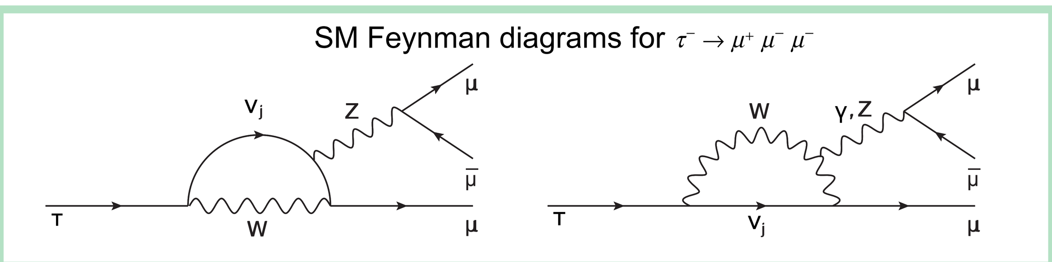
Search for the lepton flavour violating decay $\tau^- \to \mu^+\mu^-\mu^-$

Laura Gavardi on behalf of the LHCb Collaboration

"Search for violation of lepton flavour and baryon number in tau lepton decays at LHCb", Physics Letters B 724 (2013) 36-45

1) Introduction

- **Charged lepton flavour violating decays:**
  - Allowed within the Standard Model through neutrino oscillations $\to$ effect below experimental sensitivity
- $\tau^- \to \mu^+\mu^-\mu^-$:
  - SM prediction $\mathcal{B} < 10^{-40}$ [1]



  - Enhanced by New Physics $\mathcal{B} \sim 10^{-8} - 10^{-10}$ [2]
- **World's tightest upper limit (Belle, [3]):**

$\boxed{\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 2.1 \cdot 10^{-8} \text{ at } 90\% \text{ C.L.}}$

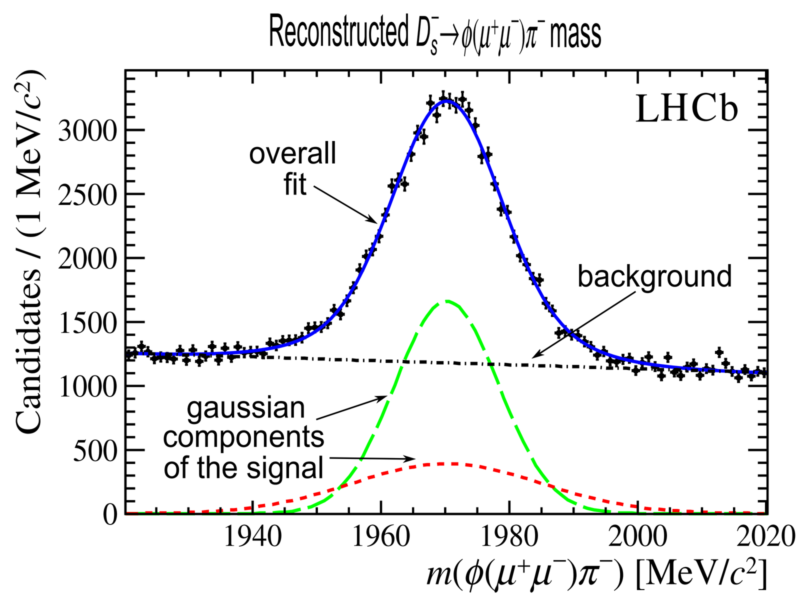
2) $\tau^- \to \mu^+\mu^-\mu^-$ at LHCb

- **τ^- production at the LHC:**
  - Large cross section ($\sim 80\mu$b) for τ^- production, $\sim 80\%$ from $D_s^- \to \tau^-\bar{\nu}_\tau$ decays
  - Total number of τ^- produced in 4π per 1fb^{-1} of pp-collisions at 7 TeV is $\sim 9 \cdot 10^{10}$
- **LHCb:** excellent performance for low-mass muons
  - Impact parameter resolution: $\sigma(IP) \sim 20\mu$m for signal tracks
  - MuonID: $\varepsilon(\mu \to \mu) \sim 97\%$, MisID$(h \to \mu) < 1\%$ $(p > 10\,\text{GeV}/c)$
  - Mass resolution for $\tau^- \to \mu^+\mu^-\mu^-$: $\sigma_m \sim 10$ MeV/c^2

3) Analysis strategy

- The background processes for the $\tau^- \to \mu^+\mu^-\mu^-$ decay consist mainly of decay chains of heavy mesons with three real muons in the final state or with one or two real muons in combination with two or one misidentified particles
- **Selection cuts** to reduce the dataset to a manageable level, whilst keeping good signal efficiency
- **Signal-background discrimination** obtained by three binned likelihoods:
  - invariant mass
  - particle identification
  - geometric and kinematic properties of the reconstructed decay e.g. the vertex quality, its displacement from the PV, the τ momentum and the isolation
- **The signal branching fraction** is measured normalising to $D_s^- \to \phi(\mu^+\mu^-)\pi^-$:

$$\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) = \mathcal{B}(D_s^- \to \phi(\mu^+\mu^-)\pi^-) \times \frac{\boxed{f_\tau^{D_s}}}{\mathcal{B}(D_s^- \to \tau^-\bar{\nu}_\tau)} \times \boxed{\frac{\varepsilon_{cal}^{REC\&SEL}}{\varepsilon_{sig}^{REC\&SEL}} \times \frac{\varepsilon_{cal}^{TRIG}}{\varepsilon_{sig}^{TRIG}}} \times \boxed{\frac{N_{sig}}{N_{cal}}} = \boxed{\alpha} \times N_{sig}$$



$f_\tau^{D_s}$ = fraction of τ leptons that originates from D_s decays

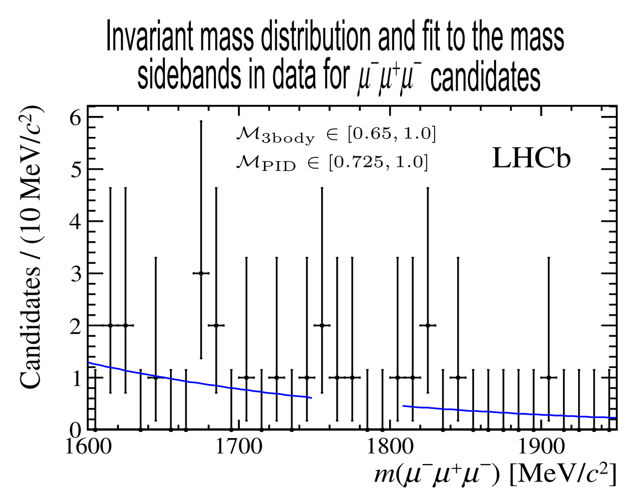
ε^{TRIG} = trigger efficiency
$\varepsilon^{REC\&SEL}$ = reconstruction and selection efficiency

N_X = number of observed events for the selected channel

α = normalisation factor

Number of $D_s^- \to \phi(\mu^+\mu^-)\pi^-$ candidates:
$N(D_s^- \to \phi(\mu^+\mu^-)\pi^-) \sim 45000$

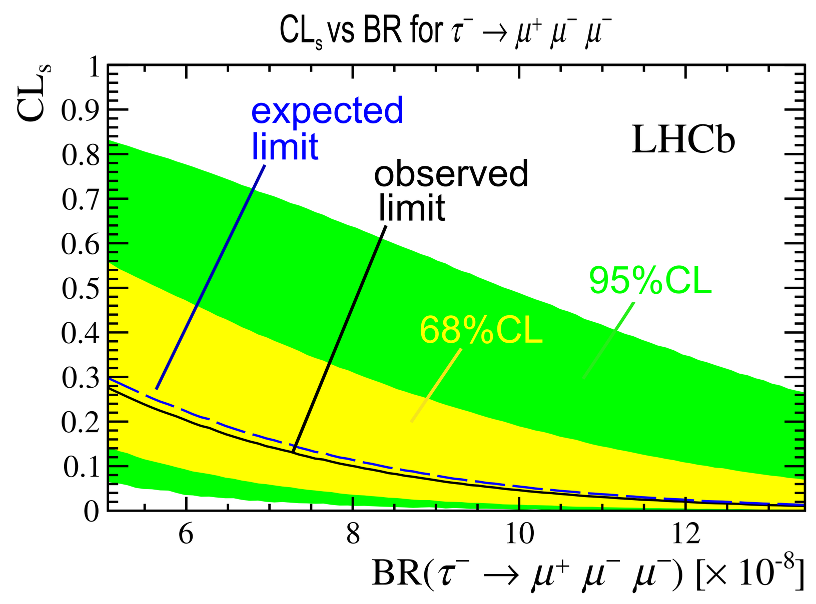
- **The expected number of background events** in each bin of the three likelihoods is evaluated by fitting the candidate mass spectra outside of the signal window



4) Results

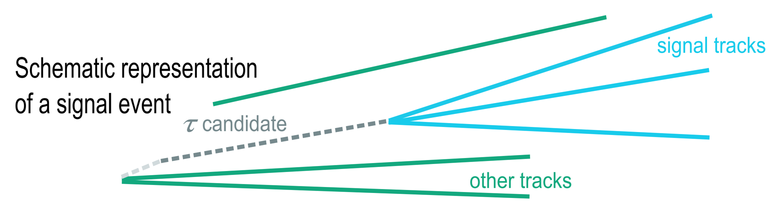
- LHCb published the first search for the $\tau^- \to \mu^+\mu^-\mu^-$ decay mode performed at a hadron collider
- No evidence for charged lepton flavour violation has been found in a dataset corresponding to 1 fb^{-1} of integrated luminosity
- The CLs method [4] has been used to set an upper limit on the branching fraction

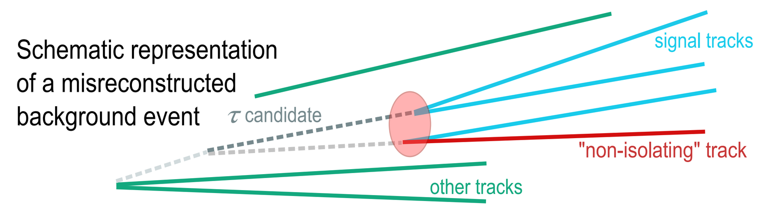
$\boxed{\mathcal{B}(\tau^- \to \mu^+\mu^-\mu^-) < 8.0 \cdot 10^{-8} \text{ at } 90\% \text{ C.L. [5]}}$



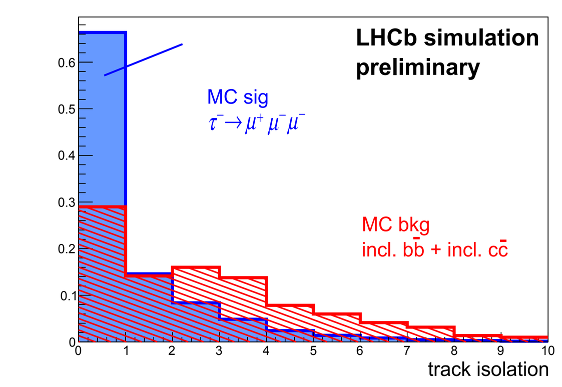
5) Outlook

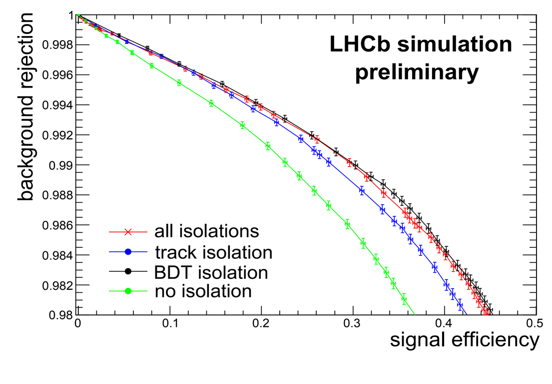
- With the data collected in 2012 (τ^- sample increased by a factor 3.5) the sensitivity of LHCb will become competitive with that of the B-factories
  $\to$ Analysis is ongoing
- Additionally to the enlarged data sample we included a new isolation variable
  Requirement: Each of the three muons track should be compatible with the τ^--vertex only and with no other vertices
  $\Longrightarrow$ the **track isolation** measures the number of background tracks that form vertices with the signal candidate tracks

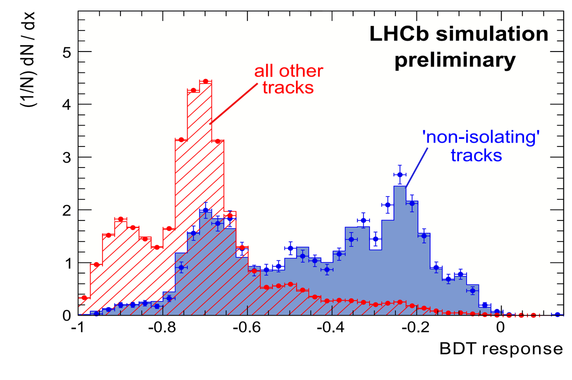




- The old track isolation variable counts the number of tracks fulfilling a set of cuts on muon-track variables
- The new isolation variable combines muon-track variables in a BDT in order to discriminate against non-isolating tracks. This yields a BDT value for each track-muon pair. The new isolation is a combination of the BDT values in each event.
- Using both isolation improves discrimination between signal and background







References

[1] M. Raidal et al., *Flavor physics of leptons and dipole moments*, Eur. Phys. J. C 57 (2008) 13
A. Ilakovac, A. Pilaftsis, L. Popov, *Charged lepton flavor violation in supersymmetric low-scale seesaw models*, Phys. Rev. D 87 (2013) 053014

[2] R.H. Bernstein and Peter S. Cooper, *Charged lepton flavor violation: an experimenter's guide*, Phys. Rep. 532(2013) 27-64

[3] The Belle Collaboration, *Search for lepton flavor violating τ decays into three leptons with 719 million produced $\tau^+\tau^-$ pairs*, Phys. Lett. B 687 (2010) 139-143

[4] A.L. Read, *Presentation of search results: the CLs technique*, J. Phys. G 28 (2002) 2693
T. Junk, *Confidence Level computation for combining searches with small statistics*, Nucl. Instrum. Meth. A 434, 435 (1999).

[5] The LHCb Collaboration, *Searches for violation of lepton flavour and baryon number in tau lepton decays at LHCb*, Phys. Lett. B 724 (2013) 36-45