Search for W_R and Heavy N In a $\tau_h \tau_\ell$ + jets Final State

Exotica Jets+X Meeting

13th May 2024

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Documentation

Status

- Analysis Note
  - AN-23-001 (v2)

- Presentations
  - Exotica MC&I (14th Feb. 2023)

Available on the CMS information server **CMS AN-23-001**

CMS Draft Analysis Note

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

Youngwan Kim[*,1] and Sihyun Jeon[2]

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CMS AN-23-001

Introduction

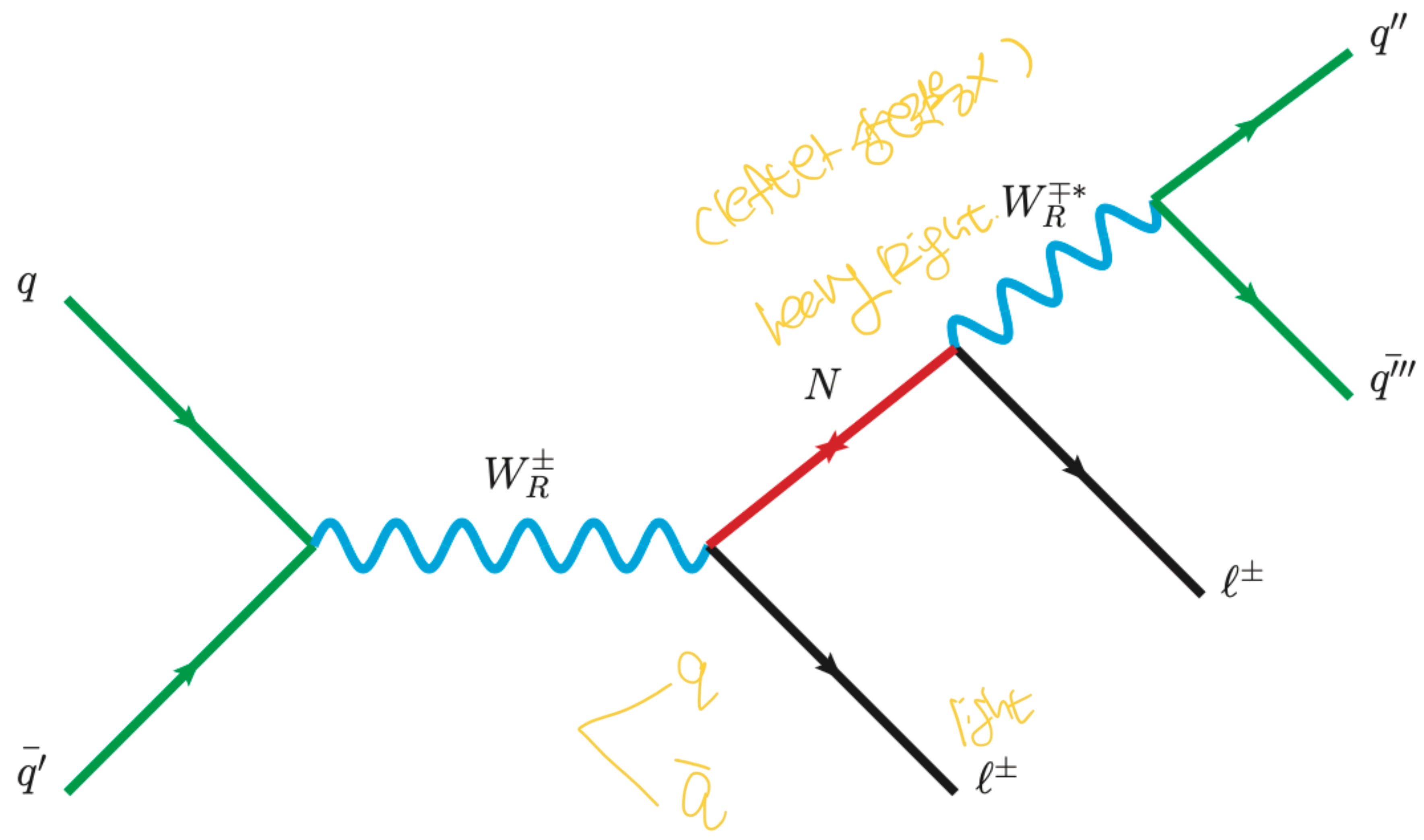
Motivation

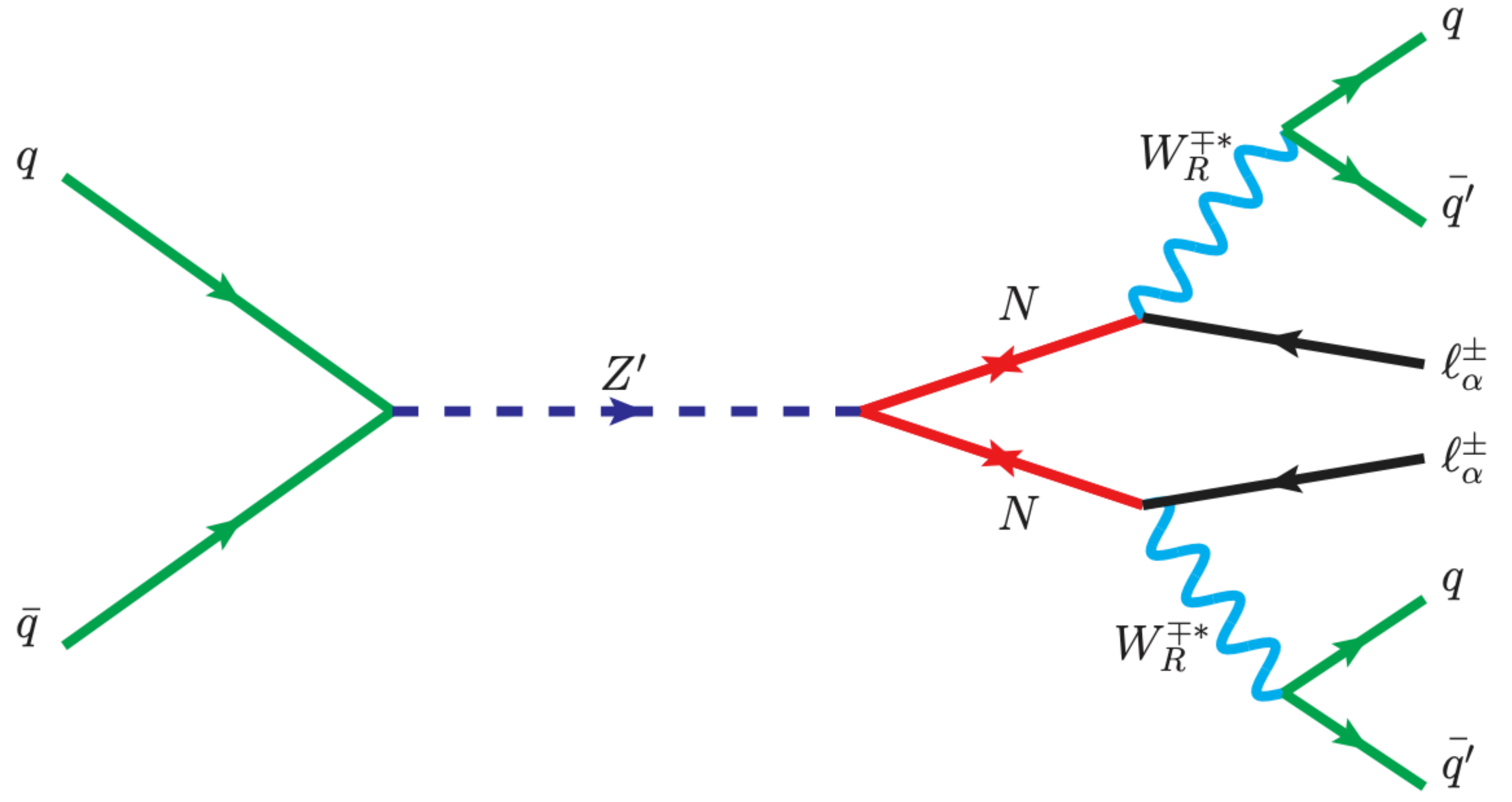
- Unsolved mysteries with neutrinos

  - 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.

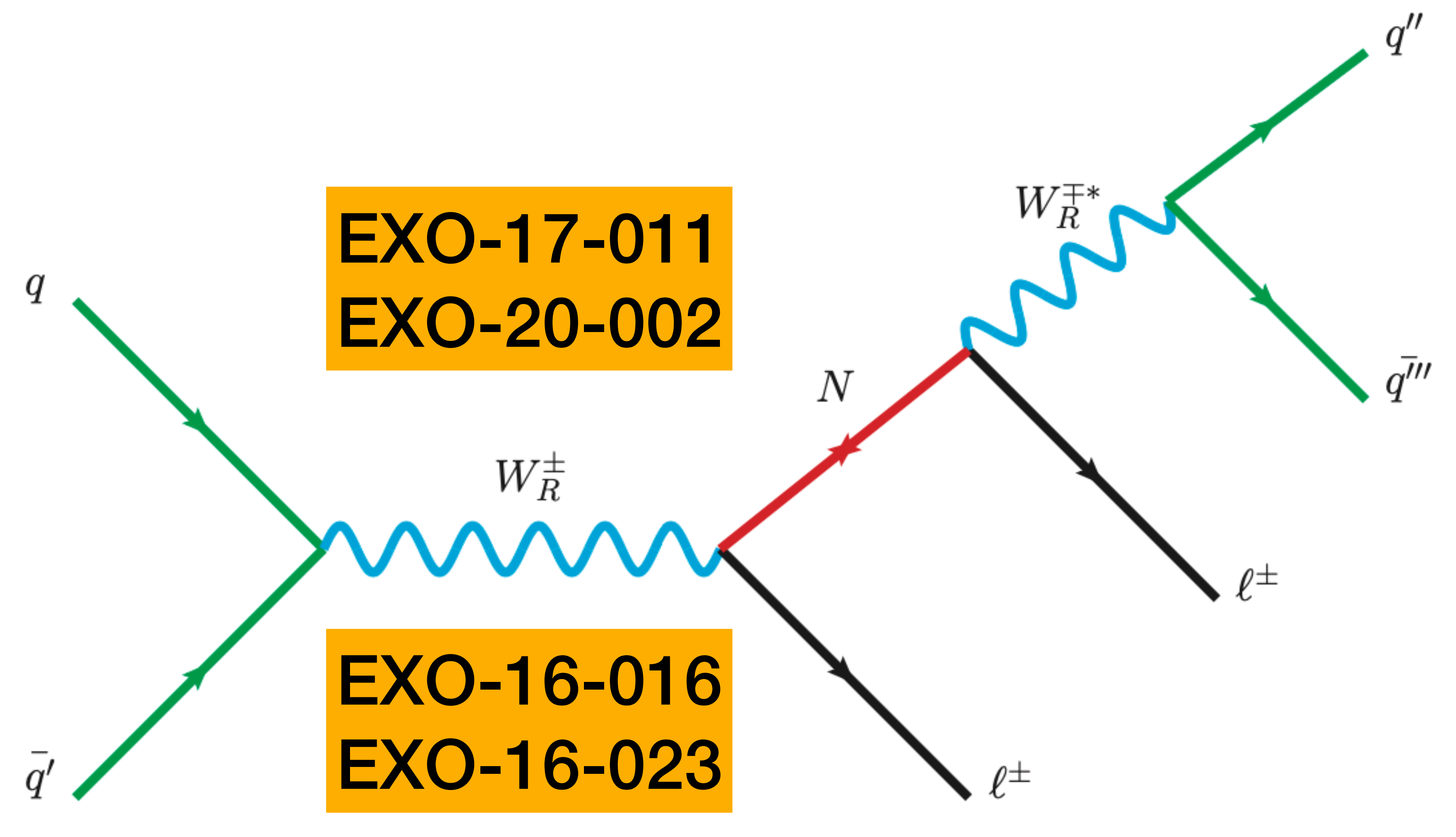


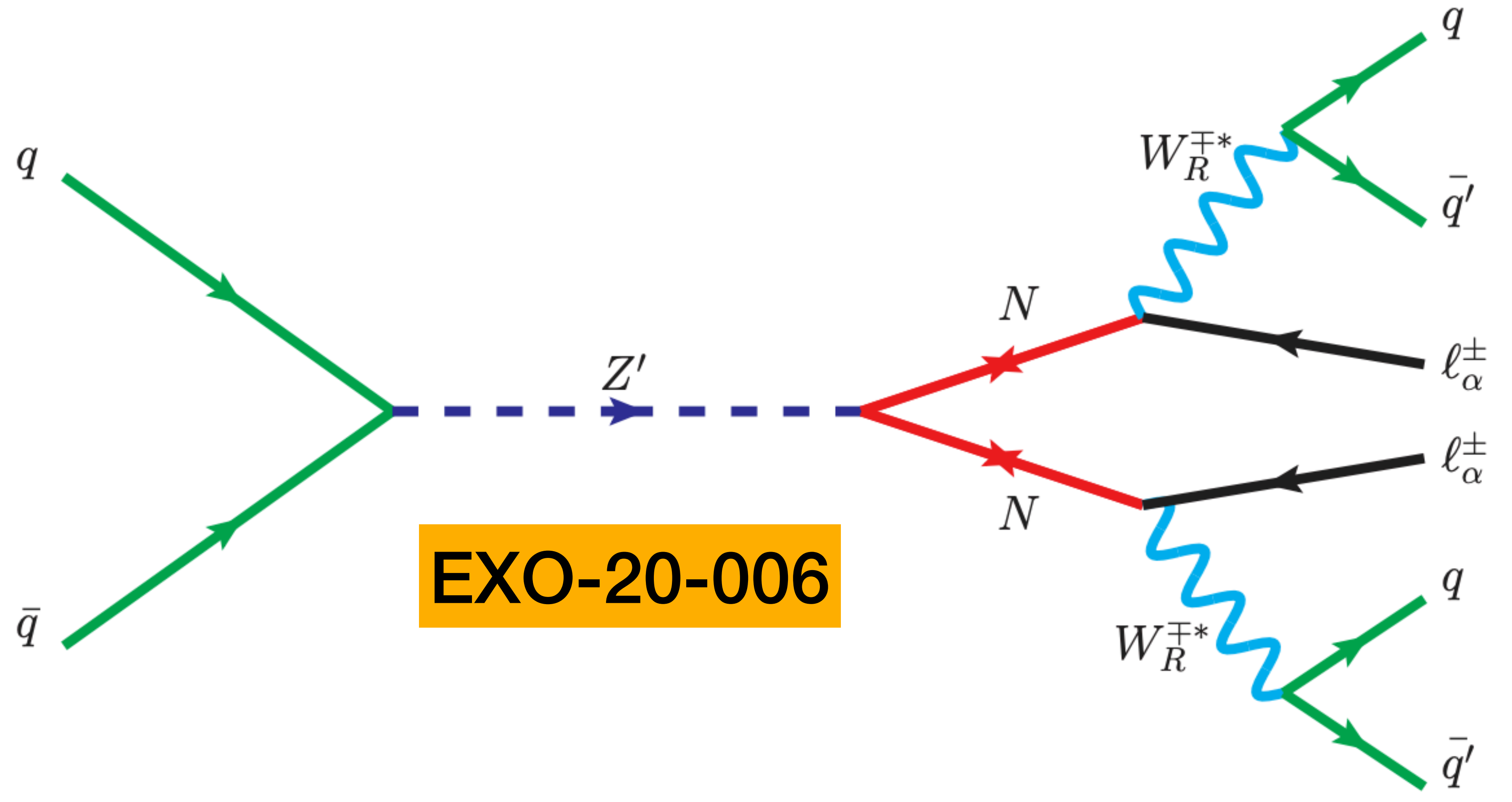


W_R Searches in CMS

Overview

- W_R and Heavy N searches :
  - 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}) (W_R induced)
      (doi:10.1007/JHEP04(2022)047)
    - EXO-20-006 : ee/μμ + jets (RunII, 137 fb^{-1}) (Z' induced)
      (doi:10.1007/JHEP11(2023)181)





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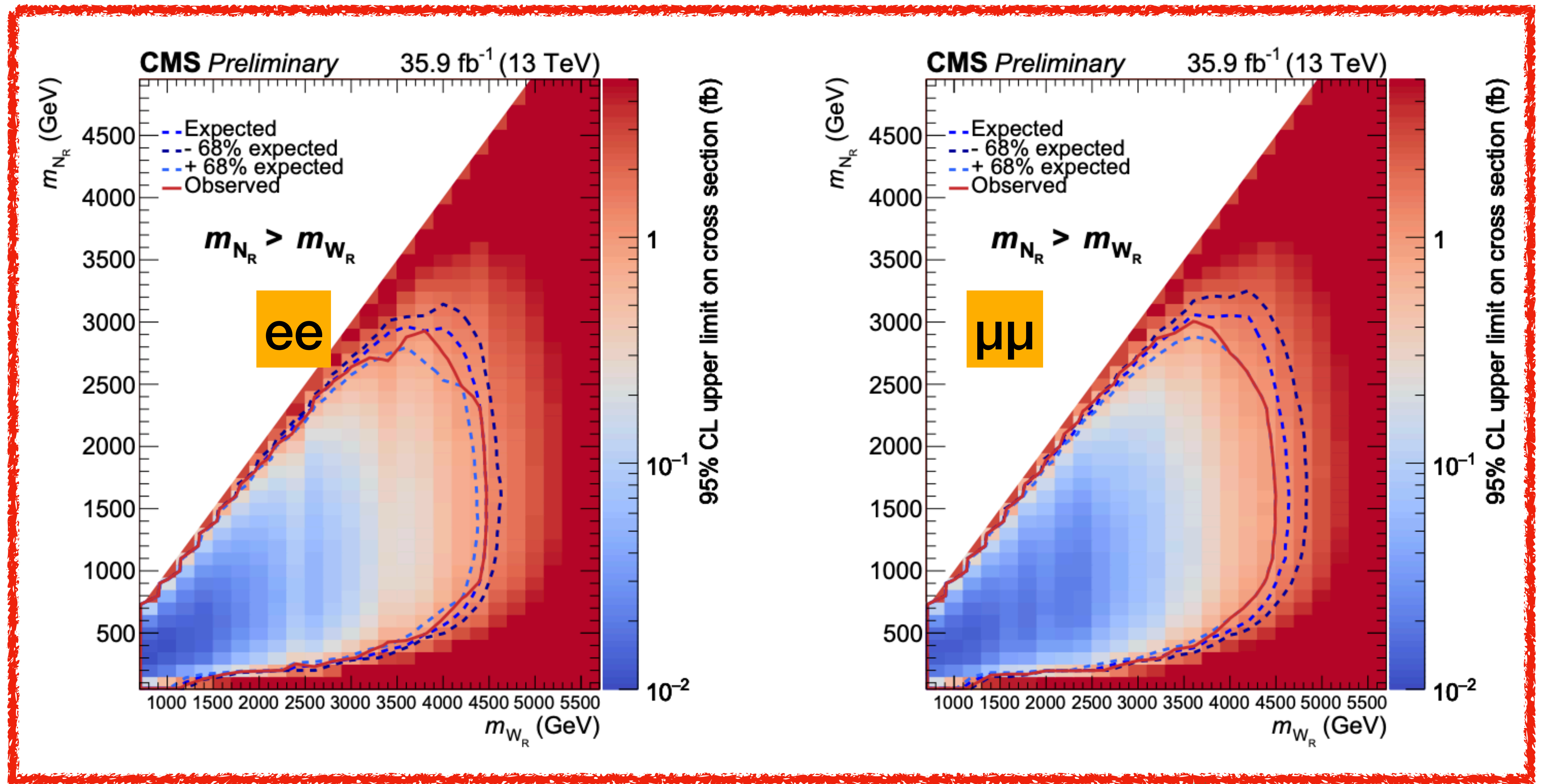
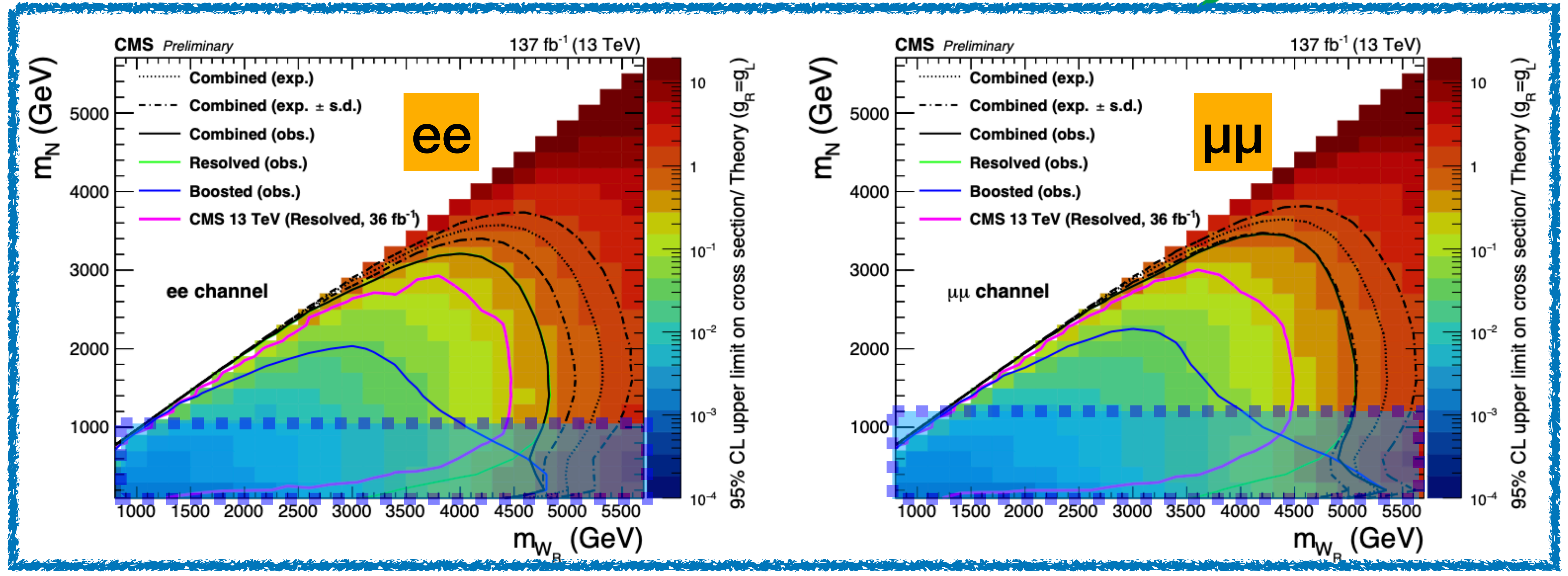
With similar analogy, trying to improve similar phase space region in tau analysis





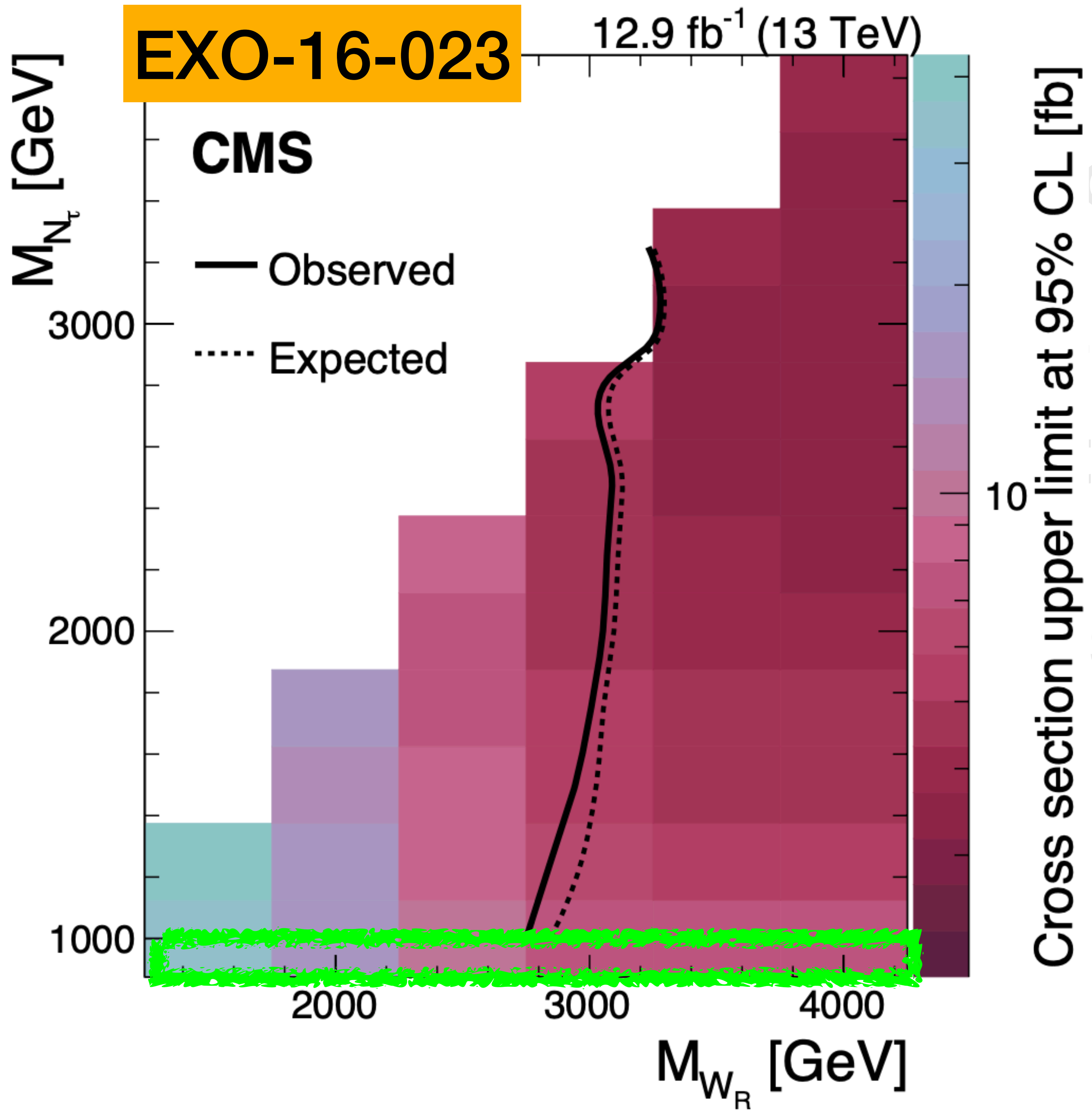
Improvement in regions with $m_{WR} >> m_N$!

Analysis Motivation

Search Strategy

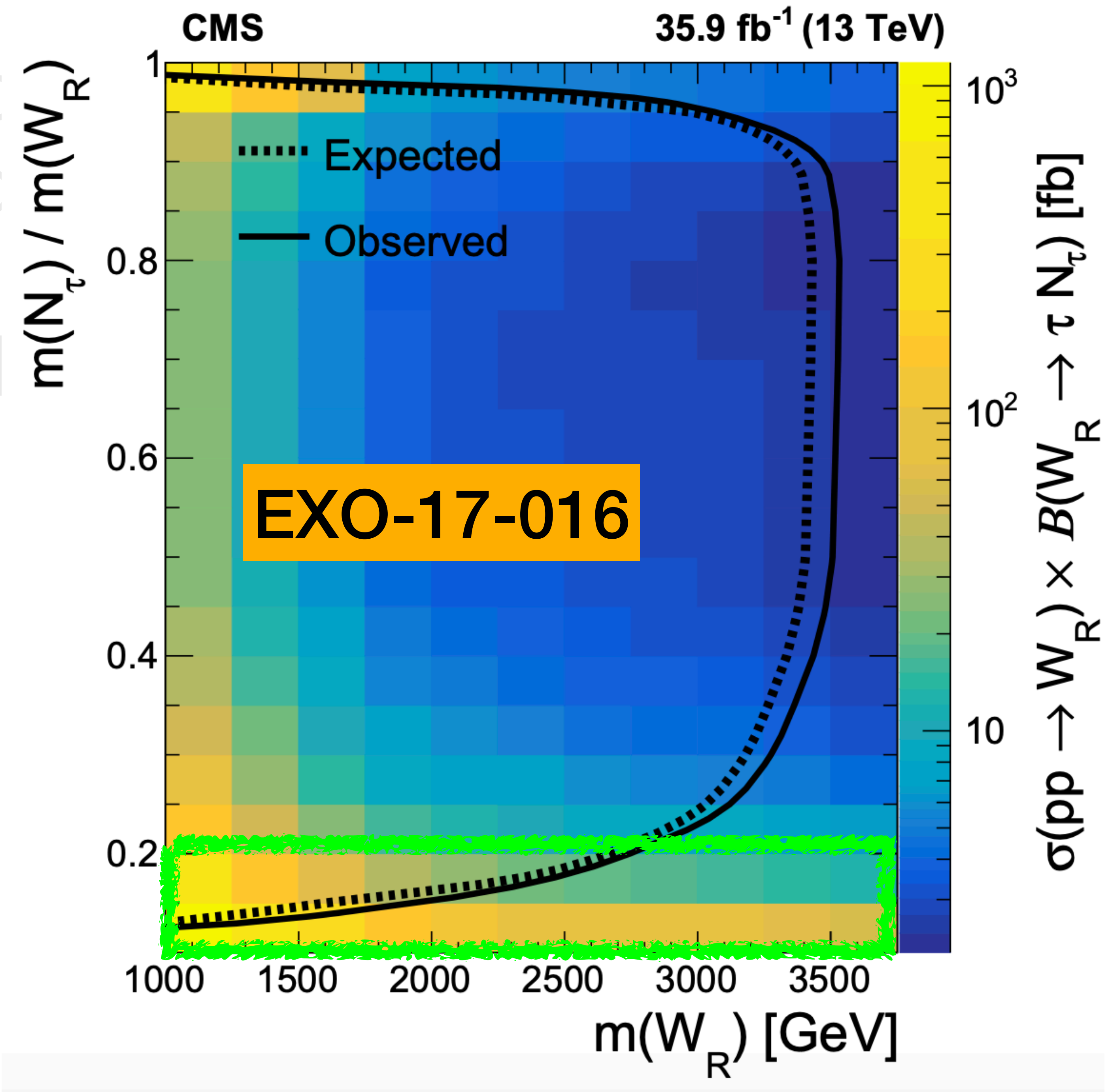
- Adding more sensitivity for W_R search in tau channels in the $\mathbf{m_{WR} >> m_N}$ region.

  - 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 $\mathbf{m_{WR} >> m_N}$ 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

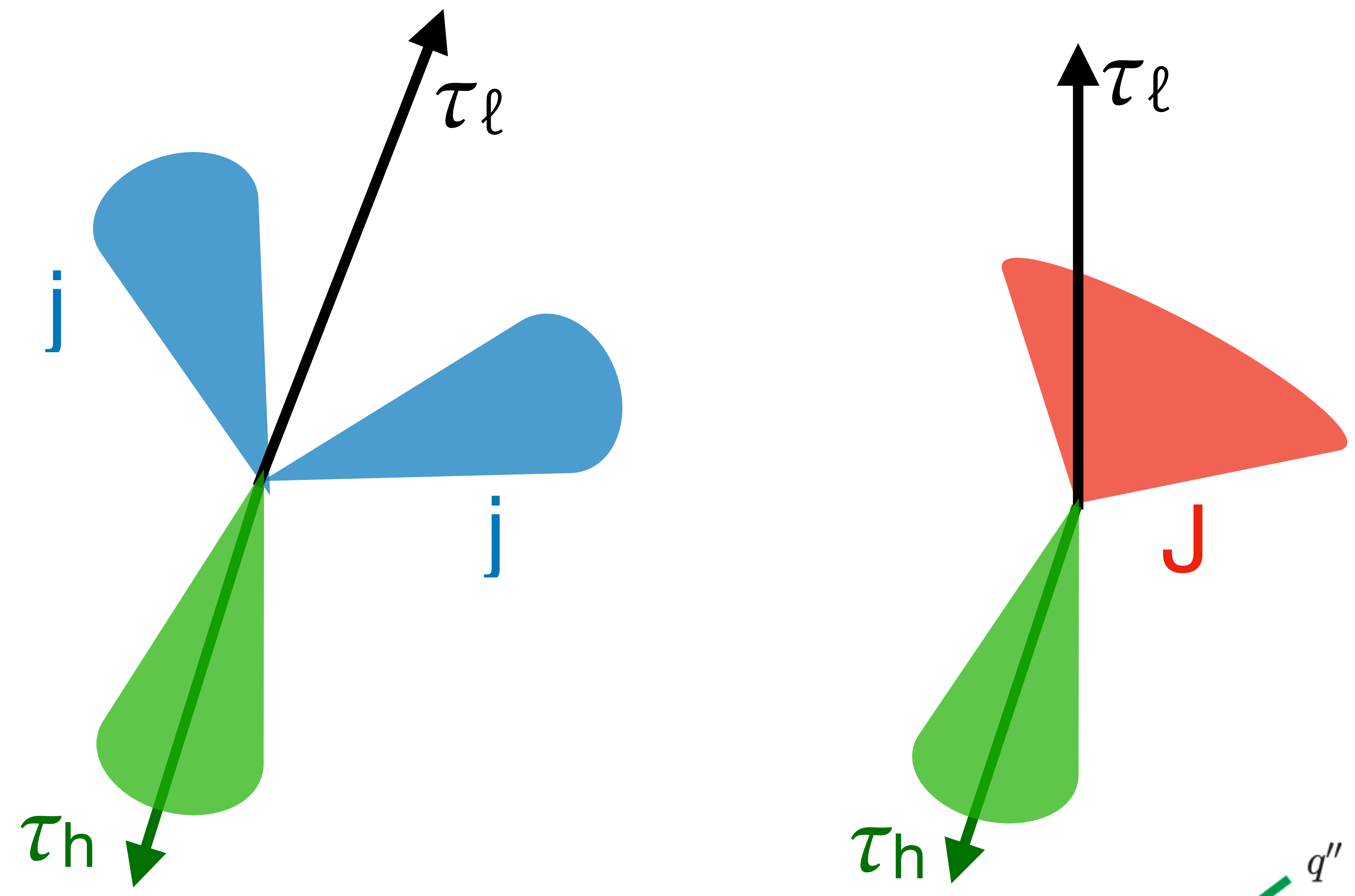
Final Objects

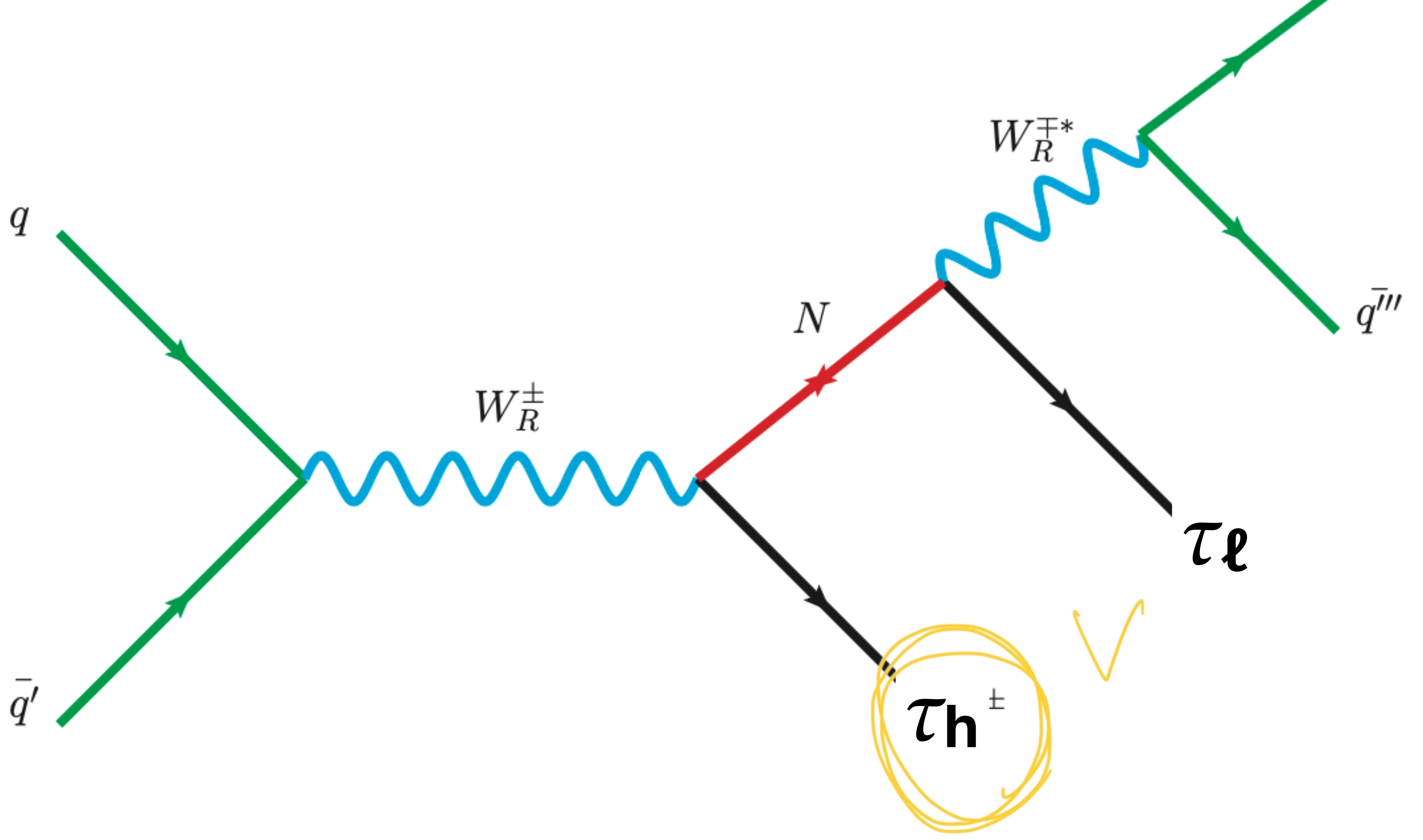
- Target channel

  - **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 ($m_{WR} >> m_N$)



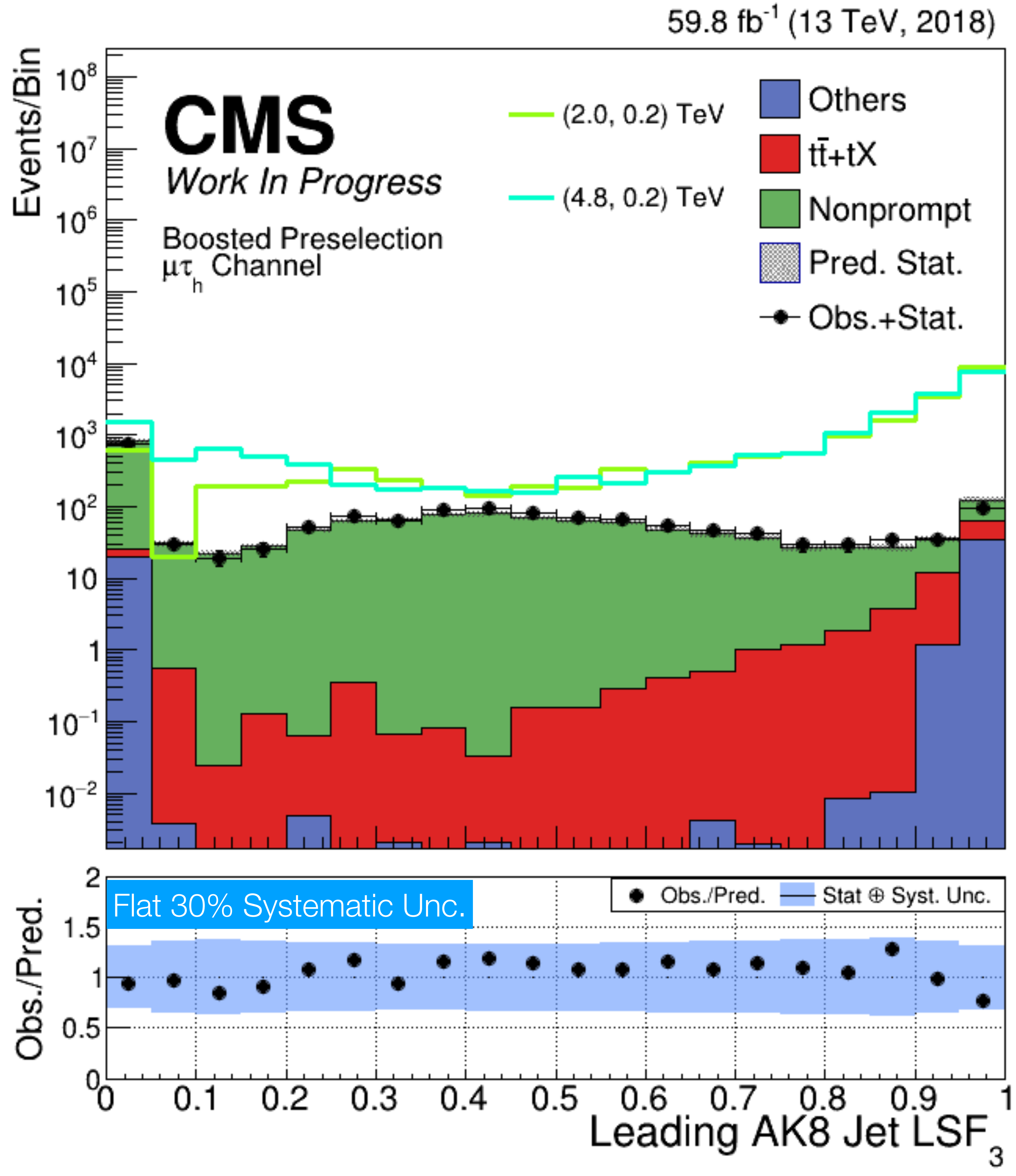


Signals
Lepton Subjet Fraction

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

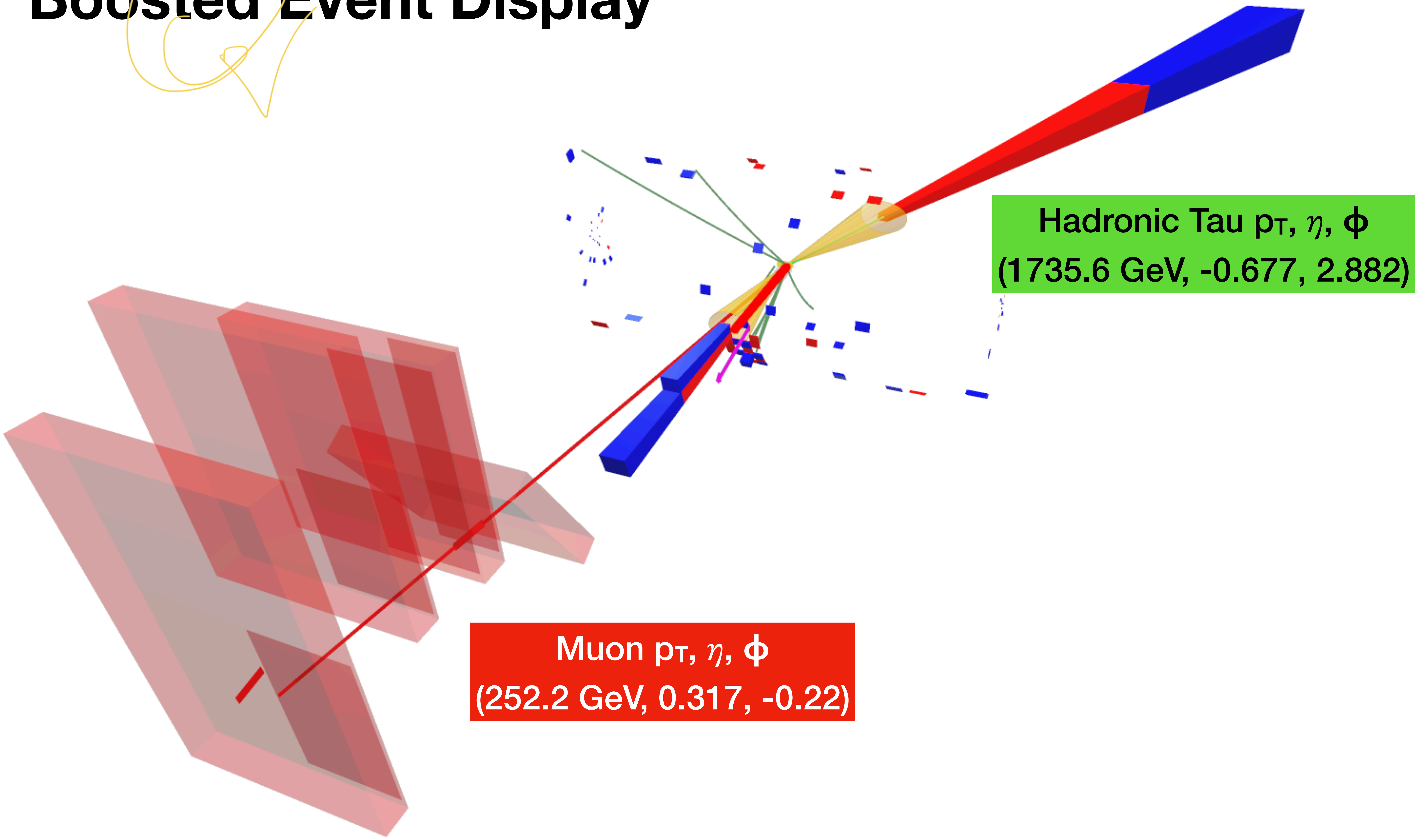
  - Variable devised to distinguish fat jets that are likely to contain a lepton :

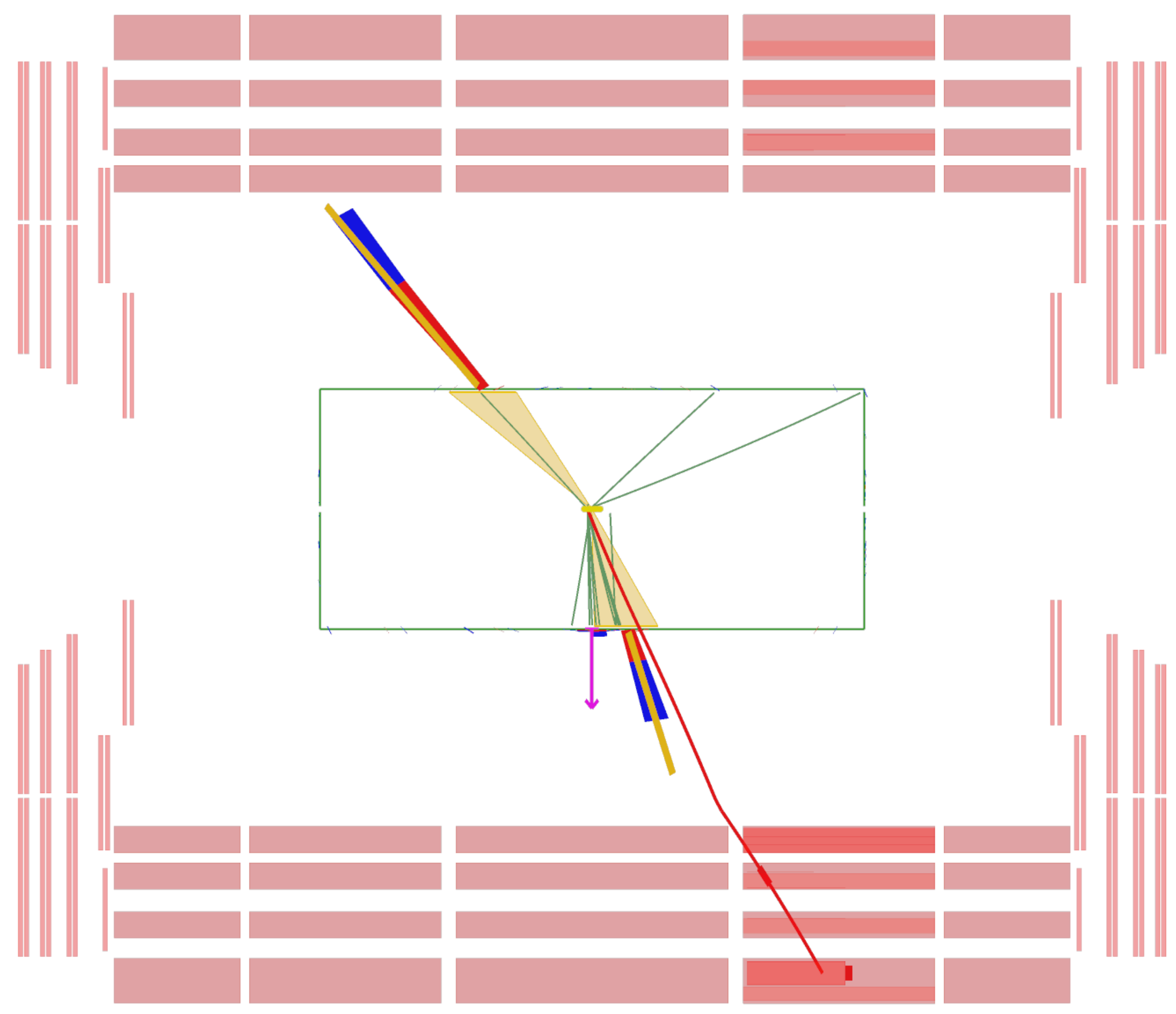
    - For a given fat jet, constituents are clustered into 3 subjets using the exclusive kT algorithm
    - Between all pair of particles, cluster them with minimum distance $d_{ij} = \min(p_T, p_T) R_{ij}$ into a single subjet until only 3 are left
    - Doing so, all leptons in the event will be associated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

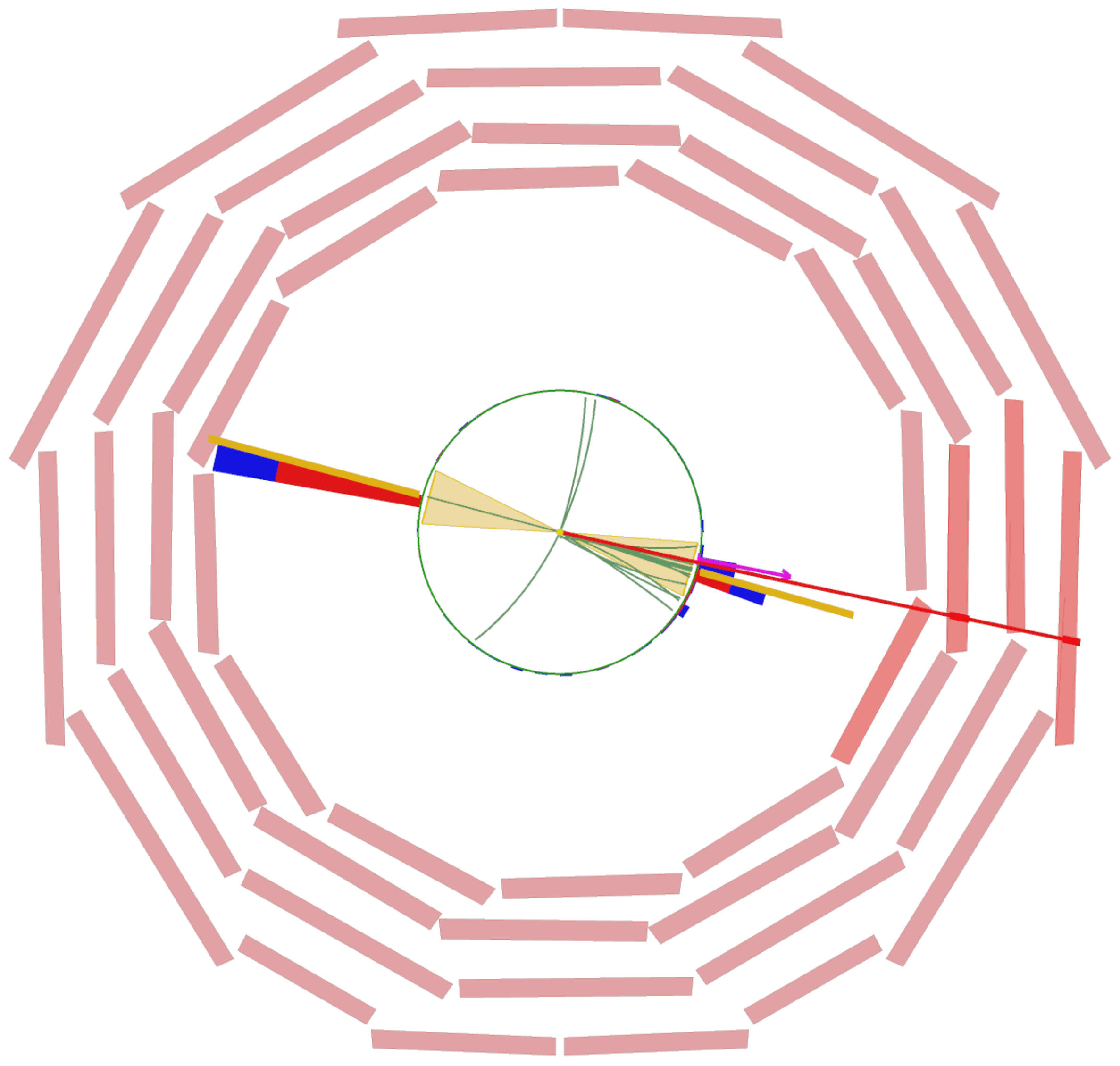


Signals

Boosted Event Display





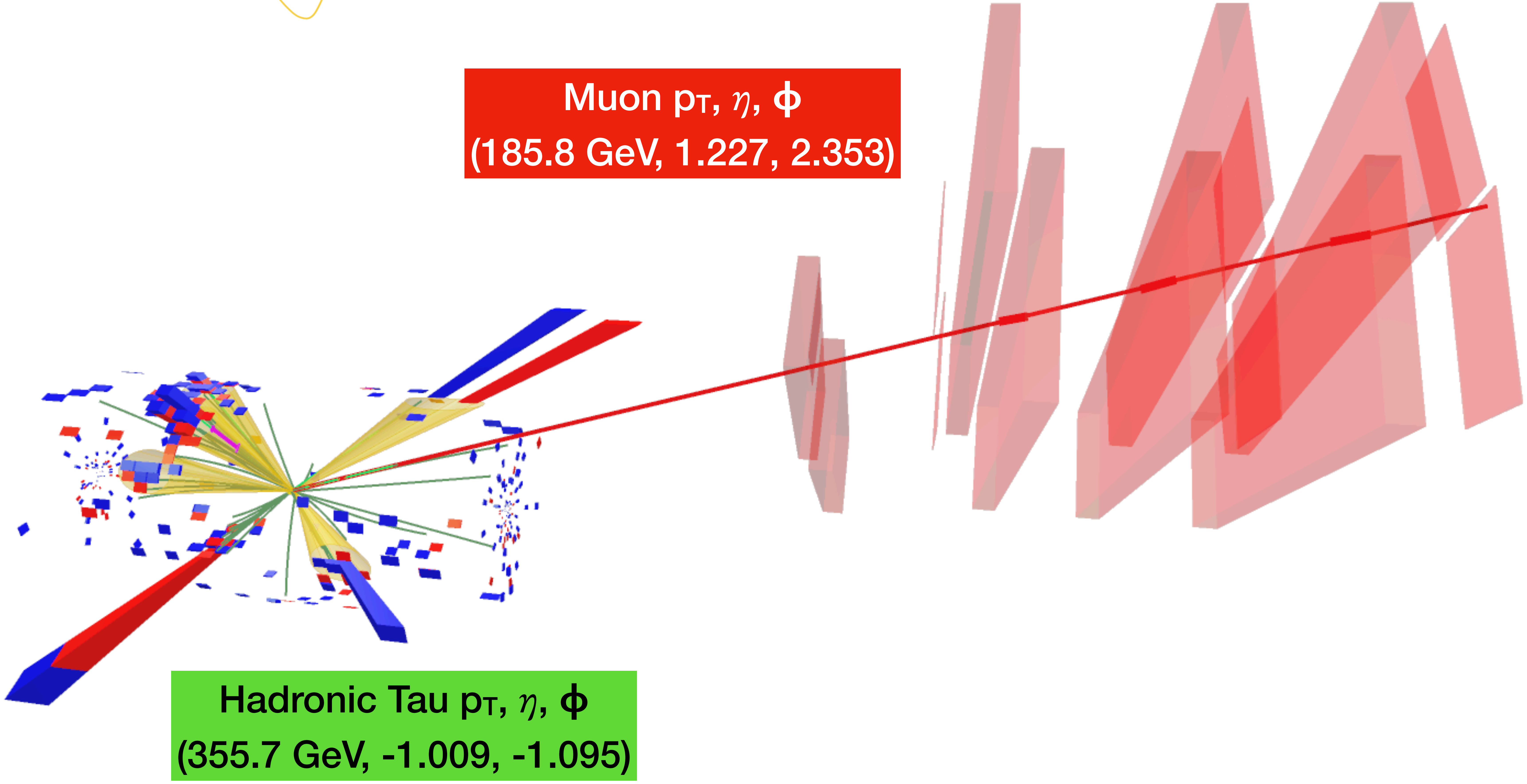


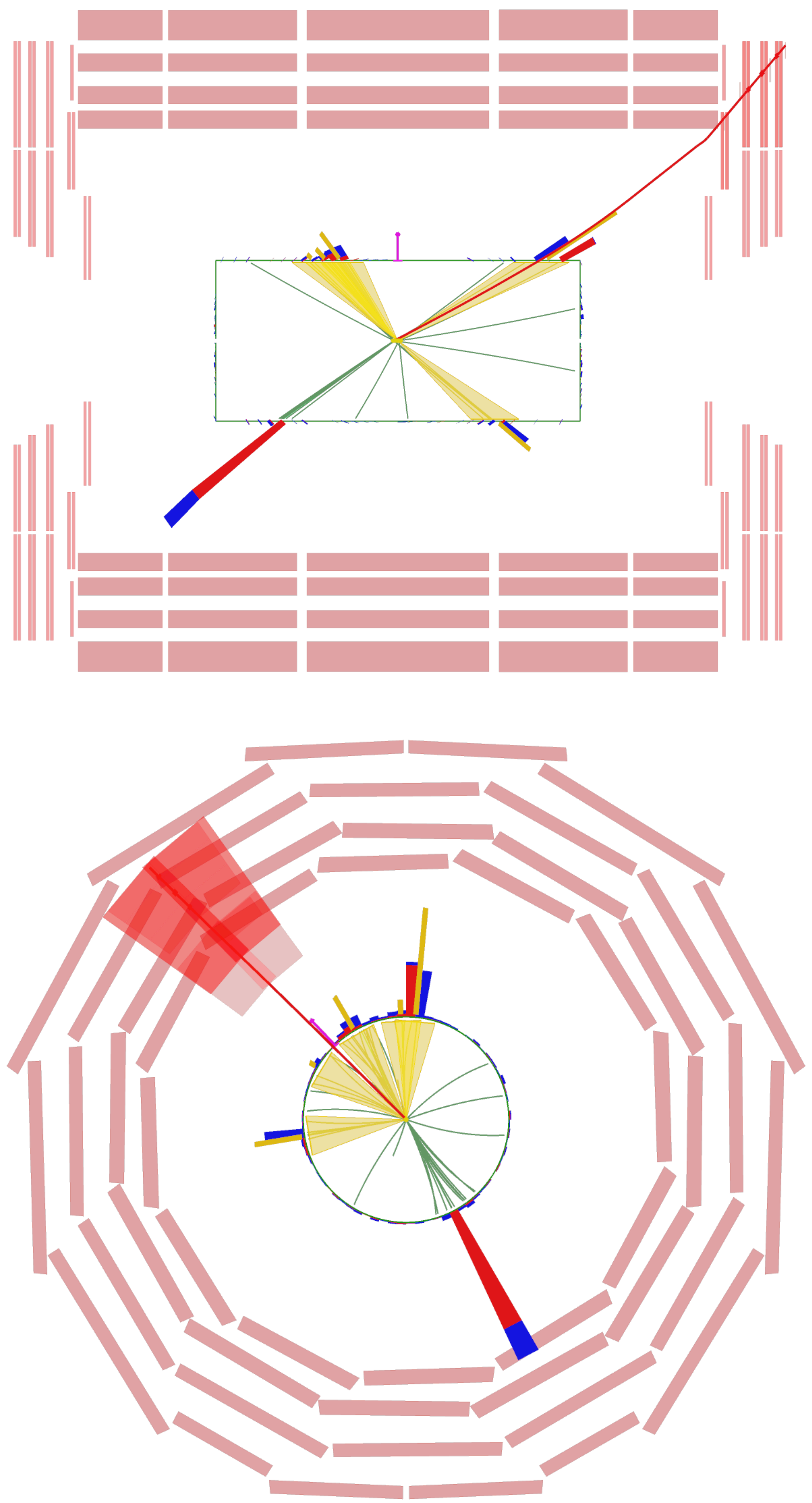
(run:lumi:event) = (1:54:81888) of (mWR,mN) = (4.8 TeV, 200GeV)

/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)

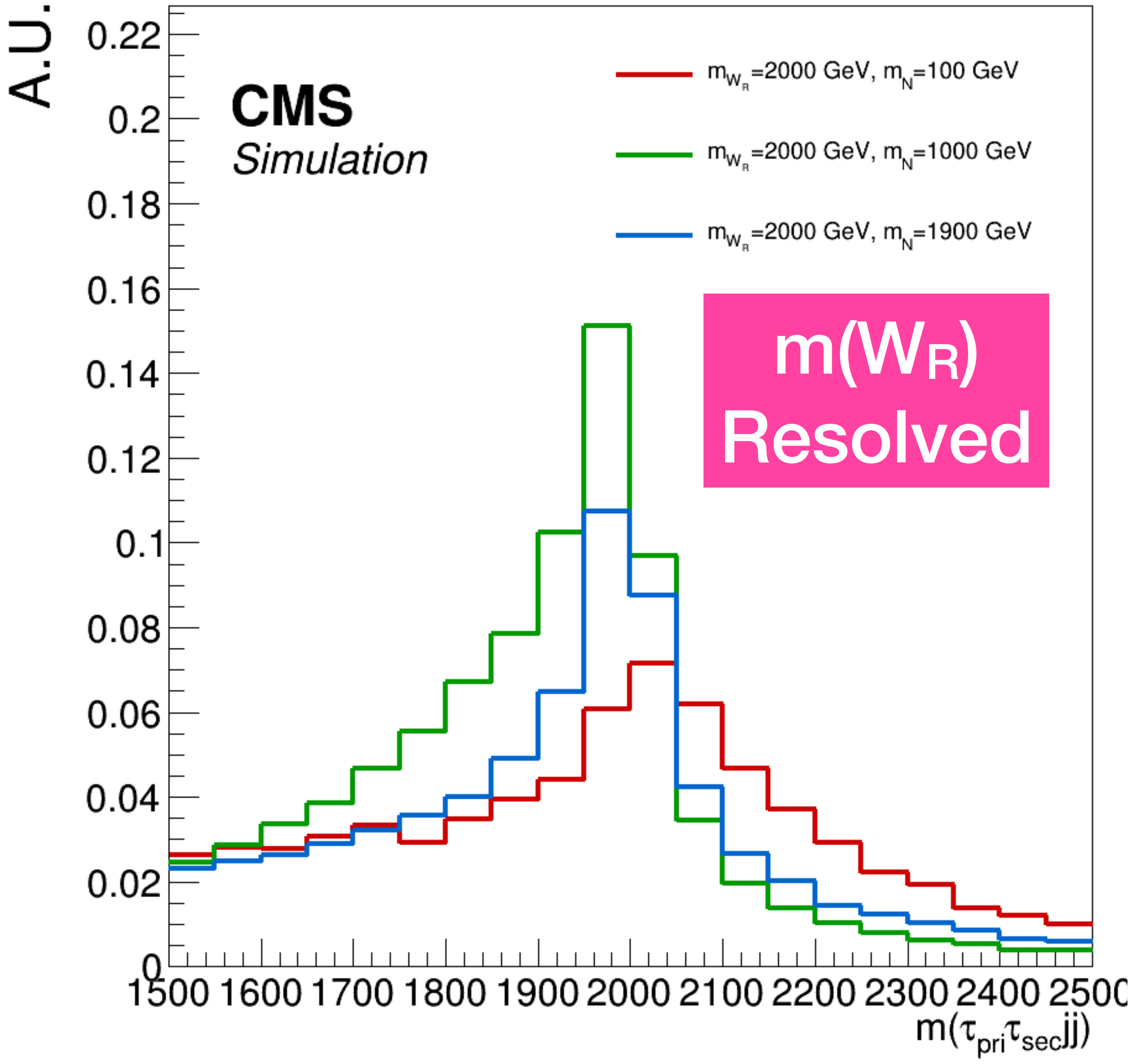
/WRtoTauNtoTauTauJets_WR4800_N4700_TuneCP5_13TeV-madgraph-pythia8/RunIISummer20UL16MiniAODAPVv2-106X_mcRun2_asymptotic_preVFP_v11-v2/MINIAODSIM

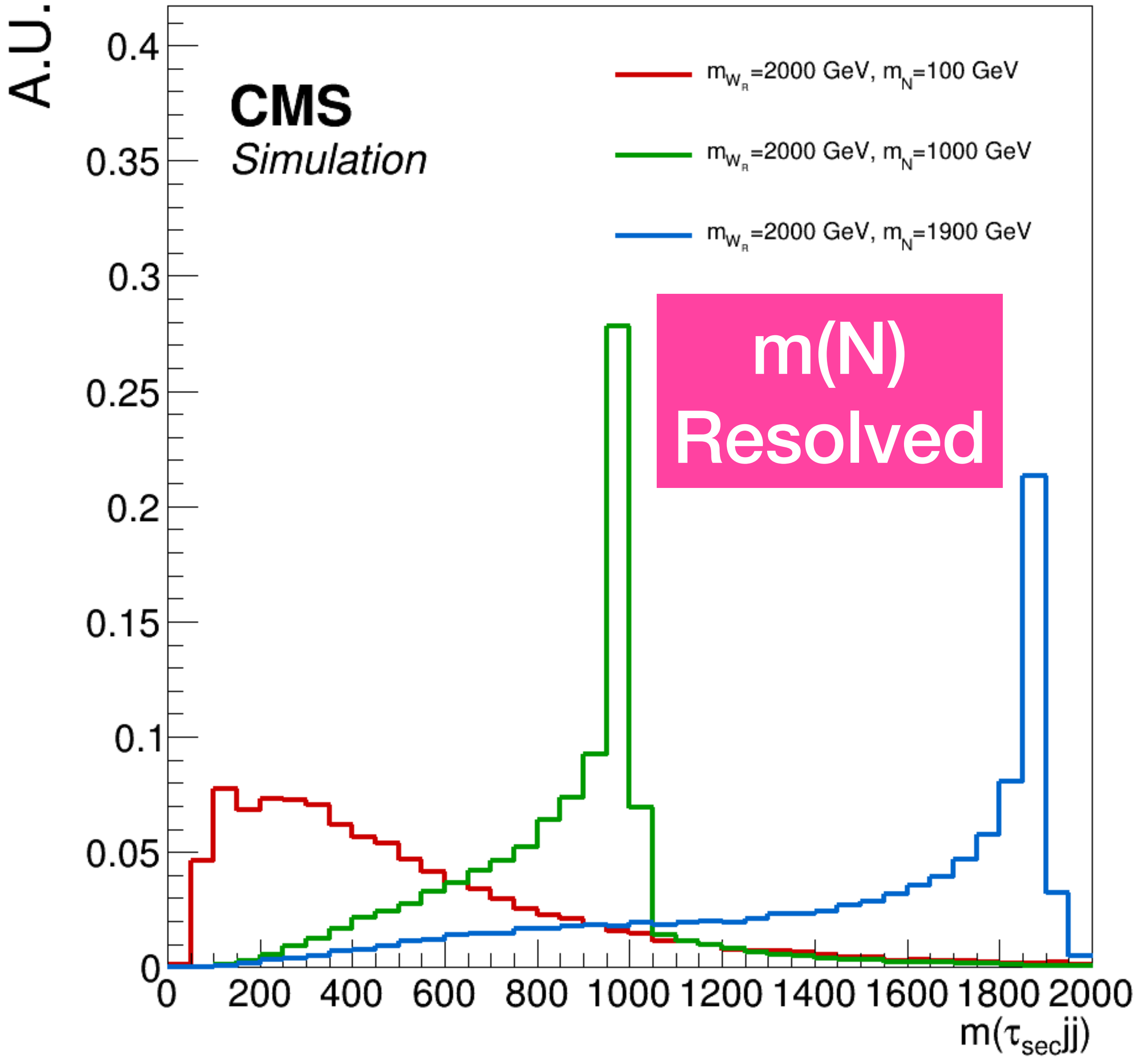
Signal Kinematics

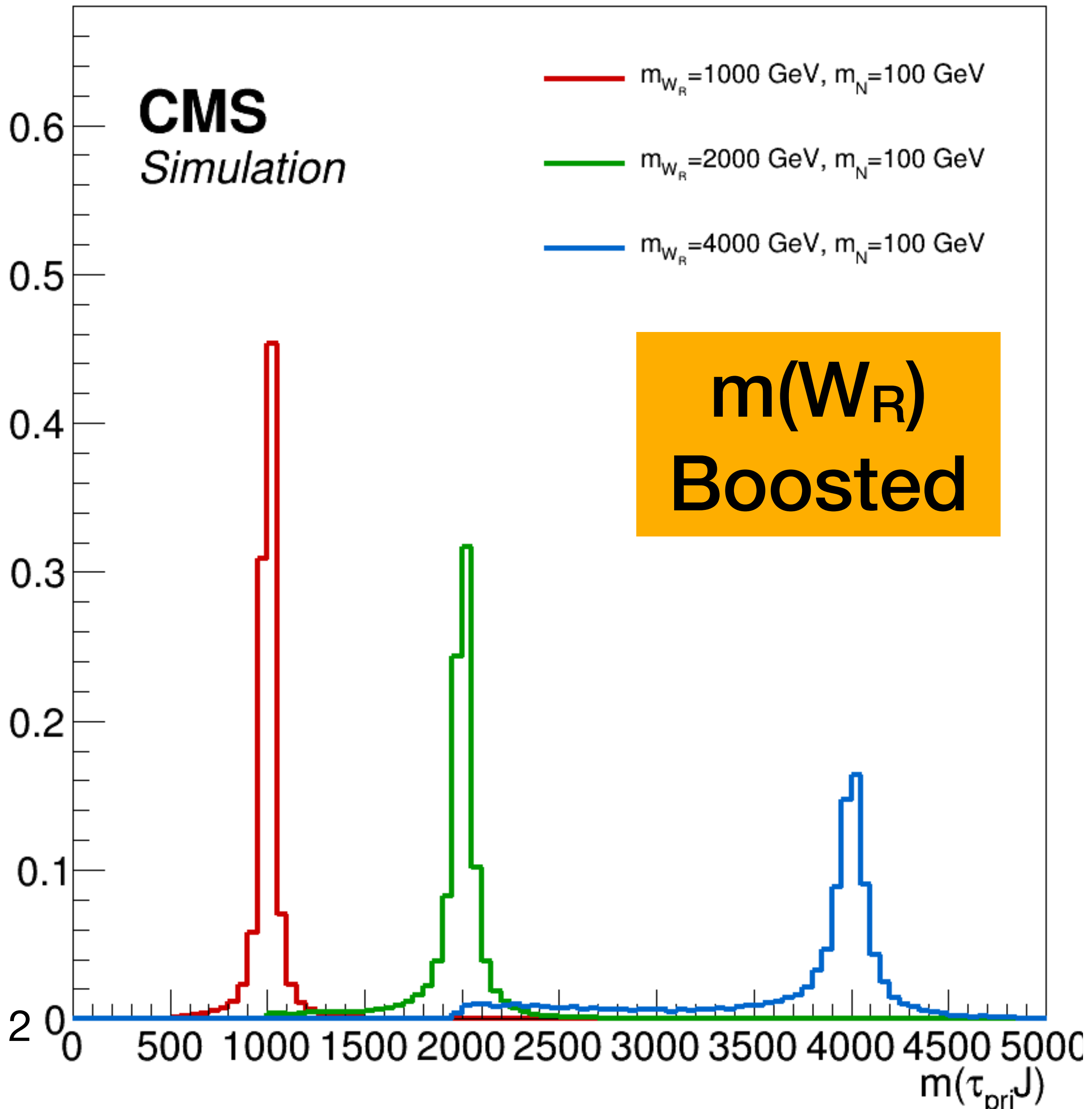
- Resolved region legend :
  - mWR = **2 TeV**
  - mN = **100,1000,1900 GeV**

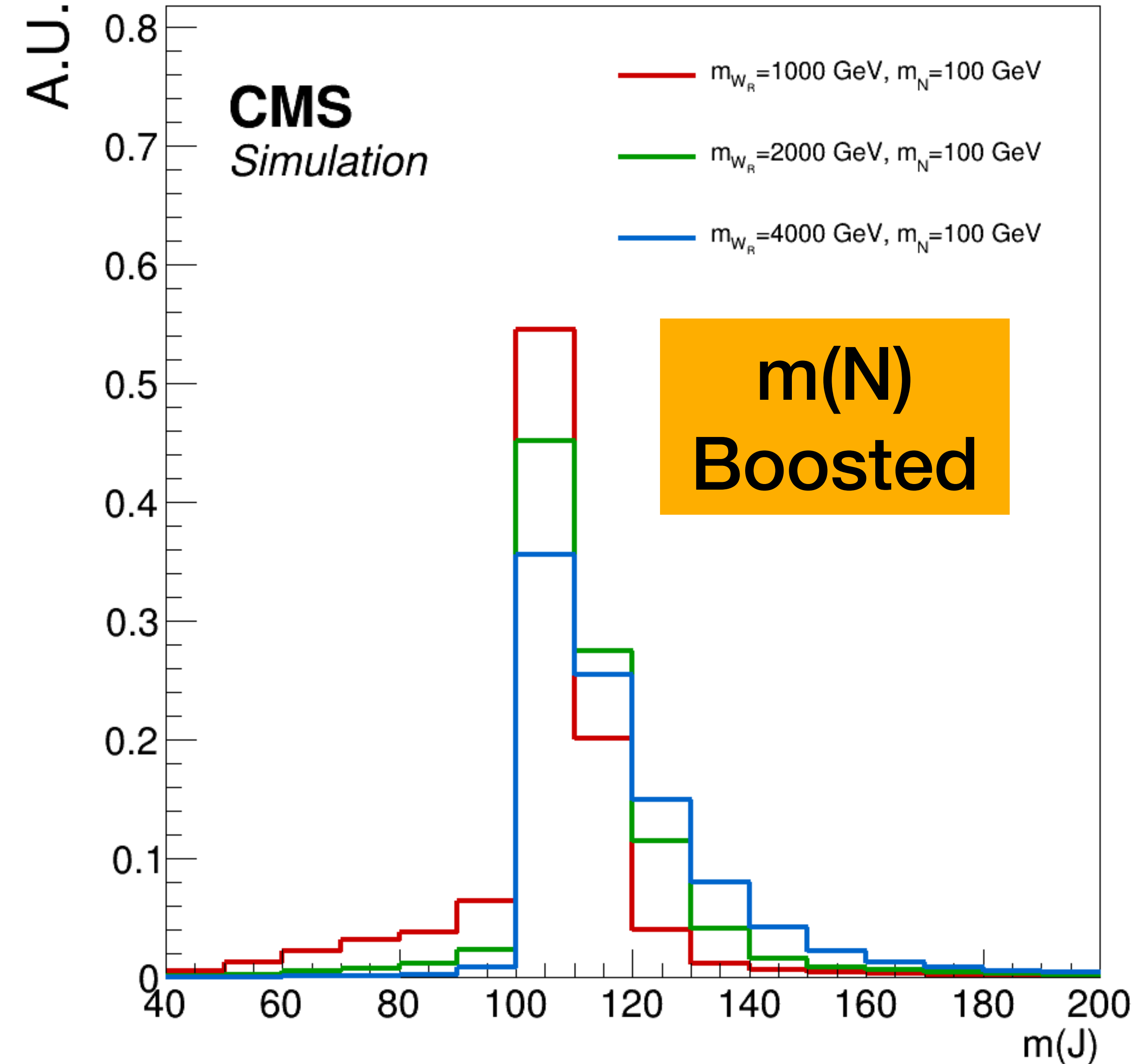
- Boosted region legend :
  - mWR = **1,2,4 TeV**
  - mN = **100 GeV**

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









Objects

Definition

- Muon
  - p_T > 50 GeV , $|\eta|$ < 2.4
  - Tight ID : POG High pT & Tracker isolation < 0.1
  - Loose ID : POG High pT
- Electron
  - p_T > 50 GeV , $|\eta|$ < 2.4
  - Tight ID : (Table)
  - Loose ID : POG HEEP ID
- Tau
  - p_T > Trigger safe cut , $|\eta|$ < 2.4
  - DecayModeNewDM & $|dZ|$ < 0.2
  - DeepTau v2.1 (vJet,vEl,vMu) = (Tight,Tight,Tight)

	Barrel	Endcap
$\sigma_{i\eta i\eta}$	$\sigma_{i\eta i\eta} < 0.0012$	$\sigma_{i\eta i\eta} < 0.0425$
$\Delta\eta^{seed}$	$|\Delta\eta^{seed}| < 0.00377$	$|\Delta\eta^{seed}| < 0.00674$
$\Delta\phi^{in}$	$|\Delta\phi^{in}| < 0.0884$	$|\Delta\phi^{in}| < 0.169$
H/E	< 0.5	
E^{-1}-p^{-1}	$|E^{-1}-p^{-1}| < 0.193$	$|E^{-1}-p^{-1}| < 0.169$
# Missing Hits	≤ 1	

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

Objects

Corrections

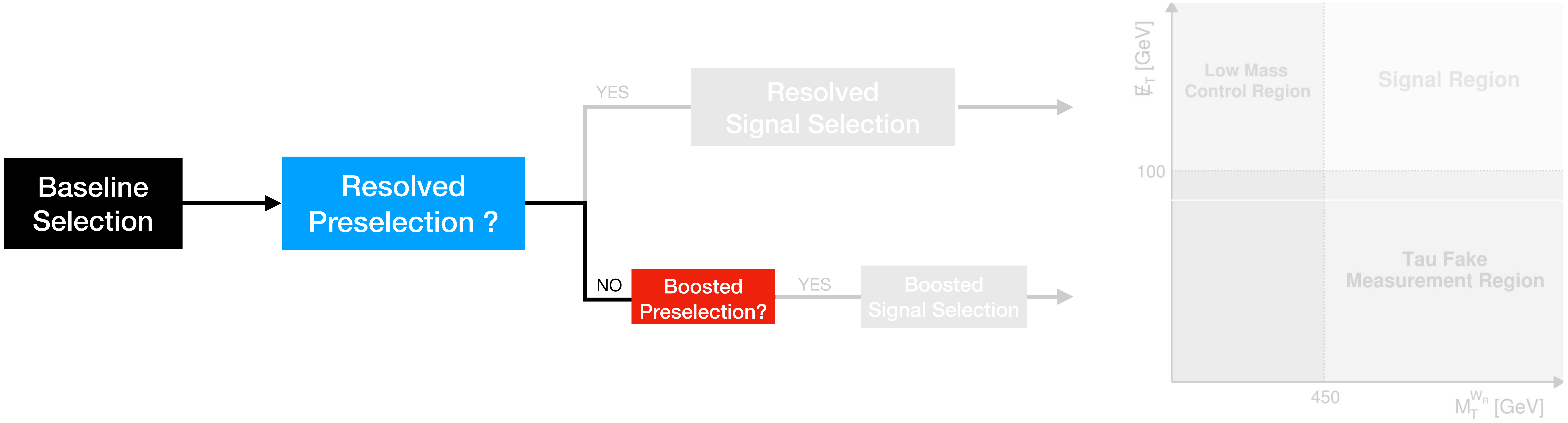
- Event
  - Pileup weight, Trigger SF, L1 Prefire weight
- Muon, Electron
  - Isolation SF , ID SF
- Tau
  - DeepTau ID SF
- Fatjet
  - LSF SF (not yet implemented for UL)
    - Using prelegacy SFs from EXO-20-002 at the moment

	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	1.02	1.05
Muon Fatjet	1.01	0.98	1.04

Region Selection

Definition



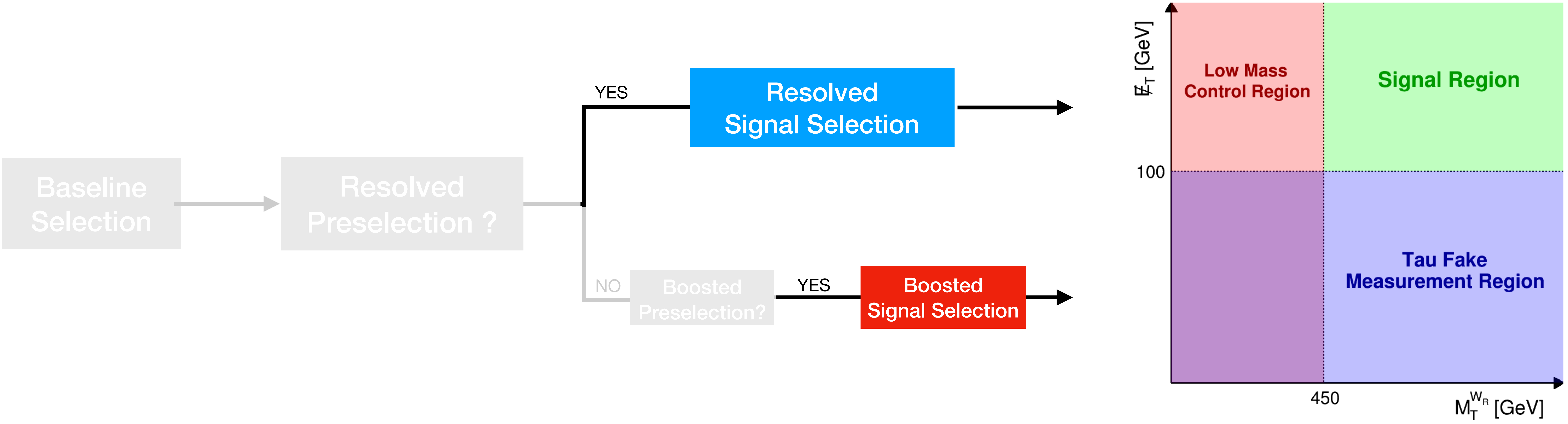
Baseline Selection
- Pass single hadronic tau trigger
- Require at least 1 hadronic tau
- Require exactly 1 loose light lepton

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

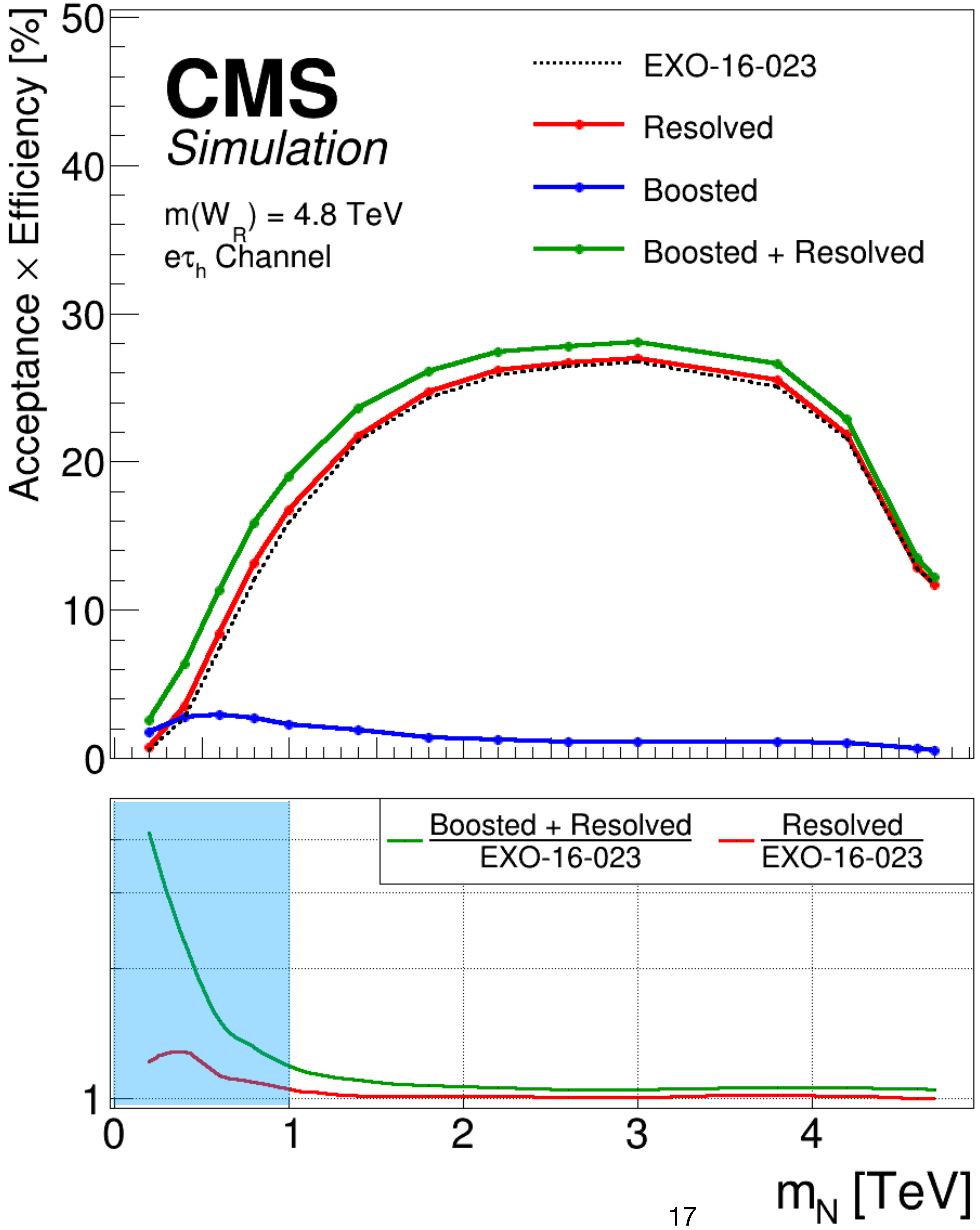
- Passing boosted preselection
- ΔR(tau, J) > 2.0 with LSF(J) > 0.6
- ΔR(lepton, J) < 0.8

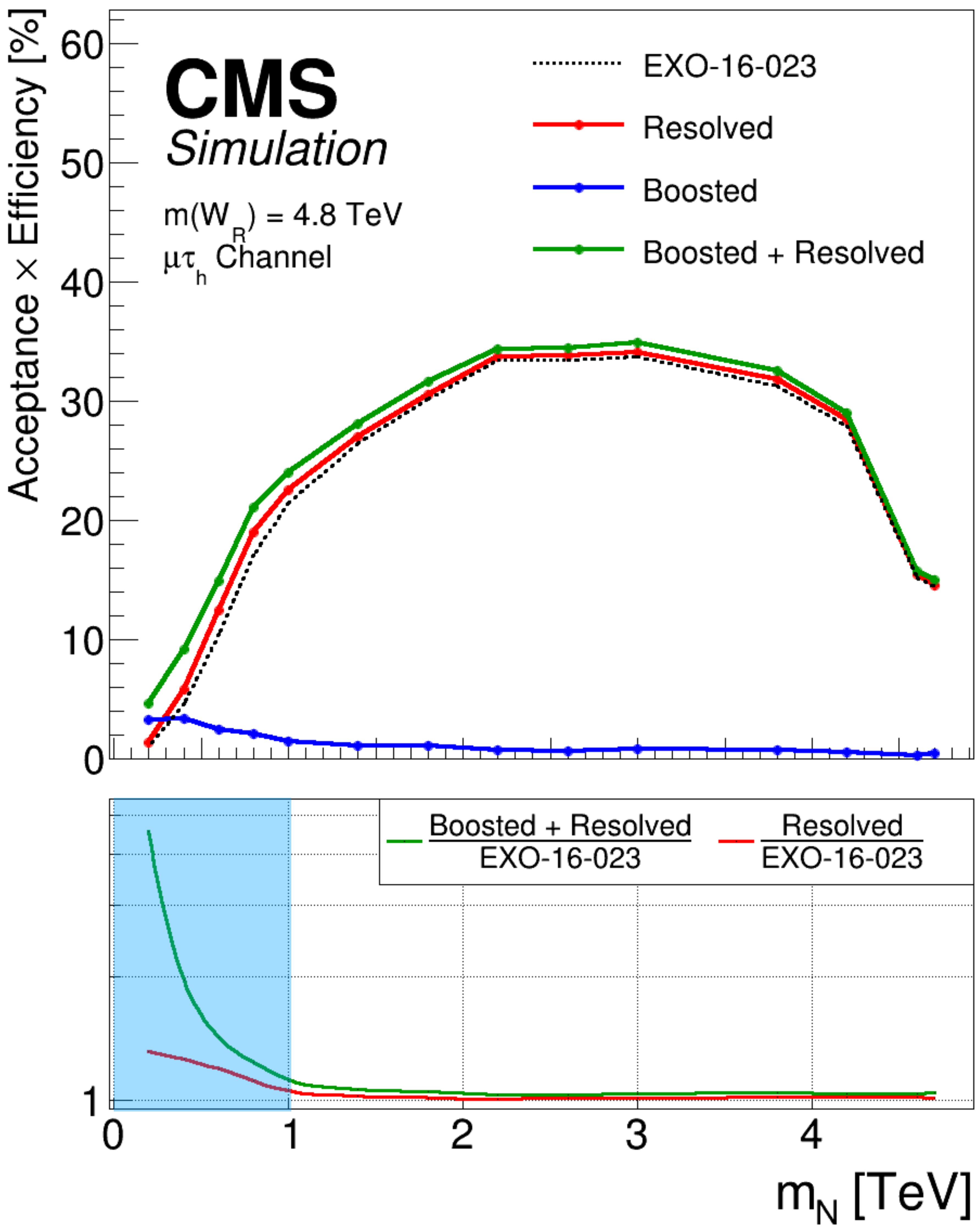
Selection Efficiency

Signals

Efficiency calculated from corresponding Gen-matched channels

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





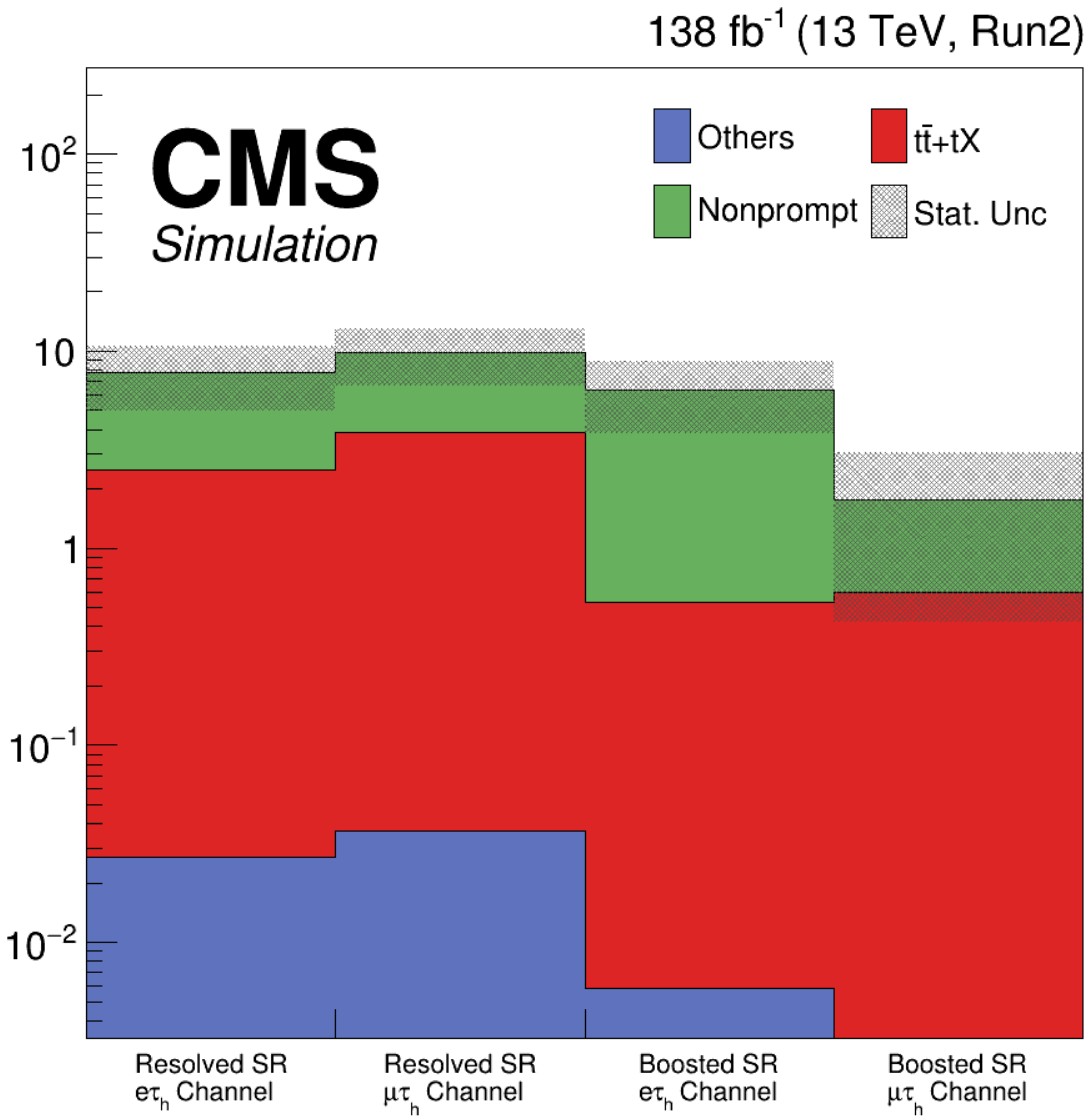
Background Estimation
Contributions

- Prompt contributions

  - Top pair, single top processes (tt+X)
  - W,Z+jets, multiboson(VV,VVV) processes (Others)

- Non-prompt 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



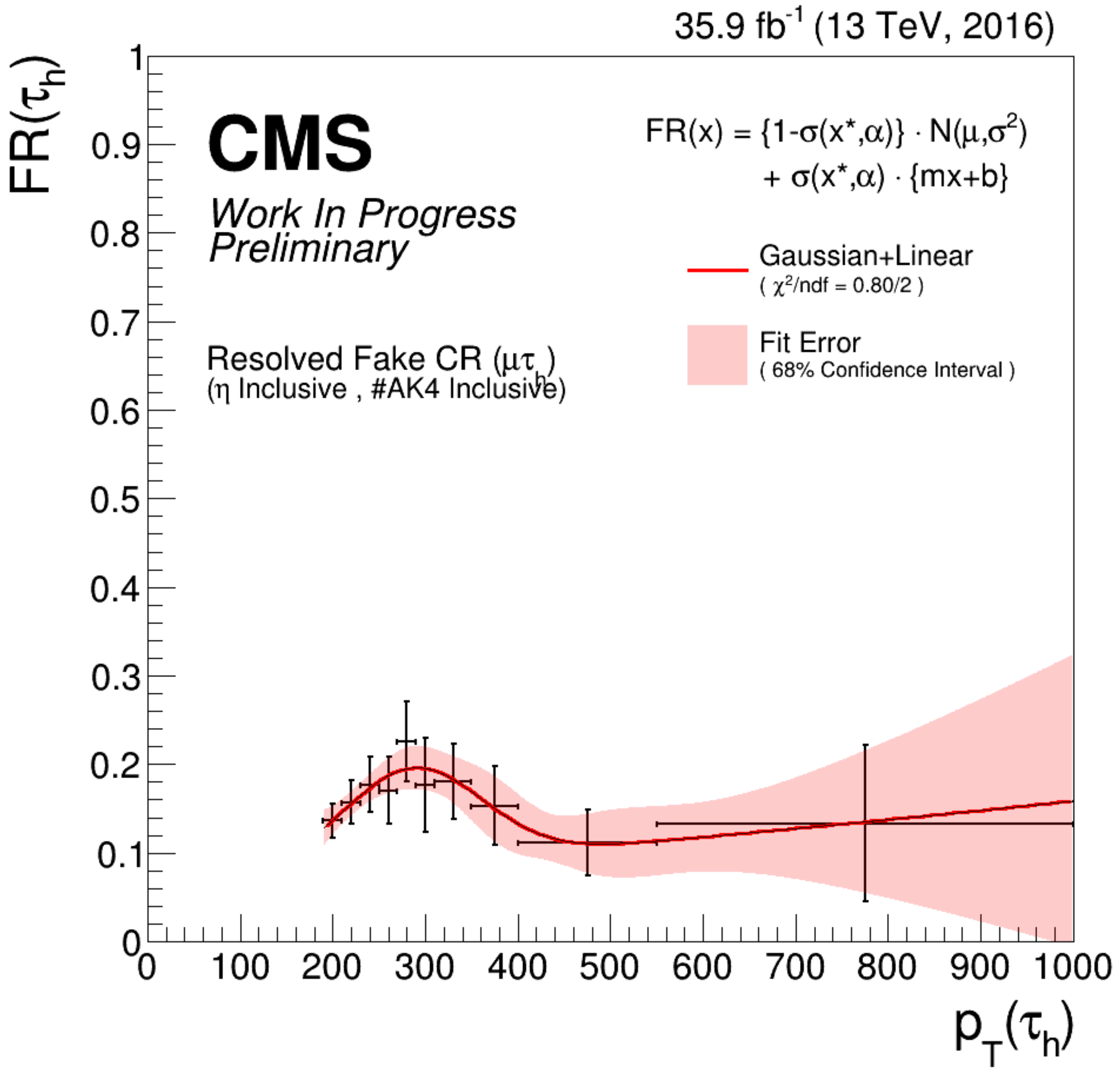
Background Estimation

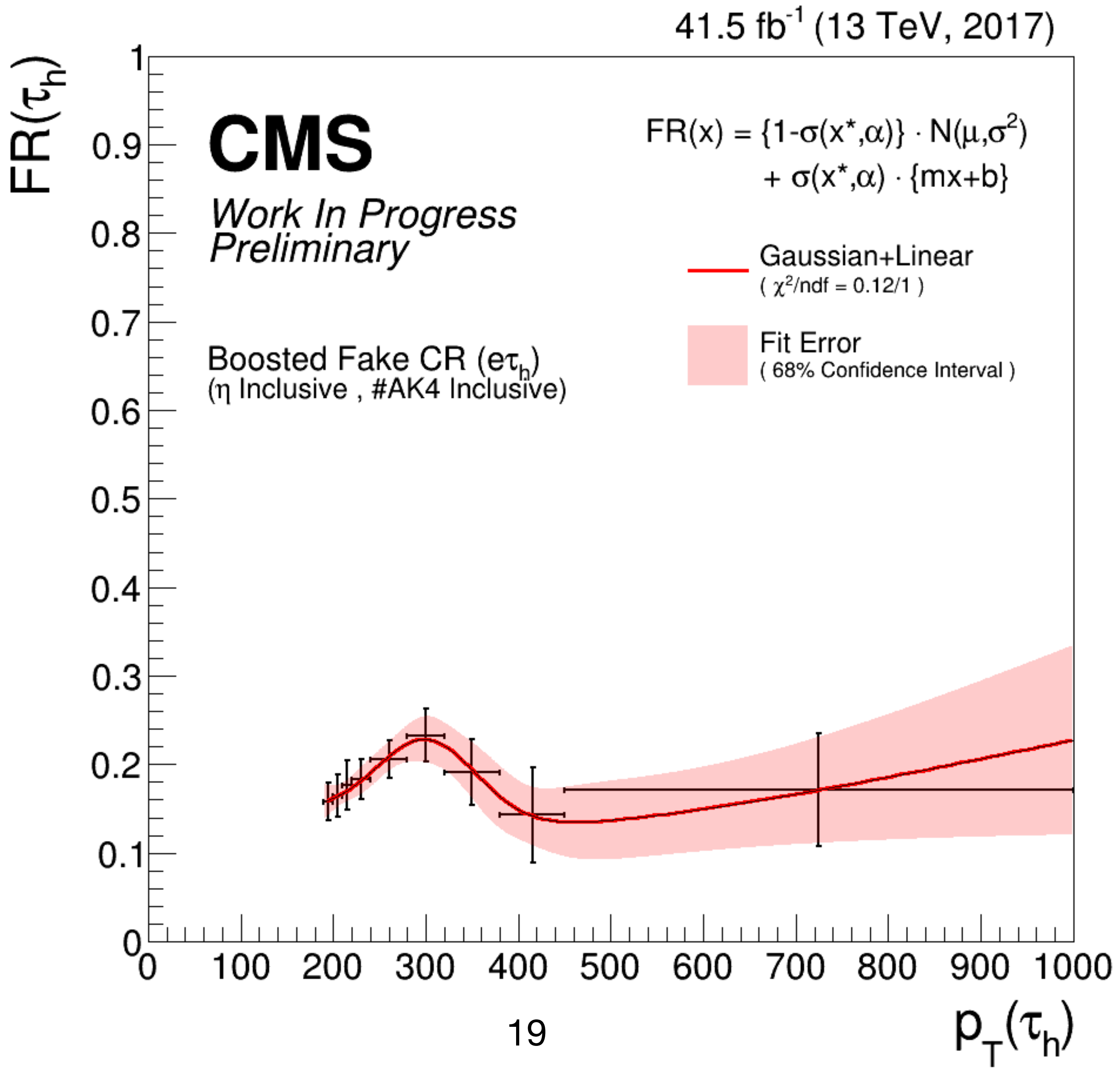
Nonprompt τ_h Contribution

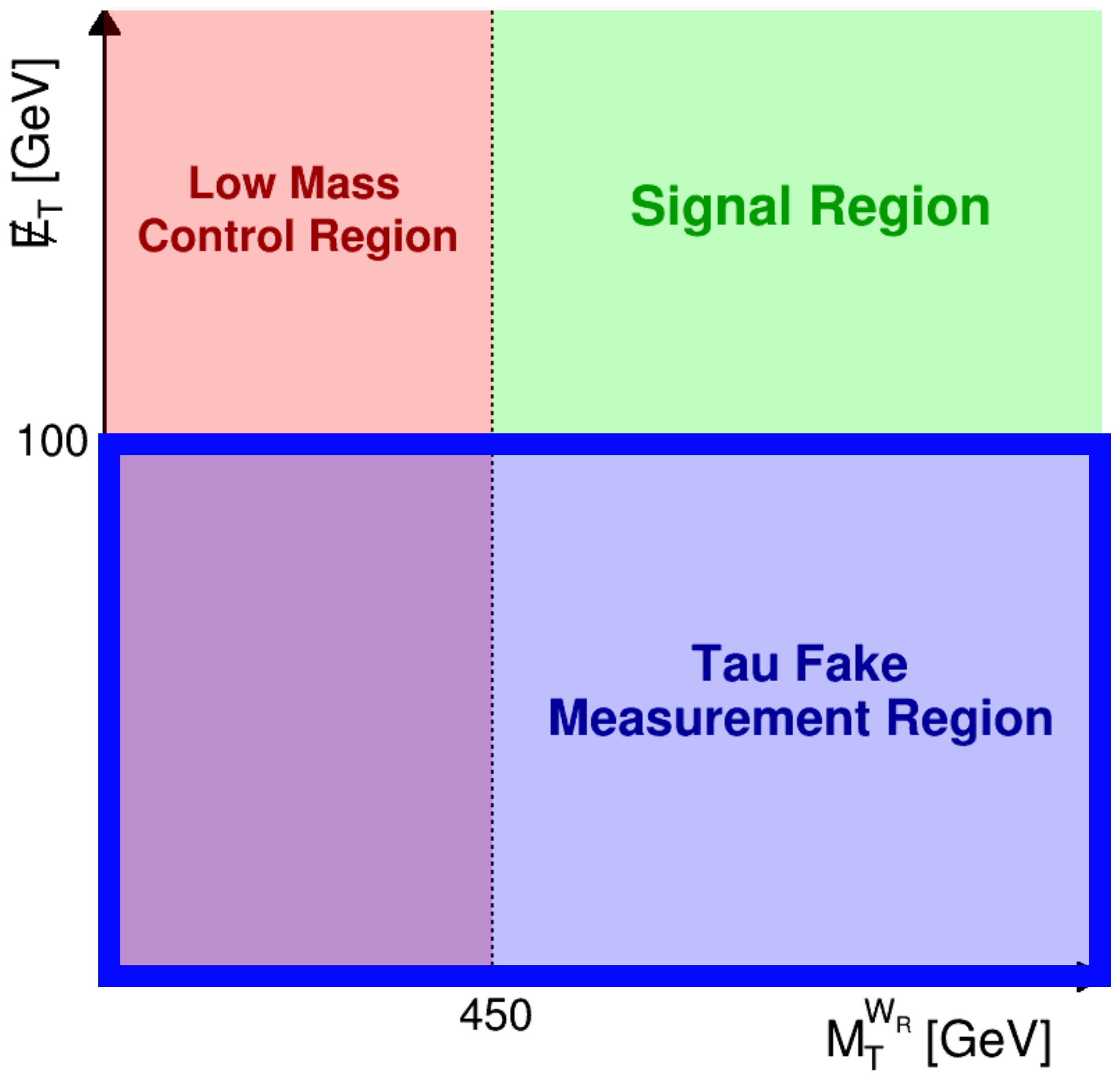
- Jets being misidentified as hadronic taus has the biggest background contribution
  - Inaccurate to estimate from MC simulations : data-driven estimation is used
- **Orthogonal region with SR** by inverting MET cut
  - Fake rate defined as loose-to-tight ratio with prompt subtraction for each kinematic region
    - Ratio between DeepTau V2.1 vsJet WP VVVLoose to Tight
  - Several functions are tested to fit fake rates (Gaussian + Polynomial, …)

Methodology borrowed from EXO-22-018

doi:10.1103/PhysRevLett.132.061801







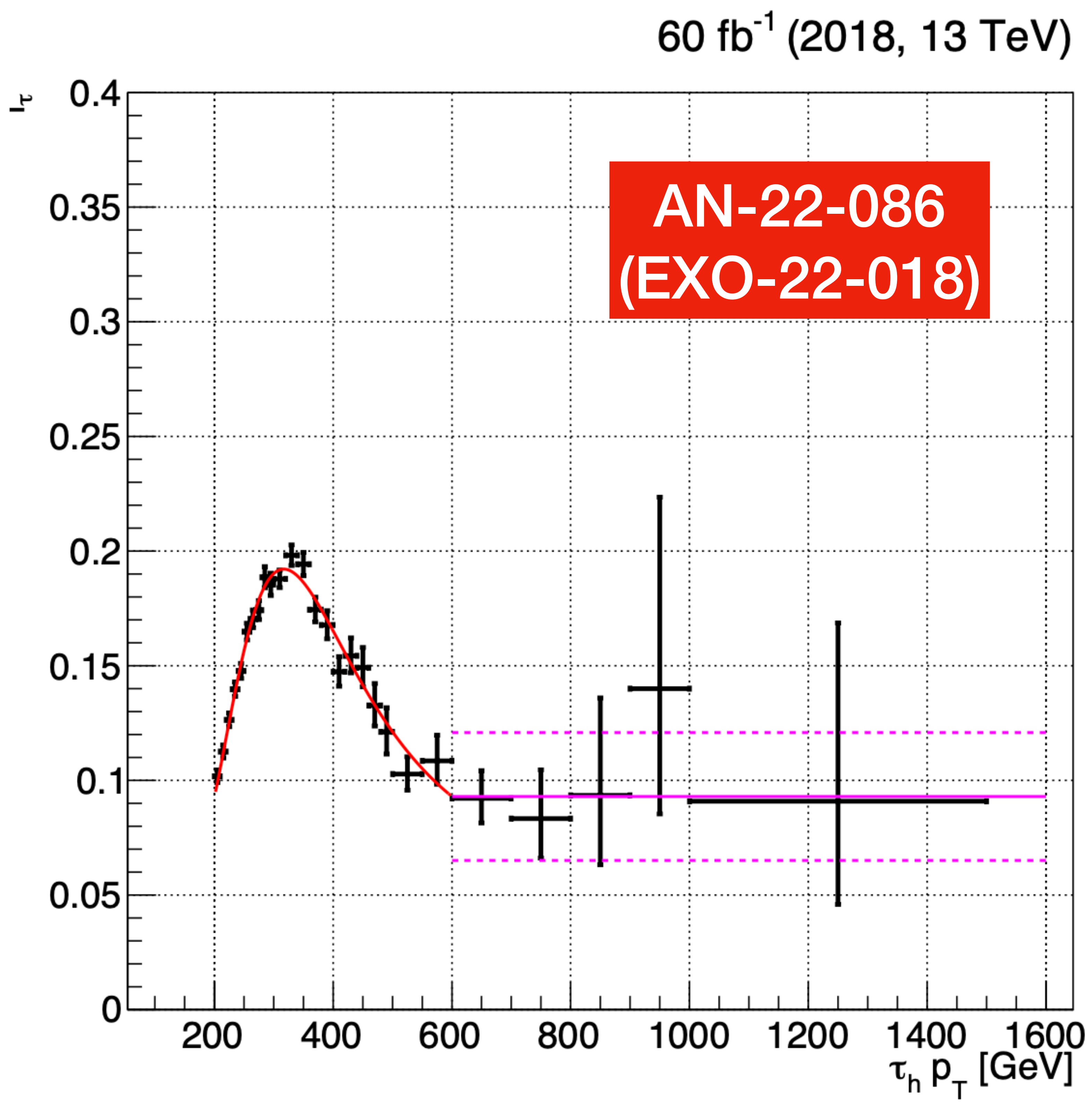
Background Estimation

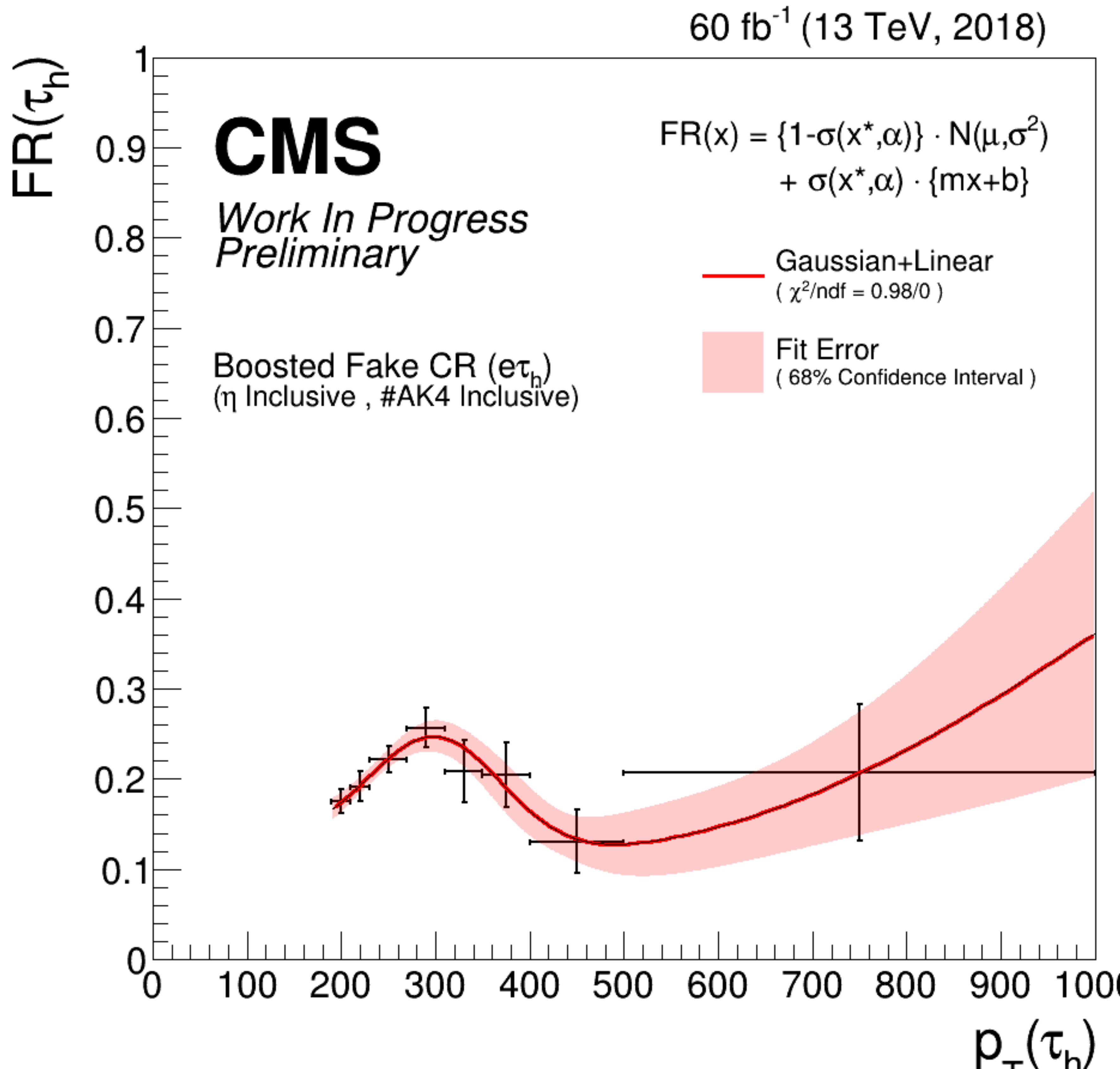
Nonprompt τ_h Contribution

- Comparison with EXO-22-018 fake measurement
  - Didn't further divide measurement region by jet multiplicity, tau |η| region
    - Instead divided by lepton flavor for each boosted and resolved signal regions
  - Different fitting method used : single function that covers high p_T used
  - Shows similar fake rates with same loose-to-tight WPs

Methodology borrowed from EXO-22-018

doi:10.1103/PhysRevLett.132.061801

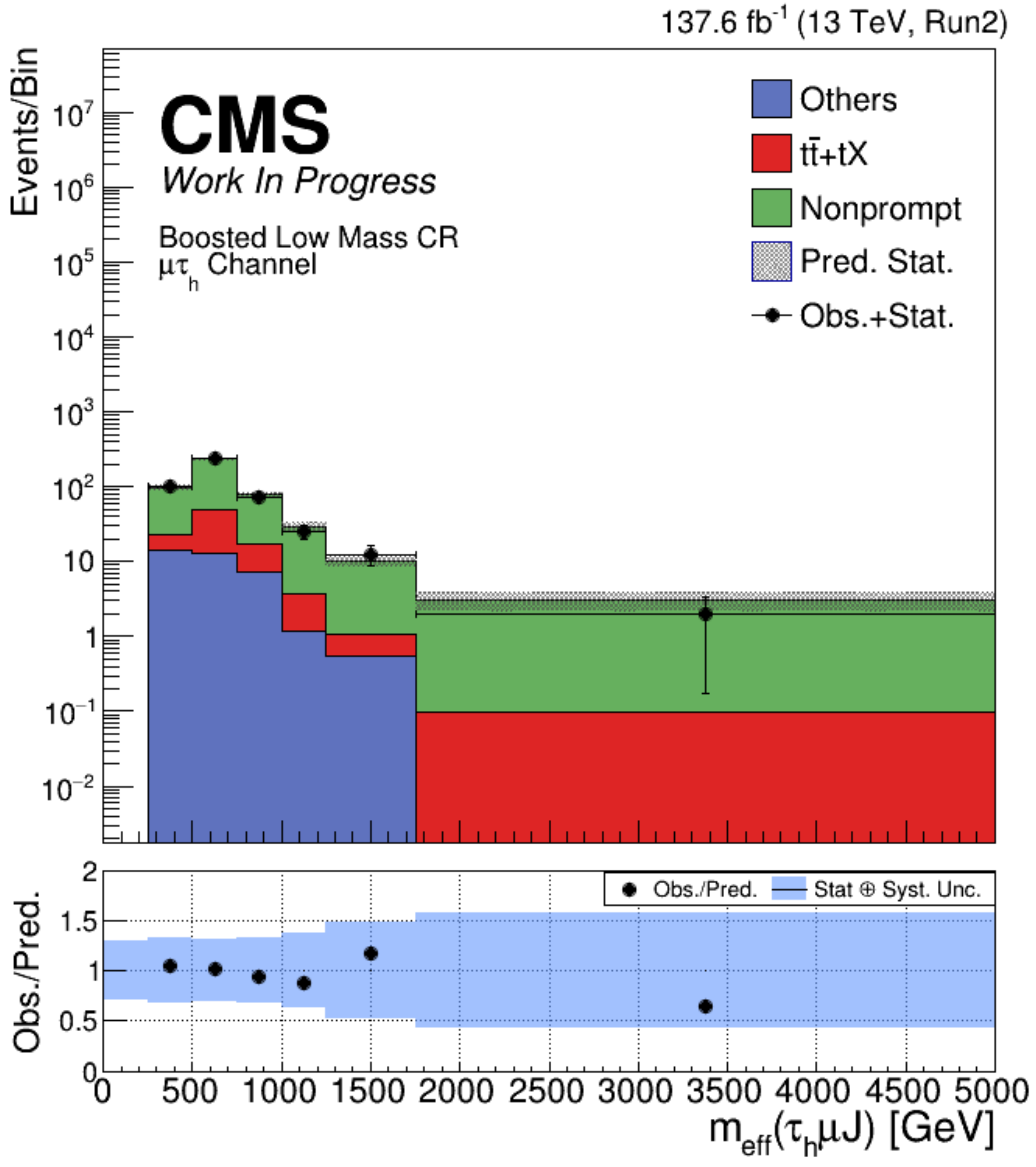


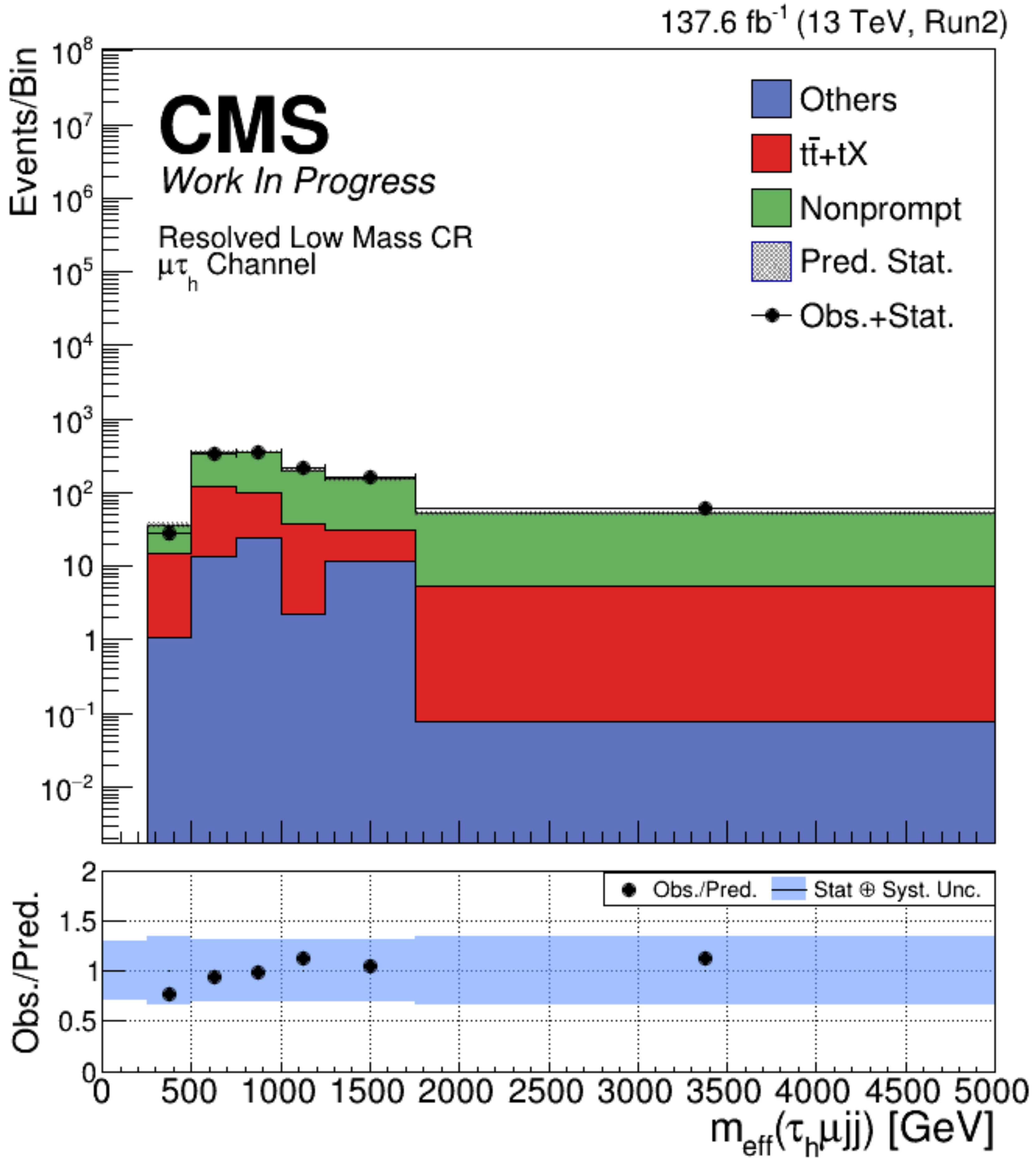


Background Estimation

Hadronic Tau Fake

- After applying hadronic tau fake rates, closure seems to agree well (fitting uncertainty not implemented yet)
- Systematic uncertainties are being studied (flat 30% uncertainty is estimated here)

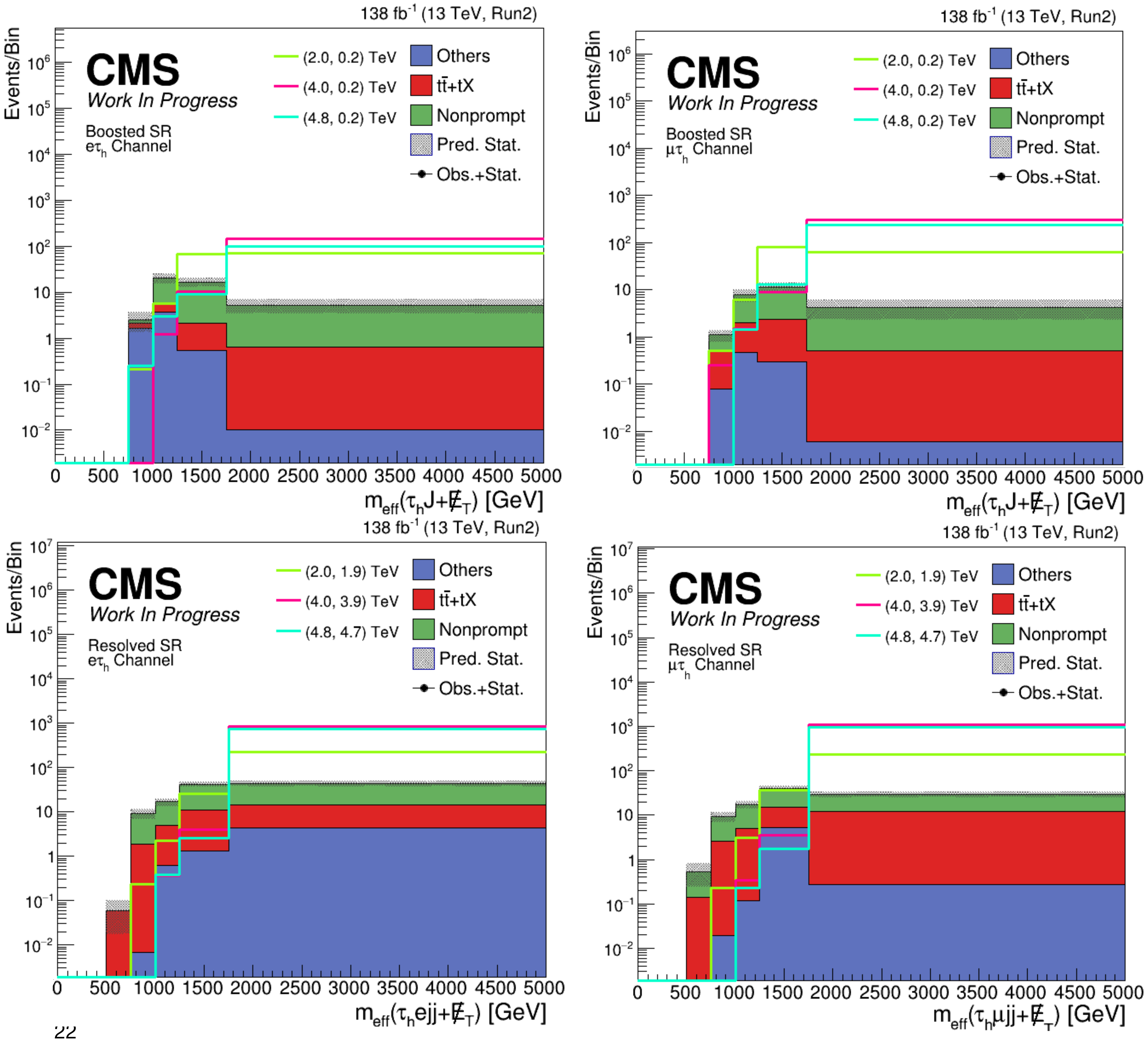




Results

Expected Limits

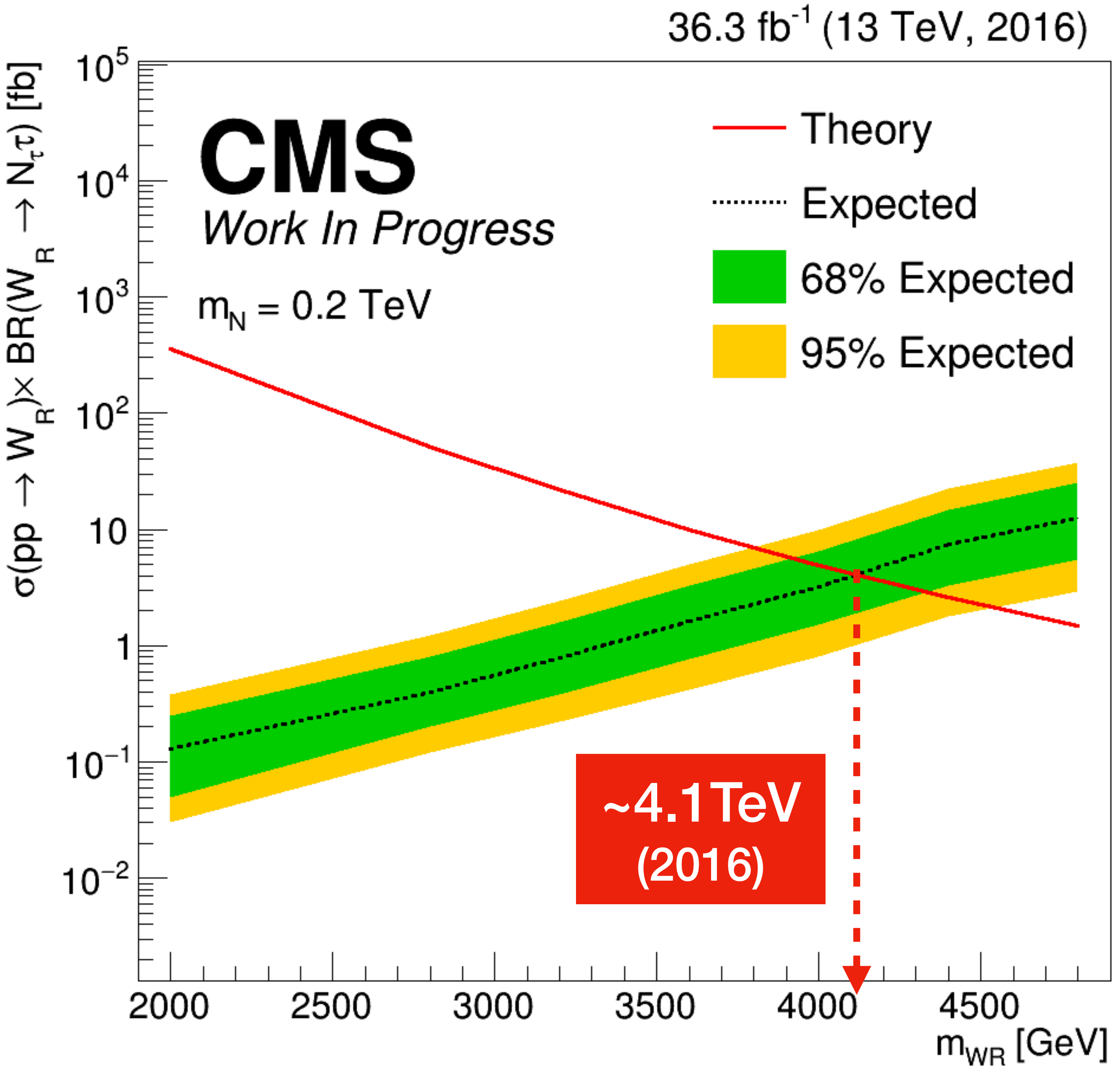
- Preliminary expected limits are extracted
  - Fitting based on reconstructed W_R mass shape : m(tau,lepton,jets,MET)
  - Used pseudo-data for limit extraction (blinded)
  - Systematics are given as a flat 30% ⊕ luminosity uncertainty for each era as it is still being studied

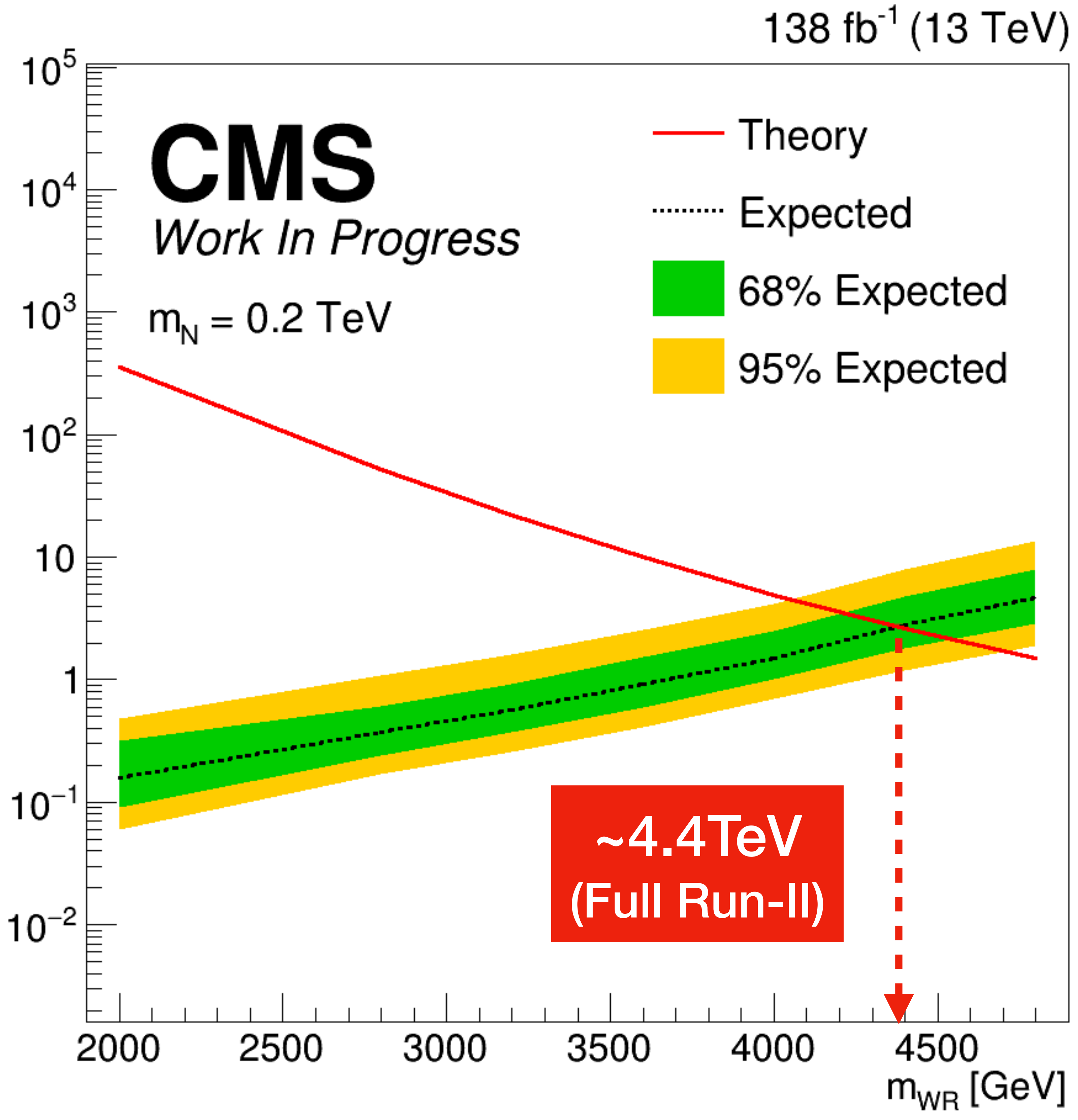


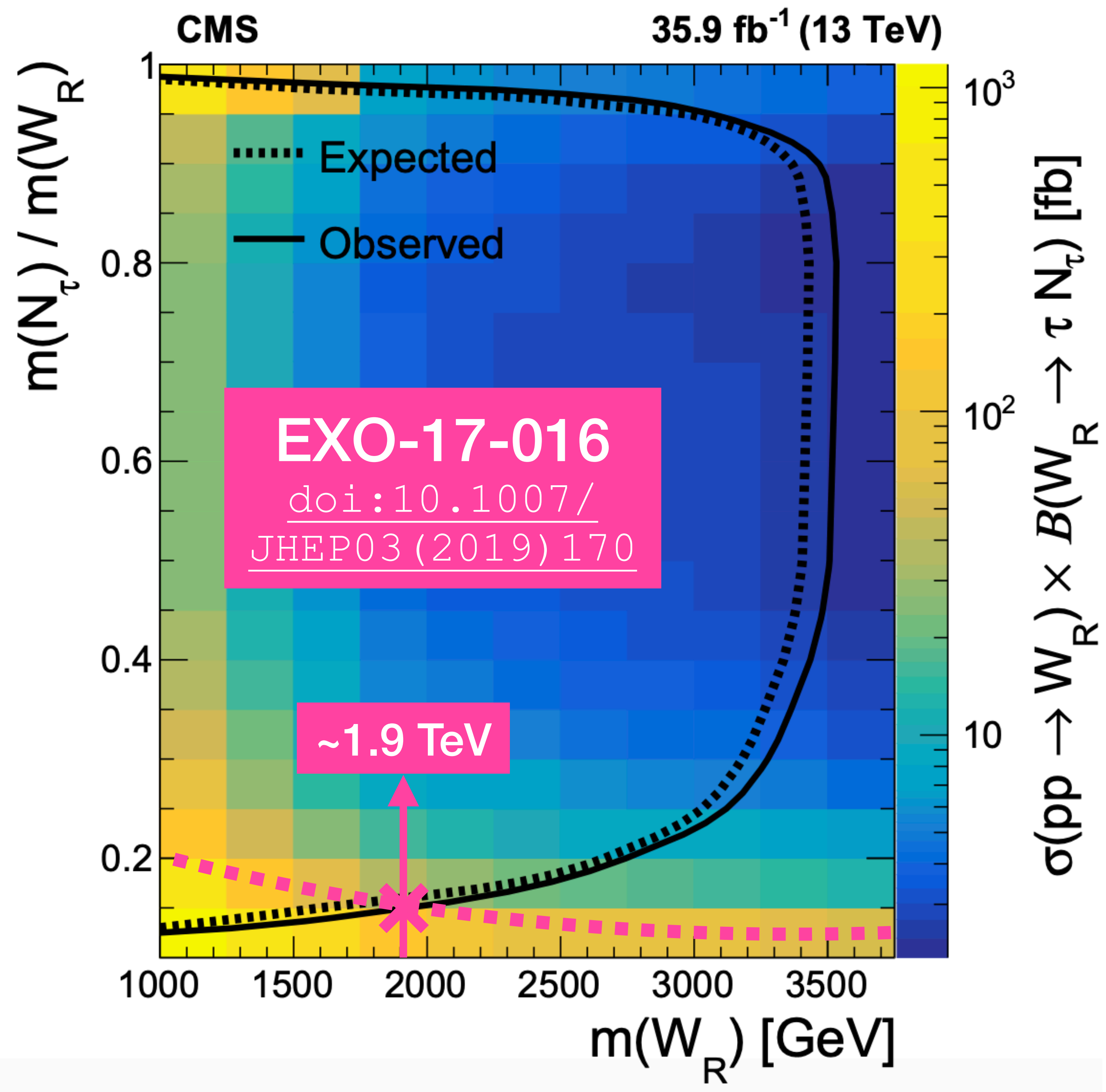
Results

Expected Limits

m_N = 0.2 TeV Scenario





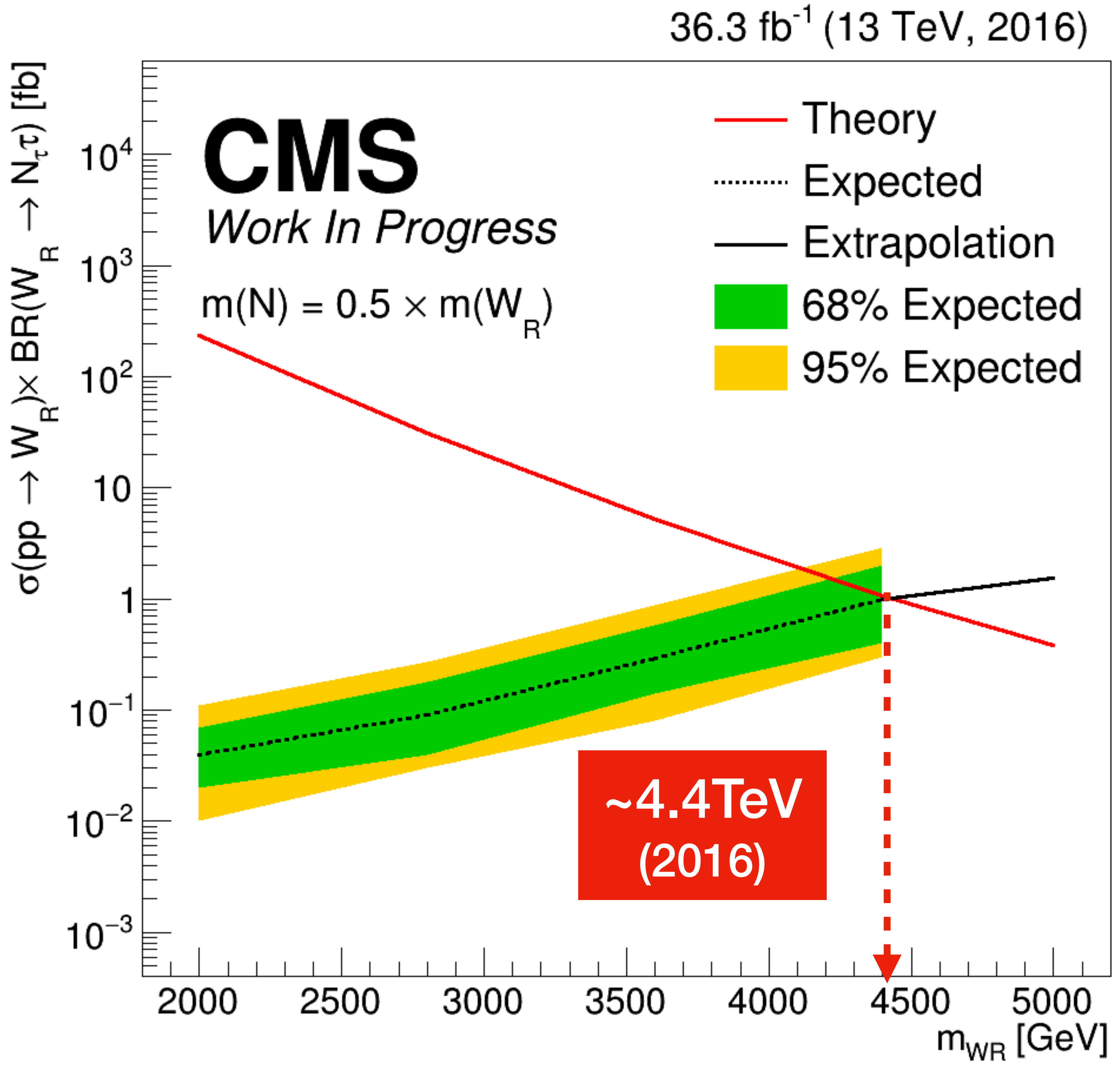


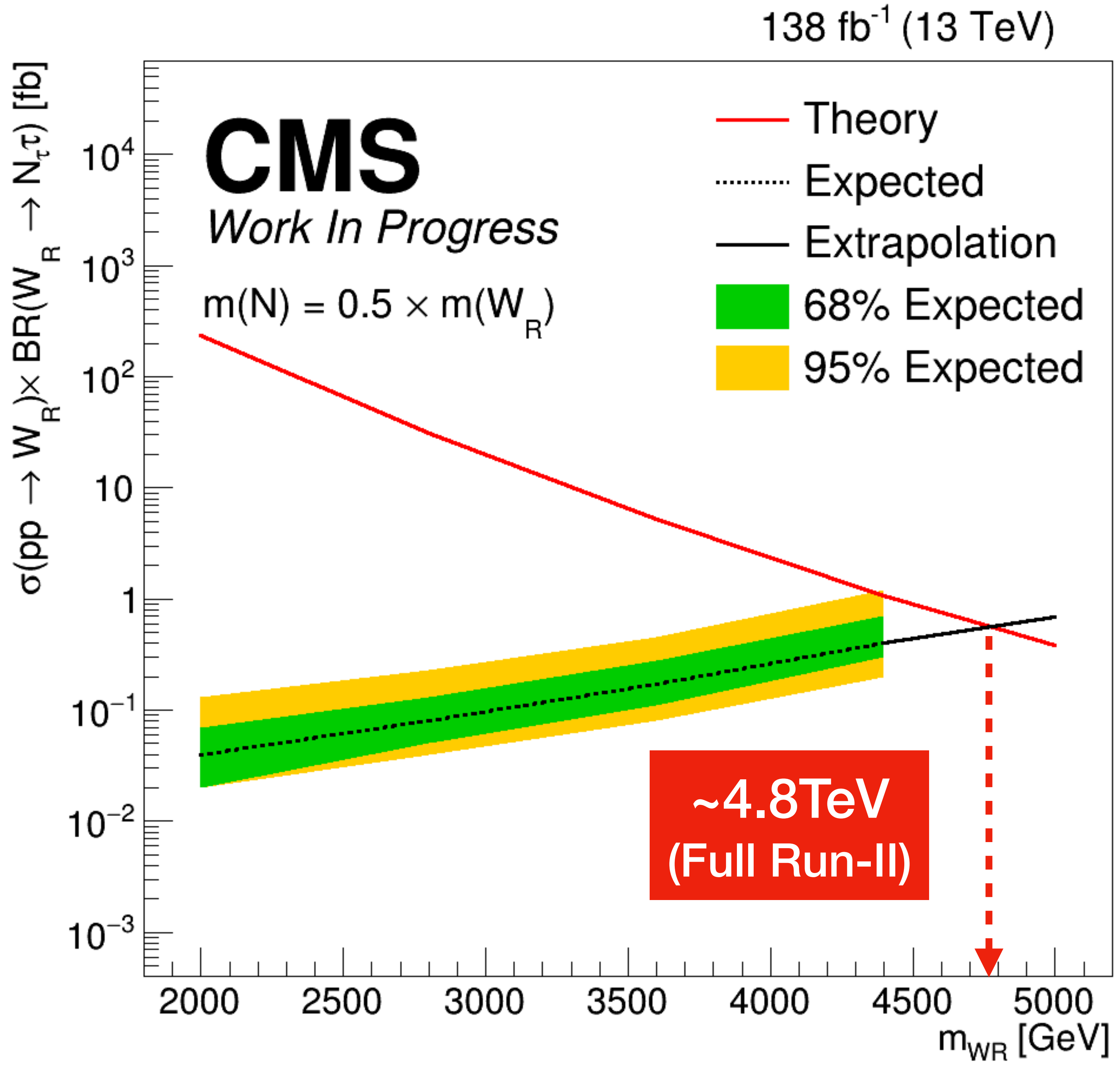
Improved sensitivity compared to previous studies!

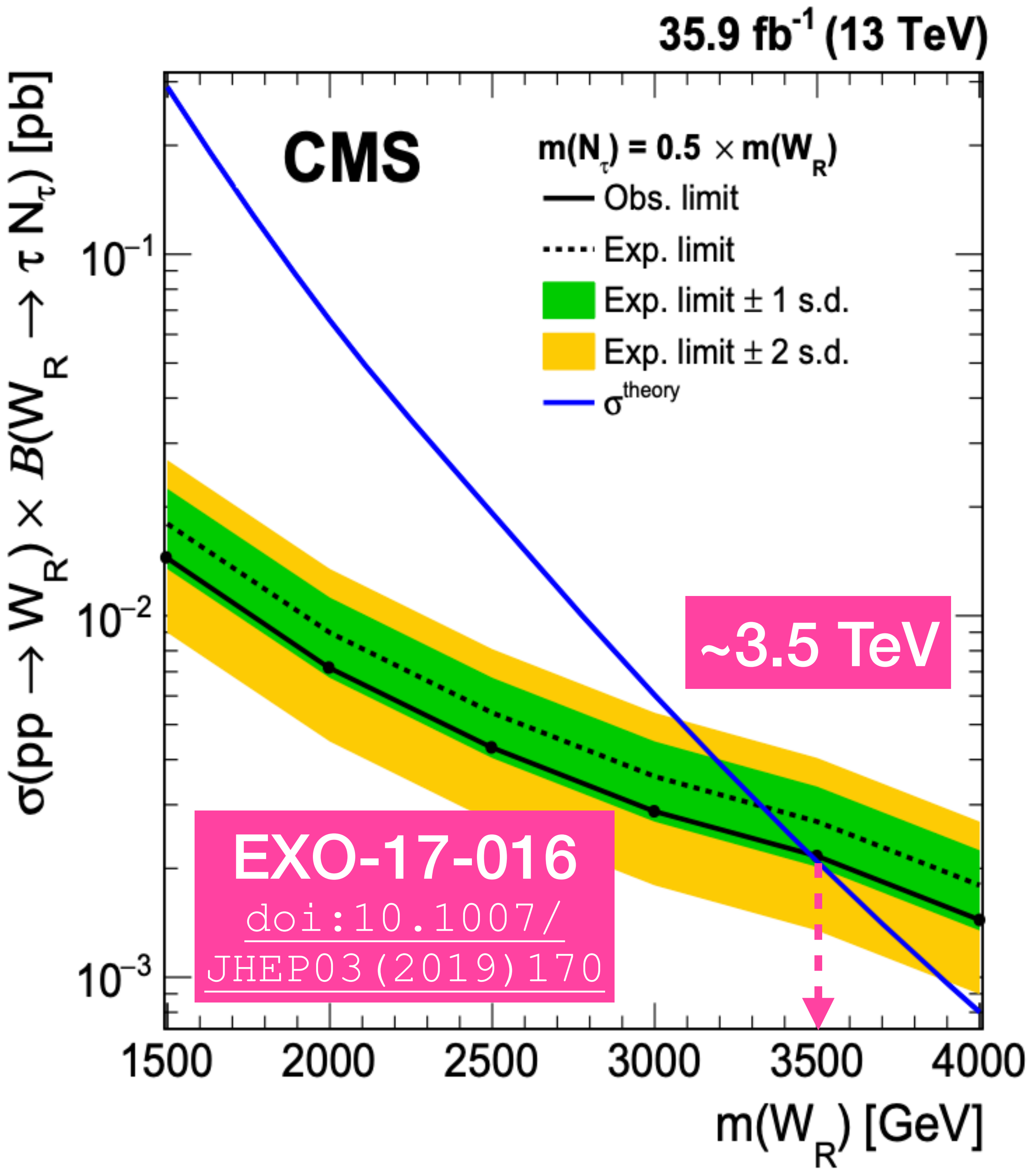
Results

Expected Limits

$m_N = 0.5 * m_{WR}$ Scenario







Improved sensitivity compared to previous studies!

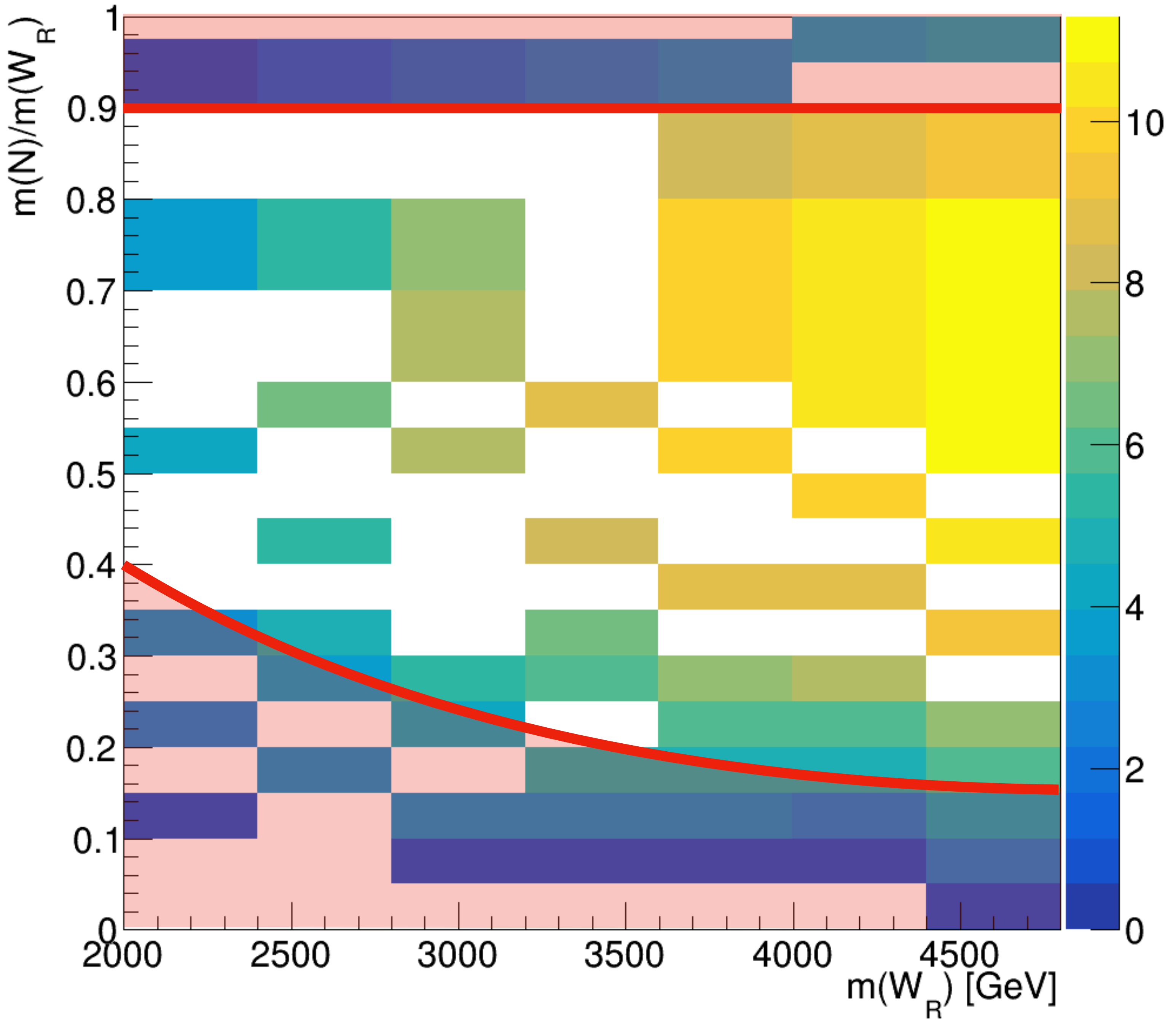
Signal

Sample Requests

- Previous request — Exotica MC&I (14th Feb. 2023)

  - m_{WR} from 1-5 TeV with 200 GeV increment ~ 21 points
  - m_N from 100 GeV to (m_{WR}-100) GeV for each m_{WR} point

    (100k events per mass points for all Run2 UL eras)



- New request plans
  - Planning to extend the m_{WR} spectrum up to 6.5 TeV after sensitivity check
    - With the same grid used in the previous request, too many points are needed
    - Will reduce the number of signal samples by changing the gap to 500GeV for m_{WR}
    - Number of events per mass points will also be optimized :
      - Low efficiency ($m_N \lesssim 800$ GeV , $m_N \sim m_{WR}$) : request more events (~250k)
      - Else with agreeable efficiency : request less events (~80k)
    - Estimated number of events per era for additional request ~ 20M (new m_{WR} points) + more (additional m_N request for previous request)
  - Request includes LHE filter that removes events with two hadronic taus
    - Current analysis targets the $\tau_h\tau_\ell$ channel (p p > W_R > τ_h N, N > τ_ℓ q q) but also planning to study the $\tau_\ell\tau_h$ channel (p p > W_R > τ_ℓ N, N > τ_h q q) , $\tau_\ell\tau_\ell$ channel (p p > W_R > τ_ℓ N, N > τ_ℓ q q) in the next iteration

Conclusion

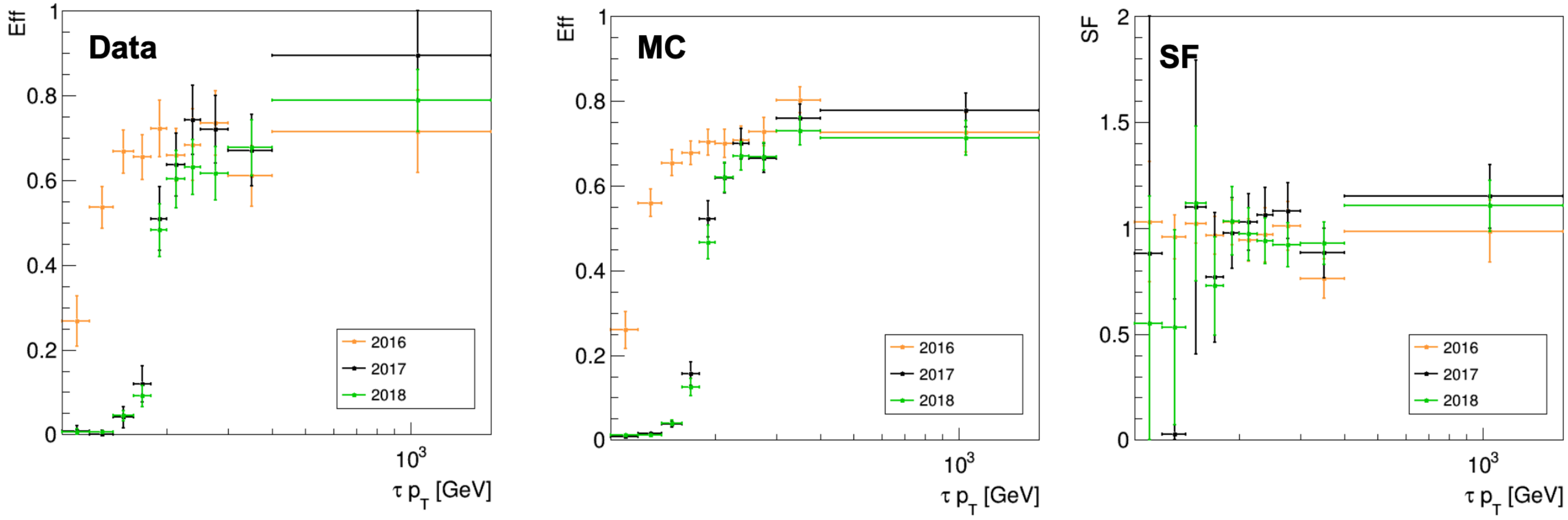
- Search for W_R and HNLs in $\tau_h\tau_\ell$ + jets final states are being actively updated
  - Targeting $\tau_h\tau_\ell$ channel (p p > W_R > τ_h N, N > τ_ℓ q q)
  - Background modeling of hadronic tau fakes well agree with data in control regions
  - Preliminary expected limits extracted from m_{WR} shape are improved compared to previous studies
  - To-Dos
    - Systematic uncertainty studies, impact studies
    - Request and scan additional signal mass points

Thank You!

Backups

Trigger Efficiency

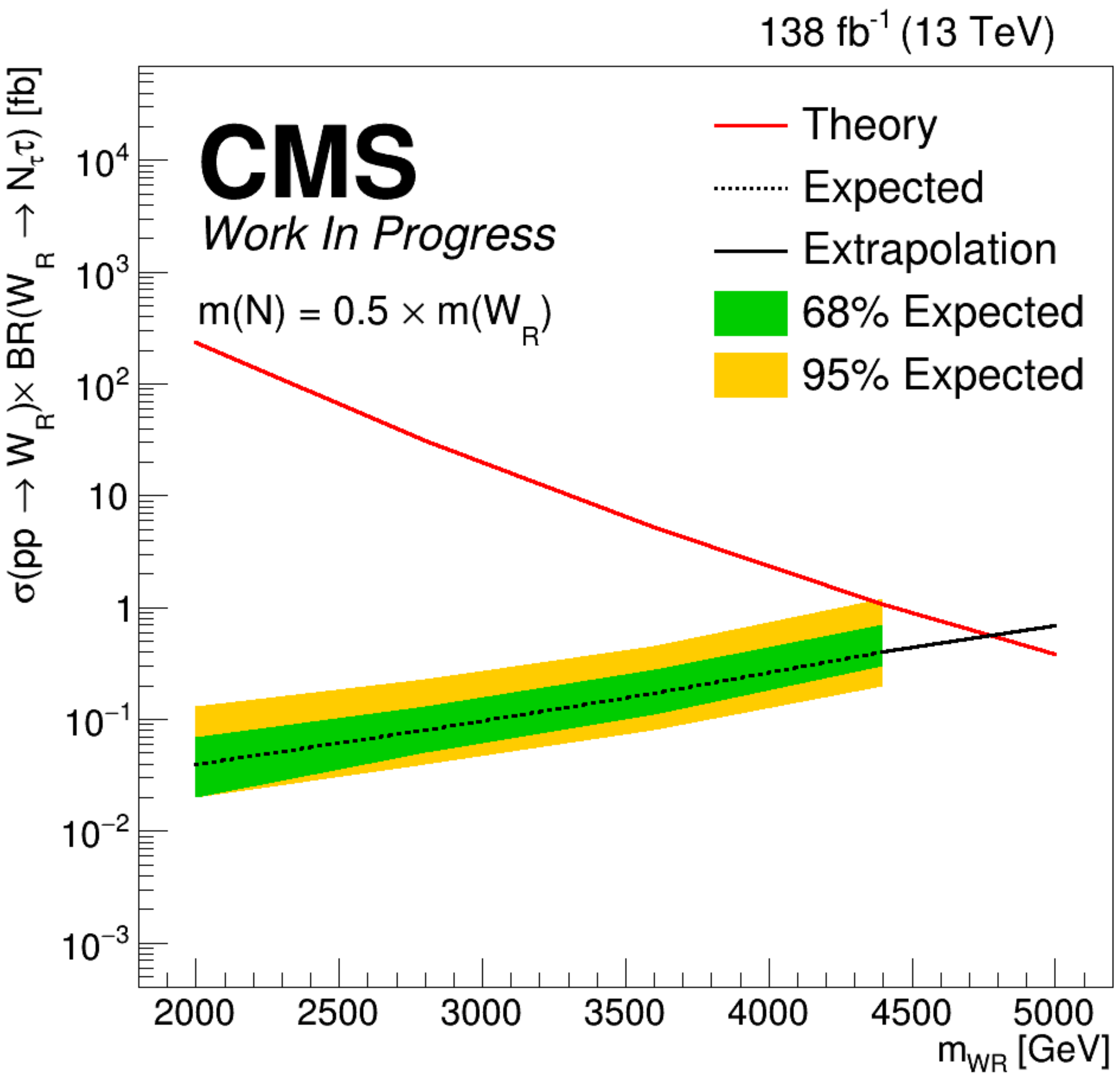
Single Tau HLT

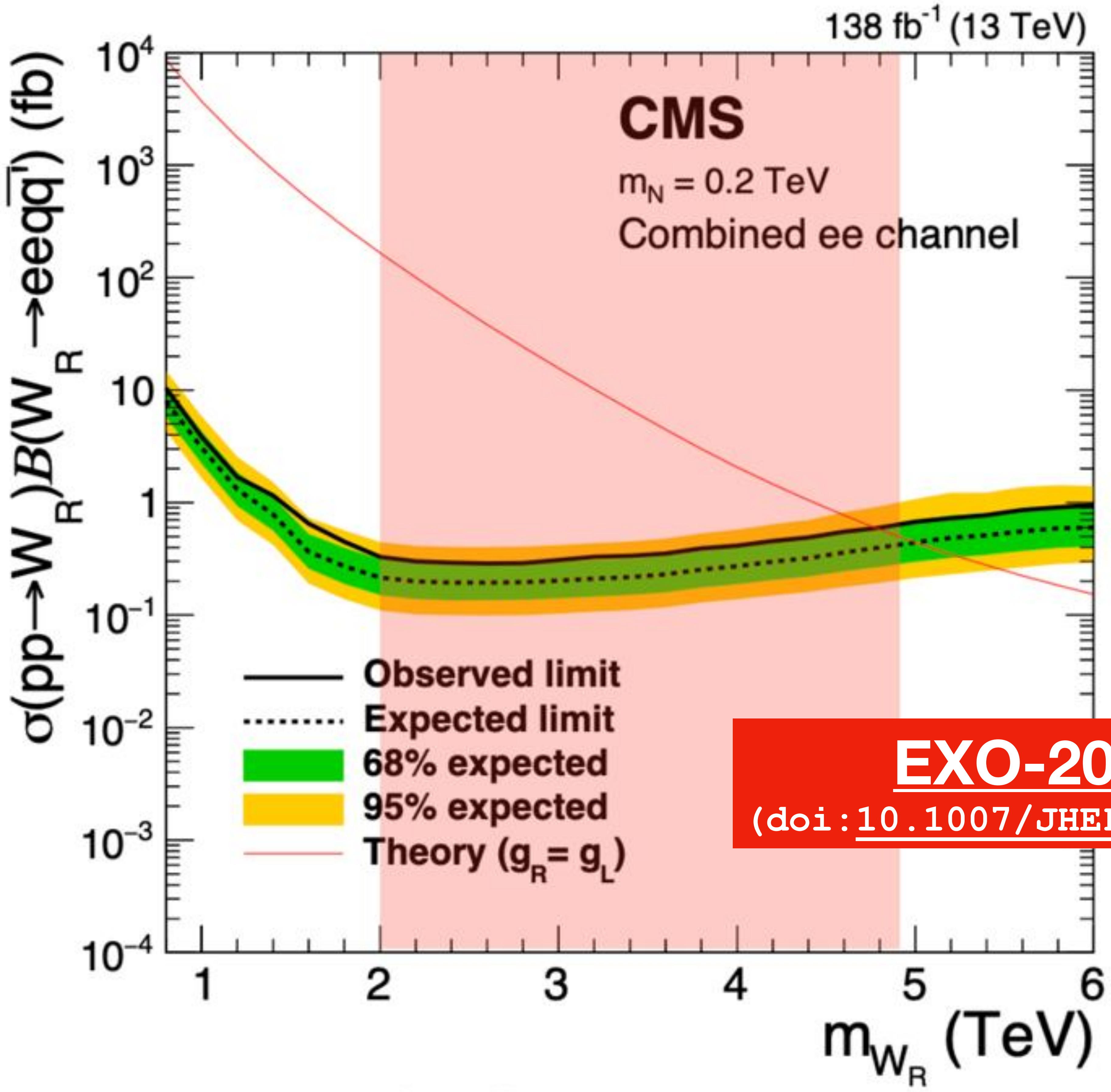


Tau ID Meeting
(14th Dec. 2020)

Limit

EXO-20-002 Comparison





EXO-20-002
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