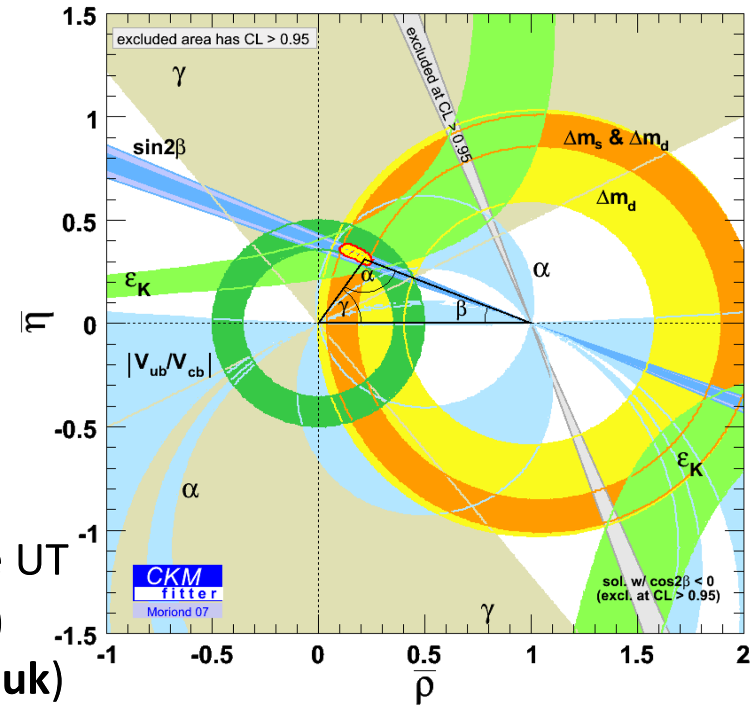
Search for New Physics in rare decays at LHCb

Victor Egorychev

Institute for Theoretical and Experimental Physics

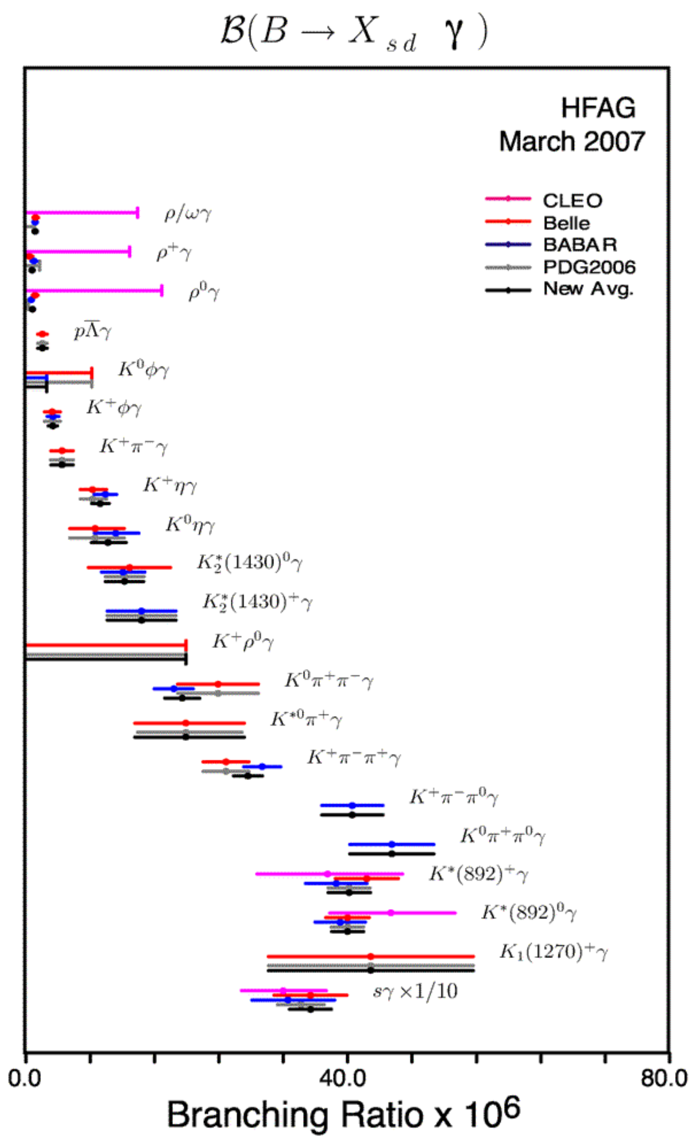
Rare decays and New Physics

- CKM model gives a remarkably consistent description of experimental results
- The most precise tests come from either tree-level B decays or from B mixing
- *Where* is the *New Physics*



  - CP violation (any inconsistencies in the UT construction will indicate the present of NP)
  (for LHCb perspectives see the talk by **S.Barsuk**)
  - Rare decays
    - penguin and box decays are particularly attractive
    - virtual new particles may alter the decay rate, CP asymmetry and other observable quantities
    - rare B decays, where penguin amplitudes play a dominate role, are excellent places to look for NP
    - the study of B-meson decays at LHCb is characterized through a high statistics and the access the B_s system

Rare decays



- Radiative penguins
- Electroweak penguins $B \to K^*ll$
- Very rare decays $B_{s,d} \to \mu\mu$
- Lepton flavor violation decays $B \to e\mu$

We are just approaching sensitivity promising for discovery

Thanks to the large statistics that can be collected by LHCb experiment, we will be able to enter a new territory in the exploration of rare B decays

Common features for LHCb analysis

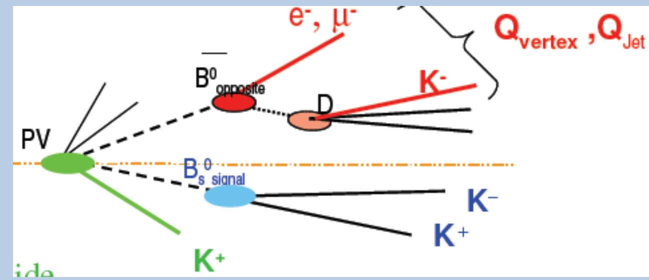
• analysis based on full detailed simulation with the realistic reconstruction chain

• Beauty particles:

- $m_b \sim 5$ GeV/c^2
- $\beta\gamma c\tau \sim O$ (1 cm)

• particles from B decays

- large p_T
- large impact parameters



pp with $\sqrt{s}$ = 14 TeV
$L = 2 \cdot 10^{32}$ cm^{-2} s^{-1}
10^{12} b-hadrons per year

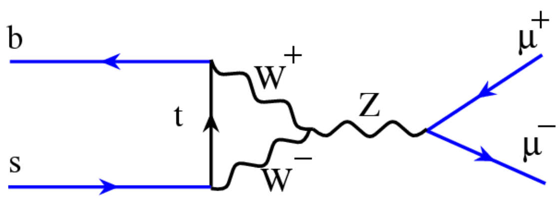
• B-decay products do not point to reconstructed primary vertex

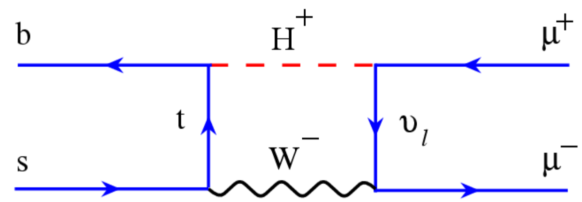
• exclusively reconstructed B-candidate does point to primary vertex

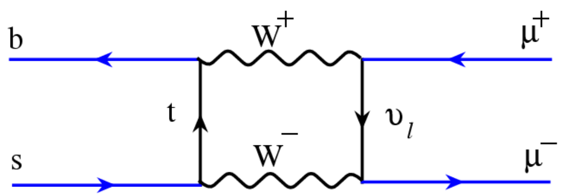
• B candidate is associated with primary vertex with minimal impact parameter (significance)

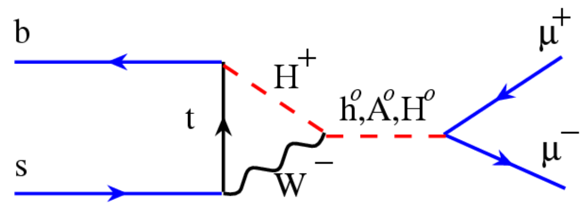
• Background – $b\bar{b}$ – production with at least one B within LHCb acceptance

Search for $B_s \rightarrow \mu^+ \mu^-$









Theoretical prediction

$$\mathcal{B}(B_s \rightarrow \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$$

BR is highly suppressed in the SM

SUSY: $\mathcal{B}(B_s \rightarrow \mu^+ \mu^-) \propto \tan^6 \beta$

tanβ – the ratio of the Higgs vacuum expectation values

BR can be *greatly enhanced* (100 x SM) for large tanβ!

A.J. Buras et al., Phys.Lett.B566 (2003) 115

Example: Constrained MSSM

Anomalous magnetic moment of muon:
Measured at BNL, disagrees with SM at 3.4σ.

$\Delta a_m = (28 \pm 8)\ 10^{-10}$

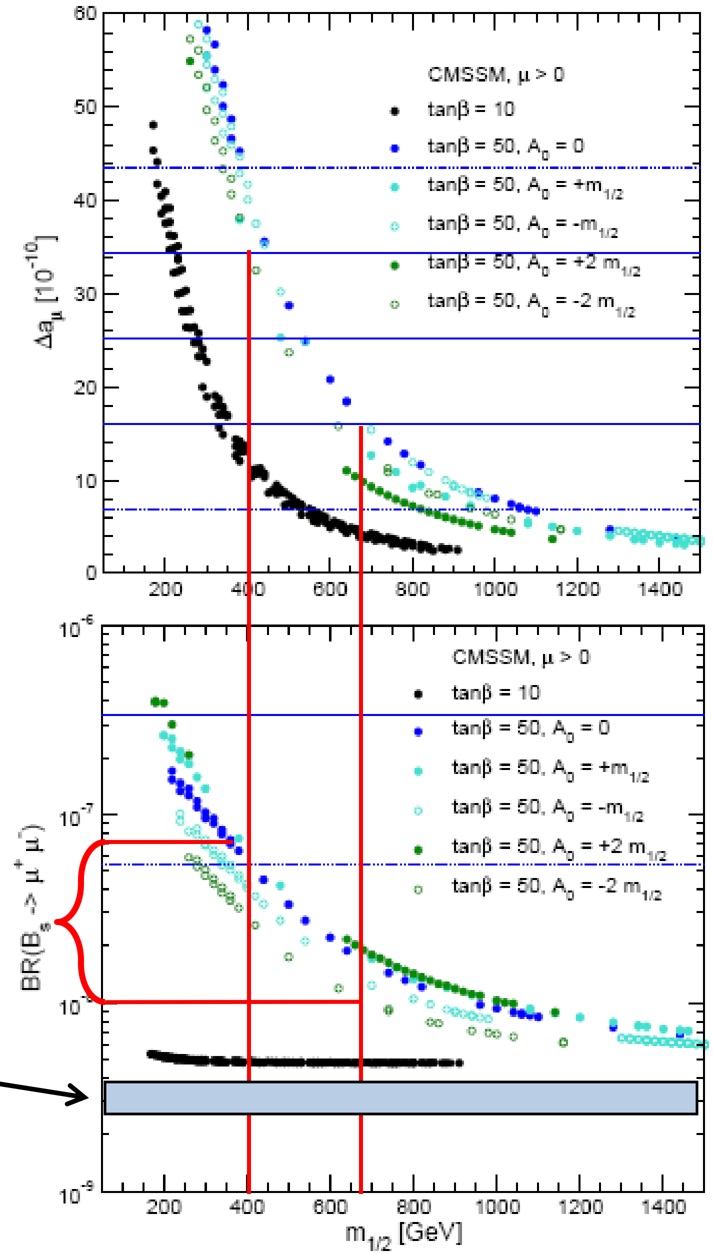
G.W.Bennett et al.,
Phys. Rev. D73 (2006) 072003

The measurement of $g_\mu - 2$ determines the mass scale of SUSY for different values A_0 and $\tan\beta$:

$400 < m_{1/2}$ (gaugino mass) $< 650\ \text{GeV}/c^2$

This mass scale is translated into a prediction for
$Br(B_s \to \mu^+ \mu^-)$ ~ a few 10^{-8} to 10^{-7}

much higher than SM



J. Ellis et al., hep-ph/0411216

Experimental status and LHCb

LP2007 conference

- CDF with 2 fb^{-1}

  $BR(B_s \rightarrow \mu^+\mu^-) < 5.8 \times 10^{-8}$ @ 95 % C.L.

- D0 with 2 fb^{-1}

  $BR(B_s \rightarrow \mu^+\mu^-) < 9.3 \times 10^{-8}$ @ 95 % C.L.

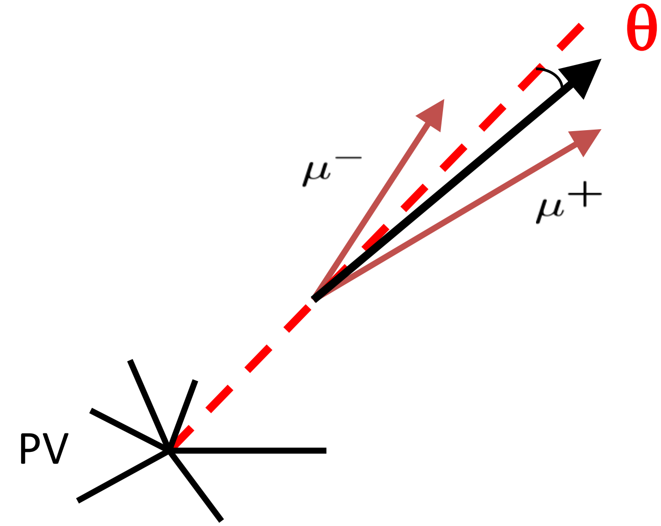
- Present limit is a factor 20 higher than SM predictions

LHCb features

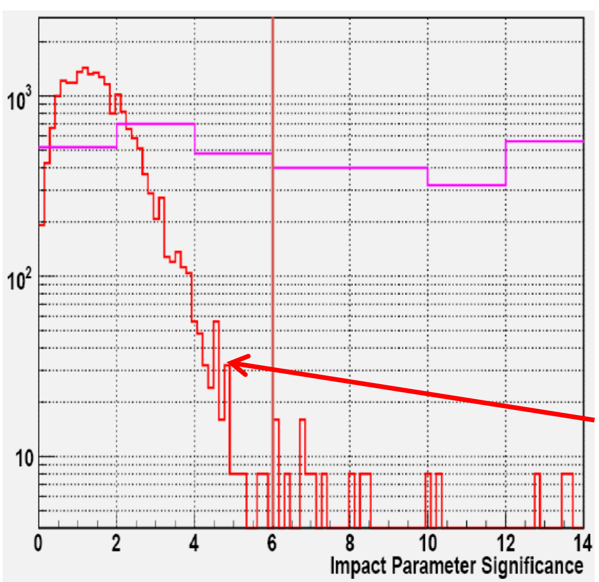
- Very efficient trigger for the signal
- Good mass resolution for background rejection (18 MeV/ c^2)
- High μ-π and μ-K separation to minimize hadron misID

$B_s \rightarrow \mu^+ \mu^-$ (soft selection)

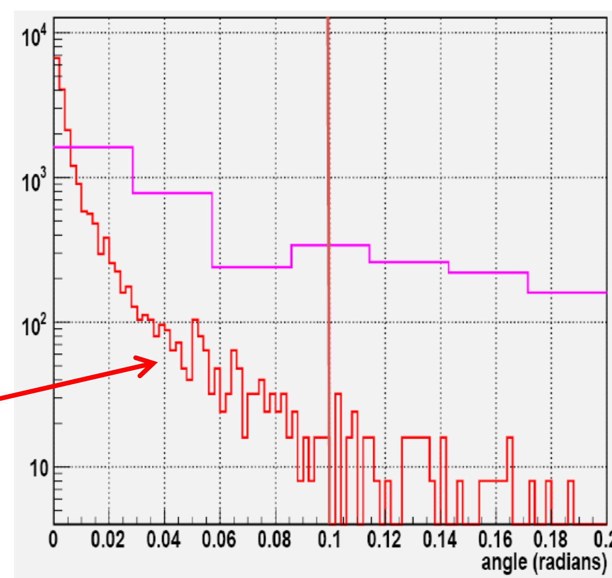
removes the biggest amount of background with signal efficiency > 90%



CERN-LHCb-2007-033
D.Martinez,
J.A.Hernando, F.Teubert



signal



$B_s \rightarrow \mu^+ \mu^-$ (N-counting method)

Geometry Likelihood

- lifetime
- muon IPS
- distance of closest approach between two μ-candidates.
- Bs Impact Parameter
- vertex Isolation

PID Likelihood

- Difference in likelihood between μ and π hypotheses (RICH + MUON info)
- Difference in likelihood between μ and K hypotheses (RICH +\MUON info)

Invariant Mass Likelihood

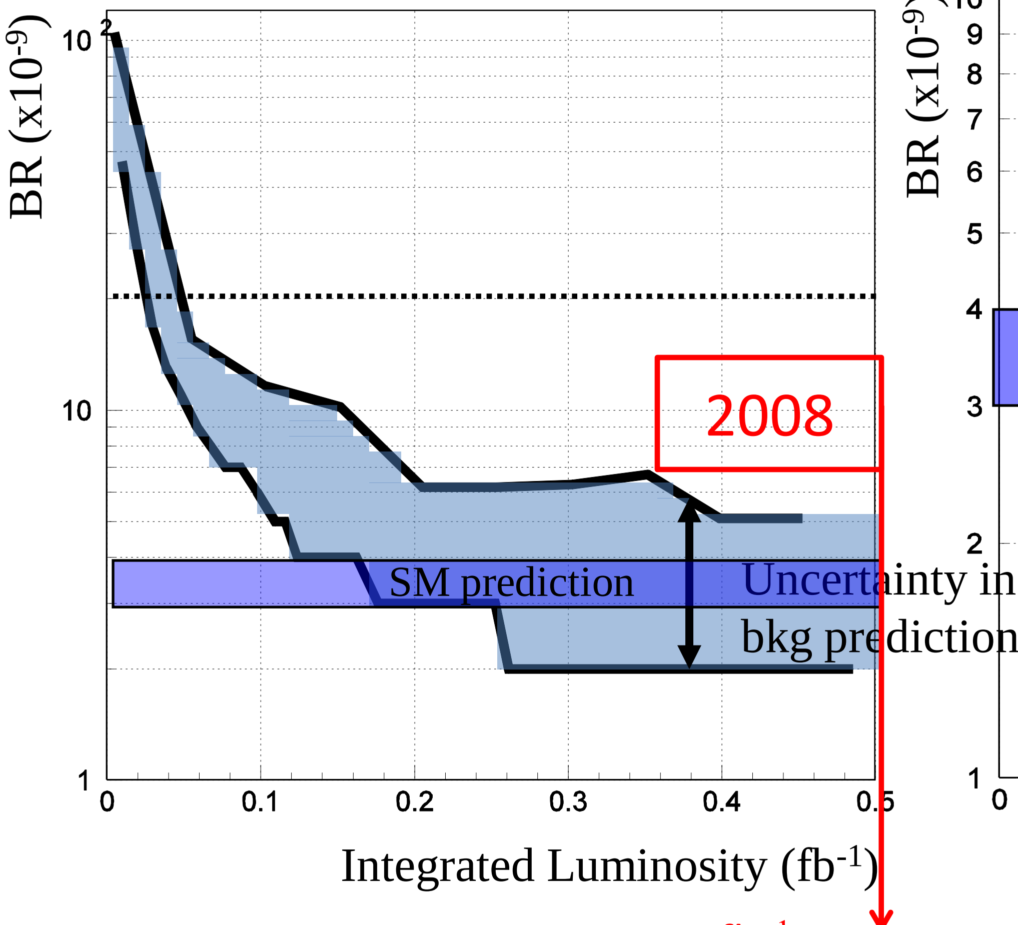
- Invariant Mass

- identify some discriminant variables
- divide the variables in N bins
- evaluate the "expected" number of events for signal/background in each bin
- compute confidence levels for observation and exclusion

$B_s \rightarrow \mu^+ \mu^-$ (LHCb perspectives)

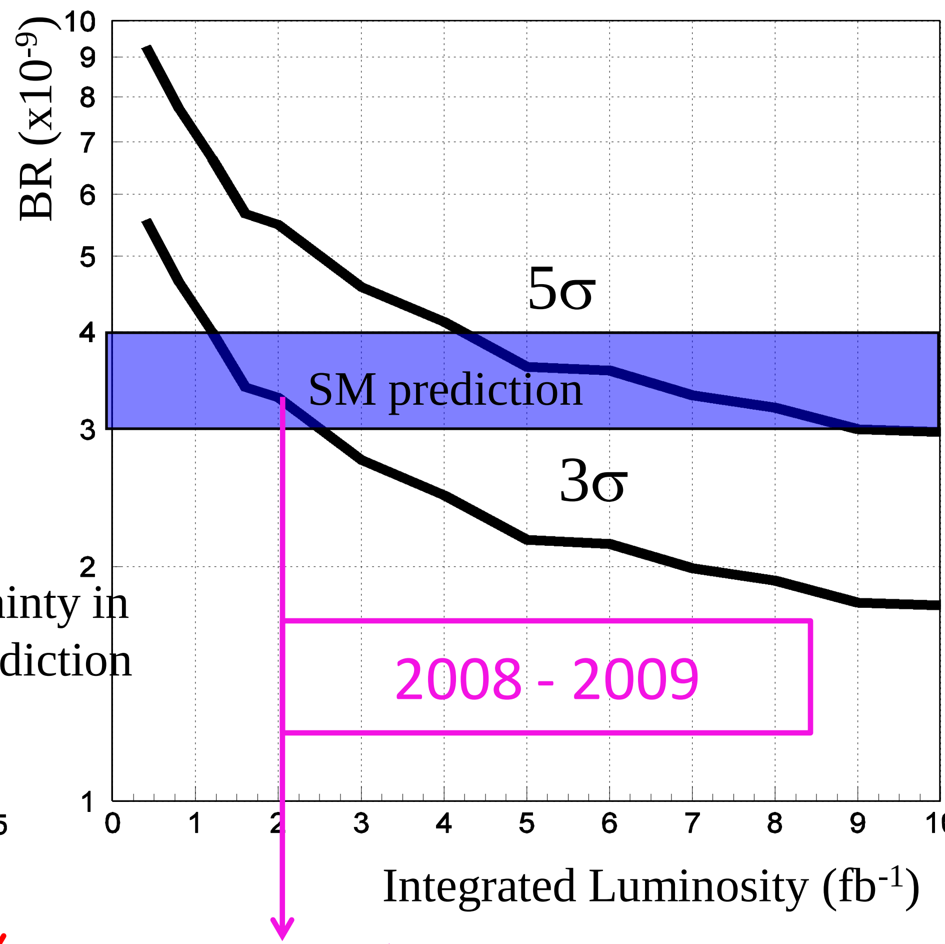
Limit at 90% C.L.

(only bkg is observed)



LHCb Sensitivity

(signal+bkg is observed)

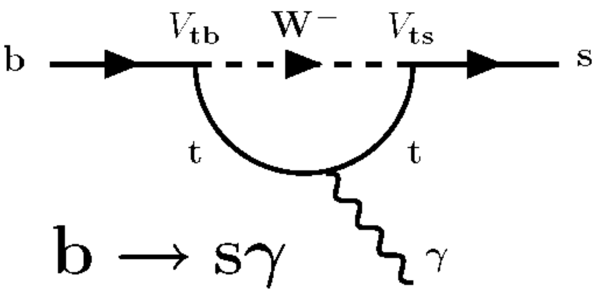


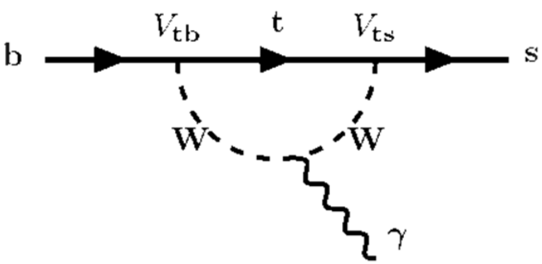
L ~ 0.5 fb^{-1}
Exclusion @ 90% CL

L ~ 2 fb^{-1}
3 σ observation if SM value

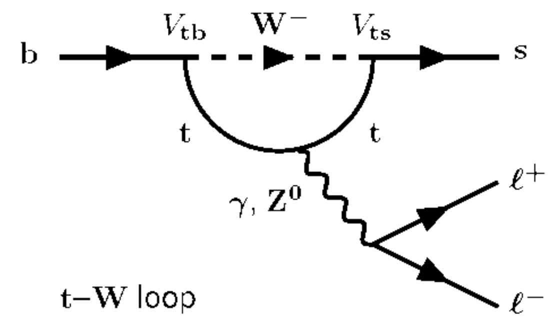
Background is assumed to be dominated by combinations of $b \rightarrow \mu^- X$ $b \rightarrow \mu^+ X$ events.

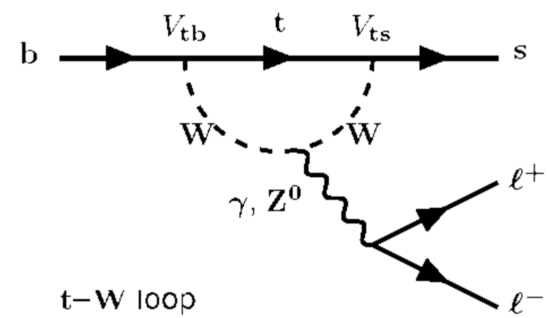
b → s γ and b → s l^+l^-



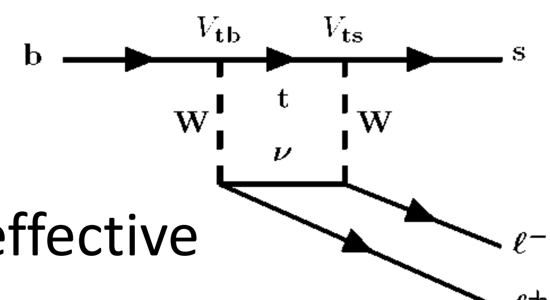


SM calculations for these rare decays are performed using an effective Hamiltonian that is written in terms of several short-distance operators





C_7^{eff}	γ penguin
C_9^{eff}	Semileptonic vector
C_{10}^{eff}	Semileptonic axial-vector



NP may alter the magnitude and/or sign of the effective Wilson coefficients

$b \to s\,\gamma$ and $b \to s\,l^+l^-$

Experimental knowledge on the Wilson coefficients comes from

- inclusive $b \to s\,\gamma$ branching fraction

  -determines the absolute value of C_7 to about 20% accuracy
  - not its sign

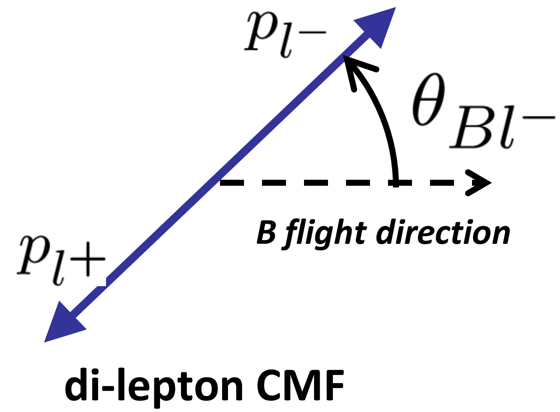
- inclusive $b \to s\,l^+l^-$ branching fraction

  -constrains C_9 and C_{10} to annular region in the C_9- C_{10} plane
  - no information on the individual signs and magnitudes of these coefficients

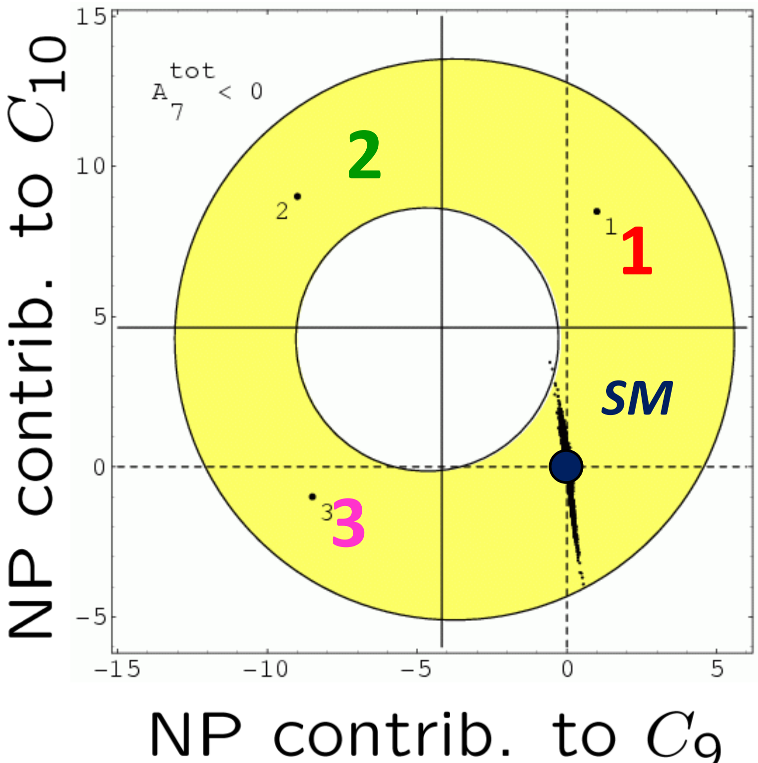
To further pin down the values, it is necessary to exploit interference effects between the contributions from different operators

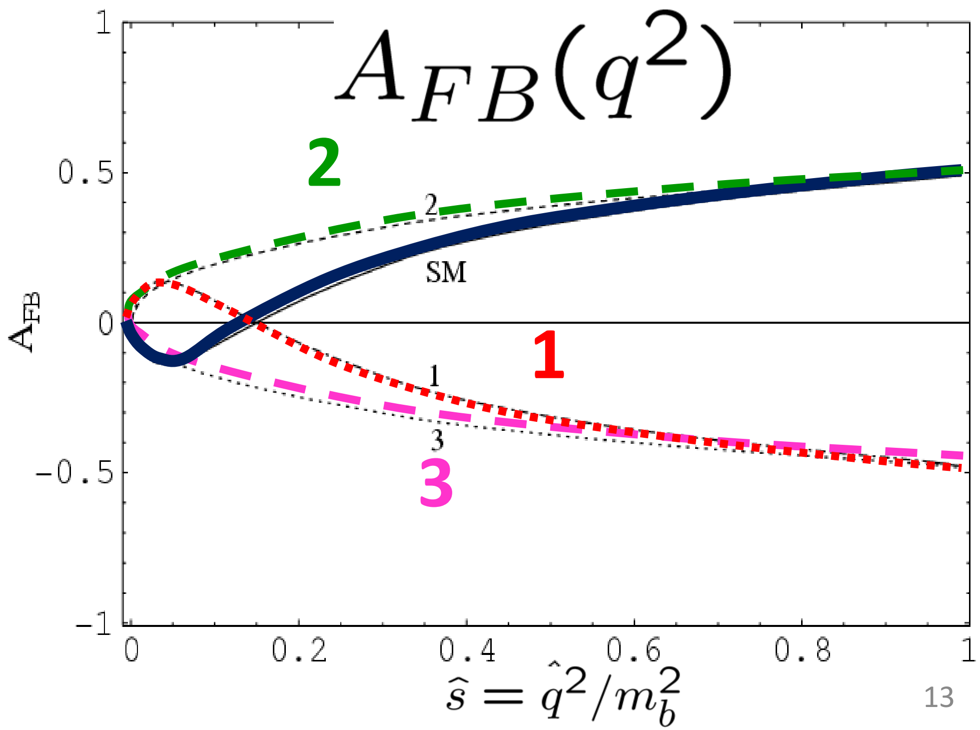
B→K* l^+l^- forward-backward asymmetry (A_{FB})

- Exclusive decays affected by hadronic uncertainties
- Vector (C_7,C_9) and axialvector (C_{10}) contributions interfere
- Relative strength of V and A couplings varies with square of di-lepton invariant mass (q^2)



A.Ali, E.Lunghi, C.Greub, and G.Hiller PRD 66, 034002 (2002).



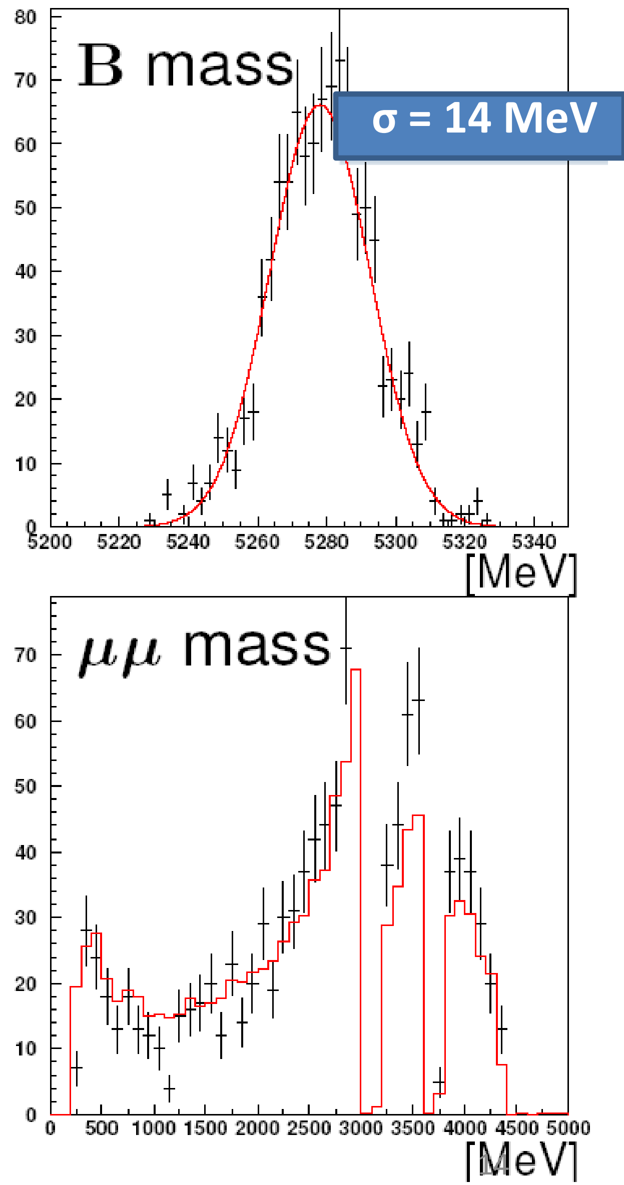


B→K* l⁺l⁻ (selection)

to avoid cuts that bias the μμ mass-spectrum

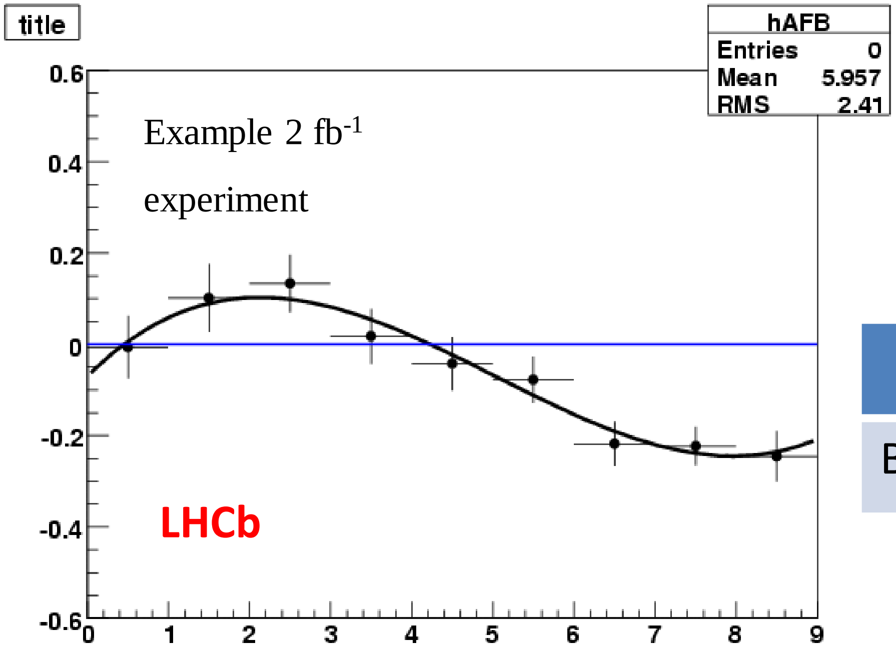
J/ψ and Ψ(2S) mass regions excluded

The μμ invariant mass distribution for reconstructed signal events before (solid) and after (crosses) selection cuts shown that the efficiency of the cuts does not depend on $m_{\mu\mu}$ up to ~3.5 GeV/c^2



CERN-LHCb-2007-038
J.Dickens, V.Gibson, C.Lazzeroni, M.Patel

$B \to K^* l^+l^-$ at LHCb



$q^2(GeV^2)$

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

decay	$N/\ 2\ fb^{-1}$	B/S
$B_d \to K^* \mu^+\mu^-$	7.7 k	0.5 ± 0.2

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

$10\ fb^{-1}$: $s_0 = 4.0 \pm 0.5\ GeV^2$ $\Rightarrow$ 13% error on C_7/C_9

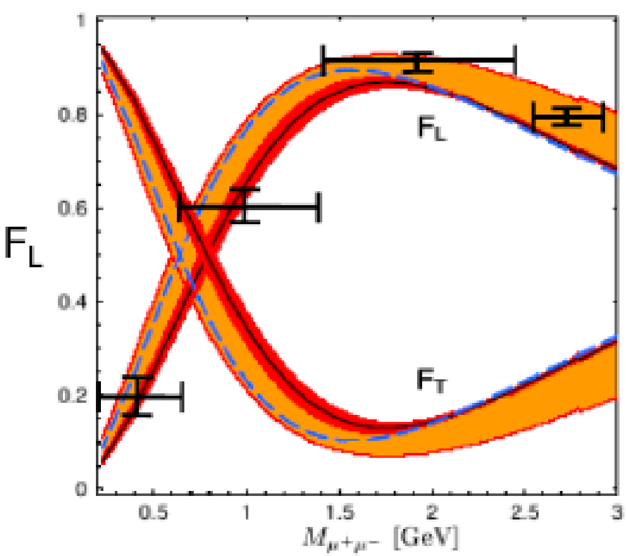
B→K* l^+l^- at LHCb

Look at decay in terms of transversity amplitudes $A_\perp$, $A_\|$, A_0 for left and right handed currents

$$A_T^{(1)}(s) = \frac{-2\mathrm{Re}(A_\| A_\perp^*)}{|A_\perp|^2 + |A_\||^2}, \quad A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_\||^2}{|A_\perp|^2 + |A_\||^2}. \qquad F_L(s) = \frac{|A_0|^2}{|A_0|^2+|A_\||^2+|A_\perp|^2}$$

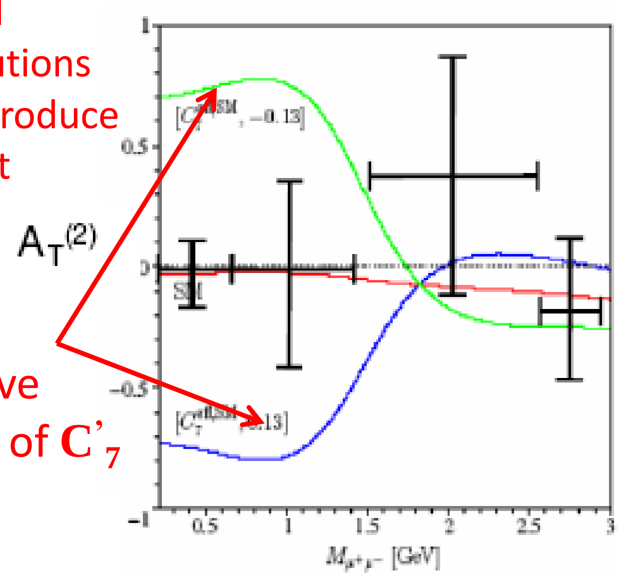
(Matias, hep-ph/0612166)

- F_L measurement looks plausible with $2\mathrm{fb}^{-1}$
- A_T^2 looks more difficult – proof of principle with $2\mathrm{fb}^{-1}$



Small RH contributions in $\mathbf{C}'_7$ produce big effect

Sensitive to sign of $\mathbf{C}'_7$



- A_T^1 requires measurement of individual helicity amplitudes → full fit to $\Gamma(\theta_l, \theta_{K^*}, \phi, s)$ – experimentally difficult

$b \to s\gamma$: direct CP asymmetry

The most effective "NP killer" – Gino Isidori, hep-ph/0401079

- One way of searching of NP is study of CP violation

$$A_{CP} = \frac{\Gamma(b \to s\gamma) - \Gamma(\bar{b} \to \bar{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\bar{b} \to \bar{s}\gamma)}$$

- Standard Model A_{CP} prediction is *theoretically clean*

$$A_{CP} = (0.42 \, {}^{+0.17}_{-0.12})\%$$

T.Hurth, E.Lungh, W.Porod Nucl Phys B704, 56 (2005)

- Large A_{CP} is smoking gun for New Physics

MFV A_{CP}	$<$ 2%	*G.D'Ambrosio et al., Nucl Phys B645, 155 (2002)*
SUSY with R-parity violation A_{CP}	~ 17%	*E.J.Chun, K.Hwang, J.C.Lee Hep-ph/0005013*

$b \rightarrow s\gamma$: photon polarization

- the polarization of the photon provides an important test of the SM

$b \rightarrow \gamma\,(L) + (m_s/m_b) \times \gamma(R)$ (mostly left-handed)

Methods:

- mixing induced CP asymmetries in $B_s \rightarrow \phi\gamma$, $B \rightarrow K_s\,\pi^0\gamma$ (B-factories)

SM extensions: amplitude of the right-handed photons grows proportional to the virtual heavy fermion mass, which can lead to the large asymmetries

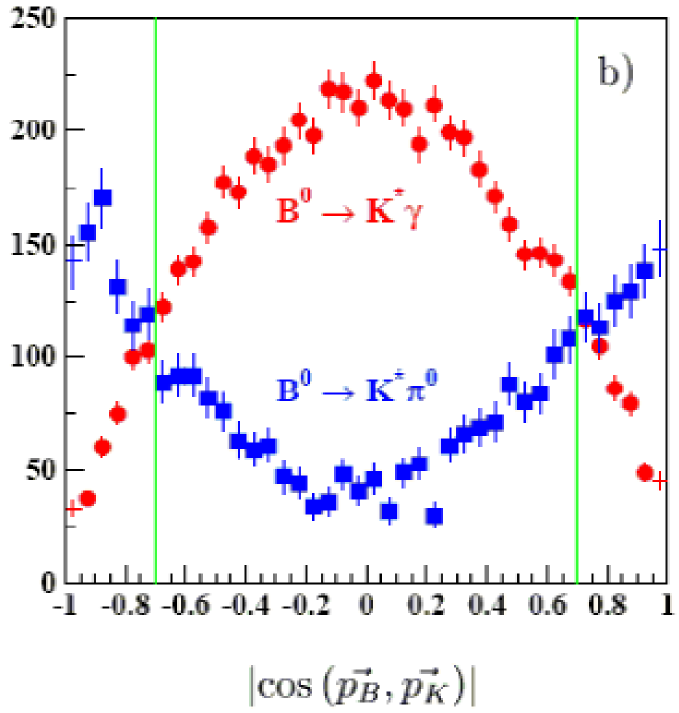
- $\Lambda_b \rightarrow \Lambda\gamma$: the angular asymmetry between the Λ_b spin and the photon momentum combined with the secondary $\Lambda \rightarrow \pi\, p$ decay polarization probes the predicted V-A structure of this decay

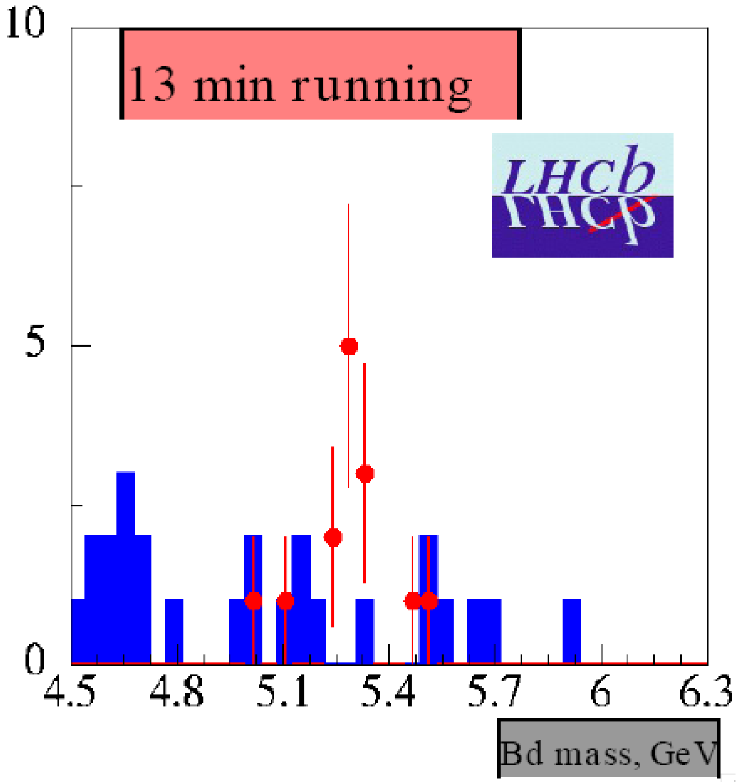
- Photon helicity can be measured directly using converted photons in $B \rightarrow K^*\gamma$ decay or parity-odd triple correlation $(P(\gamma),[P(h_1) \times P(h_2)])$ between photon and 2 out of 3 final state hadrons. Good examples are $B \rightarrow \phi K\gamma$ and $B \rightarrow K\pi\pi\gamma$ decays

$B_d \rightarrow K^*\gamma$, $B_s \rightarrow \phi\gamma$ (selection)

Special cut
(to reject background from $B_d \rightarrow K^* \pi^0$, $B_s \rightarrow \phi \pi^0$)

LHCb control channel: $B_d \rightarrow K^*\gamma$
~75k signal events per $2fb^{-1}$





angle between one daughter of the vector meson and the reconstructed B meson in the rest frame of the vector meson

CERN-LHCb-2007-030
L.Shchutska, A.Golutvin, I.Belyaev

Radiative decay at LHCb

Good physics potential to study of radiative decays

decay	N/ 2 fb^{-1}	B/S
$B_d \to K^* \gamma$	75 k	0.71 ± 0.11
$B_s \to \phi \gamma$	11.5 k	< 0.95 @ 90% CL
$B_d \to \omega \gamma$	40	< 3.5 @ 90% CL
$\Lambda_b \to \Lambda^0 \gamma$	750	< 42 @ 90% CL
$\Lambda_b \to \Lambda(1520) \gamma$	4.2 k	< 10 @ 90% CL
$\Lambda_b \to \Lambda(1670) \gamma$	2.2 k	< 18 @ 90% CL
$\Lambda_b \to \Lambda(1690) \gamma$	2.2 k	< 18 @ 90% CL

The statistical error on A_{CP} ($B_d \to K^* \gamma$) is well below 1%

The statistical error on V_{td} / V_{ts} from $B_d \to K^* \gamma$, $B_d \to \omega \gamma$ of about $O(0.1 \sqrt{(1 + B/S) / N})$

15% sensitivity to $\gamma(R)$ after 5 years

Summary

LHCb has a good potential to studies of rare B decays in a way to search for New Physics and to constrain New Physics model parameters via:

-Photon helicity in exclusive radiative penguins

- Measurement of FBA, zero point, transversity amplitudes in $b \rightarrow sll$ exclusive decays ($K^*\mu\mu$, $\phi\mu\mu$, …)

- Measurement of BR($B_{s,d} \rightarrow \mu\mu$) down to SM predictions

- Search for lepton flavor violation

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$\Lambda_b \rightarrow \Lambda(1690)\gamma$	2.2 k	< 18 @ 90% CL
$B_d \rightarrow K^* \mu^+\mu^-$	7.7 k	0.5 ± 0.2
$B_u \rightarrow K e^+ e^-$	360	~ 5
$B_u \rightarrow K \mu^+\mu^-$	4.4 k	~ 3

The challenge is to achieve that performance with real data

Back up

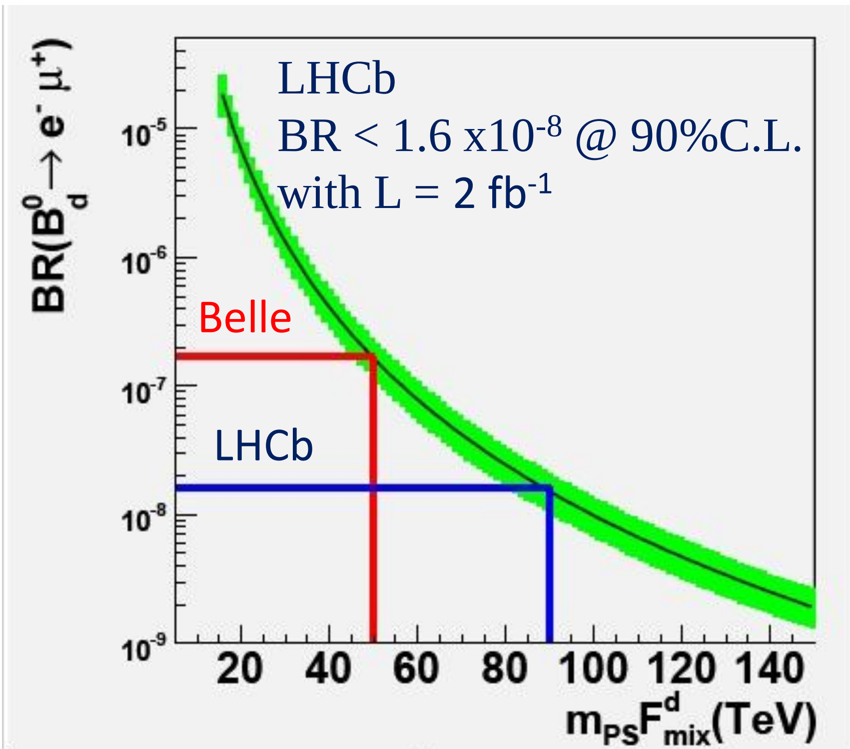
Search for LFV decays $B_{s,d} \rightarrow e^+ \mu^-$

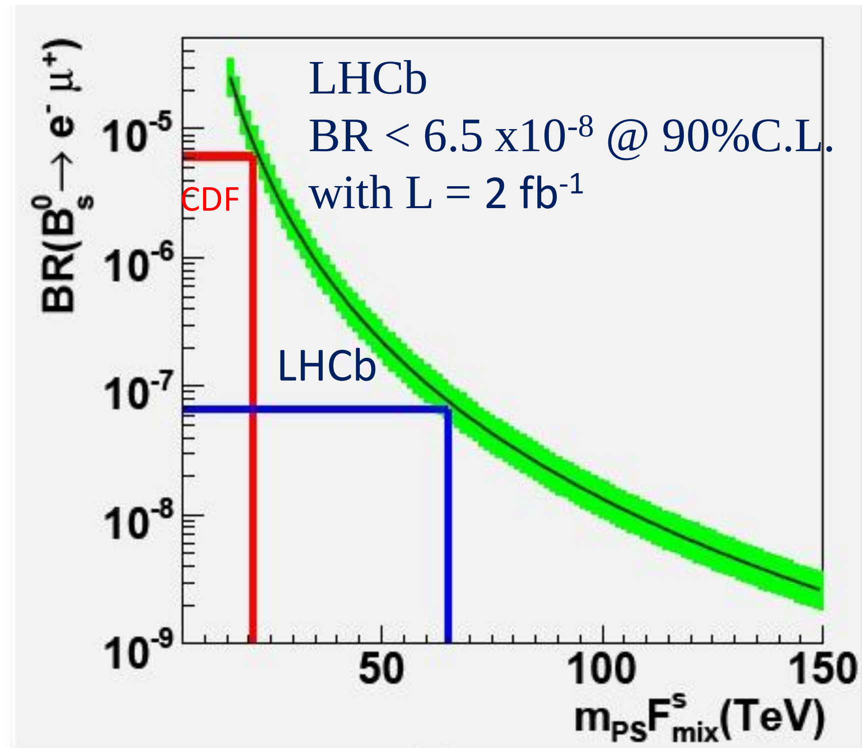
$BR(B_d \rightarrow e^+\mu^-) <$ 1.7 x10^{-7} @ 90 % C.L.

Belle collaboration,
Phys. Rev. D68 (2003) 111101

$BR(B_s \rightarrow e^+\mu^-) <$ 6.1 x10^{-6} @ 90 % C.L.

CDF collaboration,
Phys. Rev. Lett. 81 (1998) 5742





In the framework of Pati-Salam model, the limits on branching fractions can be interpreted as lower limits on the Pati-Salam Leptoquark mass, which are 90·*F d mix TeV and 65·F s mix TeV, at 90 % C.L., where the F d,s mix are factors taking into account generation* mixing within the Pati-Salam Model.