

Rare decays, radiative and $b \rightarrow \ell \bar{\ell} s$ review

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Beauty 2006
Oxford University

CKM picture

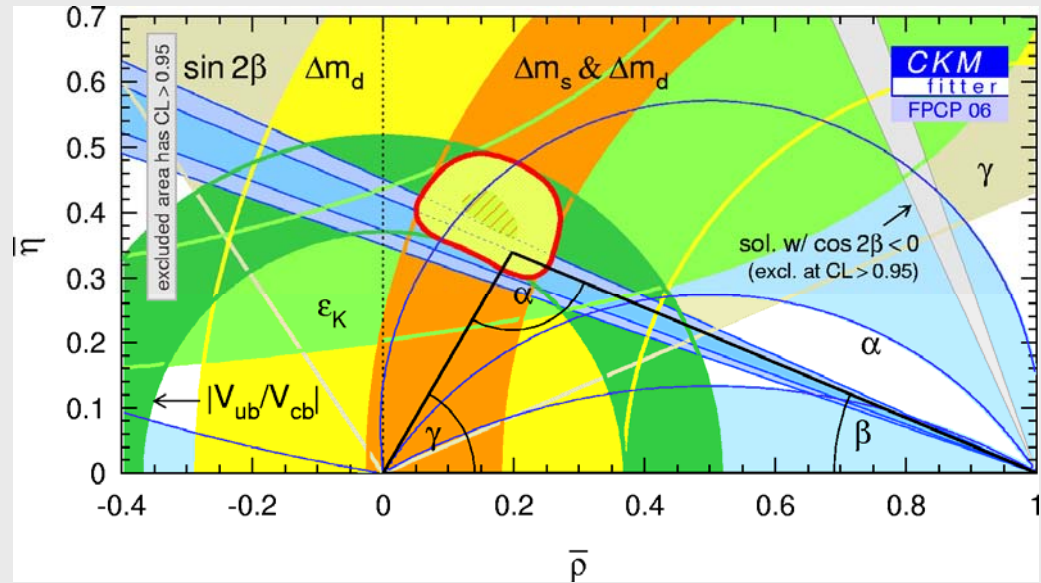
- The CKM picture is very successful, mainly obtained from:

- tree from $s \rightarrow u, b \rightarrow c$ and $b \rightarrow u$ decays
- mixing amplitudes: $\Delta B=2$ and $\Delta S=2$

- Any room for physics beyond the SM left?

- Any extension of the SM must have small effects on this sector.

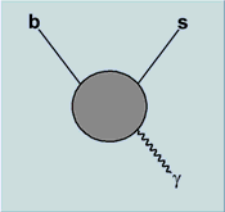
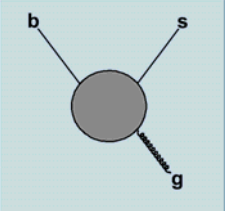
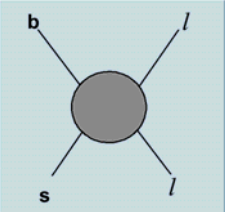
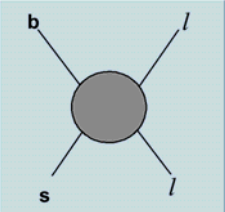
- But: We do not know much about $b \rightarrow s$ and $b \rightarrow d$!



[CKM fitter]

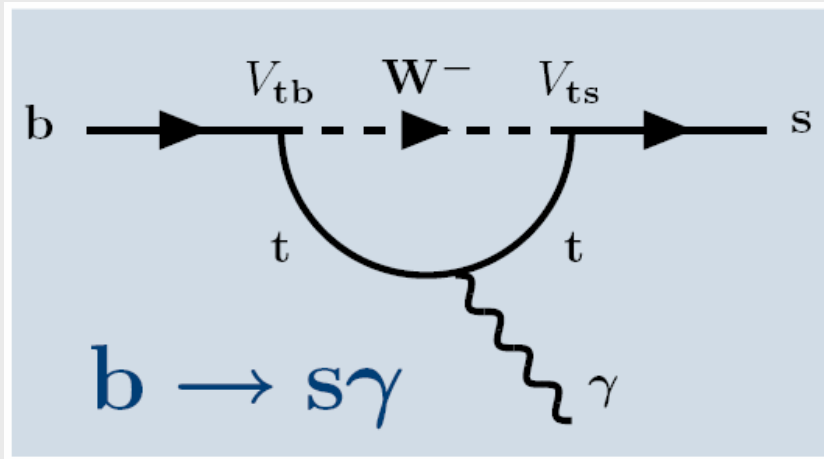
- $b \rightarrow sg$ penguins (e.g. $B \rightarrow \phi K_S$)
- $b \rightarrow q\gamma$ penguin decays
- $b \rightarrow q\ell\ell$ penguin decays

Operators & Observables

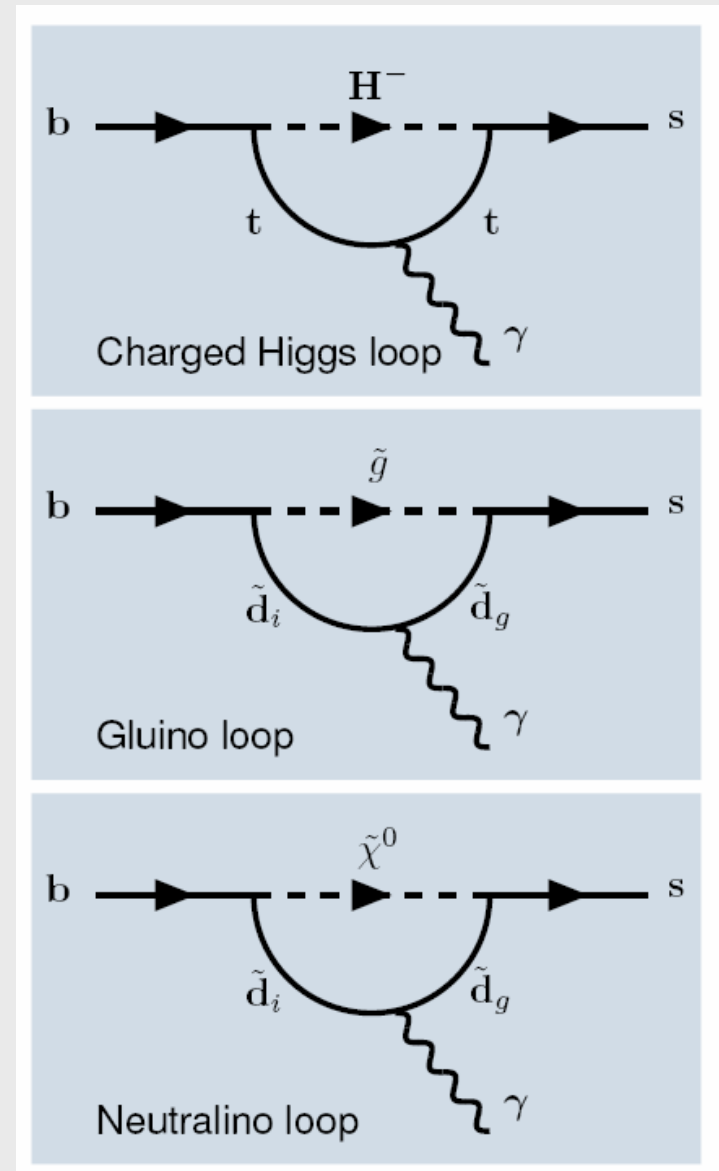
Operators	Magnitude	Phase	Helicity Flip
$O_{7\gamma}$ 	$b \rightarrow s\gamma$	$A_{CP}(b \rightarrow s\gamma)$	$\Lambda_b \rightarrow \Lambda\gamma$ $B \rightarrow K^*\ell^+\ell^-$ $B \rightarrow K^{**}\gamma$
O_{8g} 	$b \rightarrow s\gamma$ $b \rightarrow s$	$A_{CP}(b \rightarrow s\gamma)$ $B \rightarrow \phi K_S$ $B_S \rightarrow \phi\phi$	$\Lambda_b \rightarrow \Lambda\phi$ $B \rightarrow \phi K^*$
$O_{9\ell,10\ell}$ 	$b \rightarrow \ell\ell s$	$A_{FB}(b \rightarrow \ell\ell s)$	$B \rightarrow K^*\ell^+\ell^-$
$O_{S,P}$ 	$B \rightarrow \mu\mu$	$B \rightarrow \tau\tau$	$b \rightarrow s\tau\tau$

[Hiller, hep-ph/0308180]

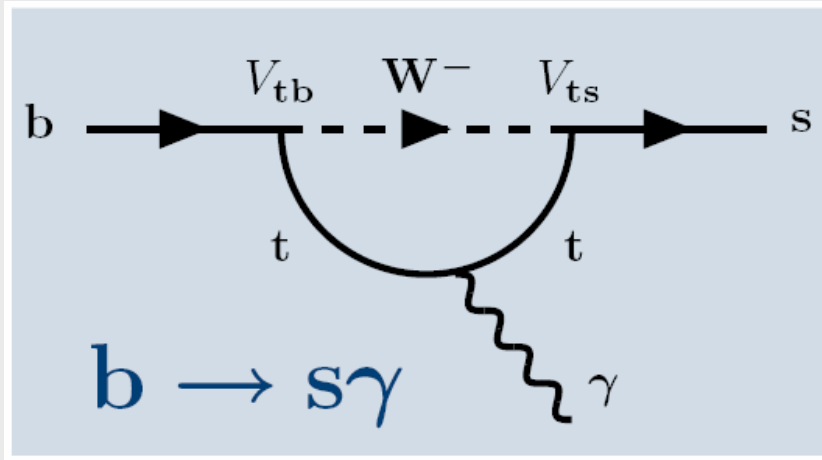
Radiative decay $b \rightarrow s \gamma$



- Amplitude $\propto |V_{ts}| C_7$
- Experiment (WA):
BR = $(3.55 \pm 0.26) \cdot 10^{-4}$
- Standard Model:
BR = $(3.7 \pm 0.3) \cdot 10^{-4}$
- But from phase and helicity flip measurements we can set very strong constraint on New Physics!



$b \rightarrow s \gamma$: photon polarization



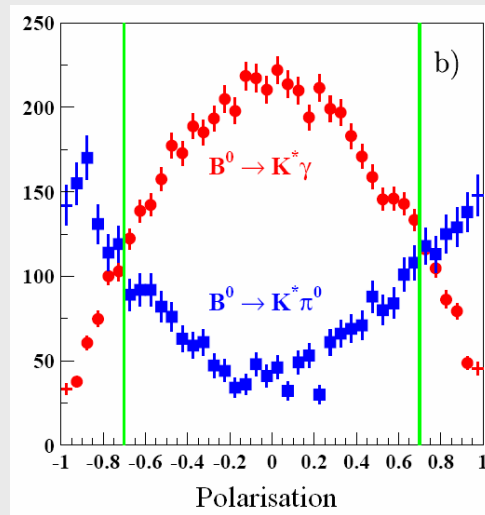
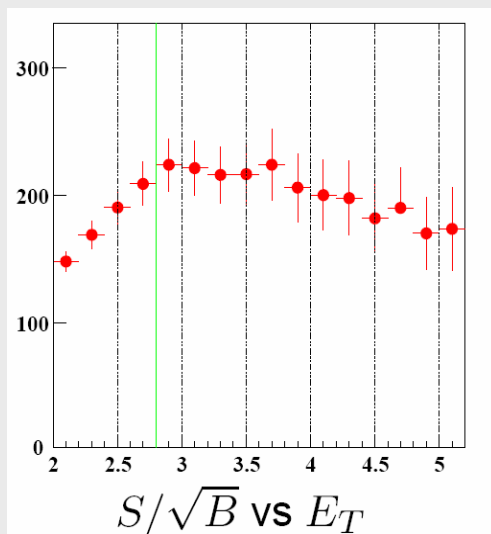
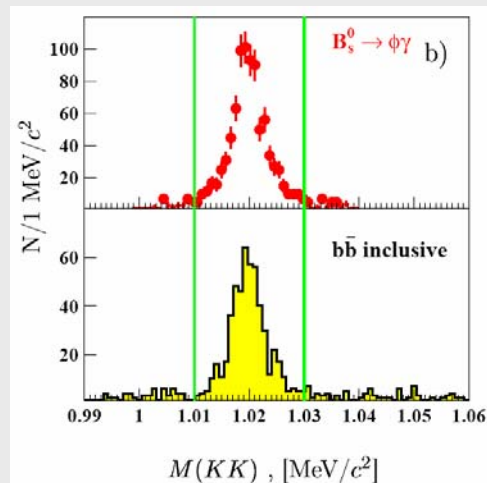
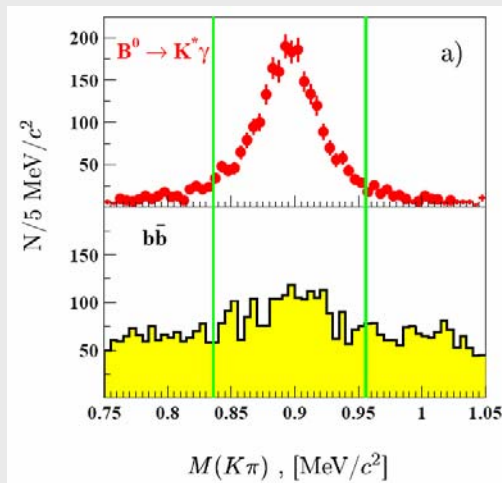
- The photon polarization is not well measured.
- (New) Right-handed operators could contribute.
- But gluons could also contribute $O(10\%)$

[Grinstein et al., Phys.Rev. D71 (2005) 011504]

Ways to measure:

- Virtual photons (eg. $b \rightarrow \ell \ell s$)
Melinkov et al., [[PLB442 381-389, 1998](#)]
- Converted photons
Grossman et al., [[JHEP06 29, 2000](#)]
- $B \rightarrow \gamma K^{**}$ ($K\pi\pi$)
Gronau & Pirjol, [[PRD66 054008, 2002](#)],
Gronau et al., [[PRL88 051802, 2002](#)]
- Time Dependent $A_{CP}(K^* \gamma)$
- Λ_b baryons
Hiller & Kagan, [[PRD65 074038, 2002](#)]

LHCb: $B \rightarrow K^* \gamma$, $B_s \rightarrow \phi \gamma$



Charged Tracks:

- Consistent with req. PID
- Inconsistent with primary vertex
- Good secondary vertex
- Consistent K^* , ϕ mass

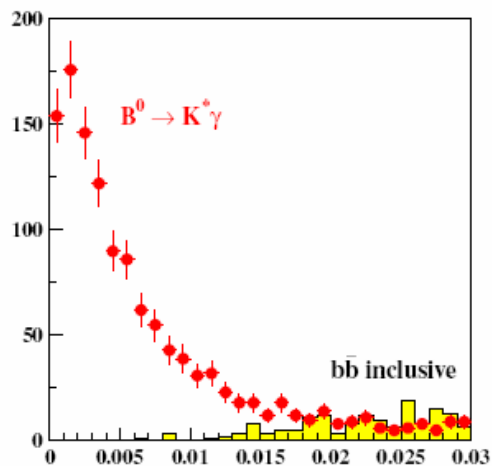
Photons:

- $E_T > 2.8 \text{ GeV}$
- Remove $B \rightarrow K^* \pi^0$, $B_s \rightarrow \phi \pi^0$ using K^* , ϕ polarization

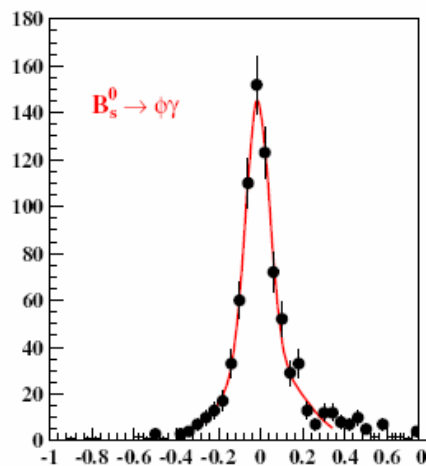
Full detector simulation

[LHCb-note-2003-090]

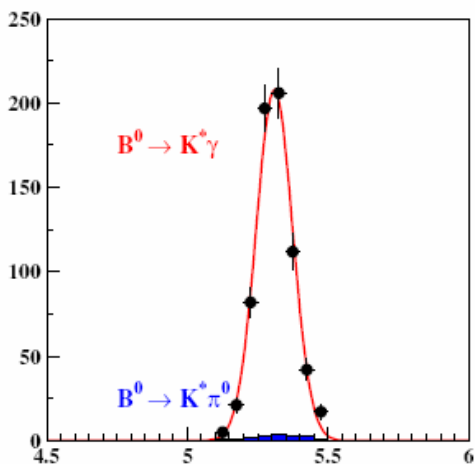
LHCb: $B \rightarrow K^* \gamma$, $B_s \rightarrow \phi \gamma$



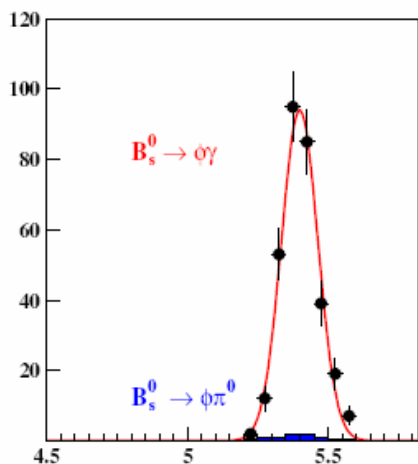
Pointing angle



$B_s \tau$ resolution



$K^* \gamma$ mass



$\phi \gamma$ mass

- Require B to point back to the Primary Vertex
- Mass resolution: 65 MeV
- Lifetime resolution: 62 fs

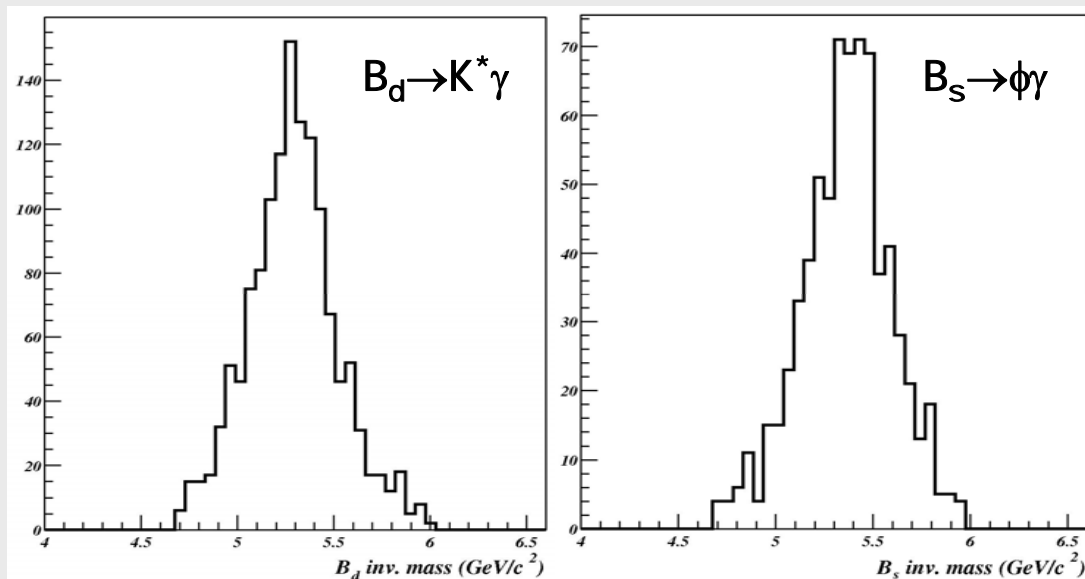
Expectations for 2 fb^{-1} :

	Yield	B/S
$B \rightarrow K^* \gamma$	35 000	<0.7
$B_s \rightarrow \phi \gamma$	9 000	<2.4
$B_s \rightarrow \omega \gamma$	9 000	<3.5

Limited by MC statistics

[LHCb note-2003-090]

ATLAS: $B \rightarrow K^* \gamma$, $B_s \rightarrow \phi \gamma$



full detector simulation

- Require a (i) μ with $p_T > 6$ GeV and (ii) a ROI in the EM CAL with $E_T > 5$ GeV
- Resolution (> 100 MeV) could be improved (not optimized offline cuts)

Expectations (on tape)
for 20 fb^{-1} :

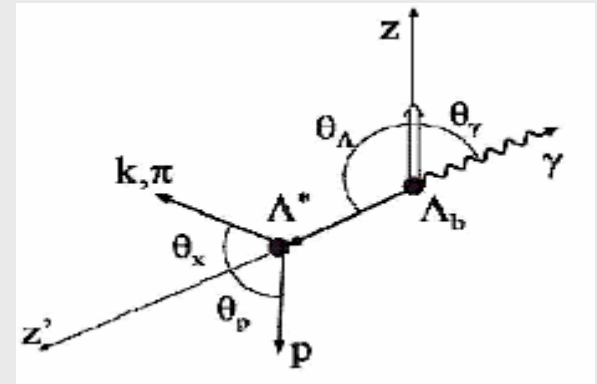
	Yield	B/S
$B \rightarrow K^* \gamma$	9 400	< 100
$B_s \rightarrow \phi \gamma$	3 200	< 400

Results limited by background statistics, B/S might be much better.

[ATLAS, phys-pub-2005-006]

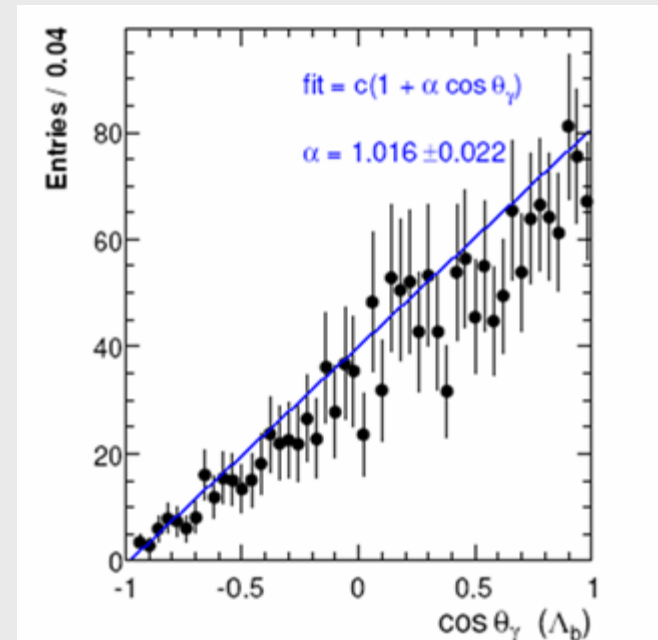
$\Lambda_b \rightarrow \Lambda \gamma$ polarization

$$r = \frac{C'_{7\gamma}}{C_{7\gamma}} \rightarrow \alpha_\gamma = \frac{1 - |r|^2}{1 + |r|^2}$$
$$\frac{d\Gamma}{d\cos\vartheta_\gamma} \propto 1 - \alpha_\gamma P_{\Lambda_b} \cos\vartheta_\gamma$$
$$\frac{d\Gamma}{d\cos\vartheta_p} \propto 1 - \alpha_\gamma \alpha_{p,1/2} \cos\vartheta_\gamma$$



But:

- $\Lambda \gamma$ does not have a distinctive secondary vertex
- Most Λ decay outside of vertex detector



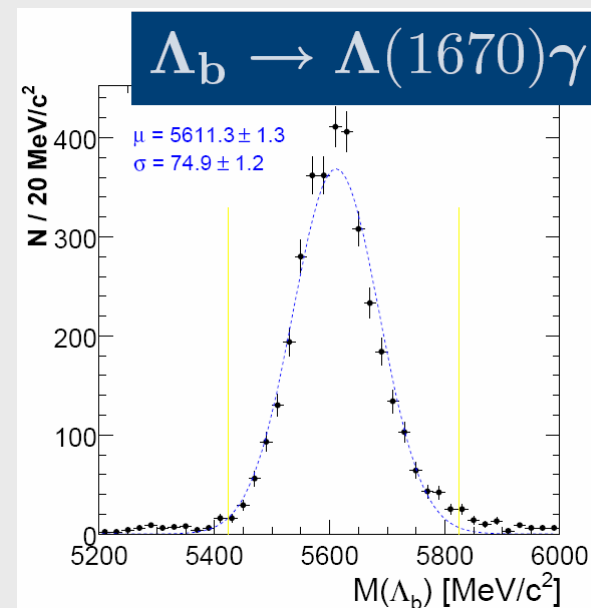
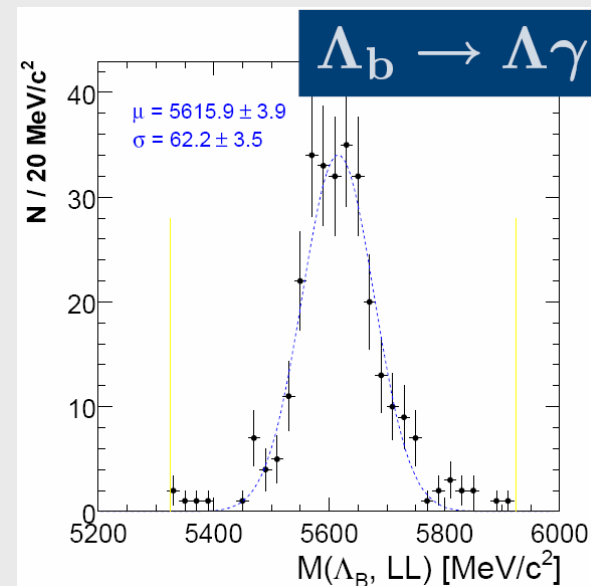
[F. Legger, T. Schietinger, hep-ph/0605245]

$\Lambda_b \rightarrow \Lambda\gamma$ polarization at LHCb

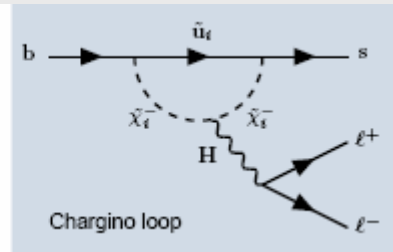
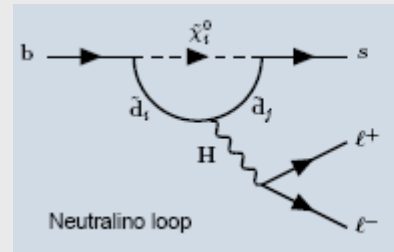
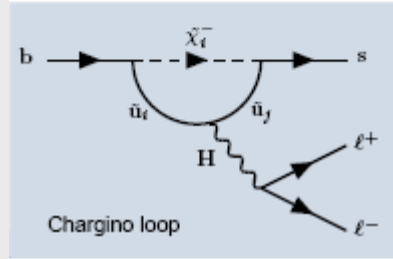
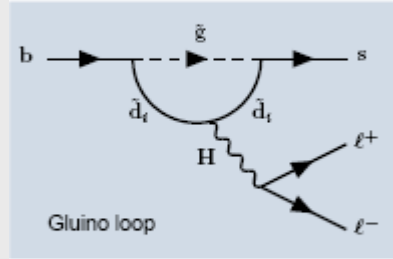
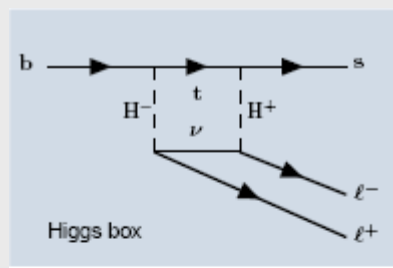
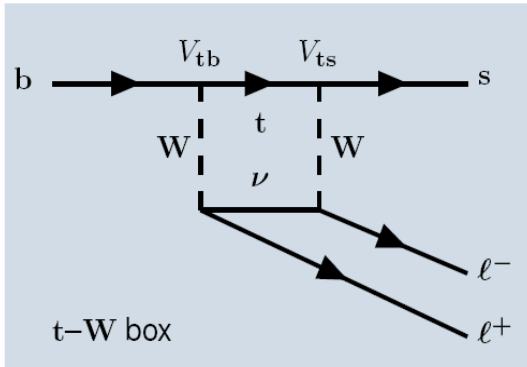
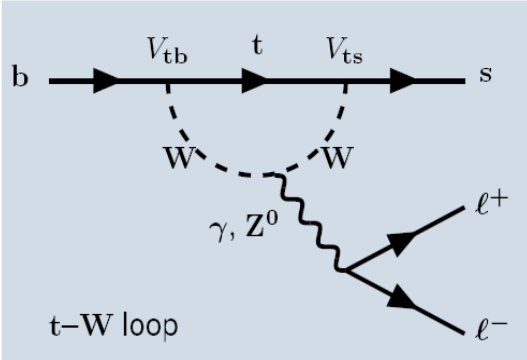
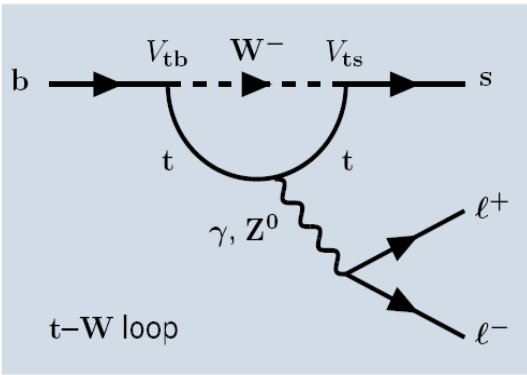
Annual (2 fb⁻¹) yields at LHCb:

	Yield	B/S
$\Lambda_b \rightarrow \Lambda\gamma$	750	<42
$\Lambda_b \rightarrow \Lambda(1520)\gamma$	4200	<10
$\Lambda_b \rightarrow \Lambda(1670)\gamma$	2500	<18
$\Lambda_b \rightarrow \Lambda(1690)\gamma$	2200	<18

- Λ^* modes have less intrinsic sensitivity: proton polarisation flat. (Use Λ_b which can be measured with $\Lambda_b \rightarrow \Lambda J/\psi$ at 1% level.) [[Hrivnac et al, hep-ph/9405231](https://arxiv.org/abs/hep-ph/9405231)]
- Combined resolution on r is 20% after 1 year.
- Need more precision to distinguish between SM and most of the SM extensions .



Electroweak decay $b \rightarrow \ell \ell s$



Suppressed by α_{EM}

■ $BR(b \rightarrow \ell \ell s)_{TH} = (4.5 \pm 1.0) \cdot 10^{-6}$

■ $BR(B \rightarrow K \ell \ell)_{TH} = (0.5 \pm 0.1) \cdot 10^{-6}$

■ Sensitive to

- Susy
- Graviton exchanges
- Extra dimensions

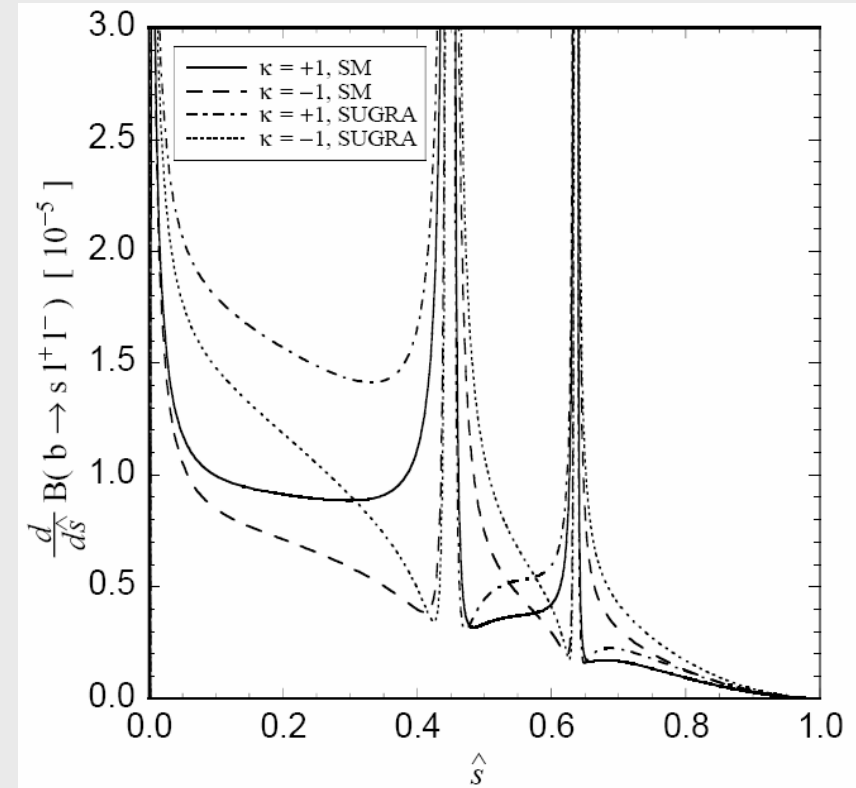
$b \rightarrow \ell \ell s$ observables

Inclusive decays well described by theory:

- Shape of dilepton mass distribution sensitive to NP.
- Standard Model branching ratio $(1.36 \pm 0.08) \cdot 10^{-6}$ (NNLL) for $s = q^2/m_b^2 < 0.25$

But:

- Inclusive decays are difficult to access experimentally.
- Exclusive decays *much* easier for experiment but affected by hadronic uncertainties.

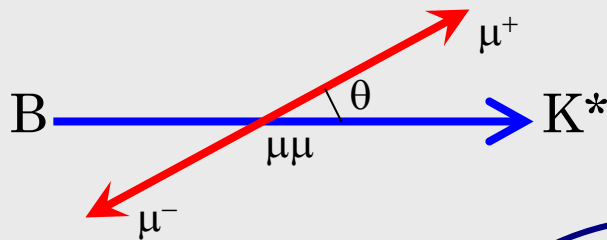


[Goto et al., hep-ph/9609512]

$b \rightarrow \ell \ell s$ exclusive

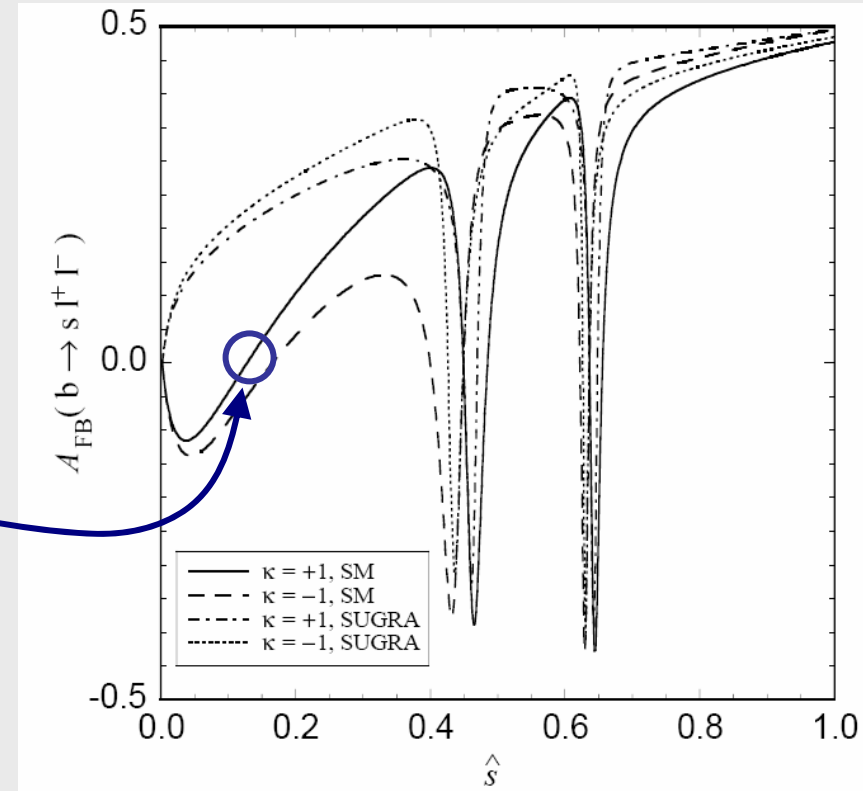
Use ratios to cancel out hadronic uncertainties:

- Forward-Backward Asymmetry (A_{FB})



- Zero of A_{FB} : $s_0 = \frac{-2C_7}{C_9(s_0)}$
 - CP asymmetry
 - CP asymmetry in A_{FB}

- Ratio of ee and $\mu\mu$ modes

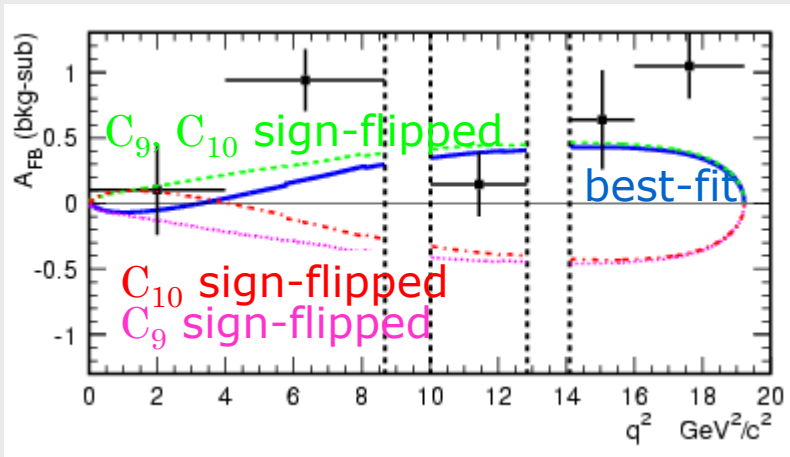


[Goto et al., hep-ph/9609512]

B-factories: current status

■ $b \rightarrow \ell \ell s \Rightarrow C_9$ and C_{10}

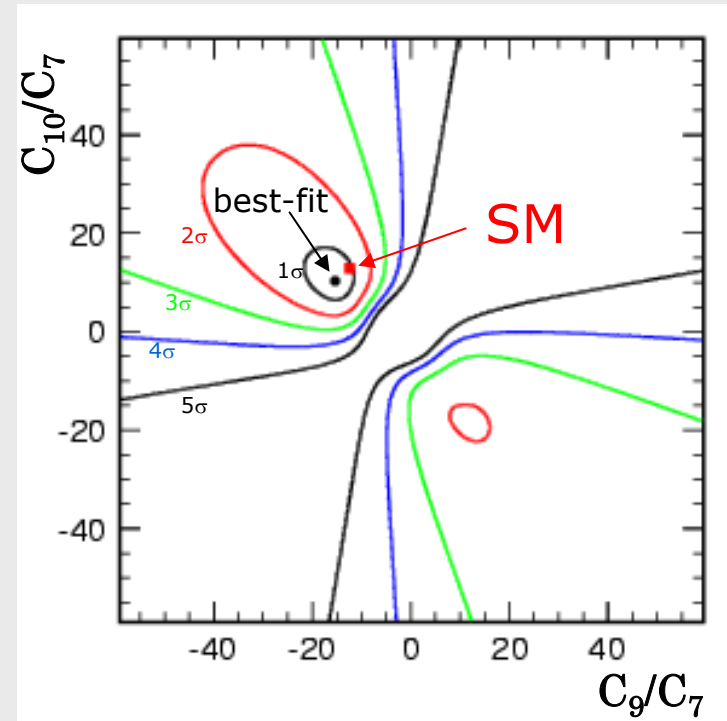
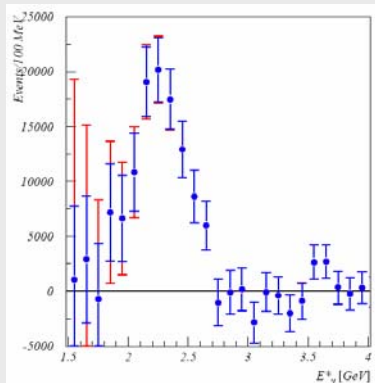
[Belle [Phys.Rev.Lett. 96 \(2006\) 251801](#)]



■ $b \rightarrow s \gamma \Rightarrow C_{7\gamma}$

[BaBar [Phys.Rev.Lett. 93 \(2004\) 061803](#)]

[BABAR-CONF-05/006, SLAC-PUB-11329]



→ In most of the SM extensions it's unlikely that the A_{FB} is very different from the SM value.

■ Need precision to find differences.

LHCb: $B \rightarrow K^* \mu \mu$ yield

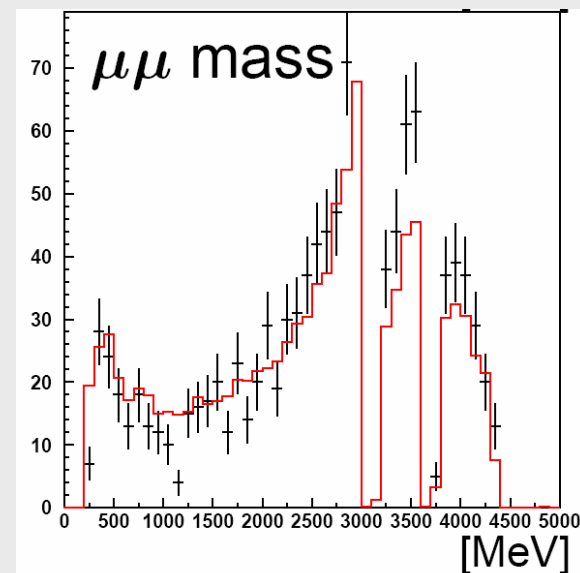
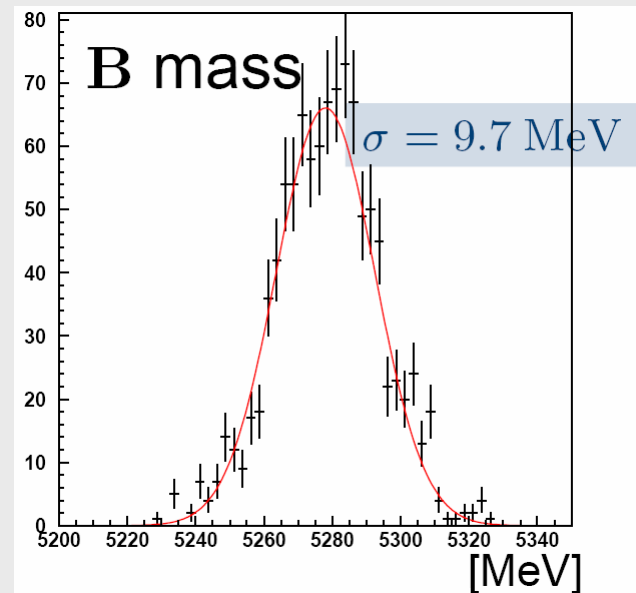
Expected signal and background yields in 2 fb^{-1} of data (10^7 s at $\mathcal{L} = 2 \cdot 10^{32}$).

Assuming the SM BR of $12 \cdot 10^{-7}$

Sample	Yield	B/S
$B \rightarrow K^* \mu \mu$	7300	
$b \bar{b}$	4400	0.6
$b \rightarrow \mu c (\mu q)$	1300	0.2
$2(b \rightarrow \mu)$	1400	0.2
J/ψ	20-80	0.003-0.01

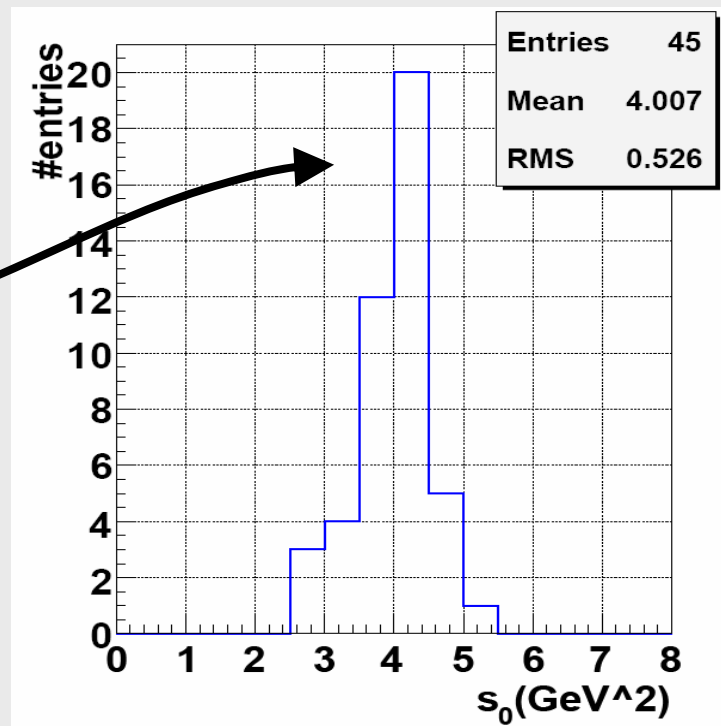
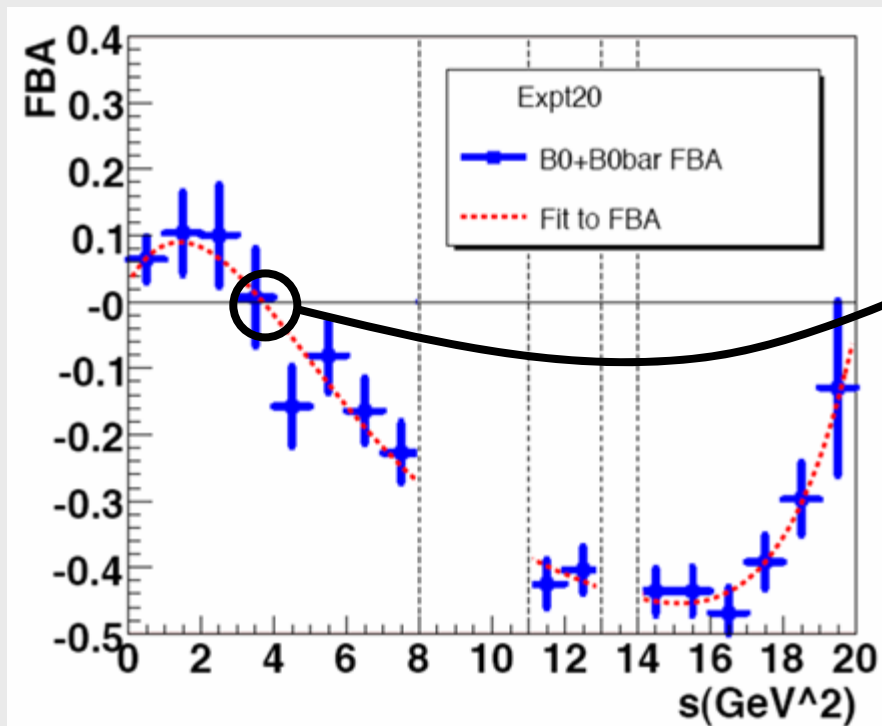
- $b \bar{b}$ bkg is dominated by non-resonant $K\pi$. The level of this bkg (and how to deal with it) is under active study.

ATLAS (20 fb^{-1}): 1400 ev. ($S/B \sim 0.1$) [[S. Viret](#)]



LHCb: Zero of $A_{FB}(B \rightarrow K^* \mu \mu)$

- Toy MC, based on full simulation results.
- Generate several experiments.



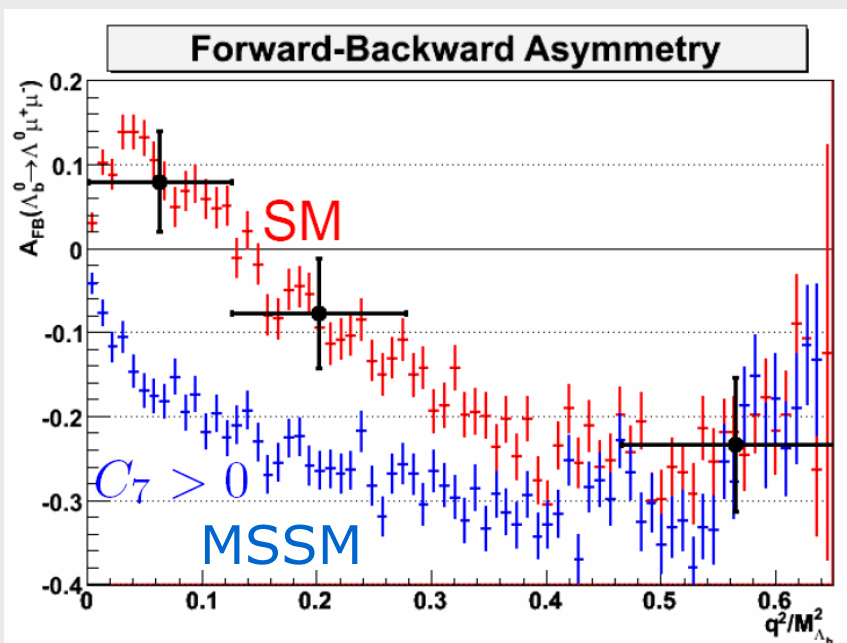
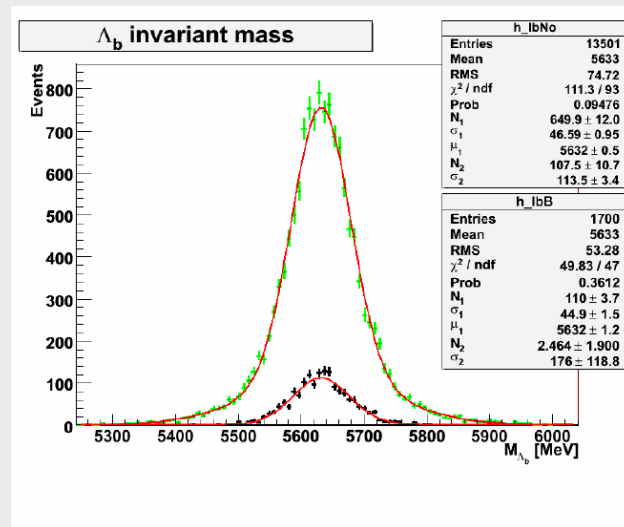
■ 2 fb^{-1} : $s_0 = (4.0 \pm 1.2) \text{ GeV}^2$

■ 10 fb^{-1} : $s_0 = (4.0 \pm 0.5) \text{ GeV}^2$

$\Rightarrow 13\%$ error on C_7/C_9

$\Lambda_b \rightarrow \Lambda \mu \mu$ at ATLAS

- $\Lambda_b \rightarrow \Lambda \mu \mu$ provides similar phenomenology as $B \rightarrow K^* \mu \mu$
- Select Λ with
 - $1 < R_\Lambda < 45$ cm
 - $\tau_{\Lambda_b} > 0.5$ ps
- Get Λ_b with 75 MeV resolution



Expectations for 30 fb^{-1} :

	Yield	Bkg
$\Lambda_b \rightarrow \Lambda \mu \mu$	800	<4000
$B^+ \rightarrow K^+ \mu \mu$	1500	<10000
$B \rightarrow K^* \mu \mu$	2500	<50000
$B_s \rightarrow \phi \mu \mu$	900	<10000

[P. Řezniček, Flavour at LHC]

R_K in $B^+ \rightarrow K^+ \ell \ell$

$$R_X = \frac{\int_{4m_\mu^2}^{q_{\max}^2} ds \frac{d\Gamma(B \rightarrow X \mu^+ \mu^-)}{ds}}{\int_{4m_\mu^2}^{q_{\max}^2} ds \frac{d\Gamma(B \rightarrow X e^+ e^-)}{ds}} \stackrel{\text{SM}}{=} \begin{cases} 1.000 \pm 0.001 & X = K \\ 0.991 \pm 0.002 & X = K^* \end{cases}$$

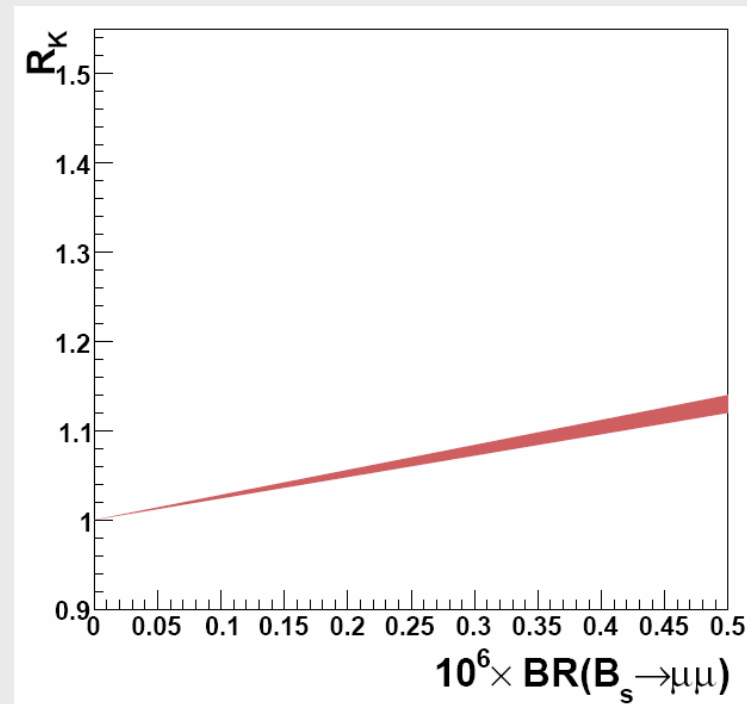
[Hiller & Krüger, hep-ex/0310219]

Deviations can be O(10%) for instance with neutral Higgs boson exchanges.

$$R_K - 1 \propto \text{BR}(B_s \rightarrow \mu\mu)$$

Experimental status:

R_X	BaBar (208 fb ⁻¹) [hep-ex/0507005]	Belle (250 fb ⁻¹) [hep-ex/0410006]
R_K	$1.06 \pm 0.48 \pm 0.05$	$1.38^{+0.39+0.06}_{-0.41-0.07}$
R_{K^*}	$0.93 \pm 0.46 \pm 0.12$	$0.98^{+0.30}_{-0.31} \pm 0.08$



$B_s \rightarrow \mu\mu$ current limit (CDF) = $1.0 \cdot 10^{-7}$ @ 90% CL [\[CDF note 8176\]](#)

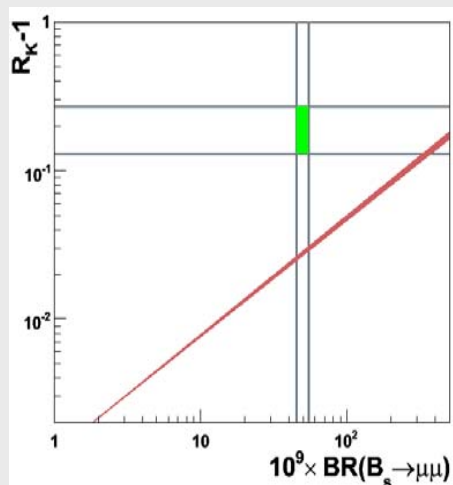
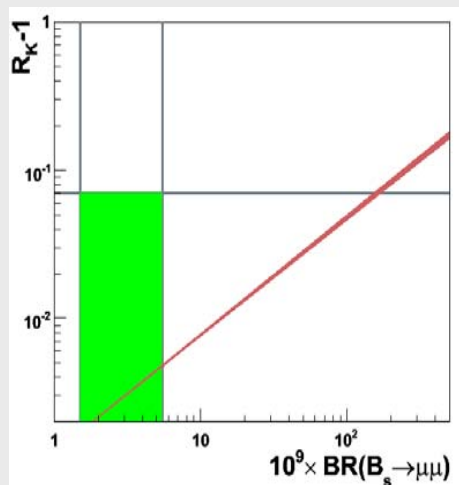
R_K measurement at LHCb

Expectations for 10 fb^{-1} :

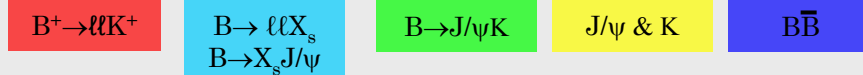
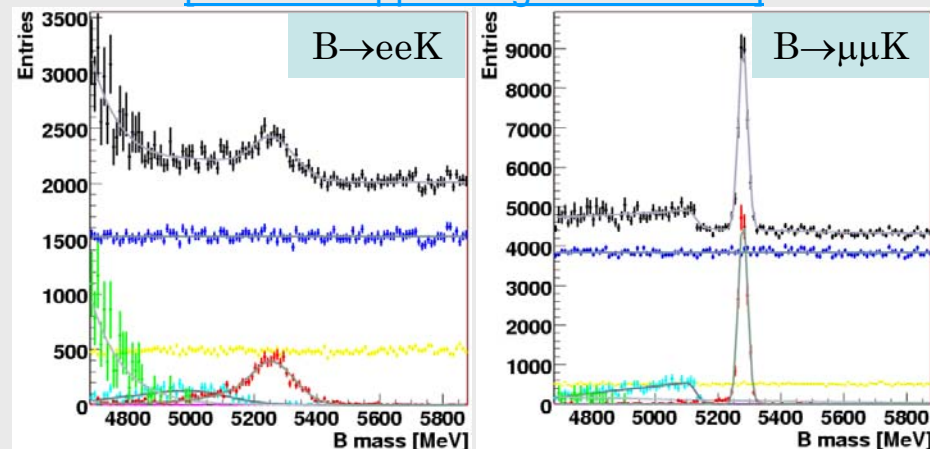
	Signal	Mean (MeV)	Sigma (MeV)
eeK	8740 ± 290	5253	73
$\mu\mu$ K	17500 ± 210	5279	15

- 3.5% error on R_K

Possible status:



[Patrick Koppenburg-Beach 2006]



- $\text{BR}(B_s \rightarrow \mu\mu)$ compatible with SM ($\sim 3 \cdot 10^{-9}$):
 - $R_K \sim 1$: Compatible with SM or MSSM with small $\tan\beta^2/m_A^2$.
 - $R_K \neq 1$: New Physics! Right-handed currents or broken lepton-universality.
- $\text{BR}(B_s \rightarrow \mu\mu)$ larger than SM: New Physics!
 - $R_K \sim 1+\epsilon$: MFV.
 - $R_K \neq 1$: as above.

Conclusions

- $b \rightarrow s\gamma$
 - BR insufficient constraint on New Physics.
 - Need to measure helicity and A_{CP} at LHC

- $b \rightarrow \ell\ell s$ very promising for New Physics
 - A_{FB} is very sensitive to New Physics
 - R_K is also interesting
 - Both can be measured at LHC

- Each of these measurements sets strong constraints on extensions of the Standard Model.

Very interesting corner of parameter space