$ $\Lambda_b \to \Lambda\mu^+\mu^-$	1	[PLB725(2013)25]
$\mathcal{B}$ $B^0 \to K^{*0}e^+e^-$	1	[JHEP05(2013)159]
$\mathcal{B}$ $B^+ \to \pi^+\mu^+\mu^-$	1	[JHEP12(2012)125]
A_I $B \to K^{(*)}\mu^+\mu^-$	3	[1403.8044]
A_{CP} $B^+ \to K^+\mu^+\mu^-$	1	[PRL111,151801(2013)]
A_{CP} $B^0 \to K^{*0}\mu^+\mu^-$	1	[PRL110,031801(2013)]
Angular $B^+ \to K^+\mu^+\mu^-$	3	[JHEP05(2014)082],[PRL111,112003(2013)]
Angular $B^0 \to K^0\mu^+\mu^-$	3	[JHEP05(2014)082]
Angular $B^0 \to K^{*0}\mu^+\mu^-$	1	[JHEP08(2013)131],[PRL111,191801(2013)]
Angular $B_s^0 \to \phi\mu^+\mu^-$	1	[JHEP07(2013)084]

Branching fraction measurements

$d\mathcal{B}/dq^2$ of $B \to K\mu^+\mu^-$ [1403.8044]

Left: $B^+ \to K^+$, Right: $B^0 \to K^0$

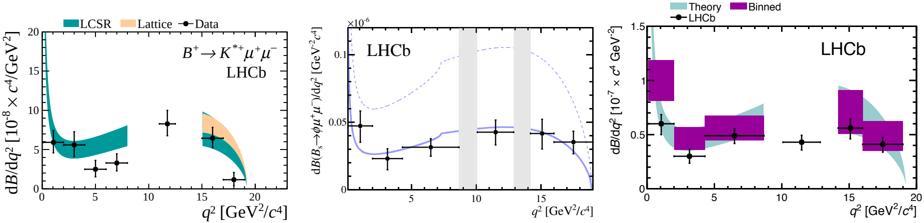


- Reconstruct K^0 as $K_s \to \pi^+\pi^-$ and $K^{*+} \to K_s\pi^+$
- Large lifetime of K_s means reduction in reconstruction efficiency
- Normalise to corresponding $B \to J/\psi K$ mode
- $d\mathcal{B}/dq^2$ for $K^+\mu^+\mu^-$ is becoming systematic dominated
- Dominant systematic is value of $\mathcal{B}(B \to J/\psi K^{(*)})$

Theory: Khodjamirian et al. [JHEP09(2010)089], Buchard et al. [PRL111(2013)162002]

$d\mathcal{B}/dq^2$ of $B^0_{d(s)} \to K^*(\phi)\mu^+\mu^-$

Left: $B^+ \to K^{*+}$, Middle $B_s \to \phi$, Right: $B^0 \to K^{*0}$,

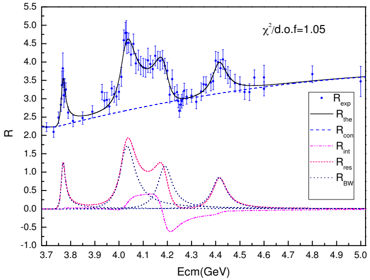


- Reconstruct $K^{*+} \to K_s\pi^+$
- Normalise to corresponding $B \to J/\psi K(\phi)$ mode
- Hint that all BFs are at low side? (theory uncertainties correlated with q^2)

Theory: Horgan et al. [PRL111(2013)162002], Bobeth et al. [JHEP07(2011)067], Altmannshofer et al. [JHEP01(2009)019], Ball et al. [PRD71(2005)014029]

$d\mathcal{B}/dq^2$ at low recoil of $B^+ \to K^+\mu^+\mu^-$

$$R(q^2) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

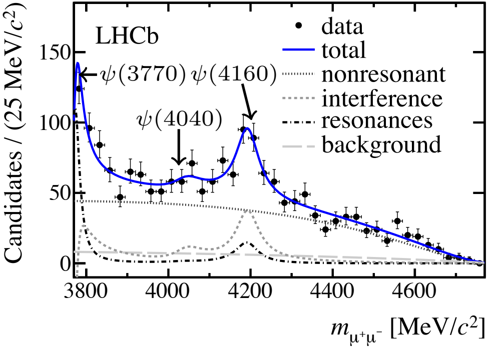


Resonance	Mass [MeV/c^2]	Width [MeV]
$\psi(3770)$	3773.2 ± 0.3	27.2 ± 1.0
$\psi(4040)$	4039.6 ± 4.3	84.5 ± 12.3
$\psi(4160)$	4191.7 ± 6.5	71.8 ± 12.3
$\psi(4415)$	4415.1 ± 7.9	71.5 ± 19.0

- Charmonium resonances 1^{--} above open charm (DD) threshold from BES
- Fits account for interference between states
- Watch out. PDG information is misleading!

$d\mathcal{B}/dq^2$ at low recoil of $B^+ \to K^+\mu^+\mu^-$ [PRL 111, 112003 (2013)]

Resonant structures clear in $3\,\mathrm{fb}^{-1}$ at low recoil



- Difficult to quantify resonances theoretically
- Predict rates and observables integrated across resonances
- Sensitive due to interference with large non-resonant component!
- Assume resonances are 1^{--} $\to$ only V non-resonant interferes, universal lepton couplings
- Take SM value for $|A^V_{nr}|^2/(|A^V_{nr}|^2 + |A^A_{nr}|^2) = (45 \pm 6)\%$
  e.g Bobeth et al. [JHEP 01 (2012)107]
- $\mathcal{B}(B^+ \to K^+\psi_{4160}(\mu^+\mu^-)) = 3.9^{+0.7}_{-0.6} \times 10^{-9}$!

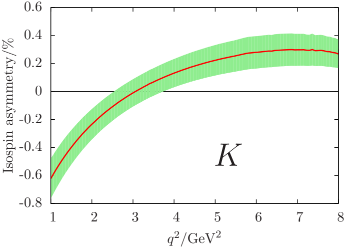
  - Presence of resonances has implications on bin choice and interpretation of measurements in this region for all such decays

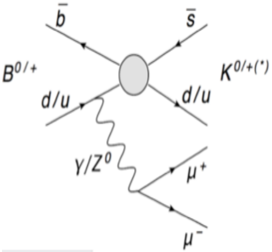
Asymmetry measurements

Isospin asymmetry measurements

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

J. Lyon, R. Zwicky [1305.4797]

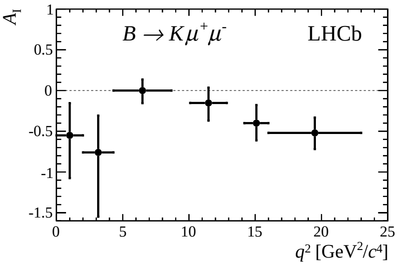


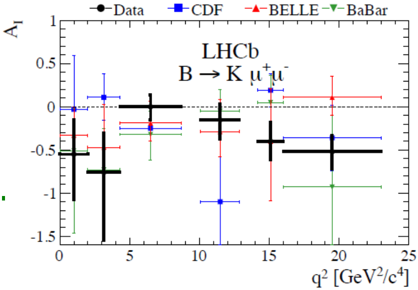


- More precise prediction than $\mathcal{B}$
- In SM expected due to:
  - Photon coupling to u and d
  - C_{uubs} at tree level but C_{ddbs} only loop level

Isospin asymmetry measurements [JHEP 07 (2012) 133]

- LHCb's 1 fb^{-1} analysis revealed a significantly negative A_I in $B \to K\mu^+\mu^-$
- Measurements from B-factories also hint at low A_I

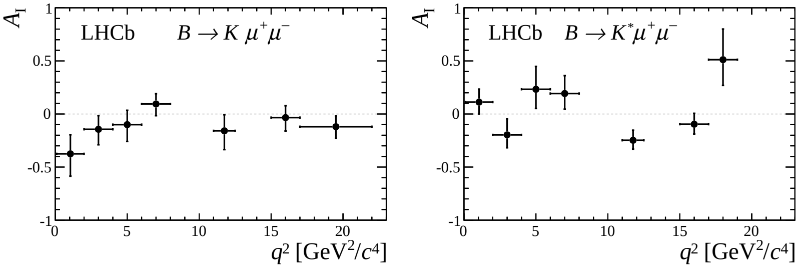




- Significance from SM between 3 and 4 σ (depending on definition of test statistic)
- Very difficult to accomodate in SM or NP models!

Isospin asymmetry measurements

- Updating to full dataset ($3\,\text{fb}^{-1}$)

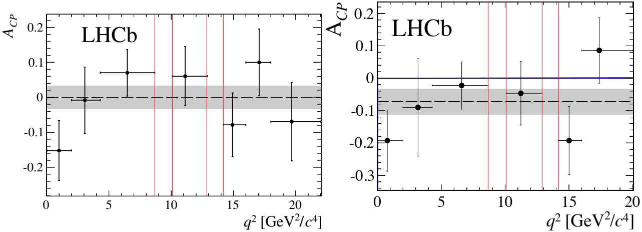


- Assume A_I in $J/\psi K^*$ modes is zero
  - Uncertainties related to $\mathcal{B}$ cancel
- Estimate p-value for difference from zero assuming data have a constant non-zero value of A_I
- Results consistent with SM, p-value of 11% (1.5σ) for $B \to K\mu^+\mu^-$

CP asymmetry measurements

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

Left: $B^+ \to K^+$, Right: $B^0 \to K^{*0}$



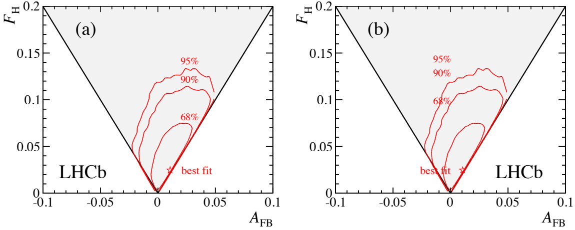
- Expected to be small in SM (10^{-4})
- Sensitive to NP affecting imaginary part of Wilsons
- Extract detector and production asymmetries using $B \to J/\psi K$ relative mode
- Consistent with zero.

Angular analyses

Angular analysis of $B^{+(0)} \to K^{+(0)}_{(s)} \mu^+\mu^-$

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

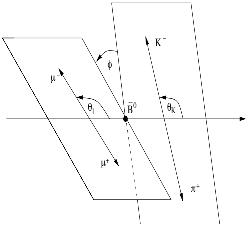
Left: $1.1 < q^2 < 6.0\,\mathrm{GeV}^2$, Right: $15.0 < q^2 < 22.0\,\mathrm{GeV}^2$



- $B \to P\mu^+\mu^-$ means only one angle of interest and two observables
  - F_H: "Flat" parameter sensitive to scalar and tensor contributions
  - A_{FB}: Forward-backward asymmetry of the muons. Deviation from zero would indicate new physics with scalar or tensor couplings (sensitivity to NP vector couplings suppressed by m_ℓ)
- Best fit point and SM lie at boundary of physical region
- Good agreement with SM
- Confidence intervals for 1 GeV q^2 bins available in ascii format

Angular analysis of $B^0_{d,s} V \mu^+\mu^-$

- Vector meson described by 3 helicity amplitudes (excluding S-wave and scalar contributions)
- Eight independent observables per B-flavour (J_is)
- Can choose basis such that reduce dependence on FF's

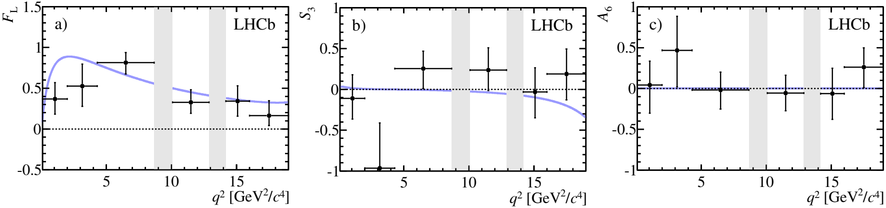


$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\phi} = \frac{9}{32\pi}\Big[J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + (J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K)\cos 2\theta_l$$
$$+J_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + J_4\sin 2\theta_K\sin 2\theta_l\cos\phi + J_5\sin 2\theta_K\sin\theta_l\cos\phi$$
$$+(J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K)\cos\theta_l + J_7\sin 2\theta_K\sin\theta_l\sin\phi + J_8\sin 2\theta_K\sin 2\theta_l\sin\phi$$
$$+J_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big], \qquad (1)$$

- $\mathcal{O}(1K)$ stats for K^{*0} and $\mathcal{O}(200)$ for ϕ means full angular fit not possible
  - Either fit projections or use angle transformations to extract observables from multiple fits
- $B_s \to \phi\mu^+\mu^-$ not self-tagging
  - Sensitive to subset of observables

Results: New observables [PRL 111,191801(2013)]

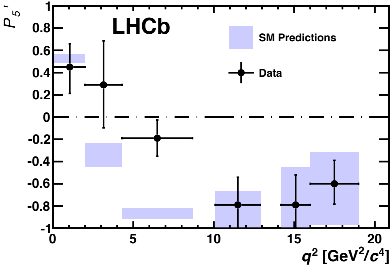
$B_s \to \phi$ Left: F_L, Middle: S_3, Right: A_6



Theory: Altmannshofer et al. [JHEP01(2009)019], Ball et al. [PRD71(2005)014029]

- $S_i = (J_i + \bar{J}_i)/(d\Gamma + d\bar{\Gamma})$
- $A_i = (J_i - \bar{J}_i)/(d\Gamma + d\bar{\Gamma})$
- $P_5' = (J_5 + \bar{J}_5)/\sqrt{F_L(1 - F_L)}$
- 1 fb^{-1} of 2011 data
- 3.7σ local tension in P_5'

Theory: Descote-Genon et al. [JHEP 05(2013)137]

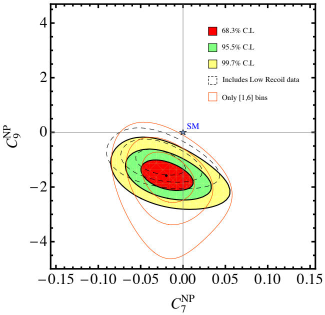


Hint of new physics?

- Combine $B_s \to \mu\mu$, $B \to K^{(*)}\mu\mu$, $B \to X_s\gamma$, $B \to K^*\gamma$ measurements to constrain New Physics
- Indicate significant deviation in di-leptonic vector operator (C_9)

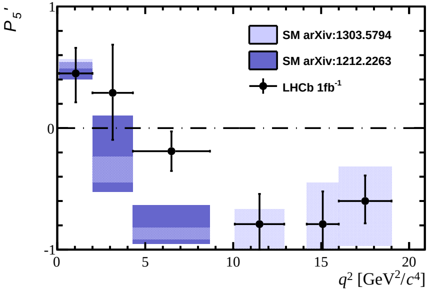
Descote-Genon et al. [arXiv:1307.5683]]

- Numerous theory papers: Descotes-Genon et al [1307.5683], Beaujean et al [1310.2478], Gauld et al [1308.1959], Hurth et al [1312.5267], Straub et al [1308.1501], Horgan et al [1310.3887],Altmannshofer et al [1403.1269], Biancofiore et al [1403.2944]...
- Consistent with Z' of mass:
  $\sim$ 35 TeV for $\mathcal{O}(1)$ couplings (tree)
  $\sim$ 7 TeV for CKM-like couplings (tree)
  Straub et al [1308.1501]
- Demonstrates the power of these searches!
- Difficult to accomodate within MSSM

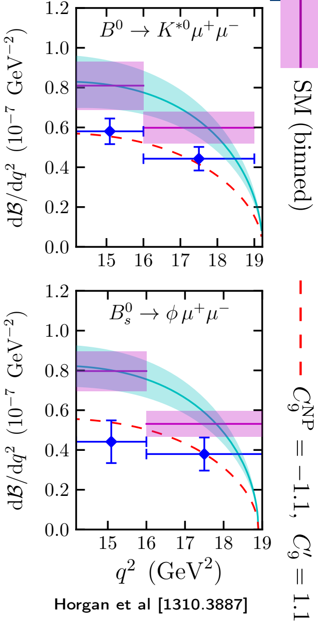


Theory uncertainties

- Unfortunately not that simple...Observables are theoretically clean at leading order



- But! Uncertainties of higher order corrections can potentially dilute the significance
- Lattice QCD predictions can help clarify situation at high q^2 → picture consistent with other interpretations!

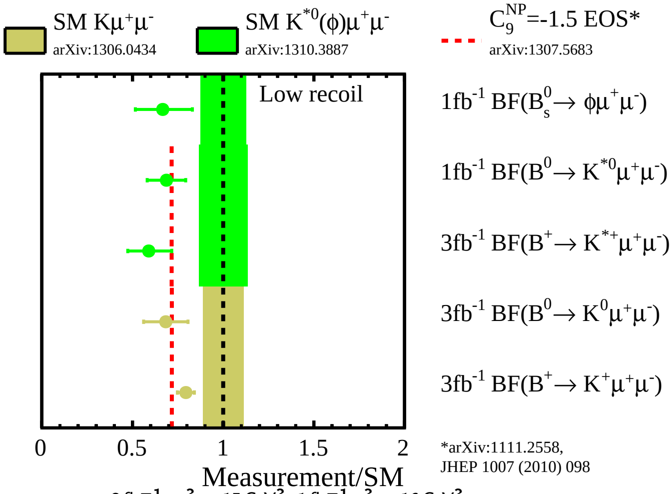


Horgan et al [1310.3887]

A consistent picture emerging?

Branching Fraction measurements at high q^2 in tension with SM predictions from the Lattice, but consistent with best fit point for NP from low q^2 data! $\rightarrow$ NP or unaccounted QCD effects? **Something new to understand!**

$B \rightarrow K$ prediction, $O_{1..6}$, O_8 @ 1-loop. 2-loop moves $\mathcal{B}$ closer to experiment



3 fb^{-1}: $q^2 > 15$ GeV^2, 1 fb^{-1}: $q^2 > 16$ GeV^2

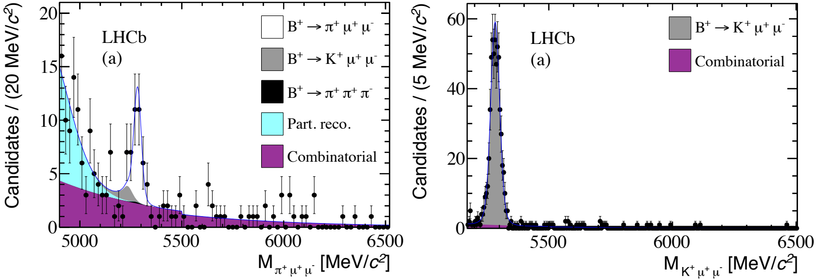
A consistent picture emerging?

Branching Fraction measurements at high q^2 in tension with SM predictions from the Lattice, but consistent with best fit point for NP from low q^2 data! $\rightarrow$ NP or unaccounted QCD effects? **Something new to understand!**

- Perform measurements in related channels (e.g $b \rightarrow d\mu^+\mu^-$ reveal information on MFV nature of NP)
- The data can help us understand QCD effects (e.g $c\bar{c}$ contributions)
  - Fit entire q^2 spetrum of $B \rightarrow K^*\ell\ell$ including light and charm resonances
  - Test extent of applicability of OPE and factorisation
- Measurements quantities with prestine theory predictions
  - Inclusive $B \rightarrow X_{s,d}\ell^+\ell^-$ c.f Belle [1402.7134], BaBar [1312.5364]

An example: $B^+ \to \pi^+\mu^+\mu^-$

- First observation, $B_F = 2.3 \pm 0.6(stat.) \pm 0.1(syst.) \times 10^{-8}$
- Can measure $R = \frac{B_F(B^+ \to \pi^+\mu^+\mu^-)}{B_F(B^+ \to K^+\mu^+\mu^-)}$ and tranlsate into $|V_{td}|/|V_{ts}|$ measurement from penguin decays



- $R = 0.053 \pm 0.014(stat.) \pm 0.001(syst.)$
- $|V_{td}|/|V_{ts}| = 0.266 \pm 0.035(stat.) \pm 0.007(syst.)$
- Neglecting FF uncertainties
- Compatible with previous measurements in $b \to s(d)\gamma$ (0.177 ± 0.043) [PRL102,161803(2009)]

So what is next

Full exploitation of available data:

- Update of $B^0 \to K^{*0}\mu^+\mu^-$ measurements with $3\,\text{fb}^{-1}$ in preparation (including S-wave extraction)
- New and updates of all analyses to $3\,\text{fb}^{-1}$: $B_s \to \phi\mu^+\mu^-$, $B^+ \to \pi^+\mu^+\mu^-$, $B_{s,d} \to \pi\pi\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$, $\Lambda_b \to pK\mu^+\mu^-$, $B \to K^{*0}e^+e^-$, $B_d \to 3h\mu^+\mu^-$

RunII data means $\sim 5\,\text{fb}^{-1}$ expected to be collected

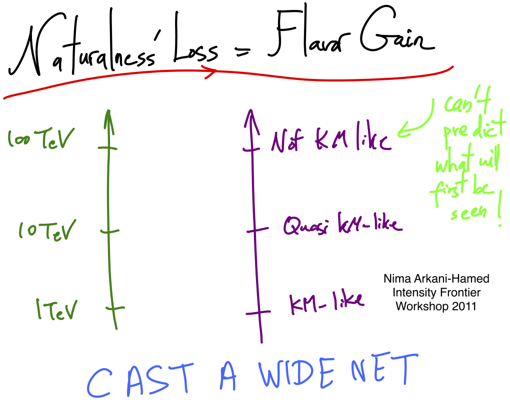
- Large datasets open up precision era in $B \to d$ transitions and measurements of $|V_{td}/V_{ts}|$ (requires precise FF calculations for $b \to d\ell\ell$)
- Look at higher J K^* states (e.g increase sensitivity to tensor NP)
- Look for final states with τ's $B \to K^{*0}\tau^+\tau^-$
- Perform fully inclusive measurements

Post 2020 data means experiment catches and surpases current theory precision

Backup

Flavour measurements are critical

- NP at $\Lambda_{NP} \sim 1\,\mathrm{TeV}$ motivated to tame fine tuning in Higgs sector
- NP at $\Lambda_{NP} \sim 1\,\mathrm{TeV}$ refuted by flavour measurements (pre LHC) $\rightarrow$CKM-like NP couplings (MFV)
- As LHC pushes Λ_{NP} to $>> 1\,\mathrm{TeV}$ lift MFV constraints
  - ▷ increase chances to see NP in flavour

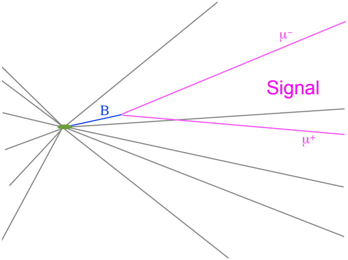


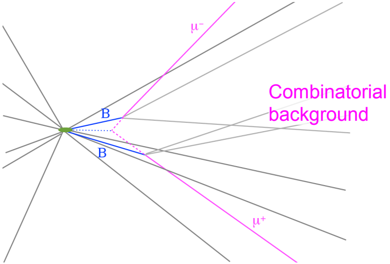
Nima Arkani-Hamed
Intensity Frontier
Workshop 2011

Experimental aspects

Selection:

- Reduce combinatorial background using Multivariate classifiers, (typically Boosted Decision Tree)
  - Using kinematic and topological information
  - Variable choice based on minimising correlation with mass
- Reduce "peaking" backgrounds using particle-ID information
  - Exclusive decays with final state hadron(s) mis-Id
  - Estimate by mixture of MC and data-driven studies





Experimental aspects

Normalisation:

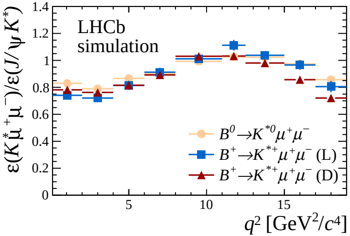
- Make use of proxy-decay (same topology) of known $\mathcal{B}$ to normalize against

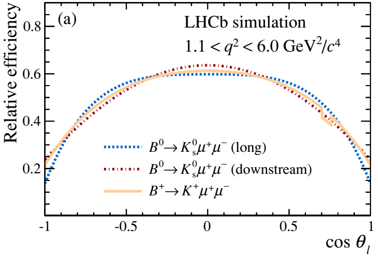
$$\mathcal{B}(sig) = \frac{N_{sig}\epsilon_{sig}}{N_{prx}\epsilon_{prx}}\mathcal{B}(prx)$$

  - Reduces experimental uncertainties

Acceptance correction:

- Efficiency parametrised depending on type of measurement of $\mathcal{B}$
  - Differential with respect to di-muon mass squared (q^2) or angular distribution of decay products of the b-Hadron
- Efficiency (ϵ) obtained from MC corrected from data



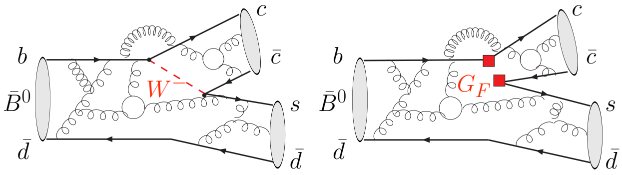


Theoretical Formalism

- Model independent approach
- "Integrate" out heavy ($m \geq m_W$) field(s) and introduce set of Wilson coefficients C_i, and operators $\mathcal{O}_i$ encoding long and short distance effects

$$\mathcal{H}_{eff} \approx -\frac{4G_F}{\sqrt{2}} V_{tb} V^*_{ts(d)} \sum_{i=1}^{10,S,P,T} (C_i^{SM} + \Delta C_i^{NP}) \mathcal{O}_i$$

- c.f. Fermi interaction and G_F



- New physics enters at the Λ_{NP} scale

Experimental concerns

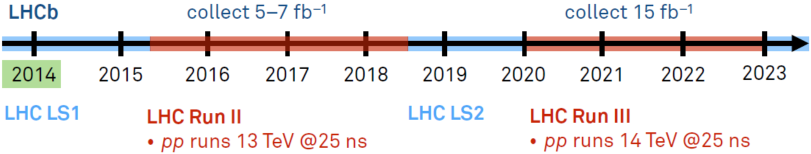
$\sim$1K reconstructed/selected $B^0 \to K^{*0}\mu^+\mu^-$ candidates in $1\,\mathrm{fb}^{-1}$ (more than all B-factory experiments combined!), not enough to perform full angular fit in infinitesimally small bins of q^2

- Notice that can simplify angular distribution by "folding" angles
  - e.g $\phi \to \phi + \pi$ for $\phi < 0$, removes $\cos\phi$ and $\sin\phi$ terms
- Different foldings can give access to different observables

$$
\begin{aligned}
\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\,\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\hat{\phi}} = \frac{9}{16\pi}\Big[& F_\mathrm{L}\cos^2\theta_K + \frac{3}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K) \; - \\
& F_\mathrm{L}\cos^2\theta_K(2\cos^2\theta_\ell - 1) \; + \\
& \frac{1}{4}(1-F_\mathrm{L})(1-\cos^2\theta_K)(2\cos^2\theta_\ell - 1) \; - \\
& S_3(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\cos 2\hat{\phi} \; + \\
& \frac{4}{3}A_\mathrm{FB}(1-\cos^2\theta_K)\cos\theta_\ell \; + \\
& A_9(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\hat{\phi} \; \Big]
\end{aligned}
$$

- Perform fit in bins of q^2.
- Bias from not accounting for S-wave in $K\pi$ negligible with these stats. Needs to be dealt with with $3\,\mathrm{fb}^{-1}$ Egede et al. [JHEP 03(2013)027]

LHCb upgrade



- Current conditions: L_{inst} up to $4 \times 10^{32} cm^{-2} s^{-1}$, $\mu \sim 1.7$
- 2020 conditions: $L_{inst} = 2 \times 10^{33} cm^{-2} s^{-1}$, $\mu \sim 5$

Higher luminosities:

- More interactions per crossing, more vertices, higher track multiplicities, more ghost tracks...
- Current trigger design has bottleneck at 1 MHz of L0
- More flexible trigger, reading out full detector at 40 MHz and HLT output at 20 kHz
- Upgrade VELO and tracking
- New photo detectors for RICH1,2 and re-optimise optics of RICH1

[LHCb-TDR-013], [LHCb-TDR-014], [LHCb-TDR-015]

LHCb upgrade

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\ \phi$)	0.10 [9]	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\ f_0(980)$)	0.17 [10]	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3} [18]	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17 [18]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08 [14]	0.025	0.008	0.02
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 % [14]	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25 [15]	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 % [16]	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9} [2]	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–$12°$ [19, 20]	4°	0.9°	negligible
	γ ($B_s^0 \to D_s K$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\ K_S^0$)	0.8° [18]	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	2.3×10^{-3} [18]	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3} [5]	0.65×10^{-3}	0.12×10^{-3}	–