Update on Dibjet Analysis

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UCL Meet

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Search for resonances below 1.2 TeV in the mass distribution of jet pairs with two jets identified as b-jets in proton-proton collisions at $\sqrt{s}$=13 TeVwith the ATLAS detector.

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Abstract

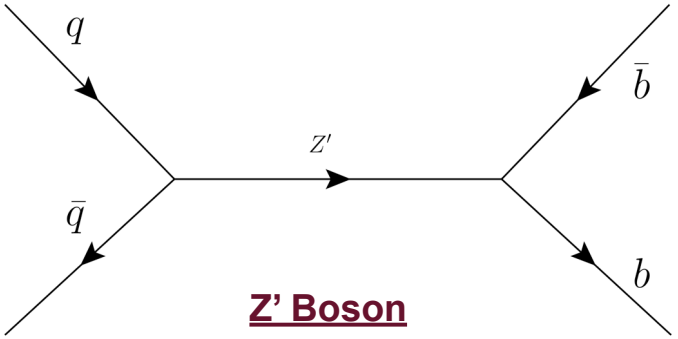
Searches for mass resonances in the b-tagged dijets invariant mass spectrum below 1.2 TeV have been performed with the ATLAS detector at the LHC. The dijet mass distribution from 0.57 TeV to 1.2 TeV is studied. The sensitivity was optimized considering a 750 GeV narrow resonance and the search was initially performed blinded in the 700-800 GeV mass region. The 2015 proton-proton collision data at $\sqrt{s}$ = 13 TeV is used, corresponding to an integrated luminosity of 3.2 fb^{-1}. No significant deviations from the Standard Model expectation have been observed and upper limits have been set on the two b tagged dijet masses at 95% confident level.

INT Note in CDS - Here

Conf Note in CDS - Here

Introduction: Motivation

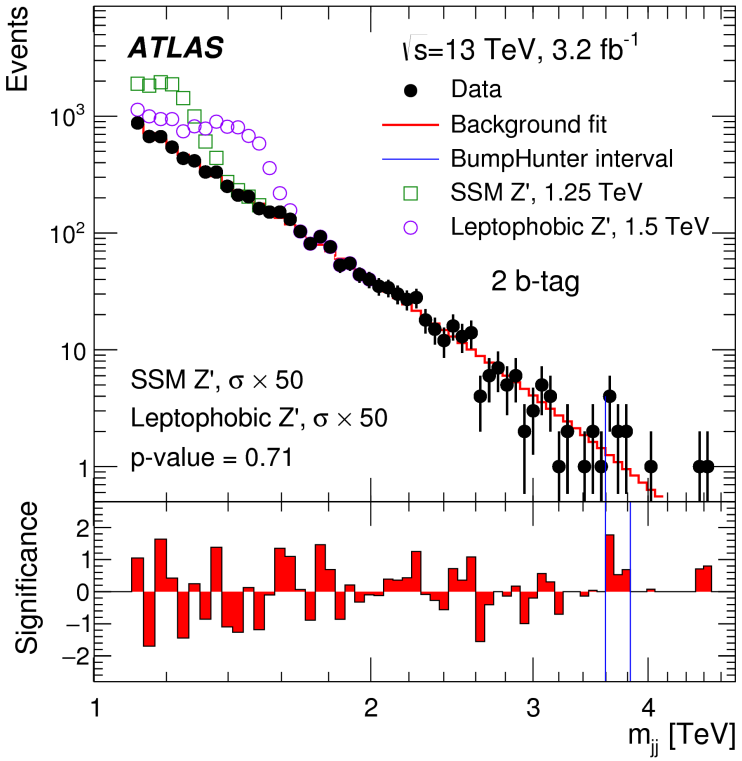
- **Many BSM models predict resonances that decay to b-quark(s)**
  - E.g. Z' Boson



Z' Boson

- **b-Tagging Increases Sensitivity**
  - Large QCD background
    - Dominated by light jets
    - *(light = u, d, s and gluon)*
  - Increased sens. to these models

- **Perform Resonance Search**
  - Similar strategy as inclusive dijet
  - Fit using smoothly falling function
  - Use BumpHunter to find excesses



- **Moriond High Mass Paper**
  - m_{jj} > 1.1 TeV
  - >= 1 b-tag and 2 b-tag category
  - No significant excesses found

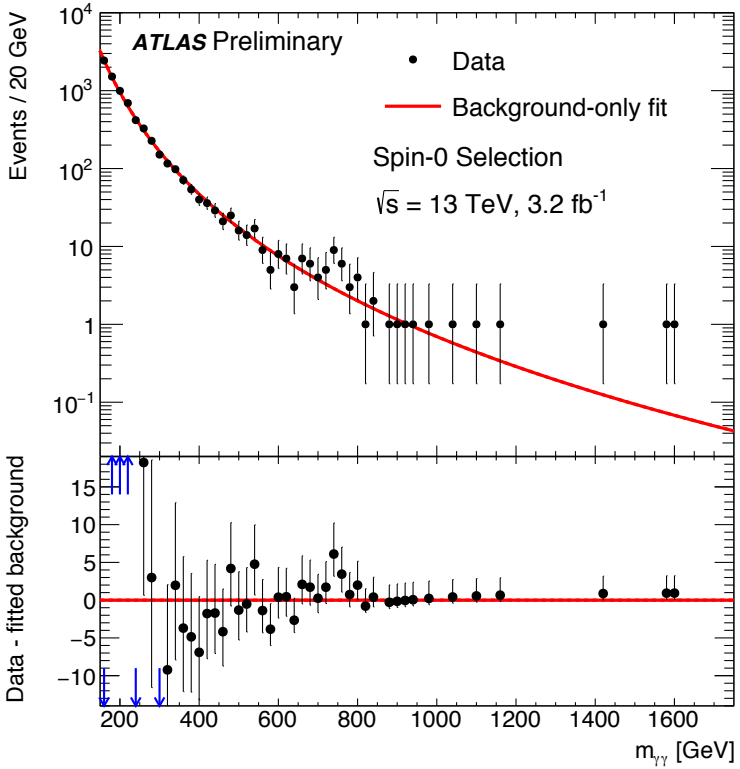
arXiv:1603.08791

Introduction: Low Mass Analysis

- **Motivation to go to lower masses**
  - **Cross over between γγ and bb?**
  - Assume scalar couples to bb and γγ only
    - Estimate $\sigma_{\gamma\gamma}$ and Γ from diphoton
    - Theorists calculate σ_{bb}, *(arXiv:1512.04933)*
      - ~0.4 pb @ 8 TeV
      - ~2.1 pb @ 13 TeV

- **Weak limits on BSM at low mass**
  - Limits on above model are weak
    - < 1pb @ 8 TeV, *(arXiv:1506.08329)*
    - No limits @ 13 TeV
  - **We should study this region…**

- **New Trigger Strategy Required**
  - Last time limited by trigger turn on
    - **HLT_j360** *(Unprescaled single jet trigger)*
  - We can use b-jet trigger
    - **HLT_j175_bmedium_j60_bmedium**
    - 566 < m_{jj} <1200



Can be done with 2015 Data

LHCP Note!

Event and Jet Selection

- **Trigger and Data**
  - **3.2 fb^{-1}**, excluding IBL off data
  - **Double b-jet trigger:**
    HLT_j175_bmedium_j60_bmedium
- **Jet Selection**
  - Anti-k$_T$ EM Topo Jets, R=0.4
  - **Leading Jet, p_T > 230 GeV**
  - **Sublead. Jet p_T > 90 GeV**
  - Both jets, |η| < 2.4
- **Event Selection**
  - **566 < m_{jj} < 1200 GeV**
    - Previously blinded 700-800 GeV
  - **|y*| < 0.6**, *y*= 0.5 *Δy*
    - Central region more sensitive to BSM
- **Offline b-Tagging**
  - **MV2c20 @ 70% WP**
    - Online tagging limits b-jet eff.
    - Gain Light jet rej. from offline

Data - *Full 3.2 fb^{-1}*

Selection criteria	N_{events}	Remain (%)	Rel. remain (%)
all	1139851904	100	100
GRL, evt cleaning	33811024	3.0	3.0
trigger	3606231	0.32	10.7
jet η	3448909	0.30	95.6
b-tag leading jet	1769740	0.16	51.3
b-tag sub-leading jet	971029	0.085	54.9
leading jet $>$ 230 GeV	269327	0.024	27.7
sub-leading jet $>$ 90 GeV	259379	0.023	96.3
y* $<$ 0.6	155186	0.014	59.8
$m_{jj} > 566$ GeV	32460	0.003	20.9

MC Z' -> bb - *m_Z = 800 GeV*

Selection criteria	N_{events}	Remain (%)	Relative remain (%)
all	19800	100%	100%
evt cleaning	11414.3	57.6%	57.6%
leading jet $>$ 230 GeV	10574.7	53.4%	92.6%
sub-leading jet $>$ 90 GeV	10458.4	52.8%	98.9%
jet η	10256.9	51.8%	98.1%
y* $<$ 0.6	7319.8	37.0%	71.4%
two b-tag	2649.9	13.4%	36.2%
trigger	2239.7	11.3%	84.5%
$m_{jj} > 566$ GeV	1709.1	8.6%	76.3%

Event and Jet Selection - Extras

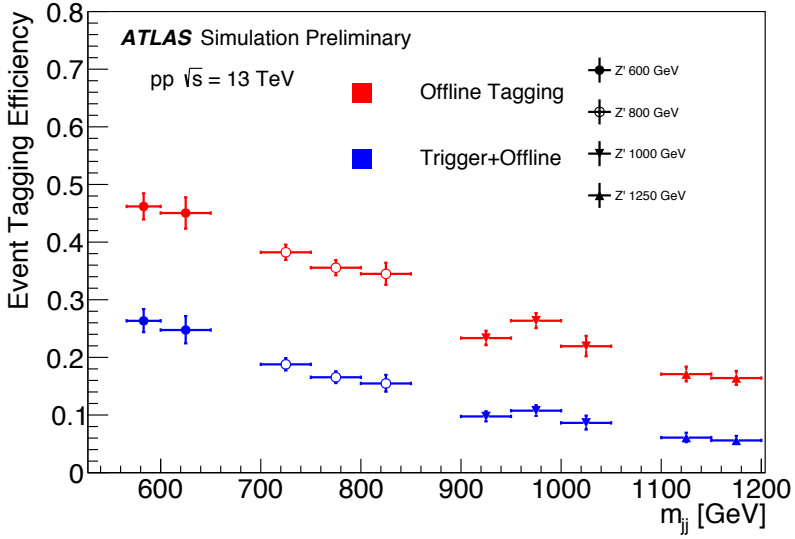
- **Offline b-Tagging**
  - **MV2c20 @ 70% OP**
    - Online tagging limits b-jet eff.
    - Gain Light jet rej. from offline

- **Operating Point Selection**
  - Preliminary
  - Various b-tagging OP
  - Acceptance efficiency of Z'
    - $m_{Z'}$ = 800 GeV
    - Emulating trigger efficiency
  - Expected # events from sideband fit
  - Expected Gaussian limits
    - Width 10% of mass

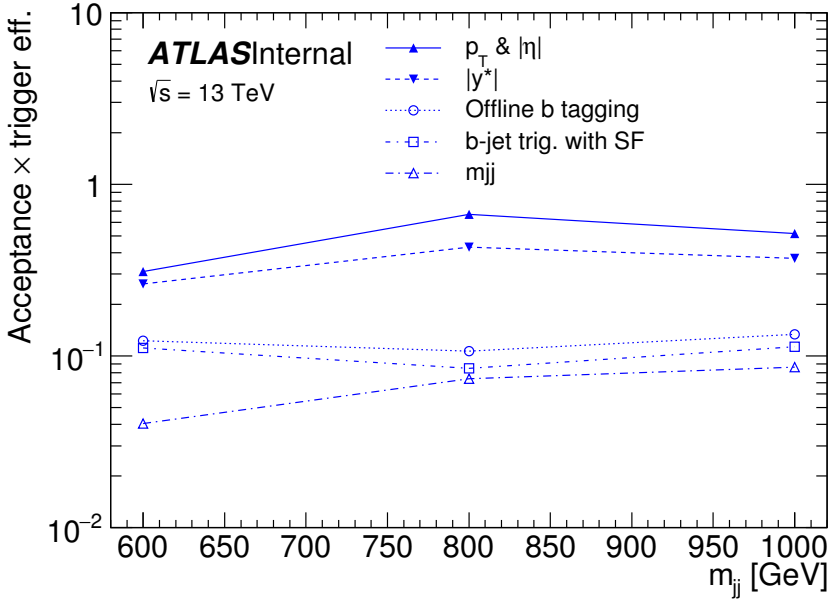
b-tag OP	Eff (%)	N_{evt}^{exp}(bkg) in SR	Exp limit (pb)
85	9	8800	1.2
77	9	6000	1.0
70	8	4400	1.0
60	6	2800	1.1

Preliminary Study for OP selection only!

Signal Tagging Efficiency

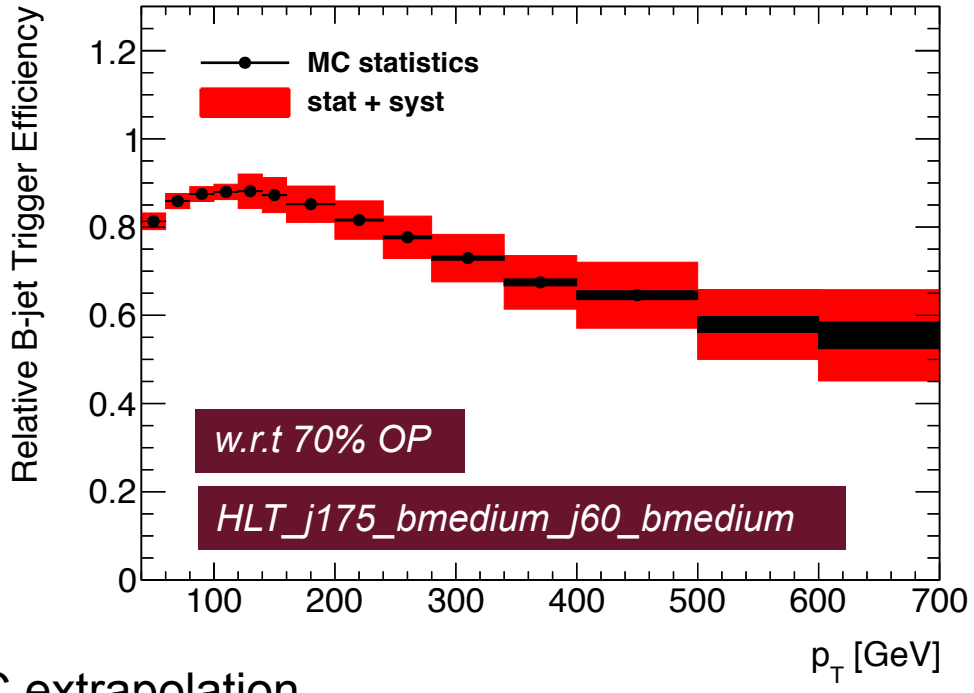


Signal Efficiency



b-Jet Triggers

- **b-Jet Triggers to get to low masses**
  - 2015 data: IP3D+SV1 Algorithm
- **HLT_j175_bmedium_j60_bmedium**
- **b-Jet Triggers Efficiency**
  - Derive b-Jet Trigger Efficiencies
    - Data driven technique
  - Use high purity ttbar sample
  - bPerf triggers (no cut applied)
  - Jet P_T < 120 GeV we can use data
  - Jet P_T > 125 GeV we use a Data/MC extrapolation



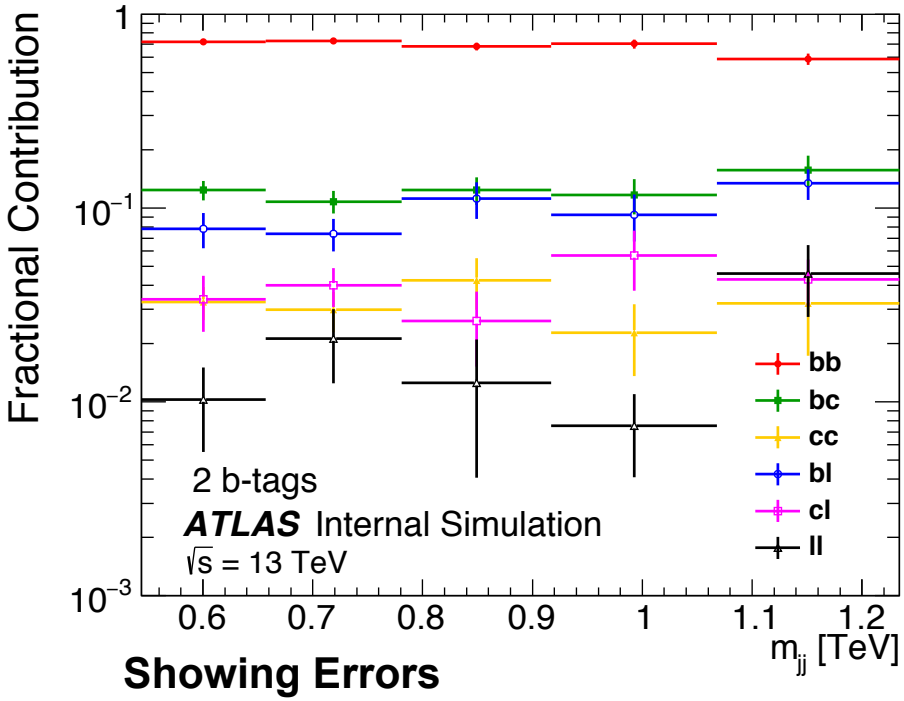
- **b-Jet Trigger Strategy**
  - Efficiencies are applied to signal samples to emulate trigger
  - Not required for background - Exact light-jet and c-jet rejections not needed
    - Use fit to model background rather than MC

$$\text{b-Jet Trig Eff. wrt offline} = \frac{\text{\# b-Jets pass offline and online b-tagging}}{\text{\# b-Jets offline b-tagging}}$$

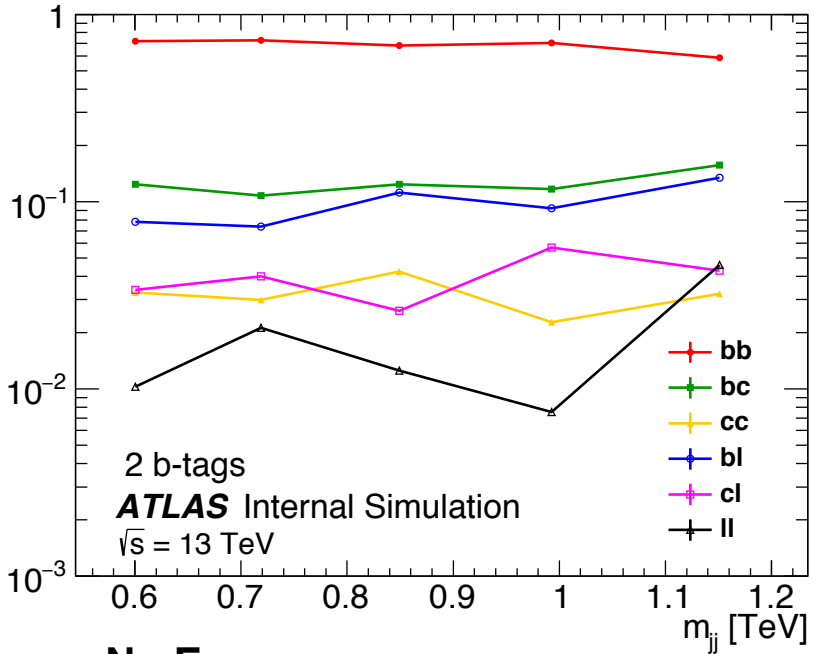
Kinematics: Flavour Composition

- **Flavour Composition from MC**
  - Applying b-tagging, emulating online b-tagging

- **Emulating online b-tagging**
  - Light/Charm online b-tagging efficiencies not known
  - Estimated from fit to non-b-jet efficiencies (slide 1)



Showing Errors



No Errors

- **Dominated by bb**
- **Flavour fractions are changing smoothly**

Statistics: Fitting

- **Using Dijet Fitting Procedure**
  - Used in high-mass inclusive dijet and b-tagged dijet search
  - 5 parameter (para.) Dijet Function :

    => 3 para.; $p_4 = p_5 = 0$

    => 4 para.; $p_5 = 0$

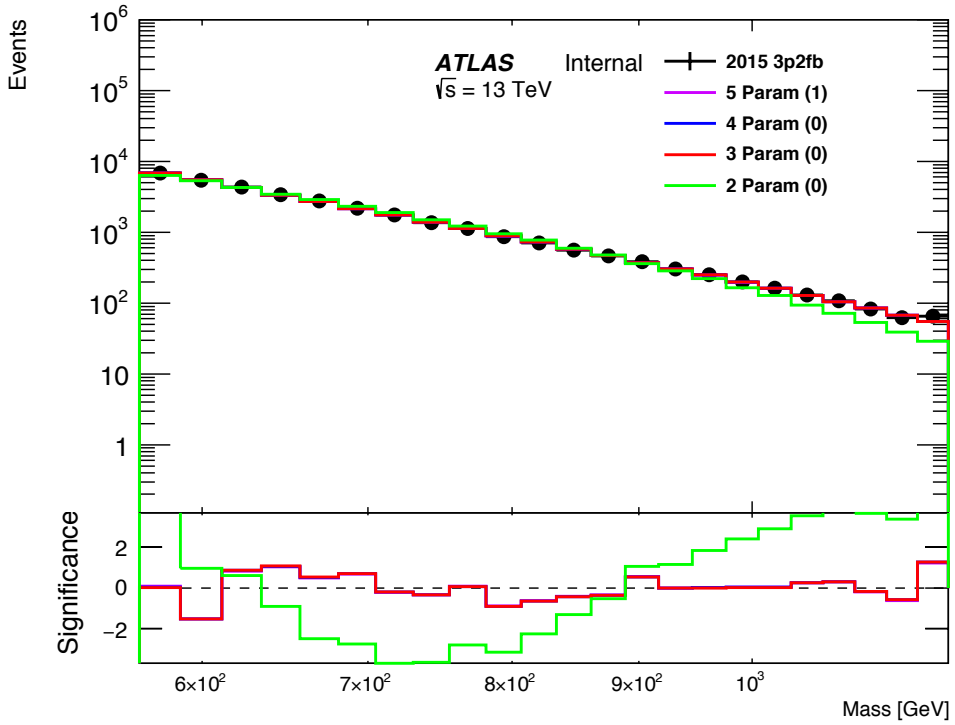
$$f(x) = p_1(1-x)^{p_2}(x)^{p_3+p_4\ln x+p_5(\ln x)^2}$$

- **Function Choice; Wilks' Statistic**
  - Begin with by choosing the 3 para. function.
  - Use Wilks' test statistic to compare 3 to 4, if it drops below a threshold switch to 4
  - Repeat for 4 to 5.

In data we choose

3 Parameter

Wilks' Stat = 0.83

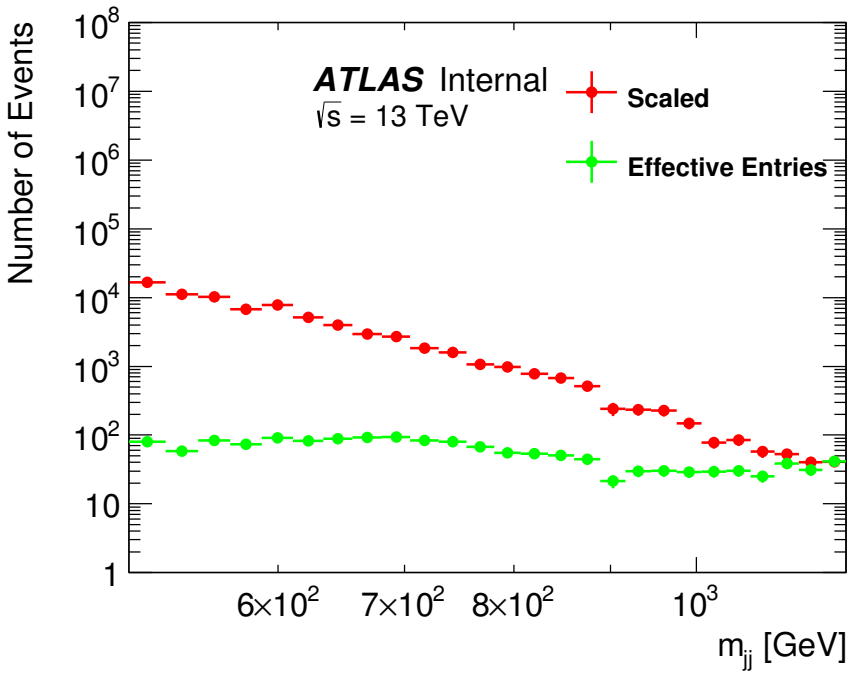


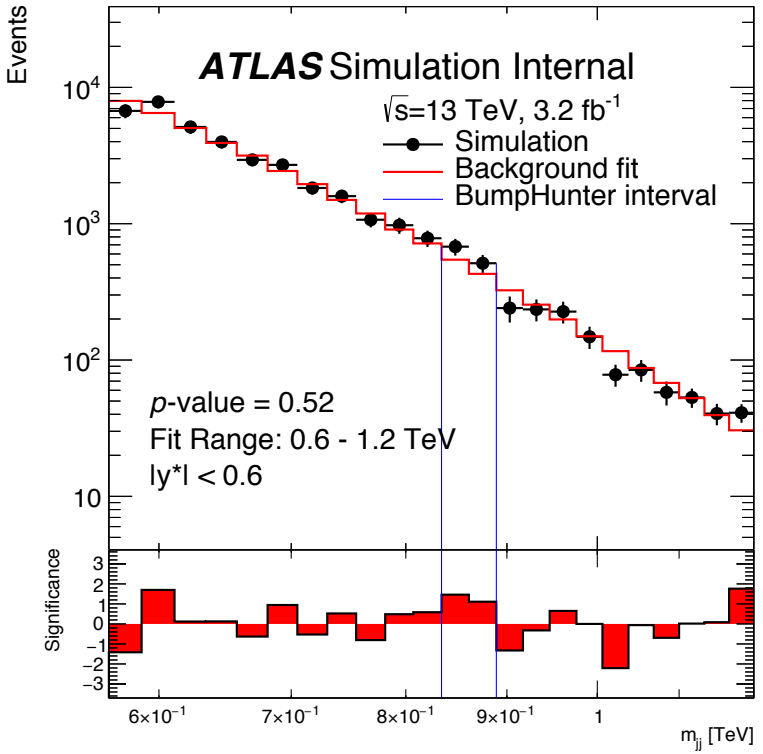
Statistics: Spurious Signal - MC

- **Confirm that fits discrepancies are not significantly occurring**
  - Fit discrepancy = A difference in shape between fitting function and background
  - Fit discrepancy may hide true signal or create fake signal
  - Test fit function by performing fits to a representative background only data set

- **Monte Carlo:** *Pythia8 Dijet Sample*
  - Same cuts as data, trigger emulated using p_T dependant trigger efficiencies *(slide 10)*
  - Problems with statistics, Effective Entries < Scaled Entries

    => Not poisson-like errors

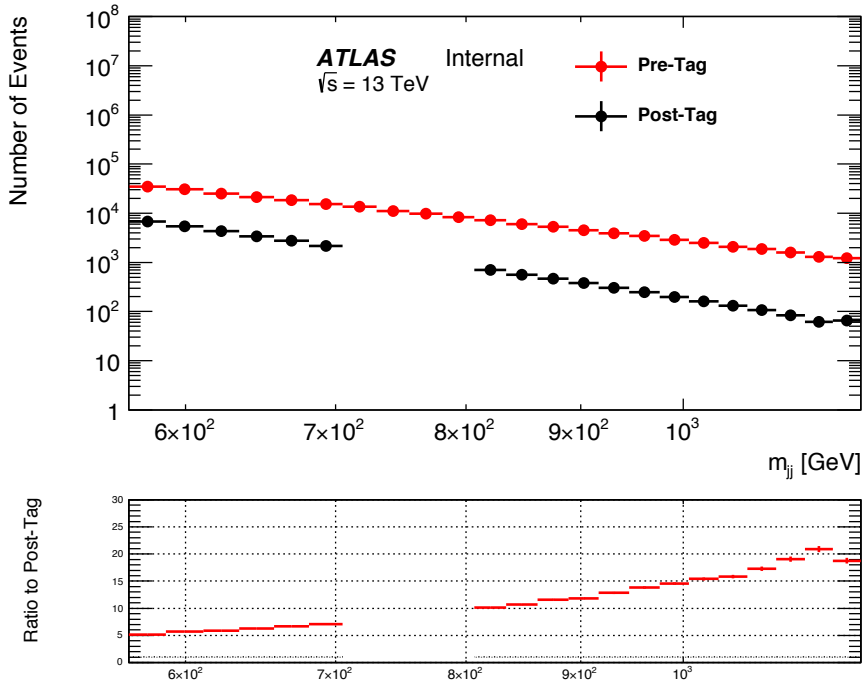


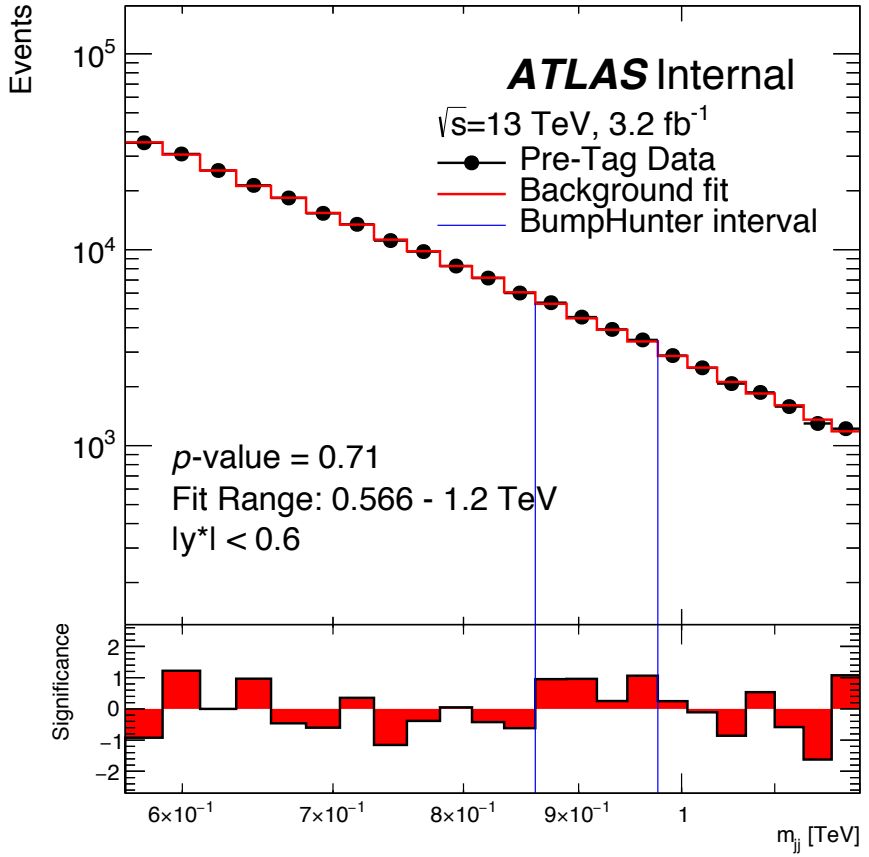


Statistics: Spurious Signal - Data, Trigger Only

- **Fit to Data with Trigger Applied**
  - b-Tagging not applied.
  - Dominated by bl, but this give us a similar, but different control region to test fitting

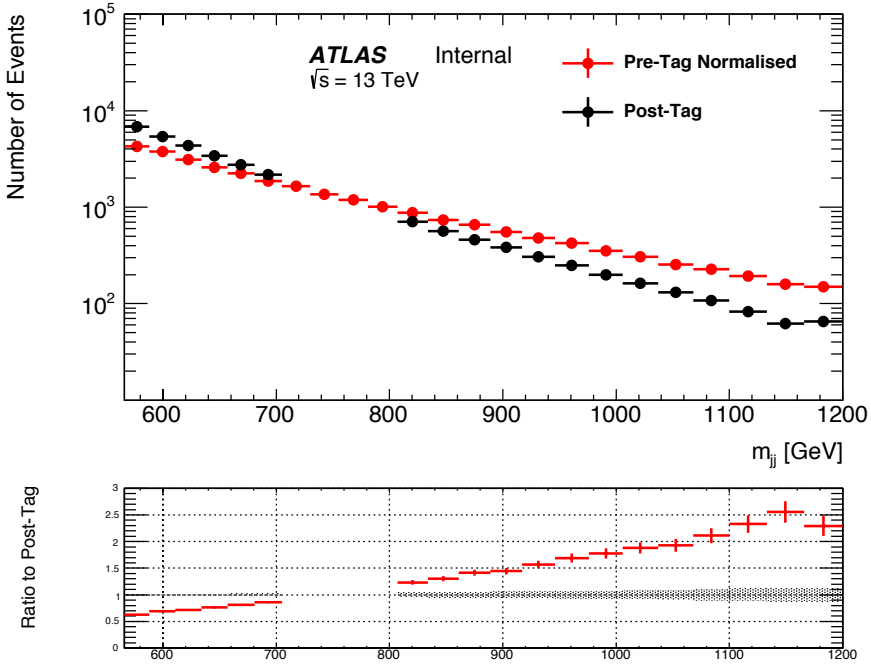
- **Overall fit is good quality**
  - No significant discrepancies
  - Possible structure in ratio

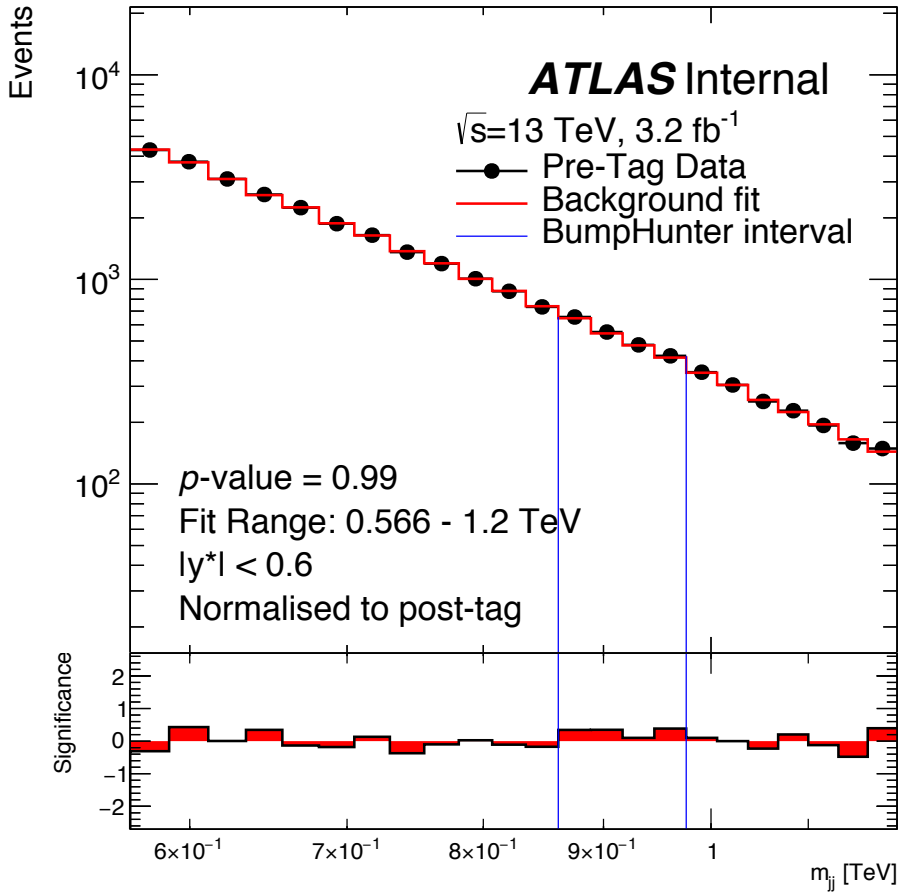




Spurious Signal: Scaled Down

- **Scale Pre-Tag to Post-Tag**
  - Actual Fluctuations in Data
    ~ 1/sqrt($N_{Pre\text{-}Tag}$)
  - Toys for p-value fluctuations
    ~ 1/sqrt($N_{Post\text{-}Tag}$) {Larger fluctuations}
  - Fit and search for bumps





We see that at post-tag scale:

fit discrepancies <<
poisson fluctuations of post-tag

99% of toys have **worse** fit

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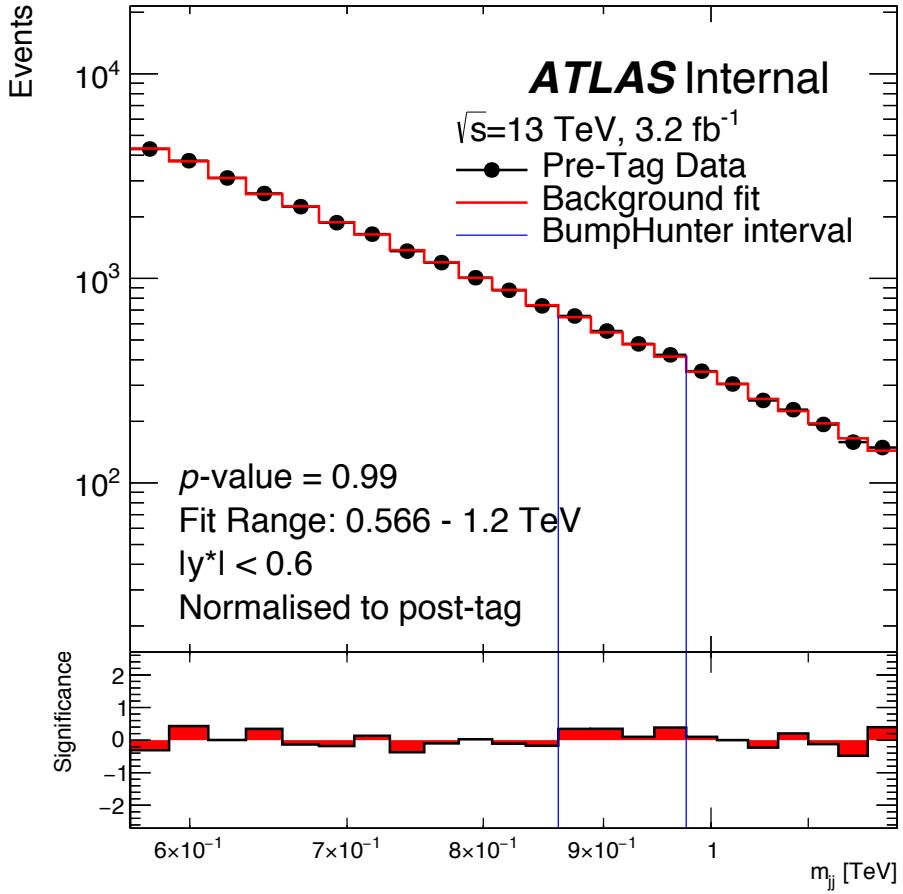
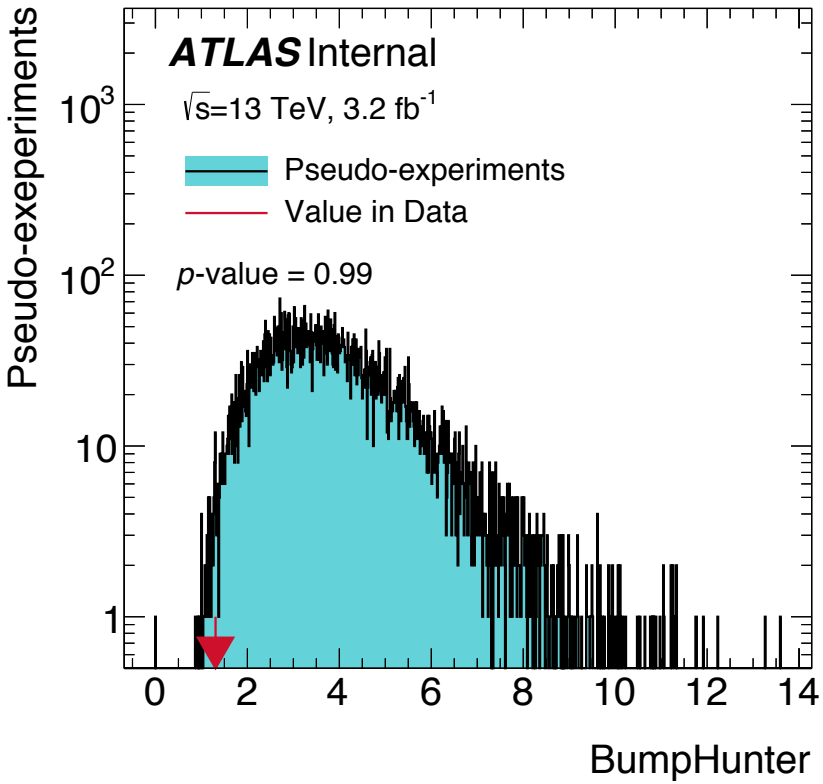




We see that at post-tag scale:

fit discrepancies << poisson fluctuations of post-tag

99% of toys have **worse** fit

Statistics: Signal Modelling

- **DM Scalar Z' Model**
  - Using LHCDMWG model
    - Done for convenience, this model exists and fits our needs.
  - Mass points; 600, 750, 800, 1000, 1200 GeV
  - Decays to *uu, dd, ss, cc* and *bb*; dominant decay is *bb,* couplings here
    - DM mass set to 10 TeV to ignore this coupling
  - Production does not include gg fusion via a quark loop.
  - But, this model can be used to calculate scalar acceptance

- **Leptophobic Z' model**
  - Model used in Moriond high mass paper
  - SM couplings to quarks, no couplings to leptons
  - Masses; 600, 750, 800, 1000 GeV
  - Problem => Z' @ 750 GeV is Z' => had had
    => Z' @ other mass points are Z' => bb
    - Looking to resolve through truth matching

- **Gaussian Limits**
  - Will set limits on a generic gaussian signal

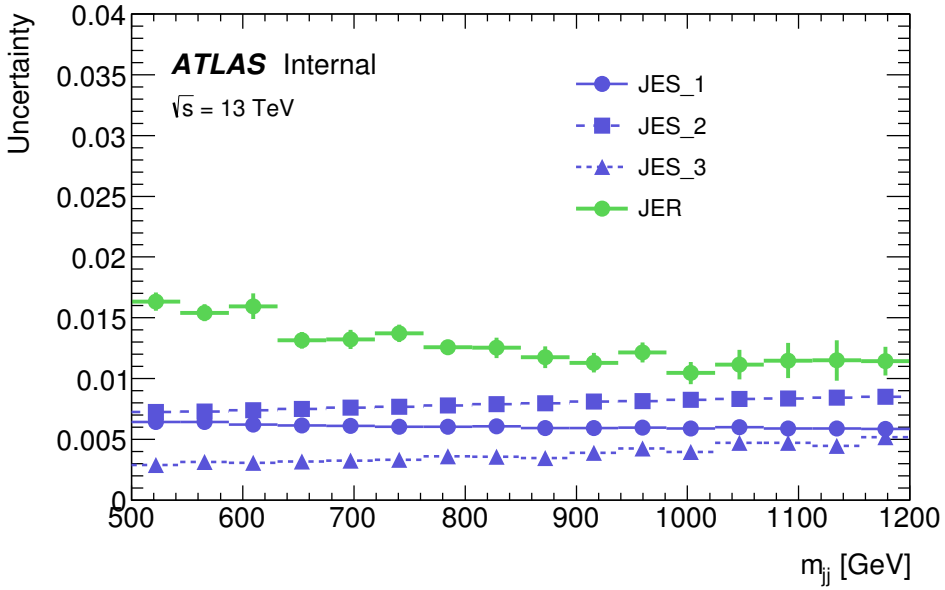
Systematics

- **Monte-Carlo (Signal)**
  - Luminosity (5%)
  - JES - Reduced 3NP
  - JER - Reduced 1NP
  - **b-tagging SF (~30%)**
  - **b-Jet trigger Efficiency (~10-30%)**

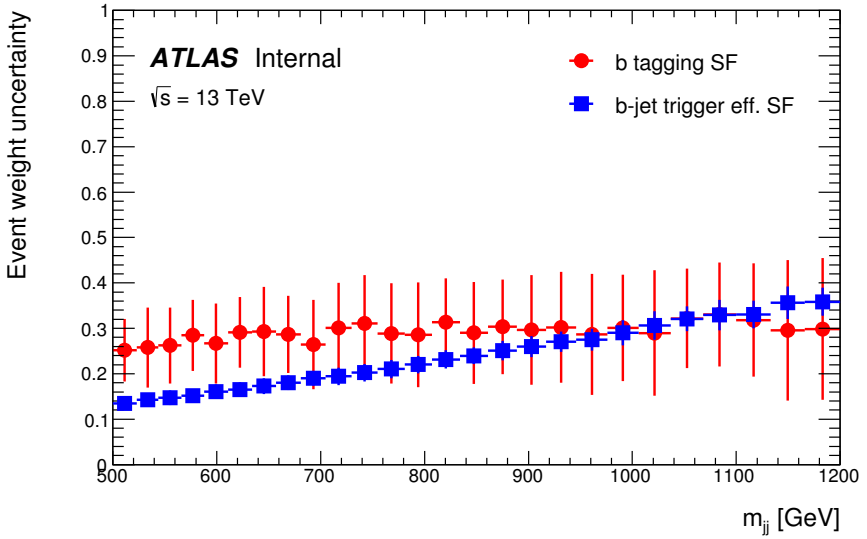
- **Background**
  - Fit function choice
    - Comparison to alt. func. (4 para.)
  - Uncertainty on fit parameters
    - Taken from pseudo-experiments

Rec. mass (GeV)	*JES (para1/para2/ para3)*	*JER*	*b-tagging SF*	*b-jet trigger eff. SF*
600	*2.5% / 2% / 1.3%*	*1.6%*	*30%*	*16%*
800	*2.4% / 2% / 1.1%*	*1.3%*	*30%*	*20%*
1000	*2% / 1.9% / 1%*	*1.1%*	*30%*	*30%*

Jet Uncertainties

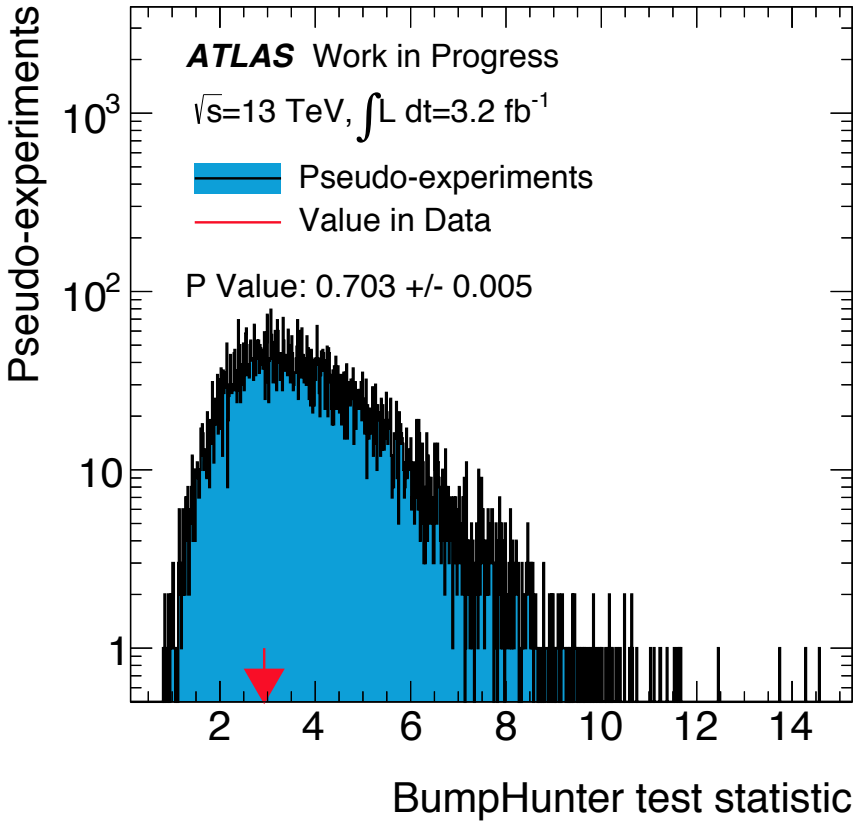


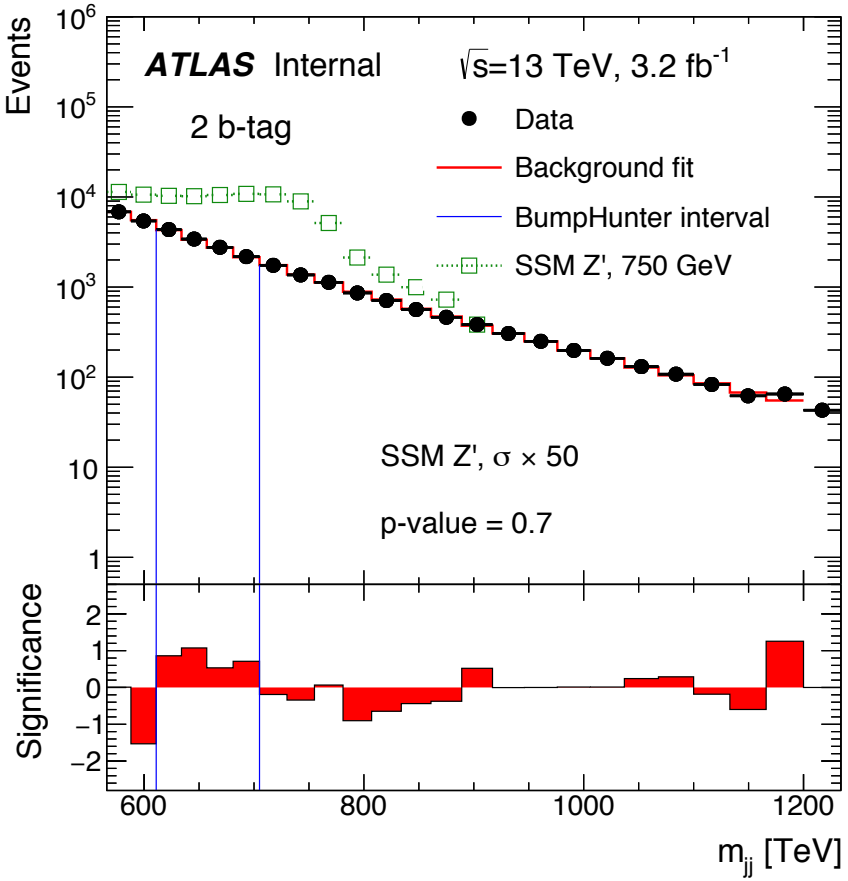
b-Tagging SF Uncertainty



Results: Search Phase

- **Currently Looking at Fitting to Sidebands**
  - 3 Parameter Fit Function
  - **Use BumpHunter Algorithm**
    - Finds most discrepant excess
    - Calculate p-values of discrepancy
      - 10,000 pseudo-exp.





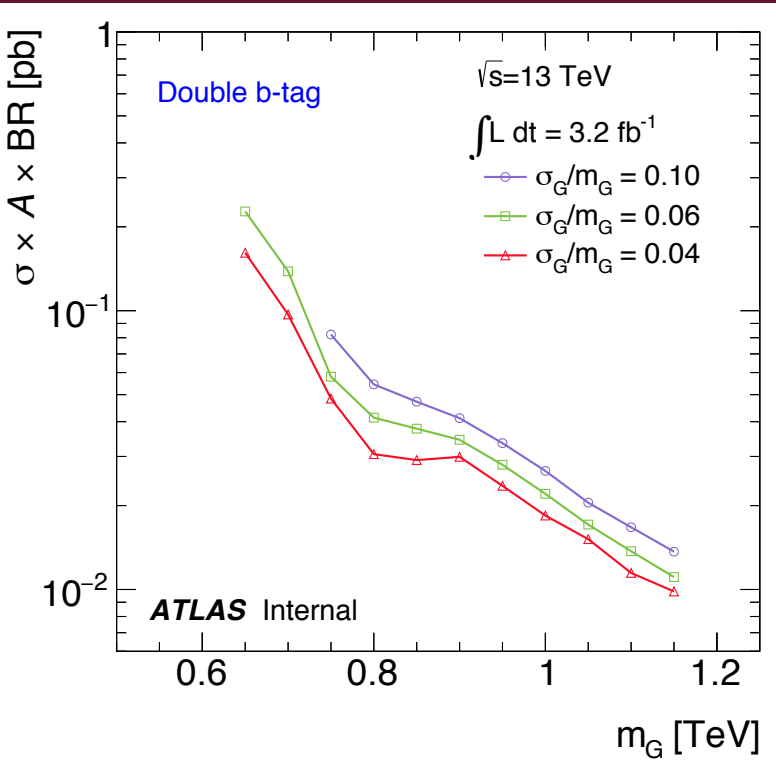
bH p-Value = 0.703

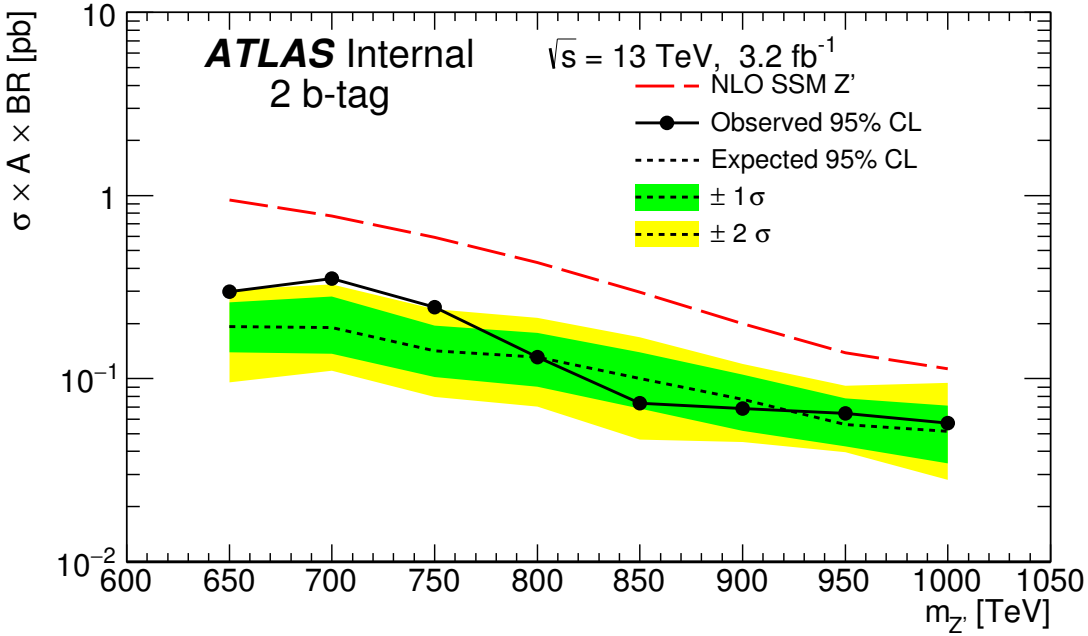
No significant discrepancy found!

Results: Limit Setting

No significant discrepancy found
Therefore move to limit setting

- **Generic Gaussian Limits**
  - Three different resonance widths
  - 10% signal width uncertainty
    - *Sum of all uncertainties that affect signal width*
  - Lumi. uncertainty
  - Fit function uncertainties





- **Leptophobic Z'**
  - $m_{Z'}$ = 600 GeV unstable
    - m_{jj} cut of 566 GeV
    - Will not use mass point
  - Full systematics included
  - We want more mass points

Estimating 750 GeV Limit

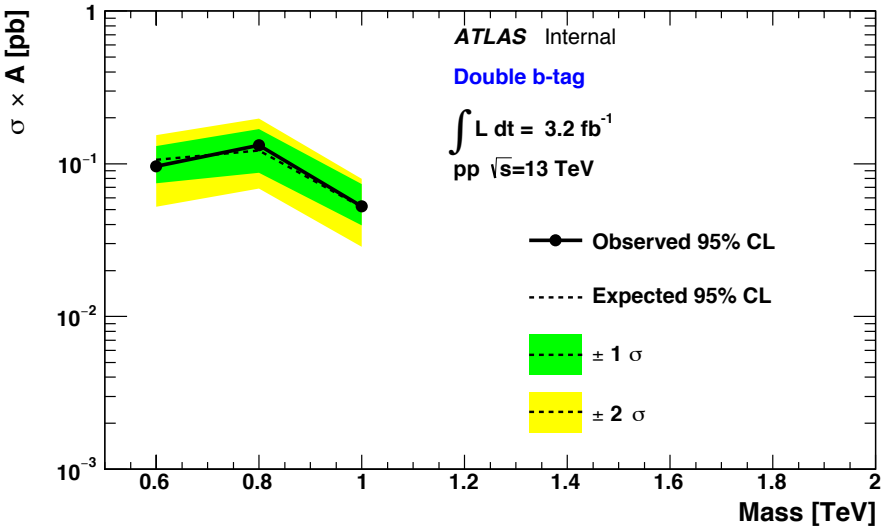
- **Target ~2.1 pb @ 13 TeV**
  - Scalar couples to bb and γγ only
    - Estimate $\sigma_{\gamma\gamma}$ and Γ from diphoton
    - Theorists calculate σ_{bb}

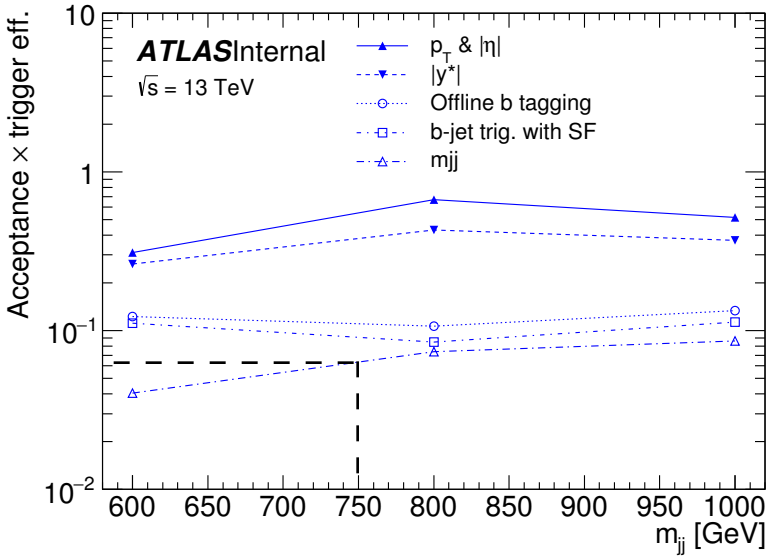
    (arXiv:1512.04933)

- **σ_{bb} x A ~ 0.1 pb**
  - From our limit plot

- **A ~ 0.07**
  - Interpolation

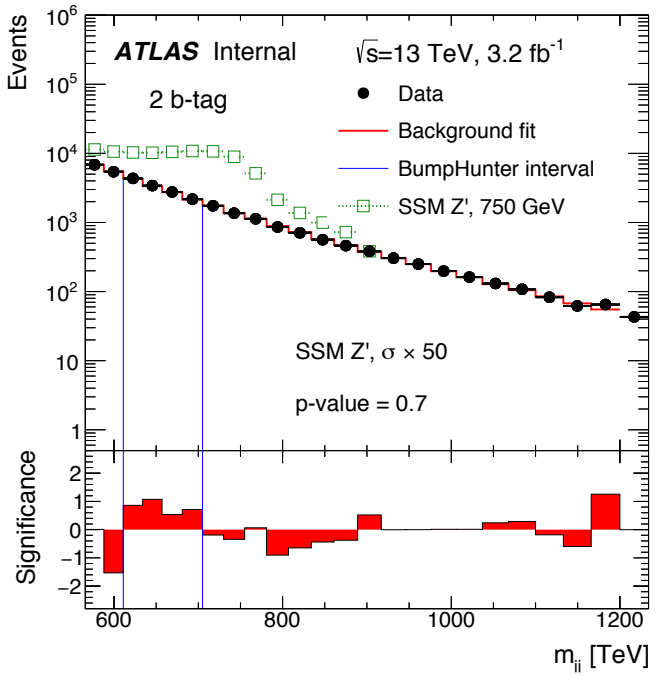
- **σ_{bb} ~ 1.5 pb**
  - Very coarse approximation
  - Not a finalised number
  - We should be able to exclude above model

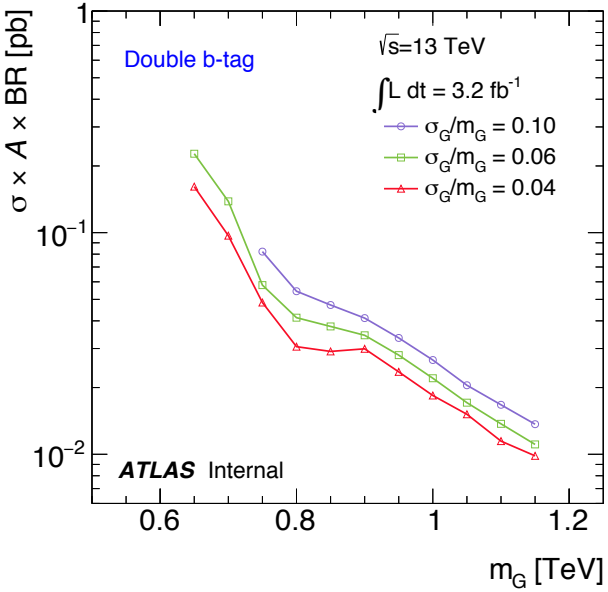




Conclusions

- **Low Mass b-Tagged Analysis**
  - Resonance decaying to bb poorly constrained at 750 GeV
  - **Use b-Triggers to get to low mass**
- **No significant discrepancy found**
  - bH p-value = 0.703
- **Systematics Ready**
  - Dominated by b-tagging and b-jet trigger
- **Limits setting**
  - Gaussian limit done
  - Leptophobic Z'
- **We should be able to exclude 2.1 pb**
  - This was our target
- **On course for LHCP**
- **We are in ATLAS Circulation**
- **ATLAS Approval Meet on wednesday**





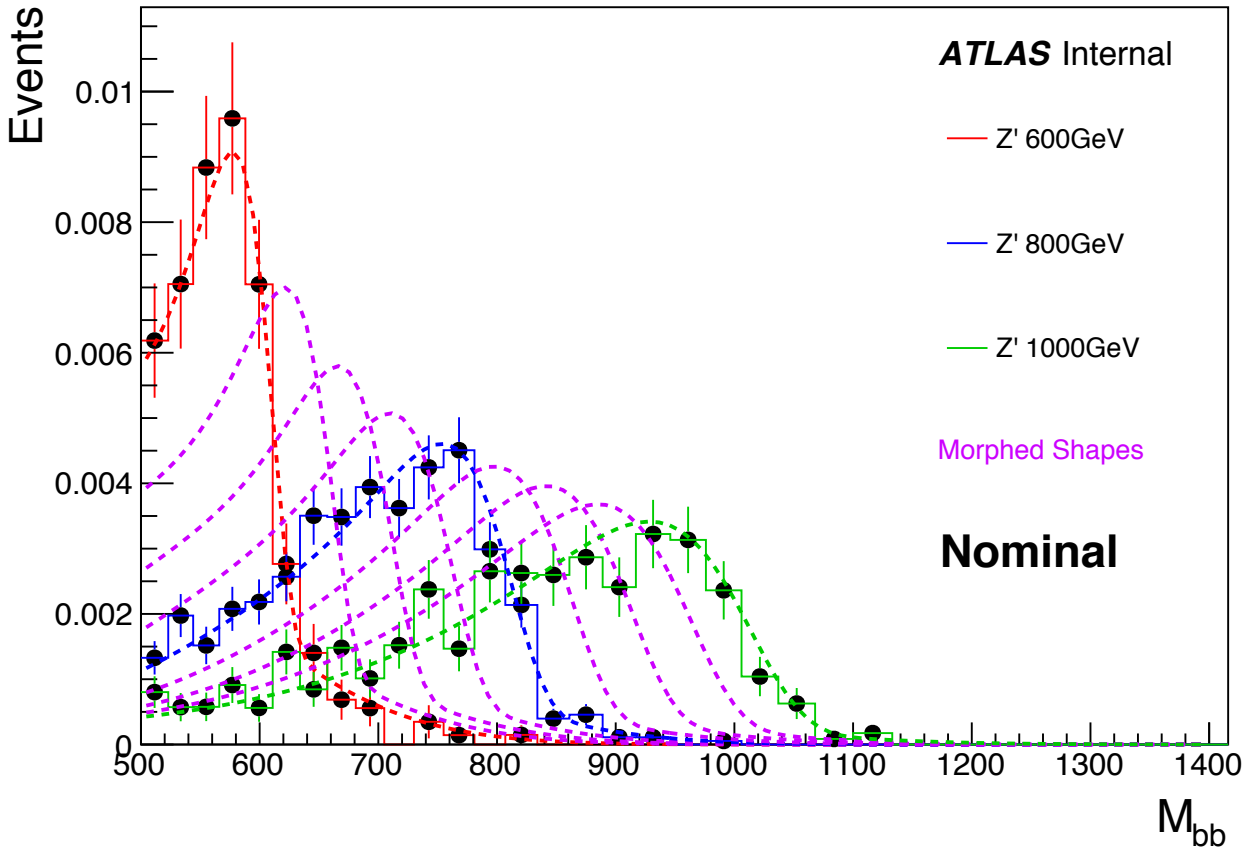
Backup!

Signal Morphing

Talk With Details

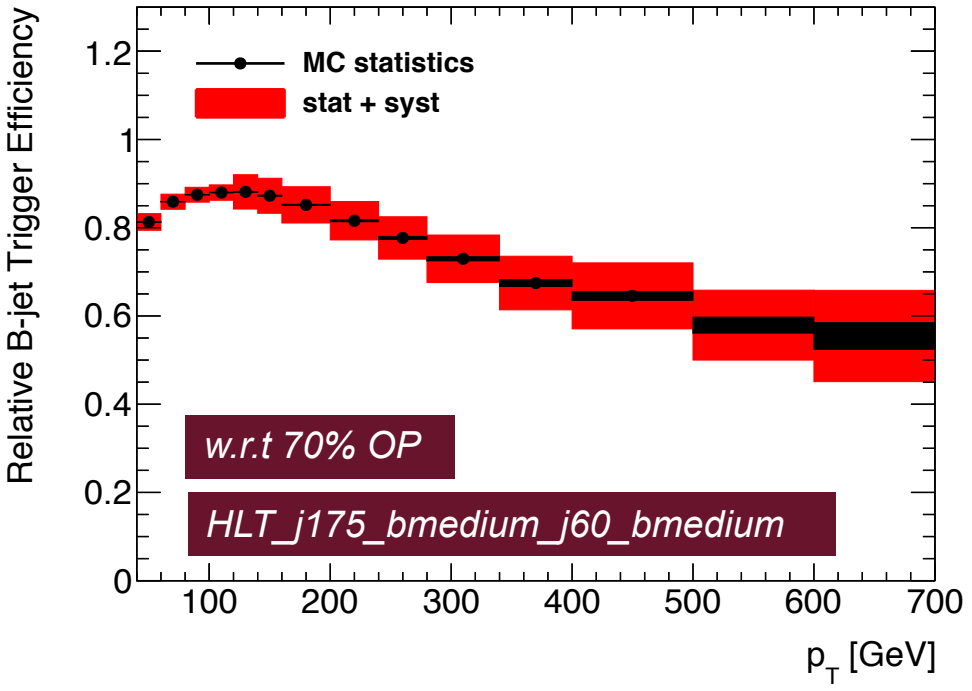
- **Parameterise Signal Shape**
  - Gaussian + Reverse Landau fit.
  - Fit to all signal points
  - Interpolate fit parameters
- **Process repeated for systs.**
  - JES 3NP, JER 1NP
  - Trigger, bTag SF
  - Fit and interpolate

This gives us more mass points: ***600, 650, 700, 750, 800, 850, 900, 950, 1000 GeV***



b-Jet Triggers: Introduction

- **b-Jet Triggers to get to low masses**
  - 2015 data: IP3D+SV1 Algorithm
- **HLT_j175_bmedium_j60_bmedium**
  - bMedium OP
    - Tighter than 70% eff. OP
  - Cut in MC doesn't match Data
- **b-Jet Trigger Strategy**
  - Derive b-Jet Trigger Efficiencies
    - Data driven technique
    - Details on the next slide
  - Efficiencies are applied to signal samples to emulate trigger
  - Not required for background - Exact light-jet and c-jet rejections not needed
    - Use fit to model background rather than MC

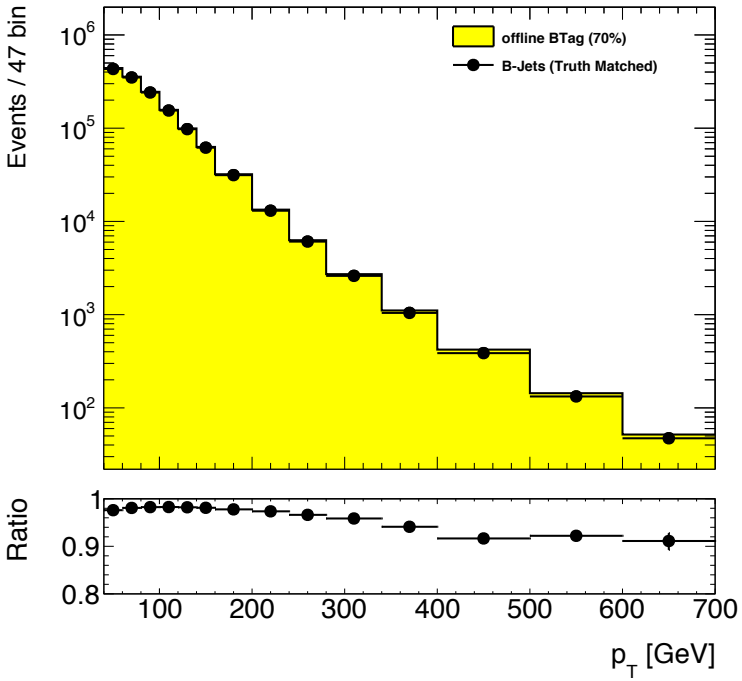


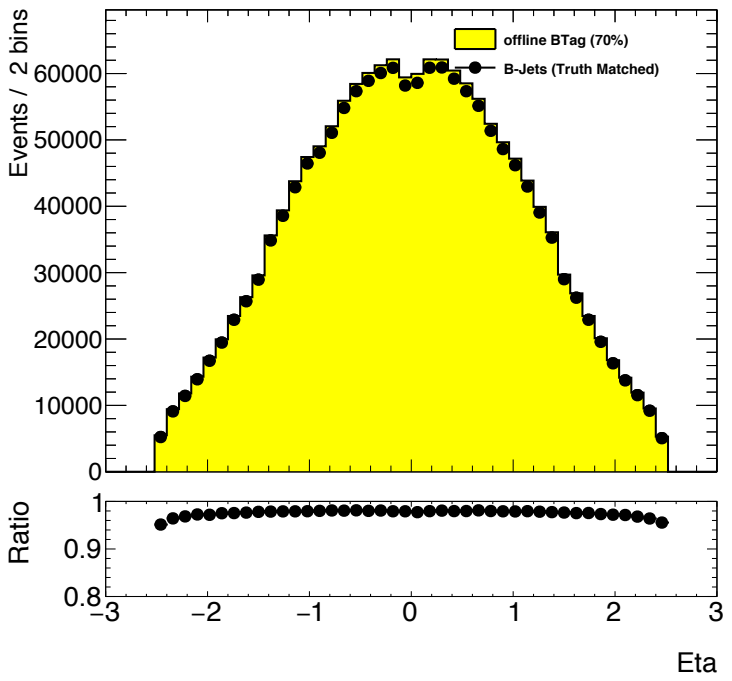
$$\text{b-Jet Trig Eff. wrt offline} = \frac{\text{\# b-Jets pass offline and online b-tagging}}{\text{\# b-Jets offline b-tagging}}$$

b-Jet Triggers: Event Selection

- **High purity b-jet sample: Di-lepton tt selection**
  - **Single lepton bperf trigger**: *HLT_(mu26_imedium/e26_tight_iloose/e26_lhtight_iloose)_2j35_bperf*
    - Calculate online b-tagging algorithms on all jets with p_T > 35 GeV
  - **1 medium electron & 1 medium muon** (p_T > 30 GeV)
  - **2 b-tagged jets**, MV2c20 @ 70% *(p_T > 30 GeV, $|\eta|$ < 2.4)*

- **Testing the b-jet purity**
  - Use truth matching to estimate purity of sample
  - High purity (>95%) at low p_T, decreases to ~90% at 700 GeV

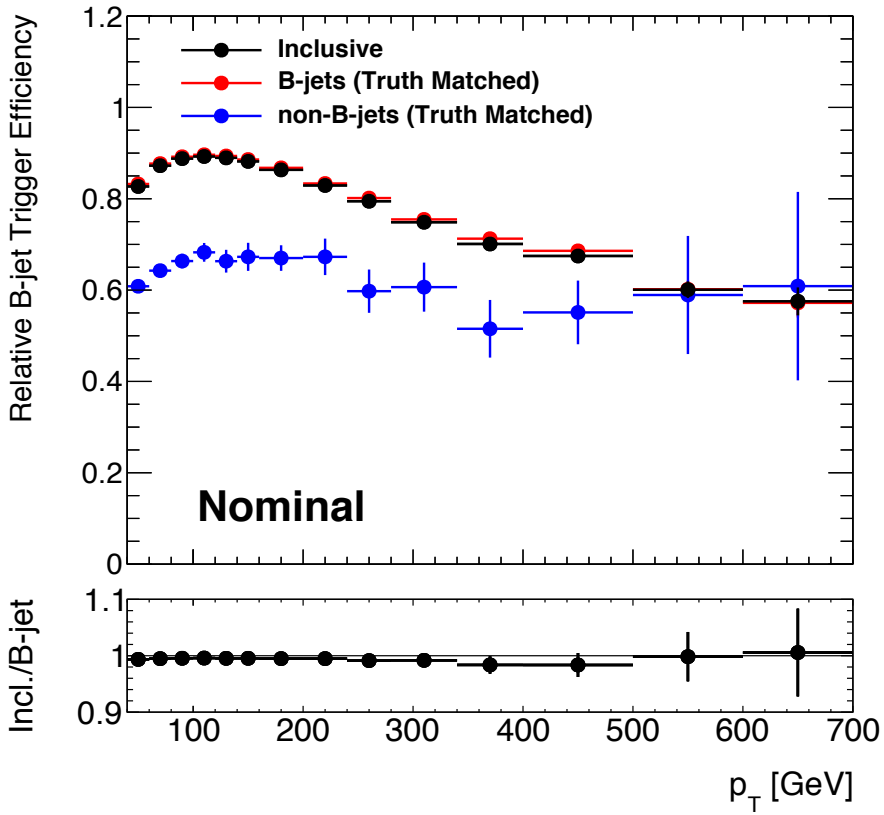


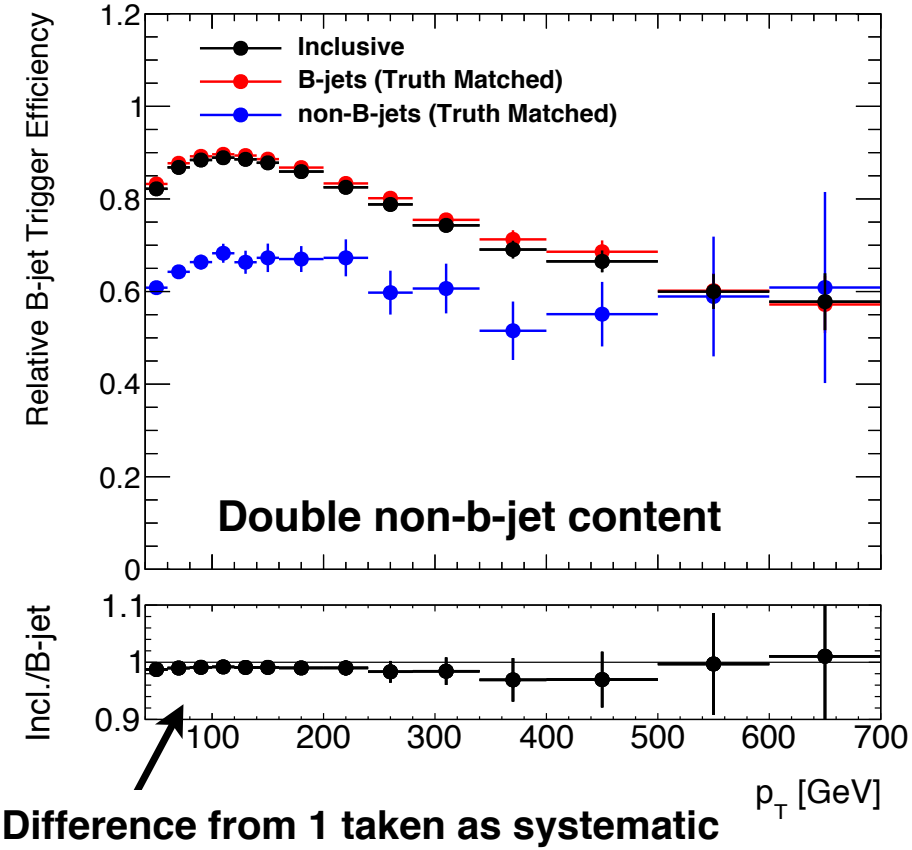


b-Jet Triggers: Sample Dependance Syst.

- **Correction account for non b-jet impurities**
  - Truth match b-jets and non-b-jets *(light, c)*
  - Correction to account for difference between inclusive and truth matched b-jets

- **Systematics to deal with MC mismodelling of flavour composition**
  - ➡ Vary the non-b-jet component of the tt sample by + 100%
  - ➡ Difference from 100% purity taken as a symmetric systematic





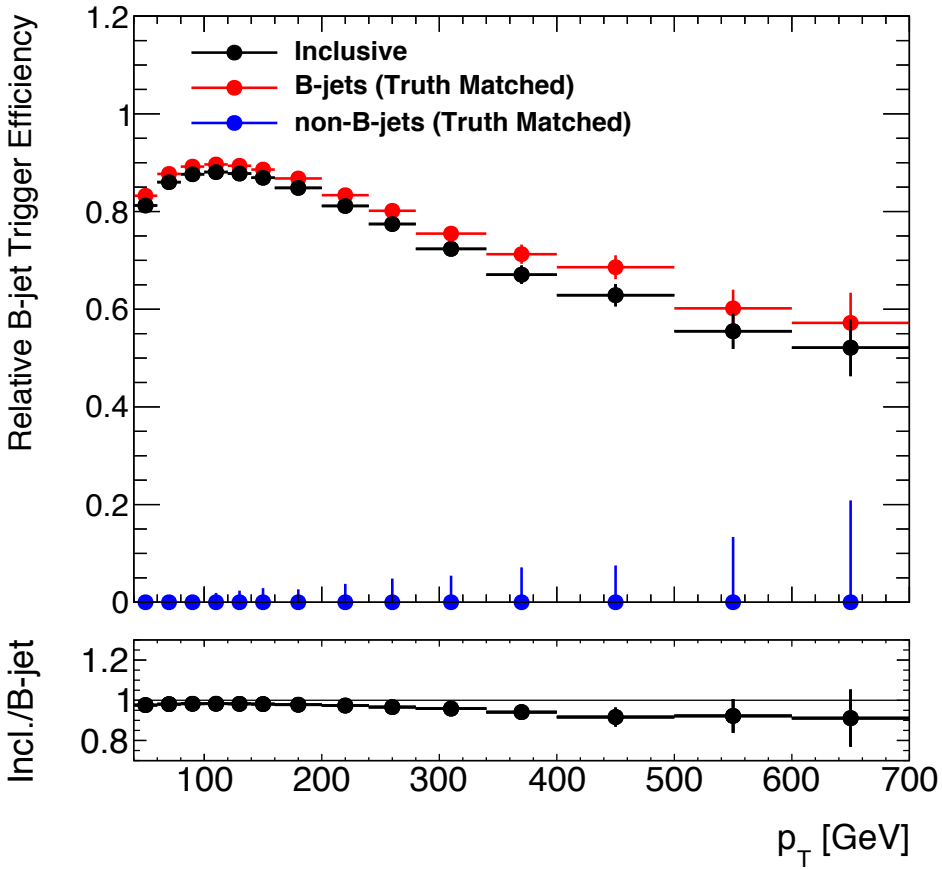
b-Jet Triggers: Sample Dependance Syst.

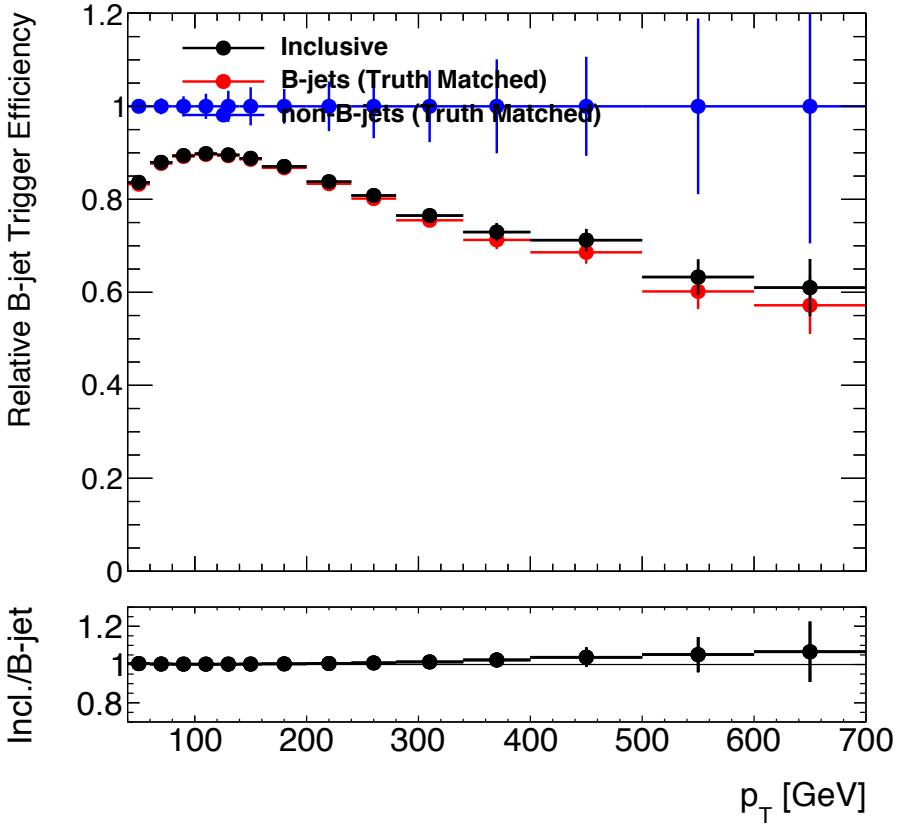
- **Systematic for MC mismodelling of the light-jet efficiency of the trigger**

➡ Consider light-jet trigger efficiency of 0 and 1

➡ The two variations have an effect on the inclusive to truth-matched ratio

➡ Take largest difference from a ratio of 1 as systematic





b-Jet Triggers: Estimating Efficiency

Jet p_T < 120 GeV

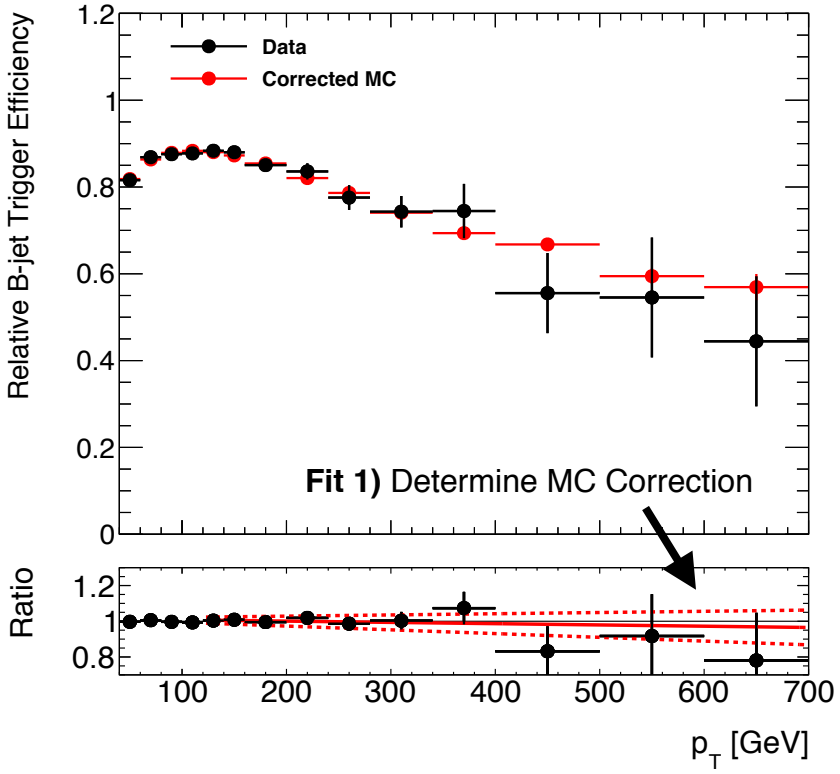
- **Data Eff. taken as central value**

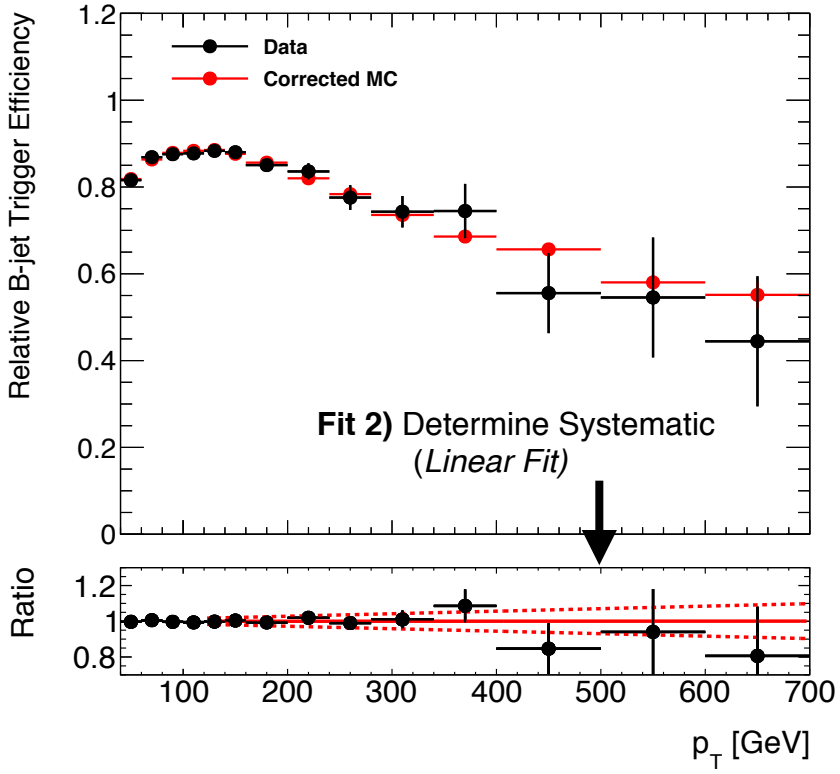
- Data/MC difference taken as syst.
- Precision of data also as syst.

Jet p_T > 120 GeV

1) **Linear fit to Data/MC eff. ratio**
   - Used to correct tail in MC eff.
   - This gives central value
2) **Linear and** 3) **Quadratic fit to Data/Corrected MC ratio**

- Largest bin by bin error of 3 fits taken
- Taken as symmetric systematic





b-Jet Triggers: Estimating Efficiency

Jet p_T < 120 GeV

- **Data Eff. taken as central value**

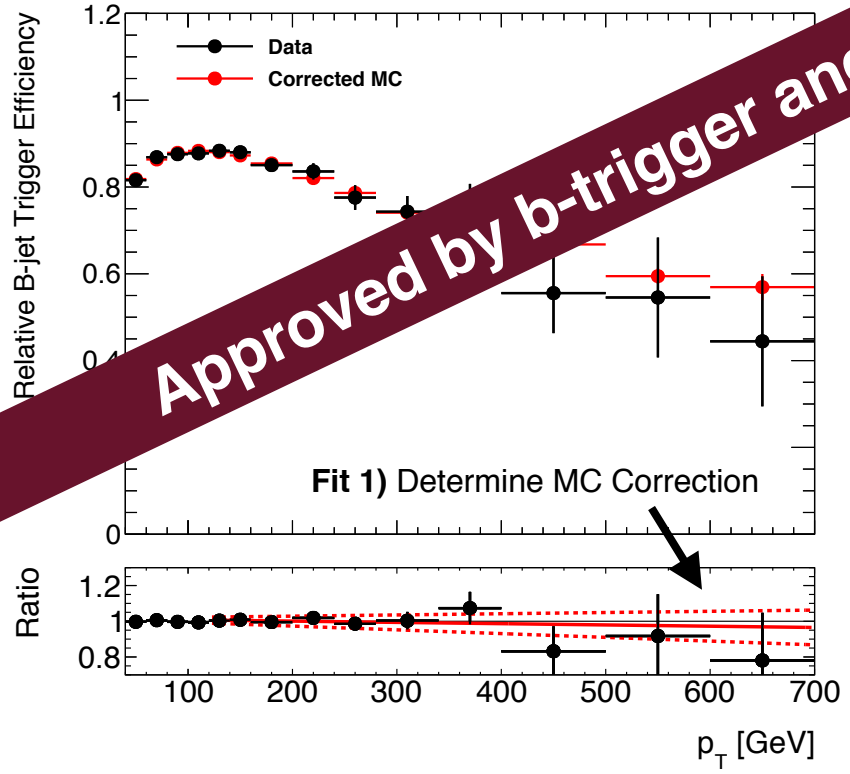
- Data/MC difference taken as syst.
- Precision of data also as syst.

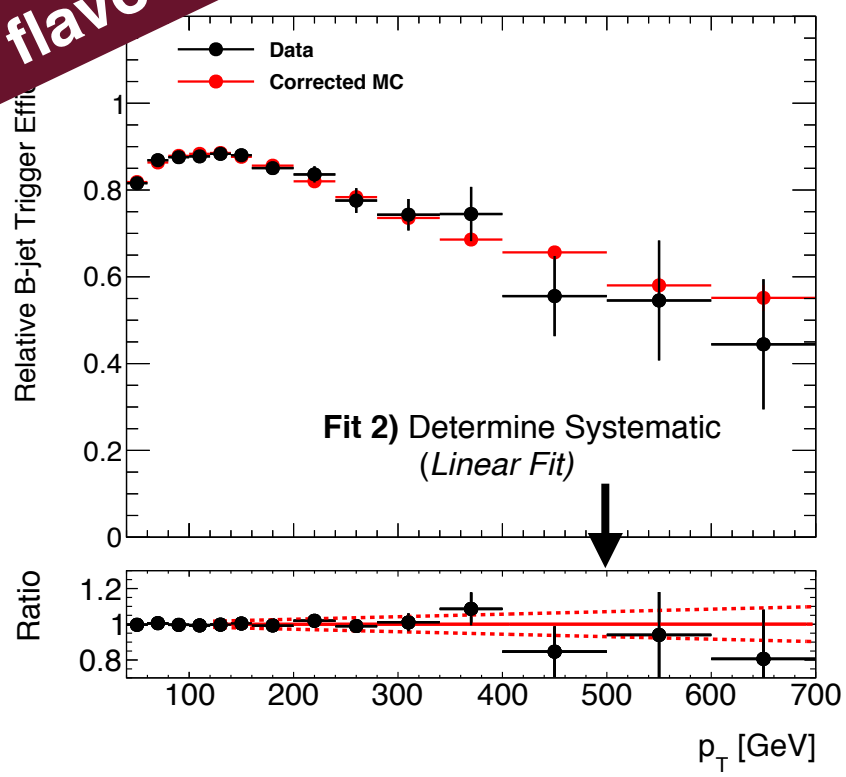
Jet p_T > 120 GeV

1) **Linear fit to Data/MC eff. ratio**
   - Used to correct tail in MC eff.
   - This gives central value
2) **Linear and** 3) **Quadratic Data/Corrected MC**

- Largest bin by [illegible] of 3 fits taken
- Taken as [illegible] systematic

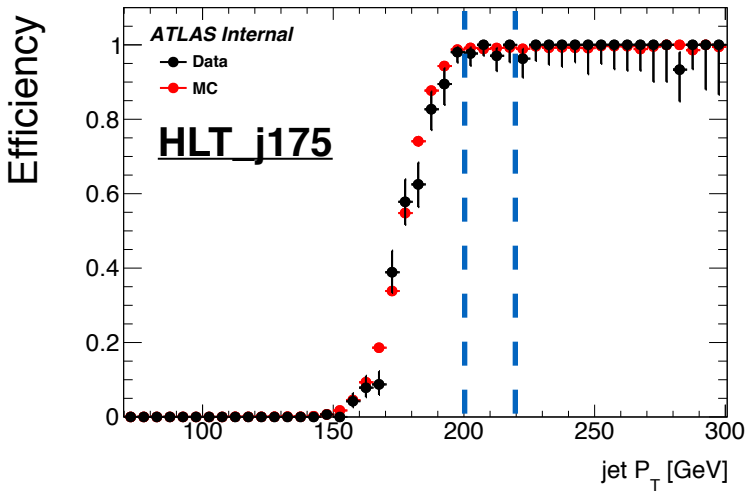
Approved by b-trigger and flavour tagging group

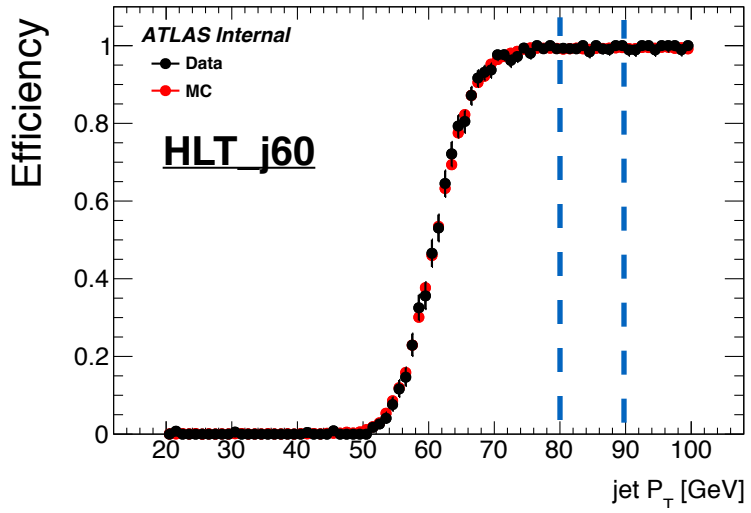




Leading Jet P_T Cut

ATL-COM-PHYS-2015-1322





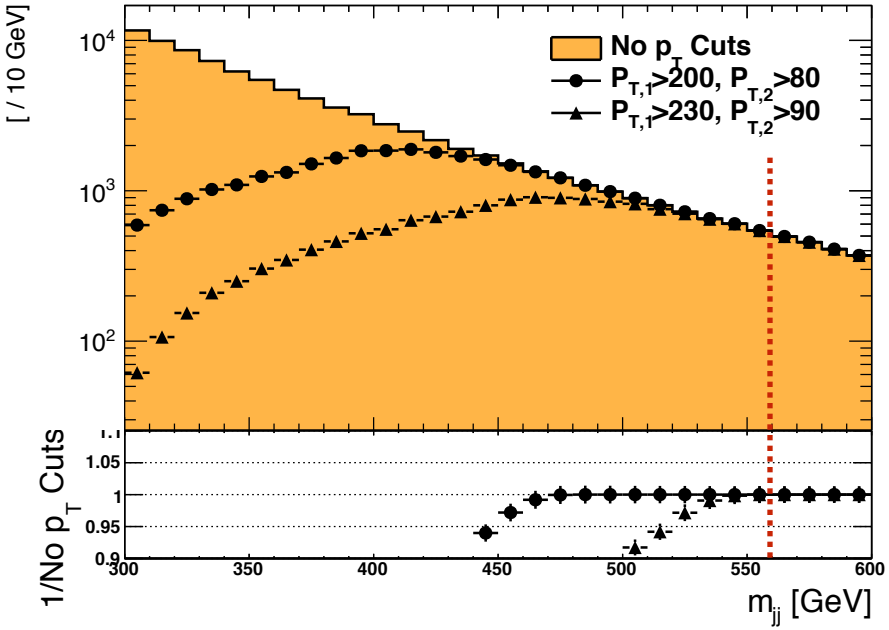
Cuts motivated by 99% Eff. Point
=> On trigger plateau

Leading Jet P_T > 220 GeV

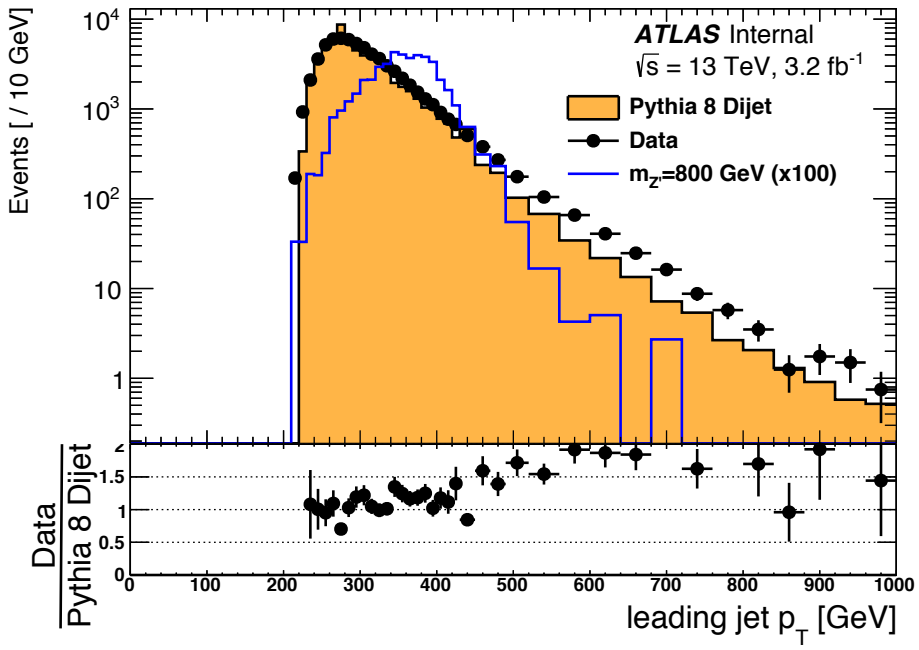
Sublead. Jet P_T > 90 GeV

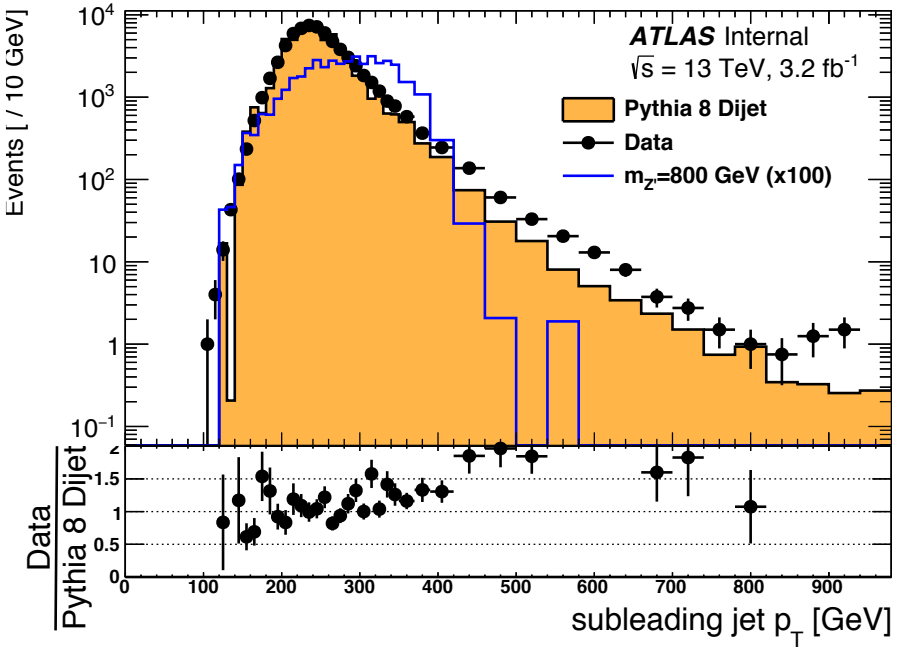
=> m_{jj} determined from turn-on

m_{jj} > 566 GeV



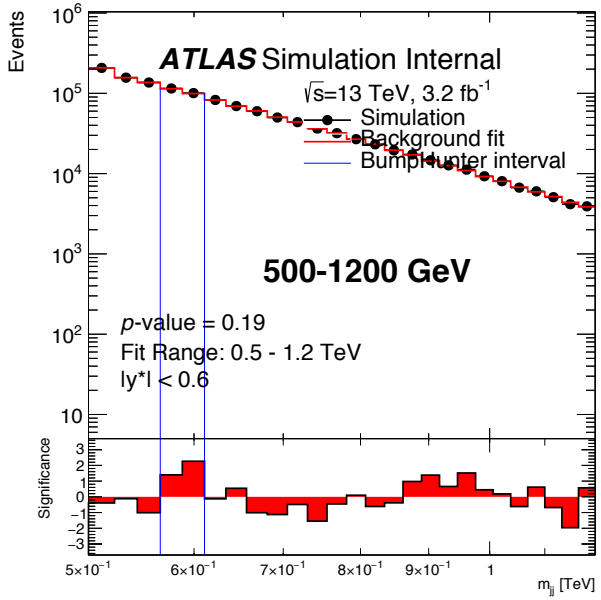
Kinematics: Validation Plots

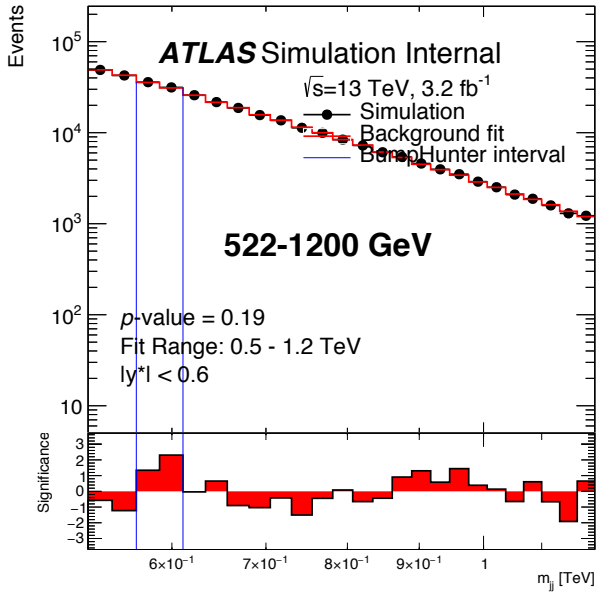


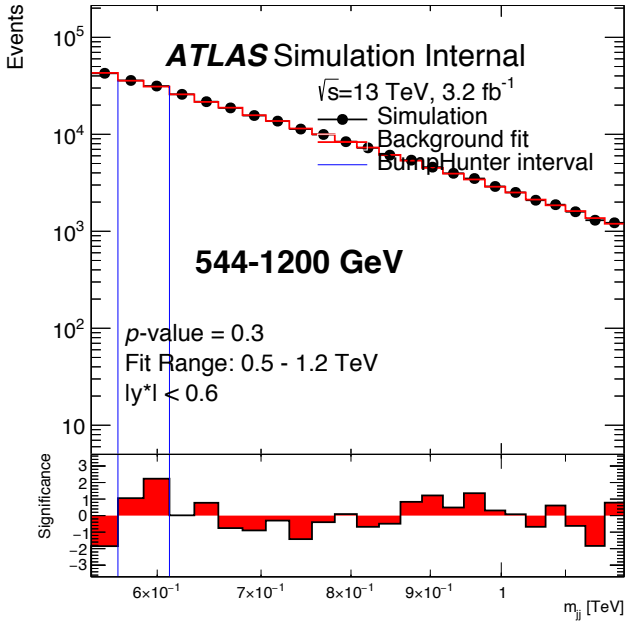


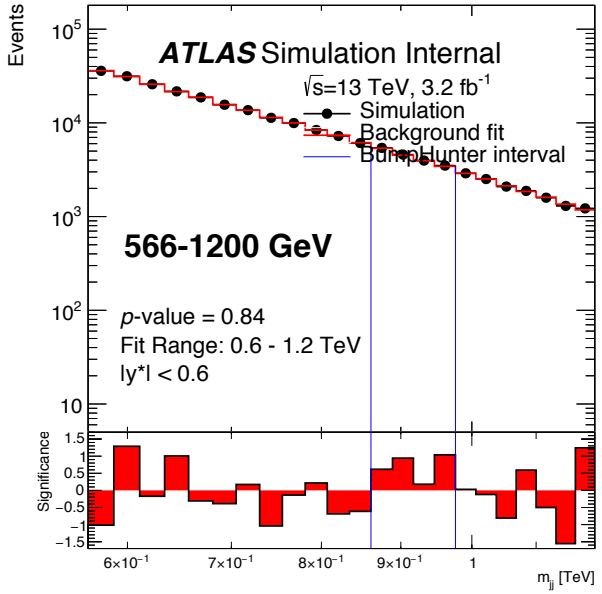
- **Emulating online b-tagging**
  - Light/Charm online b-tagging efficiencies not known
  - Thus some mismodelling expected
- **Many more validation plots available**
- **Z' with m_Z = 750 GeV being simulated now**

Spurious Signal: Full Set of Ranges









Timescale

	Request EB (latest)	First EB meet (latest)	Support note to JDM & EB	JDM Approval	Sup. Note to Exotics	Exotics Approval	Conf to ATLAS	Approval Meeting	Start of Conference
LHCP Jun 13-18	April 20	May 4	May 4	May 11	May 18	May 25	June 1	June 8	June 13

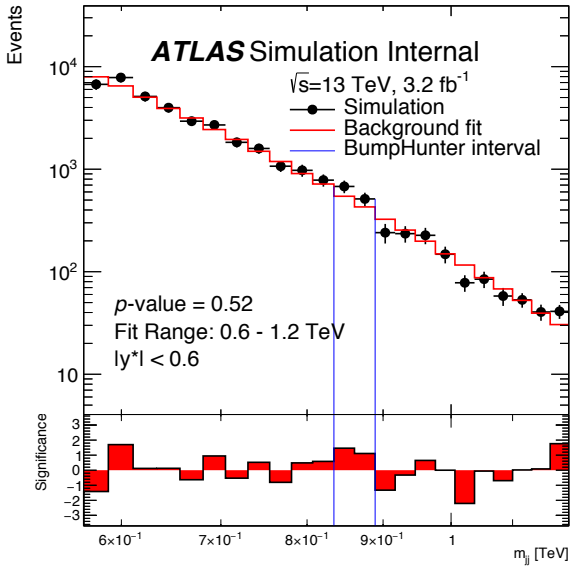
Spurious Signal - Check on S+B Fit

Laurie McClymont

Dibjet Meet

02 June 16

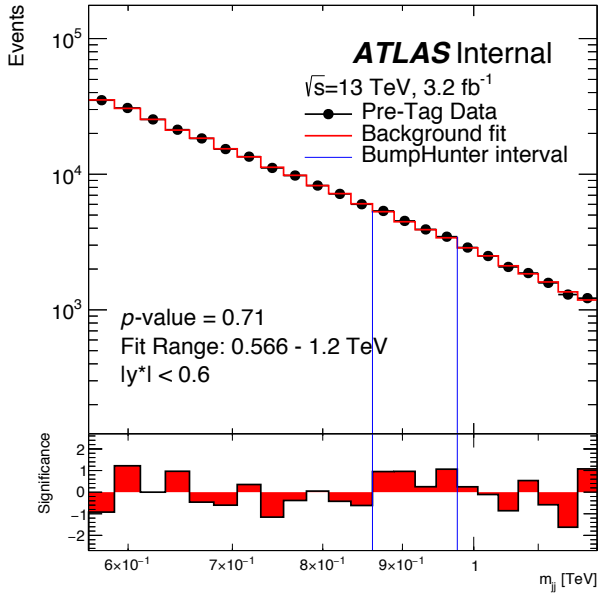
- **Spurious Signal**
  - By this we mean shape discrepancies between fit and bkgr. only causing (hiding) fake (real) signal
  - Done tests on MC and trigger only data
  - No large discrepancies seen in background only fit
  - pValues: Trigger only data = 0.71, MC = 0.52
  - No spurious signal in background only data



- **S+B Fit**
  - Comment from Koji:

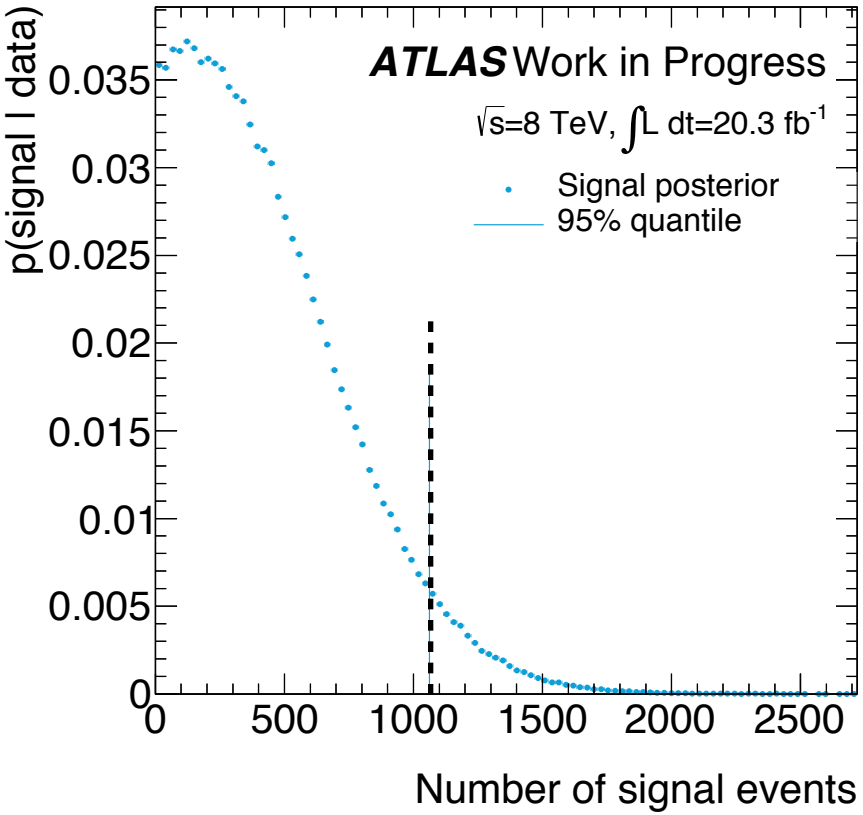
> *' l.304 / More relevant is spurious signal from signal+background fit to the background-only data (or MC) for limit setting. Has this been considered? '*

  - My understanding of this is we are asking if any shape discrepancies between bkgr. fit and bkgr. spectrum could cause biases in S+B fit.



S+B Fit

- **Signal + Background fit performed in Limit setting**
  - Floating background and signal normalisation
  - Other nuisance parameters will appear here
  - Likelihood distribution can be found for each mass point.
    - From this distribution 95% C.L limit can be found



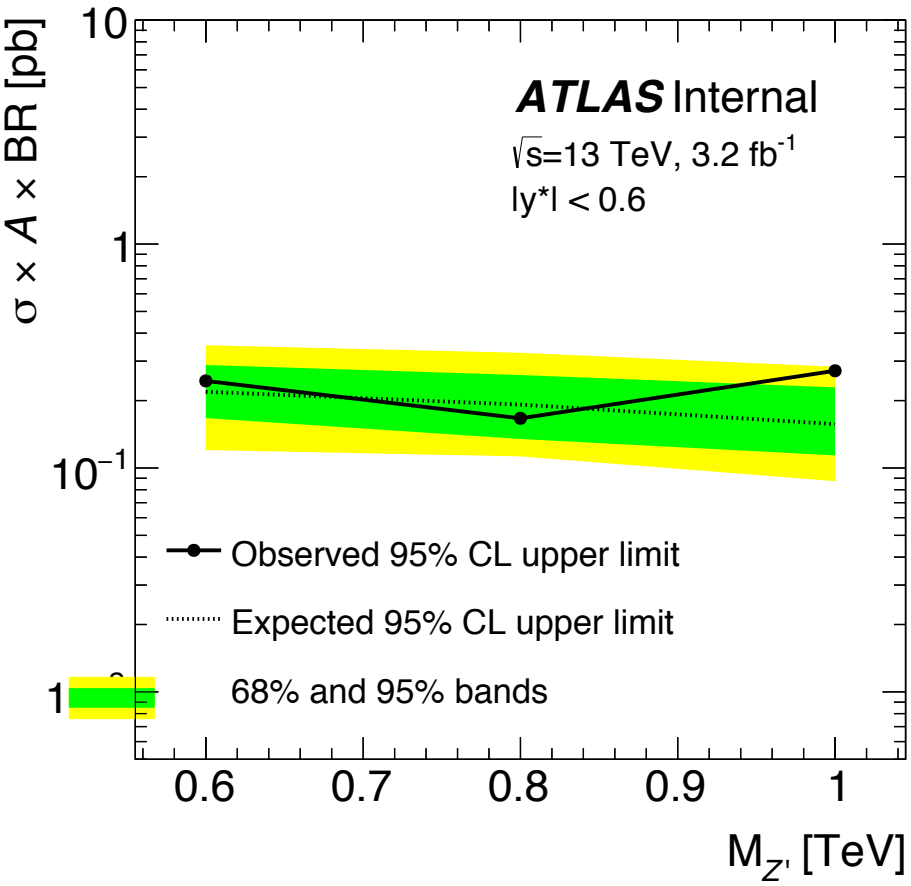
K. Pachal - Chapter 9

- **Spurious Signal**
  - Spurious signal (as well as statistical fluctuations) cause fit/data to be different
  - Fit/data discrepancies can morph the shape of likelihood distribution.
  - We get more aggressive/conservative limits depending on fluctuations

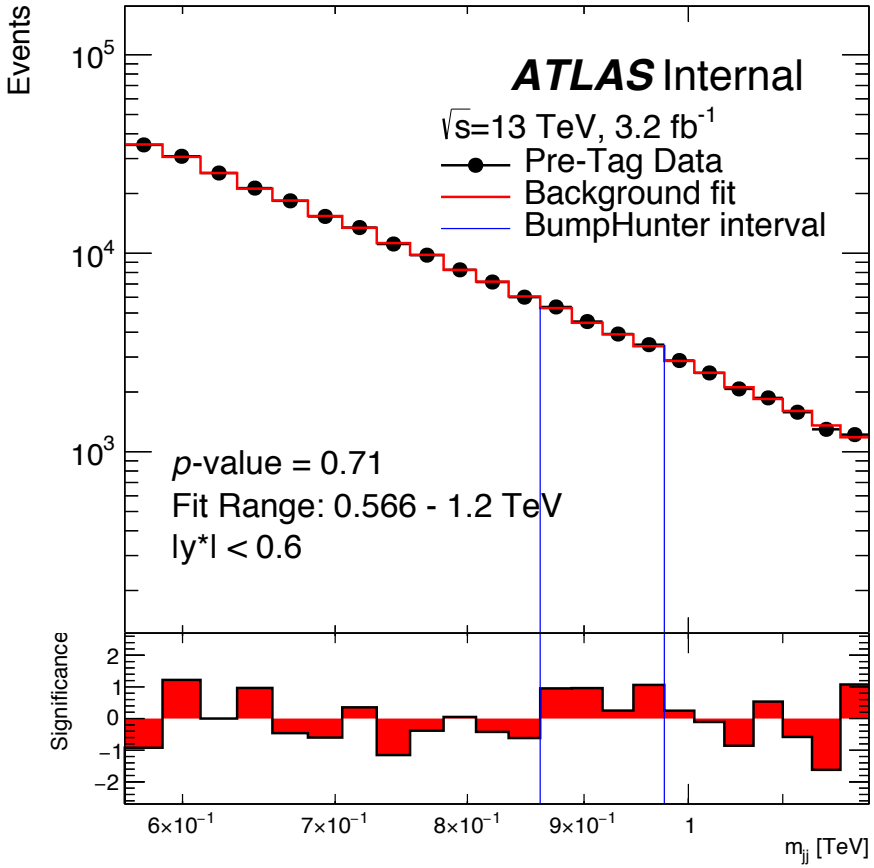
- **Expected Limits**
  - Limits taken from many pseudo-experiments thrown from fit.
  - These give distributions for expected limits
  - No spurious signal in expected limits
  - So we can compare observed to expected

Statistics: Spurious Signal - Trigger Data

- **Data:** Trigger but no offline tagging
  - Gives us a CR to test fit where we are not sensitive to bb decays
- **Signal:** Z' bb post-tag



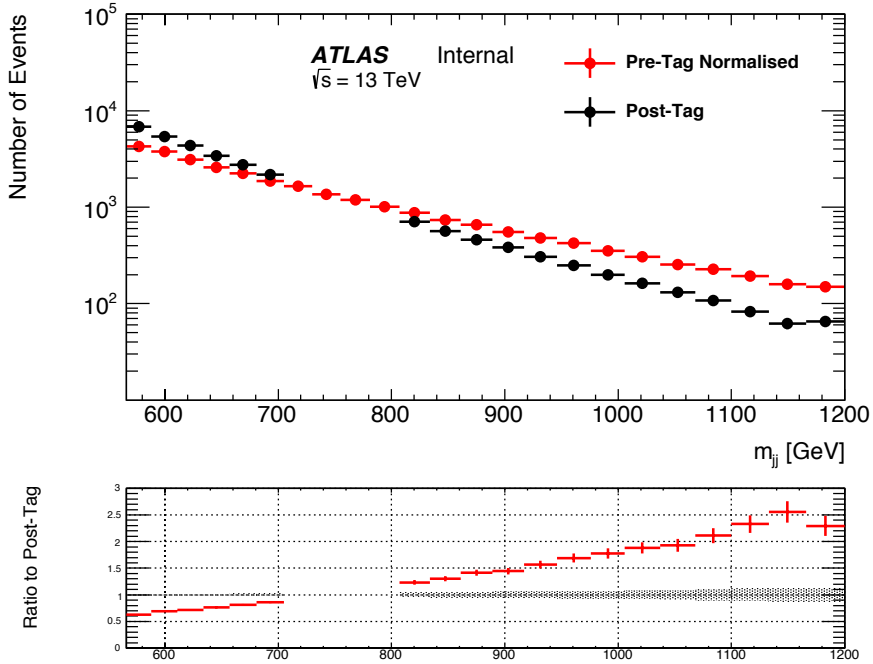
- **These are not physical limits!!!!**
- No systematics as well.
- But we can compare exp. to obs. to test for S+B fit bias

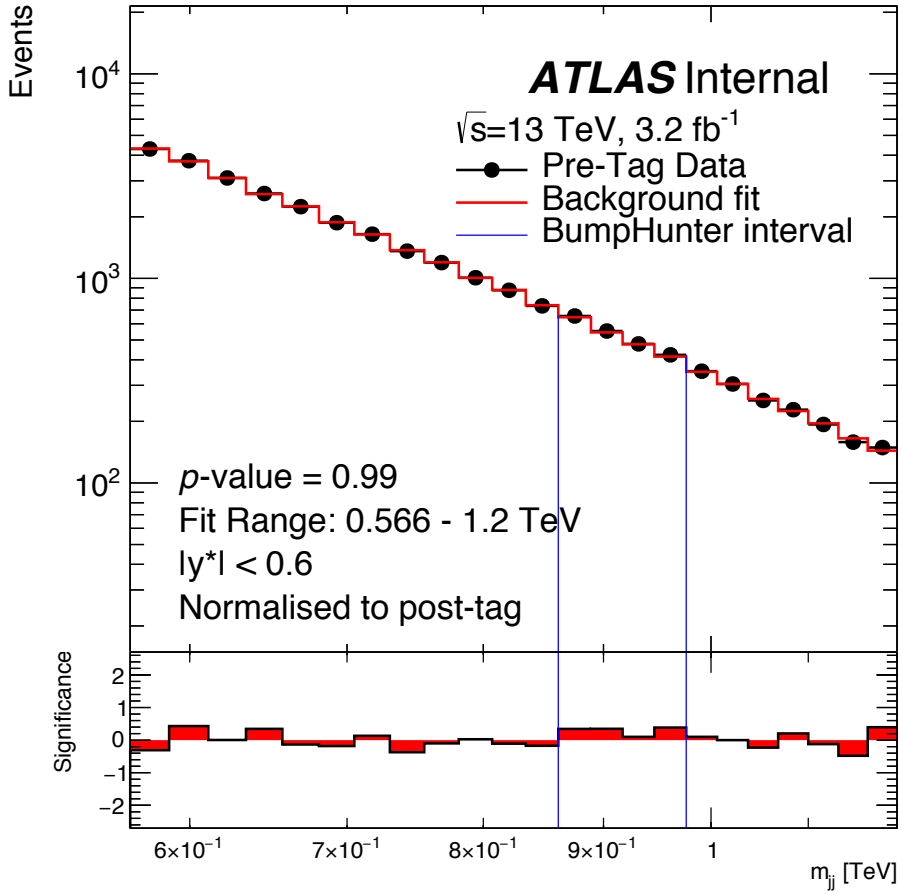


- Expected matches observed within stat. fluc. so no evidence of bias in S+B fit
- This is consisted with what we found in spurious signal test

Spurious Signal: Scaled Down

- **Scale Pre-Tag to Post-Tag**
  - Actual Fluctuations in Data
    ~ 1/sqrt($N_{Pre\text{-}Tag}$)
  - Toys for p-value fluctuations
    ~ 1/sqrt($N_{Post\text{-}Tag}$) {Larger fluctuations}
  - Fit and search for bumps





This gives us a precise data CR

Here, we are not sensitive to bb resonances

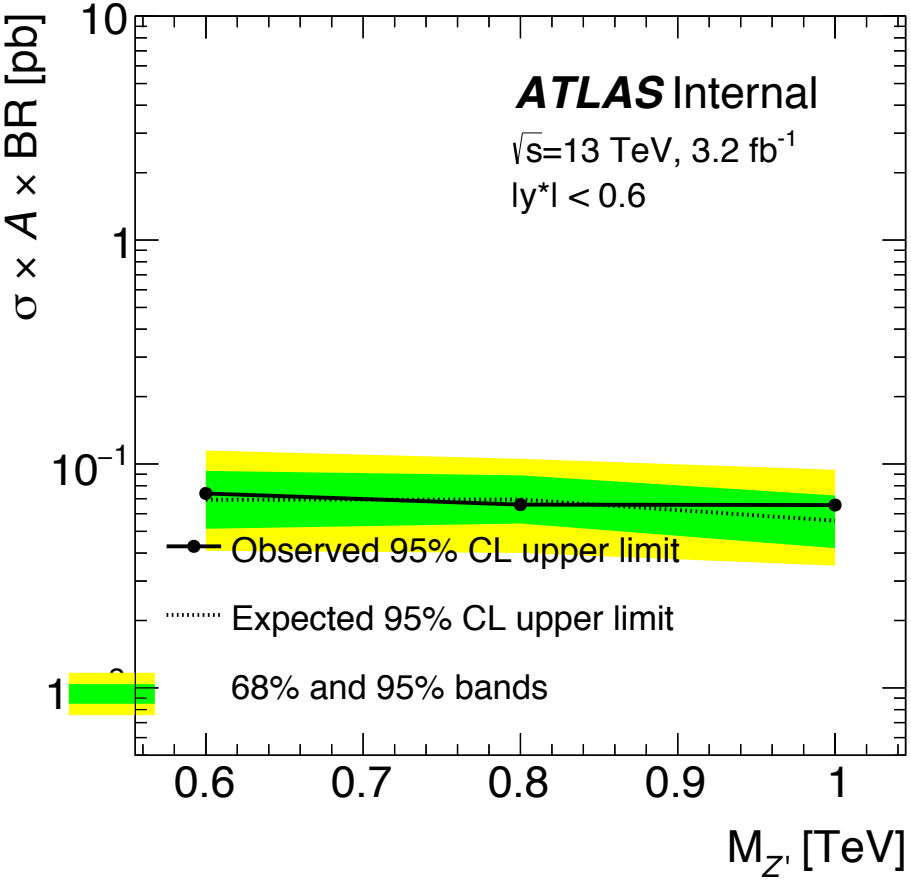
Similar shape to post-tag data set.

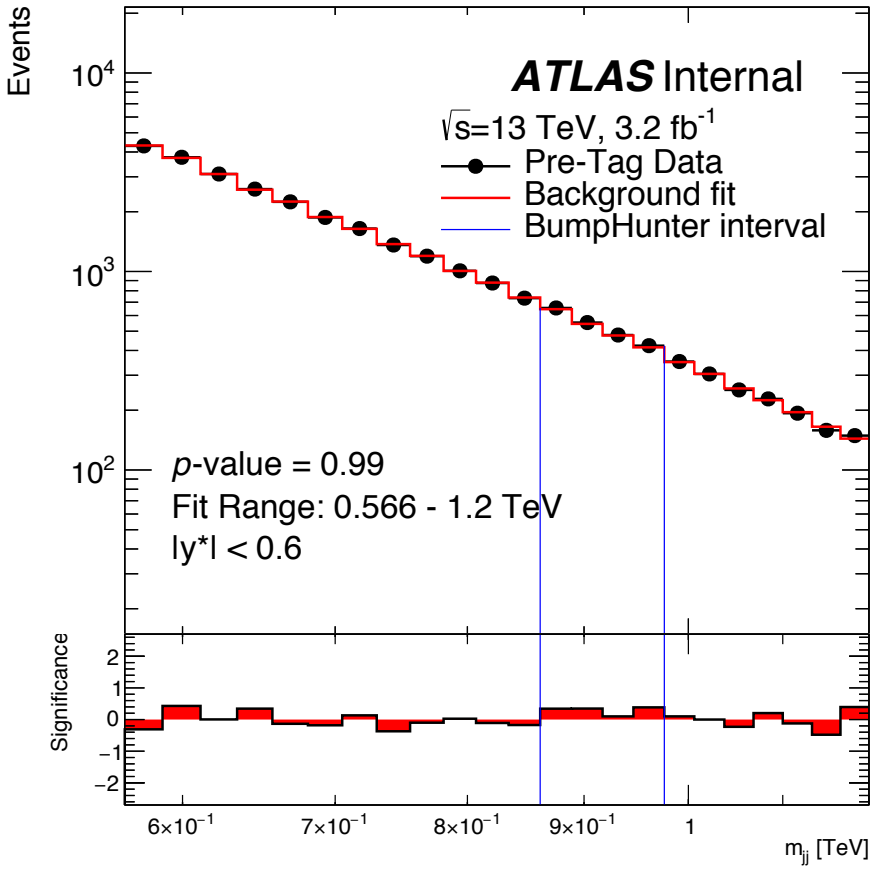
We see for background only fit quality is good

Statistics: Spurious Signal - Trigger Data Norm

- **Data:** Trigger but no offline tagging
  - Normalised to post-tag scale
  - Precise CR, not sensitive to bb
- **Signal:** Z' bb post-tag

- **Hence, these are not real limits!!!!!!**
- No systematics!
- But we can compare exp. to obs.



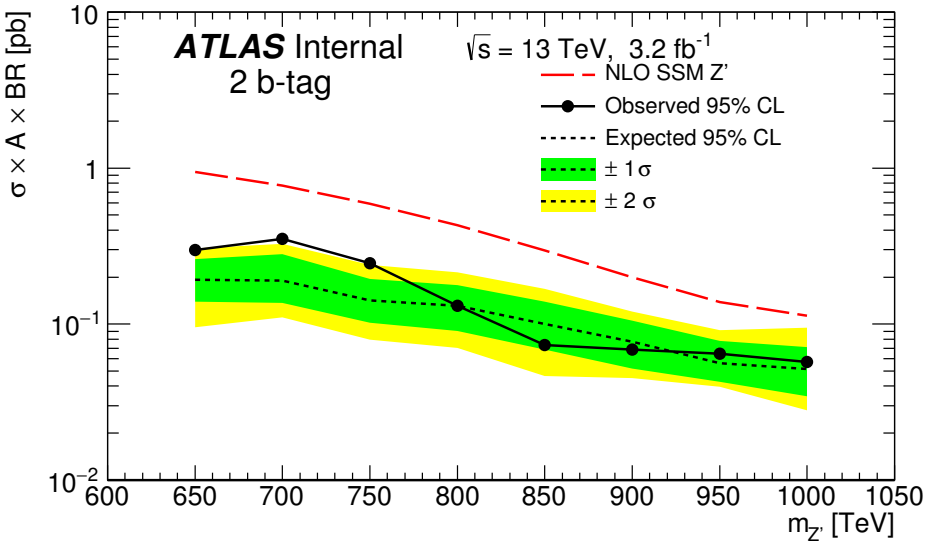


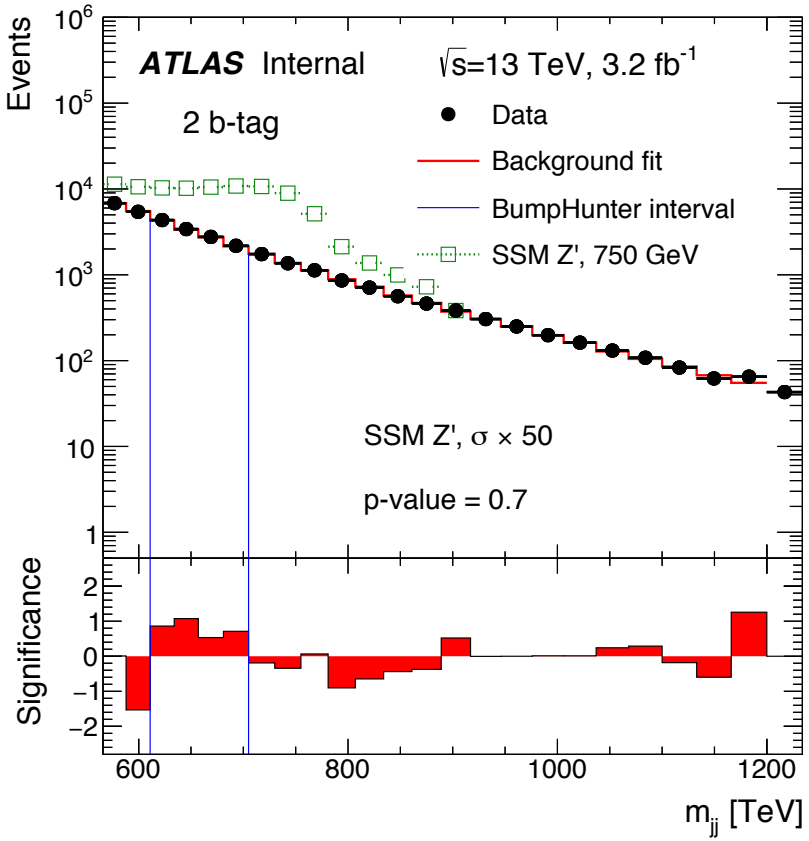
- Expected matches observed within stat. fluc. so no evidence of bias in S+B fit
- This is consisted with what we found in spurious signal test

Final Data Set

- **In addition we already look at observed vs. expected in full data set.**

  - **Data:** Full data Set
  - **Signal:** Z' bb post-tag





- Observed within expectations for data set
- No evidence of fit bias in S+B fit in final data set.

‘ l.304 / More relevant is spurious signal from signal+background fit to the background-only data (or MC) for limit setting. Has this been considered? '

1) The background only fit sees only small discrepancies, so we wouldn’t expect to see large deviations in the S+B fit

2) By comparing the expected and observed in the high-stat CR (and in the final data sample) we can see that there are no significant effects due to fit discrepancies (within error bands)
Hence, we can say no evidence of large S+B fit bias.

3) We already have systematics to account for fit function choice and fit parameters, so fit discrepancies are accounted for in systs.

Other additional tests

- Add in morphed signal points (working on this!)