# Search for Heavy Neutrinos in Same-sign Dilepton Events at $\sqrt{s}$ = 13 TeV Using the CMS Detector

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# Why heavy neutrinos?

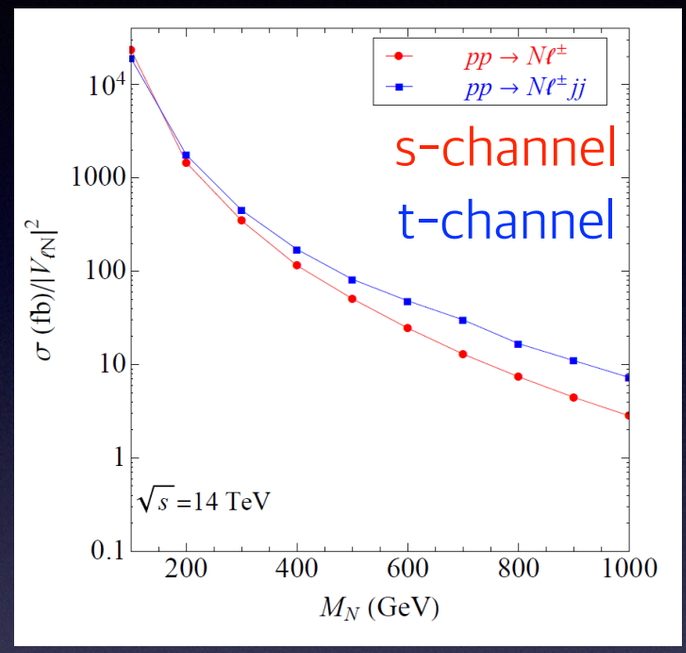
- The discovery of neutrino oscillation
  - Neutrinos have **non-zero** masses ($\Sigma m_\nu < 0.13$ eV from cosmology)
  - A right-handed massive neutrino may exist

- Seesaw mechanism
  - Explains the smallness of the SM neutrino masses ($m_\nu \propto \frac{1}{m_N}$)
  - Right-handed neutrino is very heavy
  - It may be in the TeV scale  (Dirac or Majorana)
  - Search for the TeV scale heavy neutrinos at the LHC

# Searches at the LHC

- Majorana ⇒ 50% **same-sign** (SS) lepton pair
- Searches @ 8 TeV by SNU group
  - s-channel (2l+2j) : ee, eμ, μμ
- Searches @ 13 TeV
  - 2 new channels : **t-channel**, pair production channel (2l+4j)
  - s-channel & t-channel (type I seesaw)
  - cross sections for t-channel **are not negligible** due to the collinear singularity caused by γ*

the next talk

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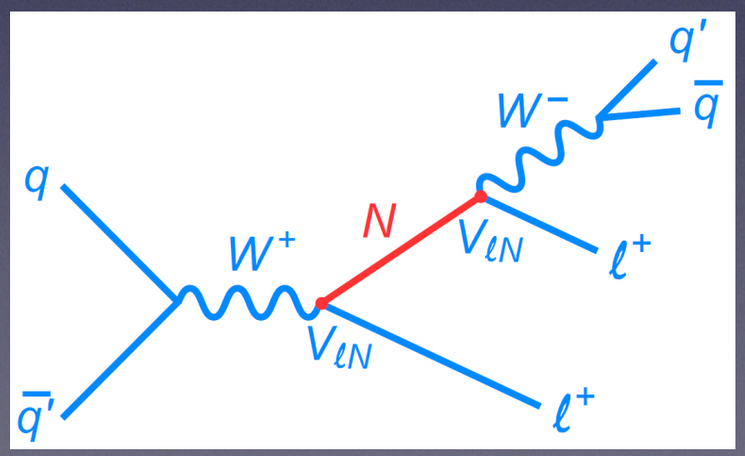
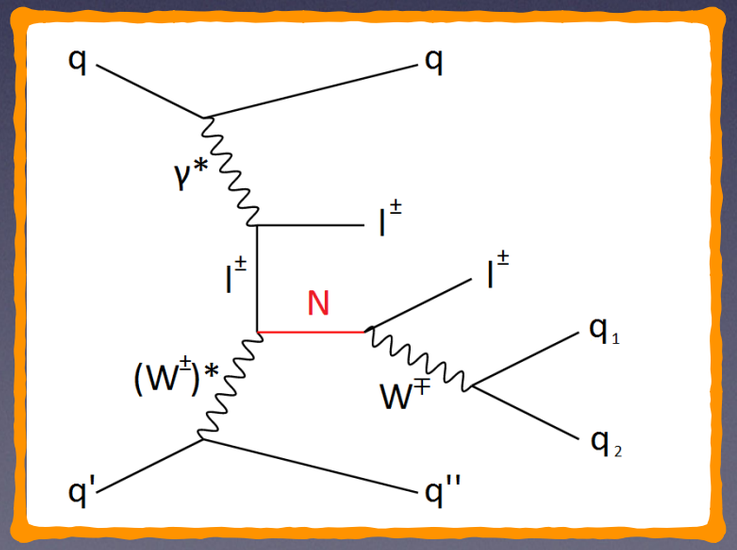
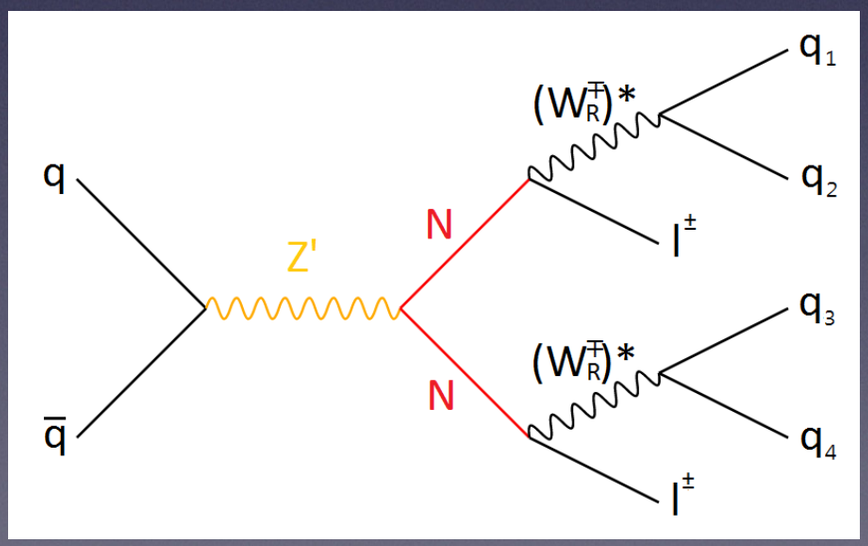



s-channel



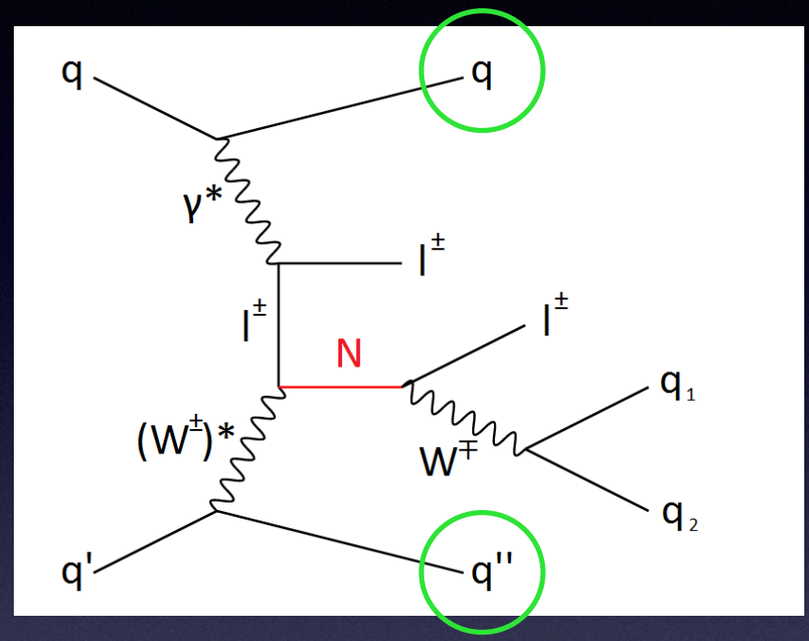

t-channel




pair production channel

# Event selection : t-channel

- Full 2016 CMS dataset : 35.9 $fb^{-1}$, 13 TeV
- Signal sample
  - Generated using MadGraph5
  - $m_N$(GeV) = 100 ~ 1500 GeV
  - same-sign (SS) lepton pair : ee, eμ, μμ
- Use dilepton triggers
- Event selection




**Leptons**

- 2 same-sign tight leptons
- $p_T$(l) > 20 GeV / 15 GeV
- m(ll) > 10 GeV
- |m(ll) – 90| < 10 GeV excluded (only for ee channel)
- No 3rd leptons

**Jets / MET**

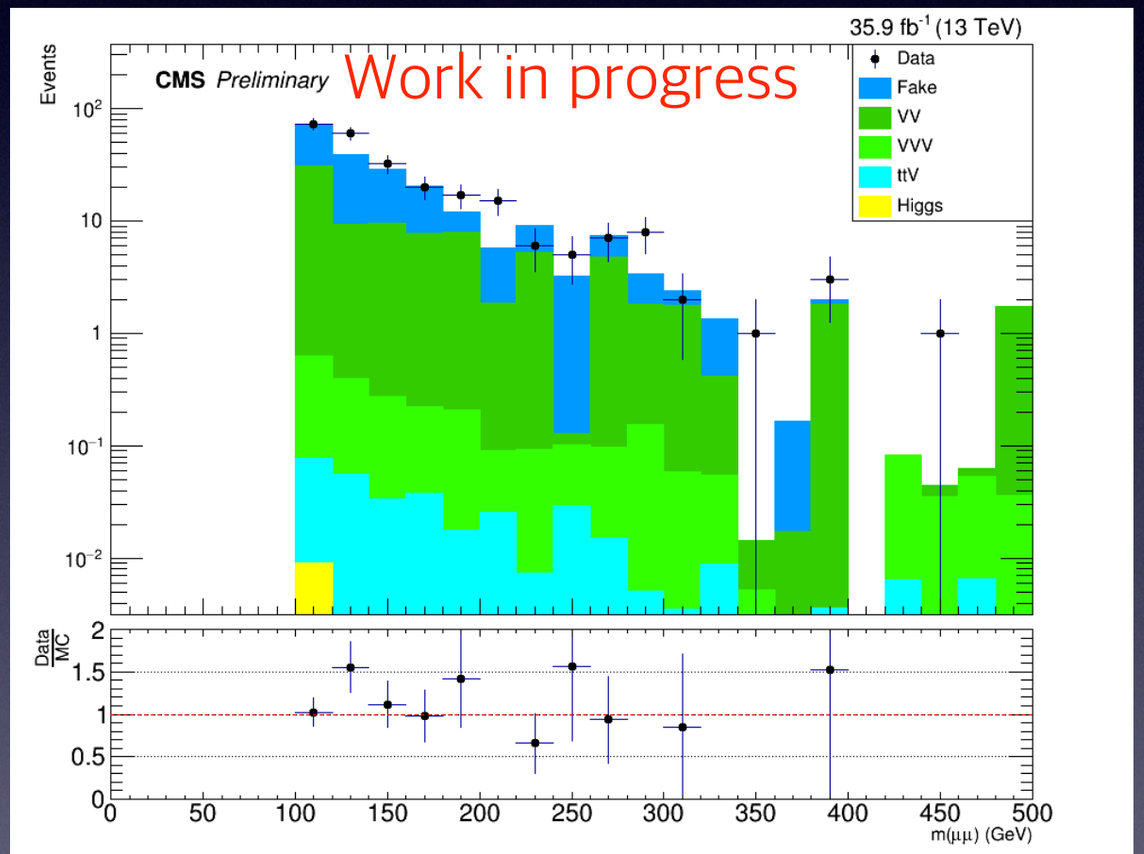
- # of jets ≥ 4
- $p_T$ > 20 GeV, |η| < 5
- two jets with m(jj) closest to $m_W$
- At least 1 jet in each |η| > 1.5 region

# Background (SS dilepton)

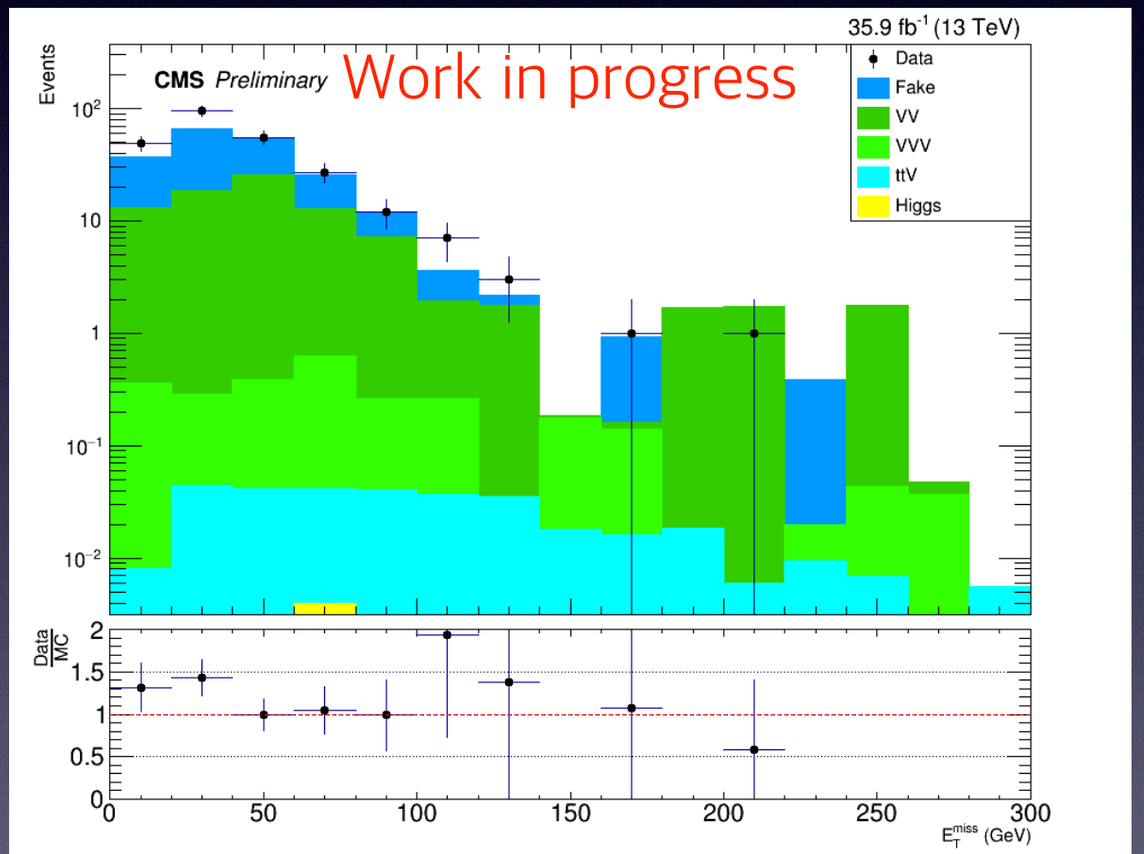
- Fake leptons
  - non-prompt lepton, other jet/γ **misidentified as isolated lepton**
  - multi-jets, W(⟶lν) + jets, ttbar in lepton+jet
  - estimated by a data driven method
- SM background
  - **di-boson**, tri-boson, ttbar+V, higgs(H⟶WW)
  - estimated using Monte Carlo simulation
- Charge flip
  - electrons with **mis-measured charge** / negligible for muons
  - mis-tracking due to $p_T$(e) resolution or **bremsstrahlung**
  - charge flip rate estimated as a function of $p_T$ & η
    - estimated using MC and scaled using data

# Control region : t-channel (μμ)

- same-sign μμ + only 1 jet, m(μμ) > 100 GeV
- check whether data and backgrounds are in agreement

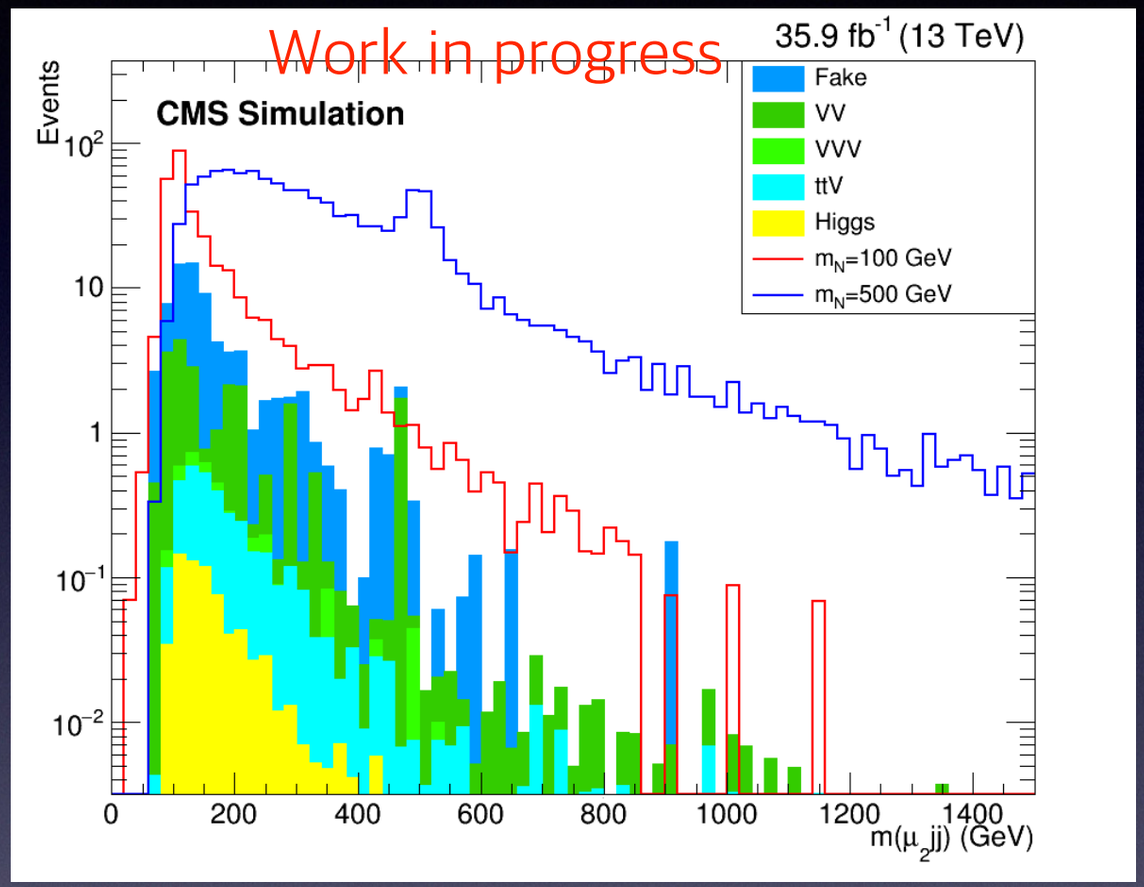


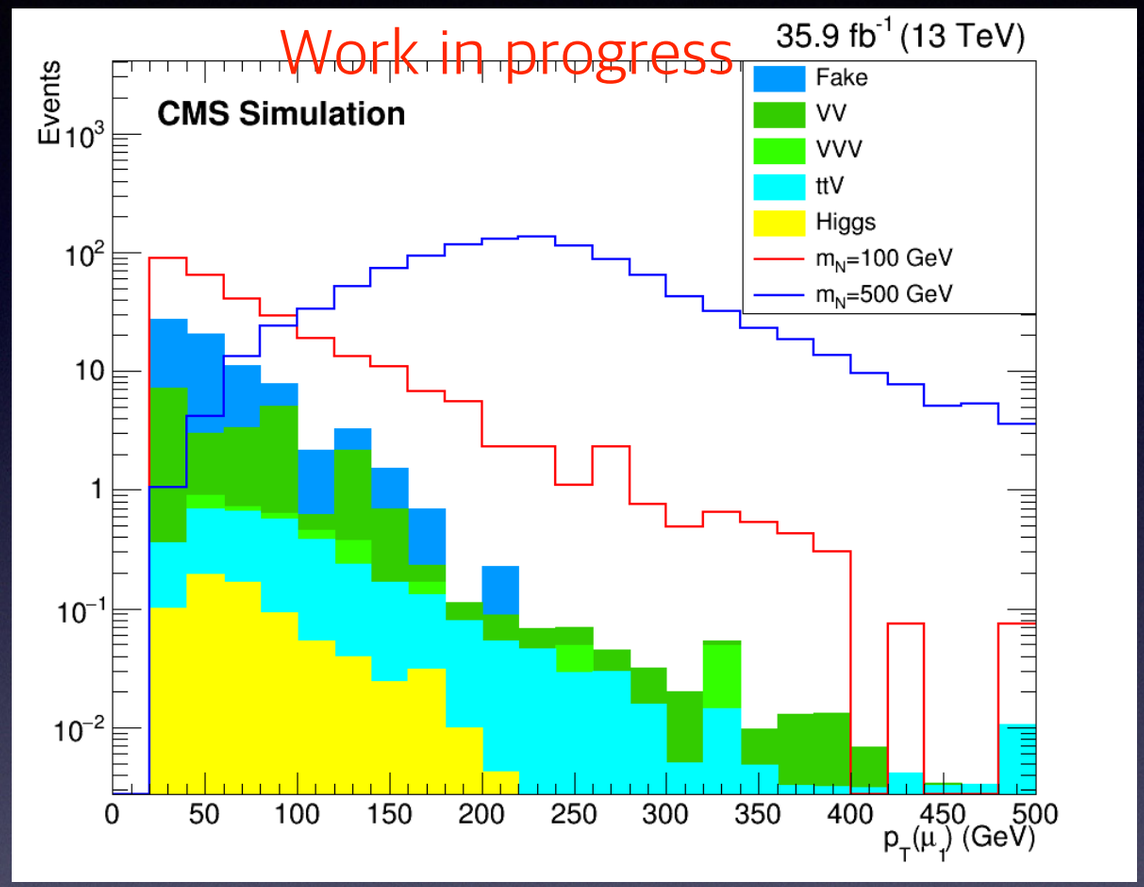

m(μ±μ±)




MET

# Signal region : t-channel (μμ)



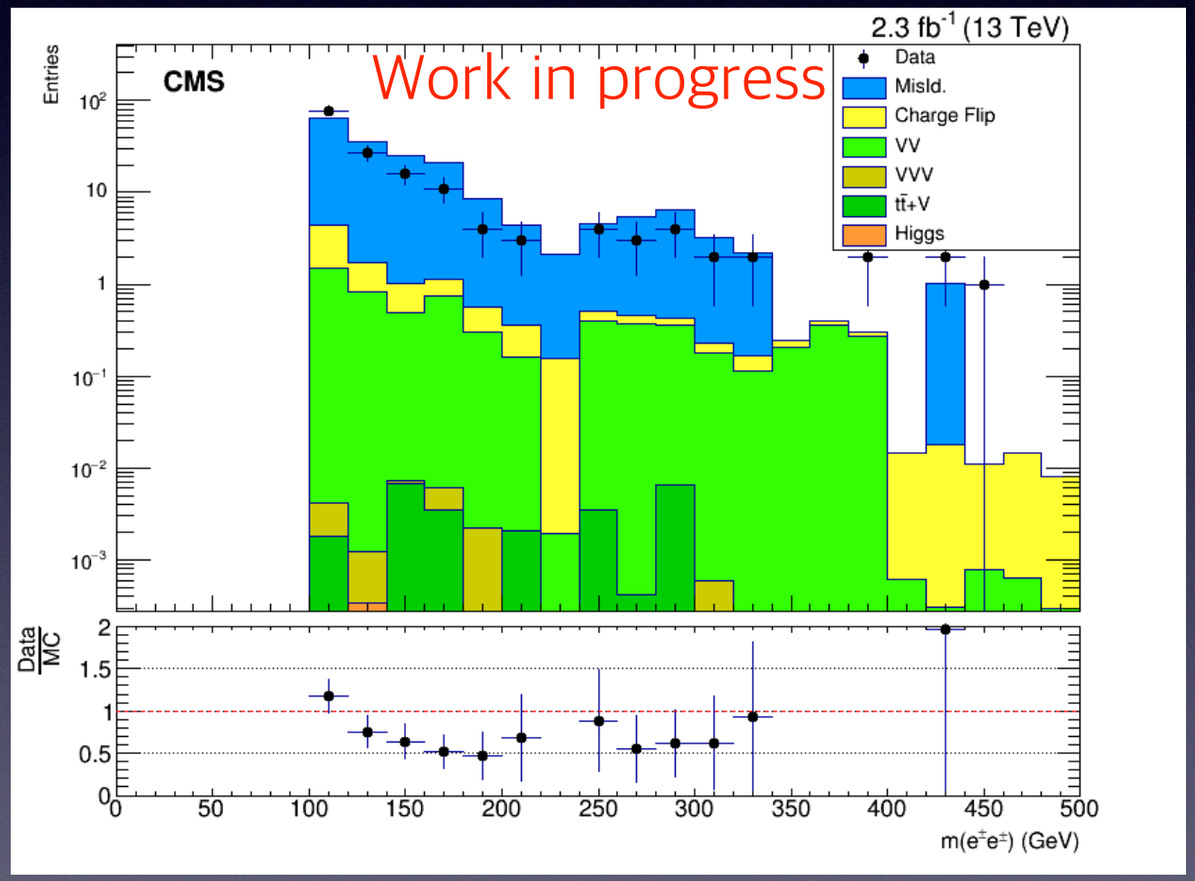

$m(\mu_2 jj)$ $p_T(\mu_1)$

$\mu_1$ : leading $p_T$ muon, $\mu_2$ : second leading $p_T$ muon

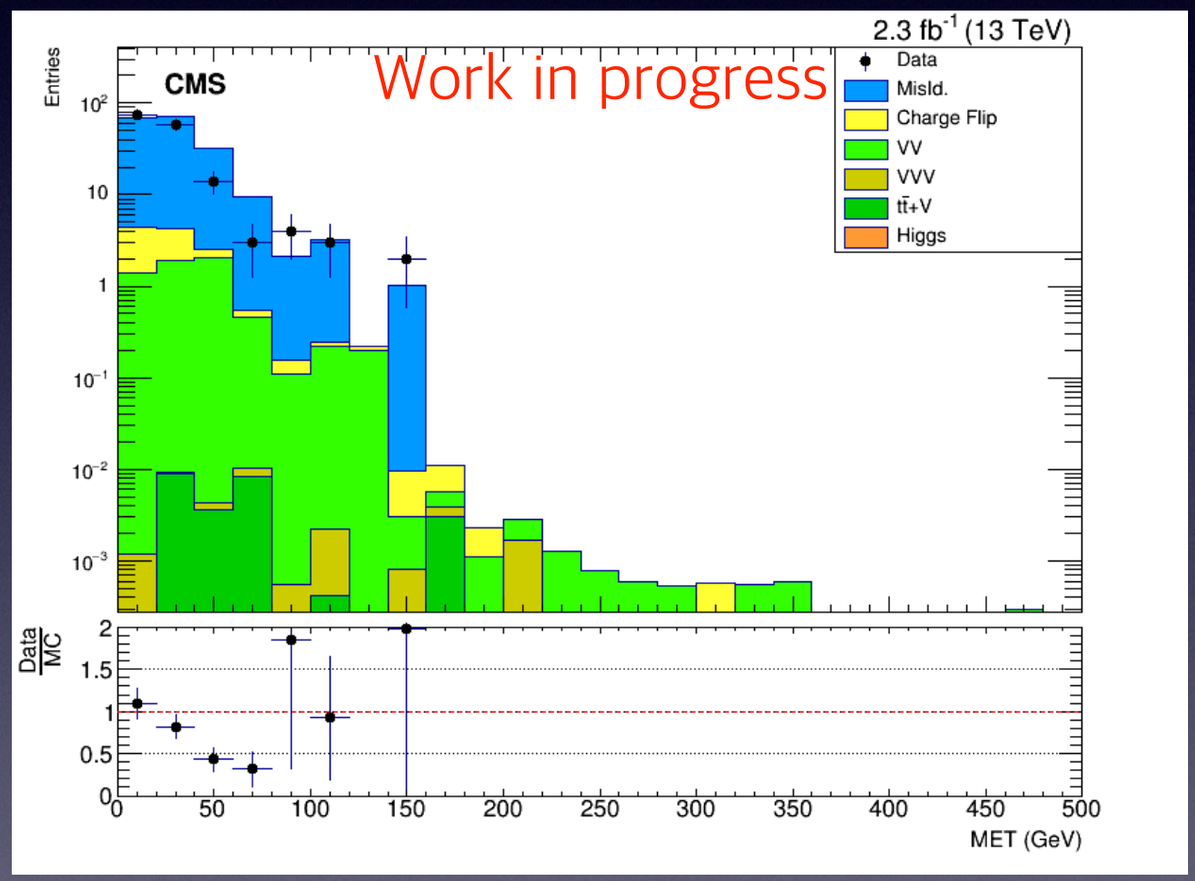
- Here, signal cross sections are set to 0.1 pb

# Control region : t-channel (ee)

- 2015 CMS dataset : 2.3 $fb^{-1}$, 13 TeV
- same-sign ee + only 1 jet, m(ee) > 100 GeV

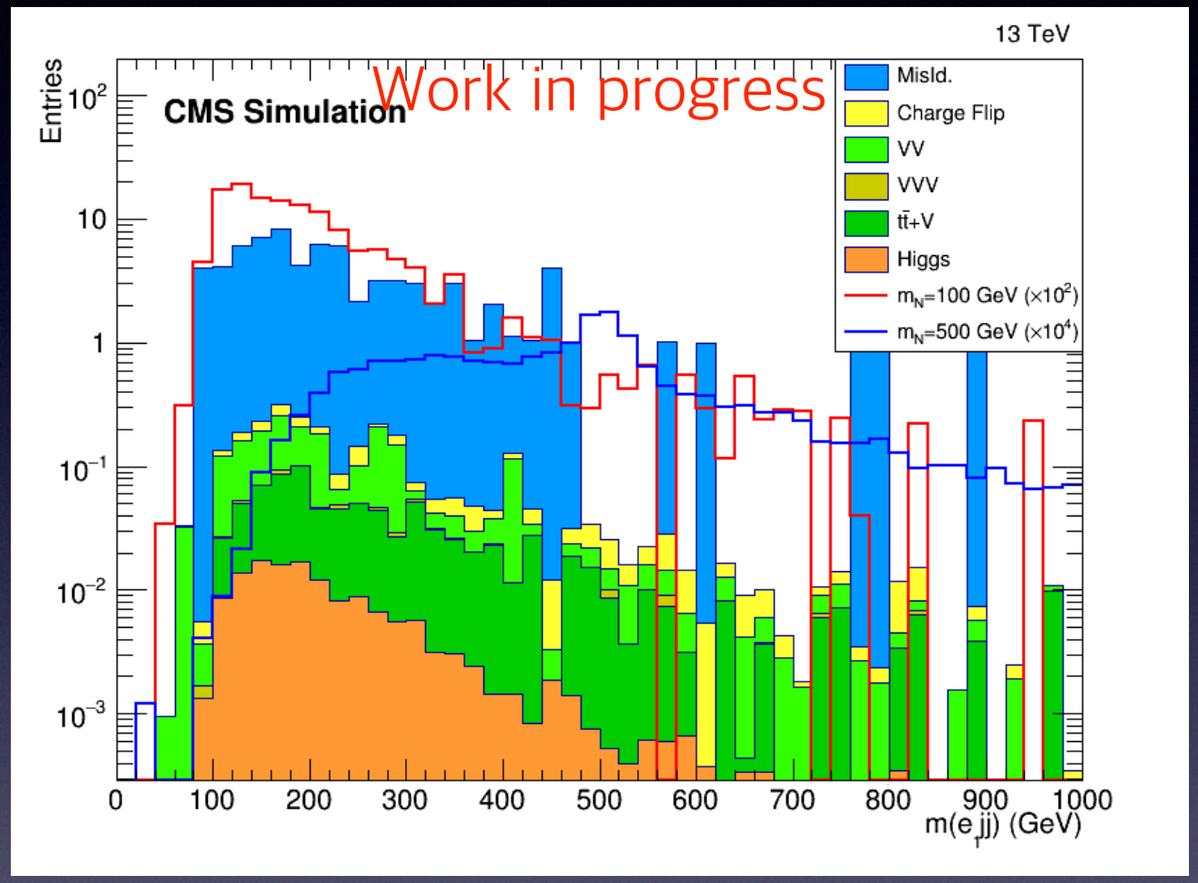


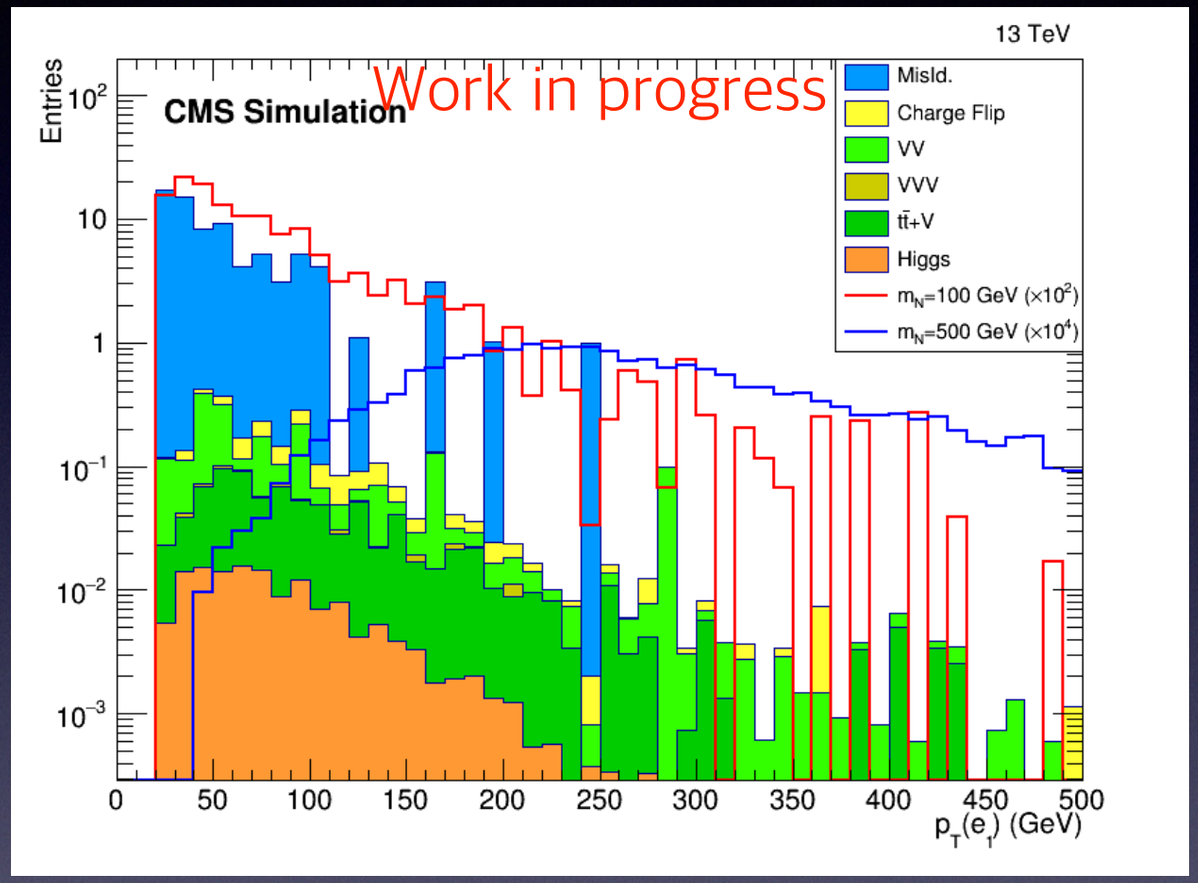

m($e^{\pm}e^{\pm}$)




MET

# Signal region : t-channel (ee)



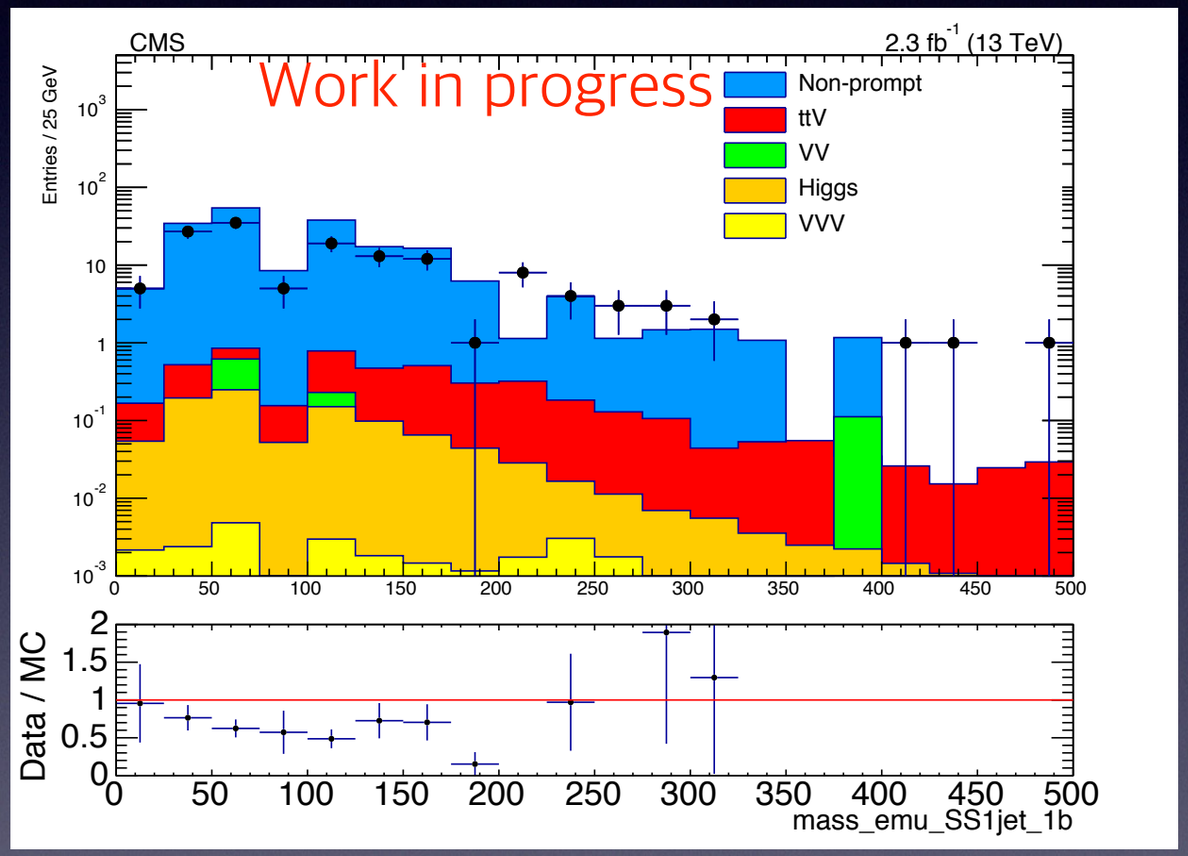




$m(e_1jj)$ $p_T(e_1)$

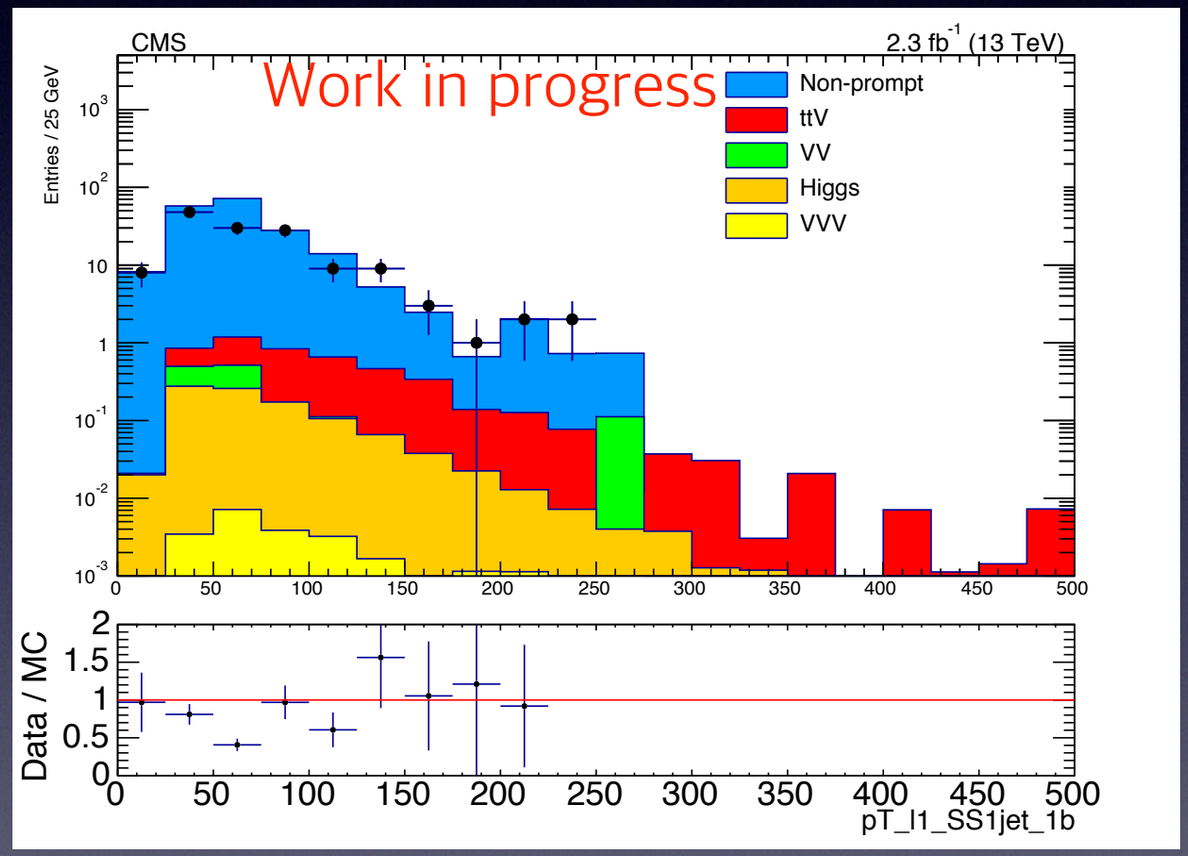
$e_1$ : leading $p_T$ electron, $e_2$ : second leading $p_T$ electron

# Control region : t-channel (eμ)

- 2015 CMS dataset : 2.3 $fb^{-1}$, 13 TeV
- same-sign eμ + only 1 b-jet




$m(e^{\pm}\mu^{\pm})$




$p_T(l_1)$

- Need to update results in ee, eμ channel with 2016 CMS dataset

# Summary & Plan

- Performing a search in same-sign dilepton channel using data at $\sqrt{s}$ = 13 TeV
  - t-channel : 2 leptons + 4 jets
  - working on the analysis with 2016 dataset (35.9 $fb^{-1}$)
- Need to improve
  - background estimation
    - charge flip, fake contribution in electron channel
  - systematic uncertainties
  - combine s-ch & t-ch results

# BACKUP

# Charge flip rate @ 13 TeV