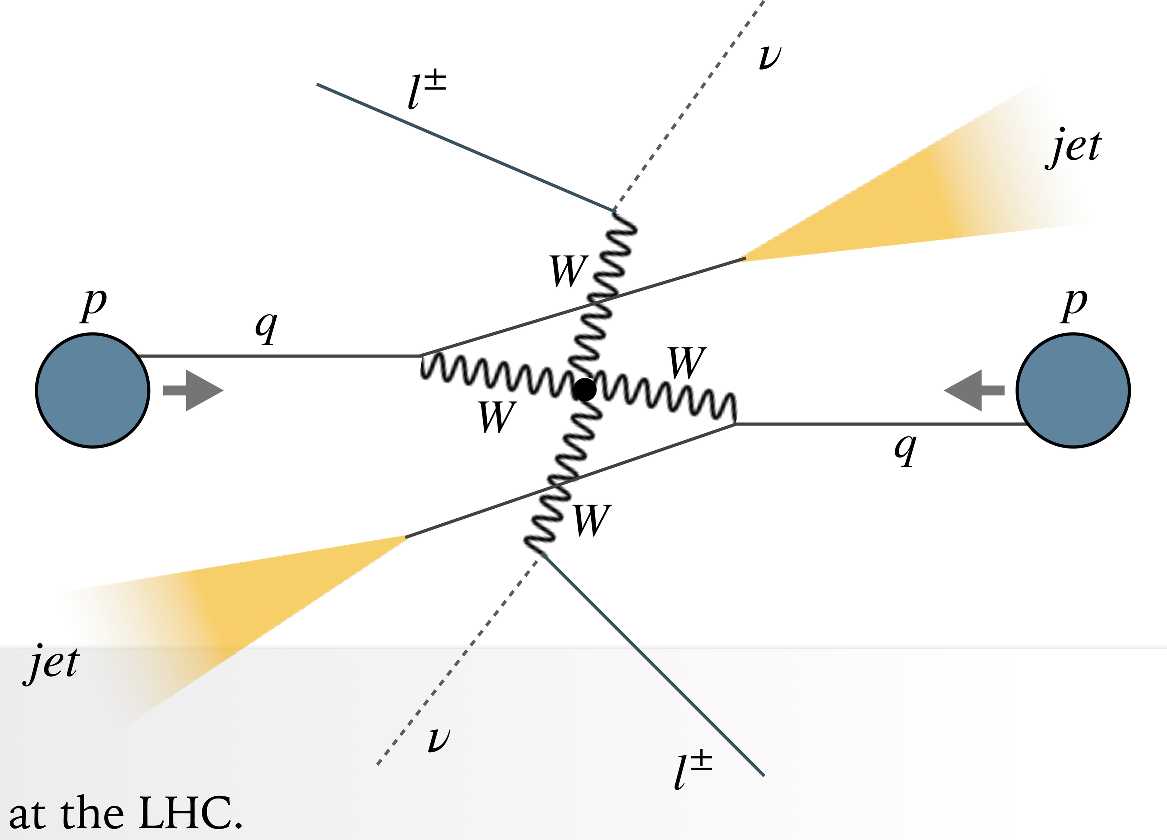
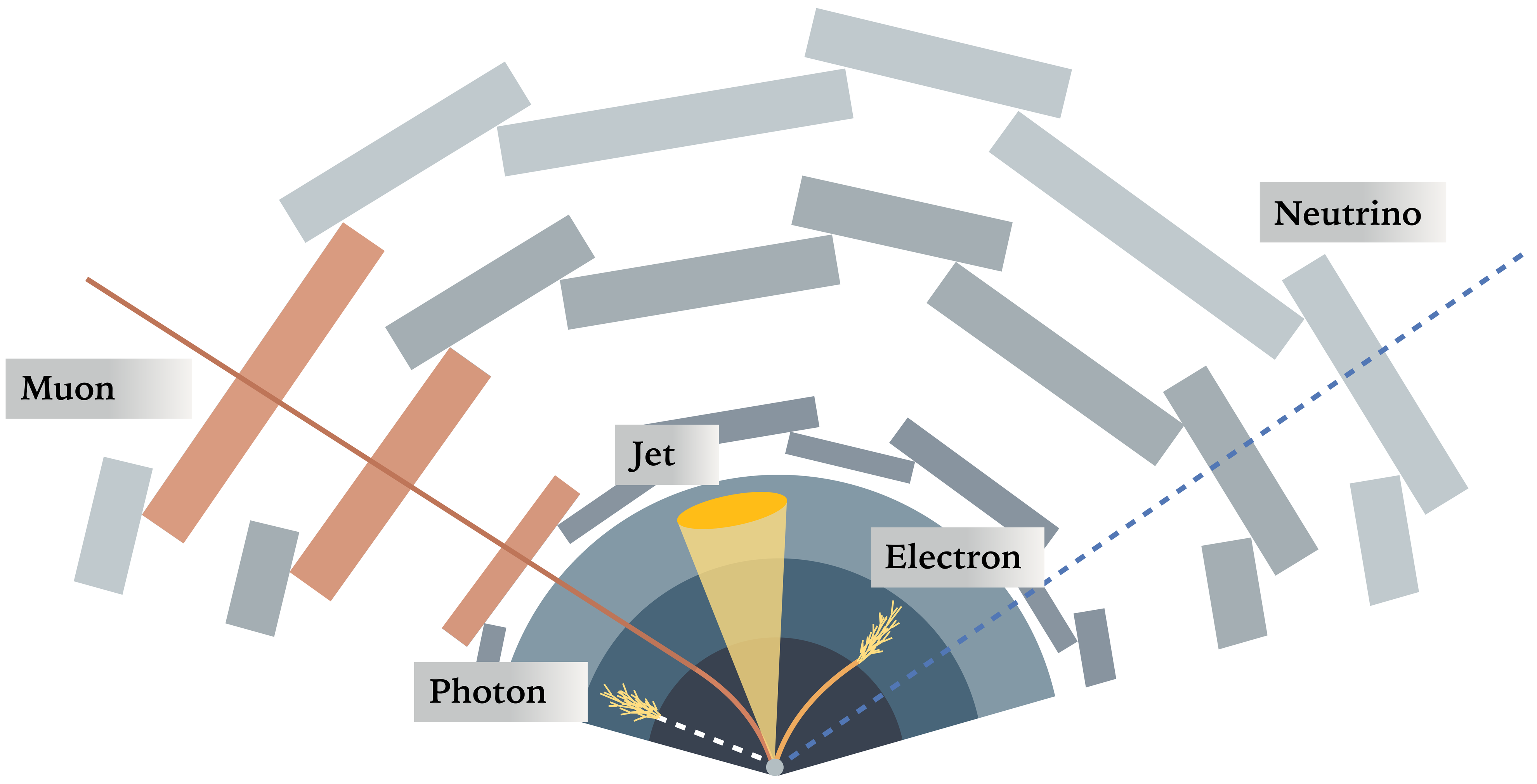
## Vector Boson Scattering

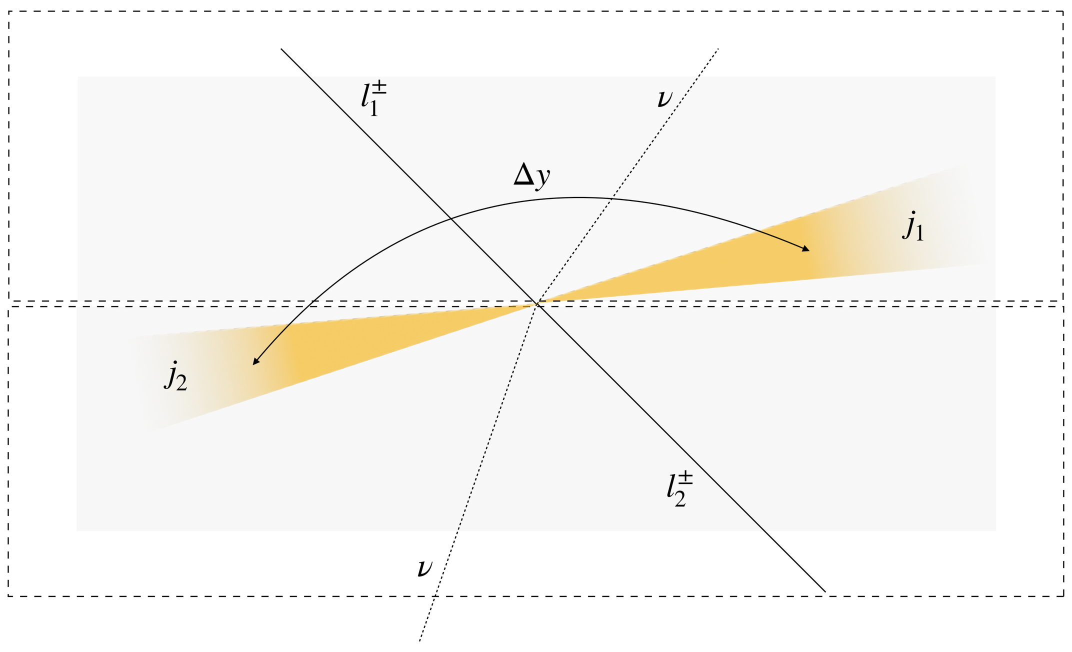
- Vector boson scattering (VBS) is one of the prominent phenomena at the LHC to probe the electroweak sector of the Standard Model.
- Tests the electroweak symmetry breaking mechanism with Higgs boson regularizing the VBS amplitude.
- Tree level sensitivity to quartic gauge couplings (QGCs).




## W±W±jj Production

- Very rare production at the LHC.
- Largest electroweak to strong production ratio among other *VV* combinations.
- Final state with two same-sign leptons, two forward jets, and neutrinos identified as missing transverse energy.
- Two jets with large invariant mass and rapidity separation tag VBS events.

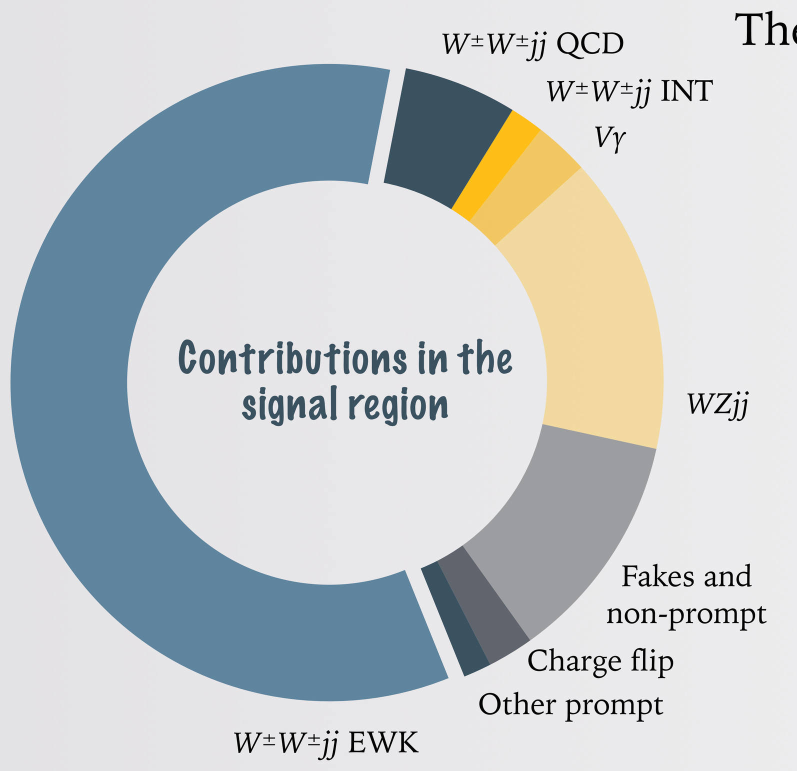



# Electroweak W±W±jj Production in ATLAS

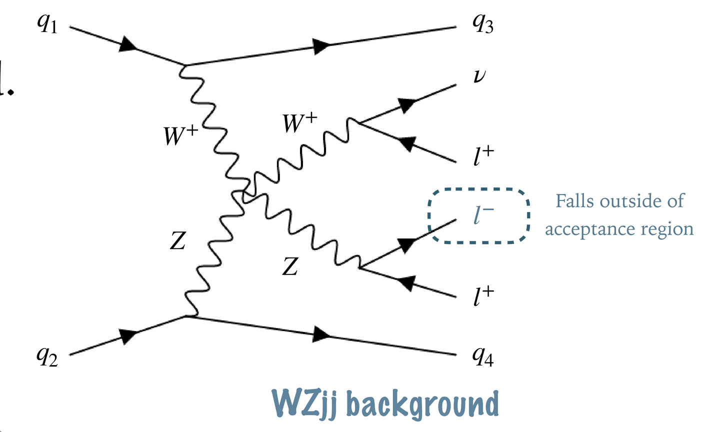
## A golden channel of vector boson scattering


Shalu Solomon | Brandeis University
On behalf of the ATLAS Collaboration

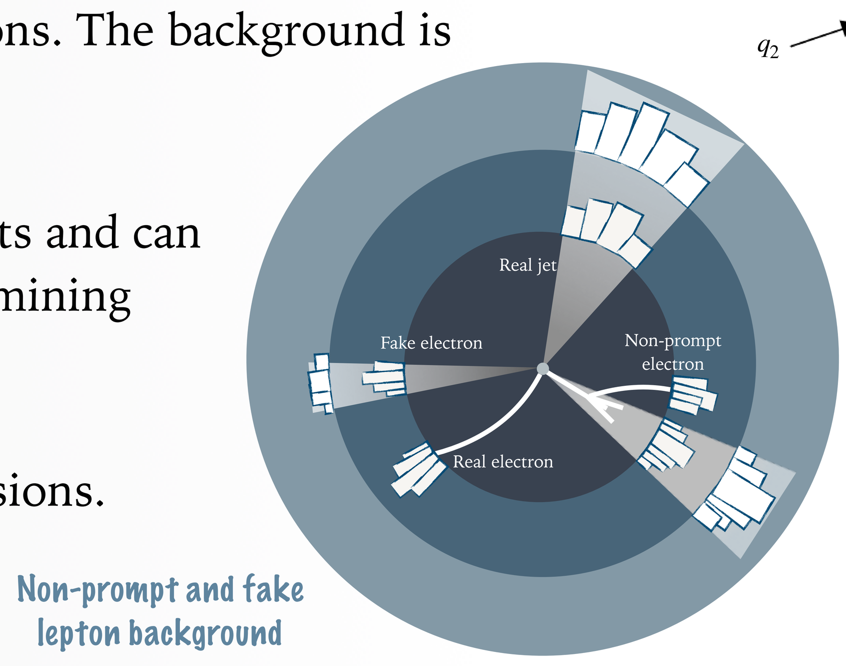

## Major Backgrounds

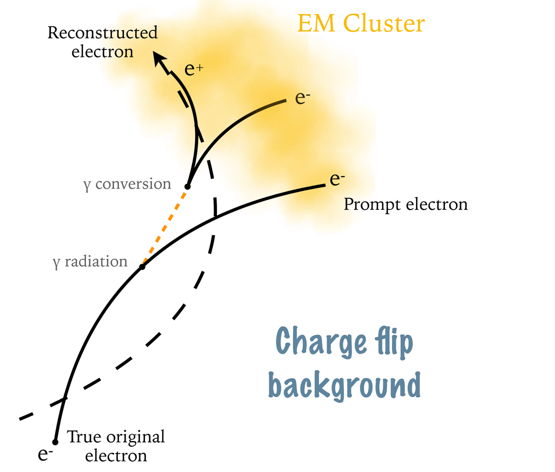



- *WZjj* process where one of the leptons falls outside of the detector acceptance is the dominant background. The background is modelled using Monte Carlo simulation and is validated in a three lepton region.




- Non-prompt leptons correspond to leptons with a hadronic origin but wrongly identified as prompt leptons. Fake leptons are jets wrongly identified as leptons. The background is suppressed by applying a b-jet veto and is derived from data.
- Charge flip affects mainly electrons due to Bremsstrahlung effects and can also occur in high $p_T$ tracks when there is an ambiguity in determining the track curvature.
- $V\gamma$ background enters electron channels through photon conversions.



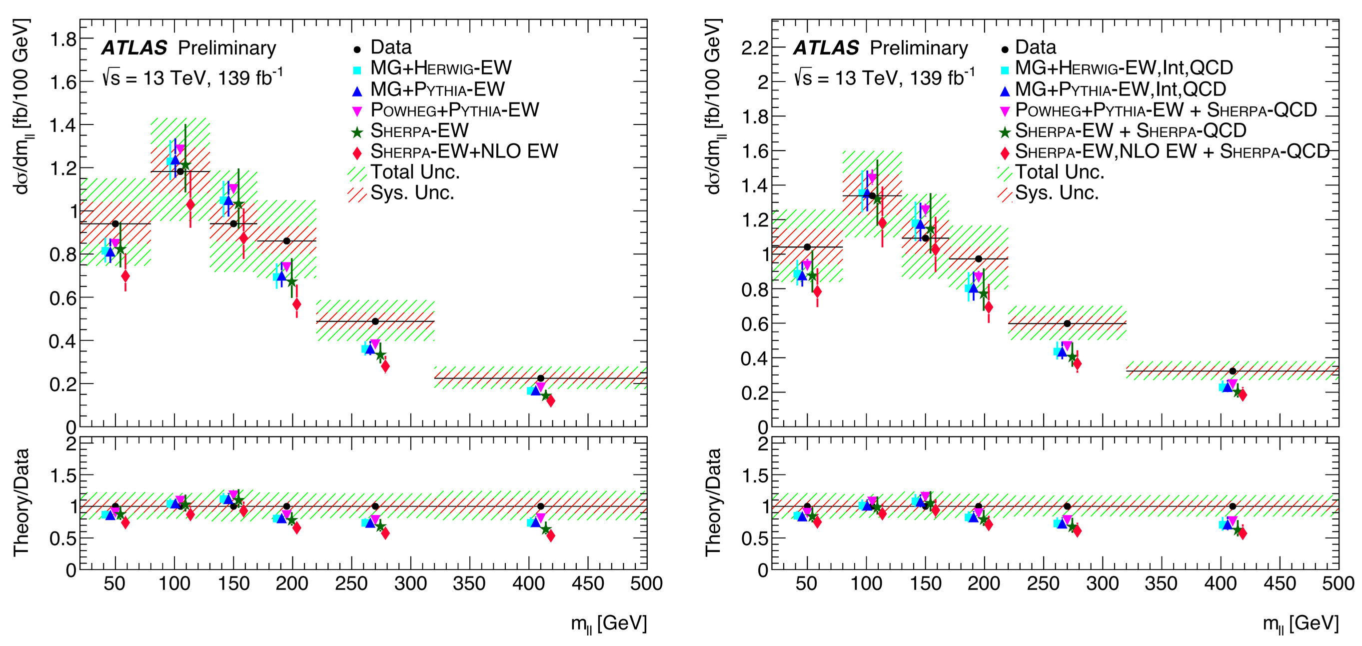

- All the other backgrounds such as top, triboson, etc., have only small contributions.

## Cross-Section Measurement

- A profile likelihood fit is performed to obtain background yields and uncertainties that maximize the likelihood with the observed data. Normalization of signal and *WZjj* background are kept freely floating.
- The measured physics objects do not reflect the kinematics of the underlying true particles due to the detector inefficiencies and limited resolution.

| Description | $\sigma_{\text{fid}}^{\text{EW}}$, fb | $\sigma_{\text{fid}}^{\text{EW+Int+QCD}}$, fb |
|---|---|---|
| Measured cross section | $2.88 \pm 0.21\,(\text{stat.}) \pm 0.19\,(\text{syst.})$ | $3.35 \pm 0.22\,(\text{stat.}) \pm 0.20\,(\text{syst.})$ |
| MG_aMC@NLO+Herwig | $2.53 \pm 0.04\,(\text{PDF}) \pm^{0.22}_{0.19}\,(\text{scale})$ | $2.93 \pm 0.05\,(\text{PDF}) \pm^{0.34}_{0.27}\,(\text{scale})$ |
| MG_aMC@NLO+Pythia | $2.55 \pm 0.04\,(\text{PDF}) \pm^{0.22}_{0.19}\,(\text{scale})$ | $2.94 \pm 0.05\,(\text{PDF}) \pm^{0.33}_{0.27}\,(\text{scale})$ |
| Sherpa | $2.44 \pm 0.03\,(\text{PDF}) \pm^{0.40}_{0.27}\,(\text{scale})$ | $2.80 \pm 0.03\,(\text{PDF}) \pm^{0.53}_{0.36}\,(\text{scale})$ |
| Powheg Box +Pythia | 2.67 | – |

- The detector effects are stripped off from the observed events through unfolding.
- Unfolded cross-section is our best understanding of the underlying true cross-section in data.

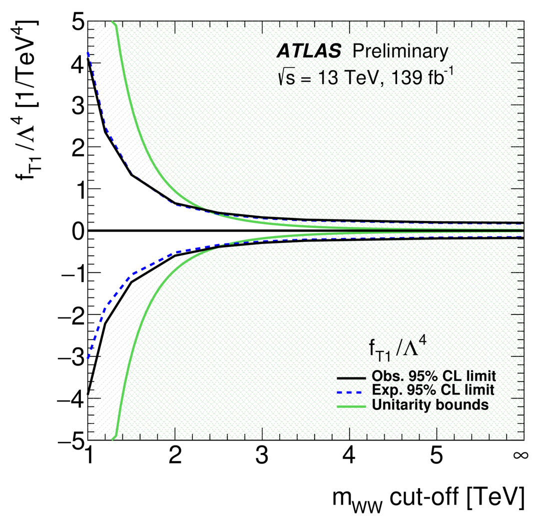



- Cross-sections are extracted for electroweak and inclusive production of $W^{\pm}W^{\pm}jj$, and the results agree with Standard Model predictions.

## Search for aQGC

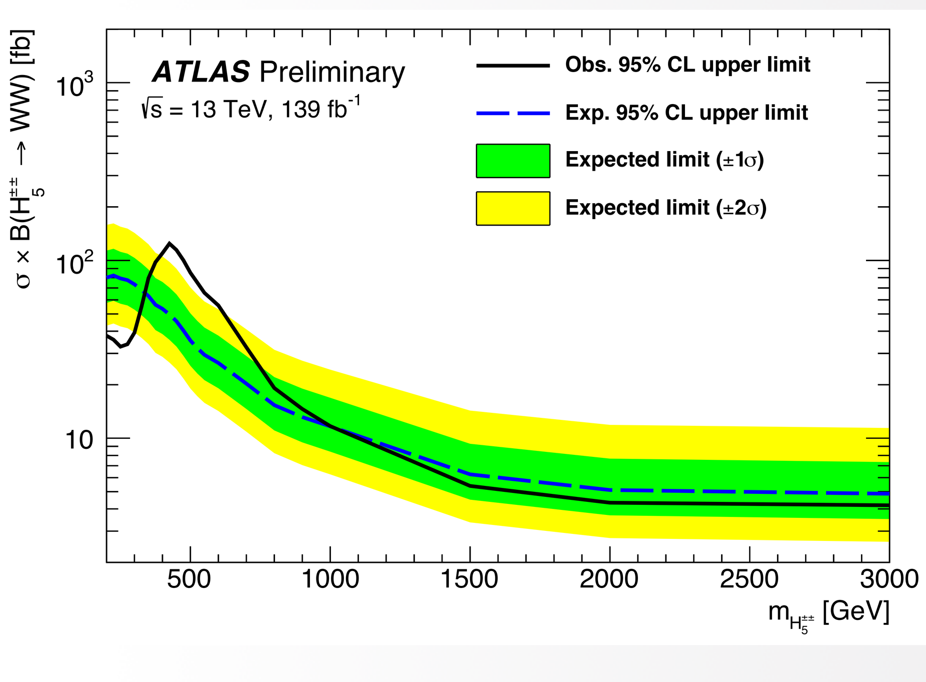
| Coefficient | Type | No unitarisation cut-off [TeV$^{-4}$] | Lower and upper limit at the respective unitarity bound [TeV$^{-4}$] |
|---|---|---|---|
| $f_{M0}/\Lambda^4$ | exp. | [-3.9, 3.8] | -64 at 0.9 TeV, 40 at 1.0 TeV |
| | obs. | [-4.1, 4.1] | -140 at 0.7 TeV, 117 at 0.8 TeV |
| $f_{M1}/\Lambda^4$ | exp. | [-6.3, 6.6] | -25.5 at 1.6 TeV, 31 at 1.5 TeV |
| | obs. | [-6.8, 7.0] | -45 at 1.4 TeV, 54 at 1.3 TeV |
| $f_{M7}/\Lambda^4$ | exp. | [-9.3, 8.8] | -33 at 1.8 TeV, 29.1 at 1.8 TeV |
| | obs. | [-9.8, 9.5] | -39 at 1.7 TeV, 42 at 1.7 TeV |
| $f_{S02}/\Lambda^4$ | exp. | [-5.5, 5.7] | -94 at 0.8 TeV, 122 at 0.7 TeV |
| | obs. | [-5.9, 5.9] | – |
| $f_{S1}/\Lambda^4$ | exp. | [-22.0, 22.5] | – |
| | obs. | [-23.5, 23.6] | – |
| $f_{T0}/\Lambda^4$ | exp. | [-0.34, 0.34] | -3.2 at 1.2 TeV, 4.9 at 1.1 TeV |
| | obs. | [-0.36, 0.36] | -7.4 at 1.0 TeV, 12.4 at 0.9 TeV |
| $f_{T1}/\Lambda^4$ | exp. | [-0.158, 0.174] | -0.32 at 2.6 TeV, 0.44 at 2.4 TeV |
| | obs. | [-0.174, 0.186] | -0.38 at 2.5 TeV, 0.49 at 2.4 TeV |
| $f_{T2}/\Lambda^4$ | exp. | [-0.56, 0.70] | -2.60 at 1.7 TeV, 10.3 at 1.2 TeV |
| | obs. | [-0.63, 0.74] | – |

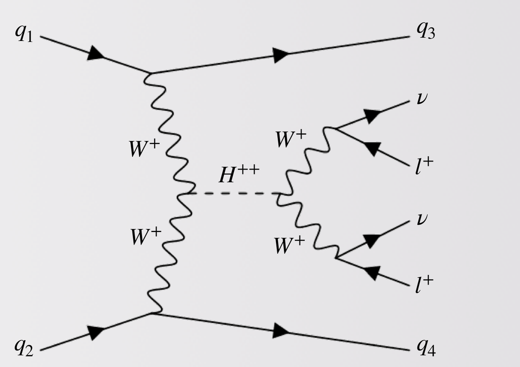
- Results are interpreted within the framework of effective field theory to search for anomalous QGC.
- Limits are set on eight dimension-8 operators.
- Limits on a given Wilson coefficient are derived by setting all others to zero.
- Contributions above a certain energy scale $E_c$ that violate unitarity are removed by restricting $m_{WW} < E_c$.
- Constraints are consistent with zero.




## Search for H±±

- In the context of Georgi-Machacek model, a search for $H^{\pm\pm}$ produced through vector boson fusion is performed.




- Model independent upper limits at 95% CL are extracted on $\sigma(H^{\pm\pm}) \times B(H^{\pm\pm} \to W^{\pm}W^{\pm})$.
- Largest excess is observed for $m_{H_5^{\pm\pm}} = 450$ GeV at $2.5\sigma$.

## Reference


ATLAS Collaboration, ATLAS-CONF-2023-023, *Measurement and interpretation of same-sign W boson pair production in association with two jets in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*


ATLAS EXPERIMENT  Brandeis UNIVERSITY