Search for the $\tau \rightarrow 3\mu$ decay at the CMS experiment at LHC

WIN2019
The 27th International Workshop on Weak Interactions and Neutrinos
3-8 June 2019, Bari (Italy).

Rosamaria Venditti
On behalf of the CMS Collaboration
Motivations

Why LFV

• The lepton flavor conservation is not protected by any particular symmetry in Nature.
• Charged Lepton flavor violation (LFV) is allowed in the Standard Model including the neutrino oscillation, with extremely small BR
  – E.g. $B(\tau \to 3\mu) \sim O(10^{-14})$
• Some extensions of the SM (SUSY, 2HDM) allow for LFV decays with sizeable branching fractions $\sim O(10^{-8})$ that can be probed with the present day experiments

Why $\tau \to 3\mu$

• 3-µ decay has very clean final state topology
• BR enhanced in some BSM models
• $\tau \to 3\mu$ observation is a powerful tool to probe the NP
State of the art

@ e-e+ colliders

BaBar: $B(\tau \to 3\mu) < 3.3 \times 10^{-8}$ at 90% CL
Belle: $B(\tau \to 3\mu) < 2.1 \times 10^{-8}$ at 90% CL

→ Best limit!!
→ update expected from Belle-II

• LHC is a $\tau$ factory! Proton-proton collisions are a prolific source of $\tau$-leptons
  – the expected inclusive production cross section at LHC is about $2 \times 10^{11}$ fb

State of the art (@ LHC)

• LHCb: $BR(\tau \to 3\mu) < 4.6 \times 10^{-8}$ at 90% CL [https://doi.org/10.1007/JHEP02(2015)121]
• ATLAS : $BR(\tau \to 3\mu) < 3.8 \times 10^{-7}$ at 90% CL [arXiv:1601.03567]
• CMS: First public results this year Topic of this talk CMS BPH-17-004
The Compact Muon Solenoid Experiment at LHC

- Event reconstruction based on the particle-flow
- Exploits information from all the CMS subdetectors
- Identify and reconstruct individual particle candidates in the event

- The Muon reconstruction combines information from the tracker and the muon system
- Detector Acceptance set by:
  - Instrumented area $\rightarrow \text{abs}(\eta)<2.4$
  - Muon Reco $\rightarrow p>2.5$ GeV

R.Venditti - Search for the $\tau \rightarrow 3\mu$ decay at the CMS experiment at LHC
\[ \tau \rightarrow 3\mu \] searches at CMS in 2016 data

- **2016 Data analyzed (pp @ 13 TeV)**
  - integrated luminosity of 33 fb\(^{-1}\)

- **Two channels:**
  - **Heavy Flavour (HF)** (\(D \rightarrow \tau \nu\), \(B \rightarrow \tau \nu\)..., \(B \rightarrow D(\tau \nu)\)...)
  - **W boson production** (\(W \rightarrow \tau \nu\))

- **HF channel:** \(\mathcal{O}(10^{12})\) produced \(\tau\) leptons
  - \(\sim 10^4 \tau \rightarrow 3\mu\) events (assuming upper limit by Belle)
  - \(\sim 10^2 \tau \rightarrow 3\mu\) events in the CMS detector acceptance
  - Challenging \(\rightarrow\) low transverse muon momenta
  - Analysis freezed and Approved

- **W channel:** \(\mathcal{O}(10^9)\) produced \(\tau\) leptons
  - \(\sim 10 \tau \rightarrow 3\mu\) events (assuming upper limit by Belle exp.)
  - Clean final state High-pT muons and large missing energy
  - Analysis in the final step of the review
τ→3µ searches at CMS in 2016 data

• 2016 Data analyzed (pp @ 13 TeV)
  – integrated luminosity of 33 fb⁻¹

• Two channels:
  – Heavy Flavour (HF) (D → τν, B → τν..., B → D(τν)...)
  – W boson production (W → τν)

• HF channel: $\mathcal{O}(10^{12})$ produced τ leptons
  – $\sim 10^4 \tau \rightarrow 3\mu$ events (assuming upper limit by Belle)
  – $\sim 10^2 \tau \rightarrow 3\mu$ events in the CMS detector acceptance
  – Challenging → Muons with low transverse momenta
  – Analysis freezed and Approved

• W channel: $\mathcal{O}(10^9)$ produced τ leptons
  – $\sim 10 \tau \rightarrow 3\mu$ events (assuming upper limit by Belle exp.)
  – Clean final state High-pT muons and large missing energy
  – Analysis in the final step of the review
τ→3µ Search Strategy (HF)

- Search for a bump at nominal τ mass peak in the invariant mass distribution of the 3µ-system
  - We expect a smoothly distributed background.
- The production rate of D and B mesons is obtained from data by measuring the event rate coming from $D_s \rightarrow \Phi \pi \rightarrow \mu \mu \pi$ decays.

- MVA discriminator for signal/background rejection
- Event categorization to improve the search sensitivity. Events are binned in
  - 3µ-system mass resolution
  - MVA discriminator
- The $\tau \rightarrow 3\mu$ signal is extracted by a simultaneous maximum likelihood fit of the thus-formed six unbinned mass distributions.
Search Strategy (HF)

- Search for a bump at nominal $\tau$ mass peak in the invariant mass distribution of the 3$\mu$-system
  - We expect a smoothly distributed background.
- The production rate of D and B mesons is obtained from data by measuring the event rate coming from $D_s \rightarrow \phi \pi \rightarrow \mu \mu \pi$ decays.

- MVA discriminator for background rejection
- Event categorization to improve the search sensitivity. Events are binned in
  - 3$\mu$-system mass resolution
  - MVA discriminator
- The $\tau \rightarrow 3\mu$ signal is extracted by a simultaneous maximum likelihood fit of the thus-formed six unbinned mass distributions.
HF Channel: Event selections

Online Selections
• **L1: 3 muons or 2 muons with kin requirement**
• **Dedicated High Level Trigger**
  – two collimated muon tracks with common vertex and $p_T > 3$ GeV
  – one track compatible with the 2$\mu$ vertex and $p_T > 1.2$ GeV
  – invariant mass (2$\mu$+trk) in the range 1.60-2.02 GeV
  – vertex(2$\mu$+trk) displaced from beam-spot by >2 sigma

Offline Selections
• **Muon Selections**
  – at least 3$\mu$ w/ $p_T > 2$ GeV per event, identified with Global algorithm
  – $dR(2\mu) < 0.8$ & $dz(2\mu) < 0.5$ cm
  – custom track-based isolation applied
• **3$\mu$ system selections**
  – charge = ±1
  – fiducial invariant mass window: [1.62-2.00] GeV
  – High quality secondary vertex
  – primary vertex refit removing the 3$\mu$ tracks
  – Veto on muon pairs with inv. mass close to $\Phi(1020)$
Mass resolution of the 3µ system

- The uncertainty on the mass of 3µ system varies since the muon momentum resolution depends strongly on the muon pseudorapidity
- The method has been studied and calibrated in the H→ZZ→4µ search
- Event categorization based on the resolution of the 3µ system mass

![Diagram showing mass resolution of the 3µ system](image)

**3µ in the barrel**
- Histograms showing the mass resolution in the barrel region.

**Barrel + endcap**
- Histograms showing the mass resolution in the barrel + endcap region.

**3µ in the endcap**
- Histograms showing the mass resolution in the endcap region.

The tau candidate mass in simulated events (D_s→τν, τ→3µ) in the 3 mass-resolution categories, actually corresponding to the pseudorapidity of the muons.
Background to signal discrimination

- Main source of background is the decay of B mesons into resonance that decays in muon pairs, with the third muon coming from mis-identified pions or kaons.

- **Multivariate approach to discriminate signal to background** → A BDT is trained
  - Signal: MC with properly mixed the D and B meson
  - Background from data using the 3μ-mass sidebands.

### BDT Input variables

#### 3μ system variables
- vertex fit $\chi^2$/ndof
- vertex displacement significance w.r.t PV
- angle between $V(3\mu)$-PV and 3μ vector
- additional track closest distance to $V(3\mu)$

#### Additional muon variables
- Inner track “Kink”
- track and STA muon position matching $\chi^2$
- track and muon segment compatibility
- Relative isolation
- Transverse I.P. significance (*)
- muon momentum

(*the smallest of the three)
Event categorization

- Additional categories introduced according to the BDT score.
- Keep the two categories with best signal-to-background purities, while excluding the background like phase space region.
- Category boundaries defined with a procedure based on the optimization of the signal significance simultaneously in all categories.
Signal normalization – $D_s$ channel

- The expected $\tau \rightarrow 3\mu$ signal event yield associated with $D_s$ can be written as:

$$N_{\text{sig}(D)} = \mathcal{L} \sigma(pp \rightarrow D_s) \mathcal{B}(D_s \rightarrow \tau \nu) \mathcal{B}(\tau \rightarrow 3\mu) A_{3\mu(D)} \epsilon_{\text{reco}}^{3\mu} \epsilon_{\text{trig(sig)}}^{2\mu}.$$
Signal normalization – $D_s$ channel

- The expected $\tau \to 3\mu$ signal event yield associated with $D_s$ can be written as:

$$N_{\text{sig}(D)} = \mathcal{L} \sigma(pp \to D_s) \mathcal{B}(D_s \to \tau \nu) \mathcal{B}(\tau \to 3\mu) A_{3\mu}(D) \varepsilon_{\text{reco}}^3 \varepsilon_{\text{trig(sig)}}^{2\mu}$$

Number of $D$s. How to estimate? BR from PDG Acceptances and efficiencies from MC
Signal normalization – $D_s$ channel

- The expected $\tau \rightarrow 3\mu$ signal event yield associated with $D_s$ can be written as:

$$N_{\text{sig}(D)} = \mathcal{L} \sigma(pp \rightarrow D_s) \mathcal{B}(D_s \rightarrow \tau\nu) \mathcal{B}(\tau \rightarrow 3\mu) A_{3\mu}(D) \frac{3\mu}{\epsilon_{\text{reco}}} \frac{2\mu}{\epsilon_{\text{trig(s)}}}.$$ 

Number of $D_s$. How to estimate?

- BR from PDG

Estimate $D_s \rightarrow \Phi\pi \rightarrow \mu\mu\pi$ events in data

$$N = \mathcal{L} \sigma(pp \rightarrow D_s) \mathcal{B}(D_s \rightarrow \Phi\pi \rightarrow \mu\mu\pi) A_{2\mu\pi} \frac{2\mu}{\epsilon_{\text{reco}}} \frac{2\mu}{\epsilon_{\text{trig(\mu\mu\pi)}}}.$$ 

Measured in data

- BR from PDG

Acceptances and efficiencies from MC

Then we rewrite

$$N_{\text{sig}(D)} = N \frac{\mathcal{B}(D_s \rightarrow \tau\nu)}{\mathcal{B}(D_s \rightarrow \Phi\pi \rightarrow \mu\mu\pi)} \frac{A_{3\mu}(D) \frac{3\mu}{\epsilon_{\text{reco}}} \frac{2\mu}{\epsilon_{\text{trig(s)}}}}{A_{2\mu\pi} \frac{2\mu}{\epsilon_{\text{reco}}} \frac{2\mu}{\epsilon_{\text{trig(\mu\mu\pi)}}}} \mathcal{B}(\tau \rightarrow 3\mu).$$ 

- BR from PDG

MC

Acceptances and efficiencies from MC

R.Venditti-Search for the $\tau \rightarrow 3\mu$ decay at the CMS experiment at LHC
Signal normalization – $D_s$ channel

- Number of produced $D_s$ can be derived from data, by selecting events compatible with the $D_s \to \Phi \pi \to \mu \mu \pi$

- Same triggers and selections as in signal region excepts:
  - two opposite signs muons
  - di-muon invariant mass is in the range $1.00$– $1.04$ GeV
  - 1 high quality track

- The number of $D_s \to \Phi \pi \to \mu \mu \pi$ events, $N$, can be easily extracted from the area below the rightmost peak.

- Uncertainty computation
  - 10% statistics
  - The ratio of the number of $D_s \to \Phi \pi \to \mu \mu \pi$ events to the number of $3\mu$ events in the sideband in seven different run periods has been measured
  - Max variations not exceeding 10%
Signal normalization — B channel

- Direct $B \rightarrow \tau + \ldots$ decays are the second largest source of $\tau$ leptons.

$$N_{\text{sig}(B)} = \mathcal{L} \sigma(pp \rightarrow B) \mathcal{B}(B \rightarrow \tau + \ldots) \mathcal{B}(\tau \rightarrow 3\mu) A_{3\mu(B)} \varepsilon_{\text{reco}}^3 \varepsilon_{\text{trig}(\text{sig})}^2$$

$$f = \frac{\sigma(pp \rightarrow B)\mathcal{B}(B \rightarrow D_s + \ldots)}{\sigma(pp \rightarrow D_s)}$$

- Fraction on $D_s$ mesons produced from $B$ decay and promptly (MC, normalization channel $f=0.24$)

- $f$ estimation validated in data, based on the $B \rightarrow D_s \rightarrow \Phi\tau \rightarrow \mu\mu\tau$ decay events
- Template fit method used, with the proper decay length distribution
- Events coming from $B \rightarrow D_s + \ldots$ are expected to have a longer tail wrt directly-produced $D_s$ mesons.
  - Proper decay length: $L = L_{MD}/p$
- Difference between data and MC is taken as sys. (11%)
Signal normalization – B channel

- Direct $B \rightarrow \tau + \ldots$ decays are the second largest source of $\tau$ leptons.

\[
N_{\text{sig}(B)} = \mathcal{L} \sigma(pp \rightarrow B) \mathcal{B}(B \rightarrow \tau + \ldots) \mathcal{B}(\tau \rightarrow 3\mu) A_{3\mu(B)} \epsilon_{\text{reco}}^{3\mu} \epsilon_{\text{trig(sig)}}^{2\mu}
\]

Fraction on $D_s$ mesons produced from $B$ decay and promptly (MC, normalization channel $f=0.24$)

\[
f = \frac{\sigma(pp \rightarrow B) \mathcal{B}(B \rightarrow D_s + \ldots)}{\sigma(pp \rightarrow D_s)}
\]

$N_{\text{sig}(B)} = N f \frac{\mathcal{B}(B \rightarrow \tau + \ldots)}{\mathcal{B}(D_s \rightarrow \phi \pi \rightarrow \mu\mu\pi) \mathcal{B}(B \rightarrow D_s + \ldots)} A_{3\mu(B)} \epsilon_{\text{reco}}^{3\mu} \epsilon_{\text{trig(sig)}}^{2\mu} A_{2\mu\pi} \epsilon_{\text{reco}}^{2\mu} \epsilon_{\text{trig(\mu\mu\pi)}}^{2\mu} \mathcal{B}(\tau \rightarrow 3\mu).
$

- $f$ estimation validated in data, based on the $B \rightarrow D_s \rightarrow \Phi\pi \rightarrow \mu\mu\pi$ decay events
- Template fit method used, with the proper decay length distribution
- Events coming from $B \rightarrow D_s + \ldots$ are expected to have a longer tail wrt directly-produced $D_s$ mesons.
  - Proper decay Lenght: $L = L M/p$
- Difference between data and MC is taken as sys. (11%)
## Systematics

### Signal modeling uncertainties

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Yield</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty on $D_s$ normalization</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Relative uncertainty in $B(D_s \to \tau\nu)$</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Relative uncertainty in $B(D_s \to \phi\pi \to \mu\mu\pi)$</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Relative uncertainty in $B(B \to D_s + \ldots)$</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Relative uncertainty in $B(B \to \tau + \ldots)$</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Uncertainty in $f (B/D)$ ratio</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Uncertainty on $D^+$ as a source of $\tau$</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Uncertainty on $B_s$ as a source of $\tau$</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>Uncertainty in number of events triggered by trimuon trigger</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Uncertainty in the ratio of acceptances $A_{sig}/A_{2\mu\pi}$</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Muon reconstruction efficiency</td>
<td>1.5%</td>
<td></td>
</tr>
<tr>
<td>Charged pion reconstruction efficiency</td>
<td>2.3%</td>
<td></td>
</tr>
<tr>
<td>BDT cut efficiency</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>Mass scale uncertainty</td>
<td>0.07%</td>
<td></td>
</tr>
<tr>
<td>Mass resolution uncertainty</td>
<td>2.5%</td>
<td></td>
</tr>
</tbody>
</table>

### Background Modeling uncertainties
- The statistical uncertainties on the observed number of background events in the signal region vary from **3 to 15%**, depending on the event subcategory.
- The systematic uncertainty is associated with the choice of the functional form. The net effect does not exceed **1%** among all event subcategories.

- Stability across different data taking periods of the ratio $N(D_s \to \phi\pi \to \mu\mu\pi)/N(D_s \to \tau \to 3\mu)$
- Difference from estimation in data on MC
- Measured in the $3\mu$ mass sidebands
- Estimated by changing PDF sets in signal simulated events.
- Estimated in $J/\psi \to \mu\mu$ events with Tag and Probe technique.
- Estimated in $Ds \to \phi\pi \to \mu\mu\pi$ simulation and data

---

R.Venditti-Search for the $\tau \to 3\mu$ decay at the CMS experiment at LHC
Signal extraction

- Signal is extracted from a maximum likelihood fit to the $3\mu$ system invariant mass, in each of the six event categories.
  - MC signal is parametrized with Crystal Ball functions
  - exponential plus a polynomial is used to model the background.
- Systematics uncertainties are treated as nuisance parameters in the fit.
- No signal excess is observed

In these plots $BR(\tau \rightarrow 3\mu)=10^{-7}$
Results

- No significant event excess is observed in the signal region.

- Qualitative representation of the analysis power to observe a signal over background
- Obtained by combining the mass distributions in the six categories, scaled by $S/(S+B)$ ratios in each category
- Expected signal ($S$) and background ($B$) event rates are extracted from the $3\mu$-mass distribution, assuming exactly the $\tau$ lepton mass.

- Upper limits on the branching fraction $BR(\tau \rightarrow 3\mu)$ are set using the modified frequentist CLs criterion

<table>
<thead>
<tr>
<th>CL</th>
<th>Expected $BR(\tau \rightarrow 3\mu)$</th>
<th>Observed $BR(\tau \rightarrow 3\mu)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>$9.9 \times 10^{-8}$</td>
<td>$8.9 \times 10^{-8}$</td>
</tr>
<tr>
<td>95%</td>
<td>$1.2 \times 10^{-7}$</td>
<td>$1.1 \times 10^{-7}$</td>
</tr>
</tbody>
</table>
Conclusions and perspectives

• Search for CLFV $\tau \rightarrow 3\mu$ decay done for the first time at CMS
• 2016 pp collisions data analyzed, $\mathcal{L}=33$/fb $\sqrt{s}=13$ TeV
• **Upper limits** $\text{Br}(\tau \rightarrow 3\mu) < 8.9 \times 10^{-8}$ at 90% CL.

• Analysis in the W channel is ongoing → Combination of the results foreseen

**Perspectives: 2017+2018 data**

✓ x3 more statistics ($\mathcal{L}=108$/fb)
✓ new, more efficient, triggers for both HF and W channels
Thanks for your attention
Backup
D and B meson decay branching fractions

<table>
<thead>
<tr>
<th>Process</th>
<th>Branching ratio</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_s \rightarrow \tau \nu$</td>
<td>$5.48 \pm 0.23%$</td>
<td>PDG [13]</td>
</tr>
<tr>
<td>$B^+ \rightarrow \tau + \nu + D^0(\ast)$</td>
<td>$2.7 \pm 0.3%$</td>
<td>PDG [13]</td>
</tr>
<tr>
<td>Other $B^+ \rightarrow \tau + X$ decays</td>
<td>$0.7%$</td>
<td></td>
</tr>
<tr>
<td>$B^0 \rightarrow \tau + \nu + D^\ast(\ast)$</td>
<td>$2.7 \pm 0.3%$</td>
<td>PDG [13]</td>
</tr>
<tr>
<td>Other $B^0 \rightarrow \tau + X$ decays</td>
<td>$0.7%$</td>
<td></td>
</tr>
<tr>
<td>$B^+ \rightarrow D_s + X$</td>
<td>$9.0 \pm 1.5%$</td>
<td>PDG [13]</td>
</tr>
<tr>
<td>$B^0 \rightarrow D_s + X$</td>
<td>$10.3 \pm 2.1%$</td>
<td>PDG [13]</td>
</tr>
<tr>
<td>$D_s \rightarrow \phi(\mu\mu)\pi$</td>
<td>$1.3(\pm 0.1) \times 10^{-5}$</td>
<td>PDG [13]</td>
</tr>
</tbody>
</table>
**Expected number of tau leptons**

<table>
<thead>
<tr>
<th>Process</th>
<th>Number of $\tau$ leptons ($33 \text{ fb}^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pp \rightarrow c \bar{c} + ...$</td>
<td>$4.0 \times 10^{12}$ (95% $D_s$, 5% $D^\pm$)</td>
</tr>
<tr>
<td>$D \rightarrow \tau\nu$</td>
<td></td>
</tr>
<tr>
<td>$pp \rightarrow b\bar{b} + ...$</td>
<td>$1.5 \times 10^{12}$ (44% $B^\pm$, 45% $B^0$, 11% $B^0_s$, 0% $B^\pm_c$)</td>
</tr>
<tr>
<td>$B \rightarrow \tau\nu + ...$</td>
<td></td>
</tr>
<tr>
<td>$B \rightarrow D(\tau\nu) + ...$</td>
<td>$6.3 \times 10^{11}$ (98% $D_s$, 2% $D^\pm$)</td>
</tr>
</tbody>
</table>
Signal and data yields

- The signal yields are shown for $B(\tau \rightarrow 3\mu) = 10^{-7}$.
- The data yields inside parentheses are in the mass ranges of $1.78 \text{ GeV} \pm 2\sigma$, where $\sigma$ is the mass resolution (12 MeV, 19 MeV, and 25 MeV for the category A, B, and C respectively).

<table>
<thead>
<tr>
<th>Category</th>
<th>Signal sub-category 1</th>
<th>Signal sub-category 2</th>
<th>Data sub-category 1</th>
<th>Data sub-category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category A</td>
<td>6.3</td>
<td>10.3</td>
<td>360(44)</td>
<td>2502(319)</td>
</tr>
<tr>
<td>Category B</td>
<td>3.9</td>
<td>18.5</td>
<td>110(27)</td>
<td>2229(449)</td>
</tr>
<tr>
<td>Category C</td>
<td>9.4</td>
<td>9.6</td>
<td>389(107)</td>
<td>1549(400)</td>
</tr>
</tbody>
</table>
HF $\tau \rightarrow 3\mu$ Search @ HL-LHC

Table 8.3: The expected numbers of signal and background events in mass window 1.55–2.00 GeV for integrated luminosity $L = 3000$ fb$^{-1}$ (for signal, $B(\tau \rightarrow 3\mu) = 2 \times 10^{-8}$ is assumed). In absence of a signal, the projected limits on $B(\tau \rightarrow 3\mu)$ are for 90% CL, which are obtained using the standard CL$_s$ methodology [140–142].

<table>
<thead>
<tr>
<th></th>
<th>Category 1</th>
<th>Category 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of background events</td>
<td>$2.4 \times 10^6$</td>
<td>$2.6 \times 10^6$</td>
</tr>
<tr>
<td>Number of signal events</td>
<td>4580</td>
<td>3640</td>
</tr>
<tr>
<td>Trimuon mass resolution</td>
<td>18 MeV</td>
<td>31 MeV</td>
</tr>
<tr>
<td>$B(\tau \rightarrow 3\mu)$ limit per event category</td>
<td>$4.3 \times 10^{-9}$</td>
<td>$7.0 \times 10^{-9}$</td>
</tr>
<tr>
<td>$B(\tau \rightarrow 3\mu)$ 90%C.L. limit</td>
<td>$3.7 \times 10^{-9}$</td>
<td></td>
</tr>
<tr>
<td>$B(\tau \rightarrow 3\mu)$ for 3$\sigma$-evidence</td>
<td>$6.7 \times 10^{-9}$</td>
<td></td>
</tr>
<tr>
<td>$B(\tau \rightarrow 3\mu)$ for 5$\sigma$-observation</td>
<td>$1.1 \times 10^{-8}$</td>
<td></td>
</tr>
</tbody>
</table>
The CMS Forward Muon System Challenge

- The CMS Muon System performed excellently up to the end of the LHC Run2
- Nevertheless, the forward region is characterized by:
  1. Smaller magnetic field
  2. Higher neutron-induced background vs low hit multiplicity

\[ \text{trigger rate is dominated by soft muons reconstructed as high } p_T \text{ muons} \]

This effect will be increased in the HL-LHC scenario (200 pile-up interactions per BX)

\[ \text{Adding a new muon station in front of ME1/1 could be a powerful tool to improve the } \]
\[ \text{muon } p_T \text{ precision} \]

---

Present CMS Muon System slice, JINST 13 (2018) P06015, 10.1088/1748-0221/13/06/P06015

Neutron flux and average number of muon hits in the present CMS Muon System CMS-TDR-013
A new tool in the endcap Muon system: the GE1/1 Station

- Present forward muon system challenges:
  1. Small magnetic field
  2. High neutron-induced background vs low hit multiplicity
- Key role of the first muon station with small scattering and higher magnetic field → muon $p_T$ estimation presently relies entirely on the CSC
  - Trigger rate is dominated by junk muons reconstructed as high $p_T$ muons
  - Adding a new muon station in front of ME1/1 could be a powerful tool to improve the muon $p_T$ precision

Large lever arm + magnetic field + good positions resolutions results in excellent discriminating power against soft muons from the bending angle

X10 reduction in Single Muon trigger rates
The CMS Experiment towards HL-LHC

New phase space accessible for physics:
- Higgs precision era (properties and couplings)
- Electroweak precision measurement
- New physics: high mass resonance, displaced signatures dark matter
- Key role of muon final state signatures

The price to pay:
- Particle densities x5-10 → Radiation damage x10
- 50(200) pile-up interactions per BX

Intensive program of detector upgrade with the goal to keep the same performance as in Run2