Search for Resonances Below 1 TeV in the Mass Distribution of jet pairs with Two Jets Identified as b-Jets in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV with the ATLAS Detector

Laurie McClymont,

for the di-b-jet analysis team

2nd. Ed Board Approval

18 May 2016

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Abstract

Searches for mass resonances in the b-tagged dijets invariant mass spectrum below 1 TeV have been performed with the ATLAS detector at the LHC. The dijet mass distribution from 0.5 TeV to 1.2 TeV is studied. The sensitivity was optimized considering a 750 GeVnarrow resonance. The 2015 proton-proton collision data at $\sqrt{s}$ = 13 TeV is used, corresponding to an integrated luminosity of 3.2 fb^{-1}. Conclusions will be added once the full mass spectrum has been unblinded.

INT Note in CDS - Here

Conf Note in CDS - Here

Changes since Approval

Cuts Fixed

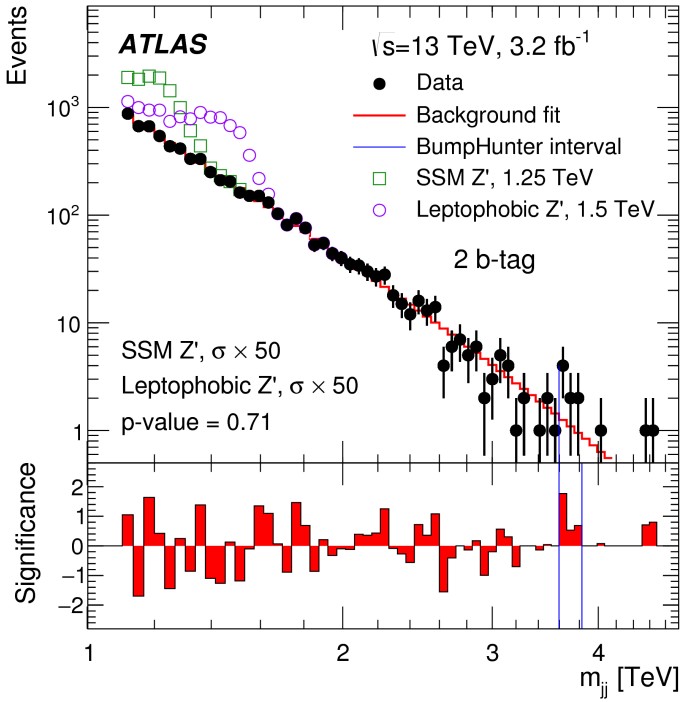
Additional Syst.

Fit Quality Tests

Signal Modelling

Introduction: Motivation

- **Many BSM models predict resonances that decay to b-quark(s)**
  - E.g. Z' Boson
- **b-Tagging Increases Sensitivity**
  - Reduce QCD background
- **Perform Resonance Search**
  - Fit using smoothly falling function
  - Use BumpHunter to find excesses
  - High mass Moriond paper =>



- **Motivation to go to lower masses**
  - **Cross over between γγ and bb?**
  - Assume scalar couples to bb & γγ
    - 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…**

Event and Jet Selection

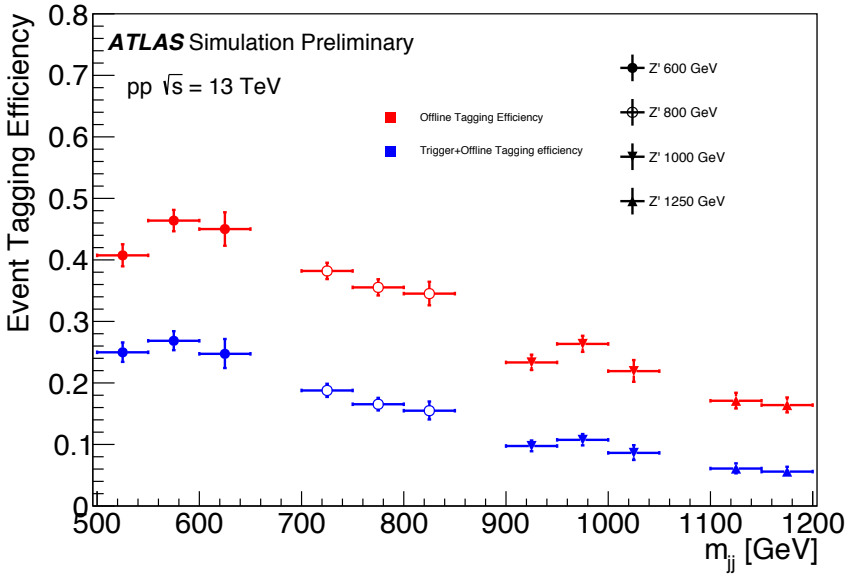
- **Trigger and Data**
  - 3.2 fb^{-1}, excluding IBL off data
  - Double b-jet trigger:
    HLT_j175_bmedium_j60_bmedium
- **Jet Selection**
  - Anti-k_T EM Topo Jets, R=0.4
  - **Leading Jet, p_T > 220 GeV***
  - **Sublead. Jet p_T > 80 GeV***
  - Both jets, |η| < 2.4
- **Event Selection**
  - **566 < m_{jj} < 1200 GeV***
    - *Currently blinding 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	95022224	100	100
GRL, Evt cleaning	94082176	99.01	99.01
Trigger	2829596	2.98	3.01
Jet η	2698350	2.83	95.36
b-tag 1st jet	1351809	1.42	50.10
b-tag 2nd jet	726938	0.77	53.78
jet_0>200 GeV	436913	0.46	60.10
jet_1>80 GeV	429133	0.45	98.22
y*	252086	0.27	58.74

To be updated

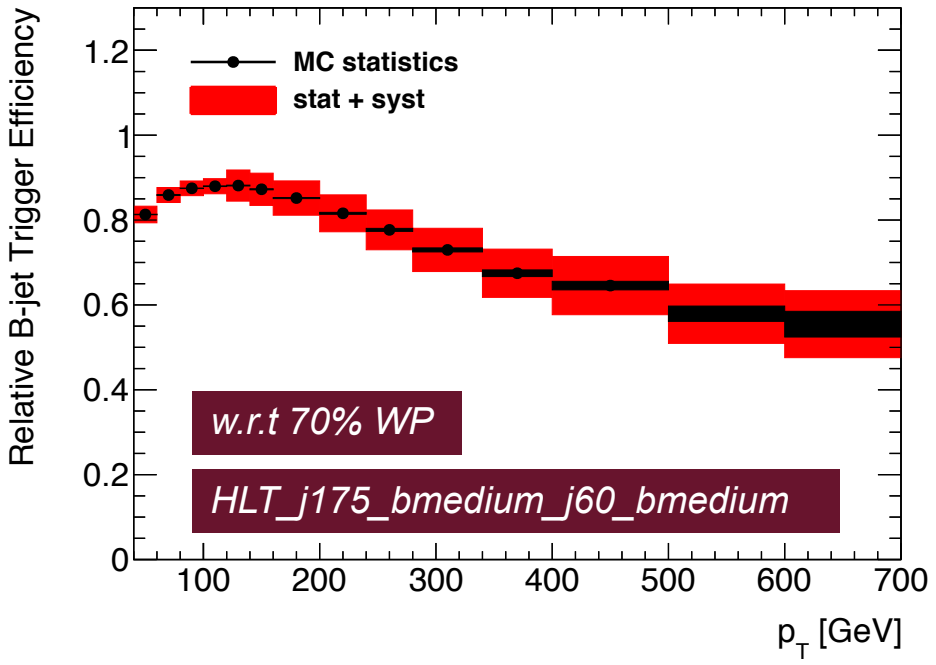
MC Z' - *m_Z = 800 GeV*



** Changed since approval meeting*

b-Jet Triggers: Introduction

- **b-Jet Triggers to get to low masses**
  - 2015 data: IP3D+SV1 Algorithm
- **HLT_j175_bmedium_j60_bmedium**
  - bMedium WP
    - Tighter than 70% eff. WP
  - 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

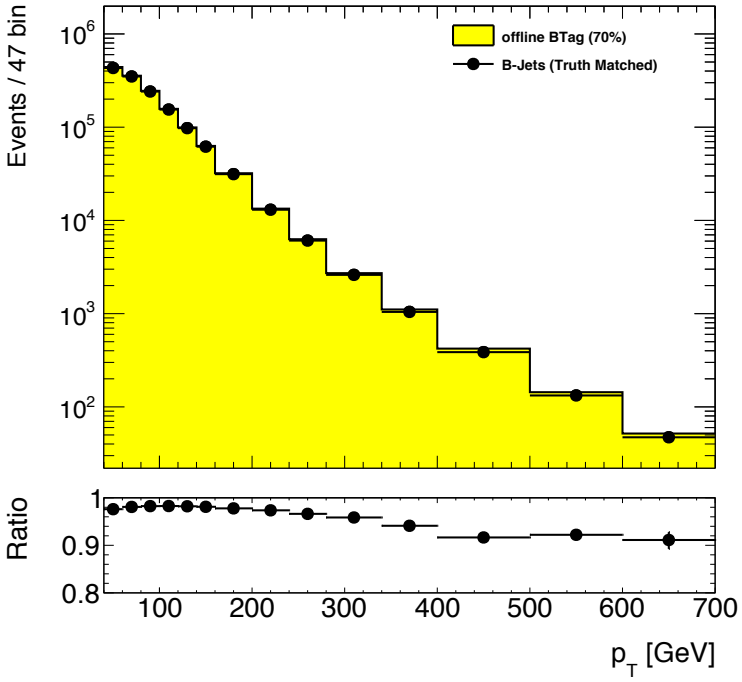


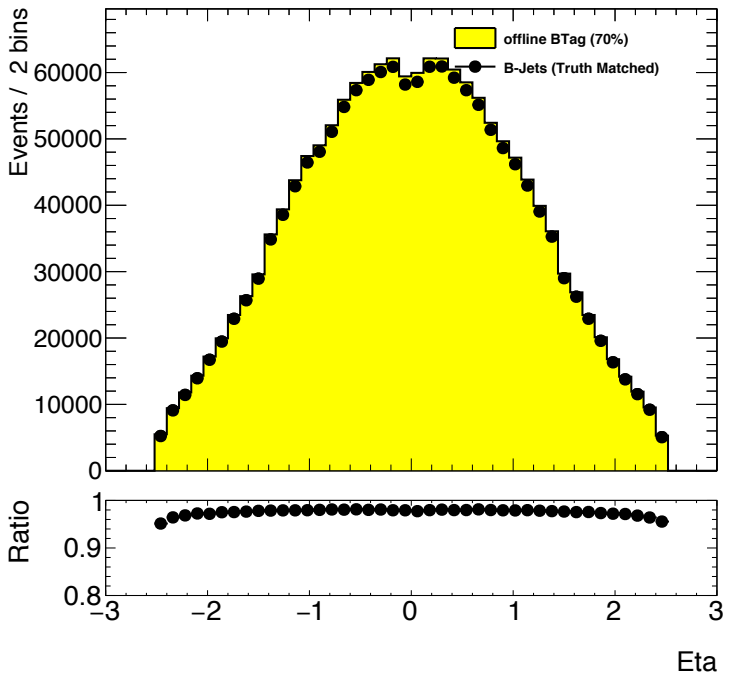
$$\text{b-Jet Trig Eff. wrt offline} = \frac{\text{\# b-Jets pass offline and online b-tagging}}{\text{\# b-Jets offline b-tagging}}$$

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 impurities in sample
  - High purity (>95%) at low p_T, decreases to ~90% at 700 GeV





b-Jet Triggers: Estimating Efficiency

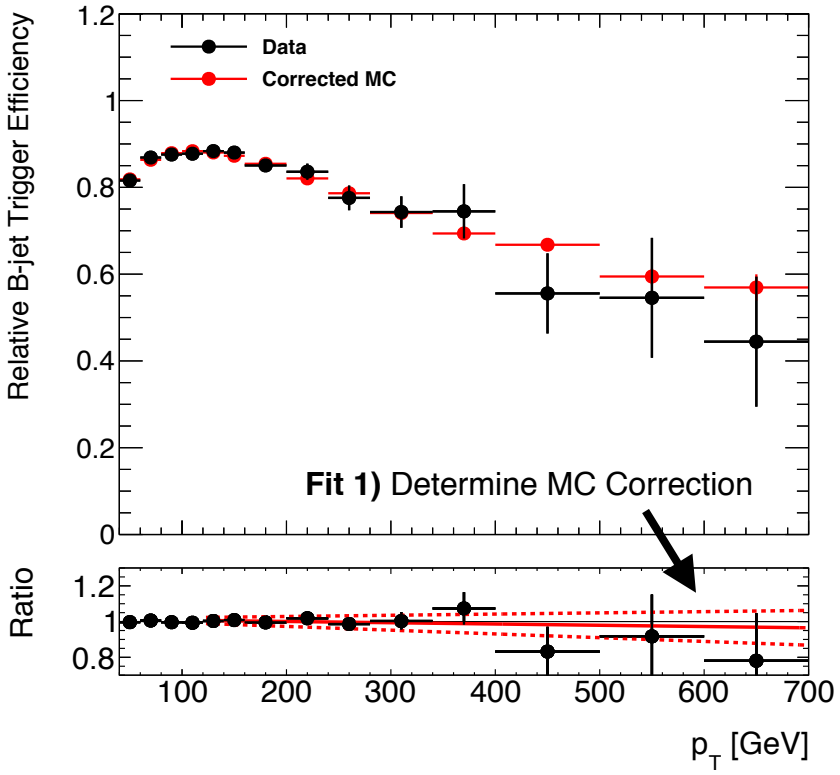
Jet p_T < 120 GeV

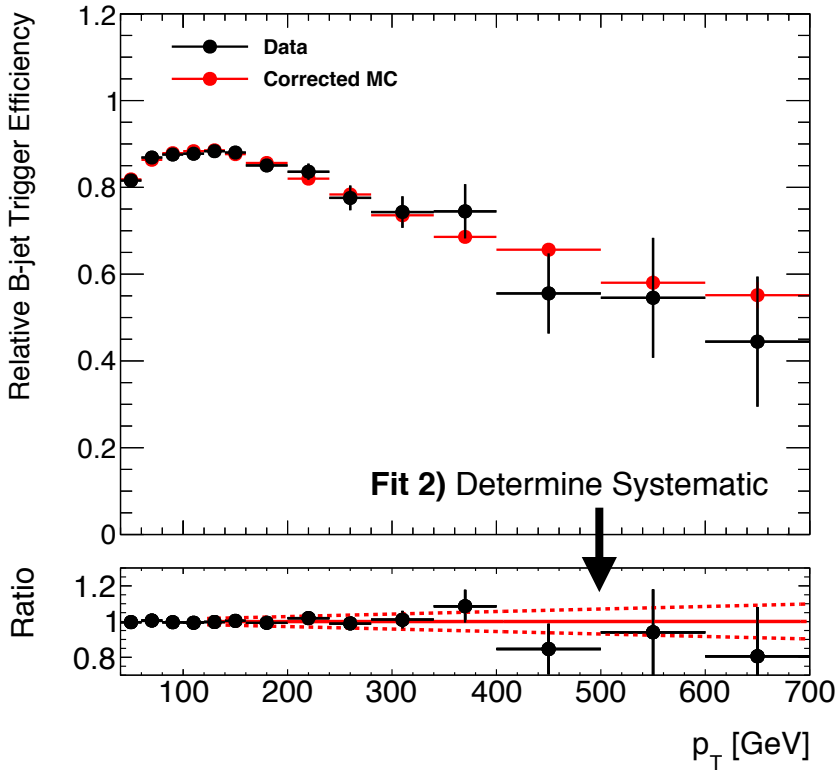
- **Data Eff. taken as central value**

- 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 fit to Data/Corrected MC ratio**
   - Errors are taken from this fit
   - Symmetric systematic

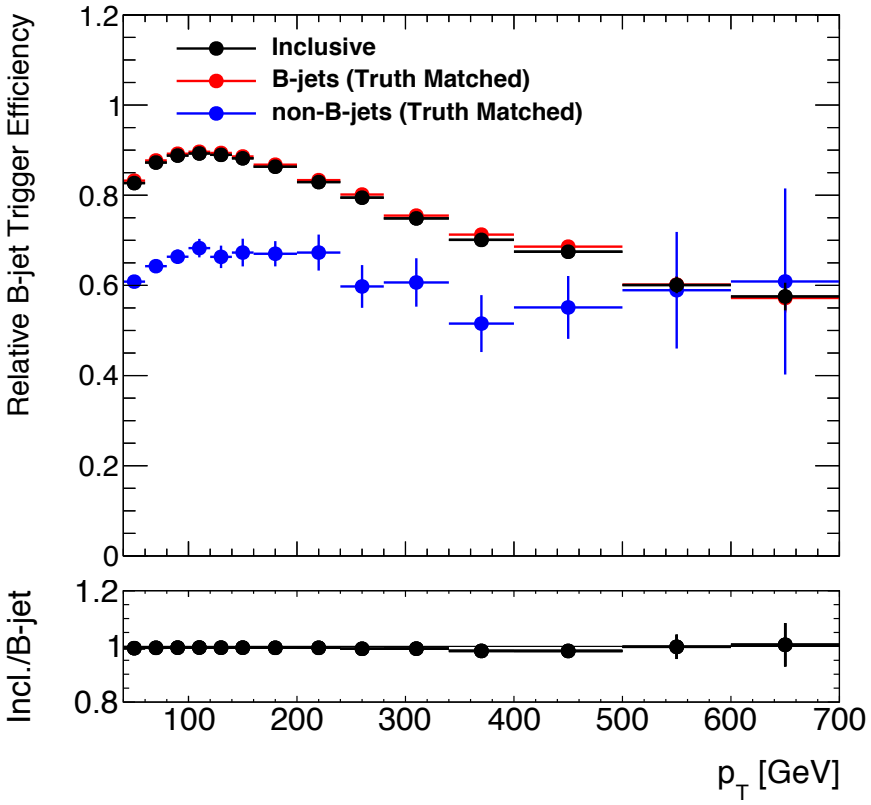


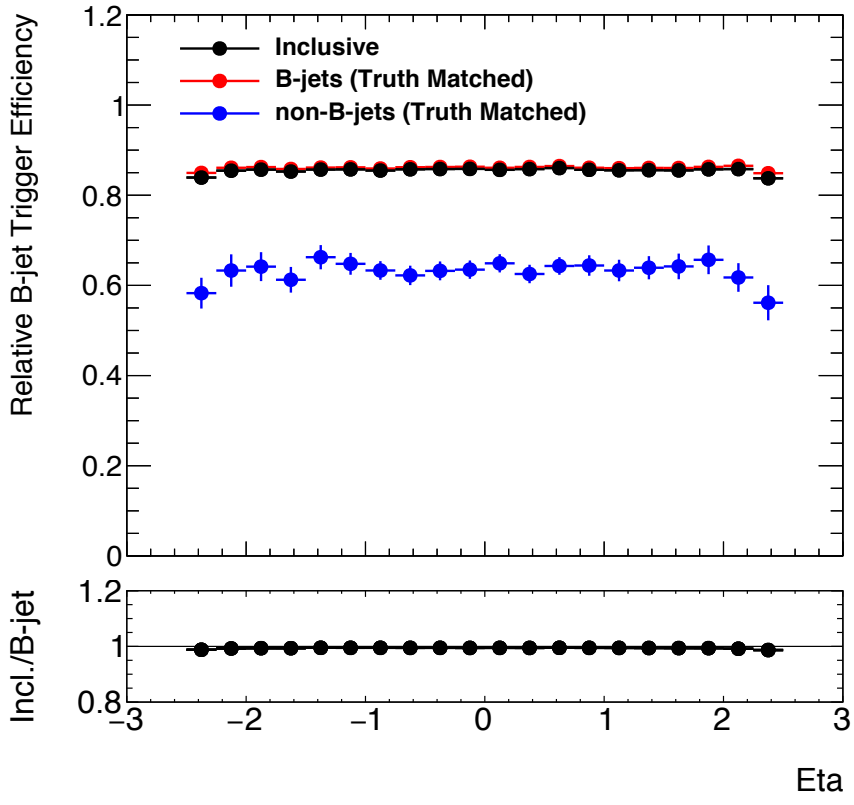


b-Jet Triggers: Sample Dependance Syst.

- **We know that we are not 100% pure in b-jets**
  - High purity (>95%) at low p_T, decreases to 90% at 700 GeV

- **Systematic to account for impurities derived from MC**
  - Truth match b-jets and non-b-jets *(light, c)*
  - Correct for difference between inclusive and truth matched b-jets





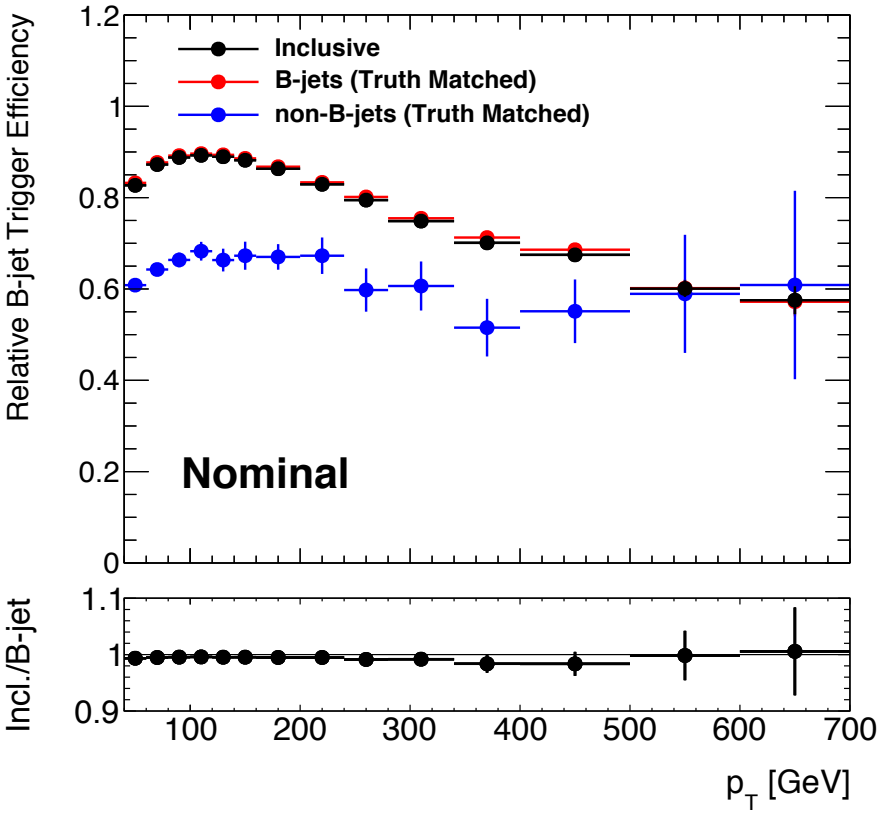
b-Jet Triggers: Sample Dependance Syst.

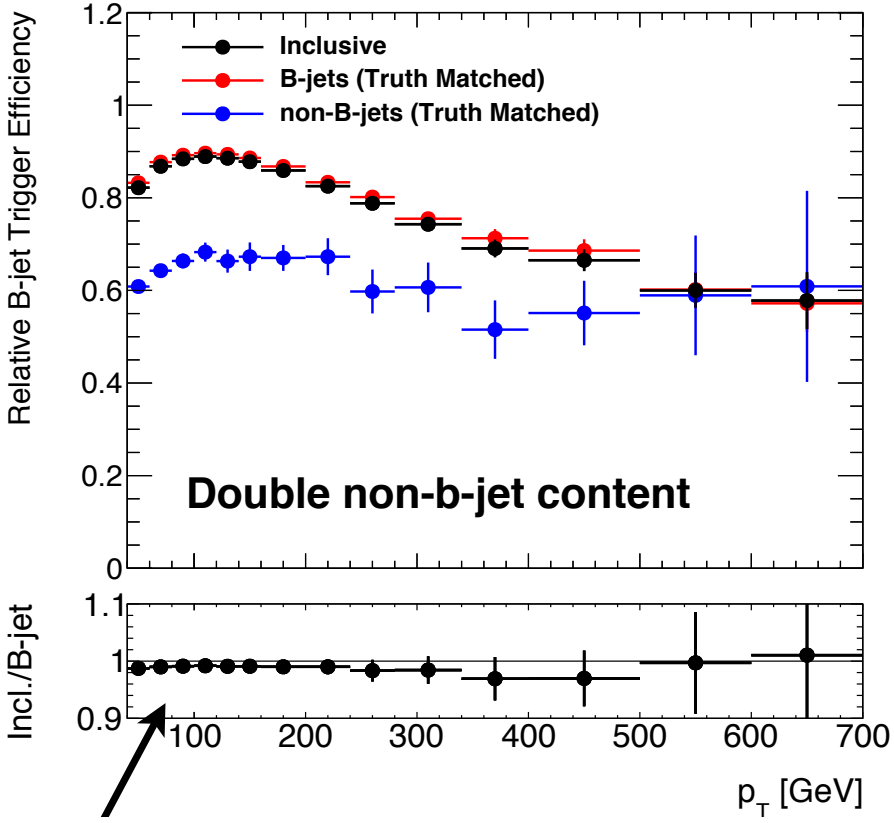
- **Additional systematics to deal with MC mismodelling of;**

1) The initial light flavour composition

=> Vary the non-b-jet component of the tt sample by + 100%

=> Difference from 100% purity taken as a symmetric systematic





Difference from 1 taken as systematic

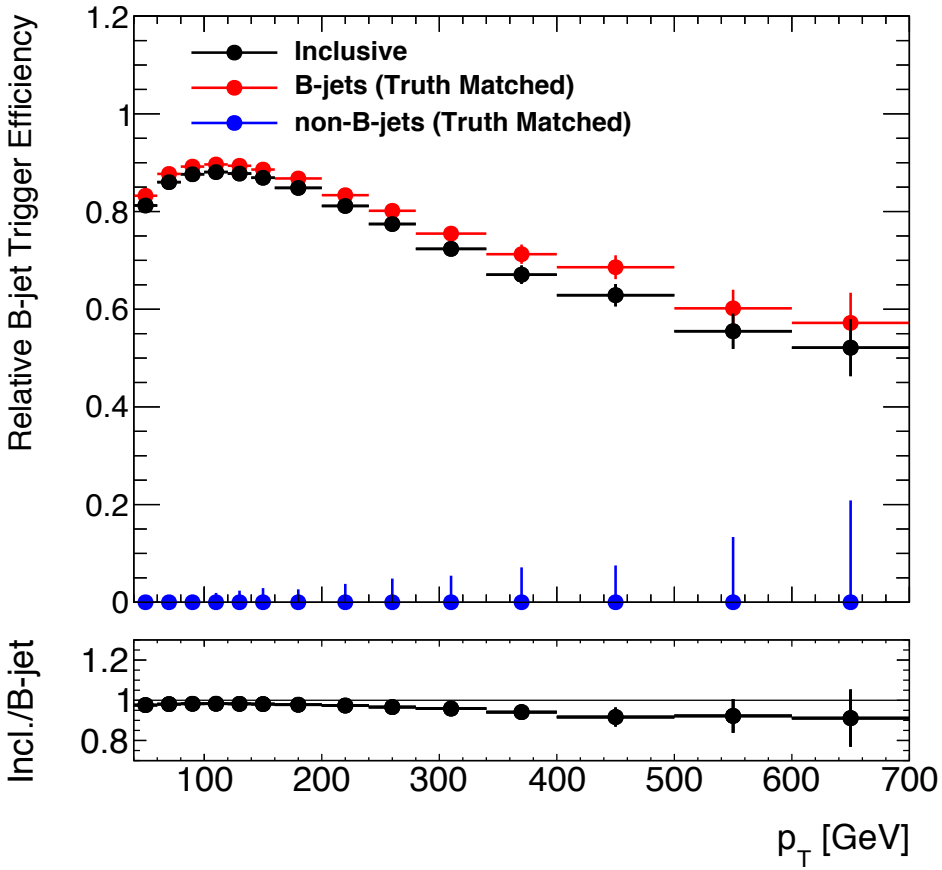
b-Jet Triggers: Sample Dependance Syst.

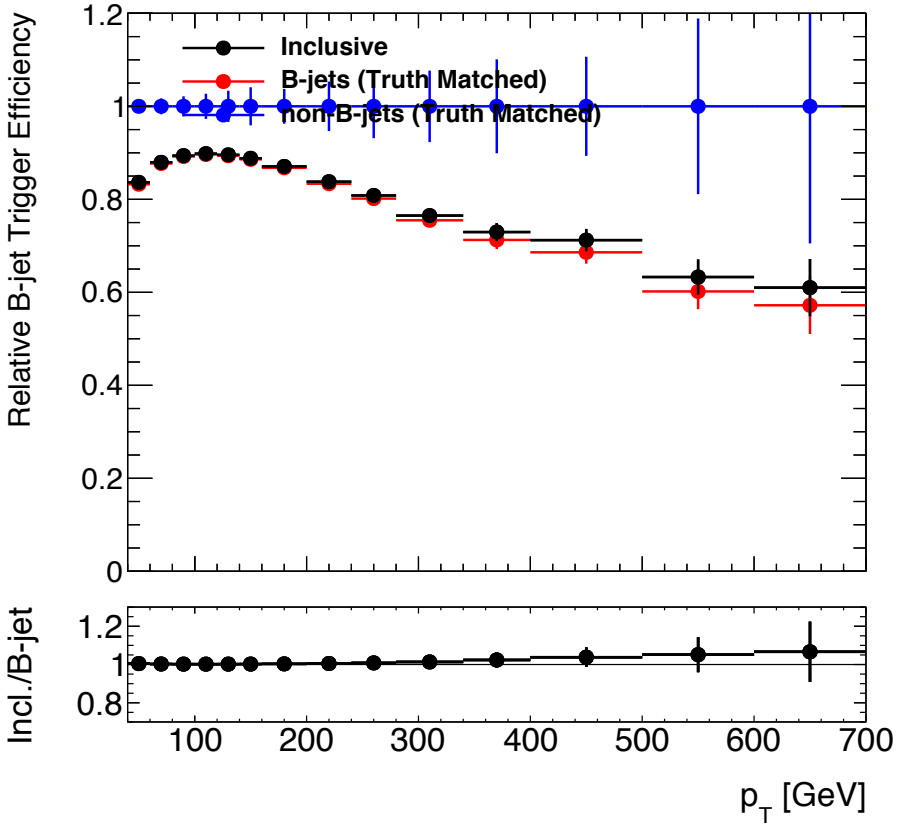
- **Additional systematics to deal with MC mismodelling of;**

2) The light-jet efficiency of the trigger

=> Vary light-jet trigger efficiency from 0 to 1

=> Take larger difference from 1 as a relative systematic uncertainty





b-Jet Triggers: Conclusion

- **Calculate b-jet trig. Eff.**
  - High purity b-jet sample
  - Use data-corrected MC

- **Dominant Systematics**

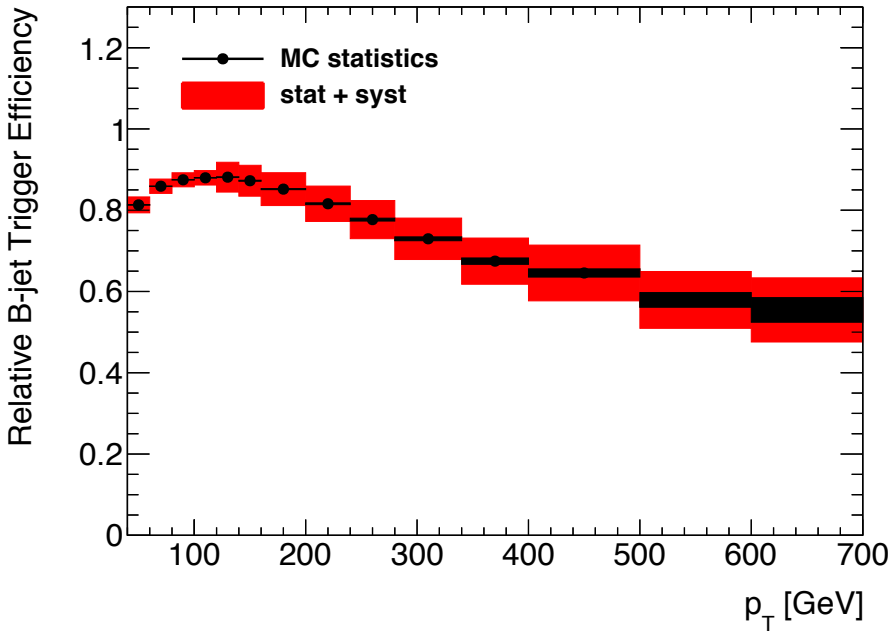
  p_T < 120 GeV:

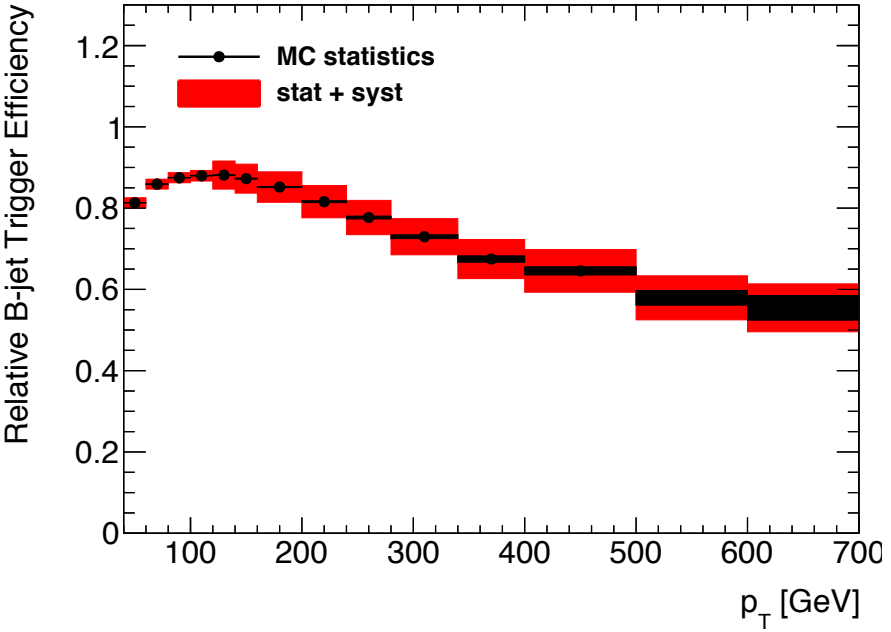
  => Normalisation + data-stat

  p_T > 120 GeV:

  => Extrapolation uncertainty

- **Other Systematics**
  - Impurity (from double b-jet content)
  - Light trigger eff.



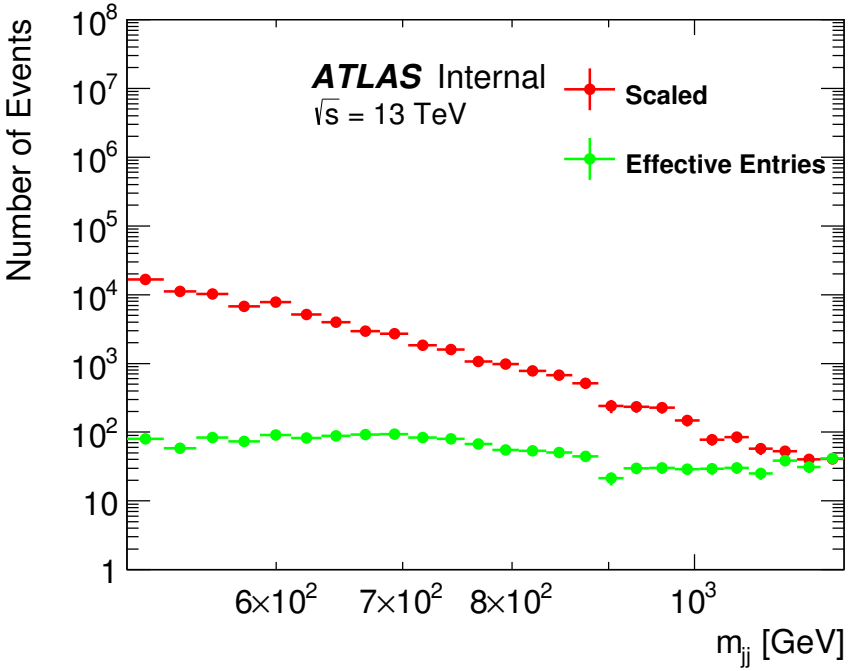


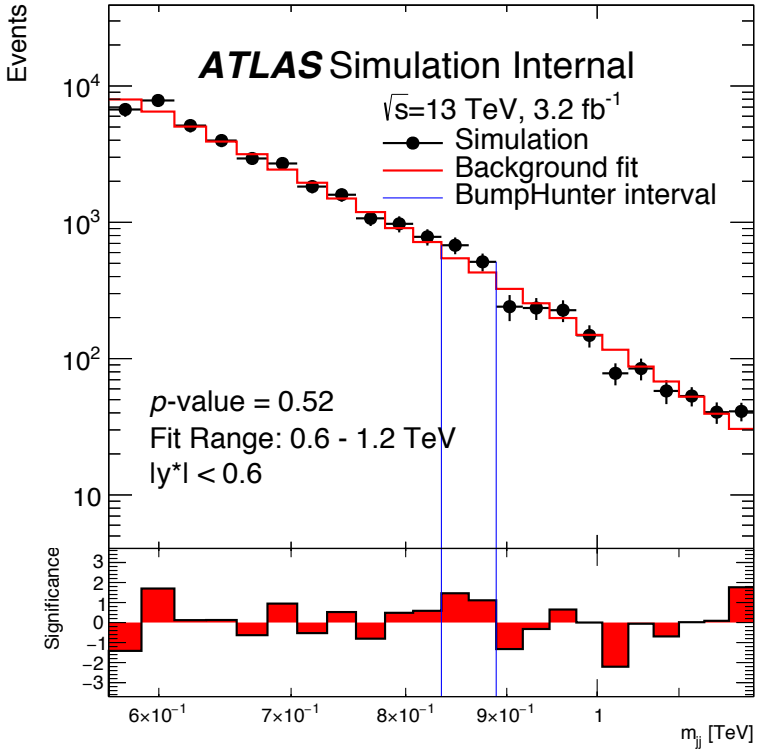
Statistics: Spurious Signal - MC

- **Confirm that fits discrepancies are not significantly occurring**
  - A fit discrepancy may fake or disguise signal
  - Fits performed to a representative background only data set can test fit function

- **Monte Carlo**
  - Pythia8 Dijet Sample, same cuts as in data
  - Except trigger, emulated using p_T dependant b-jet and non b-jet efficiencies (slide 10)
  - Problems with statistics, Effective Entries < Scaled Entries

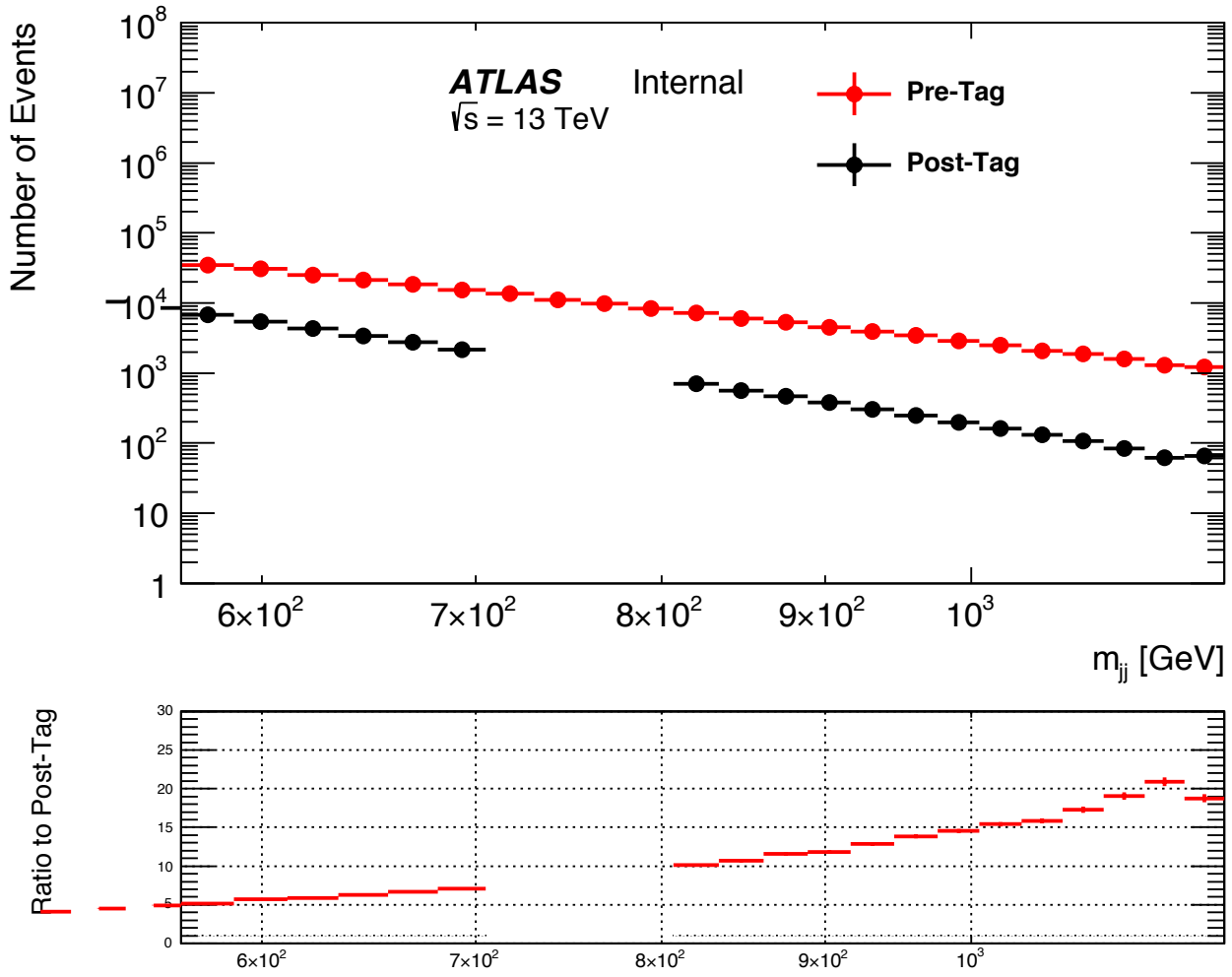
    => Not poisson-like errors





Statistics: Spurious Signal - Data, Trigger Only

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



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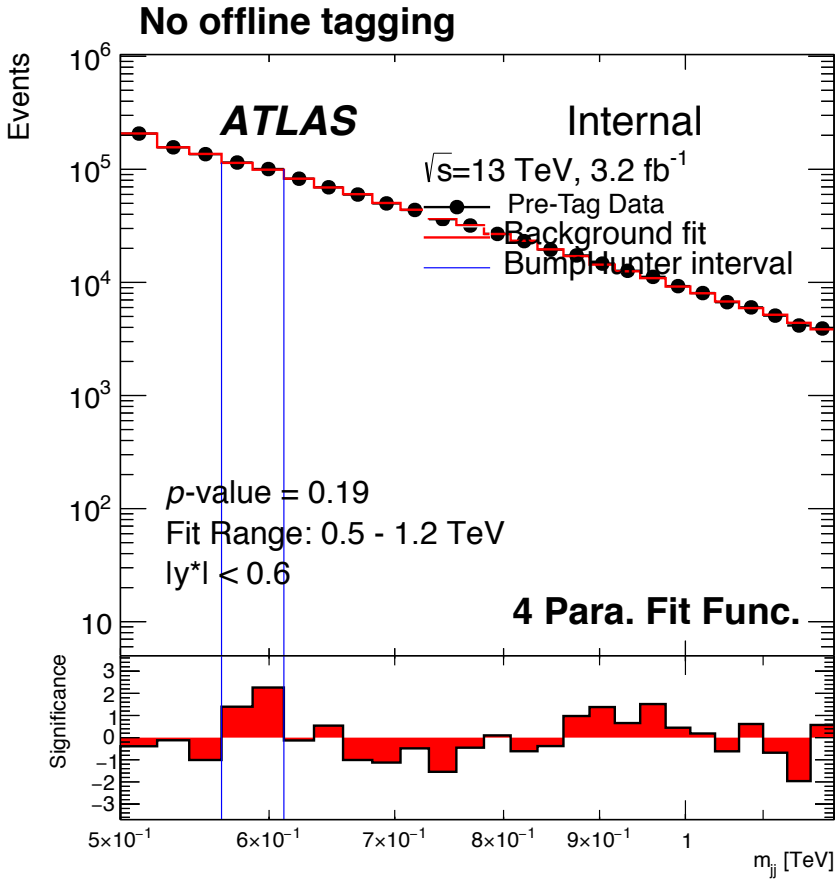
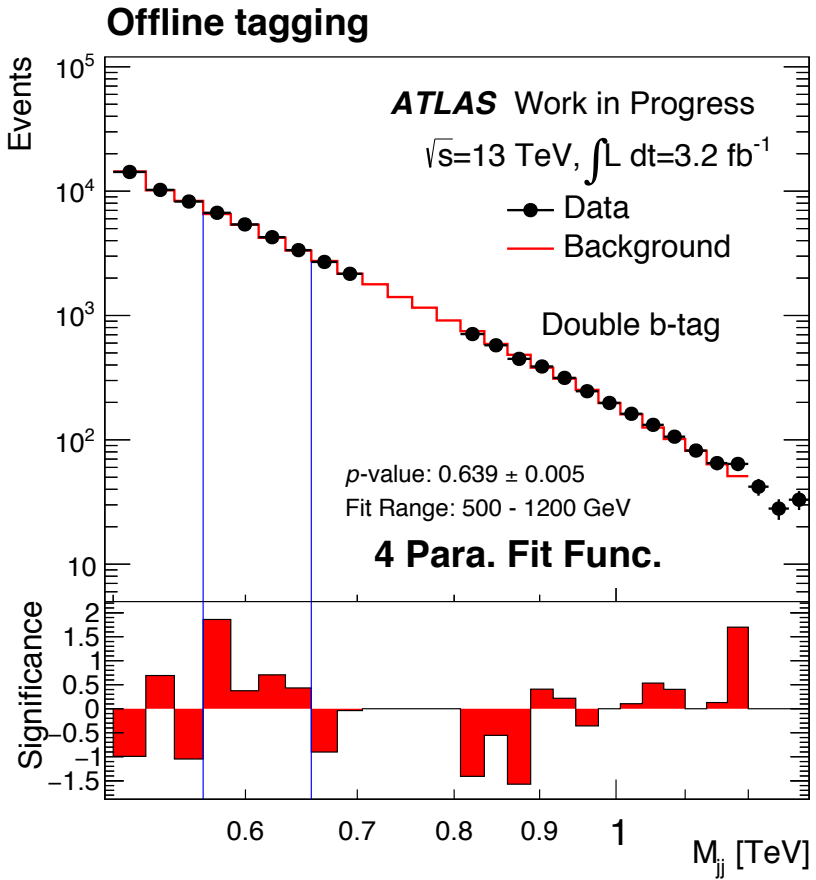
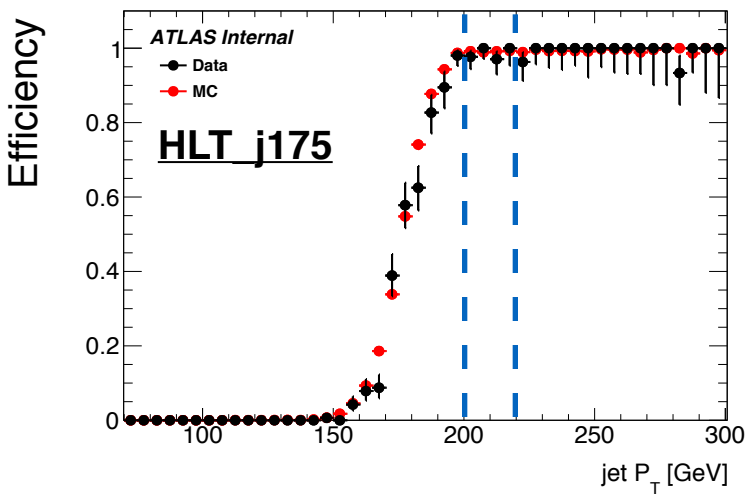
- **Fit quality: Old cuts (LJ p_T > 200 GeV, SLJ p_T > 80 GeV, m_{jj} > 500 GeV)**
  - Periodic structure, seen in ratio plot.
  - Also hints of this in blinded double b-tag spectrum

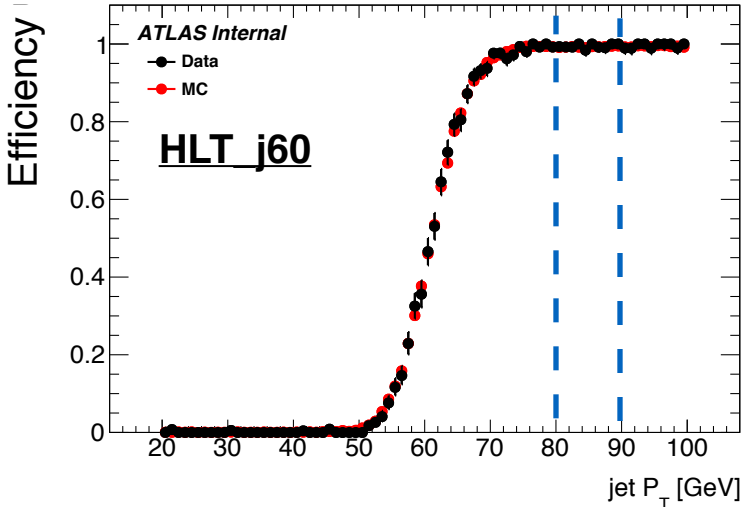




Leading Jet P_T Cut

- **Possible cause of misfit is from trigger turn on effect** ATL-COM-PHYS-2015-1322





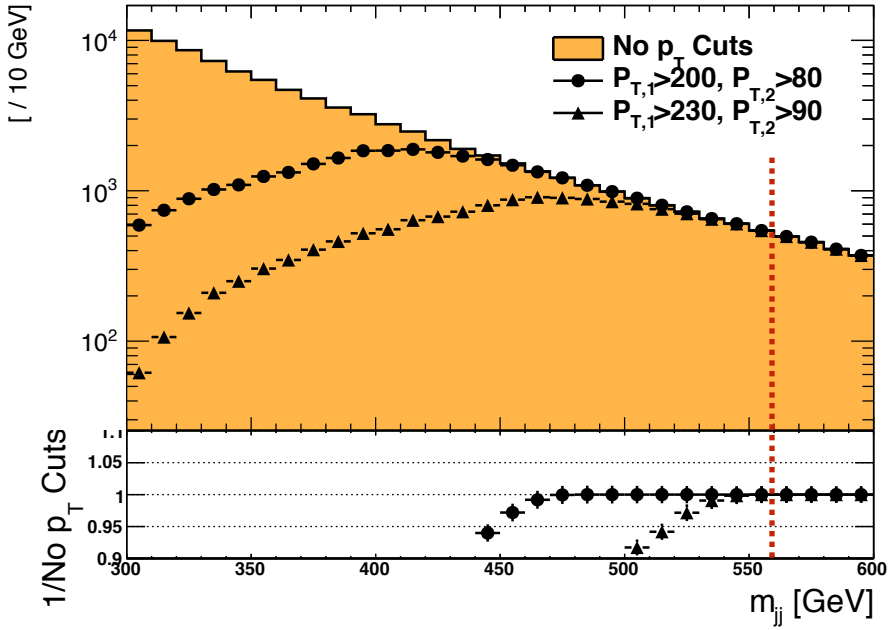
Cuts motivated by 99% Eff. Point
=> On trigger plateau

Leading Jet P_T > 220 GeV

Sublead. Jet P_T > 90 GeV

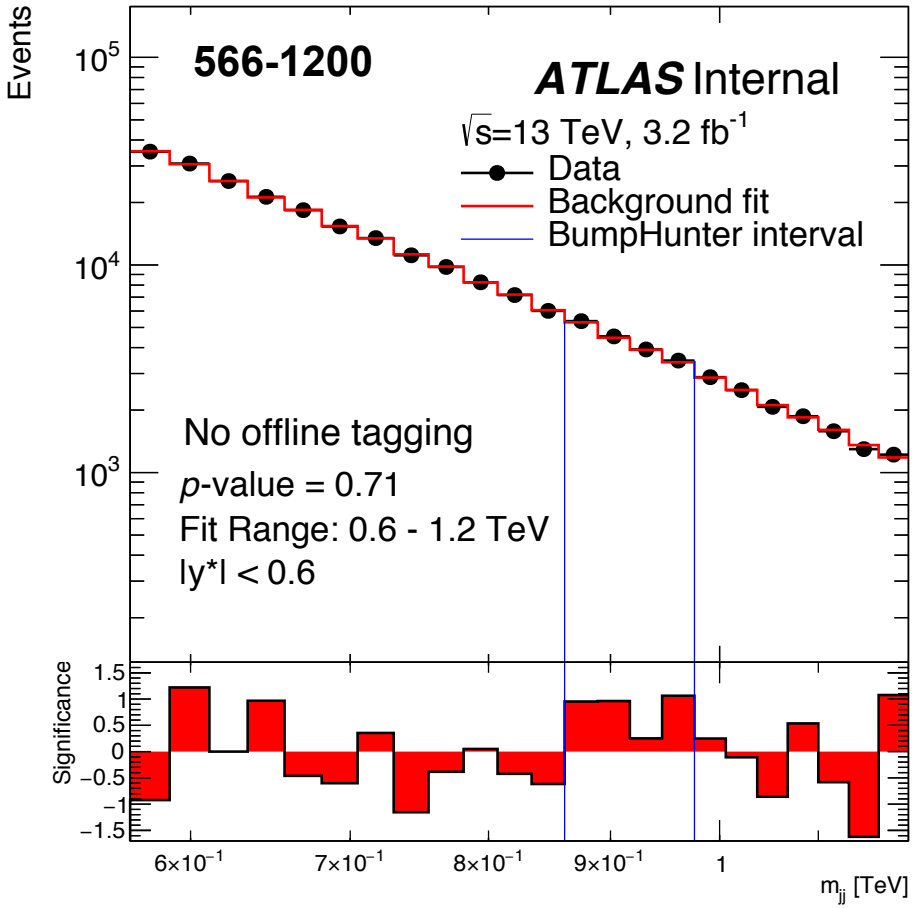
=> m_{jj} determined again

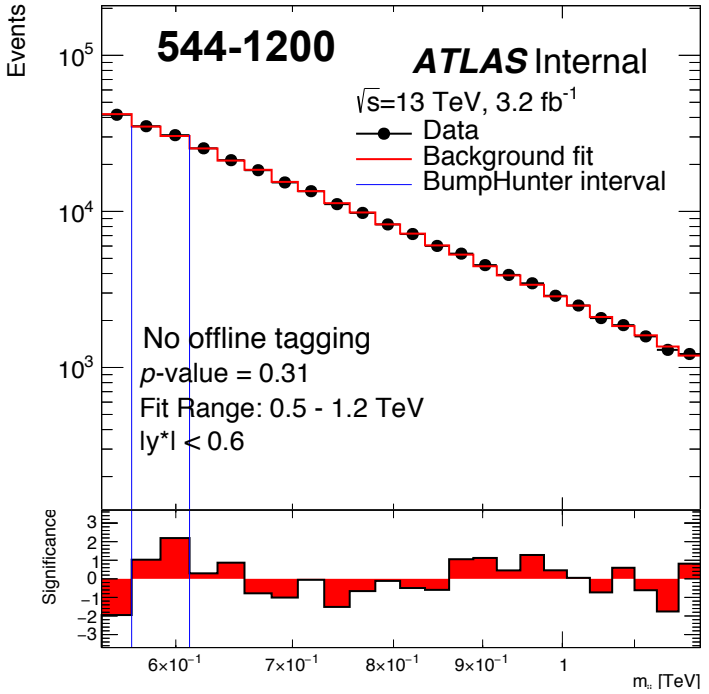
m_{jj} > 566 GeV

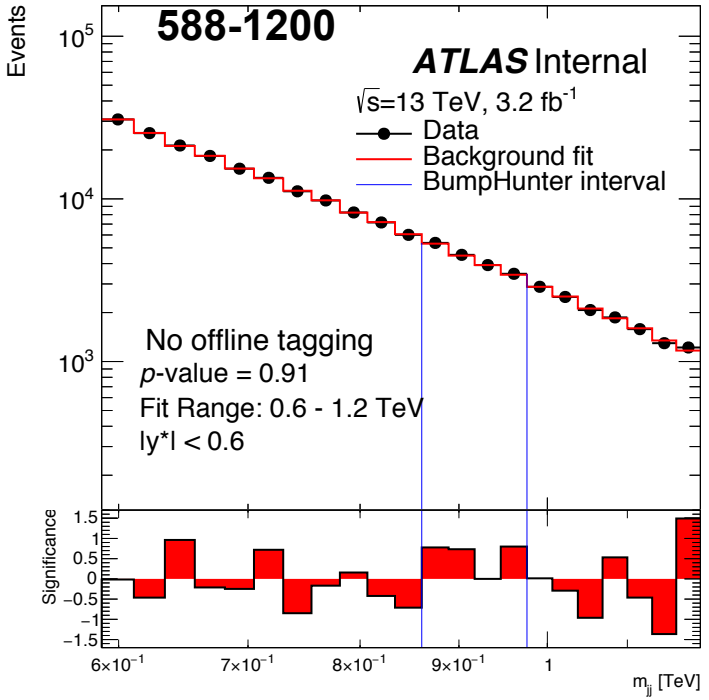


Spurious Signal

- **Changing Fit Range**
  - 544-1200 => Structure in ratio plot
  - **566-1200 => Fit OK!**
  - 588-1200 => Thrown in as well

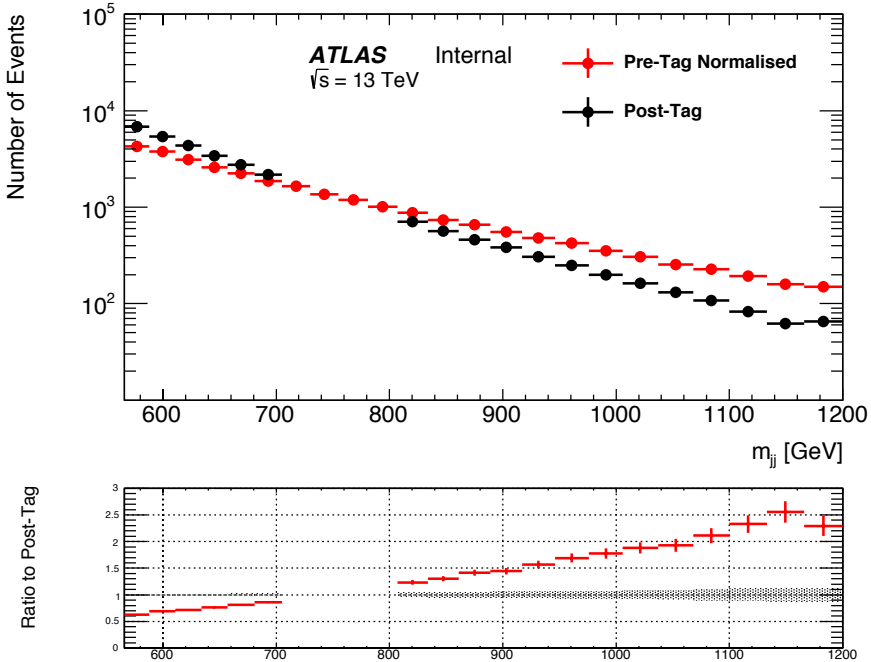


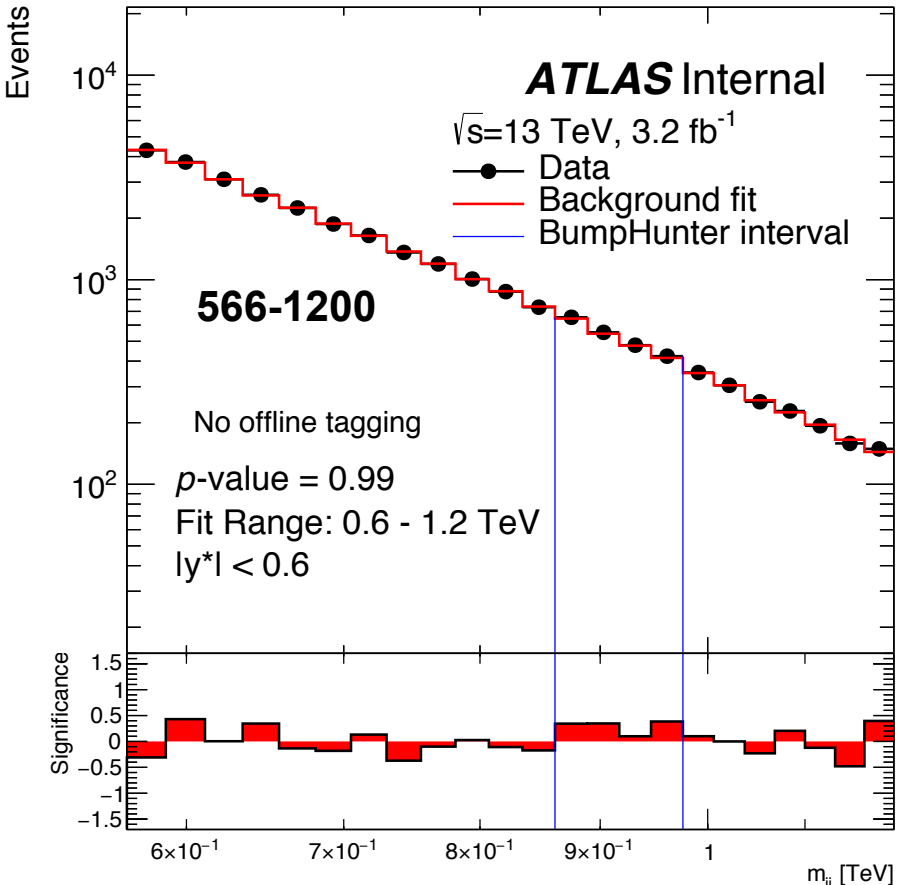




Spurious Signal: Scaled Down

- **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 (sine behaviour)
<< poisson fluctuations of post-tag

99% of toys have **worse** fit

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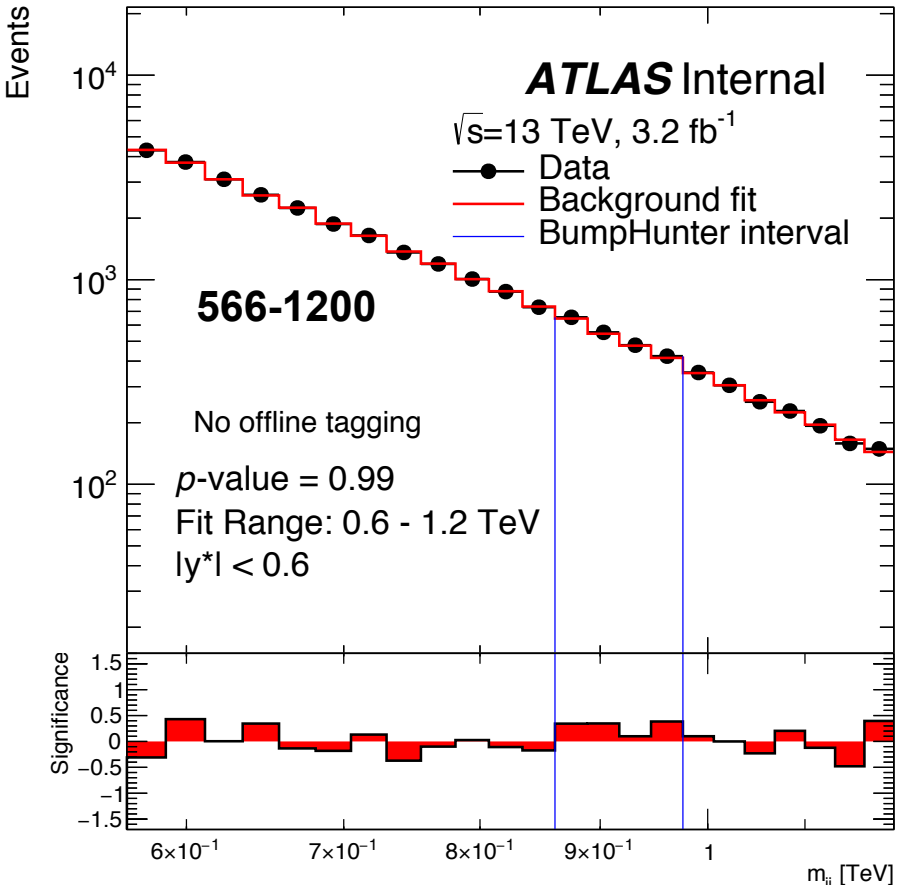

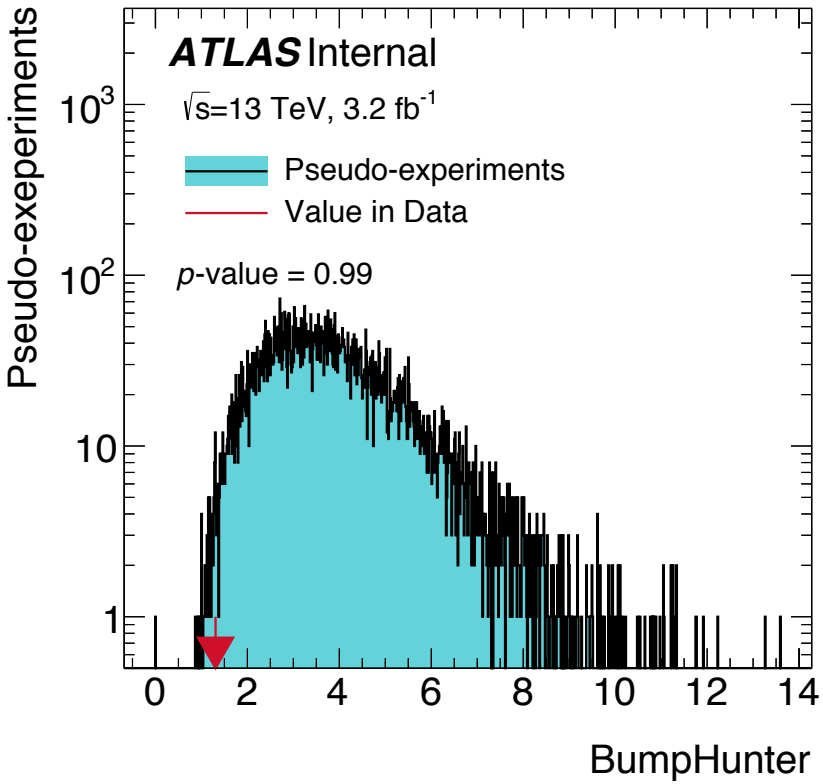

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fit discrepancies (sine behaviour)
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99% of toys have **worse** fit

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

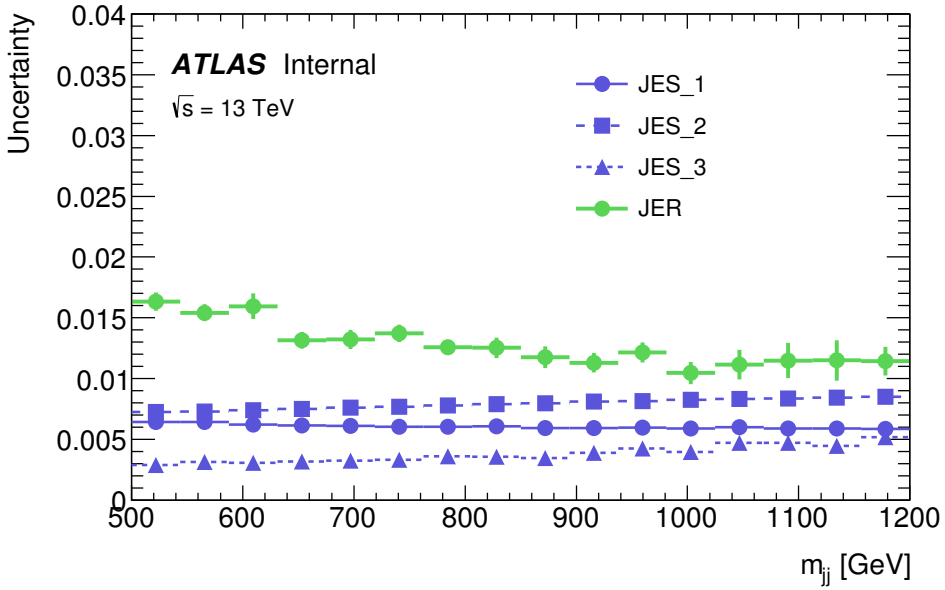
Systematics

- **Monte-Carlo (Signal)**
  - Luminosity (5%)
  - JES - Reduced 3NP (<4%)
  - JER - Reduced 1NP (<2%)
  - **b-tagging SF (~30%)**
  - **b-Jet trigger Efficiency (~10-30%)**

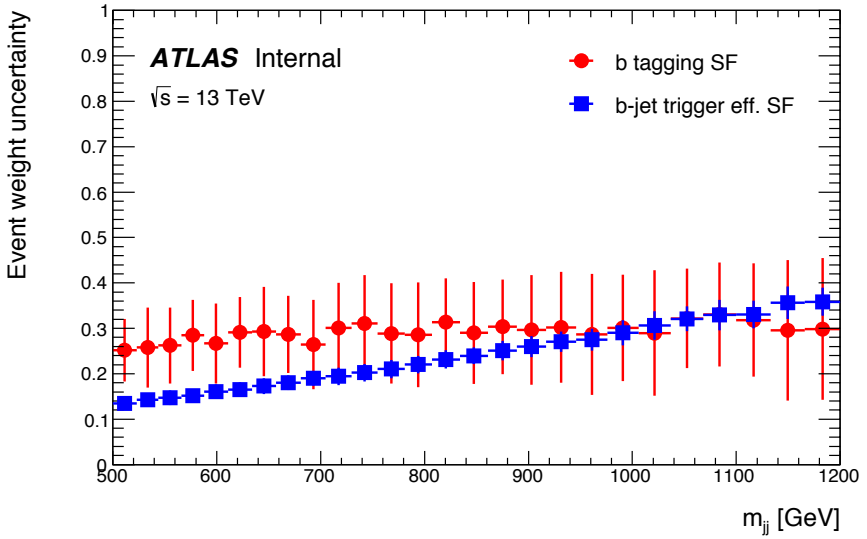
- **Background**
  - Fit function choice
    - Comparison to alt. function (5 par.)
  - Uncertainty on fit parameters
    - Taken from pseudo-experiments

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



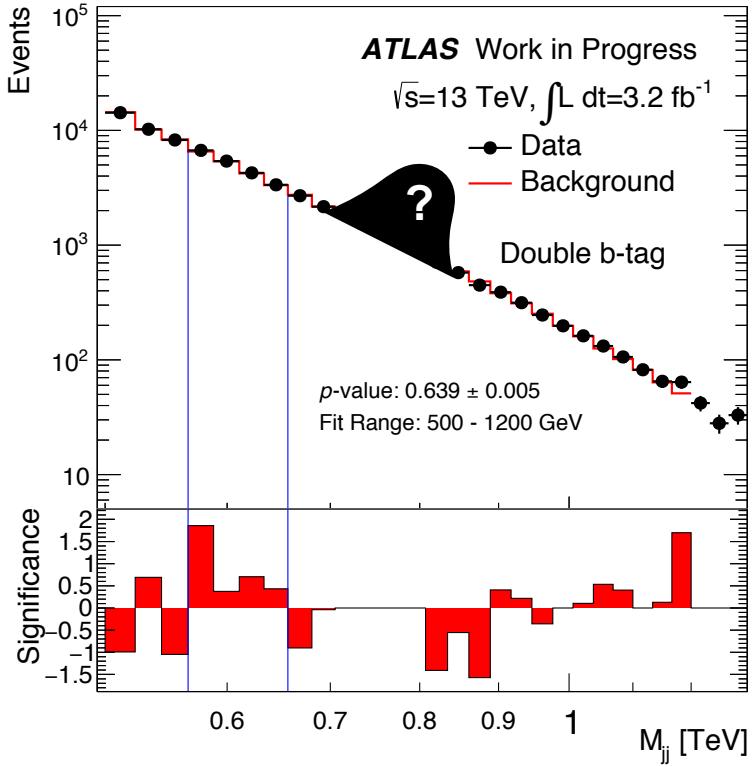
b-Tagging SF Uncertainty



Conclusions

	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

- **Low Mass b-Tagged Analysis**
  - Weak limits in bb at 750 GeV
- **Use b-Triggers to get to low mass**
  - b-Jet efficiency measured
  - Systematics studied
- **Fit quality tested**
  - Tested with Data and in MC
- **Systematics ready to go!**
  - b-tagging and b-jet trigger eff. dominant
- **We are ready to unblind (?!)**



- **Next Steps: Update all plots with unblinded data**
  New support note by end of week - On course!

Backup!

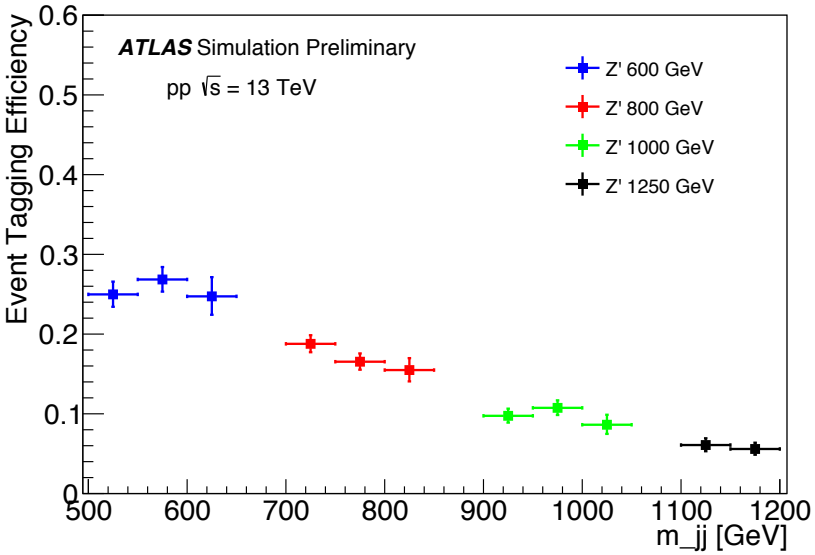
Event and Jet Selection - Extras

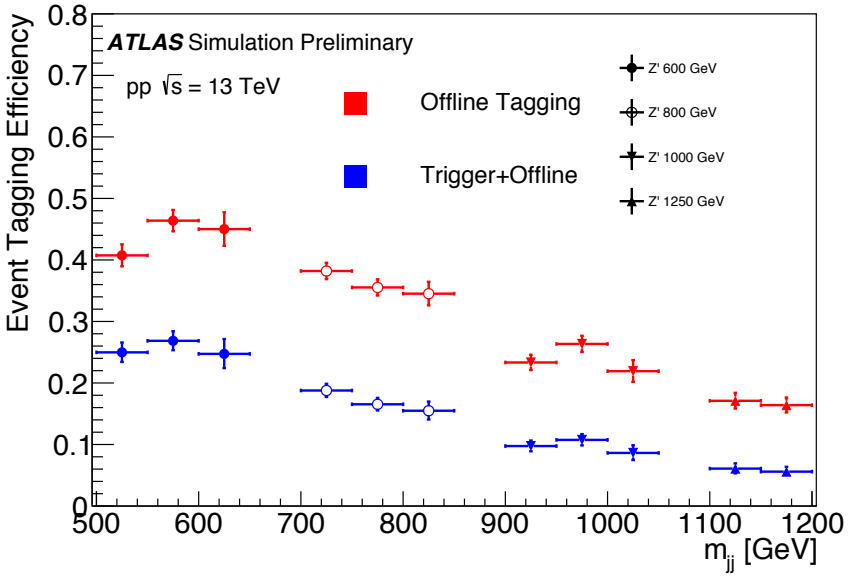
- **Offline b-Tagging**
  - **MV2c20 @ 70% WP**
    - Online tagging limits b-jet eff.
    - Gain Light jet rej. from offline

- **Working Point Selection**
  - 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

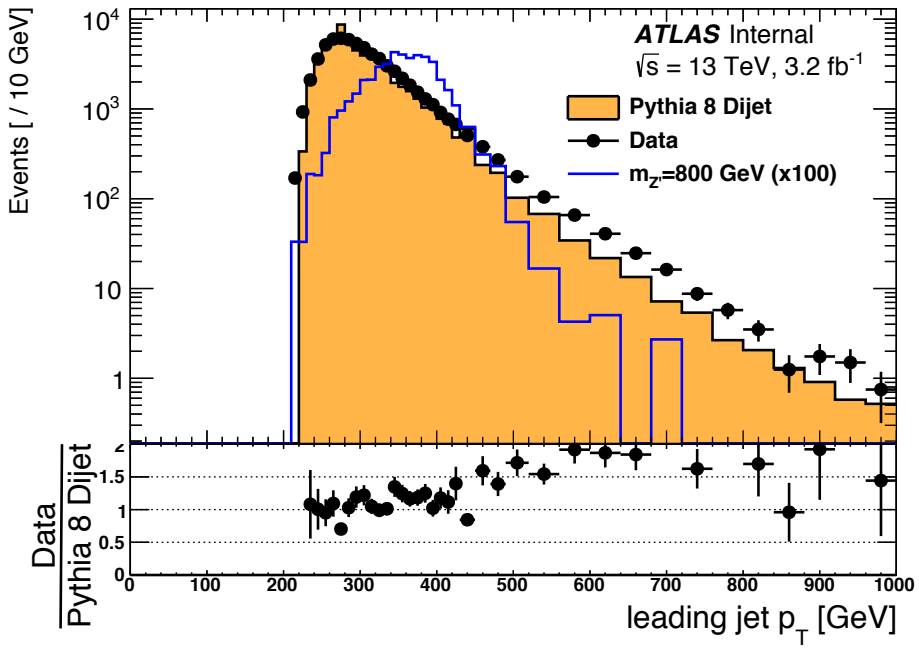
b-tag OP	Eff (%)	N_{evt}^{exp}(bkg) in SR	Exp limit (pb)
85	9	8800	1.2
77	9	6000	1.0
70	8	4400	1.0
60	6	2800	1.1

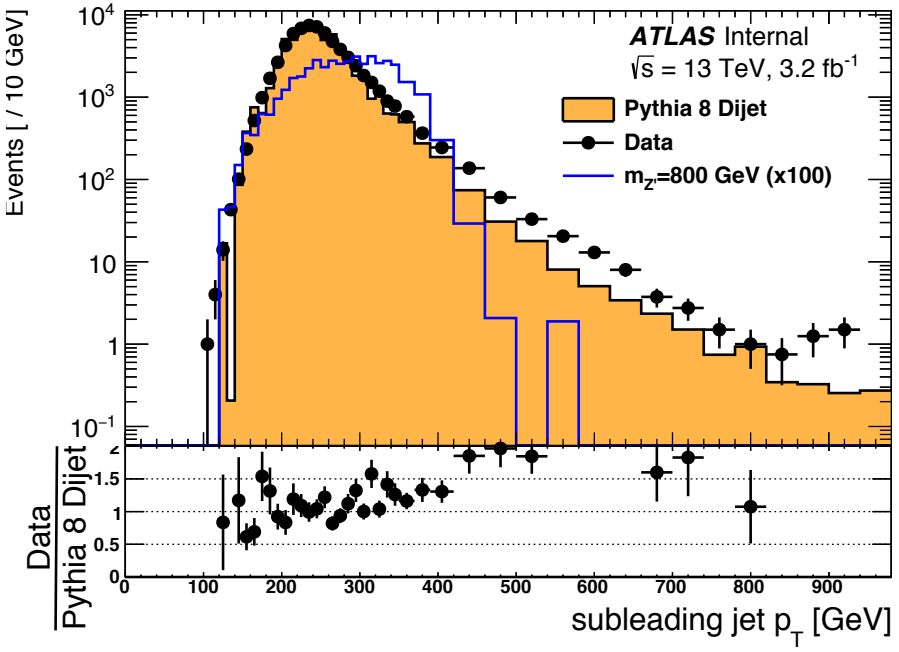
Signal Tagging Efficiency





Kinematics: Validation Plots



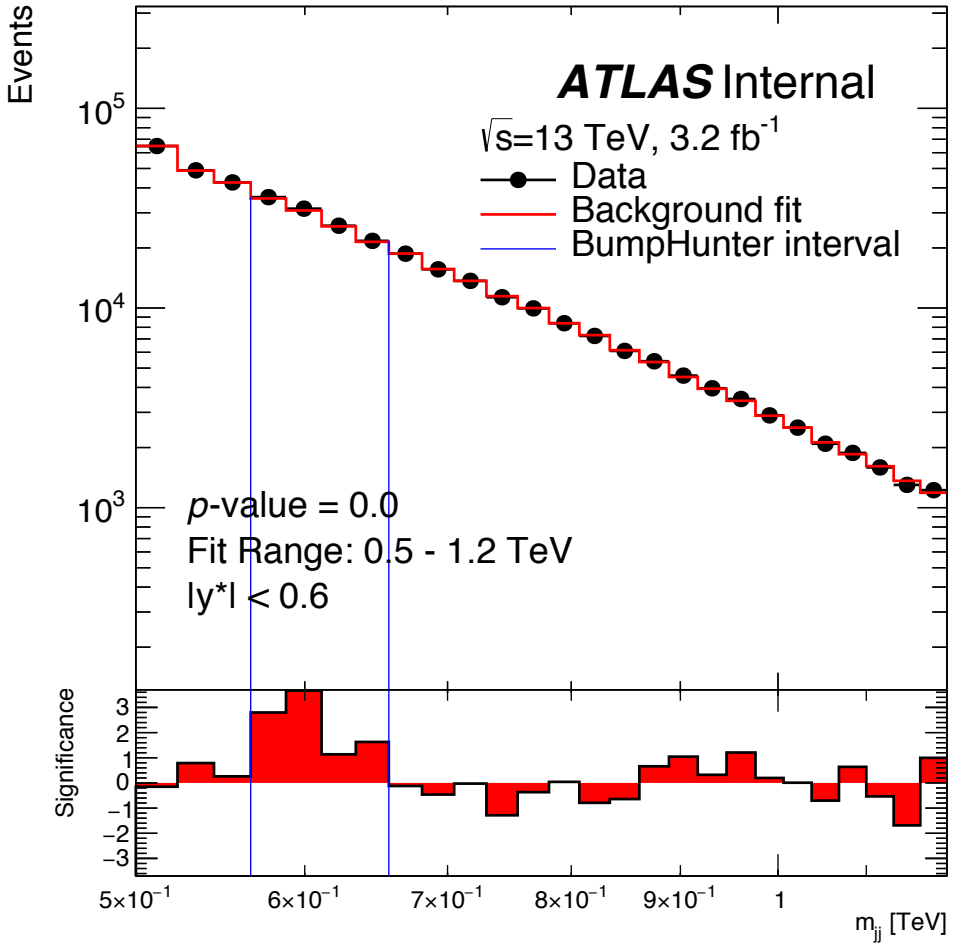


- **Emulating online b-tagging**
  - Light/Charm online b-tagging efficiencies not known
  - Thus some mismodelling expected
- **Many more validation plots available**
- **Z' with m_Z = 750 GeV being simulated now**

Spurious Signal - Additional Check

- **Check if statistical fluctuation at 566 GeV**
  - This may cause fit issues (even if not actually significant)
  - Removing up to stat edge allows fit to adjust
  - Still on old cuts (Leading jet p_T > 200 GeV, Subleading jet p_T > 80 GeV)

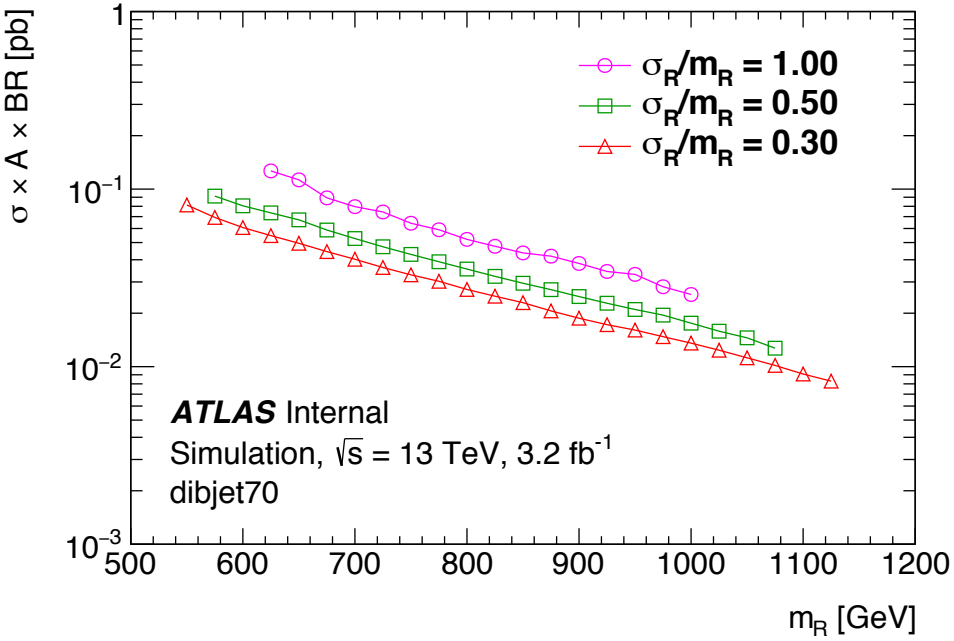
- **Remove Window**
- **Fit to Sidebands**
  - bH p-value = 0.4681
- **Then use fit with full range**
  - Rerun BumpHunter
  - bH p-value = 0.001

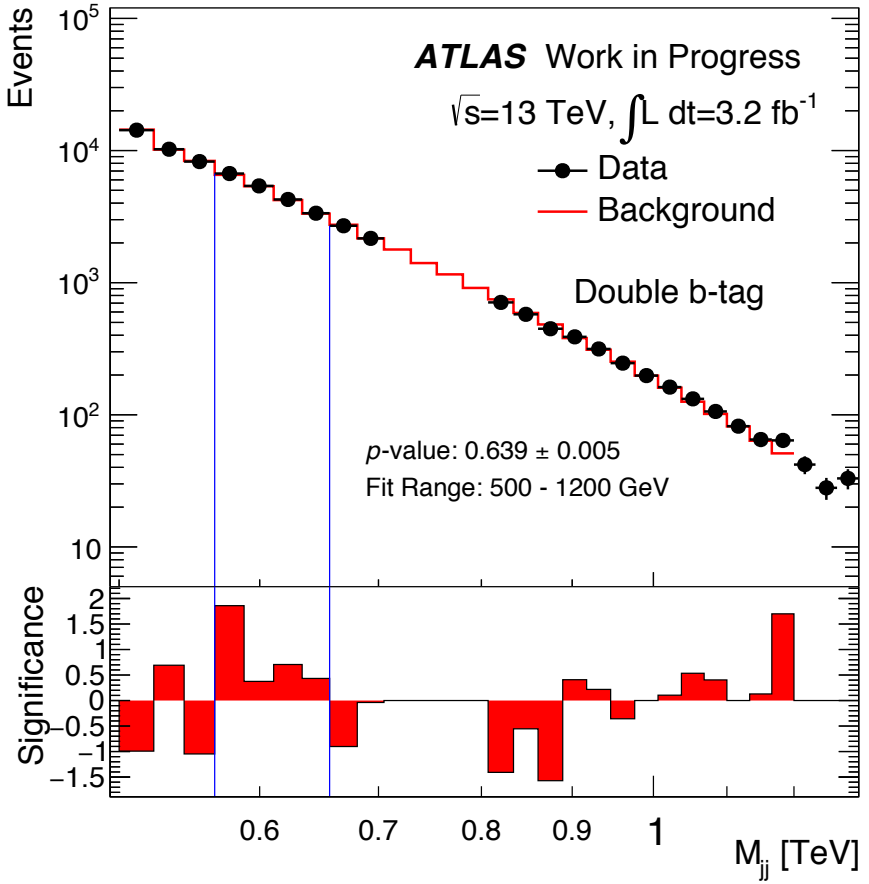


Search Phase and Limits

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

- **Generic Gaussian Expected Limits**
  - We do well compared to 2.1pb theory
    - ~20% acceptance at 750 GeV





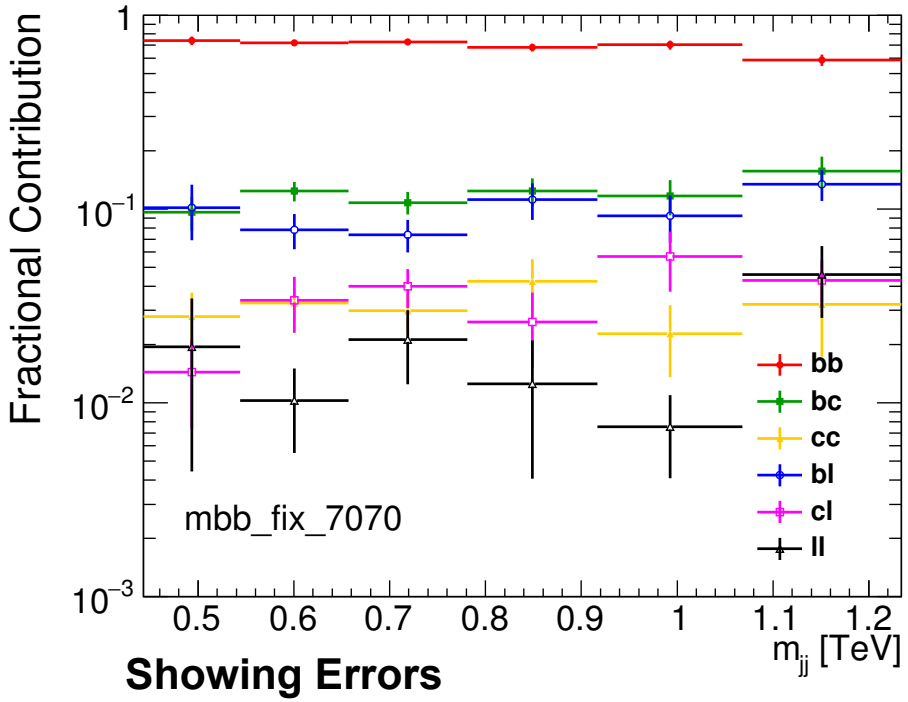
No significant discrepancy, yet…

Will be run on full range when unblinded

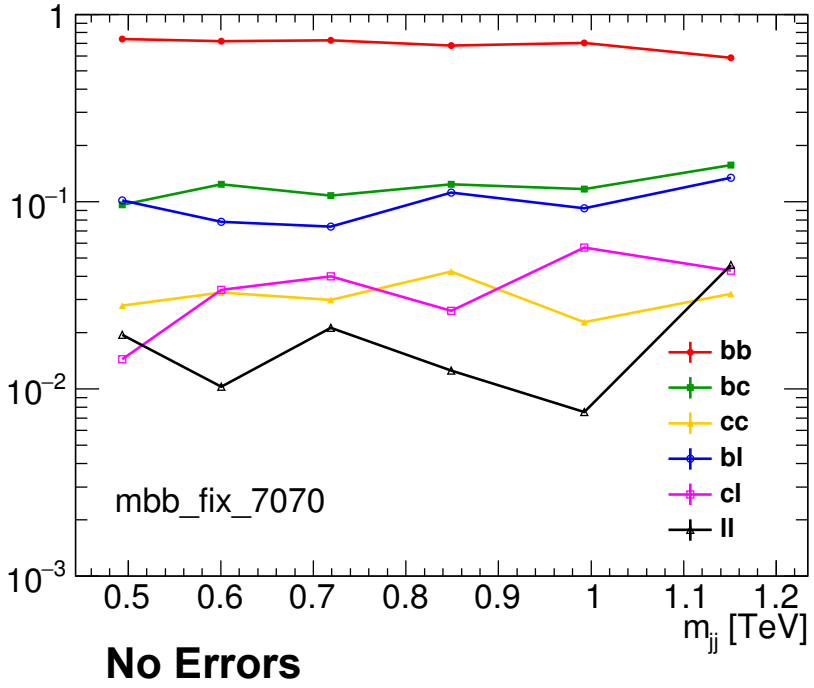
Kinematics: Flavour Composition

- **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 10)



Showing Errors



No Errors

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

Statistics: Fitting

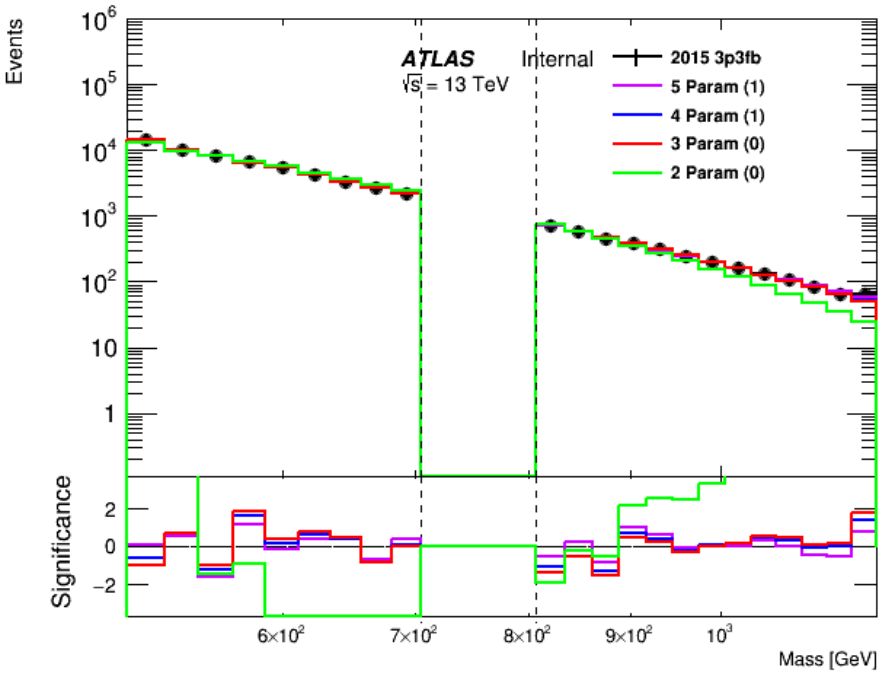
- **Using Dijet Fitting Procedure**
  - Used in high-mass inclusive dijet and b-tagged dijet search
  - 5 Par Dijet Function :

    => 3 par; $p_4 = p_5 = 0$

    => 4 par; $p_5 = 0$

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

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



- **Blinded data**

- Data blinded 700-800 GeV
- Wilks' procedure chooses 4 parameter
- This may change when we unblind…

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

HLT J60 Turn On