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Heavy flavour highlights from LHCb

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on the behalf of the LHCb collaboration

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Overview

Wide research program

more than 350
published paper!

[link to publication list](#)

Collected data:

$1 \text{ fb}^{-1} @ 7 \text{ TeV}$ } Run1
 $2 \text{ fb}^{-1} @ 8 \text{ TeV}$ }
 $2 \text{ fb}^{-1} @ 13 \text{ TeV}$ Run2

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

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

TRACKING SYSTEM

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

VELO
20 μm IP resolution

MUON SYSTEM

$\epsilon(\mu \rightarrow \mu) \sim 95\%$
at 1-3% $\pi \rightarrow \mu$ mis-identification

excellent vertex resolution
excellent momentum resolution
excellent particle identification !

CHERENKOV DETECTORS

$\epsilon(K \rightarrow K) \sim 95\%$
at 5% $\pi \rightarrow K$ mis-identification

CALORIMETERS

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

[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 $b \rightarrow s \ell \ell$ transitions

- * $b \rightarrow s \ell \ell$ transitions 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 predictions available

New particles in the loop could enhance/suppress decay rates, modify angular distributions, introduce new sources of CP violation

Anomalies in $b \rightarrow s \ell \ell$ transitions: Branching ratios

- * Measured BR are consistently lower than predicted in SM

See talk by
M. Piques

[JHEP 06 (2014) 133]

[JHEP 09 (2015) 179]

[JHEP 06 (2015) 115]

Anomalies in $b \rightarrow s$ 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

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

- ❖ 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 3.4σ from SM $\longrightarrow$

Possible explanation:

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

arxiv:1510.04239
arxiv:1503.06199

arxiv:1406.0566
arxiv:1512.07157

$\longrightarrow$ first try to subtract this effect on $B \rightarrow K \mu \mu$
[LHCb-PAPER-2016-045]

[JHEP 02 (2016) 104]

[arxiv:1503.06199]

Lepton universality: $R(K)$

See talk by
M. Piques

- * SM implies lepton universality:
 - ❖ lepton flavours are identical to one other → electroweak couplings are the same
 - ❖ Amplitude processes involving e , μ , τ 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

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

PRL 111 (2013) 162002

taking the ratio cancels
most uncertainties in
QCD transitions

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

PRL 113 (2014) 151601

Compatible with SM at 2.6σ

[PRL 103 (2009) 171801]
[PRD 86 (2012) 032012]

- * Clear motivation to explore other LFU related ratios (R_{K^*} , R_ϕ , ...)

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:

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

PRD 85 (2012) 094025

Experimental challenges:

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

R(D^{*}): distinguishing τ from μ

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

- * the μ - τ mass difference
- * the 2 extra neutrinos

$B \rightarrow D^* \tau \nu_\tau$	$B \rightarrow D^* \mu \nu_\mu$
$m_{miss}^2 > 0$	$m_{miss}^2 = 0$
E_μ spectrum is soft	E_μ spectrum is hard
$m_\tau^2 \leq q^2 \leq 10.6$	$0 \leq q^2 \leq 10.6$

[PRL 115 (2015) 111803]

R(D*): results

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

Projection of the fit model in one of the four q^2 bins

PRL 115 (2015) 111803

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

2.1 σ greater than SM

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

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

Latest HFAG average reports a **3.9 σ deviation**

<http://www.slac.stanford.edu/xorg/hfag/>

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_ϕ , ...)
- * Angular analysis of $B \rightarrow K^* e^+ e^-$

More semitauonic physics:

- * $R(D^*)$ with $B \rightarrow D^* \tau (\rightarrow 3\pi) \nu$
 - ✧ non- τ $D^* 3\pi X$ is 100x larger
 - ✧ nothing is more common than this final state in a typical B decay
- * $R(D^0)$, $R(D^+)$
 - ✧ 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
- * $R(\Lambda_c)$, $R(\Lambda_c^*)$

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](#)

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

Presented here
for the first time!

- * Looking for a new scalar particle decaying into muons

this analysis

[LHCb-PAPER-2016-052]

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

already published
[PRL 115(2015)121802]

Signal properties

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

detector resolution
 $0.1 \div 0.2$ ps

Long lifetime:

- ❖ Inflaton [JHEP1005(2010)010]
- ❖ Displaced vertex
- ❖ Almost background free
- ❖ Lower reconstruction efficiency

Short lifetime:

- ❖ Dark matter mediator [Phys.Lett.B727(2013)]
- ❖ Axion-like [Phys.Rev.D81(2010)034001]
- ❖ Prompt decay
- ❖ Contamination from SM background

Overview of the strategy

- * Unknown mass and lifetime: **2D search** (m, τ)
- * 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 $B^+ \rightarrow K^+ \mu^+ \mu^-$ $\longrightarrow$ *prompt* affect only the *low decay-time*
 - ♦ $O(5000)$ expected events
 - ❖ combinatorial background $\longrightarrow$ can be *displaced*
 - ♦ $O(1000)$ expected events
- * B candidates selected within 50 MeV around the B mass
- ❖ dimuon mass resolution between 3 and 9 MeV

[LHCb-PAPER-2016-052]

Result: di-muon mass distribution

Zero events observed in the long decay-time region!

No statistically significant excess are observed → 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 2×10^{-10} and 10^{-7}
- * Most sensitive limit for lifetime ~ 10 ps
 - ♣ For higher lifetimes candidates start to escape from the detector
 - ♣ Lower lifetimes are affected by higher background contamination

[LHCb-PAPER-2016-052]

Interpretation of the result: the inflaton model

BR of B -meson into inflaton:

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

H ——— χ

- * 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:

small lifetime

Search for strong CP violation

Strong CP problem

One of the first
results by LHCb
from Run 2

- * The QCD lagrangian could contain a " θ term" that would give rise 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

- * $BR(\eta^{(\prime)} \rightarrow \pi^+ \pi^-) < 3 \times 10^{-17}$ 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 $\eta^{(\prime)} \rightarrow \pi^+ \pi^-$ as narrow peaks in the inclusive $\pi^+ \pi^-$ mass spectra

$$BR(\eta^{(\prime)} \rightarrow \pi^+ \pi^-) = \frac{N(\eta^{(\prime)})}{N(D_{(s)}^+)} \times \frac{BR(D_{(s)}^+ \rightarrow \pi^+ \pi^+ \pi^-)}{BR(D_{(s)}^+ \rightarrow \pi^+ \eta^{(\prime)})} \times \frac{1}{\varepsilon(\eta^{(\prime)})}$$

from PDG

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

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

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

$\varepsilon(\eta) = 0.85 \pm 0.01$
 $\varepsilon(\eta') = 1.01 \pm 0.01$

[Phys. Lett. B764 (2016) 233]

$D_{(s)}^+$ yields

Dataset:

			D^+	D_s^+
* 3.0 fb ⁻¹ in Run 1		yields after selection	1.88×10^7	1.75×10^7
* 0.3 fb ⁻¹ in Run 2	→ 3.3 larger yield per fb ⁻¹		6.09×10^6	6.26×10^6
		✦ larger cross section		
		✦ higher trigger efficiency

Selection and signal ranges optimization based on the maximization of $f.o.m. = \frac{N_s}{\sqrt{N_s + N_b}}$

Fit to the $\pi^+\pi^-$ -mass spectra & limits

For each η and η' 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 Run 2:

All fitted $\eta^{(\prime)}$ 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 $b \rightarrow s \ell \ell$ 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
 - ✦ $B \rightarrow D^* \tau \nu_\tau$ was the first measurement of a $b \rightarrow c \tau \nu$ 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 $B^+ \rightarrow K^+ \chi (\rightarrow \mu^+ \mu^-)$
 - ❖ Upper limit set on $\mathcal{B}(B^+ \rightarrow K^+ \chi) \times \mathcal{B}(\chi \rightarrow \mu^+ \mu^-)$ between 2×10^{-10} and 10^{-7} as function of mass and lifetime
 - ✦ Limits supersede 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 $\eta \rightarrow \pi^+ \pi^-$ and $\eta' \rightarrow \pi^+ \pi^-$
 - ❖ Upper limits competitive or stronger than current limit

Conclusion (II)

But there is much more: **LHCb has an incredibly broad physics case!**

1. CP violation:

- ❖ CP-violating phase ϕ_s from $b \rightarrow ccs$ transitions
- ❖ B_s - $\bar{B}_s$ mixing

See talk by V. Batozskaya

2. CKM measurements

- ❖ γ combination

3. Rare decays

- ❖ $B_s \rightarrow \mu^+ \mu^-$

4. Charm physics

- ❖ CPV
- ❖ Rare decays (best limit on $D^0 \rightarrow \mu^+ \mu^-$: BR < 10⁻⁸)

5. Spectroscopy

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:

$$\frac{1}{d(\Gamma + \bar{\Gamma})/dq^2} \frac{d^4(\Gamma + \bar{\Gamma})}{dq^2 d\vec{\Omega}} = \frac{9}{32\pi} \left[\frac{3}{4}(1 - F_L) \sin^2 \theta_K + F_L \cos^2 \theta_K \right.$$

$$\begin{aligned} &+ \frac{1}{4}(1 - F_L) \sin^2 \theta_K \cos 2\theta_l \\ &- F_L \cos^2 \theta_K \cos 2\theta_l + S_3 \sin^2 \theta_K \sin^2 \theta_l \cos 2\phi \\ &+ S_4 \sin 2\theta_K \sin 2\theta_l \cos \phi + S_5 \sin 2\theta_K \sin \theta_l \cos \phi \\ &+ \frac{4}{3} A_{FB} \sin^2 \theta_K \cos \theta_l + S_7 \sin 2\theta_K \sin \theta_l \sin \phi \\ &+ S_8 \sin 2\theta_K \sin 2\theta_l \sin \phi + S_9 \sin^2 \theta_K \sin^2 \theta_l \sin 2\phi \end{aligned} \Bigg].$$

Observables (A_{FB} , F_L and 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 (*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 χ mixes with the Higgs and it is light enough

$$\Gamma(K \rightarrow \pi\chi) \propto (m_t^2 |V_{ts}^* V_{td}|)^2 \propto m_t^4 \lambda^5$$

$$\Gamma(D \rightarrow \pi\chi) \propto (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$$

$$\Gamma(B \rightarrow K\chi) \propto (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2 \longrightarrow b \rightarrow s \text{ transitions are the favourite mode}$$

- * Looking for a new scalar particle decaying into muons

$$B^+ \rightarrow K^+ \chi (\rightarrow \mu^+ \mu^-) \xrightarrow{\text{more sensitive to scalar particles (K}^+ \text{ is scalar) than}} B^0 \rightarrow K^{*0} \chi (\rightarrow \mu^+ \mu^-)$$

this analysis
[LHCb-Paper-2016-052]

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 $O(10^{-2})$ in the full mass range

Background

1. SM di-muon resonances

- ❖ $\phi, J/\psi, \psi(2S), \psi(3770), \psi(4160)$: **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

- ❖ $B^+ \rightarrow 3h (K^+ K^- K^+, K^+ K^- \pi^+, K^+ \pi^- \pi^+, \pi^+ \pi^- \pi^+)$
 - ❖ $B^+ \rightarrow \pi^+ \mu^+ \mu^-$
 - ❖ $B^0 \rightarrow K^* \mu^+ \mu^-$
-] negligible

6. $\Lambda \rightarrow p\pi, K_S^0 \rightarrow \pi^+ \pi^-$: **vetoed!**

Background summary

Background	Variable	Mass region (MeV/ c^2)	Cut
$\phi \rightarrow \mu^+ \mu^-$	$m_{\mu^+ \mu^-}$	[985, 1055]	vetoed-1 st bin
$J/\psi \rightarrow \mu^+ \mu^-$	$m_{\mu^+ \mu^-}$	[2946, 3176]	vetoed
$\psi(2S), \psi(3770) \rightarrow \mu^+ \mu^-$	$m_{\mu^+ \mu^-}$	[3586, 3850]	vetoed
$\psi(4160) \rightarrow \mu^+ \mu^-$	$m_{\mu^+ \mu^-}$	[4103, 4270]	vetoed-1 st bin
$J/\psi \rightarrow \mu^+ \mu^-$ with $K^+ \leftrightarrow \mu^+$ swap	$m_{(K\mu \leftrightarrow \mu\mu)}$	[3000, 3200]	isMuon(K^+)=0
$B^+ \rightarrow D^0(\rightarrow K\pi)X$	$m_{(\mu\mu \leftrightarrow K\pi)}$	[1840, 1890]	ProbNNmu(μ) > 0.4
$K_S^0 \rightarrow \pi^+ \pi^-$	$m_{(\mu\mu \leftrightarrow \pi\pi)}$	[443, 523]	vetoed
$\Lambda^0 \rightarrow p\pi$	$m_{(\mu\mu \leftrightarrow p\pi)}$	[1090, 1120]	vetoed

Decay-time binning

* 3 bins of time of decay:

❖ 1st bin:

♦ **prompt:** $|t| < 1 \text{ ps}$

- ▶ Contain all the $B^+ \rightarrow K^+ \mu^+ \mu^-$ events
- ▶ O(5000) expected events

❖ 2nd bin:

♦ **displaced** di-muon candidates: $1 < t < 10 \text{ ps}$

- ▶ low (combinatorial) background
- ▶ O(1000) expected events

❖ 3rd bin:

♦ **“zero background”** search: $t > 10 \text{ ps}$

- ▶ O(1) expected event

High background
&
high efficiency

Sensitive to
short lifetime

Low background
&
low efficiency

Sensitive to
long lifetime

events start to
escape from
the detector

detector resolution
 $\sim 0.2 \text{ ps}$

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

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]

- * 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 %).

Source	Uncertainty
Signal resolution	$(1.5 \div 2)\%$
MC size	$(2 \div 6)\%$
MC lifetime reweighting	$(0 \div {}^{+0}_{-20})\%$
Background mass shape mismodelling	$0.08 \times \text{stat. err.}$
Normalization branching ratio	3 %