Search for leptoquark pair production through ττττ final states with full Run-2 dataset

Stergios Kazakos (IFAE)

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Introduction

★ **Leptoquarks (LQs)** are hypothetical particles that could explain the deviations in **R(D*)/R(D)** ratio reported by the B-factories experiments and indicating a potential deviation in Lepton Flavour Universality (LFU). [more information *here*]

★ Search for **scalar LQ** pair production with **down-type LQ_3^d** (charge 1/3) using the full Run-2 dataset.

★ Their quantum numbers suggest that **down-type LQ_3^d** should couple simultaneously to a **top quark** and a **τ-lepton** or a **bottom quark** and a **neutrino** with decay modes:

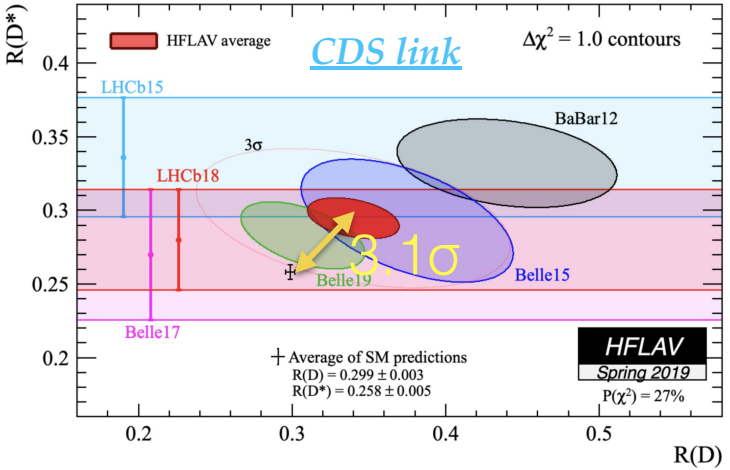
- **ττtτ** (B=1) and **τbν** (B<1)

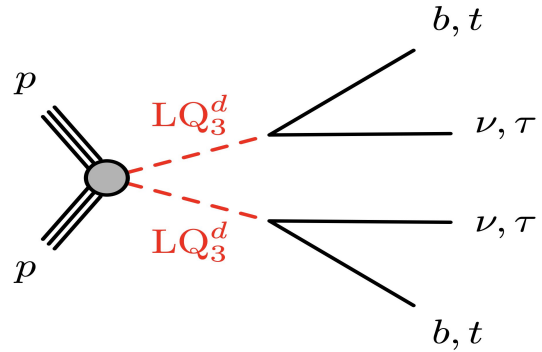
giving final states with multiple light leptons and hadronically decaying τs:

- **$t \to bW^{\pm} \to b\,(qq/\nu_\ell \ell^{\pm})$**
- **$\tau \to \nu_\tau\,(qq/\nu_\ell \ell^{\mp})$** (if qq then $\tau \equiv \tau_{had}$)

★ **First dedicated ATLAS analysis in LQLQ→ττtτ channel.**

- previous re-interpretations in HH→bτbτ & stop-pair→bττ+E_T^{miss} searches

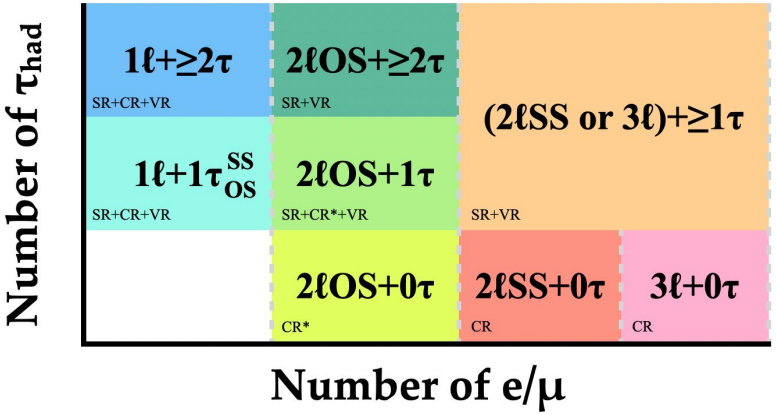




Public result: ATLAS-CONF-2020-029

Analysis strategy

★ Channel categorisation is based on **number of light leptons (e/μ)** and **number of hadronic τs**.

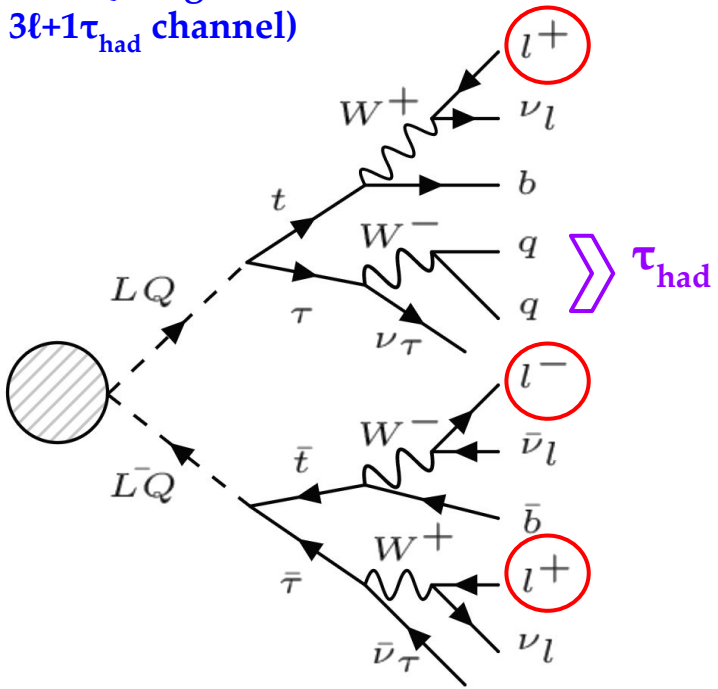


★ **Search range** is from **0.8** to **1.5 TeV** for the current result (to be extended from **0.5** to **1.6 TeV** in the publication).

★ There are **6 validation (VR)**, **17 control (CR)** and **7 signal (SR)** regions are defined that are **orthogonal** to each other.

→ Fitting $H_{T,lep}$ or **number of events** in CRs, m_{eff} in SRs.

Typical LQ diagram (e.g. 3ℓ+1τ_{had} channel)



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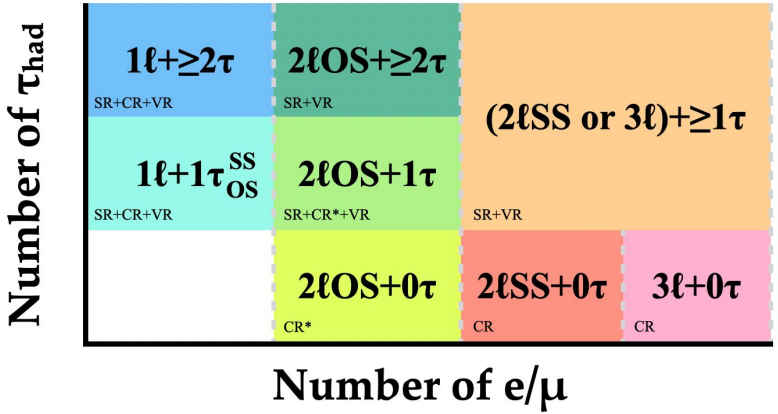

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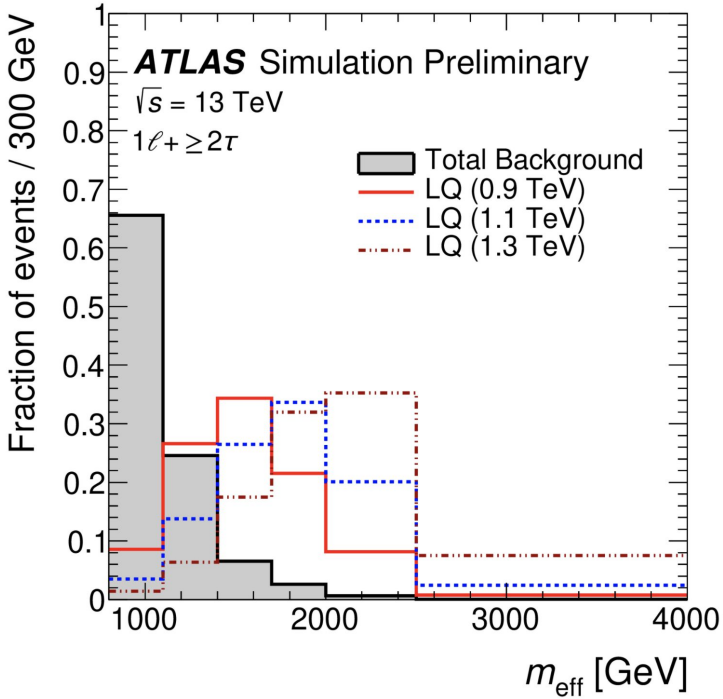

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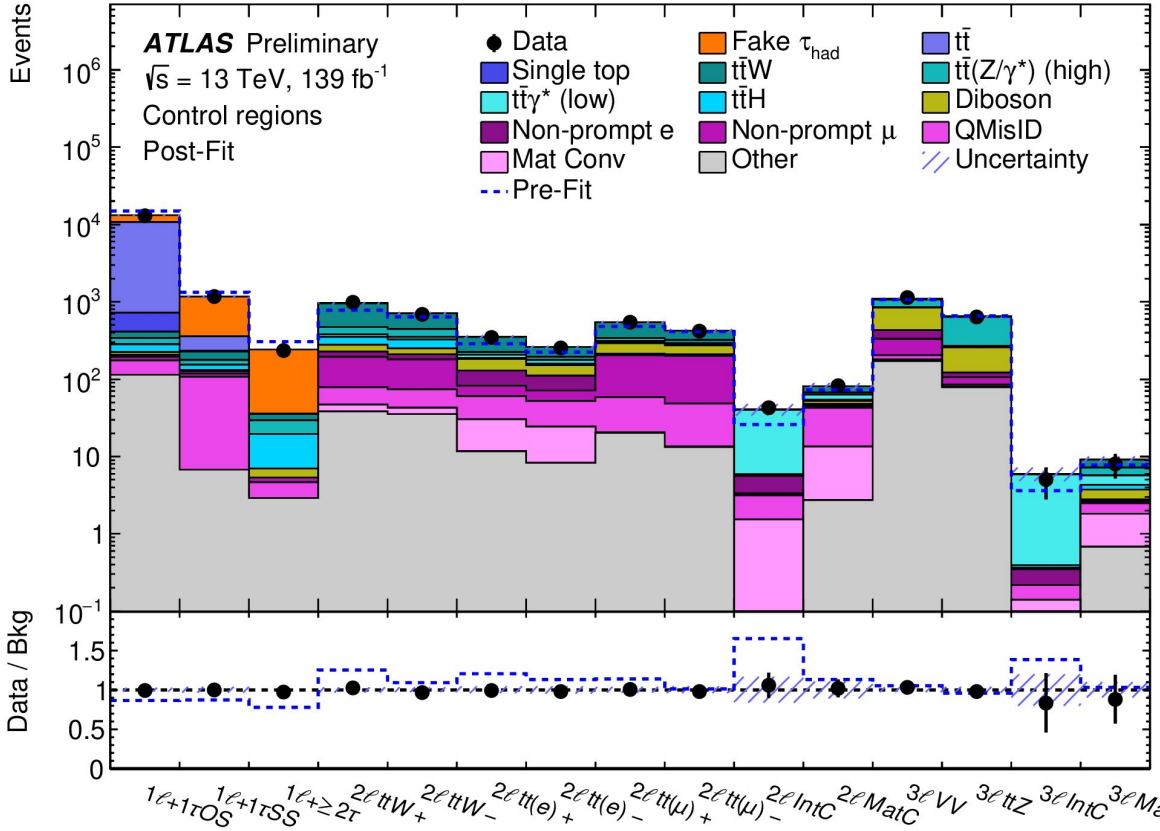
Main discriminating variable

★ $m_{eff} = \sum_{(jet,\ e,\ \mu,\ \tau)} p_T + E_T^{miss}$

Major backgrounds & BG composition (CRs)



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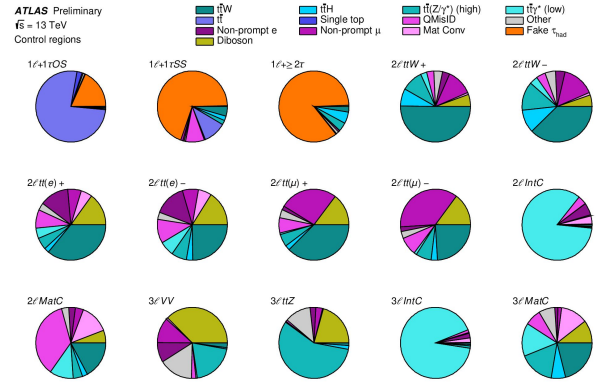
Major backgrounds (channel dependent):

★ $t\bar{t}$ (w/ fake non-prompt light leptons or fake τ_{had}), $t\bar{t}V$, $t\bar{t}H$, VV, singletop

- Reducible background is split based on truth information: **fake τ_{had}, non-prompt leptons, conversions**

- Employ data-driven approaches (similar to 4-tops and ttH-ML analyses) for **$t\bar{t}$ (w/ fake lepton or τ_{had})** and **$t\bar{t}W$** estimation.

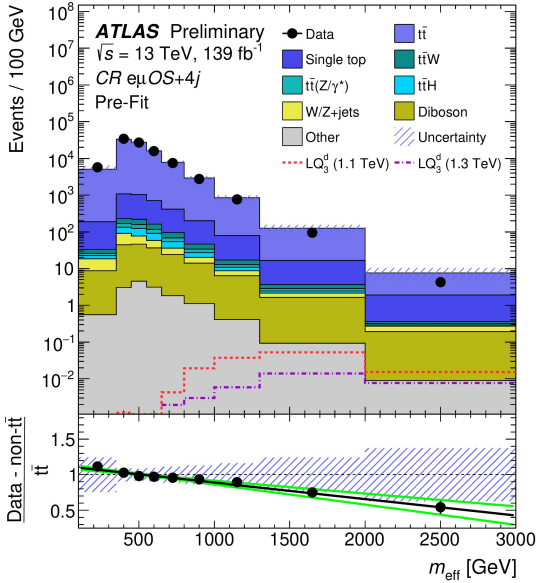


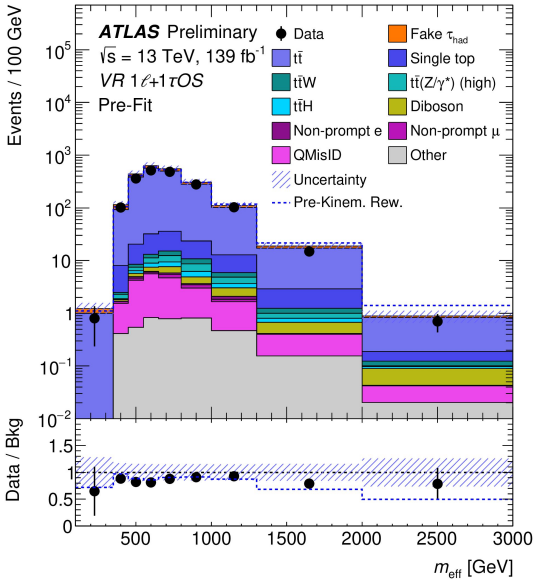
Background estimation: Kinematic RW

★ **$t\bar{t}$+jets**: Dominant background in **1ℓ** w/ **true light leptons** and **true τ_{had}s**. Substantial background in rest of the channels when there is presence of non-prompt light leptons or fake τ_{had}s from jets.

- Corrected by **njet-dependent m_{eff} RW function** derived in **eμ (opposite-sign)+0τ_{had} channel** (and referred to as "kinematic reweighting").

- The difference between the m_{eff} RW functions derived in **eμOS+0τ_{had}** and **1ℓ+1τ OS** channels is taken as systematic to account for potential differences between **dileptonic** and **semi-leptonic $t\bar{t}$** kinematics.





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★ In m_{eff} distribution the ratio of background - subtracted data over **$t\bar{t}$+tW MC** is fitted with a first order polynomial ($y=a_0+a_1 \cdot x$) **in various njet bins**.

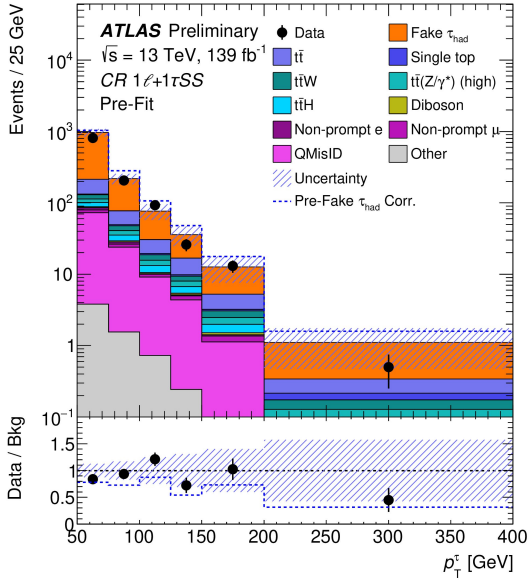
- This fit of the ratio is demonstrated in the case of **=4j** (left fig.) where the **green lines** show the fit's **statistical** uncertainty.

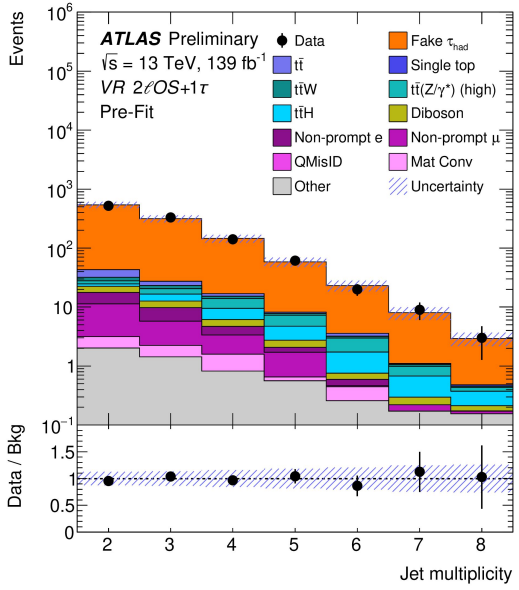
Background estimation: Fake τ_{had} correction

★ After the kinematic RW is applied **fake τ_{had} SFs** are derived in **2ℓOS+1τ (eμ)** region and are applied to fake τ_{had}s in MC in all channels.

- Systematics are evaluated by comparing fake tau SFs in **$t\bar{t}$** and **Z+jets** CRs.

★ The good modelling after the fake τ_{had} correction is demonstrated in 1ℓ+1τSS CR and 2ℓOS+1τ VR which are dominated by fake τ_{had}s (**leading tau p_T** and **njets** are shown respectively).





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Background estimation: Template fit

★ **$t\bar{t}W$, non-prompt e/μ, Int.($tt\gamma^*$)/Mat. Conv.** :
The associated normalisation factors (NFs) are derived by **2ℓSS/3ℓ+0τ channels** after a template fit (TF).

★ The TF method is used as in ttH-ML analysis:

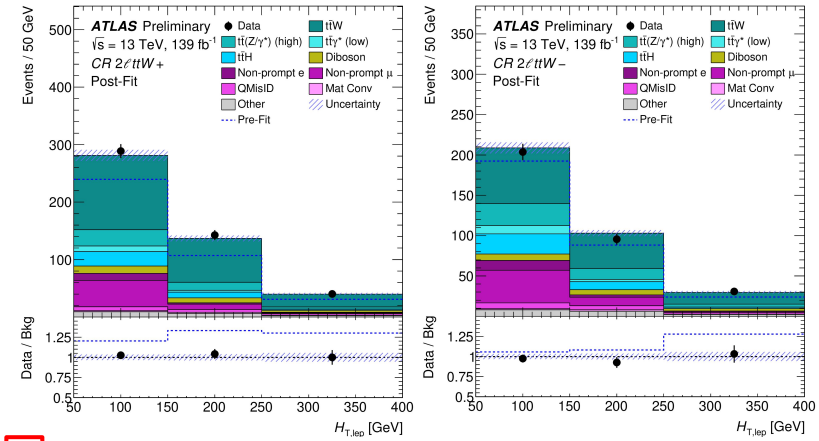
- **Five NFs** are left **free-floated**.

- The **background NFs** and the **LQ signal strength** are fitted simultaneously.

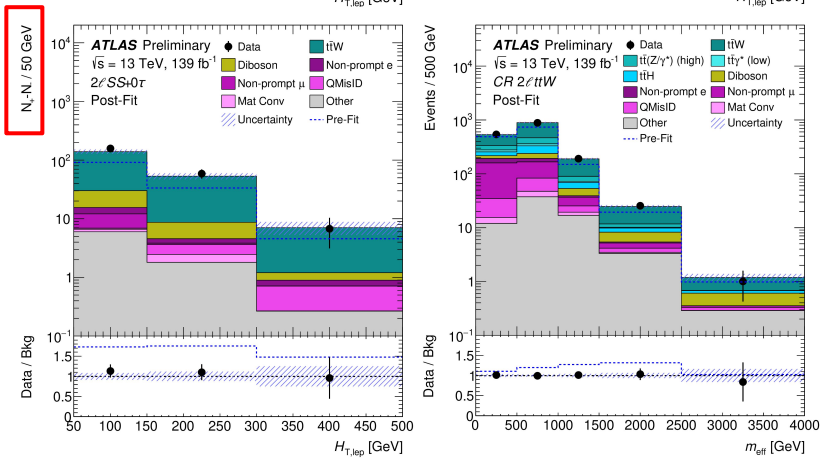
- **Number of event yields** is used in conversion CRs and $H_{T,lep}$ in the other CRs.

[ATLAS-CONF-2020-029]

Fit $H_{T,lep}$ and event yields:



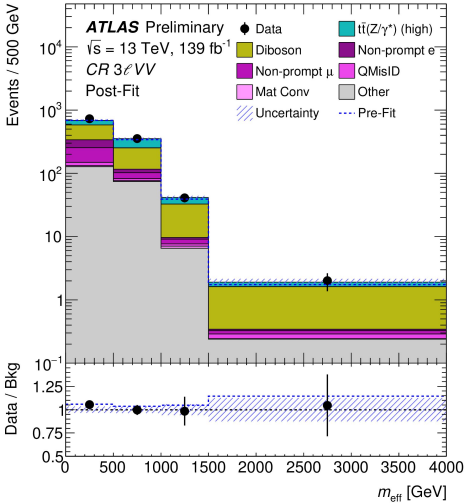
Check the result post-fit in other regions/variables:

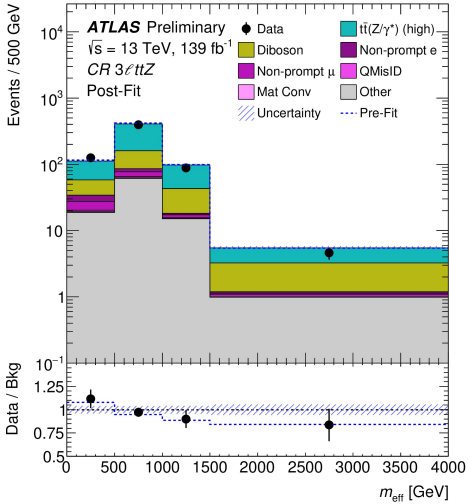


Background estimation: VV, ttZ

★ The **3ℓVV** and **3ℓttZ** CRs are used to improve the estimation of the corresponding background contributions by requiring **at least one ℓ pair** at the Z mass window (on-shell Z).

★ Background expectation is similar to the SM expectation.
→ Cross-section and modelling uncertainties are included as NPs, no need for free-floating NFs.





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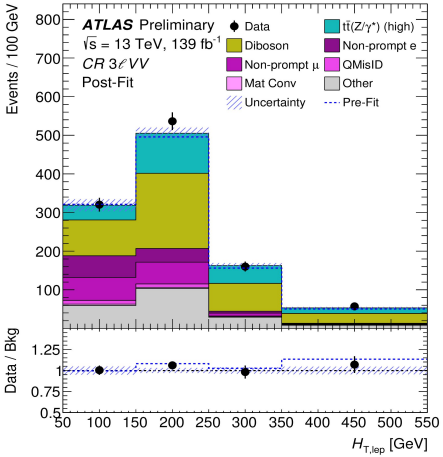
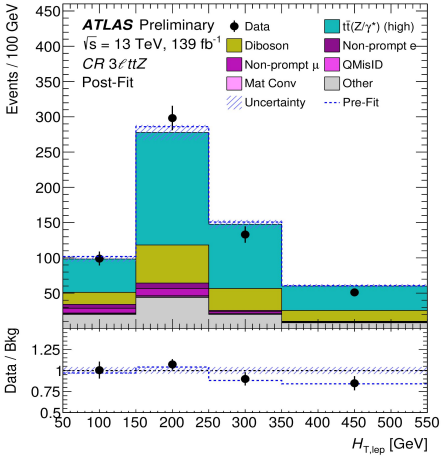
★ Good modelling pre-fit and post-fit in $H_{T,lep}$ (fitted variable) and m_{eff} (discriminating variable in SRs).





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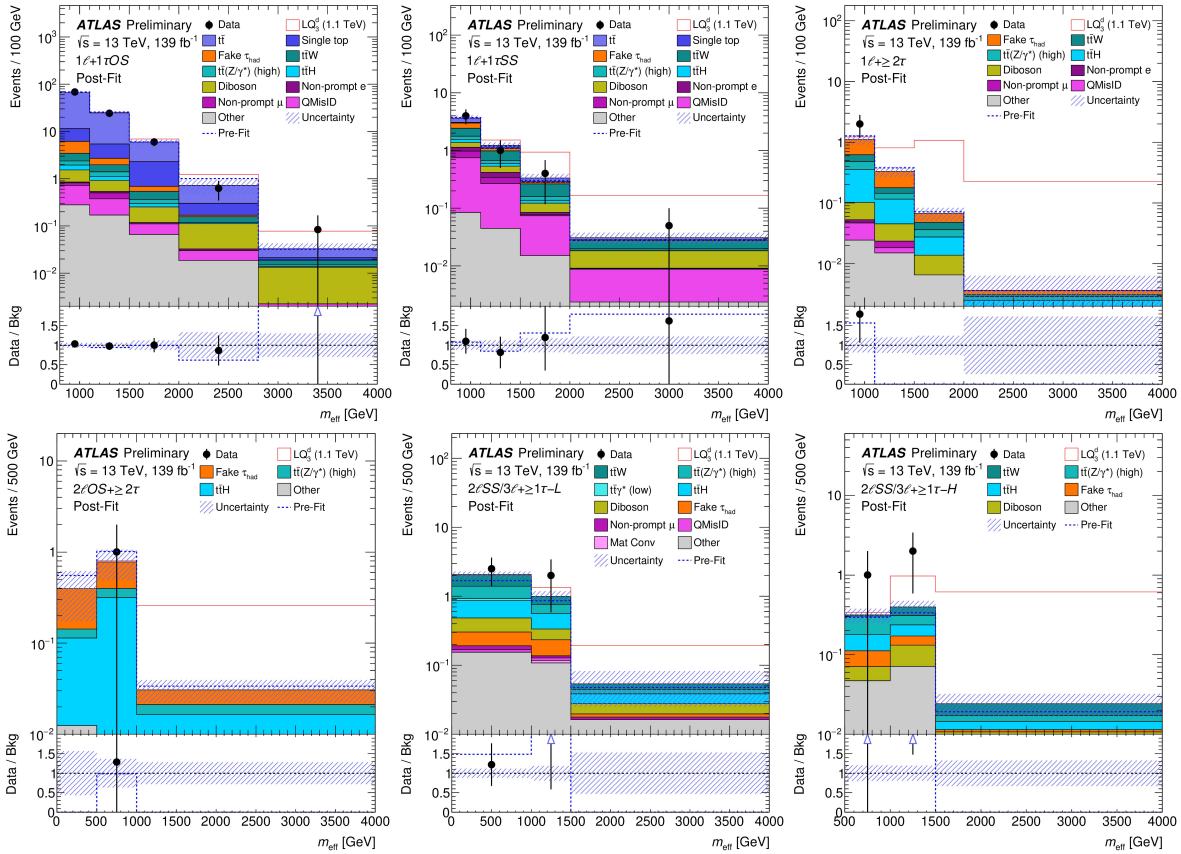
m_{eff} distribution in signal regions



★ The fitted variable (m_{eff}) is shown post-fit for all the SRs of the analysis.

★ The result is **compatible with the "no signal" hypothesis** as there are no (or not enough) real events in the most sensitive bins (right tail of m_{eff} distribution).

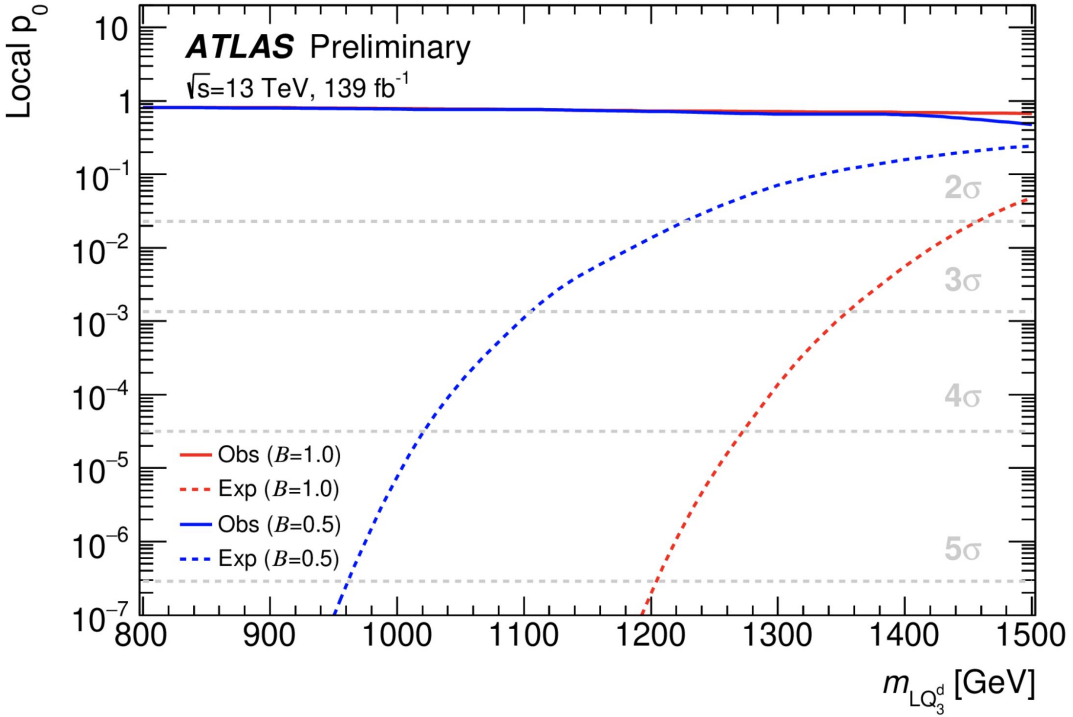
★ The **expected LQ signal** at **1.1 TeV mass point** is shown for demonstration (**μ=1**, ***B*=1**).

[ATLAS-CONF-2020-029]

p-value as a function of m_{LQ}

- The **observed** and **expected p-values** (p_0) are plotted as a function of m_{LQ} for B=1 (red) and B=0.5 (blue).
- This illustrates the significant expected sensitivity of the search, which exceeds **5 s.d.** for m_{LQ}**< 1.21 TeV** and **3 s.d.** for m_{LQ}**< 1.36 TeV** for B=1.
- Improvement of a factor of ~x10 in sensitivity (~500 GeV in m_{LQ}) w.r.t. the previous ATLAS and CMS results (36 fb^{-1}).

arxivCMS



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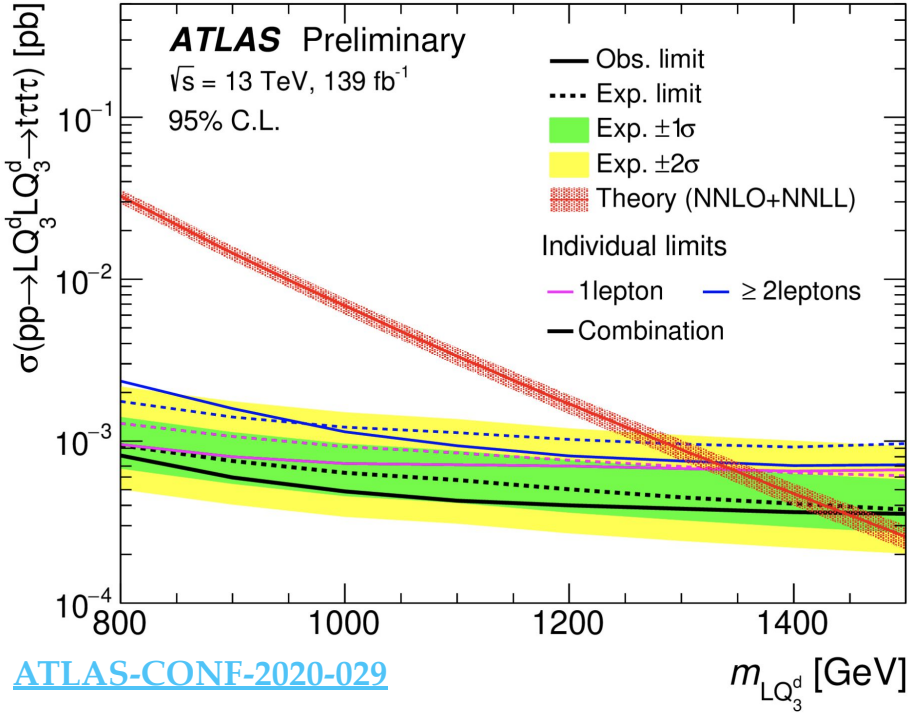
Expected and observed upper limits

★ Since no significant excess was found over the SM background prediction, **95% CL upper limits** were set on the LQ pair production cross section **as a function of** m_{LQ} (B=1).



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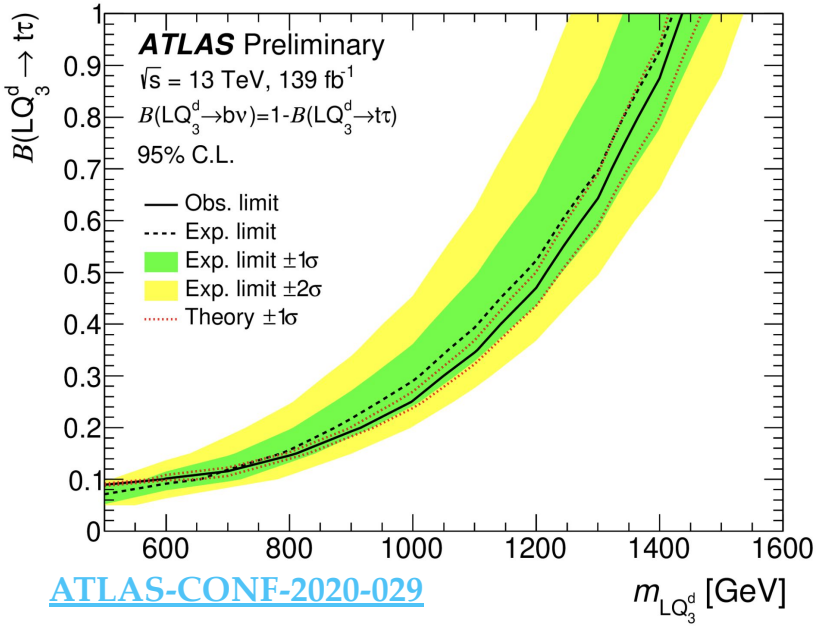

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★ Sensitivity is mostly driven by 1ℓ channels with a significant contribution from ≥2ℓ channels.

★ The combined observed lower limit for m_{LQ} in all channels is **1.43 TeV** for B=1 and **1.22 TeV** for B=0.5.

Summary

- First result of a dedicated full Run-2 ATLAS analysis in LQLQ→tττt channel is presented.
- Various modelling corrections and challenging background categorisation methods were used.
- No significant excess was found over SM prediction and upper limits were set on the LQ production cross-section.
- Upper limits were improved by **~500 GeV** (factor of ~x10 in sensitivity) w.r.t. to previous ATLAS and CMS results (36 fb^{-1}).

Backup

Object and event selection

Event (pre-)selection:
- ≥ 2 jets, ≥ 1 bjets (@ 77% DL1 WP)
- Single-lepton Trigger (1ℓ channel)
- Single- or Di-lepton Triggers (≥2ℓ channels)

Jets:
- AntiKt4EMPFlowJets
- $p_T \geq 25$ GeV
- $|\eta| < 2.5$
- JVT ≥ 0.5 ($p_T < 60$ GeV, $|\eta| < 2.4$)

Overlap removal:

Reject	Against	Criteria
Electron	Muon	$\Delta R < 0.1$
Jet	Electron	$\Delta R < 0.2$
Jet	Muon	$\Delta R < 0.2$
Tau	Electron	$\Delta R < 0.2$
Tau	Muon	$\Delta R < 0.2$
Jet	Tau	$\Delta R < 0.2$

Light leptons:

	e			μ		
	L	T	T*	L	T	T*
Identification	loose	tight	tight	loose	medium or high-p_T	medium or high-p_T
Isolation		Yes			Yes	
Non-prompt-lepton veto	No	No	Yes	No	No	Yes
Electron charge-misassignment veto	No	No	Yes		—	
Electron material-conversion veto	No	No	Yes		—	
Electron internal-conversion veto	No	No	Yes		—	
$\lvert d_0\rvert/\sigma_{d_0}$		< 5			< 3	
$\lvert z_0 \sin\theta\rvert$ [mm]		< 0.5			< 0.5	

Taus:
- Originating from PV
- 1- or 3-prong
- $p_T \geq 25$ GeV
- $|\eta| < 2.5$, not in $(1.37 \leq |\eta| \leq 1.52)$
- JetIDWP: JetRNNSig**Loose** (L) / JetRNNSig**Medium** (M)
- EleBDTWP: ELEIDBDTLOOSE

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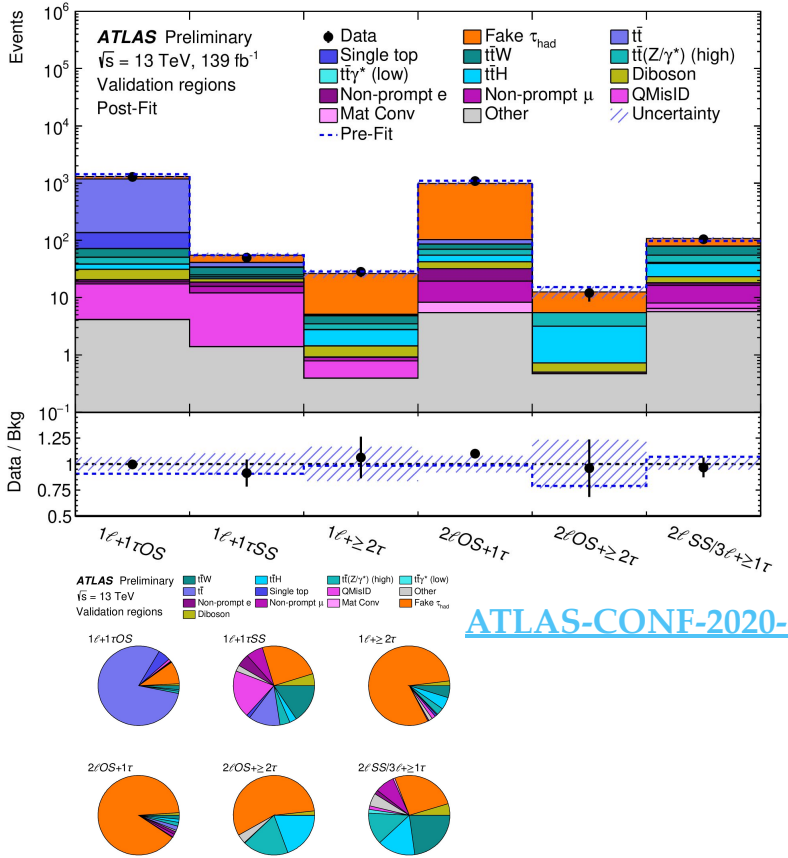
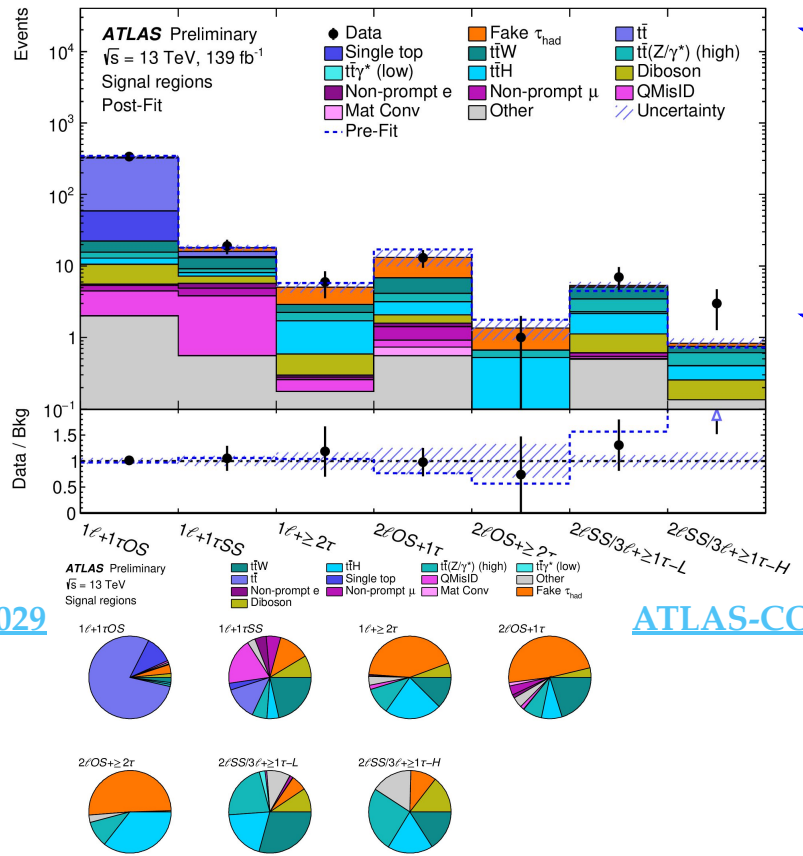
Data/MC agreement & BG composition (SRs/VRs)





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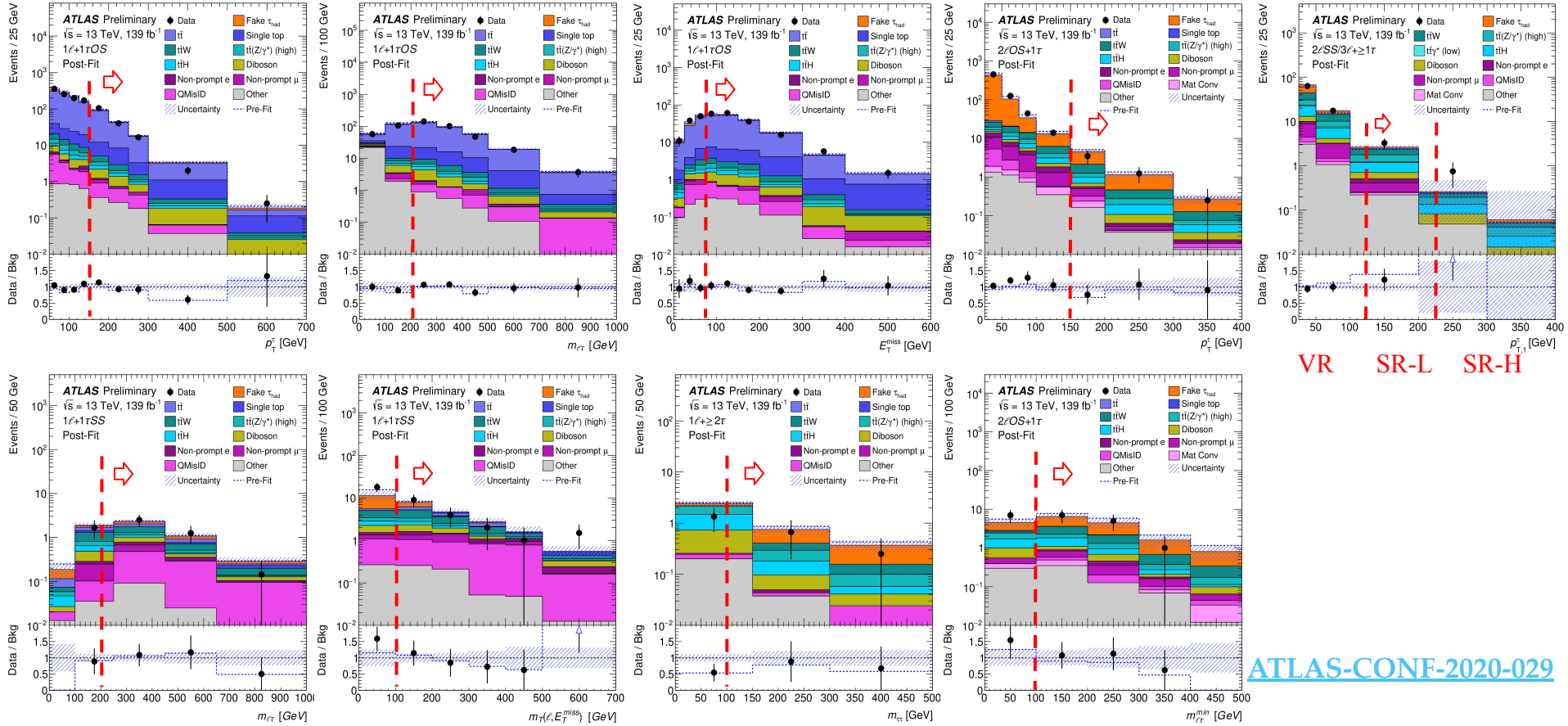
- Similar BG composition in VRs and SRs (since they're kinematically close).
- Adequate modelling in these regions both pre-fit and post-fit.

SR variables before cutting on them



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