Prospects for $B_d \rightarrow K^*\mu\mu$ at the LHC

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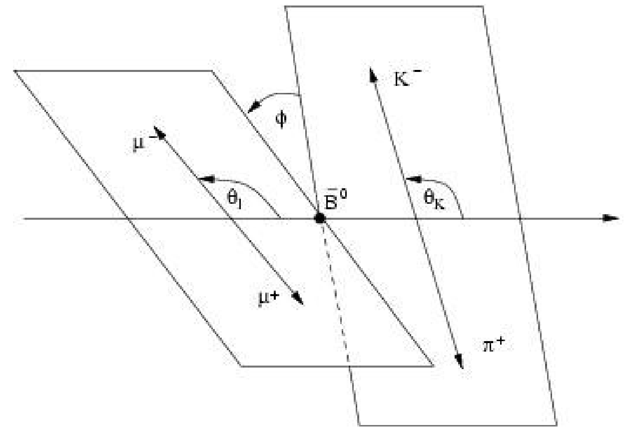
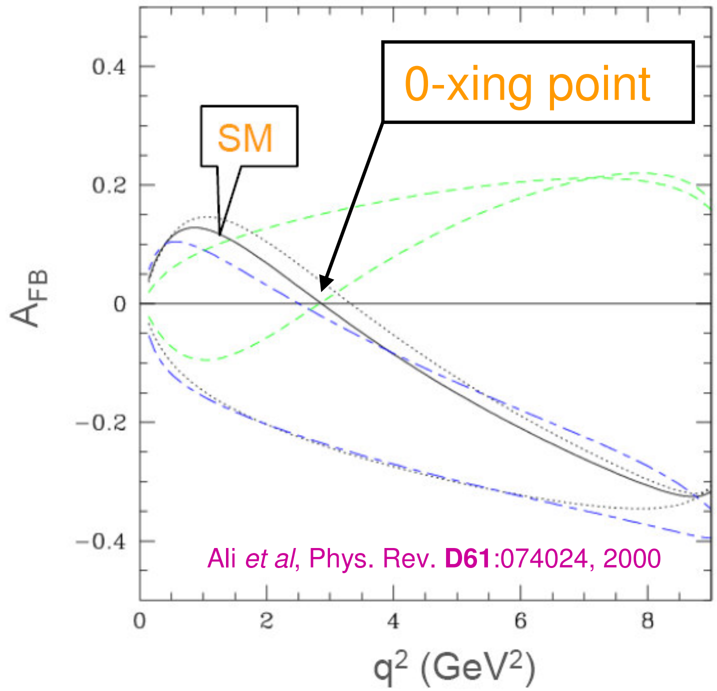
CKM 2008

Friday 12th September 2008

Introduction

- Flavour changing neutral current $b \to s$ decay that proceeds via loop diagram
- Decay described by three angles (θ_l, ϕ, θ_K) and di-μ invariant mass q^2
- Sensitive to magnetic and vector and axial semi-leptonic penguin operators
- Try to use observables where uncertainty from $B_d \to K^*$ transition form-factors cancel
  e.g. Forward-backward asymmetry A_{FB} of θ_l distribution
- In general, angular distributions as function of q^2 gives sensitivity to NP contributions



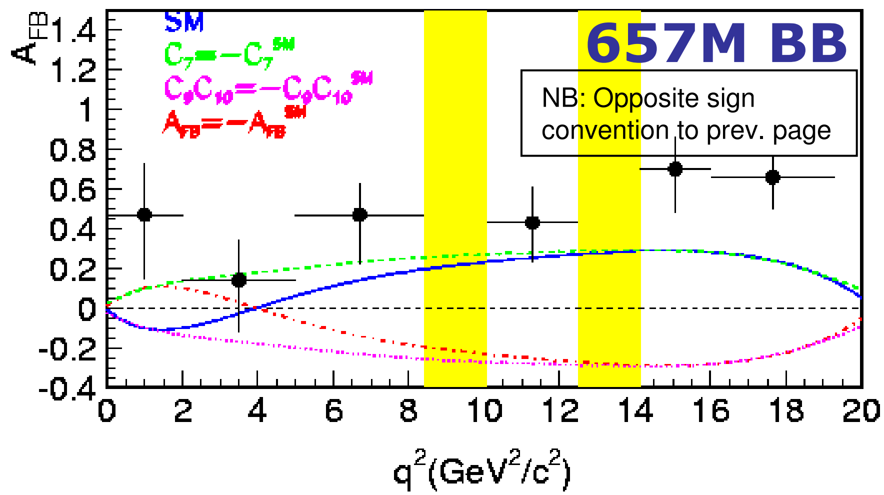


Status

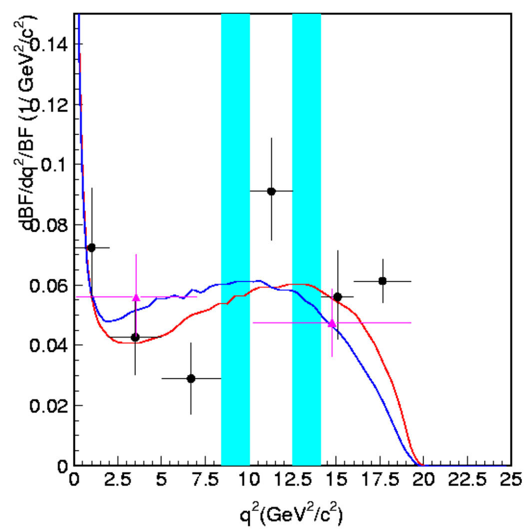
- BR measured at B-factories, in agreement with SM:
  $BR(B_d \rightarrow K^*\mu\mu) = (1.22^{+0.38}_{-0.32}) \times 10^{-6}$ [1]

- BELLE has ~230 K*ll events

- A_{FB}
  - Region with best theoretical control $1<q^2<6GeV^2$
  - If C_7 flipped would expect to see in BR and dBR/dq^2



BELLE preliminary, ICHEP 2008



[1] PDG 2006

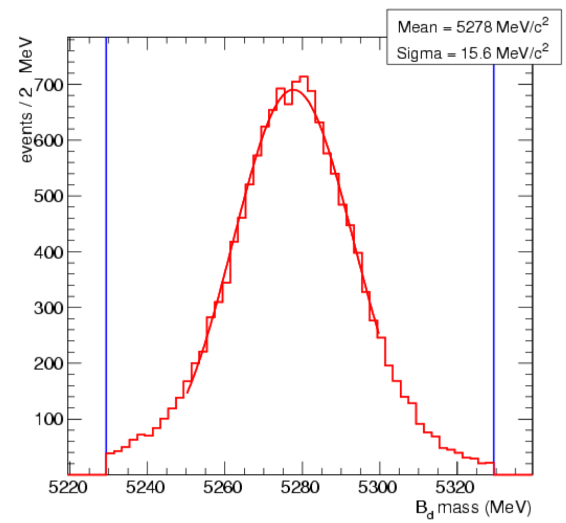
Signal Selection

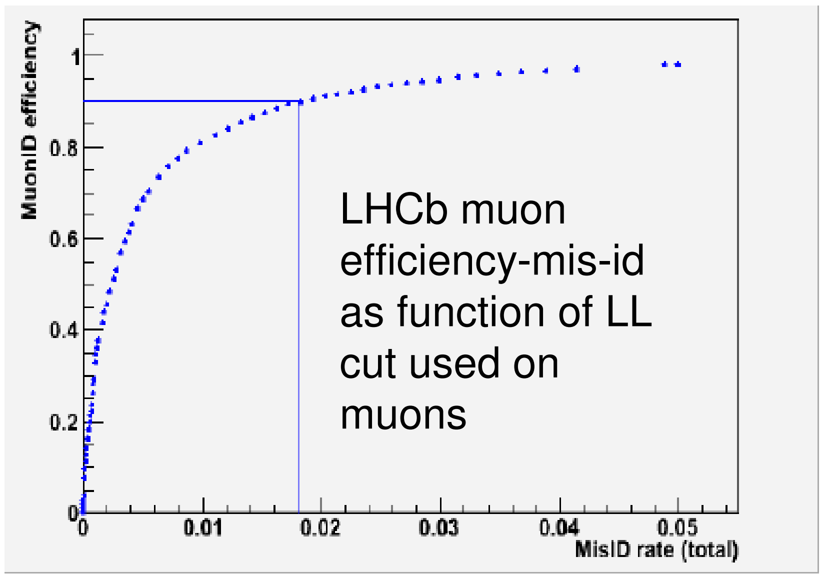
- Signal selection in LHC environment relies on finding B_d vertex, measuring momenta to determine masses
  - At LHCb:
    - B_d vertex resoln ~130μm
    - Track momenta ~0.5%
    - B_d mass ~16MeV (ATLAS: 50MeV)

- Muon-id performance important

- K/π separation from LHCb's RICH detectors also helps to suppress background

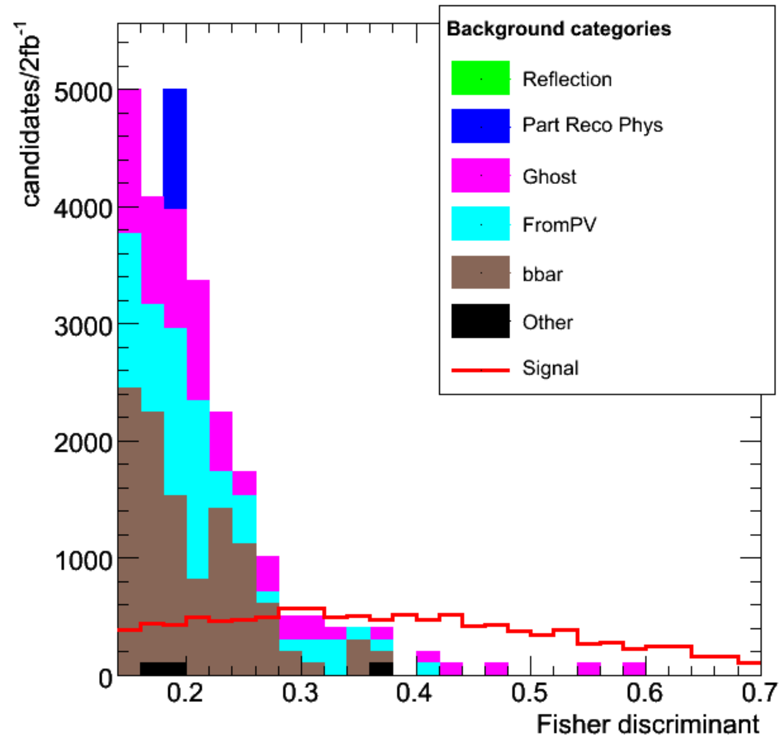
- Level 0 trigger μ p_T threshold ~1GeV





Signal Yields

- Latest generation of (full) Monte Carlo studies:
  - Total signal seln efficiency ~1.1%
  - ~7.2k signal events /2fb^{-1} (full q^2 range) (~3.7k signal events /2fb^{-1} ($q^2 < m_{J/\psi}$))
  - ~1.1k bkgrd events
  - → in 2009 might expect ~1.8k signal events

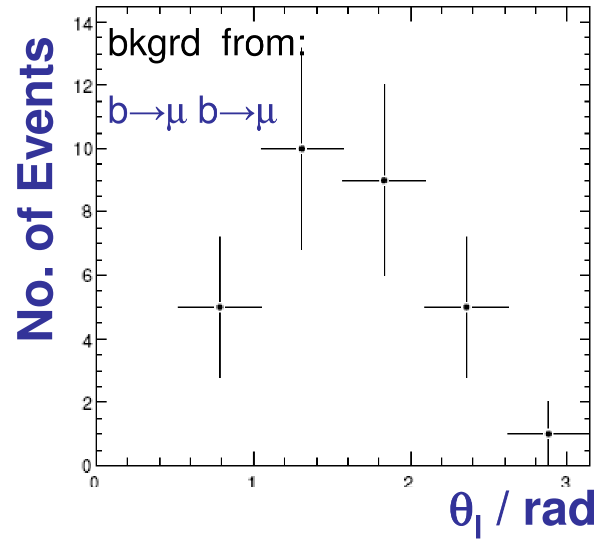


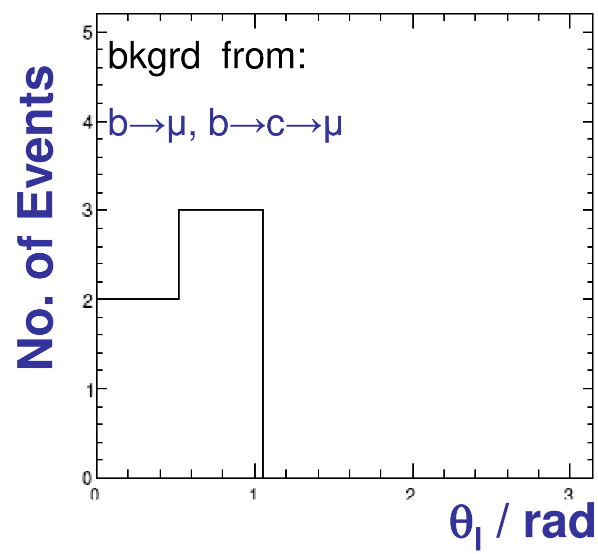
- Have started to investigate multi-variant techniques to separate signal and bkgrd

- Fisher discriminant shown right relies on B_d Flight Distance, impact parameter, PID likelihoods

Background in LHCb

- Background:
  - Dominated by genuine μ from B decays
  - Don't observe any significant background from μ mis-id
  - $b \to \mu$, $b \to \mu$ dominant contribution, symmetric distribution in θ_l – scales A_{FB} observed
  - $b \to \mu$, $b \to c \to \mu$ significant contribution, asymmetric θ_l distribution – effect on A_{FB} depends on θ_l shape
  - Non-resonant $K\pi\mu\mu$ events neglected
  - B/S ~0.2

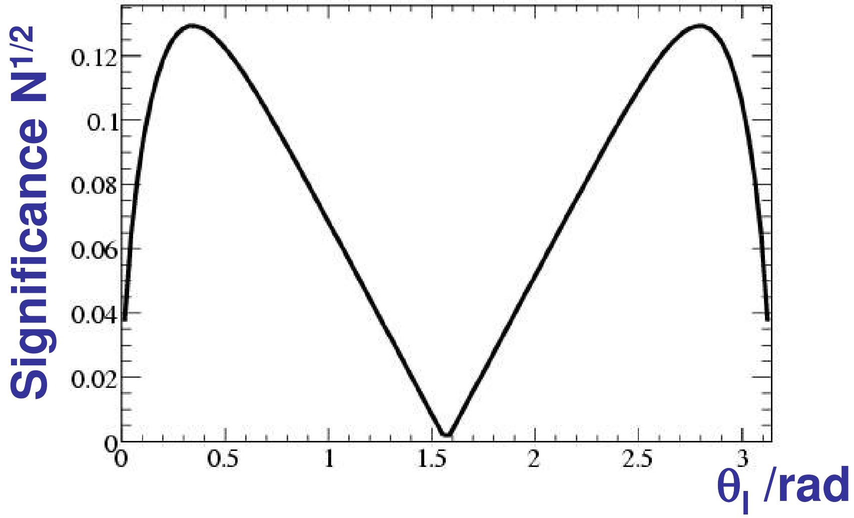


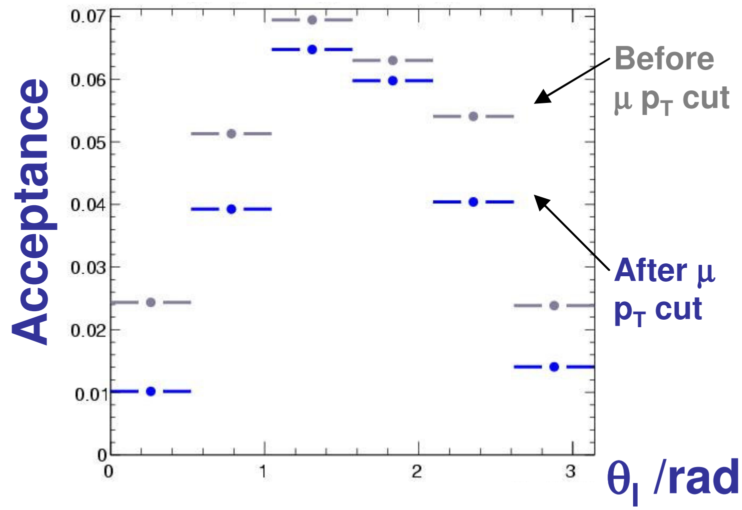


Extracting A_{FB}

- Signal events have varying sensitivity according to θ_l
- However,
  - requiring that the μ be reconstructed imposes a minimum p requirement
  - trigger makes requirements on μ p_T
- In both cases, the size of the effect is a function of q^2 – can extract acceptance function from e.g. $B_d \rightarrow K^* J/\Psi$, will need Monte Carlo to extrapolate to low q^2

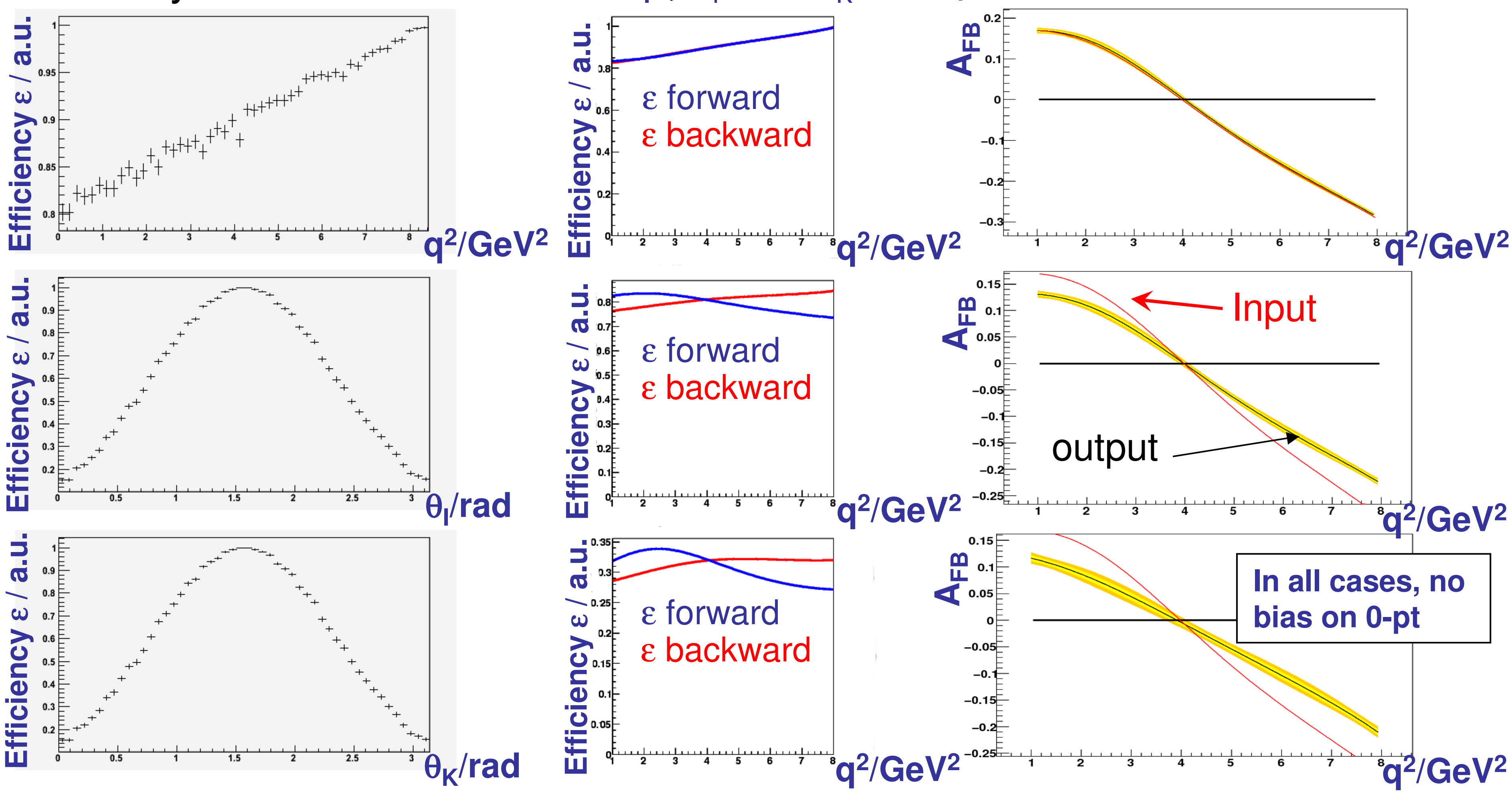
→ Will be important to understand acceptance correction





Extracting A_{FB} (cont'd)

- Toy model shows effect of q^2, θ_l and θ_K acceptance functions:



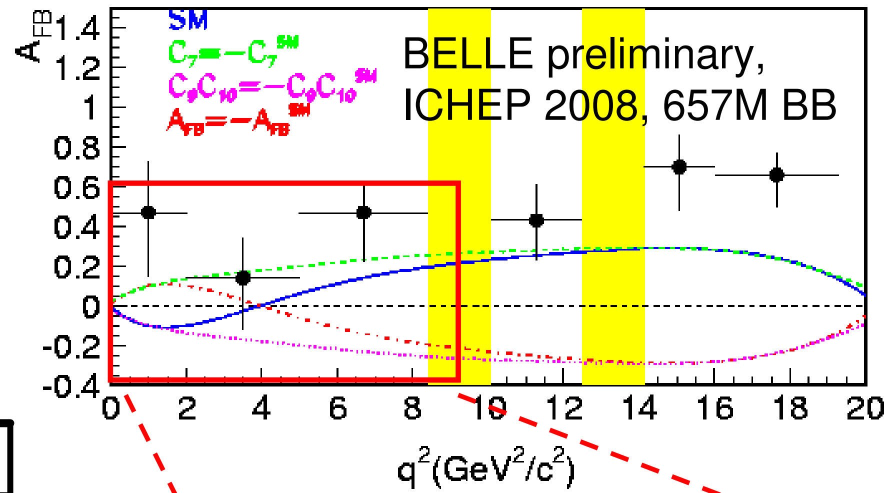
- Even if interested in A_{FB} formed from θ_l angle, need θ_K acceptance

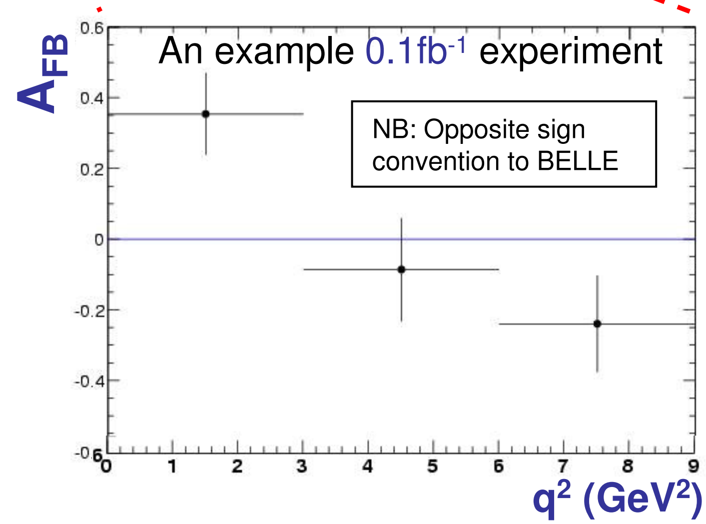
LHCb A_{FB} Sensitivity

- LHCb
  - Will already have sensitivity with 0.1fb^{-1}
  - With 0.5fb^{-1} will be able to start looking for a zero-point, s^0
  - Simple linear fit suggests precision:

	0.5 fb^{-1}	2 fb^{-1}	10 fb^{-1}
$\sigma(s^0)$	**0.8 GeV^2**	**0.5 GeV^2**	**0.3 GeV^2**

  - More complex fit methods being evaluated …





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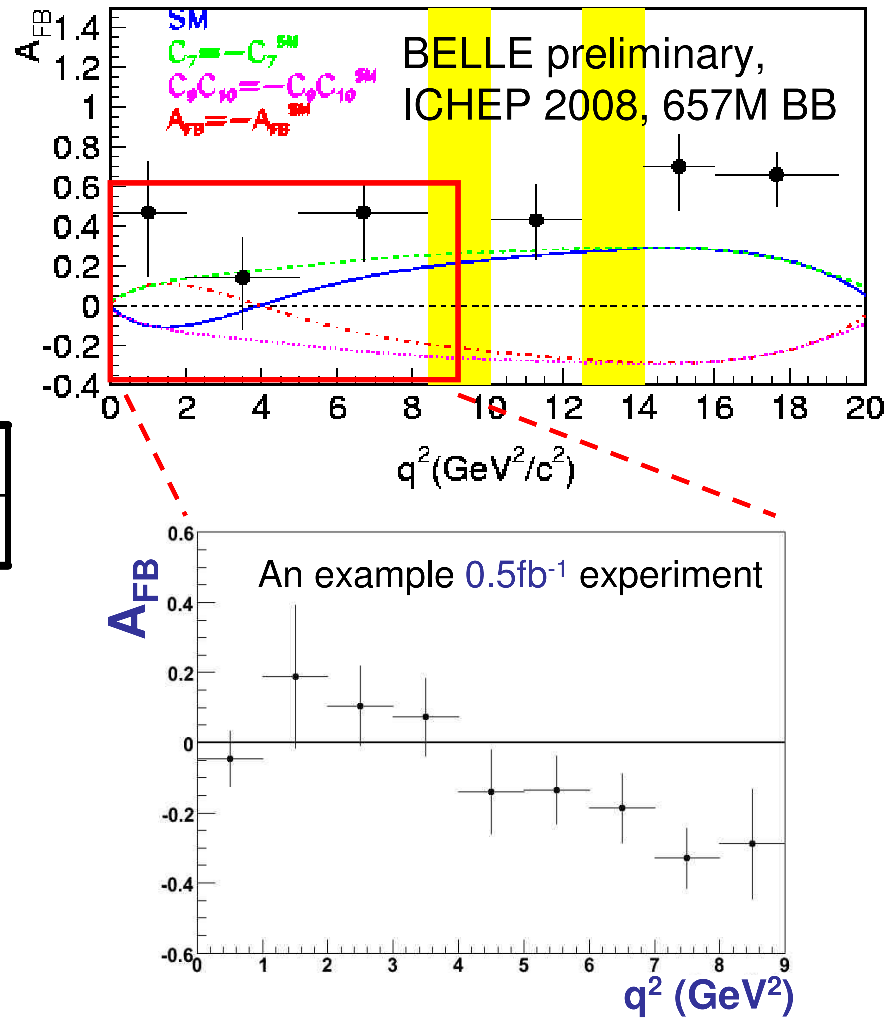
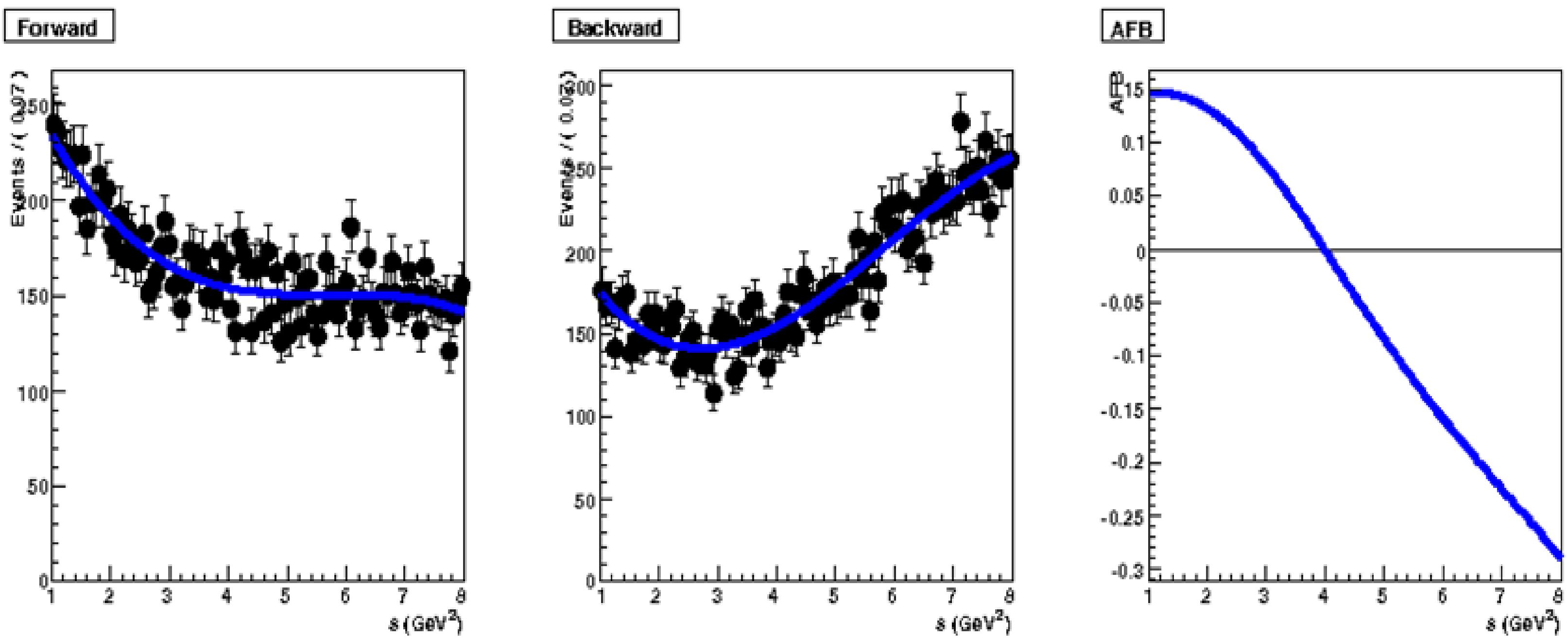


LHCb A_{FB} Sensitivity (cont'd)

- Unbinned fit of the q^2-distribution using 3rd order Chebychev polynomials to parameterise forward and backward events



- Still have to add background and acceptance corrections
- Don't have to assume linear over zero-crossing point region, remove dependence on bin-size, fit range

Projection Fits

- Decays contain much more information than θ_l, A_{FB} distributions

- Fitting projections of θ_l, ϕ, θ_K angular distributions:

$$\frac{d\Gamma'}{d\phi} = \frac{\Gamma'}{2\pi}\left(1 + \frac{1}{2}(1-F_L)A_T^{(2)}\cos 2\phi + A_{Im}\sin 2\phi\right)$$

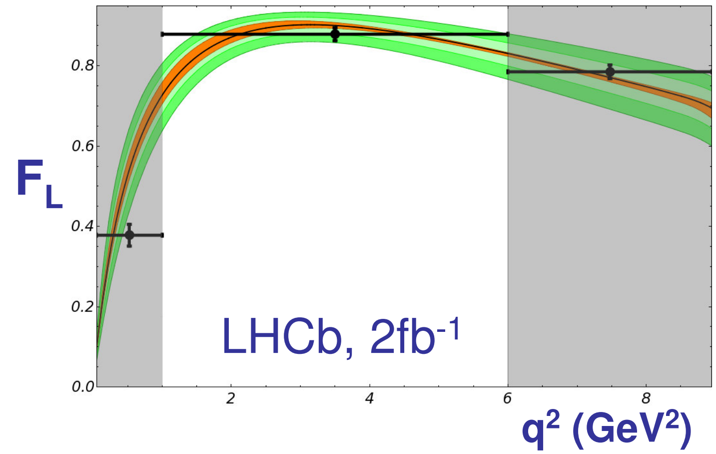
$$\frac{d\Gamma'}{d\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l) + A_{\mathrm{FB}}\cos\theta_l\right)\sin\theta_l$$

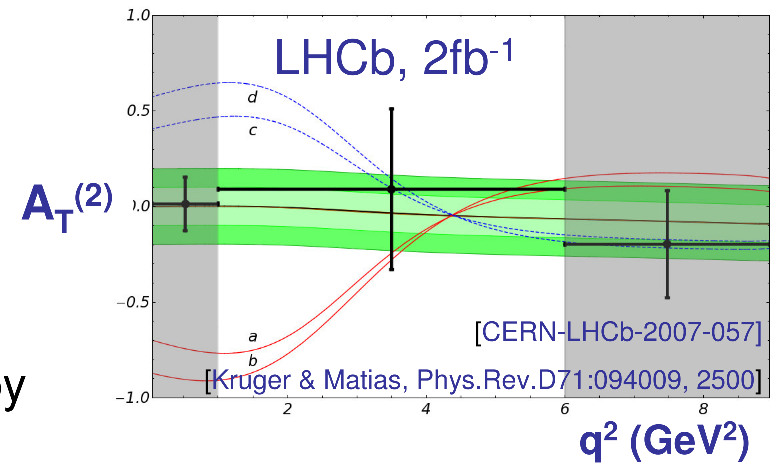
$$\frac{d\Gamma'}{d\theta_K} = \frac{3\Gamma'}{4}\sin\theta_k\left(2F_L\cos^2\theta_K + (1-F_L)\sin^2\theta_K\right)$$

$\rightarrow$ fraction of longitudinal polarization, F_L, and transverse asymmetry A_T^2

- Improves precision on A_{FB} by a factor ~2 cf. counting method

- Precision on A_T^2 relatively poor as suppressed by $(1-F_L)$ term



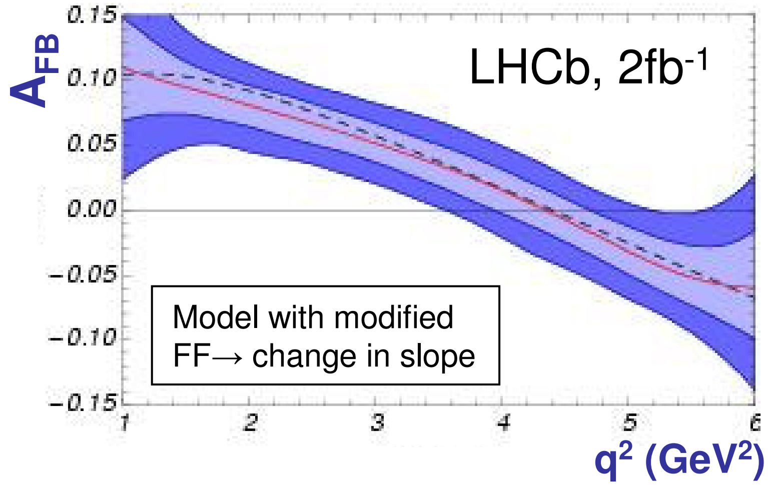


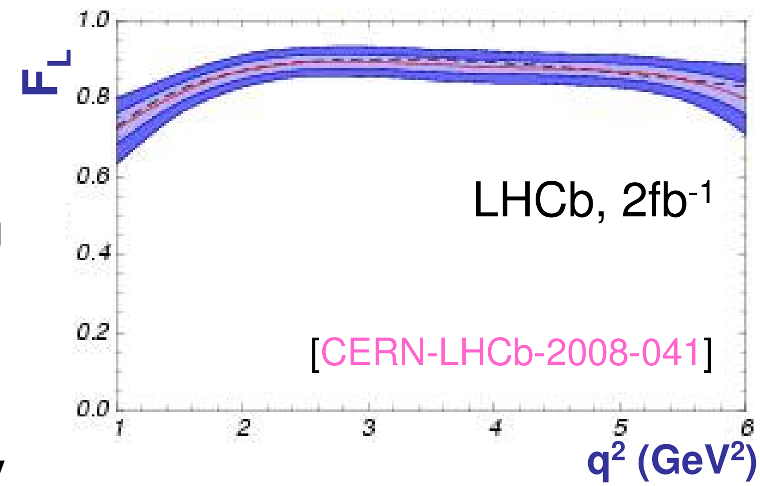
Full Angular Fit

- Full angular fit has also been investigated:

$$\frac{d^4\Gamma_{\overline{B}_d}}{dq^2\,d\theta_l\,d\theta_K\,d\phi} = \frac{9}{32\pi} I(q^2, \theta_l, \theta_K, \phi) \sin\theta_l \sin\theta_K$$

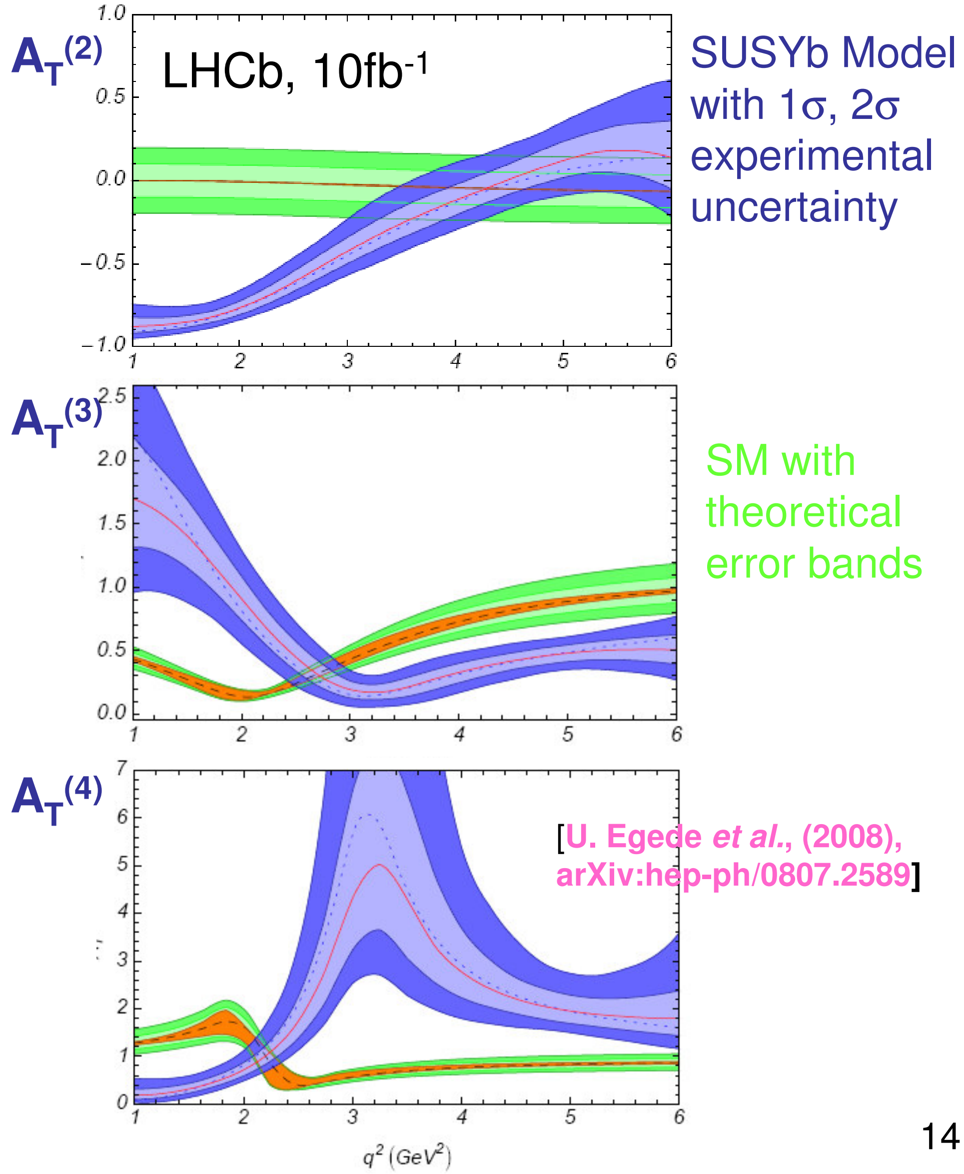
- Parameterised in terms of transversity amplitudes
  - $A_0^{L,R}$, $A_\perp^{L,R}$, $A_\parallel^{L,R}$, 6 complex numbers
- Probe chiral structure of decay
- Sensitive to observables not accessible from projection fits
- Once have enough events in each q^2 bin for fit to converge → better precision on A_{FB}, F_L, and A_T^2
- Then have all amplitudes – can form any observable …





Full Angular Fit (cont’d)

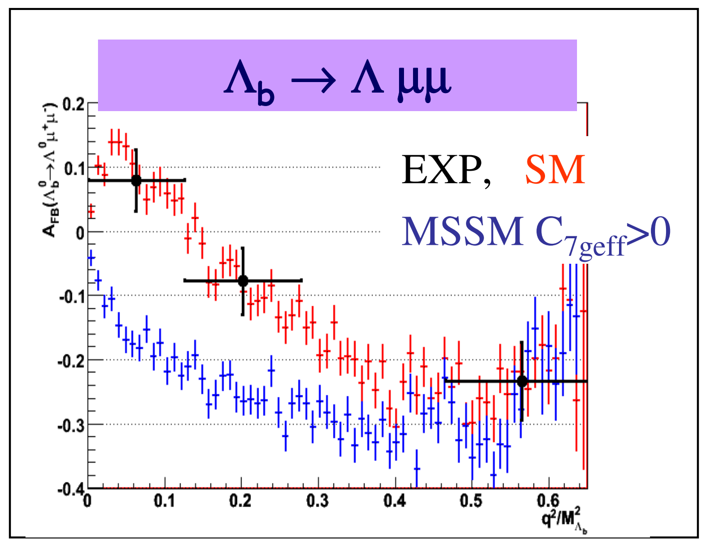
- Recent theoretical investigation has highlighted new observables A_T^3, A_T^4 with different NP sensitivity – See TH’s talk at end of this session
- Full angular fit possible with >2fb^{-1} data
- However, have to handle full acceptance correction
- Expect ~30% further improvement in precision on A_{FB} over projection method



Sensitivity of Central Detectors

- Table right from ATLAS, CMS studies on-going
- For $B_d \rightarrow K^*\mu\mu$ ATLAS expects:
  - ~0.8k signal events /10fb^{-1} (full q^2 range)
  - <3.3k bkgrd events @90%CL
- Significant numbers of $B_s \rightarrow \phi\mu\mu$ and $\Lambda_B \rightarrow \Lambda\mu\mu$ events will also be recorded – will be able to compute A_{FB} in these channels
- LHCb also investigating all these decays

30 fb^{-1} (3 years)	# of signal Events	δA_{FB} for q^2 <2.7 GeV^2 (under J/Ψ)
$B \rightarrow K^{0*}\mu\mu$	2500	4.8%
$B_s \rightarrow \phi\ \mu\mu$	900	6.0%
$B^+ \rightarrow K^{+*}\mu\mu$	4000	5.2%
$B^+ \rightarrow K^+\mu\mu$	2300	3.0%
$\Lambda_b \rightarrow \Lambda\ \mu\mu$	800	6.0%



Conclusions

- Bright prospects for investigating NP with $B_d \rightarrow K^* \mu\mu$ at the LHC
- ATLAS expects ~0.2k signal events ($2.5 fb^{-1}$) in 2009 [CMS studies on-going]
- LHCb expects ~ 1.8k signal events ($0.5 fb^{-1}$) in 2009
  With ¼ of a nominal year, will already have ~10× current B-factory statistics
- Background control significant issue, latest simulation studies still demonstrating good control B/S ~0.1-0.2
- Acceptance correction will also be important
- New methods fitting A_{FB} under investigation to reduce biases
- New methods fitting angular distributions offer improved sensitivity to A_{FB}, F_L – and new observables with different NP sensitivity A_T^2, A_T^3, A_T^4
- Other analogous channels also under investigation