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Prospects for $B_d \to K^{*0}\mu^+\mu^-$ at LHCb

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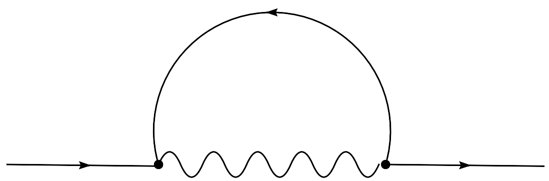
Physics at the LHC, 3rd October 2008

Introduction



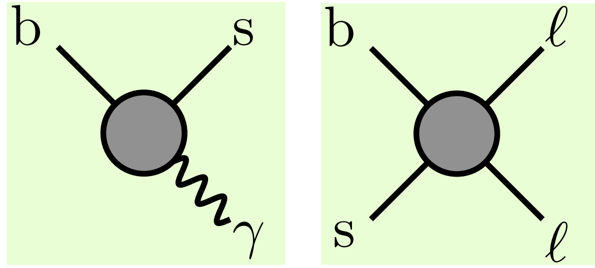
- FCNC $b \to s$ quark transitions occur via a loop
- New physics (NP) can enter the loop
- Treat with Operator Product Expansion
  - Model independent approach

$$\mathcal{H}_{\mathrm{eff}} = -\frac{4\mathbf{G_F}}{\sqrt{\mathbf{2}}}\mathbf{V}_{\mathrm{tb}}\mathbf{V}^{*}_{\mathrm{ts}}\sum_{\mathbf{i=1}}^{\mathbf{10}}[\mathbf{C_i}(\mu)\mathcal{O}_{\mathbf{i}}(\mu) + \mathbf{C'_i}(\mu)\mathcal{O}'_{\mathbf{i}}(\mu)]$$

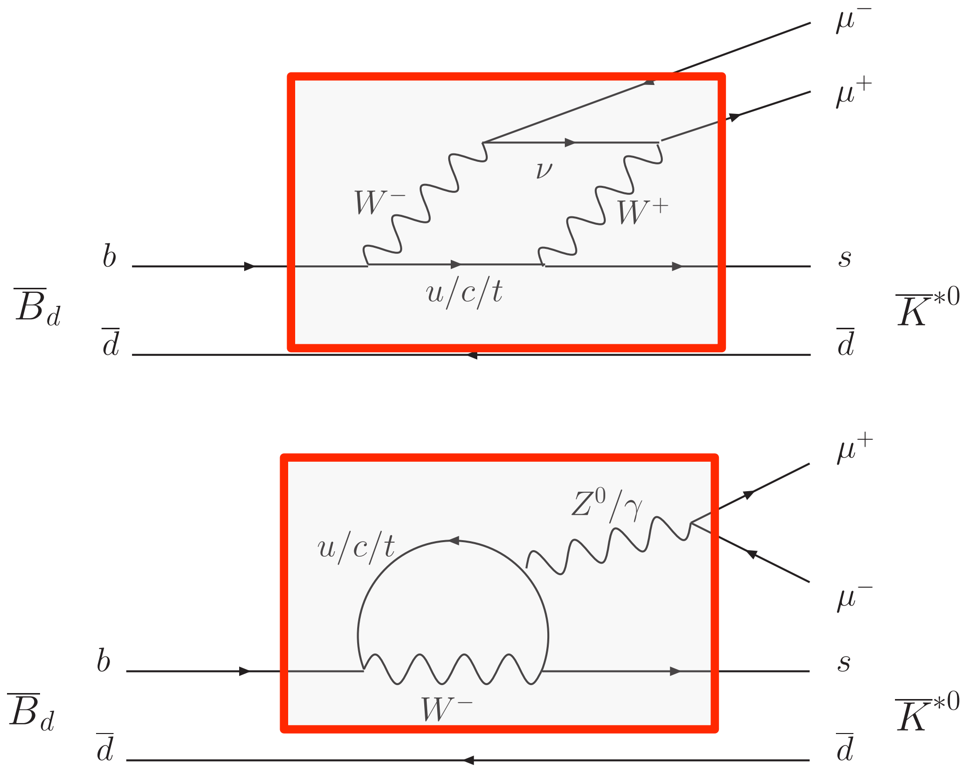
- Wilson Coefficients give short range Physics
  - Measure to discover or exclude entire classes of NP

$B_d \to K^{*0}\mu^+\mu^-$

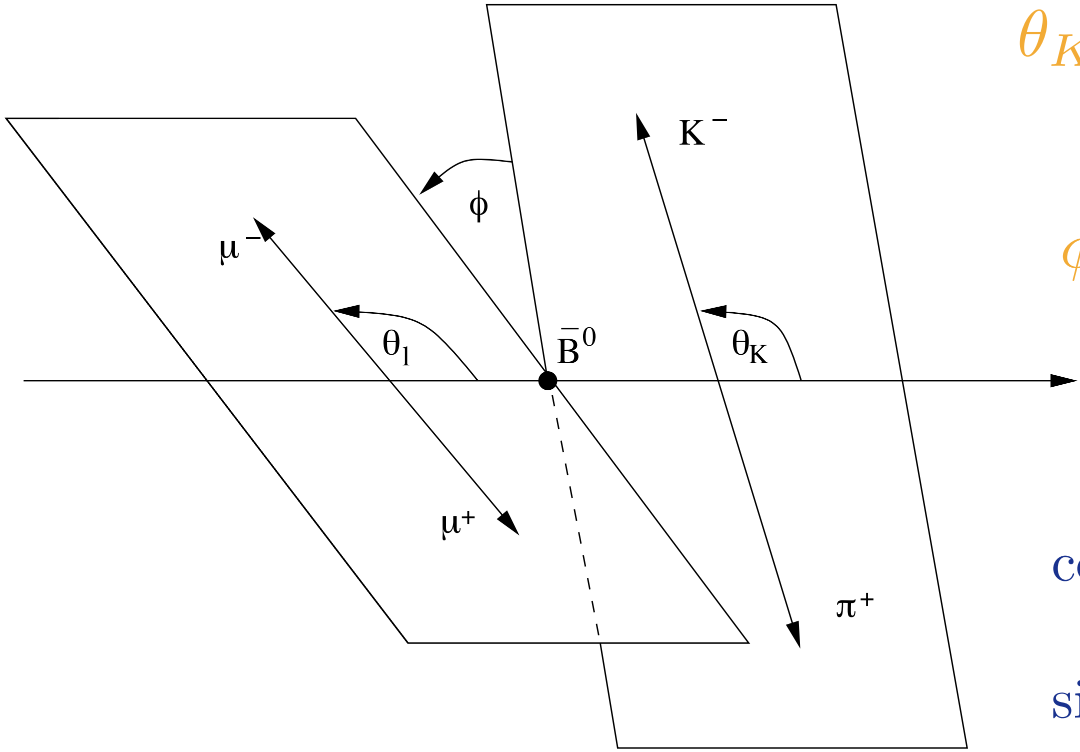
- First observed at Belle
  - $Br(B_d \to K^{*0}\mu^+\mu^-) = (1.22^{+0.38}_{-0.32}) \times 10^{-6}$
- Particles in Loop
  - Both neutral and charged NP (replace $W^{\pm}$, Z^0/γ, u/c/t)
- Sensitive to NP
  - Dominated by C_7, C_9, C_{10}
  - Studied with NP from SUSY, Littlest Higgs, Randall-Sundrum, Universal Extra Dimensions etc
- Laboratory for Studying NP
  - Complementary to direct searches
  - Offers NP model discrimination for any LHC discoveries



$O_{7\gamma}$ $O_{9,10}$



Decay Kinematics



θ_l: Angle between μ^- and B in $\mu\mu$ rest frame

θ_K: Angle between K^- and the $\bar{B}$ in the $\bar{K}^{*0}$ rest frame

ϕ: Angle between the $\bar{K}^{*0}$ and $\mu\mu$ decay planes

See e.g. arXiv: 0807.2589

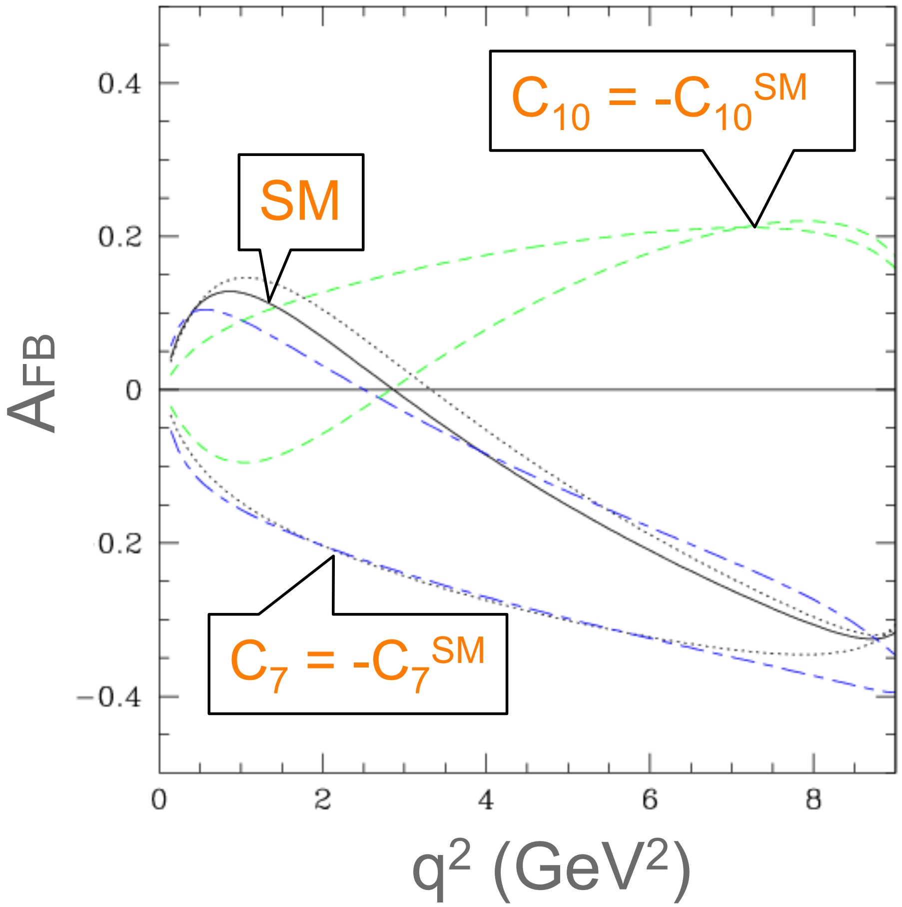
$$\cos\theta_l = \frac{q_\mu \cdot e_z}{|q_{\mu^-}|} \qquad \cos\theta_K = \frac{r_{K^-} \cdot e_z}{|r_{K^-}|}$$

$$\sin\phi = (e_l \times e_K) \cdot e_z \quad \cos\phi = e_K \times e_l$$

- Decay in terms of 3 Angles and 1 Invariant Mass
  - θ_l, θ_K, ϕ and q^2, the invariant mass squared of μ pair

$$e_z = \frac{p_{K^-} + p_{\pi^+}}{|p_{K^-} + p_{\pi^+}|}, e_l = \frac{p_{\mu^-} \times p_{\mu^+}}{|p_{\mu^-} \times p_{\mu^+}|}, e_K = \frac{p_{K^-} \times p_{\pi^+}}{|p_{K^-} \times p_{\pi^+}|}$$

What to Measure?

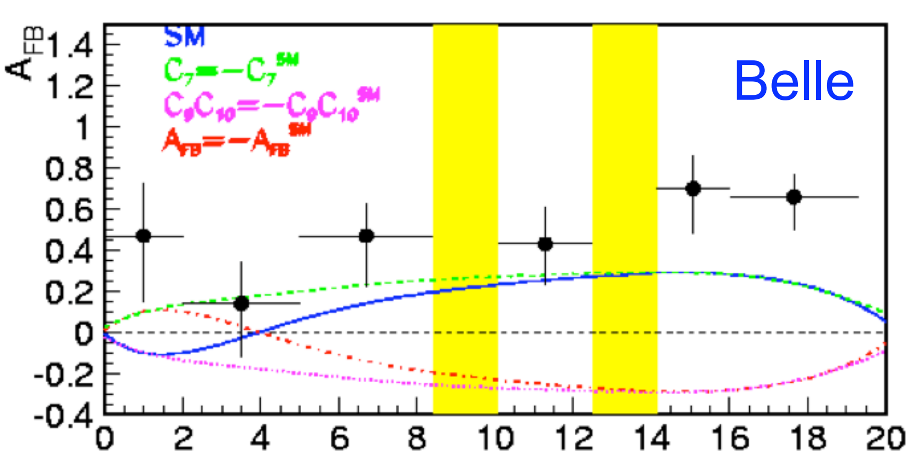


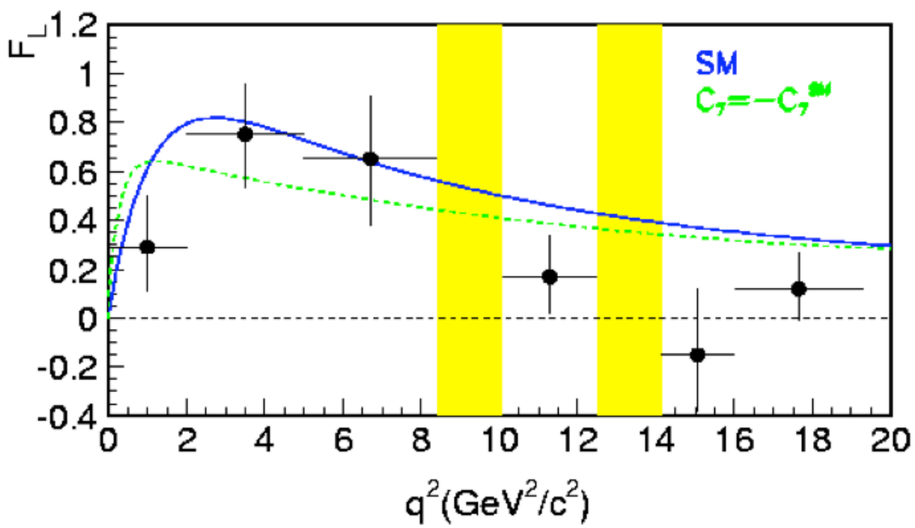
Ali *et al*, PR **D61**:074024 (2000)

- Angular observables
  - Small theory error
  - Experimentally accessible
- E.g. forward-backward asymmetry of μμ
  - Sensitive to interference between C_7, C_9 & C_{10}
- Plausible NP models
  - Large deviations
- Zero crossing point (q^2_0)
  - Low statistics (~0.5fb^{-1})
  - Form factors cancel

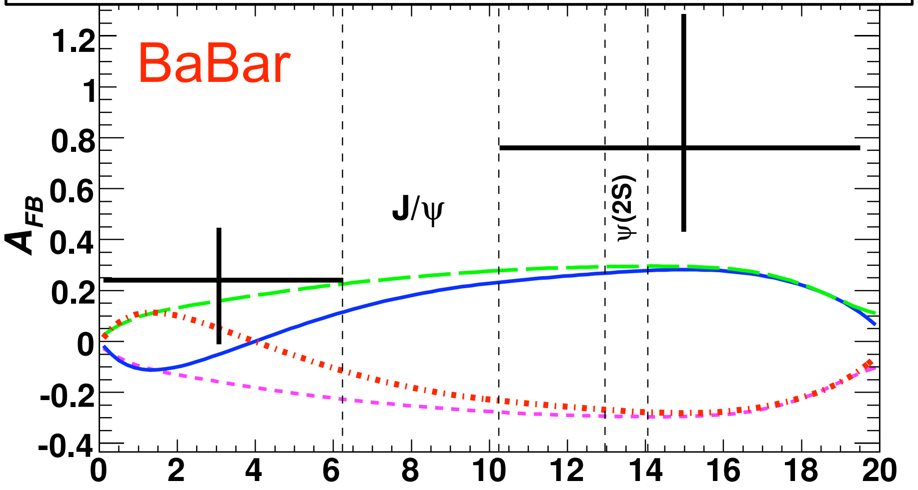
Current Status – Interesting Hints?

Belle (2008) - ICHEP
BaBar (2008) – 0804.4412

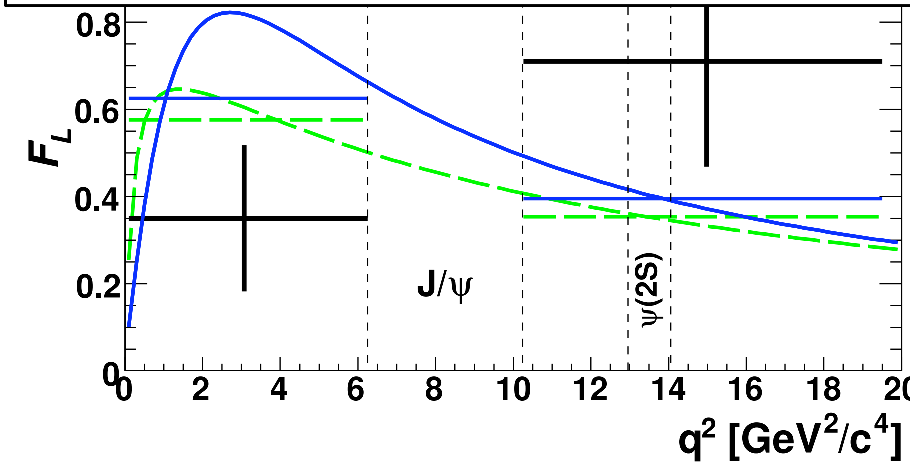




Note opposite sign convention here



F_L – longitudinal polarization of the K*



Current Status – Interesting Hints?

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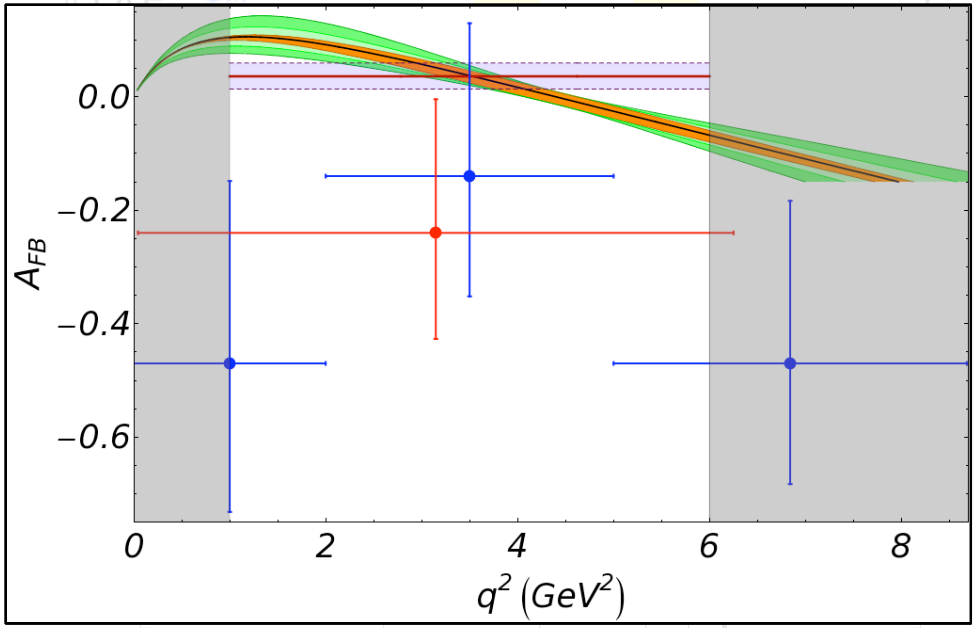
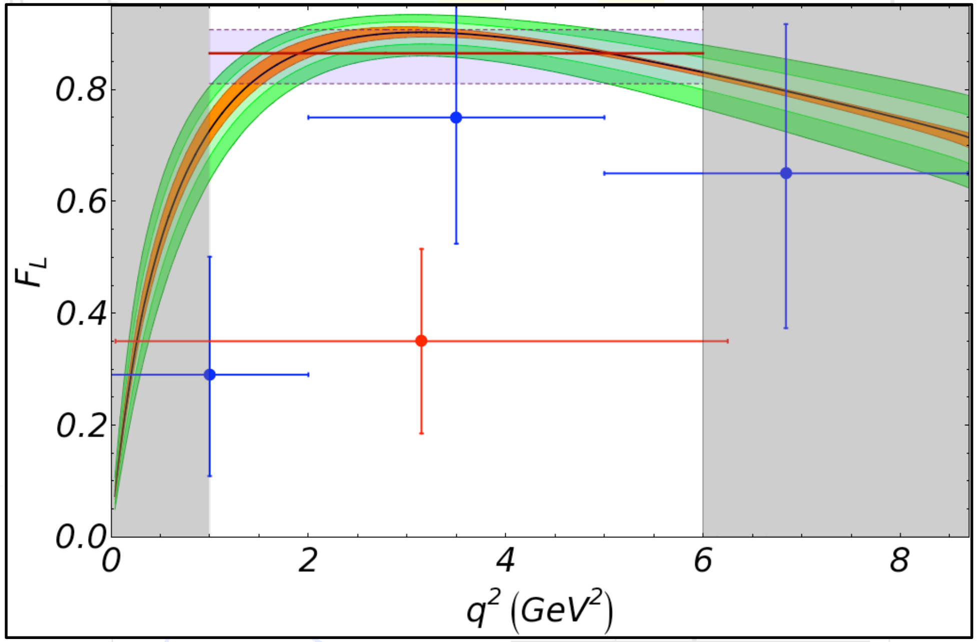
AFB



FL



Observables only <u>reliably calculable</u> in q^2 region 1-6 GeV^2/c^4

Up to LHCb to see what is really going on!

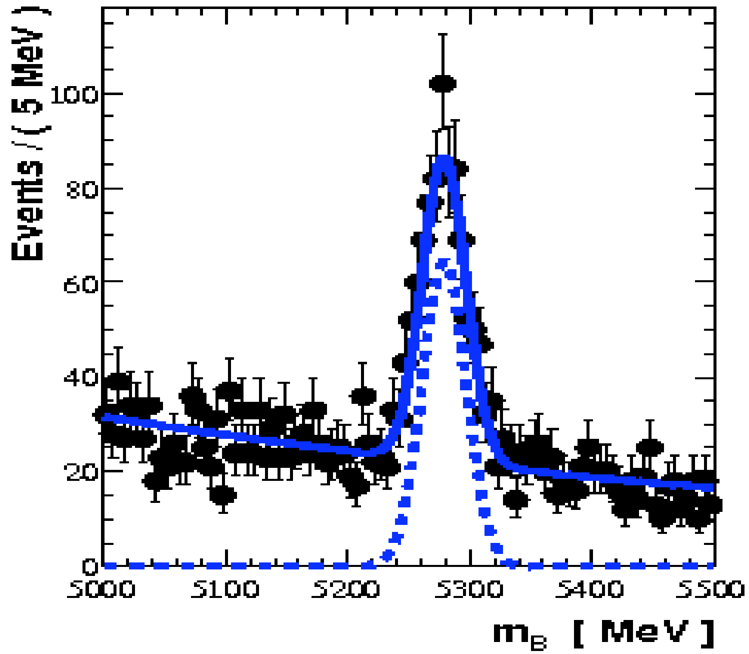
(SM + Errors from arXiv: 0807.2589)

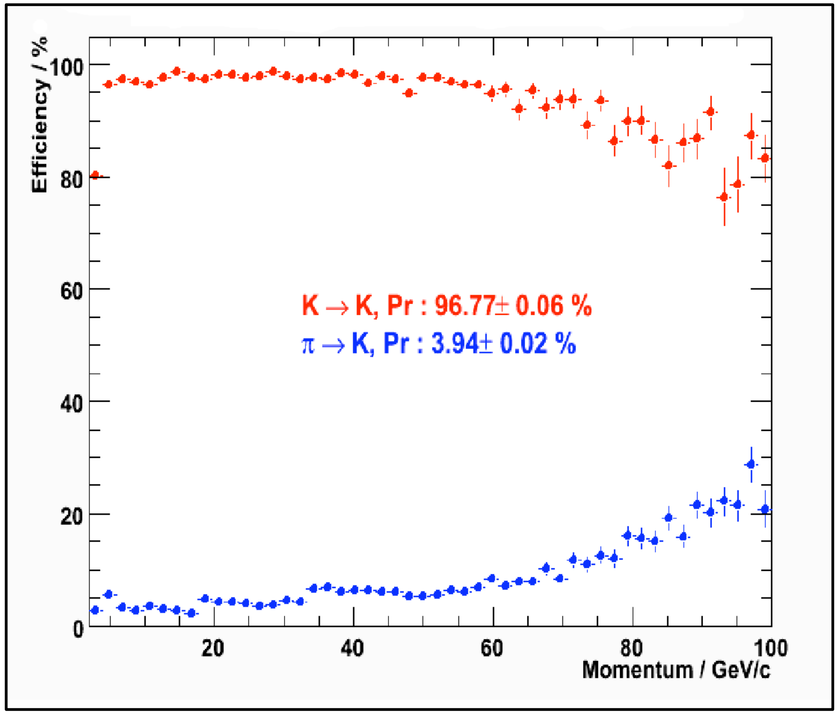
BaBar (2008) ~100 events, Belle (2008) ~ 200 events

LHCb (2010) ~ 7.2k events ?

Selecting the Signal at LHCb

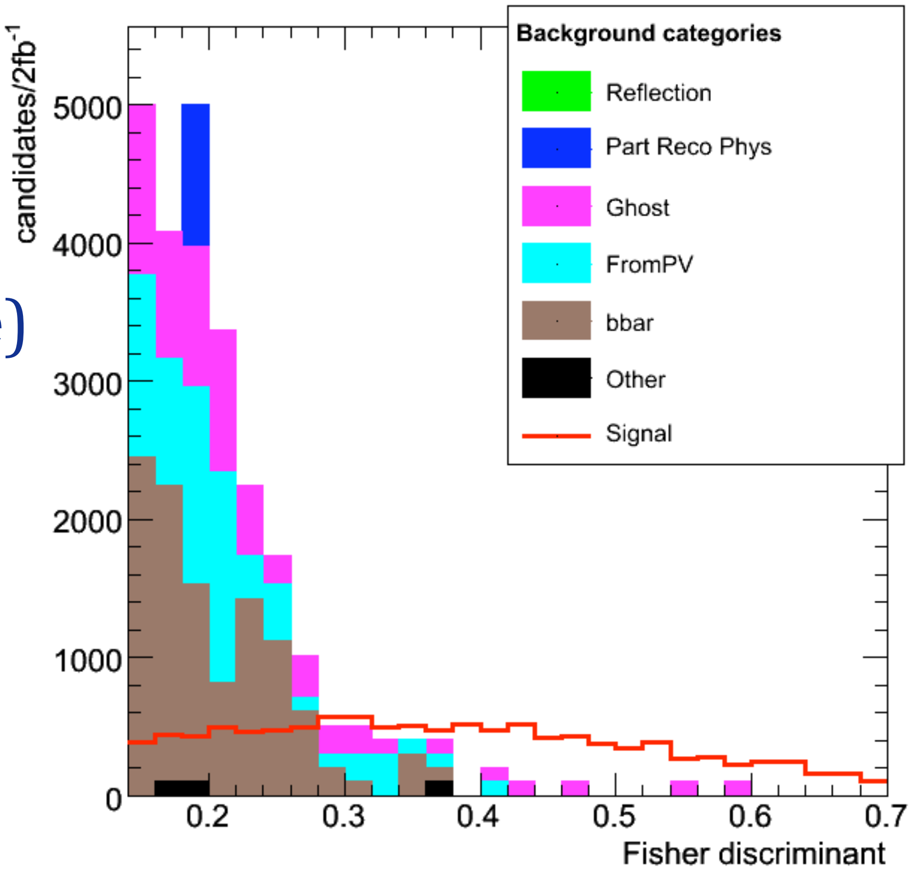
- Signal selection uses B_d vertex and daughter momenta for reconstructing masses
- B_d vertex res. ~130μm
- Track momentum ~0.5%
- μ ID performance key
- π/K separation from RICHs
  - Suppress background
- L0 μ trigger
  - μ p_T threshold ~ 1GeV





Signal Yields

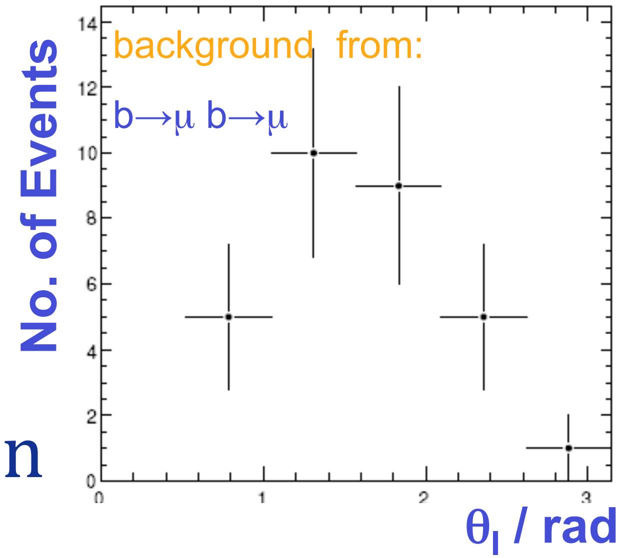
- Latest full MC studies:
  - Total selection eff. 1.1%
  - ~7.2k per $2fb^{-1}$ (full q^2 range)
    - ~3.7k per $2fb^{-1}$ ($q^2 < m_{J/\psi}^2$)
  - ~1.1k of background events
    - See CERN-LHCb-2007-038
- 2009: Expect 1.8k signal events over full q^2 range
- Simple multivariate techniques
  - Investigating Fisher for 2009/10
    - B_d flight distance, IP , PID likelihoods

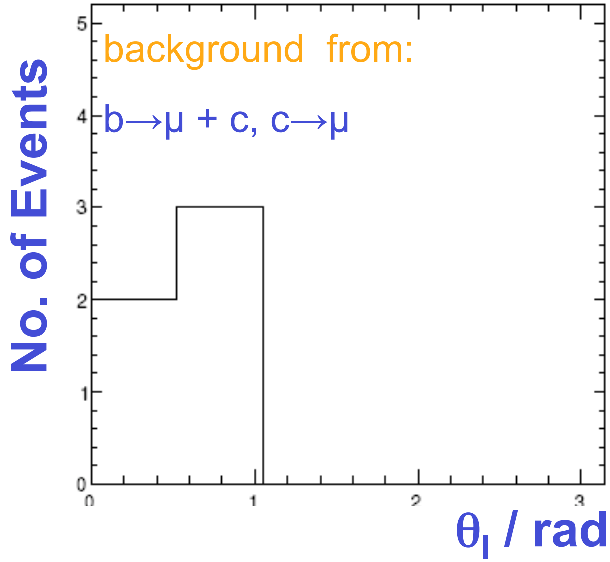


2 fb^{-1} is the expected integrated luminosity for one nominal year of smooth LHCb data taking

Background at LHCb

- Dominated by genuine μ from B_d
  - Little μ mis-ID in MC – check data!
- $b \rightarrow \mu, b \rightarrow \mu$ dominant contribution
  - Symmetric in θ_l, scales A_{FB} observed
- $b \rightarrow \mu + c, c \rightarrow \mu$ significant
  - Asymmetric in θ_l, affects A_{FB}
- Non-resonant $B_d \rightarrow K\pi\mu\mu$ unknown but probably small
  - Will measure in data





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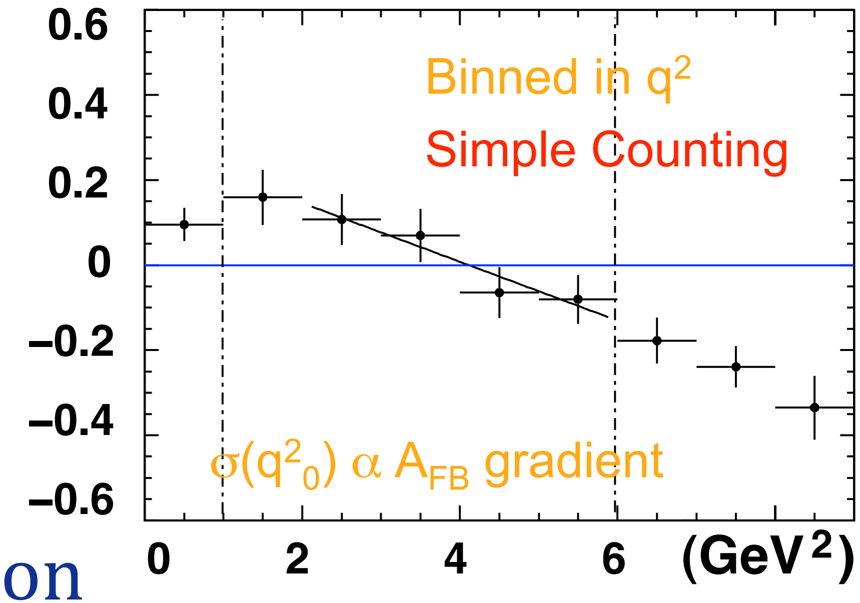
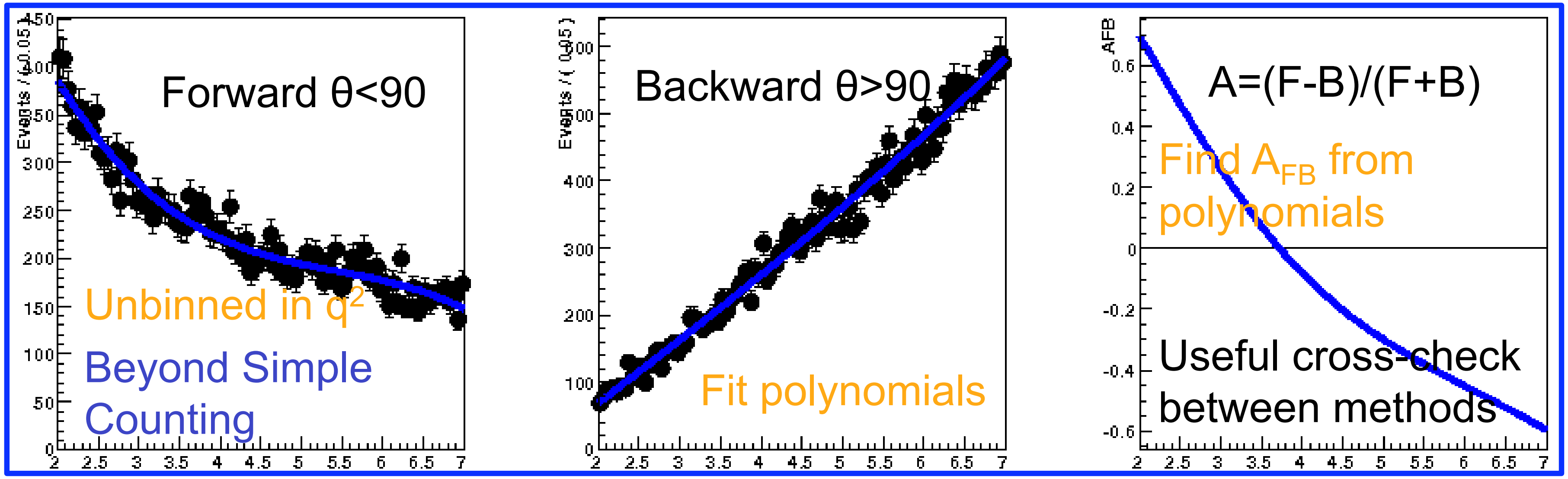
Analysis Timeline (2fb^{-1} means 1 nominal year!)

- A_{FB} first – can do a counting experiment 0.5 – 2 fb^{-1}
  - Zero crossing also accessible
  - CERN-LHCb-2007-039
- Perform fits to decay angles → F_L, $A_T^{(2)}$ 2 – 4 fb^{-1}
  - Fit just to θ_l or all three angles
  - CERN-LHCb-2007-057
- Full angular analysis
  - Many observables + improved resolution 3 – 10 fb^{-1}
  - CERN-LHCb-2008-041 (pending)
- Steps limited by understanding not statistics

Counting Experiments for AFB

- Can extract A_{FB} by counting forward and backward μ
  - Relatively simple
  - Low statistics
- Allows zero-crossing extraction
  - $\sigma(q^2_0) \sim 0.8\ \mathrm{GeV}^2/c^4$ (0.5 fb^{-1}), $0.5\ \mathrm{GeV}^2/c^4$ (2 fb^{-1})





Projection Fits

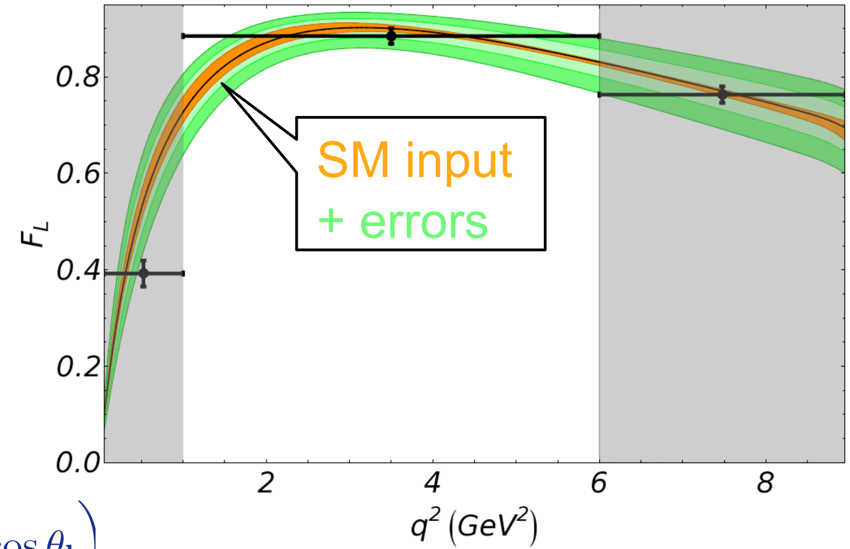
- Three decay angles → beyond θ_l
  - Angular projections of θ_l, ϕ, θ_K dist.

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

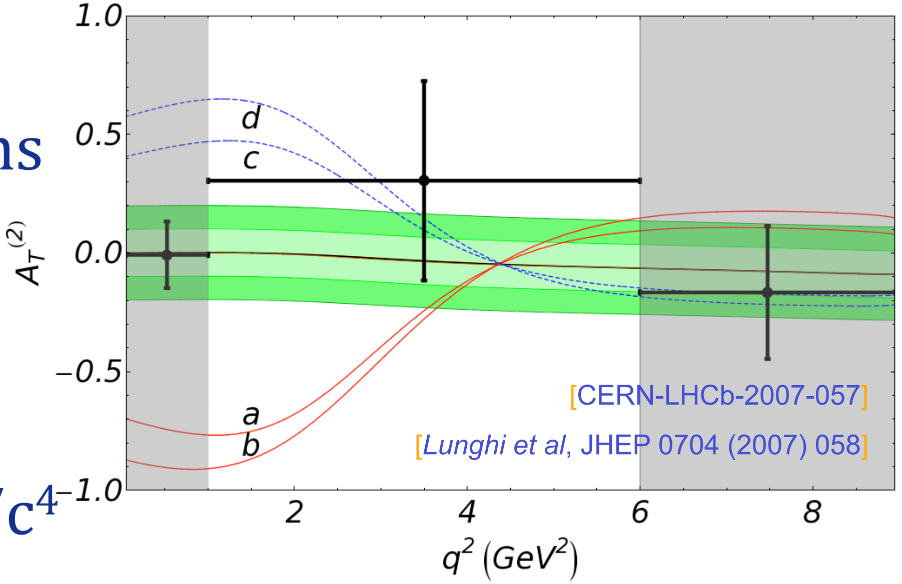
$$\frac{d\Gamma'}{d\cos\theta_l} = \Gamma'\left(\frac{3}{4}F_L\sin^2\theta_l + \frac{3}{8}(1-F_L)(1+\cos^2\theta_l) + A_{FB}\cos\theta_l\right)$$

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

- Perform simultaneous fit in q^2 bins
- Improve precision on A_{FB} by ~2
- F_L precision also improved
- Measure new observable $A_T^{(2)}$ with poor resolution in 1-6 GeV^2/c^4 region due to (1-F_L) suppression



LHCb 2fb^{-1}

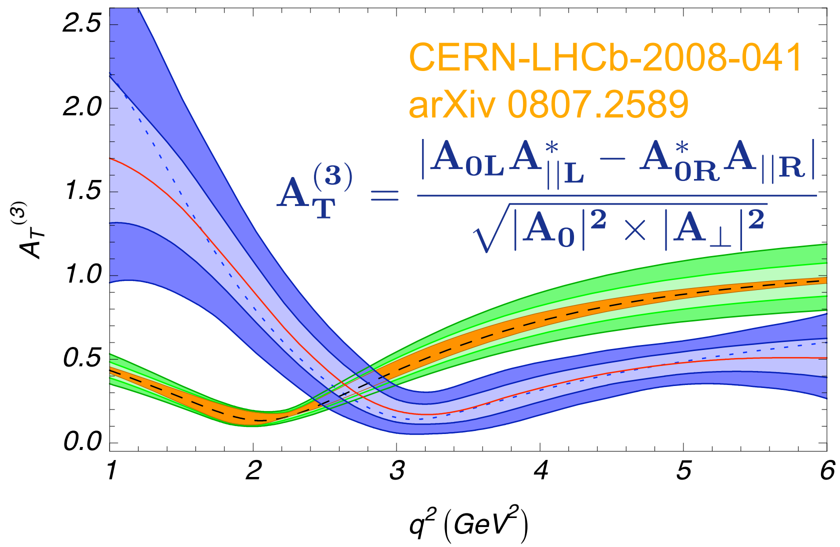


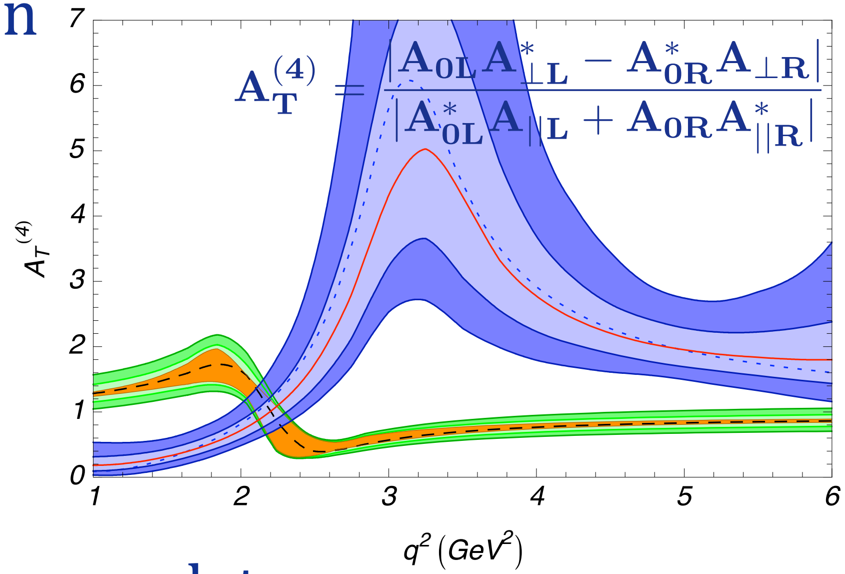
Full Angular Analysis

SM Theory Distribution

Toy fits to SUSY **model b** (C'$_7$!= 0) 1, 2σ

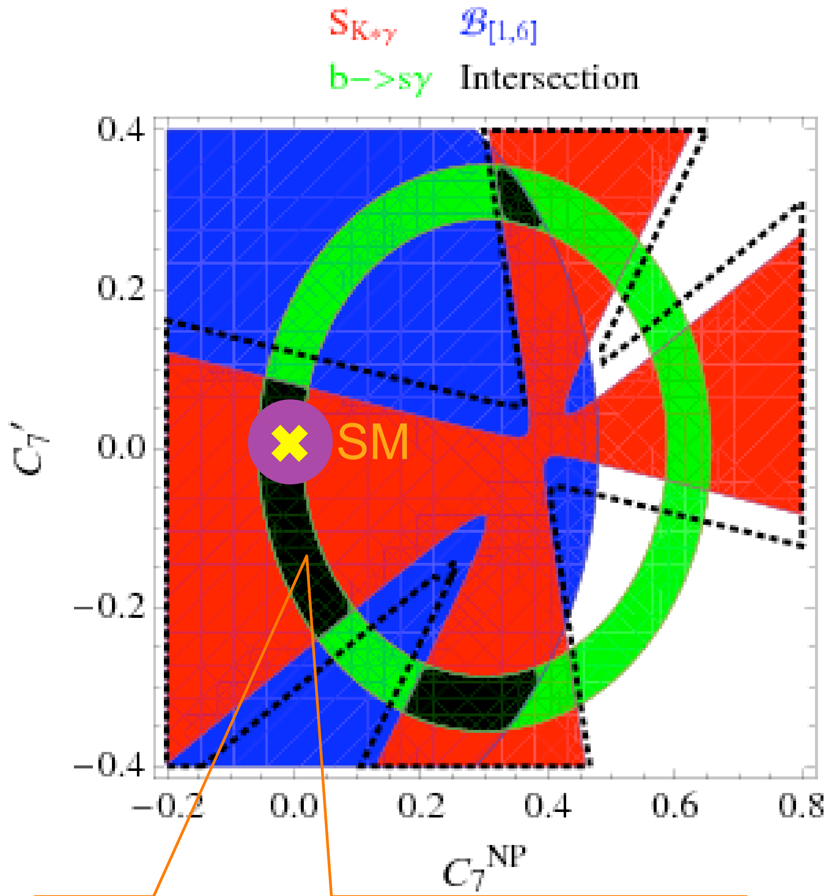
- $\frac{d^4\Gamma}{dq^2 d\theta_l d\theta_K d\phi}$ parameterized by K* spin amplitudes
  - $A_{\perp L,R}, A_{||L,R}, A_{0L,R}$
- Perform fit for amplitudes
  - Assume polynomial q^2 variation
- Calc. observables from amps.
  - New observables $A_T^{(3)}$ $A_T^{(4)}$
  - 10fb^{-1} sensitivities for SUSY input JHEP 0704 (2007) 058 model b →
- MC Fits converge with 2fb^{-1}
  - Acceptance a challenge – need more data



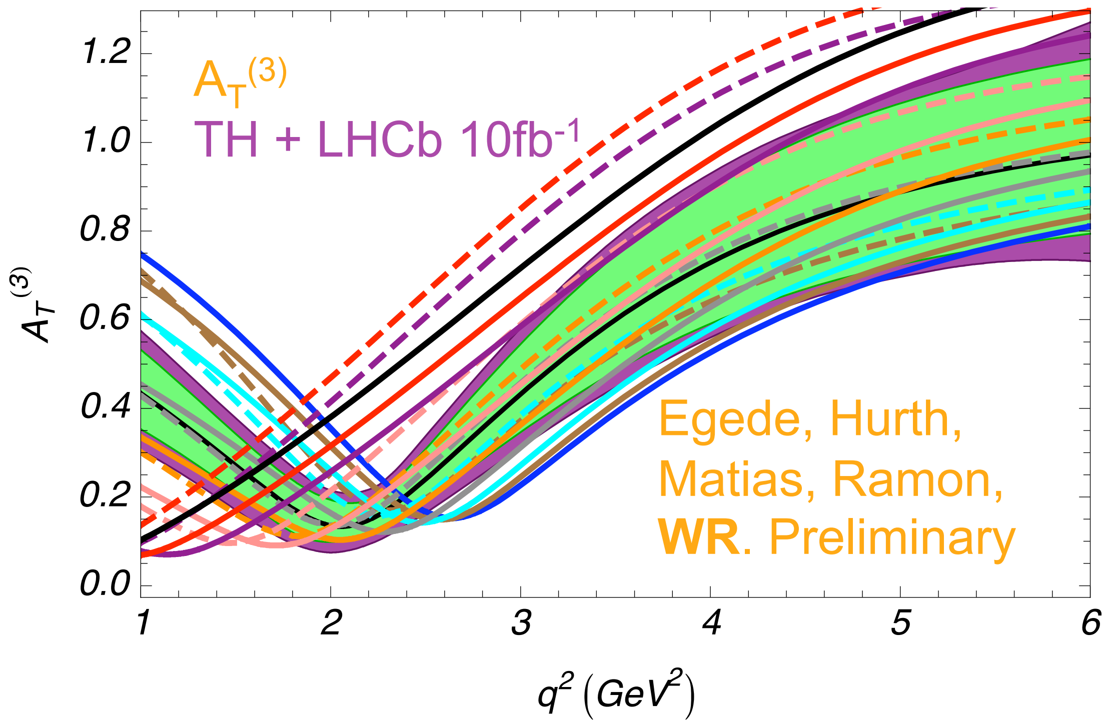


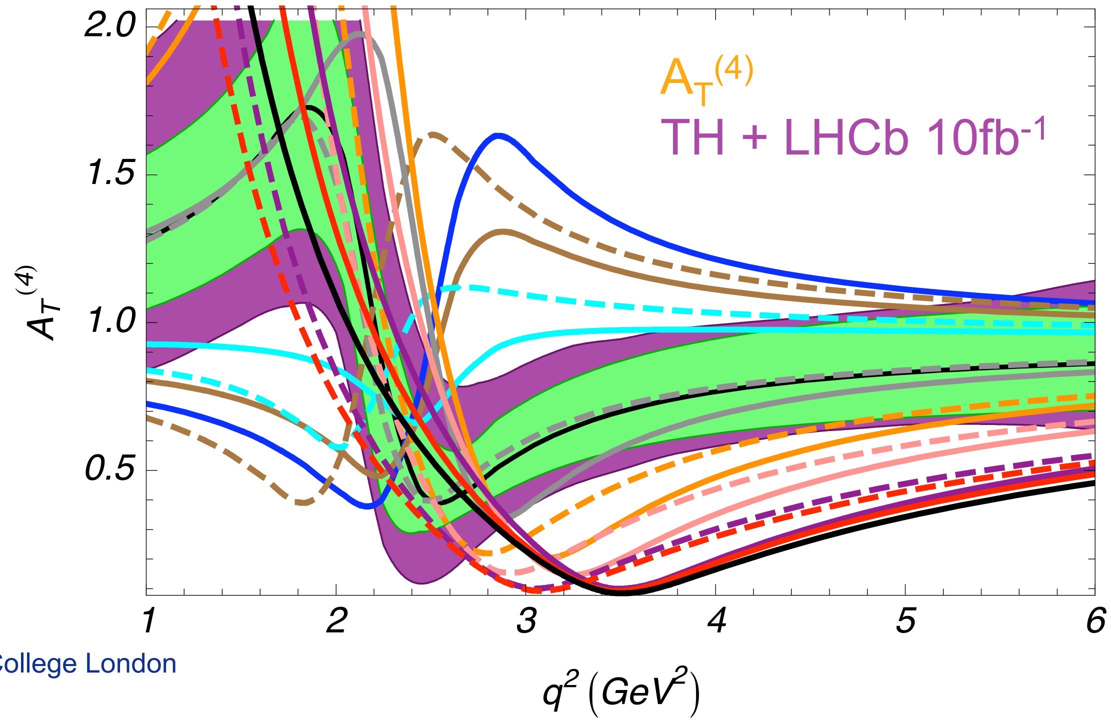
LHCb 10fb^{-1}

Finding NP in C_7



Allowed regions - C_7 real
JHEP 0807:106,2008
After 10fb^{-1} FA analysis?



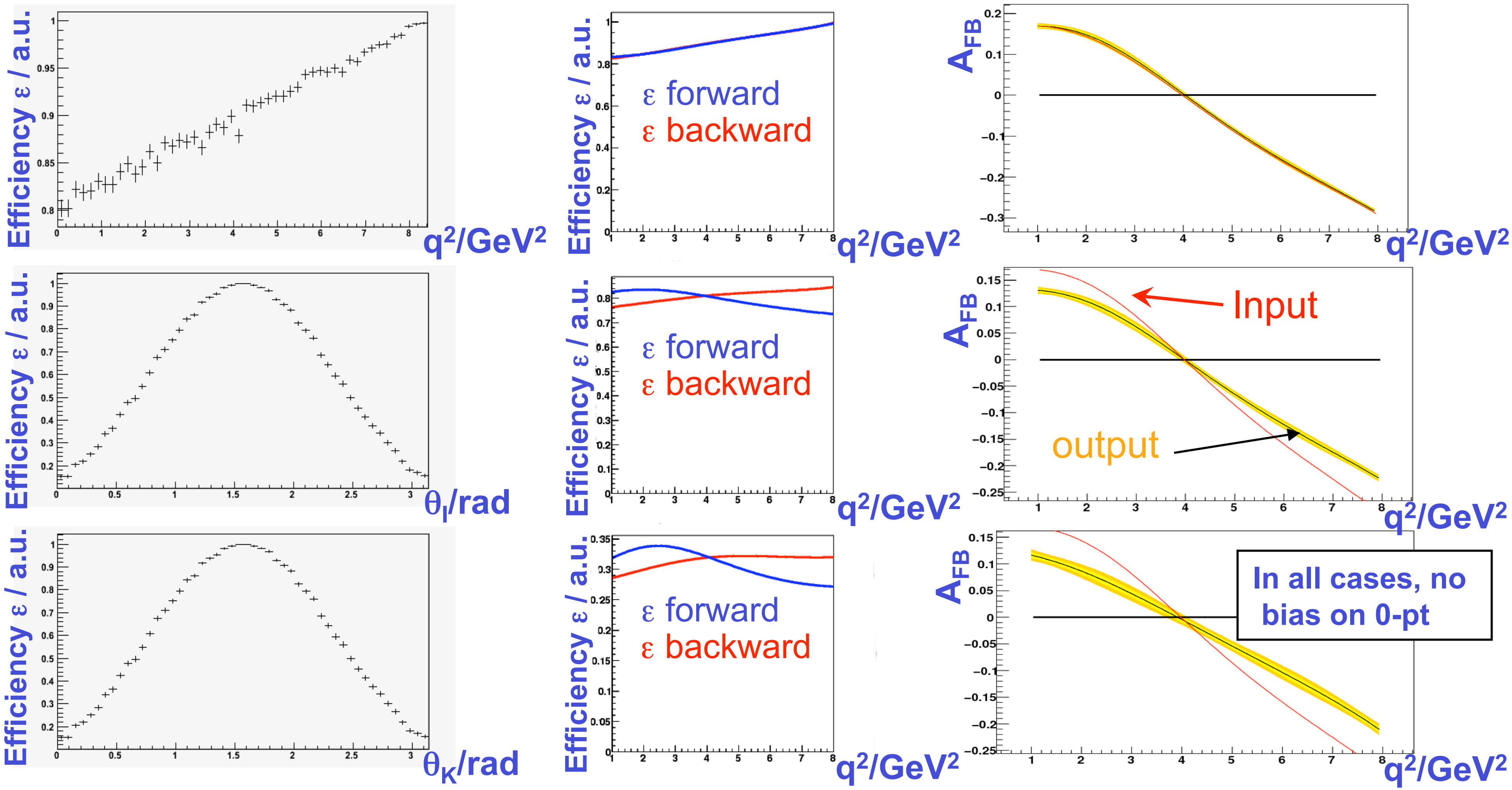


Summary $\bar{B}_d \to \bar{K}^{*0}\mu^+\mu^-$

- Excellent prospects for discovery of NP
  - Hints from B-factories + theory
- Expect 7.2k signal events per year over q^2
  - Background controllable
- Exciting Physics program
- Many observables to study
  - Counting experiments, projections, full angular
  - Real discriminating power for NP
- Exciting times ahead!

BACK UP SLIDES

Acceptance Effects for A_{FB}



- Take toy efficiencies for q^2, θ_l, θ_K
  - θ_K biases A_{FB} even though are only using θ_l directly

Outside the Theoretically Clean Region

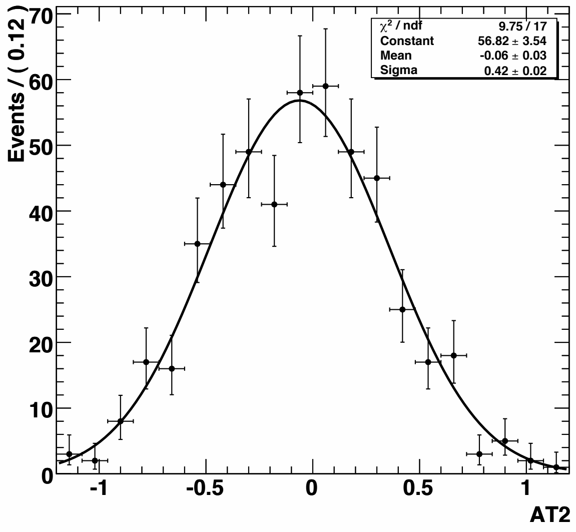
- B $\rightarrow$ Vector form factors large source of theoretical uncertainty
  - Dominated by low energy effects
  - 7 independent functions of q^2 – V, $T_{1,2,3}$, $A_{0,1,2}$
- Use SCET to reduce 7$\rightarrow$ 2 at Leading Order
  - Only valid in range 1-6 GeV^2/c^4
  - Can not handle resonances or low q^2 region
- Observables where 2 remaining FF cancel
  - $A_T^{(2,3,4)}$ and AFB zero-crossing point
- Uncertainties outside region much greater
- See Beneke et al, Nucl. Phys. B612 (2001) 26-58

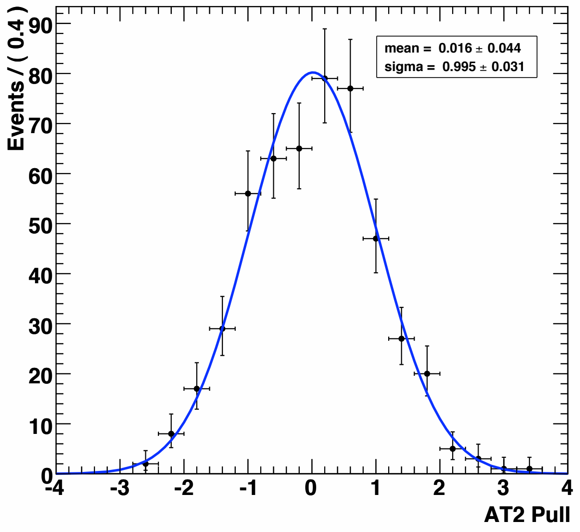
Projection Fit Resolutions

- Results from CERN-LHCb-2007-057

q^2 region (GeV^2/c^4)	A_{FB} $2\,\mathrm{fb}^{-1}$	A_{FB} $10\,\mathrm{fb}^{-1}$	$A_T^{(2)}$ $2\,\mathrm{fb}^{-1}$	$A_T^{(2)}$ $10\,\mathrm{fb}^{-1}$	F_L $2\,\mathrm{fb}^{-1}$	F_L $10\,\mathrm{fb}^{-1}$
0.05 – 1.00	0.034	0.017	0.14	0.07	0.027	0.011
1.00 – 6.00	0.020	0.008	0.42	0.16	0.016	0.007
6.00 – 8.95	0.022	0.010	0.28	0.13	0.017	0.008

Table 1: The expected resolution for measurements of the parameters A_{FB}, $A_T^{(2)}$ and F_L for the $\overline{B}_d \to \overline{K}^{*0}\mu^+\mu^-$ decay at LHCb in regions of the squared di-muon mass q^2 with 2 and $10\,\mathrm{fb}^{-1}$ of integrated luminosity.





Drell-Yan Backgrounds

- Not significant background at LHCb
- Full simulation study:
  - $b\bar{b}$ decays dominant source of μμ in mass range
  - Drell-Yan production much lower
- Reconstruction Efficiency:
  1. Fake signal → need a K* from elsewhere
  2. Wrongly associate this with μμ vertex
  3. Miss-ID rate should be very low

NP in C_7 Legend