ATLAS実験初期における
損失エネルギー・ジェットの測定
能力の理解とその改善

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JPS meeting — Mar. 30, 2009

Outline (we focus on missET today...)
1) Introduction
2) W’s transverse mass
3) Determination of missET performance with W events
4) Results with $30^{-1}$pb data
Introduction

Jets/missET appear in most of physics processes at LHC: neutrinos in ttbar and Higgs production, LSP’s in SUSY cascade decays...
  ✔ Jet energy scale could be a dominant systematic uncertainty at measurements (Tevatron experiences)
  ✔ MissET is more complicated object...(observed as an imbalance of energy against visible objects in an event)

Both are calorimeter based objects and understanding calorimeter performances and calibration are crucial. (Especially for early SUSY searches, we should validate missET reconstruction, whether our baseline performances are achieved or not..)

We here propose a method for in-situ missET resolution determination using W decays and perform a feasibility study
W’s transverse mass

Use $W \rightarrow \mu \nu$ events
  - Promising performances for muon reconstruction
  - Less fake rate compared to electrons.
  - Enough signal yield at the early stage: $\sigma \times \text{Br} \sim 10 \text{nb}$ ($\sqrt{s} = 10 \text{TeV}$, $p_T^{\mu \nu} > 15 \text{GeV/c}$)

For $W$’s decaying into leptons, the shape of transverse mass (MT) distribution is sensitive to missET resolution/scale:

- “spread” $\Leftrightarrow$ missET resolution
- “Jacobian peak” $\Leftrightarrow$ missET scale

Comparing with MC incorporating various resolution parameters, we can evaluate missET reconstruction performances.

\[ m_T = 2p_T^l E_T^{\text{miss}} (1 - \cos \Delta \phi) \]

- $p_T^l$: transverse momentum of lepton
- $E_T^{\text{miss}}$: transverse missing energy
- $\Delta \phi$: $\phi$ angular difference between lepton and missET vector
**W→μν candidates and MT**

- **Selection cuts**
  1. Fire single muon trigger \((p_T > 15\text{ GeV/c})\)
  2. One isolated muon with \(p_T > 20\text{ GeV/c}\)
  3. No tight electron above 20GeV/c
  4. missET > 20GeV (suppress QCD)

- **Signal purity \(\sim 84\%\)**

  - Shape of W’s MT is smeared due to the contamination of backgrounds \((W→\tau\nu, W→\mu\nu, \text{QCD } b\text{-jets, ttbar, } Z→\tau\tau)\).

  - To extract missET reconstruction performances correctly, we need to know these contamination effects simultaneously.

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**Table: Process and Events**

<table>
<thead>
<tr>
<th>Process</th>
<th>#Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>(W→\mu\nu)</td>
<td>122498</td>
</tr>
<tr>
<td>(W→\tau\nu)</td>
<td>13169</td>
</tr>
<tr>
<td>(Z→\mu\mu) (one\ μ\ lost)</td>
<td>5748</td>
</tr>
<tr>
<td>QCD (heavy flavor decays)</td>
<td>2940</td>
</tr>
<tr>
<td>(\text{ttbar (w in decays)})</td>
<td>725</td>
</tr>
<tr>
<td>(Z→\tau\tau)</td>
<td>405</td>
</tr>
</tbody>
</table>

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**Graph: MT Distribution**

- Breakdown of remaining events
- \(J_L\) corresponds to 30 pb⁻¹

**G4 full simulation**
General description of missET performance

missET ($p_T$ of neutrinos) is measured as the energy imbalance with “calorimeter activities (hadronic recoils) + muons”

- The resolutions are mainly described as the stochastic effect of visible calorimeter energy sum. ($\alpha x \text{sumET}^{1/2}$)
- The scale shift is caused by
  - Difference between true hadronic energy sum($\text{sumET}_{\text{truth}}$) and visible one.
  - Muons also affect the scale when undetected.

Thus missEx resolution described as\n\[
\sigma(E_{\text{miss}}) = \alpha \cdot \Sigma E_{\text{calo}}^\text{calo} + \sigma(\mu \text{ inefficiency})
\]

- To confirm our baseline performance of $\alpha=0.52$ (according to Geant4 full simulation), we need to check MT in each sumET slice. But MC sumET is uncertain. (instrumental effects, fragmentation/underlying event models alter sumET predictions)

Fit $\alpha$ and sumET scale $\beta$ simultaneously with “MT-sumEt” 2-D distributions
missET-sumET 2-D distribution

- Looking into 2D-distribution of “MT-sumEt”, we can separate BG’s.
  - QCD events cluster in the region of large SumEt after selection cuts and show small MT. (due to small $\Delta \phi$ for heavy flavor decays)
  - ttbar’s also have large SumEt (emit multiple jets), but W’s in ttbar gives higher MT.

- Remaining W/Z backgrounds cannot be separated, but their fractions to signal are determined by MC with small uncertainties.
  —given only by branching fractions and muon ID eff.
Analysis overview

Signal/BG MC templates
PDF(sumET, MT; \(\alpha, \beta\))

Inputs from measurements
Muon ID efficiencies (currently based on MC)

Fit MC templates to data using the maximum likelihood method (shape only) with 4 free parameters:
- coefficient of stochastic term "\(\alpha\""
- sumET scale "\(\beta\"
- 2 background fractions of QCD and ttbar

MT-sumEt distribution of \(W \rightarrow \mu\nu\) candidates

(SumEt shows non-linear response for small calor. activity events due to noise, then the fitting range of SumEt is set to be >100 GeV.)
Preparation of PDF’s

PDF’s are given by toy MC:
1. Smear true missEx/y according to $\alpha(\beta \times \text{SumET}_\text{truth})^{1/2}$ and scale sumET$_\text{truth}$ by $\beta$
2. Reduce muons according to their ID eff.
3. Add contributions of reduced muons into missEx/y
4. Apply offline selection cuts

Data (G4 sim.)
Result (30 pb⁻¹)

\[ \sigma_{\text{Exmss}} = 0.536 \times \text{SumEt}_{\text{rec}}^{1/2} \oplus \sigma_{\text{muon}} = 0.536 \times (0.896 \times \text{SumEt}_{\text{truth}})^{1/2} \oplus \sigma_{\text{muon}} \]

Consistent with the performances G4 sim. says. \((\alpha \sim 0.52)\)

- Almost no correlation between \(\alpha\) and \(\beta\), as expected.
- missEx resolution can be determined with an accuracy of <1% using a few 10 pb⁻¹ data.
MT/missET resolution of $W \rightarrow \mu\nu$

missET reconstruction performances can be extracted correctly.

- Data (G4 full sim.)
  - $\alpha=0.536$ (best-fit)
  - $\alpha=0.3$
  - $\alpha=0.7$
Concerning systematics

• Muon $p_T$ resolution, ID efficiencies
  • Muon $p_T$ resolution could be quite better than calorimeter objects and small effect on missET resolution
  • ID efficiency just alters the fraction of BG, so we can obtain stable fitting results. (if we keep high : $W \rightarrow \mu \nu$ signal purity)

• $p_T$ of recoil $W$ alters the MT shape and could be a dominant systematic uncertainty of MT-sumET templates, but can be reduced by using measured $Z$’s $p_T$ ($Z \rightarrow \mu \mu$)
Summary

• We performed a practical analysis using W decays to give general descriptions of missET performances.
  • Maximum likelihood fit with “MT-SumEt” 2-D distributions

• We examined the feasibility including possible background processes, and showed it works as expected.

• The fitting gives correct answers for missET performances; consistent with G4 full simulation says (baseline performance).
  • $\sigma_{MEX/Y} = 0.536 \times \text{sumET}(\text{rec})^{1/2} \oplus \sigma_{\text{muon ineff}}$
  • Can achieve an accuracy of <1% using a few 10 pb$^{-1}$ data
backup
Object definition

Muon:
• Staco combined
• $|\eta| < 2.5$
• Isolation requirement of $\text{EtCone}(\Delta R=0.2)<10\text{GeV}$

Electron:
• Tight ID
• $|\eta| < 2.5$
• $\text{EtCone}(\Delta R=0.2)<10\text{GeV}$

Etmiss/SumEt:
• RefinedMETFinal algorithm
Muon ID efficiency

ID requirement:
- Staco combined muon
- $p_T > 20\text{GeV}/c$
- $|\text{eta}| < 2.5$

trigger eff. included
Fitting procedure

maximum likelihood fit using 2D binned data of “MT-SumEt”

• 4 free parameters
  • Exmiss resolution parameter ($\alpha$), visible Etsum scale ($\beta$) and two BG fractions of QCD ($f_{QCD}$) and ttbar ($f_{top}$)
  • Signal and background PDF’s for parameters $\alpha$ and $\beta$
  • Convolute PDF’s
    • $\Sigma f_i \times \text{PDF}_i (\alpha, \beta)$; $i=W\rightarrow \mu\nu, W\rightarrow \tau\nu, Z\rightarrow \mu\mu, Z\rightarrow \tau\tau, \text{Top}, \text{QCD}$
    • $\Sigma f_i = 1$
    • $f_{W\rightarrow \tau\nu}/f_{W\rightarrow \mu\nu}, f_{Z}/f_{W\rightarrow \mu\nu}$: constant
  • Fit PDF to data (using shape only) by Minuit
    • Fitting region: SumEt > 100 GeV, MT>0
Preparation of PDF’s

1. Generate a signal/BG MC event and suppose a certain set of resolution $\alpha$ and scale $\beta$.

2. Smear truth Ex(y)miss with a given resolution in Gaussian regime.
   - Resolution = $\alpha ( \beta \times EtSumTruth )^{1/2}$
     (Truth Ex(y)miss is calculated by all interacting particles other than muons, with $|\eta|<5$)

3. Reduce muons according to the ID efficiencies $\varepsilon(p_T, \eta)$ and set Ex(y)miss:
   - $Exmiss = (smeared\ truth\ Exmiss) - \Sigma random\_binary(\ varepsilon)\times p_x^\mu$
   - $\varepsilon(p_T, \eta)$ is based on fullsim data for the moment

4. Apply the selection cuts on the event. If passed, we fill it in “MT-SumEt” histogram.
   - $SumEt = \beta \times EtSumTruth$

5. Repeat the toy event generation described above and make “MT-SumEt” histograms for various parameters.