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Exclusive $B \rightarrow X_s l^+ l^-$

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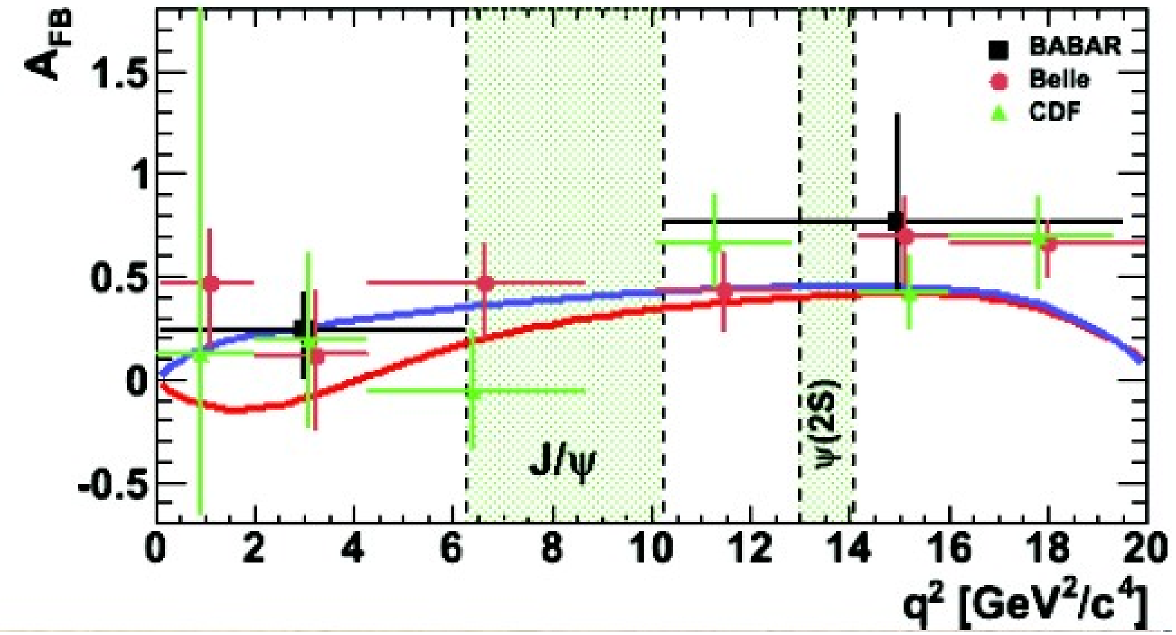
- The available experimental data
- What to measure
- An example of an analysis (LHCb!)
- Overview of results
- Future

Durham, September 2011

The past

- Belle and BaBar collected data at the Υ(4S) resonance
  - 711 fb^{-1}, and 433 fb^{-1} collected respectively
- Looked at $B \to K^{(*)} l^+ l^-$ in 10 exclusive final states
  - BaBar has around 100 events and Belle around 250
  - Both experiments can make modest improvements with current data



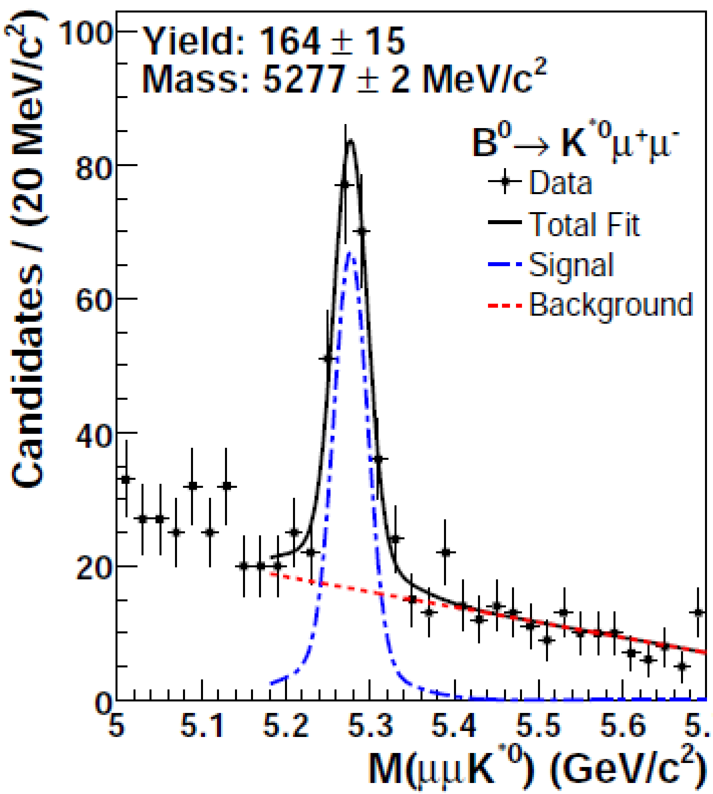
The present

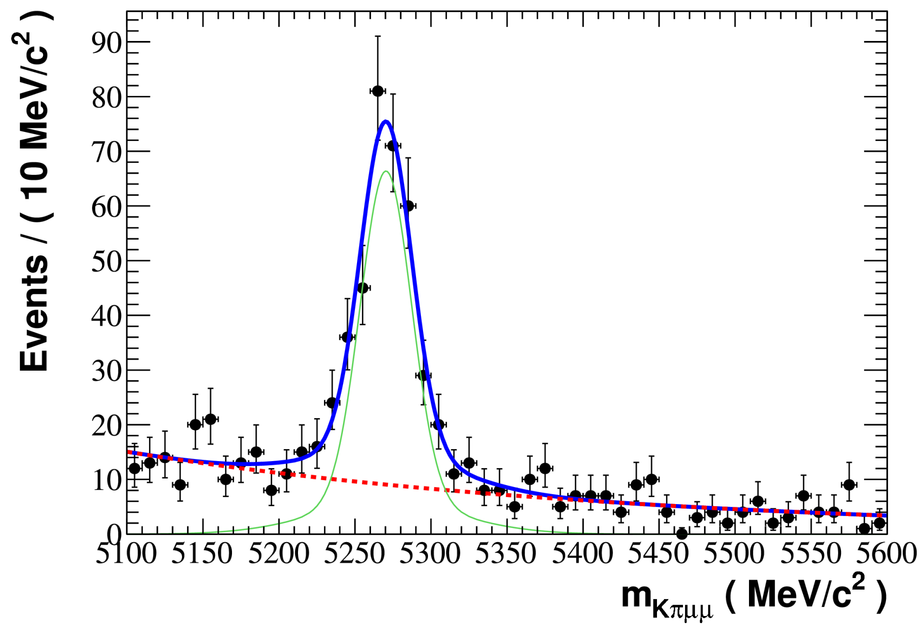
CDF presented results this summer based on 6.8 fb^{-1}

- This gives around 200 $B \to K^*\mu\mu$ in total

LHCb also this summer on 309 pb^{-1}

- This gives around 300 $B^0 \to K^{*0}\mu\mu$ events



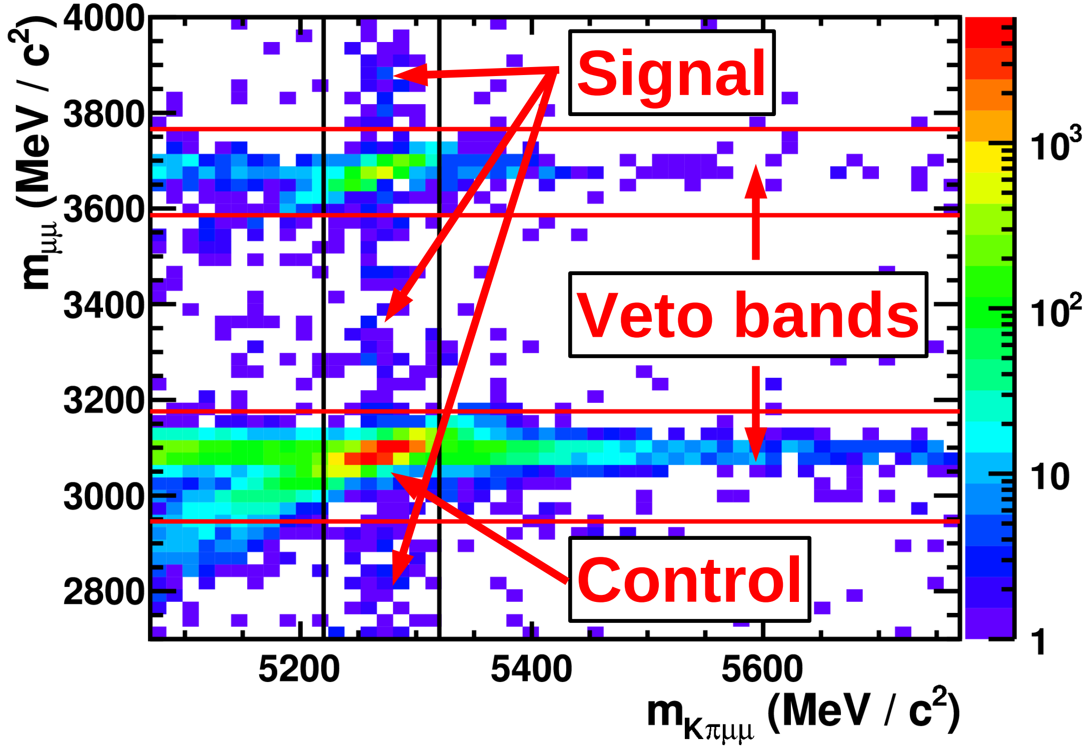


What to measure

- (Differential) Branching fractions
- Angular observables
- CP asymmetries
- Isospin asymmetries

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

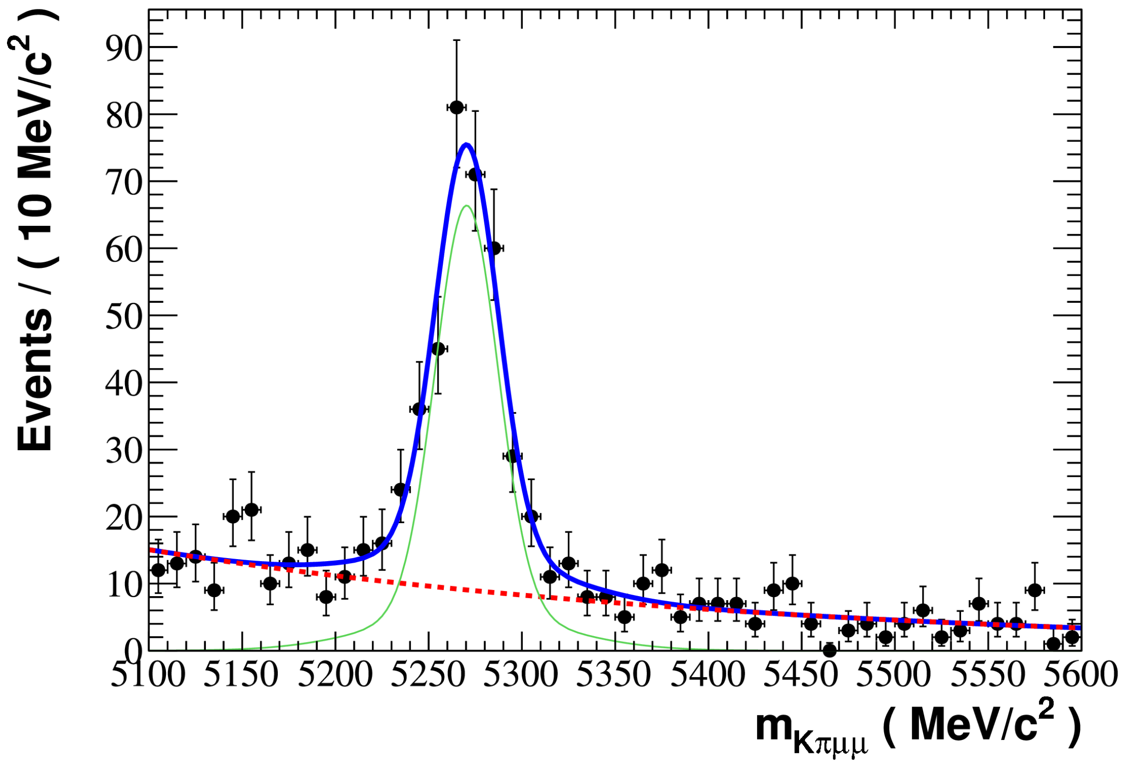
- Select events with boosted decision tree
  - Trained on $B^0 \to J/\psi K^{*0}$ control channel and signal side-band from 2010 data
- Correct for efficiency
  - Use event-by-event correction
- Verify analysis
  - Use known $B^0 \to J/\psi K^{*0}$ angular distribution
- Fit for observables
  - Perform simultaneous fit to mass and angular distribution



The signal from 309 pb^{-1}

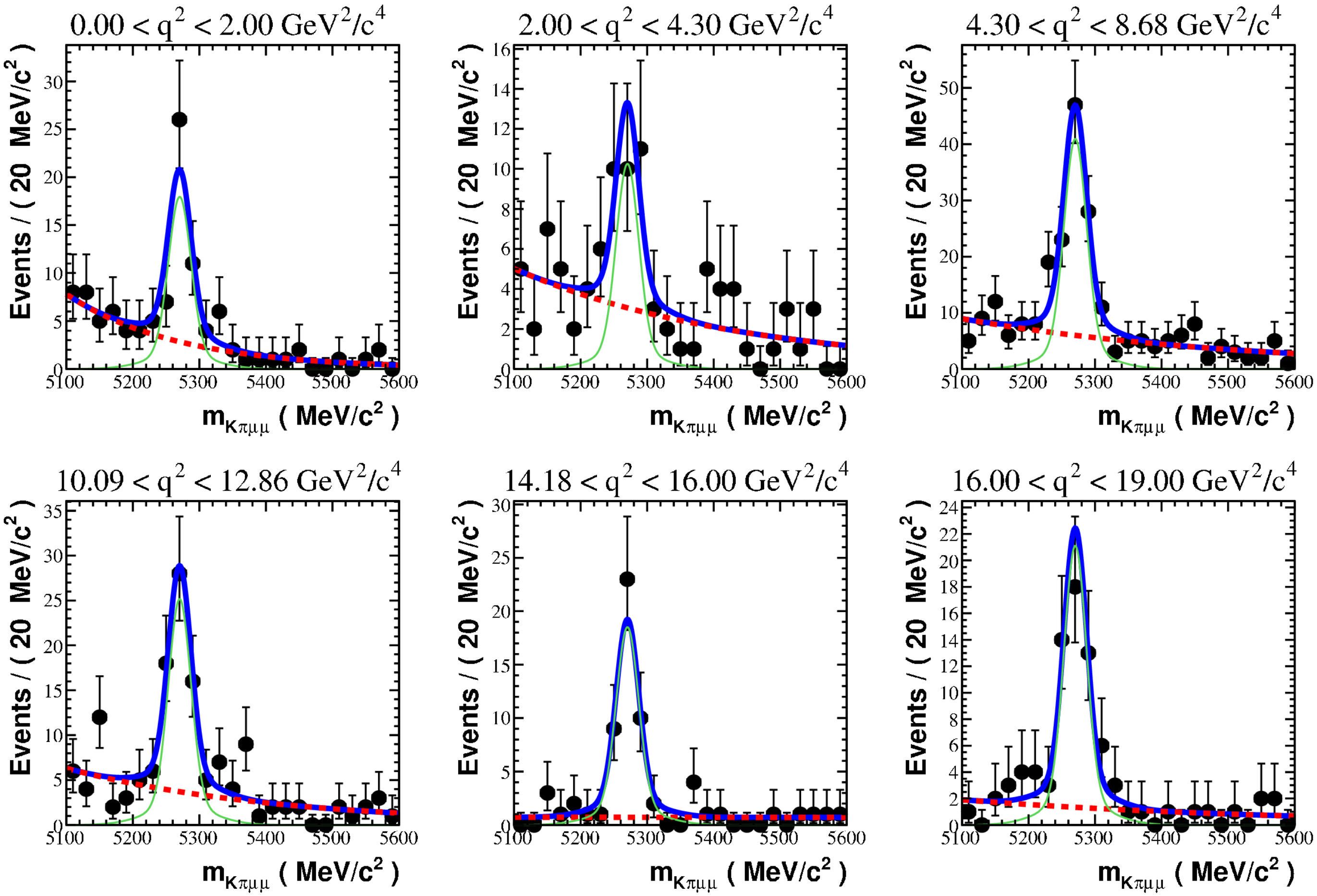
After J/ψ and ψ(2S) vetoes, LHCb see 302±20 signal events

$B^0 \rightarrow K^{*0}\mu^+\mu^-$ signal is very clean!



Regions of squared di-muon mass, q^2

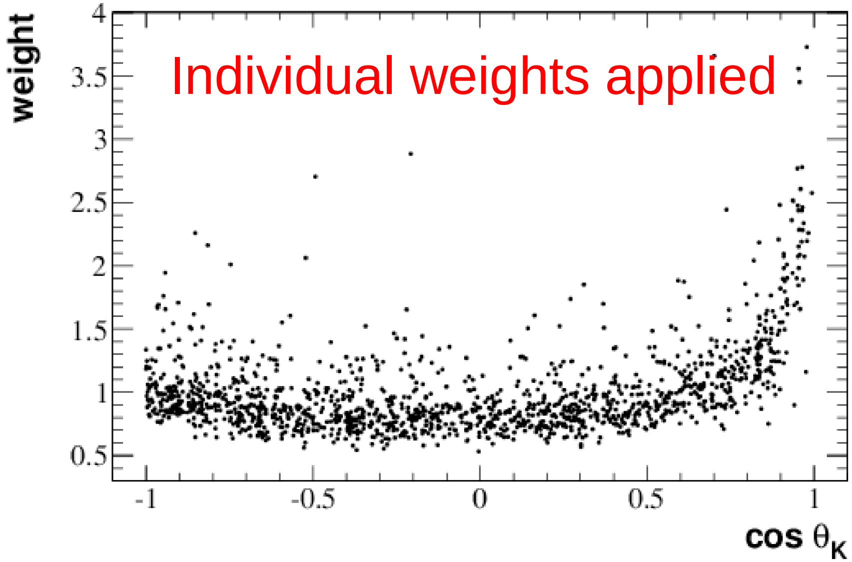
In each of the bins signal significance of 5 or higher



Efficiency correction

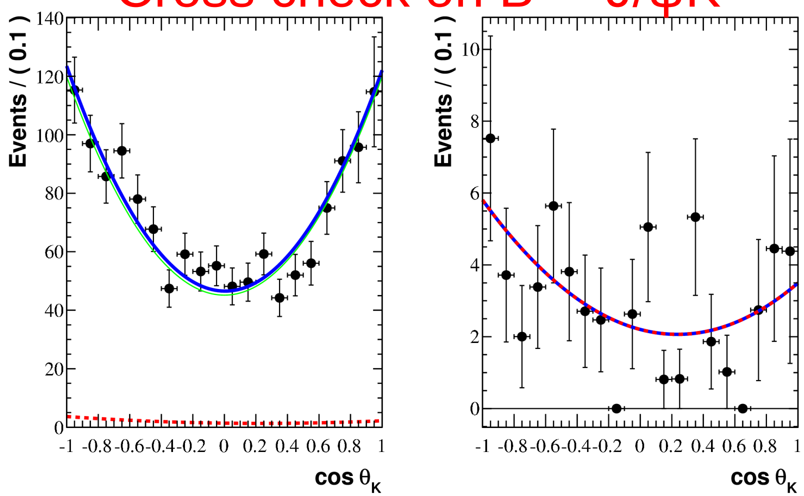
Events are individually efficiency corrected based on their kinematics in the B rest frame

- Simulation calibrated with data driven input on PID and detector resolution



Method cross checked by fitting $B^0 \rightarrow J/\psi K^{*0}$

- When including S-wave, result is in very good agreement with BaBar analysis



Fit for observables

An unbinned likelihood fit with event-by-event weights is performed for each q^2 bin

Simultaneous fit to mass, θ_K and θ_l projections

Signal

- Crystal Ball in mass

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

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

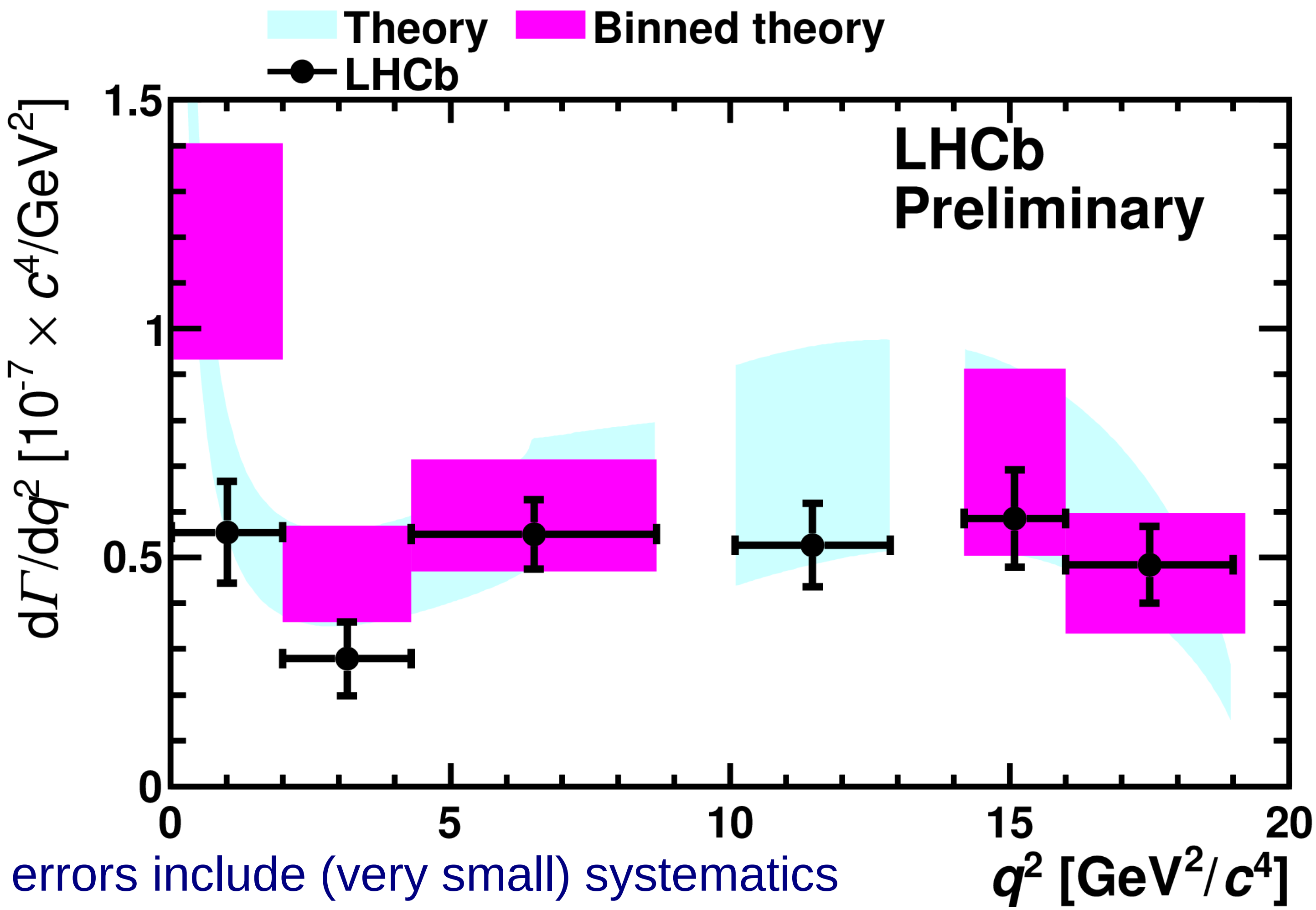
Background

- Exponential in mass
- Polynomial in angles

Systematic evaluations

- Issues related to efficiency correction
  - Variation in PID and detector resolution corrections
  - Trigger modelling
  - Uncertainty in B momentum spectra
  - Track reconstruction efficiency
- Fitting
  - Signal shape uncertainty
  - Background shape uncertainty
- The largest systematics are all dominated by statistics of data or simulation
  - Same analysis strategy can be used for much larger sample
  - Total error is never more than 10% larger than statistics only error

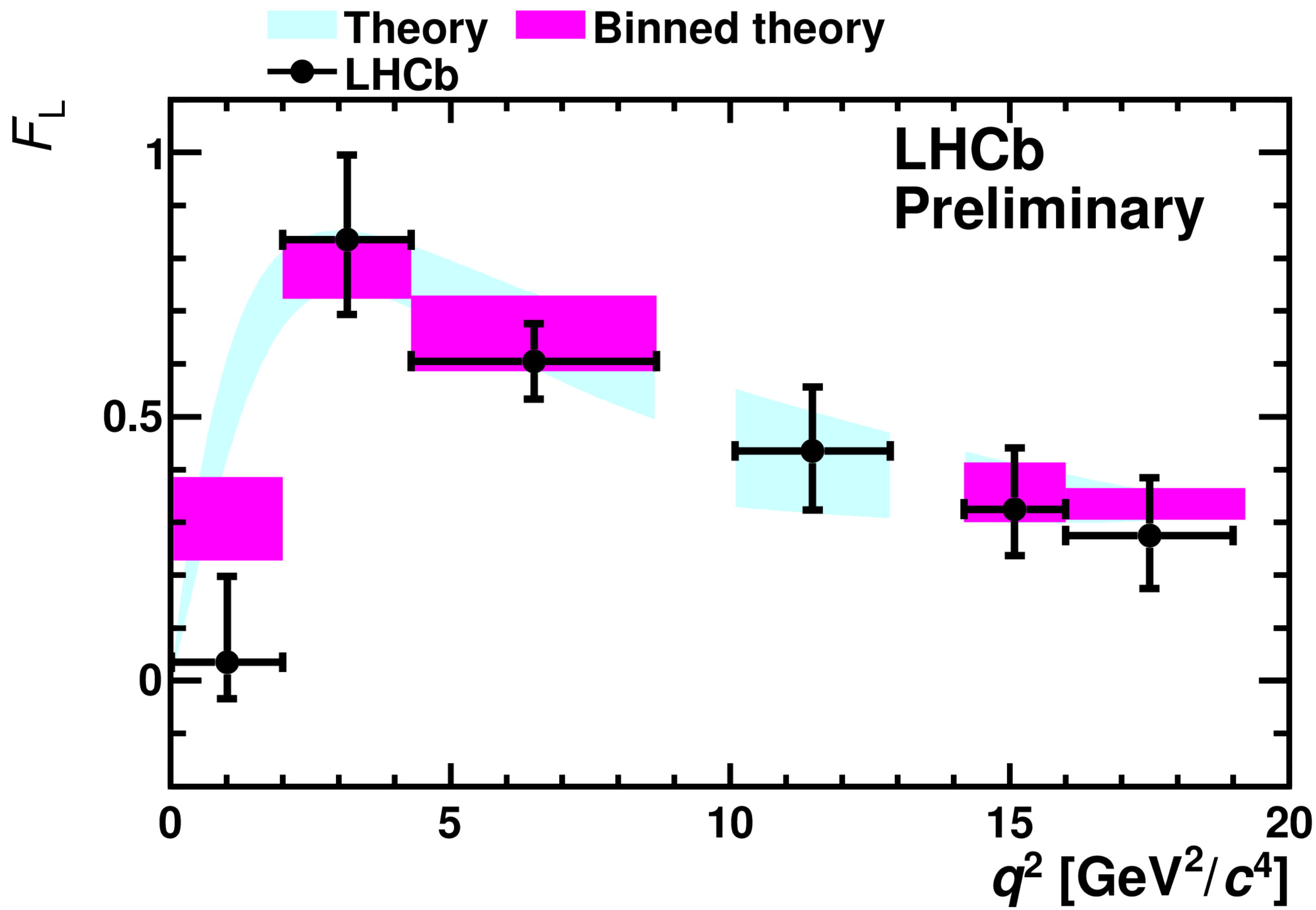
Differential decay rate



LHCb errors include (very small) systematics

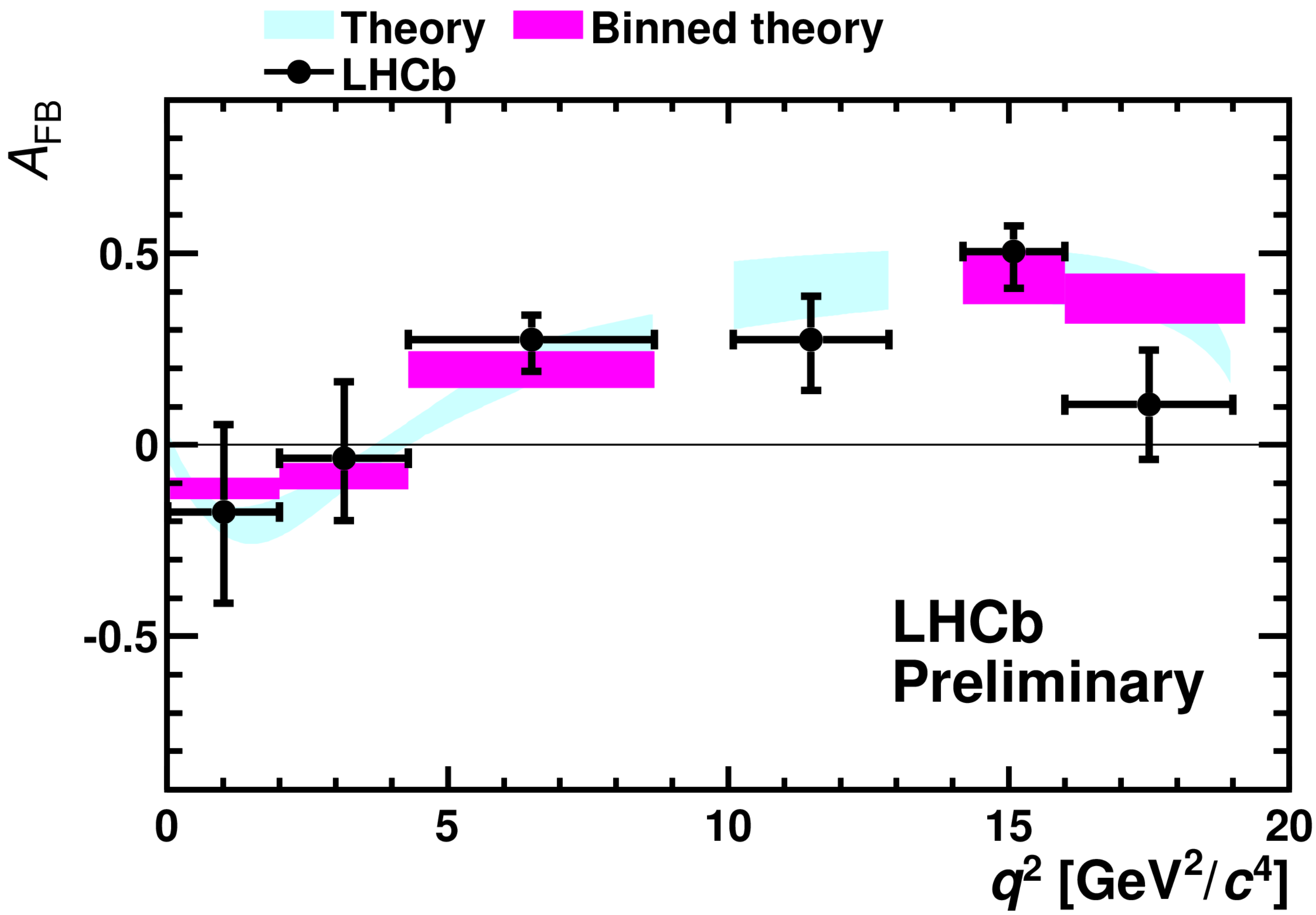
SM theory from Bobeth, Hiller, van Dyk. JHEP 1007, 098 (2010) and arXiv:1105.0376

K^{*0} longitudinal polarisation, F_L



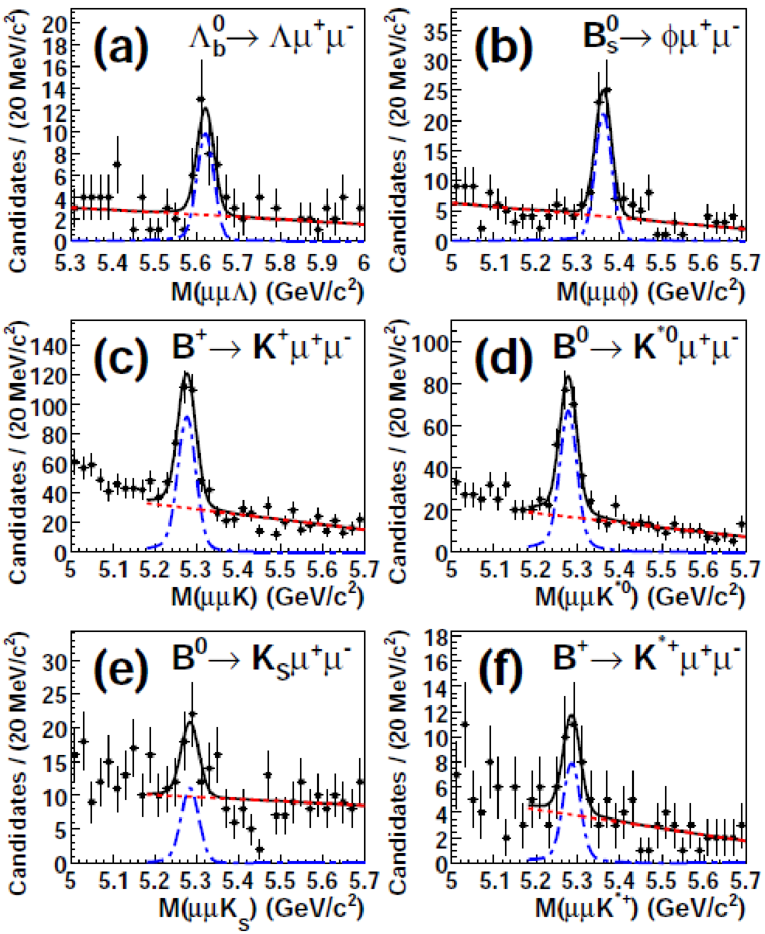
Errors from Bayesian approach with flat prior for physical region of F_L,A_{FB} plane. Systematics included.

Forward-backward asymmetry A_{FB}



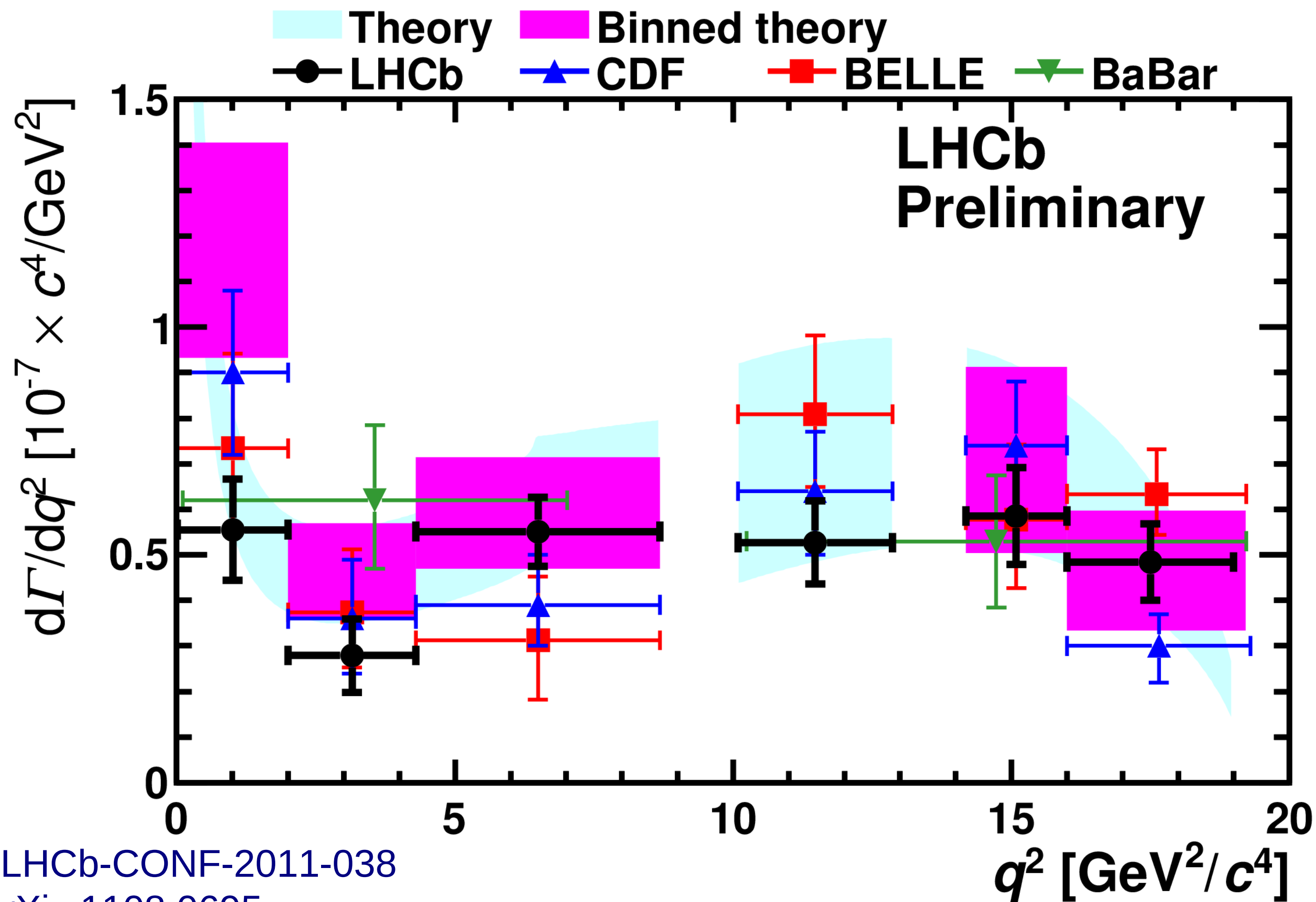
Branching fractions

CDF at the moment provides the most comprehensive set of BF measurements (arXiv:1107.3753)



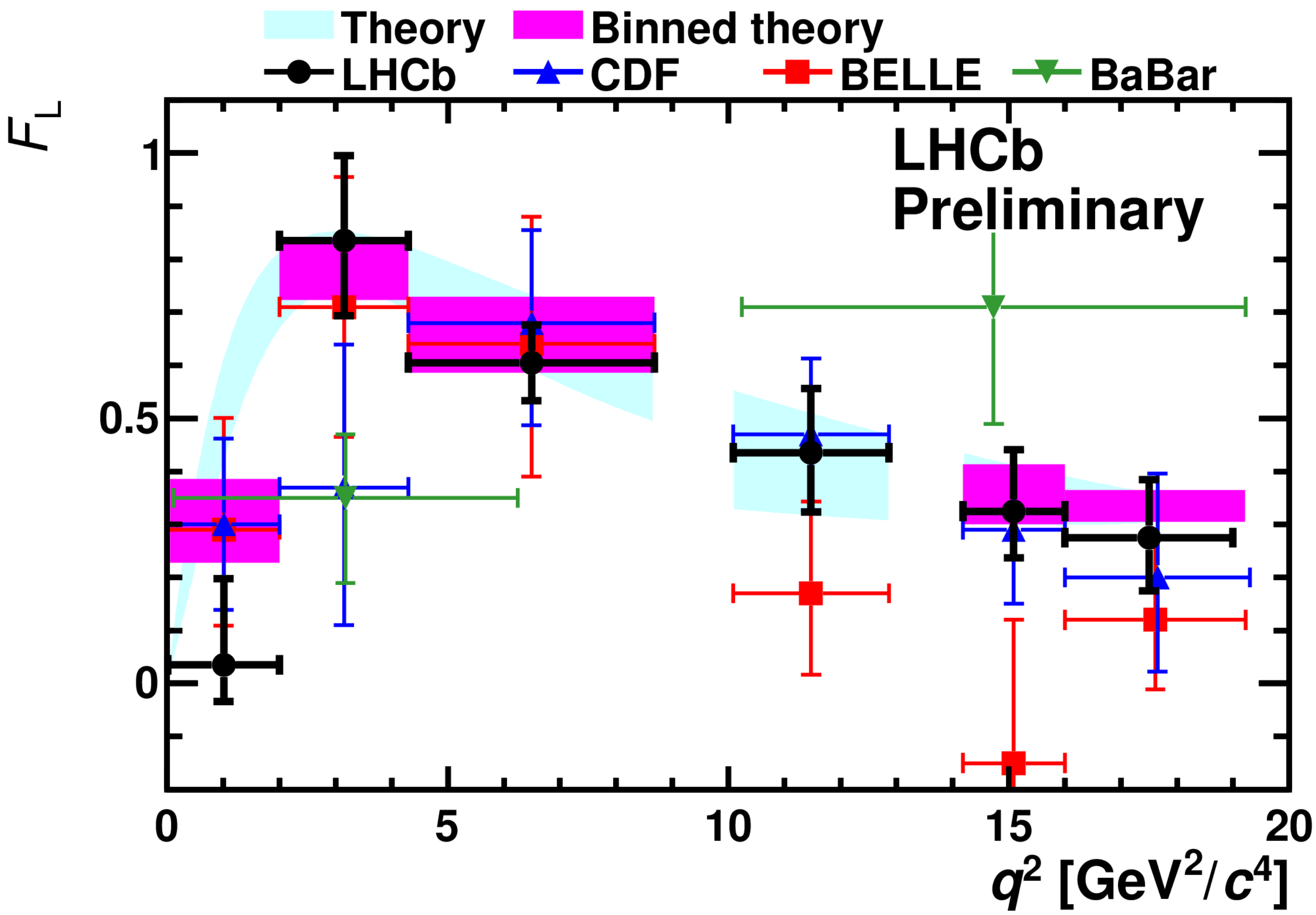
Mode	Absolute $\mathcal{B}(10^{-6})$
$\Lambda_b^0 \to \Lambda\mu^+\mu^-$	$1.73 \pm 0.42 \pm 0.55$
$B_s^0 \to \phi\mu^+\mu^-$	$1.47 \pm 0.24 \pm 0.46$
$B^+ \to K^+\mu^+\mu^-$	$0.46 \pm 0.04 \pm 0.02$
$B^0 \to K^{*0}\mu^+\mu^-$	$1.02 \pm 0.10 \pm 0.06$
$B^0 \to K^0\mu^+\mu^-$	$0.32 \pm 0.10 \pm 0.02$
$B^+ \to K^{*+}\mu^+\mu^-$	$0.95 \pm 0.32 \pm 0.08$
$B \to K\mu^+\mu^-$	$0.42 \pm 0.04 \pm 0.02$
$B \to K^*\mu^+\mu^-$	$1.01 \pm 0.10 \pm 0.05$

Differential branching fraction $B^0 \to K^{*0}\mu\mu$

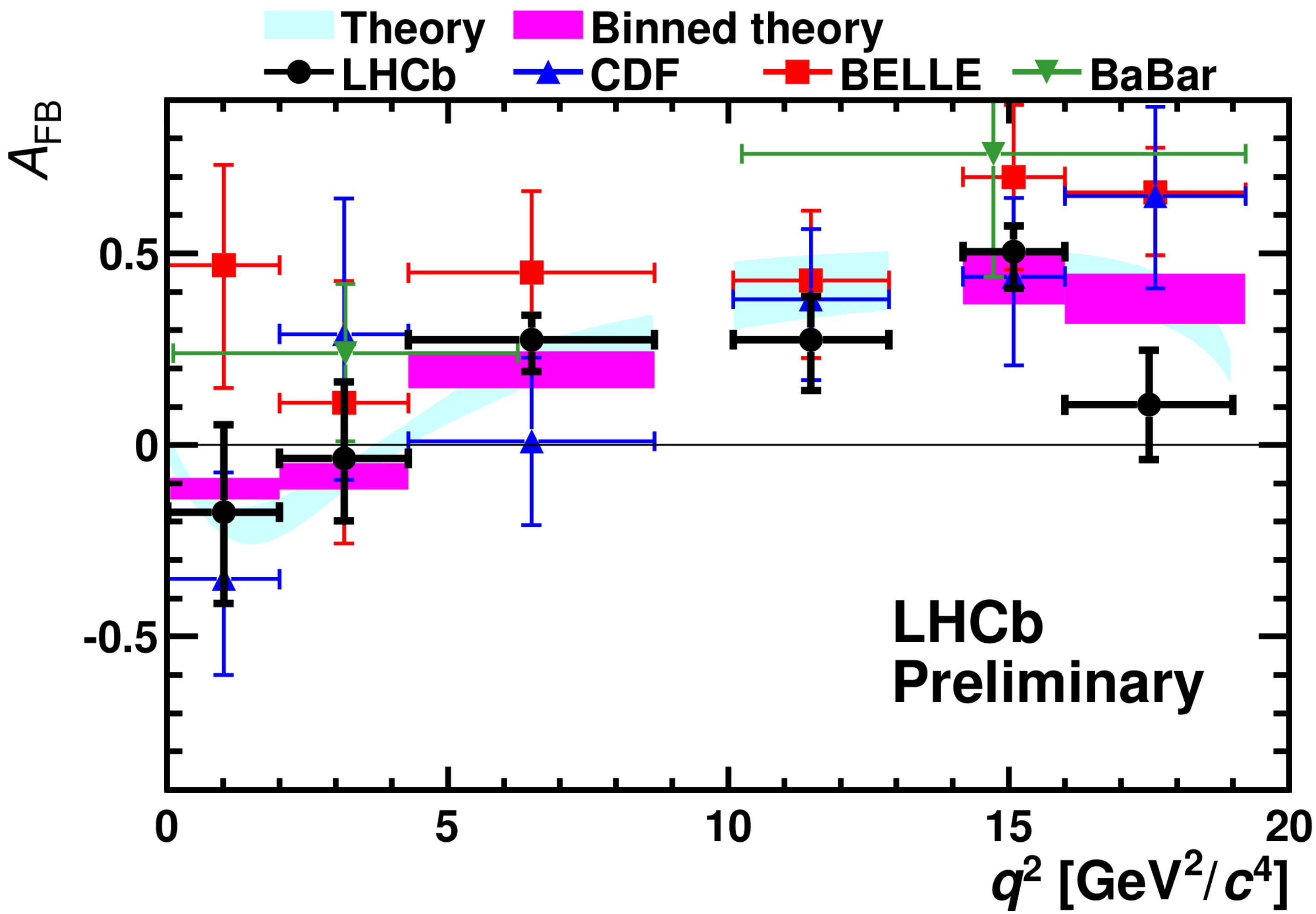


LHCb: LHCb-CONF-2011-038
CDF: arXiv:1108:0695
BELLE: PRL103:171801,2009
BaBar: PRD73:092001,2006

K^{*0} longitudinal polarisation $B^0 \rightarrow K^{*0}\mu\mu$



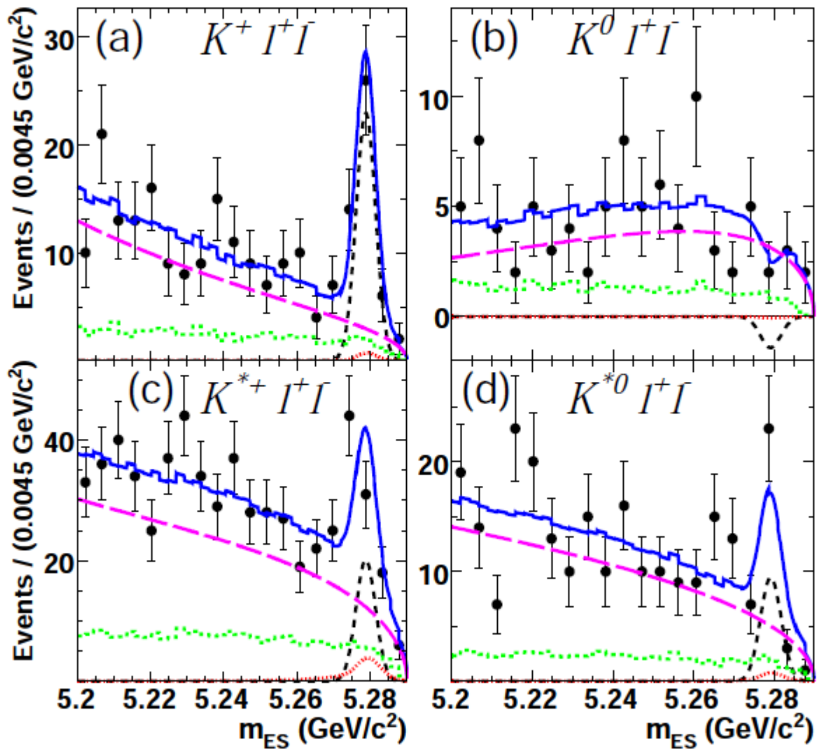
Forward-backward asymmetry $B^0 \rightarrow K^{*0}\mu\mu$



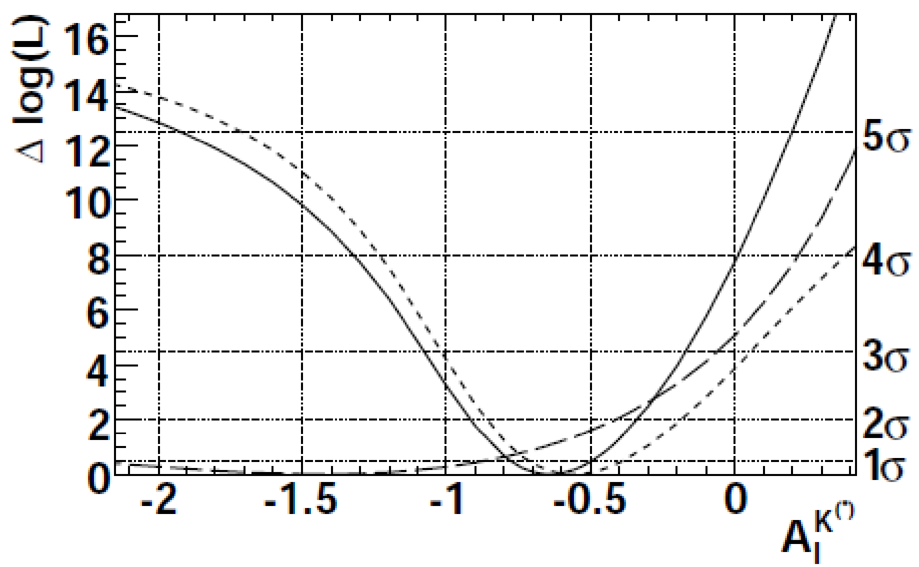
Isospin asymmetries

Most surprising result at the moment is the B→K(*)ll isospin asymmetry as measured by BaBar in PRL 102:091803,2009

BaBar mass peaks in low q² region



Likelihood curve in low q² region



Next steps from LHCb

Full angular analysis

$B^0 \to K^{*0}\mu\mu$: A_{FB} zero point, $A_T^{(2)}$, ...

Analysis of $B_s \to \phi\mu\mu$ decay

Isospin analysis in $B \to K^{(*)}\mu\mu$

$A_T^{(2)}$ in $B0 \to K^{*0}ee$

Potential best access to determination of right handed current

Determination of V_{ub}

Use BFs of $B \to K^*\mu\mu$, $B \to \rho\mu\nu$, $D \to K^*\mu\nu$, $D \to \rho\mu\nu$

Pirjol, Grinstein PRD**70** (2004) 114005

Other exclusive states

$B \to \pi\mu\mu$, $B \to \rho\mu\mu$, $\Lambda_b \to \Lambda\mu\mu$

Phenomenological problems to solve

A few phenomenological issues will soon limit our progress

S-wave contamination of Kπ system in $B^0 \to K^{*0}\mu\mu$

- From the $B^0 \to J/\psi K^{*0}$ decay we know that there is a significant S-wave component distorting the angular distribution
- Full angular distribution including interference is not available

Full time-dependent angular distribution of $B_s \to \varphi\mu\mu$

Conclusion

LHCb has just started to add high precision results on exclusive $B \to X_s \mu\mu$

- Many more results will be available in 2011 and 2012.

Isospin asymmetry is the large deviation from the SM that nobody talks about

- All other observables are at the moment fully compatible with SM

A 4th method for measuring V_{ub} is becoming possible

Some phenomenological work required for full experimental extraction of observables to proceed

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

Yield and signal significance in q^2 bins

Significance obtained from difference in log likelihood between a signal+background and a background only hypothesis. Position of peak and width fixed from $B^0 \to J/\psi K^{*0}$

$q^2(\mathrm{GeV}^2)$	n_{sig}	n_{bkg}	significance (σ)
$0 < q^2 < 2$	40.9 ± 7.5	14.4 ± 8.5	7.7
$2 < q^2 < 4.3$	23.3 ± 6.2	15.3 ± 8.6	4.9
$4.3 < q^2 < 8.68$	93.3 ± 11.3	30.0 ± 12.5	11.7
$10.09 < q^2 < 12.9$	57.3 ± 8.8	18.6 ± 9.7	9.3
$14.18 < q^2 < 16$	42.2 ± 6.8	3.6 ± 4.7	10.1
$16 < q^2 < 19$	48.1 ± 7.8	6.7 ± 6.4	9.2
$1 < q^2 < 6\,\mathrm{GeV}^2$	70.0 ± 10.2	$32. \pm 3.2$	9.4
Full	302.3 ± 20.1	91.0 ± 5.4	–

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

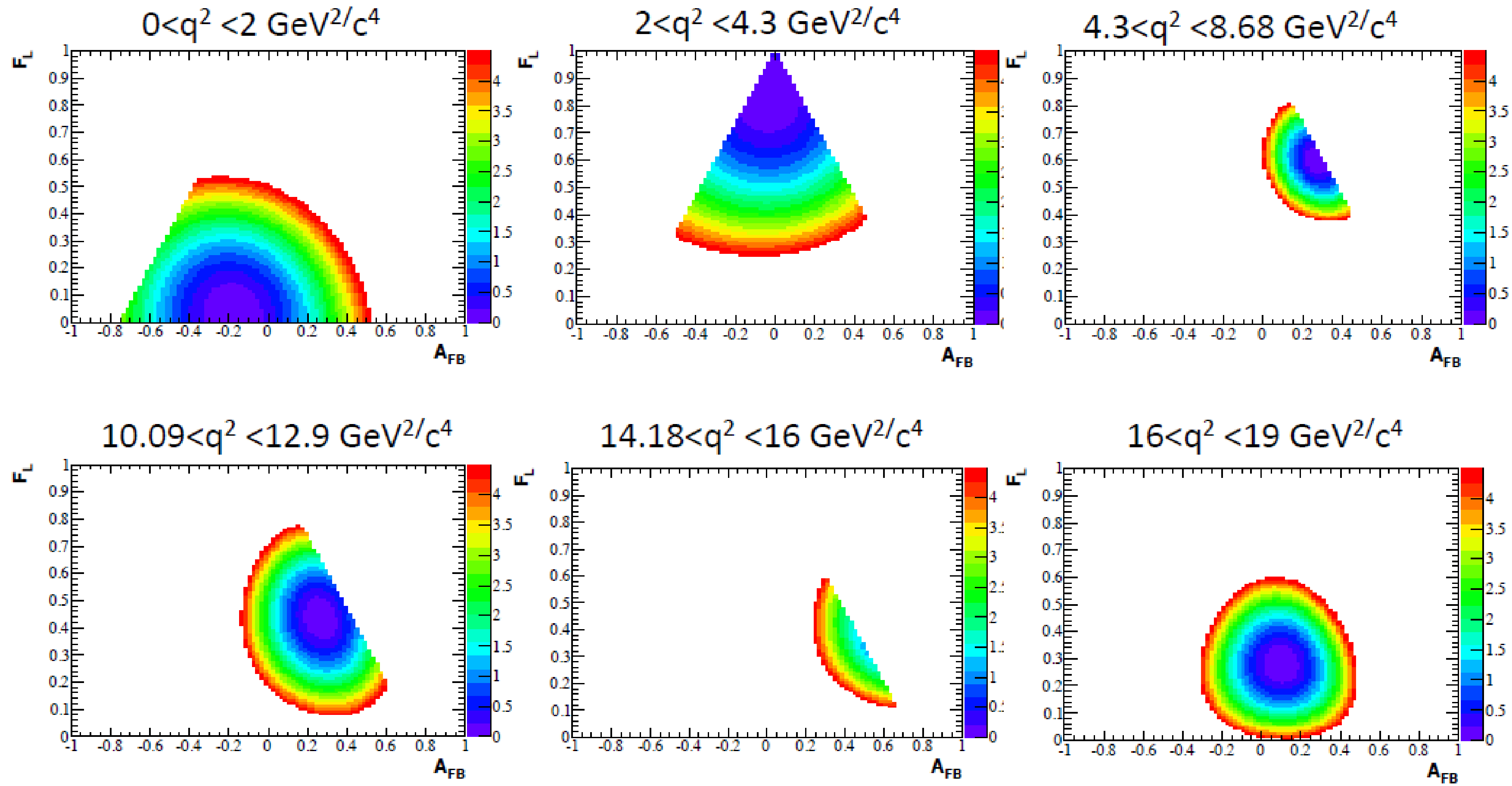
Results for A_{FB}, F_L and differential width in q^2 bins

The width is the average width in the bin in units of 10^{-7} GeV/c[4]

$q^2(\mathrm{GeV}^2)$	A_{FB}	F_L	$\mathrm{d}\Gamma/\mathrm{d}q^2$
$0 < q^2 < 2$	$-0.17^{+0.22}_{-0.23} \pm 0.06$	$0.03^{+0.15}_{-0.03} \pm 0.06$	$0.56 \pm 0.11 \pm 0.03$
$2 < q^2 < 4.3$	$-0.04^{+0.19}_{-0.15} \pm 0.06$	$0.84^{+0.15}_{-0.13} \pm 0.06$	$0.28 \pm 0.08 \pm 0.02$
$4.3 < q^2 < 8.68$	$0.28^{+0.06}_{-0.08} \pm 0.02$	$0.60^{+0.07}_{-0.07} \pm 0.01$	$0.55 \pm 0.07 \pm 0.03$
$10.09 < q^2 < 12.9$	$0.27^{+0.11}_{-0.13} \pm 0.03$	$0.44^{+0.12}_{-0.11} \pm 0.02$	$0.53 \pm 0.09 \pm 0.03$
$14.18 < q^2 < 16$	$0.50^{+0.06}_{-0.09} \pm 0.03$	$0.33^{+0.11}_{-0.08} \pm 0.04$	$0.59 \pm 0.10 \pm 0.03$
$16 < q^2 < 19$	$0.10^{-0.13}_{-0.13} \pm 0.06$	$0.28^{+0.10}_{-0.09} \pm 0.04$	$0.48 \pm 0.08 \pm 0.03$
$1 < q^2 < 6$	$-0.10^{+0.14}_{-0.14} \pm 0.05$	$0.57^{+0.11}_{-0.10} \pm 0.03$	$0.39 \pm 0.06 \pm 0.02$

Likelihoods in A_{FB},F_L plane

LHCb



Likelihoods in A_{FB},F_L plane

LHCb