Electroweak Penguin decays at LHCb

Joint UZH-ETH-PSI PhD Seminar 2015

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Universität Zürich

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Overview

Introduction

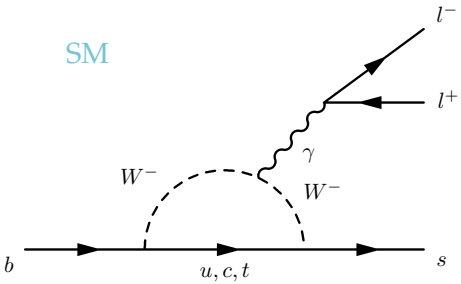
$B^0 \to K^{*0}\mu^+\mu^-$

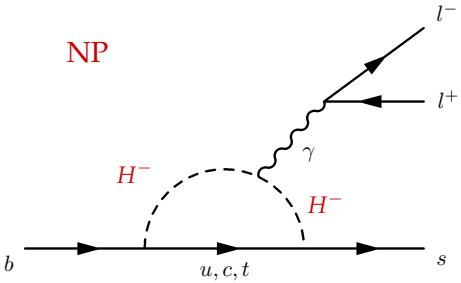
S,P,D-wave contributions to $B^0 \to K^+\pi^-\mu^+\mu^-$

Conclusion

Rare electroweak penguin decays

- Rare FCNC processes are only possible via loop diagrams in SM
  - Highly suppressed
- New, heavy particles in SM extensions can enter the loop and modify observables (branching fractions and angular distributions)

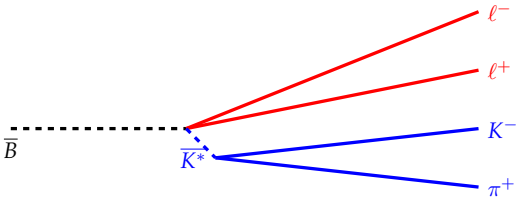


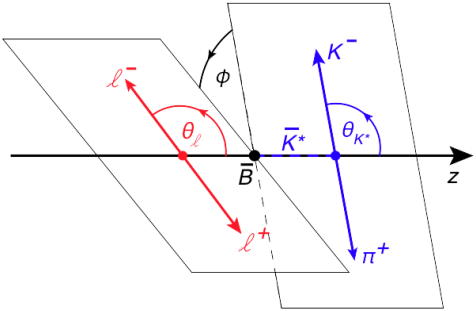


$$B^0 \to K^{*0}\mu^+\mu^-$$

Angular distribution

- Decay reconstructed as $B^0 \to K^+\pi^-\mu^+\mu^-$
- Fully described by dimuon invariant mass squared (q^2) and three angles $\vec{\Omega} = (\cos\theta_l, \cos\theta_K, \phi)$





Observables

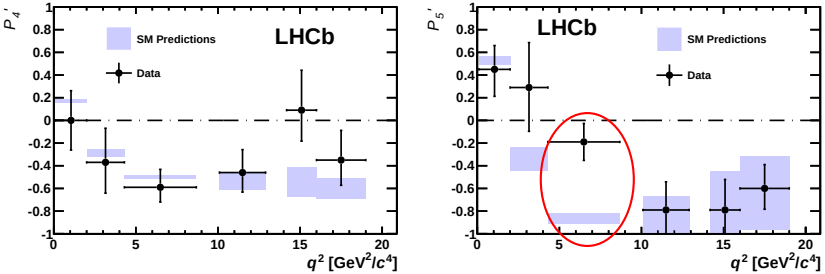
- The differential decay distribution is given by:

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\left.\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\right|_{\mathrm{P}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_{\mathrm{L}})\sin^2\theta_K + F_{\mathrm{L}}\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-F_{\mathrm{L}})\sin^2\theta_K\cos 2\theta_l - F_{\mathrm{L}}\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi + \tfrac{4}{3}A_{\mathrm{FB}}\sin^2\theta_K\cos\theta_l$$
$$+S_7\sin 2\theta_K\sin\theta_l\sin\phi + S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big]$$

- Additional sets of observables, for which the leading form-factor uncertainties cancel, can be built from F_{L} and S_3 to S_9
  - e.g. $P'_{4,5} = S_{4,5}/\sqrt{F_{\mathrm{L}}(1-F_{\mathrm{L}})}$

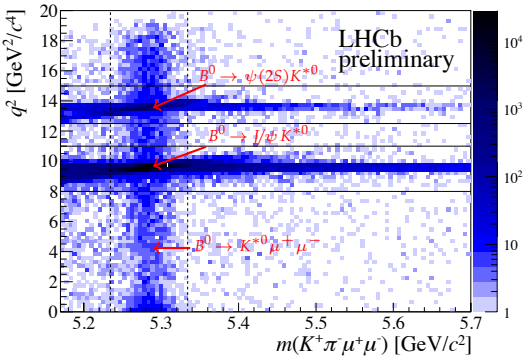
Previous analysis of $B^0 \to K^{*0}\mu^+\mu^-$ at LHCb

- Previous analysis used 1 fb^{-1} of data taken in 2011
- Less form-factor dependent observables (P_i') introduced in [PRL 111, 191801 (2013)] measured for the first time
  - 3.7σ local deviation from SM prediction [JHEP 05 (2013) 137] in P_5'!



Selection

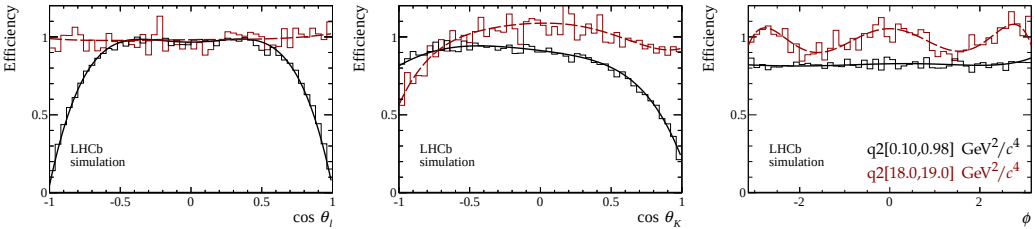
[LHCb-CONF-2015-002]



- Analysis repeated using full 3 fb^{-1} of Run I data
- Resonant modes ($B^0 \to J/\psi K^{*0}$ and $B^0 \to \psi(2S)K^{*0}$) and peaking backgrounds vetoed with kinematic and PID criteria
- Multivariate classifier used to reduce combinatorial background
  - Kinematic, particle identification and isolation variables used as input

Acceptance correction

[LHCb-CONF-2015-002]



- Trigger, reconstruction and selection distort the distributions of q^2, $\cos\theta_\ell$, $\cos\theta_K$, ϕ
- Acceptance modelled using polynomial paramerisation
- Validated in data using the control mode $B^0 \to J/\psi K^{*0}$

S-wave pollution

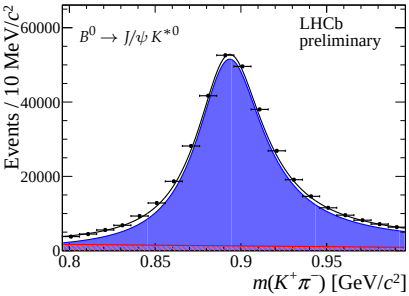
[LHCb-CONF-2015-002]

- K^{*0} reconstructed through decay channel $K^{*0} \to K^+\pi^-$
- Can also have contribution due to $K^+\pi^-$ in non-resonant S-wave configuration

➜ 6 additional observables

$$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{S+P}} = (1-F_{\mathrm{S}})\,\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}}\bigg|_{\mathrm{P}} + \frac{3}{16\pi}F_{\mathrm{S}}\sin^2\theta_\ell + \text{S-P interference}$$

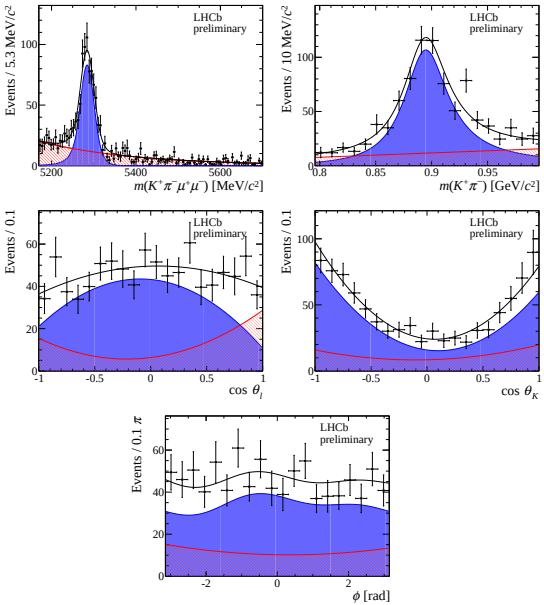
- P-wave observables scaled by factor $(1 - F_{\mathrm{S}})$
- Simultaneous fit performed to $m_{K\pi}$ to constrain F_S



Angular fit

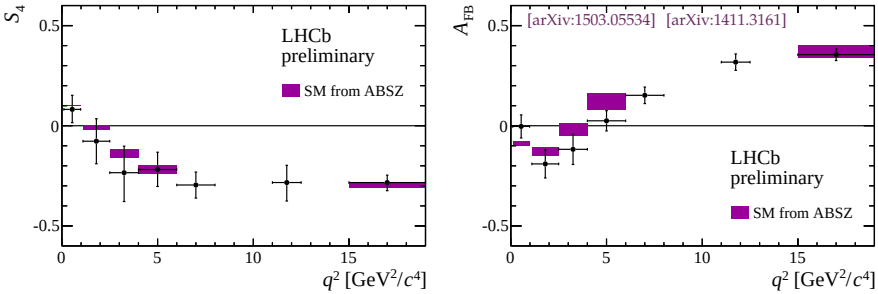
[LHCb-CONF-2015-002]

- Analysis performed in several q^2 bins
- 4D+1D simultaneous fit to $m_{K\pi\mu\mu}$, $\cos\theta_\ell$, $\cos\theta_K$, ϕ and $m_{K\pi}$
- Projections shown for q^2 bin $1.1 < q^2 < 6.0$ GeV$^2/c^4$



Results - S_4, A_{FB}

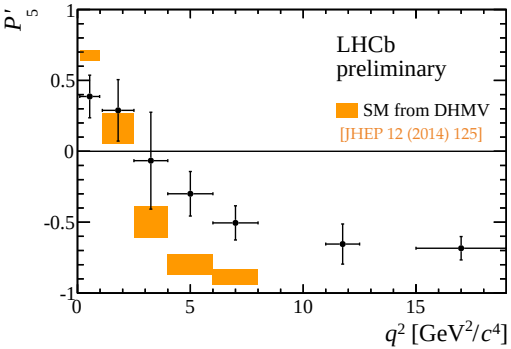
[LHCb-CONF-2015-002]



- Good agreement between data and SM prediction for S_4
- Data tends to lie systematically below SM prediction at low q^2 for A_{FB}

Results - P_5'

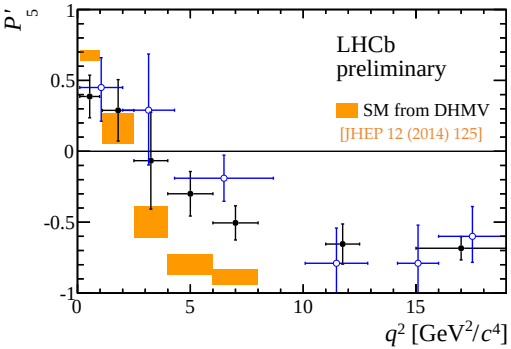
[LHCb-CONF-2015-002]



- Deviation at level of 2.9σ in both bins [4.0,6.0] and [6.0,8.0] GeV$^2/c^4$
- Naive combination results in significance of 3.7σ
- Discrepancy in P_5' confirmed!
- Compatible with 1 fb^{-1} analysis [PRL 111, 191801 (2013)]

Results - P_5'

[LHCb-CONF-2015-002]



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S,P,D-wave contributions to $B^0 \to K^+\pi^-\mu^+\mu^-$

S,P,D-wave contributions to $B^0 \to K^+\pi^-\mu^+\mu^-$

- So far analyses at LHCb have focused on the $K^*(892)$ region
- However, there are many other interesting K^* states at higher $m_{K\pi}$

	mass (MeV)	full width (MeV)	J^P
$K^*(892)$	895.81 ± 0.19	47.4 ± 0.6	1^-
$K^*(1410)$	1414 ± 15	232 ± 21	1^-
$K_0^*(1430)$	1425 ± 50	270 ± 80	0^+
$K_2^*(1430)$	1432.4 ± 1.3	109 ± 5	2^+
$K^*(1680)$	1717 ± 27	322 ± 110	1^-

- Region of $m_{K\pi}$ ~1400 MeV should contain contributions from S-,P- and D-waves
  - ★ Previously unexplored!
- Analysis dedicated to measurements in this region currently ongoing

Analysis strategy

[arXiv:1505.02873]

- Selection/acceptance correction very similar to $K^*(892)$ analysis
- However, with contribution from S-,P- and D-waves, the differential decay distribution increases in complexity
  - ➜ 41 observables!
  - ✘ Unfeasible for a Likelihood fit
- Expand in a basis of 41 orthonormal angular functions, $f_i(\vec{\Omega})$

$$\frac{d\Gamma}{dq^2 d\vec{\Omega}} = \mathcal{C} \times \left\{ \sum_{i=1}^{41} f_i(\vec{\Omega})\Gamma_i(q^2) \right\} \quad \text{where} \quad \int f_i(\vec{\Omega}) f_j(\vec{\Omega}) d\vec{\Omega} = \delta_{ij}.$$

- The orthonormal angular basis is constructed out of the spherical harmonics $Y_\ell^m \equiv Y_\ell^m(\theta_l, \phi)$ and the reduced spherical harmonics $P_\ell^m \equiv \sqrt{2\pi} Y_\ell^m(\theta_K, 0)$.

Method of Moments

- ★ Exploiting the orthonormal basis allows each Γ_i observable to be measured individually using a <u>method of moments</u> approach
- ▸ Within a given q^2 bin:

$$P(\vec{\Omega}) = \sum_i f_i(\vec{\Omega})\Gamma_i$$

$$\Gamma_i = \int_\Omega d\vec{\Omega} P(\vec{\Omega}) f_i(\vec{\Omega}) \equiv E_P[f_i]$$

$$\text{e.g. } \widehat{\Gamma}_i = \frac{1}{N}\sum_e f_i(\vec{\Omega}_e)$$

- ★ Complex likelihood fit replaced by simple counting method!
- ★ Able to measure all 41 observables and their corresponding covariance matrix

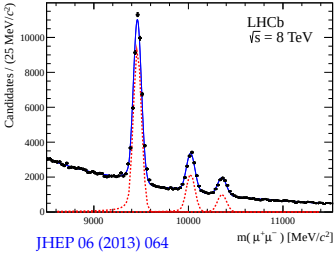
Conclusions

- Rare electroweak penguin decays are powerful probes in the search for NP
- Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ shows intriguing hints of deviations from SM predictions in the observable P_5'
- Ongoing analysis will probe the angular distribution in a previously unexplored region of $m_{K\pi}$ using a <u>method of moments</u> approach

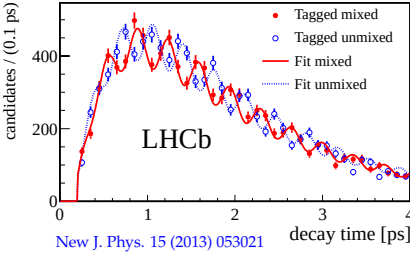
Backup

The LHCb experiment

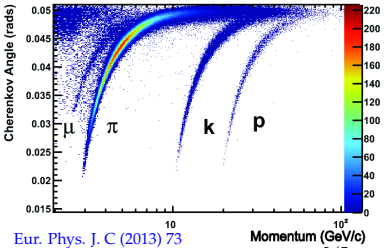
- LHCb is the dedicated heavy flavour physics experiment at the LHC
- Its primary goal is to look for indirect evidence of new physics in CP violation and rare decays of beauty and charm hadrons
- This requires:
  1. Excellent tracking
     - momentum resolution($\Delta p/p \sim 0.4\% - 0.6\%$)
     - impact parameter resolution ($\sigma_{IP} \sim 20\ \mu$m)
     - primary vertex resolution (13 μm in x and y and 71 μm in z)
  2. Excellent decay time resolution ($\sigma_\tau \sim 45$ fs)
  3. Excellent particle identification



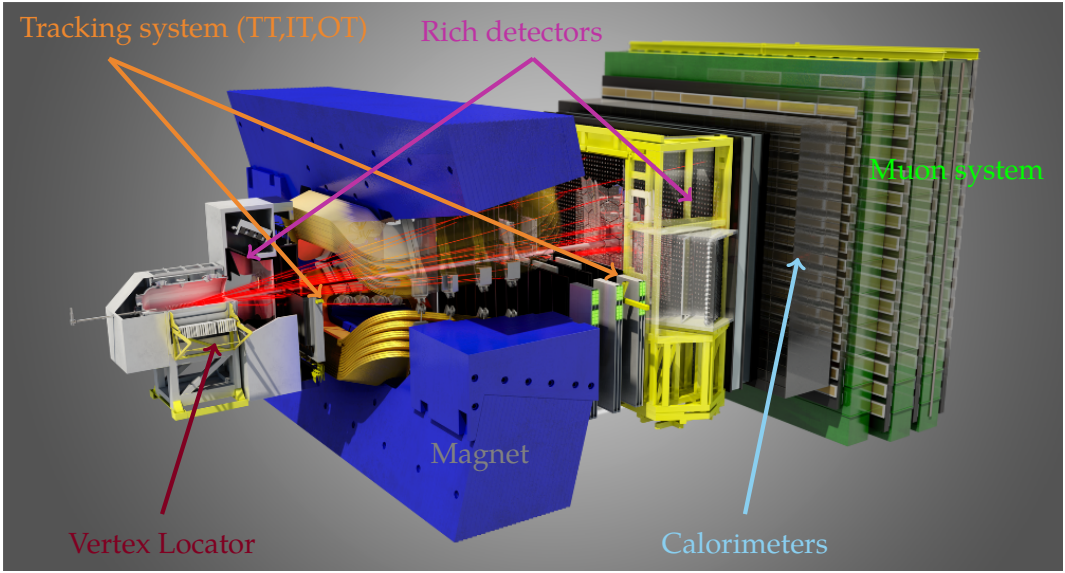
JHEP 06 (2013) 064



New J. Phys. 15 (2013) 053021

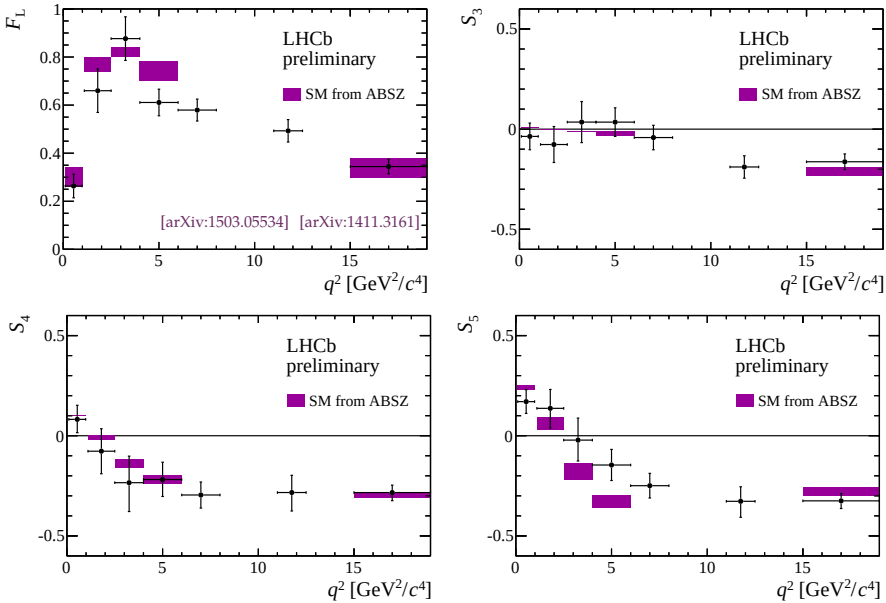


Eur. Phys. J. C (2013) 73


Tracking system (TT,IT,OT)
Rich detectors
Muon system
Magnet
Vertex Locator
Calorimeters

Results - F_L, S_3, S_4, S_5

[LHCb-CONF-2015-002]



Results - A_{FB}, S_7, S_8, S_9

[LHCb-CONF-2015-002]