Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ at CMS

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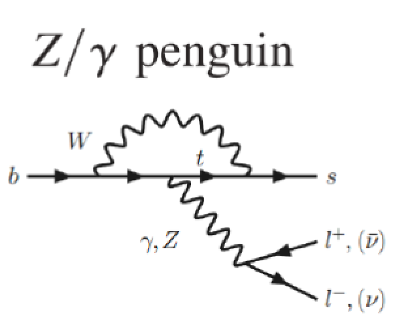
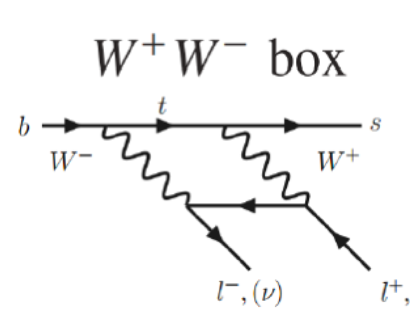
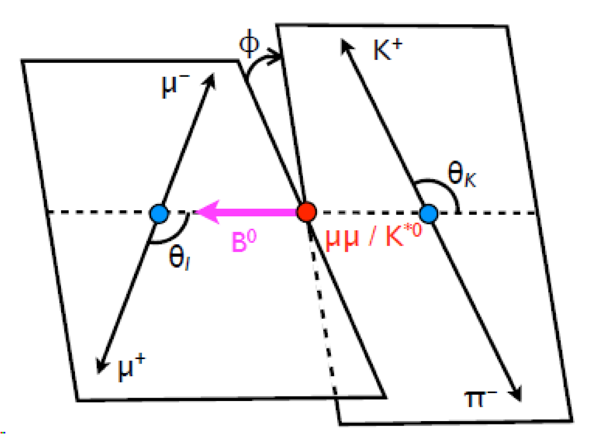
INTRODUCTION

Phenomena beyond the standard model (SM) of particle physics can become manifest directly, via the production of new particles, or indirectly, by affecting the production and decay of SM particles. The flavor changing neutral current (FCNC) processes in B meson semi-leptonic decays are particularly sensitive to possible new physics (NP) phenomena. The physics process such as $b \to s\, l^+ l^-$ transition, which proceeds at lowest order in SM via either a Z/γ penguin diagram or a W^+W^- box diagram as shown, are highly suppressed in the SM and sensitive to NP. NP may modify any of the angular variables relative to their SM values.







The CMS experiment has studied some of these quantities through $\boldsymbol{B^0 \to K^{*0}\mu^+\mu^-}$ with 7TeV data taken during 2011[1] and 8TeV data taken during 2012[2], the measurements are consistent with the SM. The LHCb and Belle Collaborations recently reported a discrepancy larger than 3 standard deviations (σ) with respect to the SM for the so-called P_5' variable [3–5]. We will also present a precise measurement of the P_5' variable, together with the P_1 variable, using a sample of $\boldsymbol{B^0 \to K^{*0}\mu^+\mu^-}$ events collected during 2012.

EVENT SELECTION

The data used has been collected by CMS detector in proton-proton (pp) collisions at center-of-mass energy 8TeV with a corresponding integrated luminosity of $20.5 \pm 0.5 fb^{-1}$.

Dedicated **low mass displaced dimuon trigger** during 2012 data taking

Most important selections to discriminate signal and reduce trigger rate:

- single muon p_T> **3.5** GeV
- Dimuon p_T> **6.9** GeV
- **1** < m(μμ) = q < **4.8** GeV
- L / σ > **3** w.r.t. beam-spot
- Vtx CL > **10%**

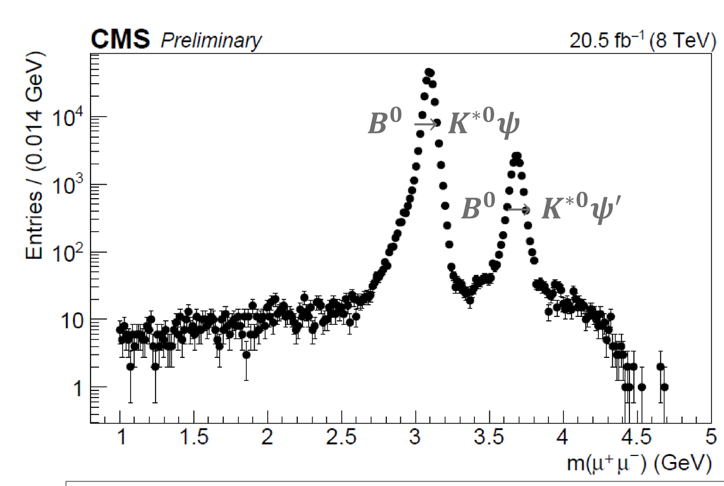
Two CP-states, $B^0 \to K^{*0}(K^+\pi^-)\mu^+\mu^-$ and $\overline{B}^0 \to \overline{K}^{*0}(K^-\pi^+)\mu^+\mu^-$, difficult to disentangle (no particle ID).

Both $K^+\pi^-$ and $K^-\pi^+$ mass hypotheses are computed

- p_T> **0.8** GeV
- DCA / σ > **2** w.r.t. beam-spot
- $|m(K\pi) - m(K^{*0})$ PDG$|$ < **90** MeV at least one of the two mass hypotheses must lie in the window
- m(KK) > **1.035 (Φ(1020))** particle

Both B^0 and $\overline{B}^0$ mass hypotheses are computed:

- p_T > **8** GeV
- $|\eta|$ < **2.2**
- $|m(K\pi\mu\mu) - m(B^0)$PDG$|$ < **280** MeV for at least one of the two mass hypotheses
- Vtx. CL > **10%**
- L / σ > **12** w.r.t. beamspot
- cos(α) > **0.9994** angle in transverse plane between B^0 momentum and B^0 line of flight (w.r.t. beam-spot)
- If more than one candidate ➜ choose best B^0 vtx CL



Signal and control samples are treated identically.
Signal candidates obtained by **J/ψ** and **ψ(2S)** rejections.

THE PROBABILITY DENSITY FUNCTION

$$\text{p.d.f.}(m,\theta_K,\theta_l,\Phi) = Y_S^C \Big[S^C(m)\, S^a(\theta_K,\theta_l,\phi)\, \epsilon^C(\theta_K,\theta_l,\phi) + \frac{f^M}{1-f^M} S^M(m)\, S^a(-\theta_K,-\theta_l,\phi)\, \epsilon^M(\theta_K,\theta_l,\phi) \Big] + Y_B B^m(m)\, B^{\theta_K}(\theta_K)\, B^{\theta_l}(\theta_l)\, B^{\phi}(\phi),$$

Correctly tagged events — Mistag fraction — Mistagged events — Background

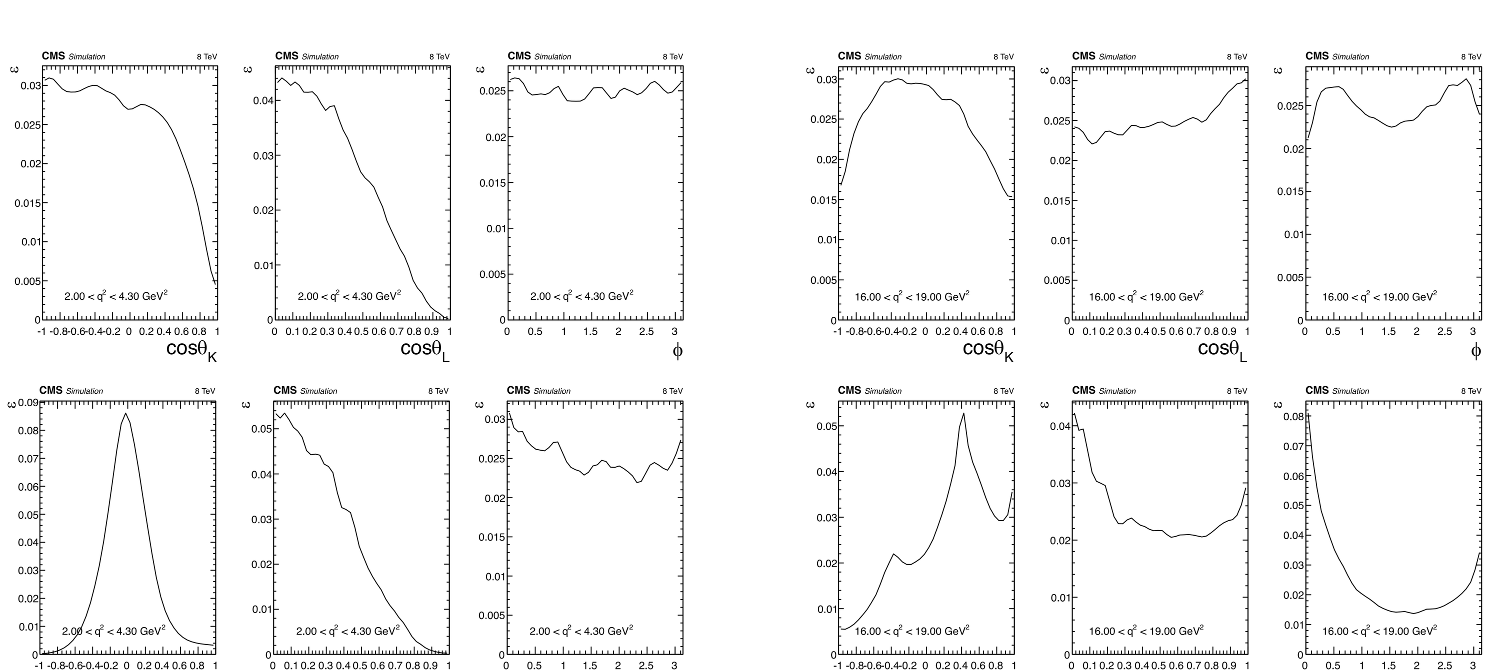
Signal contribution: mass shape (double Gaussian), decay rate, and 3D efficiency function.

Background contribution: mass shape (exponential) and factorized polynomial functions for each angular variable.

- Use un-binned extended maximum likelihood estimator.
- Measurement performed 7 times (one in each q^2 bin).

q^2 bins index	1	2	3	4	5	6	7
$m^2(\mu\mu)$ GeV^2	1-2	2-4.3	4.3-6	6-8.68	10.9-12.86	14.18-16	16-19

EFFICIENCY

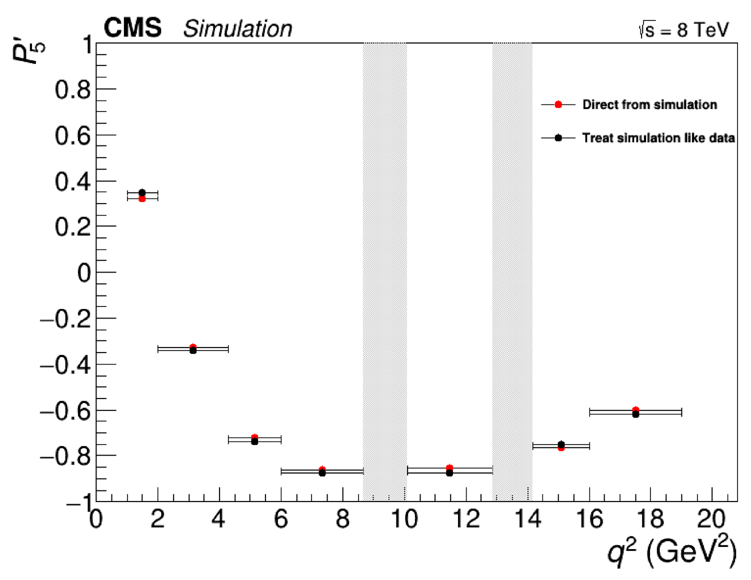


- Numerator and denominator of efficiency are separately described with non-parametric technique implemented with a kernel density estimator on un-binned distributions.
- Final efficiency distributions in the p.d.f. obtained from the ratio of 3D histograms derived from the sampling of the kernel density estimators.
- Projections of the efficiency for correctly tagged events (upper row) and wrongly tagged events (lower row), integrating over the other variables for the 2^{nd} and 7^{th} q^2 bins.

VALIDATION

Several validation steps are performed with **simulations**:

- **Large MC signal sample**: compare fit results with input values to the simulation (**simulation mismodeling**);
- **200 data-like MC signal+background samples**: compare average fit results with fit to the large MC signal sample (**fit bias**);
- **Pseudo experiments.**



Validation with **data control channels** $B^0 \to K^{*0}$J/ψ and $B^0 \to K^{*0}$ψ(2S) :

- Fit performed with F_L free to float;
- The difference of F_L with respect to PDG value is propagated to the signal q^2 bins as systematic uncertainty (**efficiency**).

SYSTEMATIC UNCERTAINTY

The total uncertainty in each q^2 bin is obtained by adding each contribution in quadrature. For each item, the range indicates the variation of the uncertainty in the signal q^2 bins.

Systematic Uncertainties	$F_L(10^{-3})$	$A_{FB}(10^{-3})$	dB/dq^2(%)	$P_1(10^{-3})$	$P'_5(10^{-3})$
Simulation mismodeling	1-17	0-37	1.0-5.5	1-33	10-23
Fit bias	0-34	2-42	–	5-78	10-119
MC statistical uncertainty	3-10	5-18	0.5-2.0	29-73	31-112
Efficiency	34	5	–	17-100	5-65
$K\pi$ mistagging	1-4	0-7	0.1-4.1	8-110	6-66
Background distribution	20-36	12-31	0.0-1.2	12-70	10-51
Mass distribution	3	1	3.2	12	19
Feed-through background	0-27	0-5	0.0-4.0	4-12	3-24
Angular resolution	6-24	0-5	0.2-2.1	2-68	0.1-12
Normalization to $B^0 \to$ J/ψ K^{*0}	–	–	4.6	–	–
F_L,F_S,A_s uncertainty propagation	–	–	–	0-126	0-200
Total Systematic Uncertainty	**41-65**	**18-74**	**6.4-8.6**	**60-220**	**70-230**

MC statistical uncertainty: fit data with 100 new efficiency distributions generated according to the simulation statistical uncertainty ➜ effect of the different efficiency functions on final result is used to estimate the systematic uncertainty.

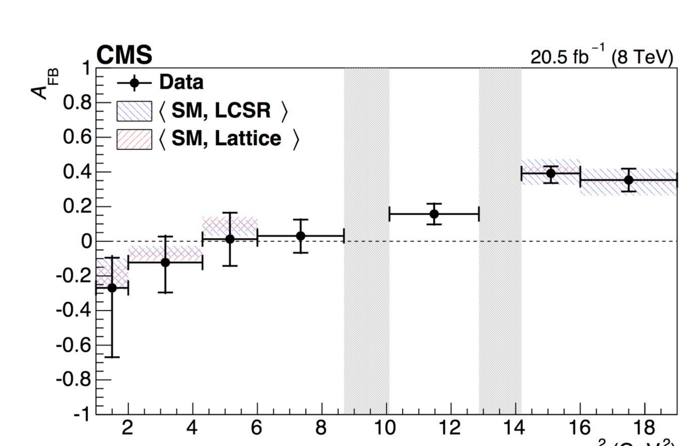
$K\pi$ mistagging: mistag fraction free to float in control channel B^0➜K^{*0}J/ψ ➜ discrepancy with respect to simulation is propagated to angular parameters.

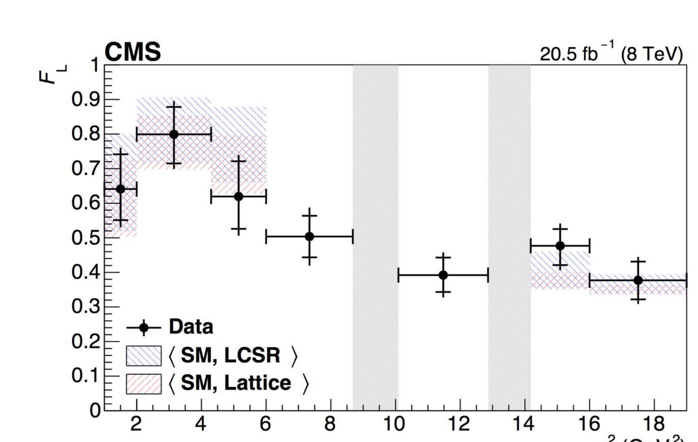
F_L, F_S, A_s uncertainty propagation:

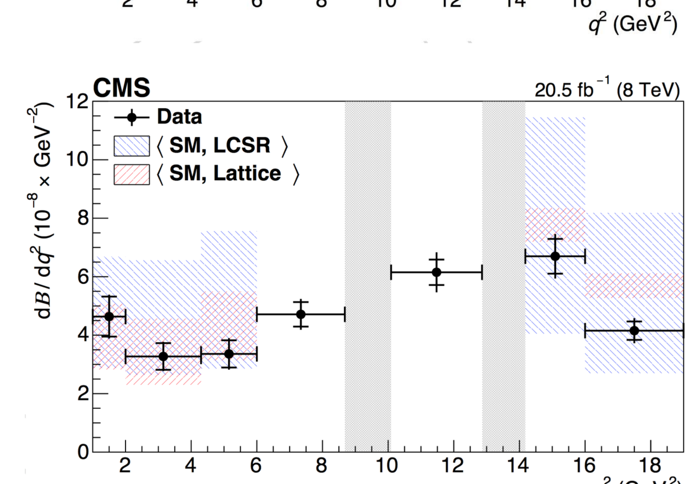
- Generate a large data, O(100×data), pseudo experiments (one per q^2);
- Fit with all 6 angular parameters free to float;
- Fit with F_L, F_S, A_s fixed;
- Ratio of uncertainties between free and partially-fixed fit is used to compute the systematic uncertainty.

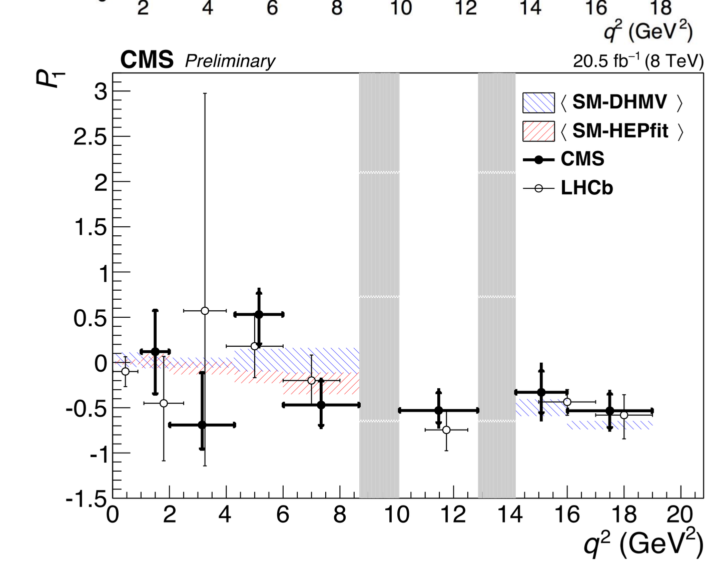
CONCLUSION AND OUTLOOK

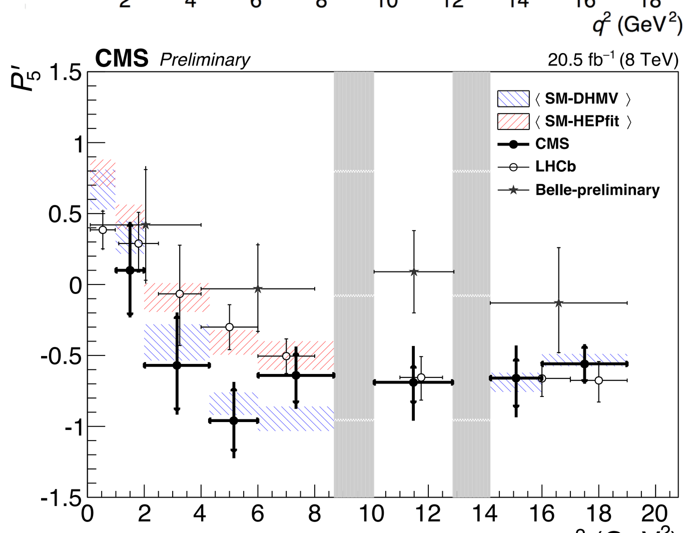
Using pp collision data recorded at √s = 8 TeV with the CMS detector at the LHC, corresponding to an integrated luminosity of $20.5 fb^{-1}$, an angular analysis has been carried out on the decay $B^0 \to K^{*0}\mu^+\mu^-$. The data used for this analysis include 1397 signal decays. For each bin of the dimuon invariant mass squared (q^2), un-binned maximum-likelihood fits were performed to the $K^+\pi^-\mu^+\mu^-$ invariant mass and two decay angles, to obtain values of A_{FB}, F_L, dB/dq^2, P_1 and P_5' parameters. The results are among the most precise to date and are consistent with standard model predictions and the other experiments' results, with a comparable or higher precision[2]. Under a higher luminosity and better trigger requirements, the data collected during 2016 by CMS detector will be more efficiently used for full angular analysis studies. Several rare decays, $B^0 \to K^{*0}\mu^+\mu^-$, $B^+ \to K^{(*)+}\mu^+\mu^-$, $B_s \to \Phi\mu^+\mu^-$ will be carefully investigated.











For parameter $\boldsymbol{P_5'}$, both SM predictions are in agreement with the CMS experimental results, albeit CMS data are slightly more compatible with SM-DHMV[6], while LHCb data with SM-HEPfit[7]. Thus we do not obtain evidence for physics beyond the SM.

[1] CMS2011: *Phys. Lett. B* **727** (2013) 77
[2] CMS2012: *PLB* **753** (2016) 424–448
[3] LHCb: *JHEP* **02** (2016) 104
[4] *JHEP* **06** (2016) 092
[5] Belle: *Phys. Rev. Lett* **118** (2017) 111801
[6] SM-DHMV: *JHEP* **01** (2013) 048, *JHEP* **05** (2013) 137
[7] SM-HEPfit: *JHEP* **06** (2016) 116, arXiv:1611.04338