Search for low-mass resonances decaying into two jets and produced in association with a photon

Phys. Lett. B 795 (2019) 56

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DPF 2019, Boston
29 July

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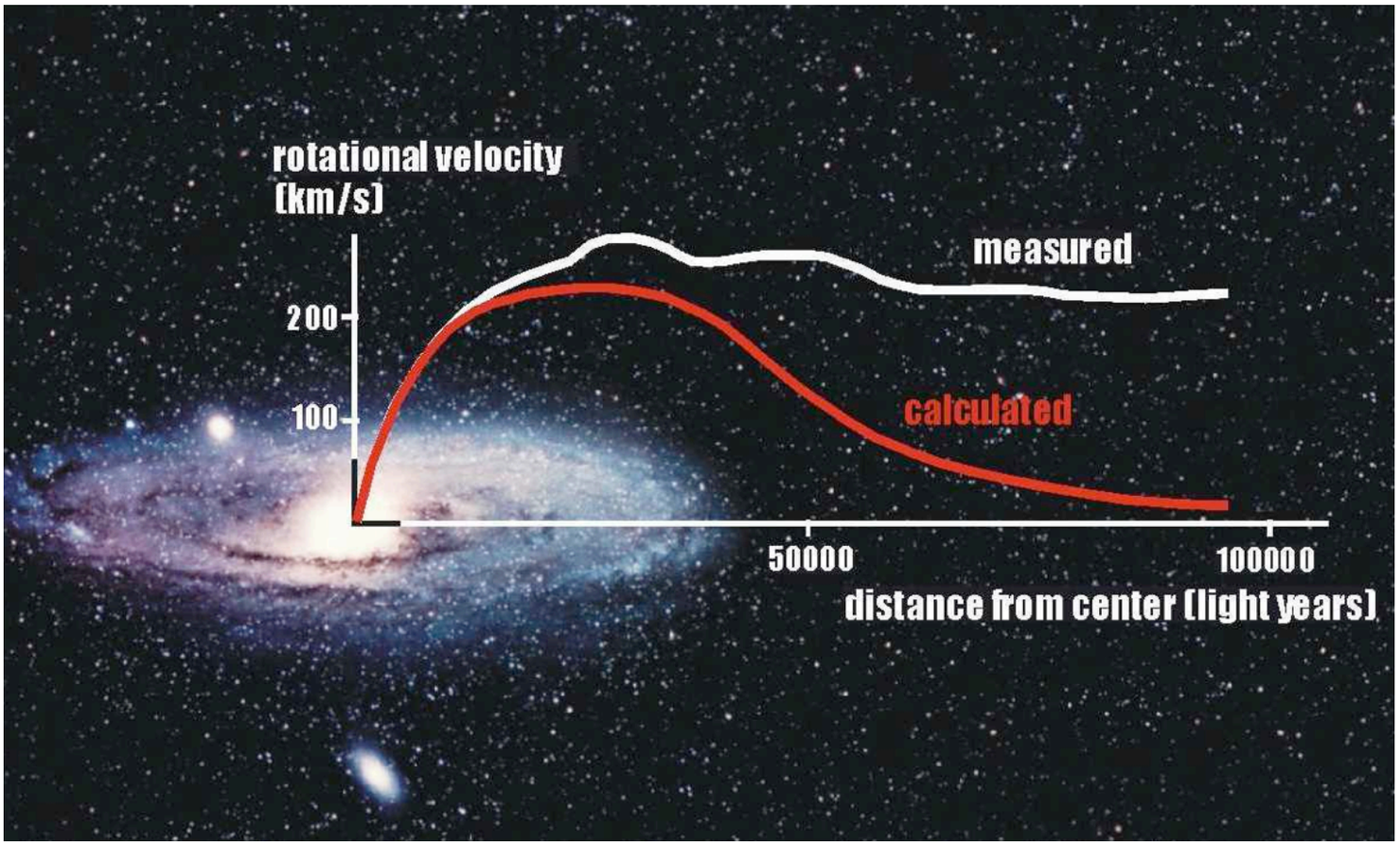
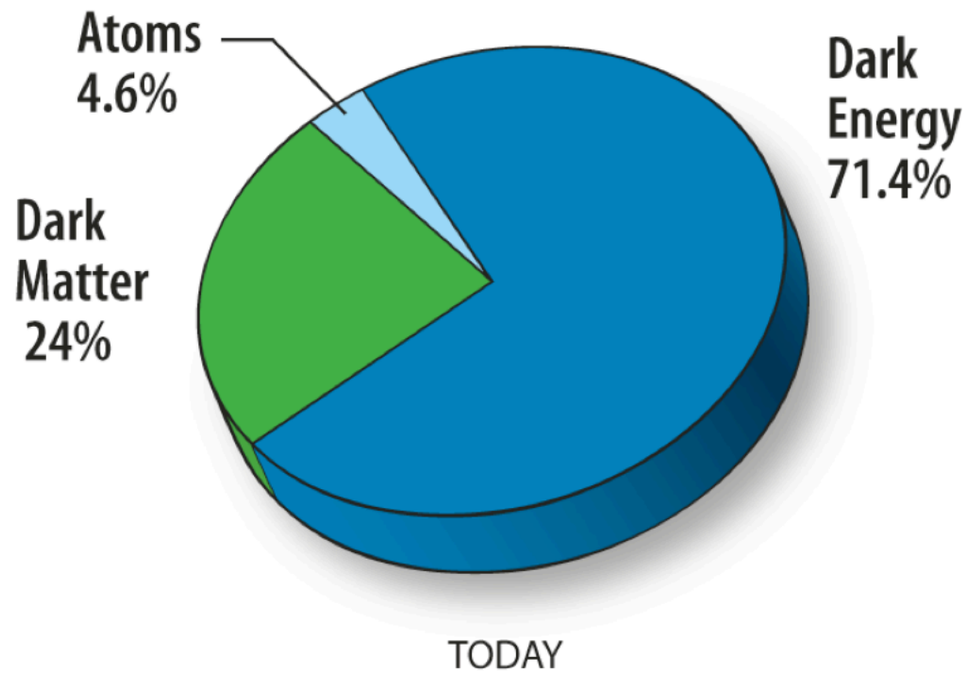
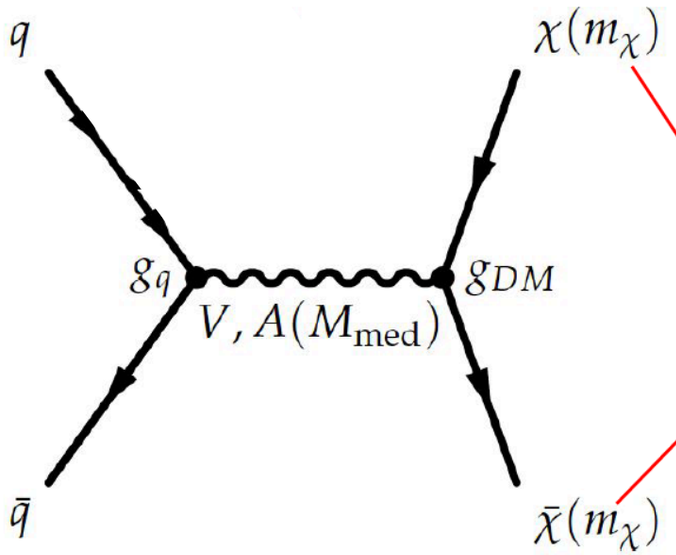
Beyond standard model





Many dark matter models predict new mediators with sizeable couplings to quarks and gluons

Leptophobic axial-vector Z'



Dirac fermion with charge under an additional U(1) gauge group

$$\mathcal{L}_{\text{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q}\gamma^\mu\gamma^5 q + g_\chi Z'_\mu \bar{\chi}\gamma^\mu\gamma^5\chi.$$

Keep minimum flavour violation

$$\Gamma_{\text{Med}} = \Gamma_{\text{DM}} + \Gamma_{\text{SM}}$$

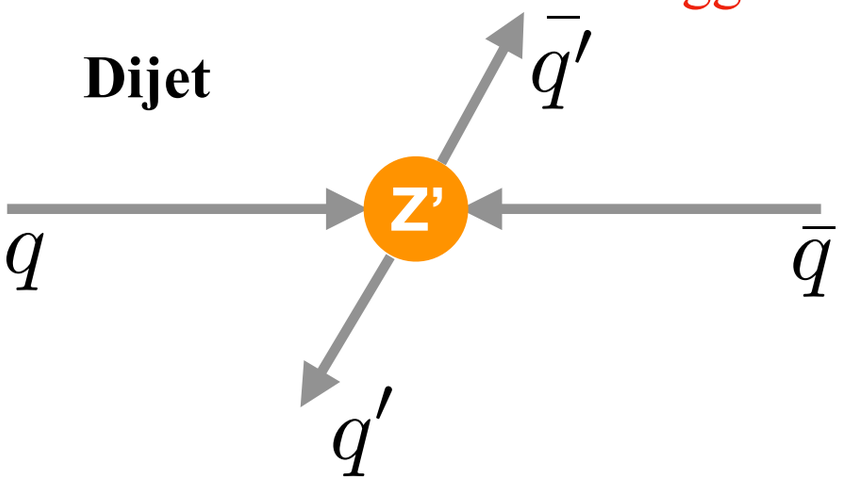
$$\Gamma_{\text{SM}} = \sum_{q\in(m_q<\frac{m_{\text{Med}}}{2})} \frac{3m_{\text{Med}}g_{SM}^2}{12\pi} \times \left(1 - \frac{(2m_q)^2}{m_{\text{Med}}^2}\right)^{3/2}$$

$$\Gamma_{\text{DM}} = \begin{cases} \frac{m_{\text{Med}}g_{\text{DM}}^2}{12\pi} \times \left(1 - \frac{(2m_{\text{DM}})^2}{m_{\text{Med}}^2}\right)^{3/2}, & \text{if } m_{\text{DM}} < \frac{m_{\text{Med}}}{2} \\ 0, & \text{otherwise} \end{cases}$$

- Benchmark model in this analysis
- Leptophobic: no coupling to leptons
- Decay to all quark flavours equally

Motivation for the associated photon

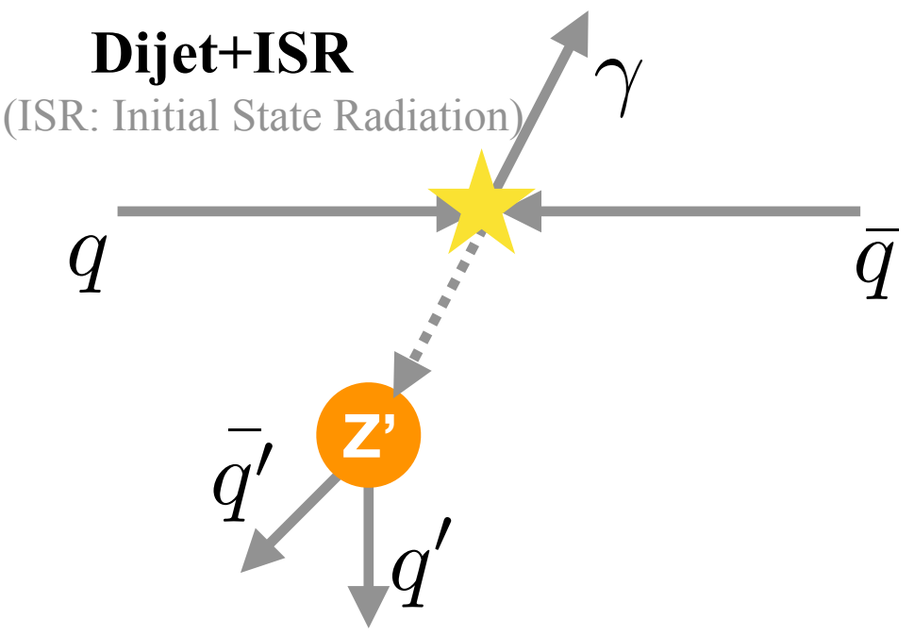
Jets fire the trigger



$m(Z') \sim 2\times p_T(q')$

poor sensitivity below 1 TeV

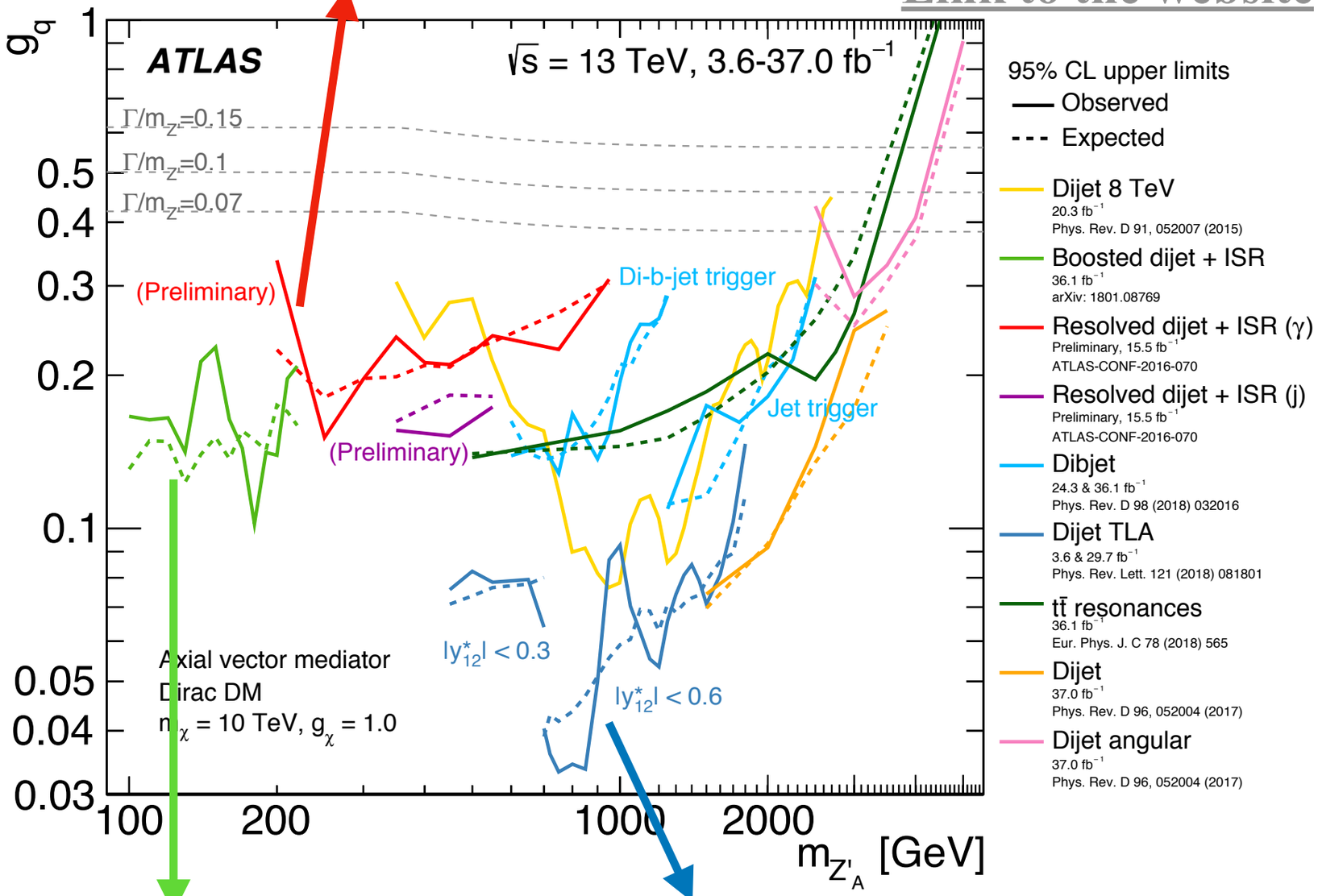
Photon fires the trigger



Allow searching for Z' with low mass

Last iteration of resolved dijet ISR:
lower statistics;
extended mass range

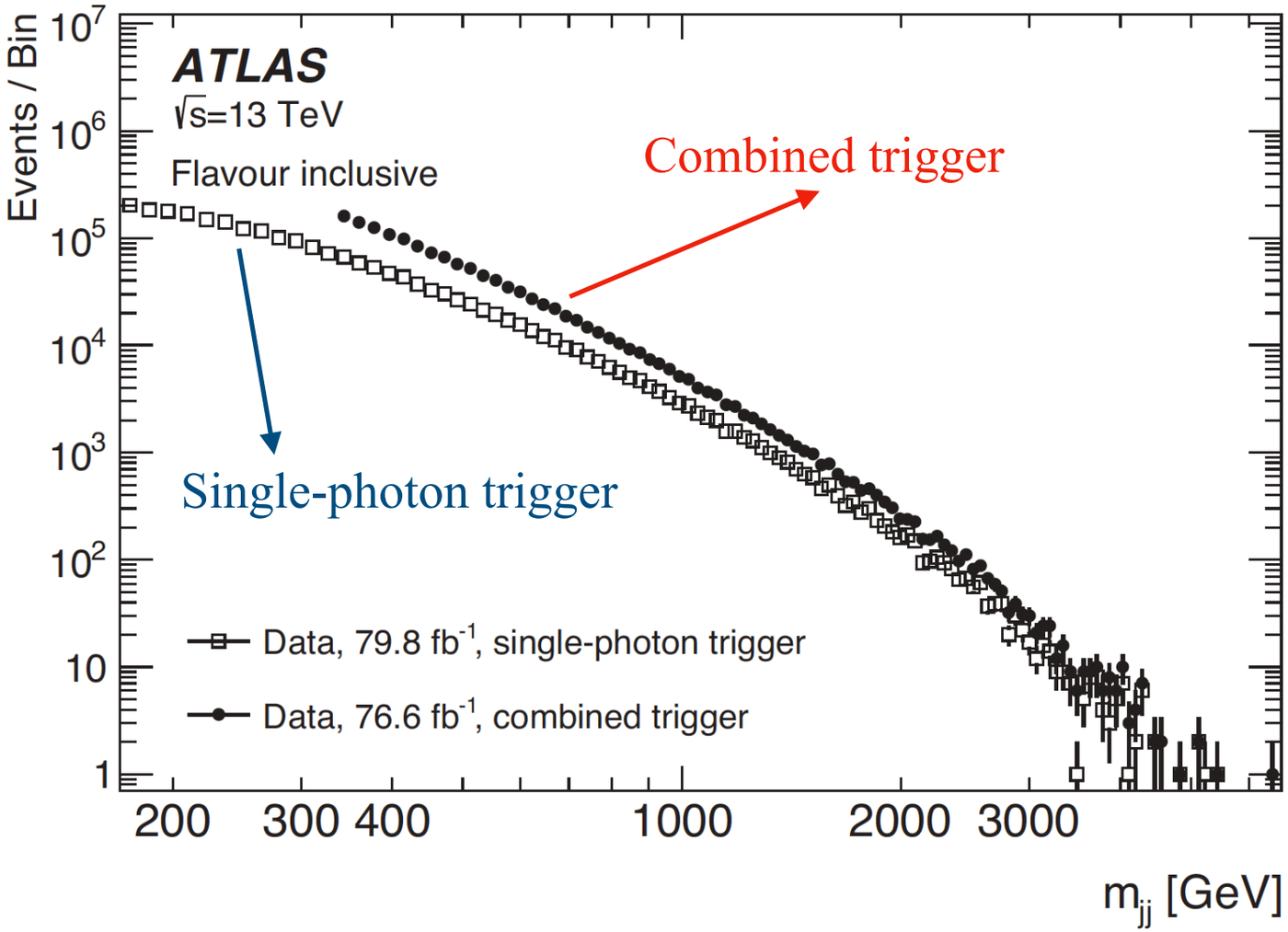
Link to the website



Boosted dijet ISR:
reach the lowest
mass region

Trigger level analysis:
high luminosity,
limited range

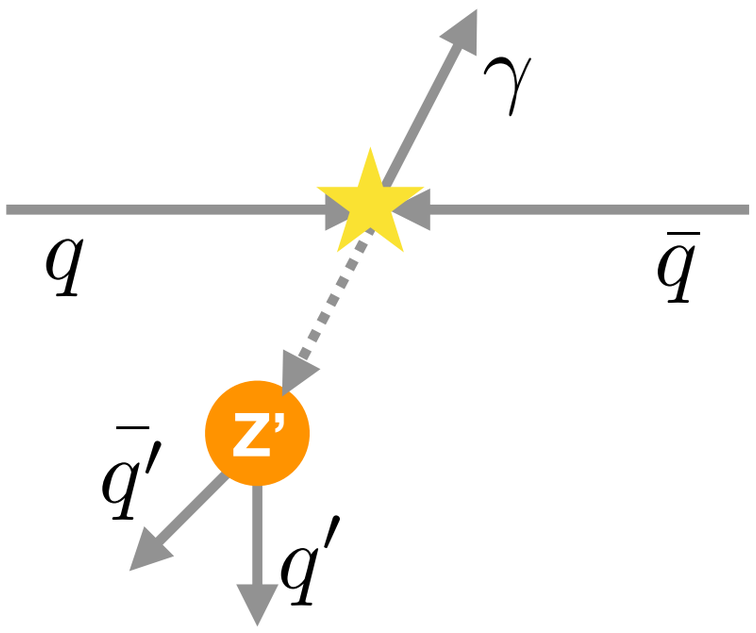
Trigger strategies



m_{jj}: total invariant mass of two selected jets

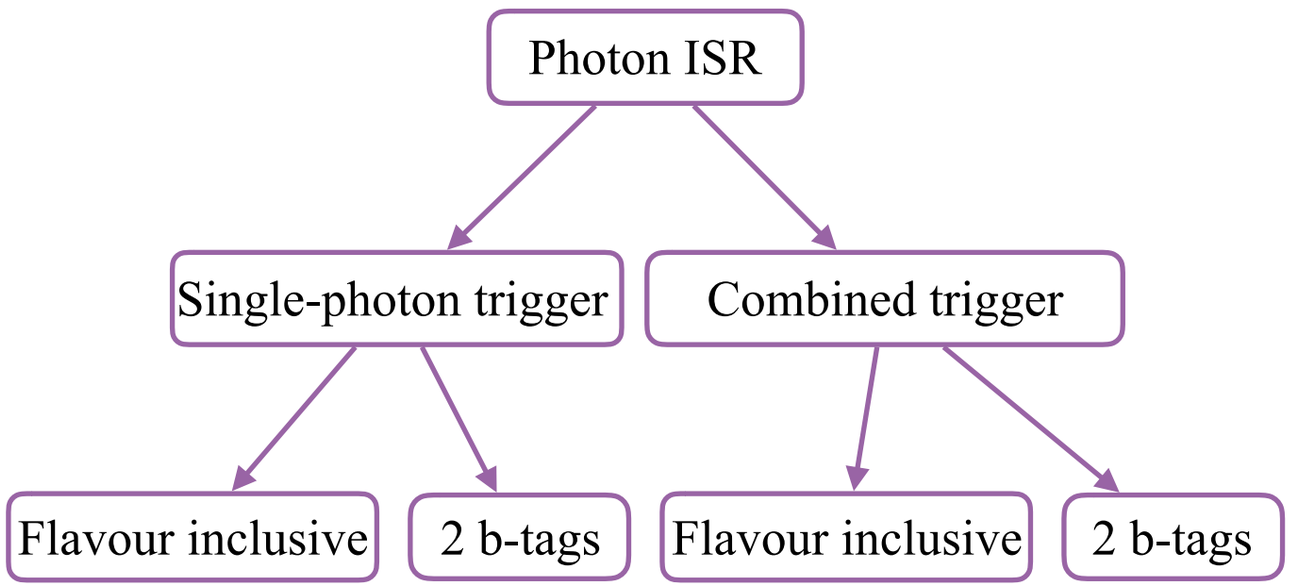
- Single-photon trigger
  - 1 high p_T photon
- Combined trigger
  - L1: 3 jets
  - HLT: 3 jets + 1 photon
  - ✦ Cons:
    - Lose about 3 fb^{-1} 2015 data
    - Cannot extend to lower mass region
  - ✦ Pro:
    - Improve the sensitivity

Event selections



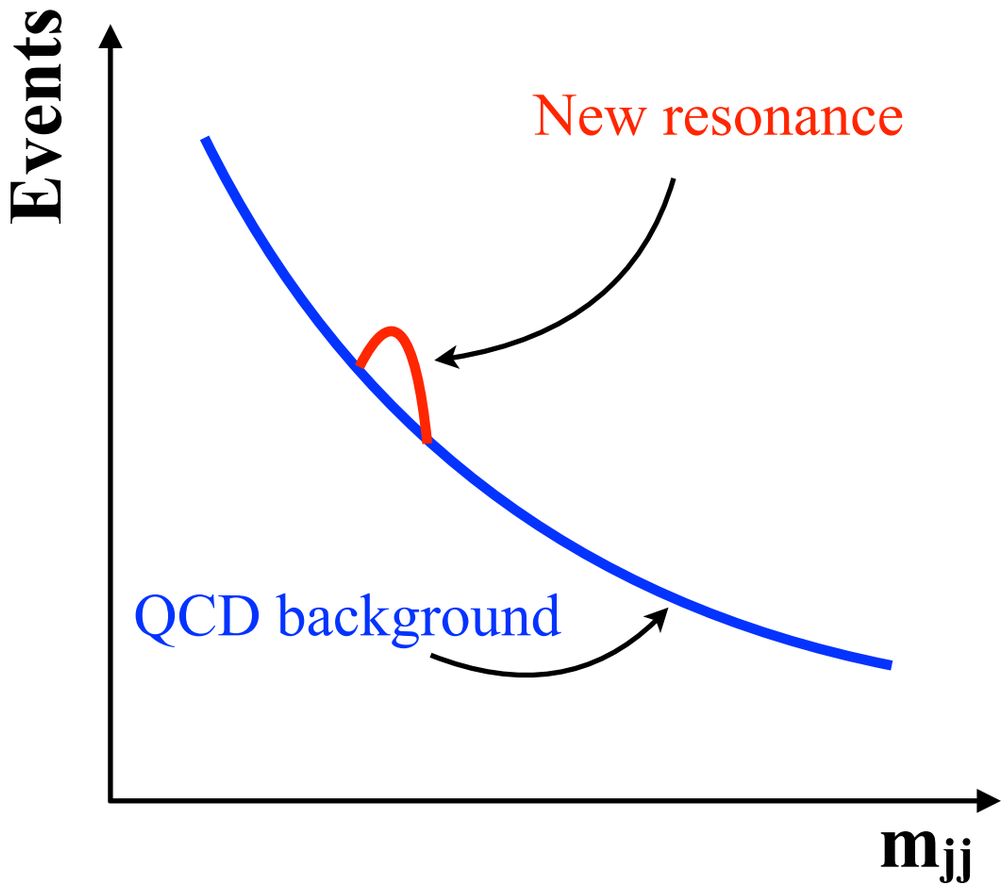
Criterion	Single-photon trigger	Combined trigger
Number of jets	$n_{\text{jets}} \geq 2$	
Number of photons	$n_{\gamma} \geq 1$	
Leading photon	$E_{\text{T}}^{\gamma} > 150$ GeV	$E_{\text{T}}^{\gamma} > 95$ GeV
Leading, subleading jet	$p_{\text{T}}^{\text{jet}} > 25$ GeV	$p_{\text{T}}^{\text{jet}} > 65$ GeV
Centrality	$\lvert y^{*}\rvert = \lvert y_1 - y_2\rvert/2 < 0.75$	
Invariant mass	$m_{\text{jj}} > 169$ GeV	$m_{\text{jj}} > 335$ GeV

y*: difference between 2 leading jets' rapidity



- Use full 2015+2016+2017 datasets (~80 fb^{-1})
- 2 leading jets are selected as candidate jets from Z'
- 2 b-tags: 2 leading jets passing DL1 fixed 77% working point

Background estimation



- The QCD background distribution is a smoothly falling spectrum
- New resonance is the local excess on the smoothly falling background
- Use smooth functions to fit the data

$$f(x) = p_1 x^{-p_2} e^{-p_3 x - p_4 x^2}$$

$$f(x) = p_1 (1-x)^{p_2} x^{p_3}$$

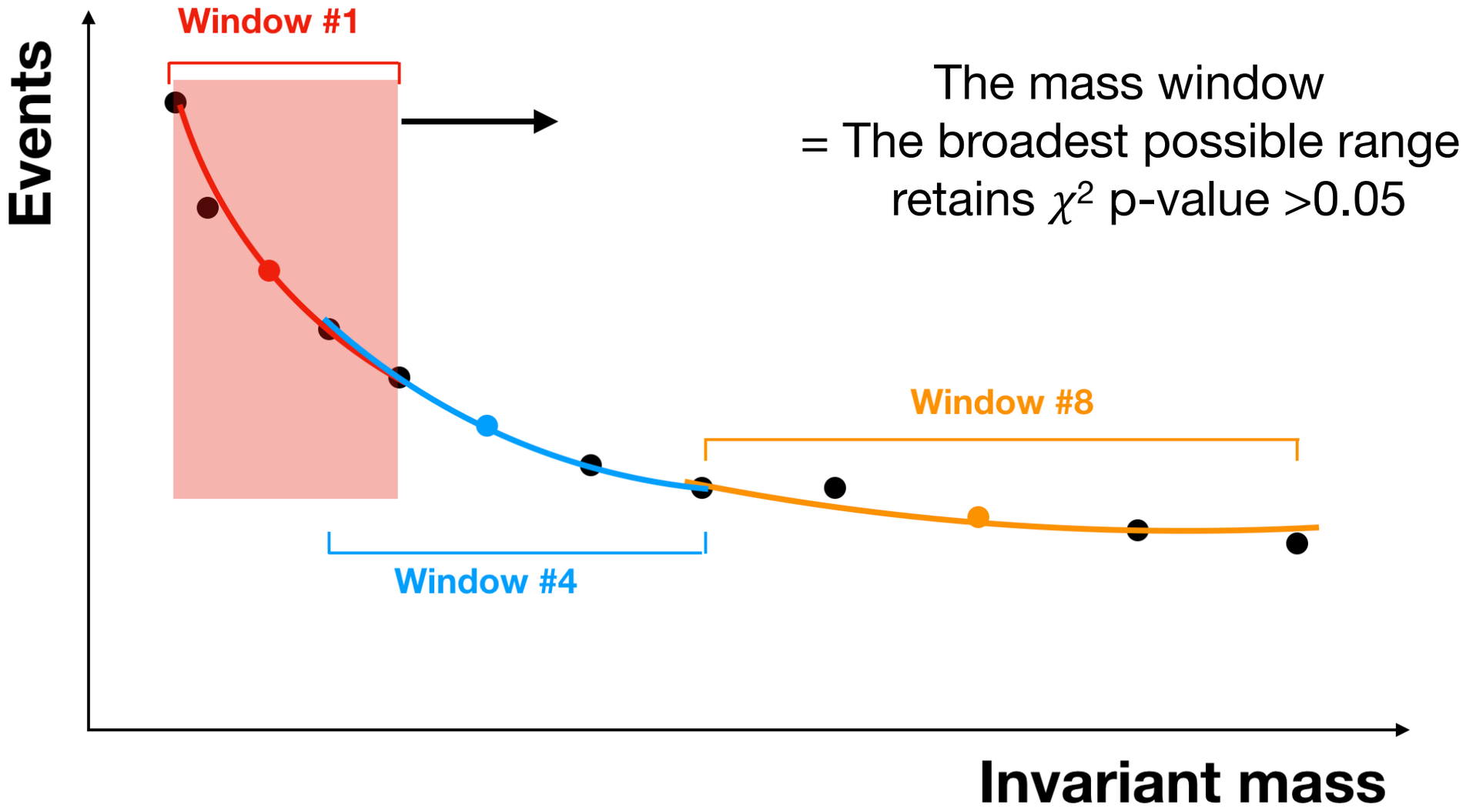
$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x + p_5 (\ln x)^2}$$

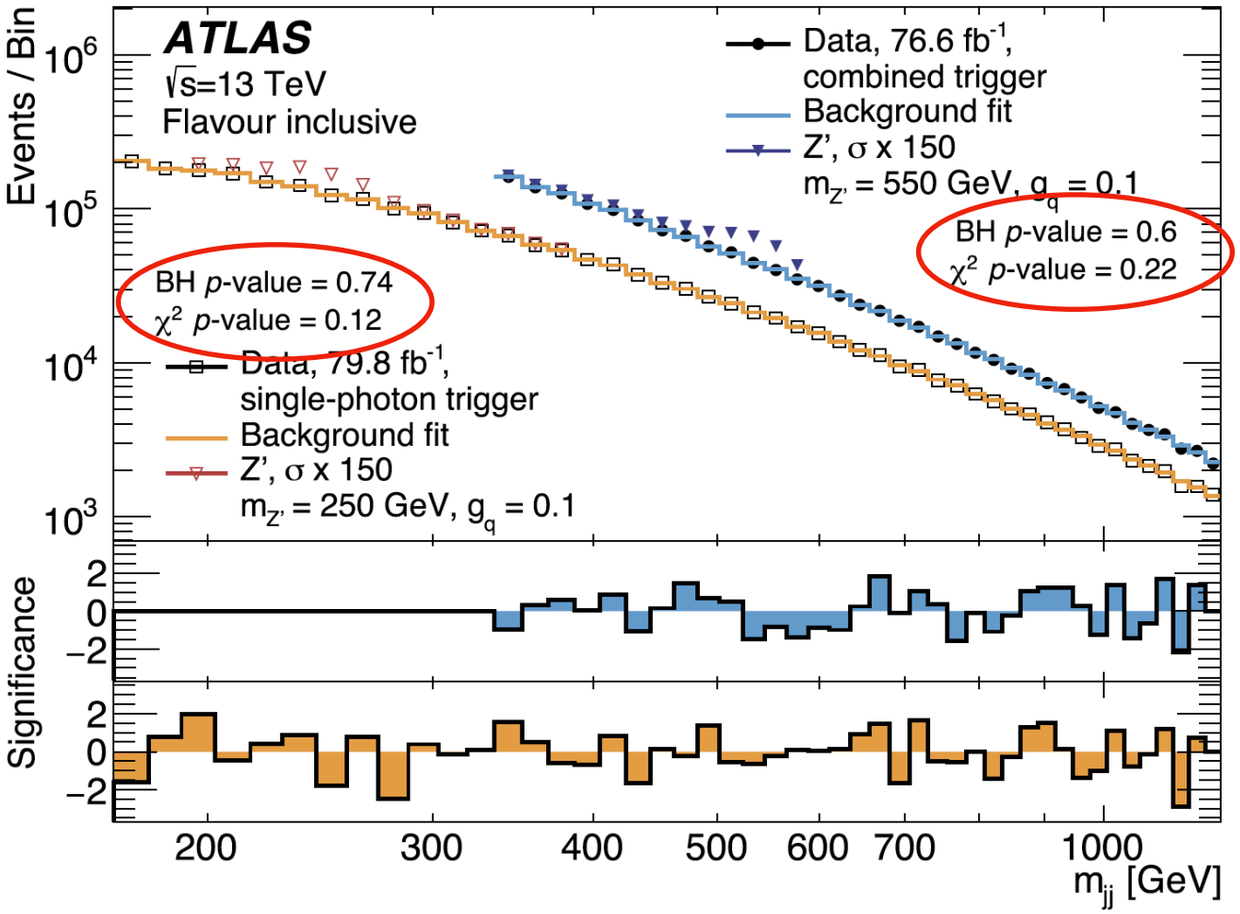
where p_i are free parameters and $x = m_{jj}/\sqrt{s}$

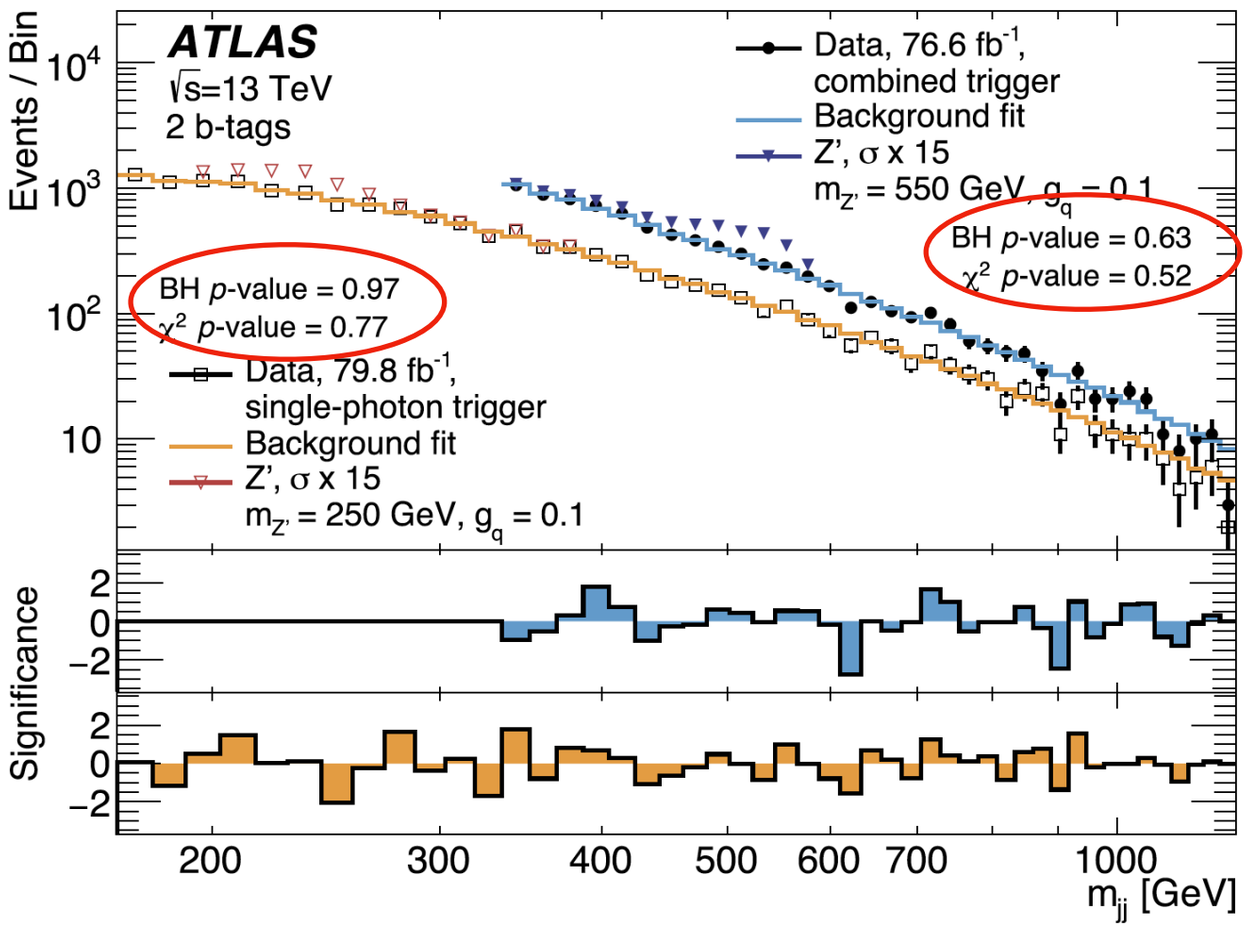
Sliding window fit (SWiFt)

- Hard to fit entire mass range with a single function due to tight constrain from high statistics data
- Successive fit of each mass bin is conducted
- Background in each mass bin is predicted by the center of fitted function in corresponding mass window



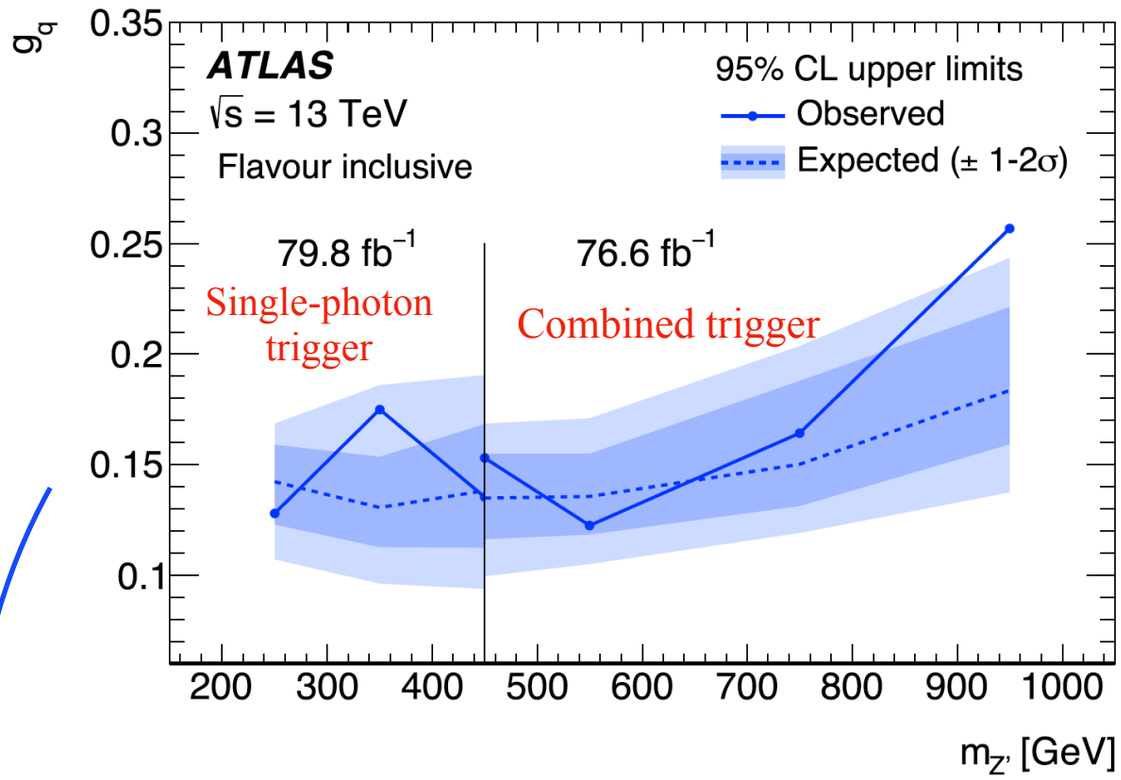
Search results

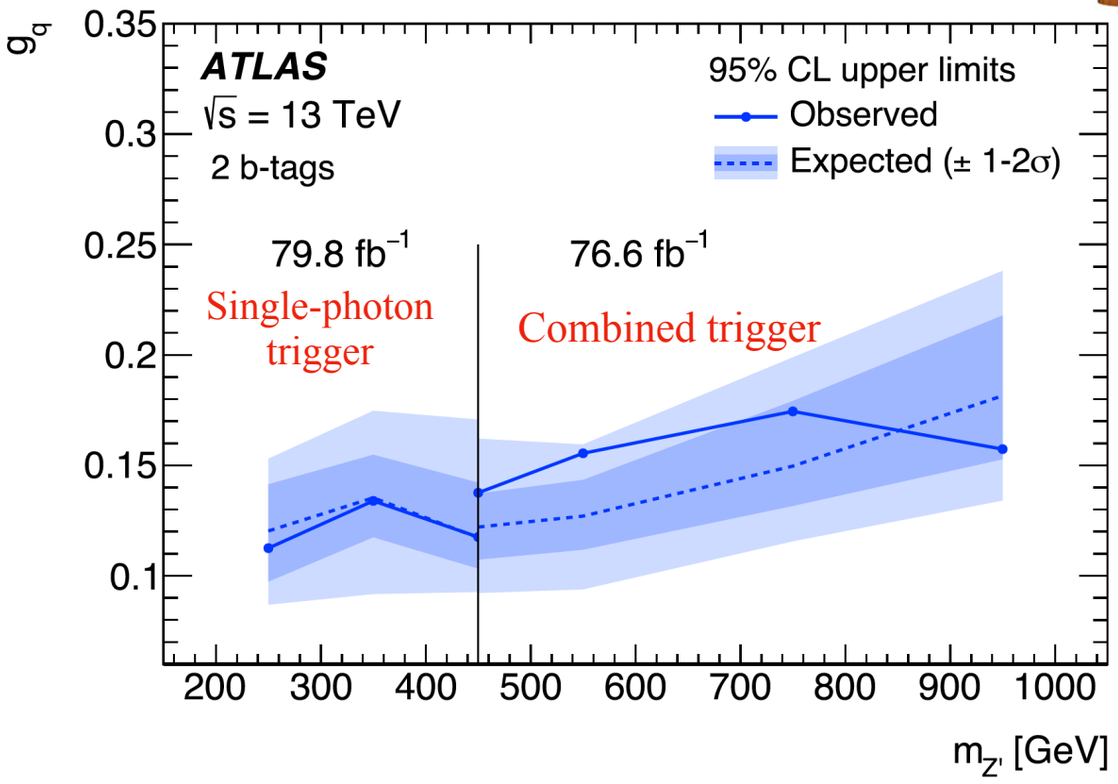


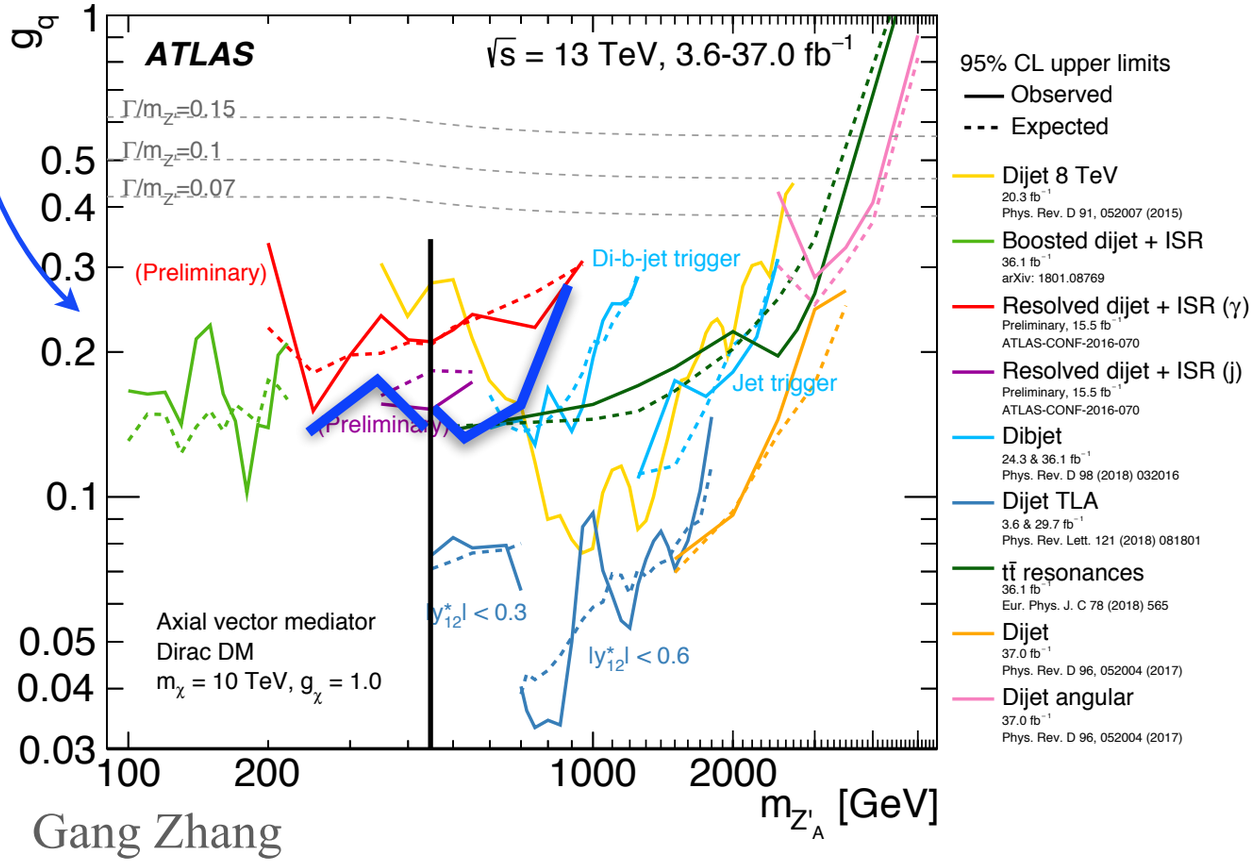


- Use Bump-Hunter to find the largest excess, from 2 bins to half spectrum
- Search phase is independent of any model
- **No evidence of new resonances was observed**

Model dependent limits

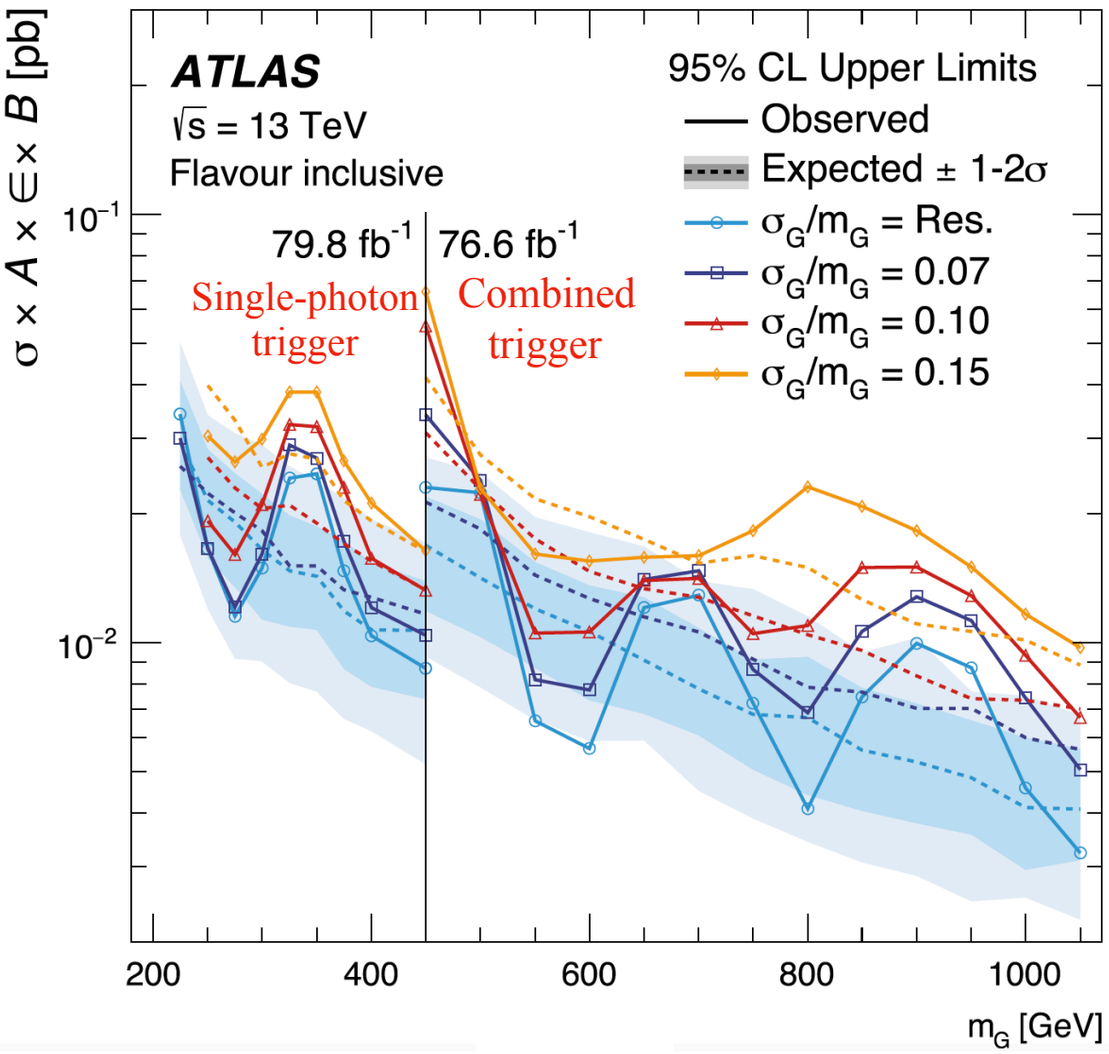


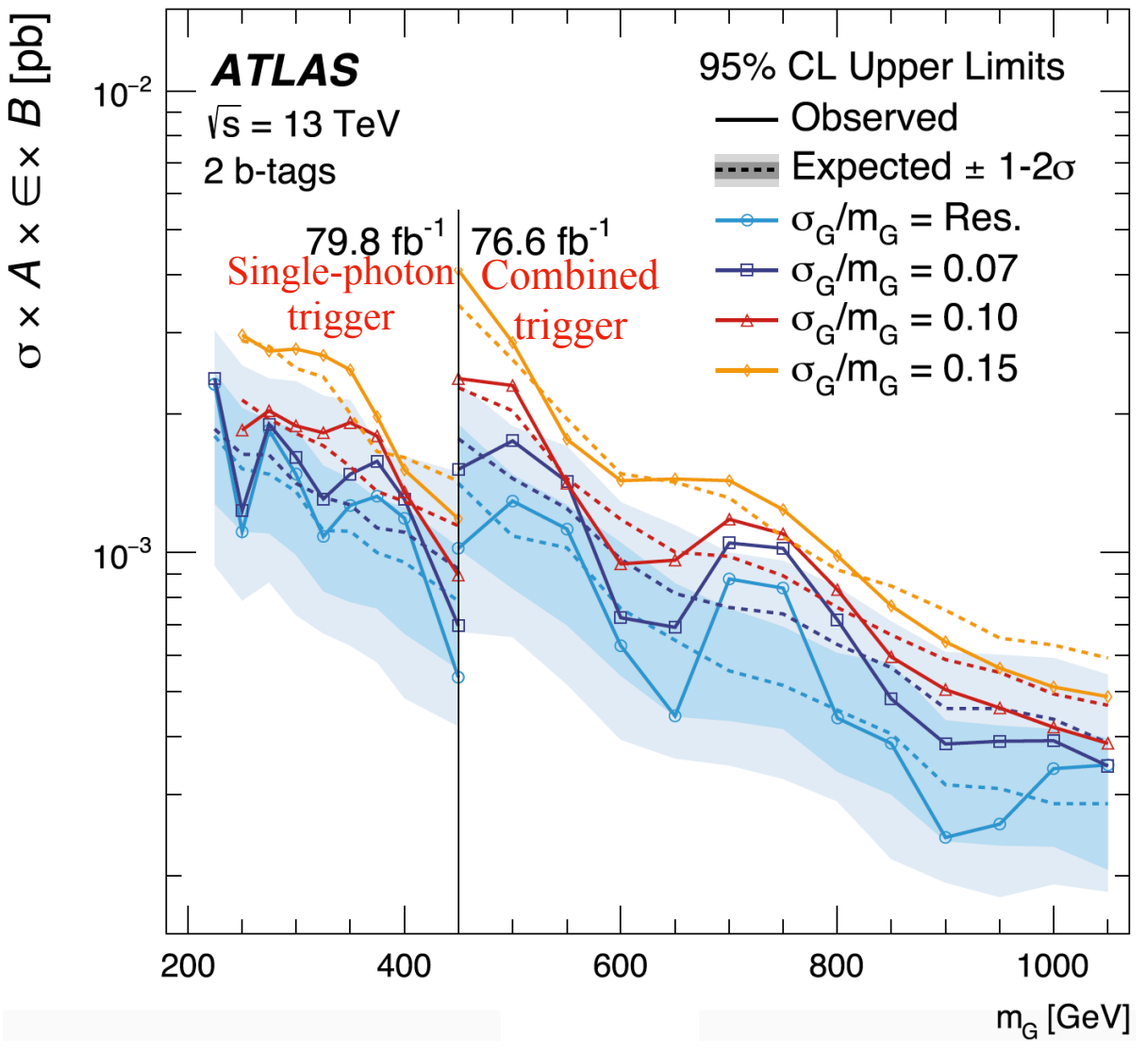




- Use Bayesian method to set limits
- B-tagged categories yield Z' limits comparable to the flavour-inclusive categories
- Stronger 95% CL upper limits

Model independent limits





- Signals are gaussian shape with different width
- Limits in 2 b-tags channels can be reinterpreted in terms of resonances decaying preferentially into b-quarks

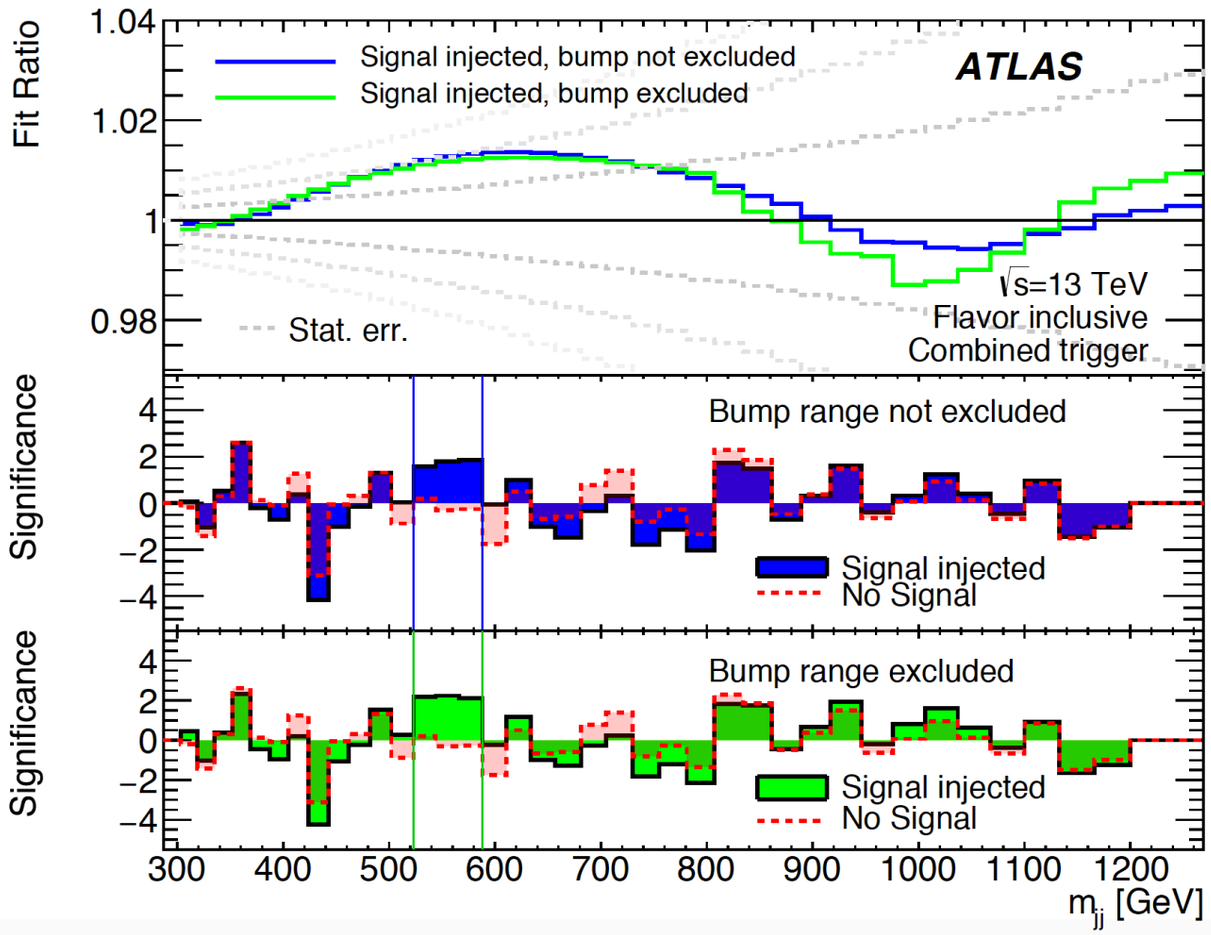
Conclusion

- Searched for the new resonance in the invariant mass spectrum of dijet pairs from 169 GeV to 1100 GeV using 80 fb^{-1} Run 2 data
- No evidence of new physics was observed
- Significantly extend the constraints on hadronically decaying resonances from 225 GeV to 1100 GeV

Thank you!

Backup

Signal injection



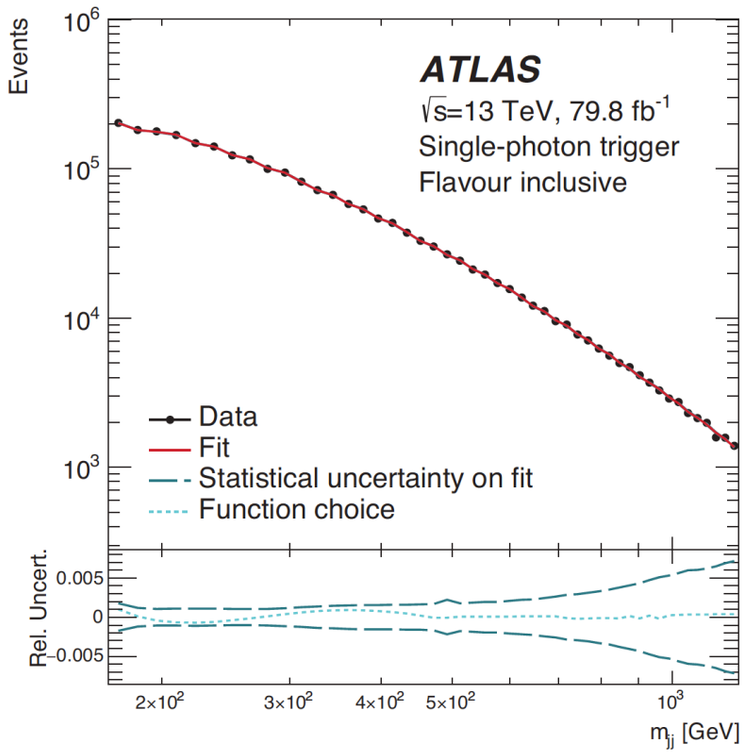
- m_{signal} = 550 GeV, Gaussian-shaped
- Bump excluded(bump not excluded): signal normalization is just above(below) the BumpHunter 0.01 p-value threshold for removal of the window corresponding to the excess
- Red area: No signal injection

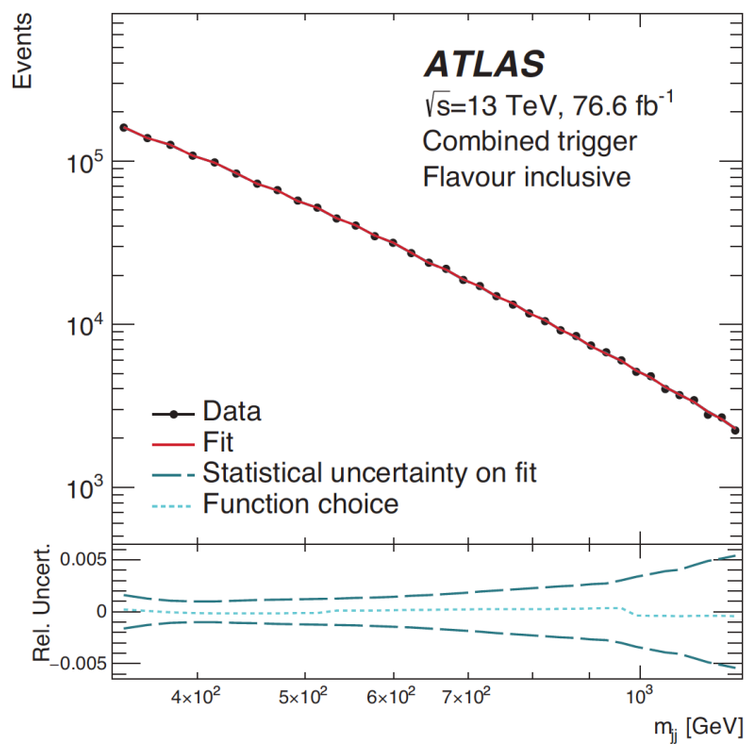
- Test all signal samples to determine the minimum allowed sizes of mass window
- Draw pseudo-experiments with statistics equivalent to the statistics of the full dataset from a smooth fit to the unblinded 15 fb^{-1} data
- When injecting a nearly-detectable signal, the background estimation agrees within statistical uncertainties with that derived when fitting a background-only distribution

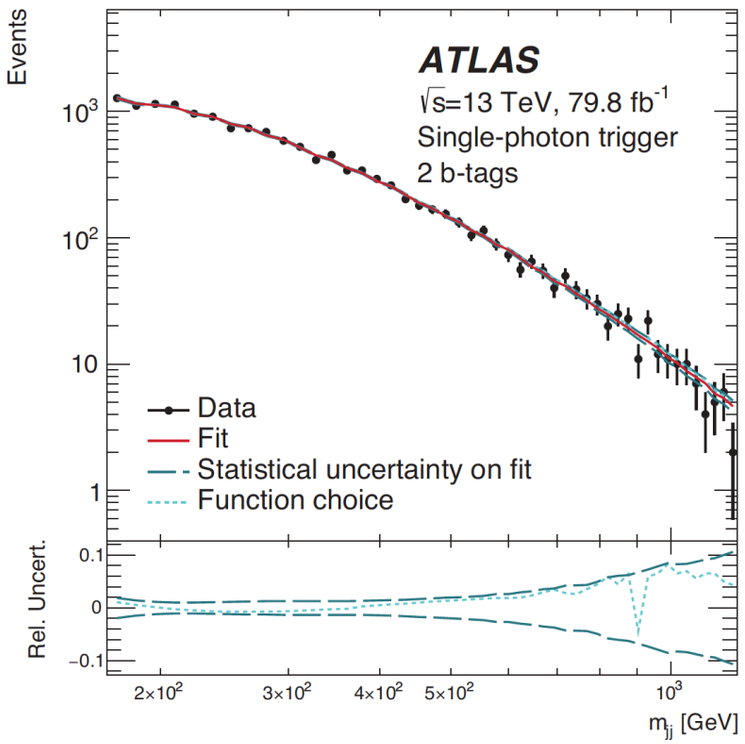
Systematics

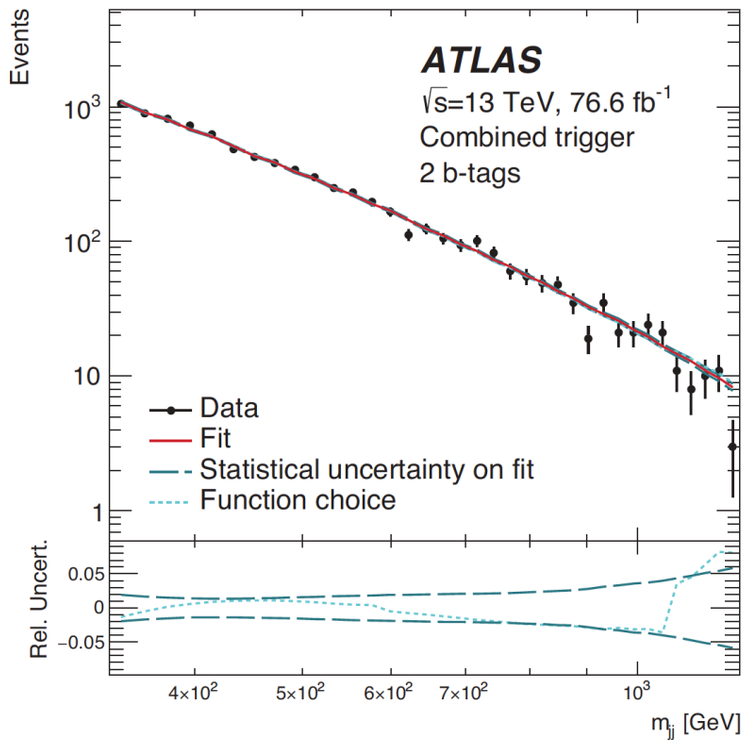
Uncertainty	Inclusive, single γ trig.	Inclusive, compound trig.	2 b-tagged, single γ trig.	2 b-tagged, compound trig.
Fit statistics	0.5% - 10% of background, depending on channel and m_{jj}			
Fit function choice	0.5% - 10% of background, depending on channel and m_{jj}			
JES	Templates for Z', 2.0% shift in Gaus. mean for model-independent limits			
JER	3.0%	3.0%	3.0%	3.0%
Photon related	2.0%	1.4%	2.0%	1.4%
Trigger efficiency	–	3.0%	–	3.0%
b-tagging SFs	–	–	~5.0%-15.0%	~5.0%-15.0%
Luminosity	2.0%	2.3%	2.0%	2.3%
PDF	1.0% Z', none for model-independent limits			

Fit uncertainty and function choice uncertainty









- The primary function yields the highest χ^2 p-value
- The function with the lowest χ^2 p-value which still results in a p-value larger than 0.05 is chosen as an alternative function