Search for W_R and HNL in a $\tau_h\tau_\ell$ + jets Final State

KCMS-Theory Joint Annual Workshop

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Introduction

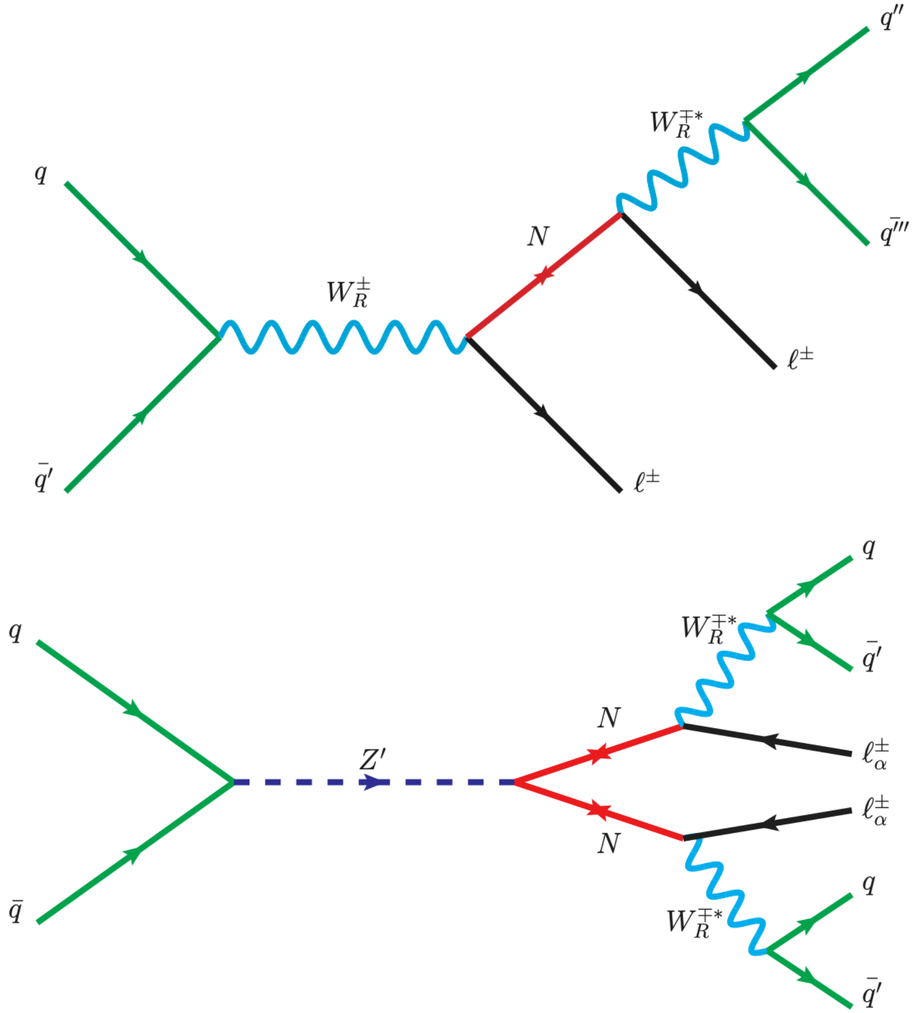
Motivation

- Unsolved mysteries with neutrinos

  - Neutrino oscillation, mass problem…
  - Unexplainable in 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.



Analysis Motivation

Search Strategy

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

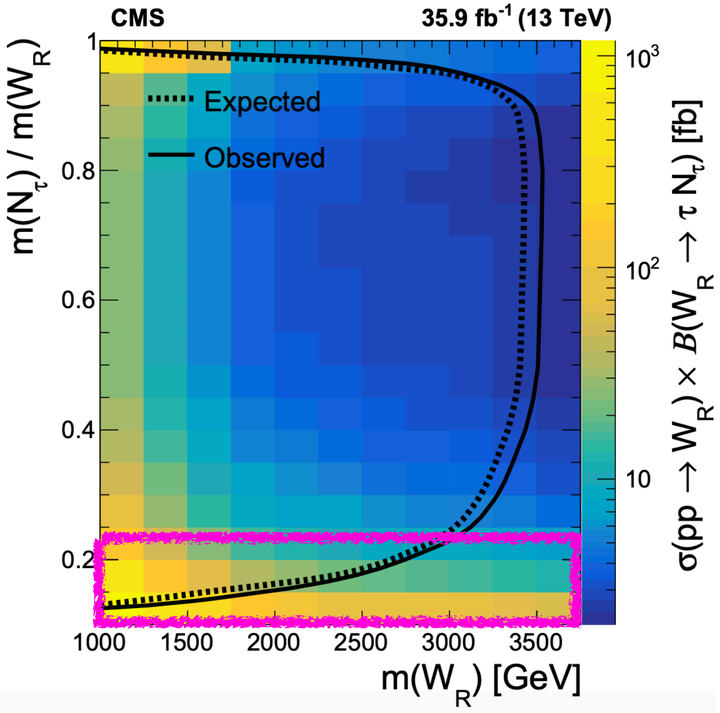
  - **Trying to add sensitivity to boosted region with $m_{WR} >> m_N$ also for the tau channels.**

  - EXO-20-002 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 in ee/μμ channel

  - 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** for the tau channel

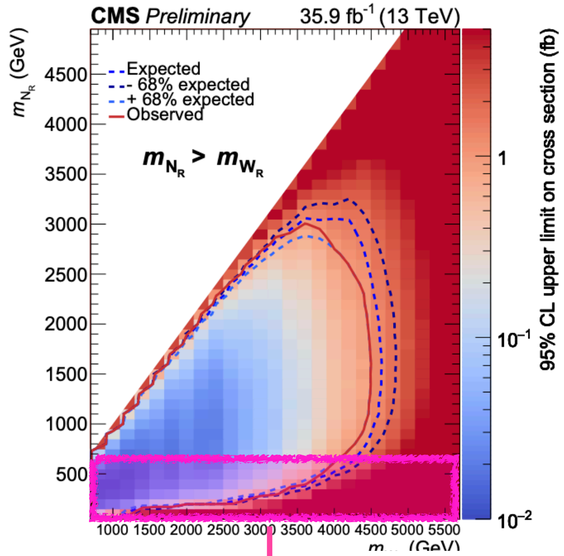
  - **Aiming to set 2D limits on cross sections on the m_{WR}, m_N mass plane.**

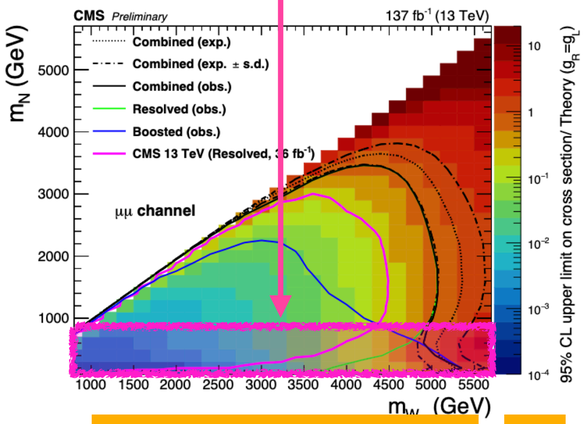
EXO-17-016 (35.9/fb)



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

EXO-17-011 (35.9/fb) μμ





EXO-20-002 (137/fb) μμ

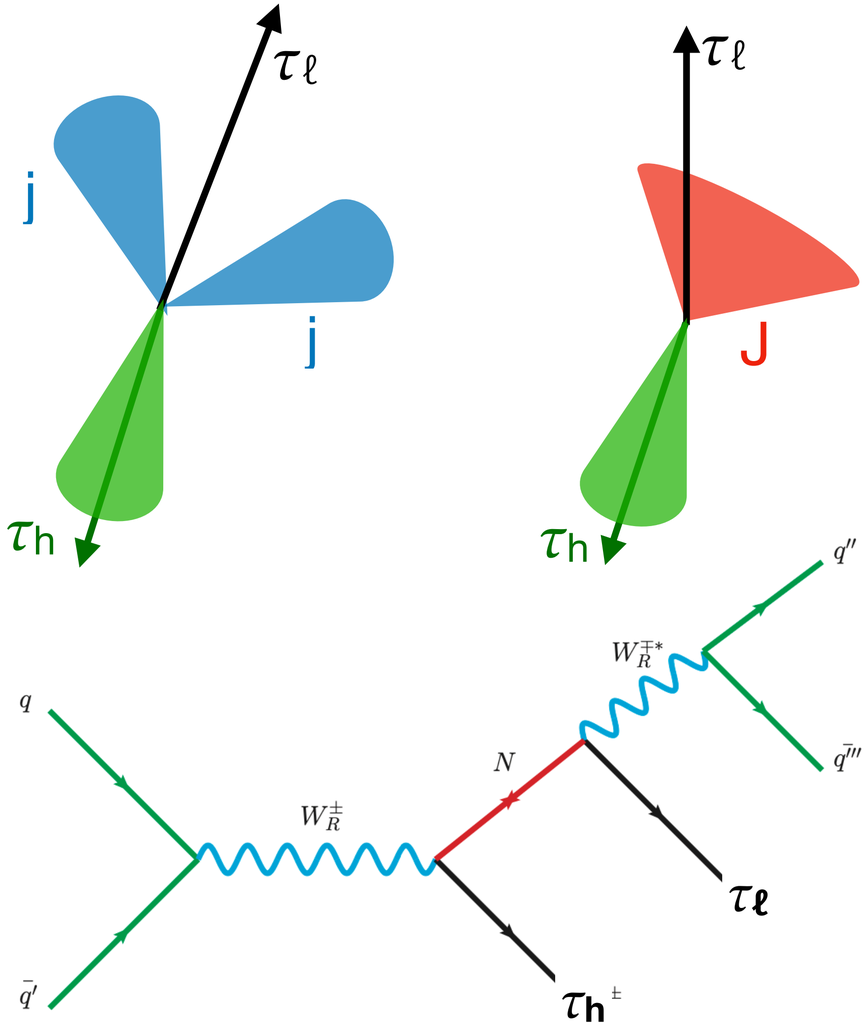
Signals
Final Objects

- 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)

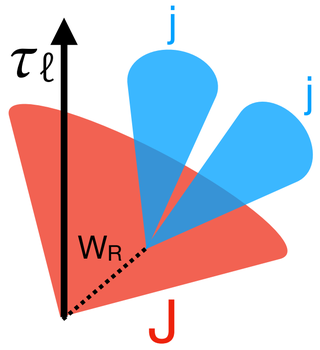
- Final state objects

  - 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

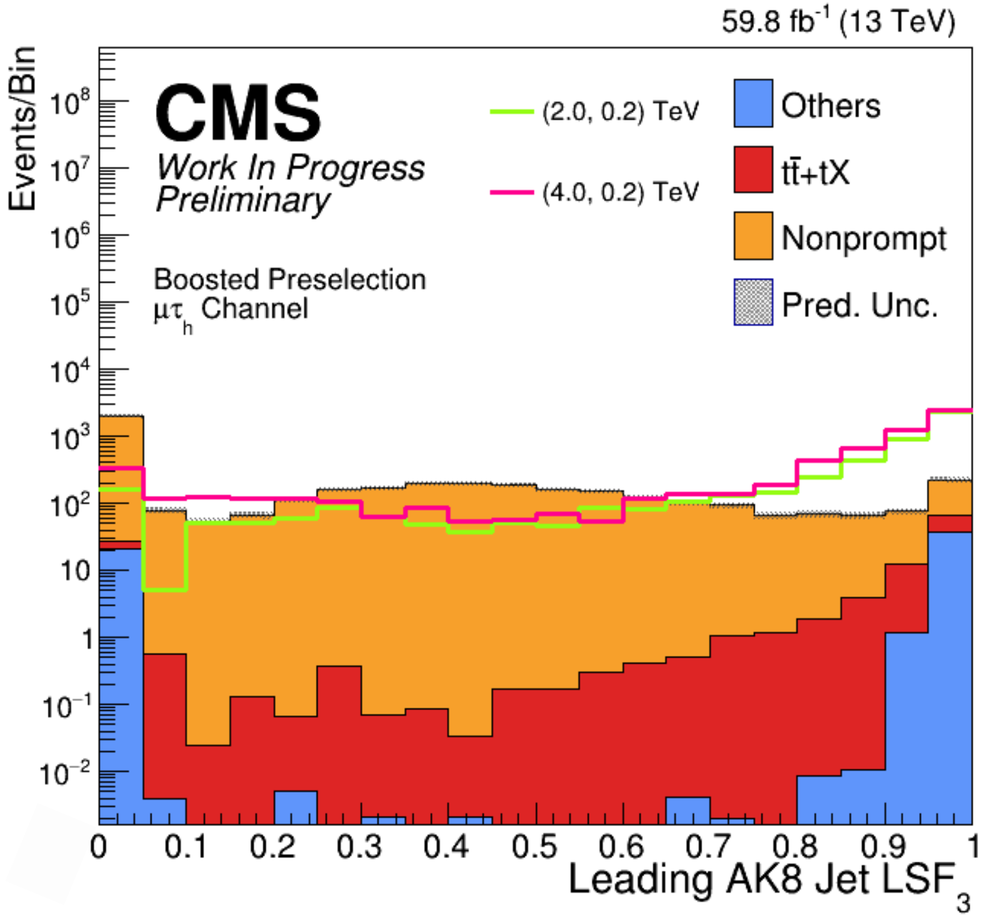
Lepton Subjet Fraction



- 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



Objects

Definitions & Corrections

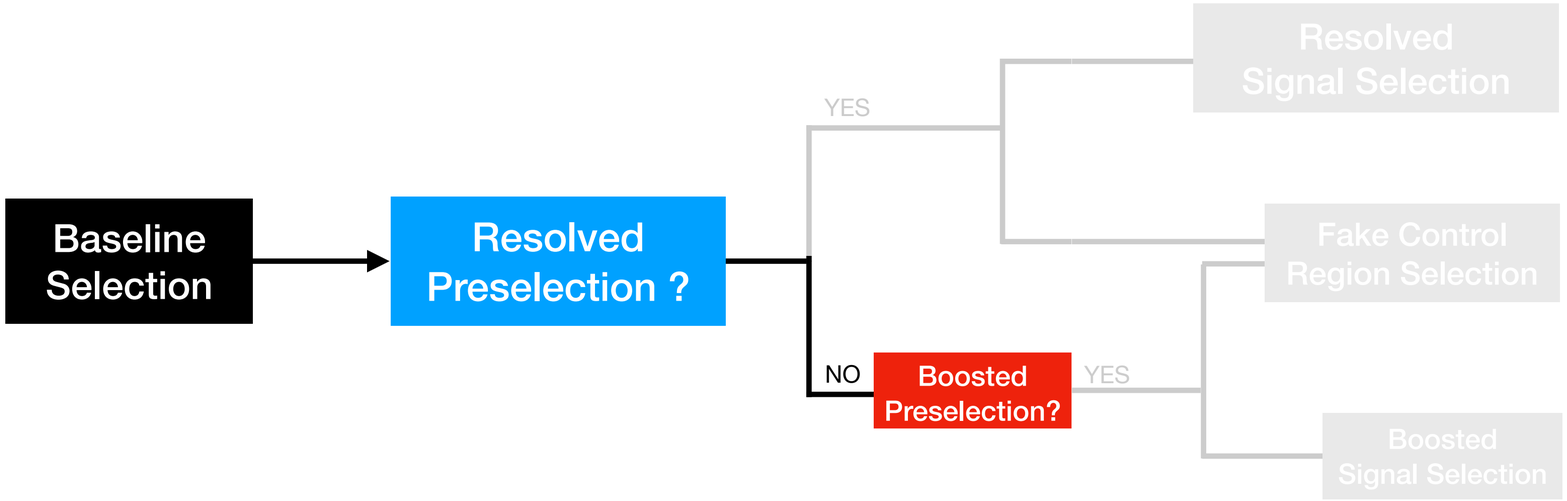
- Muon
  - p_T > 50 GeV , |η| < 2.4
  - Tight ID : POG High pT & Tracker isolation < 0.1
  - Loose ID : POG High pT
- Electron
  - p_T > 50 GeV , |η| < 2.5
  - Tight ID : POG cut based loose w/o relIsoWithEA
  - Loose ID : POG HEEP ID
- Tau
  - p_T > Trigger safe cut , |η| < 2.4
  - DecayModeNewDM & |dZ| < 0.2
  - DeepTau v2.1 (vJet,vEl,vMu) = (Tight,Tight,Tight)

✦ Corrections

- Event
  - Pileup weight, Trigger SF, L1 Prefire weight
- Muon, Electron
  - Isolation SF , ID SF
  - High-pt muon resolution
- Tau
  - DeepTau ID SF
  - Energy scale
- Jet
  - Jet energy correction
  - Fatjet LSF SF

Region Selection

Definition



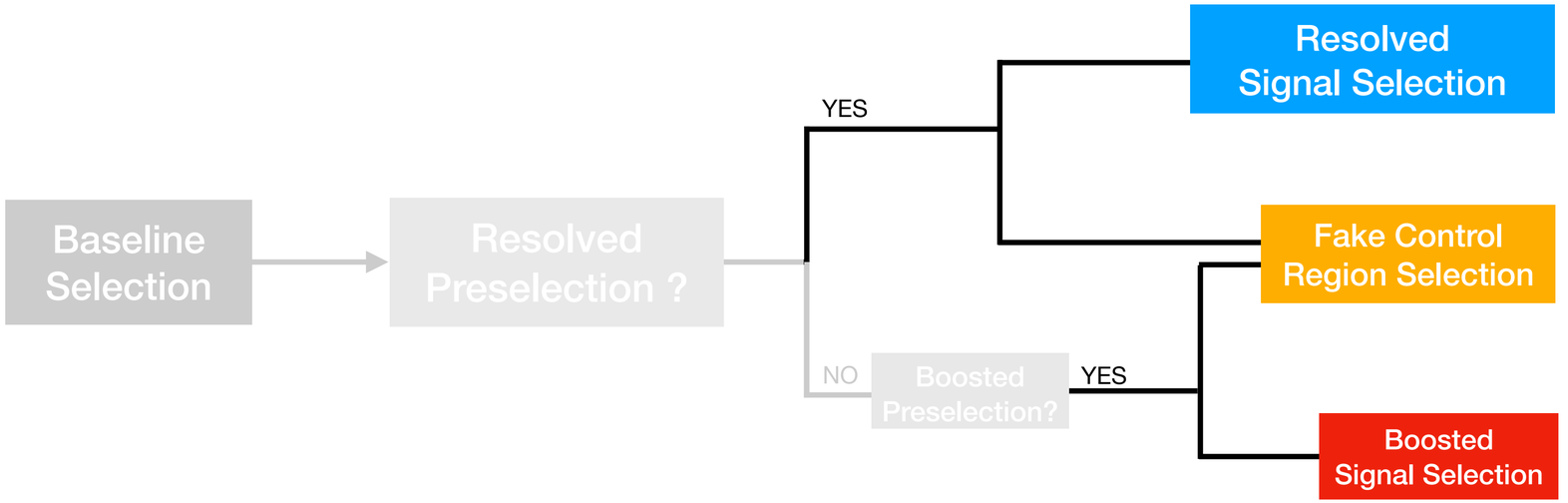
Baseline Selection
- Pass single hadronic tau trigger
- Require at least 1 hadronic tau
- Require exactly 1 loose light lepton

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
- MET > 100 GeV & m(tau, lepton, jets) > 900 GeV

Fake Control Region Selection
- Passing preselection
- MET < 100 GeV & m(tau, lepton, jets) or m(tau,fatjet) < 500 GeV

Boosted Signal Selection
- Passing boosted preselection
- ΔR(tau, J) > 2.0 with LSF(J) > 0.6
- ΔR(lepton, J) < 0.8
- MET > 100 GeV & m(tau,fatjet) > 900 GeV

Background Estimation

Contributions

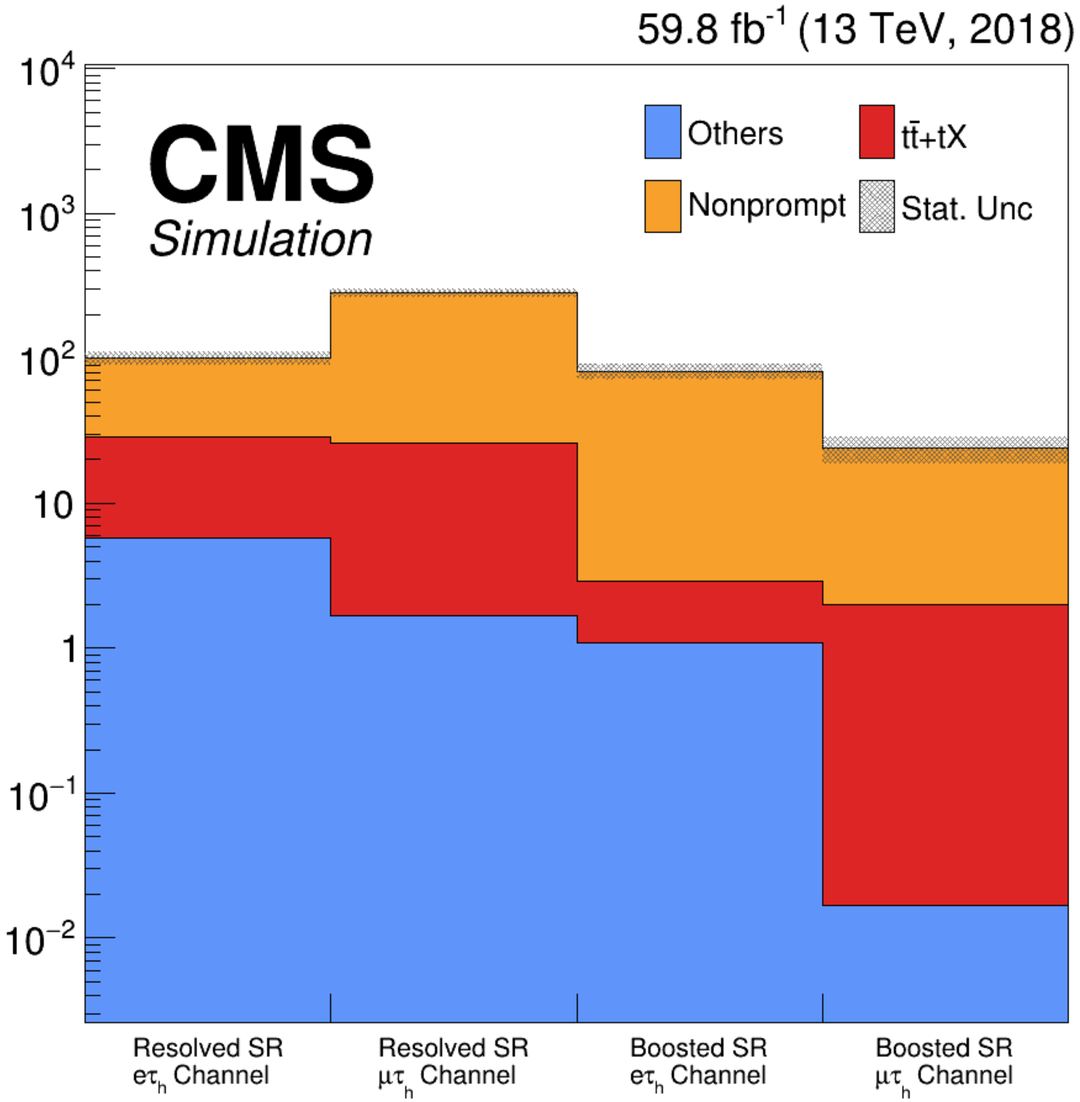
- Prompt contributions

  - Top pair, single top processes (tt+tX)
  - V+jets, 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

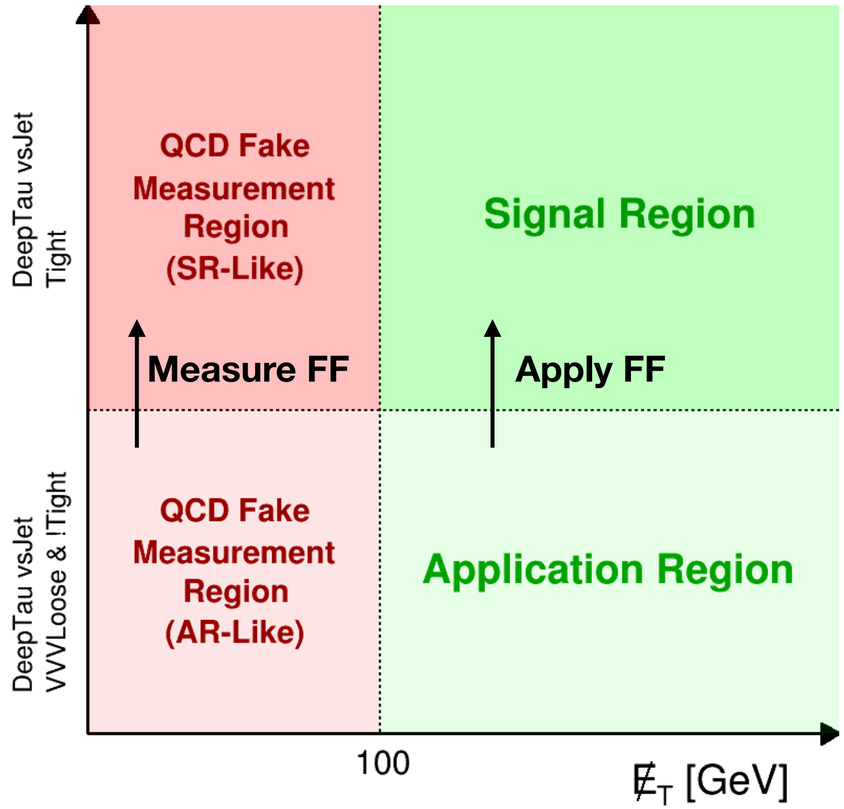
- Jets -> taus misid. has the biggest background contribution
  - Inaccurate to estimate from MC simulations : **data-driven estimation** is used
    - Fake factor (FF) is measured as a function of tau DM and pT or m_eff

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

    - 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)

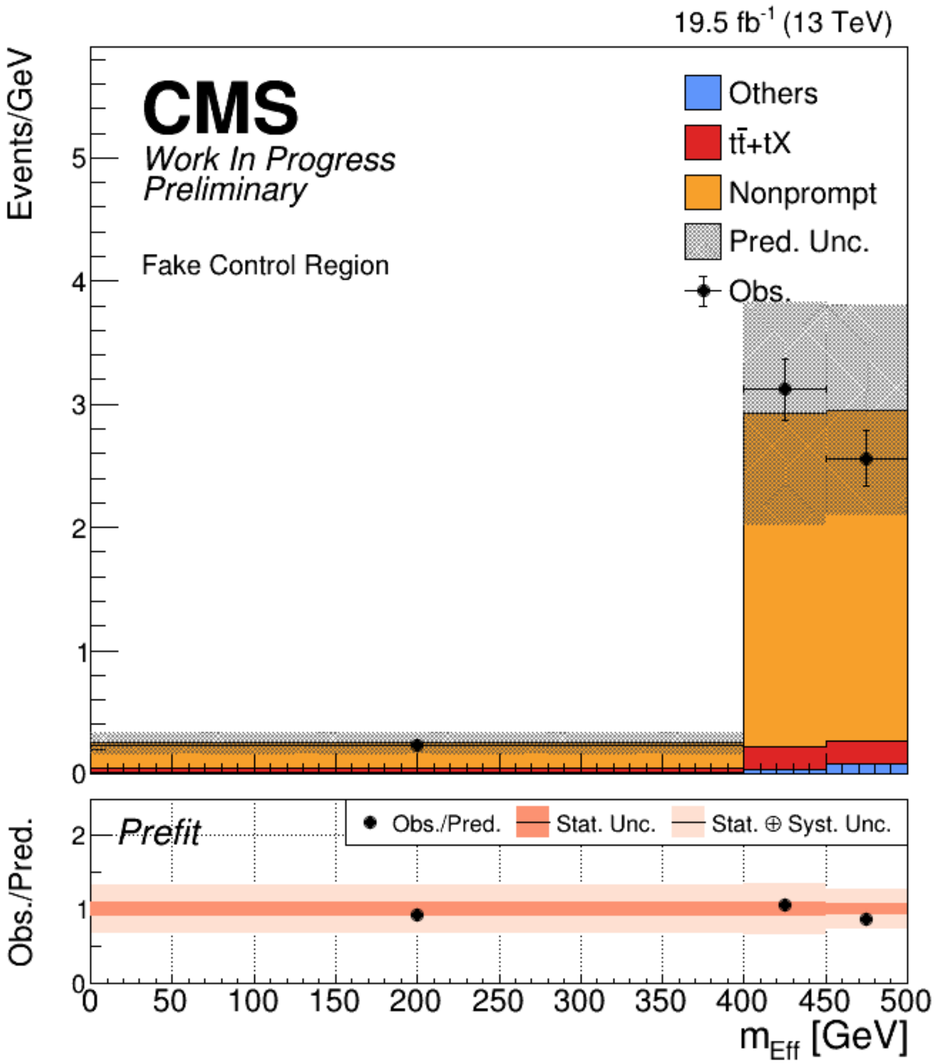
Methodology borrowed from EXO-19-016

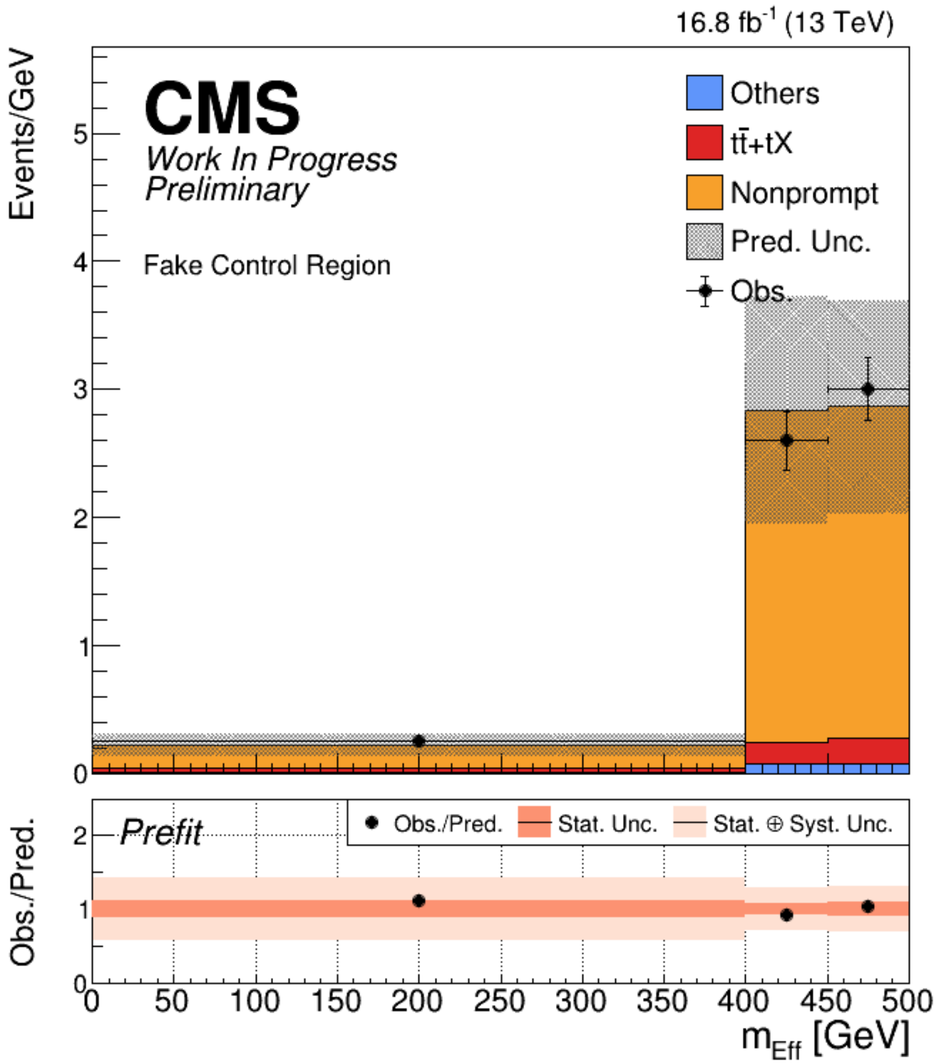
doi:10.1007/JHEP05(2024)311



Fake Control Region

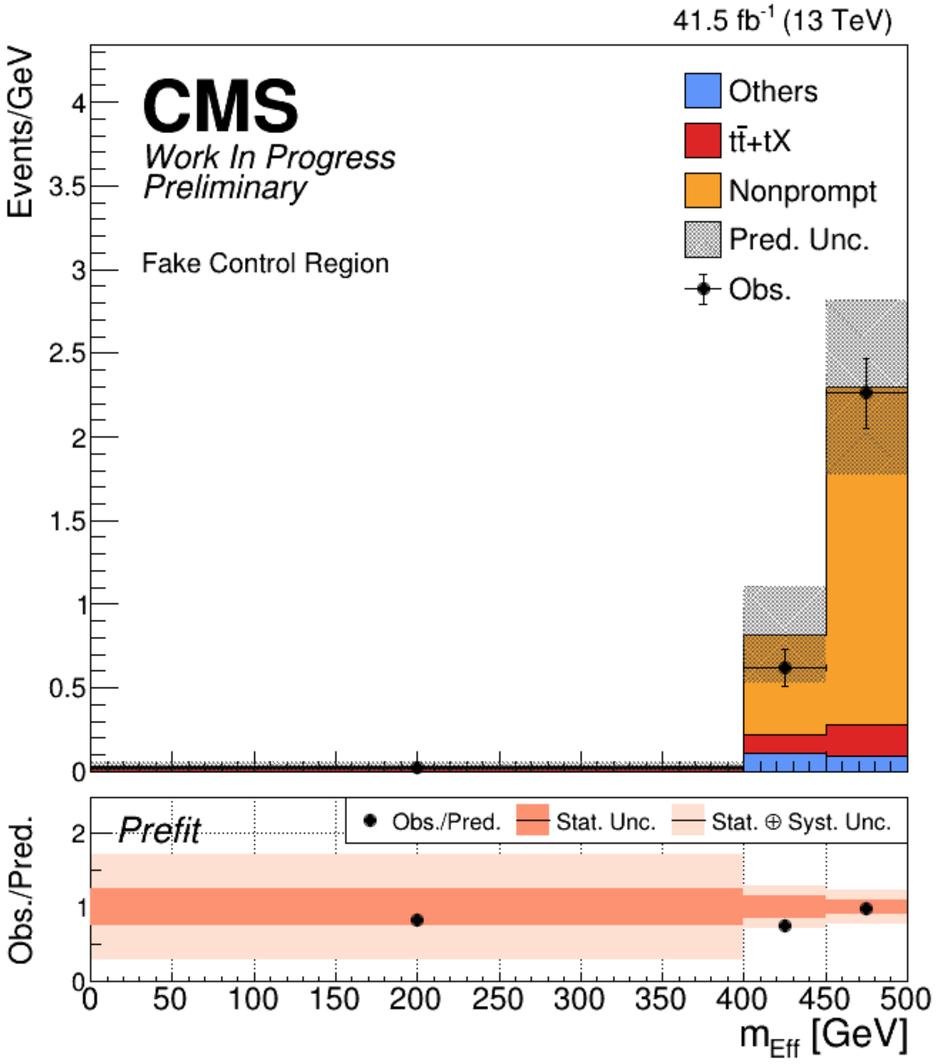
Plots

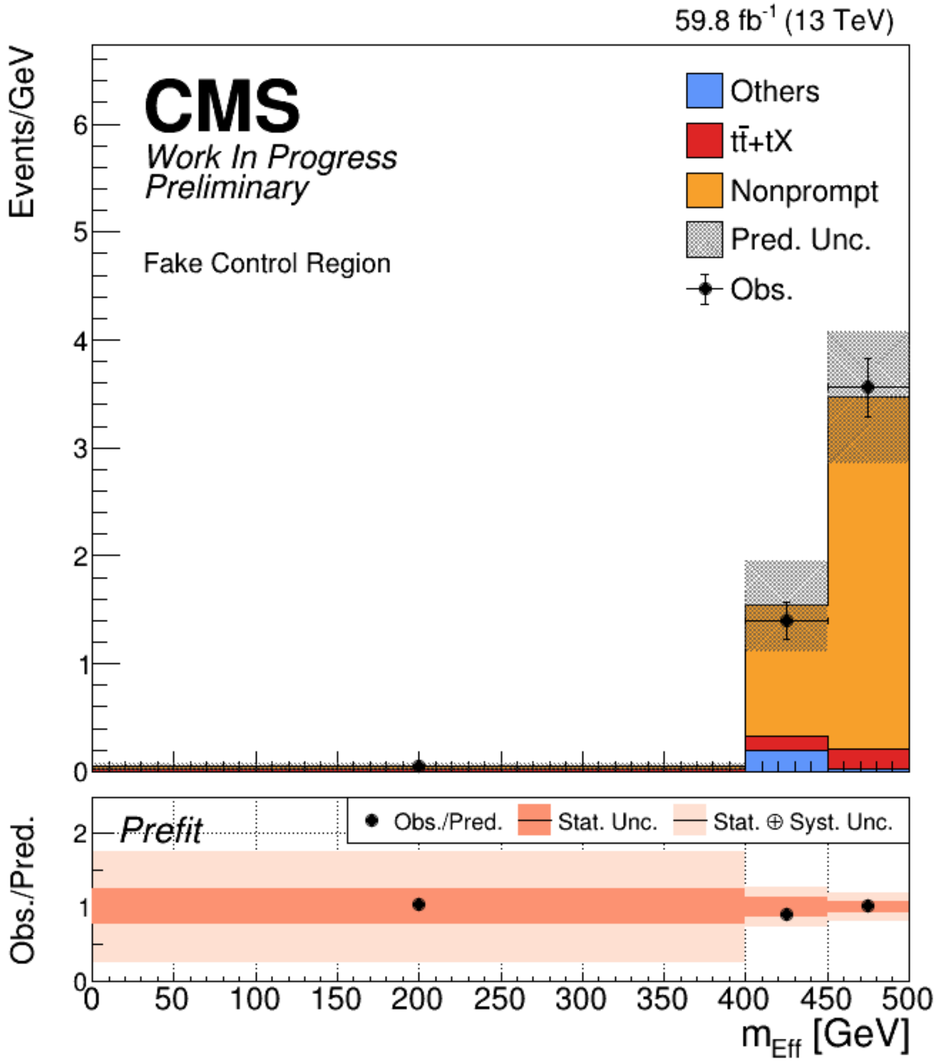




Fake Control Region

Plots





Systematics

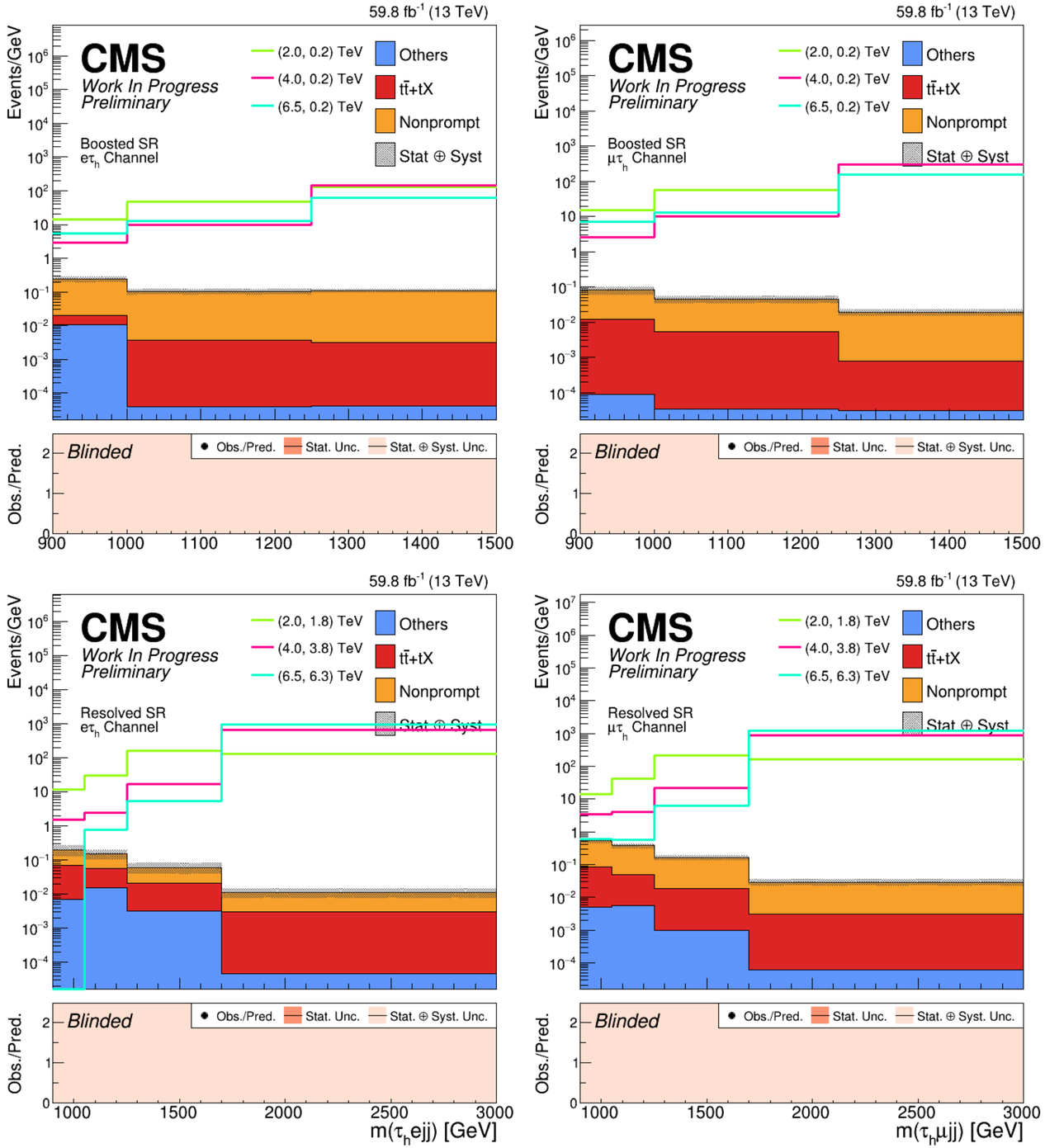
Overview

Uncertainty source		Type	Magnitude	Processes	Era correlation
Luminosity		norm.	1 – 2.5%	All Simulations	Partial
L1 Prefire		shape	–	All Simulations	No
Pileup		shape	–	All Simulations	No
Muon	Energy Scale	shape	–	All Simulations	No
	ID.	shape	–	All Simulations	Yes
	Resolution	shape	–	All Simulations	Yes
	Isolation	shape	–	All Simulations	Yes
Electron	Energy Scale	shape	–	All Simulations	No
	ID.	shape	–	All Simulations	Yes
	Resolution	shape	–	All Simulations	No
Hadronic Tau	ID.	shape	–	All Simulations	Partial
	Trigger	norm.	8 – 11%	All Simulations	No
	Energy Scale	shape	–	All Simulations	No
	Fake Rate	shape	–	Fakes	No
	Fake Norm.	norm.	30%	Fakes	Yes
Jet	Energy Scale	shape	–	All Simulations	No
	Energy Resolution	shape	–	All Simulations	No
Fat Jet	LSF	shape	–	All Simulations	No
Theory	PDF	norm.	1 – 20%	Signals	Yes
	μ_R, μ_F	shape	–	Signals	Yes
Bin-by-bin Stat.		shape.	–	All Simulations	Yes

Results

Expected Limits

- Preliminary expected limits are extracted
  - Fitting based on reconstructed W_R mass shape : m(tau,lepton,jets)
  - 2016preVFP and 2016postVFP is combined and lepton channels are combined
  - Top and Others are combined as a single process
  - Mentioned systematics are included



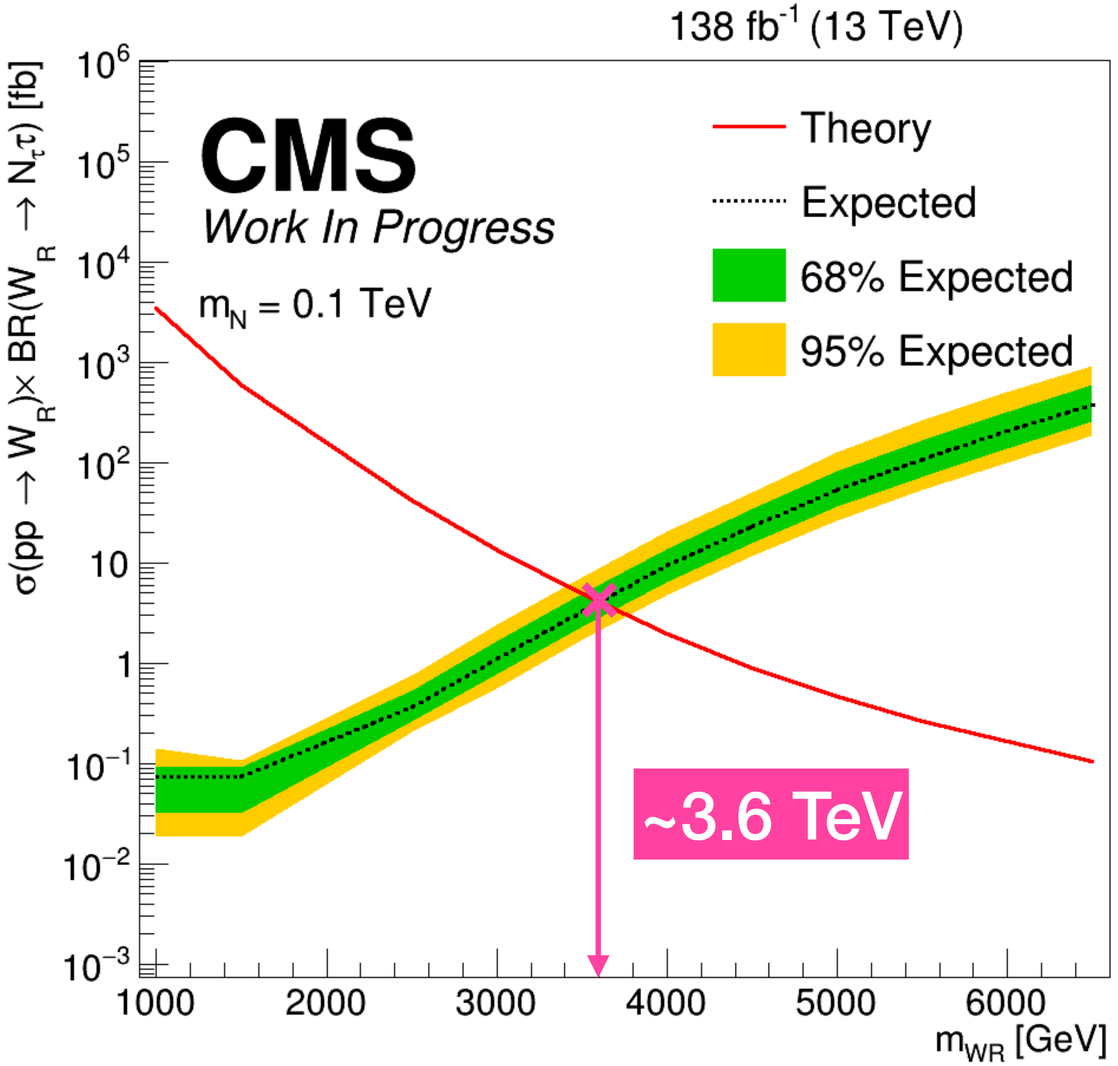
Results

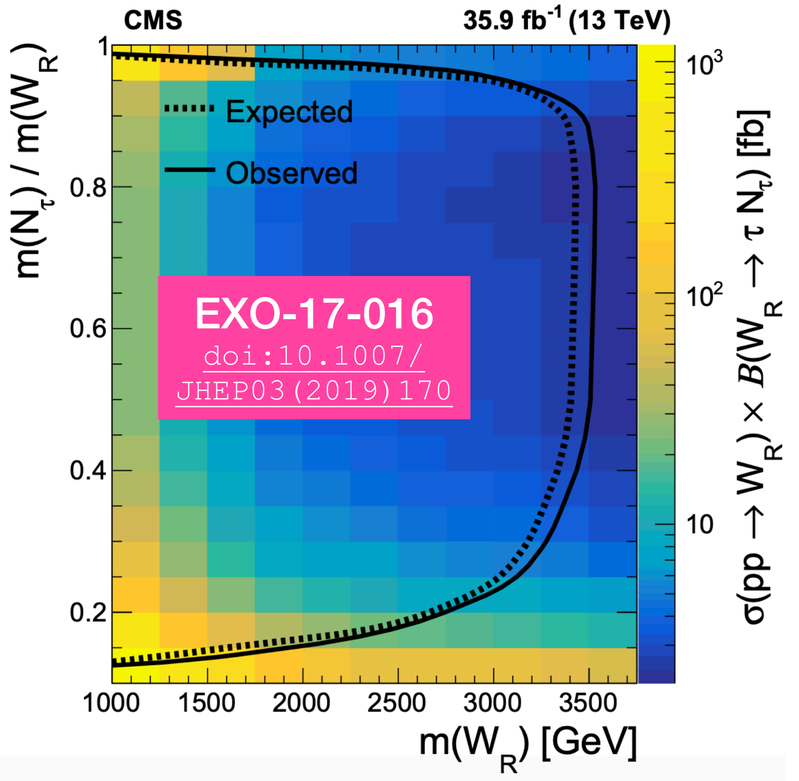
Expected Limits

m_N = 0.1 TeV Scenario

Improved sensitivity compared to previous studies!

Unset to ~3.6 TeV





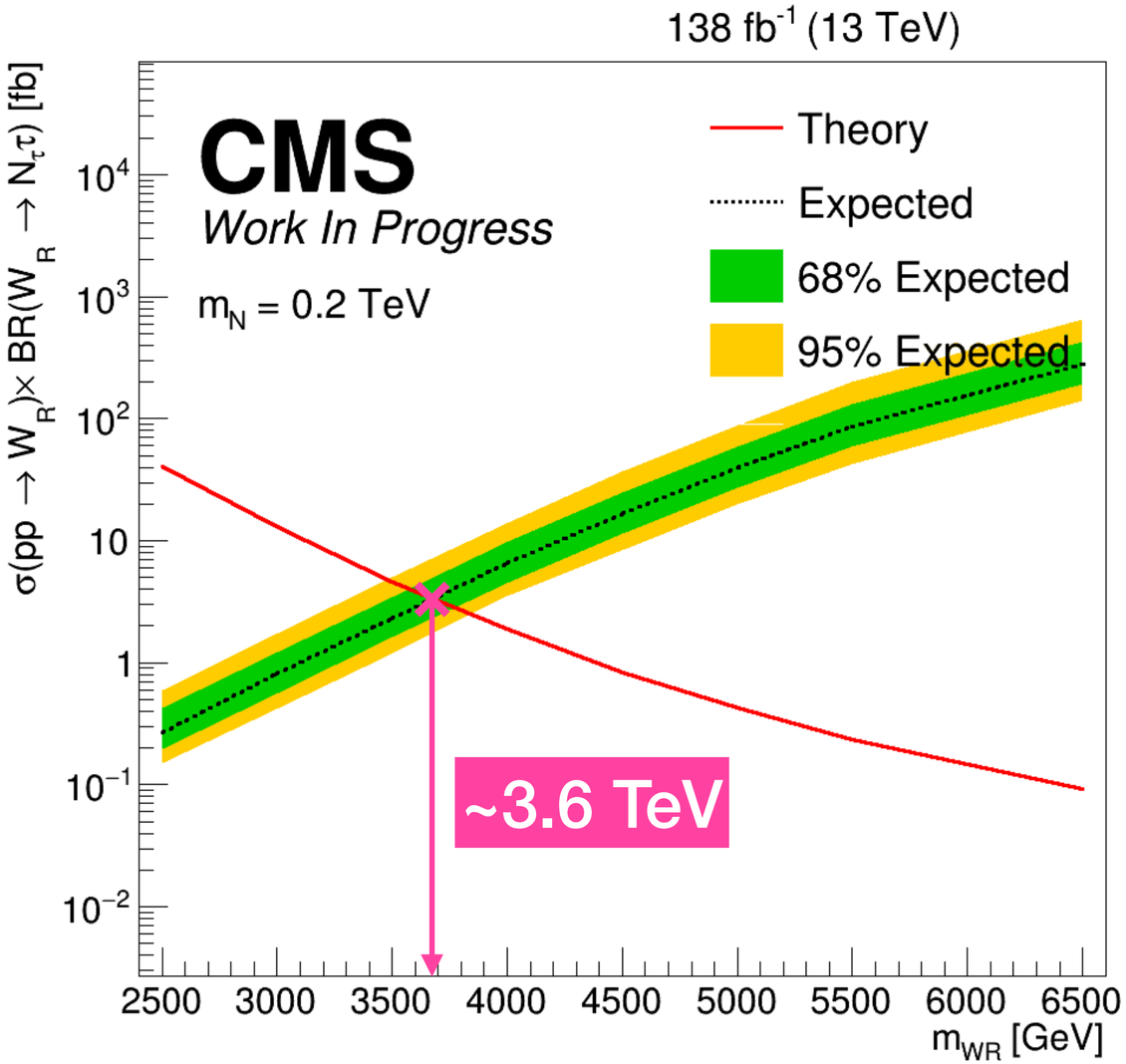
Results

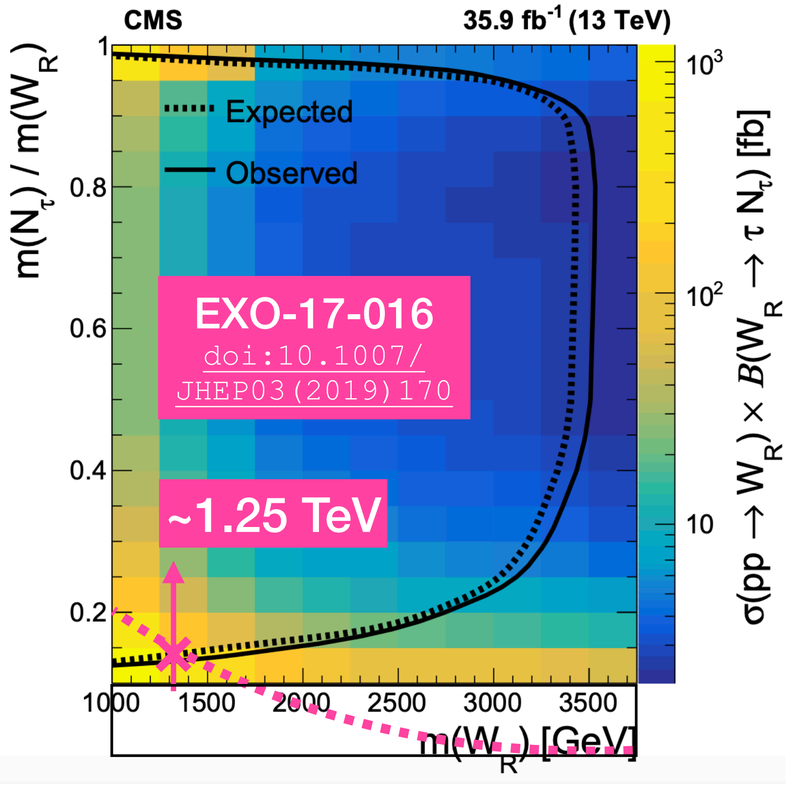
Expected Limits

m_N = 0.2 TeV Scenario

Improved sensitivity compared to previous studies!

~1.25 TeV to ~3.6 TeV

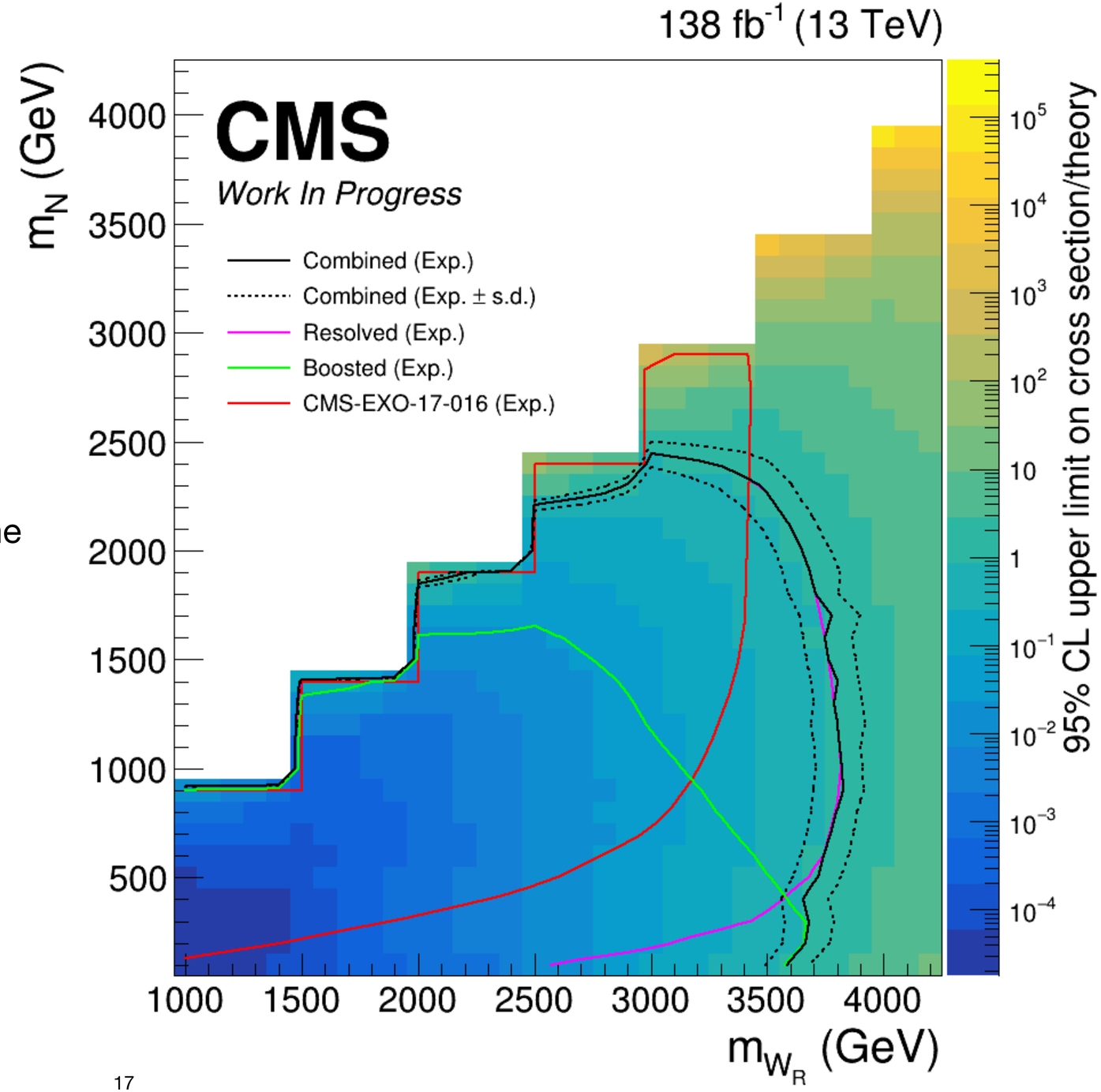




Results

Expected Limits

- 2D limits on the m_{WR}-m_N plane
  - Showing “combined” (= boosted+resolved), boosted and resolved simultaneously
  - Previous analysis is also shown which contrasts the performance of our analysis in the boosted region
    - Actual limits were not available in Hepdata, thus a private PDF extractor was used
    - This might be removed later as it is a privately extracted limit
  - Due to the bad signal granularity, we are investigating on how to plot this in a better sense



Conclusion

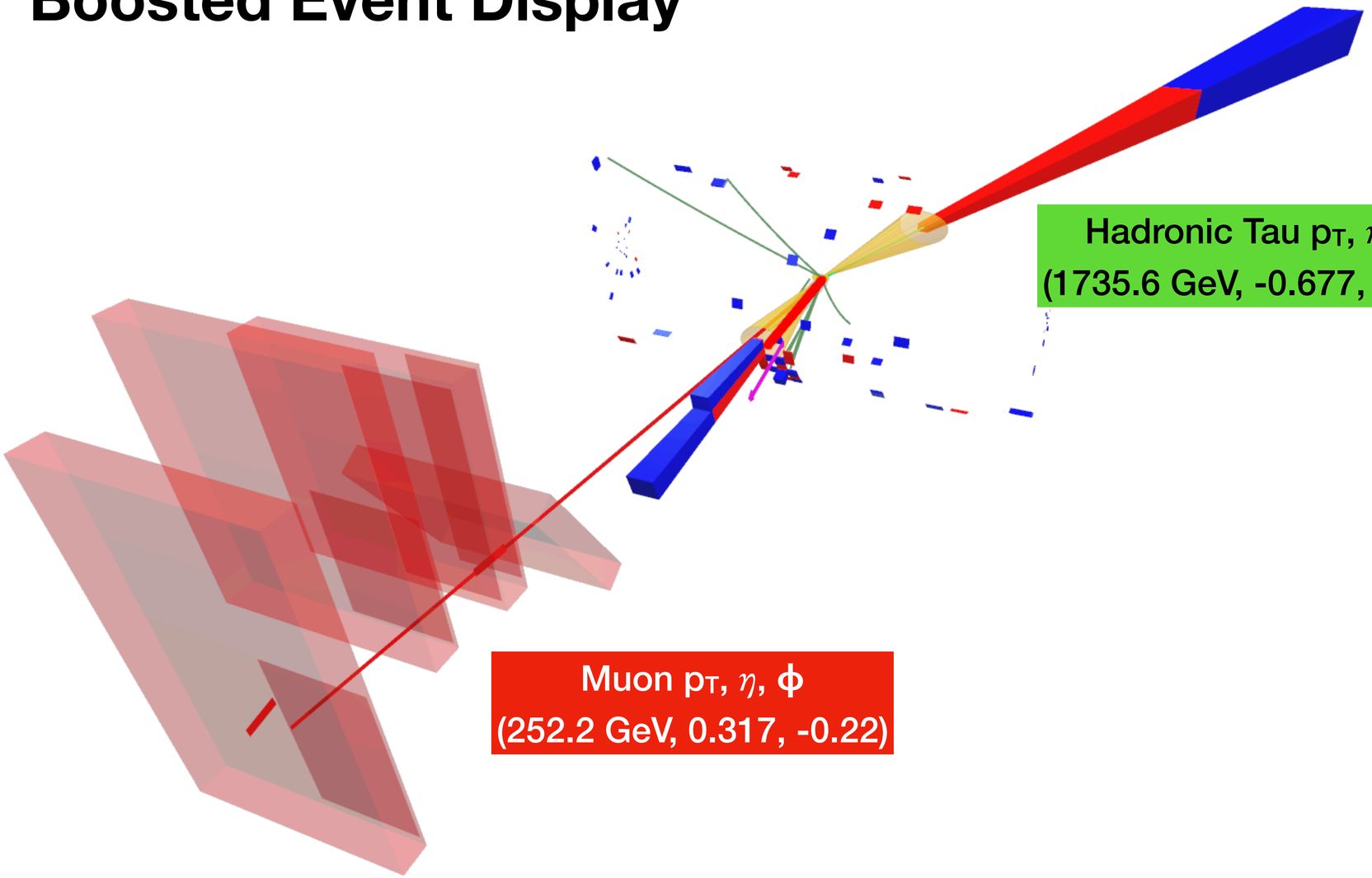
- Search for W_R and HNL in a $\tau_h\tau_\ell$ + jets final state is being actively updated
  - **The analysis is in an advanced state, ready to follow the Moriond 2025 timeline.**
  - Preliminary expected limits extracted using full Run2, improved compared to previous studies
    - **m_N = 0.1 TeV scenario : previously unset to ~ 3.6 TeV**
    - **m_N = 0.2 TeV scenario : improved from ~ 1.25 TeV to ~ 3.6 TeV**
  - **Object reviews awaiting & paper draft ongoing , getting in shape for PreApp**

Thank You!

Backups

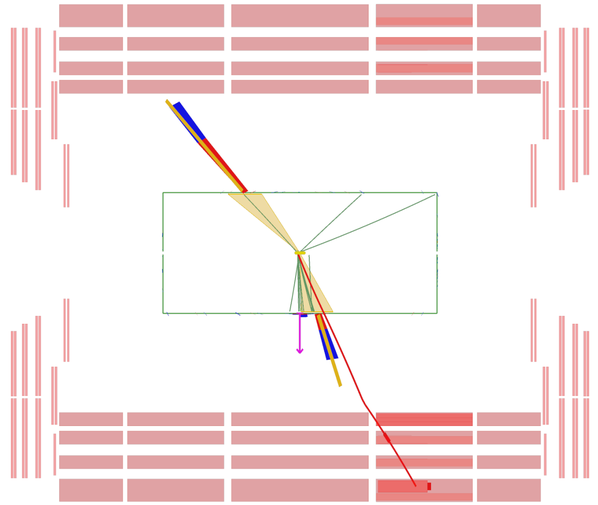
Signals

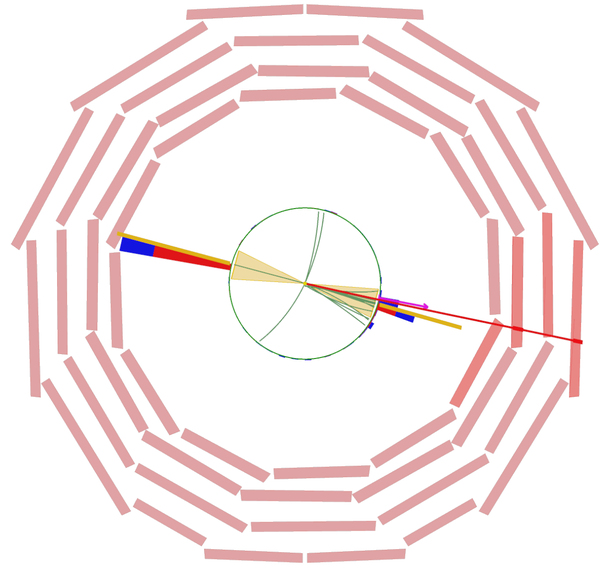
Boosted Event Display



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)



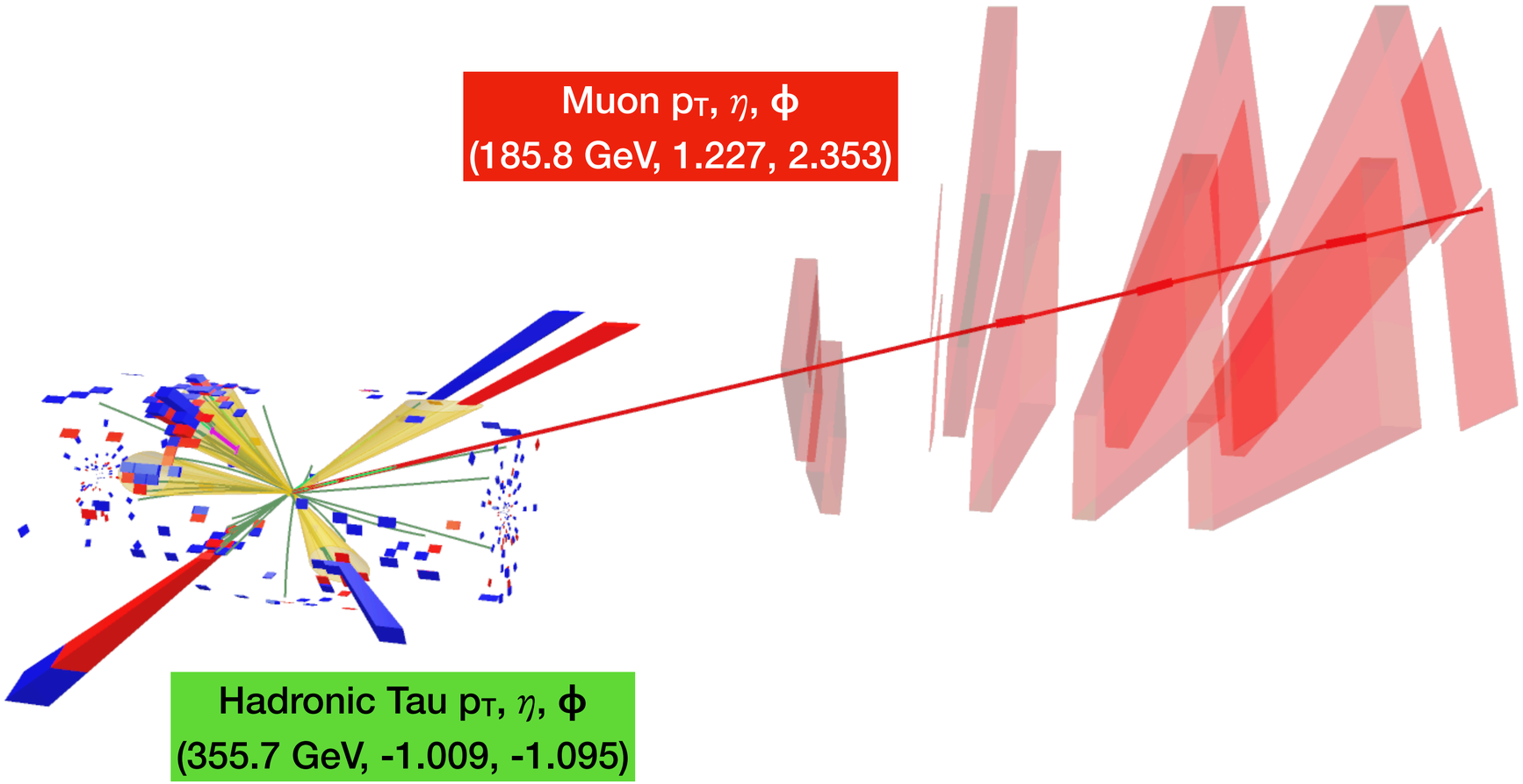


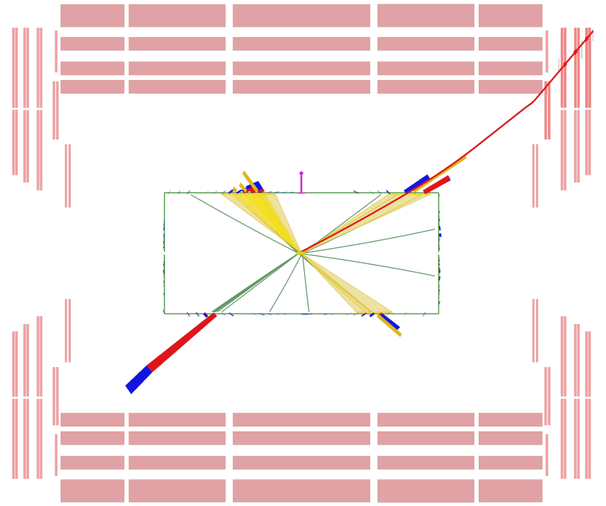
(run:lumi:event) = (1:54:81888) of (mWR,mN) = (4.8 TeV, 200GeV)

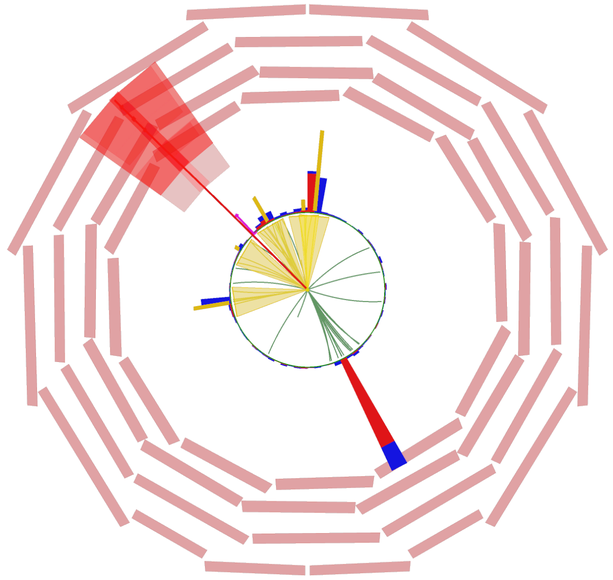
/WRtoTauNtoTauTauJets_WR4800_N200_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16MiniAODAPVv2-106X_mcRun2_asymptotic_preVFP_v11-v2/MINIAODSIM

Signals

Resolved Event Display







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

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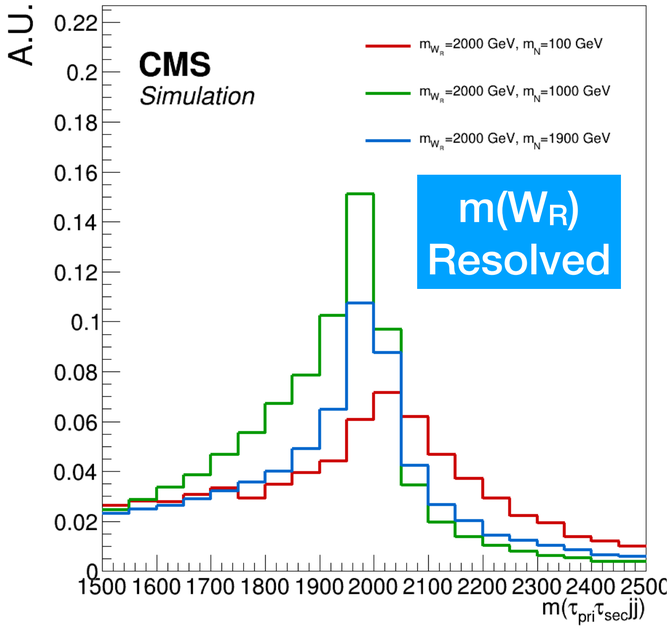
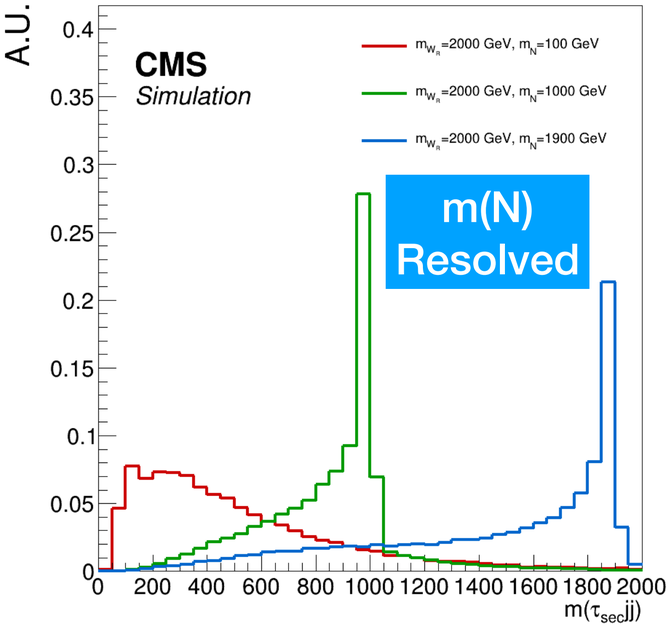
Signal Kinematics

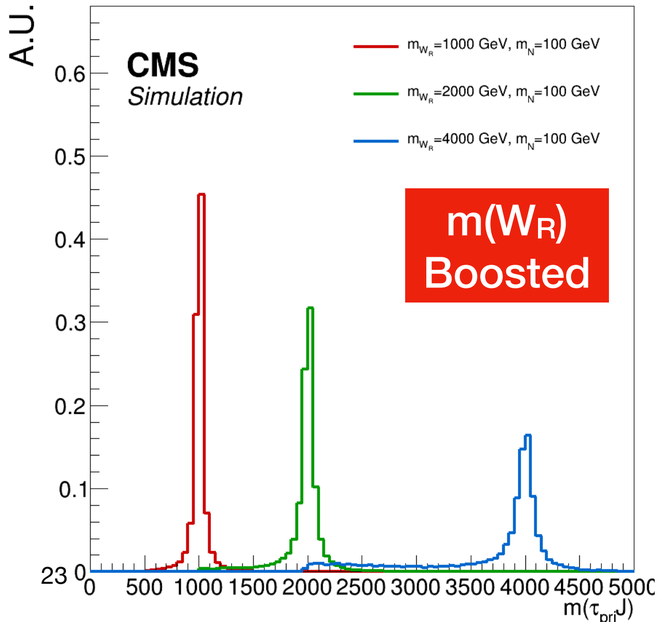
- Resolved region legend :
  - m_{WR} = **2 TeV**
  - m_N = **100,1000,1900 GeV**

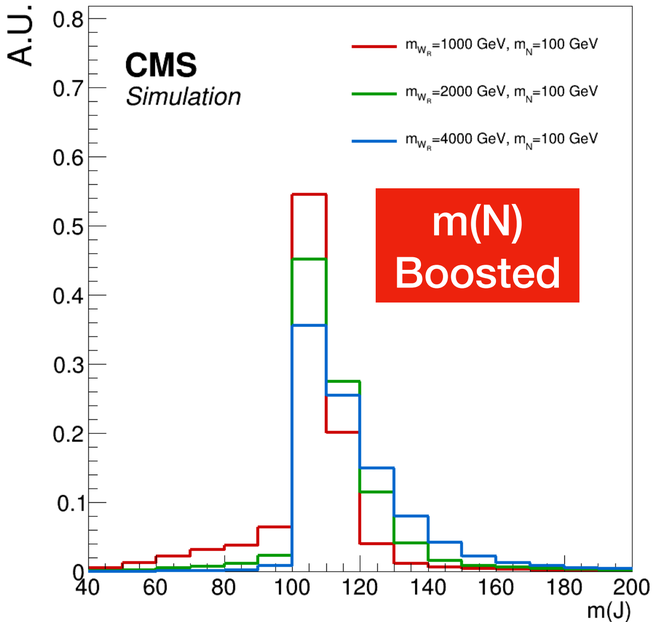
- Boosted region legend :
  - m_{WR} = **1,2,4 TeV**
  - m_N = **100 GeV**

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



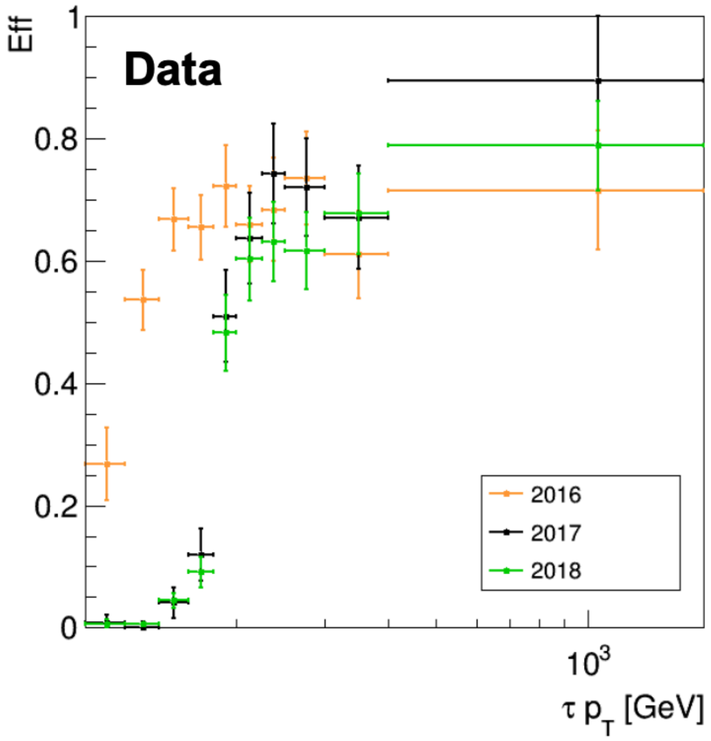


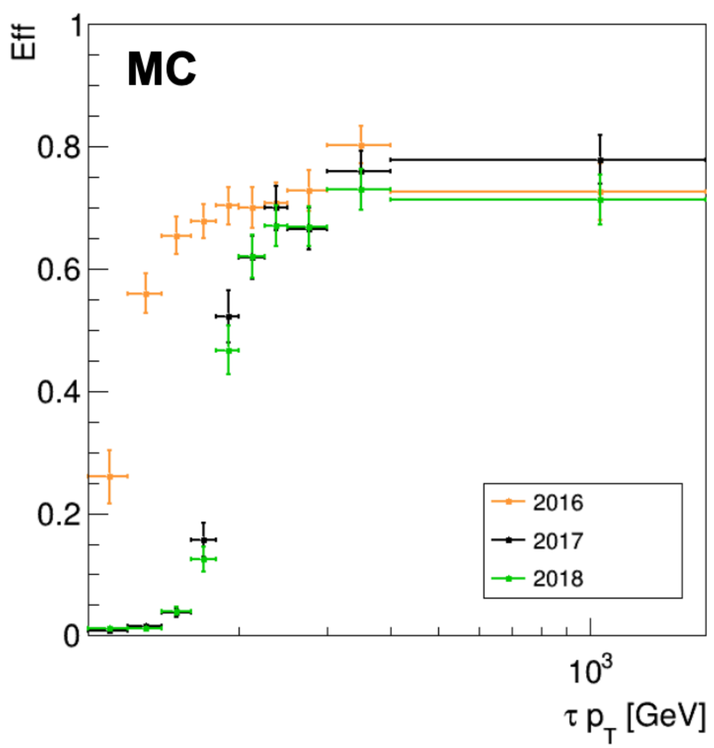


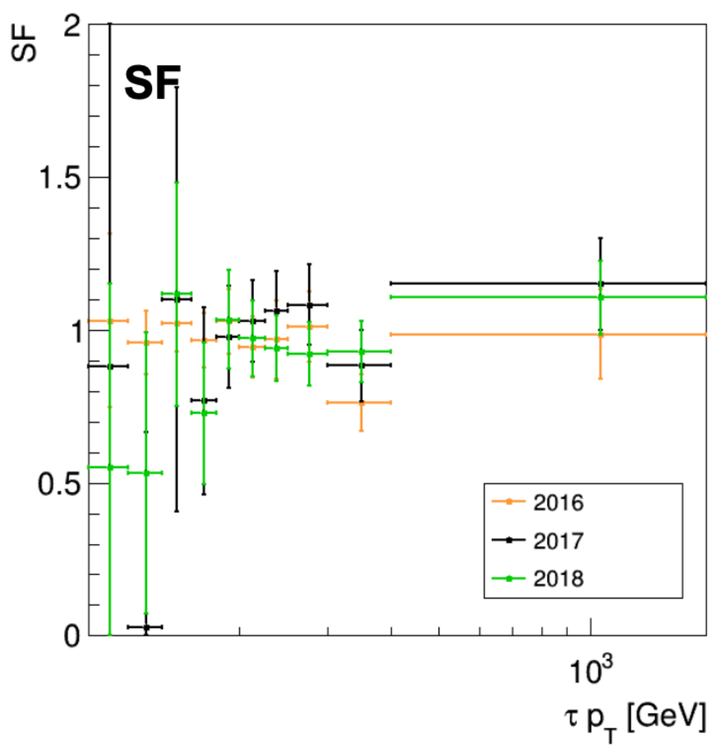


Trigger Efficiency

Single Tau HLT







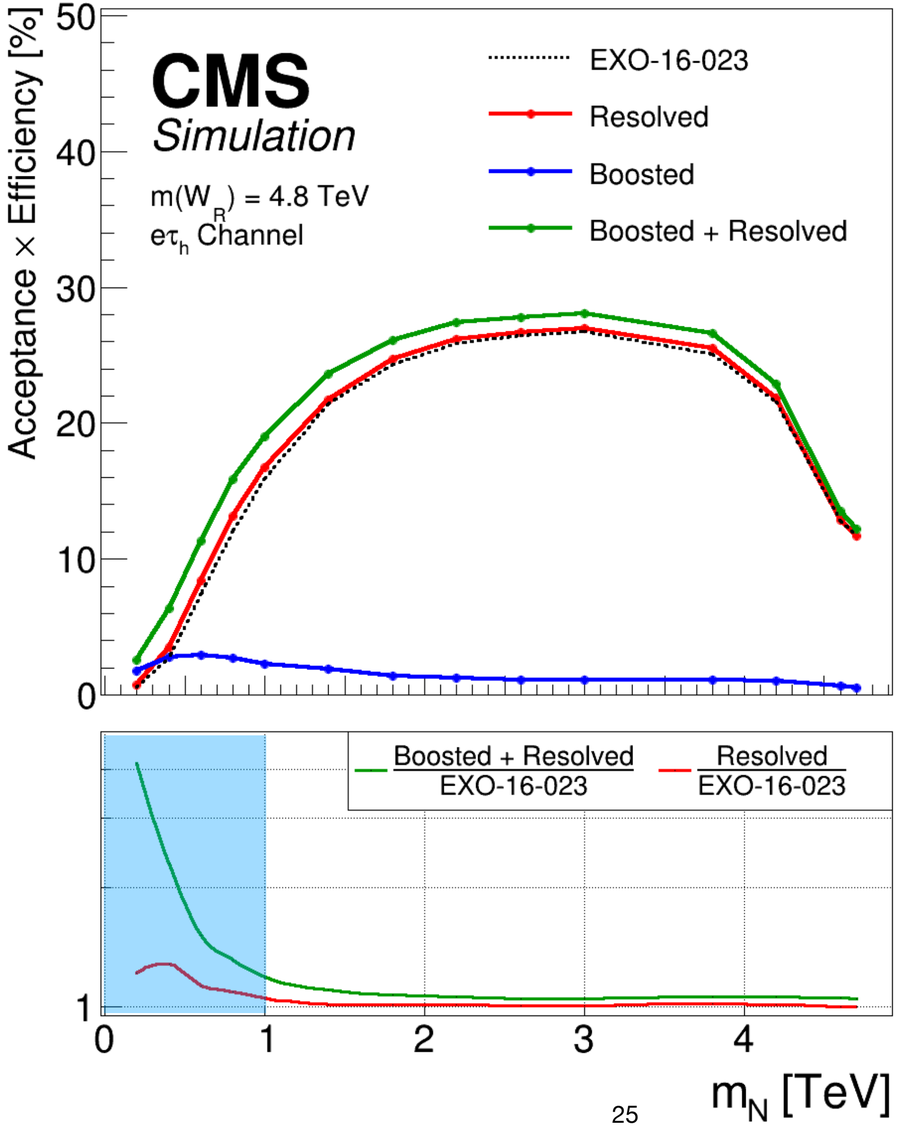
Tau ID Meeting
(14th Dec. 2020)

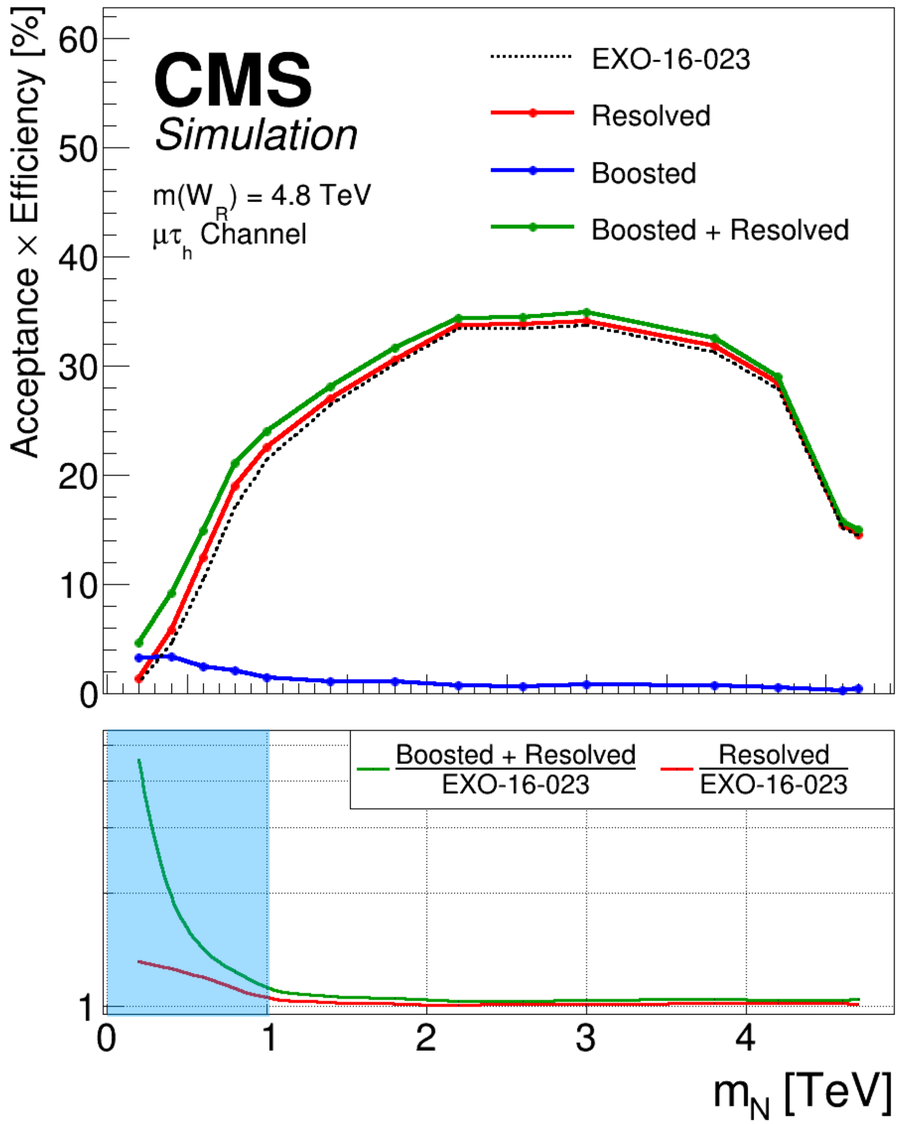
Selection Efficiency

Signals

Efficiency calculated from corresponding Gen-matched channels

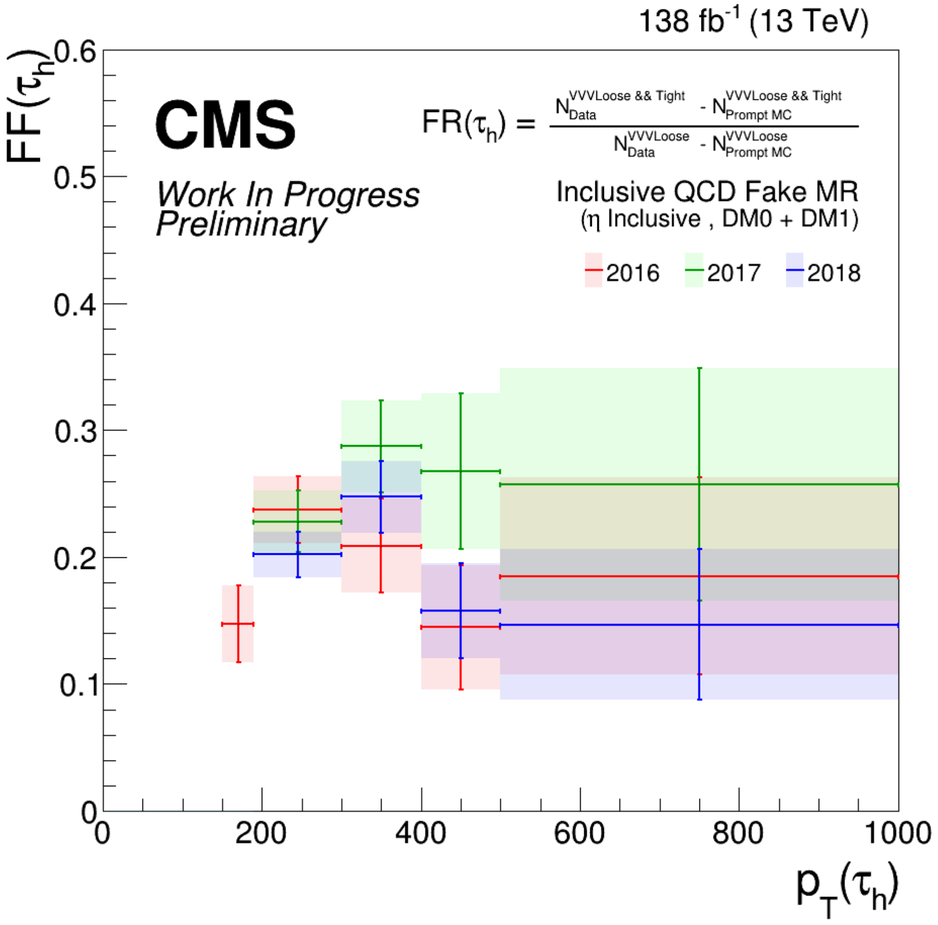
EXO-16-023 here is not exactly identical with the original selection

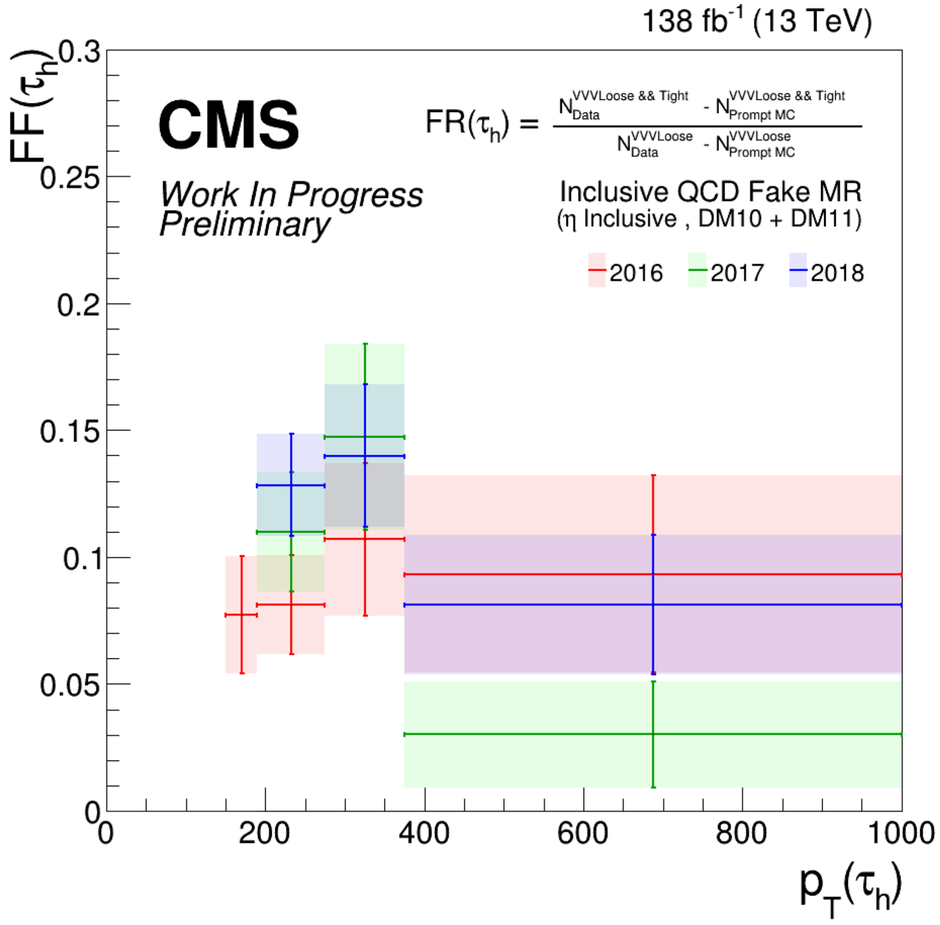




Background Estimation

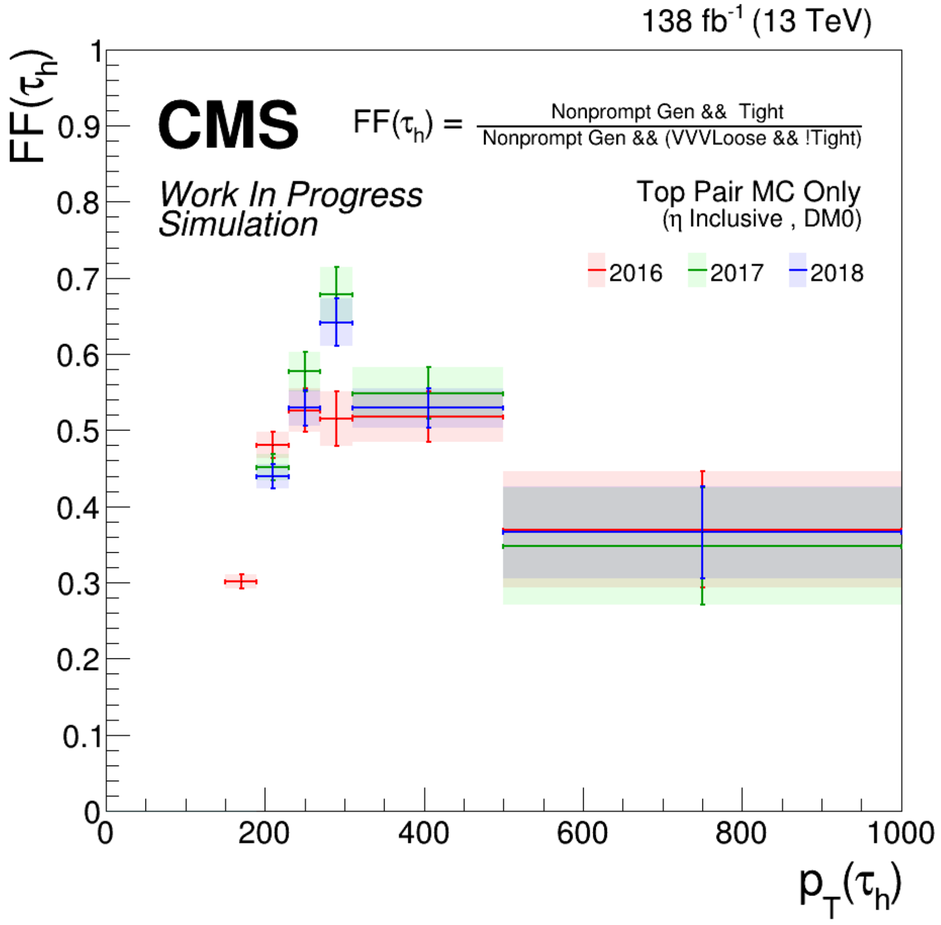
QCD FF

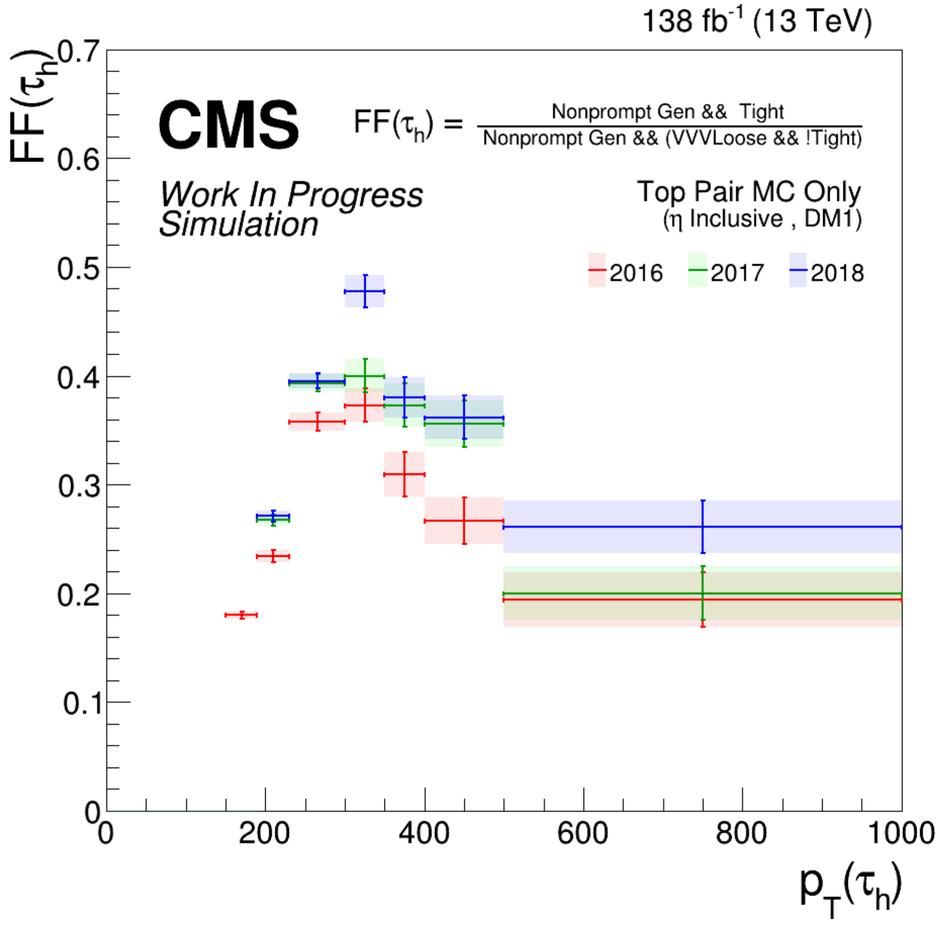




Background Estimation

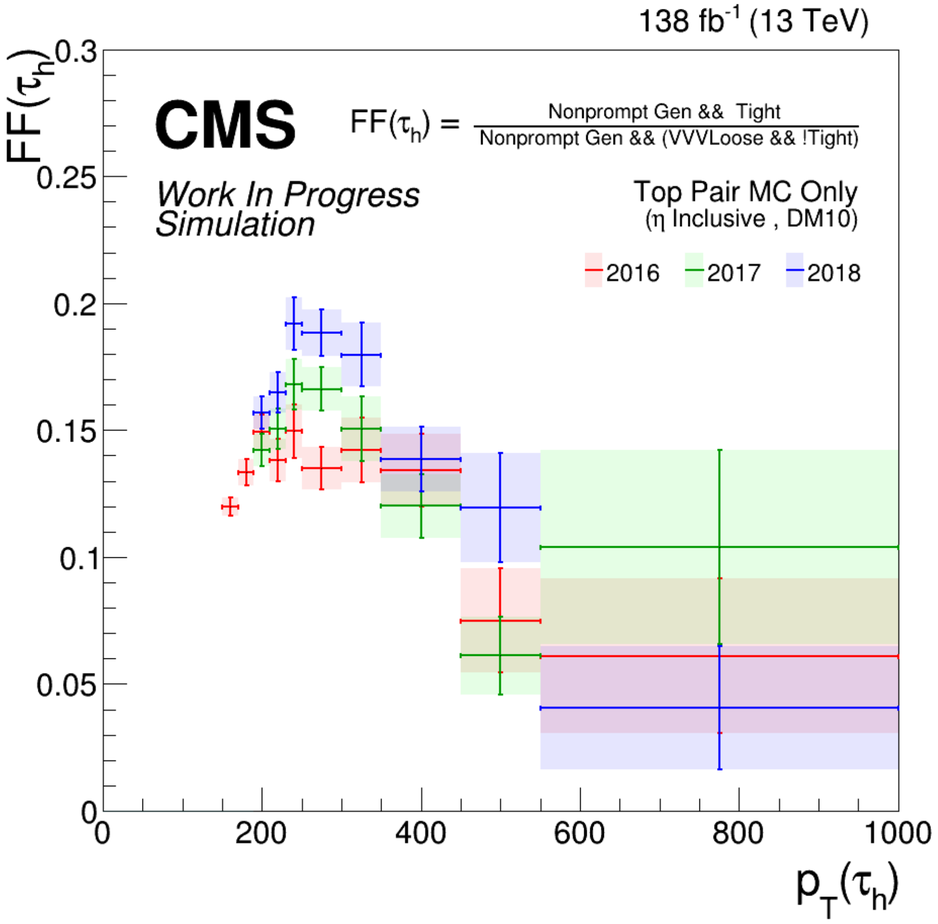
Top FF

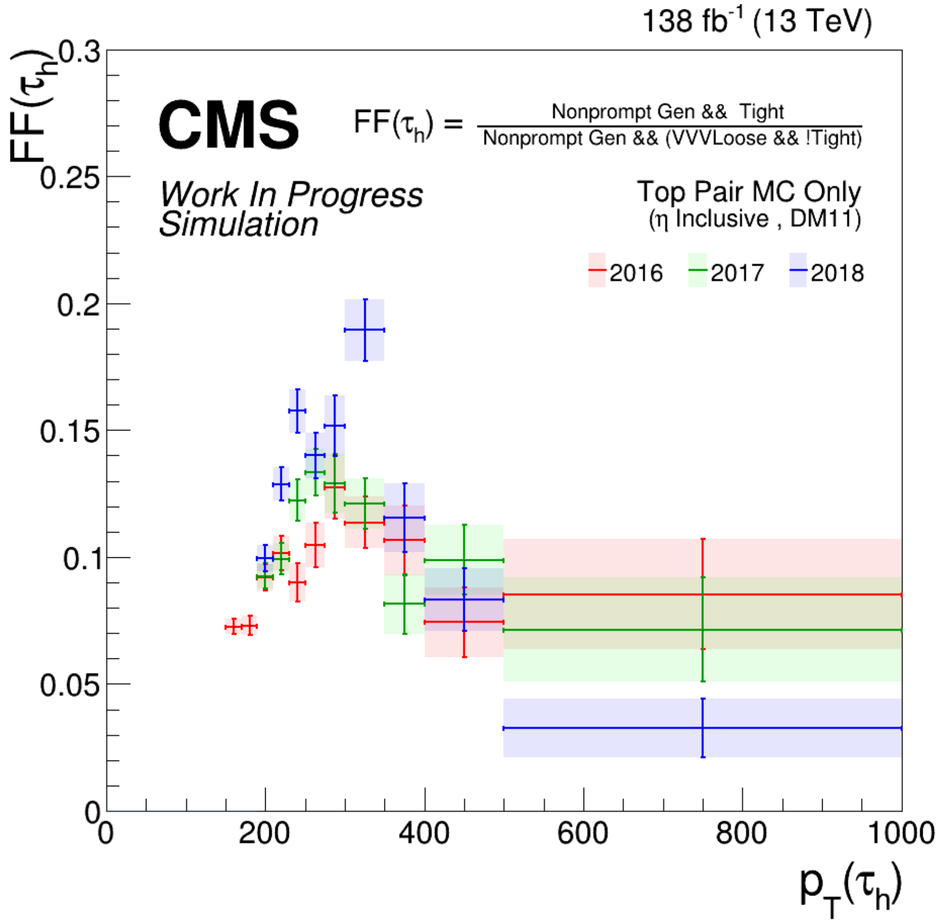




Background Estimation

Top FF

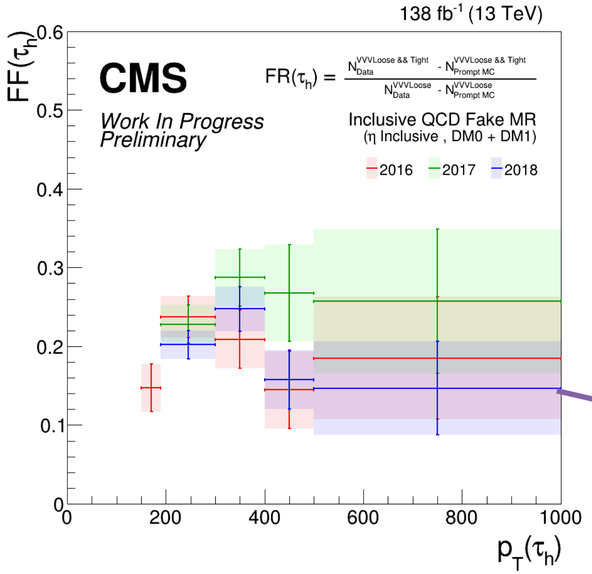


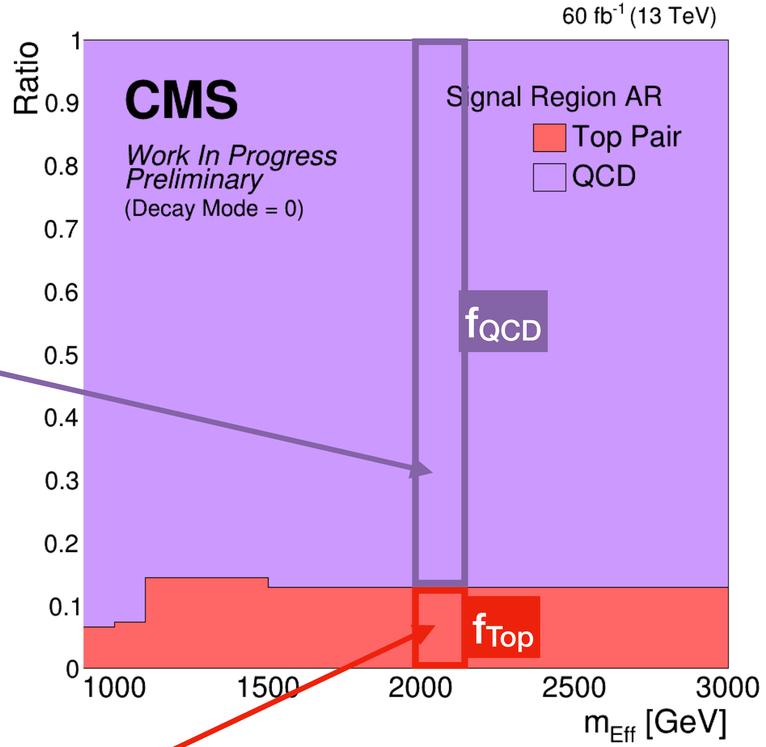


Background Estimation

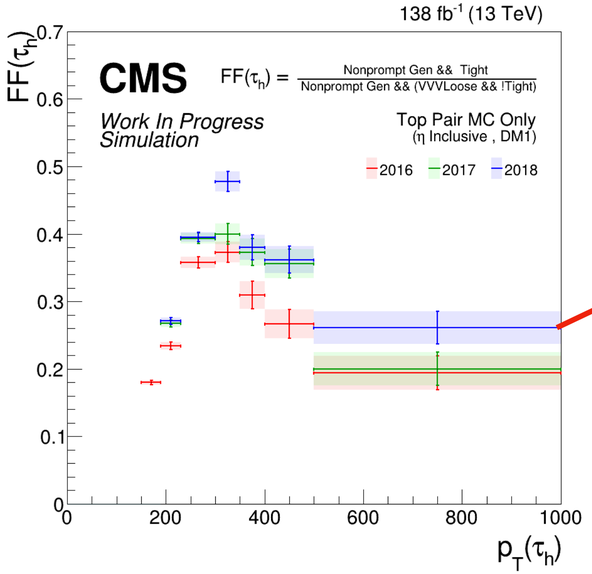
Fake Factor Application

QCD FF



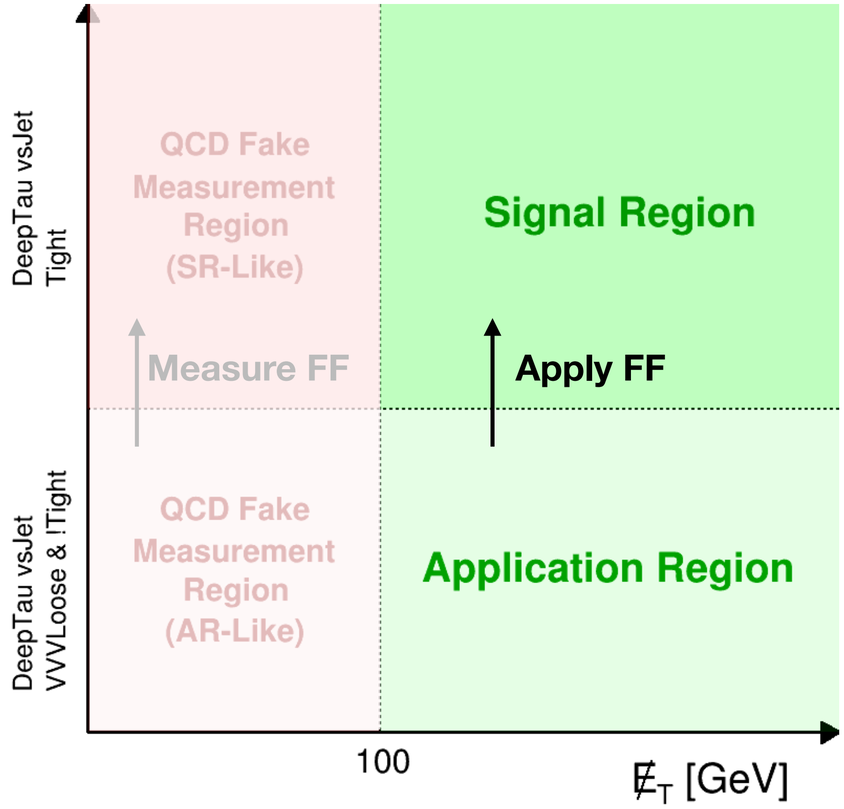


Top FF



Total FF to be applied :

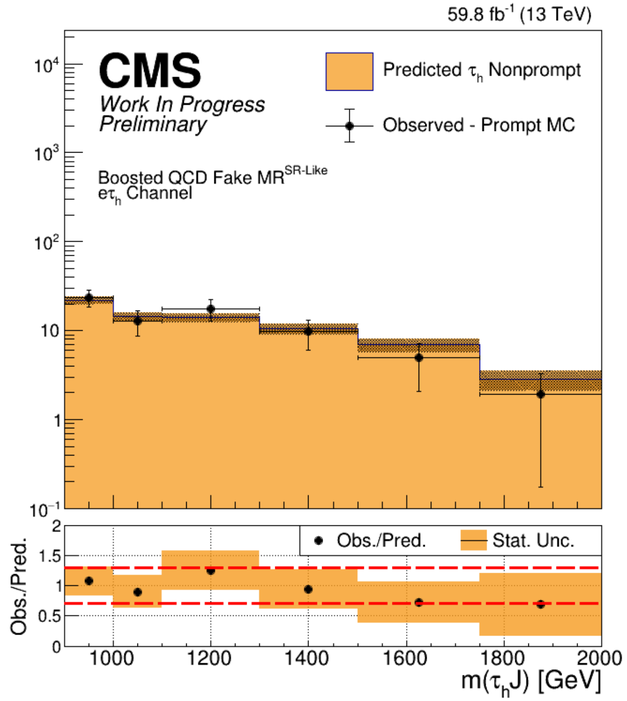
$FF = f_{QCD}\, FF_{QCD} + f_{Top}\, FF_{Top}$

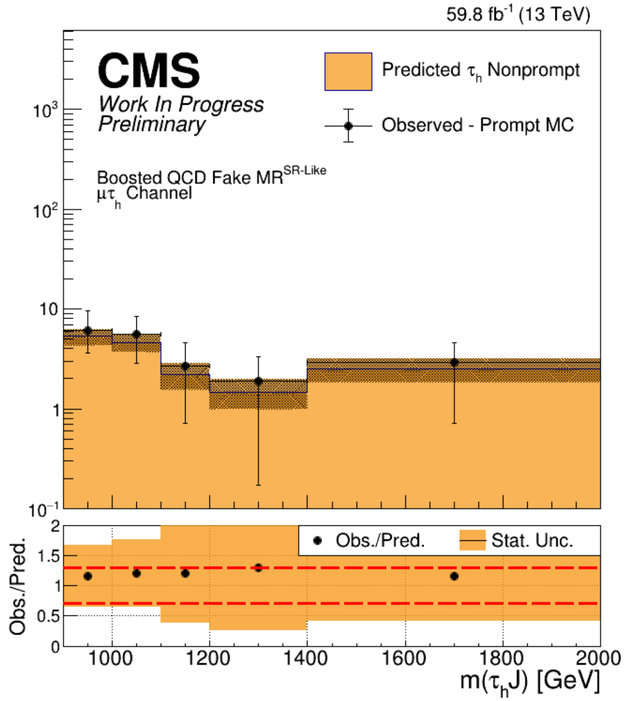


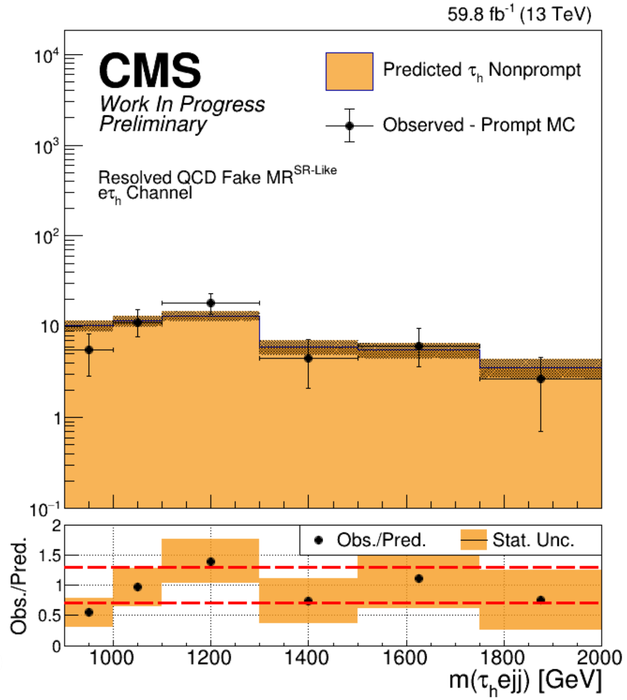
Background Estimation

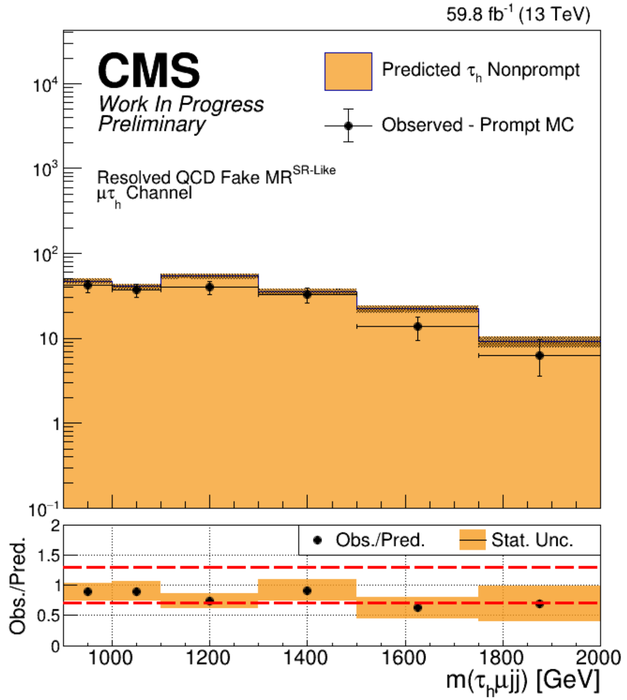
Hadronic Tau Fake

- 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







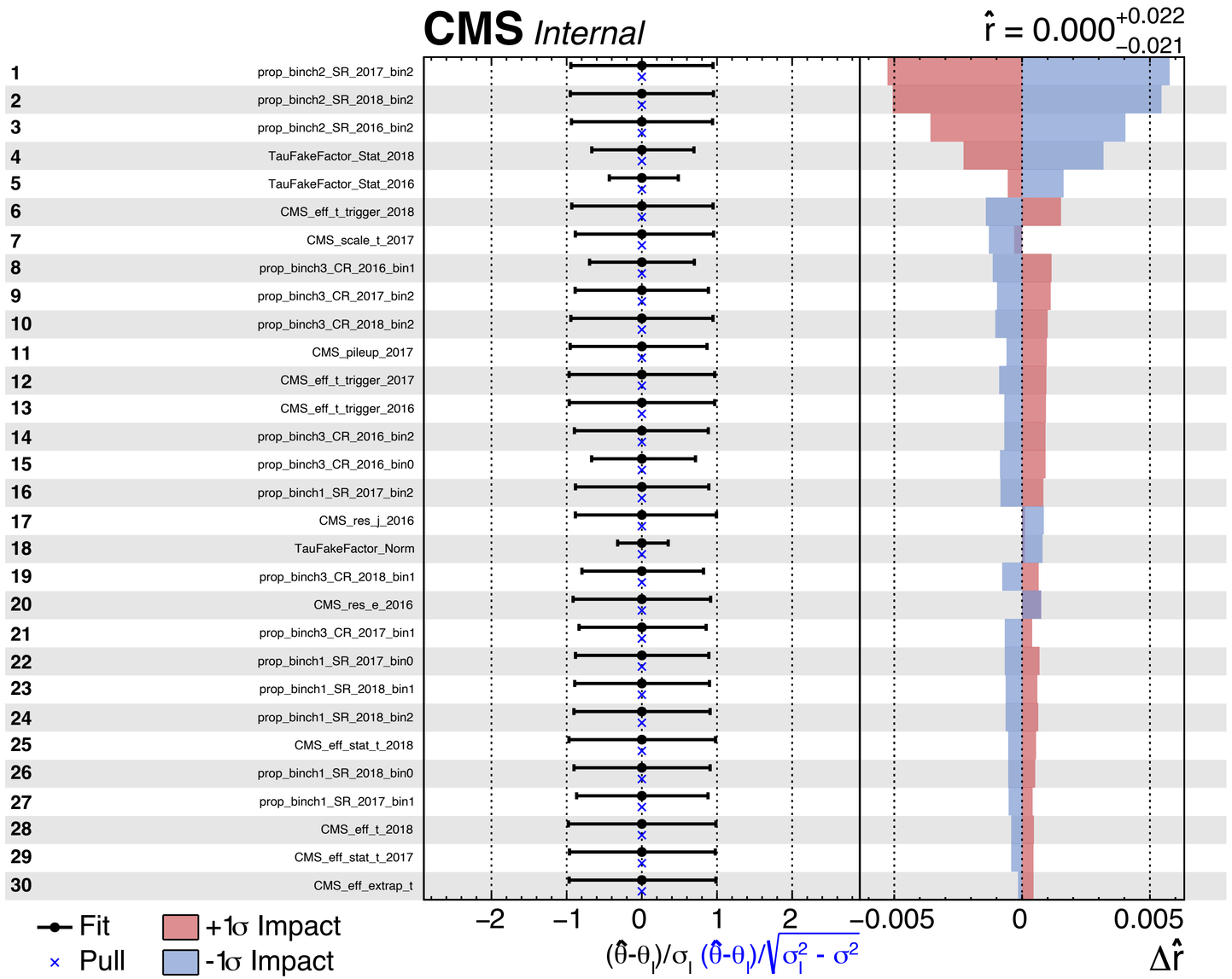


Systematics

Impacts

Updated

Background only
Asimov

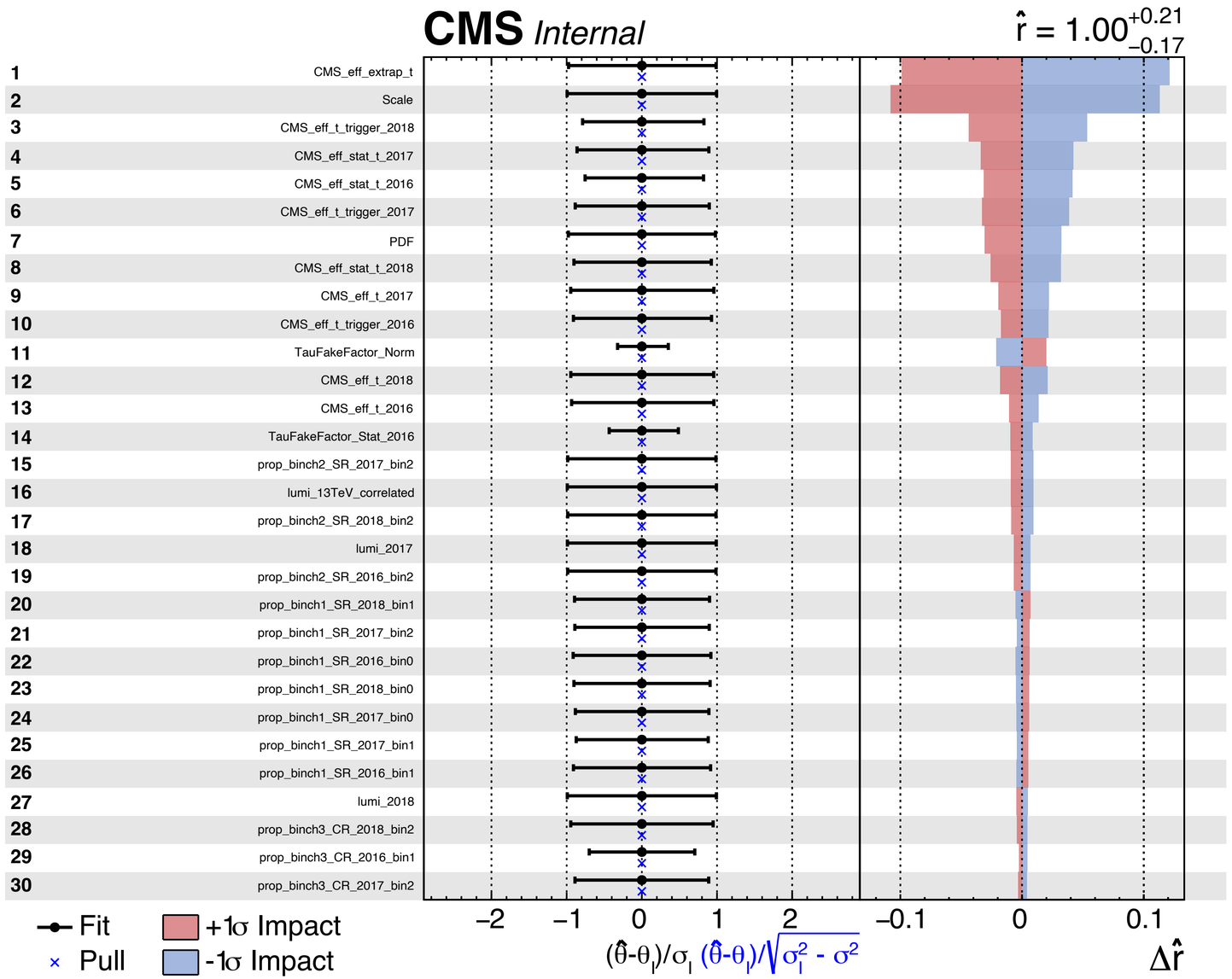


Systematics

Impacts

Updated

r=1 injected for Signal (3.5,1.0) TeV



Systematics

Impacts

Updated

r=1 injected for Signal (3.5,0.2) TeV