Searching for New Physics with Multilepton Events with the ATLAS Detector at the LHC

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Introduction

A model-independent search for anomalous production of multilepton events.

Outline of this talk

1. Why multileptons?
2. Event and object selection
   - Categorization of events
3. Background estimation and systematic uncertainties
4. Results and limits
   - Presented in a model-independent format
5. Model testing

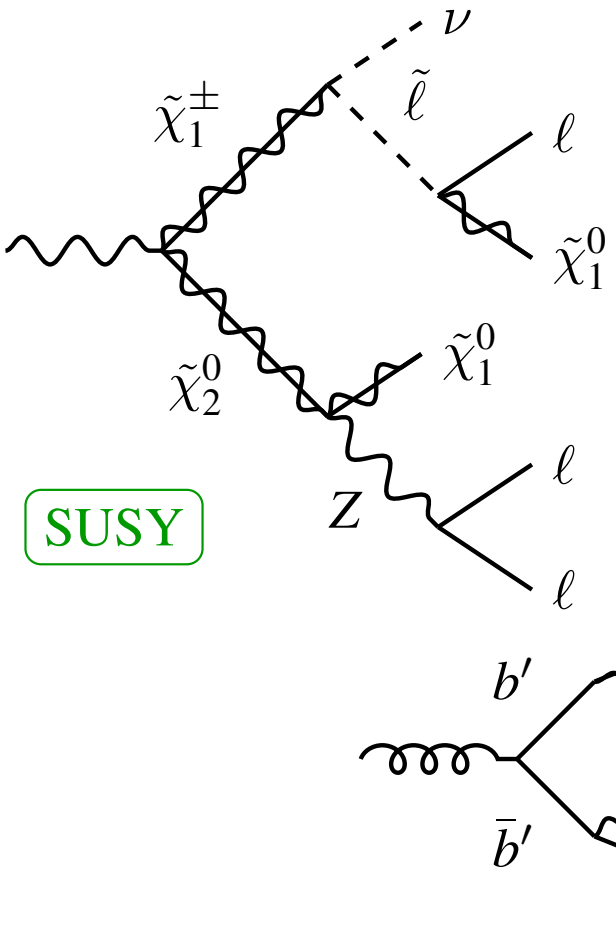
Results documented in ATLAS-CONF-2013-070

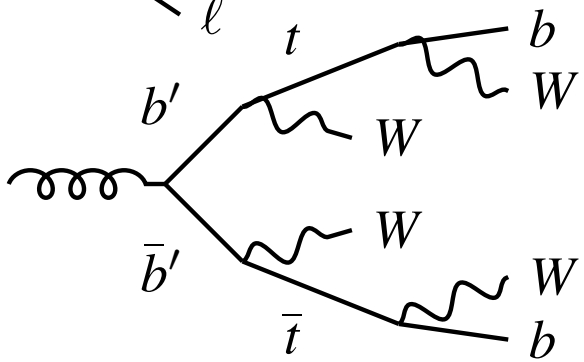
Leptons in BSM Searches

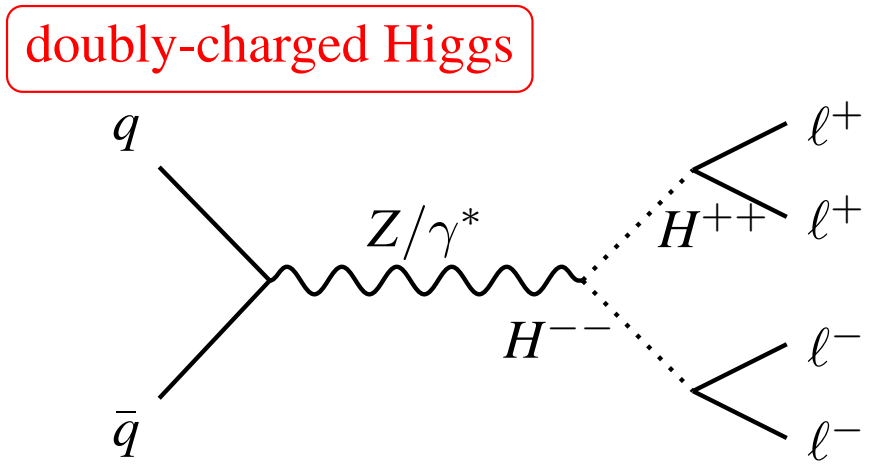
Prompt leptons are convenient probes of SM and BSM physics:

- Rare at hadron colliders
- Emerge (almost) unperturbed from the hard scatter
- "Easy" to trigger, reconstruct, identify

Events with 3+ leptons present in many new physics scenarios:







Search Strategy

Define 4 mutually exclusive signal channels, based on:

- Does the event have $\geq 3e/\mu$, or 2 e/μ and $\geq 1\tau$?
- e^+e^- or $\mu^+\mu^-$ pair (possibly with a third lepton) with $|m - m(Z)| < 20$ GeV?

Reject events with $\ell^+\ell^-$ pairs with $m(\ell^+\ell^-) < 15$ GeV (avoid low-mass resonances)

After categorization, inspect kinematic quantities of interest in each channel. Limits placed on individual channels with lower bounds on these variables:

Variable	Meaning
H_{T}	Σp_{T} of all jets in the event
m_{T}^{W}	Transverse mass of W-boson candidate (on-Z events only)

Variable	Meaning	Lower Bounds [GeV]				Additional Requirements
$H_{\mathrm{T}}^{\mathrm{leptons}}$	Σp_{T} of leading three leptons	0	200	500	800	
Min. p_{T}^{ℓ}	p_{T} of softest (third) lepton	0	50	100	150	
$E_{\mathrm{T}}^{\mathrm{miss}}$	MET_RefFinal	0	100	200	300	$H_{\mathrm{T}} < 150$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$		0	100	200	300	$H_{\mathrm{T}} \geq 150$ GeV
m_{eff}		0	600	1000	1500	
m_{eff}	$E_{\mathrm{T}}^{\mathrm{miss}}$+$H_{\mathrm{T}}$+$H_{\mathrm{T}}^{\mathrm{leptons}}$	0	600	1200		$E_{\mathrm{T}}^{\mathrm{miss}} \geq 100$ GeV
m_{eff}		0	600	1200		$m_{\mathrm{T}}^{W} \geq 100$ GeV, on-Z

Variable	Meaning	Lower Bounds		
b-tags	Number of b-tagged jets	0	1	2

Object and Event Selection

Lepton selection:

- $p_{\mathrm{T}} > 26$ GeV for triggered e/μ, > 15 GeV for subleading e/μ, > 20 GeV for τ
- Multivariate ID (e/τ)
- Impact parameter requirements (e/μ)
  - Reduces contributions from heavy-flavor decays, pileup
- Isolation requirements (e/μ)
  - Reduces non-prompt and fake leptons

Event selection:

- Single lepton triggers used:
  - At least one e or μ with $p_{\mathrm{T}} > 26$ GeV must match to a trigger
- Require 3 leptons, at least 2 e or μ

Other objects:

- Jets: $p_{\mathrm{T}} > 30$ GeV, $|\eta| < 4.5$
- b-tags: multivariate ID @ 70% efficiency working point

Background Estimation

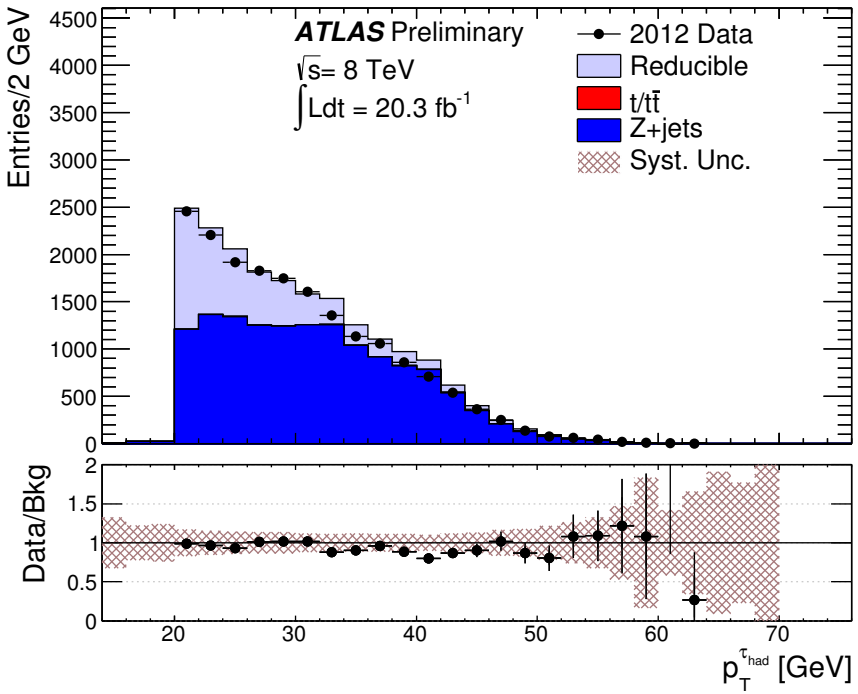
Background estimation split into two pieces:

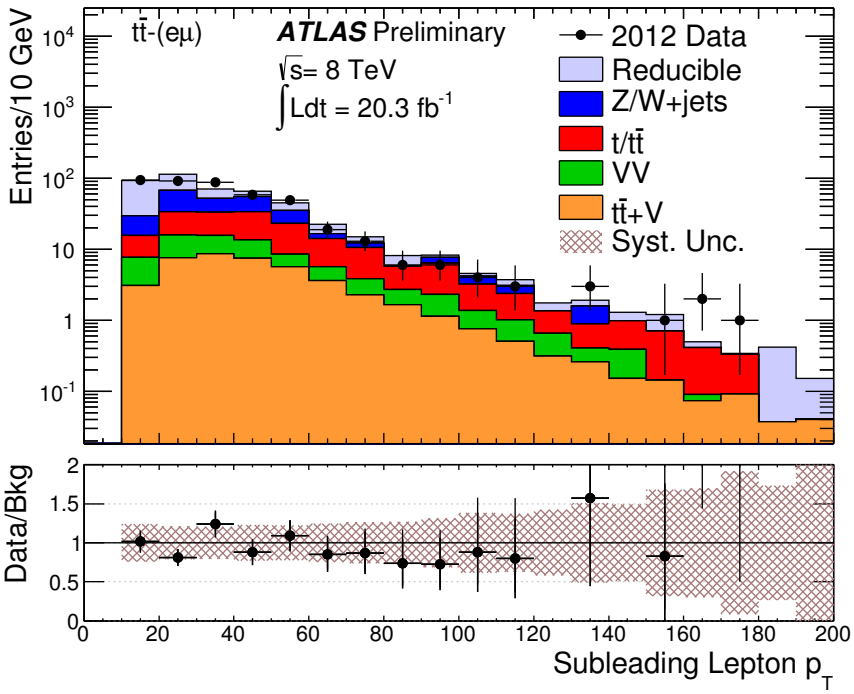
1. "Irreducible" backgrounds: events with 3 prompt leptons. Modeled with MC.
   - WZ/ZZ: SHERPA diboson samples with up to 3 jets
     - Includes γ^* contributions down to lepton mass thresholds (or 100 MeV for $\gamma^* \rightarrow ee$)
     - Also includes singly-resonant $Z \rightarrow 4\ell$ diagrams
     - Normalization and shapes cross-checked with POWHEG
   - $t\bar{t} + W/Z, t\bar{t} + WW$: MADGRAPH
   - $Z\gamma$ ($\gamma \rightarrow e$): ALPGEN
   - Triboson: MADGRAPH, negligible contributions
   - Higgs: various generators, negligible contributions.
2. "Reducible" backgrounds: events with up to 2 prompt leptons and at least 1 non-prompt or fake candidate:
   - Includes Z+jets, W+jets, $t\bar{t}$, single-top, multijets, etc.
   - Estimated with *fake-factor* method
     - Data-driven technique
     - Minimal dependence on MC

Validation Regions

Three validation regions:

- **OS Dilepton**: validate $e/\mu/\tau$ object selection, efficiencies, fakes (for τ)
- **SS Dilepton**: validate prompt and non-prompt background estimates
- **Intermediate-ID Trilepton**: validate reducible background estimates





Systematic Uncertainties

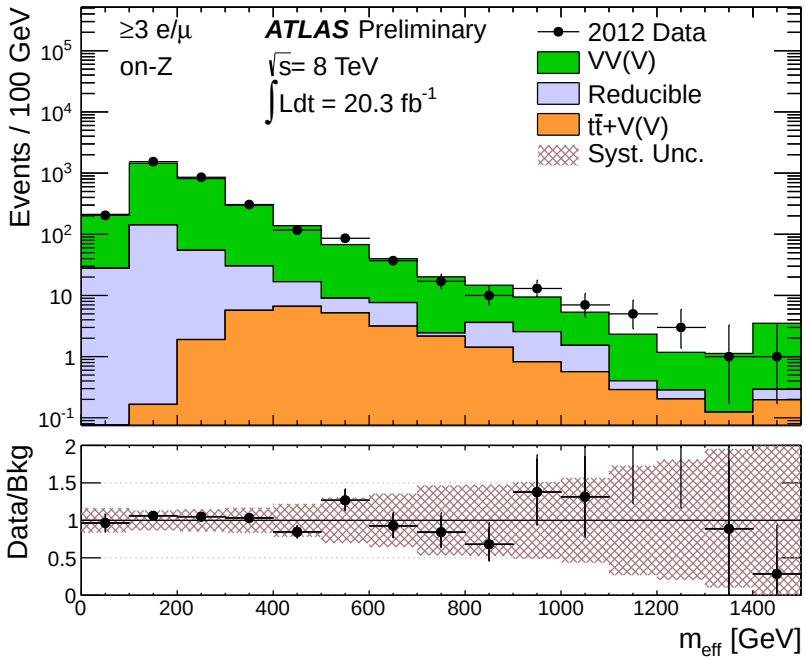
Systematics on irreducible background estimates:

- Cross-section uncertainties:
  - WZ: larger of 10% or $1.5 \times H_{\mathrm{T}}/\mathrm{TeV}$
  - ZZ: 25%
  - $t\bar{t} + W/Z$: 30%
- The uncertainties on WZ and ZZ are from comparisons of `SHERPA` (default) with `POWHEG`.

Systematics on fake-factor estimates:

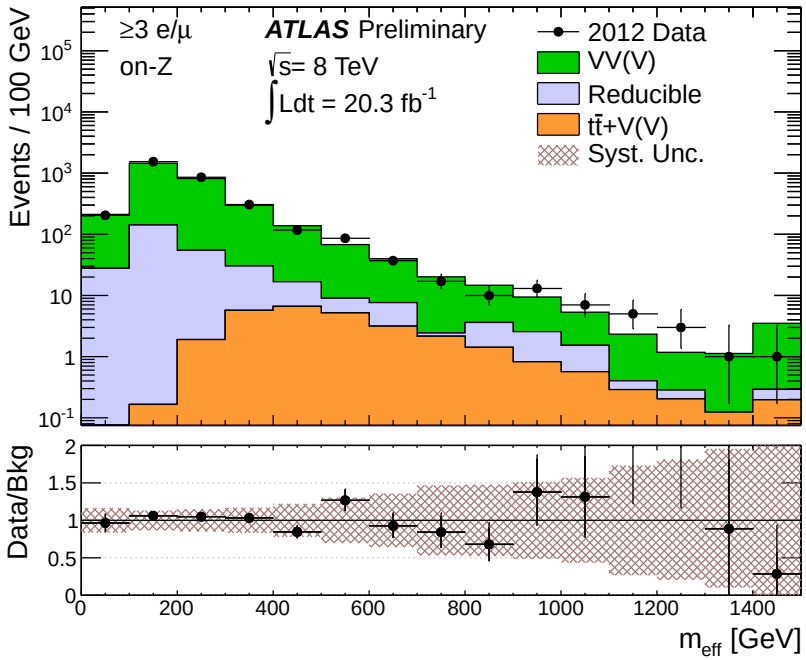
- Electrons: $\approx$30% uncertainties on fake-factors
  - mostly event selection and LF/HF differences
- Muons: rising from $\approx$30% at low p_{T} to $\approx$40% at 70+ GeV
  - driven mostly by jet activity, heavy-flavor fractions
- Taus: 25% uncertainty
  - primarily from varying selection criteria for W+jet events

Yields



m_{eff} $\geq$ [GeV]	Total	Observed
$\geq 3e/\mu$, off-Z		
600	$18 \pm 1 \pm 6$	15
1000	$2.96 \pm 0.41 \pm 1.78$	0
1500	$0.60 \pm 0.19 \pm 1.05$	0
$2e/\mu + \geq 1\tau$, off-Z		
600	$24 \pm 1 \pm 5$	27
1000	$1.4 \pm 0.4 \pm 0.8$	4
1500	$0.08 \pm 0.08 \pm 0.71$	1
$\geq 3e/\mu$, on-Z		
600	$98 \pm 4 \pm 43$	94
1000	$13 \pm 1 \pm 11$	17
1500	$2.09 \pm 0.38 \pm 2.81$	1
$2e/\mu + \geq 1\tau$, on-Z		
600	$48 \pm 2 \pm 11$	44
1000	$3.9 \pm 0.5 \pm 1.2$	4
1500	$0.06 \pm 0.05 \pm 0.71$	0

Yields



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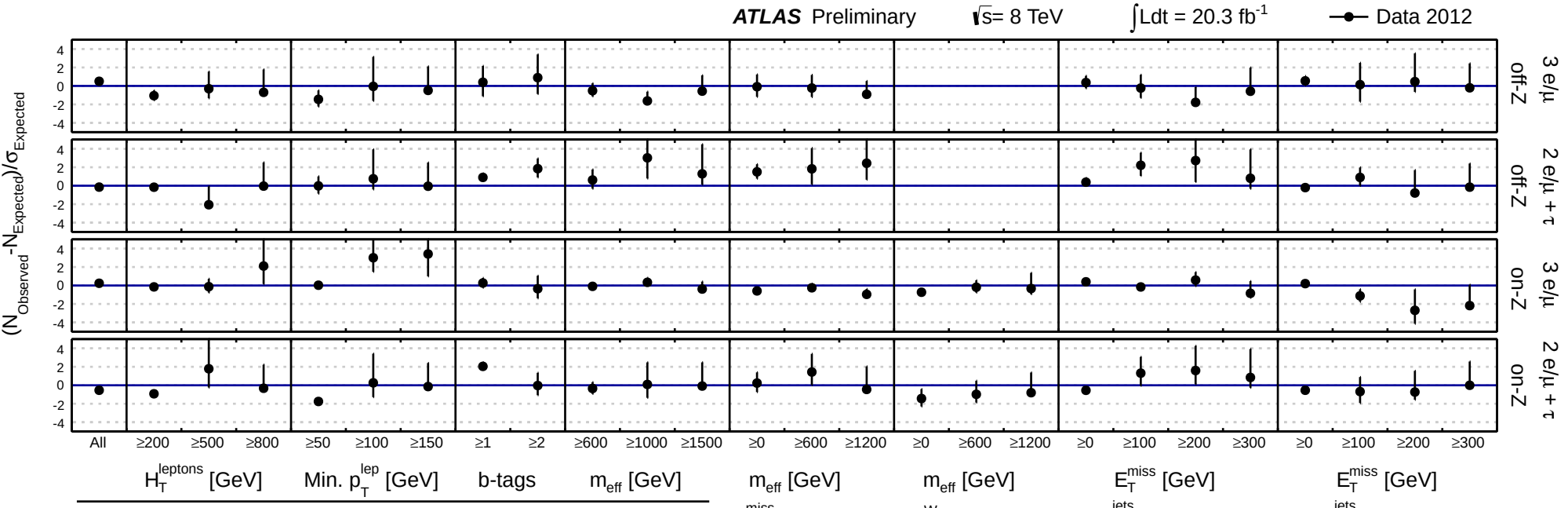
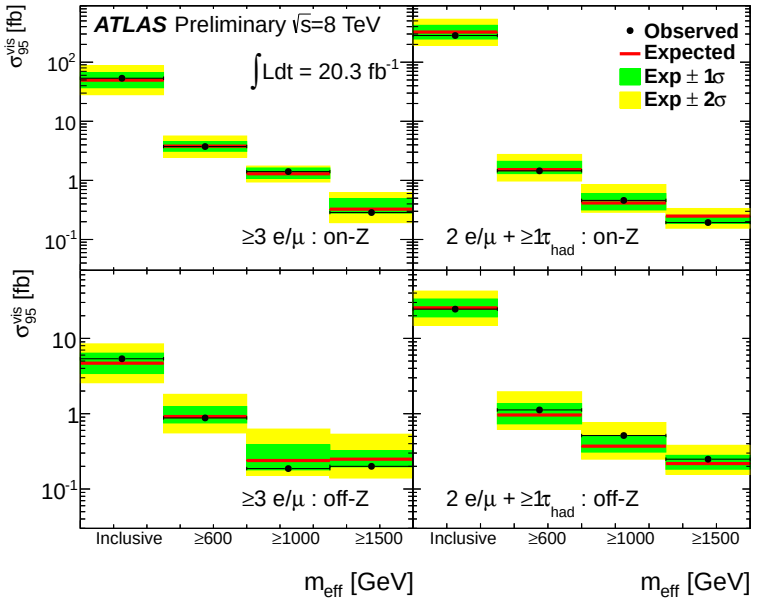


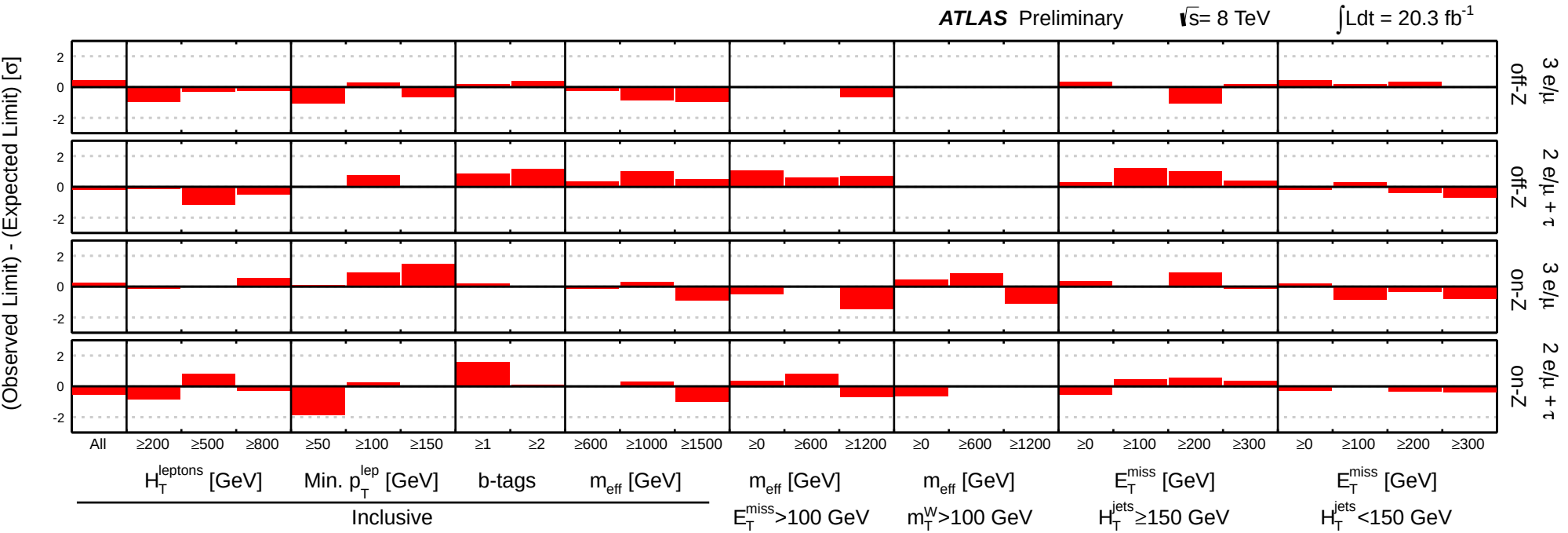
Limits

95% CL upper limits "visible cross section":

$$\sigma_{95}^{\mathrm{vis}} = \frac{N_{95}}{\int \mathcal{L} dt}$$

Note: no acceptance or efficiency taken into account...



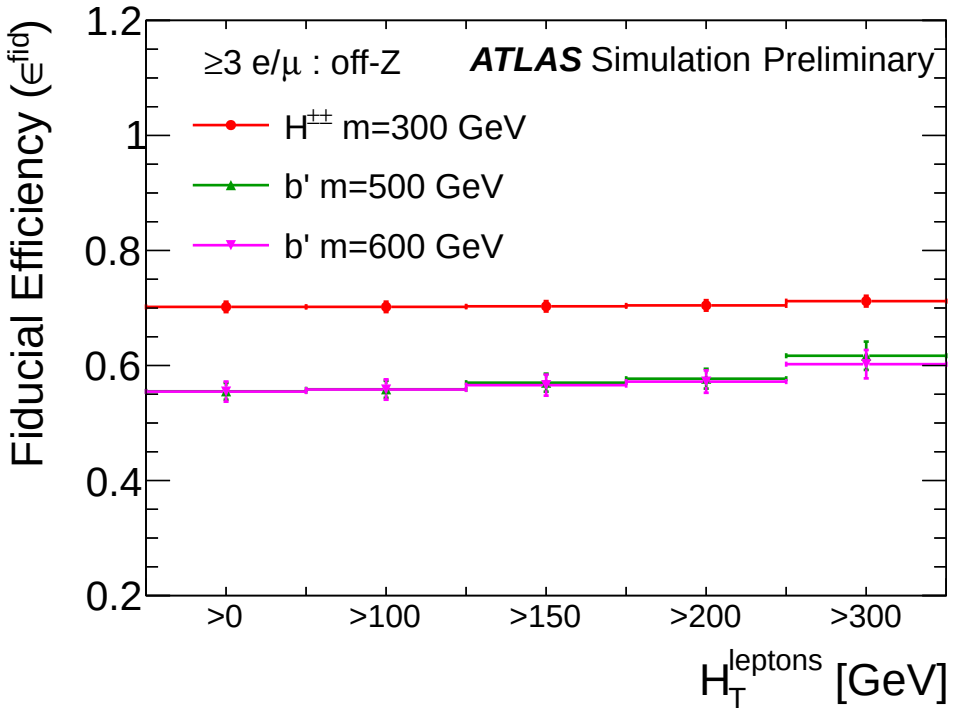


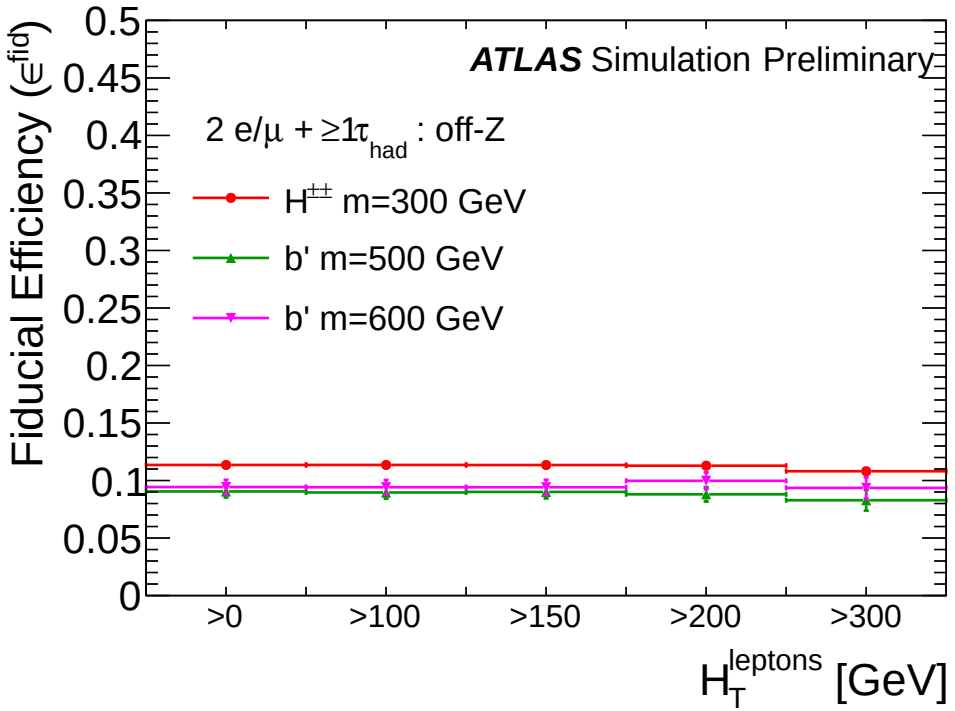
So, what now?

How can someone use these results?

$$\frac{N_{95}}{\int \mathcal{L} dt} = \sigma_{95}^{\text{fid}} \geq \sigma_{\text{NP}}^{\text{total}} \times \mathcal{A} \times \epsilon$$

- $\sigma_{\text{NP}}^{\text{total}}$: Total cross section of New Physics process
- $\mathcal{A}$: Acceptance – fraction of events we *can* see (reject events)
- ϵ: Efficiency – of events we *can* see, fraction of events we *should* see (weight events)





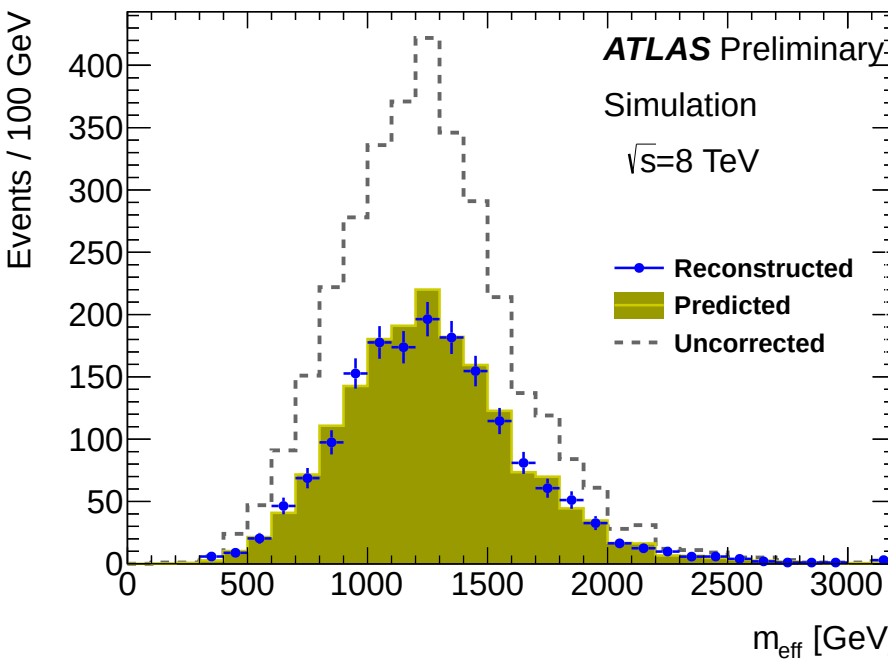
Getting around model dependence

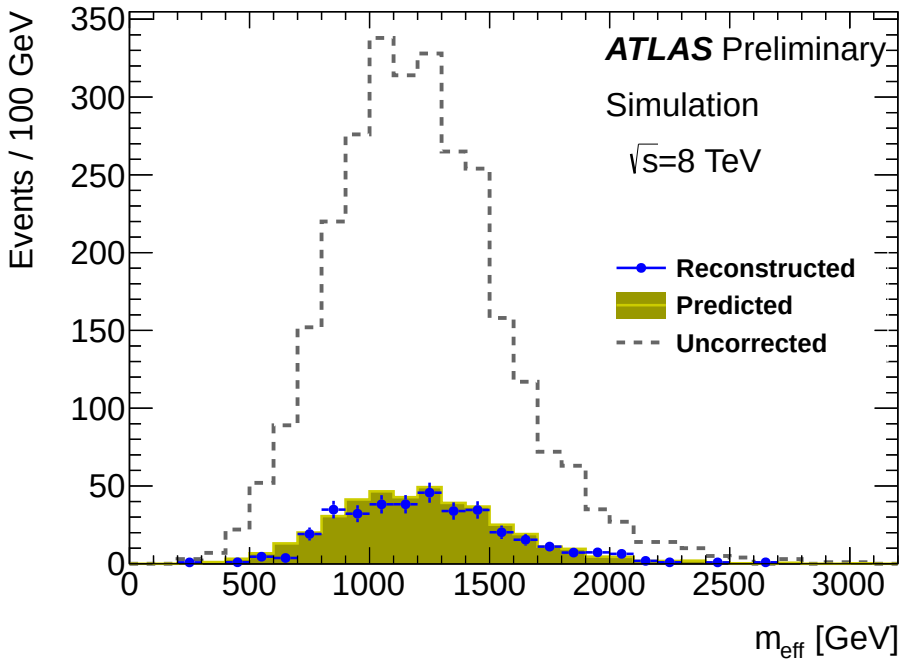
Efficiencies should also be model-independent!

- Fiducial volume at particle level: $\mathcal{A}$
  - p_{T}, $|\eta|$ requirements
  - Isolation requirements using stable particles
  - No special treatment for pileup!
- Measure ϵ in MC (WZ)

$\lvert\eta\rvert$	Prompt e	$\tau \rightarrow e$	τ_{h}
0.0–0.1	0.675±0.003	0.52±0.01	0.210±0.009
0.1–0.5	0.757±0.001	0.595±0.005	0.195±0.004
0.5–1.0	0.747±0.001	0.581±0.005	0.179±0.004
1.0–1.5	0.666±0.002	0.494±0.006	0.138±0.004
1.5–2.0	0.607±0.002	0.465±0.006	0.170±0.004
2.0–2.5	0.591±0.002	0.475±0.007	0.163±0.005

$$\epsilon^{\mathrm{fid}} = \epsilon_{\ell 1}\epsilon_{\ell 2}\epsilon_{\ell 3} \pm (10\% \text{ for } 3e/\mu,\ 20\% \text{ for } 2e/\mu{+}\tau)$$





Conclusions

Model independent search for anomalous production of multilepton events

- Results broadly consistent with expectation from SM
- Upper limits on contributions from new physics vs many kinematic variables
  - Lepton kinematics
  - $E_{\mathrm{T}}^{\mathrm{miss}}$
  - Jet (and b-jet) activity
- Efficiencies provided for model testing
  - Results designed to be (re)interpreted by everyone

Thanks for listening!