Search for high mass $Z\gamma$ resonances using leptonic Z decays in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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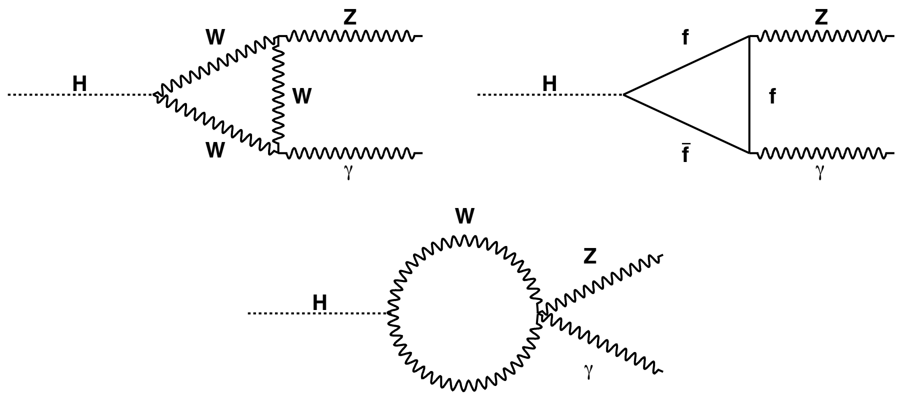
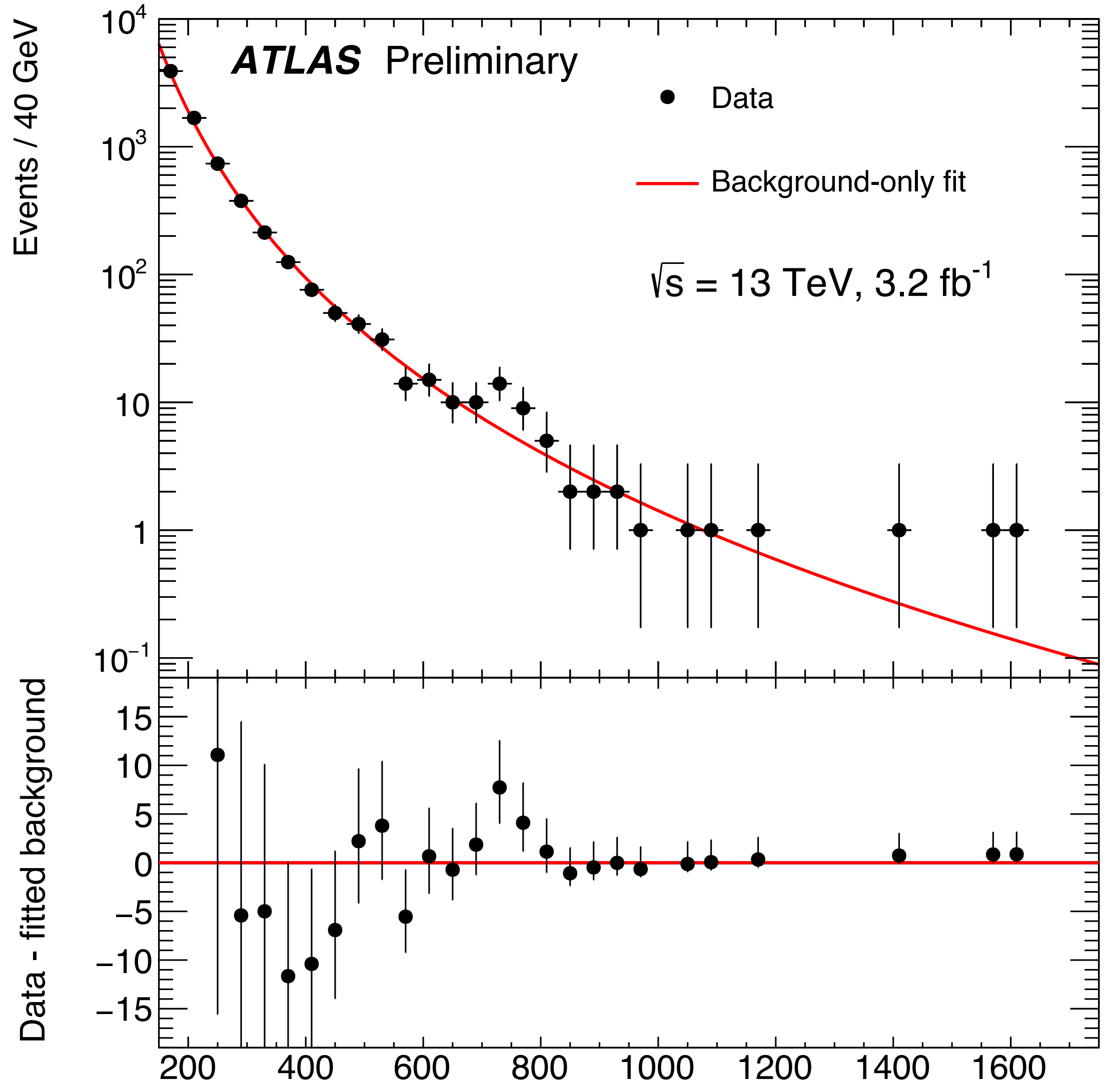
ATLAS EXPERIMENT

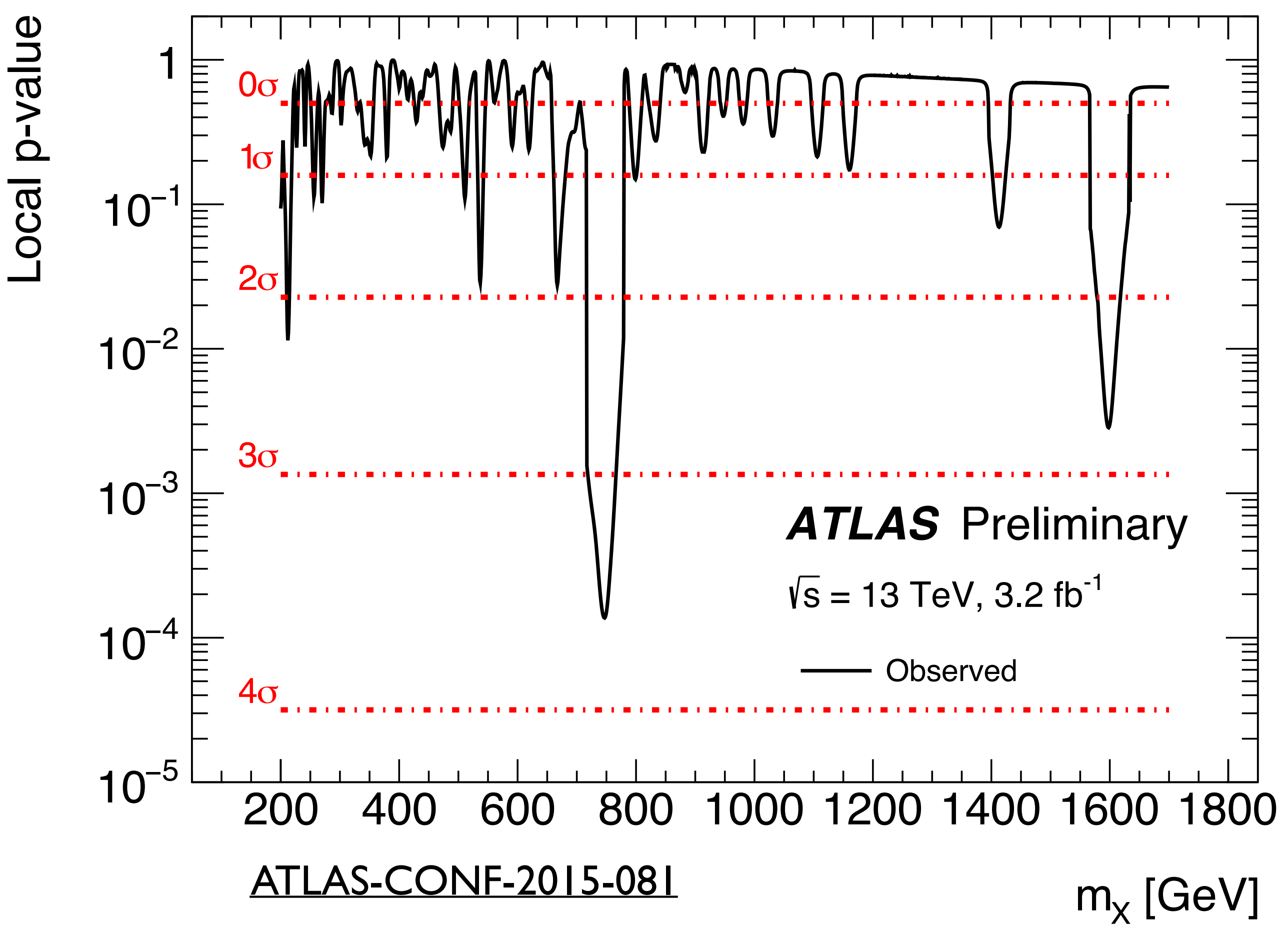
Introduction

- Search for new physics involving high mass resonances with Zγ final state
- Slight excess seen in search for heavy resonances with diphoton final state
  - Search used 3.2fb^{-1} of 13TeV data
  - Similar excess also reported by CMS
- Many theoretical interpretations put forward
- Many models also predict significant decays to Zγ final state





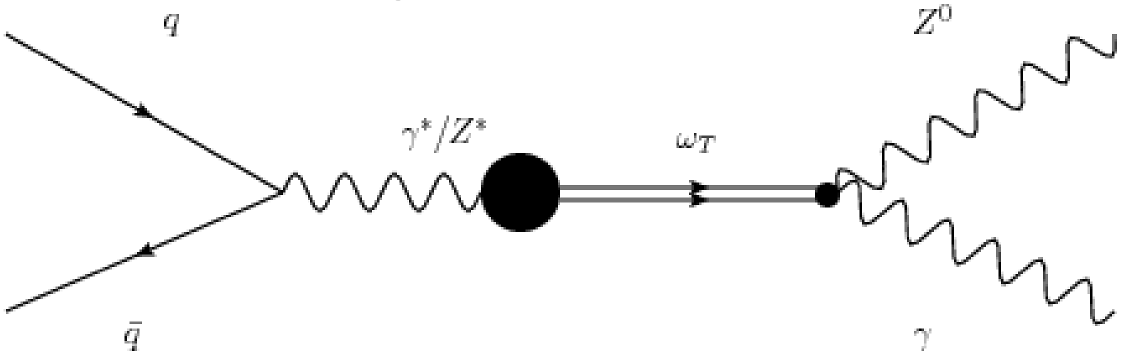
ATLAS-CONF-2015-081



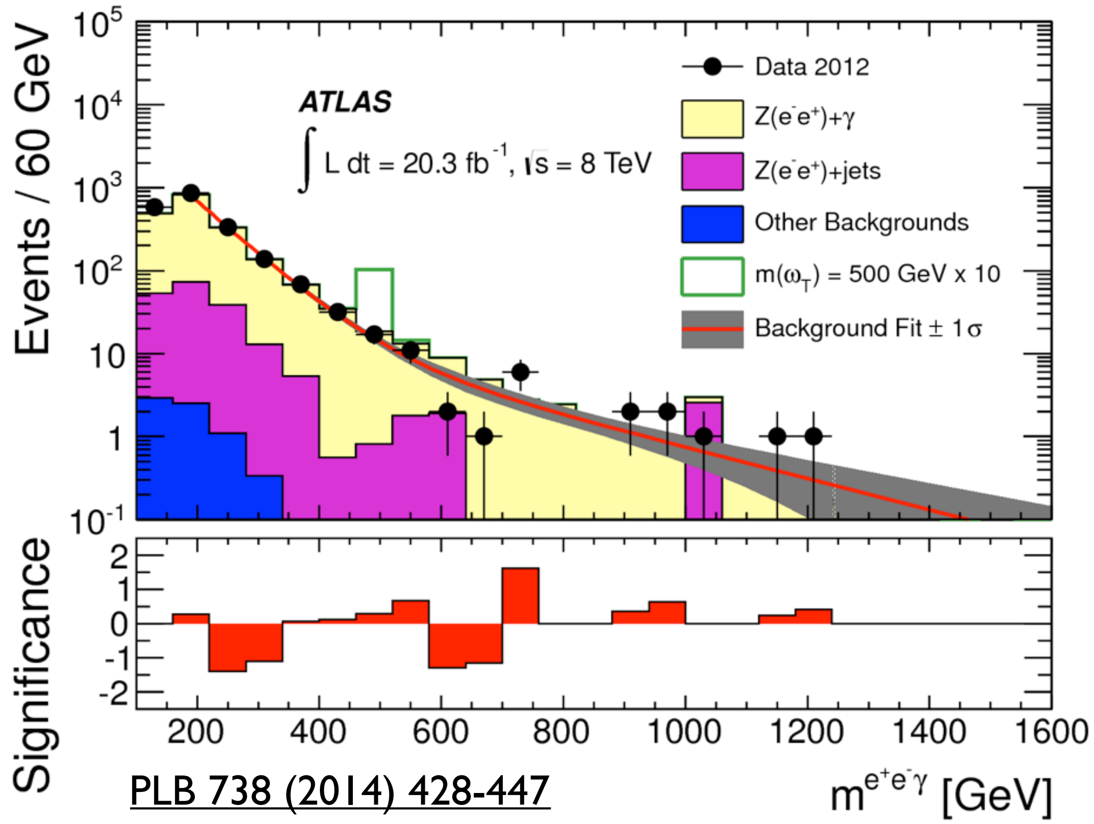
ATLAS-CONF-2015-081

Run I Results

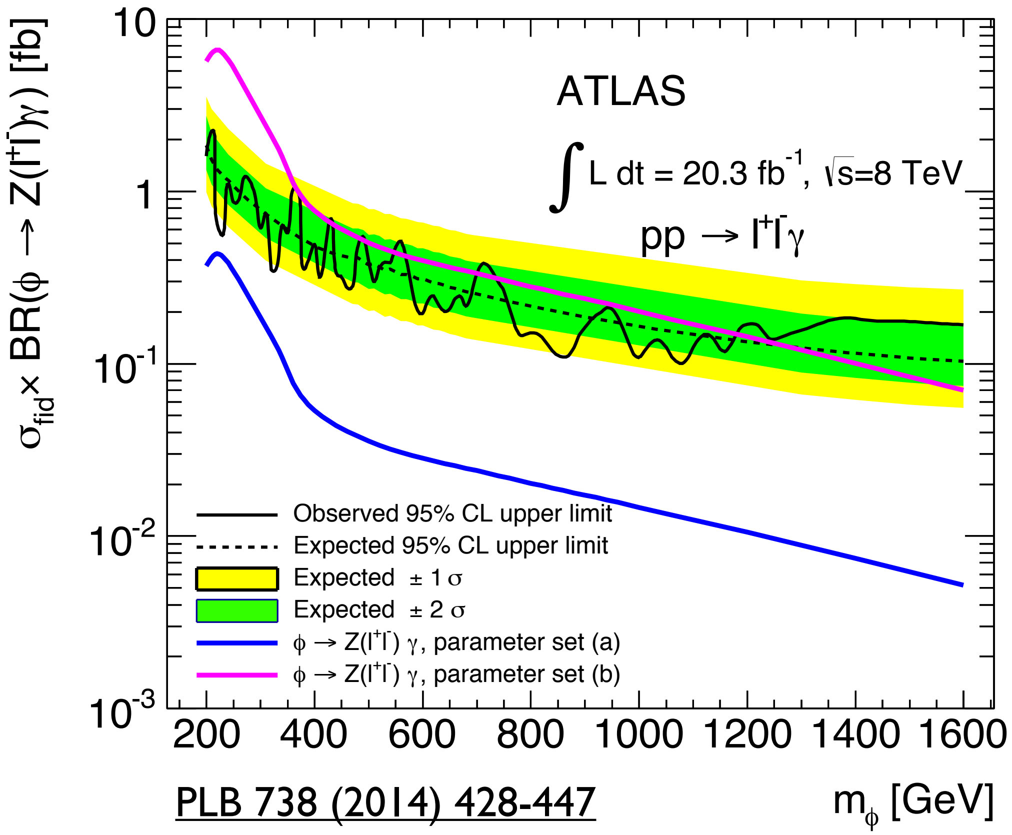
- An exotics search for high mass resonances with Zγ final state was performed
- Run I analysis published in PLB 738 (2014) 428-447
- Search for singlet scalar resonance decaying to Zγ final state
  - Used 20.3 fb^{-1} of 8TeV data
  - 1σ excess at 700GeV down to 0σ at 750GeV
- Trivial matter to extend Run 2 SM H→Zγ software to search for high mass resonances



Three-body invariant mass distribution for the $e^+e^-\gamma$ final state.
The expected signal for a resonance mass of 500 GeV is superimposed.



PLB 738 (2014) 428-447



PLB 738 (2014) 428-447

Run 2 Event Selection

- Events selected using lowest-energy unprescaled single and dilepton triggers

- Event preselection requires:
  - One photon with p_T>10GeV passing loose photon ID
  - Two isolated electrons with p_T>10GeV passing medium ID
  - Two isolated muons with p_T>10GeV and good quality
  - M(ll)>45 GeV

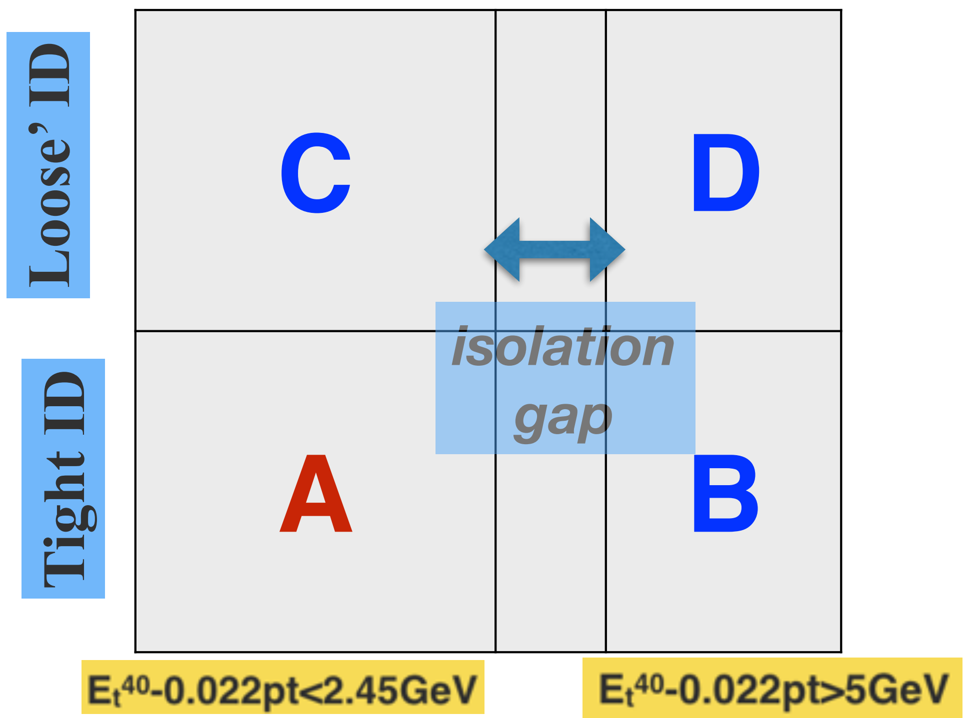
- Final selection
  - Relative photon p_T cut $p_T/M(ll\gamma)>0.3$
  - Photons must be isolated
  - $|M(ll)-mZ|<15$GeV

- Several corrections are applied to MC samples:
  - MC weight
  - Pileup weight
  - Vertex weight
  - Photon efficiency and isolation scale factors
  - Electron ID, reconstruction & isolation scale factors
  - Muon efficiency & isolation scale factors
  - Trigger scale factors

- No event categorisation is applied
  - $ee\gamma$ and $\mu\mu\gamma$ channels are not treated separately

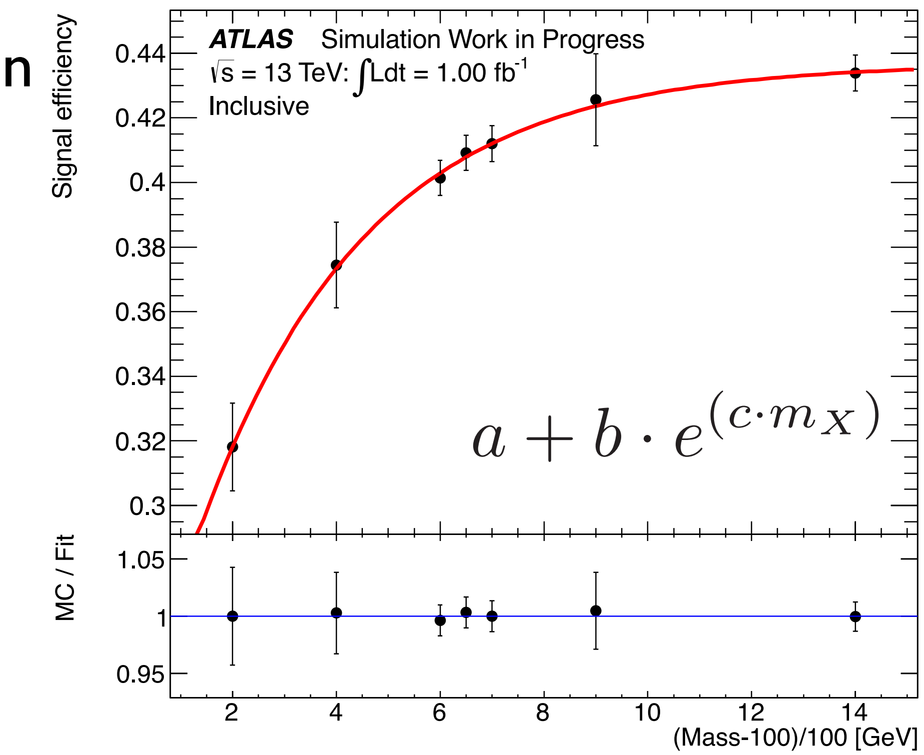
Background Composition

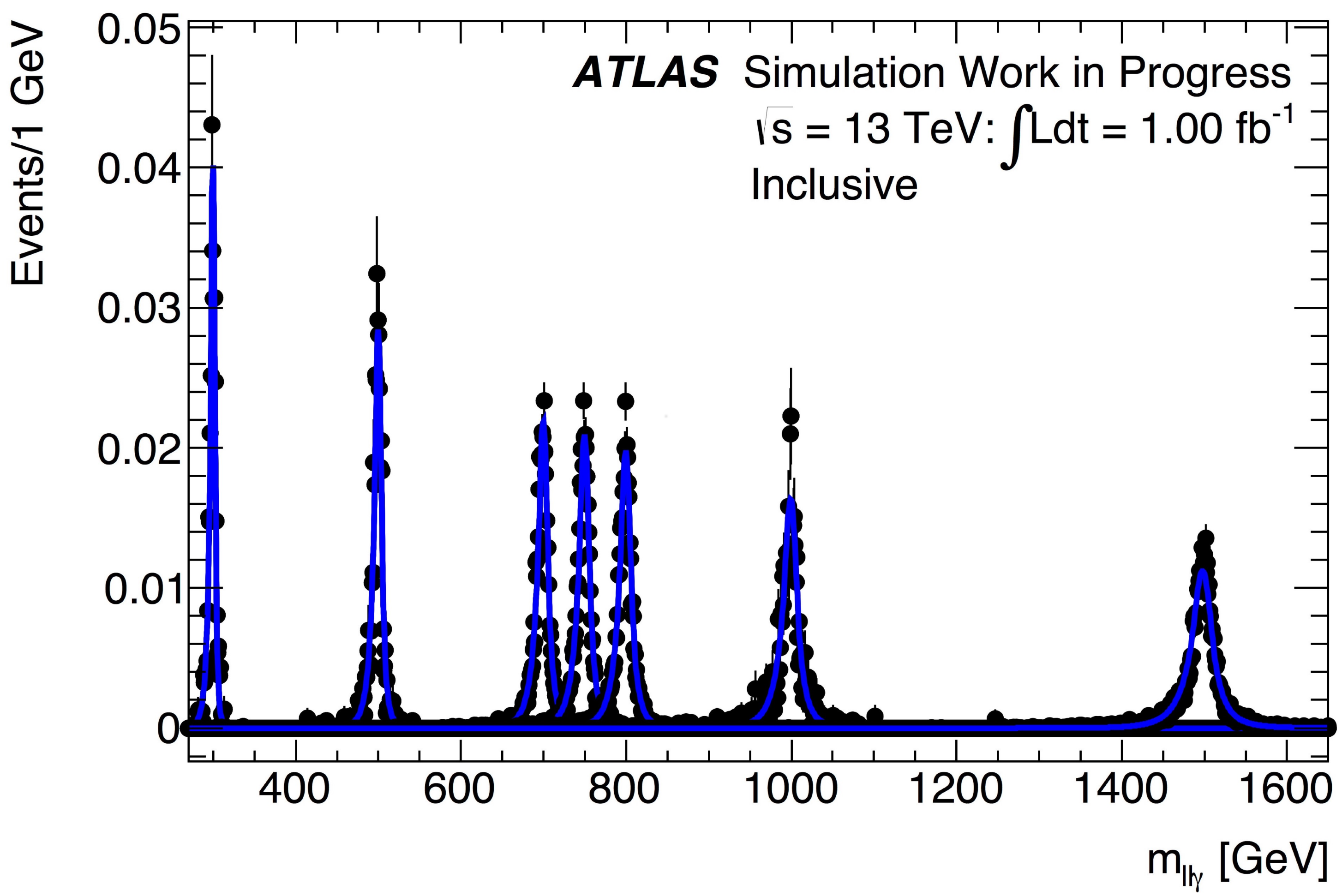
- After event selection:
  - irreducible background from Z+γ
  - reducible background from Z+Jet
  - small contribution from tt bar
- Background decomposition uses data-driven ABCD method
  - 2D sideband method based on isolation and photon ID
  - Photon ID can be:
    - Tight: satisfies all selection criteria
    - Loose': orthogonal criteria with four variables inverted
  - Isolation:
    - Isolated or non-isolated
    - Isolation gap introduced to reduce signal leakage
- Good agreement between Data and MC



Signal Modelling

- Signal MC samples generated using narrow width approximation
  - Higgs signal peak has width ~4.0MeV
- Mass points at: 200, 300, 500, 700, 750, 800, 1000, 1500 GeV
- Signal Modelled with a double-sided Crystal Ball function
  - All mass points fitted simultaneously
  - All parameters vary as a function of mass point
- Signal efficiency described by an exponential function





$$
\begin{cases}
e^{-t^2/2} & \text{if } -\alpha_{\mathrm{Lo}} \le t \le \alpha_{\mathrm{Hi}} \\
\dfrac{e^{-0.5\alpha_{\mathrm{Lo}}^2}}{\left[\frac{\alpha_{\mathrm{Lo}}}{n_{\mathrm{Lo}}}\left(\frac{n_{\mathrm{Lo}}}{\alpha_{\mathrm{Lo}}} - \alpha_{\mathrm{Lo}} - t\right)\right]^{n_{\mathrm{Lo}}}} & \text{if } t < -\alpha_{\mathrm{Lo}} \\
\dfrac{e^{-0.5\alpha_{\mathrm{Hi}}^2}}{\left[\frac{\alpha_{\mathrm{Hi}}}{n_{\mathrm{Hi}}}\left(\frac{n_{\mathrm{Hi}}}{\alpha_{\mathrm{Hi}}} - \alpha_{\mathrm{Hi}} + t\right)\right]^{n_{\mathrm{Hi}}}} & \text{if } t > \alpha_{\mathrm{Hi}},
\end{cases}
$$

Parameter dependence

Par	Mass Dependence
μ_{CB}	$a_\mu + b_\mu{*}x + c_\mu{*}x{*}x + m_X$
σ_{CB}	$a_\sigma + b_\sigma * x$
α_{lo}	$a_{\alpha lo} + b_{\alpha lo}/(x+c_{\alpha lo})$
α_{hi}	$a_{\alpha hi} + b_{\alpha hi}/(x+c_{\alpha hi})$
X	$(m_X-100)/100$

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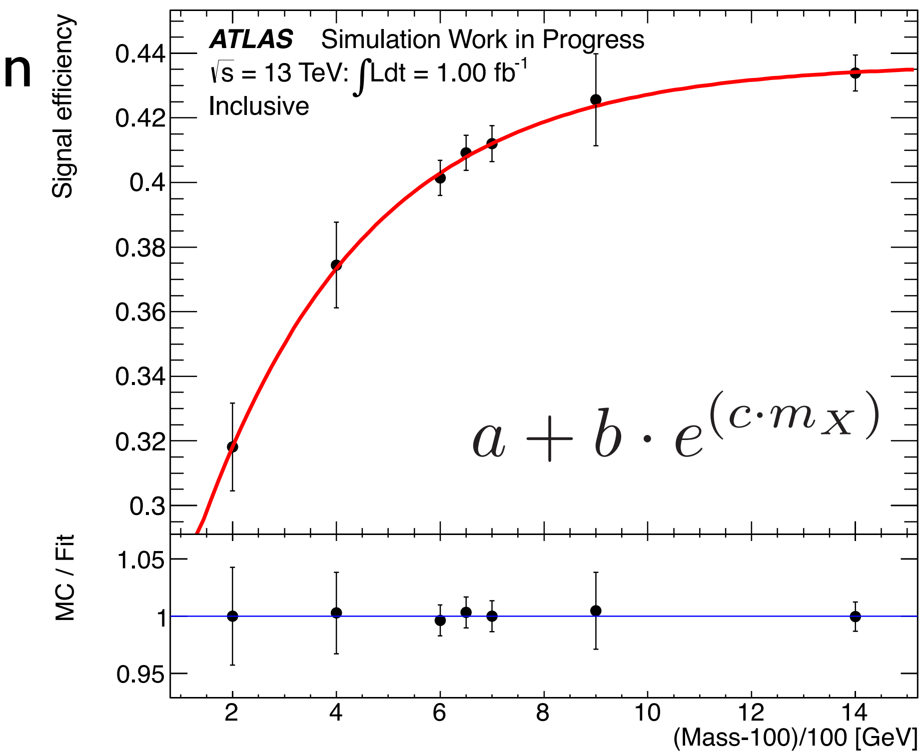

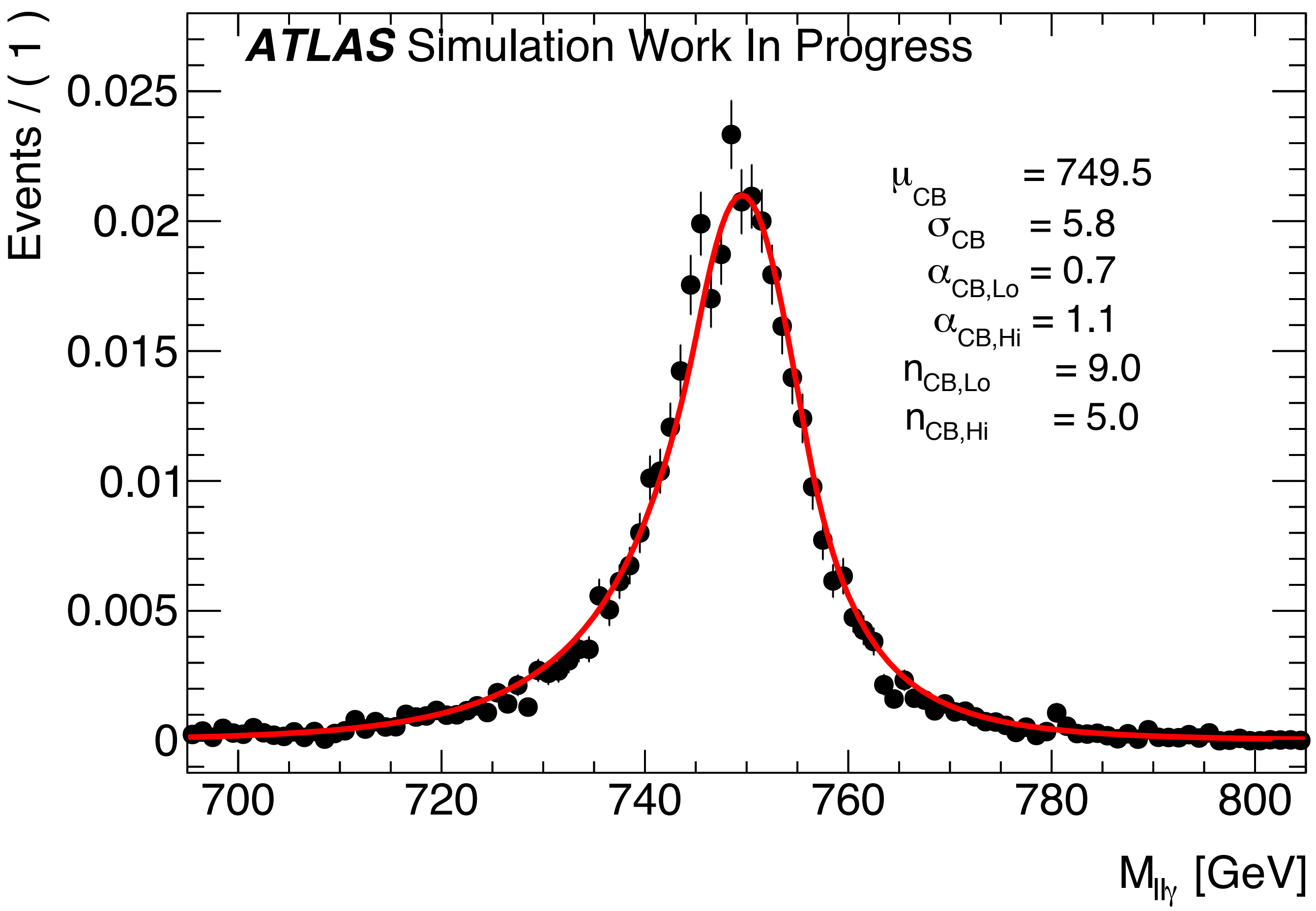

$$N \cdot \begin{cases} e^{-t^2/2} & \text{if } -\alpha_{\mathrm{Lo}} \leq t \leq \alpha_{\mathrm{Hi}} \\ \dfrac{e^{-0.5\alpha_{\mathrm{Lo}}^2}}{\left[\frac{\alpha_{\mathrm{Lo}}}{n_{\mathrm{Lo}}}\left(\frac{n_{\mathrm{Lo}}}{\alpha_{\mathrm{Lo}}} - \alpha_{\mathrm{Lo}} - t\right)\right]^{n_{\mathrm{Lo}}}} & \text{if } t < -\alpha_{\mathrm{Lo}} \\ \dfrac{e^{-0.5\alpha_{\mathrm{Hi}}^2}}{\left[\frac{\alpha_{\mathrm{Hi}}}{n_{\mathrm{Hi}}}\left(\frac{n_{\mathrm{Hi}}}{\alpha_{\mathrm{Hi}}} - \alpha_{\mathrm{Hi}} + t\right)\right]^{n_{\mathrm{Hi}}}} & \text{if } t > \alpha_{\mathrm{Hi}}, \end{cases}$$

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α_{lo}	$a_{\alpha lo} + b_{\alpha lo} / (x + c_{\alpha lo})$
α_{hi}	$a_{\alpha hi} + b_{\alpha hi} / (x + c_{\alpha hi})$
X	$(m_X - 100)/100$

Background Modelling

- Selected background model used in other searches
  - multi-jet, photon+jet and diphoton
- Class of functions have form:

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

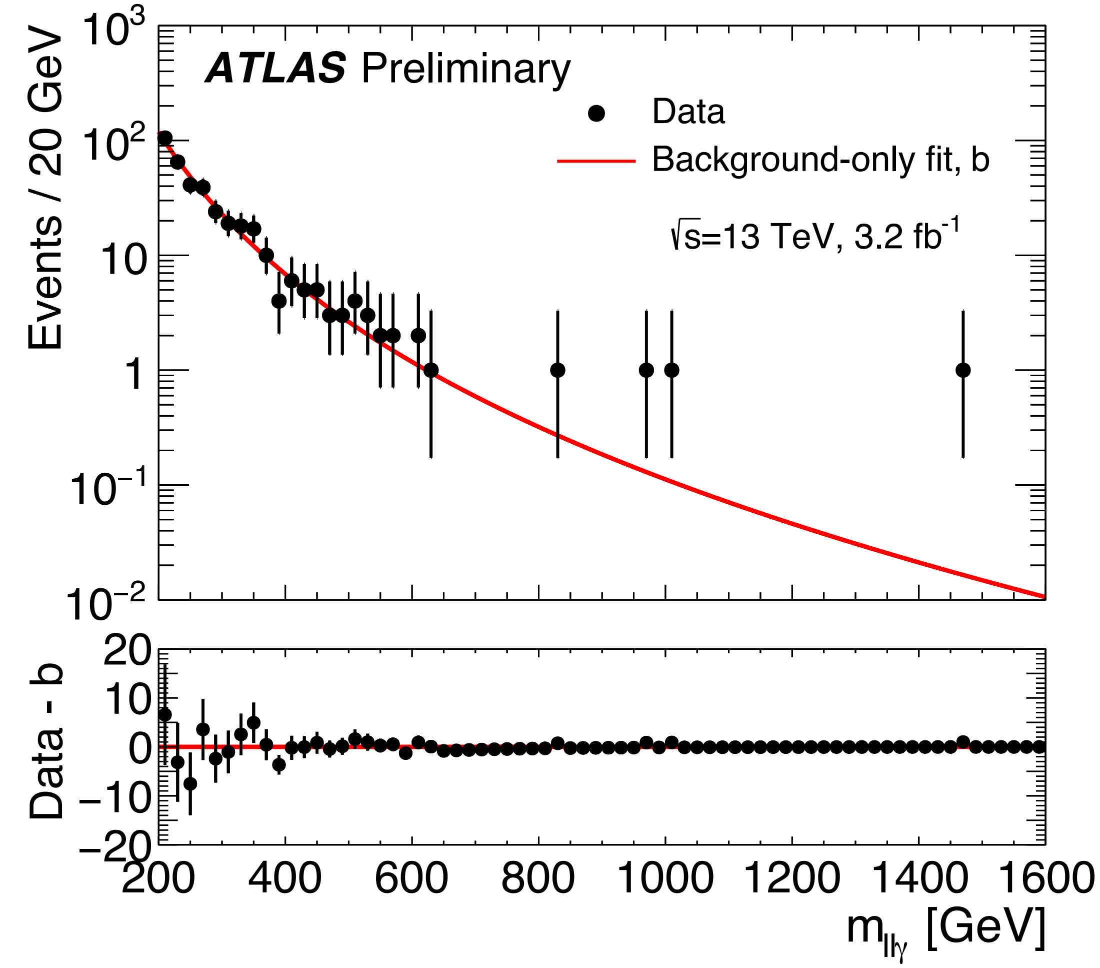
- where:

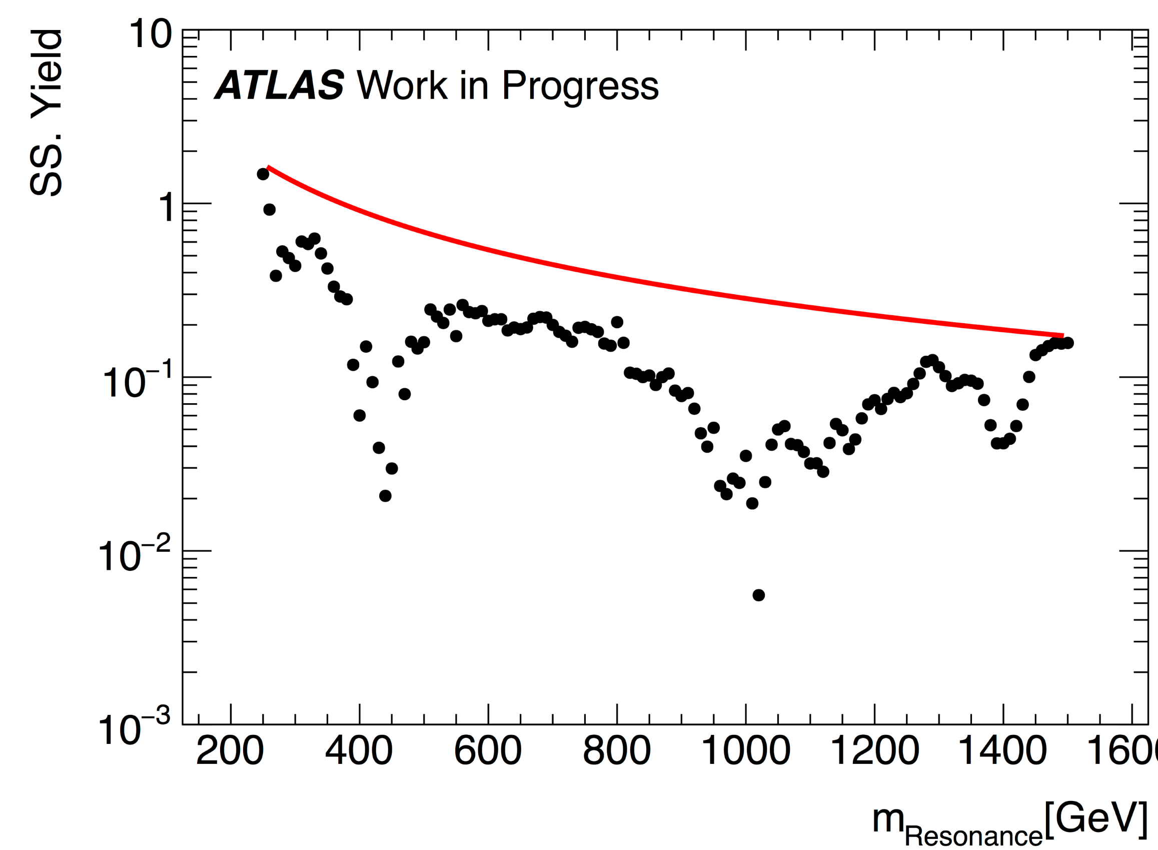
$$x = \frac{m_{\ell\ell\gamma}}{\sqrt{s}}$$

- The simplest function is:

$$f_{k=0;d=1/3}(x;b,d,\{a_k\}) = (1-x^{1/3})^b x^{a_0}$$

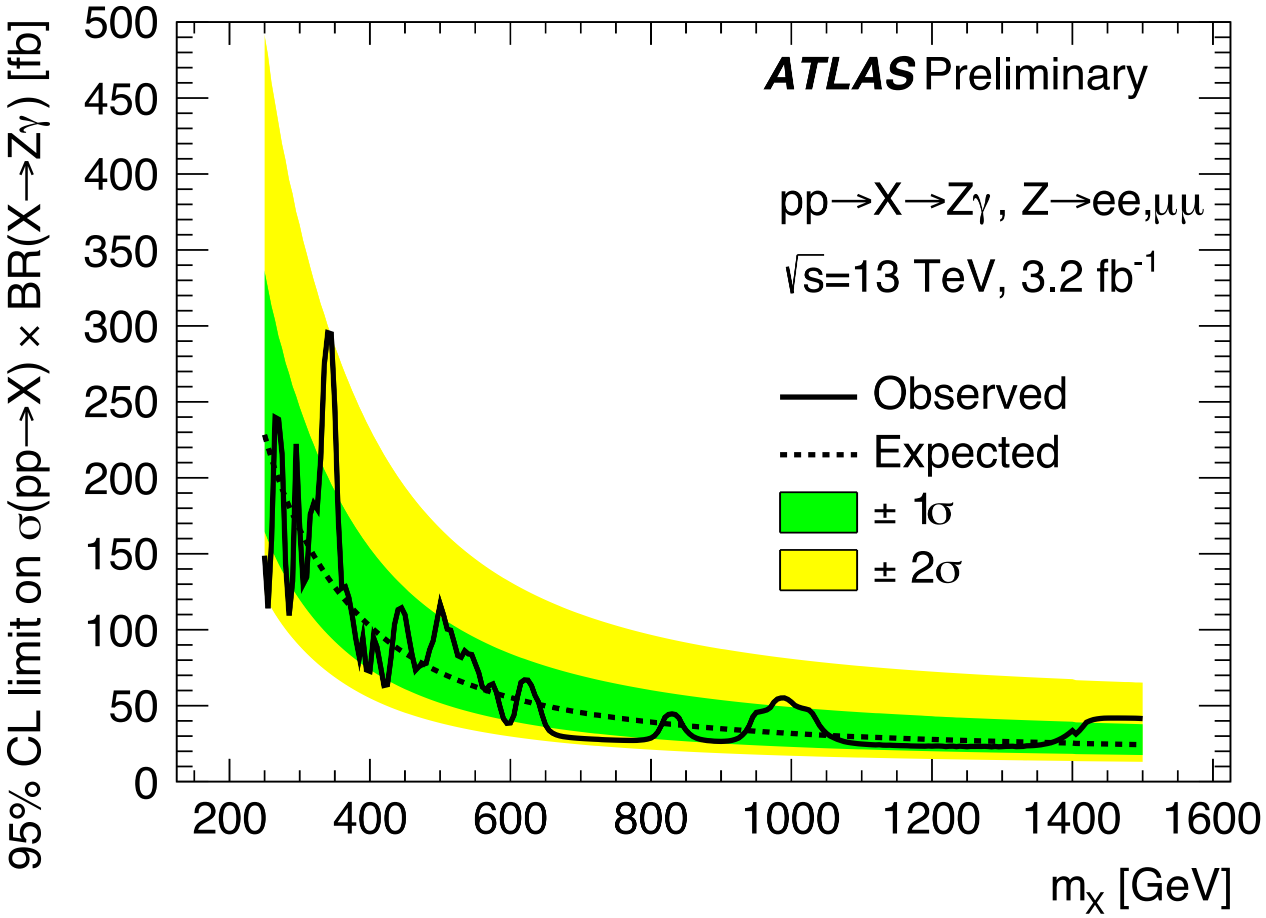
- Background is data-driven
- Model chosen for minimal "spurious signal"
  - Small bias in signal yield due to imperfect modelling of background
  - Bias must be <20% of uncertainty from background fluctuations
- Spurious signal treated as systematic uncertainty
- Parameterised by the envelope of spurious signal at each mass point

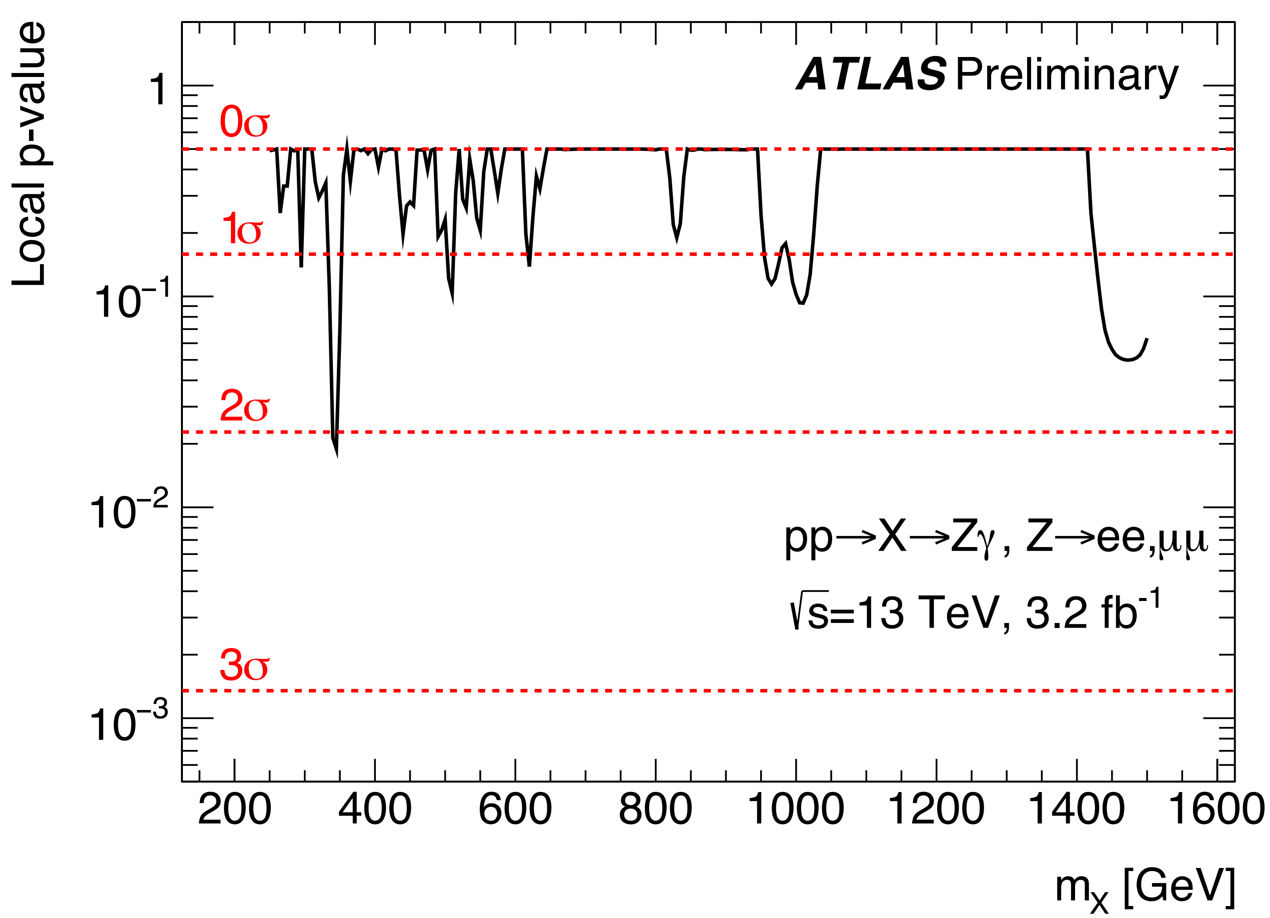




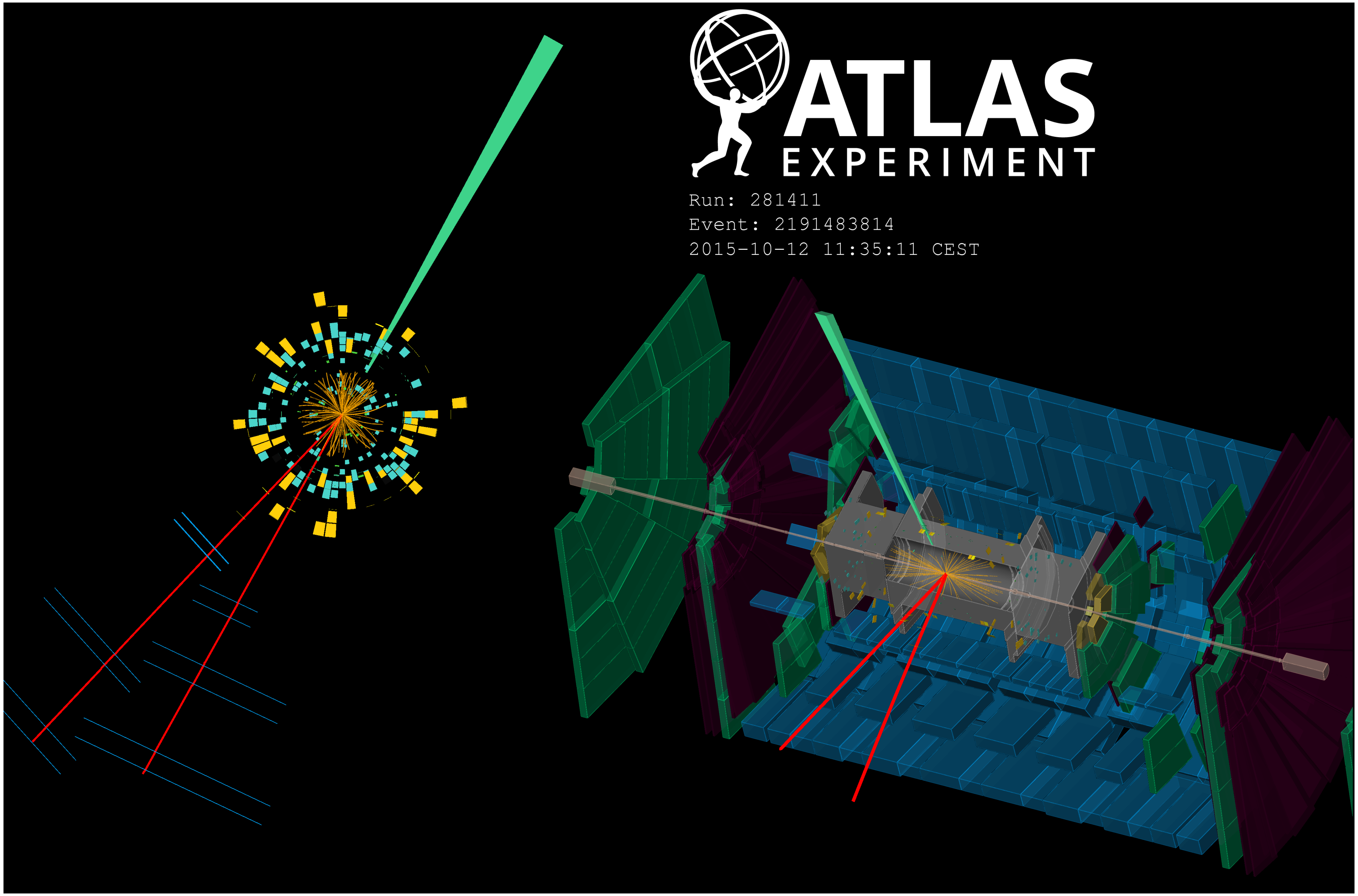
Results

- Analysis is dominated by statistical uncertainties
- Largest systematic uncertainty is on luminosity (±5%)
- Expected limits range from 24.3fb to 230fb
- Observed Limits range from 22.9fb to 296fb
- Four candidate M(llγ) events with mass > 700GeV
- Largest deviation from background-only hypothesis is ~2σ at ~350GeV





Event Displays: μμγ

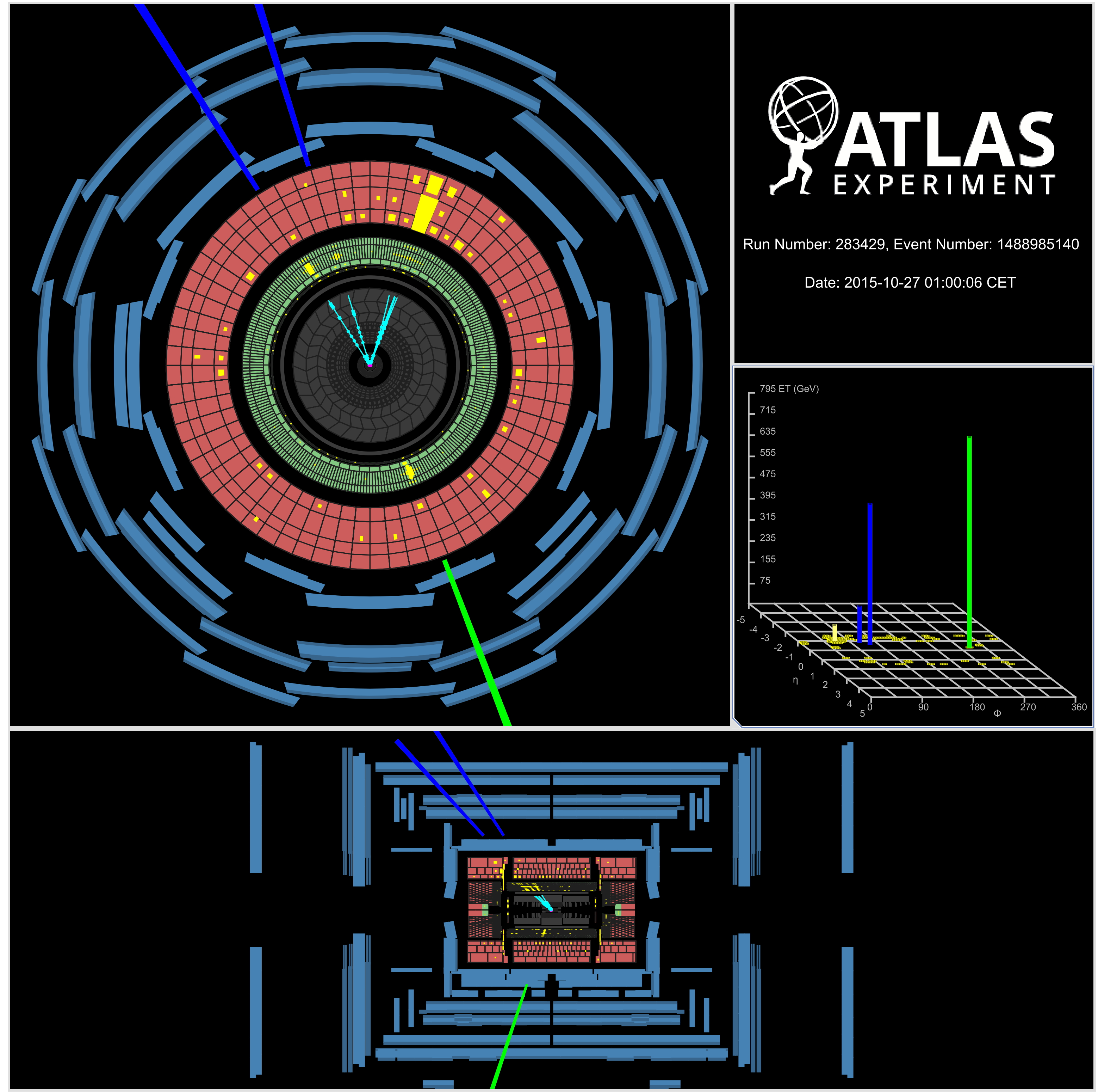


- Highest invariant mass μμγ candidate
- Photon with p_T=491 GeV
- Muons with p_T=488 GeV, 48 GeV

- M(ll) = 93.9 GeV
- M(llγ) = 1030 GeV

Event Displays: eeγ

- Highest invariant mass eeγ candidate
- Photon with p_T=795 GeV
- Muons with p_T=528 GeV, 135 GeV
- M(ll) = 91.7 GeV
- M(llγ) = 1470 GeV

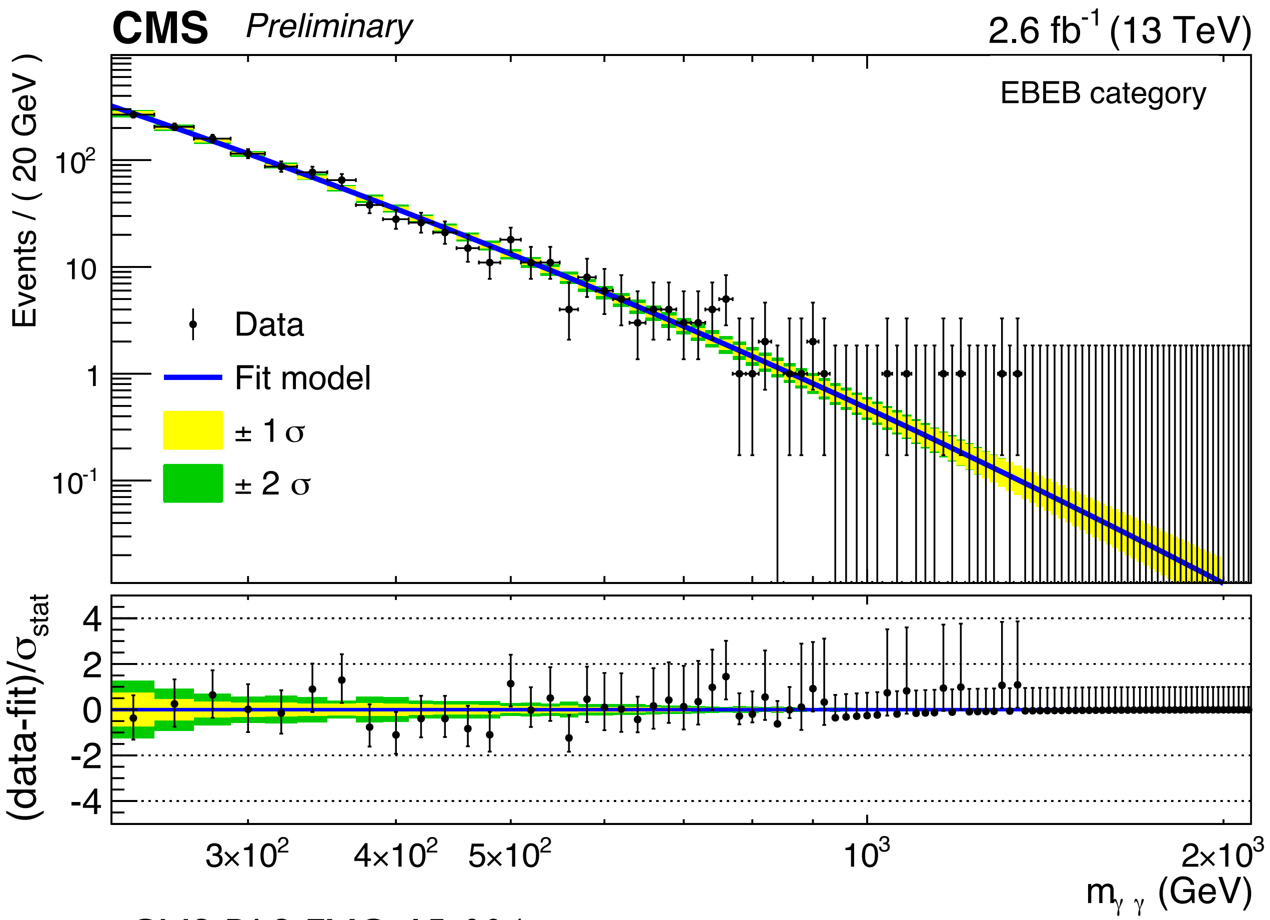


Summary

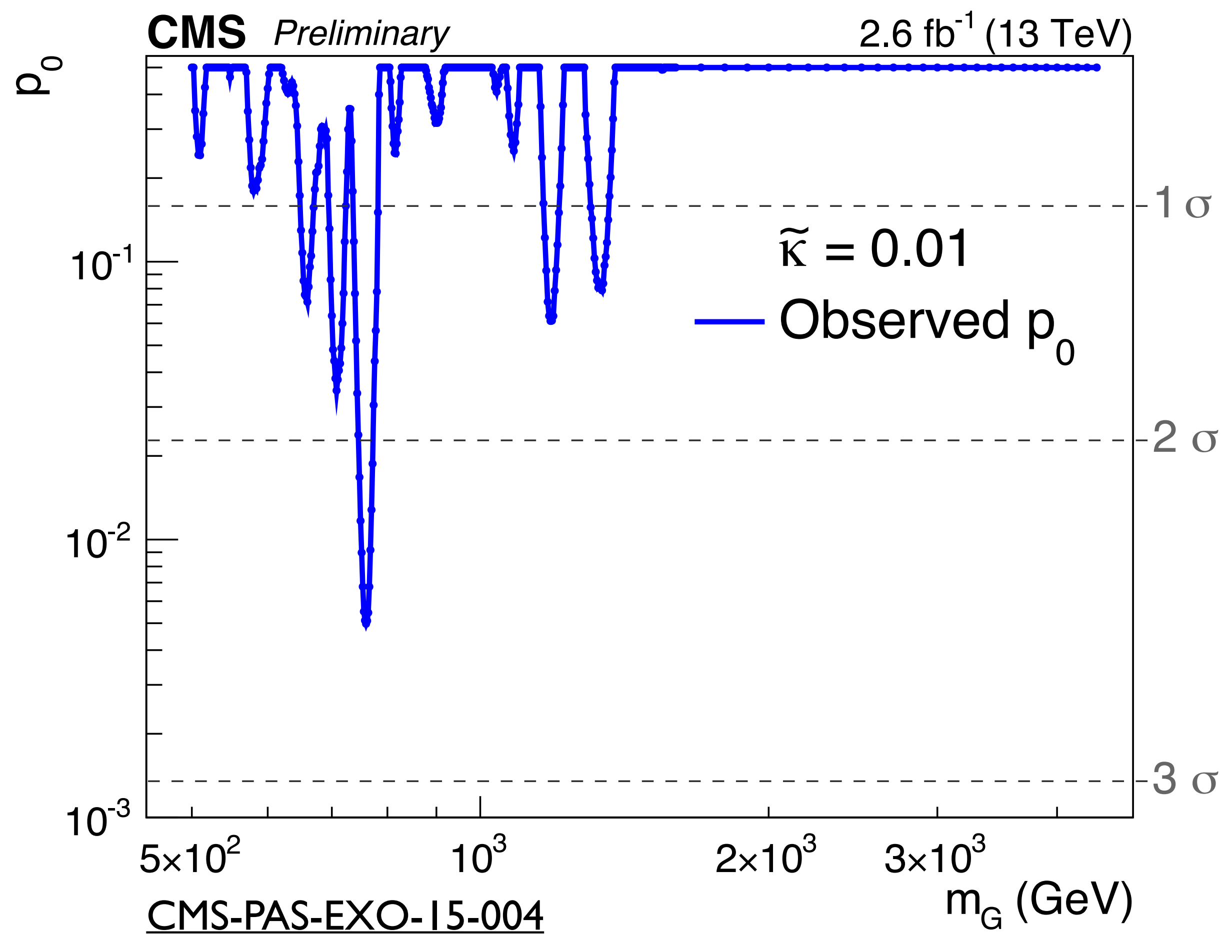
- Search has been performed for high mass resonances with a $Z\gamma$ final state
- Only four candidate $M(ll\gamma)$ events observed
- No significant deviation from SM background observed
- Largest deviation from background-only hypothesis is ~2σ at ~350GeV
- Detailed description of the analysis available in ATLAS-CONF-2016-010

Backup

CMS diphoton resonance



CMS-PAS-EXO-15-004

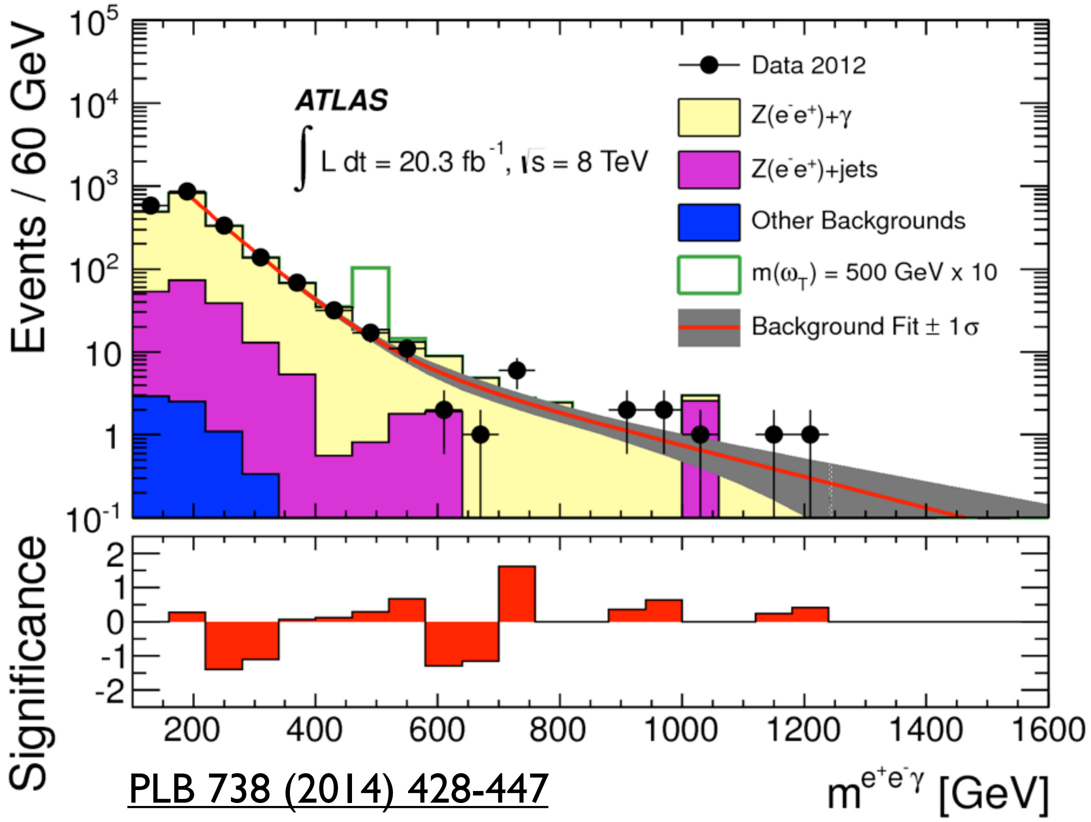


CMS-PAS-EXO-15-004

Left: selected diphoton invariant mass distribution, fitted with a background-only hypothesis, in the CMS high-mass diphoton resonance search with the 2015 data, for both photons reconstructed in the barrel calorimeter.

Right: scan of the null hypothesis p-value as a function of the resonance mass, in the hypothesis of a narrow signal.

Three-body invariant mass distribution for the $e^+e^-\gamma$ final state.
The expected signal for a resonance mass of 500 GeV is superimposed.



Three-body invariant mass distribution for the $\mu^+\mu^-\gamma$ final state.
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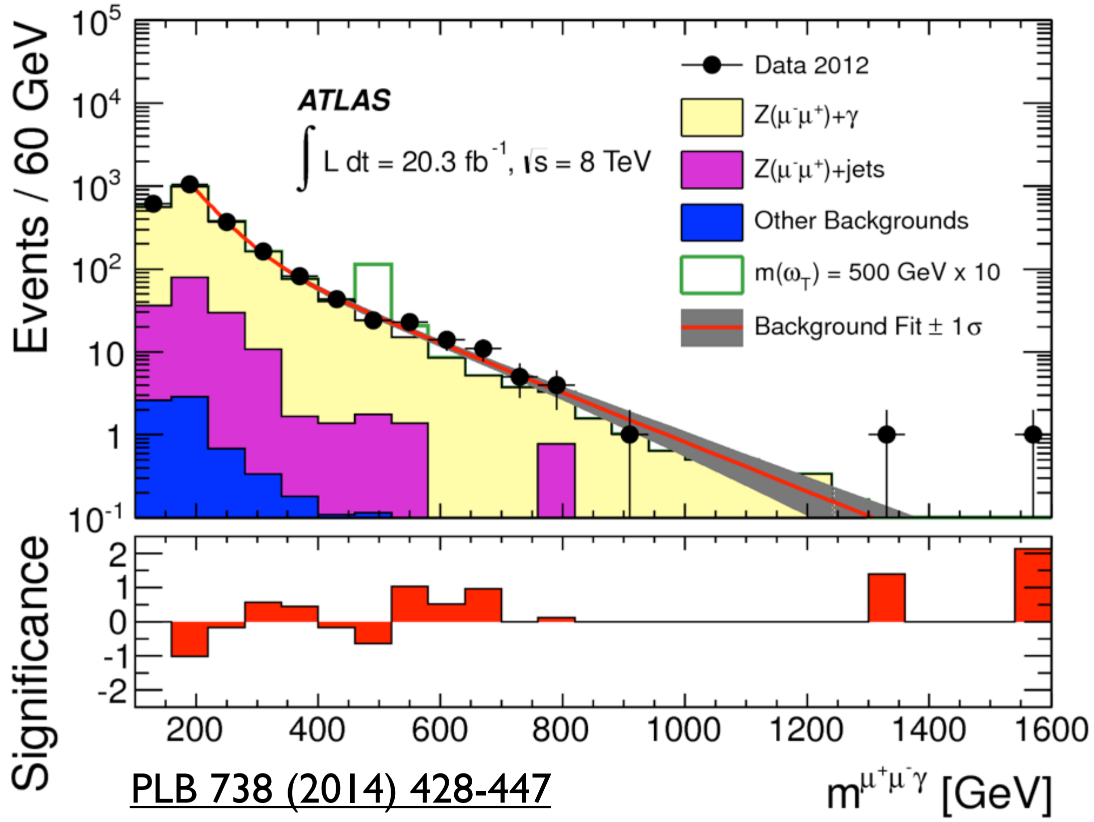
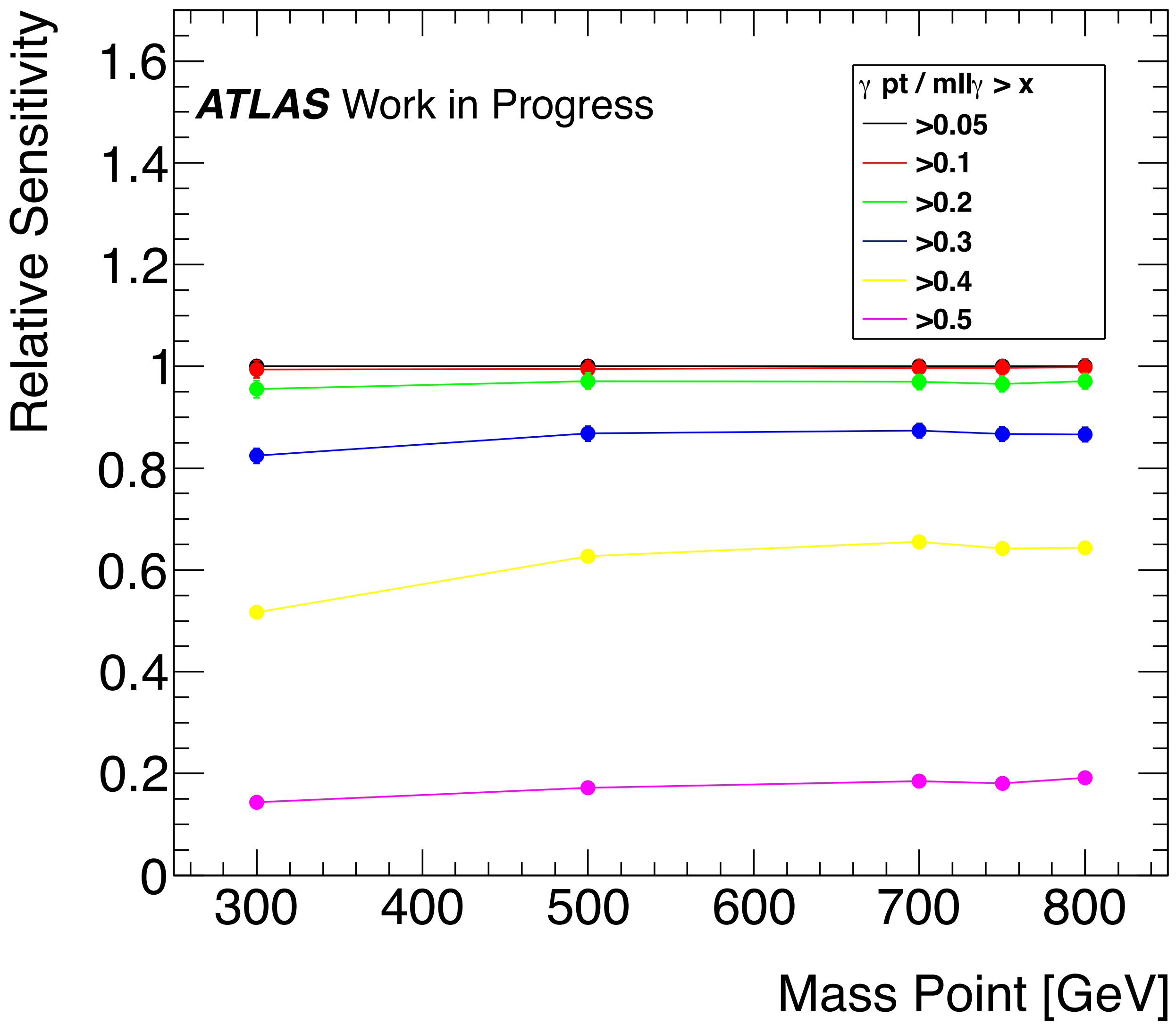
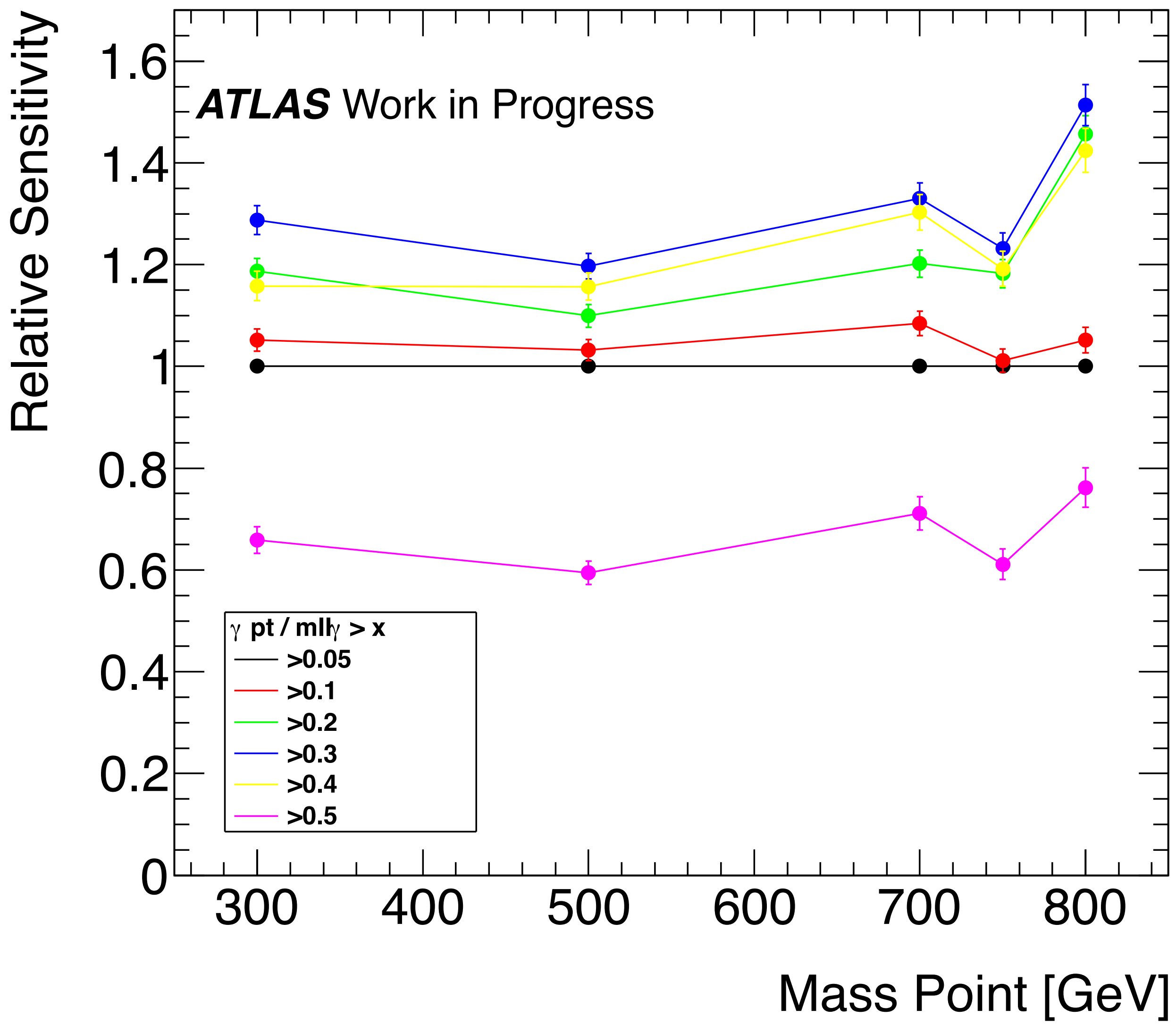


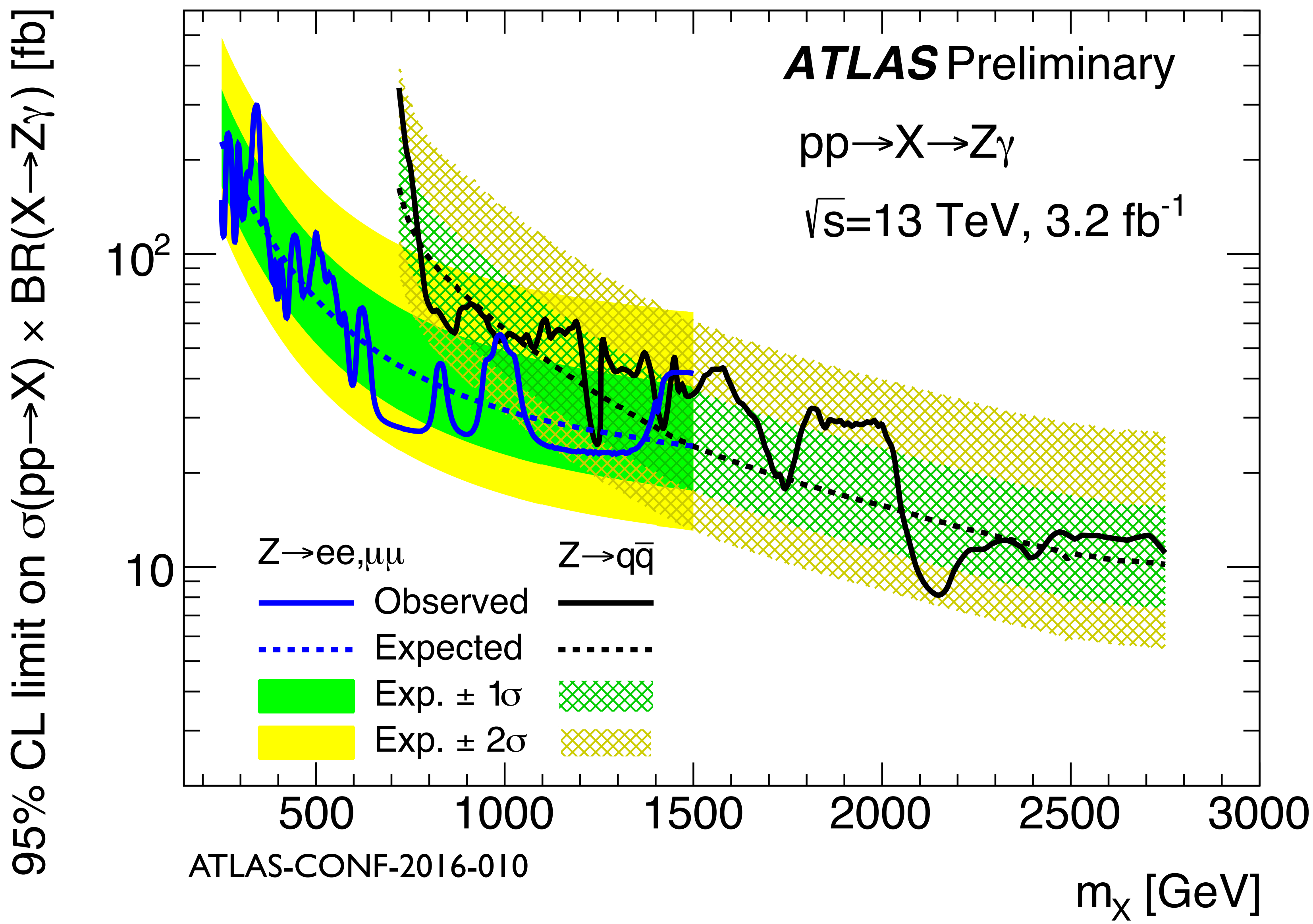
Selection Optimisation: Photon Relative Pt cut

- Sensitivity: Z= $N_s/(N_b)$ for given cut point
- Relative signal efficiency: cut efficiency of $p_T(\gamma)/M(ll\gamma)>x$
- Relative sensitivity: ratio of sensitivity of test cut point wrt to case without cut
  - Equal to $\varepsilon s/\mathrm{sqrt}(\varepsilon b)$ for the cut
- Optimal at $p_T(\gamma)/M(ll\gamma)>0.3$, with ~15% signal efficiency loss





Expected Limit: Leptonic and hadronic channels



Observed (solid lines) and median expected (dashed lines) 95% CL limits on the product of the production cross section times the branching ratio for the decay to a Z boson and a photon of a narrow scalar boson X, as a function of the boson mass m_X. The black lines correspond to the limits set with the Jγ final state, the blue lines correspond to the limits set with the llγ final state. The dark green and dark yellow hatched bands correspond to the ±1σ and ±2σ intervals for the expected exclusion limit, respectively, set with the Jγ final state. The green and yellow solid bands correspond to the ±1σ and ±2σ intervals for the expected exclusion limit, respectively, set with the llγ final state.