ATLAS EXPERIMENT

Identification of boosted hadronically decaying particles with jet substructure in ATLAS Run-2

Jason Veatch
University of Göttingen
(AG Lai)

on behalf of the ATLAS collaboration

Bundesministerium für Bildung und Forschung

BMBF-Forschungsschwerpunkt
ATLAS-EXPERIMENT
Physik bei höchsten Energien mit dem ATLAS-Experiment am LHC
FSP 103
ATLAS

Introduction

- Large-R jets played a major role in ATLAS Run-1
  - Analyses pushed into more boosted regimes
- Many new developments in Run-2
  - New jet reconstruction methods
  - Improved heavy resonance tagging
- Wide range of uses in ATLAS analyses
  - Many more uses of boosted topologies in Run-2

Developments related to large-R jets

Alternative jet definitions

- Multi-dimensional optimization of jet algorithms
  - Input objects and grooming techniques

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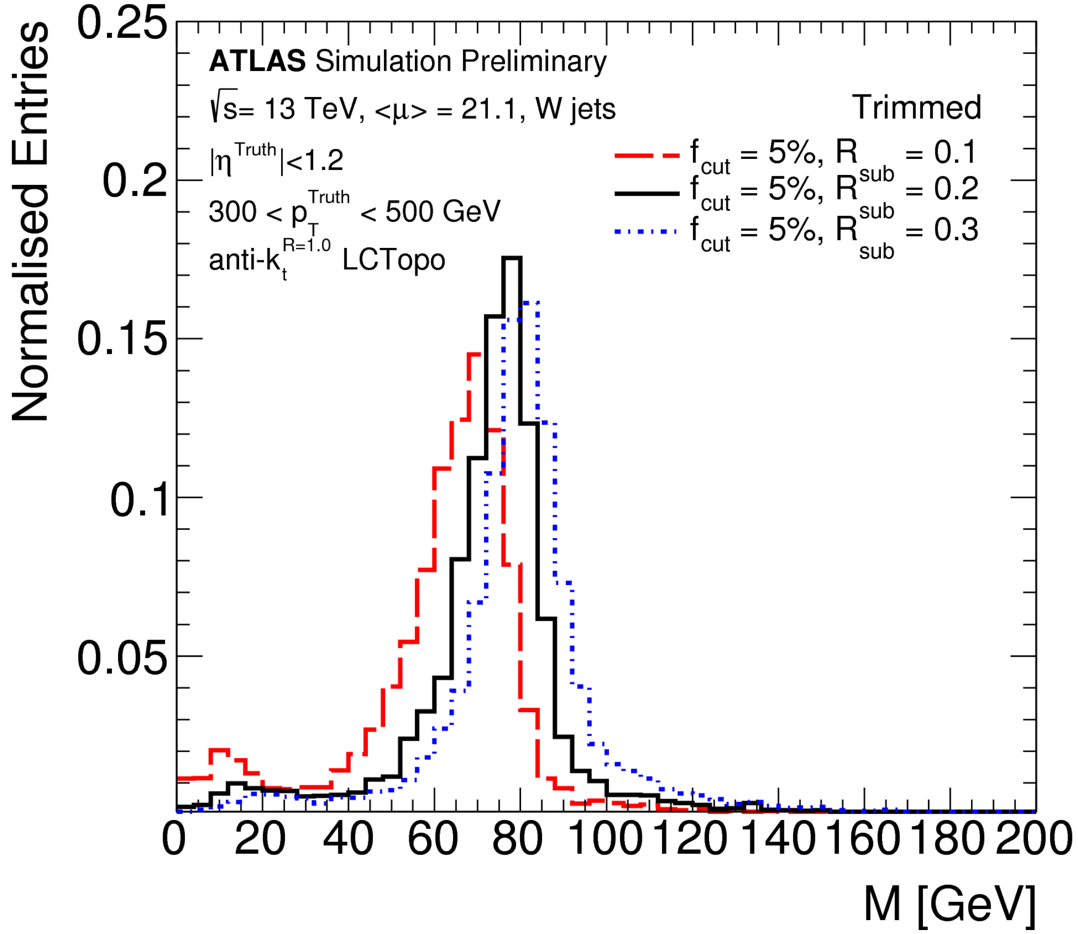
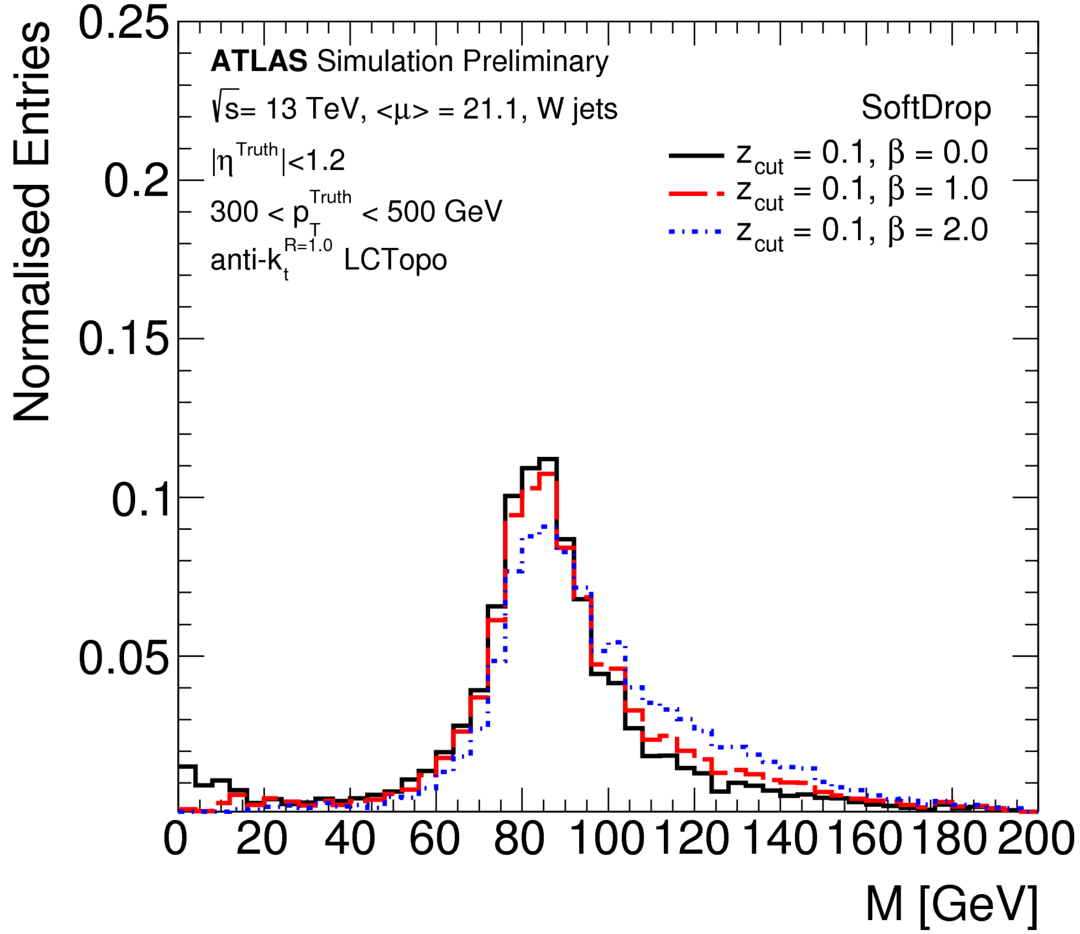
Alternative jet definitions

- Multi-dimensional optimization of jet algorithms
  - Input objects and grooming techniques
  - Differences in jet observables





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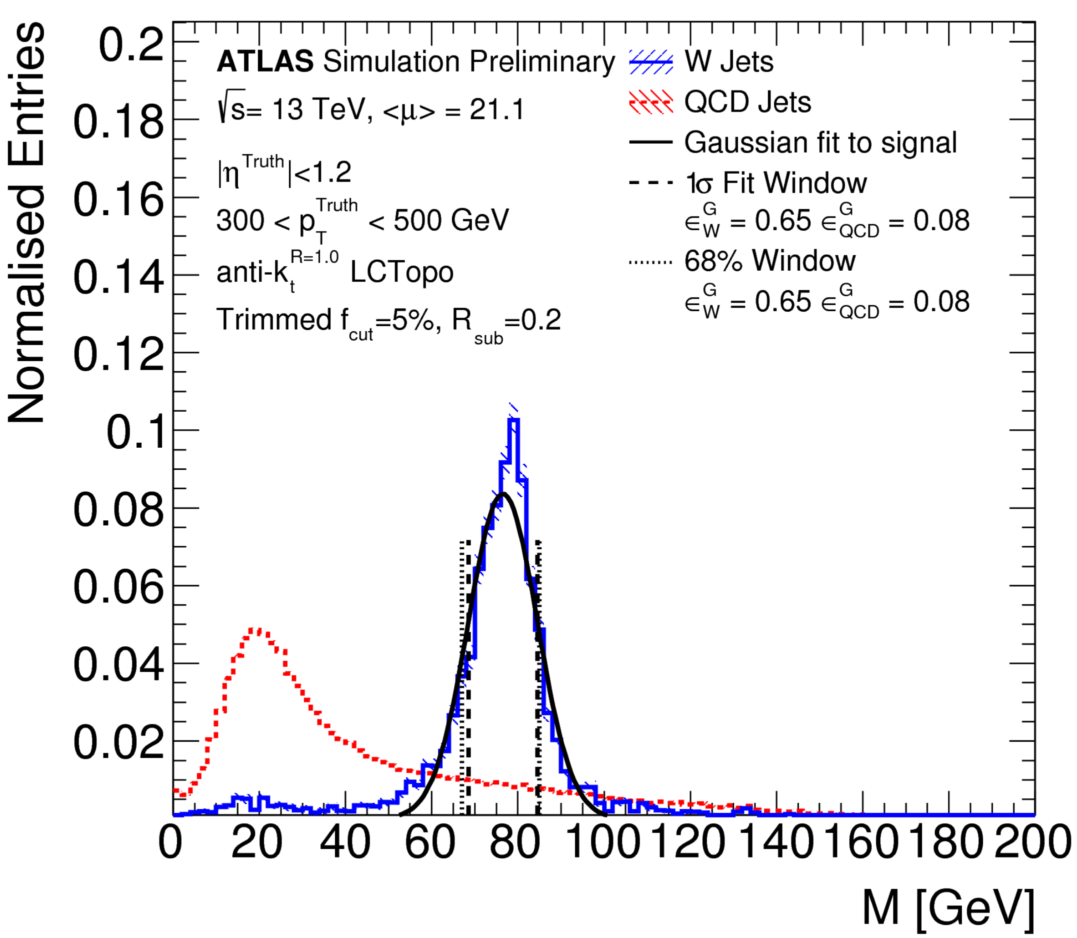
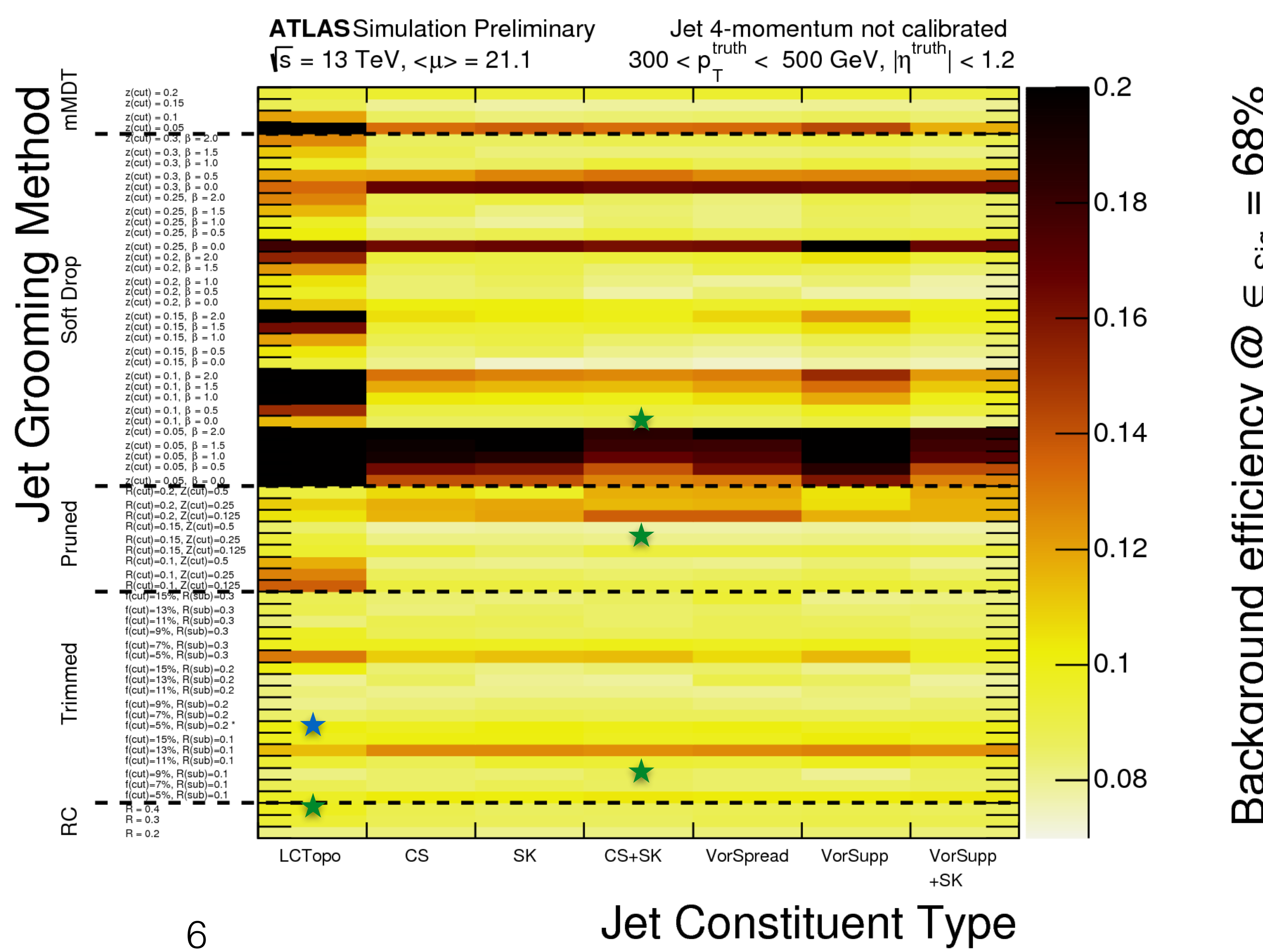
Alternative jet definitions

- Multi-dimensional optimization of jet algorithms
  - Input objects and grooming techniques
  - Background rejection





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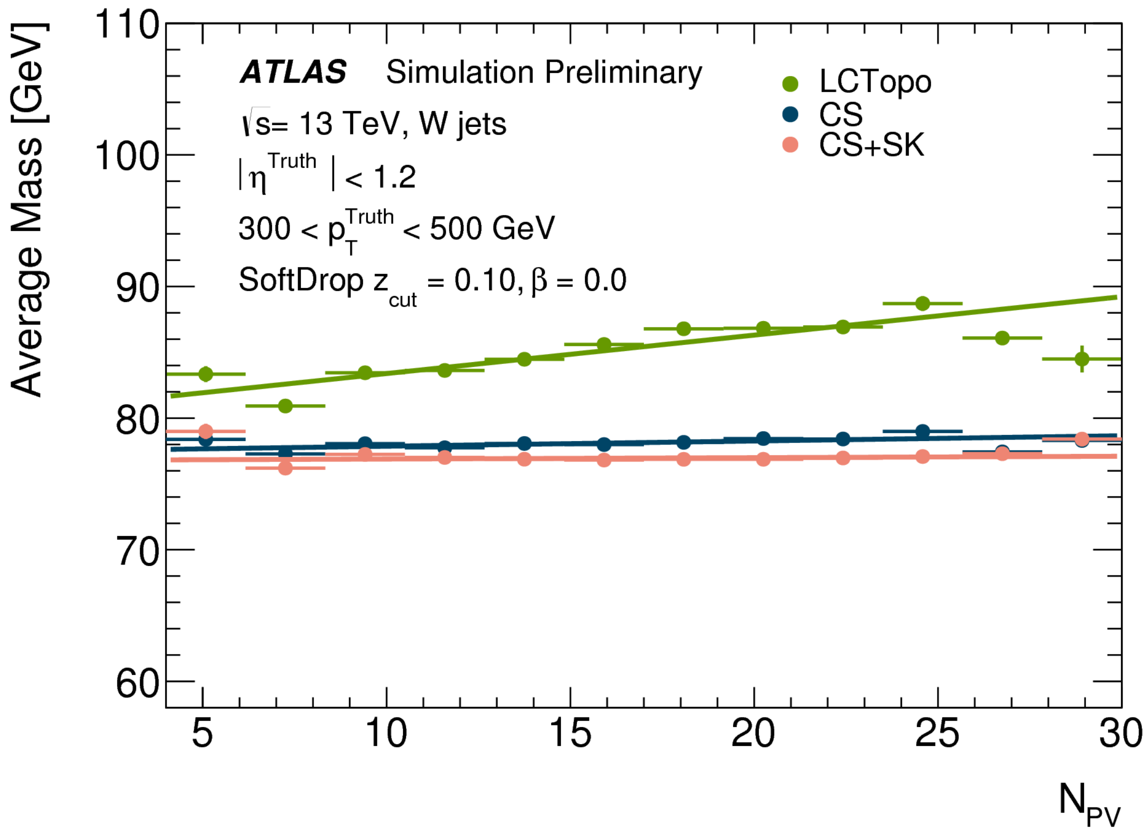
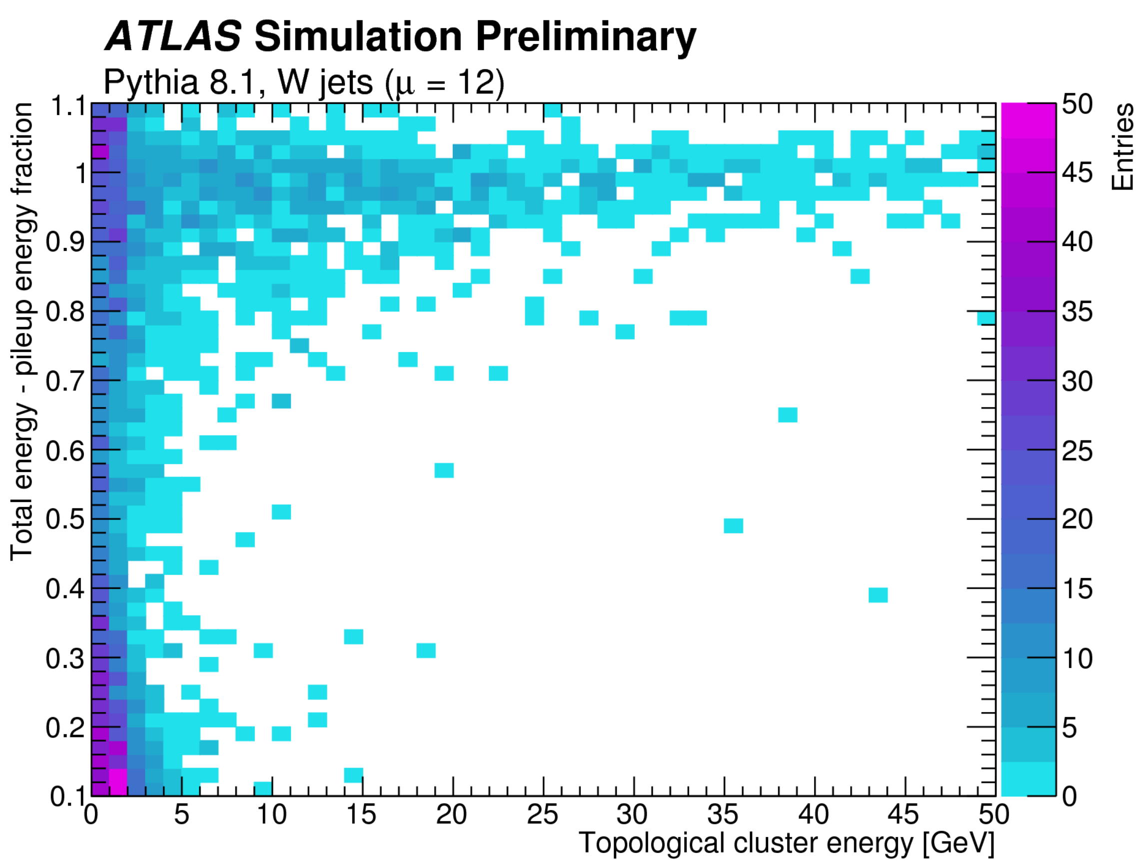
Alternative jet definitions

- Multi-dimensional optimization of jet algorithms
  - Input objects and grooming techniques
  - Pileup mitigation
    - W mass, width and D_2 measured vs <μ>
    - Constituent-level pileup mitigation already works well





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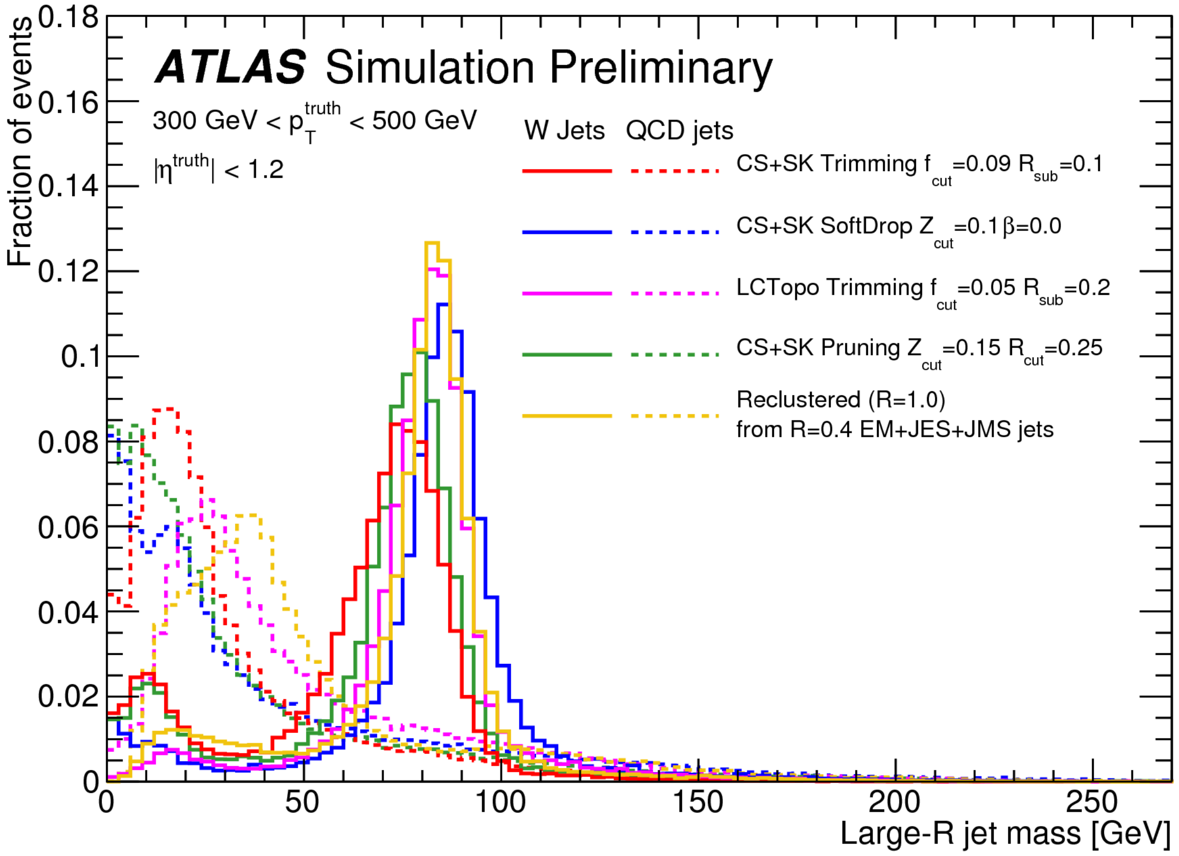
Alternative jet definitions

- Comparison of 5 different optimized configurations
  - Calibrations derived and applied



Constit Sub + SoftKiller	Soft Drop	$z_{cut} = 0.1$, $\beta = 0$
Constit Sub + SoftKiller	Pruning	$z_{cut} = 0.15$, $R_{cut} = 0.25$
Constit Sub + SoftKiller	Trimming	$R_{sub} = 0.1$, $f_{cut} = 9\%$
LCTopo	Trimming	$R_{sub} = 0.2$, $f_{cut} = 5\%$
EMTopo	Reclustering	$R = 0.4$, $f_{cut} = 5\%$

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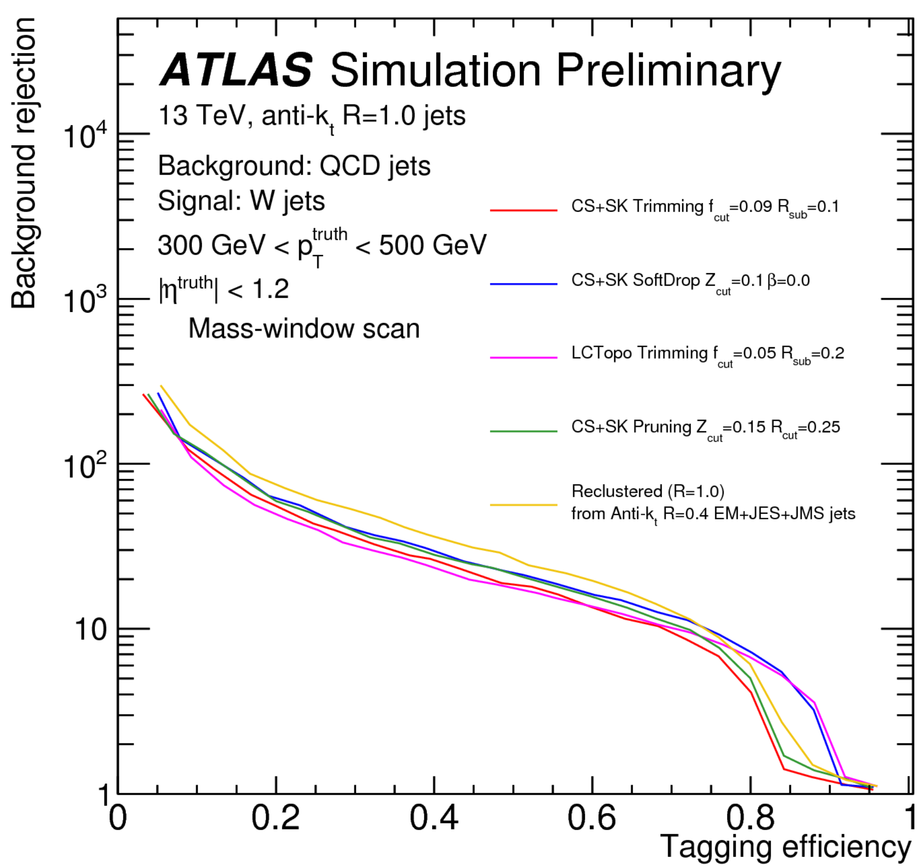
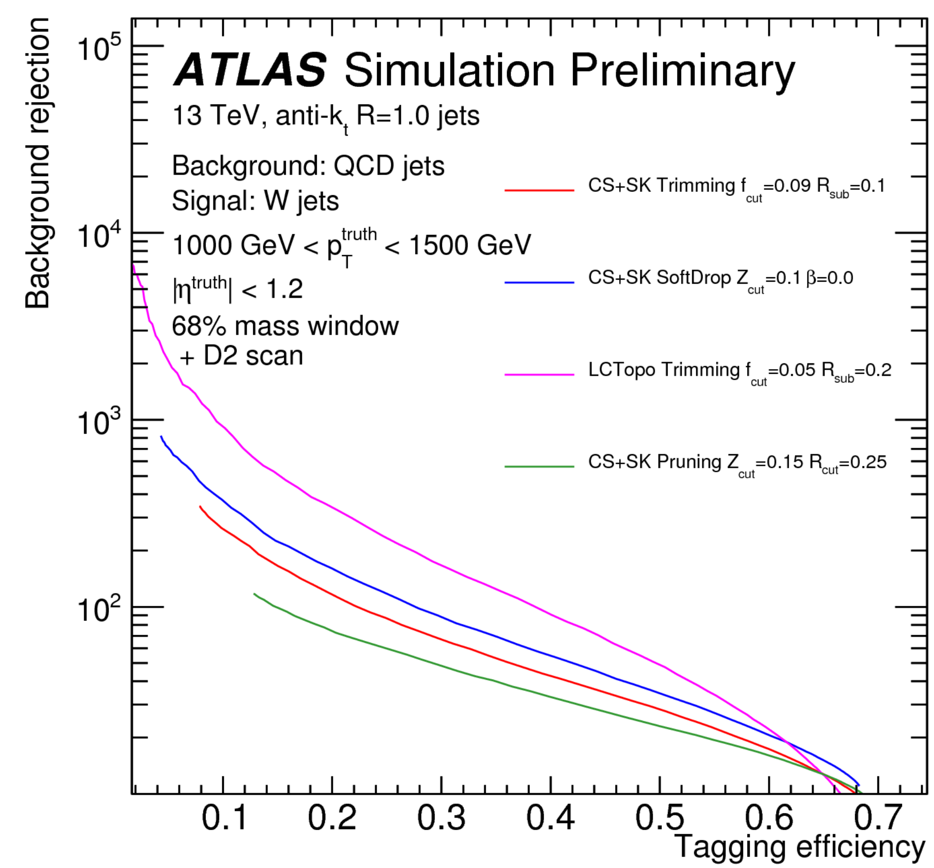
Alternative jet definitions

- Comparison of 5 different optimized configurations
    - Tagging performance comparisons
- Trade-off between mass and substructure tagging
- Current grooming optimal for mass+D_2 tagging
- Soft-drop optimal for mass-only tagging





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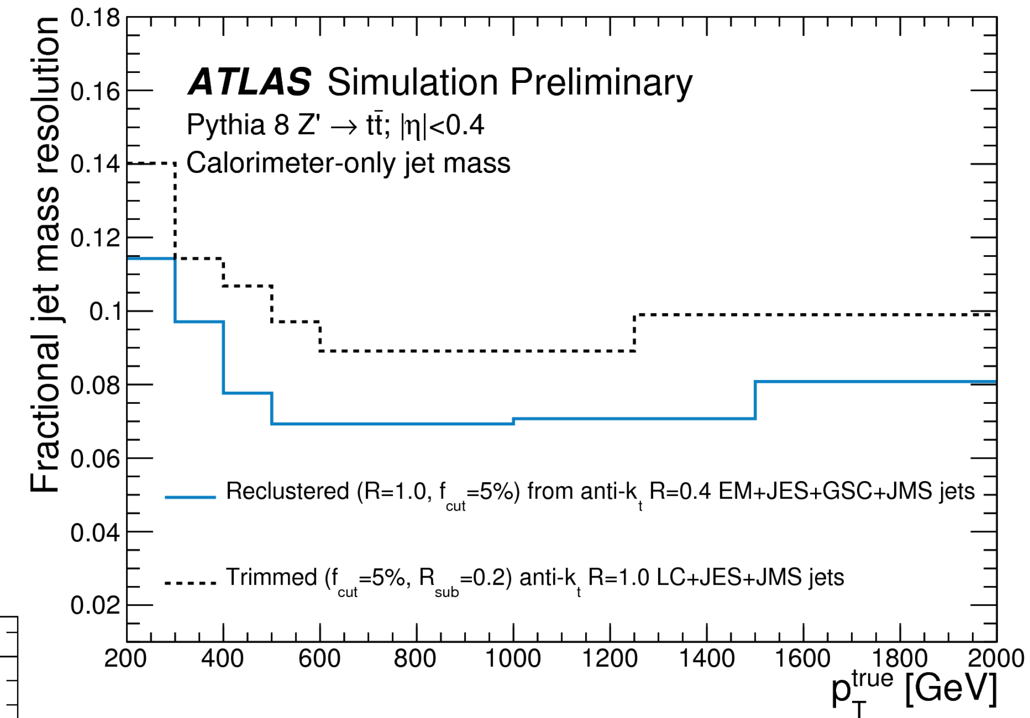
Reclustered jets

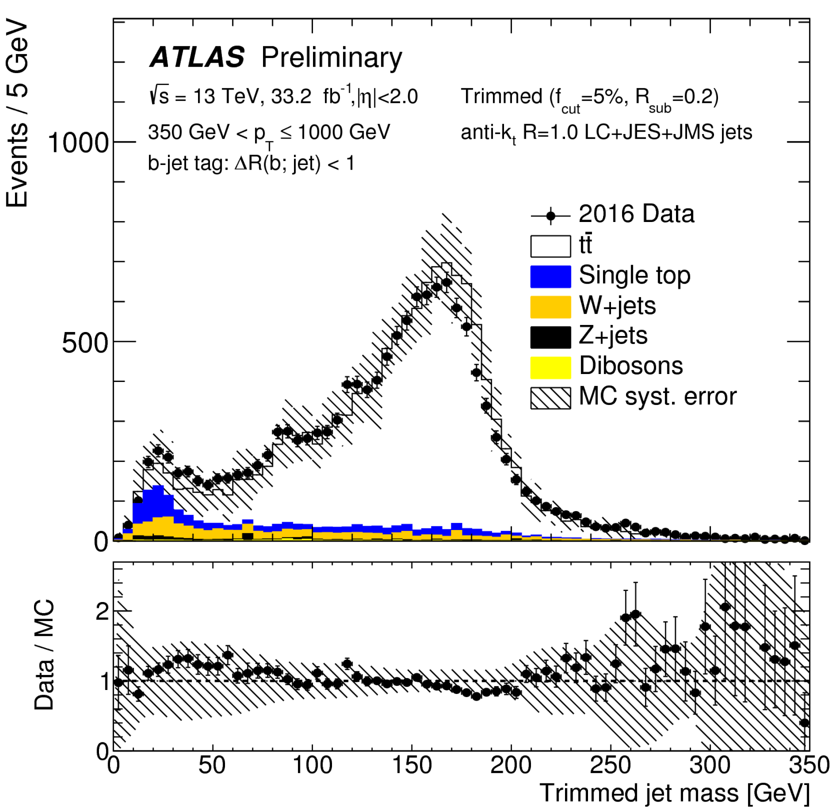
- Use calibrated R = 0.4 jets to build large-R jets

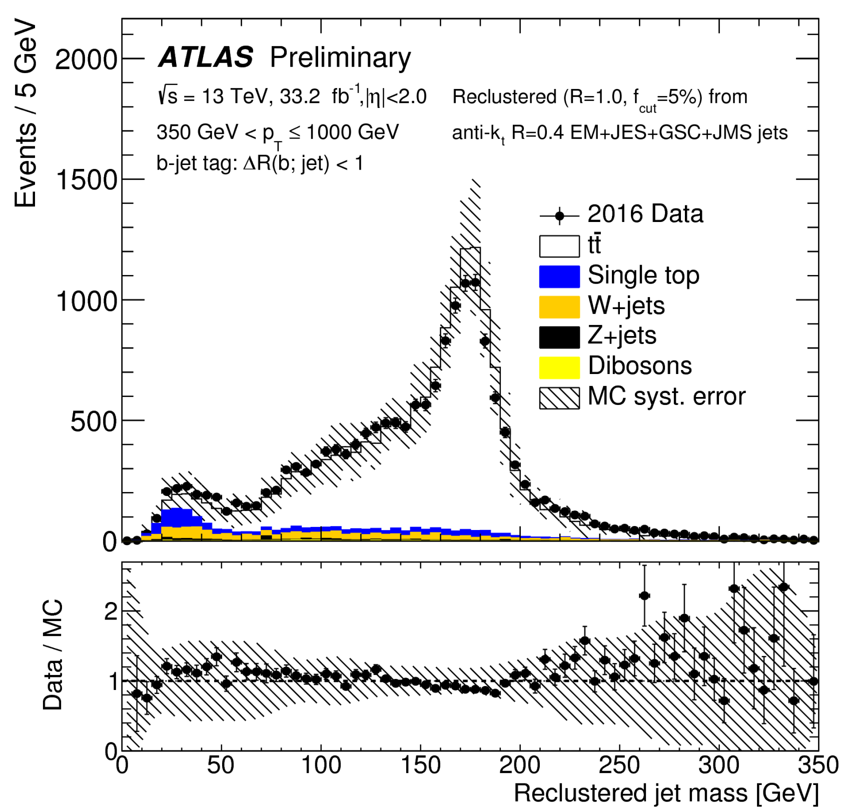
ATLAS-CONF-2017-062

Reclustered jets

- Use calibrated R = 0.4 jets to build large-R jets
  - Improved resolution



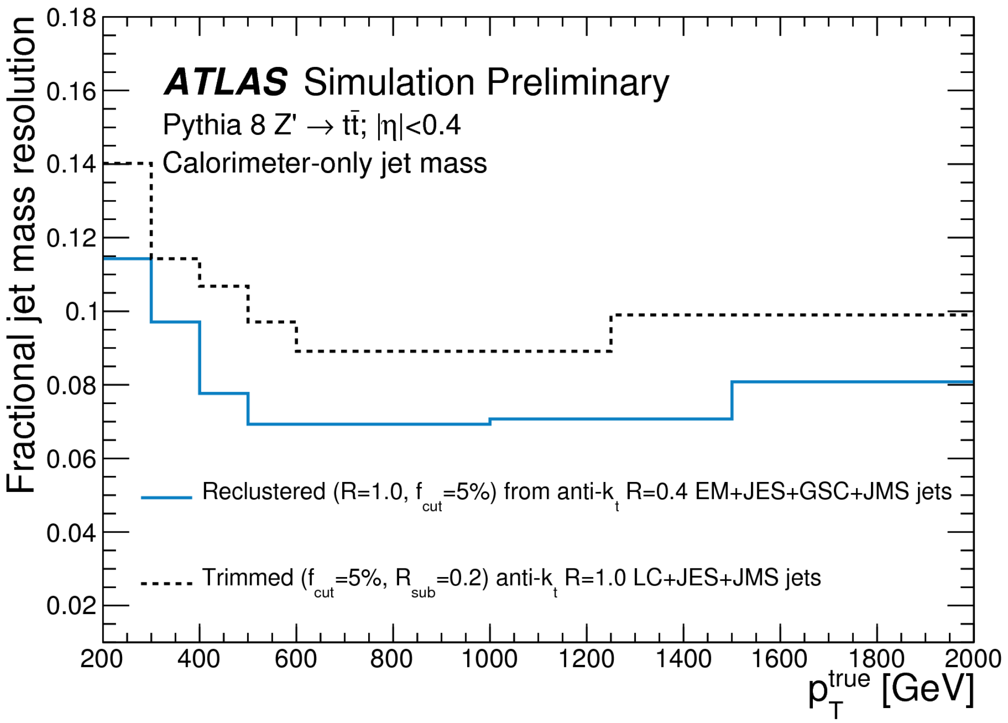


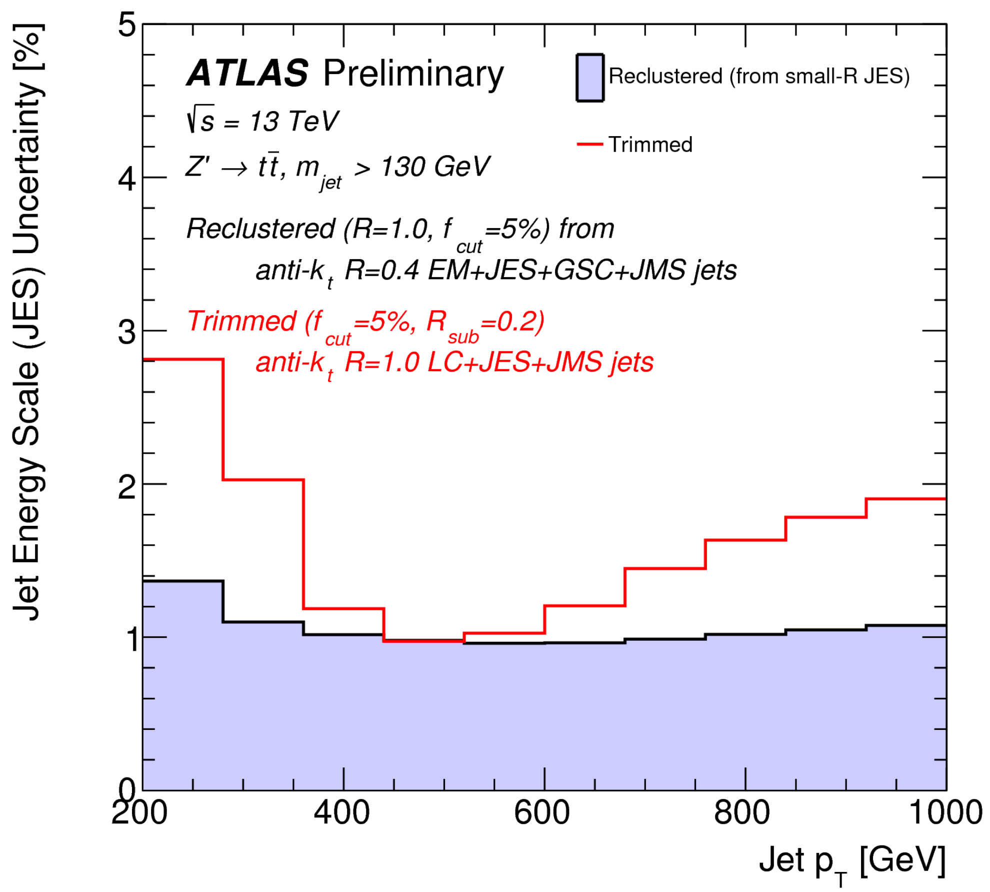


ATLAS-CONF-2017-062

Reclustered jets

- Use calibrated R = 0.4 jets to build large-R jets
  - Improved resolution
  - Lower systematic uncertainties
    - Propagated from R = 0.4 jets

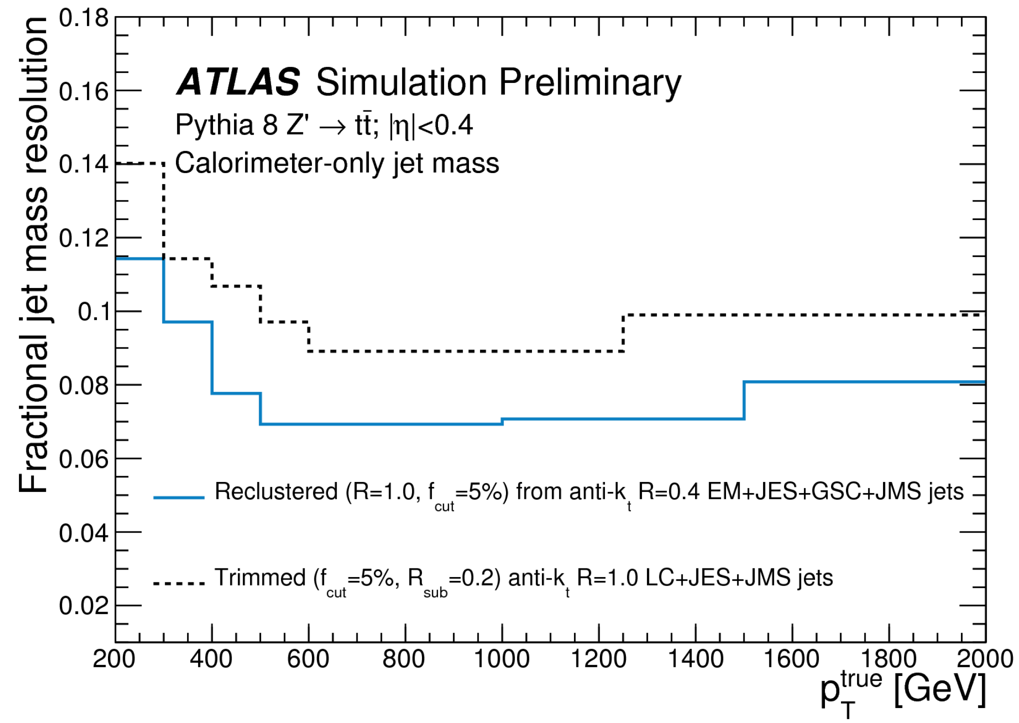


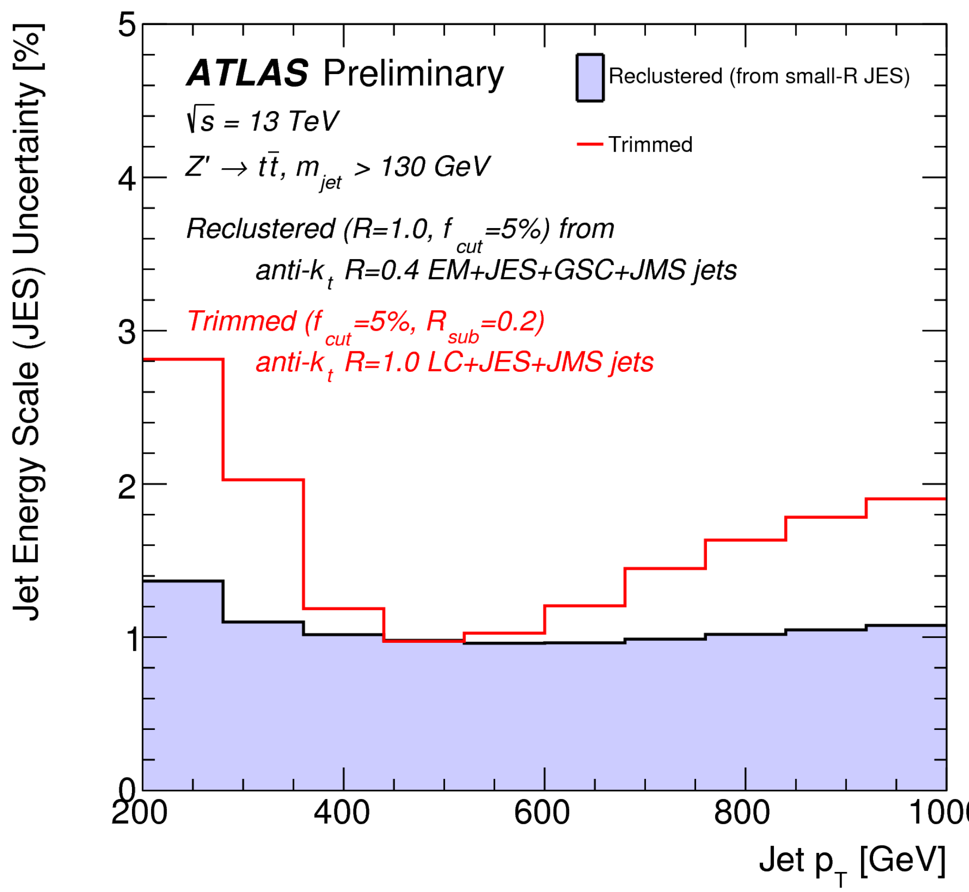


ATLAS-CONF-2017-062

Reclustered jets

- Use calibrated R = 0.4 jets to build large-R jets
  - Improved resolution
  - Lower systematic uncertainties
    - Propagated from R = 0.4 jets
- Used in many ATLAS analyses





SUSY multijet	JHEP12 (2017) 034	Anti-k_t R = 1.0
SUSY multi b-jet	arXiv:1711.01901	Anti-k_t R = 0.8
SUSY stop 0 lep	JHEP 12 (2017) 085	Anti-k_t R = 0.8 and 1.2
SUSY stop 1 lep	arXiv:1711.11520	Anti-k_t R ≤ 3.0 (variable)
VLT pairs 1 lep	JHEP 08 (2017) 052	Anti-k_t R = 1.0
tt resonances	ATLAS-CONF-2016-104	Anti-k_t R = 1.0

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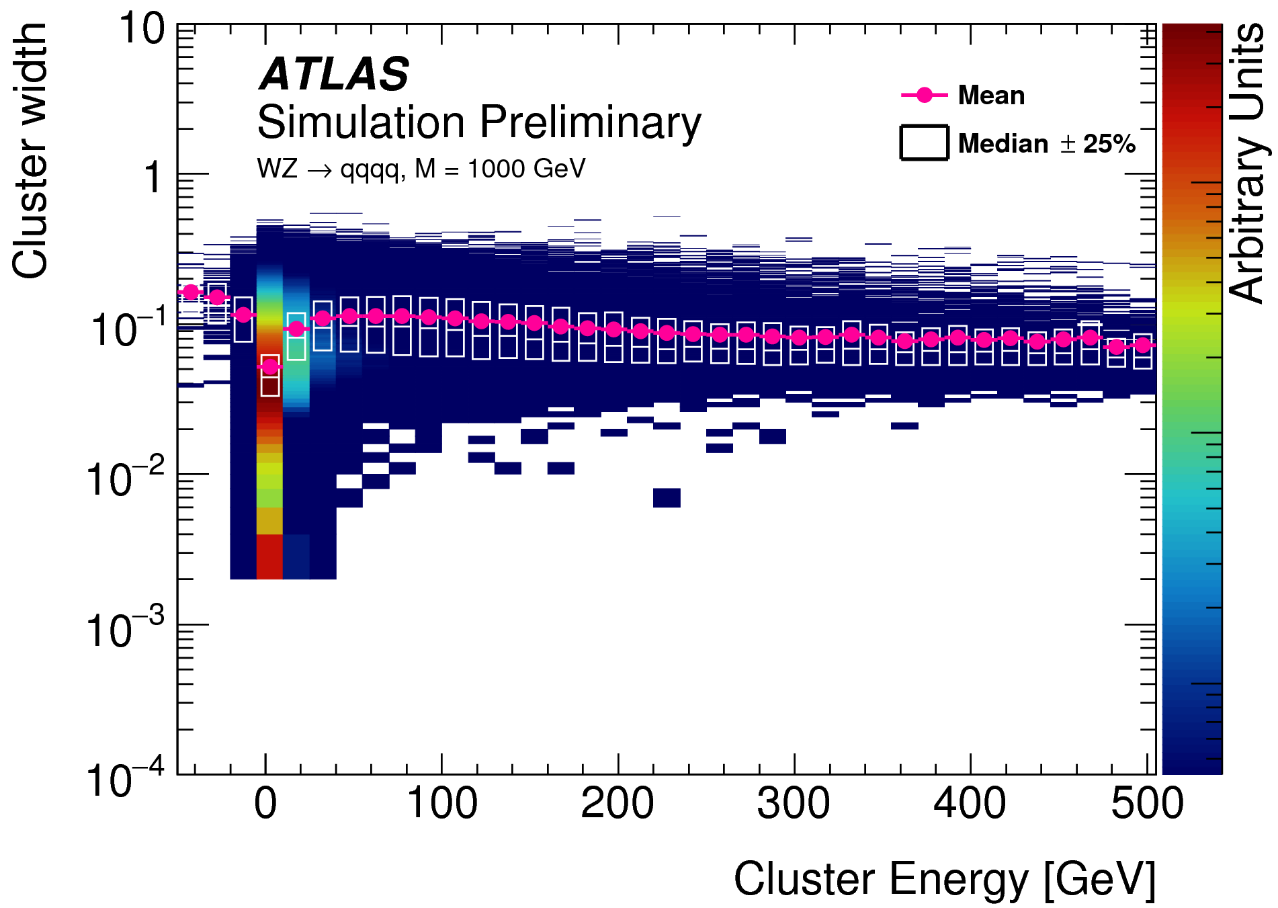
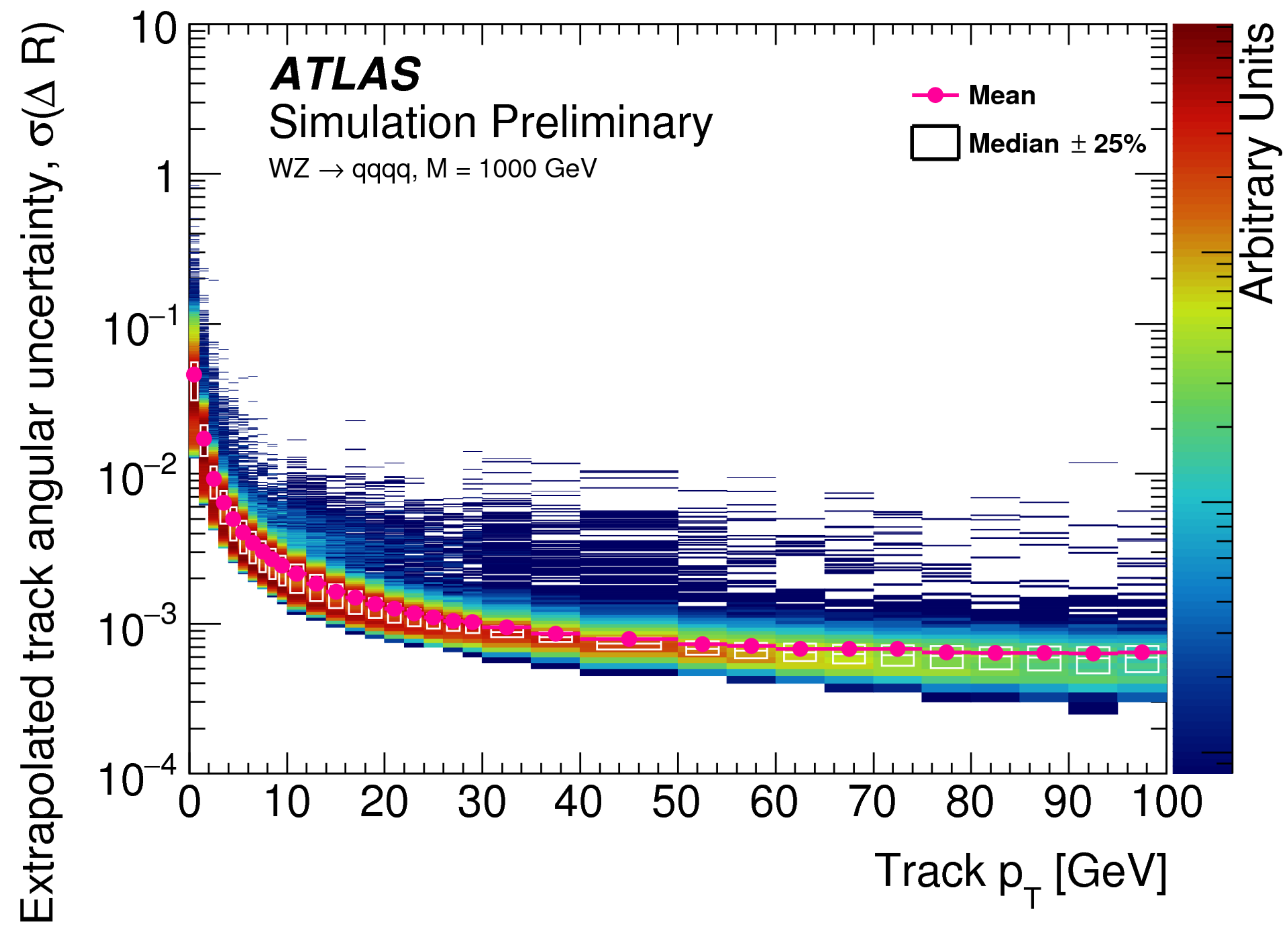
Track-CaloClusters

- Novel jet inputs using tracker and calorimeter
  - Shorthand: TCC
  - Calorimeter granularity is too coarse for boosted objects
  - Tracks included for their much better angular resolution

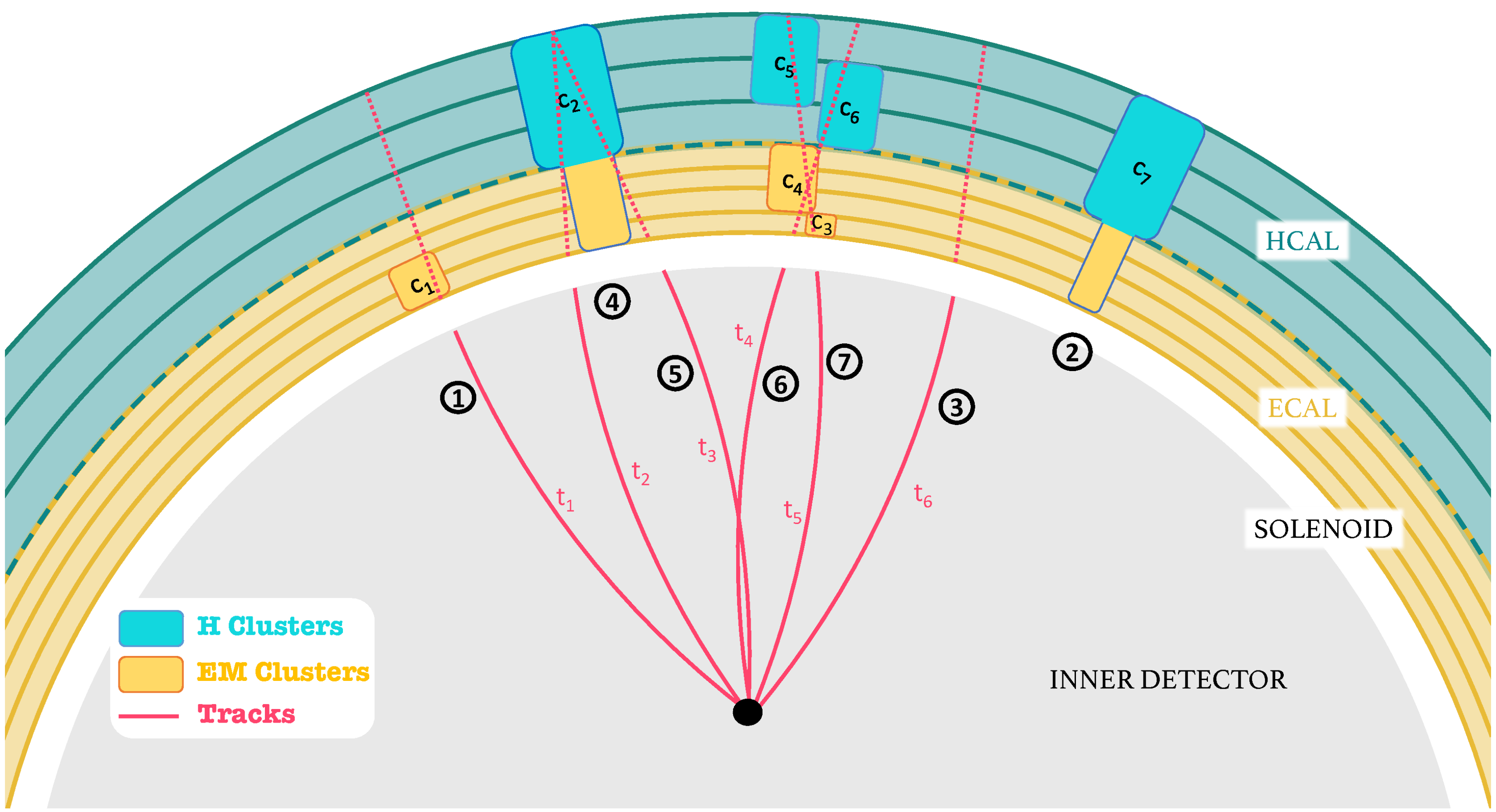




ATL-PHYS-PUB-2017-15

Track-CaloClusters

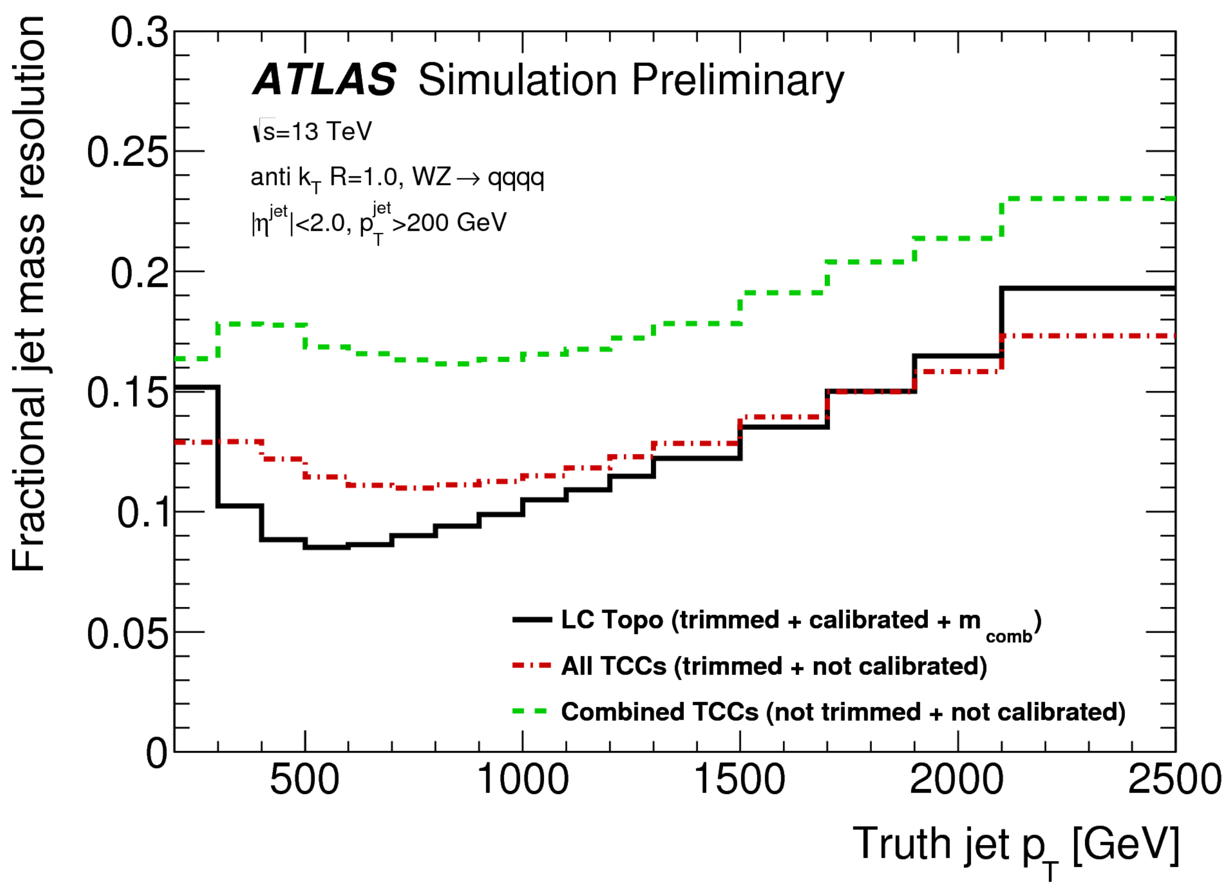
- Novel jet inputs using tracker and calorimeter
  - Tracks matched to topological clusters
  - Position from tracks and energy from clusters
  - Combined TCC: contain a cluster and ≥1 good track(s)

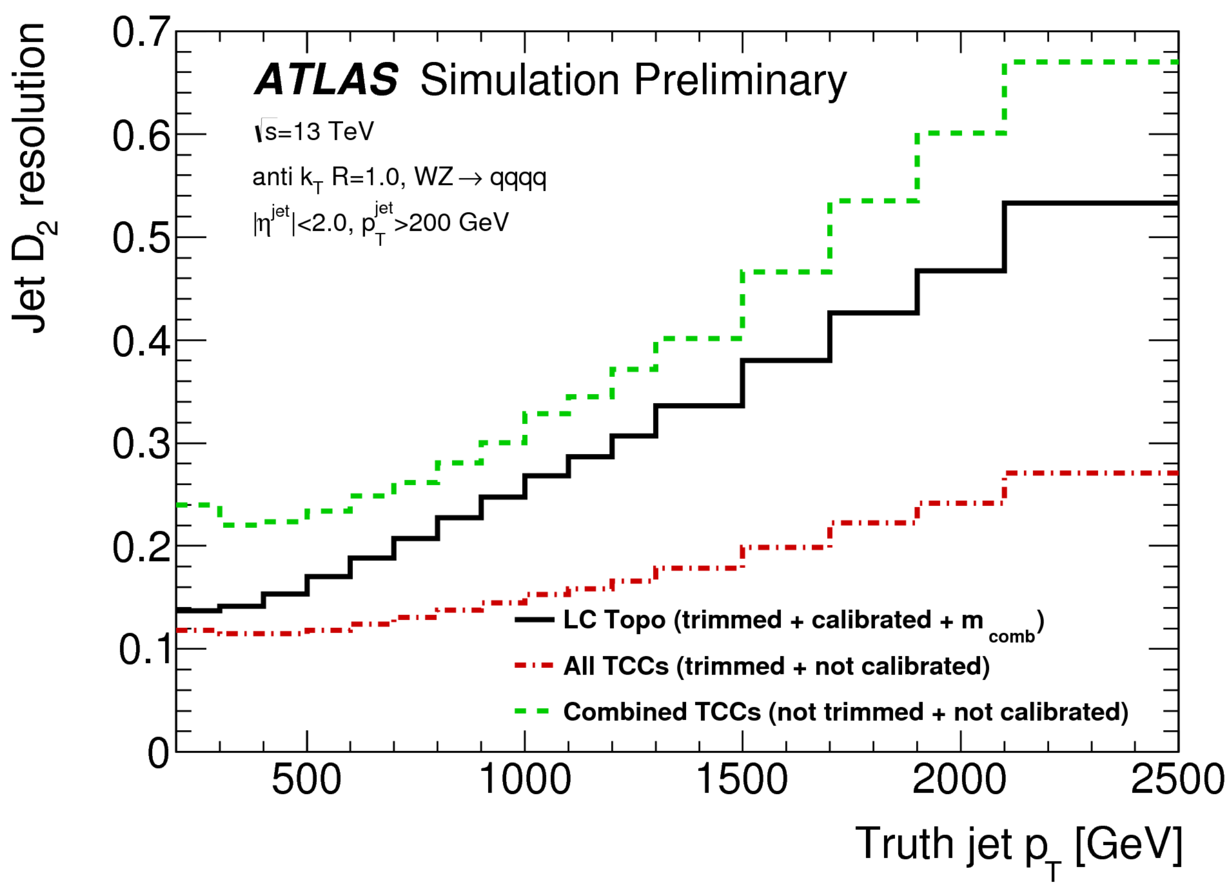


ATL-PHYS-PUB-2017-15

Track-CaloClusters

- Novel jet inputs using tracker and calorimeter
- Improved performance compared to standard jets
- New pileup suppression possible - under study
- Used in ongoing ATLAS analyses

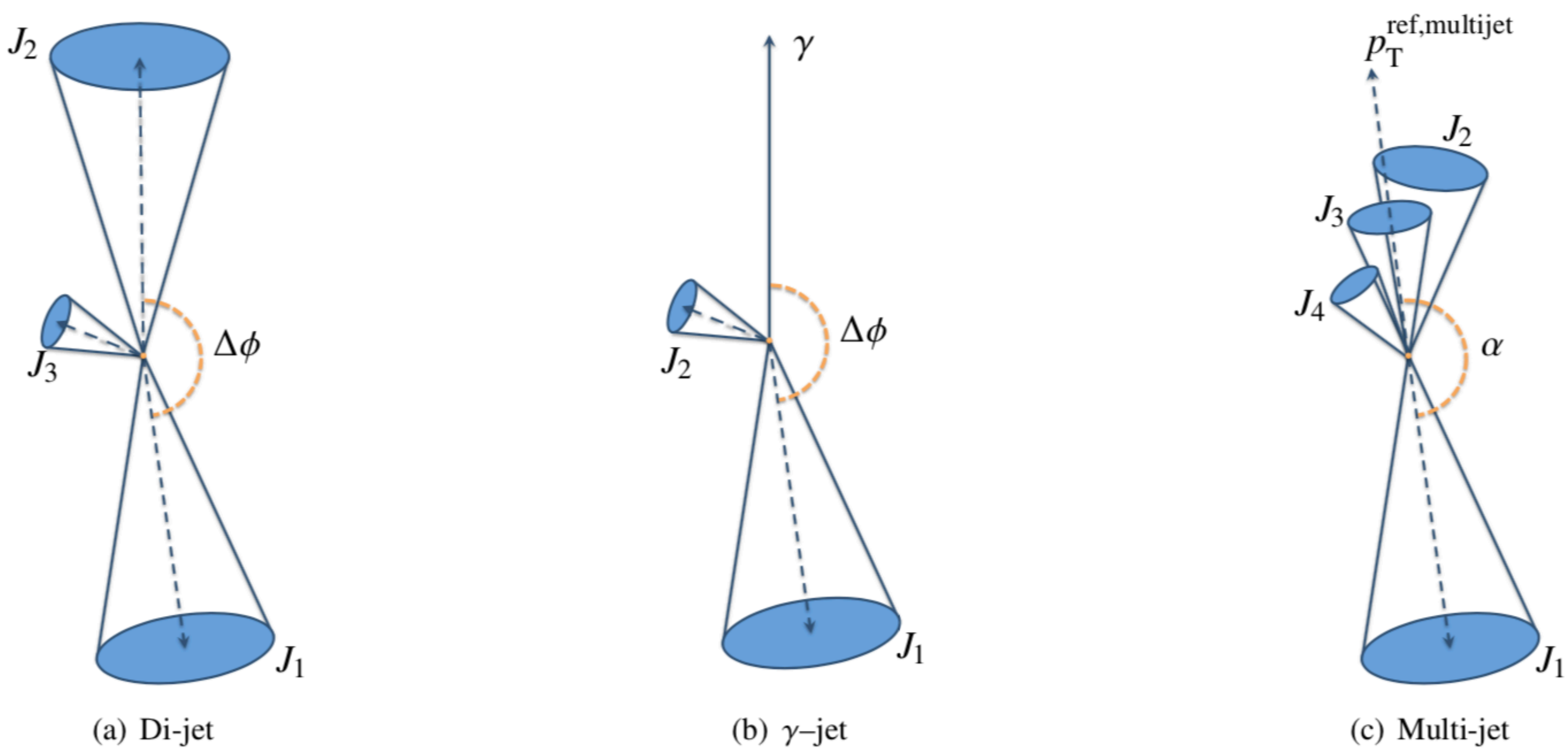




ATL-PHYS-PUB-2017-15

Measuring large-R jet response with in-situ techniques

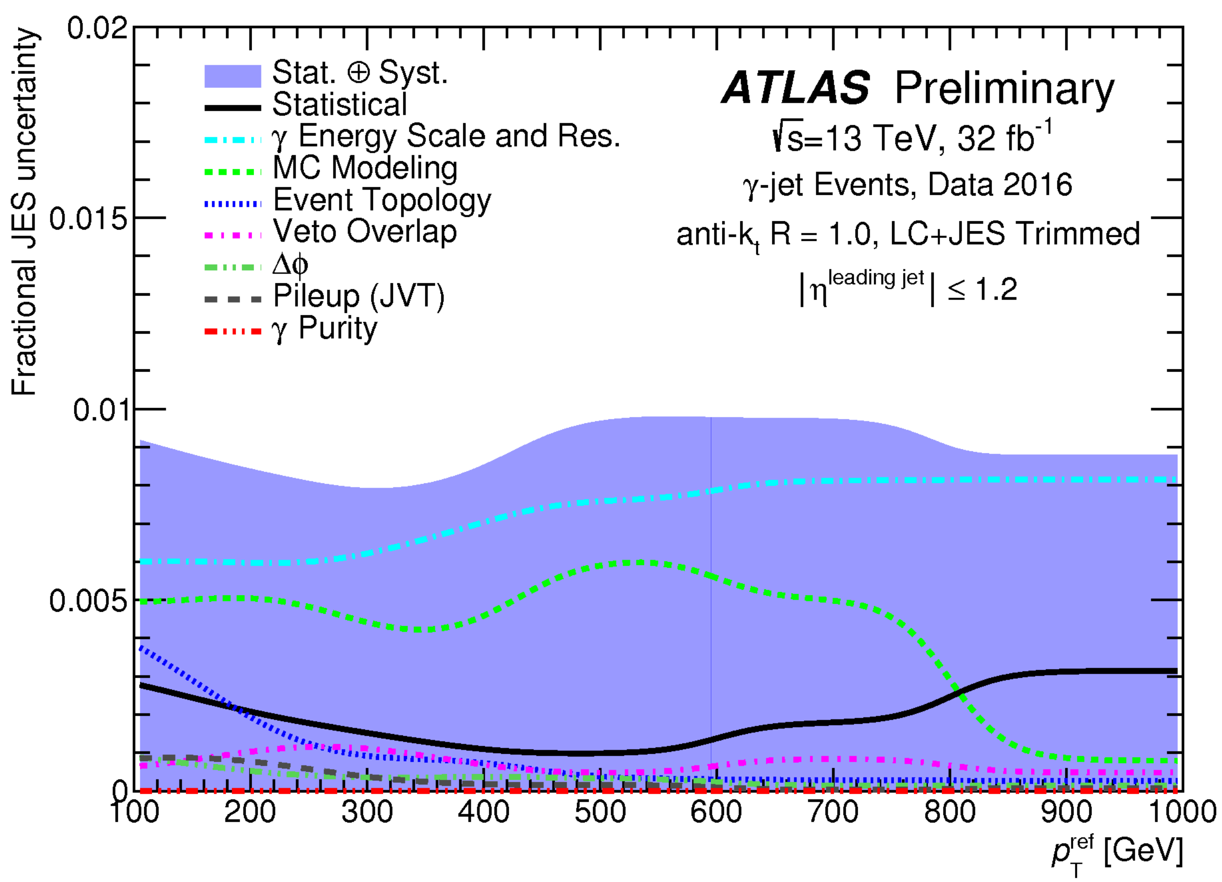
- In-situ methods used to derive large-R jet uncertainties
    - Jet Energy Scale: Jet balance method

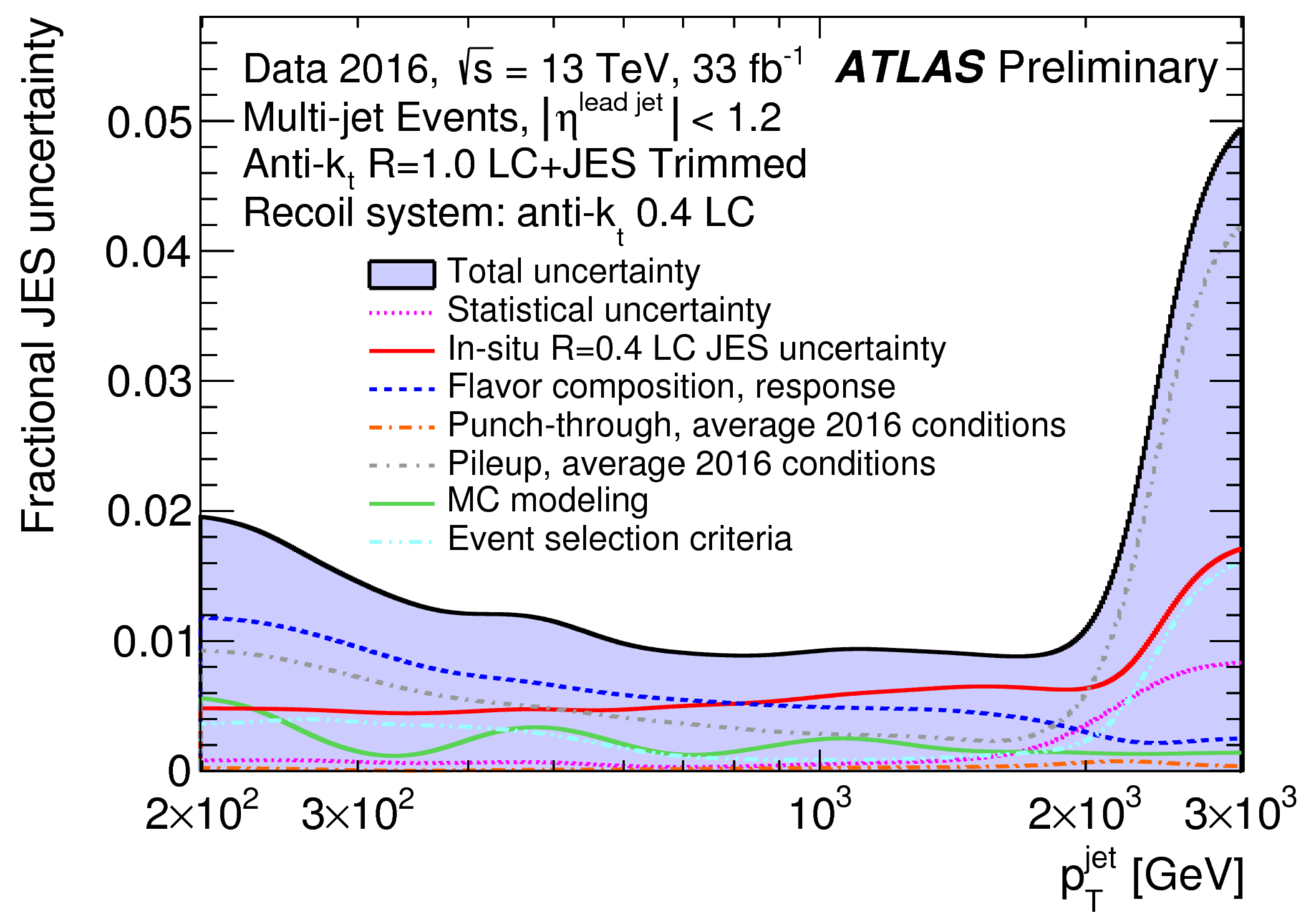


ATLAS-CONF-2017-063

Measuring large-R jet response with in-situ techniques

- In-situ methods used to derive large-R jet uncertainties
  - Jet Energy Scale: Jet balance method



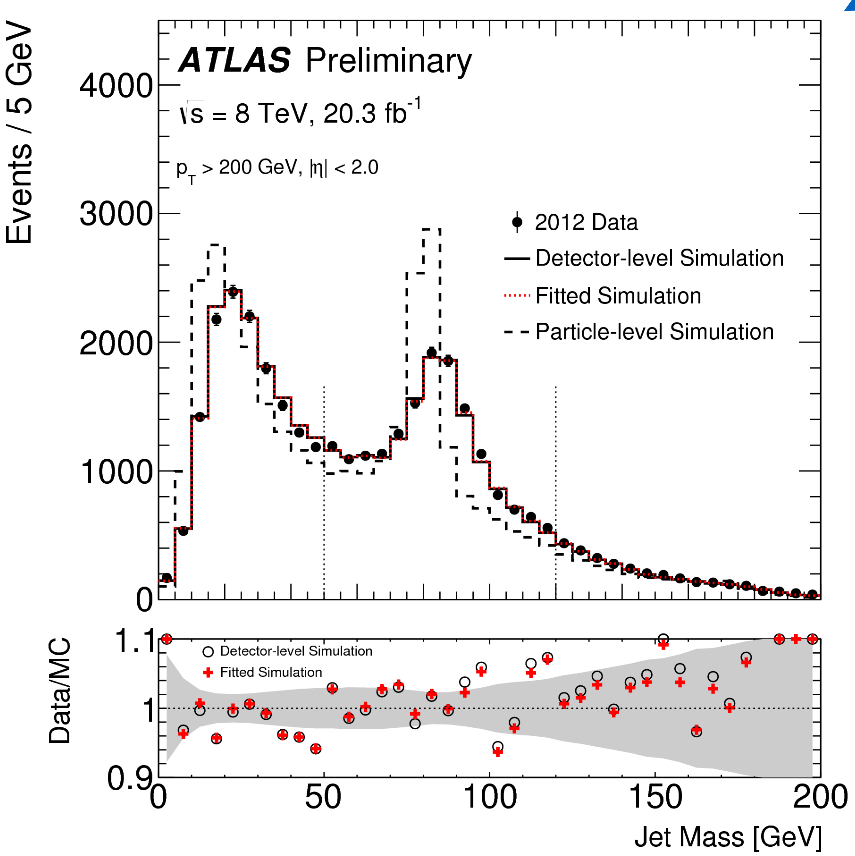


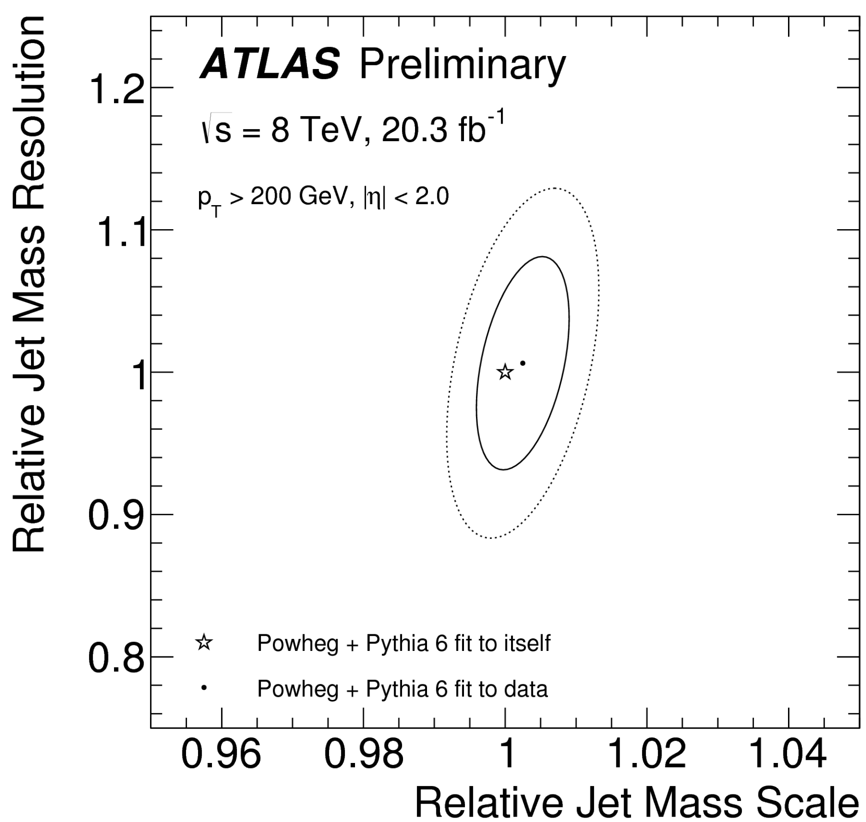
ATLAS-CONF-2017-063

Measuring large-R jet response with in-situ techniques

- In-situ methods used to derive large-R jet uncertainties
  - Jet Energy Scale: Jet balance method
  - Jet Mass Scale: Forward folding and R_{trk} methods

ATLAS-CONF-2016-008



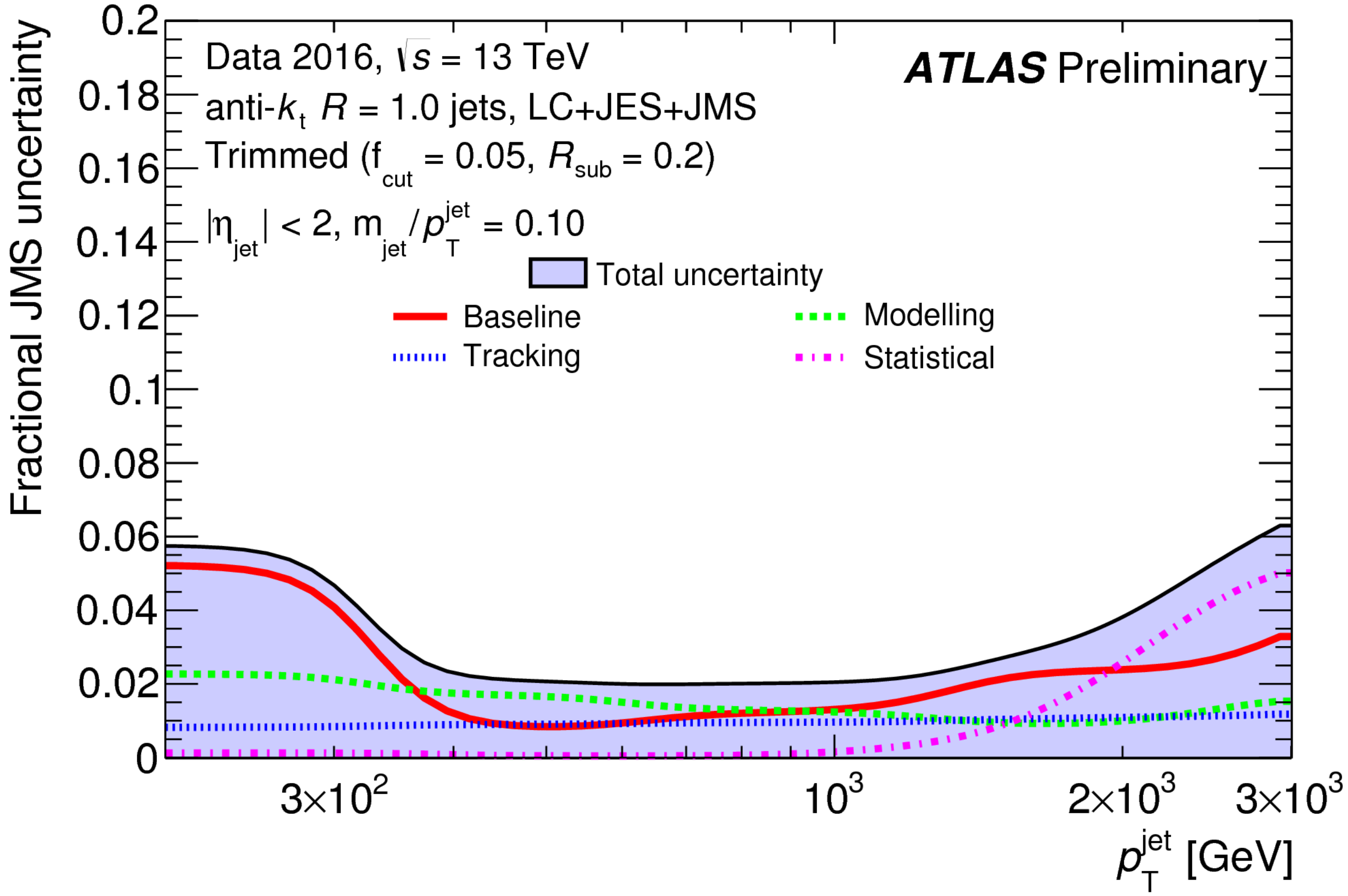


$$R_{\mathrm{trk}} = \frac{\left(\frac{p_{\mathrm{T}}^{\mathrm{calo}}}{p_{\mathrm{T}}^{\mathrm{track}}}\right)^{\mathrm{data}}}{\left(\frac{p_{\mathrm{T}}^{\mathrm{calo}}}{p_{\mathrm{T}}^{\mathrm{track}}}\right)^{\mathrm{MC}}}.$$

ATLAS-CONF-2017-063

Measuring large-R jet response with in-situ techniques

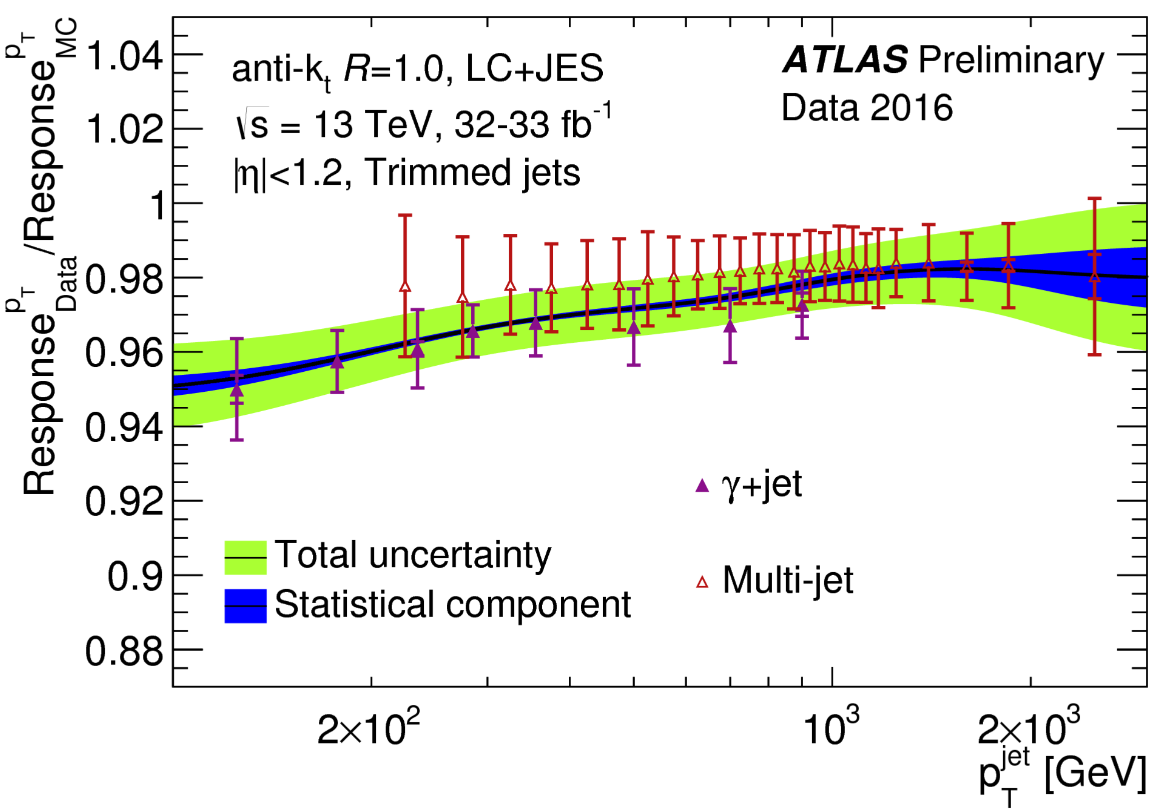
- In-situ methods used to derive large-R jet uncertainties
  - Jet Energy Scale: Jet balance method
  - Jet Mass Scale: Forward folding and R_{trk} methods

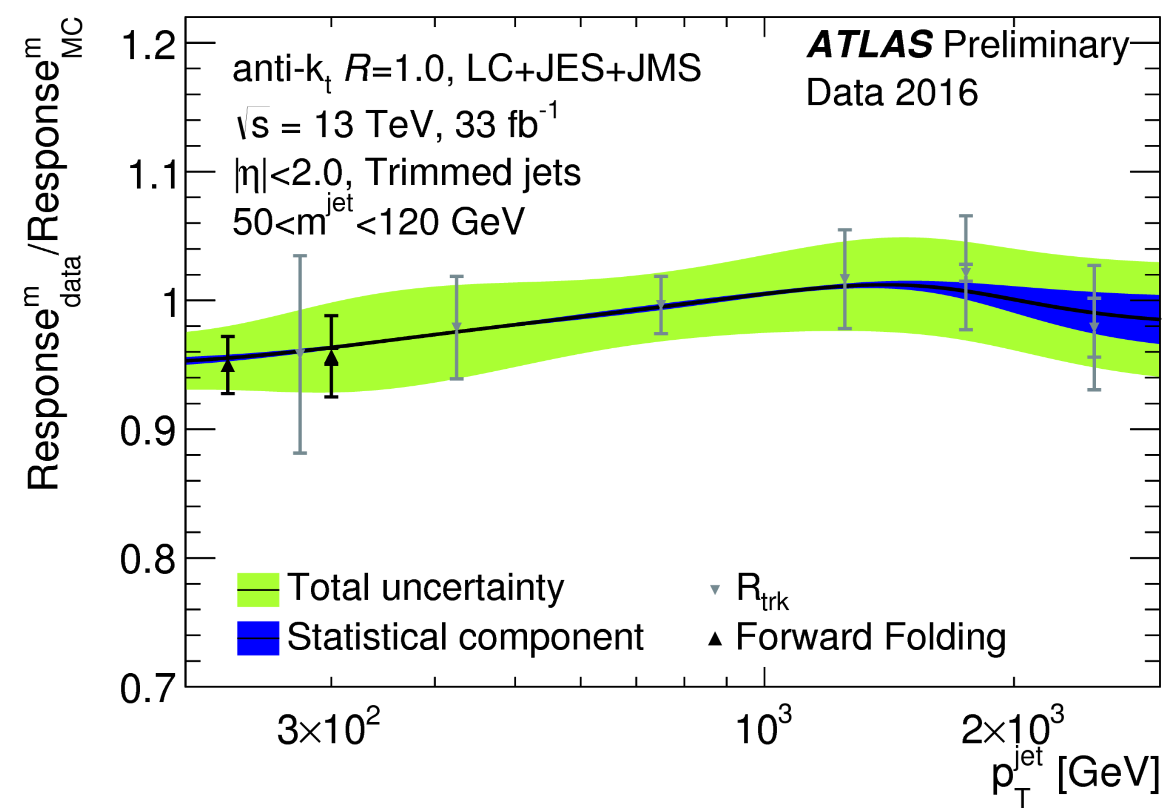


ATLAS-CONF-2017-063

Measuring large-R jet response with in-situ techniques

- In-situ methods used to derive large-R jet uncertainties
  - Jet Energy Scale: Jet balance method
  - Jet Mass Scale: Forward folding and R_{trk} methods
- Combined uncertainties constrained to < 5%



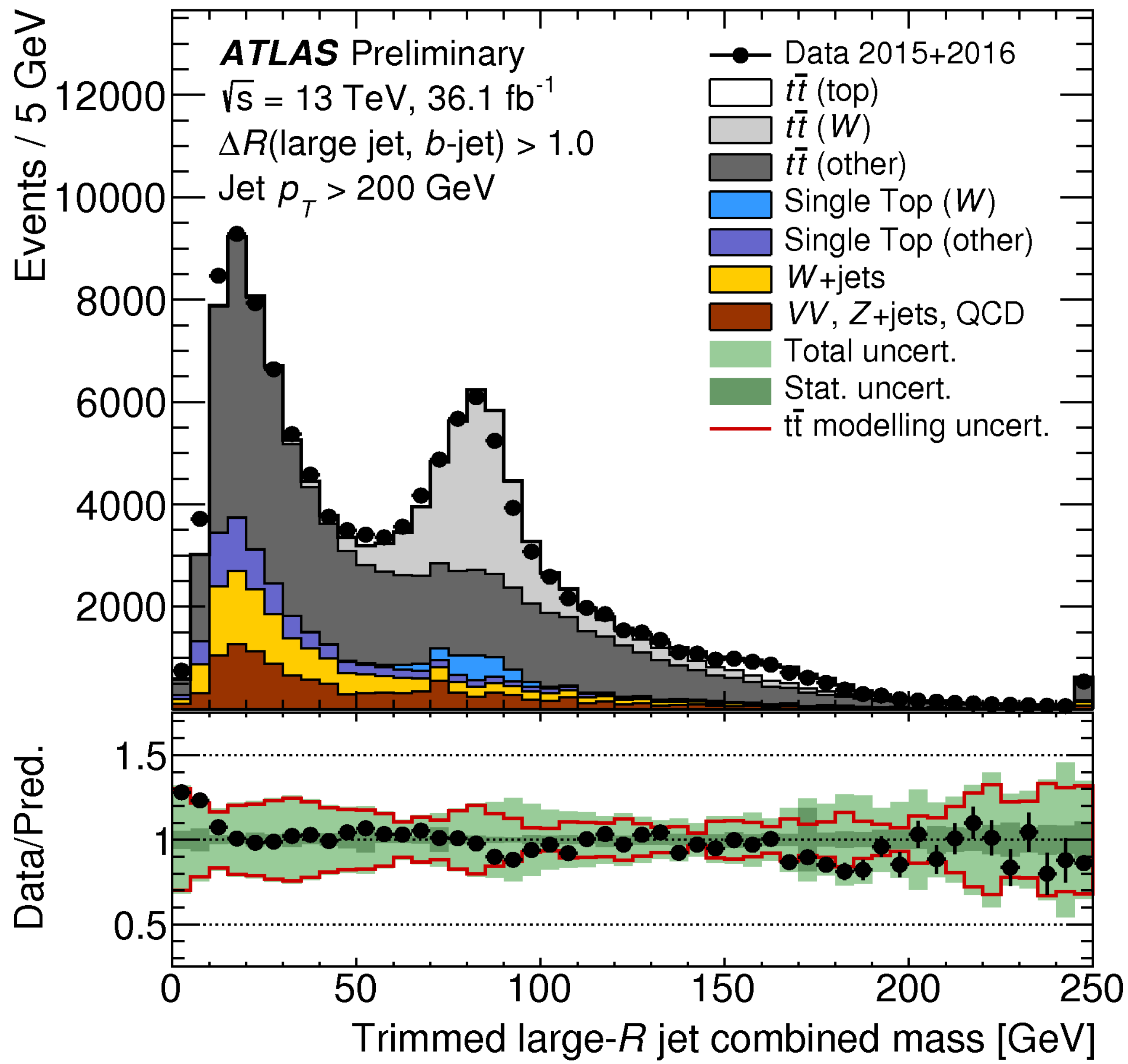


ATLAS-CONF-2017-063

Tagging heavy resonances

W tagging

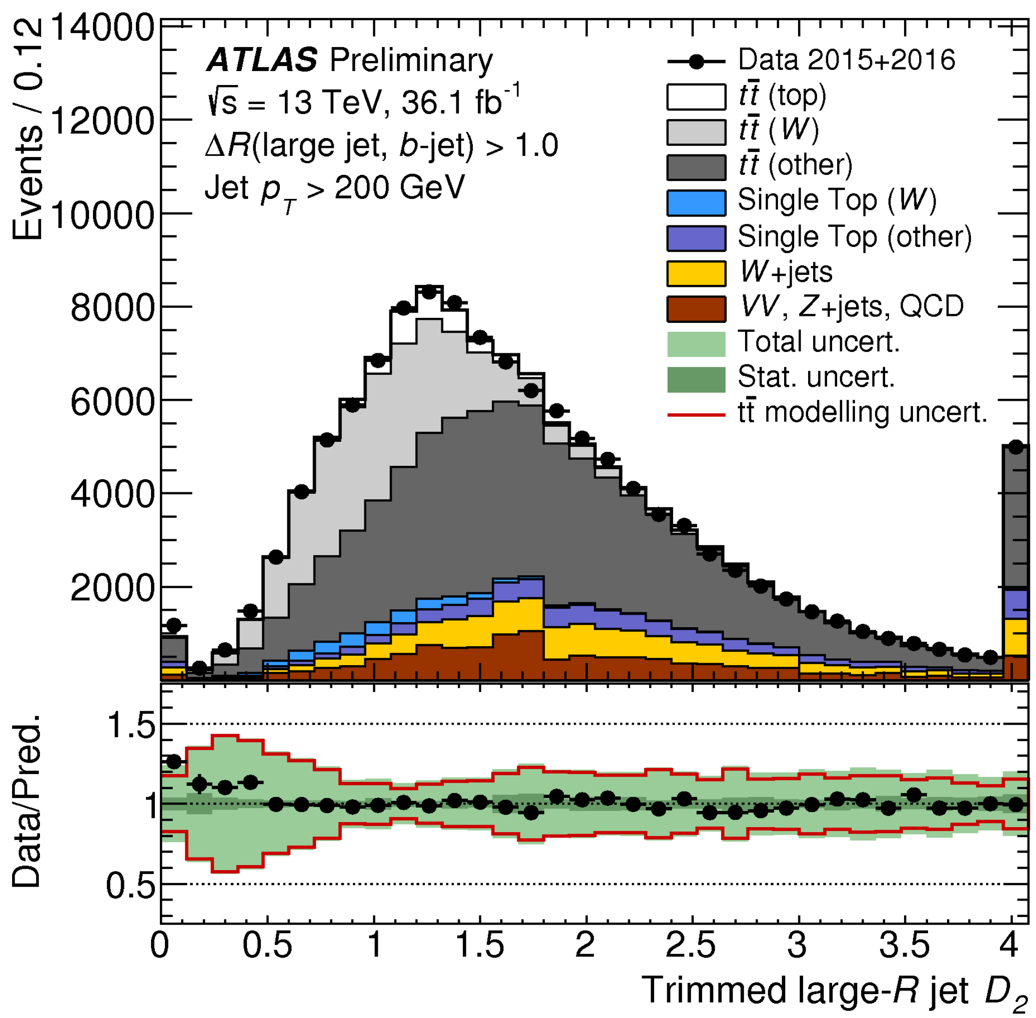
- Identify large-R jets as boosted hadronic W decays

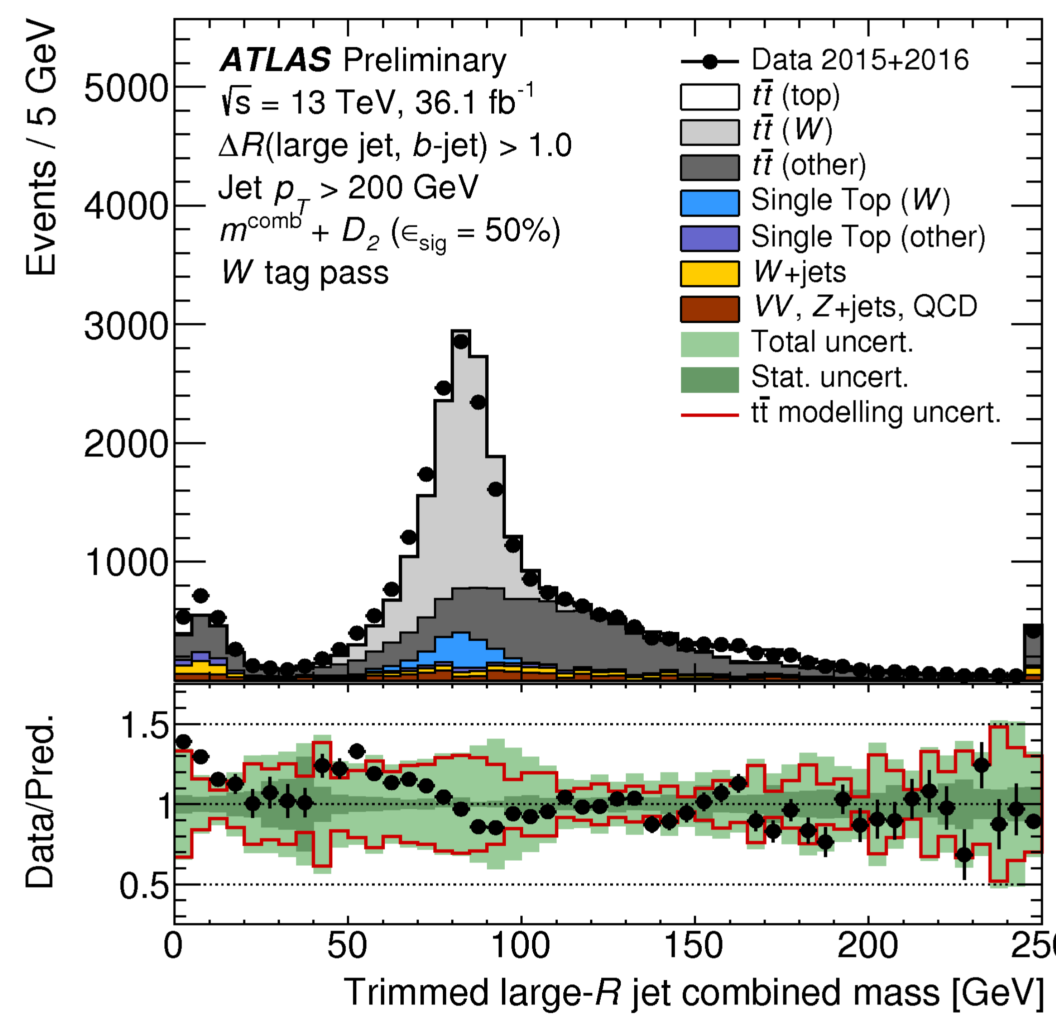


[ATLAS-CONF-2017-064]

W tagging

- Identify large-R jets as boosted hadronic W decays
- Comparison of three different tagging techniques
  - Mass/D_2
  - In-situ comparisons show good modeling in data

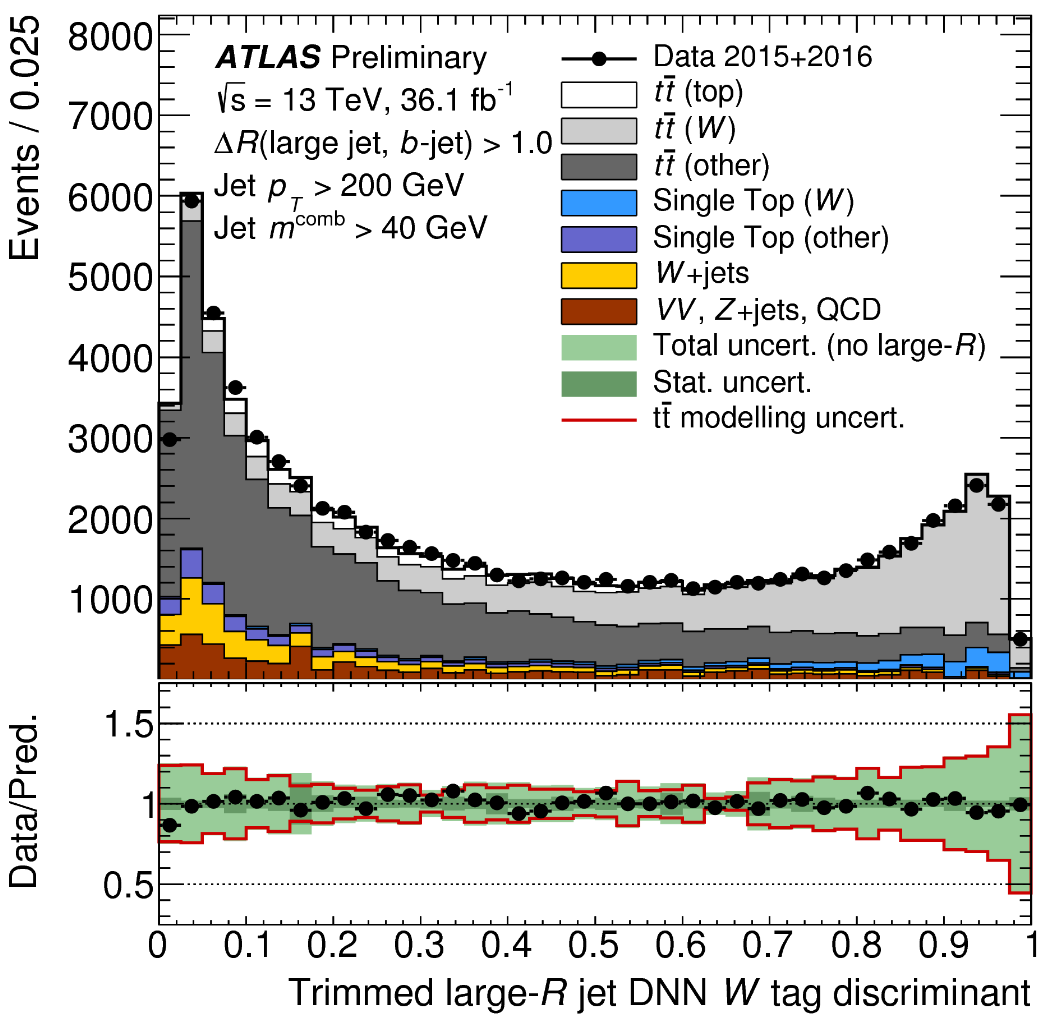


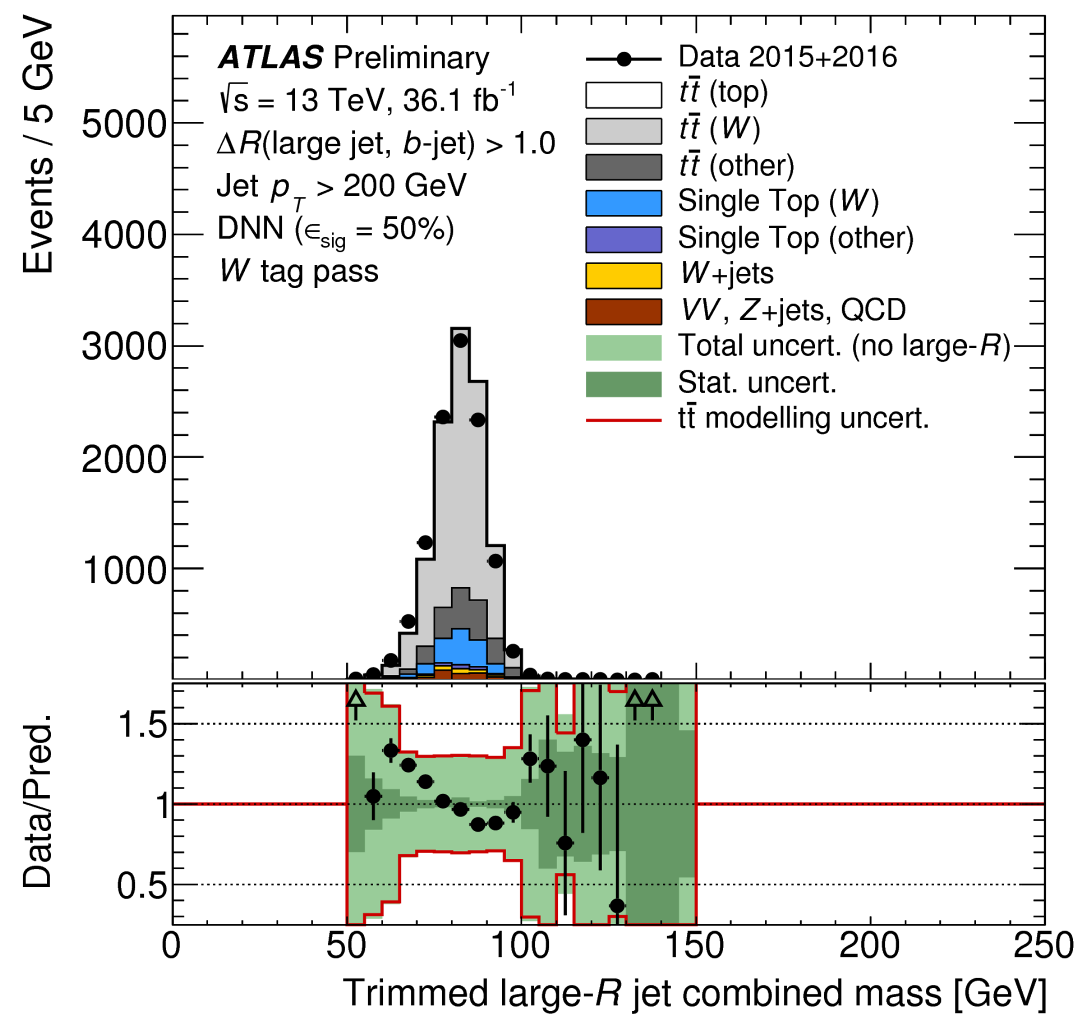


ATLAS-CONF-2017-064

W tagging

- Identify large-R jets as boosted hadronic W decays
- Comparison of three different tagging techniques
  - Mass/D_2, BDT, DNN
  - In-situ comparisons show good modeling in data

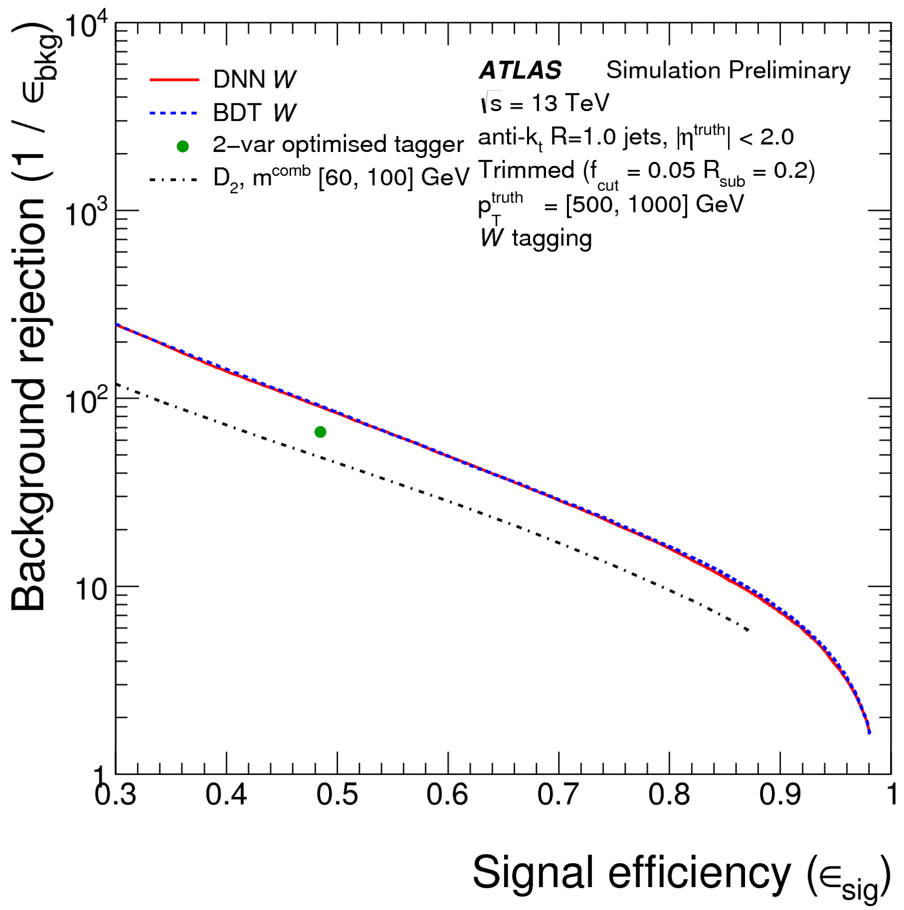




ATLAS-CONF-2017-064

W tagging

- Identify large-R jets as boosted hadronic W decays
- Comparison of three different tagging techniques
  - Mass/D_2, BDT, DNN
  - In-situ comparisons show good modeling in data
- BDT and DNN give improved performance



ATLAS-CONF-2017-064

W tagging

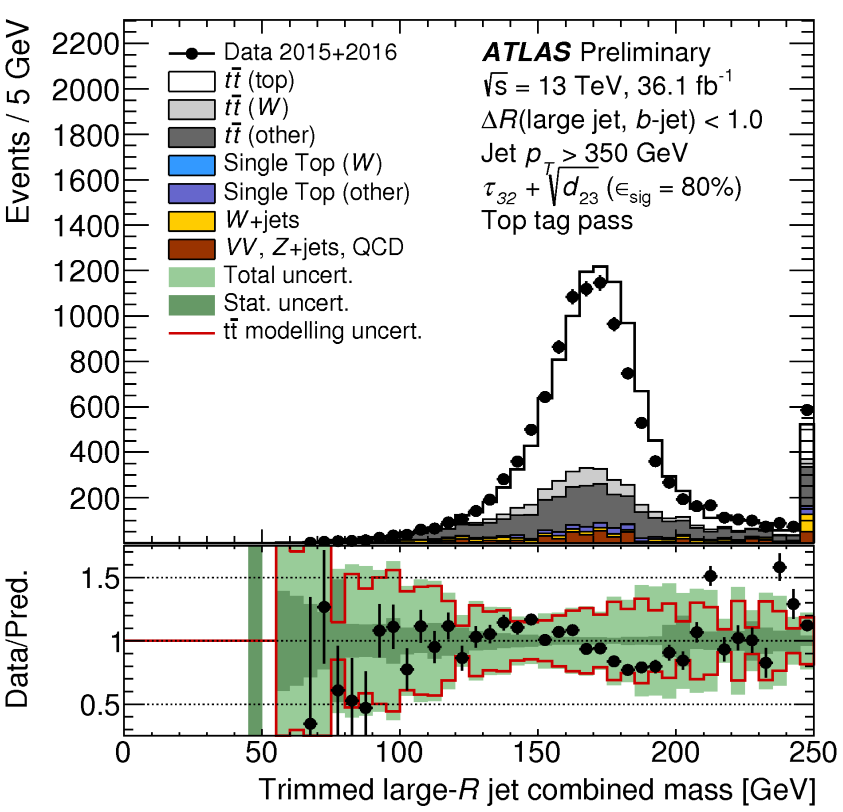
- Identify large-R jets as boosted hadronic W decays
- Comparison of three different tagging techniques
  - Mass/D_2, BDT, DNN
  - In-situ comparisons show good modeling in data
- BDT and DNN give improved performance
- Used in many ATLAS analyses

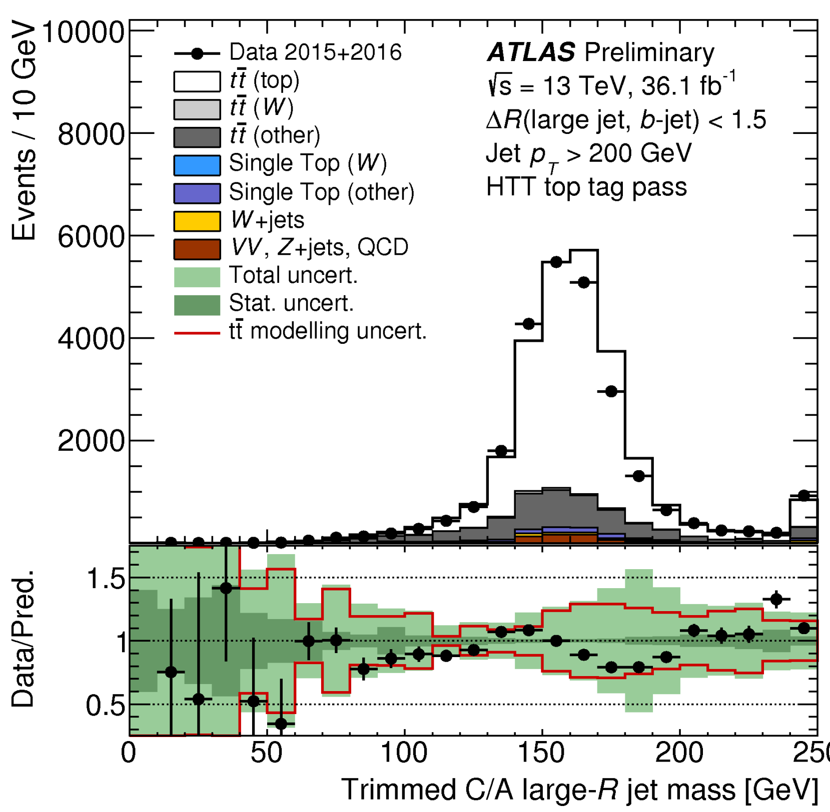
$VV \rightarrow l\nu qq$	JHEP 03 (2018) 042
$VV \rightarrow 4q$	Phys. Lett. B 777 (2017) 91
$VH \rightarrow qqbb$	Phys. Lett. B 774 (2017) 494

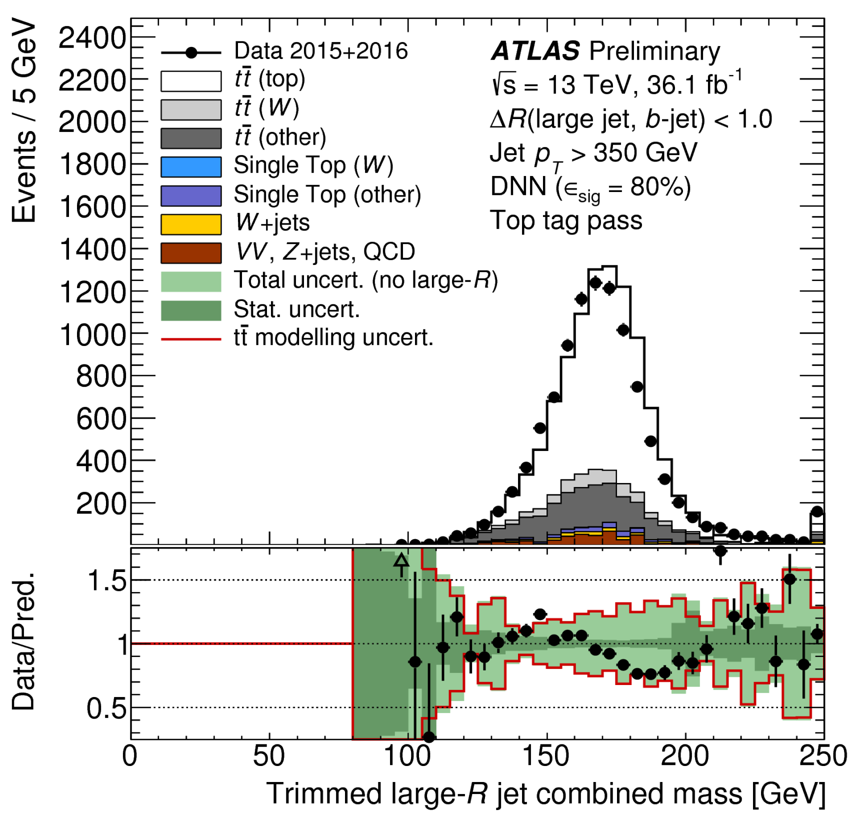
ATLAS-CONF-2017-064

Top quark tagging

- Identify large-R jets as boosted hadronic top decays
- Comparison of six different tagging techniques
  - Mass/τ_{32}(/split$_{12}$), BDT, DNN, shower deconstruction, HTT
  - In-situ comparisons show good modeling in data



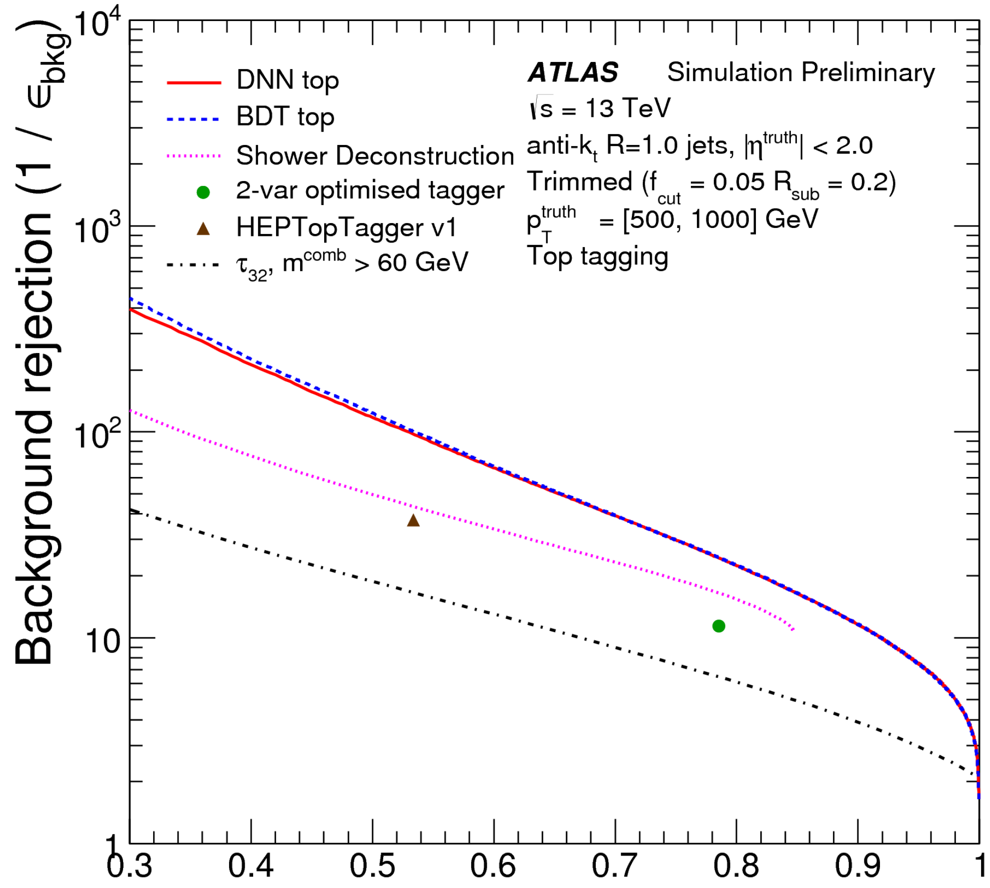




ATLAS-CONF-2017-064

Top quark tagging

- Identify large-R jets as boosted hadronic top decays
- Comparison of six different tagging techniques
  - Mass/τ_{32}(/split$_{12}$), BDT, DNN, shower deconstruction, HTT
  - In-situ comparisons show good modeling in data
- BDT and DNN give the best performance



ATLAS-CONF-2017-064

Top quark tagging

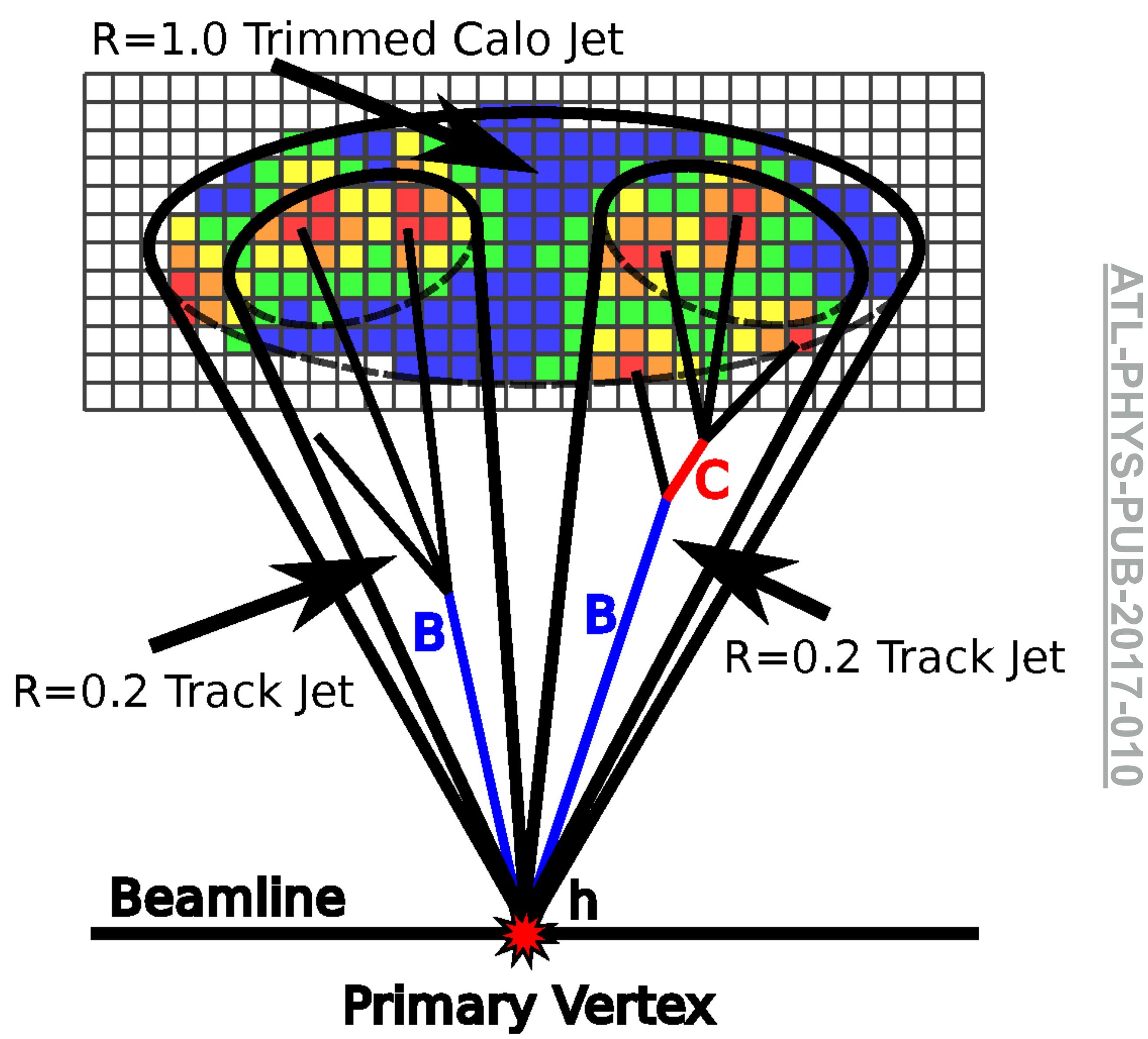
- Identify large-R jets as boosted hadronic top decays
- Comparison of six different tagging techniques
  - Mass/τ_{32}(/$split_{12}$), BDT, DNN, shower deconstruction, HTT
  - In-situ comparisons show good modeling in data
- BDT and DNN give the best performance
- Used in ongoing and published ATLAS analyses

tt diff xsec	arXiv:1801.02052

ATLAS-CONF-2017-064

H→bb tagging

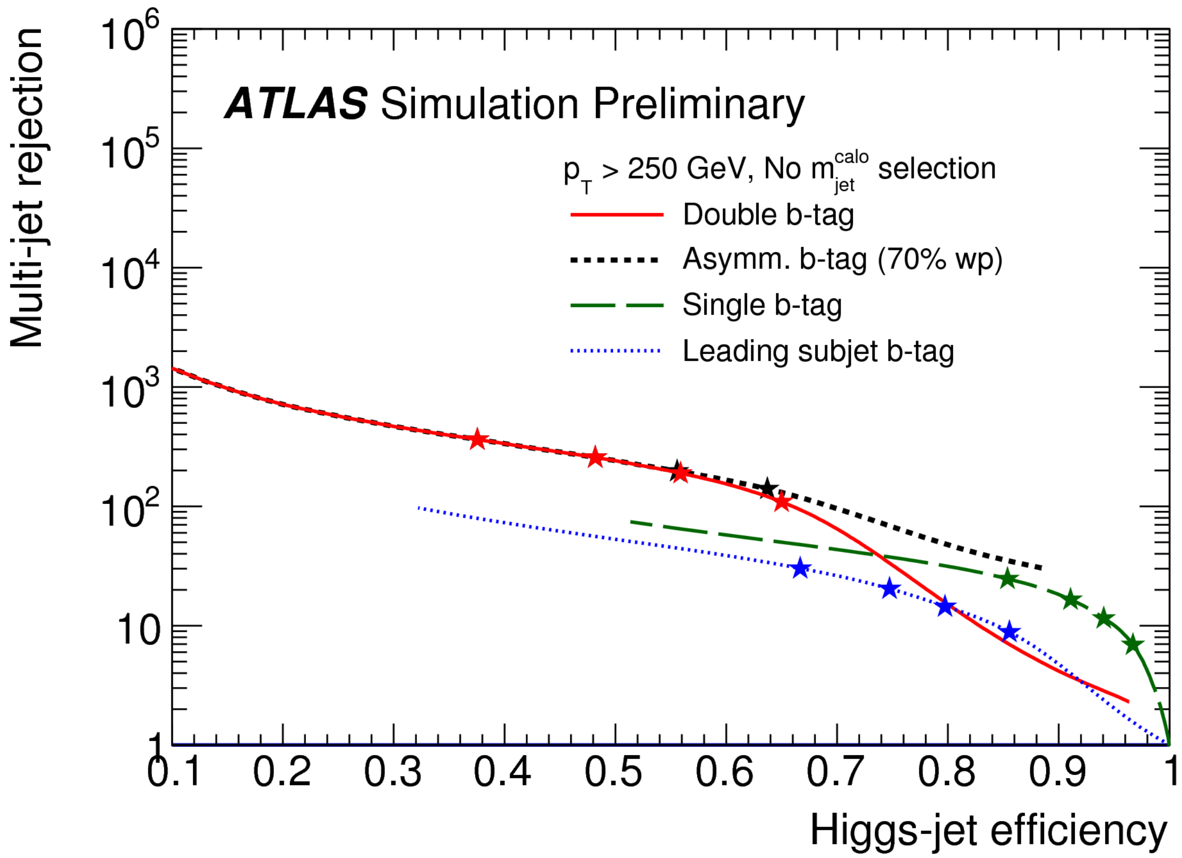
- Identify large-R jets as boosted H→bb decays

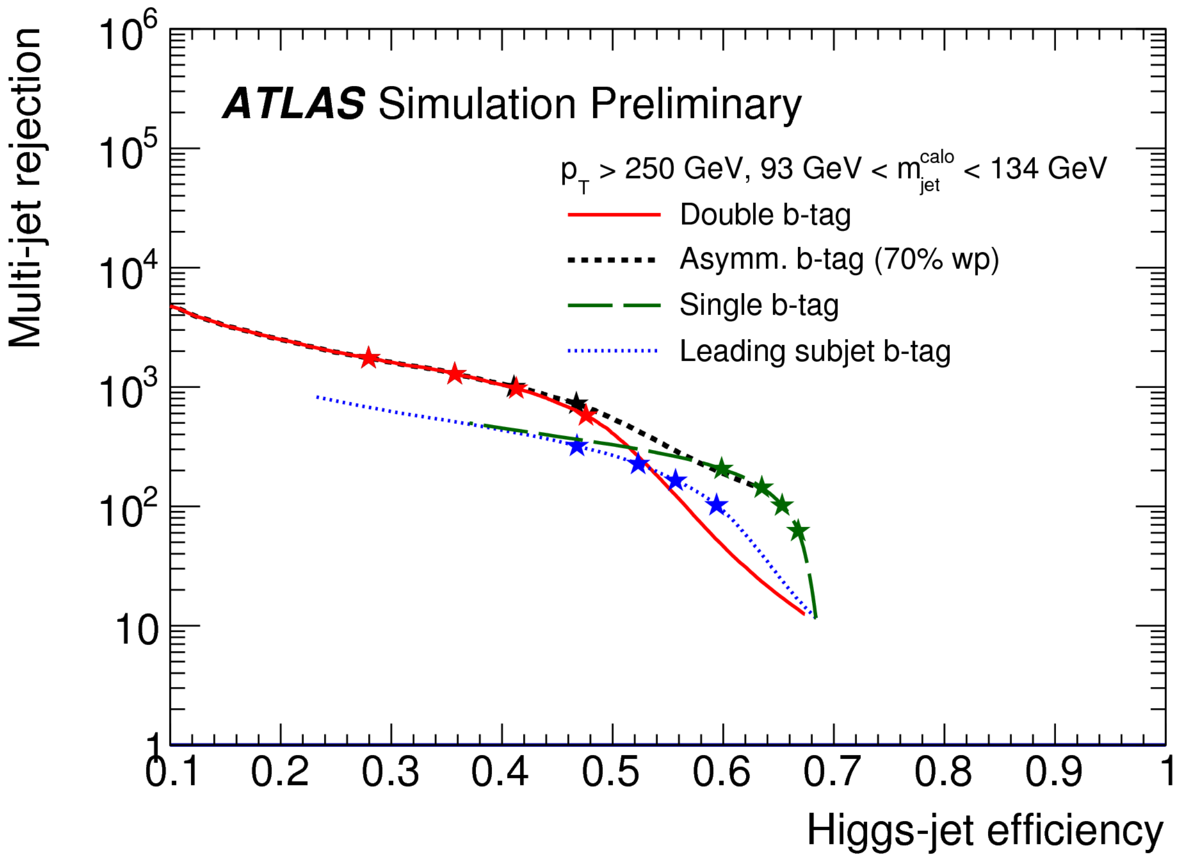


ATLAS-CONF-2016-039

H→bb tagging

- Identify large-R jets as boosted H→bb decays
  - Match b-tagged R = 0.2 track jets to large-R jet
  - Higgs mass requirement
  - Use D_2 to identify 2-prong decay





ATLAS-CONF-2016-039

H→bb tagging

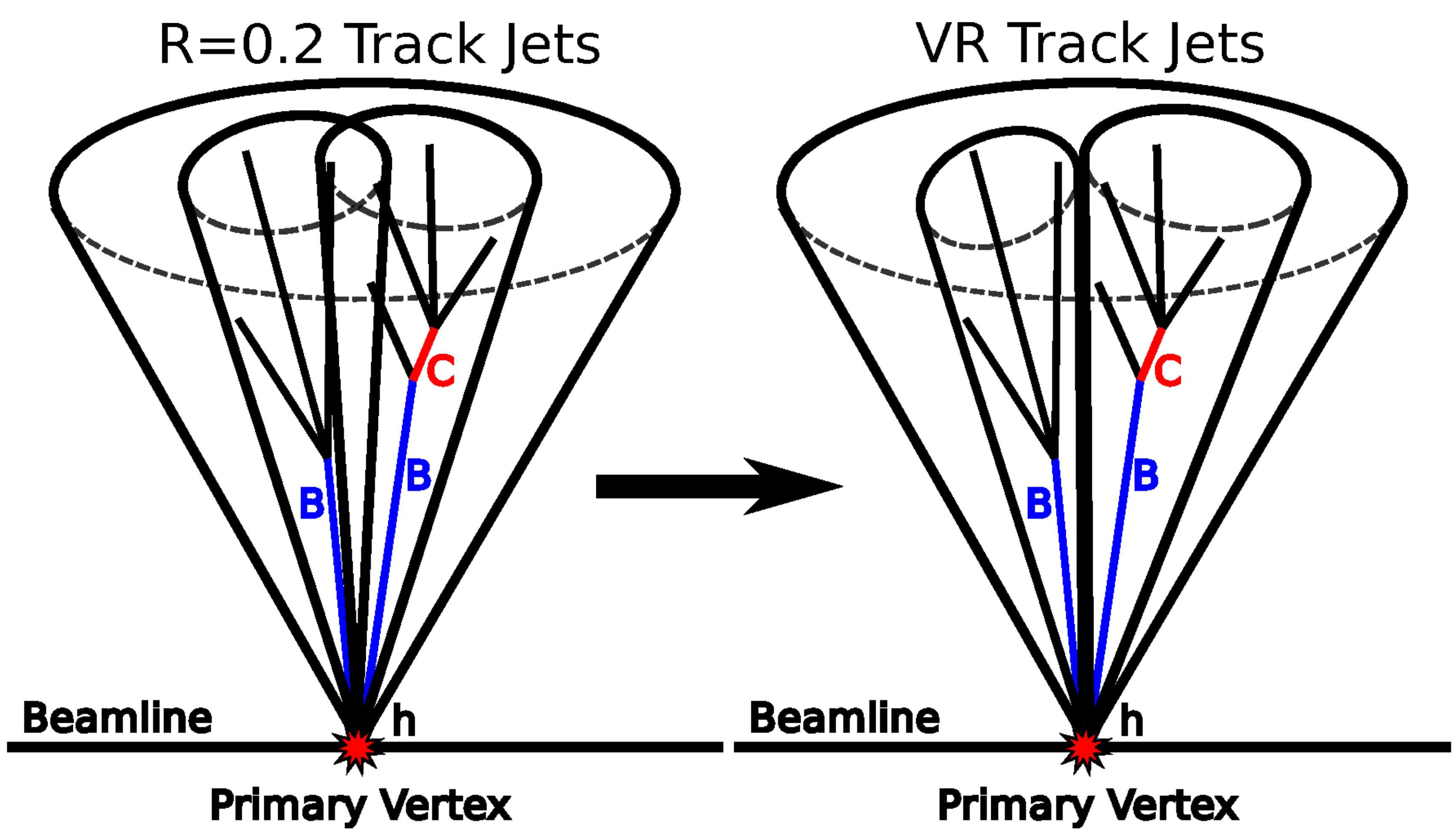
- Identify large-R jets as boosted H→bb decays
  - Match b-tagged R = 0.2 track jets to large-R jet
  - Higgs mass requirement
  - Use D_2 to identify 2-prong decay
- Used in many ATLAS analyses

DM + H→bb	JHEP12 (2017) 034
XH→qqbb	Phys.Lett. B779 (2018) 24-45
HH→4b	Phys. Rev. D 94 (2016) 052002

ATLAS-CONF-2016-039

Improved H→bb tagging

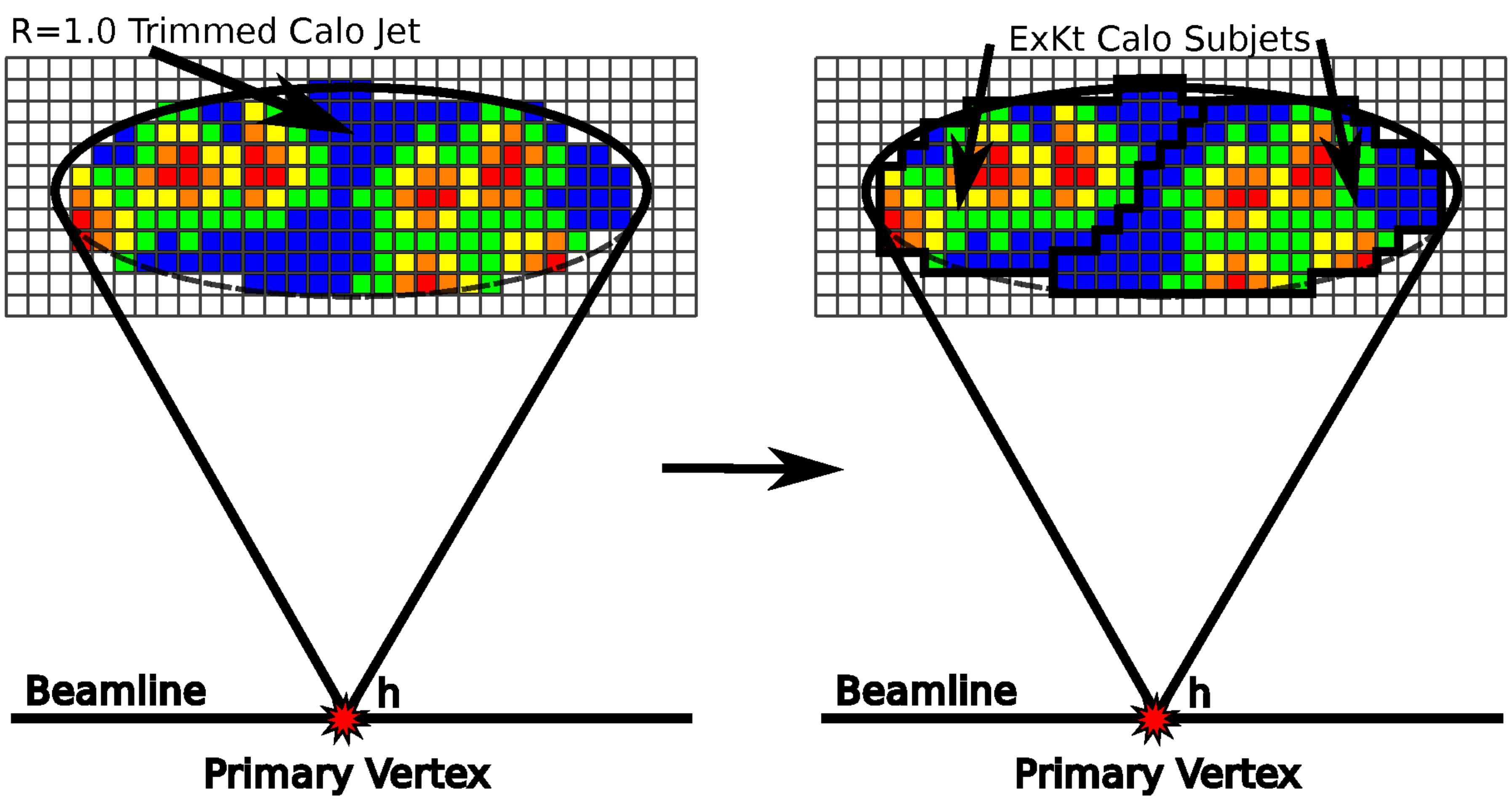
- Additional techniques to improve H→bb tagging
  - Variable-R track jets



ATL-PHYS-PUB-2017-010

Improved H→bb tagging

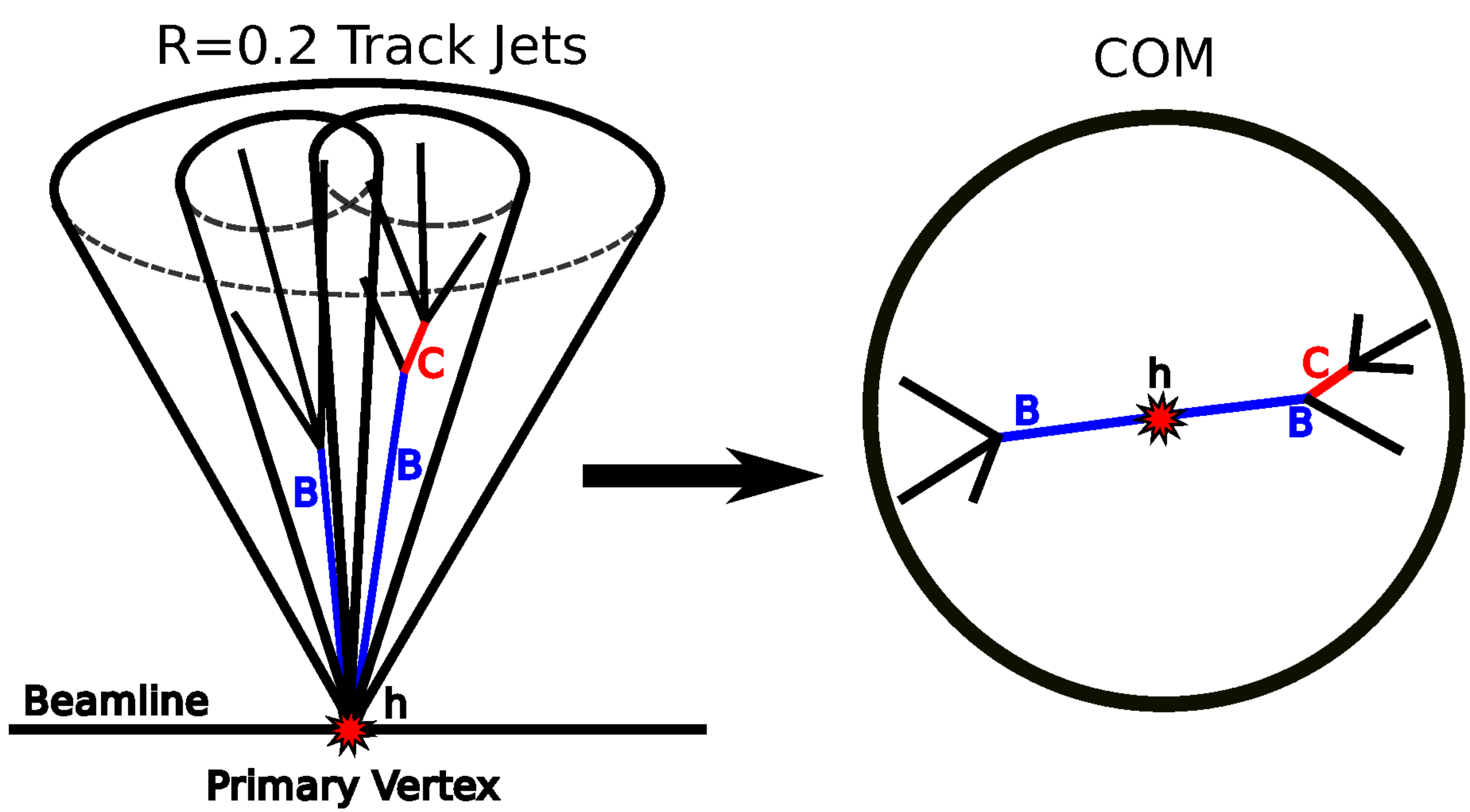
- Additional techniques to improve H→bb tagging
  - Variable-R track jets
  - Exclusive kt calorimeter subjets



ATL-PHYS-PUB-2017-010

Improved H→bb tagging

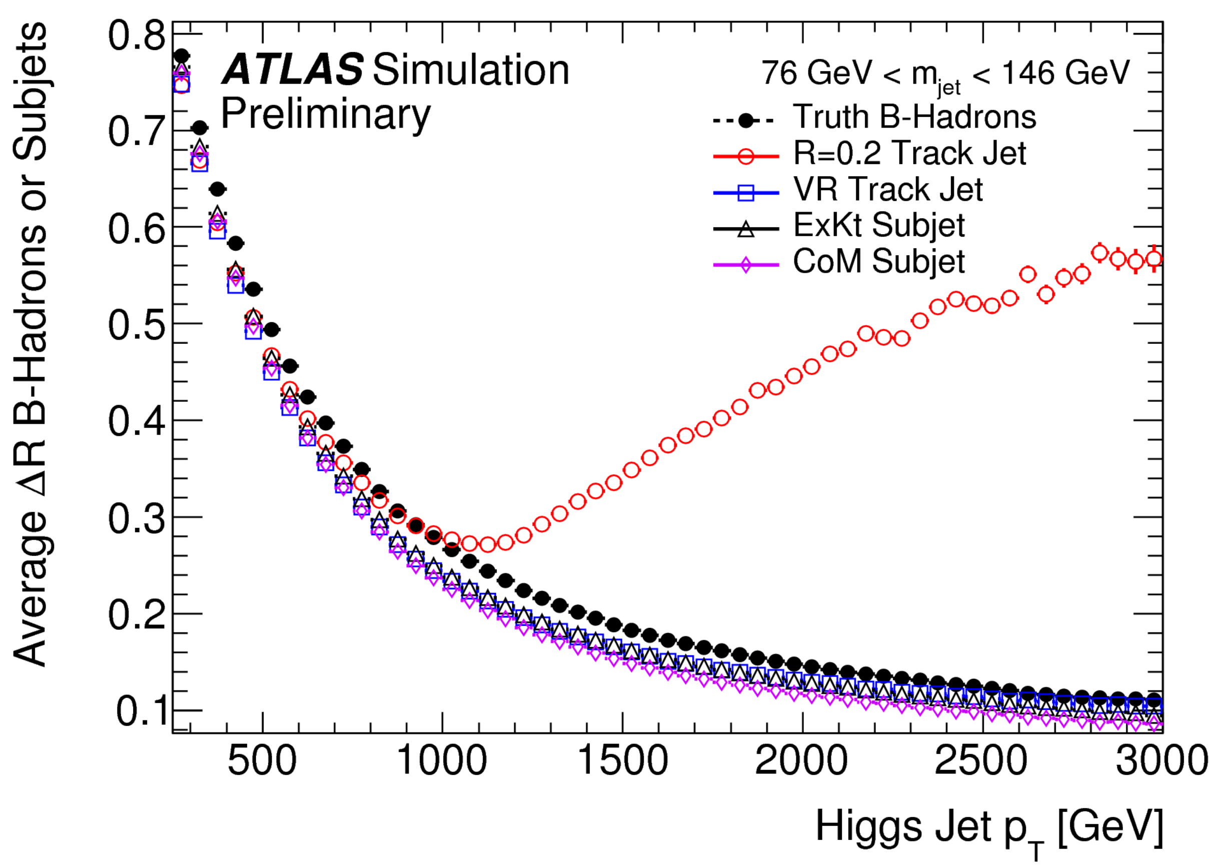
- Additional techniques to improve H→bb tagging
  - Variable-R track jets
  - Exclusive kt calorimeter subjets
  - Center of mass subjet reconstruction

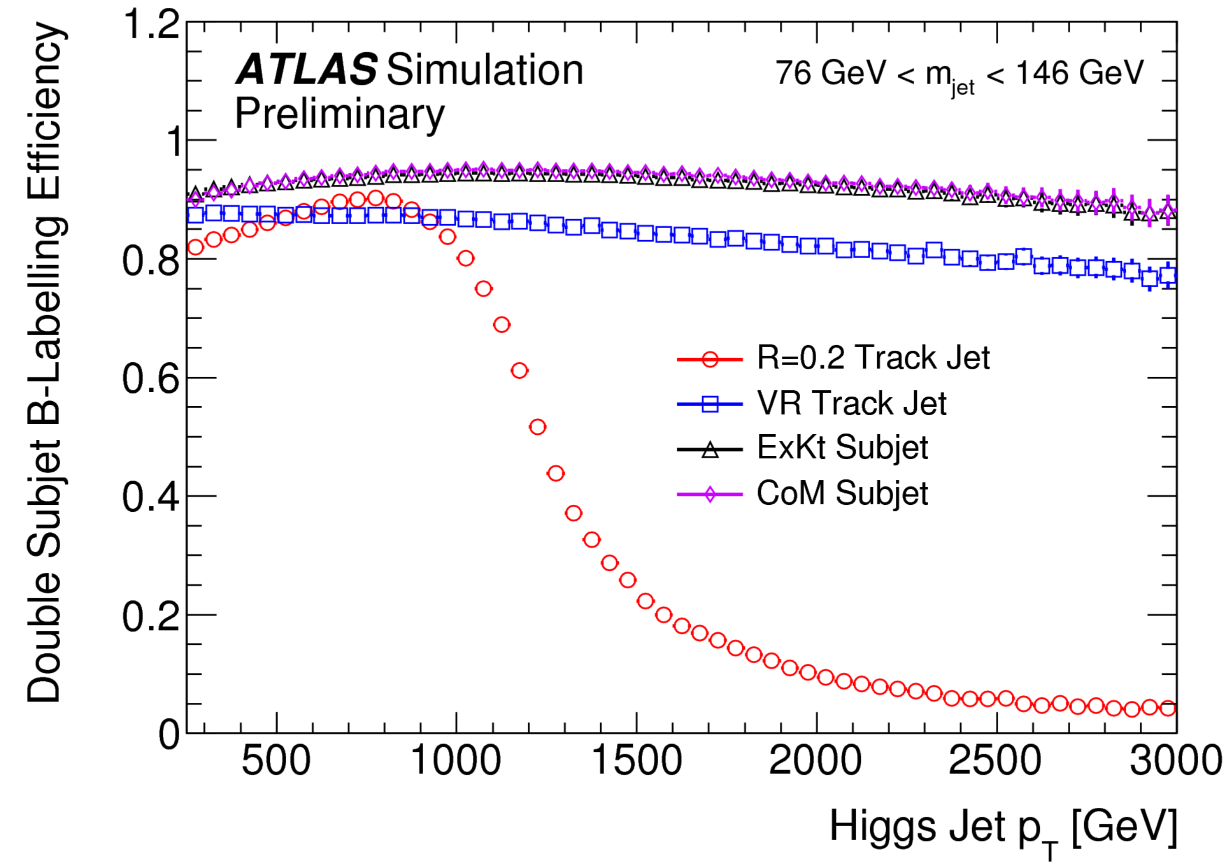


ATL-PHYS-PUB-2017-010

Improved H→bb tagging

- Additional techniques to improve H→bb tagging
  - Variable-R track jets
  - Exclusive kt calorimeter subjets
  - Center of mass subjet reconstruction
- Improvements in tagging performance





ATL-PHYS-PUB-2017-010

Improved H→bb tagging

- Additional techniques to improve H→bb tagging
  - Variable-R track jets
  - Exclusive kt calorimeter subjets
  - Center of mass subjet reconstruction
- Improvements in tagging performance
- Search for further improvements continues…

ATL-PHYS-PUB-2017-010

Conclusions and Outlook

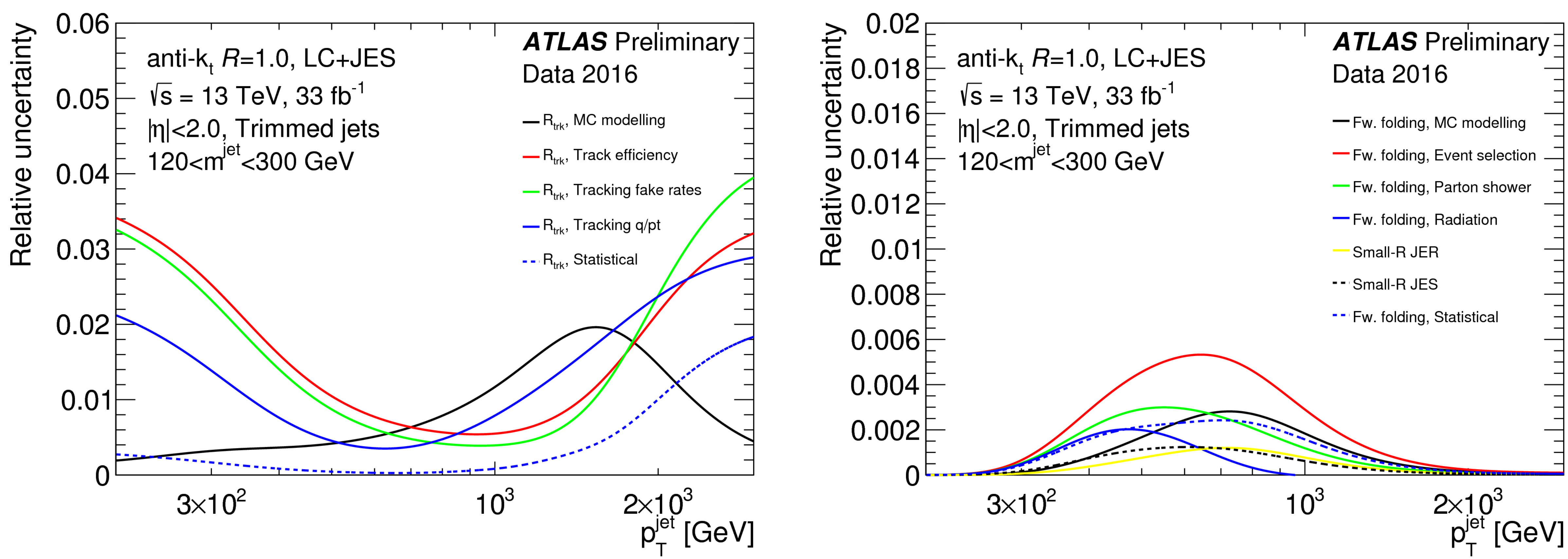
- Many new developments related to large-R jets
  - Improved large-R jet modeling and reconstruction
  - Techniques to identify heavy resonances
- Development continues as analyses rely more on boosted techniques to push limits to higher mass points
- Boosted topologies will become even more important with higher energy collisions
- Many more improvements on the way…

Thank you for your attention

Backup slides

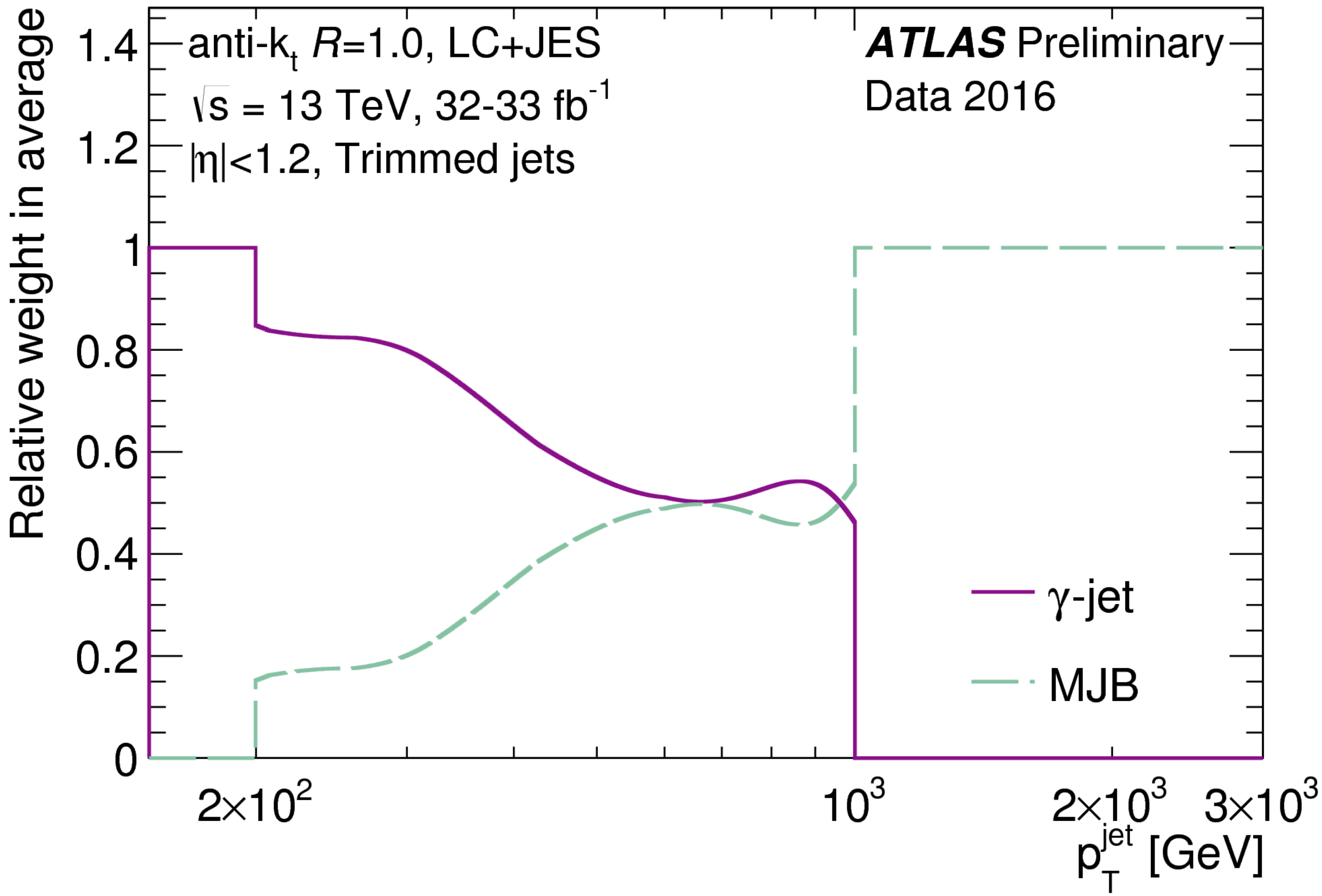
Measuring large-R jet response with in-situ techniques

- Comparison of R_{trk} and forward folding results



ATLAS-CONF-2017-063

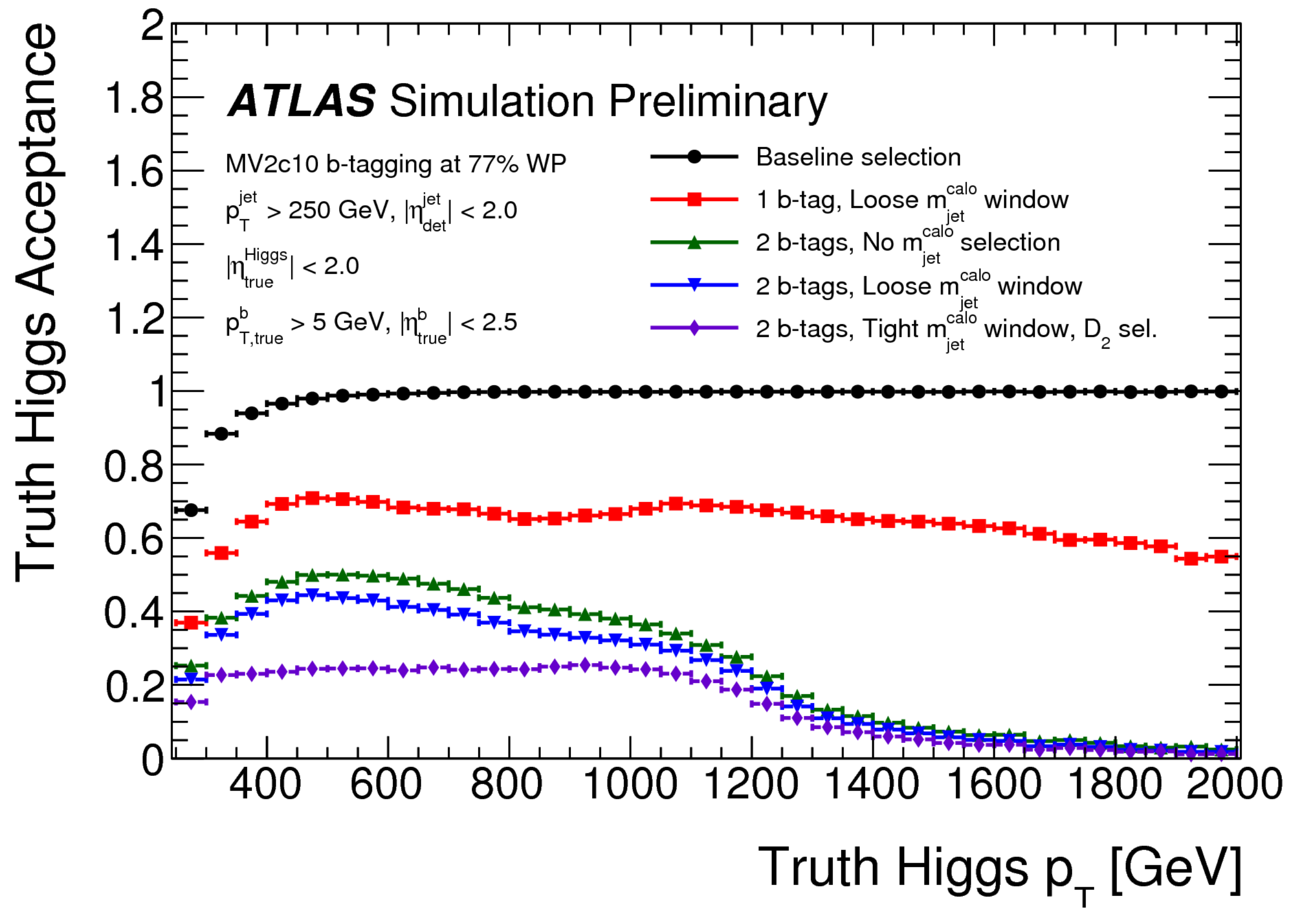
Measuring large-R jet response with in-situ techniques

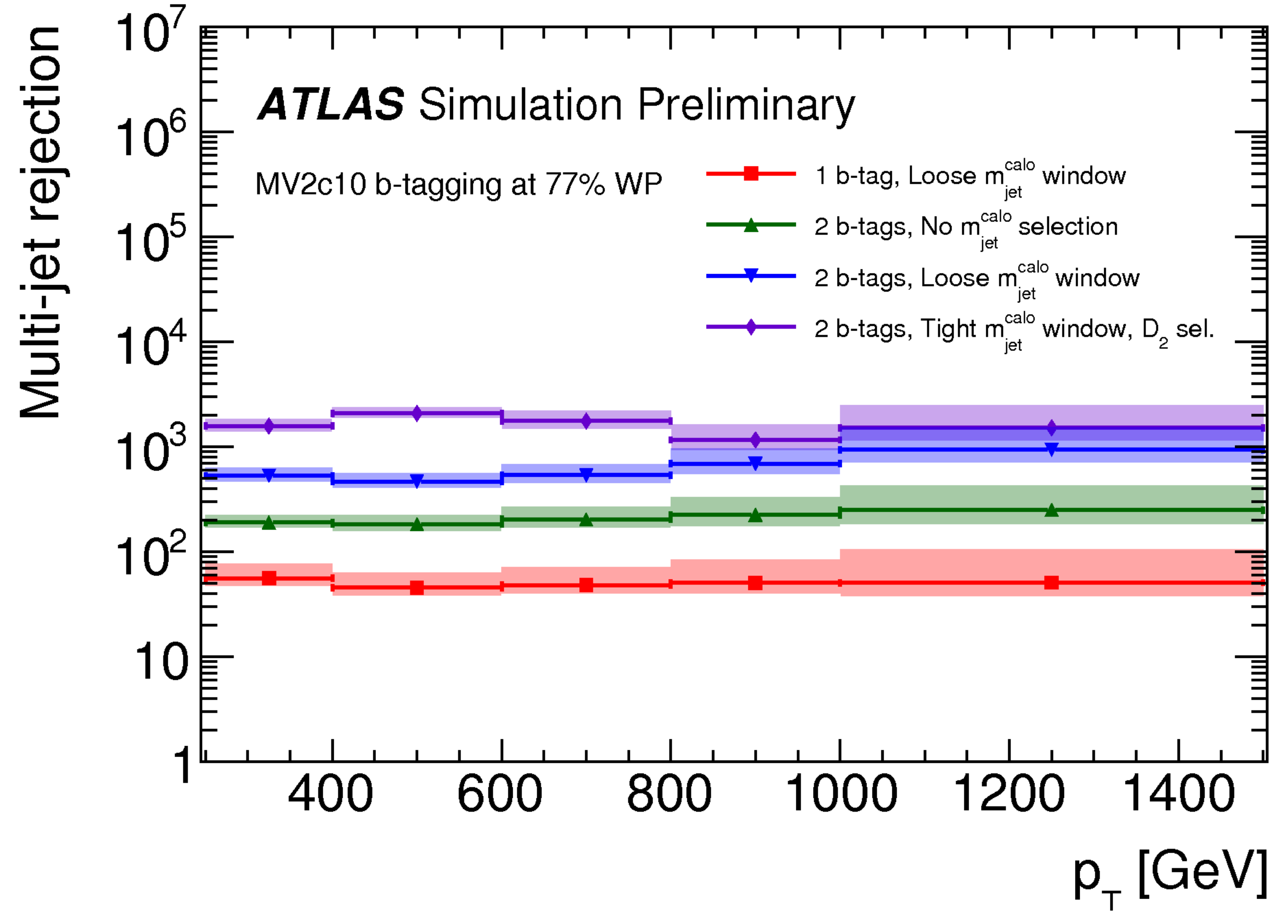


ATLAS-CONF-2017-063

H→bb tagging

- Comparison of cut levels





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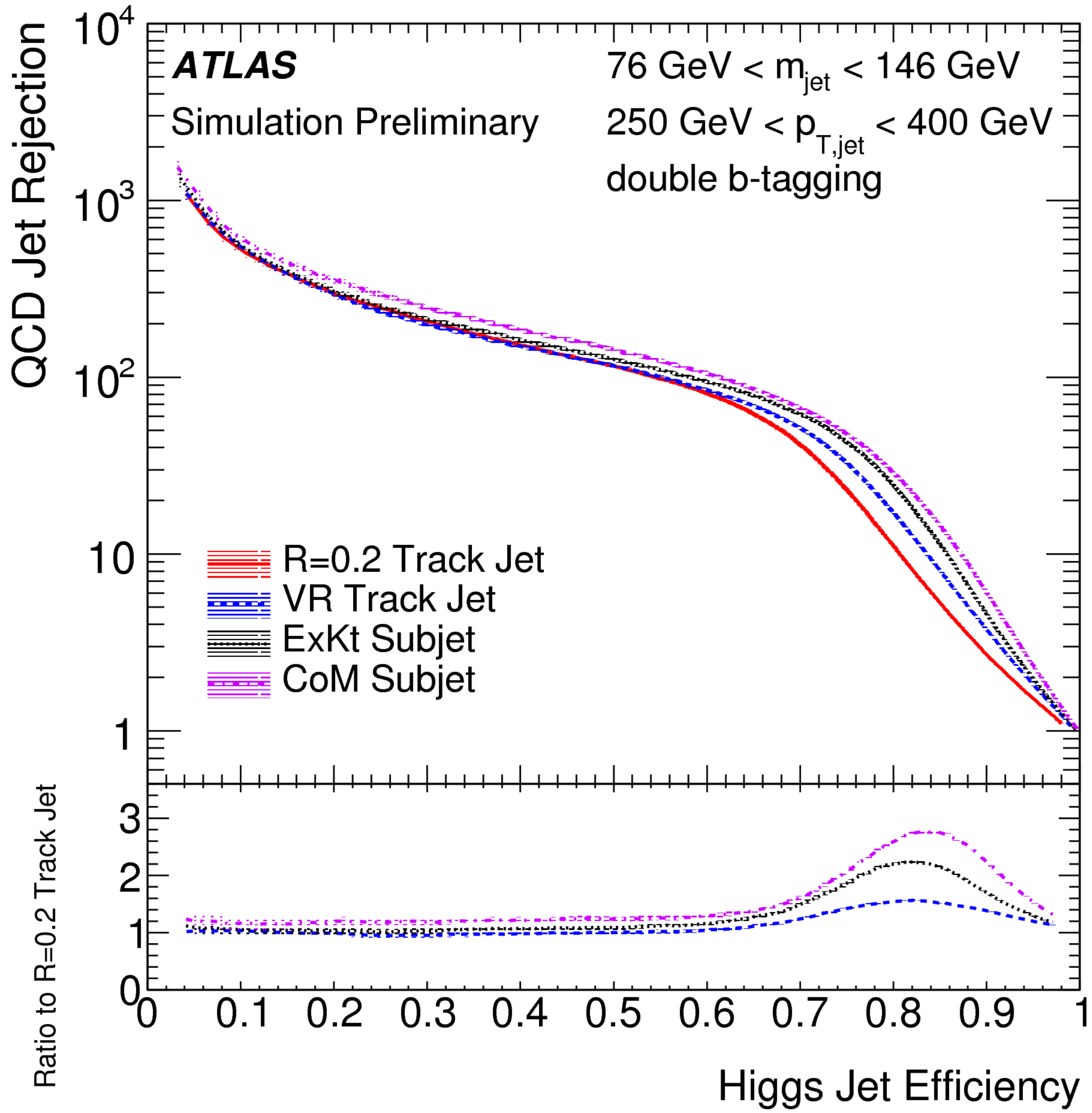
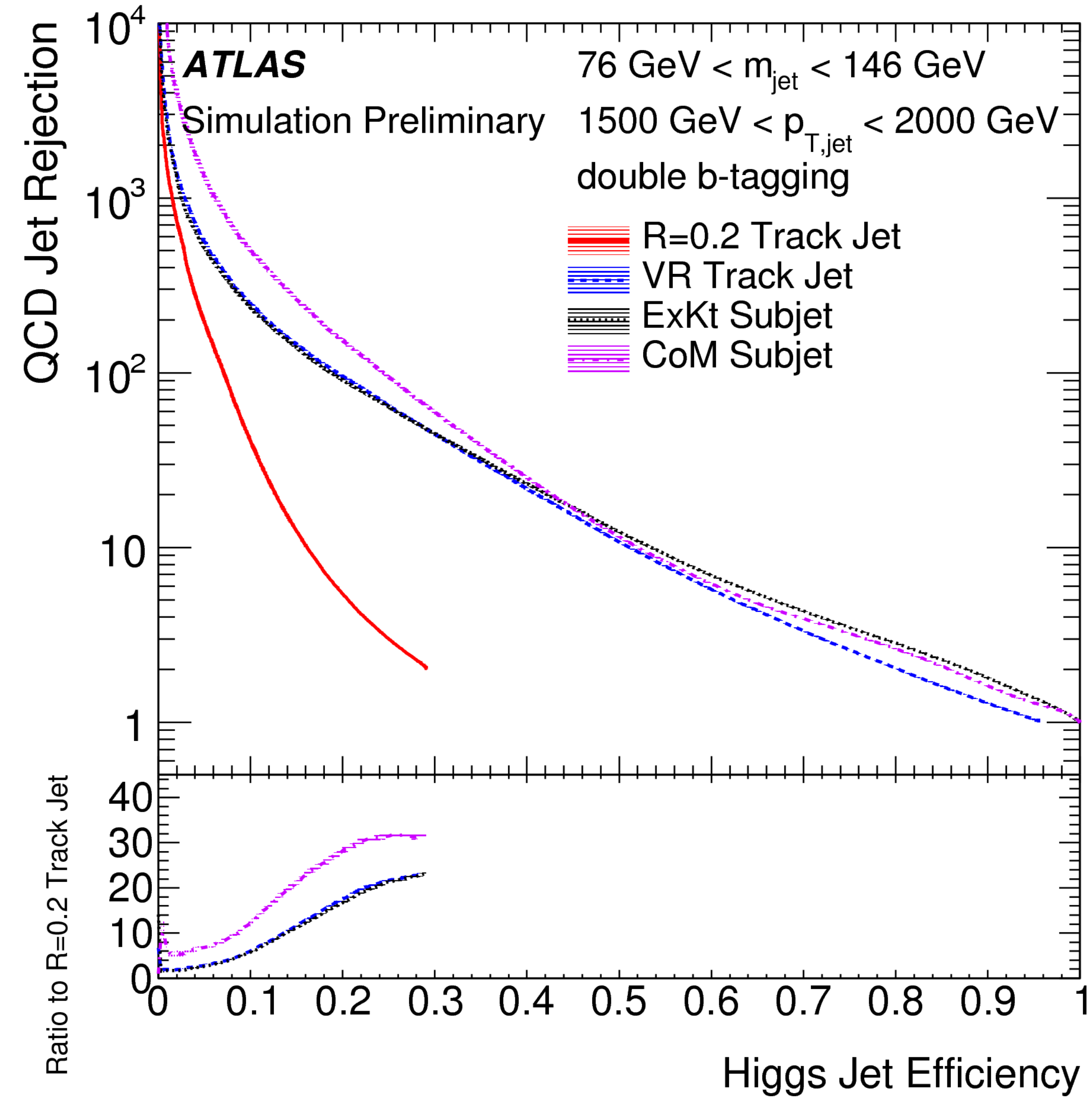
Improved H→bb tagging





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