# Search for doubly charged Higgs boson production in multi-lepton final states using 139 fb$^{-1}$ of proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

## Type-II Seesaw Mechanism

The recent experimental measurements of neutrino oscillations imply that neutrinos have non-zero masses, which are orders of magnitude below the masses of charged leptons. The type-II seesaw mechanism is one of the simplest known way to account for the smallness of the neutrino masses. It extends the Standard Model of particle physics by introducing a single scalar multiplet $H$.

In left-right symmetric models (LRSM), both left and right chiralities exist. The gauge symmetry of the LR model, namely the $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, is broken due to the right-handed triplet, which transforms according to $H_R = (1, 3, 2)$. If the Lagrangian is invariant under discrete LR symmetry, it must also contain a left-handed triplet $H_L = (3, 1, 2)$.

The neutrino masses are generated through Yukawa couplings between the SM leptonic doublet and the scalar triplets $H_{L,R}$.

Type-II seesaw model triplet:

$$H_{L,R} = (H^0, H^+, H^{++})_{L,R}$$

Doubly charged Higgs

## Process & Signature

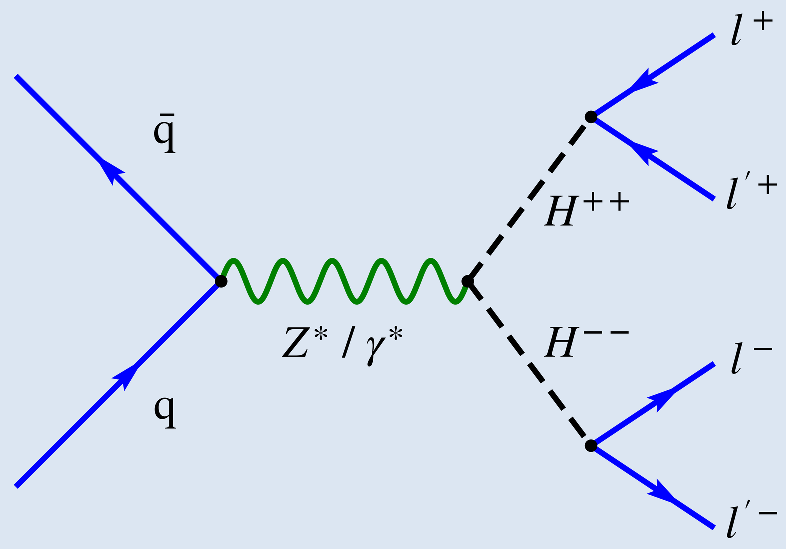
The dominant production mechanism of the doubly charged Higgs (DCH) boson is the Drell-Yan mechanism:

$$pp \to Z/\gamma^* \to H^{++}H^{--}\,.$$

The DCH can decay either into a same-charge $WW$ pair, a $\ell\ell$ pair, or a $H^{\pm}W^{\pm}$, depending on the vacuum expectation value of the left-right spontaneous symmetry breaking $v_{\Delta}$.

This search focuses on small $v_{\Delta}$ values, where only decays into a pair of same-charge leptons, irrespective of flavour combination, are allowed, $H^{\pm\pm} \to \ell^{\pm}\ell'^{\pm}$.

Lepton Flavour Violation (LFV) is allowed by the model.




The final states of the potential signal events contain prompt, isolated, and highly energetic lepton pairs with the same electric charge. Two-lepton, three-lepton, and four-lepton final states that include electrons or muons are considered.

Branching fractions of decays into all possible combinations of standard model leptons are considered equal:

$$\mathcal{B}(H^{\pm\pm} \to \ell^{\pm}\ell'^{\pm}) = 1/6,$$

where $\ell, \ell' = e, \mu, \tau$.

The search is broad, as the DCH can be interpreted in a few more models.

## Analysis Strategy

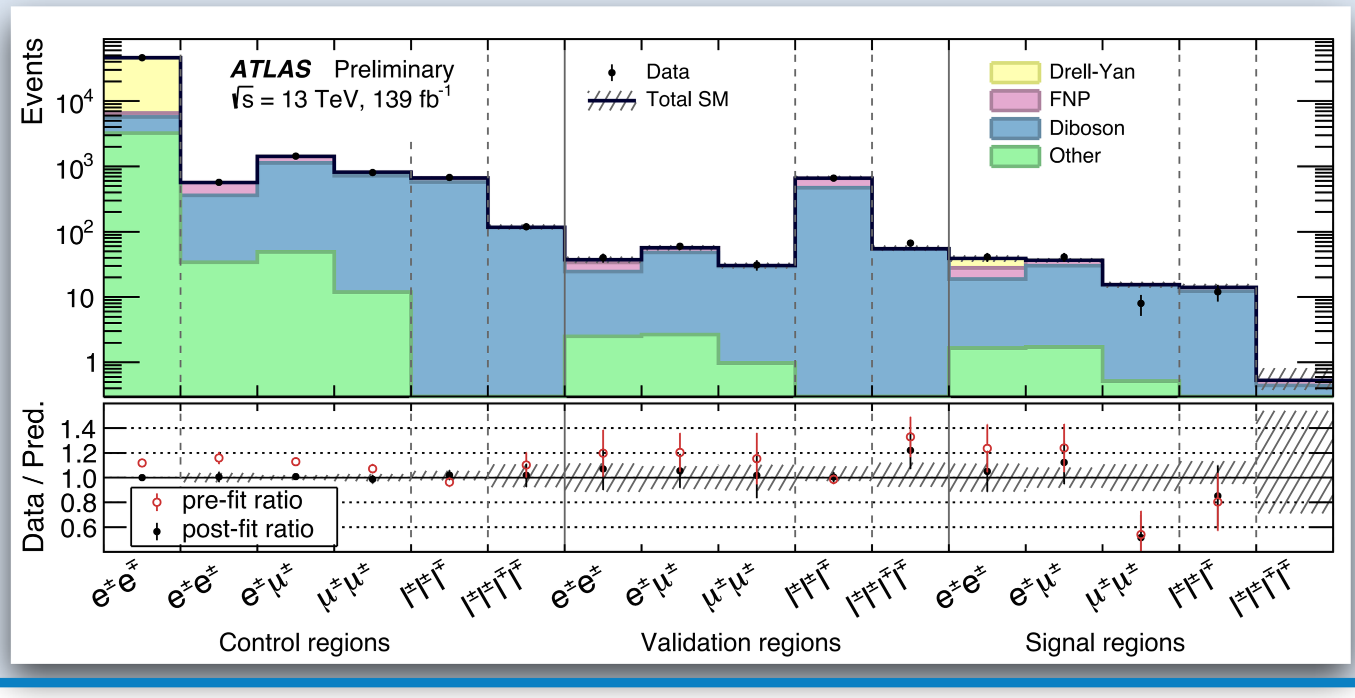
The normalisation factors of the dominant backgrounds, Drell-Yan and diboson processes, are extracted from the final binned maximum-likelihood fit of the $m(\ell^{\pm}, \ell^{\pm})_{lead.}$ distribution in all control and signal regions.

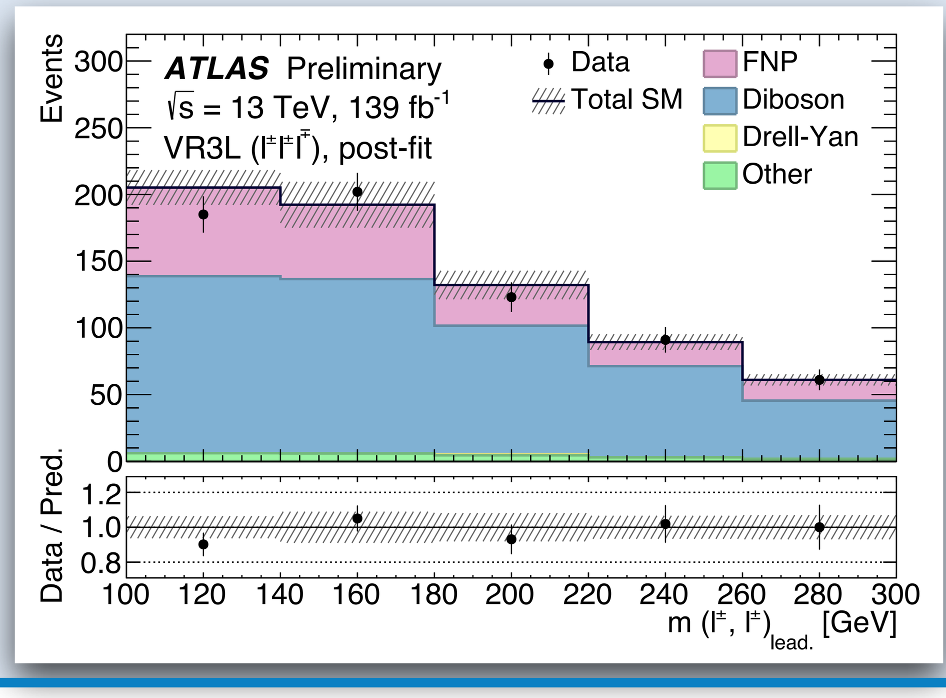
Combination of five signal regions:

- SR2L: $e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$,
- SR3L: $\ell^{\pm}\ell^{\pm}\ell^{\mp}$,
- SR4L: $\ell^{+}\ell^{+}\ell^{-}\ell^{-}$.

The Standard Model background is strongly suppressed by the unique multilepton final state signature.

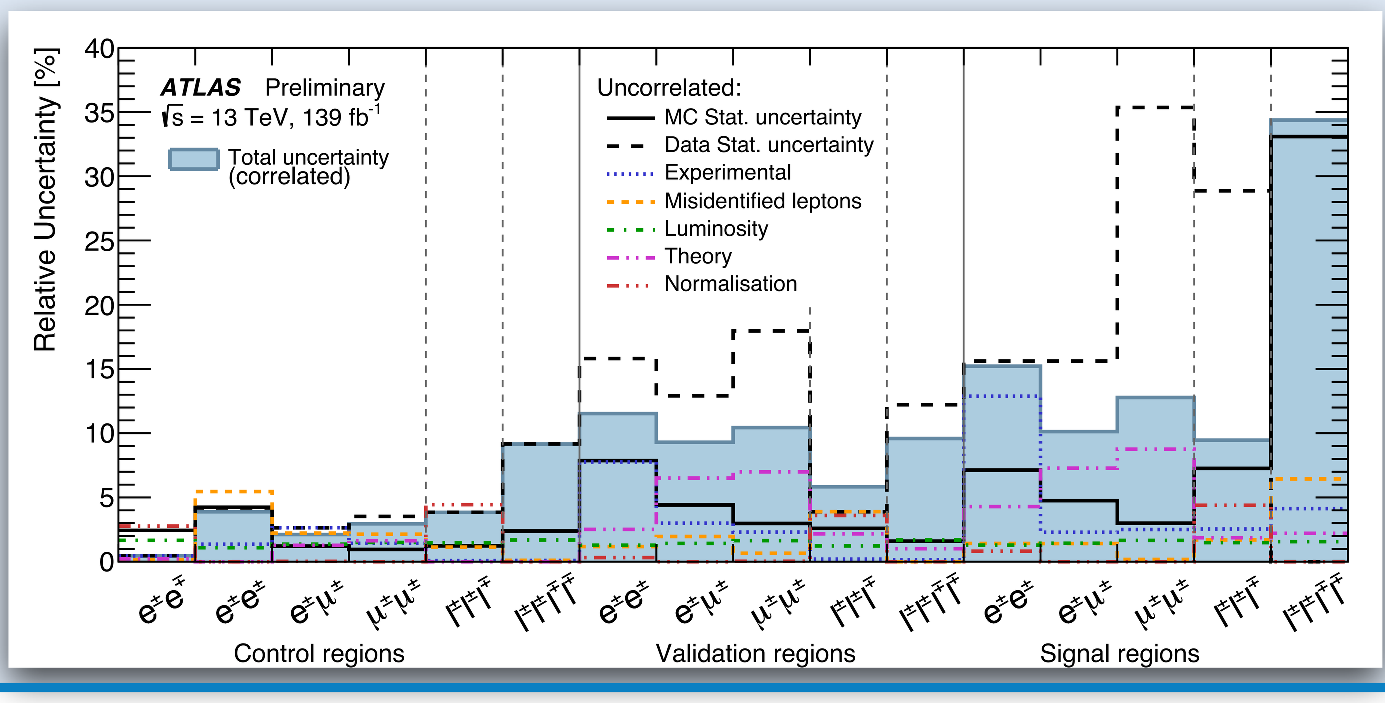
No excess observed, good agreement between data and background in all regions.




## Systematic Uncertainties

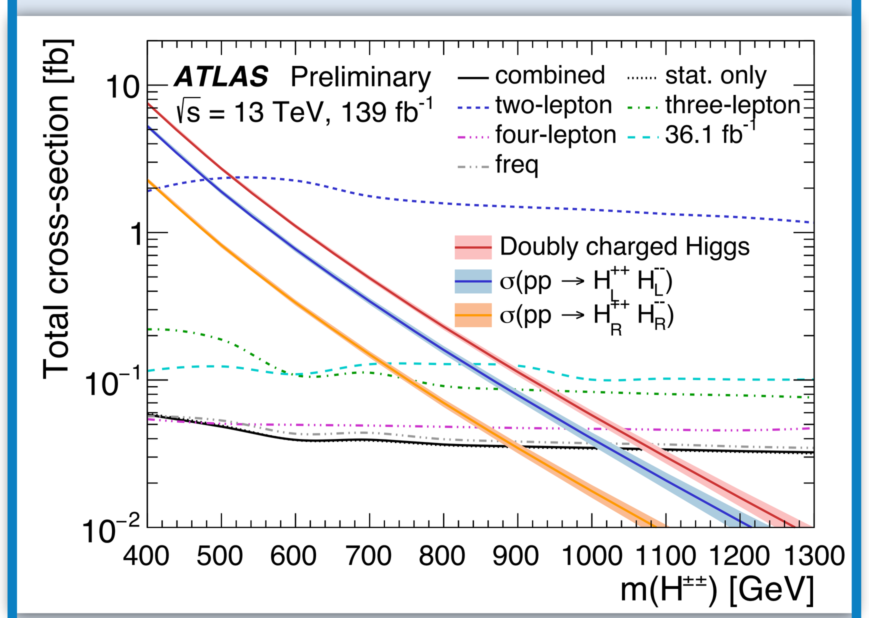
- The relative uncertainty in the total background yield: up to 35%, individual uncertainties treated as correlated across the regions.
- Theoretical: PDF set, QCD scale, $\alpha_S$, parton shower and hadronisation uncertainties.
- Experimental: lepton reconstruction, ID, isolation, triggers, and jet calibration.
- Luminosity: < 2% for the full ATLAS Run 2 period.
- Fake/non-prompt (FNP) leptons: varying selection requirements, stat. uncertainty.



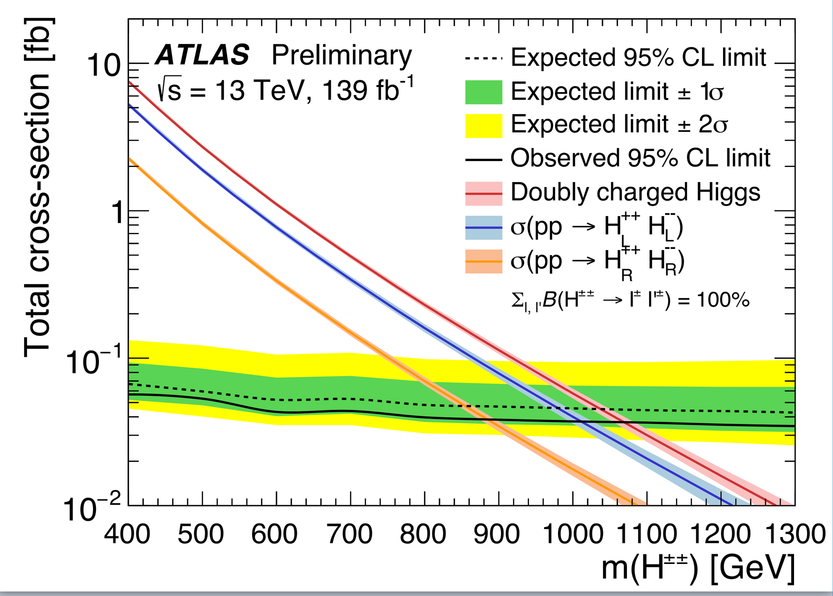

## Exclusion Limits

The search is statistically limited with no events observed in the four-lepton signal region (less than one event expected from simulation), SR4L, which is also the most sensitive one and completely drives the final result.

Observed lower mass limits vary between 520 GeV and 1030 GeV, depending on the lepton multiplicity channel.



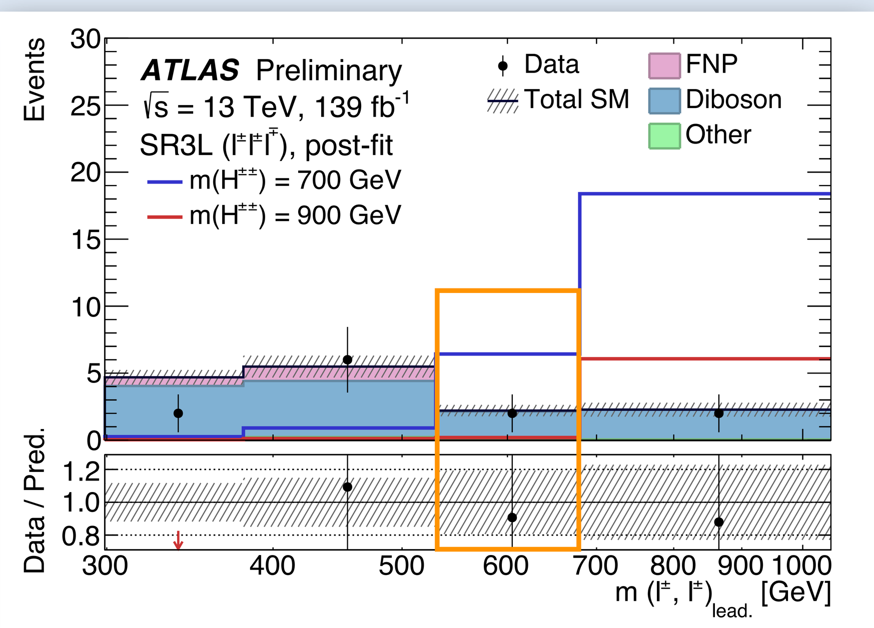

The combined observed limit on the doubly charged Higgs mass at a 95% confidence level is 1080 GeV (1040 GeV expected).

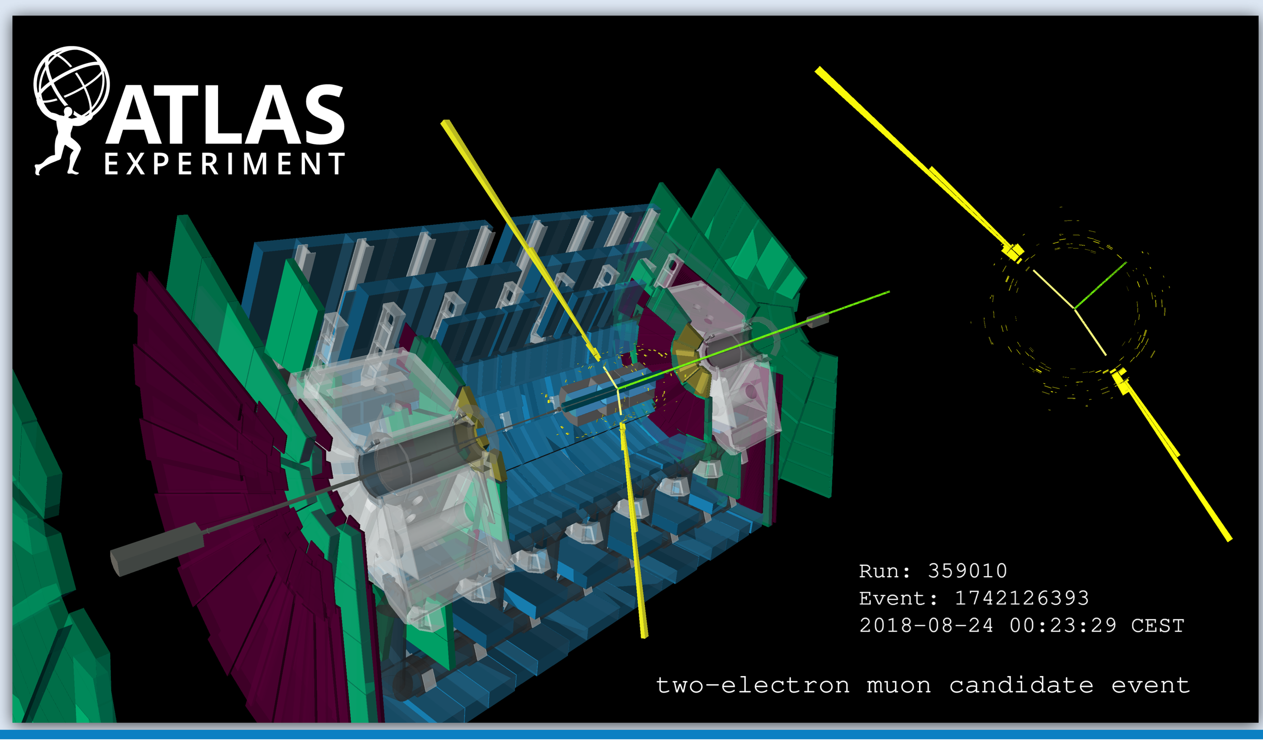



## Signal Candidate Event

A clean, high energy three-lepton signal candidate event in the two-electron muon channel ($e^+e^-\mu^-$) with a high invariant mass of 1257 GeV.

The back-to-back electrons have a $p_T$ of 517 GeV ($e^+$) and 306 GeV ($e^-$), while the muon exits very close to the beam-line and thus has a lower $p_T$ = 82 GeV.





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