Search for evidence of Type-III Seesaw mechanism in multilepton final states in pp collisions at 13 TeV

APS DPF Meeting 2017

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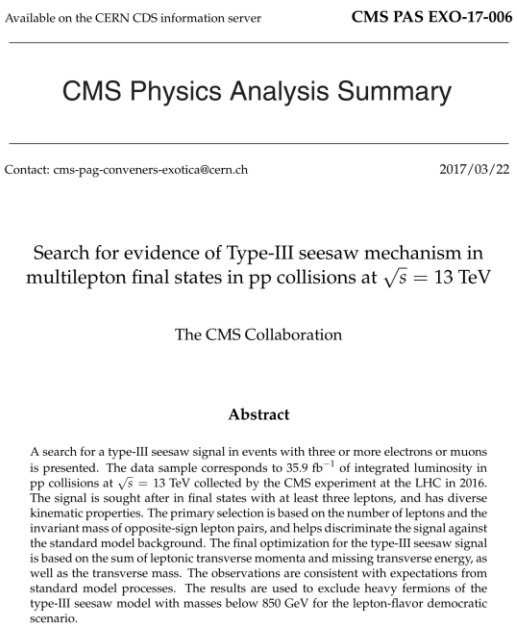
on behalf of the
CMS Collaboration

02-Aug-2017

† doi:10.1140/epjc/s10052-012-1899-z

Introduction

- Neutrino masses are extremly small, but non-zero
- Seesaw Type-III mechansim† explains that by postulating a massive SU(2) fermionic triplet: Σ^0 & $\Sigma^{\pm}$ leptons
- CMS-EXO-17-006 analysis:
  search for evidence of these heavy leptons
  in events with final states with
  at least 3 light leptons (μ & e)
- Using 35.9 fb^{-1} data of proton-proton collision collected by CMS



Available on the CERN CDS information server **CMS PAS EXO-17-006**

CMS Physics Analysis Summary

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Search for evidence of Type-III seesaw mechanism in multilepton final states in pp collisions at $\sqrt{s} = 13$ TeV

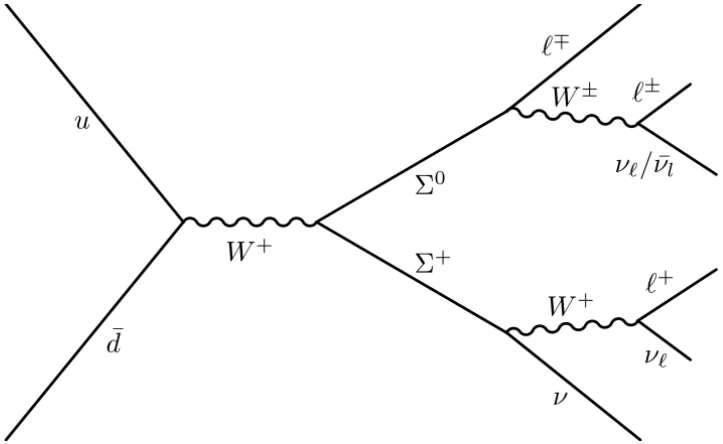
The CMS Collaboration

Abstract

A search for a type-III seesaw signal in events with three or more electrons or muons is presented. The data sample corresponds to 35.9 fb^{-1} of integrated luminosity in pp collisions at $\sqrt{s} = 13$ TeV collected by the CMS experiment at the LHC in 2016. The signal is sought after in final states with at least three leptons, and has diverse kinematic properties. The primary selection is based on the number of leptons and the invariant mass of opposite-sign lepton pairs, and helps discriminate the signal against the standard model background. The final optimization for the type-III seesaw signal is based on the sum of leptonic transverse momenta and missing transverse energy, as well as the transverse mass. The observations are consistent with expectations from standard model processes. The results are used to exclude heavy fermions of the type-III seesaw model with masses below 850 GeV for the lepton-flavor democratic scenario.

Phenomenology

- Pair production of heavy fermions: $\Sigma^+ \Sigma^0$, $\Sigma^- \Sigma^0$ & $\Sigma^+ \Sigma^-$
- Decays of heavy fermions:
  - $\Sigma^\pm \to W^\pm \nu$, $\Sigma^\pm \to Z\ell^\pm$ & $\Sigma^\pm \to H\ell^\pm$
  - $\Sigma^0 \to W^\pm \ell^\pm$, $\Sigma^0 \to Z\nu$ & $\Sigma^0 \to H\nu$
- Leptonic decays of intermediate bosons lead to multilepton final states
- Branching ratios of different decays are mass and lepton flavor dependent:
  this analysis is based on flavor democratic scenario



‡ doi:10.1016/S0370-2693(96)01493-1

Event Selection

We don't cut, but bin in certain event kinematics:

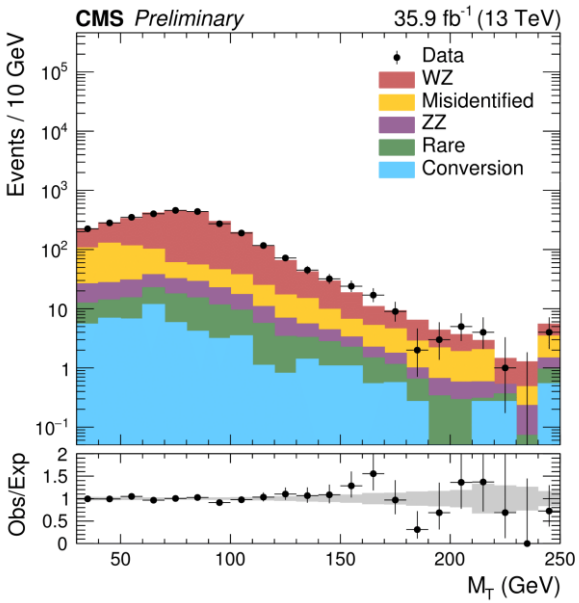
N_{leptons}	OSSF	Kinematic Variable	CR-veto
3	on-Z	M_T	$E_T^{miss} > 100\,\text{GeV}$
	above-Z	$L_T + E_T^{miss}$	-
	below-Z	$L_T + E_T^{miss}$	$E_T^{miss} > 50\,\text{GeV}$
	none	$L_T + E_T^{miss}$	-
≥ 4	1 pair	$L_T + E_T^{miss}$	-
	2 pairs	$L_T + E_T^{miss}$	$E_T^{miss} > 50\,\text{GeV}$ if on-Z

- OSSF/MOSSF: opposite sign same flavor pair/mass (onZ: 91 ± 10 GeV)
- $L_T + E_T^{miss}$: sum of lepton momenta p_T and missing energy

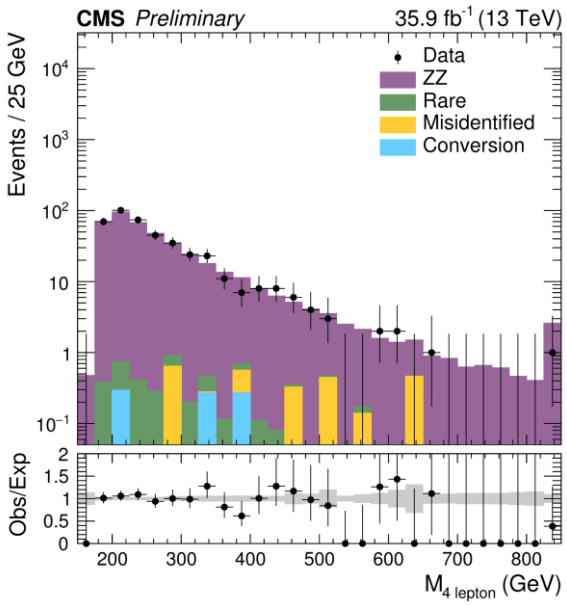
  (7 bins from 0-1050 GeV & overflow bin)
- M_T: transverse mass‡ (7 bins from 0-800 GeV & overflow bin)
- p_T tresholds: 25 / 15 / 10 GeV (lead., sublead. & sub-sublead. lepton)

Backgrounds: WZ/ZZ

- Control region: 3 leptons, OSSF pair OnZ, 50 < MET < 100 GeV
- Normalization: 1.15 ± 0.08



- Control region: 4 leptons, 2 OSSF pairs OnZ, MET < 50 GeV
- Normalization: 1.25 ± 0.06



Backgrounds: Misidentified

- We use 3D version of Matrix Method: Advanced tight-loose data-driven technique

2D:

$$\begin{pmatrix} N_{\mathrm{FF}} \\ N_{\mathrm{FP}} \\ N_{\mathrm{PF}} \\ N_{\mathrm{PP}} \end{pmatrix} = \frac{1}{(p_1 - f_1)(p_2 - f_2)} \begin{pmatrix} p_1 \cdot p_2 & -p_1 \cdot \widehat{p}_2 & -\widehat{p}_1 \cdot p_2 & \widehat{p}_1 \cdot \widehat{p}_2 \\ -p_1 \cdot f_2 & p_1 \cdot \widehat{f}_2 & \widehat{p}_1 \cdot f_2 & -\widehat{p}_1 \cdot \widehat{f}_2 \\ -f_1 \cdot p_2 & f_1 \cdot \widehat{p}_2 & \widehat{f}_1 \cdot p_2 & -\widehat{f}_1 \cdot \widehat{p}_2 \\ f_1 \cdot f_2 & -f_1 \cdot \widehat{f}_2 & -\widehat{f}_1 \cdot f_2 & \widehat{f}_1 \cdot \widehat{f}_2 \end{pmatrix} \begin{pmatrix} N_{\mathrm{LL}} \\ N_{\mathrm{LT}} \\ N_{\mathrm{TL}} \\ N_{\mathrm{TT}} \end{pmatrix}$$

Calculated

Measured

Observed

$$N_{\mathrm{TT}}^{\mathrm{Fake\ Bkg}} = f_1\ f_2\ N_{\mathrm{FF}} + f_1\ p_2\ N_{\mathrm{FP}} + p_1\ f_2\ N_{\mathrm{PF}}$$

- Prompt leptons come from bosons, fake leptons from hadronic activity
- Prompt rates are measured in 2 leptons onZ region
- Fake rates are measured in 3 leptons with 1 OSSF pair onZ & MET < 50 GeV
- Parametrization of rates as functions of lepton p_T, lepton η & particle multiplicity around the lepton

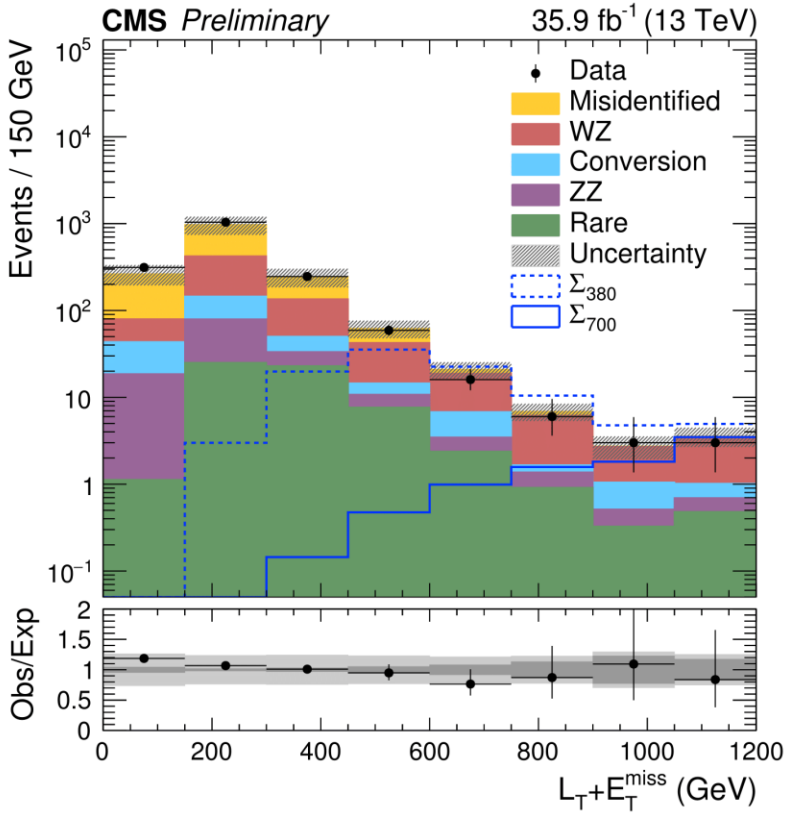
Backgrounds: Conversion

- Data-driven proxy method to estimate asymmetric photon to lepton conversions
- Photon proxy: loose photon objects are treated as leptons with randomly assigned flavor & charge
- Conversion rate is ratio of 2ℓ+γ events to 3ℓ events in designated measurement region: M(2ℓ) is belowZ, M(2ℓ+γ / 3ℓ) onZ & MET < 50 GeV

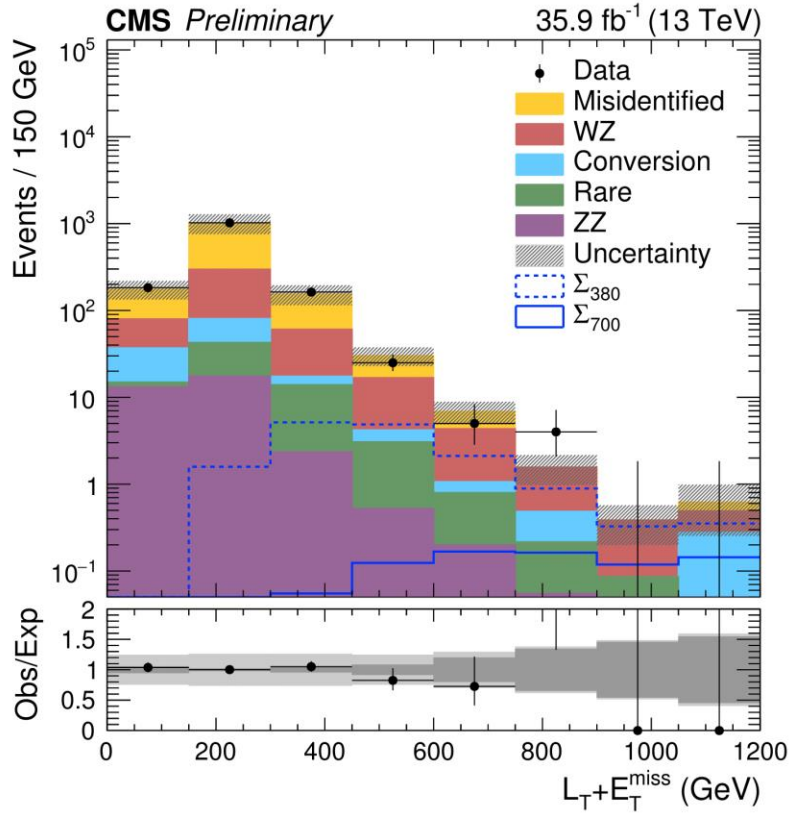
$$f_{\gamma \to l} = \frac{N_{3l} - N_{prompt} - N_{Misid}}{N_{2l+\gamma}}$$

Results: 3 lepton regions

L3AboveZ

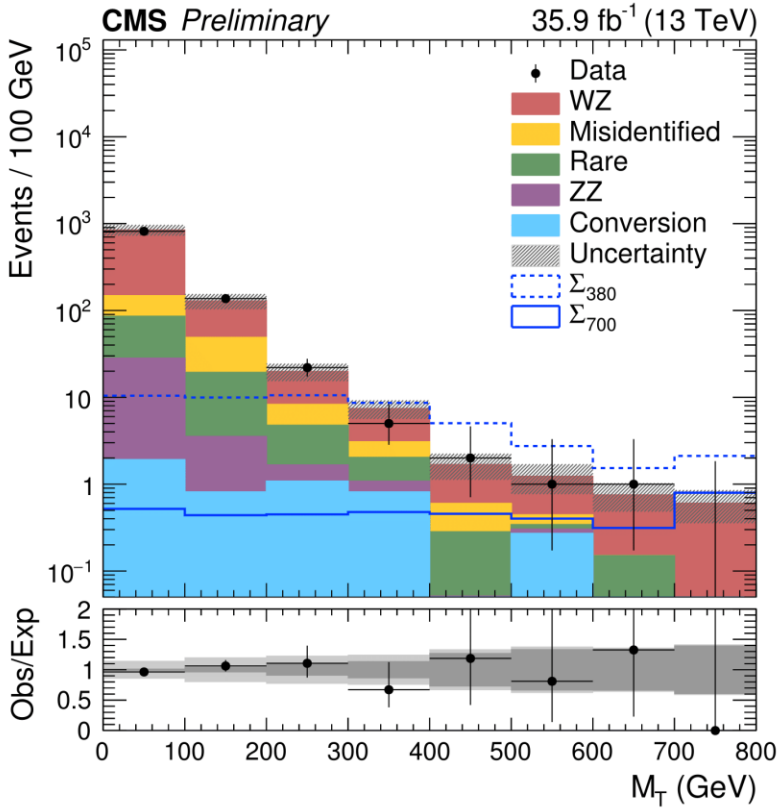


L3BelowZ

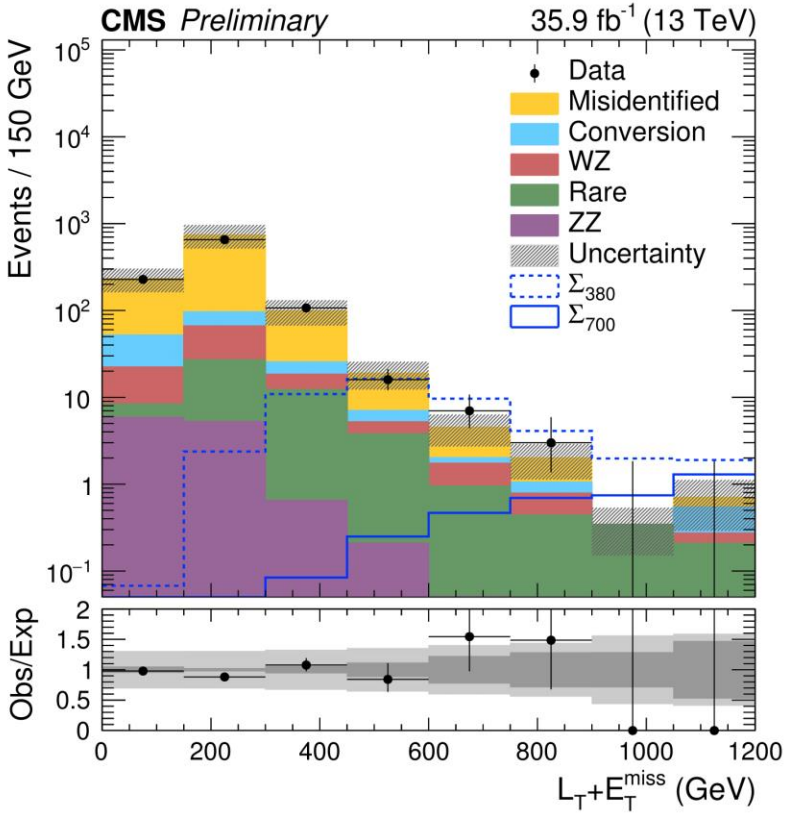


Results: 3 lepton regions

L3OnZ

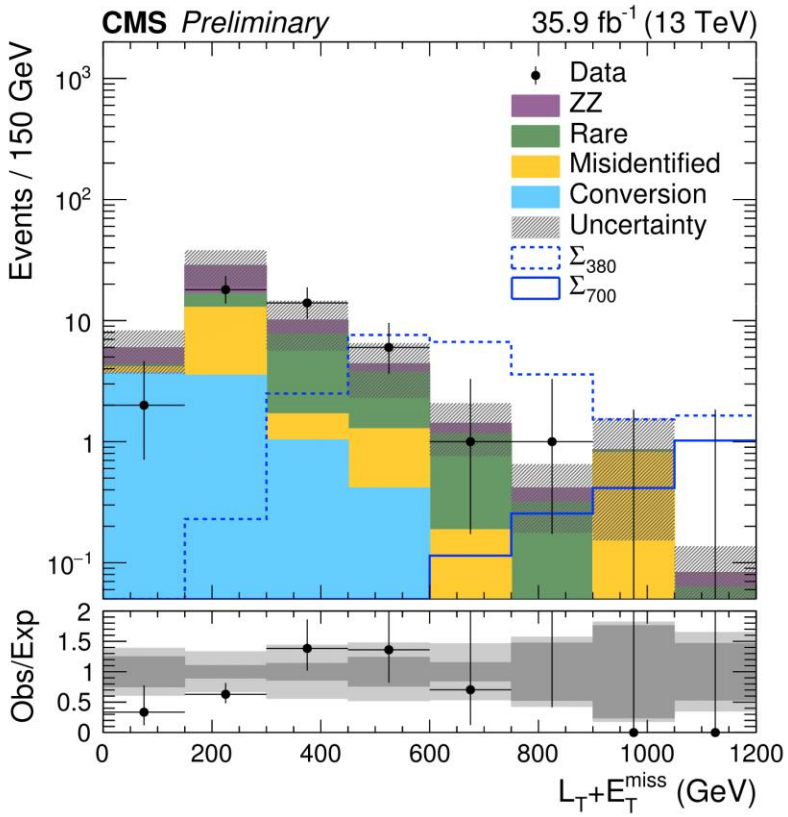


L3OSSFo

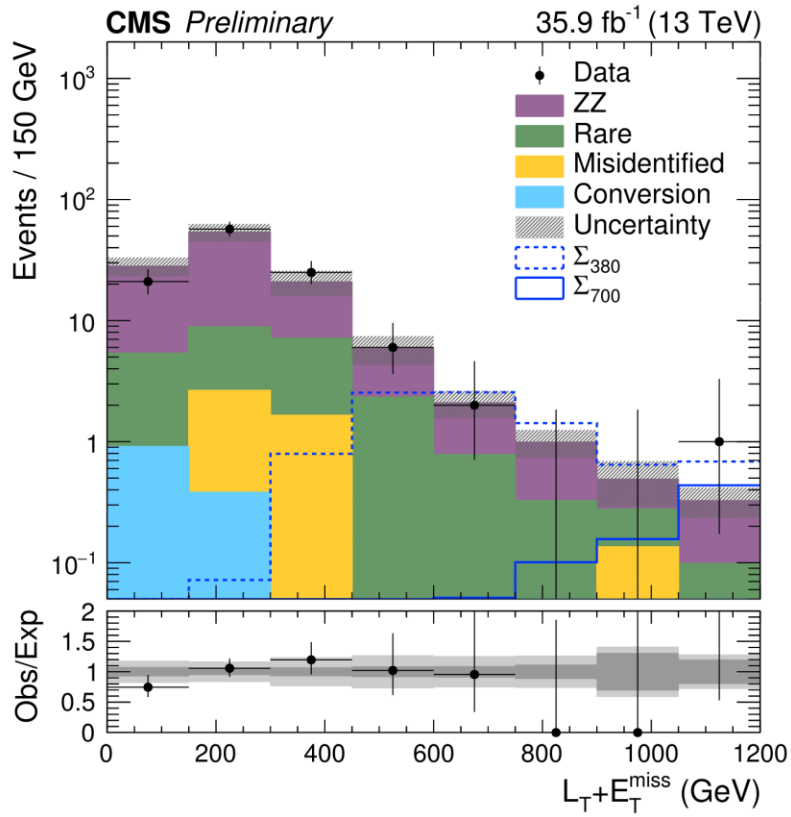


Results: 4 lepton regions

L4OSSF1

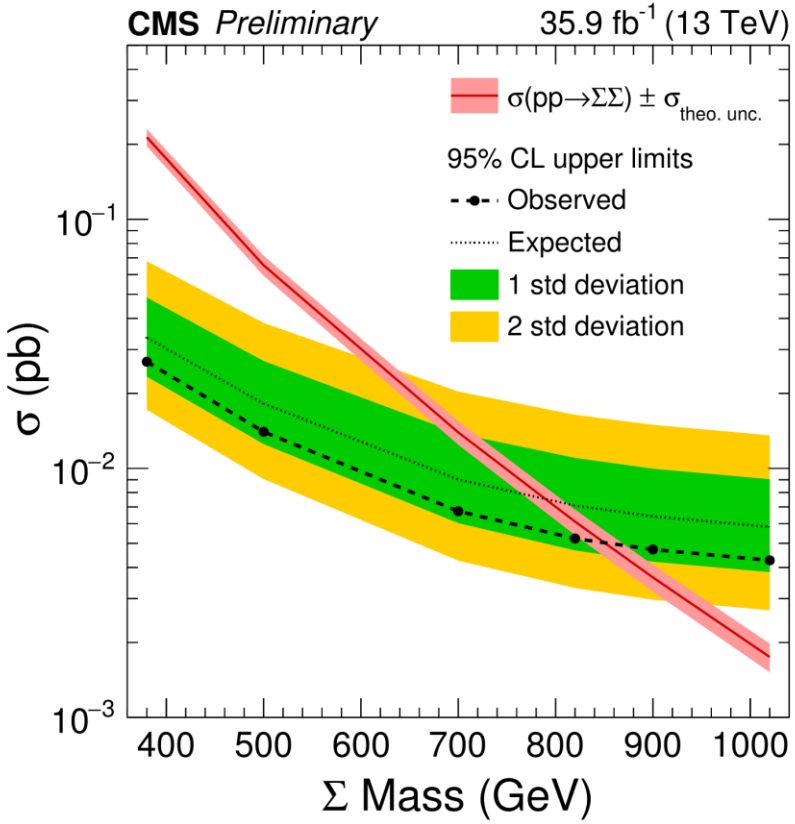


L4OSSF2



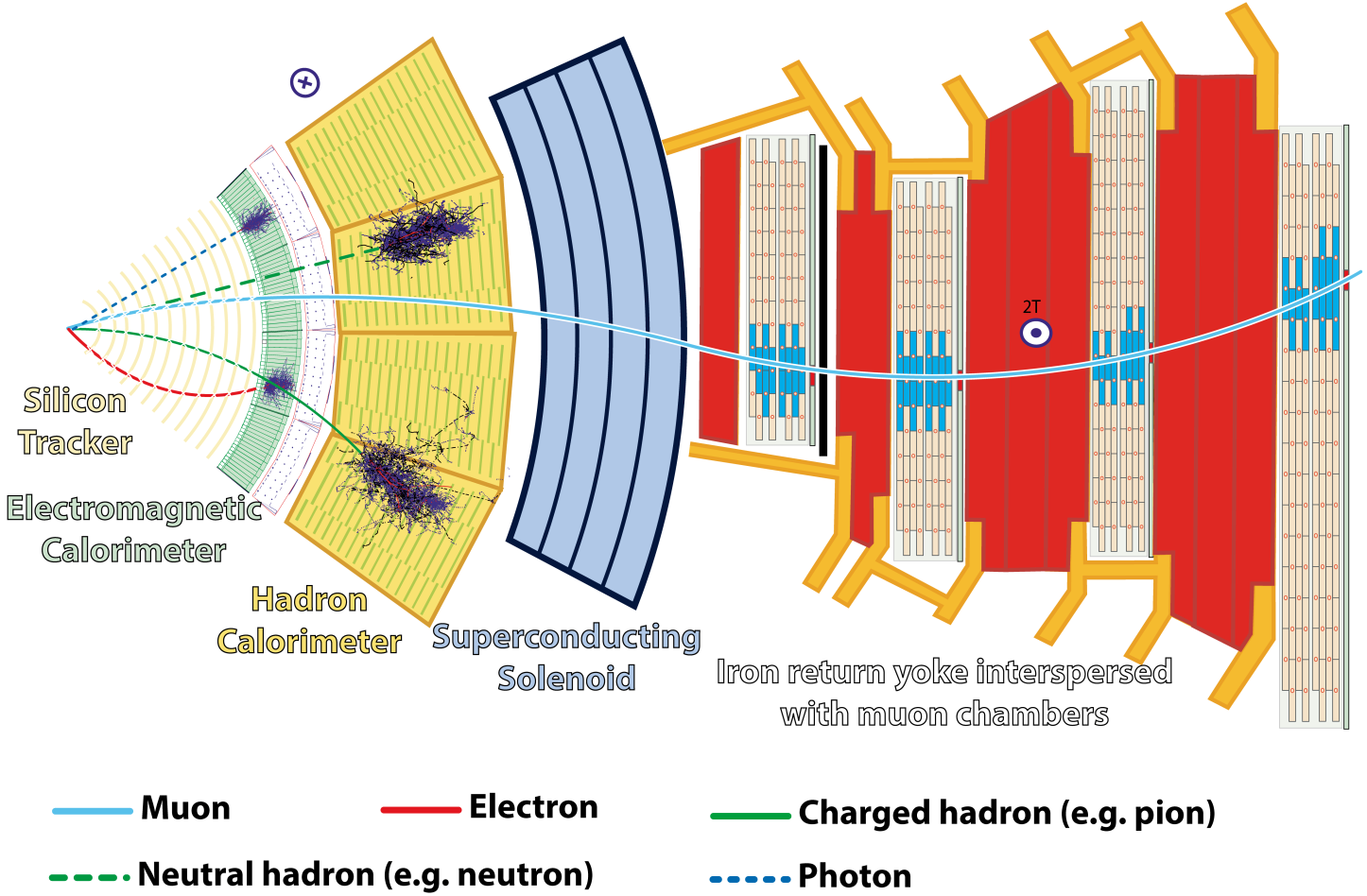
Interpretation

- No evidence of Seesaw Type-III signal has been observed
- We compute 95 % CL_S exclusion limits on the signal production cross section
- Exclude heavy fermions in the flavor democratic scenario with masses less than 850/790 GeV (observed/expected)



BACKUP SLIDES

CMS Detector



Datasets & Trigger

Datasets:

- DoubleMuon Run2017B-H (version: 03Feb2017)
- MuonEG Run2017B-H (version: 03Feb2017)
- DoubleEG Run2017B-H (version: 03Feb2017)

Trigger p_T tresholds:

- DoubleMuon: 17 GeV, 8 GeV
- MuonEG: 23 GeV, 8 GeV
- DoubleEG: 23 GeV, 12 GeV

Object Selection & ID's

Standard object ID's:

- Electrons: cut based medium ID ($p_T > 10$ GeV, $|\eta| < 2.5$)
- Muon: medium ID with DBcorr. PF isolation ($p_T > 10$ GeV, $|\eta| < 2.5$)
- Jets: Loose ID AK_4 PF Jets ($p_T > 30$ GeV, $|\eta| < 3.0$)
- MET: Type 1 corrected PF MET

Prompt lepton requirements:

- $d_z < 0.1$ cm
- $d_{xy} < 0.05$ cm

Min. invariant mass of OSSF pair: 12 GeV (veto low mass resonances)

Rare MC background

- Higgs: ttH, VBF $\rightarrow$ H $\rightarrow$ ZZ $\rightarrow$ 4ℓ, gg $\rightarrow$ H $\rightarrow$ ZZ $\rightarrow$ 4ℓ, ZH (H$\rightarrow$ ZZ $\rightarrow$ 4ℓ), WH (H$\rightarrow$ ZZ $\rightarrow$ 4ℓ)
- Triboson: WWW, WWZ, WZZ, ZZZ
- ttbar + X: ttW, ttZ, tttt
- Not normalized in any control region
- Systematic uncertainty based on ttZ/ttW measurements by CMS TOP group

More Matrix Method

- We measure fake rates in DY dominated data, as well as in DY and ttbar MC
- We also use a pile-up dependent correction factor, measured in data

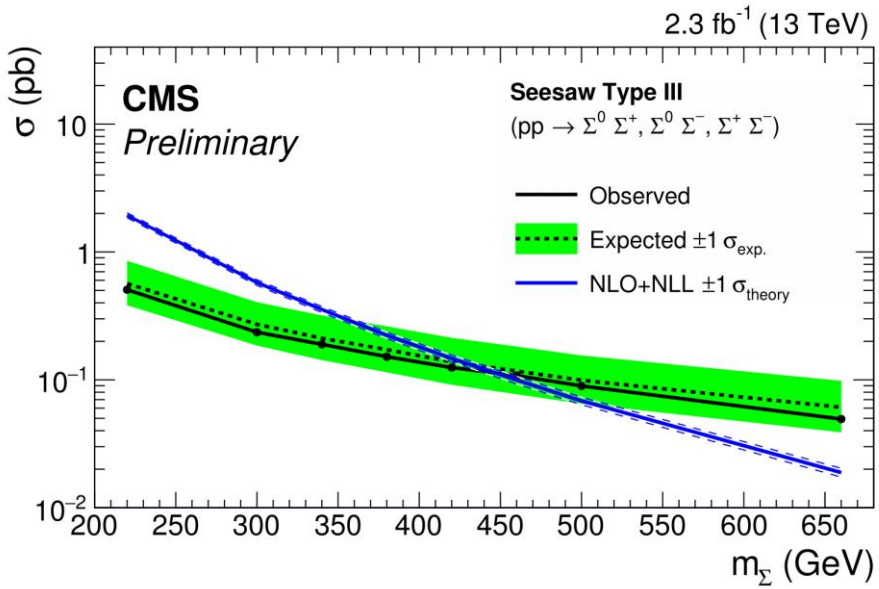
$$f_{Data} = f_{Data}^{DY} \cdot \frac{f_{MC}^{DY} + f_{MC}^{tt}}{2 f_{MC}^{DY}} . k(N_{PU})$$

Systematic Uncertainties

- Signal regions are dominated by statistics, not systematics
- Systematic uncertainties play a minor role
- Anti-/Correlations are taken into account

Source of uncertainty	Typical Variation (%)	Type	Processes
MisID lepton backgrounds (matrix method)	30	per event	Misidentified
Photon conversion backgrounds (photon proxy method)	30	per event	Conversion
Rare MC backgrounds normalization	50	per event	Rare
Electron charge misidentification	50	per event	WZ/ZZ/Rare (with charge flip)
WZ normalization	7	per event	WZ
ZZ normalization	5	per event	ZZ
Dilepton trigger	2	per event	WZ/ZZ/Rare/Signal
Electron ID & isolation	2	per electron	WZ/ZZ/Rare/Signal
Muon ID & isolation	2	per muon	WZ/ZZ/Rare/Signal
Electron energy scale and resolution	1-5	per event	WZ/ZZ/Rare/Signal
Muon momentum scale and resolution	2-10	per event	WZ/ZZ/Rare/Signal
Jet energy scale	2-8	per event	WZ/ZZ/Rare/Signal
Jet energy resolution	1-8	per event	WZ/ZZ/Rare/Signal
Unclustered energy scale	2-5	per event	WZ/ZZ/Rare/Signal
Integrated luminosity	2.6	per event	Rare/Signal
Pileup	4	per event	WZ/ZZ/Rare/Signal
PDF (on signal acceptance)	3	per event	Signal

Comparison: 2016 Result



- CMS-EXO-16-002 PAS
- Same analysis approach with pure LT+MET binning
- Different Misidentified background technique: ttbar MC + isolated track proxy method
- Limits: 440 GeV (observed), 430 GeV (expected)