Exotic Dijet Searches with ATLAS Detector

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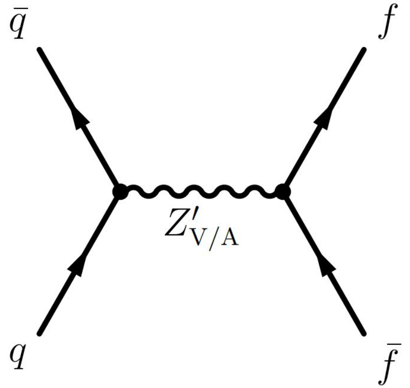
Introduction

Z'-bosons are hypothetical spin-1 vector bosons predicted in many BSM physics models. Direct Z' searches have shown to be an effective way of constraining various BSM models.

ATLAS searches for Z' decays into pairs of charged leptons set strong constraints [arXiv:1903.01400, ATL-PHYS-PUB-2023-018].

However, these searches cannot constraint Z' coupling in case of *leptophobic* scenario, when Z' does not couple to SM leptons.

ATLAS published various searches sensitive to hadronic Z' production based on various analysis strategies: [arXiv:1512.01530, arXiv:1804.03496, arXiv:1901.10917].



The Z'-q-q decay vertex would be responsible for any kind of Z' resonances on LHC.

It also would be necessary for the dark matter self-annihilation cross-section for weakly interacting massive particles.

Low-Mass Region

The straightforward way of hadronic Z' production searches are searches for two decay products of Z' (di-jet searches). Usually such analyses rely on single jet trigger, which limits lowest Z' mass region to be above 1 TeV.

To gain sensitivity to lower Z' masses, the following strategies can be used:

- One can increase statistics by collecting data at higher rate (enabling lower trigger thresholds). Due to bandwidth limitations available for single- and multi-jet triggers one have to record only minimal information. This approach requires trigger modification and referred as a trigger-level analysis.

- A complementary approach used in this talk, relies on the production of high-p_T initial-state-radiation (ISR) such as jet or photon, which recoils against Z'. This approach allows to access lower dijet masses without trigger bias, but requires more sophisticated analysis (for example for tri-jet topology).

Analysis Strategy

Exotics di-jet search for low-mass resonances decaying into two jets and produced in association with a photon or a jet performed in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector using the full Run-2 dataset [arXiv:2403.08547].

- High p_T Initial State Radiation (ISR) either jet or photon:
  recoils against the Z', allows to access low-mass region.
- b-tagging requirements for Z' decay product:
  significantly suppresses background, but makes assumptions on the Z' decay.
- Four channels are studied: $\gamma jj,\ \gamma bb,\ jbb,\ jjj$.
- Resonance mass range of 200 GeV to 650 GeV.
- Dominant backgrounds: multijet and single-photon production.
- Benchmark model is simplified leptophobic Z' axial-vector mediator signal and Gaussian-shaped bumps.

Object Reconstruction

Jets

- anti-k_t algorithm with radius parameter $R = 0.4$.
- calibrated jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$
- tight jet vertex tagger criteria for $p_{\mathrm{T}} < 60$ GeV and $|\eta| < 2.4$ to suppress pile-up

B-tagging

- using the DL1r multivariate algorithm
- 77% b-tag efficiency working point

Photons

- $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$
- tight identification and additional tight isolation requirements to suppress contamination from jets

Photon Channel : γjj, γbb

- two jets and photon with $p_{\mathrm{T}} > 150$ GeV

For the $\boldsymbol{\gamma jj}$ and $\boldsymbol{\gamma bb}$ channels the strongest discrimination variable is found to be an asymmetry:

$$y^* = \frac{|y_1 - y_2|}{2}$$

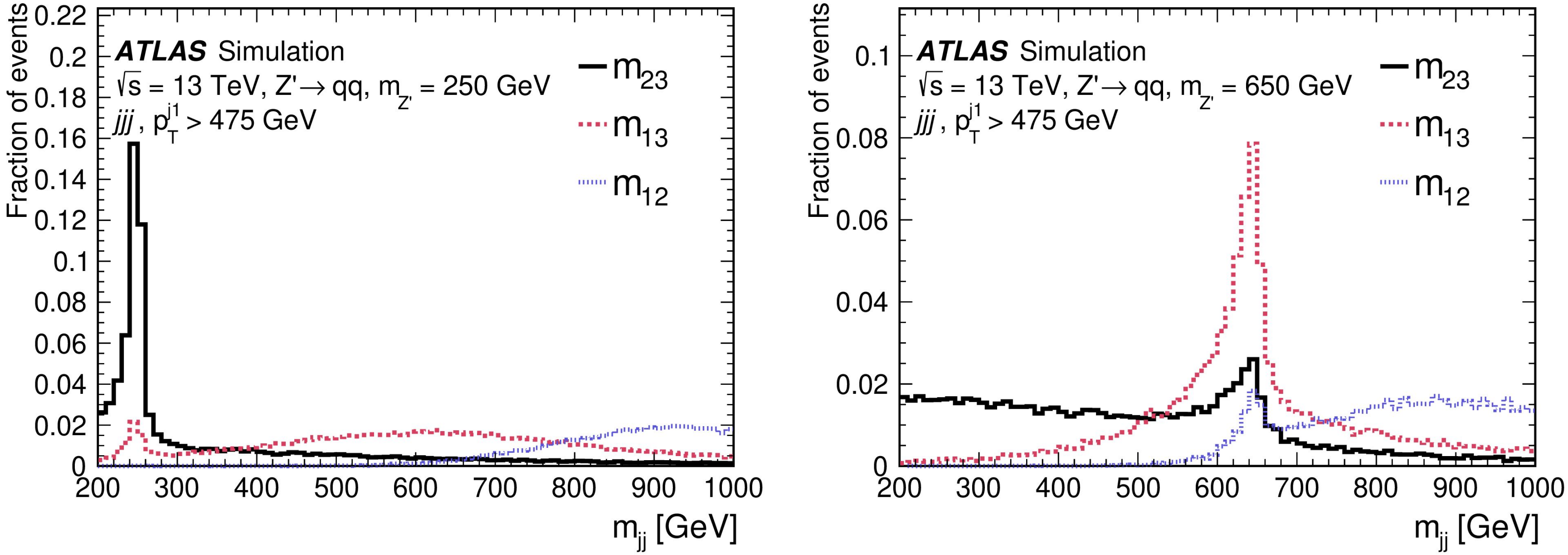
where y_1, y_2 – rapidities of the two selected jets.

- to maximise signal sensitivity $y^* < 0.825$ criteria is applied.
- for $\boldsymbol{\gamma bb}$ in addition two selected jets have to be b-tagged.

Trijet Channel : *jjj*, *jbb*

- three jets with leading jet $p_T > 475$ GeV

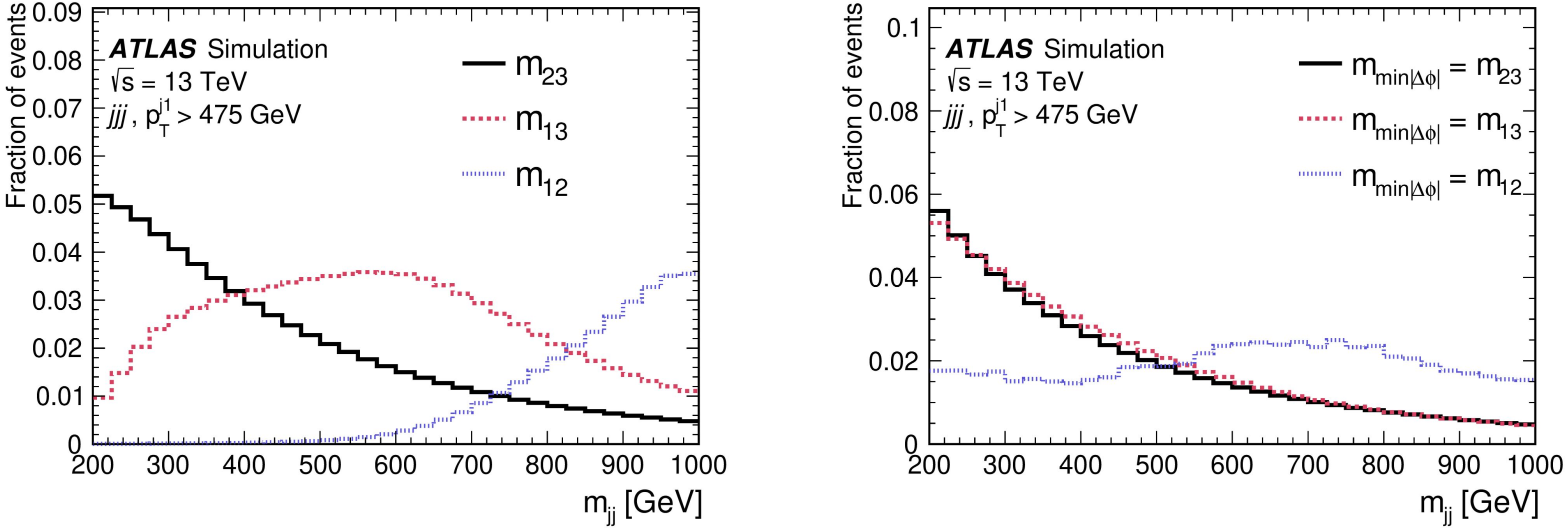
For three jets channel which of two jets combine to create resonance significantly depends on the Z' model:



Trijet Channel : *jjj* , *jbb*

For ***jjj*** channel Z' decay candidates are identified by:

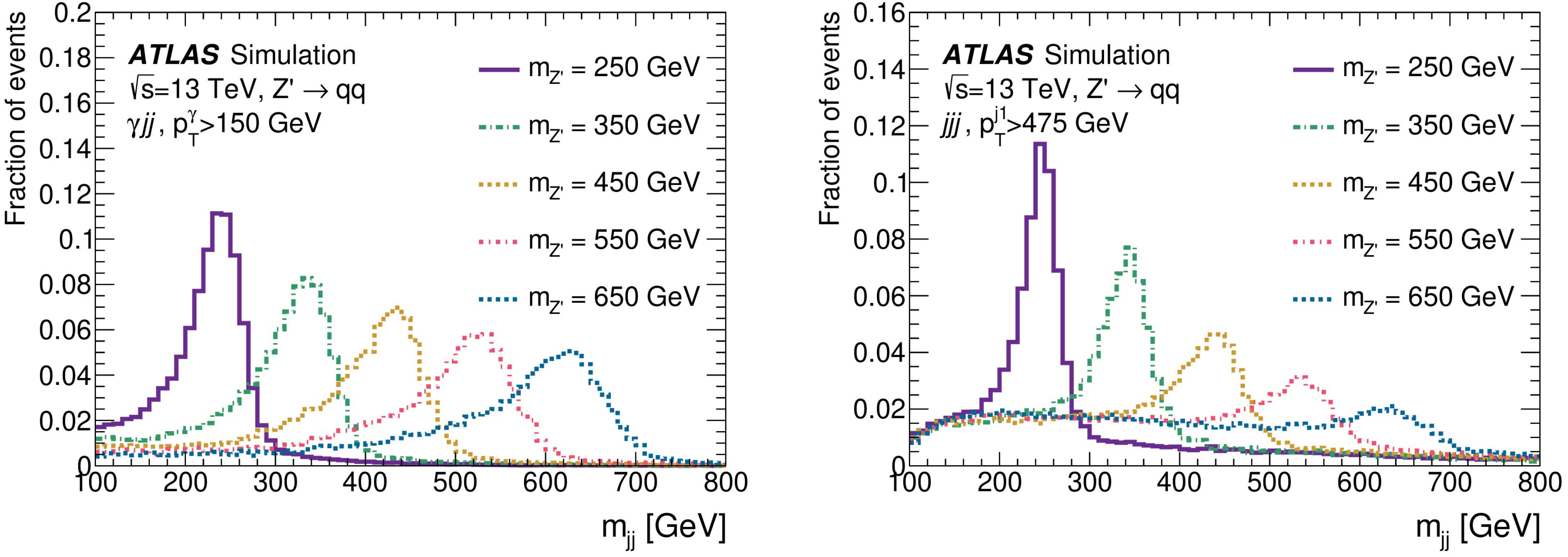
- taking jet pair with the minimum $|\Delta\phi|$
- rejecting the event if such jets correspond to the m_{12} (two p_{T}-leading jets).



- for ***jbb*** : in addition two selected jets (with min $|\Delta\phi|$) have to be b-tagged.

Signal Samples

- Benchmark model: a simplified leptophobic Z' axial-vector mediator signal.



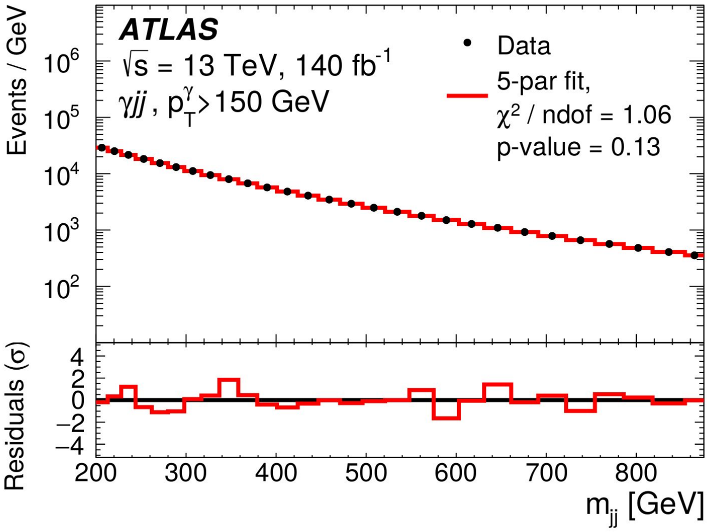
- Gaussian-shaped models with up to 15% of mass width.

Background Estimate

Background is estimated as 5 parametric function to fit m_{jj} distribution.

$$\boxed{f_B(x) = p_1(1-x)^{p_2} x^{p_3+p_4\ln(x)+p_5\ln^2(x)}}+p_6\ln^3(x)$$

$$x = m_{jj}/\sqrt{s}$$



Signal and background events are estimated by binned profile likelihood fit of a signal + background model to the m_{jj} distribution separately for each channel.

$$n_{\text{tot}}(m_{\text{jj}}) = n_S \times f_S(m_{\text{jj}}) + n_B \times f_B(m_{\text{jj}})$$

Signal shape f_S is taken as templates from Z' samples or as Gaussian-shaped signals with 5-15% widths of the signal mean.

Validation Tests

Spurious Signal

- Spurious signal tests performed to check bias of fitting approach to produce fake signal from background samples with no signal. Many pseudo-data distributions are generated from background-only fits to the simulated m_{jj} distribution with a 6-parameter function.
- n_S is determined for each pseudo-data distribution.
- S_{spur} and σ_{spur} is the median value and standard deviation of the n_S.
- Spurious signal requirement: $S_{\text{spur}}/\sigma_{\text{spur}} < 0.5$ for all Z' samples.

Signal Injection

- Tests performed to ensure that fit can extract signal with the expected signal strength.
- Required, that extracted signal is within 0.5 σ of the injected significance.
- Satisfied for all signal templates from Z' samples and all Gaussian-shaped signals with widths up to 15%.

Systematic Uncertainties

The following systematic uncertainties are included:

- **Luminosity:** uncertainty in the combined 2015–2018 integrated luminosity is 0.83%.
- **Jets:** jet energy scale and resolution is about 2–3%.
- **Photons:** identification and isolation efficiencies, energy scale and resolution is ~ 2%.
- **B-tagging:** (77% b-tag efficiency) systematic uncertainty in the b-tagging efficiency is measured using data enriched in ttbar events for jet p_{T} < 400 GeV and extrapolated to higher p_{T} regions. The impact of this uncertainty on the event selection is about 2–3%.
- **Parton Distribution Function:** NNPDF2.3lo PDF set. This uncertainty affects signal samples and ranges from 1–5% across the different channels.
- **Background Modelling:** Systematic uncertainty estimated using spurious signal approach. The spurious signal uncertainty, together with the statistical uncertainty, is one of the leading source of systematic uncertainty.

Background Fit

Fit results for all four channels.

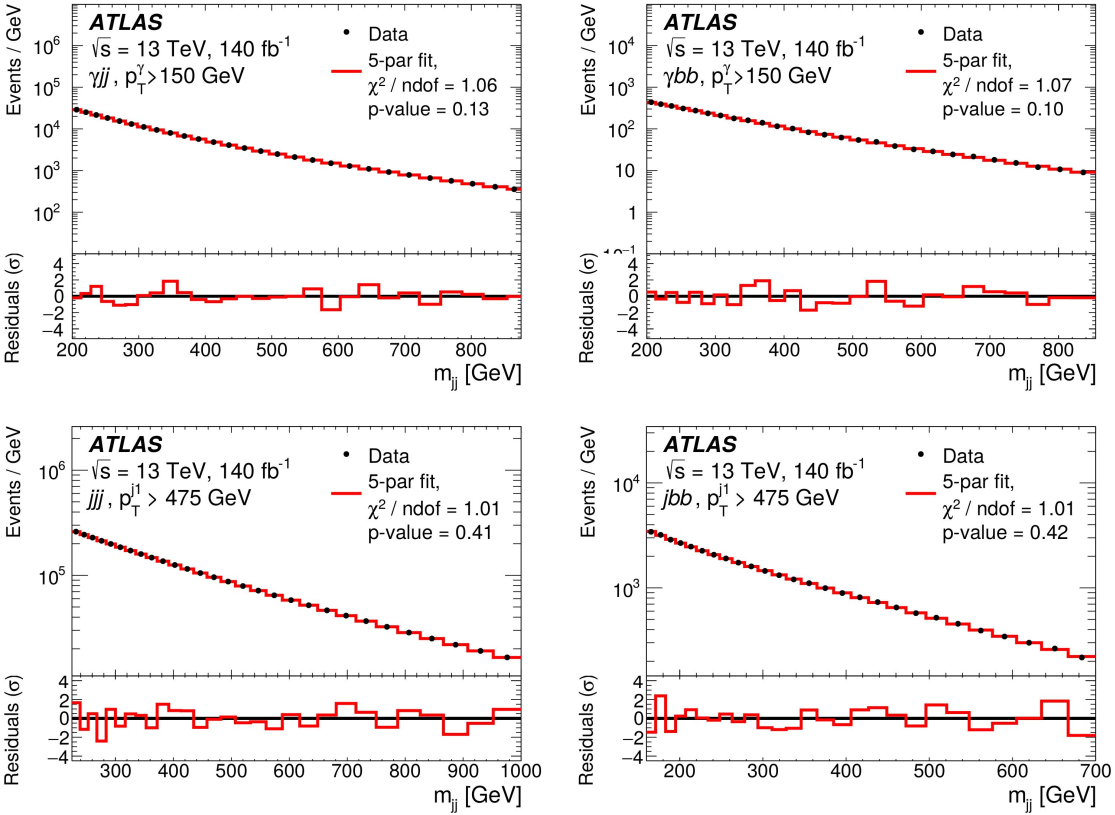
Background is modelled as 5-parameter fit function.

$$f_B(x) = p_1(1-x)^{p_2} x^{p_3+p_4\ln(x)+p_5\ln^2(x)}$$

$$x = m_{jj}/\sqrt{s}$$

Observed m_{jj} distributions are well described by smooth functionals.

arXiv:2403.08547



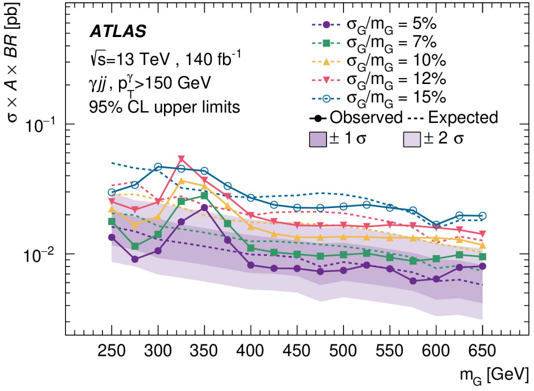
Results : Gaussian-Shaped Model

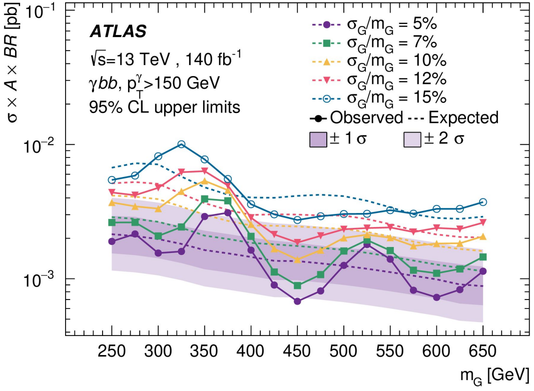
Expected and observed 95% CL upper limits on the product of the cross-section, acceptance and branching ratio (σ × A × *BR*).

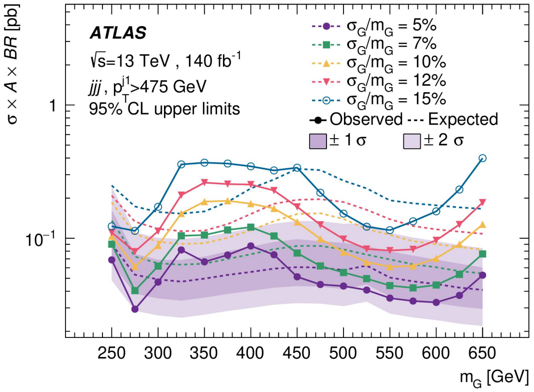
Gaussian-shaped models with: σ_G/m_G = 5%, 7%, 10%, 12%, 15%.

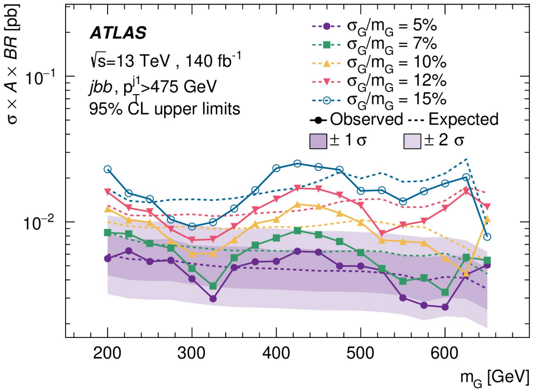
No significant excess of events beyond the Standard Model expectation is observed.

arXiv:2403.08547



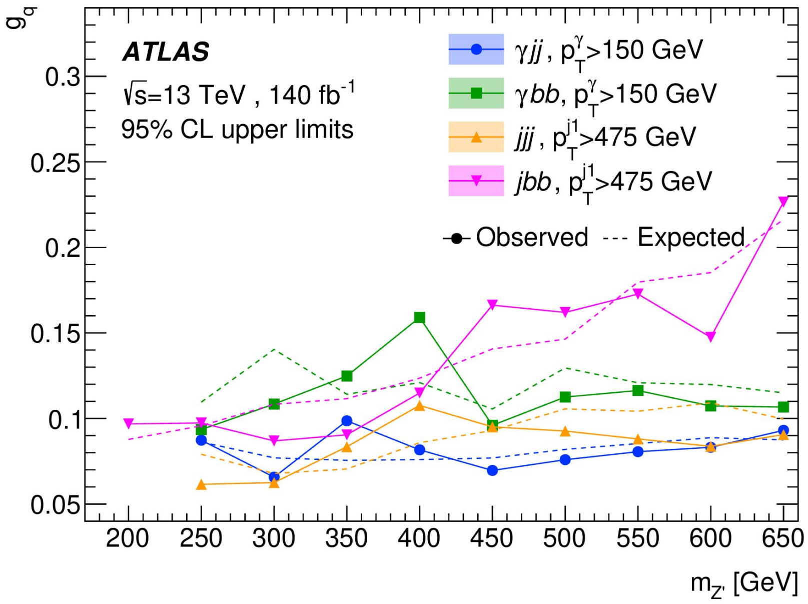


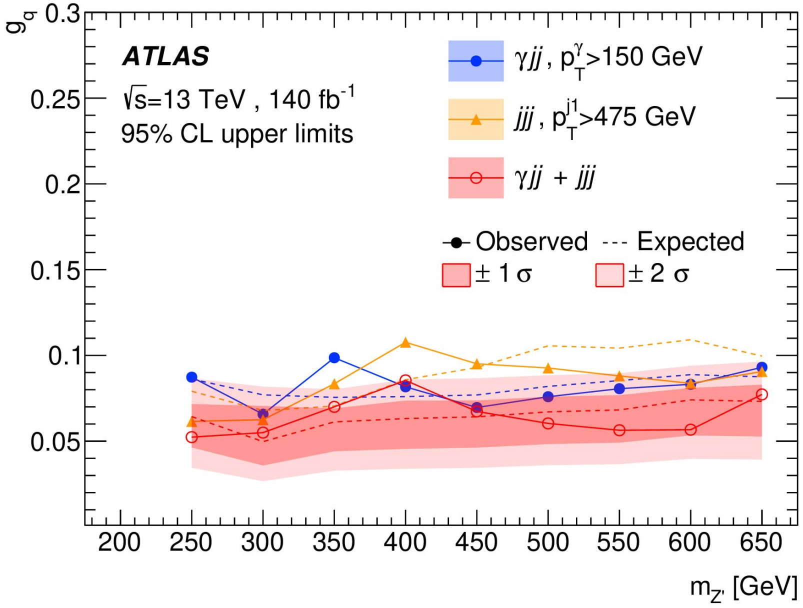




Results : Z' Model

Expected and observed 95% CL upper limits on the g_q coupling as a function of the Z' mass.



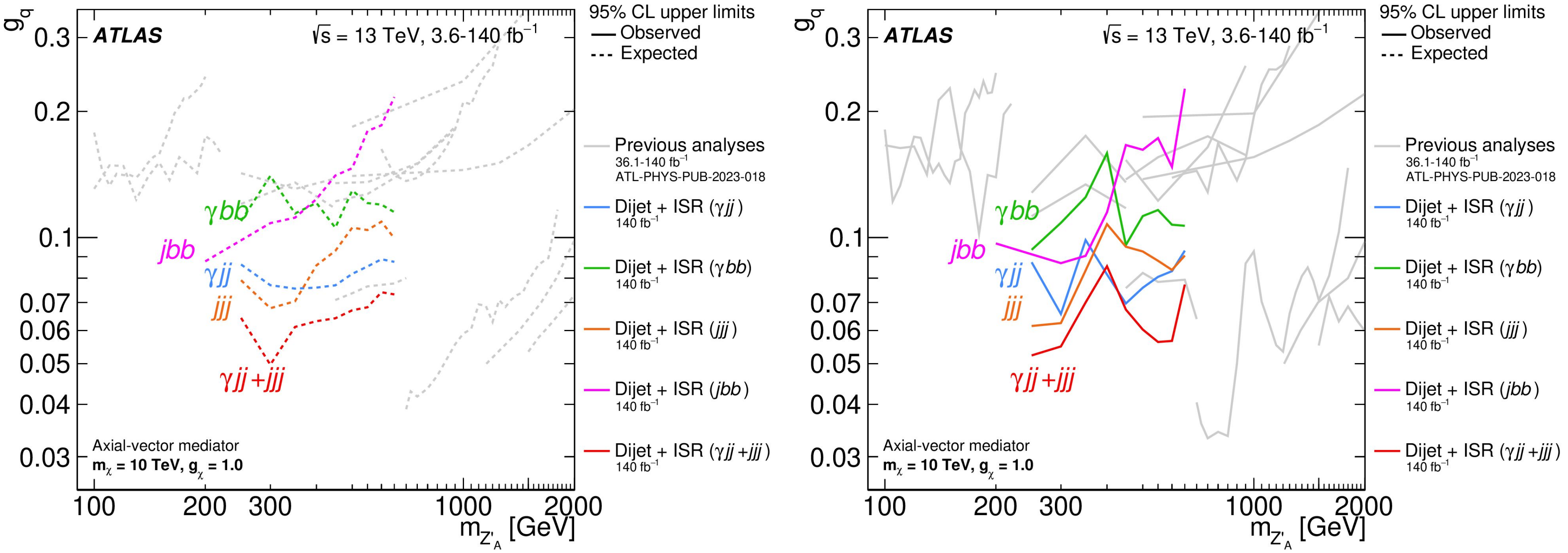


No significant excess of events beyond the Standard Model expectation is observed.

arXiv:2403.08547

Results : Z' Model

Expected (left) and observed (right) upper limits on the g_q coupling as a function of Z' mass. In comparison with the previous ATLAS results, sensitivity in the low mass region has been significantly improved by this search. arXiv:2403.08547



Conclusions

- Dijet resonances with a width up to 15% of the mass produced in association with ISR.
- Searches performed for 140 fb^{-1} of pp collisions recorded by the ATLAS at $\sqrt{s}$ = 13 TeV.
- Expands previous similar searches for full Run-2 dataset and by including ISR jet.
- Considered cases where no flavor requirements applied and
  where both of the decay products are required to be b-tagged.
- For all channels the observed m_{jj} distribution is well-described by a smooth functional fit.
  No significant excess of events beyond the Standard Model expectation is observed.
- Upper limits are set on two models: Z' axial-vector dark-matter mediators and
  Gaussian-shape signal contributions for resonant masses between 200–650 GeV.
- Search improves the limits on the Z'-q-q coupling g_q by up to 50%.
  The most stringent limits on g_q set by the γjj channel for higher Z' masses and
  by the jjj channel for lower Z' masses.
- Combination of jjj + γjj channels allowed to set limits on g_q down to 0.05–0.07.

Thank you for your attention!