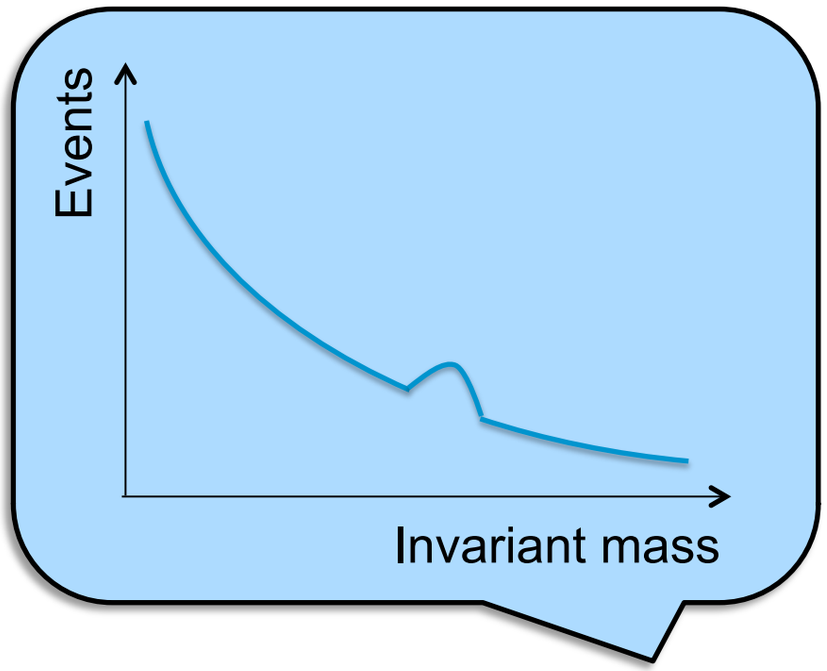
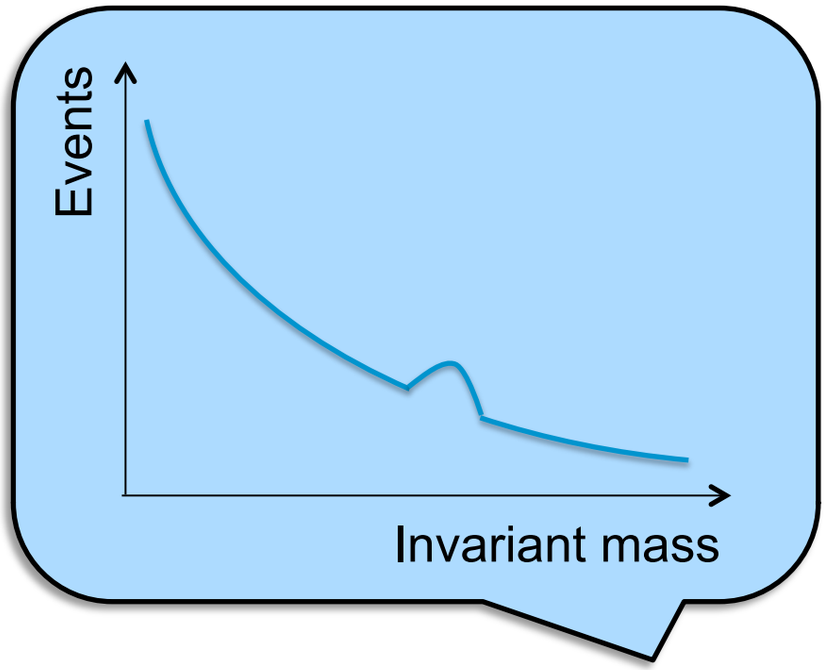
SEARCHES FOR RESONANCES IN HADRONIC FINAL STATES WITH THE ATLAS DETECTOR

Trine Poulsen
on behalf of the ATLAS collaboration

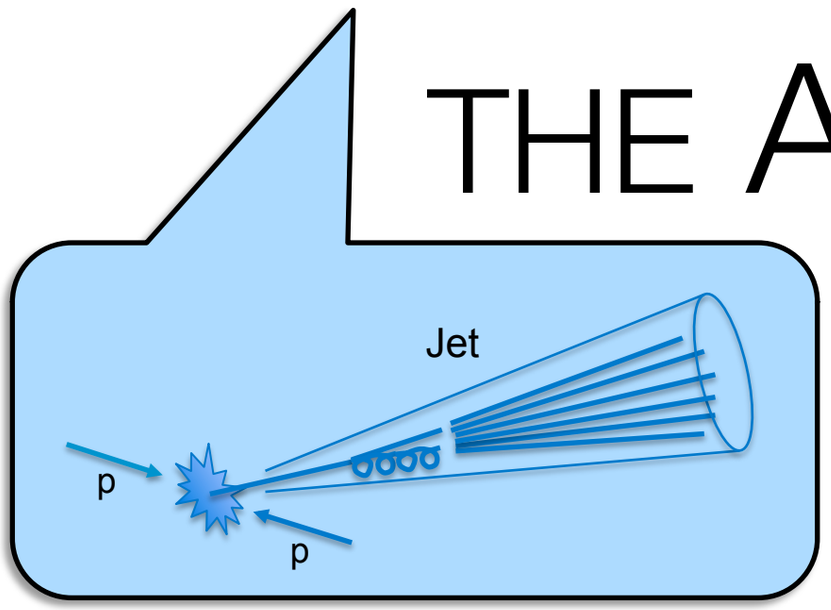
ICNFP 2019

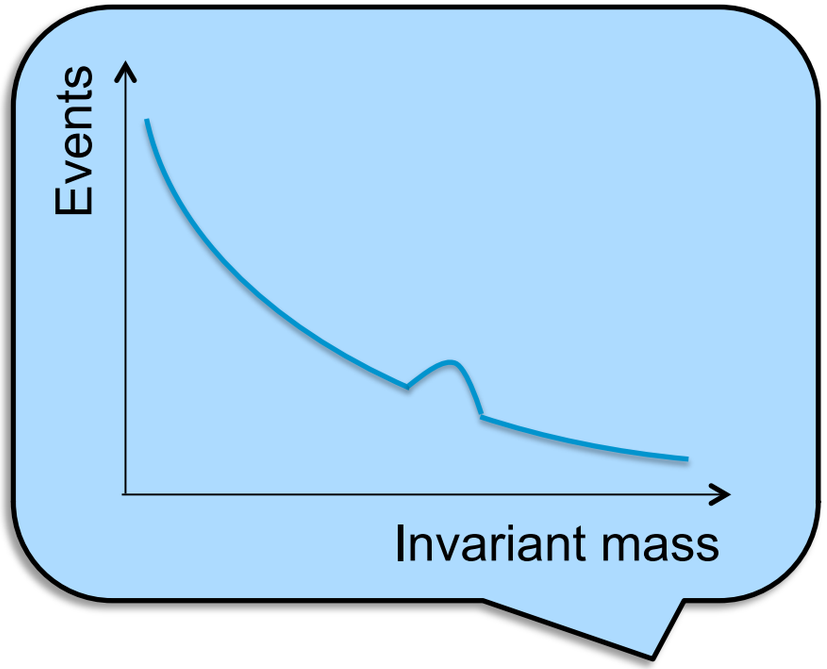


SEARCHES FOR RESONANCES IN HADRONIC FINAL STATES WITH THE ATLAS DETECTOR

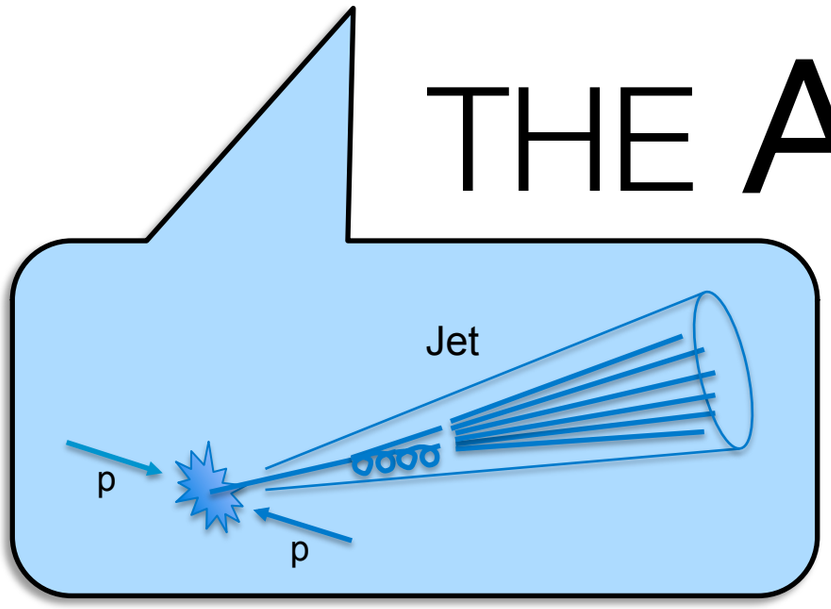


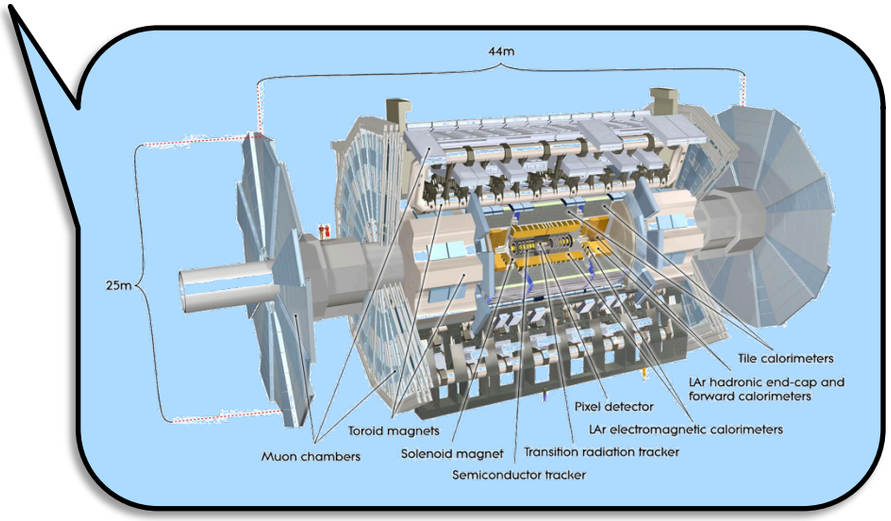
SEARCHES FOR **RESONANCES** IN **HADRONIC** FINAL STATES WITH THE ATLAS DETECTOR





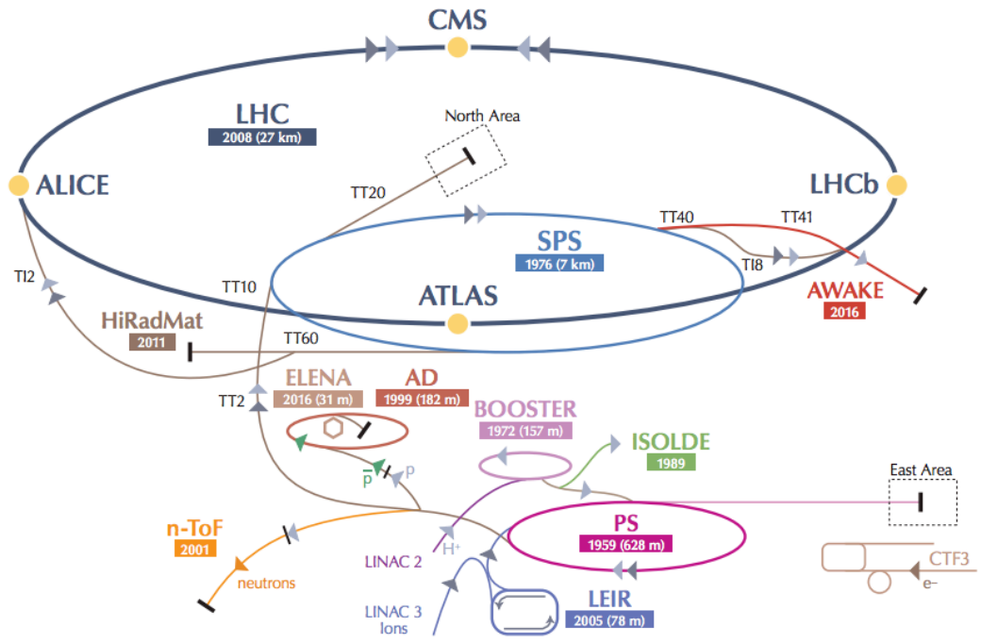
SEARCHES FOR **RESONANCES** IN **HADRONIC** FINAL STATES WITH THE **ATLAS** DETECTOR

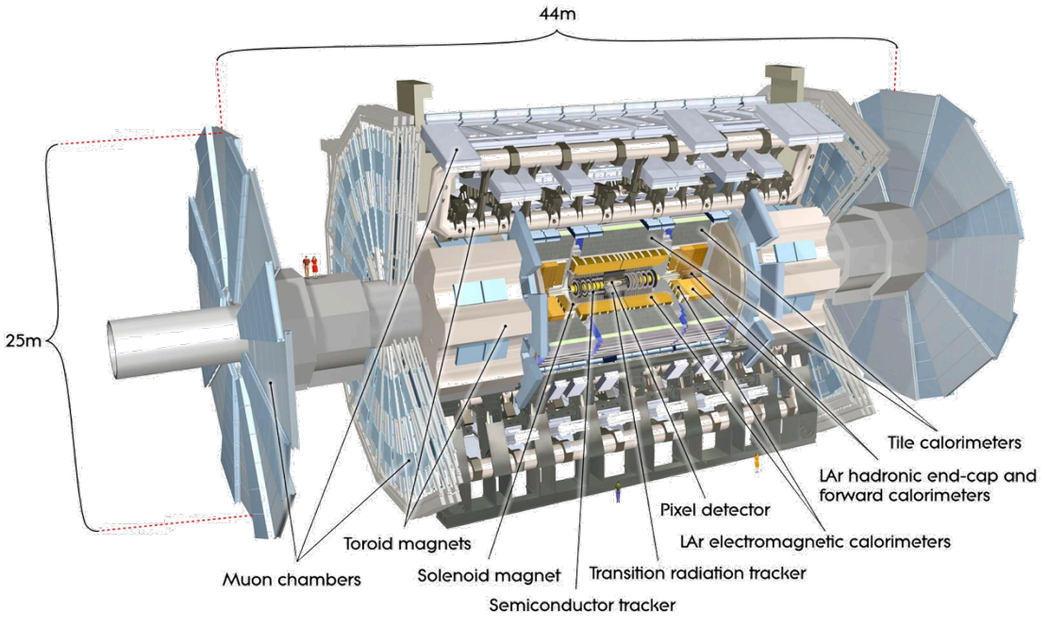




LARGE HADRON COLLIDER & ATLAS DETECTOR

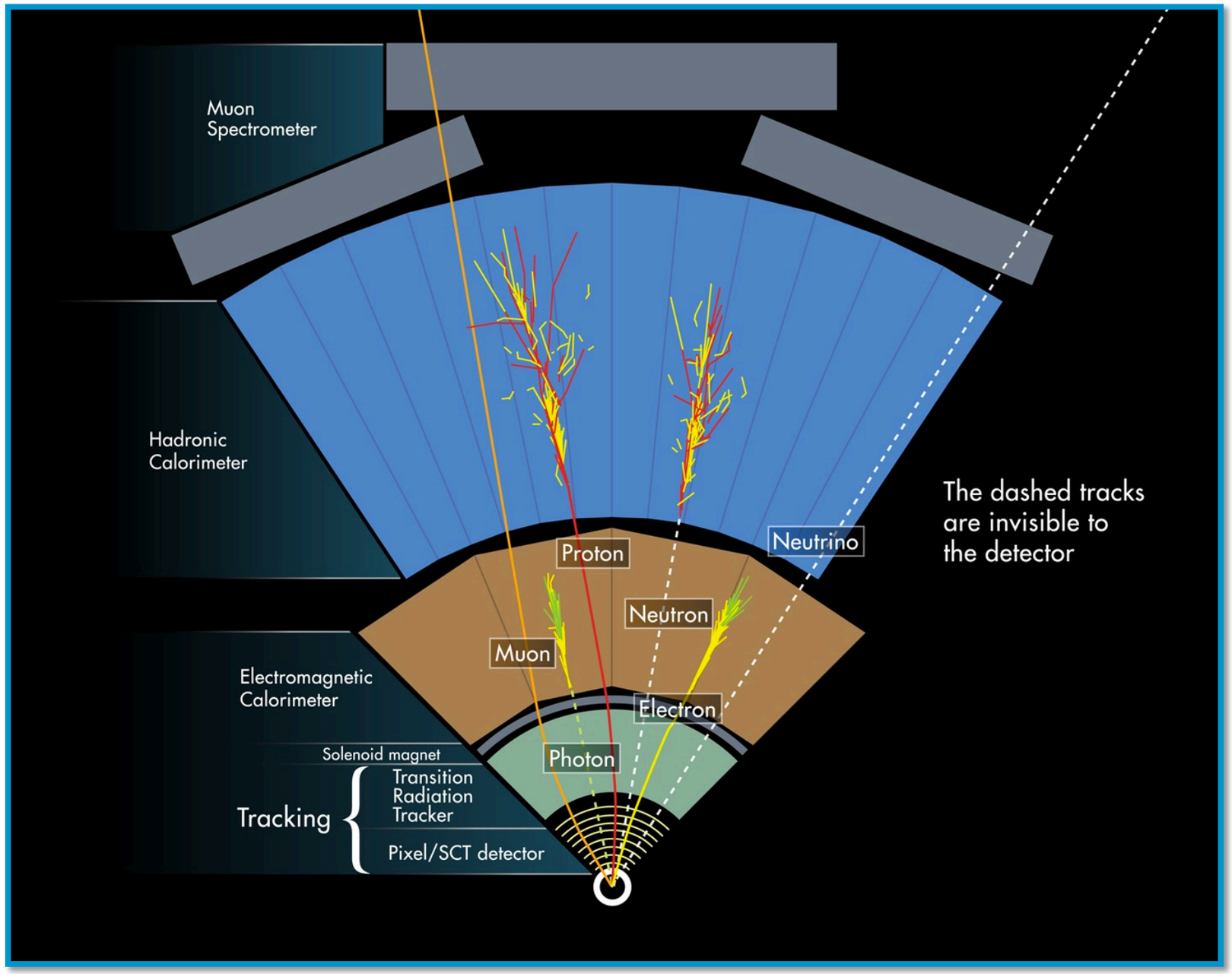
- Large Hadron Collider (LHC)
  - 27 km in circumference
  - Accelerates protons (and heavy ions)
  - 4 collision points
- ATLAS detector
  - General-purpose particle physics experiment
  - Discovery of Higgs boson in 2012 (with CMS)





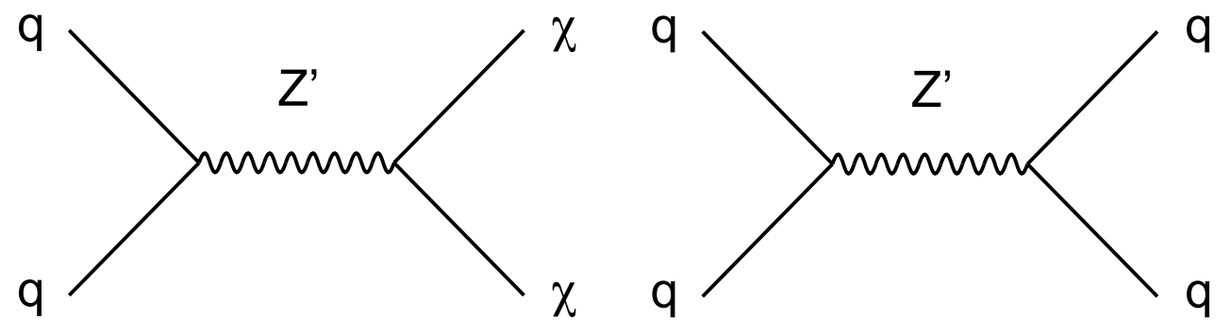
MEASURING JETS WITH THE ATLAS DETECTOR

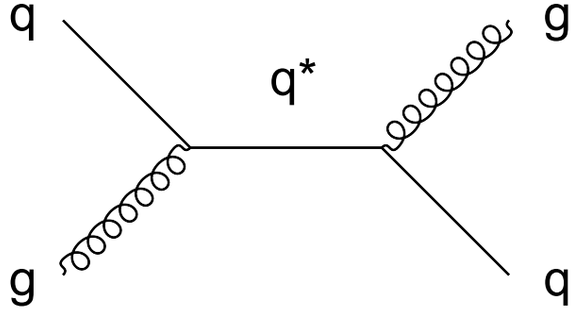
- Track jets from inner detector
- Topological cluster jets from calorimeters
  - Using anti-kt algorithm
  - R = 0.4 for small-R jets
  - R = 1 for large-R jets
- Apply jet calibrations
  - Correct jet energies and directions

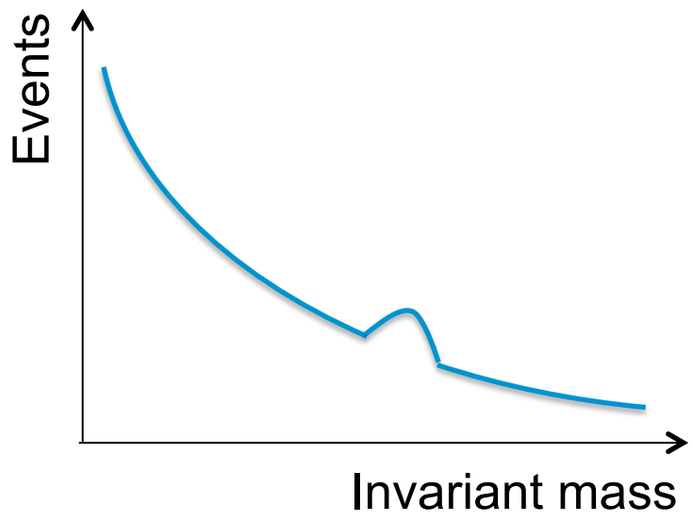


BEYOND STANDARD MODEL PHYSICS

- Z' (Dark Matter mediator)
  - Describe interaction between Standard Model and Dark Matter particles
- Excited quark
  - Compositeness
- Gaussian-shaped
  - Generic signal

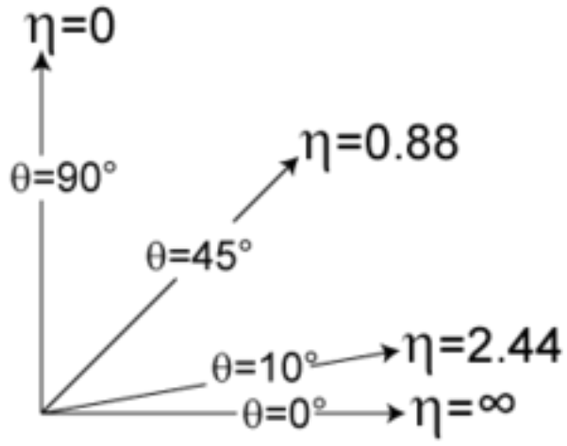


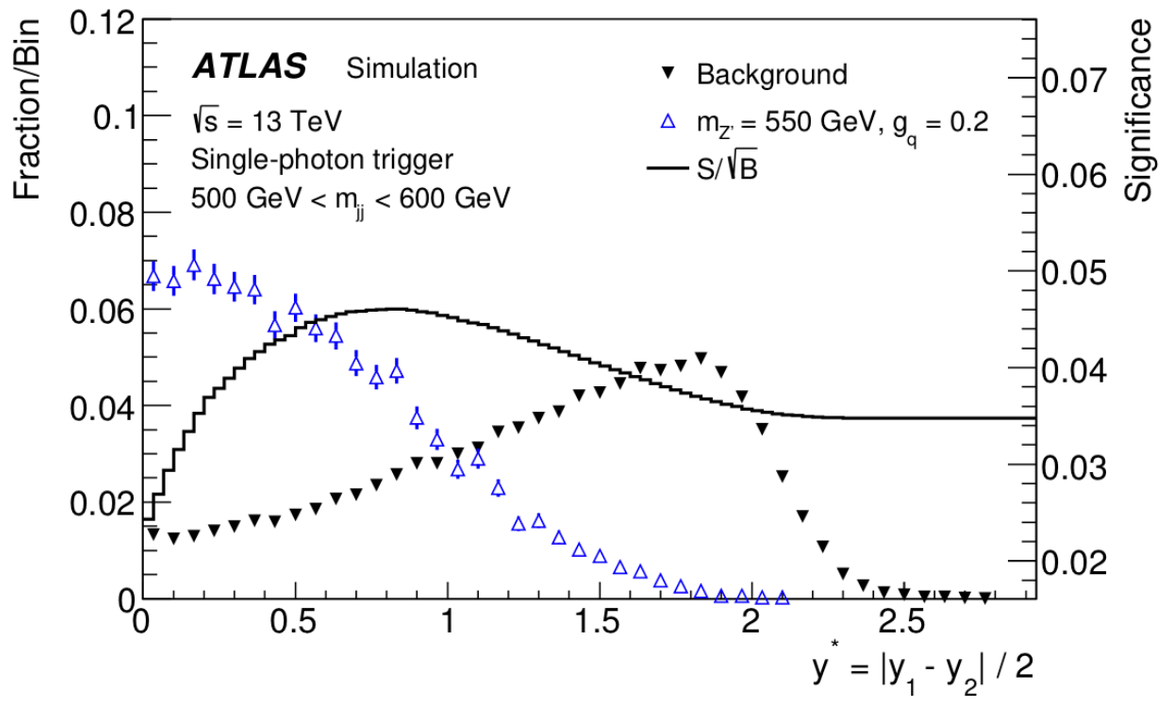




Common Kinematic Cuts

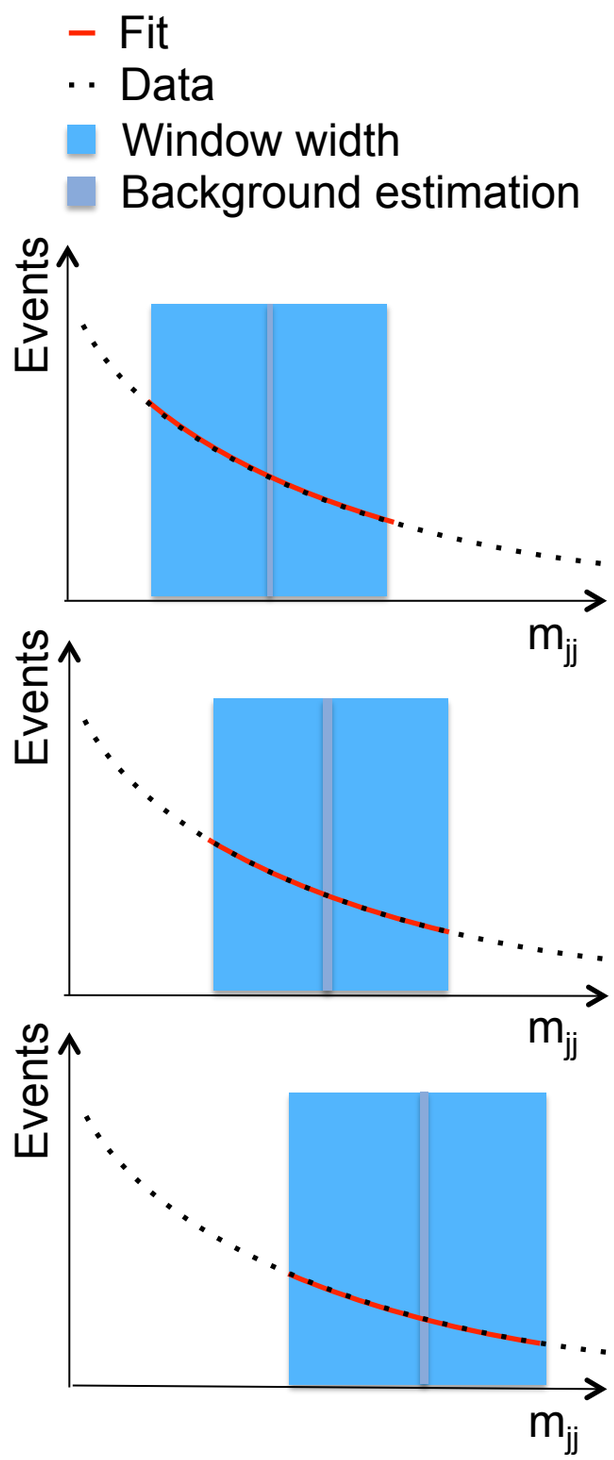
- Jet transverse momentum, p_T
  - Fully efficient triggers (usually above ~500 GeV)
  - Top- and b-tagging possible
- Jet pseudorapidity, η
  - Within detector material
- Centrality, $|y^*| = |y_1 - y_2|/2$
  - Signal present at low $|y^*|$ values
- Invariant mass, m_{jj}
  - Background fitting possible



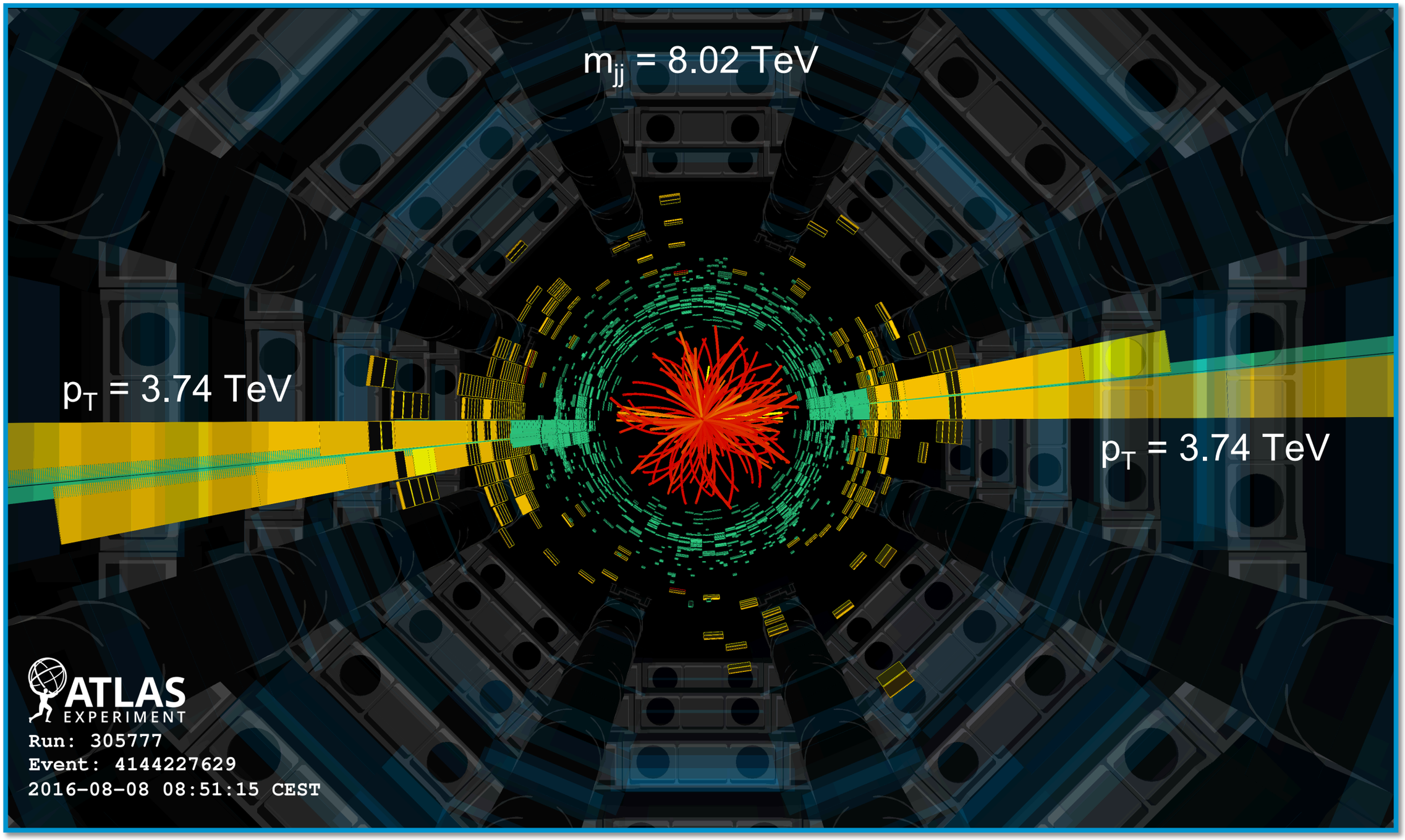


Background Estimation

- Monte Carlo (MC) simulation
  - Hard to get enough statistics
  - Modelling uncertainties
    - Unknown higher-order corrections
- Data-driven estimation
  - Dividing data in signal and control regions
- Global fit
  - Distribution needs to be smooth and preferably falling
- Sliding Window Fit
  - Doing functional fit in windows



DIJET


m_{jj} = 8.02 TeV
p_T = 3.74 TeV
p_T = 3.74 TeV
ATLAS
EXPERIMENT
Run: 305777
Event: 4144227629
2016-08-08 08:51:15 CEST

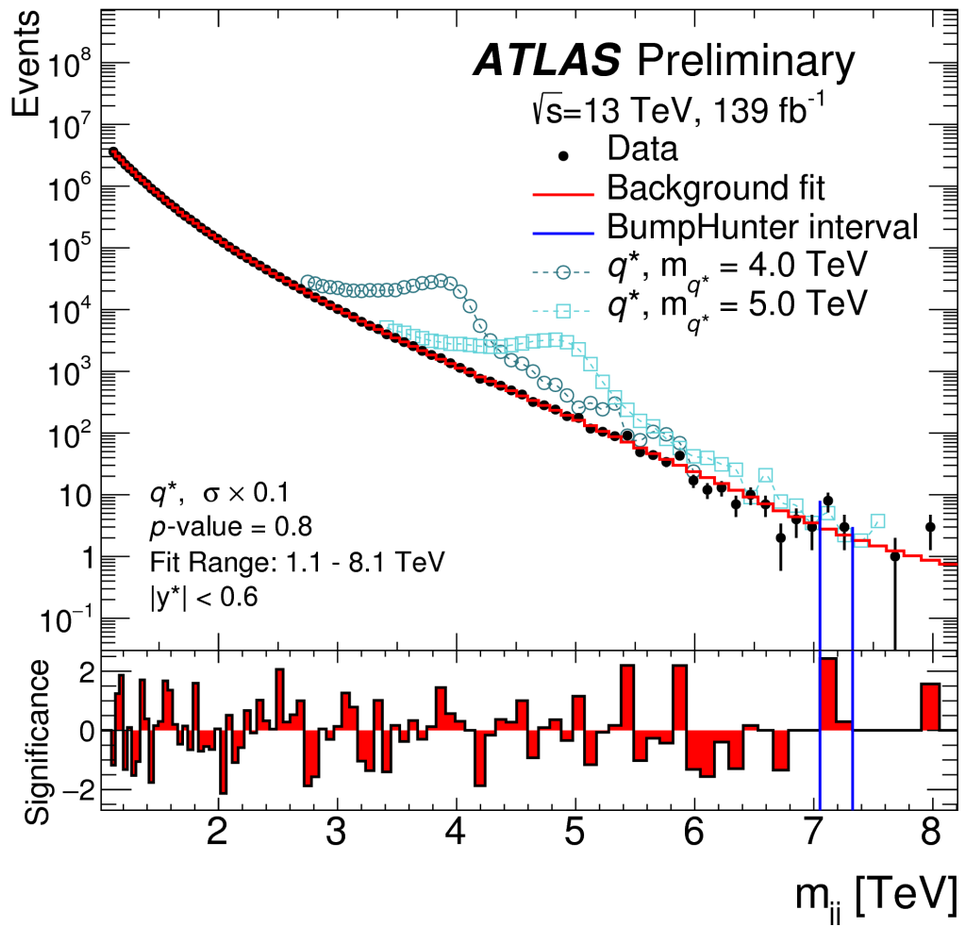
DIJET

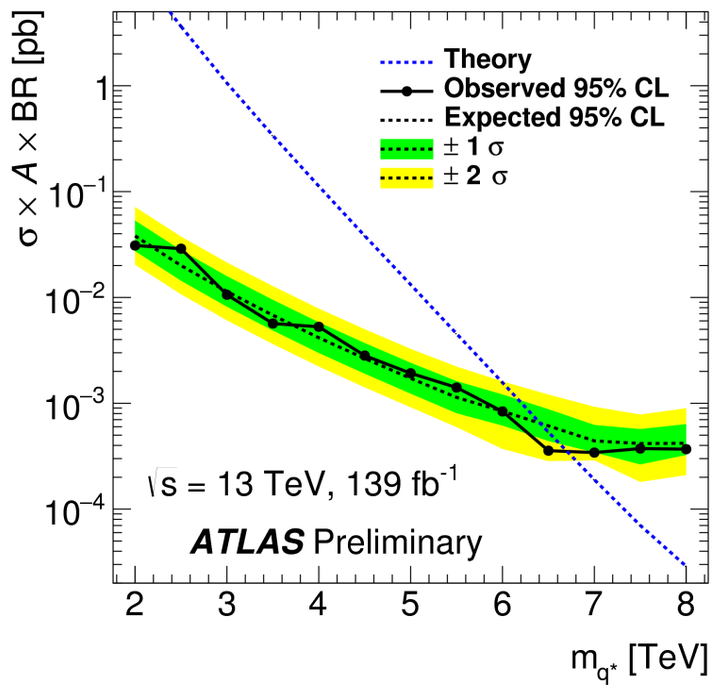
- Require at least two jets
  - Simplest topology
- Background estimation
  - Sliding Window Fit with

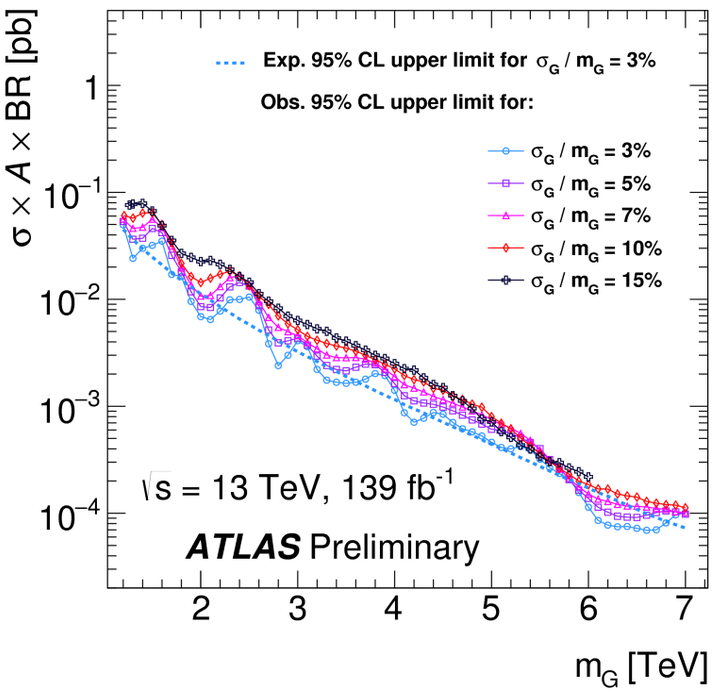
$$f(x) = p_1(1-x)^{p_2}x^{p_3+p_4 ln(x)}$$

To have fully efficient triggers and no kinematic bias

Jet p_T	$\|\Delta\varphi(jj)\|$	$\|y^*\|$	m_{jj}
> 150 GeV	> 1.0	< 0.6	> 1100 GeV







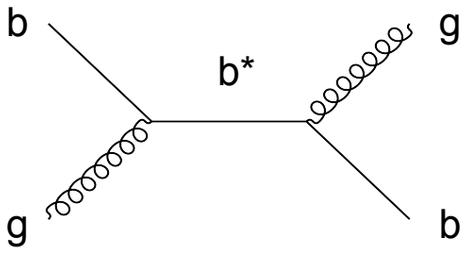
DIBJET

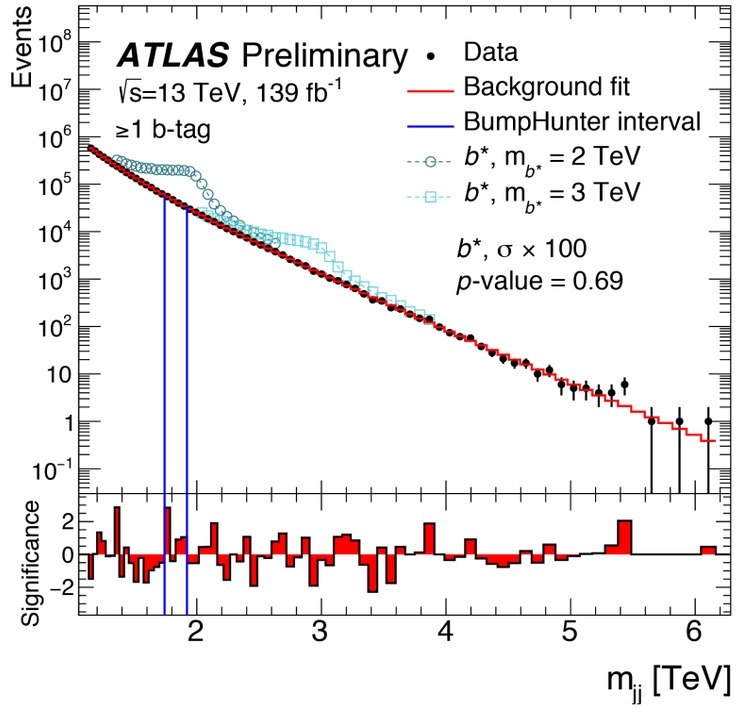
- Require at least one or both leading jets to be b-tagged
- B-tagging
  - Deep Learning Neural Network (DL1r)
- Background estimation
  - Sliding Window Fit with

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

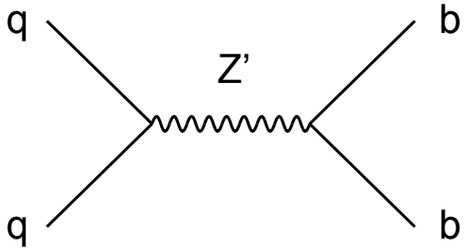
Jet p_T	$\lvert\Delta\varphi(jj)\rvert$	Jet η	$\lvert y^*\rvert$	m_{jj}
> 150 GeV	> 1.0	< 2.0	< 0.8	> 1133 GeV

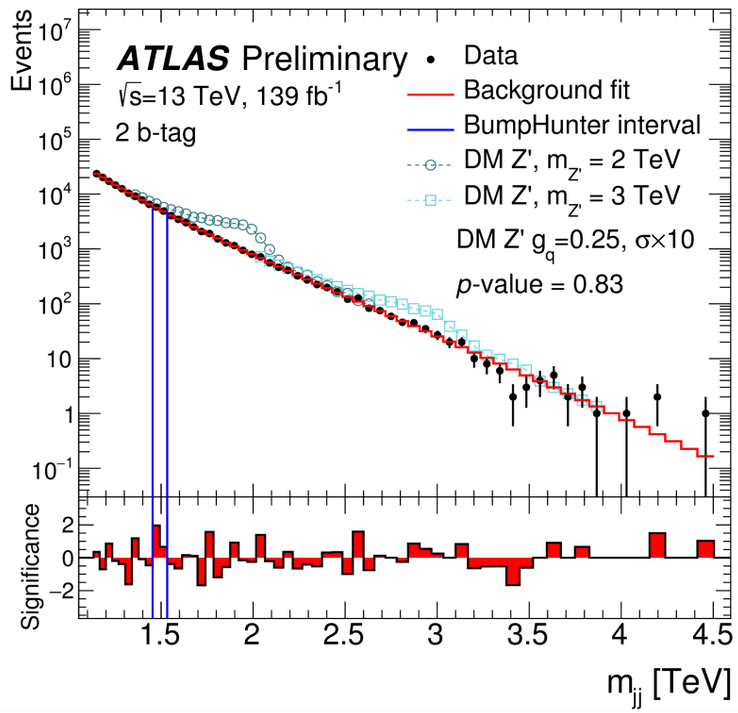
≥ 1 b-tag





2 b-tag

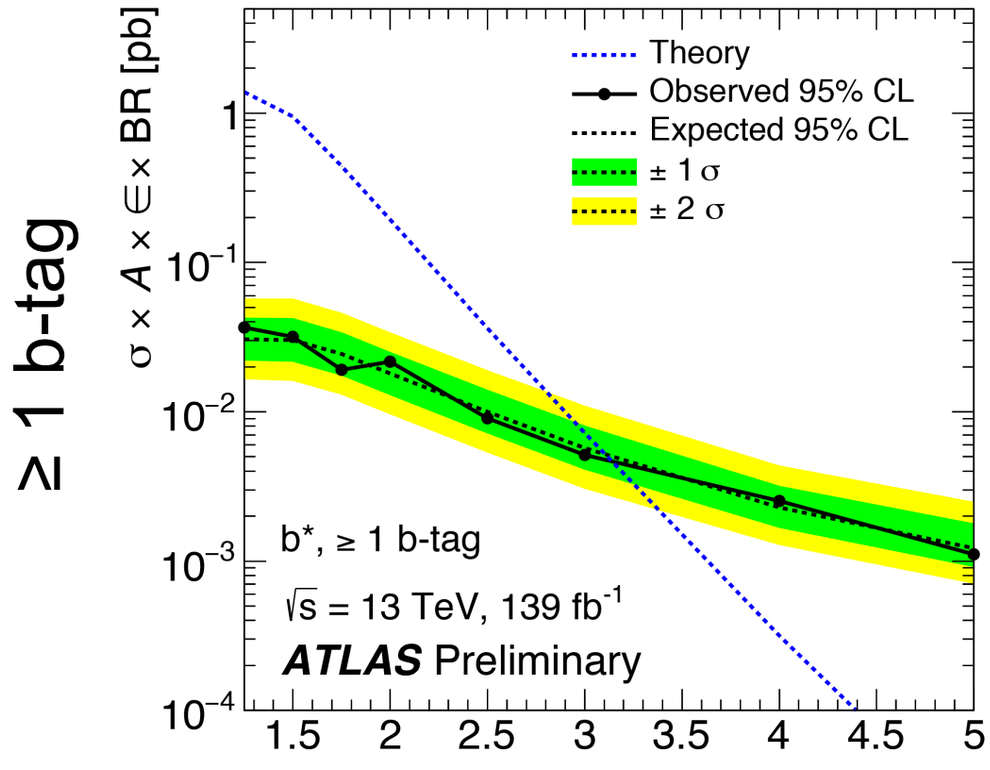




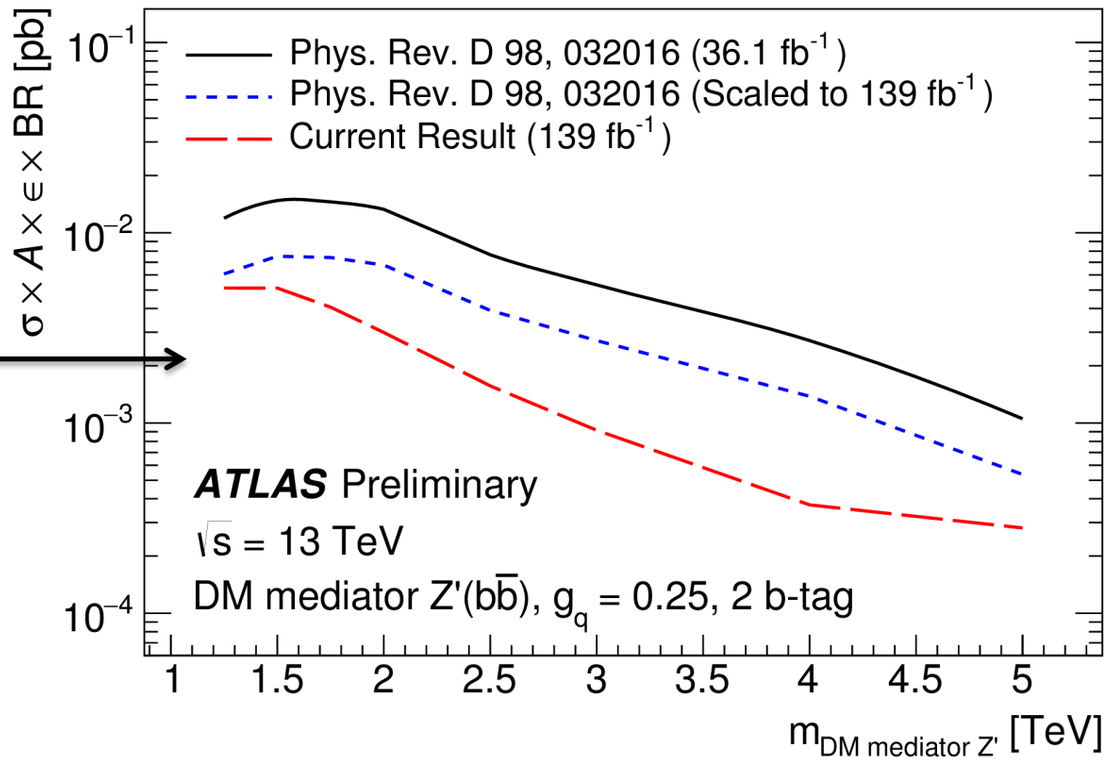
DIBJET

Category	Model	95% CL exclusion limit	
		Observed	Expected
Inclusive	q*	6.7 TeV	6.4 TeV
1b	b*	3.2 TeV	3.1 TeV
2b	DM Z'	2.9 TeV	3.0 TeV
	SSM Z'	2.6 TeV	2.6 TeV
	Graviton	2.8 TeV	2.9 TeV

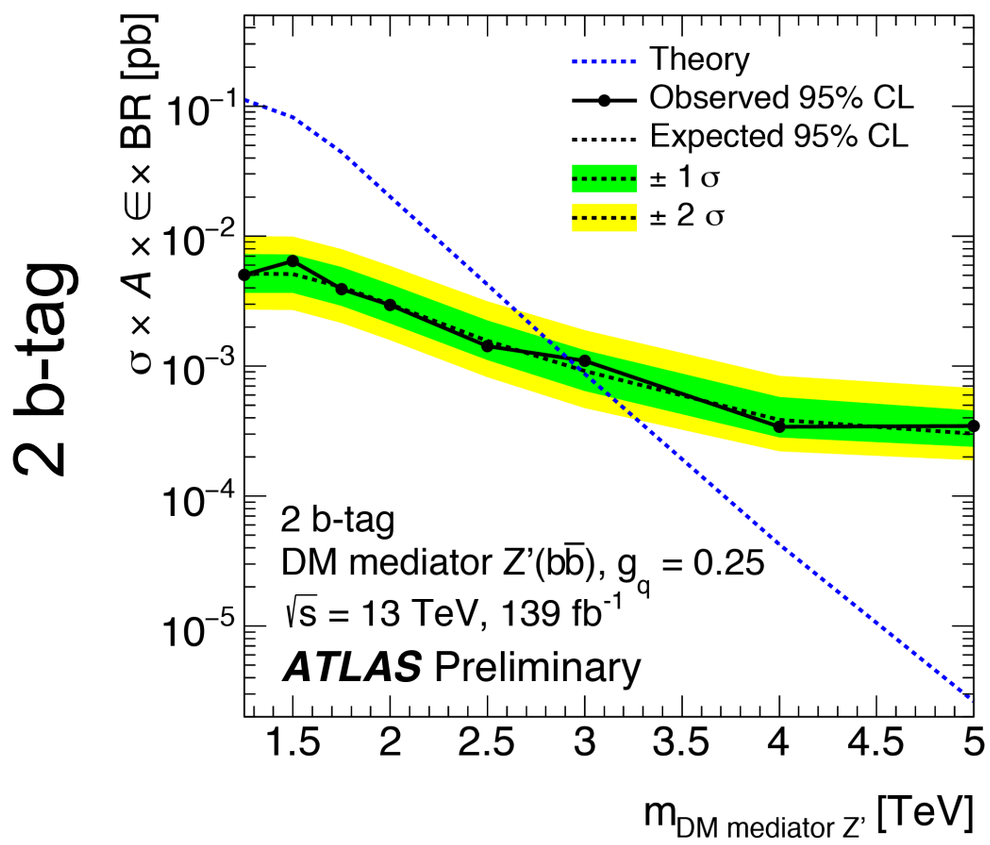
≥1 b-tag



Due to improvement in b-tagging



2 b-tag



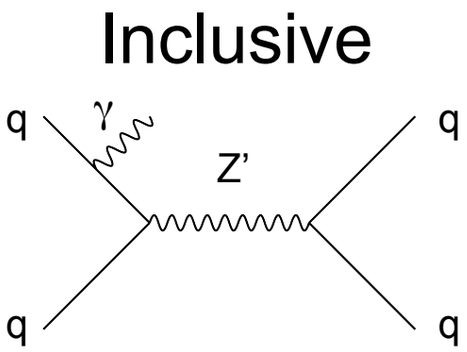
EXOT-2019-03 (ATLAS only)

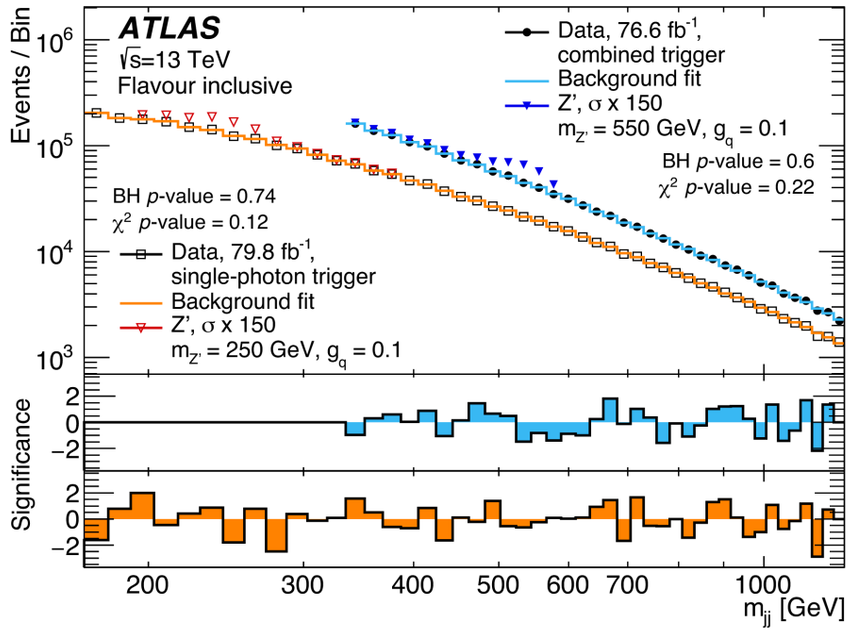
DI(B)JET+ISR

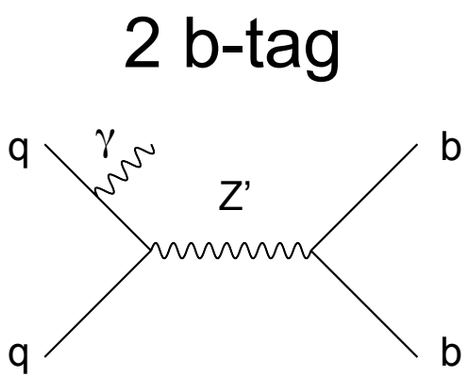
- Require initial state photon
  - Fully efficient triggers
- B-tagging
  - Deep Learning Neural Network (DL1)
- Background estimation
  - Sliding Window Fit with

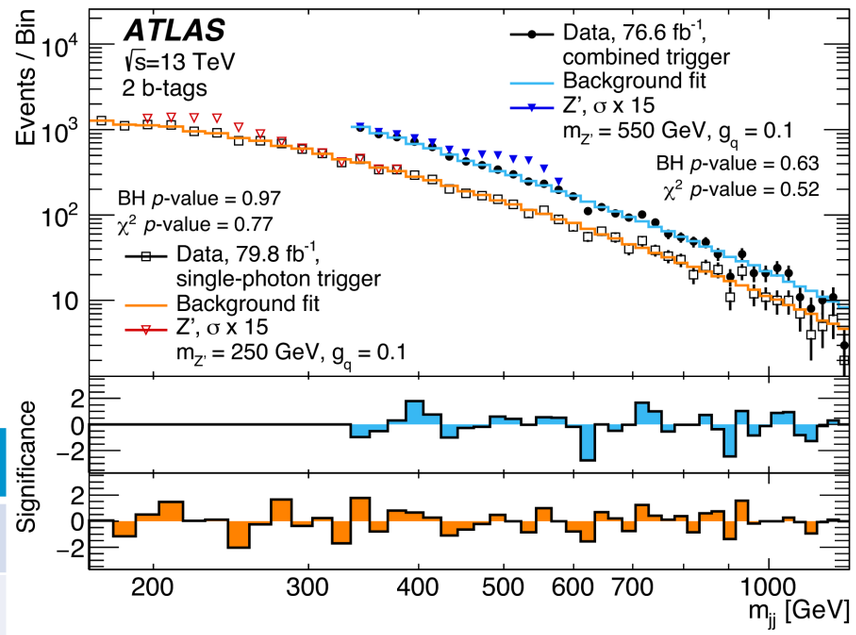
$$f(x) = p_1 x^{-p_2} e^{-p_3 x - p_4 x^2} \text{ or}$$

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







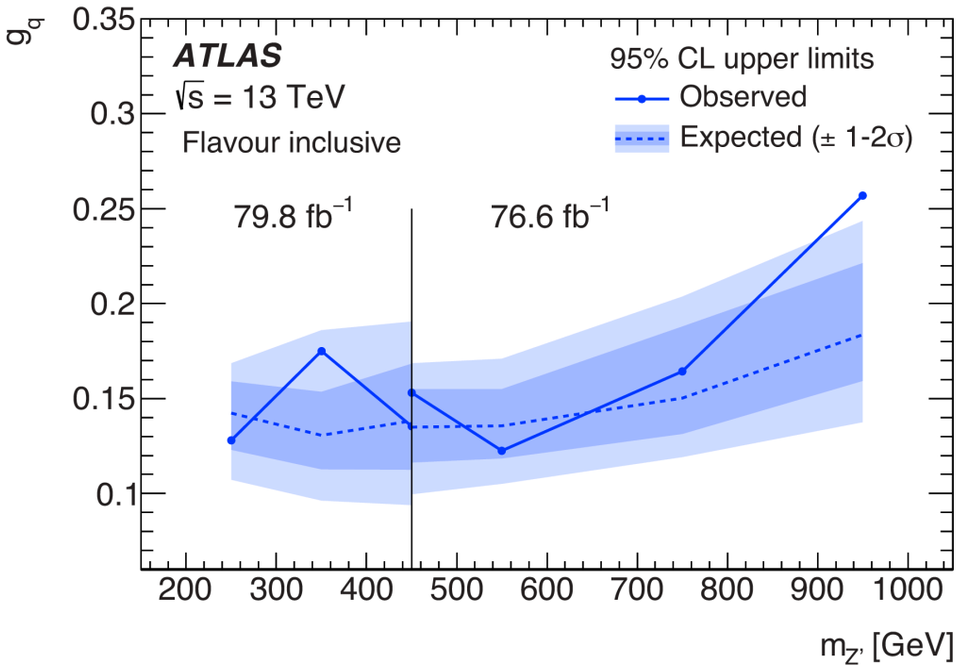


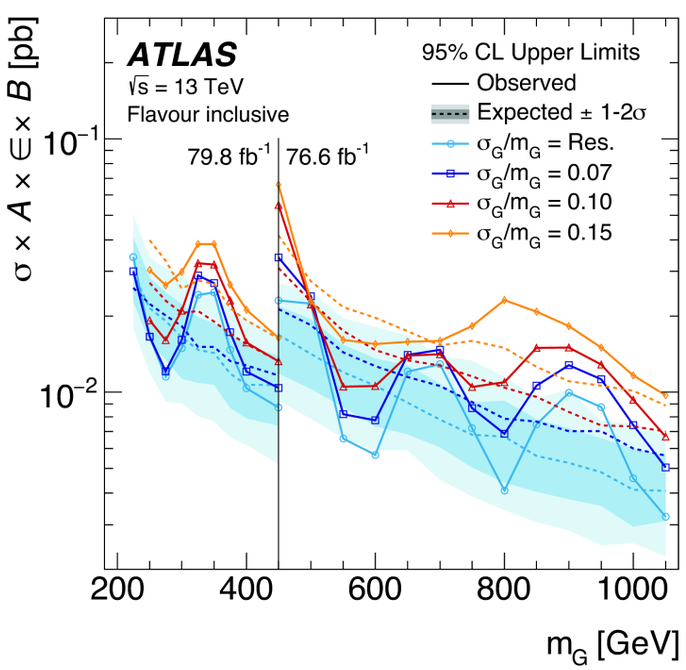
Trigger	Jet p_T	Photon E_T	|y*|	m_{jj}
Single-photon	> 25 GeV	> 150 GeV	< 0.75	> 169 GeV
Combined	> 65 GeV	> 25 GeV		> 335 GeV

Tagging	Jet η
Inclusive	> 2.8
2 b-tag	> 2.5

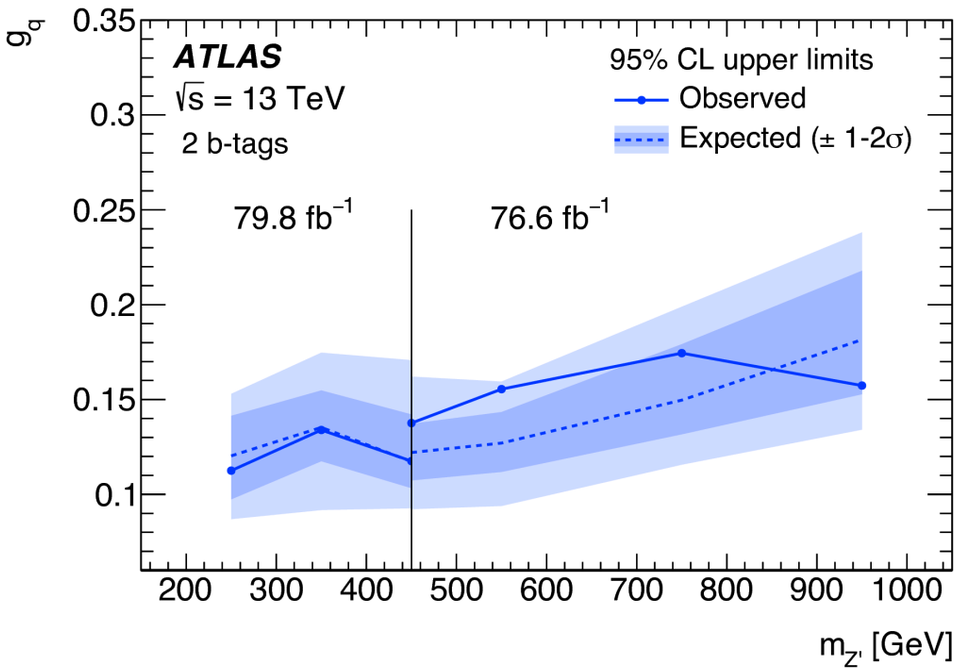
DI(B)JET+ISR

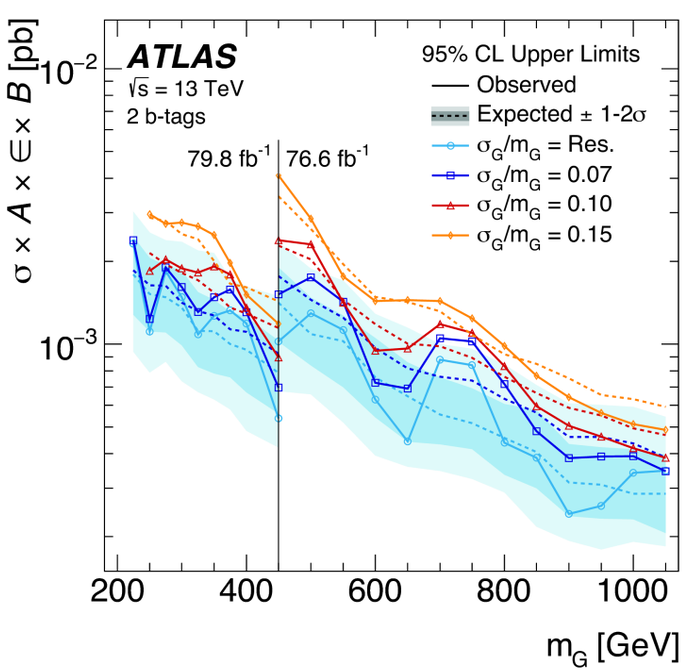
Inclusive





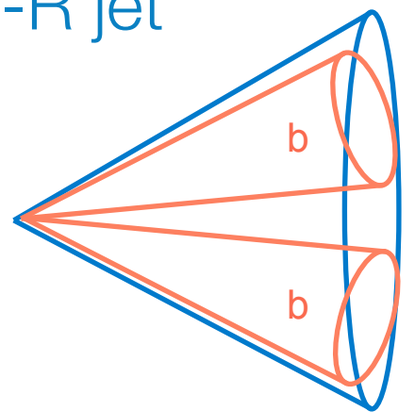
2 b-tag



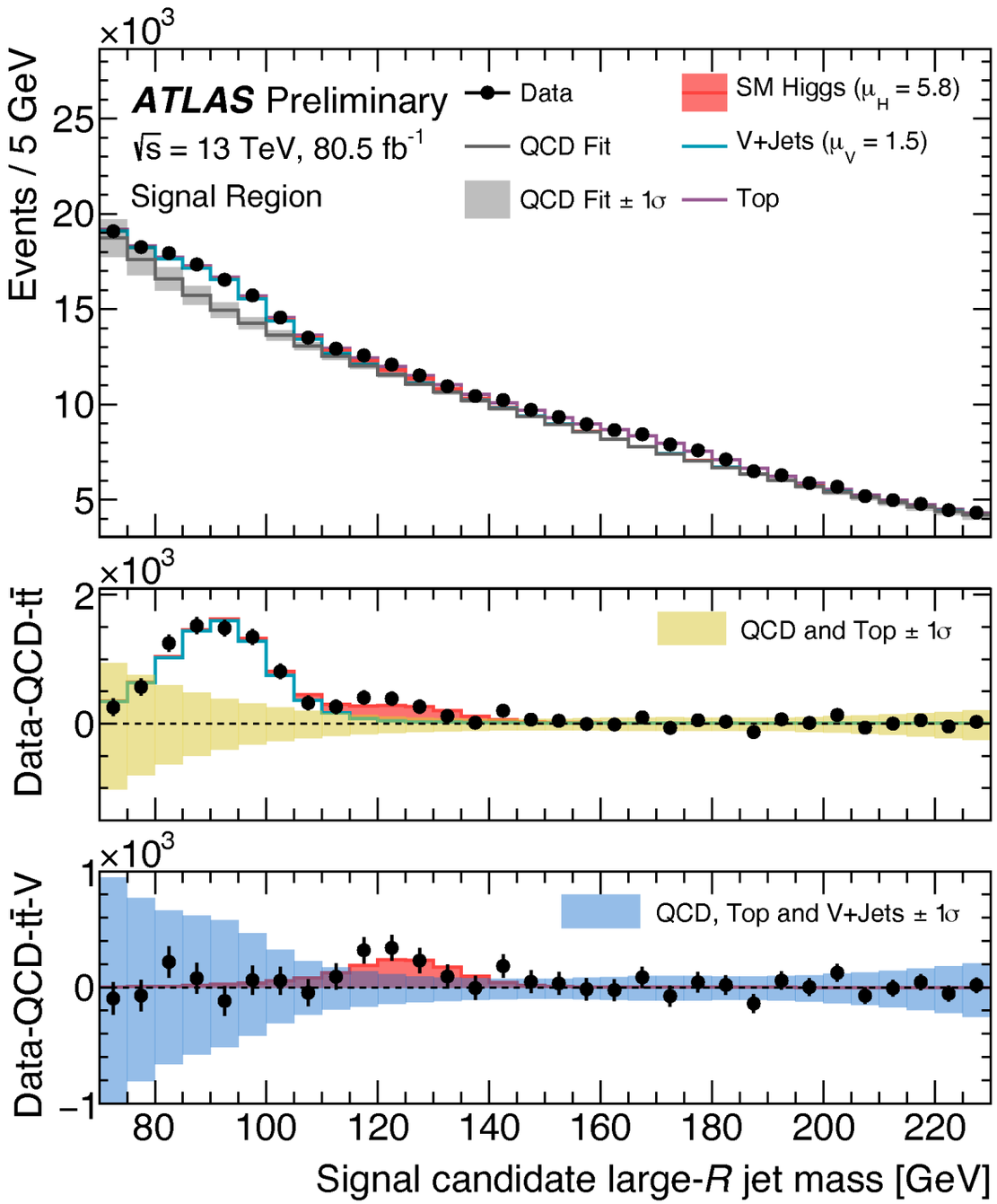


Boosted Dibjet+ISR

- Require initial state jet
  - Dibjet system so boosted that both jets are within one large-R jet
- B-tagging
  - BDT (MV2c10)
- Background estimation
  - MC for V+jets and ttbar
  - Global fit for QCD dijet



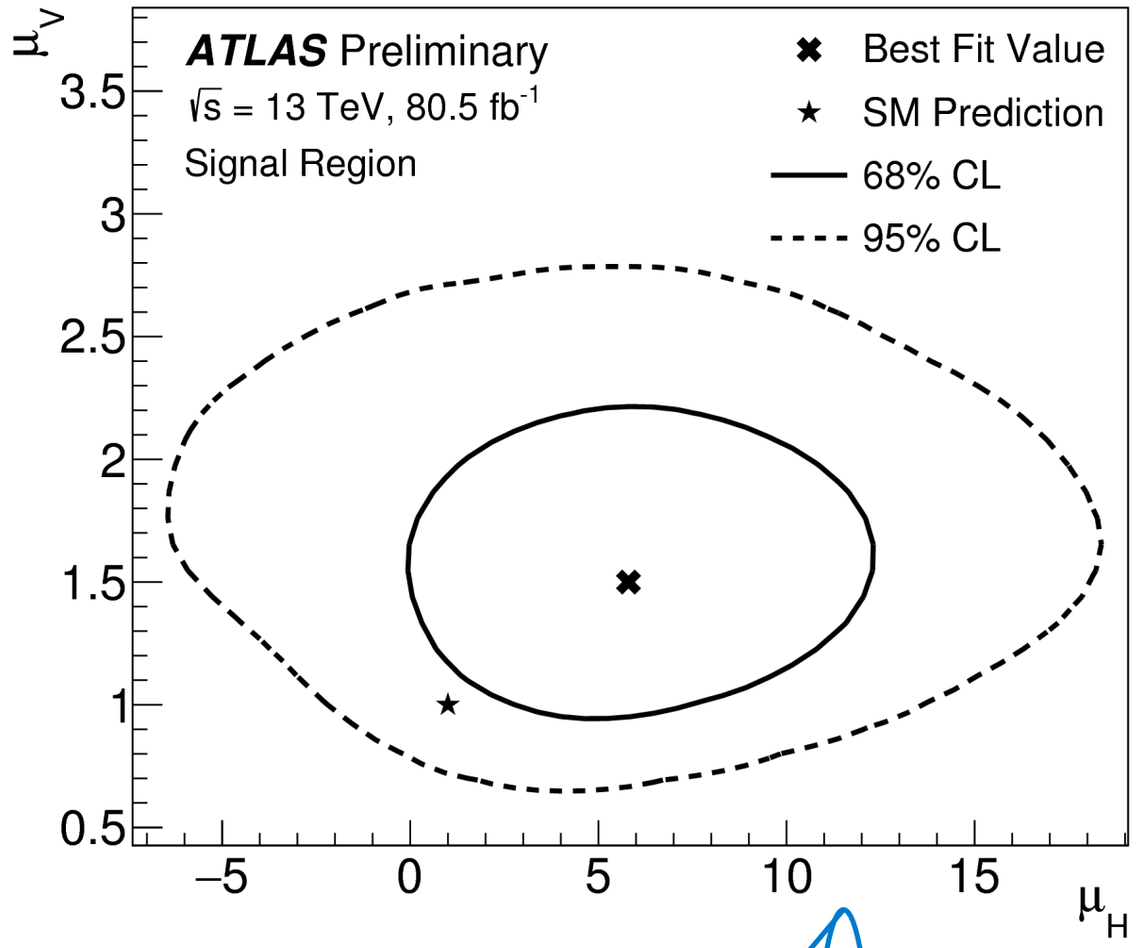
Leading large-R jet p_T	Sub-leading large-R jet p_T	Jet η	$2m_J/p_T$	m_J
> 480 GeV	> 250 GeV	< 2.0	<1	70 - 230 GeV

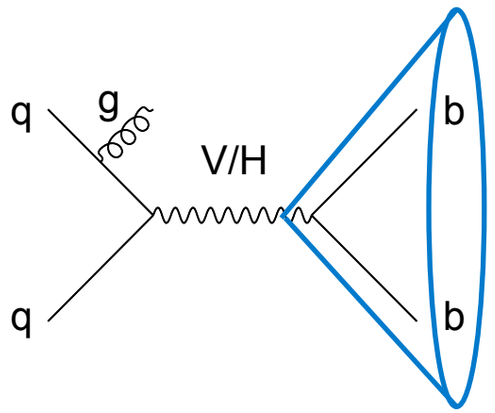


Boosted Dibjet+ISR

- Require initial state jet
  - Dibjet so boosted that both jets are within one large-R jet
- B-tagging
  - BDT (MV2c10)
- Background estimation
  - MC for V+jets and ttbar
  - Global fit for QCD dijet

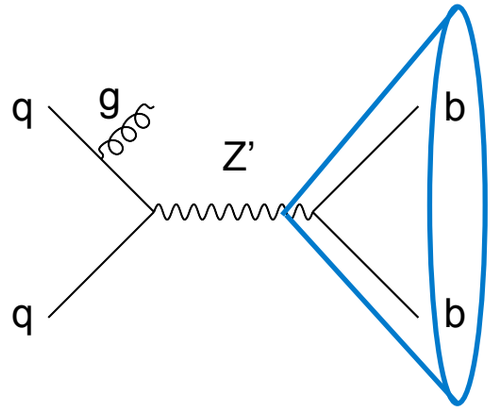
Leading large-R jet p_T	Sub-leading large-R jet p_T	Jet η	$2m_J/p_T$	m_J
> 480 GeV	> 250 GeV	< 2.0	<1	70 - 230 GeV



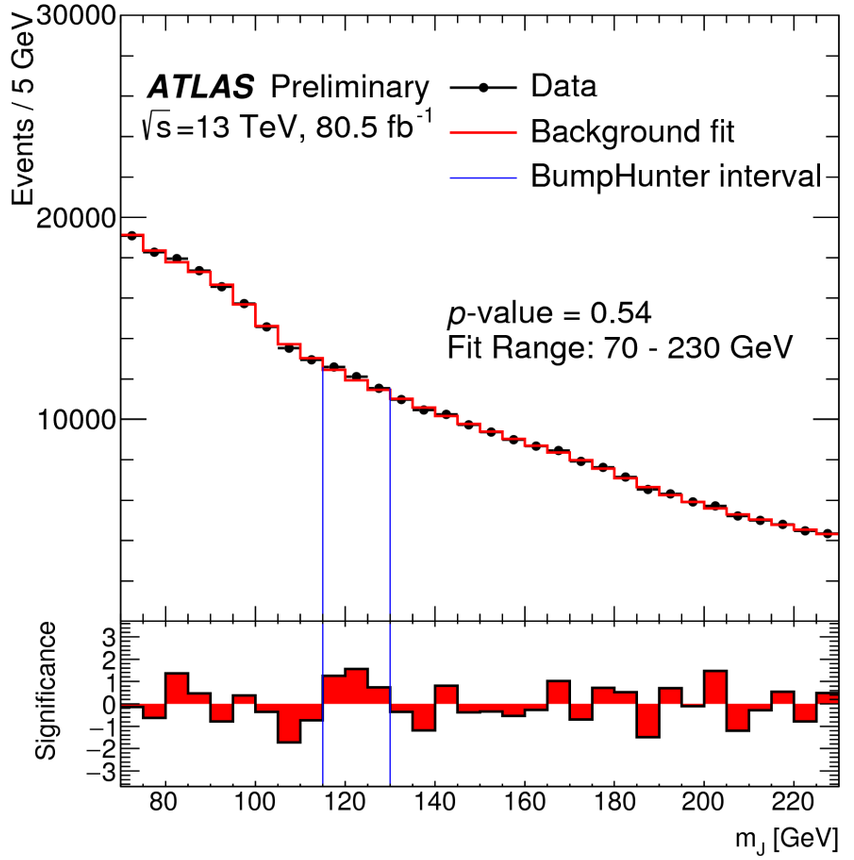


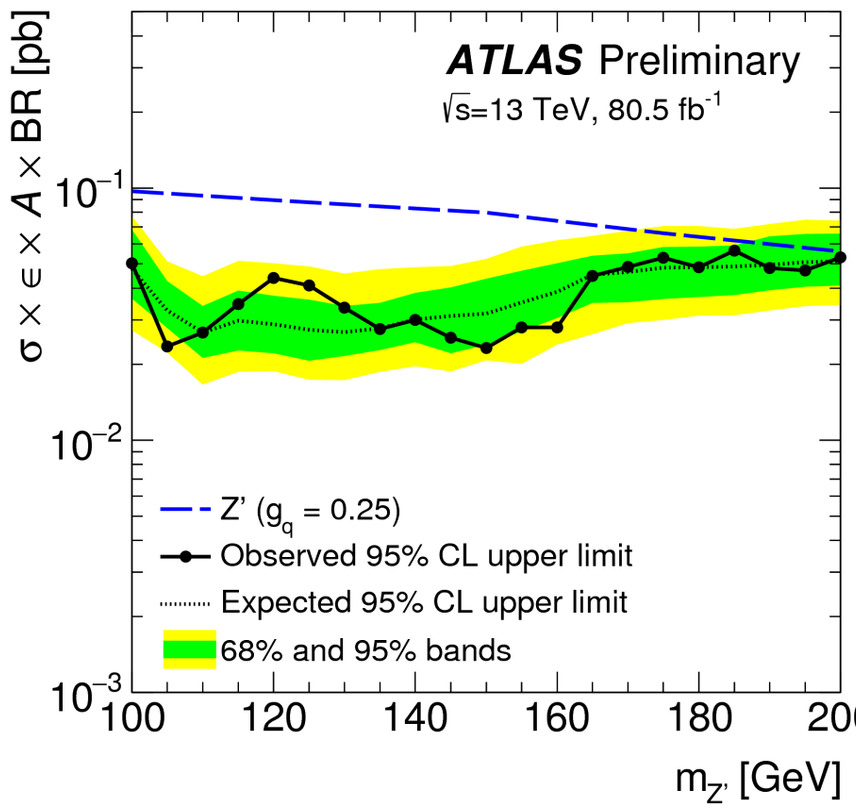
Boosted Dibjet+ISR

- Require initial state jet
  - Dibjet so boosted that both jets are within one large-R jet
- B-tagging
  - BDT (MV2c10)
- Background estimation
  - MC for V+jets and ttbar
  - Global fit for QCD dijet



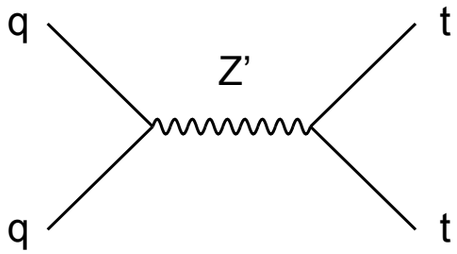
Leading large-R jet p_T	Sub-leading large-R jet p_T	Jet η	$2m_J/p_T$	m_J
> 480 GeV	> 250 GeV	< 2.0	<1	70 - 230 GeV



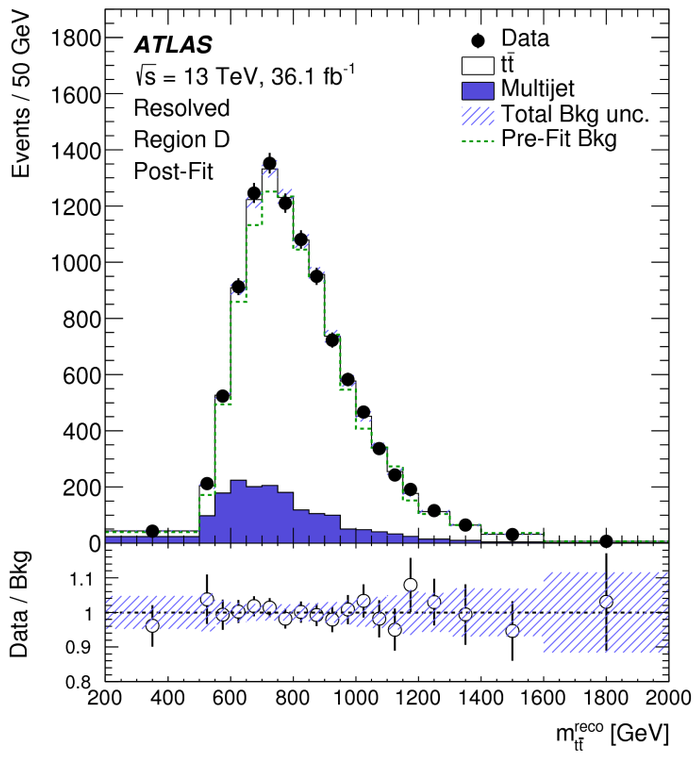


TTBAR

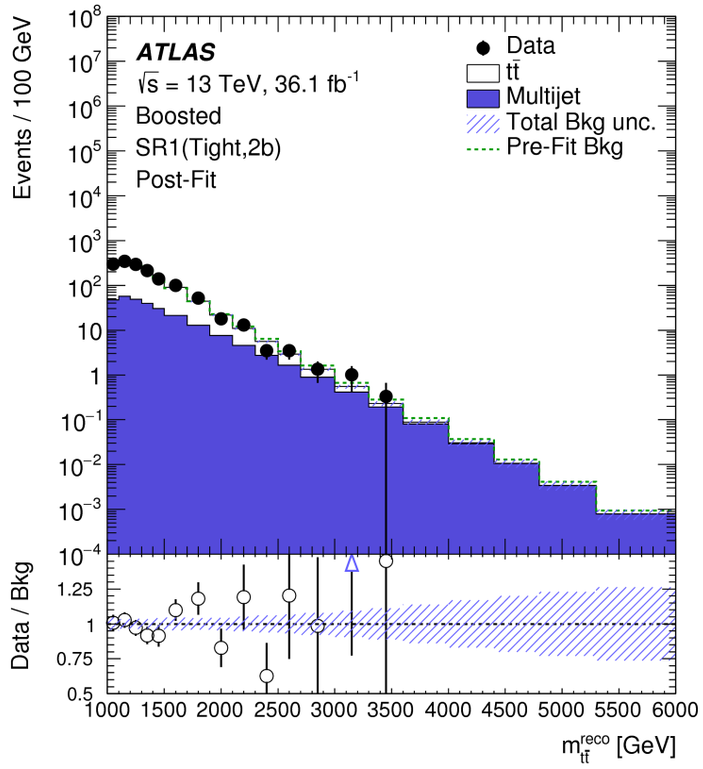
- Require two top-tags
- Top tagging
  - Resolved: “Buckets of tops”
  - Boosted: Jet mass and τ_{32}
- Background estimation
  - MC for ttbar
  - Data-driven for multijet



Resolved

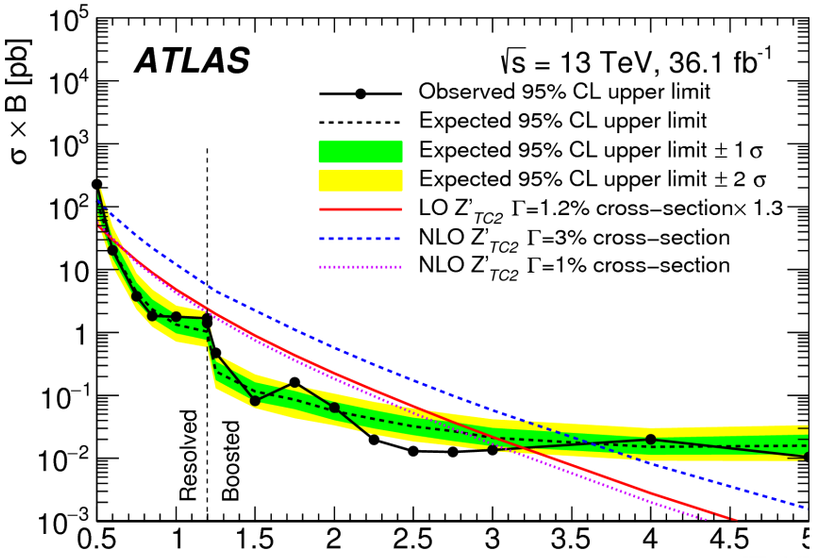


Boosted

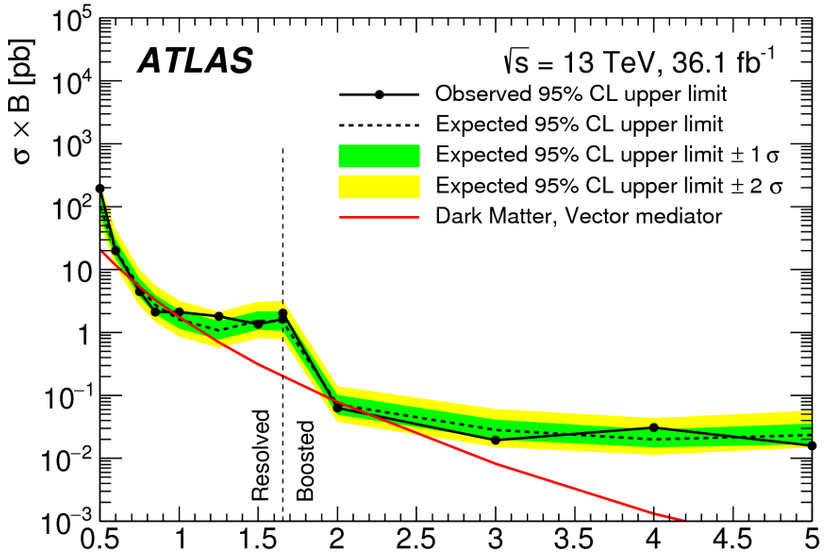


Event selection (boosted)				
Leading large-R jet p_T	Sub-leading large-R jet p_T	Jet η	$\lvert\Delta\varphi(jj)\rvert$	m_{jj}
> 500 GeV	> 400 GeV	< 2.0	> 1.6	> 1000 GeV

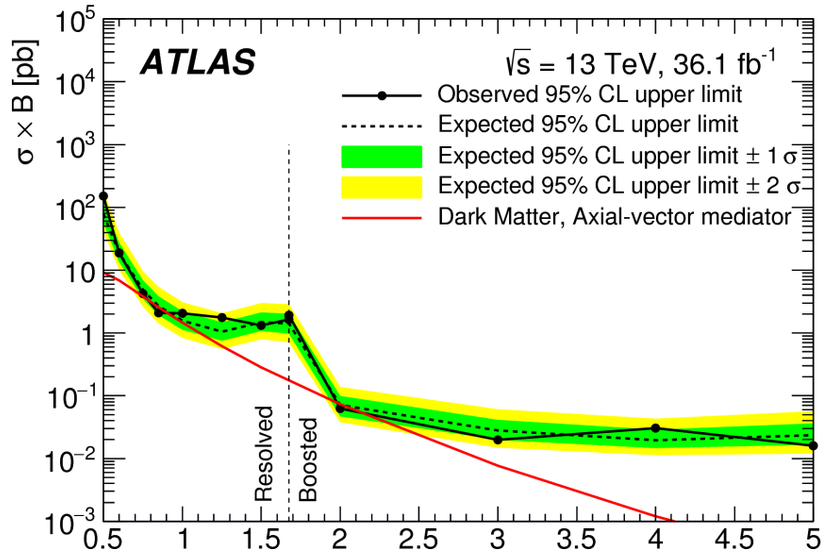
TTBAR



Z'TC2

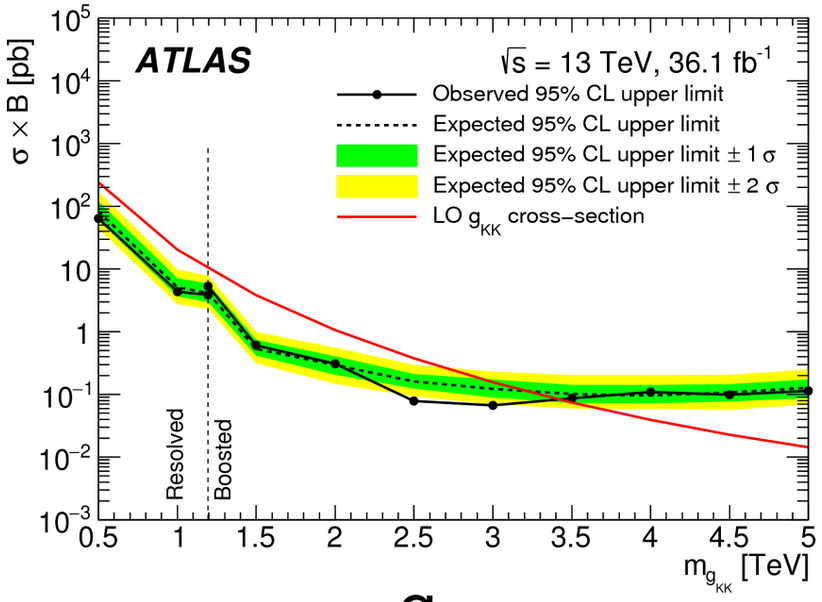


DM Z' (vector)



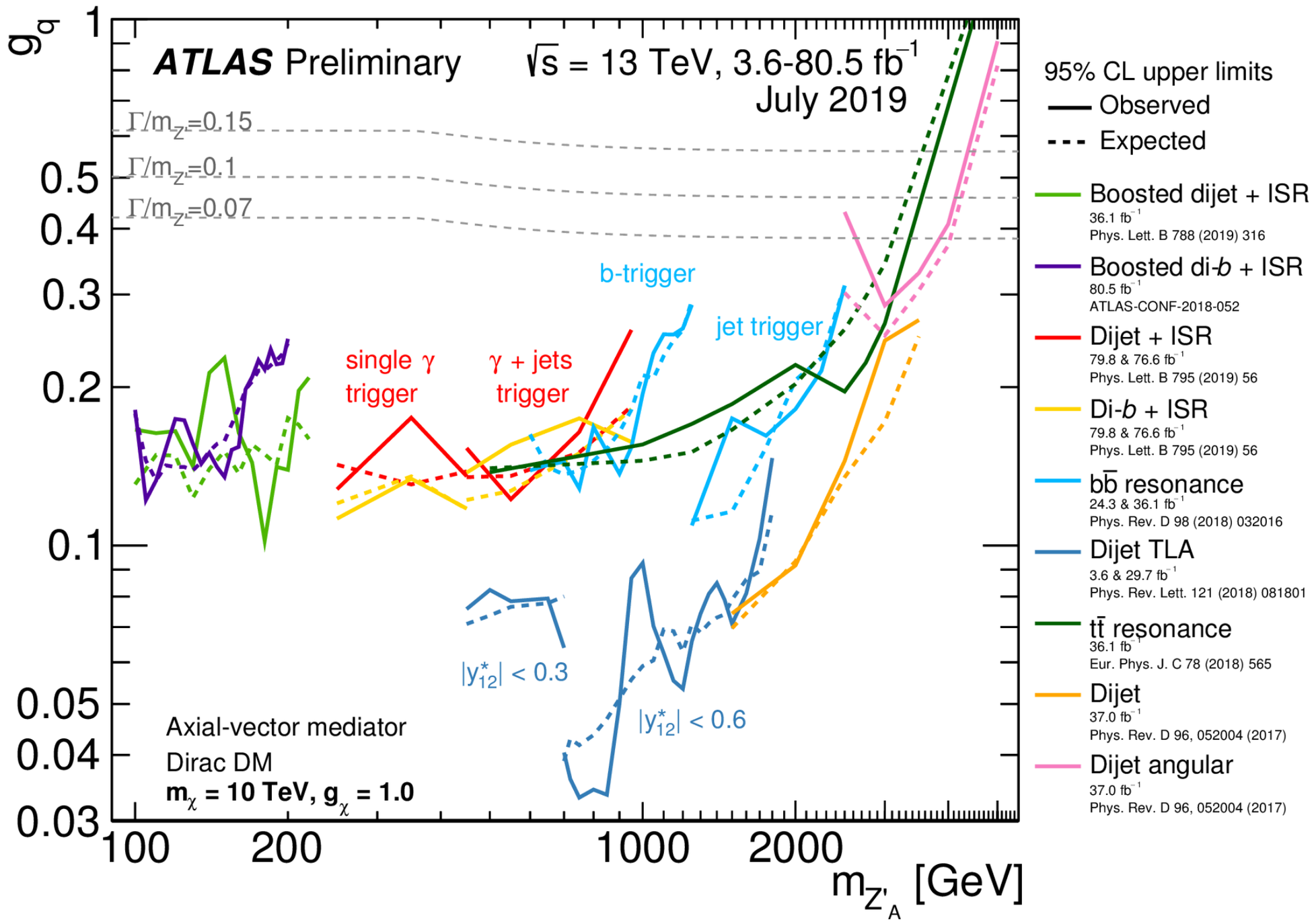
DM Z' (axial)

Model	95% CL exclusion limit	
	Observed [TeV]	Expected [TeV]
Z'_{TC2} (Γ = 1%)	[0.58,3.1]	[0.57,2.8]
Z'_{TC2} (Γ = 3%)	[0.53,3.6]	[0.51,3.6]
DM Z' (vector)	[0.74,0.97]U[2.0,2.2]	[0.75,1.07]U[2.0,2.1]
DM Z' (axial-vector)	[0.80,0.92]U[2.0,2.2]	[1.99,2.04]
g_{KK} (Γ = 30%)	< 3.4	< 3.3

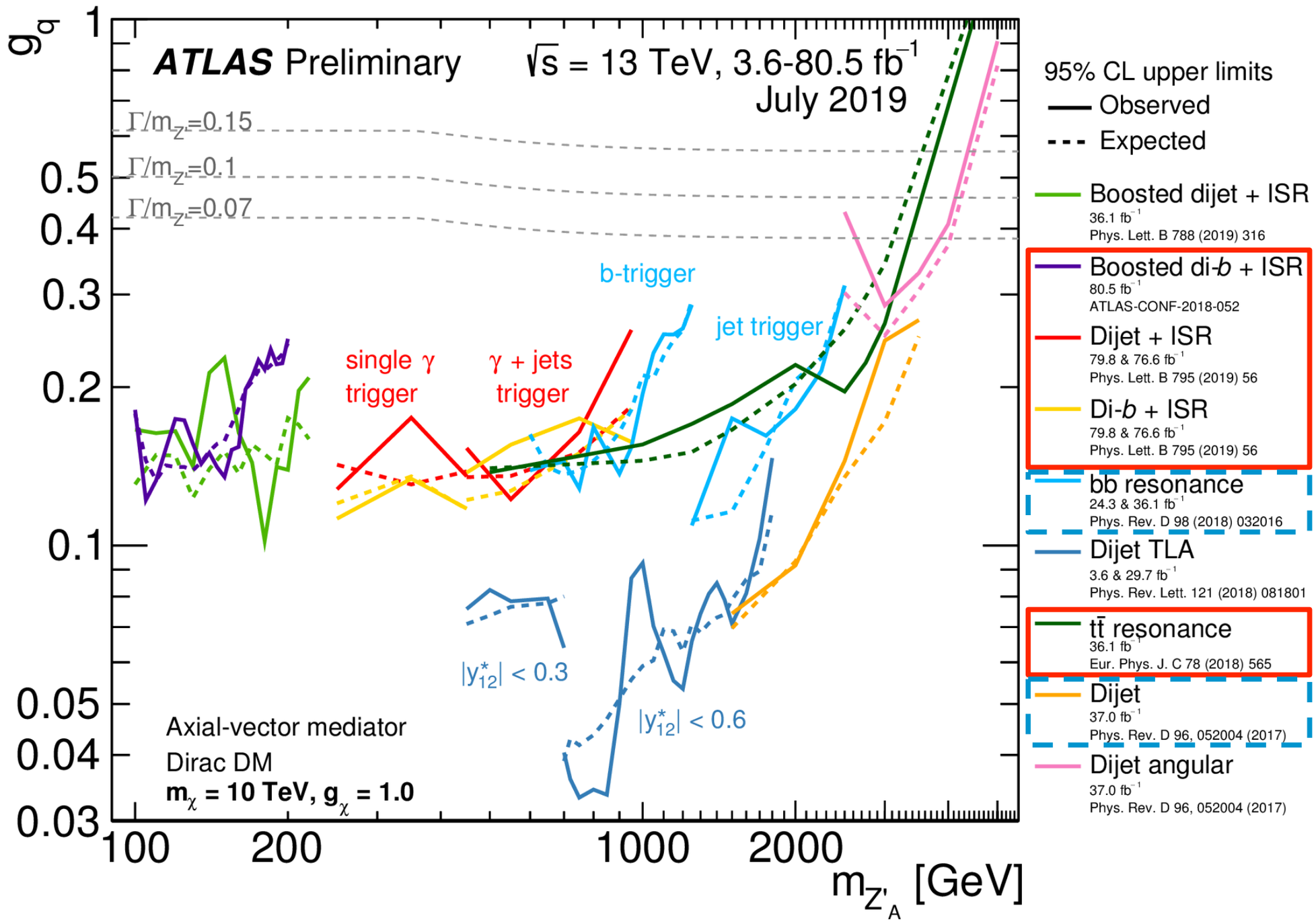


g_{KK}

Dark Matter Summary Plot



Dark Matter Summary Plot



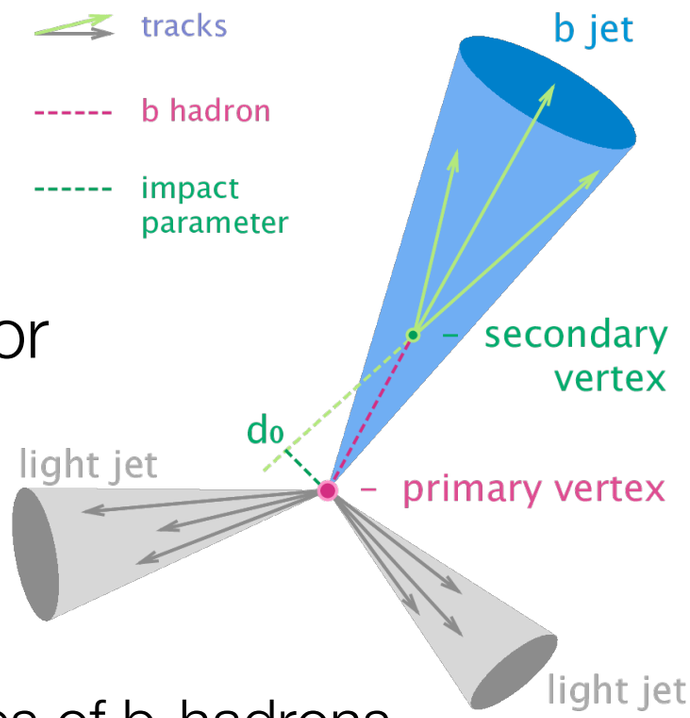
Conclusions and Outlook

- Setting limits on Z' Dark Matter mediator
  - Masses from 100 to 5000 GeV
- Moving towards Run-3 and High Luminosity LHC
  - Run-3: Collect another ~150fb^{-1} between 2021-2023
  - HL-LHC: Collect ~3000fb^{-1} between 2026-2038(?) ← Francesca's talk
- Machine Learning
  - Improve tagging
  - Tracking in high pile-up environment

BACK UP

B-TAGGING

- B-hadrons have certain characteristics which can be used to tag a jet as coming from a b-quark
  - Impact parameters of tracks
  - Displaced vertices reconstructed in the inner detector



- Different taggers
  - DL1 and DL1r
    - Deep learning neural network based on distinctive features of b-hadrons
    - DL1r includes inputs from recurrent neural network
  - MV2c10
    - Multivariate b-tagging algorithm using Boosted Decision Tree (BDT)

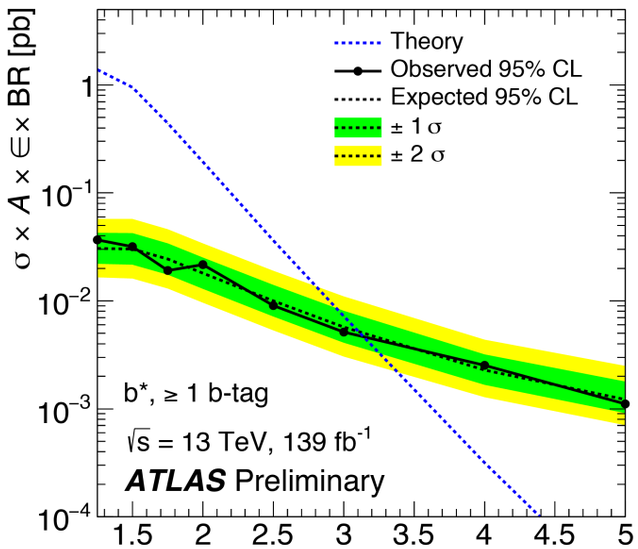
Buckets of Tops

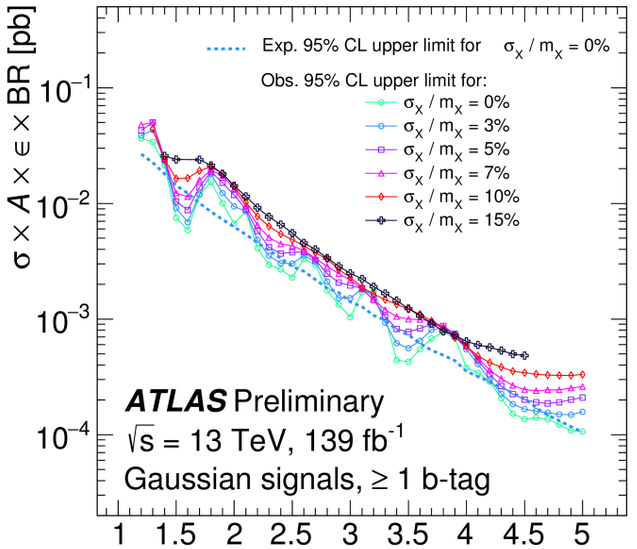
- All jets are
  - assume to originate from ttbar events
  - assigned to one of three groups (buckets)
- Buckets (B1, B2 and B3)
  - B1/B2 contain jets from the two top quarks, B3 contain all jets from extra radiation
- Assignment is made by minimizing the metric $\Delta^2 = \omega\Delta^2_{B1}+\Delta^2_{B2}$
  - Where $\Delta_{B1(2)} = |m_{B1(2)}-m_{top}|$ and $\omega=100$
- Require
  - B1 and B2 to contain exactly one b-tagged jet each
  - $155\ \text{GeV} < m_{B1(2)} < 200\ \text{GeV}$
- Additional classification depending on whether W is contained or not

DIBJET LIMITS

Category	Model	95% CL exclusion limit	
		Observed	Expected
Inclusive	q*	6.7 TeV	6.4 TeV
1b	b*	3.2 TeV	3.1 TeV
2b	DM Z'	2.9 TeV	3.0 TeV
	SSM Z'	2.6 TeV	2.6 TeV
	Graviton	2.8 TeV	2.9 TeV

≥ 1 b-tag





2 b-tag