B^0 -> K l l*
RECENT RESULTS AND PERSPECTIVES AT LHCb

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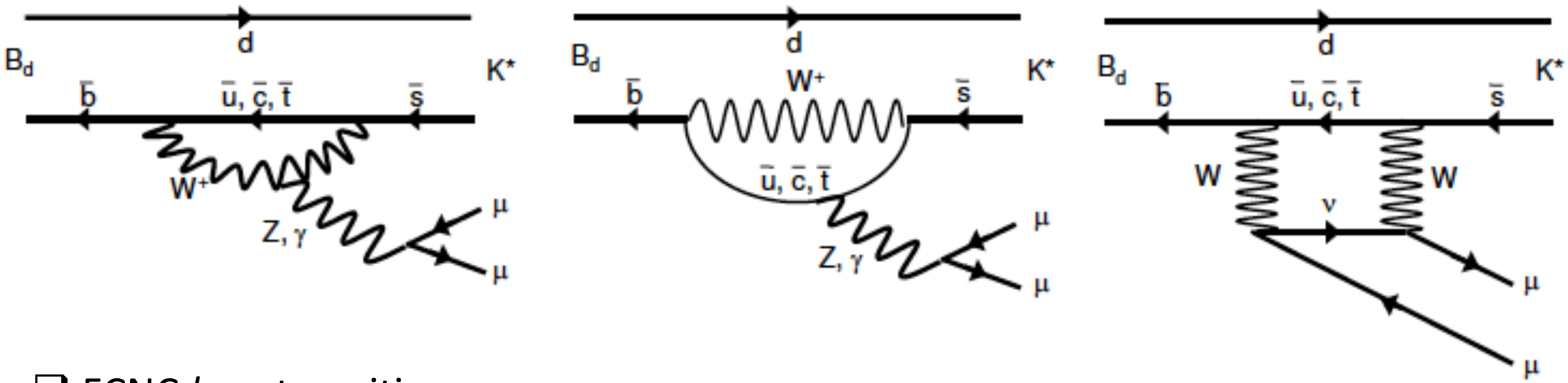
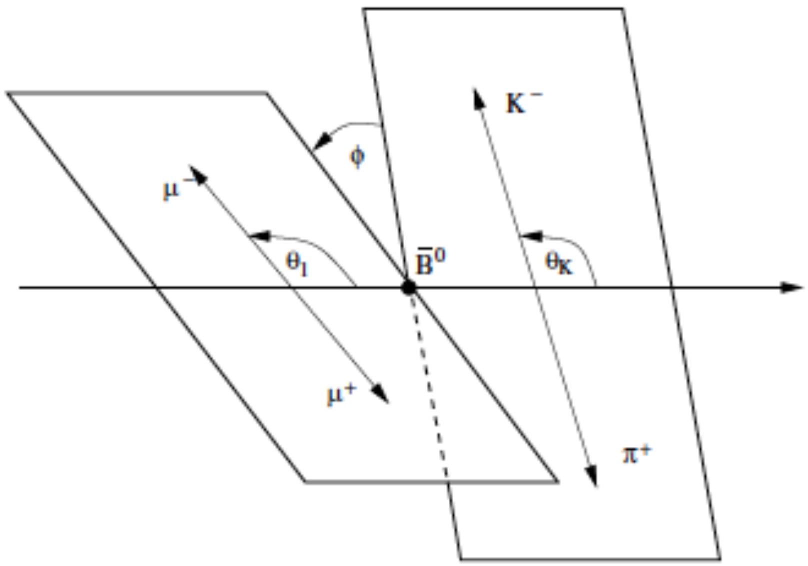
A SENSITIVE CHANNEL TO NEW PHYSICS!



- FCNC *b->s* transition
- Mediated by electroweak penguin and box diagram in SM
  (*C7* at low q^2 and *C9* and *C10* Wilson coefficients at high q^2)
- In SM: $BR=(9.8 \pm 2.1)*10^{-7}$
- Possible new physics contribution in the loops from right-handed currents and new scalar/pseudo-scalar operators.
- Can probe the helicity structure of the decay through angular observables.

ANGULAR ANALYSIS: FORMALISM (1)



The decay is totally described as function of ***q²*, θ_L , θ_K , ϕ :**

$$\frac{d^4\Gamma}{d\cos\theta_\ell \, d\cos\theta_K \, d\phi \, dq^2} \propto \Big[I_1^S + I_1^C + (I_2^S + I_2^C)\cos 2\theta_\ell + I_3 \sin^2\theta_\ell \cos 2\phi + \cancel{I_4 \sin 2\theta_\ell \cos\phi} + \cancel{I_5 \sin\theta_\ell \cos\phi} + I_6 \cos\theta_\ell + \cancel{I_7 \sin\theta_\ell \sin\phi} + \cancel{I_8 \sin 2\theta_\ell \sin\phi} + I_9 \sin^2\theta_\ell \sin 2\phi \Big]$$

Applying the transformation $\phi \to \pi - \phi$ the red terms disappear, leaving those with sensitivity to physics parameters

ANGULAR ANALYSIS: FORMALISM (2)

Expliciting the I_i terms, which contain the θ_K dependence *(with $F_T = 1-F_L$):*

$$\frac{1}{\Gamma}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[F_L\cos^2\theta_K + \frac{3}{4}F_T(1-\cos^2\theta_K) +$$
$$\frac{1}{4}F_T(1-\cos^2\theta_K)\cos 2\theta_\ell - F_L\cos^2\theta_K\cos 2\theta_\ell \ +$$
$$\frac{1}{4}A_T^2F_T(1-\cos^2\theta_\ell)(1-\cos^2\theta_K)\cos 2\phi \ +$$
$$\frac{4}{3}A_{FB}(1-\cos^2\theta_K)\cos\theta_\ell +$$
$$A_{Im}(1-\cos^2\theta_K)(1-\cos^2\theta_\ell)\sin 2\phi\ \Big]$$

- **Forward-backward asymmetry** of θ_L distribution
  - well predicted in q^2 range 1-6 GeV^2
  - zero crossing point evaluated theoretically with almost no hadronic uncertainties: 4.36+0.33-0.31 GeV^2 in SM

$$A_{\mathrm{FB}}(q^2) = \frac{\int_0^1 \frac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_{\mathrm{L}}}\,\mathrm{d}\cos\theta_{\mathrm{L}} - \int_{-1}^0 \frac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_{\mathrm{L}}}\,\mathrm{d}\cos\theta_{\mathrm{L}}}{\int_0^1 \frac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_{\mathrm{L}}}\,\mathrm{d}\cos\theta_{\mathrm{L}} + \int_{-1}^0 \frac{\partial^2\Gamma}{\partial q^2 \partial \cos\theta_{\mathrm{L}}}\,\mathrm{d}\cos\theta_{\mathrm{L}}} .$$

- **Fraction of longitudinal *K***

- **Fraction of longitudinal K^{*0} polarization**: $F_L = \dfrac{|A_0|^2}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$

- **Transverse asymmetry**: $A_T^2 = \dfrac{|A_\perp|^2 - |A_\parallel|^2}{|A_\perp|^2 + |A_\parallel|^2}$

  In helicity amplitudes: $A_T^2 \approx -2\dfrac{A_R}{A_L}$

- $A_{Im} = \dfrac{\mathrm{Im}(A_{\parallel L}^* A_{\perp L}) - \mathrm{Im}(A_{\parallel R}^* A_{\perp R})}{|A_0|^2 + |A_\perp|^2 + |A_\parallel|^2}$

Possible reparameterization:

$$A_{FB} = \frac{3}{4} F_T A_T^{Re} = \frac{3}{4}(1 - F_L) A_T^{Re}$$

$$A_{Im} = \frac{1}{2} F_T A_T^{Im} = \frac{1}{2}(1 - F_L) A_T^{Im}$$

ANGULAR ANALYSIS: FORMALISM (4)

Integrating on ϕ and θ_K :

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_l\,\mathrm{d}q^2} = \frac{3}{4}F_{\mathrm{L}}(1-\cos^2\theta_l) + \frac{3}{8}(1-F_{\mathrm{L}})(1+\cos^2\theta_l) + A_{\mathrm{FB}}\cos\theta_l$$

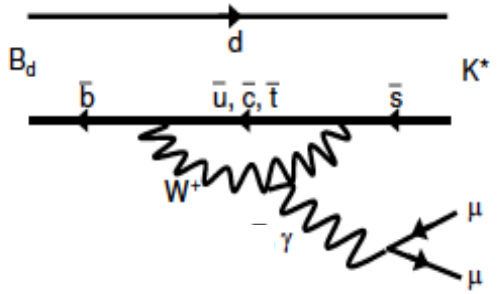
Integrating on ϕ and θ_L :

$$\frac{1}{\Gamma}\frac{\mathrm{d}^2\Gamma}{\mathrm{d}\cos\theta_K\,\mathrm{d}q^2} = \frac{3}{2}F_{\mathrm{L}}\cos^2\theta_K + \frac{3}{4}(1-F_{\mathrm{L}})(1-\cos^2\theta_K).$$

These are the **formulas used in the 2011 paper** (arXiv:1112.3515 [hep-ex]).

They have: - no S-wave contribution
- no higher K^{*0} resonances tails
- no lepton mass term (threshold effect)

B^0 -> K^*ee vs B^0 -> $K^*\mu\mu$



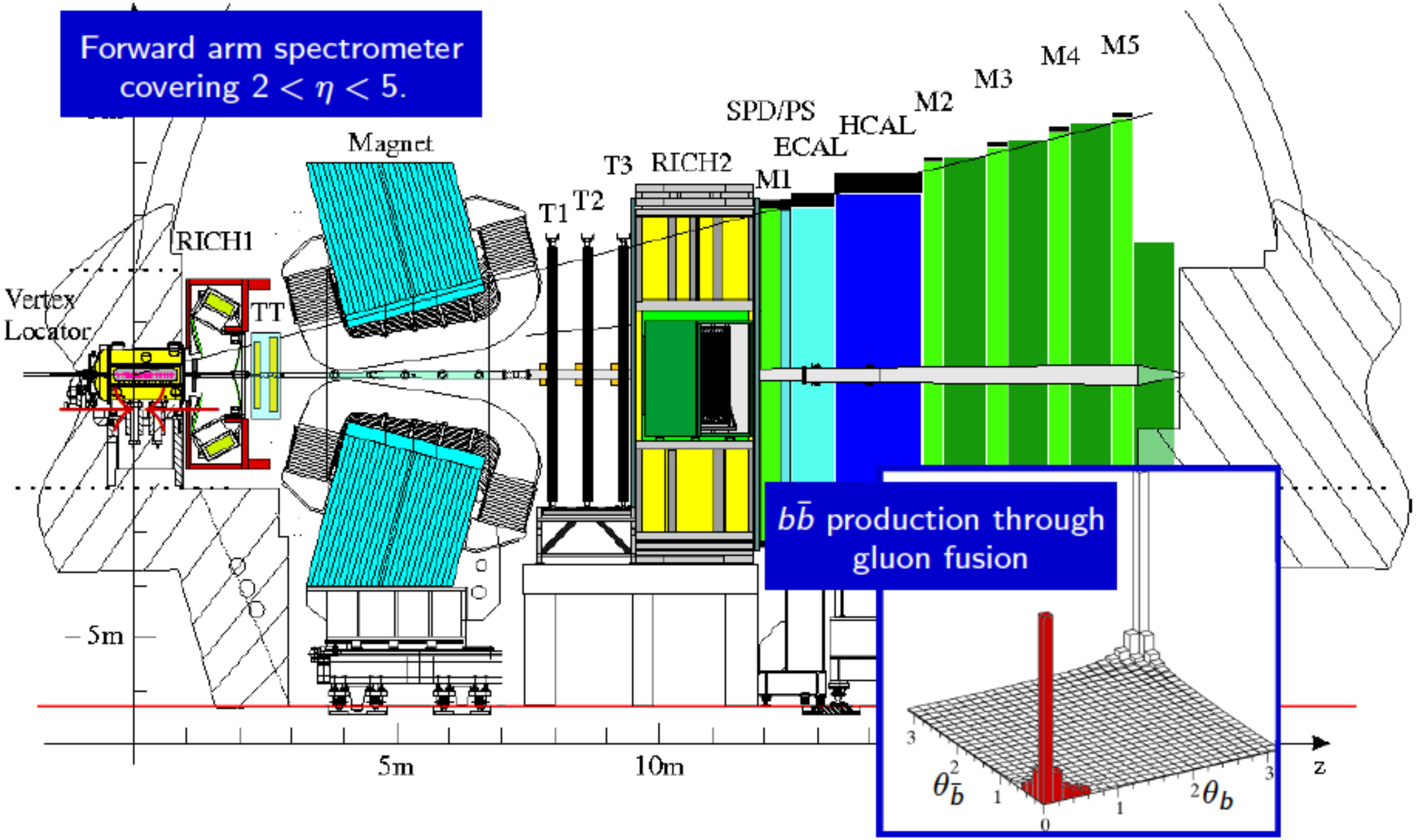
- B^0->K^*ee has in principle same informations as B^0->$K^*\mu\mu$

- At low q^2, the diagram with the photon is the dominant one
  => **measurement of the photon polarization**
  In SM photon polarization is A_R/A_L=0.04. If new physics?

- In B^0->K^*ee **no threshold effect** (i.e. lepton mass can be neglected):
  => one can reach much lower q^2 values.

- Focus on smaller q^2 region => can fold the θ_L angle to simplify the fit (no I_6)

- Unfortunately the B^0->K^*ee channel in the hadronic collider environment is experimentally **more challenging** than the one with muons:
  - trigger
  - reconstruction
  - bremssthralung recovery,
  - background subtraction…



Well working above design luminosity : 3 x 10^{32} $cm^{-2}s^{-1}$

EXPERIMENTAL CHALLENGES

- **Control of the backgrounds**
  => need efficient selection criteria providing good rejection.

- Understanding the **biases induced by the geometrical acceptance** on angular observables
  => need selection criteria designed to minimize such biases

- Control of external sources of asymmetry:
  - asymmetry in the detector (use magnet reversal)
  - production asymmetry of B vs $\overline{B}$ (few percent)

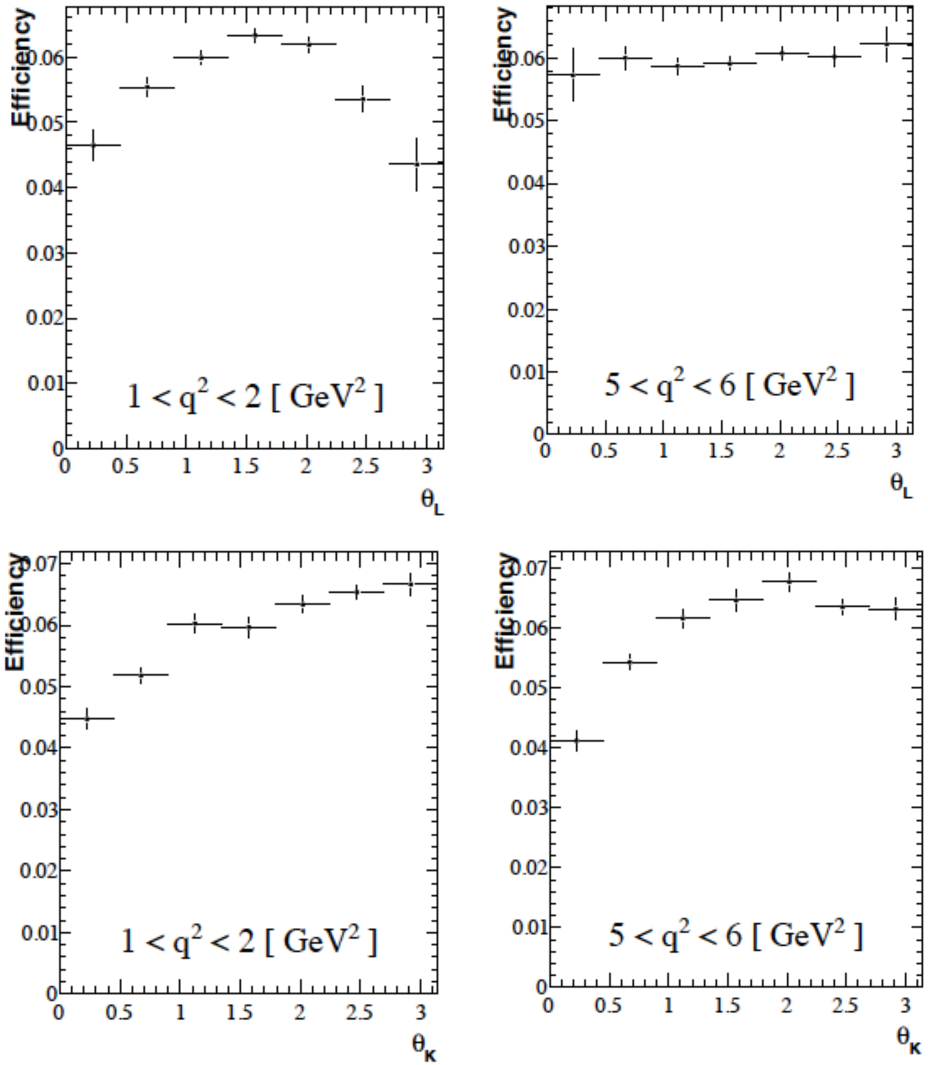
- Analysis is performed in bins of q^2, each bin having different acceptances, backgrounds,
  expected distributions….need many events in each bin

- Electron trigger and reconstruction for *B-> K*ee* channel

ACCEPTANCE EFFECTS

- Mainly due to geometry and reconstruction.
- Requirements:
  - $P(\mu) > 3\ GeV$ (=hits in the muon stations)
  - $P_T(\mu) > 300\ MeV$

  both affect the $\cos\theta_L$ acceptance.
- The effects are symmetric around $\theta_L=\pi/2$
- This alters the measurement of A_{FB}, scaling its value
- There is no impact on the zero crossing point, but the gradient being less pronounced, the error on the zero point is larger.
- Analogously for $\cos(\theta_K)$ but the acceptance is not symmetric due to the $K\ \pi$ mass difference



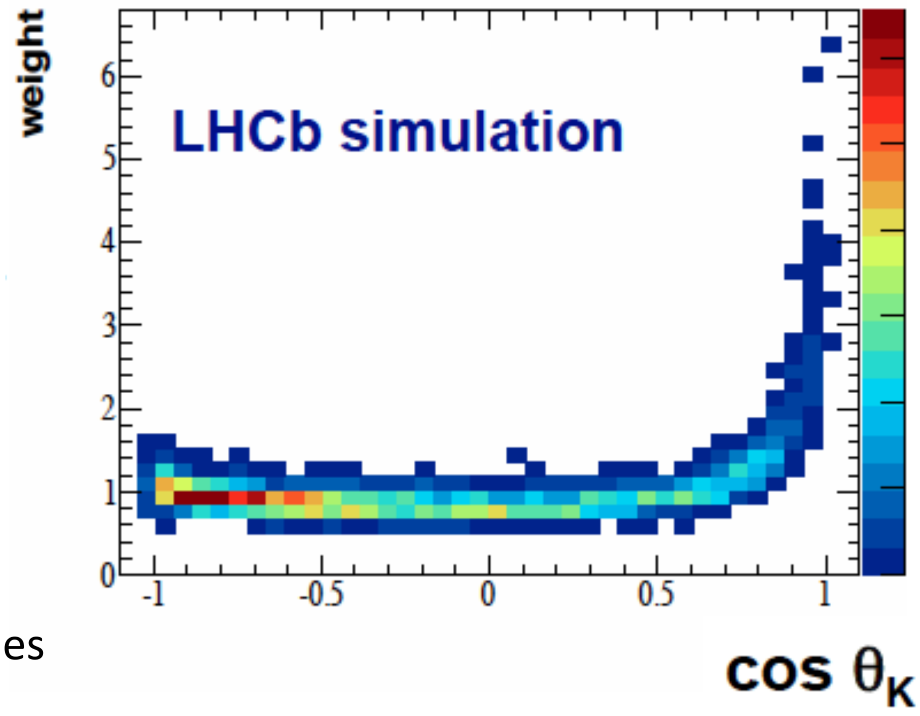
ACCEPTANCE CORRECTIONS

- Angular and q2 distributions are corrected for acceptance effects using weights from Monte Carlo simulation.

- The weights are determined event-by-event on the basis of the q^2, θ_L , θ_K of the signal candidates.

- Most of the weights are ~1

- Control channels are used to verify the good agreement with simulations for:
  - Tracking efficiency
  - Hadron (mis-)identification probabilities
  - μ (mis-)identification probabilities
  - P and η distributions



BACKGROUND EFFECTS

Different background categories give different impact:

- **Background from two μ coming from two different *B* decays**
  => gives a symmetric shape on θ_L
  => has impact only on the error of A_{FB}

- **Background from two μ coming from a single *B* decay chain**
  (one from the *B*, one from *D* for example)
  => asymmetric in θ_L , as one muon has larger P_T, so it simulates a forward event
  => has impact on the error and gives a bias on A_{FB}

- Similarly for the *K*

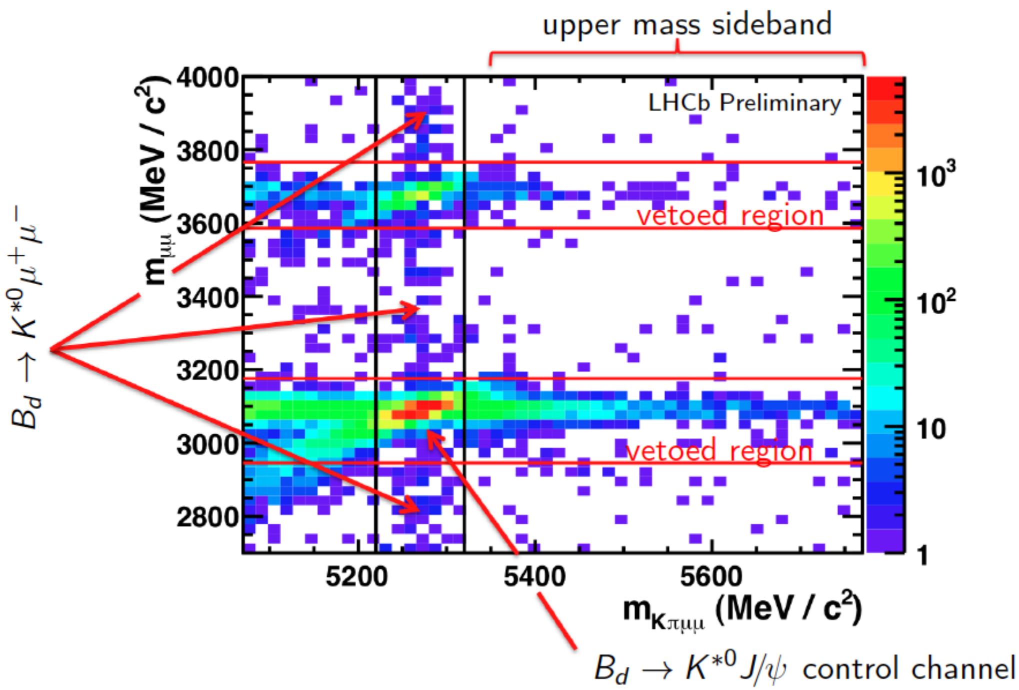
- **Backgrounds from non resonant $B^0 \to K\pi\mu\mu$ and higher K^{*0} resonances**

TRIGGER AND SELECTION

- Triggers: L0 => A single high pT muon
  HLT1 => A single high IP and high pT track
  HLT2 => Topology of the B_d decay is exploited
  No further biases on angular distributions introduced.

- For selection impact parameter significances are used rather than p_T cuts:
  - more discriminating
  - less biasing for the angular distributions

- ccbar resonances are removed using vetoes

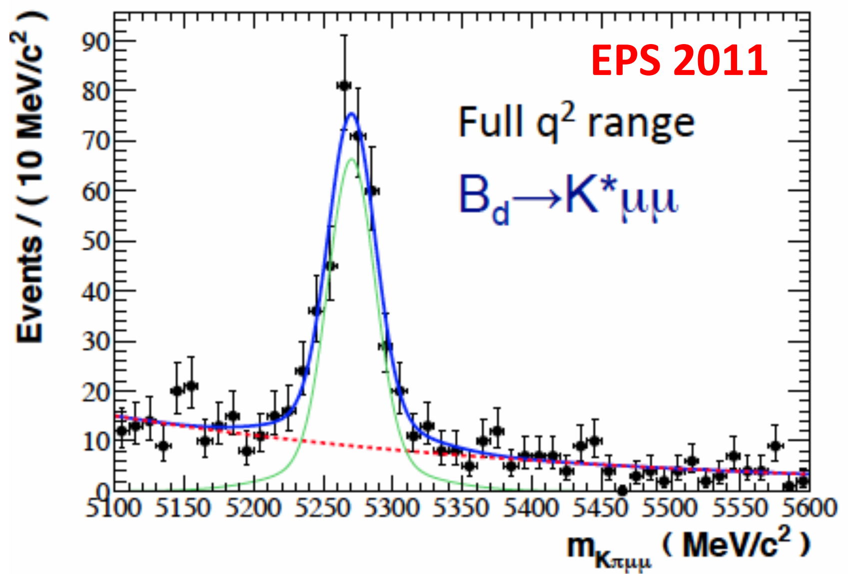


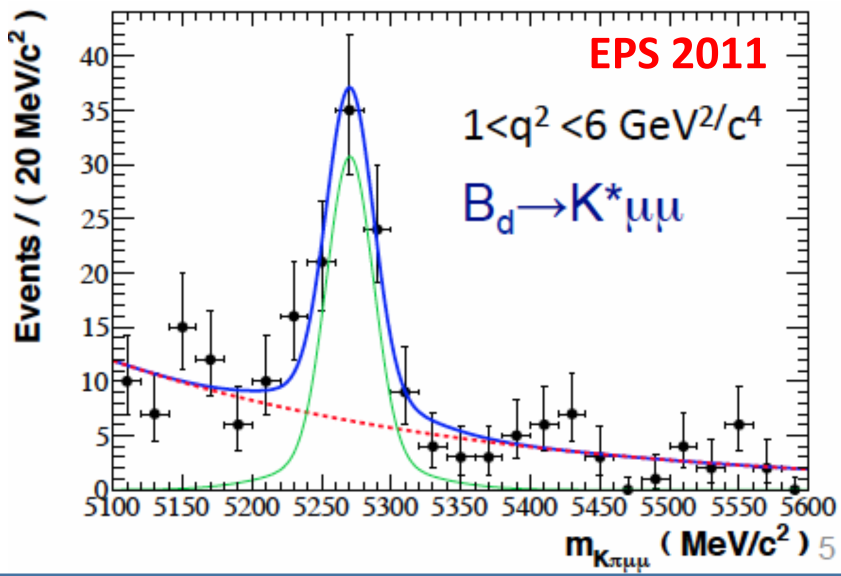
- The Boosted Decision Tree is trained on 2010 data, a sample independent from the one used for the measurement.
  Based on impact parameters, vertex and track quality, PID informations.

- Training samples are
  - $B\text{->}K^*J/\psi$ for signal
  - $B\text{->}K^*\mu\mu$ upper $m_{K\pi\mu\mu}$ sideband for background

- Purity: **S/B~0.3** (as *B* factories)

- Efficiency on angular distribution almost flat => no further biases induced





PEAKING BACKGROUNDS

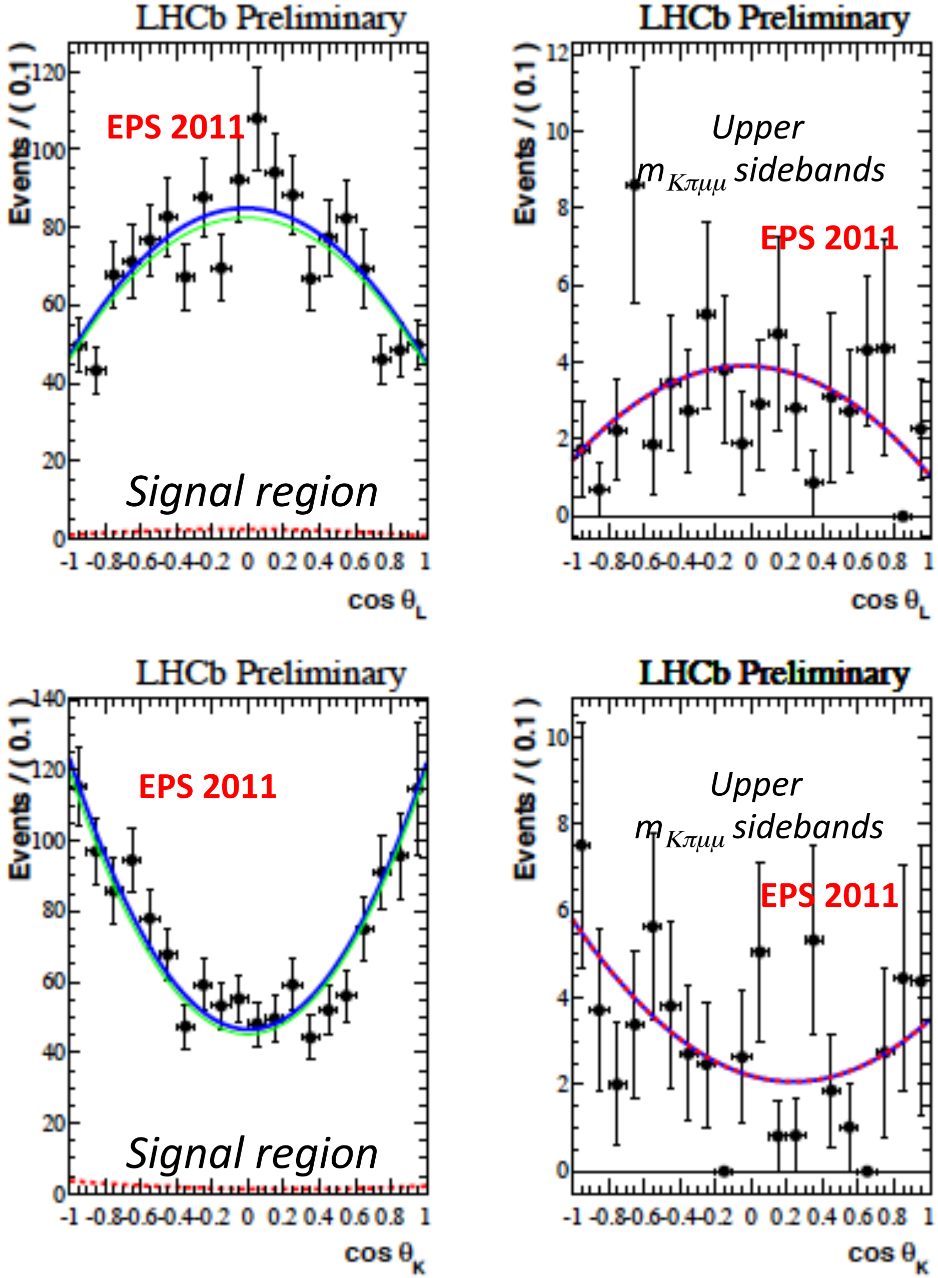
- Peaking backgrounds:
  - B_s -> $\phi\mu\mu$ if one *K is misID as* π
  - B_d -> *K* J/*ψ if π *(K) is misID as* μ and μ *is misID as* π *(K)* (passing *J/*ψ veto)
- Estimated reversing the mass hypothesis.
- *B->K**$\mu\mu$ with swapped *K* and π also taken into account in the fit
- Residual peaking backgrounds after selection is ~3% of signal, of which ~0.7% could affect asymmetry (EPS 2011).
  Further reduce to 1.8% with additional vetoes in the published result.

Source	Quantity	Signal Loss (%)
$B_s \to \phi\mu^+\mu^-$	2.3	0.1
$B^0 \to K^{*0}J/\psi$	0.7	0.1
$B^0 \to K^{*0}\mu^+\mu^-$	1.2	0.3
Total	4.2	0.5

EPS 2011

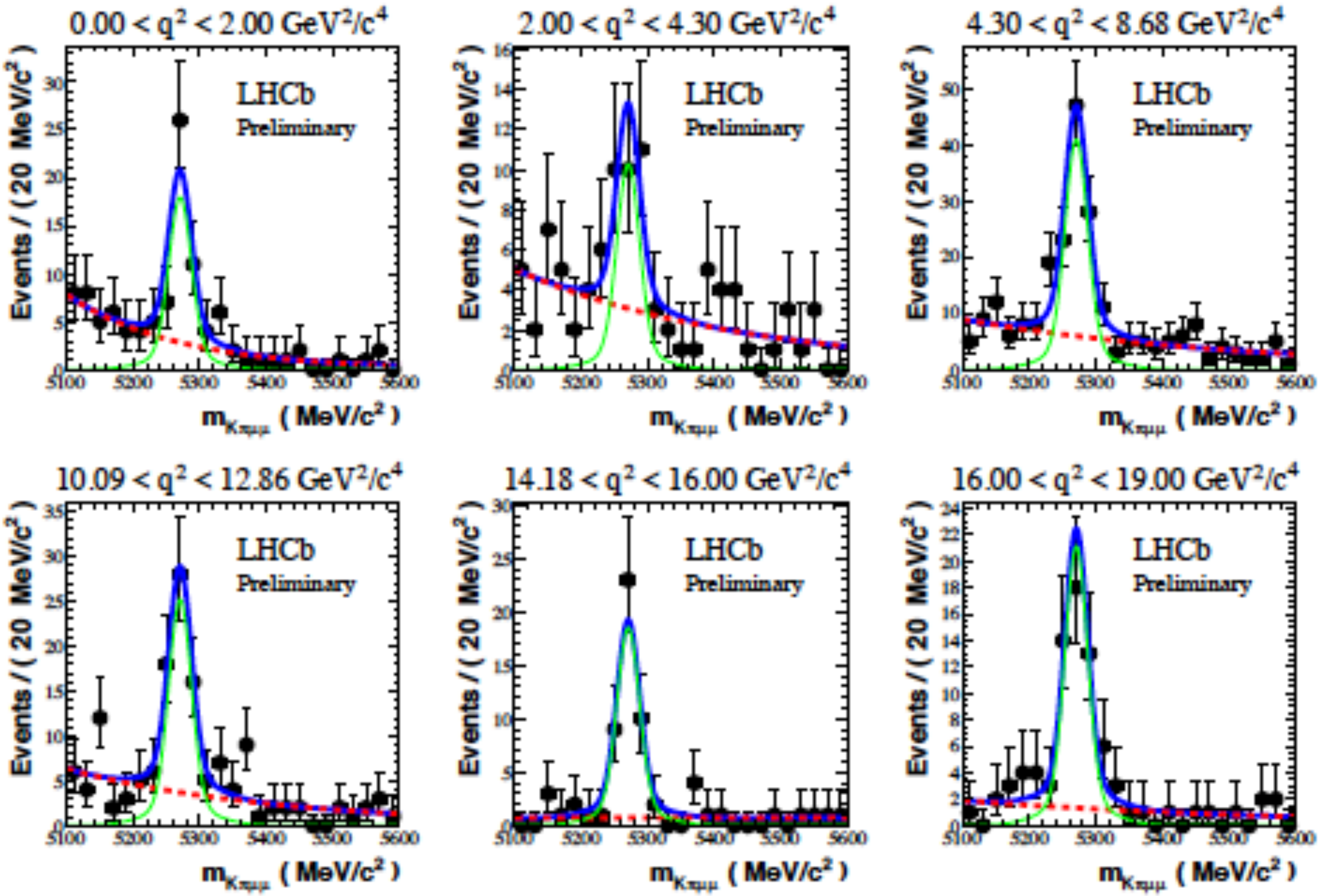
FIT PROCEDURE AND VALIDATION ON B_d -> K^* J/ψ

- Signal PDFs:
  - 3D angular pdf of $\cos\theta_L$, $\cos\theta_K$, q^2
  - double Gaussian for $m_{K\pi\mu\mu}$ PDF
- Background PDFs:
  - 2^{nd} order polynomial for angles
  - Exponential for $m_{K\pi\mu\mu}$
- Events are weighted to correct for acceptances
- A Bayesian approach is used to estimate the statistical error, with a flat prior over the physical region
- Results consistent with a simple counting approach (no angular distributions)
- Fit validated on B_d -> K^* J/ψ
  ~75 larger BR
  A_{FB} is consistent with 0 as expected
  ($900 < m_{K\pi} < 980$ MeV/c^2)



YIELDS PER q^2 BINS

EPS 2011



SYSTEMATICS UNCERTAINTIES

Sources of uncertainties:

- Data derived Monte Carlo corrections, varied within their uncertainties:
  - variation of PID performances, impact parameter resolution, track reconstruction efficiency, trigger p_T dependence

- Monte Carlo statistics

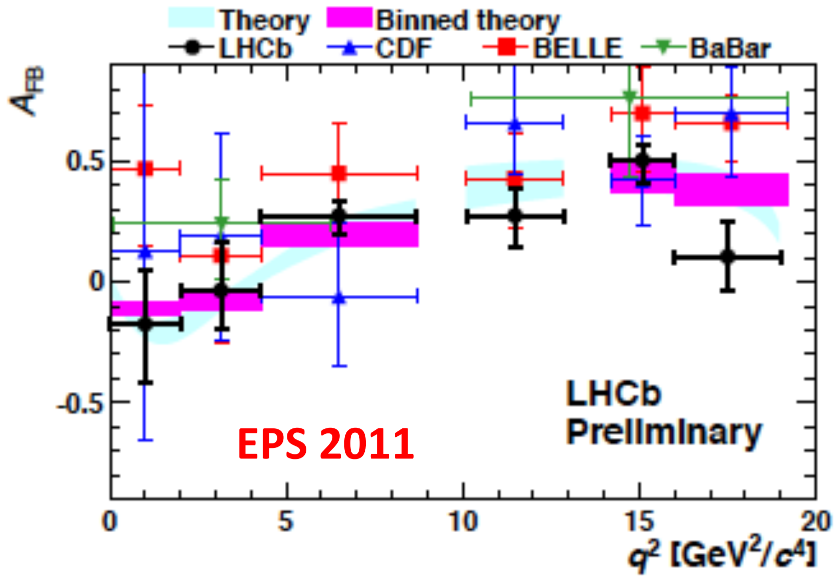
- Signal and background mass models

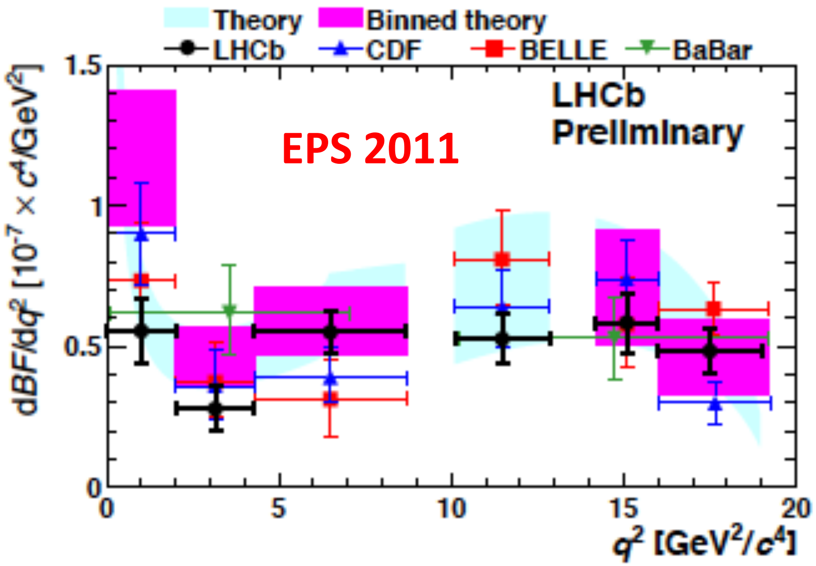
- Background angular models for A_{FB} ad F_L

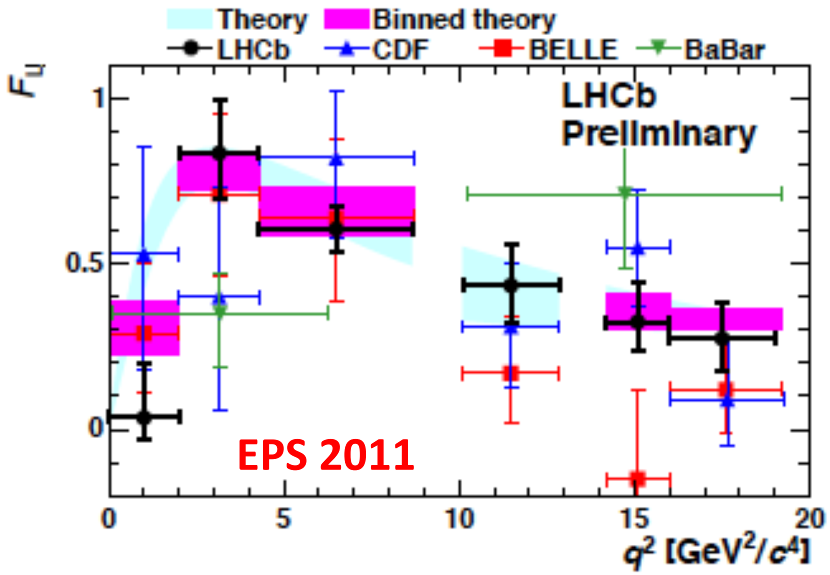
- BR(B_d->K^* J/ψ) used in normalization ($\simeq$4%)

Systematic uncertainty is currently O(30%) of the statistical uncertainty.
Improvements are expected with larger data samples.

RESULTS AND COMPARISONS (EPS 2011: LHCb-CONF-2011-038)







- Branching fractions are normalized to *BR(B_d->K* J/ψ)*
- Integrated luminosity: *~0.309 fb^{-1}*
- *LHCb* has the most precise measurements.
- In agreement with the SM predictions.
- Large asymmetry at low q^2 not confirmed.
- *Theory predictions from C. Bobeth et al., arXiv:1105.0376v2*

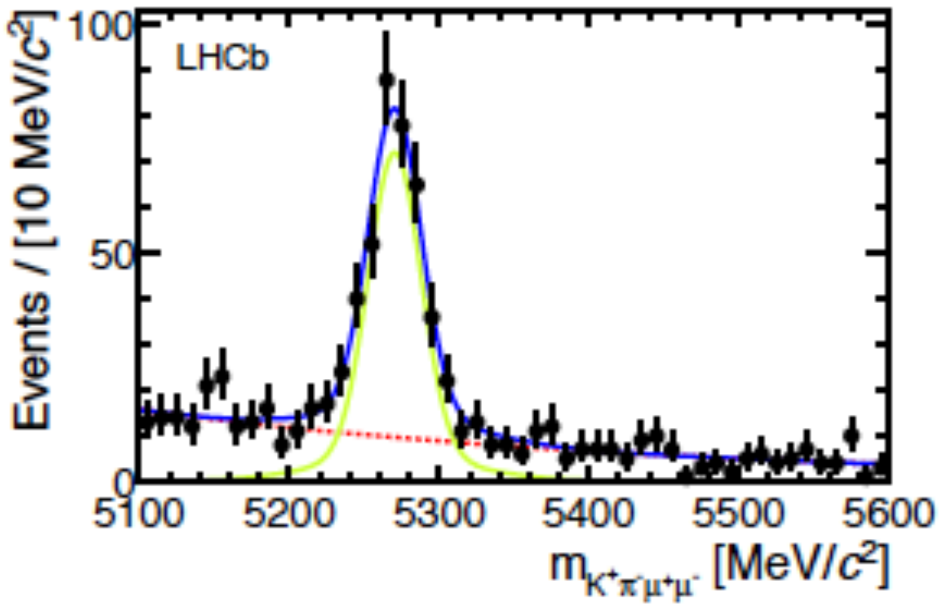
UPDATED RESULTS: (1)

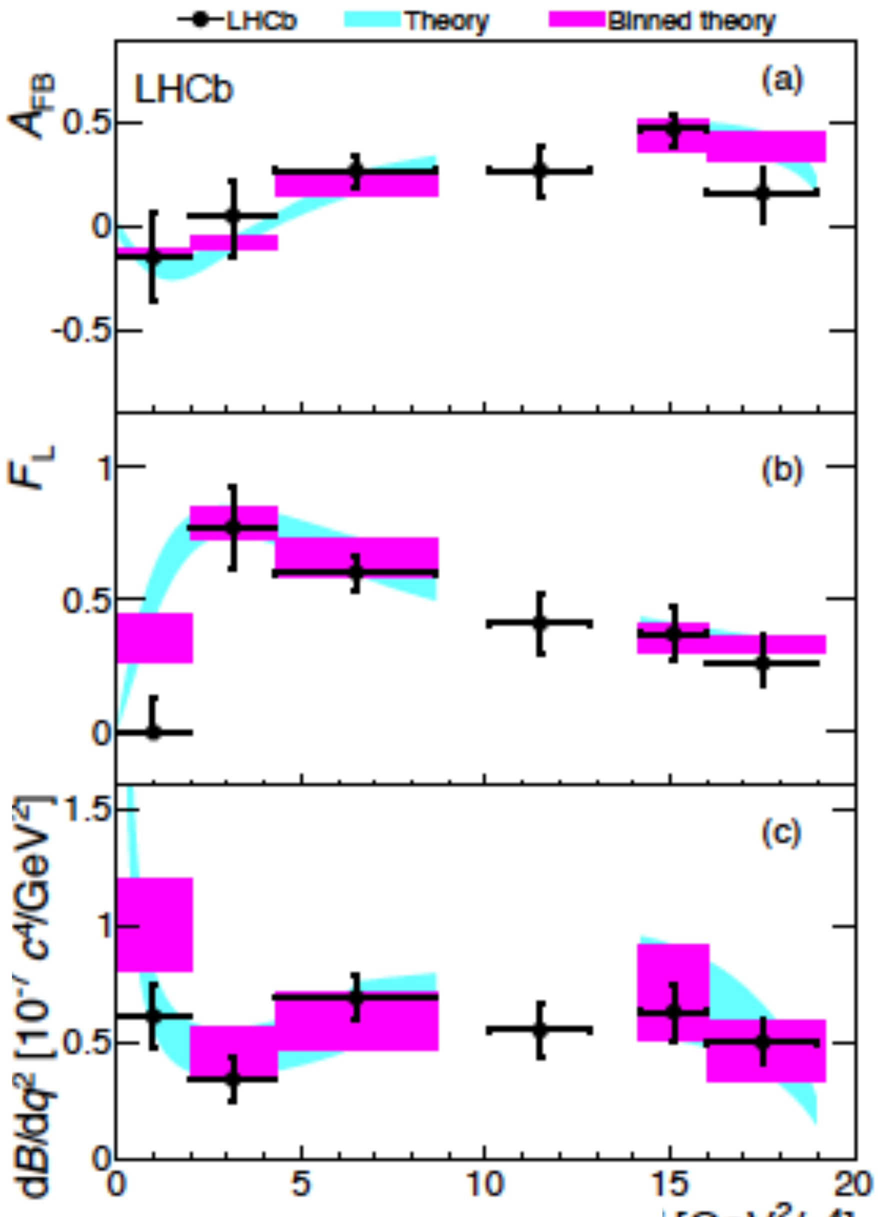
Paper published in December 2011:

''Differential branching fraction and angular analysis of the decay B^0->$K^{*0}\mu^+\mu^-$ ''

arXiv:1112.3515 [hep-ex]

Integrated luminosity: *0.37 fb^{-1}*





Theory predictions from C.Bobeth *et al.*, arXiv:1105.0376v2

UPDATED RESULTS (2)

TABLE I. Central values with statistical and systematic uncertainties for $A_{\rm FB}$, $F_{\rm L}$ and $d\mathcal{B}/dq^2$ as a function of q^2. The $B^0 \to K^{*0}\mu^+\mu^-$ signal and background yields in the $\pm 50\,{\rm MeV}/c^2$ signal mass window with their statistical uncertainties are also indicated, together with the statistical significance of the signal peak that is observed.

q^2 $({\rm GeV}^2/c^4)$	$A_{\rm FB}$	$F_{\rm L}$	$d\mathcal{B}/dq^2$ $(\times 10^{-7}\ c^4/{\rm GeV}^2)$	Signal yield	Background yield	Significance (σ)
$0.10 < q^2 < 2.00$	$-0.15 \pm 0.20 \pm 0.06$	$0.00\ ^{+0.13}_{-0.00} \pm 0.02$	$0.61 \pm 0.12 \pm 0.06$	48.6 ± 8.1	16.2 ± 2.3	8.6
$2.00 < q^2 < 4.30$	$0.05\ ^{+0.16}_{-0.20} \pm 0.04$	$0.77 \pm 0.15 \pm 0.03$	$0.34 \pm 0.09 \pm 0.02$	26.5 ± 6.5	15.7 ± 2.2	5.4
$4.30 < q^2 < 8.68$	$0.27\ ^{+0.06}_{-0.08} \pm 0.02$	$0.60\ ^{+0.06}_{-0.07} \pm 0.01$	$0.69 \pm 0.08 \pm 0.05$	104.7 ± 11.9	31.7 ± 3.3	12.4
$10.09 < q^2 < 12.86$	$0.27\ ^{+0.11}_{-0.13} \pm 0.02$	$0.41 \pm 0.11 \pm 0.03$	$0.55 \pm 0.09 \pm 0.07$	62.2 ± 9.2	20.4 ± 2.6	9.6
$14.18 < q^2 < 16.00$	$0.47\ ^{+0.06}_{-0.08} \pm 0.03$	$0.37 \pm 0.09 \pm 0.05$	$0.63 \pm 0.11 \pm 0.05$	44.2 ± 7.0	4.2 ± 1.3	10.2
$16.00 < q^2 < 19.00$	$0.16\ ^{+0.11}_{-0.13} \pm 0.06$	$0.26\ ^{+0.10}_{-0.08} \pm 0.03$	$0.50 \pm 0.08 \pm 0.05$	53.4 ± 8.1	7.0 ± 1.7	9.8
$1.00 < q^2 < 6.00$	$-0.06\ ^{+0.13}_{-0.14} \pm 0.04$	$0.55 \pm 0.10 \pm 0.03$	$0.42 \pm 0.06 \pm 0.03$	76.5 ± 10.6	33.1 ± 3.2	9.9

CONCLUSIONS

- The B^0->K^*ll channel is extremely interesting for its **sensitivity to new physics**.
- ***LHCb* has the largest sample of B^0->$K^*\mu\mu$ events**: time for precise measurements has come.
- **The *LHCb* measurements** of A_{FB}, F_L and $d\Gamma/dq^2$ **are already the most precise** available. Errors are statistically dominated.
- **The large A_{FB} asymmetry** in the low q^2 region hinted by previous experiments **is not confirmed by *LHCb***
- At the moment results are **in agreement within the errors with the SM expectations.**

NICE PERSPECTIVES AHEAD!

- LHCb has collected ~$1fb^{-1}$ of data and it will continue collecting data in 2012.

- The full angular analysis with $1fb^{-1}$ is under preparation:
  - Discussions on the set of physics parameters to measure are ongoing
  - Consider the threshold effect
  - Include a possible S-wave contribution
  - Profit of more abundant control channels
  - Improve the fittings procedure, systematics treatment

- On a longer term scale:
  - measure the $B^0 \to K^* ee$ channel
  - combine the results of $B^0 \to K^* ee$ and $B^0 \to K^* \mu\mu$

BACKUP

THRESHOLD TERM FORMULAS

$$\frac{d\Gamma}{d\cos\Theta_K d\cos\Theta_\ell d\phi} = \varepsilon(\cos\Theta_K)\times\varepsilon(\cos\Theta_\ell)\times$$

$$[I_1(\cos\Theta_K) + I_2(\cos\Theta_K)\times(2\cos^2\Theta_\ell - 1) + I_3(\cos\Theta_K)\times(1-\cos^2\Theta_\ell)\cos 2\phi$$

$$+I_6(\cos\Theta_K)\times\cos\Theta_\ell + I_9(\cos\Theta_K)\times(1-\cos^2\Theta_\ell)\sin 2\phi]$$

$$I_{1s} = \frac{3}{4}(1-F_L)\times\left(1+\frac{1}{3}\cdot\frac{4m_\ell^2}{q^2}\right) \qquad I_{1c} = F_L\times\left(1+\frac{4m_\ell^2}{q^2}\right)$$

$$I_1 = I_{1s}\times(1-\cos^2\Theta_K) + I_{1c}\times\cos^2\Theta_K$$

$$I_{2s} = \frac{1}{4}(1-F_L)\times\left(1-\frac{4m_\ell^2}{q^2}\right) \qquad I_{2c} = -F_L\times\left(1-\frac{4m_\ell^2}{q^2}\right)$$

$$I_2 = I_{2s}\times(1-\cos^2\Theta_K) + I_{2c}\times\cos^2\Theta_K$$

$$I_3 = \frac{1}{2}(1-F_L)\times A_T^{(2)}\times\left(1-\frac{4m_\ell^2}{q^2}\right)\times(1-\cos^2\Theta_K)$$

$$I_6 = 2\sqrt{1-4\frac{m_\ell^2}{q^2}}A_T^{(\mathrm{Re})}(1-F_L)\times(1-\cos^2\Theta_K)$$

$$I_9 = \frac{1}{2}(1-F_L)\times A_T^{(\mathrm{Im})}\times\left(1-\frac{4m_\ell^2}{q^2}\right)\times(1-\cos^2\Theta_K)$$

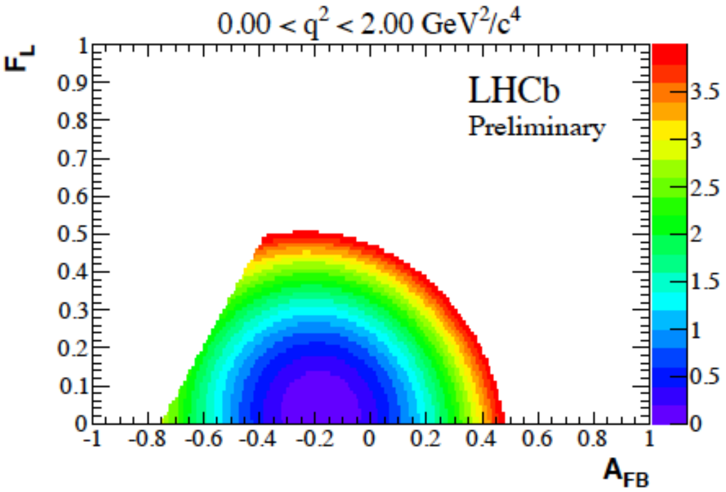
$$F_L = \frac{|A_0|^2}{|A_0|^2+|A_\perp|^2+|A_{||}|^2}$$

$$A_T^{(2)} = \frac{|A_\perp|^2-|A_{||}|^2}{|A_\perp|^2+|A_{||}|^2}$$

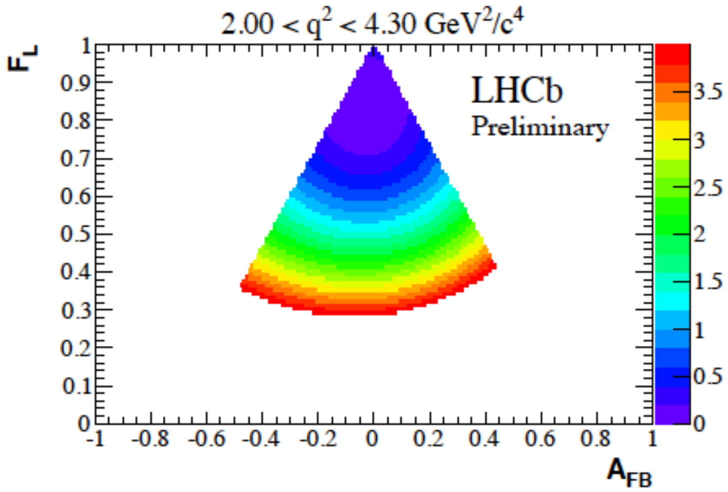
$$A_T^{(\mathrm{Im})} = \frac{2\,\mathrm{Im}\left(A_{||L}^*A_{\perp L}+A_{||R}^*A_{\perp R}\right)}{|A_\perp|^2+|A_{||}|^2}$$

$$A_T^{(\mathrm{Re})} = \frac{2\,\mathrm{Im}\left(A_{||L}A_{\perp L}^*-A_{||R}A_{\perp R}^*\right)}{|A_\perp|^2+|A_{||}|^2}$$

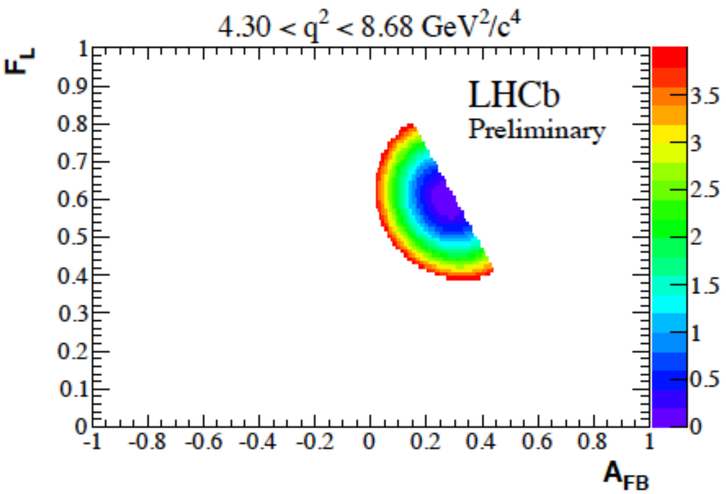
PROFILE LIKELIHOOD CONTOURS -1



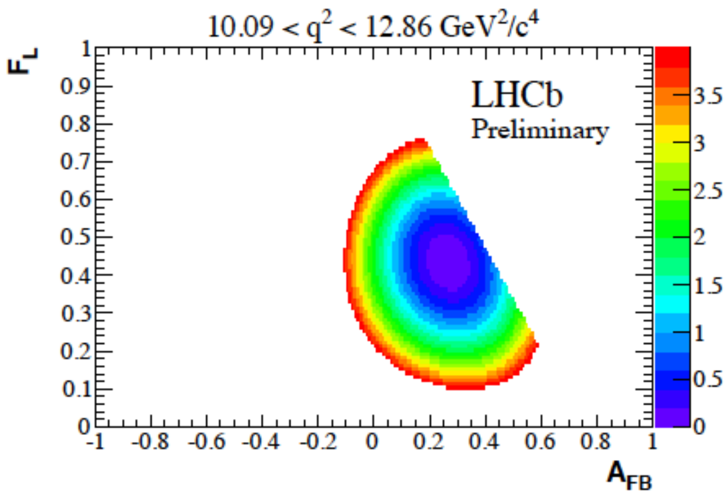
(a) $0 < q^2 < 2\,\mathrm{GeV}^2$



(b) $2 < q^2 < 4.3\,\mathrm{GeV}^2$

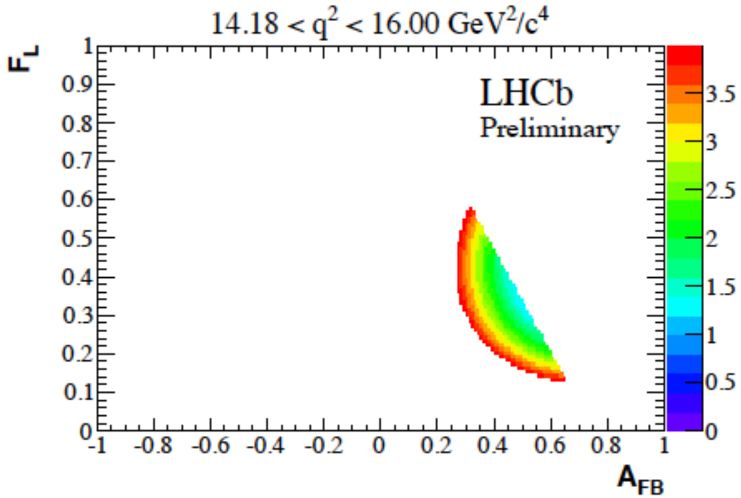


(c) $4.3 < q^2 < 8.68\,\mathrm{GeV}^2$

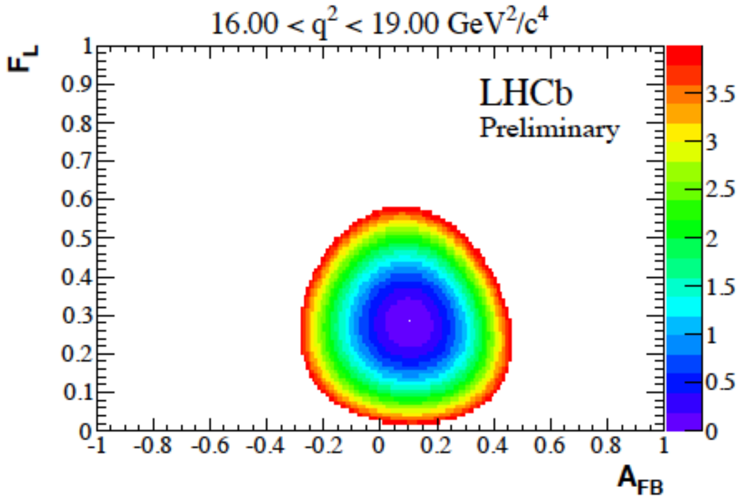


(d) $10.09 < q^2 < 12.86\,\mathrm{GeV}^2$

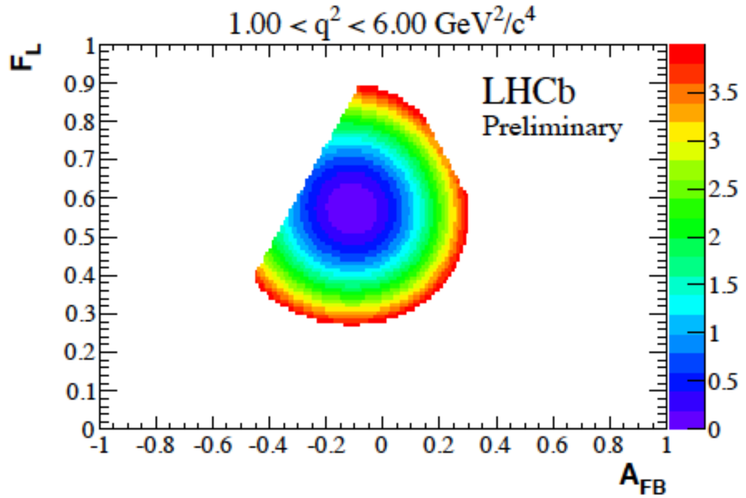
PROFILE LIKELIHOOD CONTOURS - 2



(e) $14.18 < q^2 < 16\,\mathrm{GeV}^2$



(f) $16 < q^2 < 19\,\mathrm{GeV}^2$



(g) $1 < q^2 < 6\,\mathrm{GeV}^2$