Missing Transverse Momentum (Ptmiss) in PbPb collisions with CMS detector at LHC

TNOURJI Abdellah
Supervisor : Émilien Chapon
Outlook

- Introduction
- LHC
- CMS
- Ptmiss
- Ptmiss in $Z \rightarrow \mu\mu$
  - Dataset
  - $Z$ Event selection
  - Particle Flow and constituent subtracted
  - Ptmiss
- Ptmiss in $W \rightarrow \mu\nu$
  - Dataset
  - $W$ Event selection
  - MT
- Summary and Outlook
Introduction

- At LHC a significant, unmeasured amount of energy is escaped in z direction.

- The initial and final momentum is zero in transverse direction, so the imbalance energy in transverse direction signals presence of weakly or non-interaction particle such as neutrino. \textbf{P_{\text{miss}}}

The main purpose of my project is the calculation of P_{\text{miss}} in PbPb collisions with an identified Z boson or W boson.
CMS DETECTOR
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

STEEL RETURN YOKE
- 12,500 tonnes

SILICON TRACKERS
- Track (100x100 µm): 10cm ~66M channels
- Microstrips (80x180 µm): ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
- Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
- Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
- Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
- ~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels

Determine centrality
reconstruct muons
Ptmiss

Ptmiss corresponds to the transverse momentum that is carried by weakly interacting particles.

Ptmiss can be defined as the imbalance in the transverse momentum of all particles that interact with the detector.

Ptmiss is the negative of the vectorial sum of the transverse momenta of all PF particles.

\[
Ptmiss = \sqrt{P_{xMiss}^2 + P_{yMiss}^2}
\]

\[
P_{x(y)\text{Miss}} = - \sum Pt_{x(y)}
\]

\(P_{x(y)}\) sum of transverse momentum of all PF particles in \(x(y)\) direction.
Ptmiss in Z->mumu

Data and simulation samples

The performance of missing transverse energy is presented using \( \sqrt{S_{NN}} = 5.02 \text{TeV} \) PbPb collision data collected with CMS detector in 2015, corresponding to an integrated luminosity of 400 \( \mu b^{-1} \). Also, Ptmiss is studied for the first time in this dataset.

Simulated Standard Model background sample is produced using Pyquen (based on Pythia).

Z event selection

Exactly 2 muons, \(|\eta(\mu)| < 2.4\) \(81 \text{GeV} < M(\mu\mu) < 100 \text{GeV}\)

\(p_T(\mu) > 25 \text{ GeV}\)
Invariant mass

Z Boson Mass

- MC
- Data

Ratio Data/MC vs Invariant mass (GeV)
Particle Flow and constituent subtracted

Particle Flow (PF)

Constituent Subtraction (CS)

- A method used to subtract the average underlying event background particle-by-particle.
Ptmiss Selection

- Using PF particles (with or without CS)
- ID \{ 1, 2, 3, 4, 5 \}
- Centrality \{0-10\%, 10\%-30\%, 30\%-50\%, 50\%-100\% \}

**Centrality**: quantity reflecting the impact parameter of the colliding nuclei, using the percentage of the total cross section, which is evaluated using the sum of the total energy deposited in both forward hadron calorimeters.

<table>
<thead>
<tr>
<th>ID</th>
<th>Particle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>charge hadron</td>
</tr>
<tr>
<td>2</td>
<td>electron</td>
</tr>
<tr>
<td>3</td>
<td>mu</td>
</tr>
<tr>
<td>4</td>
<td>gamma</td>
</tr>
<tr>
<td>5</td>
<td>neutral hadron</td>
</tr>
</tbody>
</table>
Centrality reweighing

The MC sample is reweighted to match the data distribution before using MC sample for any corrections:

\[
\text{Centrality reweighing} = \frac{\text{Centrality bin(data)}}{\text{Centrality bin(MC)}}
\]
$|\eta(\mu)| < 2.4$ $p_T(\mu) > 25$ GeV PF

Ptmiss not well modelled in simulation, restricting to $1 \leq \text{PFid} \leq 5$ improves modelling
\[ |\eta(\mu)| < 2.4 \ p_T(\mu) > 25\text{Gev} \ \text{PF ID \{1,5\} PF Ptmiss for different Centrality range} \]

- Chi2/NDF = 49.44/38
- 0-10%
- mean = 68 Gev

- Chi2/NDF = 44.72/39
- 10-30%
- mean = 60 Gev

- Chi2/NDF = 36.86/32
- 30%-50%
- mean = 32 Gev

- Chi2/NDF = 9.95/21
- 50-100%
- mean = 15 Gev
$|\eta(\mu)| < 2.4 \ p_T(\mu) > 25 \text{Gev} \ \text{PF} \ \text{ID} \{1,5\} \ \text{CS} \ \text{Ptmiss}$

for different Centrality range

- $\text{Chi2/NDF} = 214.70/33$  
  - 0-10%

- $\text{Chi2/NDF} = 416.026/39$  
  - 10-30%

- $\text{Chi2/NDF} = 107.50/50$  
  - 50-100%

- $\text{Chi2/NDF} = 16.20/21$  
  - 50-100%
Ptmiss in $W \rightarrow \mu \nu$

Transverse mass:
used when one particle cannot be detected directly but is only indicated by missing transverse momentum and energy

$$MT = \sqrt{2 \times Pt_{miss} \times muPt \times (1 - \cos(\Delta \varphi))}$$

Where: $\Delta \varphi$ is the angle in the transverse plane between the lepton and the direction of the missing transverse energy.
Ptmiss

MET Data/MC ID== 1 |eta|< 2.4 mupt > 25

mean 42 Gev

mean 50 Gev
Event Selection

- $p_T(\mu) > 25$ Gev
- $|\eta(\mu)| < 2.4$
- $P_{t\text{miss}} > 60$ Gev
- $M_T > 40$ Gev
- bad agreement.
- likely presence of background
Summary and outlook

Summary

• Z boson Experimentally well understood and easy to reconstruct with low background

• Calculating ptmiss is a big challenge in PbPb and its value is the key to study W boson production, but also top quark production and physics beyond the standard model

• Ptmiss resolution depends on centrality.

• Non-zero ptmiss values arise from the presence of a neutrino in the event (W boson decays), but also from the resolution of the detector (Z boson decays)

• Outlook

  • Study W boson in more details.
Thank You!
back up

For one single muon

Pt Data/MC |\(\eta| < 2.4\)
For one single muon
$|\eta(\mu)| < 2.4$ $p_T(\mu) > 25$ Gev ID==1 PF Ptmmiss

0-10%
mean 48 Gev

10%-30%
mean 30 Gev

30%-50%
mean 20 Gev

50%-100%
mean 5 Gev
$|\text{Eta}| < 2.4 \text{ mupt } > 25 \text{ CS}$

- **MET Data/MC(Weigh) ID=1**: $|\text{Eta}| < 2.4 \text{ mupt } > 25 \text{ CS}$
  - Mean: 50 Gev

- **MET Data/MC(Weigh) ID=1,5**: $|\text{Eta}| < 2.4 \text{ mupt } > 25 \text{ CS}$
  - Mean: Gev
|Eta| < 2.4 mupt > 25 ID==1 CS

MET Data/MC(Weigh) ID==1 IETAI < 2.4 mupt > 25 hiBin 0-10%

0-10%
mean
50 Gev

MET Data/MC(Weigh) ID==1 IETAI < 2.4 mupt > 25 hiBin 10%-30%

10%-30%
mean
40 Gev

MET Data/MC(Weigh) ID==1 IETAI < 2.4 mupt > 25 hiBin 30%-50%

30%-50%
mean
30 Gev

MET Data/MC(Weigh) ID==1 IETAI < 2.4 mupt > 25 hiBin 50%-100%

50%-100%
mean
15 Gev