Search for lepton flavour violation with the CMS detector

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On behalf of the CMS Collaboration

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Introduction

- In SM no known global symmetry requires lepton flavour conservation
  - Neutrino oscillation observed
- Charged LFV is a probe of BSM
  - Directly addresses physics of flavour and generation
- cLFV in SM due to non-zero neutrino mass is practically zero ==> Observation = unambiguous evidence of new physics
- CMS is a general purpose detector designed for high p_T physics at LHC (proton-proton collisions)
- LFV searches at CMS experiment
  - Higgs decay: H->μτ or eτ
  - Heavy state: X->eμ
  - τ-lepton LFV decay (HL-LHC projection)
  - *Leptoquarks (not in this talk)*

Outline of this talk (first three items)

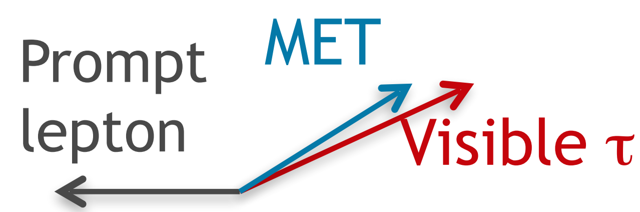
LFV in Higgs decays

- Higgs measurements so far show consistency with SM, while a significant contribution from exotic decays is still possible. Many new physics models allow Higgs LFV decays (1209.1397)
- Higgs to eμ decay is strongly constrained from the μ->eγ search limit => Br(H->eμ) < O(10^{-8})
- Weaker limits on Br(H->e/μτ) < O(0.1) from searches for τ->e/μγ and μ/e g-2 measurements
  - Direct searches for H->eτ and H->μτ promising
- CMS Run-1: a small excess (2.4σ) w.r.t. SM-only was observed for H->μτ; the best-fit branching fraction was 0.84 ± 0.38%
- H->μτ ($\mu\tau_e$ or $\mu\tau_h$) and H->eτ ($e\tau_\mu$ or $e\tau_h$) analyses updated with 2016 data (13 TeV, 36 fb^{-1}) JHEP01(2018)001, arxiv:1712.07173

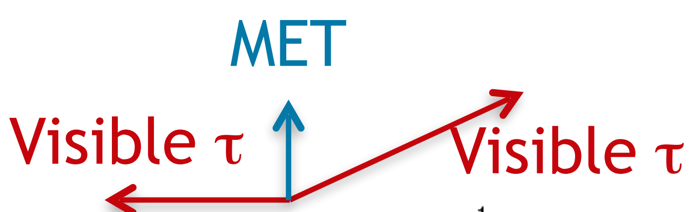
Event selection

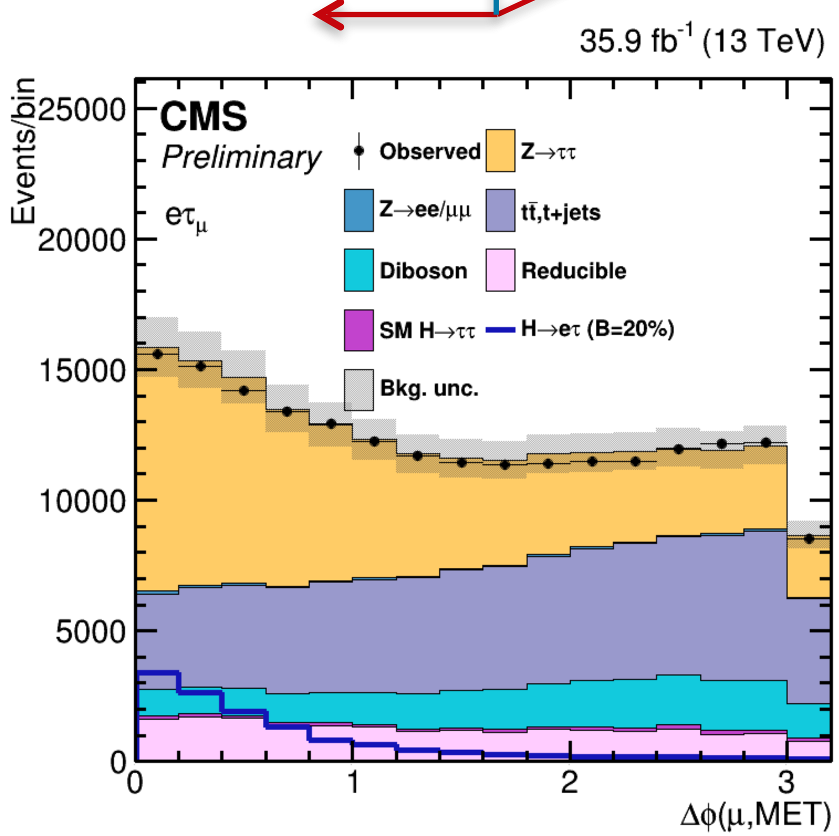
In signal, neutrinos (Missing ET) is close to aligned with the visible τ decay product

Signal event:

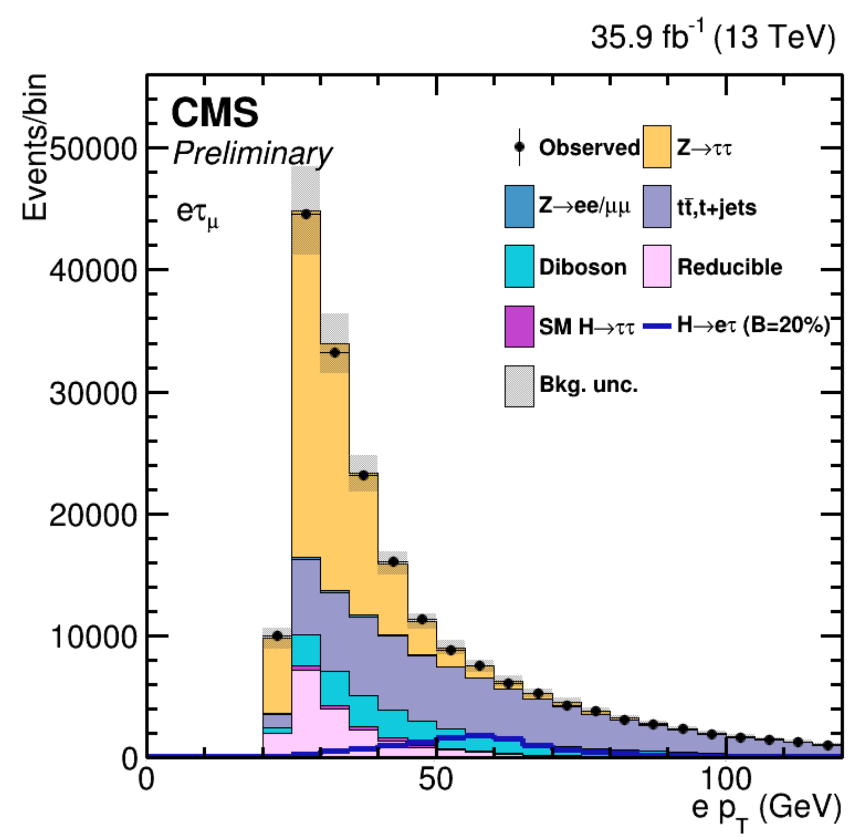


Z→ττ event:





- The main background is Z→ττ
- The decay products have on average higher p_T than in Z→ττ events (where part of the energy is lost by neutrinos in both τ decays), and in events with misidentified leptons (jet→e/μ/τ_h rate decreases with p_T)

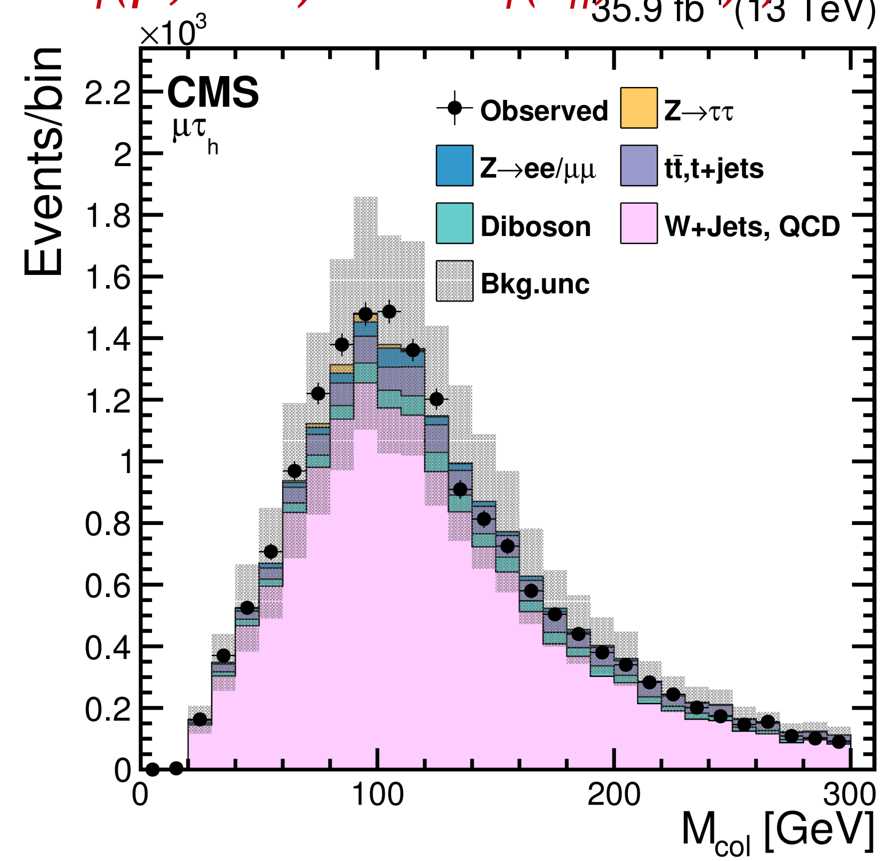


Background estimation

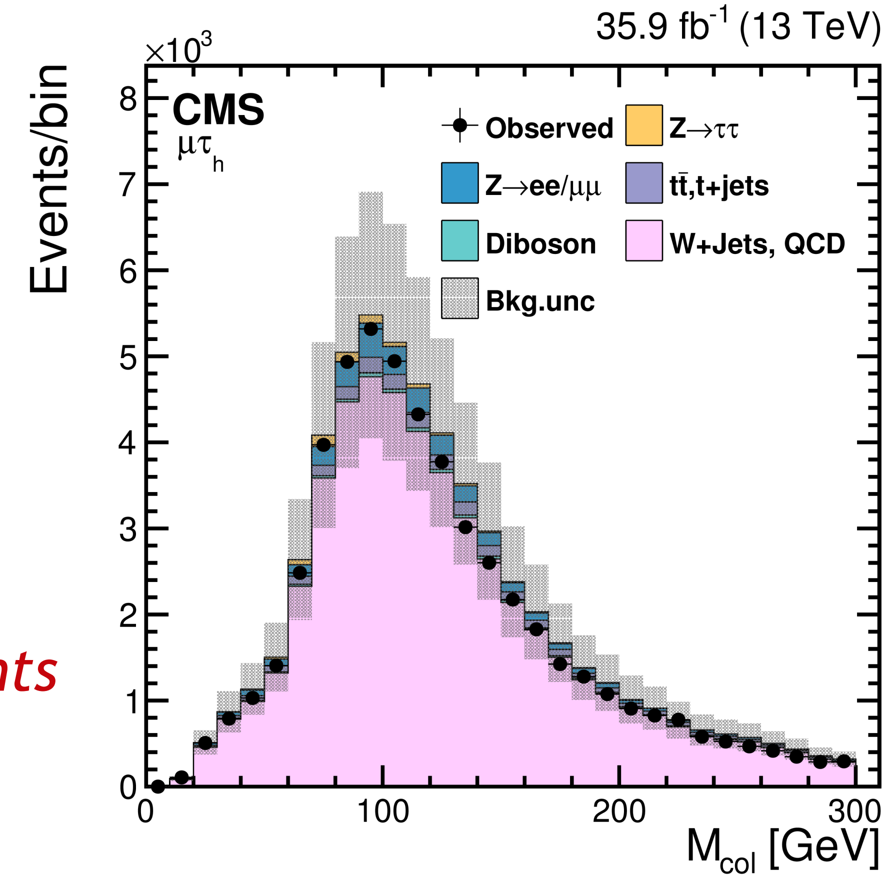
The backgrounds are estimated from MC samples, except for:

- Jet→τ_h background in the $e\tau_h$/$\mu\tau_h$ final states (mostly W+jets): observed events with anti-isolated τ_h re-weighted with a misidentification rate depending on p_T, η, and τ_h decay mode
- QCD multijet in the eμ final state: obtained from events with same-sign leptons (other MC processes subtracted from data), and re-weighted by a scale factor that accounts for same-sign/opposite-sign differences

Validation in W+jets enriched events (high $m_T(\mu,MET)$ and $m_T(\tau_h,MET)$)

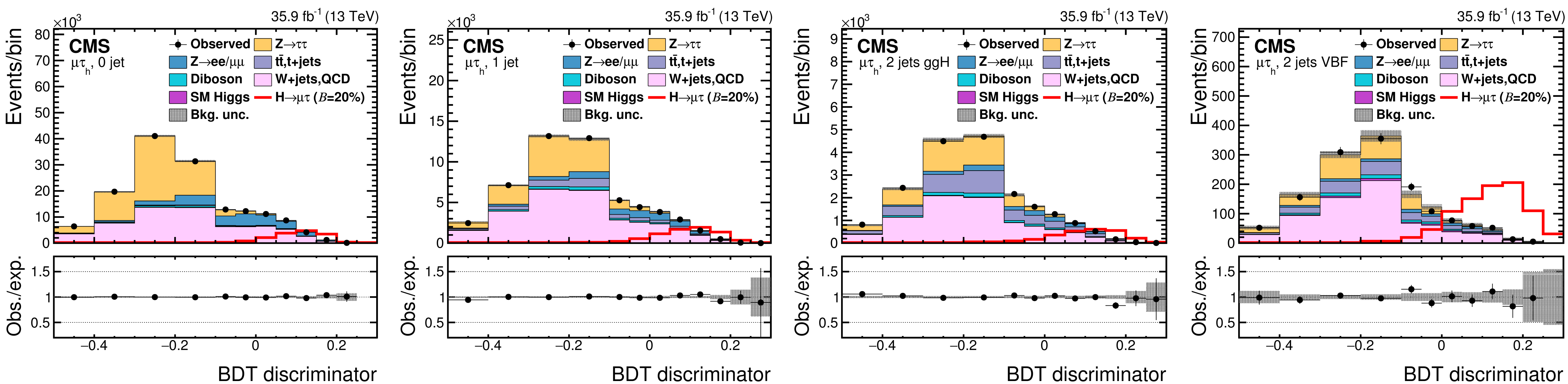


Validation in same-sign events



Signal extraction

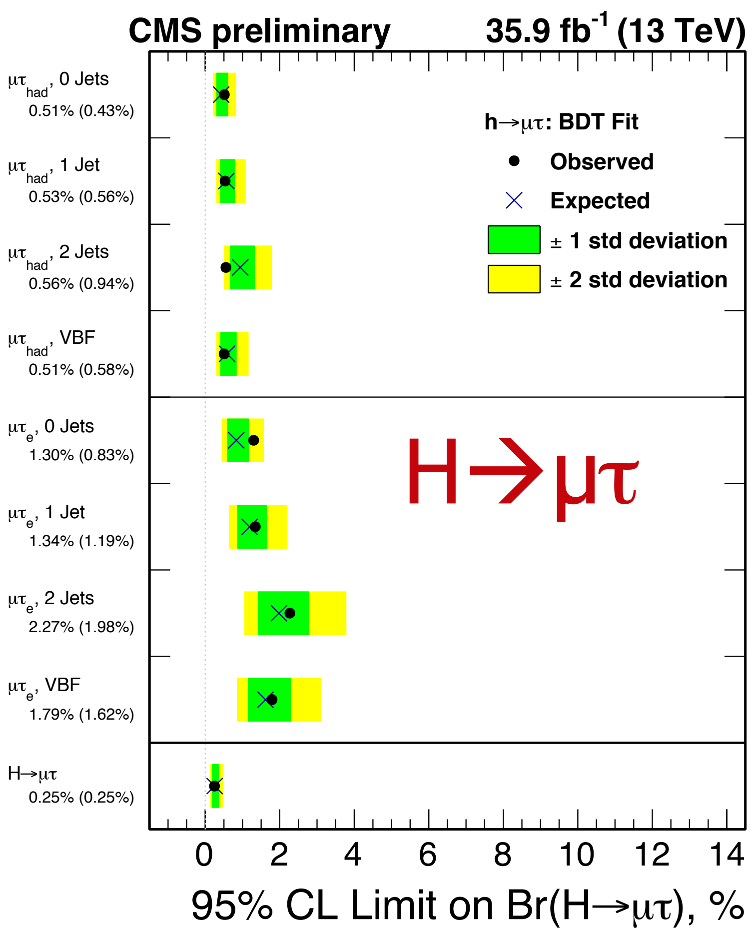
- Events divided into 4 categories to target different productions modes:
  - 0 jet: Targets gg→H events
  - 1 jet: Targets gg→H events produced in association with a jet
  - 2 jets, low mjj: Targets gg→H events with additional jets
  - 2 jets, high mjj: Targets qq→H events
- BDT trained on the signal against a selection of background samples (reducible background for $e\tau_h$ and $\mu\tau_h$, ttbar and/or $Z\rightarrow\tau\tau$ for $e\tau_\mu$ and $\mu\tau_e$)

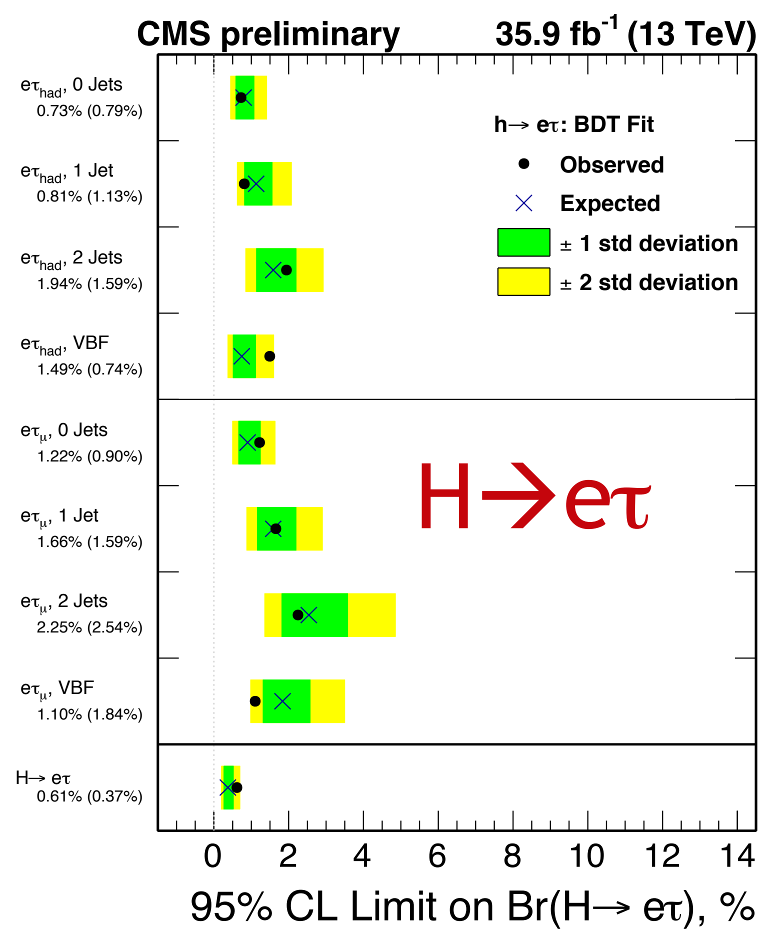


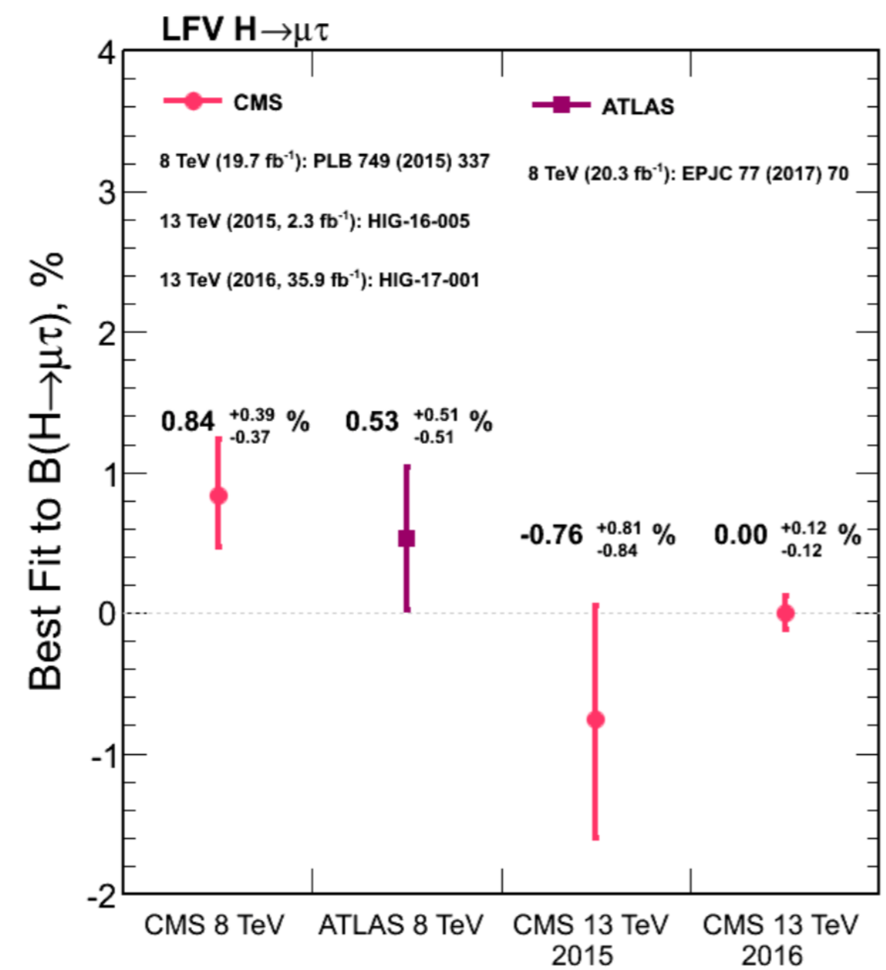
- Cross-check using a cut-based approach with the collinear mass as observable → compatible results but less sensitivity

Results of H->μτ and H->eτ searches

The most stringent to date







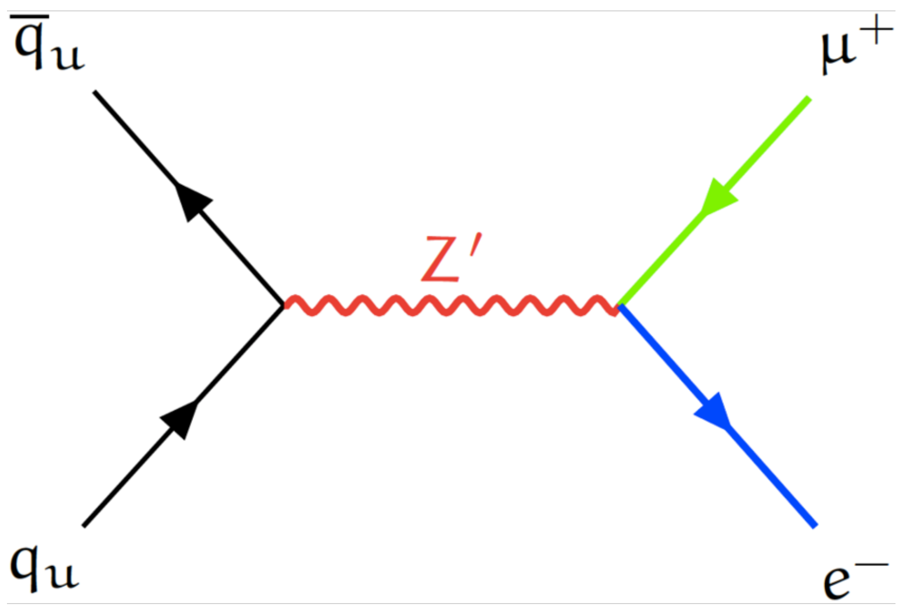
- No excess of data
- Best fit branching ratio: 0.00±0.12%
- Br(H->μτ) < 0.25% @ 95% CL

- Slight excess of data (1.6σ)
- Best fit branching ratio: 0.30±0.18%
- Br(H->eτ) < 0.61% @ 95% CL

LFV decay of heavy resonance X->eμ

2016 data (13 TeV, 36 fb^{-1})

JHEP04(2018)074, arxiv:1802.01122



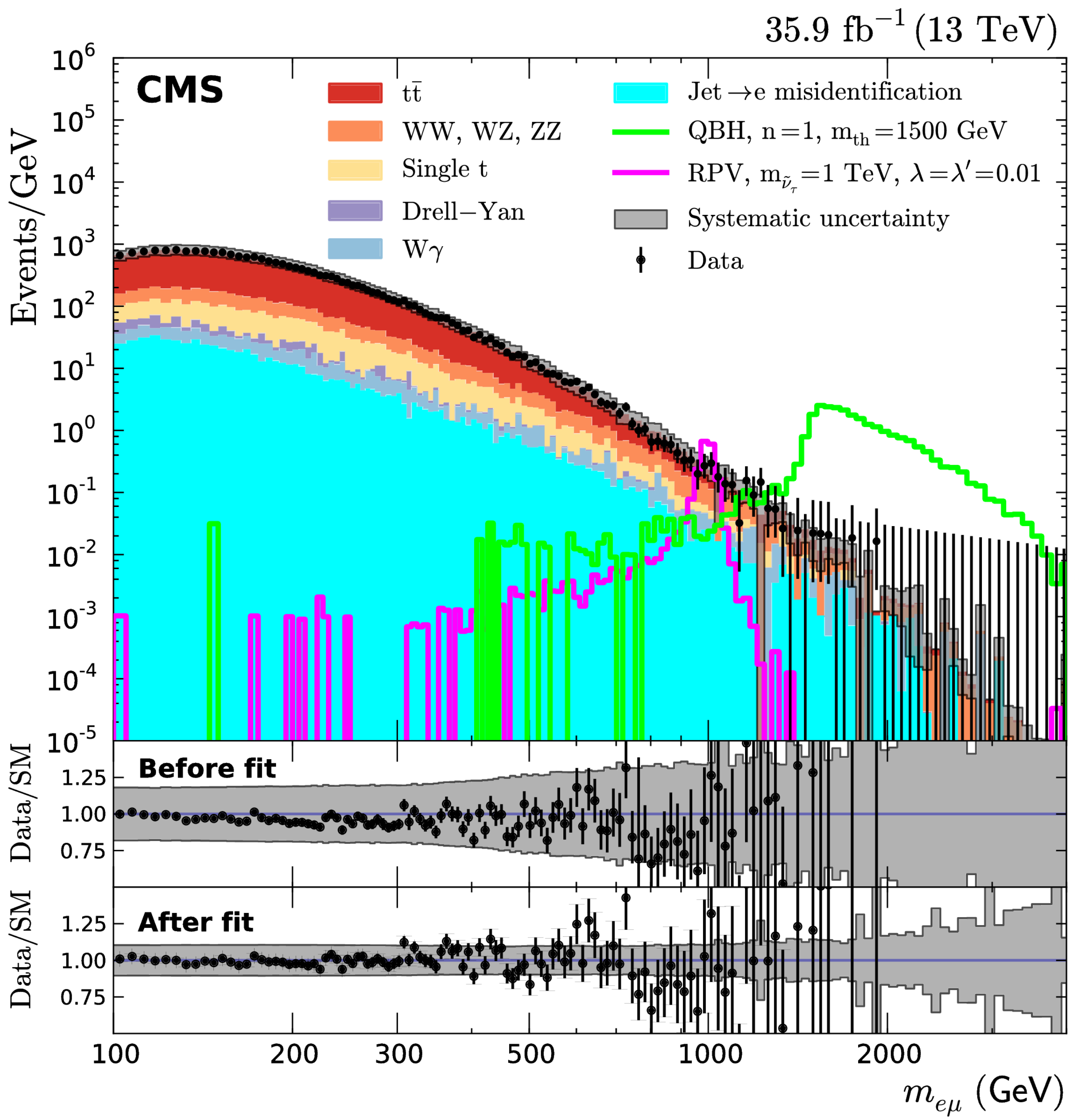
Event selections are designed to be inclusive and model independent, requiring one prompt isolated electron and one prompt isolated muon

Background estimation

- Major background: events with 2 real leptons (ttbar, WW, etc), modelled by MC
- Other background: events with at least 1 fake lepton (mostly electron), estimated using jet-to-lepton fake rate from data control sample

LFV decay of heavy resonance X->eμ

eμ invariant mass distribution



In the region m(eμ) > 1.5 TeV

Data: 4 events observed;

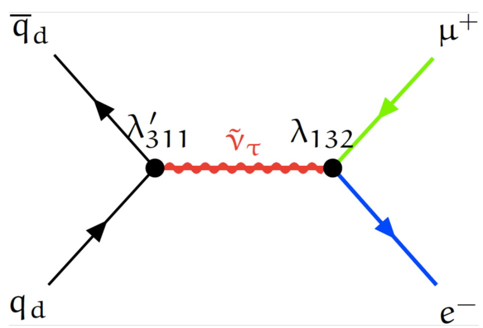
Expectation 4.64±1.28

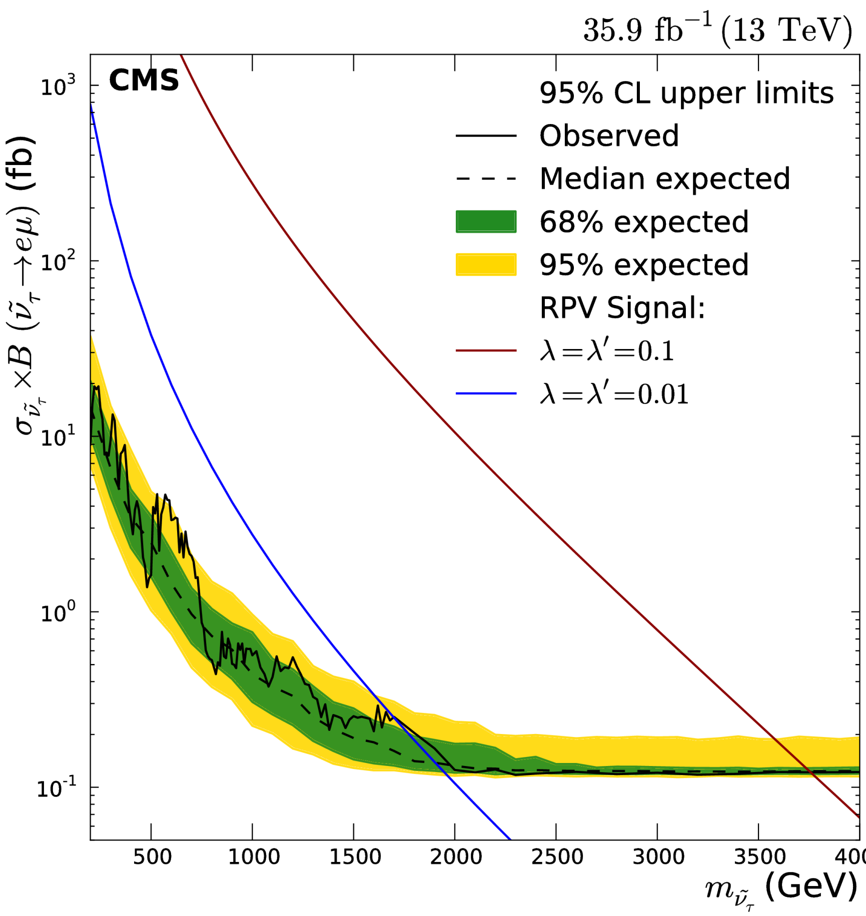
No significant excess is observed w.r.t SM expectation.

Limits are set on the product of the signal cross section and the branching fraction of signal to eμ, based on the eμ invariant mass distribution

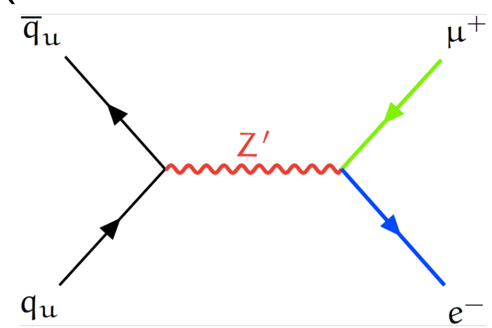
X->eμ model interpretation

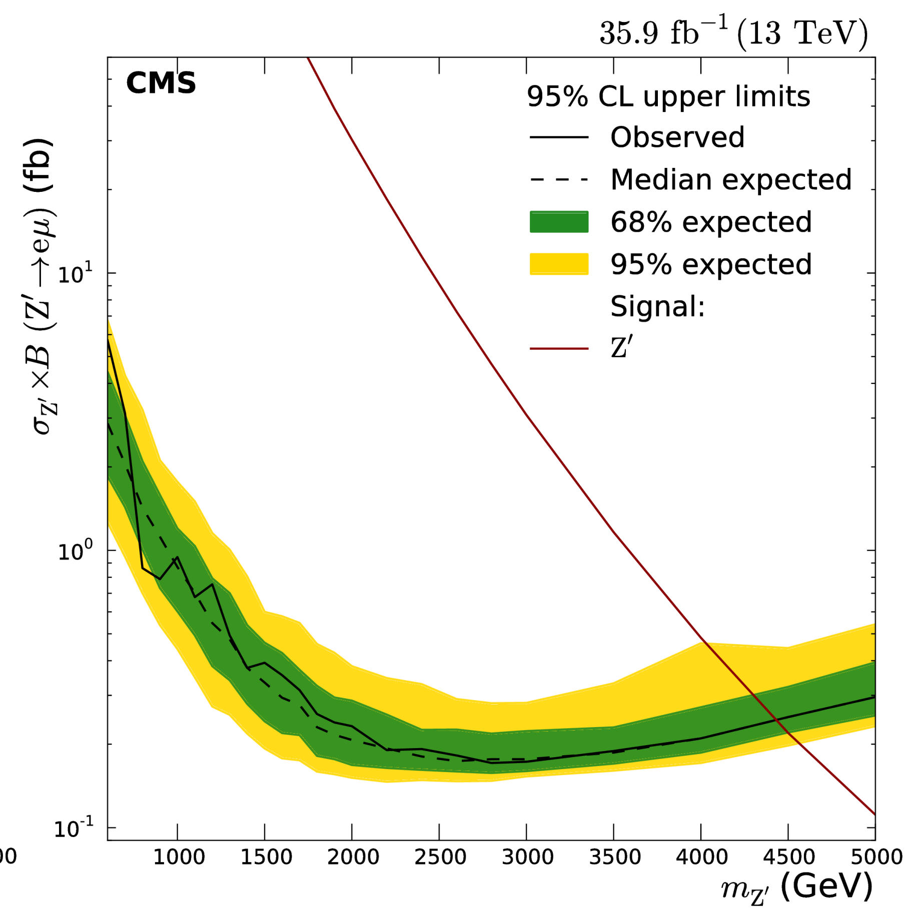
τ sneutrino production in R-parity violating SUSY (narrow resonance)



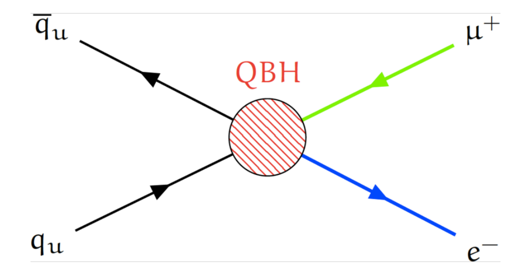


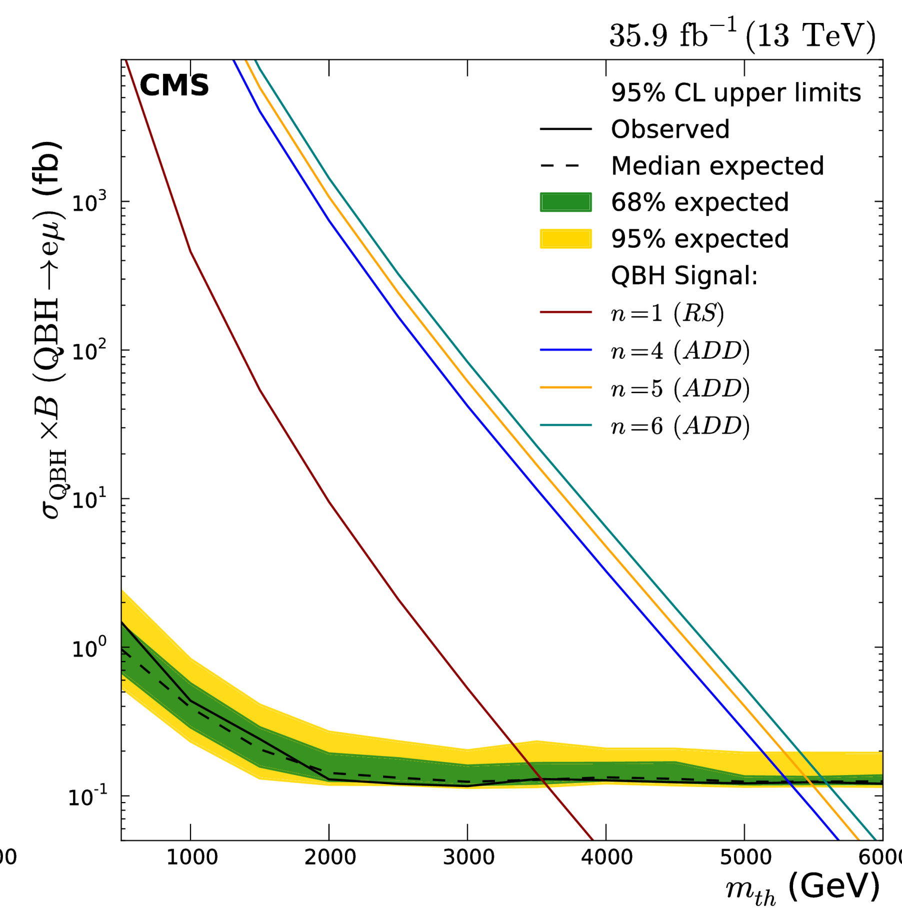
Heavy Z' gauge bosons (width 3% of the mass)





Quantum black-hole production in extra-dimension models (broader signal)



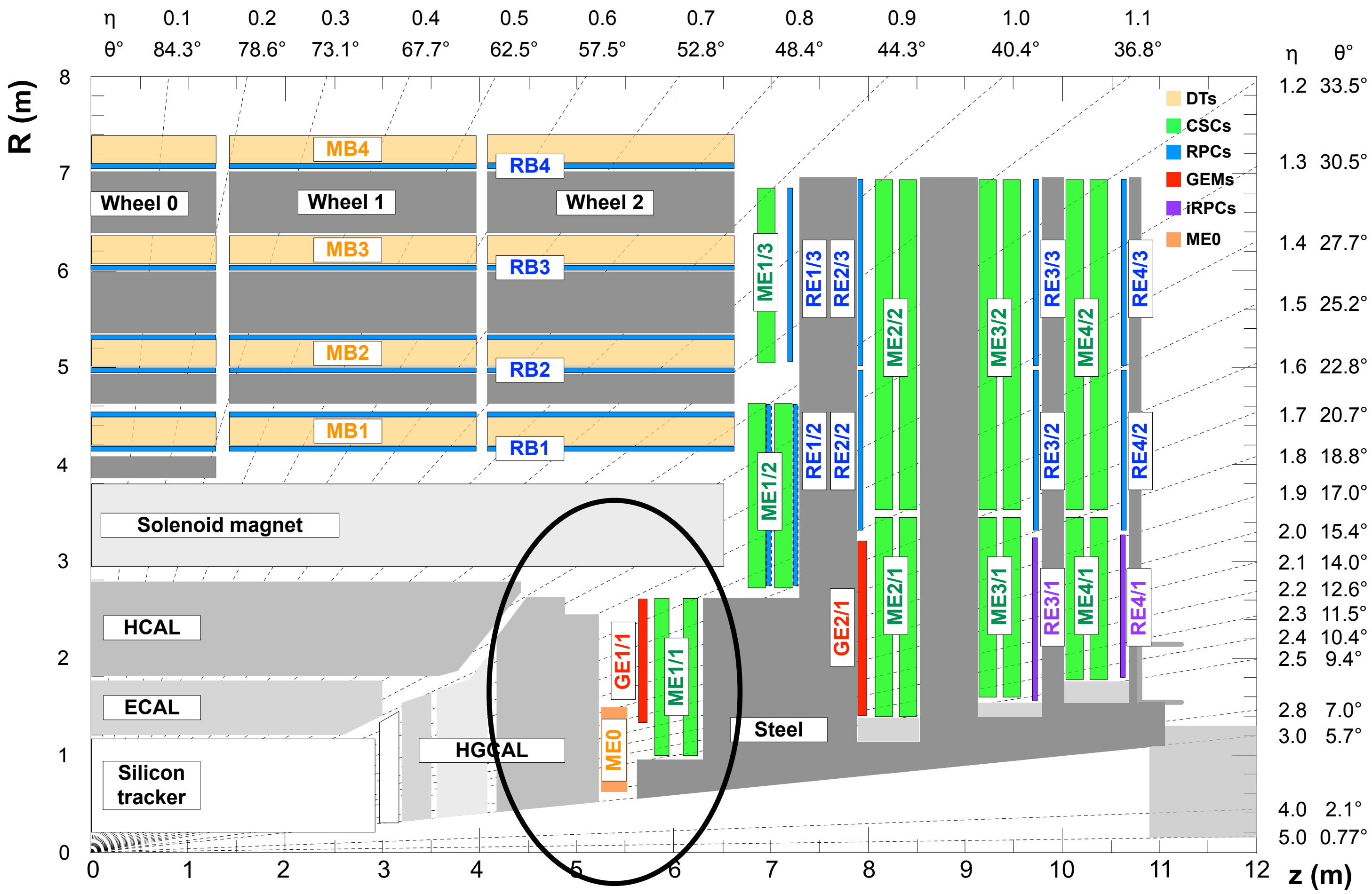


In all these interpretations, results improve previous limits by ~ 1 TeV;

The most sensitive values at colliders so far

CERN-LHCC-2017-012
CMS Muon Phase II Upgrade TDR

τ->3μ @ HL-LHC

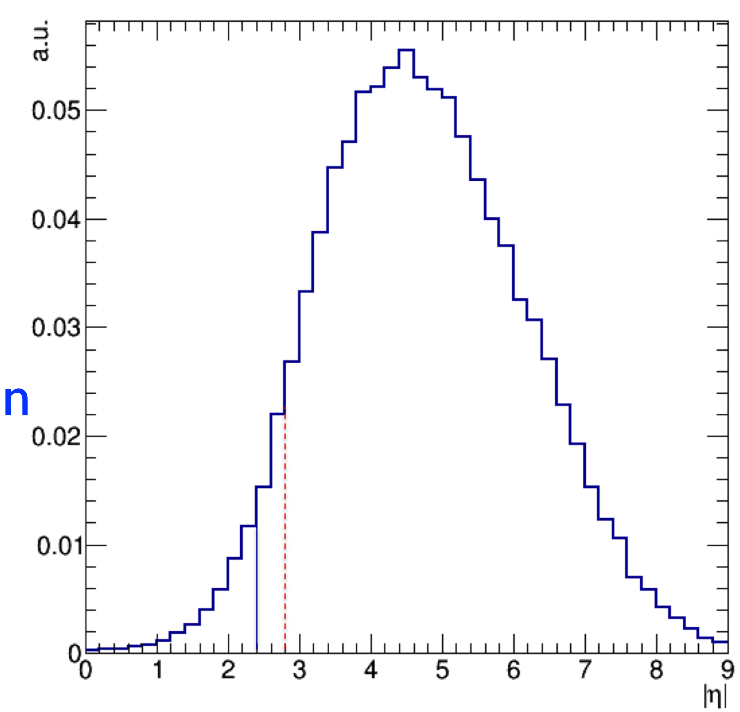


The present τ->3μ search limits:

- Belle: 2.1 x 10^{-8}
- LHCb: 4.6 x 10^{-8}

τ->3μ is used as a benchmark of CMS muon detector upgrade performance

Forward muon detectors will be enhanced. The new ME0 detector extends pseudo-rapidity from η = 2.4 to 2.8

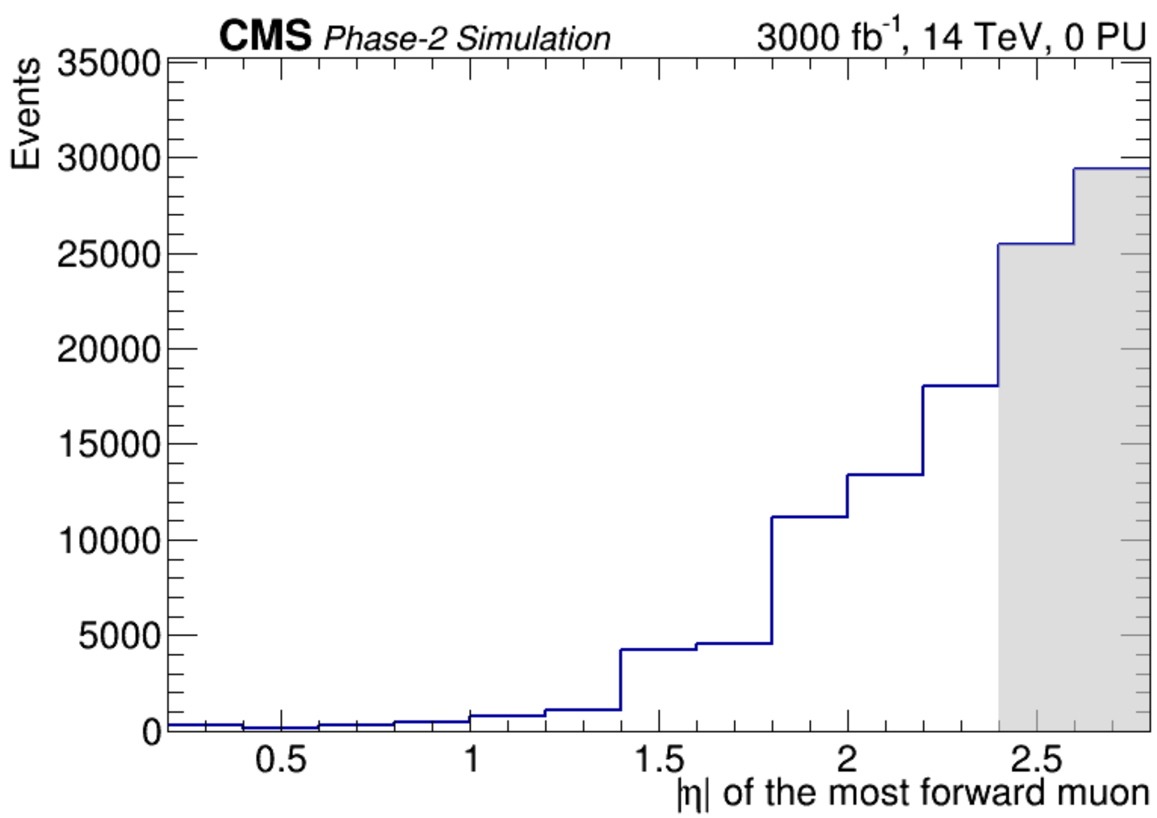


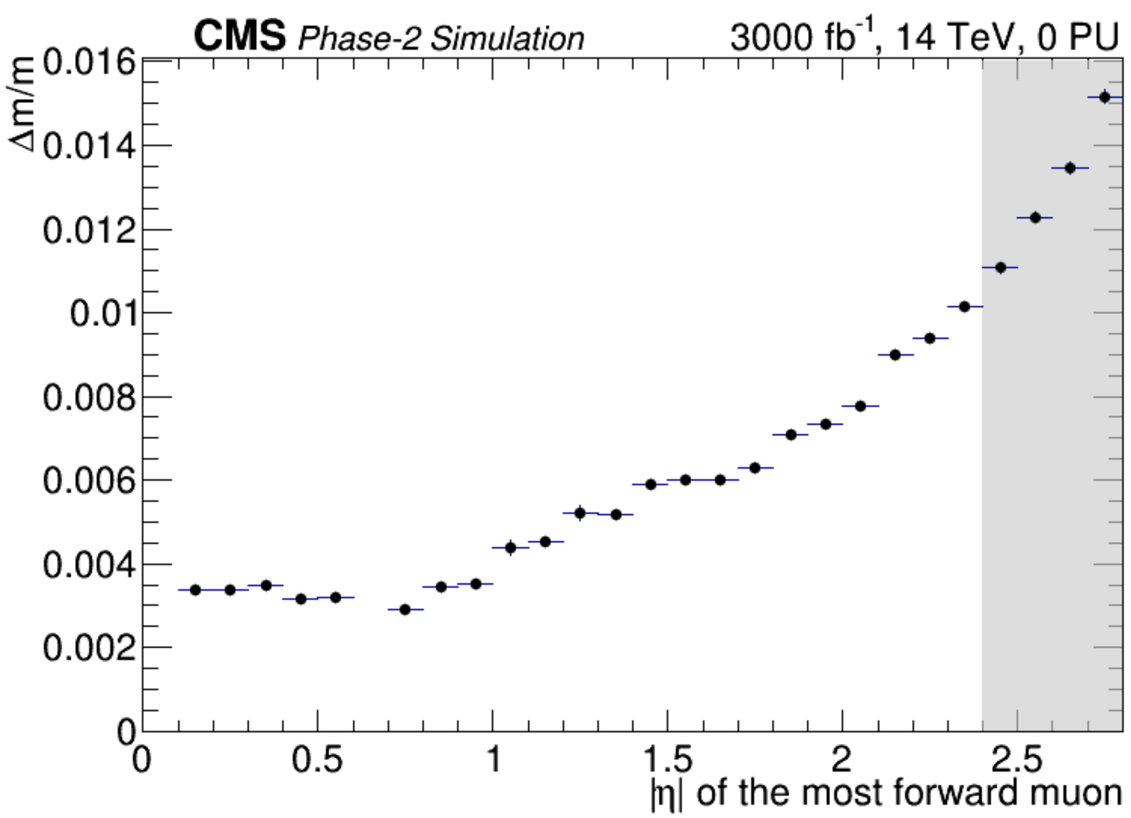
The most forward muon in τ->3μ (muon p>2.5 GeV; generator-level)

The major source of τ at LHC is D,B meson decays

τ->3μ @ HL-LHC

The shaded area corresponds to the range covered by ME0 detector only





The signal acceptance is doubled at reconstruction level with ME0 detector

But of course, these "extended" muons have worse momentum resolution

τ->3μ @ HL-LHC

Signal and background yields in [1.55, 2.00] GeV, assuming Br(τ->3μ)=2x10^{-8}

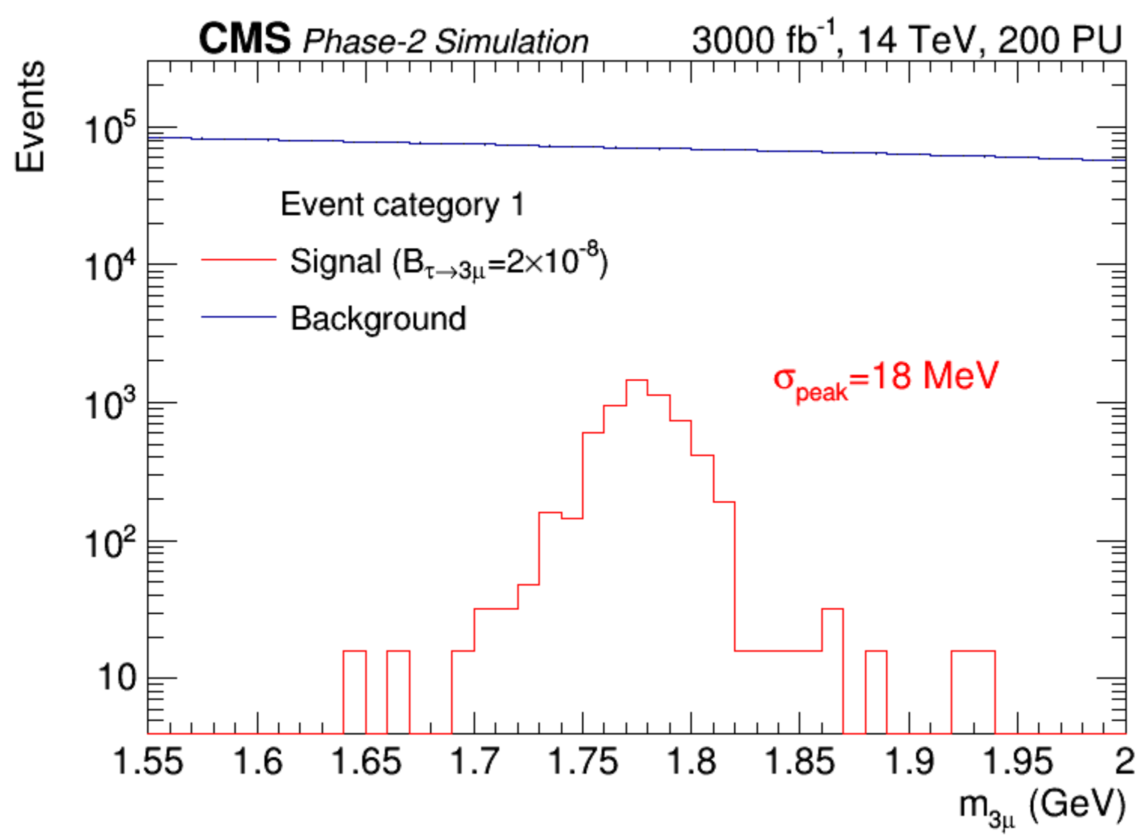
	Category 1	Category 2
Number of background events	2.4×10^6	2.6×10^6
Number of signal events	4 580	3 640
Trimuon mass resolution	18 MeV	31 MeV
$B(\tau \to 3\mu)$ limit per event category	4.3×10^{-9}	7.0×10^{-9}
$B(\tau \to 3\mu)$ 90%C.L. limit	3.7×10^{-9}	

MC simulation study

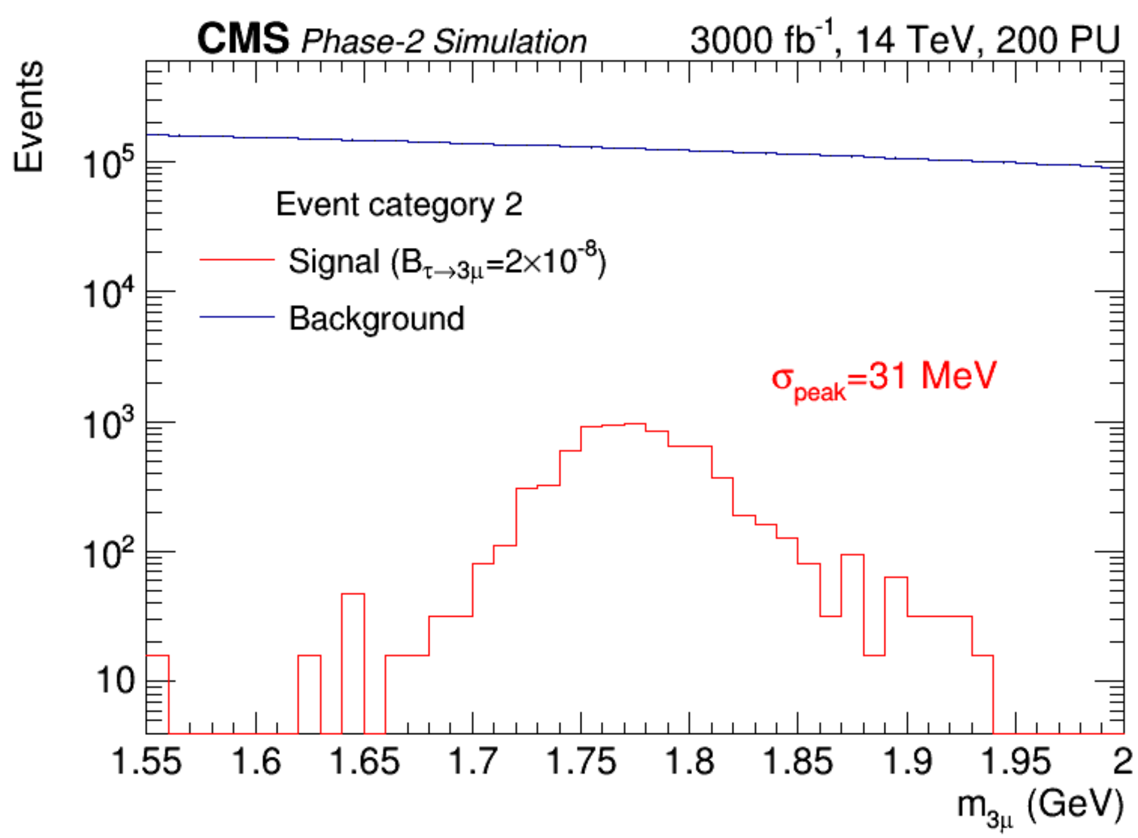
Projected to 3000 fb^{-1}

Adding ME0 detector gains 15% sensitivity

Category 1: Events without using ME0



Category 2: Events with at least one muon tagged by ME0



Note: ME0 reconstruction software was not yet optimised at the time of this study

Summary

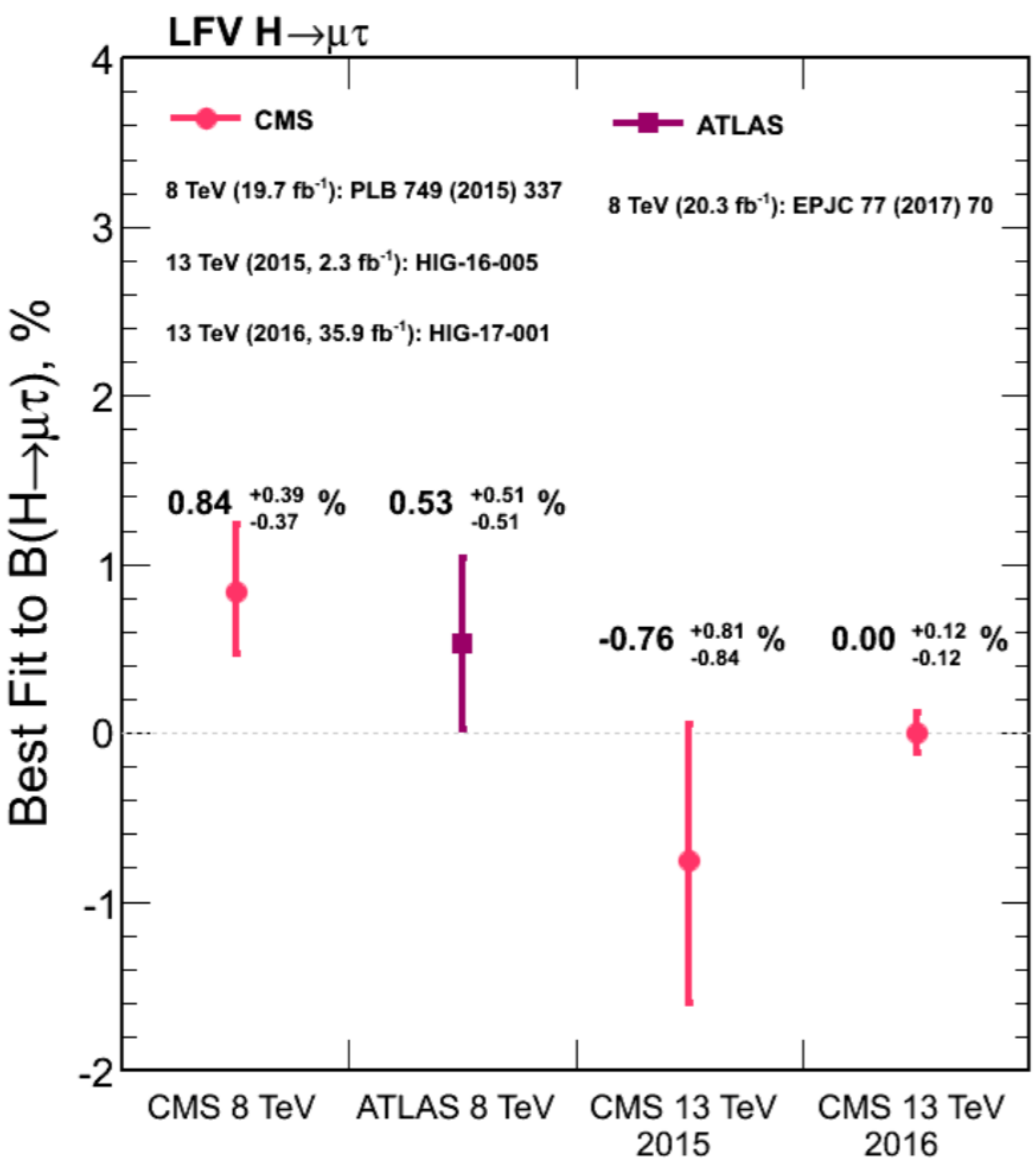
- Search for LFV decays at the CMS experiment
  - Br(H->μτ) < 0.25%; Br(H->eτ) < 0.61%
    - Previous excess in H->μτ not confirmed with new data
  - Heavy X->eμ, interpreted in various models
- More analyses using the full Run 2 (2015-2018) data to be released within one year
- CMS is also interested in LFV τ physics - stay tuned

BACK-UP

LFV Higgs

- Trigger
  - $\mu\tau$ channel: single isolated muon trigger
  - $e\tau_h$ channel: single isolated electron trigger
  - $e\tau_\mu$ channel: electron + muon trigger

Results of H→μτ and H→eτ searches



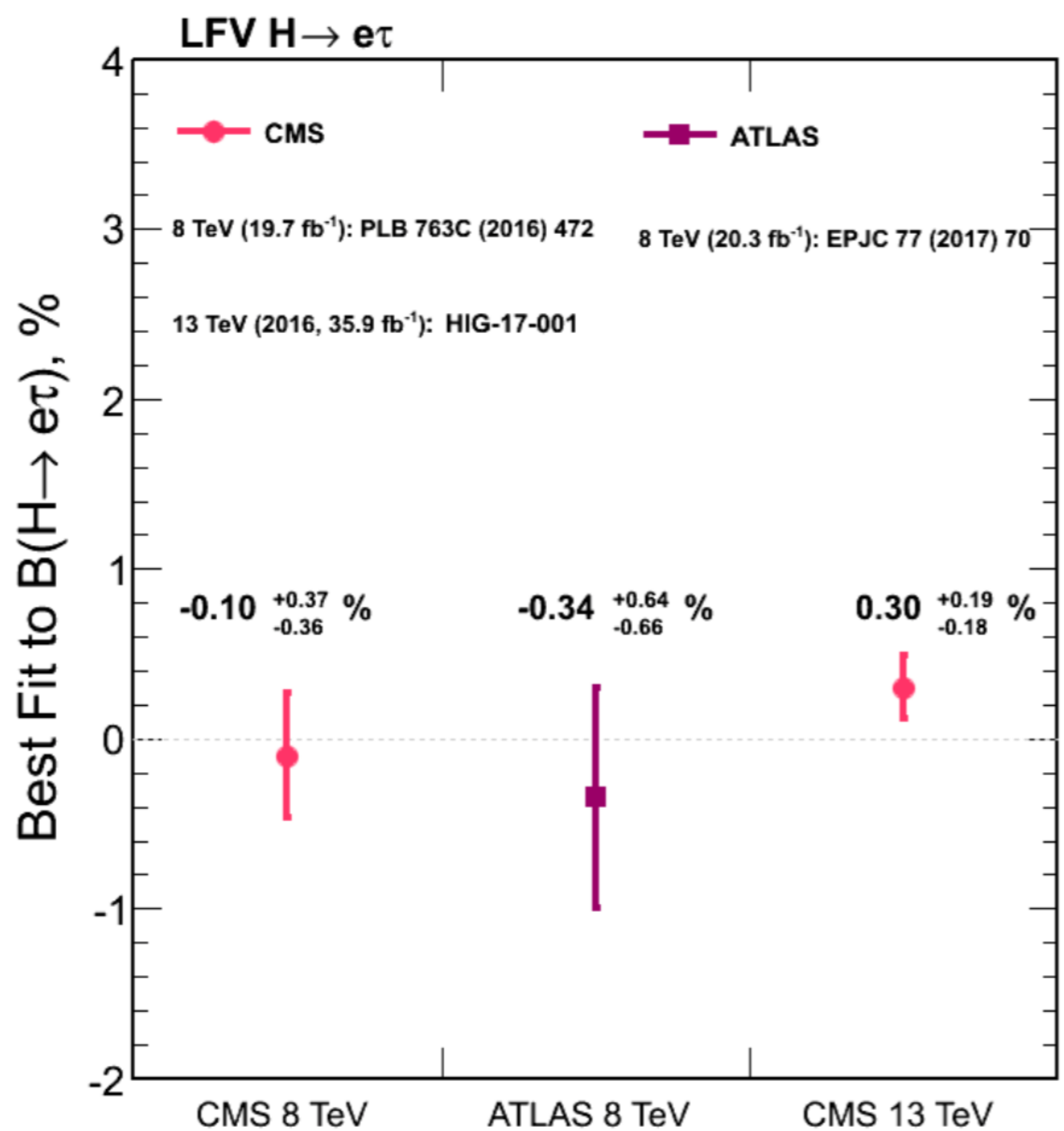


Table 1: Numbers of events for background processes, total background with its associated systematic uncertainties, and data, in four bins of eμ invariant mass.

Mass range (GeV)	$m_{e\mu} < 500$	$500 < m_{e\mu} < 1000$	$1000 < m_{e\mu} < 1500$	$m_{e\mu} > 1500$
Jet$\rightarrow$e misidentification	3601	82.8	2.92	0.849
Wγ	2462	56.2	2.76	0.562
Drell–Yan	2638	5.31	0.343	0.0145
Single t	9930	141	2.81	0.178
WW, WZ, ZZ	11126	239	13.0	2.03
$t\bar{t}$	96754	971	18.5	1.01
Total background	126513	1495	40.3	4.64
Systematic uncertainty	23495	420	13.5	1.28
Data	123150	1426	41	4

Tau production at HL-LHC (3000 fb^{-1})

	Process	# of taus	Comment
PYTHIA	pp → cc, D→$\tau\nu$	3.6×10^{14}	95% D_s, 5% $D^{\pm}$
PYTHIA	pp → bb, B→τ+...	1.4×10^{14}	44% $B^{\pm}$, 45% B^0, 11% B_s
PYTHIA	B→D($\tau\nu$)+...	0.6×10^{14}	98% D_s, 2% $D^{\pm}$
NNLO	pp → W → $\tau\nu$	6.0×10^{10}	
NNLO	pp → Z→ $\tau\tau$	1.2×10^{10}	$60 < m_{\tau\tau} < 120$ GeV

LHC is a prolific source of tau leptons: ~ 6×10^{14} at HL-LHC (3000 fb^{-1})

- **Hadronic taus:** lots, but challenging (soft, forward, poor S/B)
- **W/Z taus:** ~10^4 fewer, but relatively easier

Higgs LFV

- Lepton Flavor Violating decays of the Higgs boson would be a clear indication of physics BSM.
- Experimental LHC results:
  - **ATLAS**: 8 TeV results for H→μτ/eτ [1604.07730, 1508.03372]
  - **CMS**: H→μτ/eτ: updated with 2016 data (HIG-17-001) and no excess left, H→eμ results only with 2012 data (HIG-14-040)
  - **LHCb**: H→μτ result expected soon

- Current best limits from direct searches:

	With 8 TeV data	With 13 TeV data
BR(H→τμ)	< 1.43% (ATLAS)	< 0.25% (CMS)
BR(H→τe)	< 1.04% (ATLAS)	< 0.61% (CMS)
BR(H→eμ)	< 0.036% (CMS)	