Multileptons... and more!

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Experimental Seminar
SLAC

A little... motivation.

Today's Topic...

Search for New Phenomena in Events with Three Charged Leptons at $\sqrt{s} = 8$ TeV with the ATLAS detector

The ATLAS Collaboration

will be used as an excuse to present some nifty ATLAS results, while thinking about these keywords:

at least three charged leptons

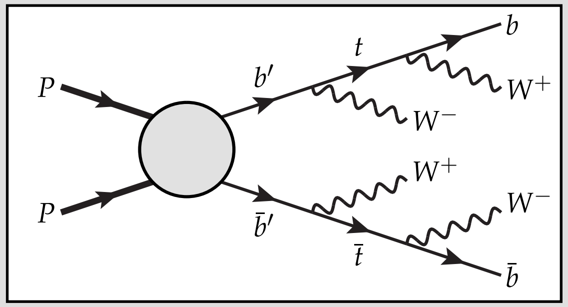
model-independent

hadronically decaying tau lepton

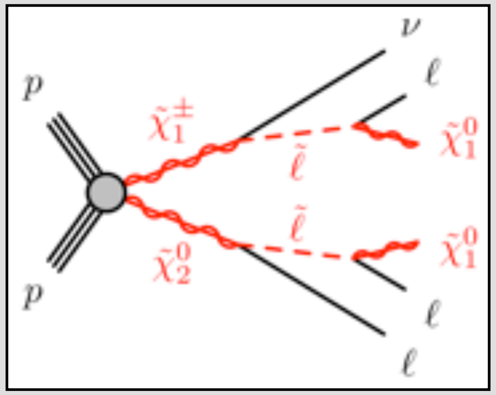
Why look in Multilepton events?

- **Because Multilepton events are sensitive to:**

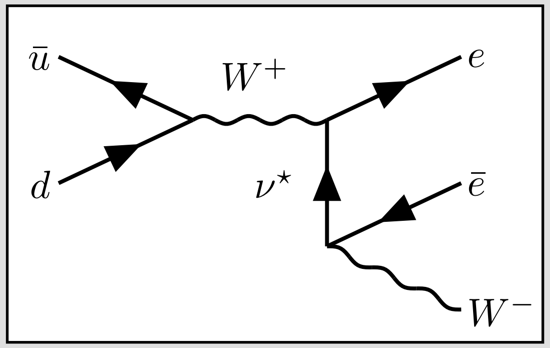
Vector-like Quarks:
Arise in 'Composite Higgs' models (including extra dimensions), these models providing a solution to the naturalness problem...



Supersymmetry:
Provides (sometimes) a dark matter candidate, solves naturalness... Multilepton final states are preferred in weakly-produced/RPV SUSY...

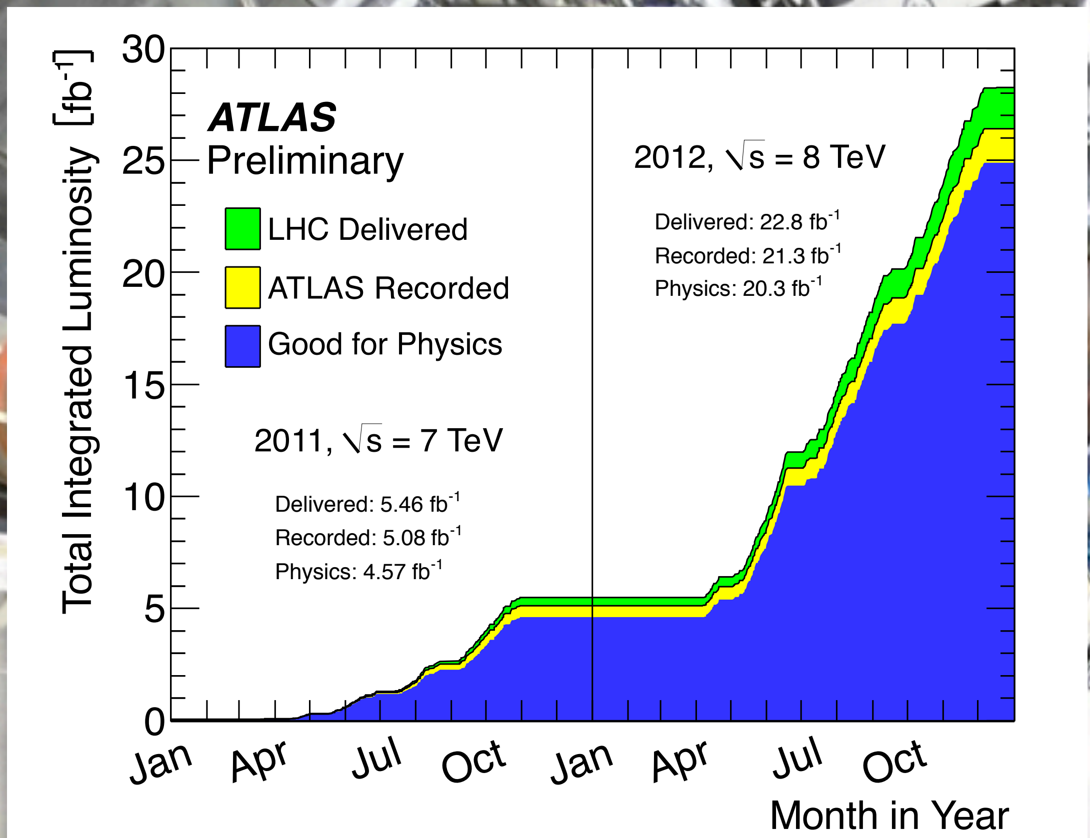


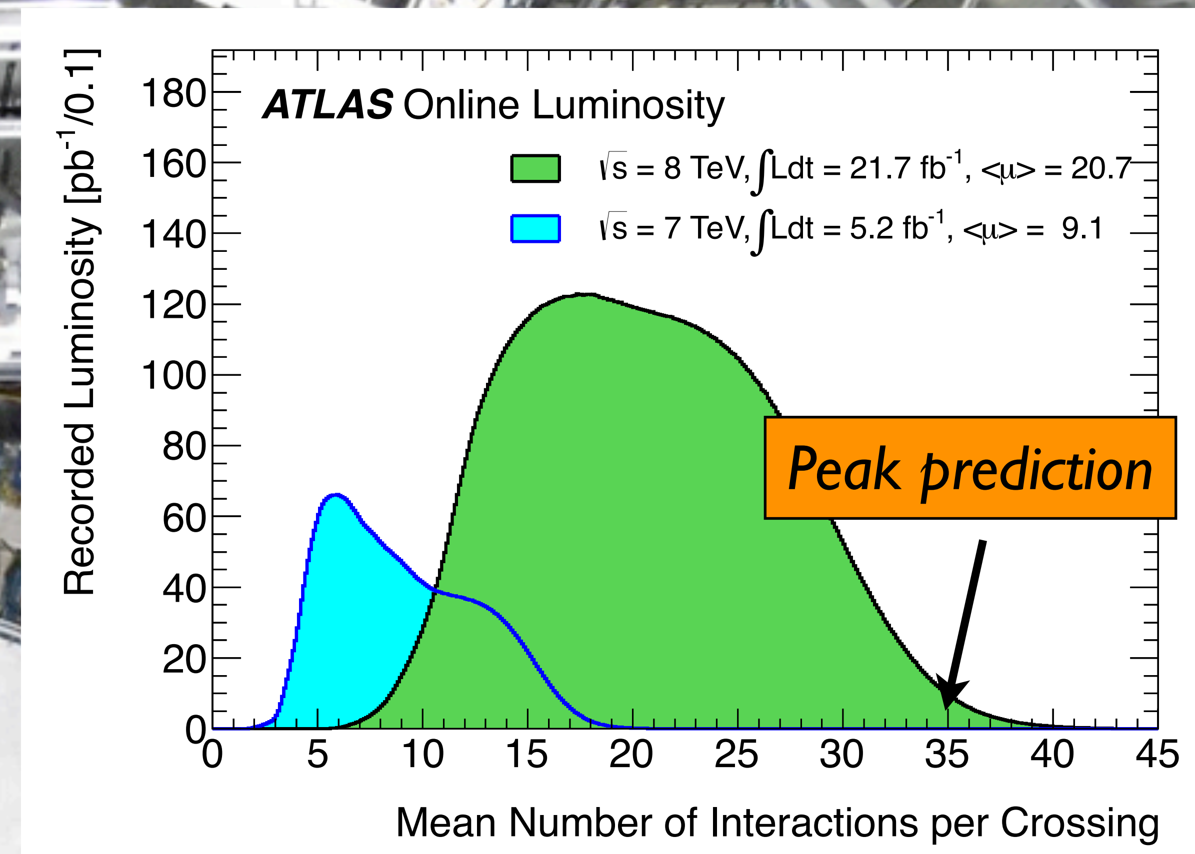
Excited Leptons/Neutrinos:
Onset of compositeness, produced through gauge-mediated and contact interactions.
Could offer an explanation for fermion mass spectrum...

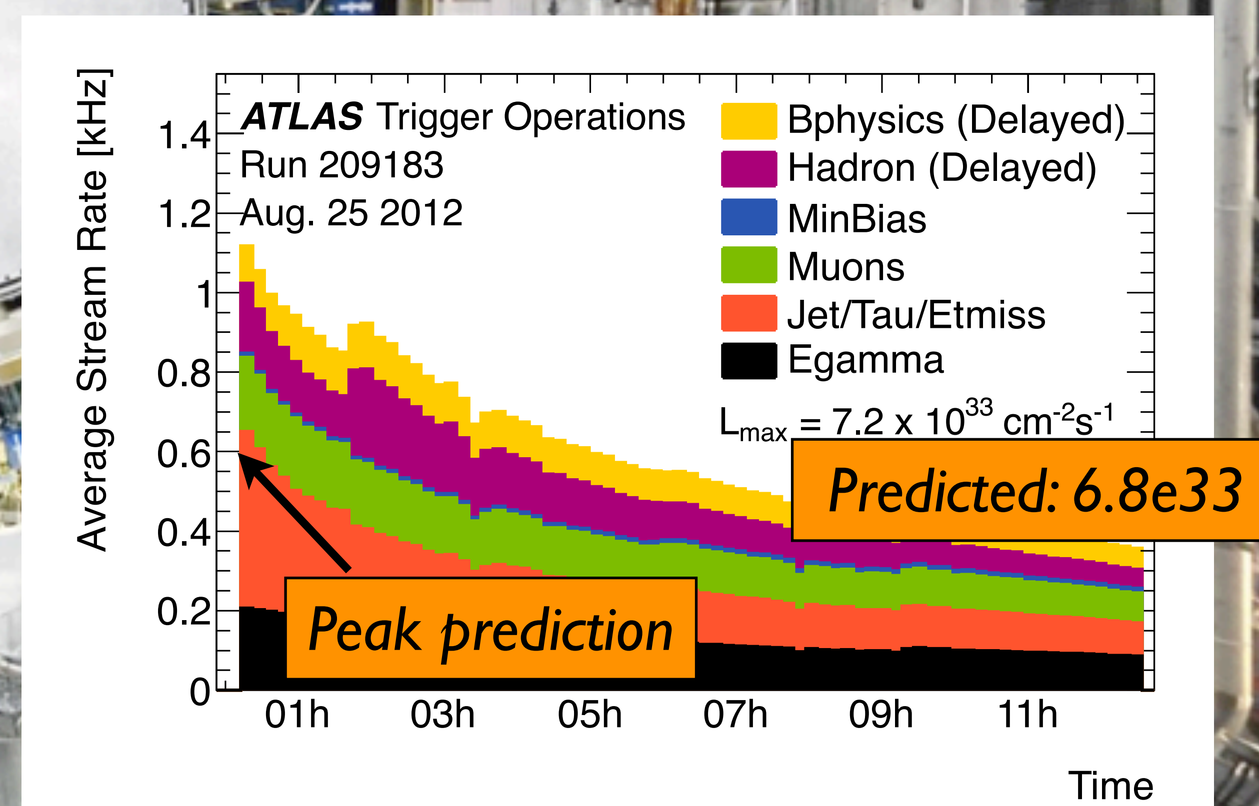


And many more...
All of these predict potentially interesting things at the O(1-10 TeV) scale...

ATLAS Performance in Run-I







ATLAS & the LHC have surpassed predictions and shown superlative performance in 2012!

Why look in Multilepton events?

Simply because it is our responsibility as experimentalists to look everywhere!
[A discovery could be right under our noses!]

Model-independence - Motivation

- **What is a model-independent search?**

  A search which is not optimized for a specific model of new phenomena. Often targeted at a specific final state, and attempting to cover a large region of phase space.

- **Why are they potentially interesting?**

  The phase space for potential new phenomena is downright immense, and focusing on a single model can lead to interesting new physics being missed!

- **Where are they potentially weak?**

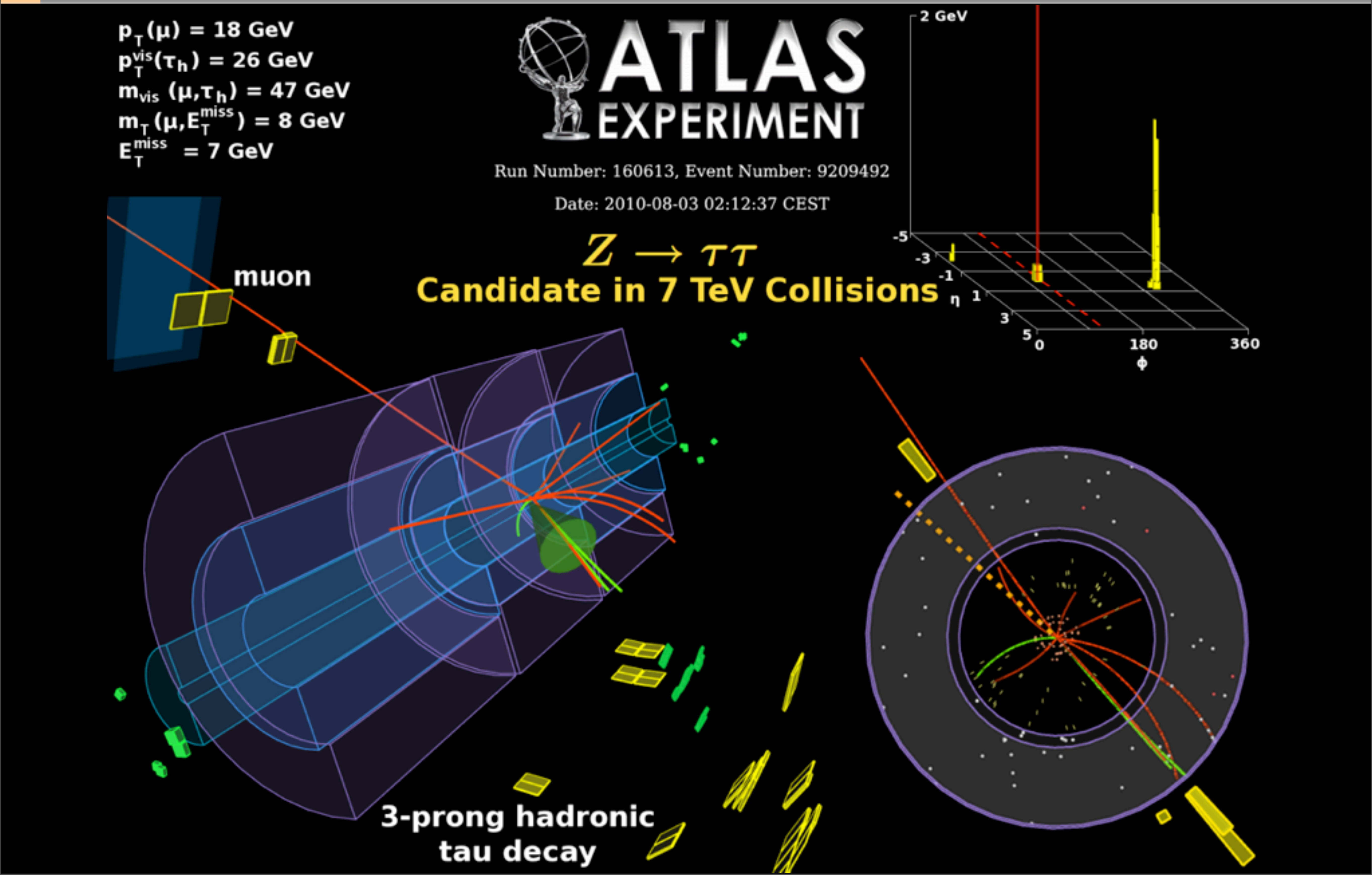
  With no 'direct focus', often experimental concerns (reconstruction thresholds, etc.) can 'guide' (read: limit) the analysis. They will also typically get outperformed by specific searches.

In the end, it's a matter of philosophy...

Interlude:

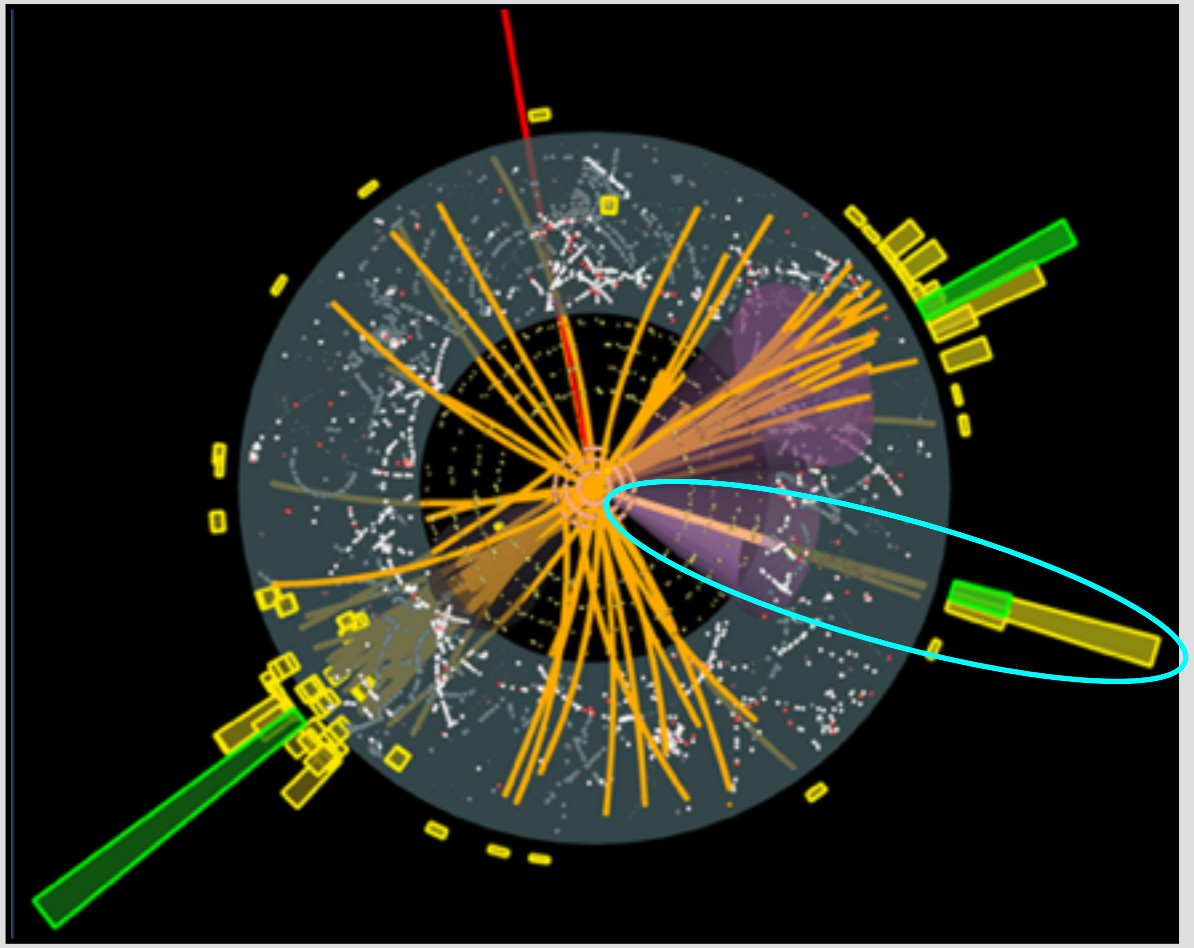
Why are taus so difficult?

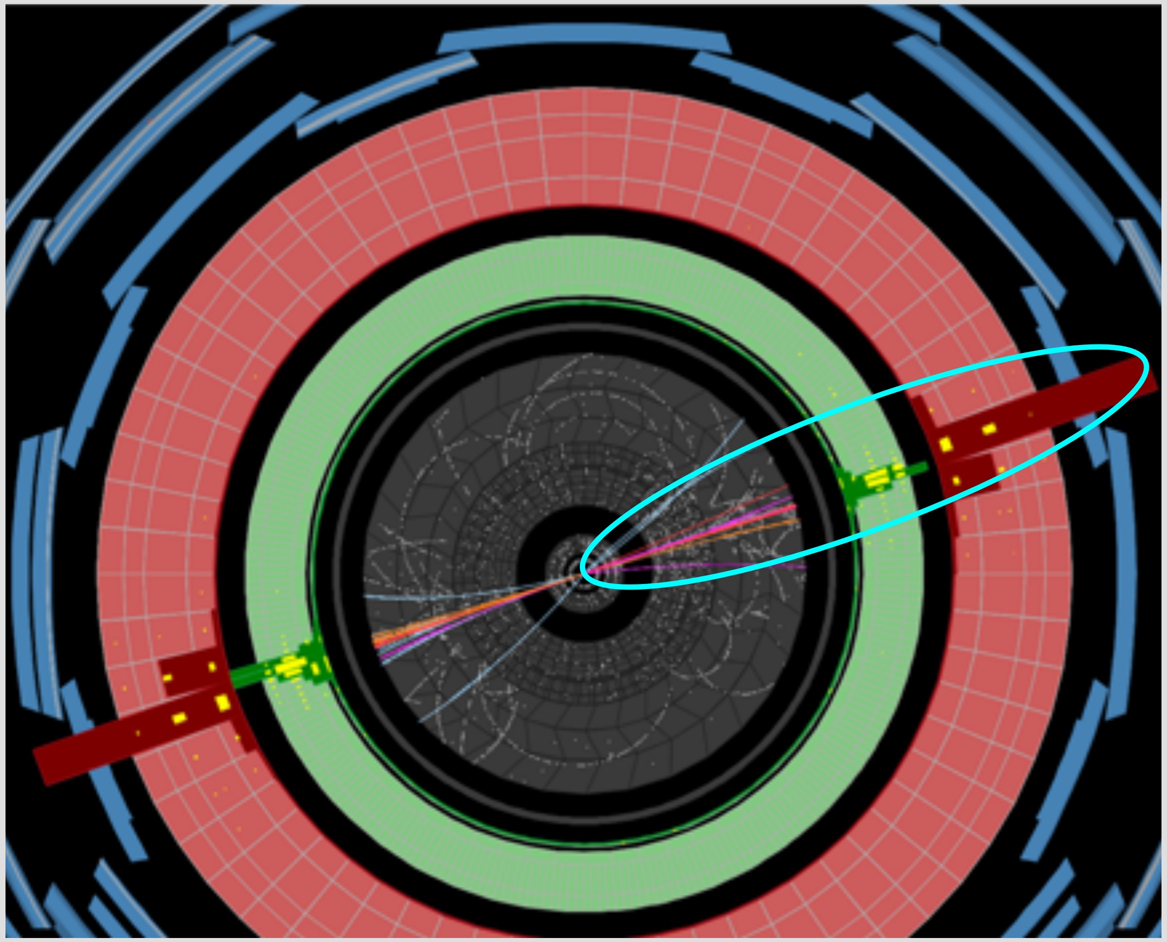
Tau candidate in data!



Taus are difficult...

- *Tau leptons are the heaviest of the leptons*
- ... They are heavy enough to decay into hadrons!
- Yet the decay into hadrons is the most distinctive of them all...





One of these is a QCD jet, the other is a tau - which is which?

How to identify taus?

- *What handles do we have on taus?*

Decay Mode	*Branching fraction*	*Looks like / Quacks like:*
$e\nu_e\nu_\tau$ / $\mu\nu_\mu\nu_\tau$	~17.5% * 2	A light lepton
$h^- + \nu_\tau$	~ 10%	1 charged track + narrowest calo deposit
$h^- + \nu_\tau + \pi_0$	~ 26%	1 charged track + narrower calo deposit
$h^- + \nu_\tau + 2\pi_0$	~ 9.5%	1 charged track + narrow calo deposit
$h^-h^-h^+ + \nu_\tau$	~ 9.8%	3 charged tracks + narrowish calo deposit
$h^-h^-h^+ + \nu_\tau + \pi_0$	~5%	3 charged tracks + running out of synonyms

- *Basically: 1 or 3 charged tracks, and a narrow calorimeter energy deposit: that's a difficult problem, since pretty much everything looks like this...*

What do we do when we're faced with a difficult problem in HEP?

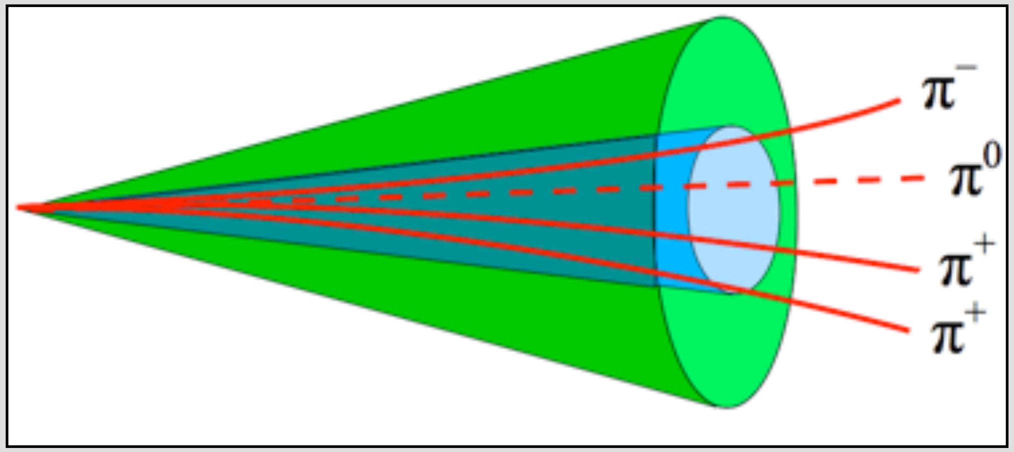
Put it in an ***MVA****!*

(This is not as cynical as it sounds!)

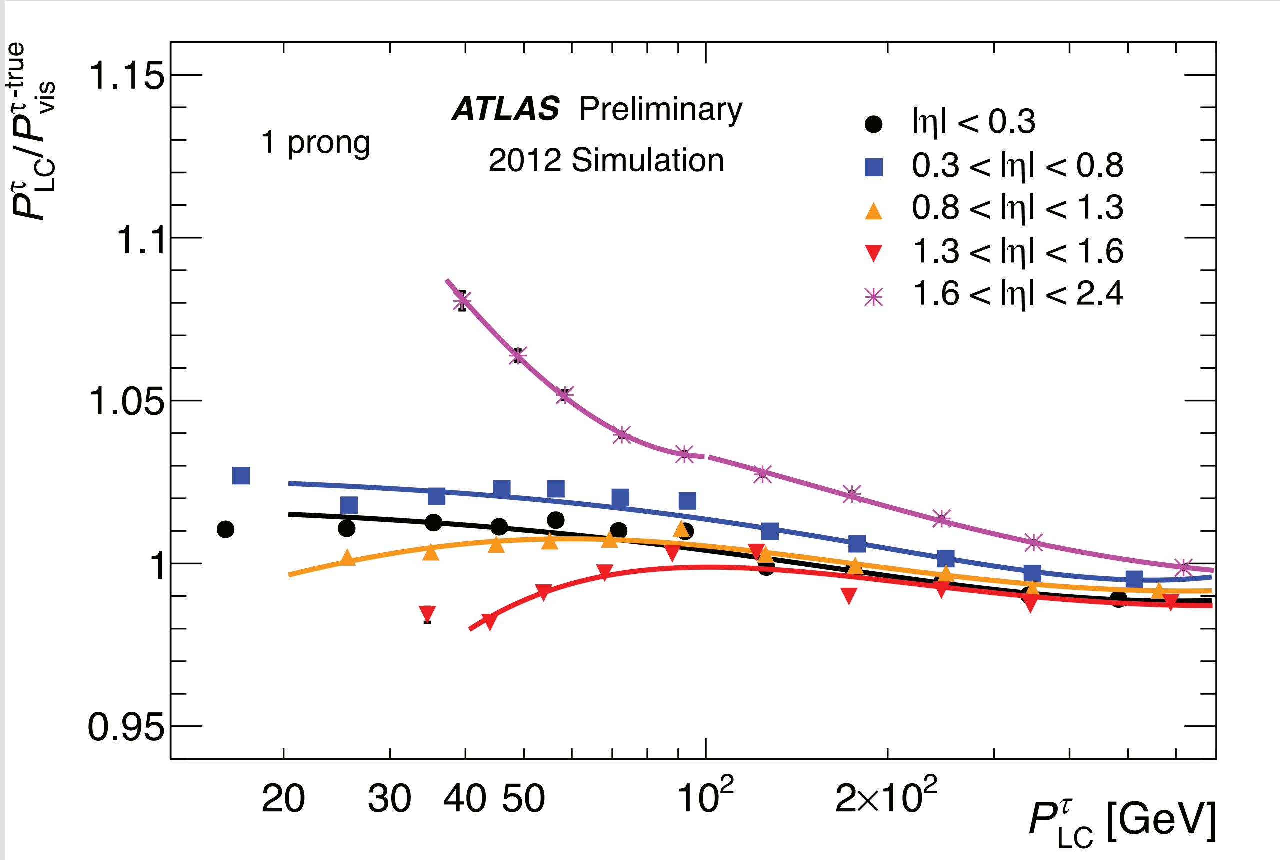
Tau Reconstruction

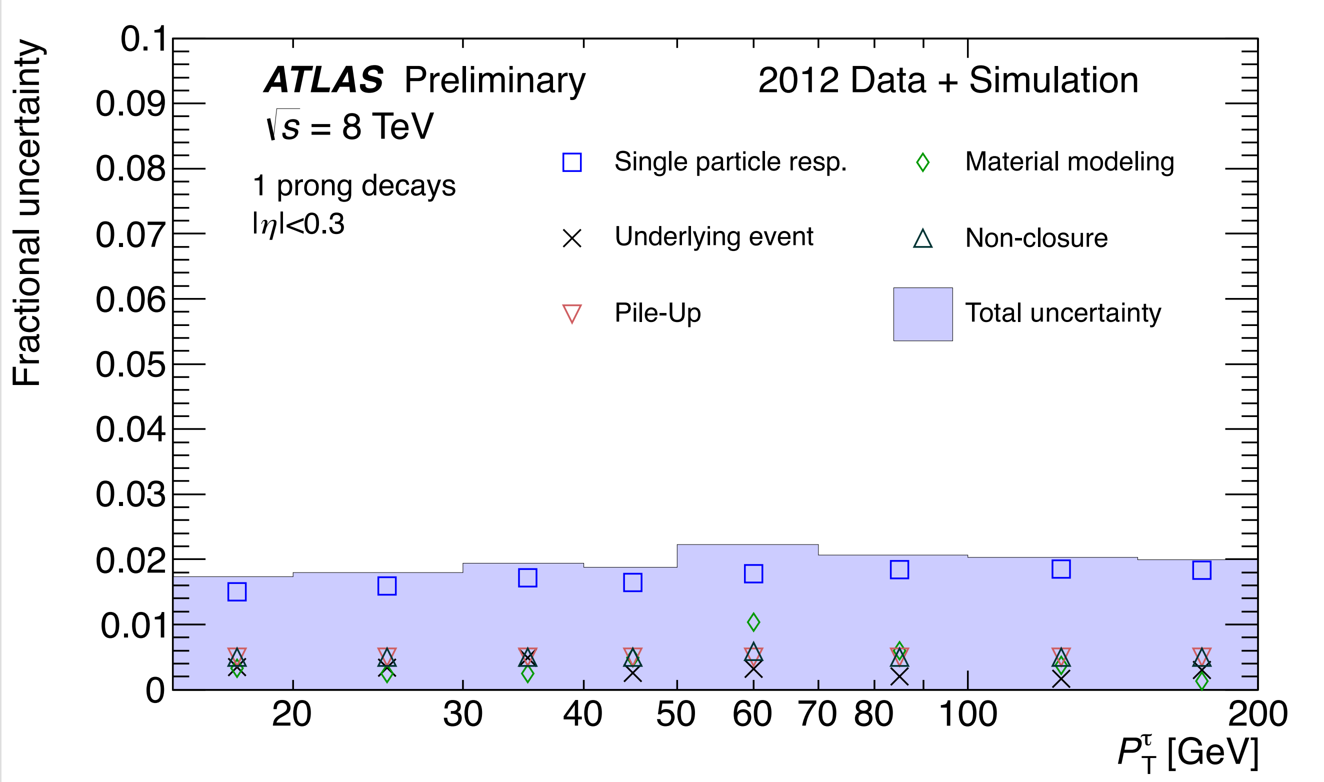
see ATLAS-CONF-2013-064
and ATLAS-CONF-2013-044

- Taus are seeded using **R**=0.4 anti-k_T jets using calorimeter topocluster as inputs
- Variables are calculated using '**core**' and '**isolation**' cones defined as **R**<0.2, **R**<0.4



- Calibration is done using the Local Hadronic Calibration method (non-compensation, dead-material, out-of-cluster effects) with an additional correction factor tailored specifically for taus



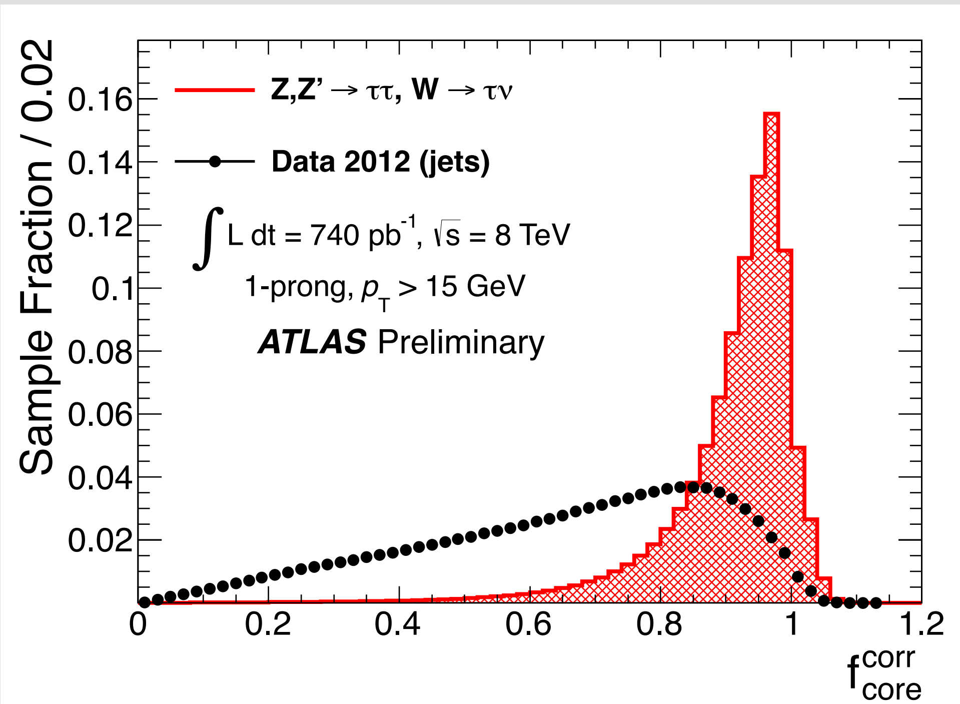


Tau Energy Scale...

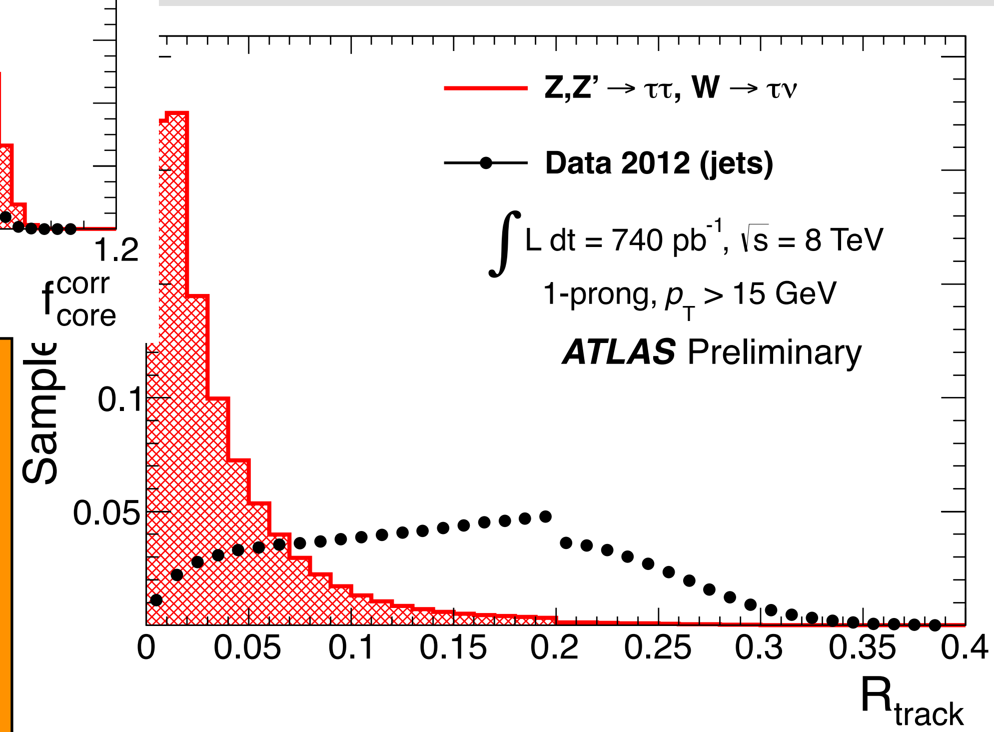
Tau Identification

see ATLAS-CONF-2013-064

- Large collection of variables offering good discriminating potential between real taus and QCD jets are used to train a **BDT**
  - A multi-variate approach is extremely helpful here as too many variables are needed to get the desired background rejection - Use of correlations also helps tremendously



Augmented with even more variables in the latest ATLAS results: ~ 50% more rejection



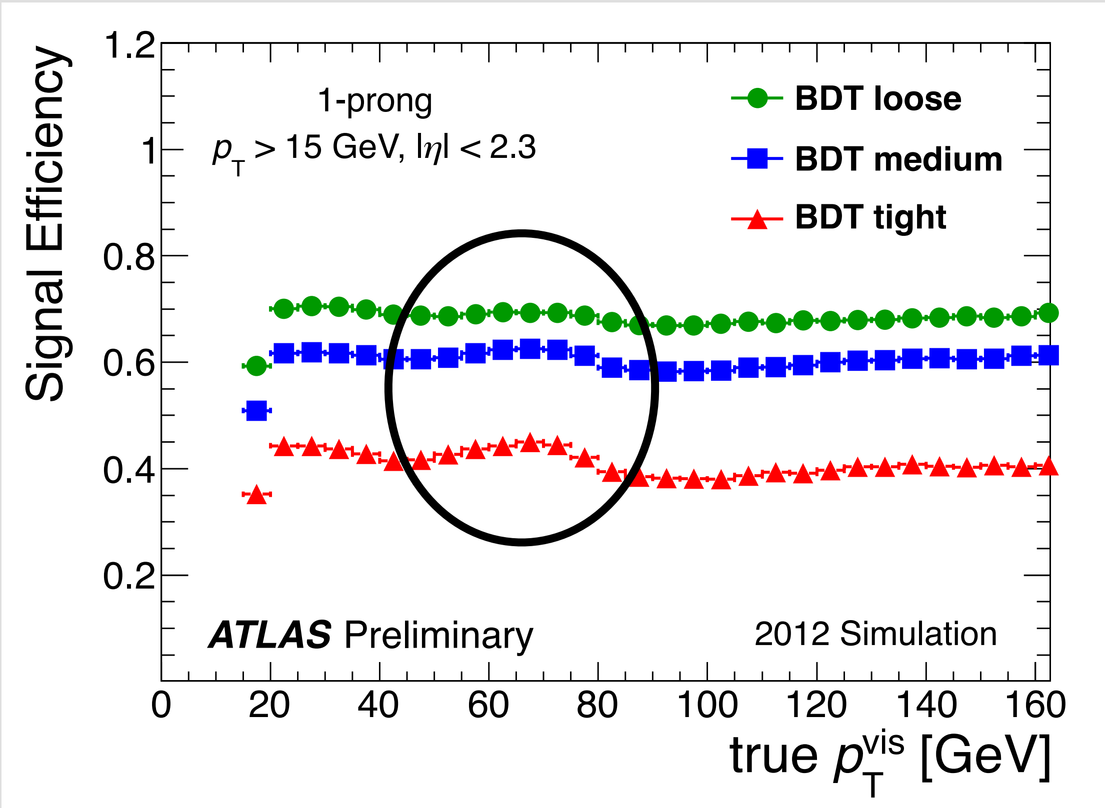
Variable	LLH tau ID 1-prong	LLH tau ID 3-prong
f_{core}^{corr}	•	•
f_{track}^{corr}	•	•
f_{track}		
R_{track}	•	•
$S_{lead\ track}$	•	
N_{track}^{iso}	•	
ΔR_{max}		•
S_T^{flight}		•
m_{tracks}		•

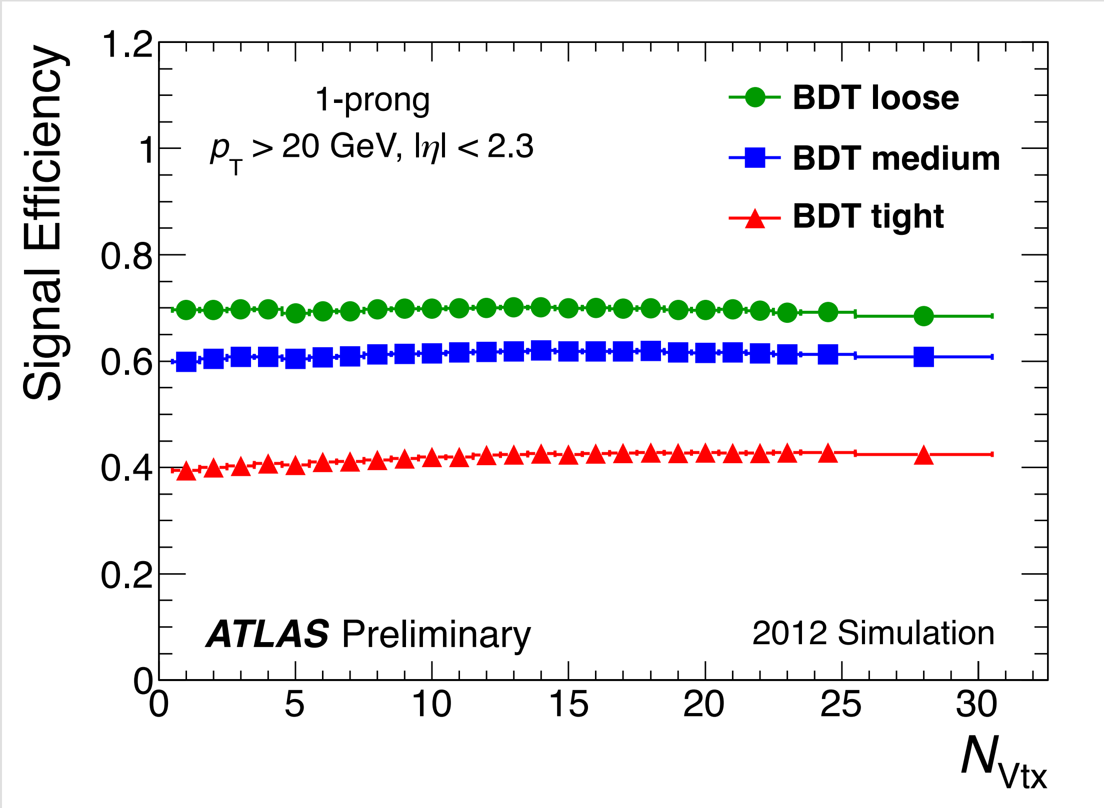
Note: Rejection looks easy, but remember we are fighting against multijet backgrounds here...

Identification Efficiency

see ATLAS-CONF-2013-064

- Training performed using MC samples (***W, Z, Z'***) and 2011 data (dijet-enriched data sample), efficiency designed to be flat as a function of candidate p_T using a sliding cut on the BDT score
- Main focus for 2012: robustness against the demanding pile-up conditions: *Cones narrowed for calorimeter variables, some variables corrected as a function of N_{vtx} (track variables untouched)*





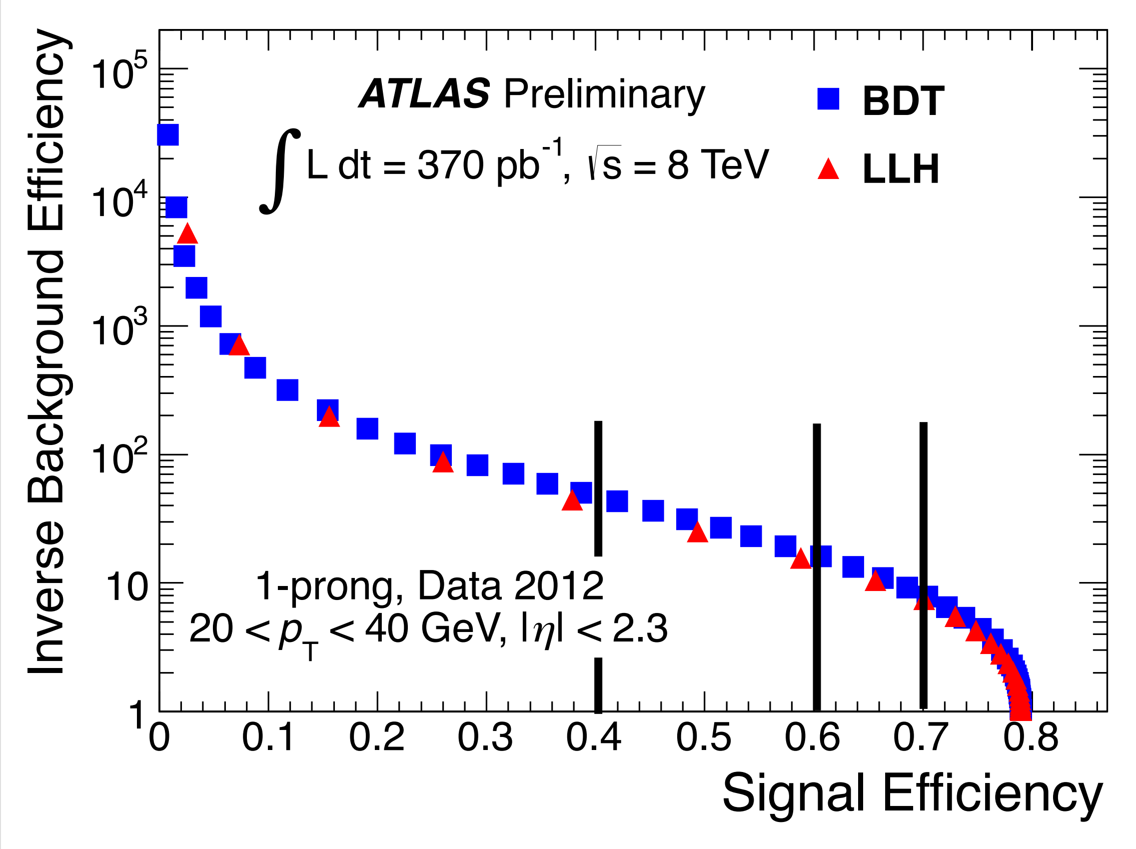
Note the low overall efficiency - Only way to get good background rejection!

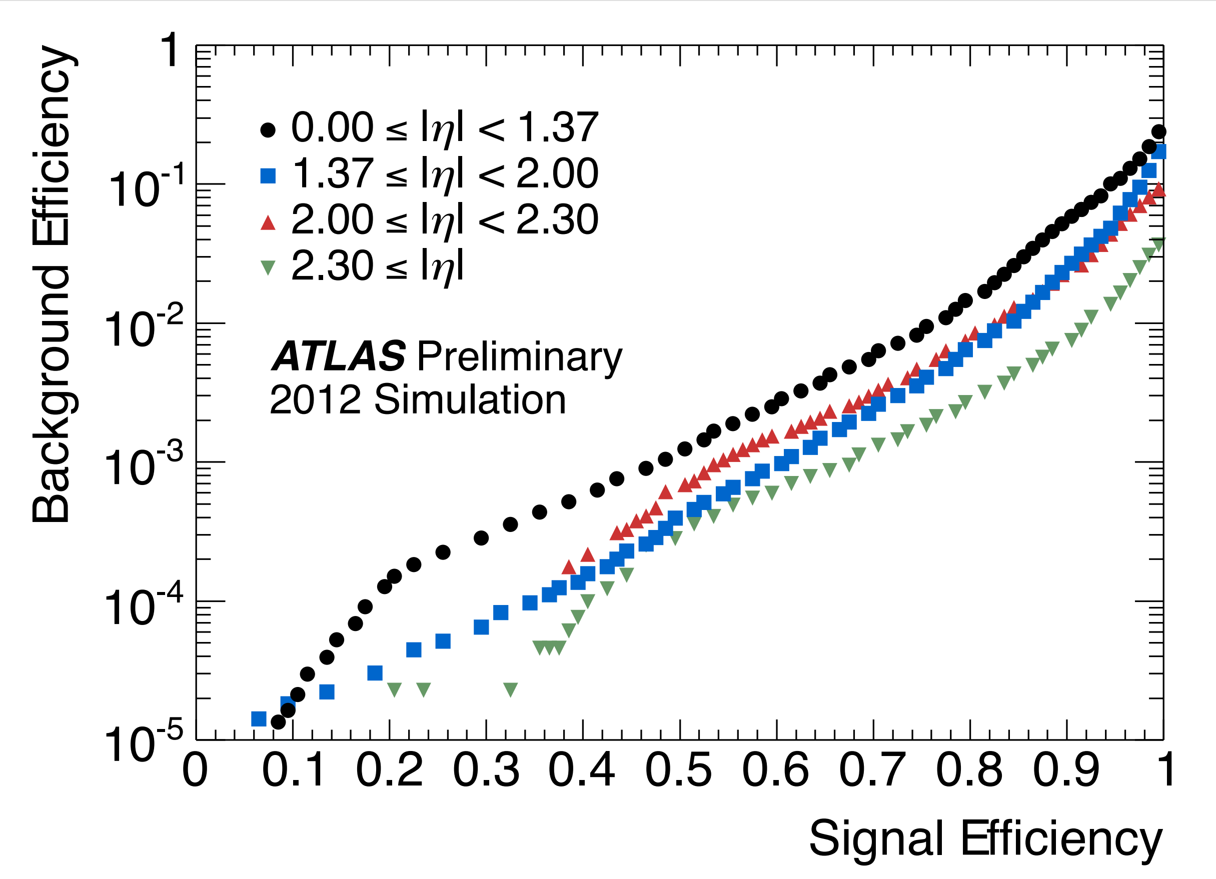
Background Rejection

see ATLAS-CONF-2013-064

- Define 3 working points with a fixed efficiency:
  *loose (70%, **Rej.** ~ 10)*
  *medium (60%, **Rej.** ~ 50)*
  *tight (40%, **Rej.** ~ 200)*

Rejection rates should be taken with a grain of salt...
Extremely flavour-dependent!



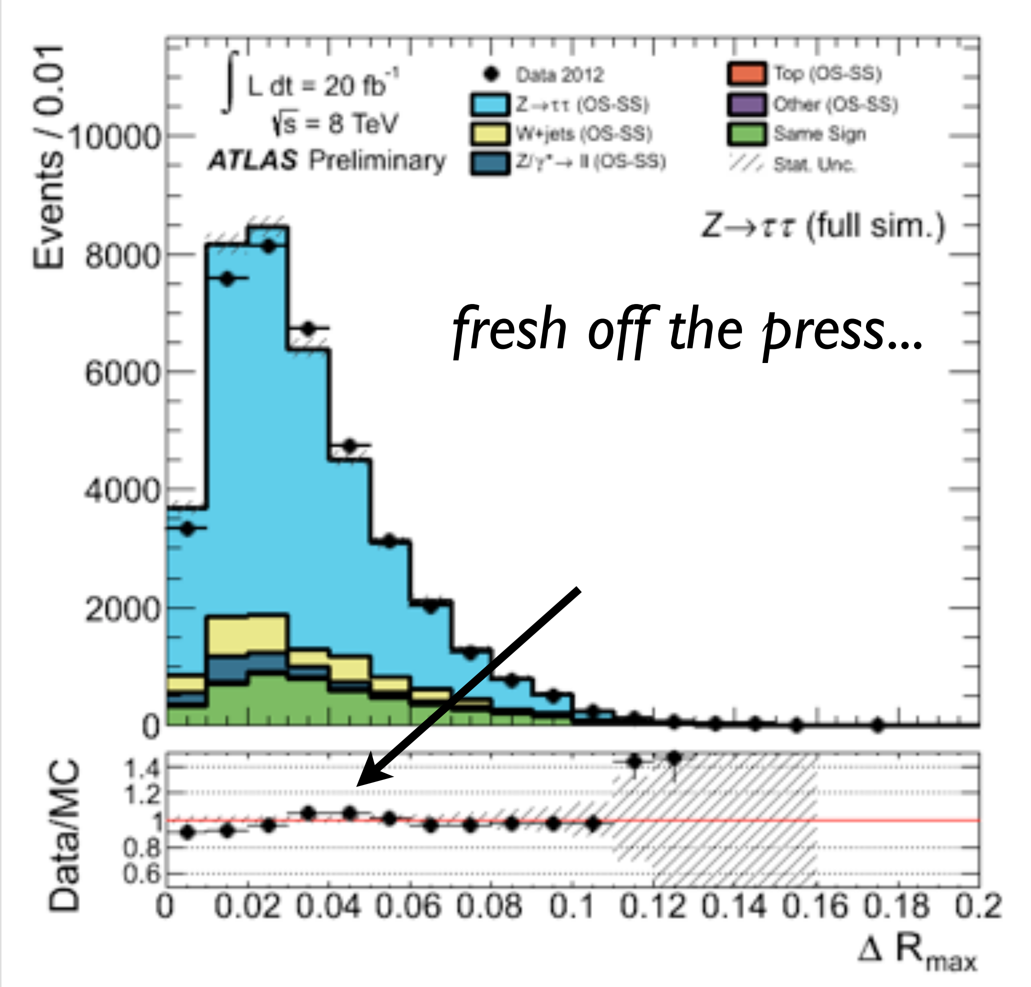


- For final states where electrons are likely to be present, a dedicated algorithm is implemented to reject fakes which fail the electron identification...
- Same methodology as the main ID, different input variables...

Efficiency Measurement

see ATLAS-CONF-2013-064

- With an identification algorithm based on MC simulations and multi-variate techniques, how do we ensure that it's doing what it should be doing in real data?
  - Verifying the agreement of the input variables is not quite enough, as correlations are also used (*and in any case, some of these variables are known not to be modeled properly!*)



Only way to be completely sure is to measure the efficiency in-situ in the data...

$$\varepsilon_{data} = N_{tau}^{ID} / N_{tau}^{total}$$

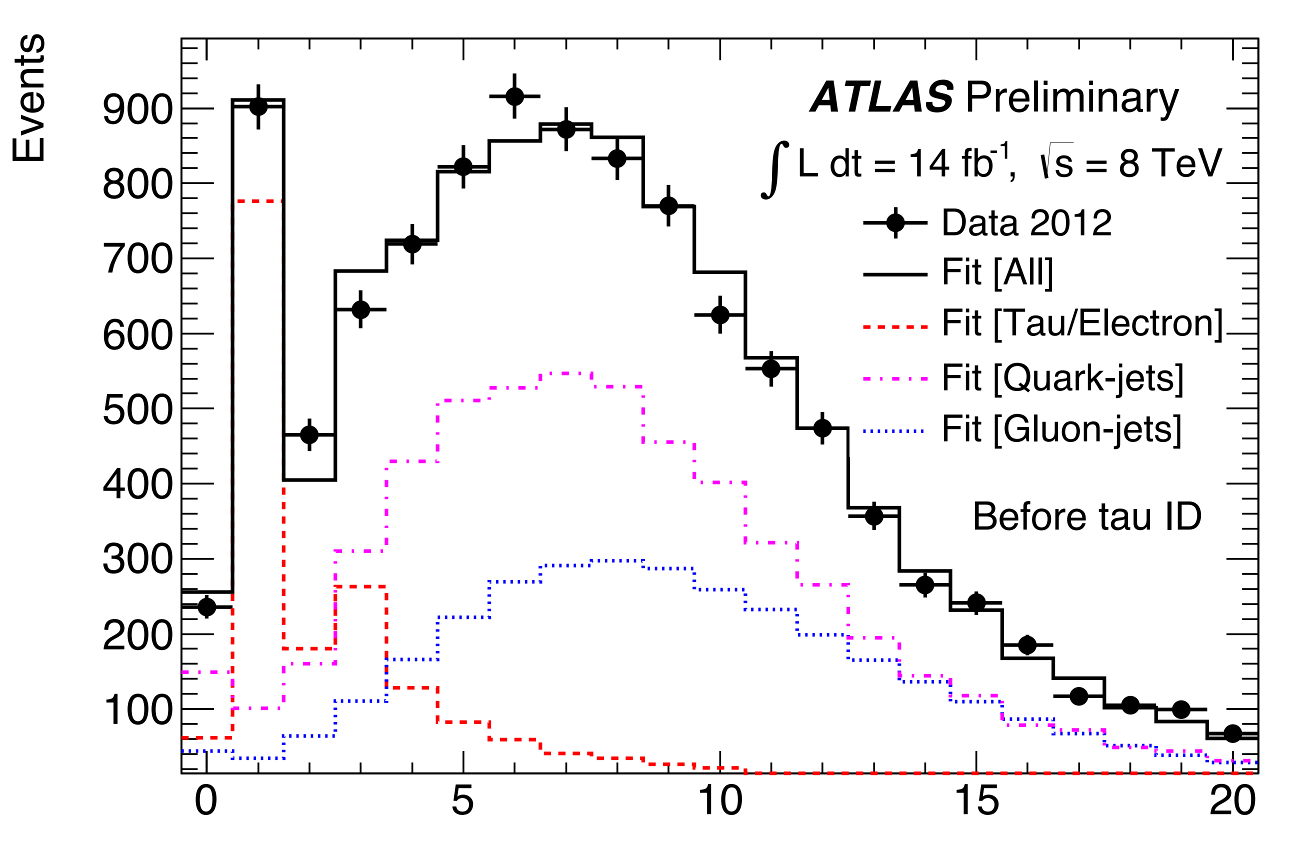
How do we ensure that we have a pure sample of taus? (Or a ***precise*** estimate of the backgrounds in a not-so-pure sample?)

‘Tag-and-probe’ measurements

see ATLAS-CONF-2013-064

- Select a final state likely to contain real taus ($Z \to \tau_\mu \tau_{had}$, for example), extract the number of signal and background events using a fit of a sensitive variable

- Pick the one variable with the largest rejection, which is known to be modeled best in MC: N_{track}



about 1000 real taus available in 2012! N_{track}^{c+c}

‘Craziest’ final-state used

ttbar → τ + jets

Template for signal:

MC

Template for backgrounds:

Data-Driven,

low E_T^{miss} CR (**multijet** events)

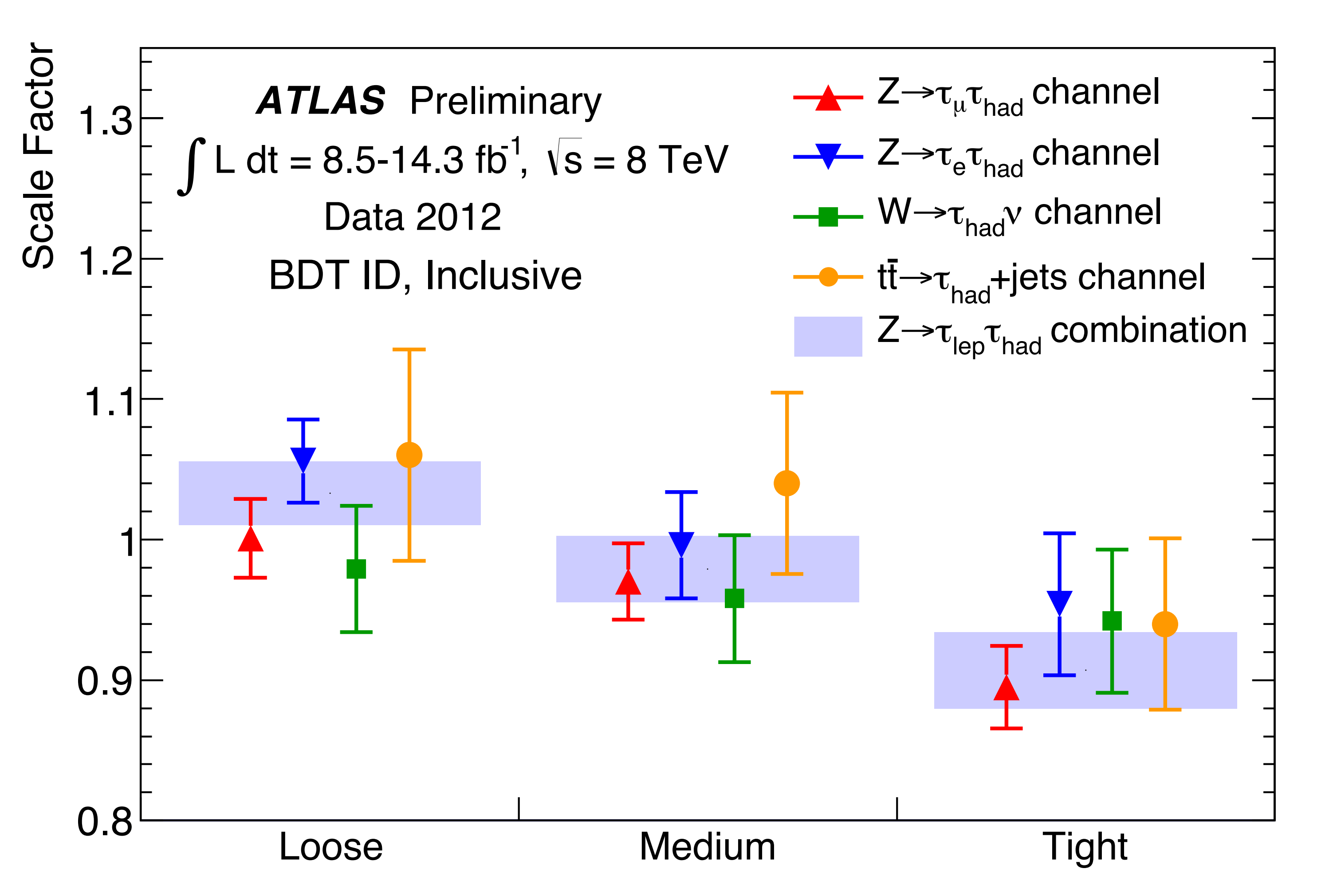
ttbar → μ + jets (**top** events)

This channel gives access to taus at a kinematic regime that cannot be accessed in the cleaner Z events!

TauID: Concluding Remarks

see ATLAS-CONF-2013-064

- Scale factors derived in 4 channels can be used to correct the tau ID efficiency in MC simulations for mis-modeling
- The uncertainty on these scale factors is driven by the Z channels, and is 2-3%: this is ultimately a hard limitation on every tau-based measurement at ATLAS



This is an extremely re-assuring plot showing that we understand the tau ID efficiency in very different event topologies and kinematic regimes...

Taus have come a long way in ATLAS!

Difficult... but rewarding?

The Search

Exotics Multilepton 8 TeV

- Search Philosophy:
  - Look for anomalous production of events with *3 or more leptons* (electrons, muons and hadronically-decaying taus)
  - *Note: Only one tau lepton is allowed per event...*
  - Test agreement of data with SM in a wide variety of signal regions inspired by interesting signatures, but not directly optimized

Cut	Electrons	Muons	Taus
Leading/Trigger E_T	$E_T \geq 26$ GeV	$p_T \geq 26$ GeV	-
Trigger Acceptance	$(\|\eta\| < 1.37) \,\|\|\, (1.52 \leq \|\eta\| < 2.47)$	$\|\eta\| < 2.4$	-
Subleading E_T	$E_T \geq 15$ GeV	$p_T \geq 15$ GeV	$p_T \geq 20$ GeV
Acceptance	$(\|\eta\| < 1.37) \,\|\|\, (1.52 \leq \|\eta\| < 2.47)$	$\|\eta\| < 2.5$	$\|\eta\| < 2.5$

Using single lepton triggers...

Signal Regions

Variable	Signal Region Definition				Additional Requirements
H_T^{leptons}	Inclusive	$\geq$200 GeV	$\geq$ 500 GeV	$\geq$ 800 GeV	
Min. p_T^{ℓ}	Inclusive	$\geq$ 50 GeV	$\geq$ 100 GeV	$\geq$ 150 GeV	
E_T^{miss}	Inclusive	$\geq$100 GeV	$\geq$ 200 GeV	$\geq$ 300 GeV	$H_T^{\text{jets}} < 150$ GeV
E_T^{miss}	Inclusive	$\geq$100 GeV	$\geq$ 200 GeV	$\geq$ 300 GeV	$H_T^{\text{jets}} \geq 150$ GeV
m_{eff}	Inclusive	$\geq$600 GeV	$\geq$1000 GeV	$\geq$1500 GeV	
m_{eff}	Inclusive	$\geq$600 GeV	$\geq$1200 GeV		$E_T^{\text{miss}} \geq 100$ GeV
m_{eff}	Inclusive	$\geq$600 GeV	$\geq$1200 GeV		$m_T^W \geq 100$ GeV, on-Z
b-tags	Inclusive	≥ 1	≥ 2		

- Additionally, events were classified in 4 categories based on:
  - Presence or absence of a hadronically-decaying tau in the event
  - Presence or absence of a OSSF lepton pair within 15 GeV of the Z mass
- Highest bin of the signal regions were chosen such that ***O(1)*** background event is expected
- In total ~ 100 signal regions! (not all independent...)

Signal Regions - Motivation

could be used for...

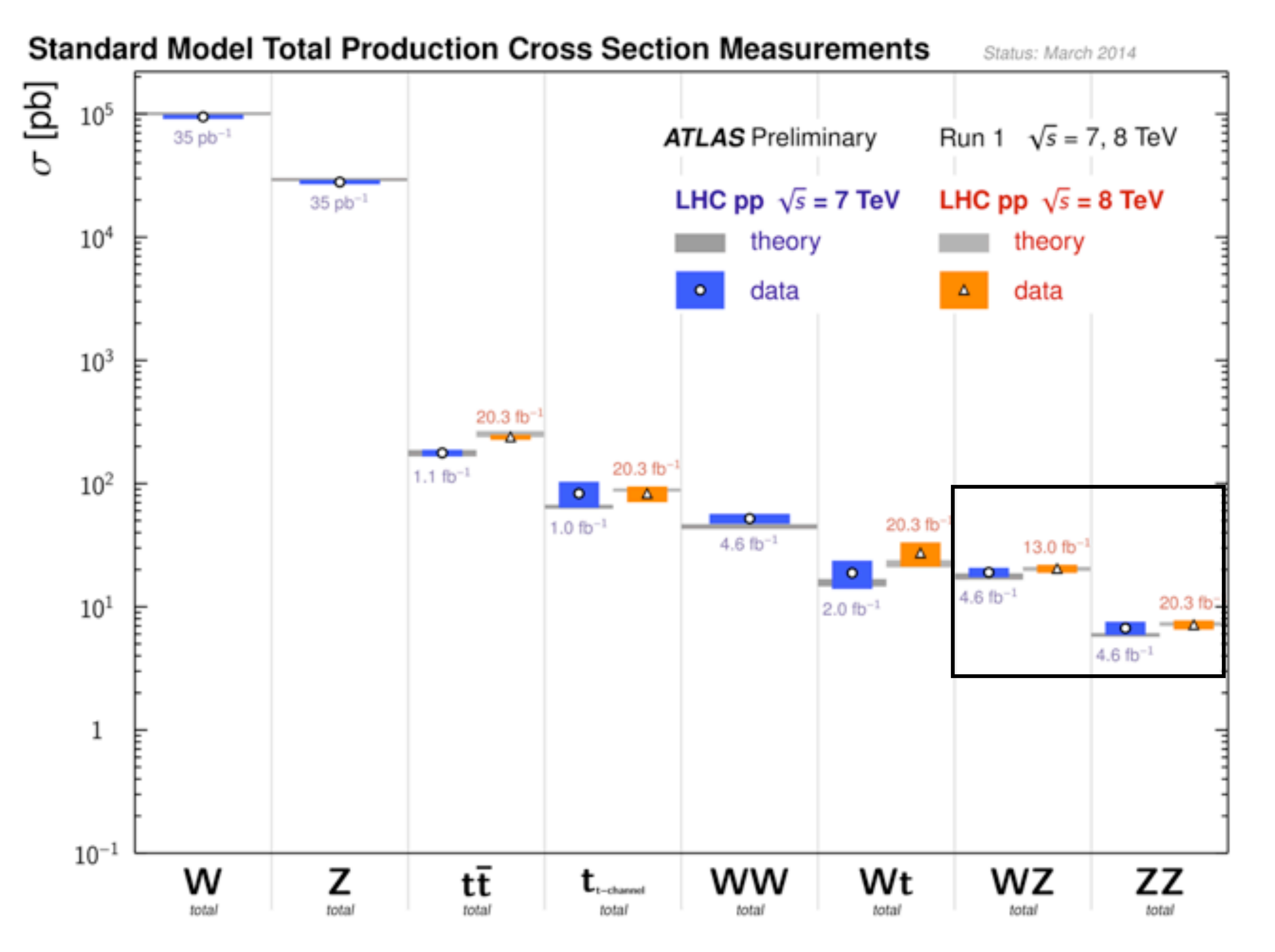
Variable	Additional Requirements		could be used for...
H_T^{leptons}		→	Higher masses
Min. p_T^{ℓ}		→	High mass decays (l*)
E_T^{miss}	$H_T^{\text{jets}} < 150$ GeV	→	Weakly-produced SUSY
E_T^{miss}	$H_T^{\text{jets}} \geq 150$ GeV	→	RPV SUSY ($\chi_1^0 \rightarrow ll\nu$)
m_{eff}			
m_{eff}	$E_T^{\text{miss}} \geq 100$ GeV	→	RPV SUSY ($\chi_1^0 \rightarrow ll\nu$)
m_{eff}	$m_T^W \geq 100$ GeV, on-Z	→	Heavy partner
b-tags		→	Vector-like quarks

Plenty of scenarios covered!

Understanding Backgrounds

- Since the analysis uses a simple cut & count methodology, the main experimental concern is the proper modeling of backgrounds
- Classified in 2 categories:
  - **Prompt Backgrounds**: Events where all 3 leptons are real and coming from the decay of gauge bosons, taus, or new particles (*excluding B decays*)
  - **Reducible Backgrounds**: At least one lepton in the event is fake (*misidentified*), usually poorly modeled in simulation

Prompt Backgrounds



Dominated by diboson production

Estimated directly using simulation, including all detector-based effects (with corrections derived in-situ)

Dominant uncertainties on the normalization come from theoretical sources

'Reducible' Backgrounds

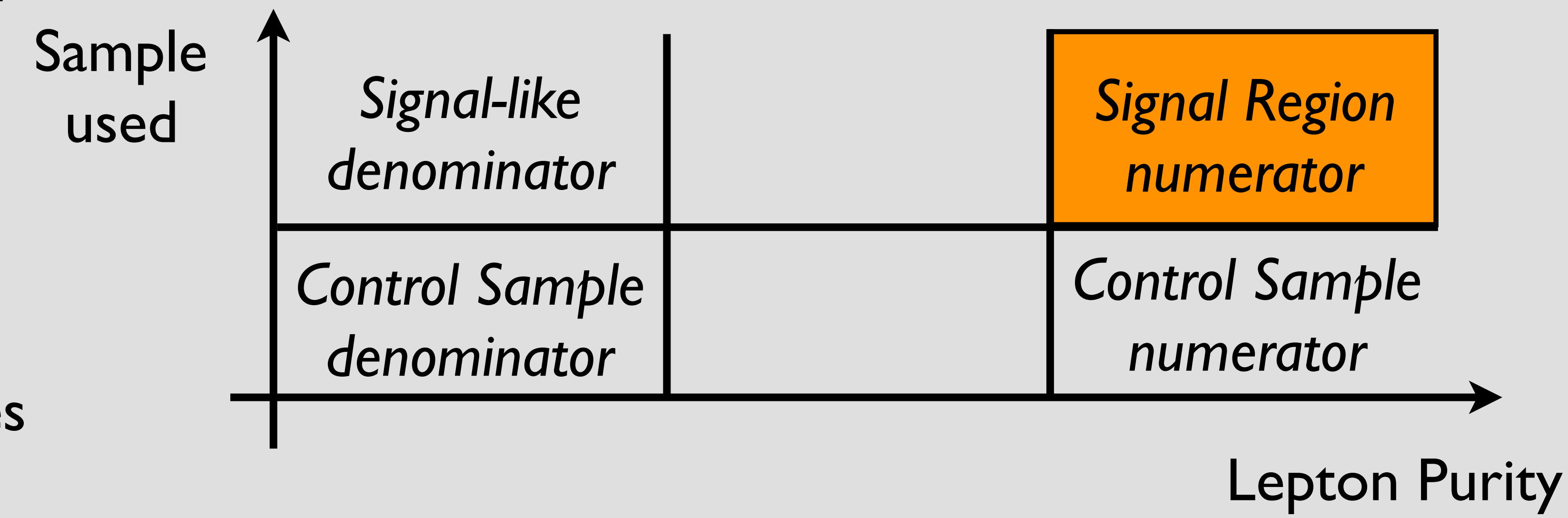
- Fakes leptons are typically very poorly-modeled in simulation
- Use a data-driven method to estimate them: '*fake-factors*'
- Dedicated estimates are used for each lepton type: sources of fakes are completely different...

The Fake-Factor Method

Define an inverted alternative lepton selection which is fake-enriched (*denominator*)

Measure the ratio
FF = $N_{num}^{CR}/N_{den}^{CR}$
in a control region dominated by fakes

Estimate the fakes in the signal region using:
$N_{fakes}^{signal} = N_{den}^{signal} * \mathbf{FF}$



Main advantage of this method:
Obtain distributions for fakes in a simple way

Tau Fake-Factors

- Define a denominator selection inverting the signal requirement:
  Numerators = IDScore > TightID
  Denominators = ***X*** *< IDScore < MediumID*

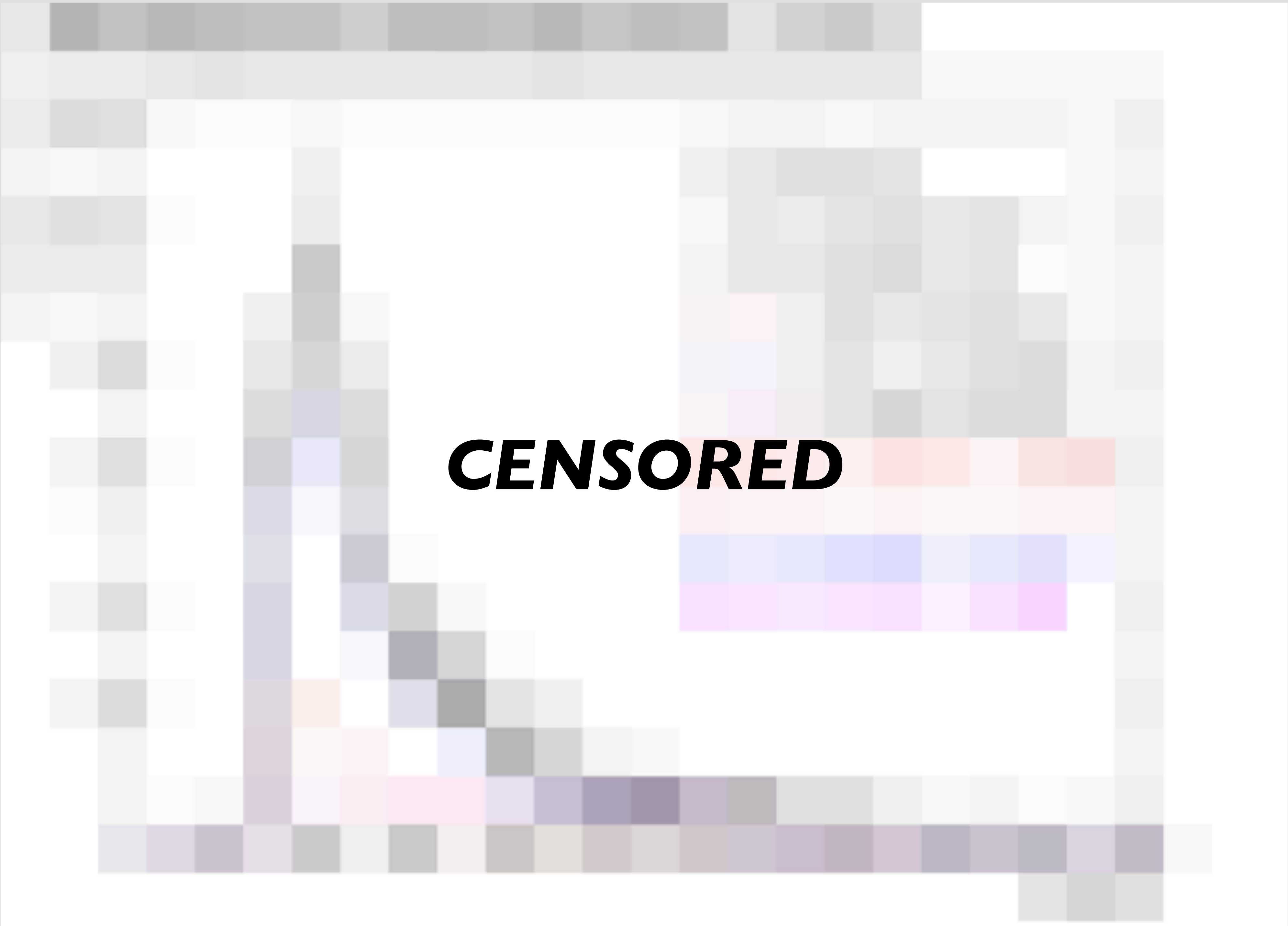
- A lower requirement on the IDScore of '**X**' is chosen such that the flavour-composition for numerator and denominator fakes is similar: more robust predictions!

- Measure the FF in a $W \rightarrow \mu \nu$ + jets control region

  Subtract $Z \rightarrow \tau_{\mu} \tau_{had}$ and ttbar contribution of real taus using simulation

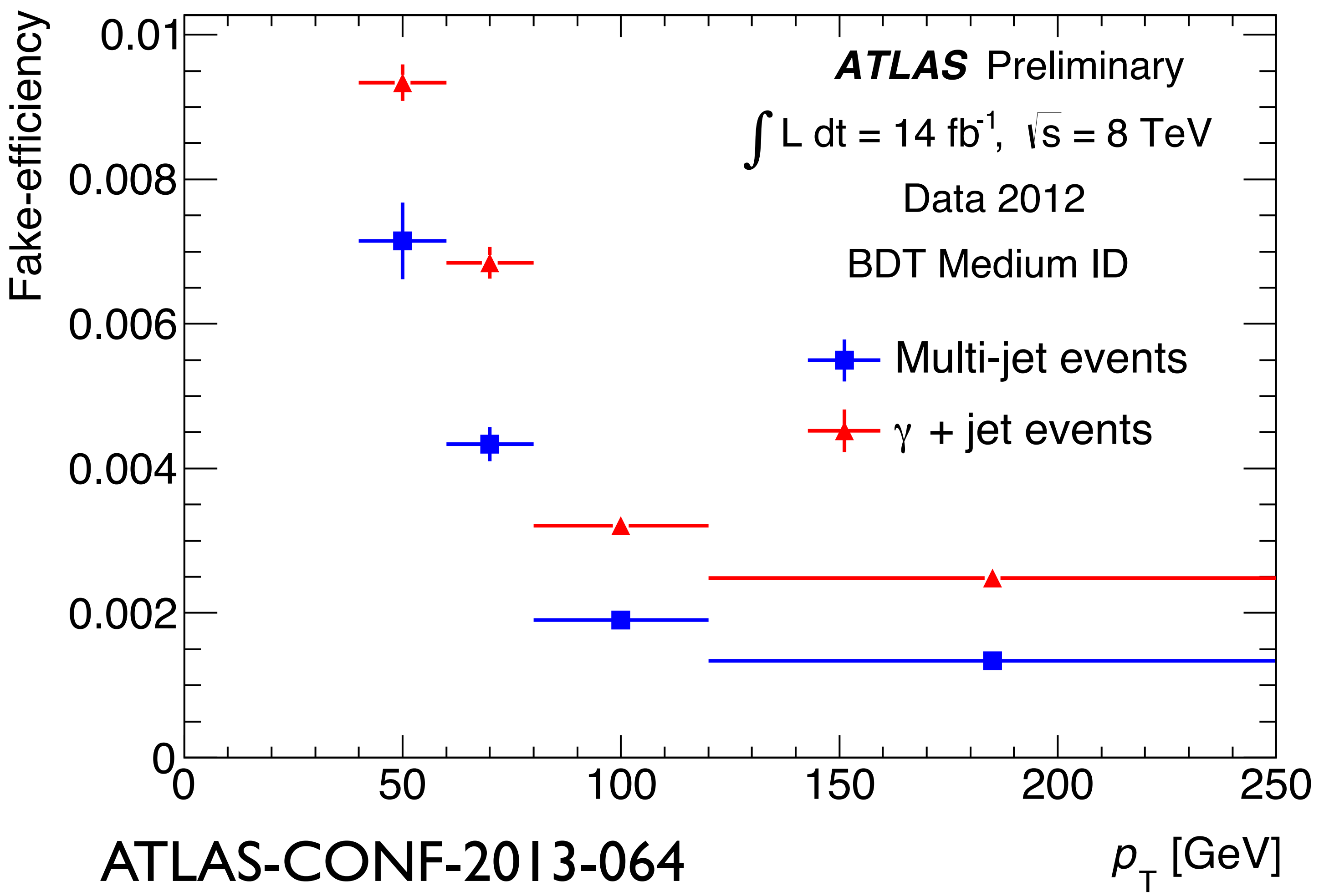
- Measurement is done as a function of p_T, η, and highest b-tagging score of any jet in the event

Tau Fake-Factors



No plots for the fake-factors included in public documentation...

Tau Fake-Factors



ATLAS-CONF-2013-064

Main associated difficulty:

Carefully choosing the sample where to derive fakes factors from is crucial...

Flavour-dependence is a sizable effect for tau fakes!

Systematics in the order of 25%: Driven by uncertainties on simulation-based prompt subtraction, requirements on the W control region, and agreement in a ttbar control region

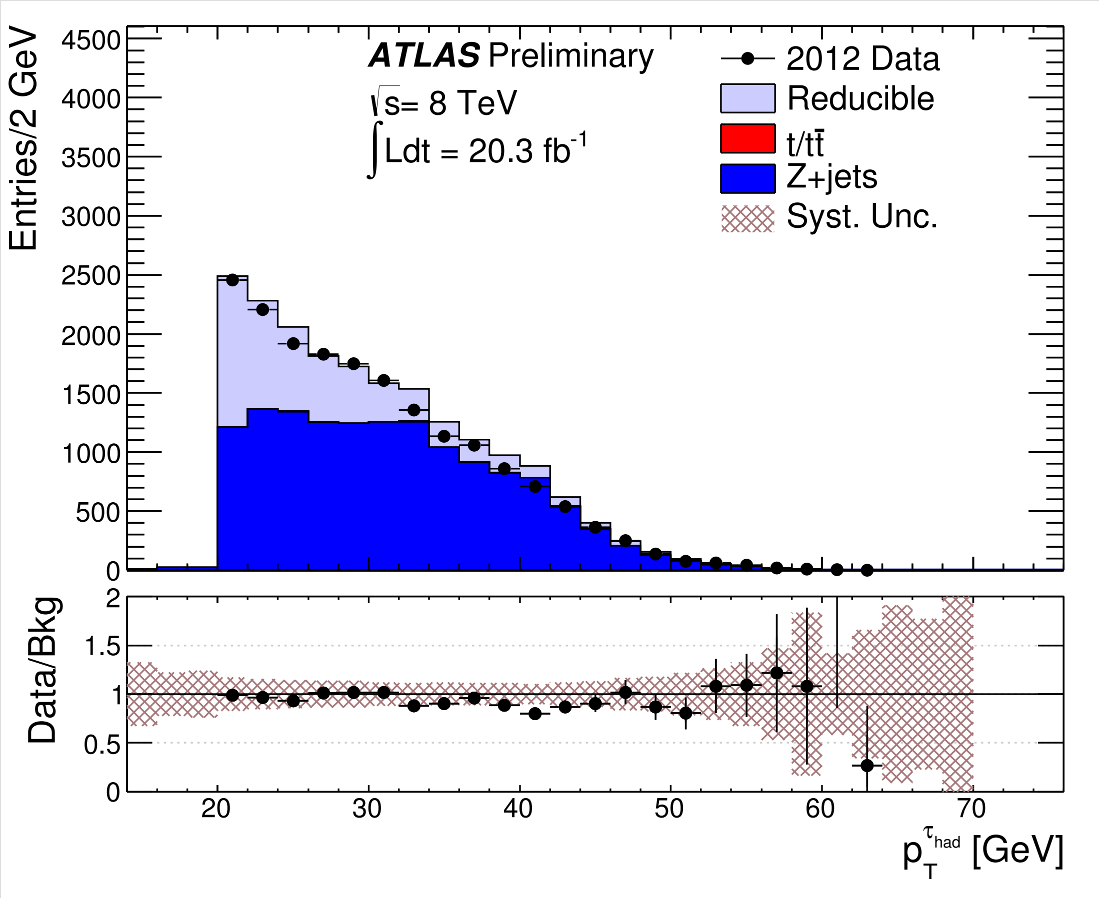
‘Reducible’ Backgrounds - e/mu

- Electron fakes are dominated by light-flavour jets
  - Derived from an inclusive sample of all electron/photon triggers, with simple requirements to veto W/Z decays
  - Systematics driven by corrections for heavy-flavour content, prompt subtraction, MC-based extrapolations, etc.

- Muon fakes are dominated by heavy-flavour decays
  - Derived in a same-sign dimuon sample, with inverted impact parameter requirements
  - Systematics driven by corrections for light-flavour content, requirements on the control sample, MC-based extrapolations, etc.

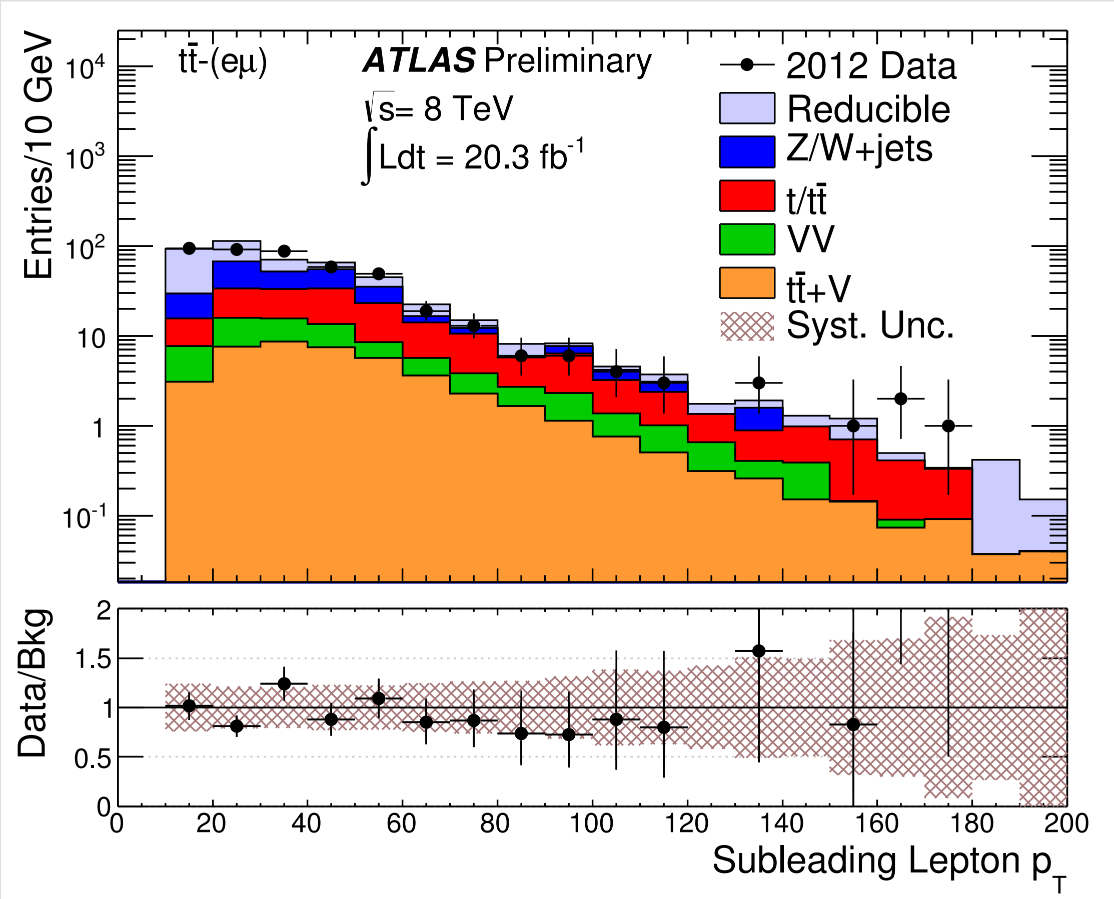
Validation Regions

- We need to be confident that we understand our ‘reducible’ backgrounds well
- Define ‘validation regions’ in data where we test the agreement of the predictions, designed to target specific effects



$Z \rightarrow \tau_{\mu}\tau_{had}$ region

Check modeling of tau prompts and fakes...



ttbar same-sign + 1 b-tag region

Check modeling of heavy-flavour fakes...

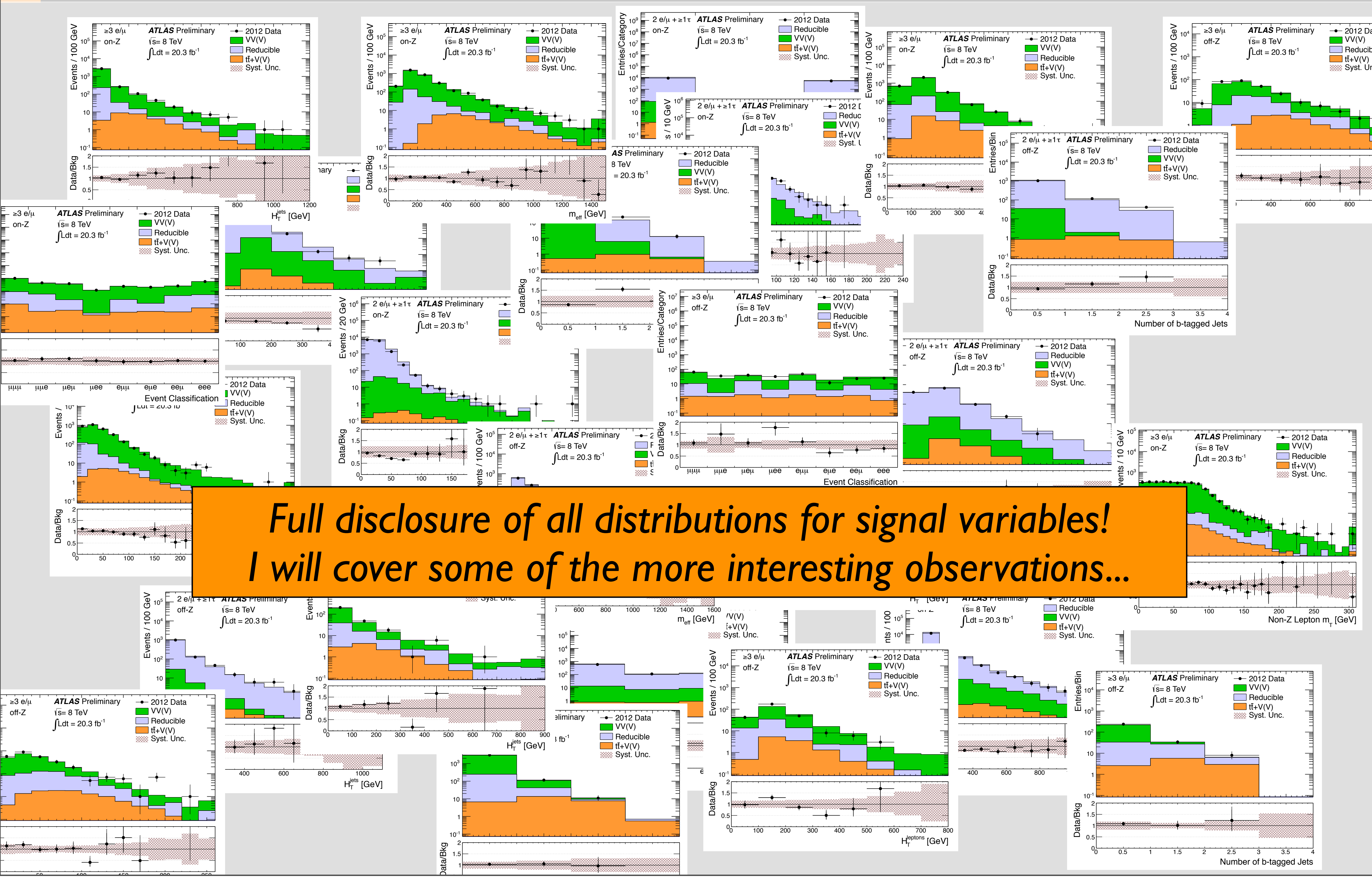
Systematic Uncertainties

Source of uncertainty	Uncertainty
Trigger efficiency	(≤ 1) – 1%
Electron energy scale	(≤ 1) – 13%
Electron energy resolution	(≤ 1) – 1%
Electron identification	(≤ 1) – 3%
Electron non-prompt/fake backgrounds	(≤ 1) – 13%
Muon momentum scale	(≤ 1) – 1%
Muon momentum resolution	(≤ 1) – 7%
Muon identification	(≤ 1) – 1%
Muon non-prompt/fake backgrounds	(≤ 1) – 51%
Tau energy scale	(≤ 1) – 4%
Tau identification	(≤ 1) – 4%
Tau non-prompt/fake backgrounds	(≤ 1) – 24%
Jet energy scale	(≤ 1) – 6%
Jet energy resolution	(≤ 1) – 3%
Soft $E_{\mathrm{T}}^{\mathrm{miss}}$ terms	(≤ 1) – 14%
Luminosity	1.8%
Cross-section uncertainties	(≤ 1) – 14%
Statistical uncertainties	1 – 25%
Total uncertainty	11 – 56%

Taken from 7 TeV paper...
PRD 87, 052002 (2013)

Dominant systematic uncertainties come from normalization of prompt backgrounds, fake estimates, and E_T^{miss} modeling...

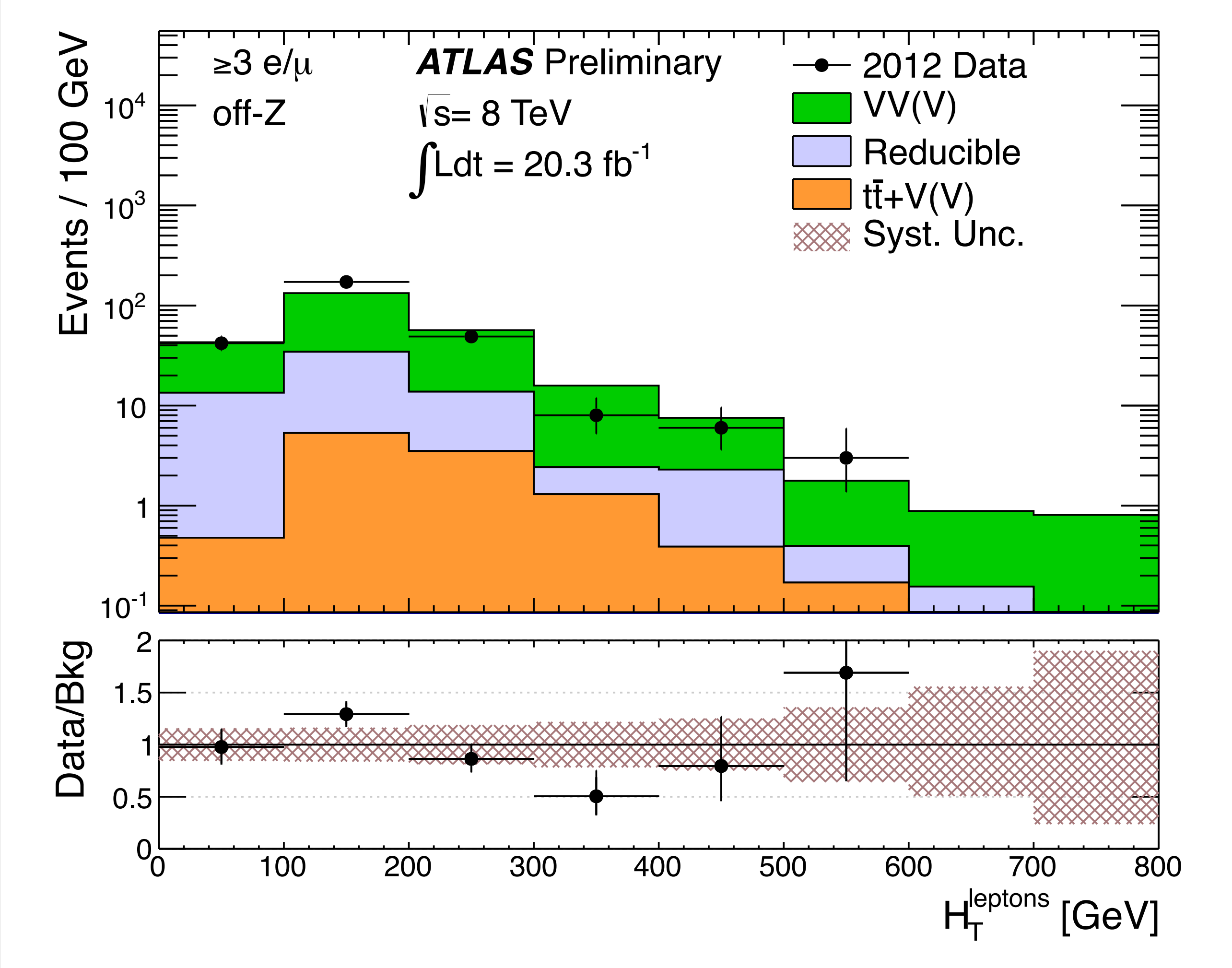
Results

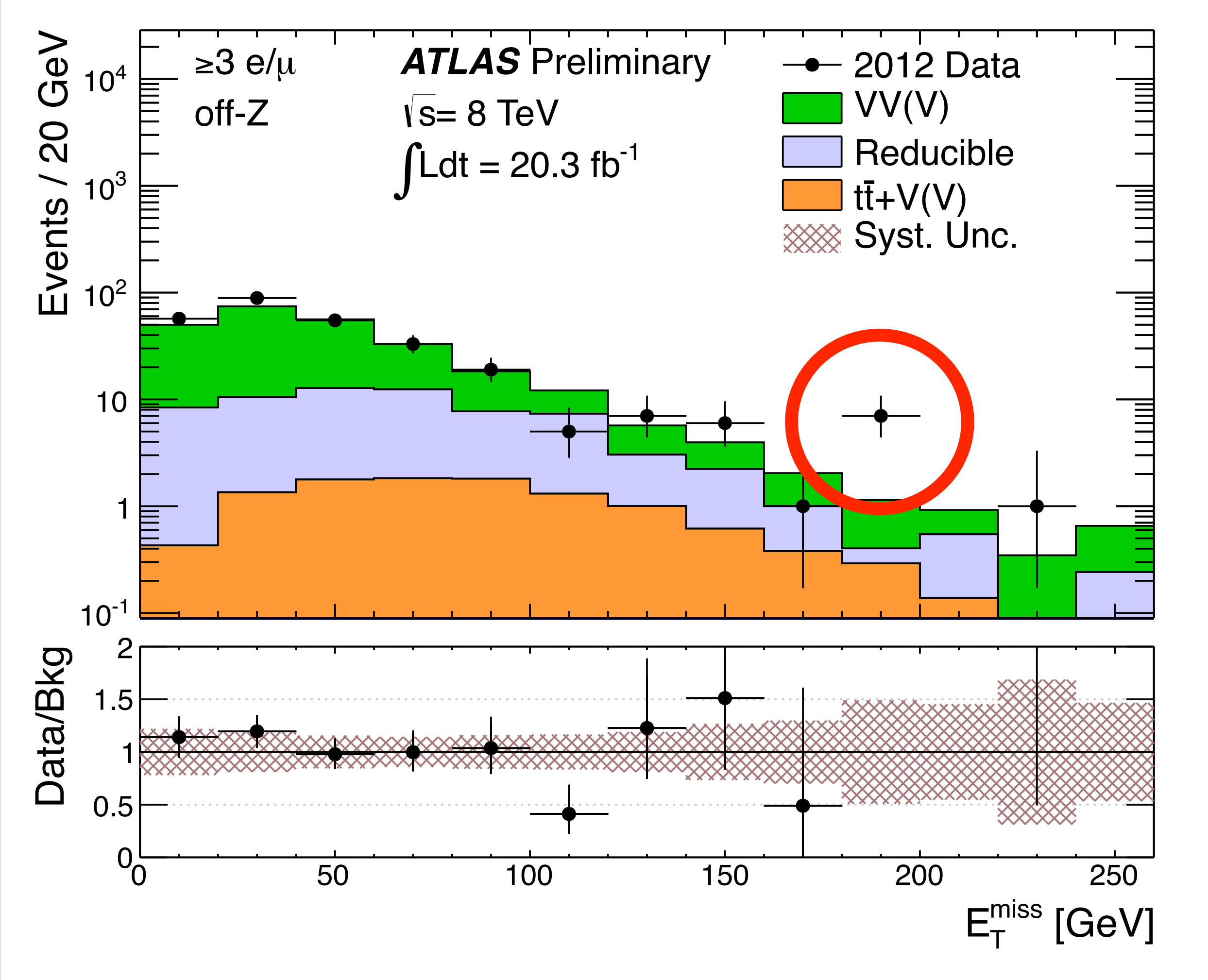


Full disclosure of all distributions for signal variables!
I will cover some of the more interesting observations…

Have we found anything?

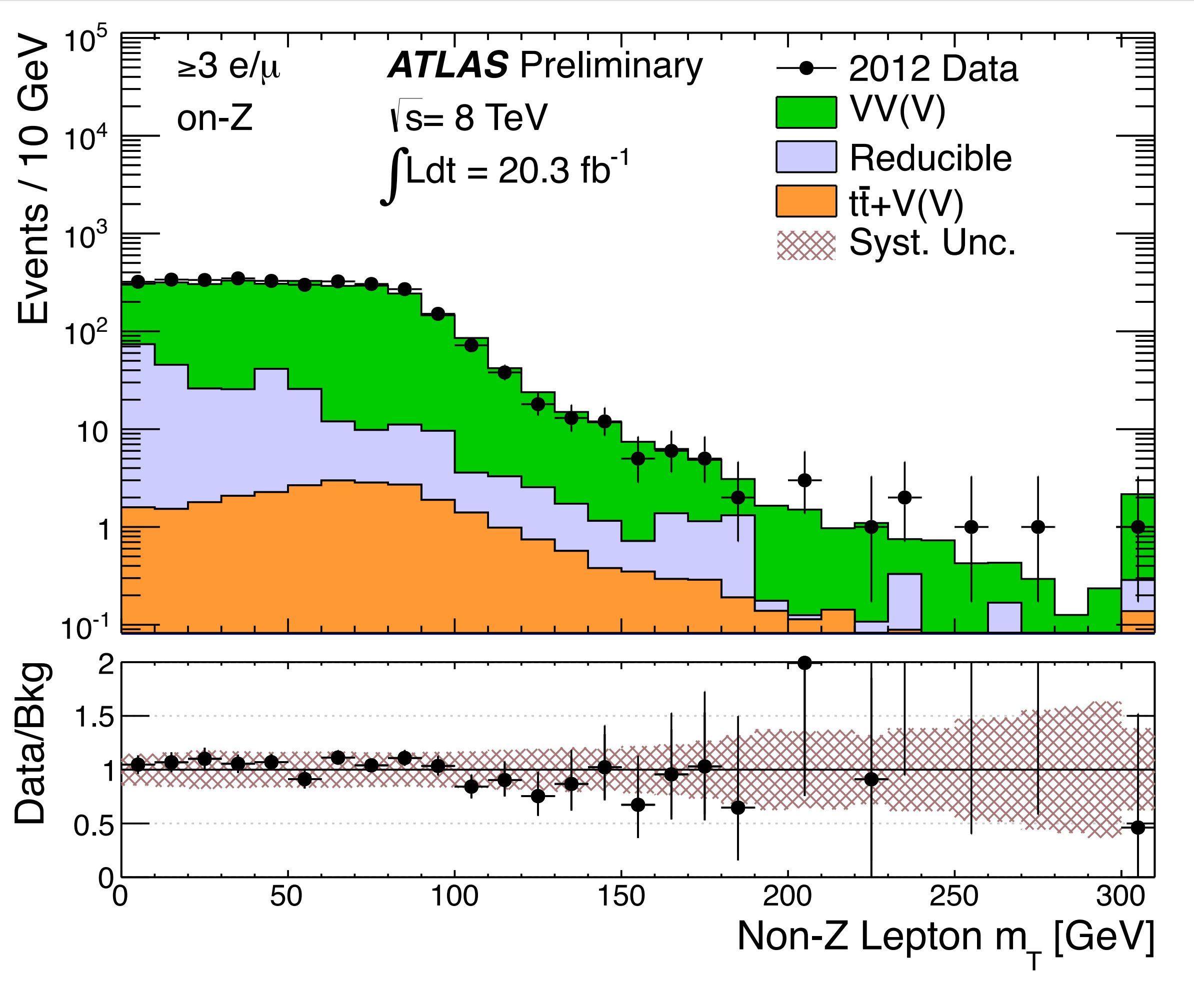
Unfortunately, no evidence of any new physics...
Data is consistent with predictions in the ~ 100 signal regions!

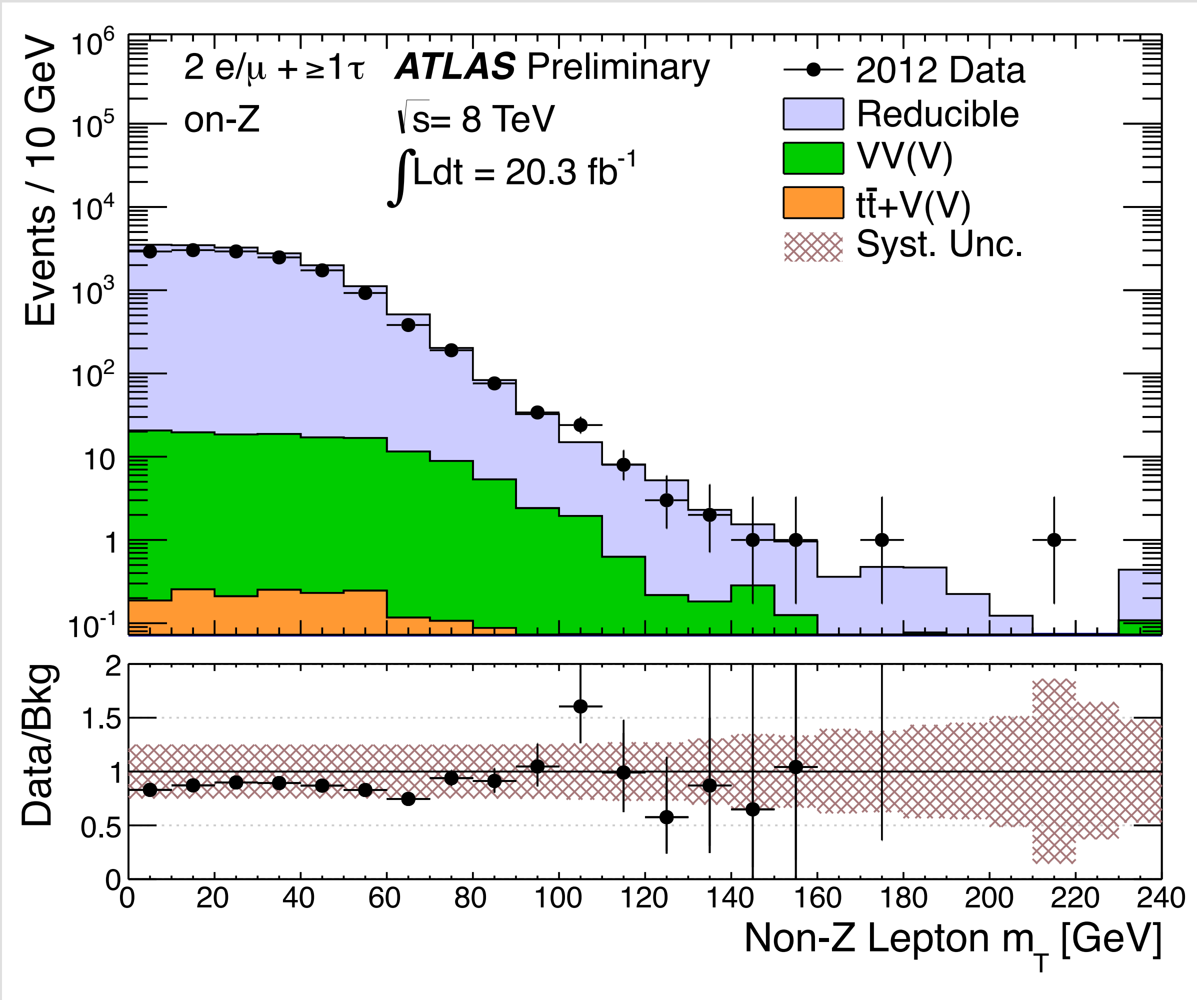




Largest ***single bin excess*** *was found in the E_T^{miss} bin of 180-200 GeV, and corresponds to a significance of 2.4 (including systematics)*

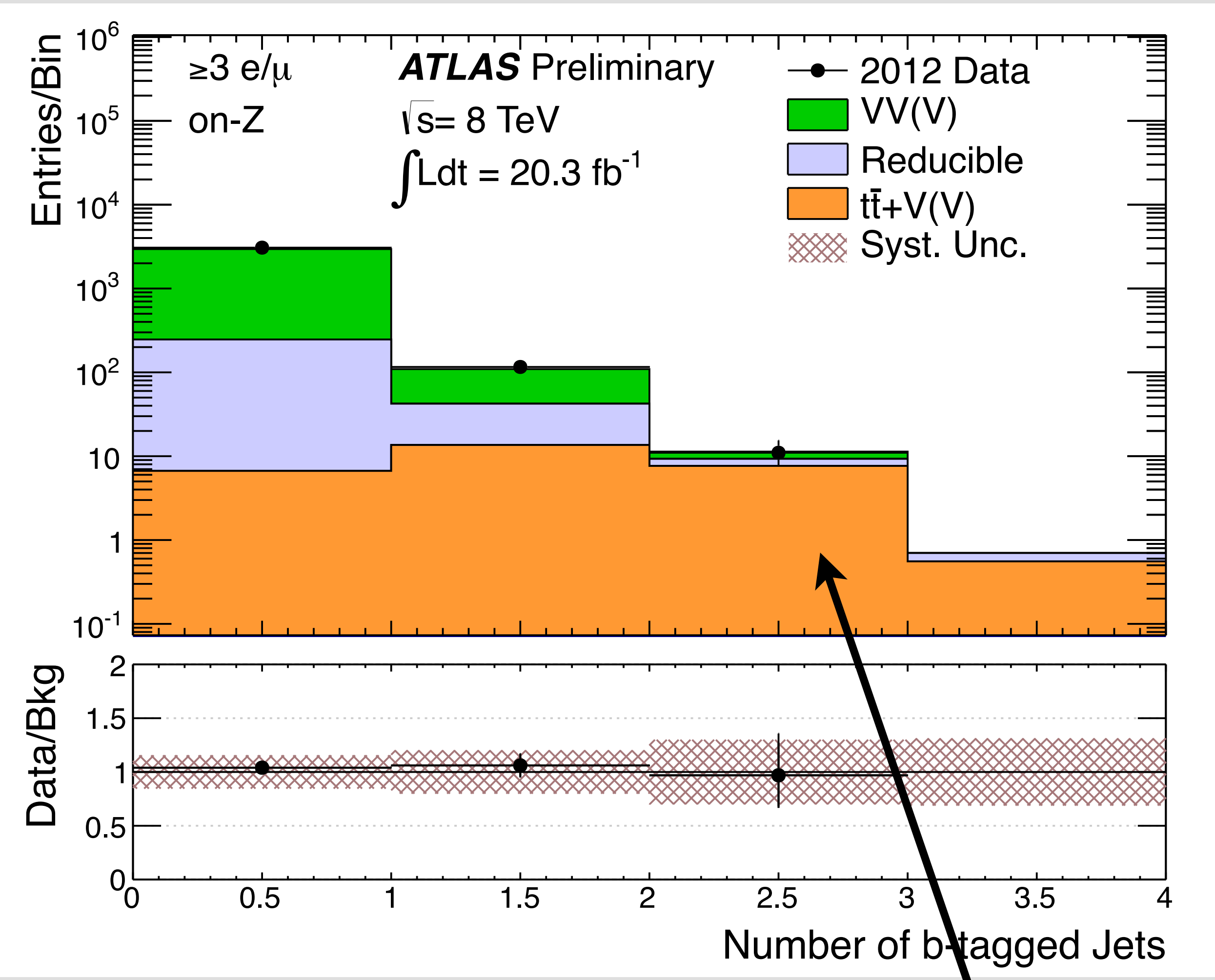
How well do we understand dibosons?





Excellent agreement in variables sensitive to di-boson production!
For the tau channel, things are not ***so*** *clear...*
This is a good visual confirmation that indeed, producing a high-sensitivity search with taus is extremely challenging

A little fun 'surprise'...

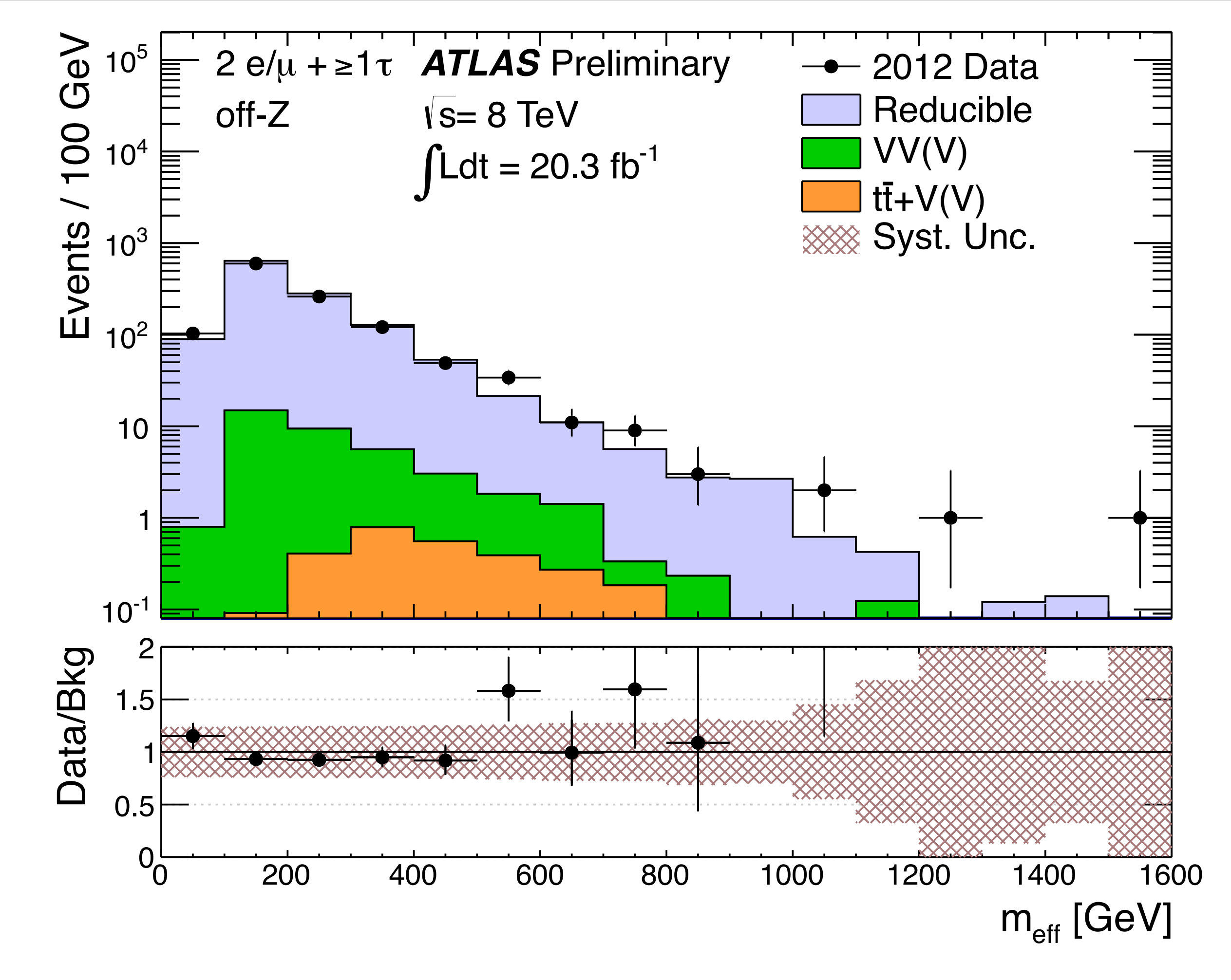


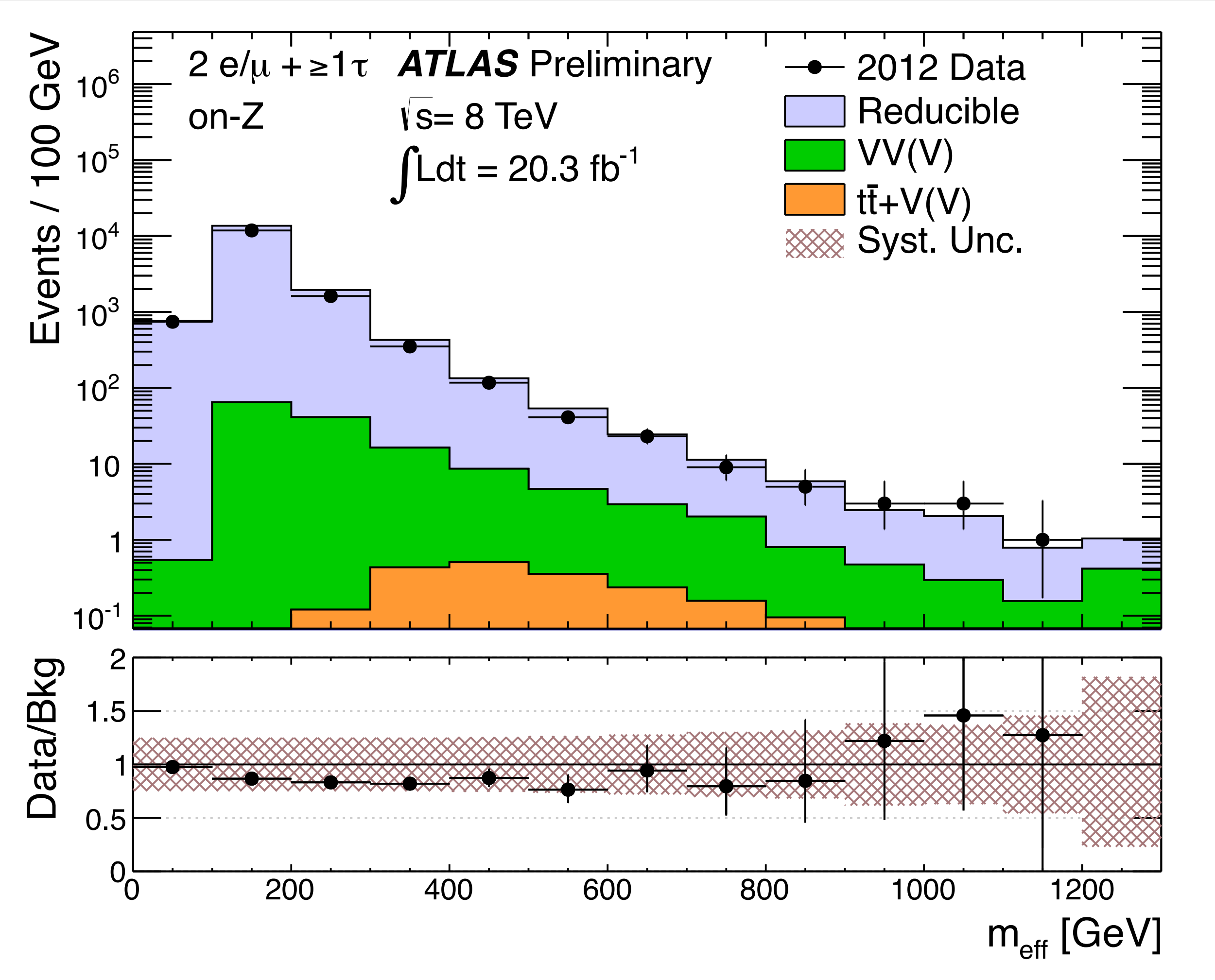
b-tags ≥	$t\bar{t}+V(V)$	$VV(V)$	Reducible	Total	Observed
		$\geq 3e/\mu$, off-Z			
1	8.7 ±0.2 ±2.7	6.7 ±0.6 ±2.0	24.8 ±2.0 ±1.3	40 ±2 ±4	42
2	3.0 ±0.1 ±1.0	0.2 ±0.1 ±0.1	3.4 ±1.0 ±0.7	6.6 ±1.0 ±1.2	8
		$2e/\mu+\geq 1\tau$, off-Z			
1	2.0 ±0.1 ±0.6	0.7 ±0.1 ±0.2	127 ±3 ±31	130 ±3 ±31	158
2	0.8 ±0.1 ±0.3	0.00 ±0.00 ±0.00	28 ±2 ±7	29 ±2 ±7	41
		$\geq 3e/\mu$, on-Z			
1	21.8 ±0.3 ±6.8	69 ±2 ±20	31 ±4 ±2	121 ±4 ±22	127
2	8.2 ±0.2 ±2.6	2.1 ±0.3 ±1.0	1.8 ±0.8 ±0.7	12 ±1 ±3	11
		$2e/\mu+\geq 1\tau$, on-Z			
1	1.5 ±0.1 ±0.5	5.4 ±0.5 ±1.7	146 ±3 ±37	153 ±3 ±37	229
2	0.5 ±0.1 ±0.2	0.1 ±0.1 ±0.1	12 ±1 ±3	13 ±1 ±3	13

First ATLAS 'evidence' of tt+V production?
Not 'highlighted' as such, no dedicated statistical study...

Some interesting features... *for tau fanatics...*

*Notice that the average **fake predictions** for the off-Z region are just about perfect, while the on-Z shows a ~ 10% level flat difference*

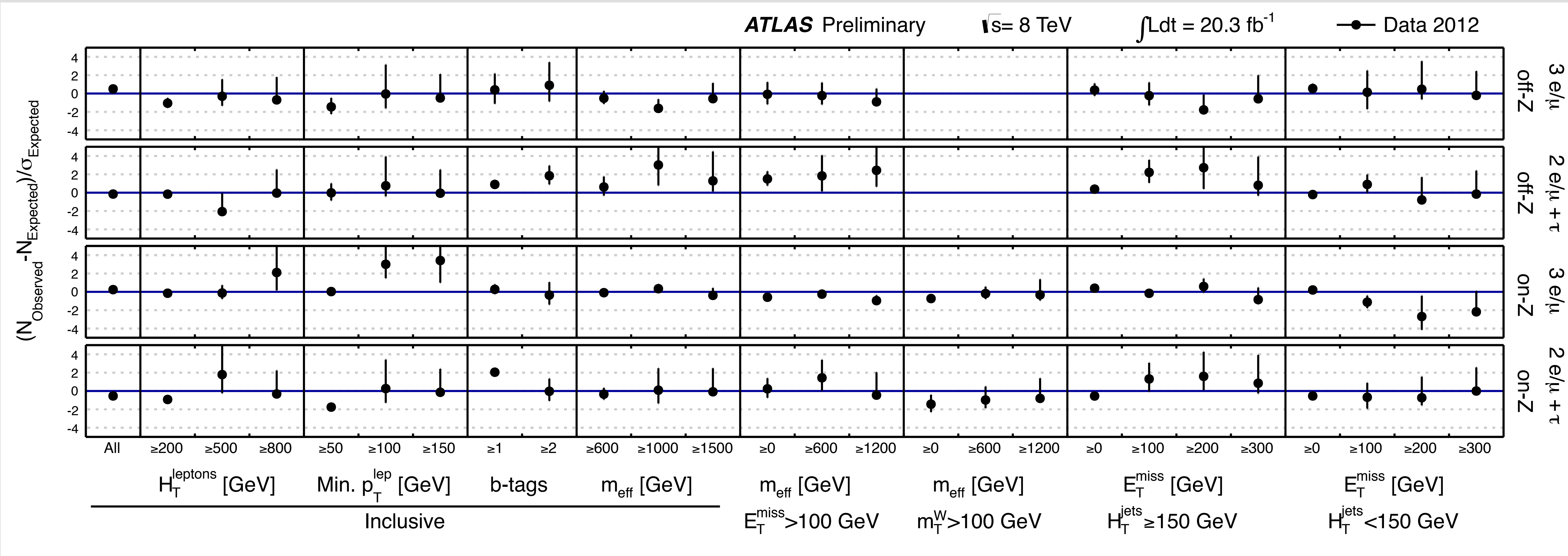




This is a consequence of using a single set of fake-factors for regions with potentially different flavour compositions - a systematic was taken for this... Limitation of the method: but no clear/easy solution to improve this...

Summarizing all results!

The biggest 'ratio plot' ever released by ATLAS?



The error bars on the dots correspond to the data statistical uncertainties, while the position on the y-axis represents the deviation as a function of the uncertainties on the background predictions

Multileptons: Event Counts

for those who prefer numbers...

Full event counts were also provided for all signal regions

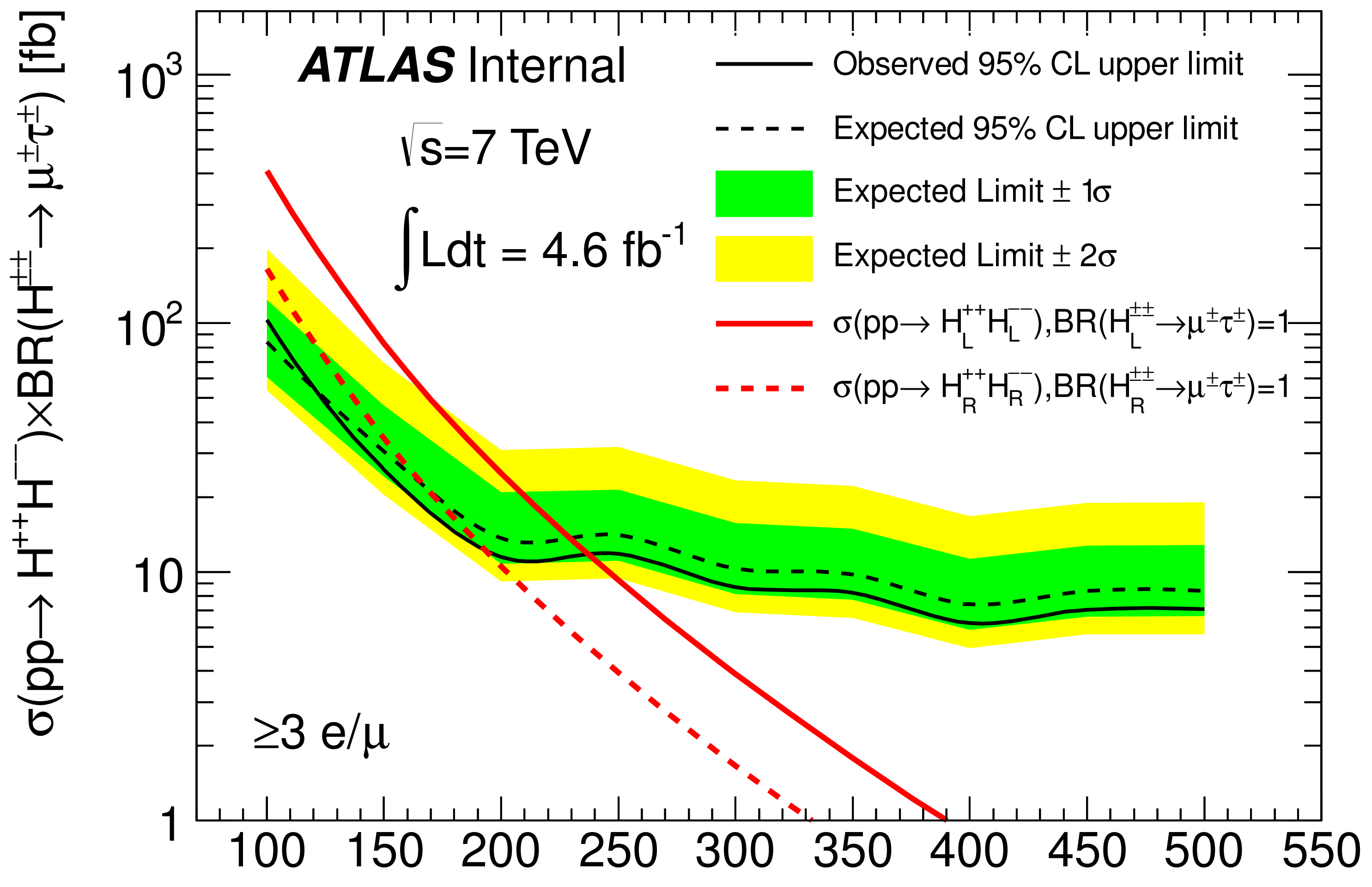
$H_T^{\text{leptons}} \geq$ [GeV]	$t\bar{t} + V(V)$	$VV(V)$	Reducible	Total	Observed
$\geq 3e/\mu$, off-Z					
200	5.5 ±0.2 ±1.7	64 ±1 ±15	13.6 ±1.9 ±2.3	83 ±2 ±16	66
500	0.29 ±0.04 ±0.09	2.9 ±0.2 ±1.4	0.29 ±0.23 ±0.69	3.5 ±0.3 ±1.5	3
800	0.02 ±0.01 ±0.01	0.5 ±0.1 ±0.2	$0^{+0.69}_{-0}$	0.5 ±0.1 ±0.7	0
$2e/\mu + \geq 1\tau$, off-Z					
200	1.01 ±0.07 ±0.31	6.0 ±0.2 ±1.3	121 ±3 ±31	128 ±3 ±31	123
500	0.02 ±0.01 ±0.01	0.14 ±0.02 ±0.03	1.7 ±0.4 ±0.8	1.9 ±0.4 ±0.8	0
800	0.00 ±0.00 ±0.00	0.01 ±0.00 ±0.00	0.02 ±0.03 ±0.71	0.03 ±0.03 ±0.71	0
$\geq 3e/\mu$, on-Z					
200	12.1 ±0.2 ±3.6	389 ±4 ±98	28 ±4 ±6	429 ±6 ±99	414
500	0.46 ±0.05 ±0.14	11.0 ±0.6 ±5.3	2.2 ±1.3 ±0.7	13.7 ±1.5 ±5.3	13
800	0.03 ±0.01 ±0.01	0.9 ±0.2 ±0.4	0.3 ±0.2 ±0.7	1.2 ±0.3 ±0.8	3
$2e/\mu + \geq 1\tau$, on-Z					
200	0.67 ±0.06 ±0.21	20.2 ±0.9 ±5.6	256 ±4 ±66	276 ±4 ±66	215
500	0.02 ±0.01 ±0.01	0.5 ±0.1 ±0.2	1.8 ±0.3 ±0.9	2.3 ±0.3 ±0.9	4
800	0.00 ±0.00 ±0.00	0.14 ±0.07 ±0.04	0.1 ±0.1 ±0.7	0.2 ±0.1 ±0.7	0

No significant deviation was found in any signal region under study

Setting Limits

(the consolation prize for not having found anything...)

Traditional Limit Setting



Taken from 7 TeV paper...
PRD 87, 052002 (2013)

What if...
There are other models such an analysis is sensitive to?
Extreme reverse engineering needed by theorists to extend the limits... (in most cases, guesswork!)

Re-interpretation - Motivation

- **What is a re-interpretation?**

  Even a search closely optimized for a specific model can be sensitive to other scenarios. With enough information about the signal regions and the exclusion limits, once can 'convert' the limits to be re-derived on a different class of models

- **Why are they potentially interesting?**

  Allows theorists to quickly check what the constraints on a new model are from past experimental results - 'bigger coverage of new phenoma phase space'

- **What are the difficulties associated with it?**

  Without a proper prescription on how the results of a search are provided, this leads to a lot of reverse-engineering for theorists, and (educated?) guesses. With a proper prescription, it just takes a lot of work ;)

*This is NOT a matter of philosophy - This is **always** useful!*

Ingredients needed for ‘Re-casting’

- Need limits presented in a model-independent way
  ie: ‘**fiducial limits**’, limits on the observed number of events

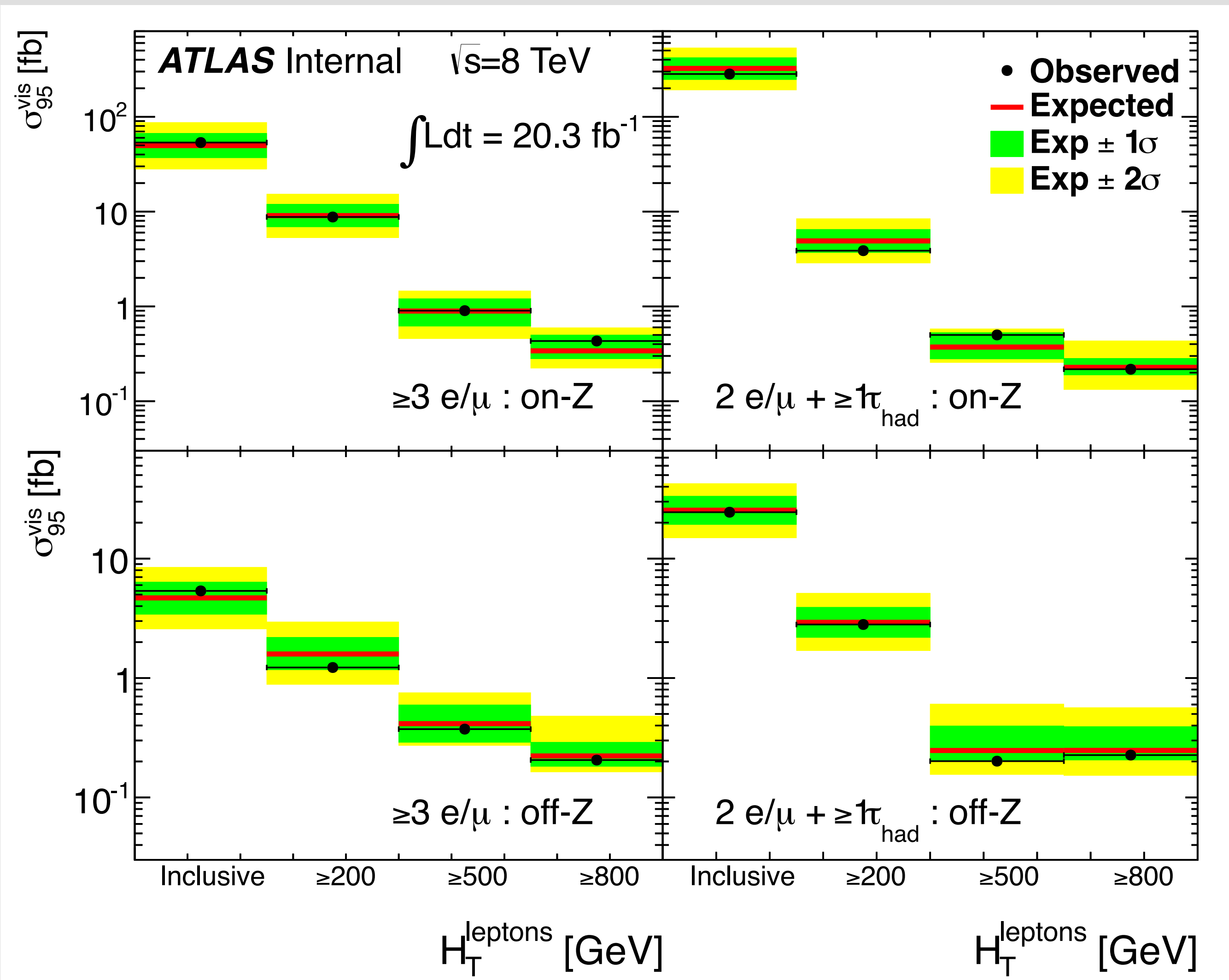
- Need a way to port these limits to any model
  ie: prescription for calculating **Acceptance** and **Efficiency**!
  (*Can be as simple as example values for a set of models - so that theorists can reverse-engineer: approach of ATLAS SUSY group*)

- **Can all analyses provide this?**
  No! And in many cases, it requires quite a bit of thinking (and a lot of effort...)
  Things that don’t really work:
  Multivariate event selection (no way to pass this to theorists)
  Strong dependency on full simulation (using unique properties of jets: doable, but might require one to re-invent fast-simulation)

Out of 20 Exotics public results released this year (CONF Notes), only 6 include the necessary basic ingredients for a re-interpretation
Recent workshop on this topic: Recommendations will be followed for papers...

Multilepton: What is included?

Limits!



$H_T^{leptons}$[GeV]	Observed	Expected	$+1\sigma$	-1σ	$+2\sigma$	-2σ
		$\geq 3(e,\mu)$, off-Z				
Inclusive	5.4	4.7	1.7	1.3	3.8	2.1
≥ 200	1.2	1.6	0.6	0.42	1.4	0.71
≥ 500	0.37	0.41	0.18	0.13	0.34	0.14
≥ 800	0.21	0.22	0.068	0.041	0.26	0.059
		$2(e,\mu)+\geq 1(\tau)$, off-Z				
Inclusive	24	25	7.9	6.1	17	11
≥ 200	2.8	2.9	0.99	0.74	2.2	1.2
≥ 500	0.2	0.25	0.15	0.042	0.36	0.092
≥ 800	0.23	0.25	0.14	0.042	0.32	0.095
		$\geq 3(e,\mu)$, on-Z				
Inclusive	54	50	17	13	37	22
≥ 200	8.8	9.1	2.9	2.2	6.2	3.8
≥ 500	0.9	0.89	0.31	0.27	0.57	0.44
≥ 800	0.43	0.34	0.16	0.06	0.26	0.12
		$2(e,\mu)+\geq 1(\tau)$, on-Z				
Inclusive	280	320	97	77	210	130
≥ 200	3.9	4.9	1.6	1.2	3.5	2
≥ 500	0.5	0.37	0.16	0.093	0.21	0.12
≥ 800	0.22	0.23	0.056	0.039	0.21	0.095

Model-independent 95% CL limits were set on the 'number of events after all selection requirements' (on the 'fiducial' cross-section)

Multilepton: What is included?

Fiducial Acceptance Prescriptions!

The σ_{95}^{vis} limits can be converted into upper limits on the cross section of a specific model as follows:

- Events from the new model are examined at the particle (MC-generator) level and kinematic requirements on the particles are applied. These include the p_{T} and η requirements for leptons and jets, and isolation requirements for the leptons. No special treatment for pileup is necessary.
- The number of events passing this selection determines the cross section for the model given the fiducial constraints, σ^{fid}.
- A correction factor must be applied to take into account detector effects. This correction factor, called ϵ_{fid}, is model-dependent, and is subject to uncertainties from detector resolution, reconstruction efficiency, pileup, and vertex selection. This correction factor represents the ratio of the number of events satisfying the selection criteria after reconstruction to all those satisfying the fiducial acceptance criteria at the particle level.
- A 95% CL upper-limit on the cross section in the new model is then given by:

$$\sigma_{95}^{\text{fid}} = \frac{N_{95}}{\epsilon_{fid} \int L\mathrm{d}t} = \frac{\sigma_{95}^{\text{vis}}}{\epsilon_{fid}}. \qquad (2)$$

Multilepton: What is included?

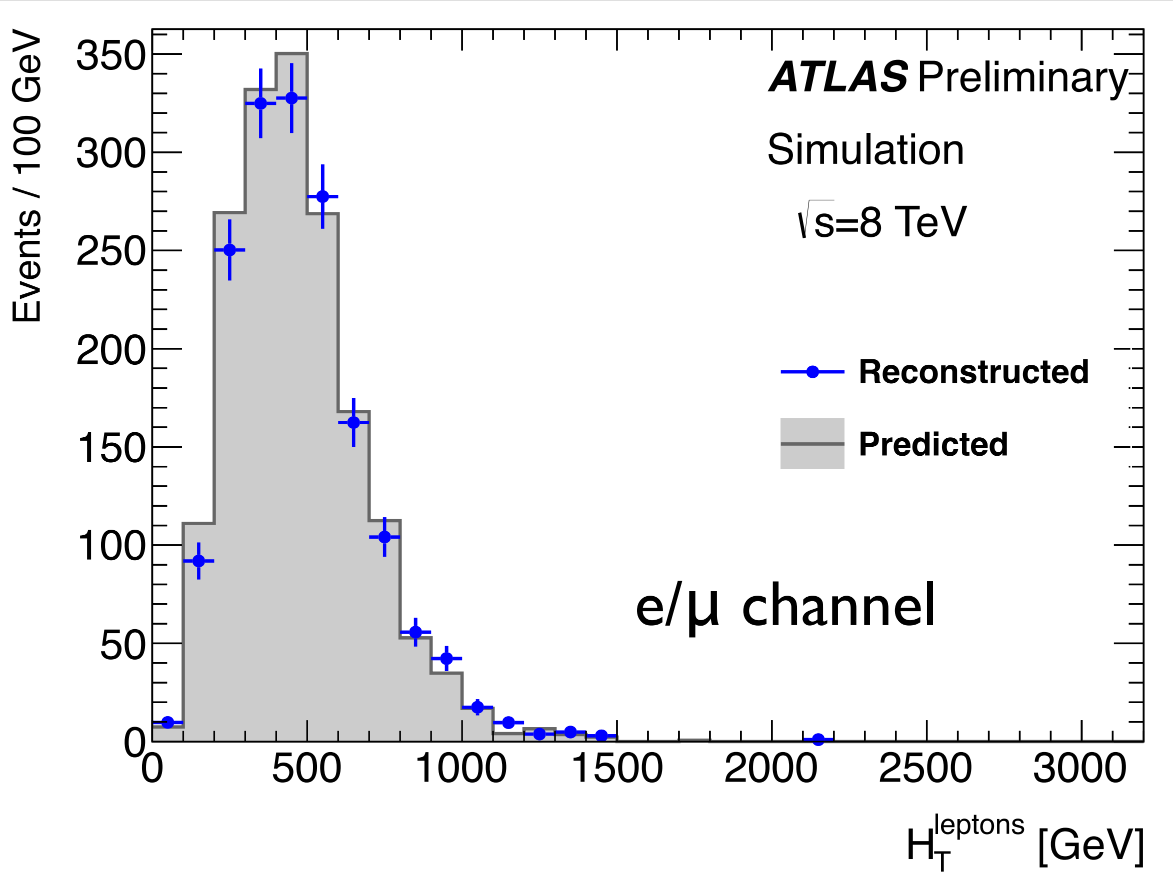
Fiducial Efficiencies!

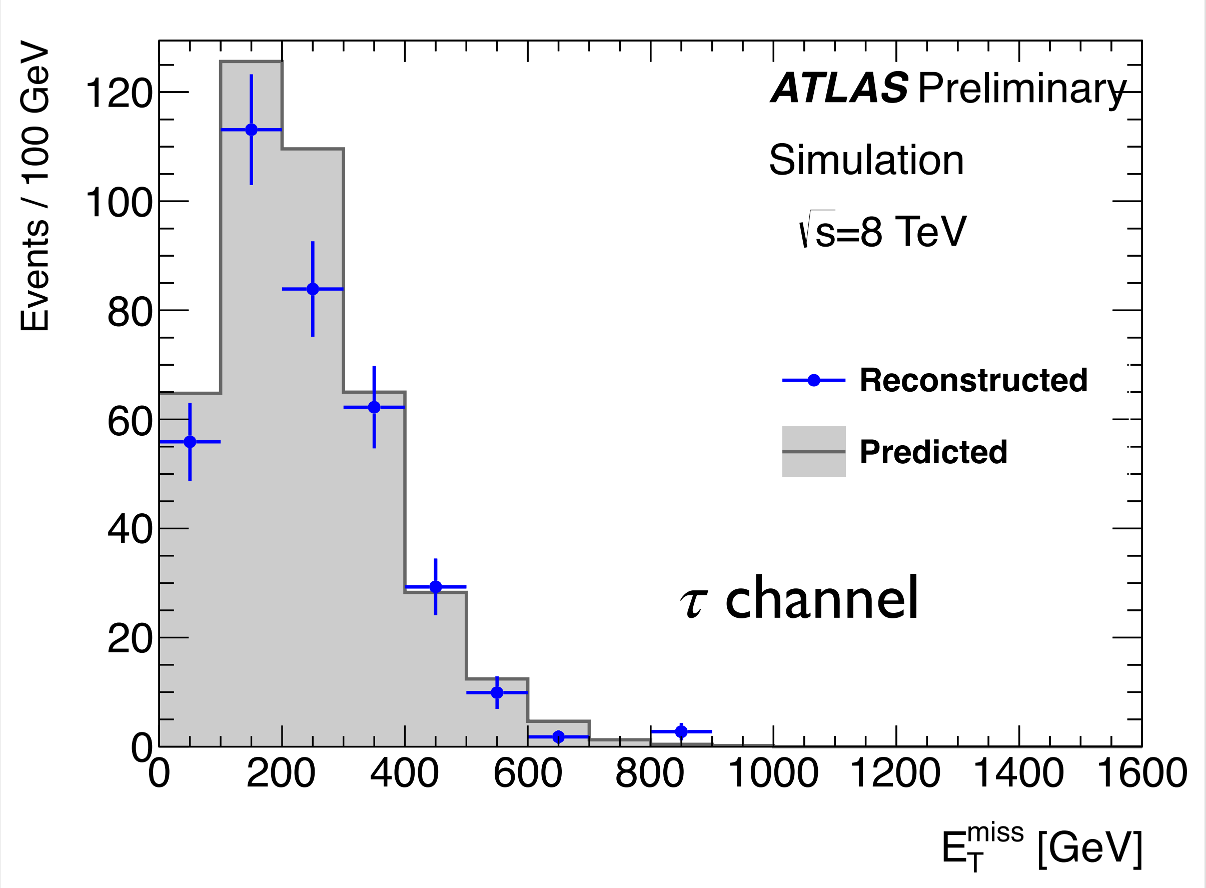
p_T [GeV]	Prompt e	$\tau \to e$	τ_h
10–15	0.045±0.001	0.027±0.002	-
15–20	0.484±0.003	0.384±0.005	0.071±0.003
20–25	0.571±0.003	0.470±0.006	0.251±0.006
25–30	0.628±0.002	0.518±0.007	0.321±0.007
30–40	0.681±0.002	0.573±0.006	0.313±0.006
40–50	0.713±0.002	0.597±0.009	0.326±0.007
50–60	0.746±0.002	0.64±0.01	0.309±0.009
60–80	0.767±0.002	0.67±0.01	0.295±0.009
80–100	0.799±0.003	0.67±0.02	0.32±0.02
100–200	0.820±0.003	0.63±0.03	0.33±0.02
200–400	0.835±0.009	0.72±0.08	0.29±0.05
400–600	0.819±0.043	-	-
≥ 600	0.829±0.104	-	-

p_T	Prompt μ		$\tau \to \mu$	
[GeV]	$\|\eta\| > 0.1$	$\|\eta\| < 0.1$	$\|\eta\| > 0.1$	$\|\eta\| < 0.1$
10–15	0.021±0.001	0.003±0.002	0.013±0.001	0.005±0.003
15–20	0.704±0.003	0.37±0.01	0.539±0.005	0.29±0.02
20–25	0.808±0.002	0.42±0.01	0.620±0.006	0.35±0.03
25–30	0.855±0.002	0.45±0.01	0.675±0.007	0.39±0.03
30–40	0.896±0.001	0.498±0.008	0.708±0.006	0.42±0.03
40–50	0.920±0.001	0.515±0.008	0.754±0.008	0.42±0.04
50–60	0.932±0.001	0.515±0.009	0.78±0.01	0.49±0.05
60–80	0.940±0.001	0.528±0.009	0.78±0.01	0.46±0.05
80–100	0.938±0.002	0.51±0.01	0.74±0.02	0.42±0.08
100–200	0.939±0.002	0.53±0.01	0.81±0.02	0.4±0.1
200–400	0.936±0.006	0.52±0.05	0.91±0.06	-
400–600	0.95±0.02	0.5±0.2	-	-
≥ 600	0.92±0.08	-	-	-

Derived from WZ events...

Multilepton: Does it work?





Prescription is tested in VLQ events

(full simulation vs. particle-level with fiducial efficiencies)

Agreement in all observables at the 10% level for the e/μ channel and at the 20% level for the τ channel

(Already included in the limit systematics)

Putting it all together with RIVET

- **RIVET**: Originally a toolkit to validate MC generators: coding fiducial selection for an analysis to compare predictions
- Wide library of functions to access particle-level quantities in a generic way
- We can use it backwards, however! If we interface it with the fiducial efficiency tables and limits, can implement an 'automatic re-interpretation tool'!
- Released as 'extra material' along with a publication
Needs to go through a round of ATLAS validation as it is considered to be an 'official result'!
- **For theorists: 'Plug-and-play': input model (HEPEVT) and cross-section, gets limits!**

Was release publicly a few weeks ago for 7 TeV results!
https://rivet.hepforge.org/analyses#ATLAS_2012_I1204447

Putting it all together...

- *Expanding on this idea, we can eventually consider the possibility of having the results of 'most' searches documented centrally in a similar way!*
    - *Could consider a framework where a model is inputted and limits are provided (with details on which search is the most constraining!). Probably a lot to learn from this!*
- *Some work on this by the theory community, but will need discipline from the experimental side to realize this vision!*
- *Stay tuned! (**ATOM**-project?)*

Outlook: Part Un

- I’ve shown the details of a **model-independent** search for new phenomena in the multilepton final state
  - *And used this as an excuse to talk about how well taus are doing in ATLAS :)*
  - *And how we can better interface our results with the theory community!*
- ‘**But we can always do better**’: limitations of what I’ve shown today:
  - Will be outperformed by a dedicated search...
  - Reduced sensitivity to resonant production (no mass variables, for example: too difficult to get fake-estimates?)
  - Limited combination possibilities (signal regions are entangled!)
  - Information about lepton charges missing (SS-type classifications: multiplication of signal regions! Other classifications can also be considered...)
  - Taus cannot be treated ‘like other leptons’ until we get another rejection of O(100) more! Is this a current push for the ATLAS TauWG? Limiting factor for searches!

Outlook: Part Deux

- Run-II of the LHC in 2015 will once again bring the capacity to probe a new kinematic regime (*the last refuge for new physics?*)
- Such a search will be repeated! But can we include large improvements? Experimental conditions will be much harder!
- At 14 TeV, triggering becomes difficult: we will need to start using **dilepton triggers** (and suffer in terms of p_T thresholds) or make the large jump to **trilepton triggers** (and the associated nightmare!!!!)
- A silver lining - With this in mind, is there some hope to yet lower the lepton kinematic requirements? (for compressed scenarios?) (Is **10, 10, 15** feasible? With **trilepton triggers**, probably!)

8 TeV paper soon incoming with improvements!
Stay tuned for RIVET implementation!

Thanks for your time!!