Search for Lepton Flavor-Violating Higgs, $H \to \tau_{\text{had}}\mu$, in 8 TeV data collected by the ATLAS experiment

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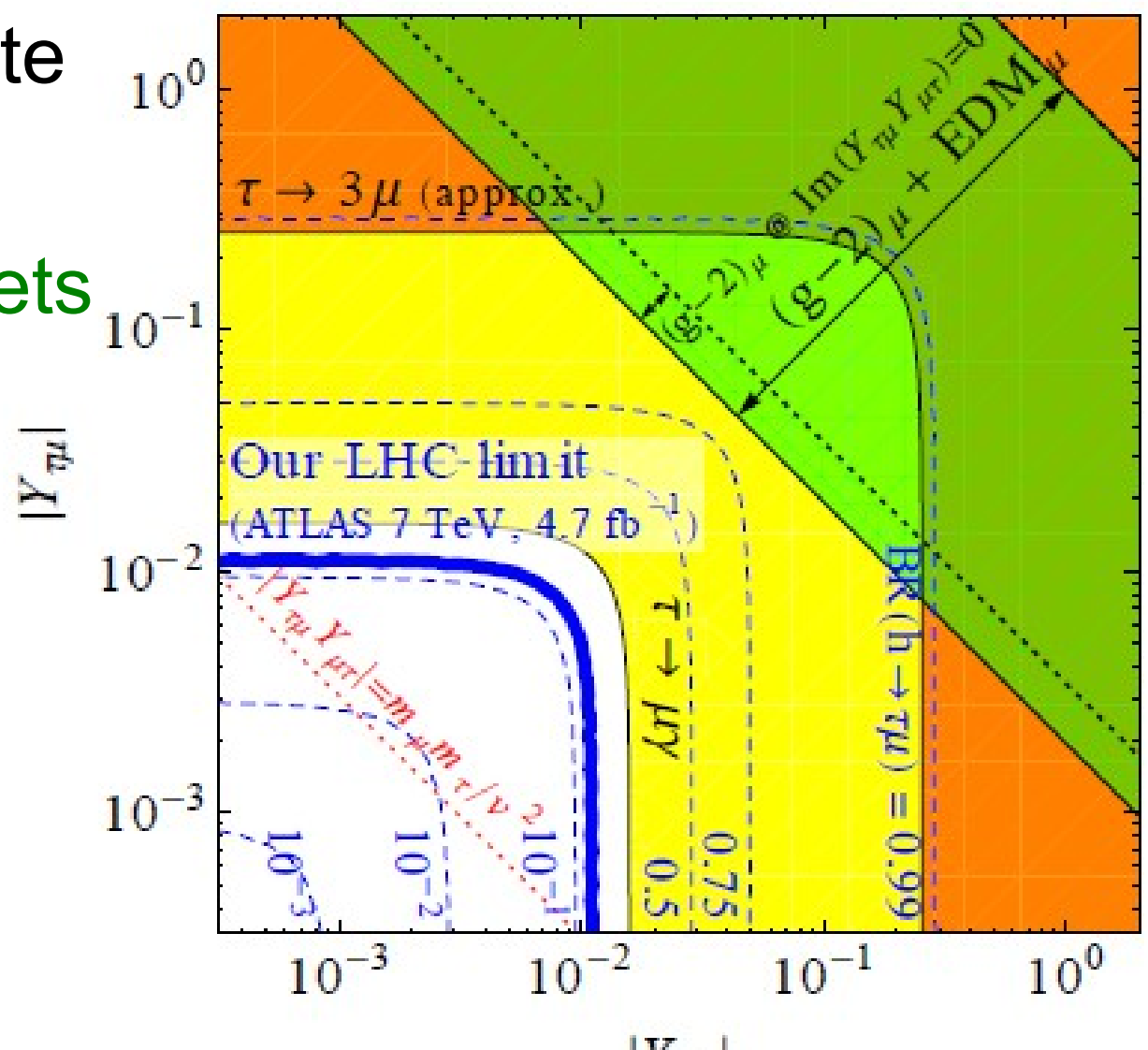
Introduction

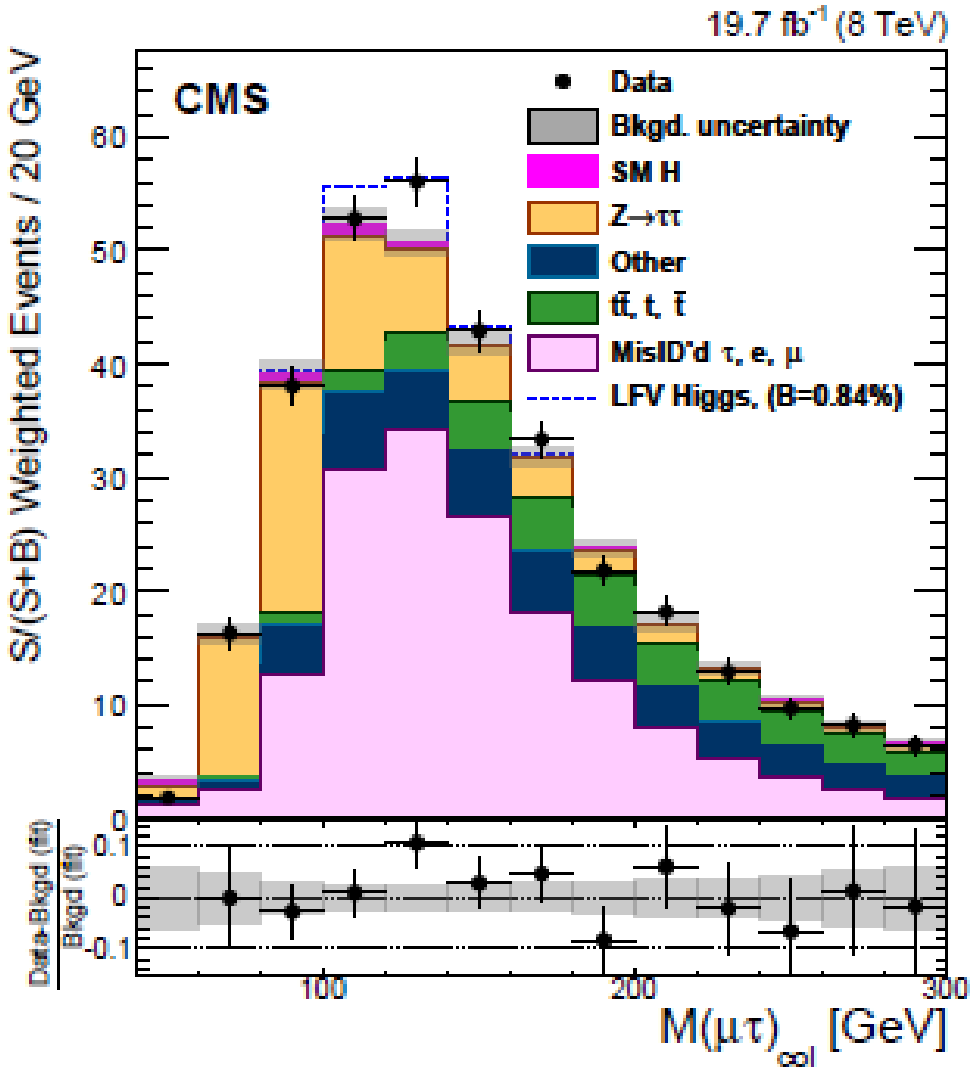
- Discovery of the Higgs Boson a great LHC success
- Higgs Boson can be a tool to discover New Physics
  - One example: presence of Lepton-Flavor-Violating (LFV) decays.
  - Can have either $H \to \tau\mu$ or $H \to \tau e$
    - $H \to \mu e$ suppressed
- Many models incorporate LFV Higgs decays
  - Multiple Higgs Doublets
  - Composite Higgs
  - Flavor Symmetry
  - Randall-Sundrum

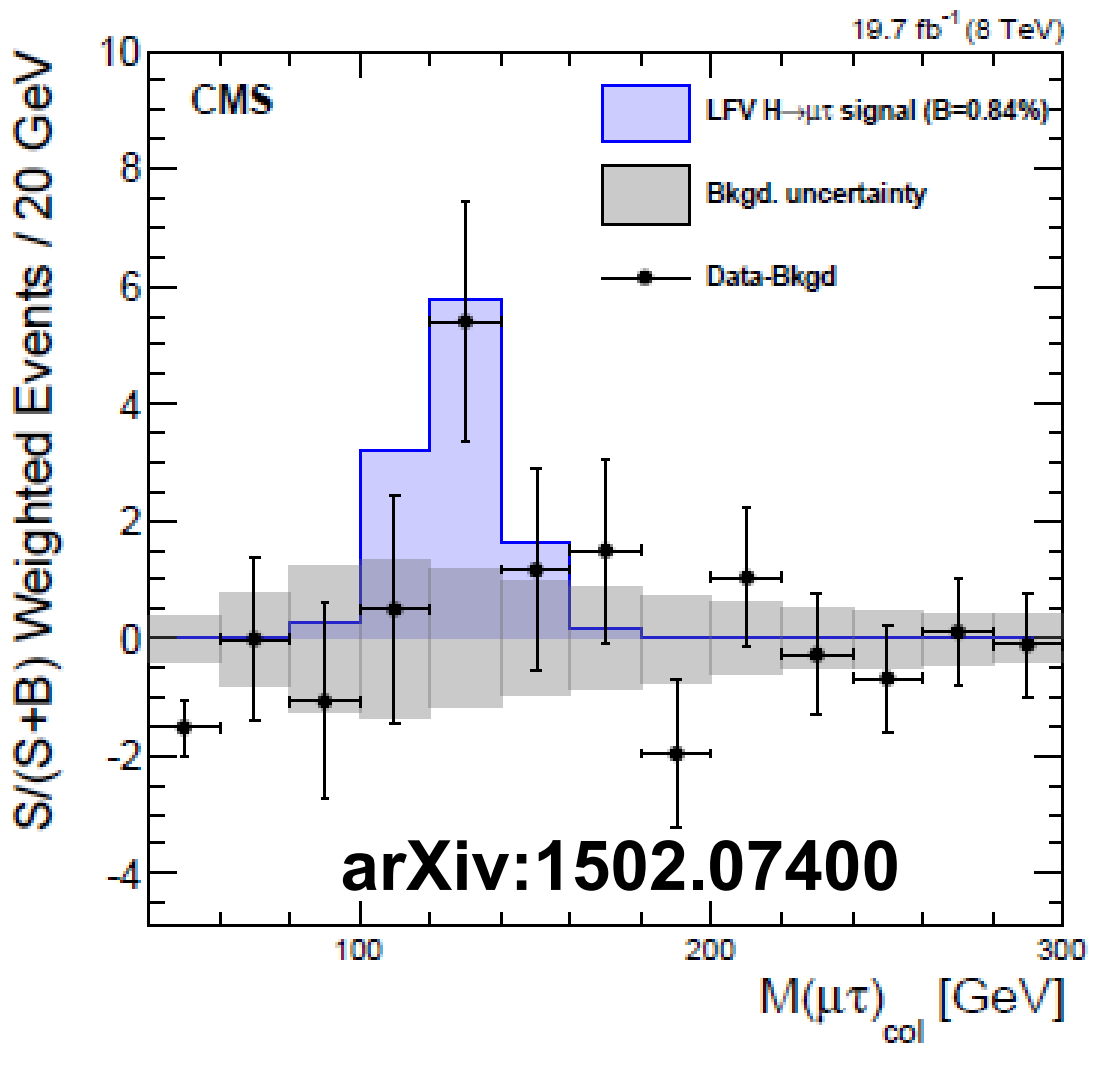


arXiv:1209.1397

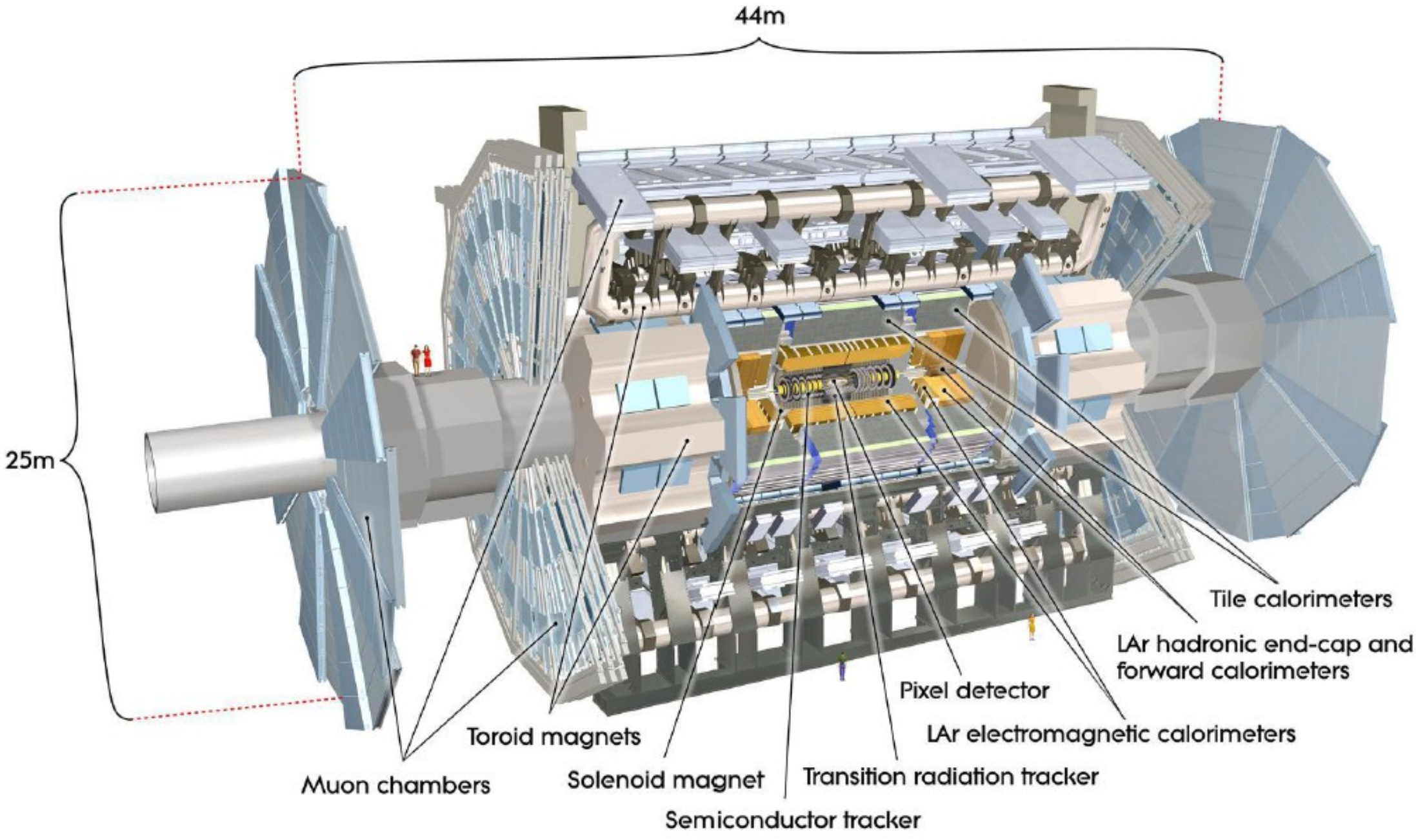
Introduction

- CMS LFV $H \rightarrow \tau\mu$ analysis
  - Leptonic and hadronic tau channels
  - 2.4σ excess in data
  - Limit on BR($H \rightarrow \tau\mu$) = 1.51%
  - Best Fit BR($H \rightarrow \tau\mu$) = (0.84 +0.39/-0.37)%



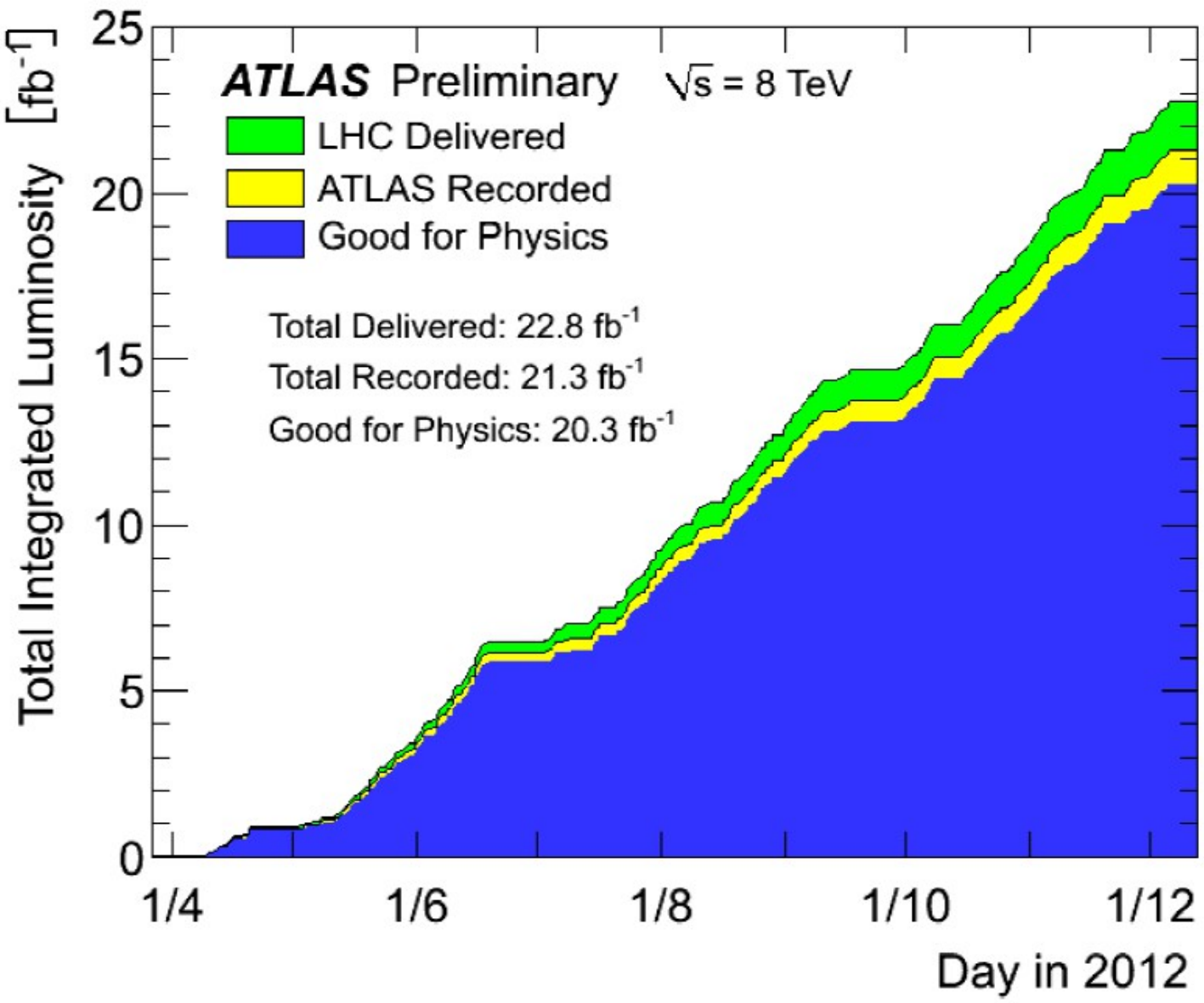


ATLAS Detector



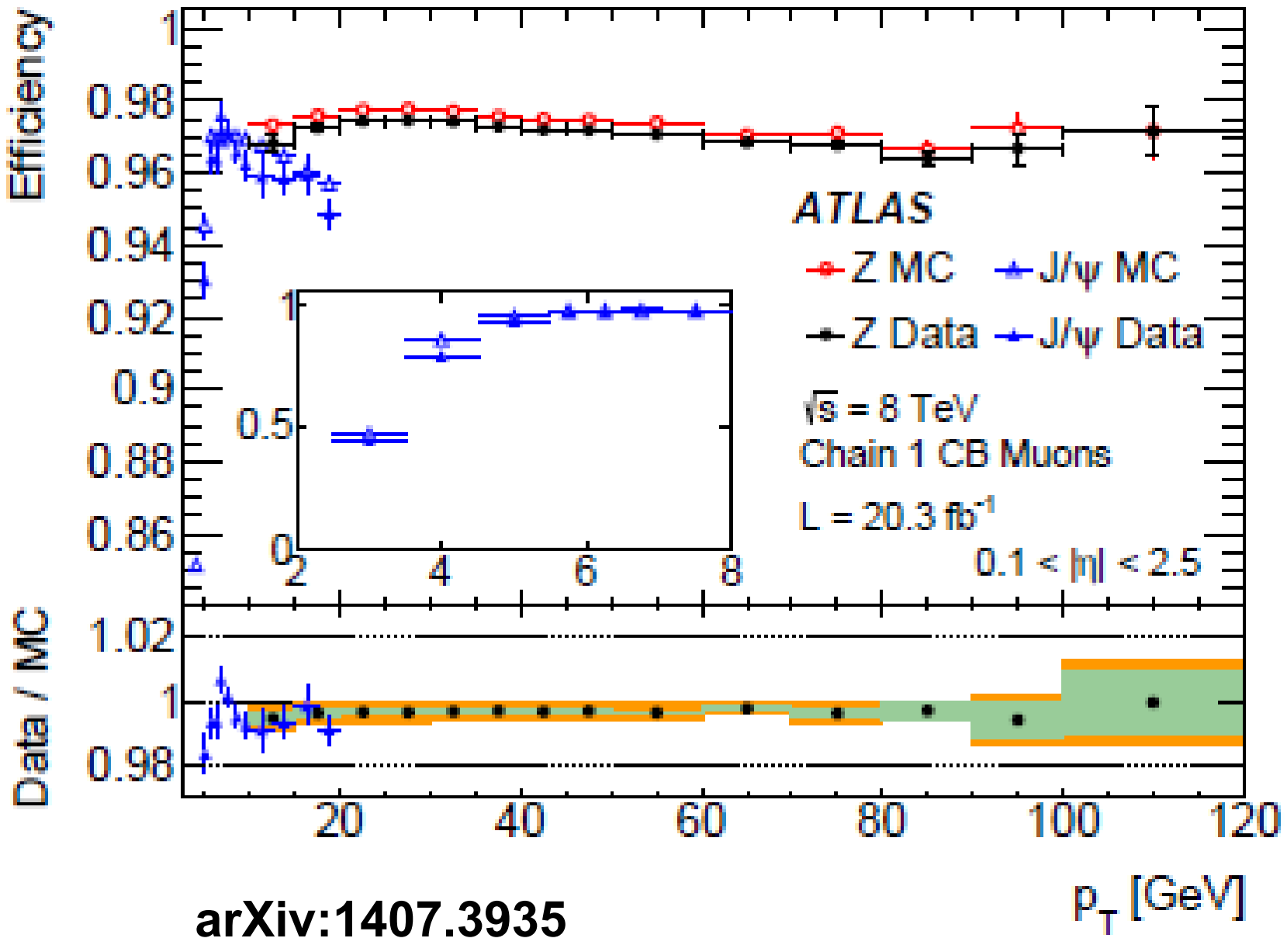
ATLAS Detector

- ATLAS had outstanding data-taking in 2012!
  - ~93% data taking efficiency
  - ~95% recorded data good for physics
    - ~400k Higgs Bosons produced.



Muon Reconstruction

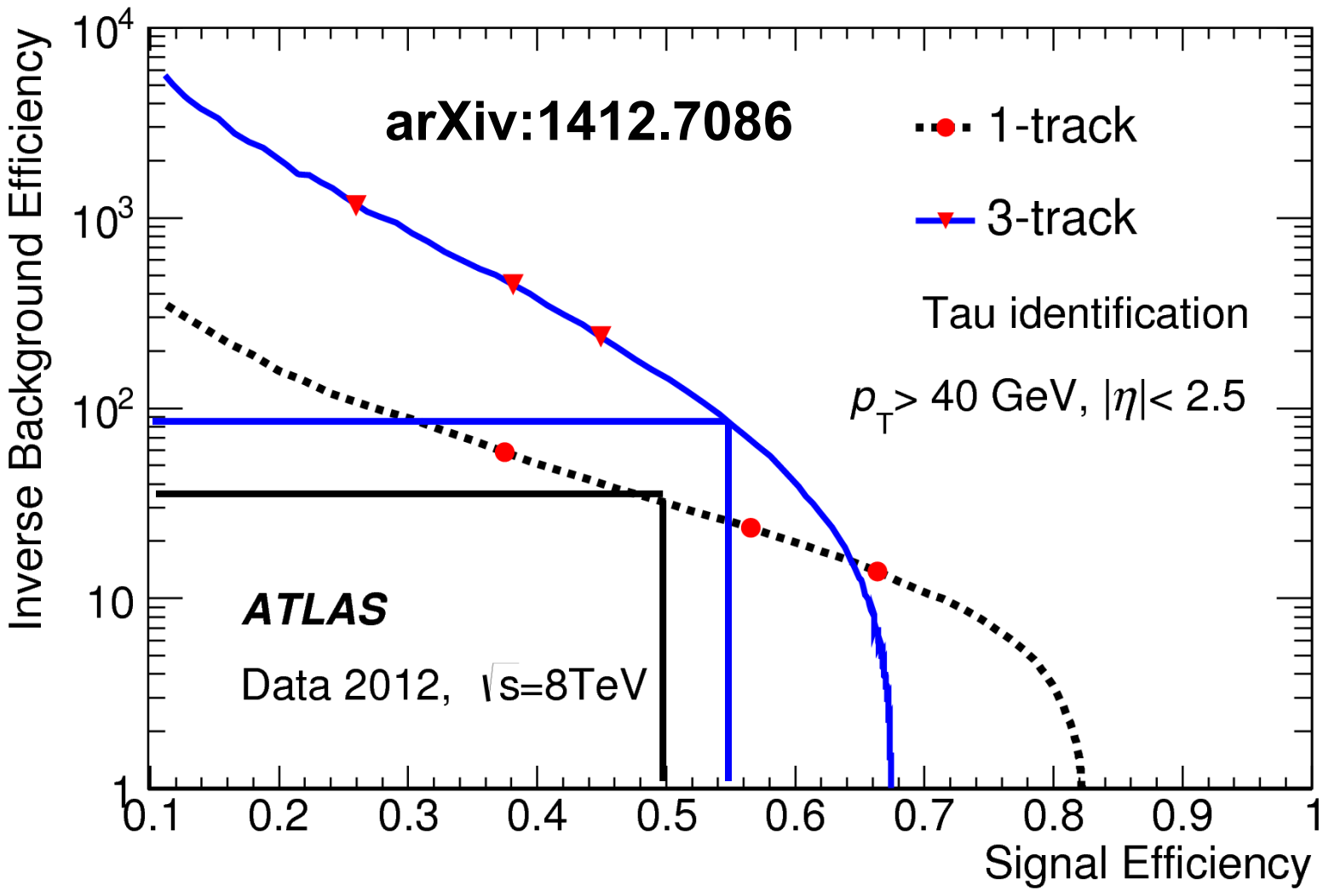
- Track in Inner Detector matched to clusters in muon spectrometer.
- Isolation requirement imposed to reject QCD
  - ET in $\Delta R < 0.2$ w.r.t. muon <6% of muon pT.
  - pT in $\Delta R < 0.4$ w.r.t. muon <6% of muon pT.
- Consider muons with $|\eta| < 2.5$



arXiv:1407.3935

Tau Reconstruction

- Use reconstructed one and three prong taus, $|\eta| < 2.5$
- Identification performed using multivariate techniques (BDT)
  - Consider variables such as core energy fraction, cluster mass, leading track momentum. etc.

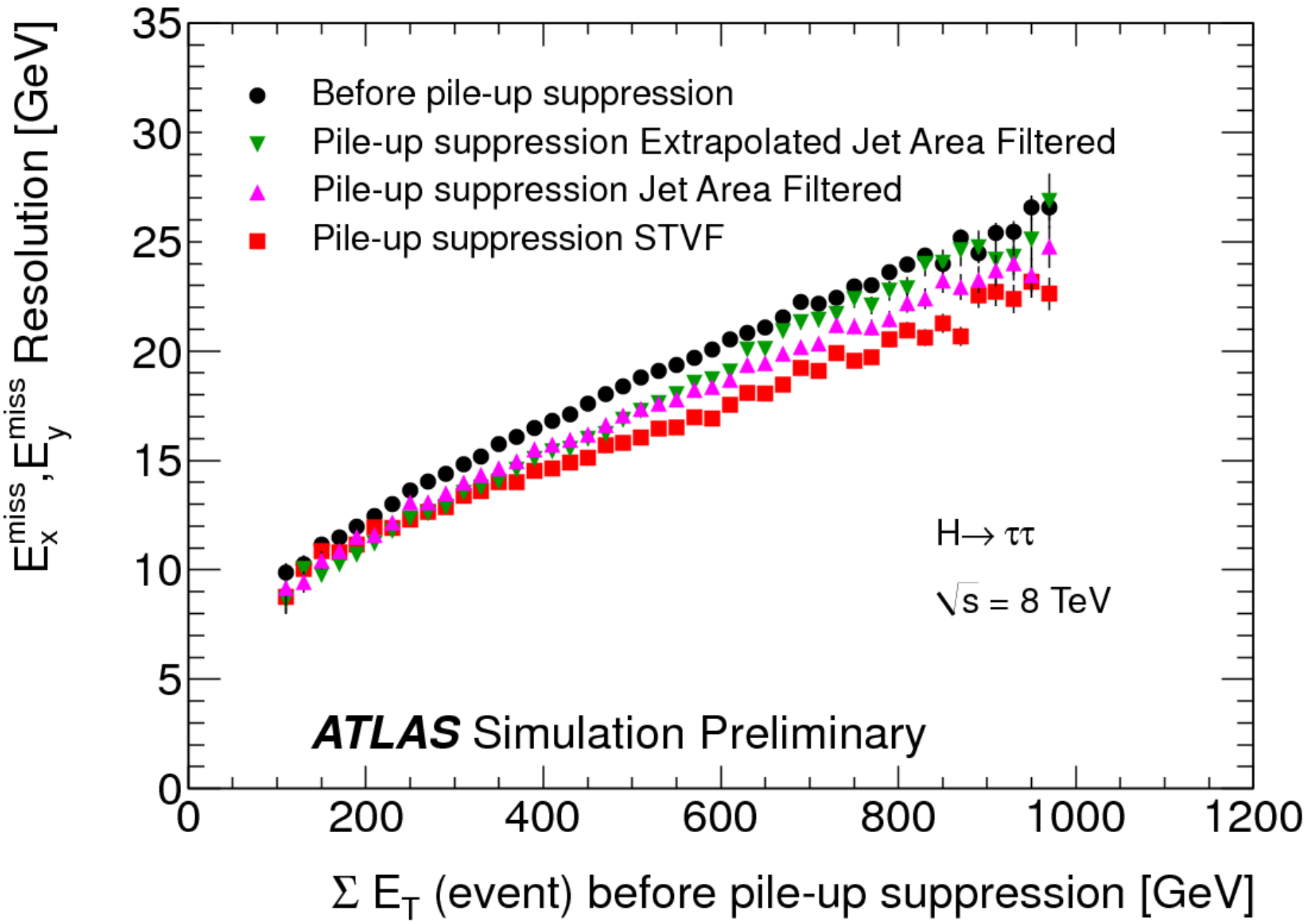


- BDT trained for 50% (55%) signal efficiency for one-prong (three-prong) taus
  - Results in 95% (99%) fake rejection

Missing Energy (MET) Reconstruction

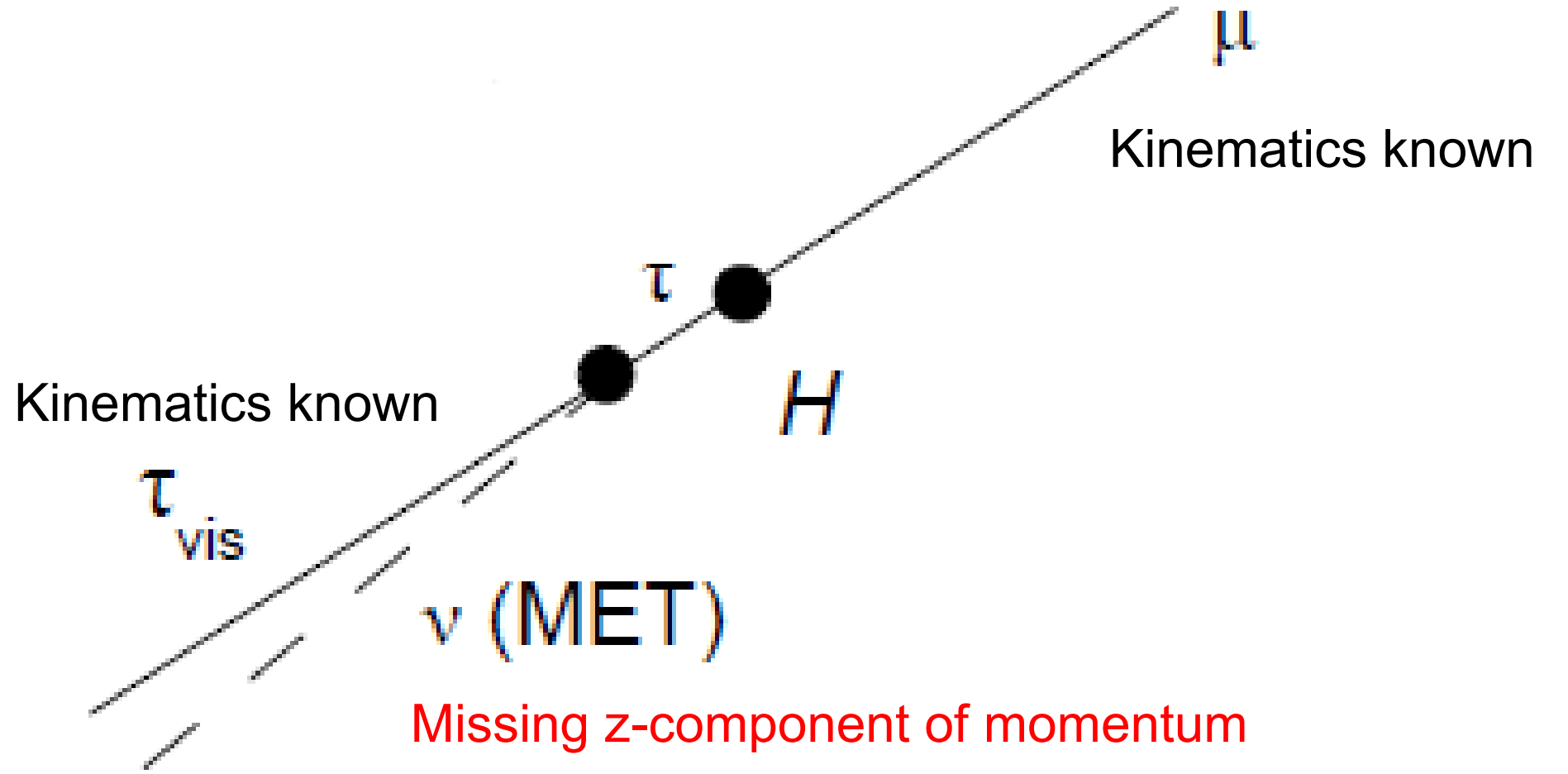
- Reconstructed from energy deposits in calorimeters
  - Energy deposits weighted based on associated physics object
  - Unassociated clusters scaled by
    Σ pT(unassociated tracks) / Σ pT(all tracks)
- Signature for neutrinos

ATLAS-CONF-2013-082



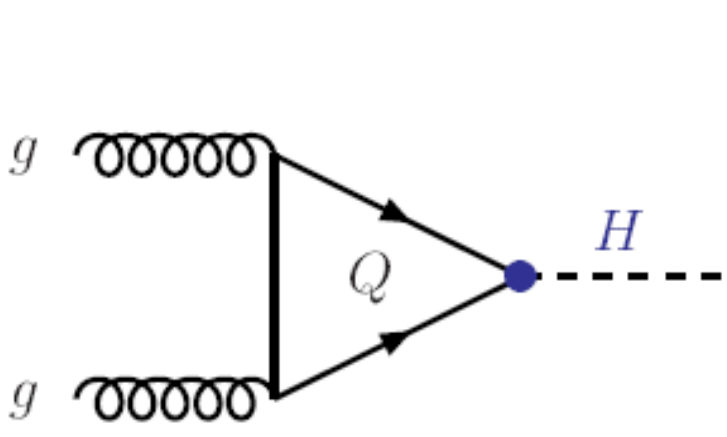
Mass Reconstruction

- Performed using Missing-Mass-Calculator (MMC) (**arXiv: 1012.4686**)
  - Modified for LFV decays
  - Use muon, visible tau, and MET kinematics to determine z-component of neutrino momentum.
  - Can obtain exact solution.

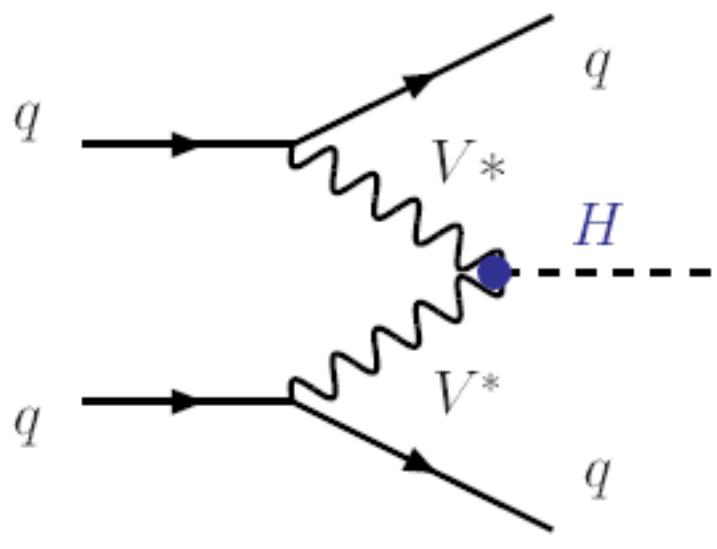


Signal Samples

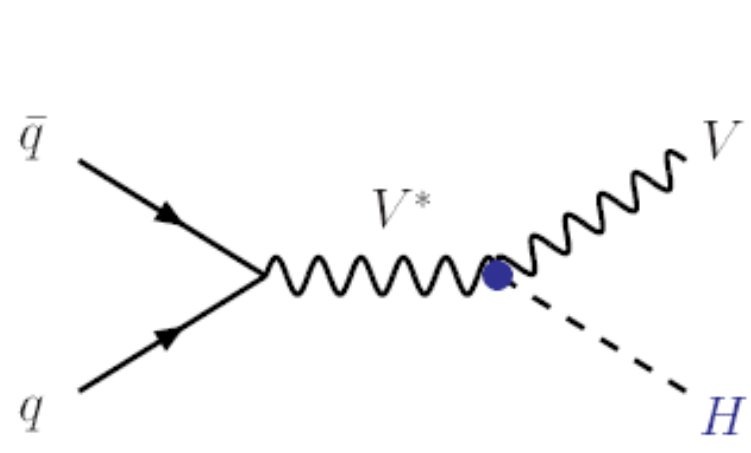
- Four different samples, depending on production
  - Gluon-Gluon Fusion (ggF)
    - Simulated at Next-to-Leading Order (NLO) using PowHeg Monte-Carlo (MC) simulator
  - Vector-Boson-Fusion (VBF)
    - Simulated at NLO using PowHeg
  - Associated Production (VH)
    - Simulated at LO using Pythia
    - Higgs decays are handled by EvtGen



ggF (19.3 pb)



VBF (1.6 pb)



VH (1.1 pb)

arXiv:1203.4199

Background Samples

W + jets:

- Dominant background
- Modeled by MC and normalized to data

Same Sign Data:

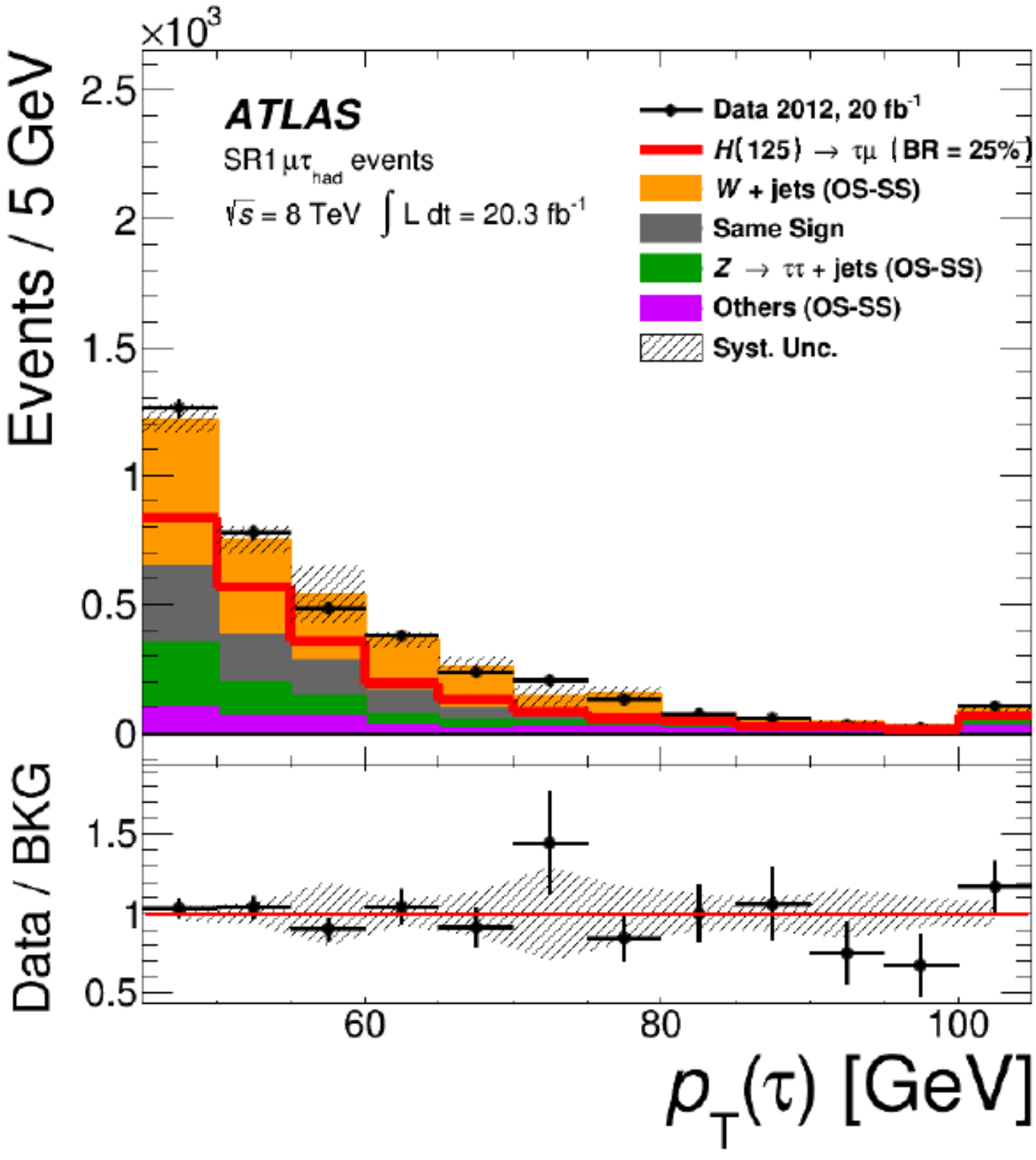
- Used to estimate QCD

$Z \rightarrow \tau\tau$:

- Modeled by data

Other Backgrounds:

- Dibosons/$H \rightarrow \tau\tau$: Modeled by MC
- $Z \rightarrow \mu\mu$/Top: Modeled by MC and normalized to data



Background Estimation

- Background consists of QCD and EWK components with fake and true taus.
- kFactors normalize MC to data.
- Formulae for total background:

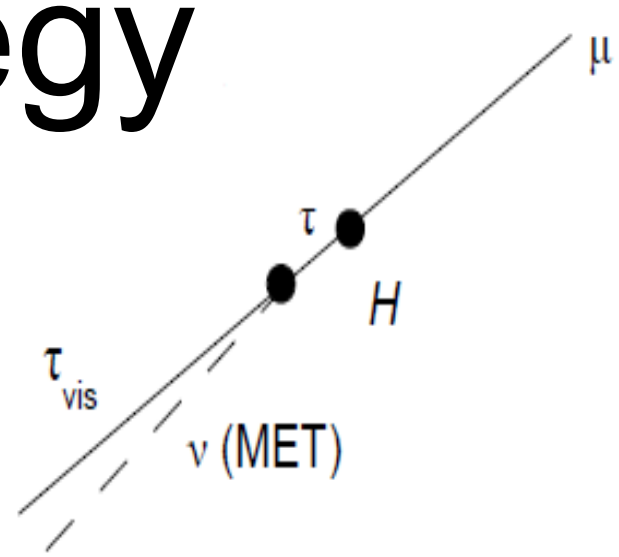
$$N_{OS}^{bckg} = r_{\mathrm{QCD}} \cdot N_{SS}^{data} + N_{add-on}^{Z\to\tau\tau} + N_{add-on}^{Z\to ll(\to\tau)}$$

$$+ N_{add-on}^{Z\to ll+jet(\to\tau)} + N_{add-on}^{W+jets} + N_{add-on}^{top} + N_{add-on}^{VV}$$

$$r_{\mathrm{QCD}} = N_{OS}^{QCD} / N_{SS}^{QCD} = 1.10 \text{ +/- } 0.13$$

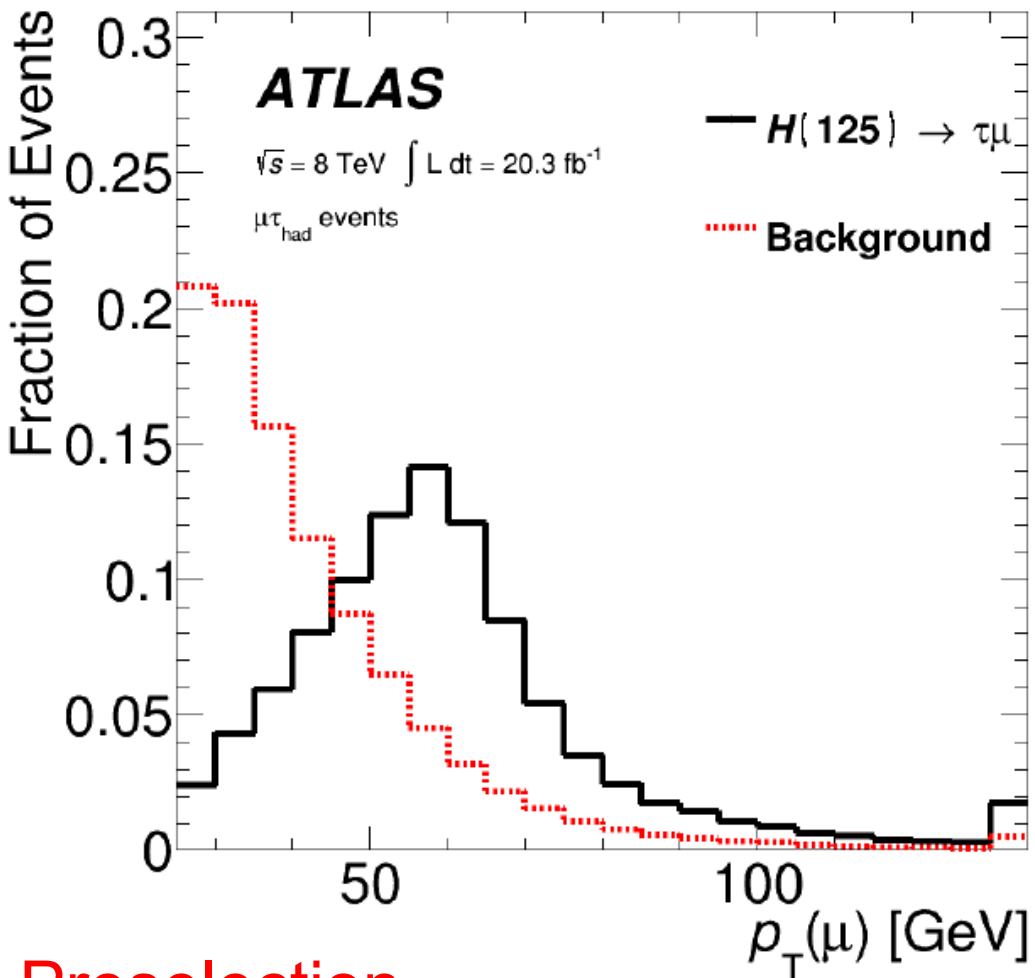
$$N_{add-on} = k^{OS} \cdot N_{OS} - r_{\mathrm{QCD}} \cdot k^{SS} \cdot N_{SS}$$

Analysis Strategy

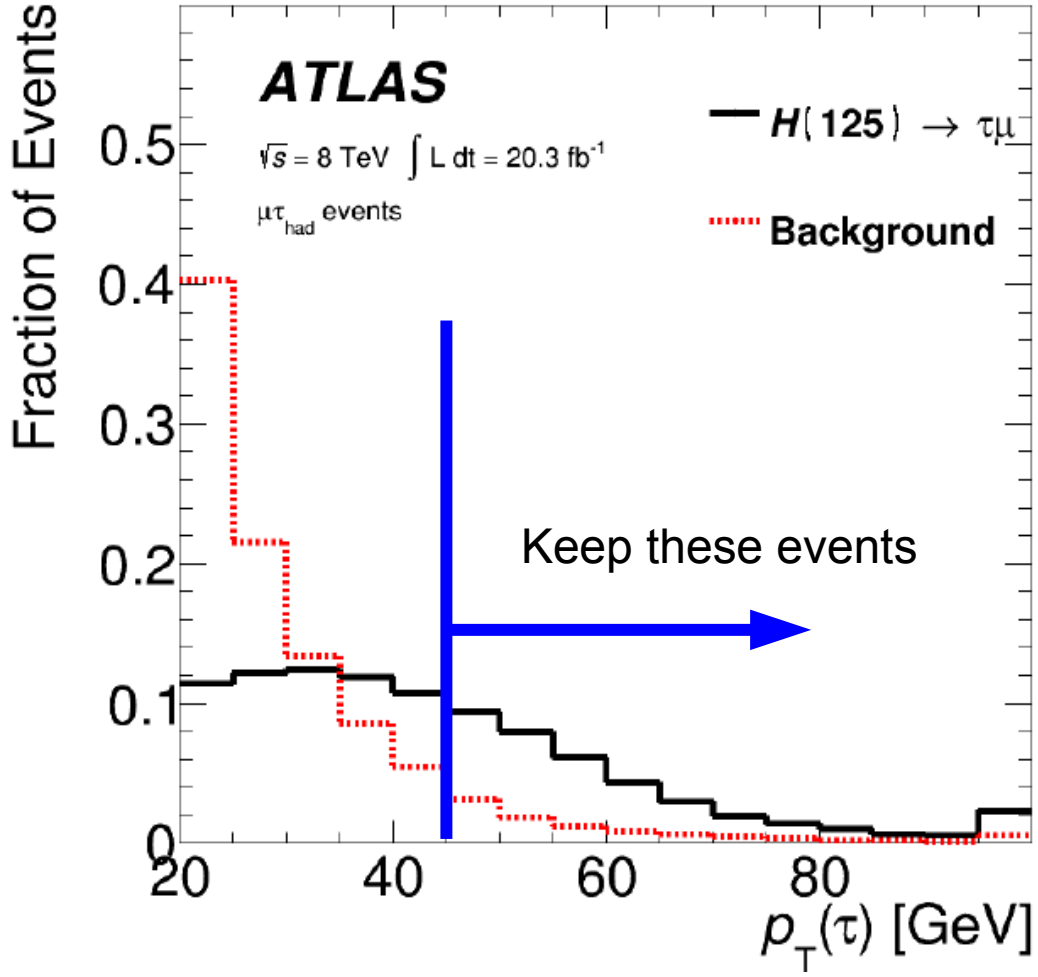


- Properties of LFV decays
  - One hard muon
  - One neutrino aligned in tau direction

Muon



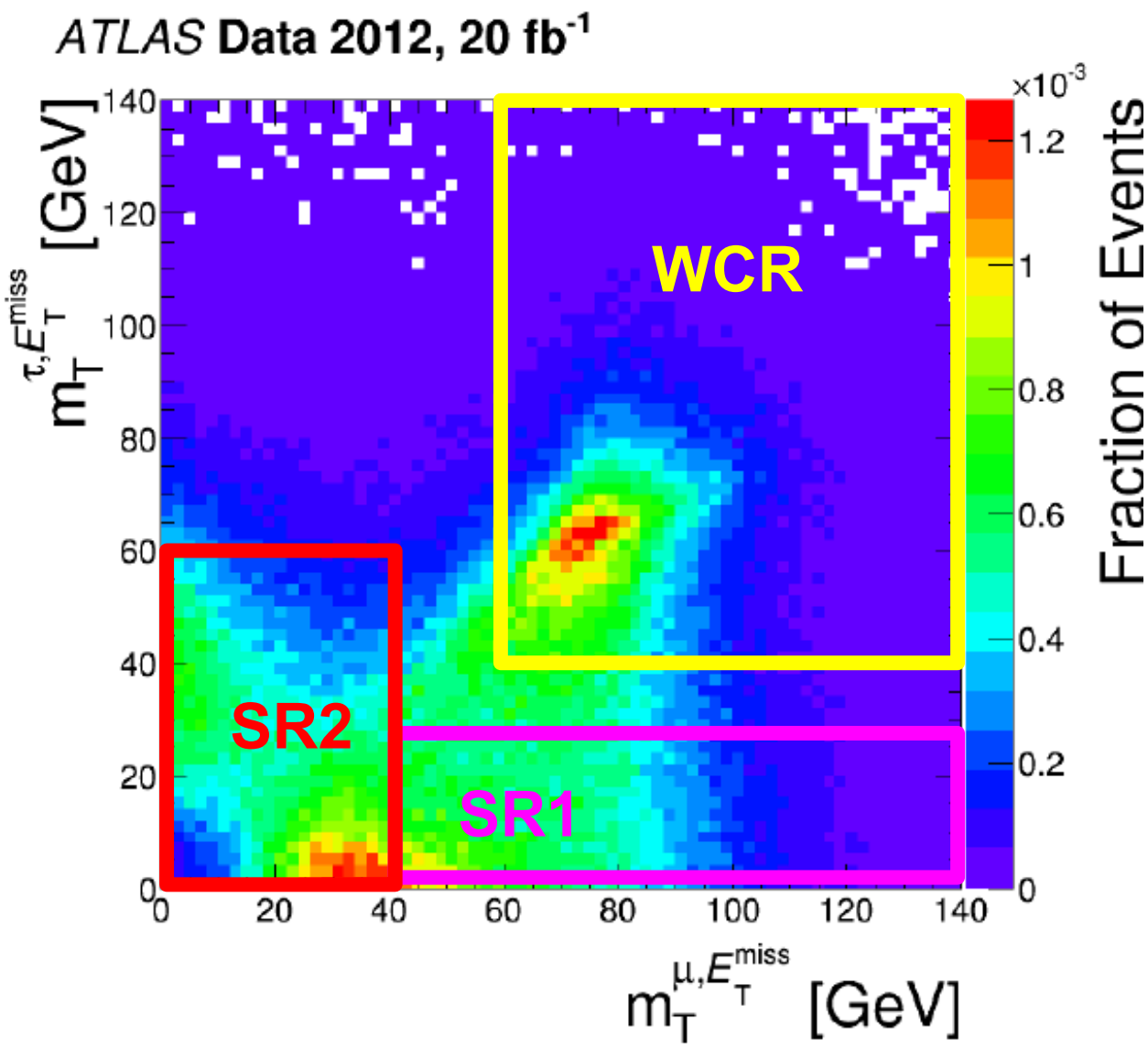
Hadronic Tau

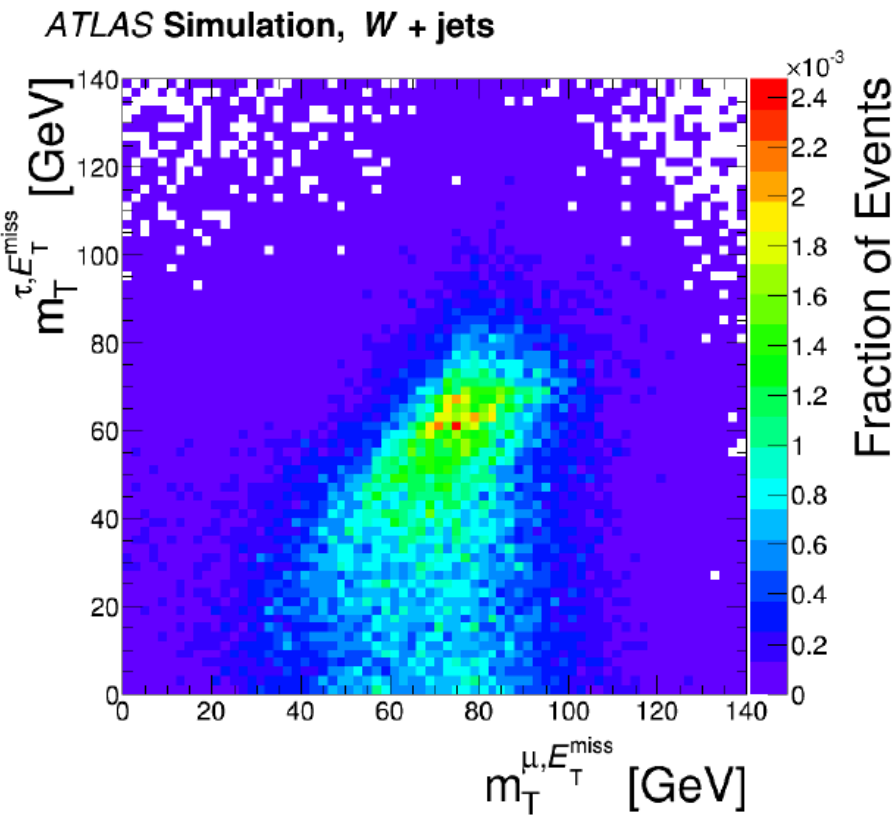


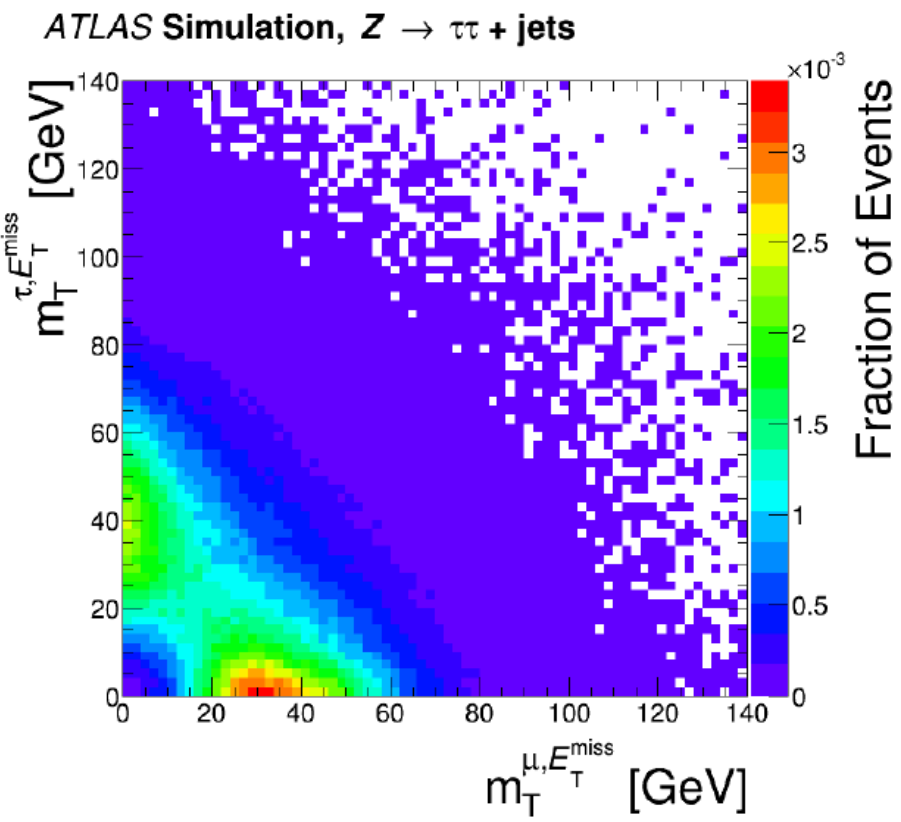
Preselection

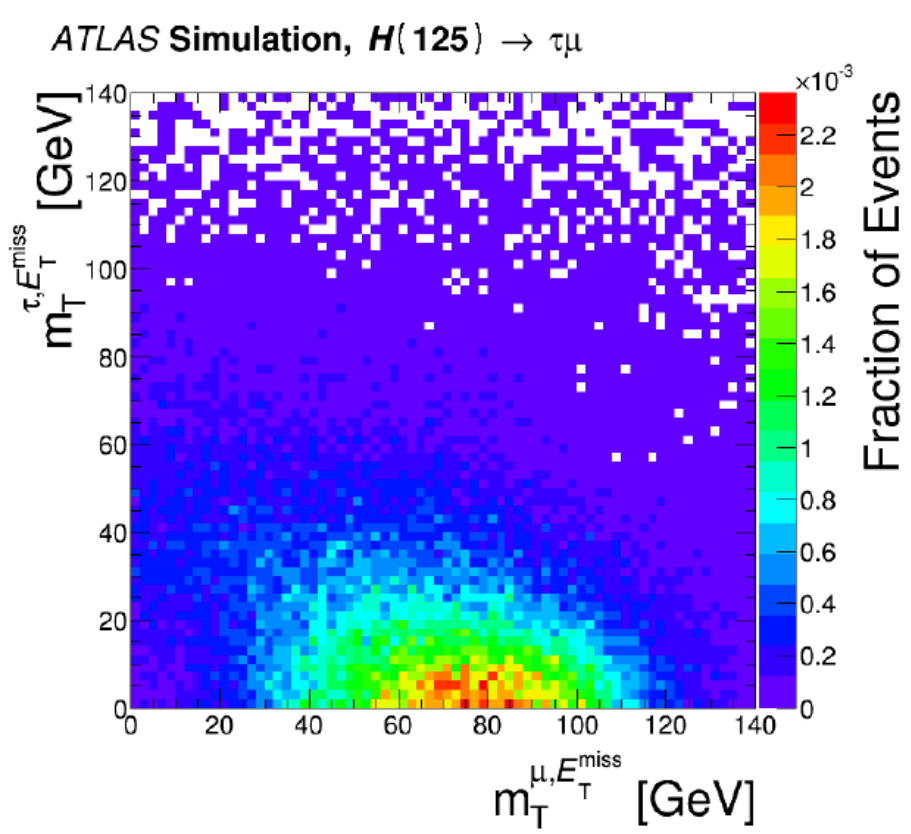
- One muon, pT > 26 GeV
- One hadronic tau, pT > 45 GeV
- Muon and tau have opposite charge
- No b-tagged jets
- MMC > 50 GeV
- $|\Delta\eta(\tau,\mu)| < 2.0$

Background Topologies



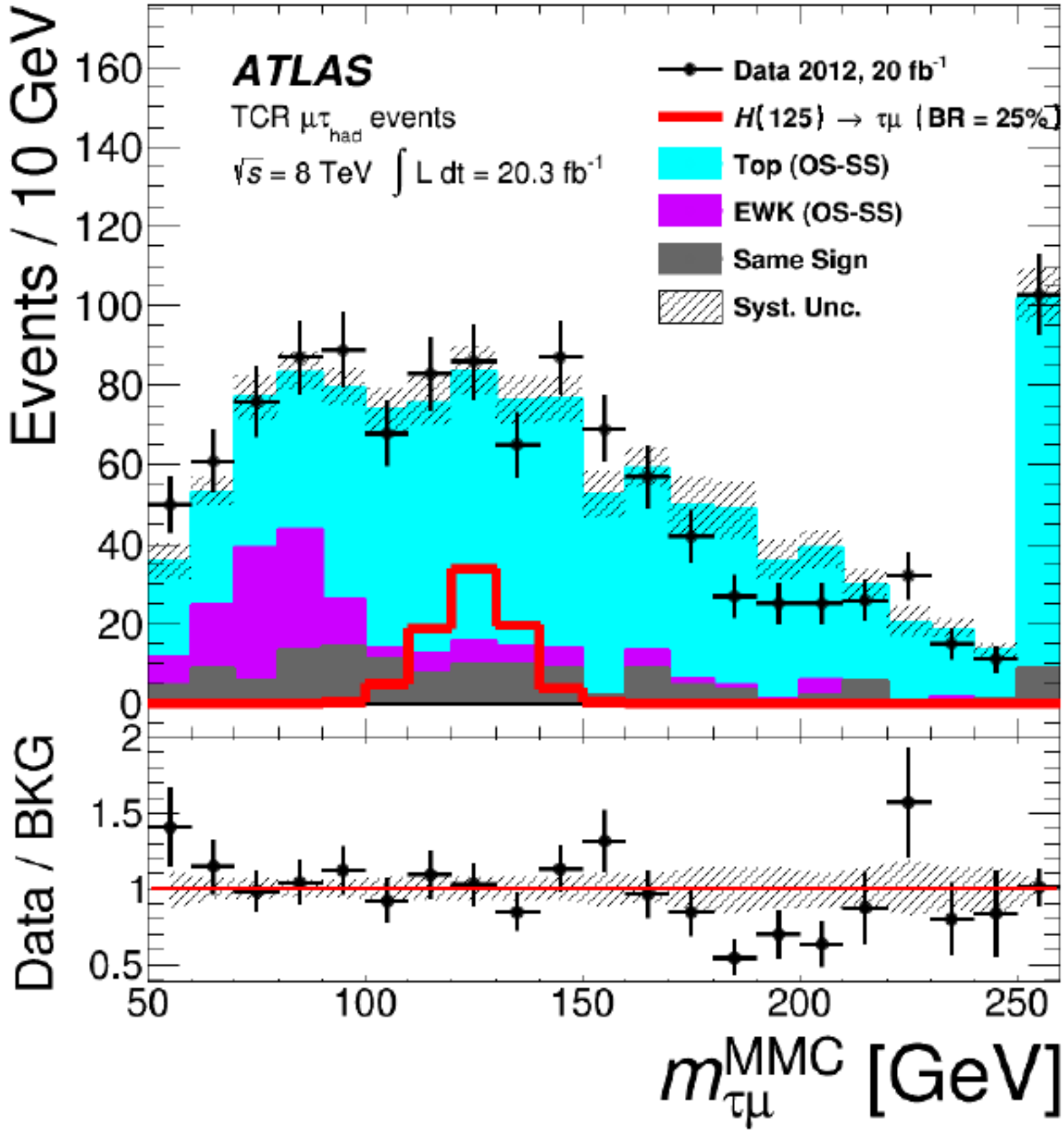






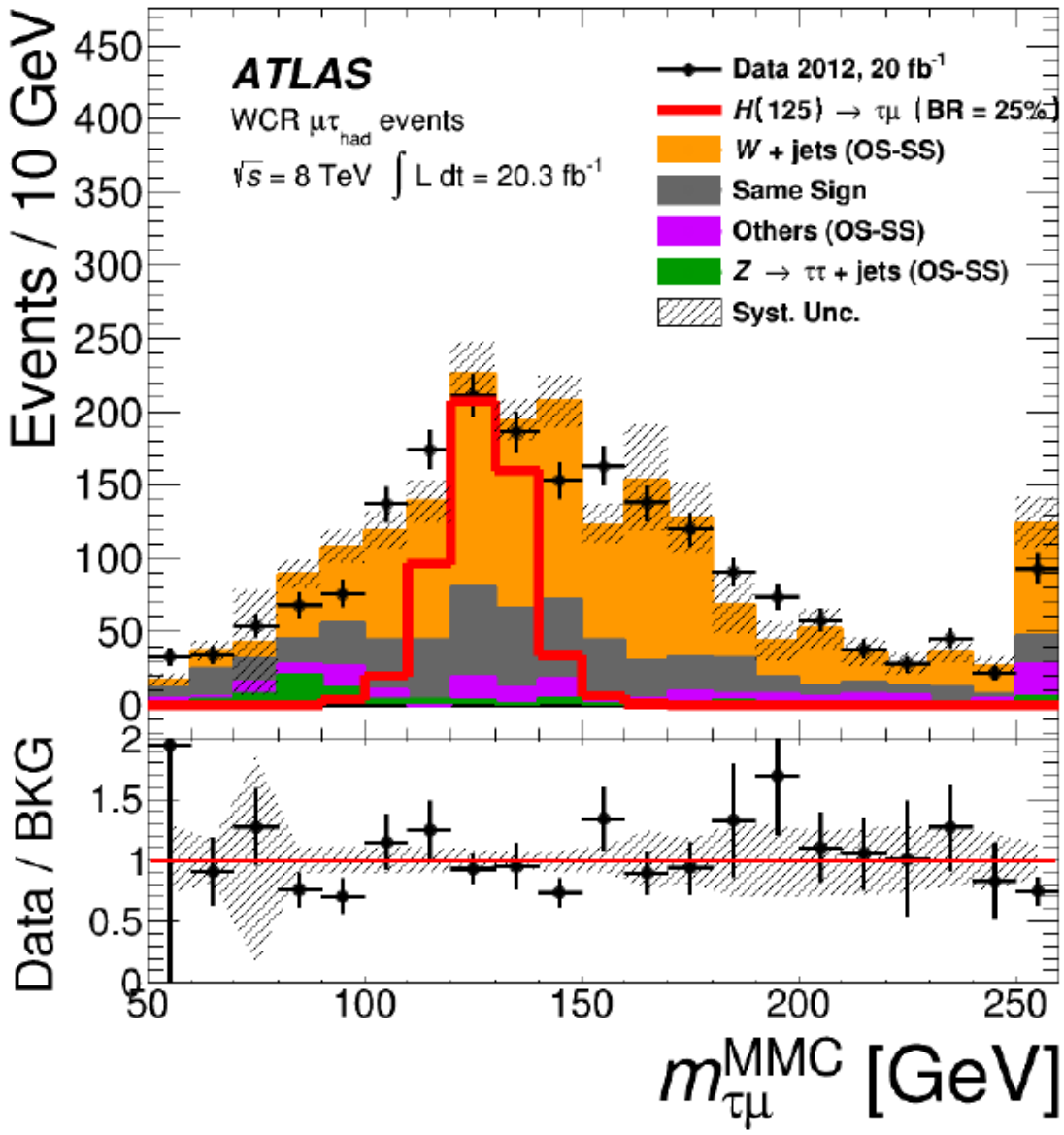
Top Control Region

- Events with ≥ 2 jets, at least 1 b-tagged
- Used to obtain k-Factors for Top background



W + jets

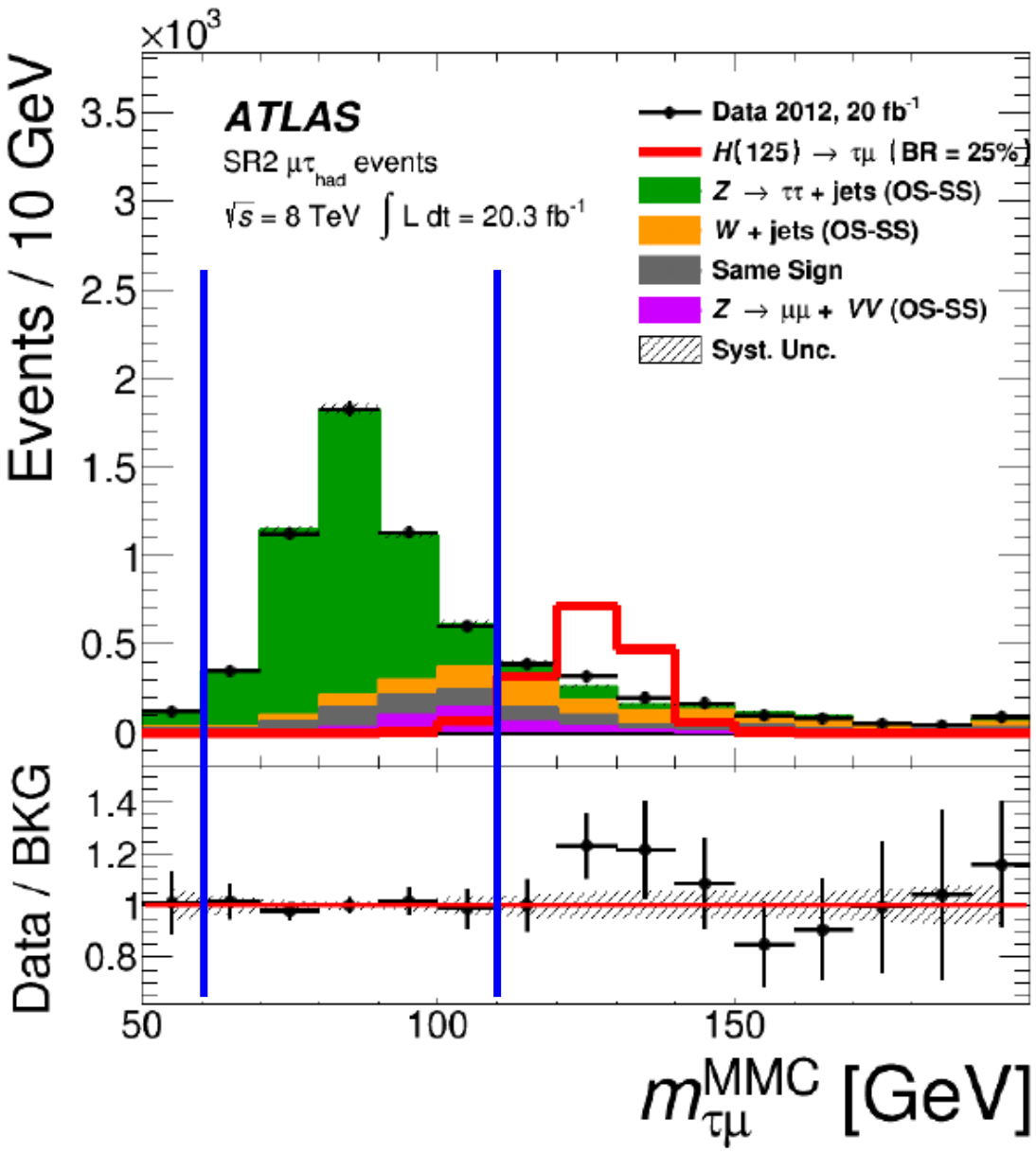
- Largest background
- k-Factors obtained in WCR

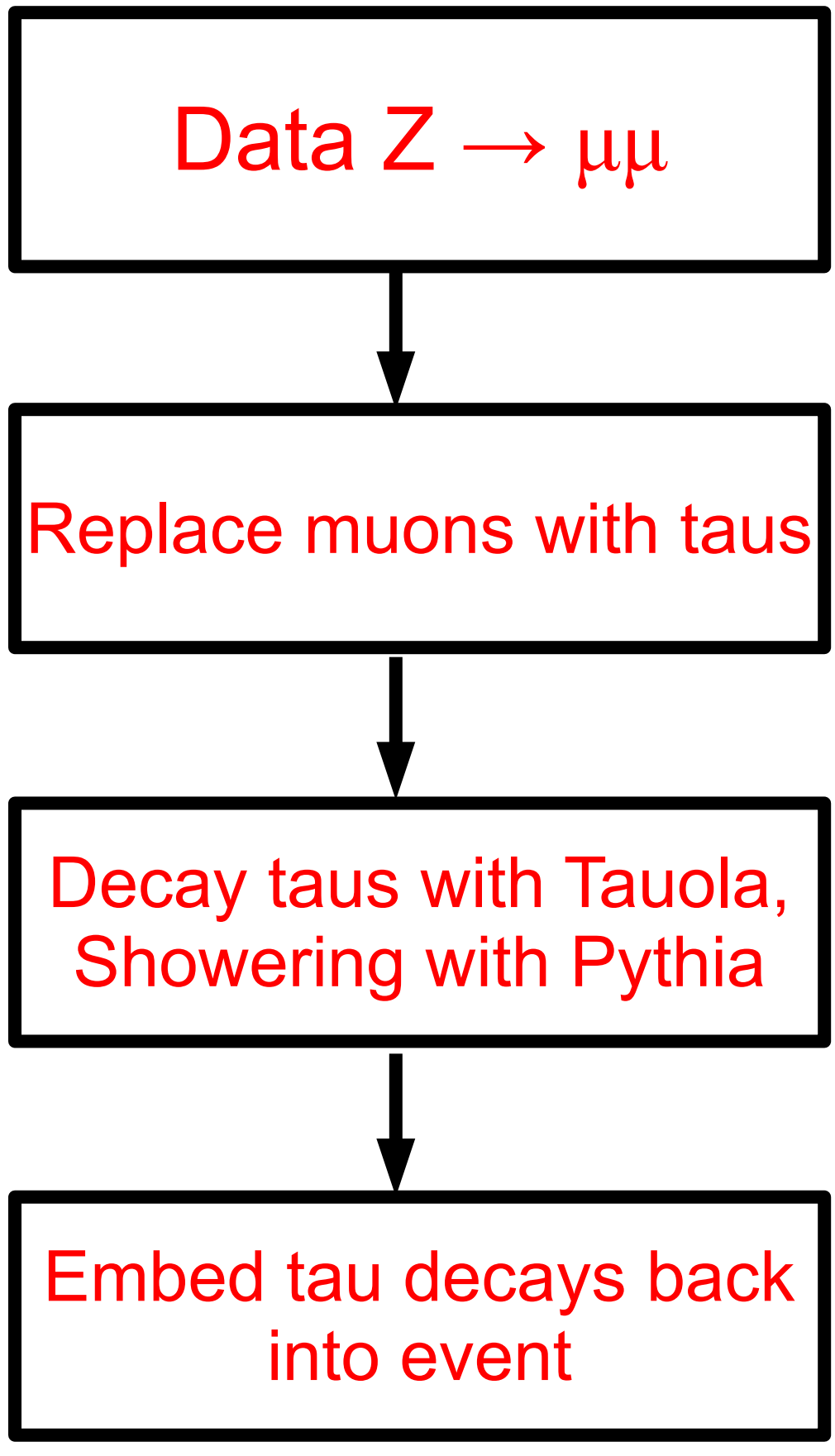


- SR1: Normalization and shape corrections obtained from MMC > 150 GeV.
  - Normalization: Floating parameter in the fit

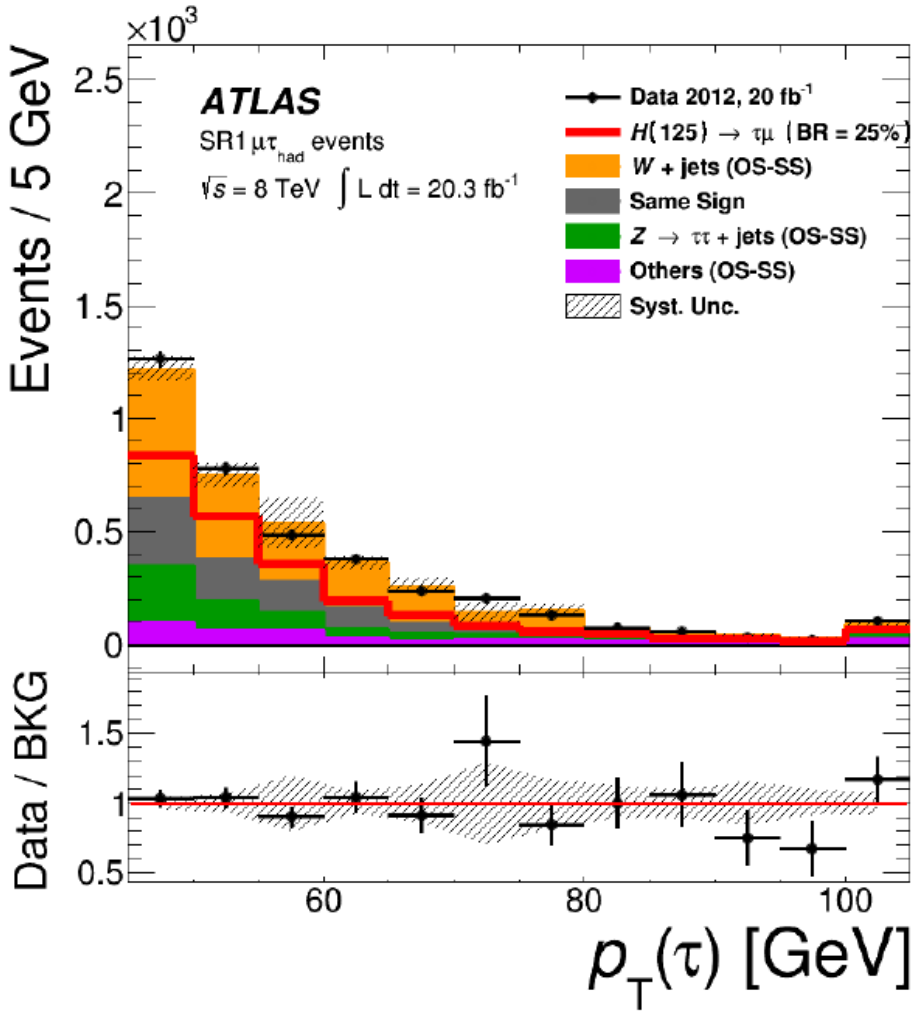
$Z \rightarrow \tau\tau$ + jets

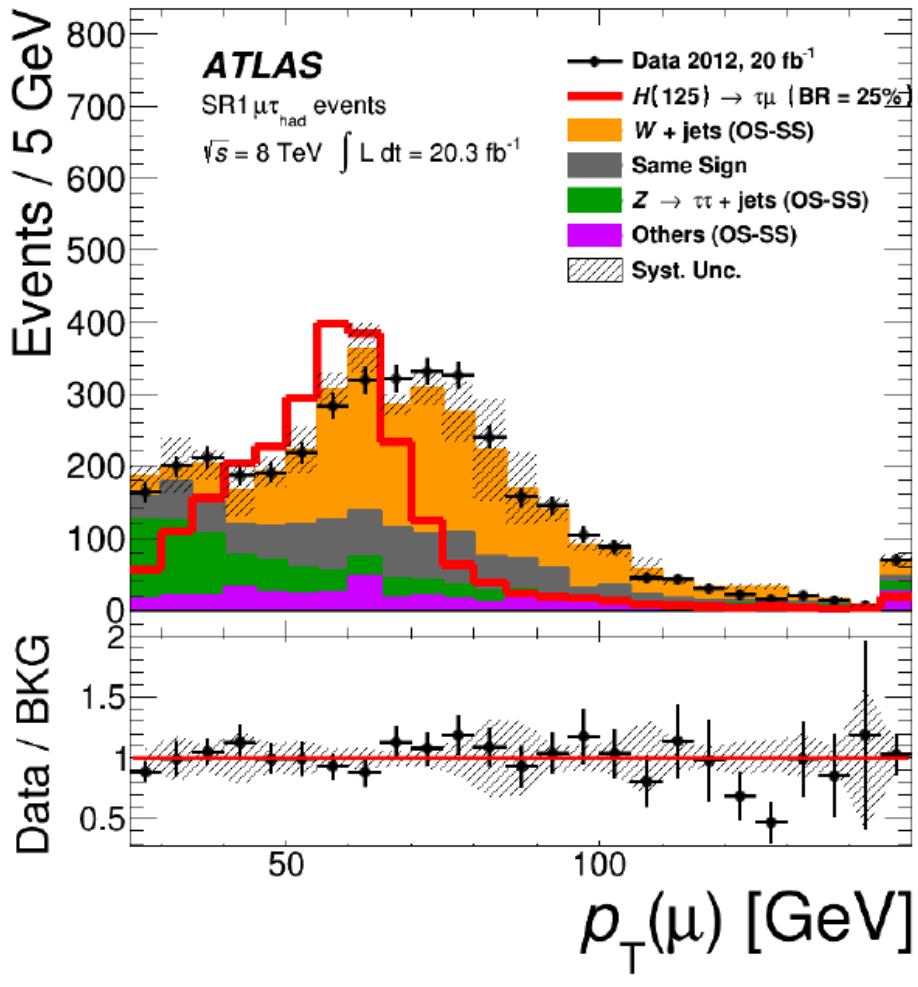
- Embedding Sample
  - Except for taus, event properties modeled by data
  - Advantages: kinematics, objects, and detector effects come from data
- Normalize in SR2 (60 – 110 GeV)
  - Free-floating parameter in fit

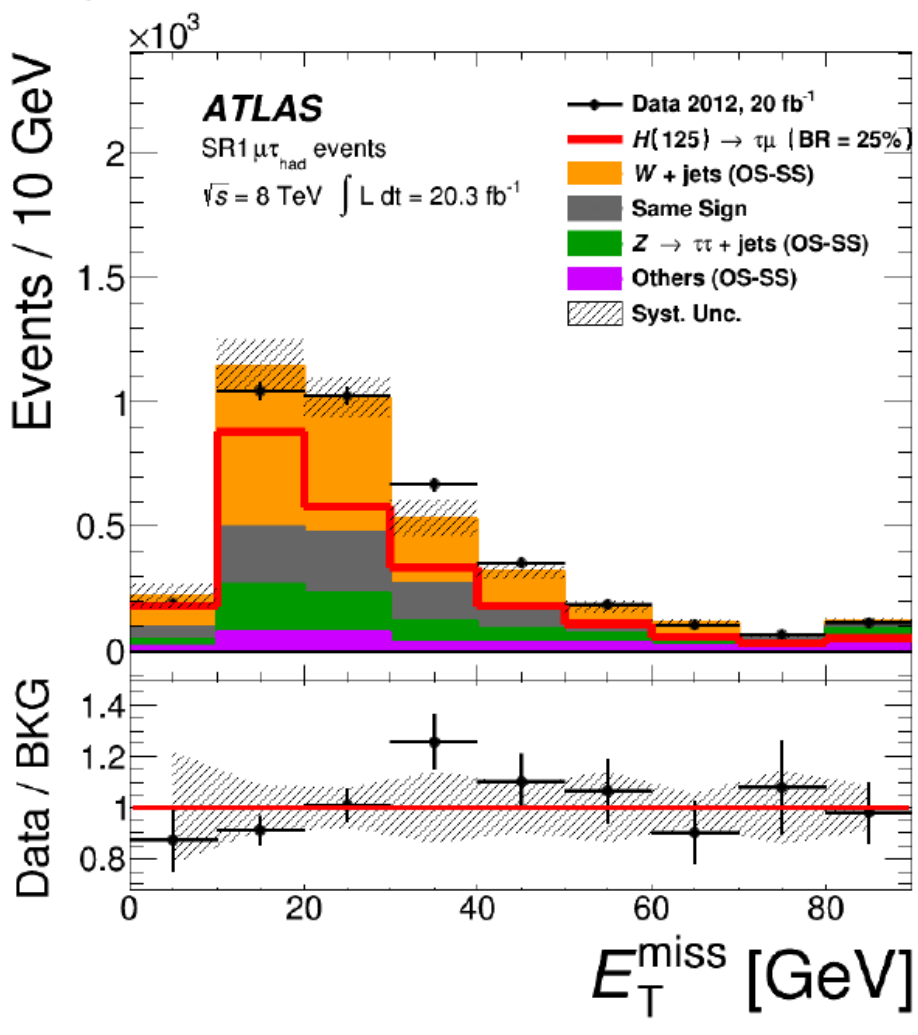




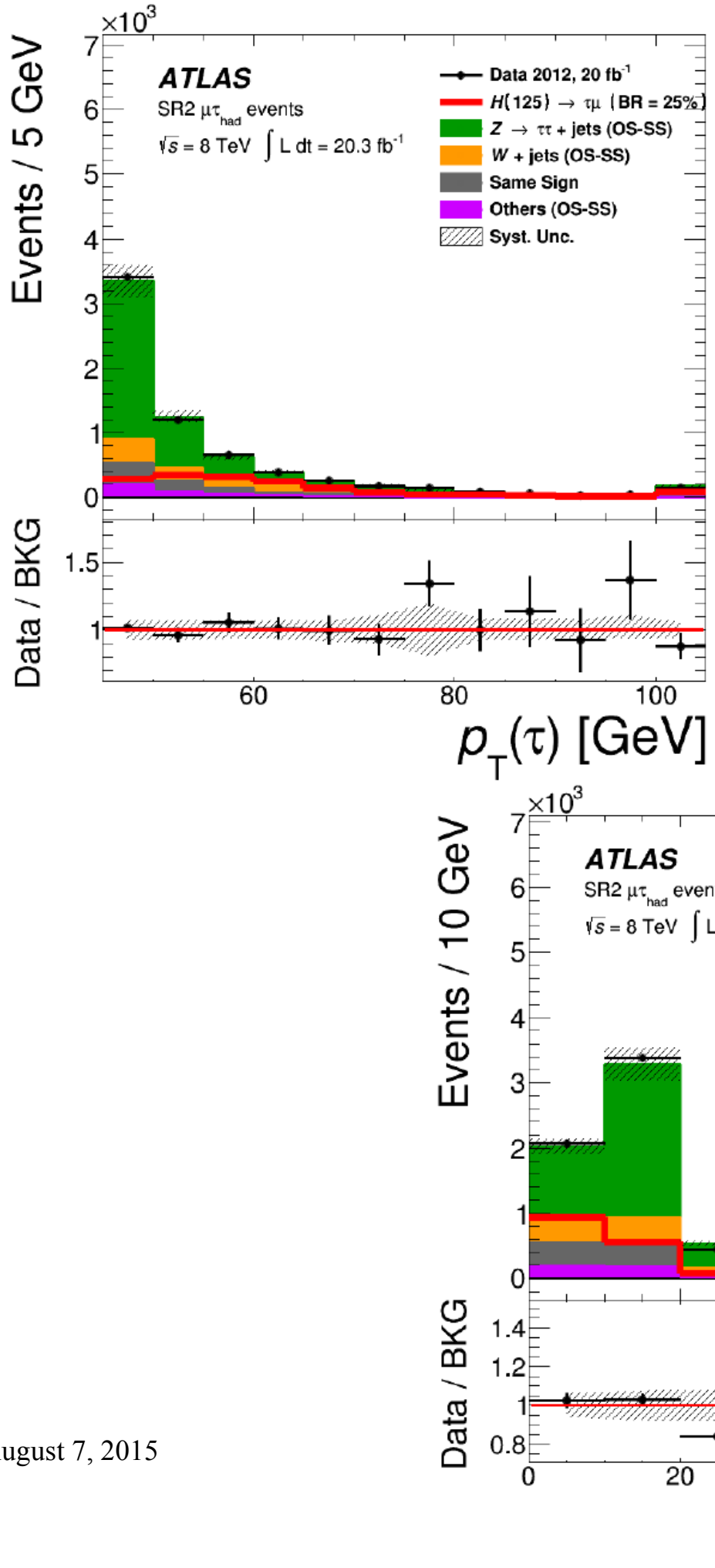
SR1 Pre-Fit Distributions

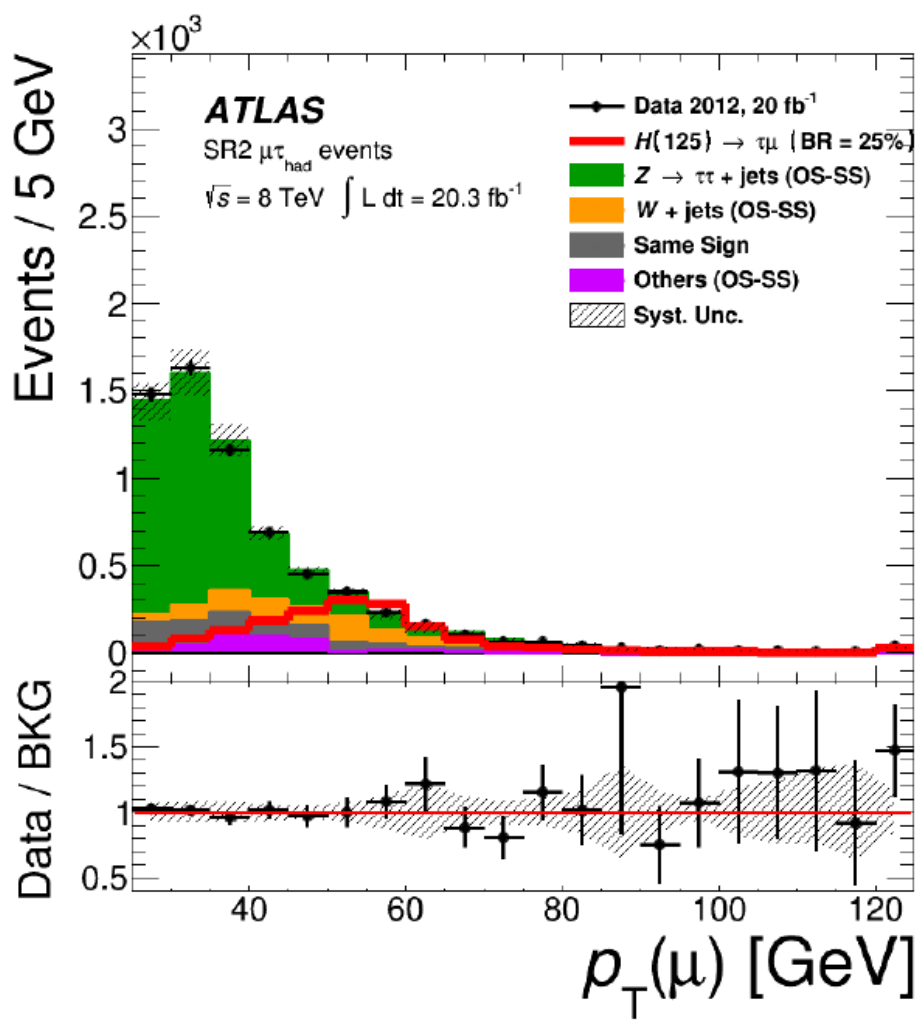


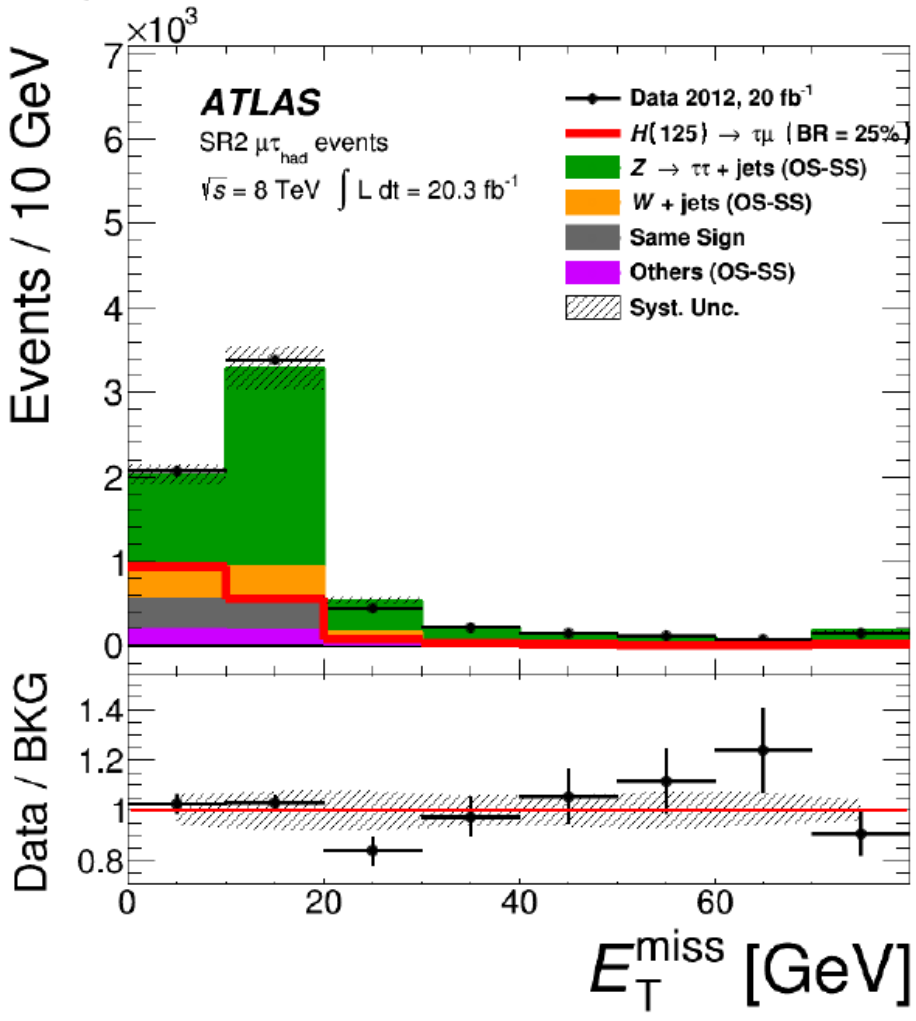




SR2 Pre-Fit Distributions







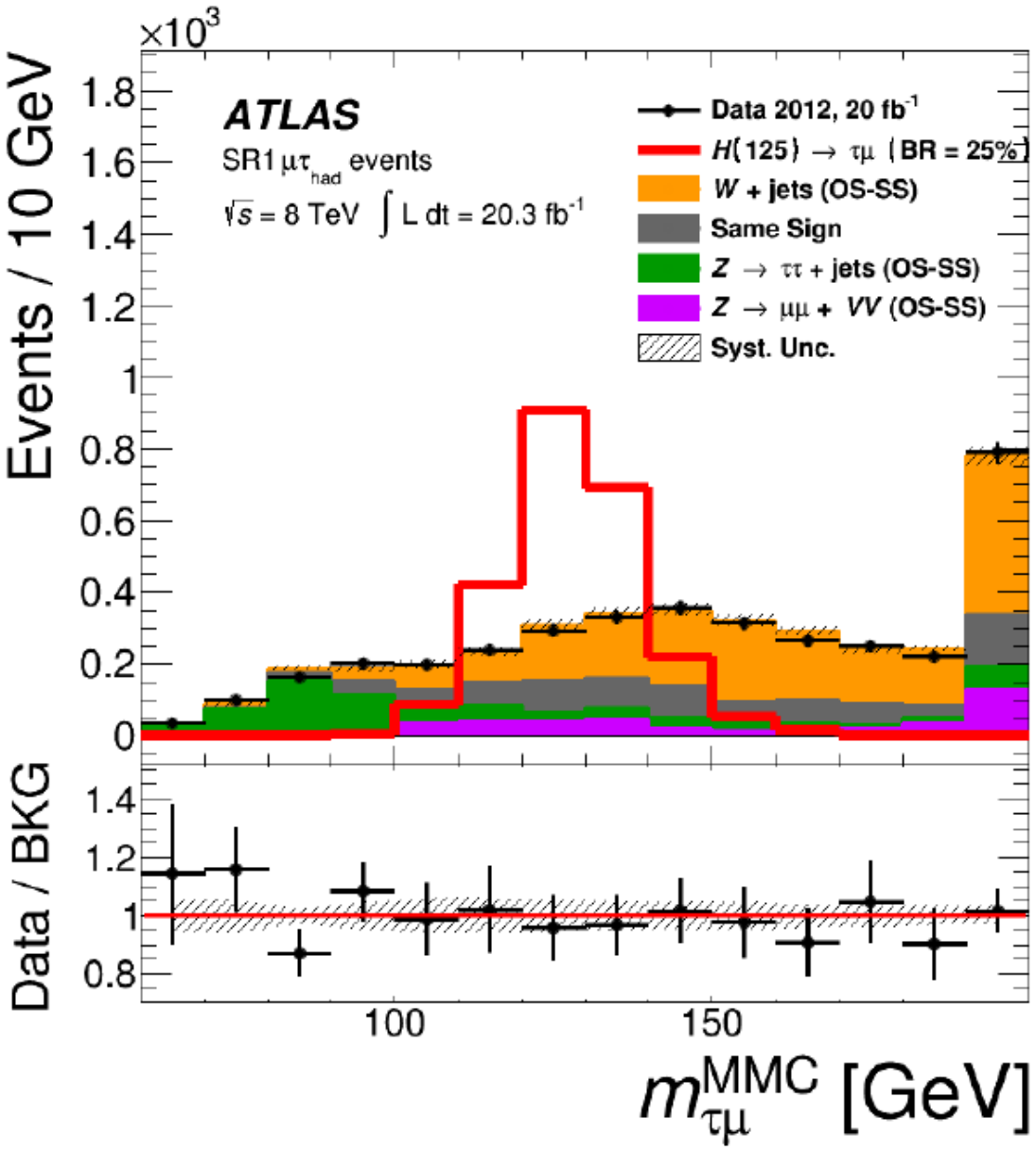
Signal Extraction

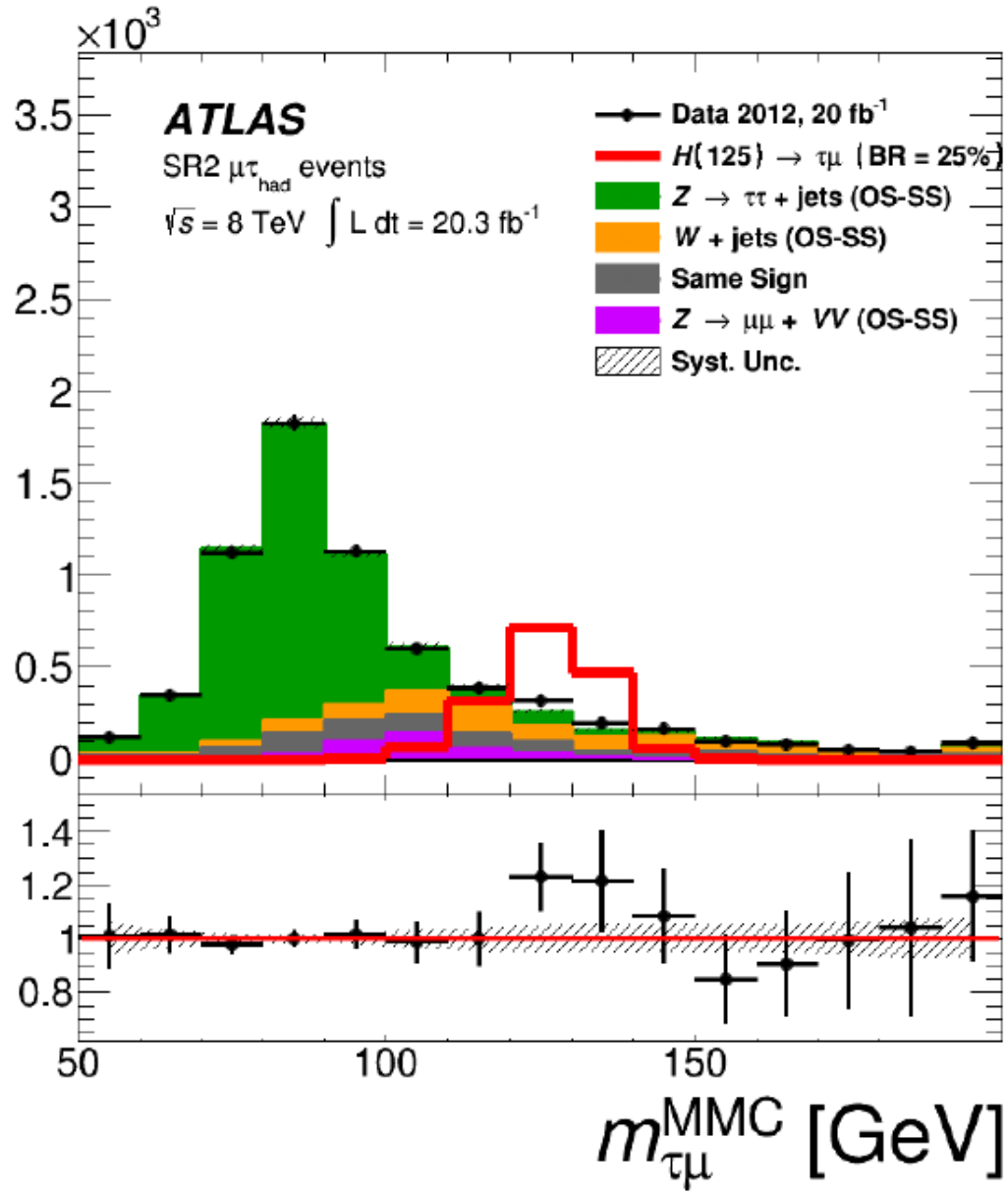
- Simultaneous binned-likelihood fit is performed on SR1, SR2, WCR, and TCR
- Shape information is used for SR1 and SR2
  - Exploit shape differences between $Z \rightarrow \tau\tau$, W + jets, and signal
  - Constrain systematic uncertainties
- Integrals of events (Single bin) for TCR and WCR
- Two floating parameters in the fit
  - W + jets normalization in SR1
  - $Z \rightarrow \tau\tau$ normalization

Post-Fit Mass Distributions

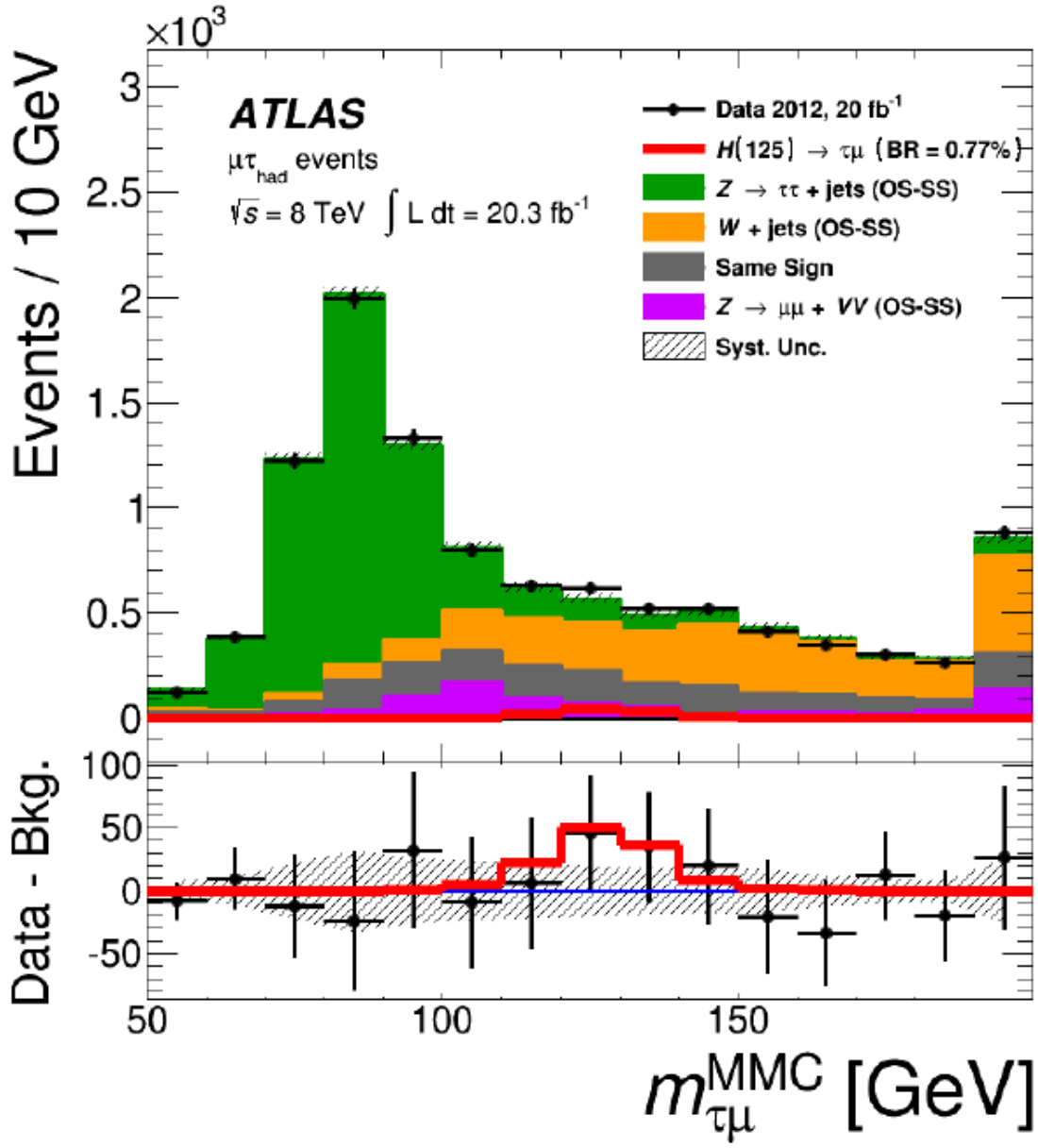
SR1

SR2





Results



Dominant Systematic: W+jets modeling in SR1 (10%)

	SR1	SR2	Combined
Expected limit on Br($H \rightarrow \mu\tau$) [%]	$1.60^{+0.64}_{-0.45}$	$1.75^{+0.71}_{-0.49}$	$1.24^{+0.50}_{-0.35}$
Observed limit on Br($H \rightarrow \mu\tau$) [%]	1.55	3.51	1.85
Best fit Br($H \rightarrow \mu\tau$) [%]	$-0.07^{+0.81}_{-0.86}$	$1.94^{+0.92}_{-0.89}$	0.77 ± 0.62

Conclusions

- A direct search for Lepton-Flavor-Violating decays has been presented.
  - Observed limit on BR($H \to \tau\mu$) = 1.85%
  - Expected limit on BR($H \to \tau\mu$) = 1.24 +0.5/-0.35 %
- More stringent constraints on BR($H \to \tau\mu$) compared to previous indirect measurements.
- Coming soon!
  - Results for search for LFV $H \to \tau_{\text{had}} e$
  - Results for LFV $H \to \tau_{lep} \mu$ and $H \to \tau_{lep} e$
  - Combined results of leptonic and hadronic channels

BACKUP

Systematic Uncertainties

Systematic Effect	% Unc.
Wj Modeling	10
rQCD	12.7
$Z \rightarrow \tau\tau$ Modeling	6
Tau Energy Scale	2-4
Luminosity	2.8
Tau ID	2-5
QCD-scale (ggH) (SR1)	10.1
QCD-scale (ggH) (SR2)	7.8
QCD-scale (VV)	5.0
PDF-scale (ggH)	7.5
PDF-scale (VBF, VH)	2.8
PDF-scale (V, VV)	4.0