Searches for heavy resonant structures in $e + \mu$, $e + \tau$, $\mu + \tau$

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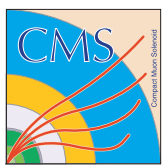
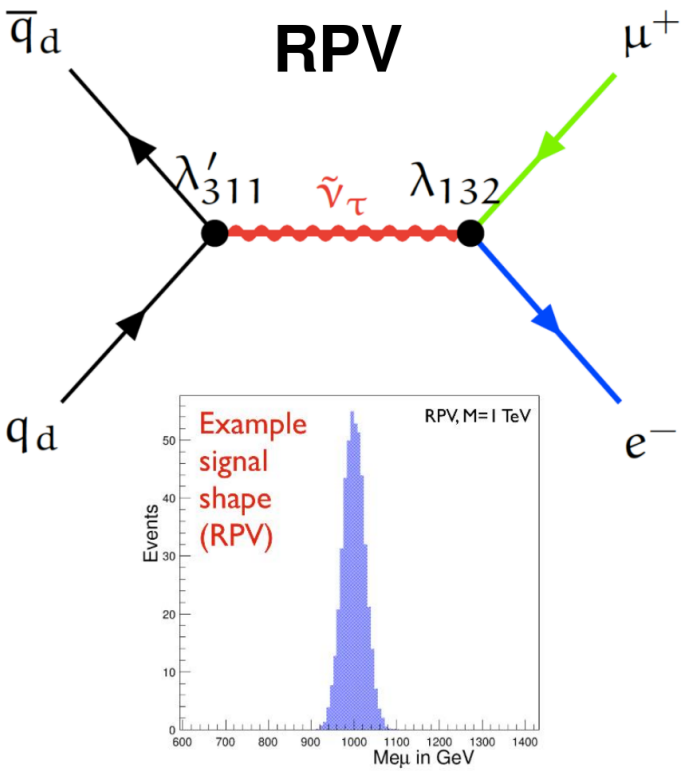


Terascale Workshop 2021

November 23, 2021

Lepton Flavour Violation

- Lepton flavour conserved in the standard model (SM)
- Neutrino oscillations imply lepton flavour violation in the neutral sector
- Lepton flavour violation (LFV) common in physics models beyond the SM



- R-parity violating supersymmetry (RPV SUSY) allows resonant production of τ sneutrino
- Sequential Standard Model (SSM) predicts new heavy gauge bosons Z'
- Quantum Black Holes (QBH)
- Search for resonant production of two charged leptons with different flavour

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Dataset & Background

Dataset

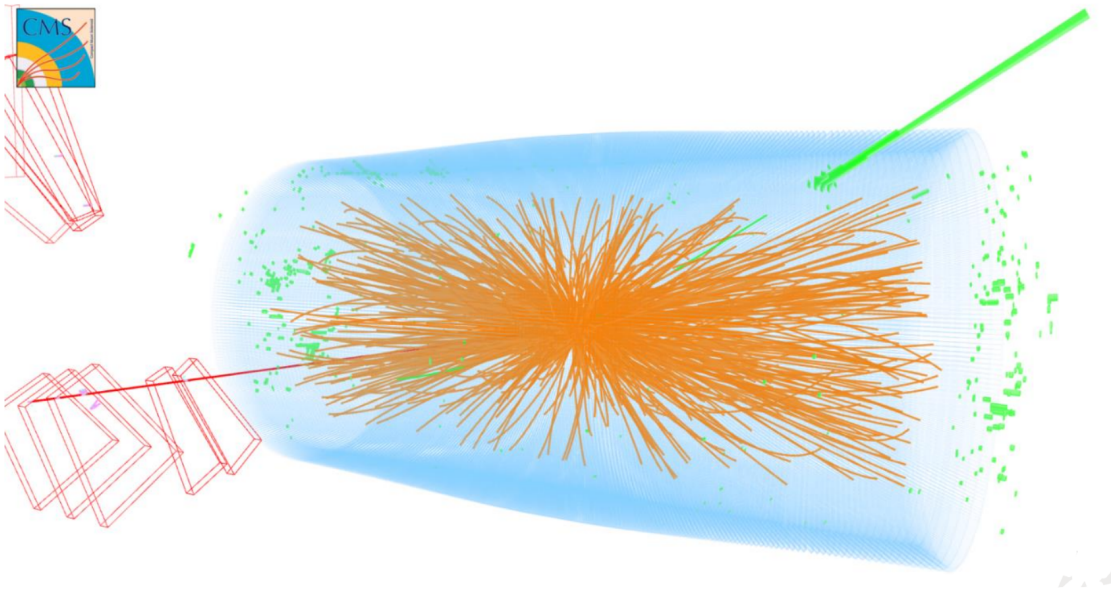
Full Run 2 data taken by CMS (2016-2018): Luminosity of 137.1 fb^{-1}

Prompt Background

Processes with two charged leptons of different flavour
(e.g. $t\bar{t}$ or Di-Boson)
Estimated from Monte Carlo

Fake Background

Jets or γ misidentified as a lepton
(e.g. W+jets, Drell-Yan)
Derived from data in addition



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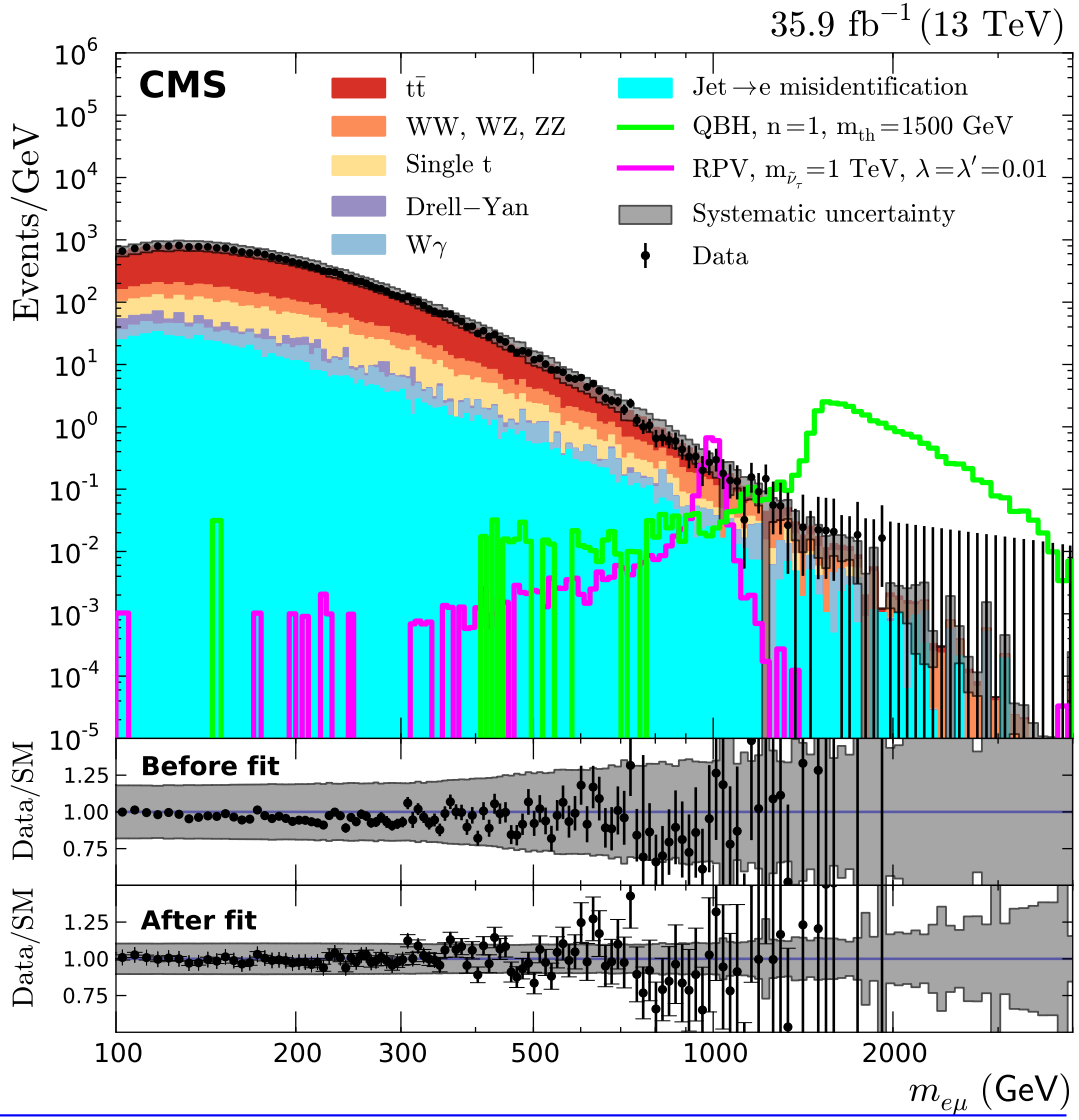
$e\mu$ channel

- Final state contains at least one e + μ
- single muon + single photon trigger
- p_T^e >35 GeV + HEEP ID
- p_T^μ >53 GeV, $|\eta|$ <2.4 + High p_T ID
- Veto electron candidate, if close to a muon to reject Bremsstrahlung



- Publication: arXiv: 1802:01122, DOI: 10.1007/JHEP04(2018)073

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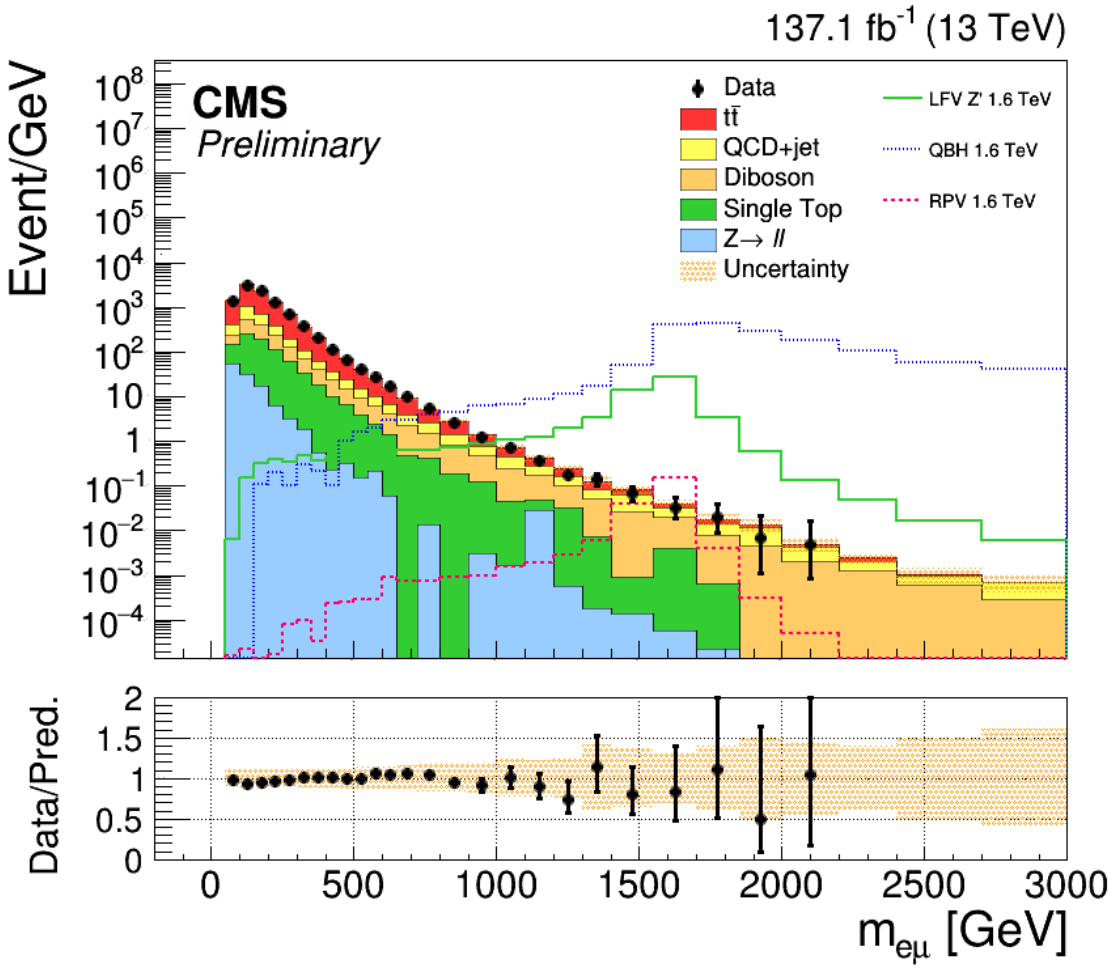

- Public as PAS: CMS PAS EXO-19-014

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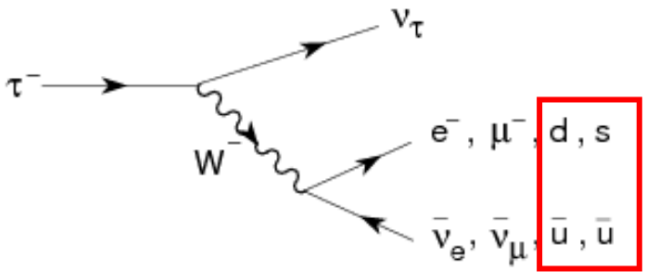
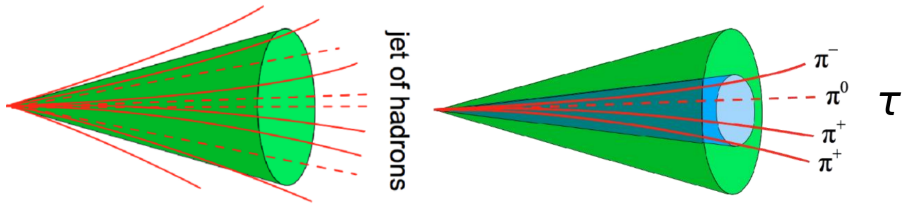
τ reconstruction



Focus on hadronic τ decay

- $\tau \rightarrow \nu_\tau + h^\pm + n(\pi^0) \approx 49.5\%$
- $\tau \rightarrow \nu_\tau + 3h^\pm + n(\pi^0) \approx 15.2\%$

- τ_{had} looks similar to a jet of hadrons



- Use isolation and fragmentation for distinction (DeepTau ID)
- Selection efficiency of $\tau \approx 65\%$ (from $\approx 45\%$ using MVA)

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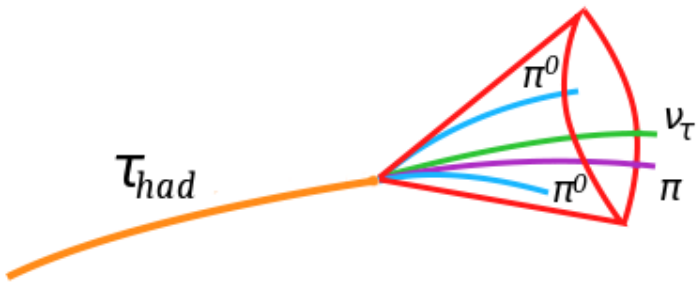
Collinear Mass

$$\tau_{had} \rightarrow \text{jet} + \nu_\tau$$

In detector: $\tau_{had} \rightarrow \tau_{vis} + p_T^{miss}$



Reconstruction of Collinear Mass

- High mass search: τ has high momentum
- Decay products will be boosted $\rightarrow p_T^{miss}$ has similar direction as τ_{vis}
- Take p_T^{miss} component in τ_{vis} vector direction $\rightarrow p_{T,coll}^{miss}$
- Fraction of energy carried by the decay products of the τ: $x_\tau^{vis} = \frac{\tau_{vis}}{\tau_{vis} + p_{T,coll}^{miss}}$
- Collinear mass derived from the visible mass using energy fraction: $m_{coll} = \frac{m_{vis}}{\sqrt{x_\tau^{vis}}}$

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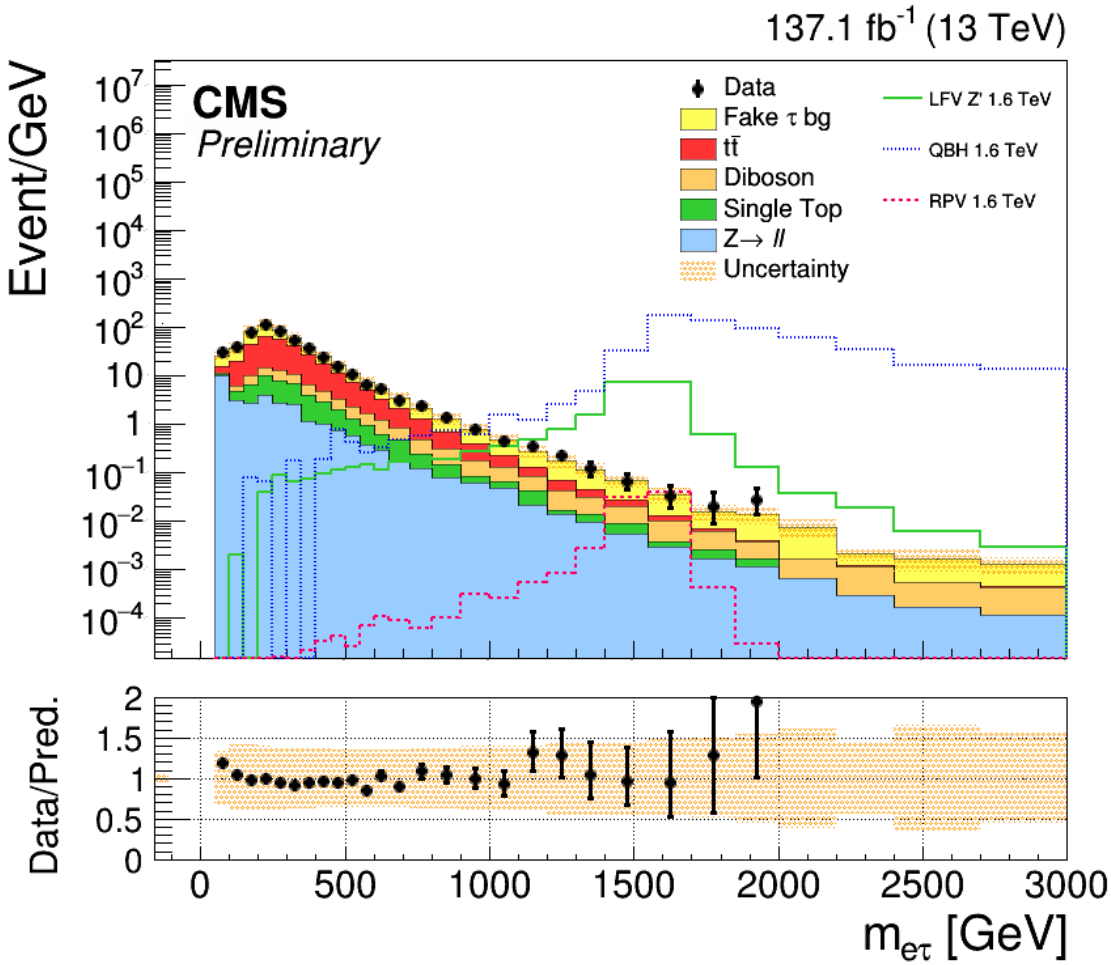
$e\tau$ channel

- Final state contains at least one $e + \tau$
- single electron + single photon trigger
- p_T^τ >30 GeV, $|\eta|$ <2.3 + DeepTau ID
- p_T^e >50 GeV, HEEP ID
- Transverse mass of e and p_T^{miss} > 120 GeV
- Veto events with high p_T μ
- Public as PAS: CMS PAS EXO-19-014



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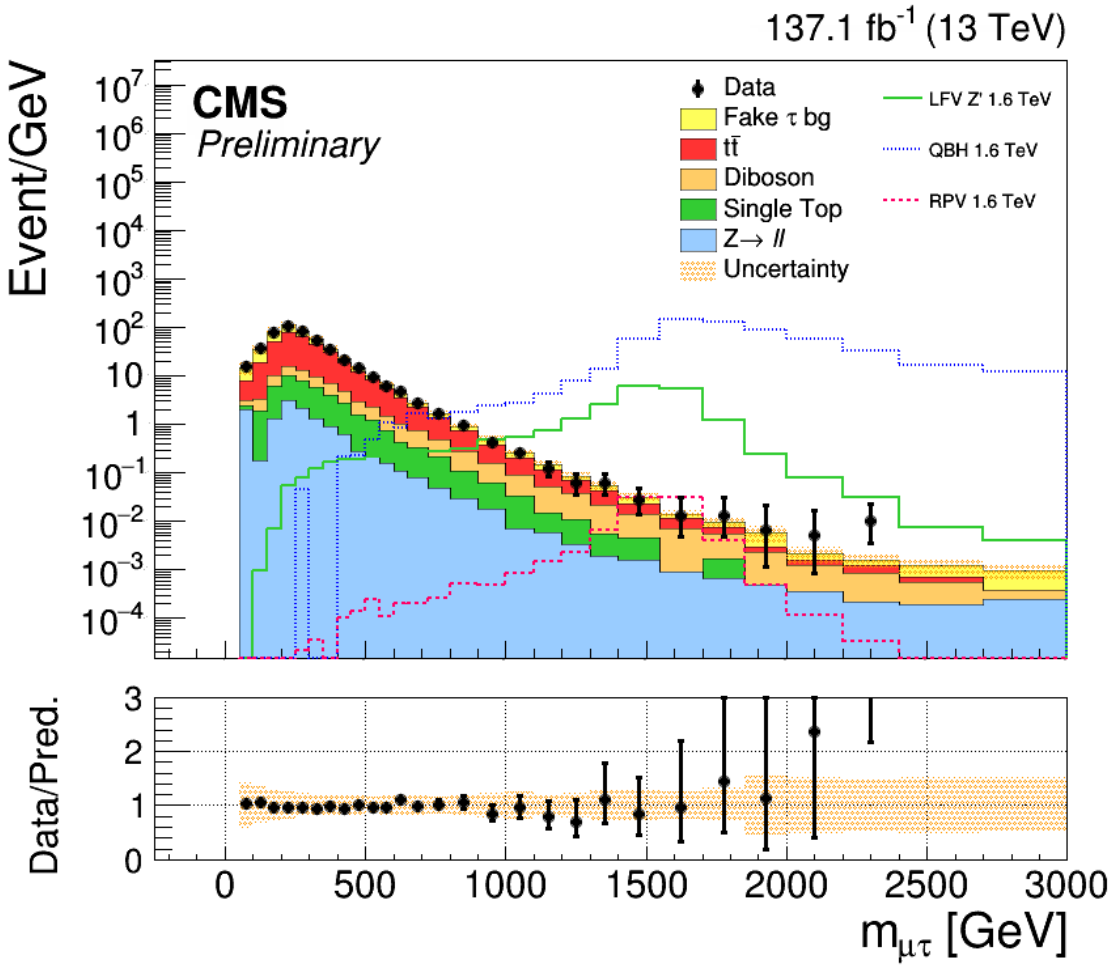
- Final state contains at least one $\mu + \tau$
- single muon trigger
- p_T^τ >30 GeV, $|\eta|$ <2.3 + DeepTau ID
- p_T^μ >53 GeV, μ as before
- Transverse mass of μ and p_T^{miss} > 120 GeV
- Veto events with HEEP e and well seperated dimuon pair

- Public as PAS: CMS PAS EXO-19-014



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Limit setting procedure

- Using Bayesian approach

$$P(theory|data) \propto P(data|theory) \cdot P(theory)$$

- Higgs Combine Tool used to set limits

Multi-bin approach:

- Uses information on signal shape
- Used for specific models (SSM, RPV, QBH)

Single-bin approach

- Uses information from just one bin
- Used to provided model-independent limit

Limit is set on $A \times \epsilon \times \mathcal{L}$

Combination of the three years done on datacard level

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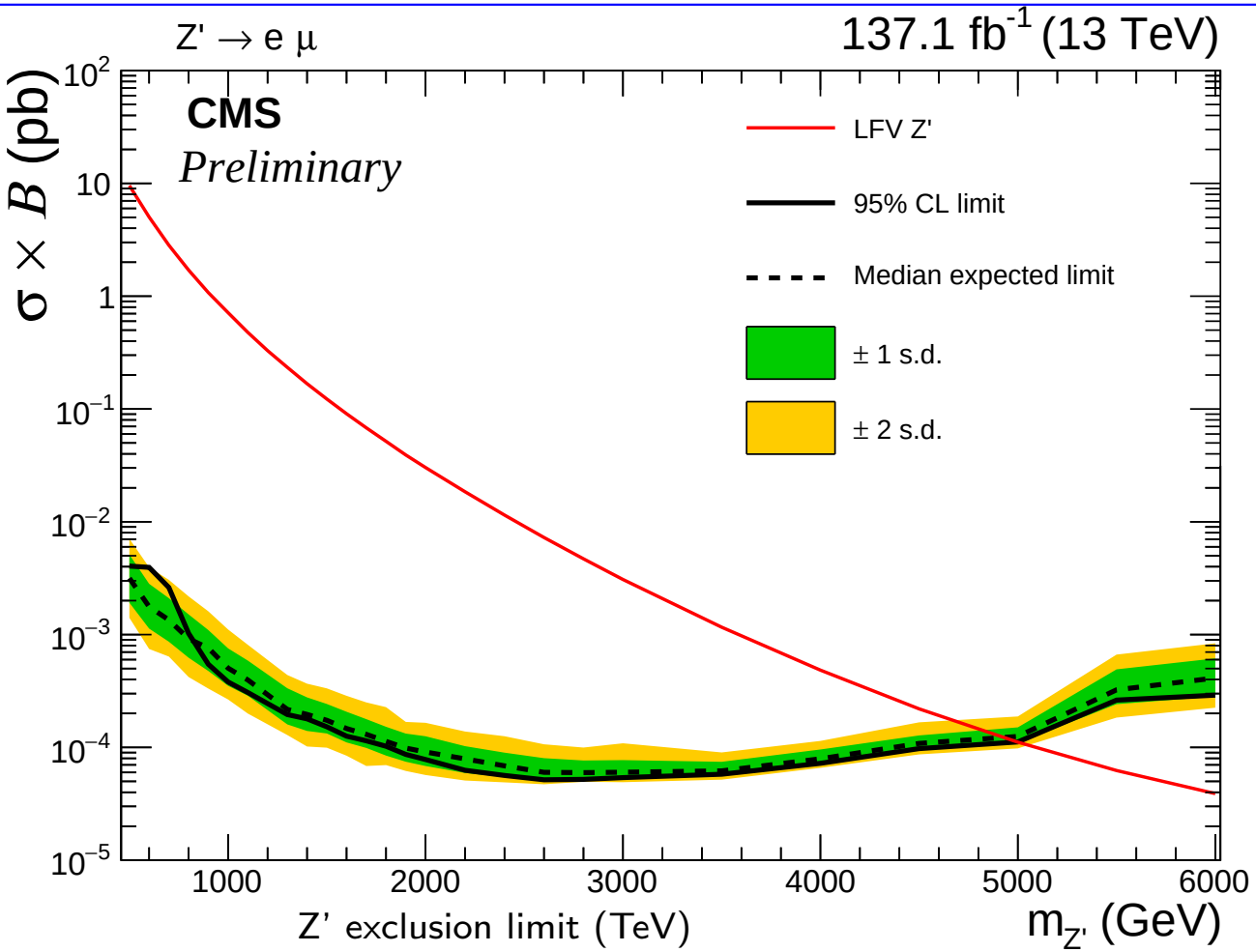
Statistical Interpretation (Z')



Channel	Z' (TeV)	RPV (TeV)	QBH
$e\mu$	5.0 (4.9)	2.2 (2.2)	5.6 (5.6)
$e\tau$	4.3 (4.3)	1.6 (1.6)	5.2 (5.2)
$\mu\tau$	4.1 (4.2)	1.6 (1.6)	5.0 (5.0)

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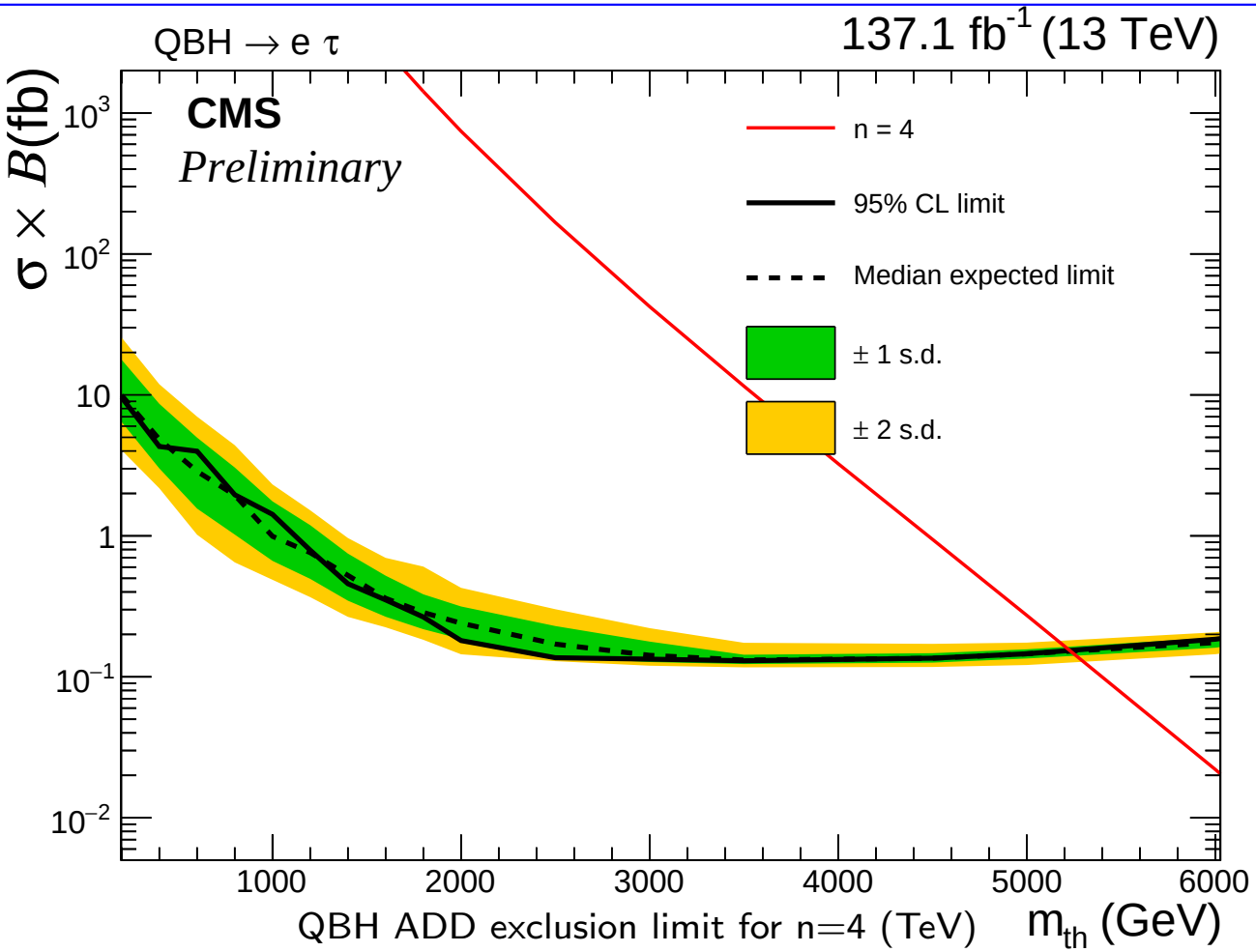
Statistical Interpretation (QBH)



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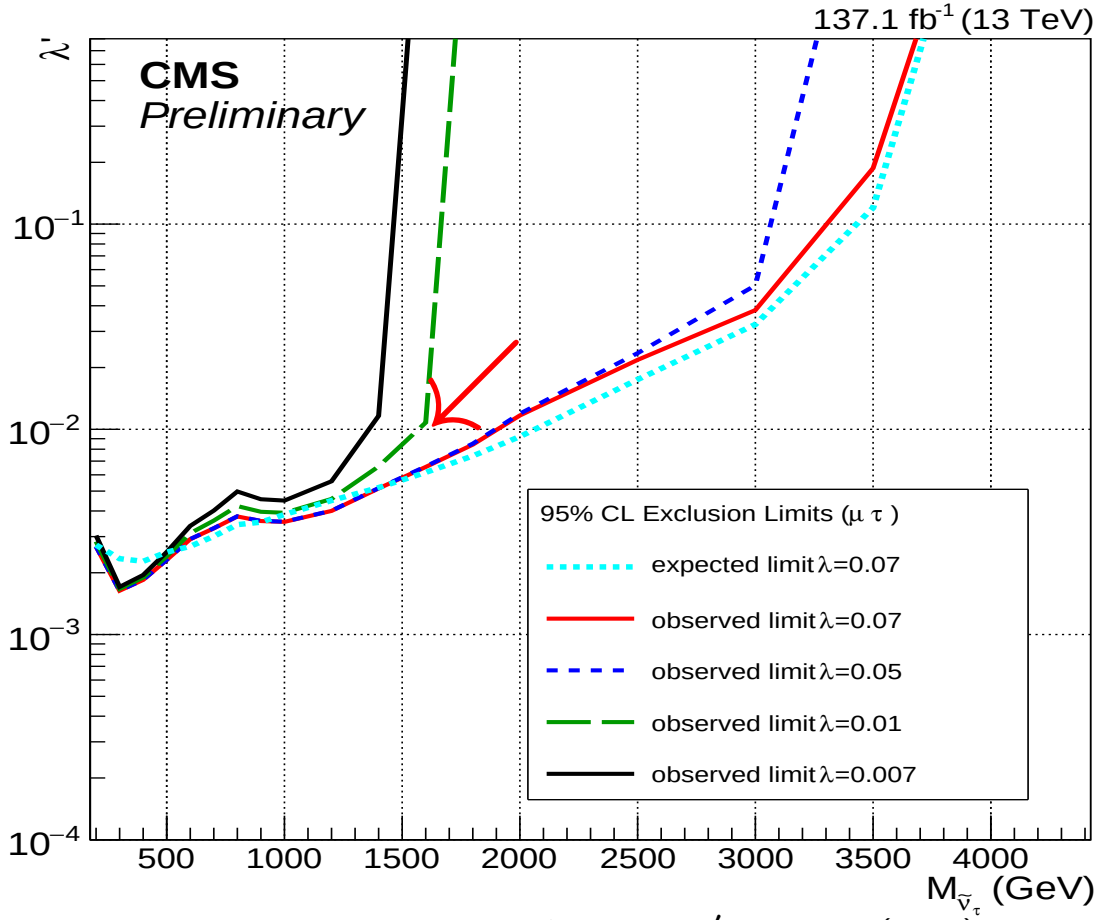
Statistical Interpretation (RPV)



RPV exclusion limit for $\lambda = \lambda' = 0.01$ (TeV)

Channel	Z' (TeV)	RPV (TeV)	QBH
$e\mu$	5.0 (4.9)	2.2 (2.2)	5.6 (5.6)
$e\tau$	4.3 (4.3)	1.6 (1.6)	5.2 (5.2)
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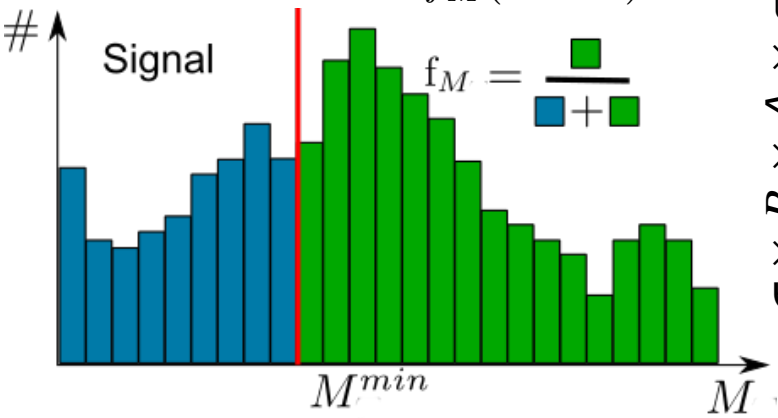
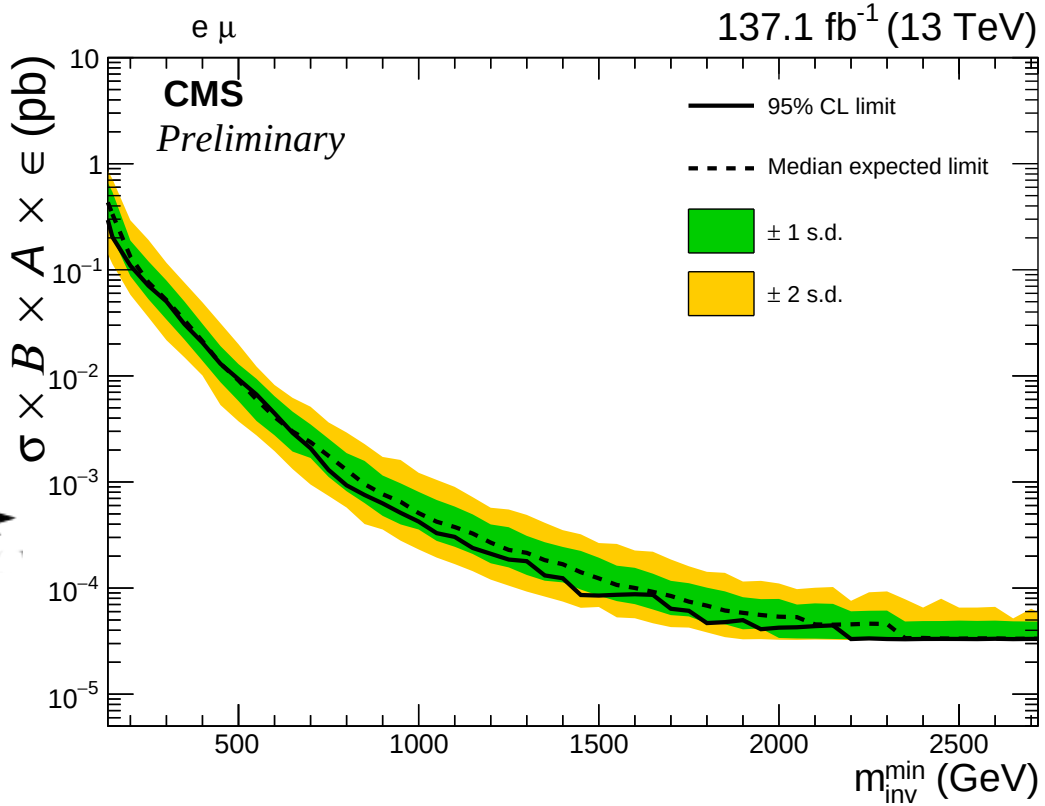
Statistical Interpretation (MI)

- We also provide model independent limits → can be applied by theorists using $f_M(M^{min})$

$$(\sigma B A \epsilon)_{excl} = \frac{(\sigma B A \epsilon)_{MI}(M^{min})}{f_M(M^{min})}$$





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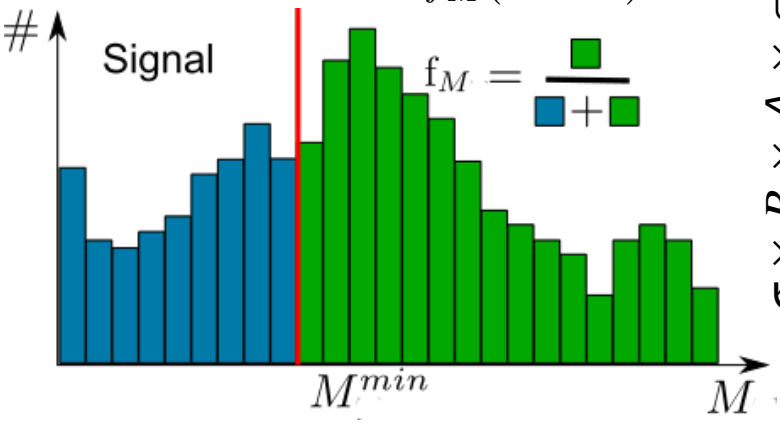

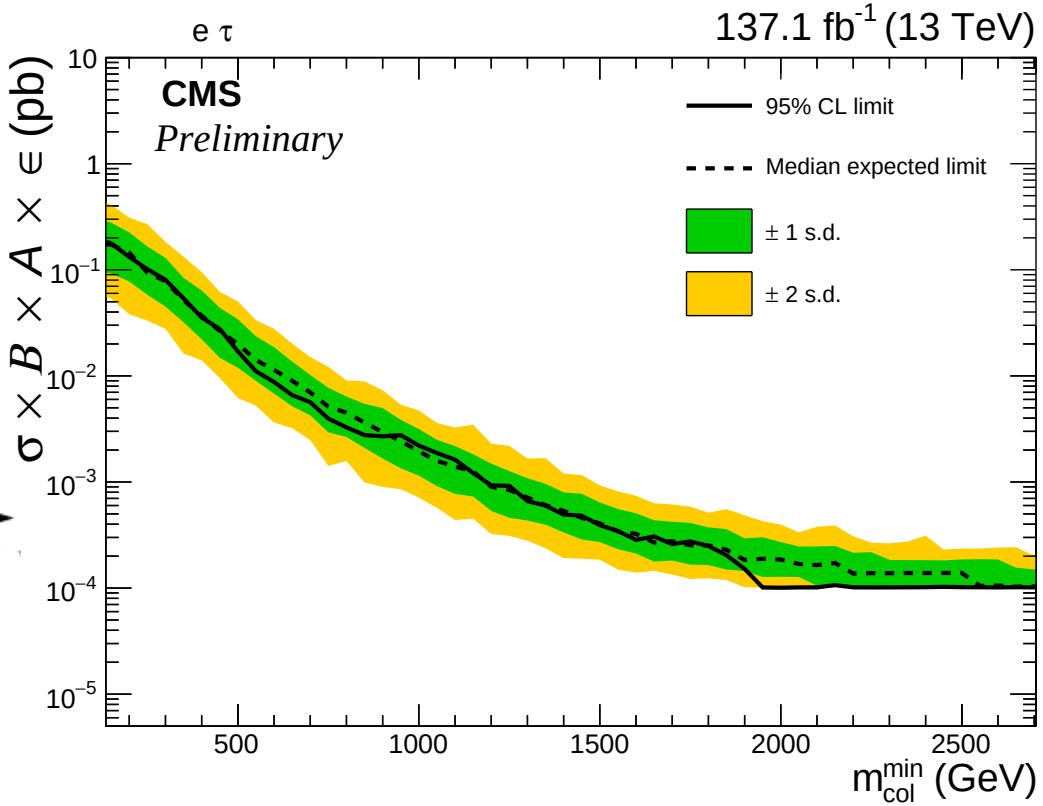

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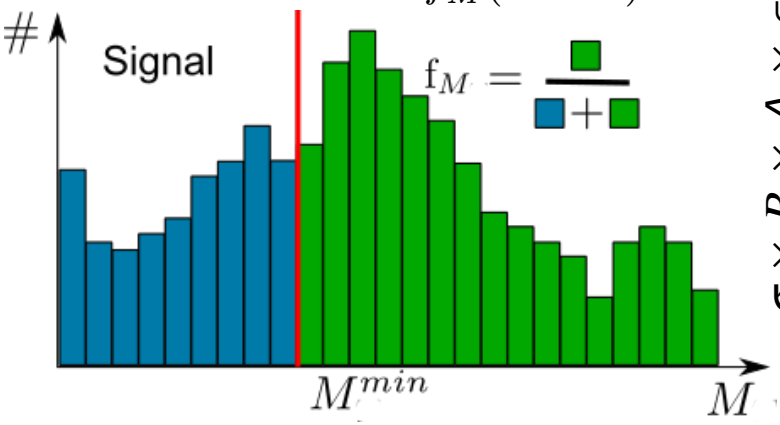

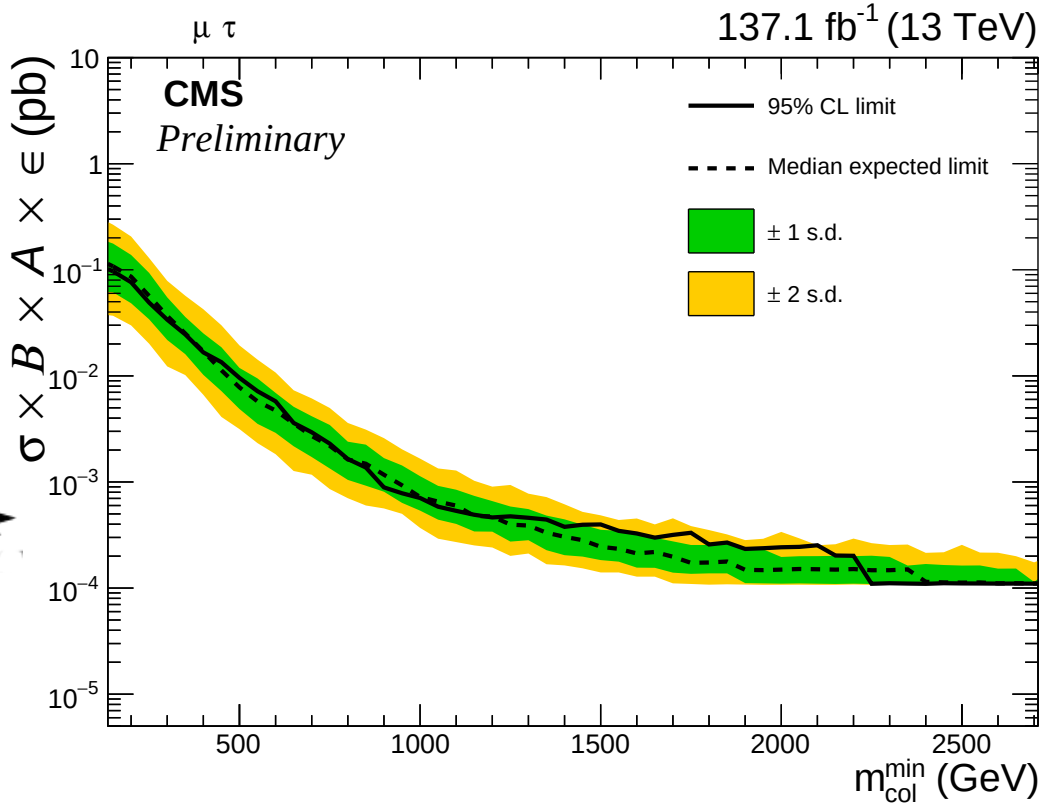

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Summary

- Presented the search for high mass lepton flavour violation (EXO-19-014)
- Analysis of all three channels was performed for the full Run 2 data
- No significant deviation from the SM prediction has been found

- Exclusion limits for SSM, QBH and RPV together with a model-independent limit have been presented
- Large improvment in the eμ channel, first τ channel limits in CMS
- PAS was made public for SUSY21, working on finalizing the paper

Thanks for your attention!

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