B(eautiful) Physics II

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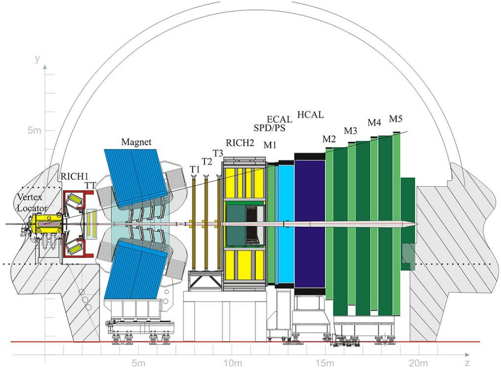
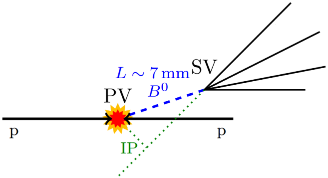
Kern- und Teilchenphysik II,
12 May, 2017

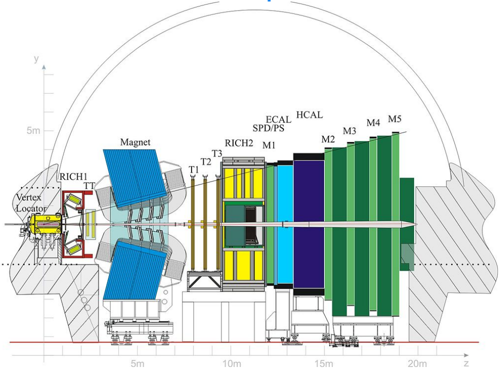
LHCb detector - tracking

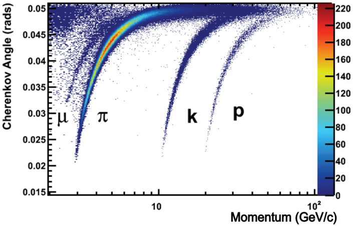




- Excellent Impact Parameter (IP) resolution ($20\ \mu$m).
  $\Rightarrow$ Identify secondary vertices from heavy flavour decays
- Proper time resolution $\sim\ 40$ fs.
  $\Rightarrow$ Good separation of primary and secondary vertices.
- Excellent momentum ($\delta p/p \sim 0.4 - 0.6\%$) and inv. mass resolution.
  $\Rightarrow$ Low combinatorial background.

LHCb detector - particle identification

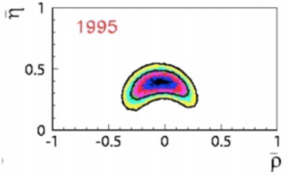




- Excellent Muon identification $\epsilon_{\mu\to\mu} \sim 97\%$, $\epsilon_{\pi\to\mu} \sim 1-3\%$
- Good $K-\pi$ separation via RICH detectors, $\epsilon_{K\to K} \sim 95\%$, $\epsilon_{\pi\to K} \sim 5\%$.
  $\Rightarrow$ Reject peaking backgrounds.
- High trigger efficiencies, low momentum thresholds. Muons: $p_T > 1.76\mathrm{GeV}$ at L0, $p_T > 1.0\mathrm{GeV}$ at HLT1, $B \to J/\psi X$: Trigger $\sim 90\%$.

Legacy of B-factories

Before the B factories



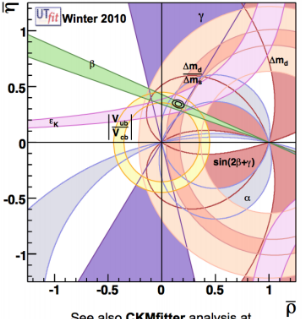
The CKM mechanism is confirmed

Nicola Cabibbo

Kobayashi and Maskawa awarded half of 2008 N.P.

Constraints on the Unitarity Triangle see http://www.utfit.org/

...and after the B factories



See also **CKMfitter** analysis at http://ckmfitter.in2p3.fr/

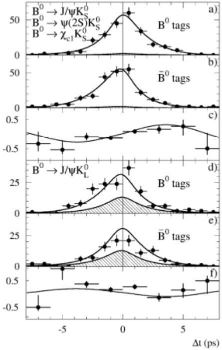
7

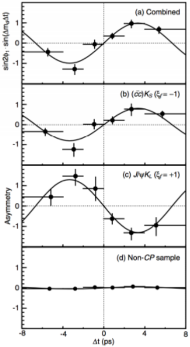
CP violation in B^0 system from B factories

- sin2β measurement from time-dependent analysis of B^0 mesons

$$A(t) \equiv \frac{\Gamma(\overline{B}^0 \to f_{CP}) - \Gamma(B^0 \to f_{CP})}{\Gamma(\overline{B}^0 \to f_{CP}) + \Gamma(B^0 \to f_{CP})} = -\eta_f \sin 2\beta \sin(\Delta m_{B^0} \Delta t)$$

$$f_{CP} = J/\psi K_S^0 \to \eta_{CP} = -1$$
$$J/\psi K_L^0 \to \eta_{CP} = +1$$



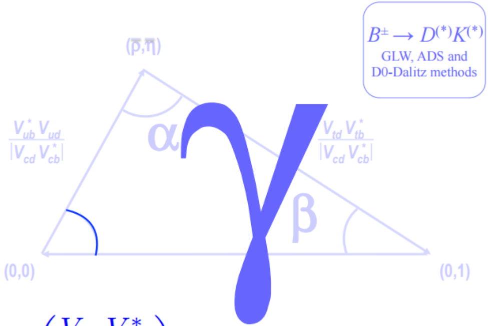


$\sin 2\beta = 0.59 \pm 0.14 \pm 0.05$

Phys.Rev.Lett. 87 (2001) 091801

$\sin 2\beta = 0.99 \pm 0.14 \pm 0.06$

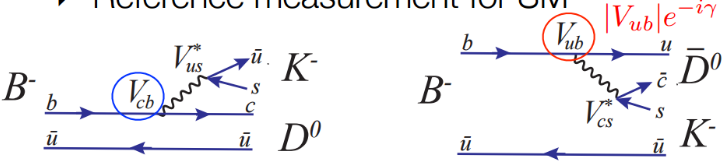
Phys.Rev.Lett. 87 (2001) 091802



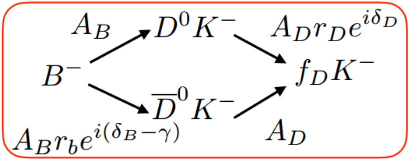
$$\gamma = -\arg\left(\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

γ from $B \to DK$

- Extracted from tree-level decays
- Reference measurement for SM



- Exploit interference between amplitudes, e.g.



$f_D = \pi^+\pi^-, K^+K^-$	GLW
$K^+\pi^-$	ADS
$K_S^0\pi^+\pi^-$	GGSZ

GLW: Gronau, London, Wyler PLB 253 (1991) 483, PLB 265 (1991) 172
ADS: Atwood, Dunietz, Soni PRL 78 (1997) 3257
GGSZ: Giri, Grossman, Soffer, Zupan PRD68 (2003) 054018

γ from $B \rightarrow DK$

ADS favoured modes

29,470 ± 230

$B^{\pm} \rightarrow (K^{\pm}\pi)_D K^{\pm}$ events

ADS suppressed modes

553 ± 34 $B^{\pm} \rightarrow (\pi^{\pm}K)_D K^{\pm}$

CP violation at 8σ

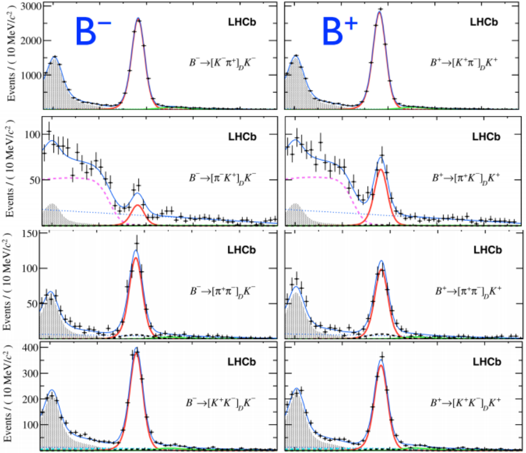
GLW modes

1,162 ± 48 $B^{\pm} \rightarrow (\pi^{+}\pi^{-})_D K^{\pm}$

3,816 ± 92 $B^{\pm} \rightarrow (K^{+}K^{-})_D K^{\pm}$

CP violation at 5σ (combined)

LHCb, PLB 760, 117 (2016)

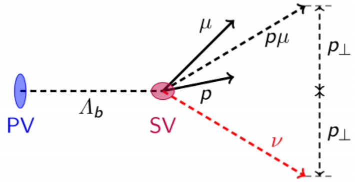


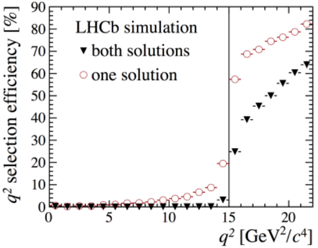
$|V_{ub}|$ from Λ_b

- Normalise yields to $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$, V_{cb} mediated decay, cancel many systematic uncertainties
- Apply tight vertex cut, PID on proton and muon, track isolation to reject 90% of background (using boosted decision tree)
- Use corrected mass to reconstruct the signal and retain events with $\sigma(M_{\rm corr}) < 100{\rm MeV}$

$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$

- Use Λ_b^0 flight direction and mass to determine q^2 with two-fold ambiguity (neutrino). Require both solutions >15 GeV^2, minimise migration to low q^2 bins





$|V_{ub}|$ from Λ_b

- Normalise yields to $\Lambda_b^0 \to \Lambda_c^+ \mu^- \bar{\nu}_\mu$, Vcb mediated decay, cancel many systematic uncertainties
- Apply tight vertex cut, PID on proton and muon, track isolation to reject 90% of background (using boosted decision tree)
- Use corrected mass to reconstruct the signal and retain events with $\sigma(M_{\text{corr}}) < 100\text{MeV}$

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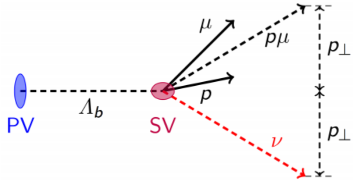
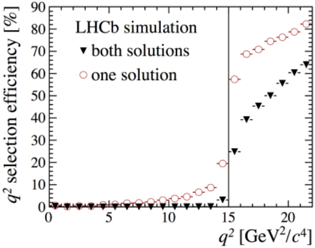




$|V_{ub}|$ from Λ_b

- Measure:

$$|V_{ub}|^2 = |V_{cb}|^2 \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu)_{q^2>15\text{GeV}^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\bar{\nu}_\mu)_{q^2>7\text{GeV}^2}} R_{FF}$$

world average	measured	LQCD [1]
$(39.5 \pm 0.8) \times 10^{-3}$	$(1.00 \pm 0.04 \pm 0.08) \times 10^{-2}$	0.68 ± 0.07

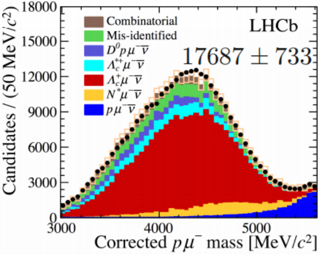
[1] W. Detmold, C. Lehner, and S. Meinel, arXiv:1503.01421

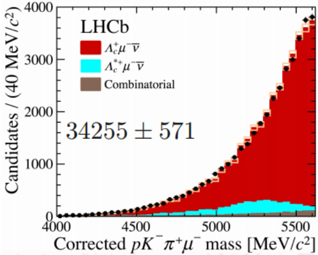
Most precise measurement

$$|V_{ub}| = (3.27 \pm 0.15 \pm 0.17 \pm 0.06) \times 10^{-3}$$

exp. LQCD $|V_{cb}|$

- Background contributions estimated using ad hoc control samples
- Largest exp. uncertainty from $\mathcal{B}(\Lambda_c^+ \to pK^+\pi^-)$

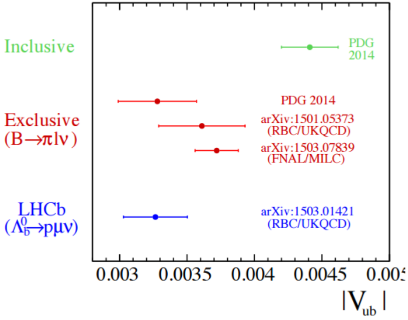


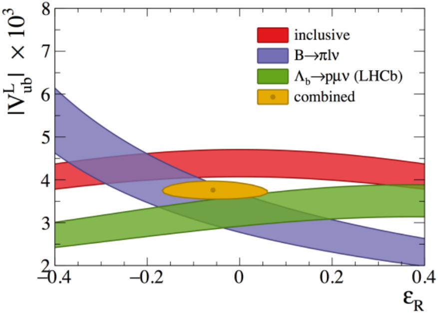


$|V_{ub}|$ Puzzle

3.5σ tension between exclusive and inclusive measurements

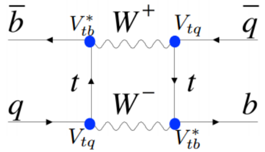
LHCb measurement does not support explanation based on right handed current added to SM





Δm_s and Δm_d

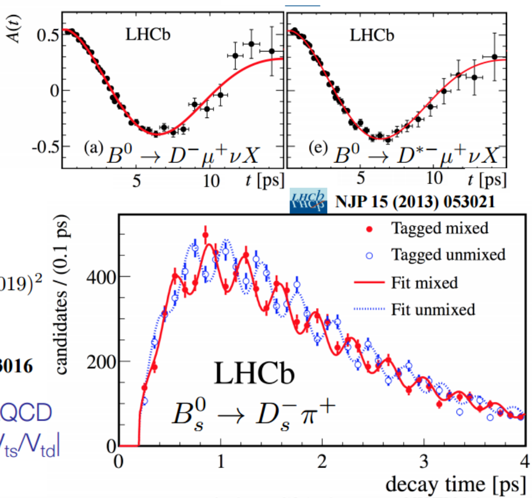
- Flavour oscillations via box diagram



$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s}}{m_{B_d}} \left| \frac{V_{ts}}{V_{td}} \right|^2 (1.206 \pm 0.019)^2$$

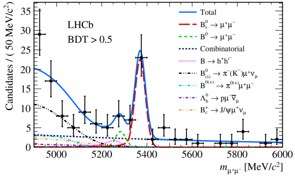
MILC, PRD 93 (2016) 113016

Theory uncertainty from LQCD dominates extraction of $|V_{ts}/V_{td}|$



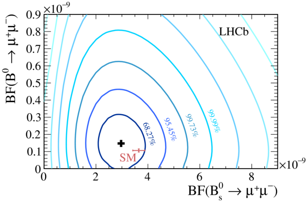
$B_{s/d} \longrightarrow \mu\mu$

$\Rrightarrow$ Golden channel for LHCb.
$\Rrightarrow$ Normalized to the $B \longrightarrow K\pi$ and $B \longrightarrow KJ/\psi$.
$\Rrightarrow$ The selection is achived by BDT trained on MC and calibrated on data.

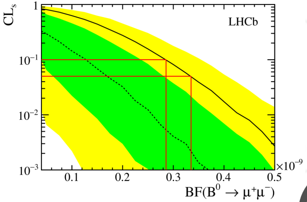


$\Rrightarrow$ $\mathrm{Br}(B^0_s \longrightarrow \mu\mu) = (3.0 \pm 0.6^{+0.3}_{-0.2})10^{-9}$

7.8 σ significant!



$\Rrightarrow$ $\mathrm{Br}(B^0_d \longrightarrow \mu\mu) < 3.4 \times 10^{-10}$, 90%CL



Effective lifetime

$\Rrightarrow$ Sensitivity to non-scalar NP.
$\Rrightarrow$ $\tau(B^0_s \longrightarrow \mu\mu) = 2.04 \pm 0.44 \pm 0.05\mathrm{ps}$

$B_{s/d} \to \mu\mu$

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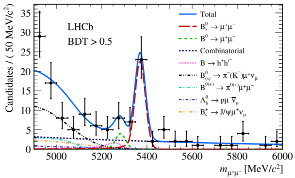
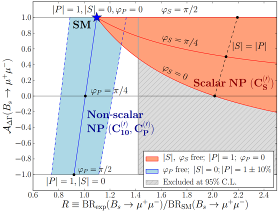
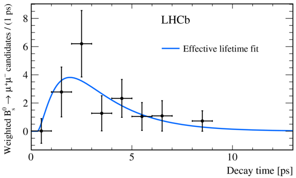
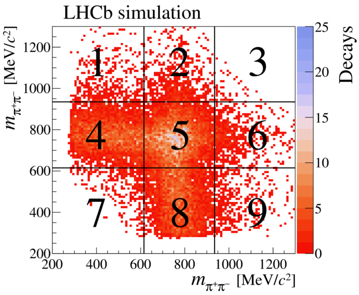


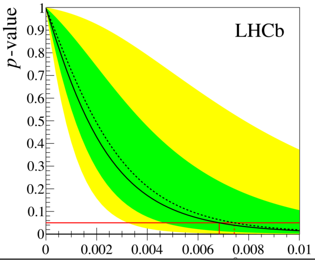


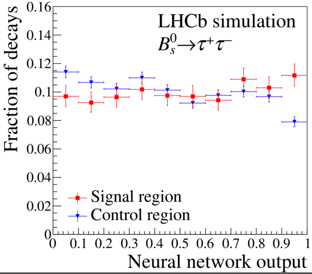


$B_{s/d} \to \tau\tau$

⇛ NP sensitivity enhanced due to the high τ mass.
⇛ More challenging: at least 2ν are escaping.
⇛ Selecting $\tau \to 3\pi\nu$, $\to$ $9.31\ \%$
⇛ Normalization channel: $B \to D(K\pi\pi)D_s(KK\pi)$.
⇛ No peak in the B mass window $\to$ fit the NN output.

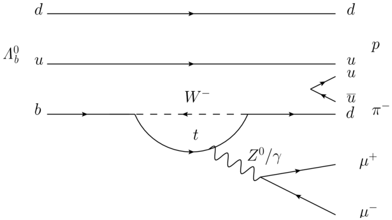






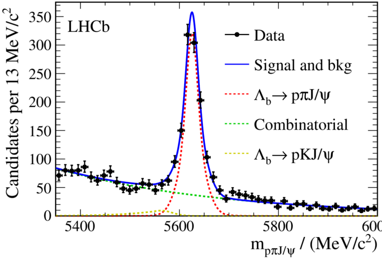
$\Lambda_b \to p\pi\mu\mu$

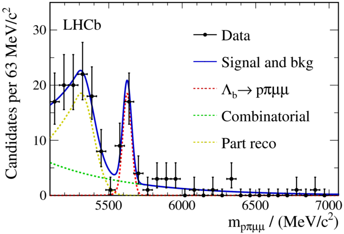
$\Rightarrow$ First observation of $b \to d$ in baryon system!
$\Rightarrow$ BDT selection trained on MC
$\Rightarrow$ Normalized to $\Lambda_b \to p\pi J/\psi$
$\Rightarrow$ With futher QCD improvements we will be able to to measure $\frac{|V_{ts}|}{|V_{td}|}$.



$\Rightarrow$ $\frac{\mathrm{Br}(\Lambda_b \to p\pi\mu\mu)}{\mathrm{Br}(\Lambda_b \to p\pi J/\psi)} = 0.044 \pm 0.012 \pm 0.007$

$\Rightarrow$ 5.5 σ significance! $\Rightarrow$ First observation.

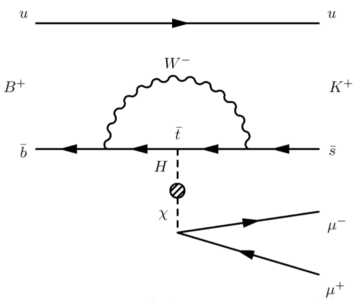


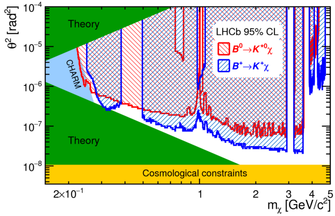


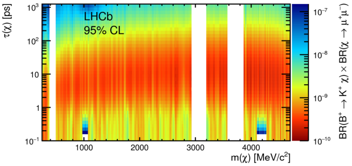
$\mathrm{Br}(\Lambda_b \to p\pi\mu\mu) =$
$(6.9 \pm 1.9 \pm 1.1^{+1.3}_{-1.0}) \times 10^{-8}$

Search for light scalars

⇛ Hidden sector models are gathering more and more attention.
⇛ Inflaton model: new scalar then mixes with the Higgs.
⇛ B decays are sensitive as the inflaton might be light.
⇛ Searched for long living particle χ produced in: $B \to \chi(\mu\mu)K$.
⇛ Analysis performed blindly as a peak search.
⇛ Light inflaton essentially ruled out:







$K_S^0 \to \mu\mu$

⇛ pp collisions create enormous amount of strange mesons.

⇛ Can be used to search for $K_S^0 \to \mu\mu$.

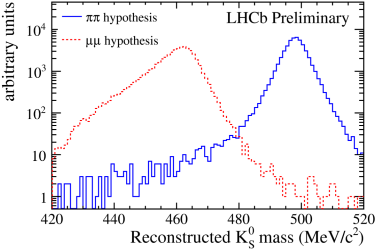
⇛ SM prediction:

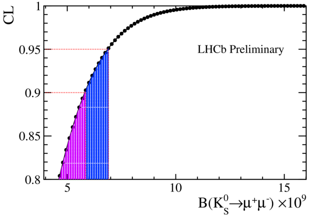
$\mathrm{Br}(K_S^0 \to \mu\mu) = (5.0 \pm 1.5) \times 10^{-12}$

⇛ Dominated by the long distance effects.

⇛ We used two types of triggers: TIS and TOS.

⇛ Bkg dominated by $K_S^0 \to \pi\pi$.





⇛ No significant enhanced of signal has been observed and UL was set:

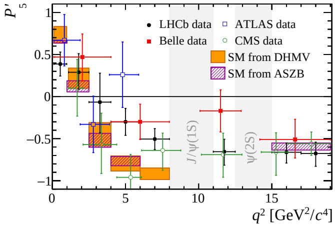
$\mathrm{Br}(K_S^0 \to \mu\mu) <$
$6.9(5.8) \times 10^{-9}$ at $95(90)\%$
CL

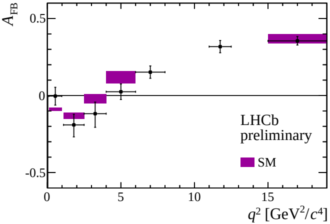
$B^0 \to K^* \mu^- \mu^+$ decay

$\Rrightarrow$ $B^0 \to K^* \mu^- \mu^+$ is a smoking gun for NP hunting!
$\Rrightarrow$ Reach angular observables makes is sensitive to different NP models
$\Rrightarrow$ In addition one can construct less form factor dependent observables:

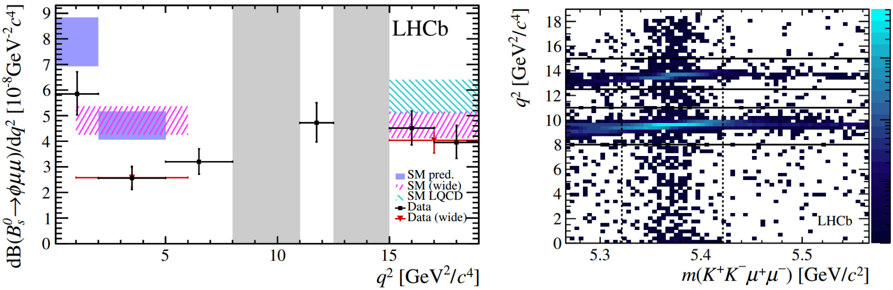
$$P_5' = \frac{S_5}{\sqrt{F_L(1-F_L)}}$$

$\Rrightarrow$ In single analysis observed $3.4\ \sigma$ discrepancy in the C_9 WC.





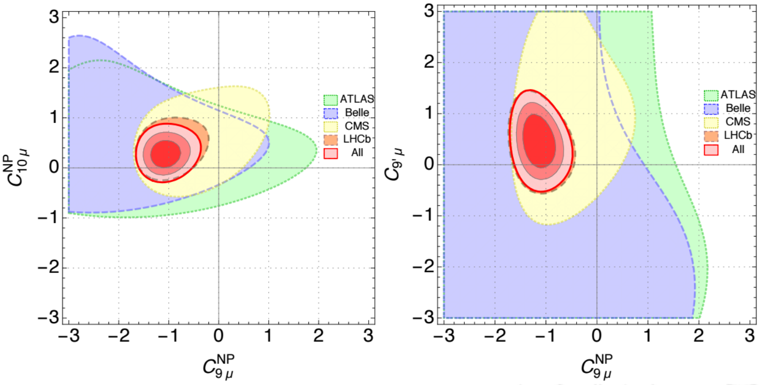
Branching fraction measurements of $B_s^0 \to \phi\mu\mu$



- Recent LHCb measurement, JHEP09 (2015) 179.
- Suppressed by $\frac{f_s}{f_d}$.
- Cleaner because of narrow ϕ resonance.
- $3.3\ \sigma$ deviation in SM in the $1 - 6\mathrm{GeV}^2$ bin.
- Angular part in agreement with SM (S_5 is not accessible).

Theory implications of $b \to s\ell\ell$

- A fit prepared by `S. Descotes-Genon, L. Hofer, J. Matias, J. Virto.`
- The data can be explained by modifying the C_9 Wilson coefficient.
- Overall there is $> 4\,\sigma$ discrepancy wrt. the SM prediction.



Summary

⇛ LHCb is the new B-factory.
⇛ A lot of consistent anomalies have been observed!
⇛ Until Belle2 starts to produce results LHCb will dominate the heavy flavour physics.

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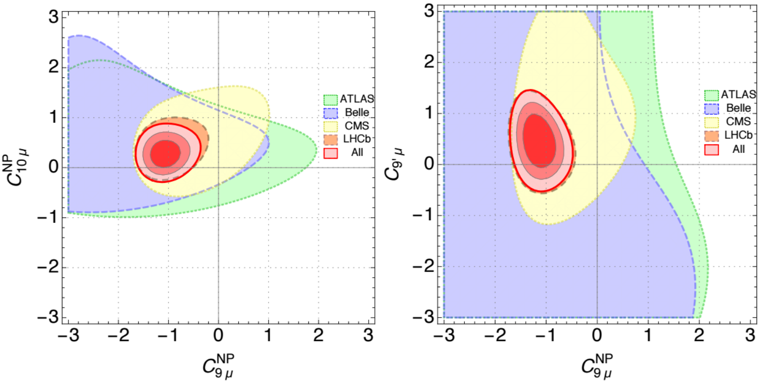


Reminder

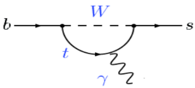
- **Operator Product Expansion and Effective Field Theory**

$$H_{eff} = -\frac{4G_f}{\sqrt{2}} V V'^{*} \sum_i \left[\underbrace{C_i(\mu) O_i(\mu)}_{\text{left-handed}} + \underbrace{C'_i(\mu) O'_i(\mu)}_{\text{right-handed}} \right],$$

i=1,2	Tree
i=3-6,8	Gluon penguin
i=7	Photon penguin
i=9.10	EW penguin
i=S	Scalar penguin
i=P	Pseudoscalar penguin

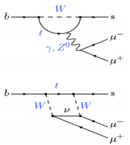
where C_i are the Wilson coefficients and O_i are the corresponding effective operators.

$b \to s\gamma$



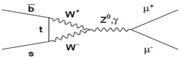
$C_7^{(\prime)}$

$b \to s\ell^+\ell^-$



$C_7^{(\prime)}, C_9^{(\prime)}, C_{10}^{(\prime)}$

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

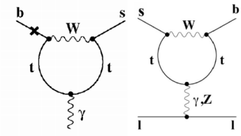


$C_S^{(\prime)}, C_P^{(\prime)}, C_{10}^{(\prime)}$

Analysis of Rare decays

Analysis of FCNC in a model-independent approach, effective Hamiltonian:

$$b \to s\gamma(^*) : \mathcal{H}^{SM}_{\Delta F=1} \propto \sum_{i=1}^{10} V^*_{ts} V_{tb} \mathcal{C}_i \mathcal{O}_i + \ldots$$



- $\mathcal{O}_7 = \frac{e}{16\pi^2} m_b \, (\bar{s}\sigma^{\mu\nu} P_R b) F_{\mu\nu}$
- $\mathcal{O}_9 = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b) \; (\bar{\ell}\gamma_\mu \ell)$
- $\mathcal{O}_{10} = \frac{e^2}{16\pi^2} (\bar{s}\gamma_\mu P_L b) \; (\bar{\ell}\gamma_\mu \gamma_5 \ell)$, ...

• **SM** Wilson coefficients up to NNLO + e.m. corrections at $\mu_{ref} = 4.8$ GeV [Misiak et al.]:

$$\mathcal{C}_7^{\rm SM} = -0.29, \; \mathcal{C}_9^{\rm SM} = 4.1, \; \mathcal{C}_{10}^{\rm SM} = -4.3$$

• **NP** changes short distance $\mathcal{C}_i - \mathcal{C}_i^{\rm SM} = \mathcal{C}_i^{\rm NP}$ and induce new operators, like

$\mathcal{O}'_{7,9,10} = \mathcal{O}_{7,9,10} \; (P_L \leftrightarrow P_R)$ ... also scalars, pseudoescalar, tensor operators...

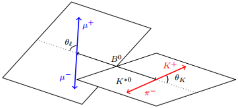
$B^0 \to K^* \mu^- \mu^+$ kinematics

⇛ The kinematics of $B^0 \to K^* \mu^- \mu^+$ decay is described by three angles θ_l, θ_k, ϕ and invariant mass of the dimuon system (q^2).

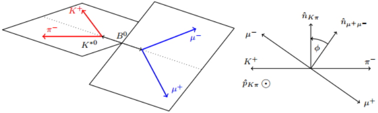
⇛ $\cos\theta_k$: the angle between the direction of the kaon in the K^* ($\overline{K^*}$) rest frame and the direction of the K^* ($\overline{K^*}$) in the B^0 ($\bar{B}^0$) rest frame.

⇛ $\cos\theta_l$: the angle between the direction of the μ^- (μ^+) in the dimuon rest frame and the direction of the dimuon in the B^0 ($\bar{B}^0$) rest frame.

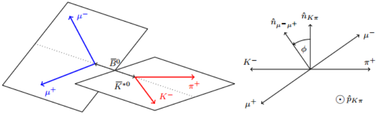
⇛ ϕ: the angle between the plane containing the μ^- and μ^+ and the plane containing the kaon and pion from the K^*.



(a) θ_K and θ_ℓ definitions for the B^0 decay



(b) ϕ definition for the B^0 decay



(c) ϕ definition for the $\bar{B}^0$ decay

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

$\Rightarrow$ The kinematics of $B^0 \to K^{*}\mu^-\mu^+$ decay is described by three angles θ_l, θ_k, ϕ and invariant mass of the dimuon system (q^2).

$$\frac{d^4\Gamma}{dq^2\, d\cos\theta_K\, d\cos\theta_l\, d\phi} = \frac{9}{32\pi}\Big[J_{1s}\sin^2\theta_K + J_{1c}\cos^2\theta_K + (J_{2s}\sin^2\theta_K + J_{2c}\cos^2\theta_K)\cos 2\theta_l$$

$$+J_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi + J_4\sin 2\theta_K\sin 2\theta_l\cos\phi + J_5\sin 2\theta_K\sin\theta_l\cos\phi$$

$$+(J_{6s}\sin^2\theta_K + J_{6c}\cos^2\theta_K)\cos\theta_l + J_7\sin 2\theta_K\sin\theta_l\sin\phi + J_8\sin 2\theta_K\sin 2\theta_l\sin\phi$$

$$+J_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big],$$

$\Rightarrow$ This is the most general expression of this kind of decay.

Transversity amplitudes

⇛ One can link the angular observables to transversity amplitudes

$$J_{1s} = \frac{(2+\beta_\ell^2)}{4}\left[|A_\perp^L|^2+|A_\parallel^L|^2+|A_\perp^R|^2+|A_\parallel^R|^2\right]+\frac{4m_\ell^2}{q^2}\mathrm{Re}\left(A_\perp^L A_\perp^{R*}+A_\parallel^L A_\parallel^{R*}\right),$$

$$J_{1c} = |A_0^L|^2+|A_0^R|^2+\frac{4m_\ell^2}{q^2}\left[|A_t|^2+2\mathrm{Re}(A_0^L A_0^{R*})\right]+\beta_\ell^2|A_S|^2,$$

$$J_{2s} = \frac{\beta_\ell^2}{4}\left[|A_\perp^L|^2+|A_\parallel^L|^2+|A_\perp^R|^2+|A_\parallel^R|^2\right], \qquad J_{2c} = -\beta_\ell^2\left[|A_0^L|^2+|A_0^R|^2\right],$$

$$J_3 = \frac{1}{2}\beta_\ell^2\left[|A_\perp^L|^2-|A_\parallel^L|^2+|A_\perp^R|^2-|A_\parallel^R|^2\right], \qquad J_4 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Re}(A_0^L A_\parallel^{L*}+A_0^R A_\parallel^{R*})\right],$$

$$J_5 = \sqrt{2}\beta_\ell\left[\mathrm{Re}(A_0^L A_\perp^{L*}-A_0^R A_\perp^{R*})-\frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}(A_\parallel^L A_S^*+A_\parallel^{R*}A_S)\right],$$

$$J_{6s} = 2\beta_\ell\left[\mathrm{Re}(A_\parallel^L A_\perp^{L*}-A_\parallel^R A_\perp^{R*})\right], \qquad J_{6c} = 4\beta_\ell\frac{m_\ell}{\sqrt{q^2}}\mathrm{Re}(A_0^L A_S^*+A_0^{R*}A_S),$$

$$J_7 = \sqrt{2}\beta_\ell\left[\mathrm{Im}(\mathrm{A}_0^\mathrm{L}\mathrm{A}_\parallel^{\mathrm{L}*}-\mathrm{A}_0^\mathrm{R}\mathrm{A}_\parallel^{\mathrm{R}*})+\frac{\mathrm{m}_\ell}{\sqrt{\mathrm{q}^2}}\mathrm{Im}(\mathrm{A}_\perp^\mathrm{L}\mathrm{A}_\mathrm{S}^*-\mathrm{A}_\perp^{\mathrm{R}*}\mathrm{A}_\mathrm{S}))\right],$$

$$J_8 = \frac{1}{\sqrt{2}}\beta_\ell^2\left[\mathrm{Im}(\mathrm{A}_0^\mathrm{L}\mathrm{A}_\perp^{\mathrm{L}*}+\mathrm{A}_0^\mathrm{R}\mathrm{A}_\perp^{\mathrm{R}*})\right], \qquad J_9 = \beta_\ell^2\left[\mathrm{Im}(\mathrm{A}_\parallel^{\mathrm{L}*}\mathrm{A}_\perp^\mathrm{L}+\mathrm{A}_\parallel^{\mathrm{R}*}\mathrm{A}_\perp^\mathrm{R})\right],$$

Link to effective operators

⇛ So here is where the magic happens. At leading order the amplitudes can be written as:

$$A_{\perp}^{L,R} = \sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{\rm eff} + \mathcal{C}_9^{\rm eff\prime}) \mp (\mathcal{C}_{10} + \mathcal{C}_{10}^{\prime}) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{\rm eff} + \mathcal{C}_7^{\rm eff\prime}) \right] \xi_{\perp}(E_{K^*})$$

$$A_{\parallel}^{L,R} = -\sqrt{2} N m_B (1-\hat{s}) \left[(\mathcal{C}_9^{\rm eff} - \mathcal{C}_9^{\rm eff\prime}) \mp (\mathcal{C}_{10} - \mathcal{C}_{10}^{\prime}) + \frac{2\hat{m}_b}{\hat{s}} (\mathcal{C}_7^{\rm eff} - \mathcal{C}_7^{\rm eff\prime}) \right] \xi_{\perp}(E_{K^*})$$

$$A_{0}^{L,R} = -\frac{N m_B (1-\hat{s})^2}{2\hat{m}_{K^*}\sqrt{\hat{s}}} \left[(\mathcal{C}_9^{\rm eff} - \mathcal{C}_9^{\rm eff\prime}) \mp (\mathcal{C}_{10} - \mathcal{C}_{10}^{\prime}) + 2\hat{m}_b (\mathcal{C}_7^{\rm eff} - \mathcal{C}_7^{\rm eff\prime}) \right] \xi_{\parallel}(E_{K^*}),$$

where $\hat{s} = q^2/m_B^2$, $\hat{m}_i = m_i/m_B$. The $\xi_{\parallel,\perp}$ are the form factors.

⇛ In practice one measures normalized J by branching fractions:

$$S_i/A_i = \frac{J_i \pm \overline{J}_i}{d\Gamma + d\overline{\Gamma}/dq^2}$$

Link to effective operators

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$$A_{\perp}^{L,R} = \sqrt{2}Nm_B(1-\hat{s})\left[(\mathcal{C}_9^{\rm eff}+\mathcal{C}_9^{\rm eff\prime})\mp(\mathcal{C}_{10}+\mathcal{C}_{10}^{\prime})+\frac{2\hat{m}_b}{\hat{s}}(\mathcal{C}_7^{\rm eff}+\mathcal{C}_7^{\rm eff\prime})\right]\xi_{\perp}(E_{K^*})$$

$$A_{\parallel}^{L,R} = -\sqrt{2}Nm_B(1-\hat{s})\left[(\mathcal{C}_9^{\rm eff}-\mathcal{C}_9^{\rm eff\prime})\mp(\mathcal{C}_{10}-\mathcal{C}_{10}^{\prime})+\frac{2\hat{m}_b}{\hat{s}}(\mathcal{C}_7^{\rm eff}-\mathcal{C}_7^{\rm eff\prime})\right]\xi_{\perp}(E_{K^*})$$

$$A_{0}^{L,R} = -\frac{Nm_B(1-\hat{s})^2}{2\hat{m}_{K^*}\sqrt{\hat{s}}}\left[(\mathcal{C}_9^{\rm eff}-\mathcal{C}_9^{\rm eff\prime})\mp(\mathcal{C}_{10}-\mathcal{C}_{10}^{\prime})+2\hat{m}_b(\mathcal{C}_7^{\rm eff}-\mathcal{C}_7^{\rm eff\prime})\right]\xi_{\parallel}(E_{K^*}),$$

where $\hat{s}=q^2/m_B^2$, $\hat{m}_i=m_i/m_B$. The $\xi_{\parallel,\perp}$ are the form factors.

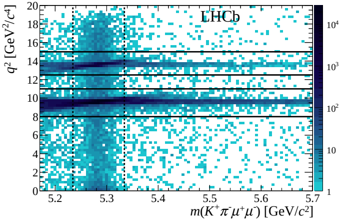
$\Rrightarrow$ Now we can construct observables that cancel the ξ form factors at leading order:

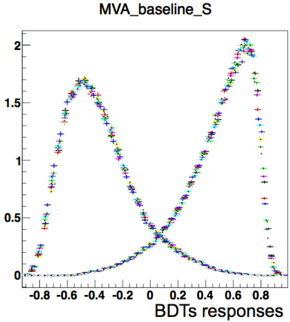
$$P_5^{\prime}=\frac{J_5+\bar{J}_5}{2\sqrt{-(J_2^c+\bar{J}_2^c)(J_2^s+\bar{J}_2^s)}}$$

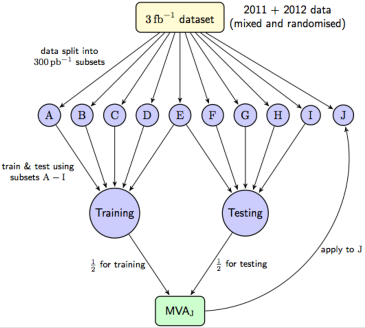
LHCb measurement of $B_d^0 \to K^* \mu\mu$

Multivariate simulation

- PID, kinematics and isolation variables used in a Boosted Decision Tree (BDT) to discriminate signal and background.
- BDT with k-Folding technique.
- Completely data driven.

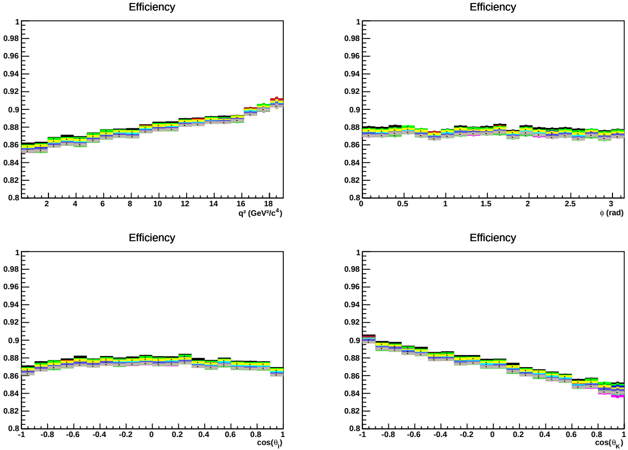






Multivariate simulation, efficiency

⇛ BDT was also checked in order not to bias our angular distribution:



⇛ The BDT has small impact on our angular observables. We will correct for these effects later on.

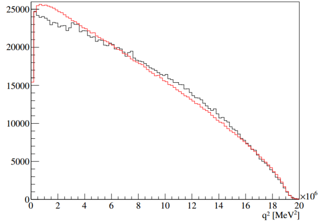
Detector acceptance

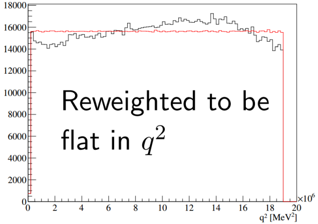
- Detector distorts our angular distribution.
- We need to model this effect.
- 4D function is used:

$$\epsilon(\cos\theta_l, \cos\theta_k, \phi, q^2) =$$
$$\sum_{ijkl} P_i(\cos\theta_l)P_j(\cos\theta_k)P_k(\phi)P_l(q^2),$$

where P_i is the Legendre polynomial of order i.

- We use up to $4^{th}, 5^{th}, 6^{th}, 5^{th}$ order for the $\cos\theta_l, \cos\theta_k, \phi, q^2$.
- The coefficients were determined using Method of Moments, with a huge simulation sample.
- The simulation was done assuming a flat phase space and reweighing the q^2 distribution to make is flat.
- To make this work the q^2 distribution needs to be reweighted to be flat.





Reweighted to be flat in q^2

Detector acceptance

- Detector distorts our angular distribution.
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$$\epsilon(\cos\theta_l, \cos\theta_k, \phi, q^2) = \sum_{ijkl} P_i(\cos\theta_l) P_j(\cos\theta_k) P_k(\phi) P_l(q^2),$$

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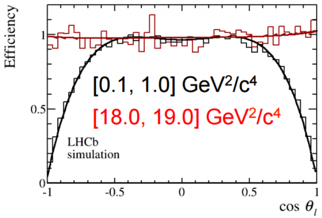
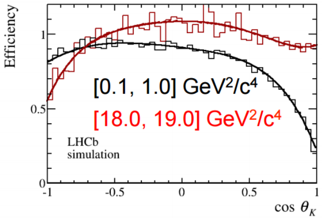
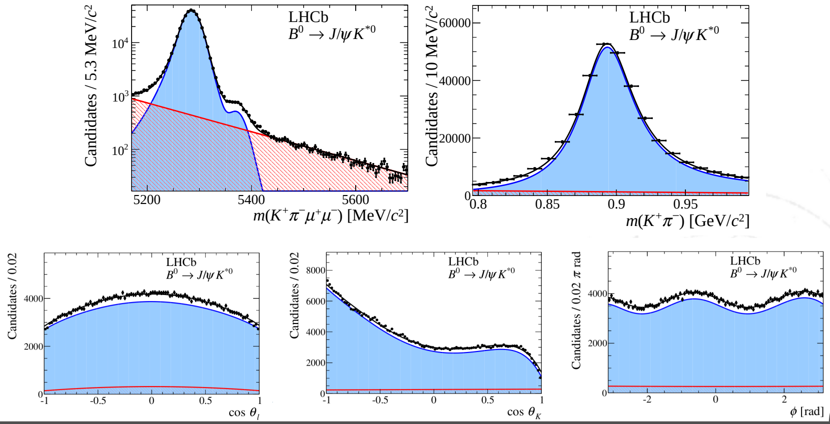


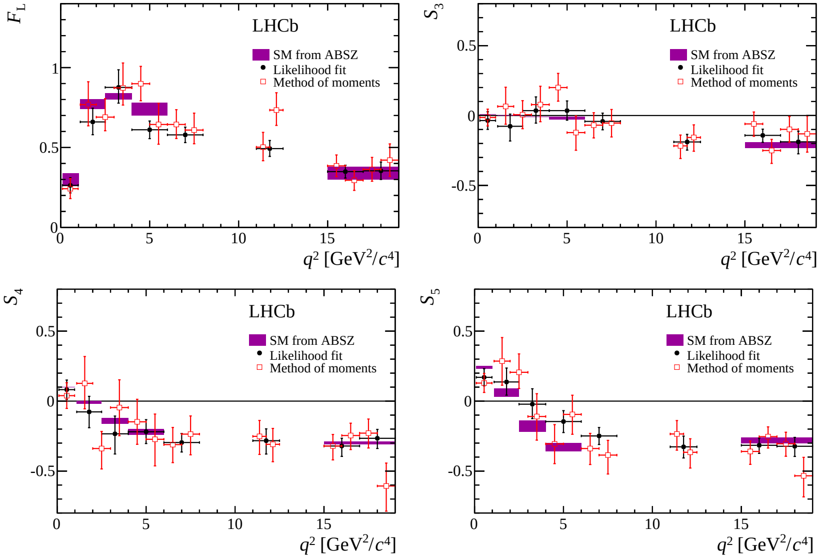


Control channel

- We tested our unfolding procedure on $B \longrightarrow J/\psi K^{*}$.
- The result is in perfect agreement with other experiments and our different analysis of this decay.

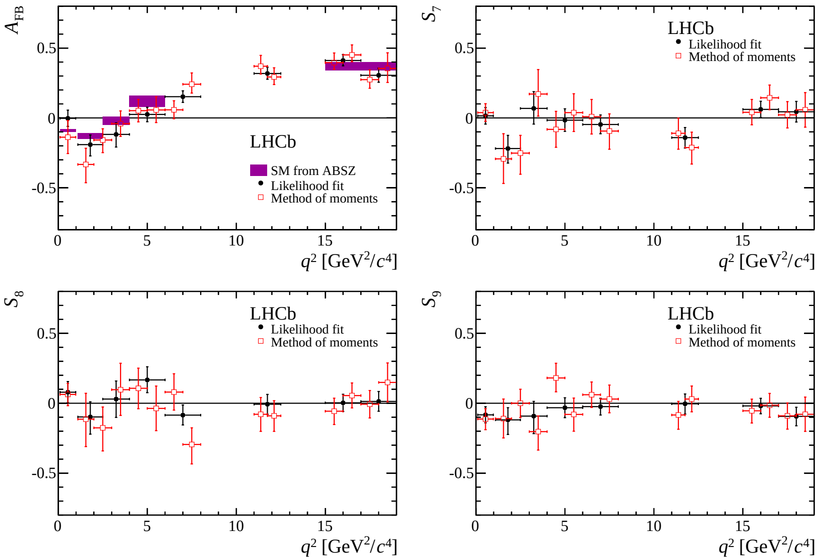


Results



F_L
S_3
S_4
S_5
LHCb
SM from ABSZ
Likelihood fit
Method of moments
q^2 [GeV^2/c^4]

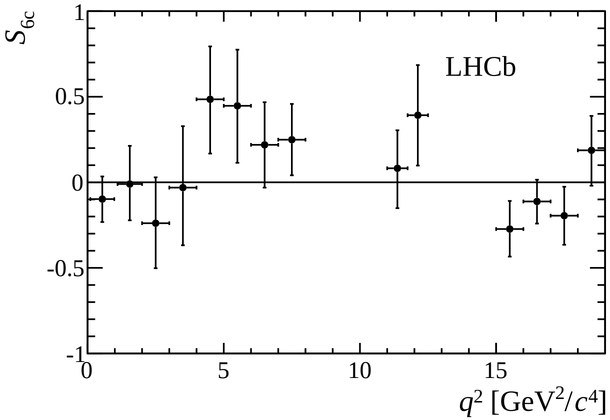
Results



A_{FB}
LHCb
SM from ABSZ
Likelihood fit
Method of moments
S_7
LHCb
Likelihood fit
Method of moments
S_8
LHCb
Likelihood fit
Method of moments
S_9
LHCb
Likelihood fit
Method of moments
0.5
0
-0.5
0
5
10
15
q^2 [GeV^2/c^4]

Results

⇛ Method of Moments allowed us to measure for the first time a new observable:



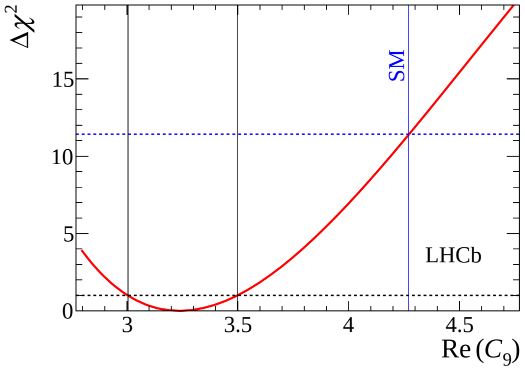
Compatibility with SM

$\Rightarrow$ Use EOS software package to test compatibility with SM.
$\Rightarrow$ Perform the χ^2 fit to the measured:

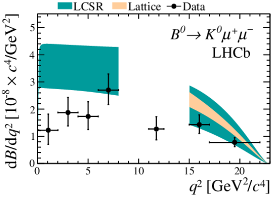
$$F_L, A_{FB}, S_{3,...,9}.$$

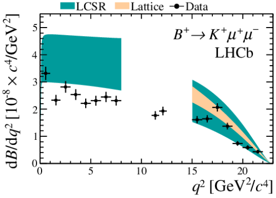
$\Rightarrow$ Float a vector coupling: $\Re(C_9)$.
$\Rightarrow$ Best fit is found to be $3.4\ \sigma$ away from the SM.

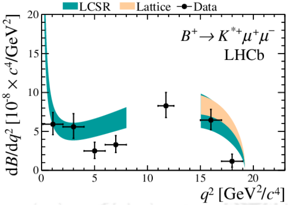
$$\Delta\Re(C_9) \equiv \Re(C_9)^{\text{fit}} - \Re(C_9)^{\text{SM}} = -1.03$$



Branching fraction measurements of $B \to K^{*\pm}\mu\mu$

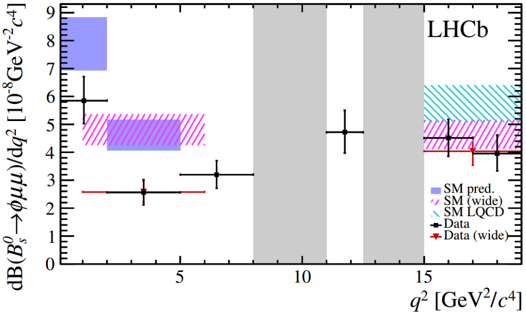






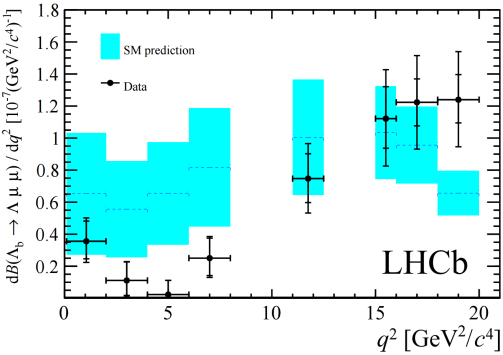
- Despite large theoretical errors the results are consistently smaller than SM prediction.

Branching fraction measurements of $B_s^0 \to \phi\mu\mu$



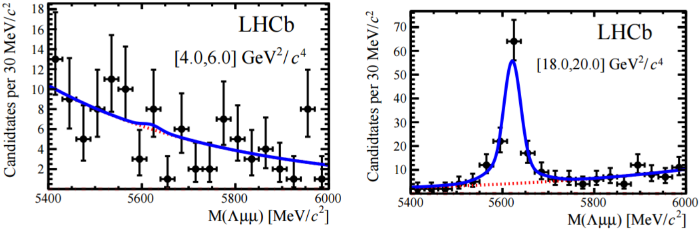
- Recent LHCb measurement [JHEPP09 (2015) 179].
- Suppressed by $\frac{f_s}{f_d}$.
- Cleaner because of narrow ϕ resonance.
- $3.3\ \sigma$ deviation in SM in the $1 - 6\mathrm{GeV}^2$ bin.

Branching fraction measurements of $\Lambda_b \to \Lambda\mu\mu$



- This years LHCb measurement [JHEP 06 (2015) 115]].
- In total ~ 300 candidates in data set.
- Decay not present in the low q^2.

Branching fraction measurements of $\Lambda_b \to \Lambda\mu\mu$

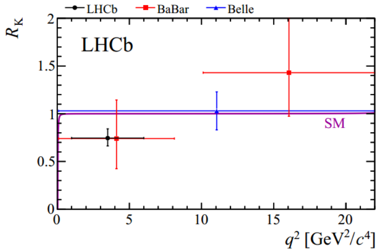


- This years LHCb measurement [JHEP 06 (2015) 115]].
- In total ~ 300 candidates in data set.
- Decay not present in the low q^2.

Lepton universality test

$$R_K = \frac{\int_{q^2=1\,\mathrm{GeV}^2/c^4}^{q^2=6\,\mathrm{GeV}^2/c^4} (\mathrm{d}\mathcal{B}[B^+ \to K^+\mu^+\mu^-]/\mathrm{d}q^2)\mathrm{d}q^2}{\int_{q^2=1\,\mathrm{GeV}^2/c^4}^{q^2=6\,\mathrm{GeV}^2/c^4} (\mathrm{d}\mathcal{B}[B^+ \to K^+e^+e^-]/\mathrm{d}q^2)\mathrm{d}q^2} = 1 \pm \mathcal{O}(10^{-3}) .$$

- Challenging analysis due to bremsstrahlung.
- Migration of events modeled by MC.
- Correct for bremsstrahlung.
- Take double ratio with $B^+ \to J/\psi K^+$ to cancel systematics.
- In $3\mathrm{fb}^{-1}$, LHCb measures $R_K = 0.745^{+0.090}_{-0.074}(stat.)^{+0.036}_{-0.036}(syst.)$
- Consistent with SM at 2.6σ.



- Phys. Rev. Lett. 113, 151601 (2014)

Grab it While it's Hot!

⇛ Yesterday(18.04) we shown a new preliminary result: CERN Seminar

⇛ We measured the ratio:

$$R_{K^*} = \frac{\mathcal{B}(B \to K^* \mu\mu)}{\mathcal{B}(B \to K^* ee)}$$

Grab it While it's Hot!

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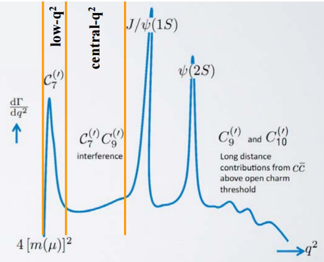
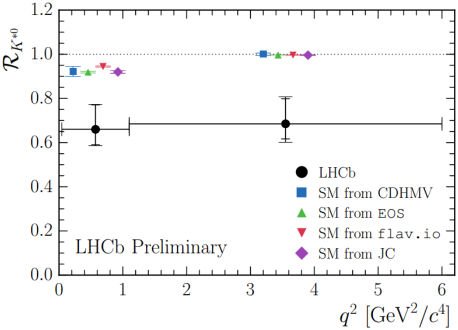
⇛ We measured the ratio:

$$R_{K^*} = \frac{\mathcal{B}(B \to K^* \mu\mu)}{\mathcal{B}(B \to K^* ee)}$$

⇛ Measurement performed in two q^2 bins.

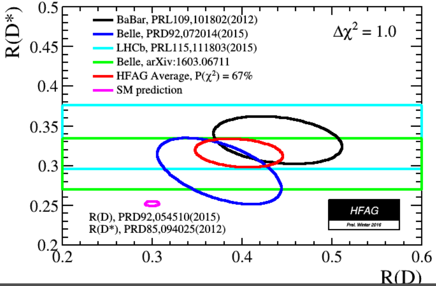
⇛ Normalized in double ratio to $B \to K^* J/\psi$.





There is more!

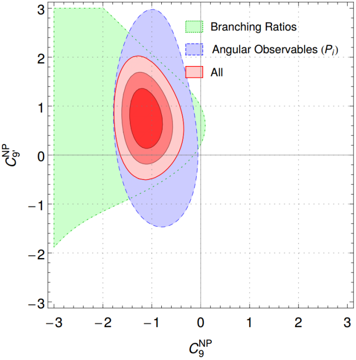
- There is one other LUV decay recently measured by LHCb.
- $R(D^*) = \dfrac{\mathcal{B}(B \to D^* \tau \nu)}{\mathcal{B}(B \to D^* \mu \nu)}$
- Clean SM prediction: $R(D^*) = 0.252(3)$, PRD 85 094025 (2012)
- LHCb result: $R(D^*) = 0.336 \pm 0.027 \pm 0.030$, HFAG average: $R(D^*) = 0.322 \pm 0.022$
- $3.9\ \sigma$ discrepancy wrt. SM prediction

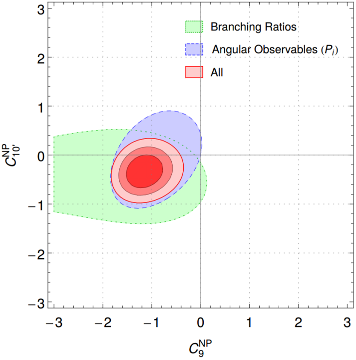


Global fit to $b \longrightarrow s\ell\ell$ measurements

Theory implications

- The data can be explained by modifying the C_9 Wilson coefficient.
- Overall there is around $4.5\ \sigma$ discrepancy wrt. SM.





Grab it While it's Hotter!

⇛ Today(19.04) there was already first paper with the phenomenological work about this measurement: arxiv::1704.05340 J. Matias, et. al.

1D Hyp.	All					LFUV				
	Best fit	1 σ	2 σ	Pull$_{SM}$	p-value	Best fit	1 σ	2 σ	Pull$_{SM}$	p-value
$\mathcal{C}_{9\mu}^{NP}$	-1.10	$[-1.27, -0.92]$	$[-1.43, -0.74]$	5.7	72	-1.76	$[-2.36, -1.23]$	$[-3.04, -0.76]$	3.9	69
$\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{10\mu}^{NP}$	-0.61	$[-0.73, -0.48]$	$[-0.87, -0.36]$	5.2	61	-0.66	$[-0.84, -0.48]$	$[-1.04, -0.32]$	4.1	78
$\mathcal{C}_{9\mu}^{NP} = -\mathcal{C}_{9\mu}'$	-1.01	$[-1.18, -0.84]$	$[-1.33, -0.65]$	5.4	66	-1.64	$[-2.12, -1.05]$	$[-2.52, -0.49]$	3.2	31
$\mathcal{C}_{9\mu}^{NP} = -3\mathcal{C}_{9e}^{NP}$	-1.06	[-1.23,-0.89]	[-1.39,-0.71]	5.8	74	-1.35	$[-1.82, -0.95]$	$[-2.38, -0.59]$	4.0	71