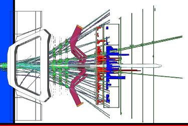
B decays into τ lepton pairs and related rare transitions

Giampiero Mancinelli, Justine Serrano
Centre de Physique des Particules de Marseille
Jérôme Charles
Centre de Physique Théorique



Introduction

τ leptons offer a unique window to new observables and phenomena:

- its sizable mass allows to test both right-handed and left-handed couplings
- its decay into measurable products leads to a variety of angular observables, that are related to the couplings to the τ spin
- the comparison of a transition with τ leptons with its counterpart with muons or electrons allows stringent tests of lepton universality, which is a signature of the SM.

After **$B_{(s)} \to \mu\mu$, $B \to K^*\mu\mu$** it becomes crucial for LHCb to explore other B decays involving τ leptons, which have different sensitivities to NP, theoretical uncertainties, and experimental effects.

$B \to K^* \tau\tau$ is mediated by loop **FCNC** diagrams in the SM and is **not yet measured** as $B \to K^* ll$ ($l=e,\mu,\tau$) → dimensionless observables as ratios of matrix elements with dependence on hadronic form factors strongly suppressed

Only measure: BABAR arXiv:hep-ex/0511015 - $BR(B_d \to \tau^+\tau^-) < 4.1 \times 10^{-3}$ @ 90%CL

$B \to K^*\tau^+\tau^-$ decay not yet been seen: BR expected $(O)10^{-7}$

The experimental status

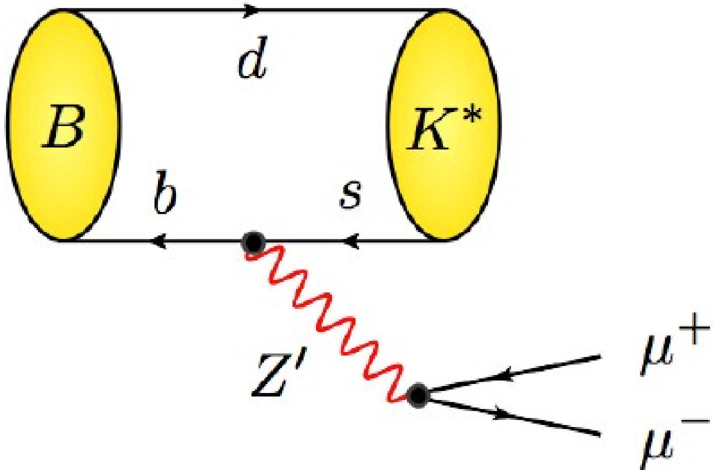
B → τν is the simplest B decay from the hadronic point of view
measured by BABAR and Belle at a higher level than the SM prediction,
however a more recent and precise measurement by Belle proved to be in agreement with the pure SM prediction

For **B → D * τν** decays, BABAR and Belle have measured the ratio of the τ modes with respect to their μ/e counterparts to be significantly larger than the SM predictions - This kind of effect could be also seen in the B→(X)tautau decays

The large like-sign di-muon asymmetry observed by the D0 Collaboration (disproved by LHCb?) can be explained by a large $B_s \to \tau^+\tau^-$ BR

The anomaly observed in the P'_5 observable of the **B→K*μμ** decay by LHCb can be explained by the Z' existence

Existence of NP containing an additional neutral gauge boson (Z') with flavour changing quark couplings have been largely discussed in recent literature. In these models, the branching ratio of $\mathbf{B_s \to \tau^+\tau^-}$ **could be dramatically enhanced, up to the percent level.**



Experimental challenges

Reconstructing tau decays at LHCb is very challenging because of the non detectable neutrinos in the final state

No results involving tau hadronic decays have been made public by the collaboration yet, but extensive studies are going on, and results are expected in the coming months.

The CPPM group joined this effort searching for the rare decay $\mathbf{B_s \to \tau^+\tau^-}$.

The presence of the K* should make the signal reconstruction easier as it allows to locate the B decay vertex.

Difficulty (e.g. for $\mathbf{B_s \to \tau^+\tau^-}$) is the presence of:

a huge combinatorial background

many exclusive partially reconstructed backgrounds (physics bg)

data-driven analysis complicated (no perfect control regions)

We tested many strategies (1-2 dimentional fits), multivariate analyses, different ways to deal with control samples (same sign), or control regions (dalitz plane...), with and without MC inpout

Topological inclusive vertexing

The CPPM group is developing an **inclusive event vertexing algorithm**, based on a technique developed in SLD (called ZVTOP)

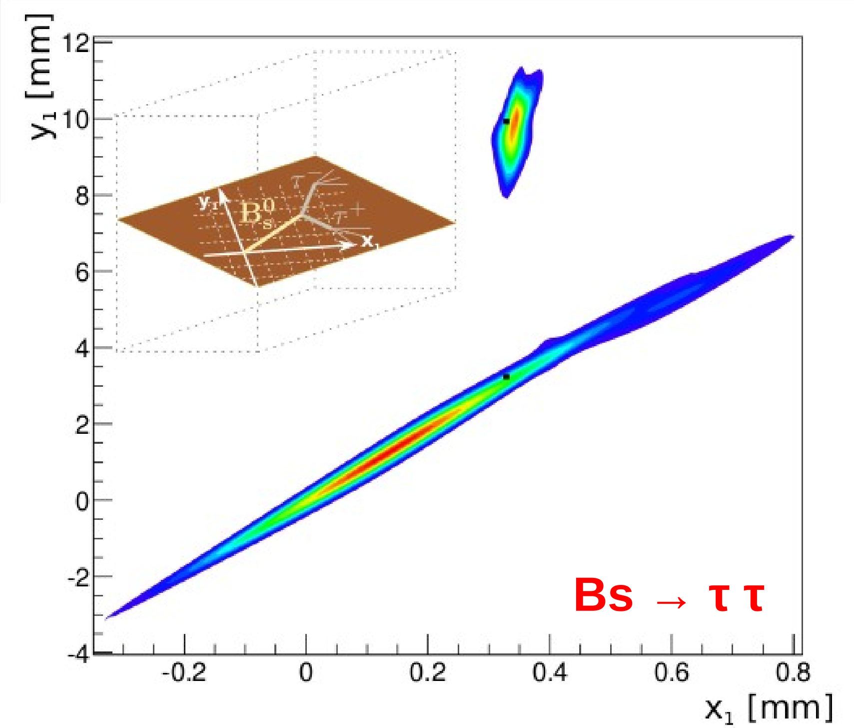
reconstruct vertexes with a global function taking a list of tracks as input and

returning a probability to have a vertex at each point.

This alternative aims at reconstructing efficiently signal candidates as well as defining powerful variables (as B or tau or track isolation degrees) able to reject combinatorial and physical backgrounds

Application is already underway in the **$B_{(s)} \rightarrow \mu\mu$** improved analysis

Application in ***b-tagging*** and in the **reconstruction of exotics** is foreseen



Phenomenological inputs

In the construction of **best discriminating variables**

e.g. τ reconstruction using the hadronic decay $\tau \rightarrow \pi\pi\pi\nu$ has been performed by a PhD student in the Lausanne group. She investigated the possibility to reconstruct the Bs determining the B and τ momenta from the measurable quantities of the event. The system leads to a 8th order polynomial equation to be solved, for which finding the true solution is a highly non trivial task. This work was not pursued further. Alessandro Mordá, together with Jerome, has already devised a method to reduce the relevant equation to one of order 4, which can be analytically solved, without loss of information.

In the **identification of possible physics background** sources

In the construction of the **best observables,** beyond the branching ratio itself, that can be extracted once a sufficiently large number of events has been accumulated.

NOTE: The finite τ mass introduces new form factors and new non trivial angular observables wrt lighter leptons.

Finally in the **interpretation of the actual and/or prospective data**

Use of **CKMfitter** project, a powerful modular analysis framework dedicated to the flavor sector of the SM and various generic NP scenarios

The collaboration

Collaborative aspects of the project are numerous.

The **skills** of the two involved teams are **complementary**

CPPM:

expertise on the measurement of rare decays at CPPM (first evidence for $B_s \to \mu\mu$ differential branching fraction and angular analysis of the $B \to K^*\mu\mu$ decay)

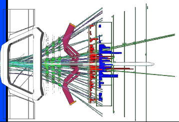
CPT

expertise on phenomenological data interpretation at CPT (the first basis for the theoretical calculation of heavy-to-light decays such as $B \to K^* \tau \tau$ + rebuilding of the CKMfitter software

Already collaborating with the co-direction of Alessandro Mordà's OCEVU PhD thesis

The postdoctoral project is a natural extension of AM's thesis,

- the tools currently under development to reconstruct τ leptons in LHCb
- phenomenologically $B_s \to \tau \tau$ and $B \to K^* \tau \tau$ would receive similar contributions from non standard couplings if a NP scenario proves to hold in nature.



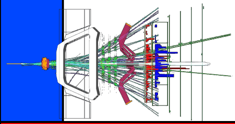
The people/budget involved

Name	Position[1]	Laboratory
Andrey Tayduganov	PD	CPPM/CPT
Alessandro Mordá	PhD	CPPM/CPT
Giampiero Mancinelli	DR	CPPM
Justine Serrano	CR	CPPM
Julien Cogan	CR	CPPM
Jérôme Charles	CR	CPT
Sebastien Descotes-Genon	DR	LPT-Orsay

[1] (PR, DR, MCF, CR, PhD, PD=postdoc,…)

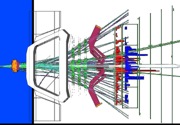
Andrey just arrived Nov 3rd

Amounts in €	Total budget needed	Funding already acquired	Requested from OCEVU			
			2014	2015	2016	>2017
Equipment[1]						
Computing[1]						
Travel expenses[2]						
Colloquia[3]	3000				1000	2000
Operating budget						
TOTAL	3000					



Tasks (more or less...)

Name	Nature of the contribution to the project
Giampiero Mancinelli	• analysis chain implementation and supervision • isolation tools • development of the ZVTOP inclusive vertexing algorithm
Justine Serrano	• τ-related analysis tools • fit, toy studies, and limits • adapt the $B \rightarrow K^*ll$ (l=e, mu) analysis tool to the tau case
Alessandro Mordà	• τ-related analysis tools • Isolation tools • improve $B_s \rightarrow \tau\tau$ analysis @ LCHb in collaboration with the postdoctoral fellow
Julien Cogan	• τ-related analysis tools with ZPTOP • background characterization • control samples
Jérôme Charles	• coordinate the construction of the best $B \rightarrow K^* \tau\tau$ observables and their implementation in CKMfitter • theoretical/phenomenological analysis scenarios
Andrey Tayduganov	• improve $B_s \rightarrow \tau\tau$ analysis @ LCHb • $B_s \rightarrow K^* \tau\tau$ analysis strategy • theoretical/phenomenological analysis scenarios
Sébastien Descotes-Genon	• correlations of the $B \rightarrow K^* \tau\tau$ observables with other similar transitions in specific CKMfitter scenarios



Expected results, perspectives

The first expected important result of the project is

- the **feasibility demonstration of the measurement of $B \to K^* \tau\tau$ at LHCb**
  - (MC signal production is already completed)
- first results based on real data concerning the **branching fraction** measurement are expected during the course of the project.

If the signal statistics is large enough, angular observables can be also studied on data. Otherwise, prospective studies for the LHCb upgrade will be performed.

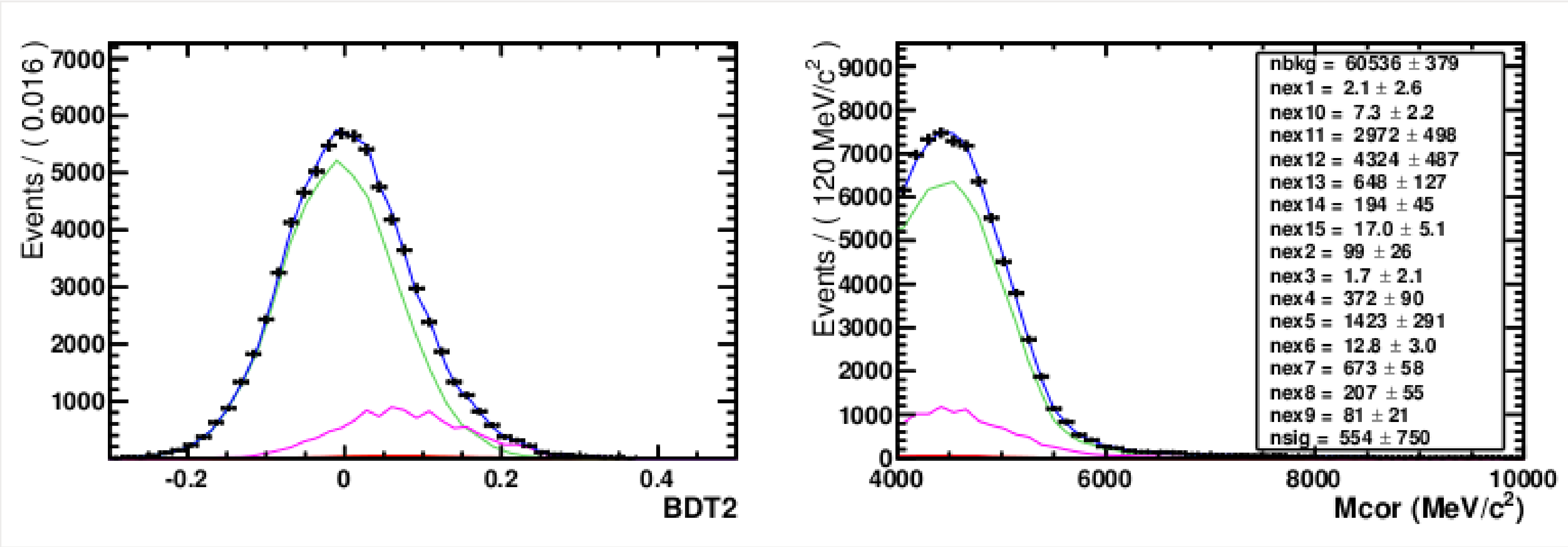
LHCb is the **only experiment** which will be able to perform this kind of measurements in the coming 20 years

- The future B-factory Belle II in Japan will not have a sufficient amount of Bs
- The general purpose experiments at the LHC do not have a dedicated trigger
- The branching ratio measurement of $B_s \to \tau\tau$ is however mentioned in the physics case of the TLEP collider project under study at CERN

Lepton flavor violating (LFV) decays are forbidden in the SM, but they exist in several New physics scenarios as the Pati-Salam model [17], or the Two Higgs doublet models [18]. LHCb is searching for different types of LFV decays as $\tau \to \mu\mu\mu$, $B_{(s)} \to e\,\mu$.
No decays including taus have been looked at. The best (BABAR) upper limit at 2.2×10^{-5} on **$B \to \tau\,\mu$** at 90% CL.

BACKUP

Expected results, perspectives



Fast MC study for the **Bs → τ τ** (3π, μ) final state. Fit result for $0.5 fb^{-1}$.

Extrapolating these results the expected **upper limit is ~ 5×10^{-3}** at 95% C.L. reachable using all modes and $3 fb^{-1}$.

Already theoretically interesting and of the same order of the limit on the Bd mode set by BABAR.
We expect to achieve better performances, based on our previous experience in $B_s \to \mu\mu$, by a factor ~10 using the improved stripping selection, more sophisticated discriminating variables, and, possibly, a different fit strategy (à la $B_s \to \mu\mu$ for example).
Given the large number of possible improvements and optimizations needed, the **contribution** of the new CDD Is going to be **crucial**.