Missing Energy and Tau-Lepton Reconstruction in ATLAS

Stefan Stonjek
Max-Planck-Institut für Physik

Physics at LHC Seminar
27-May-2008

Outline

- $E_{T,miss}$
  - Reconstruction algorithms
  - Refinement
  - Performance
- Tau-jet reconstruction
  - Reconstruction algorithms
  - Performance

Why $E_{T,miss}$ and tau

- $E_{T,miss}$ is vital for almost all physics analyses
  - In particular for new physics
    - New physics is supposed to appear at high $E_{T,miss}$

- Tau leptons provide a good handle to new physics
  - Like: H / A → tau + tau
  - Tau decays
    - 35% leptonically (tau → e/μ + neutrino + tau-neutrino)
    - 65% hadronically (tau → tau-jet + tau-neutrino)
  - Tau-jet identification is important

What is $E_{T,miss}$

- Not all energy originating from the hard interaction is measured in the detector
  - E.g. neutrinos
- Sum of transverse Energy (E_T) measured int the detector should be 0
  - Protons collide head on
  - $E_{T,miss}$ = - SUM(E_T)$_{\text{all visible particles}}$
- Reconstruction of $E_{T,miss}$ is hampered by detector imperfection and wrong particle identification

$E_{T,miss}$ reconstruction algorithms

- Cell-based
  - Only calorimeter cells which survive a noise suppression are counted
  - Noise suppression
    - Threshold based (threshold = n × σ ; n=2)
    - Topo cluster based (only use cells from topo clusters)
      - » Calorimeter cells above threshold “a” are used as seed cells
      - » Neighboring cell above threshold “b” are added to the cluster
      - » Border cells have to be above threshold “c”
    - π_0 – efficiency nearly 1 for 4/2/0 (> 4 GeV)
- $E_{T,miss} = E_{T,miss,calo} + E_{T,miss,muon} + E_{T,miss,cryo}$

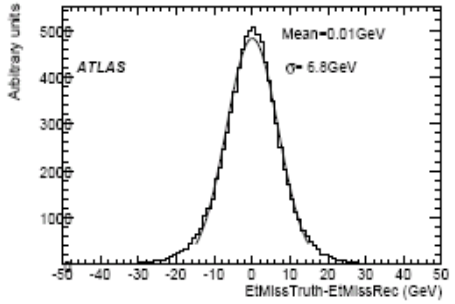
Cell based

- $E_{T,miss} = E_{T,miss,calo} + E_{T,miss,muon} + E_{T,miss,cryo}$

- Calorimeter
  - Separate energy calibration for Electromagnetic or hadronic showers
    - H1-like or local-hadronic
- Muon
  - Only muons with $|\eta| < 2.7$ (muon spectrometer geometry)
  - For $|\eta| < 2.5$, muon spectrometer track matched with inner detector track
    - Reduce fake muons
    - Muon energy from muon spectrometer only (Avoid double counting)
- Cryostat
  - Between LAr EM-calorimter and hadronic Tile-calorimeter
    - ½ interaction length of uninstrumented material
  - Jet energy has to be corrected

Refinement of Cell Based

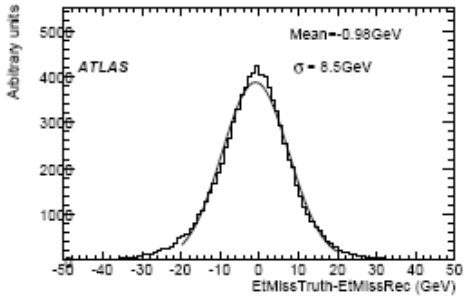
- Topo clusters are assigned to reconstructed and identified objects
  - Order: electron, photon, muon, had tau, b-jet, light jet
  - Clusters belonging to two objects are assigned to first (above list) object
  - If same class, energy is spread proportionally
  - Cell calibration is adjusted accordingly
- Physics objects are better reconstructed
- Unassigned clusters are used as well



with

unassigned Topo clusters

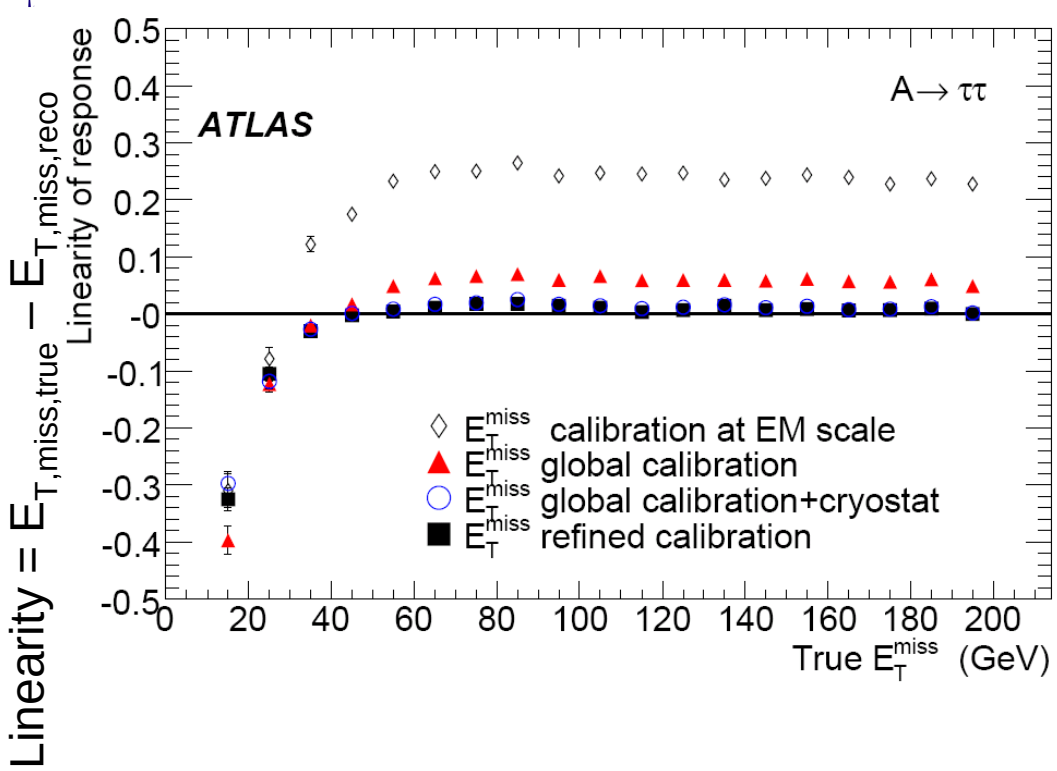
without

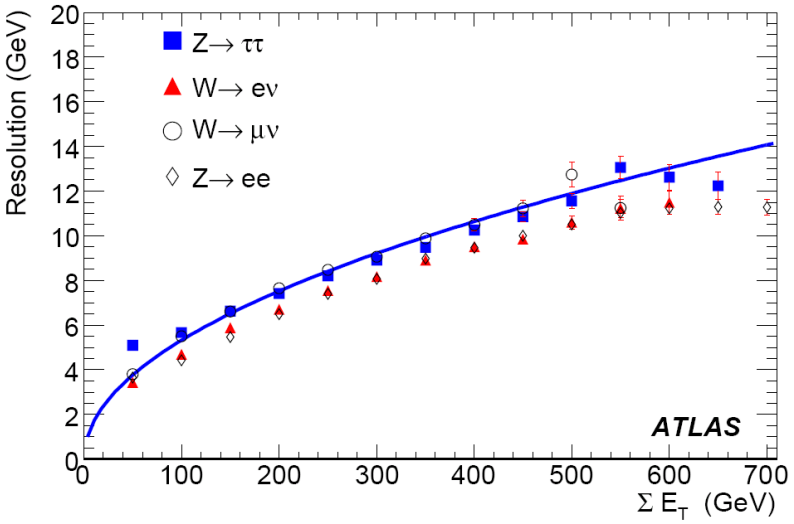


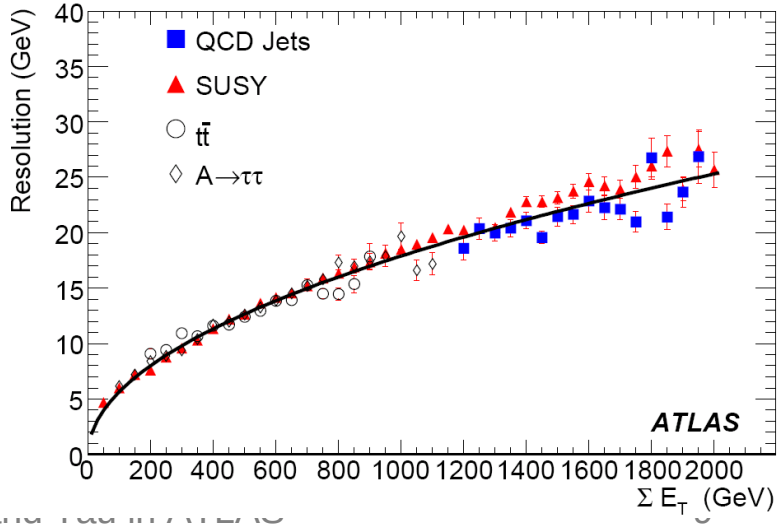
Object based

- Start with physics objects
  - Distinguish between high (e/γ, μ, τ, jets) and low (π^0, $\pi^{\pm}$, unclustered) p_T objects
  - Mostly based on calorimeter
  - Muons like in Cell-based
- Add calorimeter cells which are not related to high-p_T physics objects
  - Mini-jets are constructed from unassigned topo clusters ($\pi^{\pm}$ or π^0 (if $E_{had} < 2\%$ and $P_T > 10$ GeV))
  - Unassociated depositions are added to the E_T calculation
- Performance of both methods are very similar
  - Not specified which method was used for which plot

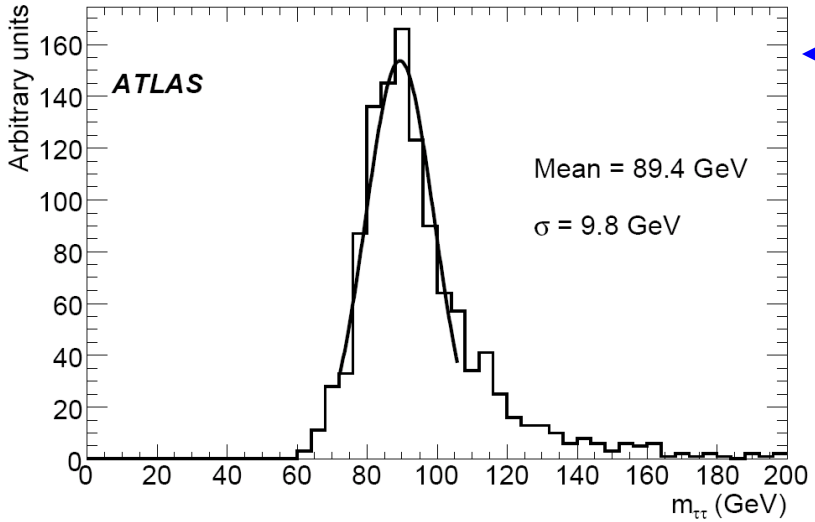
Resolution / Linearity





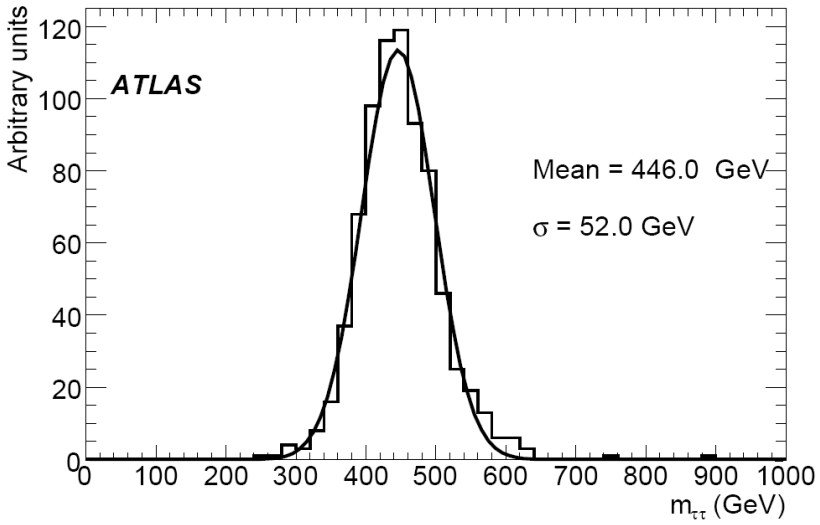


Performance



- $Z \rightarrow$ tau + tau

- $A \rightarrow$ tau + tau
- m_A = 450 GeV



- Tail due to non-Gausian effects caused by $E_{T,miss}$ mismeasurement

Fake $E_{T,miss}$

- Muons
  - Fake or missed high p_T muon
- Calorimeter
  - Cracks
  - Leakage
- Instrumental defects
  - E.g. calorimeter cells will fail

- Real data will provide a better calibration

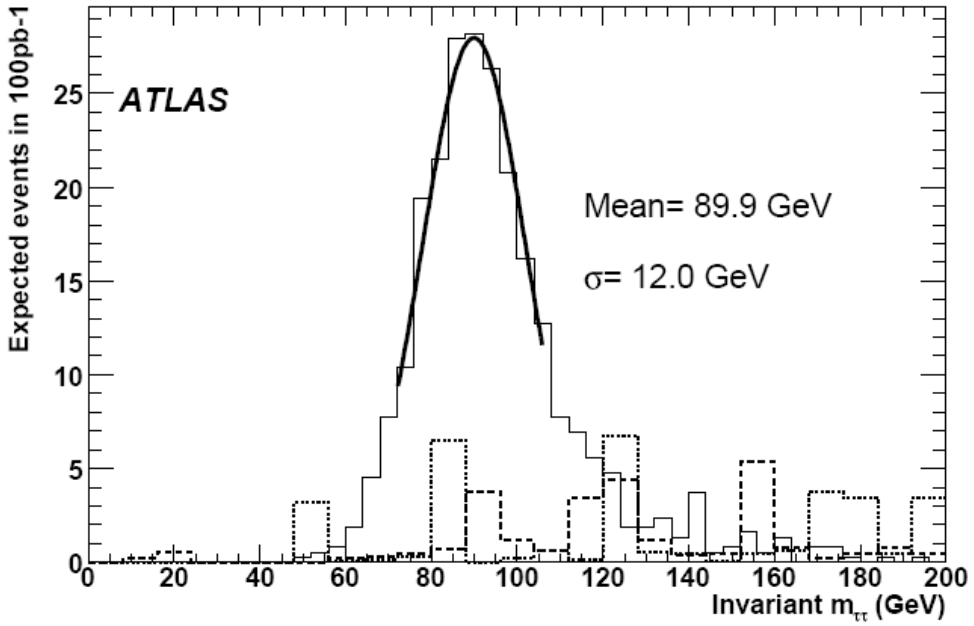
Performance with Real Data

- Minimum bias events
  - $E_{T,miss,meas}$ = 4.3 GeV (no beam gas or halo)

- Well known physics
  - Calibrate $E_{T,miss}$ scale

- Z → leptop + lepton
- W → lepton + neutrino

- W / Z mass is well known

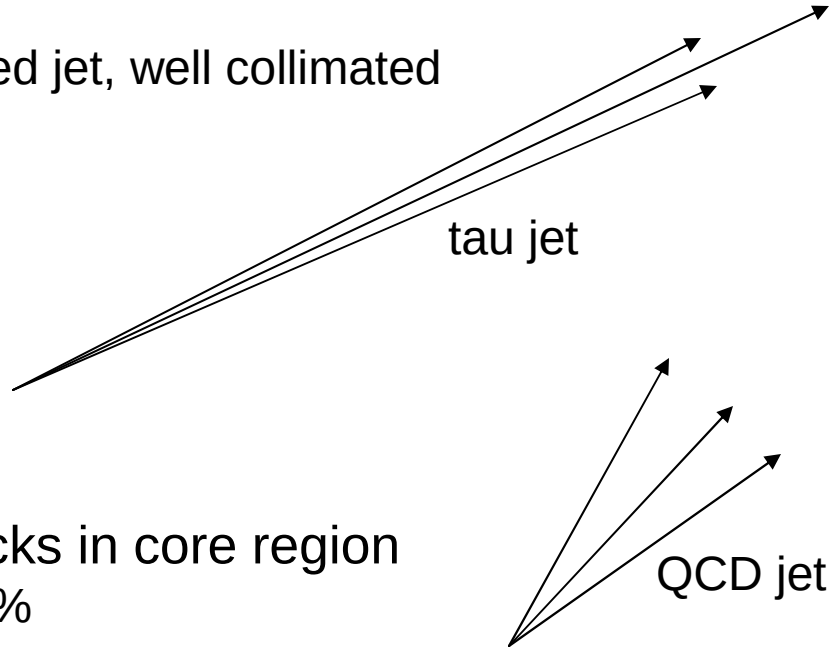


Tau decay

- Tau → muons/electron: 17.4%/17.8% (+ tau neutrino and muon/electron neutrino)
- Tau → hadrons: 64.8% (+ tau neutrino)
  - One-prong: one charged pi
    - $\pi^{\pm}$ + neutrino: 22.4% of one-prong
    - $\pi^{\pm}$ + n π^{0} + neutrino: 73.5% of one-prong
  - Three-prong: three charged pi
    - $3\pi^{\pm}$ + neutrino: 61.6% of three-prong
    - $3\pi^{\pm}$ + n π^{0} + neutrino: 33.7% of three-prong
  - Only 0.1% five-prong
    - to hard to detect in multi-jet environment

Tau reconstruction algorithms

- General idea
  - Pencil like (very narrow) shaped jet, well collimated
    - Difficult to quantify
  - Leading track
- Two algorithms
  - Calorimetry based
  - Track-based
- Both calculate charge from tracks in core region
  - Charge misidentification < 3.6%



- Tau production and decay well seperated in space and time
  - Lifetime = 0.29 ps ; c × lifetime = 87.11 μm
  - Secondary vertex identification seems possible (if more than one charged product)

Calorimeter based algorithm

Starting from calorimeter clusters the following variables are calculated

1) Electromagnetic-Radius
2) Isolation in the calorimeter
3) Charge of candidate
4) Number of associated tracks
5) Number of hits in the η strip layer
6) Transverse energy in the η strip layer
7) Lifetime signed pseudo impact parameter significance
8) E_T over P_T of the first track

- Likelihood of all of the above

- (1,2,4,5,6) Pencil-like, well collimated jet
- (7) 2-dim “secondary vertex” (three prong only)
- (8) leading track caries a large fraction of jet energy (one prong)

Track based algorithm

- Seeded by a good quality track (leading track)
- Combined with up to 6 tracks in core region (η,φ) and associated calorimeter information to form a candidate

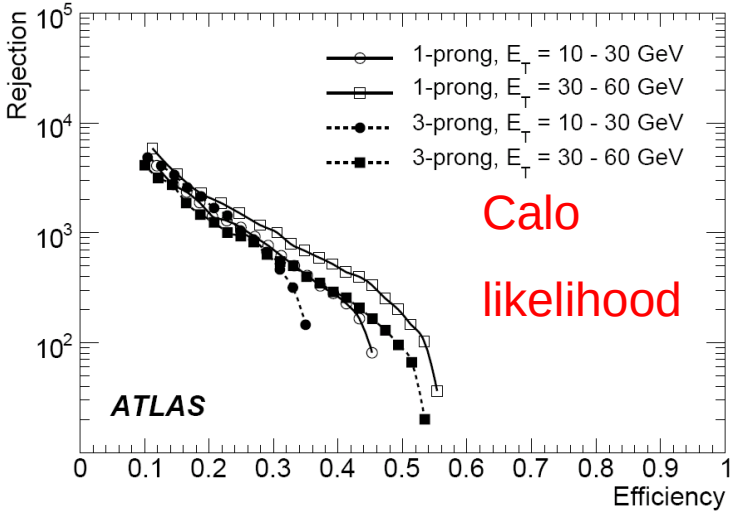
- Energy flow approach

- Identification with calorimeter and tracking information
  - Track
    - Width of the tracks ; invariant mass of track system
    - number of tracks in the isolation cone
  - Calo
    - Electromagnetic radius ; Number of strips ; width of deposit in the strips
    - Faction of energy in outer ring $0.1 < \Delta R < 0.2$; isolation energy $0.2 < \Delta R < 0.4$
  - Track and calo
    - Visible mass ; Visible mass from energy flow
    - Energy in had-Cal relative to sum of track momenta

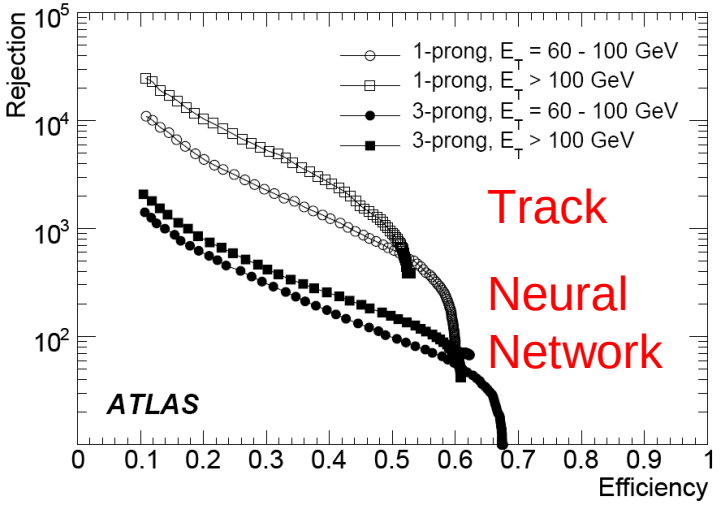
- Overall identification by cuts or MVA or Neural Net

Rejection rates / Efficiency

- Both algorithms work well
  - Calo better for hight E_T
  - Track better for low E_T
- About to be merged



Process	$Z \rightarrow \tau\tau$	$W \rightarrow \tau\nu$	QCD events
	Reconstruction		
track-based	$\varepsilon = 39.1\%$	$\varepsilon = 37.1\%$	$R = 210$
calo-based	$\varepsilon = 49.8\%$	$\varepsilon = 55.3\%$	$R = 50$
	Reconstruction and identification		
track-based (cuts)	$\varepsilon = 30.1\%$	$\varepsilon = 26.2\%$	$R = 550$
track-based (neural network)	$\varepsilon = 27.9\%$	$\varepsilon = 22.6\%$	$R = 1630$
calo-based (likelihood medium)	$\varepsilon = 31.3\%$	$\varepsilon = 25.8\%$	$R = 1640$
calo-based (likelihood tight)	$\varepsilon = 24.1\%$	$\varepsilon = 17.5\%$	$R = 3550$

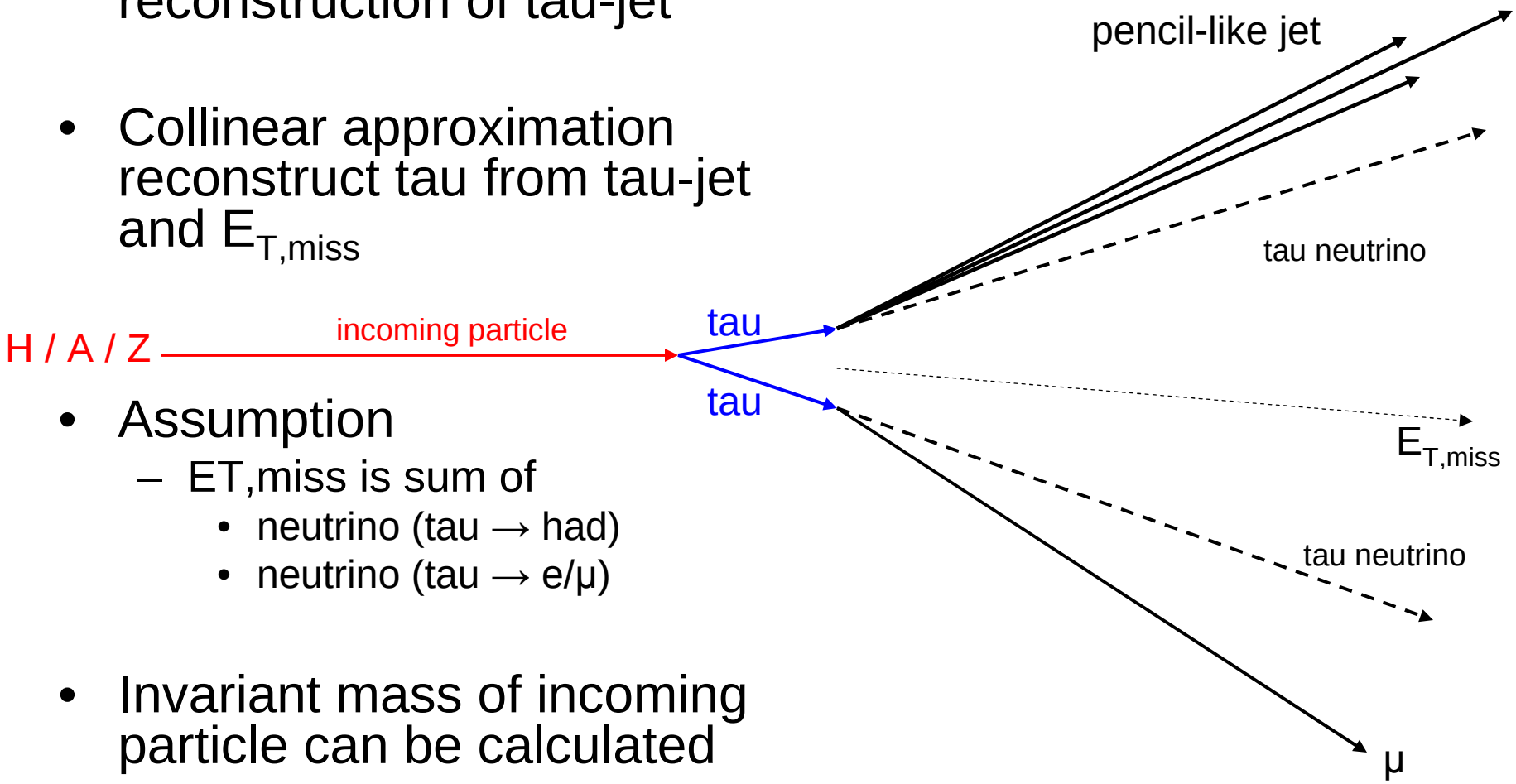


Fake tau

- Main source of fake taus: QCD jets
- Fake rate: several per mile to several percent
- Much more QCD-jets than tau-jets
- For good measurements fake rate has to be determined

Collinear approximation

- Tau reconstruction is reconstruction of tau-jet
- Collinear approximation reconstruct tau from tau-jet and $E_{T,miss}$



- Assumption
  - ET,miss is sum of
    - neutrino (tau → had)
    - neutrino (tau → e/μ)
- Invariant mass of incoming particle can be calculated

Summary and Outlook

- Tau events are a handle for new physics at LHC
- A good $E_{T,miss}$ reconstruction is important for tau analyses

- First data will improve $E_{T,miss}$ and tau reconstruction


The End

$E_{T,miss}$ and pile-up