Neutrino physics

Search for heavy Majorana neutrinos in $e^{\pm}e^{\pm}$ + jets and $e^{\pm}\mu^{\pm}$ + jets events in proton-proton collisions at $\sqrt{s} = 8$ TeV

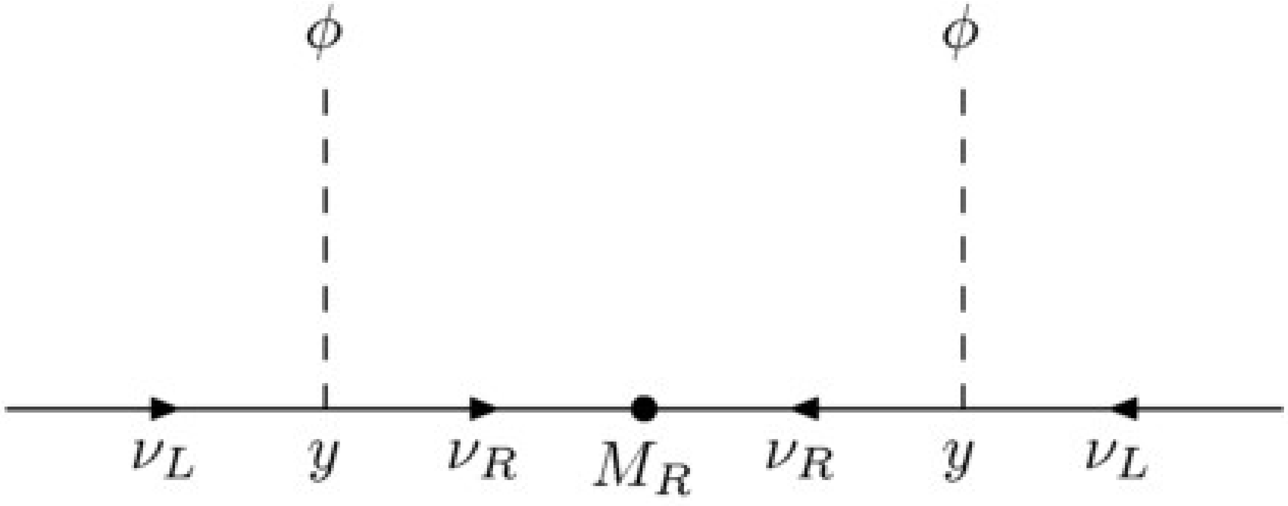
The CMS collaboration

AEPSHEP 2016 Student presentation
Group 1

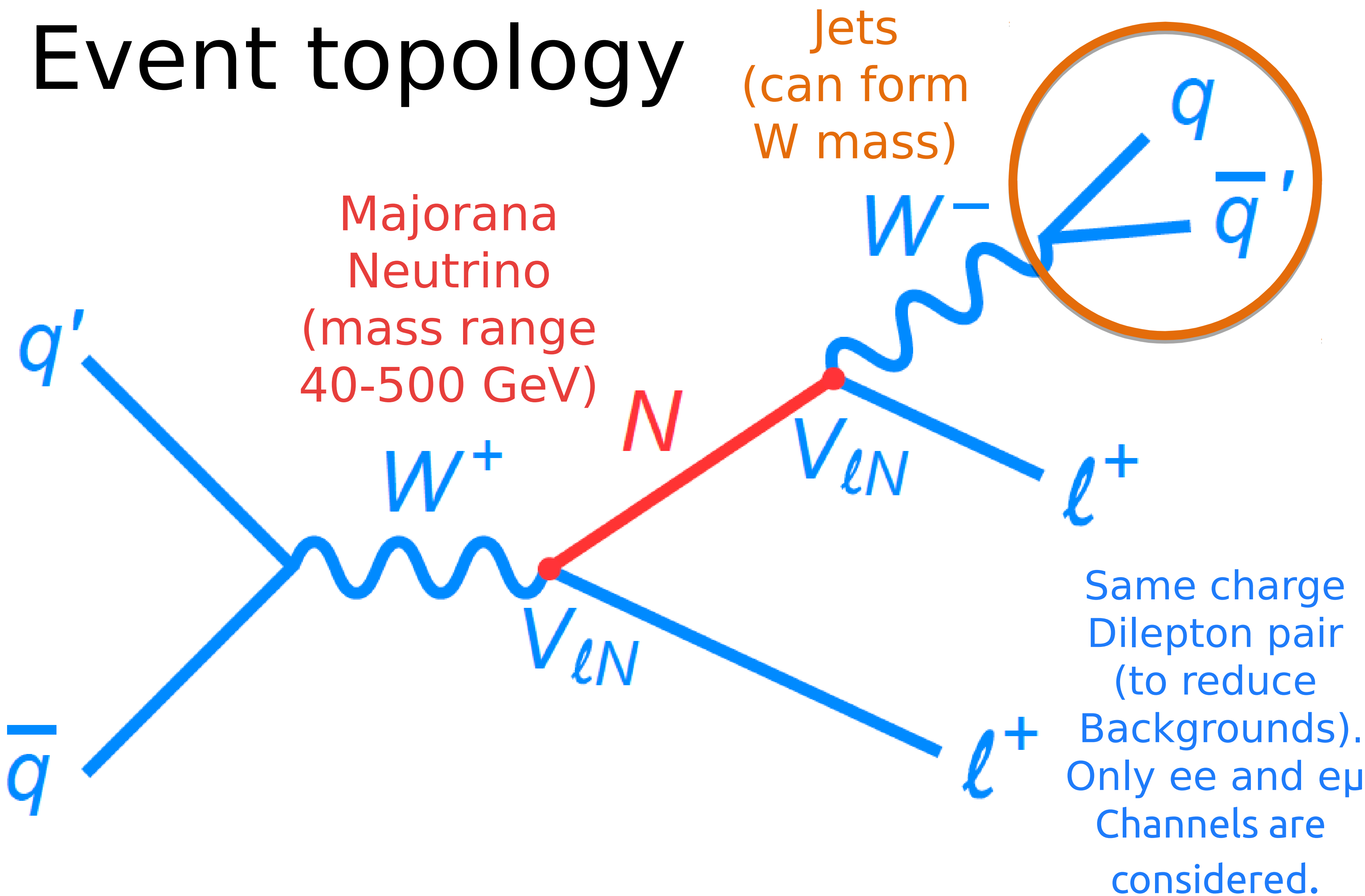
Introduction

Motivation

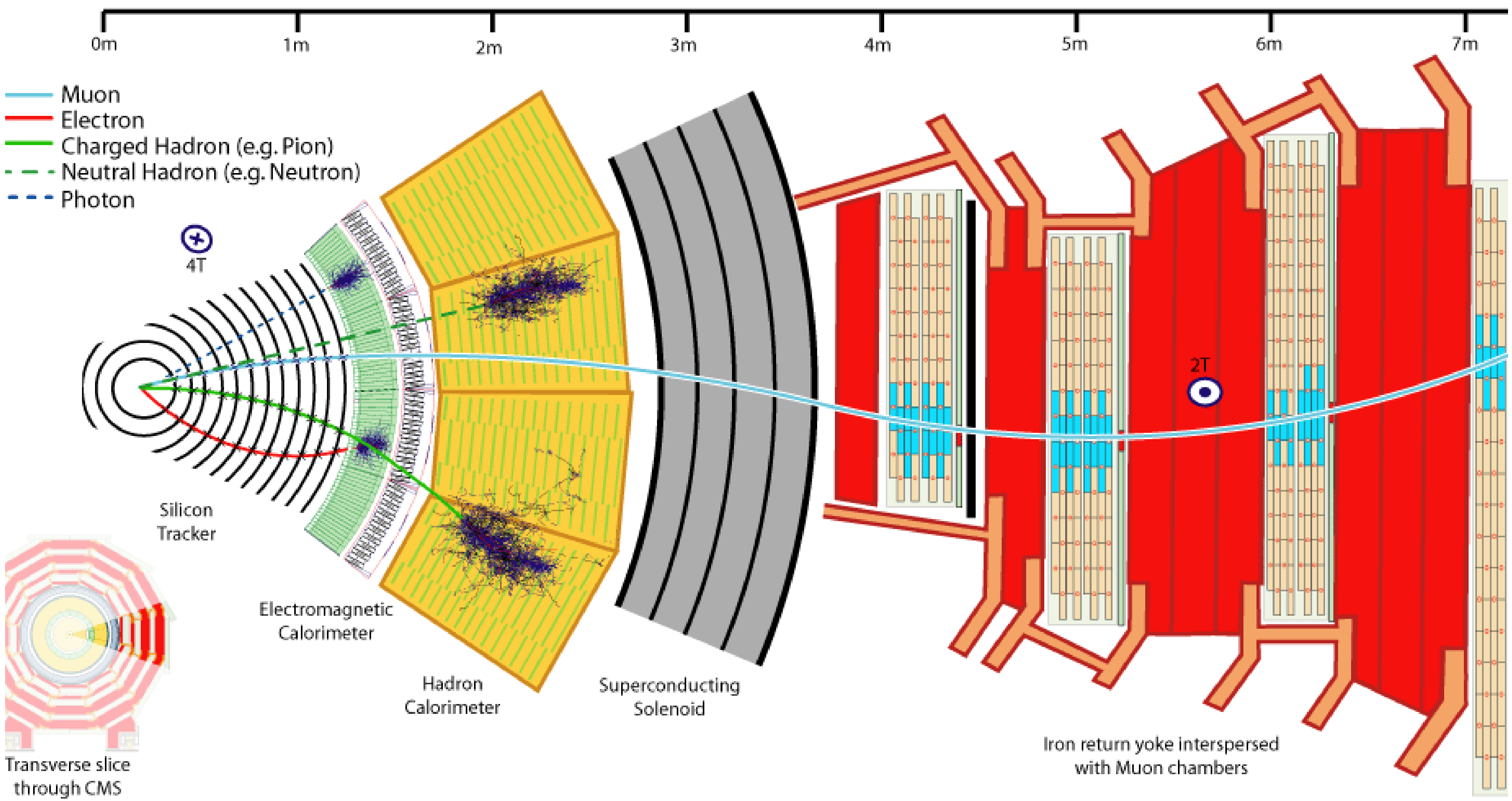
- In the SM neutrinos are massless but neutrino oscillation experiments indicate that they are massive.
- Different “seesaw” models have been suggested to generate light neutrino masses.
- Seesaw Type-1 proposes a heavy Majorana neutrino which mixes with the SM neutrinos.
- Search for a heavy Majorana neutrino is performed with CMS detector using 19.7 fb^{-1} of pp collisions collected until 2012 at $\sqrt{s}$ = 8 TeV.



Event topology



Detector


0m
1m
2m
3m
4m
5m
6m
7m
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS

Data sample and event selection

Event Selection

- Data set: 19.7 fb^{-1}, collected in 2012 with the CMS detector.
- Trigger: dilepton triggers, efficiency ~94%.
- Electron selection:
  - p_T > 15 GeV passing tight ID (gap region excluded).
  - Relative Isolation < 0.09 for barrel and 0.05 for endcap.
- Muon selection: p_T > 10 GeV passing loose ID.
- Jets Selection:
  - p_T >20GeV and $|\eta|$ <2.5 and passing loose jetID.
  - **$\Delta R_{(lep,jet)}$ >** 0.4 with pileup removal using "effective area correction".

Preselection Criteria

- Two same charge leptons.
- P_T > 20 GeV for leading lepton and P_T > 15 GeV for trailing lepton.
- M_{ee} > 10 GeV.
- For Suppression of Background
  - Background coming from Diboson:
    - Events with a third lepton with P_T > 10 GeV and loose requirement are removed.
  - Background coming from top quark decays:
    - B-tagged jets are rejected.

Final selection

Two types of (signal) selection criteria depending on neutrino mass hypothesis: low mass region ($m_N < m_W$) and high mass region ($m_N > m_W$)

Mass region	MET	m(lljj)	m(ll)	m(jj)	p_T^{j1}
Low-mass	< 30 GeV	< 200 GeV	> 10 GeV	< 120 GeV	> 20 GeV
High-mass	< 35 GeV	> 80 GeV	> 15 GeV	50-110 GeV	> 30 GeV

- Final discriminating variables:
  - P_T of leading (trailing) lepton
  - P_T of leading jet
  - Invariant mass of two leptons and two selected jets
  - Invariant mass of sub leading leptons and two selected jets
  - Invariant mass of two leptons
- Acceptance after optimization:
  - Signal acceptance from 0.19 – 0.39% for m_N = 40 GeV
  - Signal acceptance from 14-17% for m_N = 500 GeV

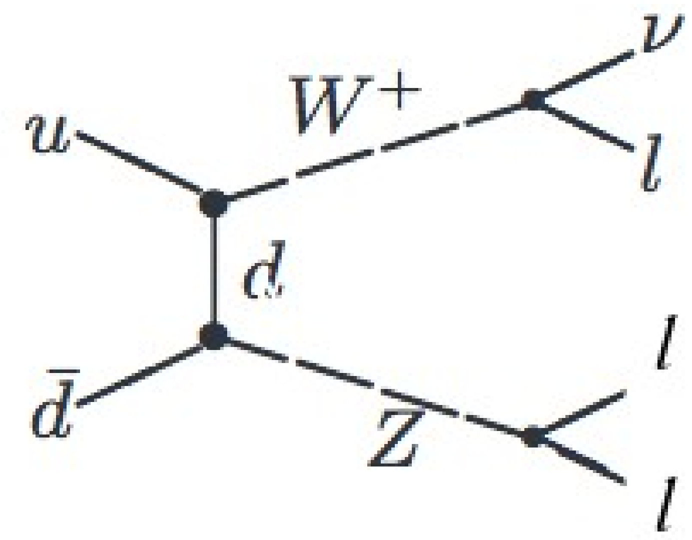
Background estimation

Misidentified leptons

- Most important background: jets misidentified as leptons.
  - Approximately 67% of the total background.
  - Dominant background in the low mass region.
- MC cannot be used due to limited statistics and that the shower process not being modeled exactly.
- Evaluate with data driven background prediction method.

Prompt same charge leptons

- Second most important background.
- Sources: WW, WZ, ZZ, ttV, H → VV (V = Z,W).
- Evaluated with MC.
- Background reduced by specific cuts (for example, rejecting events close to the Z peak).



Opposite charge lepton pairs

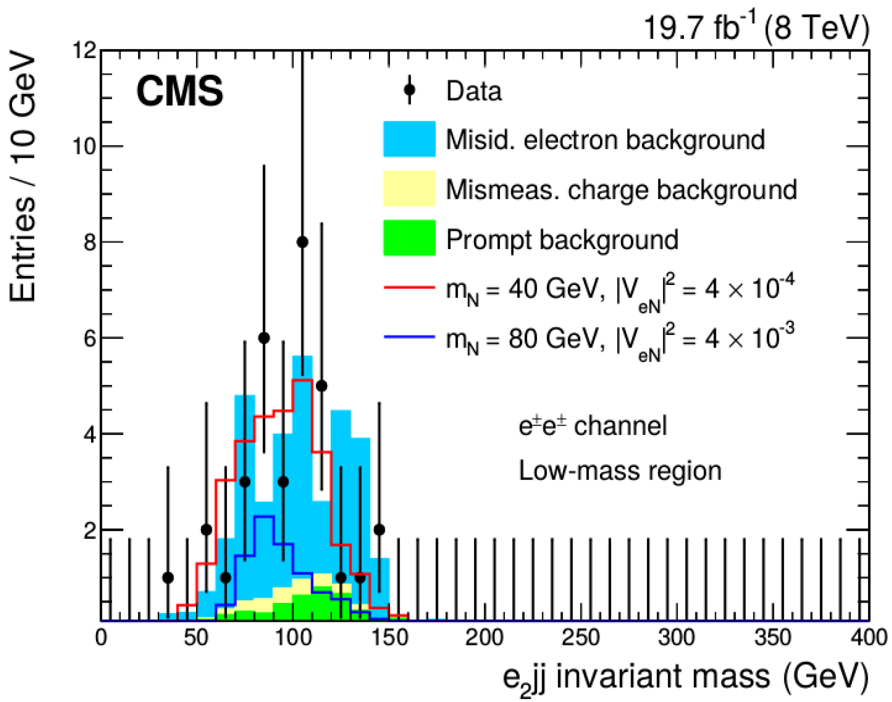
- Charge of one lepton is mismeasured.
- Negligible for muons (verified by MC and cosmic muons).
- For electrons: use $Z \rightarrow e^+e^-$ MC to obtain the probability of charge mismeasurement, and correct the probability in the data by applying scale factors .

Systematic uncertainties

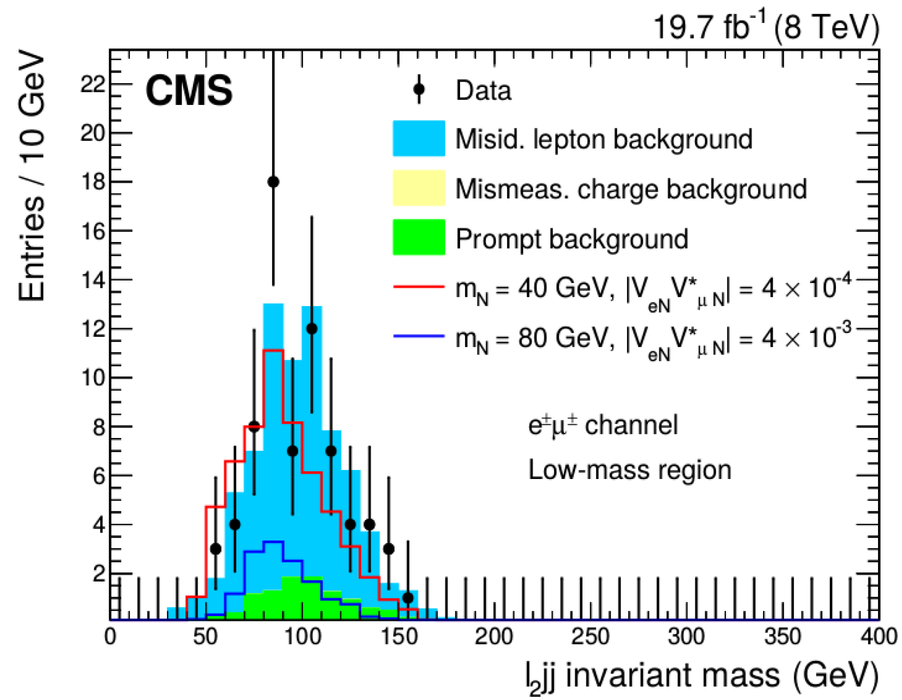
Channel / Source	ee signal (%)	ee bkgd. (%)	eμ signal (%)	eμ bkgd. (%)
Simulation:				
SM cross section	--	9-25 (9-25)	--	9-25 (9-25)
Jet energy scale	6-8 (1-3)	5 (7)	4-8 (1-2)	8 (7)
Jet energy resolution	3-7 (2-3)	10 (7)	3-10 (2-3)	10 (6)
Event pileup	2-3 (0-2)	4 (1)	2-3 (0-2)	3 (2)
Unclustered energy	1-3 (1-2)	4 (5)	1-3 (1-2)	5 (1)
Integrated luminosity	2.6 (2.6)	2.6 (2.6)	2.6 (2.6)	2.6 (2.6)
Lepton selection	2 (2)	2 (2)	2 (2)	2 (2)
Trigger selection	6 (6)	6 (6)	6 (6)	6 (6)
b tagging	0-1 (1-2)	2(1)	0-1 (1-2)	1(1)
PDF (shape)	2.0 (2.0)	--	2.0 (2.0)	--
PDF (rate)	3.5 (3.5)	--	3.5 (3.5)	--
Renormalization / factorization scales	8-10 (1-6)	--	8-10 (1-6)	--
Signal MC statistical uncertainty	5-15 (1-6)	--	3-7 (1-3)	--
Data-Driven:				
Misidentified leptons	--	40 (40)	--	35 (35)
Mismeasured charge	--	12 (12)	--	12 (12)

Results

Low mass region

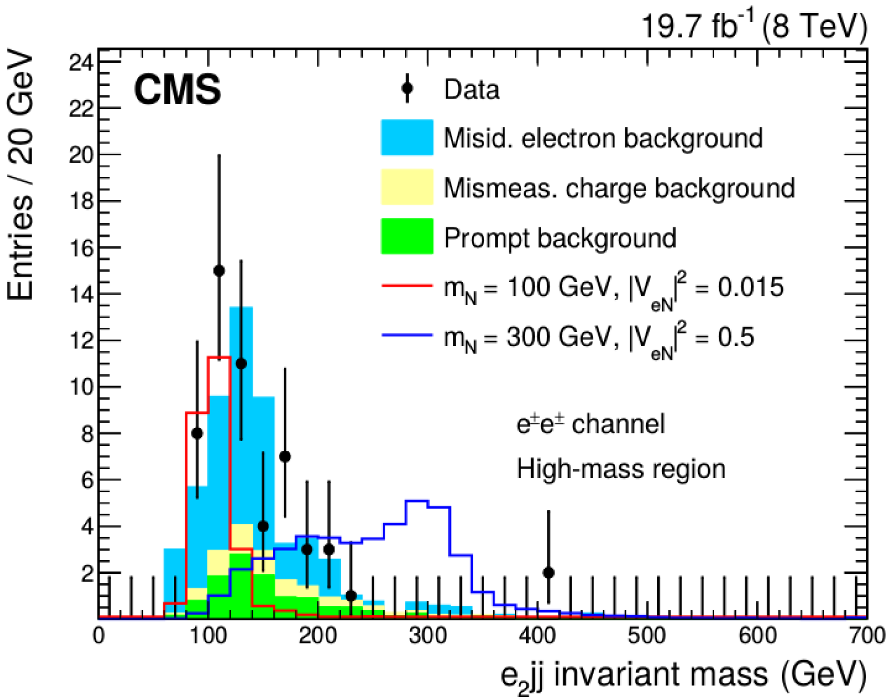


ee channel

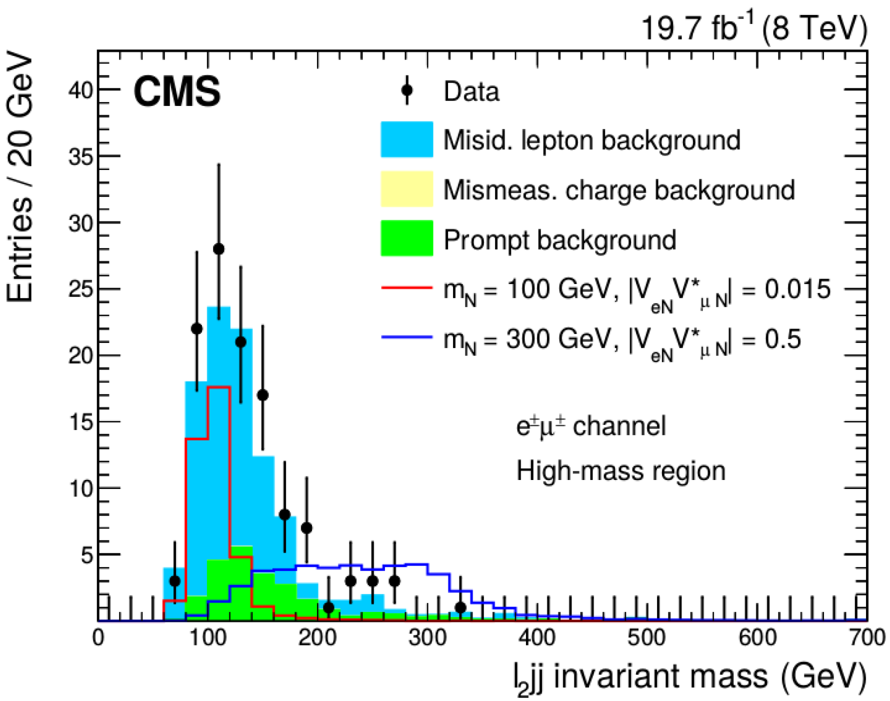


eμ channel

High mass region



ee channel



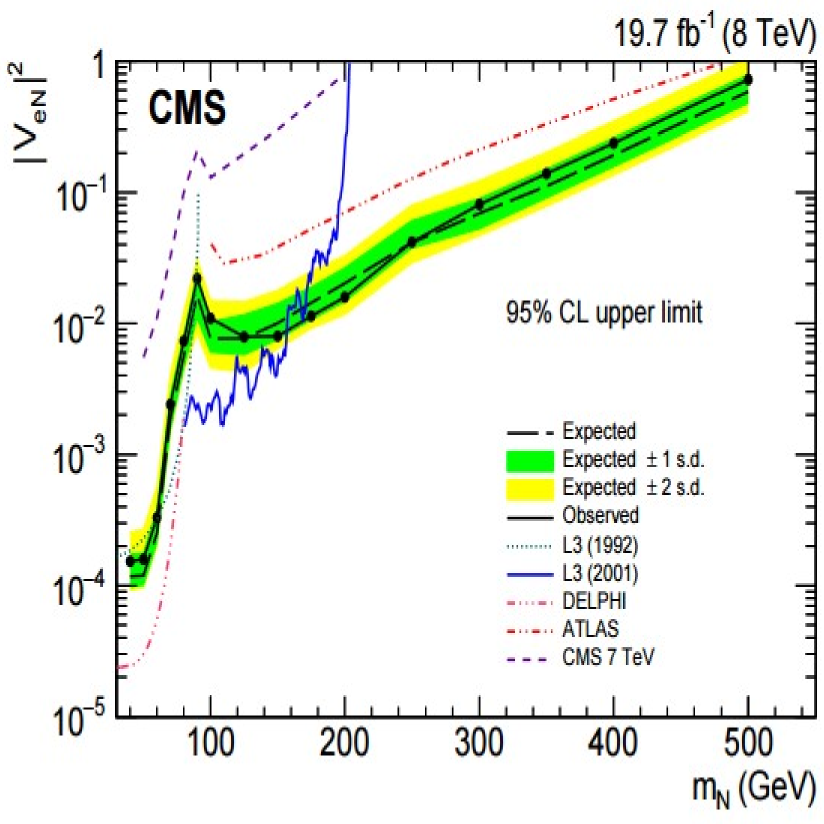
eμ channel

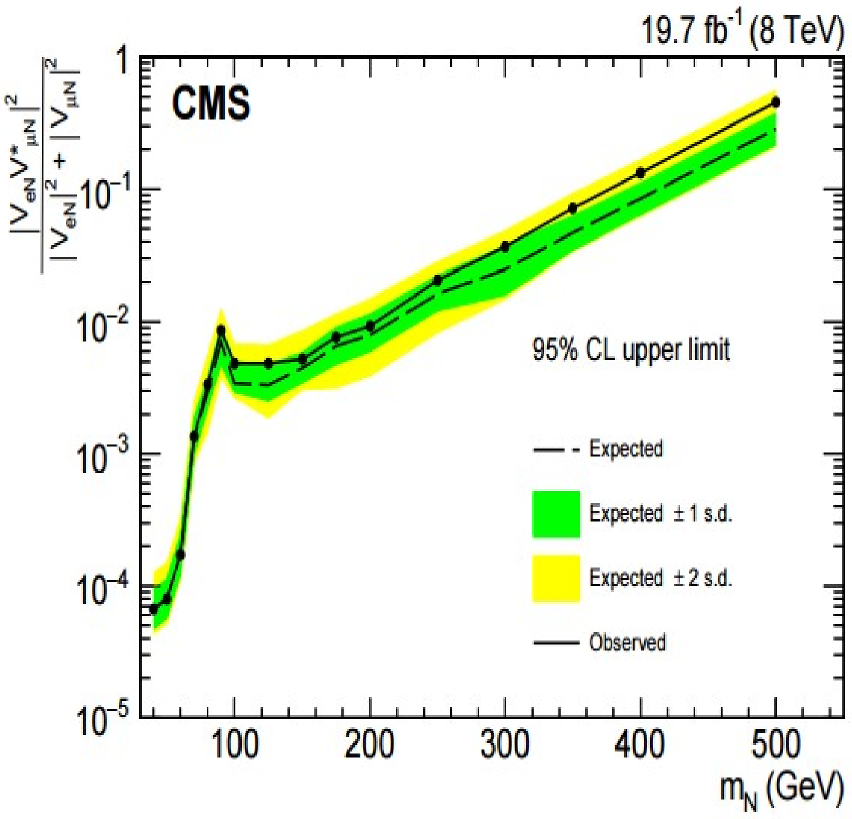
Yield table

Channel / Region	Prompt bkgd.	Misid. bkgd.	Charge mismeas. bkgd.	Total bkgd.	N_{obs}
ee / Low-mass	$4.0 \pm 0.4 \pm 0.8$	$26.7 \pm 3.2 \pm 10.7$	$2.00 \pm 0.03 \pm 0.24$	$32.6 \pm 3.2 \pm 10.7$	33
ee / High-mass	$10.8 \pm 0.7 \pm 2.2$	$36.9 \pm 3.6 \pm 14.8$	$6.99 \pm 0.09 \pm 0.84$	$55.4 \pm 3.6 \pm 14.8$	54
eμ / Low-mass	$10.4 \pm 0.7 \pm 2.1$	$63.4 \pm 4.1 \pm 21.5$	$0.07 \pm 0.01 \pm 0.01$	$73.9 \pm 4.1 \pm 21.6$	71
eμ / High-mass	$24.1 \pm 1.1 \pm 4.8$	$75.6 \pm 4.3 \pm 25.7$	$0.24 \pm 0.01 \pm 0.01$	$99.8 \pm 4.5 \pm 25.8$	117

There is a good compatibility between the number of observed events and predicted backgrounds.

Exclusion limits





For the ee channel, these are the most restrictive direct limits for heavy Majorana neutrino masses above 200 GeV.

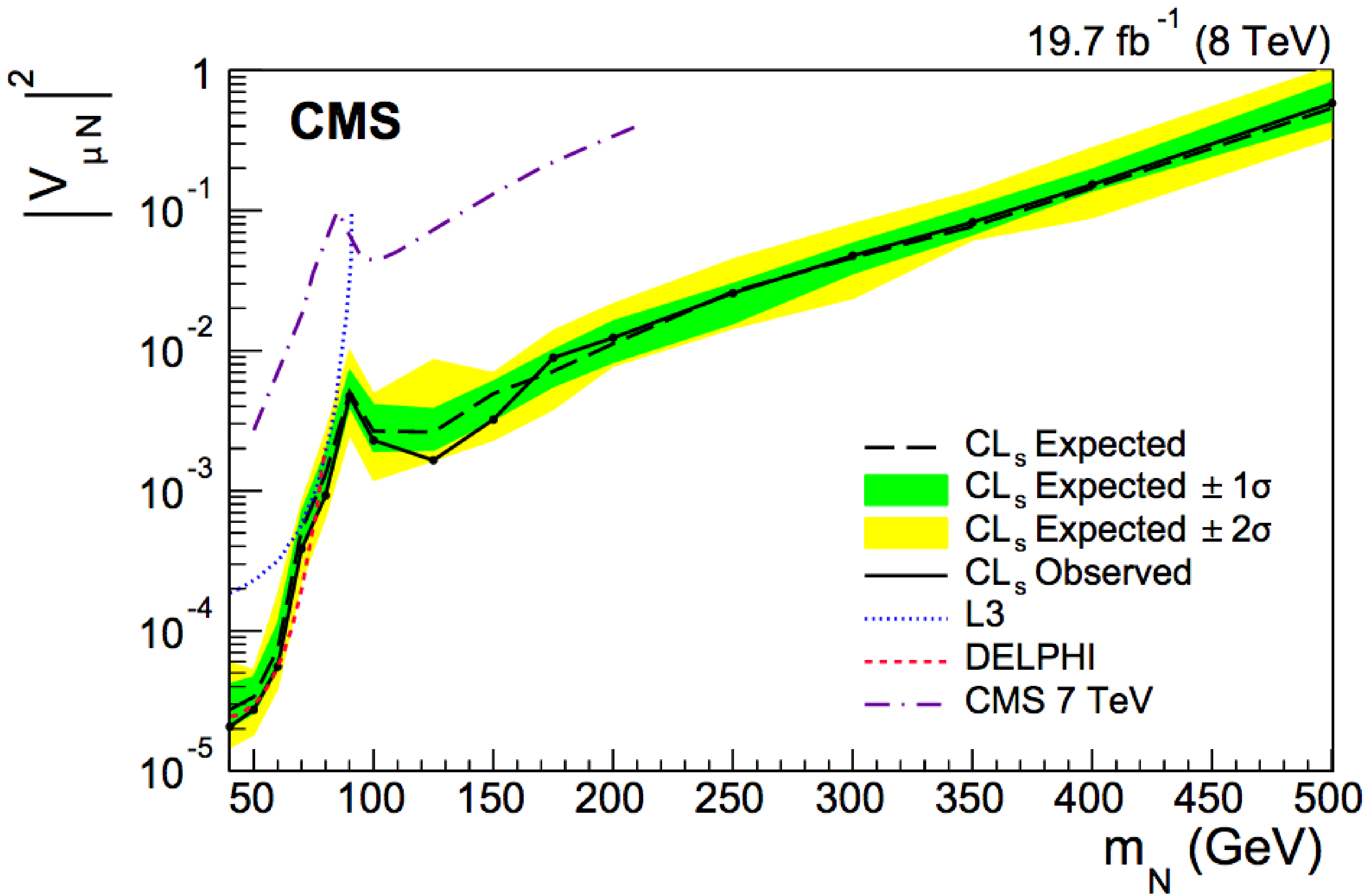
For the eμ channel, the first direct limits are set on this quantity for masses above 40 GeV.

Summary and conclusion

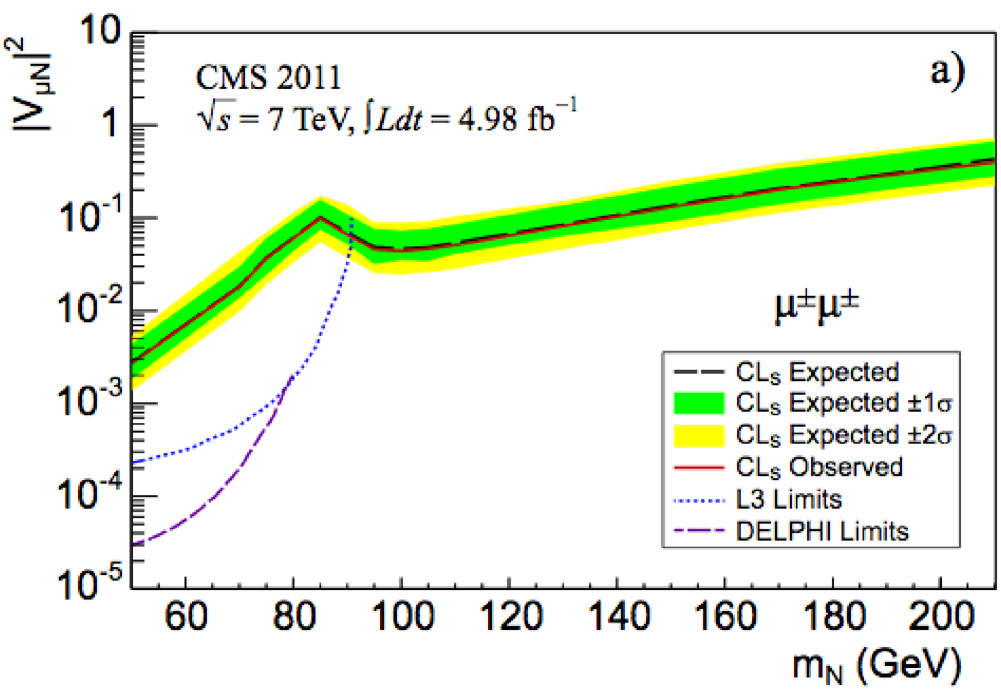
- A search for heavy Majorana neutrinos was performed with the CMS detector using 19.7 fb^{-1} of data collected until 2012 with the CMS detector.
- We have two search regions: low mass ($m_N < m_W$) and high mass ($m_N > m_W$).
- No excess of events compared to SM expectations was observed.
- Newer restrictive limits were set for the ee channel, and the first limits set for the eμ channel.

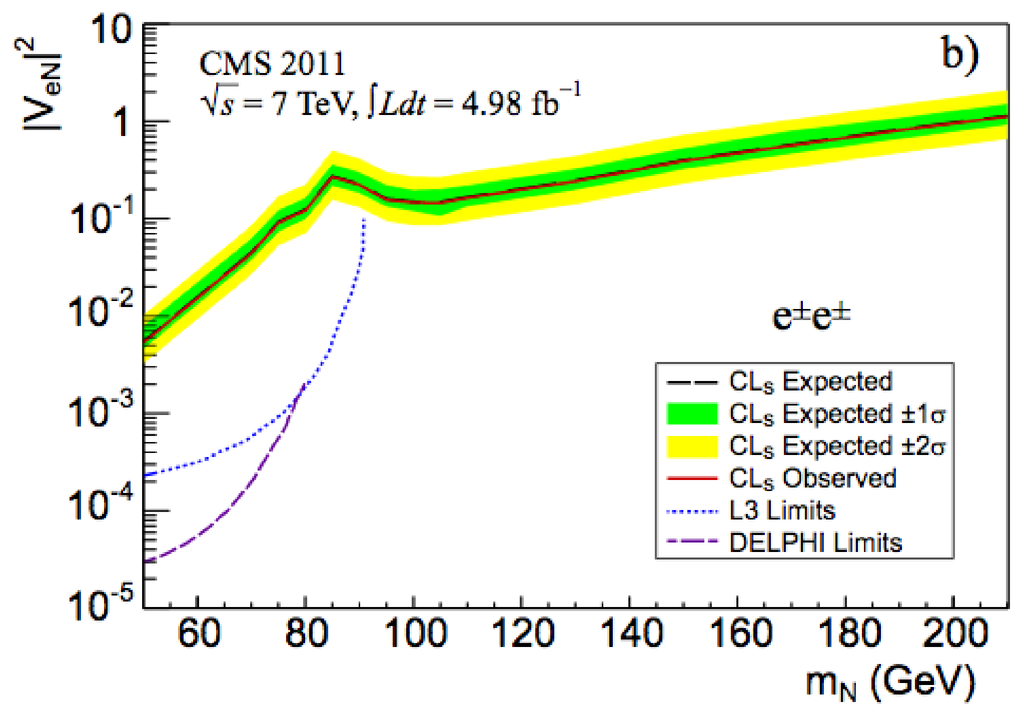
Backup slides

CMS μμ channel

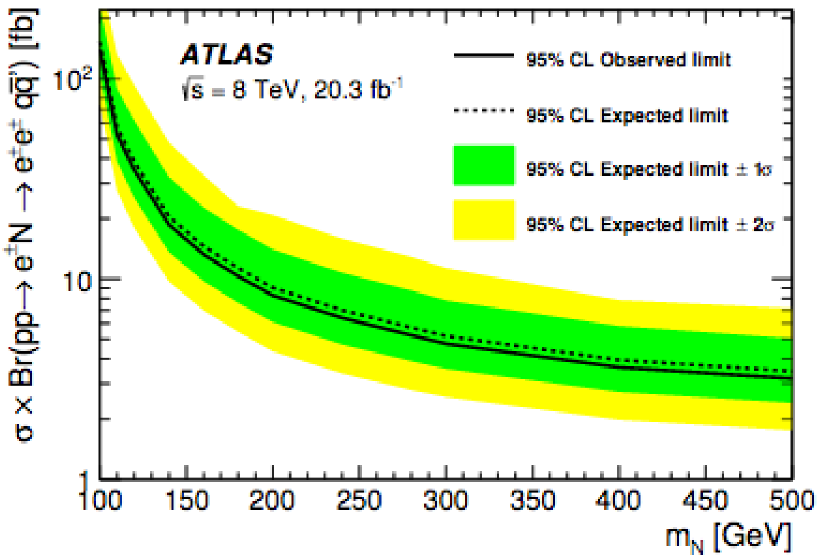


CMS previous search

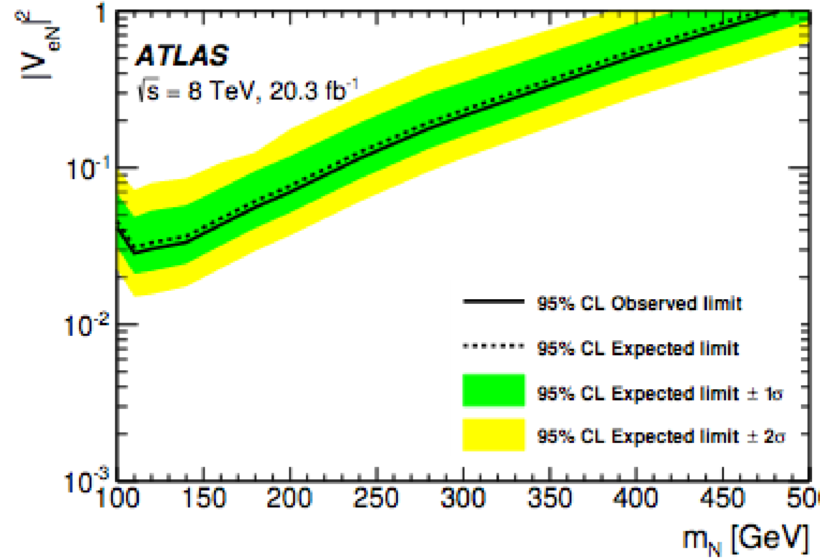




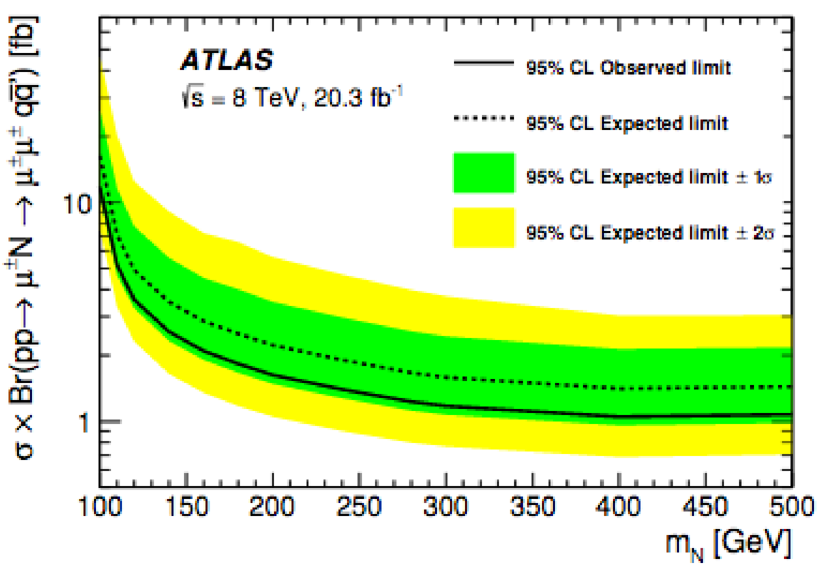
ATLAS minimal Type-I seesaw mechanism signal region



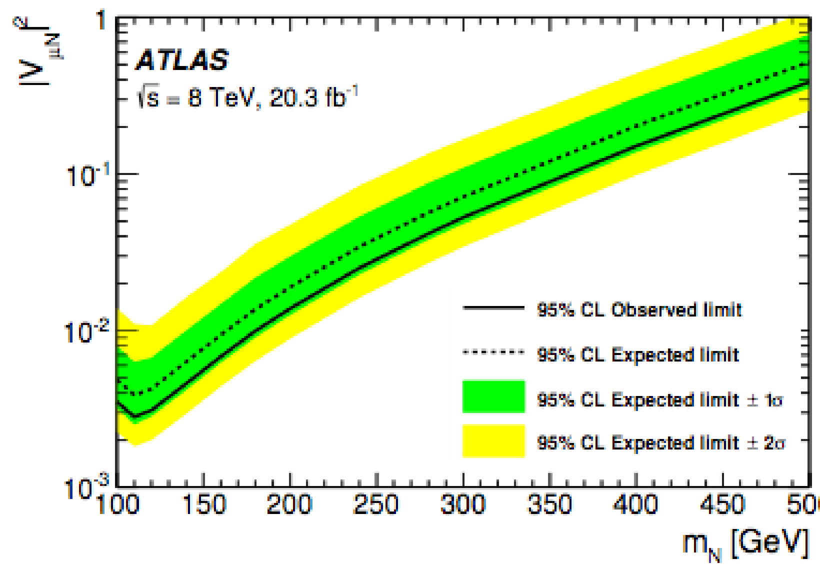
(a)



(b)



(c)



(d)

Backup – Why this topology?

- Can also have a “VBF”-like topology, with jets radiated directly from initial state
- Leaves the leptons weakly boosted in the transverse plane
- If Majorana neutrino exists, the invariant mass should form distinctive peak

Jet ID Selection

The most recent analysis of the Particle Flow Jet
the AN-14-227.

PF Jet ID	Loose	Tight
Neutral Hadron Fraction	< 0.99	< 0.90
Neutral EM Fraction	< 0.99	< 0.90
Number of Constituents	> 1	> 1
Muon Fraction	< 0.8	< 0.8
And for -2.4 <= eta <= 2.4 in addition apply		
Charged Hadron Fraction	> 0	> 0
Charged Multiplicity	> 0	> 0
Charged EM Fraction	< 0.99	< 0.90

*Official HEEP Selection v4.1 (2012 version, out of date)

Variable	Barrel	Endcap
E_T	> 35 GeV	> 35 GeV
	$\|\eta_{sc}\| < 1.442$	$1.56 < \|\eta_{sc}\| < 2.5$
isEcalDriven	=1	=1
$\|\Delta\eta_{in}\|$	< 0.005	< 0.007
$\|\Delta\varphi_{in}\|$	< 0.06	< 0.06
H/E	<0.05	<0.05
$\sigma_{i\eta i\eta}$	n/a	<0.03
E_{2x5}/E_{5x5}	>0.94 OR E_{1x5}/E_{5x5} > 0.83	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et +0.28rho	<2.5 +0.28.rho for Et<50 else
		<2.5+0.03*(Et-50) +0.28.rho
Track Isol: Trk Pt	<5	<5
Inner Layer Lost Hits	<=1	<=1
|dxy|	<0.02	<0.05

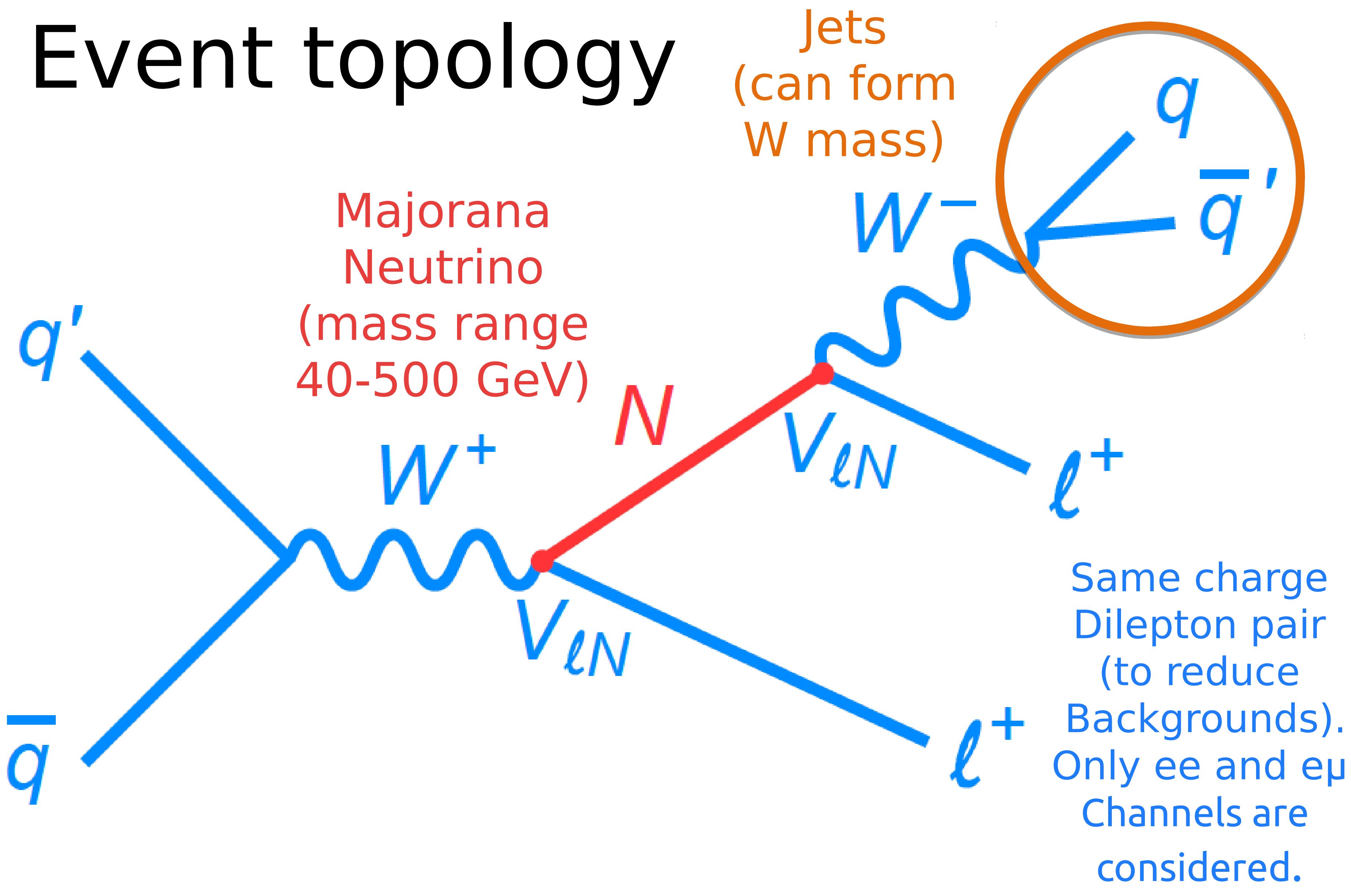
Final selection requirements

m_N (GeV)	$p_T^{\ell_1}$ (GeV)	$p_T^{\ell_2}$ (GeV)	$p_T^{j_1}$ (GeV)	$m(\ell^\pm\ell^\pm jj)$ (GeV)	$m(\ell_2 jj)$ (GeV)	$m(\ell^\pm\ell^\pm)$ (GeV)	Acc. × Eff. (%)
ee channel:							
40	>20	>15	>20	80-160	<120	10-60	0.19 ± 0.01
50	>20	>15	>20	80-160	<120	10-60	0.26 ± 0.02
60	>20	>15	>20	80-160	<120	10-60	0.22 ± 0.01
70	>20	>15	>20	80-160	<120	10-60	0.09 ± 0.01
80	>20	>15	>20	80-160	<120	10-60	0.32 ± 0.02
90	>20	>15	>30	>120	60-120	>15	0.46 ± 0.03
100	>20	>15	>30	>120	80-120	>15	1.9 ± 0.1
125	>25	>25	>30	>140	105-145	>15	4.2 ± 0.1
150	>40	>25	>30	>195	125-175	>15	6.5 ± 0.1
175	>45	>30	>30	>235	155-200	>15	6.4 ± 0.1
200	>65	>40	>30	>280	160-255	>15	8.4 ± 0.1
250	>110	>40	>40	>300	—	>15	10.6 ± 0.1
300	>120	>40	>40	>320	—	>15	14.0 ± 0.2
350	>120	>40	>40	>360	—	>15	16.1 ± 0.2
400	>120	>40	>40	>360	—	>15	17.2 ± 0.2
500	>120	>40	>40	>360	—	>15	16.6 ± 0.2
eμ channel:							
40	>20	>15	>20	80-150	—	>10	0.39 ± 0.02
50	>20	>15	>20	80-150	—	>10	0.46 ± 0.02
60	>20	>15	>20	80-150	—	>10	0.38 ± 0.01
70	>20	>15	>20	80-150	—	>10	0.14 ± 0.01
80	>25	>15	>20	90-200	—	>10	0.58 ± 0.02
90	>40	>15	>30	>120	<130	>45	0.57 ± 0.02
100	>40	>30	>30	>130	<135	>45	1.71 ± 0.04
125	>40	>30	>30	>140	<160	>45	5.2 ± 0.1
150	>45	>30	>30	>150	<230	>45	9.5 ± 0.1
175	>60	>35	>35	>170	<240	>45	10.9 ± 0.1
200	>75	>35	>35	>200	<330	>45	11.9 ± 0.1
250	>80	>40	>35	>260	<390	>45	15.6 ± 0.1
300	>110	>40	>35	>310	<490	>45	16.0 ± 0.1
350	>110	>40	>35	>360	<550	>45	16.1 ± 0.1
400	>120	>40	>35	>380	<600	>45	16.2 ± 0.1
500	>120	>40	>35	>380	<700	>45	14.1 ± 0.1

Data driven background prediction method

- Two types of leptons: tight and loose
- Use sample of multi jet events and get P(high|loose) for a jet.
- In signal sample:
  - $N_{n\bar{n}}$ (one tight lepton and one loose lepton),
  - $N_{\overline{nn}}$ (two loose leptons).
- Background events:
  - $N_{nn} = f(N_{n\bar{n}}, N_{\overline{nn}}, p)$.

Event topology



Sensitive to

Probability of charge mismeasurement

- Estimate background by applying weights to the events in the data with opposite charged leptons.

$$W_{cm} = \frac{w_{cm_1}}{1 - w_{cm_1}} + \frac{w_{cm_2}}{1 - w_{cm_2}}$$

- Scale factors are calculated using data samples of $Z \rightarrow e^+e^-$ where the invariant mass of the e^+e^- pair is between 76 and 106 GeV.

Note: Main uncertainties are comes from the misidentified leptons and mismeasured charge showed in the table. Others are cited from previous works.

Channel / Source
Simulation:
SM cross section: use to prompt backgroud
Jet energy scale: scale factor for the MC according to the data :cited from the official
Jet energy resolution:cited from the previous work
Event pileup: some hits from unwanted interactions and unwanted jets :cited from the official
Unclustered energy:the energy outside the cluster :cited from the official
Integrated luminosity:
Lepton selection:
Trigger selection
b tagging : uncertainty for identification of jets originated from b quark
PDF (shape), PDF (rate) : signal description **The ALPGEN signal Monte Carlo parton distribution function uncertainty is estimated using the method in Ref. [39]. We look also at the effect of using three different PDFs on the signal yield**
Renormalization / factorization scales :MC
Signal MC statistical uncertainty
Data-Driven:
Misidentified leptons:Data-driven fake rate method(background group): 1.varying the background estimate with respect to the isolation requirement for the loose leptons 2.varying the pT requirement for the tag jet
Mismeasured charge :take the weighted average of the uncertaintices on the scale factors used in charge mismeasured part