Reconstruction techniques in supersymmetry searches in the ATLAS experiment

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on behalf of the ATLAS Collaboration

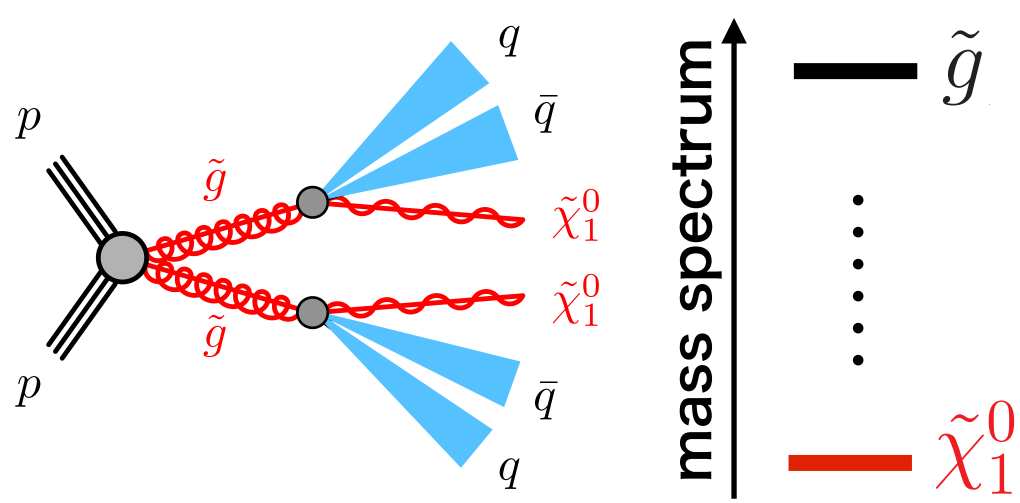
25th international conference on supersymmetry and the unification of fundamental interactions (SUSY17)

December 14, 2017

Introduction

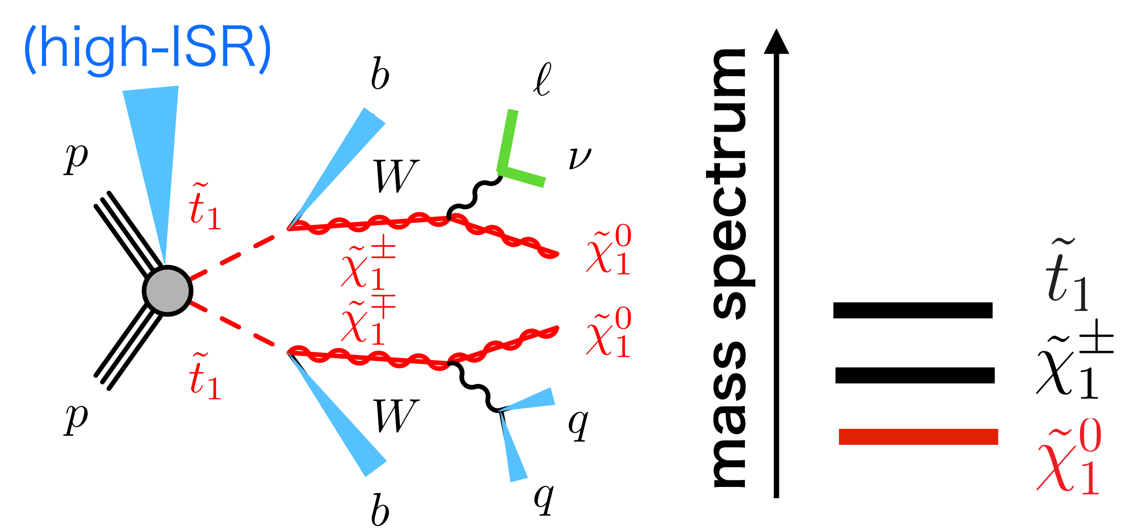
- Although we have searched for SUSY particles for wide theoretical parameter regions (up to 2 TeV for strong searches), they are not discovered yet.
- Experimentally challenging signature becomes more important for the discovery.

Strong searches:



- Objects: **high-p_T jets** and **high E_T^{miss}**
- Precise low-statistics background estimation

Compressed SUSY searches:



- Objects: **low-p_T lepton/jets** and **low E_T^{miss}**
- **ISR to boost the SUSY particles**

Overview of reconstruction techniques

1. Lepton reconstruction efficiencies

- extension to low-p_T leptons (muon: 4 GeV, electron: 4.5 GeV) New!

2. The reclustered jet reconstructions New!

- variable-R jet reconstruction New!

3. Precise background estimations

- Z($\rightarrow \nu\nu$)+jets and fake lepton/E_T^{miss}

4. Specific signal topologies

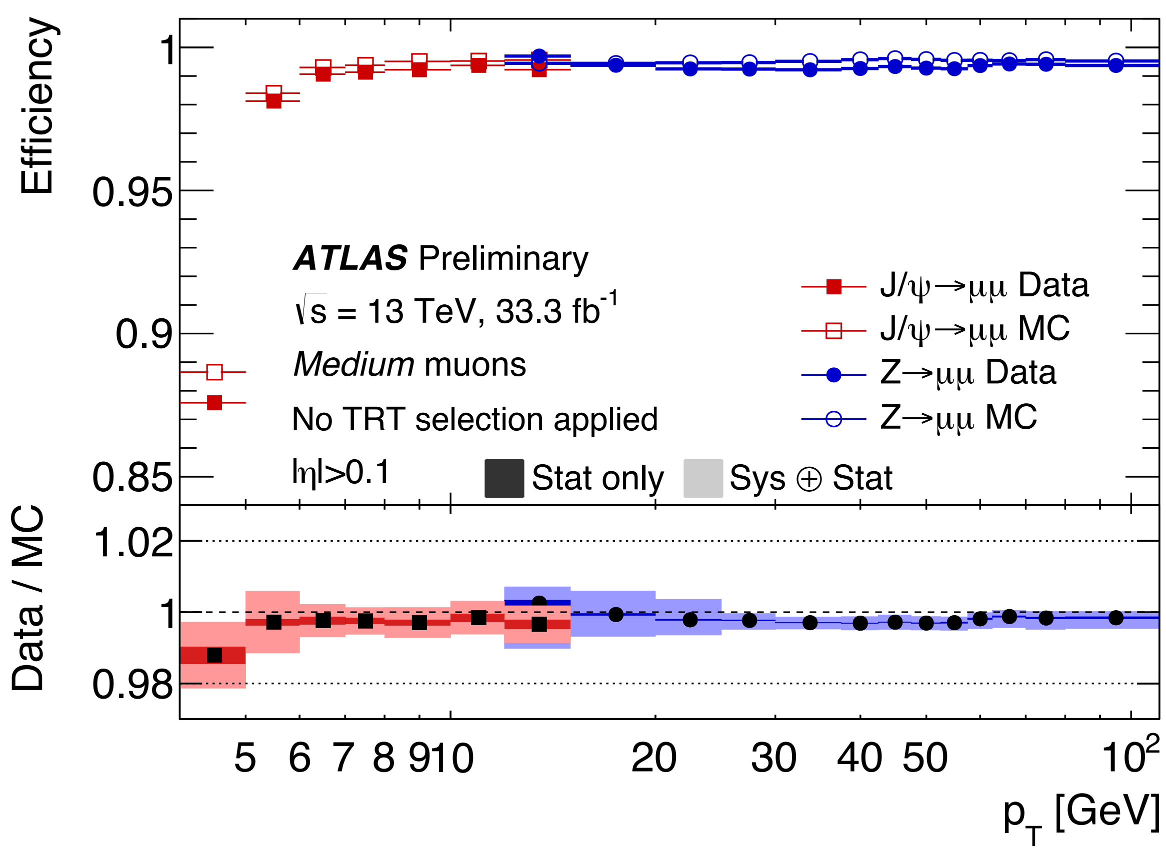
- high-p_T b-tagging
- signal + ISR topology

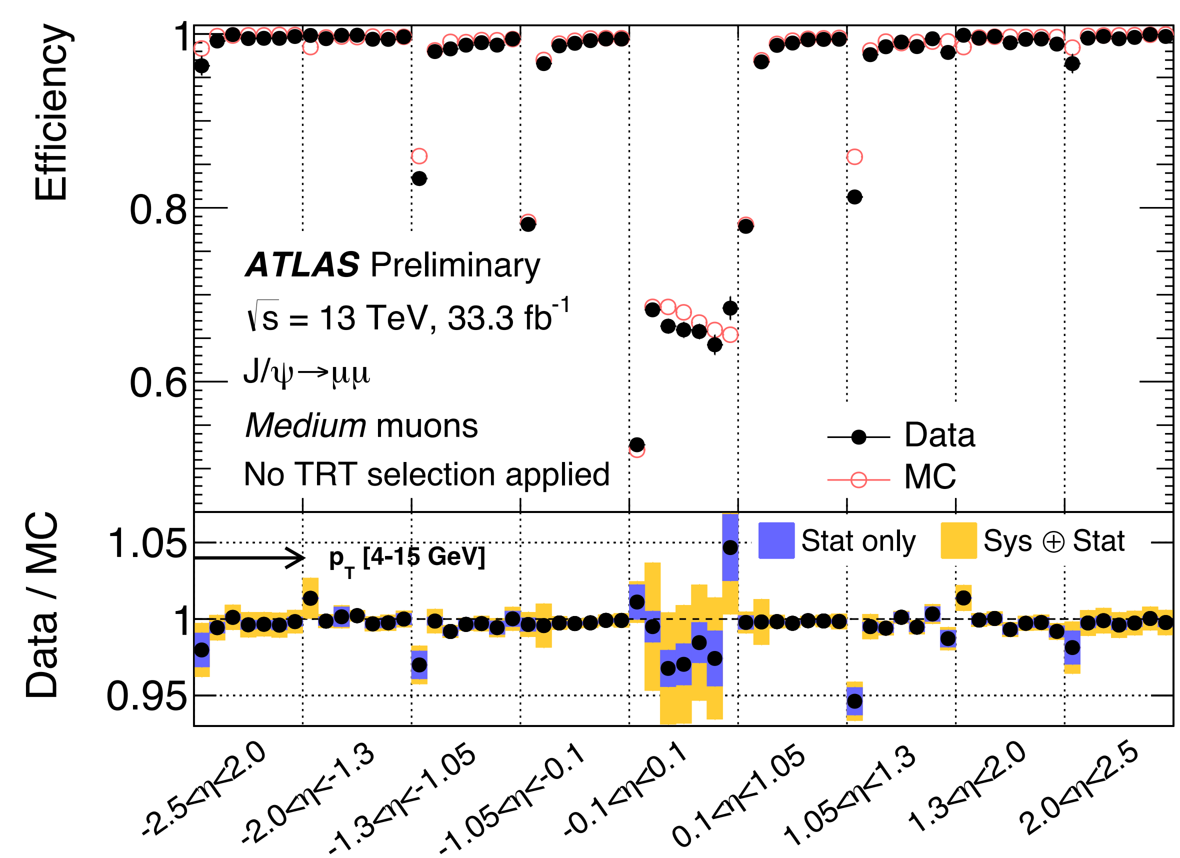
Lepton reconstruction efficiencies

[ATLAS-CONF-2016-024]
[arXiv:1603.05598]

- Muon (Electron) reconstruction efficiencies and correction factors are estimated for leptons in $J/\Psi \rightarrow \mu\mu$ (ee) and $Z \rightarrow \mu\mu$ (ee) events as a function of p_T (E_T) in a range **p_T > 4 GeV (E_T > 4.5 GeV)**.
- **Muon efficiency is higher than 95%** in each η regions except for the regions with detector gaps and/or services.
  (Electron efficiency is higher than 75% except for the regions with calorimeter gaps.)

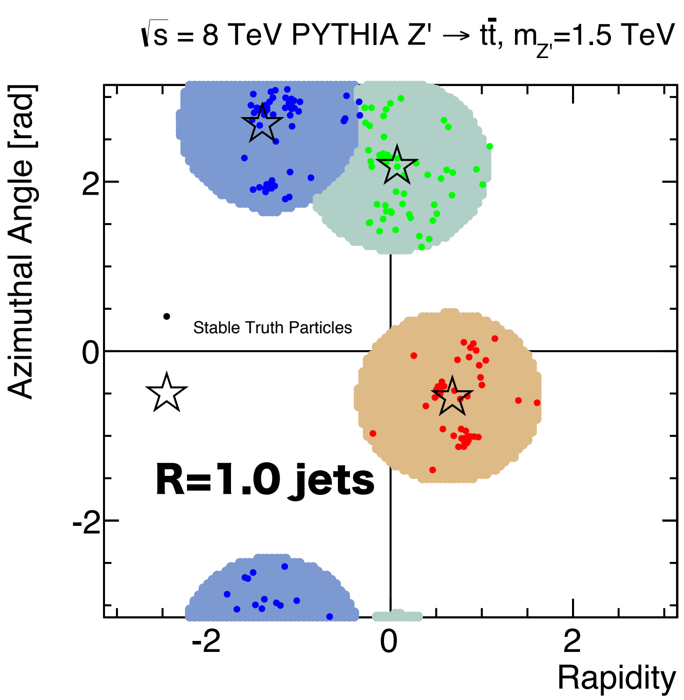
Examples: Muon reconstruction efficiencies



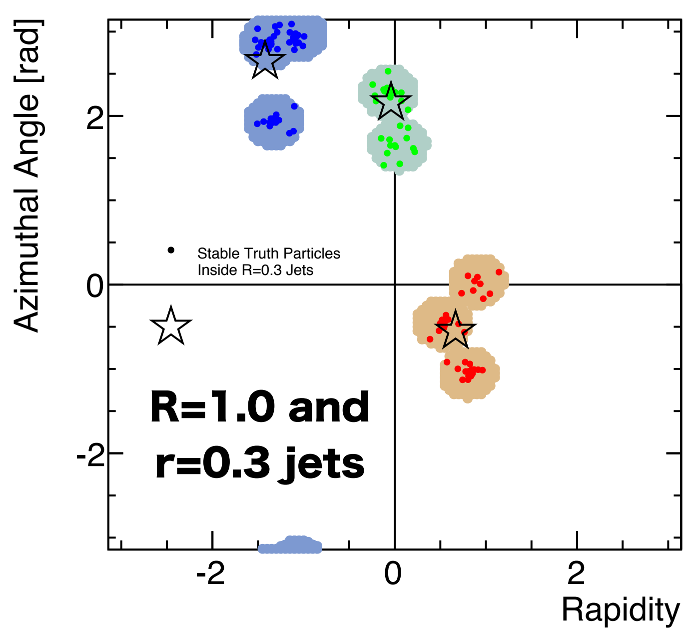


Jet reclustering algorithm [arXiv:1407.2922]

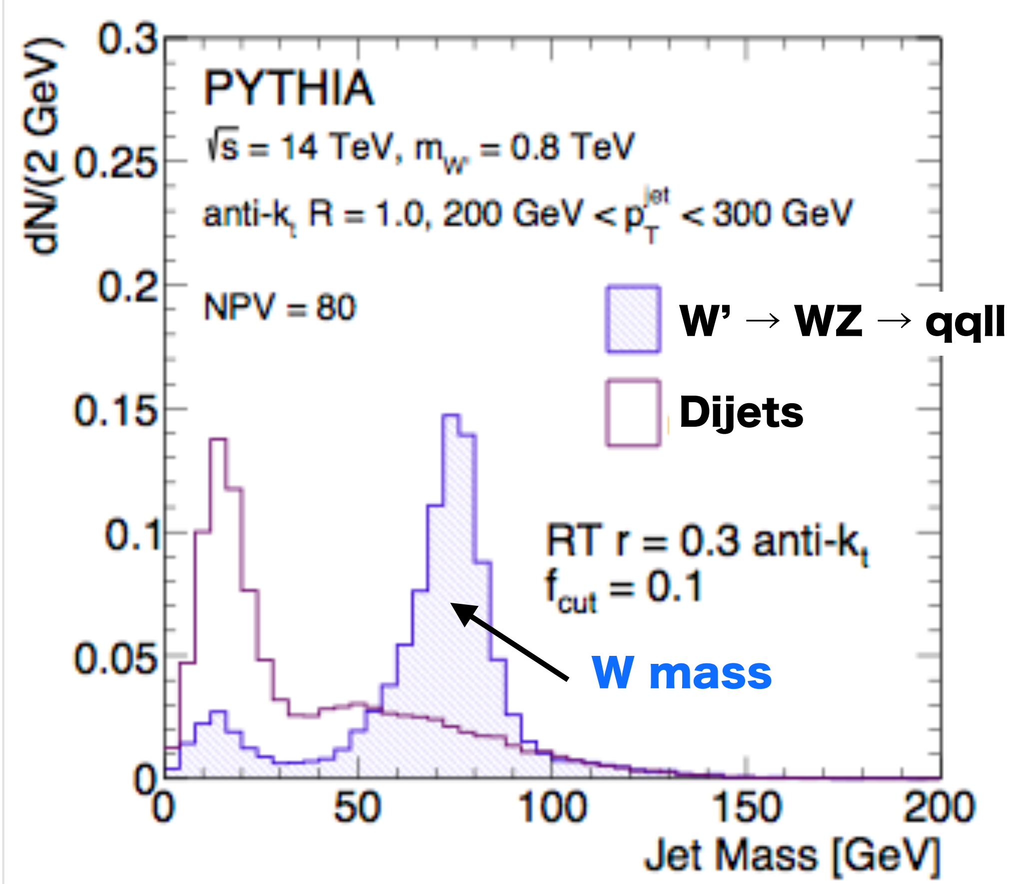
- Fixed large radius (R) jets (R=1.0) have good reconstruction performances for high-p_T jets, but they may not be optimal for each analysis.
- **New reclustered large-R jets** (R=1.0) are developed by the new reclustering algorithm with **small radius jets** (r=0.3, 0.4, etc).
  - The calibration is not necessary because using the **calibrated small-R jets.**
    - The calibration for small-R jets contains the **pile-up suppression**.
  - The reclustered large-R jets have **smaller energy-scale uncertainty (~1%).**



Fixed large-R jets



Reclustered large-R jets



W/dijets mass reconstructions

Variable-R jets reconstruction [arXiv:1711.11520]

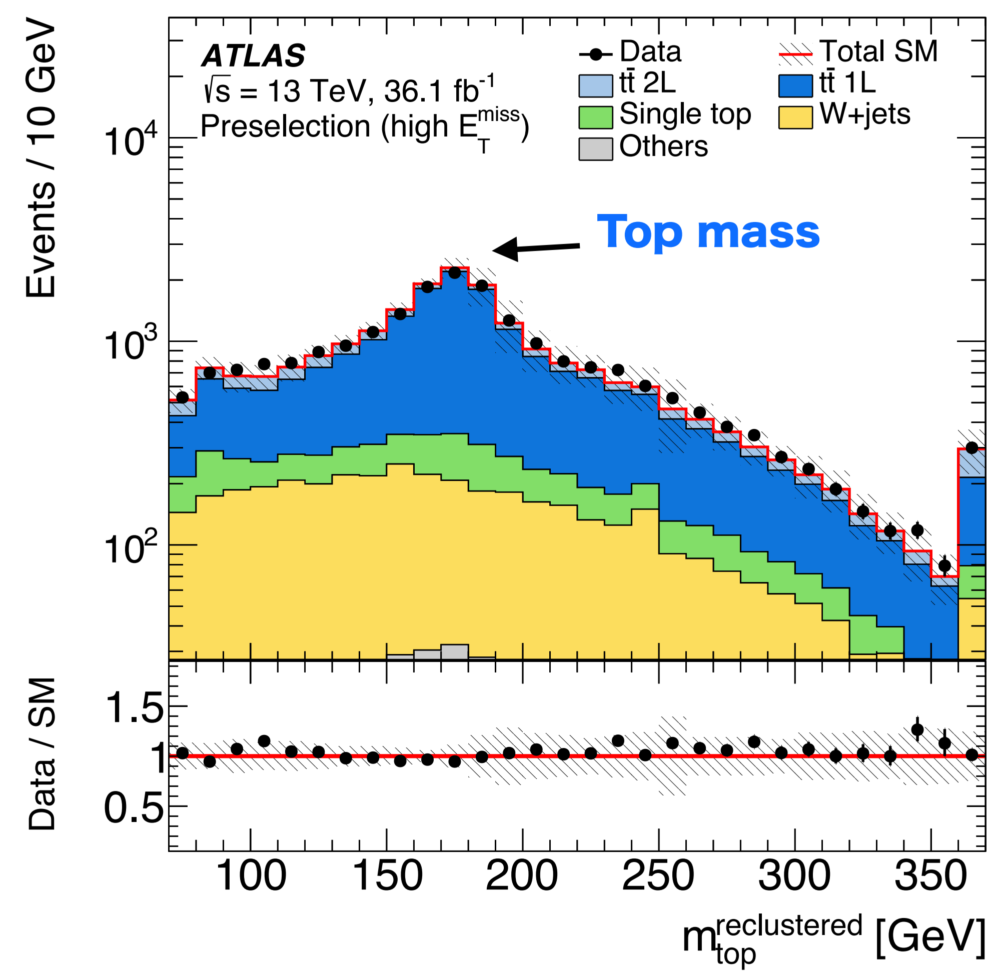
- The reclustering algorithm with small-R jets can reconstruct **variable-R jets**.
- They are useful for the reconstruction of **the top-quark** or **W boson** with hadronic decay.

Reconstruction method

- All small-R jets (r=0.4) are **clustered with an initial large-R parameter R_0**, e.g. $R_0 = 3.0$.
- The parameter R of each large-R jet is then **iteratively reduced to an optimal R,**

$$R\,(p_{\mathrm{T}}) = 2 \times m / p_{\mathrm{T}}$$

(p_T: p_T of the large-R jet, m: candidate's mass)



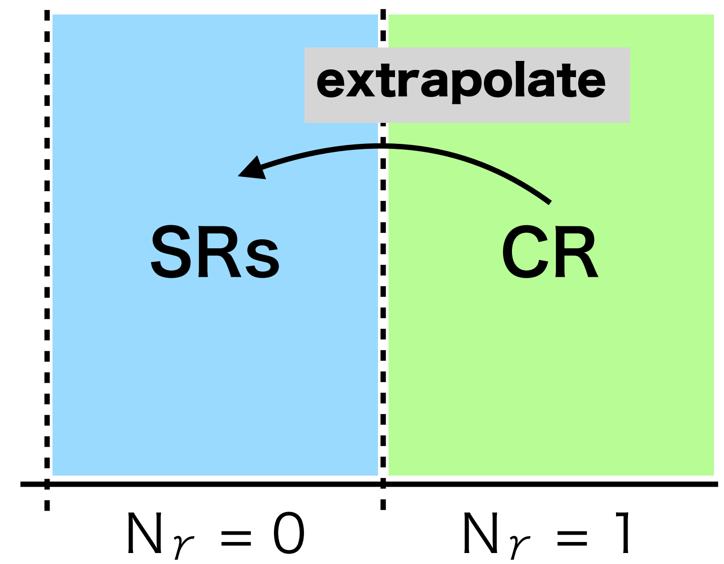
stop1L, $\tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$

Z($\to \nu\nu$)+jets background estimation

- The dominant background in Signal Region (SR) is estimated by using Control Region (CR) :

$$N_{\mathrm{Data,SR}} = N_{\mathrm{MC,SR}} \times \boxed{\frac{N_{\mathrm{Data,CR}}}{N_{\mathrm{MC,CR}}}}$$

= scale factor (SF)

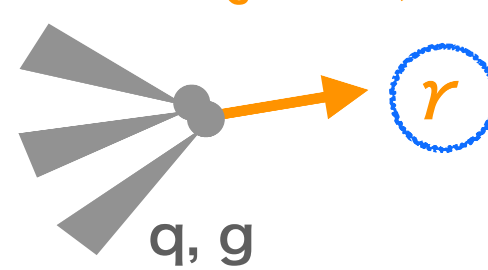


- Z($\to \nu\nu$)+jets background is dominant for **squark/gluino** pair production in **all jets** final state [ATLAS-CONF-2017-022].

- The modeling uncertainty of Z ($\to \nu\nu$) + jets is large.
  $\to$ data-driven method with γ+jets is used.

- γ+jets corrected to model Z+jets
  $\to$ Knowing corrections to high accuracy more important than accuracy on γ+jets or Z+jets alone

γ+jets (require 1γ) : CR



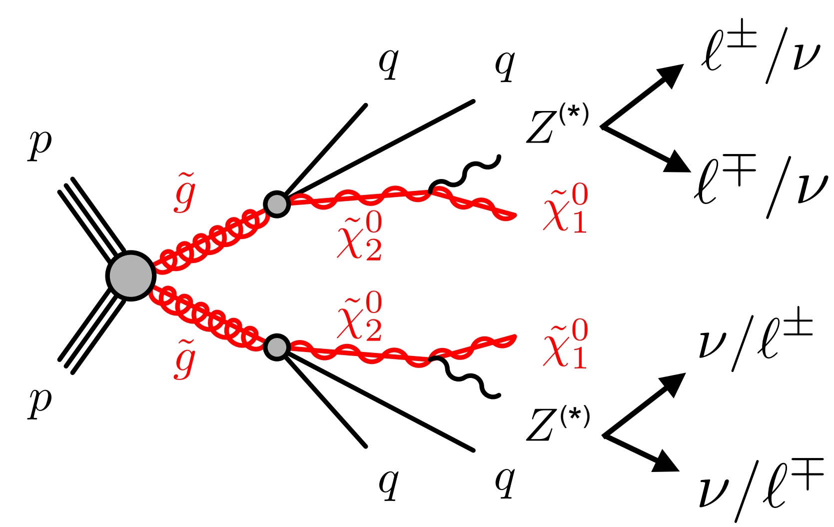
Treat as $Z \to \nu\nu$ (E_T^{miss})

The maximum contribution to the overall background uncertainty is **a few %**.

Fake lepton/E_T^{miss} background estimations

Fake lepton background

- Fake lepton background arises from **mis-identified jets**.
- **Fake lepton modeling at very low-p_T**, which is **new**, **challenging**, and **important** for the compressed SUSY scenarios with soft leptons.
- The quantitative estimation of the fake lepton is obtained by data-driven **fake factor method**.



gluino 2L

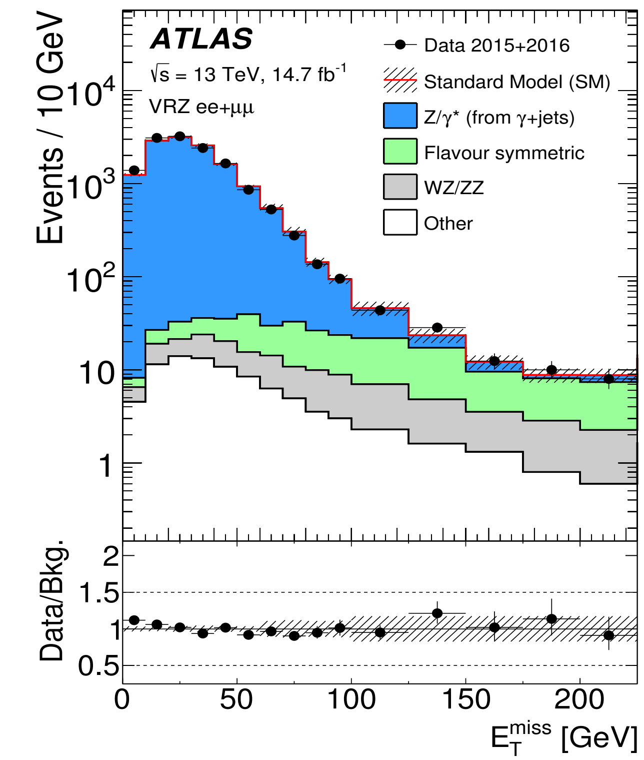
Fake E_T^{miss} backgrounds

- Fake E_T^{miss} backgrounds arise from
  - **mis-measurements** of jets or leptons
  - **neutrinos from b- and c-** semi-leptonic decays
- Fake E_T^{miss} backgrounds due to
  - **Z/γ^*+ jets**: in the search for **electroweak** and **gluino** pair productions in the **two leptons** final state → **γ+jets reweighting method**
  - **QCD/multi-jets**: in the search for **squark/gluino** pair production in the **all jets** final state → **jets smearing method**

Techniques for fake E_T^{miss} background reconstructions

γ+jets reweighting method [ATLAS-CONF-2017-039]

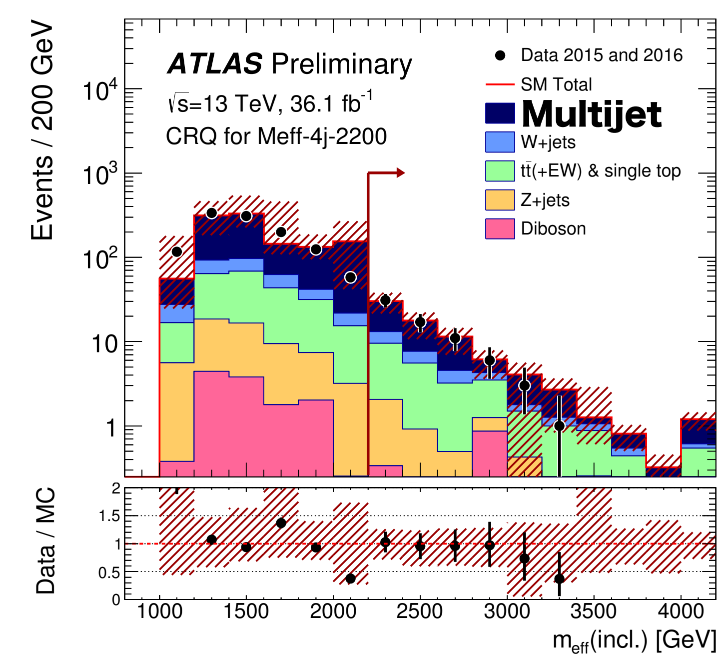
- The γ+jets events are used to produce a E_T^{miss} template in Z+jets.
- The difference of the p_T distribution and resolution between the lepton and the photon is **corrected**.
  - The p_T distribution of the smeared γ is **reweighted to match the p_T distribution of Z** reconstructed by ee/$\mu\mu$.



dilepton pair (1611.05791)

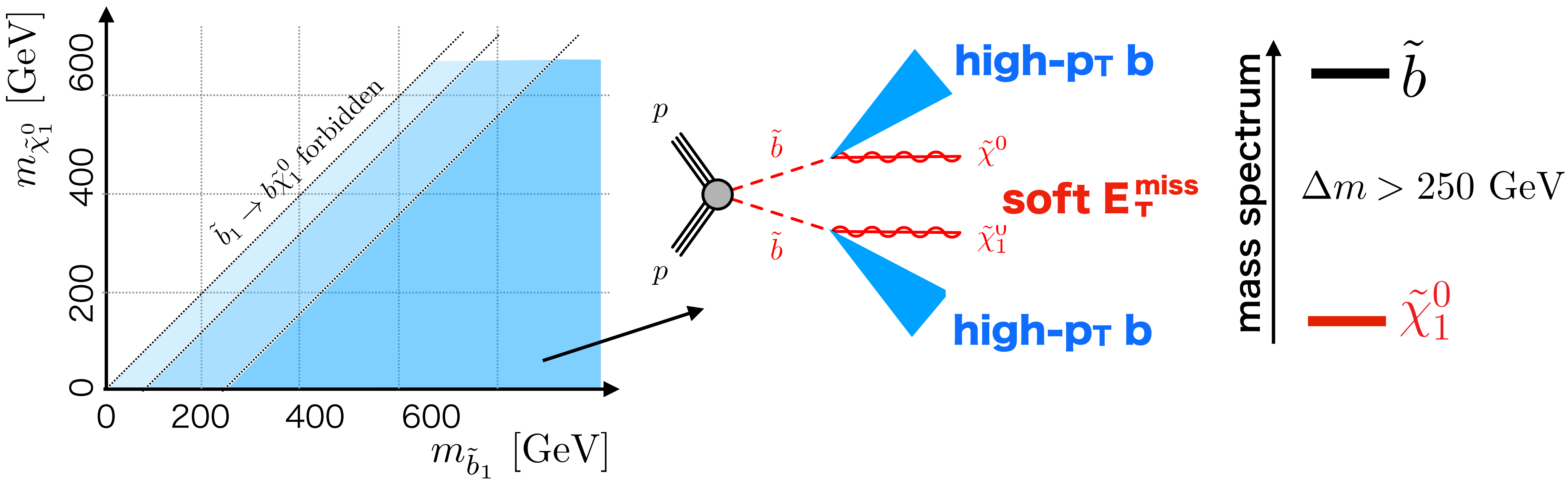
Jets smearing method [arXiv:1208.0949]

- **Smeared events** are generated by multiplying $R(p_T) = p_T^{reco}/p_T^{truth}$ to well-measured multi-jet events.
- The **$R(p_T)$ of jets** is initially estimated from MC, and then **modified to agree** with data in dedicated samples.
- Final smeared events are used to **estimate the distributions of variables defining the CRs and SRs**.



squarks/gluino 0L

Specific signal topology with high-p_T b-tagging [arXiv:1708.09266]

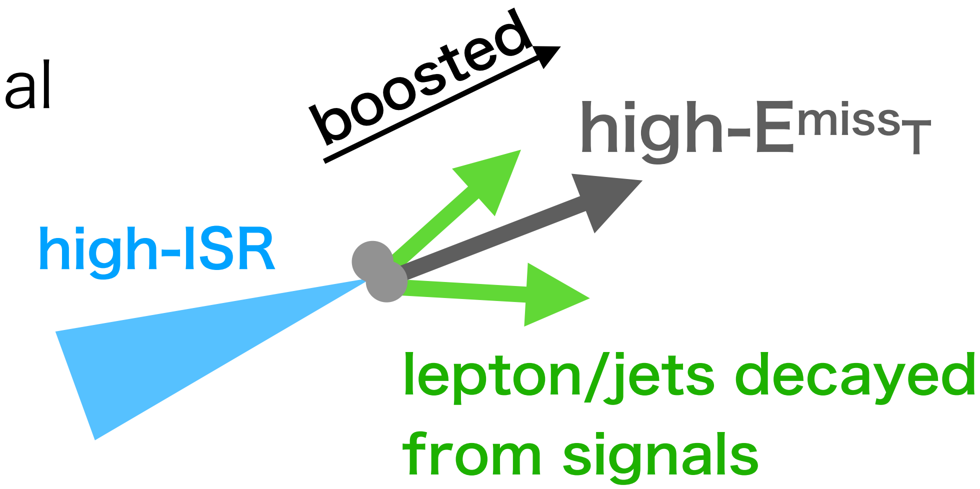


- In case of the search for **direct sbottom pair production**, dedicated signal region **with high-p_T b-jets** is defined for zero-lepton channel.
  - The events with **high-p_T b-jets (v_1, v_2) is reconstructed** by using the **cotransverse mass (m_{CT}) variable** which is the mass of pair-produced semi-invisibly decaying heavy particles:

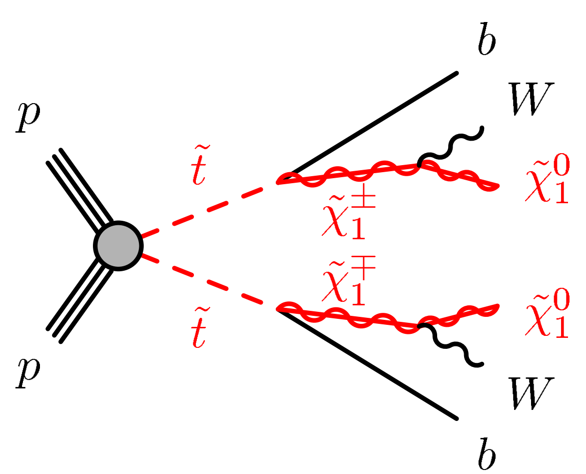
$$m_{\rm CT}^2(v_1,\ v_2) = [E_{\rm T}(v_1) + E_{\rm T}(v_2)]^2 - [\vec{p}_{\rm T}(v_1) - \vec{p}_{\rm T}(v_2)]^2$$

Specific signal topology (signal + ISR) for signals with compressed mass spectra

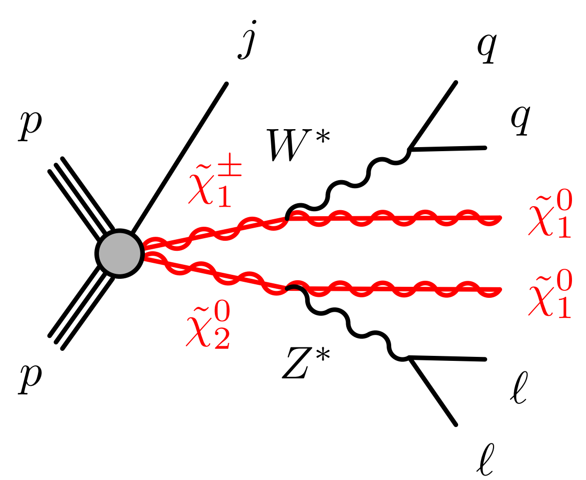
- Additional **ISR** with **high momentum** in the signal topologies is required for the signals with compressed mass spectra.
  - Relatively **high E_T^{miss}**, can be used for **trigger** (>230 GeV plateau).



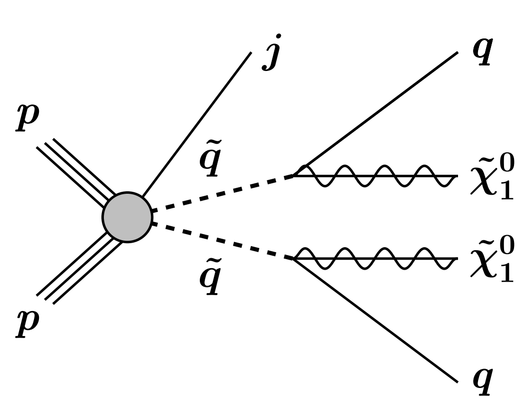
- **Eight Run-2 papers for SUSY searches** containing the compressed mass spectra rely on the ISR techniques. Examples:



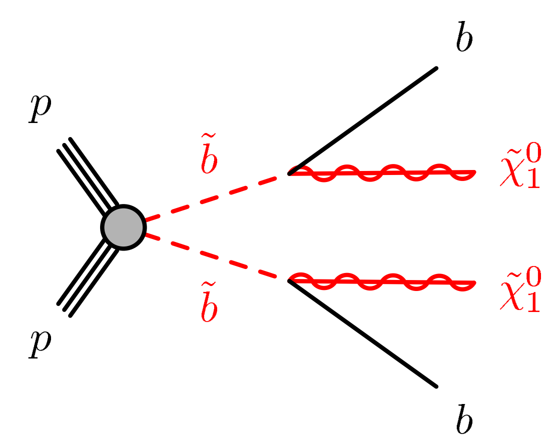
stop



electroweak



DM



sbottom

Summary

- We have searched for the SUSY particles for wide theoretical parameter regions, but they have not yet been discovered.
- To achieve the discovery of the SUSY particles,
  - The data driven method to **extract number of the dominant background** such as Z+jets event **can provide accurate analyses**.
  - **Reconstruction techniques have been improved** and wider momentum region of the leptons and jets is covered.
  - With the analyses for the high-p_T b-tagging, sbottom searches can be covered until high mass region.
  - With the analyses for the **SUSY+ISR event topology**, SUSY with **compressed mass spectra can be searched** for.

We will keep developing new "reconstruction techniques" to discover the SUSY particles!

Backup

Search for sbottom/stop pair production in events with (high-p_T) b-tagged jets and E_T^{miss}

References:

- Search for SUSY at13 TeV, arXiv:1708.09266v1 [link]
- Search for SUSY at 8 TeV, arXiv:1308.2631v1 [link]
- Internal Note: ATL-COM-PHYS-2016-1697 [link for only ATLAS collaboration]
- Cotransverse mass, arXiv:0802.2879v3 [link]

Discriminating variables for high p_T b-tagging

- Cotransverse mass (m_{CT}) is used to measure the mass of pair-produced semi-invisibly decaying heavy particles.
- Two visible particles are b-quarks (v_1, v_2), and two invisible particles are $\tilde{\chi}_1^0$ (X_1, X_2), m_{CT} can be defined as:

$$m_{\mathrm{CT}}^2(v_1,\ v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\vec{p}_{\mathrm{T}}(v_1) - \vec{p}_{\mathrm{T}}(v_2)]^2,\ m_{\mathrm{CT}}^{\mathrm{max}} = \frac{m_i^2 - m_{\mathrm{X}}^2}{m_i}.$$

($m_{\mathrm{CT}}^{\mathrm{max}}$ is the kinematic endpoint, “i” is initially pair-produced particle.)

- $\mathcal{A}$ is the p_T asymmetry of the leading two jets:

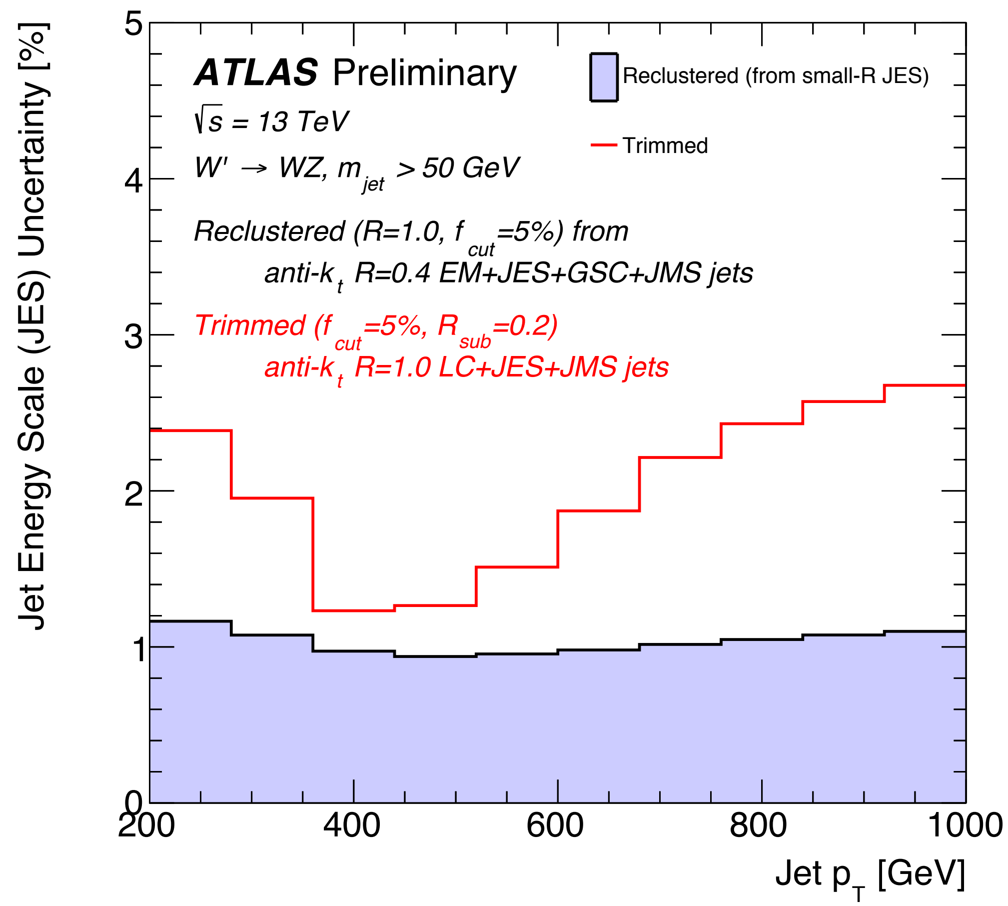
$$\mathcal{A} = \frac{p_{\mathrm{T}}(j_1) - p_{\mathrm{T}}(j_2)}{p_{\mathrm{T}}(j_1) + p_{\mathrm{T}}(j_2)}.$$

- This variable can discriminate different topologies with two more jets.
  - signal-like: high-ISR + low-2nd jets → $\mathcal{A}$ **tend to be close to one.**
  - bkg-like: all jets are comparable → $\mathcal{A}$ **tend to be close to zero.**

Studies of re-clustered large-R jets

JES Uncertainty [1407.2922]

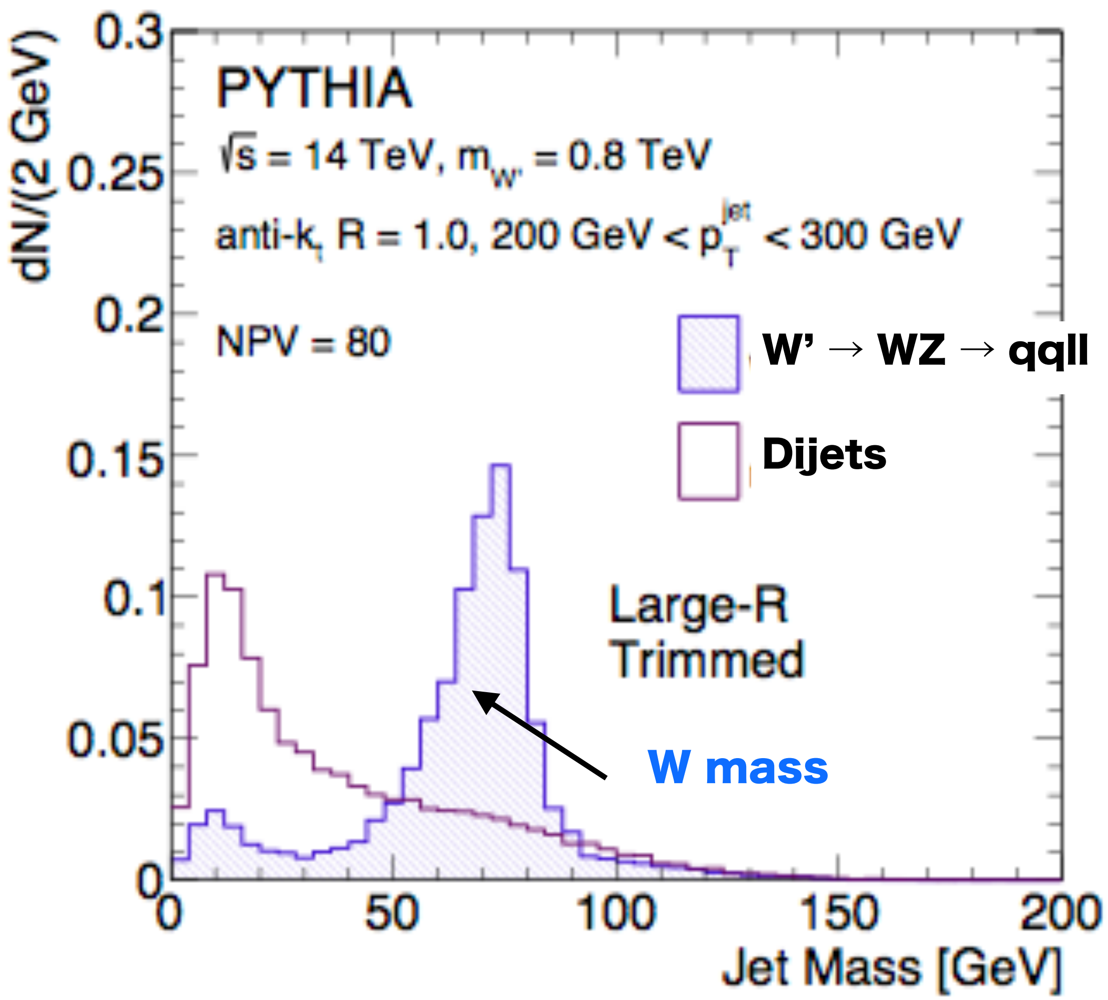
- The reclustered large-R jets have **smaller jet-energy-scale (JES) uncertainty (~ 1%).**



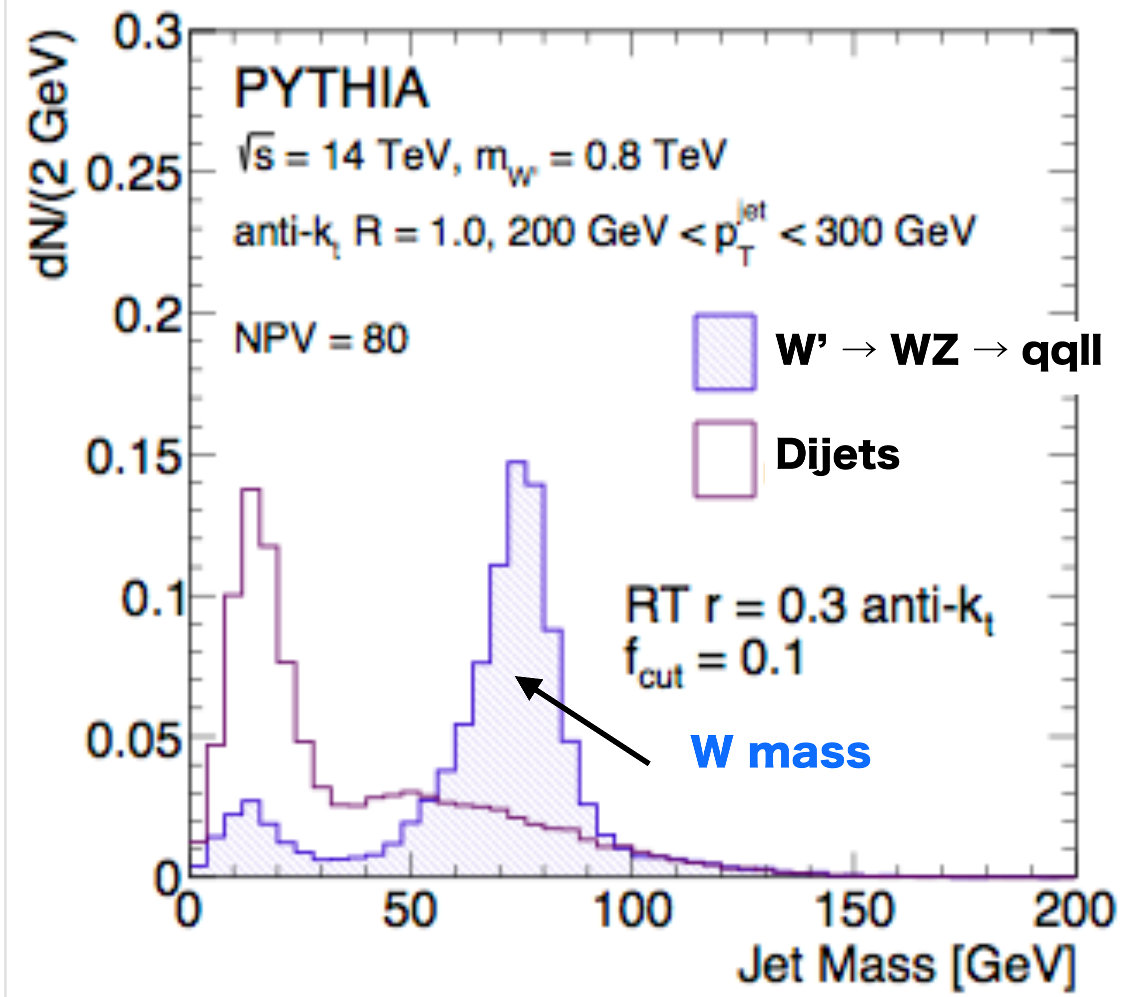
Comparison of JES Unc.

(ATLAS-CONF-2017-062)

Compare W boson masses



Fixed large-R jets

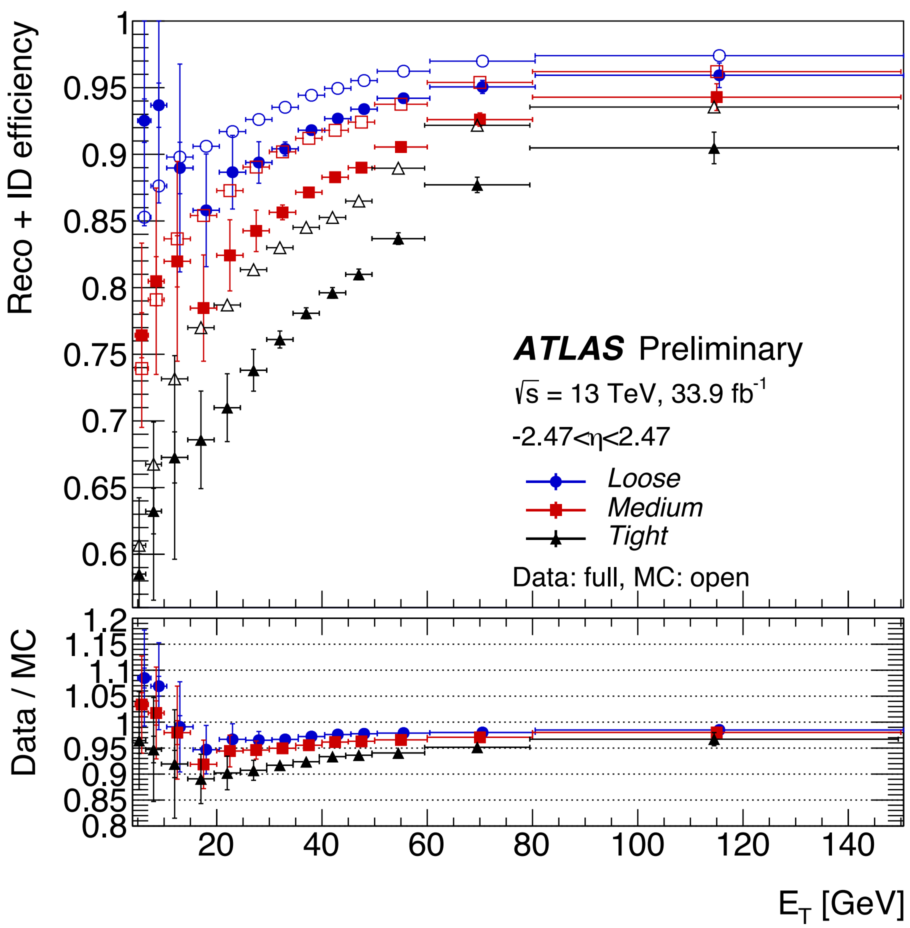


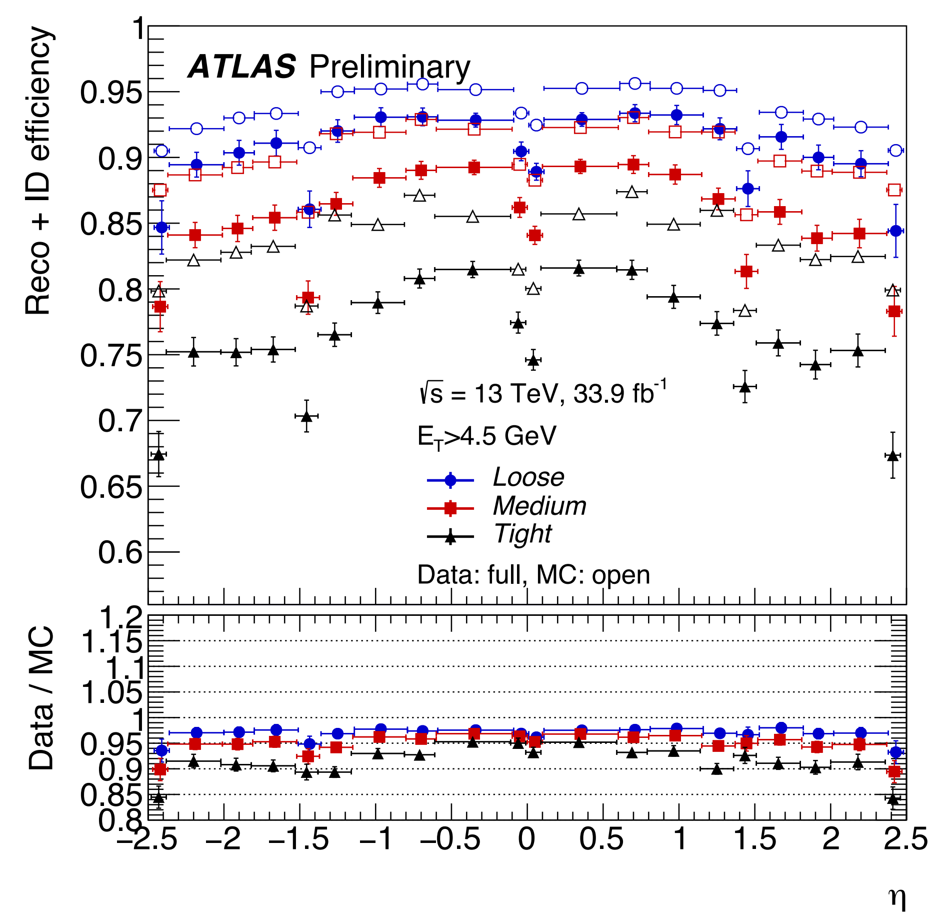
reclusetered large-R jets

Studies of the lepton reconstruction efficiencies

Electron efficiency [ATLAS-CONF-2016-024]

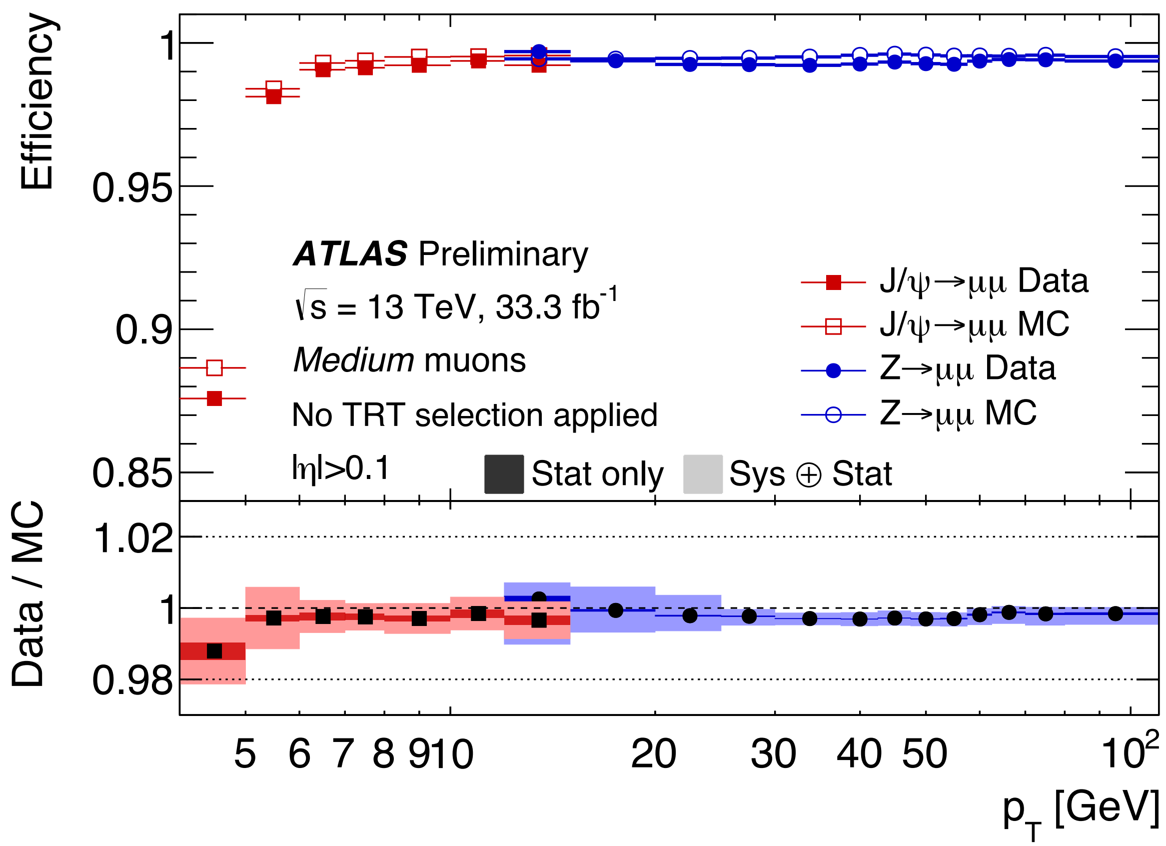
- **Efficiency is higher than 75%** except for the regions with calorimeter gaps.
  - The lower efficiencies in data than MC arise from the transition radiation tracker condition and mis-modeling of calorimeter shower shapes in detector simulation.
  - The plots are showing the $Z \rightarrow ee$ efficiencies in data and MC.

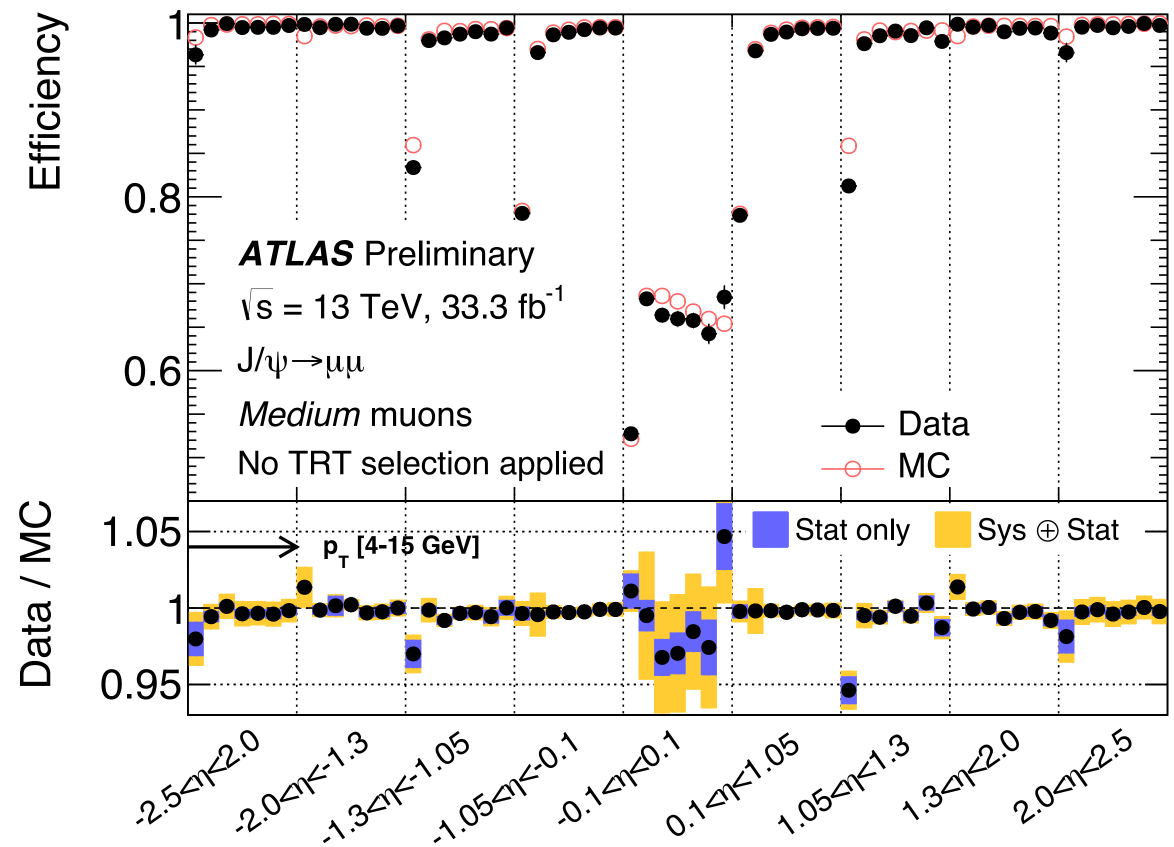




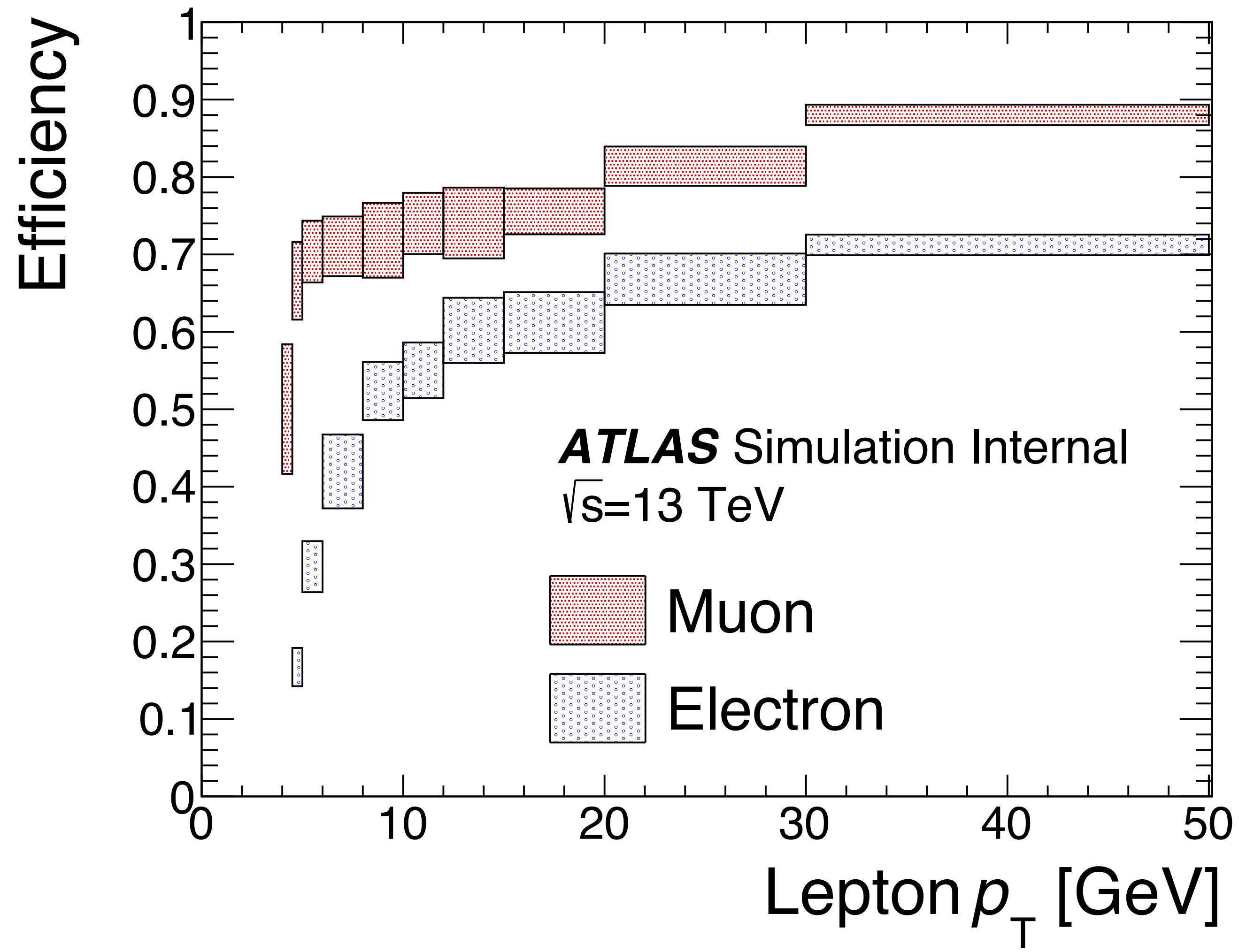
Muon efficiency [arXiv:1603.05598]

- A reconstruction efficiency in different η regions is measured in seven p_T bins (p_T = 4-5, 5-6, 7-8, 8-10,10-12, and 12-15 GeV)





Lepton efficiencies



- Lepton efficiencies studied by using the MCs are estimated for the higgsino and slepton searches.
- Uncertainty band represent the range of efficiencies observed across all signal samples for the given p_T bin.
- The η-dependence is also applied and it is consistent with values of electron and muon estimated in 2015.