

Angular analyses at CMS

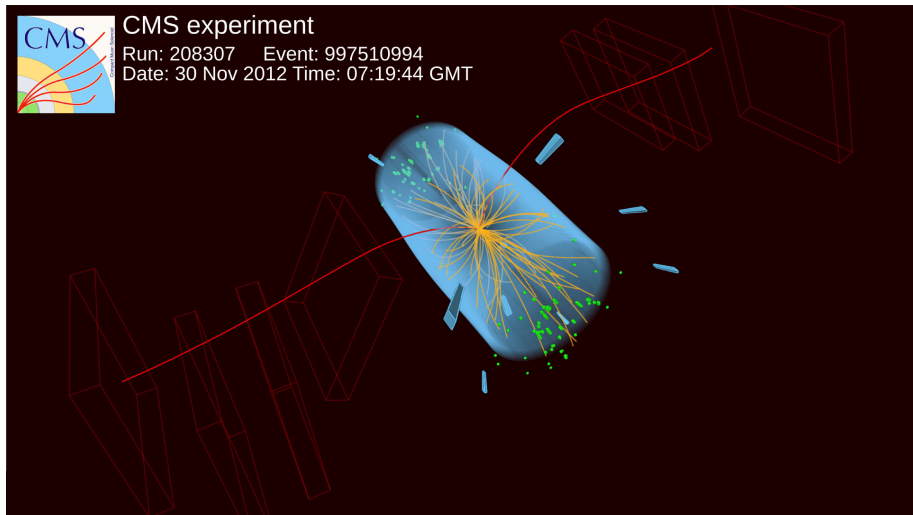
Alessio Boletti¹

on behalf of the CMS collaboration

Rare B Decays workshop
Apr 18th, 2016

¹ INFN & Universita' di Padova

Angular analyses at CMS



Angular analyses at CMS

$$B^+ \rightarrow K^{*+} \mu \mu$$

- analysis ongoing
- too few events to measure complete P_i set
- aiming at F_L , A_{FB} and dBR/dq^2

$$B^+ \rightarrow K^+ \mu \mu$$

- analysis ongoing
- scalar K meson: only A_{FB} and dBR/dq^2 measured

$$\Lambda_b \rightarrow \Lambda \mu \mu$$

- analysis started

Angular analyses at CMS

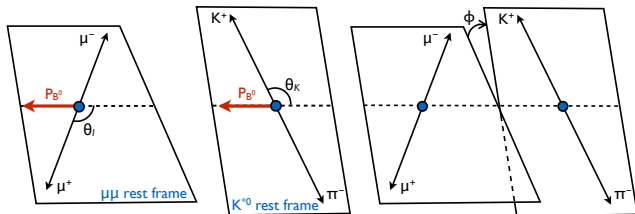
$B^0 \rightarrow K^{*0} \mu\mu$ with reduced parametrization

- public paper [Phys. Lett. B **753** (2016) 424-448]
- F_L , A_{FB} and dBR/dq^2 measured

$B^0 \rightarrow K^{*0} \mu\mu$ with complete parametrization

- analysis ongoing
- aiming the measurement of P'_5
- no approved results

$$B^0 \rightarrow K^*(892)^0 \mu^+ \mu^-$$



Four-particle final state topology

- three decay angles: θ_K, θ_I, ϕ
- the square of dimuon invariant mass: q^2

CP-averaged angular distribution

$$\begin{aligned}
 \frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{dq^2 d\cos\theta_K d\cos\theta_l d\phi} = & \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right. \\
 & + \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_l - F_L \cos^2 \theta_K \cos 2\theta_l \\
 & + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi + \frac{4}{3} A_{FB} \sin^2 \theta_K \cos \theta_l \\
 & + S_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi + S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi \\
 & \left. + S_5 \sin 2\theta_K \sin \theta_l \cos \phi + S_7 \sin 2\theta_K \sin \theta_l \sin \phi + S_8 \sin 2\theta_K \sin 2\theta_l \sin \phi \right]
 \end{aligned}$$

3D angular distribution with 8 free parameter

- challenging fit
- convergence problems with few events

CP-averaged angular distribution

$$\begin{aligned}
 \frac{1}{d\Gamma/dq^2} \frac{d^4\Gamma}{dq^2 d\cos\theta_K d\cos\theta_l d\phi} = \frac{9}{32\pi} & \left[\frac{3}{4}(1 - F_L) \sin^2\theta_K + F_L \cos^2\theta_K \right. \\
 & + \frac{1}{4}(1 - F_L) \sin^2\theta_K \cos 2\theta_l - F_L \cos^2\theta_K \cos 2\theta_l \\
 & + \cancel{S_3 \sin^2\theta_K \sin^2\theta_l \cos 2\phi} + \frac{4}{3} A_{FB} \sin^2\theta_K \cos\theta_l \\
 & + \cancel{S_9 \sin^2\theta_K \sin^2\theta_l \sin 2\phi} + \cancel{S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi} \\
 & \left. + \cancel{S_5 \sin 2\theta_K \sin \theta_l \cos \phi} + \cancel{S_7 \sin 2\theta_K \sin \theta_l \sin \phi} + \cancel{S_8 \sin 2\theta_K \sin 2\theta_l \sin \phi} \right]
 \end{aligned}$$

Integrating out the ϕ angle

- no problems with efficiency: quite flat in ϕ
- measurement of F_L and A_{FB}

S-wave component

$$\frac{1}{\Gamma} \frac{d^3\Gamma}{d \cos \theta_K d \cos \theta_l dq^2} = \frac{9}{16} \left\{ \left[\frac{2}{3} F_S + \frac{4}{3} A_S \cos \theta_K \right] (1 - \cos^2 \theta_l) \right. \\ \left. + (1 - F_S) \left[2F_L \cos^2 \theta_K (1 - \cos^2 \theta_l) \right. \right. \\ \left. \left. + \frac{1}{2} (1 - F_L) (1 - \cos^2 \theta_K) (1 + \cos^2 \theta_l) + \frac{4}{3} A_{FB} (1 - \cos^2 \theta_K) \cos \theta_l \right] \right\}$$

Also $K\pi$ couple produced in S-wave configuration

- F_S , fraction of S-wave $K\pi$
- A_S , S-P waves interference term
- Small contribution, but need to be included in the PDF

Data samples

Dataset

2012 data: 20.5 fb^{-1} at $\sqrt{s} = 8 \text{ TeV}$

Signal and control channels naturally defined in q^2 bins

- 7 signal bins (1–19 GeV)
- $B^0 \rightarrow K^* J/\psi$ control channel ($|q - m_{J/\psi}| < 3\sigma_q$)
- $B^0 \rightarrow K^* \psi'$ control channel ($|q - m_{\psi'}| < 3\sigma_q$)

Flavour mistag

- No PID: no difference between pion and kaon
- B^0 flavour determined with the $K\pi$ invariant mass
- 12–14% of events mistagged
- their contribution considered in the PDF, with flipped angles

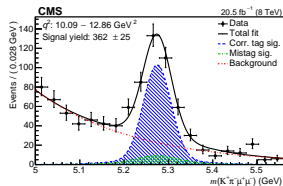
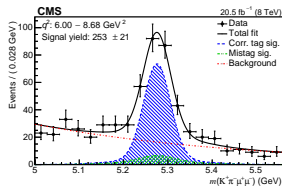
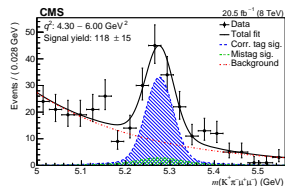
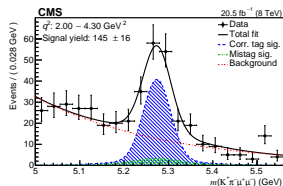
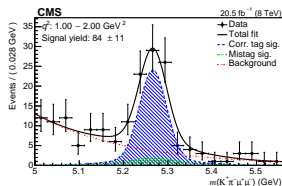
Efficiency

2D efficiency function

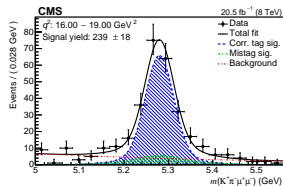
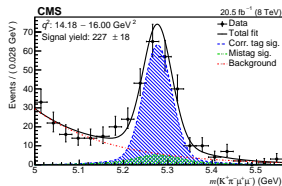
- computed on MC simulation
- 3rd degree $(\cos \theta_K)$ \times 5th degree $(\cos \theta_K)$ polynomial
- fitted to binned efficiency
- both for correctly and wrongly tagged events

efficiency function multiplies the fit PDF

Signal yields



Signal
 Mistagged signal
 Background



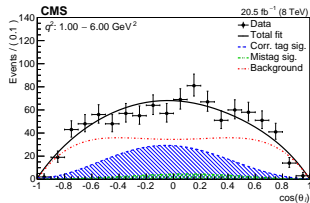
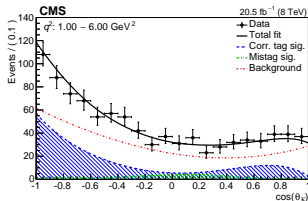
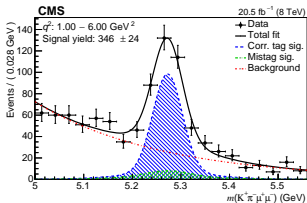
- A total of more than 1400 signal events
- Clear yields in all the q^2 bins
- Same yields in the ongoing full angular analysis

Fit strategy

Unbinned likelihood fit performed in each q^2 bin

- Fitted $m(K\pi\mu\mu)$, $\cos\theta_K$, $\cos\theta_l$
- Background shapes from fit to $m(B_0)$ sidebands
- Signal $m(B_0)$ shapes and fraction of mistagged events from MC

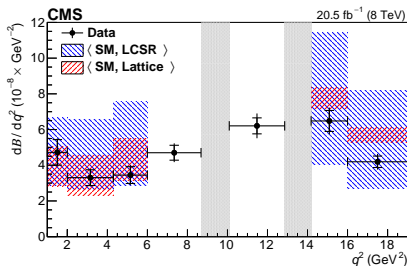
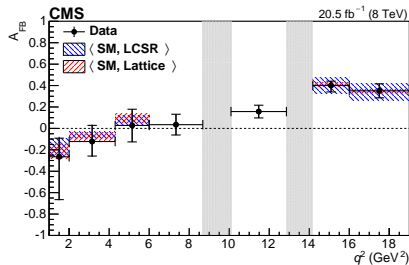
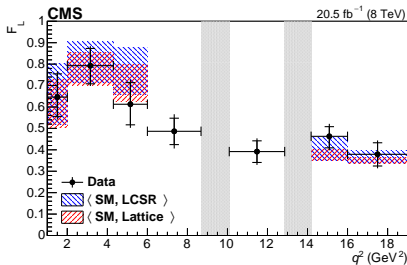
Example of fit in special bin $1 < q^2 < 6 \text{ GeV}^2$



Systematic uncertainties

Systematic uncertainty	$F_L (10^{-3})$	$A_{FB} (10^{-3})$	$d\mathcal{B}/dq^2$ (%)
Simulation mismodeling	1–17	0–37	1.0–5.5
Fit bias	0–34	2–42	—
MC statistical uncertainty	3–10	5–18	0.5–2.0
Efficiency	34	5	—
$K\pi$ mistagging	1–4	0–7	0.1–4.1
Background distribution	20–36	12–31	0.0–1.2
Mass distribution	3	1	3.2
Feed-through background	0–27	0–5	0.0–4.0
Angular resolution	6–24	0–5	0.2–2.1
Normalization to $B^0 \rightarrow J/\psi K^{*0}$	—	—	4.6
Total systematic uncertainty	41–65	18–74	6.4–8.6

Results



- Shorter error bars: statistical only
- **Blue boxes:** SM predictions, form-factors with light-cone sum rules at low q^2 and extrapolated to high q^2 [JHEP 09 (2010) 089, JHEP 02 (2013) 010]
- **Red boxes:** SM predictions, form-factors by lattice calculations

[Phys. Rev. D 89 (2014) 094501]

Conclusions

No CMS P_i results public yet

- Complex analysis with 4D fit
- Many systematic uncertainties to be calculated

But new results is arriving

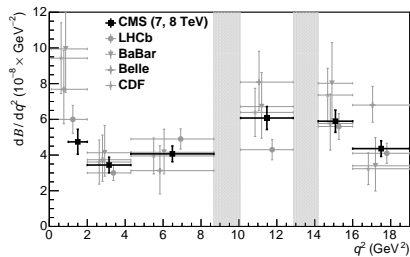
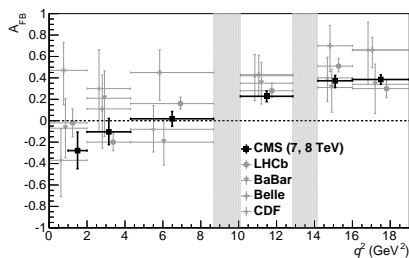
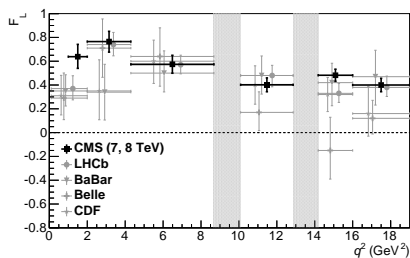
- CMS P'_5 measurement
- B^+ angular analyses

Backup

Table of results

q^2 (GeV ²)	Signal yield	F_L	A_{FB}	$d\mathcal{B}/dq^2$ (10 ⁻⁸ GeV ⁻²)
1.00–2.00	84 ± 11	0.64 ^{+0.10} _{-0.09} ± 0.07	-0.27 ^{+0.17} _{-0.40} ± 0.07	4.6 ± 0.7 ± 0.3
2.00–4.30	145 ± 16	0.80 ± 0.08 ± 0.06	-0.12 ^{+0.15} _{-0.17} ± 0.05	3.3 ± 0.5 ± 0.2
4.30–6.00	117 ± 15	0.62 ^{+0.10} _{-0.09} ± 0.07	0.01 ± 0.15 ± 0.03	3.4 ± 0.5 ± 0.3
6.00–8.68	254 ± 21	0.50 ± 0.06 ± 0.06	0.03 ± 0.10 ± 0.02	4.7 ± 0.4 ± 0.3
10.09–12.86	362 ± 25	0.39 ± 0.05 ± 0.04	0.16 ± 0.06 ± 0.01	6.2 ± 0.4 ± 0.5
14.18–16.00	225 ± 18	0.48 ^{+0.05} _{-0.06} ± 0.04	0.39 ^{+0.04} _{-0.06} ± 0.01	6.7 ± 0.6 ± 0.5
16.00–19.00	239 ± 18	0.38 ^{+0.05} _{-0.06} ± 0.04	0.35 ± 0.07 ± 0.01	4.2 ± 0.3 ± 0.3

7+8 TeV combination vs. other experiments



- Not present the last LHCb result