Selected hot topics from ATLAS

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Introduction

After the discovery of a Higgs-like boson, the standard model (SM) is a complete (but for an axion) and self-consistent renormalisable theory.

So far, SM in good agreement with data.

A lot of questions still need answers:

– How to accommodate gravity ?

– Hierarchy problem: $m_{EW}/M_{Pl} \sim 10^{-16}$

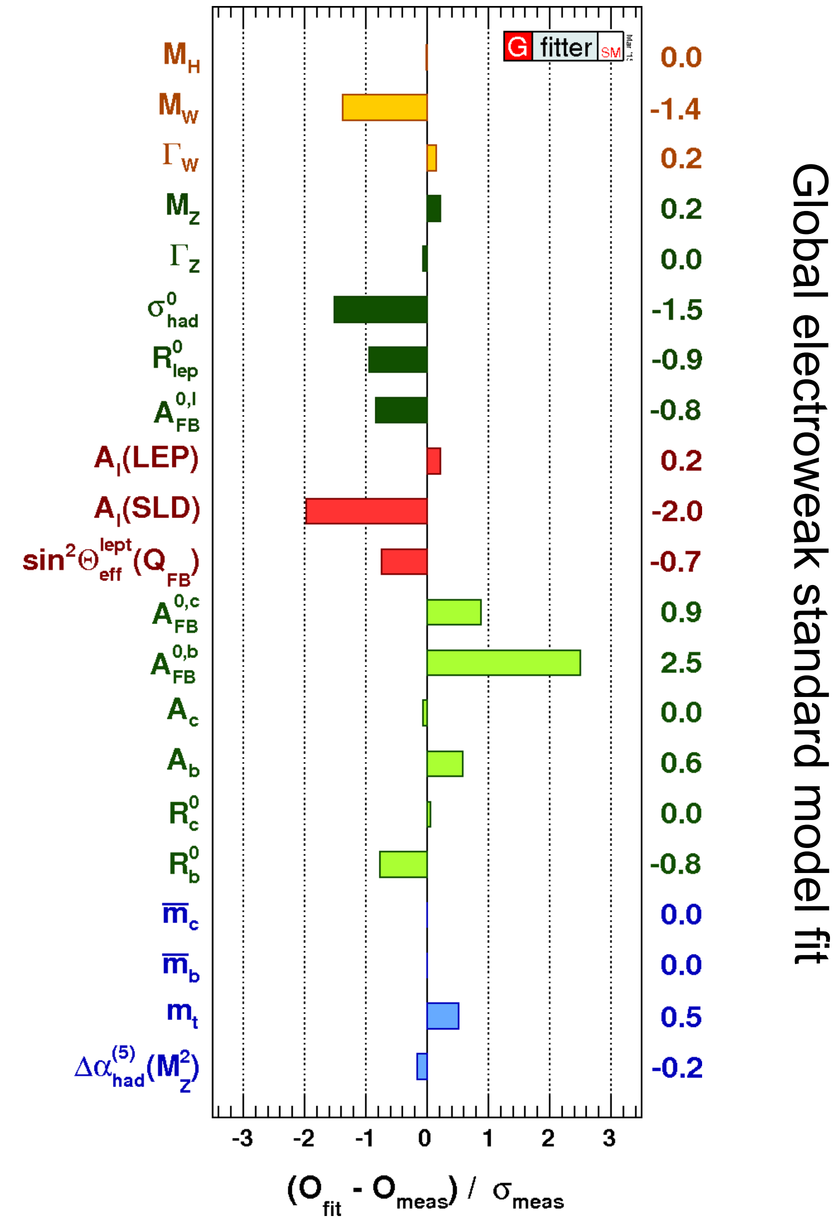
– What is dark matter ?

– Matter-antimatter asymmetry

– Origin of generations ?

– ...

Physics beyond the SM is well motivated.



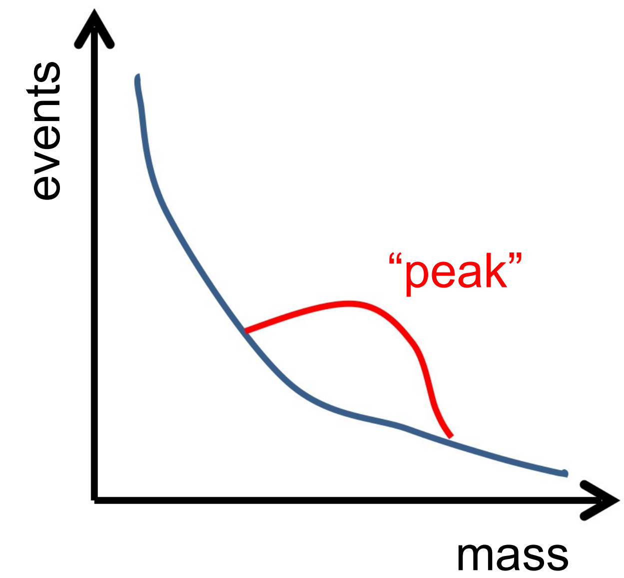
Diphoton “bump hunt”

Search strategy

In this talk:

- Pick a simple final state (e.g. $e^+ e^-$).
- Reconstruct invariant mass.
- Confront observed mass spectrum to SM expectation.

Deviations from SM could manifest themselves as “peak” (resonance) or as broad “shoulders”.

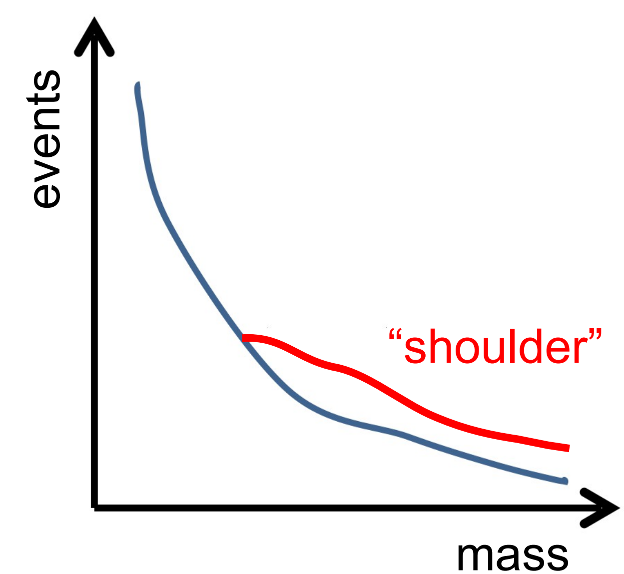


Large number of models that:

- aim at solving at least one of the problems of SM listed on previous slide,
- predict peak or shoulder in one of the final states considered in this talk.

Two approaches to estimate of SM background:

- detailed simulations of shape of mass spectrum
- smooth functional form fitted to data



Resonances in past discoveries

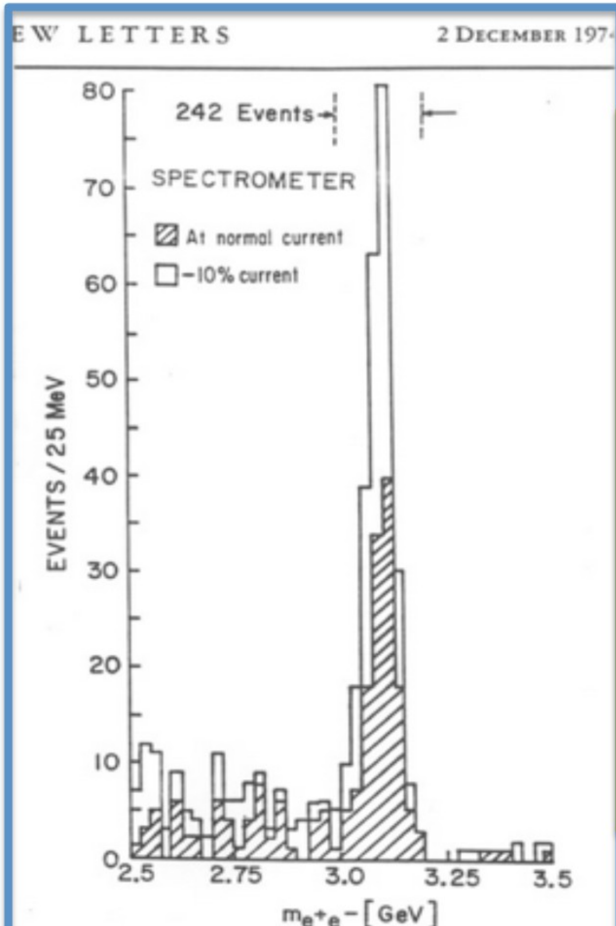
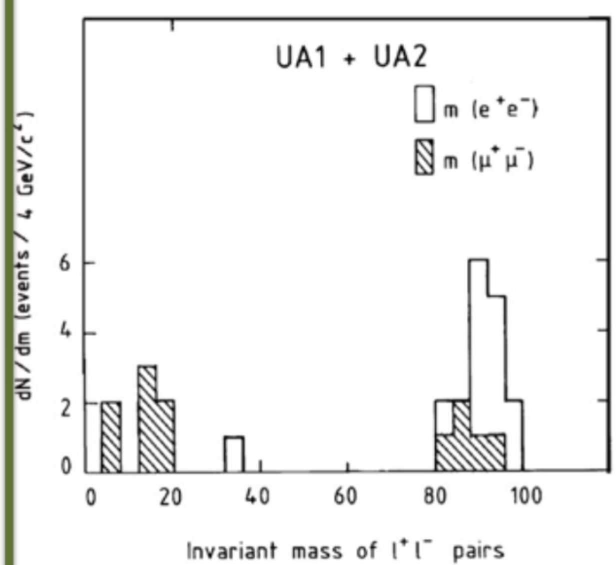
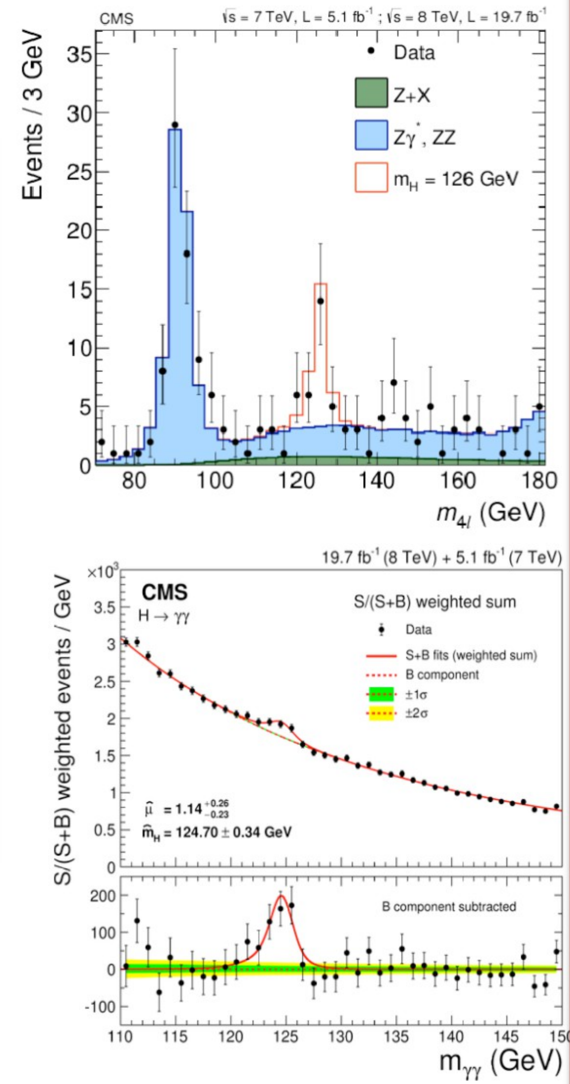


FIG. 2. Mass spectrum showing the existence of J. sults from two spectrometer settings are plotted wing that the peak is independent of spectrometer rents. The run at reduced current was taken two nths later than the normal run.

J/Psi



Z



Higgs

3

Di-photon final state

Many extensions of the SM predict high-mass states that decay to two photons

Example/benchmark models:

Spin 0
Extended Higgs sector

Example: 2HDM

5 physical states h^0, H^0, A^0, $H^{+/-}$

under certain conditions,
scalar and/or pseudo-scalar
states can have sizable
branching ratio to di-photons

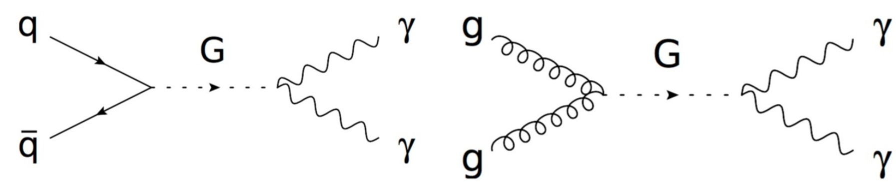
Spin 2
Randall-Sundrum graviton

Model predicts tower of
Kaluza-Klein (KK) graviton excitations;
first state at TeV mass scale

Phenomenology:

M_{G^*} = mass of lightest KK excitation

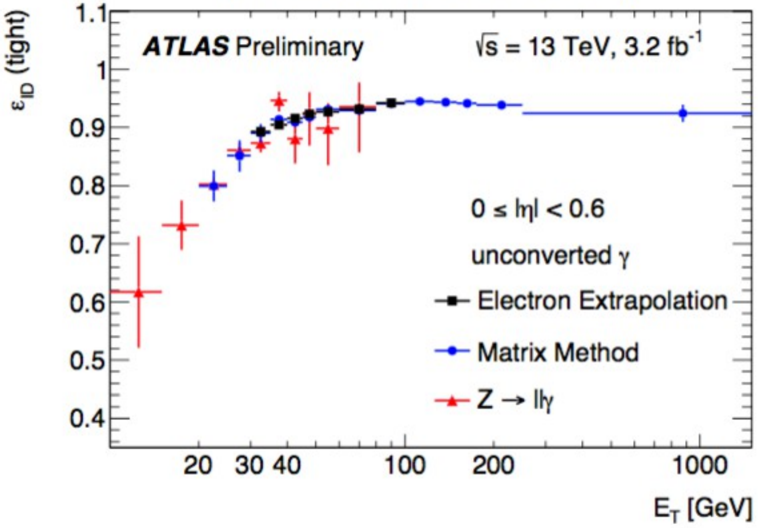
κ/M_{Pl} = dimensionless coupling to SM fields

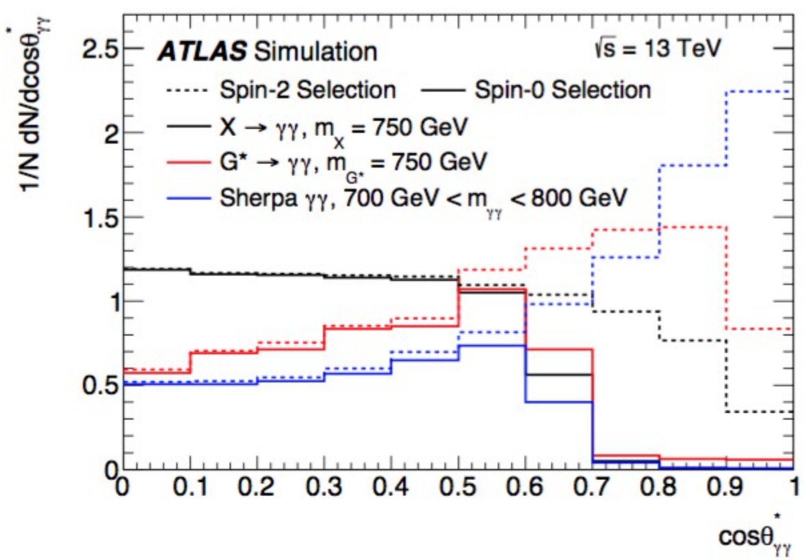


Event selection

- Common event selection:
  - Diphoton trigger (35/25 GeV), 99% efficient
  - 2 tightly identified photons, isolated using calorimeter and tracks (> 90% purity)
- Different kinematic selections:
  - Spin-2: $p_T > 55$ GeV
  - Spin-0: $p_{T1} / m_{\gamma\gamma} > 0.4$, $p_{T2} / m_{\gamma\gamma} > 0.3$
    → suppresses small scattering angles, i.e. large cos $\theta_{\gamma\gamma}^*$ (or $\Delta\eta_{\gamma\gamma}$)
    - +20% sensitivity w.r.t. fixed p_T cuts beyond 600 GeV

γ identification efficiency

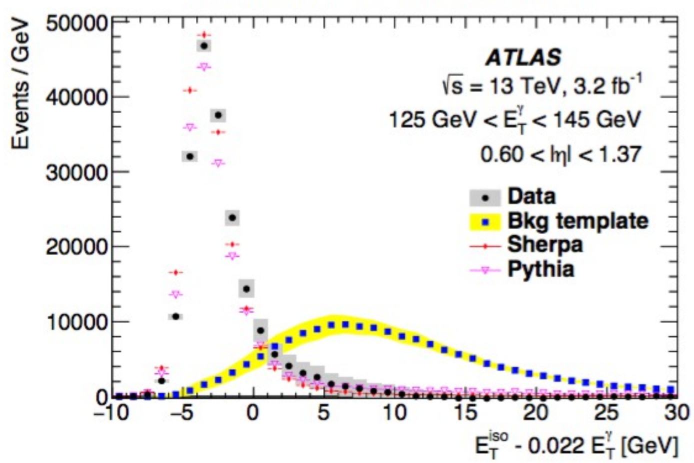




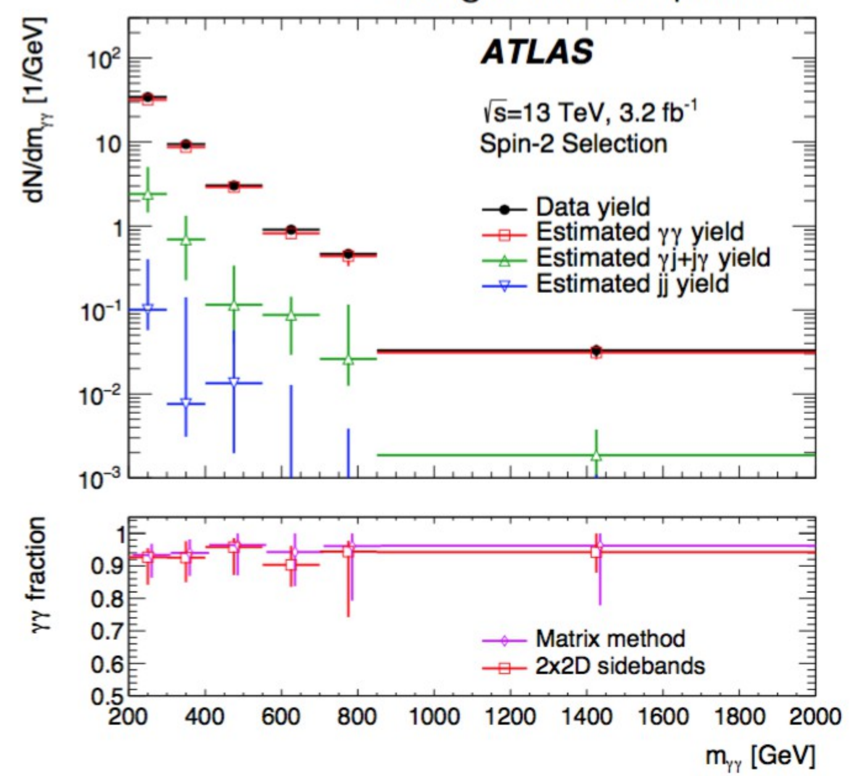
Isolation, sample composition

- Backgrounds from γγ, γ+jet, jet+jet. Processes with $e^{\pm} \rightarrow \gamma$ negligible
- Photon ID and isolation used for background rejection and purity estimate
  - Isolation studied with $Z \rightarrow e^+e^-$, ℓℓγ and γ+X
  - High γγ purity, checked with different methods
    - Spin-2 selection: $(94^{+3}_{-7})\%$
    - Spin-0 selection: $(93^{+3}_{-8})\%$

Isolation E_T distribution



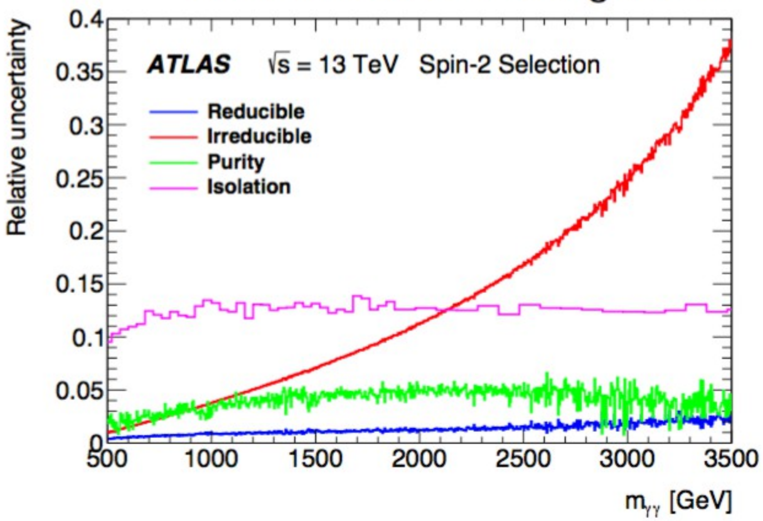
Background composition



Background modelling

- Spin-2: MC template (extend to multi-TeV range)
  - γγ shape from DIPHOX NLO parton level calculation, re-weight Sherpa full-sim
    - Uncertainties from isolation (±7%), scale variations (±5%), PDF (2-35%)
  - γ+jet, jet+jet shape from control regions, normalisation from purity estimate
  - Overall normalisation from data

Uncertainties on the bkg model



- Spin-0: fit to data

$$x = \frac{m_{\gamma\gamma}}{\sqrt{s}}$$

$$f_{(k)}(x; b, \{a_k\}) = N(1 - x^{1/3})^b x^{\sum_{j=0}^{k} a_j (\log x)^j}$$

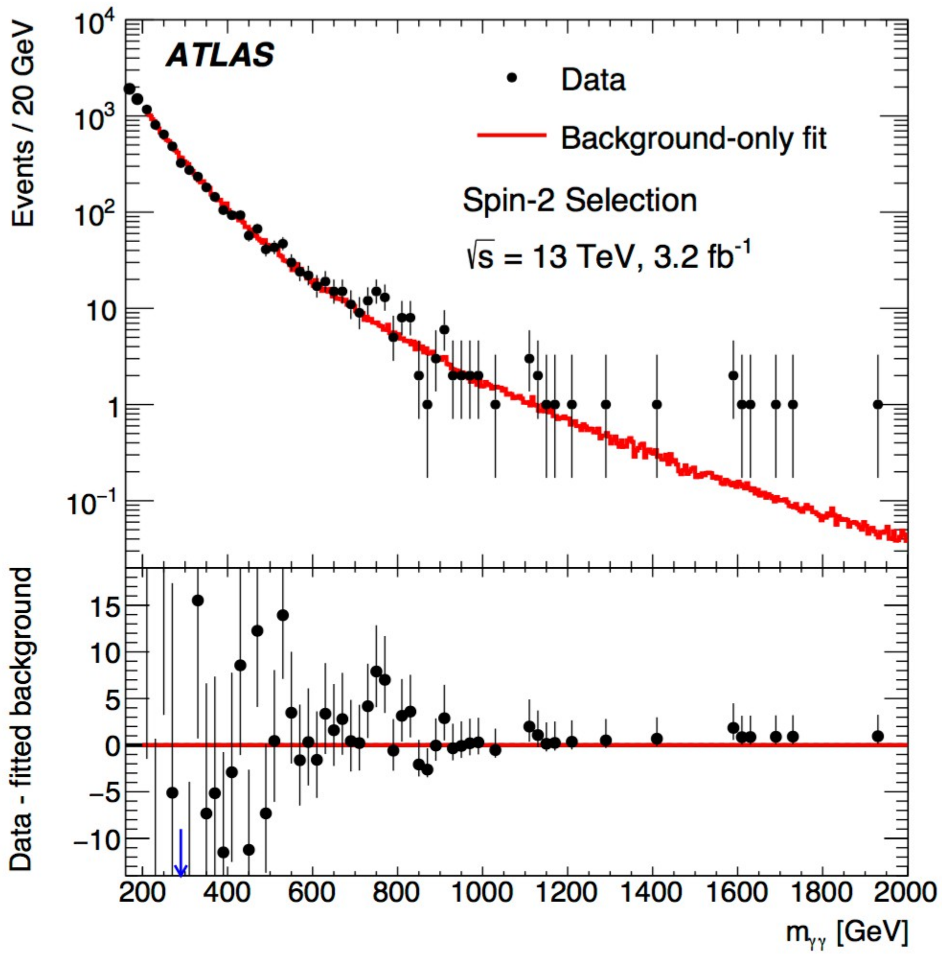
  - Validation of functional form and uncertainty from simulation + variations above
    - Systematics smaller than 30% of statistical error and decreasing with mass

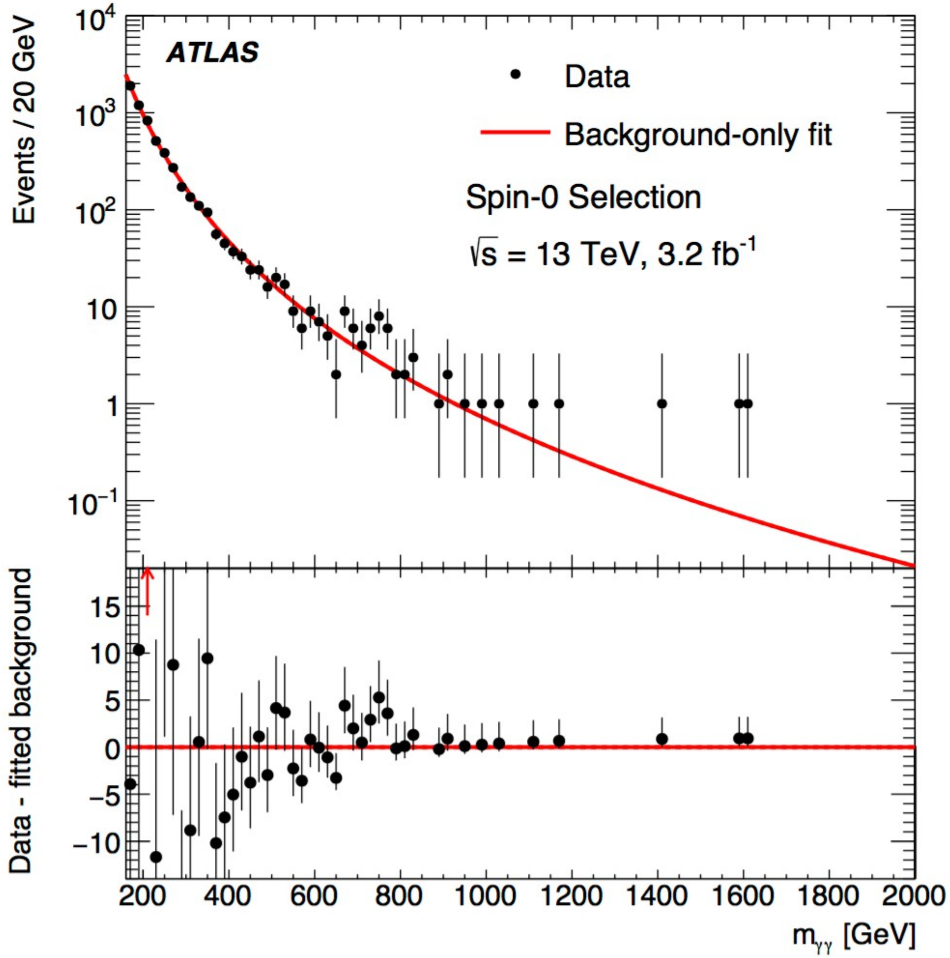
Background modelling

(from paper, 2015 data)

Investigated signal region	Background from MC extrapolation	Background from functional form
m = 750 GeV, Γ/m = 6%		
720–780 GeV, spin-2 selection	20.1 ± 0.3 ± 0.7	21.9 ± 1.2 ± 0.4
720–780 GeV, spin-0 selection	6.7 ± 0.1 ± 0.4	6.8 ± 0.7 ± 0.3
m = 1500 GeV, Γ/m = 6%		
1440–1560 GeV, spin-2 selection	1.14 ± 0.02 ± 0.09	1.51 ± 0.27 ± 0.08
1440–1560 GeV, spin-0 selection	0.32 ± 0.01 ± 0.04	0.33 ± 0.11 ± 0.04

Results based on 2015 data

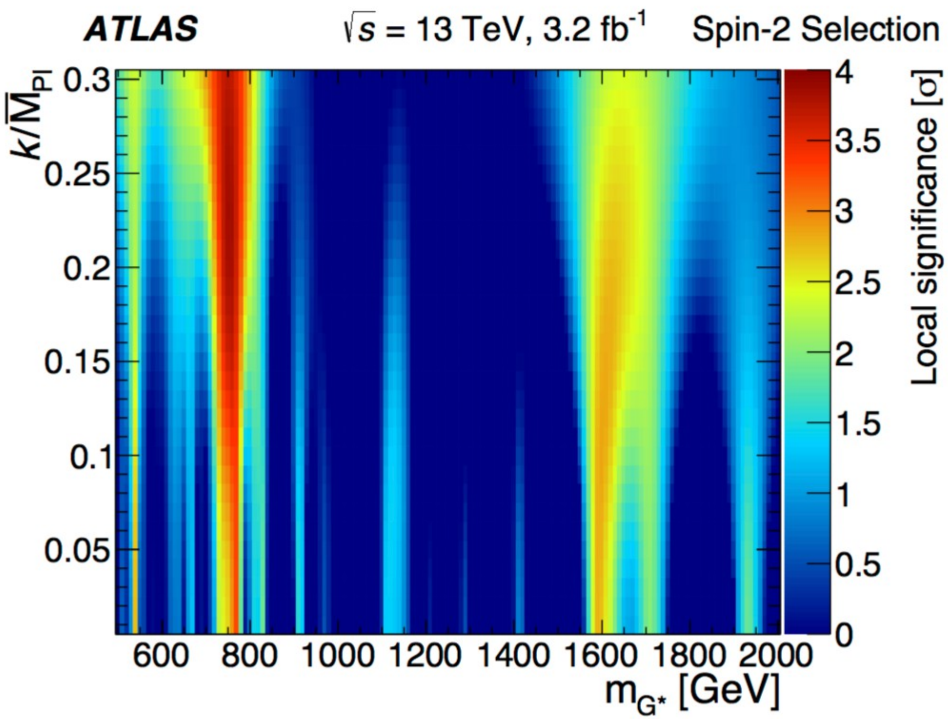


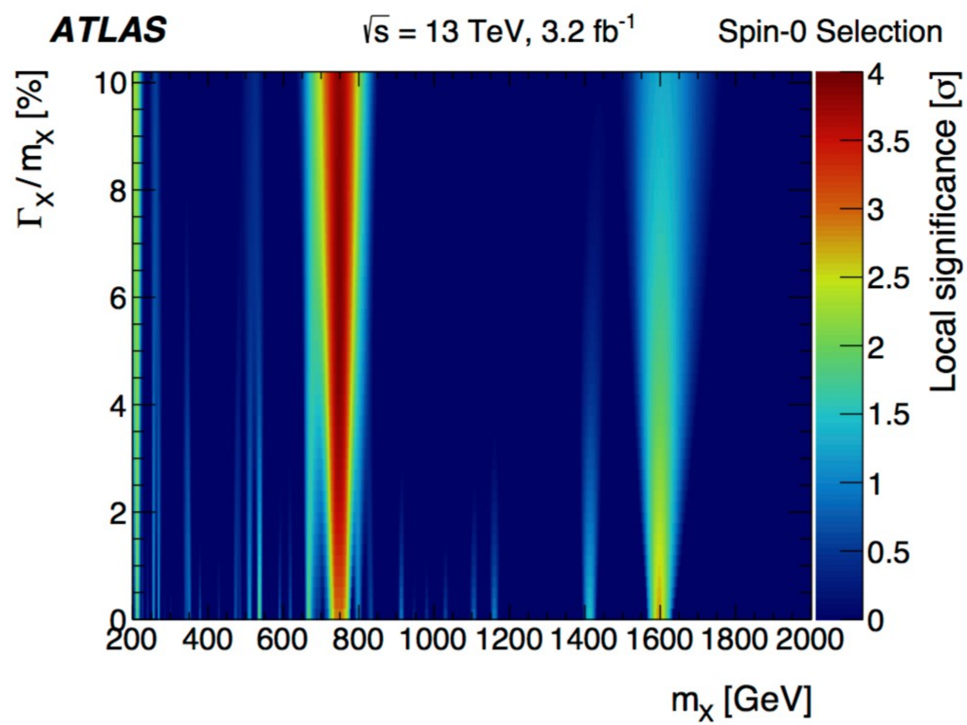


Broad excesses around $m_{\gamma\gamma}$ = 750 GeV

Results based on 2015 data

Significances in the mass vs. k/M_{Pl} (width) plane





Broad excesses around $m_{\gamma\gamma}$ = 750 GeV

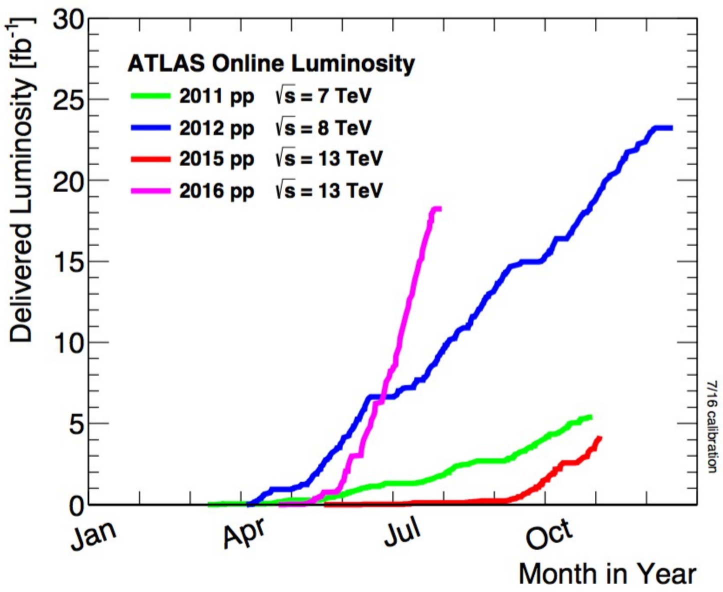
3.8σ – 3.9σ local significance

(2.1σ global, i.e. to find such an excess anywhere in the search region)

2016 data !

Impressive performance of the LHC

- Peak luminosity beyond design
- ATLAS data-taking efficiency > 90%
- 12.2 fb^{-1} of 2016 data analysed
  - Data taken until July 16



With the higher pileup conditions of the 2016 data, more work is needed to complete the analysis in the extended acceptance of the spin-2 selection

The reprocessed 2015 data: spin 0

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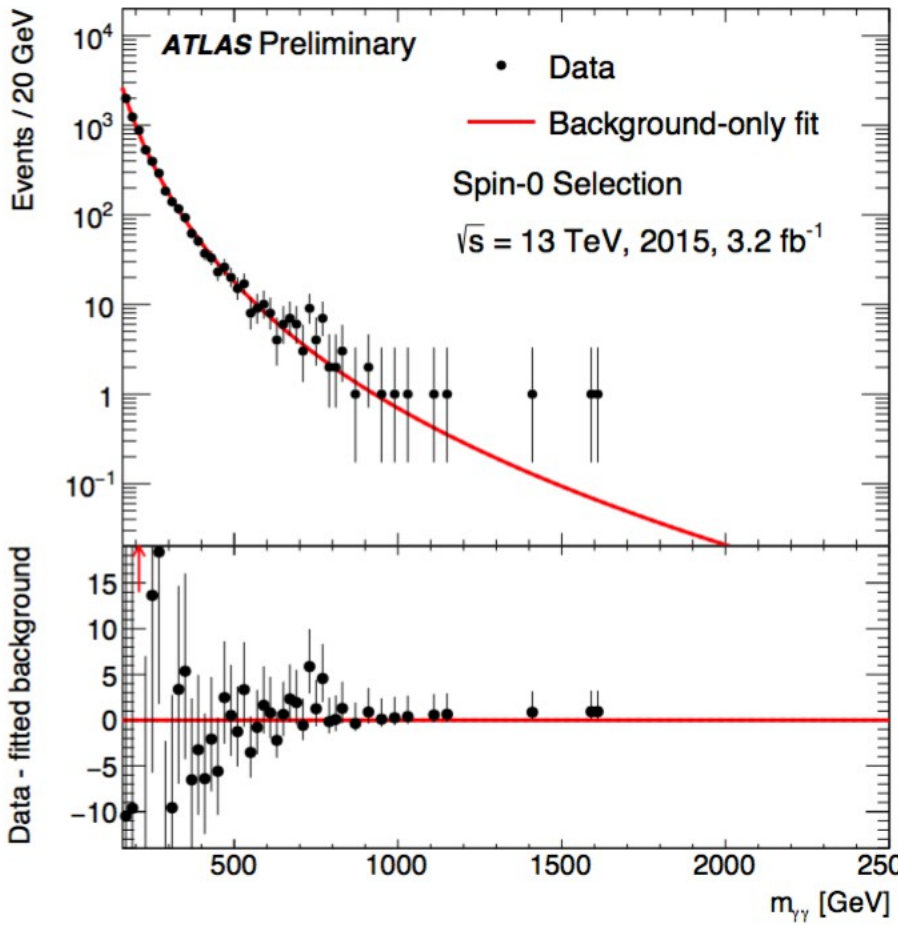
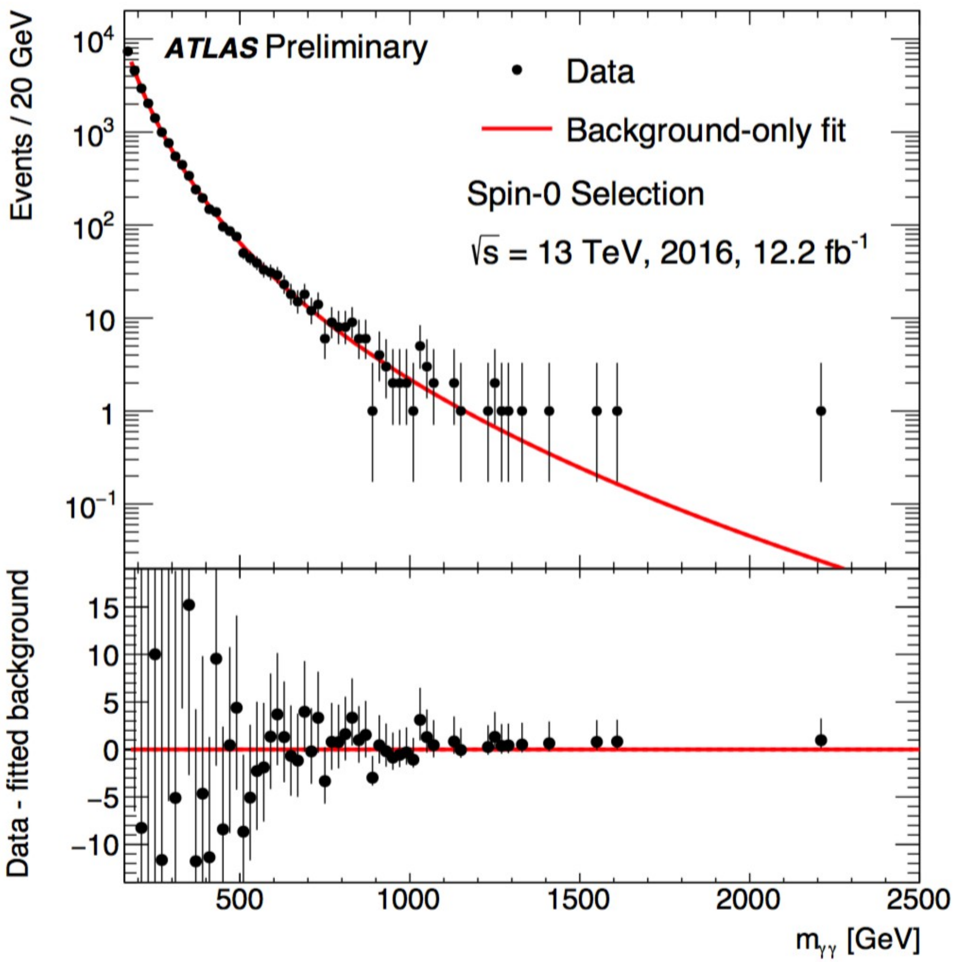
- 2015 reprocessed and reanalysed
  - Excess @ 750 GeV → 730 GeV
  - 3.9σ → 3.4σ local significance
    - Basically 2 events affected by new reconstruction and calibration

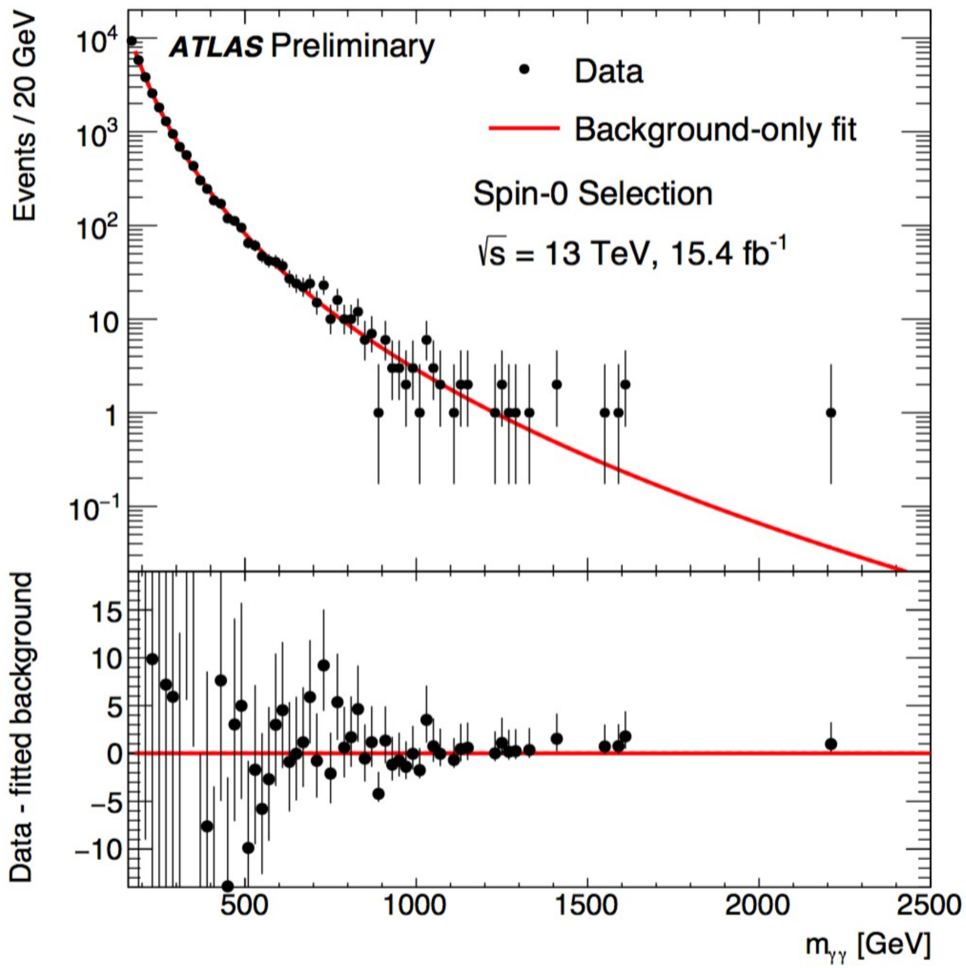


New results: spin 0

2016 only



2015 + 2016



No significant excess in 2016 data;
compatibility between 2015 and 2016 datasets for signal cross section at 730 GeV: 2.7σ

New results: significances for narrow-width signal

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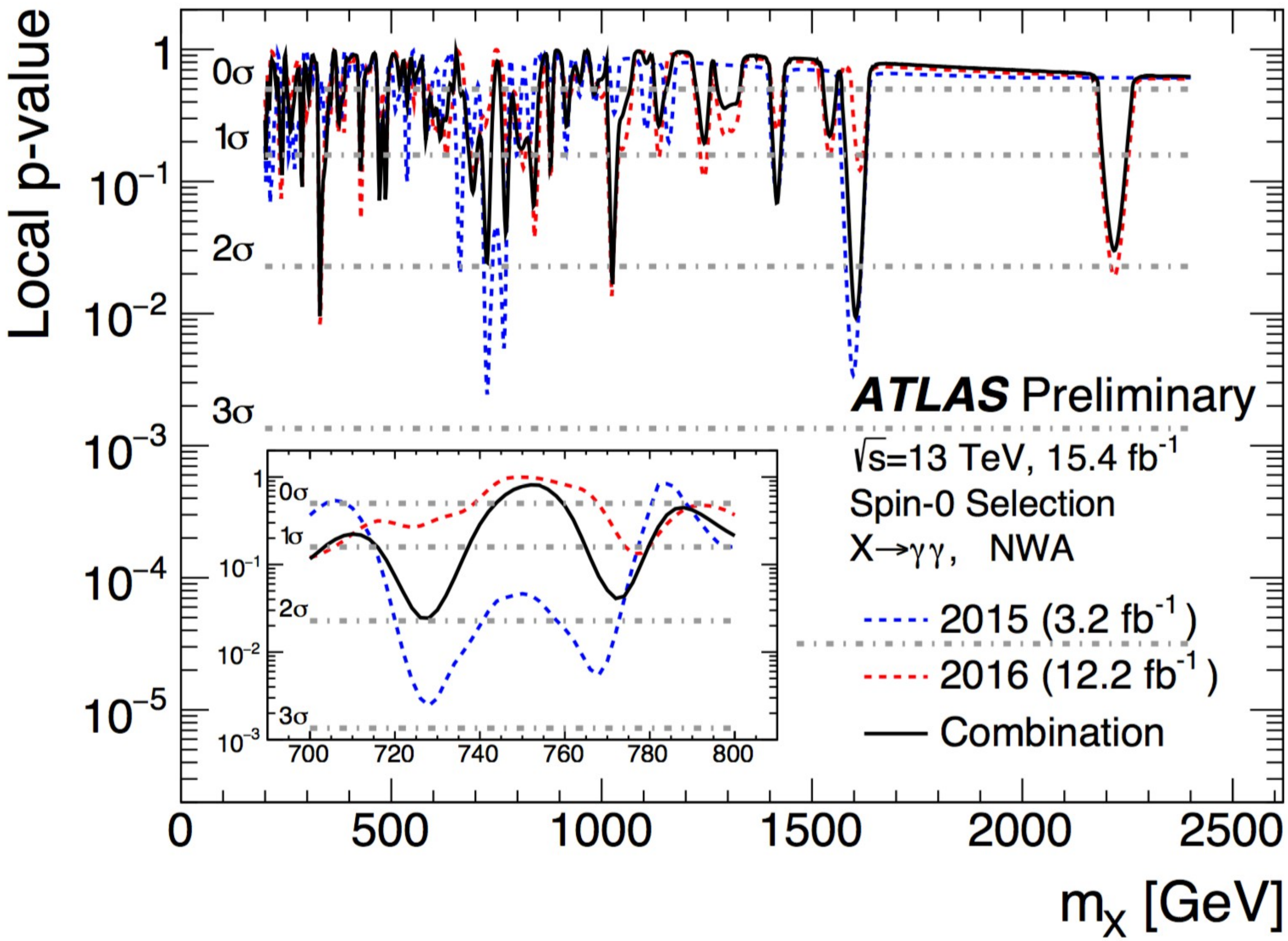
Largest significance for combined dataset is found at 1.6 TeV (2.4σ local)



New results: significances for large-width signal ($\Gamma_X/m_X = 10\%$)

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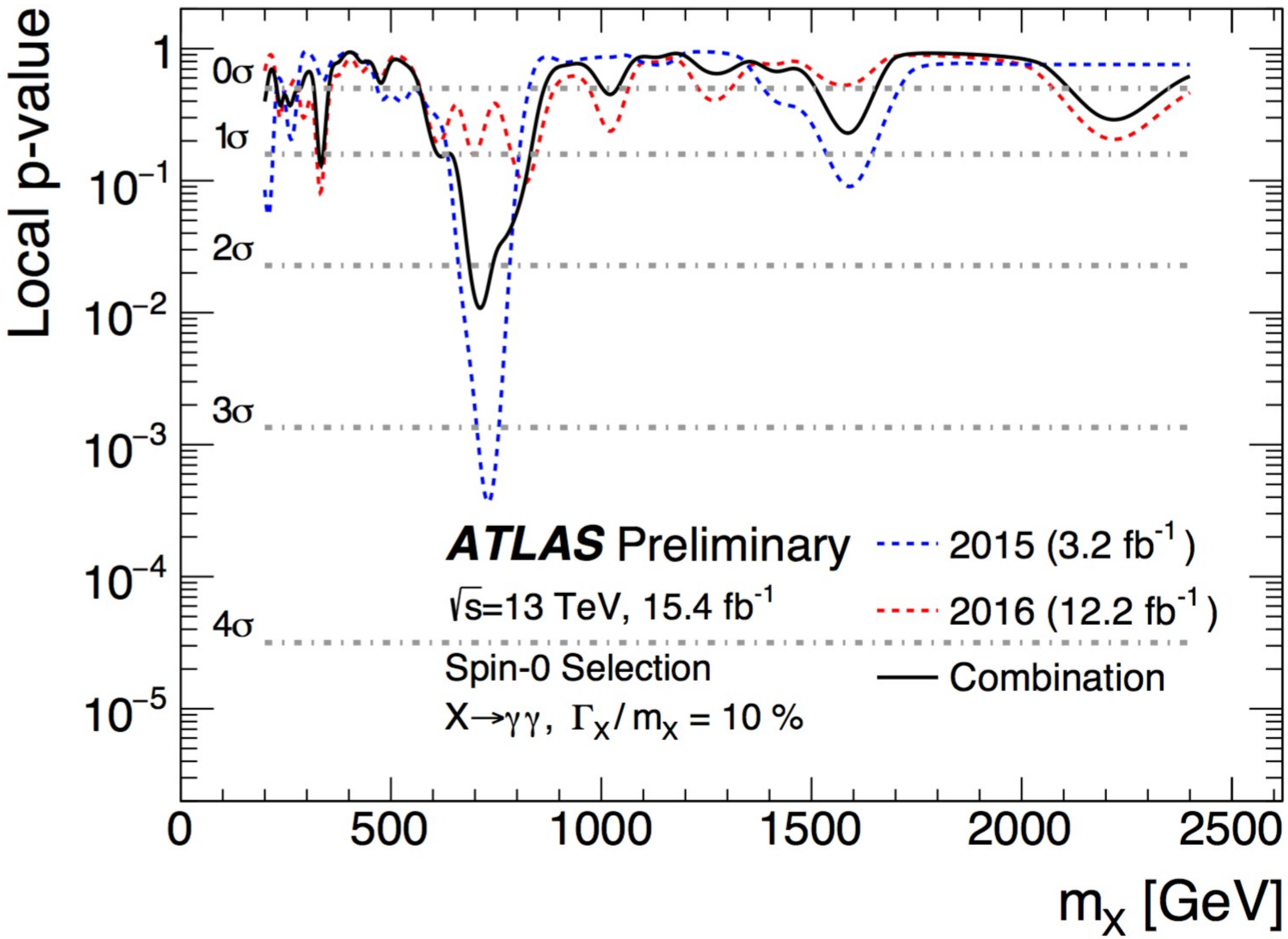
Around 700 – 800 GeV: 2.3σ local significance at 710 GeV for combined dataset



Limits

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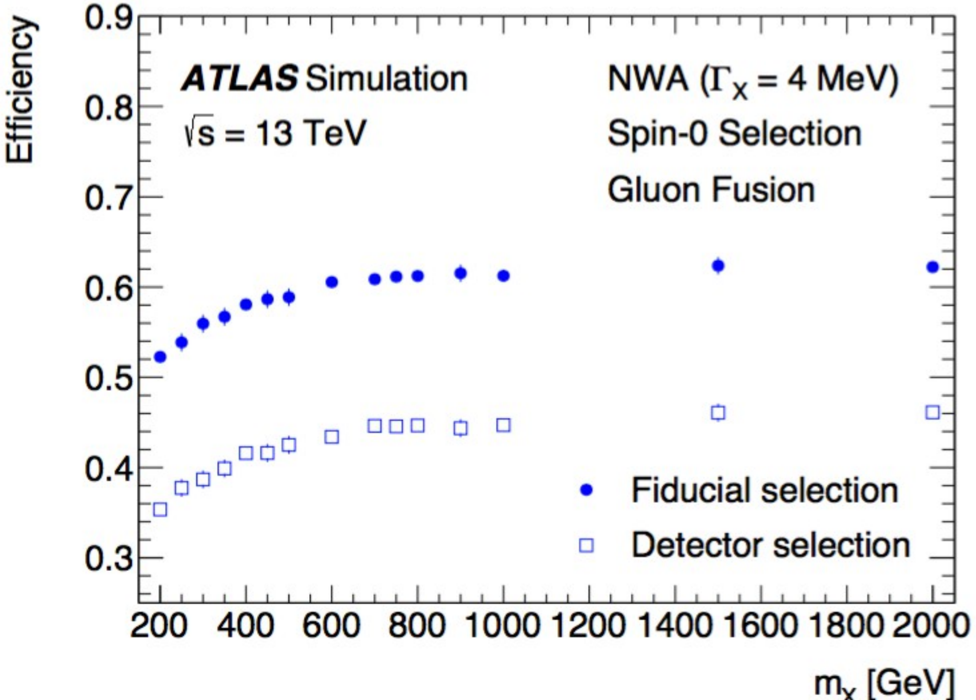
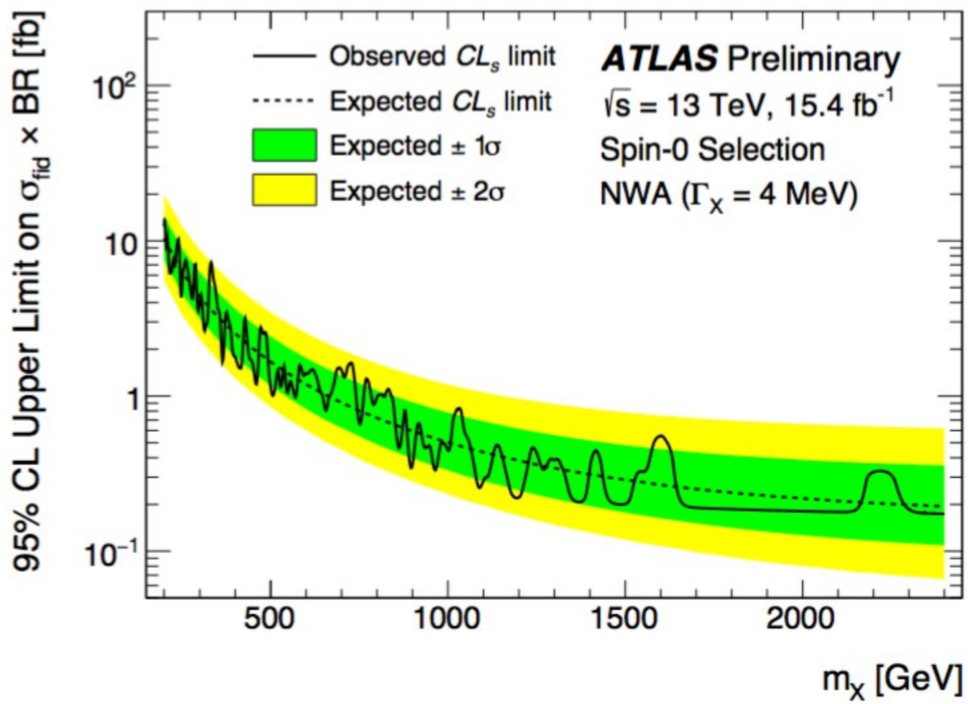


(from paper)



“Bump hunts” in similar final states

Di-lepton final state

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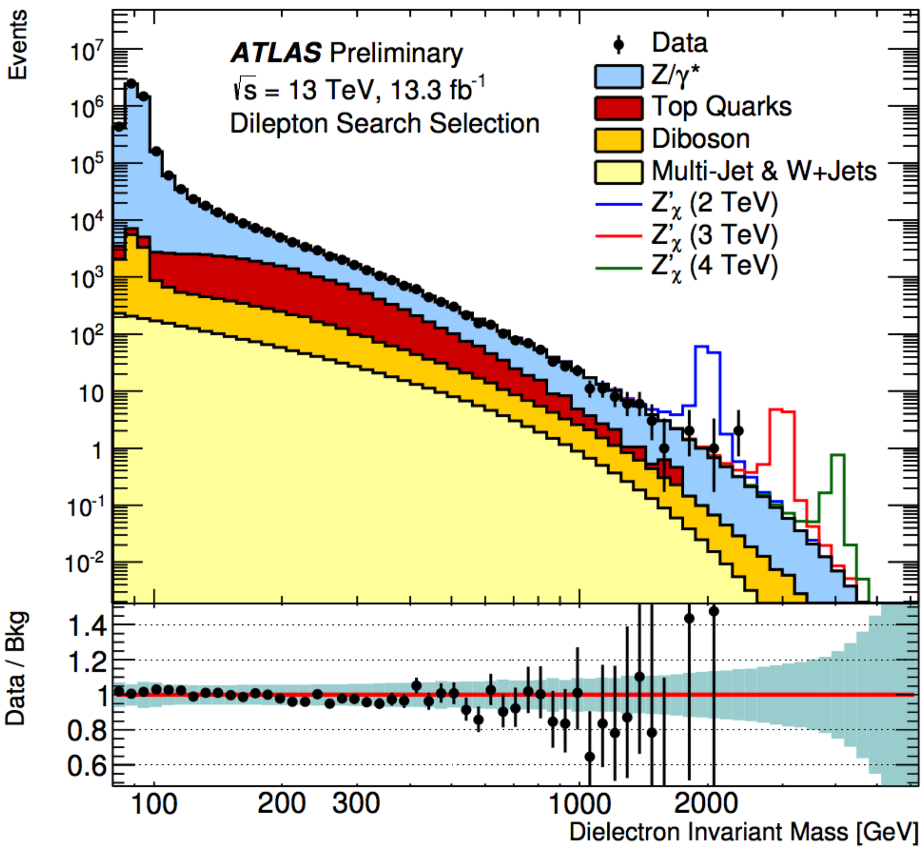
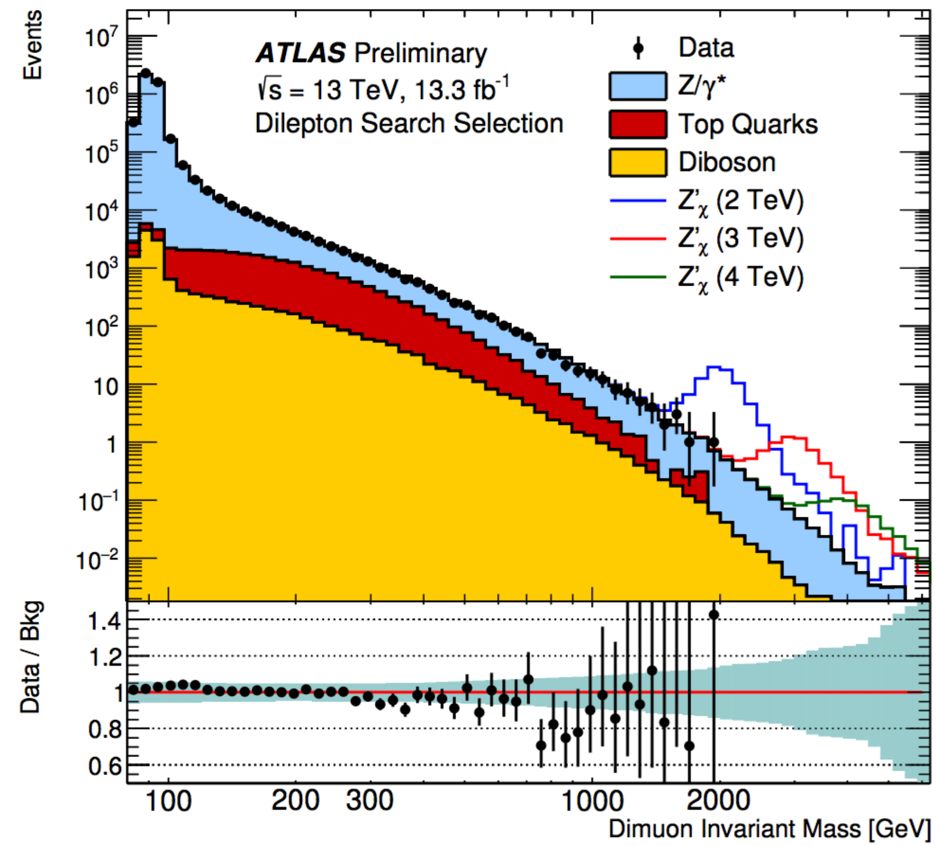
Main background: Z/γ^*
- simulate shape at NNLO
- normalise to data at low mass (Z peak)

Search for resonances and (or broad deviations).

di-electrons



di-muons



Di-lepton final state

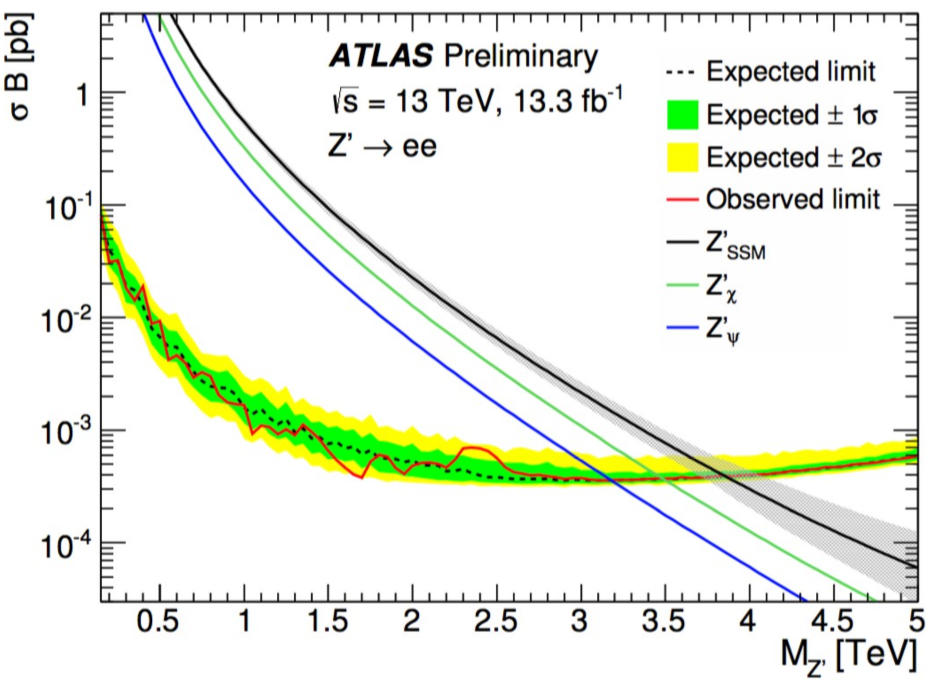
ATLAS-CONF-2016-045

Report exclusion limits as model-independently as possible.

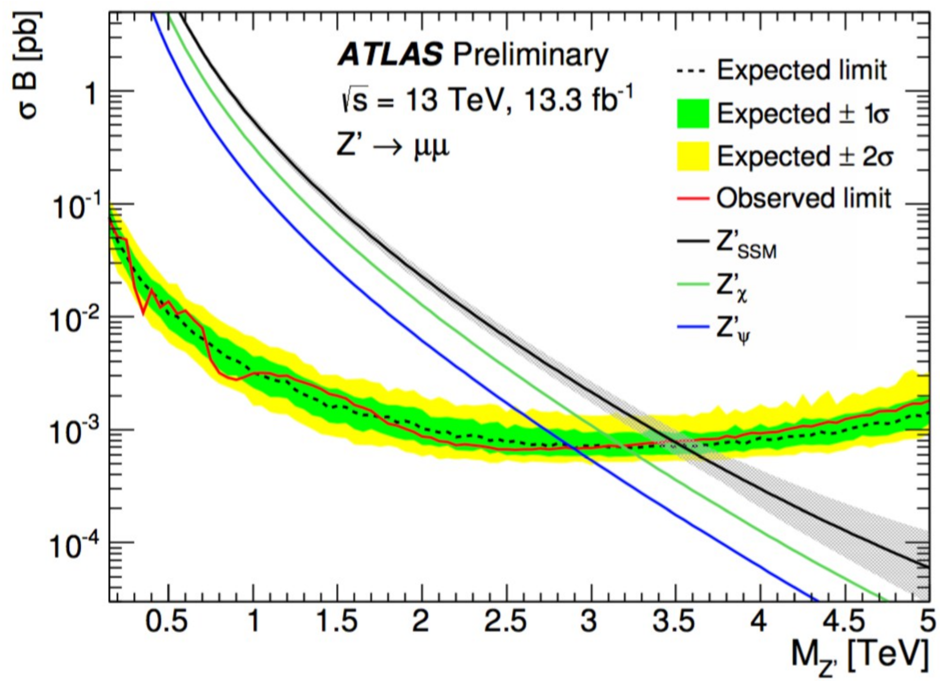
Show limits on $\sigma \times B$ as a function of resonance mass.

Superimpose mass-dependent model predictions for $\sigma \times B$.

di-electrons



di-muons



Zγ final state

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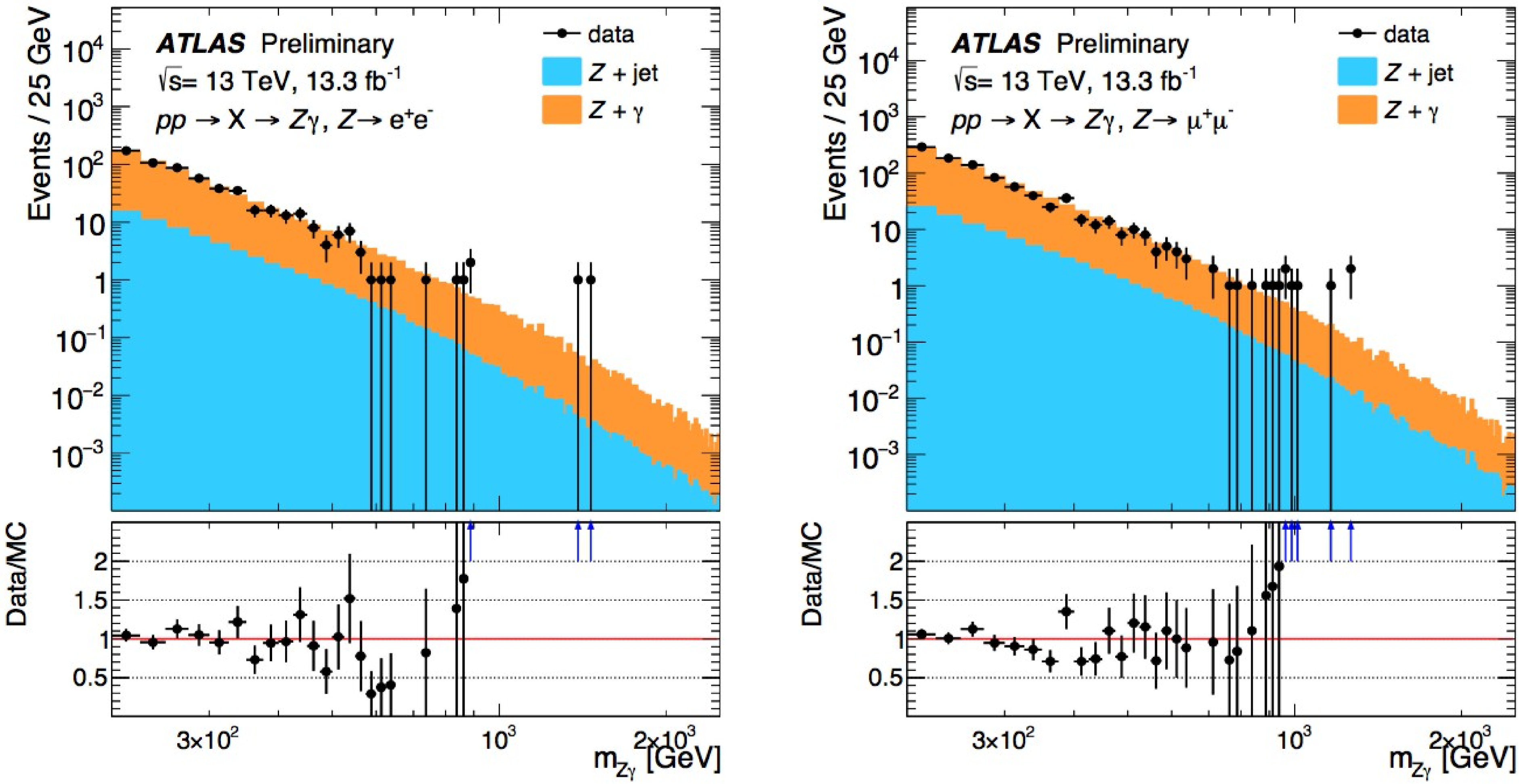
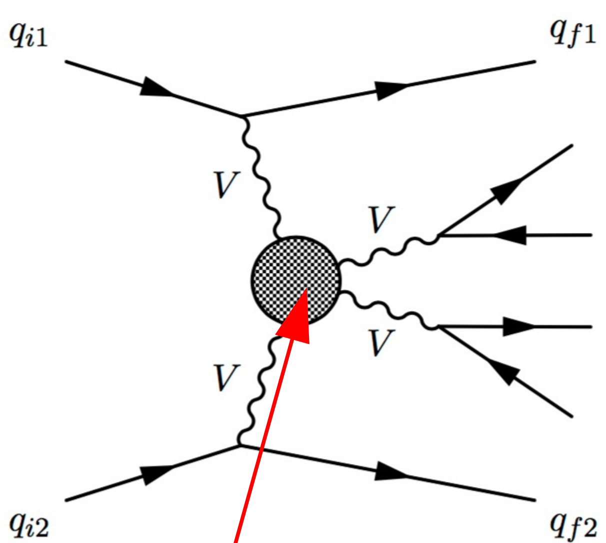


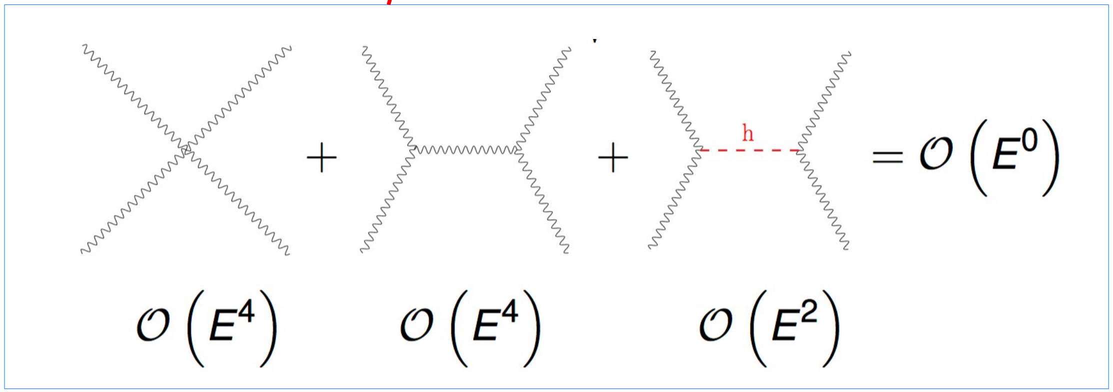
Search for heavy neutral resonances in Vector Boson Fusion

Theoretical motivation

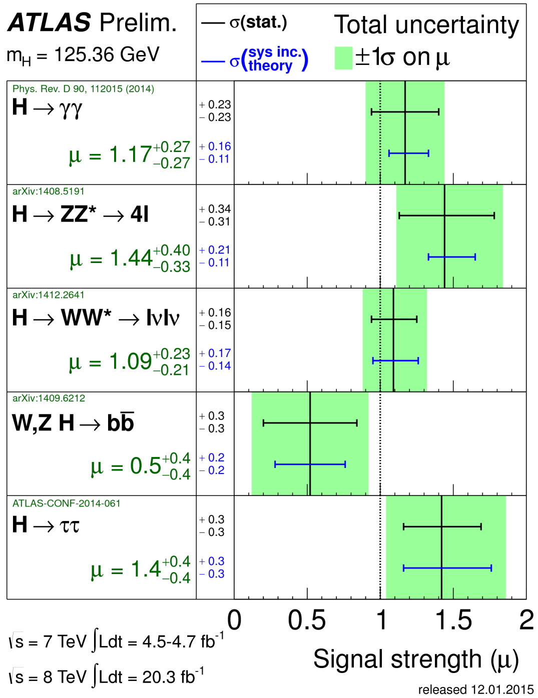
Vector boson scattering:



In a nutshell:
the "blob" in the standard model



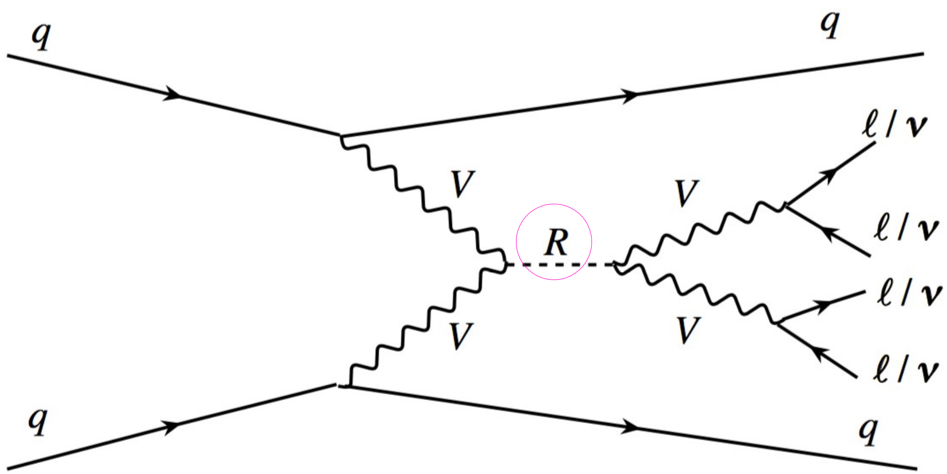
M. Sekulla's talk yesterday



Production rates for 125 GeV boson are consistent with predictions for SM Higgs within current uncertainties.

If values of Higgs coupling to vector bosons do not exactly take the values predicted by SM: alternative mechanism may be needed to restore unitarity; new resonances may appear.

Theoretical motivation



If the new resonances (R) have weak or no coupling to fermions:
VBS process could provide best sensitivity to these resonances in searches at the LHC.

New resonances predicted e.g. in composite Higgs, triplet Higgs, extra dimension models.

Type	Spin J	Isospin I	Electric Charge	Γ/Γ_0
σ	0	0	0	6
ϕ	0	2	$--, -, 0, +, ++$	1
ρ	1	1	$-, 0, +$	$\frac{4}{3}(\frac{v^2}{m^2})$
f	2	0	0	$\frac{1}{5}$
t	2	2	$--, -, 0, +, ++$	$\frac{1}{30}$

Use benchmark model with effective chiral lagrangian, implemented in Whizard.

Five new resonances of different spin and isospin.

Experimental considerations

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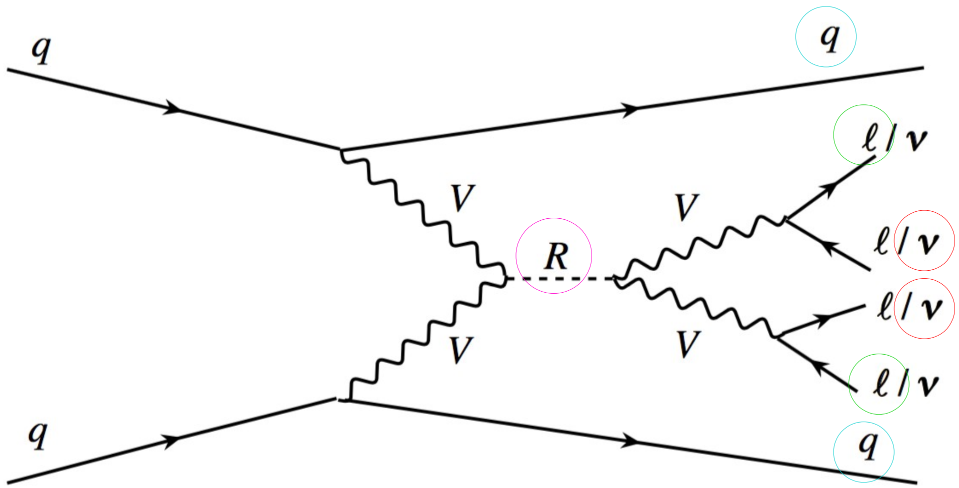

Signature:

- two charged leptons
- missing transverse energy
- two forward jets

Main backgrounds:

- Z+jets for ee and μμ channels
- t tbar for the eμ channel

#	Selection criteria
1	event preselection requirements, see text
2	exactly two leptons with $p_{\mathrm{T}} > 25$ GeV
3	pass single lepton trigger and trigger matching
4	third lepton veto
5	dilepton mass $m_{\ell\ell} > 40$ GeV
6	$q_{\ell_1} \times q_{\ell_2} < 0$
7	$\lvert m_{\ell\ell} - m_Z \rvert > 25$ GeV in the ee and $\mu\mu$ channels
8	at least two selected jets with $p_T > 30$ (50) GeV and $\lvert\eta\rvert < 2.5$ ($2.5 < \lvert\eta\rvert < 4.5$)
9	b-jet veto
10	$E_{\mathrm{T}}^{\mathrm{miss}} > 35$ GeV
11	$m_{jj} > 500$ GeV
12	$\lvert\Delta\eta_{jj}\rvert > 2.4$
13	$\eta_{j_1} \times \eta_{j_2} < 0$
14	lepton centrality $\zeta > -0.5$
15	$f_{\mathrm{recoil}} < 2.0$

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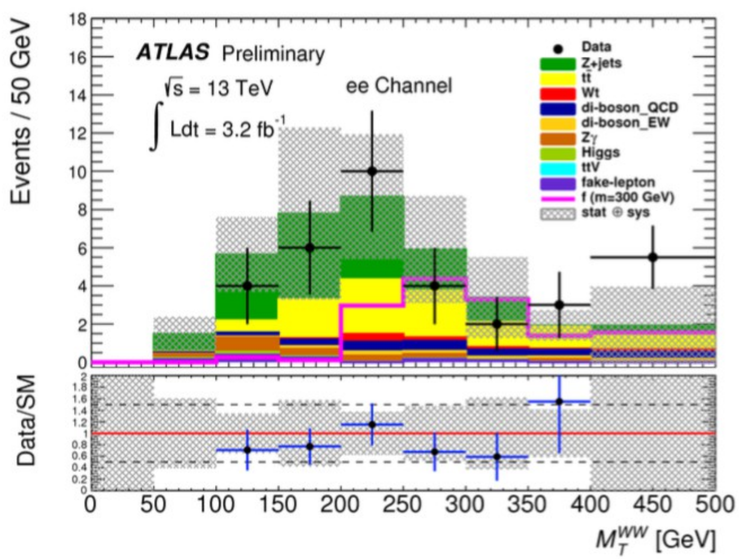
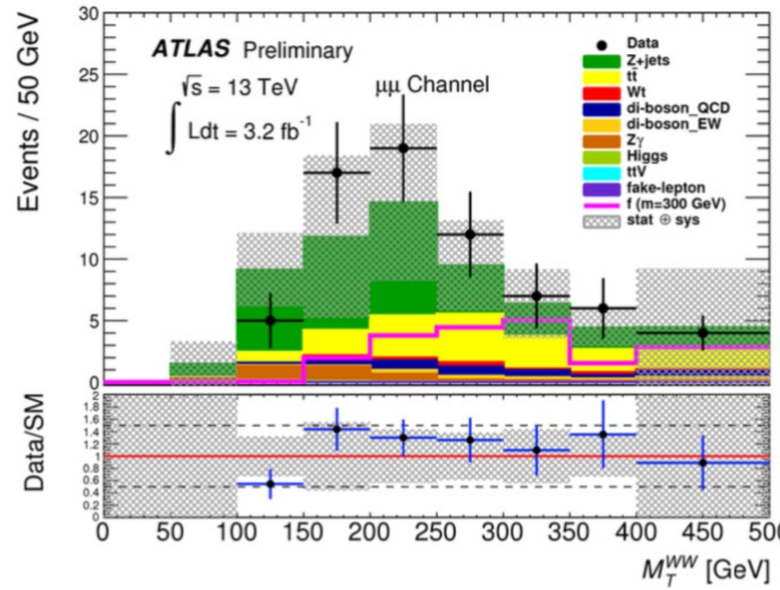
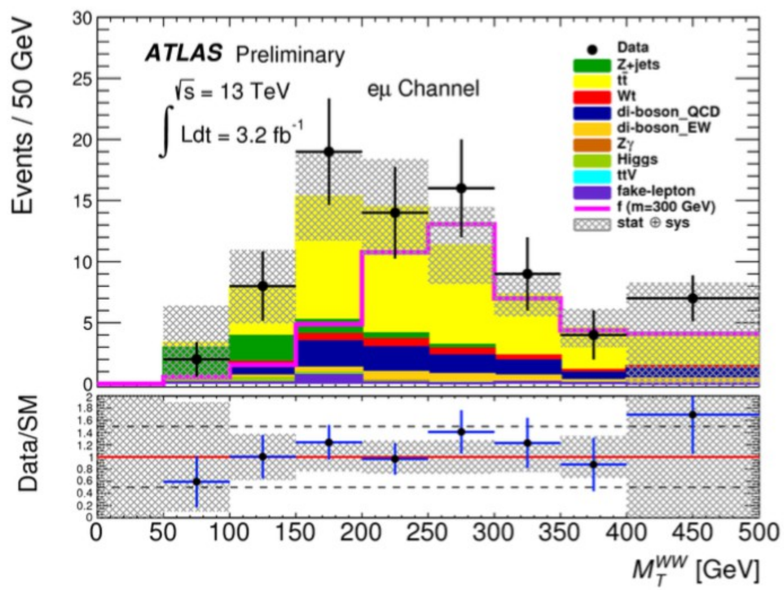
Results







Observed 95% CL exclusion limits in 200-500 GeV mass region:

380 – 220 fb for the σ particle

460 – 240 fb for the ϕ particle

330 – 270 fb for the ρ particle

340 – 260 fb for the f particle

310 – 260 fb for the t particle

Search for resonances decaying to VH [qqbb final state]

Hierarchy problem (cf. slide 2): huge radiative corrections to Higgs boson mass.

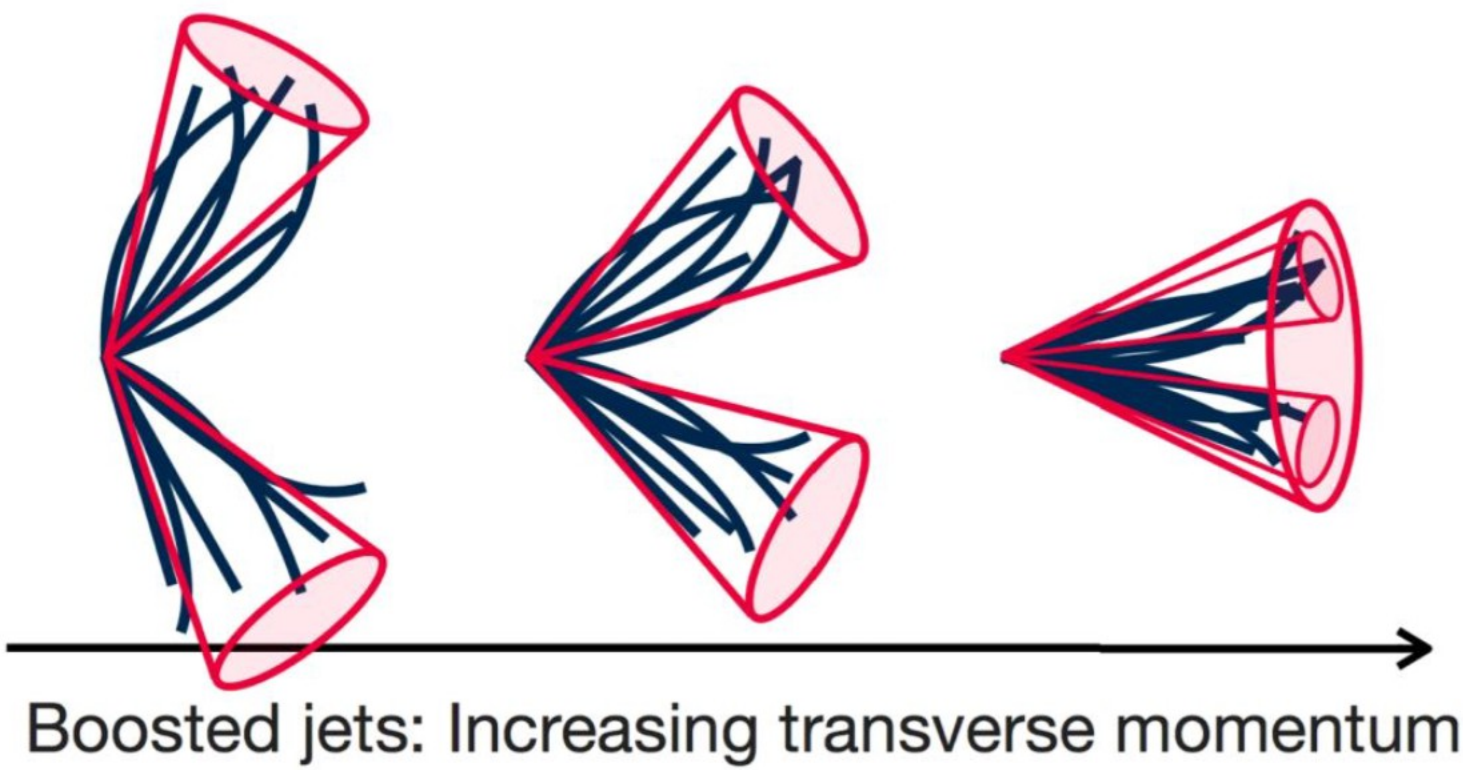
It is natural to expect new physics, at a mass scale not far above the Higgs mass, that couples to the Higgs boson – e.g. a new resonance that decays to a Higgs and other SM particles.

Reconstructing W/Z/H → qq

EW bosons have masses O(~100 GeV).

Searching for resonances with masses in the range of a few hundred GeV to a few TeV.

=> Wide range of values of boson p_T leading to distinct topologies for their hadronic decays:



VH → qqbb

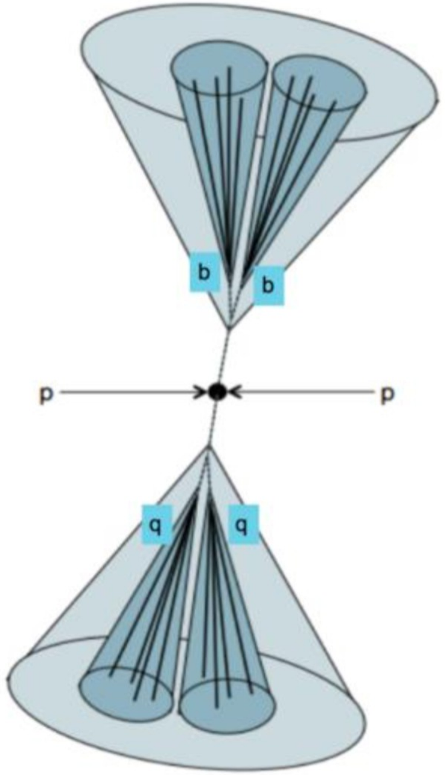
Complements VH → llbb/lνbb/ννbb (2015 results just published, updates coming soon)

Benefits from large branching fraction of W(Z) → qq: 67% (70%)

- qqbb competitive at high resonance mass (where multi-jet background diminishes)

Topology: 2 trimmed large-R (R = 1.0) anti-k_T jets with p_T > 450 GeV and p_T > 200 GeV

- V candidate: standard boson tagging (50% efficiency working point)
- H candidate: $75 < m_H < 145$ GeV, b-tagged small-radius track-jets



Dominant background: multi-jet events.
Data-driven estimate using the 0-b-tag sample

- Normalisation from 0-tag to t-tag and 2-tag sample in high-mass sideband of Higgs candidate
- Tested in validation region (low-mass V candidate sideband)

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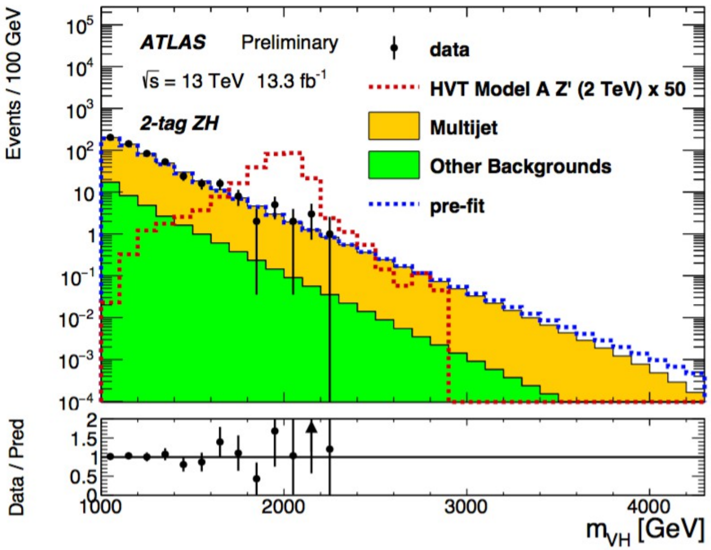
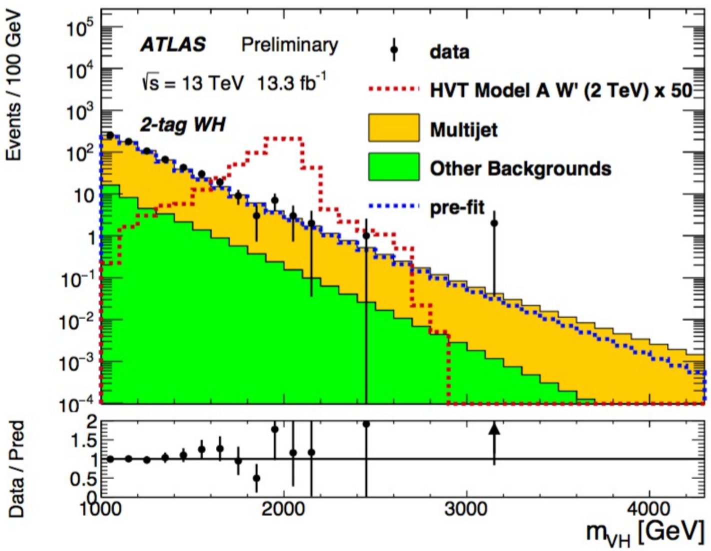
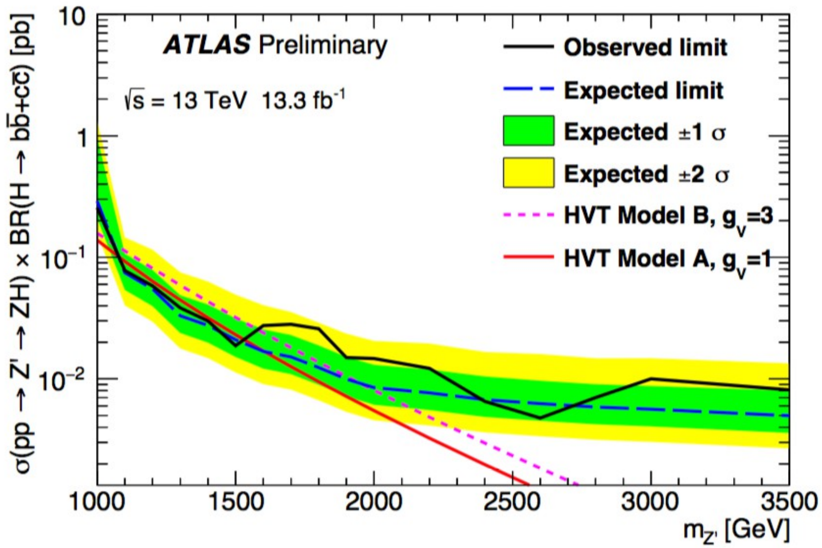
VH → qqbb

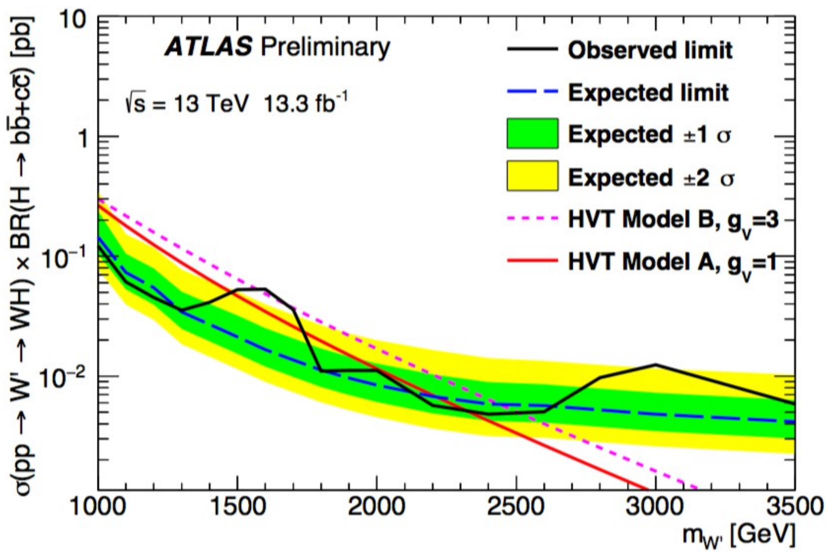




No excess observed in the data over the predicted background.

Sensitivity to σ x BR down to a few fb for resonance masses above 2 TeV.





Conclusions

A deluge of new results from the ATLAS collaboration for the Summer 2016 conferences:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Summer2016-13TeV

For this talk, made the choice to elaborate on a few selected highlights.
Specifically, highlighted three very different types of searches for physics beyond the standard model.

Classic “bump hunts”

Diphotons:
- spin 0 analysis updated with combined 2015+2016 dataset
- no excess with a global significance above 1σ
- broad excess around 750 GeV in 2015 data is not seen in 2016 data for spin 0 analysis

Dedicated search for new resonances produced in vector boson fusion

→ contribution to study of the scattering amplitude of longitudinal gauge bosons

Search for resonances decaying to VH (with highly boosted V and H)

Looking forward to the even larger data set that we continue to collect.

Acknowledgements

During the preparation of this talk, I have made ample use of slides from the following collaborators of mine:

Nikos Konstantinidis

Bruno Lenzi

Christos Leonidopoulos

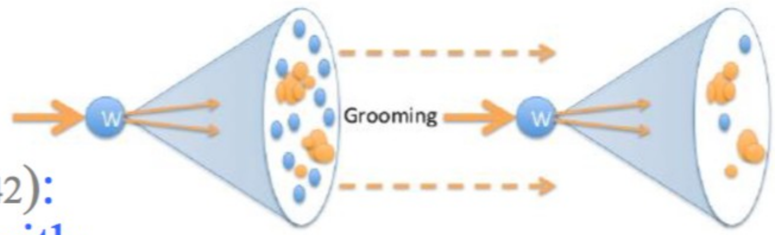
as well as slides from the following colleague from across the ring:

Chiara Rovelli

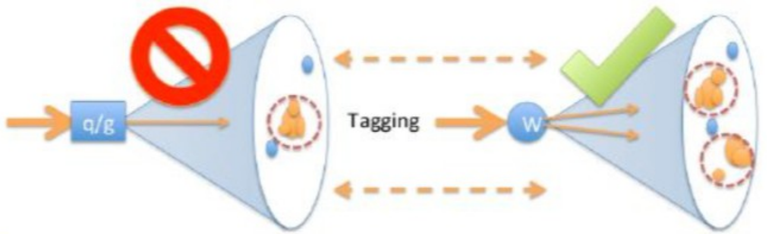
Additional material

Large-R jet techniques

- **Grooming:** to minimize impact of energy deposits from pile-up interactions
  - ATLAS mainly uses "Trimming" (arXiv:0912.1342): re-cluster with k_t R=0.2 and remove sub-jets with
  $$p_T^{\text{subjet}} / p_T^{\text{jet}} < 0.05$$



- **W/Z boson tagging:** ATL-PHYS-PUB-2015-033
  - m_J consistent with m_W/m_Z within $\pm$15GeV
    - W and Z windows overlap
  - Sub-structure consistent with two-prong decay
    - Most popular variable: $D_2^{(\beta=1)}$ (arXiv: 1409.6298, 1507.03018)
    - Typical WP: ε=50%, QCD rejection factor ~50



- **Higgs boson (b-) tagging:** ATL-CONF-2016-039
  - Match to anti-k_t R=0.2, b-tagged track-jets