

MICHIGAN STATE
UNIVERSITY

Searches for s-channel production of new resonances in ATLAS

On behalf of the ATLAS Collaboration

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Blois Conference.

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Introduction - Starting at the End

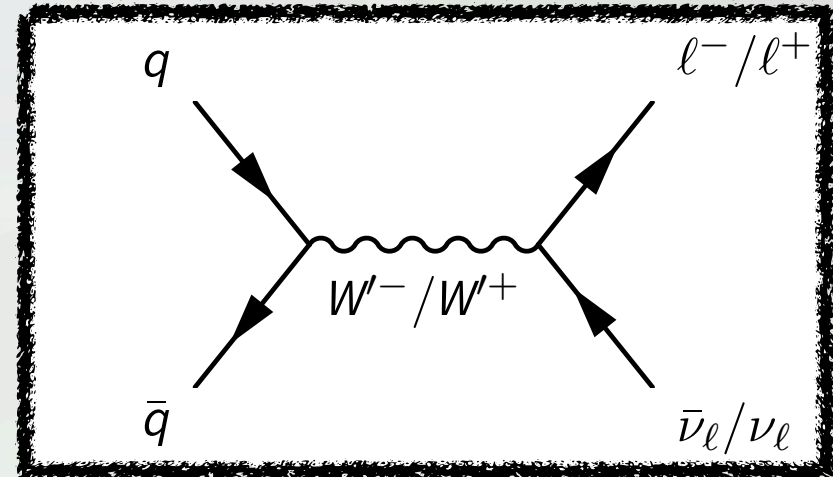
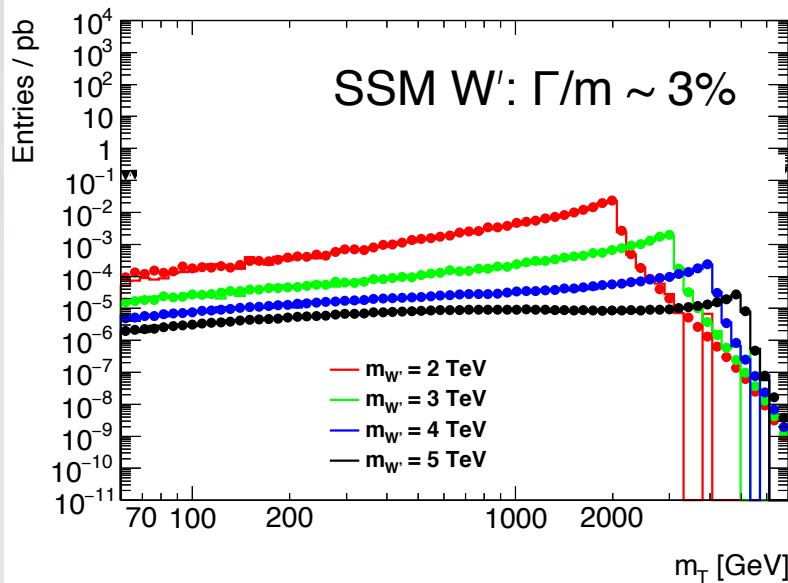
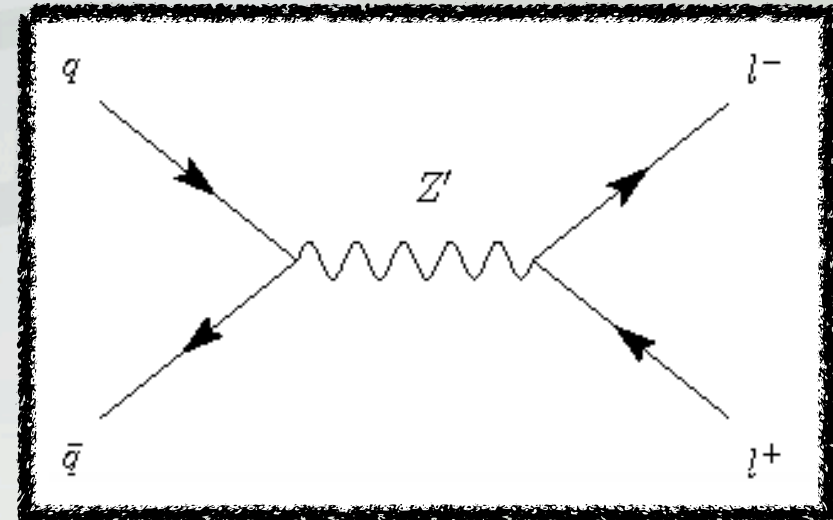
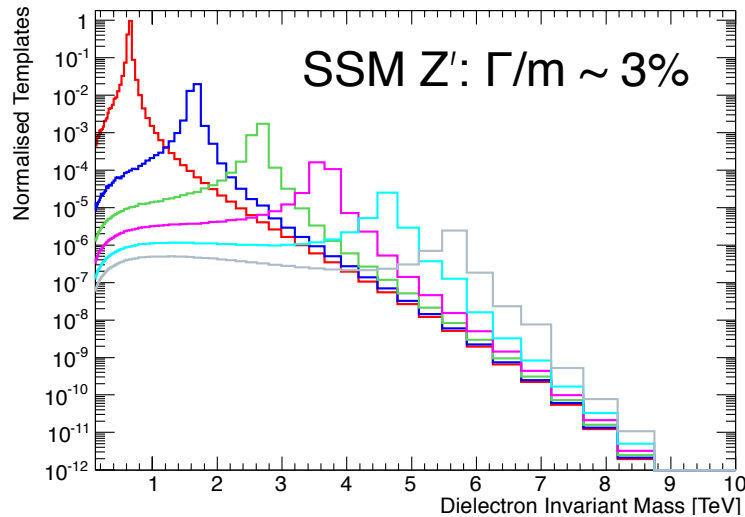
- We have not discovered anything - **YET** - and you all know that...
- Still useful to go through our latest results, see any tantalising hints.



- But I also want to do something different in this talk...
- Take a look at the **bigger picture** , and where we should go **next** .

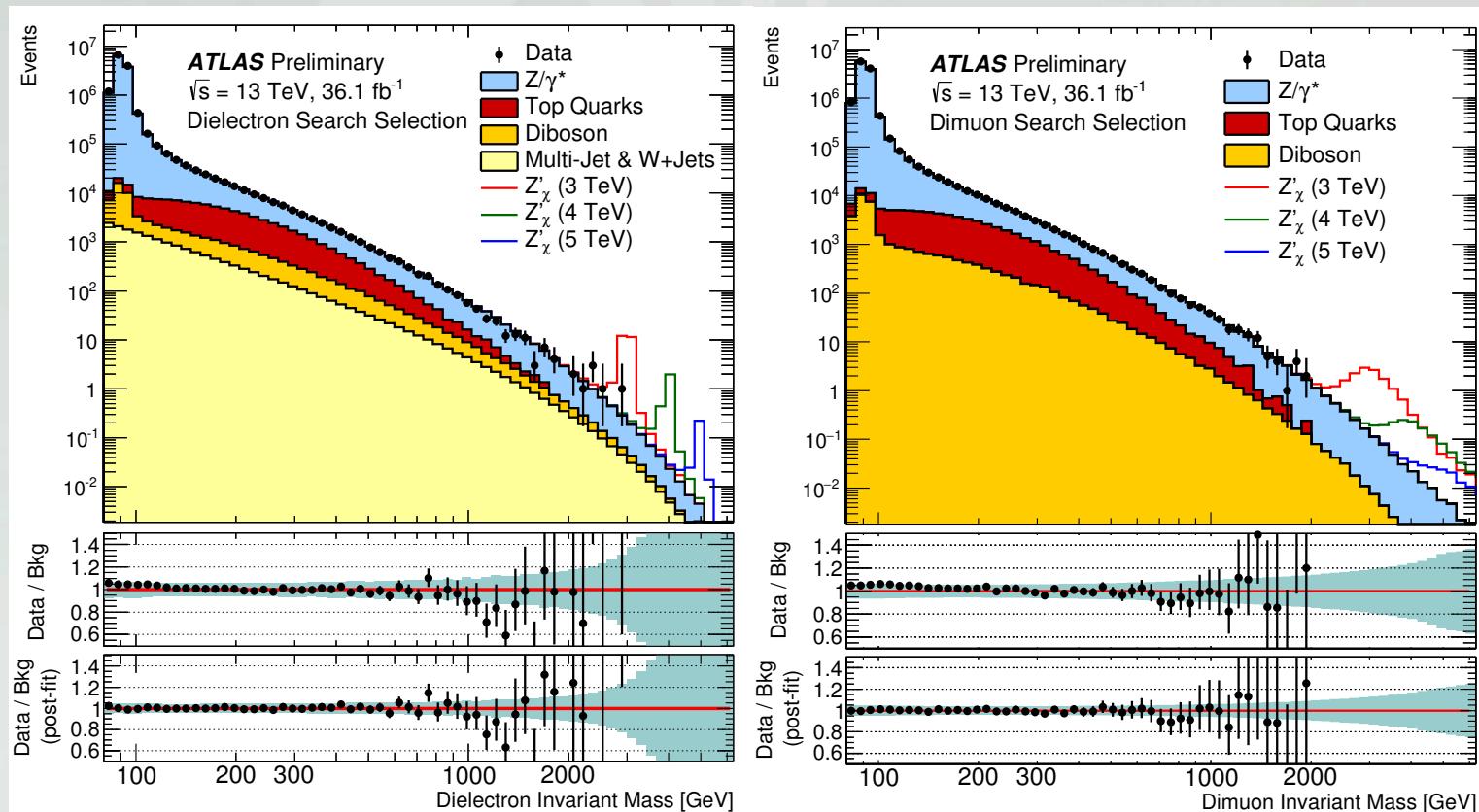
Theoretical Motivation: Z'/W' Gauge Bosons

Many theories Beyond the Standard Model (BSM) predict new phenomena which give rise to leptonic final states, such as **narrow resonances**.



Dilepton Signatures: $ee/\mu\mu$

- Benefits from a **relatively clean and small background** (Drell-Yan dominates).
- The **fake background** (any event which contains at least one jet faking a lepton), was estimated using a **data-driven method**.
- Studied the effect of varying resonance **width and interference** on the sensitivity.



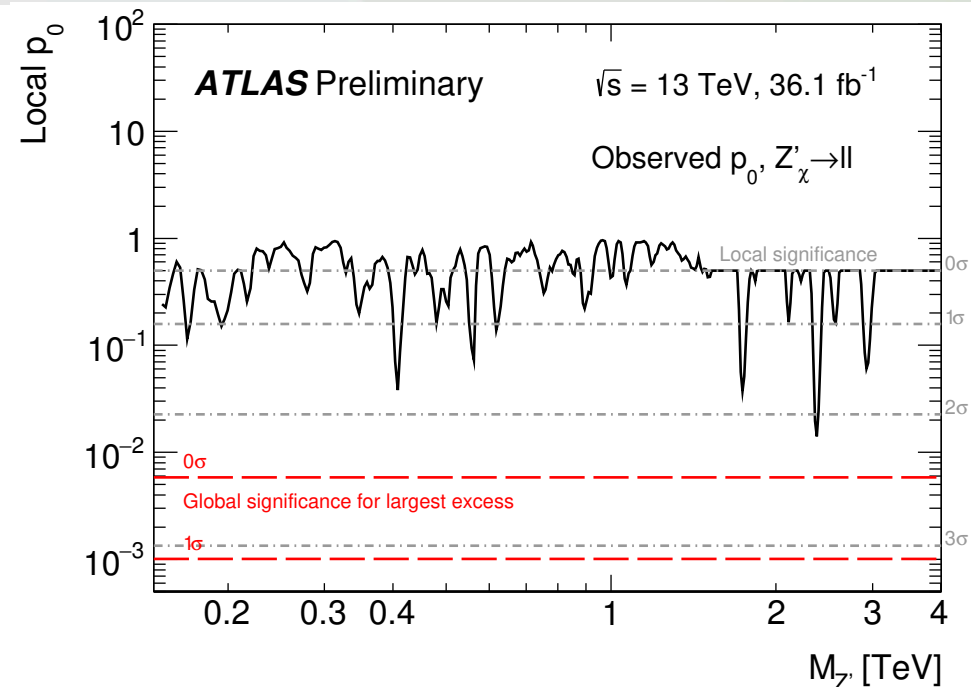
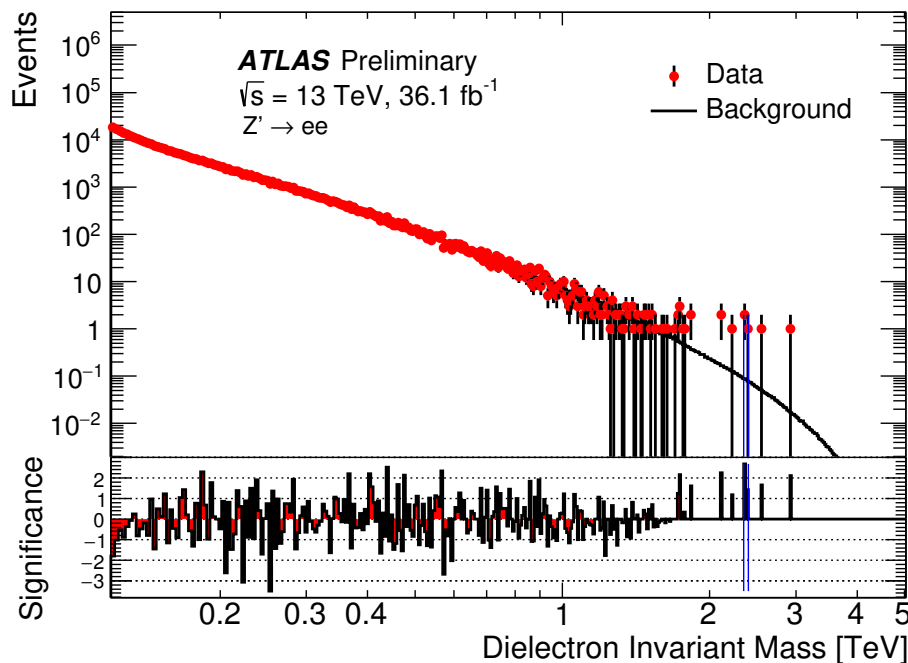
N.B. Like other searches shown today, the PDF uncertainty is one of the largest systematics!

Dilepton Signatures: $ee/\mu\mu$

- Use BumpHunter to search agnostically for an excess.
- Log-likelihood ratio test quantifies significance of a narrow Z' -like excess.

$$q_0 = -2 \ln \left[\frac{\mathcal{L}(\text{data}|0, \hat{\theta}_0)}{\mathcal{L}(\text{data}|\hat{\mu}, \hat{\theta})} \right] \quad \text{for } \hat{\mu} \geq 0,$$

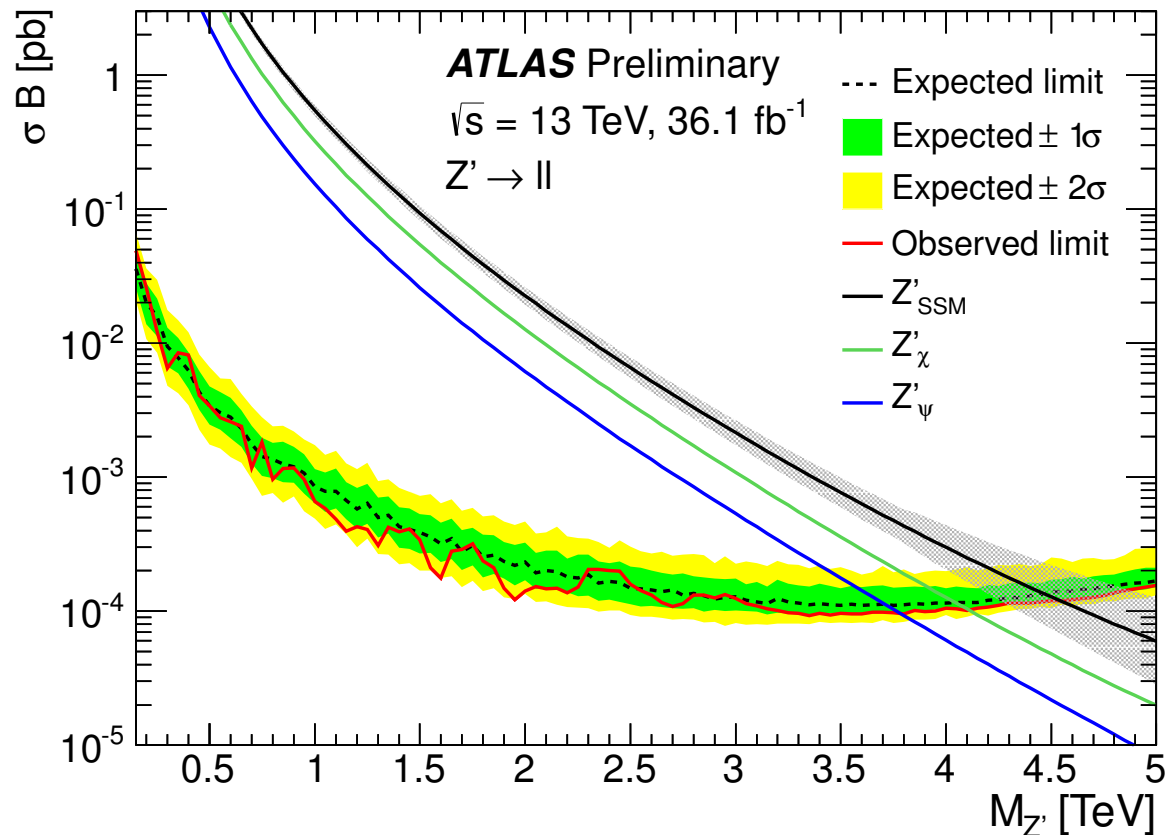
$$p_0 = P(q_0 \geq q_0^{obs} | \text{background-only}) = \int_{q_0^{obs}}^{\infty} f(q_0|0, \hat{\theta}_0^{obs}) dq_0$$



Dilepton Signatures: $ee/\mu\mu$

Ref 1

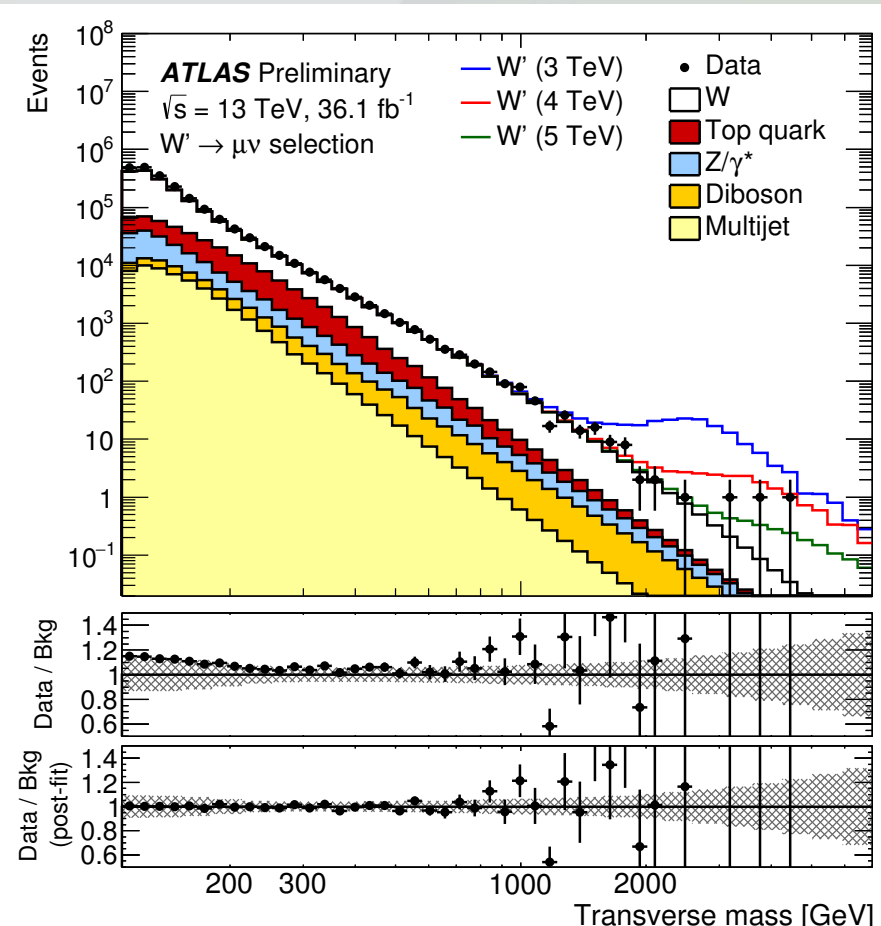
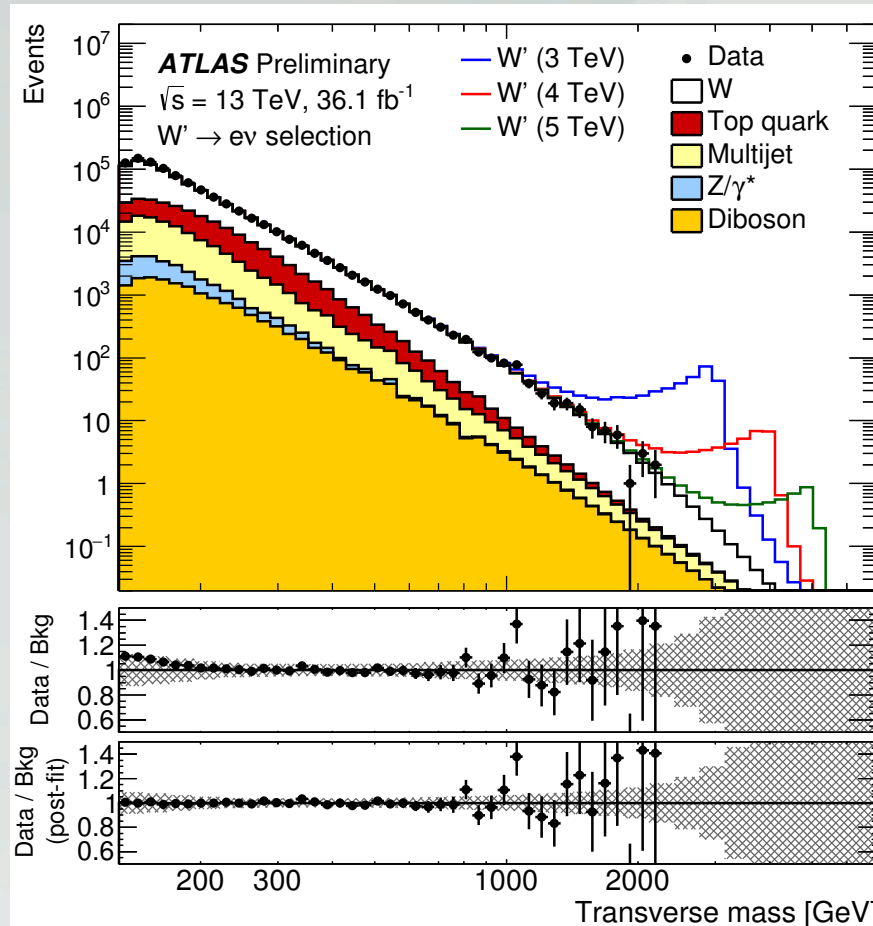
- Set exclusion limits on the parameter of interest (σ_B) at 95% credibility level and convert into limit on the Z' pole mass.
- Use a Bayesian approach, and Markov Chain Monte Carlo (MCMC) to marginalise the likelihood, integrating out the nuisance parameters.



Z' Model	Lower Observed Mass Limit [TeV]		
	ee	$\mu\mu$	ll
SSM	4.3	4.0	4.5
χ	3.9	3.6	4.1
ψ	3.6	3.3	3.8

Lepton+MET Signatures: $e\nu/\mu\nu$

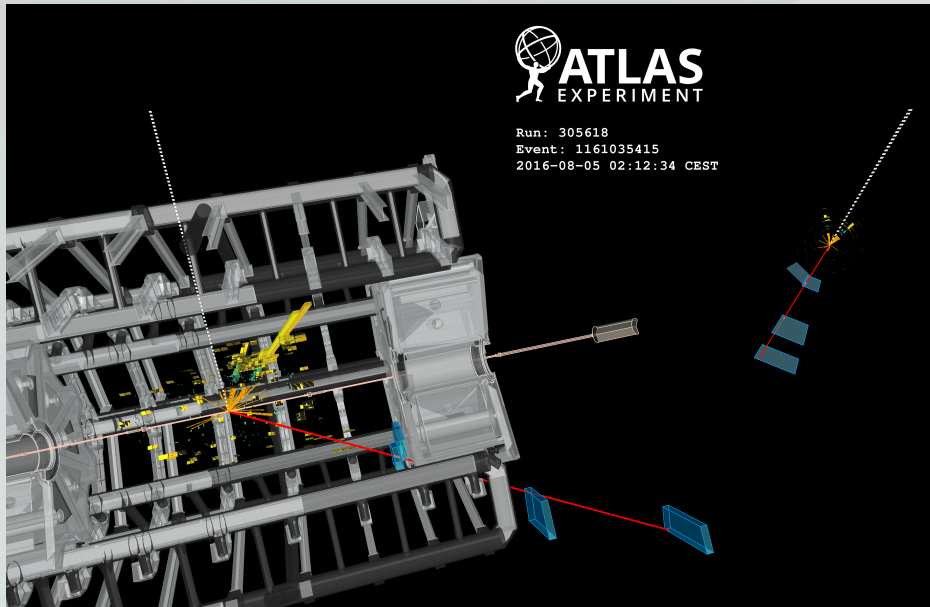
- Very similar to the dilepton search, teams work closely together.



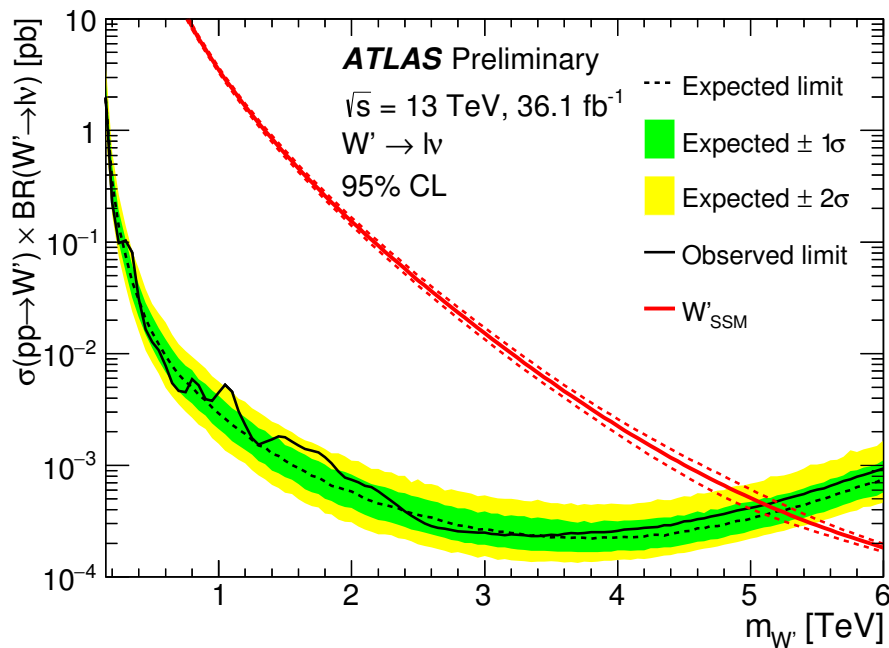
- Low m_T discrepancy accounted for by jet energy scale and missing energy sys.
- A few very high m_T events in the muon channel!

Lepton+MET Signatures: $e\nu/\mu\nu$

Ref 2



Very high mT event ~ 4.5 TeV!
 Muon $p_T = 2.8$ TeV.
 MET = 1.9 TeV.



W' Model	Lower Observed Mass Limit [TeV]		
	$e\nu$	$\mu\nu$	$l\nu$
SSM	5.22	4.45	5.11

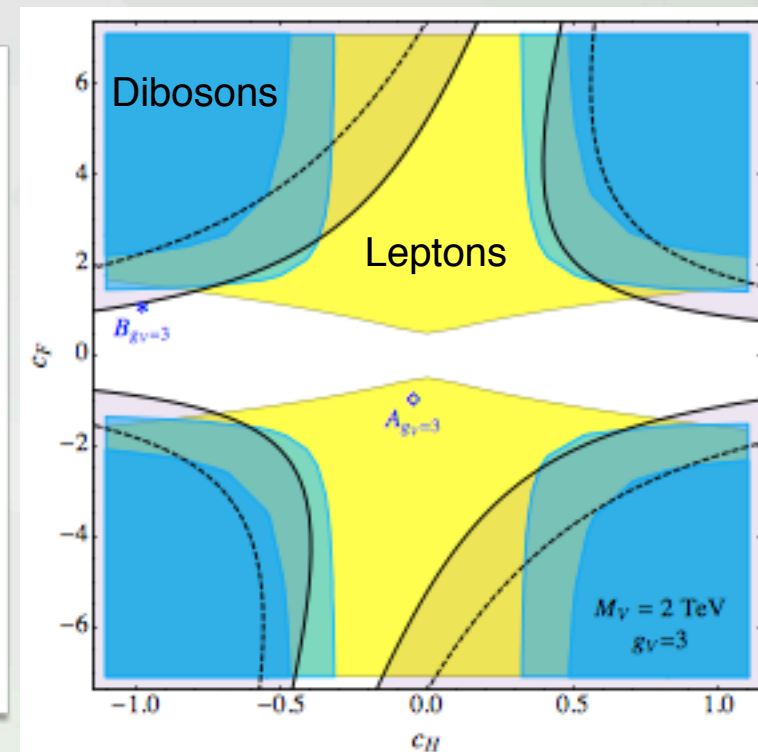
Leptonic Signatures: The Bigger Picture!

- The “fast and lightweight” search era of the LHC is coming to an end.
 - Clean search channels such as dilepton and diphoton will not get a sizeable increase in sensitivity for at least a year.
 - Predicted dataset ~ 150 /fb, by the end of Run-2.
- Searches could start to look into exclusive signal regions.
 - Instead of inclusive Z' search, look for $Z' + 1$ jet, $Z' + 2$ jets, etc.
 - Start to use missing energy cuts, and jet vetoes, eke out signal.
- One could also turn to a wider combination of search channels.
 - Give the maximum feedback to theorists to help point us forward.
 - Be ready for if/when a signal does appear, to characterise it fast.
- Discussion about how to provide theorists the most useful results.
 - Fiducial limits (can we come to a group-wide standard?).
 - How to be more model independent for re-interpretations?

Leptonic Signatures: The Bigger Picture!

- All of these discussions, and more, are currently happening in ATLAS.
- For example, on the grand combination topic:
 - General heavy vector resonance interpretation in terms in singlet and triplet representations.
 - Parameterise signal in N-dimensional coupling space, and produce results on the multitude of various relationships.

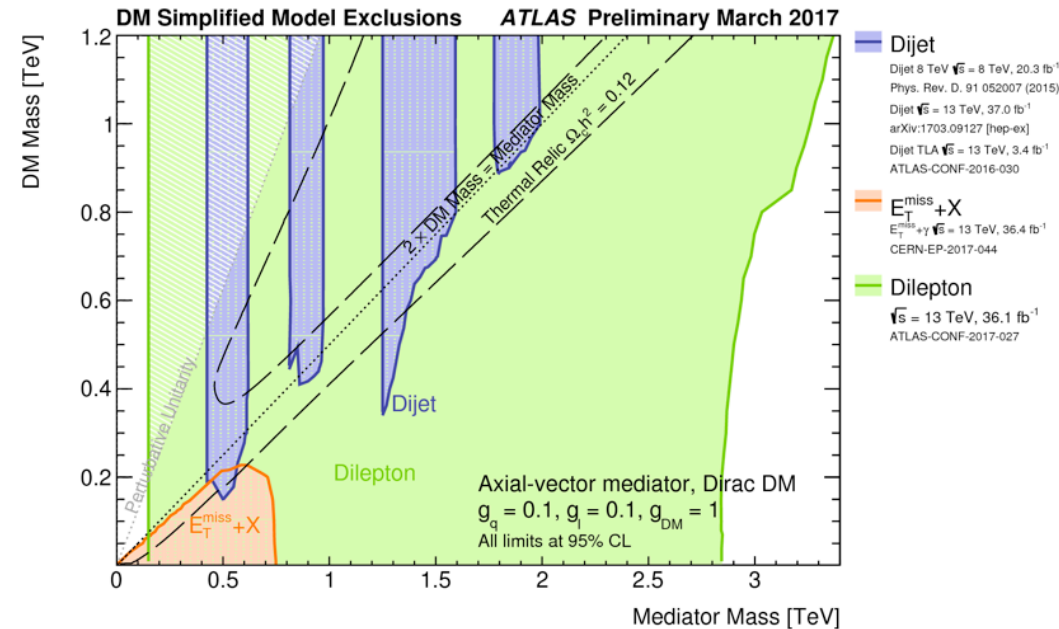
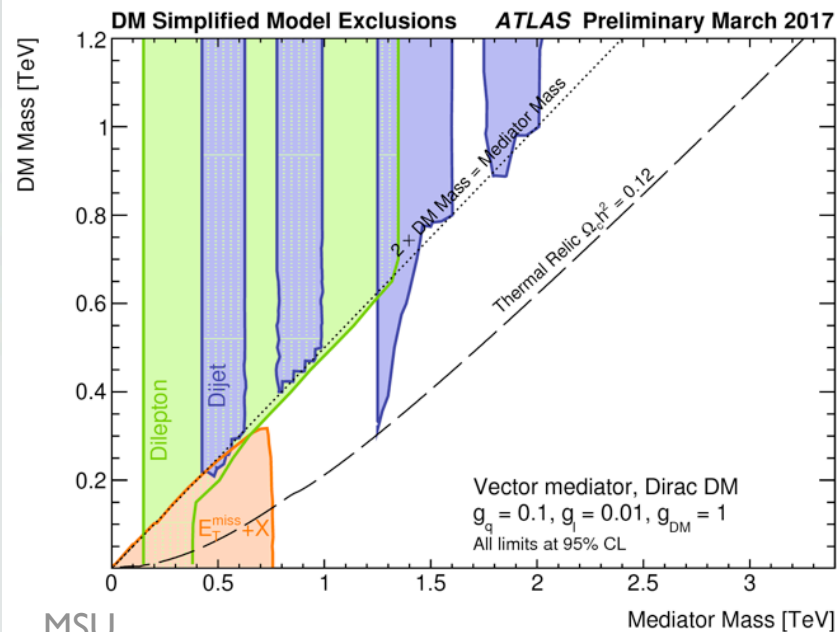
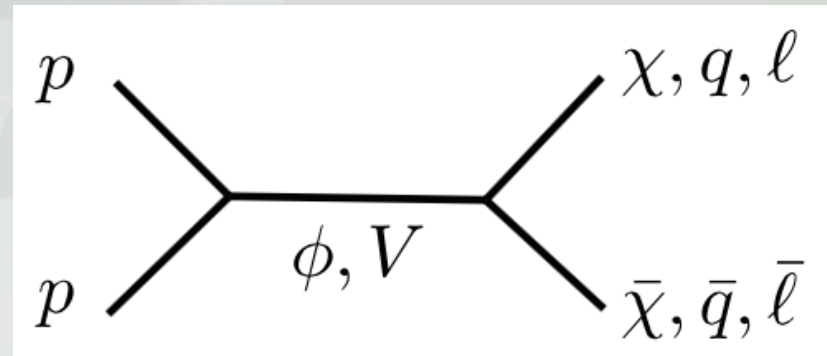
Channel	$V^0 \in (1, \mathbf{3})_1$	$V^+ \in (1, \mathbf{3})_1$	$V^0 \in (1, \mathbf{1})_0$ $\in \mathbf{3}$ of $SU(2)_R$	$V^+ \in (1, \mathbf{1})_1$ $\in \mathbf{3}$ of $SU(2)_R$
ll	□	×	□ □	×
$l\nu$	×	□	×	×
$l\nu_R$	×	×	×	□ □
jj	□	□	□ □	□ □
tb	×	□	×	□ □
tt	□	×	□ □	×
WW	□	×	□ □	×
ZZ	×	×	×	×
Zh	□	×	□ □	×
WZ	×	□	×	□ □
Wh	×	□	×	□ □
$W\gamma$	×	□	×	□ □
hh	×	×	×	×



Leptonic Signatures: The Bigger Picture!

Ref 4

- Also reinterpreting limits where possible - such as Dark Matter!
- Simplified DM model with a mediator decaying to DM and SM particles.
- Complementary to Mono-X Searches!
- Phase space explored as a function of mediator coupling to q and ℓ .
- Some regions where dilepton constraints are very strong!
Others dominated by dijets, etc.

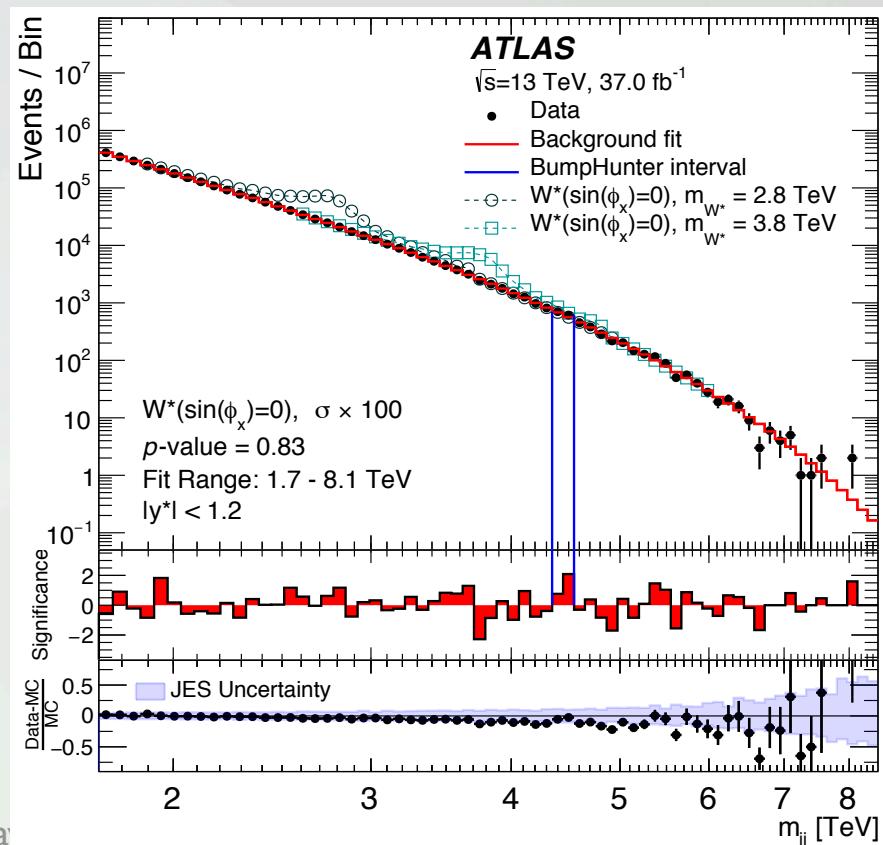
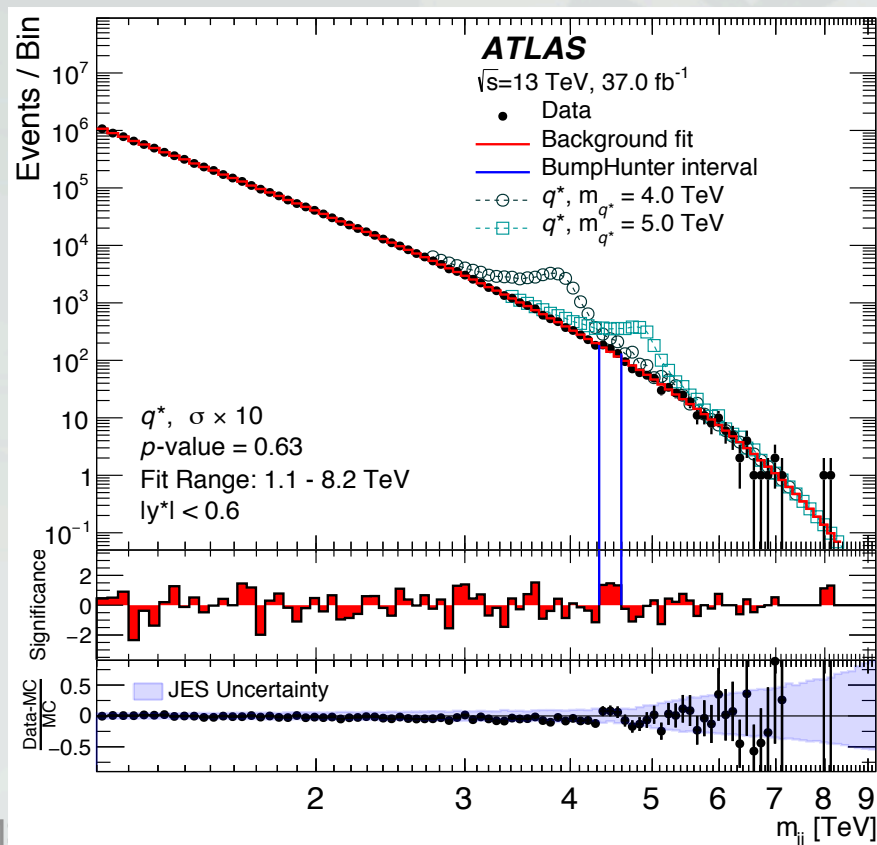


Dijet Signatures

- Searches for new phenomena, such as excited quarks in composite models, in events with two or more jets, taking **two highest-pT jets** to compute invariant mass.
- SM QCD processes are the dominant background to this search. A **data-driven background estimate** is derived by **fitting a smooth functional** form to m_{jj} .

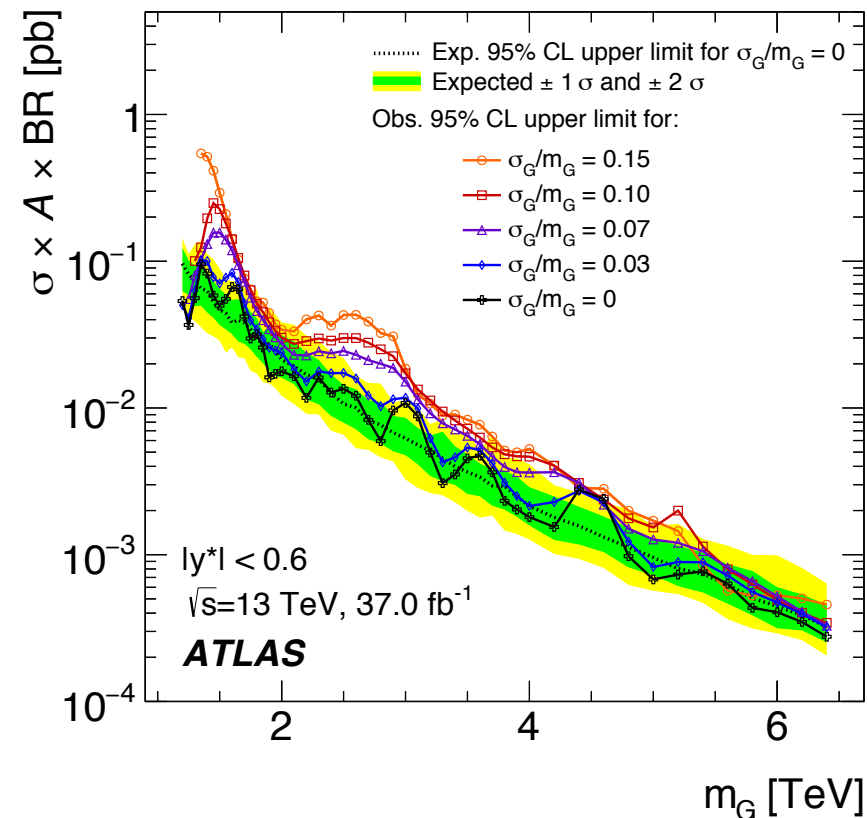
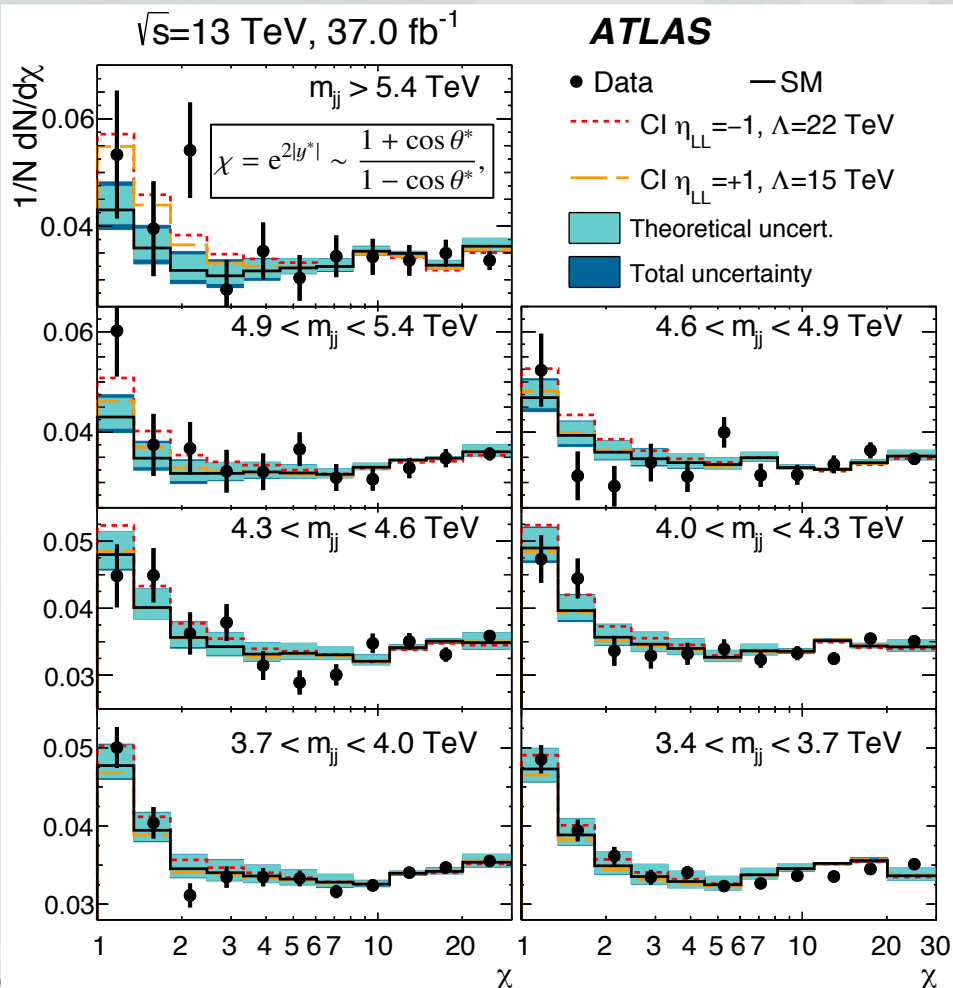
$$y = \frac{1}{2} \ln \left[\frac{E + p_z}{E - p_z} \right],$$

$$y^* = (y_1 - y_2) / 2$$



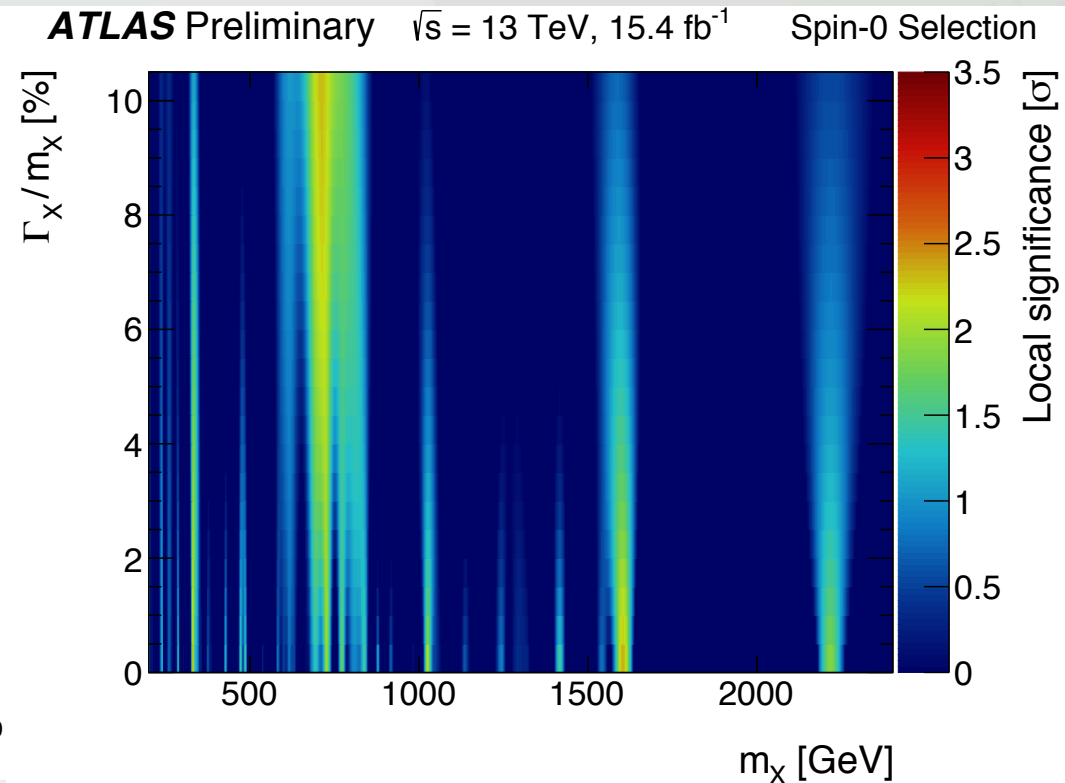
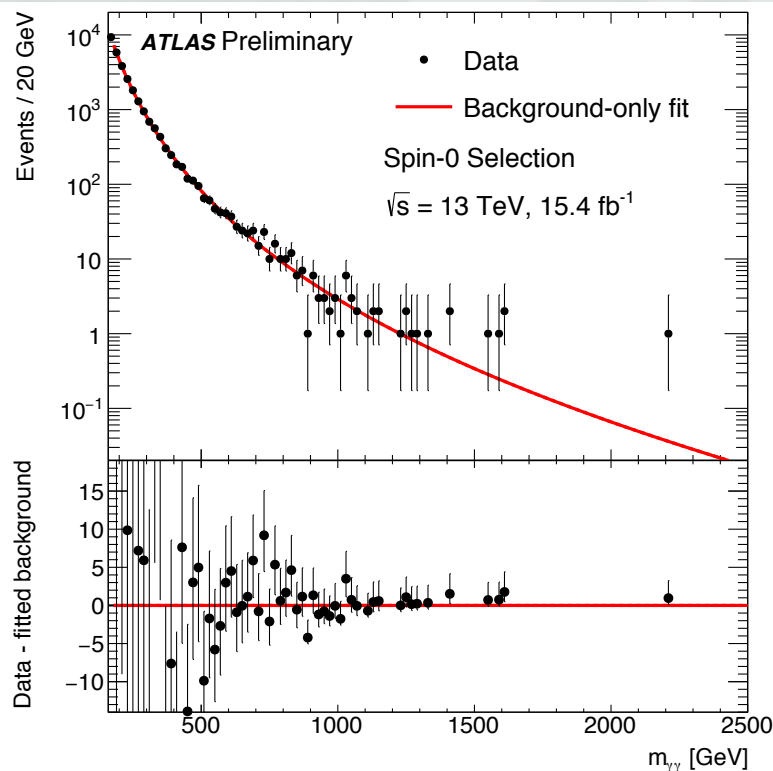
Dijet Signatures

- Can also exploit angular variables to provide constraints on non-resonant signals.
- Among other results, this search provides limits for a **Gaussian shape** with various **widths (0-15%)**. There is an aim for most Exotics searches to provide generic (or “re-usable”) results like this by the end of Run-2, along with $A^*\epsilon$ curves, etc.

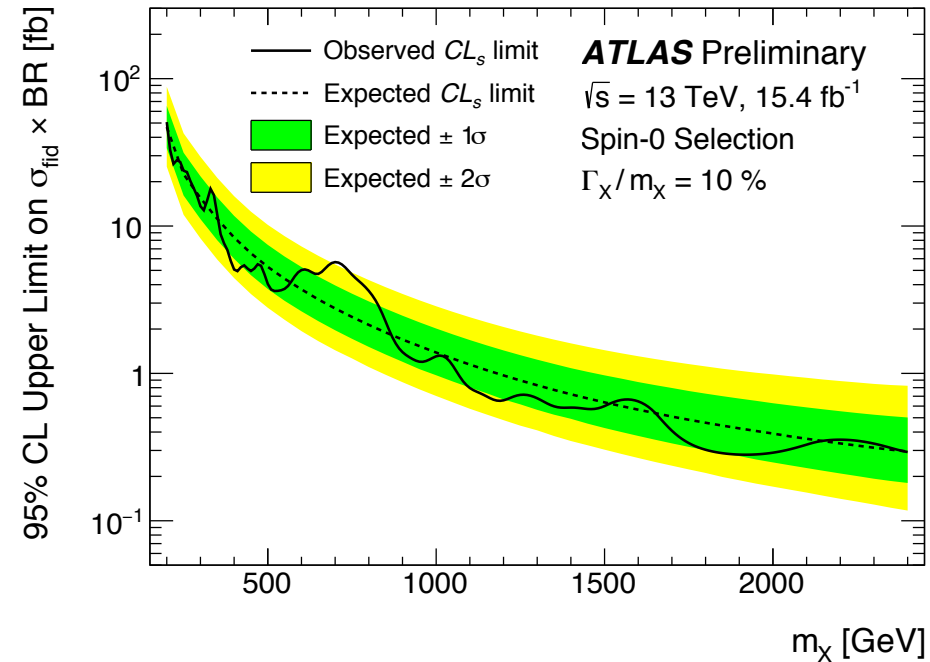
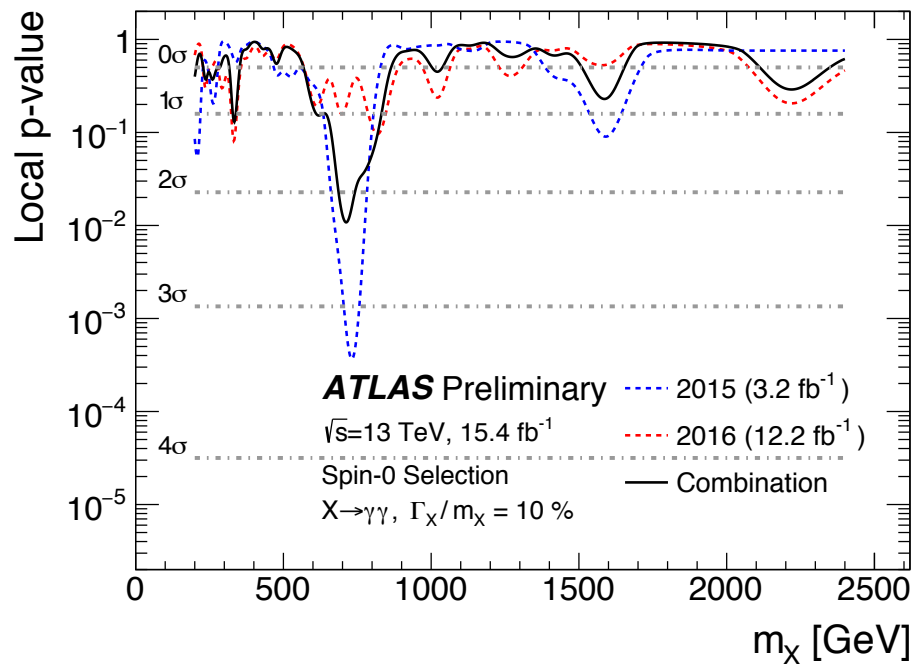


Diphoton Signatures

- This search also offers a **very clean experimental signature** with excellent mass resolution and modest backgrounds.
- Two signal scenarios are considered: a **Spin-0 Scalar** that may arise from an **extended Higgs Sector**, or a **Spin-2 Graviton** such as in the **RS Model**, which seeks to address the hierarchy problem by invoking **warped extra spatial dimensions**.
- The dominant background comes from **irreducible prompt $\gamma\gamma$ production** processes, followed by one or both photons coming from **misidentified electrons/jets**.



Diphoton Signatures



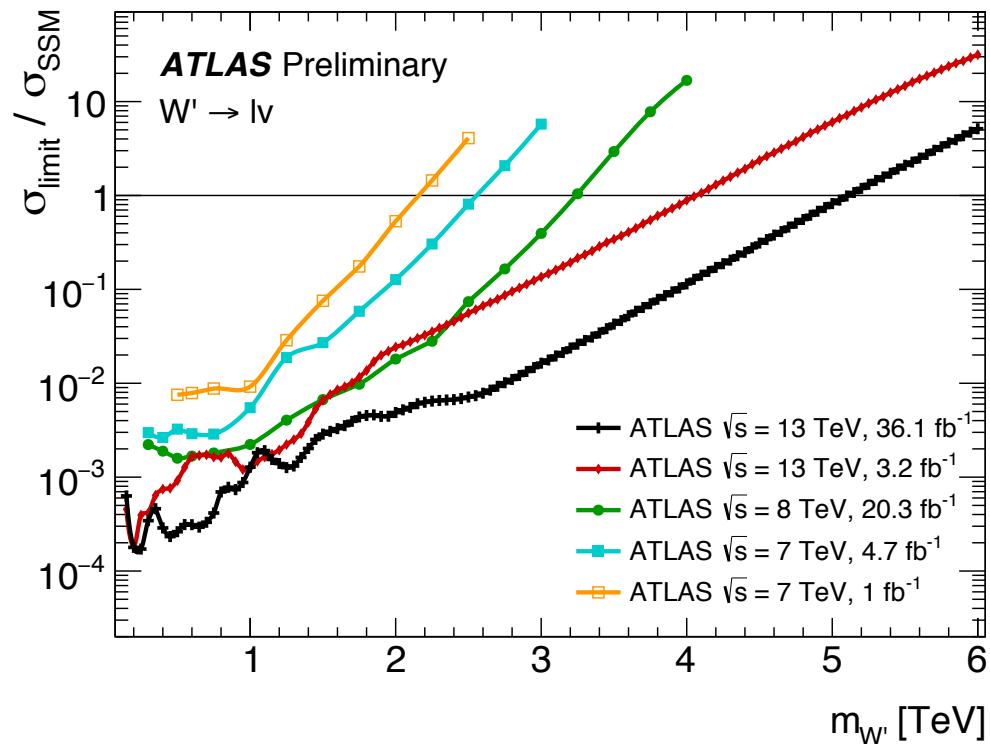
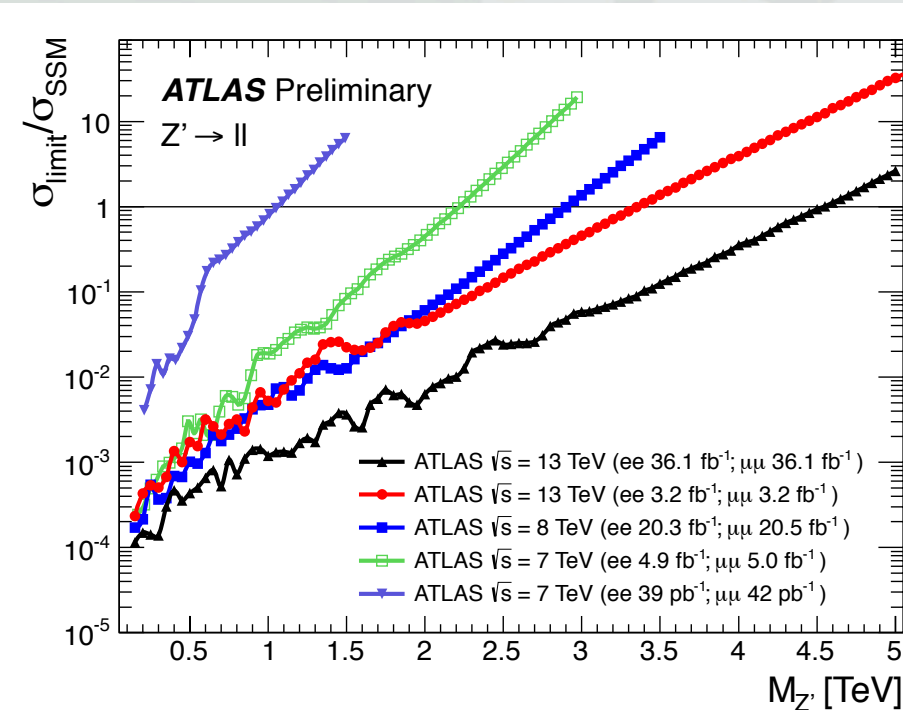
- The search phase uses a similar LLR method to the Z'/W' leptonic search.
- In the absence of a significant excess, limits are set on the fiducial cross-section times branching ratio at 95% CL, using a modified frequentist approach (CLs).
- Unfortunately the initial excess in 2015, continues to decrease in significance.

Diphotons: More things that go Bump in the night?

- Diphoton excitement reminded people “[don't write-off the low mass region](#)”
- In this new era of the LHC with large integrated luminosities, we will have an **unprecedented level of statistical precision** from the data.
- We can use this precision to look for ever narrower resonances with smaller cross-sections, and even exploit distinct parts of the detector (**barrel vs endcap**).
- This also goes for other signatures - such as the leptonic searches.

Conclusions - Ending at the Beginning

- Many resonance searches have been performed with the ATLAS detector at the LHC, using ~ 36 /fb at $\sqrt{s} = 13$ TeV.
- Continual improvements to analysis techniques, and novel search approaches, have lead to ever increasing sensitivity to new physics.
- Unfortunately **no significant excesses** over the Standard Model expectation have yet been observed in these searches.



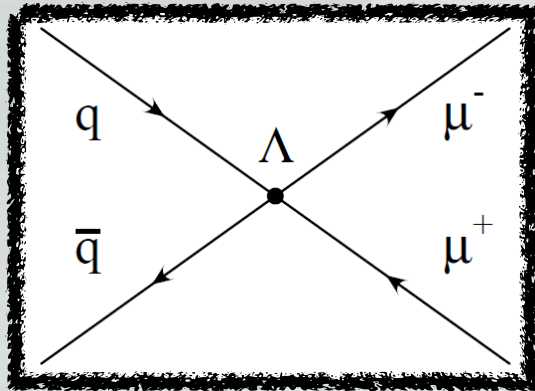
References

- **Ref 1:** <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-027/>. **Moriond CONF Note 2017.**
- **Ref 2:** <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2017-016/>. **Moriond CONF Note 2017.**
- **Ref 3:** <https://arxiv.org/abs/1402.4431>. **Accepted by JHEP (2014).**
- **Ref 4:** https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/index.html#ATLAS_DarkMatter_Summary
- **Ref 5:** <https://arxiv.org/abs/1703.09127>. **Paper submitted to PRD.**
- **Ref 6:** <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2016-059/>. **ICHEP CONF Note 2016.**

Backup Slides

Theoretical Motivation: Other Interesting Models

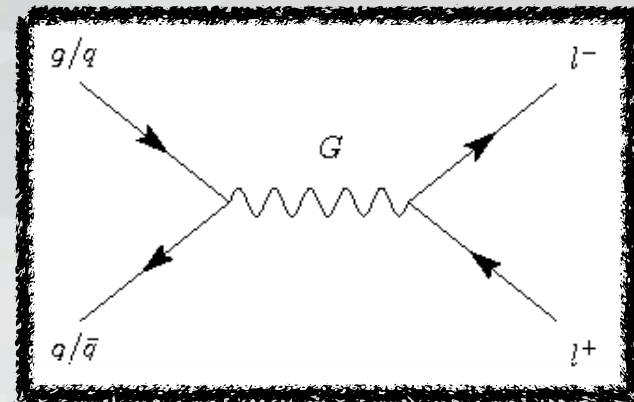
Contact Interactions



$$\frac{d\sigma}{dm_{\ell\ell}} = \frac{d\sigma_{DY}}{dm_{\ell\ell}} - \eta \frac{F_I}{\Lambda^2} + \frac{F_C}{\Lambda^4}$$

- q - ℓ compositeness, with scale, Λ .
- Non-resonant excess over the SM invariant mass spectrum.
- η describes whether the interference is constr./destr. and sets L/R handed couplings.

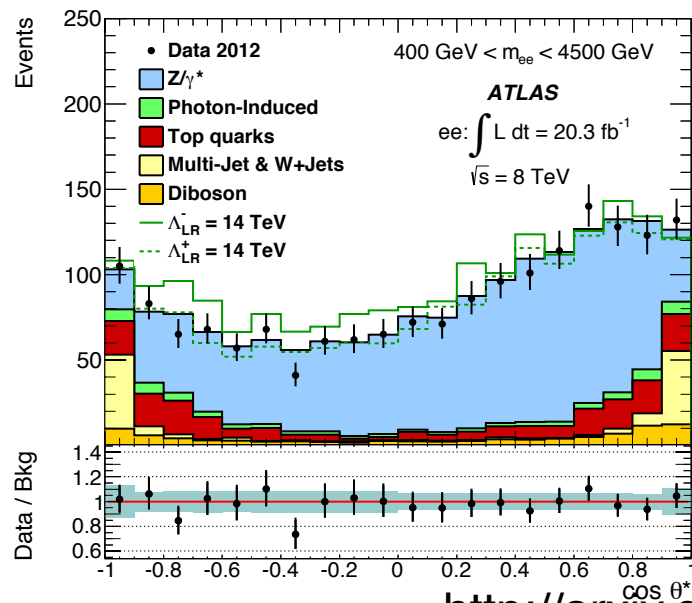
Randall-Sundrum (RS) Graviton



- Posit warped extra spatial dimensions to explain the hierarchy between the Planck and electro-weak (EW) scale.
- Graviton (G^*) has Spin-2, and allowed to decay to SM particles including $\gamma\gamma$.
- Parameters of interest: M_{G^*} , k/M_{Pl} .

$$\mathcal{L} = - \left(\frac{G_0^{\mu\nu}}{\overline{M}_{Pl}} + \sum_{n>0} \frac{G_n^{\mu\nu}}{\Lambda_\pi} \right) T_{\mu\nu}, \text{ where } \Lambda_\pi = \overline{M}_{Pl} e^{-\pi k R}$$

Forward Background Asymmetry in Leptonic Searches



<http://arxiv.org/abs/1407.2410>

