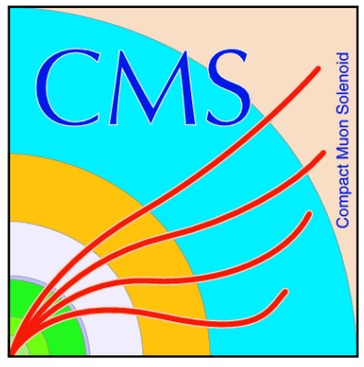
University of Zurich[UZH]
Physik-Institut

# Improving $M_{bb}$ resolution in ZH→llbb

Two staged approach : b-specific jet corrections followed by jet corrections with MET



# Technical details

- Jet energy resolution = RMS[($p_{T,genB}$ - $p_{T,recoJet}$)/$p_{T,genB}$]
  - $p_{T,genB}$ = $p_T$ of the generator level b-quark
  - $p_{T,recoJet}$ = $p_T$ of the reconstructed jet

- **Goal:** provide an estimate of the true b-quark energy and correct the reconstructed jet energy

- A correction function is computed in order to approximate the reconstructed b-jet energy to the MC generated b-quark energy

- The method exploits Multi-Layer Perceptron Neural Networks (implemented in ROOT) in two steps:
  - b-specific correction
  - MET-specific correction

# b-specific correction

- A first Neural Network is trained using:
  - **b-specific input variables (Secondary Vertex)**

    # tracks in the SV, $p_T$ of the leading track
    vtx-mass, vtx-$p_T$ - mass and $p_T$ of the SV
    vtx-2dL, vtx-2deL - 2D flight lenght and error of the SV

    **8 input variables**
  - **jet kinematic input variables**

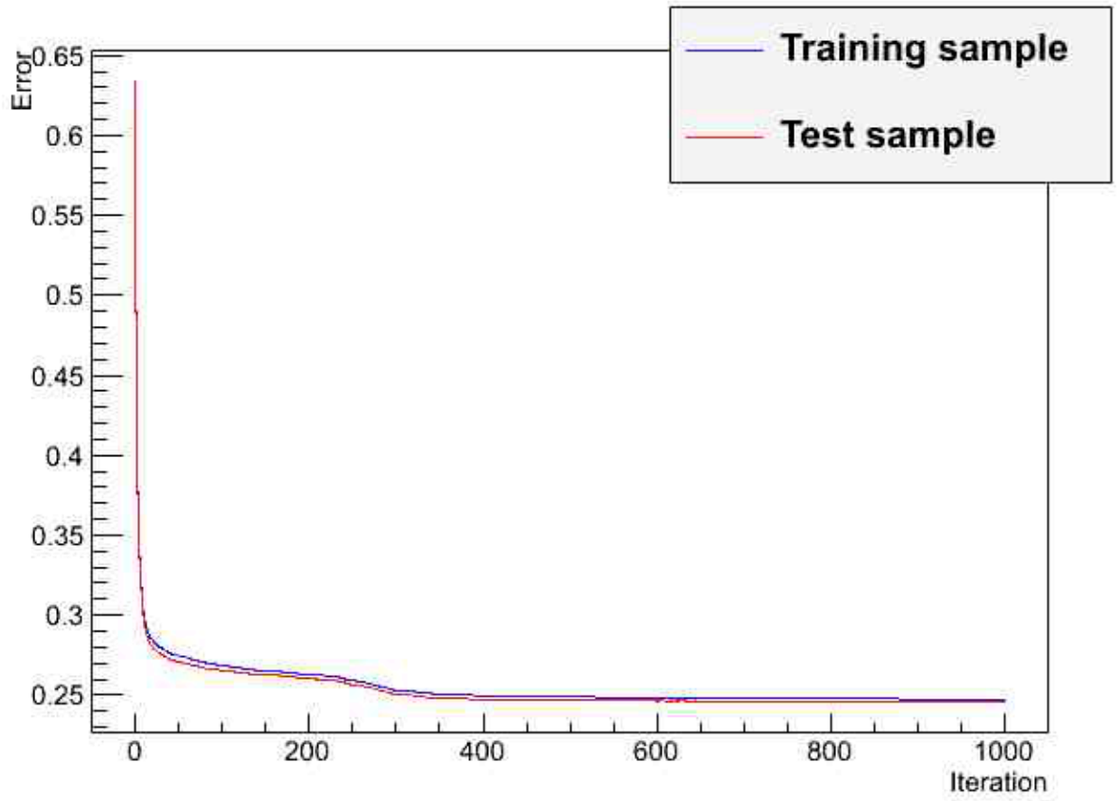
    jet energy and $p_T$ (CMS standard correction)

- Target a scale factor: **SF = $p_{T,genB}/p_{T,recoJet}$**

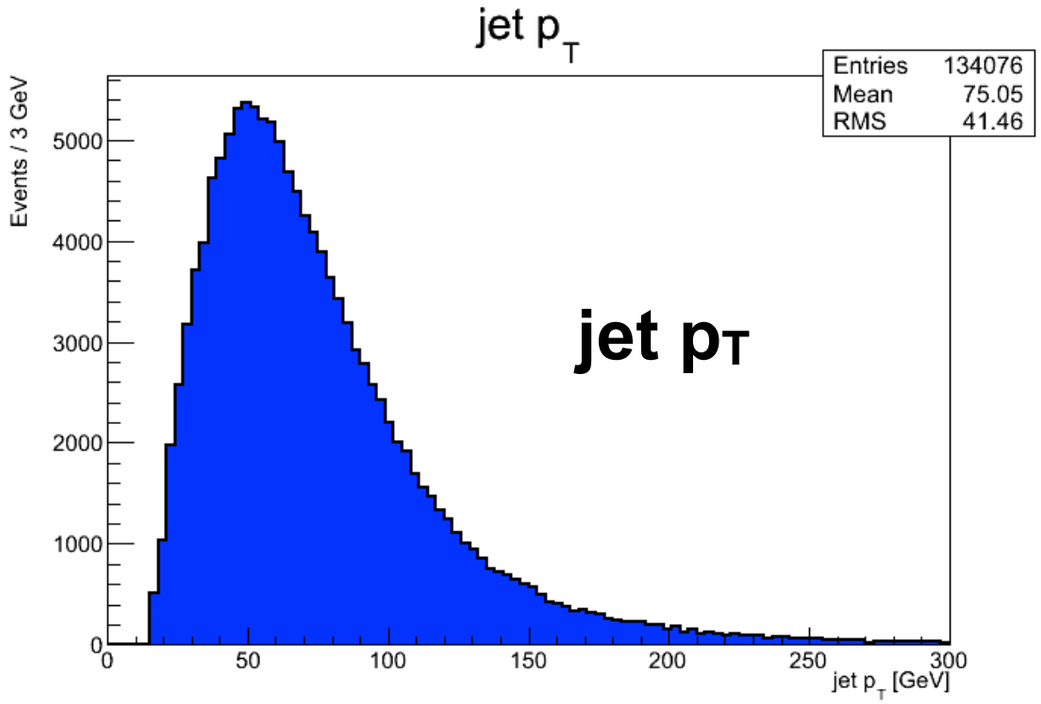
- Output: correction factor which is applied to the jet and MET
  - b-corrected $jet_{1,2}$ energy and $p_T$
  - b-corrected MET

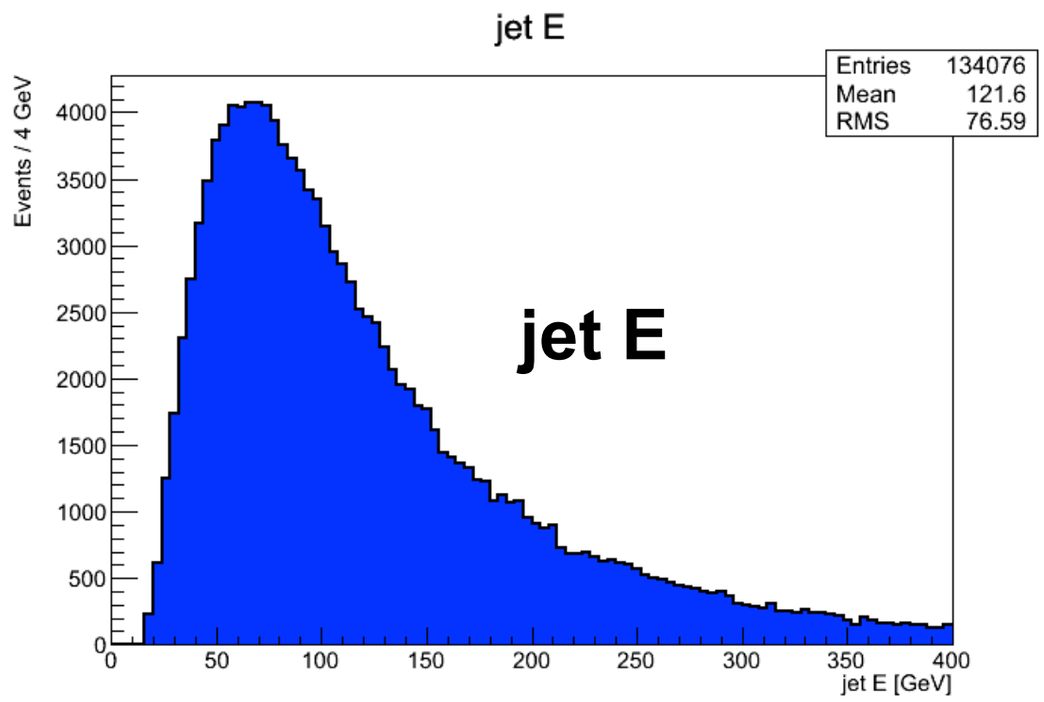
# b-specific correction

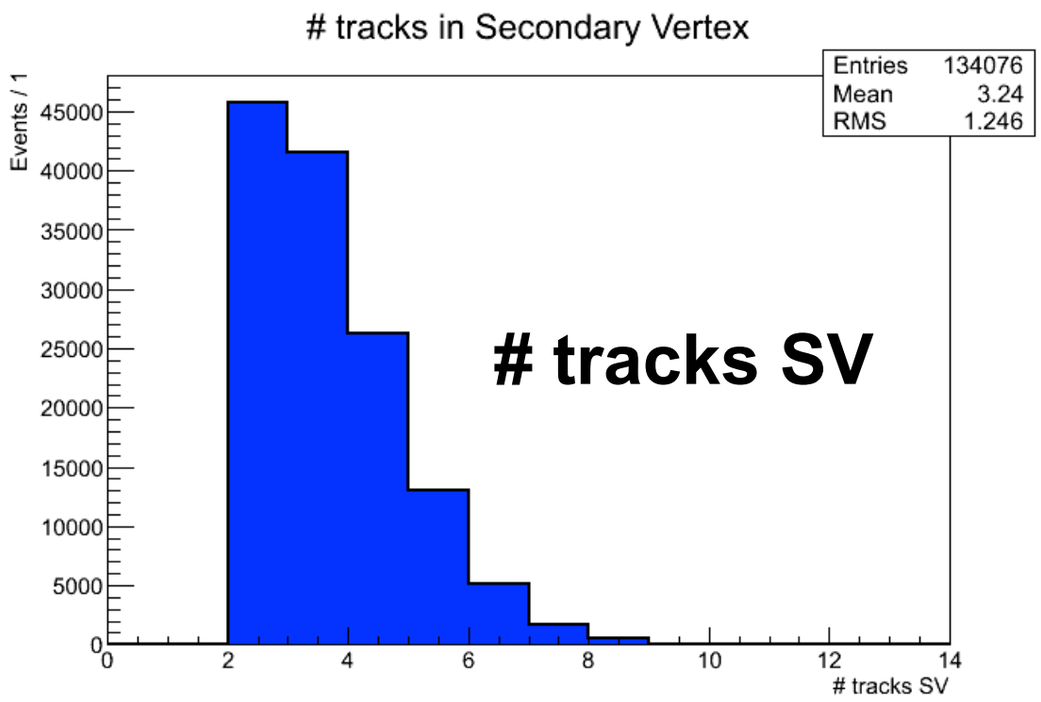
- BFGS method with 1 hidden layer of 16 neurons for 1000 epochs
- On a sample of b-tagged jets from Higgs candidate matching the generator level b-quarks, chosen from a MC of ZllHbb events @ $M_H$ = 125GeV
- jet-quark match → $dR = \sqrt{(\phi_{genB} - \phi_{jet})^2 + (\eta_{genB} - \eta_{jet})^2} < 0.5$

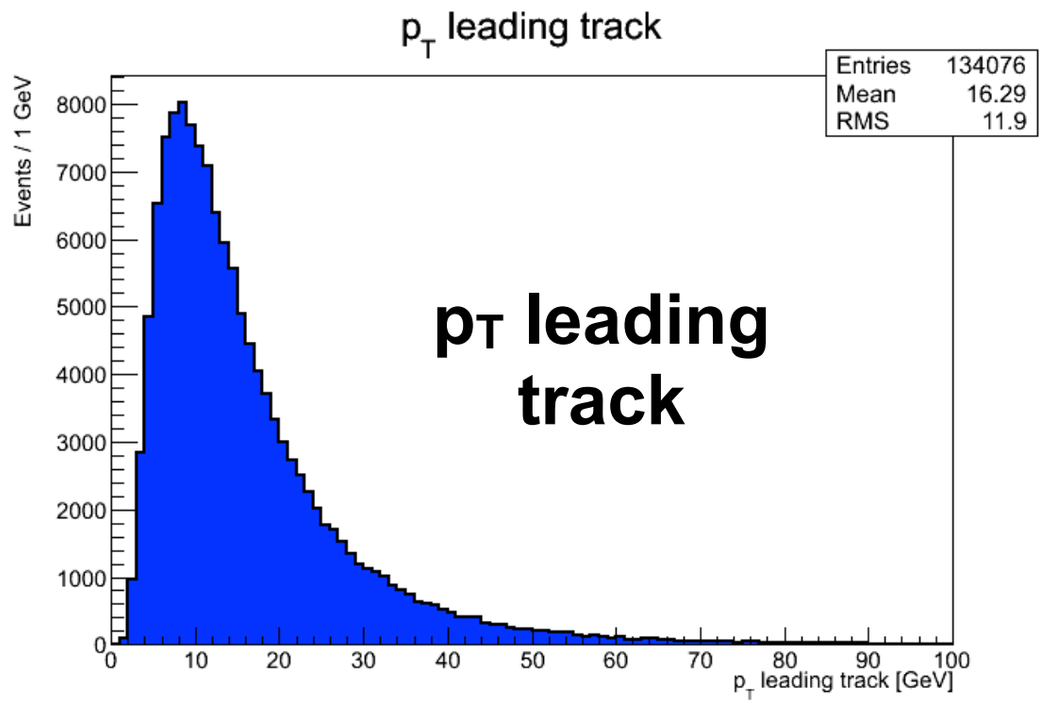


# b-correction: input variables

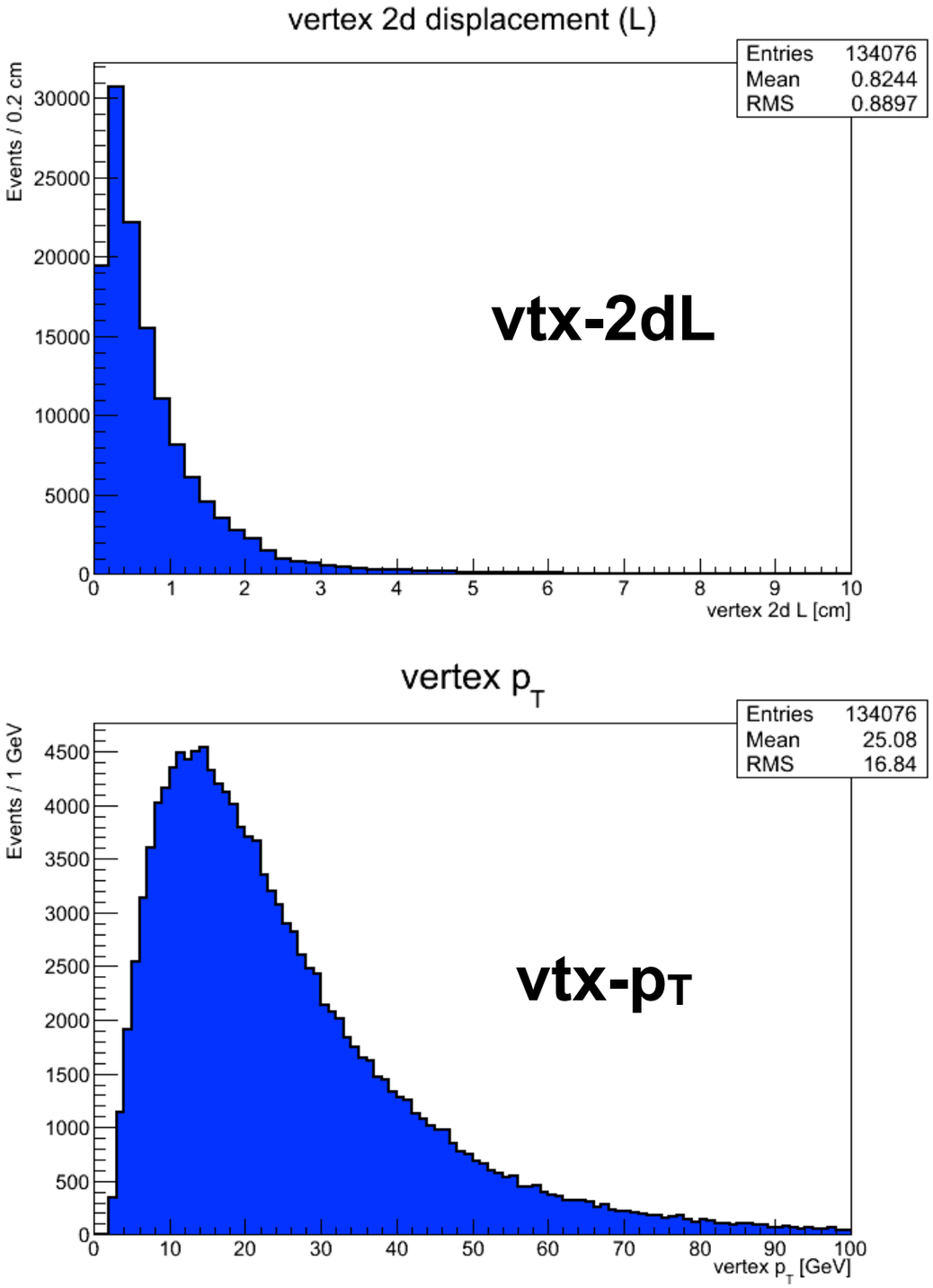


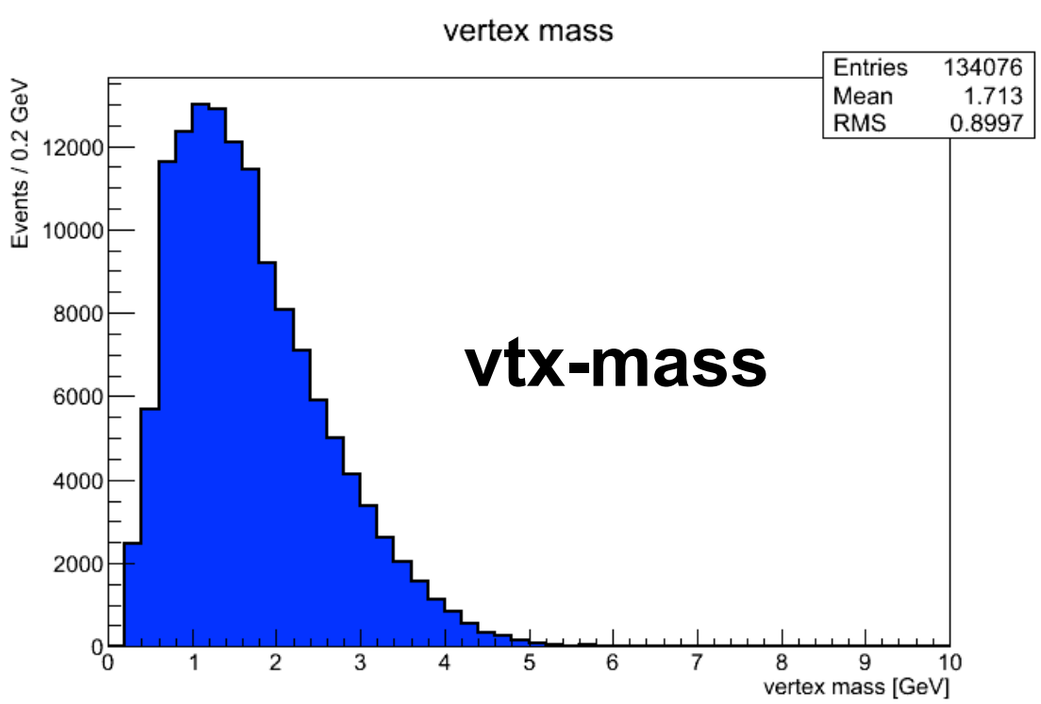
# b-correction: input variables









# MET-specific correction

- A second Neural Network is trained using
  - **MET-specific input variables**

    b-corrected MET, MET phi, MET-$jet_{1,2}$ projection
  - **jet kinematic input variables**

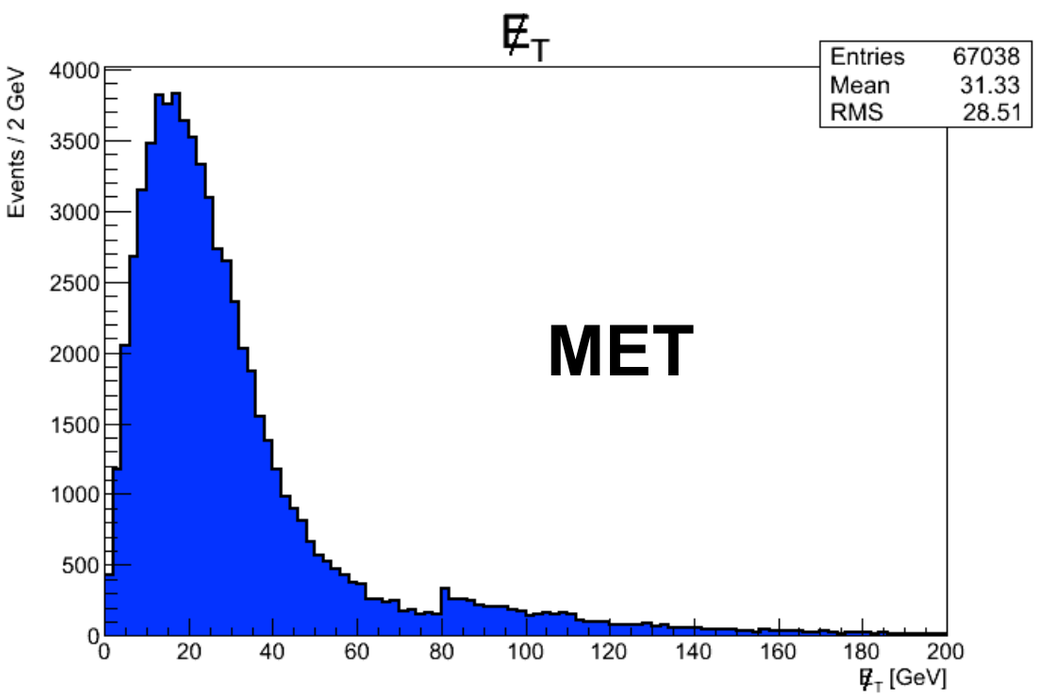
    b-corrected $jet_{1,2}$ energy and $p_T$, $jet_{1,2}$ eta, $jet_{1,2}$ phi
  - **PU correction**

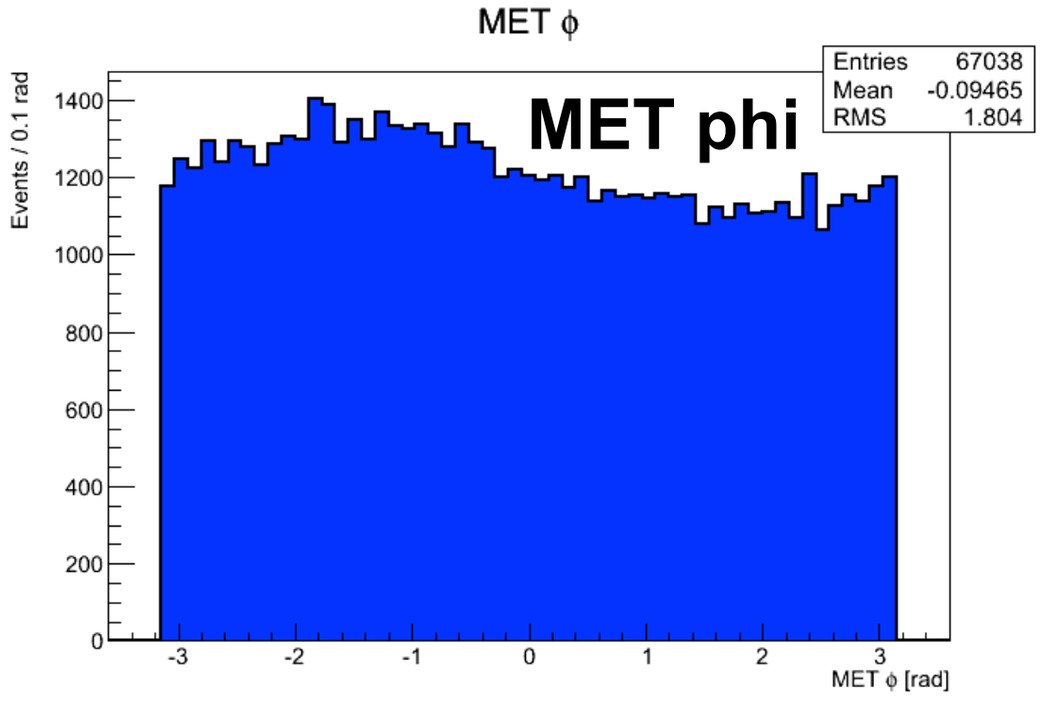
    # Primary Vertices

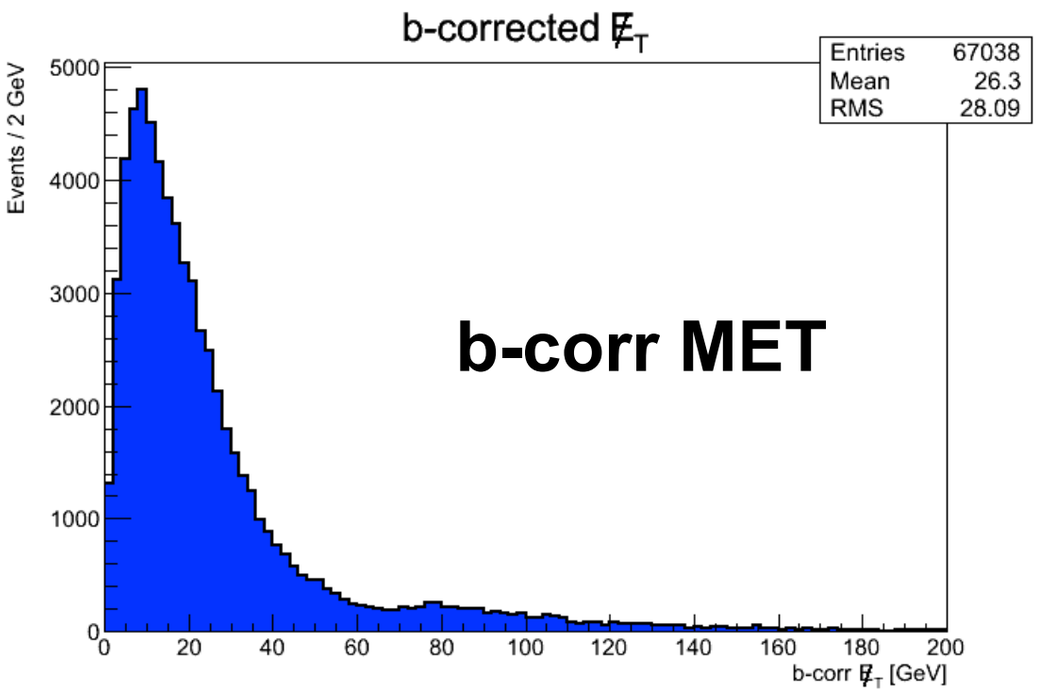
**11 input variables**

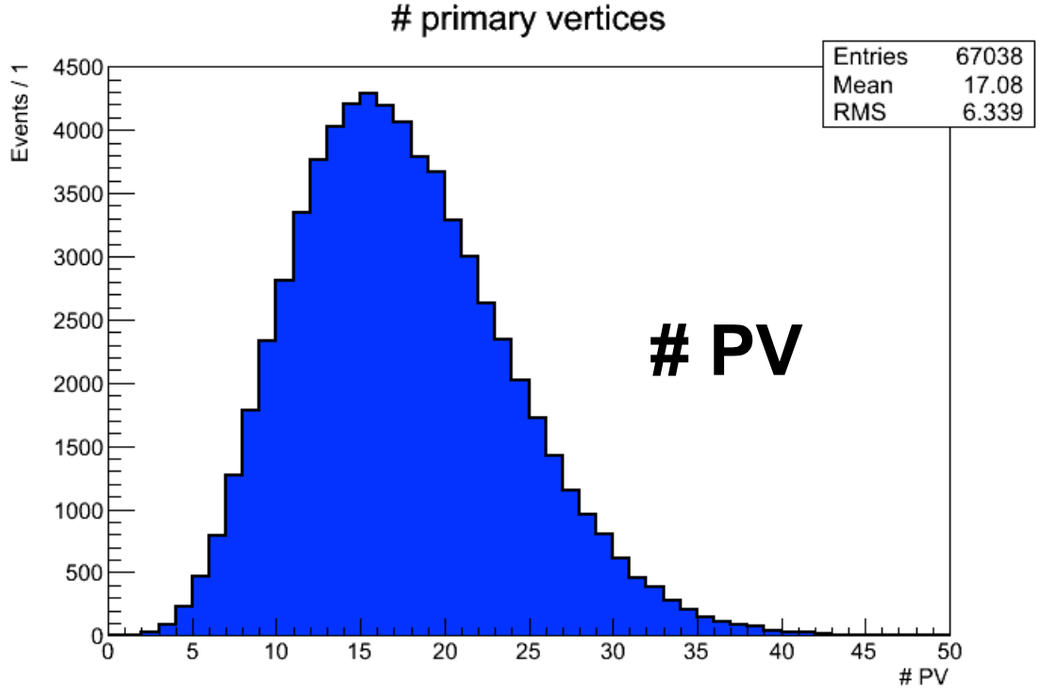
- Target two scale factors (one for each jet): **SF = $p_{T,genB}/p_{T,recoJet}$ (b-corr)**
- Outputs: two correction factors which are applied to the jets
  - b+MET-corrected $jet_{1,2}$ energy and $p_T$
- BFGS method with 1 hidden layer of 22 neurons for 1000 epochs
- On a sample of b-tagged jets matching with generator level b-quarks chosen from a MC of ZllHbb events @ $M_H$ = 125GeV

# MET-correction: input variables

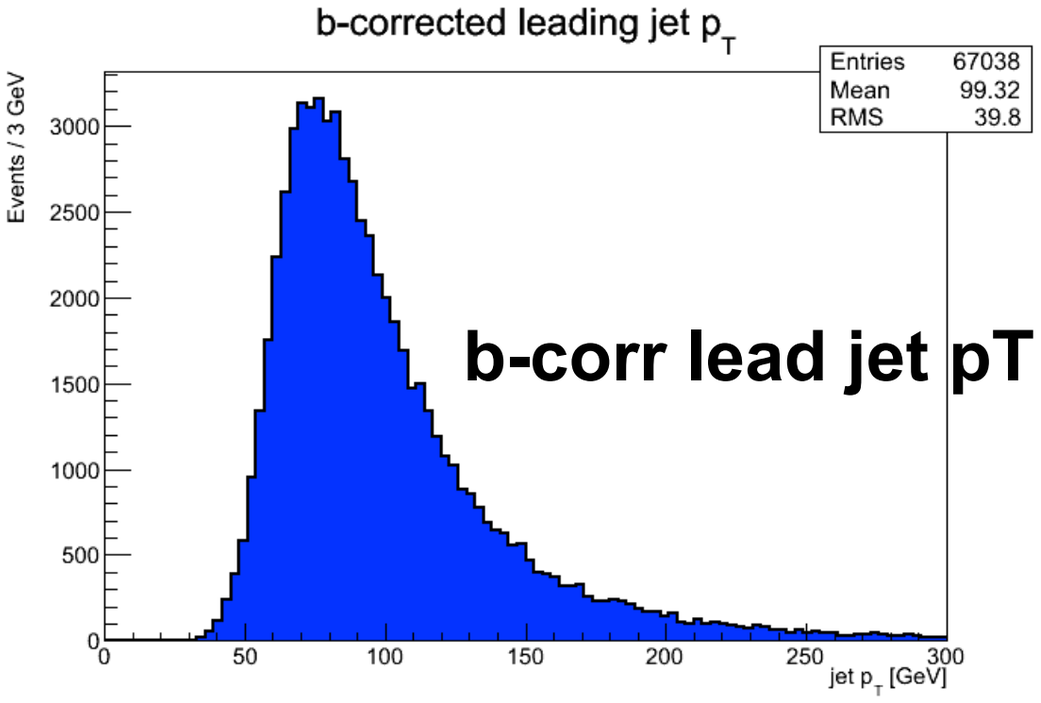


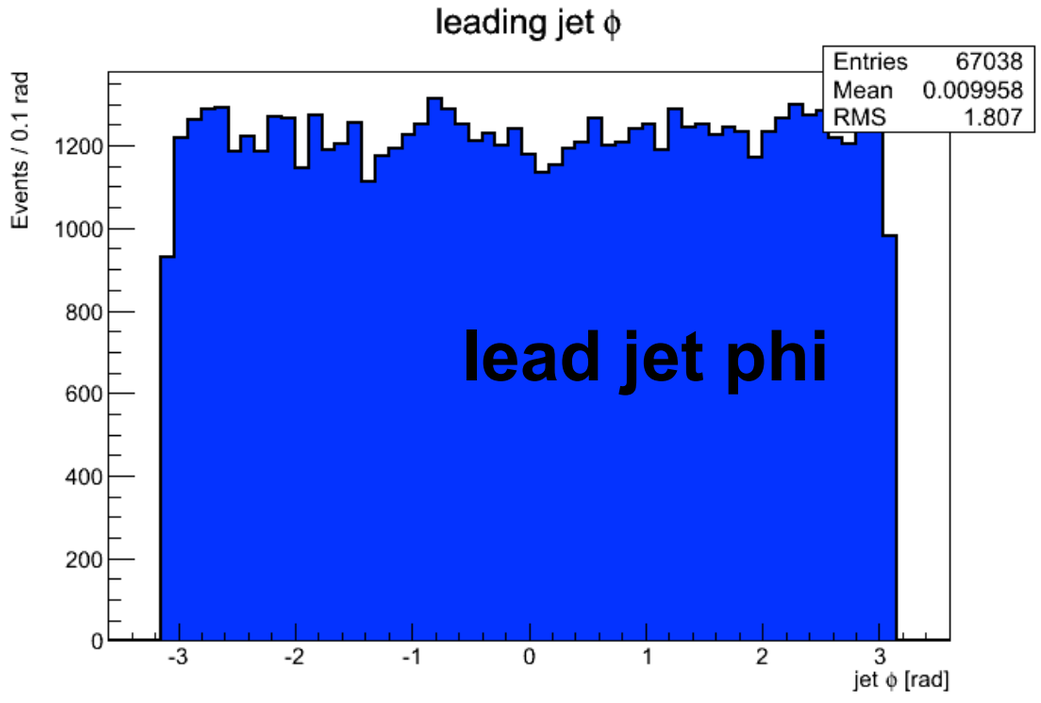



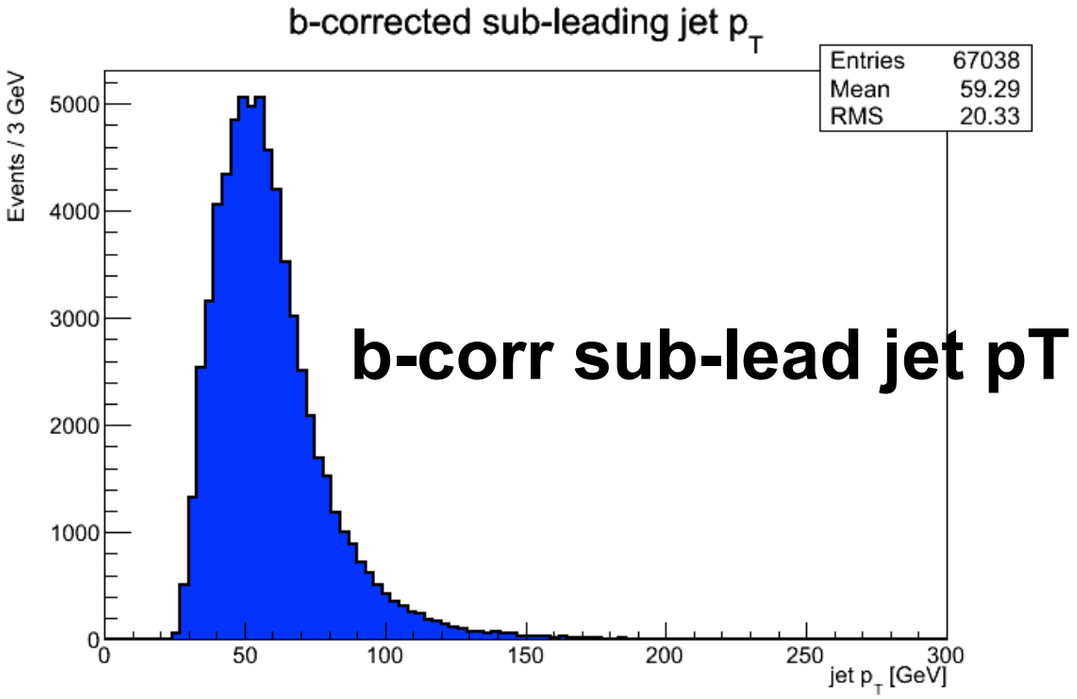



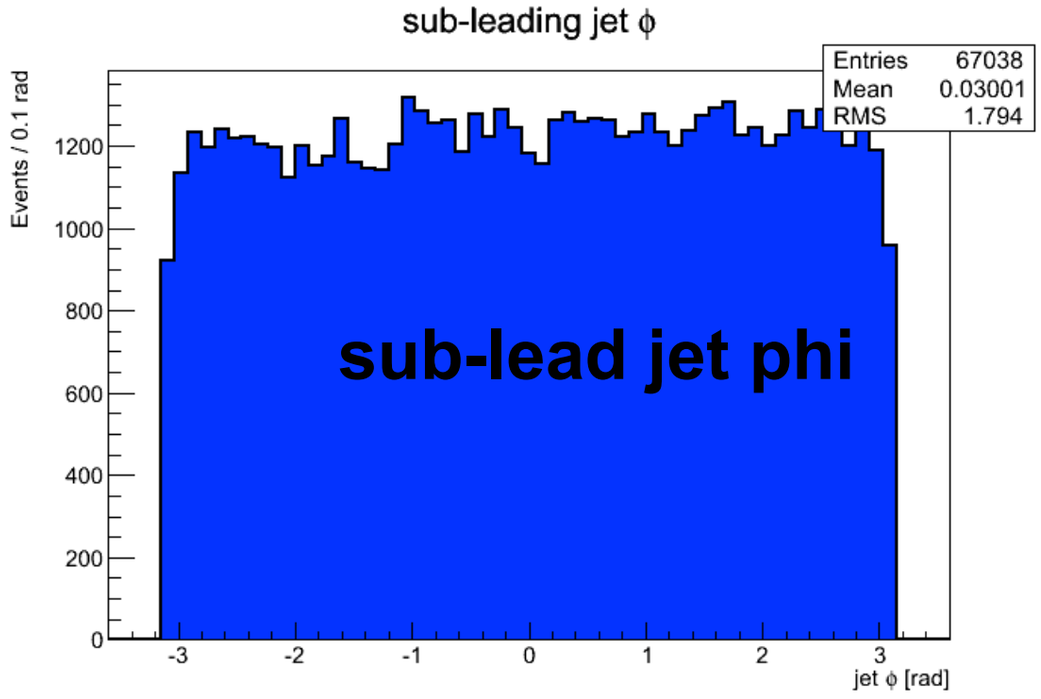



# MET-correction: input variables

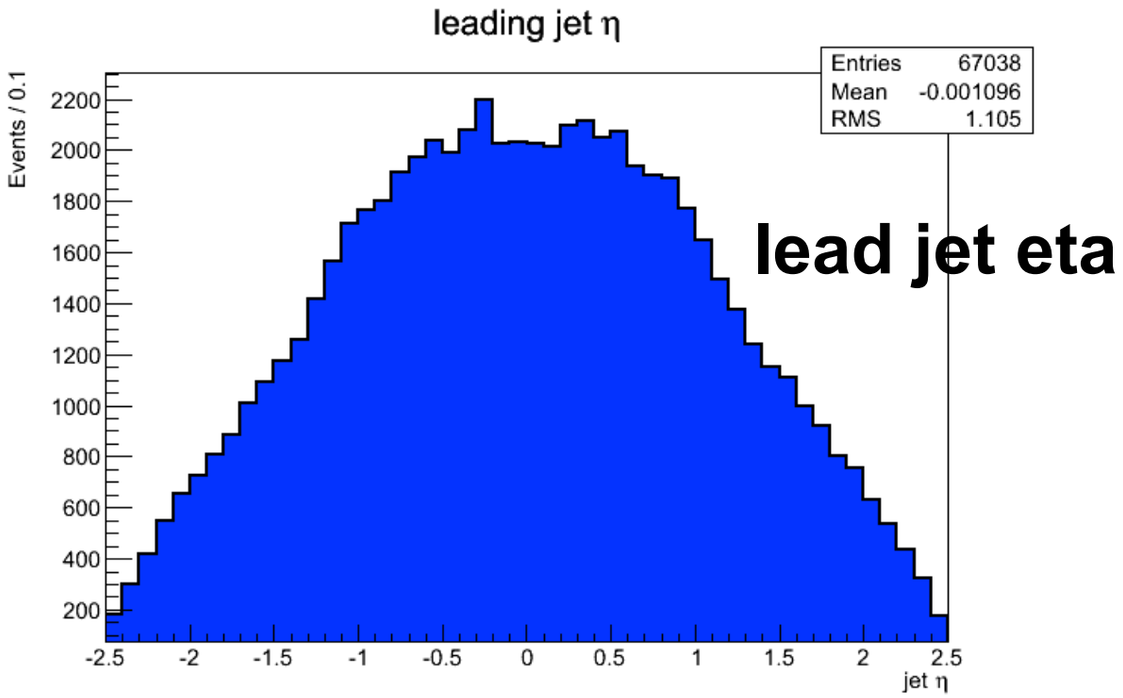


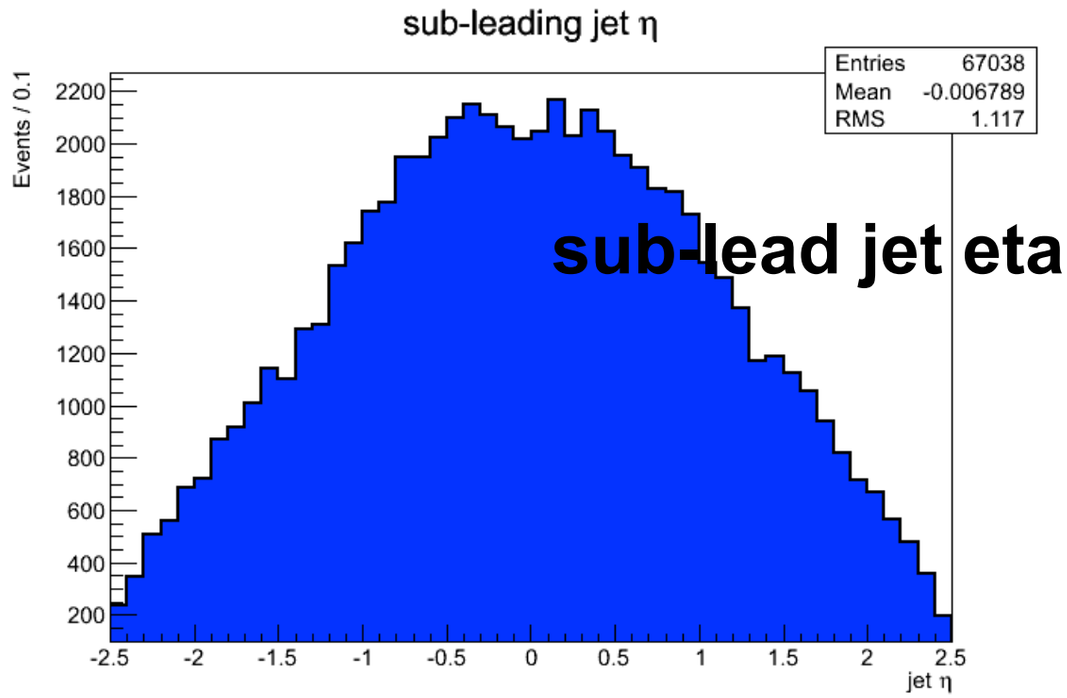



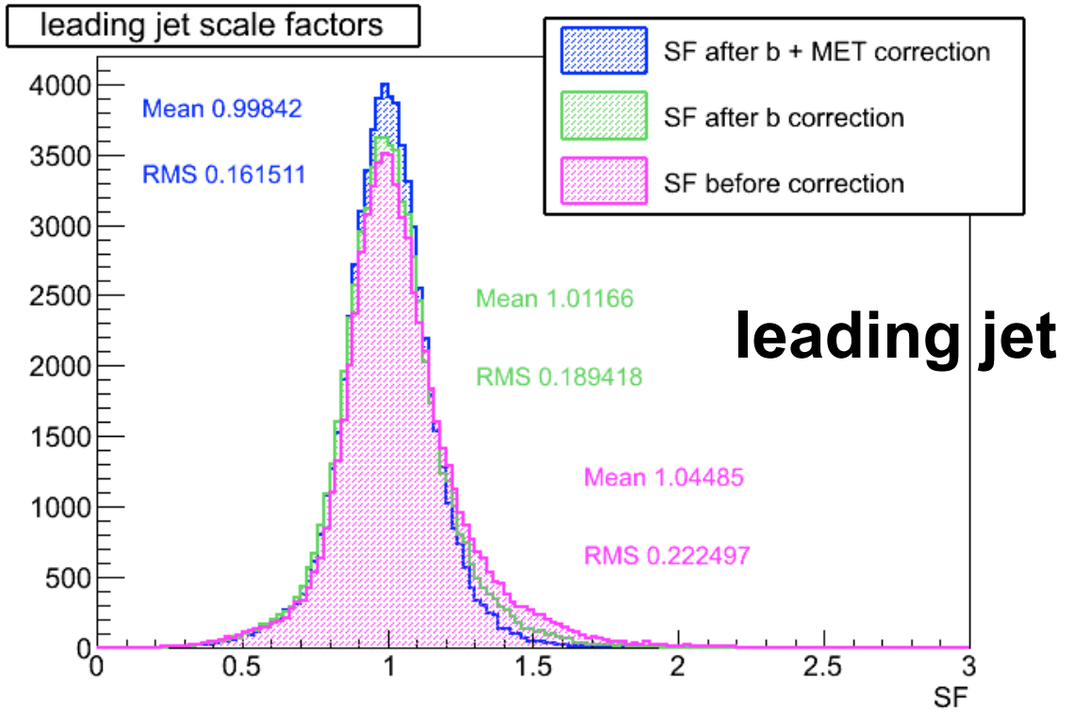
# MET-correction: input variables

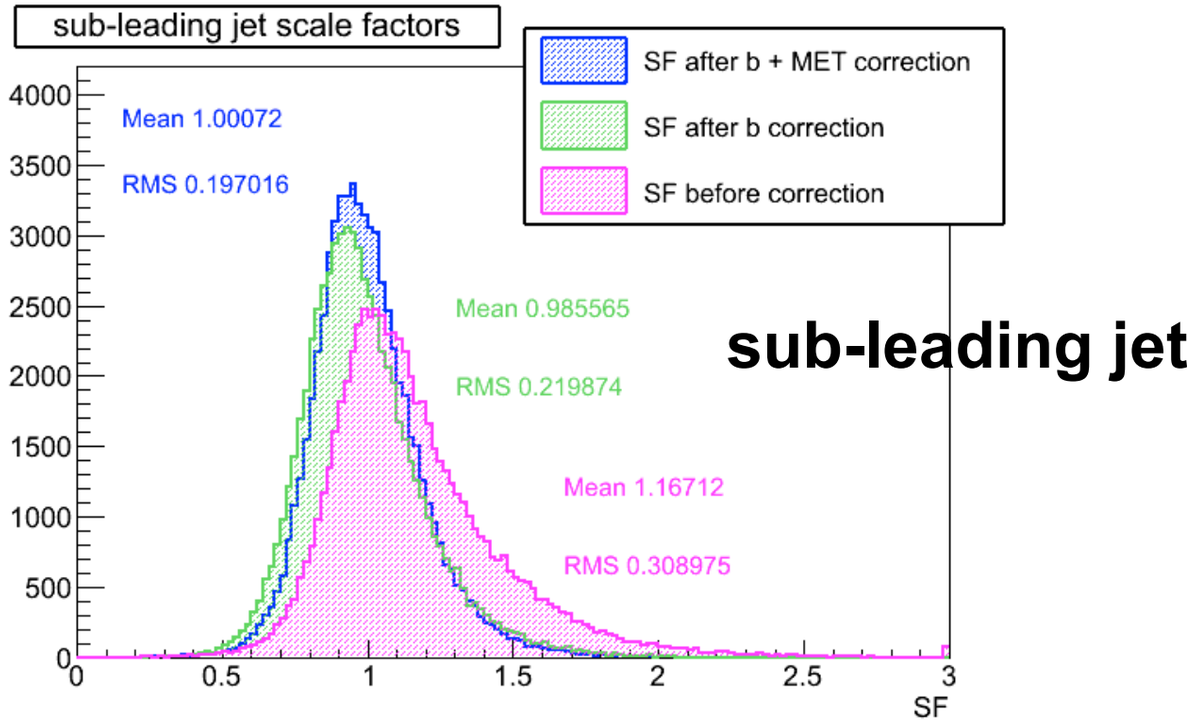


# Scale factors

$SF = p_{T,genB}/p_{T,recoJet}$ —NNb correction→ $SF_b = p_{T,genB}/p_{T,recoJet}$ (NNb-corr) —$NN_{MET}$ correction→ $SF_{MET} = p_{T,genB}/p_{T,recoJet}$ (NNMET-corr)



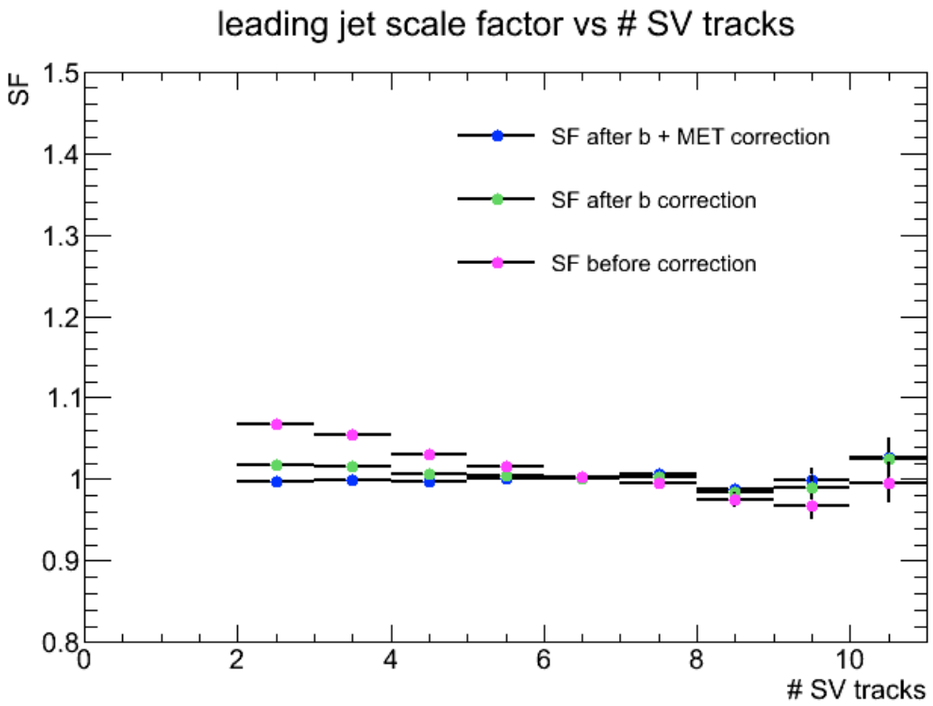

- Jets selection:
  - 2 b-tagged jets from the Higgs candidate with pT > 20 GeV, dR < 0.5
  - no selection applied on additional jets

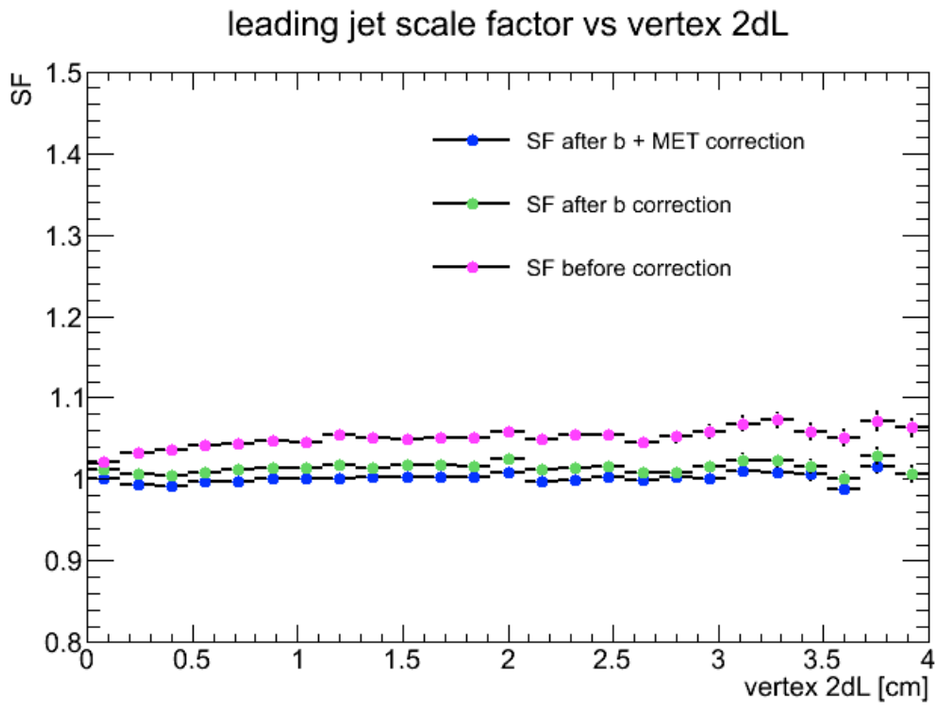
# Scale factors

## Scale factors vs # SV tracks

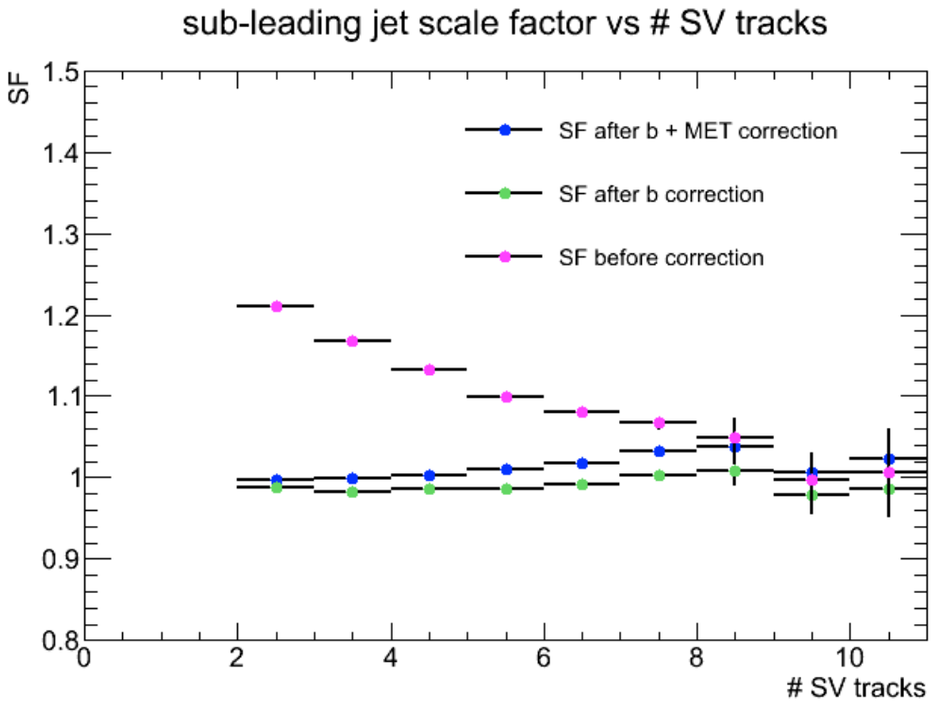
## Scale factors vs vertex 2dL

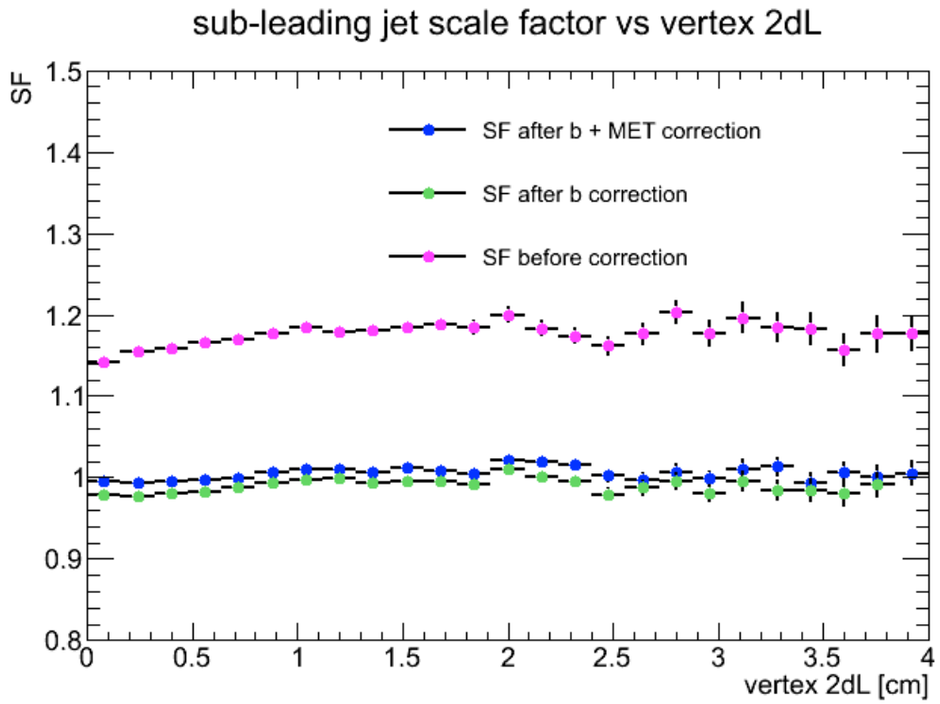
**leading jet**




**sub-leading jet**



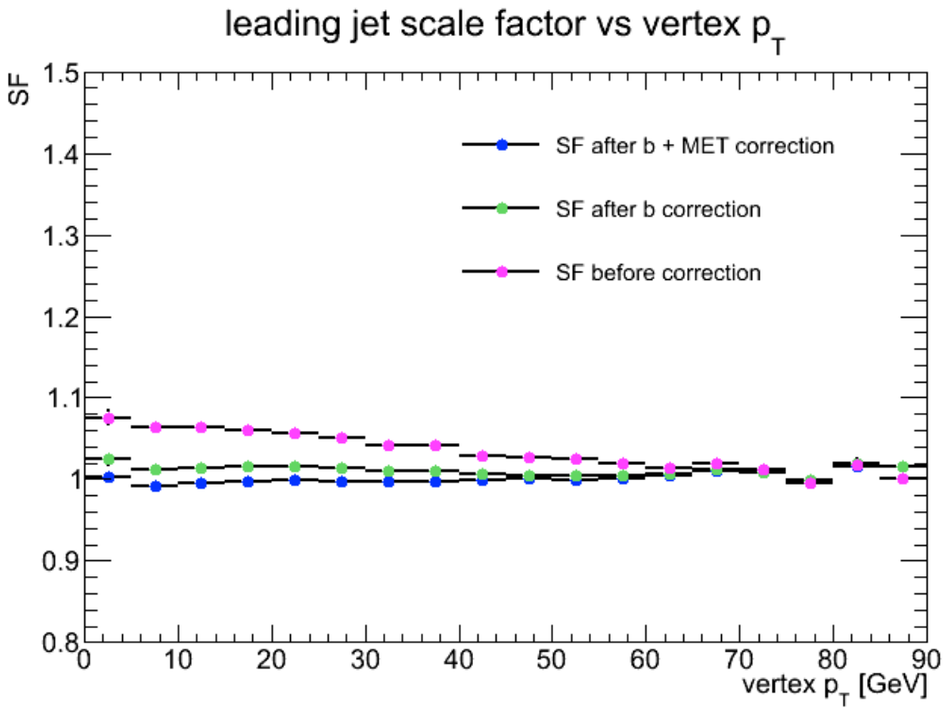



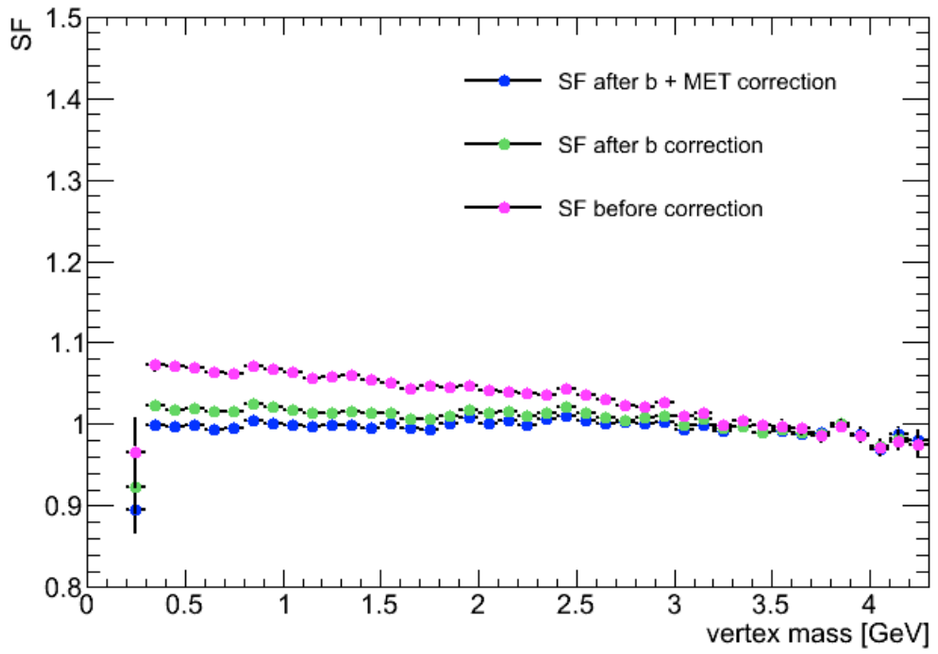
# Scale factors

## Scale factors vs vertex pT

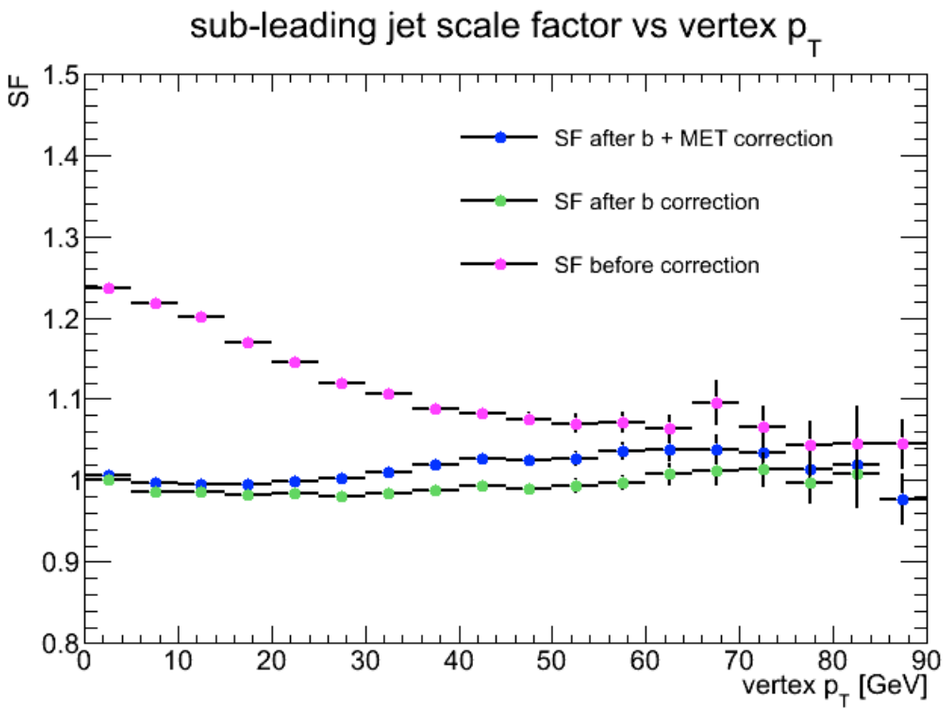
## Scale factors vs vertex mass

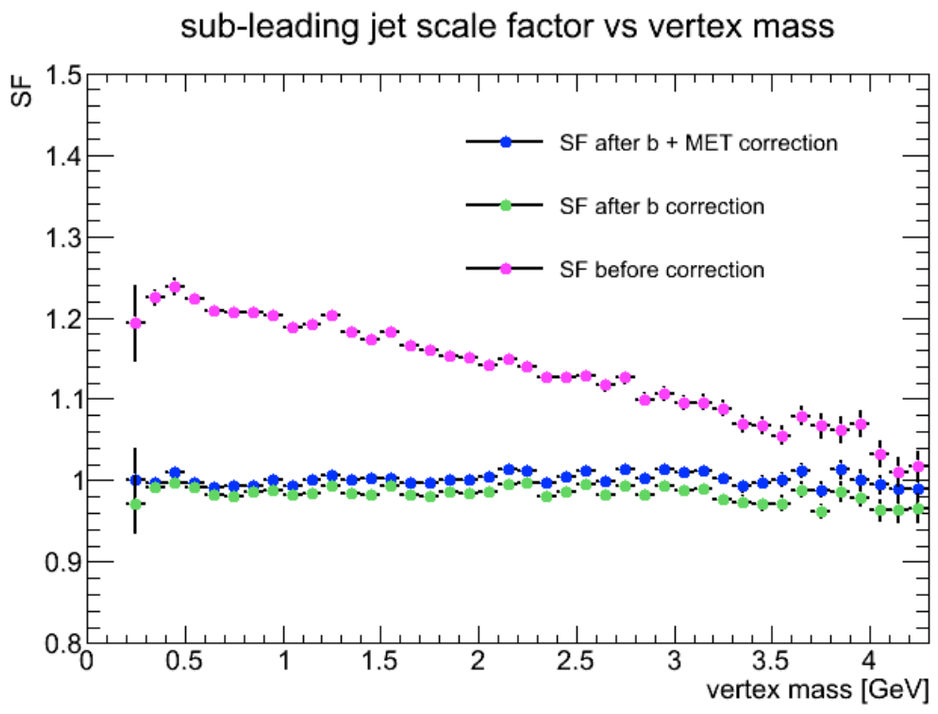
**leading jet**




**sub-leading jet**



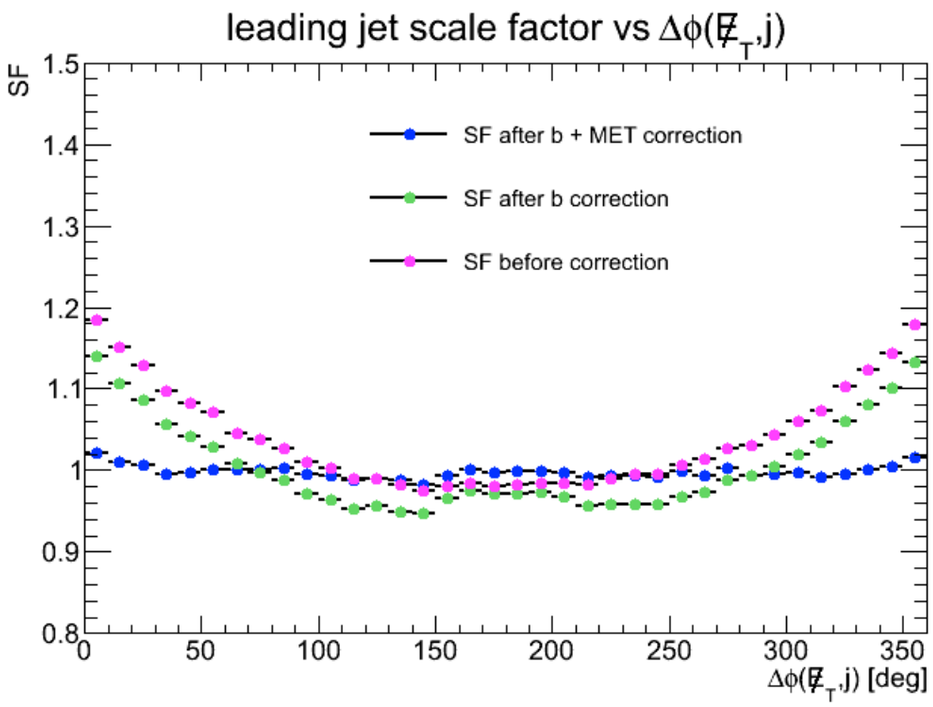



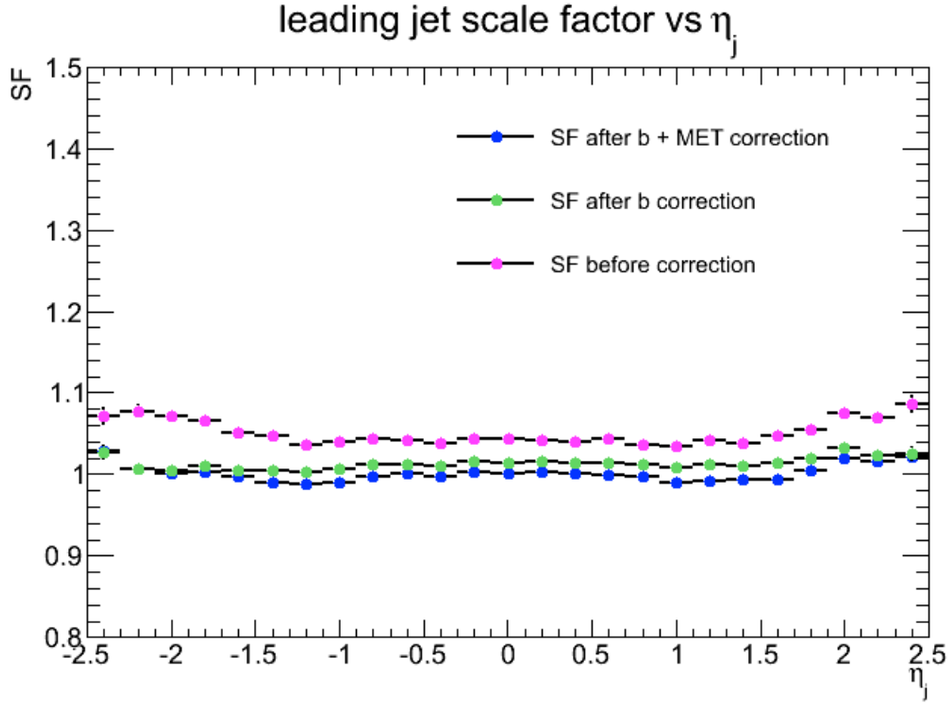
# Scale factors

## Scale factors vs ΔPhi(MET,j)

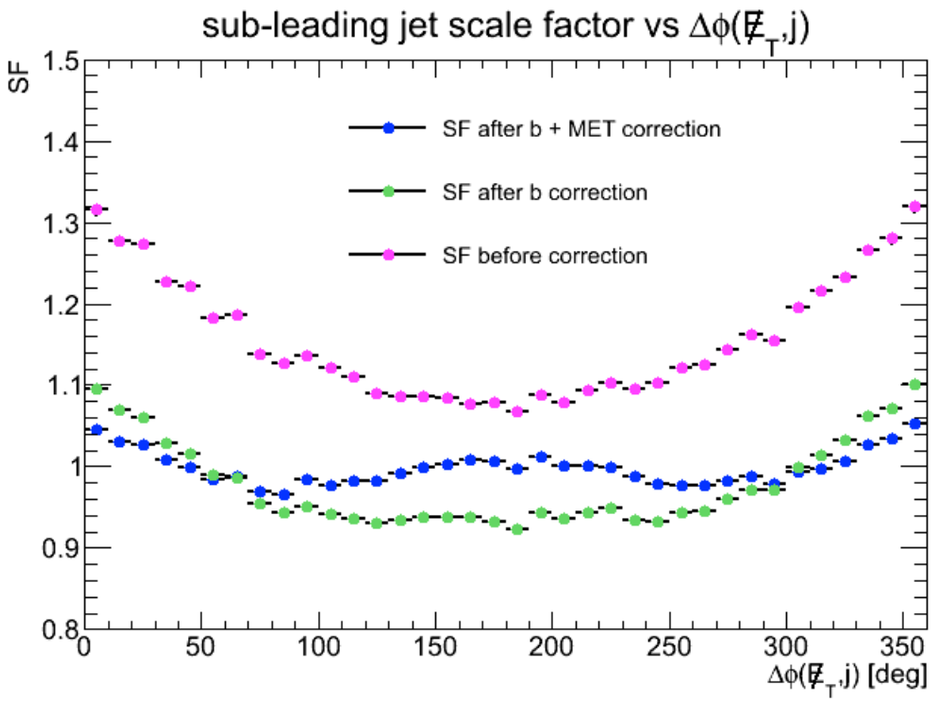
## Scale factors vs jet eta

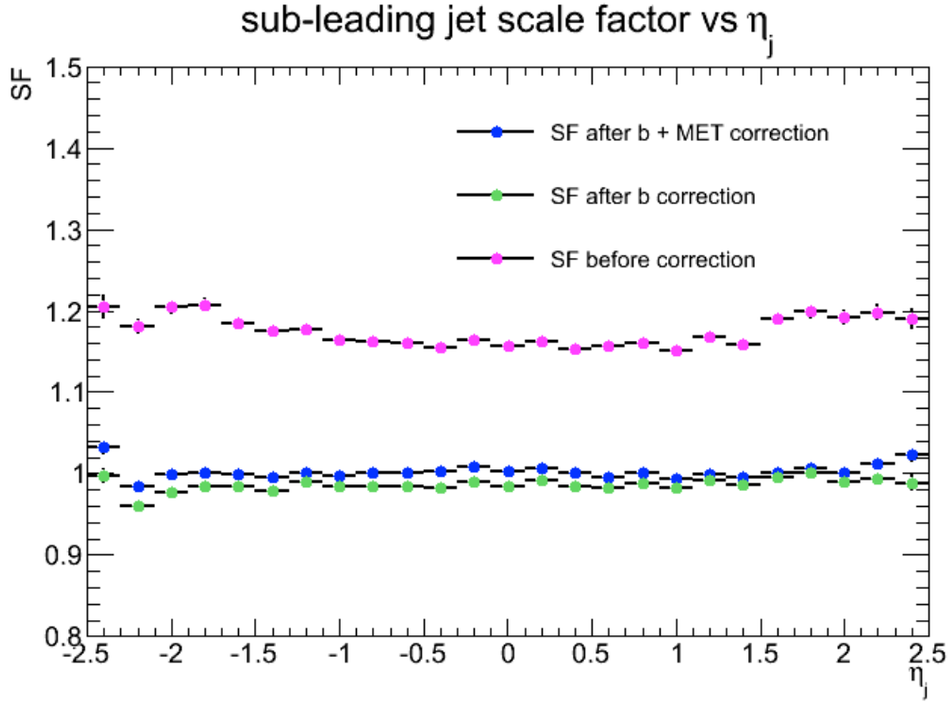
**leading jet**




**sub-leading jet**



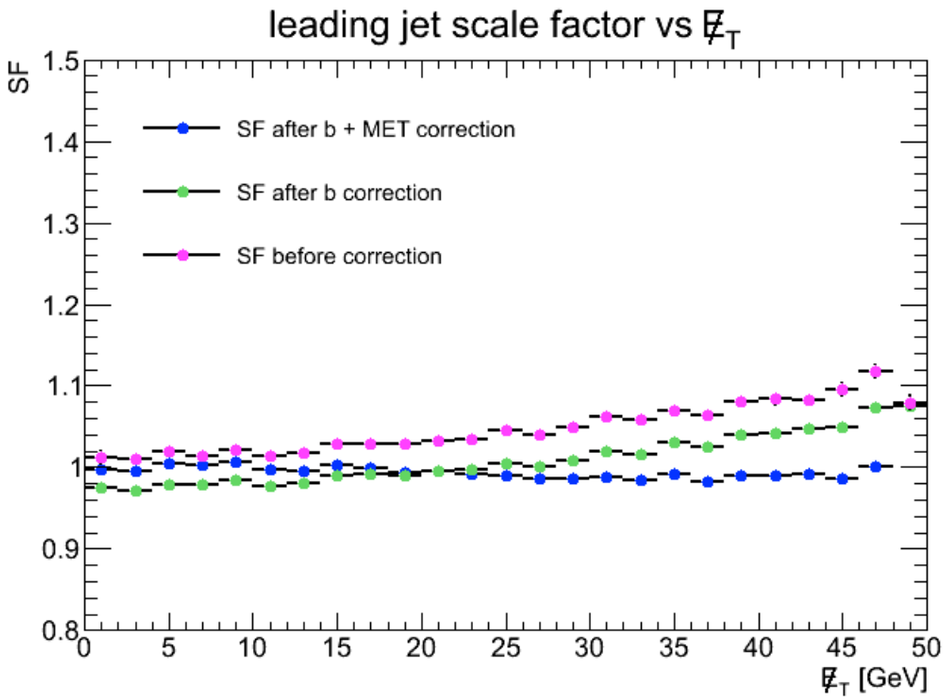



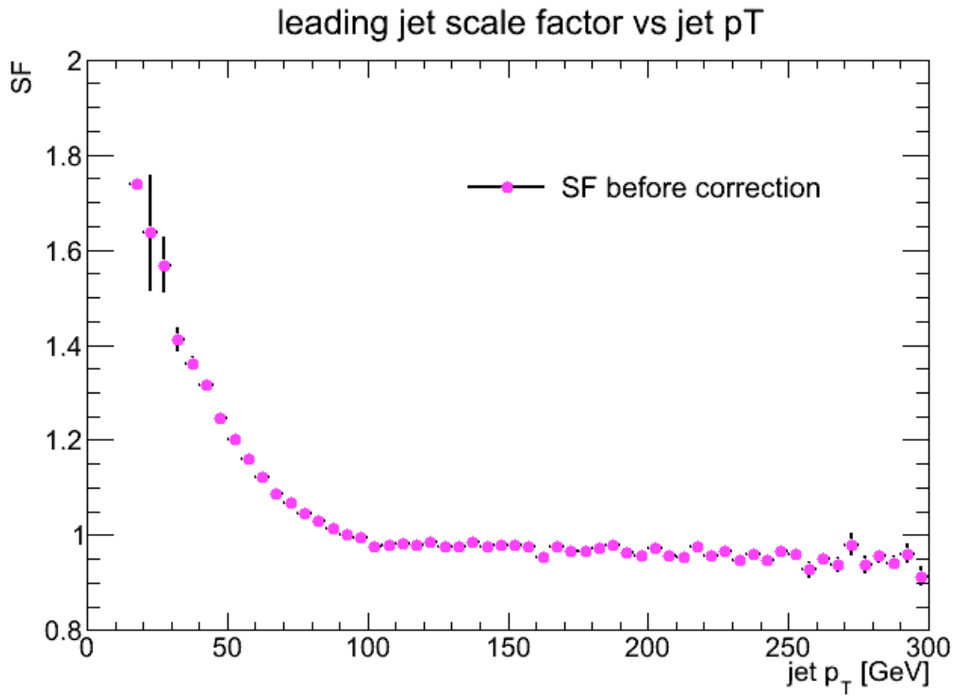
# Scale factors

## Scale factors vs MET

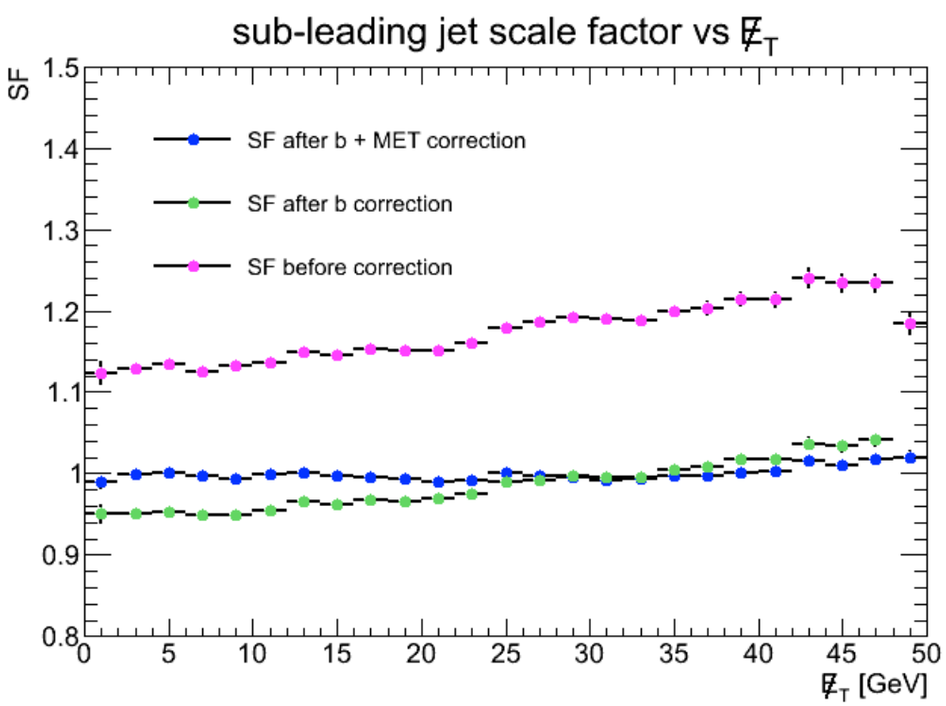
## Scale factors vs jet pT

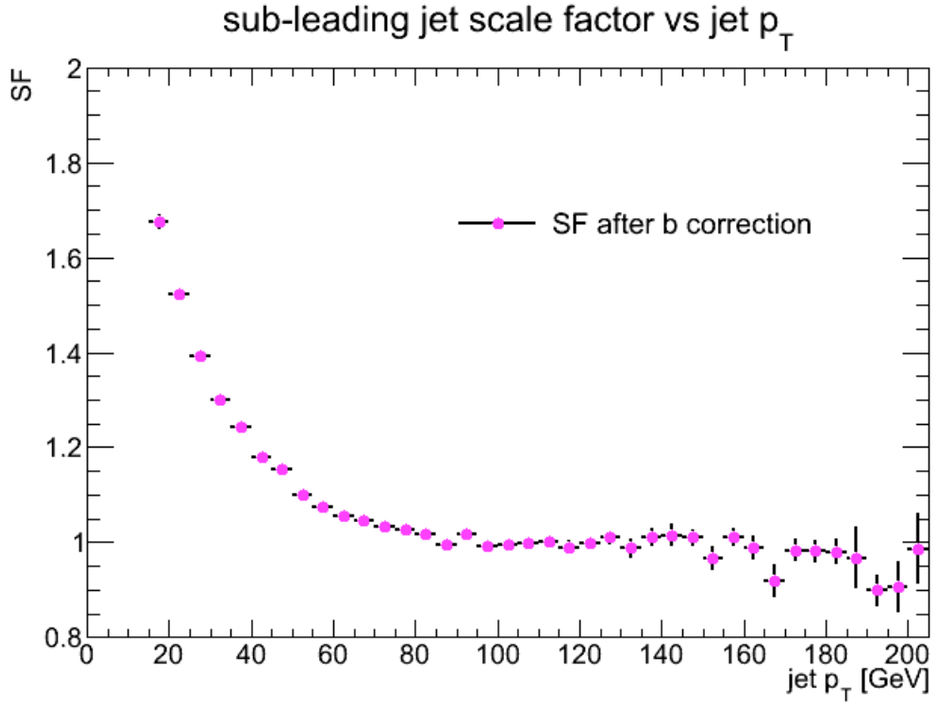
**leading jet**




**sub-leading jet**



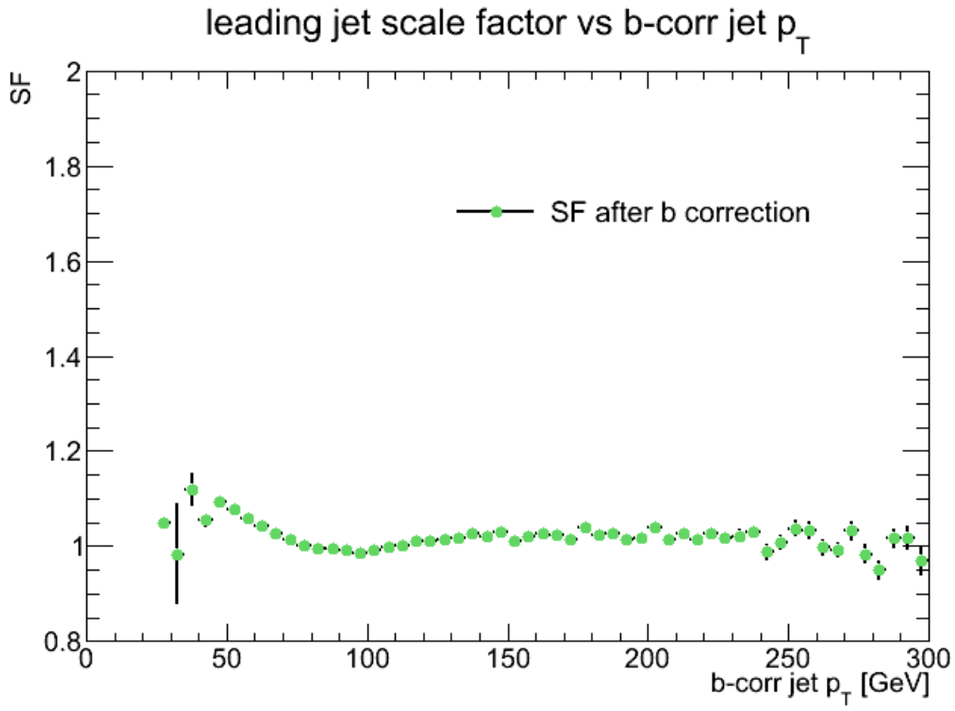



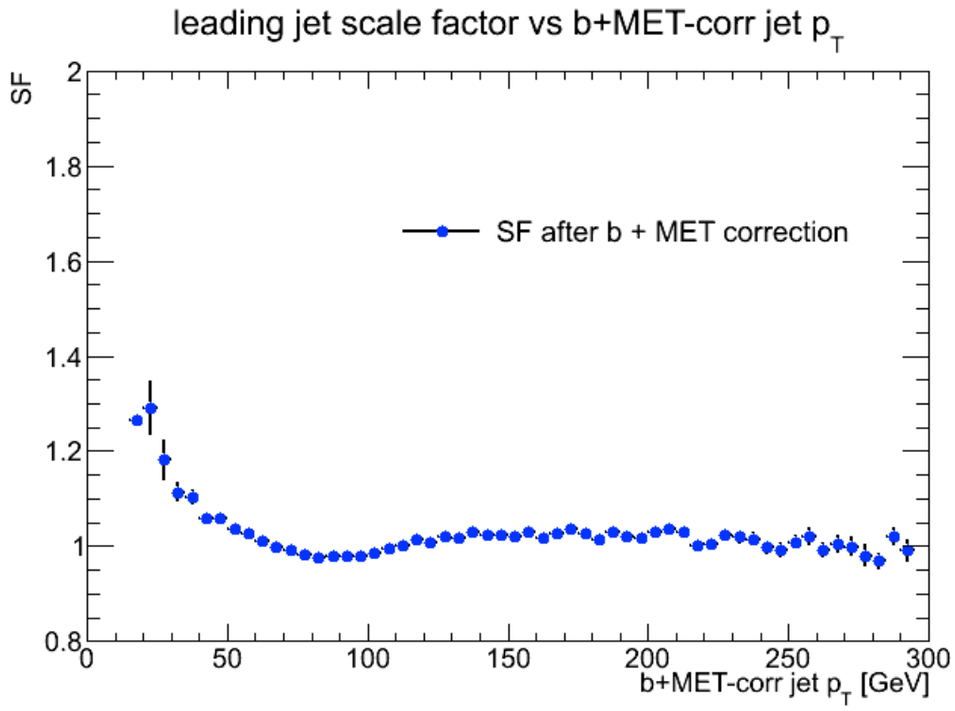
# Scale factors

## Scale factors vs b-corr jet pT

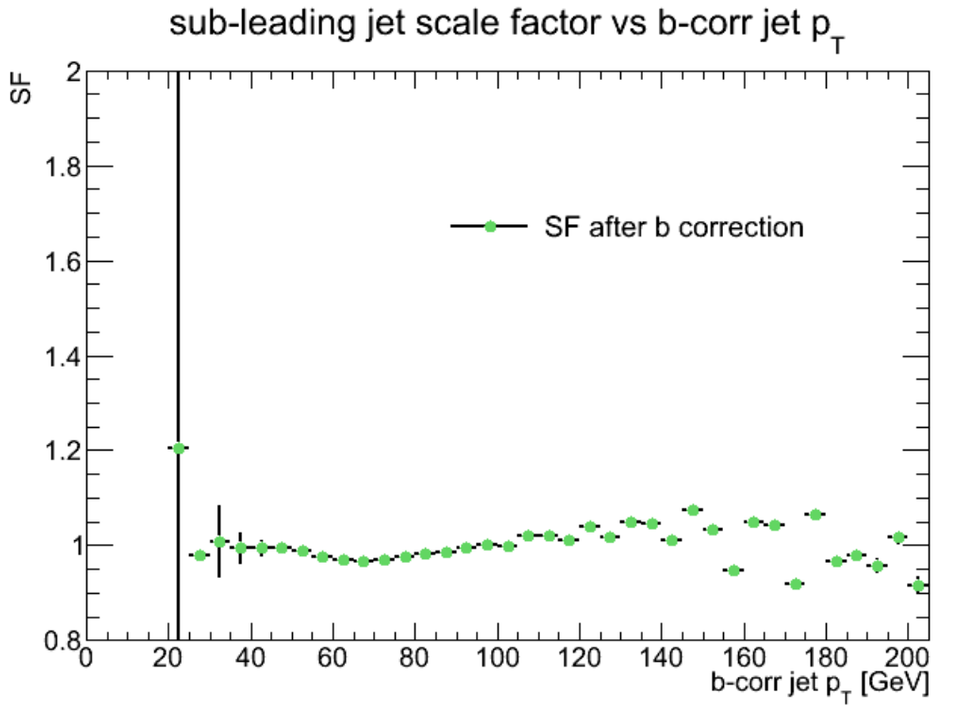
## Scale factors vs b+MET-corr jet pT

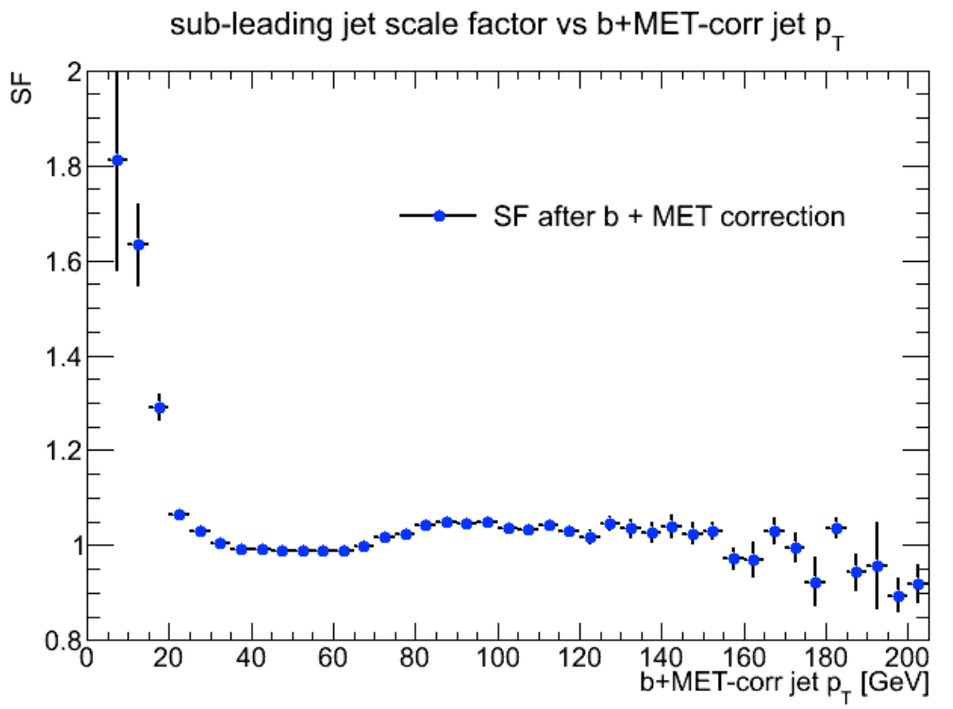
**leading jet**




**sub-leading jet**



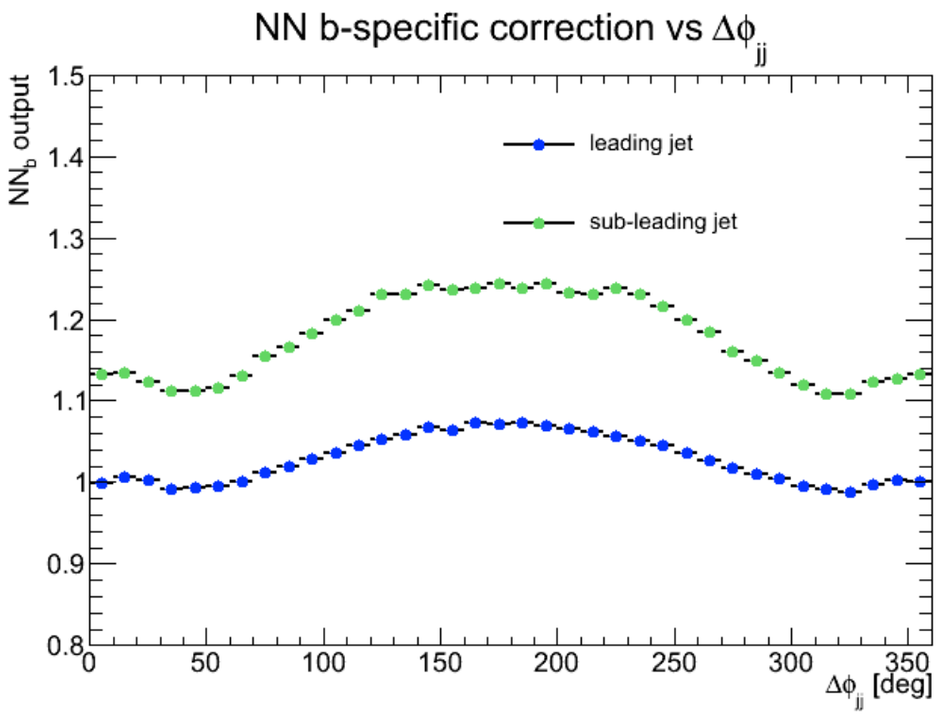



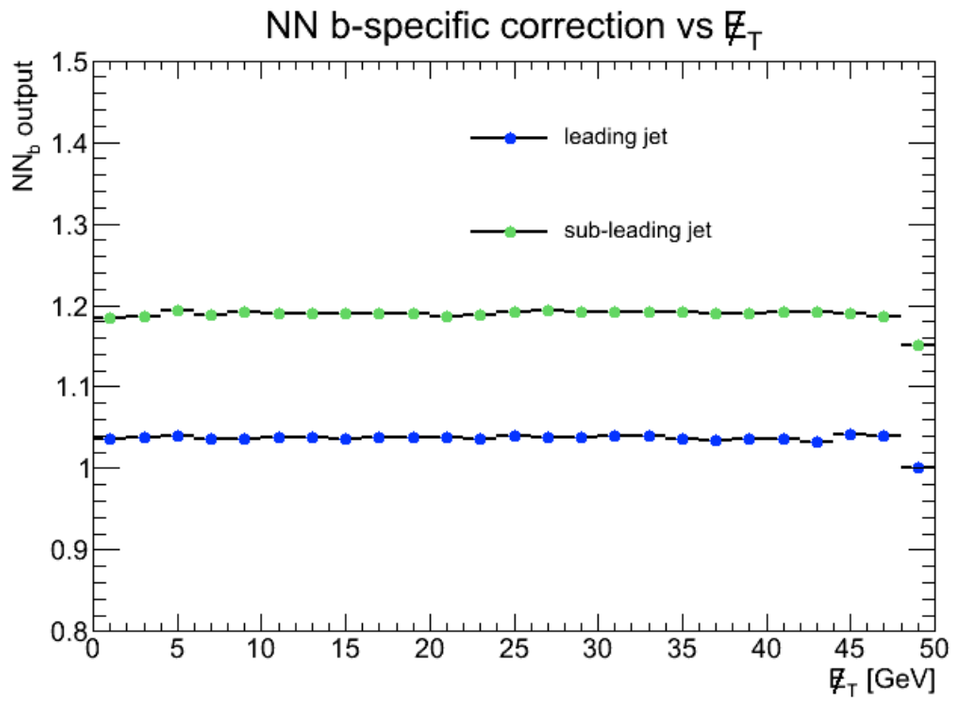
# NN correction factors

## NN output vs ΔPhi(j,j)

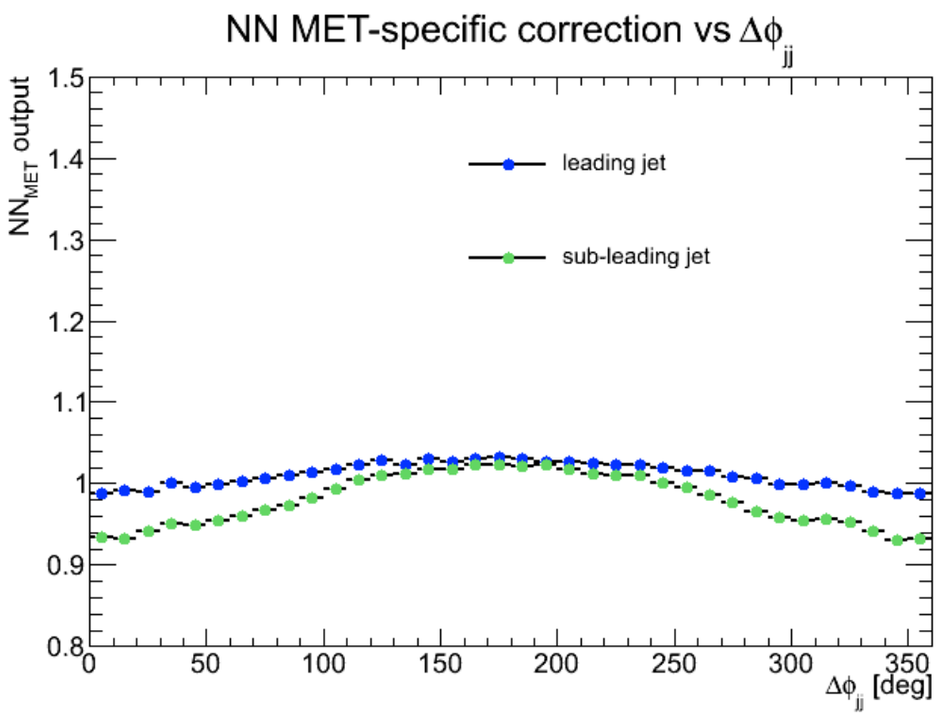
## NN output vs MET

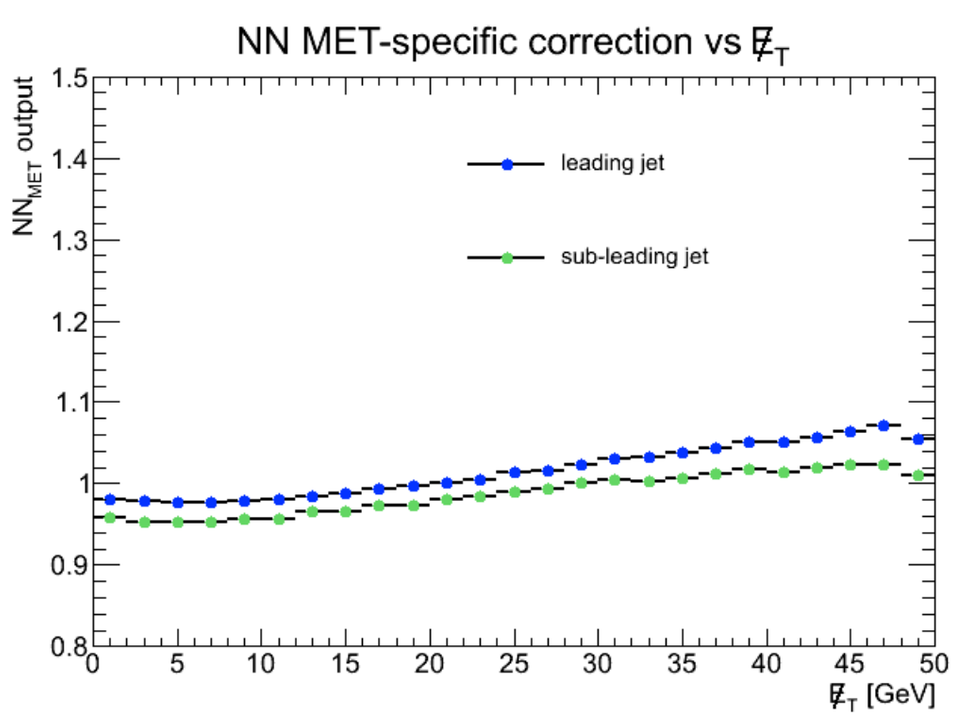
**$NN_b$ output**




**$NN_{MET}$ output**

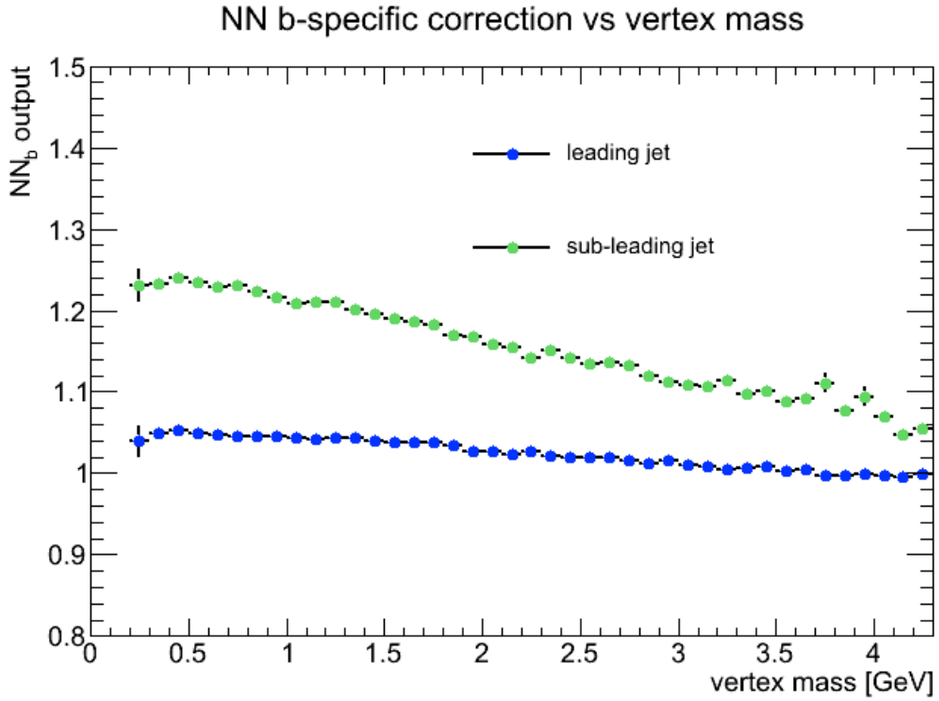


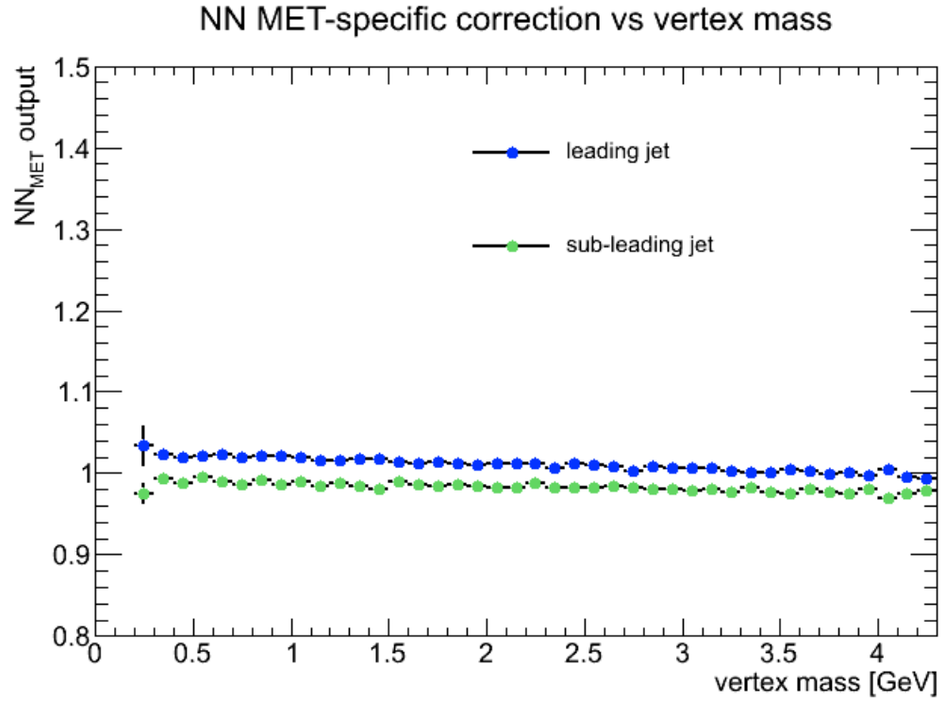
# NN correction factors

## NN output vs vertex mass

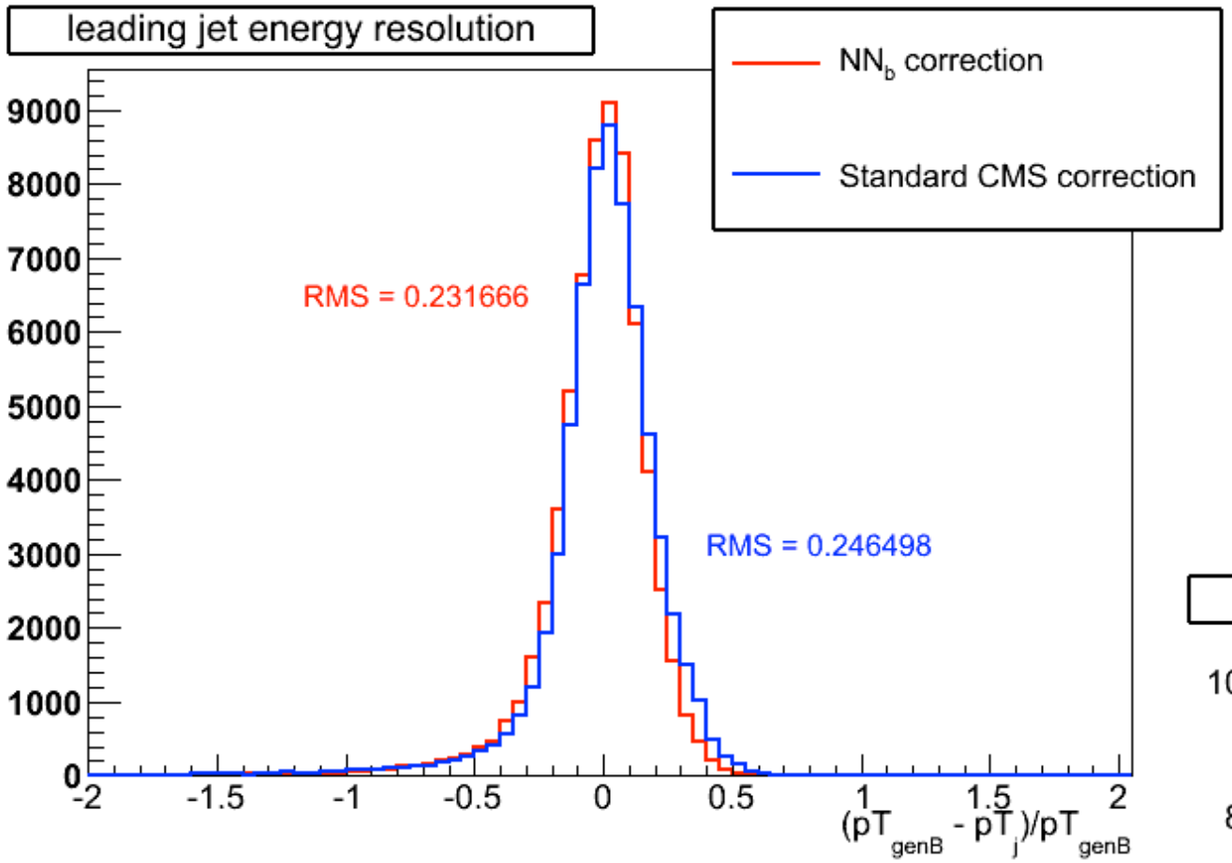
### $NN_b$ output




### $NN_{MET}$ output

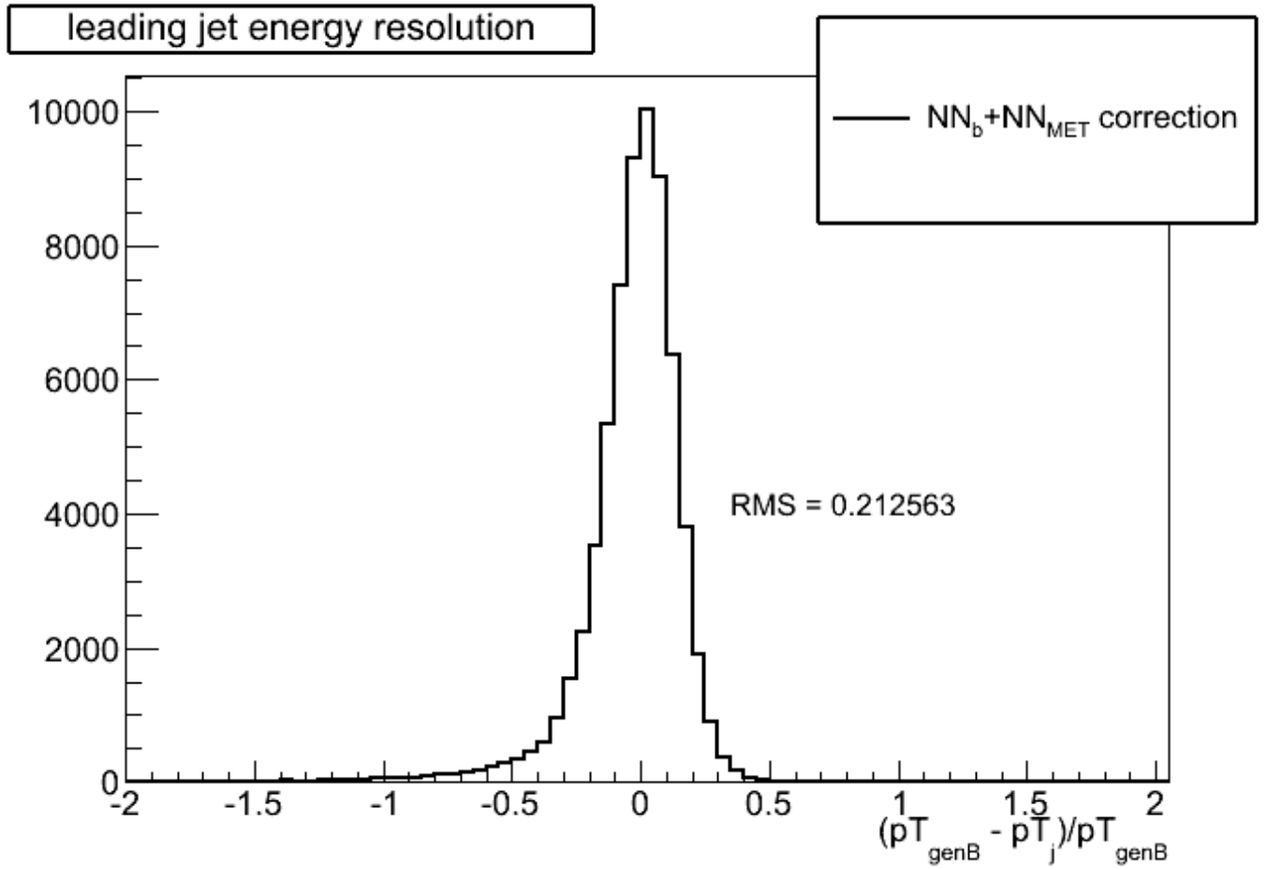


# jet energy resolution




Jets selection:

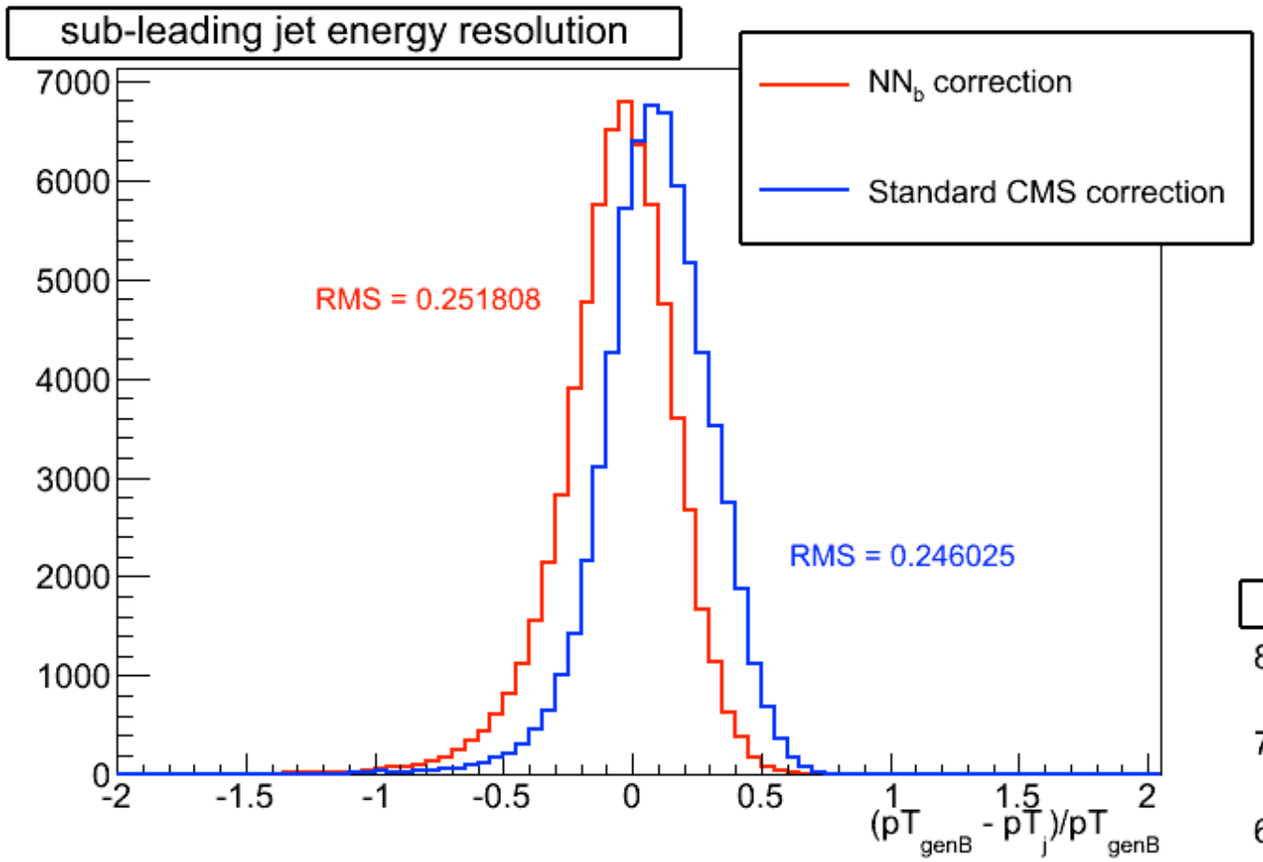
- 2 b-tagged jets from the Higgs candidate with pT > 20 GeV, dR$_{genB,j}$ < 0.5
- no selection applied on additional jets




## > Leading jet energy resolution improved

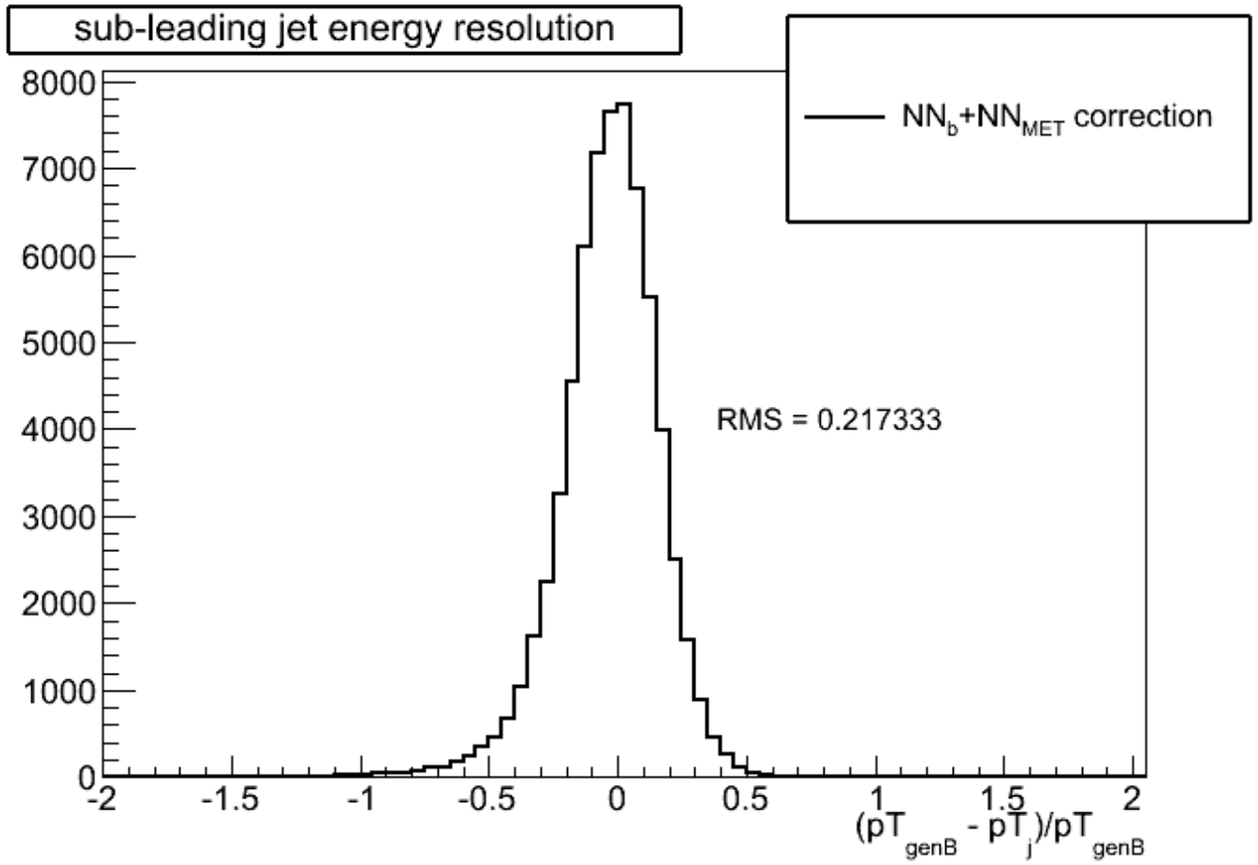
- from ~23% to ~25% after NN$_b$ correction
- from ~23% to ~21% after NN$_{MET}$ correction

# jet energy resolution

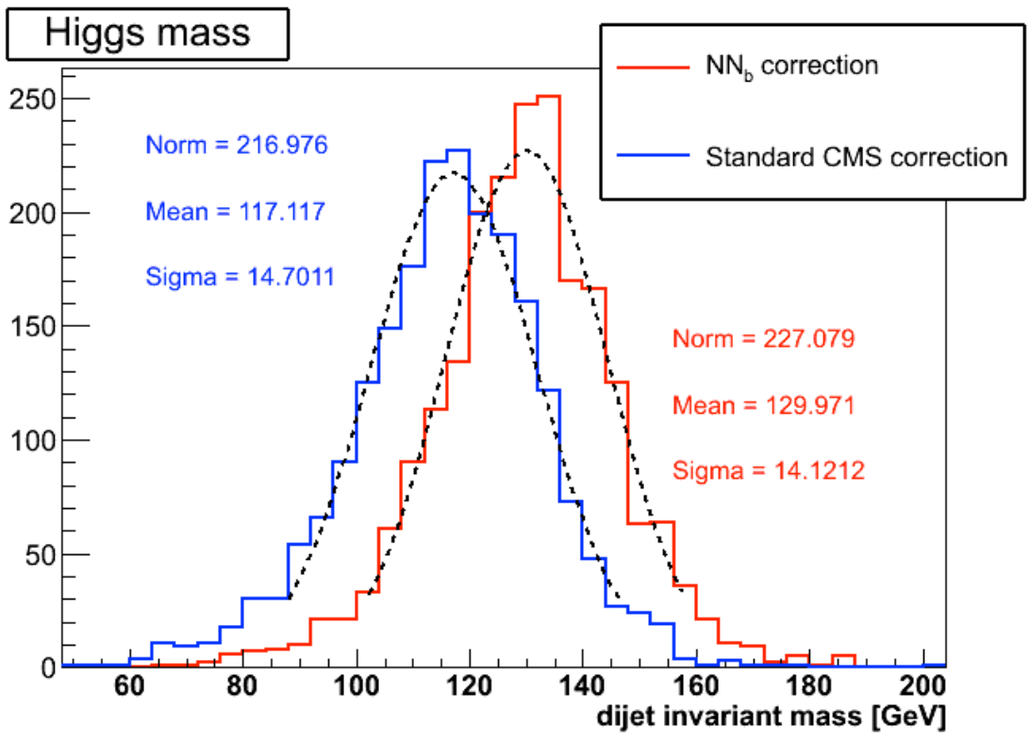



- Jets selection:
  - 2 b-tagged jets from the Higgs candidate with pT > 20 GeV, dR < 0.5
  - no selection applied on additional jets

- **Sub-leading jet energy resolution improved**
  - from ~25.2% to ~24.6% after $NN_b$ correction
  - from ~25% to ~22% after $NN_{MET}$ correction

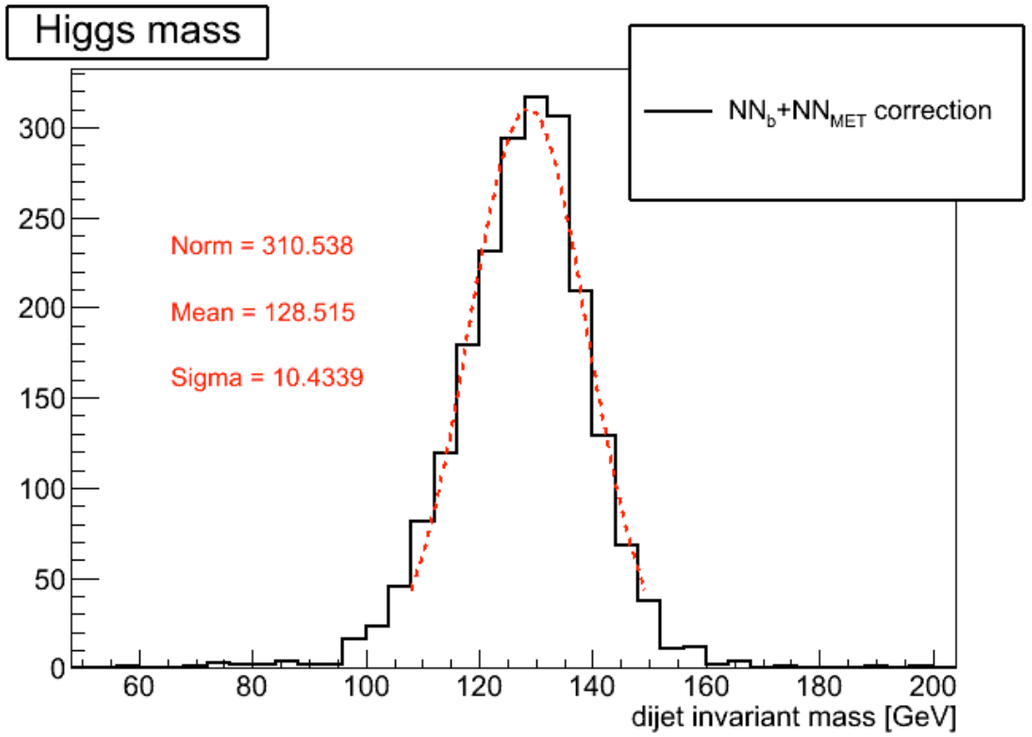


# Reconstructed dijet invariant mass




- Leptons selection
  - pT > 20 GeV
  - |eta| < 2.5
  - # additional leps = 0

- Jets selection
  - pT > 20 GeV
  - |eta| < 2.5
  - CSV l-j > 0.9
  - CSV sl-j > 0.5
  - # additional jets = 0
  - # fat jets = 0

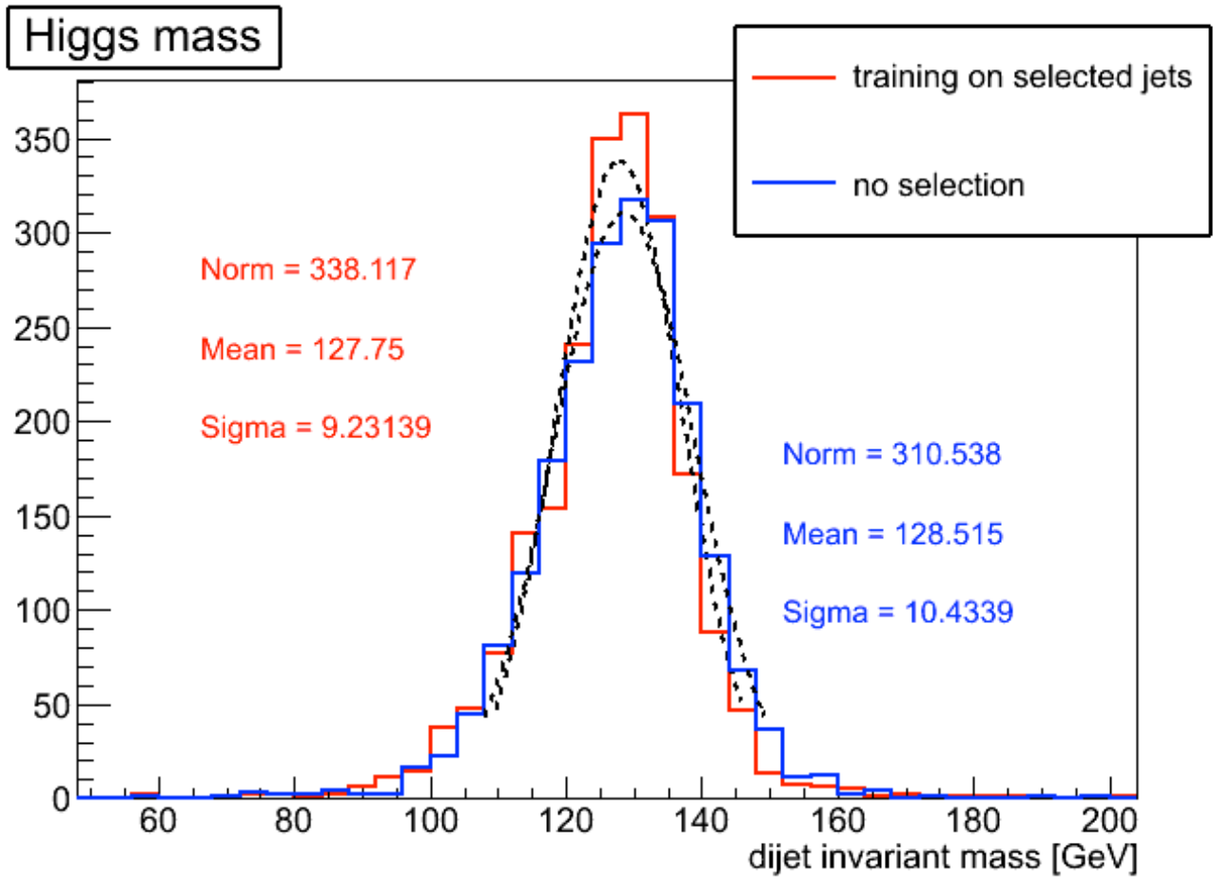



Higgs dijet invariant mass resolution improved

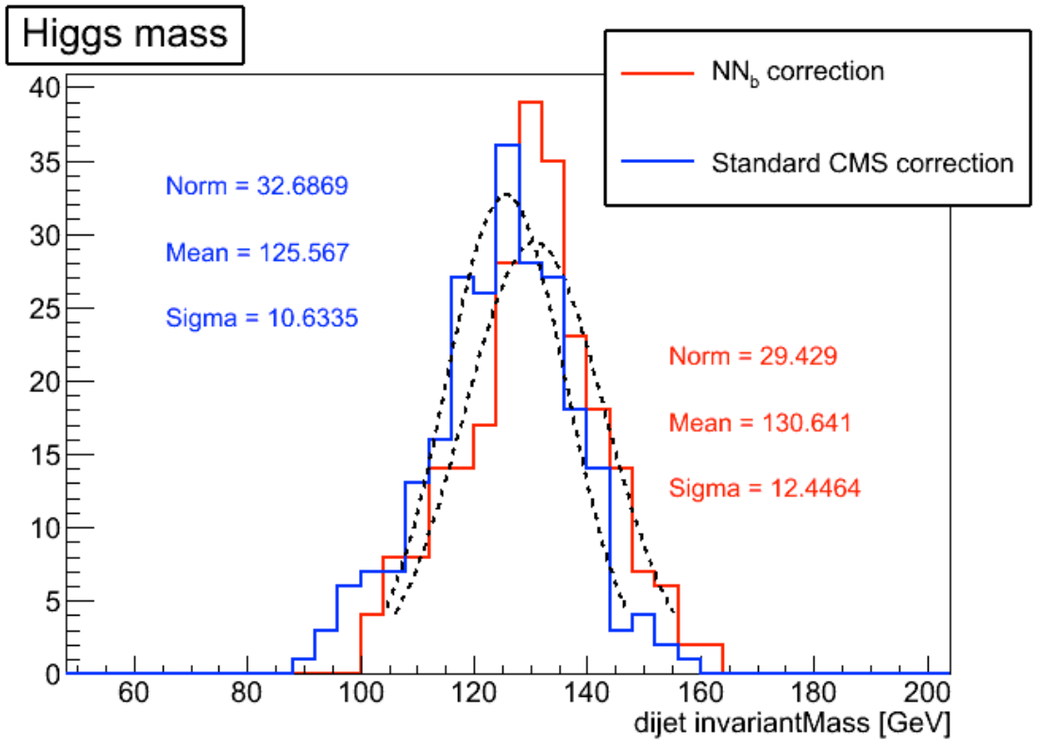
- from ~13% to ~11% after $NN_b$ correction
- from ~11% to ~8% after $NN_{MET}$ correction

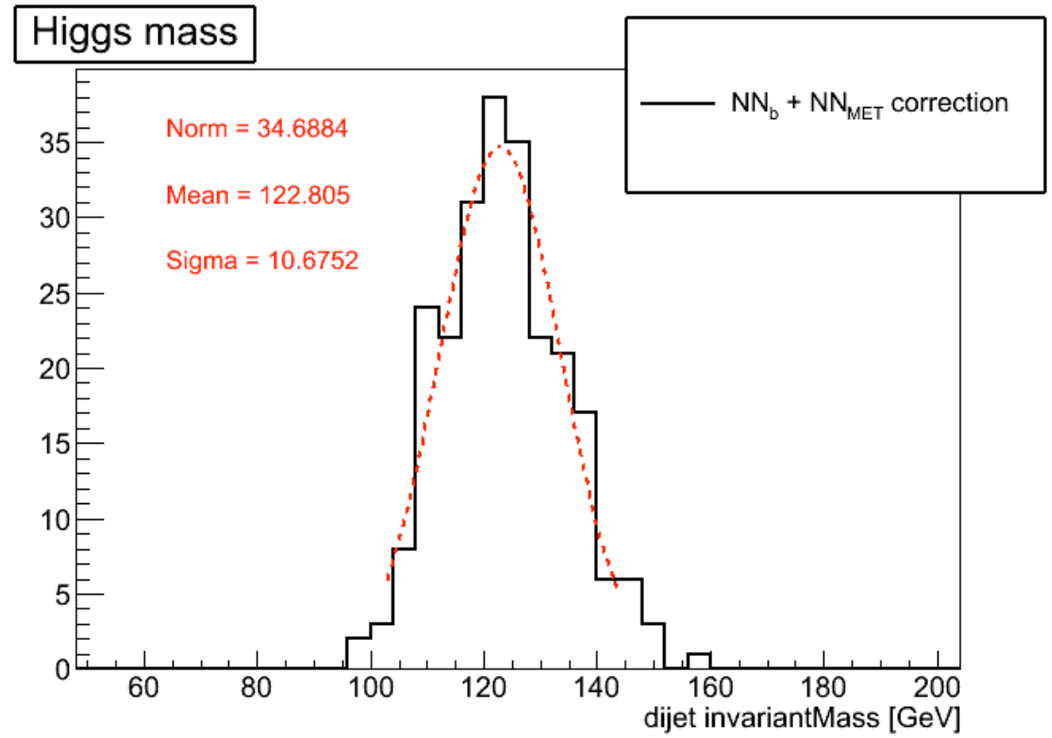
# Reconstructed dijet invariant mass

- $NN_{MET}$ trained again on a selected sample of events
  - jets with pT > 20 GeV, eta < 2.5
  - CSV l-j > 0.9, CSV sl-j > 0.5
  - # additional jets = 0, # fat jets = 0
- Further improvement of the Higgs mass resolution from ~8% to ~7%



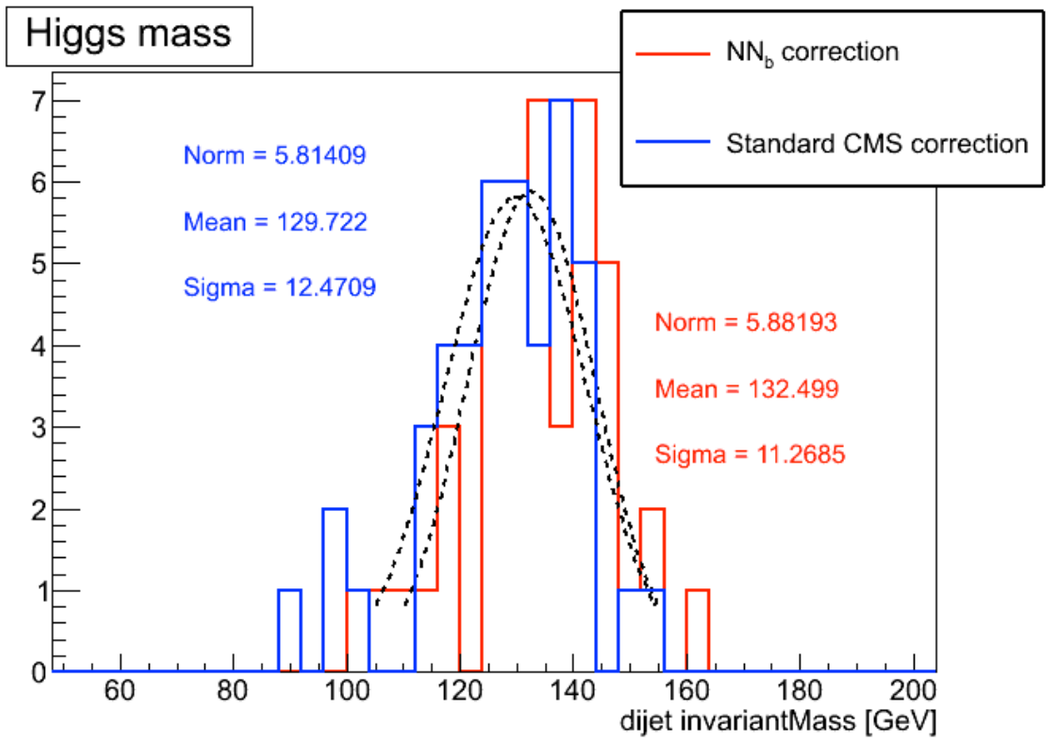
# Boosted Higgs

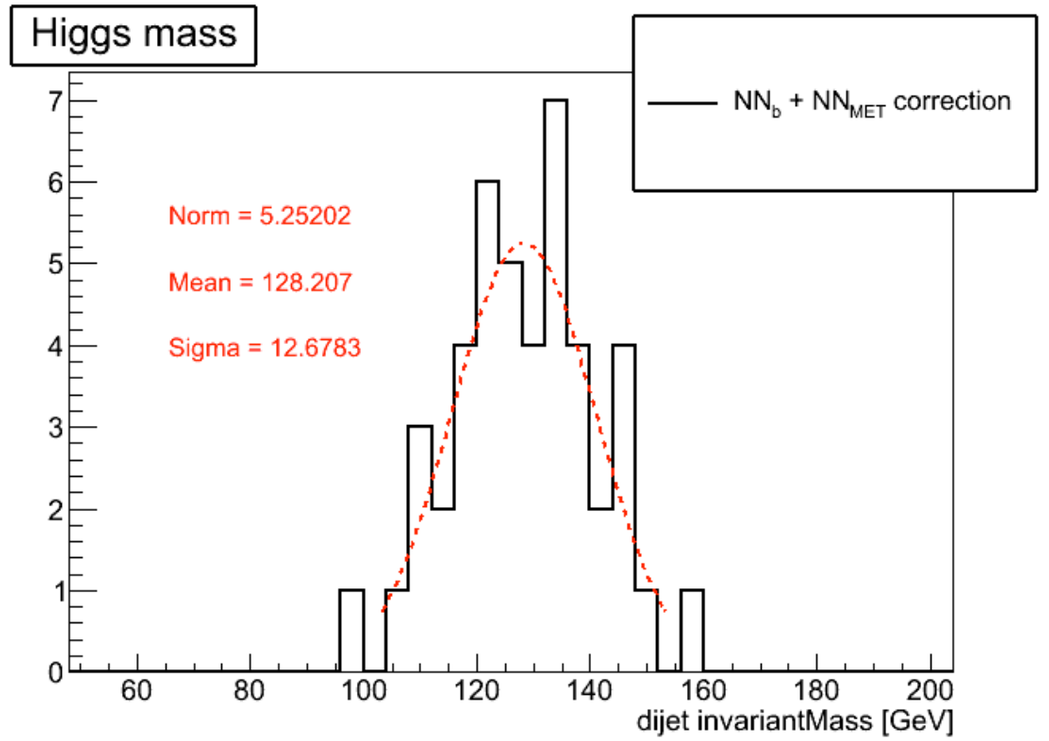



- Higgs dijet invariant mass resolution for **H $p_T$ > 150 GeV**
  - 8.5% before correction
  - 9.5% after b-correction
  - 8.7% after MET-correction

# Boosted Higgs




> Higgs dijet invariant mass resolution for **H $p_T$ > 200 GeV**

- 9.6% before correction
- 8.5% after b-correction
- 9.9% after MET-correction

# Reconstructed dijet invariant mass

- A bias of the jet-energy correction with respect to a particular Higgs mass in the training is avoided training the NNs @$M_H$ = 110-135 GeV (5 GeV steps)
- Then the NN correction function is evaluated on each of the Higgs boson masses in the range
- Resolution improved from the standard-corrected jets result of ~13% to the NNs-corrected jets result of ~9% (~30%)