Search for New Physics in rare heavy flavour decays at LHCb

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On behalf of the LHCb Collaboration

2nd International Conference on Particle Physics
in Memoriam Engin Arik and Her Colleagues
20-25 June 2011 - Doğuş University, Istanbul, Turkey

Outline

- Rare decays at LHCb
- Search for $B^0_{d,s} \to \mu^+\mu^-$
- $B^0_d \to K^*\mu^+\mu^-$
- Photon polarisation in $b \to s\gamma$
- Search for lepton number violating $B^+ \to h^-\mu^+\mu^+$
- Conclusions and outlook

At this conference:

- Victor Coco - Electroweak and QCD measurements at LHCb
- Julian Wishashi - Search for New Physics in CP violating measurements at LHCb
- Stephane Monteil - Stephane Review of LHCb Results

Heavy flavour rare decays at LHCb

New Physics can be discovered in two ways:

$\longleftarrow$ Producing new (**real**) particles
... *opening the door*

$\longrightarrow$ Studying flavour physics and rare decays looking for new (**virtual**) particles
... *looking through the keyhole*

Rare decays:

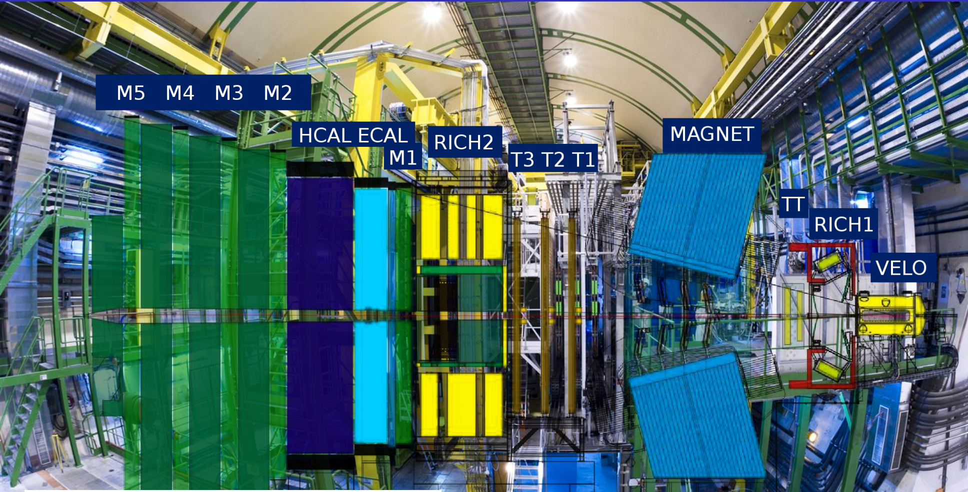
- Suppressed or forbidden in SM
  $\Rightarrow$ NP can play a major role
- Sensitive to **higher energy ranges** than directly accessible
- If NP not found **strong constraints** on parameter space

At LHCb:

- Huge cross-section for charm and beauty: $\sigma(pp \rightarrow b\bar{b}X) \sim 300\mu b$ at 7 TeV [Phys. Lett. B 694-209]
- Large forward acceptance
- Large boost

Dataset: 37 pb^{-1} in 2010, about 300 pb^{-1} expected for the summer,
1 fb^{-1} for the end of 2011

LHCb detector



Efficient trigger: 90% on leptonic final states

Very good mass resolution $\delta p/p \sim$ 0.35% to 0.55%

Particle identification $\varepsilon(\mu \to \mu) \sim 90\%$ for $\varepsilon(h \to \mu) < 1\%$ [$p >$10 GeV/c]

Excellent vertex resolution $\sigma(IP) \sim 25\mu m$ at p_{T} =2 GeV/c

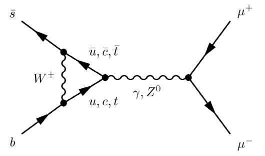
$B^0_{d,s} \to \mu^+\mu^-$: introduction

- Flavour Changing Neutral Current and helicity suppressed, proceed through loop diagrams in Standard Model
- Precise SM predictions [Phys. Rev. D 80,014503]
  $\mathcal{B}^{SM}(B^0_s \to \mu^+\mu^-) = (3.35 \pm 0.32) \cdot 10^{-9}$
  $\mathcal{B}^{SM}(B^0 \to \mu^+\mu^-) = (0.10 \pm 0.01) \cdot 10^{-9}$
- $\mathcal{B}(B^0_{d,s} \to \mu^+\mu^-) \propto \frac{\tan^6\beta}{M_A^4}$ in MSSM

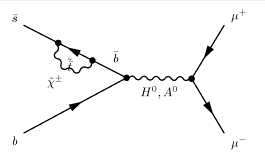
Experimental status :

	$\mathcal{B}(B^0 \to \mu^+\mu^-)$	$\mathcal{B}(B^0_s \to \mu^+\mu^-)$	
CDF	$< 7.6 \cdot 10^{-9}$	$< 4.3 \cdot 10^{-8}$	[CDF Public note 9892 (2009)]
D0		$< 5.1 \cdot 10^{-8}$	[Phys. Lett. B693, 539 (2010)]
LHCb	$< 1.5 \cdot 10^{-8}$	$< 5.6 \cdot 10^{-8}$	[Phys. Lett. B699 330-340 (2011)]

▷ There is room for new physics discovery



(a) SM diagram



(b) MSSM diagram

Direct and indirect searches for new physics

Correlations between tan β and M_A in NUHM1 5σ discovery

$$H, A \to \tau^+\tau^- \quad \to jets \quad \text{(solid line)}$$
$$\to jets + \mu \quad \text{(dashed line)}$$
$$\to jets + e \quad \text{(dotted line)}$$

in CMS with 30 or 60 fb^{-1} [Eur.Phys.J.C52,383(2007)]

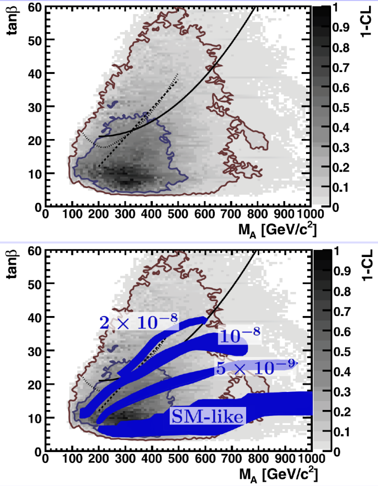
Regions compatible with a given value of $\mathcal{B}(B^0_s \to \mu^+\mu^-)$
LHCb calculation

[SuperIso Comput. Phys. Comm. 180, 1718 (2009)]

[SoftSUSY Comput. Phys. Comm. 143, 305 (2002)]

$B^0_s \to \mu^+\mu^-$ powerful probe of New Physics

[Buchmueller et al., Eur.Phys.J.C64-391]



Analysis strategy

Soft selection Reduce data to manageable level
Keep maximum efficiency for signal

Discrimination between signal and background using 2 dimensional likelihood:

- Di-muon invariant mass
- Geometrical Likelihood, multivariate method holding information of topology and kinematics

Calibration Rely on data control samples as much as possible

Normalisation Convert observed events into $\mathcal{B}$ through known channels

Limit Compare experimental observations to expectation and measure or exclude value using CLs method

Selection

Soft selection

- Pairs of opposite charged muons with high quality tracks
- Common vertex displaced from PV
- Mass window $\pm 600\,\mathrm{MeV}/\mathrm{c}^2$

High signal efficiency

$\Rightarrow$ expected 0.3 (0.04) events for Standard Model signal $B^0_s \to \mu^+\mu^-$ ($B^0 \to \mu^+\mu^-$)

Rejects most of the background

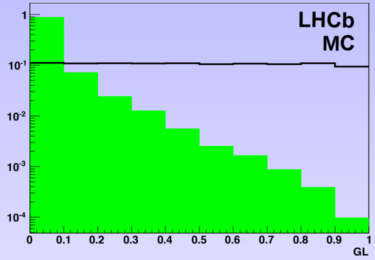
$\Rightarrow$ about 300 events left in signal [$\pm 60\,\mathrm{MeV}/\mathrm{c}^2$] region

- Background dominated by combinatorial $b\bar{b} \to \mu\mu X$ (90%) and fake plus muon (10%, again combinatorial)
- Peaking mis-identification background ($B \to hh'$) negligible $<$ 0.1 events in signal region

Geometrical Likelihood

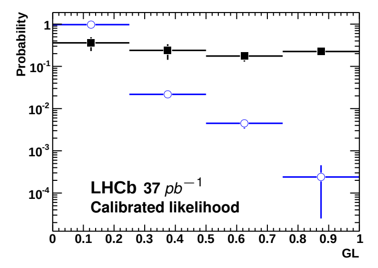
Exploit geometry and kinematics of event:

- $\mu\mu$ distance of closest approach
- B impact parameter w.r.t PV
- B lifetime
- B p_{T}
- μ Impact parameter significance
- μ isolation



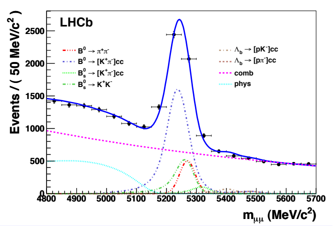
Variables are decorrelated and an MVA classifier is built
flat for signal and peaked at 0 for background by construction
Calibrated on data:

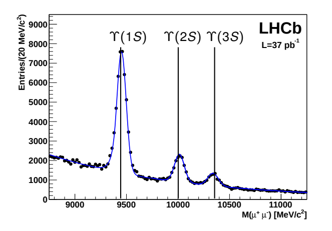
- $B \to hh'$ for signal
- Mass sidebands for background



Signal invariant mass

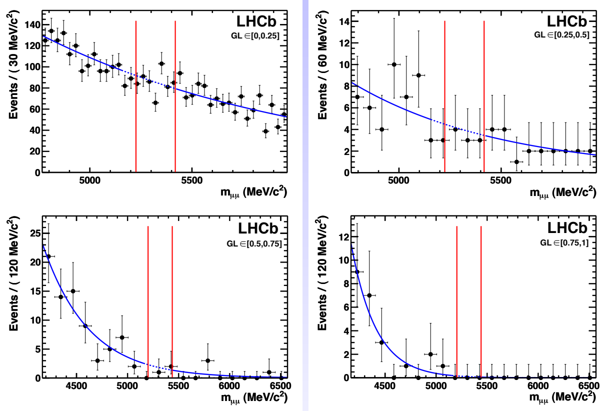
- Mass averages obtained from $B^0 \to K^+\pi^-$ and $B^0_s \to K^+K^-$ (with PID)
- Mass resolution from two methods:
  - Quarkonia dimuon decays (J/ψ, $\psi(2S)$, $\Upsilon(1,2,3S)$):
    Invariant mass modelled with Crystal Ball functions or Gaussians
  - Inclusive $B \to hh'$ without particle identification (μ masses assigned)





Two methods combined: $\sigma_M = 26.7 \pm 0.9 \mathrm{MeV/c^2}$

Background expectation



Background expectations extracted from fits to mass sidebands in 4 GL bins

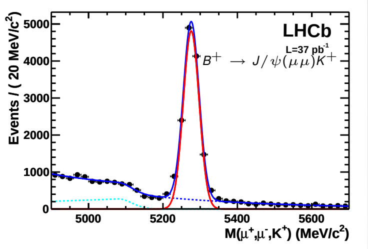
Normalisation

$$\mathcal{B}(B^0_q \to \mu^+\mu^-) = \mathcal{B}_{\text{norm}} \times \frac{\varepsilon_{\text{norm}}}{\varepsilon_{\text{sig}}} \times \frac{f_{\text{norm}}}{f_{B^0_q}} \times \frac{N_{B^0_q \to \mu^+\mu^-}}{N_{\text{norm}}} = \alpha_{B^0_q \to \mu^+\mu^-} \times N_{B^0_q \to \mu^+\mu^-}$$

- $\frac{f_{\text{norm}}}{f_{B^0_q}}$ is the ratio of probabilities for a b to fragment in the normalisation and signal channels
  - Used value for $\frac{f_{B^0}}{f_{B^0_s}} = 3.71 \pm 0.47$ [HFAG]

Three normalisation channels with selection close to the signal one

- $B^+ \to J/\psi(\mu\mu)K^+$
  Same trigger, and μ-ID, good $\mathcal{B}$ precision
- $B^0_s \to J/\psi(\mu\mu)\phi(KK)$
  Same trigger, and μ-ID, bad $\mathcal{B}$ precision, no f ratio
- $B^0 \to K^+\pi^-$
  Same topology but hadronic trigger



Results are compatible and averaged:

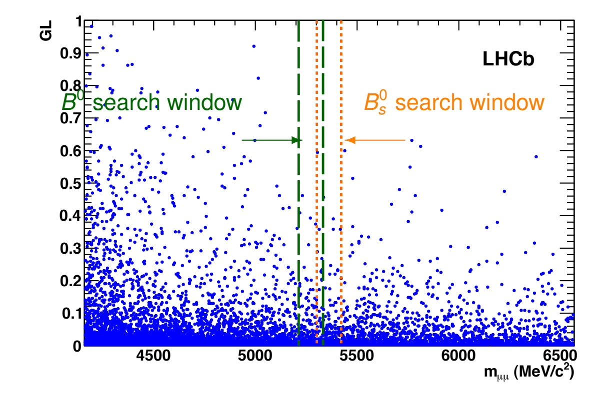
$$\alpha_{B^0_s \to \mu^+\mu^-} = (8.6 \pm 1.1) \cdot 10^{-9}$$
$$\alpha_{B^0 \to \mu^+\mu^-} = (2.24 \pm 0.16) \cdot 10^{-9}$$

Observed distribution

Limit computation:

- 4×6 bins in GL and $M_{\mu\mu}$
- Expected signal and background yields
- Evaluate compatibility with observed in:
  - S+B hypothesis
  - B hypothesis

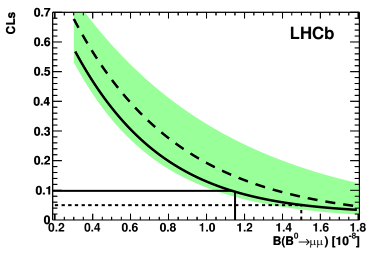
$$CL_S = CL_{S+B}/CL_B$$



Limit on $B^0 \to \mu^+\mu^-$

Observed distribution of events

Mass bin (MeV/c^2)	GL bin [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	59	2	0	0
[−40, −20]	67	0	0	0
[−20, 0]	56	2	0	0
[0, 20]	60	0	0	0
[20, 40]	42	2	1	0
[40, 60]	49	2	0	0
Sum	333	8	1	0
Bkg exp.	353	8.9	1.85	0.12



LHCb measures with $37pb^{-1}$ at $\sqrt{s} = 7$ TeV: [Phys. Lett. B699 (2011) 330-340]

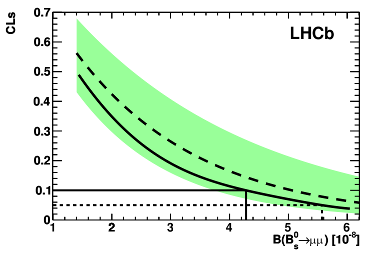
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.2\ (1.5) \cdot 10^{-8} \text{ at 90\% (95\%) C.L.}$$

Expected limit $< 1.4\ (1.8) \cdot 10^{-8}$

Limit on $B^0_s \to \mu^+\mu^-$

Observed distribution of events

Mass bin (MeV/c^2)	GL bin [0, 0.25]	[0.25, 0.5]	[0.5, 0.75]	[0.75, 1]
[−60, −40]	39	2	1	0
[−40, −20]	55	2	0	0
[−20, 0]	73	0	0	0
[0, 20]	60	0	0	0
[20, 40]	53	2	0	0
[40, 60]	55	1	0	0
Sum	335	7	1	0
Bckg exp.	329	7.36	1.51	0.081



LHCb measures with $37 pb^{-1}$ at $\sqrt{s} = 7$ TeV: [Phys. Lett. B699 (2011) 330-340]

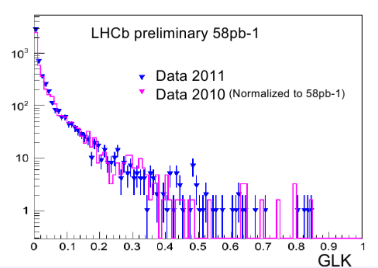
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) < 4.3\ (5.6) \cdot 10^{-8} \text{ at } 90\%\ (95\%) \text{ C.L.}$$

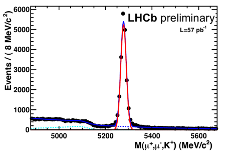
Expected limit $< 5.1\ (6.5) \cdot 10^{-8}$

Validation with 2011 data

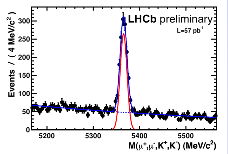
Quality of 2011 data:

- = Yields per pb^{-1} comparable to 2010
- = Resolution and signal to background unchanged
- + Use of full particle identification system
- + Improving in multivariate discriminant
- $\longrightarrow$ We will be able (at least) to extrapolate 2010 data

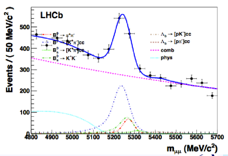




(a) $B^+ \to J/\psi K^+$



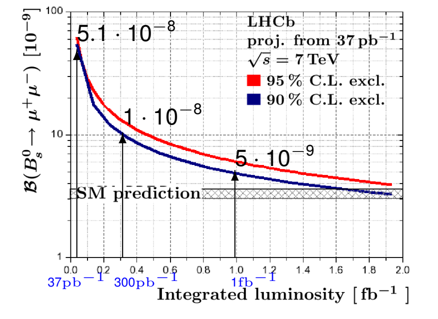
(b) $B^0_s \to J/\psi\phi$



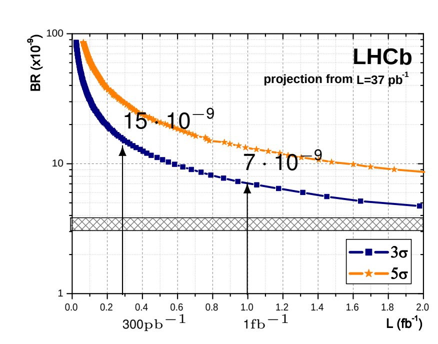
(c) $B \to h^+ h'^-$

Prospects

$B^0_s \to \mu^+\mu^-$ exclusion at 90% C.L.



$B^0_s \to \mu^+\mu^-$ discovery

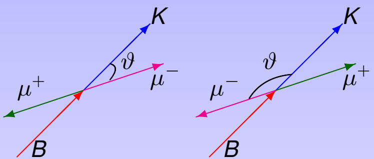


With 2011 data will explore the $\mathcal{B} \sim (5-10)10^{-9}$ range.

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

FCNC $b \to s$ transition
Angular distribution as a function of $q^2 = m_{\mu\mu}$

- Sensitive to magnetic, vector and axial vector operators
- $\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\vartheta\,\partial q^2} = \frac{3}{4}F_L\sin^2\vartheta + \frac{3}{8}(1-F_L)(1+\cos^2\vartheta) + A_{FB}\cos\vartheta$
- A_{FB} forward backward asymmetry
- F_L longitudinal polarisation



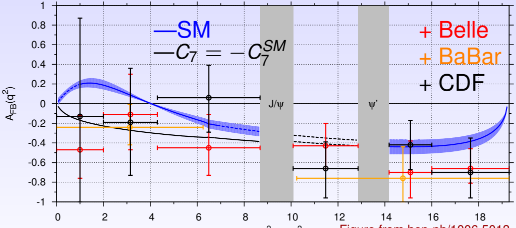
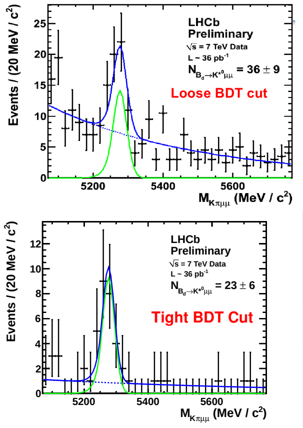


Figure from hep-ph/1006.5013

$B_d^0 \to K^* \mu^+ \mu^-$ at LHCb

Analysis strategy

- Two selections
  - Cut based
  - Multivariate (Boosted Decision Trees)
- Correct acceptance using MC
- Cross-check with $B_d^0 \to J/\psi K^*$



$B_d^0 \to K^* \mu^+ \mu^-$ observed:

- First results expected for this summer
- With 200 pb^{-1} LHCb gets competitive with CDF and B-factories
- About 1000 (600) events expected in $1 fb^{-1}$ with B/S$\sim$ 1(0.2)

Photon polarisation in $b \to s\gamma$

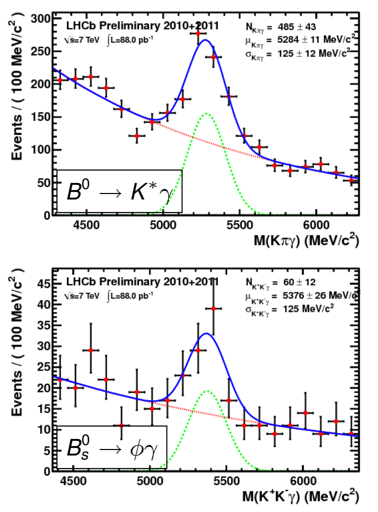
- In SM the photon comes out leftly (rightly) polarised for b ($\bar{b}$) decays.
- Wrong polarisation is proportional to $\sin\psi \approx \frac{m_s}{m_b}$
- Loops can host NP particles; branching ratio not necessarily being modified, Right-handed fermions can change the photon polarisation.
- CP asymmetry in mixing can be exploited to measure photon helicity
  $\mathcal{A}(t) = \frac{\Gamma(t)-\bar{\Gamma}(t)}{\Gamma(t)+\bar{\Gamma}(t)} \propto \sin(2\psi)$

$B^0 \longrightarrow K^*\gamma$

- Reference for others radiative decays
- Direct *CP* violation measurement

$B_s^0 \longrightarrow \phi\gamma$

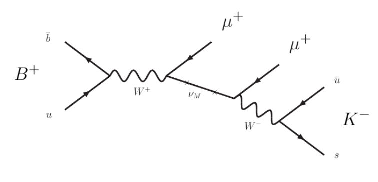
- This summer: measurement of $\frac{\mathcal{B}(B_s^0 \to \phi\gamma)}{\mathcal{B}(B^0 \to K^*\gamma)}$
- Later: time dependent decay rate



Search for $B^+ \to h^- \mu^+ \mu^+$decays

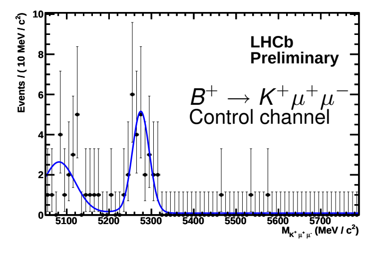
Search for $B^+ \to K^- \mu^+ \mu^+$and $B^+ \to \pi^- \mu^+ \mu^+$

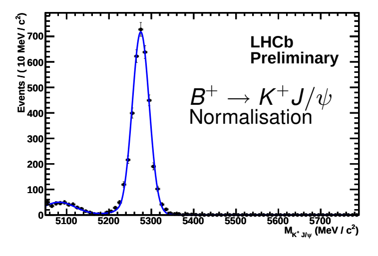
- Lepton number violation: $\Delta L = 2$
- Possible in models with Majorana neutrinos
- Main contribution: s channel with ν_M on shell



Analysis strategy:

- Tight selection tuned on opposite sign $B^+ \to K^+ \mu^+ \mu^-$
- Double blind analysis





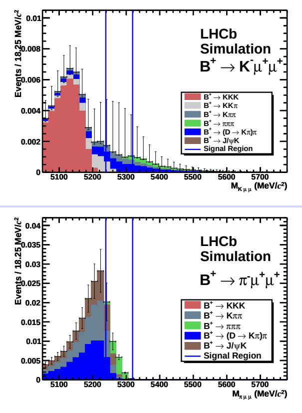
Search for $B^+ \to h^- \mu^+ \mu^+$decays

Exclusive peaking background:

- Study on MC
- PID performances from data
- All well below 0.1 events in signal region

Combinatorial background:
$< 0.5(0.4)$ events expected in mass window for $B^+ \to K^-(\pi^-)\mu^+\mu^+$

Unblinding same sign:
No events were observed in both mass sidebands and signal region.



Observed limit at 90% C.L. :

- $\mathcal{B}(B^+ \to K^- \mu^+ \mu^+) < 4.3 \cdot 10^{-8}$
- $\mathcal{B}(B^+ \to \pi^- \mu^+ \mu^+) < 4.5 \cdot 10^{-8}$

A factor 40 (30) of improvement from previous best limits at CLEO. [Phys. Rev. D 65 (2002)]

Conclusions and outlook

- Rare decays are crucial to **understand** Physics beyond SM
- LHCb with $37pb^{-1}$ has shown its potential:
  - $B^0_{d,s} \to \mu^+\mu^-$ has already competitive measurements
    $\Rightarrow$ 2011 data will explore 10^{-8} range
  - $B^0_d \to K^*\mu^+\mu^-$ measurements will be competitive very soon
  - Rare radiative channels observed, results expected soon
  - Improved limit on Lepton number violating $B^+ \to h^-\mu^+\mu^+$decays
- 2011 year will offer very interesting results on a wide range of rare processes in charm and beauty (and more...)
  $D^0 \to \mu\mu \quad D^0 \to e\mu \quad \tau \to \mu\mu\mu \quad B \to \tau\mu \quad B^0_s \to \mu\mu\gamma \quad B^+ \to K^+\mu\mu/ee$ etc...

So, even if we still can not open the *door* of New Physics,
we can look in the *keyhole* to understand whom we are waiting for!

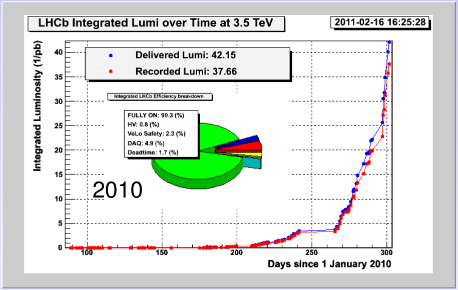
In memoriam

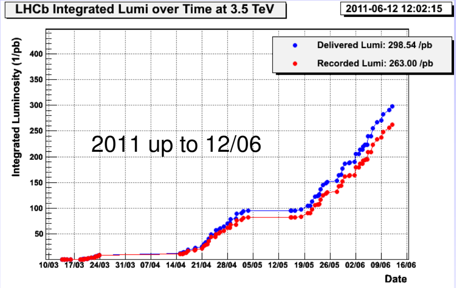
A special thought for

which was a Summer Student at CERN in 2006 like me.

Additional material

Running LHCb



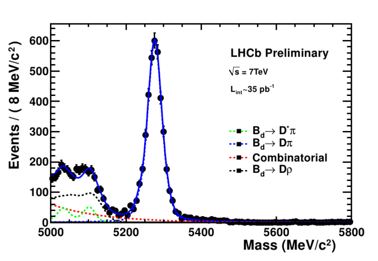


f_d/f_s at LHCb

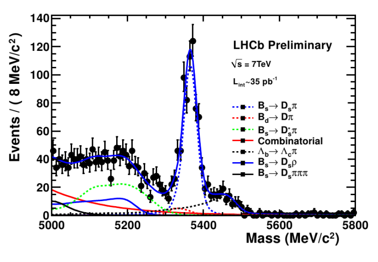
- Currently using HFAG average
  $\frac{f_{B^0}}{f_{B^0_s}} = 3.71 \pm 0.47$
- 13% of accuracy

Measurement at LHCb
Preliminary results

1. from $B^0 \to D^{\pm}K^{\mp}$,$B^0 \to D^{\pm}\pi^{\mp}$ and $B^0_s \to D_s^{\pm}\pi^{\mp}$ relative yields
   [Fleischer et al. Phys.Rev.D83-014017(2011)]
   $\frac{f_d}{f_s} = 4.02 \pm 0.52$ with 35 pb^{-1}
   [CERN-LHCb-CONF-2011-013]
2. from semileptonic decays
   $\frac{f_d}{f_s} = 3.84 \pm 0.34$ with 3 pb^{-1}



(a) $B^0 \to D^{\pm}\pi^{\mp}$



(b) $B^0_s \to D_s^{\pm}\pi^{\mp}$