Search for Resonances in Diphoton Events with 3.2fb^{-1} at $\sqrt{s}$=13 TeV in ATLAS

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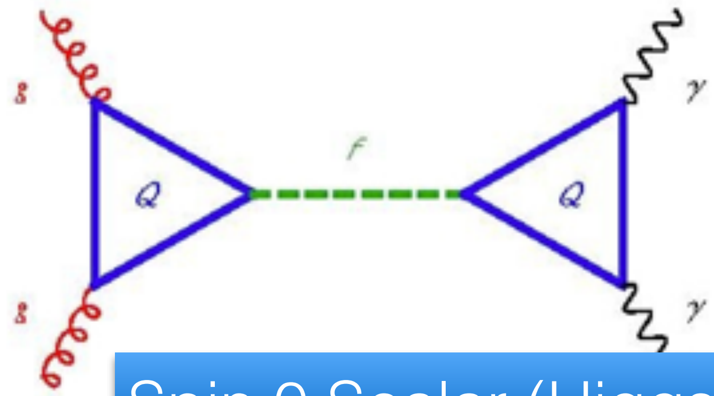
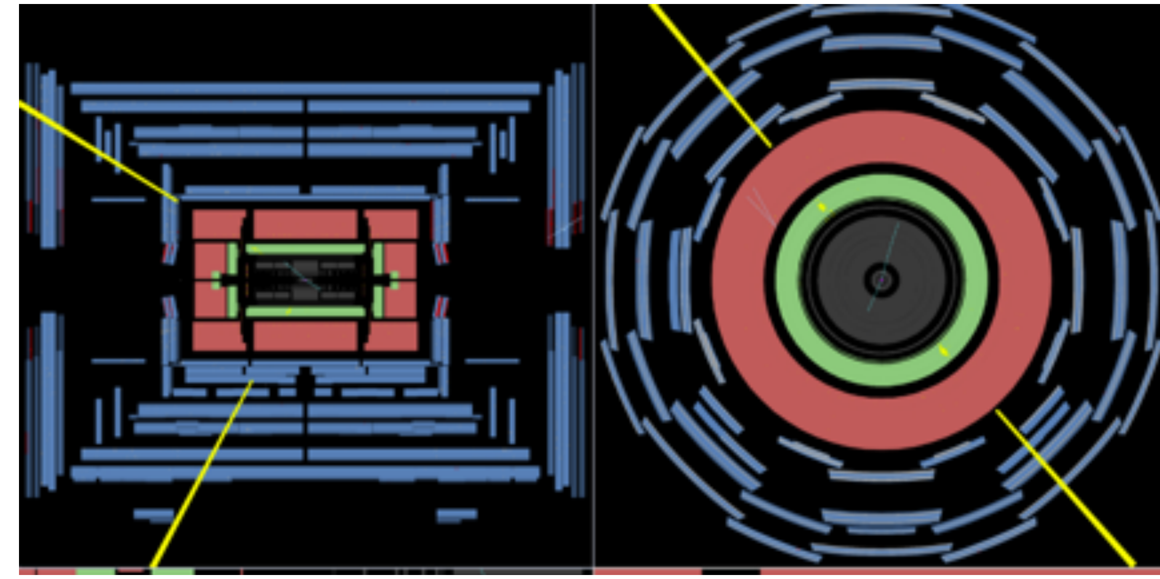
What are we looking for?

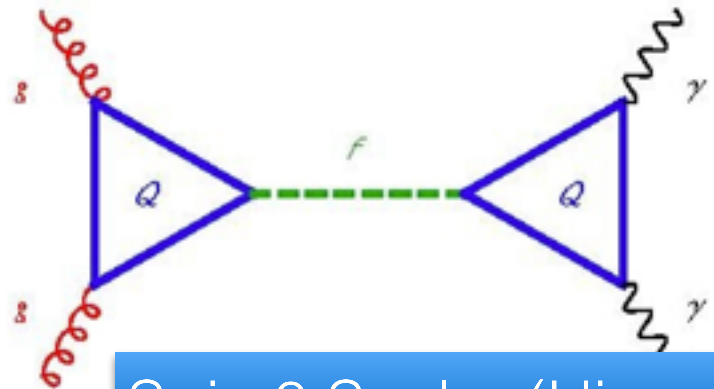


Spin 0 Scalar (Higgs Like)

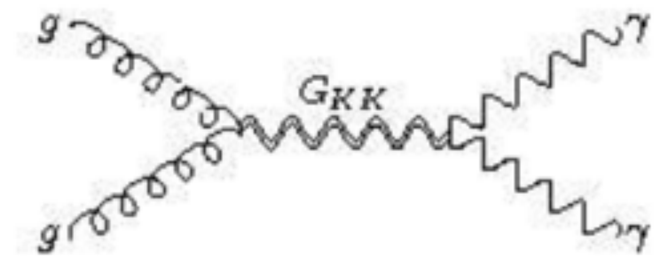


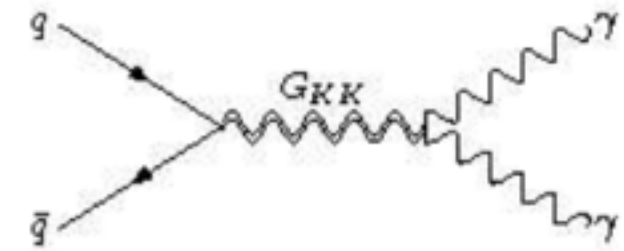
- Spin 0 Scalar , Higgs-like?
- Mass Range 200-2000 GeV
  with a Γ of up to 10% of the mass
  (@ m_S=800 GeV, Γ up to 80 GeV)
- Search based on gg
  (VBF, ttH and VH cross checked)

What are we looking for?



Spin 0 Scalar (Higgs Like)





SPECIFIC MODEL: Spin 2 Graviton

- Spin 0 Scalar , Higgs-like?
- Mass Range 200-2000 GeV with a Γ of up to 10% of the mass (@ m_S=800 GeV, Γ up to 80 GeV)
- Search based on gg (VBF, ttH and VH cross checked)

- Use Randall-Sundrum model graviton as benchmark
- Search 500-5000 GeV with $\kappa/\bar{M}_{p\ell} = 0.01 - 0.3$
- $$\boxed{\Gamma_{G^*} = 1.44\left(\frac{\kappa}{\bar{M}_{p\ell}}\right)^2 m_{G^*}}$$

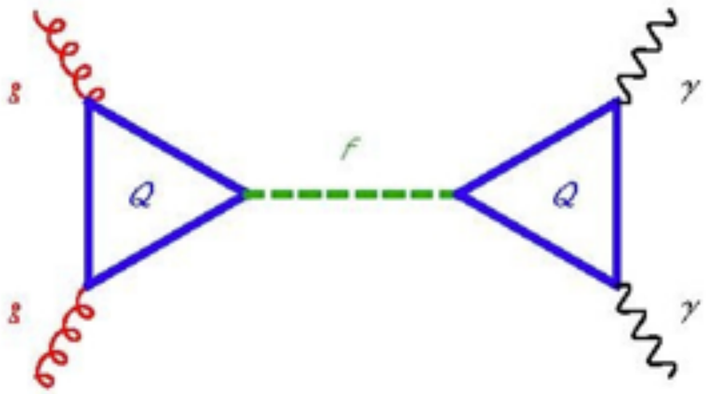
$$\boxed{\begin{array}{l} @\kappa/\bar{M}_{p\ell} = 0.1 \\ \Gamma_{G^*} = 10-30\ GeV\ @m_{G^*} = 800-2200\ GeV \end{array}}$$

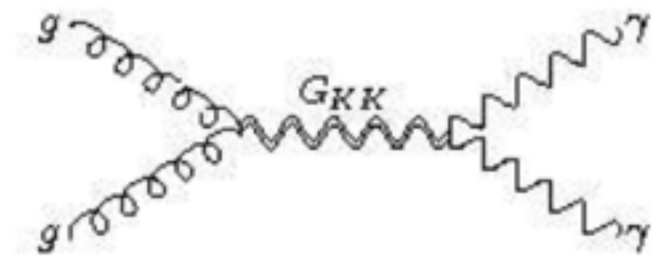
- Production via gg and qq

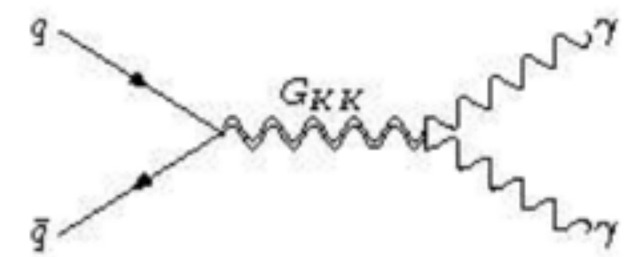
@800 GeV Δm(Det)~10GeV

Main physics difference is the angular distribution of the Photons in the DiPhoton rest frame, which is isotropic for a scalar, and forward enriched for Graviton

What are we looking for?

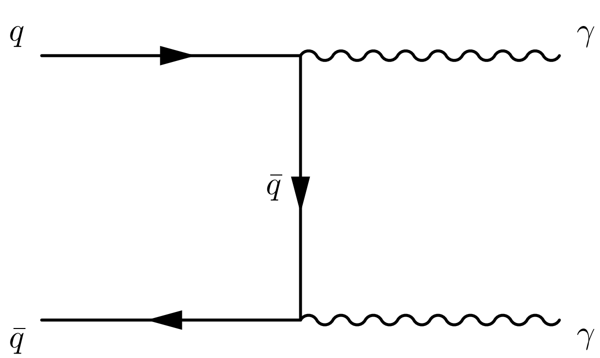




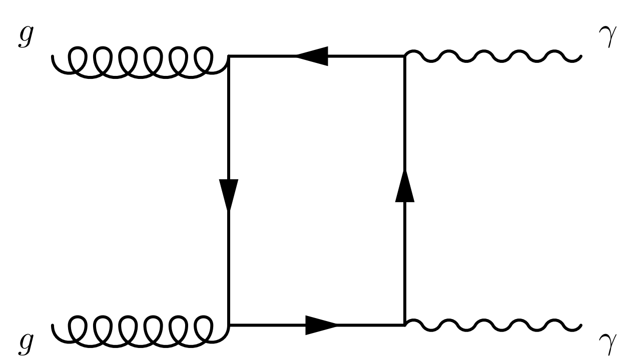


Irreducible BG

born



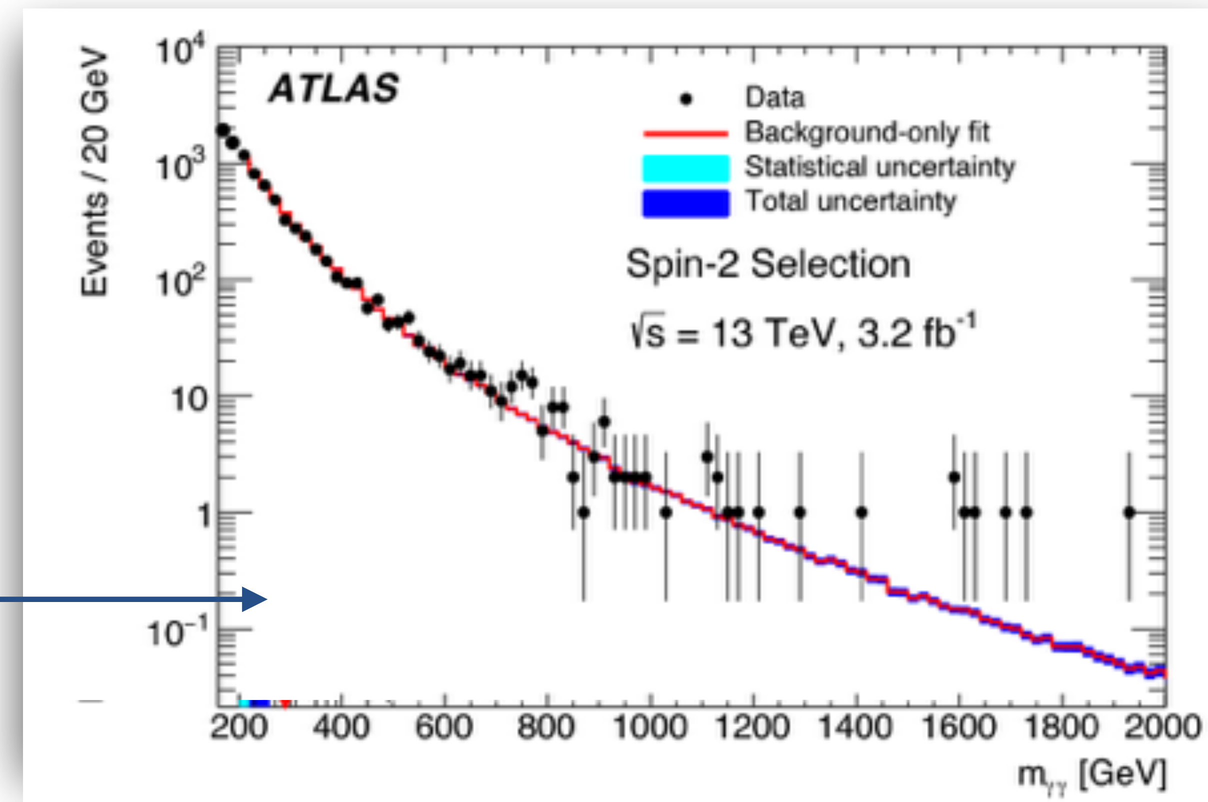
box



Diphox NLO (parton level)
OR
SHERPA multi-leg LO (fully simulated)

For spin 2 -MC, Correct SHERPA with DIPHOX

For spin 0 - Functional fit,DATA based,
validated with SHERPA



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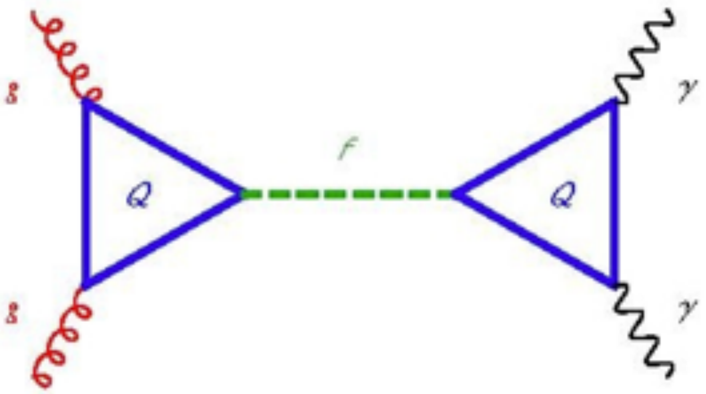

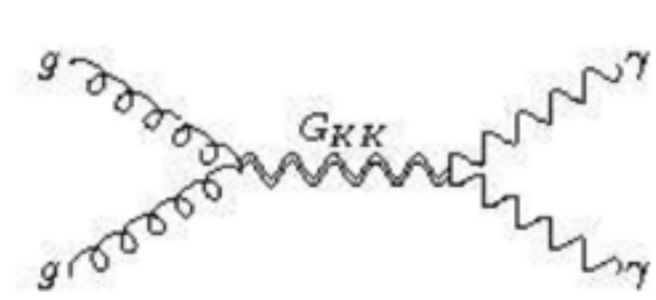

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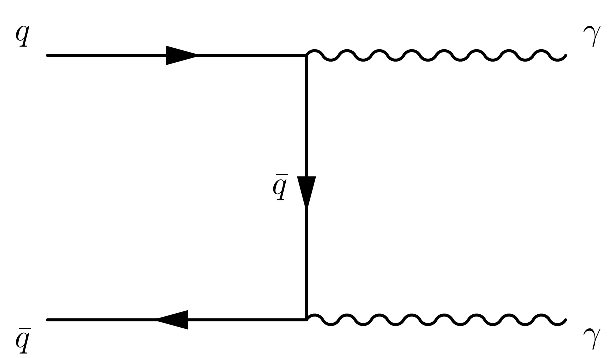

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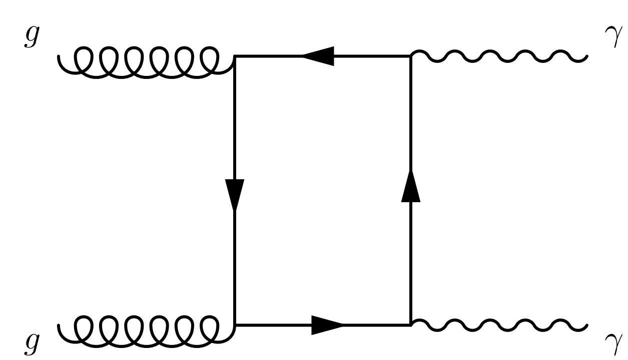
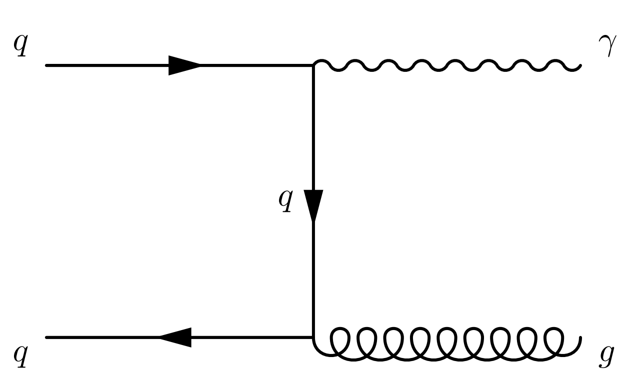
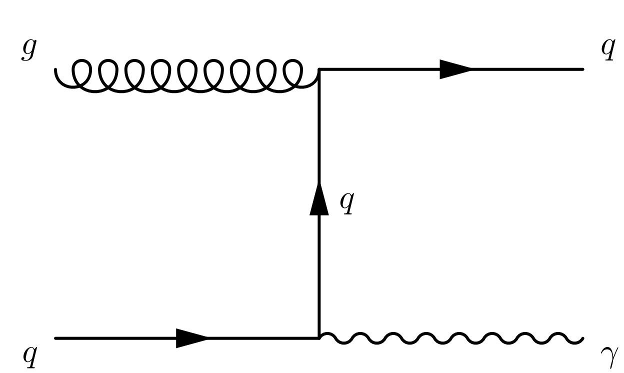


Reducible BG

fake photons from jets : jγ,γj'jj





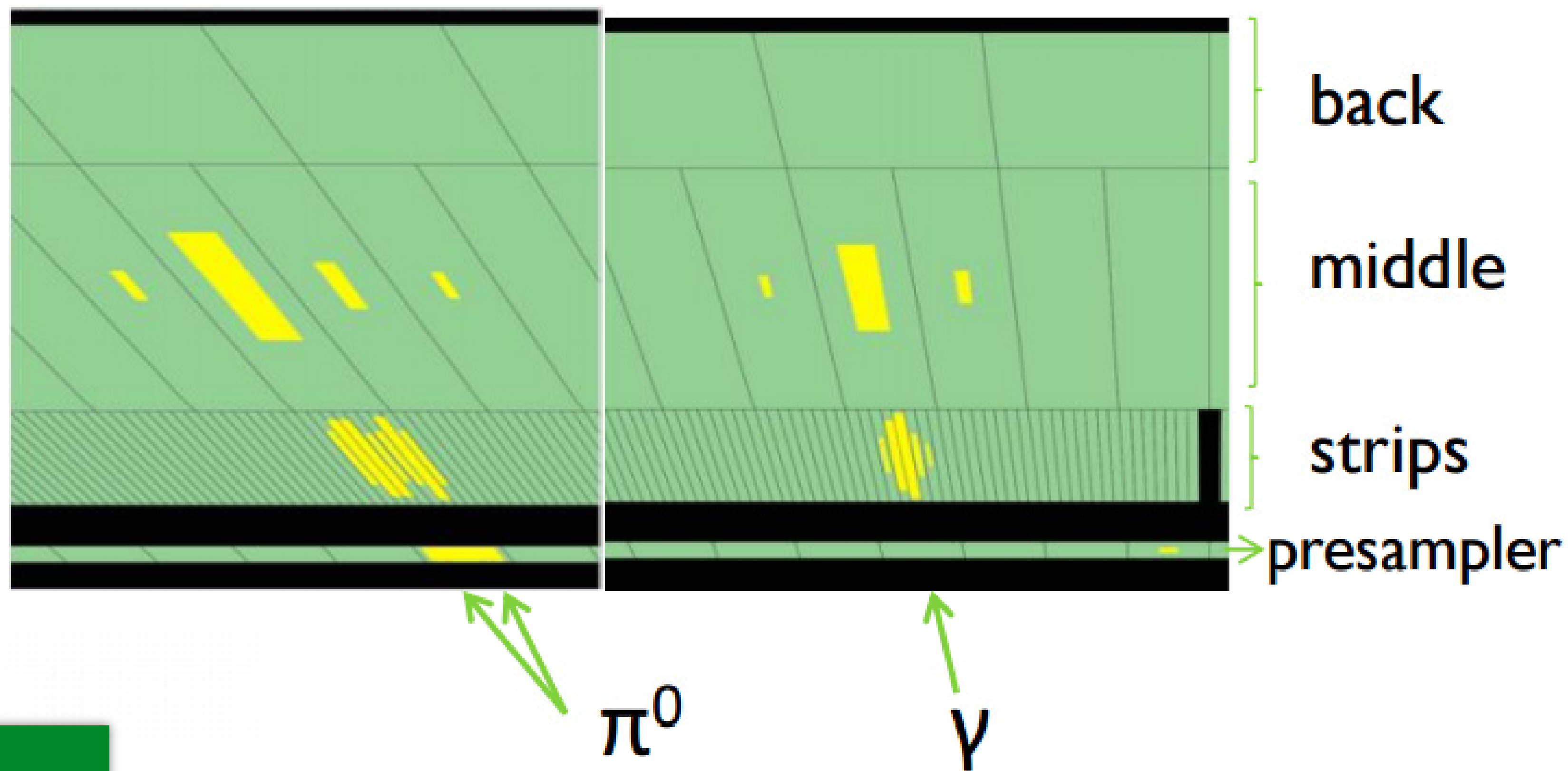
Require
Tight isolated Photons
reducing fakes rate
by an order of magnitude

Photon ID

- Identification performed by applying cuts on the shape of the electromagnetic shower in the calorimeter, and the fraction of energy deposited in the hadronic calorimeter.

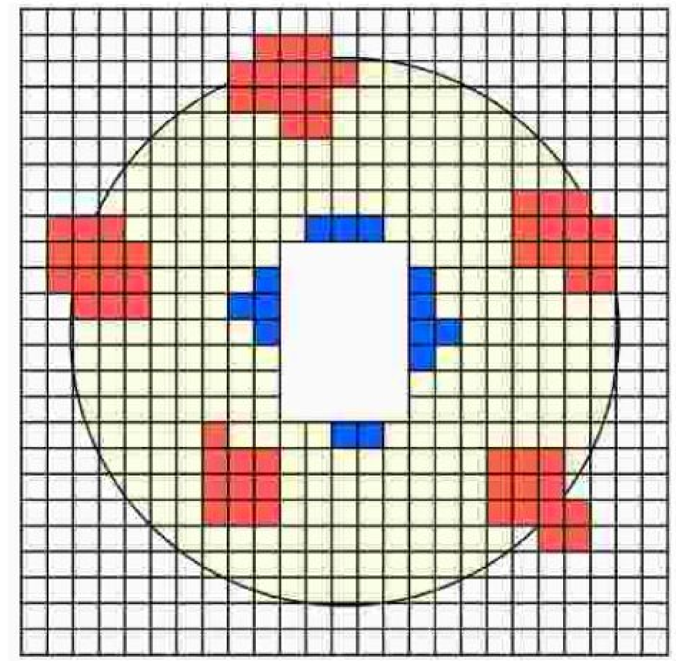
- Photon ID is η and conversion dependent

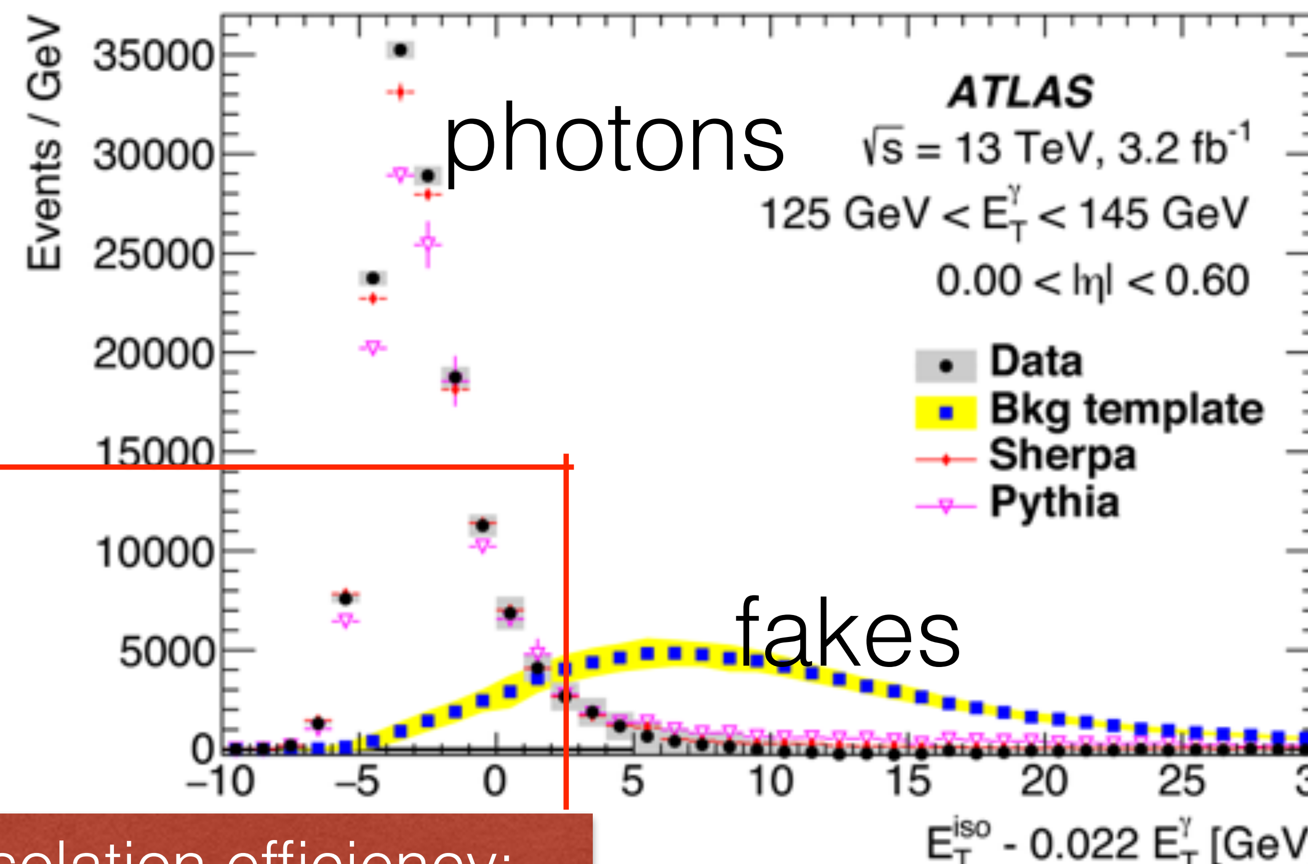
- Calorimeter granularity allows to separate photons from pions



Efficiency:
85% (E_T=50GeV)-95%(E_T=200GeV)
Uncertainty:
±1% - ±5% for E_T >50GeV
η & E_T dependent
(uncertainty measured MC vs DATA)

- Tight Isolation is used for reducible BG rejection (fake photons)
- Both **calorimeter isolation** and **track isolation** ARE **required.**
  - Calo isolation $\mathbf{E_T^{ISO}}$ → sum of E_T of energy clusters within $\Delta R = 0.4$
    - Ignore $\Delta\eta\times\Delta\phi = 0.125\times0.125$ centered on photon
    - Subtract out-of-cone energy from isolation
  - $E_{T,iso} - 0.022\ E_T < 2.45$ GeV
  - Track isolation → scalar sum of track p_T (p_T>1GeV) within $\Delta R = 0.2$ & consistent with selected primary vertex $p_{T,iso} < 0.05\ E_T$





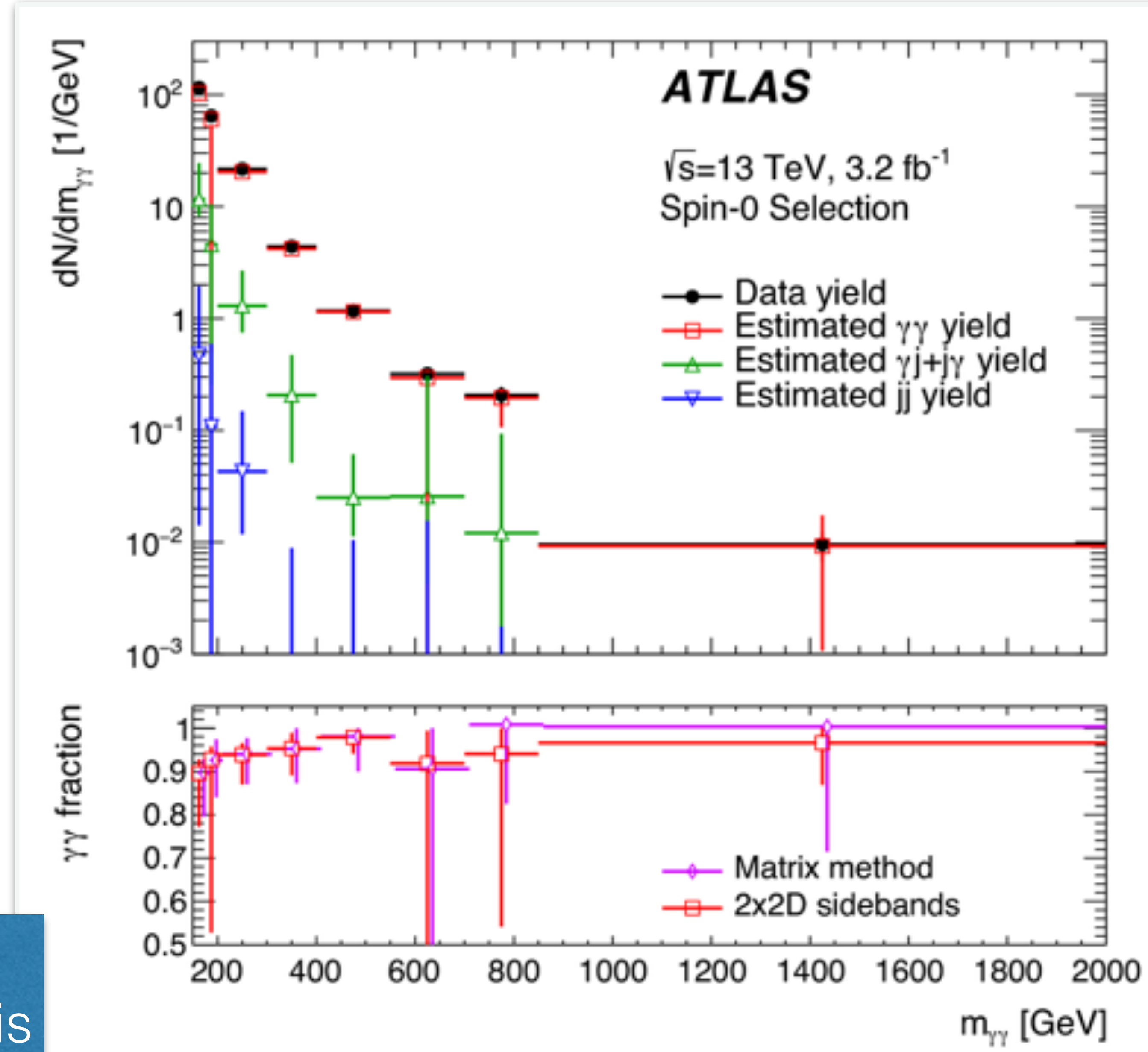
Isolation efficiency:
90 - 96% (E_T=100-500)
Isolation uncertainty:
1-2%

Decomposition of BG

- Using sophisticated methods (Matrix & Sidebands) we estimate the BG composition (γj,jγ,jj)

- The resulting **inclusive purity** is

$$Purity_{\gamma\gamma} = 93^{+3}_{-8}\%$$



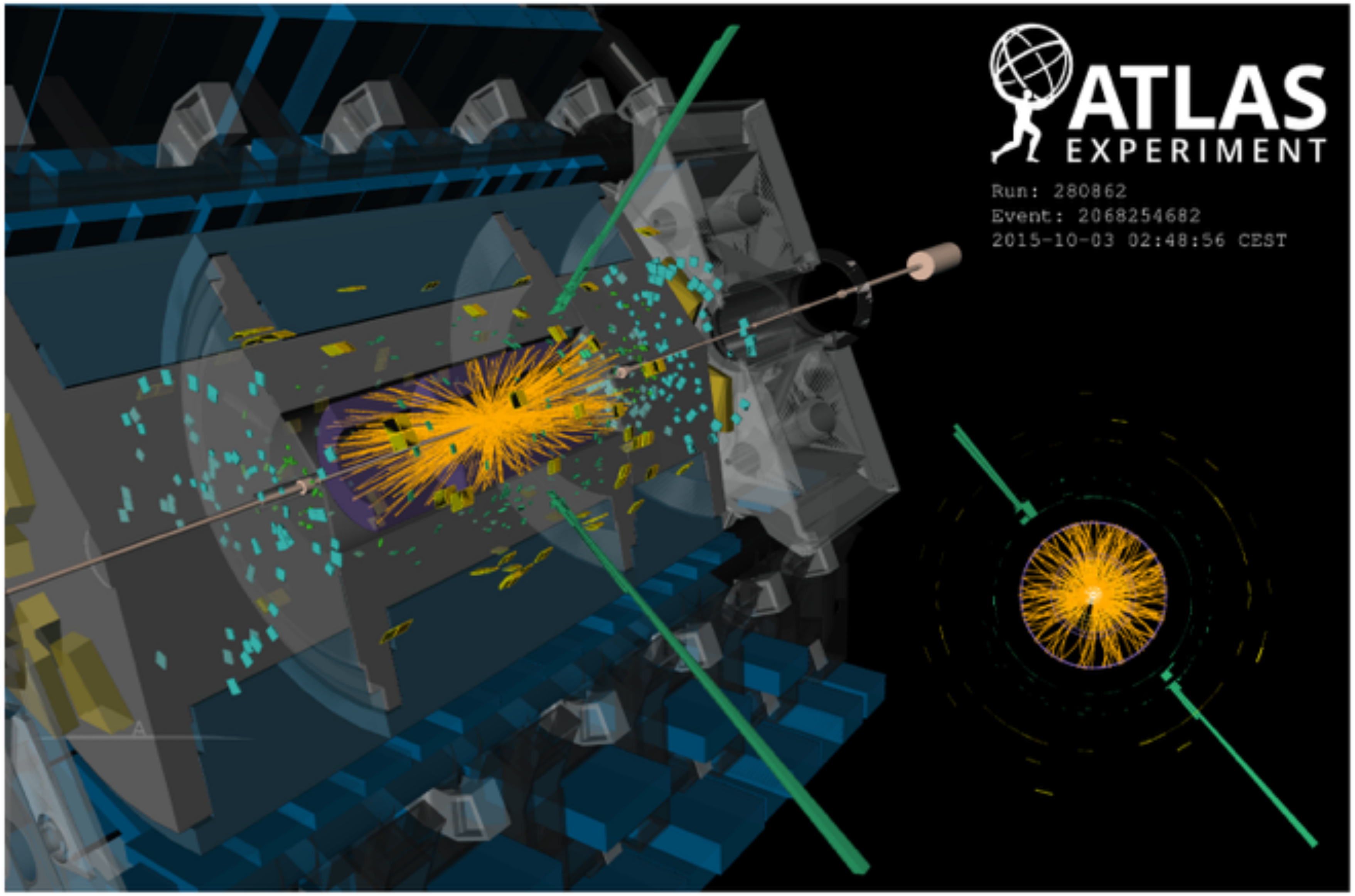
Similar purity for the spin 2 analysis

Trigger & Pre-Cuts

Trigger: p_T>35 (25) GeV for leading (subleading) photon.

Tight photon ID with
$E_T^{\gamma 1}$ > 40 GeV, $E_T^{\gamma 2}$ > 30 GeV (“baseline”)

2 Isolated Photons



Trigger & Pre-Cuts

Spin 2

VS

Spin 0

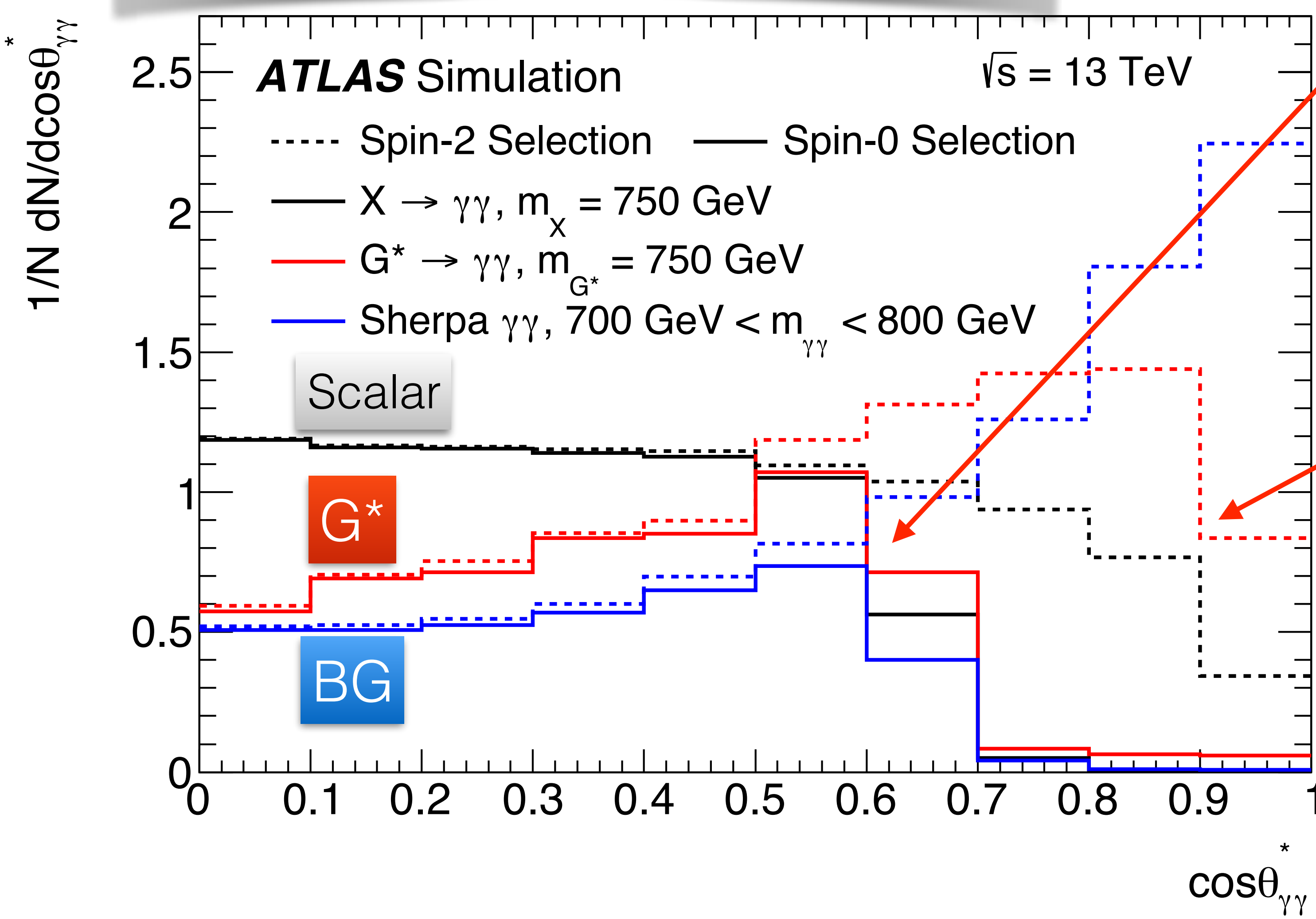
$E_T^{\gamma 1} > 55$GeV,$E_T^{\gamma 2} > 55$GeV.
Preserve acceptance at high mass.

Optimized for Higgs-like signal:
$E_T^{\gamma 1} > 0.4 m_{\gamma\gamma}$,$E_T^{\gamma 2} > 0.3 m_{\gamma\gamma}$.
+20% significance for $m_X > 600$ GeV.

$$\cos\theta^* = \frac{\sinh(\eta_{\gamma_1} - \eta_{\gamma_2})}{\sqrt{1 + \left(p_T^{\gamma\gamma}/m_{\gamma\gamma}\right)^2}} \cdot \frac{2 p_T^{\gamma_1} p_T^{\gamma_2}}{m_{\gamma\gamma}^2}$$

Collins Sopper

Spin 0 cuts will reduce the sensitivity to the Graviton signal



Spin 2 Selection

Determining the Background

Monte Carlo simulation (Spin 2) VS **Functional Form (Spin 0)**

Monte Carlo simulation (Spin 2):

- **Correct multi-leg LO SHERPA (fully simulated) with NLO Diphox**
- Search goes up to 5000 GeV-> **Shape from MC, Normalisation from Data**
- Reducible BG determined from DATA, extrapolated with function to high $m_{\gamma\gamma}$

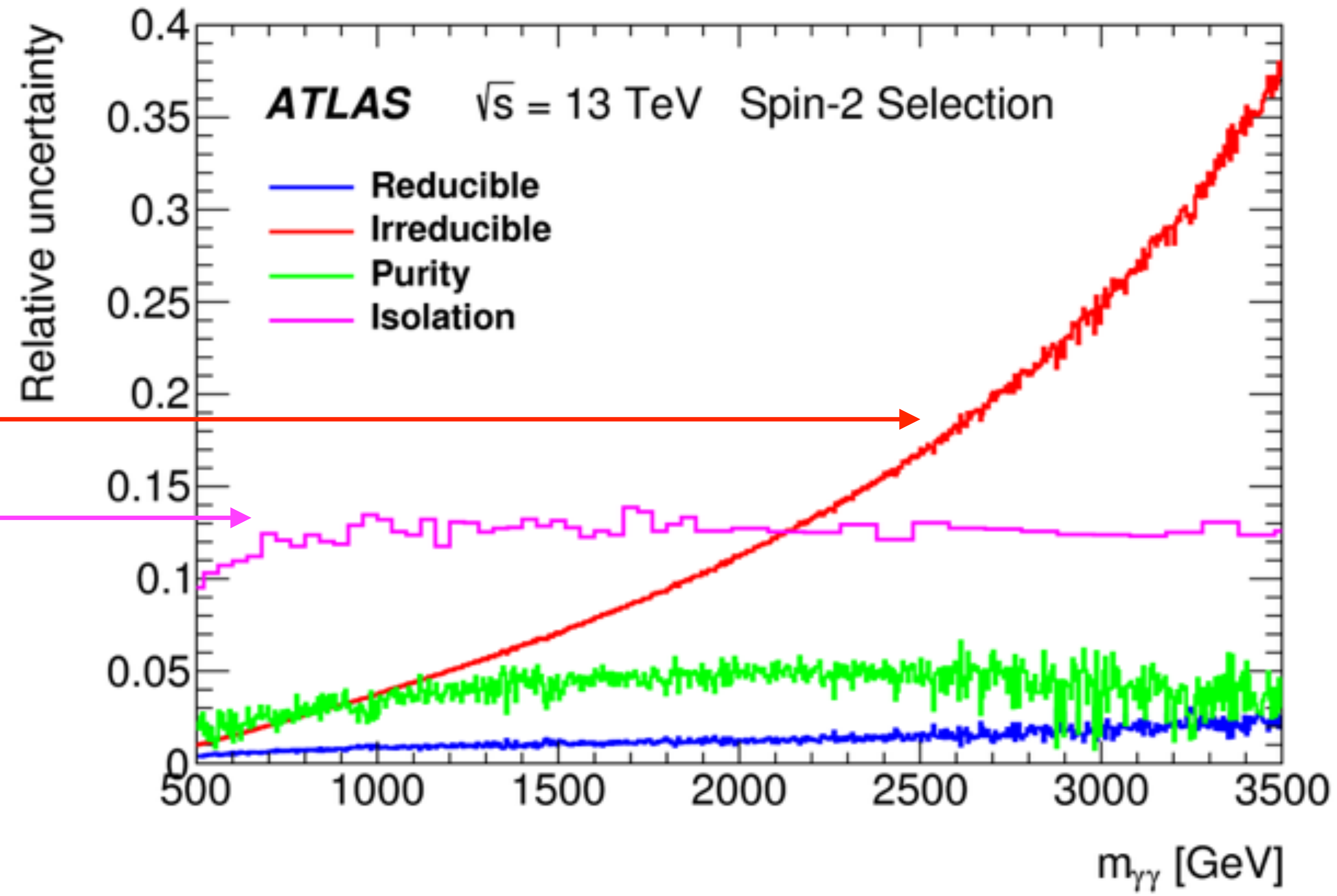
Functional Form (Spin 0):

- Use multi-leg LO SHERPA to obtain and validate the functional form
- Function is then fitted and constrained by DATA all over the relevant mass range (150-2000 GeV)
- Use smooth functional form

All methods to obtain background (MC and data based) are giving consistent results

Monte Carlo simulation (Spin 2)

- Price of MC in uncertainties
- PDF and Renormalisation Scale QCD (Irred) takes off to 35% @ 3500 GeV
- Isolation uncertainty (due to parton level matching with full simulation)



Determining the BG (spin 0 functional form)

- Use the following functional form:

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

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

- Use statistical chi^2 based test to determine the number of d.o.f-> k=0

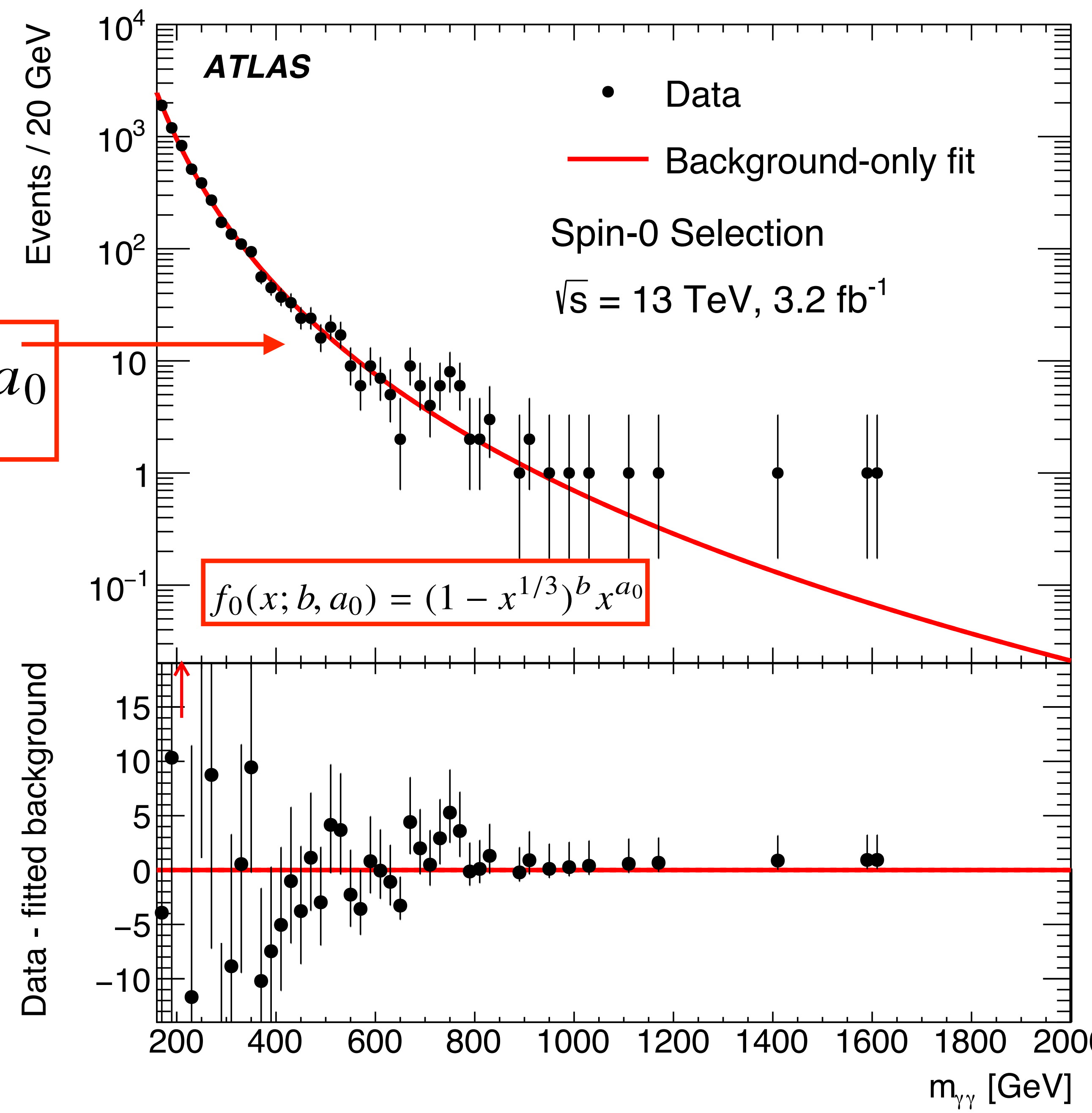
$$\boxed{f_0(x; b, a_0) = (1 - x^{1/3})^b x^{a_0}}$$

  - 2 shape d.o.f. (+Normalization)

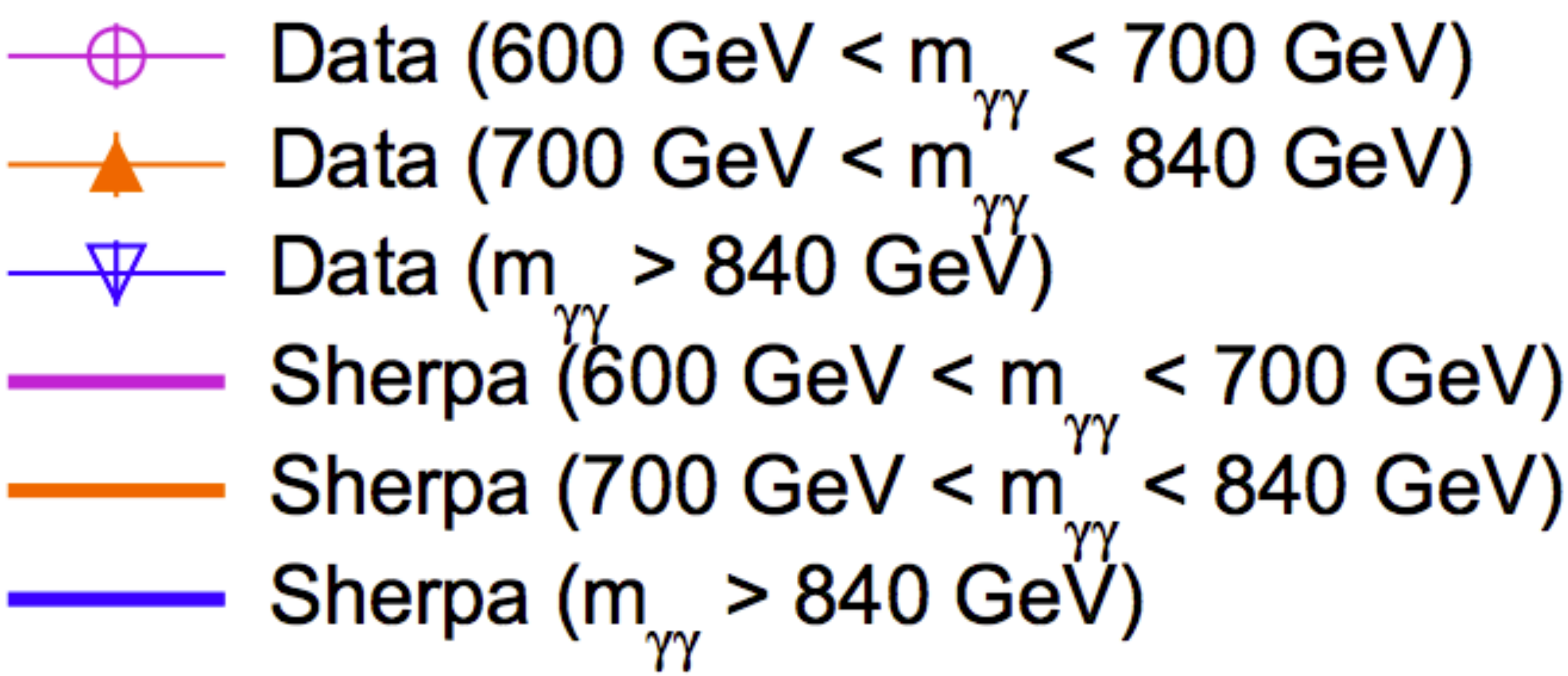
- Validate with MC (Sherpa based + reducible BG template)

- Fit s+b with b-only template. The resulting "signal" is considered spurious. We require spurious signal<20% b-uncertainty

7391 (2878) events for $m_{\gamma\gamma}$ > 150 (200) GeV



Cross checks (Kinematic Distributions)



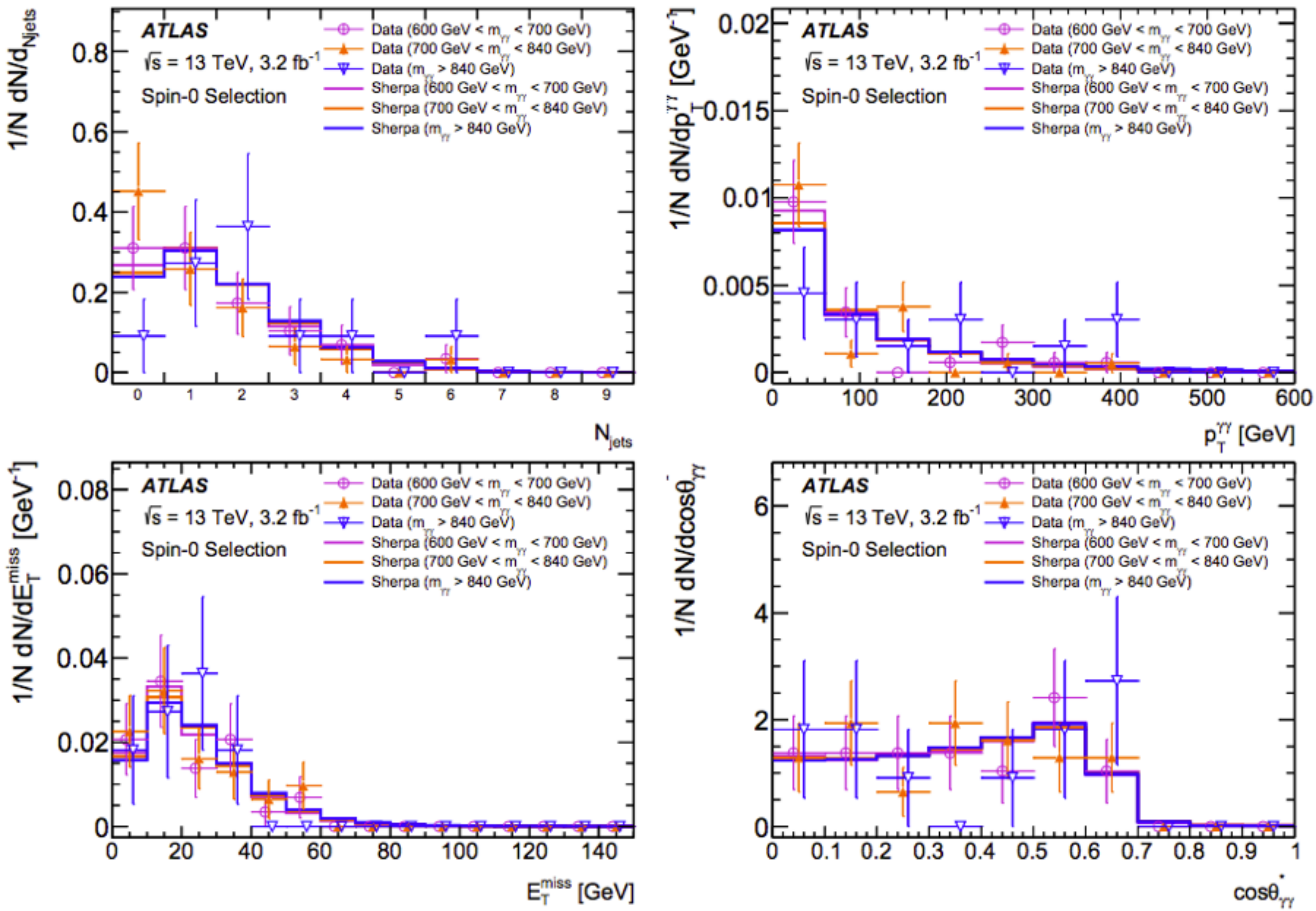
$$\cos\theta^{*}(beam, forward\ going\ photon)$$

$$n_{jets}$$

$$E_{T}$$

$$p_{T}(\gamma\gamma)$$

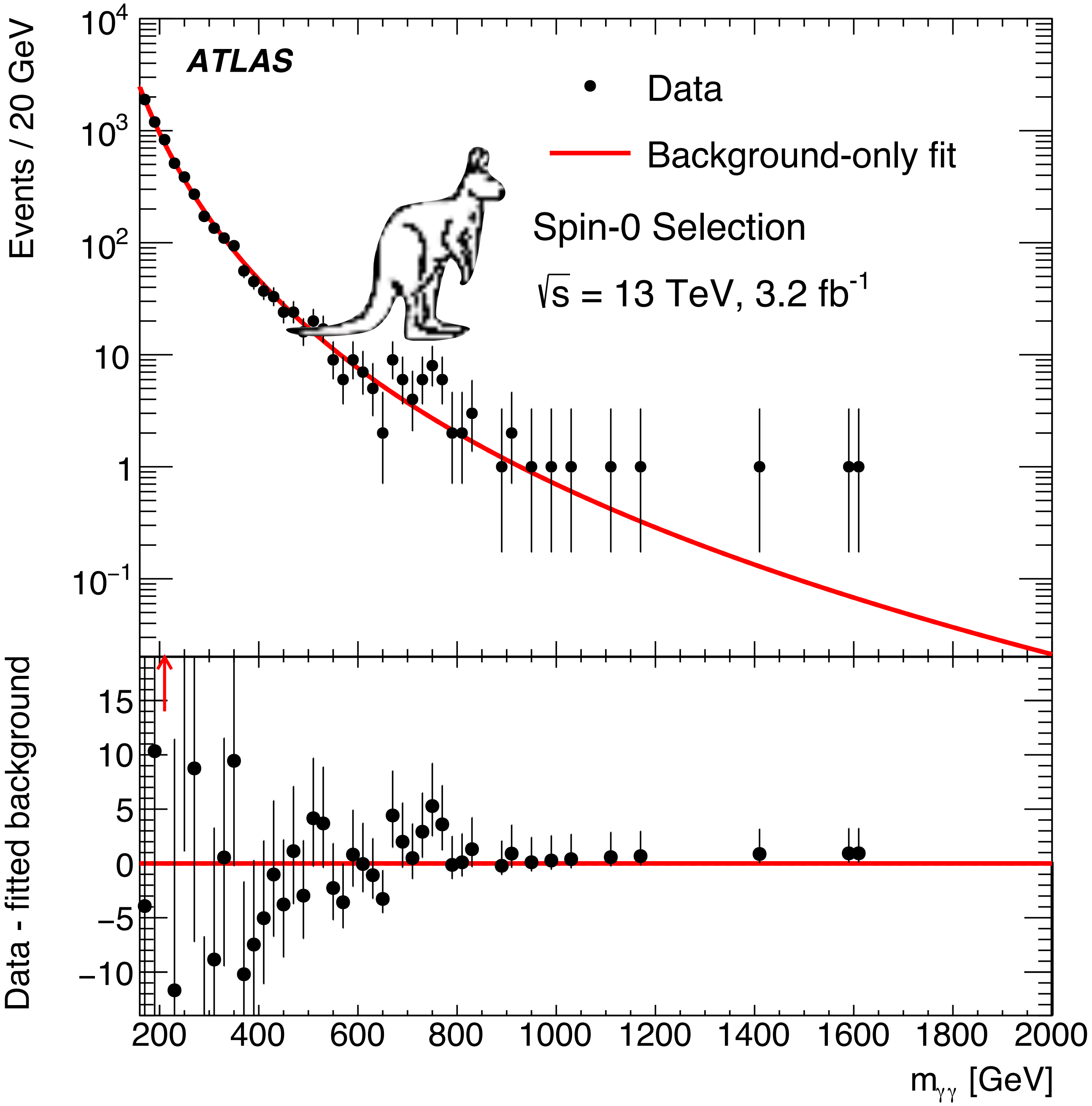
Cross checks (Kinematic Distributions)



RESULTS

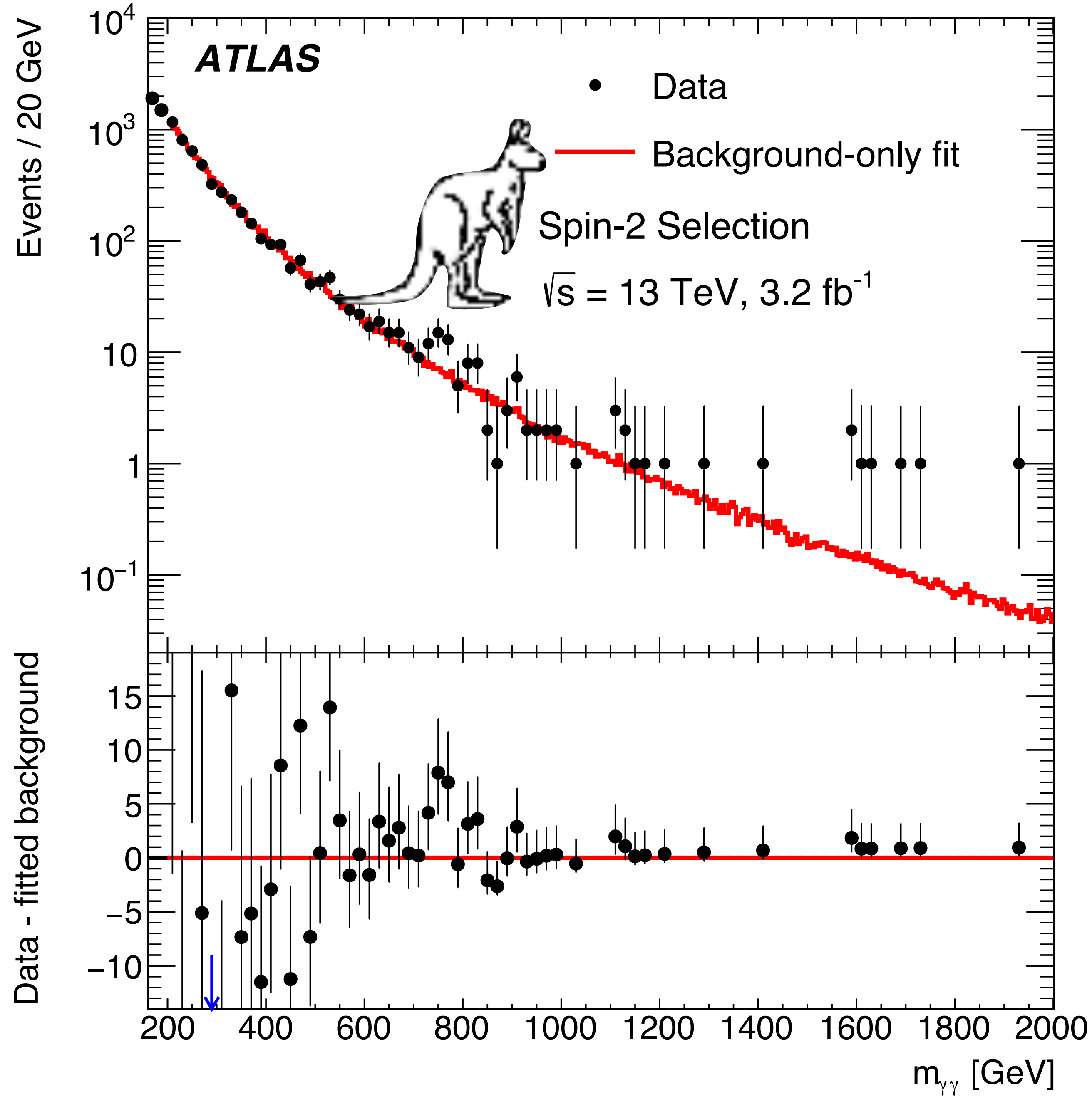
Spin 0

7391 (2878) events for $m_{\gamma\gamma}$ > 150 (200) GeV



Spin 2

5066 events for $m_{\gamma\gamma}$ > 200 GeV



Spin 0

Largest significance

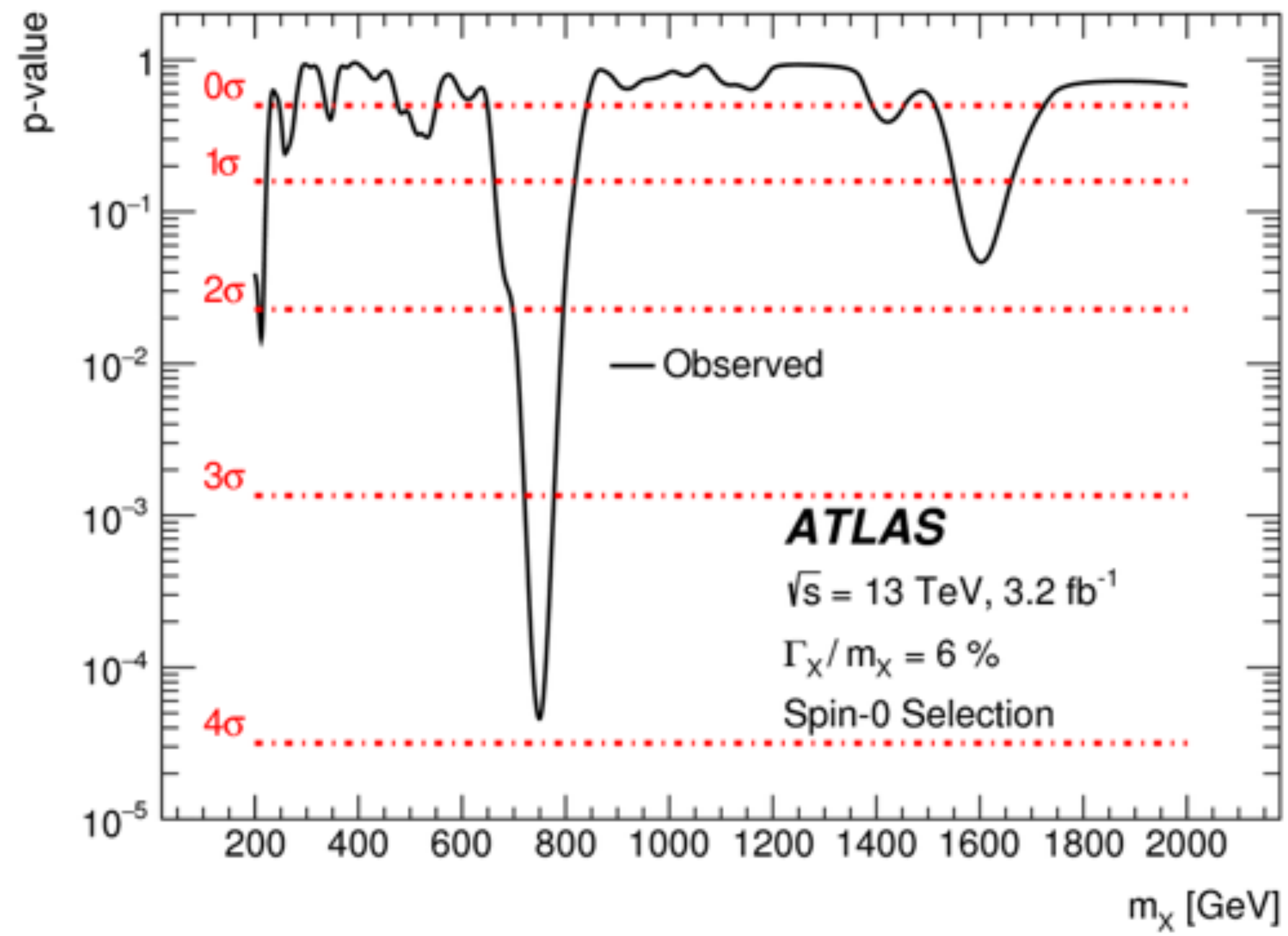
$m_X \sim 750\text{GeV}, \Gamma_X \sim 45\text{GeV}(6\%)$

Local Z = **3.9σ**

Any peak with Z>3.9σ
with m=200-2000 will draw our attention

$$P_{global}(u) \approx p_{local}(u) + E(n_{u_0})e^{\frac{u_0-u}{2}}$$

$$p_{local} = 5\cdot 10^{-5}$$
$$u_0 = 0$$
$$n_{u_0} = 7 \pm 2.6$$
$$u = Z^2 = 3.9^2 = 15.2$$
$$p_{global} = 5\cdot 10^{-5} + (7\pm 2.6)e^{-15.2/2} = (2.2-4.8)10^{-3}$$
$$Z_{global} \sim 2.7 \pm 0.1\sigma$$



The LEE is even stronger when you consider another dimension
(the width range (0-10%m) should also be taken into account)

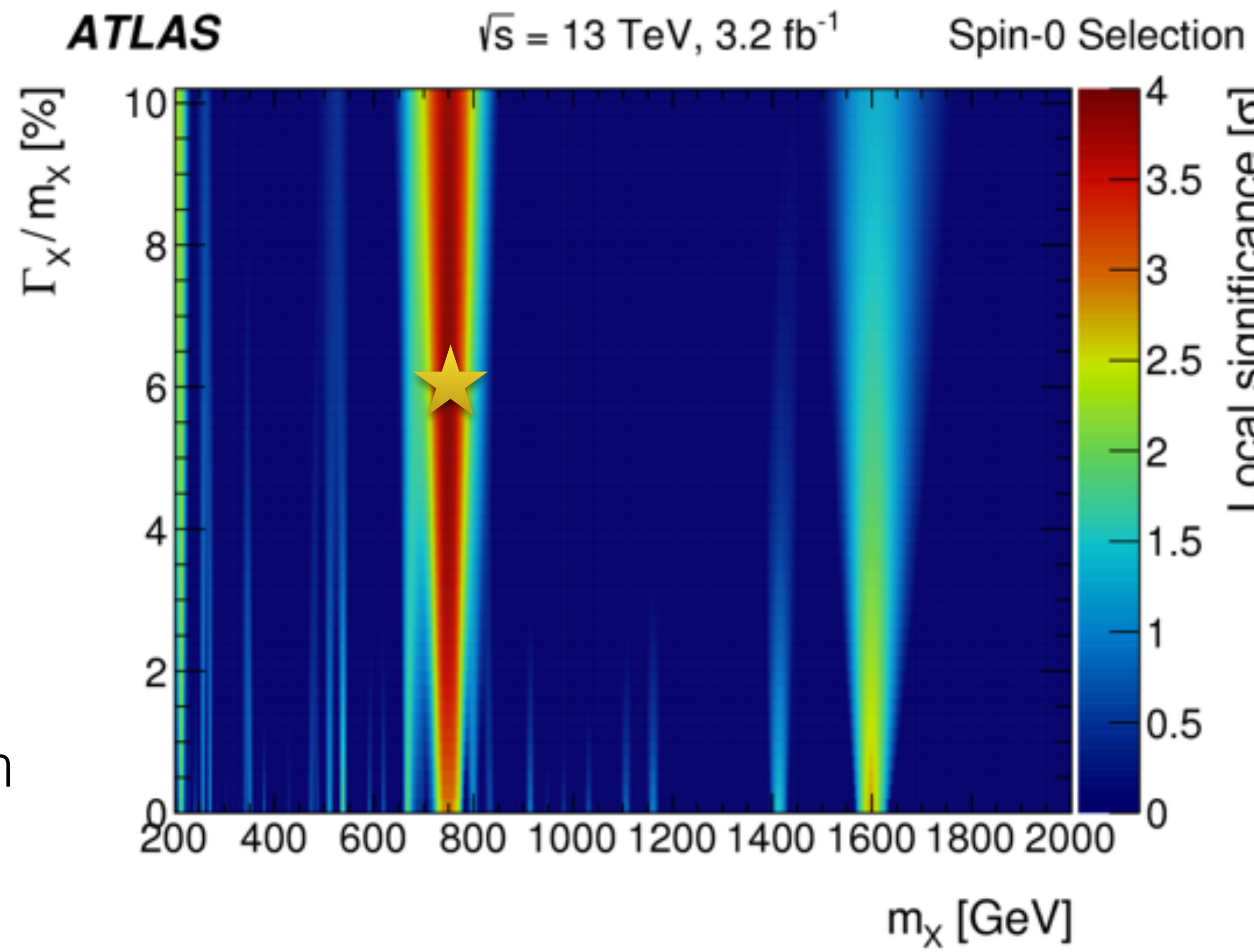
Spin 2

2D Scan

Largest significance

$m_X \sim 750$GeV, $\Gamma_X \sim 45$GeV(6%)

Local Z = 3.9σ



m=200-2000 GeV
Γ_X/m_X=0-10%

Use toys or asymptotic formula from
O. Vitells et. al. Astropart. Phys. 35 (2011) 230–234, arXiv:1105.4355

$$\boxed{\begin{aligned} Z_{local} &= 3.9\sigma \\ Z_{global} &= 2.1\sigma \end{aligned}}$$

2.1σ is not something to write home about

Spin 2

Largest significance

$m_G \sim 750\text{GeV}, \kappa/M_{Pl} \sim 0.23$

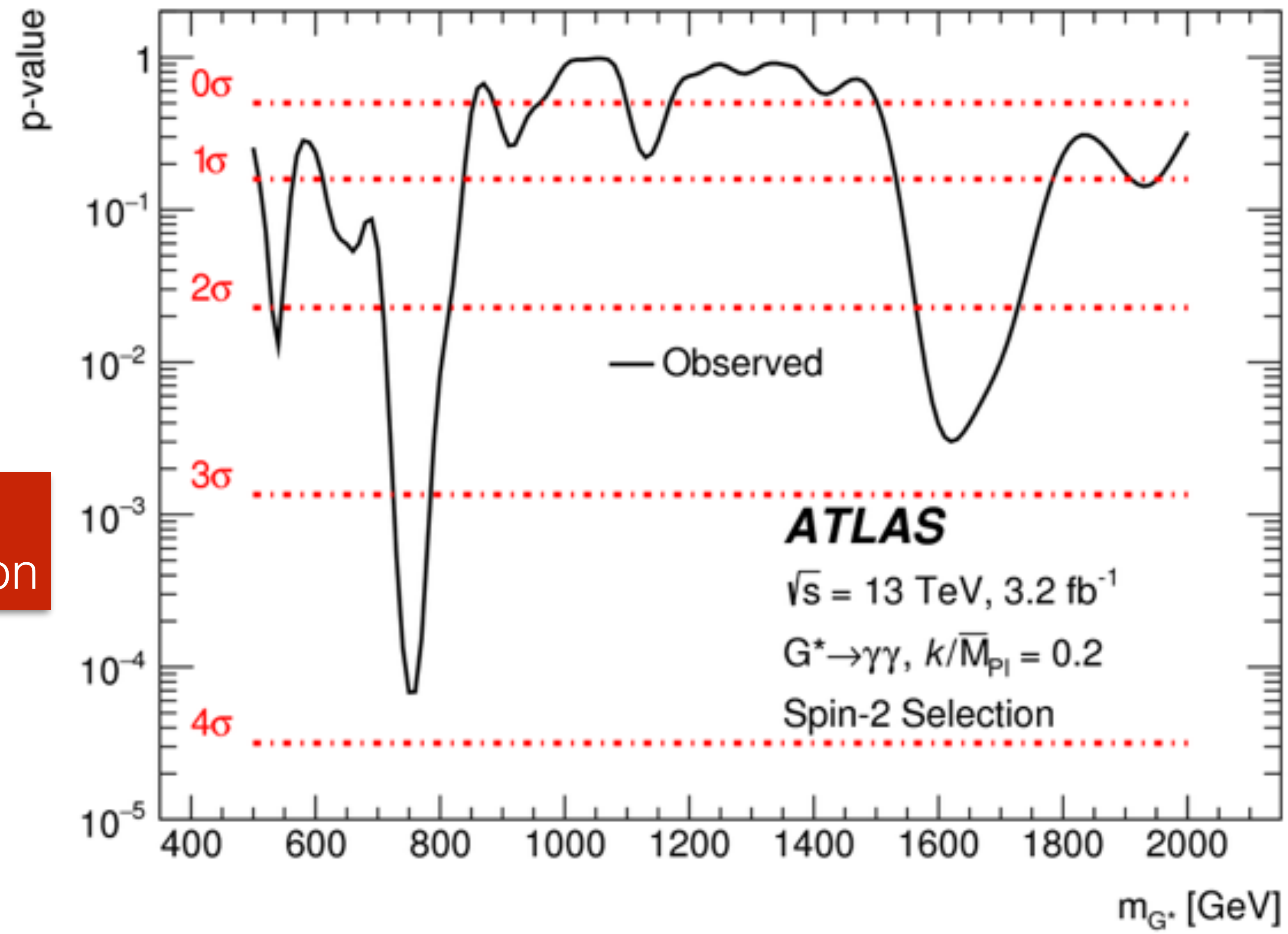
$(\Gamma_G \sim 57 \text{ Gev} \sim 7\% m_G)$

Local Z = 3.8σ

Any peak with Z>3.8σ
with m=500-2000 will draw our attention

$$P_{global}(u) \approx p_{local}(u) + E(n_{u_0})e^{\frac{u_0-u}{2}}$$

$$p_{local} = 7 \cdot 10^{-5}$$
$$u_0 = 0$$
$$n_{u_0} = 3$$
$$u = Z^2 = 3.8^2 = 14.4$$
$$p_{global} = 7 \cdot 10^{-5} + (3 \pm 1.7)e^{-14.4/2}$$
$$Z_{global} \sim 2.8^{+0.2}_{-0.1}\sigma$$



The LEE is even stronger when you consider another dimension
(the coupling k/MPL range (0.01-0.3) should also be taken into account)

Spin 2

2D Scan

Largest significance

$m_G \sim 750$GeV, $\kappa/M_{Pl} \sim 0.23$

($\Gamma_G \sim 57$ Gev~7%m_G)

Local Z = **3.8σ**

m=500-2000 GeV
k/M_{PL}=0.01-0.3

Use toys or asymptotic formula from
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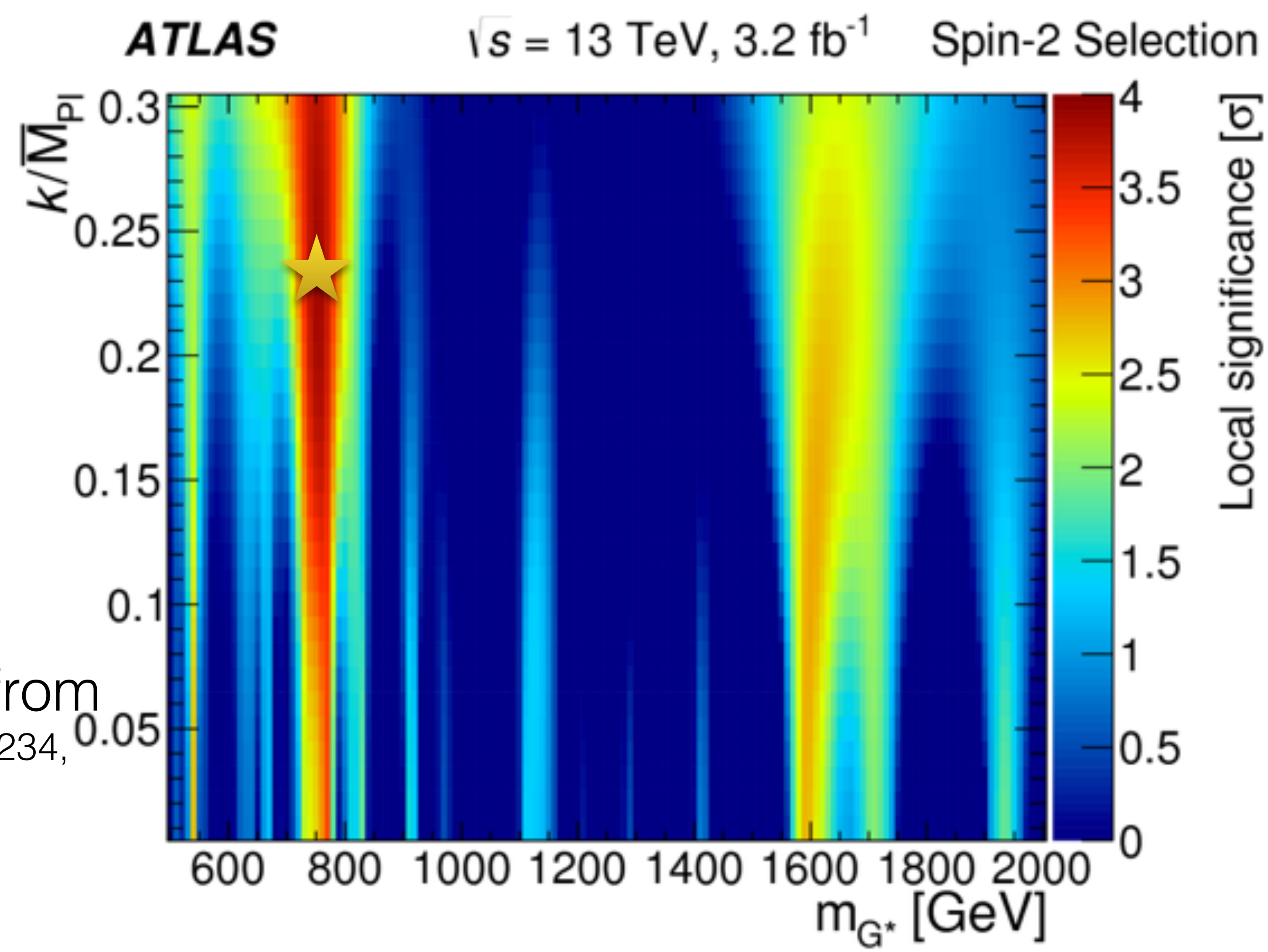
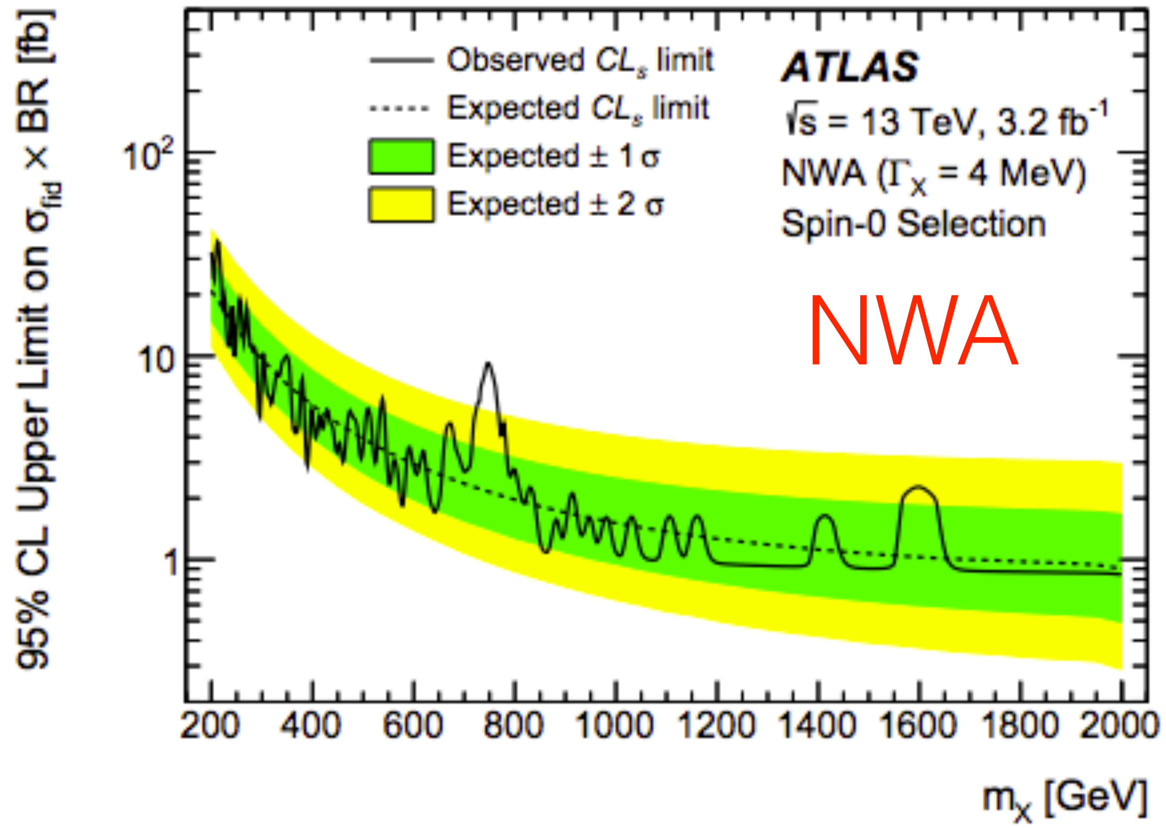
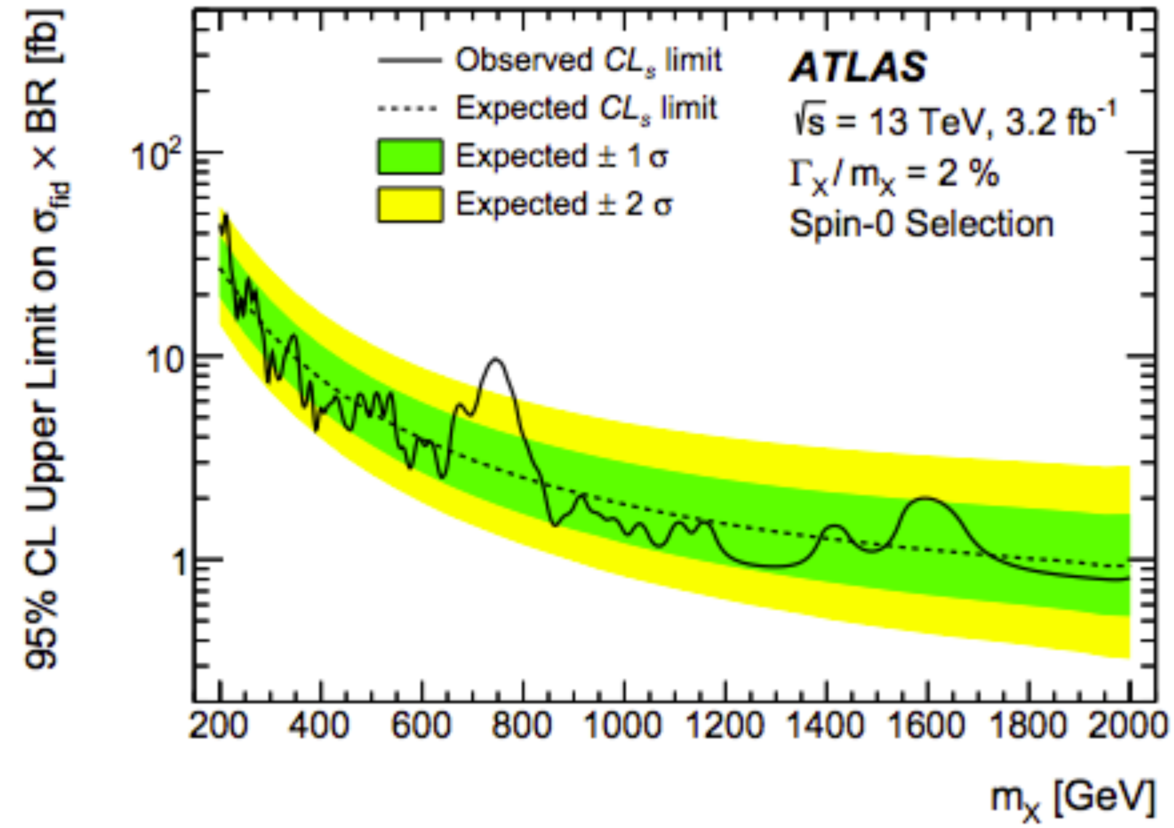


$$Z_{local} = 3.8\sigma$$
$$Z_{global} = 2.1\sigma$$

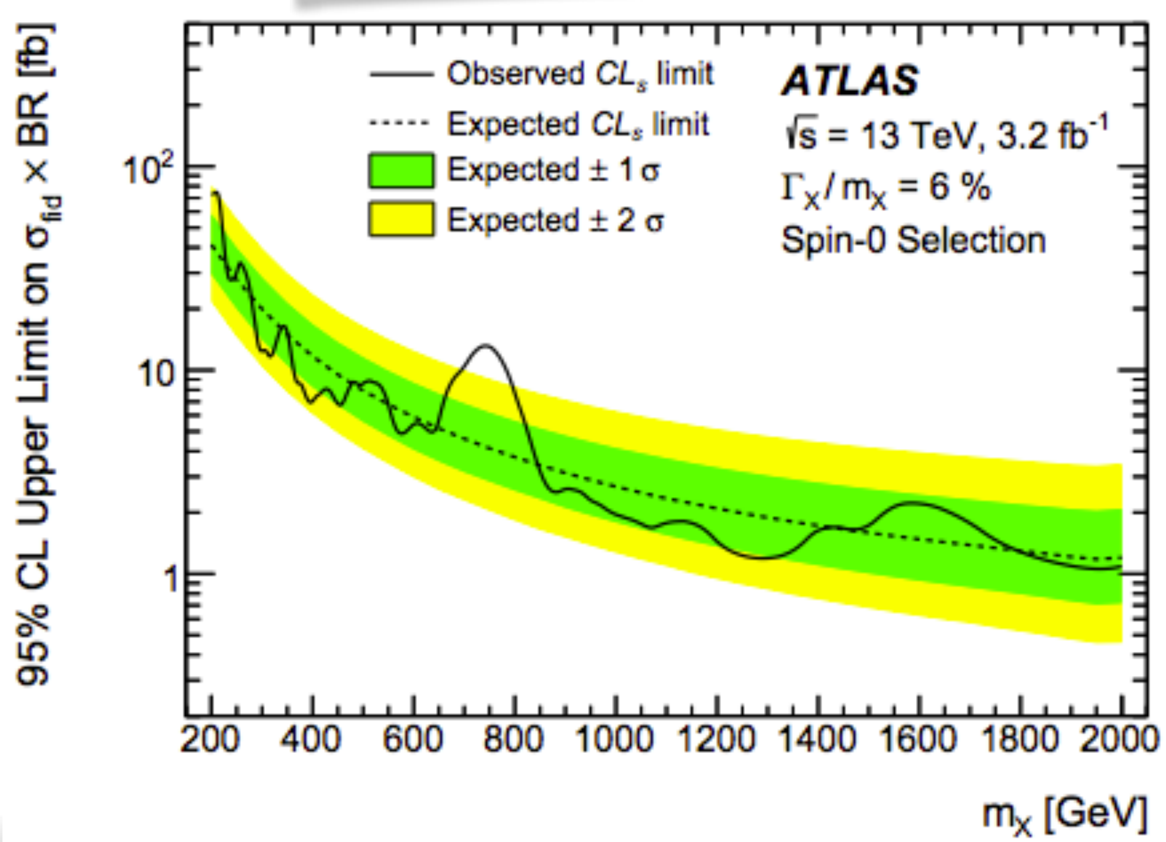
2.1σ is not something to write home about

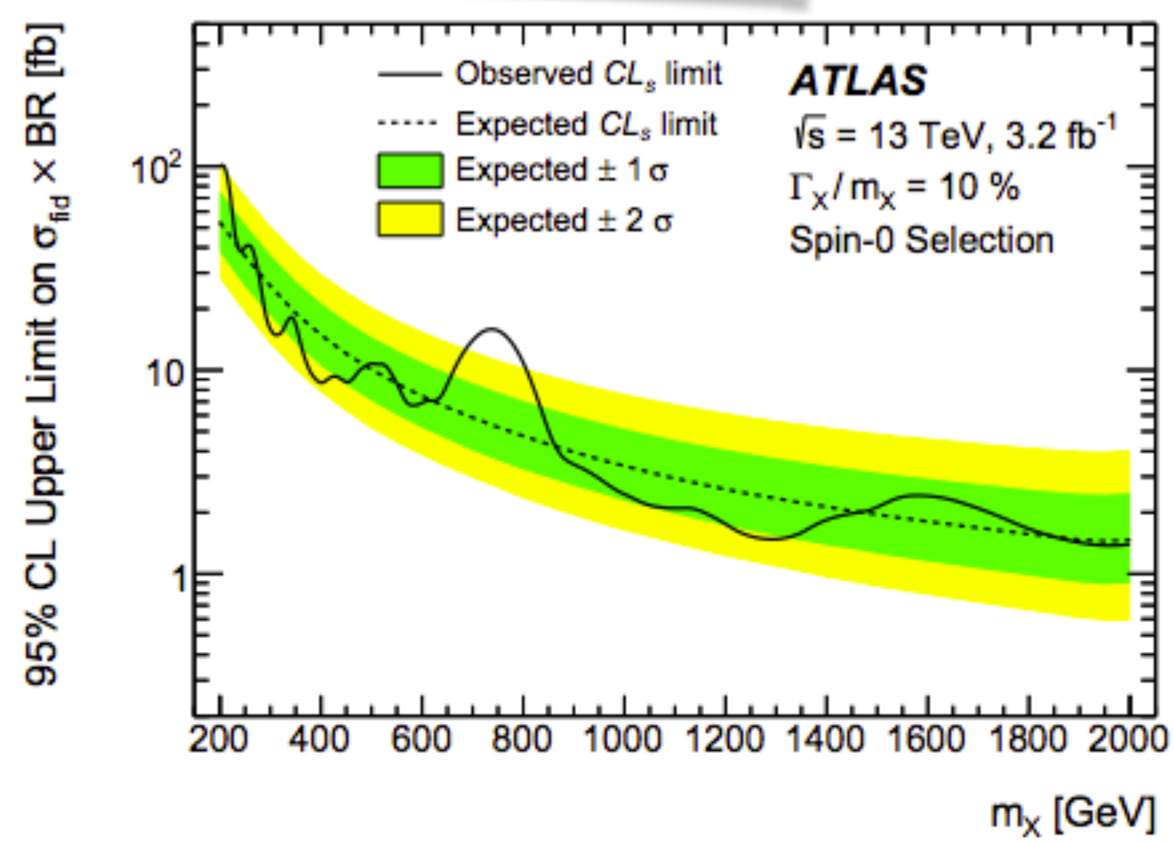
LIMITS ON fiducial σxBR spin 0 ($|\eta_\gamma| < 2.37$)



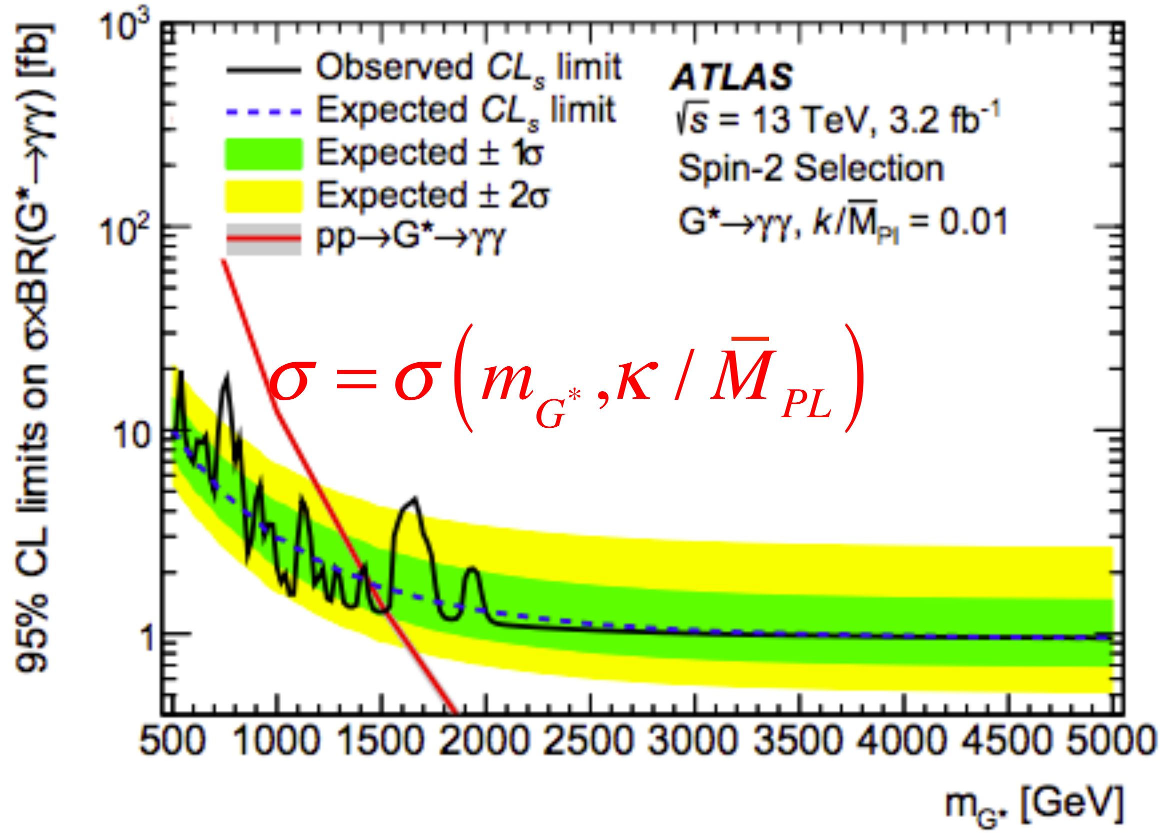


NWA $\sigma \times BR < 35\ fb\ \ @m_S = 200\ GeV$ $\sigma \times BR < 1\ fb\ \ @m_S = 2000\ GeV$

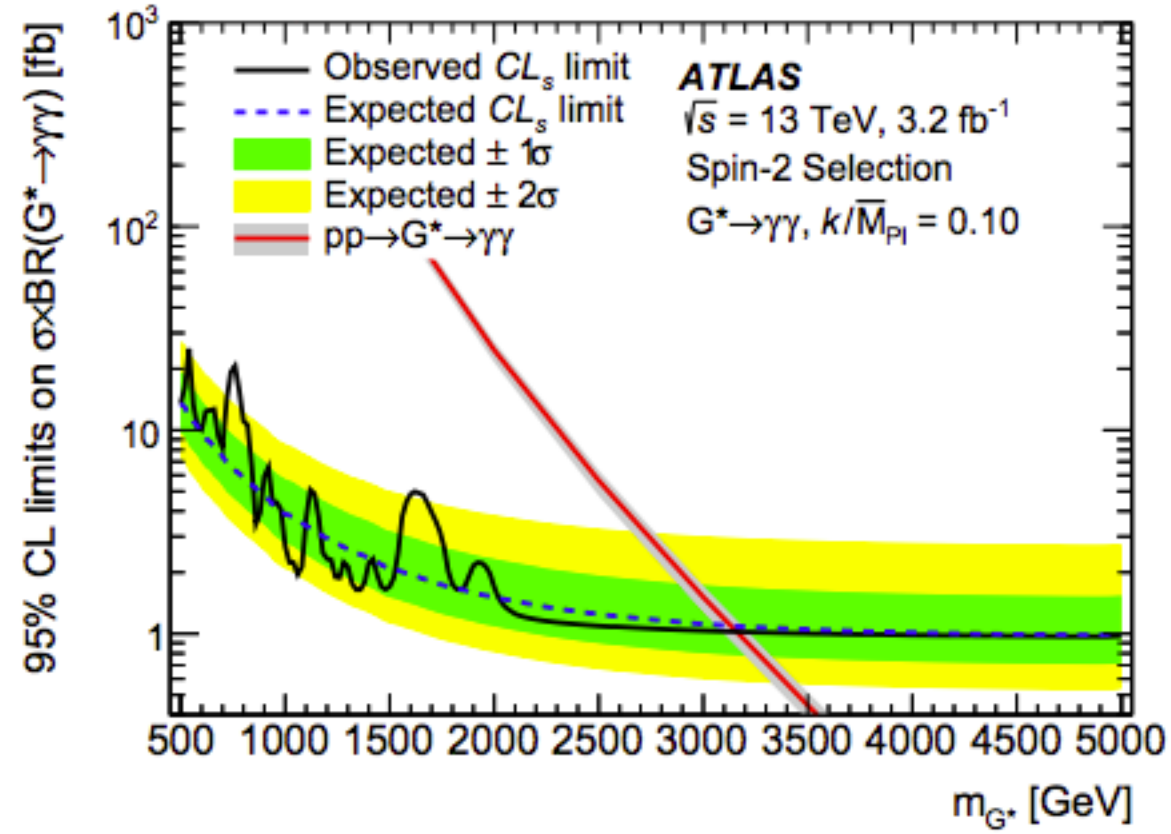




LIMITS ON σxBR spin 2

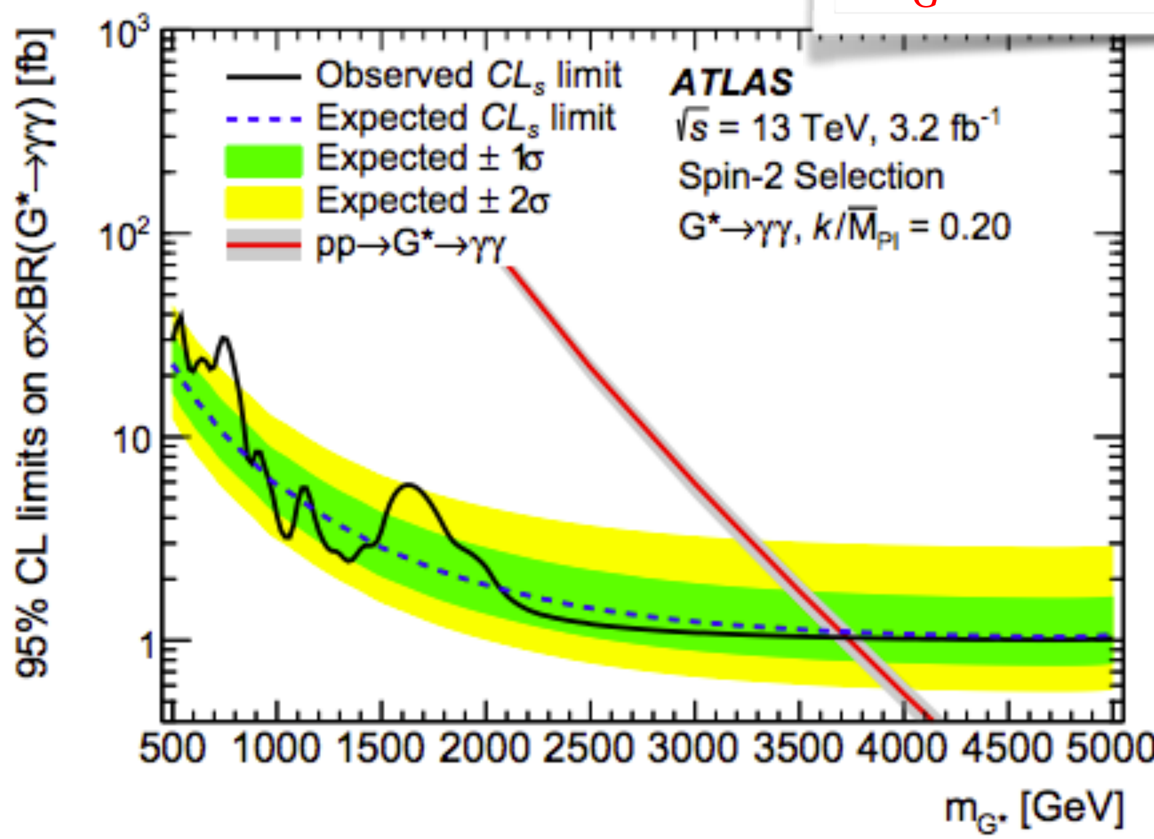


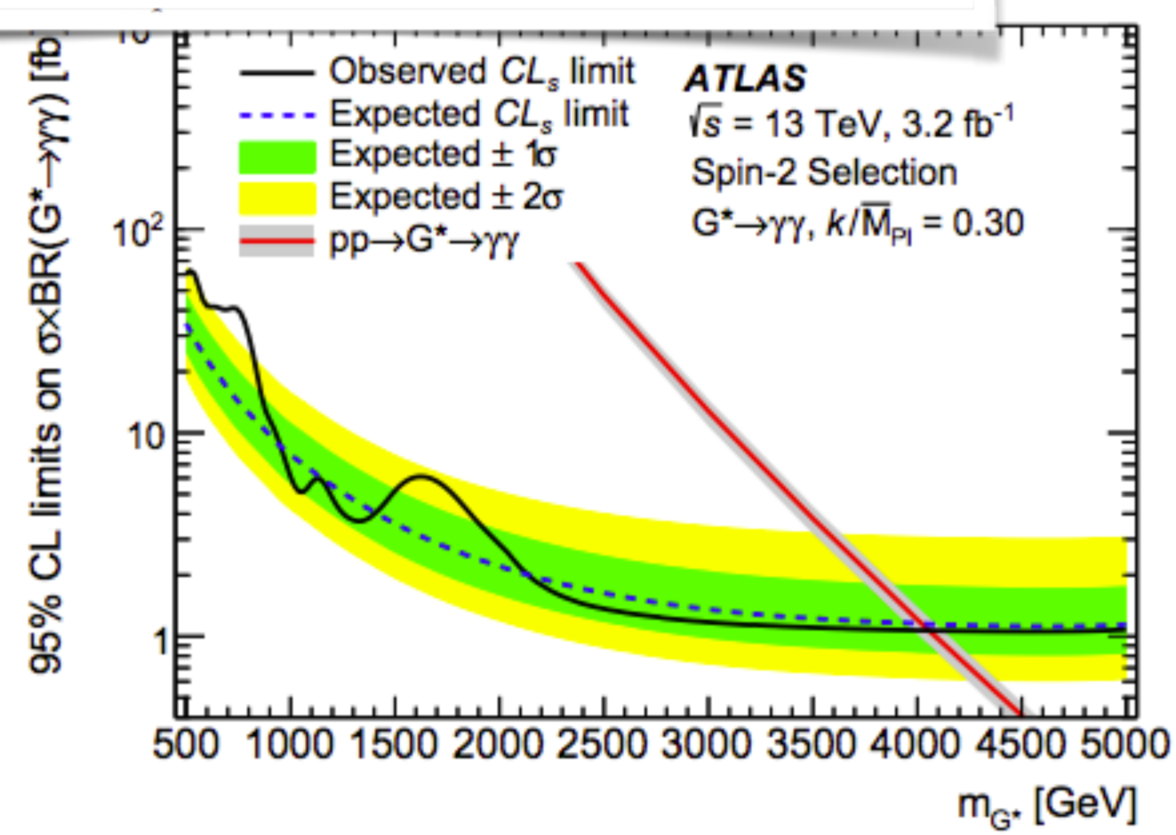
$$\sigma=\sigma\left(m_{G^*},\kappa/\bar{M}_{PL}\right)$$



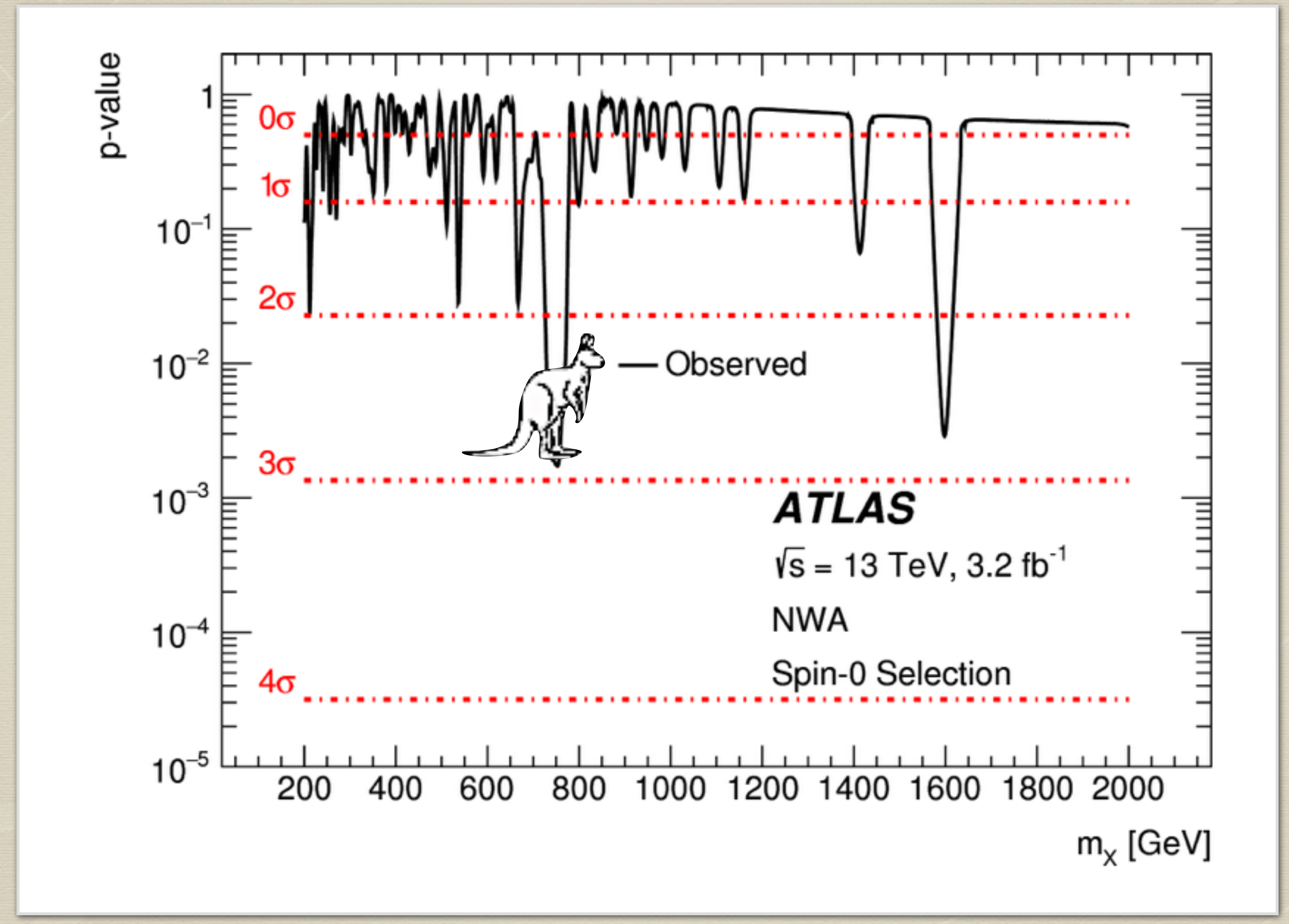
One Can Derive Lower Bounds on m_{G^*} for given κ/M_{PL}

$$m_{G^*}>1.5-4.1\,TeV\ \ for\ \ \kappa/\bar{M}_{PL}=0.01-0.30$$

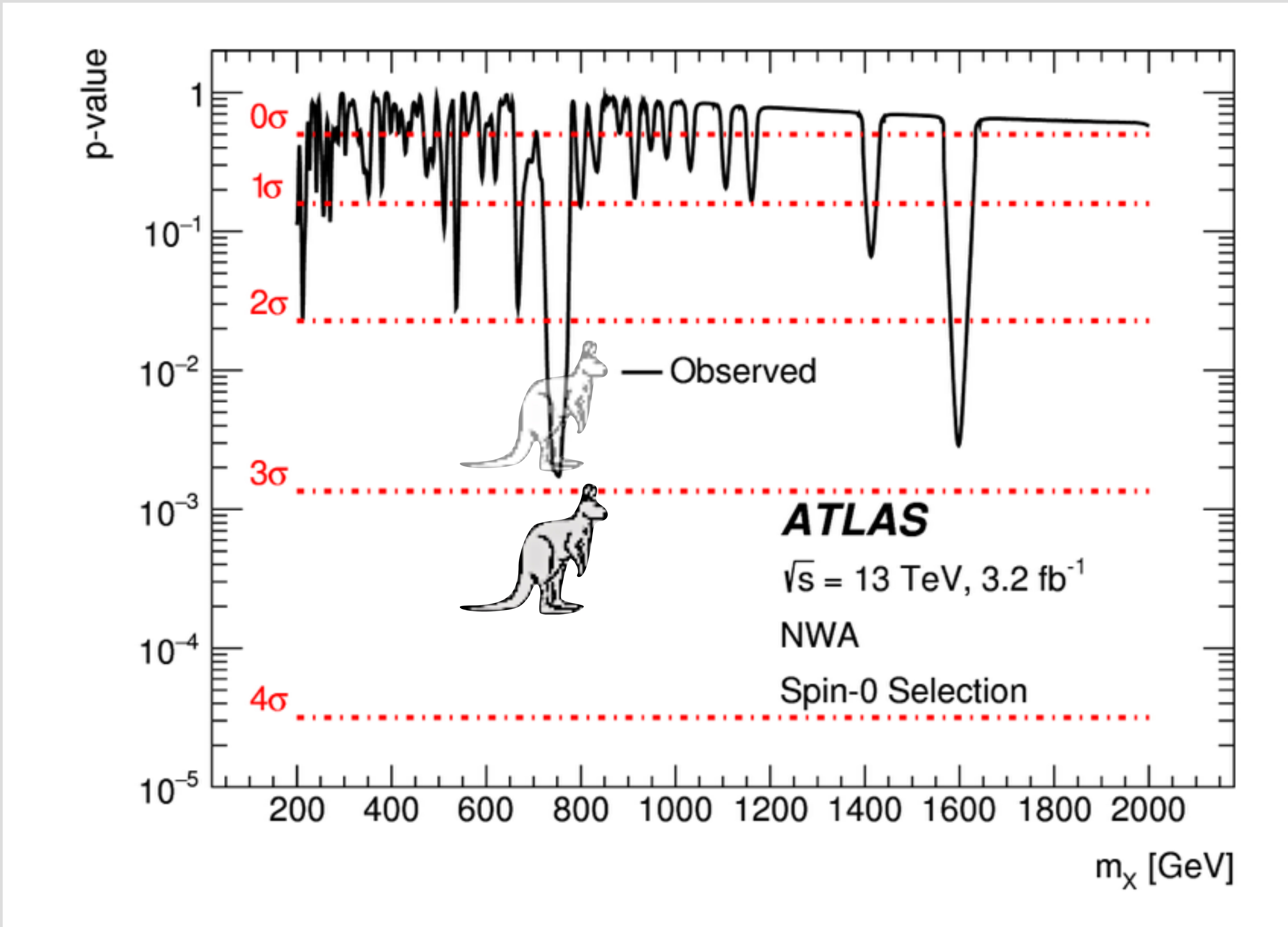




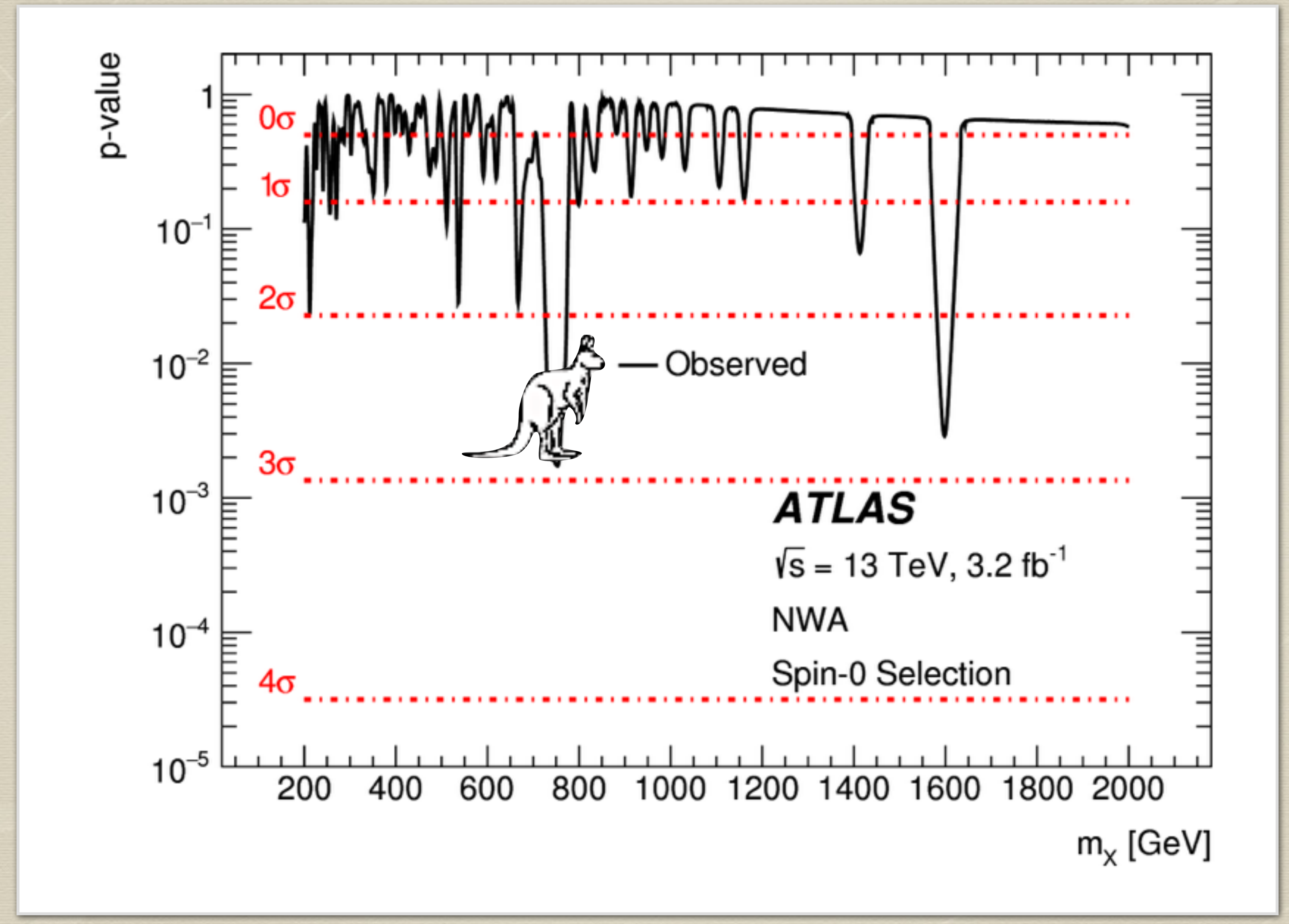
CONCLUSIONS: Where do we go from here?



CONCLUSIONS: Here? (establishing a signal!)

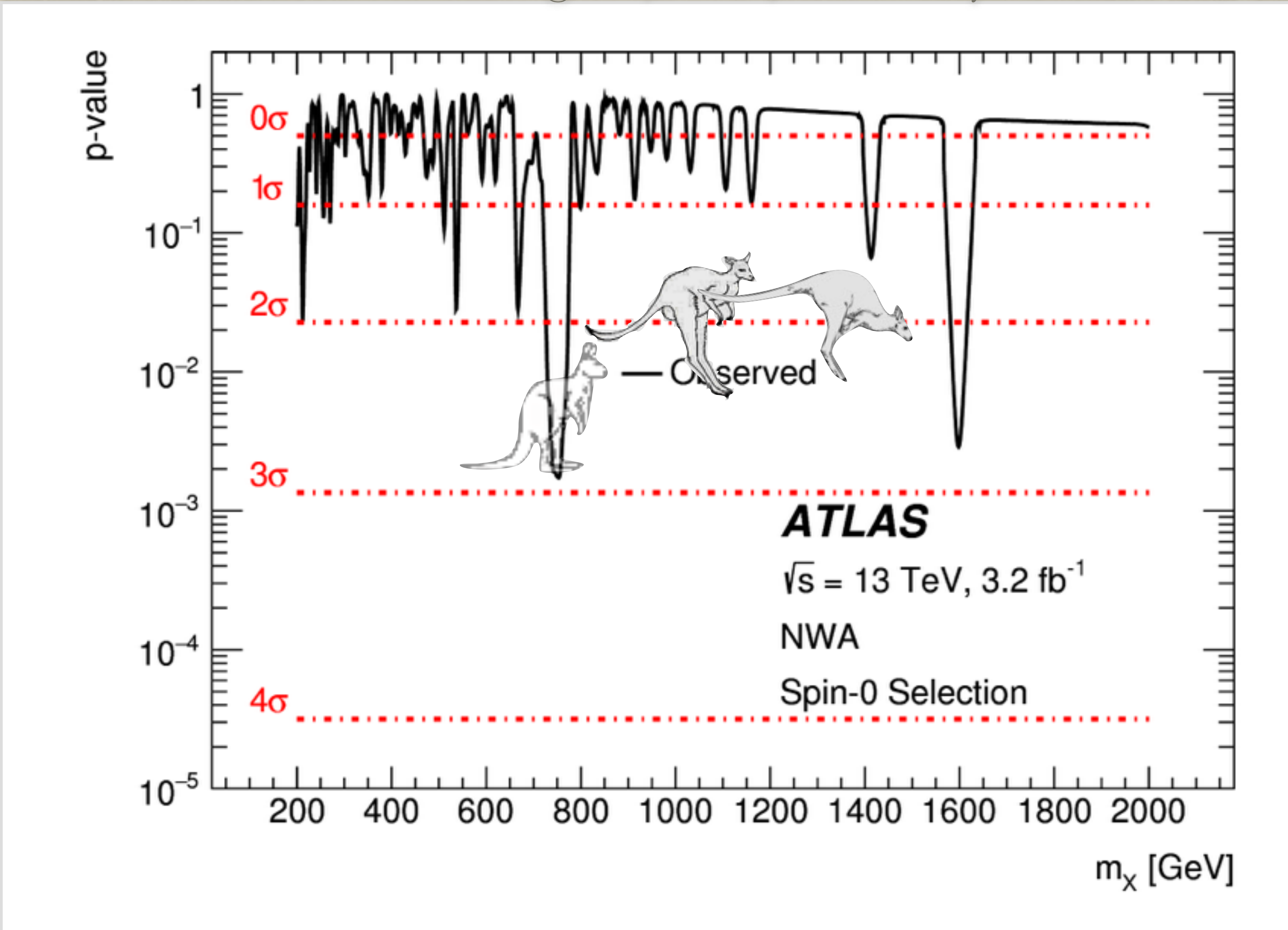


CONCLUSIONS: OR



CONCLUSION: Elsewhere?

where the wild roses grow, since, all beauty must die (N. Cave)



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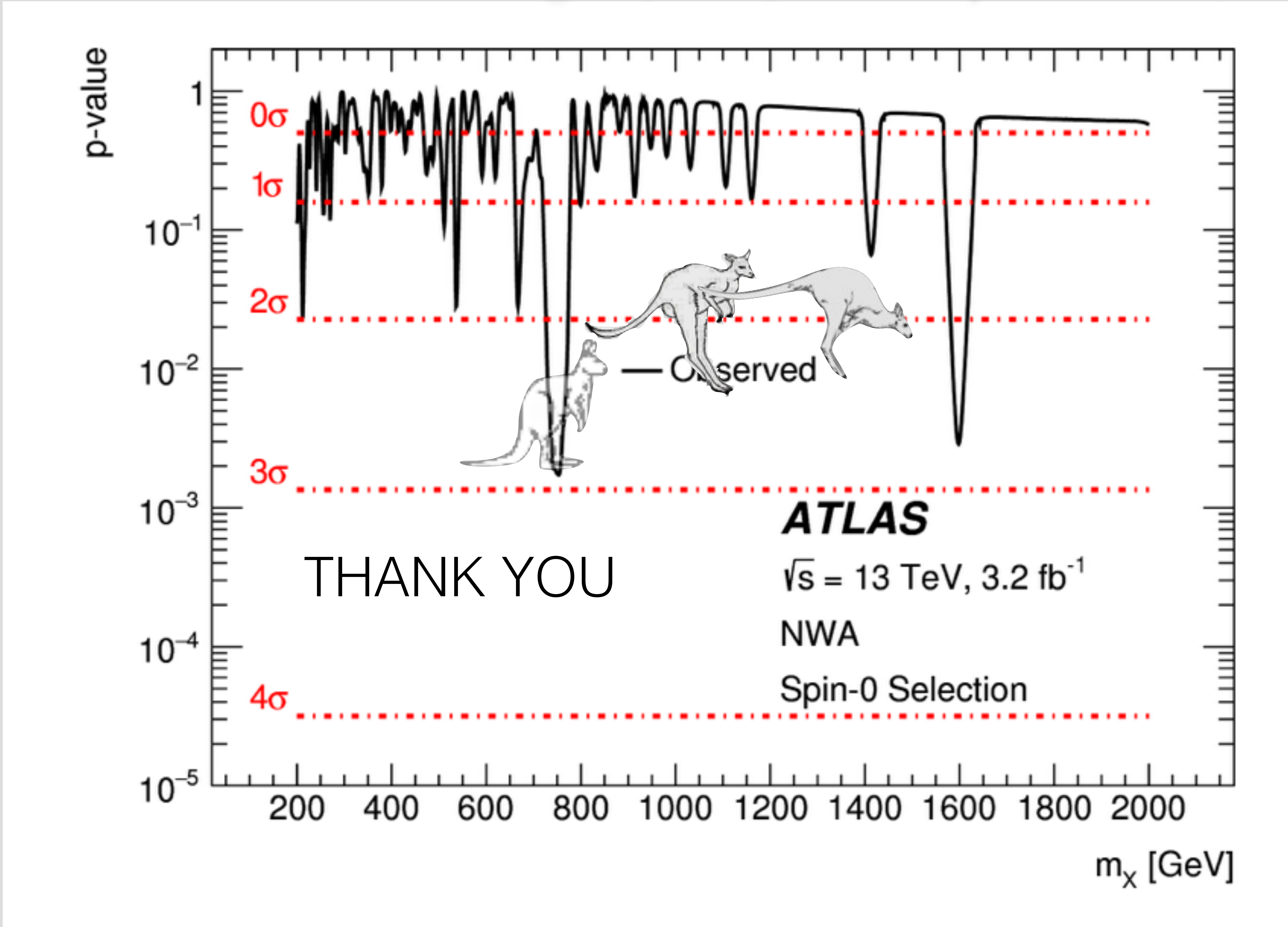

BACKUP