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A new approach in the search for New Physics in $b \to s\ell^+\ell^-$ decays

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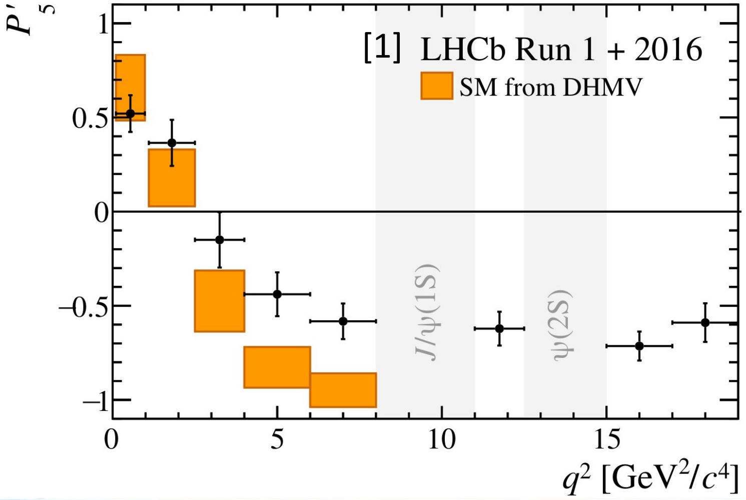
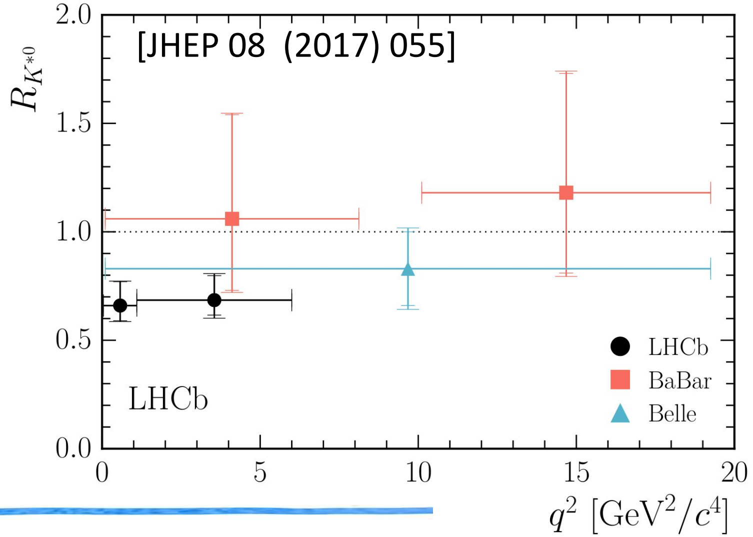
LHCb

Anomalies in rare B decays

- FCNC can only occur at loop-level, therefore could be sensitive to NP at higher energy scales

- Recent measurements confirmed some of the anomalies already observed in $B^0 \to K^{0*}\ell\ell$ and $B^+ \to K^+\ell\ell$ decays (see Elena's and Davide's talks)





[1] https://doi.org/10.1103/PhysRevLett.125.011802

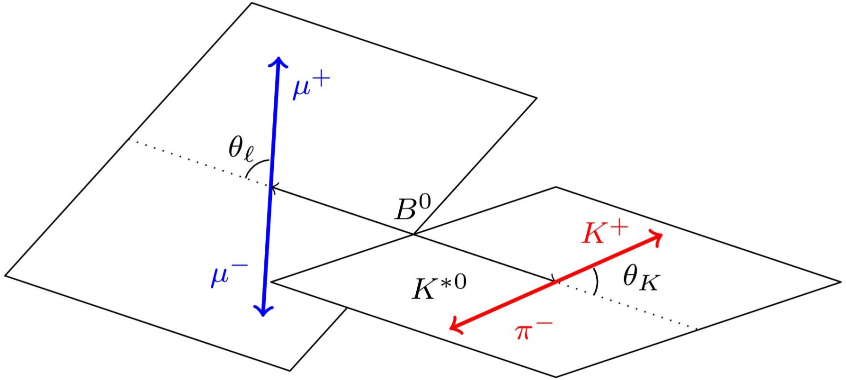
The $B^0 \to K^{*0}\ell^+\ell^-$ amplitude

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i C_i \mathcal{O}_i$$

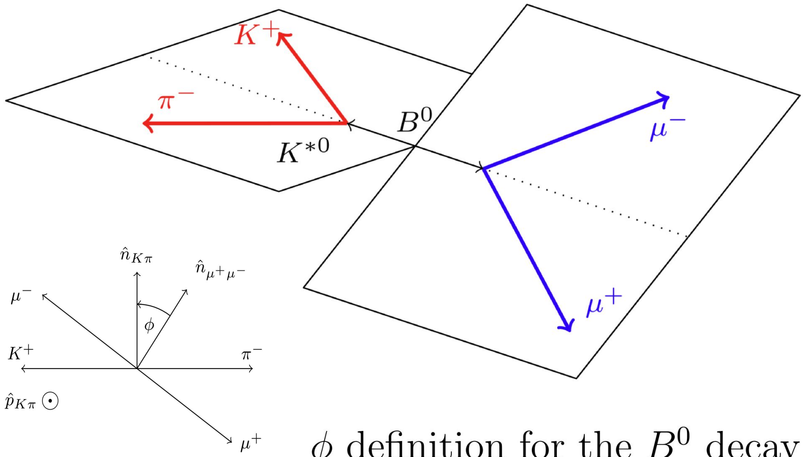
WC, *short distance* physics

local operators, *long distance* physics

$$\frac{8\pi}{3}\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = (J_{1c} + J_{2c}\cos 2\theta_l + J_{6c}\cos\theta_l)\cos^2\theta_K$$
$$+ (J_{1s} + J_{2s}\cos 2\theta_l + J_{6s}\cos\theta_l)\sin^2\theta_K$$
$$+ (J_3\cos 2\phi + J_9\sin 2\phi)\sin^2\theta_K\sin^2\theta_l$$
$$+ (J_4\cos\phi + J_8\sin\phi)\sin 2\theta_K\sin 2\theta_l$$
$$+ (J_5\cos\phi + J_7\sin\phi)\sin 2\theta_K\sin\theta_l$$



θ_K and θ_ℓ definitions for the B^0 decay



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$$\mathcal{A}_\lambda^{(\ell)L,R} = \mathcal{N}_\lambda^{(\ell)}\left\{(C_9^{(\ell)} \mp C_{10}^{(\ell)})\mathcal{F}_\lambda(q^2) + \frac{2m_bM_B}{q^2}\left[C_7^{(\ell)}\mathcal{F}_\lambda^T(q^2) - 16\pi^2\frac{M_B}{m_b}\mathcal{H}_\lambda(q^2)\right]\right\}$$

Normalization
factor

Form factor
(LFU)

Non-local
hadronic matrix element
(LFU)

The $B^0 \to K^{*0}\ell^+\ell^-$ amplitude

$$\mathcal{H}_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb}V_{ts}^* \sum_i C_i \mathcal{O}_i$$

WC, *short distance* physics

local operators, *long distance* physics

The measured Wilson's coefficients can be shifted from SM due to:

1. **NP contributions**
2. **NLH matrix element pollution**

$$C_i \to \tilde{C}_i = C_i^{SM} + C_i^{(\ell)NP} + C_i^{\mathcal{H}}$$

$$\mathcal{A}_\lambda^{(\ell)L,R} = \mathcal{N}_\lambda^{(\ell)}\left\{(C_9^{(\ell)} \mp C_{10}^{(\ell)})\mathcal{F}_\lambda(q^2) + \frac{2m_b M_B}{q^2}\left[C_7^{(\ell)}\mathcal{F}_\lambda^T(q^2) - 16\pi^2\frac{M_B}{m_b}\mathcal{H}_\lambda(q^2)\right]\right\}$$

Normalization factor

Form factor (LFU)

Non-local hadronic matrix element (LFU)

Isolating NP through LFU

$$C_i \to \tilde{C}_i = C_i^{SM} + C_i^{(\ell)NP} + C_i^{\mathcal{H}}$$

Need to break the
degeneracy to access NP

Retrive the "clean" NP contributions in the Wilson coefficients measuring the LFU test:

$$\boxed{\Delta C_i = \widetilde{C}_i^{(\mu)} - \widetilde{C}_i^{(e)} = C_i^{(\mu)NP} - C_i^{(e)NP}}$$

Isolating NP through LFU

Need to bre
degeneracy

Retrive the
coefficients

<u>Our analysis aims to:</u>

- provide a direct fit to the ΔC_i
- ignore the NLH contribution by focussing on LFU quantities

$$\Delta C_i = \widetilde{C}_i^{(\mu)} - \widetilde{C}_i^{(e)} = C_i^{(\mu)NP} - C_i^{(e)NP}$$

Analysis strategy

Perform an **unbinned extended** ML fit to the decay channels

$B^0 \to K^{*0} e^+ e^-$ and $B^0 \to K^{*0} \mu^+ \mu^-$ using the full LHCb dataset .

- Extract $\Delta C_9, \Delta C_{10}$ simultaneously from electrons and muons
- Amplitude and all the remaining parameters are treated as nuisance and shared between electrons and muons
- NLH matrix element parametrized as

$$\mathcal{H}_\lambda = \frac{1 - z z^*_{J/\psi}}{z - z_{\psi(2S)}} \cdot \frac{1 - z z^*_{J/\psi}}{z - z_{\psi(2S)}} \cdot \left[\sum_{k=0}^{K} \alpha_k^{(\lambda)} z^k \right] \mathcal{F}_\lambda$$ [2]

Analysis strategy

- **unbinned** in $\cos\theta_K, \cos\theta_L, \phi, q^2, m_B, m_{K\pi}$

variables in the amplitude

constrain background

constrain S-wave

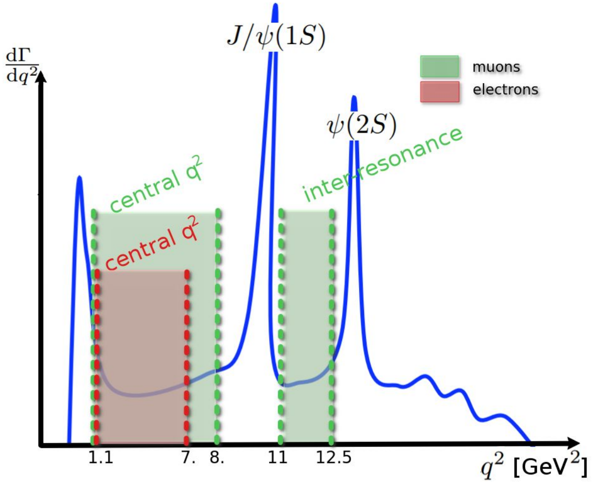
- **extended**

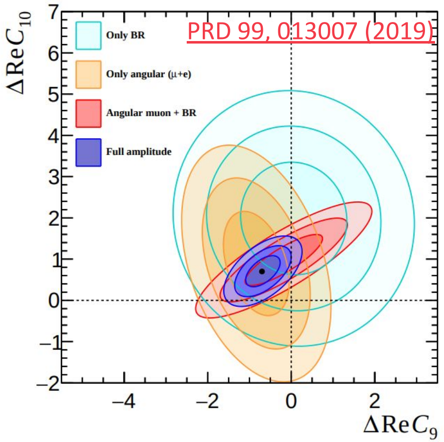
The observed yield adds an additional constraint

$$\lambda_{sig} \propto \frac{\tau_B}{\hbar} \int_{q^2 \in Q_i} \frac{d\Gamma}{dq^2} dq^2$$

depends on Wilson coefficients

increases sensitivity!





Selection and main differences

Channels are selected similarly by requiring:

- four tracks in the final state of good quality coming from displaced vertex
- information from PID compatible with decay hypothesis
- mass from K and π within 100 MeV from K^{*0} mass

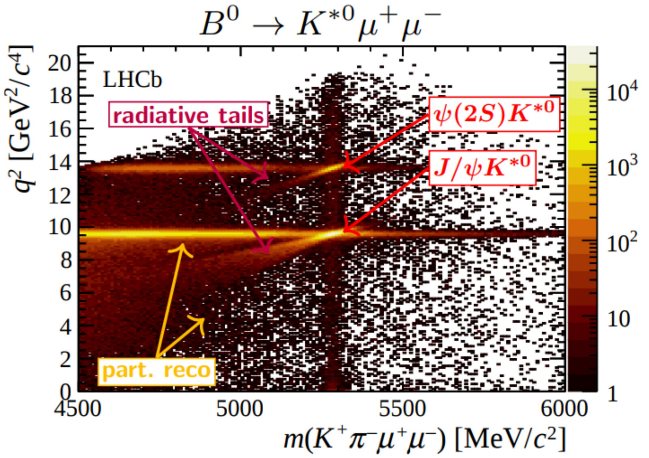
Two main differences:

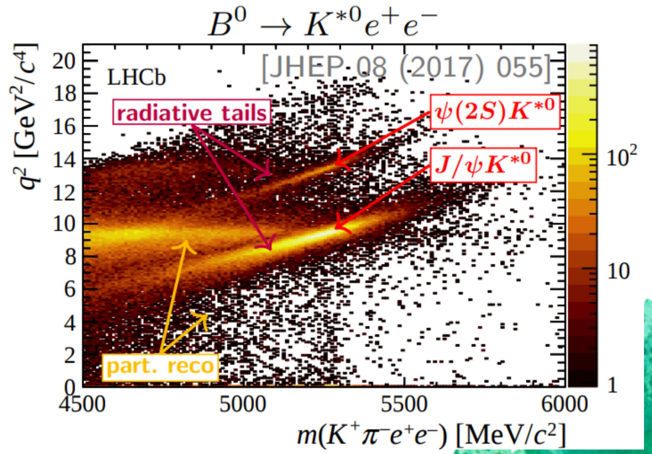
- Trigger efficiency: muons are triggered more efficiently than electrons

roughly x5 more muons than electrons

- Bremsstrahlung: electrons lose more energy than muons

very different momentum resolution





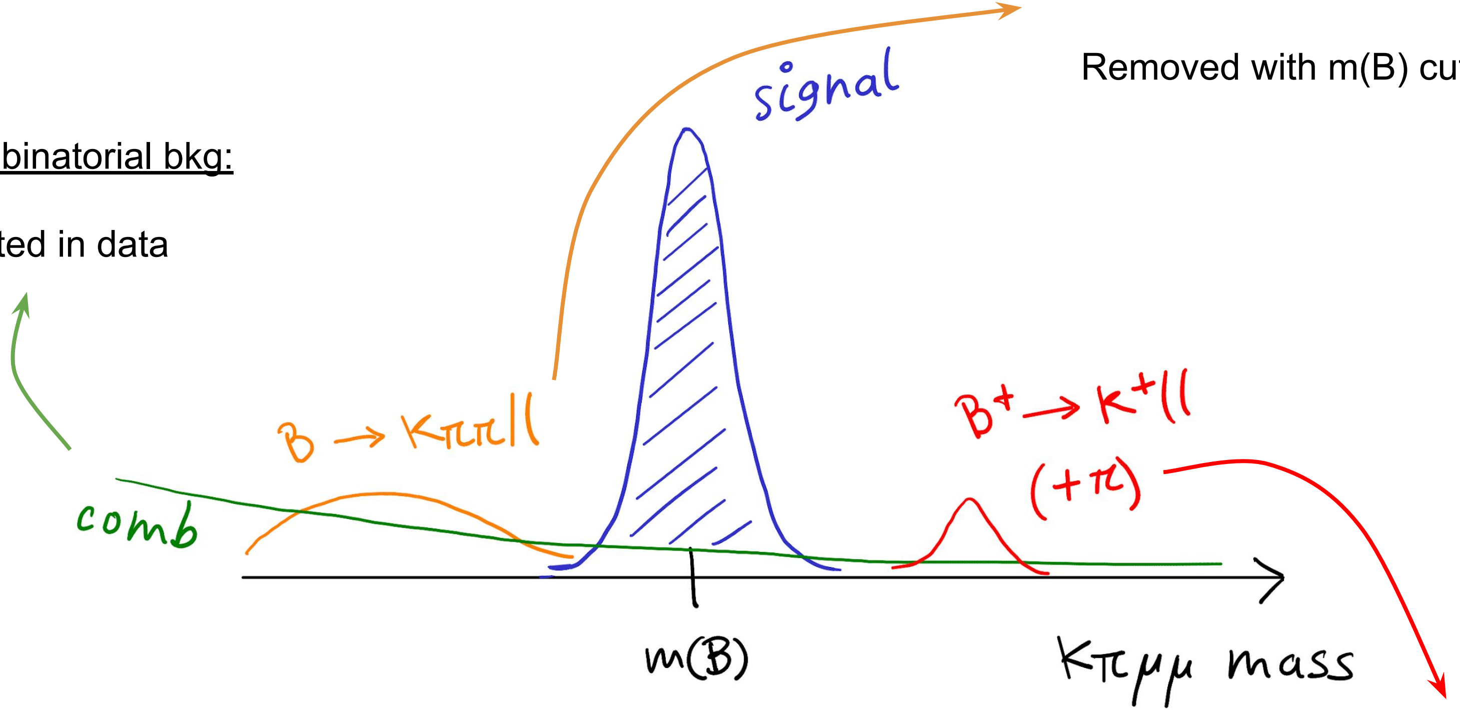
Backgrounds in $B^0 \to K^{*0}\mu^+\mu^-$

Partially reconstructed bkg:

Removed with m(B) cut

Combinatorial bkg:

Floated in data

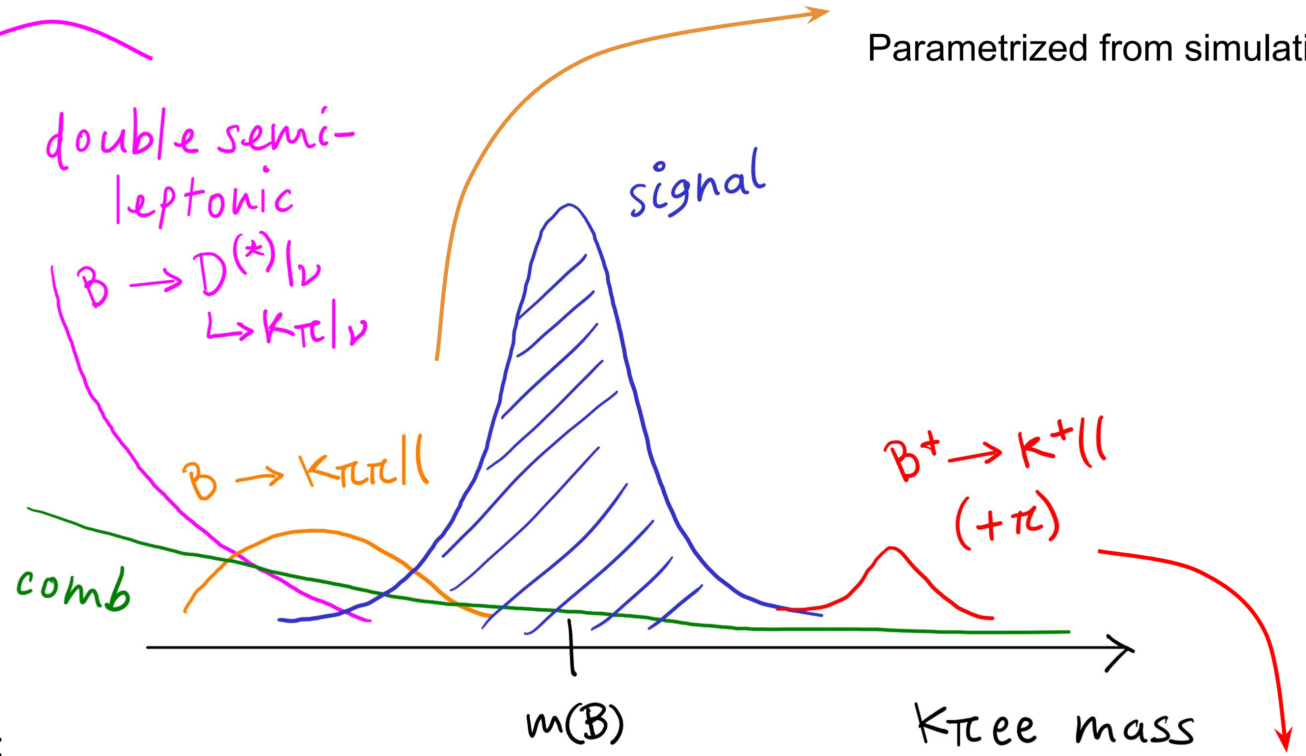


Removed with veto:

$$max(m_{K^+\ell\ell}, m_{(\pi^+\to K^+)\ell\ell}) < 5100\ \mathrm{MeV/c}^2$$

Backgrounds in $B^0 \to K^{*0} e^+ e^-$

Parametrized from control region



Partially reconstructed bkg:

Parametrized from simulation

Combinatorial bkg:

Floated in data

Removed with veto:

$max(m_{K^+\ell\ell}, m_{(\pi^+\to K^+)\ell\ell}) < 5100\ \mathrm{MeV/c}^2$

Toy studies - sensitivity

A simplified sensitivity study of the measurement has been performed with 200 toys:

- **No background for muons** and **no S-wave**
- **Signal** for muons and electrons:
  - $C_9, C_{10}, \Delta C_9, \Delta C_{10}$
  - Form factors K*(892) and CKM parameters (gaussian constraint)
  - charm-loop parametrization
  - generated in $\Delta C_9 = -1.4$ and $\Delta C_9 = -\Delta C_{10} = -0.7$ scenario
- **Combinatorial** in electrons: slope of exponential, angular parameters and yield
- **DSL and partially reconstucted background** in electrons: yield only

The **statistics** considered is the one corresponding to the 9 fb^{-1} collected.

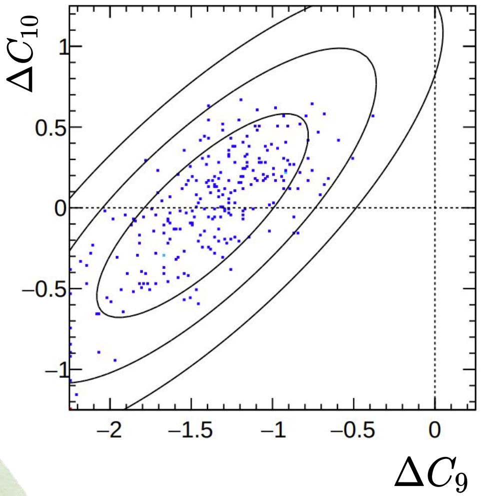
Toy studies - sensitivity

Table 1: Expected sensitivity for Run1 and Run2 statistics

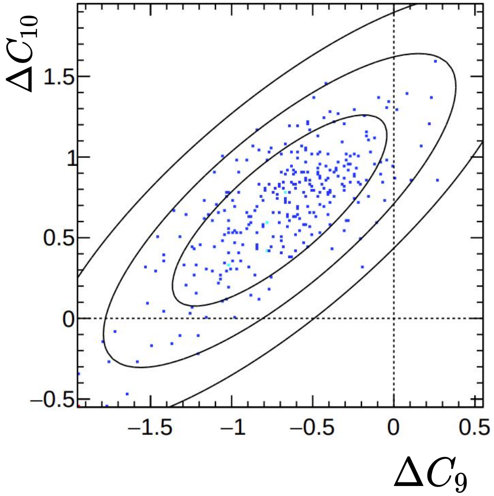
NP model	ΔC_9	$\sigma\Delta C_9$	ΔC_{10}	$\sigma\Delta C_{10}$	ρ	σ_{LFU}
$\Delta C_9 = -1.4$	-1.43 ± 0.03	0.43 ± 0.02	-0.05 ± 0.03	0.42 ± 0.02	0.79 ± 0.03	4.9
$\Delta C_9 = -\Delta C_{10}$	-0.70 ± 0.03	0.44 ± 0.02	0.67 ± 0.02	0.39 ± 0.02	0.79 ± 0.02	4.7

	# of events
$B^0 \to K^{*0}e^+e^-$ - central q^2	480
$B^0 \to K^{*0}\mu^+\mu^-$ - central q^2	2720
$B^0 \to K^{*0}\mu^+\mu^-$ - interRes q^2	965

$\Delta C_9 = -1.4$



$\Delta C_9 = -\Delta C_{10} = -0.7$



An important cross-check

Need to prove:

- good control over our simulation
- no ~~LFU~~ behavior is artificially introduced

A standard cross-check in $R_{K^{*0}}$ is to verify that:

$$r_{J/\Psi} = \frac{N_{B^0 \to K^* J/\Psi(\to \mu\mu)}}{\epsilon_{B^0 \to K^* J/\Psi(\to \mu\mu)}} \cdot \frac{\epsilon_{B^0 \to K^* J/\Psi(\to ee)}}{N_{B^0 \to K^* J/\Psi(\to ee)}} = 1$$

These results:

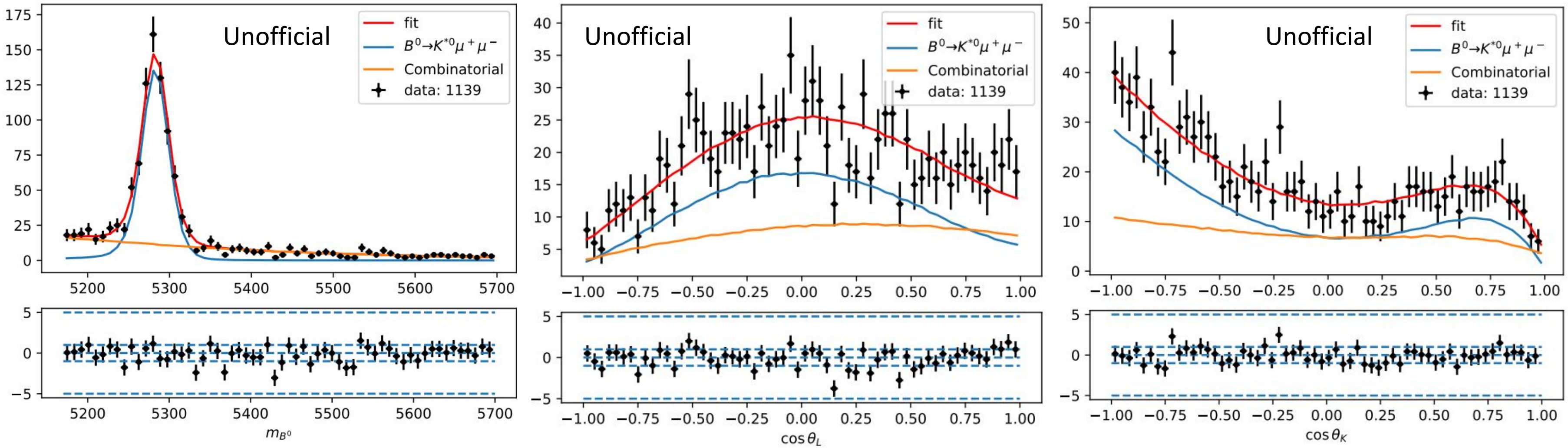
- are still preliminary
- only the statistical error is reported

Table 1: Measured values of $r_{J/\Psi}$

Type	L0I	L0L!
2011	0.970 ± 0.018	1.011 ± 0.015
2012	1.041 ± 0.014	1.023 ± 0.012
2015	0.980 ± 0.024	0.983 ± 0.019
2016	0.992 ± 0.024	0.999 ± 0.026
2017	0.995 ± 0.012	1.000 ± 0.012
2018	1.001 ± 0.012	0.982 ± 0.011

Fit to $B^0 \to K^{*0}\ell^+\ell^-$ data

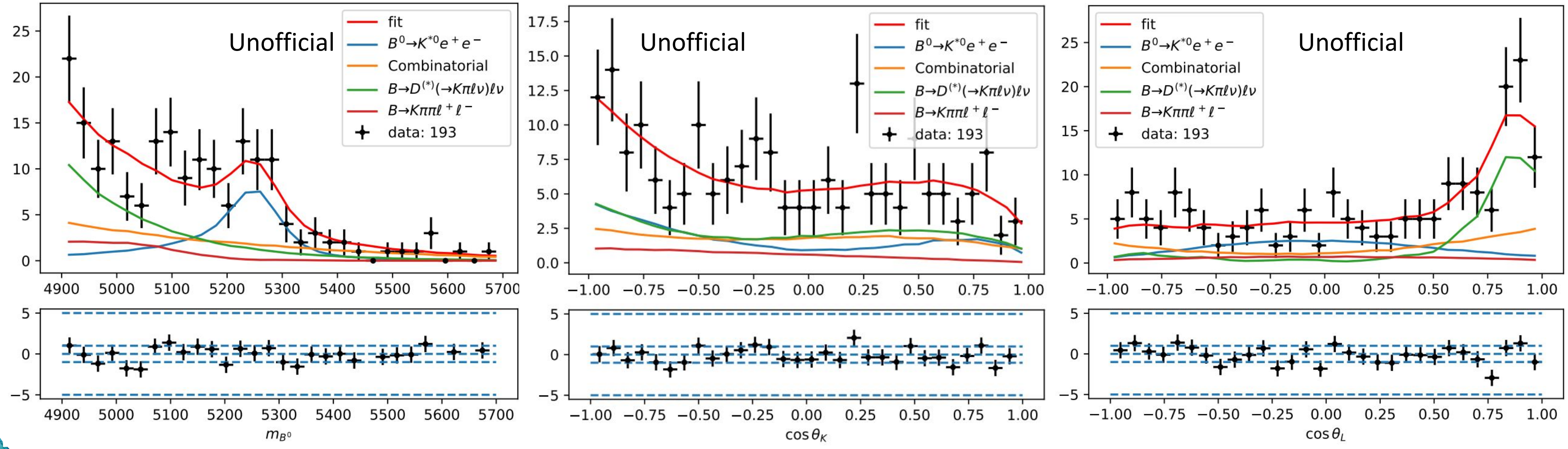
- First attempts to perform a blind fit have been successful



Fit to $B^0 \to K^{*0}\ell^+\ell^-$ data

- First attempts to perform a blind fit separately have been successful

- A further optimization of the fit strategy based on toy studies must follow before the final configuration is chosen



Summary

An unbinned amplitude analysis of $B^0 \to K^{*0} \ell^- \ell^+$, as proposed here, tests the *non-LFU* nature of NP in this class of decays, regardless of the “charm-loop” contribution.

The high sensitivity estimated from toys makes the measurement quite interesting and exiciting

Final remarks

- The analysis is in an advanced state, with few but important details to be finalized

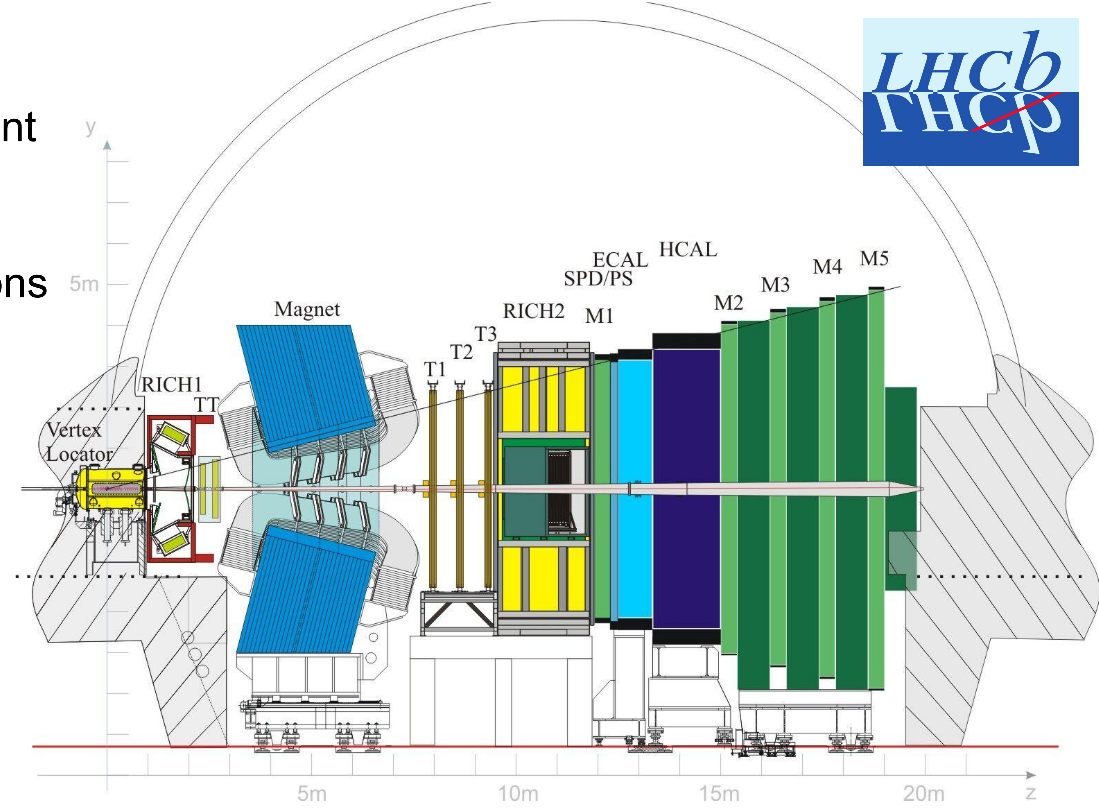
- Next work focus on deciding the final fit strategy and pre-unblinding procedure, together with the estimation of the most important systematics

Backup

Data samples

- Dataset collected at LHCb experiment @ CERN
- Forward single-arm spectrometer specialized in the physics of B mesons thanks to:
  - vertex resolution
  - tracking and momentum resolution
  - particle identification

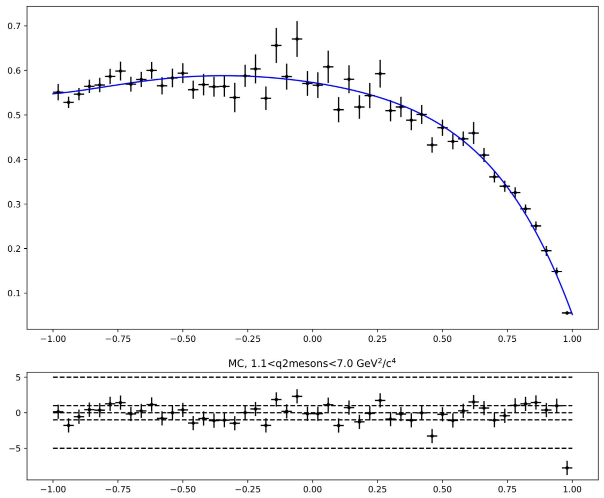
- 3 fb^{-1} pp collisions at $\sqrt{s} = 7, 8$ TeV between 2011-12
- 5.7 fb^{-1} at $\sqrt{s} = 13$ TeV between 2015-18



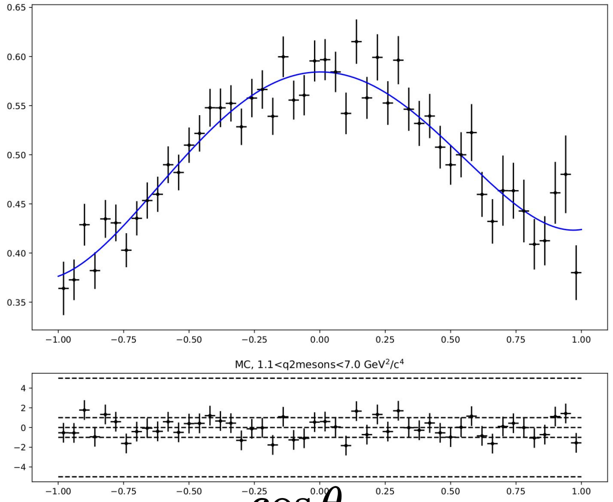
Describing the effect of the detector

The distortion introduced by the reconstruction and the selection of our dataset can be studied with the help of simulation.

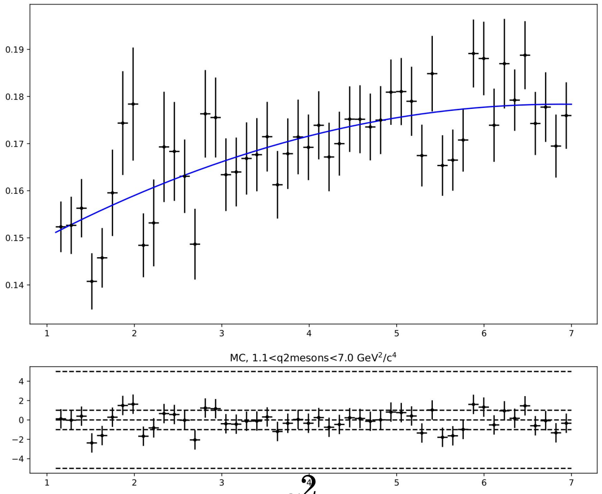
It can be described as a function of the variables of interest and used in the fit together with the signal pdf (more on Zhenzi's talk).



$\cos\theta_K$



$\cos\theta_L$



q^2

An important cross-check

BR is used as constraint on number of expected signal events for muons and electrons

close relationship with $R_{K^{*0}}$ measurement.

$$\lambda_{sig} \propto \frac{\tau_B}{\hbar} \int_{q^2 \in Q_i} \frac{d\Gamma}{dq^2} dq^2$$

depends on Wilson coefficients

A standard cross-check is to verify that:

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These results are still preliminary since few details in the corrections to the simulation are to be finalized. Only the statistical error is shown.