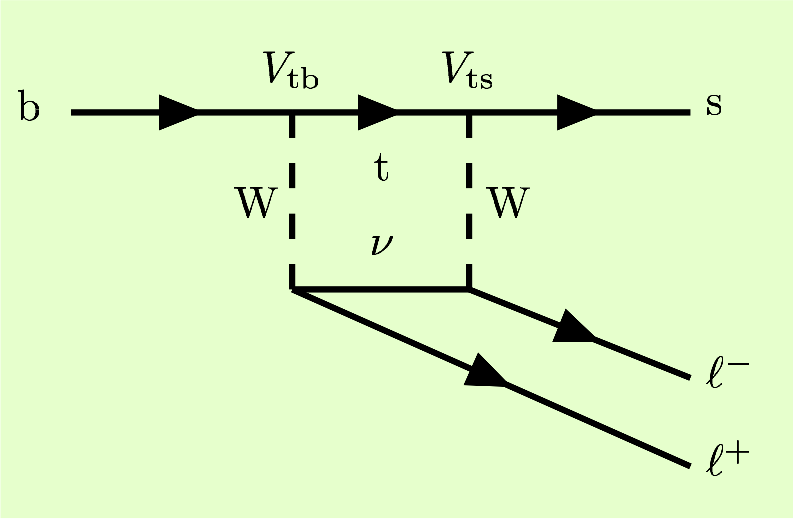
$\mathrm{B}\to\ell\ell\mathrm{K}^{(*)}$ prospects at LHCb

- Theoretical motivation
- Zero of FBA in $\mathrm{B}^0\to\mu\mu\mathrm{K}^*$
- R_{K} in $\mathrm{B}^\pm\to\mu\mu\mathrm{K}^\pm$ and $\mathrm{B}^\pm\to\mathrm{ee}\mathrm{K}^\pm$

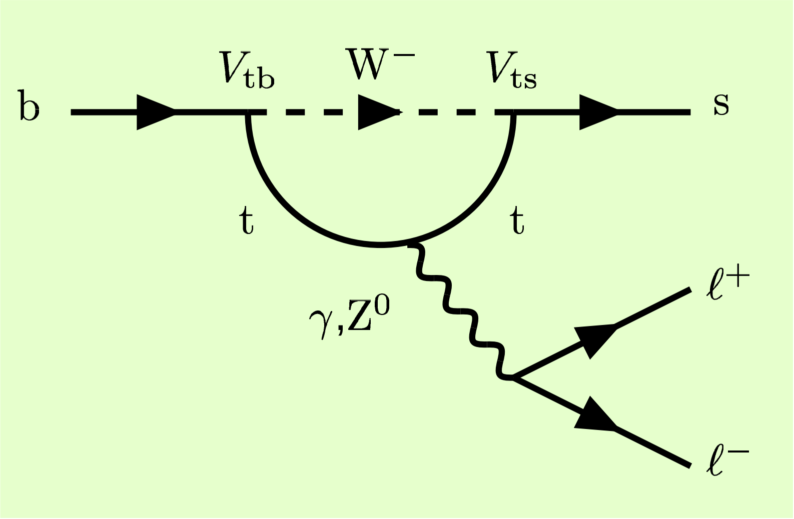
Flavour in the Era of the LHC
7–10 Nov. 2005
CERN, Geneva

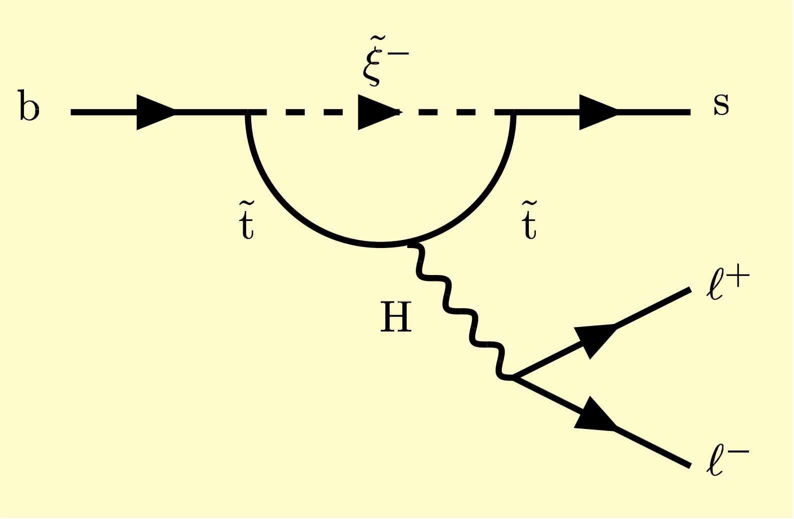
Patrick Koppenburg
CERN / PH / LBC
On behalf of the LHCb collaboration

$b \to s\ell\ell$ decays

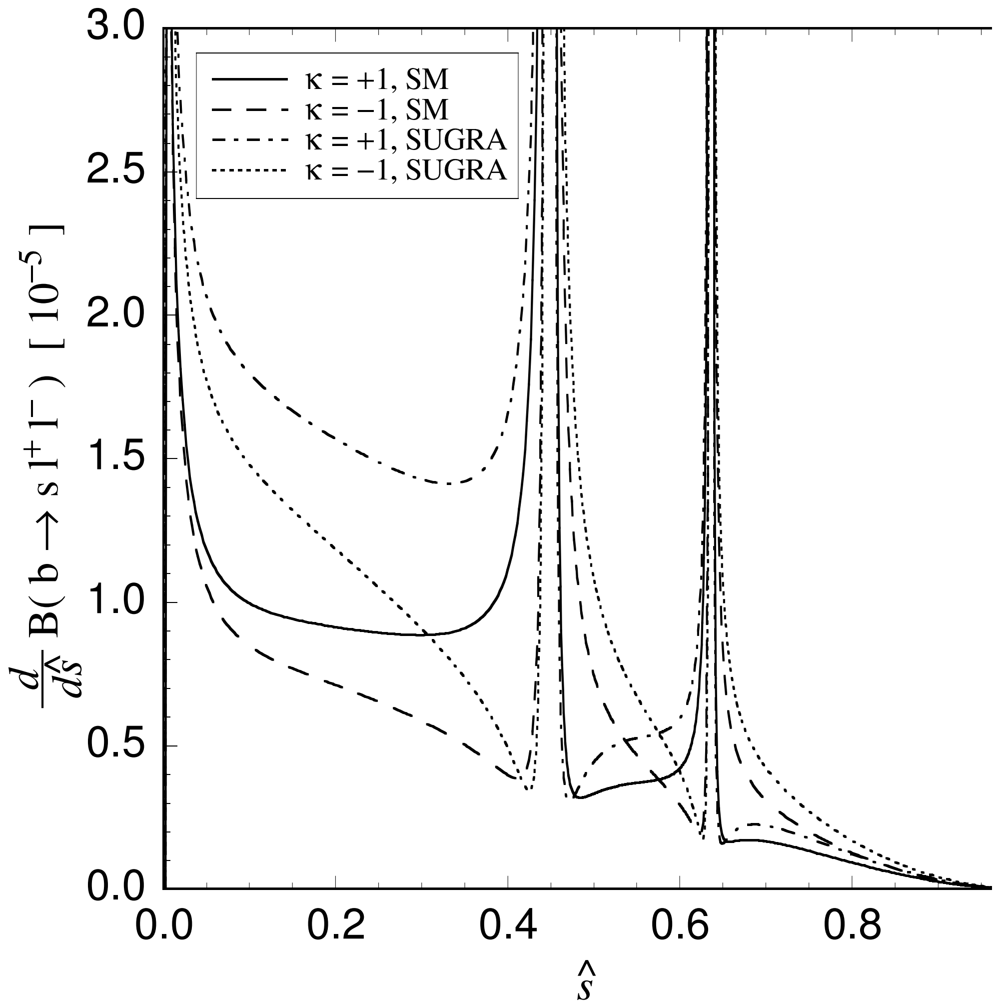


- Second-order diagram
- Sensitive to
  - SuSy,
  - graviton exchanges,
  - extra dimensions





$b \to s\ell\ell$ decays

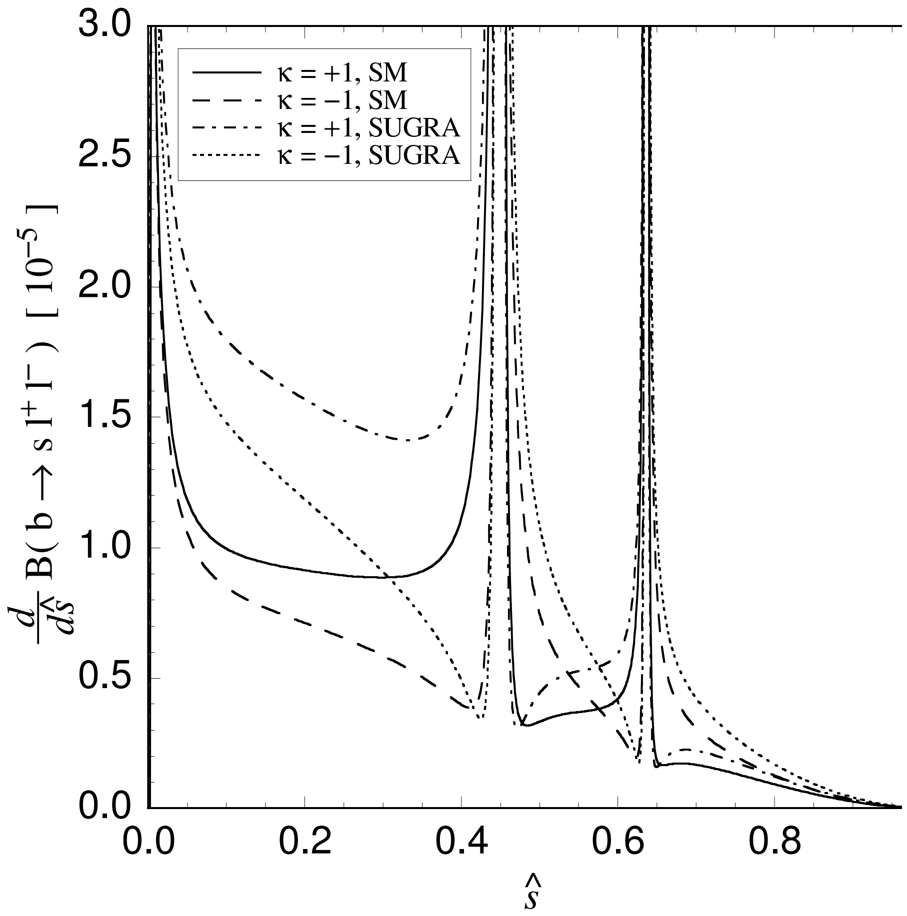


- Second-order diagram
- Sensitive to
  - SuSy,
  - graviton exchanges,
  - extra dimensions
- Well known SM branching ratio $(1.36 \pm 0.08) \cdot 10^{-6}$ (NNLL) for $s = q^2/m_{\rm b}^2 < 0.25$
- Inclusive decays difficult to access at hadron colliders
- Exclusive decays affected by hadronic uncertainties

Observables

Solution: Use ratios where hadronic uncertainties cancel out

- CP asymmetry



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

Observables

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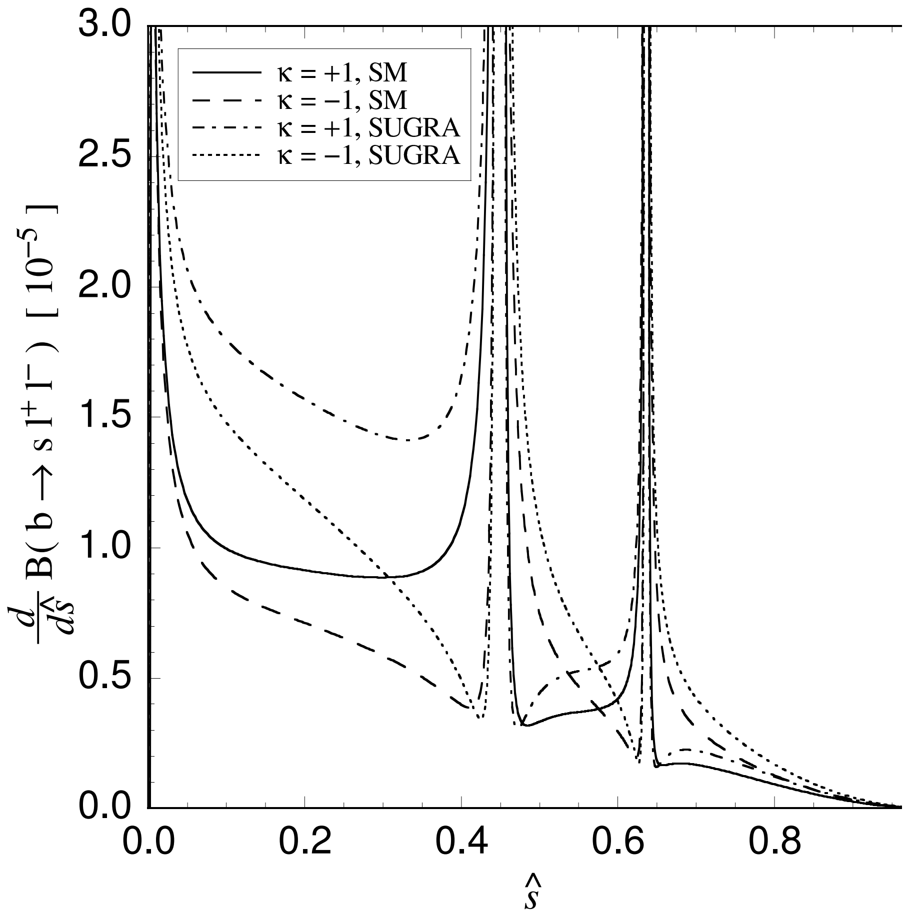
- CP asymmetry
- ✔ Ratio of ee and $\mu\mu$ modes



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

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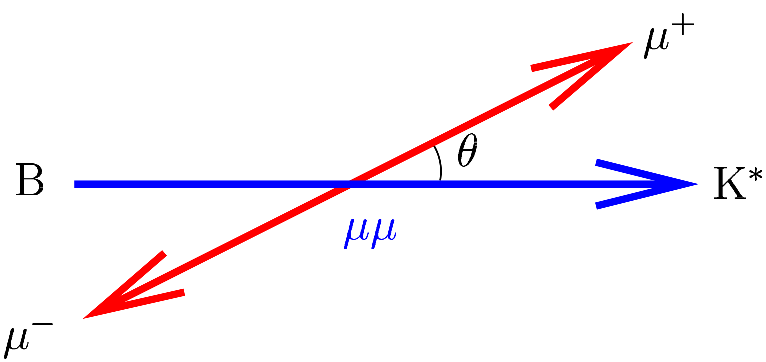
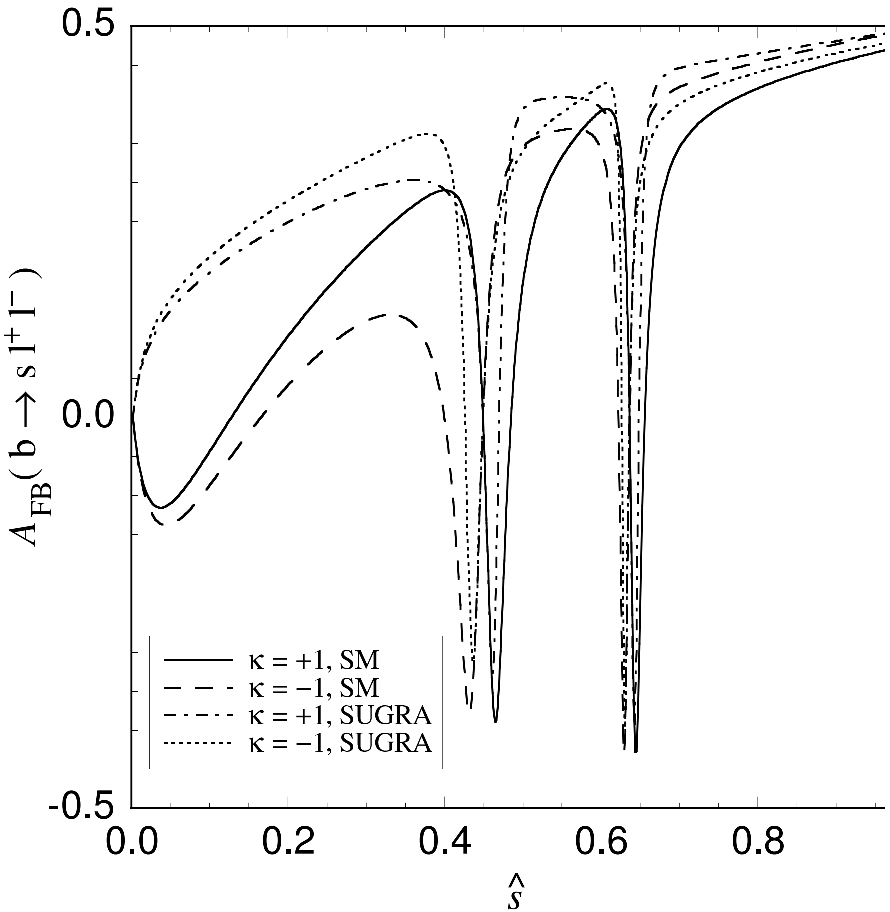
- Forward-backward asymmetry





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

Observables

Solution: Use ratios where hadronic uncertainties cancel out

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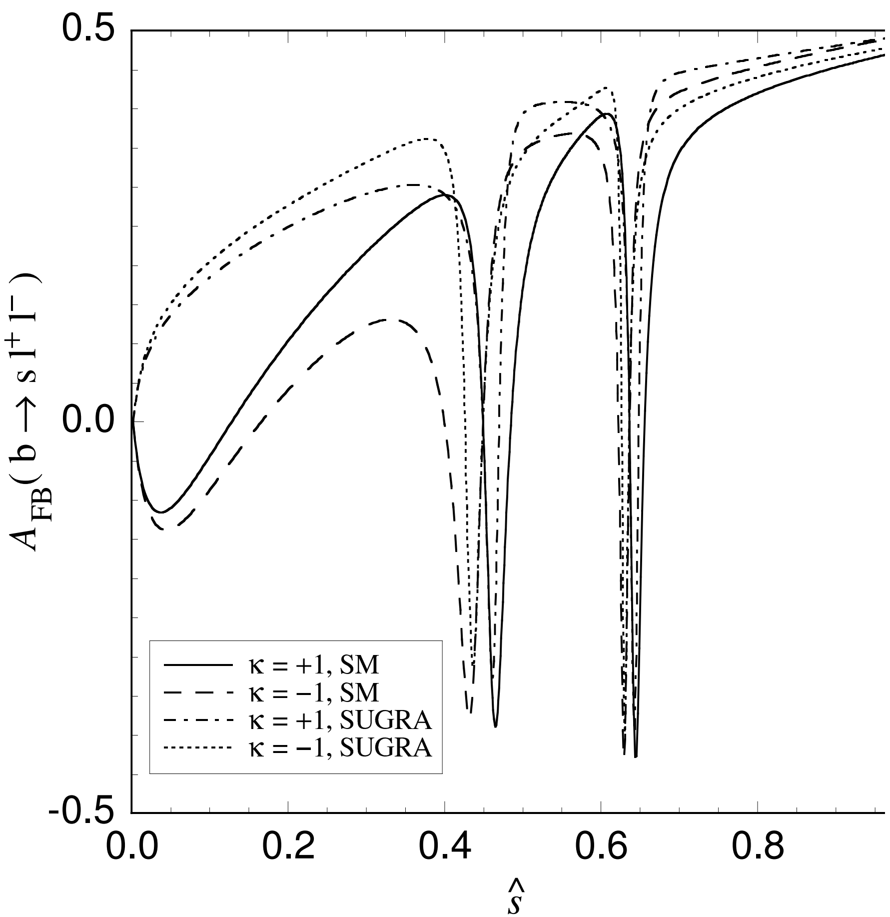
- CP asymmetry in FBA

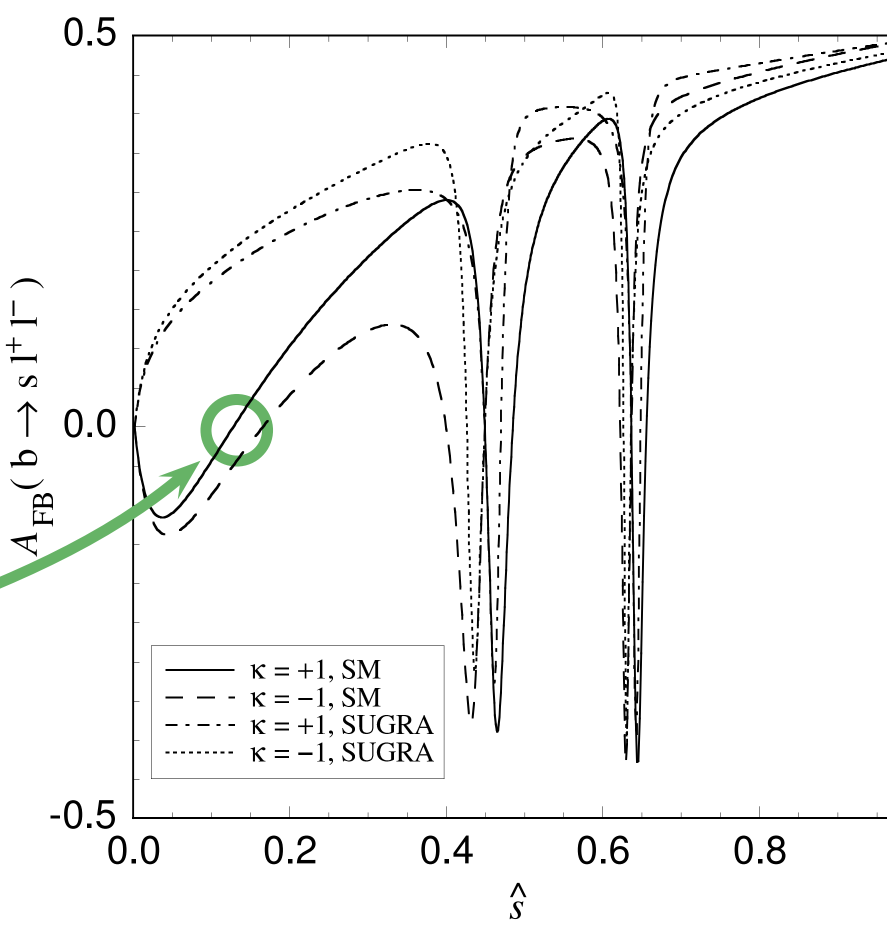


[Goto et. al, hep-ph/9609512]

Observables

Solution: Use ratios where hadronic uncertainties cancel out

- CP asymmetry
- ✔ Ratio of ee and $\mu\mu$ modes
- Forward-backward asymmetry
- CP asymmetry in FBA
- ✔ Zero of FBA $s_0 = \frac{-2C_7^{\mathrm{Eff}}}{C_9^{\mathrm{Eff}}(s_0)}$



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

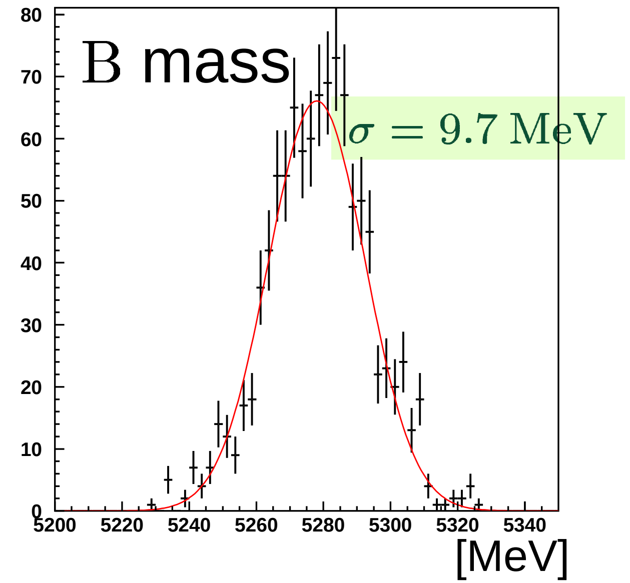
Zero of FBA in $\mathrm{B}^0 \to \mu\mu\mathrm{K}^*$

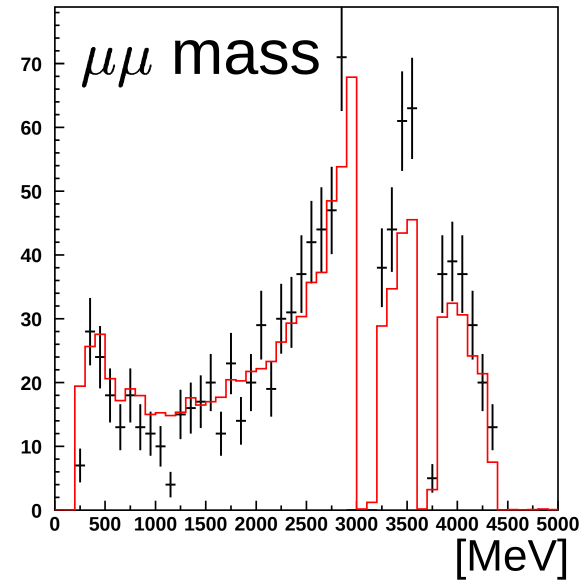
Jose Helder Lopes
Public LHCb notes 2003-104 & 2005-010

$B^0 \to \mu\mu K^*$ selection

Main selection criteria:

$\mu\ p_T$	> 900 MeV
$\pi\ p_T$	> 200 MeV
π and K IP	$> 2\sigma$
$K^*\ p_T$	> 900 MeV
$\mu\mu$ and $K^*\ \chi^2$	< 8
$B\ \chi^2$	< 10
B IP	$< 3.5\sigma$
$\mu\mu$ and K^* PV separation	$> 1.5\sigma$
J/ψ veto	2900–3200 MeV
$\psi(2S)$ veto	3650–3725 MeV
K^* mass	$m_{K^*} \pm 100$ MeV





Optimised for BR.
Maybe not optimal for zero of FBA

$B^0 \to \mu\mu K^*$ selection

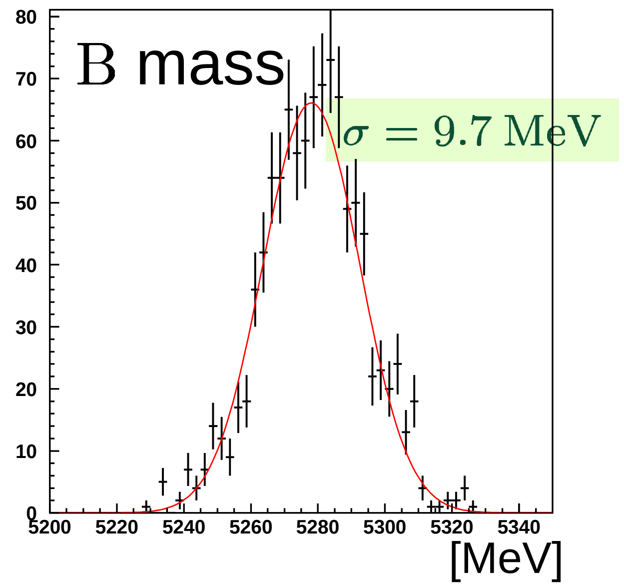
Expected signal and background yields in 2 fb^{-1} of data, i.e 10^7 s at $\mathcal{L} = 2 \cdot 10^{32}$.

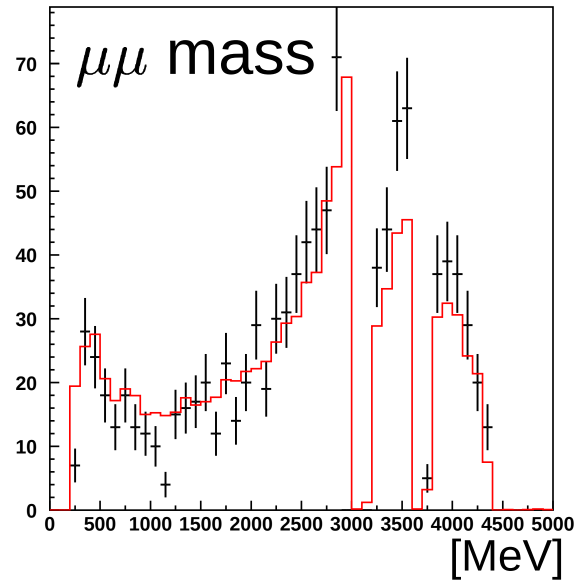
Assuming the SM BR of $12 \cdot 10^{-7}$

Sample	Stats.	Yield	B/S
$B^0 \to \mu\mu K^*$	50k	4400 ± 100	
$B\overline{B}$	11M	1000–11700	0.2–2.6
$b \to \mu c(\mu q)$	200k	500–1900	0.1–0.4
$2\ (b \to \mu)$	1.8M	750 ± 130	0.17 ± 0.03
J/ψ	200k	20–80	0.02–0.1

B/S ratios limited by low background MC statistics

2003 MC, Geant 3 —to be updated

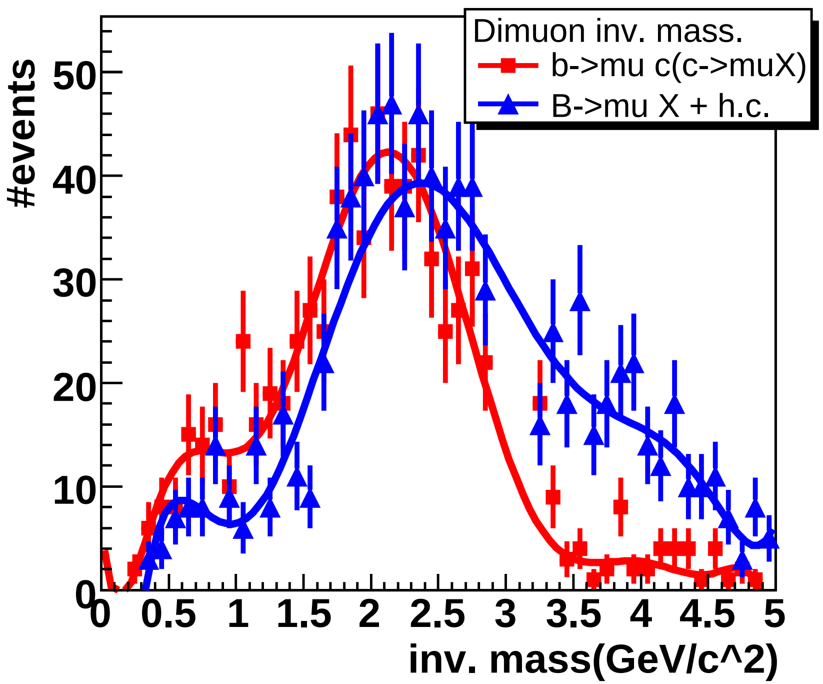


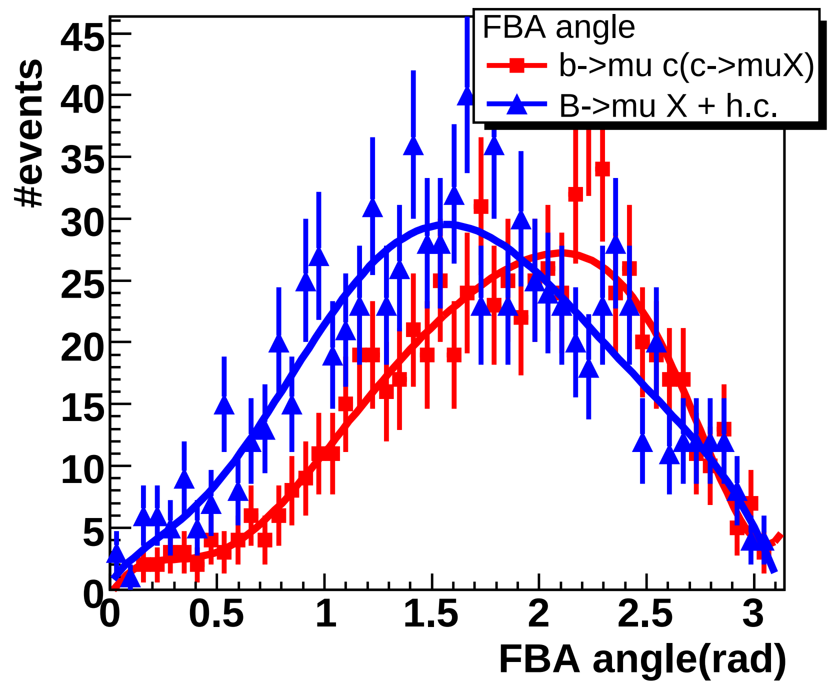


Toy MC

To assess errors on FBA: run many pseudo-experiments with reasonable signal and data assumptions.

- Use reconstructed dimuon mass spectrum and FBA angle





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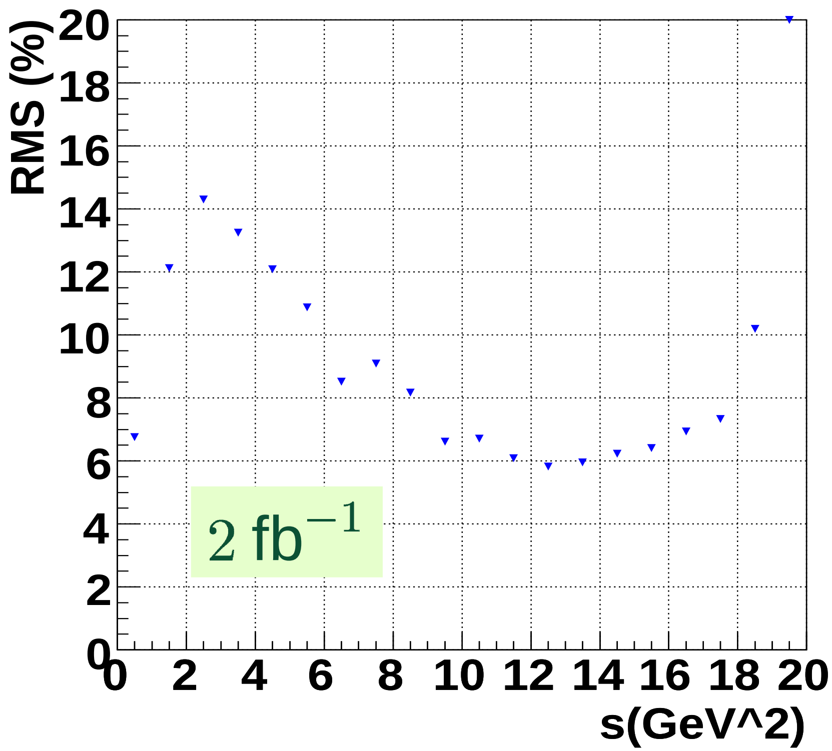
- Use reconstructed dimuon mass spectrum and FBA angle

$\rightarrow$ Get errors on dimuon mass spectrum



Relative errors on branching fraction after 1 year:

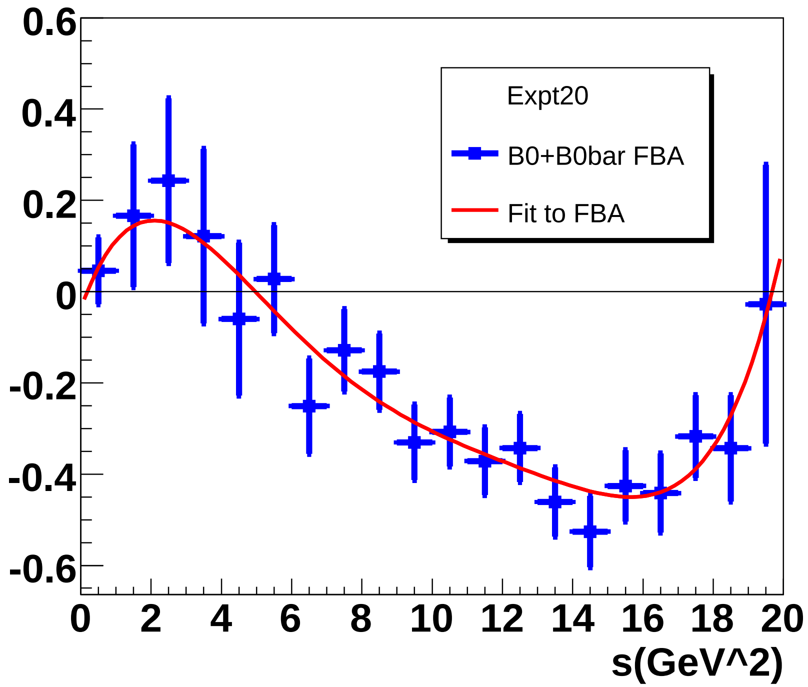
$$1\text{–}6\ \mathrm{GeV}^2:\quad \pm 5.7\%$$

$$> 14\ \mathrm{GeV}^2:\quad \pm 3.2\%$$

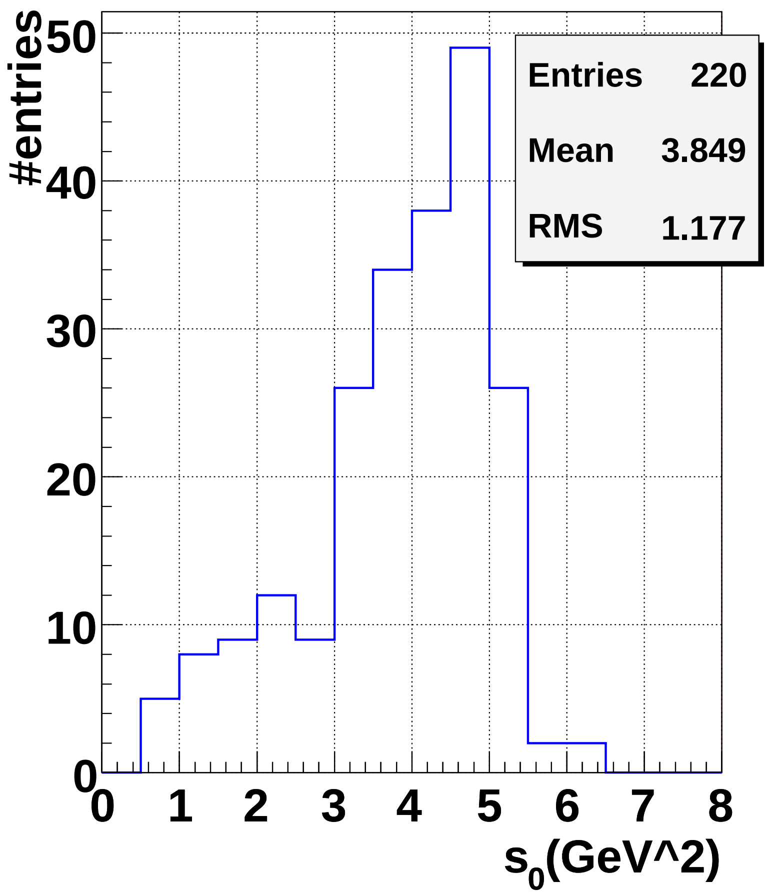
Much less than hadronic uncertainties

Zero of FBA

- $2\ \text{fb}^{-1}$: $(4.0 \pm 1.2)\ \text{GeV}^2$ with 4% inefficiency



Typical FBA(s) measurement

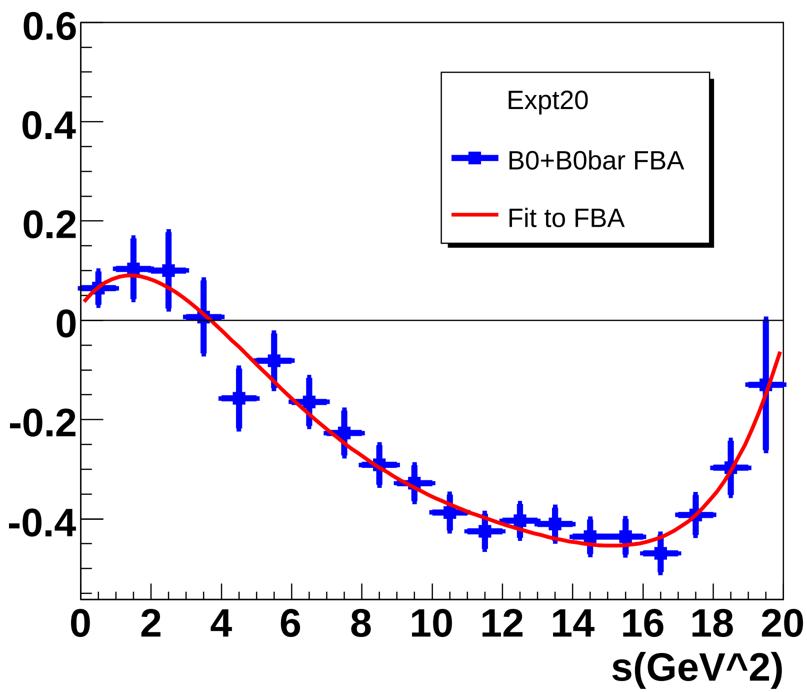


Spread of s_0

Zero of FBA

- $2\ \mathrm{fb}^{-1}$: $(4.0 \pm 1.2)\ \mathrm{GeV}^2$ with 4% inefficiency
- $10\ \mathrm{fb}^{-1}$: $(4.0 \pm 0.5)\ \mathrm{GeV}^2$

$\Rightarrow$ 13% error on $C_7^{\mathrm{Eff}}/C_9^{\mathrm{Eff}}$



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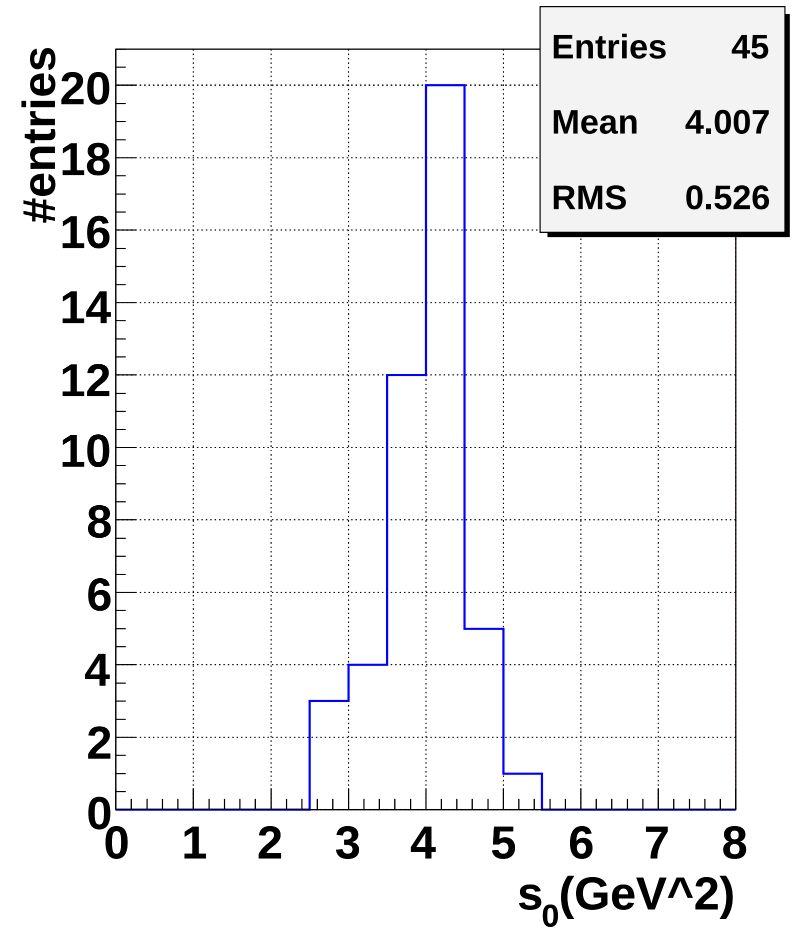


Spread of s_0

R_{K} in $\mathrm{B}^{\pm}\to\mu\mu\mathrm{K}^{\pm}$ and $\mathrm{B}^{\pm}\to\mathrm{eeK}^{\pm}$

Patrick Koppenburg

Work in Progress

$\mathrm{B}^{\pm}\to\ell\ell\mathrm{K}^{\pm}$

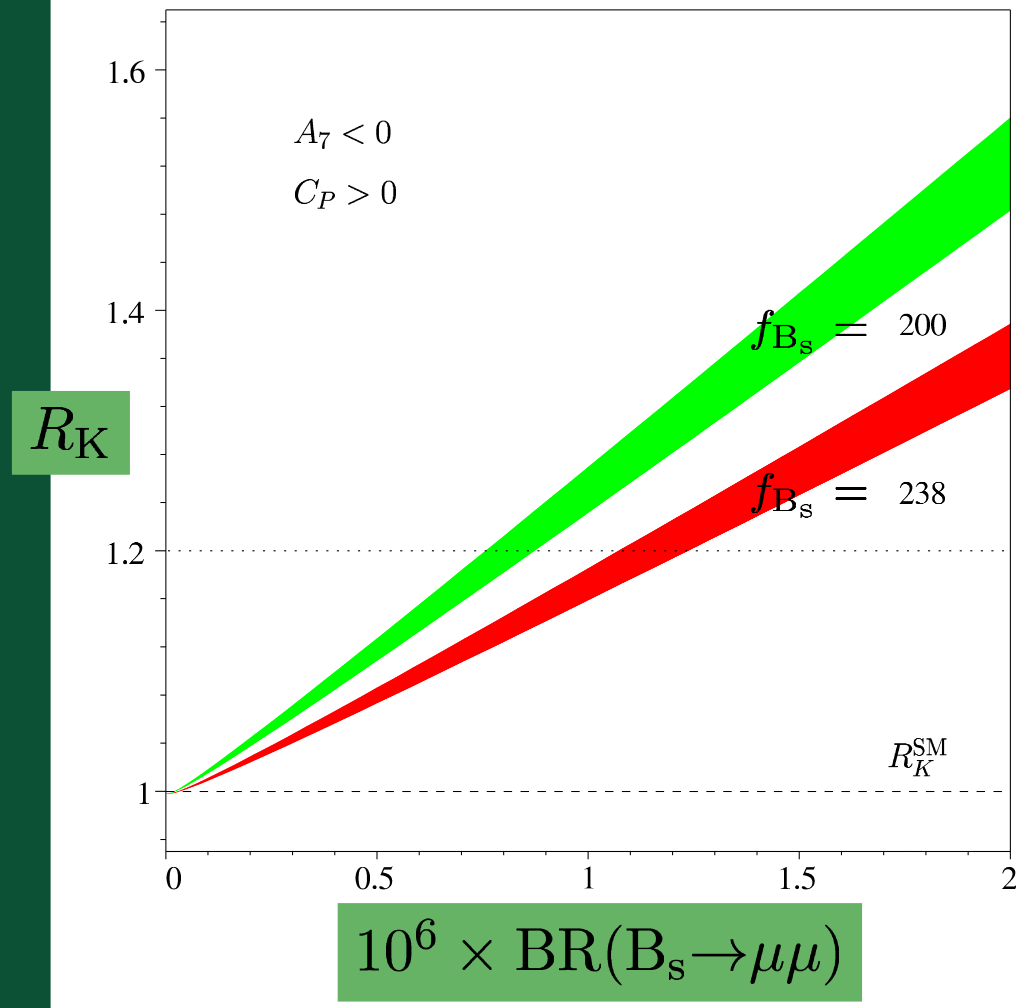
Measure the ratio: [Hiller & Krüger, hep-ph/0310219]

$$R_{\mathrm{X}} = \frac{\int_{4m_\mu^2}^{q^2_{\text{max}}} \mathrm{d}s \frac{d\Gamma\left(\mathrm{B}\to\mathrm{X}\mu^+\mu^-\right)}{\mathrm{d}s}}{\int_{4m_\mu^2}^{q^2_{\text{max}}} \mathrm{d}s \frac{d\Gamma(\mathrm{B}\to\mathrm{X}\mathrm{e}^+\mathrm{e}^-)}{\mathrm{d}s}} = \begin{cases} 1.000 \pm 0.001 & \mathrm{X}=\mathrm{K} \\ 0.991 \pm 0.002 & \mathrm{X}=\mathrm{K}^* \end{cases}$$

Corrections to unity can be large ($\mathcal{O}(10\%)$) in models that distinguish between lepton flavours, like interactions involving neutral Higgs bosons (typically MSSM at large $\tan\beta$).

In this study we integrate in the range $4m_\mu^2 \leq s \leq 6\,\mathrm{GeV}^2$

Relation to $\mathrm{B_s} \to \mu\mu$



[Hiller & Krüger, hep-ph/0310219]

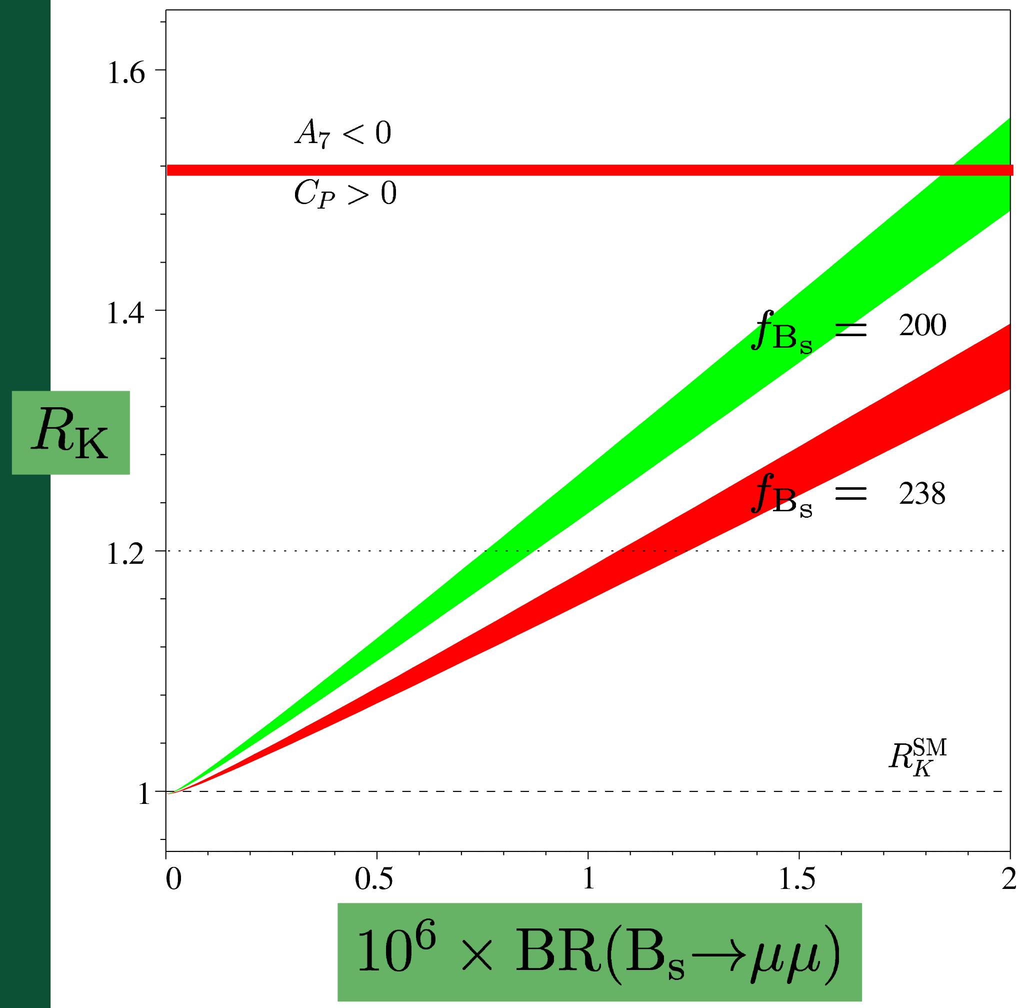
$R_{\mathrm{K}} \propto \mathrm{BR}(\mathrm{B_s} \to \mu\mu)$

Assuming:

- right-handed currents negligible
- (Pseudo-)scalar couplings $\propto m_\ell$, (à la neutral higgs, not the case for broken R-parity)
- No CP-phases beyond the SM
- ...

I.e. SM, MSSM with MFV at large $\tan\beta$...

Relation to $B_s \to \mu\mu$



[Hiller & Krüger, hep-ph/0310219]

Experimental status:

$\boldsymbol{R_X}$	BaBar ($208\ \mathrm{fb}^{-1}$) [hep-ex/0507005]
R_K	$1.06 \pm 0.48 \pm 0.05$
R_{K^*}	$0.93 \pm 0.46 \pm 0.12$
	Belle ($250\ \mathrm{fb}^{-1}$) [hep-ex/0410006]
R_K	$1.38\ ^{+0.39}_{-0.41}\ ^{+0.06}_{-0.07}$
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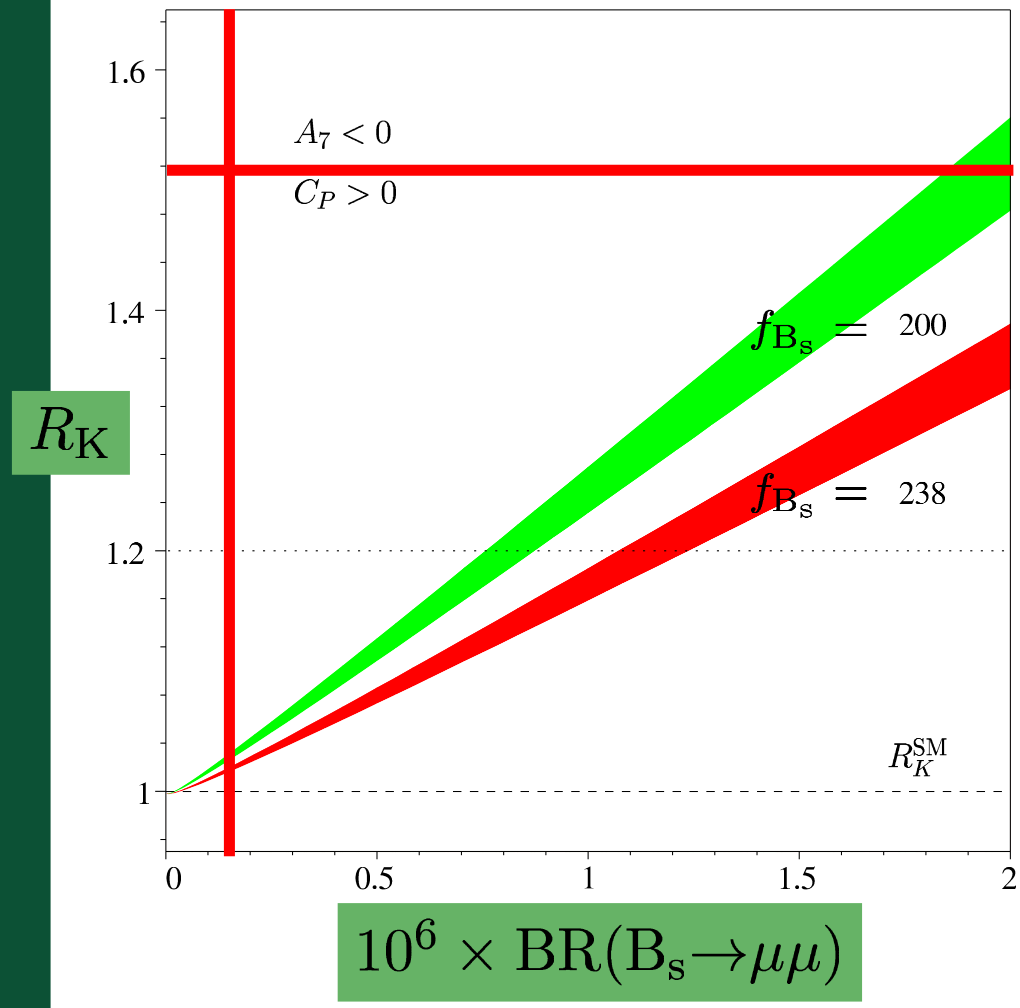
Relation to $\mathrm{B_s}\to\mu\mu$



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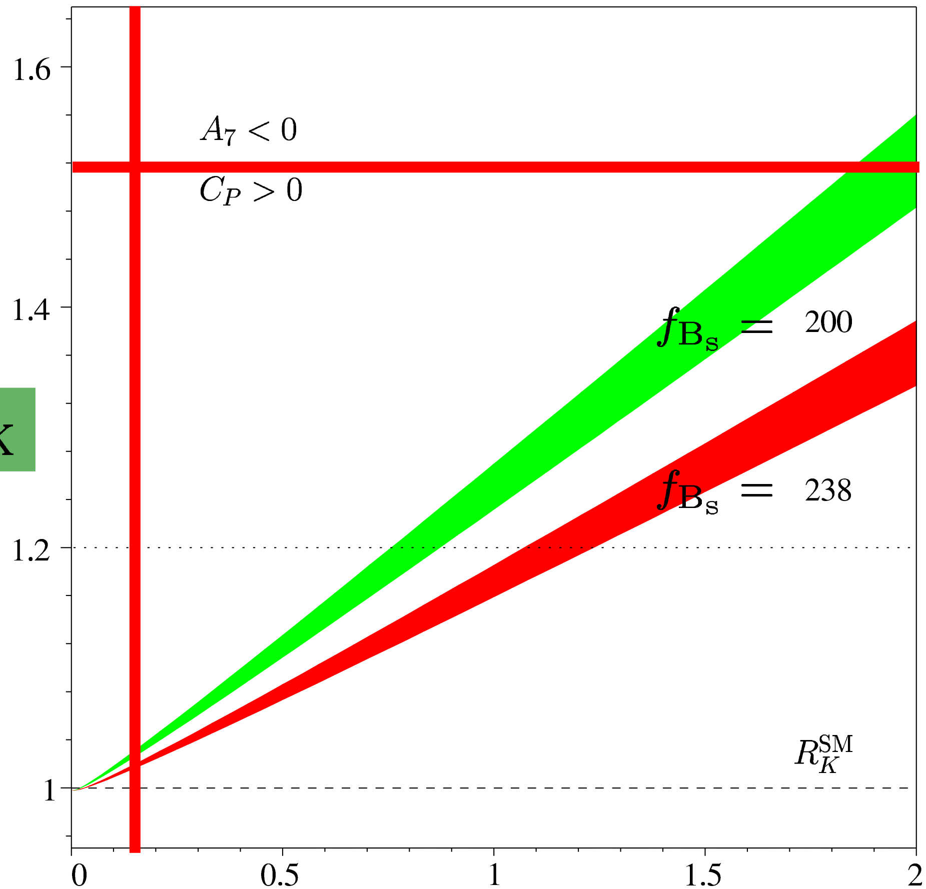
$\mathbf{B_s}\to\boldsymbol{\mu\mu}$: The present CDF limit is $1.5 \cdot 10^{-7}$ at 90% CL [hep-ex/0508036]

Relation to $\mathrm{B_s}\to\mu\mu$



R_K

$10^6 \times \mathrm{BR}(\mathrm{B_s}\to\mu\mu)$

- We also plan to **measure** the $\mathrm{B_s} \to \mu\mu$ branching fraction
- A disagreement would imply New Physics beyond a minimal model
  - R-parity violating SuSy
  - right-handed couplings
  - …

[Hiller & Krüger, hep-ph/0310219]

$B^{\pm} \to \ell\ell K^{\pm}$ Selection

	Selection
ℓ p_T , K p_T	≥ 1500 MeV
K IP significance	≥ 2
$\ell\ell$ χ^2	≤ 9
B χ^2	≤ 30
B IP significance	≤ 4
B flight significance	≥ 5
B mass window	± 500 MeV

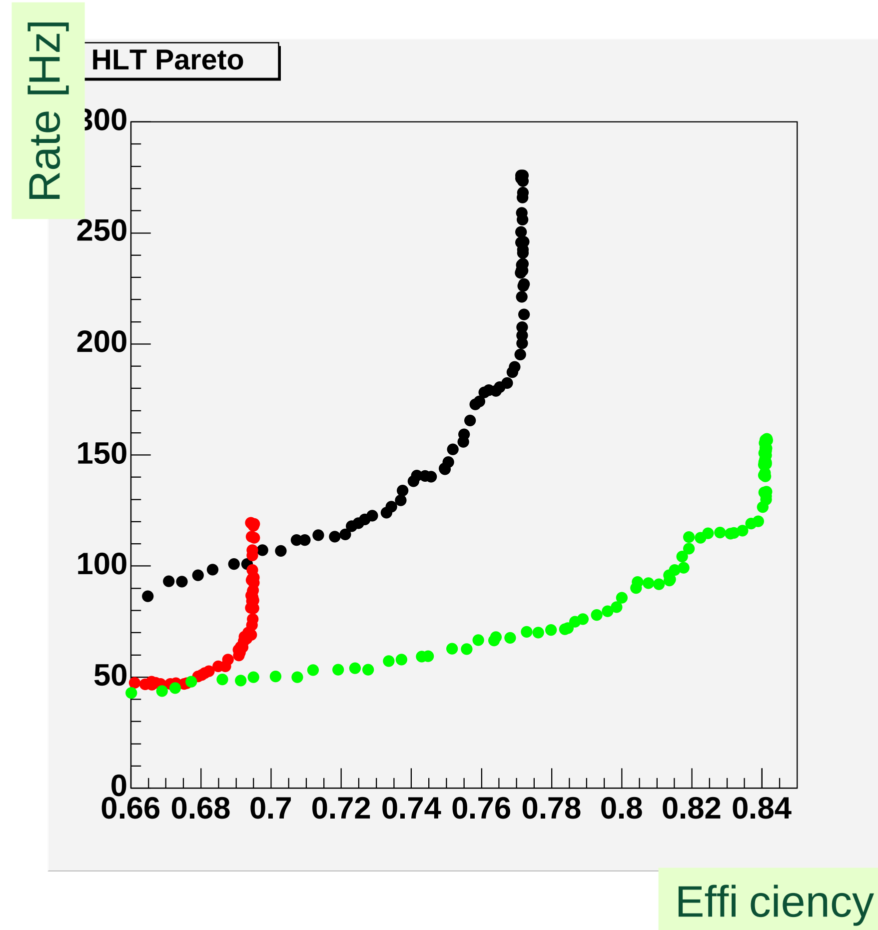
- Selection optimised to minimize R_{K} error in one year
- 2004 MC, Geant 4
- Statistics: 18M $\mathrm{B\overline{B}}$, 4M $\mathrm{J}/\psi \to \ell\ell$, 2M signal and specific backgrounds. More to come.

Trigger

- High trigger efficiency in L0 and L1 because of the leptons
- In the HLT we require the signal to be fully reconstructed

$\rightarrow$ Which is difficult for electrons

- 68% for ee at 70 ± 8 Hz
- 75% for $\mu\mu$ at 130 ± 12 Hz



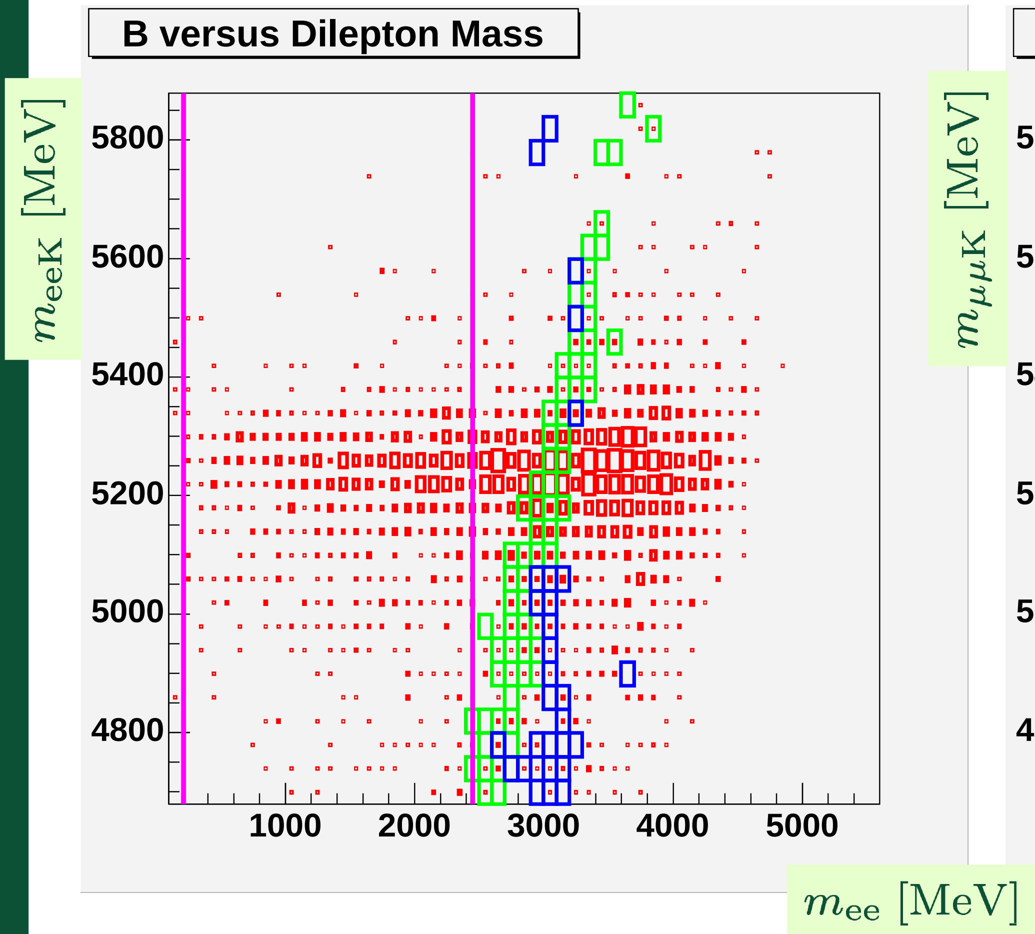
One solution is to develop an inclusive dilepton trigger.
Selection cuts:

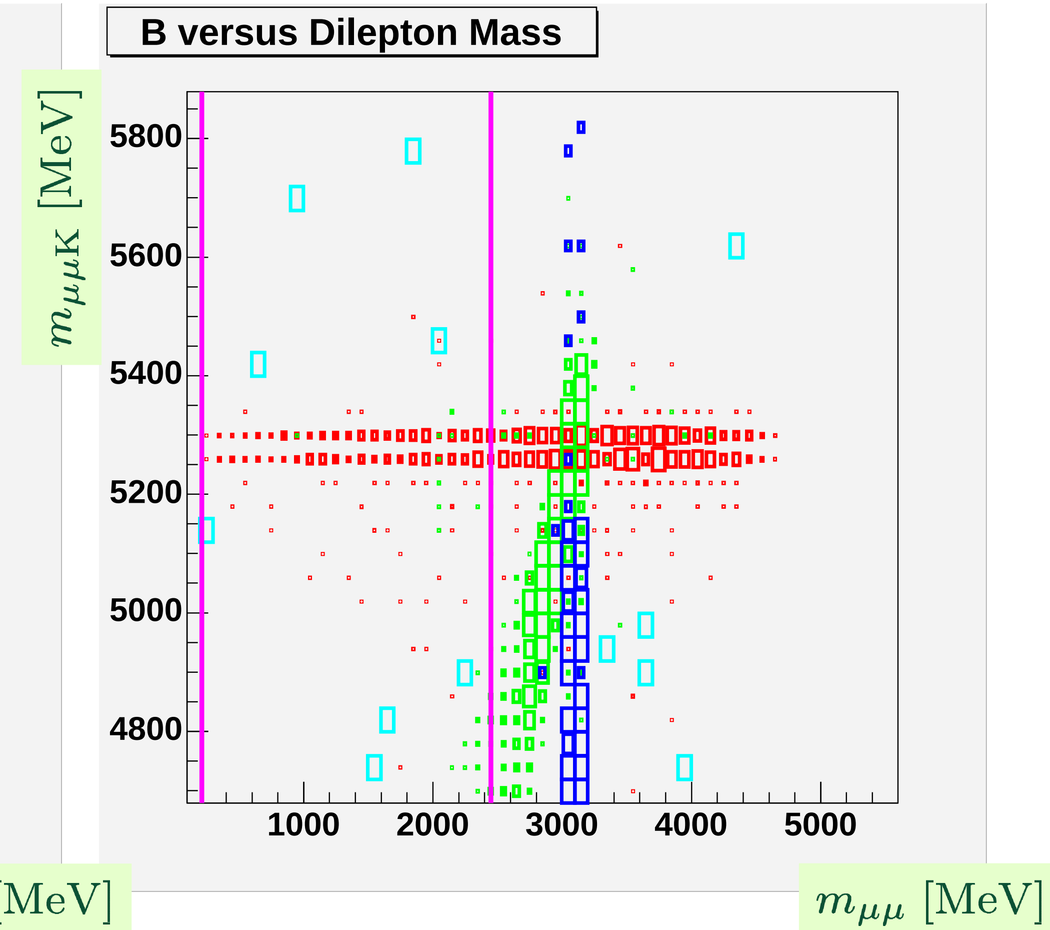
ℓ p_T	≥ 500 MeV
$\ell\ell$ χ^2	≤ 9
$\ell\ell$ p_T	≥ 1250 MeV
$\ell\ell$ flight signif.	≥ 2

B versus dilepton mass after selection

$B \to eeK$

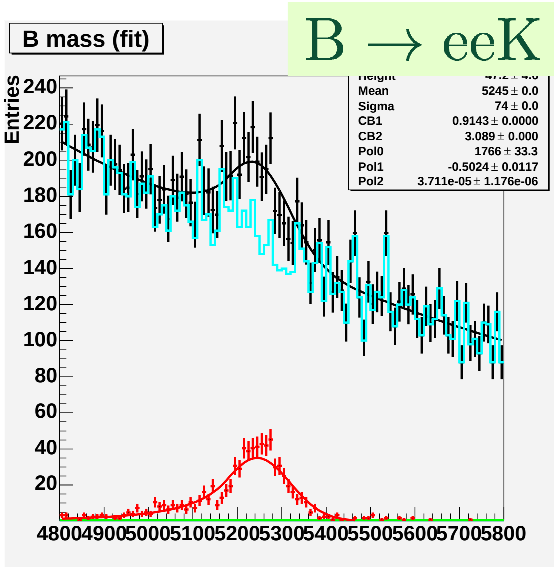
$B \to \mu\mu K$

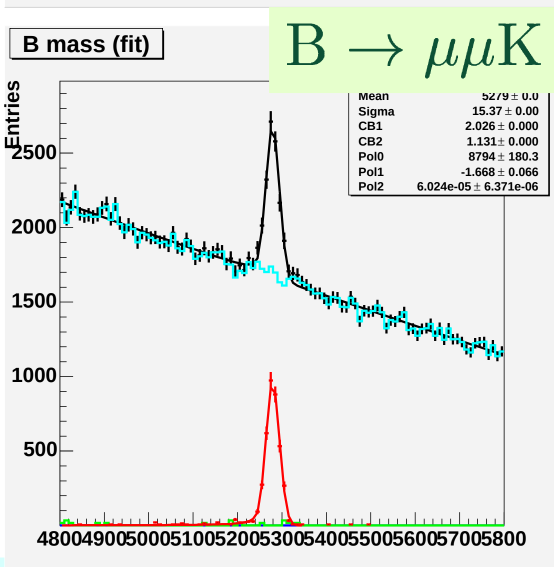




Signal $J/\psi K$ J/ψ $B\bar{B}$ ($\mu\mu K^*$ missing)

R_{K} with $2\ \mathrm{fb}^{-1}$





Signal $\mathrm{J}/\psi\mathrm{K}$ J/ψ $\mathrm{B\overline{B}}$

- The signal is fitted by a Crystal-Ball function
- The background is fitted by a 2^{nd}-order polynomial
- The parameters of the Crystal-Ball function are fixed from the signal MC

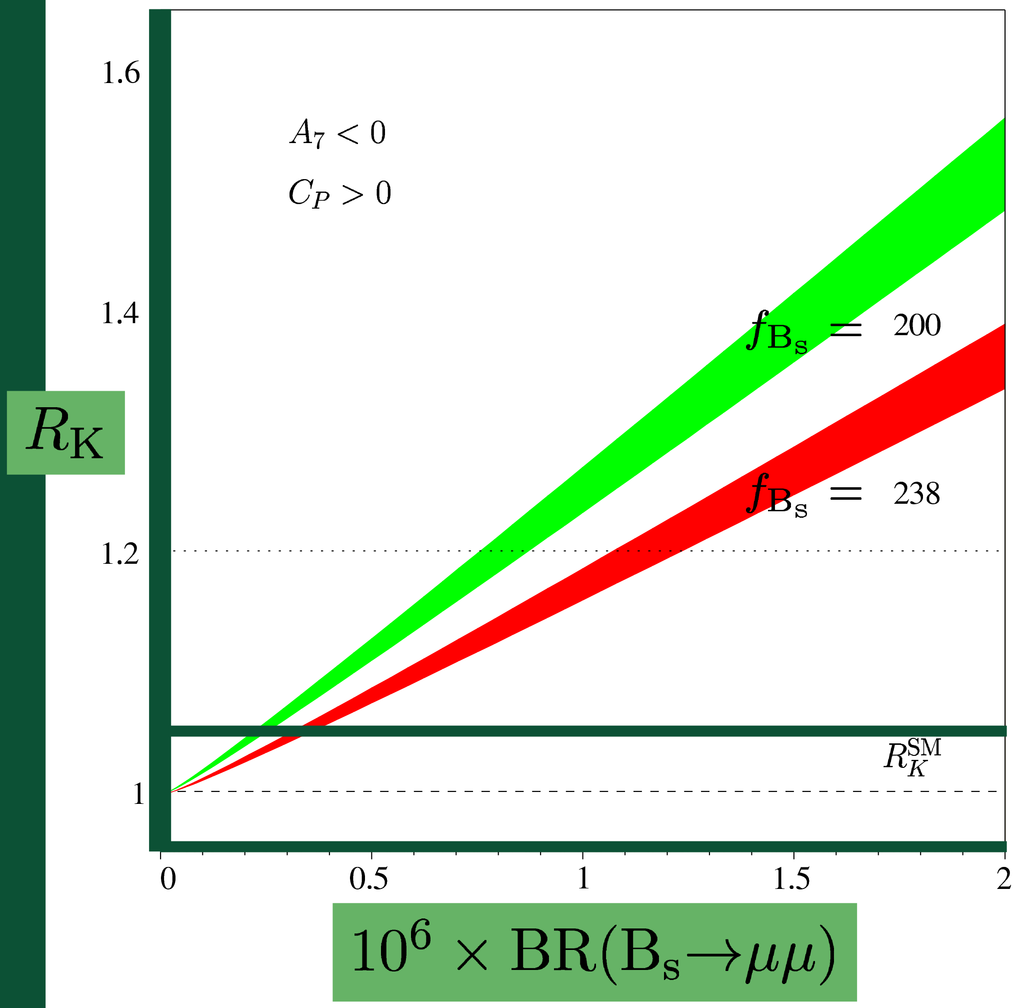
	Height	Mean	Sigma
eeK	47.2 ± 4.6	5245 MeV	74 MeV
$\mu\mu$K	1013 ± 31	5279 MeV	15 MeV

$\Rightarrow R_{\mathrm{K}} = 1$ (fixed) ± 0.10

… or as good as with $2.5\ \mathrm{ab}^{-1}$ at a B factory

(Zoom)

Possible status with $10\ \mathrm{fb}^{-1}$

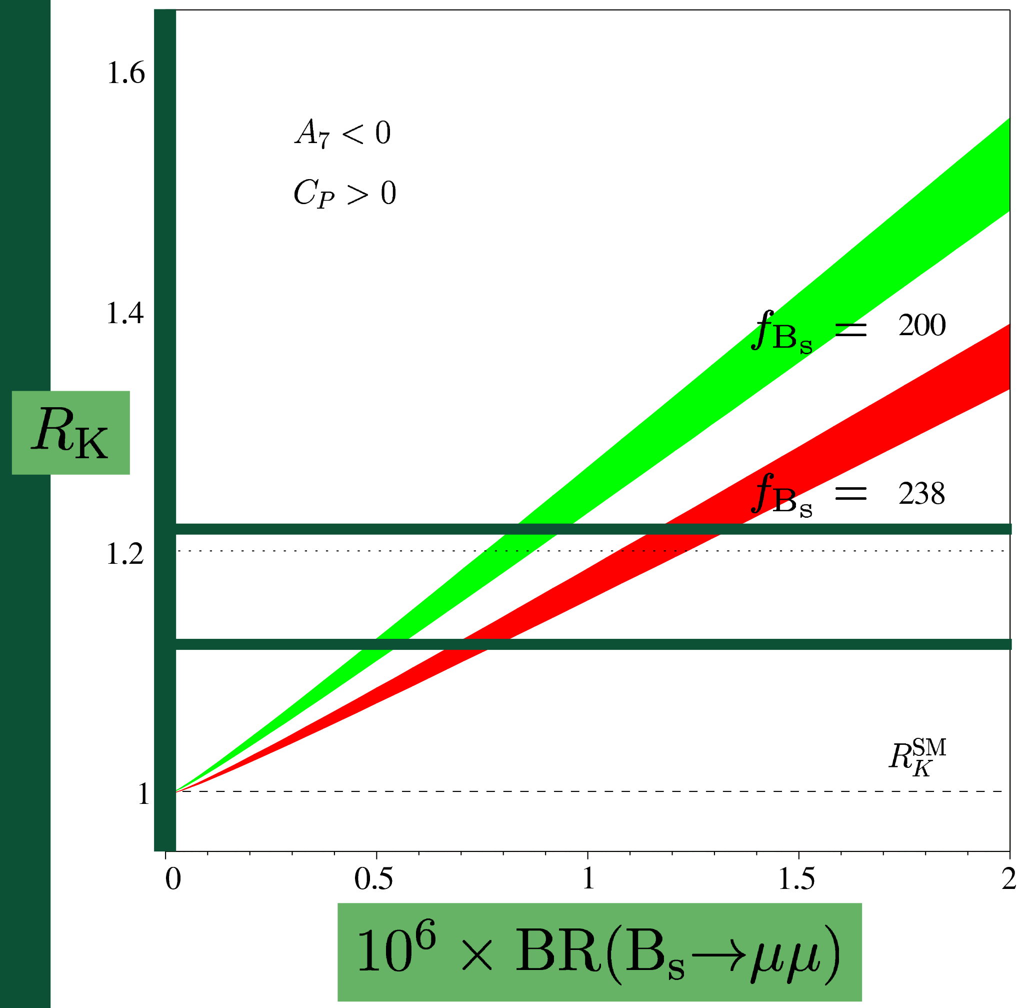


In 2012, measure $\mathrm{B_s} \to \mu\mu$ and get 4.5% error on R_K:

- $\mathrm{BR}(\mathrm{B_s} \to \mu\mu)$ compatible with SM ($\sim 3 \cdot 10^{-9}$)
  - $R_\mathrm{K} \sim 1$: Compatible with SM or MSSM with small $\tan\beta^3/m_A^2$

[Hiller & Krüger, hep-ph/0310219]

Possible status with 10 fb^{-1}



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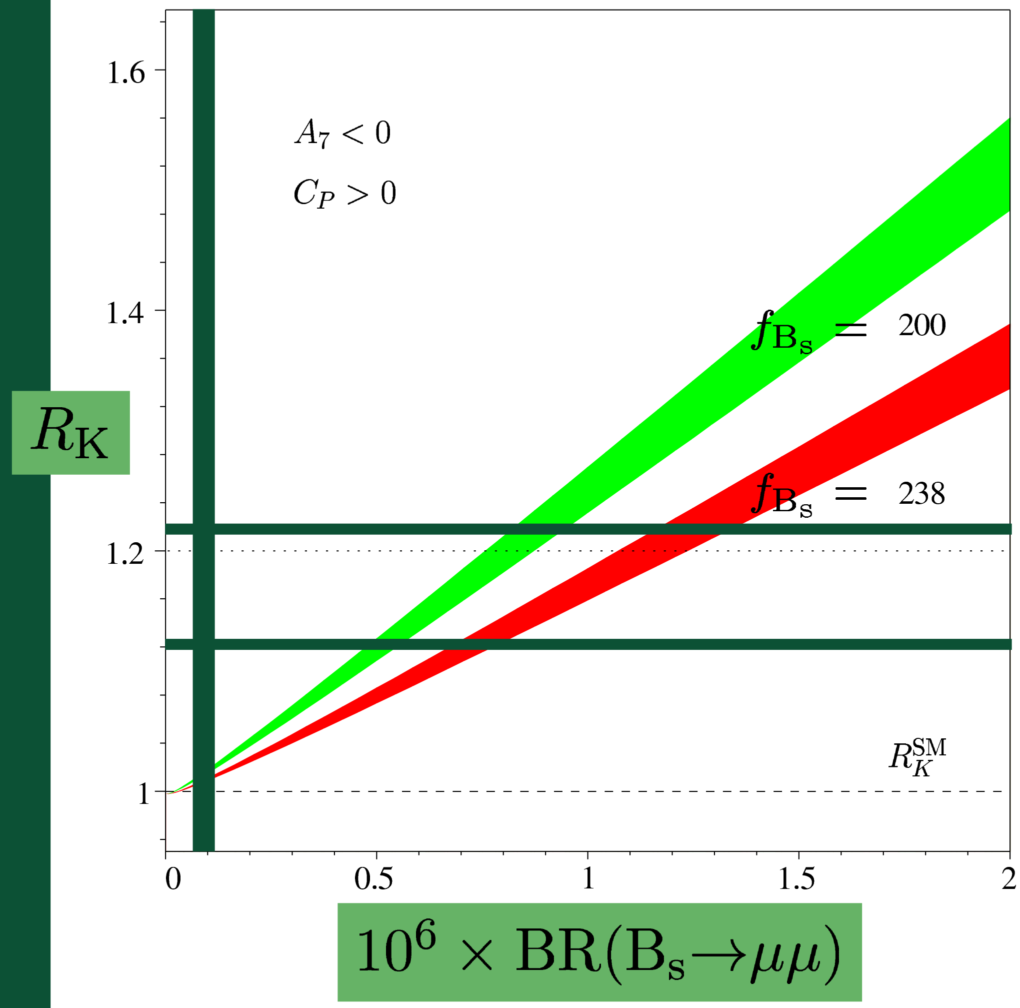
  - $R_K \neq 1$: New Physics — Right-handed currents or broken lepton-universality

Possible status with $10\ \mathrm{fb}^{-1}$



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  - $R_K \neq 1$: New Physics — Right-handed currents or broken lepton-universality
- $\mathrm{BR}(\mathrm{B_s} \to \mu\mu)$ larger than SM: New Physics
  - R_K sets constraints on NP parameters

Conclusions

- $\mathrm{B^0 \to \mu\mu K^*}$ one of the top priorities at LHCb:
  - Can get 13% error on $C_7^{\mathrm{Eff}}/C_9^{\mathrm{Eff}}$ with 10 fb^{-1}
  - More optimisation work needed
- $\mathrm{B^\pm \to \ell\ell K^\pm}$ promising at LHCb
  - Get 10% error on R_{K} in one year
  - Control channel for $\mathrm{B^0 \to \mu\mu K^*}$ FBA
  - $R_{\mathrm{K^*}}$ with $\mathrm{B^0 \to \mu\mu K^*}$: to be studied

Ready for Penguins at CERN !