Search for a high mass diphoton resonance using the ATLAS detector

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On behalf of the ATLAS Collaboration

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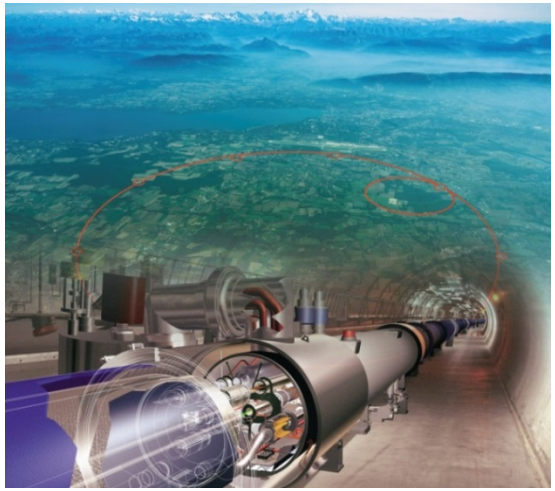
Outline

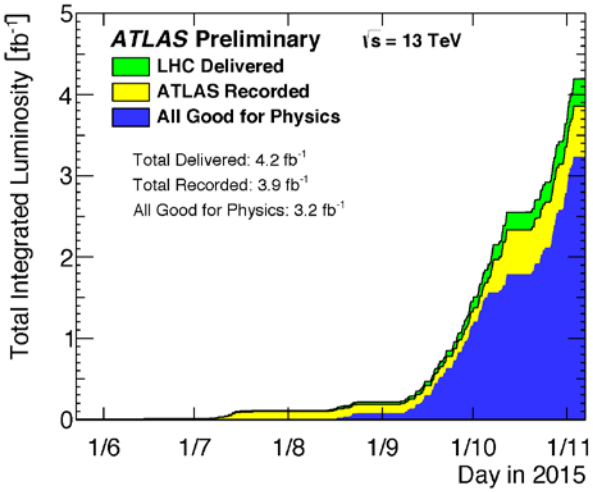
- LHC and Atlas detector
- Identification and reconstruction of photons
- Analysis Models and Results from 7 and 8 TeV
- 13 TeV analyses:
  - Analysis strategy
  - Event selection
  - Signal and Background modeling
  - Results
- Conclusion and prospects

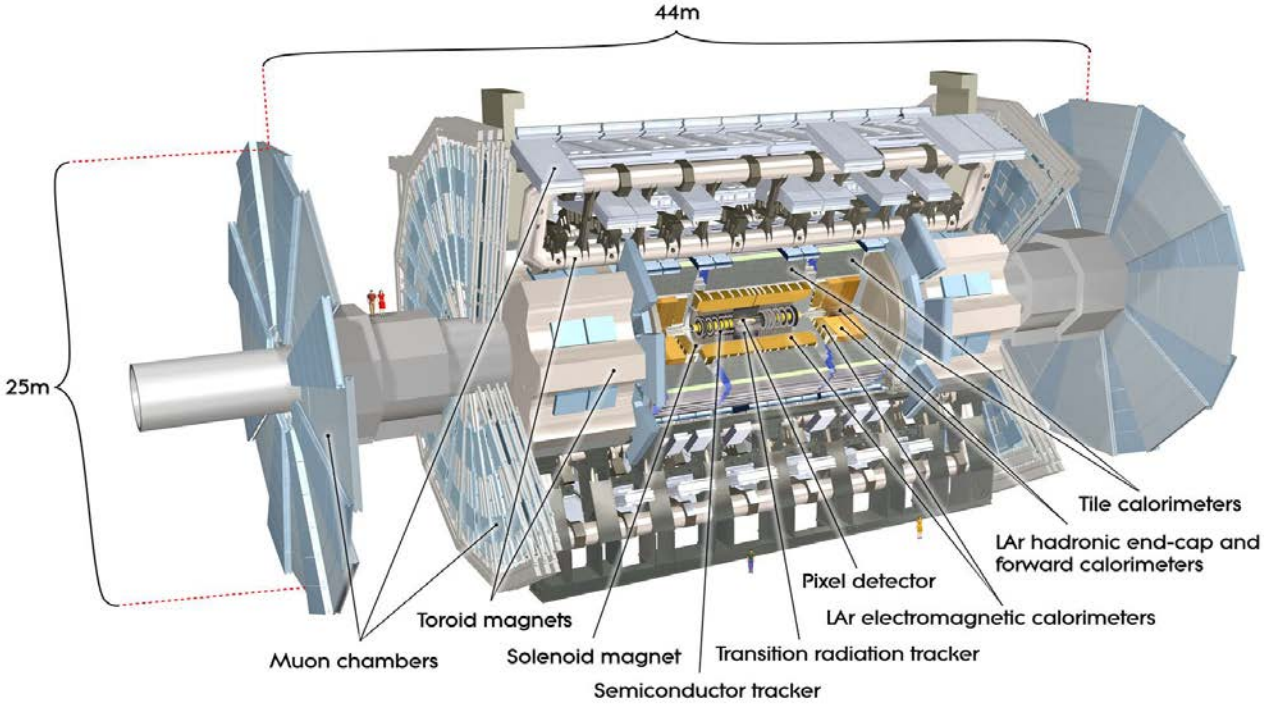
ATLAS experiment at LHC

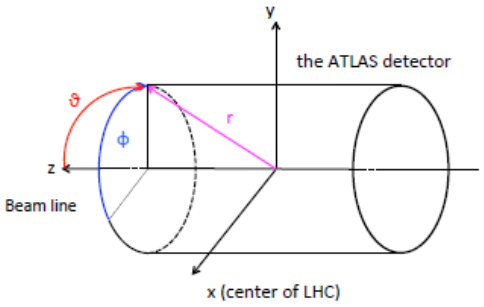


- pp collisions
- Run-1: 7 and 8 TeV (20 fb^{-1})
- Run-2: 3.2 fb^{-1} (2015)

arXiv:1606.03833 (June 13th)

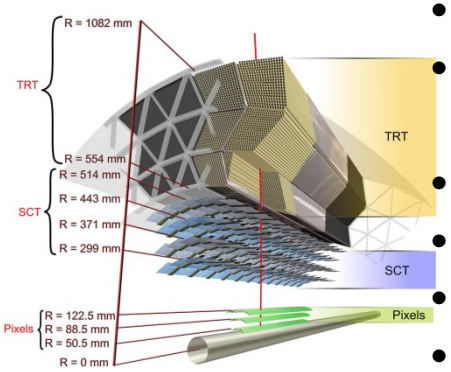






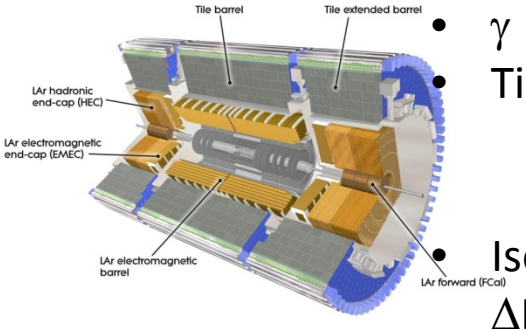
$$\eta = -\ln\tan(\frac{\theta}{2})$$

Photon Reconstruction and Identification

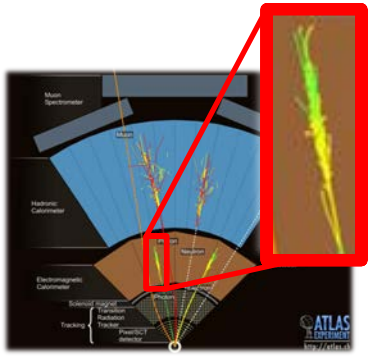


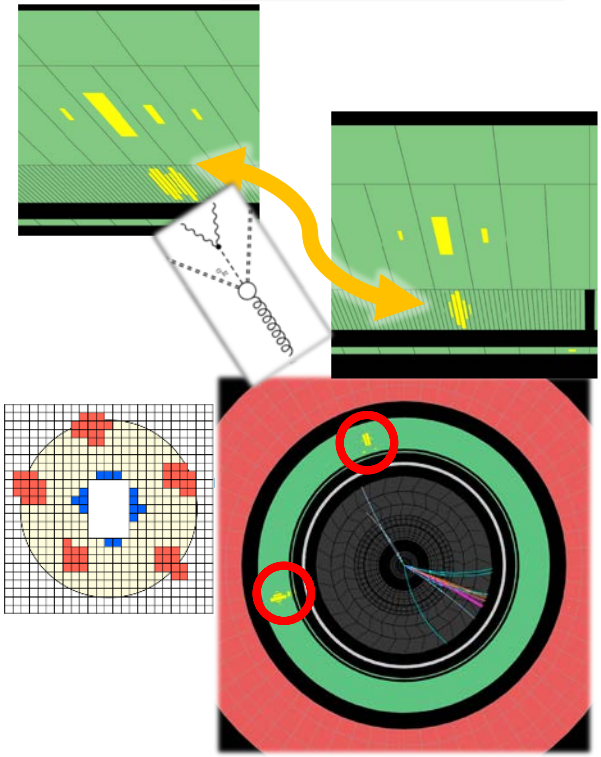
- Clean signature
- Good mass resolution of diphoton system
- Moderate level of background (prompt $\gamma\gamma$)

- γ from energy deposits in the ECAL
- Tracks to determine electron or γ candidate
- Calorimeter Energy resolution: 1.2%
- γ cluster reconstruction eff.~ 100%

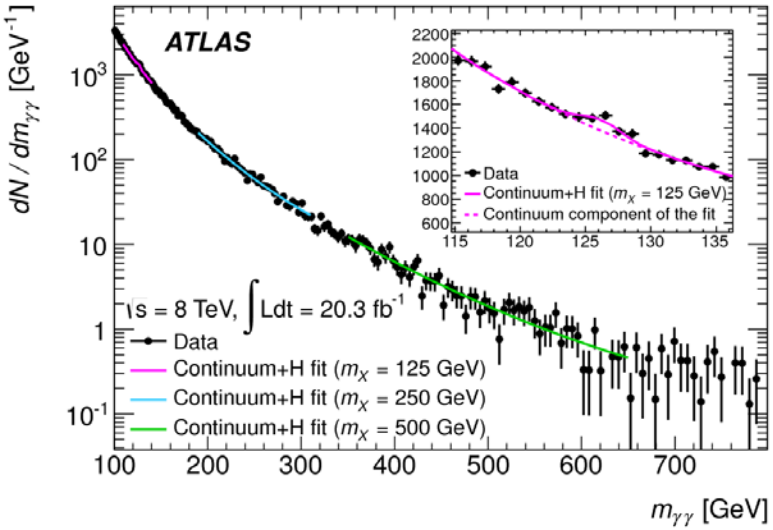


- γ ID : tight and loose selections
- Tight ID efficiency:
  - 85% at E_T~50 GeV
  - 95% at E_T~200 GeV
- Isolation Energy in the CALO in a cone of $\Delta R=(\Delta\phi^2+\Delta\eta^2)^{0.5}=0.4$
- Track Isolation variable (p_T^{iso}) in a cone of $\Delta R=0.2$





Resonances in diphoton channel at 8 TeV in BSM (Spin 0) Higgs searches

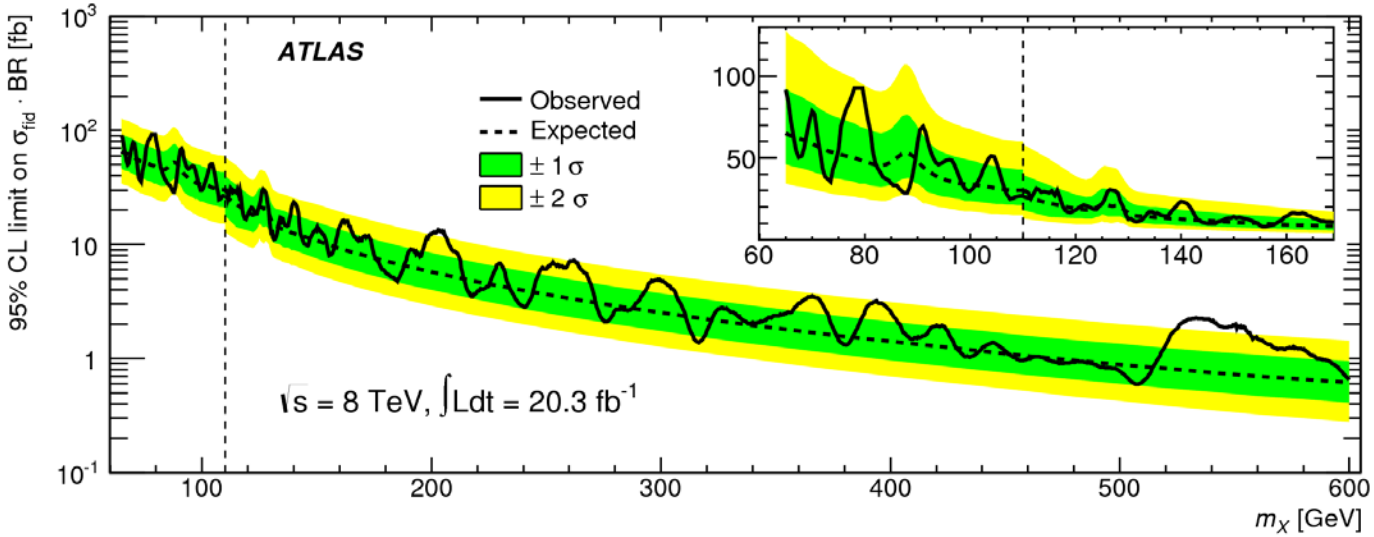


Phys. Rev. Lett. 113, 171801 (2014)

Spin 0 heavier Higgs (> 125 GeV)

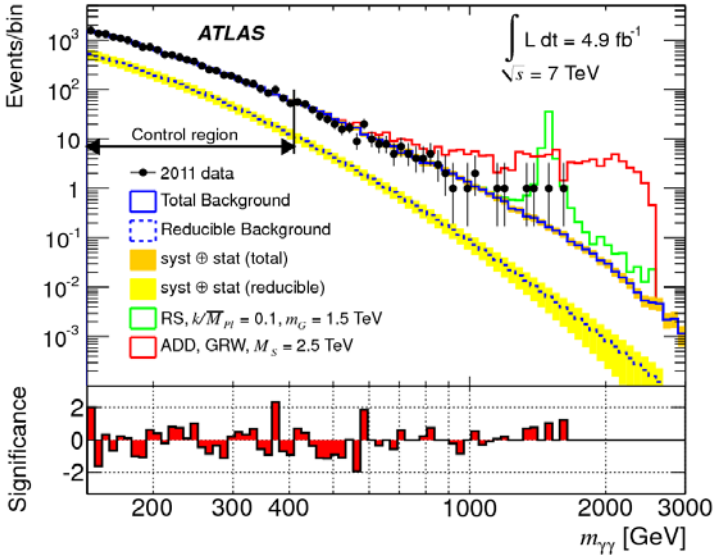
- Several extensions of Higgs sector foresee additional scalar States
- Narrow resonance

No significant excess found up to 600 GeV

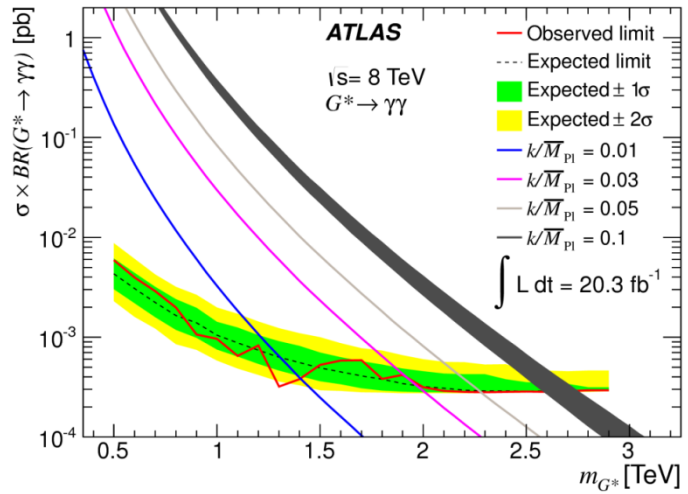


Resonances in diphoton channel
7 and 8 TeV in Graviton (Spin 2) analyses

New J. Phys. 15 (2013) 043007



Phys. Rev. D 92, 032004 (2015)



Performed in Randall Sundrum (RS) or ADD (Large Extra Dimension) models

- Additional dimensions where only gravity propagates → Reduced effective value of the Planck scale in the SM brane
- For the RS Graviton the coupling with the SM, $k/\overline{M}_{pl}$ is proportional to the width of the resonance

Graviton m_{G*} excluded to 2.66 TeV for $k/\overline{M}_{pl}$ =0.1

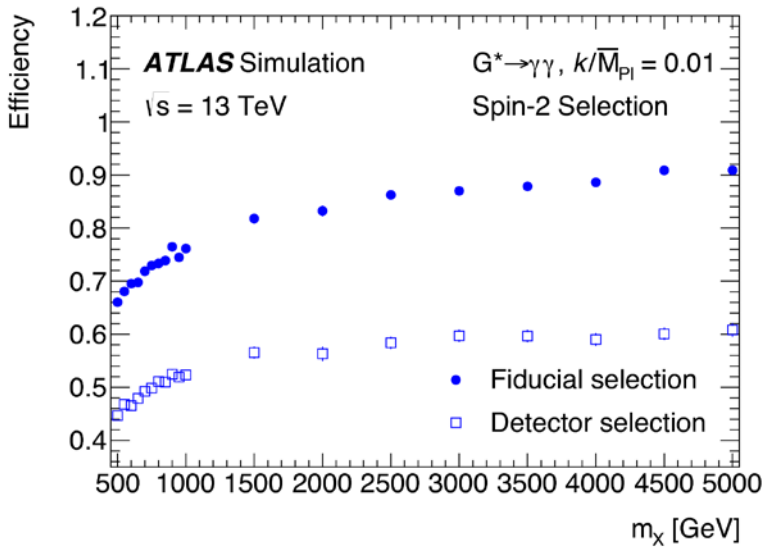
Analysis Strategy for the 13 TeV 2015 data

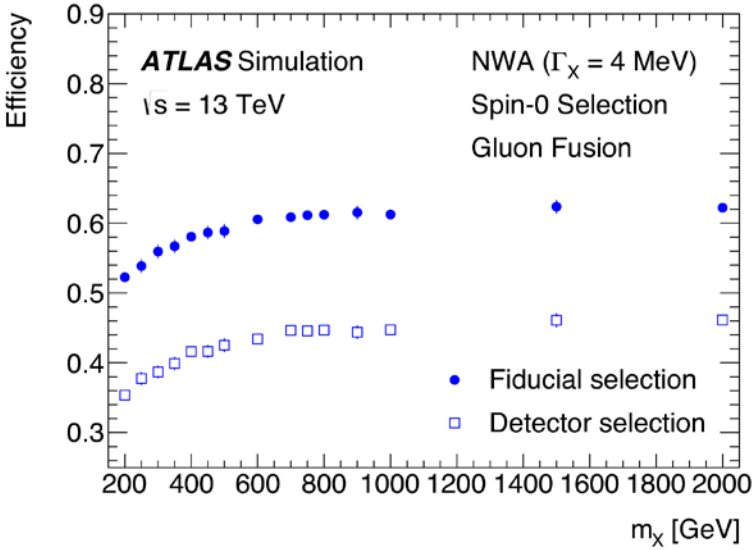
- Spin 0:
  - Extended Higgs sector in mass range [200 GeV;2 TeV] and widths up to 10% of m_X ($\Gamma_X/m_X < 0.1$)
  - Signal modeled using Powheg-Box+Pythia 8
  - Background modeled using data-driven method, smooth function fitted to data
- Spin 2:
  - Randall-Sundrum model with graviton excitation G* in mass range [500 GeV;5 TeV] and dimensionless coupling k/M_{pl} ranging from 0.01 to 0.1 (13 TeV → 0.3); $\Gamma_{G^*}=1.44(k/M_{pl})^2 m_{G^*}$
  - Signal modeled using Pythia 8
  - Background modeled using MC template method built from Sherpa LO multi-leg, MC reweighed by fixed order NLO QCD
- Signal + Background fit the $m\gamma\gamma$ distribution
- Statistical treatment: test the Background (B) only hypothesis over the S+B hypothesis on data

13 TeV Analyses: Event Selection

- 2 γ of highest p_T in $|\eta|<2.37$
- Diphoton trigger: 35 and 25 GeV E_T threshold
- Spin-2 : $p^{\gamma}_T > 55$ GeV
- Spin-0 : $p^{\gamma}_T/M_{\gamma\gamma} > 0.4$ (0.3) Leading (subleading) γ
- Calorimeter En. Isolation $< 0.022\, p^{\gamma}_T + 2.45$ GeV
- Tracking p_T Isolation $< 0.05\, p^{\gamma}_T$
- Primary vertex selected using the γ pointing technique

Fiducial acceptance ●
Fiducial acceptance x detector efficiency □

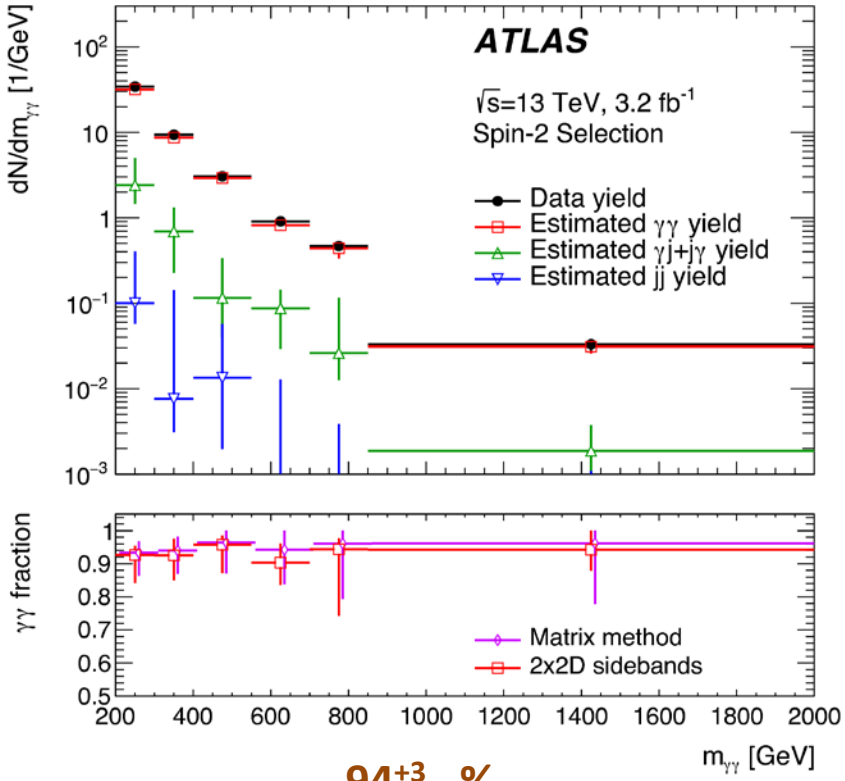




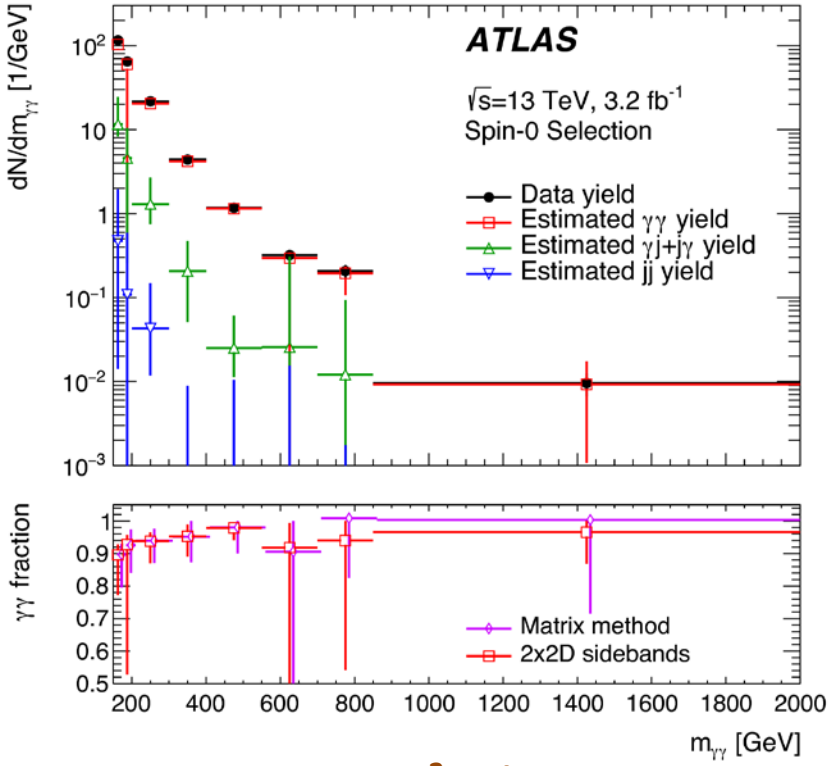
Purity of the selected diphoton sample

Checked with:

- 4x4 matrix method
- 2x2 sidebands method



94^{+3}_{-7} %



93^{+3}_{-8} %

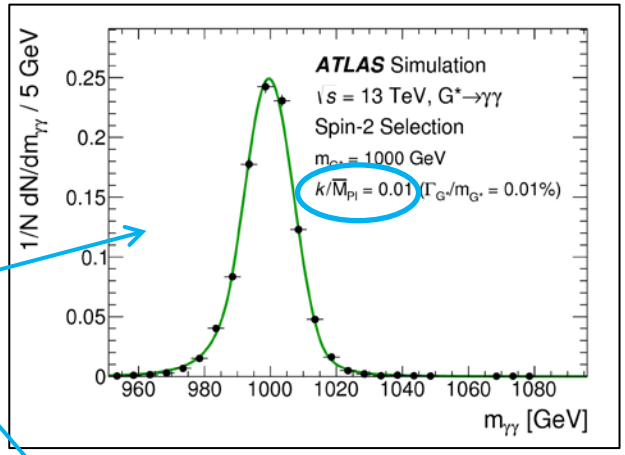
Signal Modeling

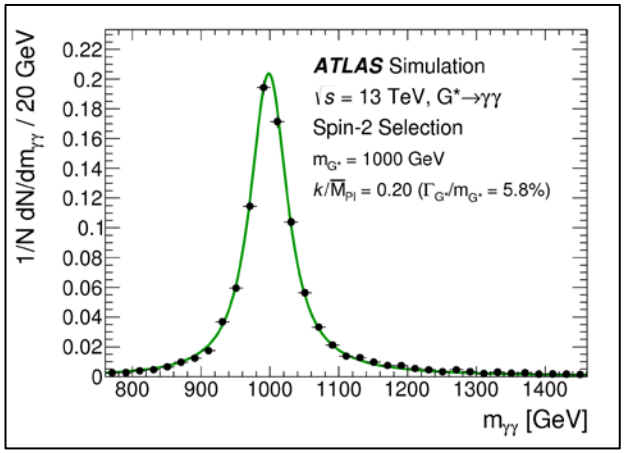
Convolution of detector resolution described by a DSCB (Double-Sided Crystal Ball)

Spin 2:

with Breit-Wigner-like on the mass line shape of RS graviton model

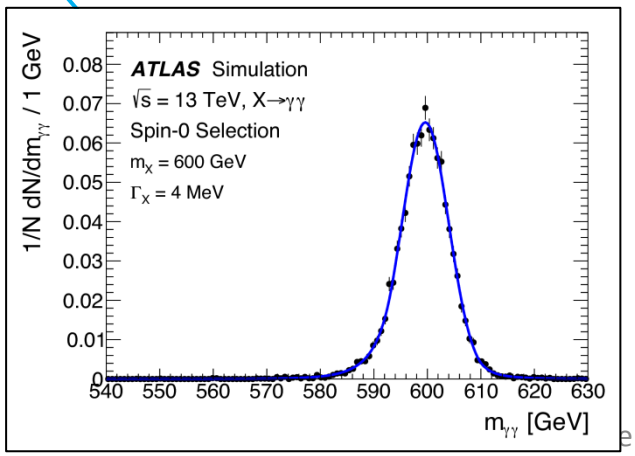
Show mainly the detector resolution

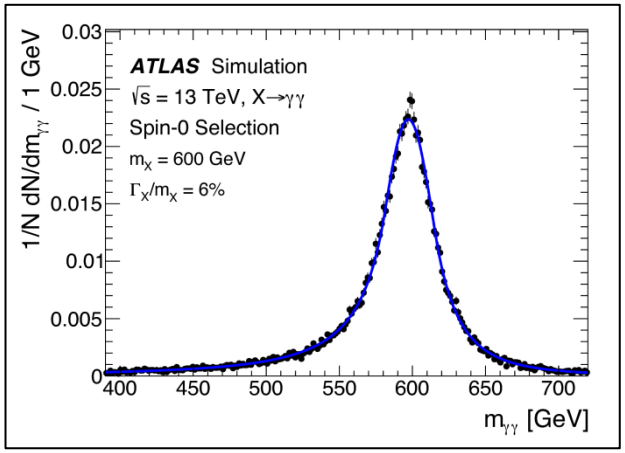




Spin 0:

With mass line shape of Higgs-like particles using PowHeg-box+Pythia8





Spin 2: Background Modeling (1)

Irreducible background

- Fully simulated Sherpa multi-leg LO mγγ
- Normalized to data at low mass [200,500] GeV
- The NLO QCD parton-level calculation Diphox is used to describe the shape of the mass spectrum of the irreducible γγ background
- The result from Diphox is used to reweight the Sherpa in Fullsim samples
- → mγγ shape uncertainties:
  - PDF eigenvector variations: 40% at 3.5 TeV
  - PDF choice : up to 5%
  - parton-level photon isolation modelling: up to 10%
  - QCD renormalisation and factorisation scale: up to 5%

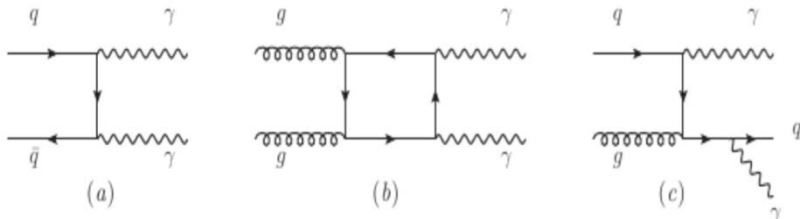


Figure 2: Feynman diagrams of photon pair production, at the lowest order in terms of α_s.

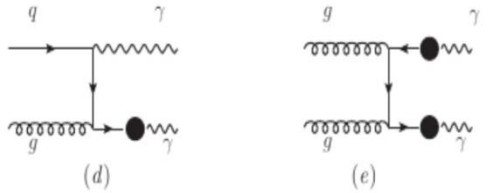
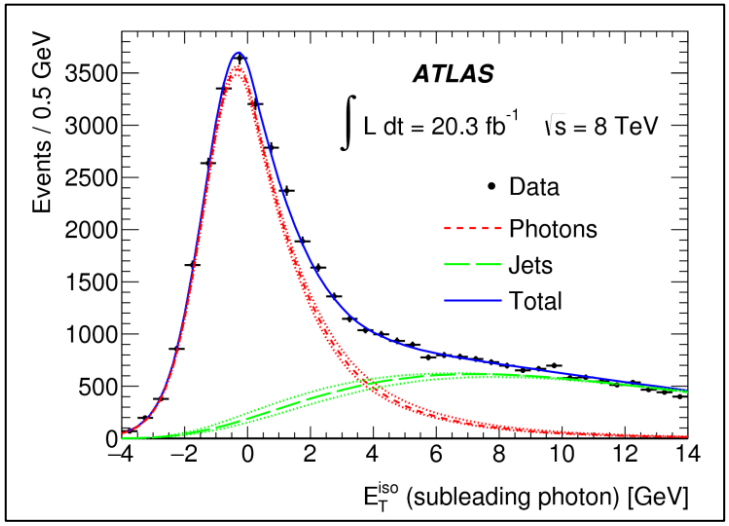


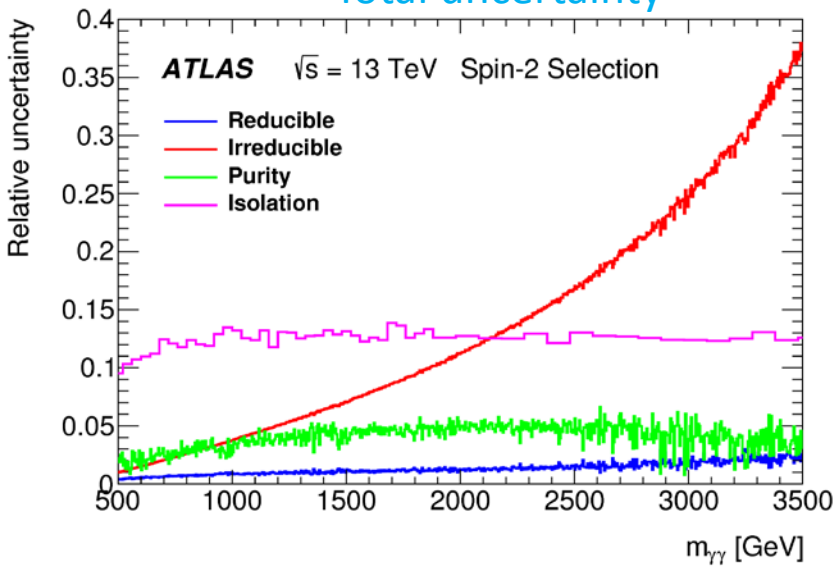
Figure 3: Feynman diagrams of the fragmentation contribution at LO to the irreducible background.

Spin 2: Background Modeling (2)

- Reducible background is γj , jγ , jj (leading, sub-leading)
- Shape from reducible background in anti-tight γ ID
- Normalization from fit to Isolation distributions in control regions at low mass [200,500] GeV



Total uncertainty



← Dominated by PDFs

← Parton-level Isolation cut in Diphox

Spin 0: Background Modeling

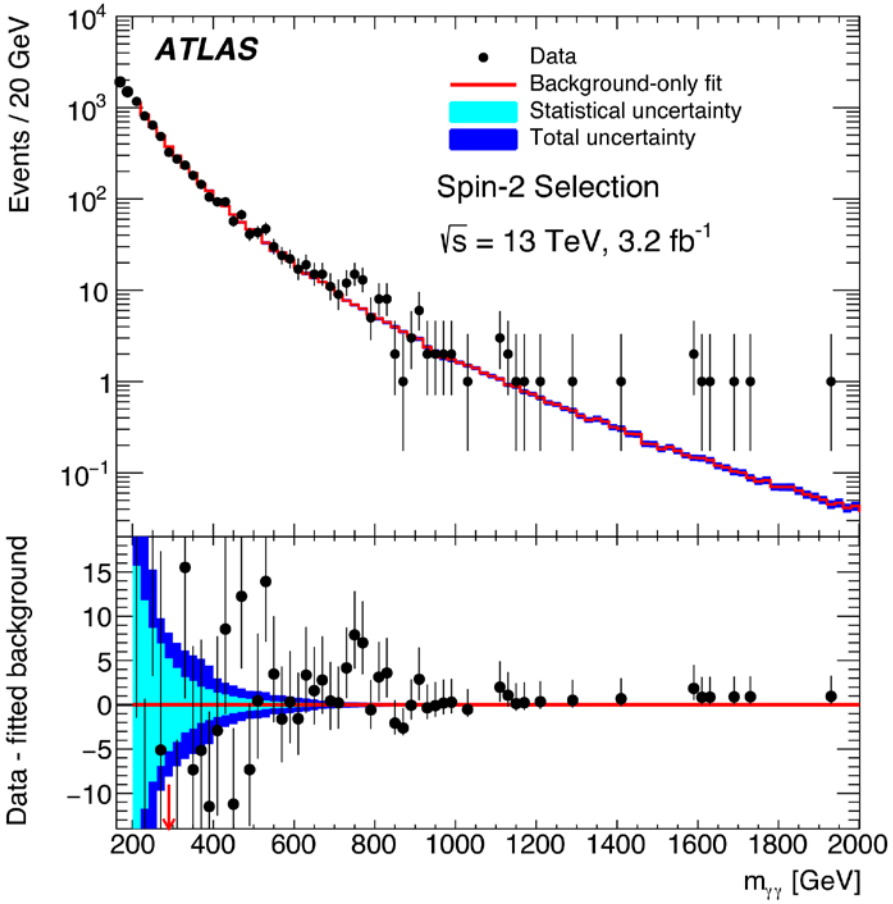
mγγ shape is a function fit on data

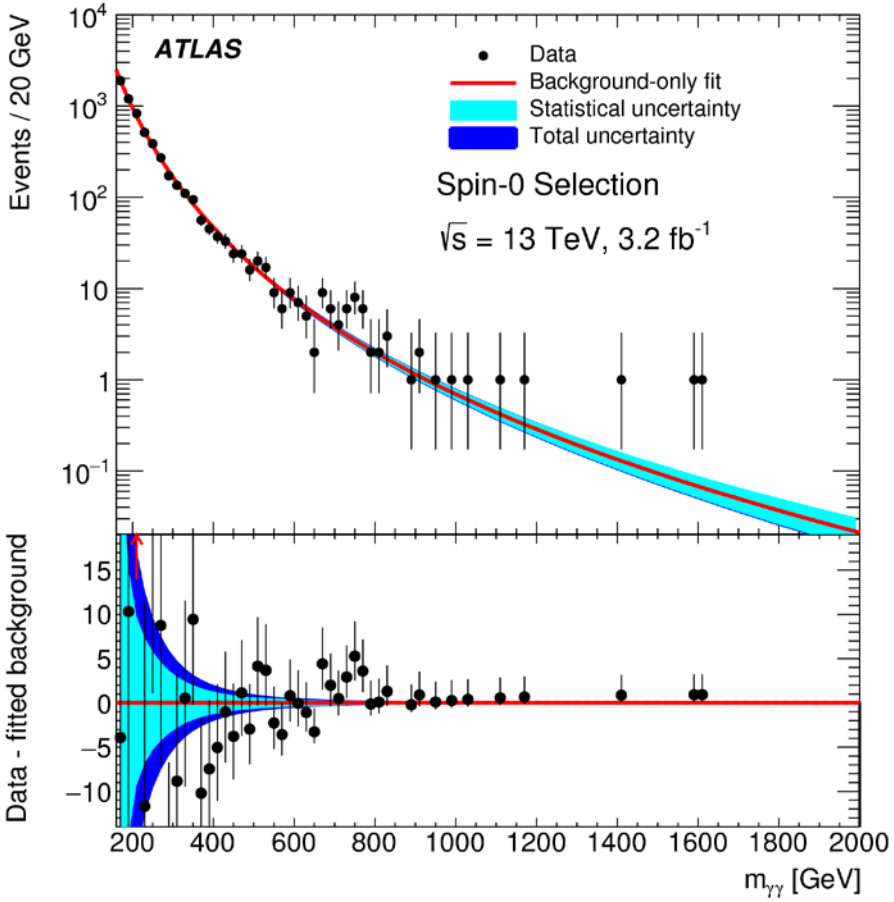
$$f_{(k)}(x; b, \{a_k\}) = N(1 - x^{1/3})^b x^{a}$$

- Fit function chosen from S+B fit to background template only, built using γγ Sherpa MC and γj/jj from a control sample data → fitted S (spurious signal)
- S < 20% of the statistical uncertainty on the fitted signal yield

Spurious signal found in background ~ 20 to 0.04 events from 200 GeV to 2 TeV

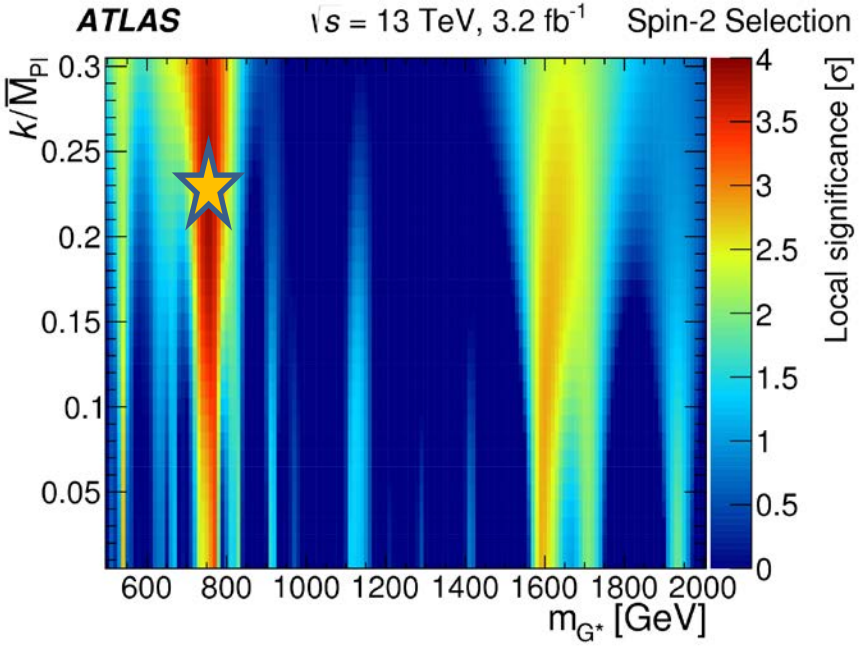
Diphoton Mass distributions
13 TeV – 2015 data



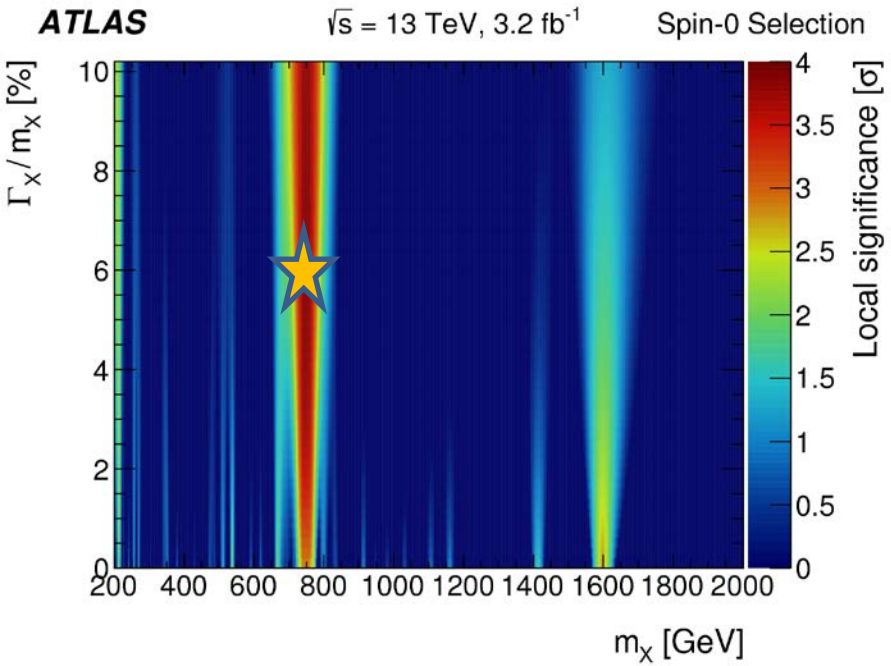


Significances
scan in the mass-width plane

Largest deviation at 750 GeV
and coupling $k/\bar{M}_{pl}$=0.23 (57 GeV)
Local σ=3.8; Global σ=2.1

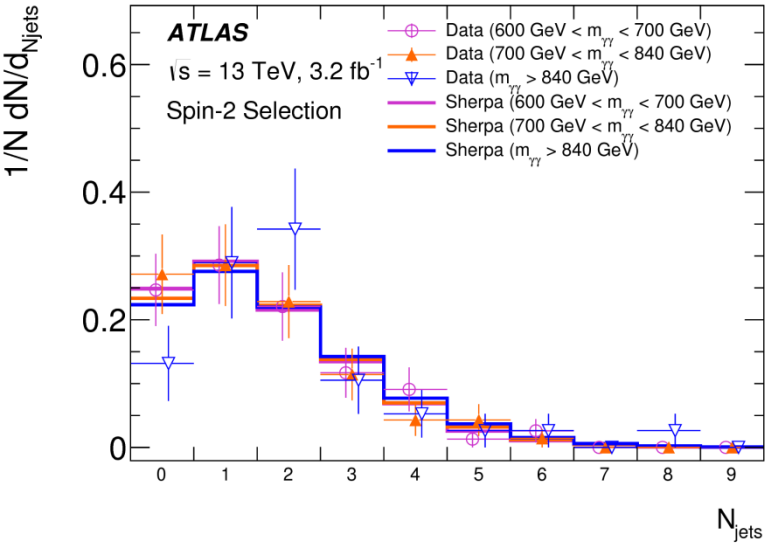


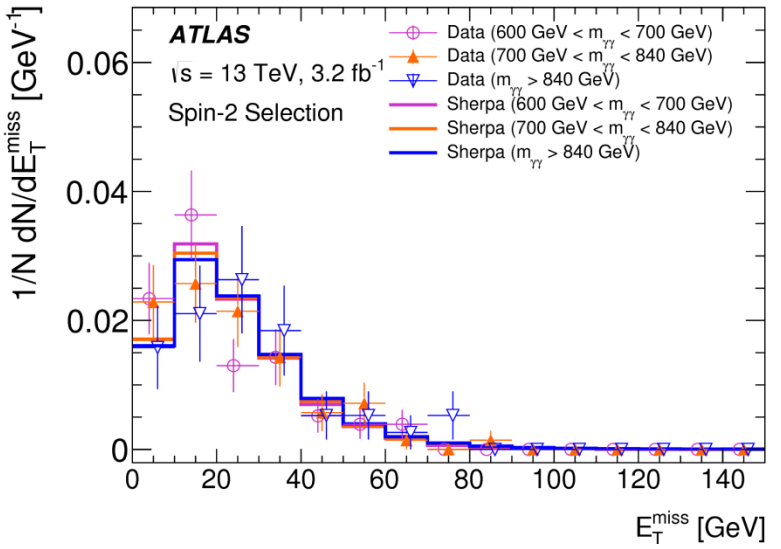
Largest deviation at 750 GeV
and Γ_X/m_X=6% (45 GeV)
Local σ=3.9; Global σ=2.1

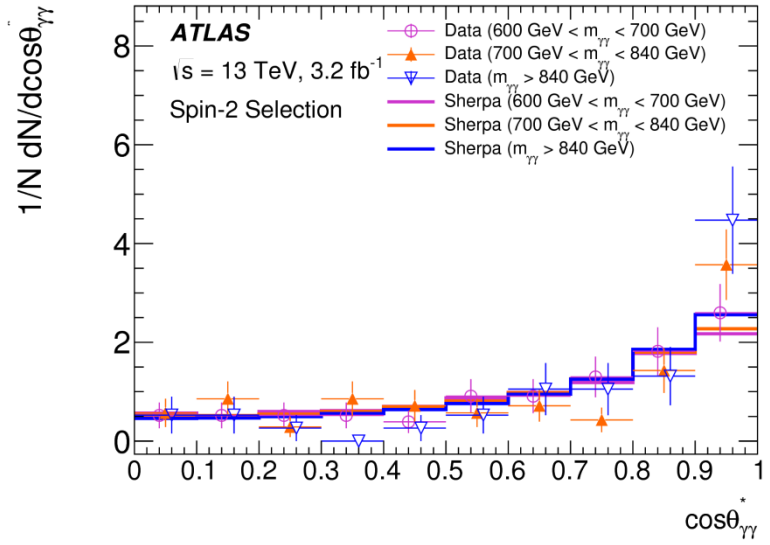


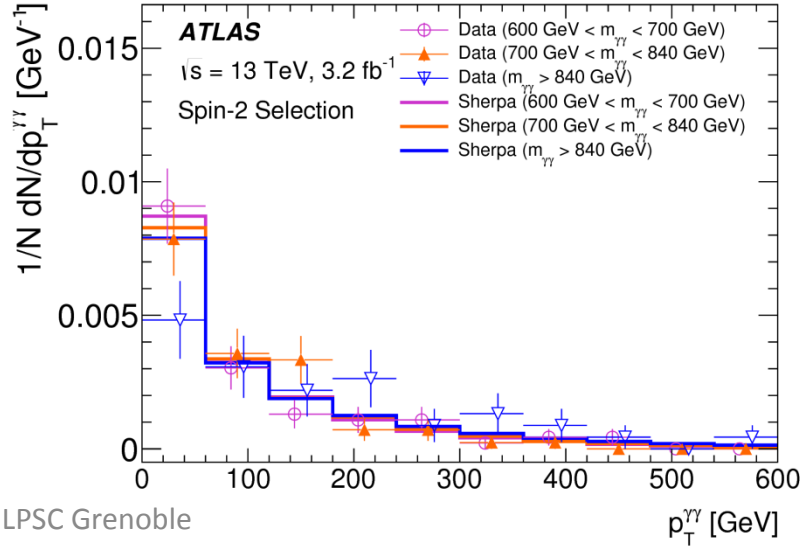
Global significance: called also, the look elsewhere effect :
Search in a large bi-dimensional phase space ($k/\bar{M}_{pl}$, m_X) or (Γ_X, m_X).
Background-only MC toys were used in
→ m_X range: [500,2000] GeV; $k/\bar{M}_{pl}$ range: [0.01,0.3]; Γ_X range: [0%,10%]

Checks of kinematic distributions in excess region and side bands

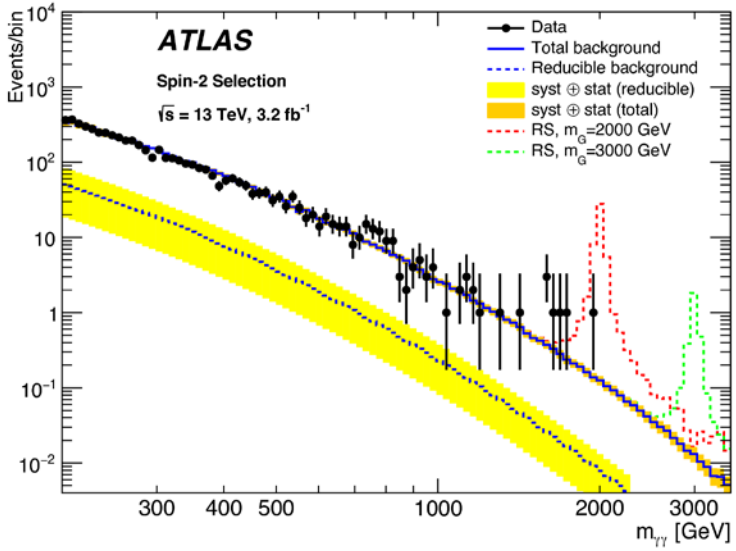


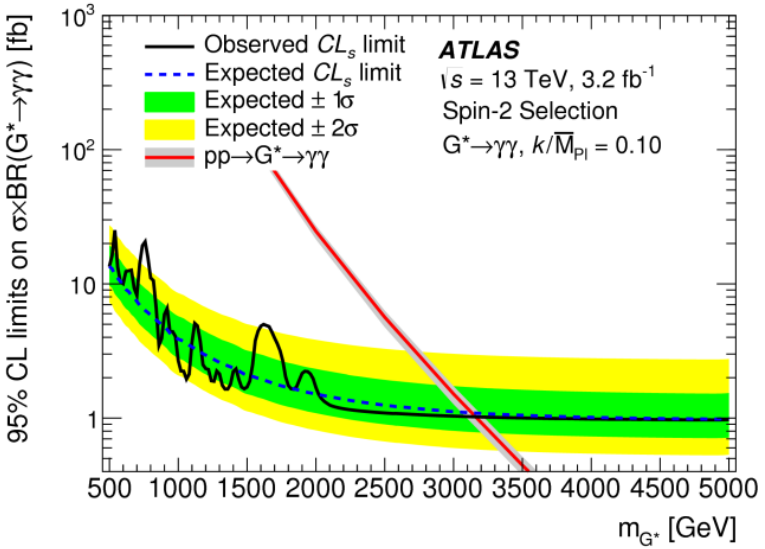






Graviton Searches with RS Model
Limits Settings





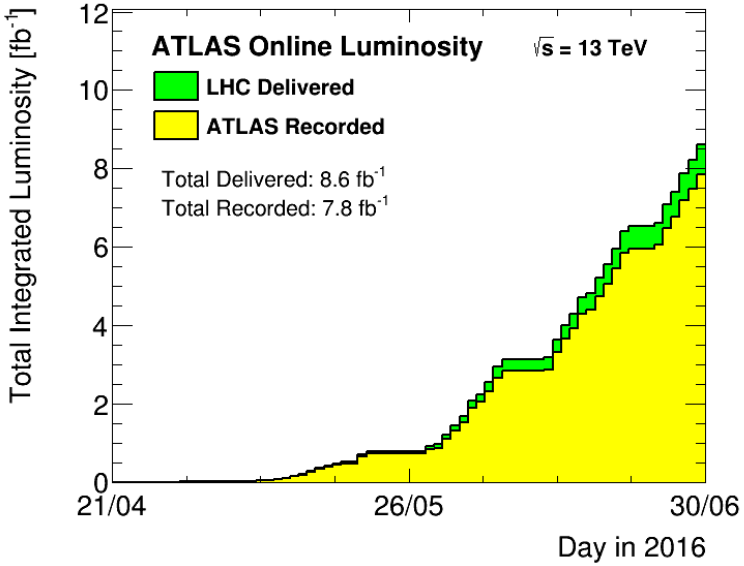
- Observed limits are compared with theory prediction (red line)
- m_{G^*} exluded to 3.4 TeV for $k/\overline{M}_{pl}=0.1$ (2.66 TeV@8TeV)

Conclusion & Prospects

- Observation of an excess at 750 GeV @ Global significance of 2.1 σ @ 13TeV
- Limit settings for the RS Graviton mass up to 3.4 TeV @ 13TeV (2.66@8 TeV)

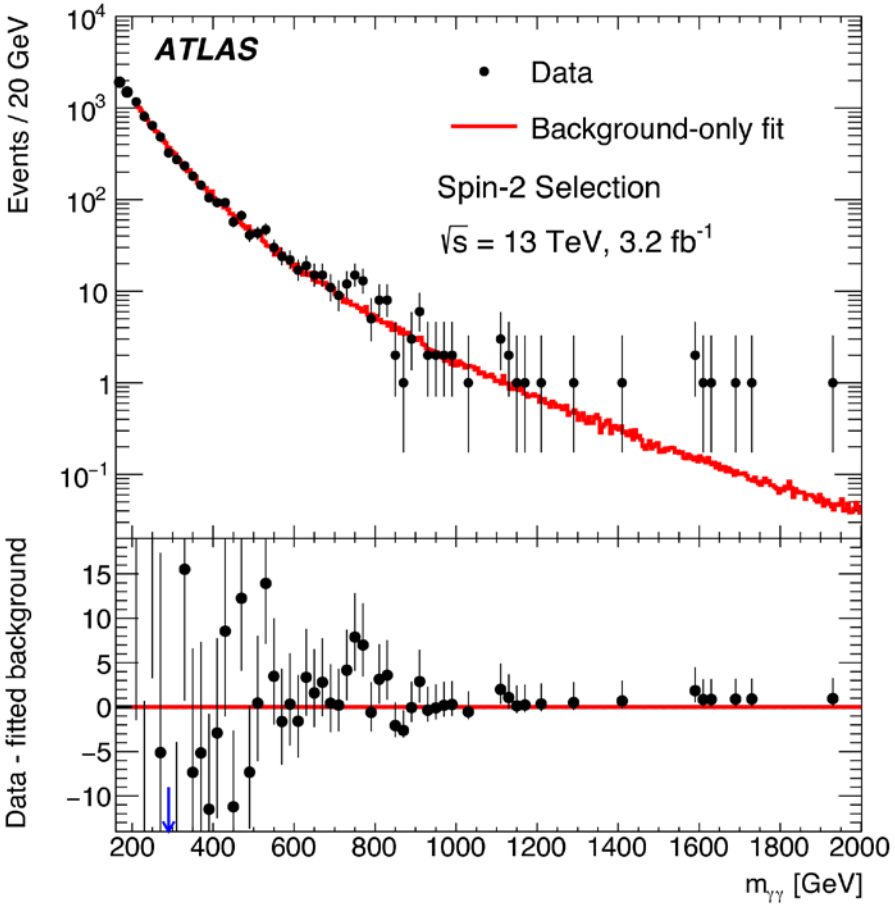
arXiv:1606.03833

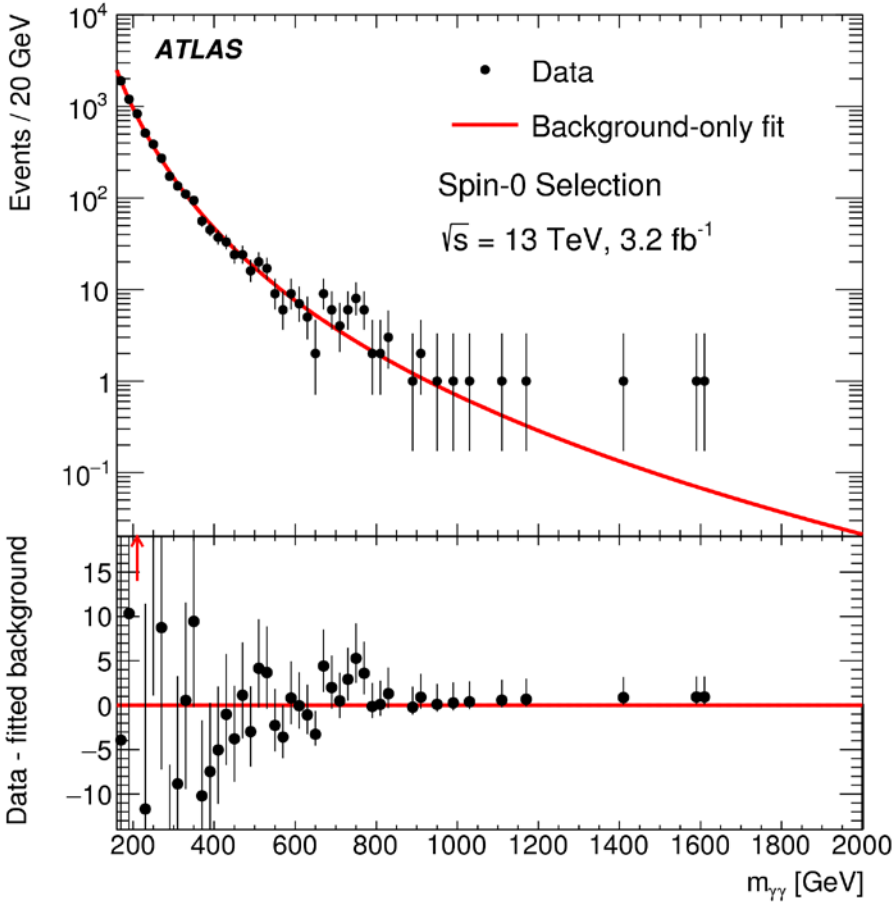
- More to come with 2016 data → ICHEP 2016



Back-up

Diphoton Mass distributions
13 TeV – 2015 data



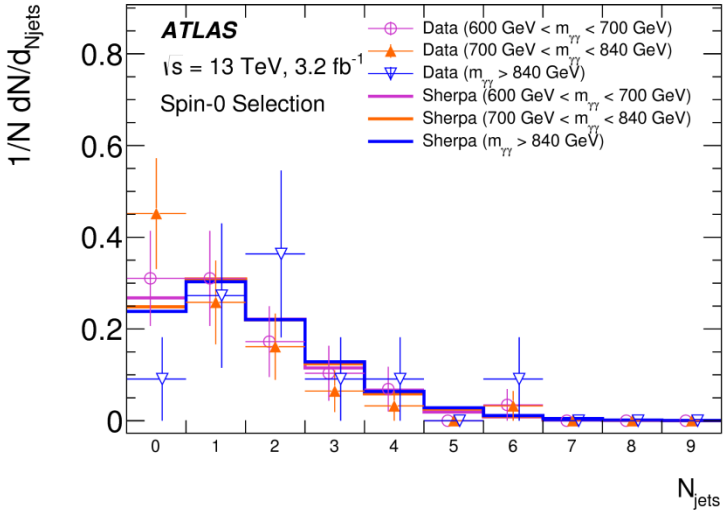


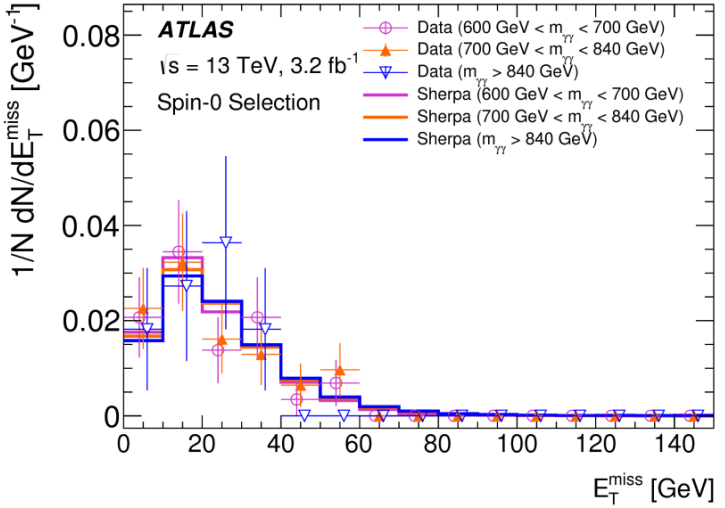
Investigated signal region	Background from MC extrapolation	Background from functional form
$m = 750$ GeV, $\Gamma/m = 6\%$		
720–780 GeV, spin-2 selection	$20.1 \pm 0.3 \pm 0.7$	$21.9 \pm 1.2 \pm 0.4$
720–780 GeV, spin-0 selection	$6.7 \pm 0.1 \pm 0.4$	$6.8 \pm 0.7 \pm 0.3$
$m = 1500$ GeV, $\Gamma/m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

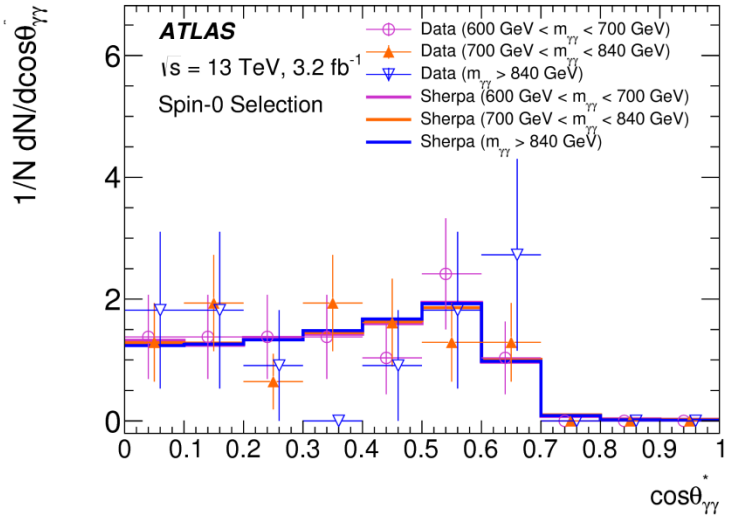
	Spin-2 Selection		Spin-0 Selection	
	Free width	Narrow width	Free width	Narrow width
	13 TeV			
Mass for the largest excess	750 GeV	770 GeV	750 GeV	750 GeV
Width over mass for the largest excess	8%	-	6%	-
Local significance	3.8	3.3	3.9	2.9
Global significance	2.1		2.1	
	8 TeV			
Local significance (at 13 TeV best-fit)	-		1.9	
	8 TeV - 13 TeV Compatibility			
Gluon–gluon scaling (4.7)	2.7	2.2	1.2	1.5
Quark–antiquark scaling (2.7)	3.3	2.4	2.1	2.0

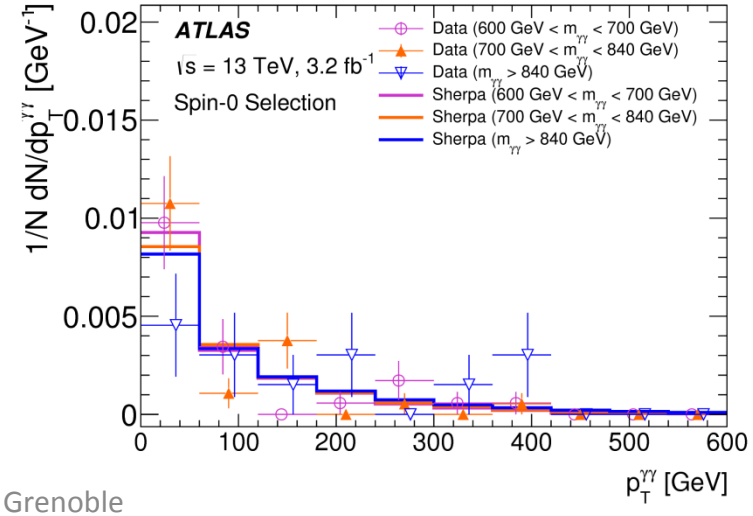
Uncertainty	Spin-2 search	Spin-0 search
Signal mass resolution (mass dependent)	$^{+(30-60)\%}_{-(20-40)\%}$	$^{+(40-60)\%}_{-(30-45)\%}$
Signal photon identification (mass dependent)	$\pm(2$–$3)\%$	
Signal photon isolation (mass dependent)	$\pm(2$–$1)\%$	$\pm(4$–$1)\%$
Signal production process	N/A	$\pm(3$–$6)\%$ depending on Γ
Trigger efficiency	$\pm 0.6\%$	
Luminosity	$\pm 5.0\%$	

Checks of kinematic distributions in excess region and side bands
Spin 0



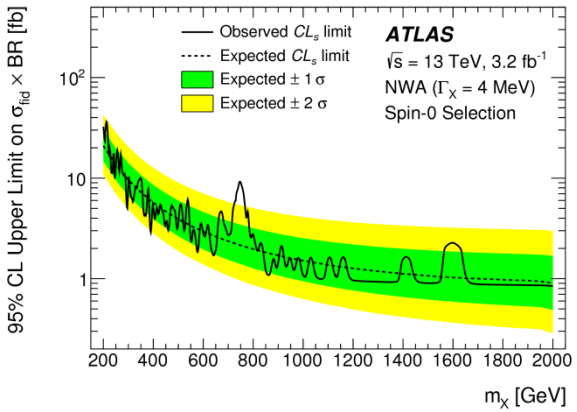


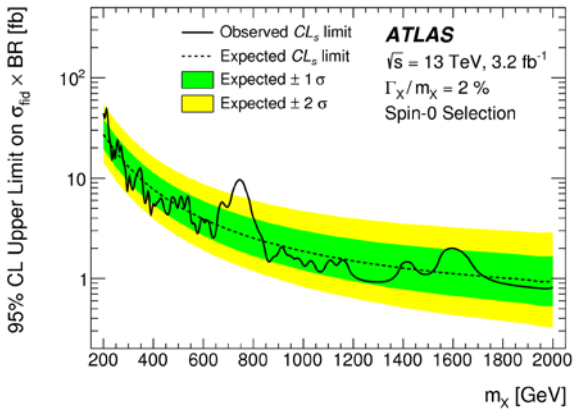


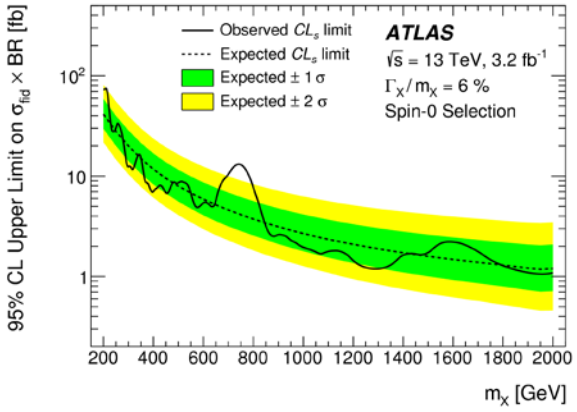


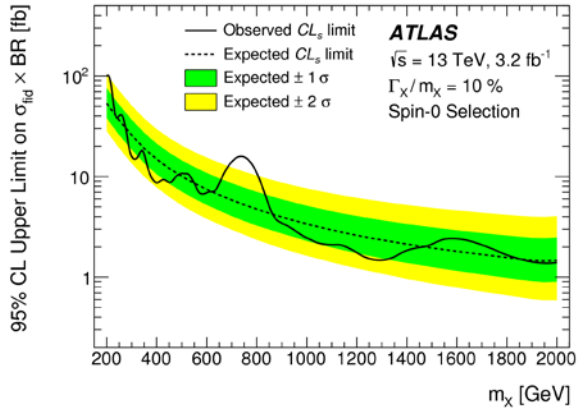
Limits Settings – spin 0

Limits are in terms of the fiducial cross section and they are within the expected error bands (except for 750 GeV bump)



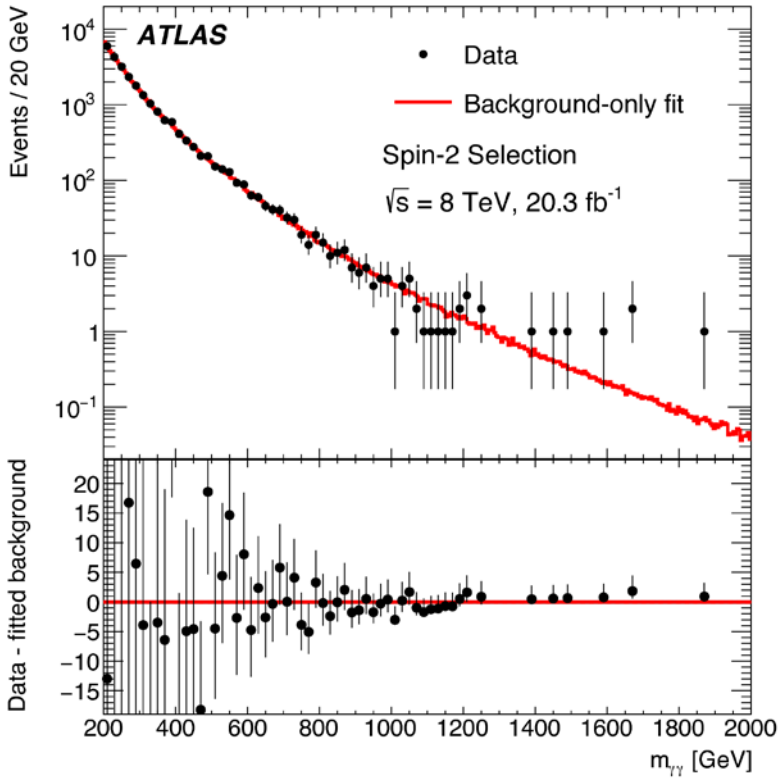




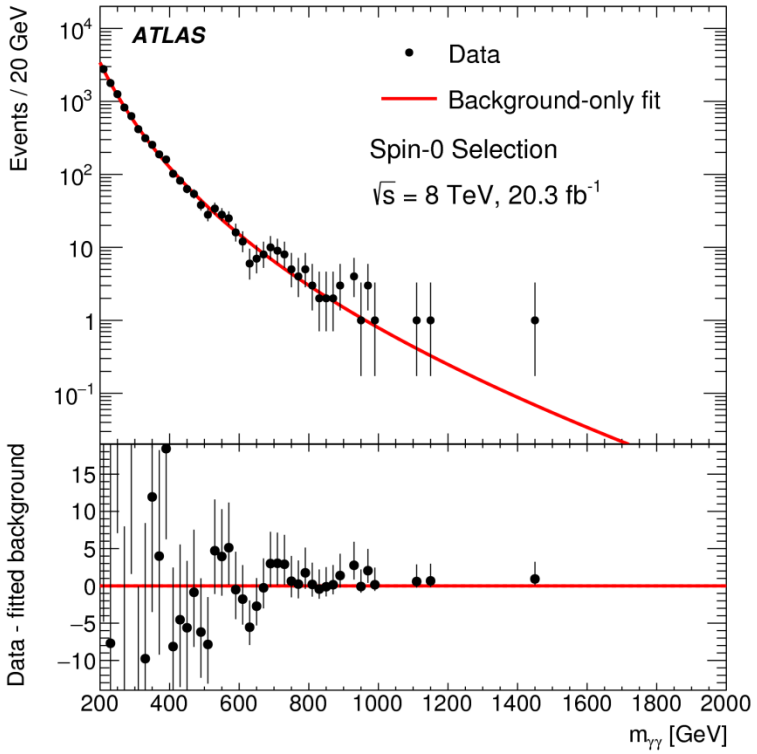


Diphoton Mass distributions of the 8 TeV re-analyzed data

No Excess found



2 σ significance is found at 750



Analysis	13 TeV σ local	13 TeV σ global	8 TeV compatibility
Scalar	3.9 σ	2 σ	1.2 σ (gg) – 2.1 σ (qq)
Graviton	3.8 σ	2.1 σ	2.7 σ (gg) – 3.3 σ (qq)