Search for Vector-Like Quarks ($T' \to t(Wb)H(WW^*) \to t(l\nu b)H(4q)$) Decay with the CMS Detector at centre of mass energy 13 TeV.

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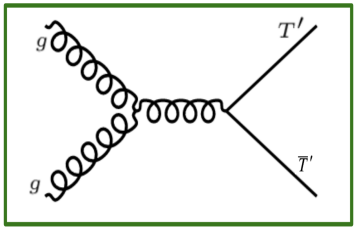
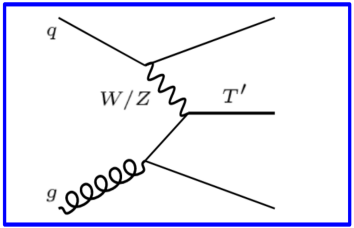
Introduction: Vector-Like Quarks

- **Motivations :**
  - The observed lightness of Higgs mass
  - **Divergence in radiative corrections to Higgs boson mass**
  - High Yukawa coupling of top quark associated with Higgs boson
- **Vector like quarks(VLQ):**
  - Hypothetical spin 1/2 particles with color charge
    - Left & right handed components behave same
  - Mass for VLQ is independent of Yukawa couplings to a Higgs doublet
  - Decay through mixing with SM quarks
    - $T' \rightarrow W + b$, $T' \rightarrow Z + t$, **$T' \rightarrow H + t$**
  - Production via
    - QCD processes $\rightarrow$ **Pair production cross section depends on M_{VLQ}**
    - Single production from SM quarks and EW gauge bosons$\rightarrow$ **Couplings are of EW strength or below**



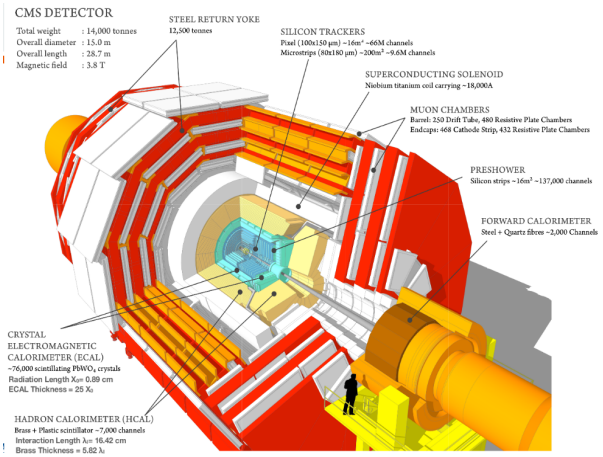
Pair production



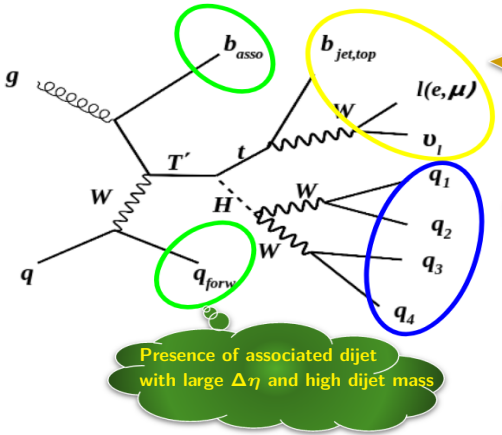
Single production

The CMS Detector

- CMS detector is one of the general purpose detectors, collecting data in the LHC beamline
- Consists of sub-detectors:
  - Tracking System
  - Electromagnetic Calorimeter
  - Hadronic Calorimeter
  - Magnet System of strength 3.8T
  - Muon System
- For full LHC-Run2, CMS has collected and processed data of Total Integrated Luminosity($\int$L.dt=137 fb^{-1})



T′ Decay: Feynman Diagram



High P_T(> 50GeV)bjet
+
Non-isolated lepton with
High P_T(> 50GeV)
+
E_T^{miss}

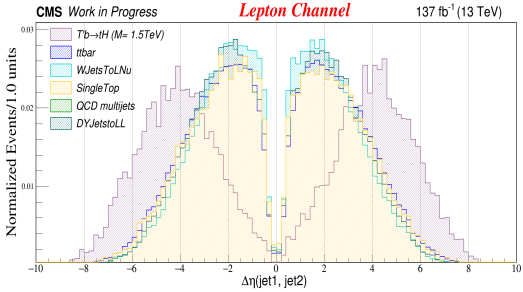
Fully Merged:Higgsjet
Required new tagger,
H→4qjet based on
Deep boosted tagger

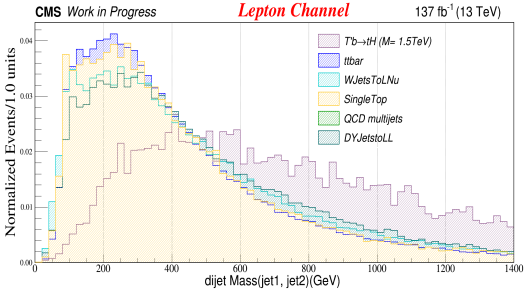
T′ as combination of:
Higgsjet+bjet+l(e, μ)+E_T^{miss}

- Dominant background are from top-like events(ttbar and single top)
- Secondary background are QCD multijets, Wjets, DYjets

Forward dijet Definition

- Forward jet based on presence of pair of associated jets with large $\Delta\eta$ leading to high dijet mass
  - **Forward dijet is defined as pair of jet having highest $\Delta\eta$ among all jets in the event**
  - **$\Delta\eta$ and dijet mass distribution of forward dijet are compared for signal and background**

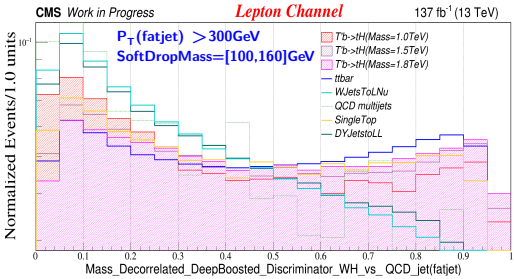


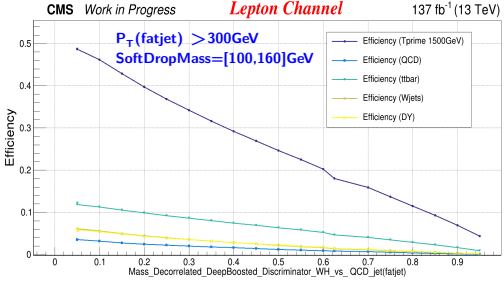


- **Background events have low $\Delta\eta$ and low dijet mass**
- **Signal events have high $\Delta\eta$ and high dijet mass**
- **Selection of forward dijet $\rightarrow \Delta\eta(j_1, j_2) > 2.4$ AND dijet mass > 500 GeV(#slide 20,23)**

Deep Tagger Study: H→4q jet Tagger

- Multi-class classifier for top, W, Z, Higgs and QCD jets, based on standard anti-kT R=0.8 (AK8) jets having
  - Nominal version → jet mass dependency
  - Mass decorrelated version → independent of jet mass
- It provides discriminator for heavy object (top/W/Z/H) jets vs QCD jets
  - Standard discriminants : W → jets vs QCD jet and T → jets vs QCD jets
  - Experimental discriminants: WH vs QCD jets **(applied to the analysis)**



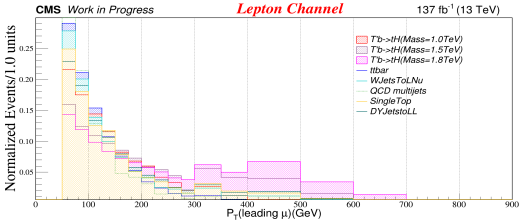


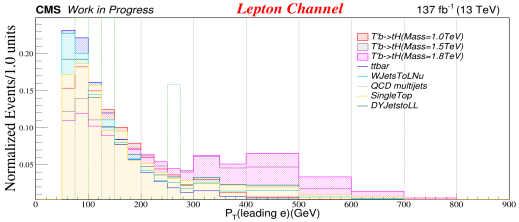
Signal vs Background Study for T′ Mass points

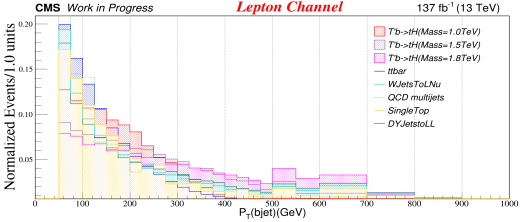
Event Selection Applied

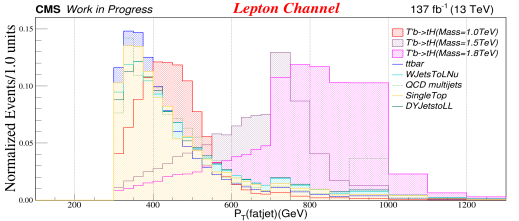
- Lepton trigger applied
  - For Muon Channel: **HLT_MU_50||HLT_OldMu100||HLT_TkMu100**
  - For Electron Channel:**HLT_Ele50_CaloIdVT_GsfTrkIdT_PFJet165||HLT_Ele115_CaloIdVT_GsfTrkIdT||HLT_Photon200**
- Primary Vertex, PV > 0
- N(lep) ≥ 1 AND N(jet) ≥ 1 , here lep = electron(muon)
- $E_T{}^{miss} > 50$ GeV
- Fatjet selection (N(fatjet) ≥ 1)
  - P_T(fatjet) > 300 GeV
  - $|\eta$(fatjet)$| < 2.4$
  - **SoftDrop mass = [100, 160] GeV**
  - **DeepBoosted Discriminator WHvsQCD > 0.20**
- S_T > 700 GeV, Here $S_T = \sum P_T($ $E_T{}^{miss}$, leading lepton, leading bjet and leading fatjet)
- **N(forwjet) = 2 AND N(bjet) = 1**
- Weight applied: $w_{Lumi} \times w_{Pileup} \times w_{L1PreFiring} \times w_{btag} \times w_{lepton}$

Kinematic Distributions



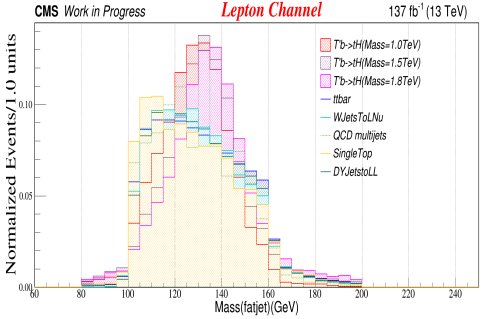


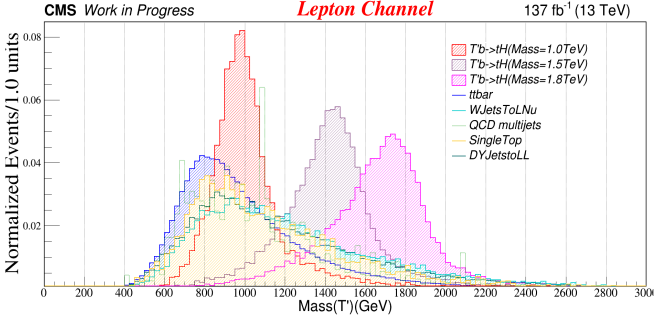




- **Signal Events in high P_T range conclude boosted topology**

Reconstructed Mass Distributions: fatjet & T′





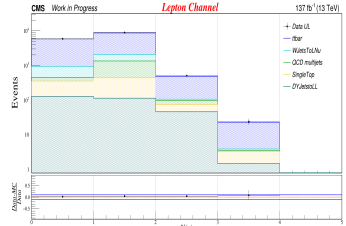
- T′ reconstructed with combination of four vector of (E_T^{miss}, lepton, bjet and fatjet)
- **Signal Events in high P_T range conclude boosted topology**

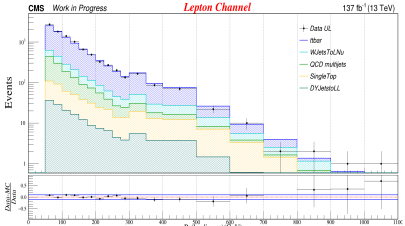
Data Validation in Background Enriched Region for LHC-Run2 Data

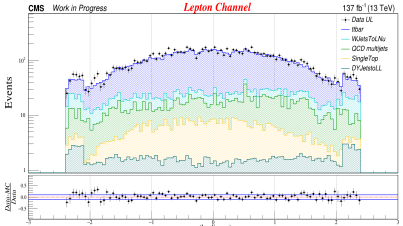
Control Region-Top Selection

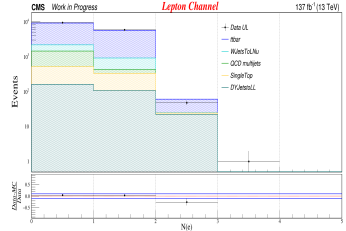
- Top-events(ttbar and single top) compromised $\sim$ 80% of background events
- Next we design control region to predict these backgrounds
- Lepton trigger applied
- Primary Vertex, PV > 0
- N(lep) ≥ 1 AND N(jet) ≥ 1 , Here lep = electron(muon)
- $E_T^{miss} > 50$ GeV
- Fatjet selection (N(fatjet) ≥ 1)
  - P_T(fatjet) > 300 GeV
  - $|\eta$(fatjet)$| < 2.4$
  - **SoftDrop mass = [100, 220] GeV**
- $S_T > 700$ GeV, Here $S_T = \sum P_T($ E_T^{miss}, leading lepton, leading bjet and leading fatjet)
- **N(forwjet) = 2 AND N(bjet) ≥ 1**
- **Side-band region selected around Higgs mass for, top-enriched, with similar to SR's kinematics and keeping SR blinded**
- **Mass(fatjet) excluding window of [110,140]GeV**
- Weight applied: $w_{Lumi} \times w_{Pileup} \times w_{L1PreFiring} \times w_{btag} \times w_{lepton}$

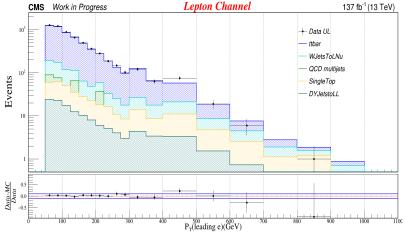
Kinematic Distributions: Lepton

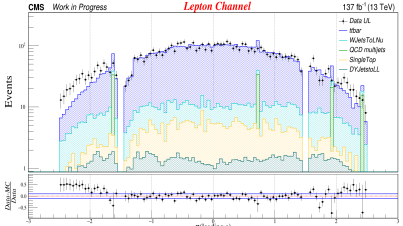






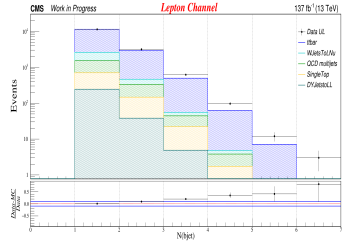


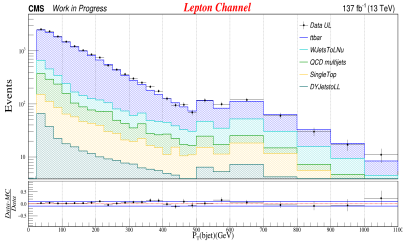


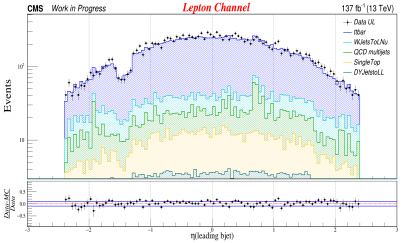


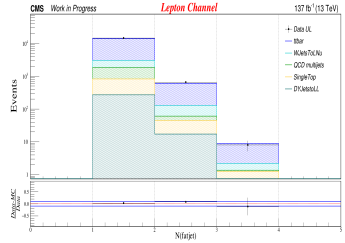
- **Good Data-MC agreement holds for both leptons**

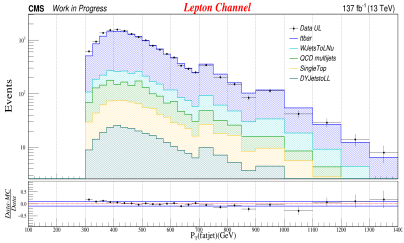
Kinematic Distributions: Leading bjet and fatjet

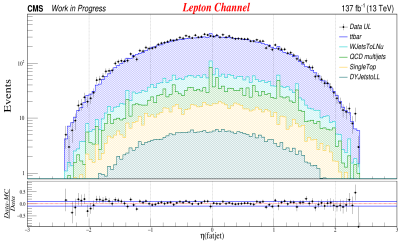






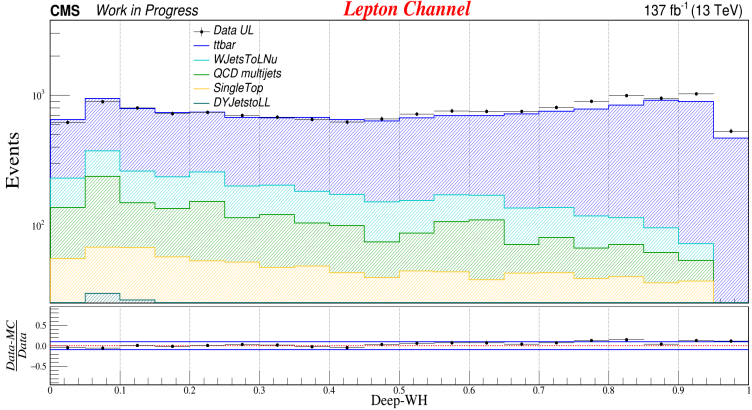






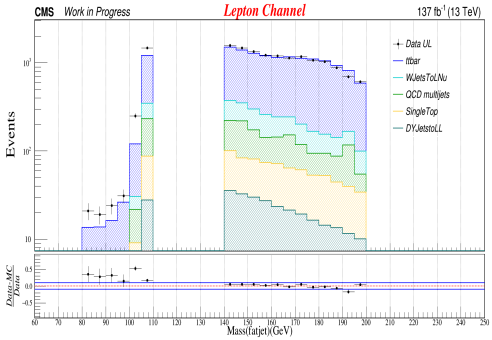
- **Good Data-MC agreement**

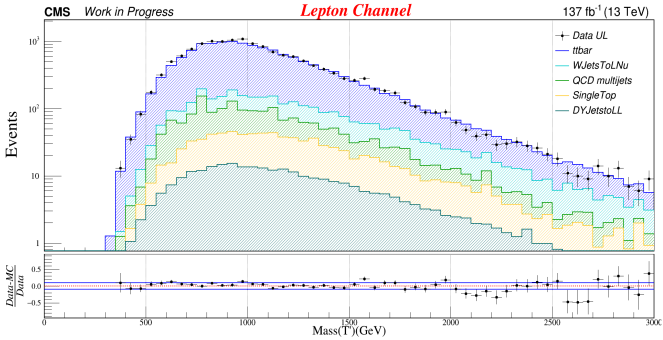
Deep-WH Spectra: fatjet



- **Deep-WH spectra is corrected by deep-tagger SF**
- **Good data-mc agreement for fatjet**

Reconstructed Mass Distributions: fatjet & T′





- **Good Data-MC agreement especially in Mass(fatjet) distribution**

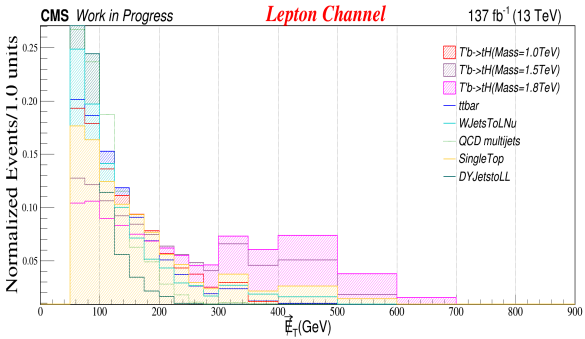
Summary/Next Steps

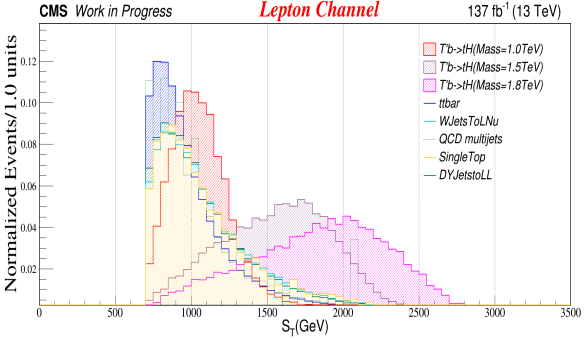
- LHC-Run2 Data of Total Integrated Luminosity($\int$L.dt=137 fb^{-1}) analysed
  - Forward dijet pair selected as per decay topology
  - Higgs$\rightarrow$4q tagger designed using Deep Boosted WH vs QCD discriminator
  - T$'$ fully reconstructed based on signal region study
  - Specially designed Control Region(top-like events) explored
    - Data analysed keeping signal region blinded
    - Scale factors for major object applied $\rightarrow$ (btag, lepton, Higgstag)
    - Data-MC validation shows good agreement for major variables

- Next Steps
  - Background estimation using control region-top
  - Inclusion of Systematic Uncertainities
  - Estimate limit and significance of analysis
  - Last, go for Pre-Approval and then Publication of analysis

Thank You & Back Up Slides

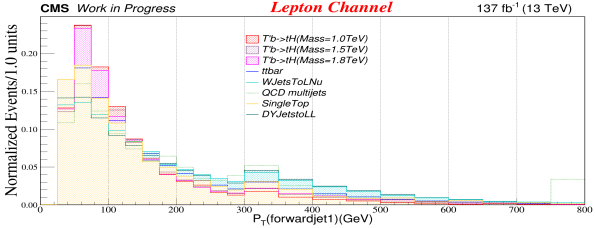
E_T^{miss} & S_T Distribution

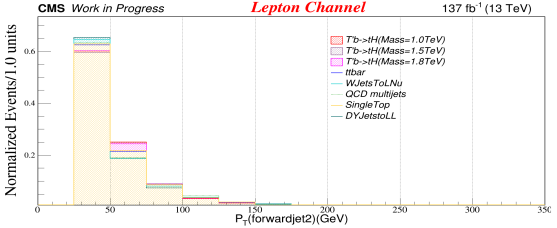


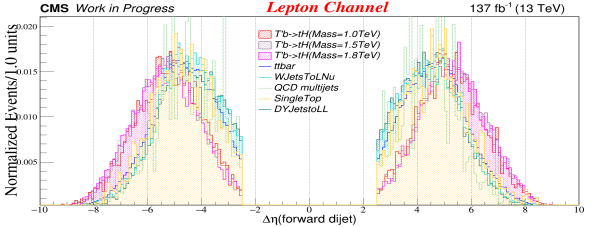


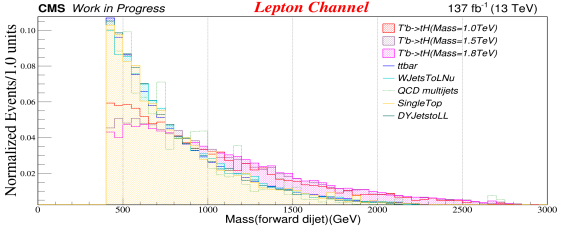
- **Signal Events in high P_T range conclude boosted topology**

Kinematic Distributions: forward dijet



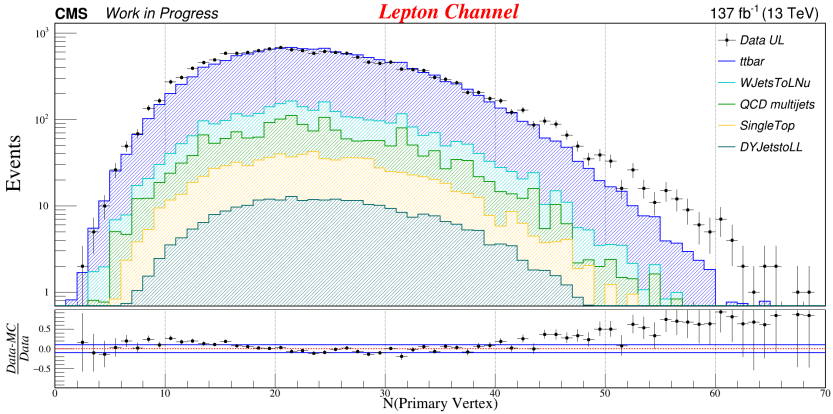






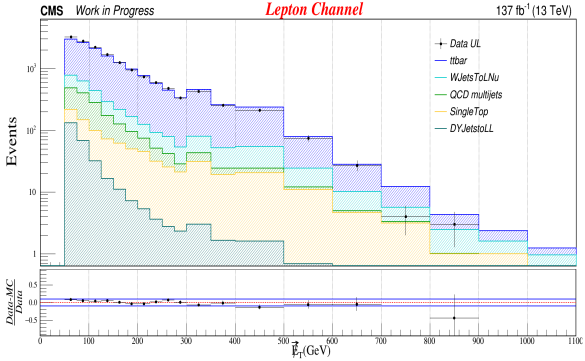
- **Signal Events in high P_T range conclude boosted topology**

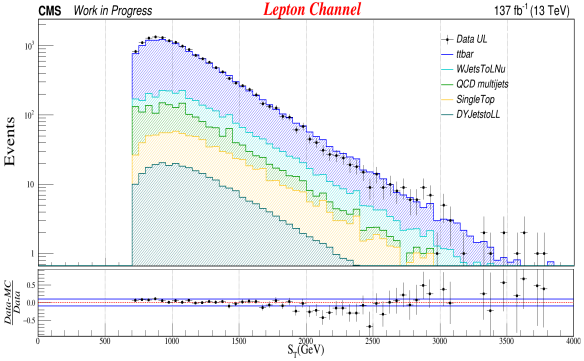
Primary Vertex Distribution



- **Good Data-MC agreement**

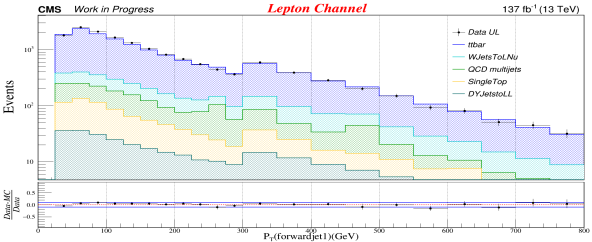
E_T^{miss} & S_T Distribution

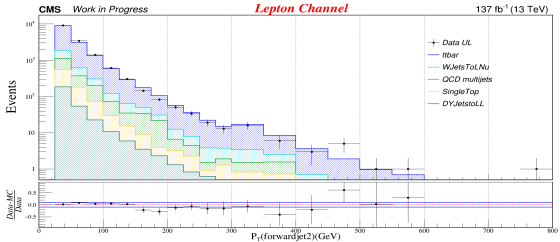


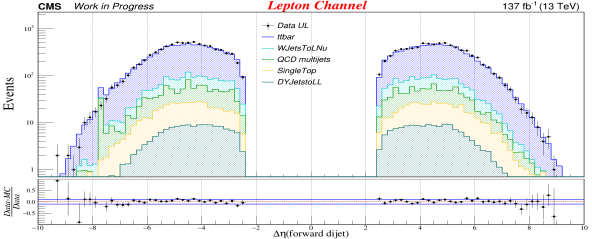


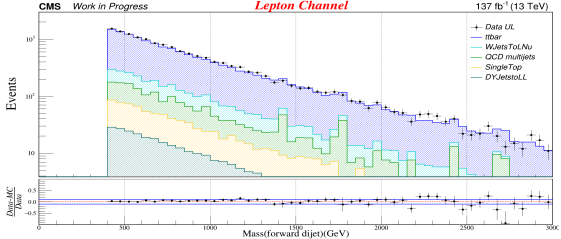
- **Good Data-MC agreement**

Kinematic Distributions: forward dijet









- **Reasonable Data-MC agreement**