

Rare Decays at LHCb

Greg Ciezarek, on behalf of the LHCb collaboration

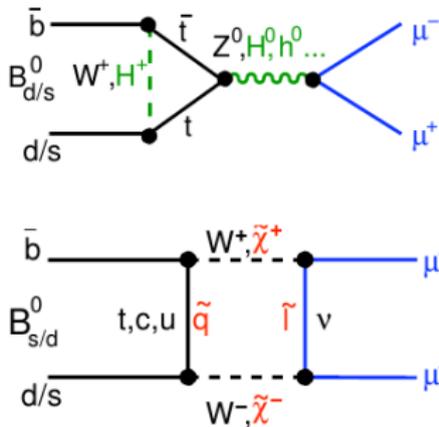
Imperial College London

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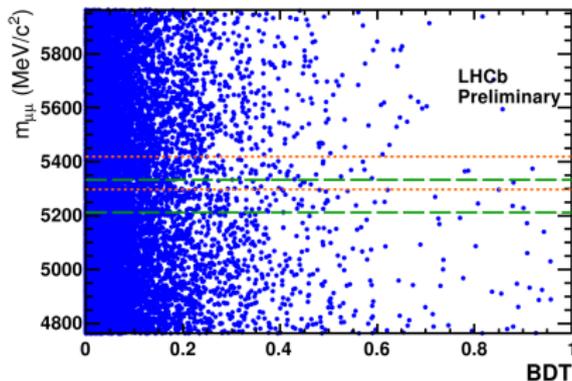
Introduction

- New particles enter into loop diagrams, if they exist
- Their influence may measurably change observables:
 - Branching fraction (total or differential)
 - Angular distribution
 - CP asymmetry
- Look in processes which only occur at loop level in SM - FCNCs
- Will cover broad range of rare FCNC processes - $B_q^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ were covered in more detail in the talk on Monday:
 - “CPV and rare B decays at LHCb” by T.Blake
- Will discuss most general physics implications

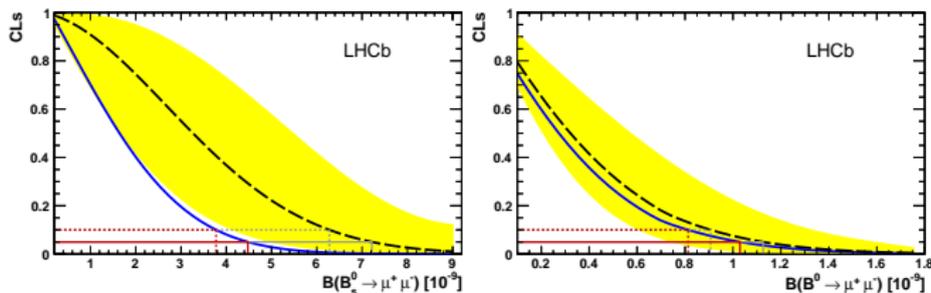
$$B_q^0 \rightarrow \mu^+ \mu^-$$



- Extremely suppressed in SM (prediction: $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.2 \pm 0.2) \times 10^{-9}$) [1]
- Particularly sensitive to scalar, pseudo-scalar operators
- Previous limit from LHCb, CMS combination [2, 3] a factor ~ 3 above SM prediction



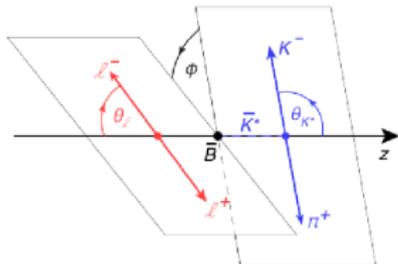
- Reduce combinatorial background using a BDT
- Bin $B_q^0 \rightarrow \mu^+ \mu^-$ events in BDT output, mass (2D distribution above)
- Normalise to three modes: $B^+ \rightarrow J/\psi K^+$, $B_s^0 \rightarrow J/\psi \phi$, and $B^0 \rightarrow K^+ \pi^-$
 - Results from all three consistent
- Set limits using CL_s method [4]

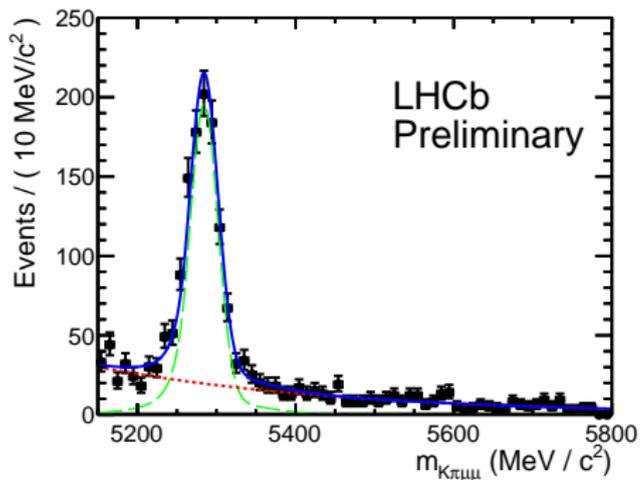


- Limit set for $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$ (left, $\sim 1.3 \times$ SM prediction),
 $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 1.0 \times 10^{-9}$ (right), both 95% C.L.
- Tightest indirect constraint on new scalar, pseudo-scalar operators
- Fitted $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = 0.8_{-1.3}^{+1.8} \times 10^{-9}$, consistent with SM (and zero)
- New physics could still suppress $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-)$

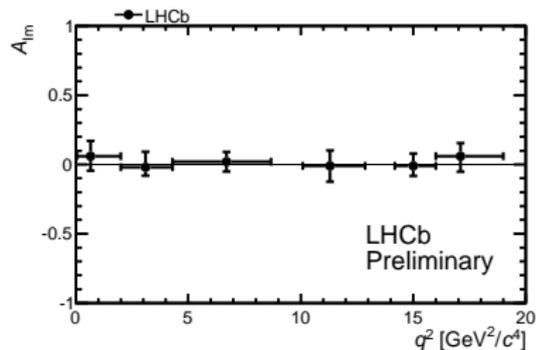
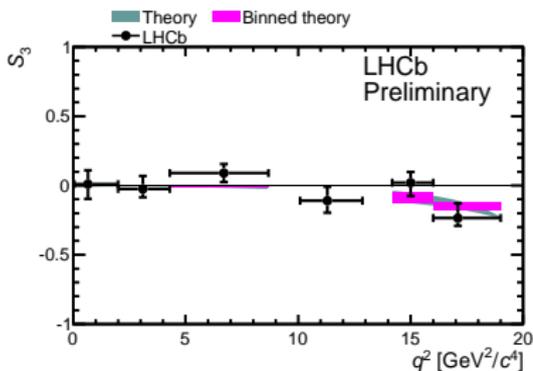
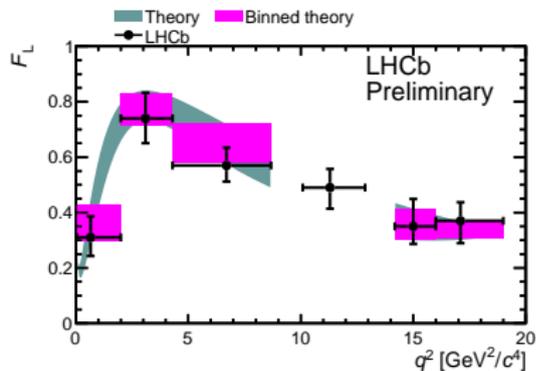
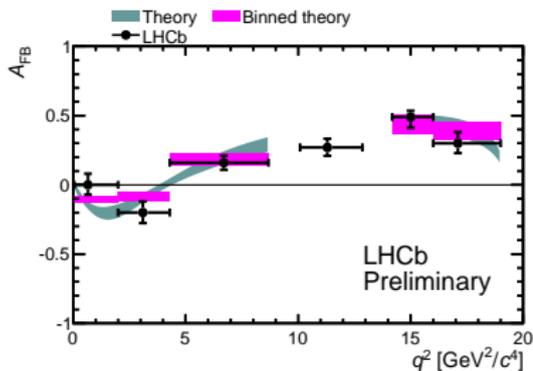
$$B^0 \rightarrow K^{*0} \mu^+ \mu^-$$

- Angular distribution of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ a sensitive test of new physics
- Described by three angles (θ_L, θ_K, ϕ), with the angular distribution varying with dimuon mass (q^2)
- Can be parameterised in terms of theoretically clean observables, with differing new physics sensitivities
 - A_{FB} , the forward-backward asymmetry
 - F_L , the fraction of K^{*0} longitudinal polarisation
 - $S_3 \propto A_T^2(1 - F_L)$, the asymmetry in K^{*0} transverse polarisation [5]
 - A_{IM} , a T-odd CP asymmetry [6]

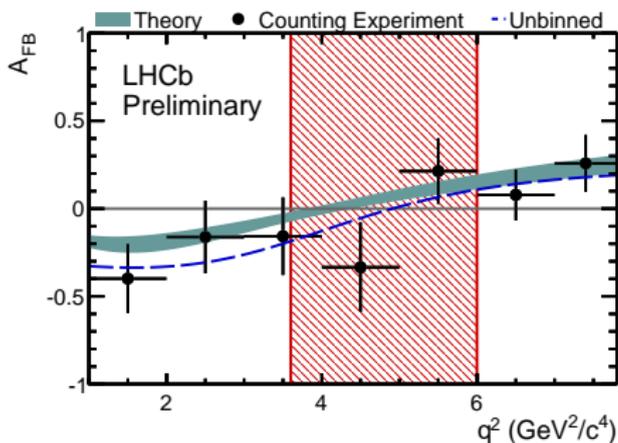




- Combinatorial background suppressed using a BDT selection
- Peaking backgrounds rejected with PID requirements
- $900 \pm 34 B^0 \rightarrow K^{*0} \mu^+ \mu^-$ candidates
- Correction applied for angular bias arising from detector acceptance, taken from simulation
- Bin in q^2 , 4D angular fit (3 angles + B mass)



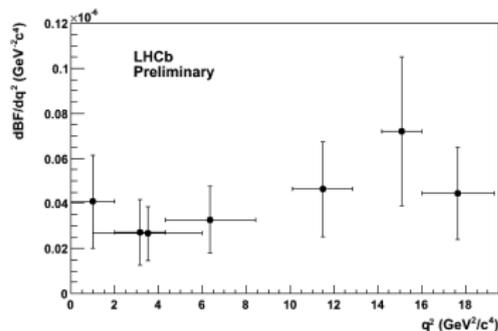
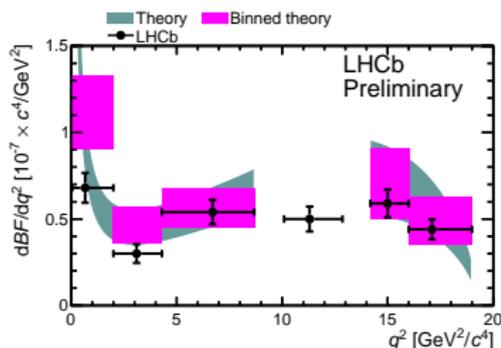
- Most precise measurements to date
- All consistent with SM [7]



- Zero-crossing point in q^2 of A_{FB} (q_0^2) an especially sensitive observable
- SM predictions range from 4-4.3 GeV^2/c^4 [7, 8, 9]
- World's first measurement made: $q_0^2 = 4.9_{-1.3}^{+1.1}$
- Consistent with SM

Differential branching fractions

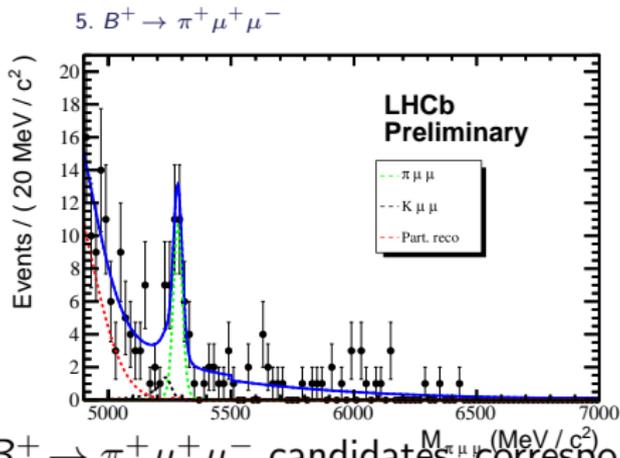
- Measurement made of $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ (left) and $B_s^0 \rightarrow \phi \mu^+ \mu^-$ (right) differential branching fraction



- $B_s^0 \rightarrow \phi \mu^+ \mu^-$ (differential) branching fraction measurements:
 - $\mathcal{B}(B_s^0 \rightarrow \phi \mu^+ \mu^-) = (0.78 \pm 0.01(\text{stat.}) \pm 0.06(\text{syst.}) \pm 0.28(\mathcal{B})) \times 10^{-6}$
- All consistent with SM predictions [10]

$$B^+ \rightarrow \pi^+ \mu^+ \mu^-$$

- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ is a $b \rightarrow d \mu^+ \mu^-$ transition
 - None yet observed
- CKM suppressed cousin to $B^+ \rightarrow K^+ \mu^+ \mu^-$
- Current limit is $< 6.9 \times 10^{-8}$, from BELLE [11]
- SM prediction $(1.96 \pm 0.21) \times 10^{-8}$ [12]
- May be enhanced by new physics, even with $b \rightarrow s \mu^+ \mu^-$ constraints
- Sensitive to MFV-violating physics

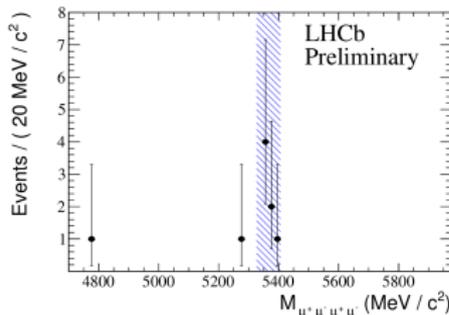


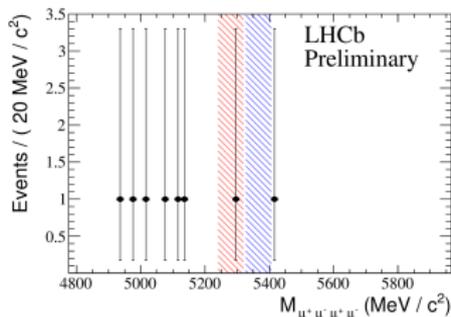
- $25.3^{+6.7}_{-6.4} B^+ \rightarrow \pi^+ \mu^+ \mu^-$ candidates, corresponding to a significance of 5.2σ
- $(B^+ \rightarrow \pi^+ \mu^+ \mu^-) = (2.4 \pm 0.6 \text{ (stat)} \pm 0.2 \text{ (syst)}) \times 10^{-8}$
- Consistent with SM prediction of $(1.96 \pm 0.21) \times 10^{-8}$
- Rarest B decay observed, first $b \rightarrow d \mu^+ \mu^-$ transition
- Possible future interest:
 - Extract $|\frac{V_{cd}}{V_{ts}}|$ (measure \mathcal{B} relative to $B^+ \rightarrow K^+ \mu^+ \mu^-$)
 - CPV potential larger in $b \rightarrow d \mu^+ \mu^-$ than $b \rightarrow s \mu^+ \mu^-$ [13]
 - Large A_{FB} or F_H ?

$$6. B_s^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$$

$$B_q^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$$

- SM process: $B_q^0 \rightarrow \mu^+ \mu^- \gamma^*$ with $\gamma^* \rightarrow \mu^+ \mu^-$
- Non-resonant BR predicted to be $10^{-10} - 10^{-11}$ [14]
- Sensitive to:
 - Four-point vertices
 - eg sGoldstinos ($B_s^0 \rightarrow S(\rightarrow \mu^+ \mu^-)P(\rightarrow \mu^+ \mu^-)$)
- Resonant mode: $\mathcal{B}(B_s^0 \rightarrow J/\psi(\rightarrow \mu^+ \mu^-)\phi(\rightarrow \mu^+ \mu^-)) = (2.3 \pm 0.9) \times 10^{-8}$ [15] (observed yield consistent with expectation)

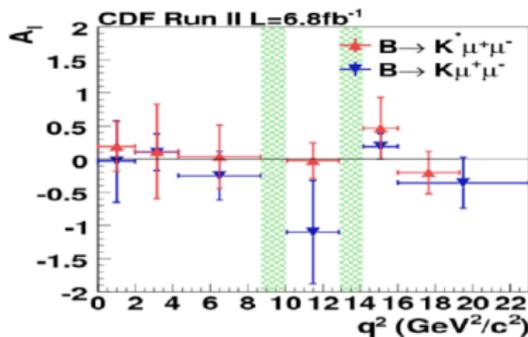
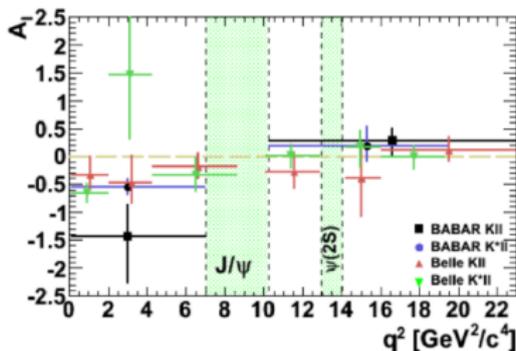




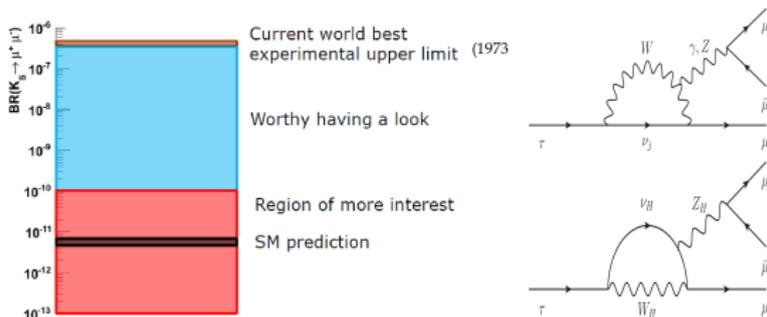
- Number of observed events consistent with background expectation
- Set a limit on signal events using a CL_s method
- Normalise the limit on signal events to a branching fraction limit, assuming a phase space $B_q^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ distribution
- $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-) < 1.3 \times 10^{-8}$,
 $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-) < 5.4 \times 10^{-9}$ at 95% confidence level

Upcoming results

- CPV in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$
 - $< 10^{-3}$ in SM
 - New V-A couplings could enhance this to $\sim 10\%$ at high q^2 [16]
- $B \rightarrow K^{(*)} \mu^+ \mu^-$ isospin asymmetry
 - Asymmetry in $B^0 \rightarrow K^{0(*)} \mu^+ \mu^-$, $B^+ \rightarrow K^{+(*)} \mu^+ \mu^-$ as a function of q^2
 - Previous results from BaBar, Belle, CDF do not agree well with SM [17, 18, 19]



- $B^0 \rightarrow K^{*0} e^+ e^-$
 - Angular analysis at low q^2
 - Can extract the photon polarisation in $b \rightarrow s \gamma$
- $\Lambda_b^0 \rightarrow \Lambda \mu^+ \mu^-$
 - Branching fraction measurement
 - Differential branching fraction, angular analysis in future
 - Similar physics sensitivity to $B^0 \rightarrow K^{*0} \mu^+ \mu^-$
- $B^+ \rightarrow K^+ \mu^+ \mu^-$
 - Differential branching fraction, angular analysis
 - A_{FB}, F_H zero in SM, sensitive to tensor operators (C_T, C_{TE}) [20]



- $K_S^0 \rightarrow \mu^+ \mu^-$
 - Probe CP violating phase in $s \rightarrow d\ell^+\ell^-$ amplitude [21]
 - $\mathcal{B}(K_S^0 \rightarrow \mu^+ \mu^-)$ range for new physics, SM [22] shown in plot
 - Should extend the present limit considerably.
- $\tau^+ \rightarrow \mu^+ \mu^- \mu^+$
 - $\mathcal{B}(\tau^+ \rightarrow \mu^+ \mu^- \mu^+) \sim 10^{-50}$ in SM
 - Sensitive LFV measurement

Conclusion

- $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ - Worlds most precise measurements
- $B_s^0 \rightarrow \phi \mu^+ \mu^-$ - Worlds most precise measurements
- $B^+ \rightarrow \pi^+ \mu^+ \mu^-$ - Worlds first observation (of any $b \rightarrow d \mu^+ \mu^-$ mode), rarest B decay
- $B_q^0 \rightarrow \mu^+ \mu^-$ - Worlds best limits
- $B_q^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$ - Worlds first limit
- Many more measurements to come this year

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