The multilepton searchlight at CMS

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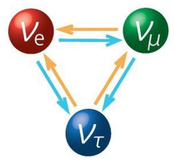
1) Why Beyond Standard Model physics ?

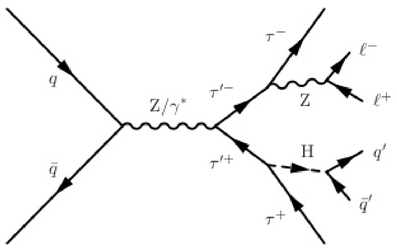
- Dark Matter : No potential candidate in SM.
- Neutrino oscillations : Mass of neutrinos and their smallness not explained.
- Baryon asymmetry : CP violation?
- Hierarchy problem : Extra generation of matter particles?

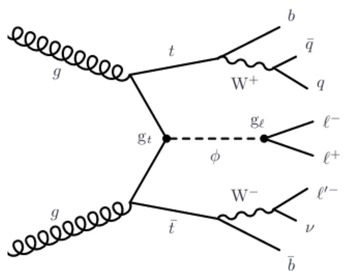


2) BSM physics may give multiple leptons

Vector-Like Lepton (VLL) doublet

- Two non-chiral, mass-degenerate fermions : τ' & ν'_τ
- Arise in models like SUSY & large ED.
- Yukawa coupling to SM leptons, same quantum numbers.
- τ' decay through Z/h, ν'_τ decay through W.
- Total 8 distinct production and decay modes.



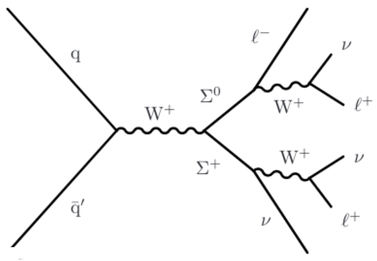


A new light scalar in SM : φ

- Arise in extended Higgs sectors, SUSY, dark sector.
- Simplified model – CP-even or CP-odd φ, produced with top quark pairs.
- Production cross section proportional to g_t^2. Decay controlled by g_ℓ^2.
- φ decays to electrons or muons.

Type-III Seesaw Mechanism : fermionic triplet

- Mass-degenerate : Dirac Σ^+, Σ^- and a Majorana Σ^0.
- SM neutrinos are Majorana, coupling to Σ^0.
- $\Sigma^0\Sigma^\pm$ or $\Sigma^\pm\Sigma^\mp$ production; decay through W/Z/h.
- All mixing angles to different lepton flavors studied.
- Total 27 distinct production and decay modes.

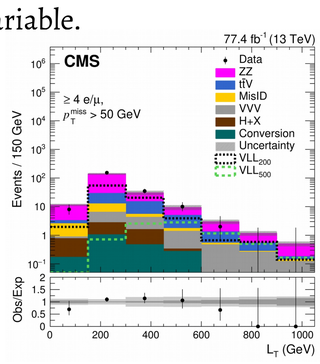


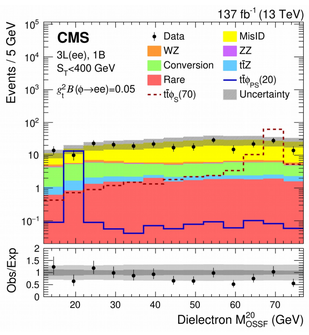
3) Multilepton Analysis Strategy

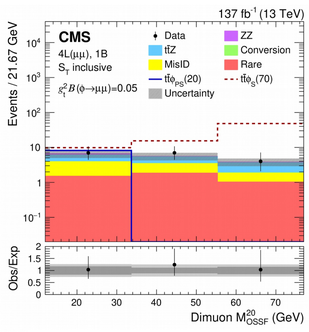
- Event categories : **≥4L, 3L and 2L + ≥1τ (L=e/μ)**
- Regions divided kinematically, signal populates them differently from SM.
- Counting experiment combining bins of discriminating variable.

VLL doublet signal regions

$N_{leptons}$	p_T^{miss} (GeV)	CR veto
≥4e/μ	<50	2 OSSF on-Z pairs and p_T^{miss} < 50 GeV
	>50	
3e/μ	<150	OSSF on-Z pair and p_T^{miss} < 100 GeV, or OSSF below-Z pair and p_T^{miss} < 50 GeV, or OSSF below-Z pair and on-Z $m_{3\ell}$
	>150	
2e/μ OS (or SS) + ≥1τ_h	<150	p_T^{miss} < 50 GeV
	>150	





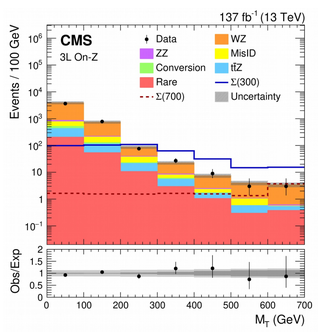


ttφ signal regions

Label	$N_{leptons}$	N_{OSSF}	M_{OSSF}	N_b	Variable and range (GeV)		Number of bins		
						S_T (GeV)	0–400	400–800	>800
3L(ee/μμ) 0B	3	1	off-Z	0	M^{20}_{OSSF}	[12,77]	13	13	5
					M^{60}_{OSSF}	[106,356]	10	10	10
3L(ee/μμ) 1B	3	1	off-Z	≥1	M^{20}_{OSSF}	[12,77]	13	13	5
					M^{60}_{OSSF}	[106,356]	10	10	10
						S_T (GeV)	0–400	>400	
4L(ee/μμ) 0B	≥4	≥1	off-Z	0	M^{20}_{OSSF}	[12,77]	3	2	
					M^{60}_{OSSF}	[106,356]	3	2	
						S_T inclusive			
4L(ee/μμ) 1B	≥4	≥1	off-Z	≥1	M^{20}_{OSSF}	[12,77]	3		
					M^{60}_{OSSF}	[106,356]	3		

Type-III Seesaw signal regions

Label	$N_{leptons}$	N_{OSSF}	M_{OSSF} (GeV)	p_T^{miss} (GeV)	Variable and range (GeV)		Number of bins
3L below-Z	3	1	<76	—	$L_T+p_T^{miss}$	[0, 1200]	6
3L on-Z	3	1	76–106	>100	M_T	[0, 700]	7
3L above-Z	3	1	>106	—	$L_T+p_T^{miss}$	[0, 1600]	8
3L OSSF0	3	0	—	—	$L_T+p_T^{miss}$	[0, 1200]	6
4L OSSF0	≥4	0	—	—	$L_T+p_T^{miss}$	[0, 600]	2
4L OSSF1	≥4	1	—	—	$L_T+p_T^{miss}$	[0, 1000]	5
4L OSSF2	≥4	2	—	>100 if both pairs are on-Z	$L_T+p_T^{miss}$	[0, 1200]	6



4) Event selection

Preselection

- Single lepton (e/μ) triggers for all years 2016, 2017 and 2018; pT ≳ 30GeV.
- Min invariant mass of same flavor light lepton pair > 12GeV, ΔR>0.4 between all leptons.

Objects reconstructed with the Particle-flow algorithm such as Muons, Electrons, Taus, Jets and missing transverse momentum (p_T^{miss}).

Muons
- pT>10GeV, |η|<2.4
- Prompt, isolated

Electrons
- pT>10GeV, |η|<2.5
- Prompt, isolated
- GSF electrons (accounts for bremsstrahlung)

Jets & p_T^{miss}
- pT>30GeV, |η|<2.1, anti-k_t (R=0.4)
- B-tagging : DeepCSV algorithm
- p_T^{miss} computed with PF objects

Taus
- pT>20GeV, |η|<2.3
- Prompt, isolated
- 1-prongs and 3-prongs
- MVA identification
- Cleaning against e/μ.

5) Standard Model Backgrounds

Background source	Leading processes	Estimation method	Notes
Irreducible	WZ, ZZ, ttZ, Zγ	Simulation	Normalized in 3L/4L CRs
Misidentified (jets → leptons)	DY, WW, $t\bar{t}$	Data	Developed in p_T^{miss}<50 GeV 2L/3L CRs and MC
Photon conversions (asymmetric)	DY, WW, $t\bar{t}$	Simulation	Normalized in p_T^{miss}<50 GeV 3L CRs
Rare	VVV, ttV, Higgs	Simulation	No normalization

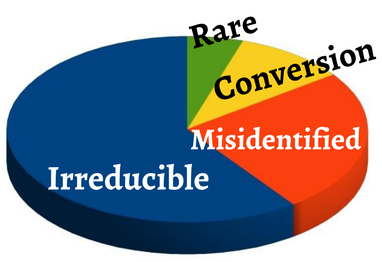
Prompt Background CRs

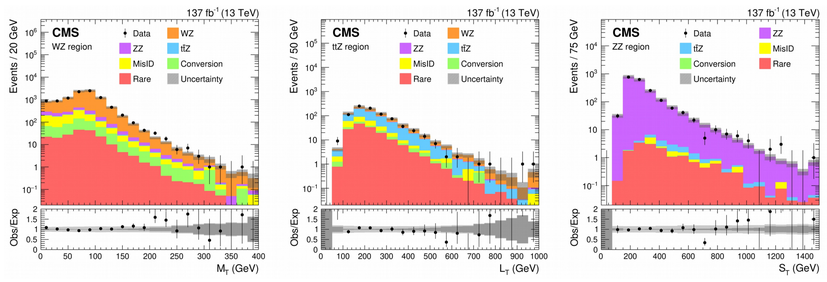
WZ
- 3L
- 1 OSSF pair
- OSSF mass OnZ [(91±15)GeV]
- 50<p_T^{miss}<100 GeV
- No b-tagged jets

ttZ
- 3L
- 1 OSSF pair
- OSSF mass OnZ [(91±15)GeV]
- p_T^{miss}< 100 GeV, S_T> 350 GeV
- At least 1 b-tagged jet

ZZ
- 4L
- 2 distinct OSSF, OnZ pair
- OSSF mass OnZ [(91±15)GeV]
- p_T^{miss} < 100 GeV
- At least 1 b-tagged jet

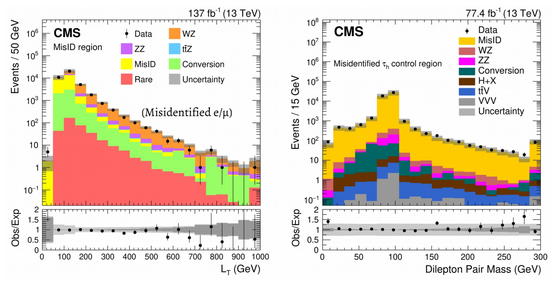
Conversion
- 3L
- 1 OSSF pair, mass < 76 GeV
- M_{3L} ~ (91±15)GeV
- p_T^{miss} < 50 GeV





Misidentified leptons

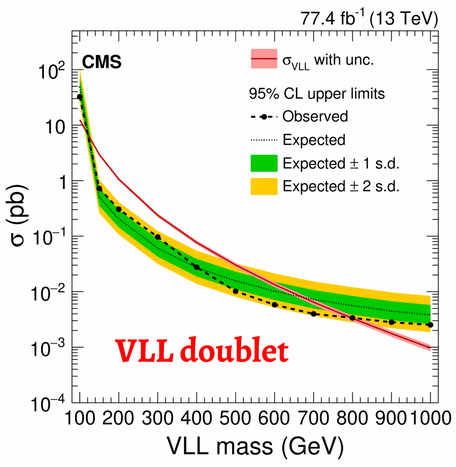
3D matrix method
- Universal prompt and fake rates for leptons.
- Rates measured using low p_T^{miss} OnZ CR, parametrized by lepton pT, η and the multiplicity of tracks in the event.
- Rates corrected using simulation for tt+jets effects.

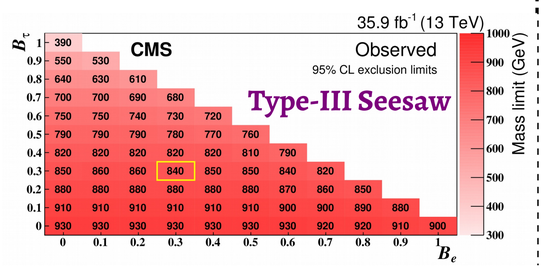


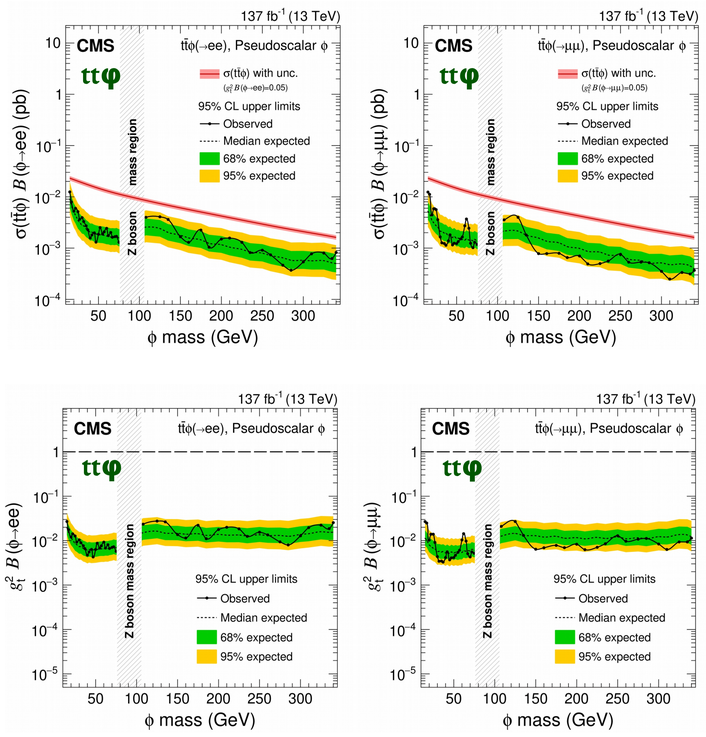
Uncertainties

- Largely dominated by the WZ, ZZ, and ttZ normalization factors (~25%) as well as the misidentified lepton contributions (30-40%).
- Contributions from rare (50%), conversion (20%), and those due to scale factors & electron charge misidentification (1-10%) have a negligible impact.

6) Interpreting the results







7) Future plans

- A comprehensive and inclusive full Run2 multilepton result.
- Adding tau-enriched channels : 1L+≥2τ, 2L+≥2τ, 3L+≥1τ.
- Many probes : light leptons, taus, b-jets and p_T^{miss}.
- Additional signal models : Xφ, VLL singlet, Right handed neutrinos.
- Classic cut-and-count as well as machine learning based techniques.
- Model-independent limits in the various multilepton signal regions.

	1ℓ	2ℓ	3ℓ	≥4ℓ
0τ	—	—	Done	Done
1τ	On the wish list	Done / NEW	NEW	
≥2τ	NEW	NEW		

In bins of b-jets & p_T^{miss}

References -

Vector-Like Leptons : Phys. Rev. D 100, 052003 (2019)

ttPhi & type-III Seesaw : arXiv:1911.04968 [hep-ex] (2019) (Submitted to JHEP)

Type-III Seesaw : Phys. Rev. Lett. 119, 221802 (2017)

Posters@LHCC: Students' Poster Session at the 2020 Winter LHCC meeting, CERN (Geneva)