Search for RPV SUSY in multi-jet final states

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on behalf of the Analysis Team* (paper)

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- University of Bern
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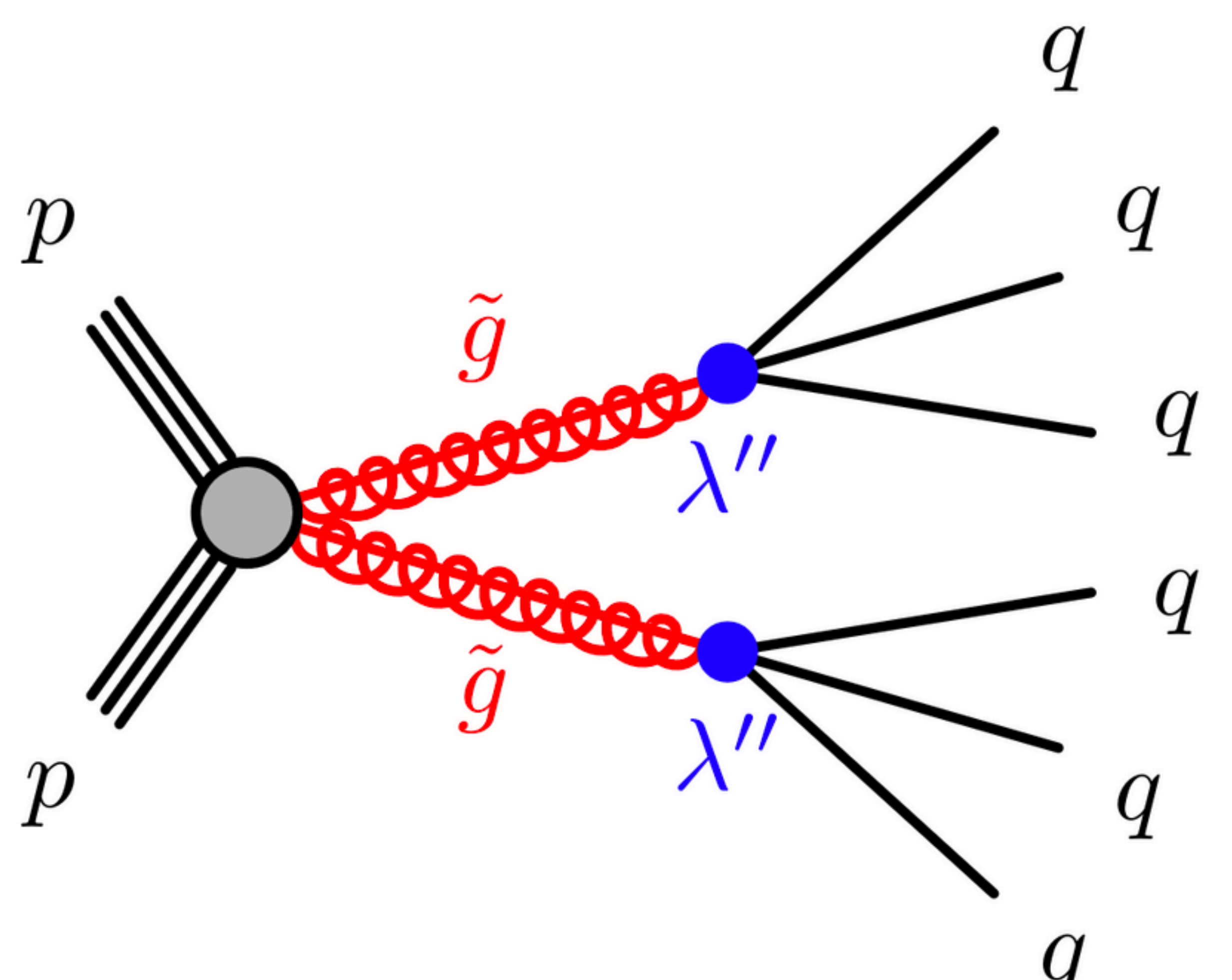
Motivation



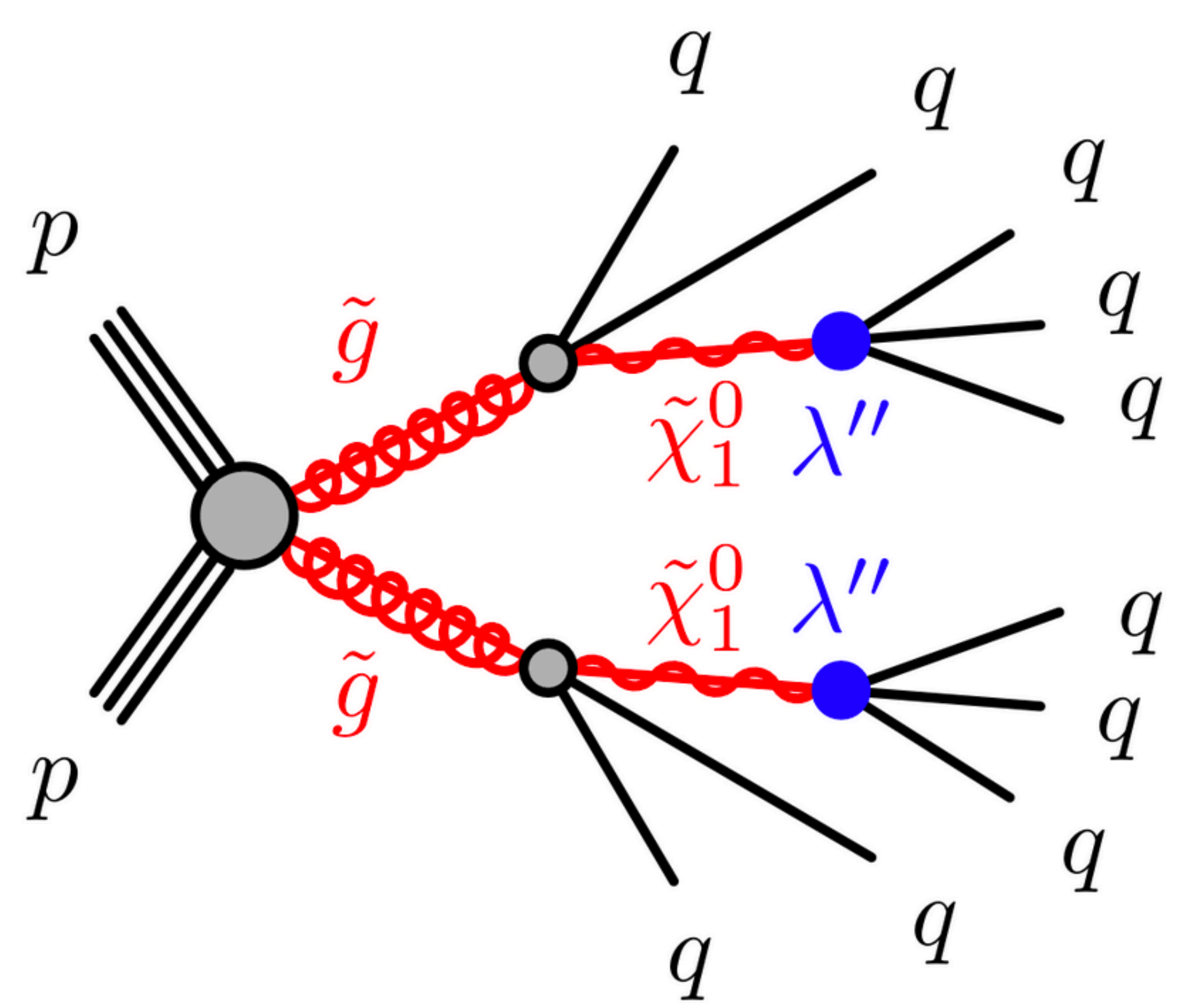
2x3 - direct decay

◉ Importance of exploring SUSY variants

- Focus on relaxing experimental constraints

◉ R-Parity-Violating (RPV) SUSY

- RPV models have less restrictive limits
- Challenging final states without significant MET
- Comparatively looser limits that RPC searches

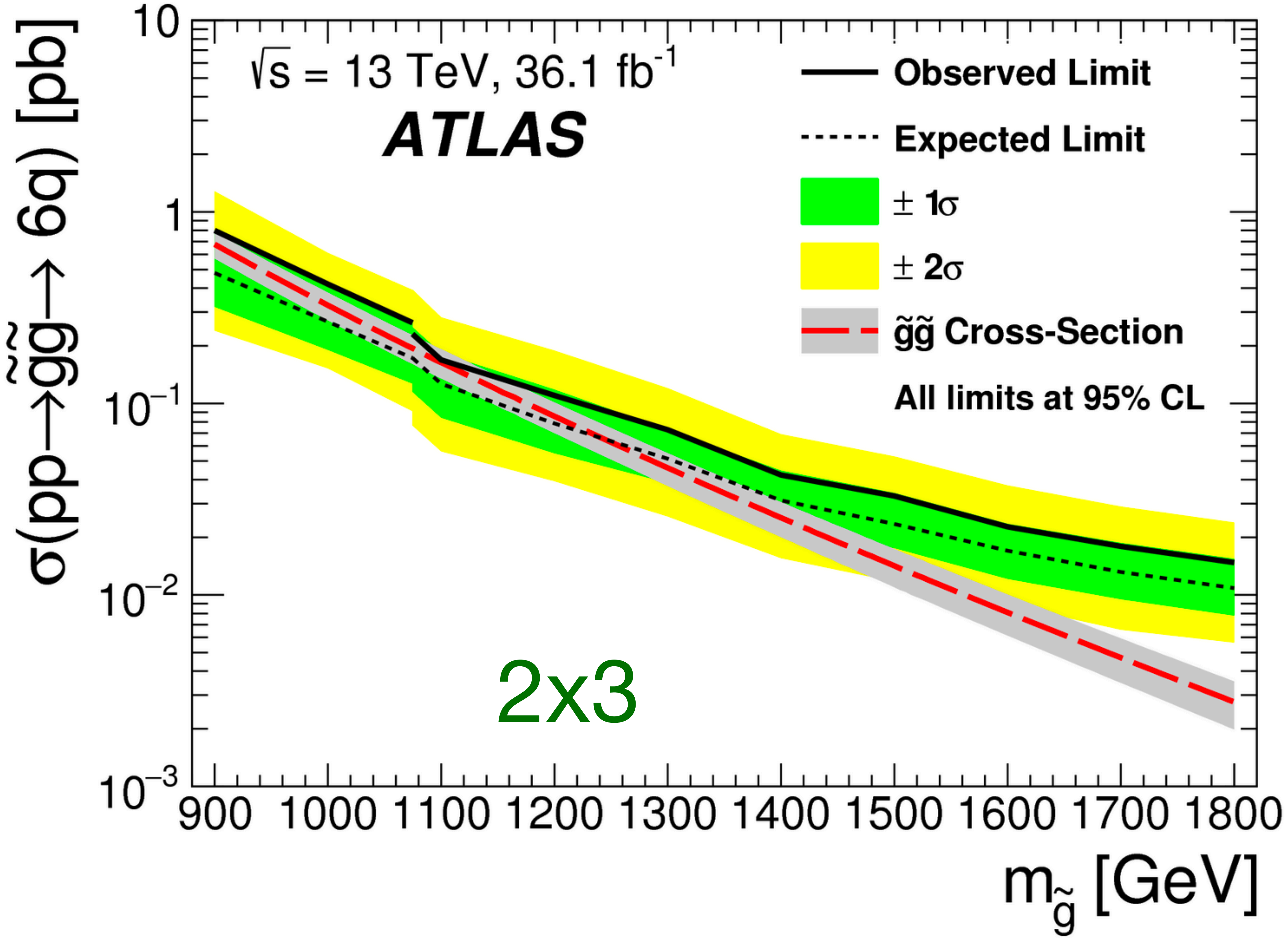


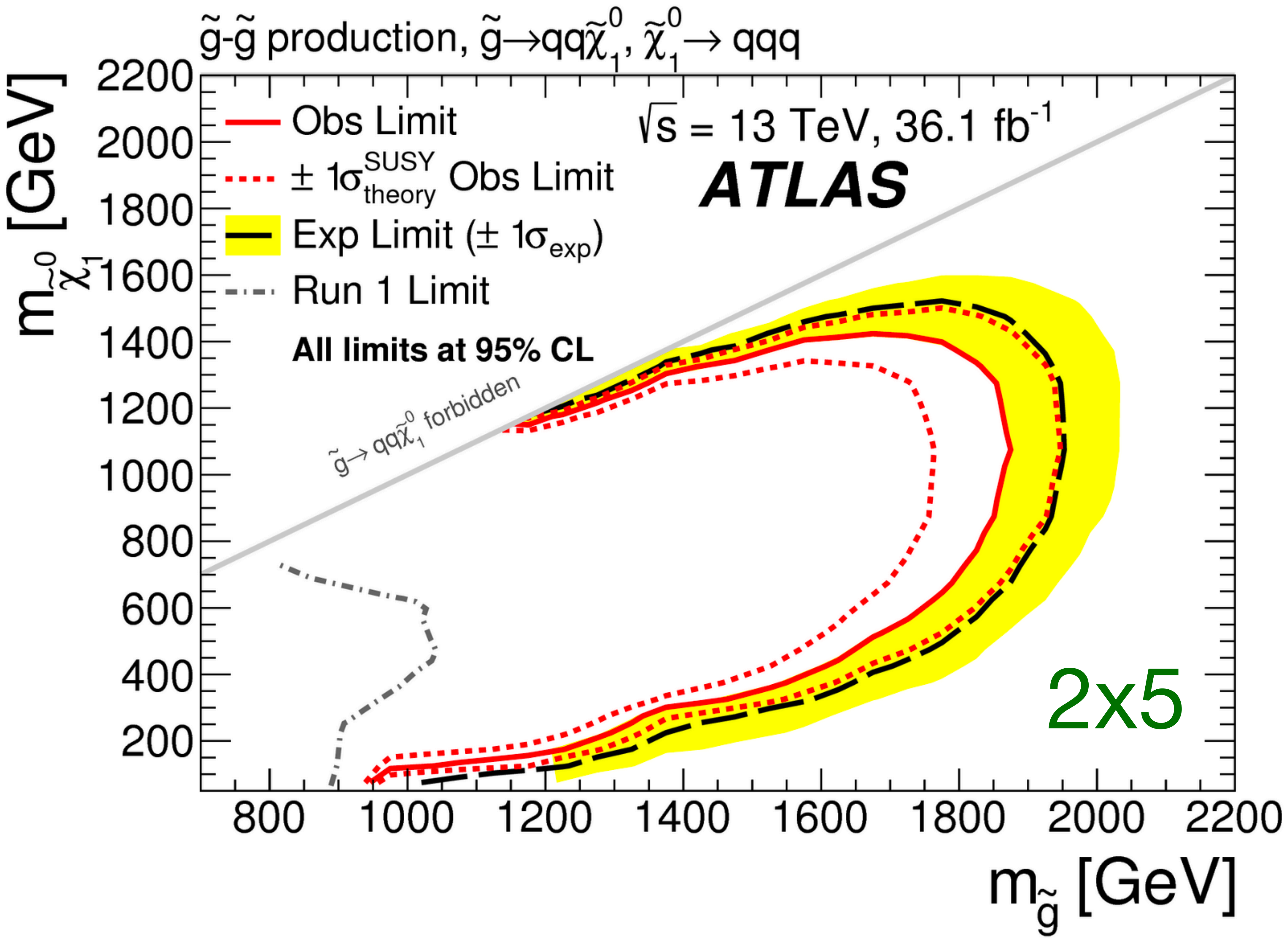
2x5 - cascade decay

$$W_{\mathrm{RPV}} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \boxed{\frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k}$$

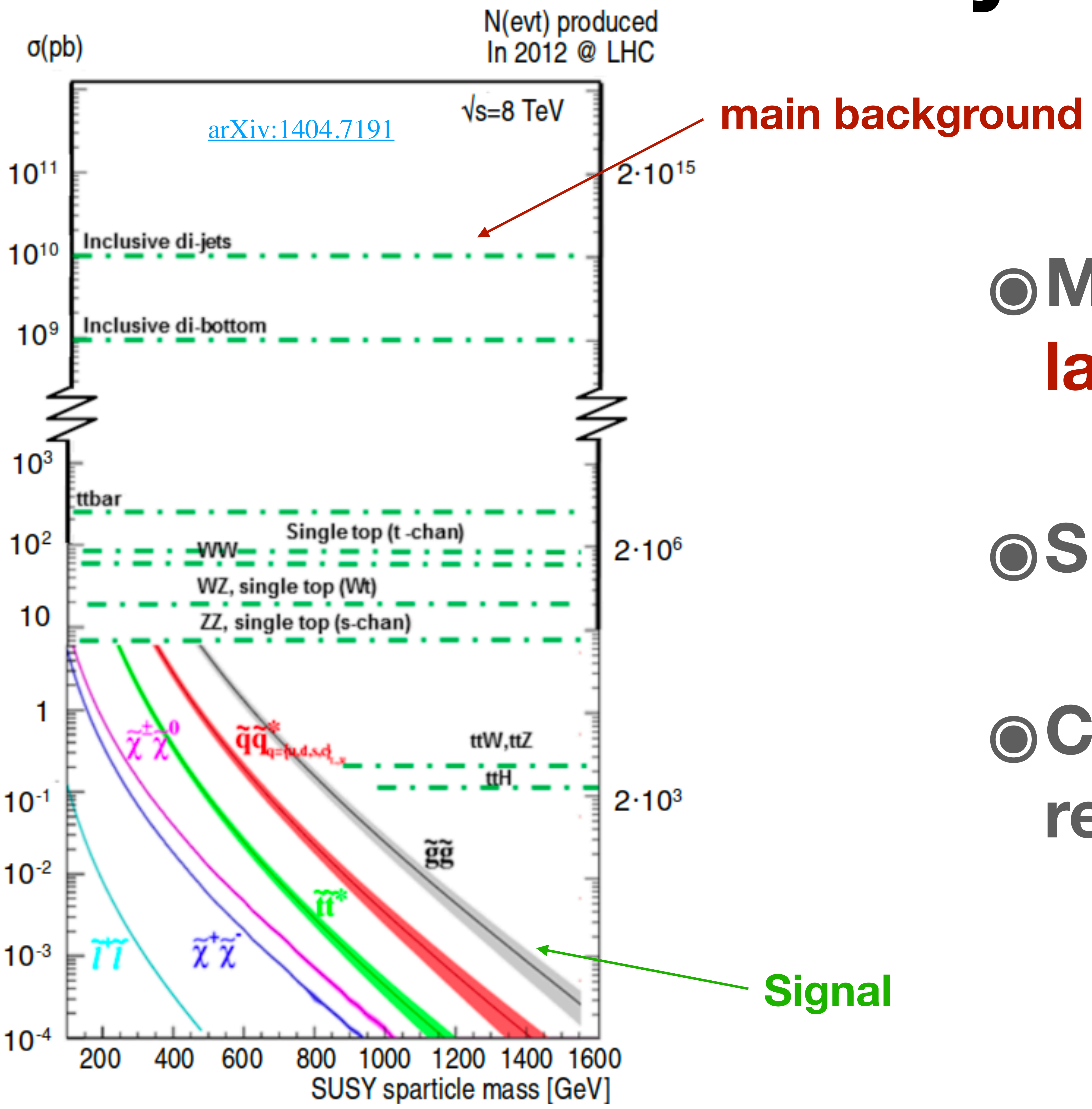
Previous Limits

- **Partial Run-2 analysis published (paper)**
  - For the 2x3 model, Run-1 limits remain the same





Key Challenges



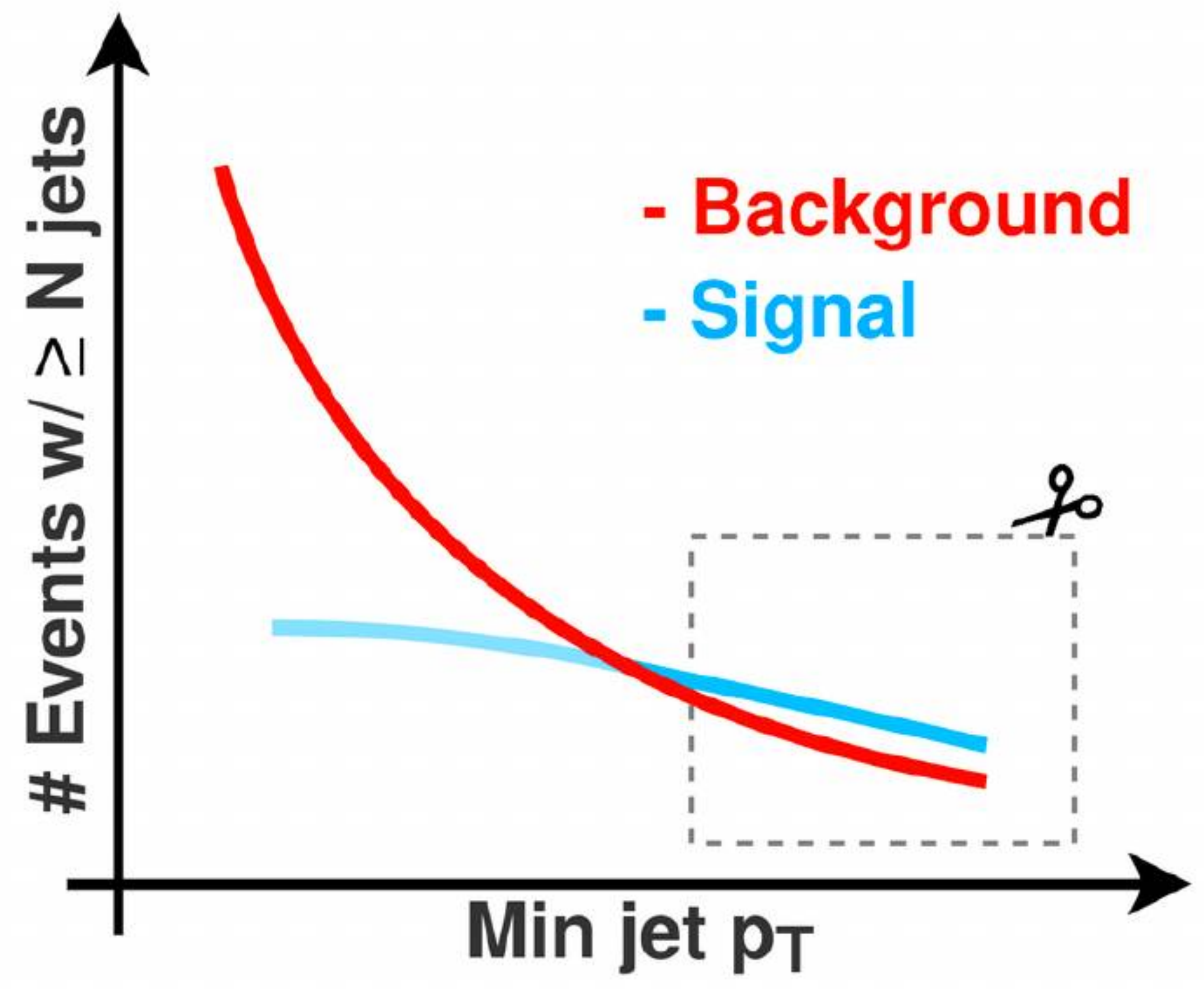
- Multi-jet (QCD) background has **vastly larger x-section** compared to signal
- Simulation of QCD is imperfect
- Complex combinatorics in event reconstruction

Analysis Strategy

Drawings courtesy of
Stefano Franchellucci

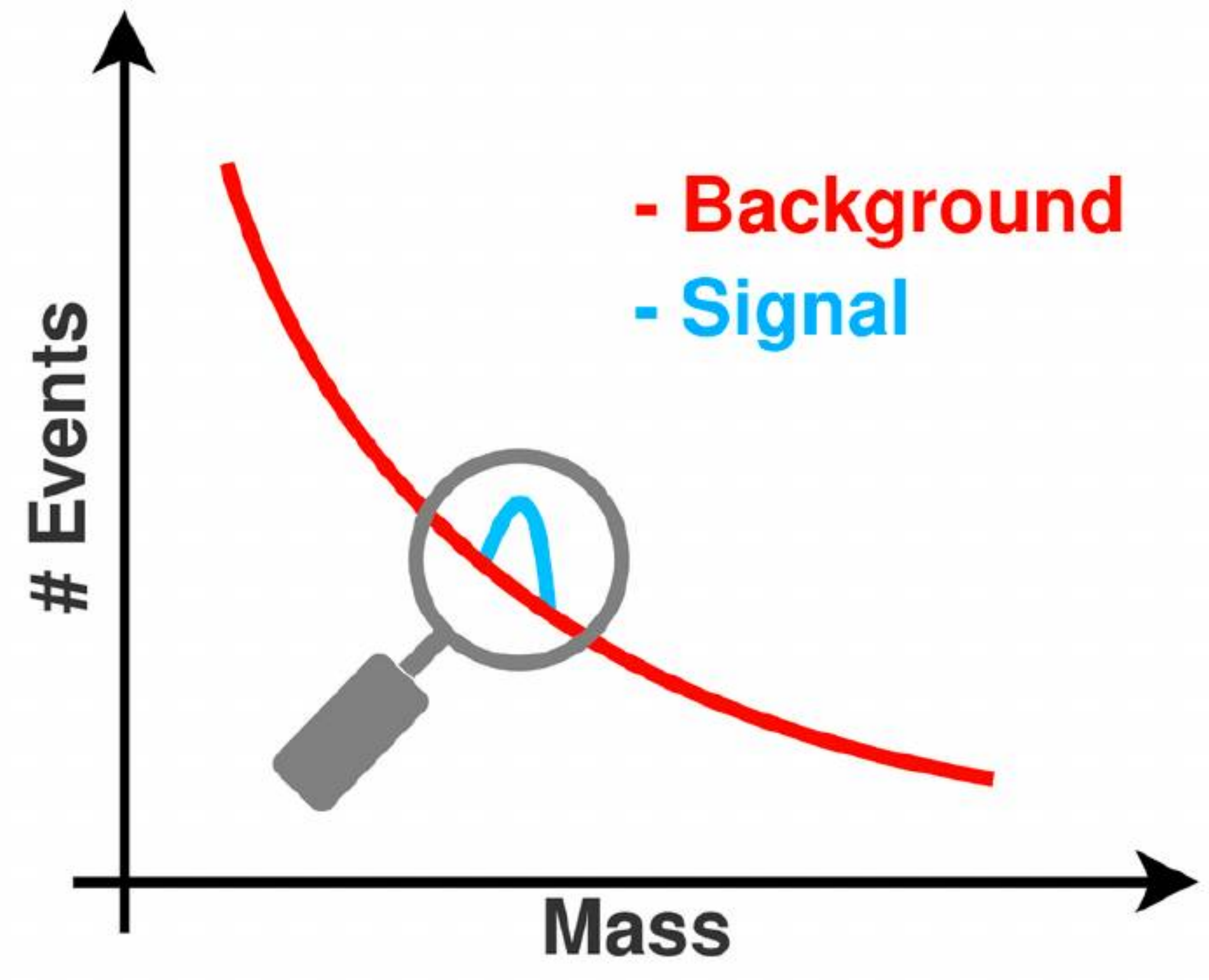
◉ Jet Counting (Cut & Count)

- Utilizes jet kinematics, event shapes and b-tagging for analysis

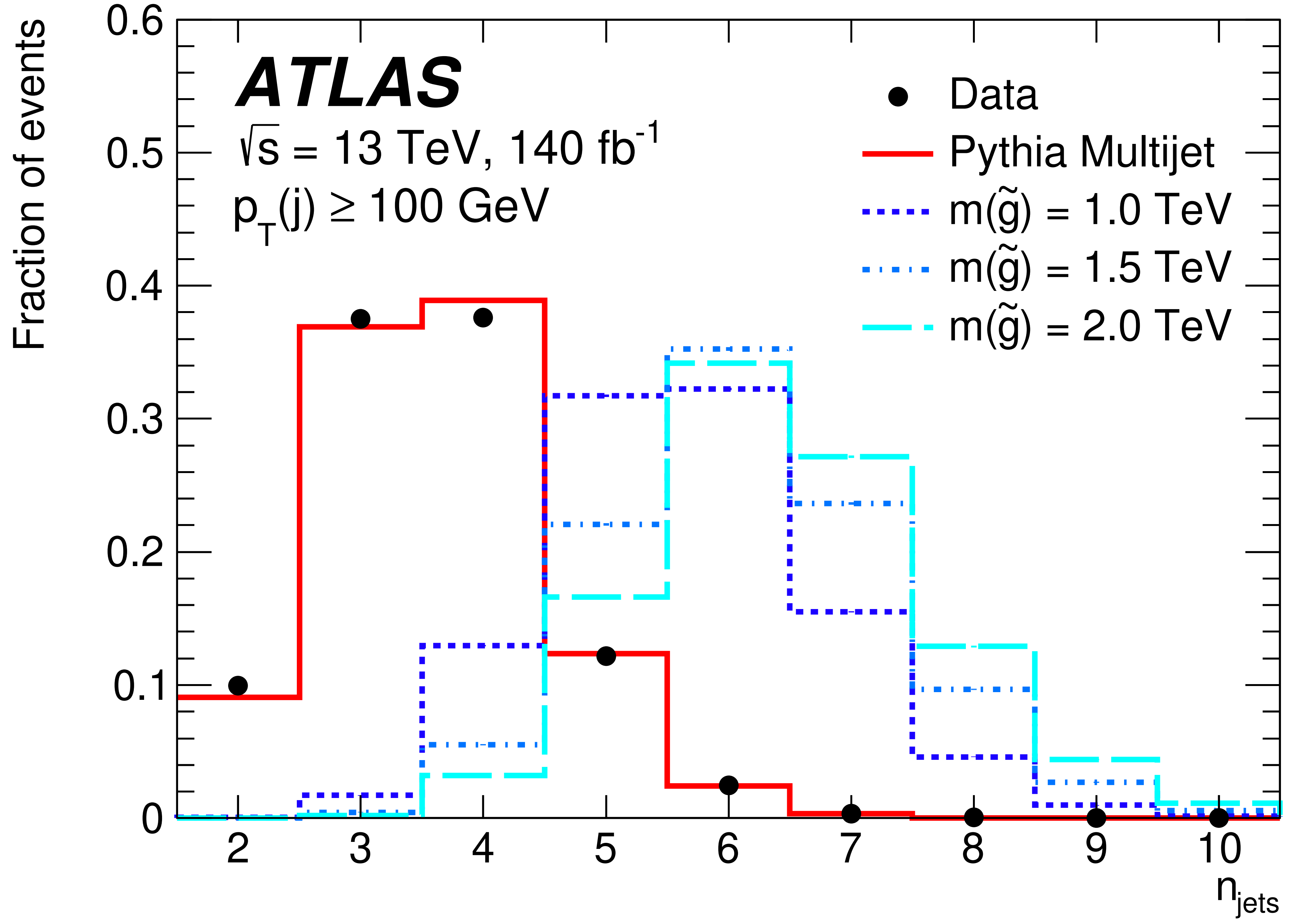


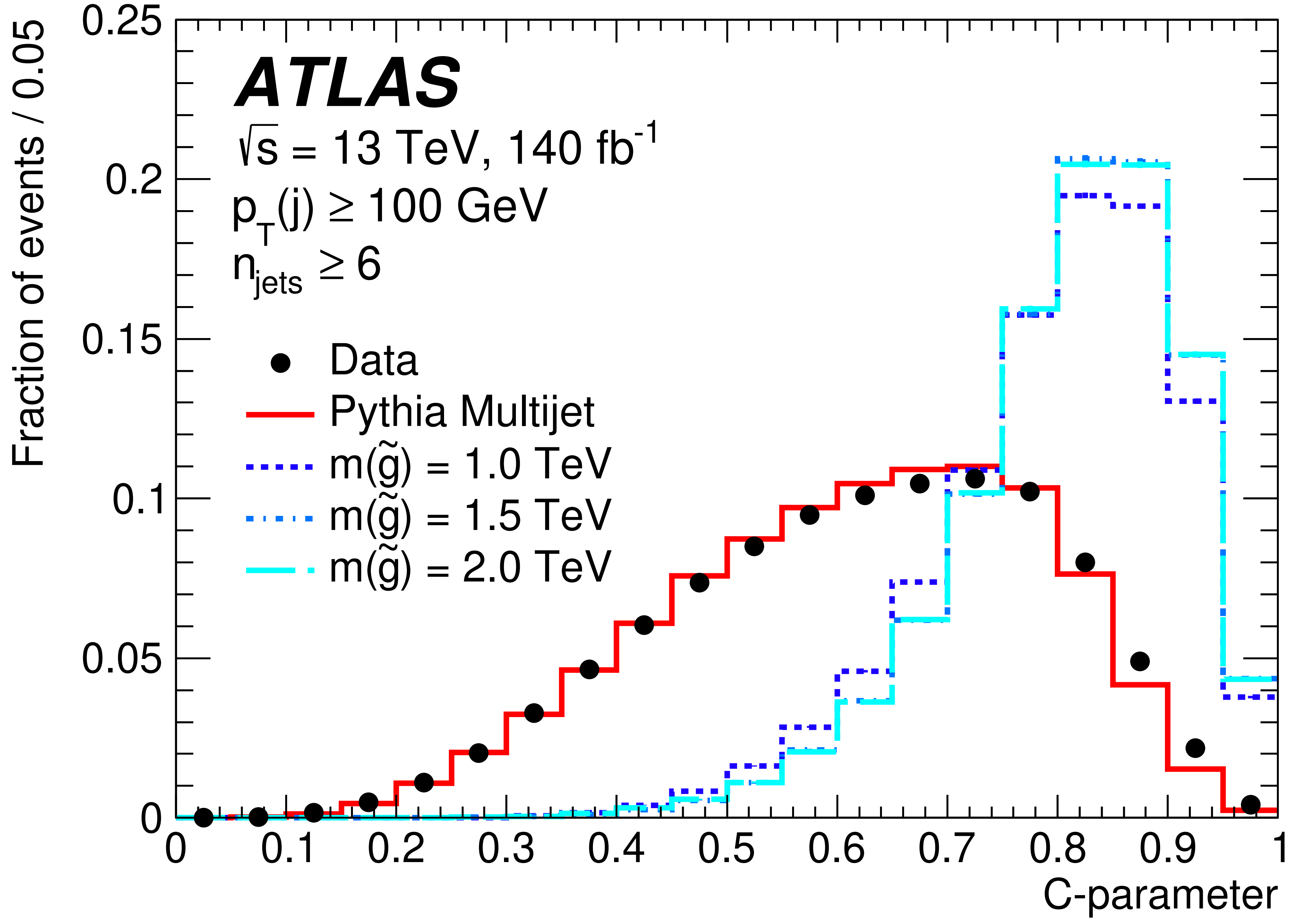
◉ Mass Resonance (ML + bump hunting)

- Employs machine learning to reconstruct gluino 4-momenta



Common Selections





- **Increased number of energetic jets**
  - Strong p_T selections at high multiplicity
- **Broader energy spread in final state**
  - Utilization of event shape variables

Jet Counting Method - Search Regions

- Investigate for an excess of events feauturing high-energy jets
- Specific signal regions teilored to different mass points and b-tag multiplicities
- Sensitive to both direct gluino decay and cascade schenarios

	n_{jets}	$p_{\text{T}}(j)$ [GeV]	C	$n_{b-\text{jets}}$
SR1	≥ 7	≥ 180	≥ 0.90	–
SR2	≥ 7	≥ 220	≥ 0.90	–
SR3	≥ 7	≥ 240	≥ 0.90	–
SR4	≥ 8	≥ 180	≥ 0.85	–
SR5	≥ 8	≥ 210	≥ 0.85	–
SR1bj	≥ 7	≥ 180	≥ 0.85	≥ 2
SR2bj	≥ 8	≥ 180	≥ 0.85	≥ 2

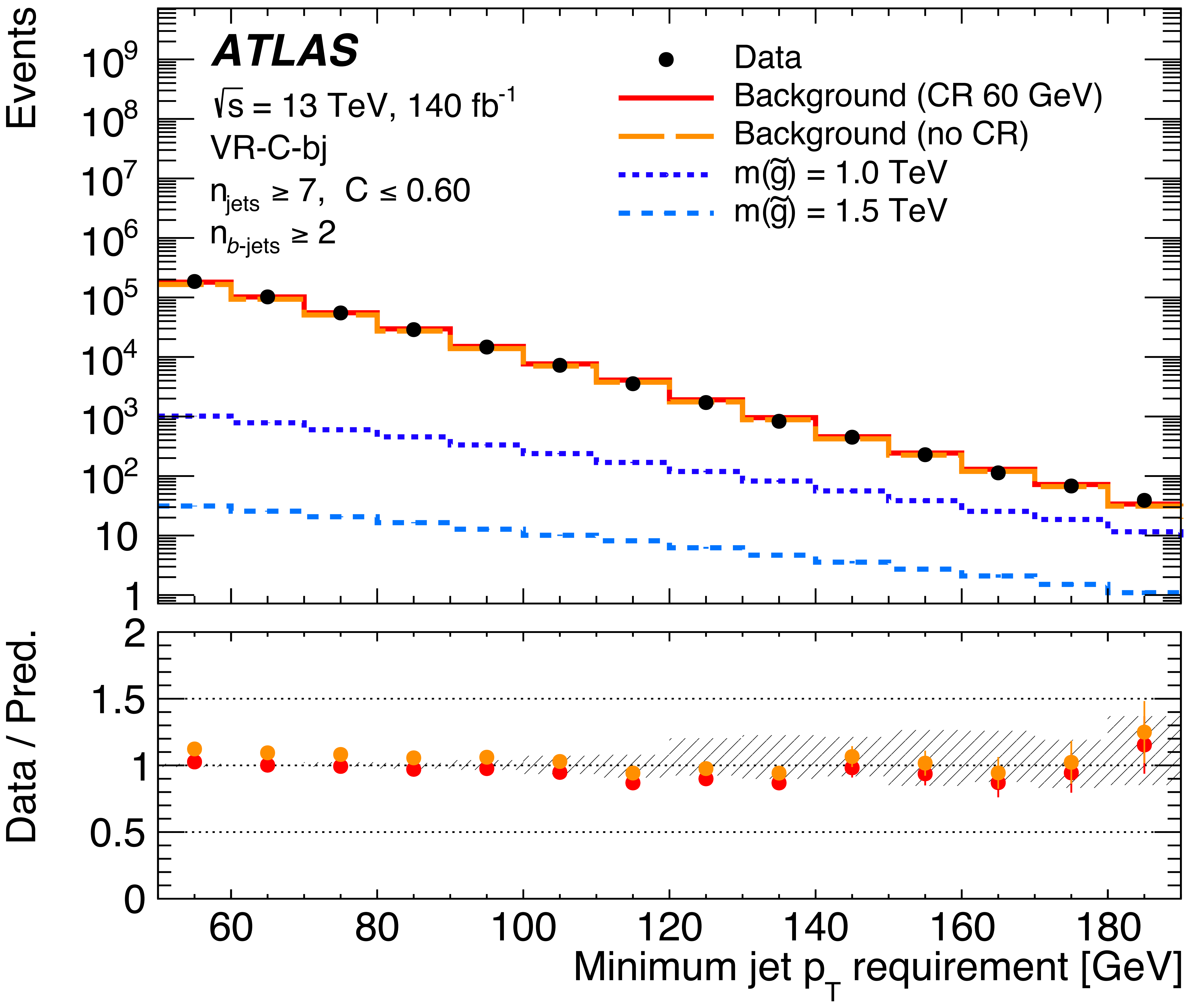
Jet Counting Method - Background Estimation

- **Method similar to previous analyses**
  - **$\sqrt{s}$ = 7 TeV, $\sqrt{s}$ = 8 TeV**

- **Use MC to estimate scaling factors across jet multiplicities, with data for normalization**

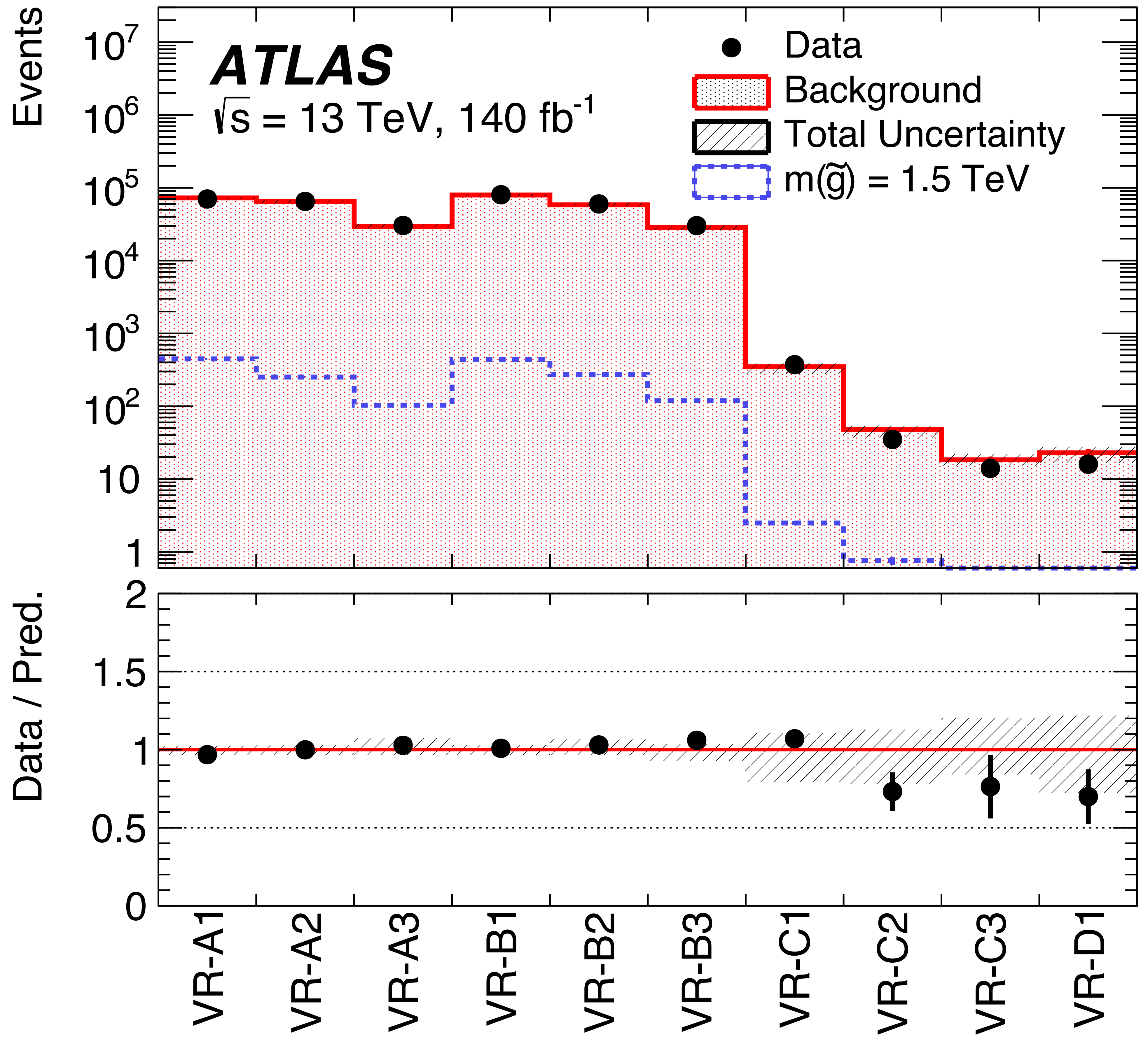
$$N^{\text{extr.}}_{\geq 7\text{jets}} = \sum_{i=7}^{9} w_{5i} \cdot N^{\text{Data}}_{5-\text{jets}} \cdot \frac{N^{\text{MC}}_{i-\text{jets}}}{N^{\text{MC}}_{5-\text{jets}}}$$

$$w_{5i} = \frac{s_i}{s_5}; \qquad s_i = \left. \frac{N^{\text{Data}}_{i-\text{jets}}}{N^{\text{MC}}_{i-\text{jets}}} \right|_{p_T \geq 60\text{ GeV}}$$



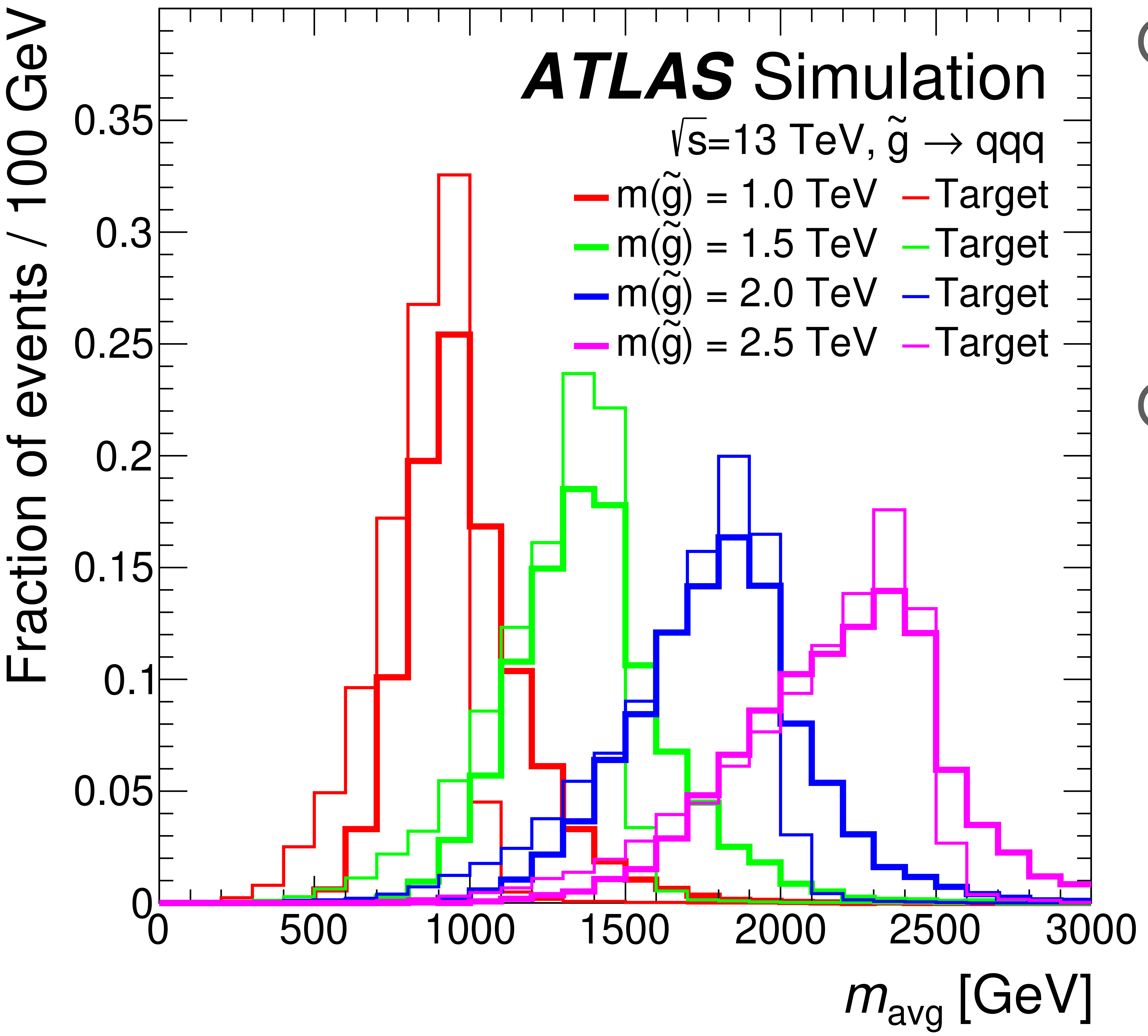
Jet Counting Method - Background Validation

- Validation of the method in the phase space close to the SRs
- **Consisent across all regions within 1 sigma**



	n_{jets}	$p_T(j)$ [GeV]	C	Background Expectation	Data
VR-A1		≥ 180	≥ 0.80	73000^{+1800}_{-2400}	70184
VR-A2	5	≥ 160	≥ 0.85	65000^{+1800}_{-2200}	64985
VR-A3		≥ 150	≥ 0.90	30000^{+2100}_{-1000}	30360
VR-B1		≥ 120	≥ 0.80	80000^{+2100}_{-2800}	80271
VR-B2	6	≥ 110	≥ 0.85	58000^{+3900}_{-1800}	59997
VR-B3		≥ 100	≥ 0.90	28000^{+1000}_{-2000}	30212
VR-C1		≥ 180		350^{+37}_{-72}	372
VR-C2	≥ 7	≥ 220	≤ 0.60	47^{+6}_{-10}	35
VR-C3		≥ 240		18^{+4}_{-3}	14
VR-D1	≥ 8	≥ 180	≤ 0.60	23^{+5}_{-6}	16

Mass Resonance - Event Reconstruction



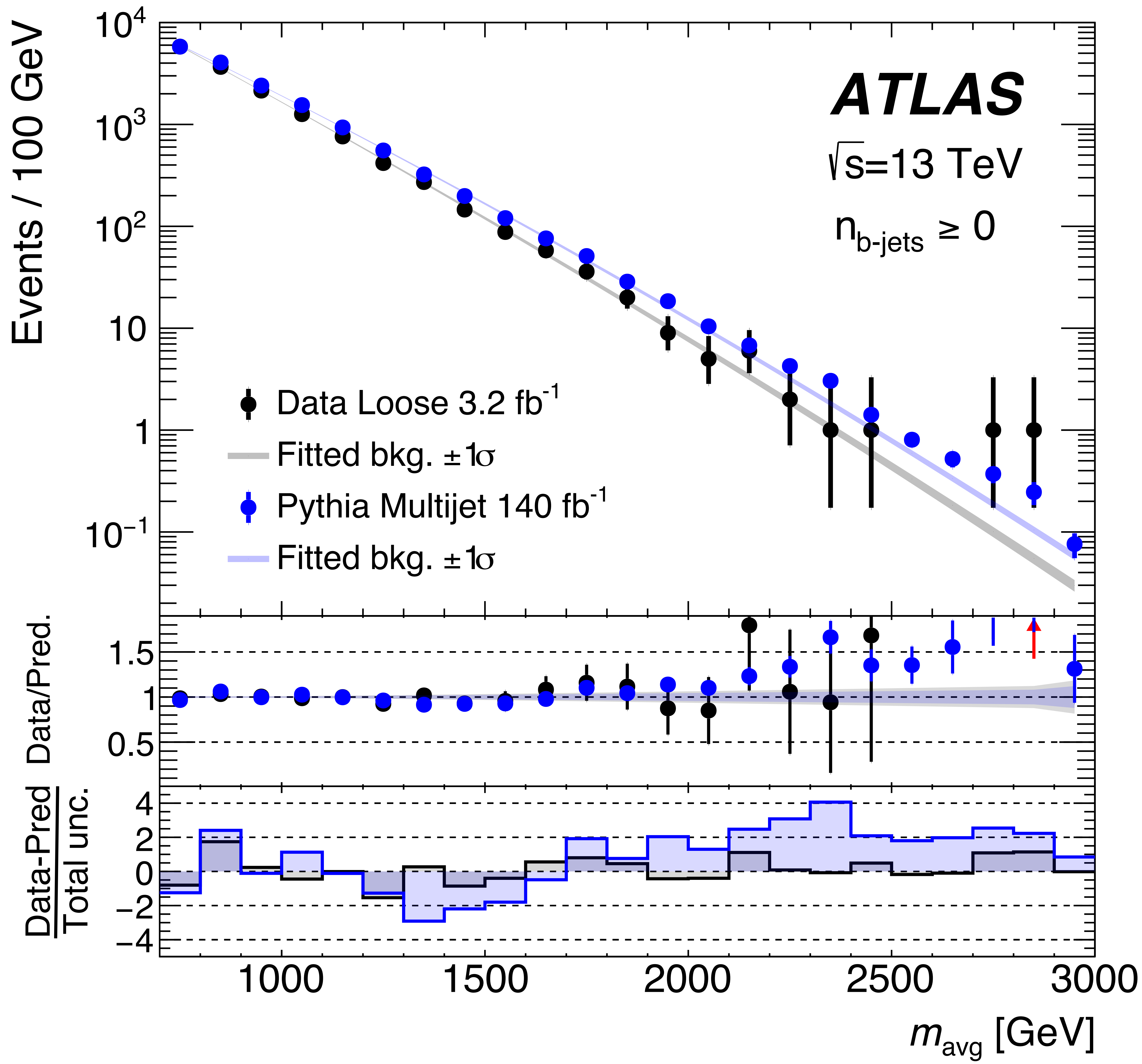
- **Aim: Utilize gluinos 4-momenta to dermine their mass**
- **ML used for event reconstruction:**
  - Mitigates combinatorial background
  - Features a novel transformer-inspired architecture
  - A single model trained across all signal points simultaneously

Mass Resonance - Background Estimation

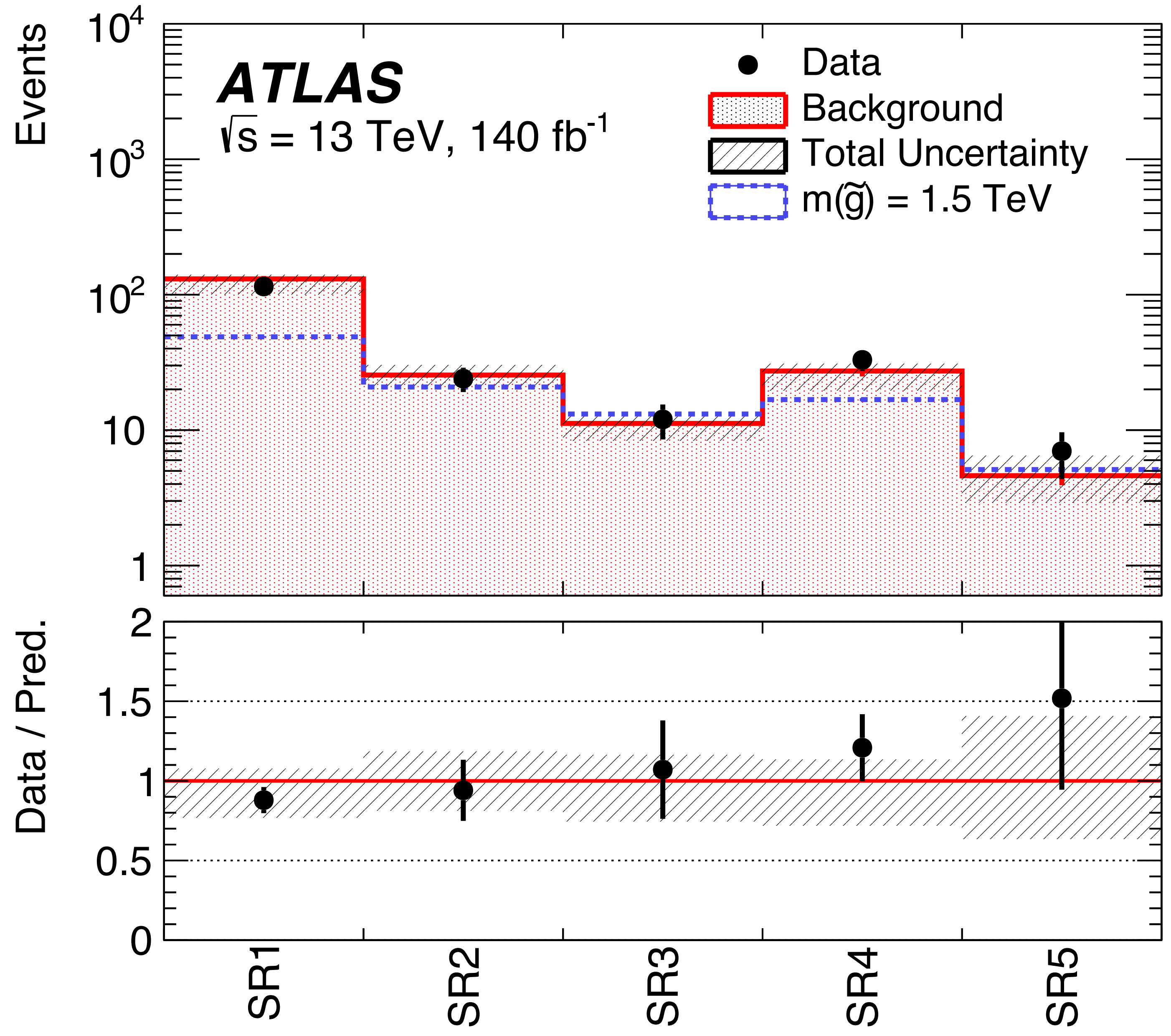
- Conduct a traditional **bump-hunt** analysis on the **average-mass spectrum**
- Fit with a **functional form** (3+1 parameters)

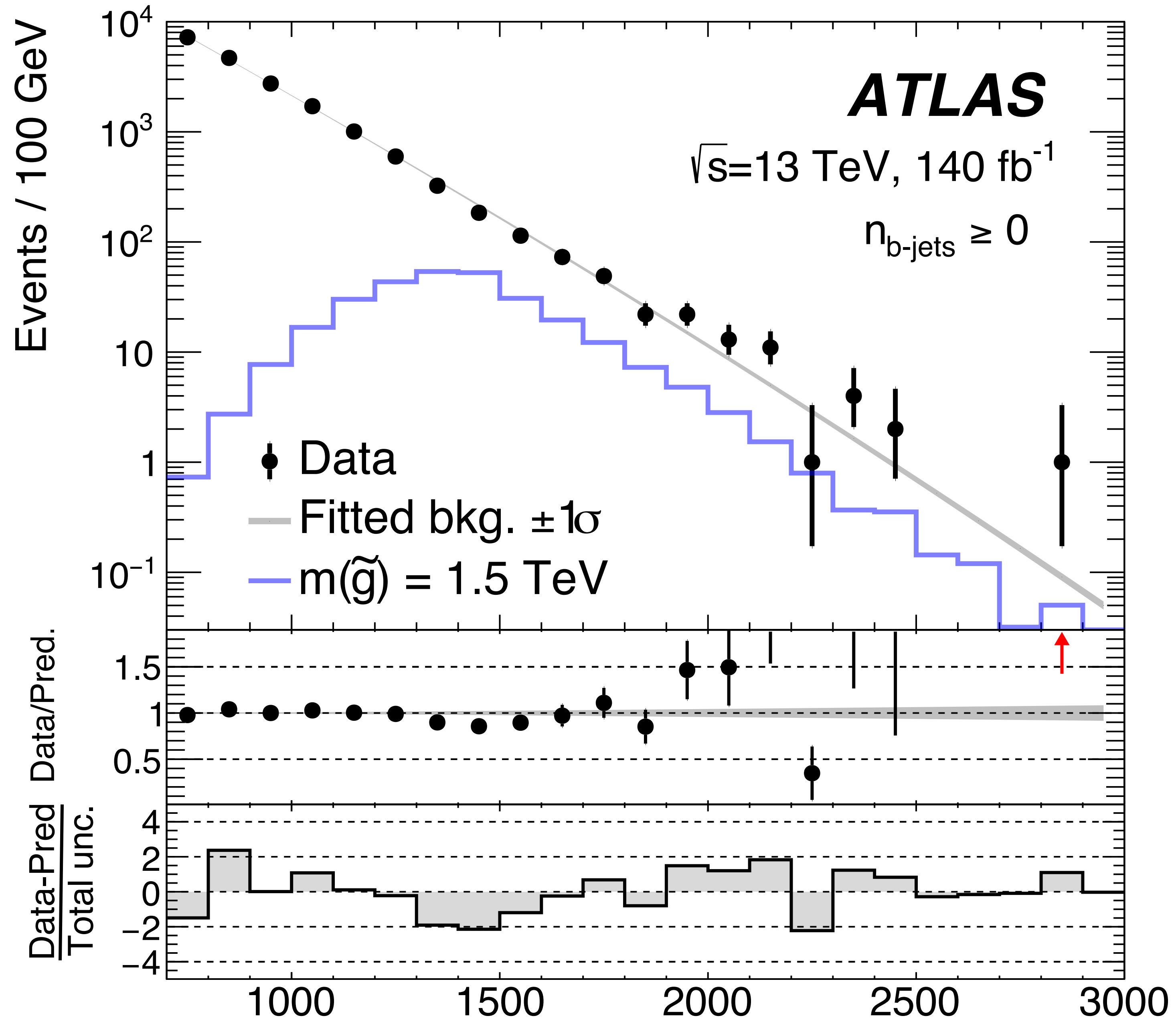
$$f(x) = p_1 (1-x)^{p_2} x^{p_3 + p_4 \ln x}$$

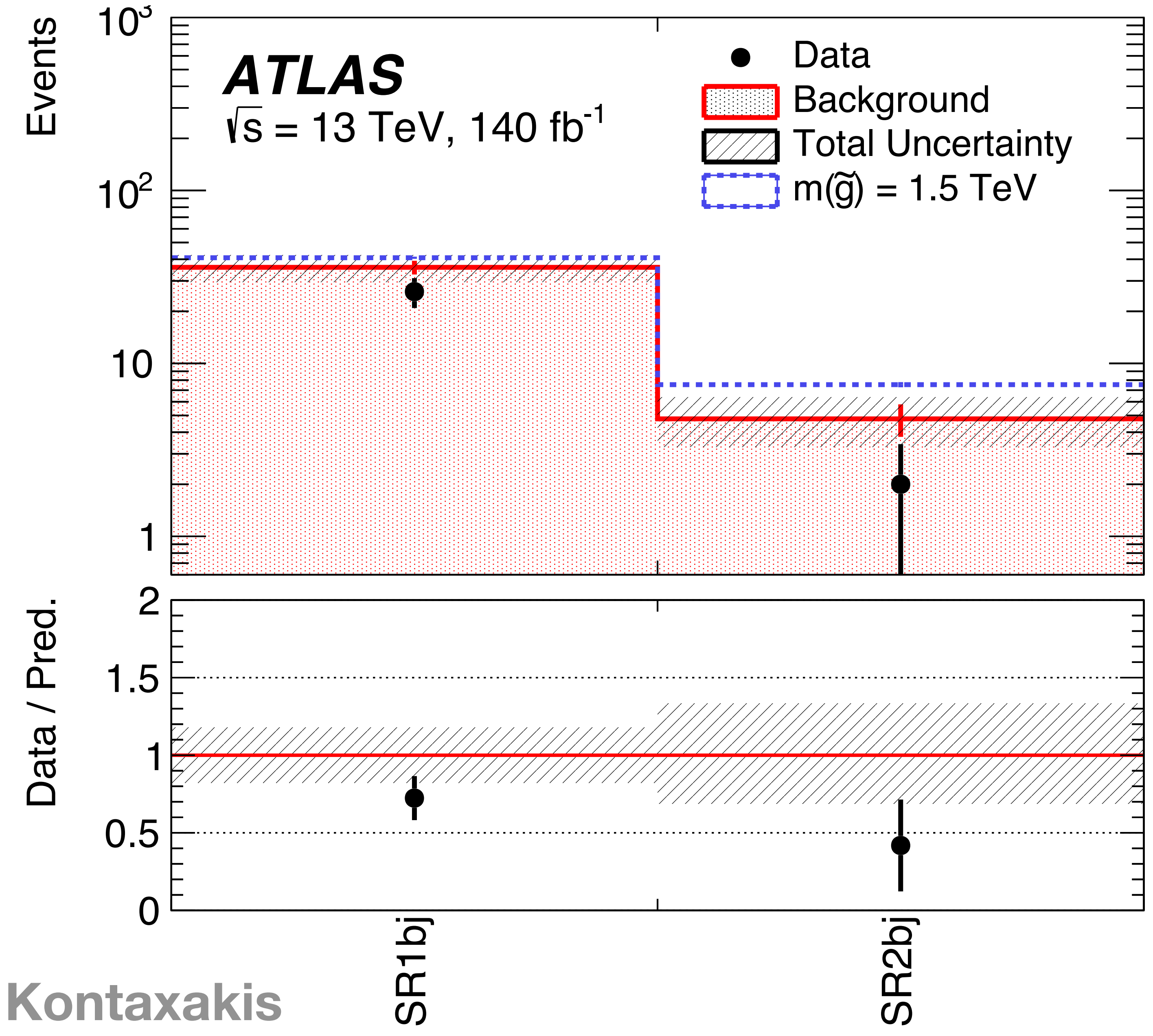
- Introduced "spurious signal" systematic (p_4)
- Method validated using **both** MC multi-jet and a "loose" data sample

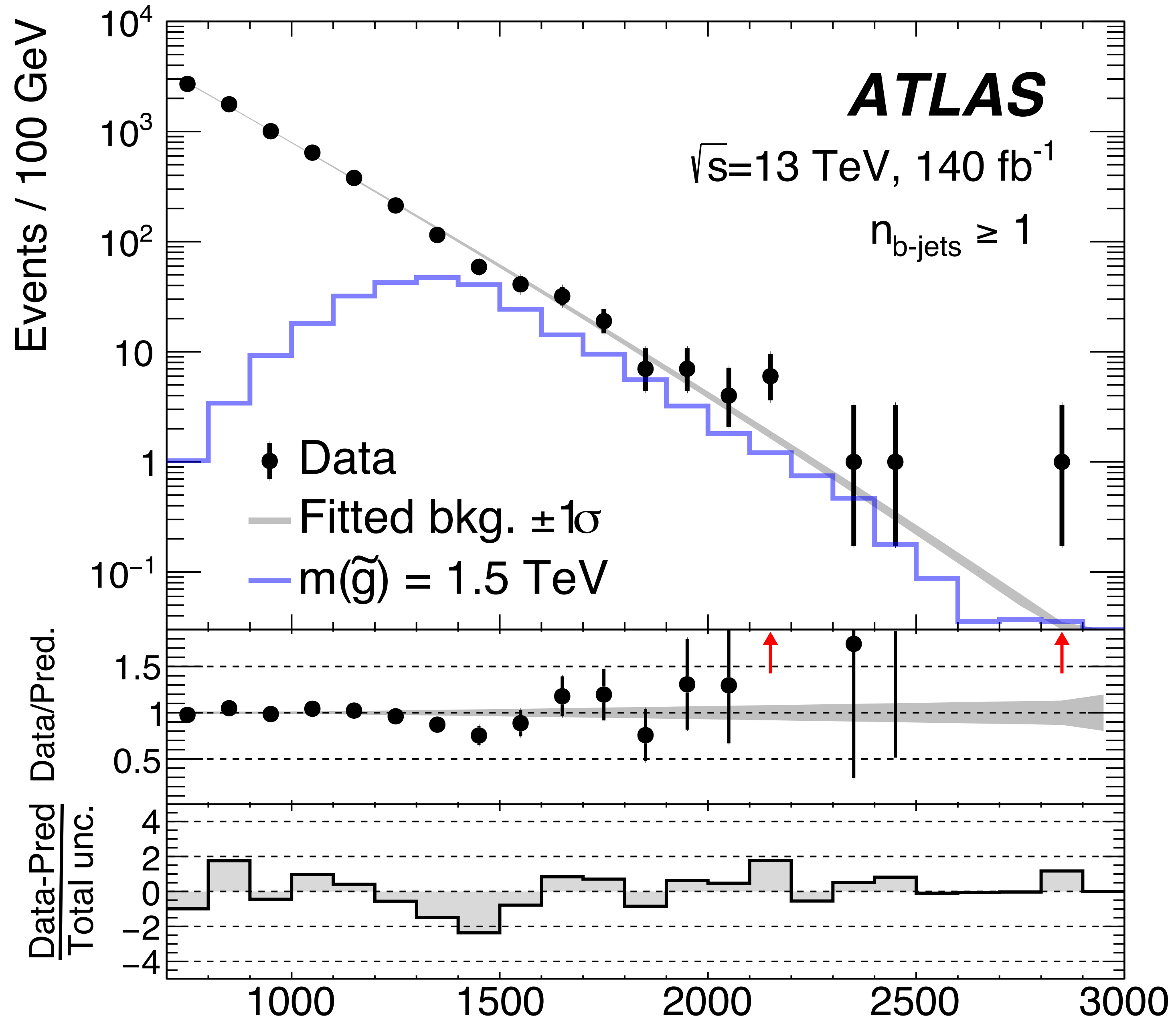


Unblinded Results



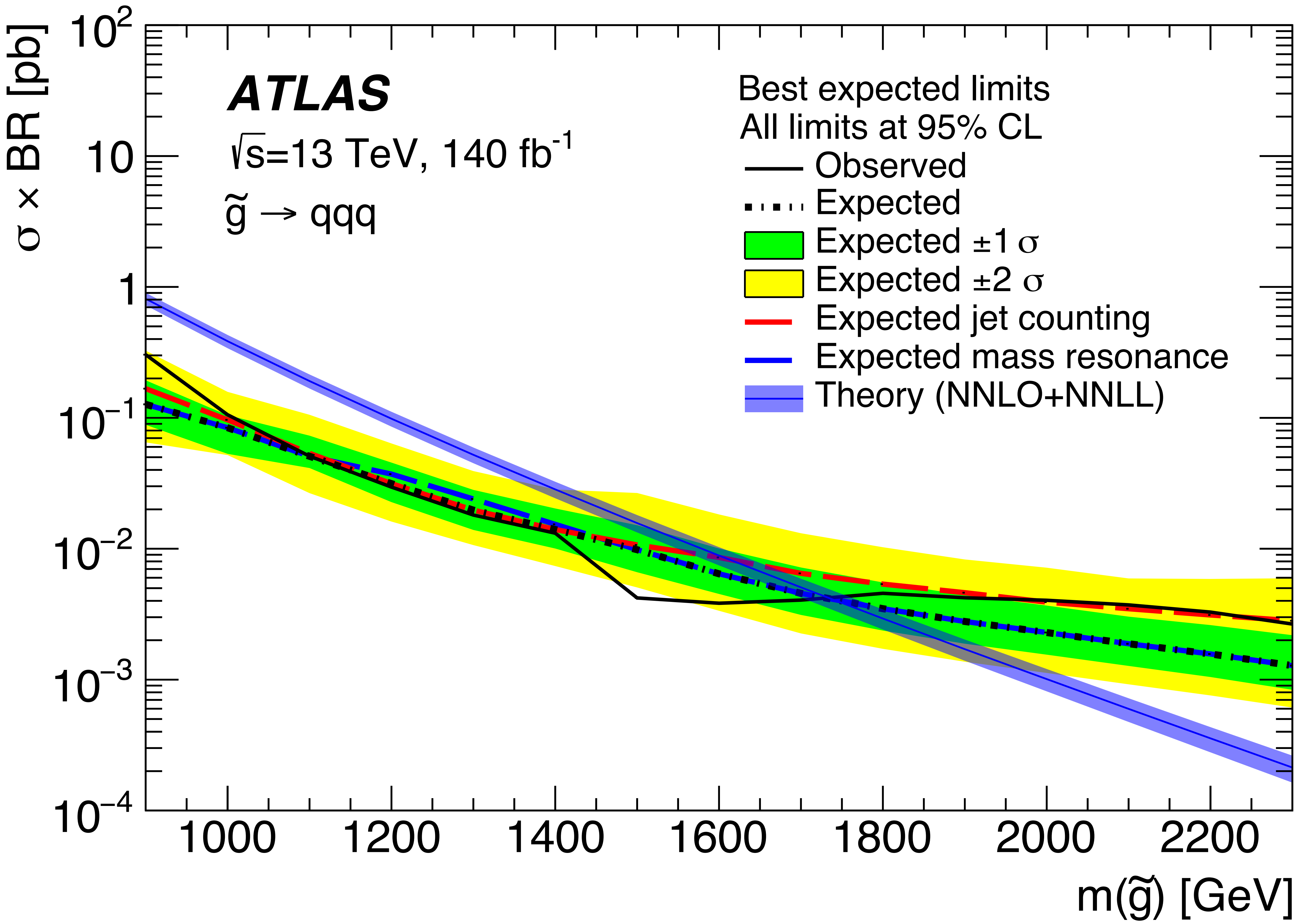


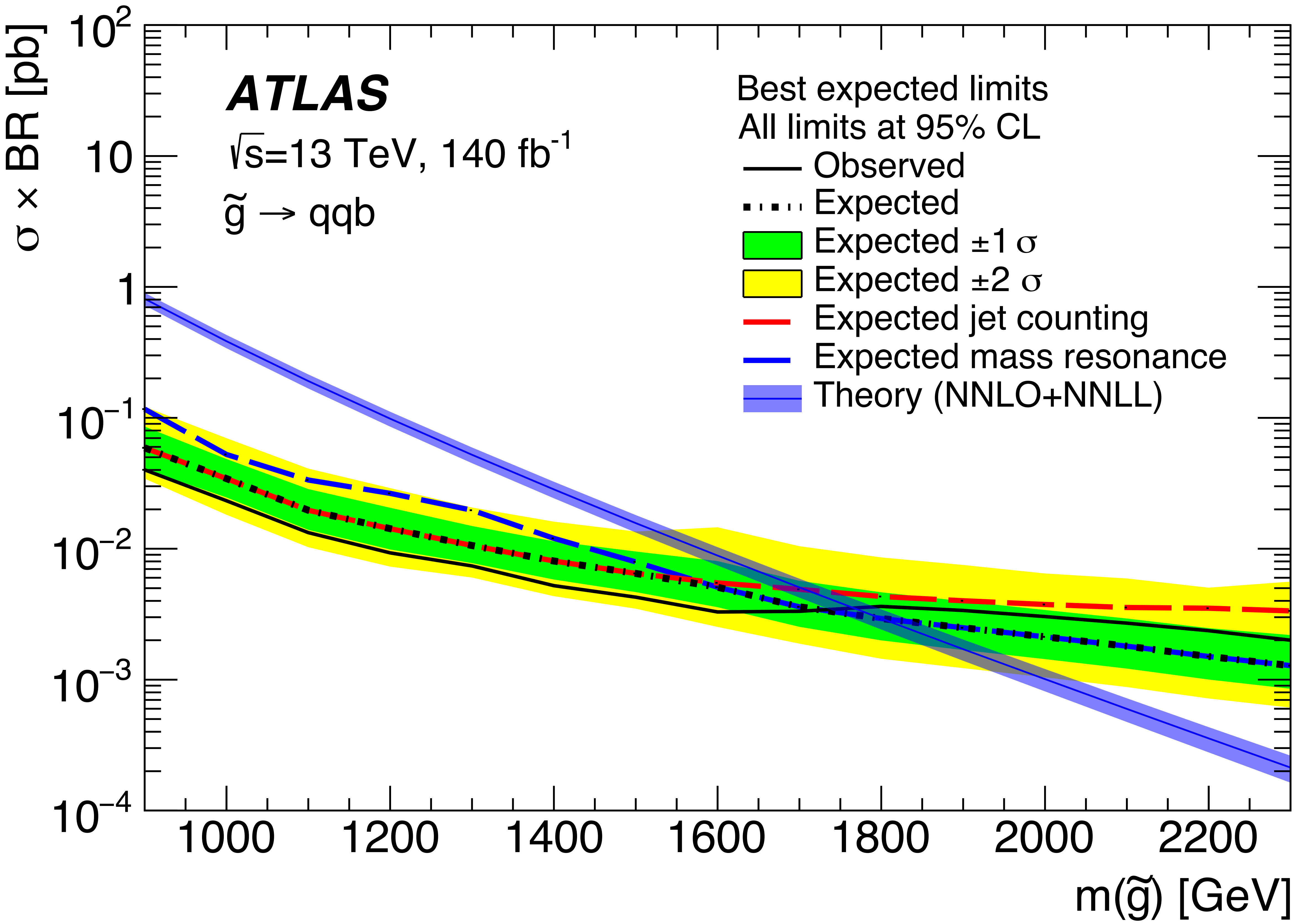




- **No excess seen in any of the SRs with both methods…**
- **…establishing limits at a 95% confidence level following the CLs method**

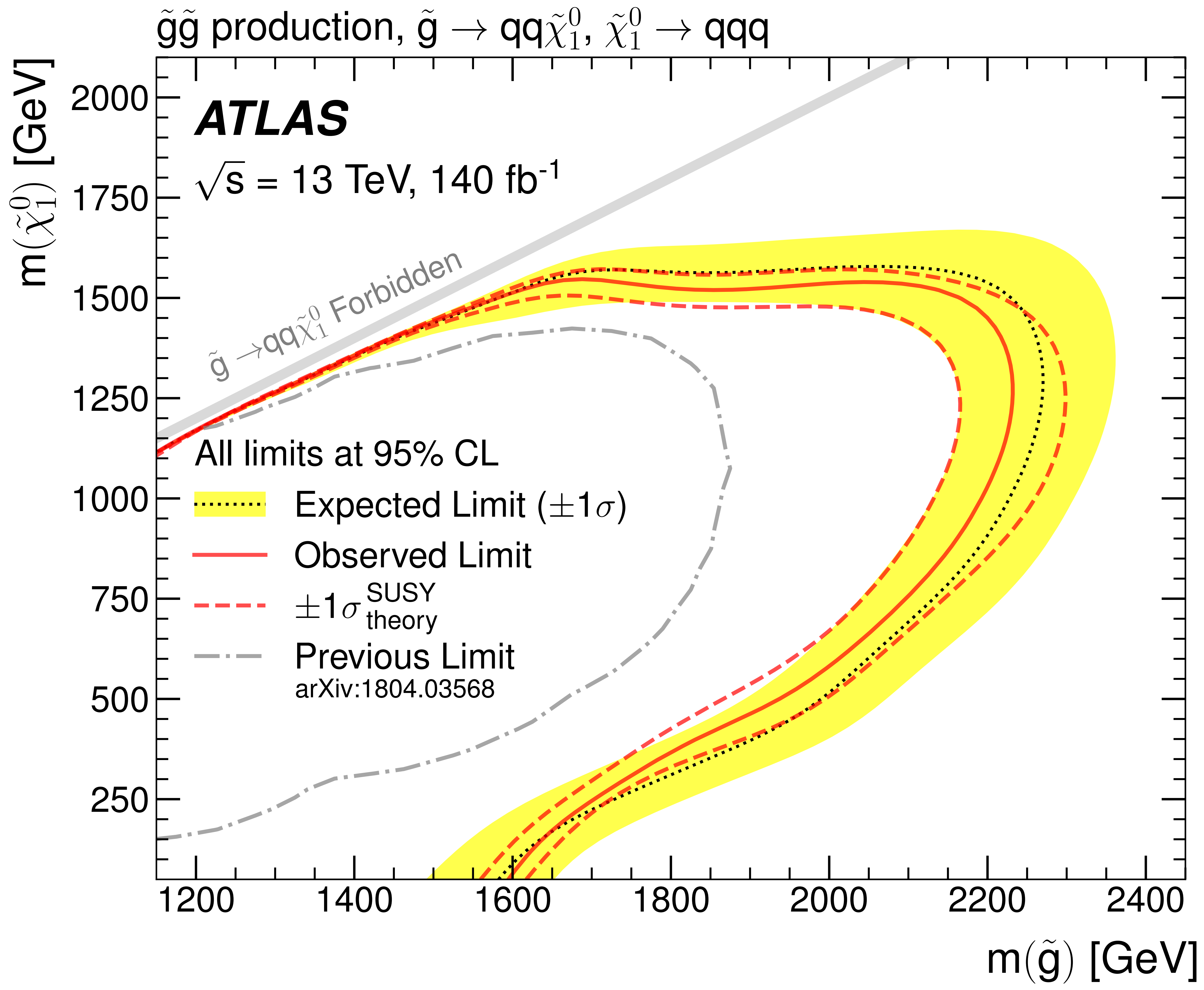
Limits (direct decay)

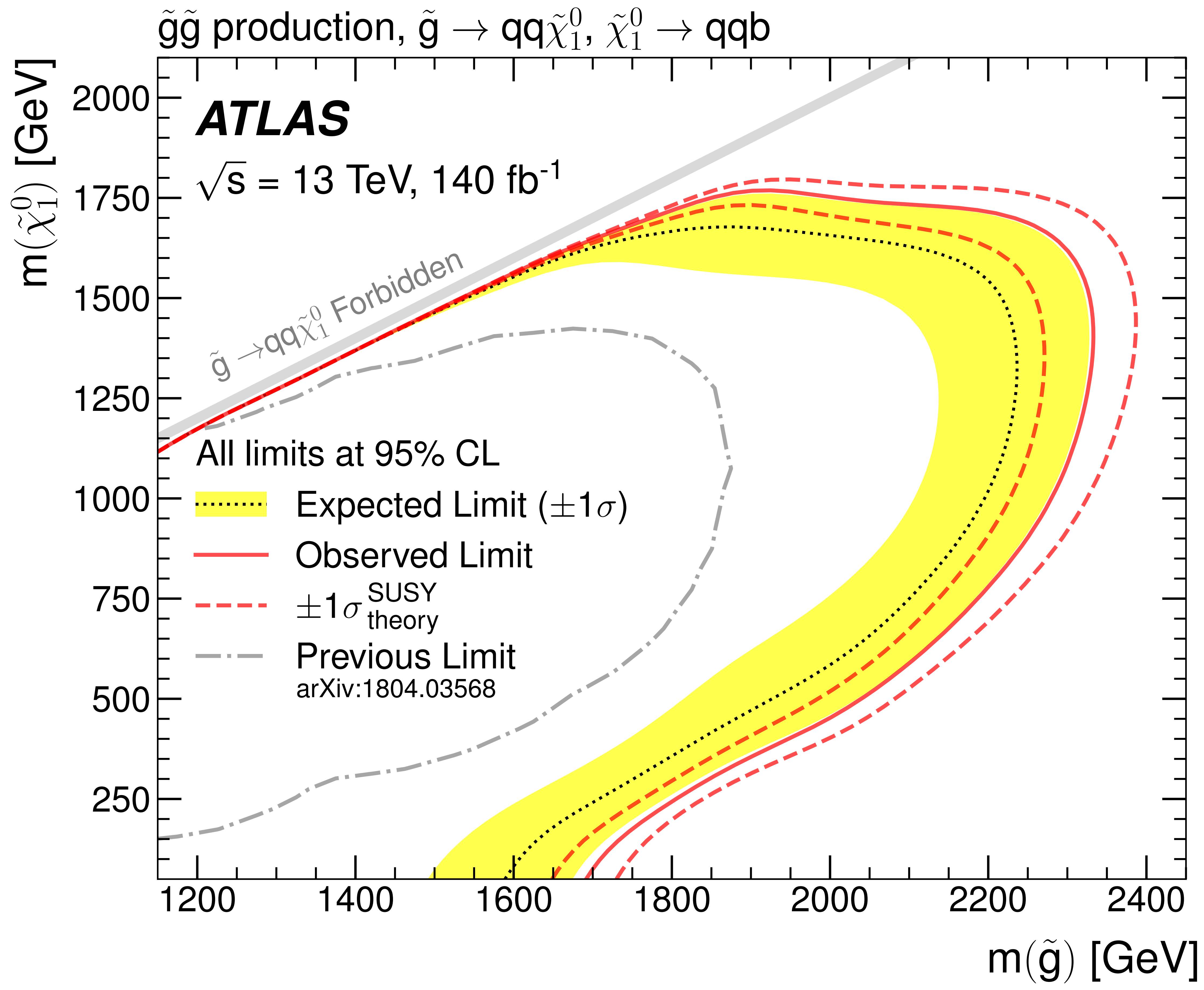




- **Cut & Count method reached sensitivity down to x-sections of ~0.01pb**
- **The ML method improved the limit by a factor of 2**

Limits (cascade decay)





- **Cut & Count method only**
- **Limits are <u>hugely extended</u> compared to the previous analysis**

Summary

- **A search for RPV SUSY was conducted in a multi-jet final state using two complementary approaches:**
  - Optimized Cut & Count based on jet kinematics and event shapes
  - A novel ML tool for gluino reconstruction

- **No excesses were observed compared to the expected background:**
  - New limits were set, improving previous results by approximately an order of magnitude in x-section

- **Work in progress and outlook:**
  - Reinterpretation using different coupling values trying to cover large phase space of SUSY (even for RPC)
  - Investigating the same final states with TLA

Backup Slides

Systematic Uncertainties

◉ Modeling Uncertainties

- Signal theory uncertainties
- Multi-jet and theory uncertainties from MC being used in background estimate for the jet counting method

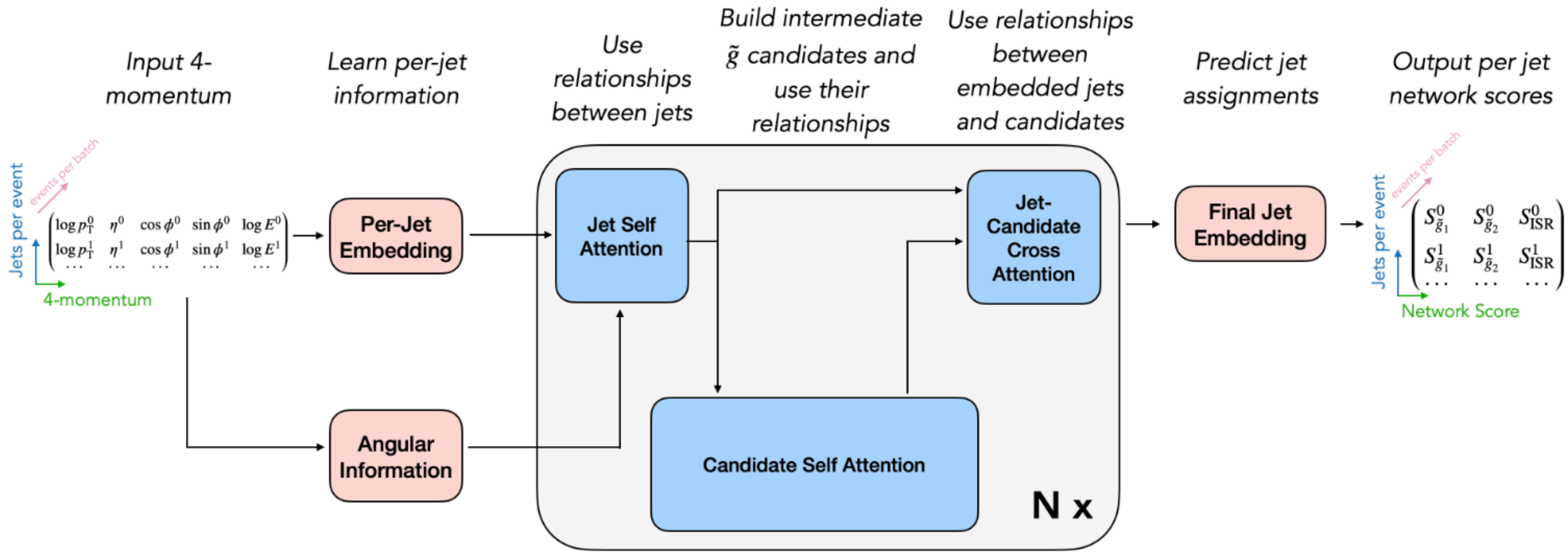
◉ Experimental Uncertainties

- Global Reduction JES with 23 nuisance parameters (NPs)
- Simple JER with 8 NPs
- b-tagging and jet-vertex tagging scale factor variations

◉ Methodology

- Closure uncertainties of high C validation regions of jet counting method
- Spurious signal systematic from choice of background function for the mass resonance method

Machine Learning Architecture



More details here: link