Heavy flavour highlights from LHCb

A. Mauri
on the behalf of the LHCb collaboration

XXIII Epiphany conference, Krakov, 9-12 Jan. 2017
Jan. 9th, 2017
Overview

Wide research program

* Search for long living scalar particle  new!
* Search for strong CP violation  from Run2

more than 350 published paper!

link to publication list

Collected data:

1 fb\(^{-1}\) @ 7 TeV
2 fb\(^{-1}\) @ 8 TeV
2 fb\(^{-1}\) @ 13 TeV

\{ Run1, Run2 \}

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The LHCb detector

LHCb is a forward spectrometer placed at LHC

- Pseudorapidity range: $2 < \eta < 5$
- focused on the study of $b$ and $c$ decays

**VELO**
20 $\mu$m IP resolution

**TRACKING SYSTEM**
$\Delta p/p = 0.5\%$ at 20 GeV
to $0.8\%$ at 100 GeV

**CHERENKOV DETECTORS**
$\varepsilon(K \rightarrow K) \sim 95\%$
at 5% $\pi \rightarrow K$ mis-identification

**CALORIMETERS**
ECAL: $\sigma_{E/E} \sim 1\% \oplus 10\%/\sqrt{E}$ [GeV]

**MUON SYSTEM**
$\varepsilon(\mu \rightarrow \mu) \sim 95\%$
at 1-3% $\pi \rightarrow \mu$ mis-identification

excellent vertex resolution
excellent momentum resolution
excellent particle identification

![Diagram of LHCb detector](image)

[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]
Introduction

✴ Astonishing success of the SM so far!
  ✤ works beautifully up to few hundreds GeV
  ✤ must be an effective theory valid up to some scale

✴ Good reasons to believe that it is incomplete are still there:
  ✤ Missing dark matter candidate
  ✤ insufficient CP violation for the generation of a matter dominated universe

✴ We must search for:
  ✤ New sources of CP violation
  ✤ New particles, interactions, symmetries (and their breaking)
    ✤ directly produce new particles in high energy collisions
    ✤ look for indirect effects from virtual particles in precisely predicted SM processes
  ✤ explore higher mass scales than the current collider energies
Anomalies in $b\to sll$ transitions

- $b\to sll$ transition are powerful probes of New Physics
  - FCNC proceeding via loop diagrams only (“penguin” or box)
  - suppressed in the SM, more sensitive to New Physics
  - many precise SM prediction available

New particles in the loop could enhance/suppress decay rates, modify angular distributions, introduce new sources of CP violation
Anomalies in $b\to s ll$ transitions: Branching ratios

* Measured BR are consistently lower than predicted in SM

See talk by M. Pikies

A. Mauri (UZH)
Anomalies in $b\rightarrow s\mu\mu$ transitions: Angular analysis

- Study the full angular distribution of the 4 final state particles ($\cos \theta_l$, $\cos \theta_K$, $\phi$, $q^2$) in $B^0 \rightarrow K^* \mu^+ \mu^-$
- Observables are function of the Wilson coefficients

$$H_{eff} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum_i \left[ C_i (\mu) O_i (\mu) + C'_i (\mu) O'_i (\mu) \right]$$

- Clean set of variables where hadronic form factor uncertainties cancels out (e.g. $P'_5$)

$$P'_5 = \frac{S_5}{\sqrt{F_L (1 - F_L)}}$$

global fit to $B \rightarrow K^* \mu \mu$ is $3.4\sigma$ from SM

Possible explanation:
- New physics $\rightarrow \Delta \text{Re}(C_9) = -1.04 \pm 0.25$
- *charm loop effect* (unexpectedly large hadronic effect)

first try to subtract this effect on $B \rightarrow K \mu \mu$

[LHCb-PAPER-2016-045]
Lepton universality: $R(K)$

* SM implies lepton universality:
  * lepton flavours are identical to one other $\Rightarrow$ electroweak couplings are the same
  * Amplitude processes involving $e, \mu, \tau$ should be the same once the effects depending on the different mass are factorised out

* Lepton non-universality would be a clear sign of NP

\[
R(K)^{SM} = \frac{BR(B^+ \rightarrow K^+\mu^+\mu^-)}{BR(B^+ \rightarrow K^+e^+e^-)} = 1 \pm O(10^{-3})
\]

$R(K) = 0.745^{+0.090}_{-0.074} \pm 0.036$

Compatible with SM at $2.6 \sigma$

* Clear motivation to explore other LFU related ratios ($R_{K^*}, R_{\phi}, \ldots$)

See talk by M. Pikies
Lepton universality: $R(D^*)$

Tree level decays $B \rightarrow D^* \mu \nu_\mu$ and $B \rightarrow D^* \tau \nu_\tau$ are studied:

* In the SM the only difference is the mass of the lepton
* Theoretically clean prediction:

$$R(D^*)^{SM} = \frac{BR(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)}{BR(\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu)} = 0.252 \pm 0.003$$

Experimental challenges:

* Missing neutrino $\Rightarrow$ no narrow peak to fit!
* $\tau \rightarrow \mu \nu \bar{\nu}$ (BR $\sim 17\%$): muonic and tauonic modes have identical visible final state
* background from partially reconstructed B decays
R(D\(^*\)): distinguishing \(\tau\) from \(\mu\)

The separation of the signal from the normalization is achieved by exploiting:

* the \(\mu-\tau\) mass difference
* the 2 extra neutrinos

\[
\begin{array}{|c|c|}
\hline
B \rightarrow D^*\tau\nu_\tau & B \rightarrow D^*\mu\nu_\mu \\
\hline
m^2_{\text{miss}} > 0 & m^2_{\text{miss}} = 0 \\
E_\mu \text{ spectrum is soft} & E_\mu \text{ spectrum is hard} \\
m^2_\tau \leq q^2 \leq 10.6 & 0 \leq q^2 \leq 10.6 \\
\hline
\end{array}
\]

Alternately

\[
q^2 = (p_\ell + p_\nu)^2 = (m_\tau - E_\nu)^2
\]

\[\text{[PRL 115 (2015) 111803]}\]
R(D*): results

* Binned $m_{miss}^2$, $E_\mu^*$ and $q^2$ distributions are fitted using a three dimensional template (signal from MC and backgrounds from data)

\[ R(D^*) = 0.336 \pm 0.027 \pm 0.030 \]

2.1σ greater than SM

If New Physics couples more to 2\textsuperscript{nd} and 3\textsuperscript{rd} generation, we expect:

\[ R(K) < 1 \quad \text{and} \quad R(D^*) > R(D^*)_{SM} \]

**HFAG**

Latest HFAG average reports a 3.9 σ deviation

Future prospects

LHCb confirmed a pattern of flavour anomalies (firstly seen at B-factories)
* Clear motivation to explore other LFU related processes

More "penguin" decays:
* Ratios ($R_{K^*}, R_\phi, \ldots$)
* Angular analysis of $B \rightarrow K^* e^+ e^-$

More semitauonic physics:
* $R(D^*)$ with $B \rightarrow D^* \tau (\rightarrow 3\pi) \nu$
  * non-$\tau D^* 3\pi X$ is 100x larger
  * nothing is more common than this final state in a typical B decay
* $R(D^0), R(D^\pm)$
  * require careful evaluation of feed-down from $D^*$
* $R(D_s)$ with $B_s \rightarrow D_s \tau \nu$
* $R(J/\psi)$ with $B_c \rightarrow J/\psi \tau \nu$
  * clean $J/\psi \rightarrow \mu \mu$ can partially compensate for low $B_c$ production
* $R(\Lambda_c), R(\Lambda_c^\star)$
Search for a long-living scalar particle

* There is a long list of theoretical models that predict the existence of new particles that couple to the SM sector by mixing with the Higgs.

* Inflaton, axion-like, dark matter mediator models also predict the new boson to be light.

\[
\begin{pmatrix}
H \\
\chi
\end{pmatrix}
= \begin{pmatrix}
\cos \theta & -\sin \theta \\
\sin \theta & \cos \theta
\end{pmatrix}
\begin{pmatrix}
H' \\
\chi'
\end{pmatrix}
\]

* Looking for a new scalar particle decaying into muons

\[B^+ \rightarrow K^+ \chi(\rightarrow \mu^+ \mu^-)\]

more sensitive to scalar particles (K\(^+\) is scalar) than

\[B^0 \rightarrow K^{*0} \chi(\rightarrow \mu^+ \mu^-)\]

Presented here for the first time!

[This analysis [LHCb-PAPER-2016-052]

already published [PRL 115(2015)121802]
Signal properties

- Depending on coupling to the SM, we can identify two **lifetime regimes**:

  **Long lifetime:**
  - Inflaton [JHEP1005(2010)010]
  - Displaced vertex
  - Almost background free
  - Lower reconstruction efficiency

  ![Long lifetime diagram]

  ![Short lifetime diagram]

  **Short lifetime:**
  - Prompt decay
  - Contamination from SM background

  ![Short lifetime diagram]

  detector resolution 0.1÷0.2 ps
Overview of the strategy

- Unknown mass and lifetime: **2D search** \((m, \tau)\)
- Peak search in the **dimuon mass** distribution
  - step of \(\frac{1}{2}\sigma_m\)
  - signal region: \(\pm 2\sigma(m_\chi)\)
  - background region:
    - signal sideband
    - assume local-linearity
  - SM resonances must be vetoed
    - \(\phi, J/\psi, \psi(2S), \psi(3770), \psi(4160)\) vetoed!
- We define 3 bins of **time of decay**
- Upper limit set with the CLs method
  - as function of mass and lifetime

Strategy reference
[M. Williams, JINST 10 (2015) P06002]
Selection & background

- Trigger on muons
- Multivariate selection (MVA):
  - High rejection of combinatorial background
- Main background sources:
  - SM $B^+ \rightarrow K^+ \mu^+ \mu^-$
    - $O(5000)$ expected events
  - Combinatorial background
    - $O(1000)$ expected events
- B candidates selected within 50 MeV around the B mass
  - Dimuon mass resolution between 3 and 9 MeV

[Figure: LHCb simulation scaled to data]

A. Mauri (UZH)
Result: di-muon mass distribution

Zero events observed in the long decay-time region!

No statistically significant excess are observed \( \rightarrow \) we set excluded limits!
95% CL excluded BR

* We set a 95% CL upper limit as a function of the mass and lifetime
* Limits are between $2 \times 10^{-10}$ and $10^{-7}$
* Most sensitive limit for lifetime $\sim 10$ ps
  - For higher lifetimes candidates start to escape from the detector
  - Lower lifetimes are affected by higher background contamination

Up to a factor of 20 better than previous limits from $B^0 \rightarrow K^{*0} \chi (\rightarrow \mu^+ \mu^-)$

[LHCb-PAPER-2016-052]
Interpretation of the result: the inflaton model

**BR of $B$-meson into inflaton:**

$B^+ \to K^+ \chi$ is more sensitive to new scalar particle

[PRD 83, 054005 (2011)]

- We put a limit on the mixing angle as a function of the mass
- Excluded region improved and close to completely excluded the allowed parameter space

**BR of the inflaton into muons:**

$\chi_0^* \to K \to \mu^+ \mu^-$

$\chi_{1/2} \to K \to \mu^+ \mu^-$

$\chi_{3/2} \to K \to \mu^+ \mu^-$

$\chi_5 \to K \to \mu^+ \mu^-$

$\chi_{10} \to K \to \mu^+ \mu^-$

$\chi_{0} \to K \to \mu^+ \mu^-$

$\chi_{1} \to K \to \mu^+ \mu^-$

$\chi_{2} \to K \to \mu^+ \mu^-$

$\chi_{3} \to K \to \mu^+ \mu^-$

$\chi_{4} \to K \to \mu^+ \mu^-$

$\chi_{5} \to K \to \mu^+ \mu^-$

$\chi_{6} \to K \to \mu^+ \mu^-$

$\chi_{7} \to K \to \mu^+ \mu^-$

$\chi_{8} \to K \to \mu^+ \mu^-$

$\chi_{9} \to K \to \mu^+ \mu^-$

$\chi_{10} \to K \to \mu^+ \mu^-$
Strong CP problem

* The QCD lagrangian could contain a "θ term" that would give raise to CP violation in strong interactions
* No strong CP violation observed so far
* $\theta_{QCD} \lesssim 10^{-10}$ from neutron electric dipole moment (nEDM) [Atom. Nuclei 70 (2007) 349]

fine-tuning problem

The decays $\eta \rightarrow \pi^+ \pi^-$ and $\eta' \rightarrow \pi^+ \pi^-$ violate CP

* $BR(\eta^{(i)} \rightarrow \pi^+ \pi^-) < 3 \times 10^{-17}$ [PRD 52 (1995) 248]

Any larger observed BR would be sign of New Physics

Current world best limit:

* $BR(\eta \rightarrow \pi^+ \pi^-) < 1.3 \times 10^{-5}$ at 90% CL (KLOE $\phi(1020) \rightarrow \eta\gamma$) [Phys. Lett. B606 (2005) 276]
* $BR(\eta' \rightarrow \pi^+ \pi^-) < 5.5 \times 10^{-5}$ at 90% CL (BESIII $J/\psi \rightarrow \gamma\pi^+ \pi^-$) [Phys. Rev. D84 (2011) 032006]
Search strategy

* Exploit the large sample of prompt charm mesons $D^+_{(s)} \rightarrow \pi^+\pi^+\pi^-$
* Search for $\eta^{(')} \rightarrow \pi^+\pi^-$ as narrow peaks in the inclusive $\pi^+\pi^-$ mass spectra

\[
BR(\eta^{(')} \rightarrow \pi^+\pi^-) = \frac{N(\eta^{(')} \rightarrow \pi^+\pi^-)}{N(D^+_{(s)} \rightarrow \pi^+\pi^+\pi^-)} \times \frac{BR(D^+_{(s)} \rightarrow \pi^+\pi^+\pi^-)}{BR(D^+_{(s)} \rightarrow \pi^+\eta^{(')} \rightarrow \pi^+\pi^+\pi^-)} \times \frac{1}{\varepsilon(\eta^{(')})}
\]

Observed $\eta^{(')} \rightarrow \pi^+\pi^-$ candidates

Total number of $D^+_{(s)}$ meson reconstructed in the $\pi^+\pi^+\pi^-$ final state

from PDG

small correction to the efficiency as function of the $\pi^+\pi^-$ mass

$\varepsilon(\eta) = 0.85 \pm 0.01$

$\varepsilon(\eta^{(')} = 1.01 \pm 0.01$

$D_{(s)}^+$ yields

**Dataset:**

- 3.0 fb$^{-1}$ in Run 1
- 0.3 fb$^{-1}$ in Run 2

*yields after selection*

**$D^+$**

- 1.88 x 10$^7$
- 6.09 x 10$^6$

**$D_s^+$**

- 1.75 x 10$^7$
- 6.26 x 10$^6$

- Larger cross section
- Higher trigger efficiency

**Discontinuity due to two different trigger streams**


Selection and signal ranges optimization based on the maximization of 

$$f.o.m. = \frac{N_s}{\sqrt{N_s + N_b}}$$

A. Mauri (UZH)
For each \( \eta \) and \( \eta' \) there are four separate spectra:

* Each spectrum is fitted with:
  * 4th order polynomial for the background shape
  * double Gaussian for the signal shape

Total sum of \( D^+, D_s^+ \), Run1 and Run2:

All fitted \( \eta^{(i)} \) yield are compatible with zero

Limits set at 90% CL:

* \( BR(\eta \rightarrow \pi^+\pi^-) < 1.6 \times 10^{-5} \) comparable to the existing limit
* \( BR(\eta' \rightarrow \pi^+\pi^-) < 1.8 \times 10^{-5} \) 3 times better than the current limit!
Conclusion (I)

New physics must be out there and **flavour physics is a promising sector**

- **Some tensions** are appearing in different $b \to sll$ channels
  - potentially interpretable in coherent way as New Physics and/or induced by QCD effects
- This pattern is coherent with LFU $R(K)$ measurement
  - insensitive to QCD effects.
- $R(D^*)$ marks the beginning of a vast exploration in several semileptonic channels
  - $B \to D^*\tau\nu_\tau$ was the first measurement of a $b \to c\tau\nu$ decay at a hadron collider
- Fundamental to study new channels

Two searches have been presented:

1. A search for an hypothetical new scalar particle in the decay $B^+ \to K^+ \chi (\to \mu^+\mu^-)$
   - Upper limit set on $\mathcal{B}(B^+ \to K^+ \chi) \times \mathcal{B}(\chi \to \mu^+\mu^-)$ between $2 \times 10^{-10}$ and $10^{-7}$ as function of mass and lifetime
   - Limits superseed previous search
   - Interpretation of the result in term of the inflaton model
     - We almost excluded the allowed parameter space for a light inflaton
2. A search for the strong CP violating decay $\eta \to \pi^+\pi^-$ and $\eta' \to \pi^+\pi^-$
   - Upper limits competitive or stronger than current limit
But there is much more: **LHCb has an incredibly broad physics case!**

1. **CP violation:**
   - CP-violating phase $\phi_s$ from $b \to ccs$ transitions
   - $B_s - \bar{B}_s$ mixing

2. **CKM measurements**
   - $\gamma$ combination

3. **Rare decays**
   - $B_s \to \mu^+\mu^-$

4. **Charm physics**
   - CPV
   - Rare decays (best limit on $D^0 \to \mu^+\mu^-$: $\text{BR} < 10^{-8}$)

5. **Spectroscopy**

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**See talk by V. Batozskaya**
backup
\( B \rightarrow K^*\mu\mu \) **ANGULAR ANALYSIS**

Study the full angular distribution \((\theta_l, \theta_K, \phi)\) of the 4 final state particles.

Described by eight independent observables:

\[
\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^4(\Gamma + \bar{\Gamma})}{dq^2 d\Omega} = \frac{9}{32\pi} \left[ \frac{3}{4} (1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right. \\
+ \frac{1}{4} (1 - F_L) \sin^2 \theta_K \cos 2\theta_l \\
- F_L \cos^2 \theta_K \cos 2\theta_l + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi \\
+ S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + S_5 \sin 2\theta_K \sin \theta_l \cos \phi \\
+ \frac{4}{3} A_{FB} \sin^2 \theta_K \cos \theta_l + S_7 \sin 2\theta_K \sin \theta_l \sin \phi \\
+ S_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi \left. \right] .
\]

Observables \((A_{FB}, F_L, S_j)\) are function of the Wilson coefficients.

A cleaner set of observables, where hadronic form factor uncertainties cancels at the leading order, can be defined (\textit{JHEP 1305(2013)137}), ex:

\[
P_5' \equiv \frac{S_5}{\sqrt{F_L (1 - F_L)}}
\]
R(D*)

Most discriminating kinetic variables are:

* muon energy
* missing mass squared \( m_{miss}^2 = (p_B^\mu - p_D^\mu - p_\mu^\mu)^2 \)
* squared four-momentum transfer to the leptons \( q^2 = (p_B^\mu - p_D^\mu)^2 \)

computed in the B rest frame.
**Why at LHCb?**

- **Main production via B meson:**
  - if \( \chi \) mixes with the Higgs and it is light enough
    \[
    \Gamma(K \rightarrow \pi\chi) \propto (m_t^2 \vert V_{ts}^*V_{td} \vert)^2 \propto m_t^4\lambda^5
    \]
    \[
    \Gamma(D \rightarrow \pi\chi) \propto (m_b^2 \vert V_{cb}^*V_{ub} \vert)^2 \propto m_b^4\lambda^5
    \]
    \[
    \Gamma(B \rightarrow K\chi) \propto (m_t^2 \vert V_{ts}^*V_{tb} \vert)^2 \propto m_t^4\lambda^2
    \]
  - \( b \rightarrow s \) transitions are the favourite mode

- **Looking for a new scalar particle decaying into muons**
  - more sensitive to scalar particles (\( K^+ \) is scalar) than
    \[
    B^+ \rightarrow K^+\chi(\rightarrow \mu^+\mu^-)
    \]
  - already published
    [PRL 115(2015)121802]

- **\( \mathcal{B}(\chi \rightarrow \mu^+\mu^-) \):**
  - dominant till the hadronic threshold (\( \chi \rightarrow 2h, \chi \rightarrow 3h \))
  - always significant \( \mathcal{O}(10^{-2}) \) in the full mass range

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**A. Mauri (UZH)**
Background

1. SM di-muon resonances
   - φ, J/ψ, ψ(2S), ψ(3770), ψ(4160): vetoed!

2. SM $B^+ \rightarrow K^+ \mu^+ \mu^-$
   - Irreducible, same final state and topology
   - Prompt!
   - $O(5k)$ events

3. Combinatorial background
   - Can be displaced!

4. Background from $B^+ \rightarrow D^0 X$
   - $D^0 \rightarrow K\pi \rightarrow$ removed with additional PID requirement
   - $D^0 \rightarrow \pi^+\pi^-, K^+K^- \rightarrow$ negligible

5. Other B decays
   - $B^+ \rightarrow 3h (K^+K^-K^+, K^+K^-\pi^+, K^+\pi^-\pi^+, \pi^+\pi^-\pi^+)$
   - $B^+ \rightarrow \pi^+\mu^+\mu^-$
   - $B^0 \rightarrow K^*\mu^+\mu^-$

6. $\Lambda \rightarrow p\pi, K^0_S \rightarrow \pi^+\pi^-$: vetoed!
## Background summary

<table>
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<tbody>
<tr>
<td>$\phi \rightarrow \mu^+ \mu^-$</td>
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<tr>
<td>$J/\psi \rightarrow \mu^+ \mu^-$</td>
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<tr>
<td>$\psi(2S), \psi(3770) \rightarrow \mu^+ \mu^-$</td>
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<tr>
<td>$\psi(4160) \rightarrow \mu^+ \mu^-$</td>
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<tr>
<td>$J/\psi \rightarrow \mu^+ \mu^-$ with $K^+ \leftrightarrow \mu^+$ swap</td>
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<tr>
<td>$B^+ \rightarrow D^0(\rightarrow K\pi)X$</td>
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<tr>
<td>$K^0_S \rightarrow \pi^+ \pi^-$</td>
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<td>$\Lambda^0 \rightarrow p\pi$</td>
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<td>$m_{\mu^+ \mu^-}$</td>
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<td>$m_{(K\mu\leftrightarrow\mu\mu)}$</td>
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<td>$m_{(\mu\mu\leftrightarrow K\pi)}$</td>
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<td>[1090, 1120]</td>
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<tr>
<td>vetoed-1\textsuperscript{st} bin</td>
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<tr>
<td>isMuon($K^+$)=0</td>
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<tr>
<td>ProbNNmu($\mu$) &gt; 0.4</td>
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<tr>
<td>vetoed</td>
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<td>vetoed</td>
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</table>
Decay-time binning

* 3 bins of time of decay:
  * 1\textsuperscript{st} bin:
    * \textbf{prompt}: \(|t| < 1\) ps
      * Contain all the \(B^+ \rightarrow K^+ \mu^+ \mu^-\) events
      * \(O(5000)\) expected events
  * 2\textsuperscript{nd} bin:
    * \textbf{displaced} di-muon candidates: \(1 < t < 10\) ps
      * low (combinatorial) background
      * \(O(1000)\) expected events
  * 3\textsuperscript{rd} bin:
    * \textbf{“zero background”} search: \(t > 10\) ps
      * \(O(1)\) expected event

* Bins combined afterwards into a single Likelihood \(\mathcal{L} = \prod_{\text{bins}} \mathcal{L}_i\)

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A. Mauri (UZH) - VRD meeting
Inflaton model

Interpretation of the result in the inflaton model.

* Branching ratio of the inflaton into muons:
  * between 1 and ~1%

* Lifetime:
  * varies of several order of magnitude
  * scale as $\tau \propto \frac{1}{\theta^2}$

[Bezrukov, Light inflaton after LHC8 and WMAP9 results, JHEP 07 (2013) 140]
Systematics

* Sources:
  - signal resolution
  - signal efficiency (MC size)
  - background mass-shape mis-modelling
  - Normalization branching ratio

* The impact of these uncertainties on the excluded limit is found to be minimal (on average it is enhanced by only 2%).

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<th>Source</th>
<th>Uncertainty</th>
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<td>Signal resolution</td>
<td>(1.5 ÷ 2)%</td>
</tr>
<tr>
<td>MC size</td>
<td>(2 ÷ 6)%</td>
</tr>
<tr>
<td>MC lifetime reweighting</td>
<td>(0 ÷ 0.08% ± 0.20)%</td>
</tr>
<tr>
<td>Background mass shape mismodelling</td>
<td>0.08 × stat. err.</td>
</tr>
<tr>
<td>Normalization branching ratio</td>
<td>3 %</td>
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