New Physics search with LHCb

A.Hicheur (EPF Lausanne)

Moriond QCD 2008

Outline

- General framework describing weak decays
  - Where to dig for NP?
- Studies covered in this talk
  - B_s oscillations
    - Measurement of oscillation parameters with $b \to c\,\bar{c}\,s$
  - Radiative and EW penguin decays (FCNC transitions)
    - $b \to s\gamma$
    - $b \to sll$
  - Very rare decays: $B_s \to \mu\mu$

New physics and B decays: where?

A. Fundamentals

Weak decays of Hadrons are described by effective Hamiltonians:

$$H_{eff} = \sum_i C_i(\mu) O_i(\mu)$$

i = 1-2: trees
i = 3-6,8: g penguin
i = 7: γ penguin
i = 9,10: EW penguin

Derived using Operator Product Expansion + renormalization group to sum up the radiative corrections

C_i Wilson coefficients integrate physics from high energy (weak scale) down to $\mu \sim 1$ GeV scale. Perturbative regime.

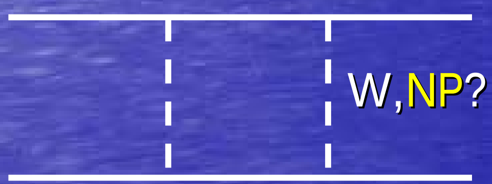
Matrix elements of operators O_i : non perturbative calculations

C_i/O_i mix under RG equations: use effective C_i^{eff}

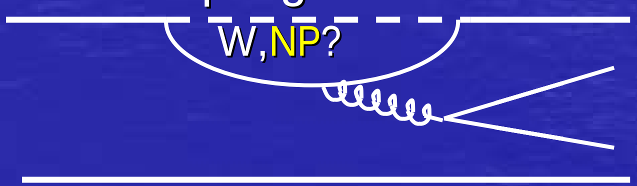
→ New physics will show up through C_i coefficients

Loop diagrams: where we expect new particles to show up

box



penguin



B. Impact on observables: BR, time asymmetries, forward/backward asymmetry, polarizations, ... Asymmetries less penalized by uncertainties coming from $<O_i>$

LHCb experiment

- **pp collisions @ 14 TeV**

Correlated forward $b\bar{b}$ production $\sigma_b \approx 500\ \mu b$

- **Forward spectrometer**

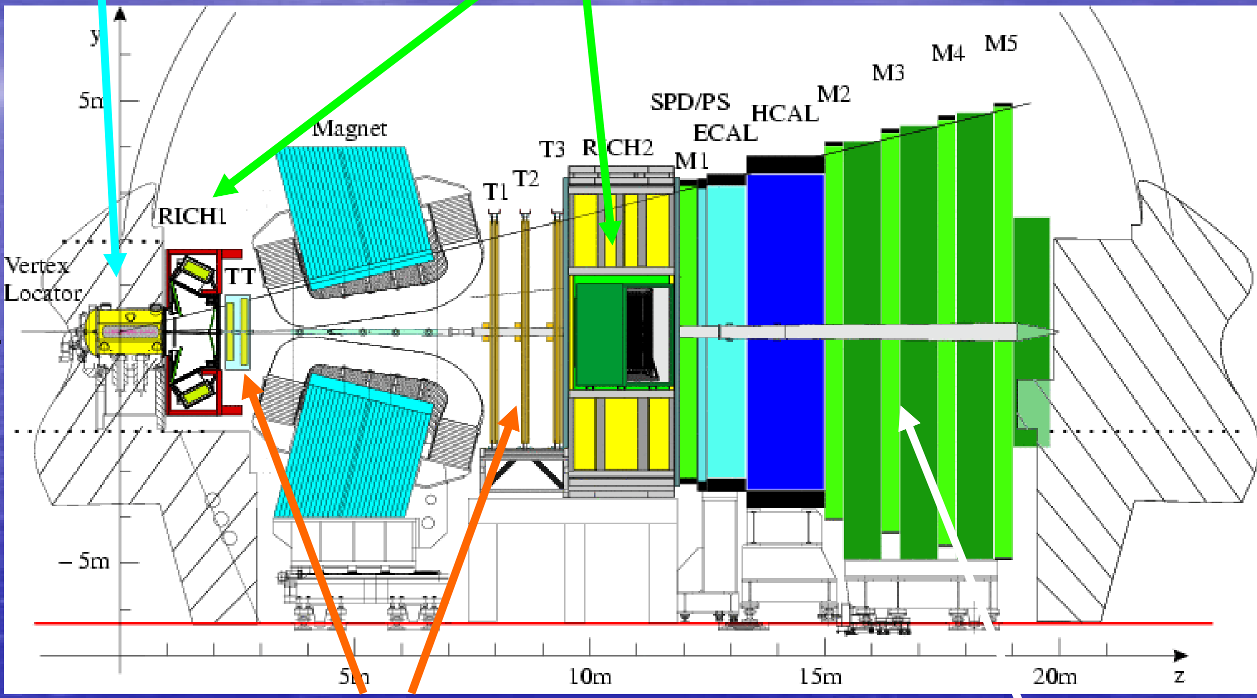
Need prim. & b vertex reco for time measurements + subsequent decays separation

Proper time resolution

~ 30 – 40 fs

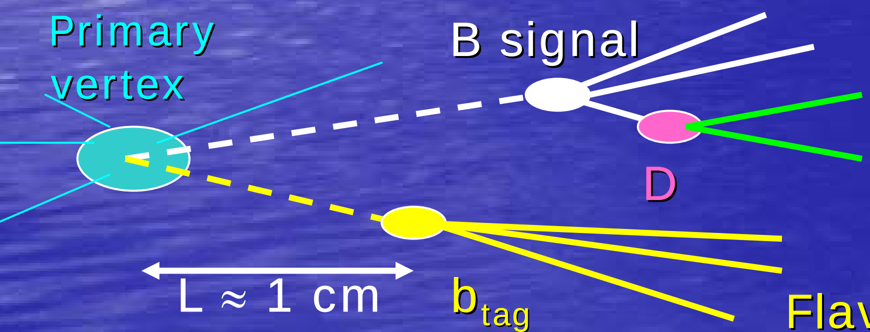
Vertexing

RICH system for PID



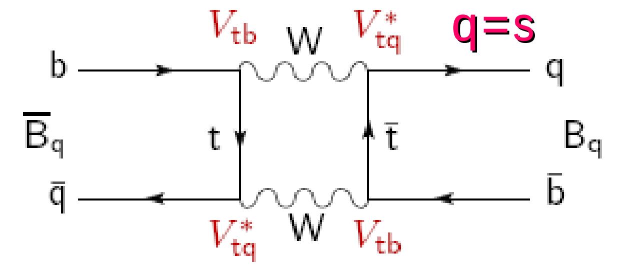
Tracking ($\delta p/p$ = 0.4%)

Muon detector

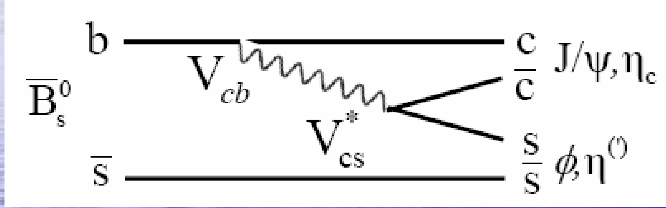


New physics in B_s oscillations (+ decays)

- B_s mixing phase $\phi_M = \varphi_s$
  - $2\mathrm{Arg}[V_{ts}^{*}V_{tb}] = -2\lambda^2\eta$ in SM predictions ~ -0.04 (5% error)
  - Substantial deviation can be detected early



- Golden decays b→ c cbar s studied



$\phi_D \approx 0$

Tree dominated

No NP contribution in decay

$$\mathcal{A}_{CP}(t) = \frac{\Gamma[\overline{B}_s(t) \to f] - \Gamma[B_s(t) \to f]}{\Gamma[\overline{B}_s(t) \to f] + \Gamma[B_s(t) \to f]}$$

Final phase for asymmetry ratio ≈ φ_s

$$\mathcal{A}_{CP}^{\text{mix-ind}}(t) = -\frac{\eta_f \sin\phi_s \sin(\Delta M_s\, t)}{\cosh(\Delta\Gamma_s\, t/2) - \eta_f \cos\phi_s \sinh(\Delta\Gamma_s\, t/2)}$$

Time dependent asymmetry: extraction of φ_s and $\Delta\Gamma_s$ (ΔM_s obtained from control sample $B_s \to D_s^- \pi^+$)

CERN-LHCb-2006-047
CERN-LHCb-2007-027
CERN-THESIS-2007-051
CERN-LHCb-2007-101

Sensitivities on ϕ_s

- Admixture of CP eigenstates (η_f = -1, +1)
  - $B_s \to J/\Psi(\mu^+\mu^-)\Phi(K^+K^-)$
    - Large yield, improved sensitivity with 3 angles analysis
- CP Even eigenstates (η_f = +1)
  - $B_s \to J/\Psi(\mu^+\mu^-)\eta(\gamma\gamma,\pi^+\pi^-\pi^0)$, $J/\Psi(\mu^+\mu^-)\eta'(\pi^+\pi^-\eta,\rho^0\gamma)$, $\eta_c(h^+h^-h^+h^-)\Phi(K^+K^-)$
    - Low yield, high background
  - $B_s \to D_s^+(K^+K^-\pi^+)D_s^-(K^+K^-\pi^-)$
    - Low yield, degradation of proper time resolution

Decay mode	Yield (/2 fb^{-1})	$\sigma(\phi_s)$
$J/\Psi\eta_{\gamma\gamma}$	8.5k	0.109
$J/\Psi\eta_{\pi\pi\pi 0}$	3k	0.142
$J/\Psi\eta'_{\pi\pi\eta}$	2.2k	0.154
$J/\Psi\eta'_{\rho\gamma}$	4.2k	0.08
$\eta_c\Phi$	3k	0.108
$D_s^+D_s^-$	4k	0.133
All CP eig.	-	0.046
$J/\Psi\Phi$	130k	0.023
All modes	-	0.021

Current experimental status (D0, arXiv:0802.2255 – 2.8 fb^{-1}):

$-1.20 < \varphi_s < 0.06$ @ 90% CL

($0.06 < \Delta\Gamma_s < 0.30$ ps^{-1} @ 90% CL)

Impact of new physics

UTfit Collaboration, arXiv:0707.0636
See also arXiv:0801.1833

- Model-independent modeling of NP effects:

$$\frac{\langle B_s | H_{eff}^{tot} | \bar{B}_s \rangle}{\langle B_s | H_{eff}^{SM} | \bar{B}_s \rangle} = C_{B_s} e^{2i\phi_{B_s}}$$

$$\Delta M_s = C_{B_s} (\Delta M_s)^{SM}$$

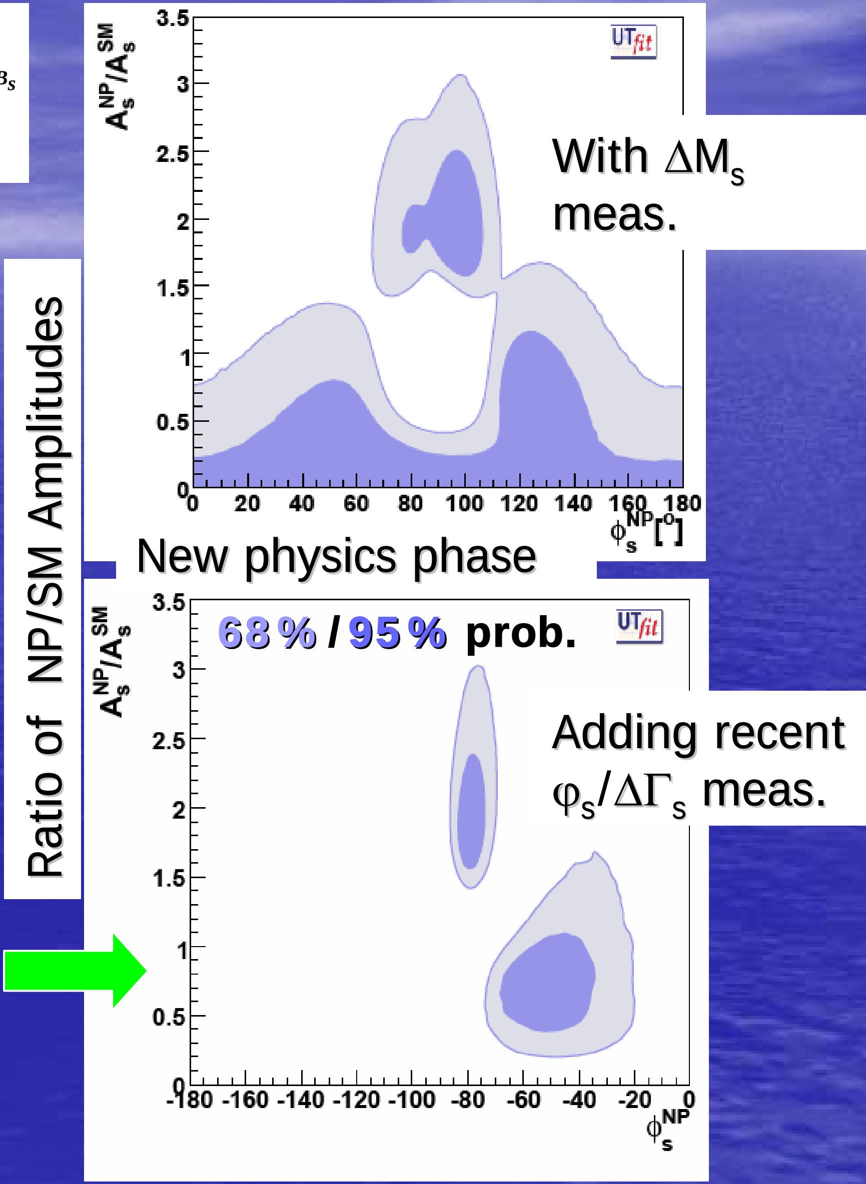
$$\sin(\varphi_s) \rightarrow \sin(\varphi_s - 2\phi_{B_s})$$

$$\Delta\Gamma_s = \cos^2(2\phi_{B_s})\left(\Delta\Gamma_s\right)^{SM}$$

Two NP scenarios considered:

- Minimal Flavour Violation
  - No additional CP violating phase
- Next to Minimal Flavour Violation
  - Possible modification of the SM phase

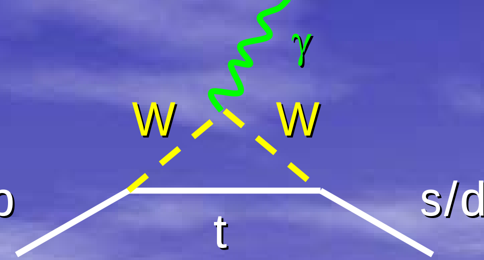
Recent fit shows >3σ NP effect and tends to rule out MFV

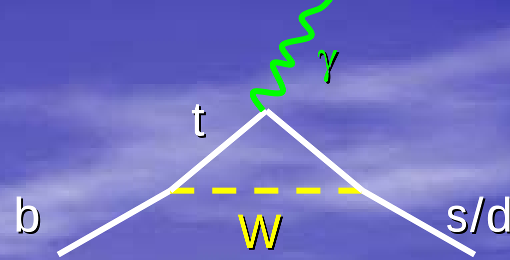


UTfit Collaboration, arXiv:0803.0659

Look forward to first LHCb data!

b→s/d γ





EM dipole operator: $O_7 \sim \bar{q}\sigma^{\mu\nu}(m_b R + m_q L) b F_{\mu\nu}$
for b→q γ

γ R polarization suppressed by m_q/m_b

- Constrain $|C_7^{eff}|$ (+ loose NP constrain in the C_7-C_8 plane)
- Measured X_s γ BR (Belle, BaBar, CLEO) in good agreement with SM predictions
  - Systematics limited
- Mostly rely on asymmetries as a sensitive probe of new physics
  - Direct CP asymmetry suppressed in SM $\frac{\Gamma(b\to s\gamma)-\Gamma(\bar{b}\to\bar{s}\gamma)}{\Gamma(b\to s\gamma)+\Gamma(\bar{b}\to\bar{s}\gamma)} < 1\%$
  - Mixing induced CP asymmetry γ R-helicity suppressed

$$\frac{\Gamma(B^0(t)\to V^0\gamma)-\Gamma(\bar{B}^0(t)\to V^0\gamma)}{\Gamma(B^0(t)\to V^0\gamma)+\Gamma(\bar{B}^0(t)\to V^0\gamma)} \propto C\cos(\Delta m t) - S\sin(\Delta m t)\left(\cosh\left(\frac{\Delta\Gamma t}{2}\right)\right)$$

C ~ 0

S ∝ m_q/m_b

NP (e.g MSSM with R-parity violation) can generate substantial direct CP (O(10%)) and/or γ_R

$B_d \to K^{*0}\gamma$ & $B_s \to \phi\gamma$

Selection:

γ: neutral ECAL cluster without association to a track, transverse energy cut to remove (π^0) bkg

Reconstruct $K^{*0} \to K^+\pi^-$ & $\phi \to K^+K^-$:

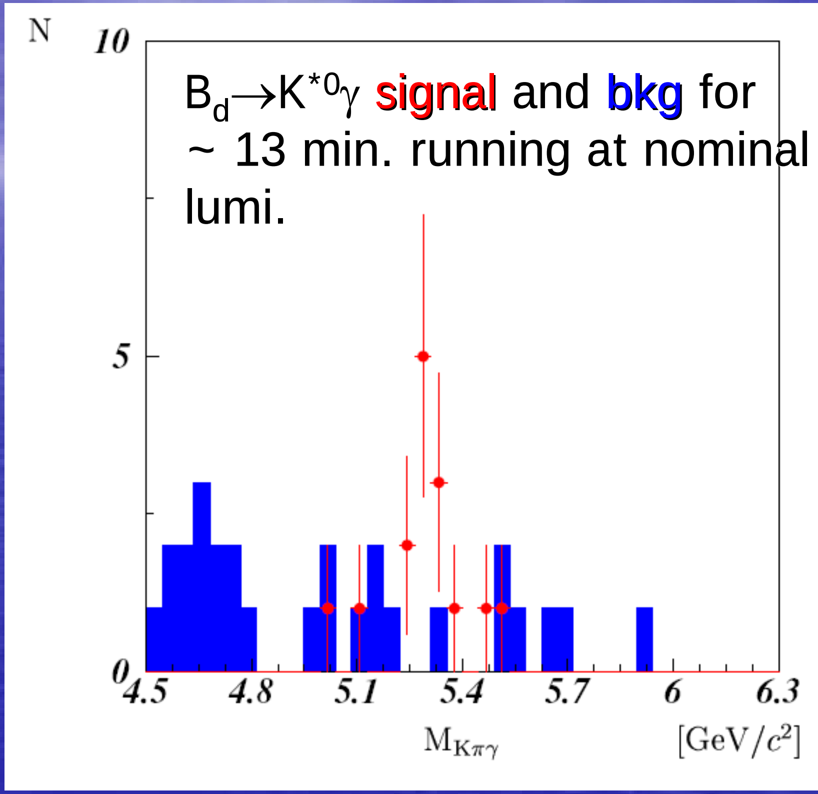
Particle ID and IP significance cuts applied to K/π

KK & $K\pi$ vertex quality cut

Use B flight to reject background from prim vtx

Generic background: inclusive bbar

Specific background: $B_d \to K^{*0}\pi^0$ & $B_s \to \phi\pi^0$, rejected by K^{*0}/ϕ Helicity cut



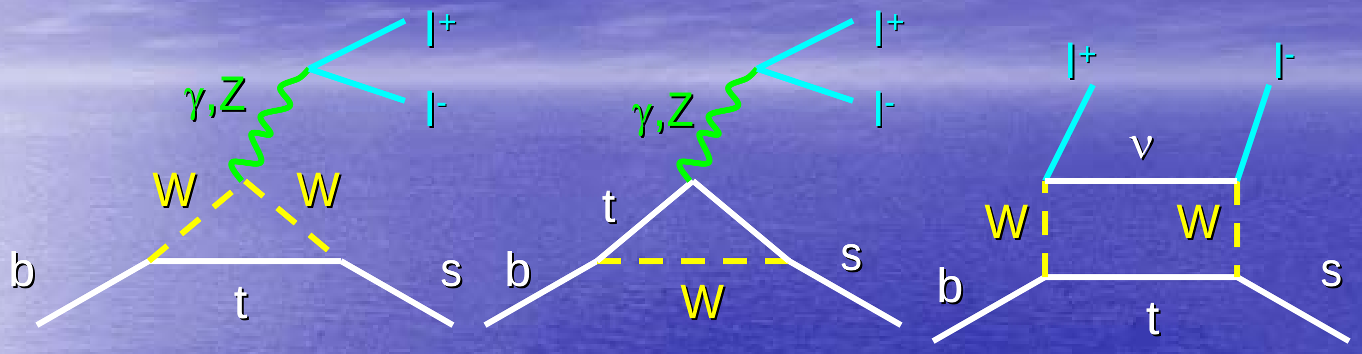
CERN-LHCb-2007-030

Yields: expect 68k $B_d \to K^{*0}\gamma$ and 11k $B_s \to \phi\gamma$ evts for $2fb^{-1}$

Sensitivity to A_{CP} smaller than 1%

On-going studies on extraction of γ_R fraction in $B_s \to \phi\gamma$ CERN-LHCb-2007-147

$b \rightarrow s l^+ l^-$



Amplitude dominated by contributions of C_9^{eff}, C_{10}, and C_7^{eff}

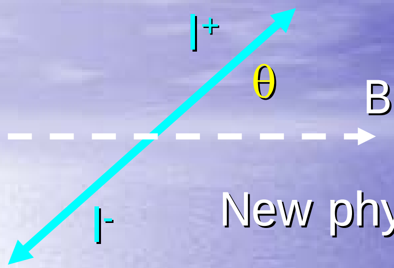
Mostly governed by $|C_9^{eff}|^2$, $|C_{10}|^2$ and sign of C_7^{eff}

Look for asymmetries to better probe size and magnitude of coefficients

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

CERN-LHCb-2007-038
CERN-LHCb-2007-039
CERN-LHCb-2007-057

Lepton pair forward-backward asymmetry as a function of $s = m^2(l^+l^-) = q^2$



$$A_{FB}\left(\hat{s} = \frac{q^2}{m_b^2}\right) \propto C_{10}\left(\mathrm{Re}\, C_9^{eff}\, \hat{s} + 2C_7^{eff}\right)$$

A. Ali *et al.*, Phys. Rev. D **55**, 4105 (1997)

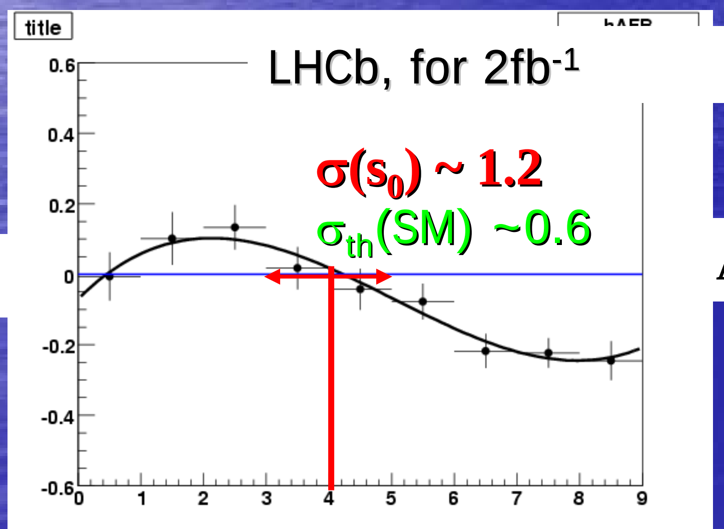
New physics can drastically affect A_{FB} shape

In particular, zero A_{FB} point s_0, $A_{FB}(s_0)=0$ is very sensitive to NP and could be predicted with less theoretical uncertainties in SM

Selection requires cuts that don't distort $m^2(\mu^+ \mu^-)$

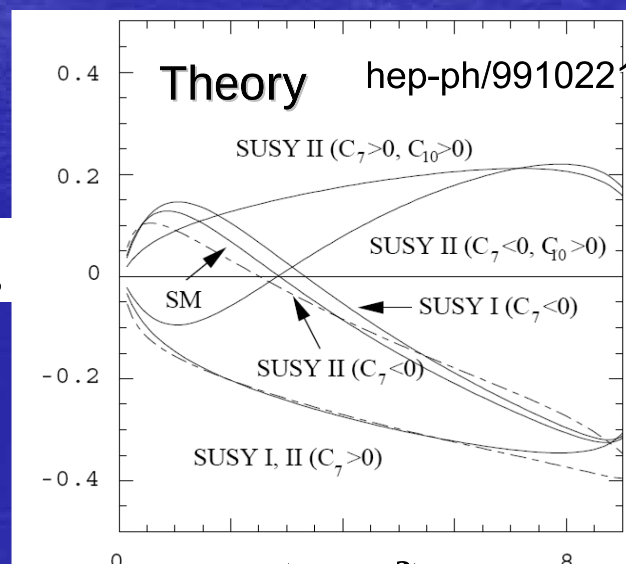
Removal of J/Ψ and Ψ' mass windows. Expect 7.2 k for 2 fb^{-1} (assuming BR = 1.22 10^{-6})

A_{FB}



s (GeV²)

A_{FB}



s (GeV²)

With 10 fb^{-1}: precision on s_0 better than theoretical uncertainties

$B^+ \to K^+ l^+ l^-$ CERN-LHCb-2007-034

$$R_X = \frac{\int_{s_{min}}^{s_{max}} ds \frac{d\Gamma(B \to X\mu\mu)}{ds}}{\int_{s_{min}}^{s_{max}} ds \frac{d\Gamma(B \to Xee)}{ds}} = 1 + O\left(\frac{m_\mu^2}{m_b^2}\right) \text{ in SM}$$

$$s_{min} = 4m_\mu^2,\ s_{max} = (m_B - m_X)^2$$

R_K(Theory) = 1 (to a high precision) Phys. Rev.D69:074020, 2004.

Sizeable deviations could come from Scalar and Pseudo-Scalar lepton operators enhanced by neutral Higgs coupling

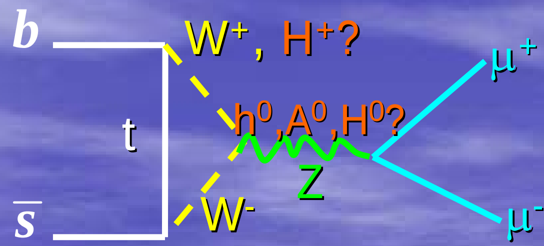
Background from X l^+l^- with badly reconstructed X

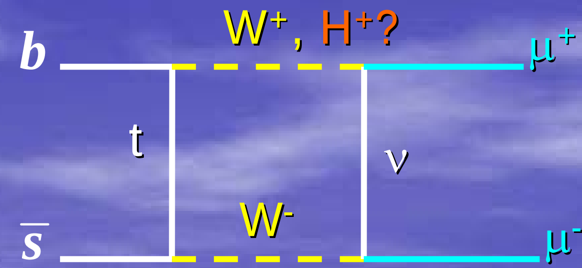
Peaking background from $J/\psi K$ removed with m(ll) cut

Expected yields for 2fb^{-1} - $B^+ \to K^+\mu^+\mu^-$: 3.8k, $B^+ \to K^+e^+e^-$: 1.9k

Experimental error on R_K expected to be 4.3% for 10 fb^{-1}

$B_s \to \mu\mu$





SM rate is suppressed by ~ m_μ^2/m_B^2. Prediction: 3.4 10^{-9} (current Tevatron UL is 20 times larger)

Possible enhancement in CMSSM (with MFV hypothesis): same operators as for R_K

$$BR(B_s \to \mu^+\mu^-) \propto \frac{m_b^2 m_\mu^2 \tan^6\beta}{M_{A^0}^4}$$

hep-ph/9909476
hep-ph/0110121
hep-ph/0210145
hep-ph/0207241

Rate could be substantially enhanced

Experimentally ideal for reconstruction in LHCb:

Easy to trigger, good mass resolution (18 MeV), good μ ID

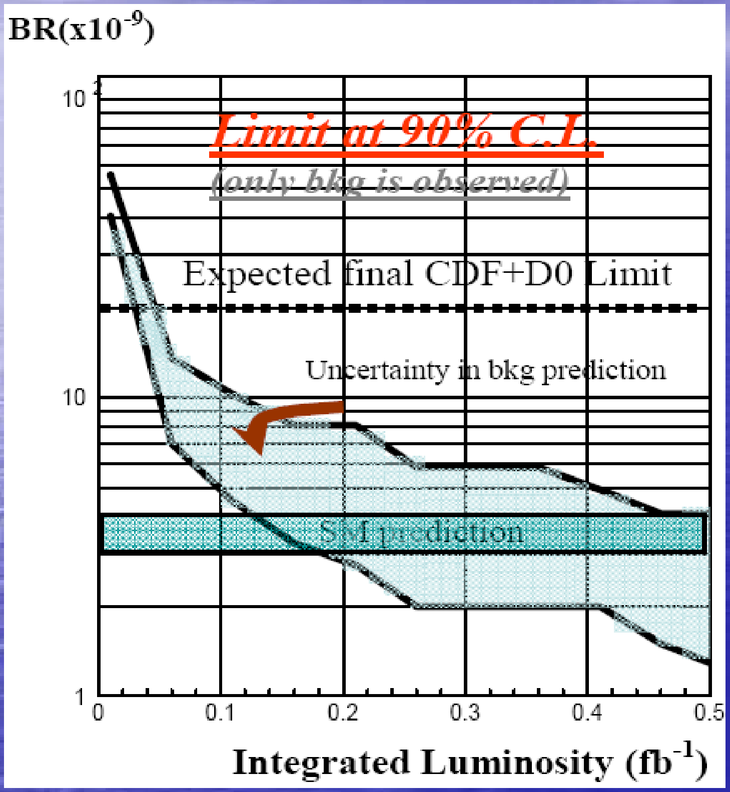
CERN-LHCb-2007-033

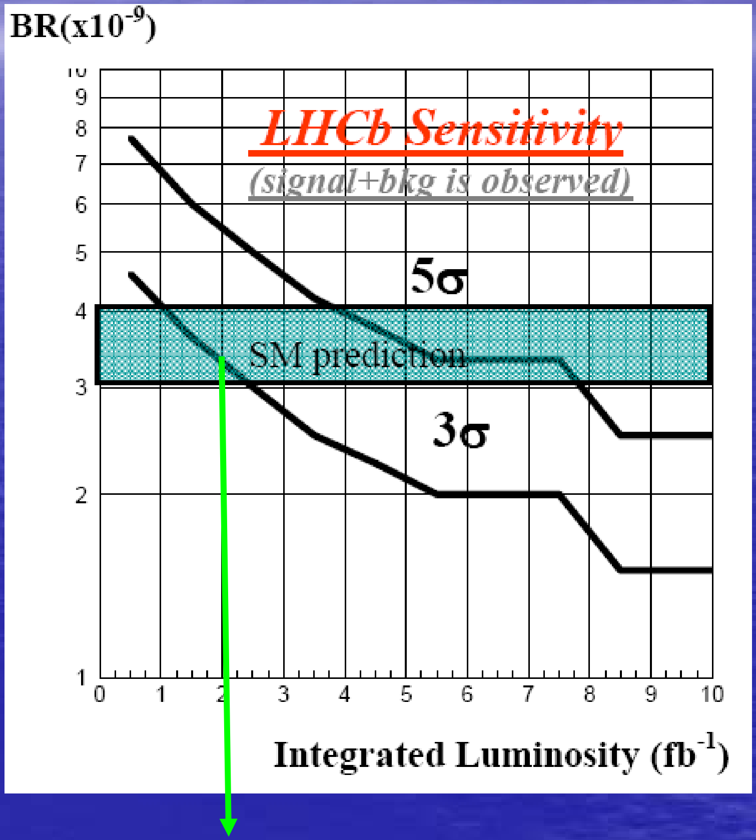
Suffers from large background, main contribution comes from $b \to \mu X$.

Combine PID, vertices and invariant mass to reduce it.

Expect ~ 70 evts for 2 fb^{-1}

$B_s \to \mu\mu$: sensitivity results





3σ observation possible with $2fb^{-1}$, 5σ discovery with $5fb^{-1}$

Limit at 90% CL already with 0.5 fb^{-1}

Conclusions

- Exclusion limits on NP scenarios will show up with the first months of data taking
- Very important 2 fb^{-1} milestone: will know the answers to several questions, e.g:
  - ϕ_s SM or not SM? First exciting hints are already showing up!
  - Zero point position for A_{FB} in K^*ll modes?
  - $B_s \to \mu\mu$ SM or not SM?
- After 5 years: clear view of NP impact on b physics. NP will be either uncovered or drastically constrained
- LHCb upgrade: run with 10 x (nominal luminosity)
  - further probe the flavour structure of NP or
  - Make SM CP violation precision tests + reduce statistical uncertainties on rare decays

Back up

CPV phase

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{\equiv V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

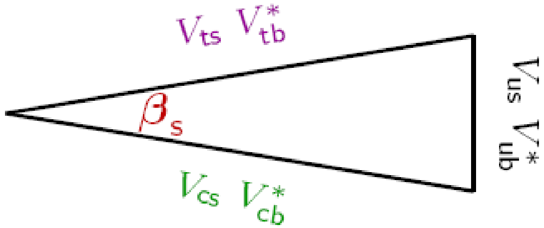
- V_{CKM} unitary
  - $\longrightarrow$ 3 angles
  - $\longrightarrow$ 1 complex phase $\Rightarrow$ $\not{C}\not{P}$

(sb) orthogonality relation:

$$\underbrace{V_{us}V_{ub}^*}_{\mathcal{O}(\lambda^4)} + \underbrace{V_{cs}V_{cb}^*}_{\mathcal{O}(\lambda^2)} + \underbrace{V_{ts}V_{tb}^*}_{\mathcal{O}(\lambda^2)} = 0$$

with Wolfenstein's parameterization

$\longrightarrow$ squashed (sb) triangle



$$\Rightarrow \beta_s \equiv \chi \equiv \arg\left[-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right] \approx \lambda^2\eta + \mathcal{O}(\lambda^4) \approx \arg(V_{ts}) - \pi$$

Measurement of β_s for study of $\not{C}\not{P}$ in B_s–$\overline{B}_s$ system $\Leftrightarrow$ β for B_d–$\overline{B}_d$ system

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = \left(\frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}\right)\frac{\bar{A}_f}{A_f}$$

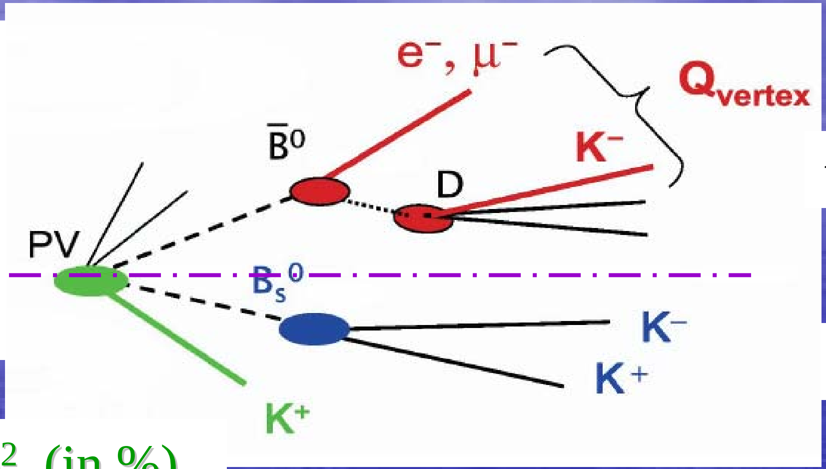
Other NP studies considered in LHCb

- NP CPV in gluonic penguins
  - $B_s \to \phi\phi$
  - γ angle with $B \to hh$
- LFV: $B_s \to e\mu$
- Open Charm physics: D^0 mixing, ACP, rare decays. Sensitive to NP as well
- Jets: see V.Coco's talk

Tagging performance

e, μ from semi-leptonic decays
$K^{\pm}$ from the $b \to c \to s$
jet/vertex charge

same side π/K



tagging B

signal B

Tagging power $\varepsilon D^2 = \varepsilon(1-2\omega_{tag})^2$ (in %)

Tag	εD^2
Muon	1.0
Electron	0.4
Kaon	2.4
Jet/vertex charge	1.0
Same side	2.1

Combined tagging power for B_S in LHCb is ~ 6%

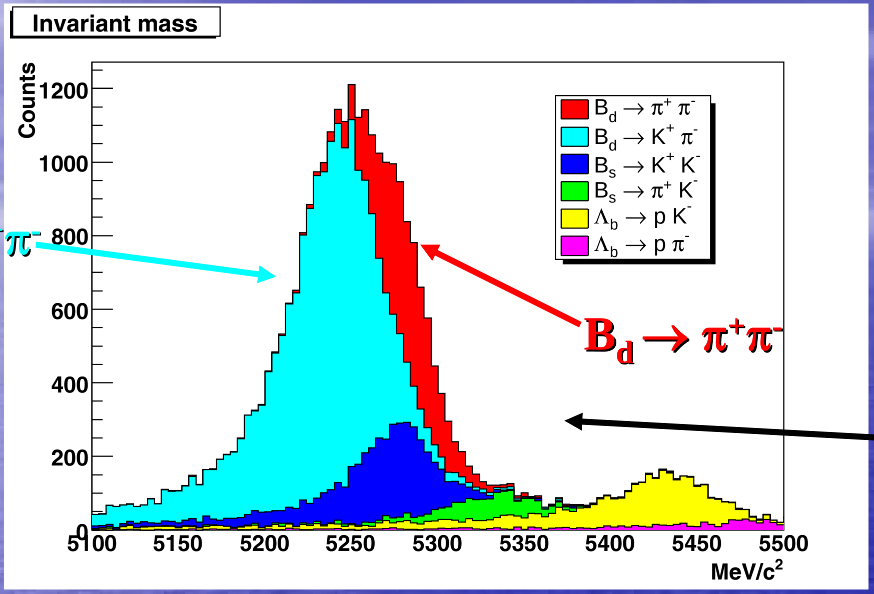
Note ~2% at the Tevatron
~30% at B-Factories

Tagging power for B^0 ~ 4%
(reduced same side tagging)

Recent Neural Network based study achieved 9% for B_S tagging!

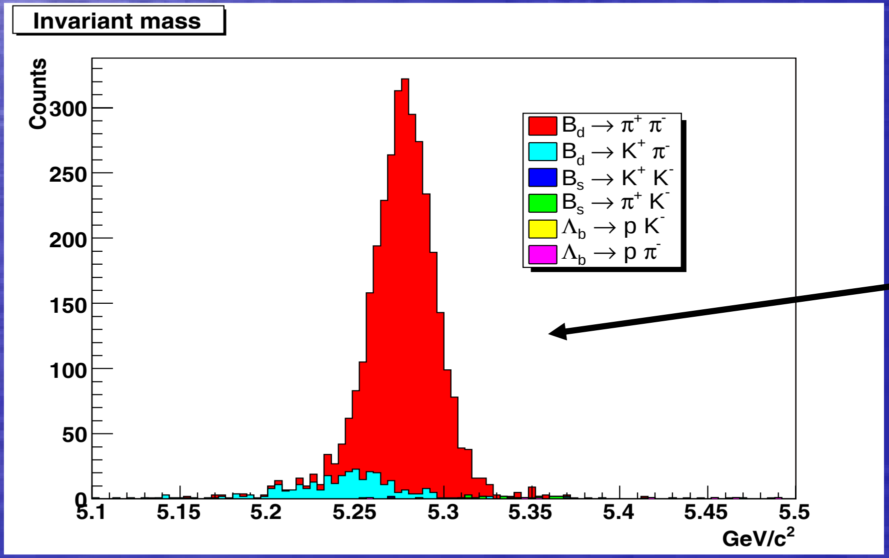
PID

$B_d \to K^+\pi^-$



$B_d \to \pi^+\pi^-$

No particle ID



With particle ID

Supplements

Parameters	$J/\psi\ \phi$	$\eta_c\ \phi$	D_sD_s	$J/\psi\eta(\gamma\gamma)$	$J/\psi\eta(\pi\pi\pi)$	$D_s\pi$	$J/\Psi\ \eta'(\pi^+\pi^-\ \eta(\gamma\gamma))$
2 fb^{-1} yield [k events]	131	3	4	8.5	3	120	2.2
Background level B/S	0.12	0.6	0.3	2.0	3.0	0.4	1.0
Mass σ_{B_s} [MeV/c]	14	12	6	34	20	14	19
Mean $< \tau_{fit}^{err} >$ [fs]	29.5	26.2	44.4	30.4	25.5	32.9	33.0
Scale factor Σ_τ	1.22	1.16	1.26	1.22	1.32	1.21	19
Wrong tag ω_{tag} [%]	33	31	34	35	30	31	31
Tagging ε_{tag} [%]	57	66	57	63	62	63	64

$K^*\gamma$: B/S ~ 0.7

$\phi\gamma$: B/S < 0.6

$K^*\mu\mu$: B/S ~ 0.5

Kee: B/S ~ 15

$K\mu\mu$: B/S ~ 1.7

$Bs\rightarrow\mu\mu$: B/S ~ 10000

Impact of new physics (2)

- Model-independent modeling of NP effects:

$$\frac{\langle B_s | H_{eff}^{tot} | \bar{B}_s \rangle}{\langle B_s | H_{eff}^{SM} | \bar{B}_s \rangle} = 1 + h_s e^{2i\sigma_s}$$

$$\Delta M_s = \left|1 + h_s e^{2i\sigma_s}\right| (\Delta M_s)^{SM}$$

$$\sin(\varphi_s) \rightarrow \sin(\varphi_s - \arg(1 + h_s e^{2i\sigma_s}))$$

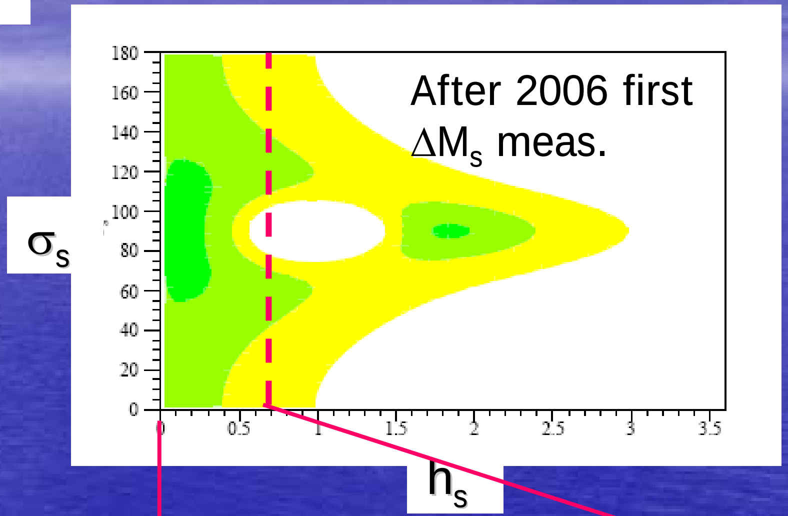
$$\Delta\Gamma_s = \cos^2(\arg(1 + h_s e^{2i\sigma_s}))\left(\Delta\Gamma_s\right)^{SM}$$

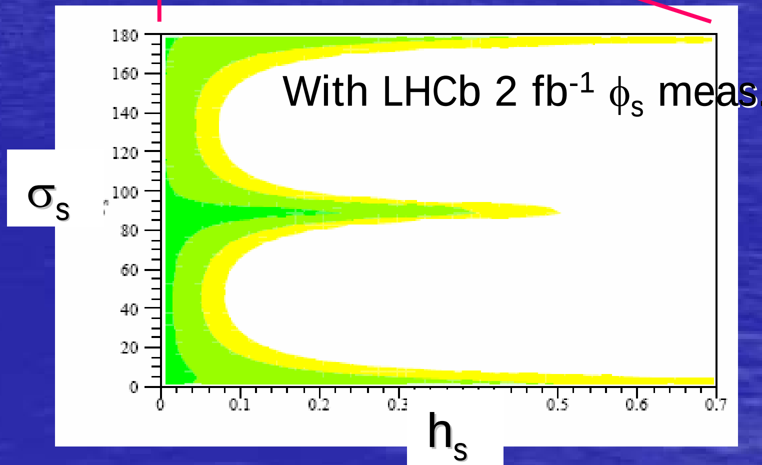
Two NP scenarios considered:

- Minimal Flavour Violation: $\sigma_s \sim 0$ [$\pi/2$]
  - No sizeable deviations
- Next to Minimal Flavour Violation $\sigma_s > 0$ [$\pi/2$]
  - Possible modification of the SM phase
  - Important constraint from ϕ_s measurement

Current $h_s < 3.0$: still room for New Physics.
Goes down to 0.1 with 2 fb^{-1} LHCb data

Allowed regions with CL > 0.90, 0.32, 0.05





Z.Ligeti et al., Phys.Rev.Lett. 97 (2006) 101801

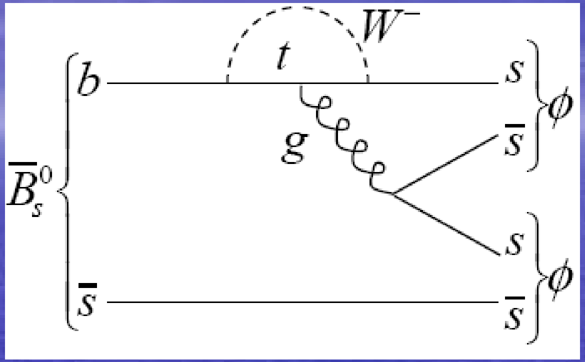
Comparing b→ c cbar s and b→ s sbar s

Smoking gun $B_s \to \phi\phi$: pure FCNC penguin.

In SM: mixing phase = decay phase

→ In SM, no sizeable CP violating phase

→ Any substantial deviation = signature of New Physics. Comparing to b→ c cbar s decays enables to disentangle NP contribution to mixing and decay



Reconstruct Bs →φ(KK)φ(KK), same analysis as for J/φΨ (mass, proper time, transversity angles). Proper time resolution a bit worse (K pairs have small opening angle, affecting vertex resolution)

With 2 fb^{-1}, expect yield of 3.1k with a sensitivity to weak phase of 0.11

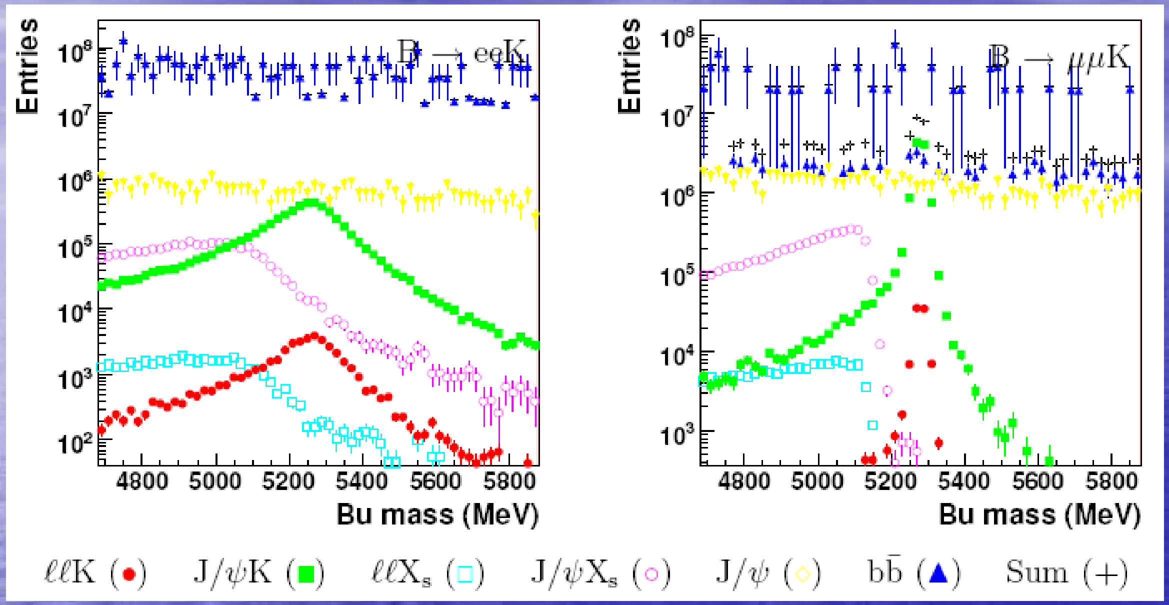
CERN-LHCb-2007-047

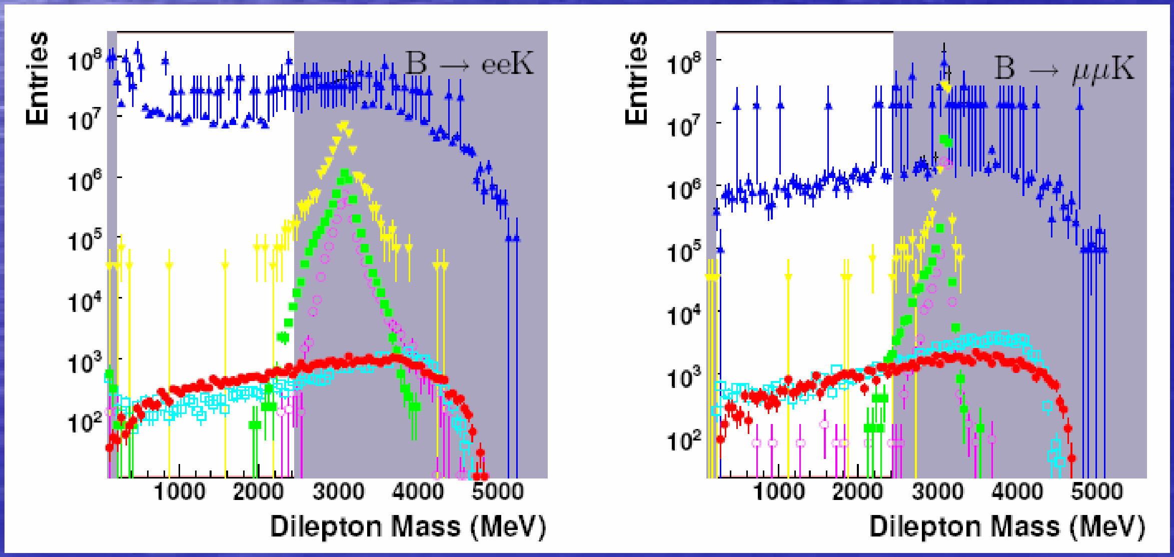
Other radiative decays studies: expected yields

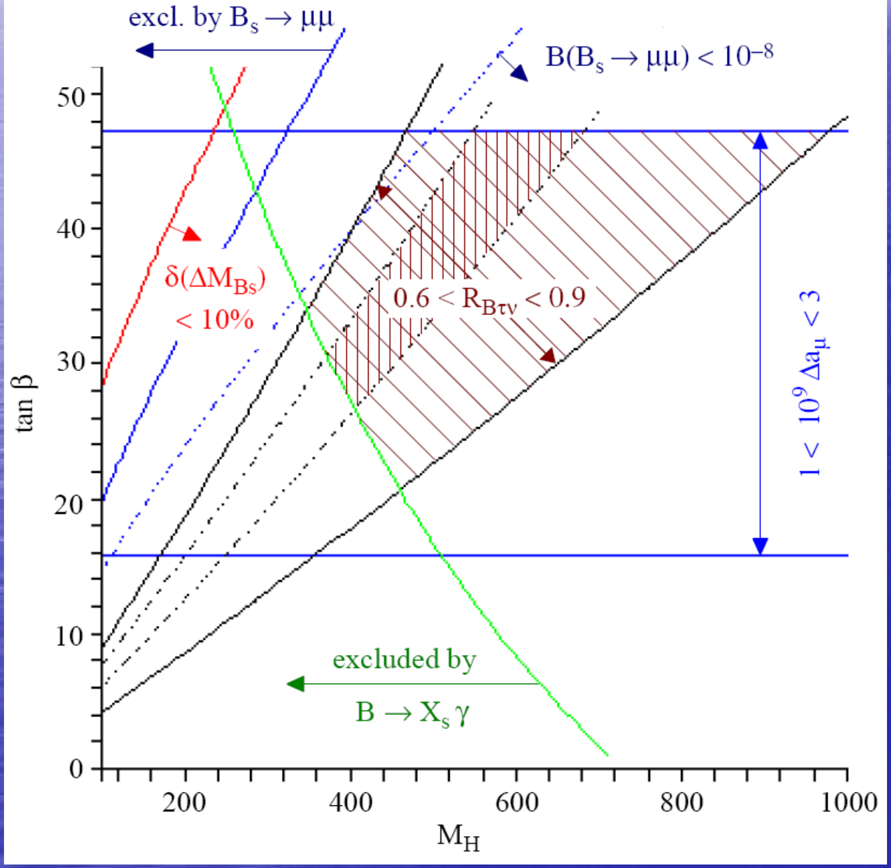
- $B_d \to \omega\gamma$ ~ 40 evts/2 fb^{-1}
- $\Lambda_b \to \Lambda\gamma$ ~ 750 evts/2 fb^{-1}
- $\Lambda_b \to \Lambda(1520)\gamma$ ~ 4.2k evts/2 fb^{-1}
- $\Lambda_b \to \Lambda(1670)\gamma$ ~ 2.2k evts/2 fb^{-1}
- $\Lambda_b \to \Lambda(1690)\gamma$ ~ 2.2k evts/2 fb^{-1}

CERN-LHCb-2006-012

CERN-LHCb-2006-013


Entries
$B \to eeK$
Bu mass (MeV)
$B \to \mu\mu K$
$\ell\ell K$ (●) $J/\psi K$ (■) $\ell\ell X_s$ (□) $J/\psi X_s$ (○) J/ψ (◇) $b\bar{b}$ (▲) Sum (+)


Entries
$B \to eeK$
Dilepton Mass (MeV)
$B \to \mu\mu K$



T.Hurth, hep-ph/0612231