Prospects of Lepton Flavor Violation searches in the τ→3μ channel at HL-LHC with upgraded CMS detector

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Motivations and present status

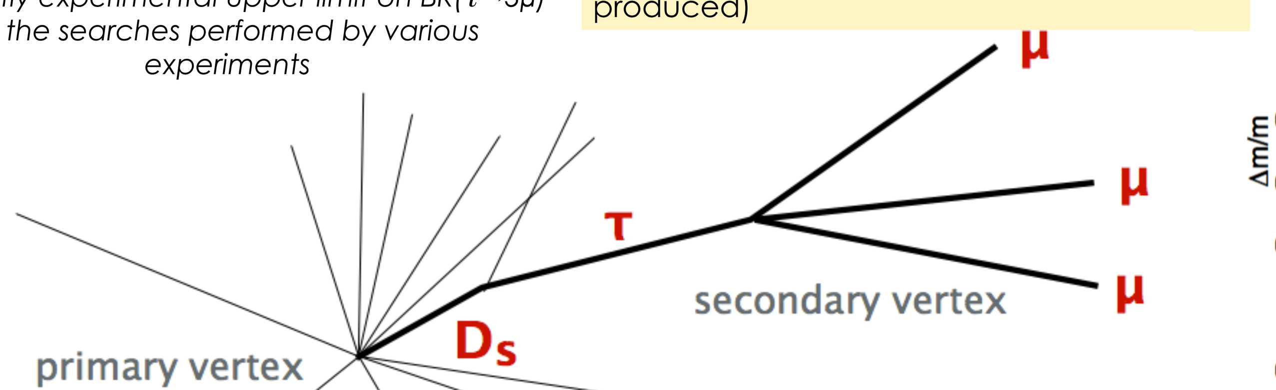
There are no fundamental symmetries explicitly forbidding lepton flavour violation (LFV) processes. They can happen:

- in the standard model via neutrino oscillations: BR(τ→3μ)~O(10^{-14})
- In BSM are "naturally" enhanced: BR(τ→3μ)~O(10^{-8})

	Experimental limits (90% CL)
Belle	2.1×10^{-8} [1]
BaBar	3.3×10^{-8} [2]
ATLAS (√s=8 TeV)	3.8×10^{-7} [3]
LHCb (Run1)	4.6×10^{-8} [4]

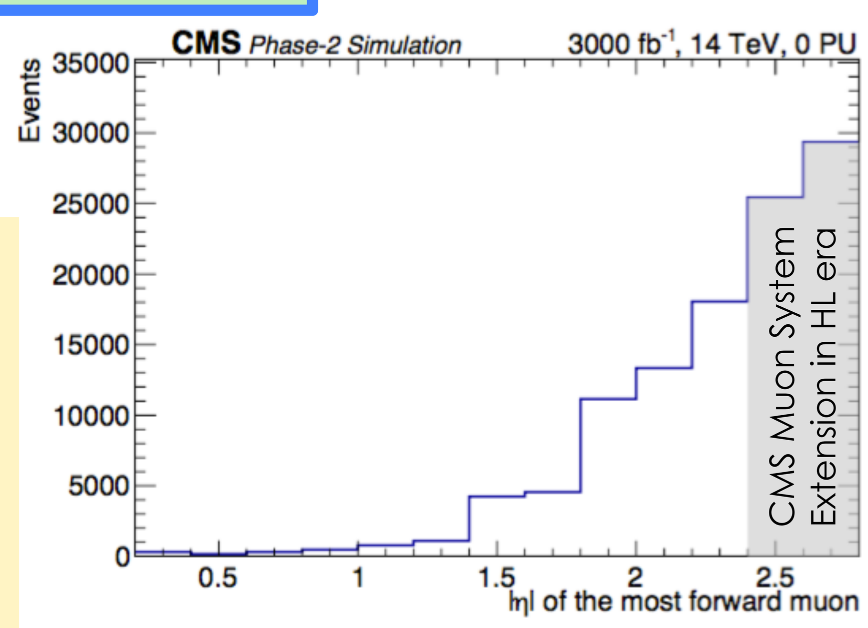
Currently experimental upper limit on BR(τ→3μ) in the searches performed by various experiments

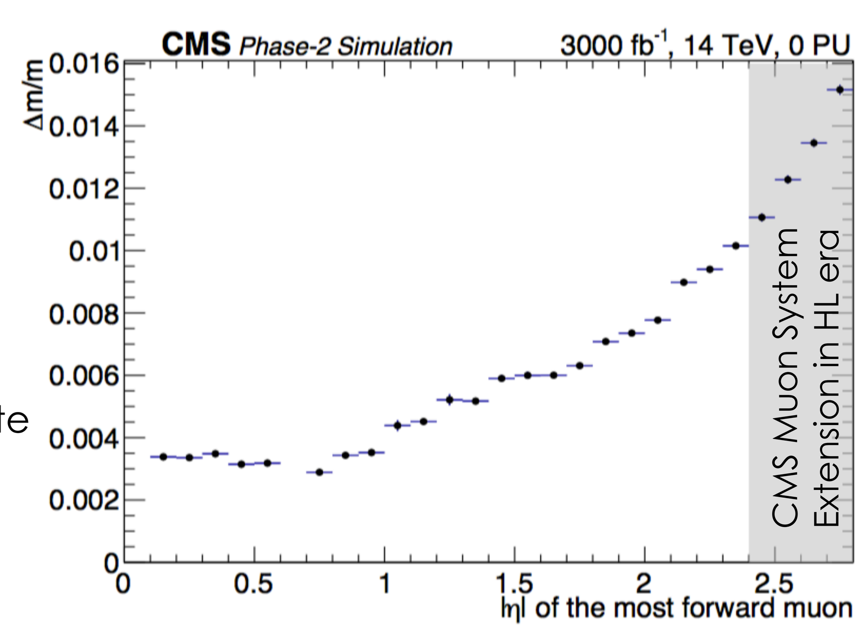
At LHC, τ→3μ decay is one of the "cleanest" LFV decay channel:
- Clear final state topology
- Tau lepton's large mass→large phase space for decays
- couplings for new physics may be enhanced for heavy particles
- High luminosity allow to reach the precision needed (~10^{15} τ-leptons produced)



The main source of τ in pp collisions is D_s→τ decays. Challenging final state
- very low momenta of the final state leptons
- significantly boosted in the forward direction (top right).
- Only about 1.3% of signal events have all three muons with p > 2.5 GeV
- |η| < 2.4, the current CMS muon system acceptance.

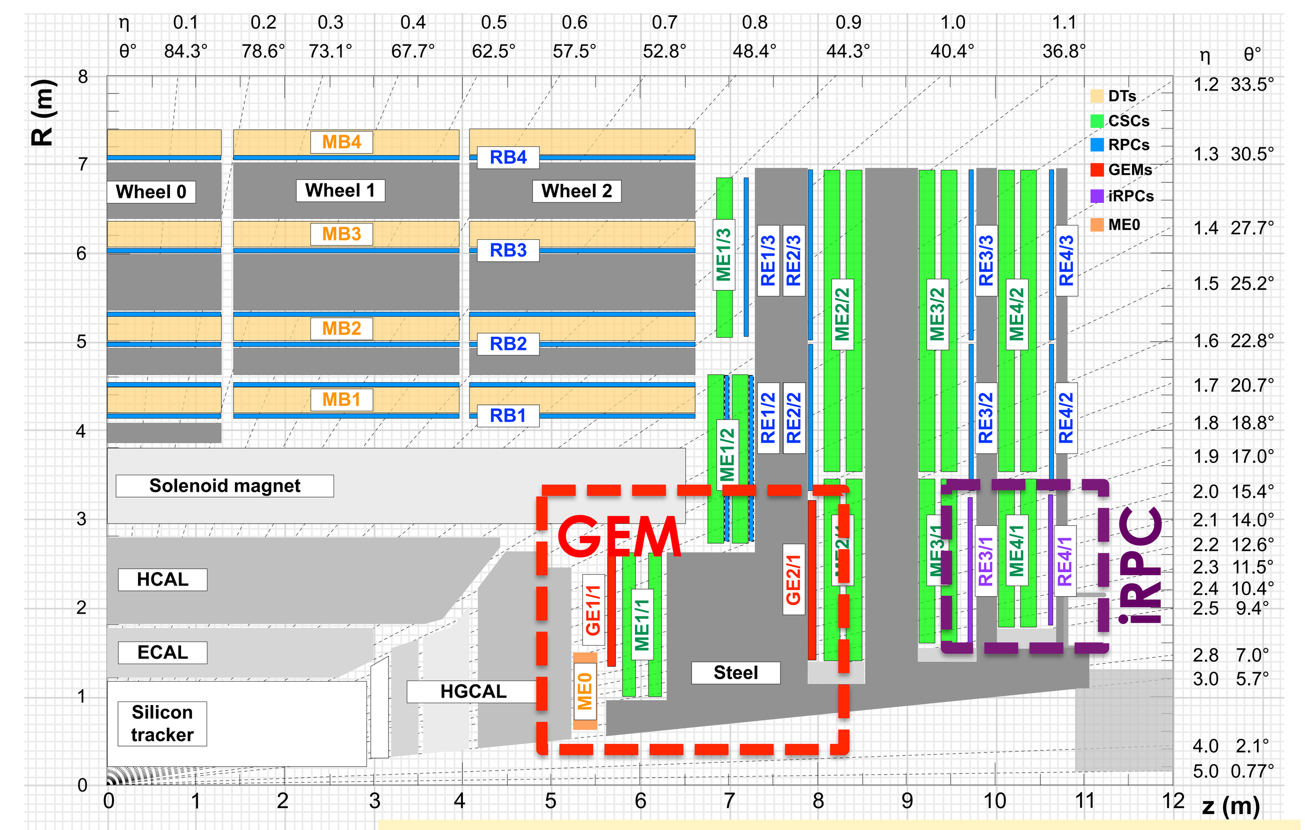
→Difficult backgorund rejection





The CMS Upgrade towards HL-LHC era

To extend the sensitivity for new physics searches, a major upgrade of the LHC has been decided, the High Luminosity LHC starting from 2023.
To maintain the present excellent performance of the CMS experiment [5,6], an upgrade of the detector is also foreseen to cope the Run4 collision conditions.



HL-LHC
- sqrt(s)=14 TeV
- Pile-up = 200
- L_{int} = 3000 fb-1

CMS Upgrades most relevant for this analysis
- ✓**Enhanced forward muon system [7]:**
  - –improved momentum measurement at L1 Trigger
  - –extended eta-coverage from 2.4 to 2.8
- ✓**Track-trigger capabilities for tracks with p_T>2 GeV**
- ✓**Higher trigger bandwidth** (100 kHz →750 kHz)

Reconstruction of muon hits in GEM-CSC tandems allows one the measurement of the muon momentum→improvement of the purity of reconstructed low momentum muons. The muon momentum measurement with ME0 station is not yet implemented.

Analysis Procedure

Main Background

– B meson events: B→μν D +X, D→μν +X, additional μ either from π/K decay in flight or accidental alignment of charged hadron track with first muon station.
– Reducible background coming from pile-up interactions superimposed to the primary one.

Basic signal acceptance

– |η|< 2.8, p > 2.5 GeV→ factor of 2 gain due to extension of muon η-acceptance (from 2.4 to 2.8)

Muon reconstruction

– Tracker-muons: Tracker track + at least one matching segment in Muon System
– Signal efficiency in acceptance is about 30%
– The events gained with the Muon System extension have a modest trimuon mass resolution

Preselections applied to exploit the final state topology

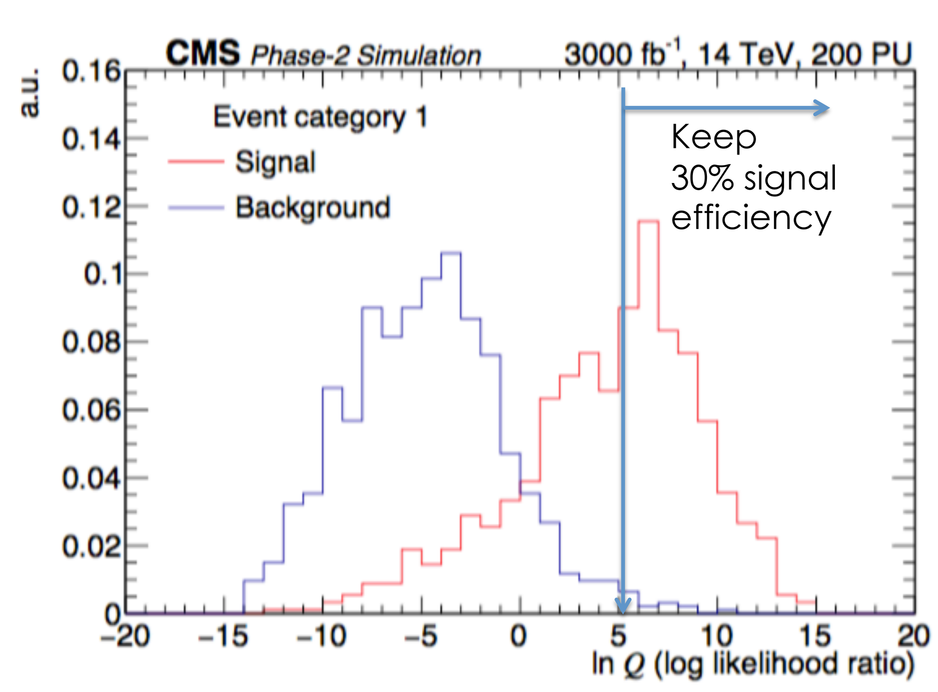
– Electric charge of the 3-muon system=±1
– minimum trimuon vertex χ2 fit
– minimum transverse displacement of the trimuon vertex
– maximum distance between the three muons in the eta-phi plane

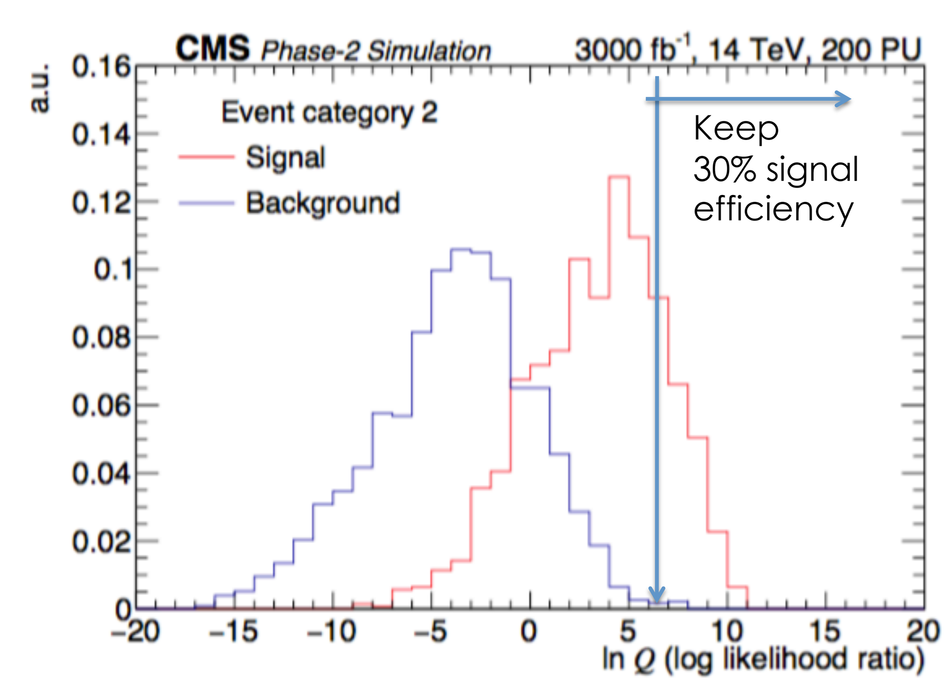
Event categorization to optimize the signal extraction

– Category 1: events reconstructed using the present muon chambers
– Category 2: events with at least one ME0-only muon

Likelihood Discriminator

In order to separate efficiently signal from B-mesons background, a discriminant Q is built as a product of ratios of 1D signal and background probability density functions for more than a dozen observables. The most discriminating are:
- Normalized χ2 of the re-fitted tri-muon vertex
- transverse displacement of tri-muon vertex with respect to the primary interaction,
- angle between tri-muon direction and the line connecting the primary interaction and the tri-muon vertex,
- minimum DR distance among three pairs of muons in a trimuon event candidate,
- the highest and lowest momenta among three muons in a trimuon event candidate,
- number of b quark jets.





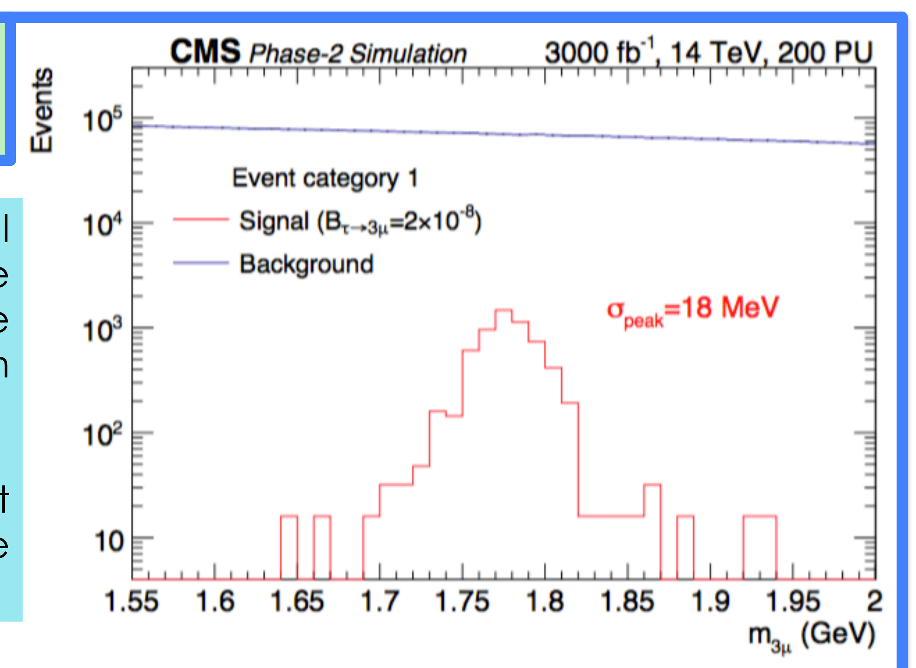
Results: CMS Phase 2 Sensitivity

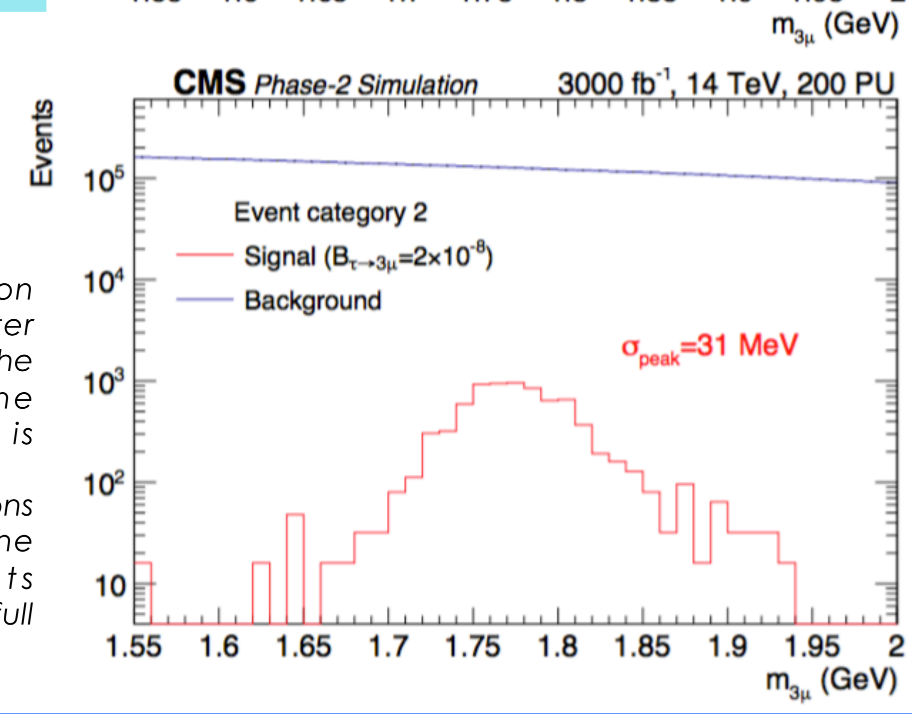
The invariant mass of the tri-muon system is used as a final discriminant for the signal extraction. A fit for a signal peak over the continuum background constrained by the sidebands can be used to asses a number of signal events (or an upper limit on the number of signal events). Ds→Φπ→ μμπ decays to derive the normalization directly from data assuming a 10% systematic error on the process cross section.

The difference in the two results in the two categories, that allows to quantify the impact of the new upgrade muon system in this search, can be re-interpreted as an effective gain in integrated luminosity ~1.35 from 3000 to 4000 fb^{-1}

	Category 1	Category 2
Number of background events	2.4×10^6	2.6×10^6
Number of signal events	4 580	3 640
Trimuon mass resolution	18 MeV	31 MeV
$B(\tau \to 3\mu)$ limit per event category	4.3×10^{-9}	7.0×10^{-9}
$B(\tau \to 3\mu)$ 90%C.L. limit	3.7×10^{-9}	
$B(\tau \to 3\mu)$ for 3σ-evidence	6.7×10^{-9}	
$B(\tau \to 3\mu)$ for 5σ-observation	1.1×10^{-8}	

The expected number of signal and background events in mass window 1.55– 2.00 GeV for L=3000 fb^{-1} (for signal, BR(τ→3μ) = $2x10^{-8}$ is assumed). In absence of a signal, the projected limits on , BR(τ →3μ) are for 90% CL, which are obtained using the standard CLs methodology [140–142].





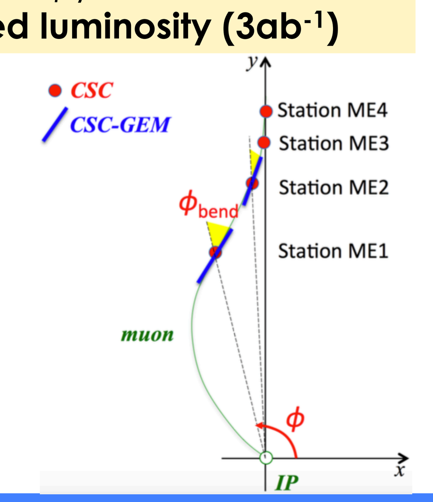
The expected trimuon mass distribution after the requirement on the lnQ observable. The assumed BR(τ→3μ) is $2x10^{-8}$. Background fluctuations are emulated for the statistics of events expected with the full HL-LHC dataset.

Conclusions & Perspectives

Present best limit: BR(τ→3) < 2.1×10^{-8} at 90% CL
Belle-II projection for 50 ab^{-1}: 4×10^{-10} at 90% CL
HL-LHC is a prolific source of tau leptons:
– Both hadronic and electroweak taus can be exploited
– each branch is being explored by CMS (and ATLAS)

Simulated analysis for the **Upgraded CMS** at HL-LHC shows that an upper limit on BR(τ→3μ)=**3.7×10^{-9} can be achieved with the full integrated luminosity (3ab^{-1})**

LHC analyses are not limited by the number of taus, but rather by how well one can separate signal from large background→ plenty of opportunities for further optimization.
Example: exploit the ME0 station for the muon momentum measurementin the CMS forward region at the trigger level and in the offline reconstruction.



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