Rare dileptonic $B^0_{(s)} \to \ell\bar{\ell}$ decays @ LHCb

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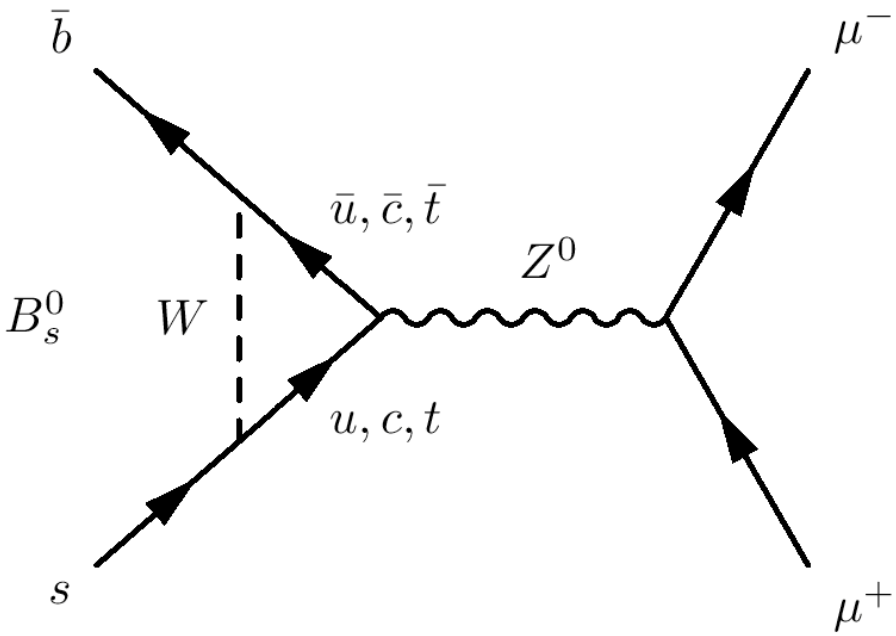
19 Novembre 2014

⋆Supported by the OCEVU Labex (ANR-11-LABX-0060) funded by the "Investissements d'Avenir" French government program

$B^0_{(s)} \to \ell\bar{\ell}$: motivations

Dileptonic decays of $B^0_{(s)}$ mesons imply a Flavour Changing Neutral Current (FCNC).



Very rare in Standard Model (SM):

- loop suppression
- helicity suppressed

But their rates could be enhanced in New Physics (NP) scenarios

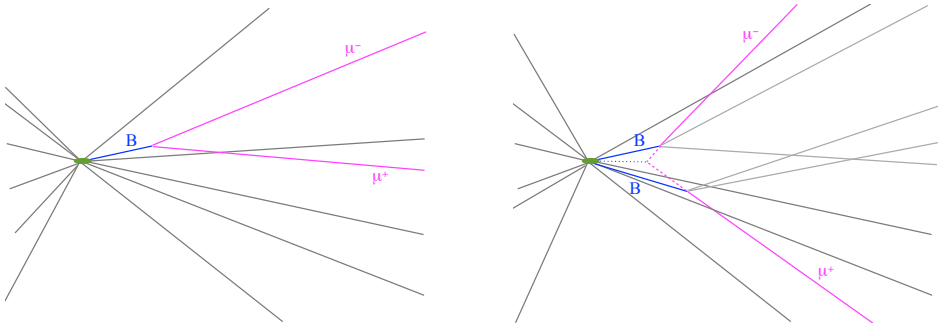
In SM [Bobeth *et al.*, PRL 112, 101801 (2014)]:

$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.65 \pm 0.23) \times 10^{-9}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.06 \pm 0.09) \times 10^{-10}$$
$$\mathcal{B}(B^0_s \to \tau^+\tau^-) = (7.73 \pm 0.49) \times 10^{-7}$$
$$\mathcal{B}(B^0 \to \tau^+\tau^-) = (2.22 \pm 0.04) \times 10^{-8}$$

- $\mu\mu$: **First evidence** for $B^0_s \to \mu^+\mu^-$ @ 3.5σ with $2.1 fb^{-1}$ [LHCb, Phys. Rev. Lett. 110 021801]
- Current status $\tau\tau$:
  - $\mathcal{B}(B^0 \to \tau^+\tau^-) < 4 \cdot 10^{-4}$ @ 90% CL by BaBar
  - $\mathcal{B}(B^0_s \to \tau^+\tau^-)$ **not yet constrained**

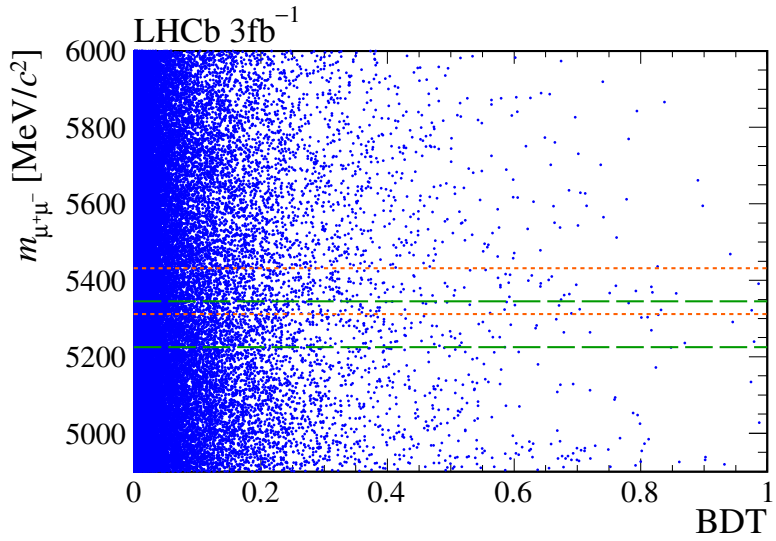
$B^0_{(s)} \to \mu^+\mu^-$ [LHCb, Phys. Rev. Lett. 111 101805]

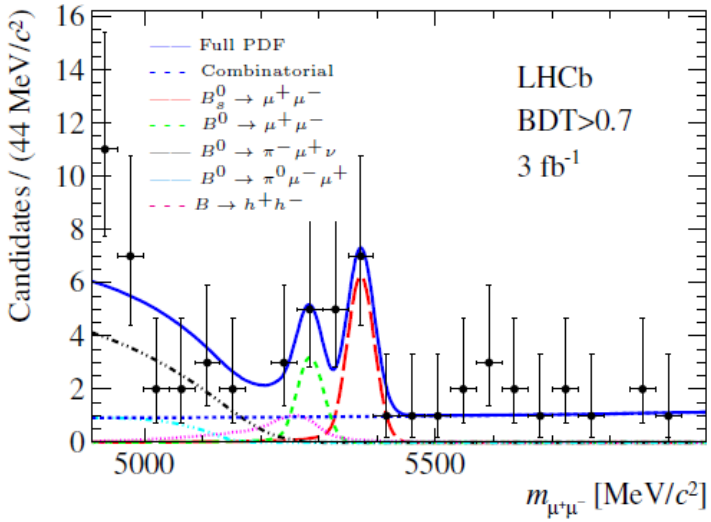
- Good tracks with high impact parameter
- Displaced secondary vertex with good pointing to the Primary Vertex
- Good μ identification



2D classification geometry $\otimes$ invariant mass $m_{\mu^+\mu^-}$

$\leftarrow$ bkg-like sig-like $\rightarrow$





Events yields determination through a simultaneous unbinned likelihood fit in 8 BDT bins

Final Results:

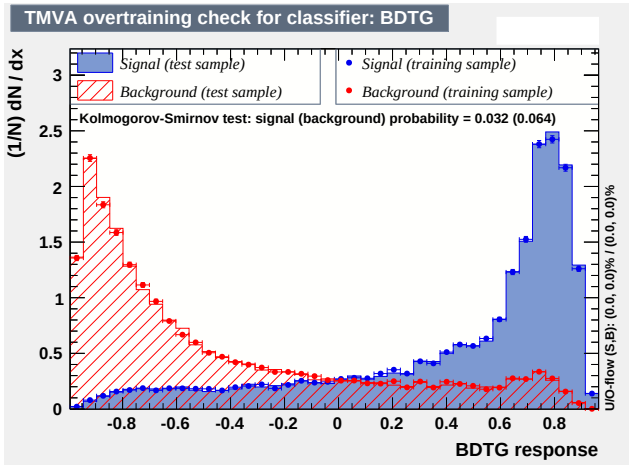
$$\mathcal{B}(B^0_s \to \mu^+\mu^-) = 2.9^{+1.1}_{-1.0} \times 10^{-9} \text{ @ } 4\sigma,$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.7^{+2.4}_{-2.1} \times 10^{-10} \text{ @ } 2\sigma$$

No evidence for $B^0 \Rightarrow$ upper limit:

$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 6.3(7.4) \times 10^{-10} \text{ @ } 90(95)\% \ CL$$

$B^0_{(s)} \to \mu^+\mu^-$ - State of Arts

- The LHCb result has been combined with the one of CMS getting the first observation of $B^0_s \to \mu^+\mu^-$ and the first evidence for $B^0 \to \mu^+\mu^-$
- New actions have been started for the update of the analysis with $3.1 fb^{-1}$ and the next run of LHC:
  - definition of new *isolation* variables based on a topological reconstruction algorithm (ZVtop)



  - collaboration with other group-institutes involved in the LHCb rare decay analysis (Frascati-Pisa) to combine that variable with other isolation ones defined by them
  - implementation of the ZVtop isolation software tool in the LHCb official code for the preliminary selection (Stripping legacy of RunI)
  - optimization of the final MultiVariate classifier:
    - use of new isolation variables
    - study of the background composition
    - introduction of new variables to fight these sources of backgrounds

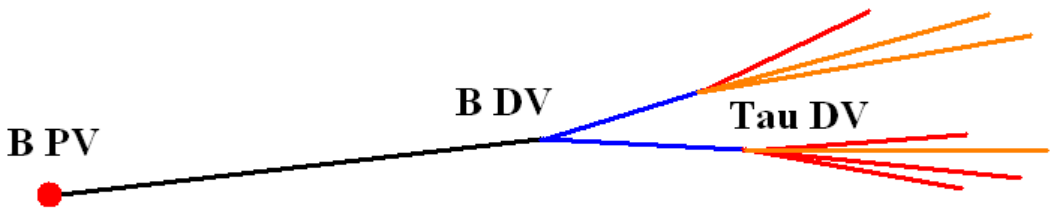
$B_s^0 \longrightarrow \tau^+\tau^-$

- **Motivations**
  - New Physics effects could be observed in processes involving third generation particles ($B^0_{(s)} \longrightarrow D^{(\star)}\ell\bar{\nu}_\ell$ ratio anomalies, A_{sl})
  - possibility of studying angular observables potentially sensitive to New Physics (golden channel!)
- **Challenges**

τs decay quickly in the detector and we must reconstruct them from their daughter particles

- at least one neutrino for each τ decay (1 for hadronic or 2 for leptonic channels) $\Rightarrow$ at least **2 unreconstructable neutrinos** and so...
- we cannot completely reconstruct the two τ momenta, hence neither $\tau^\pm$ invariant mass nor the decay topology
- a $B^0_{(s)} \longrightarrow \mu\mu$-like analysis (*i.e.* 2D classification geometry $\otimes$ invariant mass) is not straightforward

B_s
τ
visible (charged) tracks
neutral tracks (ν, π^0)



$B_s^0 \to \tau^+\tau^- \to (3\pi\nu)^+(3\pi\nu)^-$

- only 2 neutrinos
- 2 3-prong vertexes
- reconstruction of the decay plane: kinematic constraints & partial neutrino momentum reconstruction
- needs 6-charged tracks in the detector acceptance
- $\mathcal{B}(\tau \to 3\pi\,\nu_\tau) = 9.31\%$
- $\mathcal{B}(\mathbf{B_s \to \text{ final state}}) \simeq \mathbf{6.7 \times 10^{-9}}$

Same effective $\mathcal{B}$ as $B_s \to \mu\mu$!

Backgrounds

- $\tau \to 3\pi\nu$:
  - 3 random tracks from a common point
  - prompt $D_{(s)}^{(\star)} \to 3\pi X$
- $B_s \to \tau\tau \to (3\pi\nu)(3\pi\nu)$:
  - **2 "combinatorial" τ**
  - **2 true τ coming from 2 semileptonic $B_{(s)}$ decays**
  - **1 or 2 $D_{(s)}^{(\star)}$ from 2 hadronic or semileptonic $B_{(s)}$ decays**
  - resonant: one hadronic or semileptonic $B_{(s)}$ decay with misID $D_{(s)}^{(\star)}$ (due to $D_{(s)}^{(\star)} \to \tau\nu_\tau X$)

• **Even taking into account the future upgrade of the detector, is unlikely that any observable other than the $\mathcal{BR}$ itself (an Upper Limit) can be measured LHCb**

$B_s^0 \to \tau^+\tau^- \to (3\pi\nu)^+(3\pi\nu)^-$

In the events we select we know the following quantities:

- B origin vertex
- 3d sides of triangle $\overrightarrow{w}_\pm$
- 4-momenta $p^\mu_\pm$ of $(3\pi)_\pm$ system

Let's assume that the pattern we observe is generated by a $B_s \to \tau\tau \to (3\pi\nu)(3\pi\nu)$ chain.

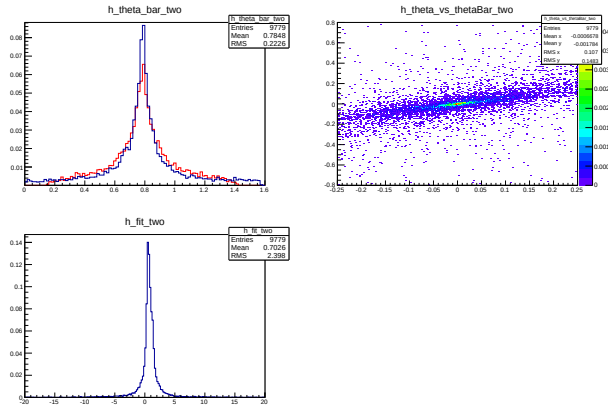
Can we reconstruct the two τ candidates momenta?

Thanks to the collaboration with CPT

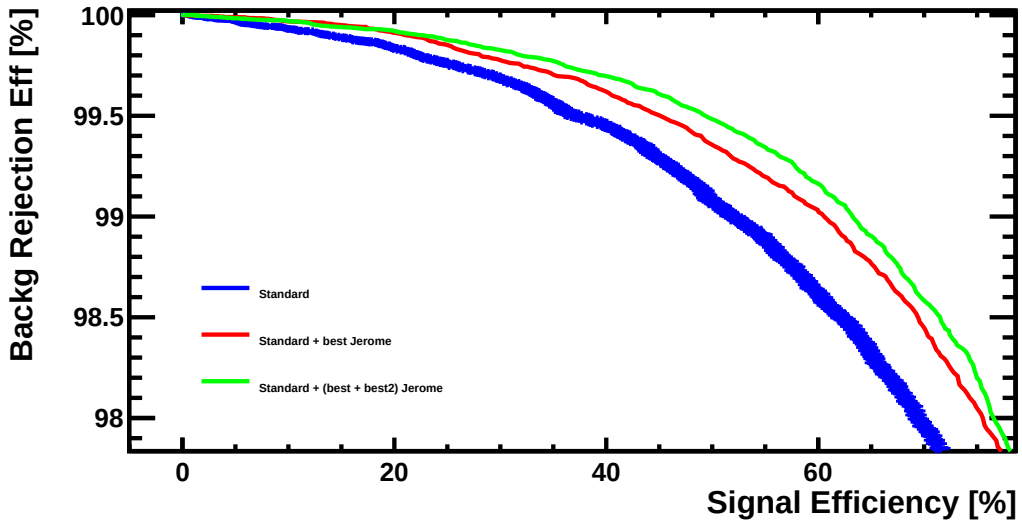
- a new parametrization of the problem has been found, which is based on a manifestly Lorentz-covariant approach and allows to
- reduce the solution of the problem to **an equation of 4^{th} degree depending on only one Lorentz-invariant event-dependent parameter**

$B_s^0 \to \tau^+\tau^- \to (3\pi\nu)^+(3\pi\nu)^-$

- This parameter is an **angle that is sensitive to the asymmetry between the two sides of the decay triangle**, so that **it could be approximated by some geometrical measurement**



- Moreover, other functions of the observable quantities appearing in the algorithm (in addition to the two τ momenta) can be used as discriminating variables against the backgrounds



$B_s \to \tau\tau \to (3\pi\nu)(3\pi\nu)$ - State of arts & Prospects

- **So far**:
  - several analysis strategy attempts (all of them share the issue of the PDFs calibration)
  - work on τ reconstruction and extraction of discriminating variables
  - implementation of isolations tools in the offical LHCb codes for legacy Stripping of RunI

- **Priority** is finalize the analysis for the measurement of the (UL on) $\mathcal{BR}$:
  - choose (define) the final discriminating variable to be fitted
  - define a strategy for PDFs calibration:
    - find control region in data (how to define it?)
    - use of MC generated samples (huge production required to be reliable)
  - signal yield extraction, computation normalization coefficient, fit the dataset
  - combination with the result from $B_s \to \tau\tau \to (3\pi\nu)(\mu\nu\nu)$

- **Prospects** (in view of future high luminosity *ee* machines):
  - Study the possibility of measuring angular observables
  - understand which of them survive the lack of the neutrino reconstruction, in addition to the τ polarization
  - all aspects which are not yet been studied in literature

Human resources & production

Name	Position	Lab	#PM '13/14	Nature of the contribution to the project
A. Mordá	PhD	CPPM CPT	12/12	All aspects of the $3\pi 3\pi$ mode definition of new discriminating variables
G. Mancinelli	DR	CPPM	3/3	Project supervision, isolation variables tuning and redefinition, BDT calibration
J. Serrano	CR	CPPM	3/3	All aspects of the $3\pi\mu$ mode, BDT calibration
J. Cogan	CR	CPPM	1/2	Exclusive decays and normalization samples. Tuple production, background characterization
J. Charles	CR	CPT	3/4	Definition of new discriminating variables through a better kinematical parametrization of the decay

- **Scientific production**
  - R. Aaij et al. (LHCb Collaboration), *"Measurement of the $B_s^0 \to \mu^+\mu^-$ Branching Fraction and Search for $B_s^0 \to \mu^+\mu^-$ Decays at the LHCb Experiment"*, Phys. Rev. Lett. 111, 101805 (2013)
  - E. Meggiolaro, A. Mordá , *"Remarks on the $U(1)$ axial symmetry and the chiral transition in QCD at finite temperature"*, Phys. Rev. D88, 096010 (2013)

- **Talks & posters at conferences & workshops**
  - *"Rare $B^0_{(s)}$ dileptonic decay at LHCb"*, Journées de Rencontres des Jeunes Chercheurs, Barbaste, Lot et Garonne - 4 Decembre 2013
  - *"Rare $B^0_{(s)}$ dileptonic decays at LHCb"*, Rencontres de Physique de la Vallée d'Aoste, La Thuile - 25 February 2014
  - *"On the possibility of measuring $\mathcal{B}(B_s \to \tau\tau)$ @ LHCb"*, Flavor of New Physics in $b \to s$ transitions, Paris - 2 Juin 2014
  - *"Branching ratio measurement of $B^0_{(s)} \to \mu^+\mu^-$ decay at LHCb"* Poster presented at JSED

Foreseen action in 2015

- Publication of the improved $B_s \to \mu\mu$ analysis using the $3.1 fb^{-1}$ dataset collected in Run 1 of LHC
- If $B_s \to \tau\tau$ analysis is mature enough, publication of a common LHCb note and an article in a major scientific review
- Depending on time constraints, phenomenological work devoted to understand which observables in the $B_s \to \tau(\to 3\pi\nu)\tau(\to 3\pi\nu)$ decay survive the lack of the neutrino reconstruction, in view of the future high luminosity *ee* machine
- Summer/Fall '15 : defence Alessandro Mordá's thesis

Human resources

Name	#PM '15	Nature of the contribution to the project
Alessandro Mordá	9	All aspects of the $3\pi 3\pi$ mode - thesis writing
Giampiero Mancinelli	3	Project supervision, new data taking
Justine Serrano	3	All aspects of the $3\pi\mu$ mode, new data taking
Julien Cogan	3	ZVtop alternative selection
Jérôme Charles	3	work on angular observables