Search for Resonances in the Mass Distribution of Jet Pairs with One or Two Jets Identified as *b*-Jets in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector

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UCL Meeting

4 March 2015

Outline

- **Analysis Overview**
  - Analysis Status
  - Motivation
  - Search Strategy
  - Results

- **Flavour Fraction Studies**
  - Background flavour composition
  - Robustness to flavour fraction studies
  - Spurious signal tests.

Analysis Status

- **b-Tagged di-jet resonance search**
- **Aiming for a paper for Moriond**
- **Progress:**
  - Open Presentation - 29/02/2016
  - ATLAS Circulation - 03/02/2016
  - Open Presentation - Next week?
- **Documentation**:
  - Paper Draft: ATLAS-EXOT-2015-22
  - INT Note: ATL-COM-PHYS-2015-1324

ATLAS Paper Draft

Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

EXOT-2015-22

Version: 1.1

To be submitted to: Phys. Lett. B

Supporting internal notes

ATL-COM-PHYS-2015-1324 https://cds.cern.ch/record/2062417

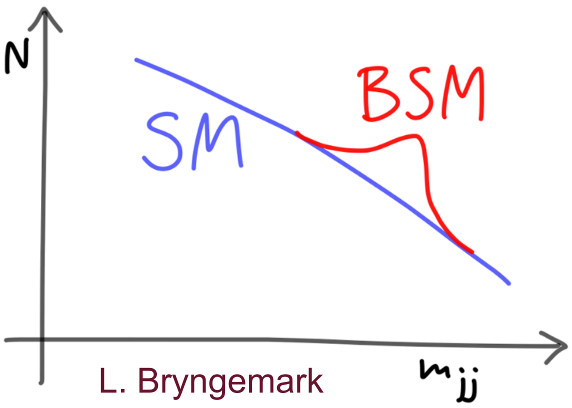
Comments are due by: 25 Feb 2016

Abstract

Searches for high-mass resonances in the di-b-jet invariant mass spectrum are performed using an integrated luminosity of 3.2 fb^{-1} of proton–proton collisions with a centre-of-mass energy of $\sqrt{s} = 13$ TeV recorded by the ATLAS detector at the Large Hadron Collider. The dijet events are divided into categories with one or two jets identified as containing a b-hadron. No evidence of anomalous phenomena is observed in these two categories and upper limits are obtained on the production cross section of narrow resonances in the mass range considered $1.2--5$ TeV. For a benchmark model calculated at leading order QCD, excited b^* quarks are excluded with masses below 2.1 TeV at 95% credibility level. Contributions of a Gaussian signal shape with effective cross sections ranging from approximately 0.3–0.001 pb are also excluded in the mass range $1.5 - -5$ TeV.

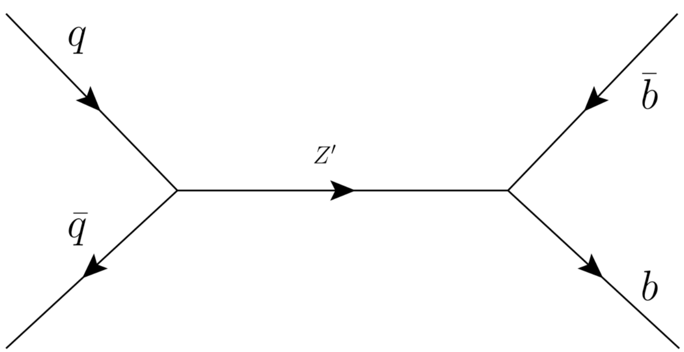
Analysis Strategy

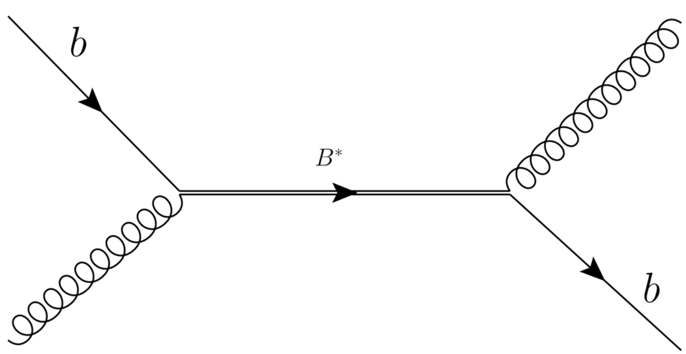
- Follow similar analysis strategy to inclusive di-jet analysis.
  - **Search for resonance in invariant mass spectrum**.
  - Fit QCD background using smoothly falling function.



- **In addition, b-tagging is applied.**
  - Two categories - 1 and 2 b-tags

- **Search for generic di-jet resonance**
  - Gaussian with width similar to benchmark models.
  - Two Benchmark models
    1) **Z' => bb**, double b-jet final state
       - We look at both a SSM Z' and a Leptophobic Z'
    2) **b* => bg**, single b-jet final state
  - Set limits on Z', b* and Gaussian signal



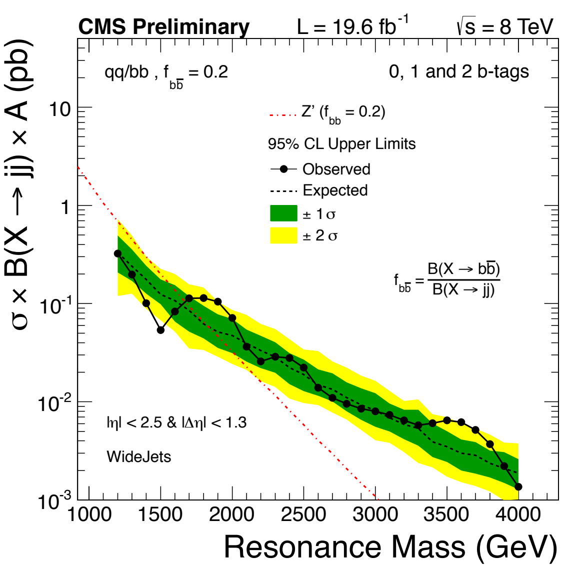


Motivation

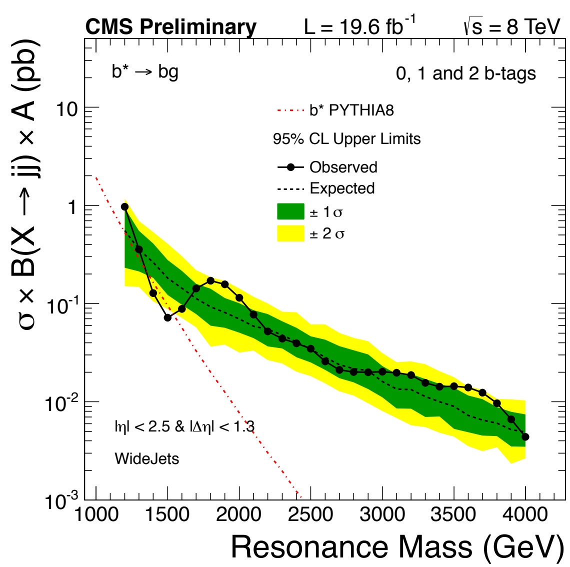
- Many BSM models predict heavy particles that decay into bb or bg.
  - Z', b*, RS Graviton...
  - b-Tagging can be used to reduce light dominated QCD background
  - Hence increased sensitivity to these models.

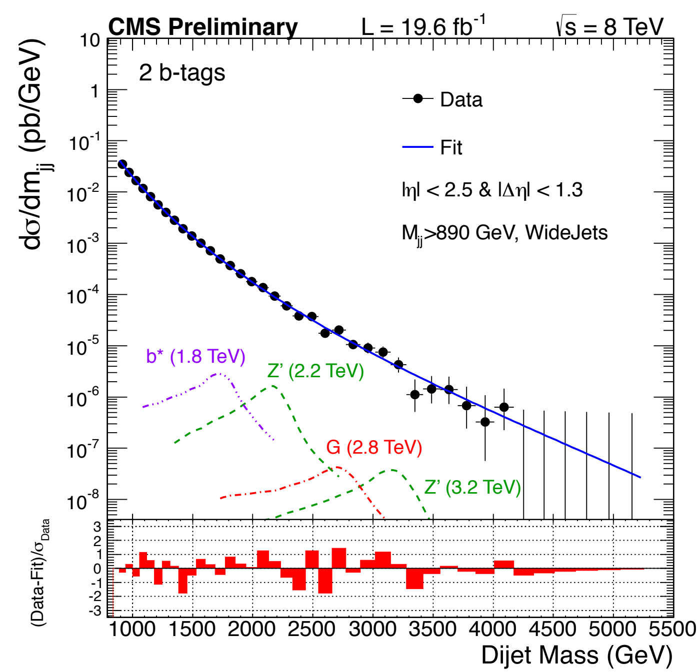
- Generic search performed searching for high mass resonance decaying to b-tagged jets.
  - Performed at CDF and CMS - ([CMS-PAS-EXO-12-023](CMS-PAS-EXO-12-023))
  - No ATLAS result from Run-1

Z' excluded at 1.7 TeV



b excluded at 1.5 TeV*





Data and Event/Jet Selection

- **Data Used**
  - **3.2 fb^{-1}** of data.
  - Excluding runs with IBL Off
  - **HLT_j360**
    - Unprescaled single jet trigger

- **Jet Selection**
  - Anti-Kt EM Topo Jets, R=0.4
  - Jet Cleaning Applied
  - $p_T > 50$ GeV
  - **$|\eta| < 2.4$**, in tracking volume.

- **Event Selection**
  - At least two jets.
  - **$m_{jj} > 1.1$ TeV**, on the trigger plateau.
    - Leading-jet $p_T > 440$ GeV
  - **$|y^*| < 0.6$**, where $y^*=0.5^*(y_1 - y_2)$
    - More sensitive to BSM physics.

- **b-Tagging** (Next Slide)

Data

Selection criteria	N_{events}	Remain (%)	Rel. remain (%)
All	3.31478e+07	100%	100%
LAr	3.30707e+07	99.77%	99.77%
tile	3.30675e+07	99.76%	99.99%
NPV(+SCT)	3.30635e+07	99.75%	99.99%
Trigger	2.1681e+07	65.41%	65.57%
Jet selection	2.13722e+07	64.48%	98.58%
Trigger efficiency	1.16798e+07	35.24%	54.65%
Jet cleanning	1.16738e+07	35.22%	99.95%
Leading jet	4.66451e+06	14.07%	39.96%
Jet η	4.50223e+06	13.58%	96.52%
y*	2.52035e+06	7.60%	55.98%
m_{jj} >1.1 TeV	633885	1.91%	17.69%
Inclusive one *b*-tag	113124	0.34%	17.85%
Exclusive one *b*-tag	106743	0.32%	94.36%
Two *b*-tag	6381	0.02%	5.98%

Z' => bb: 1.5 TeV

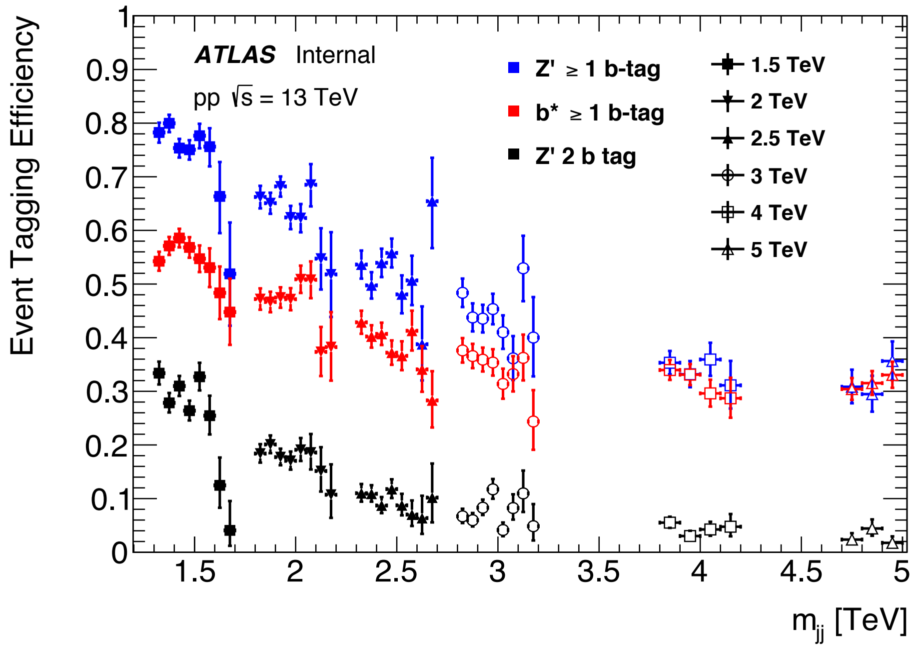
Selection criteria	N_{events}	Remain (%)	Rel. remain (%)
All	15000	100%	100%
Trigger efficiency	11394	75.96%	78.06%
Jet cleaning	11394	75.96%	100%
Leading jet	9692	64.61%	85.06%
Jet η	9592	63.95%	98.98%
y*	6367	42.45%	66.38%
m_{jj} >1.1 TeV	4596	30.64%	72.18%
Inclusive one *b*-tag	3522	23.48%	76.64%
Exclusive one *b*-tag	2253	15.02%	63.95%
Two *b*-tag	1270	8.47%	56.37%

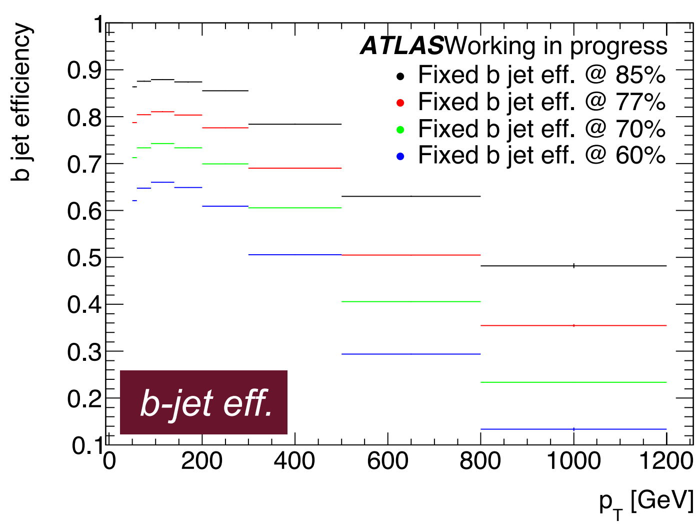
B-Tagging Strategy

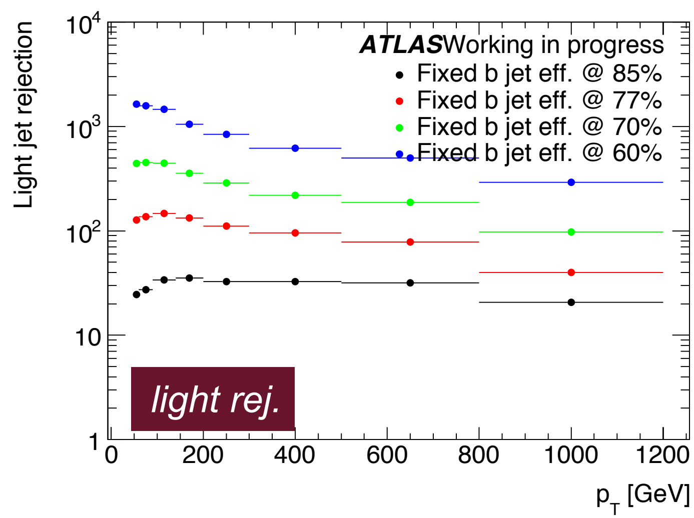
- **MV2c20** - **Fixed 85% Eff. WP**
  - MV2c20 > -0.7887
  - Calibrated and supported
  - Good sensitivity

- b-jet eff. ~ 50% at jet-p_T ~ 1 TeV
- Light-jet rejection ~ 30
  - Approximately flat
  - Good for background modelling.

- Two Categories
  - **"1b"** = ≥ 1 b-tag
  - **"2b"** = 2 b-tags





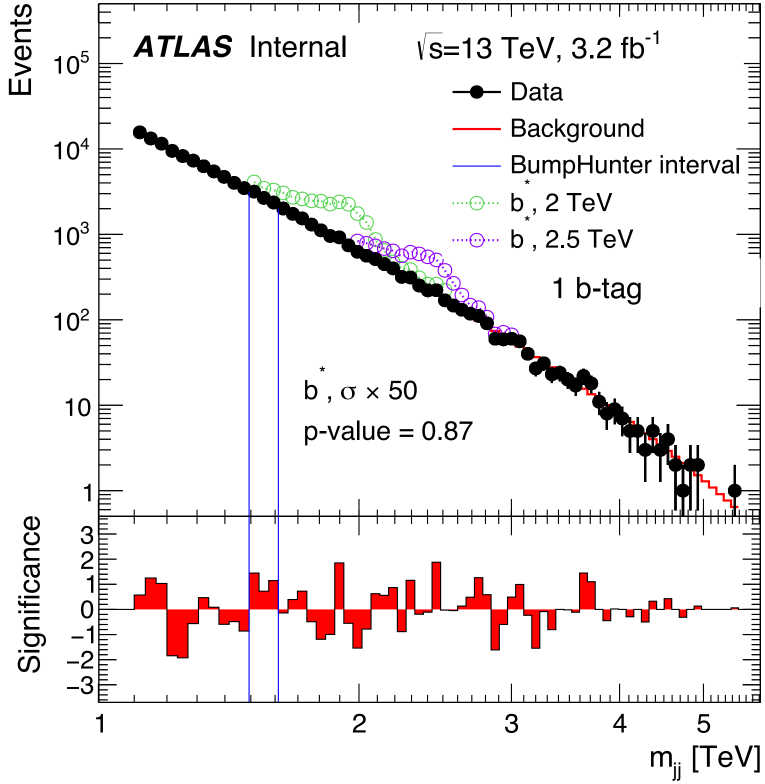


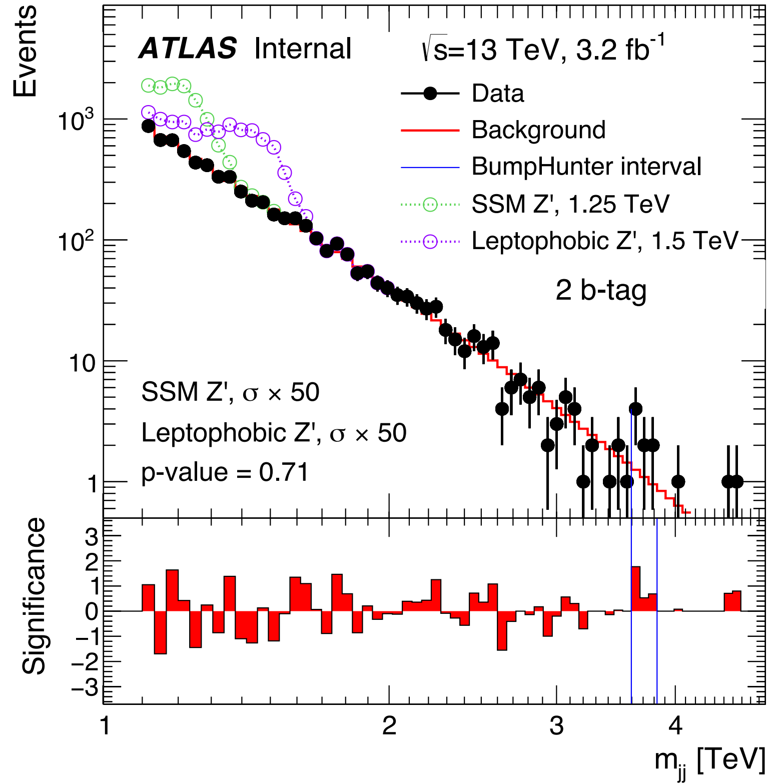
Data - Bump Hunter

- **Mass spectra in two b-tag categories**
  - $3.2\ \mathrm{fb}^{-1}$ of data, full data set
  - Background fitted with smoothly falling function

$$f(z) = p_1(1-z)^{p_2} z^{p_3}$$
$$\text{where} \quad z = m_{jj}/\sqrt{s}$$

- **BumpHunter searches for excesses**
  - Searches for statistically significant deviations.
  - Consecutive bins with smallest probability from background fluctuations
- **No excess found more significant than 3σ**



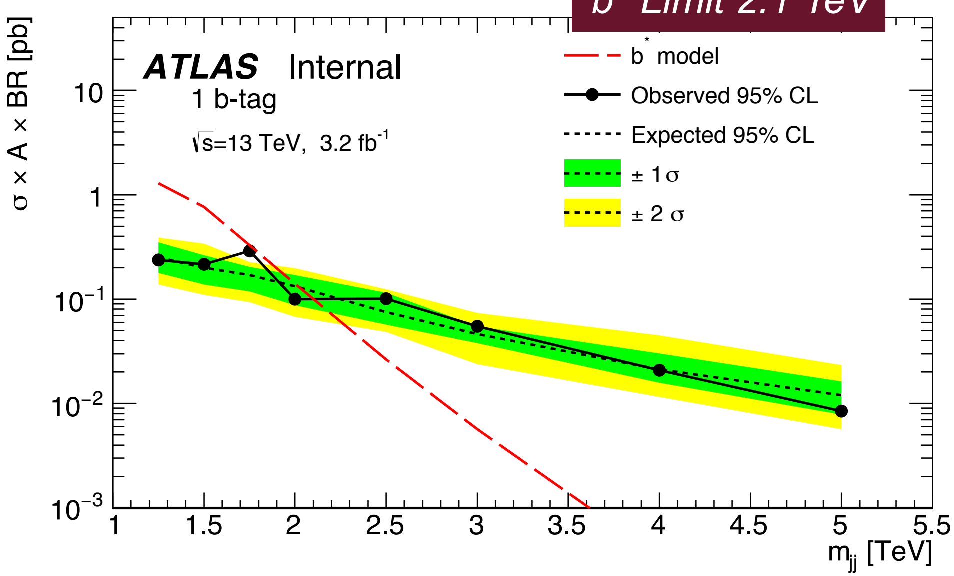


Limit Setting - b* and Z’

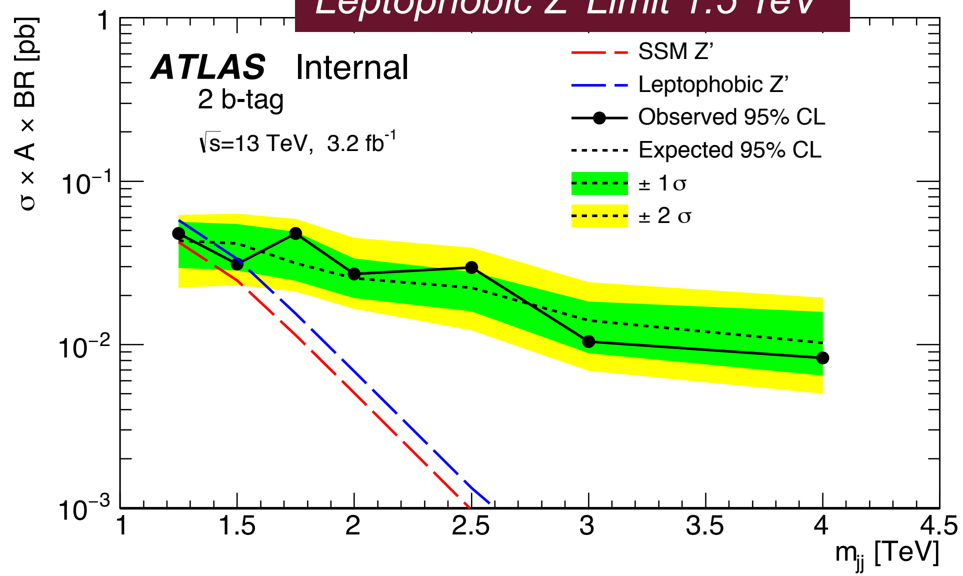
- **95% C.L. upper limits set for *b** and *Z’***
  - Use bayesian approach for limit setting
  - No correction for acceptance

- **Systematics:**
  - Luminosity uncertainty - 5% - From luminosity group
  - Background uncertainty
    - Uncertainties on fit function choice and fit parameters
  - Signal uncertainties
    - JES and bJES Uncertainties = Combined 6%
    - An additional BJES uncertainty < 2%
    - *b*-tagged scale factor uncertainty - 20-50% for masses 1.1-5 TeV

b Limit 2.1 TeV*



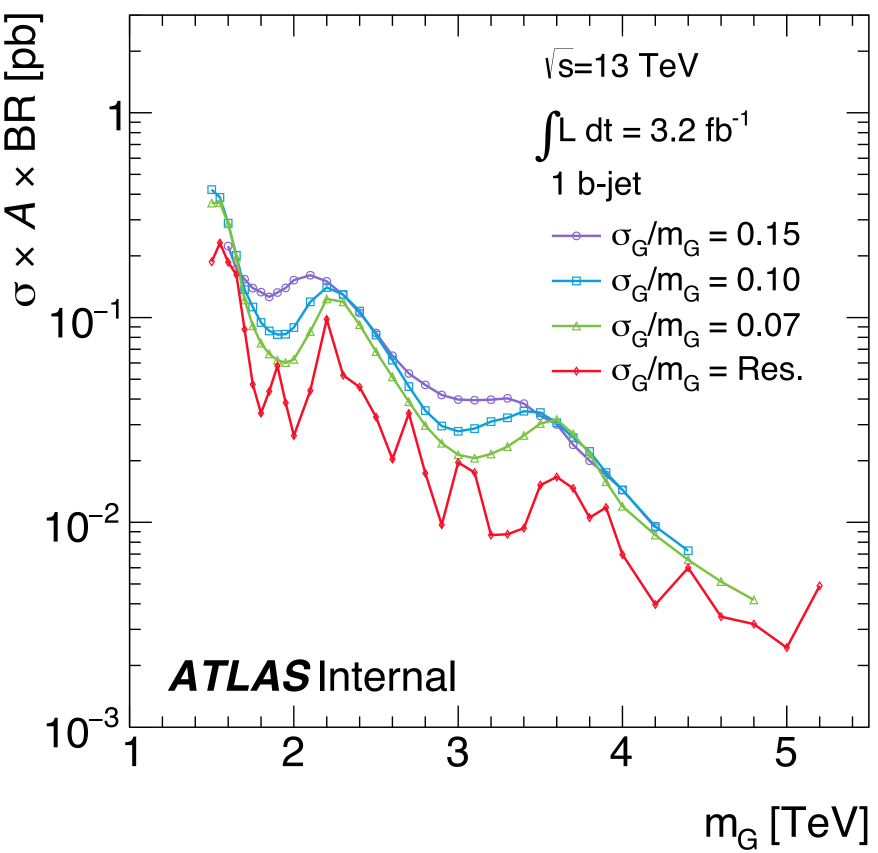
Leptophobic Z’ Limit 1.5 TeV

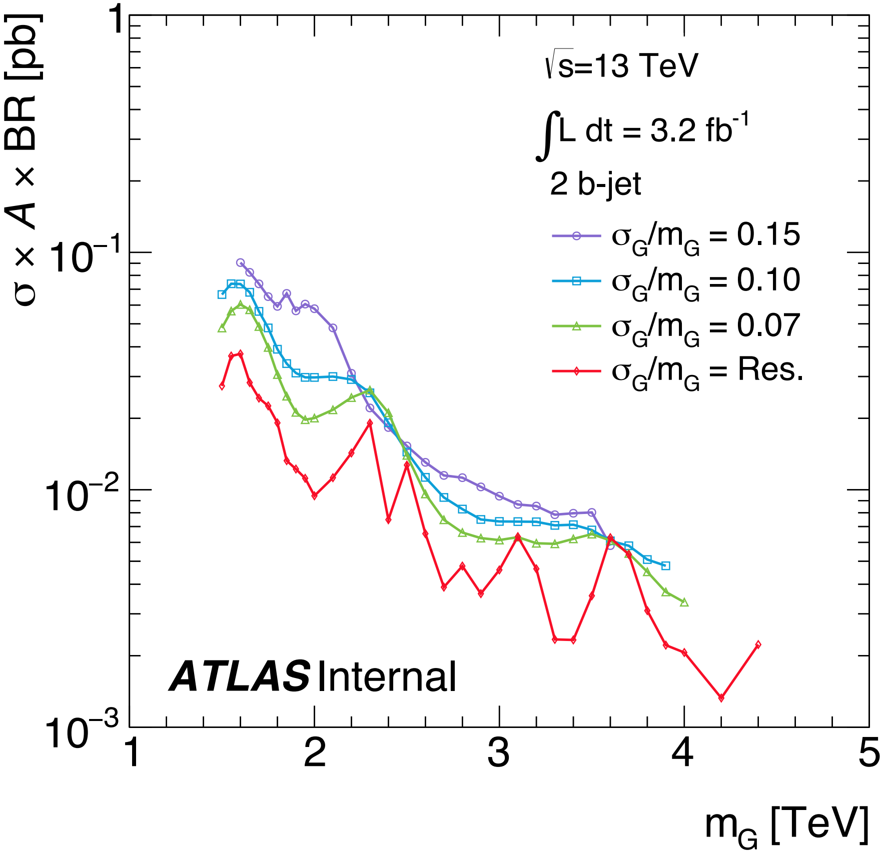


Limit Setting - Gaussian Signal

- **95% C.L. upper limits set for Gaussian Signal**
  - Use bayesian approach for limit setting
  - No correction for acceptance

- **Gaussian Signal Shape**
  - Varied signal width: From detector resolution to 15% of resonance
  - Exclusion on effective cross section: 0.3 - 0.001 pb in mass range 1.5 - 5 TeV

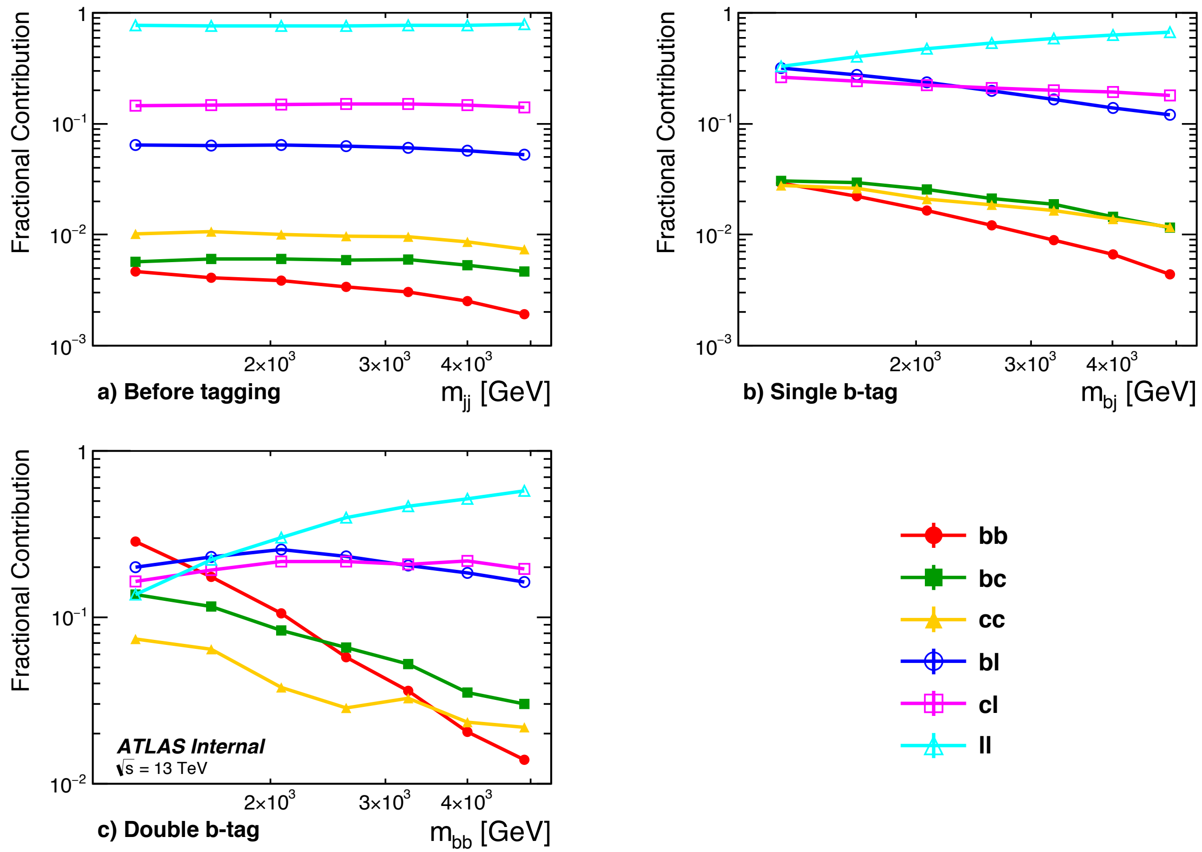




Flavour Composition Studies

Getting the Flavour Fractions

- Flavour composition of the single b-tag and double b-tag changes as a function of mass.
  - This is due to b-tagging efficiency dependance on jet-pT



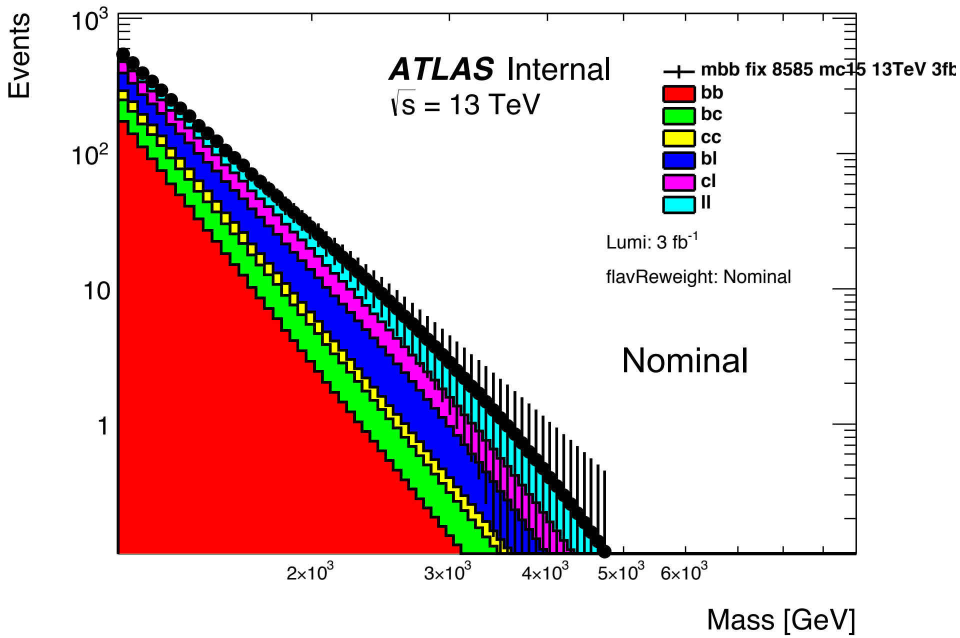
- We want to understand how varying the flavour composition will affect the fitting function.
  - Are the fitting functions robust to changes flavour composition?
  - Do we need an additional systematic for this?

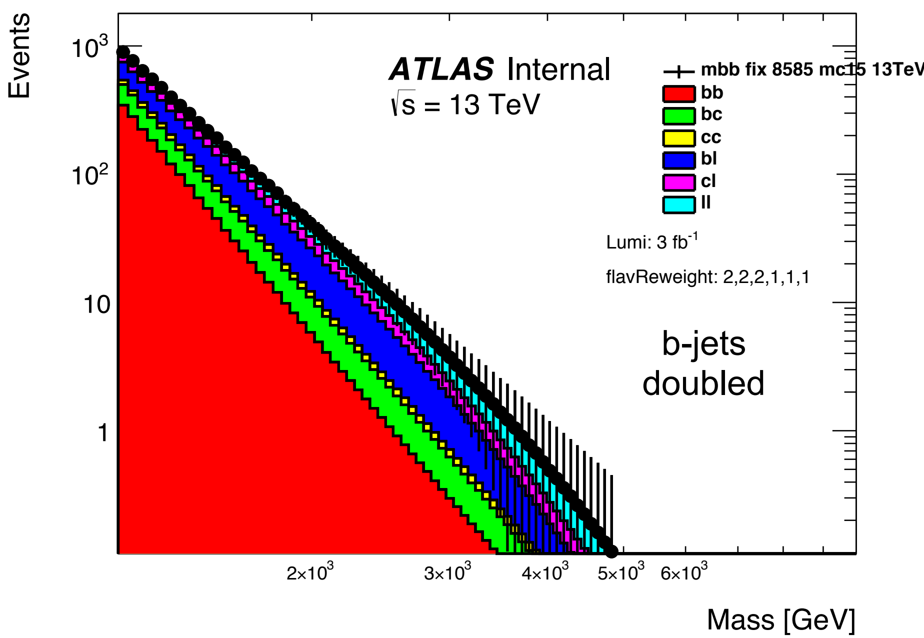
- Vary the amount that different flavour combinations contribute and fit.

Stacking the Flavour Fractions

- Take mass spectrum of each flavour combination from MC (bb, bc, cc, bl, cl, ll)
  - Fit to each spectrum scaled to 20ifb using our fitting function.
  - Use the fit each combination as a template.

- Create new scaled like distributions.
  - Adding templates from fits to 20 fb^{-1} scaled to 3 fb^{-1}
  - Adding the fractions in different ways to produce various spectra

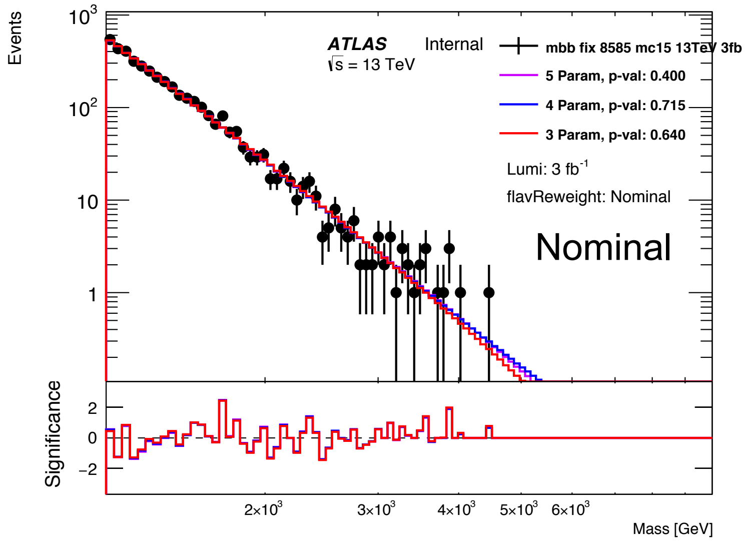


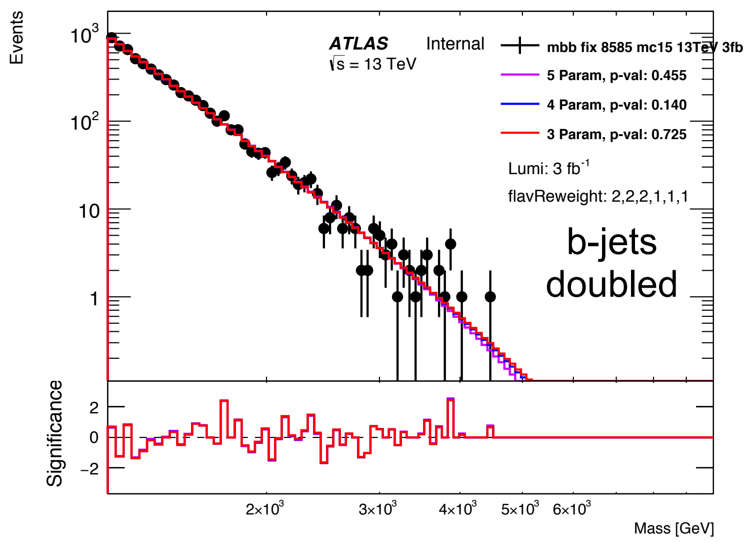


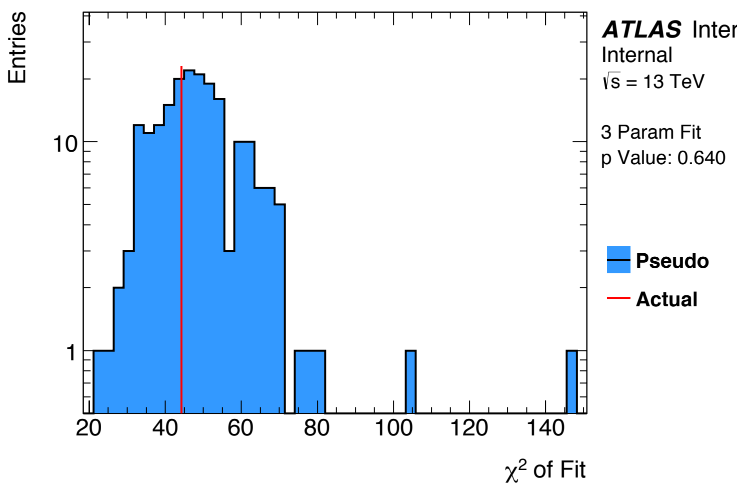
Data-Like p-Values

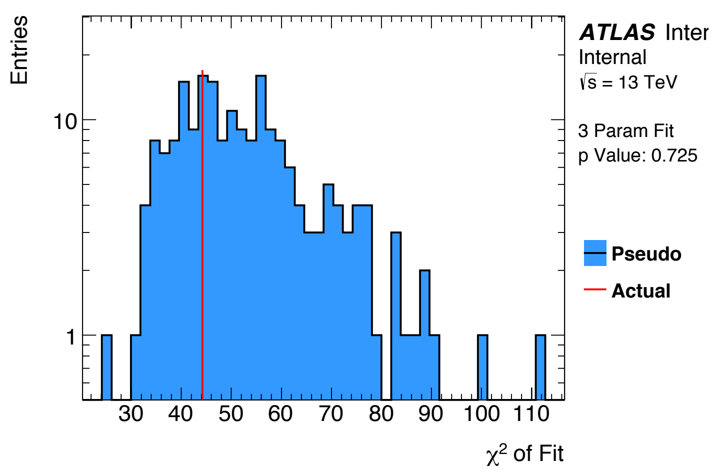
- By applying poisson fluctuations we can create 'data-like' distribution
- These are fitted using the 3, 4 and 5 parameter fit function
- Fitting function:

$$f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x+p_5(\ln x)^2}, \quad \text{with } x \equiv m_{jj}/\sqrt{s}$$



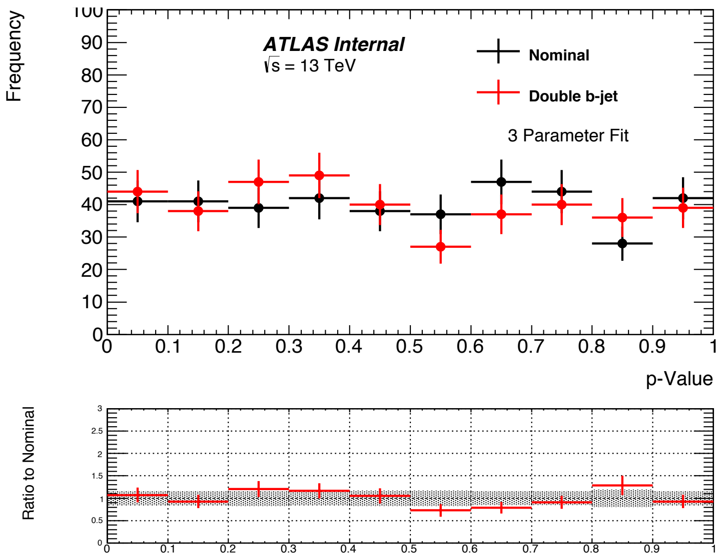


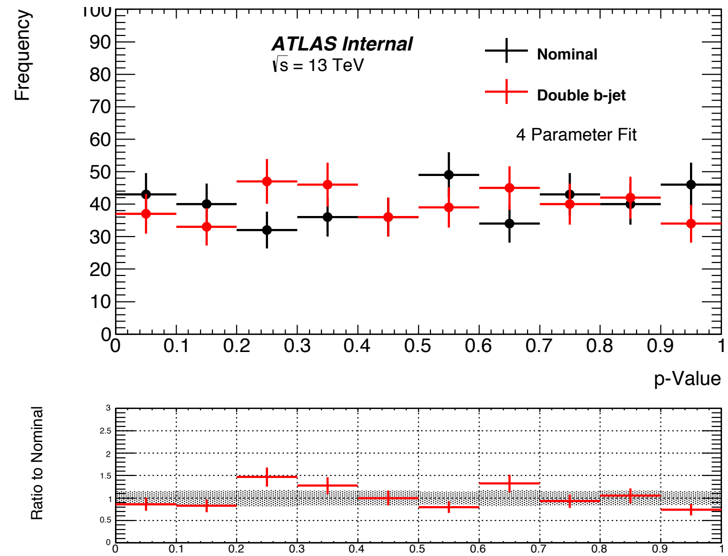


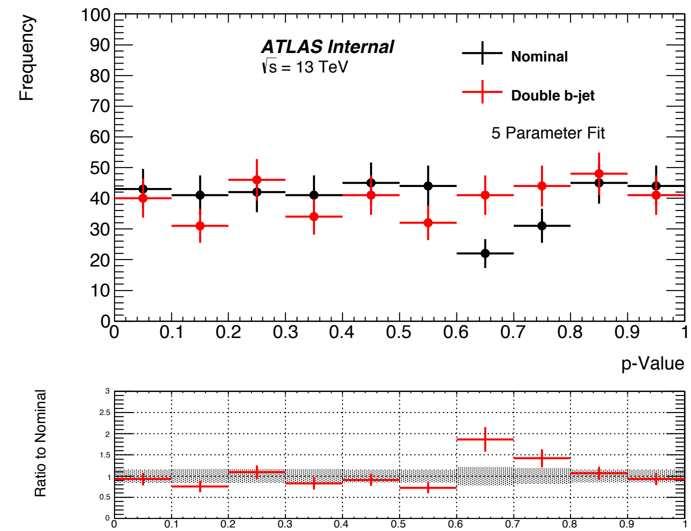


p-Value studies

- Different sets of poisson fluctuations means a different ‘data-like’ spectrum
- Each ‘data-like’ dist. can be fitted to, giving a different p-value for each fit variation.
- 400 different data-like distributions have been studied





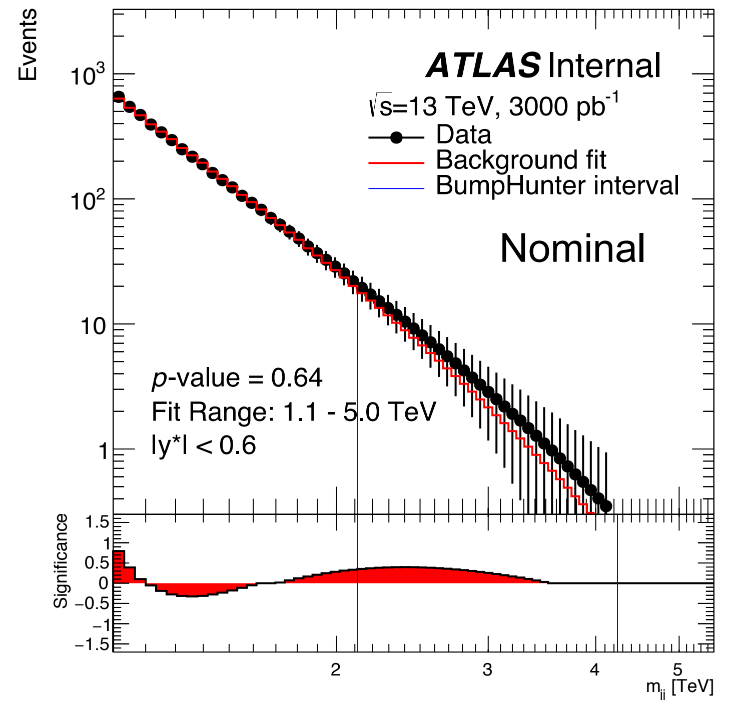


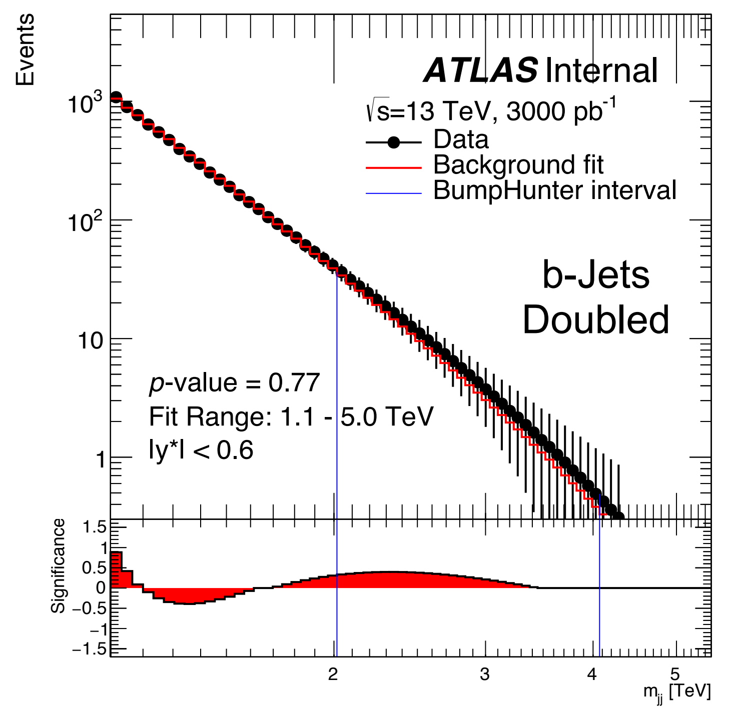
Mean p-values

	3-Para. Fit	4-Para. Fit	5-Para. Fit
Nominal	0.492 +/- 0.014	0.508 +/- 0.015	0.488 +/- 0.015
b-jet Doubled	0.478 +/- 0.014	0.495 +/- 0.014	0.514 +/- 0.022

Spurious Signal

- Spurious signal
  - If there is discrepancy between fit and data then this can be mistaken as signal
- Test for spurious signal
  - Use scaled spectra before Poisson noise
  - Fit to this spectra using fit function
  - BumpHunter will identify discrepant region
  - BH then can calculate p-value
- Mass Range of Fit
  - 1.1 - 5 TeV
  - Larger than mass range in data.

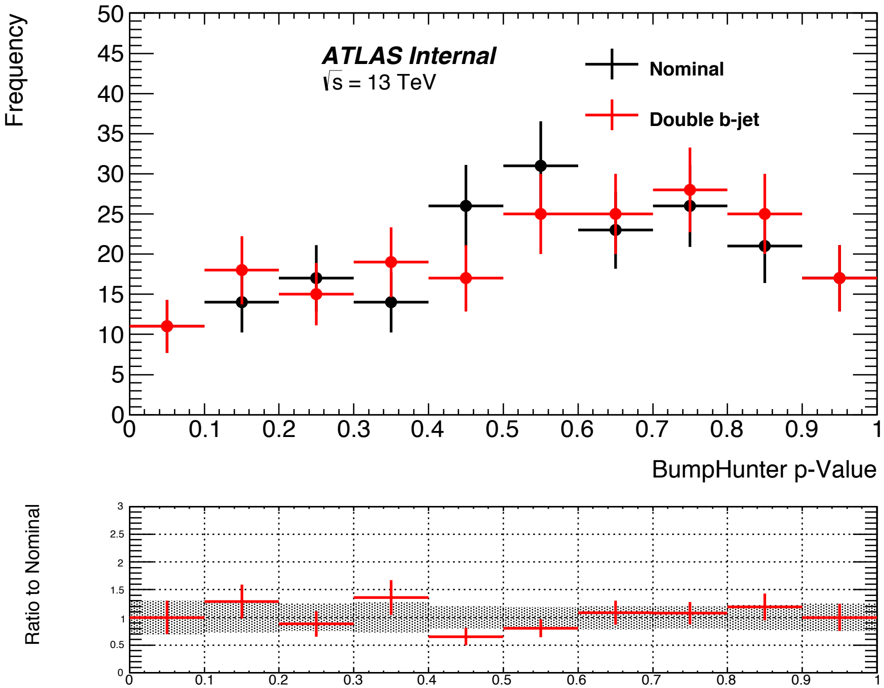




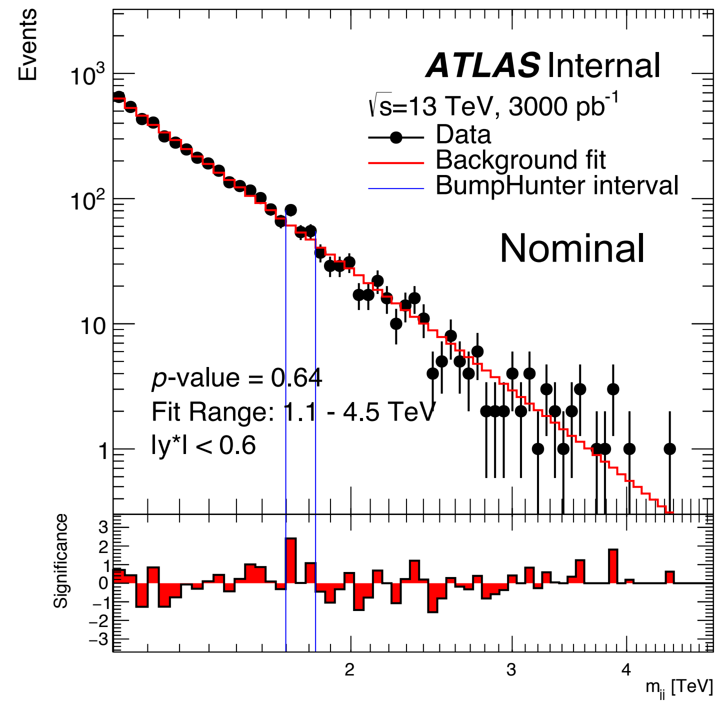
- No significant spurious signal found.
- Consistent p-Value in both flavour composition cases
- Wide discrepant region
  - Unlike benchmark models

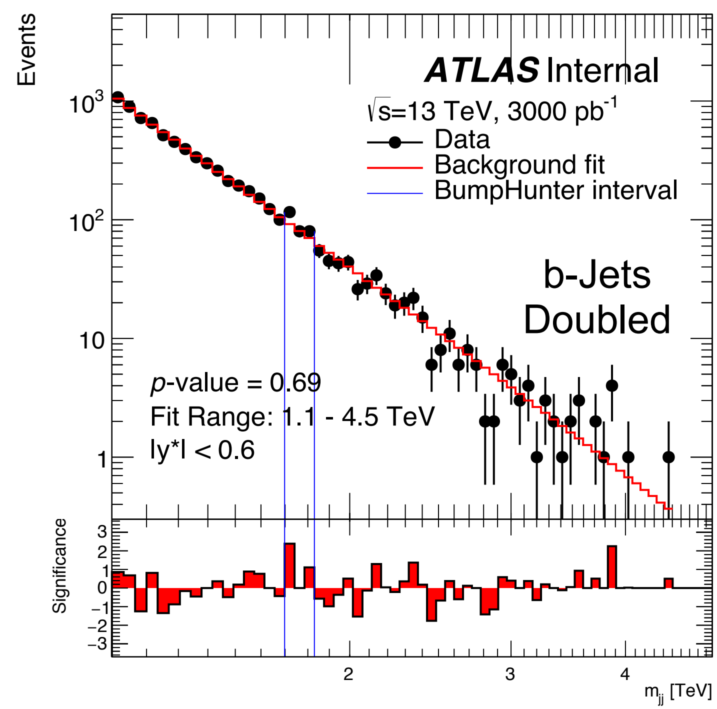
Spurious Signal - Data Like

- Test for spurious signal in data-like distributions
  - Repeat process after poisson fluctuations
  - Try 200 different set of poisson fluctuations.



- No clear bias in p-value
  - No large ‘false alarm’ rate
  - Poisson fluctuations dominate discrepancy
- Consistent for both flavour composition cases





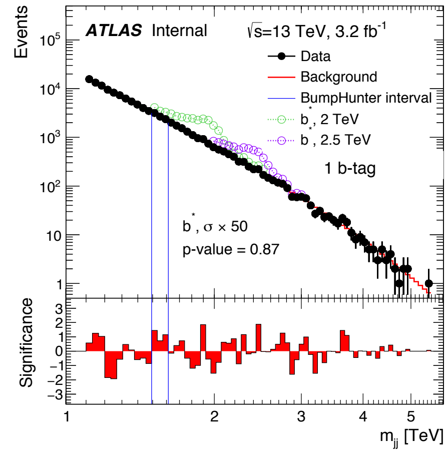
Summary

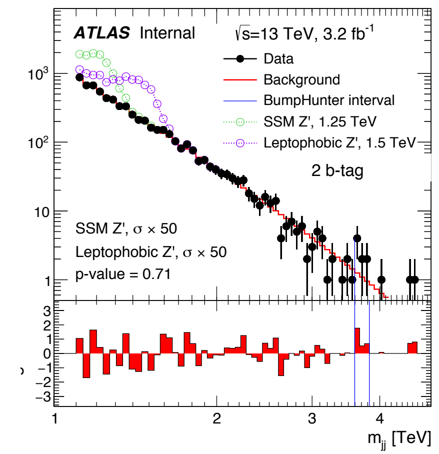
- **b-Tagged di-jet search**
  - First such analysis at ATLAS
  - Similar strategy to inclusive di-jet analysis
  - Use of very high pT b-tagging

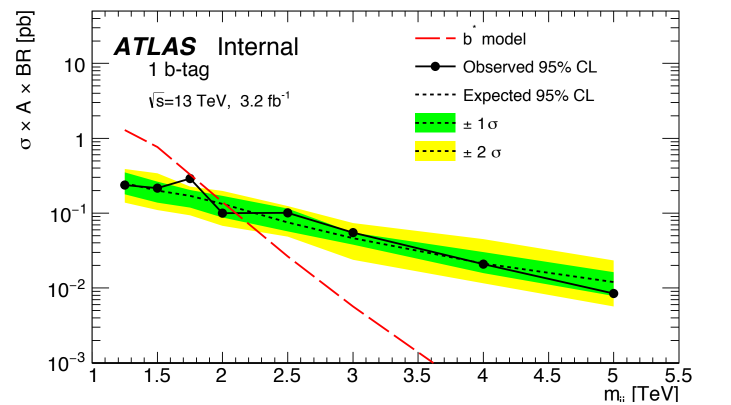
- **Searched 3.2 fb^{-1} of data**
  - Inclusive 1 b-tag and 2 b-tag spectra
  - No significant excess observed
  - Limits set on b* and leptophobic Z'
  - Also set limit on generic Gaussian signal

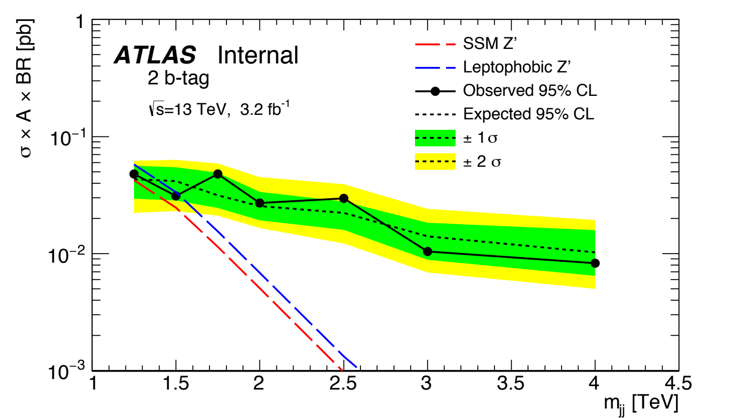
- **Fit robust to changes in flavour composition**
  - Fit p-value consistent when flavour comp. is changed
  - No need for additional systematic.
  - No spurious signal introduced.

- **On course for Moriond paper!**
  - Paper and INT Note written
  - Comment from Open Presentation Addressed
  - In circulation now!









Backup!

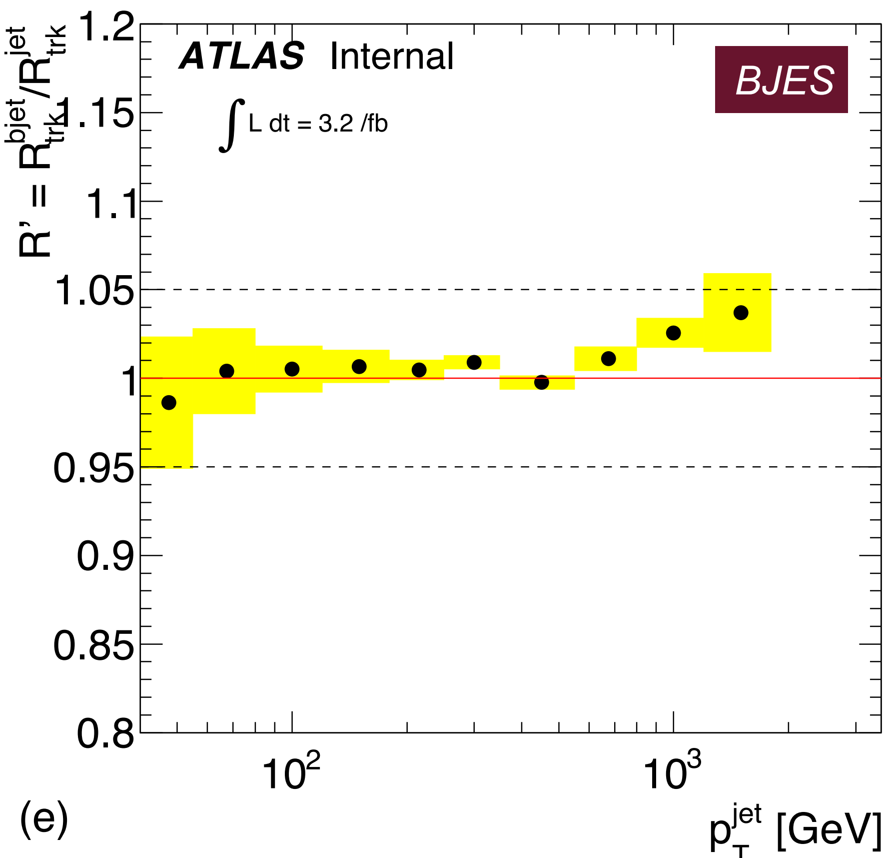
- Calculate using ratio of tracks within jet cone to reconstructed calo jet.
  - Use a double ratio between b-tagged jets and inclusive jets

- Additional bJES uncertainty < 2.6 for pT range
  - Applied on top of normal JES of 1-5%
  - Total b-Jet uncertainty of 6% assigned.

- Approved in JES/JER Meetings

$$R' = \frac{< r^{trk}_{bjet} >_{Data} / < r^{trk}_{bjet} >_{MC}}{< r^{trk}_{inc} >_{Data} / < r^{trk}_{inc} >_{MC}}$$

where $r^{trk} = \frac{\sum \vec{p}_T^{\,trk}}{p_T^{jet}}$



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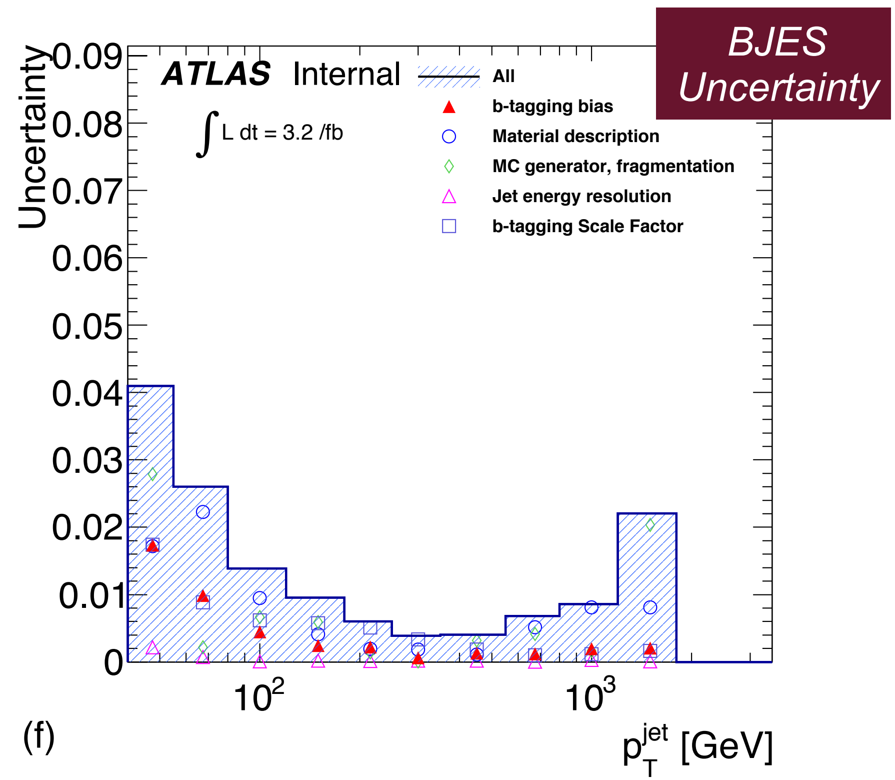

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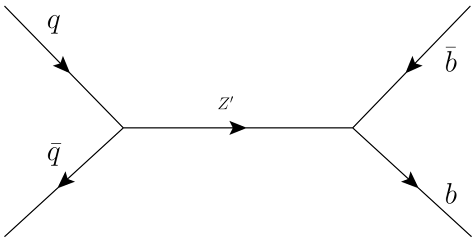
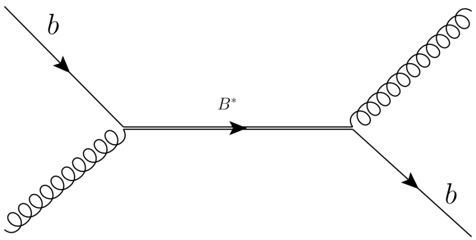
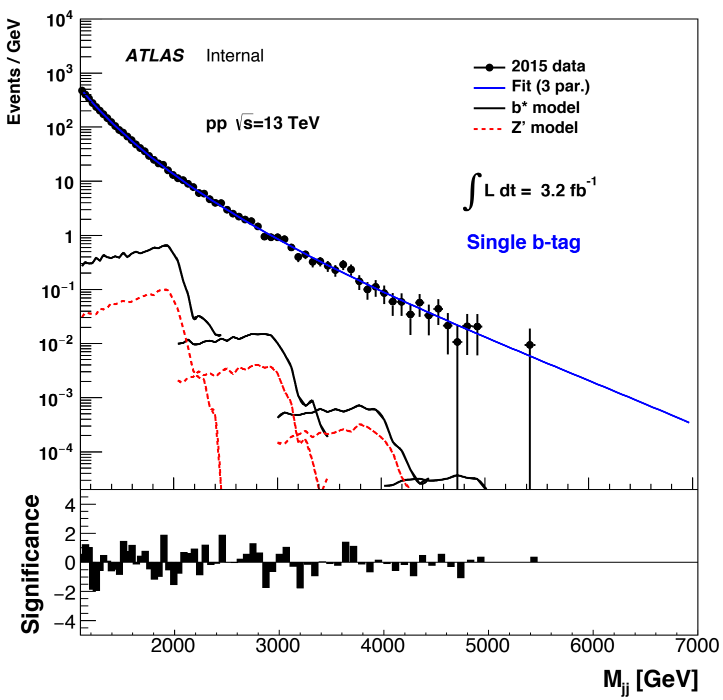
Signal Models

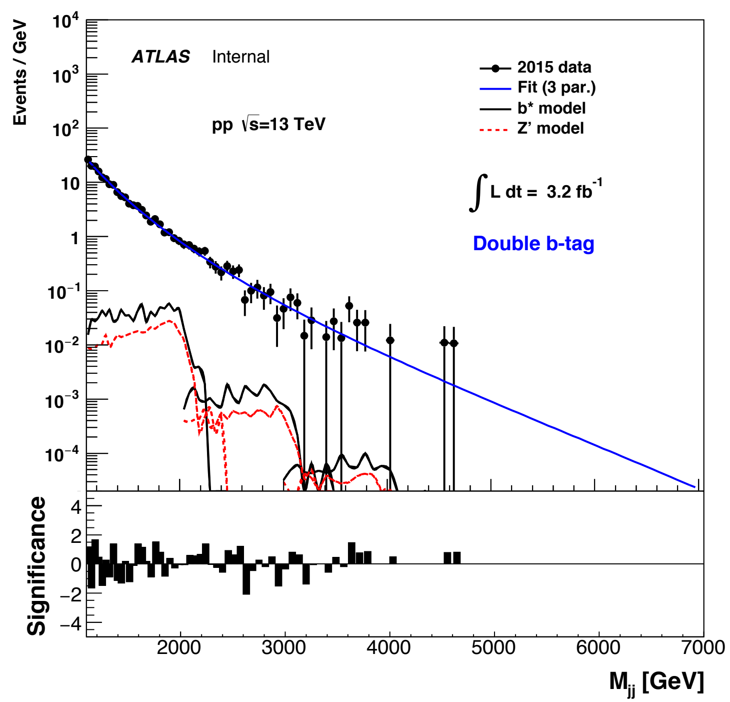
- Benchmark models - We can set limits here.
  - **Z' => bb** - 1.25, 2, 3 and 4 TeV
    - SSM and Leptophobic
  - **b* => b+X** - 1.25, 2, 3, 4 and 5 TeV
  - **Generic Gaussian**
  - Templates taken from MC samples





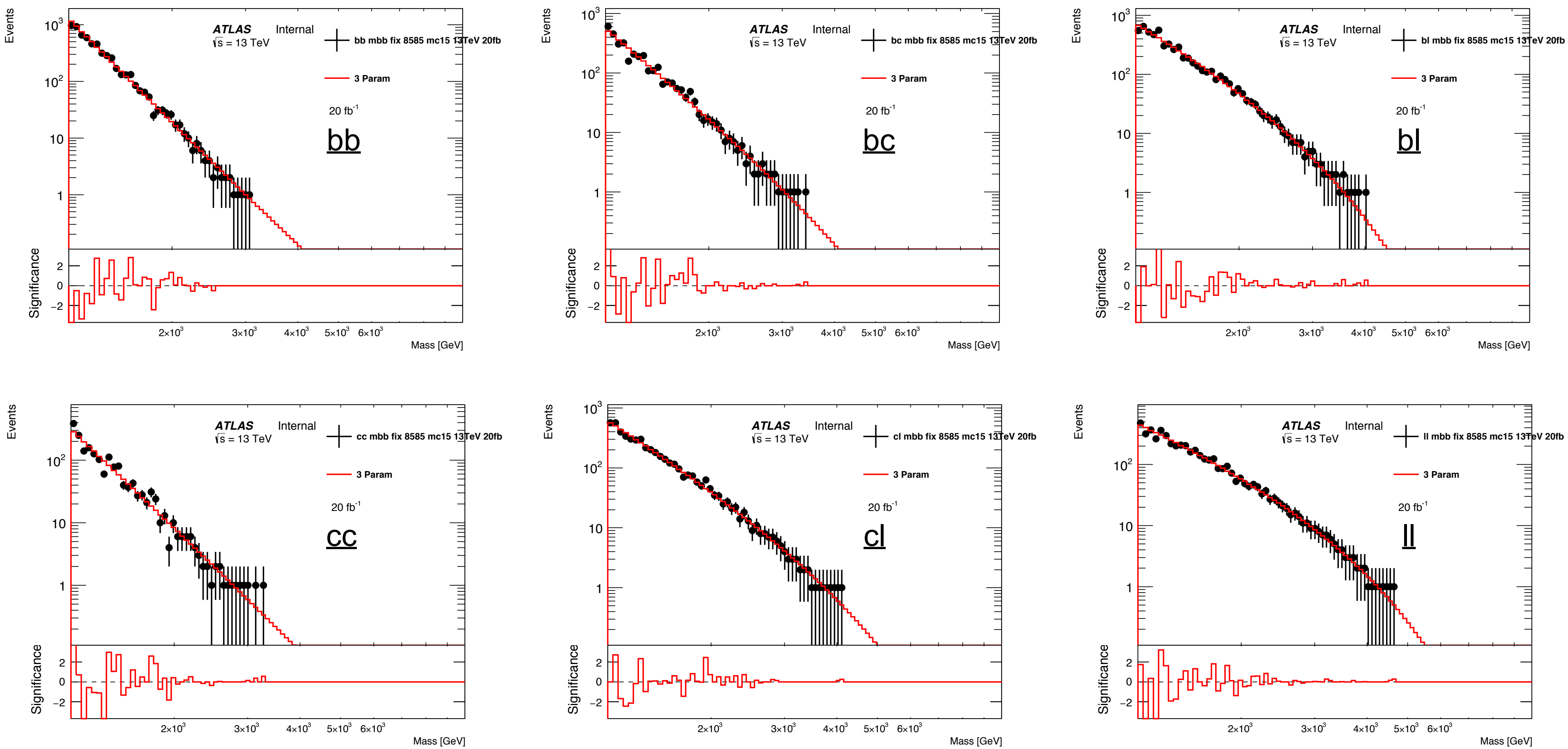
- Generic search performed for a Gaussian signal.
  - Resonance width taken from the benchmark





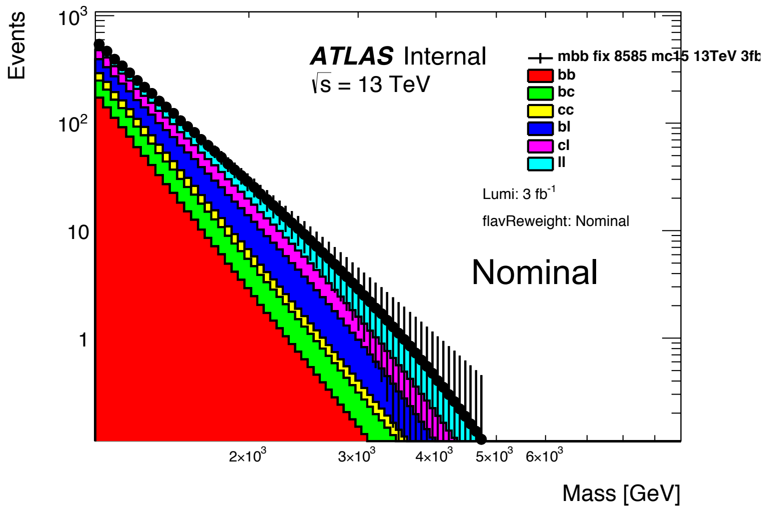
Getting the Flavour Fractions

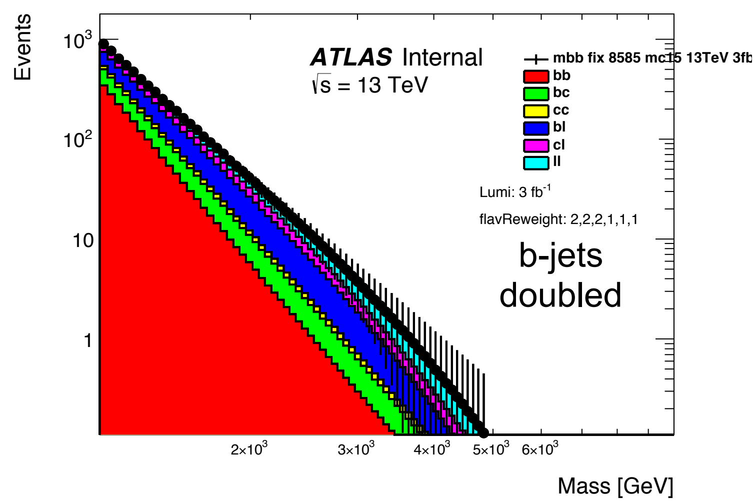
- Flavour fractions are extracted from MC using truth information
- The dijet mass spectrums for these flavour fractions are then scaled to 20fb^{-1}
- The dijet mass spectrums are fitted to using the **3-parameter** fit function.

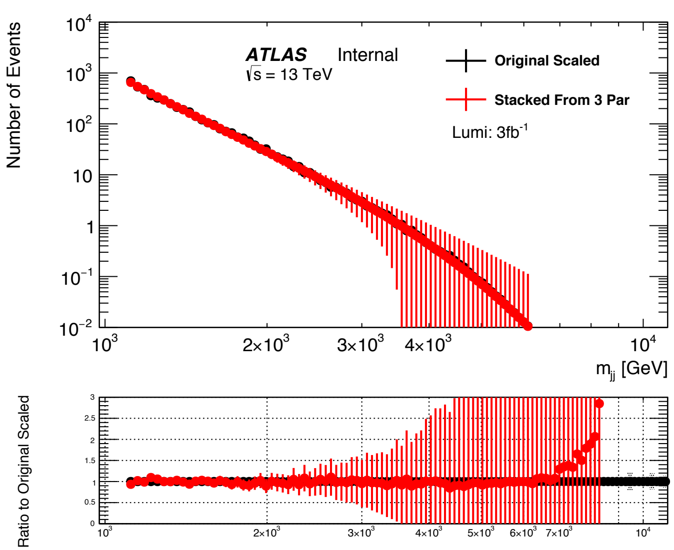


Stacking the Flavour Fractions

- Creates new scaled like distributions.
  => Adding templates from fits to 20 fb^{-1} scaled to 3 fb^{-1}
  => Adding the fractions in different ways to produce various spectra

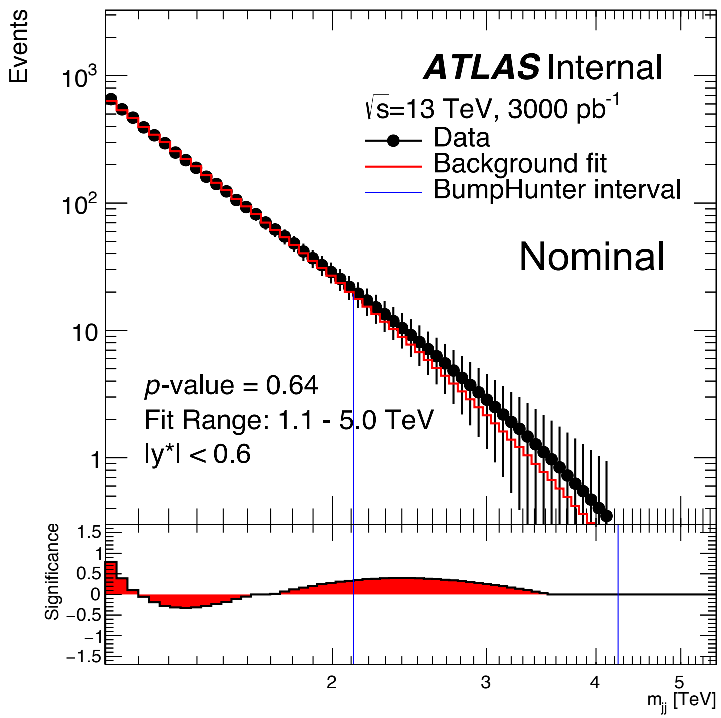


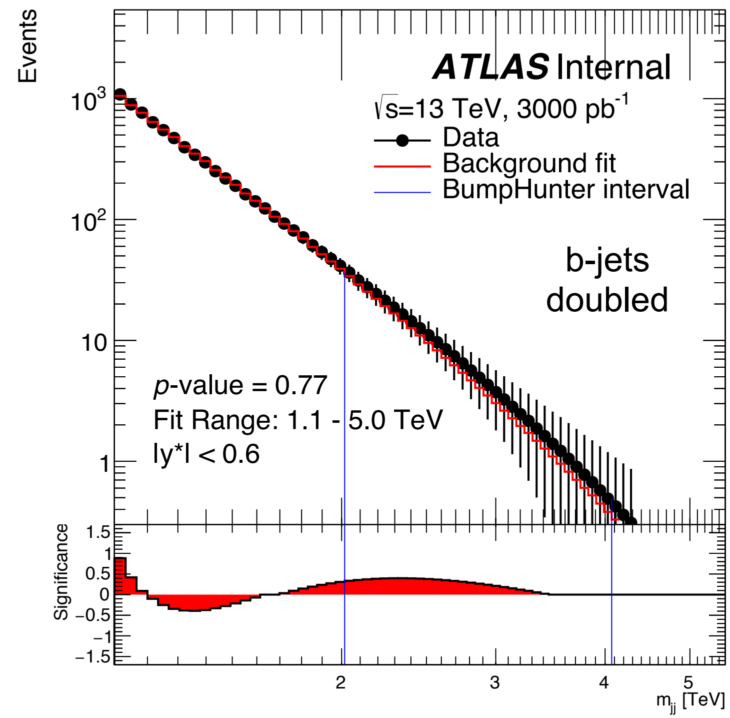


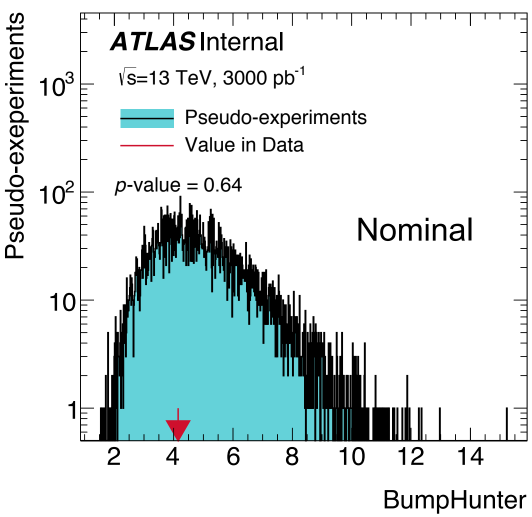


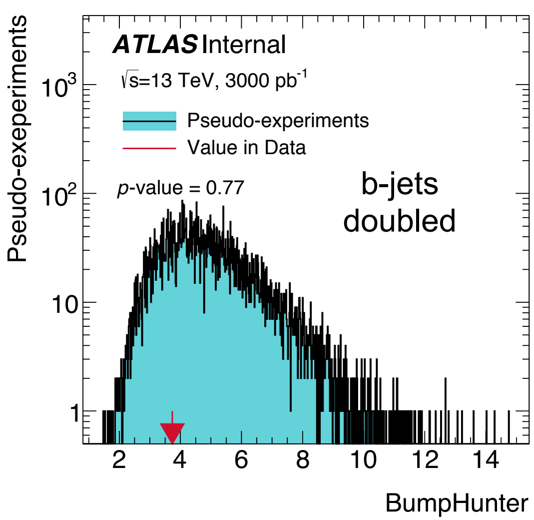
- Able to reproduce MC up to large masses.
- We conclude that the procedure of fitting to flavour fractions then stacking is appropriate.

Test for Spurious Signal - Results









- No significant spurious signal found.
- Consistent p-Value in both flav. composition cases
- Wide discrepant region => Unlike benchmark models