Search for heavy Majorana neutrino in trilepton channel at 13 TeV using the CMS detector

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2017. 6. 16.

2017 2nd BRL WORKSHOP

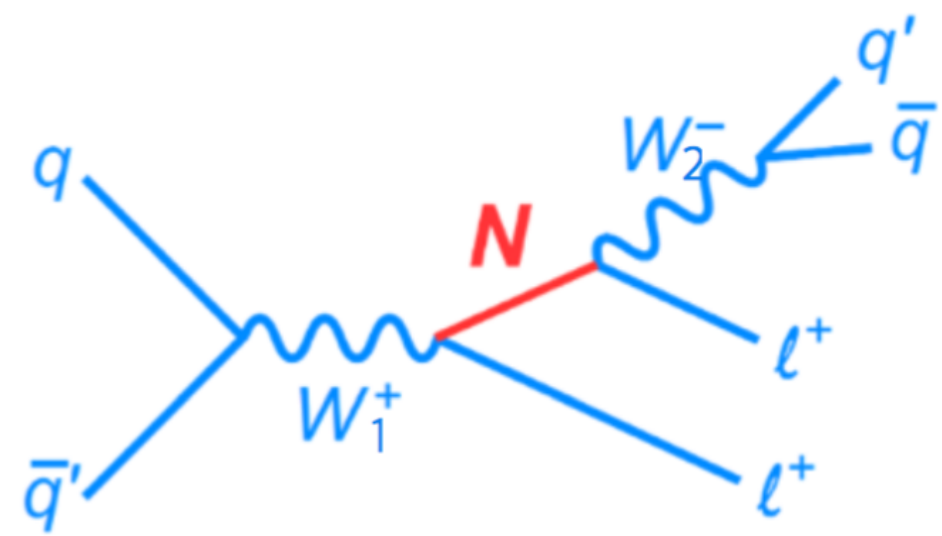
Introduction

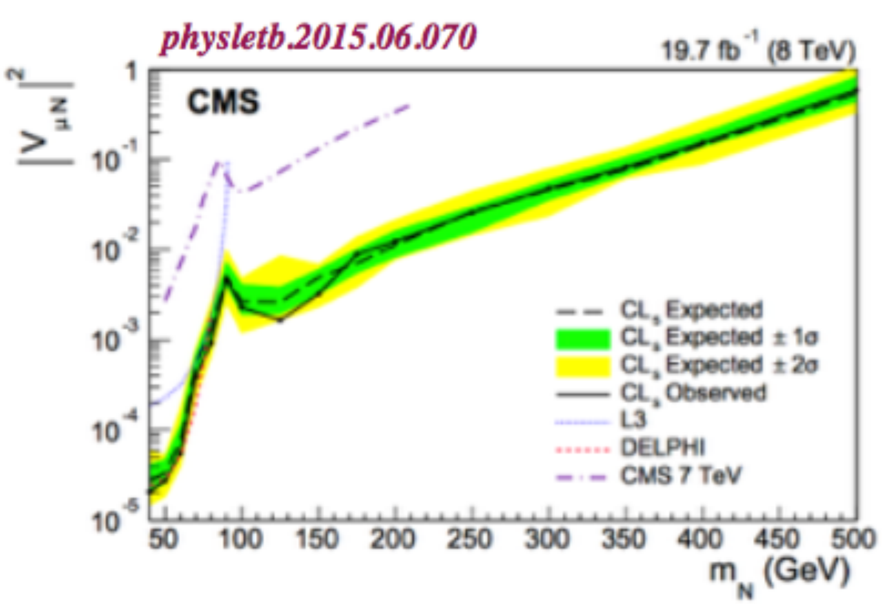
Neutrino oscillation indicates that neutrino mass is not 0
-> Possibility for Right-handed neutrinos to exist

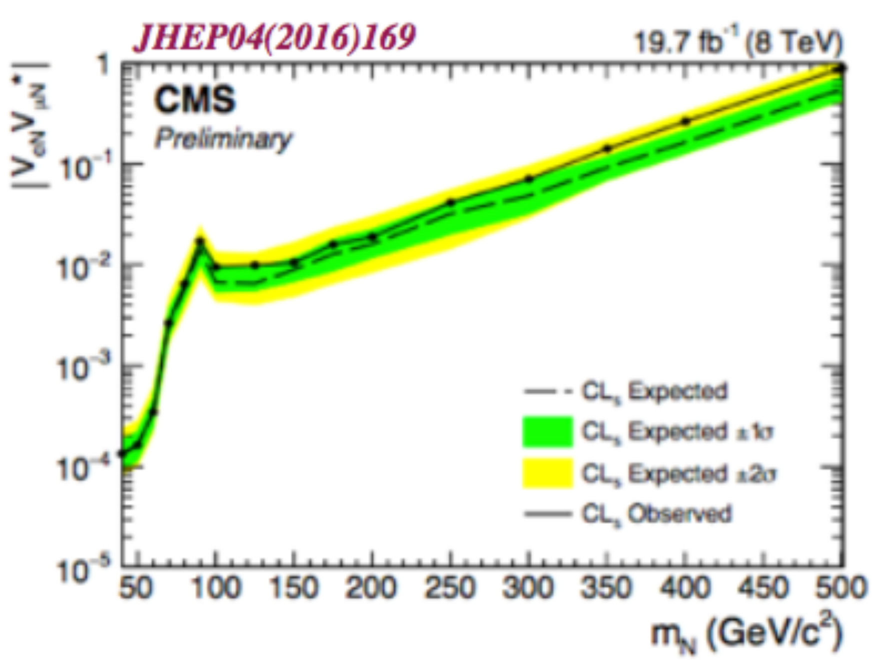
Seesaw mechanism
-> Explains the smallness of standard model neutrino mass by introducing Right-handed neutrinos
-> Right-handed neutrinos are assumed to be heavy
-> Search for TeV scale Heavy Neutrinos(HN) at the LHC

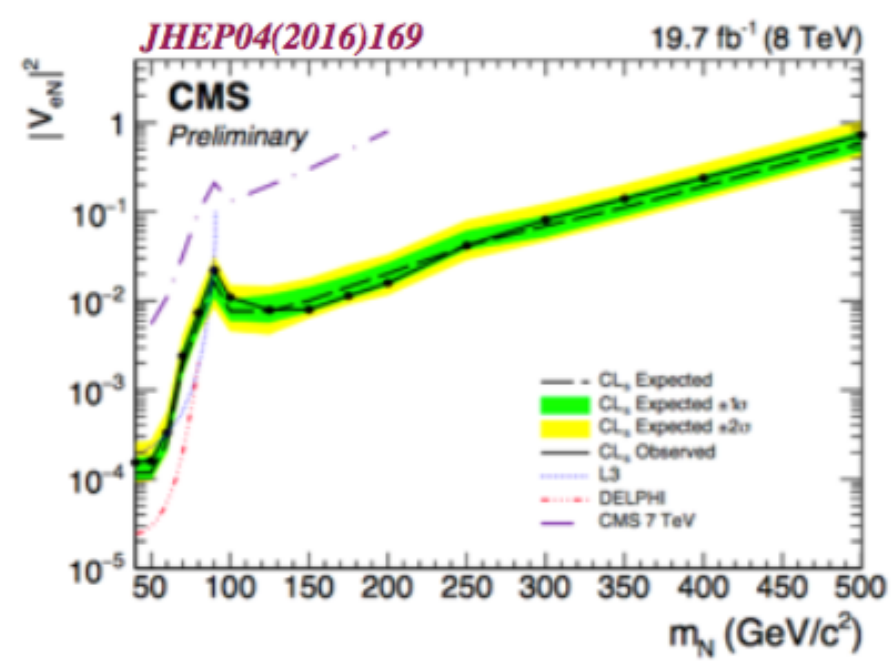
Previous Searches

Search for HN has been done in Same-Sign Dilepton Channel at 8 TeV using CMS data



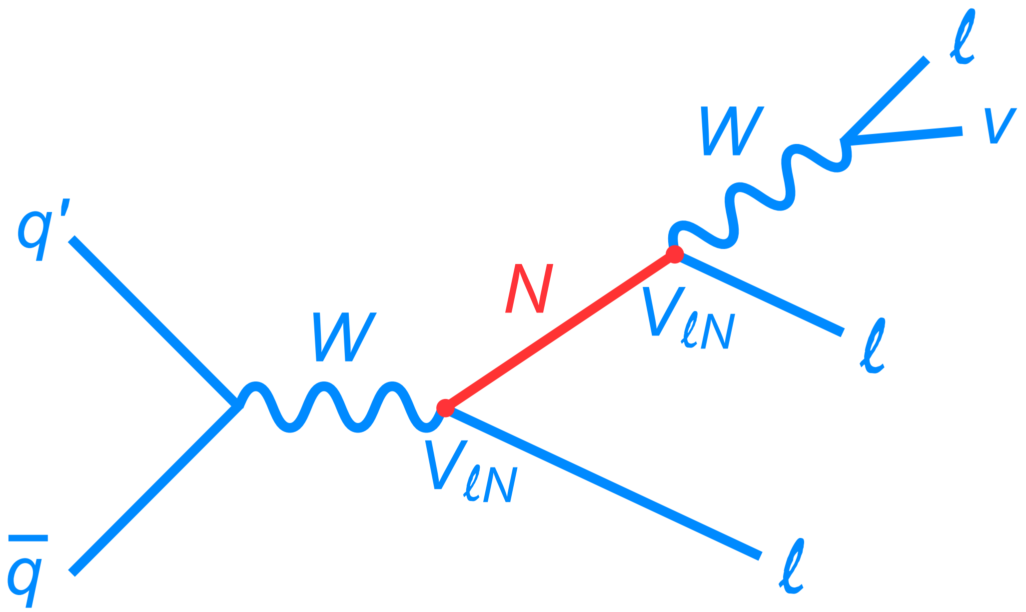






Searches in Trilepton Channel

Extension on search
-> W decays into lepton (muon or electron) : Trilepton



Search for HN, mass range 5 ~ 1000 GeV
MuMuMu channel : 2 SS muons and 1 OS muon
MuMuE channel : 2 SS muons and 1 OS electron

Searches in Trilepton Channel

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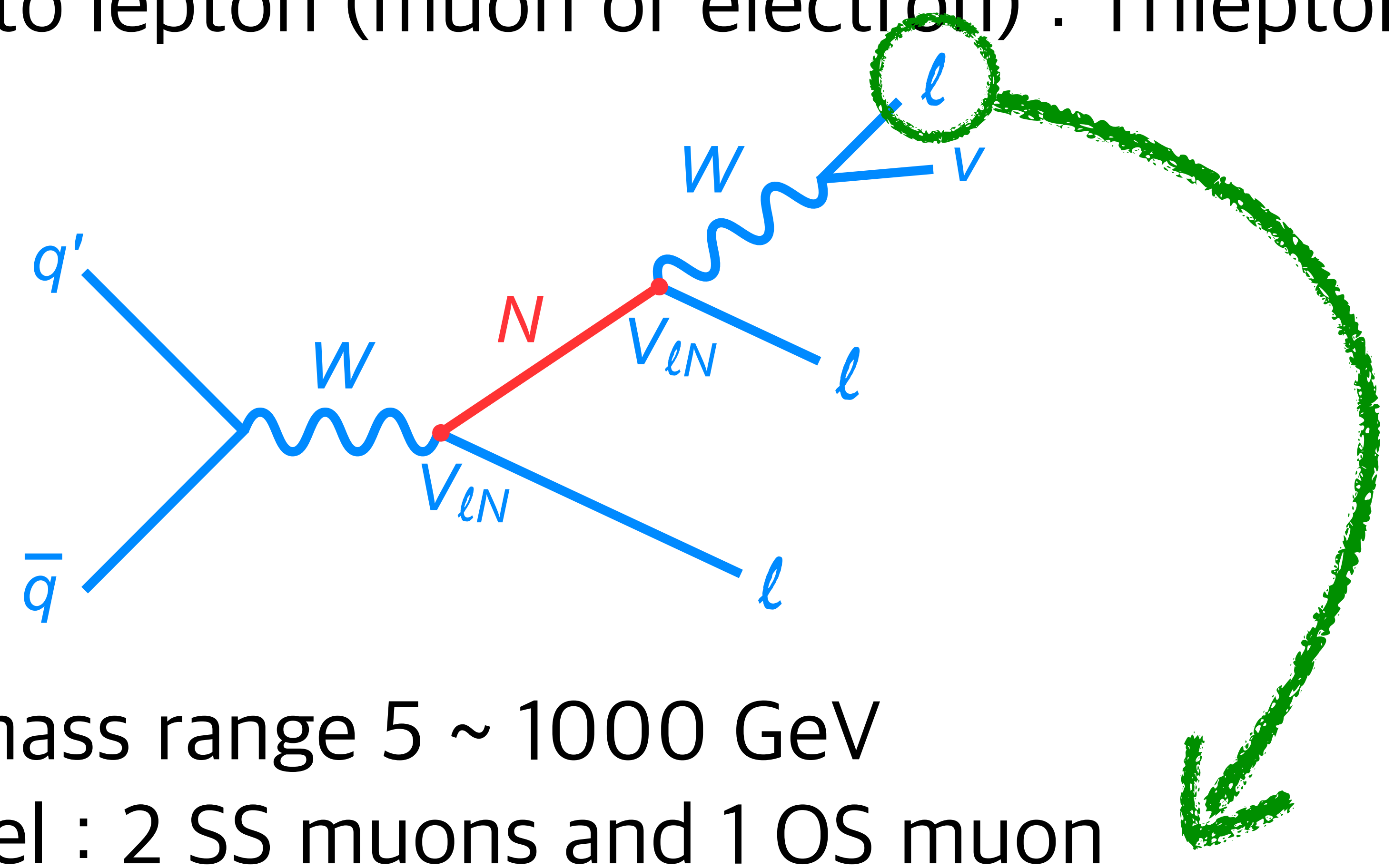


Search for HN, mass range 5 ~ 1000 GeV
MuMuMu channel : 2 SS muons and 1 OS muon
MuMuE channel : 2 SS muons and 1 OS electron

Object Selection

<u>Muon</u>

-> High Pt isolated muons
-> Pt > 10 GeV, $|\eta| < 2.4$
-> $|dXY| < 0.05$ cm, $|dXY/\sigma(dXY)| < 3.0$
-> Isolation < 0.1

<u>Electron</u>

-> High Pt isolated electrons
-> Pt > 10 GeV, $|\eta| < 2.5$
-> Isolation < 0.0588(barrel) & 0.0571(endcap)

Data/Background Samples

Data : Dimuon dataset, 2016 13TeV 35.9 fb^{-1} from CMS

Prompt leptons : MonteCarlo simulation
-> Main : diboson(VV), boson+photon(Vgamma)
-> Others : triboson(VVV), ttbar+boson(ttV)

Fake leptons : data-driven method
-> Jets misidentified as leptons
-> Estimation is done by using the fake rate matrix

Control Region

<u>Prompt Contribution</u>

-> WZ Selection (MuMuMu Channel)

: mass of OS muon pair ~ Z mass (10 GeV window)

: MET > 30 GeV

-> Verify WZ MonteCarlo

<u>Fake Contribution</u>

-> Z+lepton Selection

: mass of OS muon pair ~ Z mass (10 GeV window)

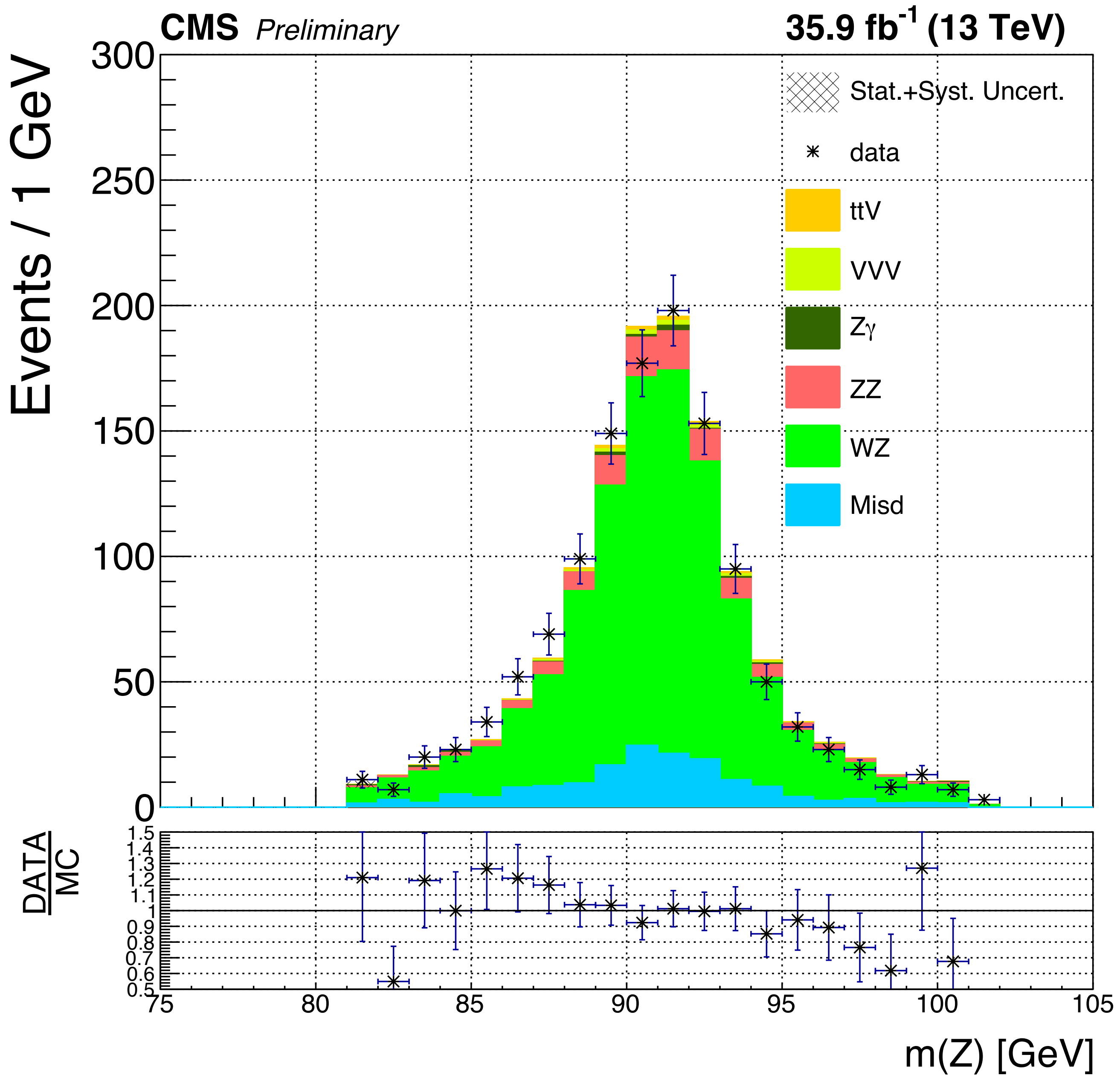
: MET < 20 GeV

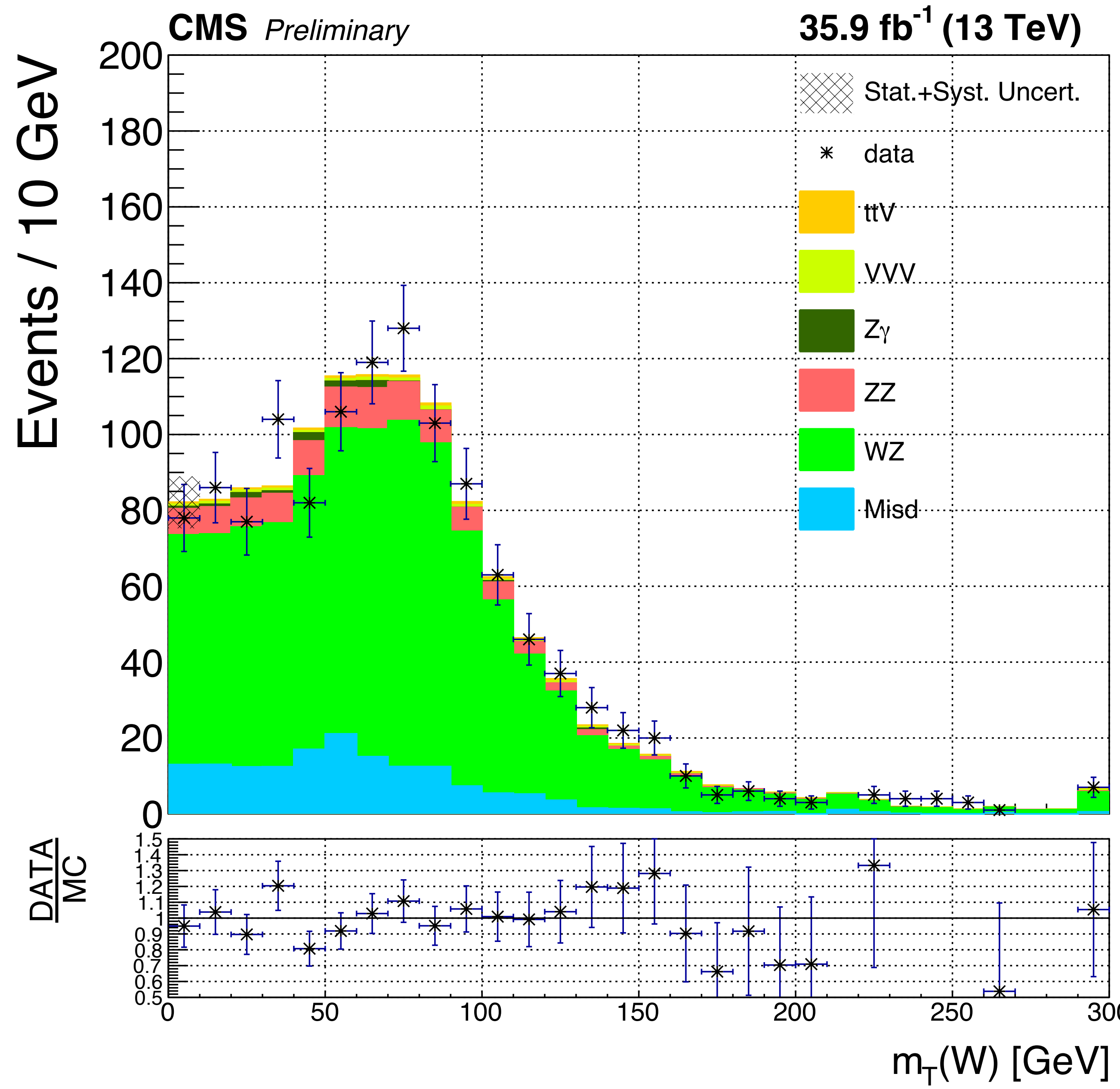
: additional lepton can be considered as fake lepton

-> Verify fake rates obtained from data

Control Region

Prompt contribution (3 muons in WZ selection)



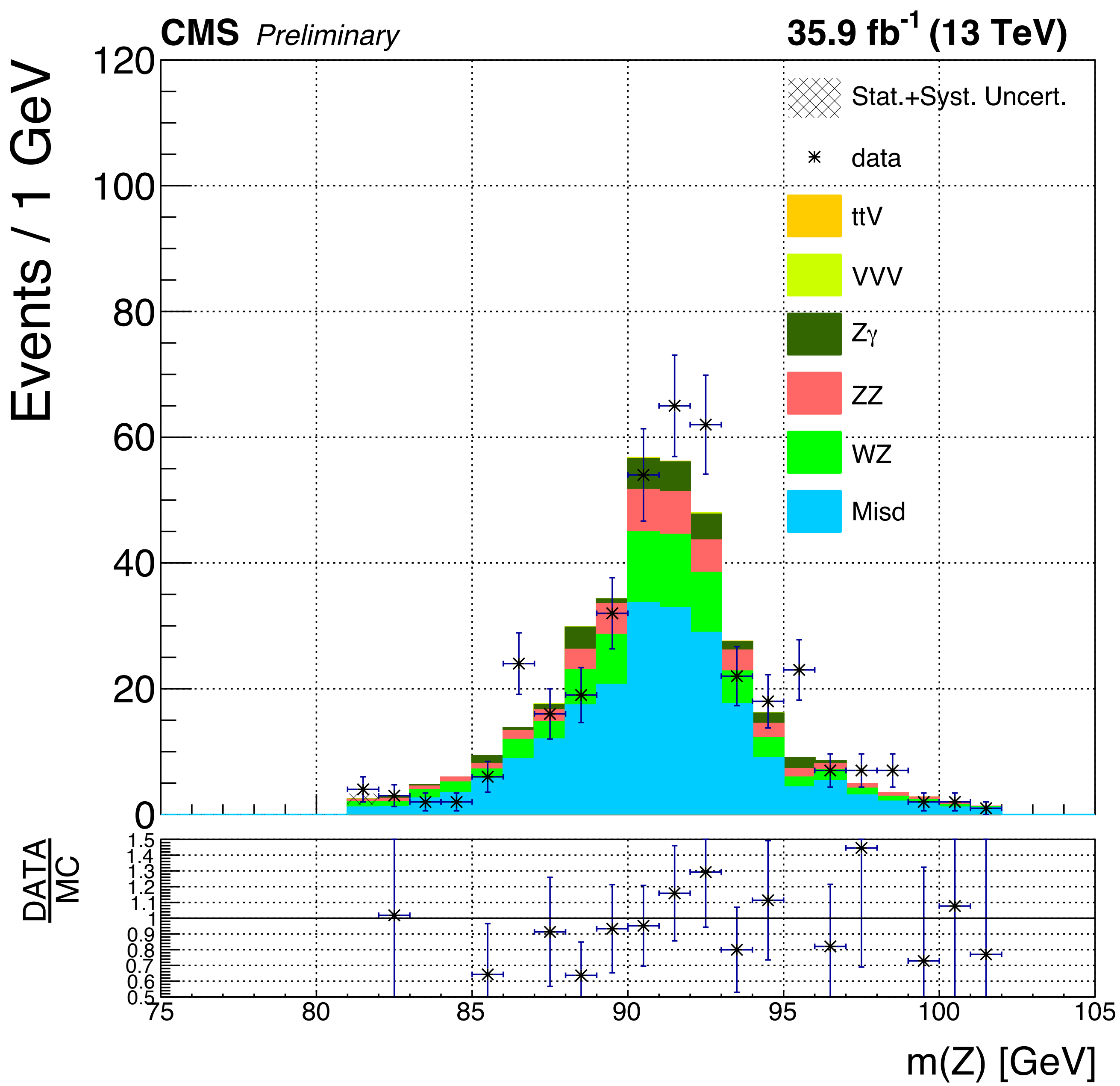


Z candidate mass

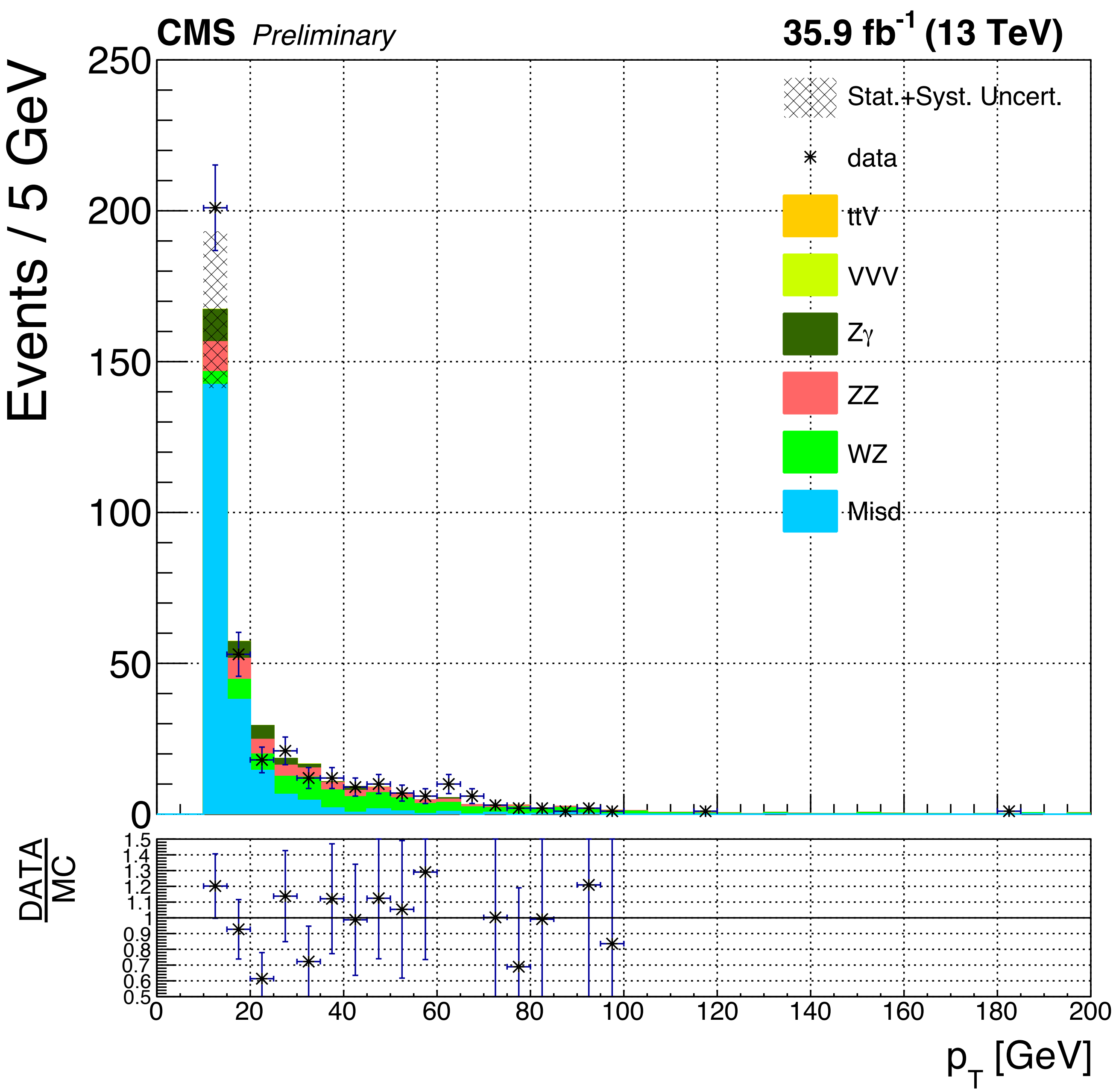
W candidate transverse mass

Control Region

Fake contribution (3 muons in Z+lepton selection)



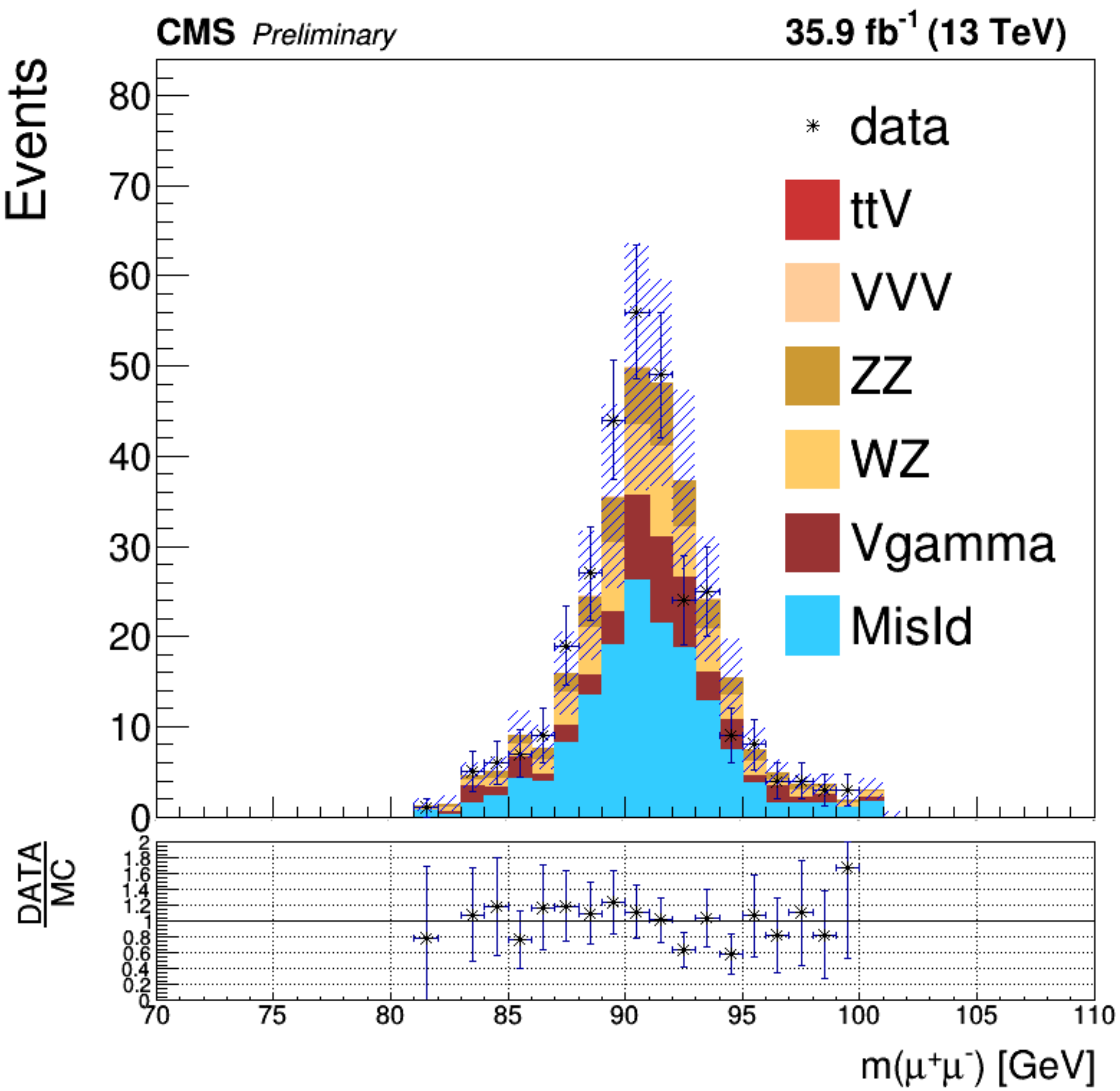
Z candidate mass



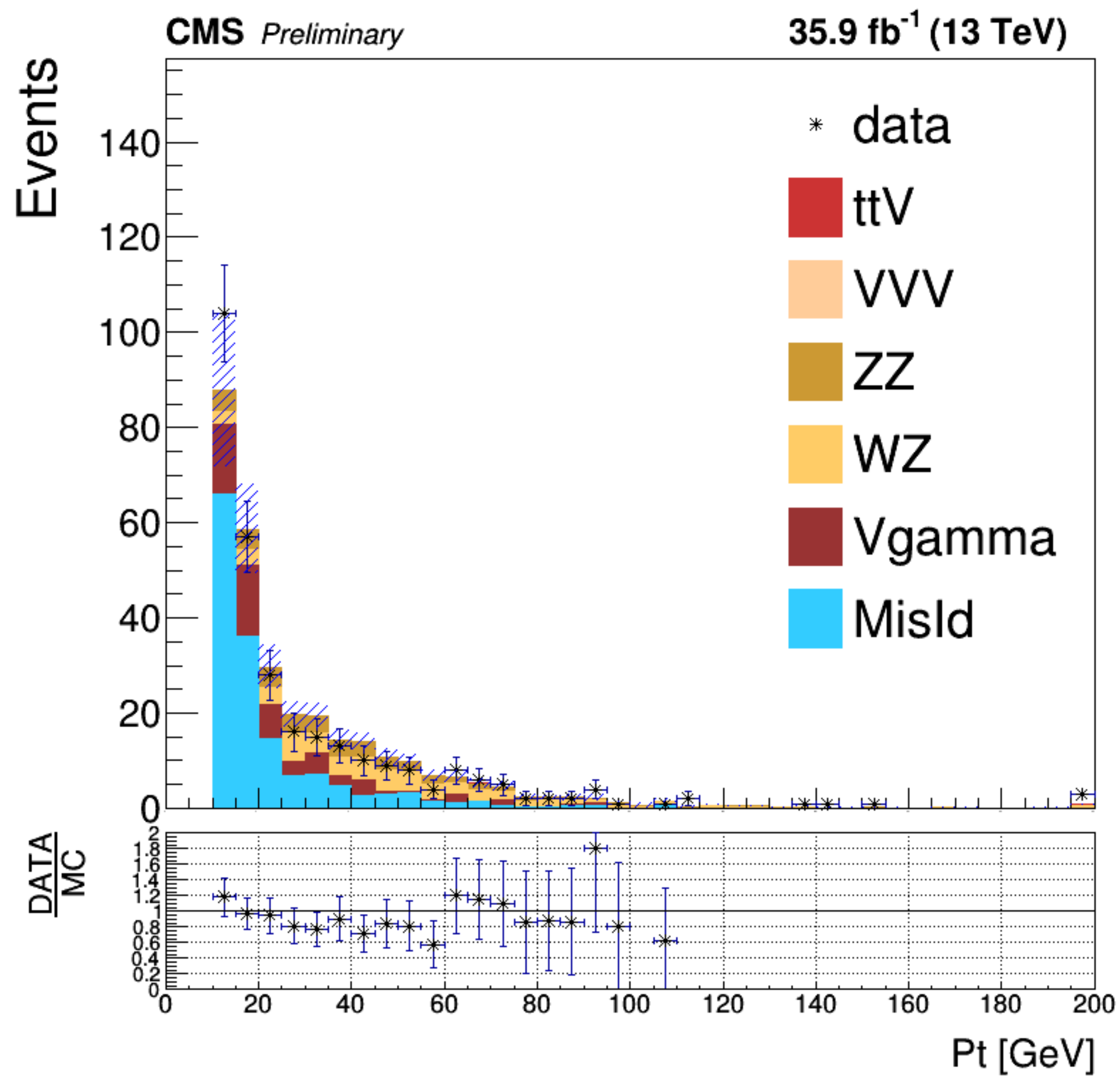
trailing lepton Pt

Control Region

Fake contribution (2muons+electron in Z+lepton selection)



Z candidate mass



trailing lepton Pt

Event Selection

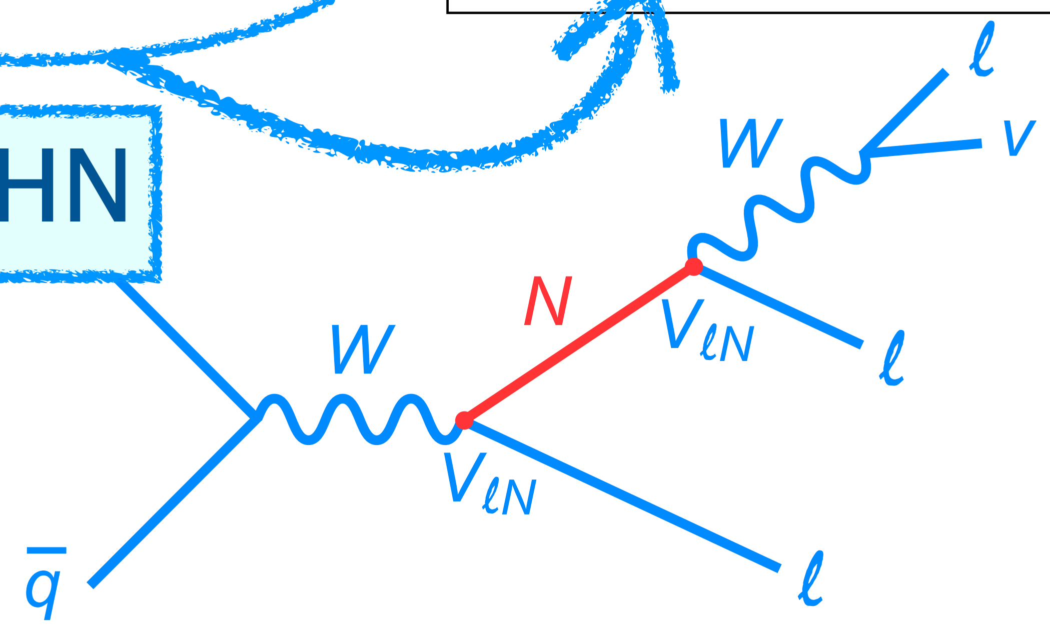
Same-sign dimuon and one opposite-sign muon/electron
Pt : leading muon 20 GeV & others 10 GeV
Veto event with b-tagged jets (Pt > 30 GeV)

Obtain Pz of neutrino from W mass(80.4 GeV) constraint

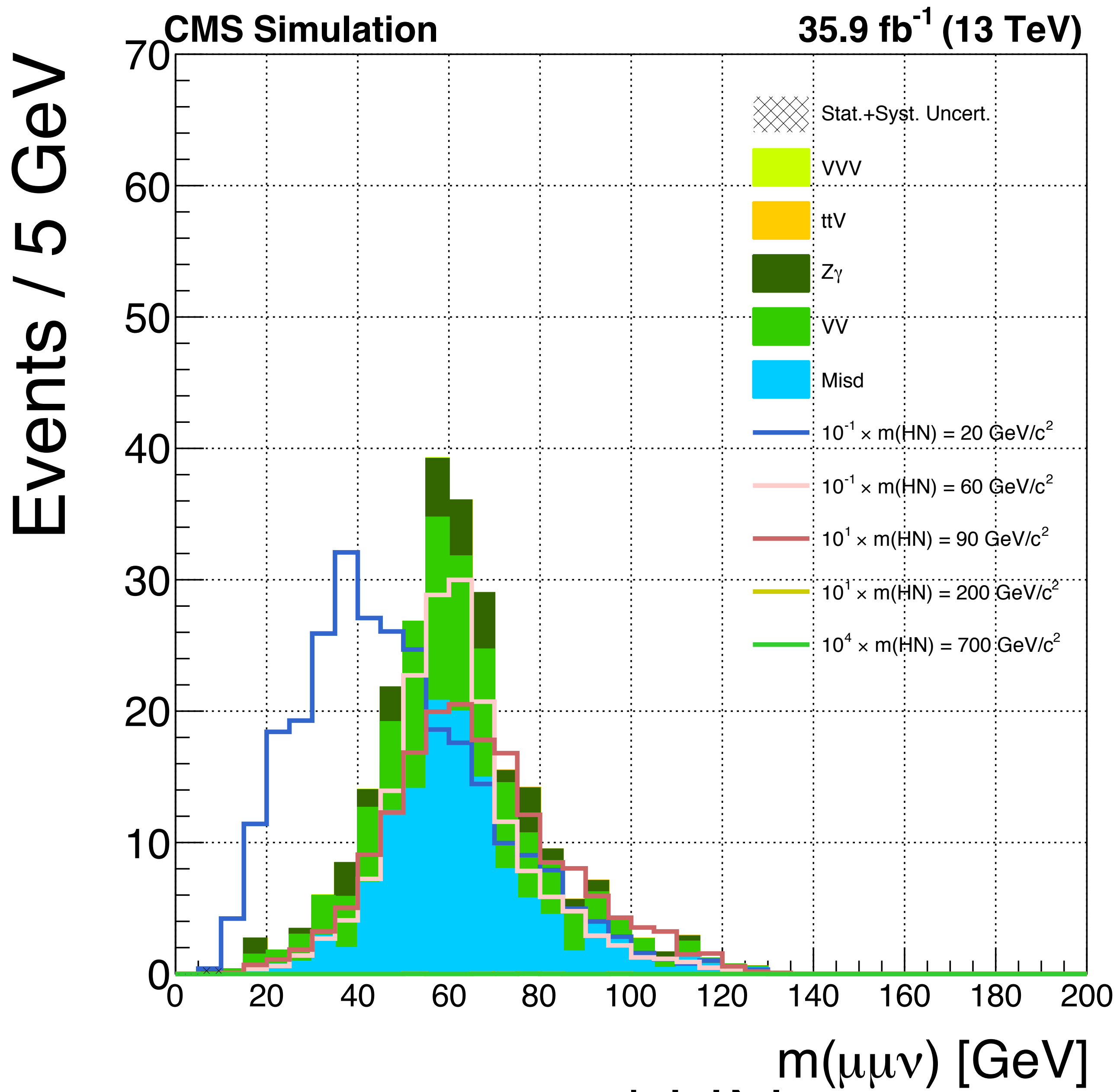
$$W(E,\vec{p}) = lep(E,\vec{p}) + nu(E,p_x,p_y,p_z)$$

$$Px = MET \times cos\phi$$
$$Py = MET \times sin\phi$$
$$\mathbf{Pz} = ?$$

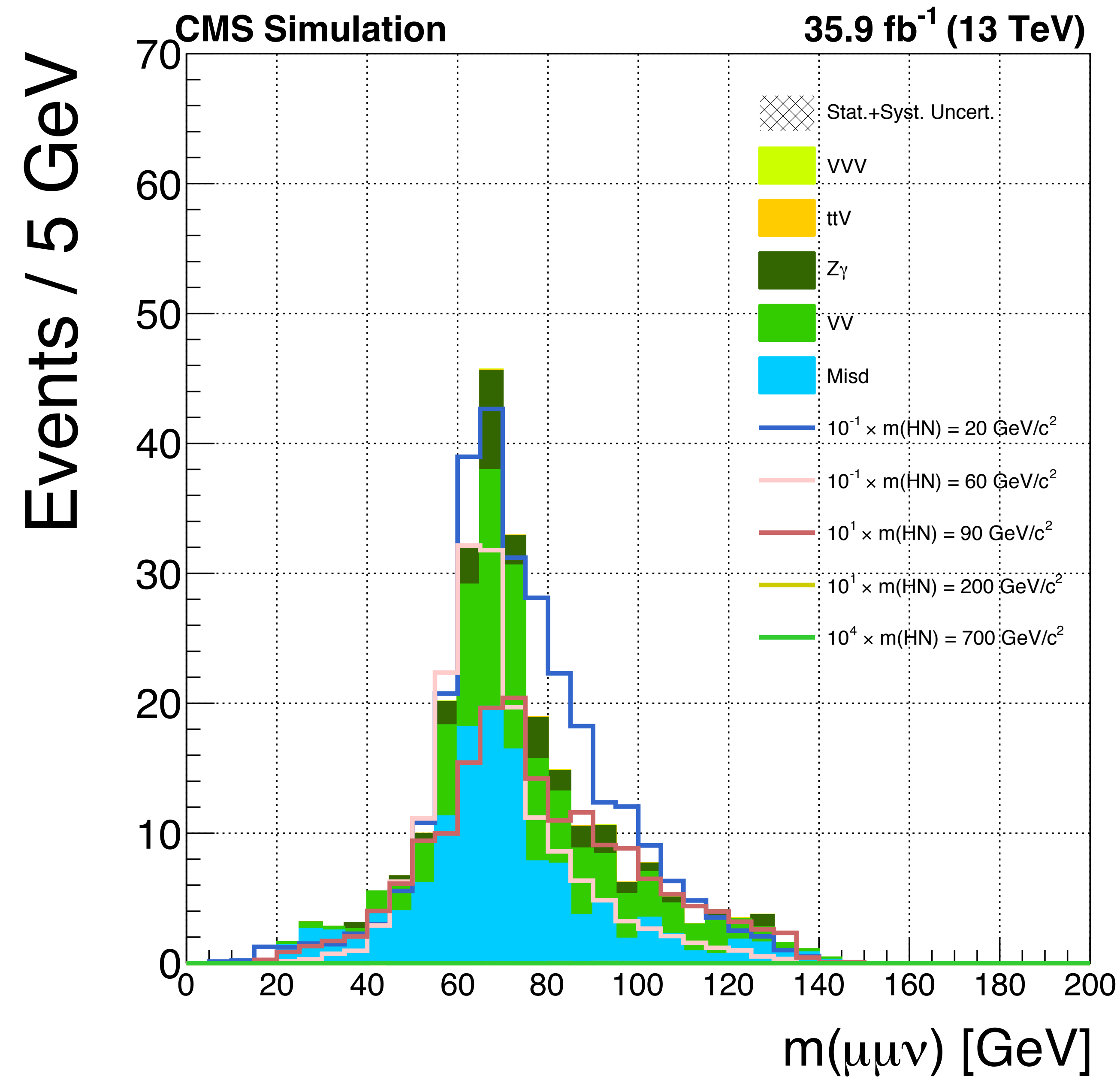
Fully reconstruct 4 vector of HN



HN Mass Reconstruction



reconstructed HN mass
(20 GeV HN)



reconstructed HN mass
(60 GeV HN)

Cut Optimisation

# of events	Fake	Prompt	Total
MuMuMu	127.75	132.87	260.62
MuMuE	52.56	10.86	63.42

Optimise cuts for cut and count method using Punzi

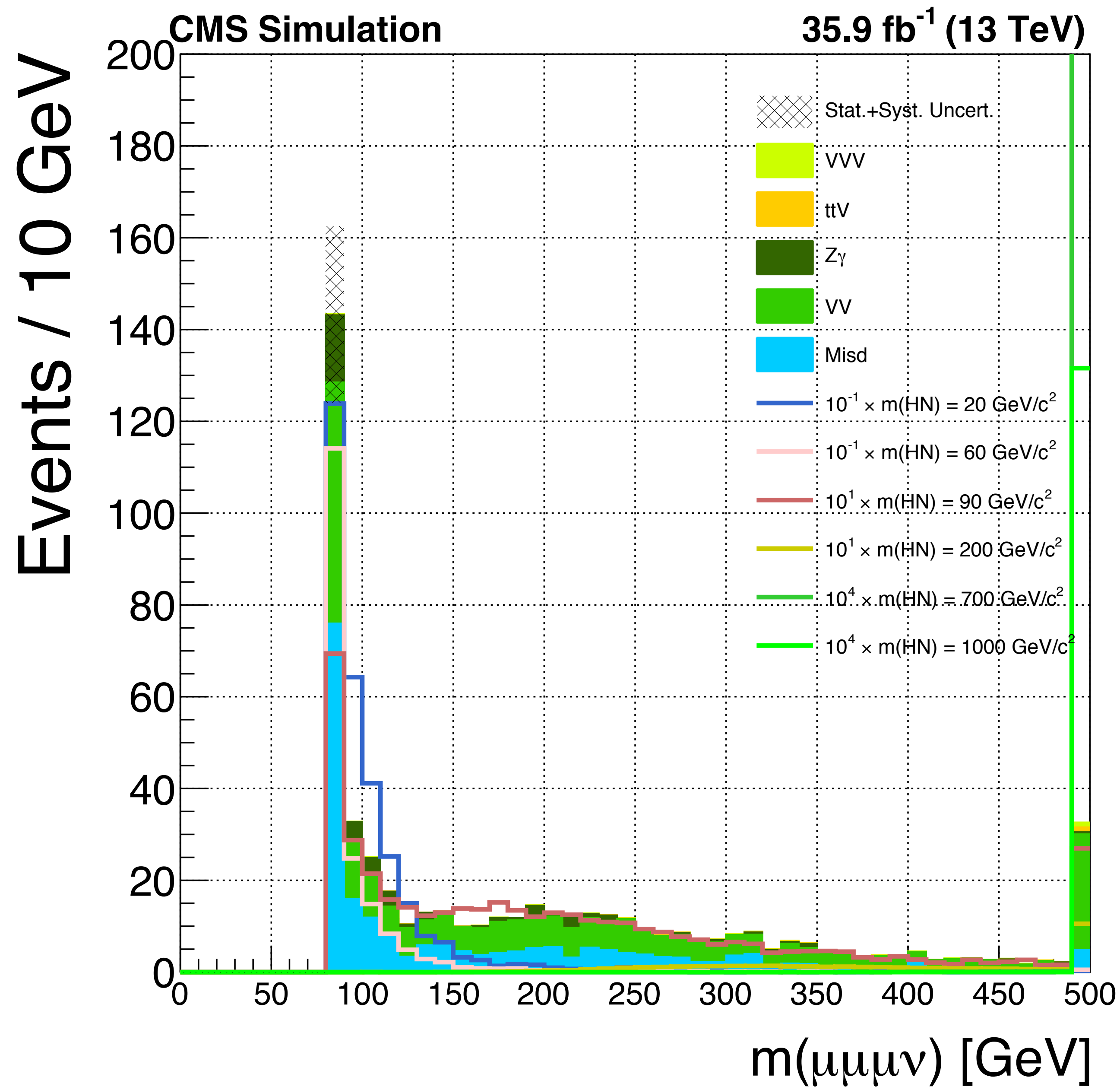
Optimisation Variables

-> Pt of leptons, MET, reconstructed W/HN mass

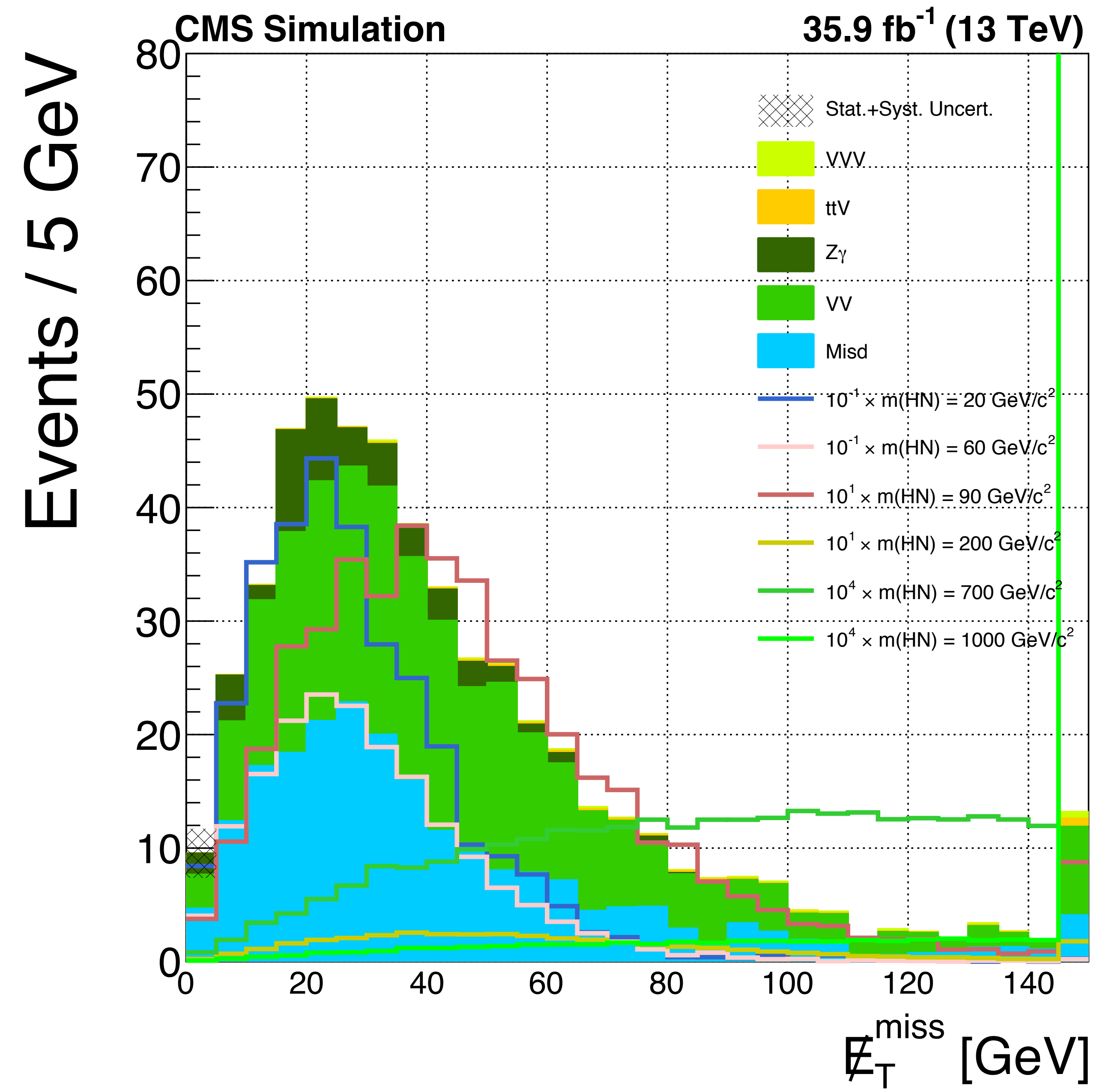
-> Additional variables for MuMuMu channel

: deltaR(OS) and mass(OS)

Optimisation Variables

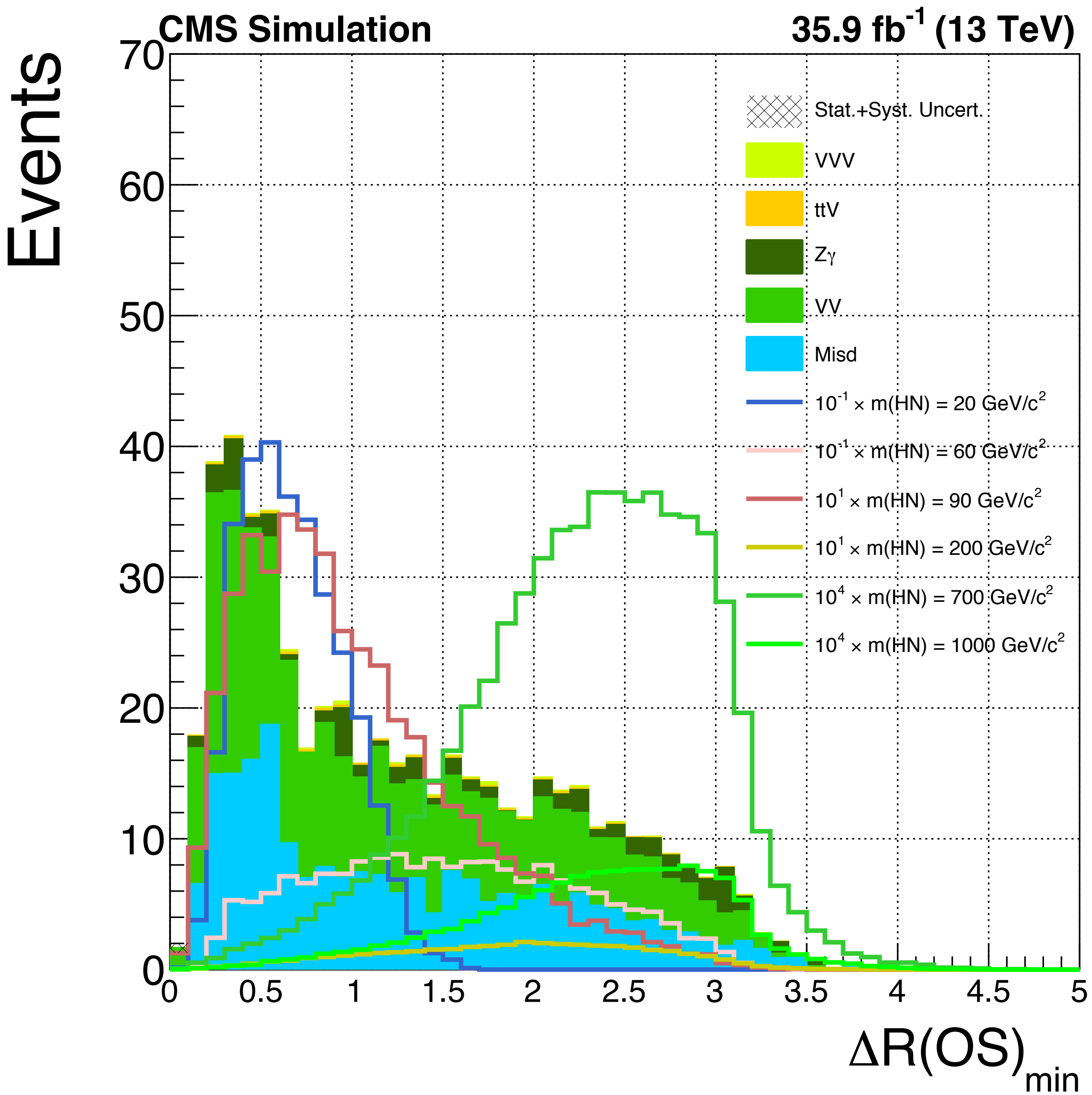


reconstructed W mass

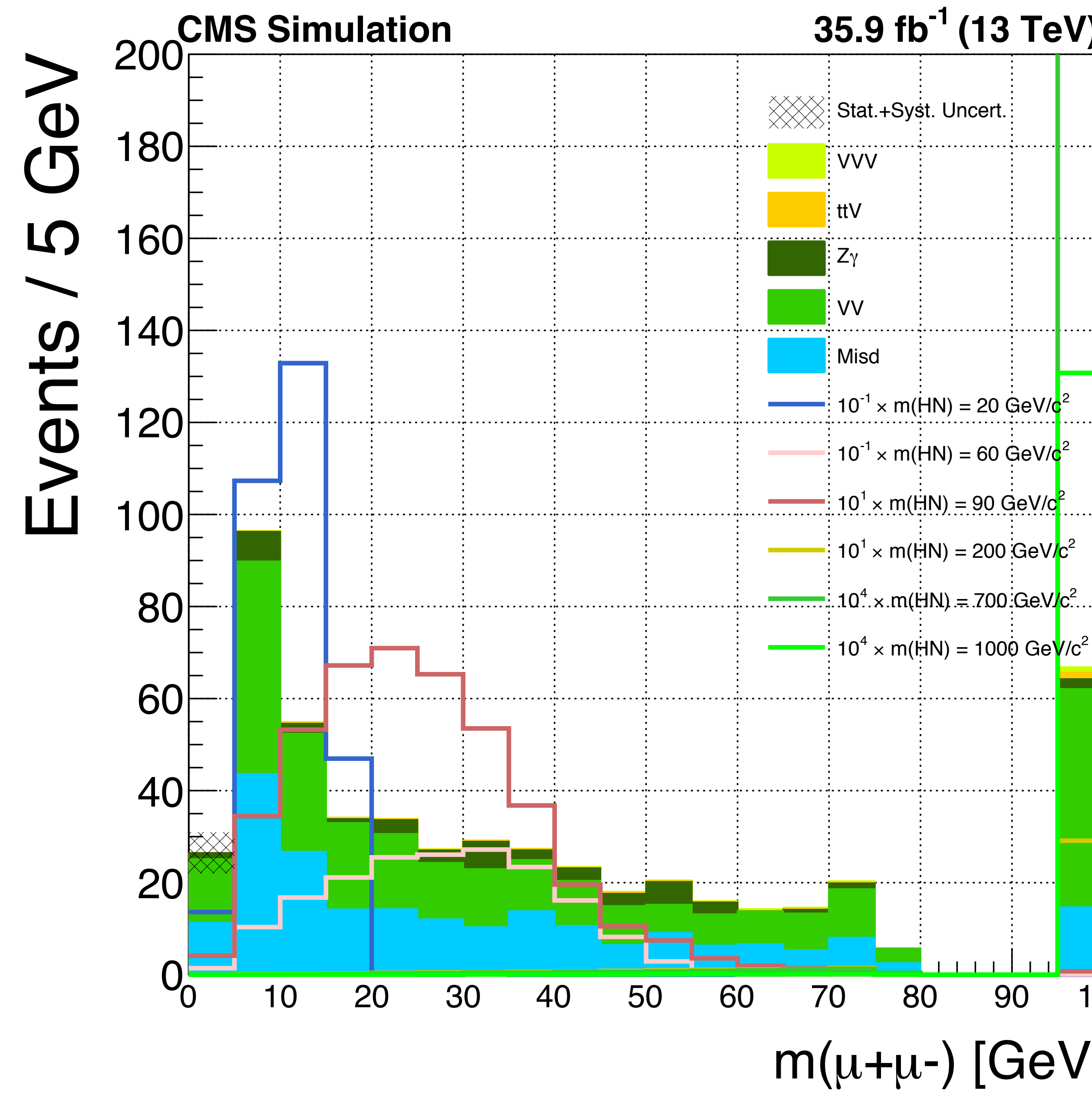


MET

Optimisation Variables



deltaR(OS)



mass(OS)

Systematic Uncertainty

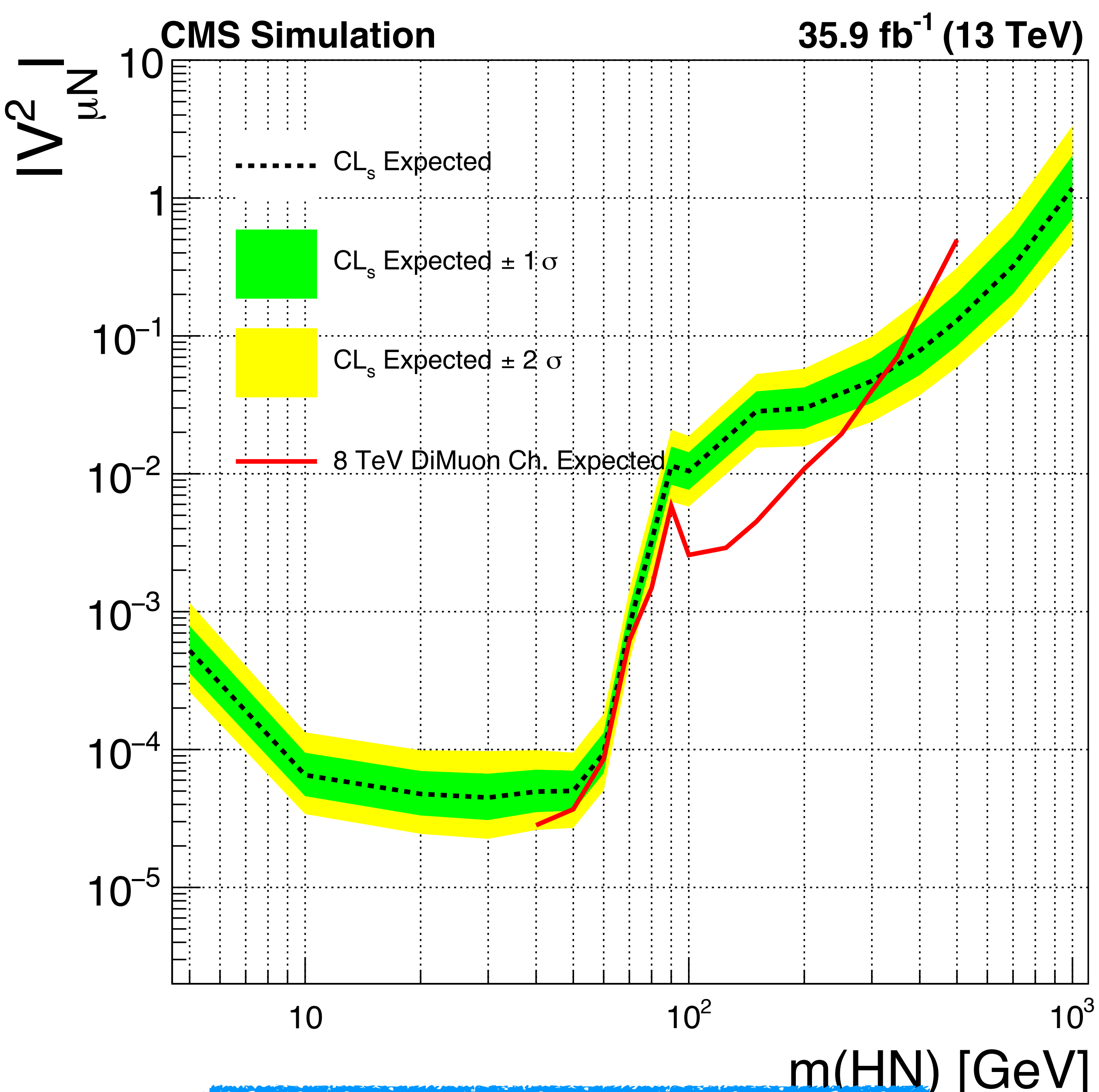
Table 15: Summary of systematic uncertainties on the signal prediction.

Source	Majorana Neutrino Mass (GeV/c^2) 40	60	150	700
Integrated Luminosity	2.60%	2.60%	2.60%	2.60%
Muon Momentum Scale	0.17%	0.32%	1.72%	3.95%
Muon ID	0.97%	1.04%	0.30%	0.25%
Jet Energy Scale	3.12%	1.45%	0.11%	0.10%
Unclustered Energy	5.29%	2.32%	0.43%	0.08%
Pileup Model	2.12%	1.75%	0.51%	0.49%
Trigger Efficiency	0.00%	0.07%	0.03%	0.02%

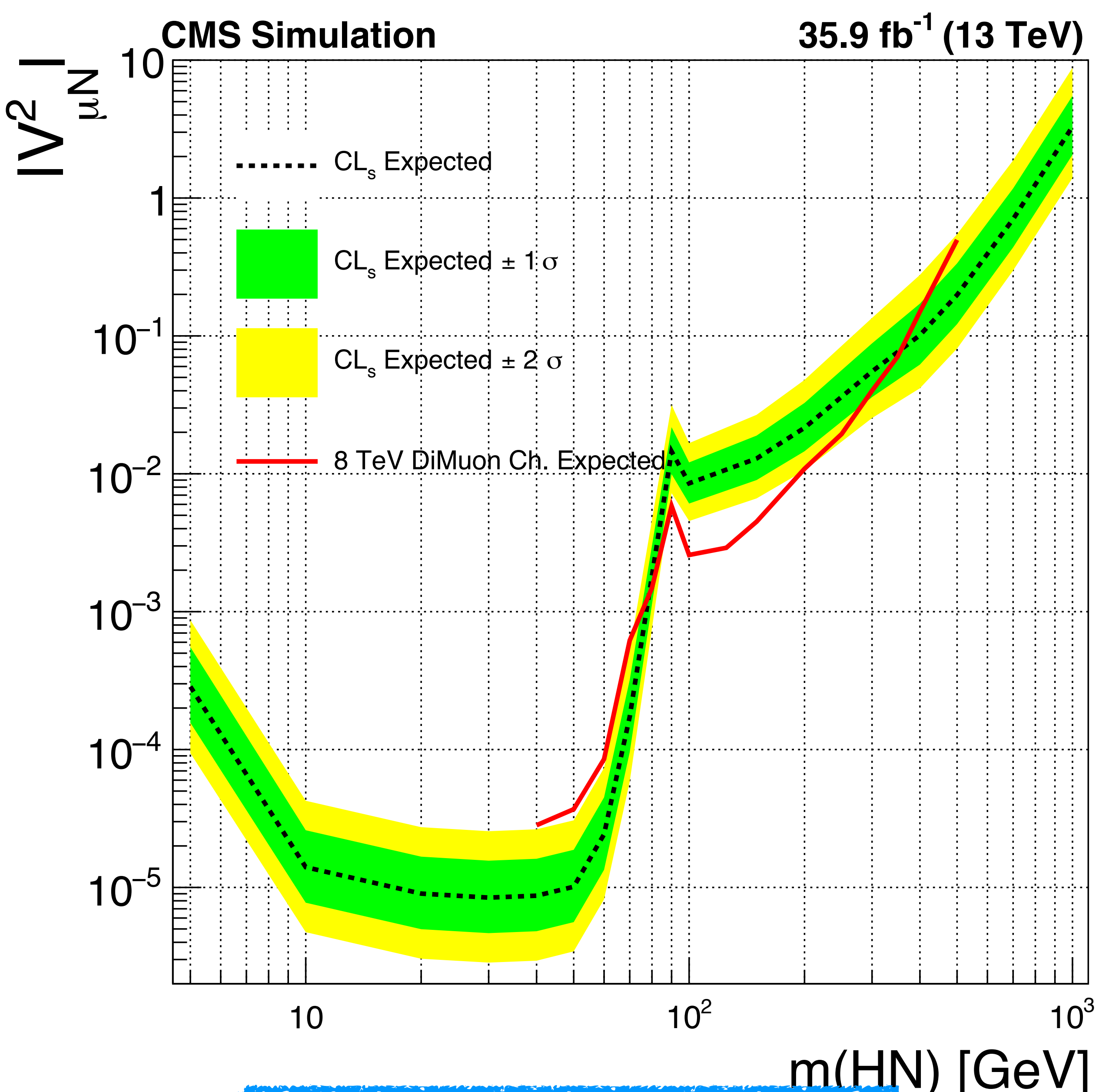
Table 16: Summary of systematic uncertainties on the SM background

Source	Majorana Neutrino Mass (GeV/c^2) 40	60	150	700
Integrated Luminosity	2.60%	2.60%	2.60%	2.60%
Muon Momentum Scale	0.98%	1.06%	2.56%	11.92%
Muon ID	0.89%	1.00%	0.41%	0.40%
Jet Energy Scale	1.08%	3.03%	1.15%	1.41%
Unclustered Energy	6.96%	4.06%	1.45%	1.25%
Normalization	10.47%	9.99%	10.81%	13.22%
Pileup Model	3.80%	2.45%	0.22%	1.13%
Trigger	0.00%	0.02%	0.23%	0.53%

Result



MuMuMu Channel



MuMuE Channel

Summary

- We have performed s-channel Heavy Majorana Neutrino searches in trilepton final states using 2016 13 TeV Data
- Using MuMuMu and MuMu(SS)E datasets, we extract limits on muon mixings
  - Optimised selections for each signal mass points
  - Upper limits on mixing square are obtained
  - Planned to combine both channel
- Analysis is documented in AN-16-486

Backup Slides

Systematic Uncertainty

MuMuMu Channel

8.2 Uncertainties on the Background Estimate

The systematic uncertainties on the fake background estimation comes from the half Sample test results (5% for each fake rate values as described in Section 6.1.3), the variation of the large $Sig(d_{xy})$ muon selection (12% as described in Section 6.1.5), and Monte Carlo closure results (35% as shown in Table 7).

The dominant uncertainty on the SM background estimation comes from the normalizations : 7% for ZZ, 9% for WZ, 17% for $Z\gamma$, 50% for triboson, and $t\bar{t}$ plus boson production [5].

MuMuE Channel
fake background : 50% given (study ongoing)

4.7 Event Preselection Requirements

After the requirement of three muons as described above, events were required to satisfy the following criteria:

- exactly three muons, passing the tight ID described in Section 4.3
- events with a 4^{th} muon, passing loose ID are removed
- leading muon $p_T > 20$ GeV/c (to comply with the trigger threshold)
- invariant mass of OS muon pairs, $m(OS)$:
  - $m(OS) > 4$ GeV/c^2 (to remove γ involved processes, and to match to MC generation level cuts (upper left plot in Figure 4)). We denote the event selection up to this step as "Basic Selection"
  - $|m(OS) - m(Z)| > 15$ GeV/c^2, where $m(Z)$ is the invariant mass of Z-boson (upper right plot in Figure 4)
- $|m(\mu\mu\mu) - m(Z)| > 15$ GeV/c^2 (to remove $Z\gamma$ process (lower left plot in Figure 4))
- remove event with at least one b-tagged jet (b-jet veto)
  - CSVv2 medium working point is used (lower right plot in Figure 4)

Fake Rate Method

- Monte Carlo does not simulate non-prompt backgrounds perfectly (DY+jets : two muons and a jet identified as muon)
  ->Use data-driven method

[Dataset] DoubleMuon

[Triggers]

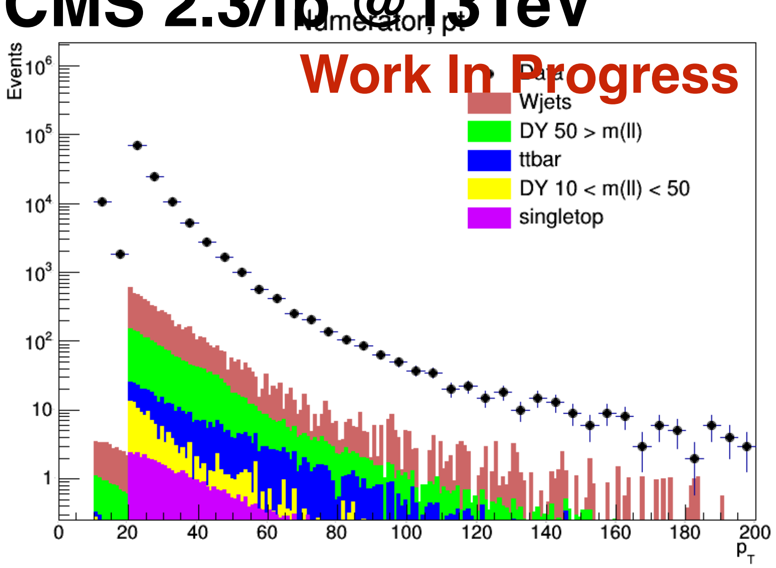
- HLT_Mu8_v : muon Pt 10~20 GeV
- HLT_Mu17_v : muon Pt 20~ GeV

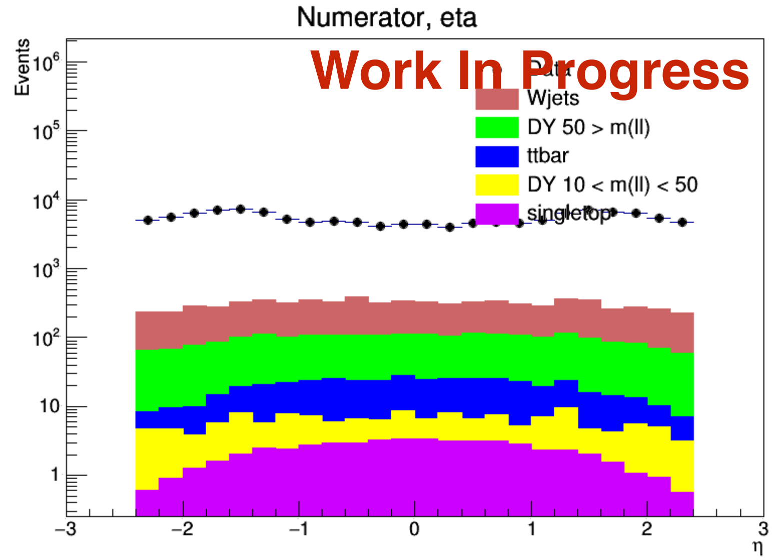
[Background samples]

- singletop, DY, ttbar, Wjets, Diboson

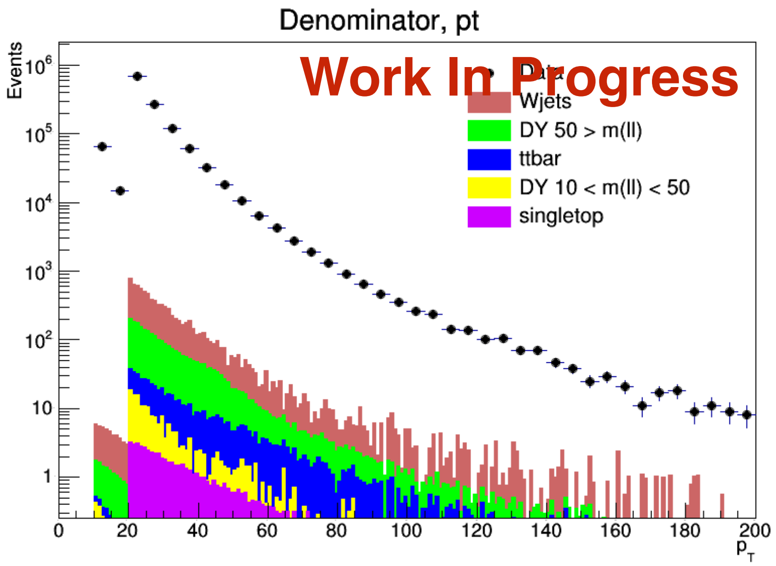
Fake Rate Method

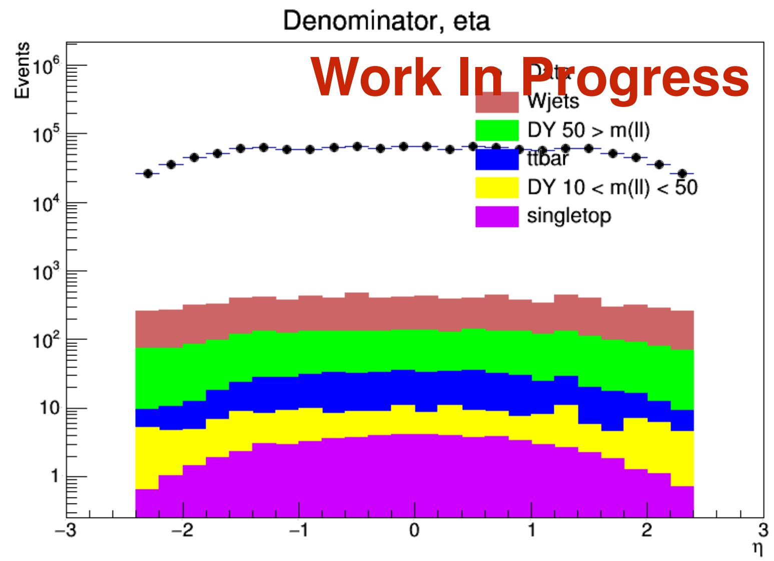
CMS 2.3/fb @13TeV





Numerator
Pt, Eta
(Isolation < 0.1)

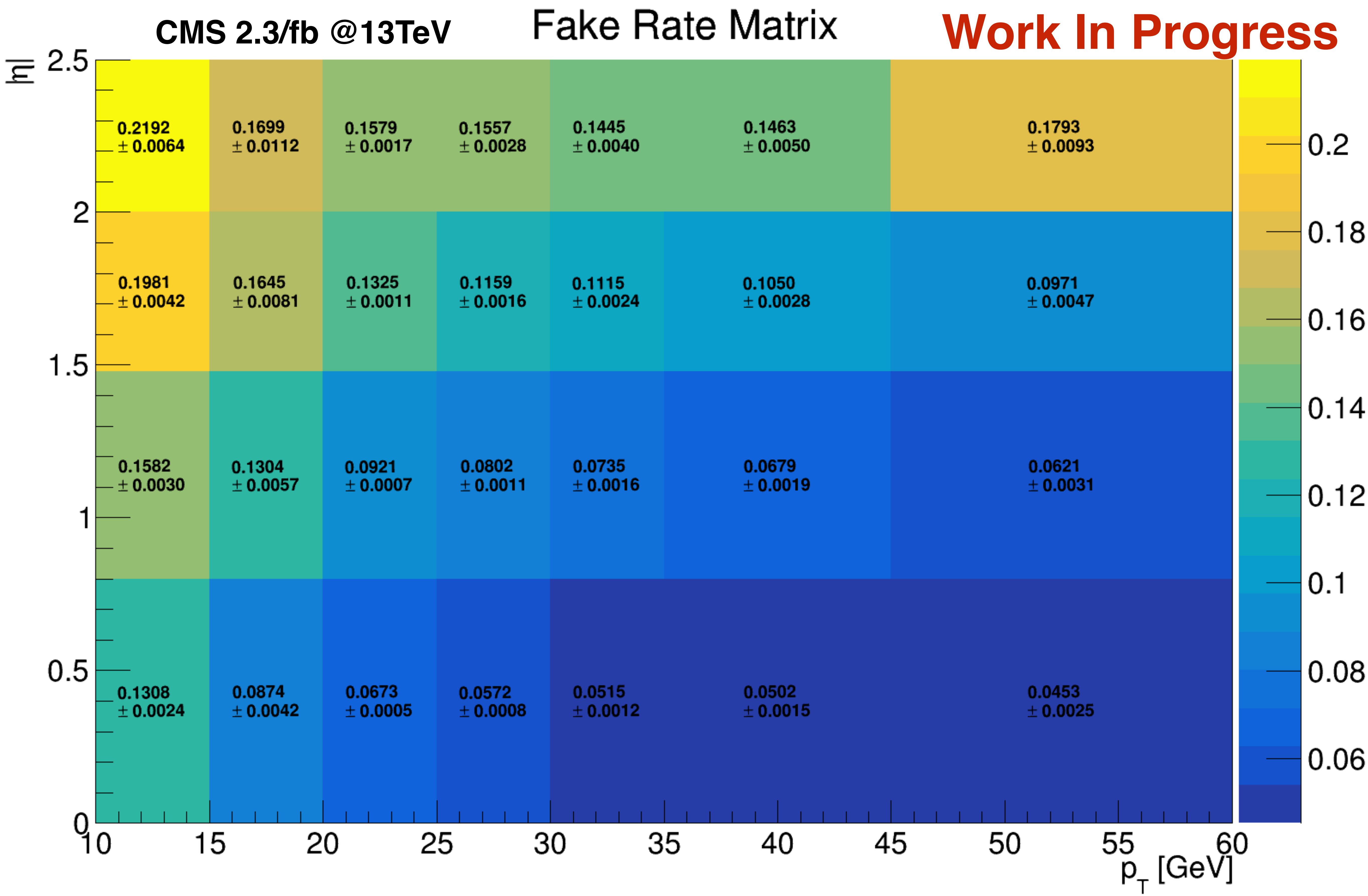




Denominator
Pt, Eta
(Isolation < 0.6)

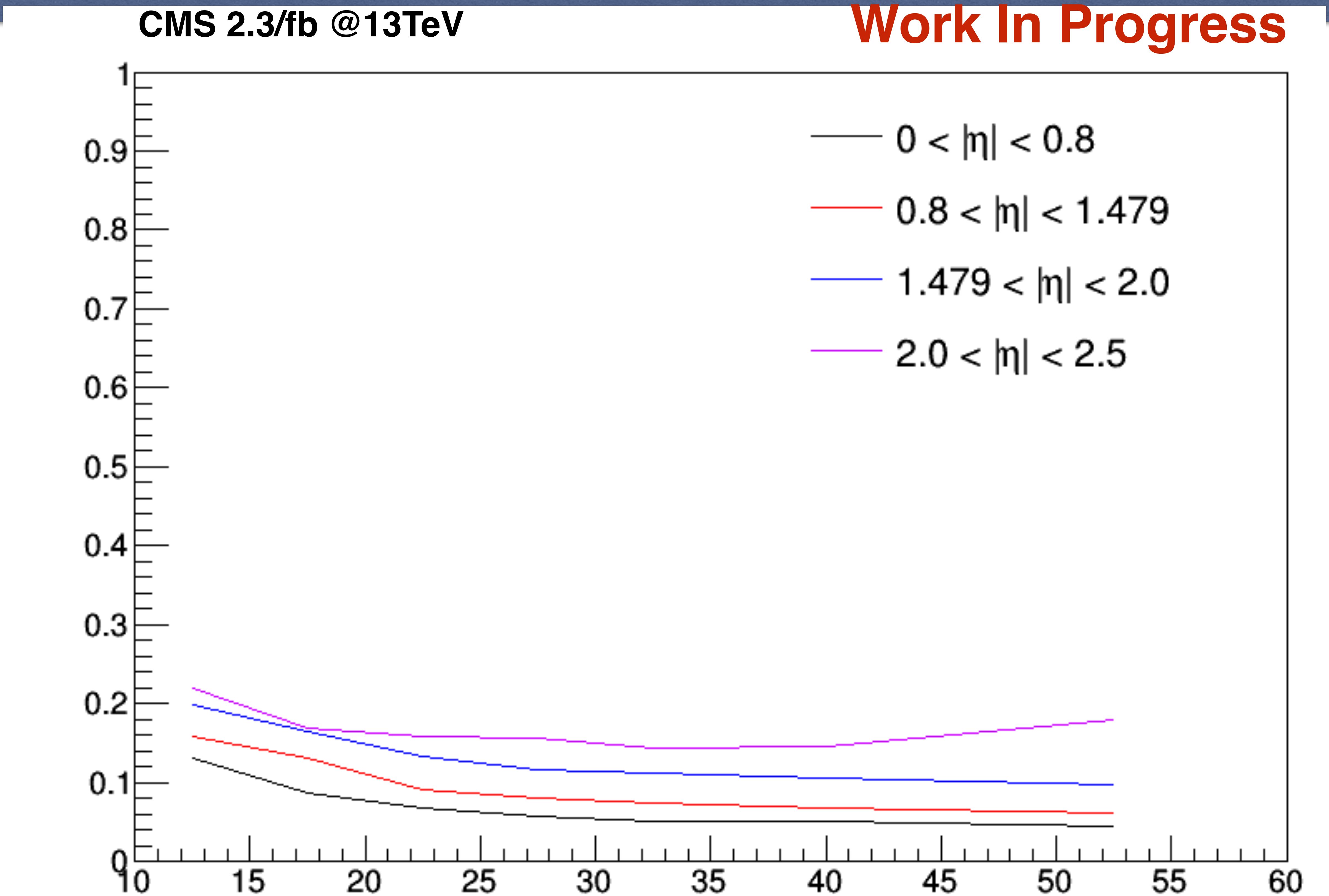
(fake rate) = num(data - prompt) / den(data - prompt)

$$N_{\mathrm{TTT}} = \sum_{\mathrm{TTL}} \frac{\mathrm{FR}}{1-\mathrm{FR}} - \sum_{\mathrm{TLL}} \frac{\mathrm{FR}\cdot\mathrm{FR}}{(1-\mathrm{FR})\cdot(1-\mathrm{FR})} + \sum_{\mathrm{LLL}} \frac{\mathrm{FR}\cdot\mathrm{FR}\cdot\mathrm{FR}}{(1-\mathrm{FR})\cdot(1-\mathrm{FR})\cdot(1-\mathrm{FR})}$$



CMS 2.3/fb @13TeV
Fake Rate Matrix
Work In Progress
|η|
2.5
2
1.5
1
0.5
0
0.2192 ± 0.0064
0.1699 ± 0.0112
0.1579 ± 0.0017
0.1557 ± 0.0028
0.1445 ± 0.0040
0.1463 ± 0.0050
0.1793 ± 0.0093
0.1981 ± 0.0042
0.1645 ± 0.0081
0.1325 ± 0.0011
0.1159 ± 0.0016
0.1115 ± 0.0024
0.1050 ± 0.0028
0.0971 ± 0.0047
0.1582 ± 0.0030
0.1304 ± 0.0057
0.0921 ± 0.0007
0.0802 ± 0.0011
0.0735 ± 0.0016
0.0679 ± 0.0019
0.0621 ± 0.0031
0.1308 ± 0.0024
0.0874 ± 0.0042
0.0673 ± 0.0005
0.0572 ± 0.0008
0.0515 ± 0.0012
0.0502 ± 0.0015
0.0453 ± 0.0025
10
15
20
25
30
35
40
45
50
55
60
p_T [GeV]
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06

Fake Rate Method



Fake Rate Method

[Muon selection]

- $|dXY| < 0.05$ cm, $|dXY/\sigma(dXY)| < 3.0$

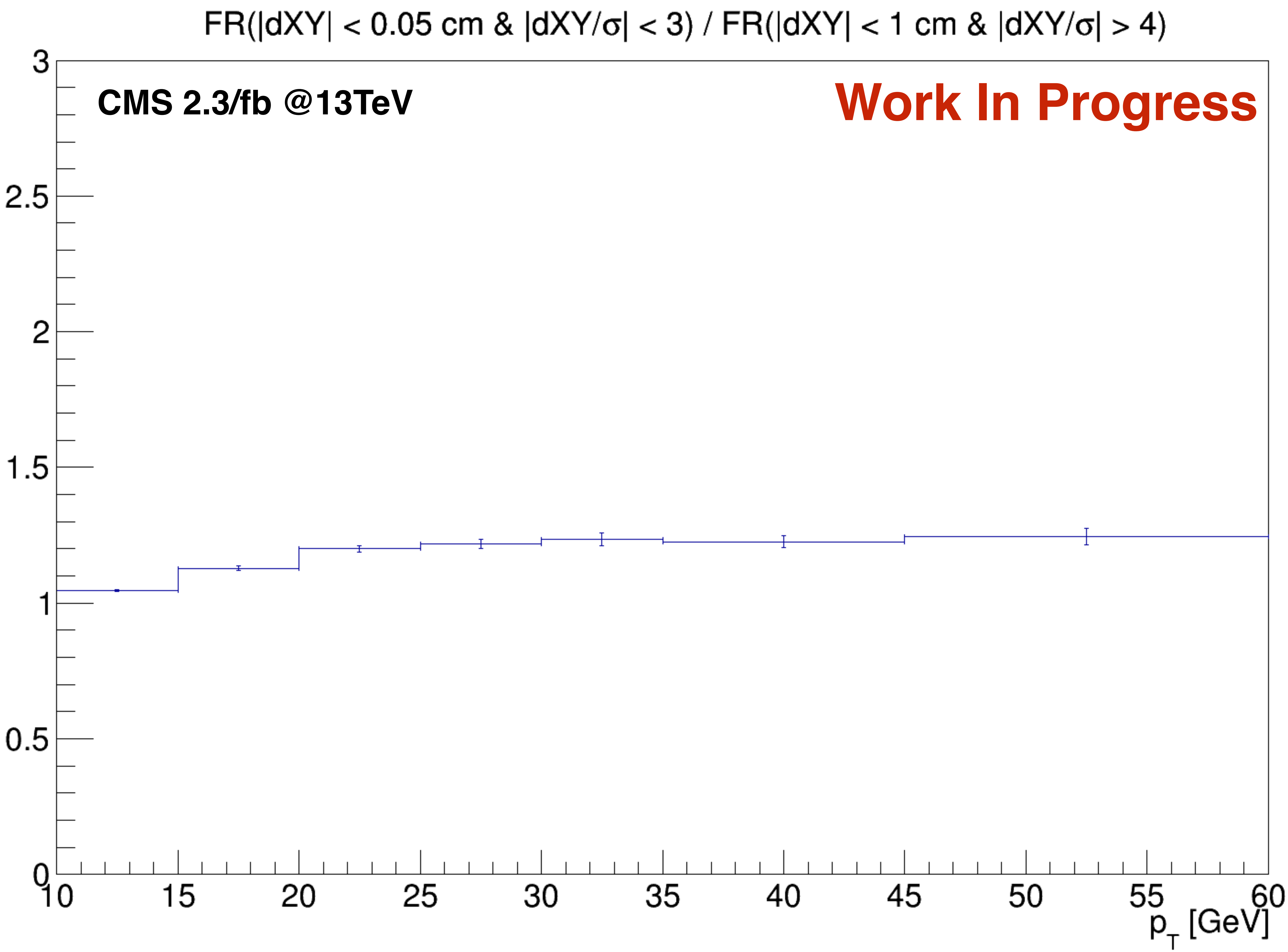
[Fake muon selection]

- $|dXY| < 1.00$ cm, $|dXY/\sigma(dXY)| > 4.0$

- Difference in impact parameter selections

  -> Apply scale factor obtained from muon enriched QCD samples (divided by Pt bins)

(scale factor) = FR(muon selection) / FR(fake muon selection)


FR(|dXY| < 0.05 cm & |dXY/σ| < 3) / FR(|dXY| < 1 cm & |dXY/σ| > 4)
CMS 2.3/fb @13TeV
Work In Progress
3
2.5
2
1.5
1
0.5
0
10
15
20
25
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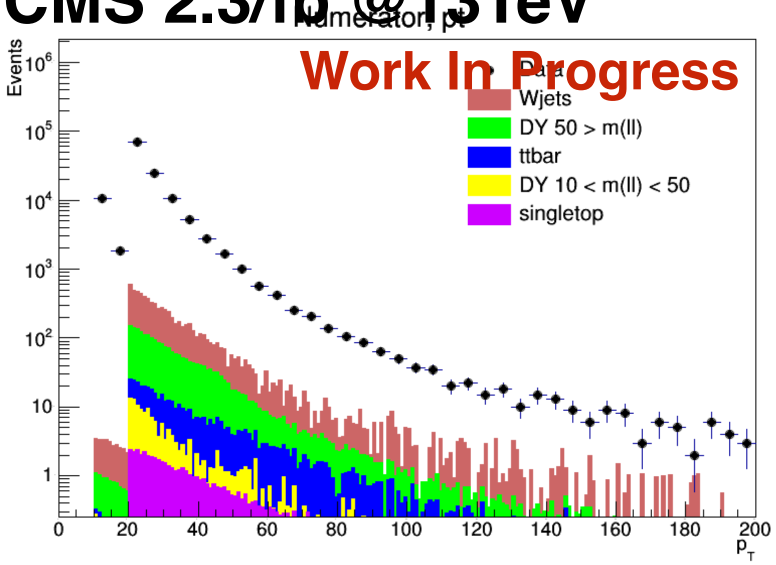

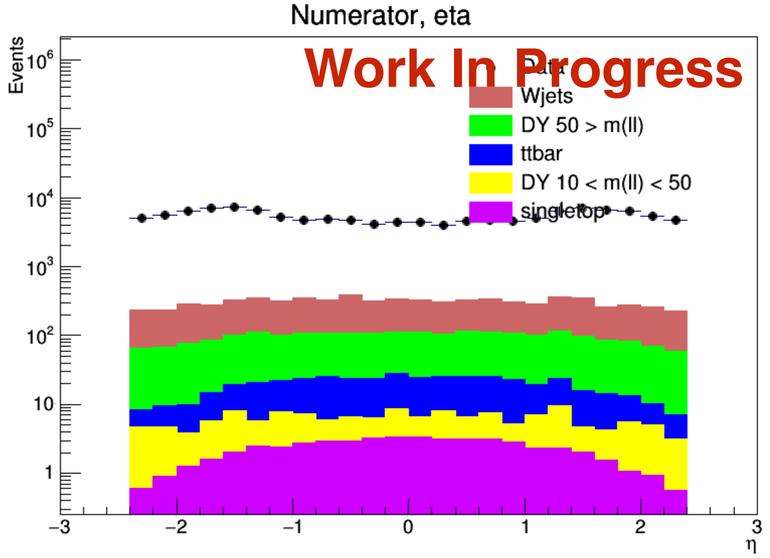

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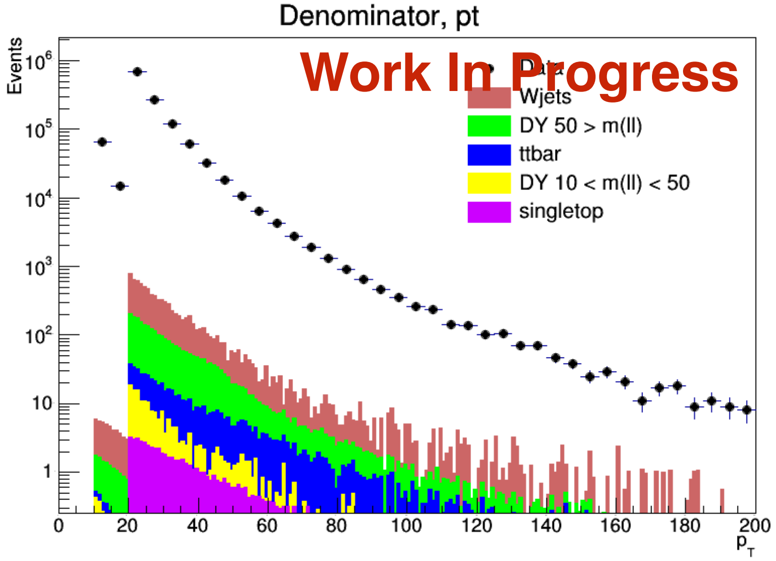
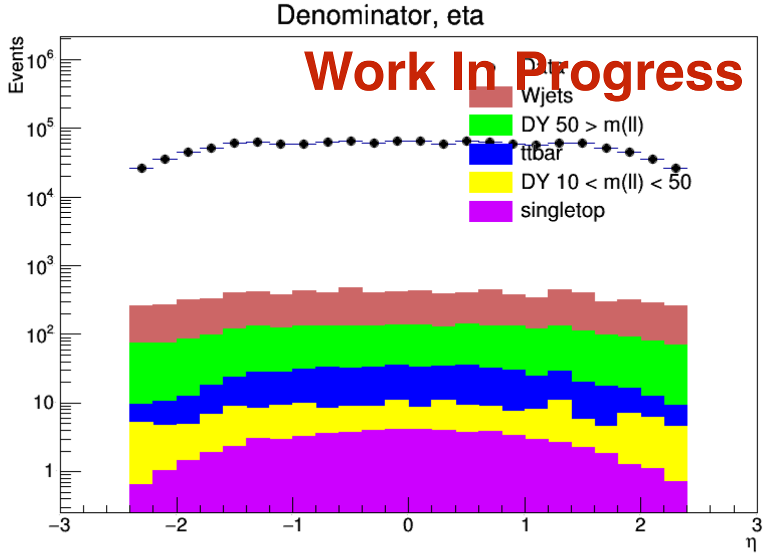
Pt, Eta
(Isolation < 0.1)





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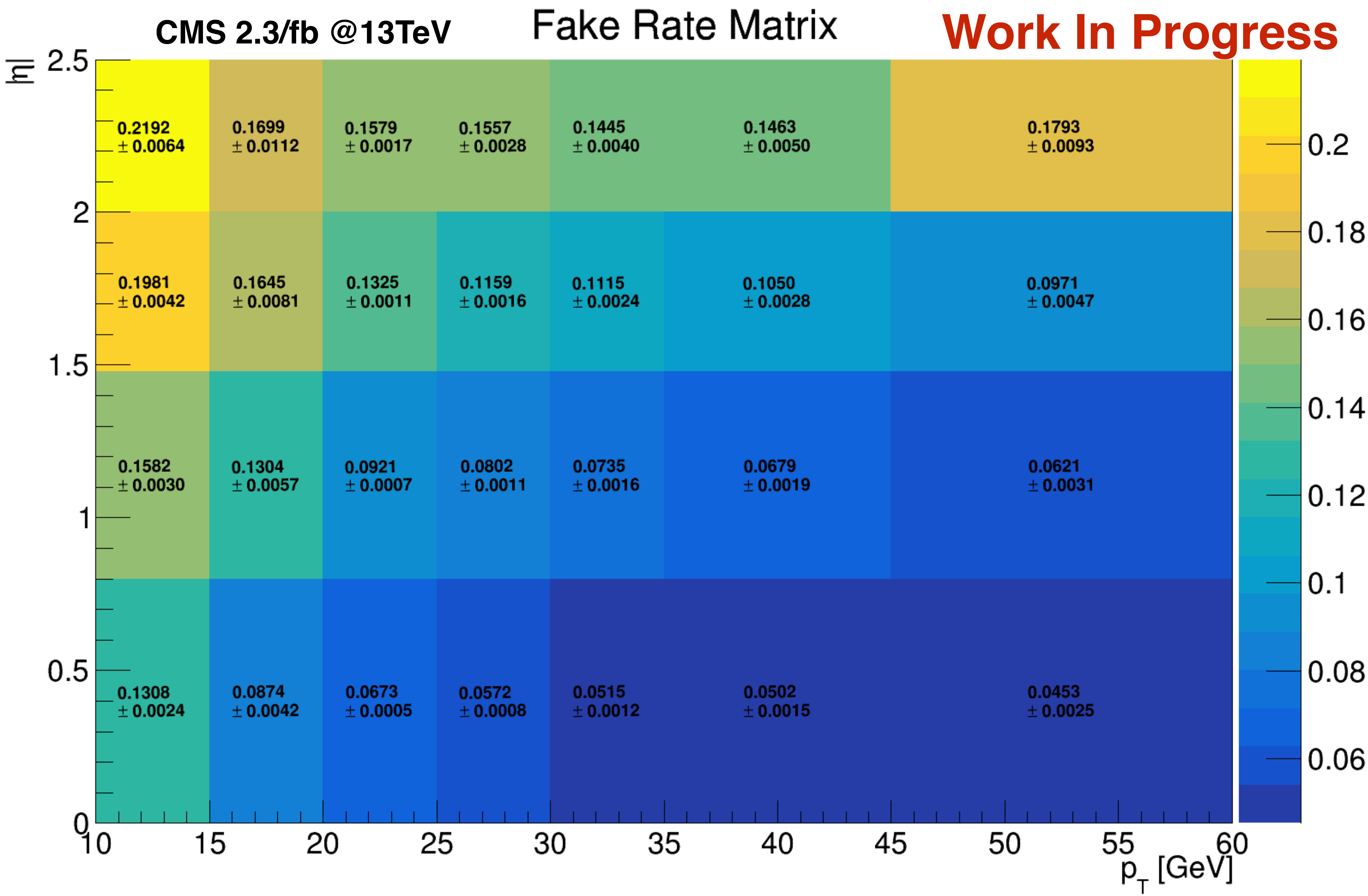
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10
15
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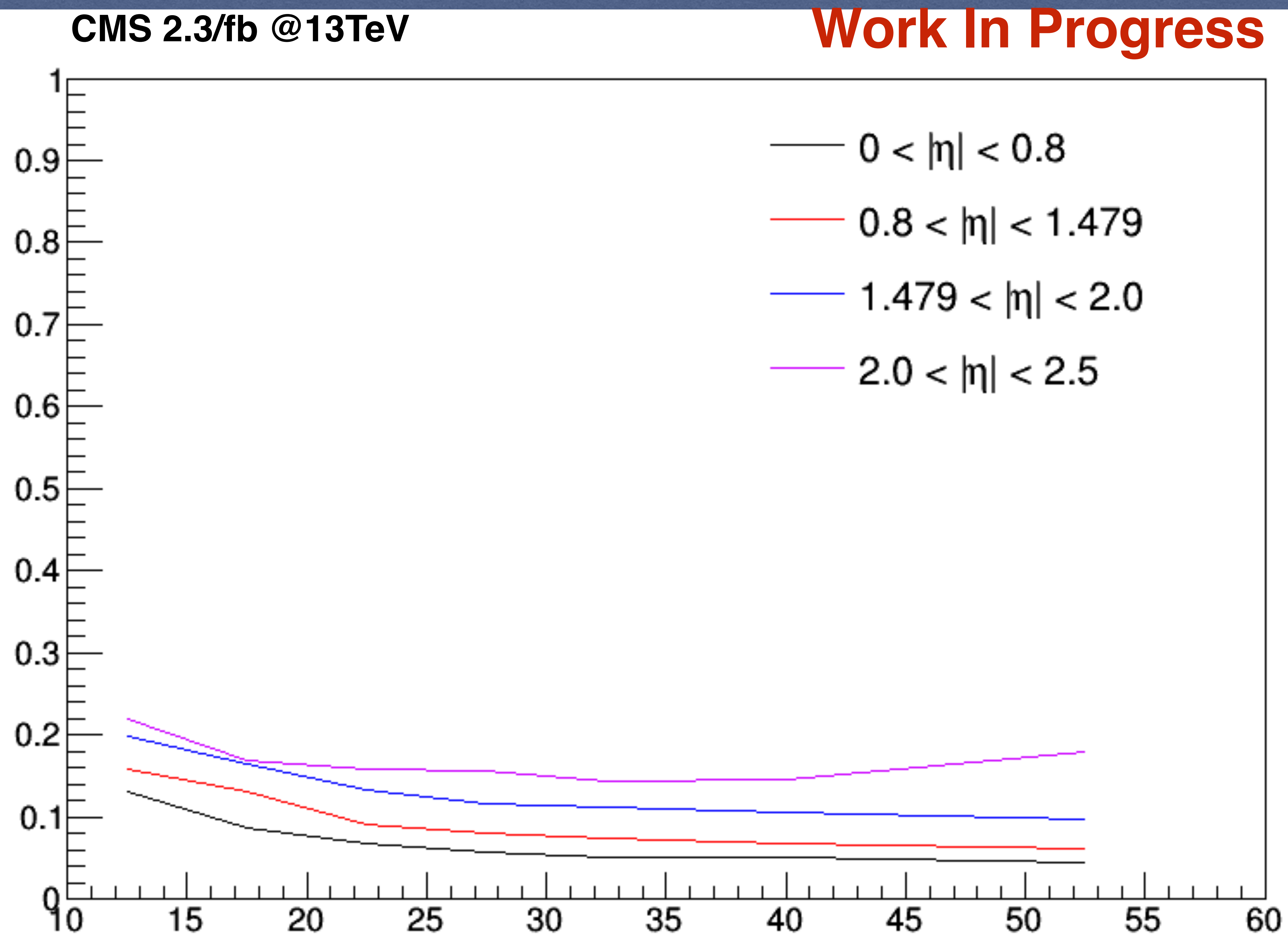
55
60
p_T [GeV]
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06

Fake Rate Method



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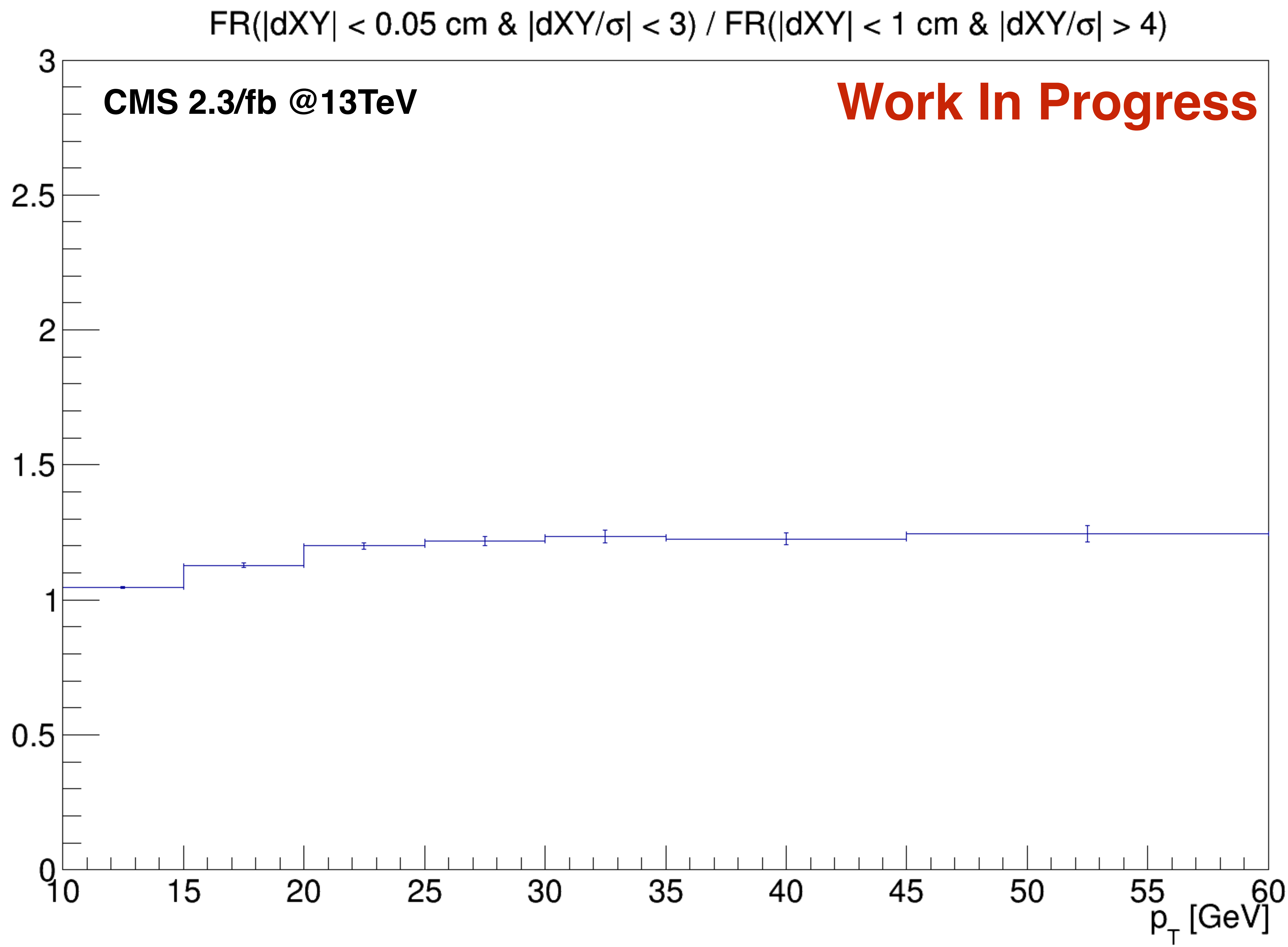
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CMS 2.3/fb @13TeV
Work In Progress
3
2.5
2
1.5
1
0.5
0
10
15
20
25
30
35
40
45
50
55
60
p_T [GeV]

Cut Optimization

Optimise cuts for each HN mass points using punzi method

$$(punzi) = \frac{\epsilon}{1 + \sqrt{B_{tot} + \delta B_f^2 + \delta B_p^2}}$$

B_{tot} = total background
δB_f = fake uncertainty
δB_p = prompt uncertainty
ϵ = signal efficiency

<u>Optimisation Variables</u>

-> Pt of leptons, MET, reconstructed W/HN mass
-> Additional variables for MuMuMu channel
: deltaR(OS) and mass(OS)