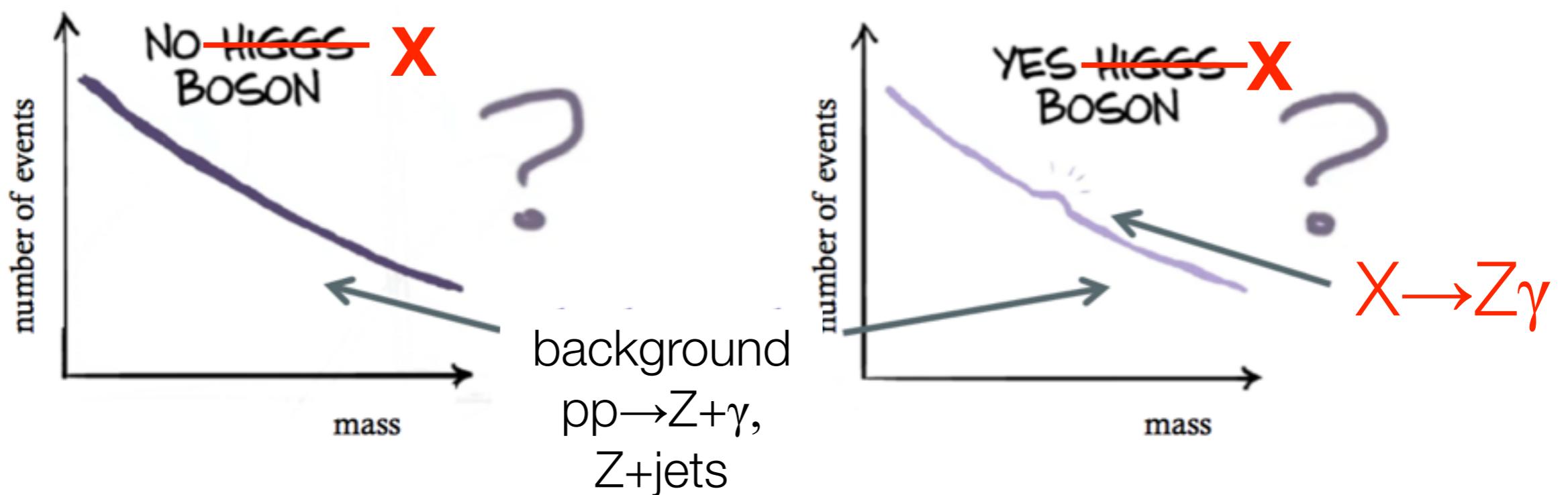




Search of high-mass $Z+\gamma$ resonances in 13 TeV data with the ATLAS detector

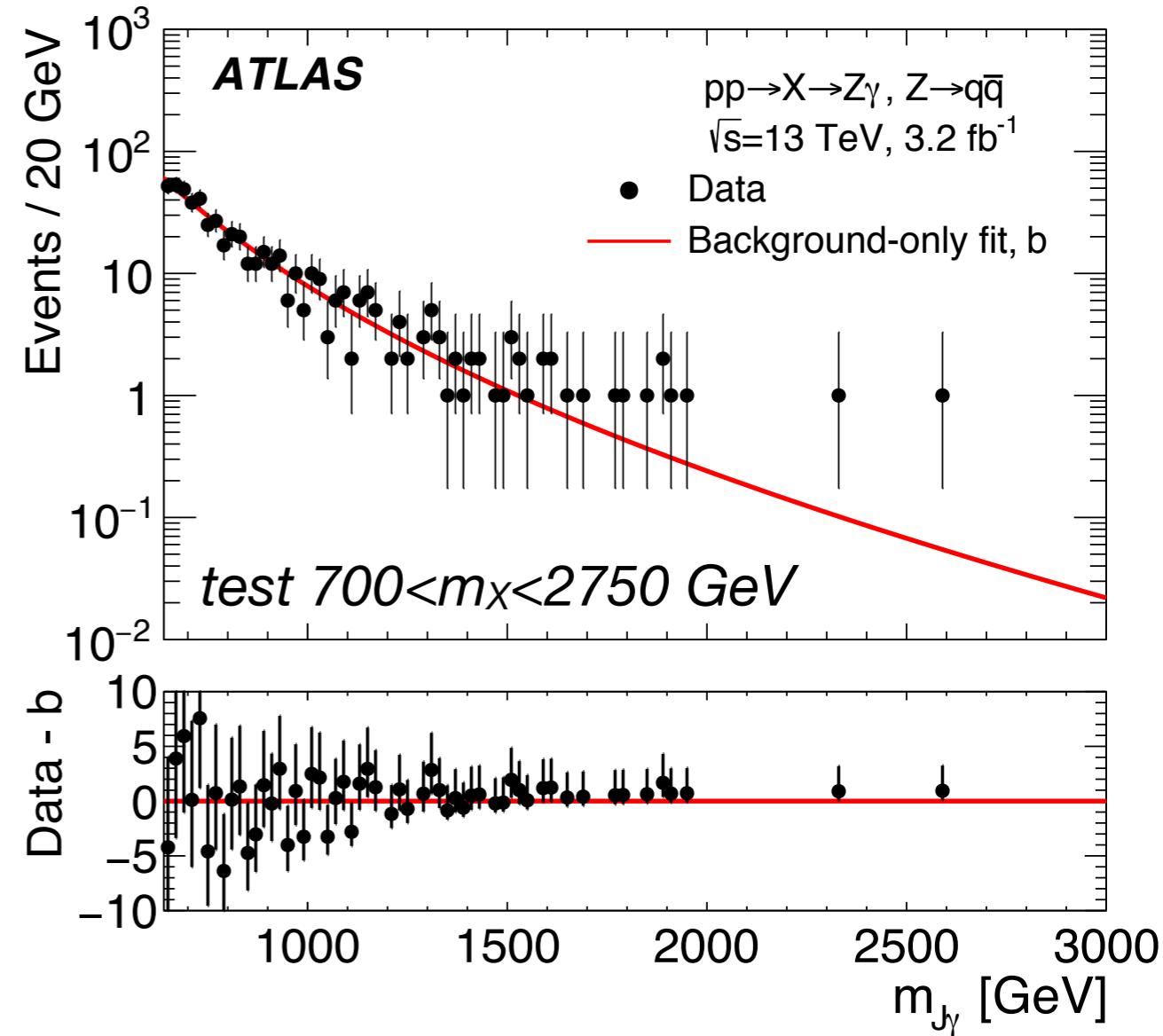
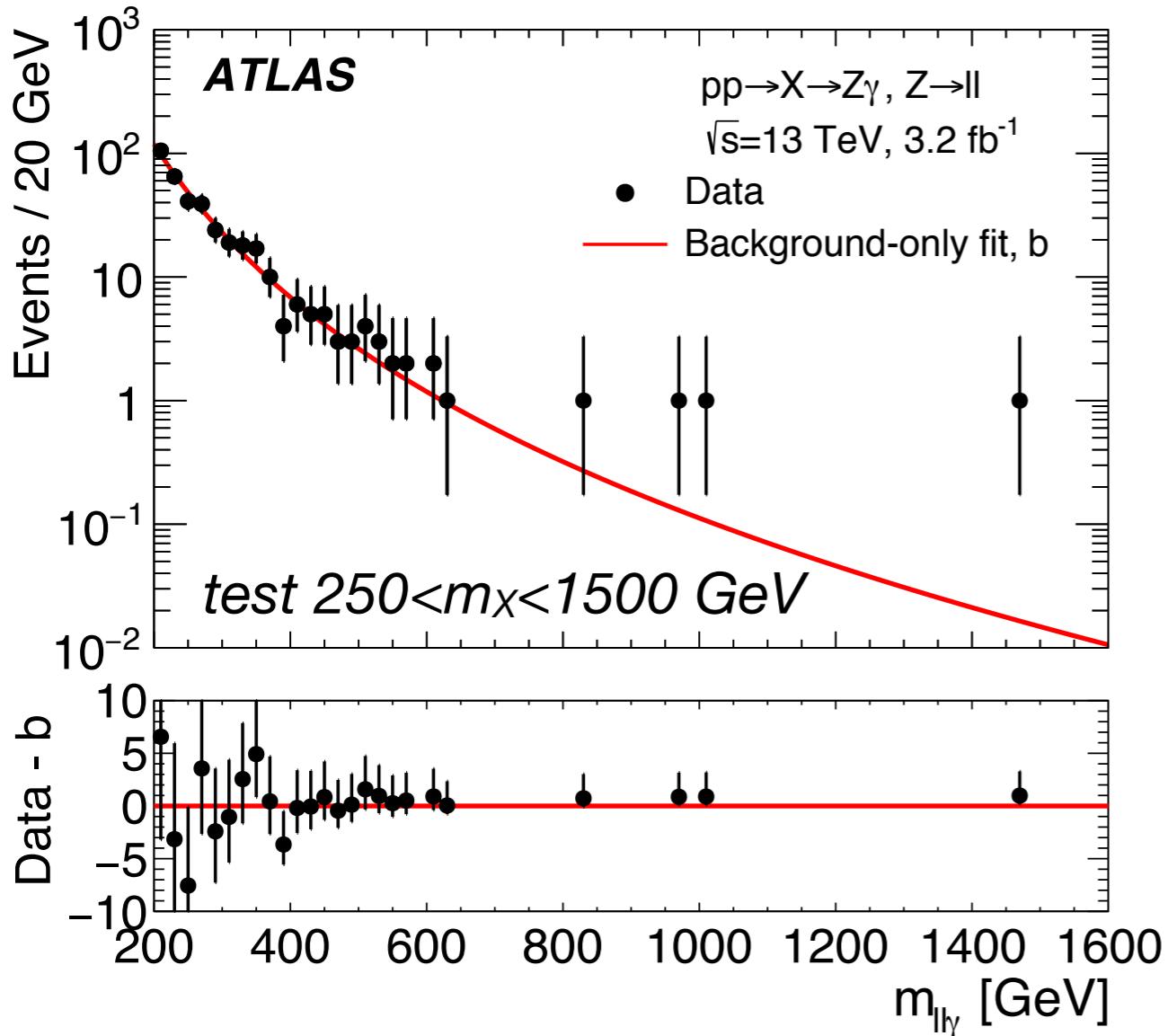
G. Marchiori (LPNHE-Paris)
on behalf of the ATLAS Collaboration

ICHEP Conference, Chicago, 5 August 2016



Previous results (winter 2016)

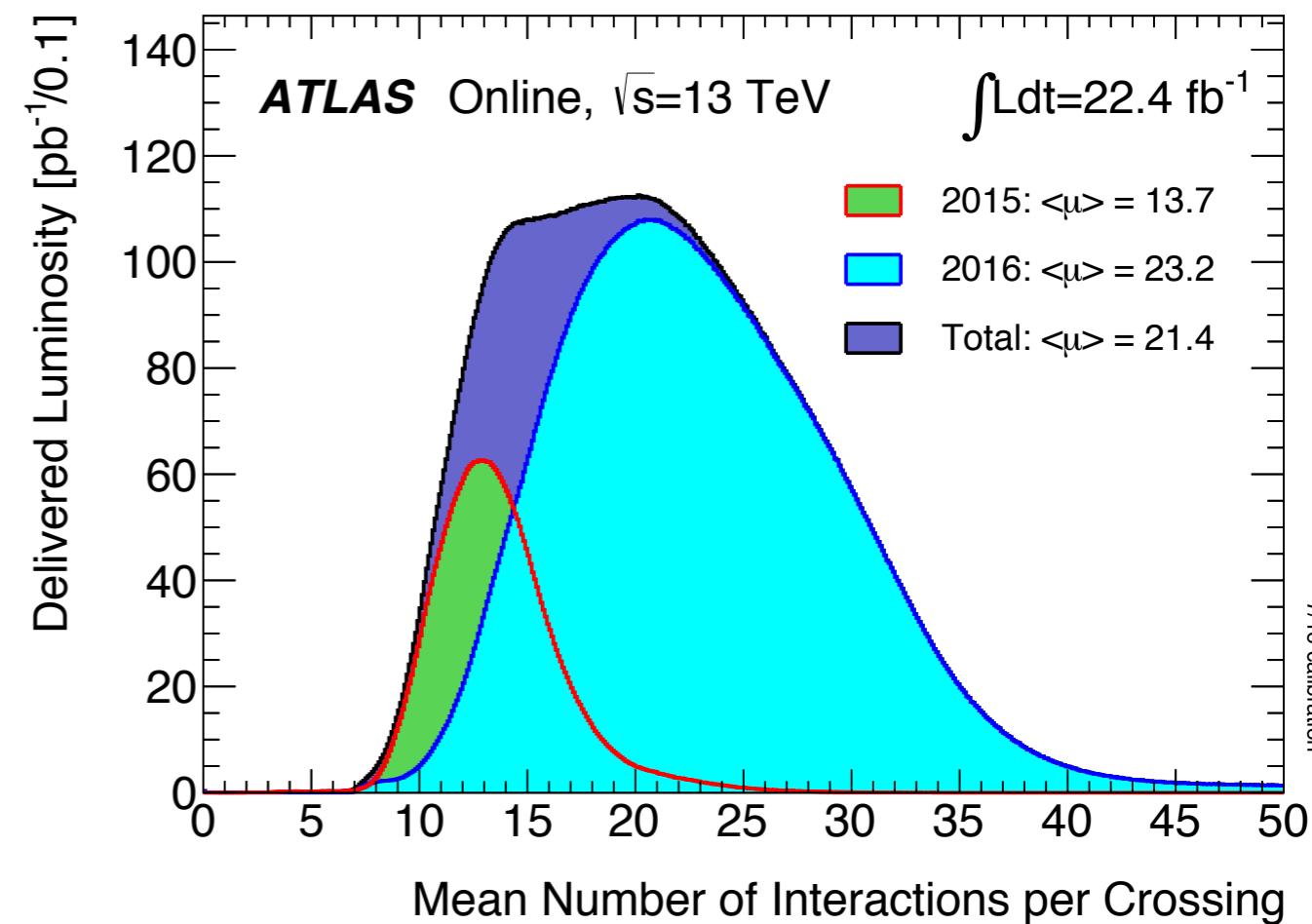
- **3.2 fb⁻¹ ($\pm 2.1\%$) of 13 TeV data (2015)**
- Benchmark signal model: **narrow scalar** produced in **gluon fusion** (Powheg+Pythia8)
- **Z $\rightarrow l^+l^-$ ($l=e, \mu$; BR=6.7%) and Z $\rightarrow q\bar{q}$ (BR=70%) in boosted regime (q $q\rightarrow J$)**



- **No significant excess** observed for $250 < m_X < 2750$ GeV
- Largest deviation from bkg-only $\sim 2\sigma$ for $m_X = 350$ GeV

Main updates wrt the previous results

- 2015 data analysis: **combination of limits from leptonic and hadronic analyses** in overlapping regions ([arXiv:1607.06363](https://arxiv.org/abs/1607.06363)), will be shown at the end of the talk
- 2015+2016 data ([ATL-CONF-2016-044](#)):
 - **only leptonic analysis** has been updated
 - **addition of 10.1 fb^{-1} ($\pm 3.7\%$) of 13 TeV data collected in 2016 (**total: 13.3 fb^{-1}**) allows to **extend mass reach** of leptonic analysis to 2.4 TeV**
 - split dataset in **two categories ($l=e, \mu$)** to exploit **different $m_{ll\gamma}$ resolution**
 - small improvements on lepton and photon **reconstruction and calibration**, also to deal with larger pile-up



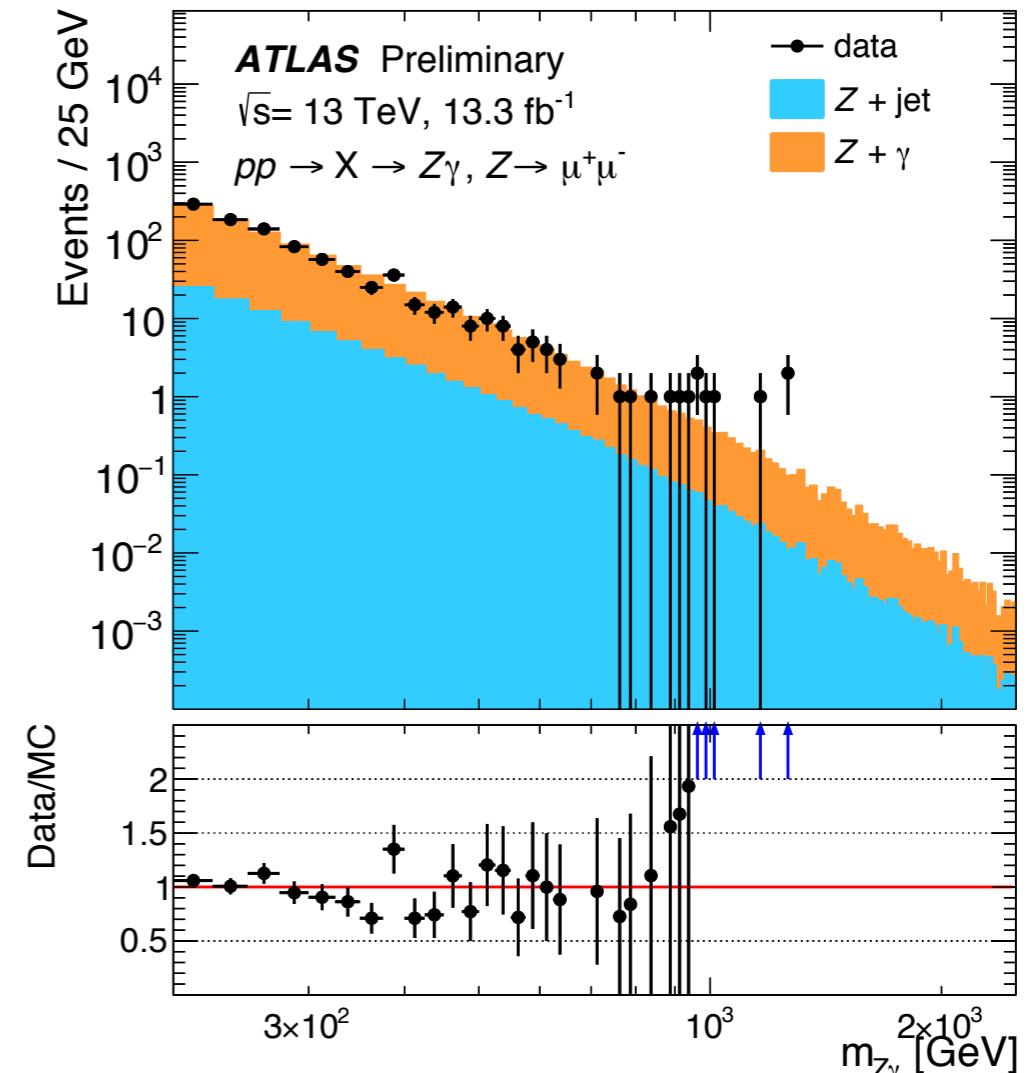
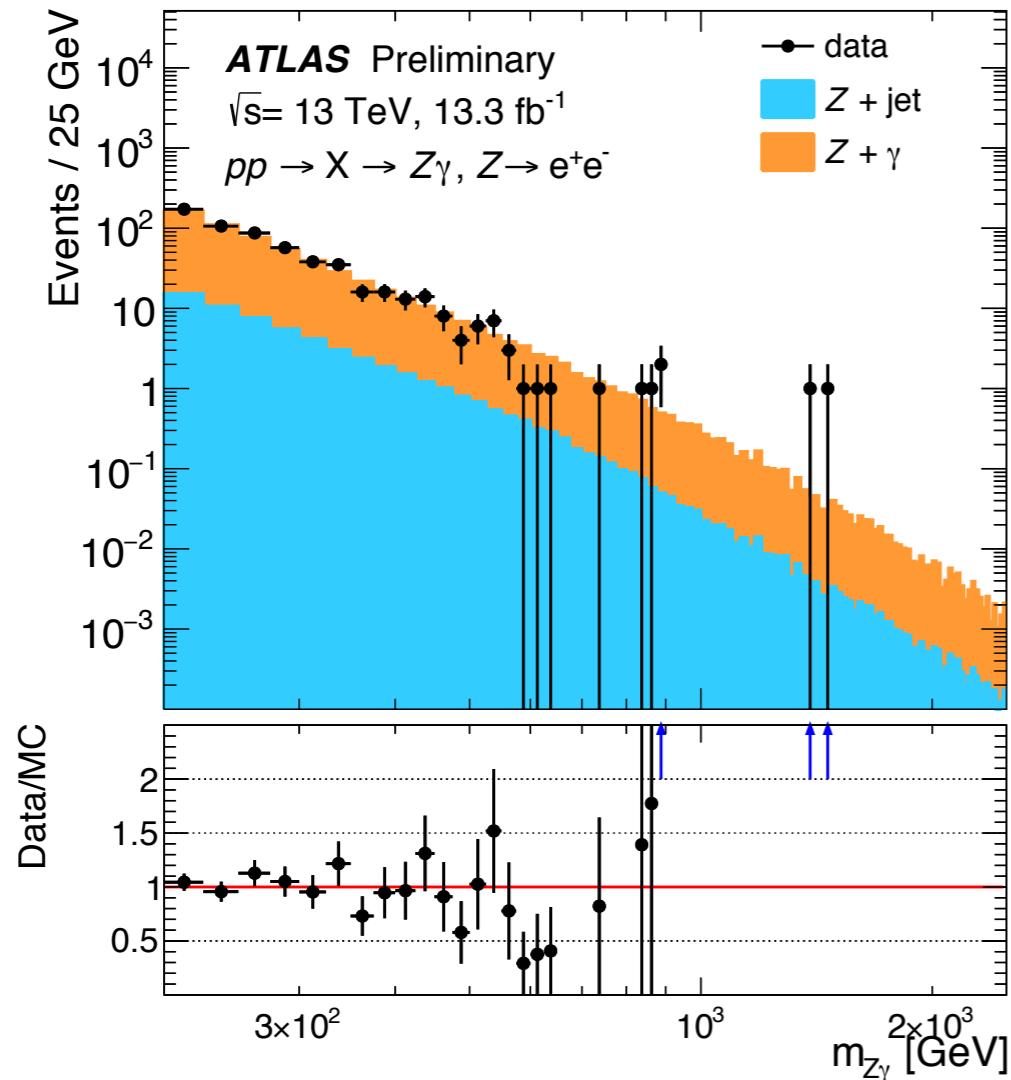
Event selection

- Selection criteria **similar to 2015 analysis**
 - single and di-lepton triggers
 - two **isolated, opposite-sign leptons** ($p_T^e > 19 \text{ GeV}$, $p_T^\mu > 24, 10 \text{ GeV}$) with $m_{ll} \sim m_Z$
 - isolation computed in small ΔR cones, subtracting contribution from other lepton to avoid inefficiencies at high m_X
 - one **isolated photon**, $p_T/\gamma/m_{ll\gamma} > 0.3$ (exploit spin-0 isotropic decay in X center-of-mass reference frame)
 - **quality requirements on leptons and photon** (tracks, hits in muon detector, shower shape in calorimeter, track-cluster match..)
 - $m_{ll\gamma} > 200 \text{ GeV}$

	ee	$\mu\mu$	Total
Events	306	485	791
Highest mass	1.5 TeV	1.3 TeV	1.5 TeV

Sample composition

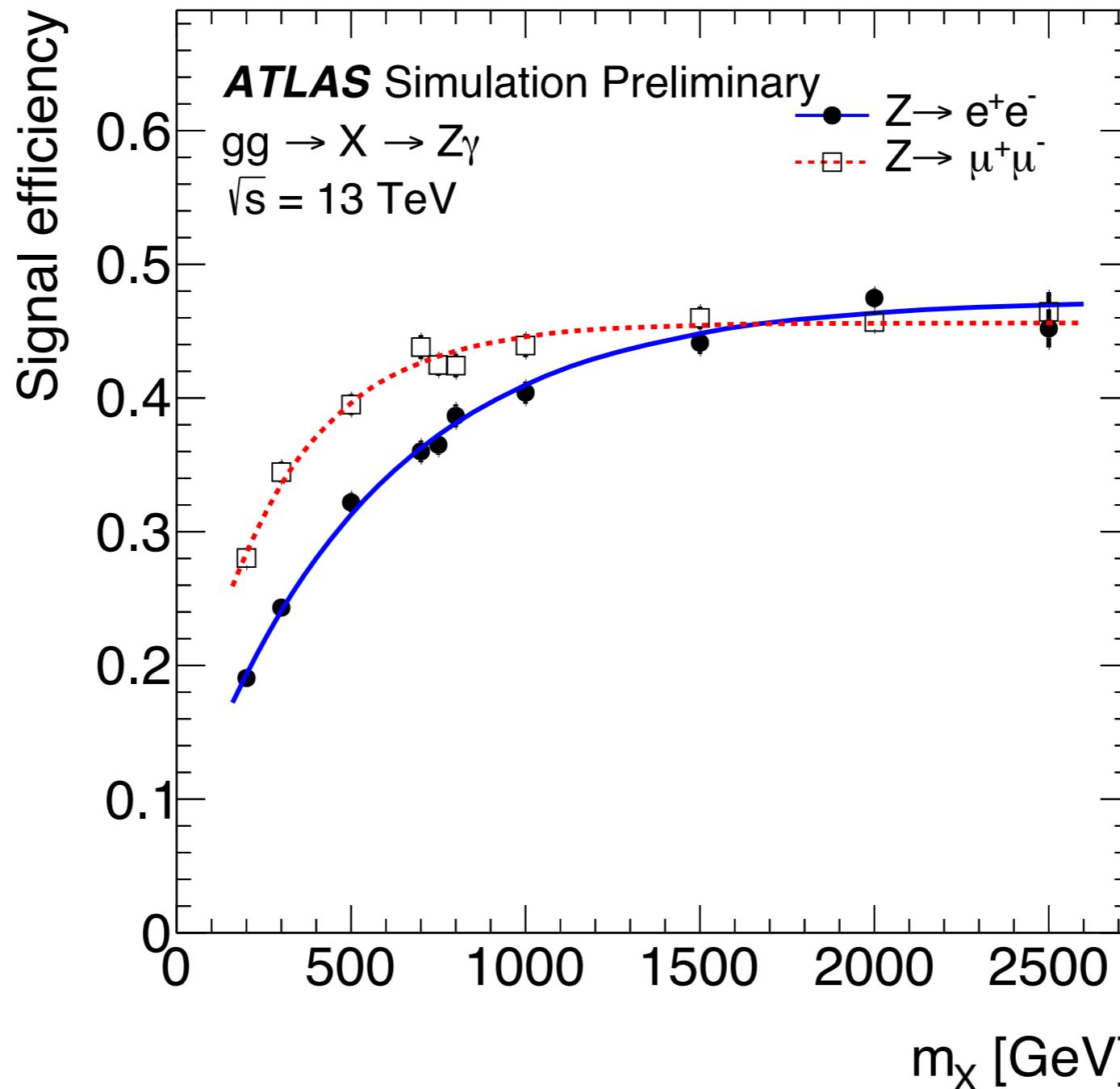
- Fractions of **Z+ γ** and **Z+jet** events studied with 2 **data-driven methods** based on identification and isolation of photon candidate



- Z+ γ fraction $\sim 90\%$**
- Good agreement** between different methods
- Fractions not used in final fit** to data, but only for bias studies (“spurious signal”) related to the choice of the functional form that models the background

Signal efficiency vs m_X

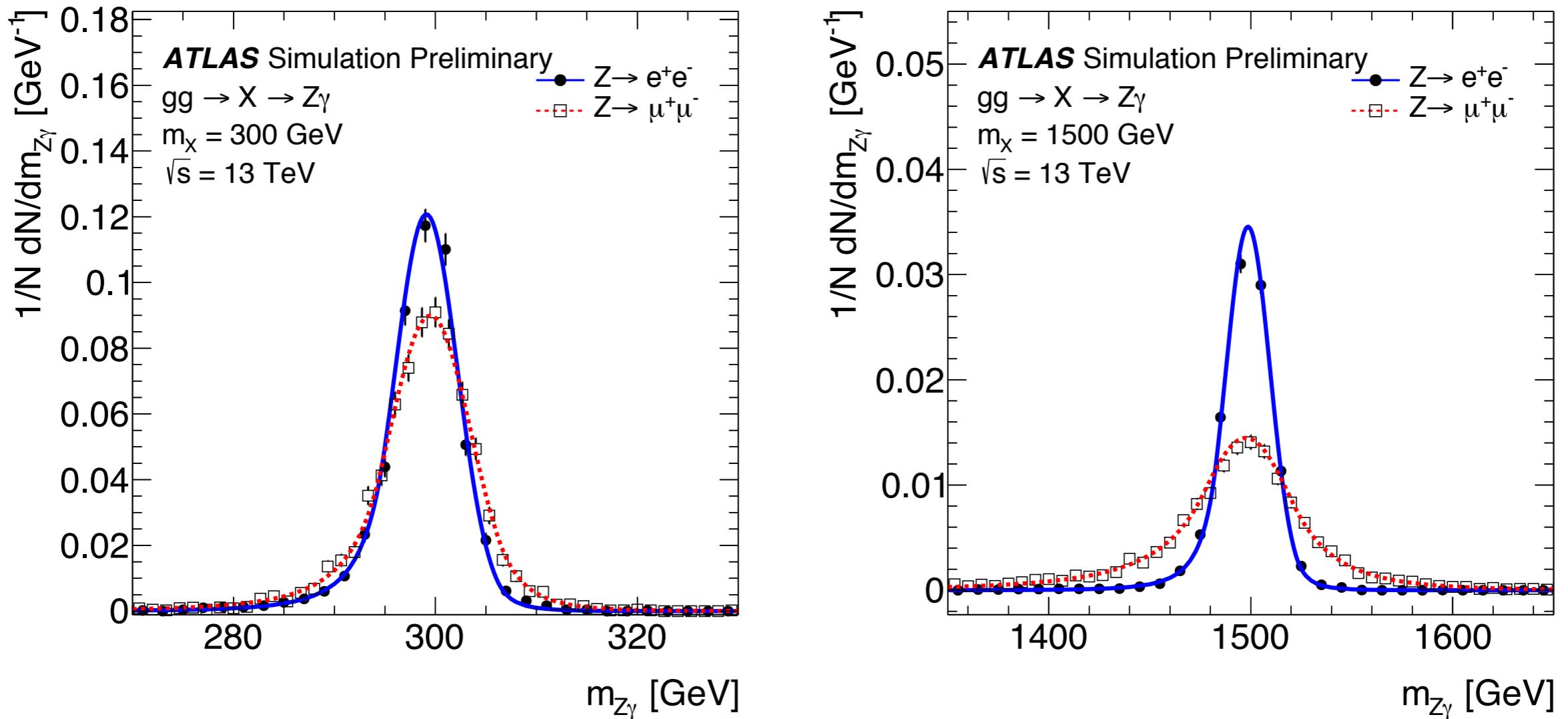
- 20–45%, from fit ($a+b \cdot \exp(cm_X)$) of efficiencies of MC samples generated at fixed masses between 200 GeV and 2.5 TeV and passed through full detector simulation



- Small uncertainties (1–2% each) from γ and lepton reco, ID, isolation, trigger

Signal invariant mass distribution

- **Double-sided Crystal-Ball function** (Gaussian with power-law tails)
- **Parameters** described by **polynomial functions of mass**, extracted from simultaneous fit to all generated samples



- **Resolution 1–0.6% ($e\bar{e}\gamma$), 1–1.4% ($\mu\bar{\mu}\gamma$) for $m_X=250\text{--}2400 \text{ GeV}$ [Z-mass constraint: ~20% improvement except in $Z \rightarrow ee$ at high mass]**
- **Uncertainties:** l,γ energy scales (<% on $\langle m \rangle$) and resolution (**10–35% on σ_m**)

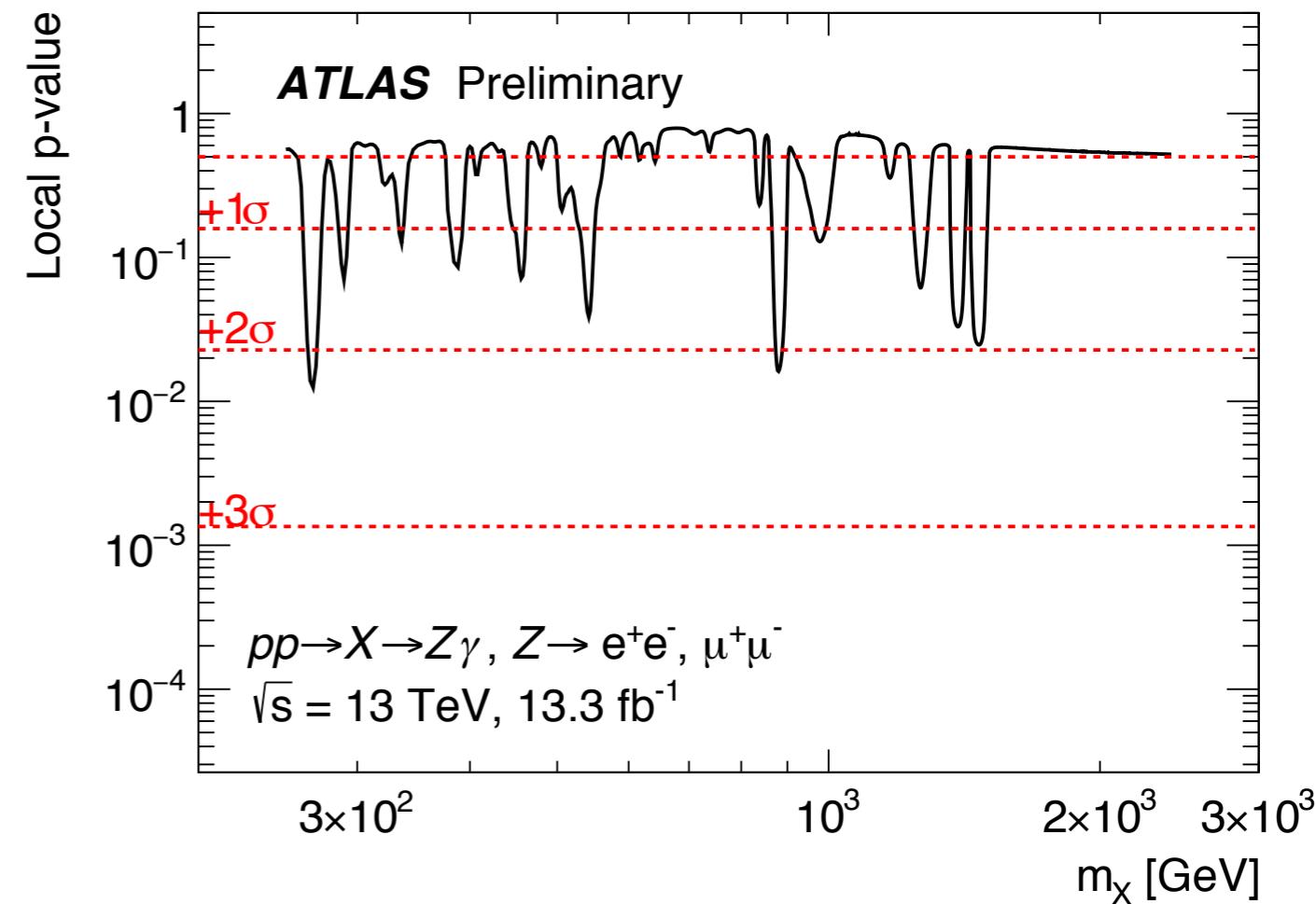
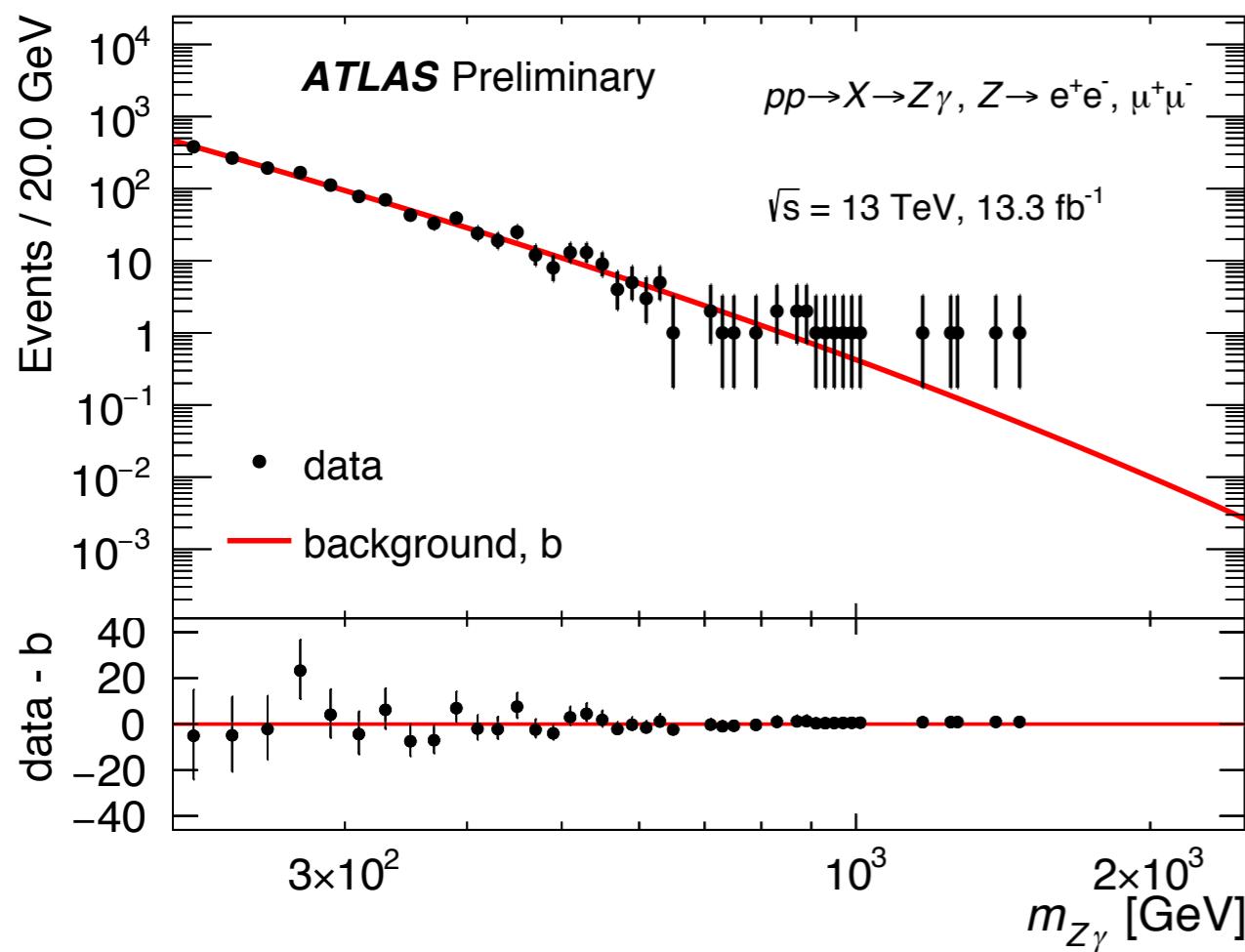
Background invariant mass distribution

- background modelled with **functional form**:

$$f_{\text{bkg}}(x) = N(1 - x^k)^{p_1} x^{p_2} \quad x = m_{\ell\ell\gamma}/\sqrt{s}, \quad k=1/3$$

- **N, p₁, p₂ = free parameters** in fit to data
- f with **minimum number of free parameters** chosen among those that
 - **fit well a bkg-only control sample**: small bias on signal, quantified as “**spurious signal**” in signal+bkg fit to high-statistics (Z+γ) + (Z+jet) bkg control sample: <20% of bkg uncertainty
 - **fit well the data** (no significant improvement of fit quality when adding more degrees of freedom)
- **uncertainty related to bkg model = spurious signal**

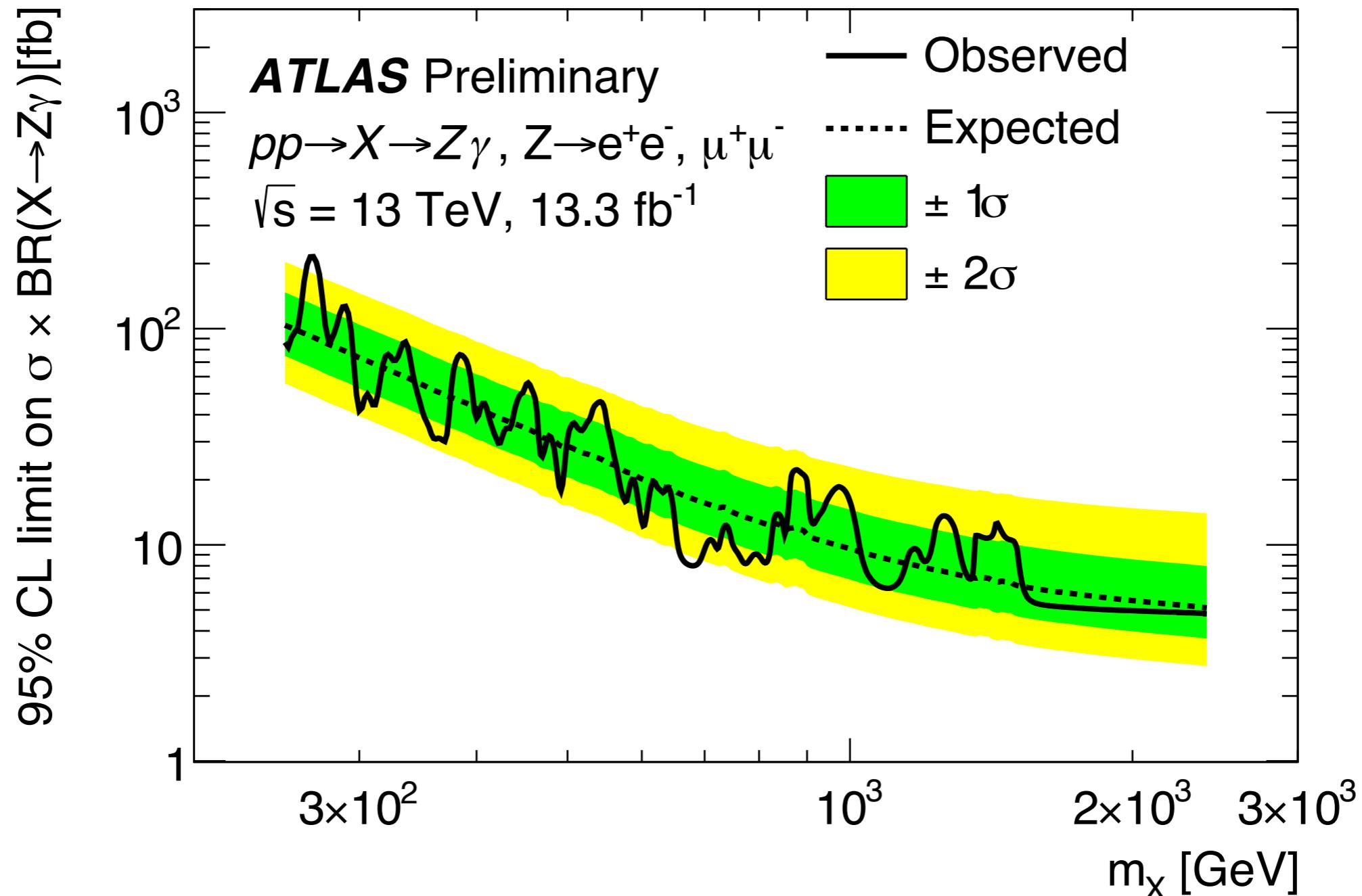
Results



- No significant excess
- Good fit quality
- Largest deviation from bkg-only hypothesis **in $250 < m_X < 2400 \text{ GeV}$** : local significance of **$\sim 2.2\sigma$ at $m_X \sim 270 \text{ GeV}$**

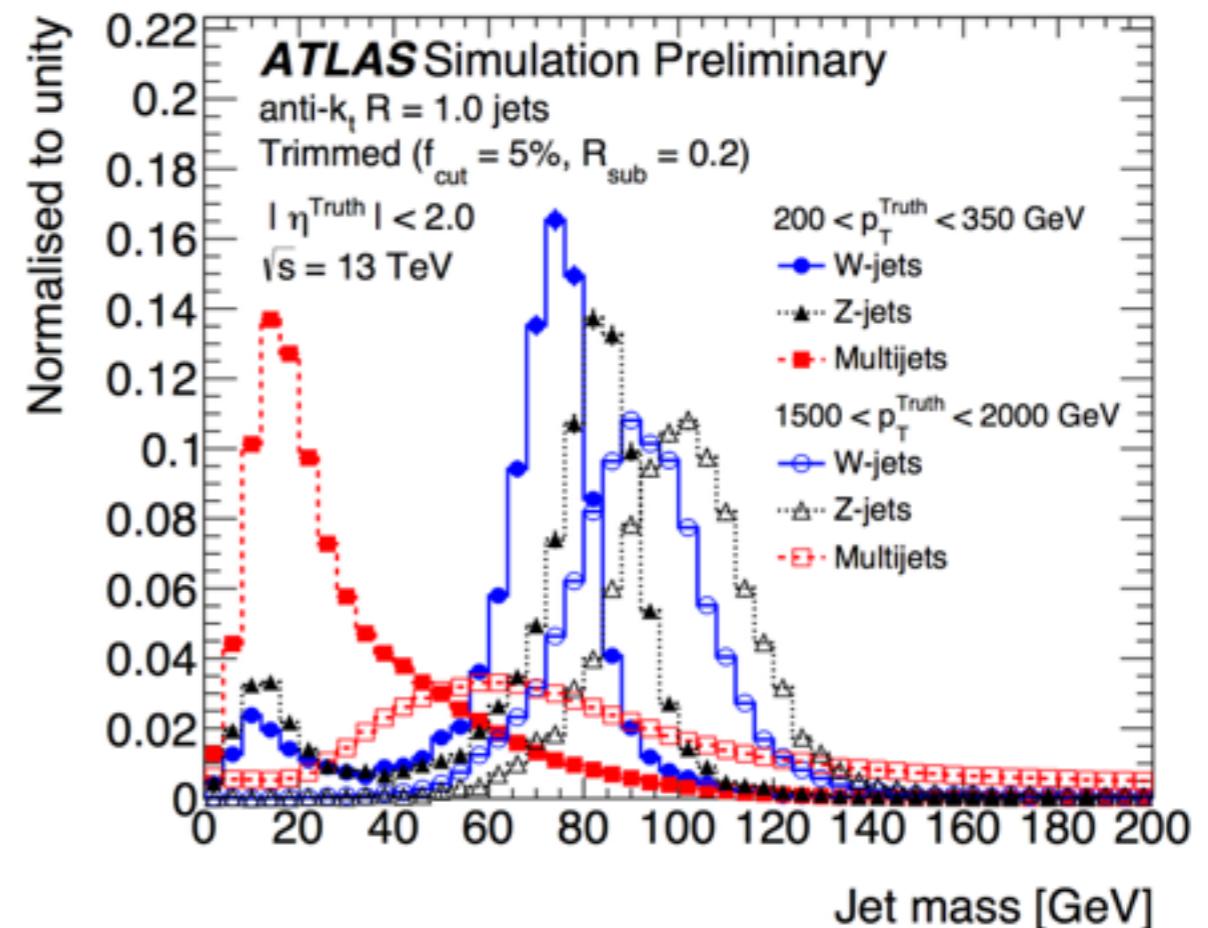
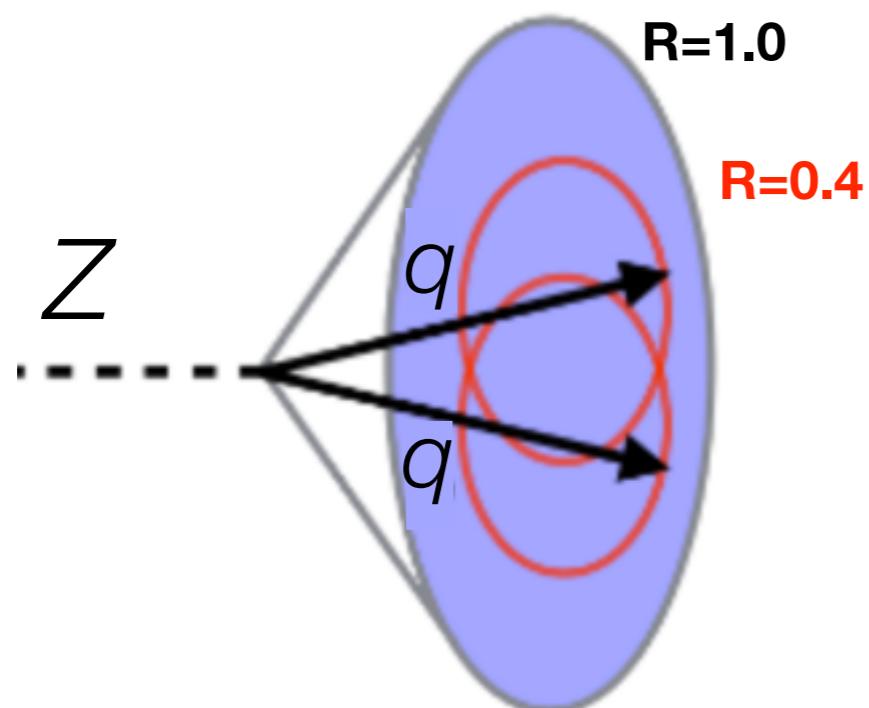
Limits on $\sigma(pp \rightarrow X)^* \text{BR}(X \rightarrow Z\gamma)$

- 95% CL upper limits set with **CL_s method (w/ asymptotic approximation of test statistic)**
- **Expected: 5–105 fb, observed: 5–215 fb**



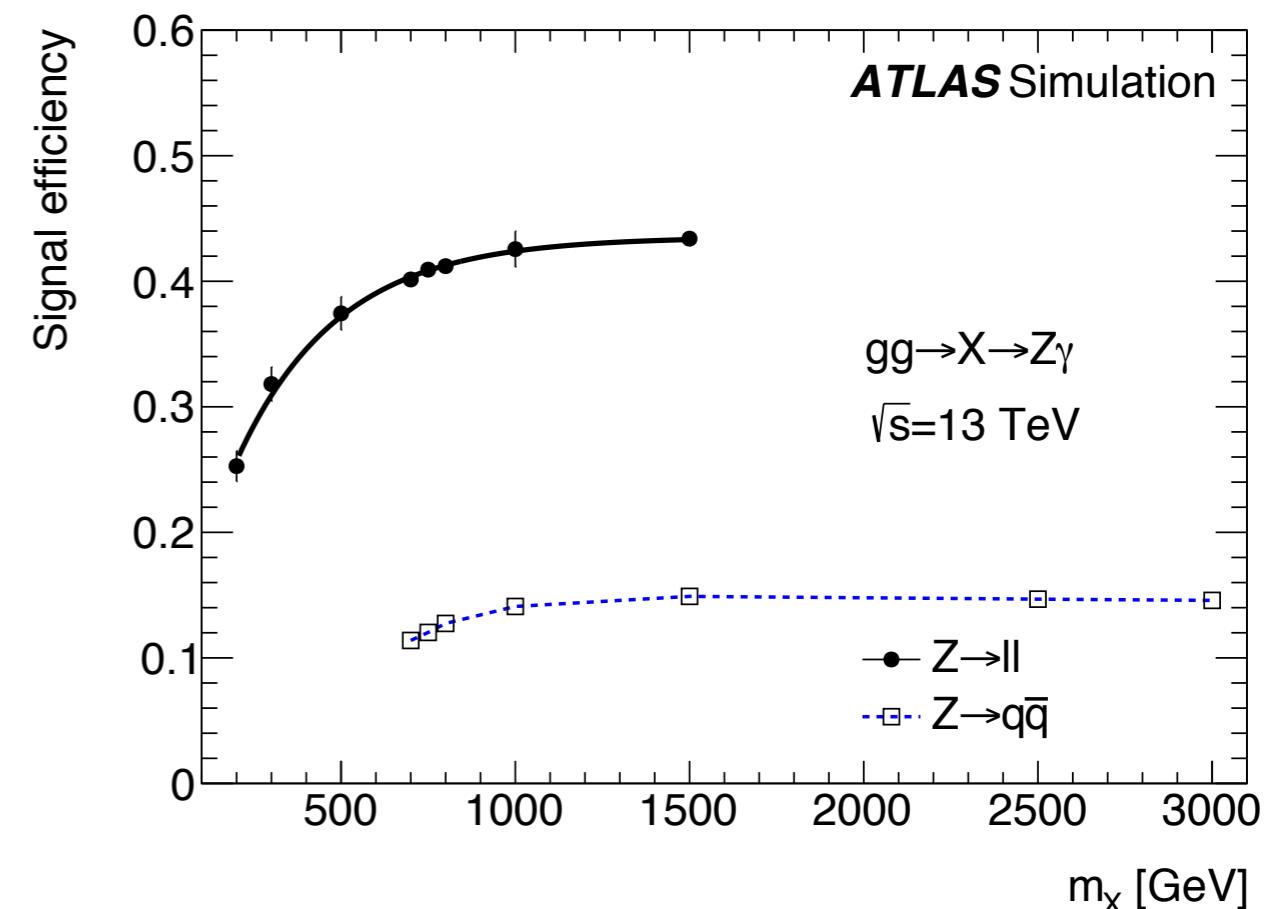
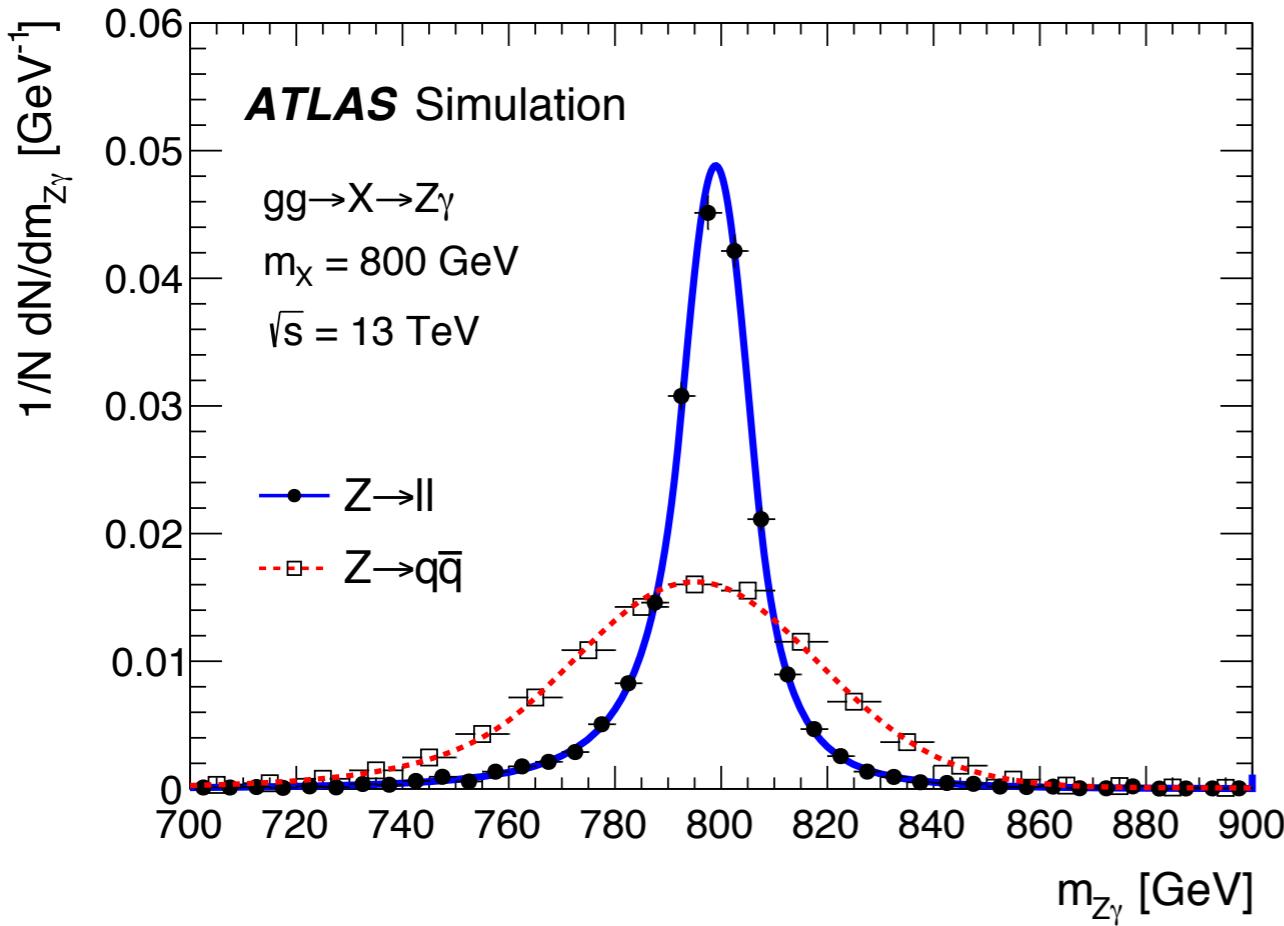
Previous 13 TeV analysis (2015 data only)

- Main difference = inclusion of **hadronic final states**, in **boosted regime**
 - $m_X > 700$ GeV: majority of events lead to **overlapping quark-jets**
 - **complementary** to leptonic analysis: worse purity, but $\text{BR}(Z \rightarrow q\bar{q}) \sim 10^* \text{BR}(Z \rightarrow ll)$ leads to sensitivity at high mass where there are no events in leptonic analysis
- In events collected with **single-photon triggers** require a **R=1.0 anti- k_t , trimmed jet** ($R_{\text{sub}}=0.2$, $p_T^{\text{sub}}/p_T^J > 5\%$), with **mass and substructure** (N-point energy correlation functions, associated tracks) **consistent with Z boson**



Z(qq) γ search: brief recap

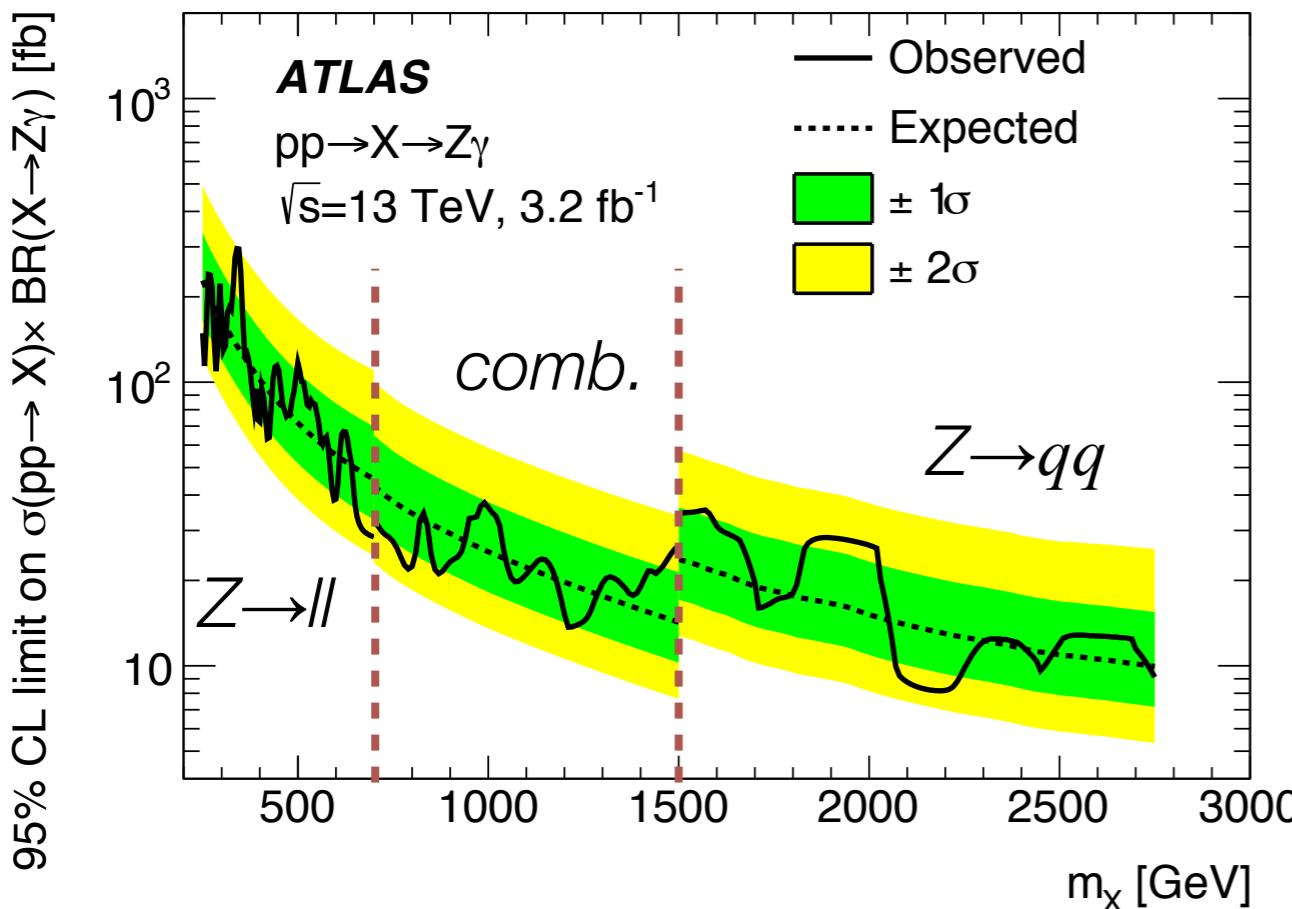
- $p_T\gamma > 250 \text{ GeV}, |\eta^\gamma| < 2.37$ (excl. $1.32 - 1.57$) $p_T^J > 200 \text{ GeV}, |\eta^J| < 2, m_{J\gamma} > 640 \text{ GeV}$
- mass resolution $\sim 3\text{--}1.7\%$, efficiency vs $10\text{--}15\%$ for $m_X = 700\text{--}2750 \text{ GeV}$



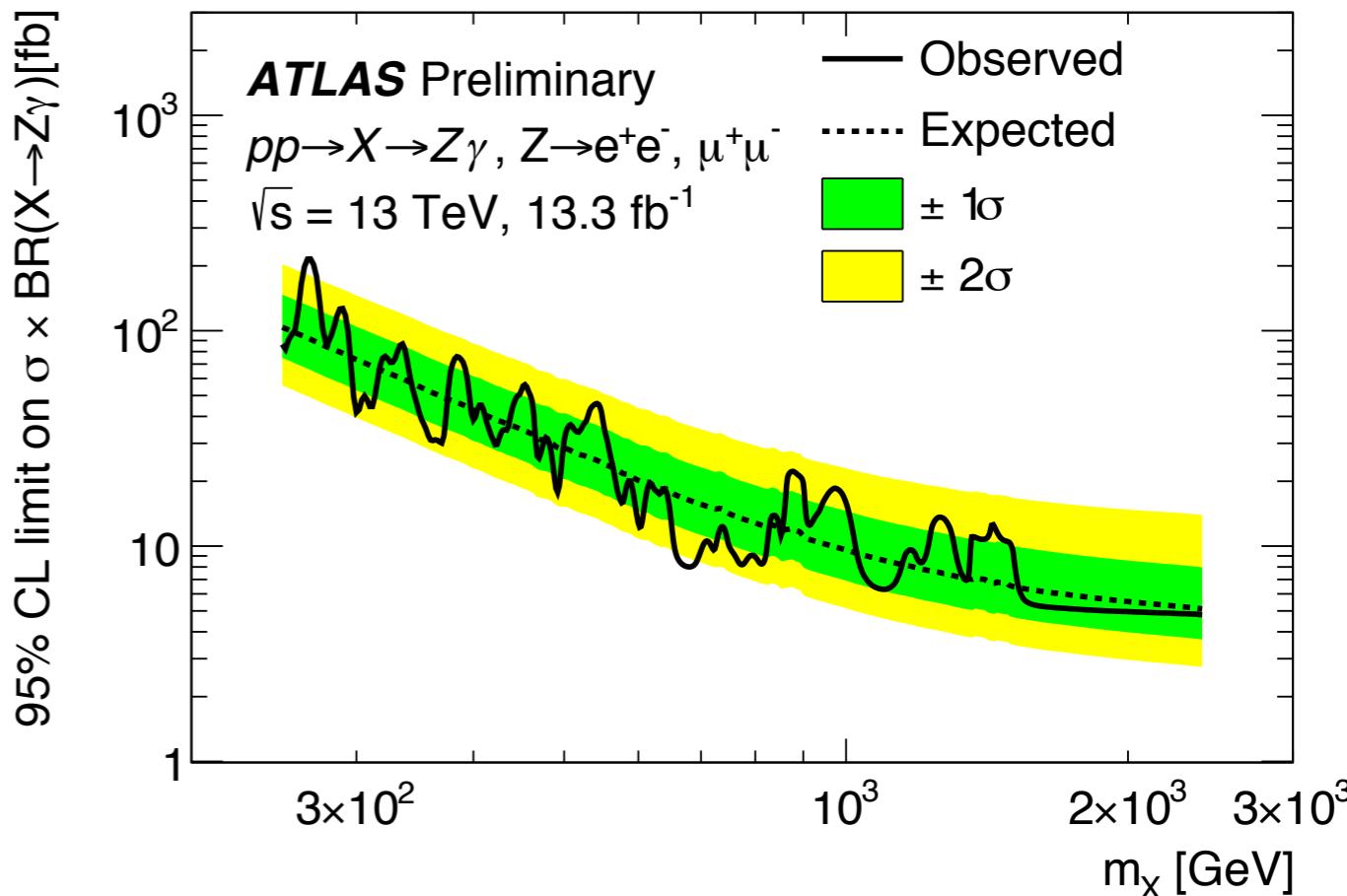
- main uncertainties: jet mass and energy resolution (20% extra smearing). Worsen the limits (with stat only uncertainties) by 4–5% each at 700 GeV and 1–2% each at 2.7 TeV. Smaller impact from jet mass and energy scale (known to $\sim 6\%, 2\%$)

Results of the 2015-only analysis

2015 data, $Z \rightarrow ll + Z \rightarrow qq$



2015+2016 data, $Z \rightarrow ll$



- observed limits ~ 8 – 300 fb
- combination in overlapping range can improve single results by up to $\sim 40\%$
- at same lumi, highest masses probed by hadronic analysis only
- $Z \rightarrow ll$ 2015 vs 2015+2016: at low m_X , sensitivity with new data improves with $\sim \sqrt{L}$; at high m_X , as L

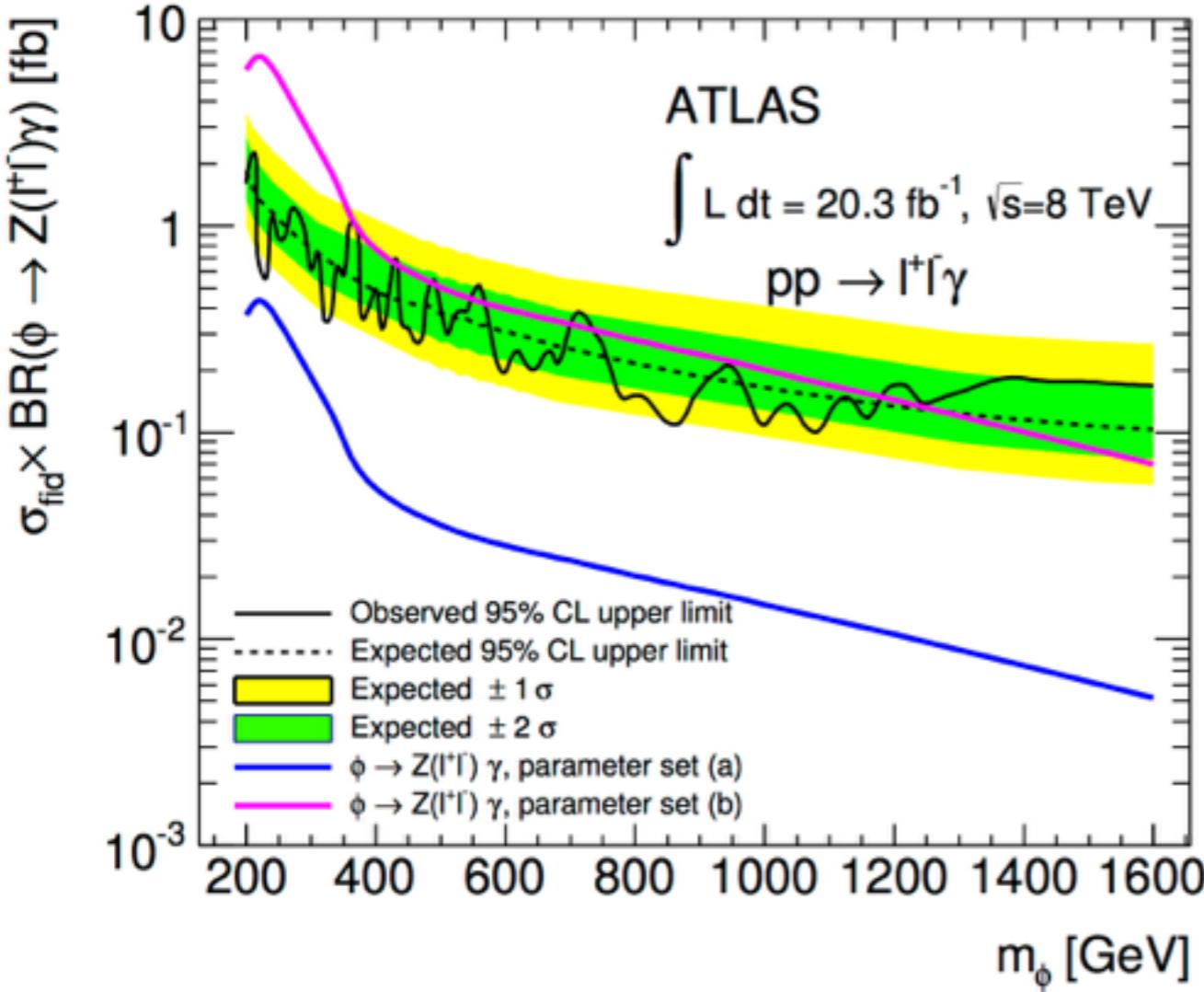
Conclusion

- **Z+ γ resonance search performed using 13 TeV ATLAS data (2015+2016)**
 - **Z \rightarrow ll ($l=e, \mu$):** 13.3 fb $^{-1}$ of 2015+2016 data
 - **Z \rightarrow qqbar:** 3.2 fb $^{-1}$ of 2015 data
 - **Use of boosted-jet techniques (Z \rightarrow qqbar) extends sensitivity to high masses where there is no statistics from the cleaner leptonic final state**
- **No localised excess found for masses between 250 GeV and 2.75 TeV**
- **Upper limits ~5–215 fb on $\sigma(pp\rightarrow X)^*\text{BR}(X\rightarrow Z\gamma)$ assuming spin-0 resonance produced in gluon fusion**
- References:
 - [arXiv:1607.06363](https://arxiv.org/abs/1607.06363)
 - [ATL-CONF-2016-044](https://cds.cern.ch/record/2203422)

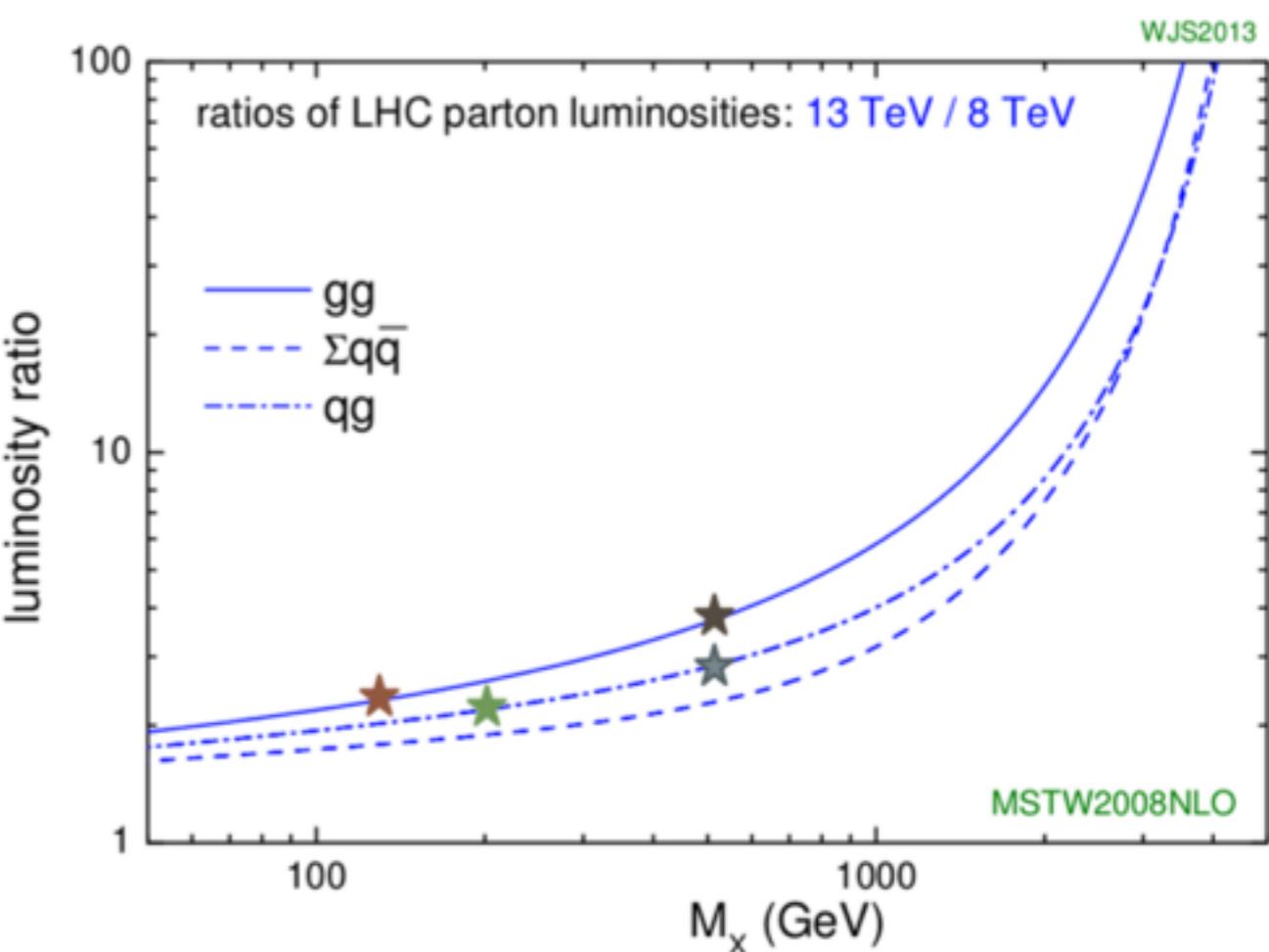
Bonus slides

ATLAS 8 TeV results

Limits on the fiducial x-section ($A \sim 0.5$)

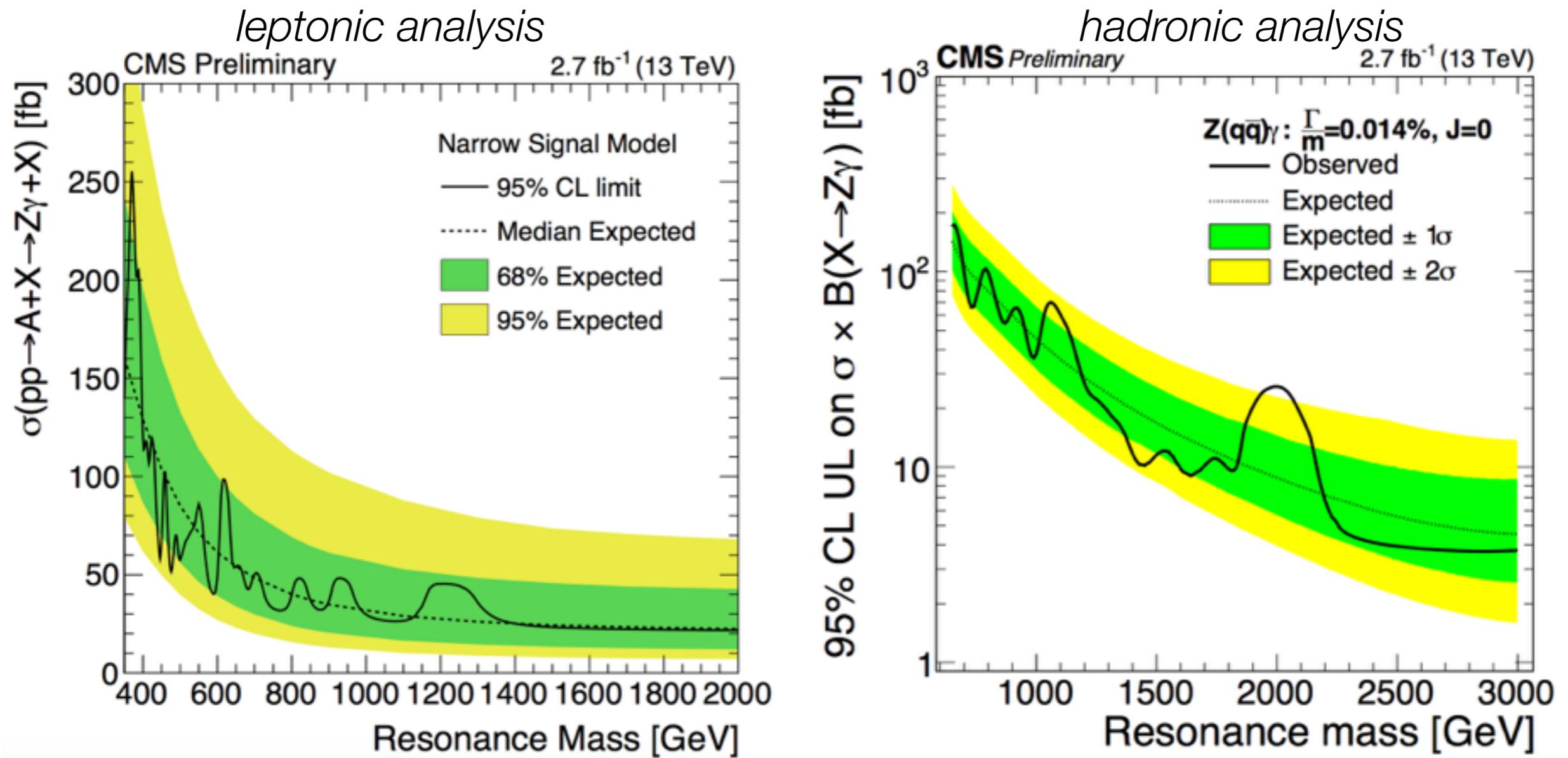


Parton luminosities 13 TeV / 8 TeV



- Left plot also includes a factor $\text{BR}(Z \rightarrow ll) = 6.7\%$
- Limits on total xsection: divide by $\sim 0.5 * 0.067 \Rightarrow$ multiply by factor 30
- Assuming gluon fusion, results at 13 TeV more stringent than 8 TeV except at very low m_X (lepton and photon p_T thresholds)

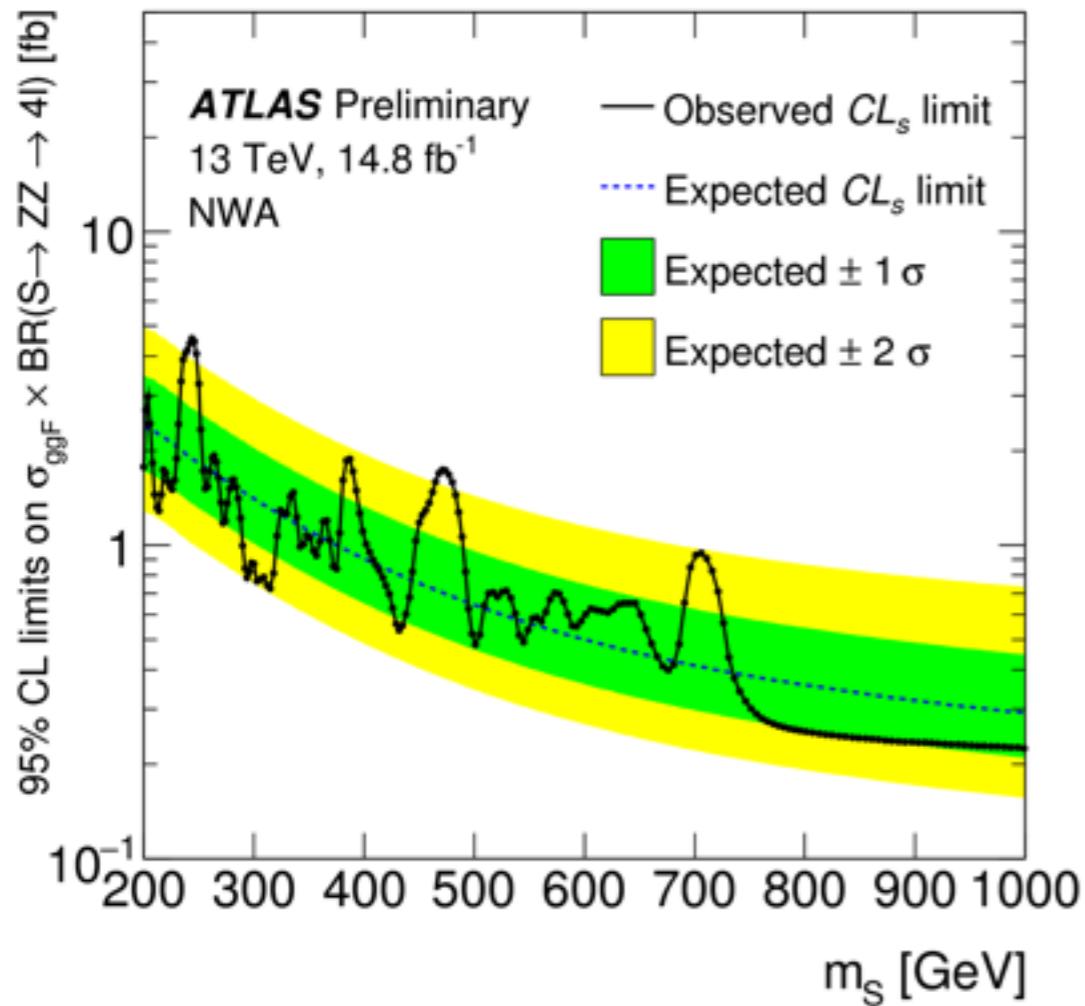
CMS 13 TeV results



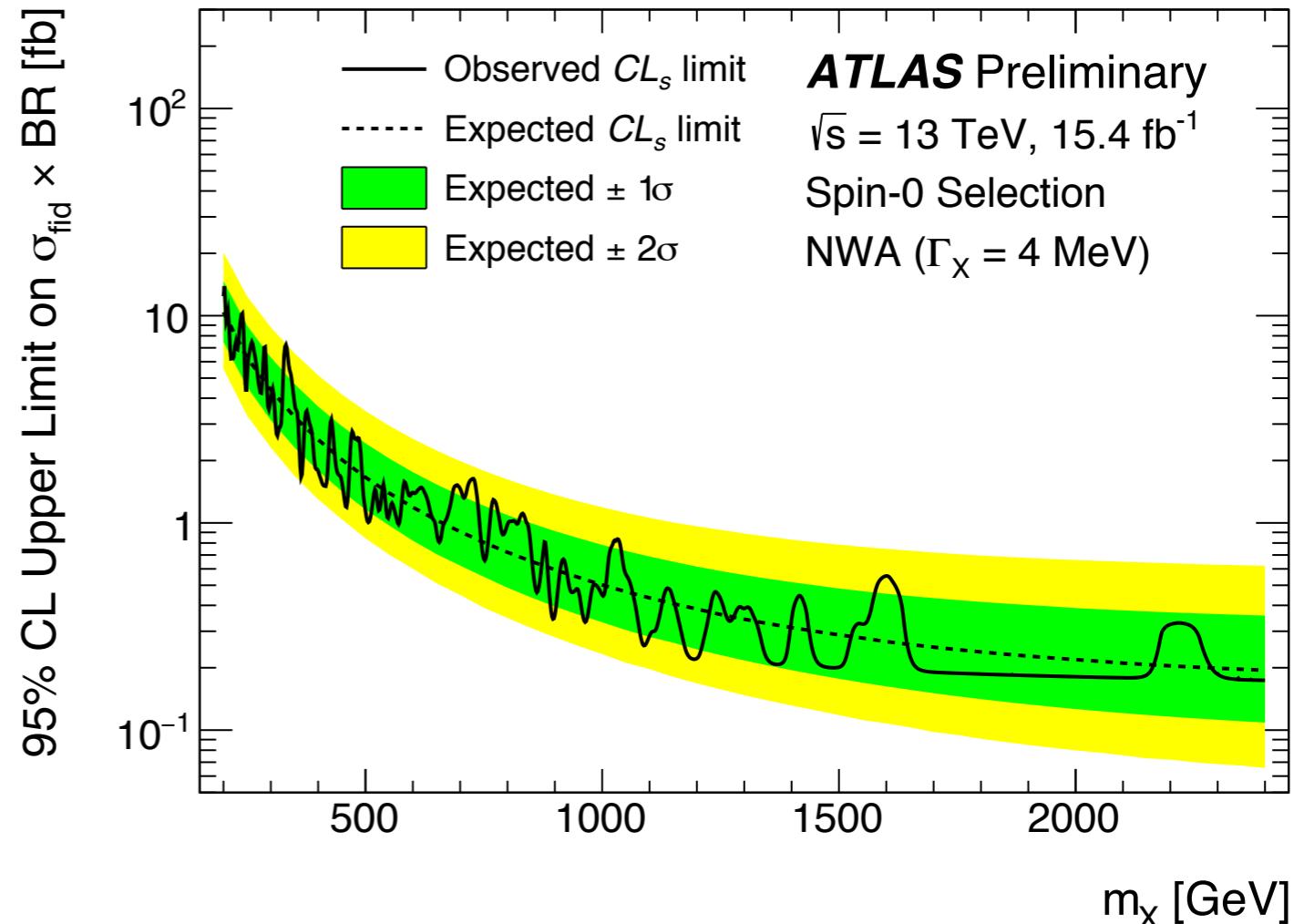
- Limits computed with asymptotic formulae as ATLAS
- Efficiency: $e\bar{e}\gamma = 25\text{--}45\%$, $\mu\bar{\mu}\gamma = 35\text{--}55\%$ for $m_X = 350\text{--}2000 \text{ GeV}$, $q\bar{q}\gamma = 12\text{--}22\%$ for $m_X = 650\text{--}3000 \text{ GeV}$

Other diboson results

$ZZ \rightarrow 4l$

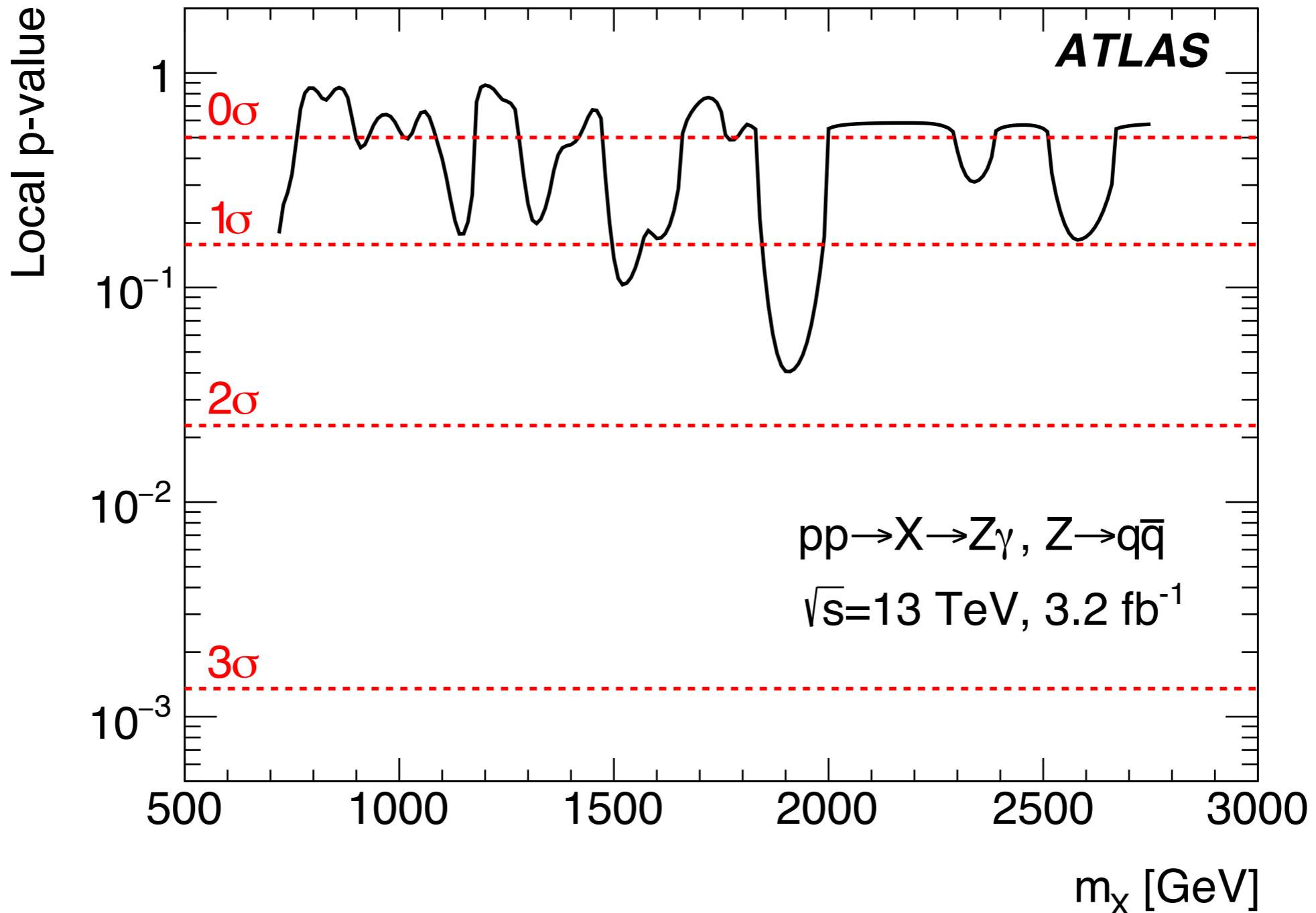


$\gamma\gamma$



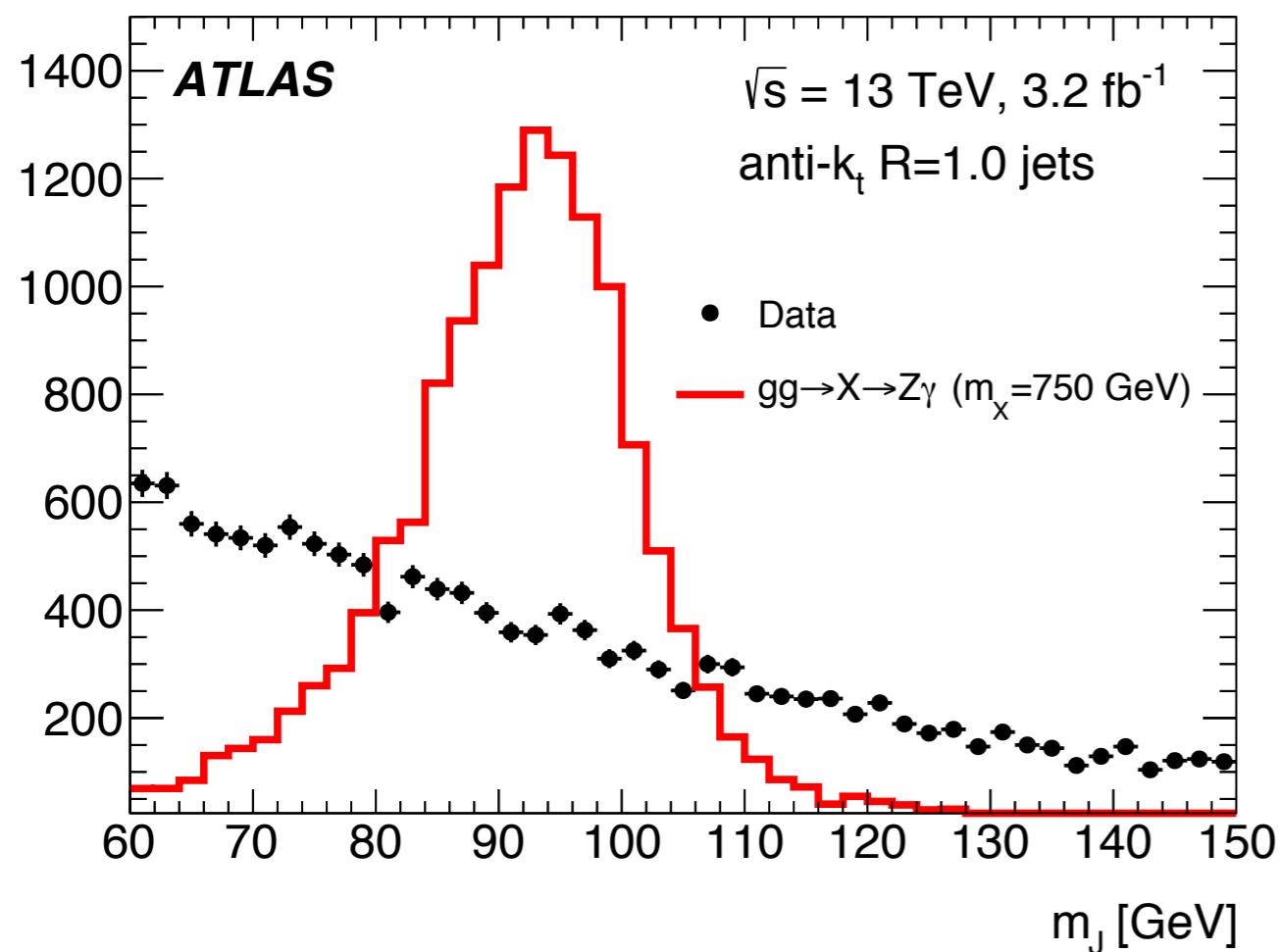
- Note that ZZ result includes $BR(Z \rightarrow ll)^2 = 0.45\%$
- More details and results in talks by B. Lenzi and K. Koneke

Hadronic analysis - local p-value

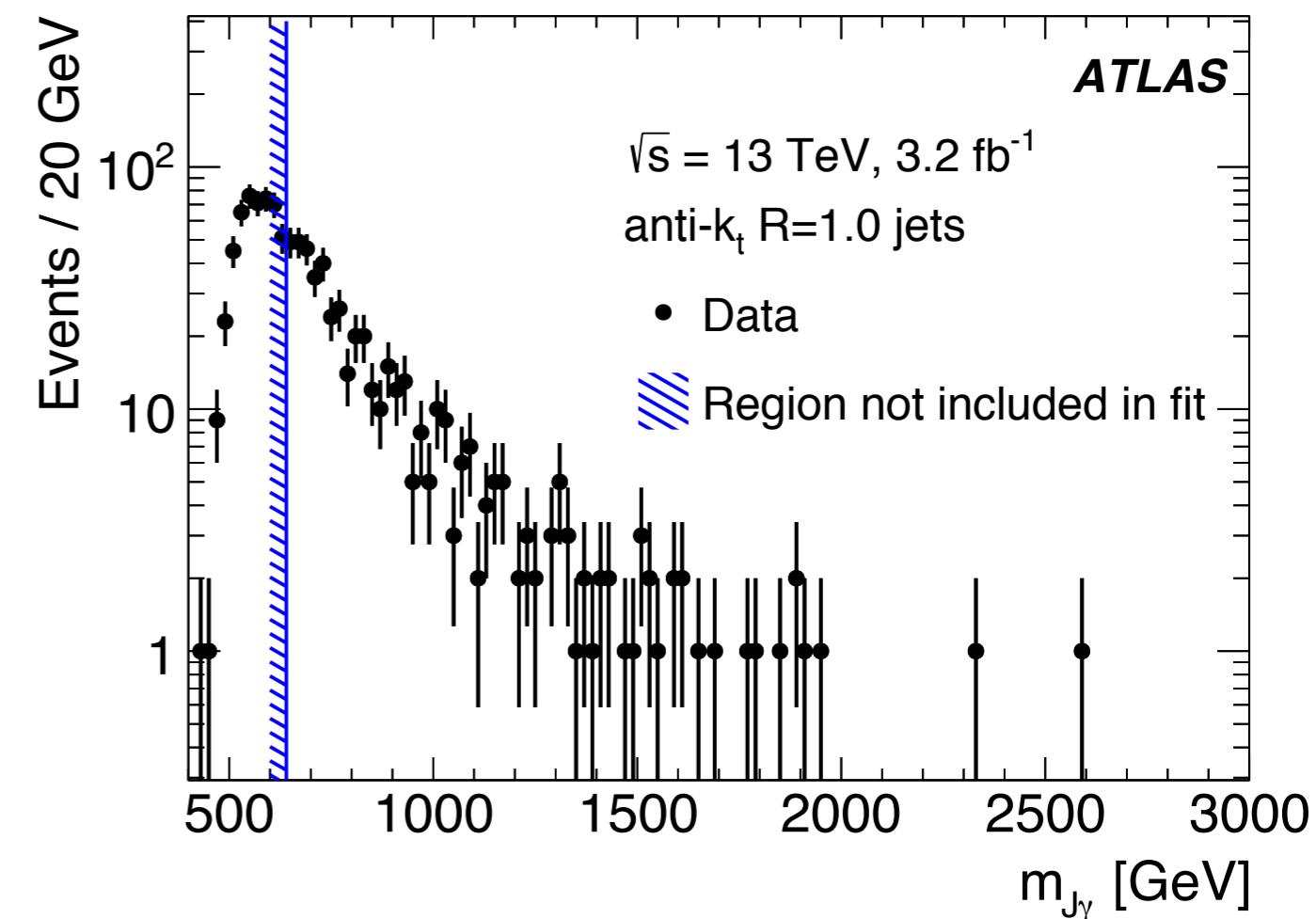


Hadronic analysis - jet and jet+photon masses

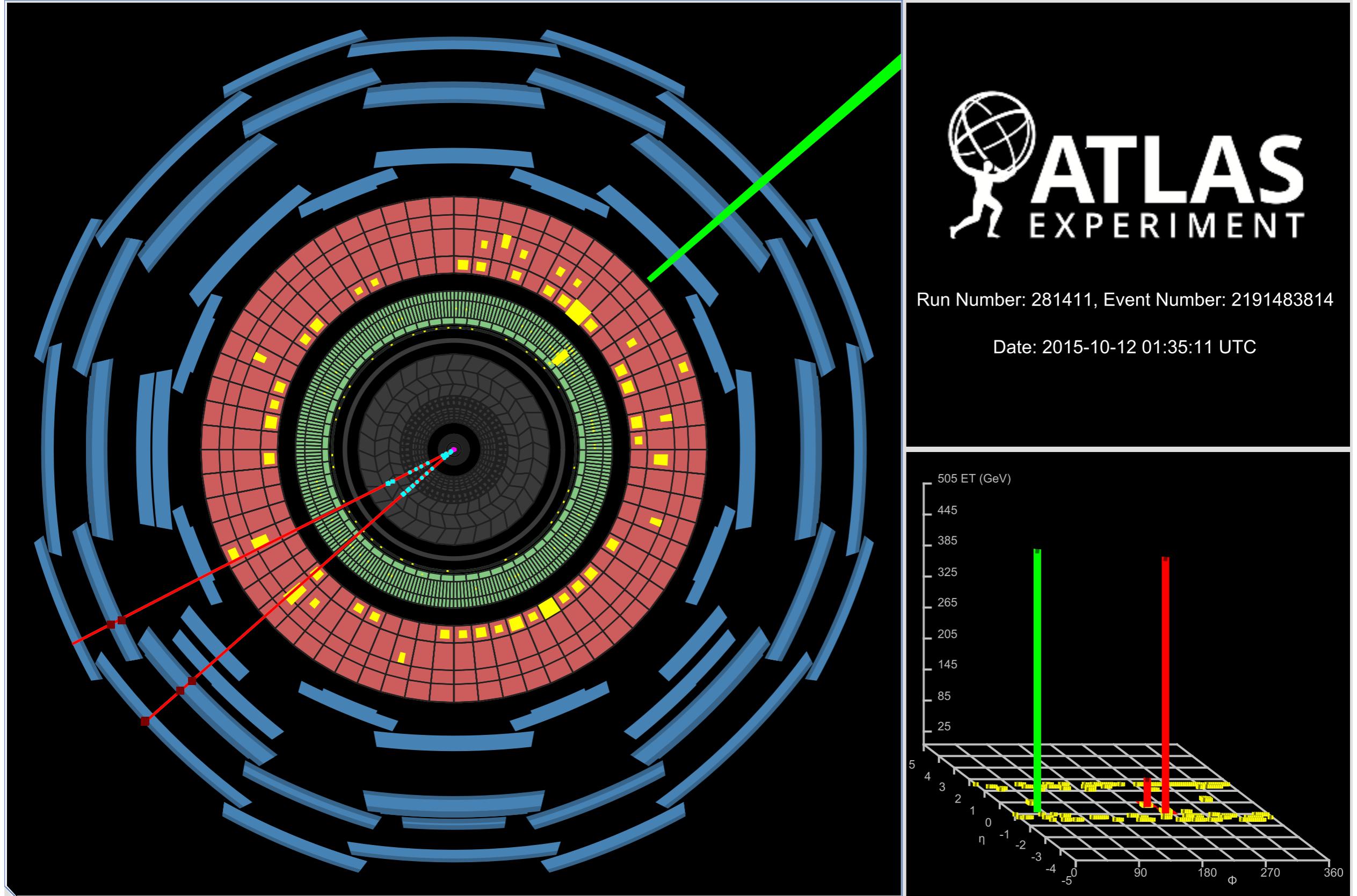
no substructure cuts



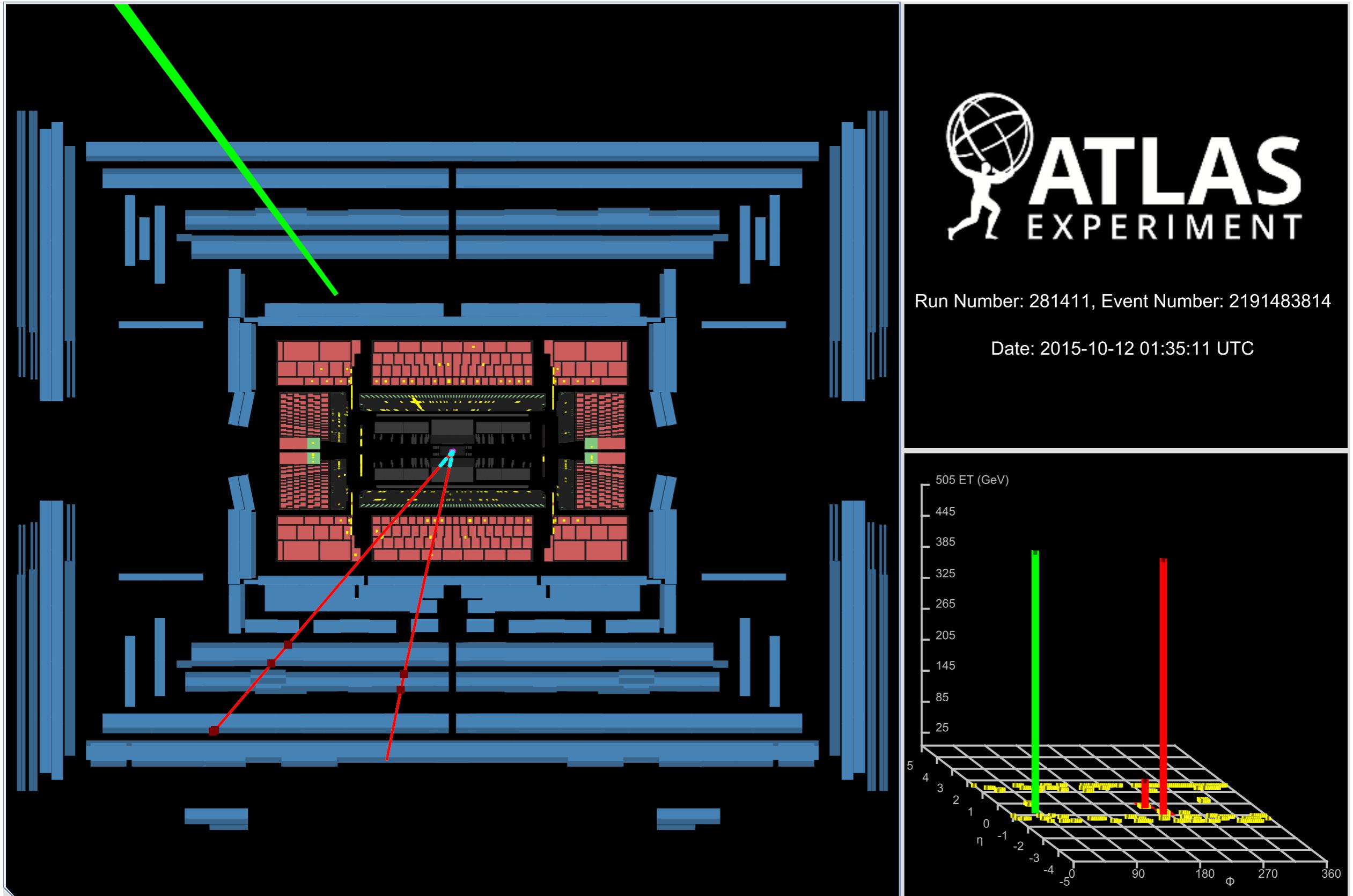
after full selection



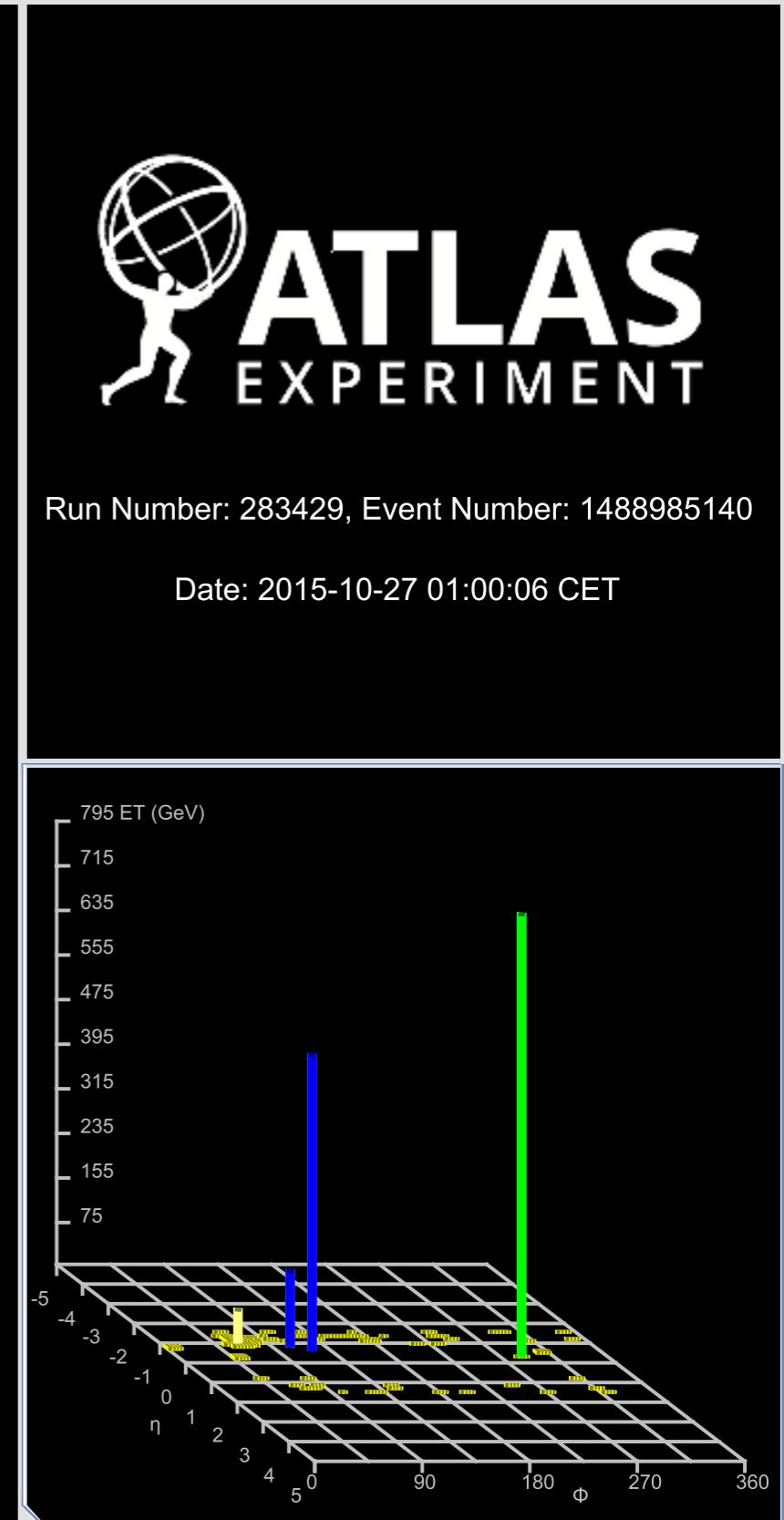
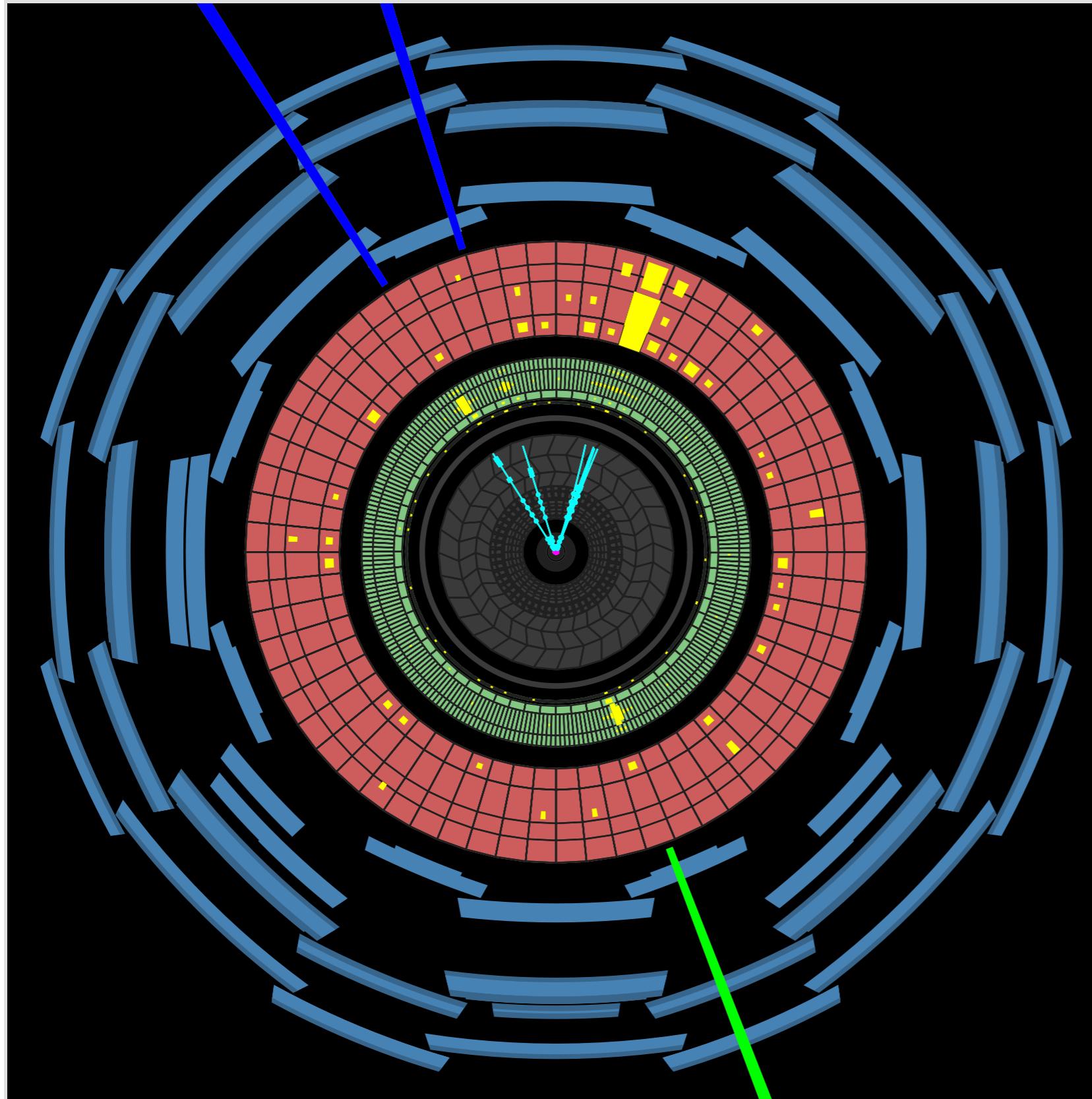
Event displays ($p_T^{\text{trk}} > 5 \text{ GeV}$, $E^{\text{cell}} > 250 \text{ MeV}$)



Event displays



Event displays



Event displays

