Updates on W_R and HNL Search In a $\tau_h\tau_\ell$ + jets Final State

Exotica Jets+X Meeting

9th Sep. 2024

Youngwan Kim[1], Sihyun Jeon[2], Un-ki Yang[1], John Almond[1], Michael Krohn[3], Billy Jackson[3], Sean Poczos[3], Jeremy Mans[3]

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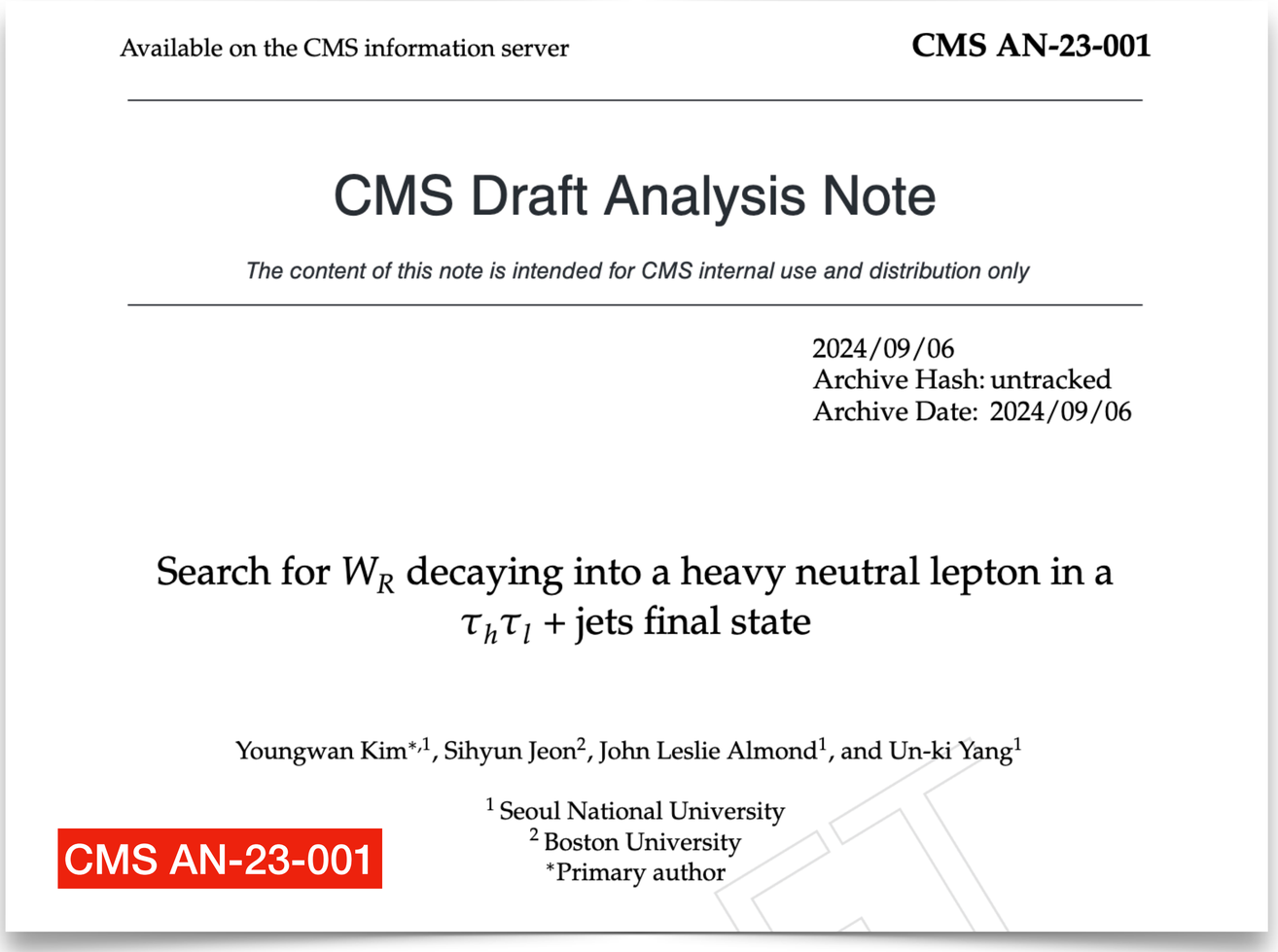
Analysis Status

Overview

- Documentation
  - AN-23-001 (v4)
    - Sent out to conveners for the first time before this presentation
- Presentations
  - Exotica MC&I (14th Feb. 2023)
  - Exotica Jets+X (13th May 2024)
- Updates
  - Nonprompt background estimation method following EXO-19-016 fake factor method
  - Including major systematic sources
  - Used newly processed 2018 signal samples
    - **This presentation mainly focuses on 2018 results**
    - 2016,2017 has similar overall picture ; relevant plots included in backups

** Slides with updates since last Jets+X presentation will include a box :* **Updated**



Available on the CMS information server

CMS AN-23-001

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2024/09/06
Archive Hash: untracked
Archive Date: 2024/09/06

Search for W_R decaying into a heavy neutral lepton in a $\tau_h\tau_l$ + jets final state

Youngwan Kim*[,1], Sihyun Jeon[2], John Leslie Almond[1], and Un-ki Yang[1]

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CMS AN-23-001

Introduction

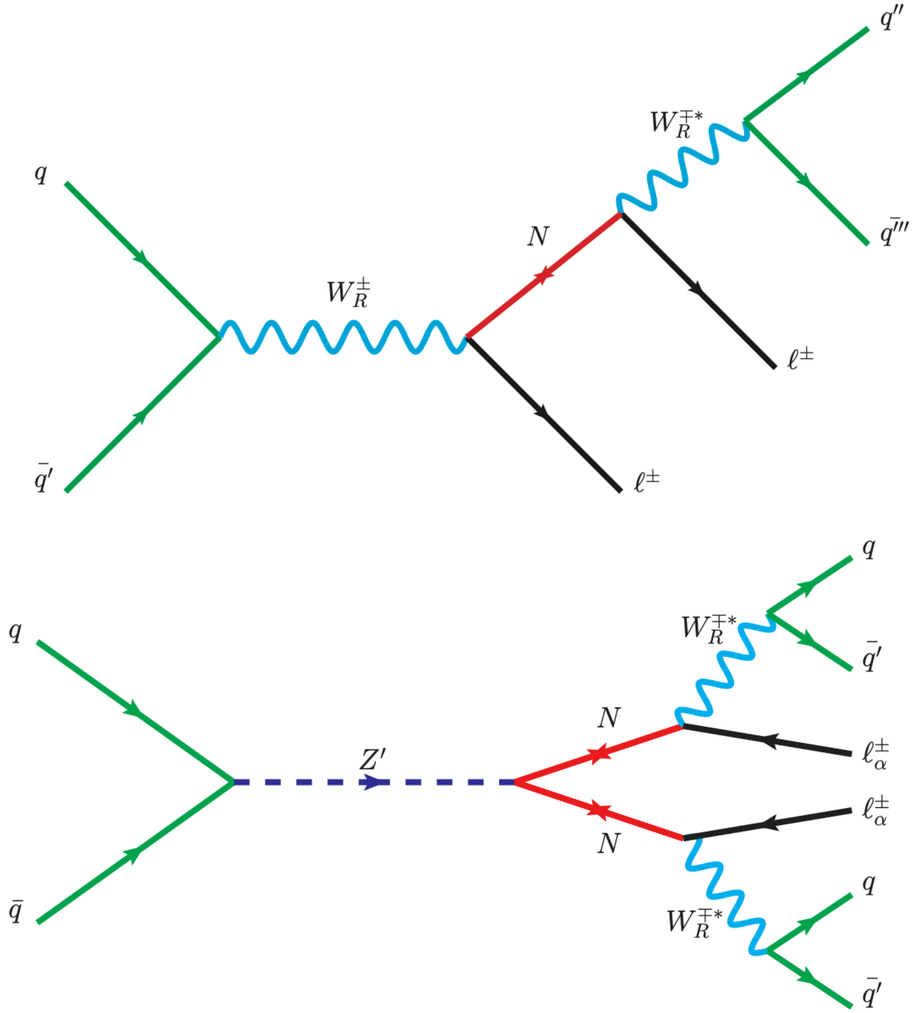
Motivation

- Unsolved mysteries with neutrinos

  - Non-zero neutrino mass from oscillation observations
  - Nature of neutrino mass also yet unknown
    - All unexplainable within the bounds of the SM

- Left-Right Symmetric Model (LRSM)

  - Requires a new SU(2) symmetry between left handed and right handed particles
  - Such symmetry introduces new “right handed gauge bosons” (W_R,Z_R)
  - Predicts the existence of heavy right-handed neutrinos (N)
  - Explains the SM neutrino mass problem via the seesaw mechanism.



W_R Searches in CMS

Overview

- W_R and Heavy N searches since Run 2 :

  - LQ+LRSM inclusive search in τ channels :

    - EXO-16-016 : $\tau_h\tau_h$ + jets (2015 data, 2.1 fb^{-1})
      (doi:10.1007/JHEP03(2017)077)

    - EXO-16-023 : $\tau_\ell\tau_h$ + jets (2016 data, 12.9 fb^{-1})
      (doi:10.1007/JHEP07(2017)121)

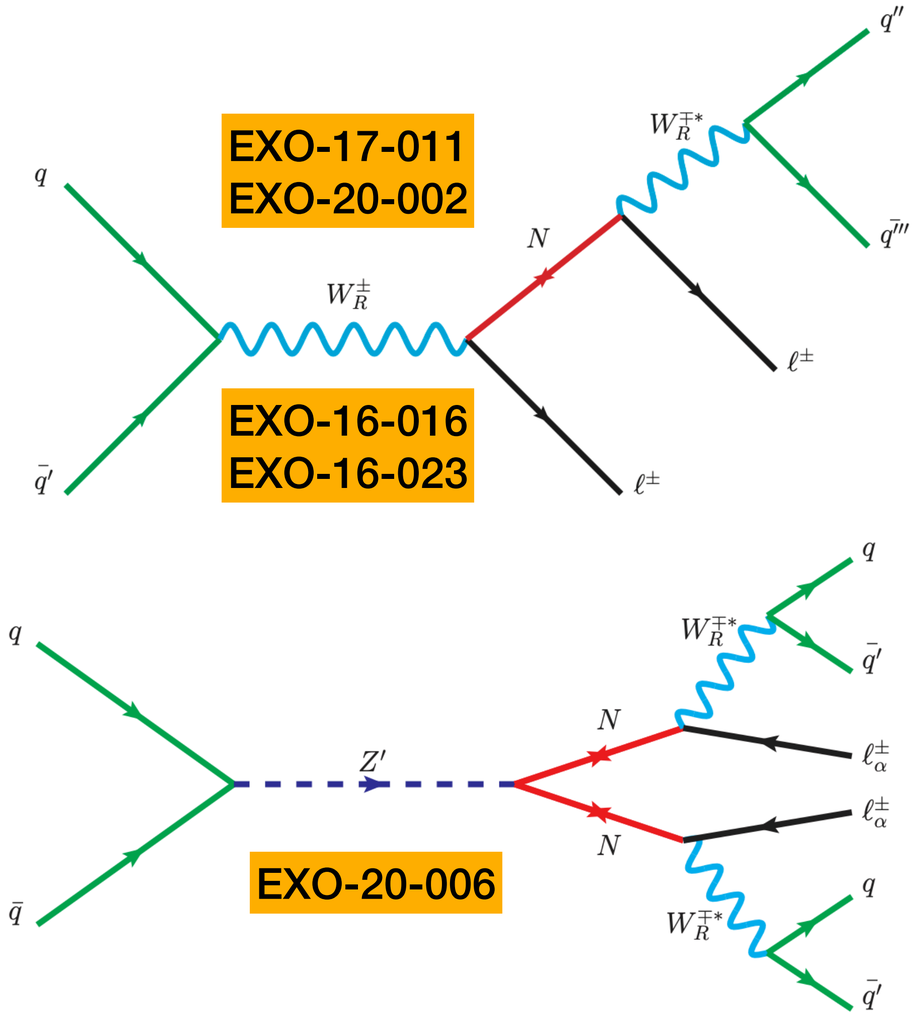
    - EXO-17-016 : $\tau_\ell\tau_h$ + jets (2016 data, 35.9 fb^{-1})
      (doi:10.1007/JHEP03(2019)170)

  - LRSM only search in ee/μμ channels :

    - EXO-17-011 : ee/μμ + jets (2016, 35.9 fb^{-1})
      (doi:10.1007/JHEP05(2018)148)

    - EXO-20-002 : ee/μμ + jets (RunII, 137 fb^{-1})
      (doi:10.1007/JHEP04(2022)047)

    - EXO-20-006 : ee/μμ + jets (RunII, 137 fb^{-1}) (the only Z' induced search)
      (doi:10.1007/JHEP11(2023)181)



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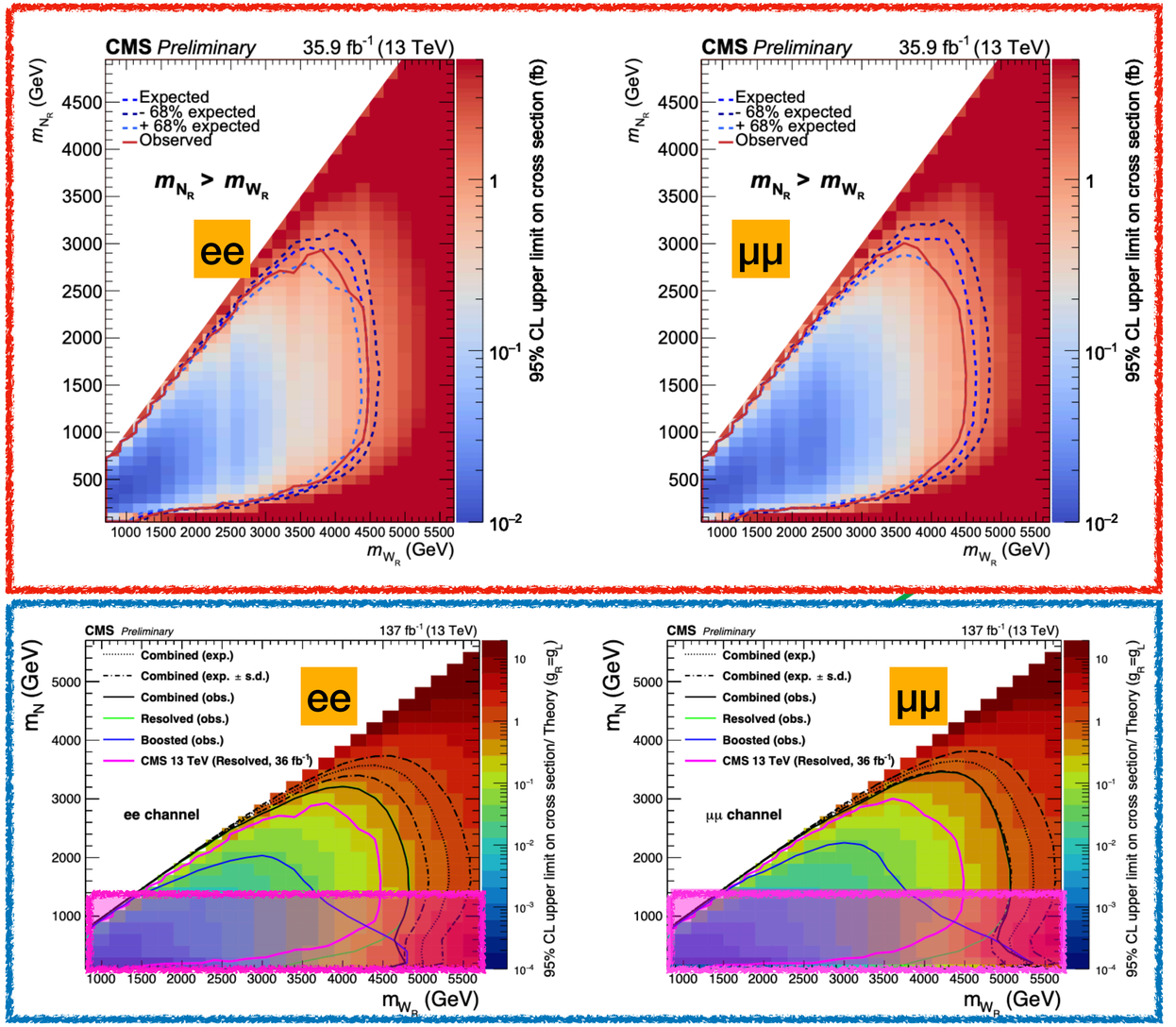
With similar analogy, trying to improve similar phase space region in tau analysis



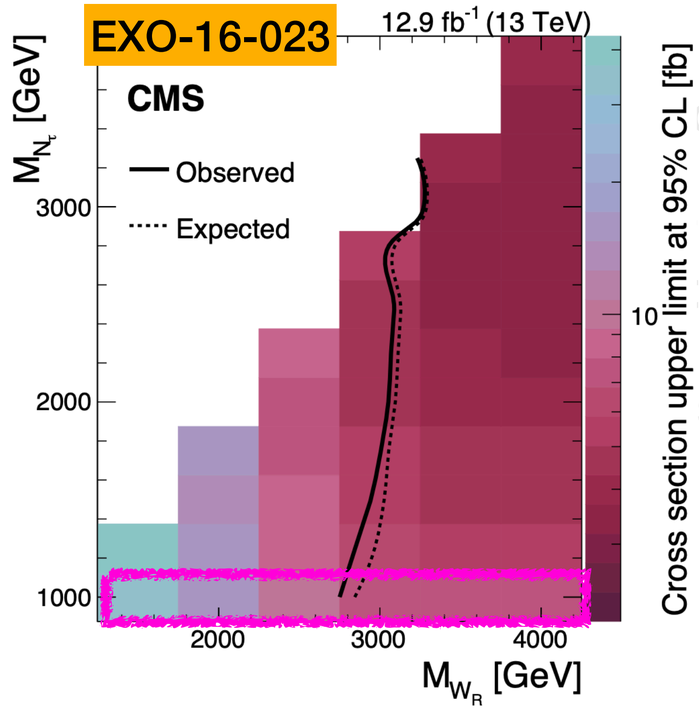
Improvement in regions with $m_{WR} >> m_N$!

Analysis Motivation

Search Strategy

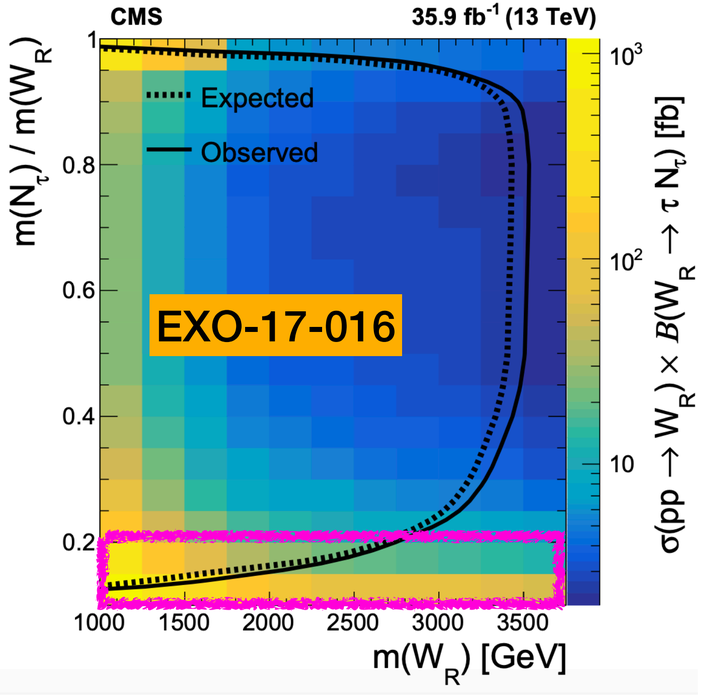
- Adding more sensitivity for W_R search in tau channels in the $m_{WR} >> m_N$ region.

- Trying to add sensitivity to boosted region with $m_{WR} >> m_N$ also for the tau channels.



Enhancing the boosted regions !
($m_{WR} >> m_N$)

Improved statistics for full Run-II
(137 /fb)



Analysis Motivation

Search Strategy

- Adding more sensitivity for W_R search in tau channels in the **$m_{WR} >> m_N$** region.

  - Trying to add sensitivity to boosted region with $m_{WR} >> m_N$ also for the tau channels.

  - Previous study was able to scan a wider range of phase space, especially for the **boosted regions** which was not showing good sensitivity in similar studies before.

  - Applying lessons learned from EXO-20-002 by taking advantage from jet substructures with leptons merged inside a boosted fatjet, from especially using the **lepton subjet fraction (LSF_3) algorithm**.

  - **Aiming to set 2D limits on cross sections on the m_{WR}, m_N mass plane.**

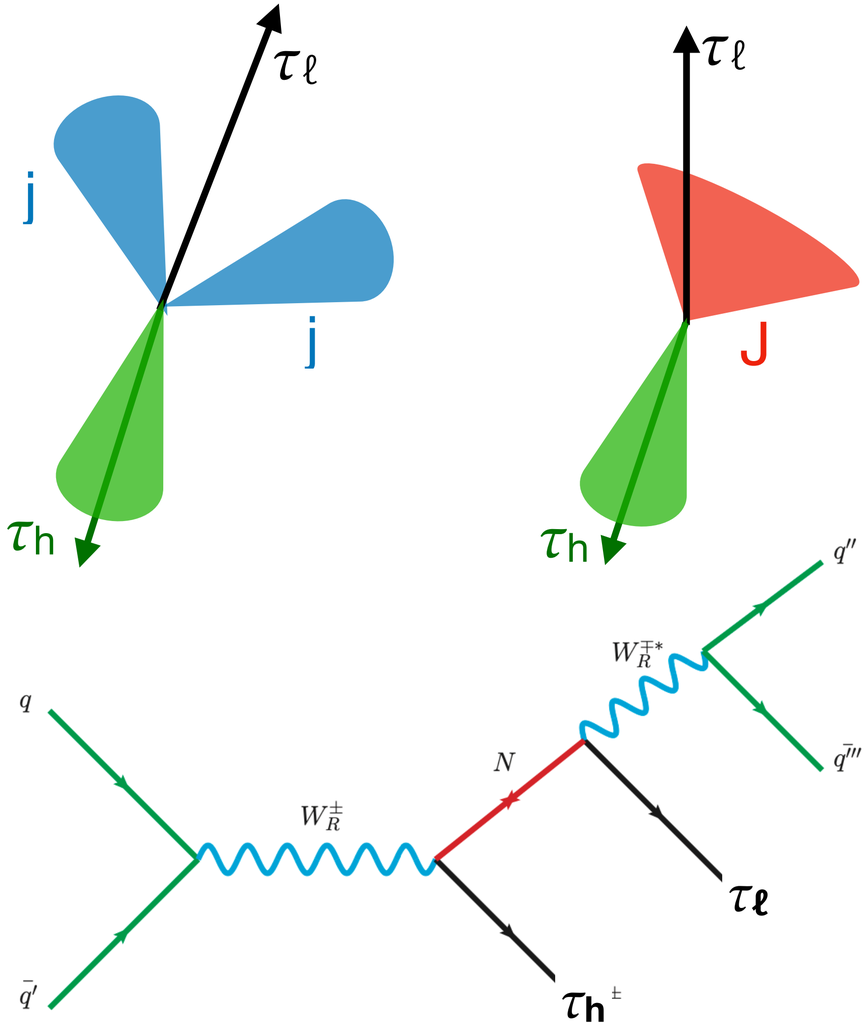
Signals
Final Objects

- Target channel

  - **p p > τ_h N, N > τ_ℓ j j** is targeted order to mimic the previous study utilizing LSF algorithms
    (τ_h : hadronic tau , τ_ℓ : leptonic tau)

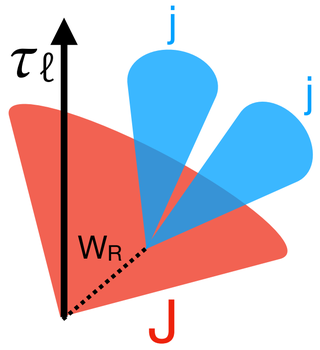
- Final state objects

  - Isolated τ_h & leptons + jets (back to back)
  - Kinematics of final state objects differ dramatically by the ratio of WR and N mass
    - Resolved : leptonic tau near 2 AK4 jets ($m_{WR} \sim m_N$)
    - Boosted : leptonic tau inside AK8 jet with bad isolation ($m_{WR} >> m_N$)



Signals

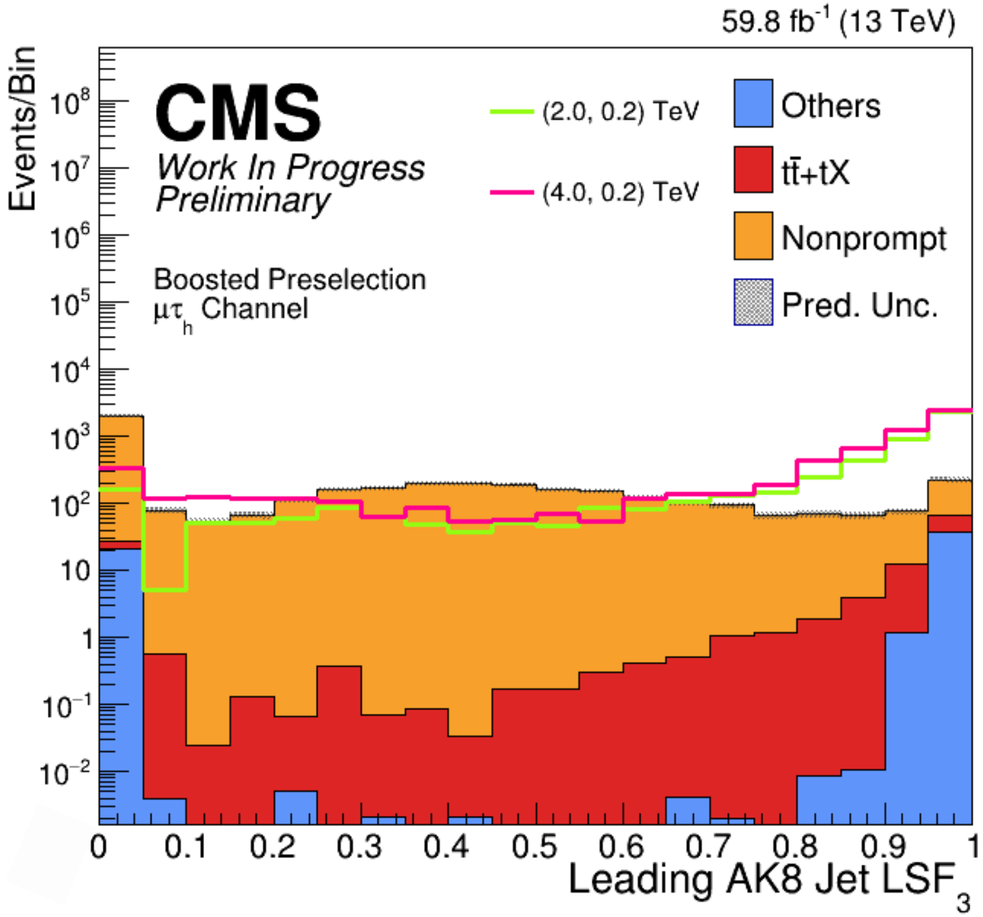
Lepton Subjet Fraction



- Lepton Subjet Fraction (LSF_3)
  [doi:10.1007/JHEP04(2015)079]

  - Variable devised to distinguish fat jets that are likely to contain a lepton :

    - For a given fat jet, constituents are clustered into 3 subjets using the exclusive kT algorithm
    - Between all pair of particles, cluster them with minimum distance $d_{ij} = \min(p_T,p_T)R_{ij}$ into a single subjet until only 3 are left
    - Doing so, all leptons in the event will be associated with a subjet
    - LSF is then defined by the pT ratio of the lepton to the associated subjet

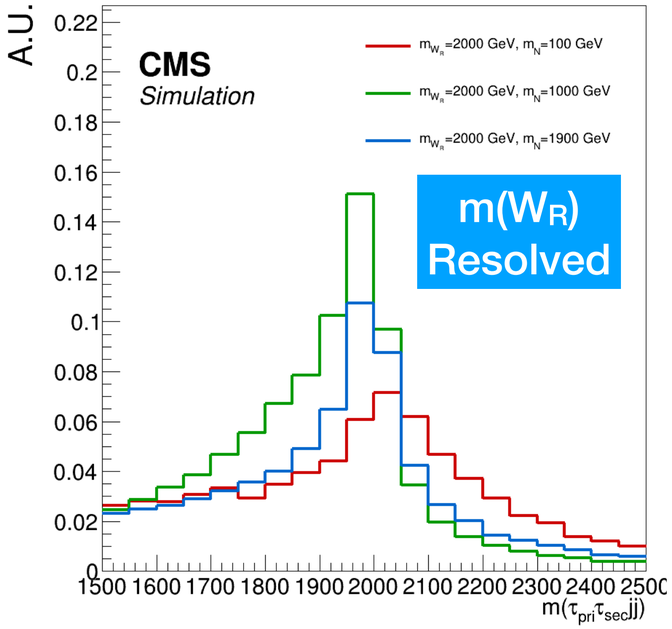


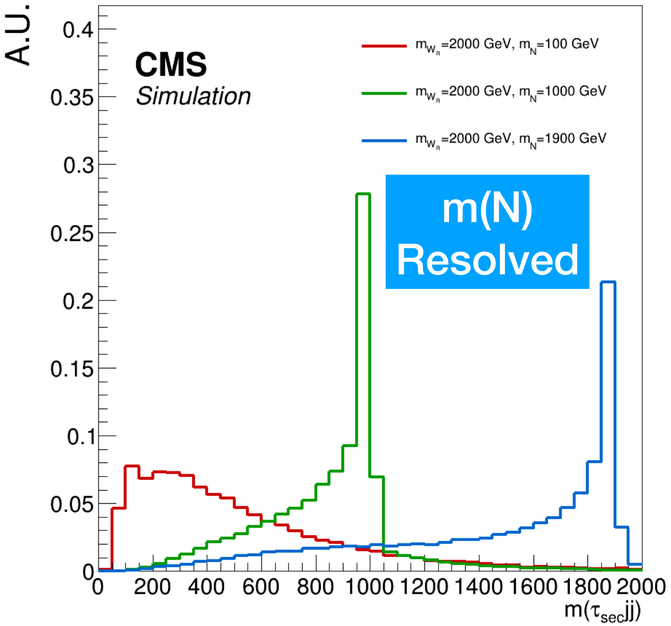
Signal Kinematics

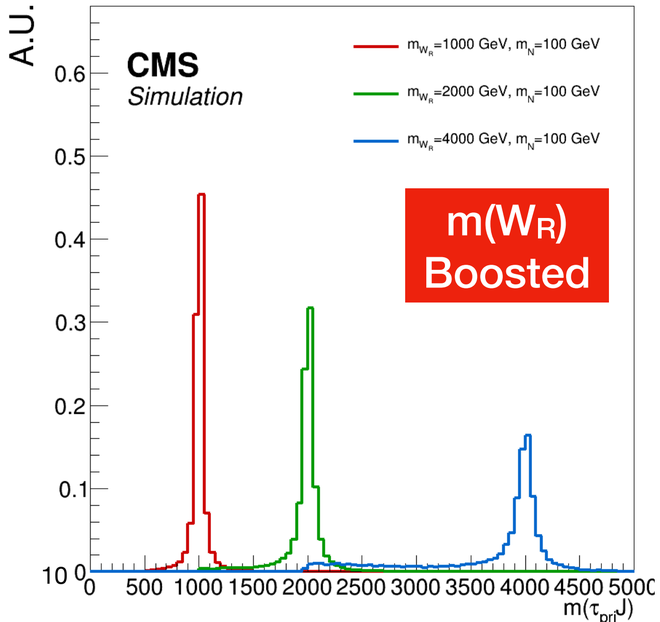
- Resolved region legend :
  - m_{WR} = **2 TeV**
  - m_N = **100,1000,1900 GeV**

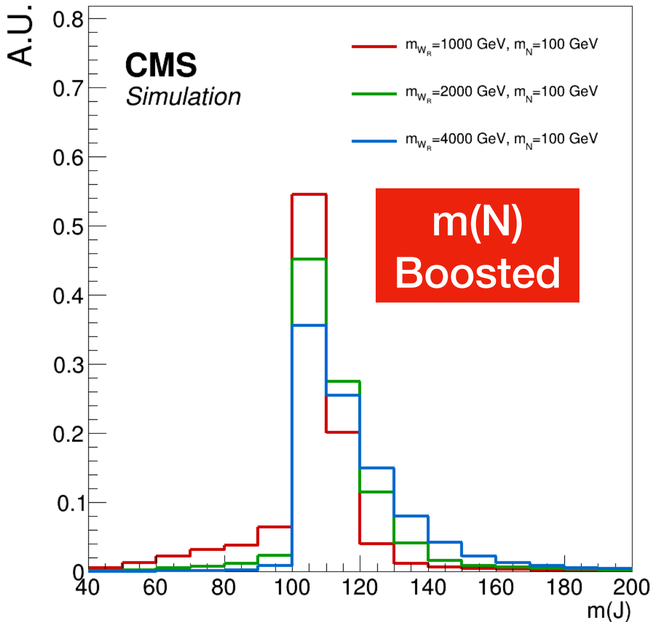
- Boosted region legend :
  - m_{WR} = **1,2,4 TeV**
  - m_N = **100 GeV**

(Using mass points having more sensitivity in the boosted selection ; mWR >> mN)









Objects
Definition

- Muon
  - p_T > 50 GeV , |η| < 2.4
  - Tight ID : POG High pT & Tracker isolation < 0.1
  - Loose ID : POG High pT

Requirement	Loose	Tight
$\|\eta\|$	< 2.4	< 2.4
p_T	> 53 GeV	> 53 GeV
ID	HighPt	HighPt
Isolation	-	Relative Tracker Isolation < 0.1

- Electron
  - p_T > 50 GeV , |η| < 2.4
  - Tight ID : POG cut based loose w/o relIsoWithEA
  - Loose ID : POG HEEP ID

Requirement	Loose	Tight
$\|\eta\|$	< 2.4	< 2.4
p_T	> 53 GeV	> 53 GeV
ID	Cut Based Loose without relIsoWithEA	HEEPv7

- Tau
  - p_T > Trigger safe cut , |η| < 2.4
  - DecayModeNewDM & |dZ| < 0.2
  - DeepTau v2.1 (vJet,vEl,vMu) = (Tight,Tight,Tight)

	2016	2017	2018
Trigger	`HLT_VLooseIsoPFTau140_Trk50_eta2p1`	`HLT_MediumChargedIsoPFTau180HighPtRelaxedIso_Trk50_eta2p1`	
Trigger Safe p_T Cut	150 GeV	190 GeV	

Objects
Corrections

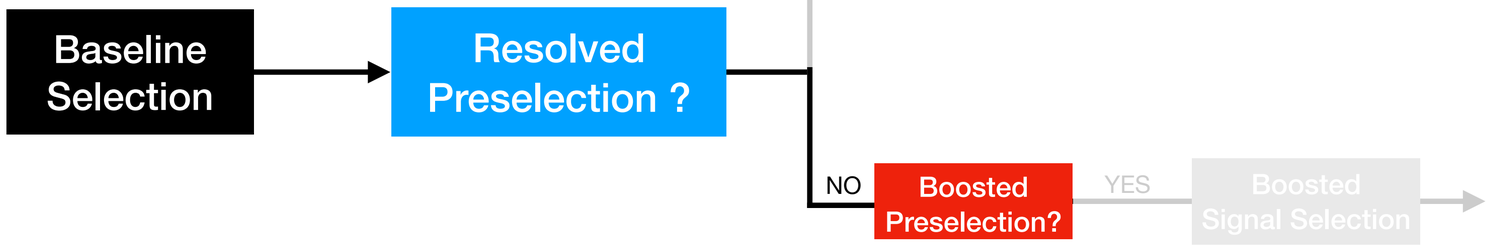
- Event
  - Pileup weight, Trigger SF, L1 Prefire weight
- Muon, Electron
  - Isolation SF , ID SF
- Tau
  - DeepTau ID SF
  - Energy scale
- Fatjet
  - LSF SF (not yet derived for UL)
    - Using prelegacy SFs from EXO-20-002 at the moment
    - Studying compatibility of LSF distributions between UL and prelacy

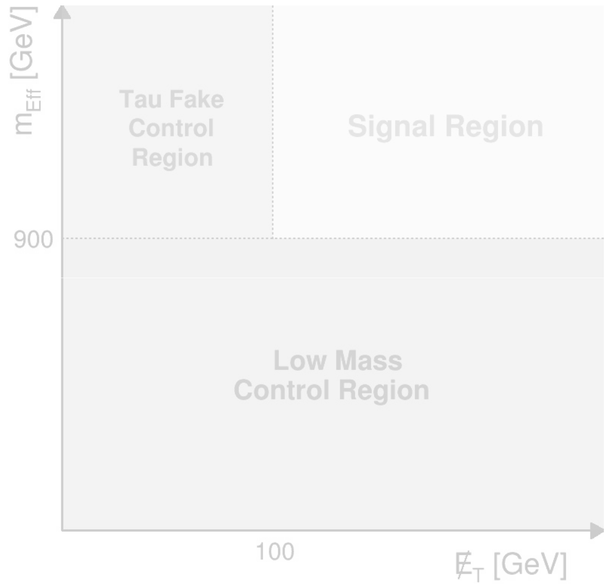
	2016	2017	2018
Trigger	`HLT_VLooseIsoPFTau140_Trk50_eta2p1`	`HLT_MediumChargedIsoPFTau180HighPtRelaxedIso_Trk50_eta2p1`	
Trigger Scale Factor	0.88 ± 0.08	1.08 ± 0.10	0.87 ± 0.11

LSF SF	2016	2017	2018
Electron Fatjet	1.04 (+0.09/-0.08)	1.02 (+0.08/-0.08)	1.05 (+0.07/-0.06)
Muon Fatjet	1.01 (+0.06/-0.06)	0.98 (+0.07/-0.07)	1.04 (+0.06/-0.05)

Region Selection

Definition





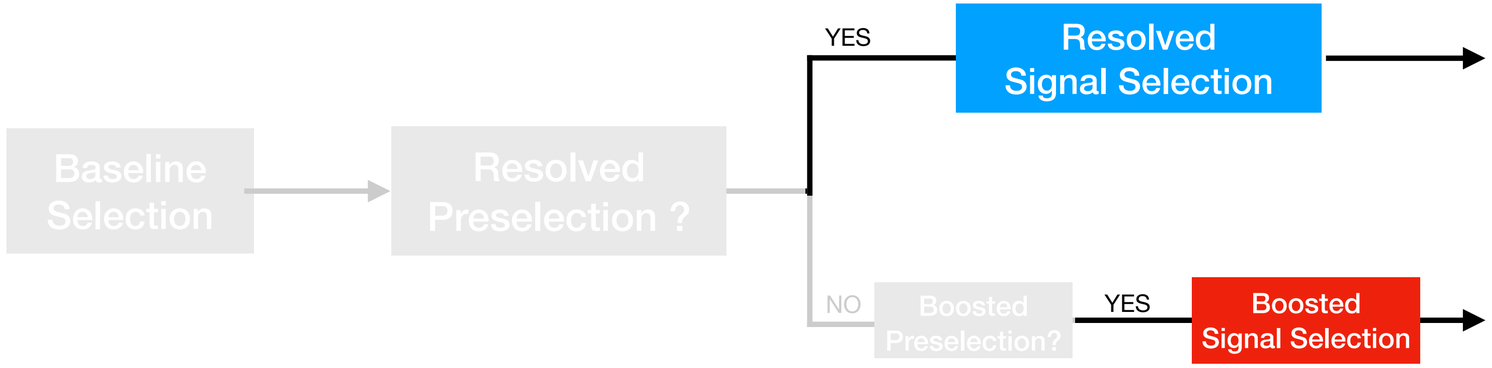
Baseline Selection
- Pass single hadronic tau trigger
- Require at least 1 hadronic tau
- Require exactly 1 loose light lepton

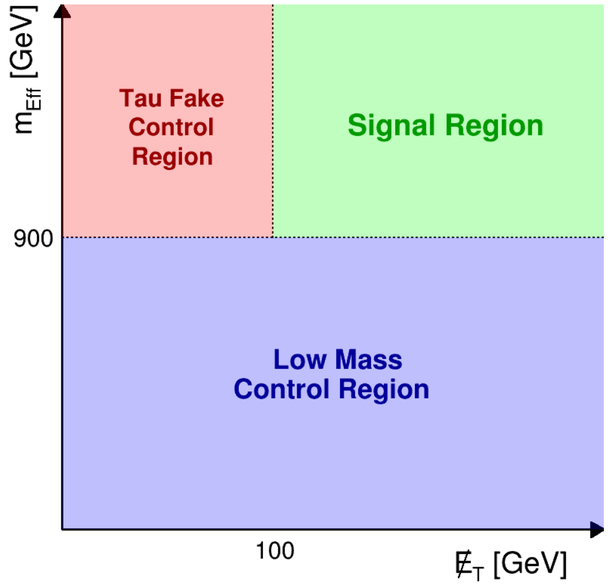
Resolved Preselection
- Passing baseline selection
- Has at least 2 AK4 jets (j)
- Has at least 1 tight lepton

Boosted Preselection
- Passing baseline selection
- Failing resolved preselection
- Has at least 1 AK8 jet (J)

Region Selection

Definition





Resolved Signal Selection

- Passing resolved preselection
- ΔR(lepton, jet) > 0.4

Boosted Signal Selection

- Passing boosted preselection
- ΔR(tau, J) > 2.0 with LSF(J) > 0.6
- ΔR(lepton, J) < 0.8

Background Estimation

Contributions

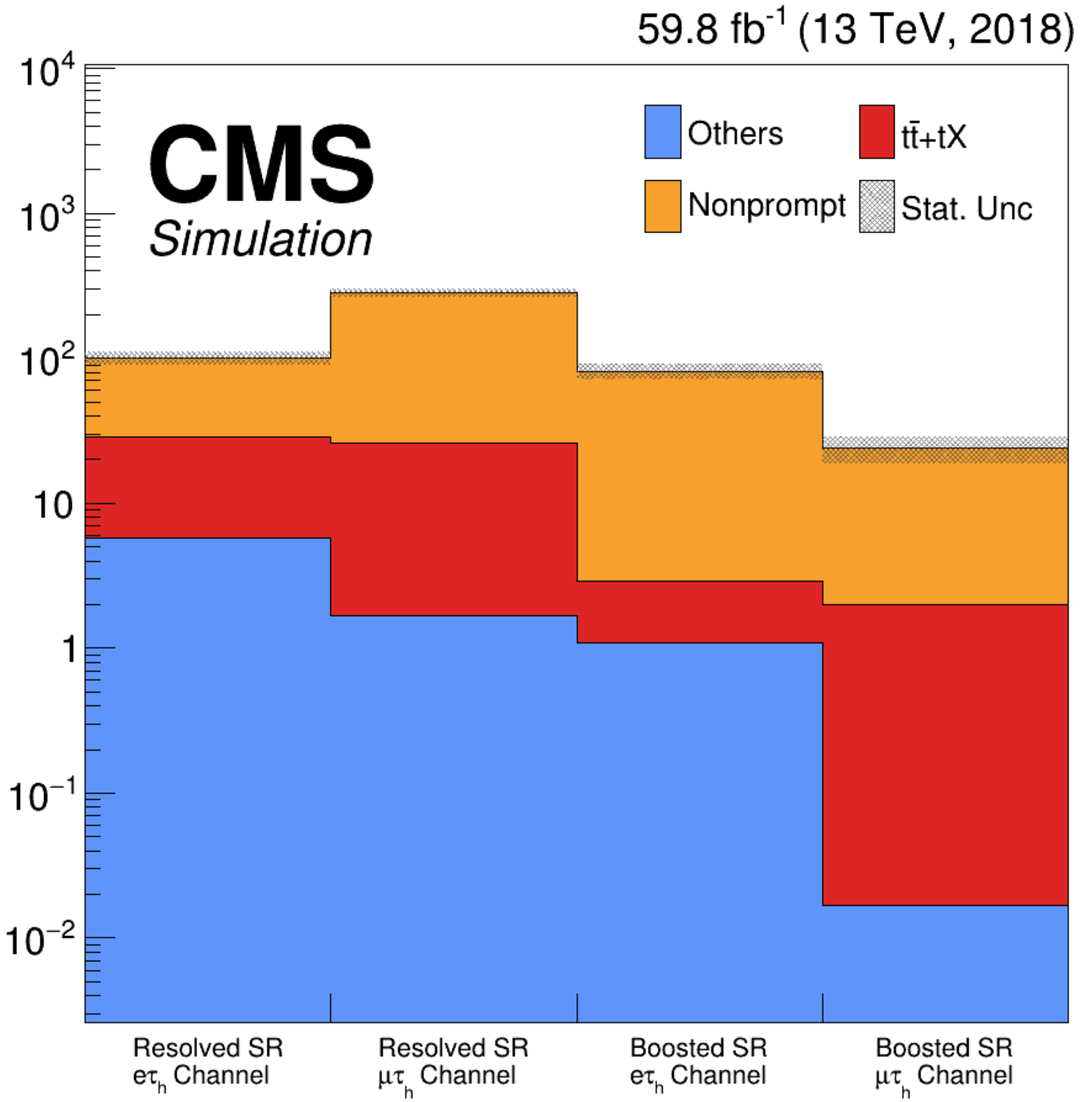
- Prompt contributions

  - Top pair, single top processes (tt+tX)
  - Multiboson(VV,VVV) processes (Others)

- Nonprompt contributions

  - Contributions from “faked” objects
  - Mostly from QCD and W,Z+jet processes
  - Both hadronic tau and light lepton have fake contributions, where hadronic taus have the biggest non-prompt contribution

    - Hadronic taus : Data-driven estimation
    - Light leptons : MC estimation



Background Estimation

Fake Factor Method

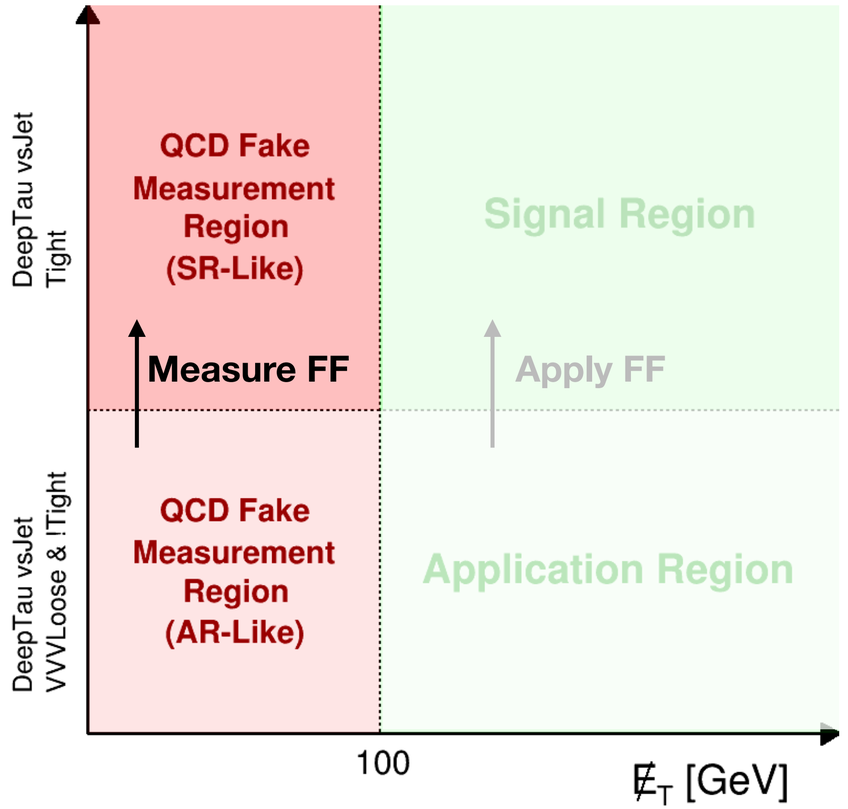
Updated

- Jets -> taus misid. has the biggest background contribution
  - Inaccurate to estimate from MC simulations : **data-driven estimation** is used
    - Fake factor (FF) is measured as a function of tau DM and pT or m_eff

$$FF = \frac{N^{\text{SR-Like}}_{\text{Data}} - N^{\text{SR-Like}}_{\text{Prompt}}}{N^{\text{AR-Like}}_{\text{Data}} - N^{\text{AR-Like}}_{\text{Prompt}}}$$

    - FFs are also measured with respect to different background contributions
      - QCD : measurement region (MR) set by inverting MET cut
        - Tau pT and DM (0+1 and 10+11; 0-prong and 1-prong respectively)
      - Top : no suitable MR constructed ; used MC
        - Tau pT and DM (0,1,10, and 11 individually)

Methodology borrowed from EXO-19-016
doi:10.1007/JHEP05(2024)311

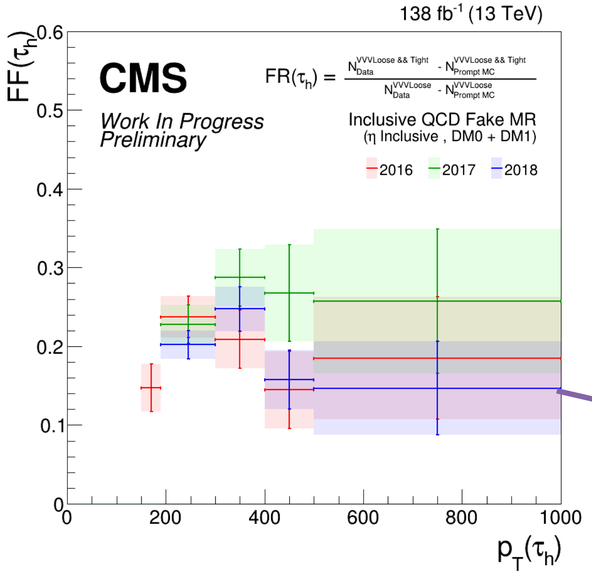


Background Estimation

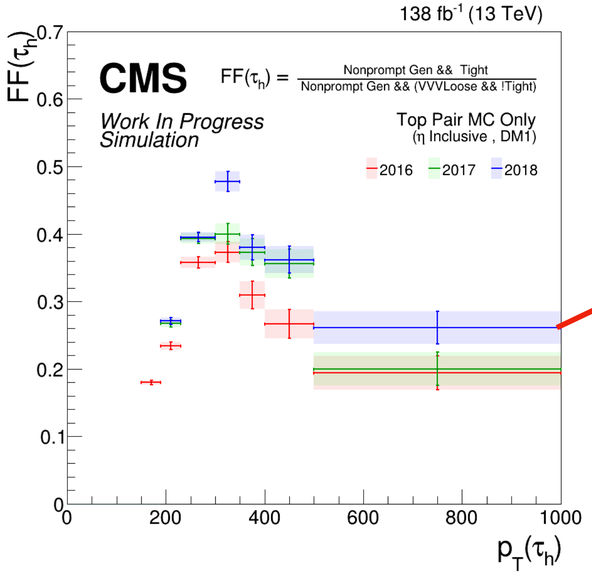
Fake Factor Application

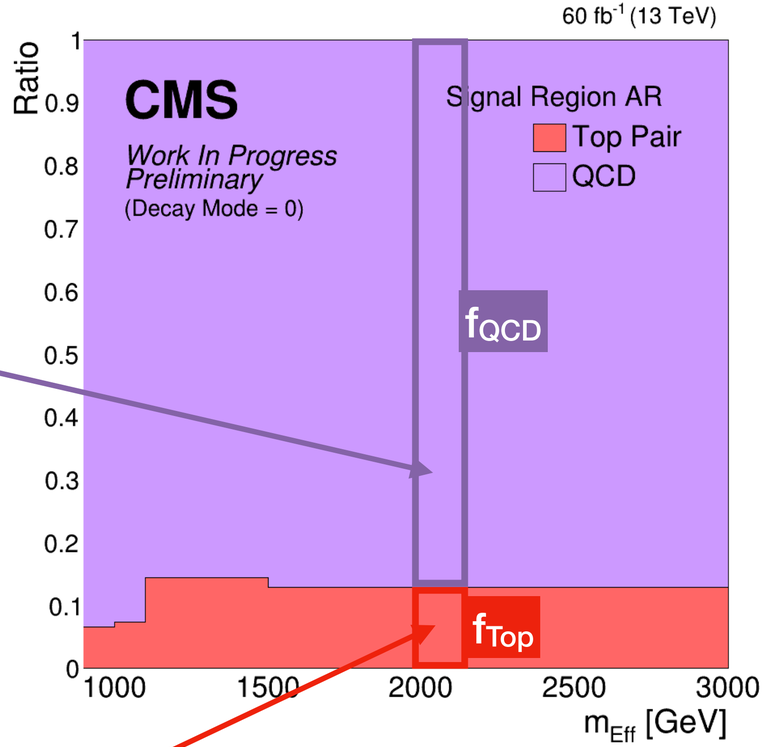
Updated

QCD FF



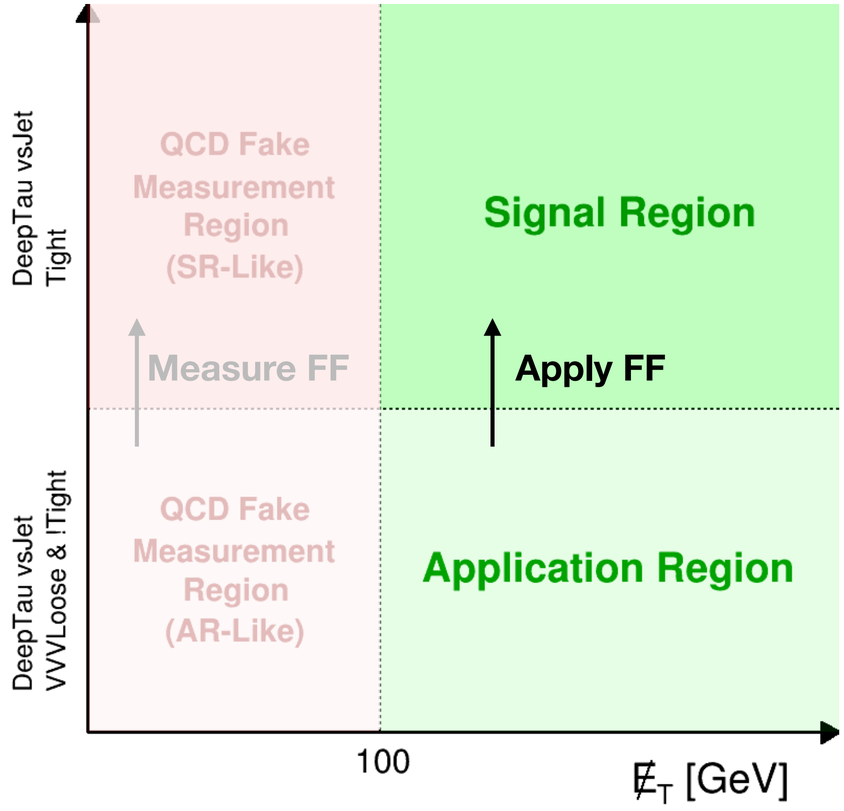
Top FF





Total FF to be applied :

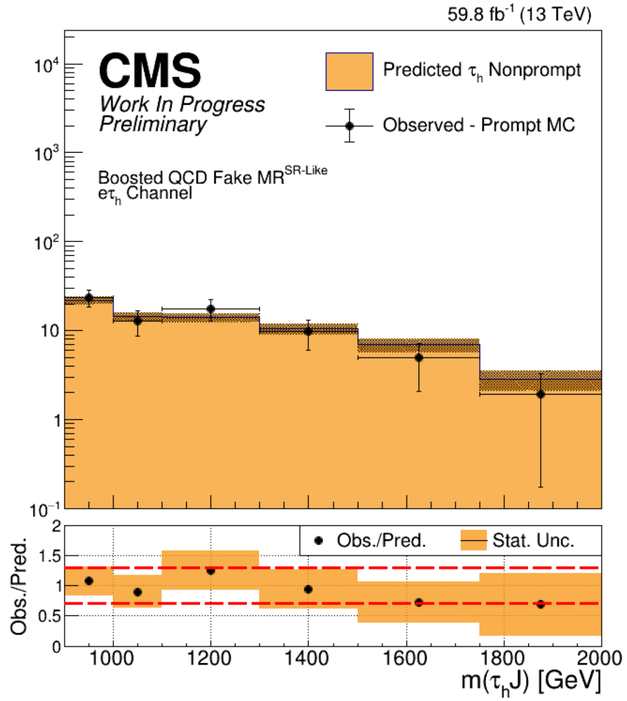
$FF = f_{QCD}\, FF_{QCD} + f_{Top}\, FF_{Top}$

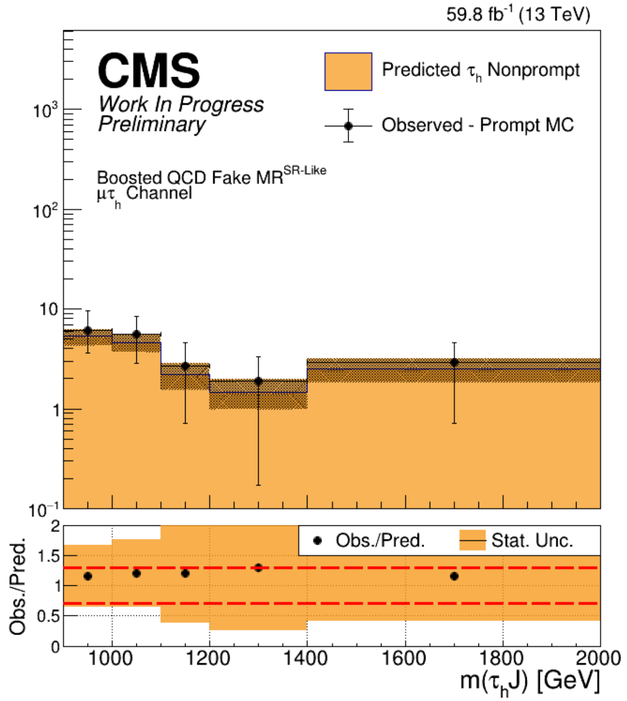


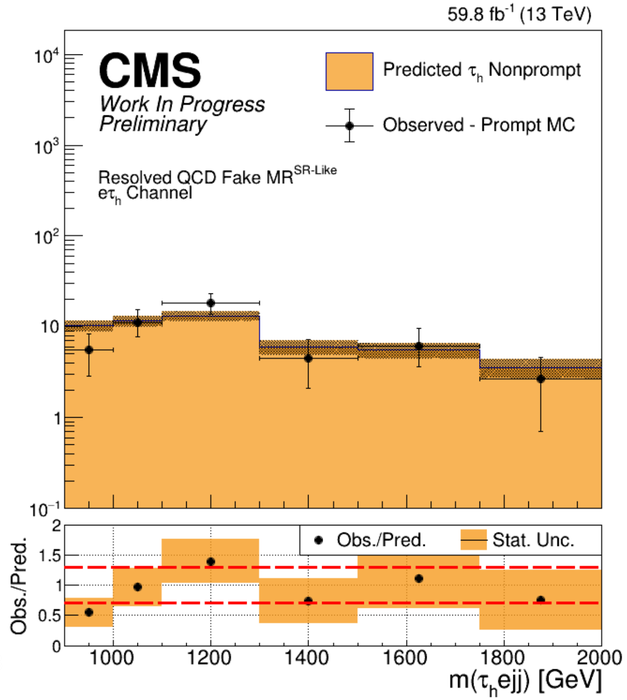
Background Estimation

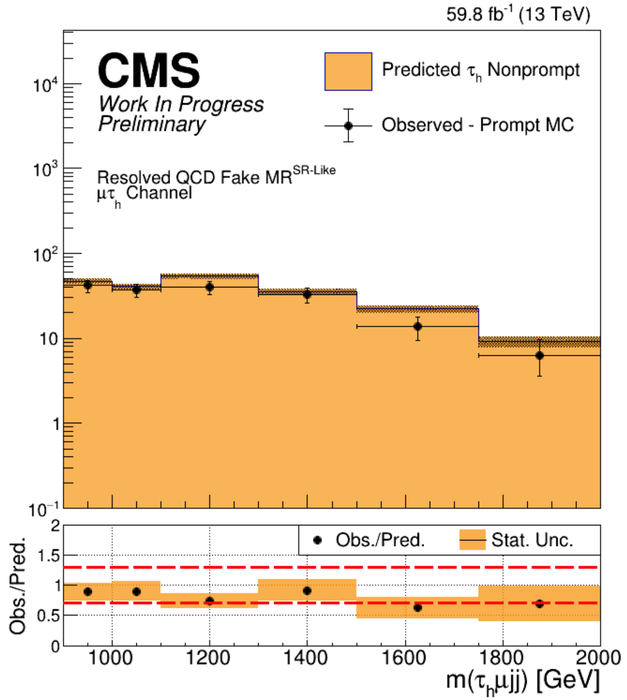
Hadronic Tau Fake

- After applying fake factors and compare with data, closure seems to agree well within overall 30% normalization uncertainty
- 30% flat uncertainty applied as systematics to nonprompt contributions



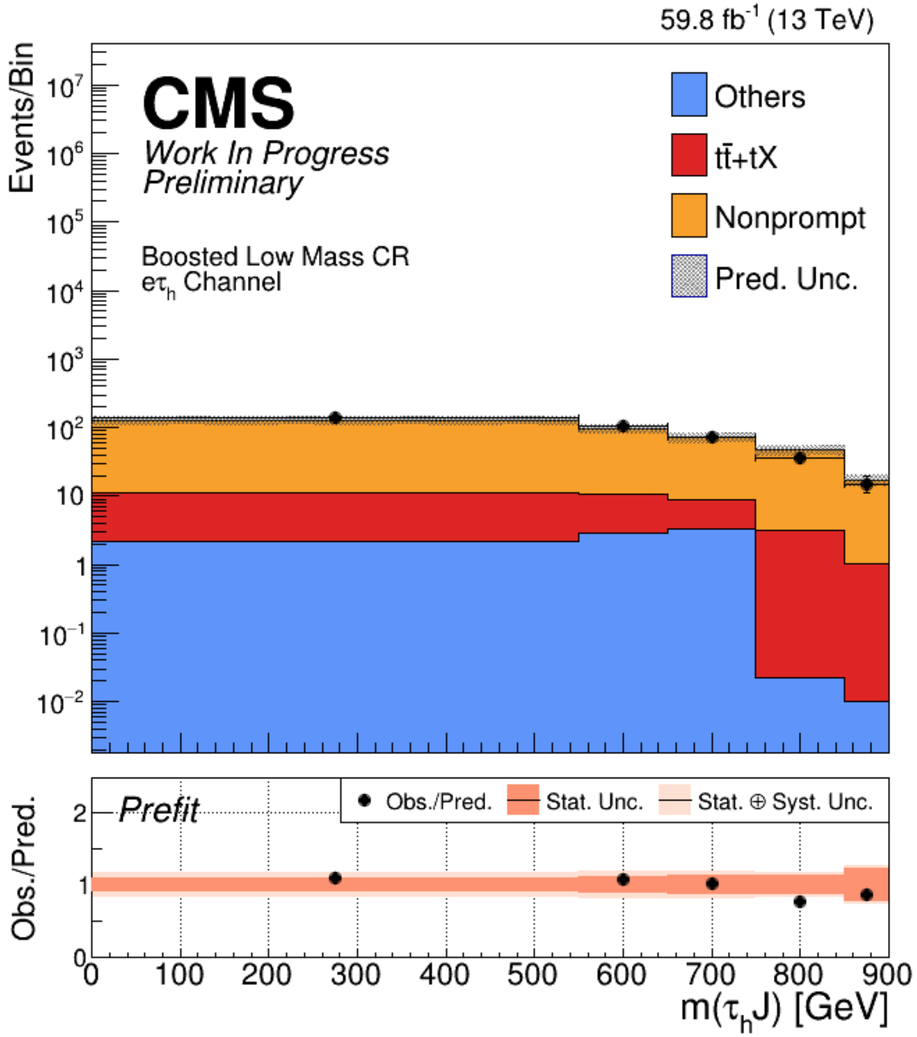


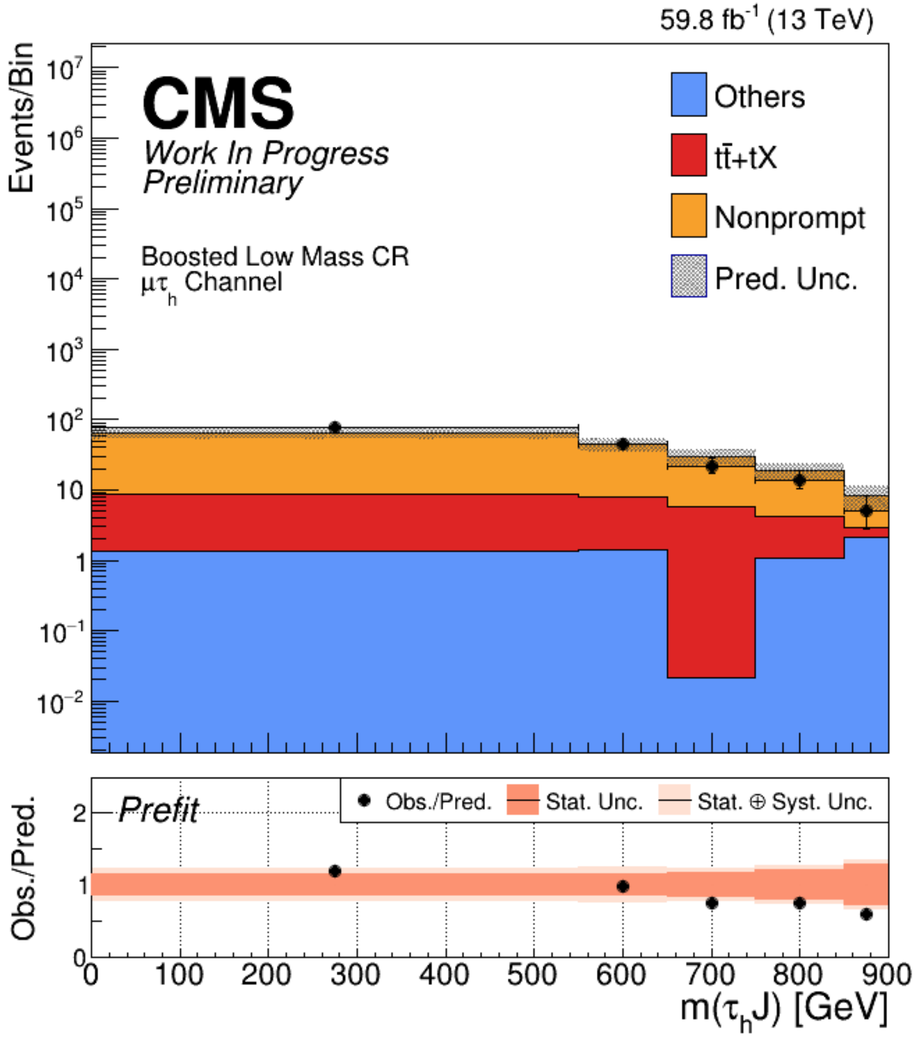




Control Region

Plots





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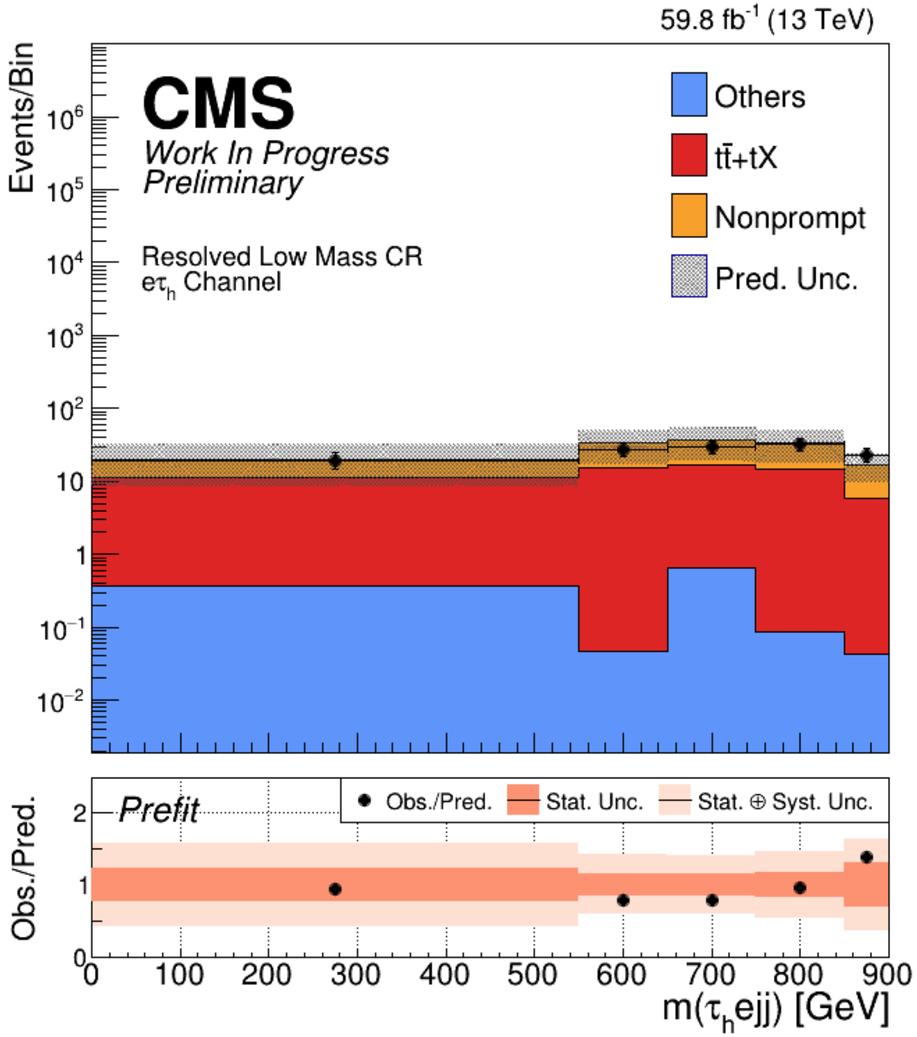
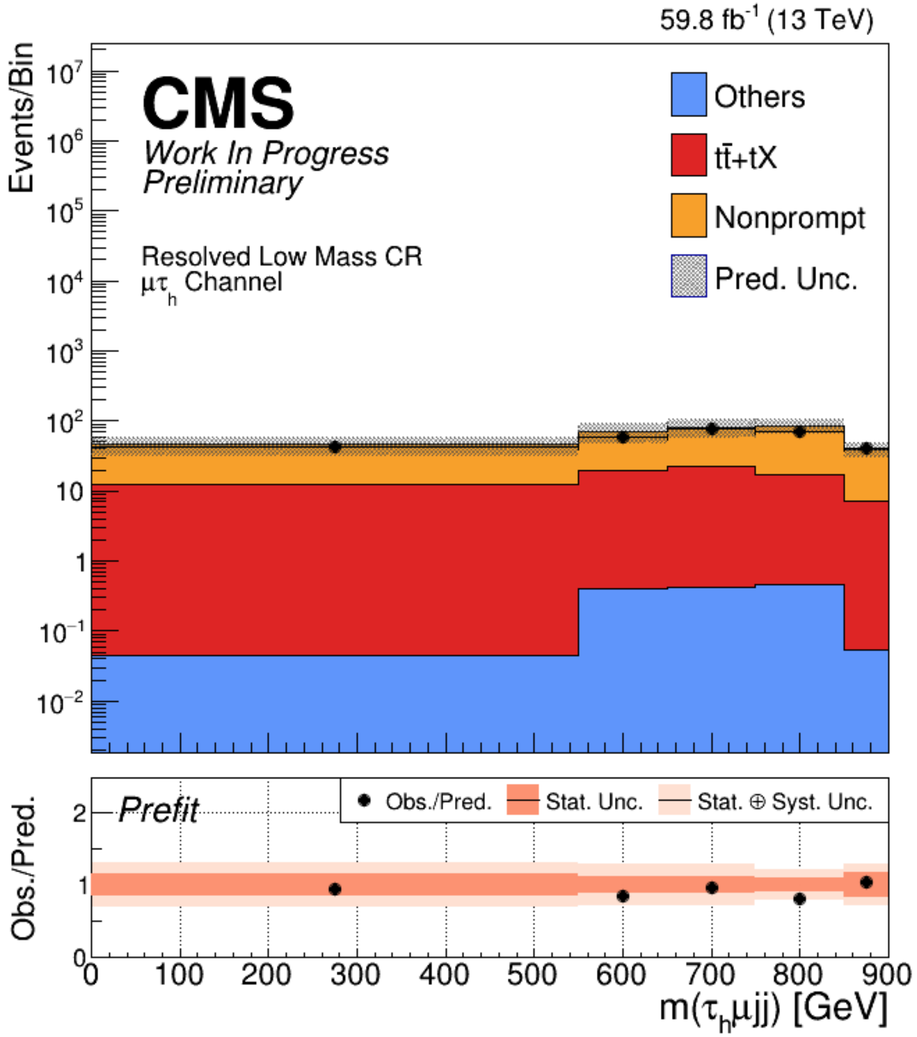




Systematics
Overview

Updated

- In previous iteration, no specific systematic source was considered thus a dummy 30% was applied
- Major systematics included, taken hints from other hadronic tau final state LRSM studies :
  - Jet : Energy scale
  - Tau : Energy scale, ID SF
  - Fake : FF statistical error, normalization
  - Theory : PDF, scale
  - Others : Luminosity, trigger SF

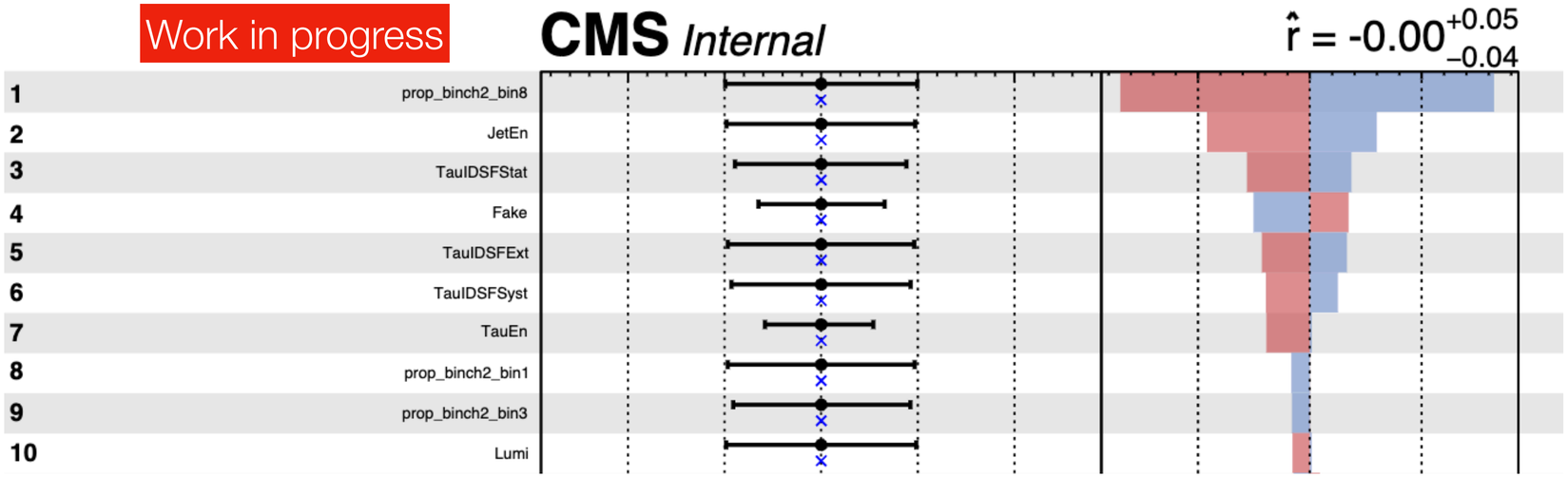
Uncertainty source		Type	Magnitude	Processes
Luminosity		norm.	$1-2.5\%$	All Simulations
Hadronic Tau	ID.	shape	–	All Simulations
	Trigger	norm.	$8-11\%$	All Simulations
	Energy Scale	shape	–	All Simulations
	FF Stat.	shape	–	Nonprompts
	FF Norm.	norm.	30%	Nonprompts
Jet	Energy Scale	shape	–	All Simulations
Theory	PDF	shape.	–	Signals
	μ_R, μ_F	shape	–	Signals

Systematics

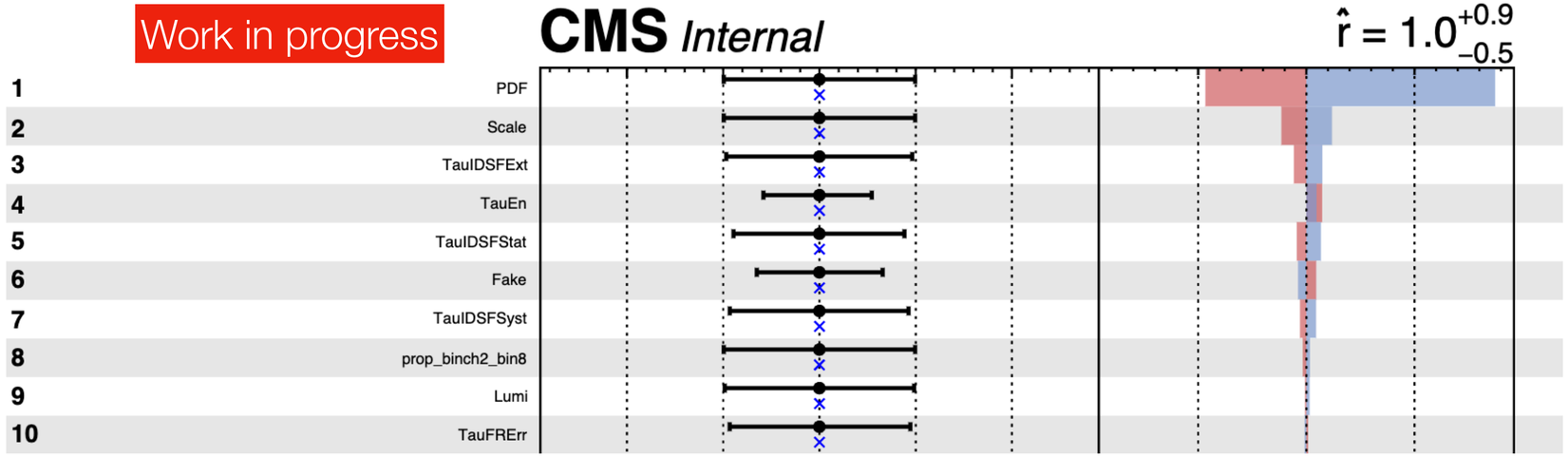
Impacts

Updated

Background only
Asimov



Signal injected (r=1)
Asimov

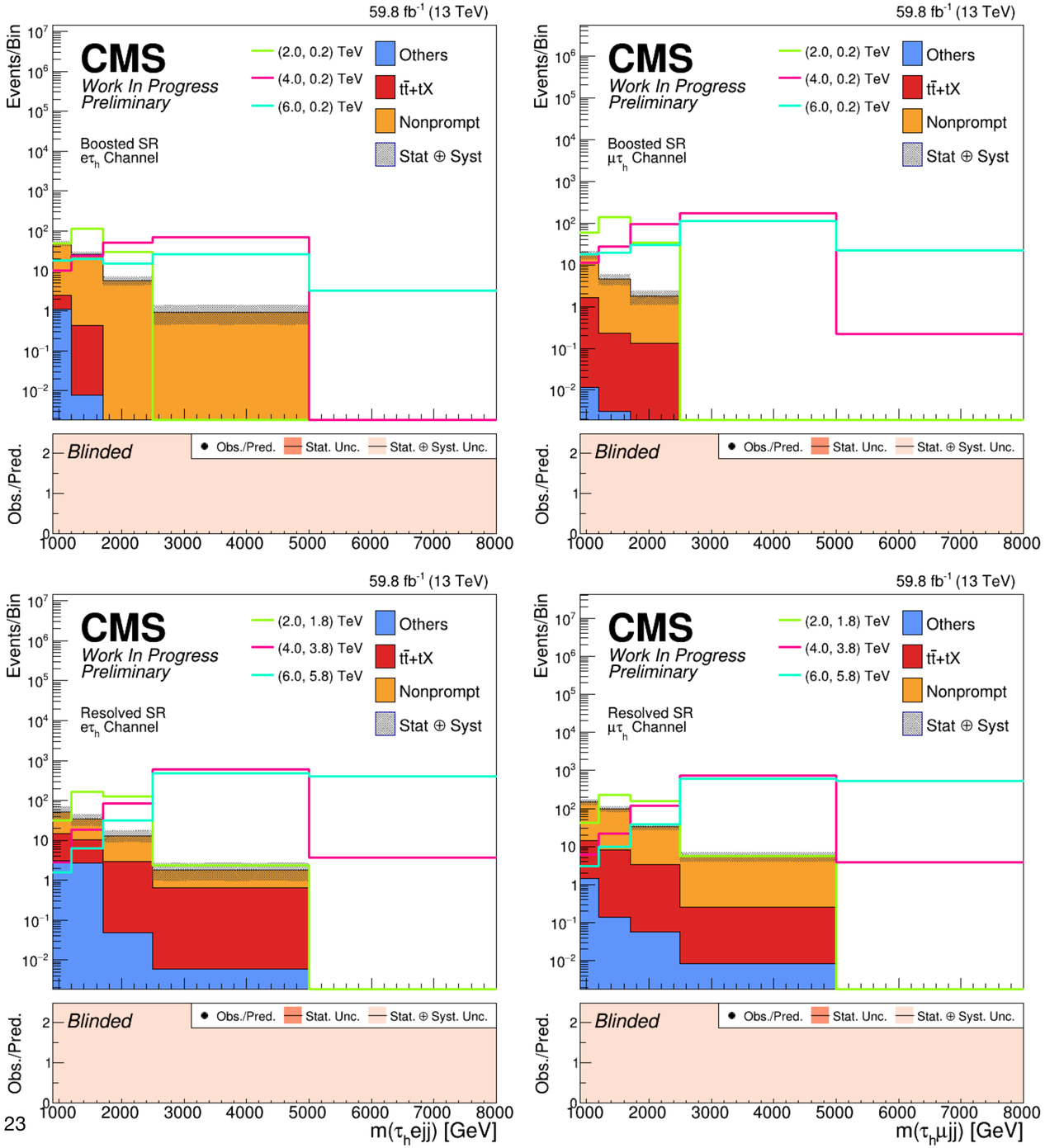


Results

Expected Limits

Updated

- Preliminary expected limits are extracted
  - 2018 only as samples from other eras are still being produced
  - Fitting based on reconstructed W_R mass shape : m(tau,lepton,jets)
  - Mentioned systematics are included
  - Binning optimization for stable fitting is being studied



Results

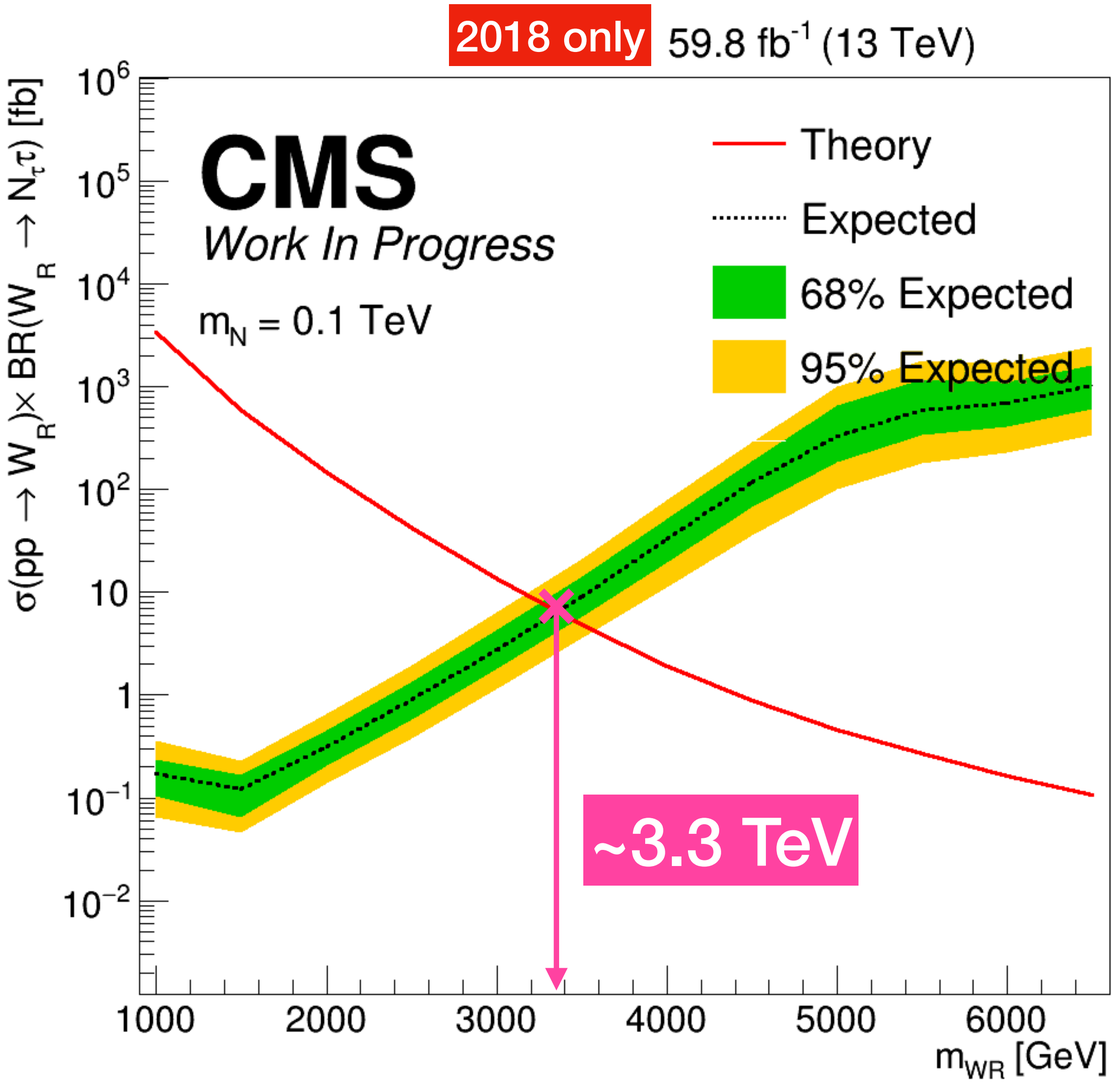
Expected Limits

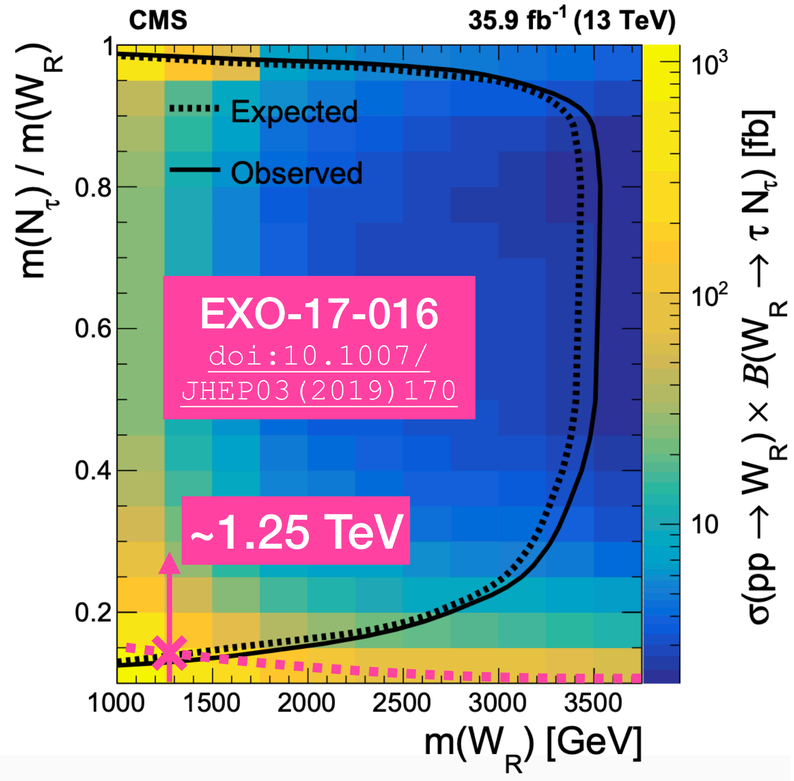
m_N = 0.1 TeV Scenario

Updated

Improved sensitivity compared to previous studies!

~1.25 TeV to ~3.3 TeV





Results

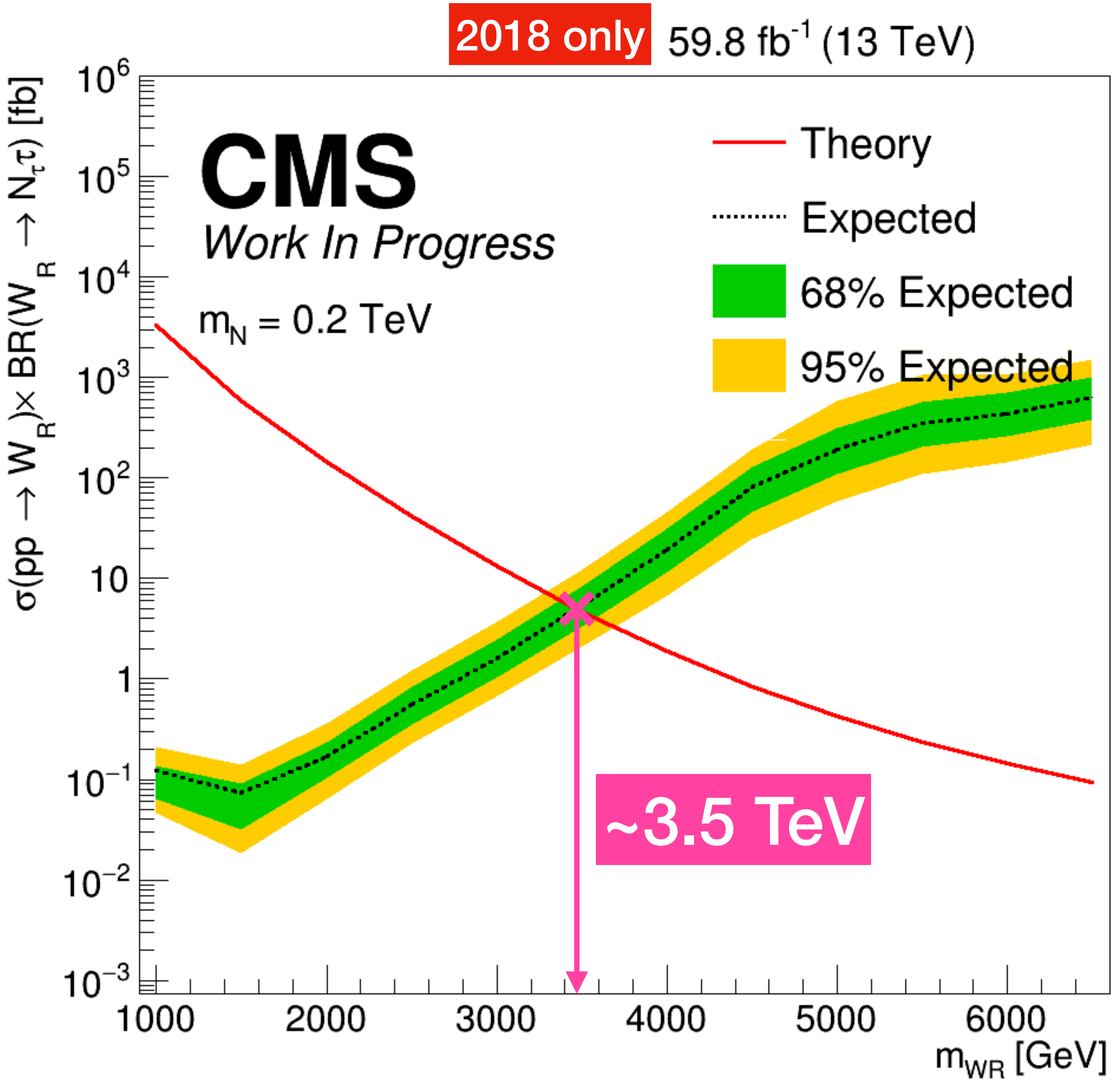
Expected Limits

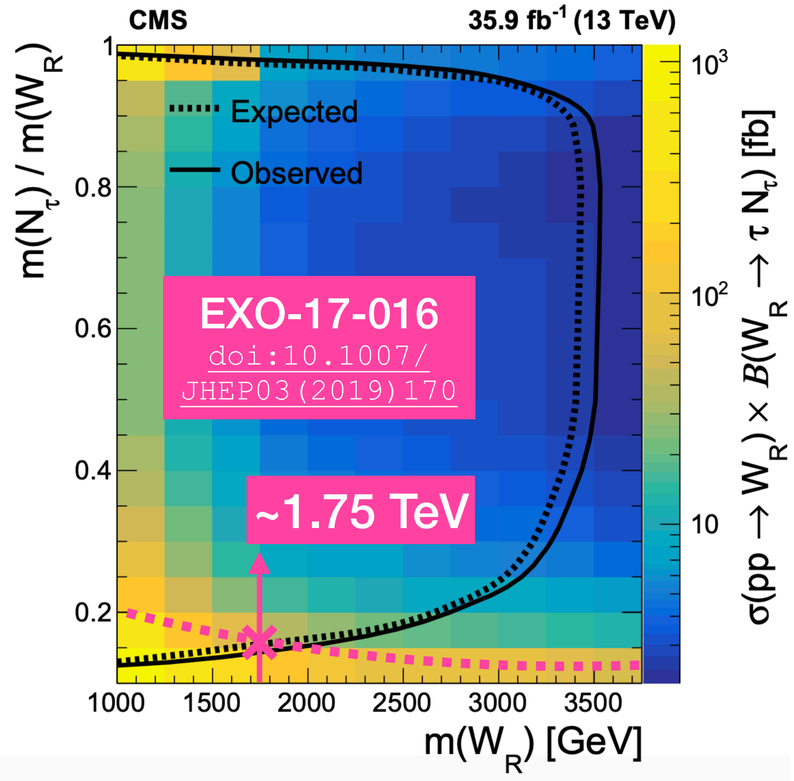
m_N = 0.2 TeV Scenario

Updated

Improved sensitivity compared to previous studies!

~1.75 TeV to ~3.5 TeV





Conclusion

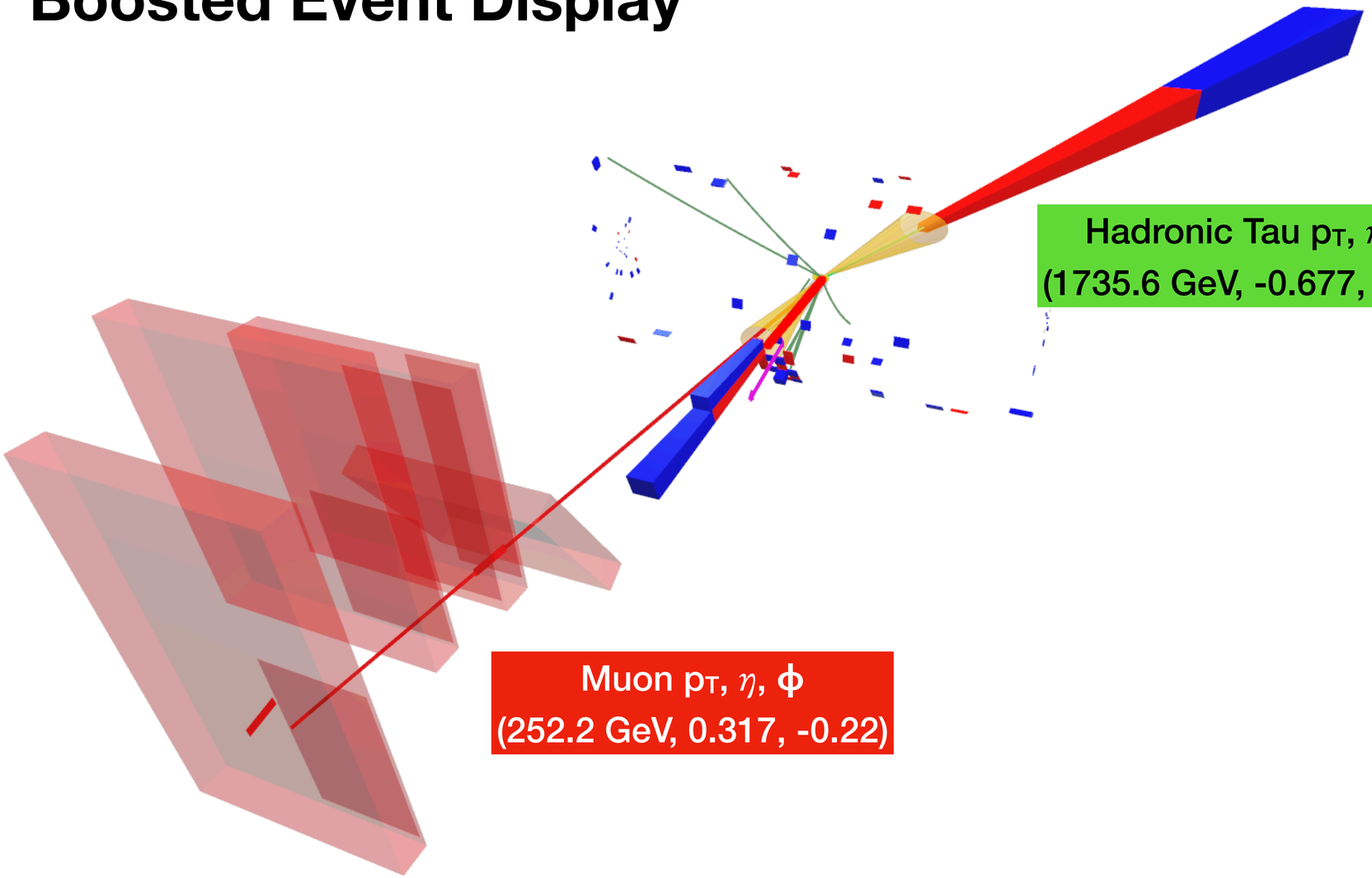
- Search for W_R and HNL in a $\tau_h\tau_\ell$ + jets final state is being actively updated
  - Updated background modeling of hadronic tau fakes show good agreement with data in CRs for all years
  - Included major systematics for today's result, but only for 2018
    - Would like to ask for PC lane priority production for the rest of the years 2016, 2017 signal samples
    - Will include all systematics for all era in the next iteration
  - Preliminary expected limits extracted using only 2018, improved compared to previous studies
    - mN = 0.1 TeV scenario : improved from ~ 1.25 TeV to ~ 3.3 TeV
    - mN = 0.2 TeV scenario : improved from ~ 1.75 TeV to ~ 3.5 TeV
  - First iteration of AN has been sent out to conveners
    - Expecting to do a full status report for Run 2 only before winter

Thank You!

Backups

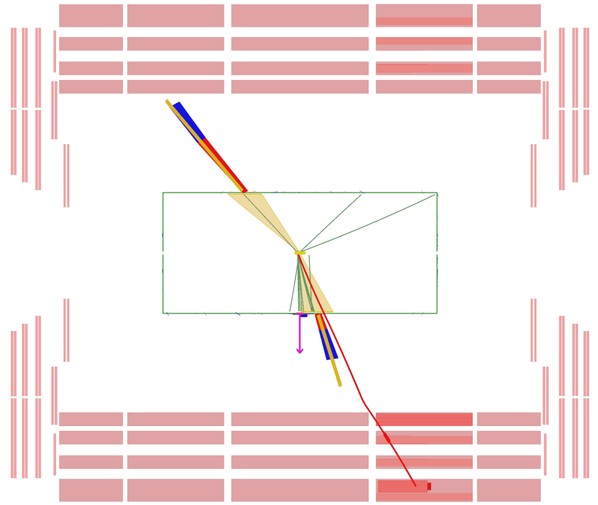
Signals

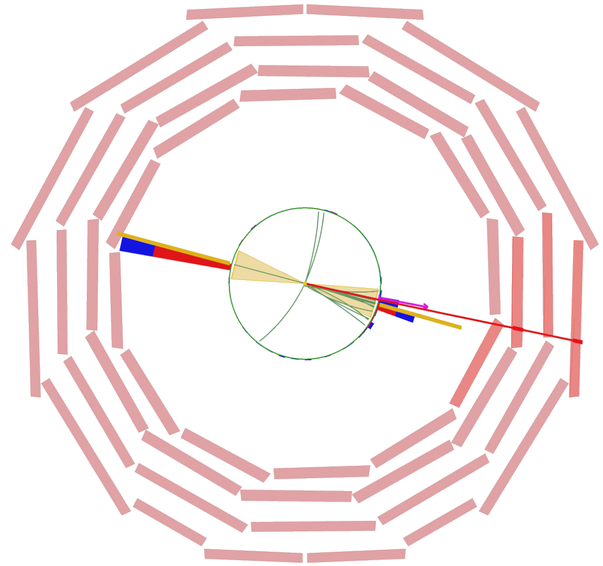
Boosted Event Display



Hadronic Tau p_T, η, ϕ
(1735.6 GeV, -0.677, 2.882)

Muon p_T, η, ϕ
(252.2 GeV, 0.317, -0.22)



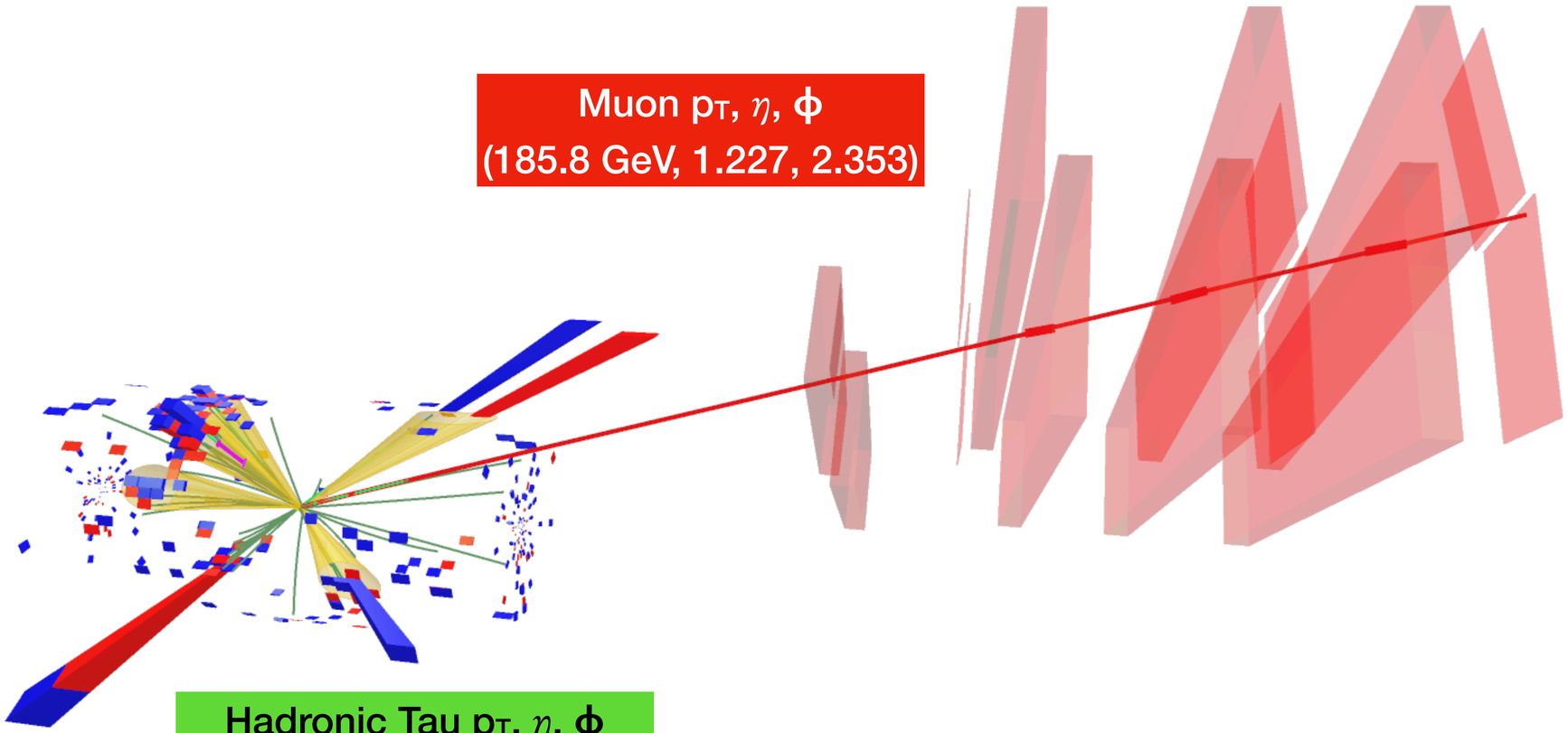


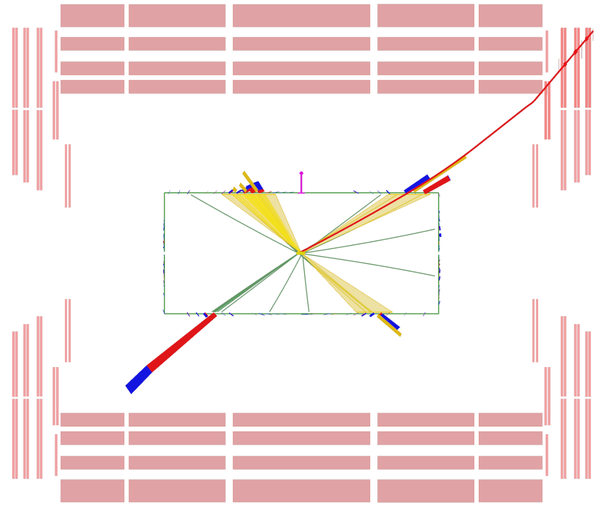
(run:lumi:event) = (1:54:81888) of (mWR,mN) = (4.8 TeV, 200GeV)

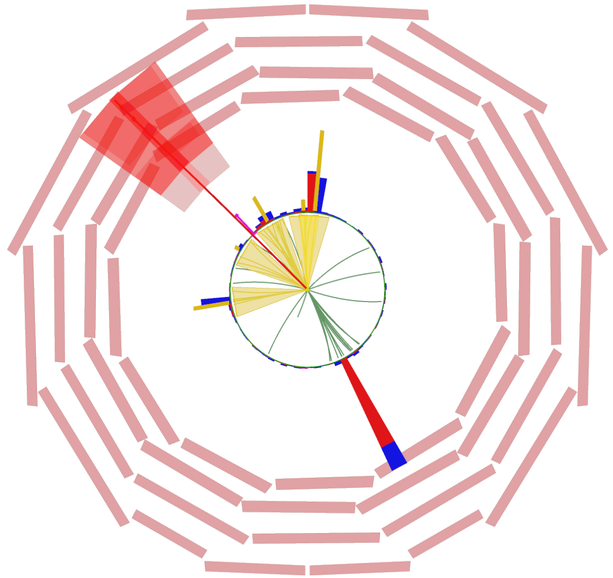
/WRtoTauNtoTauTauJets_WR4800_N200_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16MiniAODAPVv2-106X_mcRun2_asymptotic_preVFP_v11-v2/MINIAODSIM

Signals

Resolved Event Display





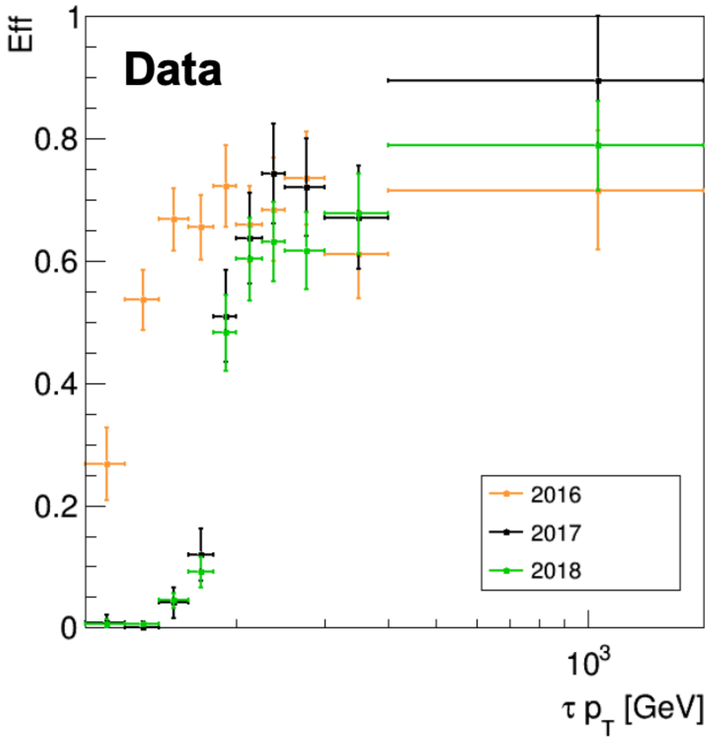


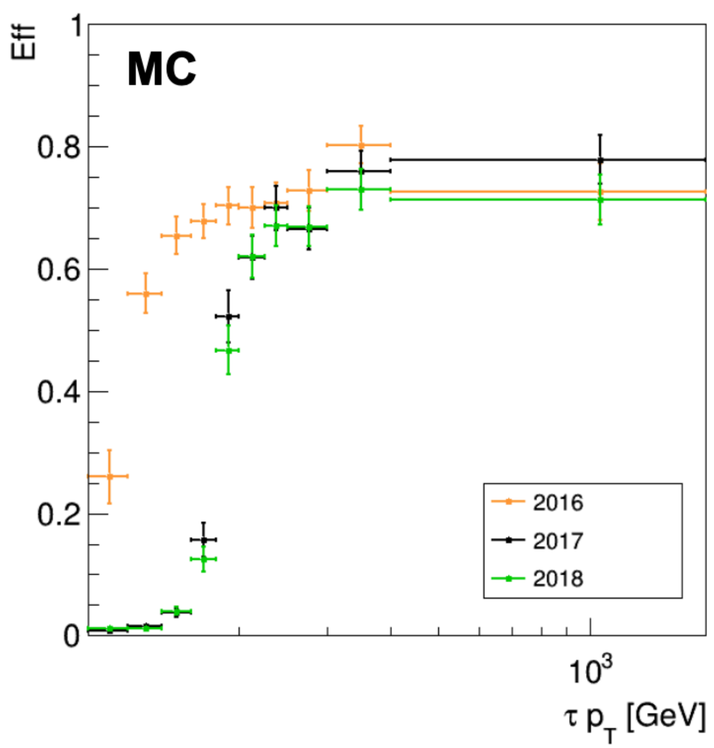
(run:lumi:event) = (1:24:37770) of (mWR,mN) = (4.8 TeV, 4.7 TeV)

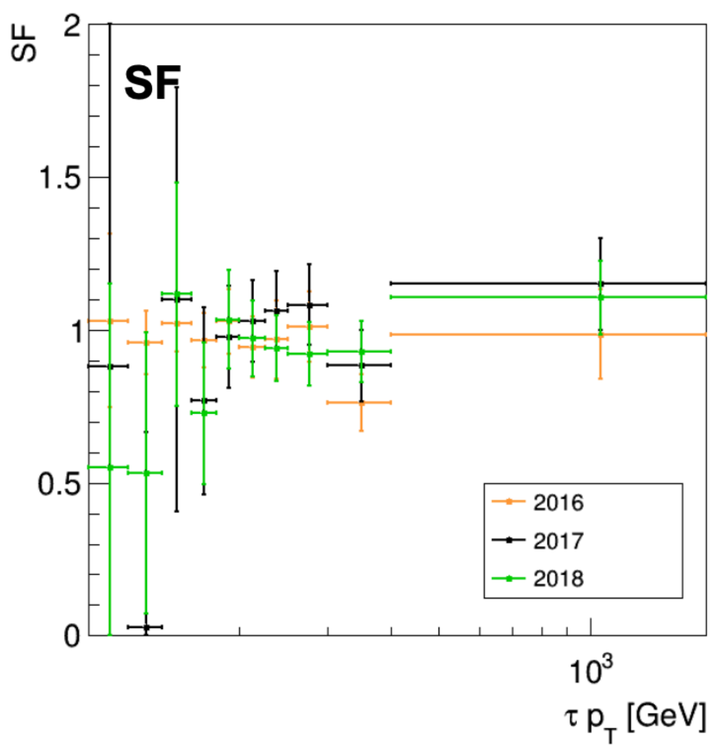
/WRtoTauNtoTauTauJets_WR4800_N4700_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16MiniAODAPVv2-106X_mcRun2_asymptotic_preVFP_v11-v2/MINIAODSIM

Trigger Efficiency

Single Tau HLT







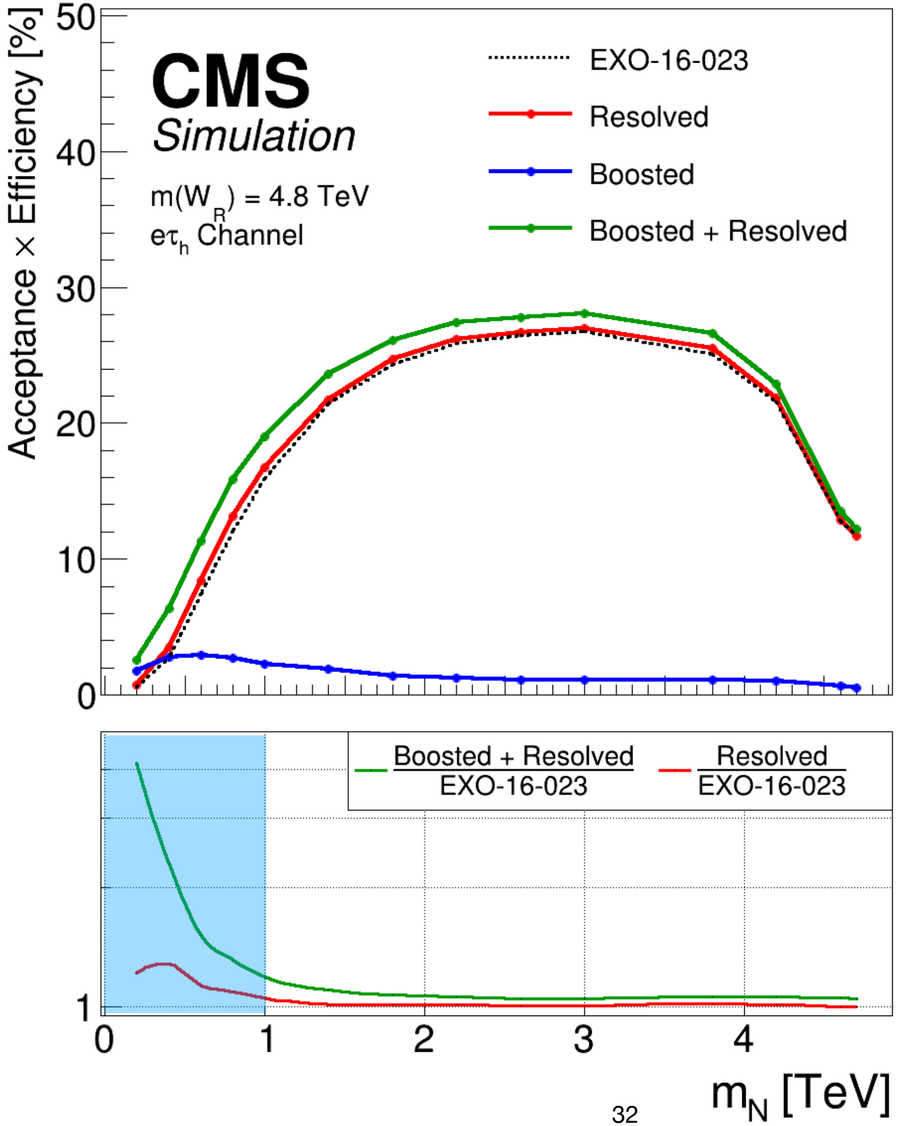
Tau ID Meeting
(14th Dec. 2020)

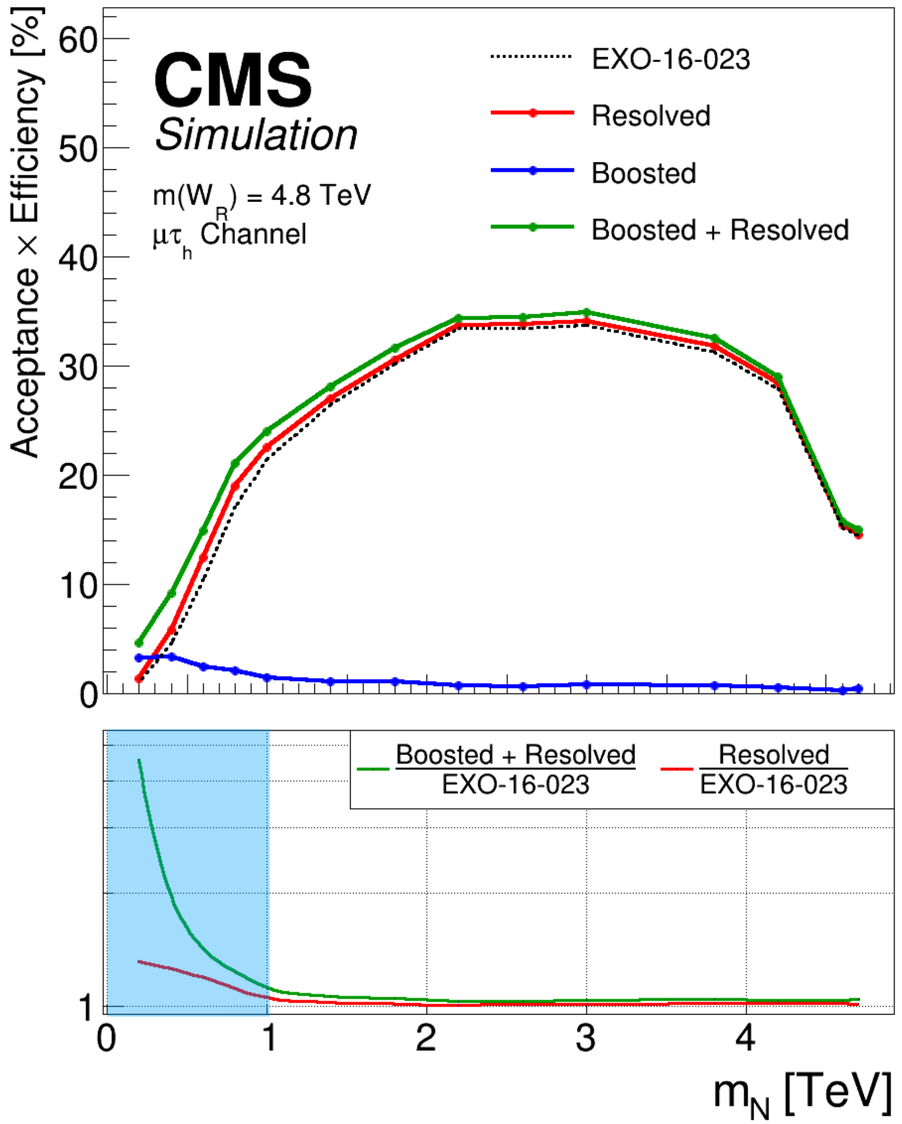
Selection Efficiency

Signals

Efficiency calculated from corresponding Gen-matched channels

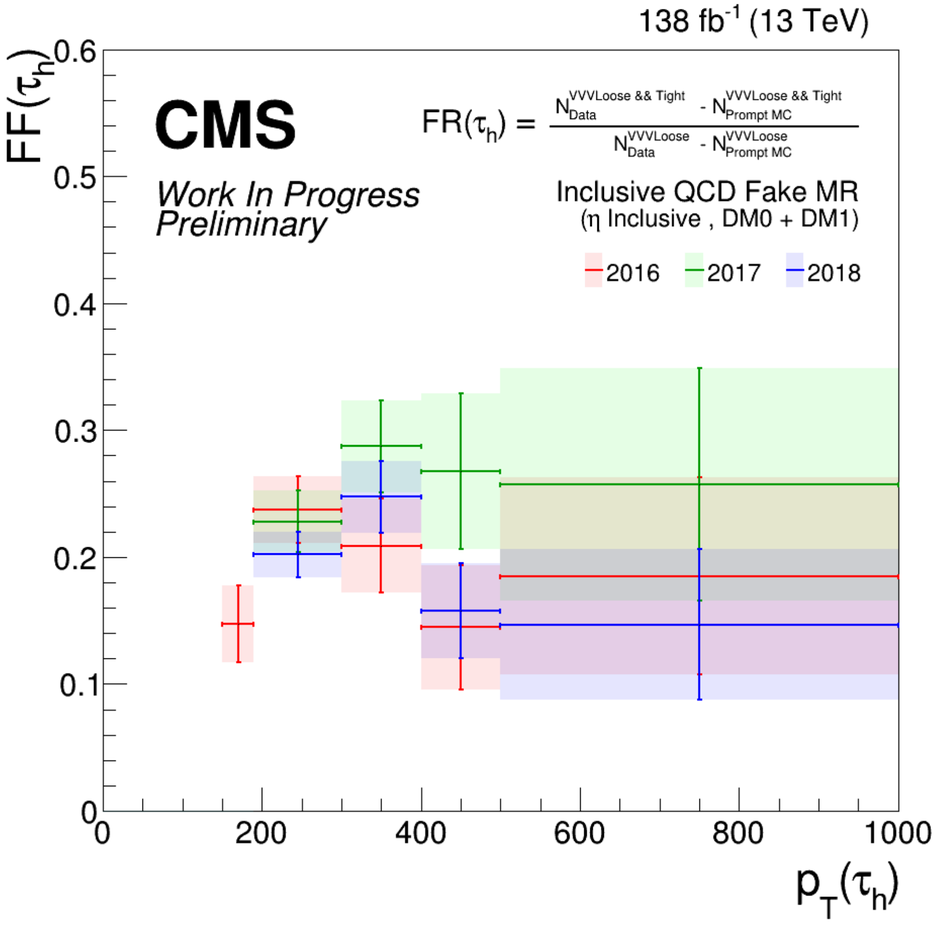
EXO-16-023 here is not exactly identical with the original selection

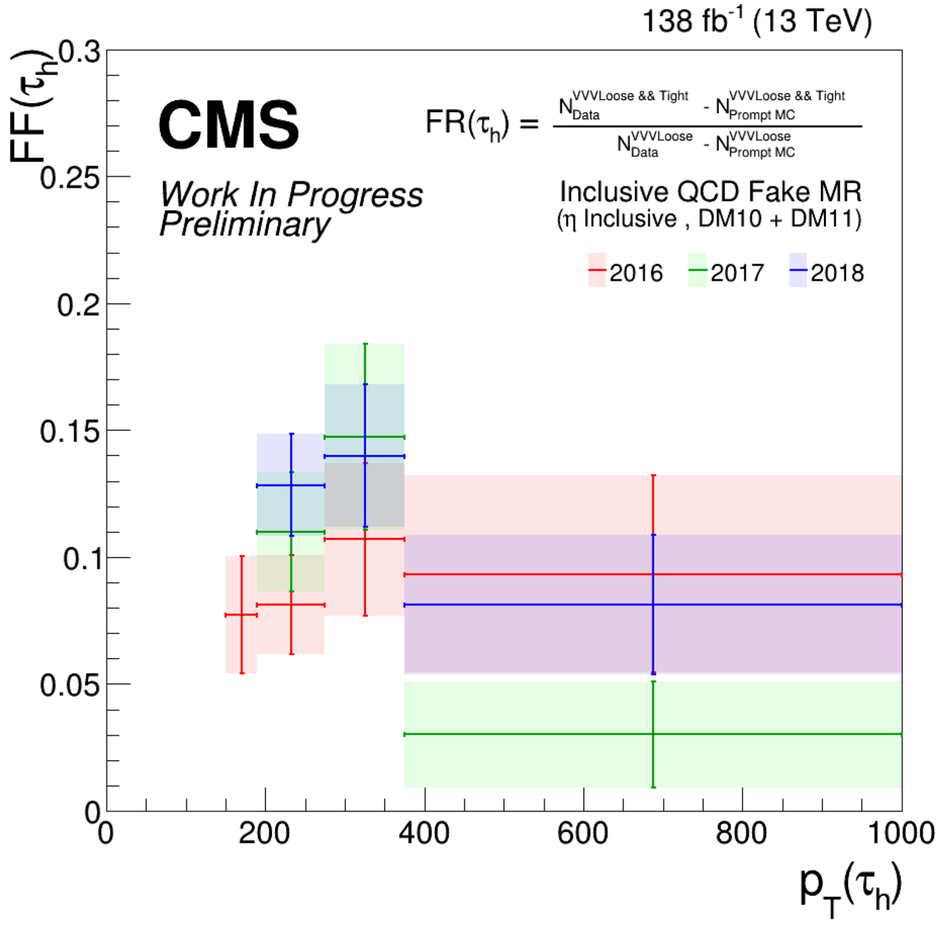




Background Estimation

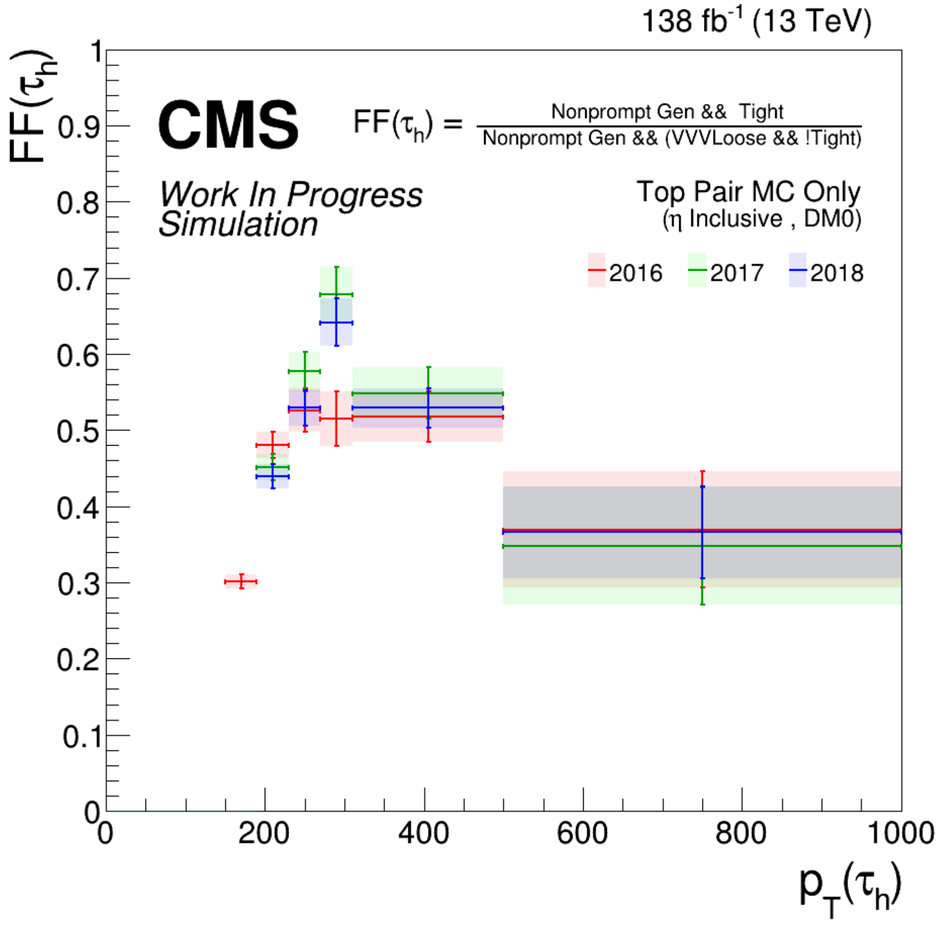
QCD FF

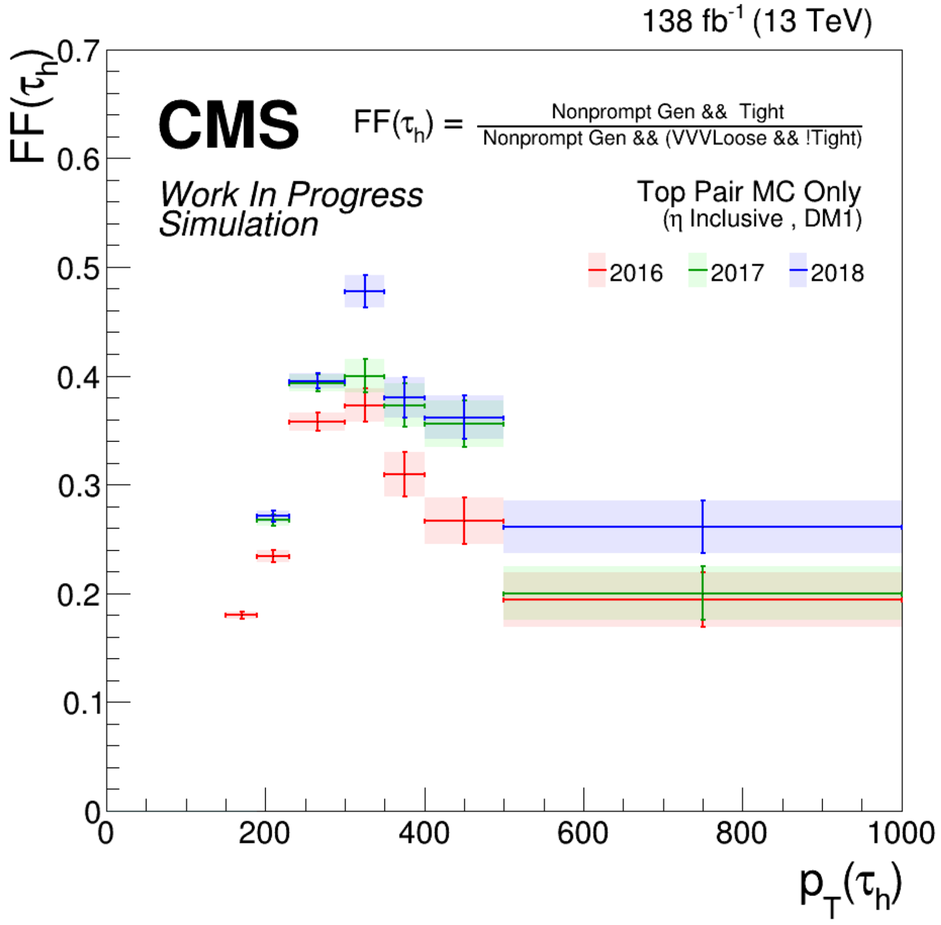




Background Estimation

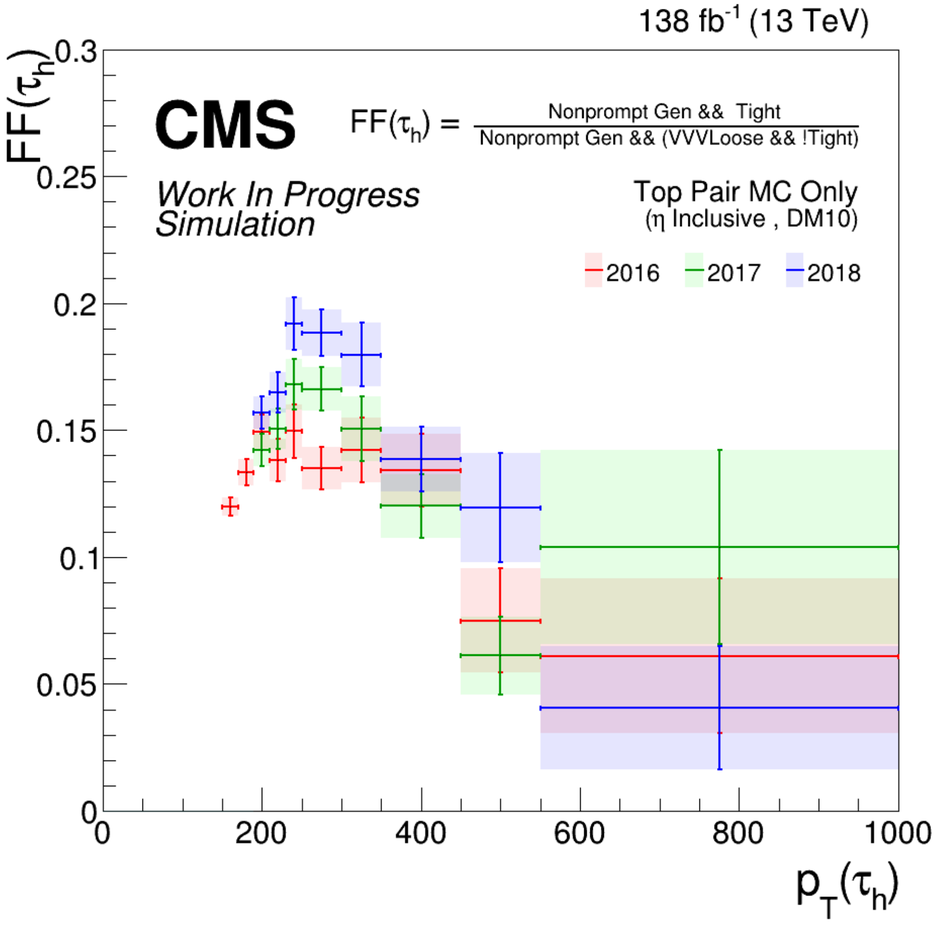
Top FF

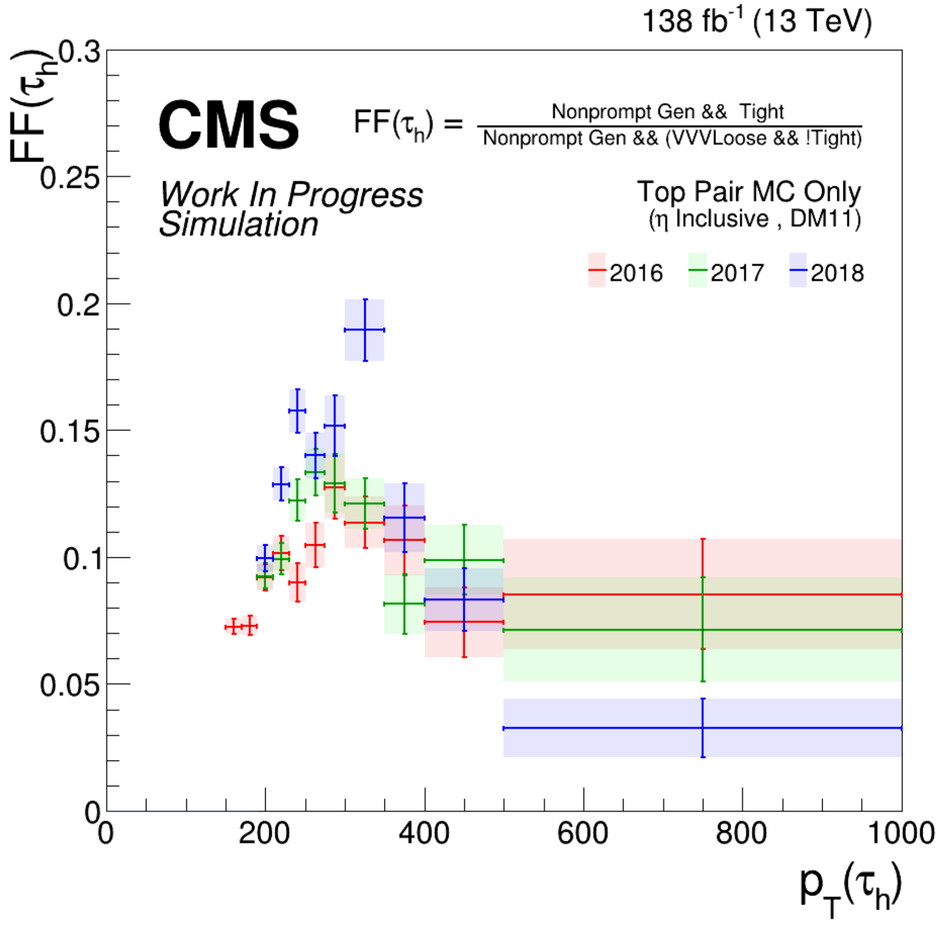




Background Estimation

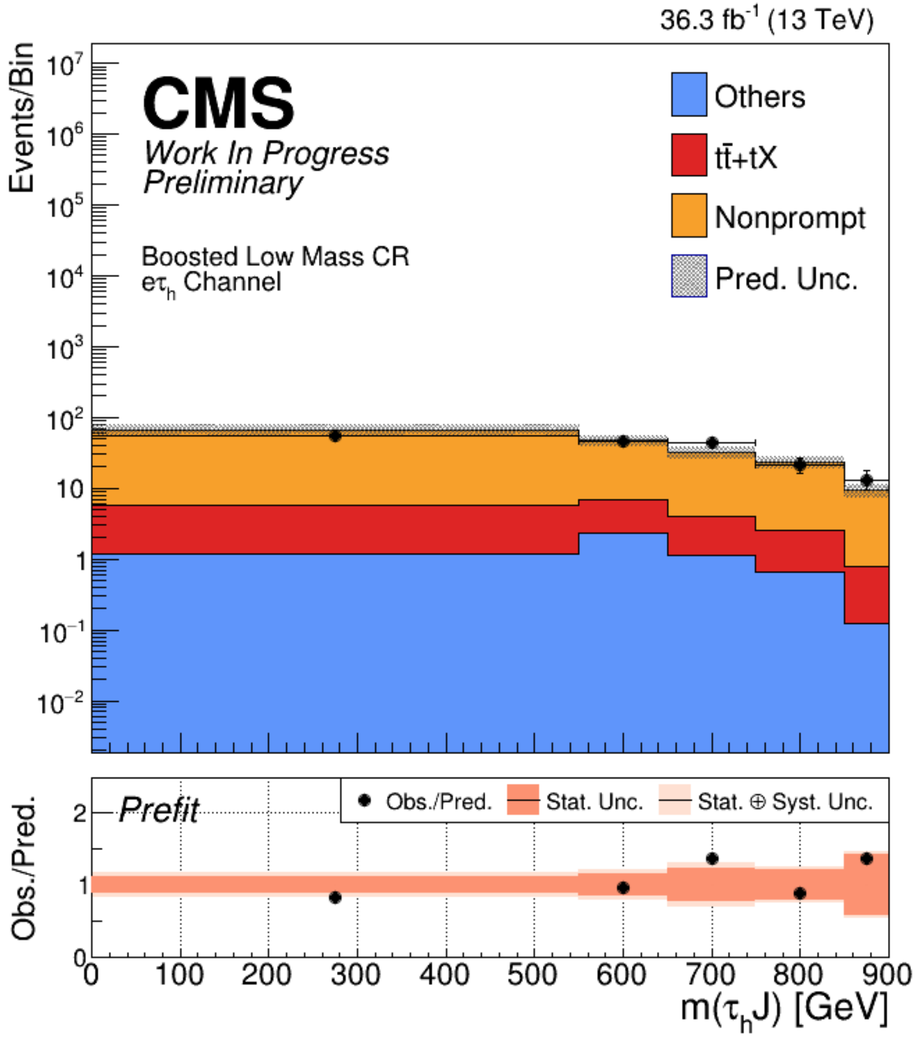
Top FF

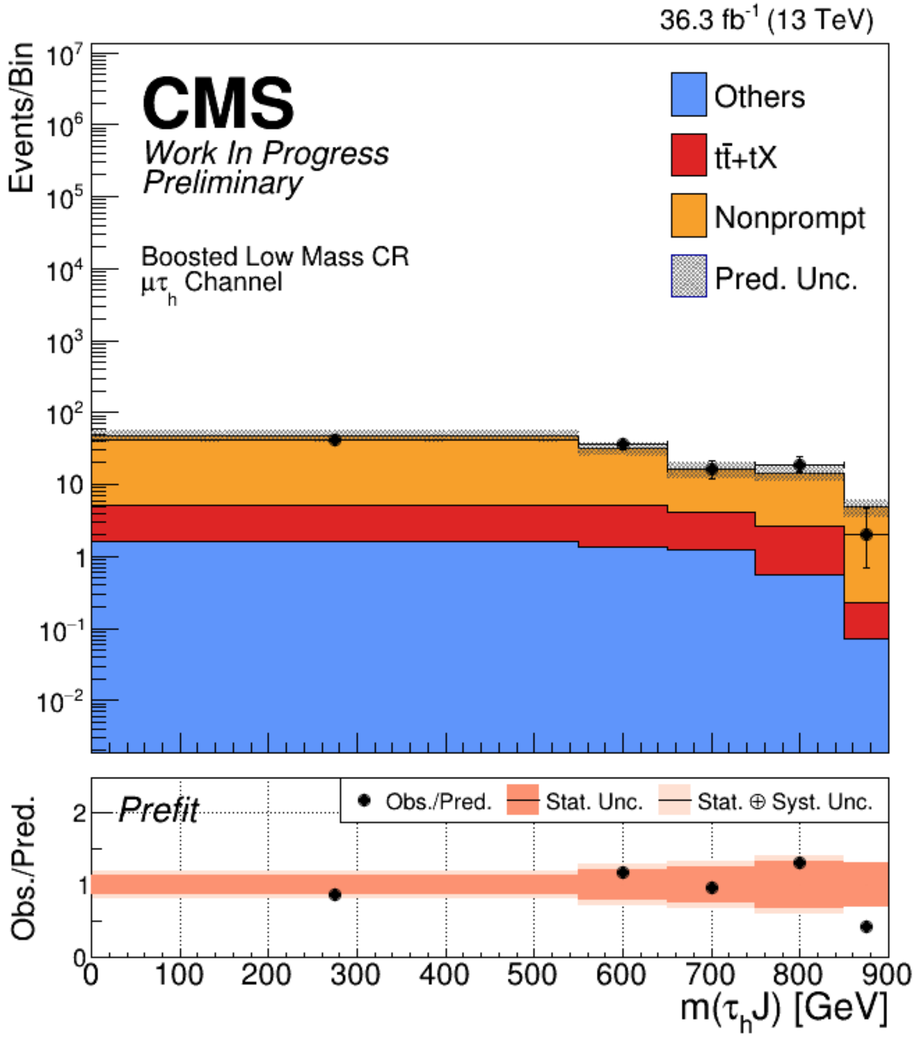




Control Region

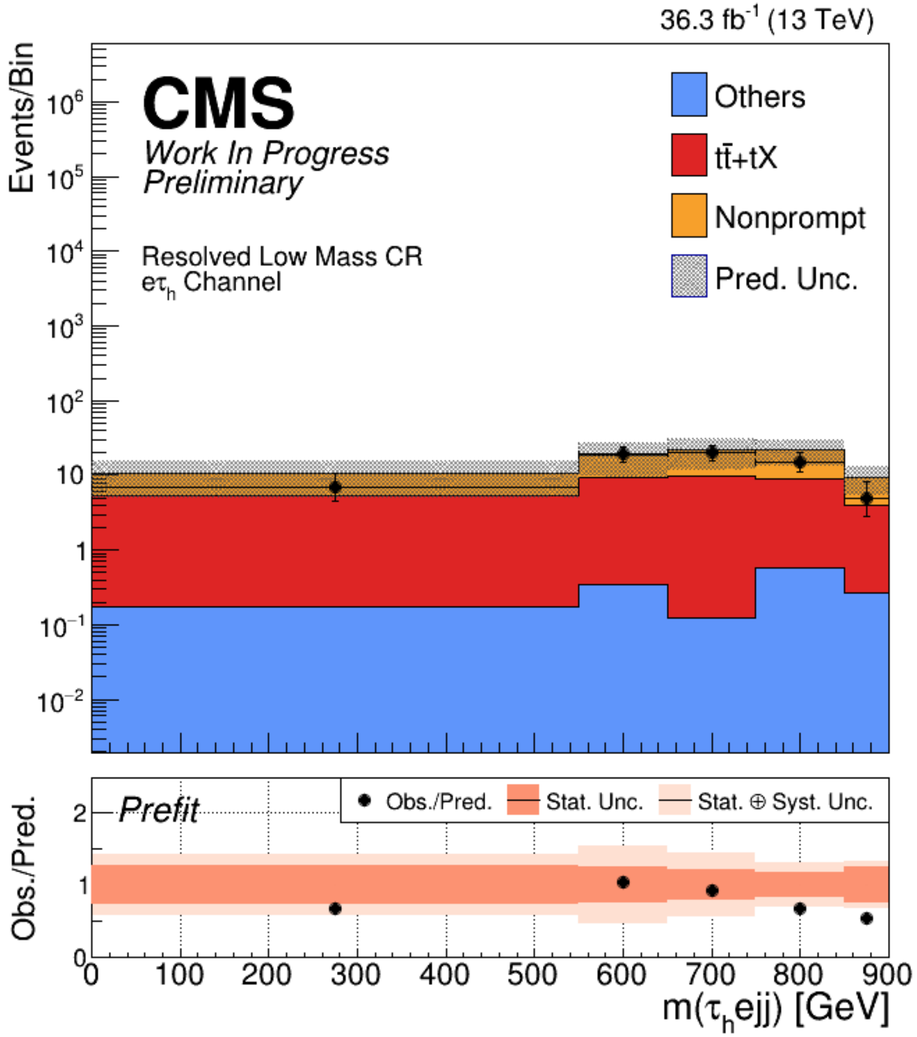
2016 Plots

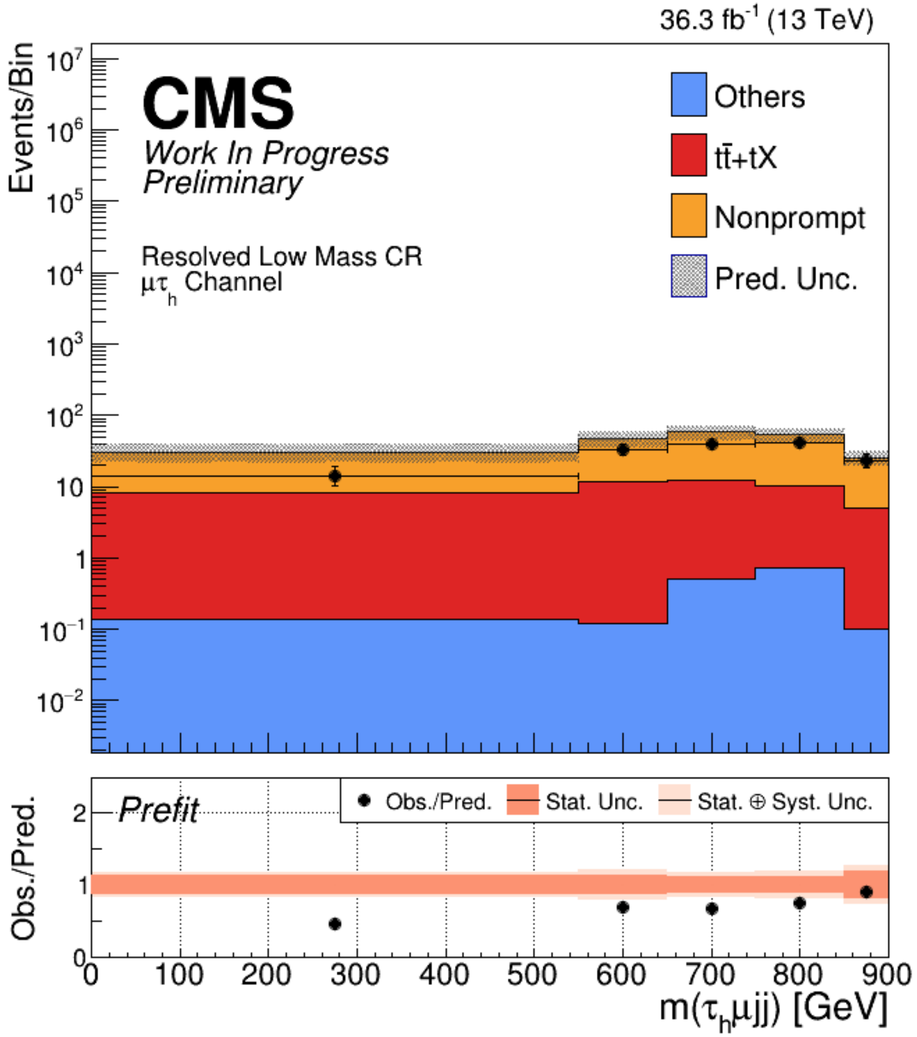




Control Region

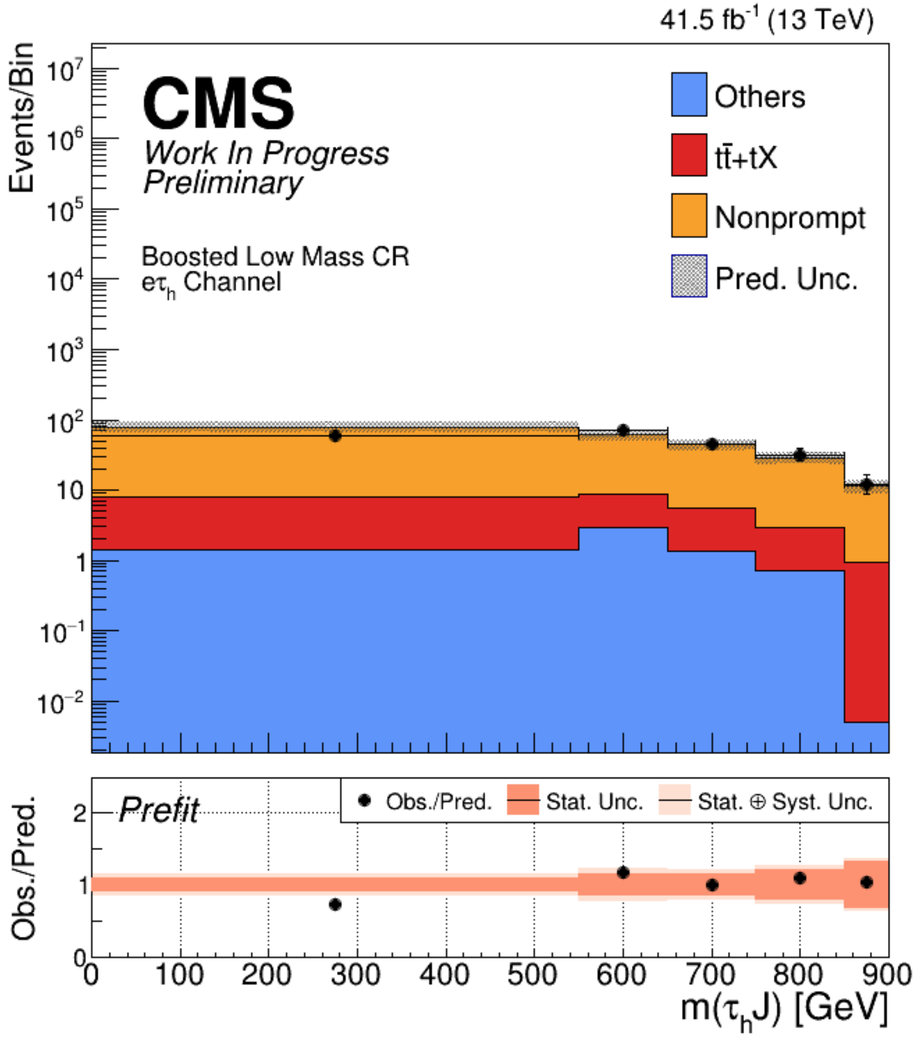
2016 Plots

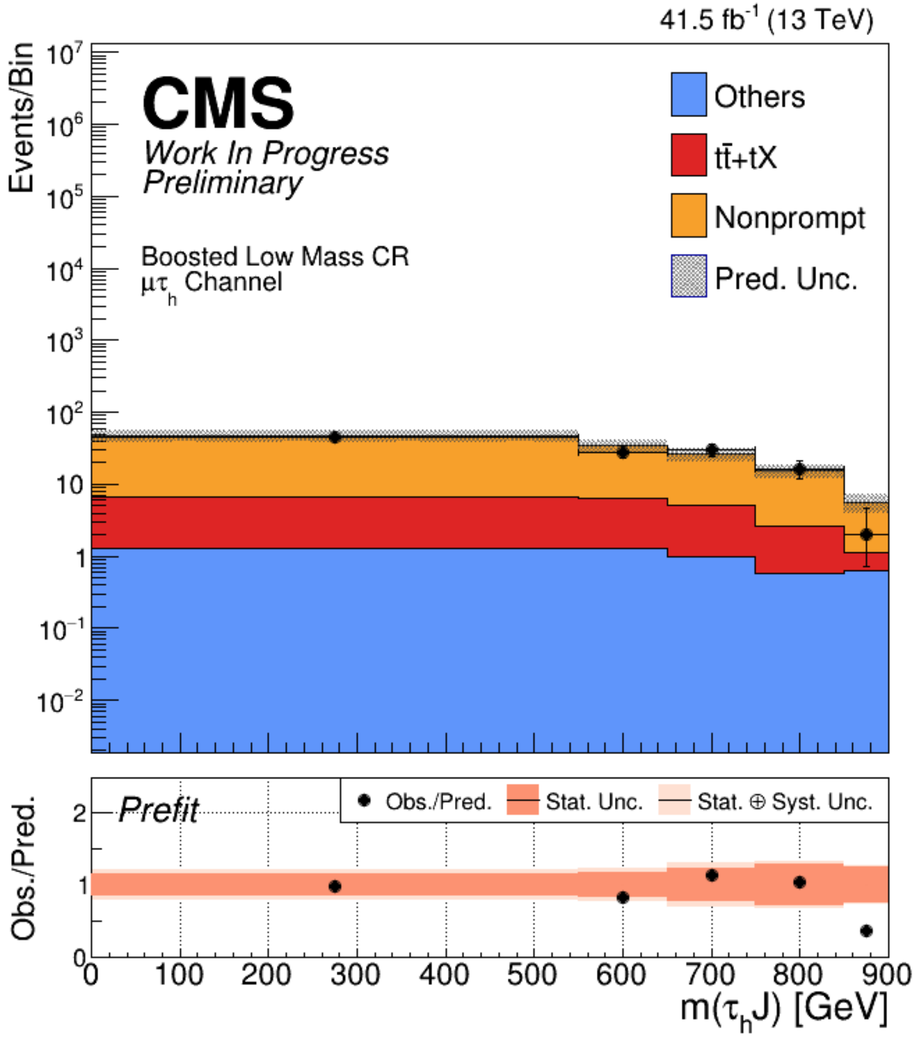




Control Region

2017 Plots





Control Region

2017 Plots