Higgs mass reconstruction using MAOS momentum at the LHC

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Summary

**Higgs mass reconstruction using MAOS momentum at the LHC**

We applied $M_{T2}$-Assisted On-Shell (MAOS) momenta to reconstruct Higgs mass in the Higgs mass range $130 \sim 180 \; GeV$. $M_{T2}$ is of generalization of transverse mass to the event producing two invisible particles such as neutrinos.$[1]$  

The MAOS Higgs mass distribution gives us a good determination to approximate the Higgs boson mass in $H \rightarrow W^+ W^-$. 

**Keywords**: Mass reconstruction, Higgs mass, MAOS, $M_{T2}$, Transverse mass.
Chapter 1

Introduction

Finding the Higgs boson through experiment would prove that the Higgs field exists, and this is one of the main goals of the CMS experiment at the LHC. In the Higgs mass range $130 \sim 180 \text{ GeV}$, Higgs mainly decays to $WW$ pair. So it is best channel to search for the Higgs boson in the Standard Model. However, this channel involves two neutrinos, and we cannot reconstruct the Higgs mass directly. Therefore, we attempted to use kinematic variable, $M_{T2}$-Assisted On Shell (MAOS) to approximate the neutrino's momenta. With these MAOS momenta, we can reconstruct Higgs mass which becomes true Higgs mass.[2]
Chapter 2

Higgs Boson in Standard Model (SM)

2.1 Higgs Boson in Standard Model (SM)

The universe is made of 6 kinds of quarks and 6 kinds of leptons. These 12 fundamental particles known in Standard Model (SM) stuck together by four forces of nature. The Higgs boson is the only Standard Model particle that has not been observed. Higgs boson was first hypothesised by Peter Higgs in 1964.

In the Standard Model (SM), The Higgs particle gives masses to $W^\pm$, and $Z$ weak gauge bosons through electroweak symmetry breaking. Moreover, the Higgs boson would explain the difference between the massless photon and the massive $W^\pm$ and $Z$ bosons. The Large Hadron Collider (LHC) at CERN is expected to provide experimental evidence that Higgs particle is exist.

2.2 Higgs Mechanism

In the Standard Model (SM), the electroweak interactions are described by a gauge field theory based on the $SU(2) \times U(1)$ symmetry group. $SU(2) \times U(1)$ electroweak symmetry is broken by the Higgs mechanism.
A single complex doublet of scalar Higgs fields transform as a doublet under $SU(2)$. Two complex scalar fields $\phi$ are introduced:[5]

$$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$$

$$= \begin{pmatrix} \phi_1 + i \phi_3 \\ \phi_2 + i \phi_4 \end{pmatrix}$$

(2.1)

with lagrangian which is invariant under local $SU(2) \times U(1)$ transformation.

$$\begin{align*}
L &= \bar{\psi}_L \gamma^\mu [i \partial_\mu - g T^a W_\mu - \frac{g'}{2} Y B_\mu] \psi_L + \bar{\psi}_R \gamma^\mu [i \partial_\mu - \frac{g'}{2} Y B_\mu] \psi_R \\
&\quad - \frac{1}{4} W_{\mu\nu} \cdot W^{\mu\nu} - \frac{1}{4} B_{\mu\nu} \cdot B^{\mu\nu} \\
&\quad + (i \partial_\mu \phi - g \frac{\tau}{2} \cdot W_\mu \phi - \frac{g'}{2} Y B_\mu \phi)(i \partial_\mu \phi - \frac{g}{2} \cdot W_\mu \phi) - \frac{g'}{2} Y B_\mu \phi) \\
&\quad - \mu^2 \phi^\dagger \phi - \lambda (\phi^\dagger \phi)^2
\end{align*}$$

(2.2)

The Higgs potential $V(\phi^\dagger \phi)$ is defined as [5]

$$V(\phi^\dagger \phi) = \mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

(2.3)
Figure 2.1: Higgs potential.

In the right panel, Fig. 2.1, circle of degenerate minimum is

$$|\phi| = \sqrt{-\frac{\mu^2}{2\lambda}} \equiv \frac{v}{\sqrt{2}} \quad (2.4)$$

when we choose a particular direction in the internal SU(2) space for the minimum [5]

$$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \quad (2.5)$$

This vacuum expectation value in eq (2.3) breaks $SU(2) \times U(1)$ symmetry.

and becomes

$$\phi(x) = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + H(x) \end{pmatrix} \quad (2.6)$$

when we apply eq (2.3) to the eq (2.1), the Lagrangian is
\[ L = \frac{1}{2} (\partial_{\mu} H)(\partial^{\mu} H) - \frac{1}{4} F_{\mu\nu} \cdot F^{\mu\nu} \] 

\[ - \frac{1}{2} W_{\mu}^+ \cdot W^{\mu\nu} + \frac{g^2 v^2}{4} (W_{\mu}^a W^a) \] 

\[ - \frac{1}{4} Z_{\mu} \cdot Z^{\mu\nu} + \frac{1}{8} (g^2 + g'^2) Z_{\mu} Z^\mu \cdots \] 

(2.7)

in this case, \( SU(2)_L \times U(1)_Y \rightarrow U(1)_{em} \) symmetry is broken. From this Lagrangian (2.7), three massless Goldstone bosons are generated, which are absorbed to give masses to the \( w \) and \( z \) gauge bosons.[5]

\[ m_w = \frac{1}{2} g v = 80 \text{ GeV} \] 

(2.8)

\[ m_z = \frac{v}{2} \sqrt{g^2 + g'^2} v = \frac{m_w}{\cos \theta_w} = 90 \text{ GeV} \] 

(2.9)

where Weinberg angle is defined as \( \sin^2 \theta_w = 0.225 \pm 0.05 \).

The remaining component of the complex doublet becomes the Higgs boson – a new fundamental scalar particle. The Higgs boson mass is given by

\[ m_H = \sqrt{2 \lambda v^2} = \sqrt{-2\mu^2} \] 

(2.10)

where \( \lambda \) is the Higgs self-coupling parameter and \( v \) is the expectation value of the Higgs field [5]

\[ v \approx 246 \text{ GeV} \] 

(2.11)
since $\lambda$ is presently unknown, the value of the SM higgs boson mass cannot be predicted. Although the Higgs mass cannot be predicted in the Standard Model, the mass range is excluded by some experiments. It is presented in 2.3

## 2.3 Higgs mass and branching ratios

The cross section for the production of SM Higgs bosons is given in Fig.2.2 for pp collisions at the LHC. The largest channel for production of the Higgs boson is $pp \rightarrow H$ gluon fusion, with the qqH coupling.

![Image of Standard Model Higgs boson production cross sections](image)

**Figure 2.2:** Standard Model Higgs boson production cross sections.
The proportion of decays to a particular decay mode is called the branching ratio. The Fig.2.3 shows the branching ratios depend on the Higgs mass. For masses below $130\, GeV$, the Higgs decays mainly in a pair of $b$ quarks. The decay into a pair of tau leptons is also important in that region of mass. The search in the 2 photons final state is relevant for a Higgs mass lower than $150\, GeV$. A Higgs boson with mass $m_H > 135\, GeV$ decays predominantly to $W$ boson pairs with one of the $W$’s potentially off mass–shell. In this mass range inclusive production through gluon fusion is dominant at the LHC, with the best sensitivity occurring around $160 \sim 170\, GeV$, where the $WW$ decay mode is fully open. So $H \to WW$ is the best channel for the Higgs search in the mass range $135\, GeV \leq m_H \leq 180\, GeV$.\textsuperscript{[6]}

![Figure 2.3: Standard Model Higgs boson decay branching ratios.](image)

Higgs mass limits is $m_H < 114\, GeV$ by Large Electron - Positron Collider (LEP) experiment at 95\% confidence level. And as of July 2010, combined data from
CDF and DØ experiments at the Tevatron have excluded the Higgs mass in the range between $158 \sim 175 \text{ GeV}$ at 95% confidence level\cite{7}.

Figure 2.4: Standard Model Higgs boson decay width.
Chapter 3

The Large Hadron Collider (LHC) and the Compact Muon Solenoid (CMS) Experiment

3.1 Large Hadron Collider (LHC)

LHC is the largest and high energy particle accelerator which is 27 kilometers in circumference. When the protons are accelerated around 99.9999% the speed of light. They go around that 27 kilometers 11,000 times a second and collide with another beam of protons going in the opposite direction. The center of mass energy is \( \sqrt{S} = 14 \text{ TeV} \).

Fig3.1 shows the LHC experiments and the preaccelerators. The path of the protons begins at linear accelerators (marked p and Pb, respectively). They continue their way in the booster (the small unmarked cycle), in the Proton Synchrotron (PS), in the Super Proton Synchrotron (SPS) and finally they get into the 27 km LHC tunnel. There are 4 large experiments CMS, ATLAS, ALICE, and LHC b.[8]
3.2 Compact Muon Solenoid (CMS) detector

CMS is a general purpose particle detector to be operated in high-energy collisions at the Large Hadron Collider (LHC) at CERN. It is 21.6 meters wide and 15 meters in diameter, with 12,500 tons of total weight. CMS detector consists of 4 main sectors: tracking systems, calorimeters, magnet and muon systems.

Innermost part is silicon-based tracking system which measures momentum of particles. It provides precise measurements of track trajectories.

In the next layer of the detector, the energies of the particles are measured in calorimeters. The first calorimeter is designed to measure the energies of electrons and photons. Electrons and photons are stopped by the Electromagnetic Calorimeters (ECAL), allowing their energy to be measured, and then in the next layer, the Hadronic Calorimeters (HCAL), hadrons, deposit most of their energy.
Only muons and neutrinos fly through trackers and calorimeters. At the end of the detector, there are many irons to stop muon since muon has strong penetration depth. Neutrinos, however, are neutral and since they hardly interact at all they escape detection. By adding up the momenta of all the detected particles, and assigning the missing momentum to the neutrinos, we are able to tell where these particles.

Figure 3.2: Overall view of the CMS detector.
3.2.1 Coordinate conventions

The shape of CMS detector is cylindrical and forward-backward symmetric since the detector is in the Center of Mass frame. When the beam line is on the z-direction, the geometry of detector can be easily described in the \((r, \eta, \phi)\) coordinate system.

The azimuthal angle \(\phi\) is measured from the x-axis in the x-y plane. The polar angle \(\theta\) is measured from the z-axis.[8]

The pseudo rapidity \(\eta\) is related to the polar angle \(\theta\) and is invariant under lorentz boost along z-axis.

\[
y = \frac{1}{2} \ln \left( \frac{E^+ p_z}{E^- p_z} \right) = - \ln \tan \left( \frac{\theta}{2} \right) \equiv \eta
\]  

(3.1)
3.2.2 Trackers

The tracking detector of CMS is currently the largest silicon detector in the world. It has $205^2$ of silicon sensors (approximately the area of a tennis court) comprising 76 million channels.

Particles emerging from collisions first meet the tracking systems, made of silicon. These accurately measure the positions of passing charged particles. Especially when a charged particle go through the matter, atom in the materials are ionized by absorbing the kinetic energy of the moving particle via electromagnetic interaction.[8]

It allows us to reconstruct their tracks, so it provides precise measurements of track trajectories. The inner tracker aims to reconstruct and match all reconstructed high pt electrons and muons produced at the $\eta < 2.6$, and to recognize all tracks with $p_T > 2 \text{ GeV}$. Microstrip gas chambers, silicon and
pixel detectors provide the granularity sufficient to operate at the highest luminosity.

### 3.2.3 Magnet

Between the calorimeters and Muon system in the CMS detector, there are huge solenoid magnets that bend electrically charged particles. Charged particles follow spiralling paths in the CMS magnetic field and the curvature of their paths reveal their momenta. This takes the form of a cylindrical coil of superconducting cable that generates a magnetic field of 3.8 Teslas, about 100,000 times that of the Earth. It enables us to design the CMS detector compact as it is correctly named.[9] The magnetic field is confined by a steel 'yoke' that forms the bulk of the detector’s weight of 12,500 tones.[8]

### 3.2.4 Calorimeters

**Electromagnetic Calorimeters (ECAL)**

Calorimeters divided in two parts. Electromagnetic Calorimeters (ECAL) and Hadron Calorimeters (HCAL).

The CMS ECAL consists of a hermetic homogeneous calorimeter made of 61200 lead tungstate (PbWO4) crystals in the central barrel part, 7324 crystals in each of the two endcaps, and a preshower detector in front of the endcap crystals. ECAL stops photons, electrons.
Photon is electrically neutral so it passes through the tracker undetected and not bent by the magnetic field. They interact in the ECAL in a similar way to electrons, producing electromagnetic showers that leave their energies in the form of light that is detected.

Electrons are electrically charged particles bend in the field and leave signals in the tracker, enabling their paths to be reconstructed. The amount of bend depends on the momentum they carry, with the radius of curvature, r, being given by the momentum, p, divided by 0.3xB, where B is the magnetic field strength (3.8 T in CMS). Electrons are slowed to a stop in the transparent lead tungstate crystals of the ECAL, producing a shower of electrons, photons and positrons along the way and depositing their energy in the form of light, which is detected. The amount of light is proportional to the electron energy.[8]

**Hadron Calorimeters (HCAL)**

Charged hadrons, such as protons are bent by the magnetic field and travel straight through the ECAL leaving almost no signals. Upon reaching the HCAL they are slowed to a stop by the dense materials, producing showers of secondary particles along the way that in turn produce light in thin layers of plastic scintillator material. The amount of light is proportional to the energy of the incoming hadron.

Neutral hadrons, such as neutrons, travel straight through the Tracker and ECAL, without being bent by the magnetic field or leaving any signals. Like charged hadrons, they are slowed to a stop in the HCAL, depositing their energy and leaving signals in the form of light in the plastic scintillators. The
amount of light is proportional to the energy of the incoming hadron. [8]

3.2.5 Muon system

Outermost part of the CMS is Muon system. The muon system consists of three types of gaseous detectors which are used to identify and measure muons.

Muon leaves signals in the tracker and muon chambers almost nothing seen in the calorimeters. These are perhaps the easiest particles to identify in CMS: no other charged particles pass through the whole detector. Being charged, they are bent by the field in one direction inside the solenoid and in the opposite direction outside. [8]

Reliable and efficient identification and high energy resolution (of about 1% over the large momentum range) for muons, photons and electrons are emphasized in the design considerations.
Chapter 4

$M_{T2}$-Assisted On Shell (MAOS) reconstruction of Higgs mass

4.1 $M_{T2}$-Assisted On Shell (MAOS)

Let us consider Higgs to dilepton decays at the LHC.

$H \rightarrow W^+(p+k) W^-(q+l) \rightarrow \ell^+(p) \bar{\nu}(k) \ell^-(q) \nu(l)$ with $\ell = e, \mu$,

where $p, q$ denotes transverse momentum of each leptons and $k, l$ denotes transverse momentum of each neutrinos.

In this case, each $W$ boson decays to one lepton and one neutrino. The neutrinos, however, fly through whole detectors and only leaves missing momentum.\cite{10} Since each neutrino's momenta are unknown, we cannot reconstruct the Higgs mass directly. Therefore, we used kinematic variable $M_{T2}$, which is a generalized transverse mass to an event with two missing particles.\cite{11}

Final state momentum in beam direction is unknown since we do not know the initial partonic center of mass frame in proton-proton collision at hadron collider. When the beam line is in the $z$-direction, there is a value, transverse
momentum which is invariant under longitudinal boost. From which we can measure transverse momentum on the transverse plane.\[12\] The transverse energies of lepton and neutrino are defined as

\[ E_T^\ell = \sqrt{(p_T^\ell)^2 + m_\ell^2} \quad \text{and} \quad E_T^\nu = \sqrt{(p_T^\nu)^2 + m_\nu^2} \quad (4.1) \]

We can define transverse mass of W boson\[13\][14]

\[ m_T^2(p_T^\ell, p_T^\nu; m_\nu) = m_\ell^2 + m_\nu^2 + 2(E_T^\ell E_T^\nu - p_T^\ell \cdot p_T^\nu) \quad (4.2) \]

where \( m_\nu \) and \( p_T^\nu \) denote the invariant mass and transverse momentum of the missing neutrino.\[15\]

We only know the sum of \( p_T^{\nu_1}, p_T^{\nu_2} \), such that their sum gives the observed missing transverse momentum \( p_T^{\nu_1} + p_T^{\nu_2} = p_T^{\text{missing}} \). Not knowing the MET vector splitting, the minimization is performed with the constraint \( p_T^{\nu_1} + p_T^{\nu_2} = p_T^{\text{missing}} \), where the Missing Transverse Energy (MET) is constrained to the missing transverse momentum.\[16\]

\[ m_\ell^2 \geq M_{T2}^2 \quad (4.3) \]

\[ \equiv \min \left[ \max \left\{ m_T^2(p_T^\ell, p_T^{\nu_1}), m_T^2(p_T^\ell, p_T^{\nu_2}) \right\} \right] \]

We can obtain directly \( M_{T2} \) from experimentally measured parameters.\[17\] Minimization is done by trying all possible trial neutrino momenta.\[18\]
When there are \( N \) invisible particles in the process we can define \( m_{TN} \) as well. Once each momenta of neutrinos are obtained, we call it MAOS momentum of neutrino, and using them we can construct the MAOS Higgs mass:[1]

\[
(m^{\text{MAOS}}_H)^2 \equiv (p + k_{\text{maos}} + q + l_{\text{maos}})^2
\] (4.4)

where \( k_{\text{maos}} \) and \( l_{\text{maos}} \) denote the reconstructed MAOS momenta of each neutrino.

MAOS momenta is useful not only for the mass measurement of SM but also for super-symmetric particles which always involves at least two invisible particles.

### 4.2 Monte-Carlo sample

We used the PHythia6 to generate simulated samples of \( H \rightarrow W^+ W^- \rightarrow \mu^+ \mu^- \nu[19] \) with CMSSW 3.6.2 for detector simulation and event reconstruction. In this thesis we only consider muon but not electron in the final states. We also included dominant backgrounds coming from \( \bar{q}q \rightarrow WW \rightarrow \mu^+ \nu \mu^- \bar{\nu} \) and \( t \bar{t} \rightarrow WW \rightarrow b \mu^+ \nu b \mu^- \bar{\nu} \) in which two top quarks decay into a pair of \( W \) bosons and two \( b \) jets.

Effective cross-section \( \sigma \) has been made in Table 4.1.
Table 4.1: Effective cross-section $\sigma$ for both signal and backgrounds.

<table>
<thead>
<tr>
<th>Process</th>
<th>Effective cross-section (fb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \mu^- \bar{\nu}$ for $m_H = 130$ GeV</td>
<td>9.13</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \bar{\nu}$ for $m_H = 140$ GeV</td>
<td>16.67</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \bar{\nu}$ for $m_H = 150$ GeV</td>
<td>24.73</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \bar{\nu}$ for $m_H = 160$ GeV</td>
<td>34.12</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \bar{\nu}$ for $m_H = 170$ GeV</td>
<td>31.70</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \bar{\nu}$ for $m_H = 180$ GeV</td>
<td>28.10</td>
</tr>
<tr>
<td>$qg \rightarrow WW \rightarrow \mu^+ \nu \mu^- \bar{\nu}$</td>
<td>54.58</td>
</tr>
<tr>
<td>$t \bar{t} \rightarrow WW \rightarrow b\mu^+ \nu \bar{b}\mu^- \bar{\nu}$</td>
<td>2.05</td>
</tr>
</tbody>
</table>

4.3 Sample Selection

We finalized cuts to maximize the significance.

- Two opposite-sign muons with $p_T > 15 GeV$ and $|\eta| < 2.5$
- Muon isolated $p_T < 3 GeV$
- No jets with $p_T > 20 GeV$
- $M_{T2} > 40 GeV$
<table>
<thead>
<tr>
<th>Process</th>
<th>No cuts</th>
<th>After final selection</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 130$</td>
<td>5004</td>
<td>1255</td>
<td>0.251</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 140$</td>
<td>3872</td>
<td>1236</td>
<td>0.319</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 150$</td>
<td>1824</td>
<td>714</td>
<td>0.391</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 160$</td>
<td>1680</td>
<td>1272</td>
<td>0.757</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 170$</td>
<td>2840</td>
<td>1442</td>
<td>0.508</td>
</tr>
<tr>
<td>$H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 180$</td>
<td>1914</td>
<td>912</td>
<td>0.476</td>
</tr>
<tr>
<td>$q\bar{q} \rightarrow W W \rightarrow \mu^+ \nu \mu^- \nu$</td>
<td>5652</td>
<td>896</td>
<td>0.159</td>
</tr>
<tr>
<td>$t \bar{t} \rightarrow WW \rightarrow b \mu^+ \nu b \mu^- \nu$</td>
<td>730</td>
<td>137</td>
<td>0.188</td>
</tr>
</tbody>
</table>

Table 4.2: Number of $m_{H_{mag}}$ events before and after final selection.

Figure 4.2: Transverse momentum, $\eta$ and $\phi$ of muons in $H \rightarrow W^+ W^- \rightarrow \mu^+ \nu \mu^- \nu$ for $m_H = 160$ GeV.
4.4 Mass Reconstruction of Higgs using MAOS.

We reconstructed Higgs mass using MAOS methode. In Fig.4.3, for the each Higgs mass $130 \sim 180 \text{ GeV}$, the $m_{\mu \mu}^{\text{MAOS}}$ distribution has a clear peak at the true Higgs mass after final selection including $M_{T2}$ cut.[16] This cut is also useful since it enhances the accuracy of the MAOS reconstruction of the neutrino momenta and the significance $\frac{S}{\sqrt{S+B}}$. 
Figure 4.3: The $m_{\mu\mu}$ distribution after final selection for the each Higgs mass $130 \sim 180 \text{ GeV}$ at $L = 5 fb^{-1}$. 
Figure 4.4: Mean of $m_{HOAS}^\text{MOAS}$ vs true Higgs mass.

The Fig.4.4 shows good linearity between mean of $m_{HOAS}^\text{MOAS}$ and true Higgs mass.

We performed pseudo-experiments to estimate the mass sensitivity of the method. Template histogram of signal plus backgrounds were used to generate events for a given $m_{HOAS}$ at Fig.4.5.

Then comparisons to various templates allowed us to obtain $\chi^2$ as a function of $m_{HOAS}$. $\chi^2$ is defined as

$$\sum_{n=1}^{50} \frac{(\text{observed events} - \text{expected events})^2}{\text{expected events}}$$

(4.5)

where the n denotes the number of bins of x-axis.

A $\chi^2$ fit analysis has been made in Fig.4.6.
Figure 4.5: The expected $m_{H}^{\text{miss}}$ distributions assuming $L = 5 \text{ fb}^{-1} (\text{left})$ and $10 \text{ fb}^{-1} (\text{right})$ for Higgs mass $150 \sim 170 \text{ GeV}$.
Figure 4.6: The $\chi^2$ distributions assuming $L = 5 fb^{-1}(left)$ and $10 fb^{-1}(right)$ for Higgs mass $150 \sim 170 GeV$. 
From the result of a parabolic fit to $\chi^2$ versus $m_H$ distribution in Fig.4.6, we obtain the mass resolutions which is defined as $\frac{1}{\sqrt{a}}$. 'a' is a coefficient of quadratic term of $\chi^2$ fit.[20] Each mass resolution has been made in Table 4.3.

<table>
<thead>
<tr>
<th>$m_H^{max}$ (GeV)</th>
<th>150</th>
<th>160</th>
<th>170</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 $fb^{-1}$</td>
<td>5.624</td>
<td>6.198</td>
<td>4.713</td>
</tr>
<tr>
<td>10 $fb^{-1}$</td>
<td>3.336</td>
<td>3.115</td>
<td>3.436</td>
</tr>
</tbody>
</table>

Table 4.3: Mass resolution (GeV) for each Higgs mass.

One thing they have in common is the mass resolution is smaller at 10 $fb^{-1}$ than 5 $fb^{-1}$.

It seems that Higgs boson discovery requires at least more luminosity than 5 $fb^{-1}$. Luminosity is currently about $43.2 \ p\ fb^{-1}$ in November 2010.[21]

The result including plots in this section shows us that MAOS momentum would be a good kinematic variable to approximate Higgs boson mass at the LHC.
Conclusions

In this analysis, we have discussed the MAOS method to determine the Higgs boson in dileptonic decay with missing energy. The method can be applied to any processes, in which mother particles are pair-produced and each decays to one invisible and some visible particles. It helps us to search for the Higgs mass measurement at the LHC.
국문 초록

거대 강입자 가속기에서 MAOS 운동량을 이용한 히크스입자의 질량 재구성

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표준 모형의 히크스 입자의 질량을 130 ~ 180 GeV 영역대로 본다면 $H \rightarrow W^+ W^-$ 가 주요한 분해과정으로 히크스가 2개의 W 보존으로 분해하고 각각의 W 보존은 한 개의 레pton과 중성미자로 분해한다. 중성미자는 검출기에 혼적을 남기지 않으므로, 즉 중성미자 각각의 질량을 모르기 때문에 히크스입자의 질량을 정확하게 재구성 할 수 없다. 그래서 $M_{T2}$-Assisted On-Shell (MAOS)라는 알고리즘을 이용해 히크스입자의 질량을 재구성 하는게 이 연구의 목적이다.

Transverse mass는 검출기에서 범이 충돌하는 쪽을 z-축이라 할 때 범위인과 수직이 되는 운동량과 에너지에 의해 정의된다. 이 Transverse mass의 확장된 개념인 $M_{T2}$ 변수를 이용한 MAOS 운동량을 적용해 히크스 입자의 질량을 재구성하였고 MAOS 방법이 기존의 방법보다 효과적임을 확인하였다. 이 분해과정에 대해 각각 LHC에서 CMS 실험을 위한 CMSSW를 이용해 Monte Carlo Simulation을 수행하였다.

본 연구에서는 이렇게 MAOS 방법을 적용한 각각의 결과를 비교하고 이 방법이
보이지 않는 입자가 있는 붕괴과정에서도 재구성이 가능하여 더 정확한 힌스입자의 질량을 예측 할 수 있음을 확인 하였다.
References


