Light Higgs Discovery Potential with ATLAS, Measurements of Couplings and Impact on Model Discrimination

**Junichi TANAKA
ICEPP, Univ. of TOKYO**

On behalf of the ATLAS Collaboration

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Outline

- LHC Schedule
 - ATLAS Detector
 - Motivation
1. Light Higgs Discovery Potential
 - Production cross section and branching ratio of SM Higgs
 - $H \rightarrow \gamma\gamma$, $H \rightarrow \tau\tau$ and $H \rightarrow WW$
 - Discovery potential
 2. Measurement of Couplings and Model Discrimination
- Summary

LHC Schedule

LHC is composed of 1232 superconducting dipole magnet.

- Length = 14m
- Provide $B=8.3\text{Tesla}$ working at 1.9 Kelvin
- 90% of them were assembled.
- 40% of them were installed in the LHC tunnel.

**Two general-purpose pp experiments:
ATLAS and CMS**

- April, 2007 : cosmic and single beam
- Summer, 2007 : physics run $\rightarrow L = \sim 0.1\text{fb}^{-1}$ in 2007 **Calibration** with lower energy $\sim$ Tevatron?
- $L = \sim$ a few fb^{-1} in 2008 **SUSY?, Higgs?** with 14TeV
- $L = \sim 10\text{fb}^{-1}$ in 2009, then increase the luminosity to the design.

Higgs

ATLAS Detector

ATLAS		Detector characteristics	
		Width:	44m
		Diameter:	22m
		Weight:	7000t
CERN AC - ATLAS V1997

E,P resolution

– $\mu \sim 2\%$

- $e, \gamma \sim 1.5\%$

- jet $\sim 8\%$

for E,P $\sim 100\text{GeV}$

- Inner tracking system :
2T solenoid magnet
- Liq. Ar EM calorimeter
- Muon spectrometer : air-
core toroidal magnet

Detector construction is on going!

Motivation

- Discovery of Higgs boson is one of the most important purposes of LHC.
 - At the present we, ATLAS, focus on studies with the early physics data.
 - How to calibrate/estimate/evaluate what we need using data of 0.1-1.0fb⁻¹.
- After the discovery,
 - We have to identify the Higgs Boson. Is it SM Higgs or something else?
 - > We measure mass, coupling, spin, CP and so on.

In this talk,

1. Discovery Potential of Light Higgs at ATLAS
 - $H \rightarrow \gamma\gamma$, $H \rightarrow \tau\tau$ and $H \rightarrow WW$
2. Measurement of Coupling and Discrimination between SM and MSSM

1. Discovery Potential of Light Higgs at ATLAS

- The present experimental data prefers light Higgs ($M_H < \sim 200\text{GeV}$) to heavy.
 - SUSY predicts the existence of a light Higgs, whose mass is less than $\sim 130\text{GeV}$.
- Experimental signature of MSSM Lightest CP-even Neutral Higgs is similar to SM Higgs.
 - Signal rate is different with the SM case due to couplings.
 - > Can use this characteristics in order to distinguish MSSM from SM (see the next topics).
- Studies of SM Higgs are shown here.
 - $M_H < \sim 140\text{GeV}$: $H \rightarrow \gamma\gamma$ and $H \rightarrow \tau\tau$
 - $M_H > \sim 130\text{GeV}$: $H \rightarrow WW$

LEP EWWG, March 06

SM Higgs Production and Decay at LHC

LEP EWWG, March 06

$114.4 < m_H < 207 \text{ GeV}/c^2$ @95% C.L.

Excluded by LEP

$bb, \tau\tau, \gamma\gamma, WW, ZZ$ can be observed in the low mass region.

Observation of Higgs by multi modes

Can extract coupling information.

$H \rightarrow \gamma\gamma$

- Study of inclusive analysis, mainly $gg \rightarrow H \rightarrow \gamma\gamma$, has been continued.
 - Huge BG $\rightarrow S/B \sim 3\%$

R ... Signal
G ... Irreducible BG
B ... Reducible BG

Up-to-date x-sec and BR
Photon ID etc.

$\rightarrow$ Almost same result as our TDR result

H → γγ

- VBF and H+1jet analysis
 - S/B is much better than inclusive analysis.

[Idea of "H+1jet"]

- GF with additional one jet
- VBF : one of two forward jets is out of acceptance.

S is good.
S/B is not so good.

S is limited.
S/B is good.

12th June, 2006

$$H \rightarrow \gamma\gamma$$

[Working on]

- Study of additional jet(s)
 - Uncertainty from such a jet in the analysis of H+1jet and VBF
 - Understand it by using Alpgen, MC@NLO and so on.
- Photon calibration : energy scale and resolution
- Photon ID : Fake photons from jets
 - When π^0 in a jet carries most of the jet energy, this π^0 can be misidentified as a photon.
 - > A jet rejection factor of ~ 5000 for $P_t > 25\text{GeV}$ is obtained for a photon ID efficiency $\sim 80\%$.
- Conversion (recovery)
 - $\sim 40\%$ of gamma is converted. Some of them cannot be identified as gamma.
- Photon angle correction : help of calorimeter pointing

VBF $H \rightarrow \tau\tau$

- We can observe a Higgs mass peak on the right side of the Drell-Yan peak.
- We can reconstruct $M(\tau\tau)$, which corresponds to Higgs mass, using missing E_t with the collinear assumption.

Eur.Phys.J.,C32(2004)19

$$\tau^+ \tau^- \rightarrow \ell\ell 4\nu$$

Eur.Phys.J.,C32(2004)19

VBF $H \rightarrow \tau\tau$

[Working on]

- Study of 3rd jet
 - Rapidity gap is a crucial signature of VBF.
 - Understand this uncertainty using several generators.
- Tau identification
 - Reject QCD backgrounds and keep/increase signal events
 - We have developed a “track based” tau reconstruction tool.
- Mass reconstruction
 - Resolution of Missing Et
- Background estimation using real data
 - A tail from the Drell-Yan peak is in the signal region.
 - Estimation of this tail using real data is a key issue.
 - > Under study.

VBF H- > WW -> ll νν

- H- > WW dominates when Higgs mass relatively becomes large.
($M_H > \sim 130 \text{ GeV}$)
- Cannot observe a Higgs peak.
-> Check transverse mass.

$$M_T = \sqrt{2P_T(\ell\ell)E_T^{miss}(1 - \cos \Delta\phi)}$$

- S/B is good.

[working on]

- Background estimation is a key issue.
 - Use real data
 - > Under study

Discovery Potential of SM Higgs

Eur.Phys.J.,C32(2004)19

Can discover Higgs with
 $L=30\text{fb}^{-1}$ by $>8\sigma$
($M_H > 114\text{GeV}$: LEP limit)

$M_H < 200\text{GeV}$:

- Light case: VBF $\tau\tau/\gamma\gamma$
 - Heavy case: VBF WW
- Can observe Higgs
by multi-modes.

$M_H > 200\text{GeV}$:

- $H \rightarrow ZZ \rightarrow 4l$

$\sim 5\sigma$ with $L=10\text{fb}^{-1}$

-> **Discovery of Higgs
in 2009 or before**

N.B. : Not include new results.

2. Measurement of Coupling and Discrimination between SM and MSSM

- Yukawa coupling
-> Prove the origin of mass
- Check the linearity of Yukawa coupling as a function of fermion mass.

Ratio of Couplings

- In the low mass region, we can measure event rates of Higgs with multi modes. So we can extract coupling information, particularly, determination of ratios is possible with a model-independent way.

Accuracy of measurement of "ratio of coupling constants" wrt $g^2(H,W)$

ATLAS-PHYS-2003-030

With 300 fb^{-1} :

- Yukawa
 - g_t^2 : 15-30%
 - g_b^2 : 35-70%
 - g_τ^2 : 25-50%
- Gauge Boson
 - g_z^2 : 10-40%

$g_b \rightarrow \text{"VBF } H \rightarrow b\bar{b}\text{"}$

Absolute Coupling Determination

- Need a help of theory to obtain the absolute values of couplings.

Assumption [hep-ph/0407190] :

- HVV (V=W,Z) couplings cannot be larger than the SM case, namely,
 - $g^2(H,W) < g_{SM}^2(H,W)$
 - $g^2(H,Z) < g_{SM}^2(H,Z)$

This constraint is valid in generic multi-Higgs-doublet models. (eg. MSSM)

With 2x300fb⁻¹:

- Yukawa
 - g_t^2 : 25-40%
 - g_b^2 : 45-90%
 - g_τ^2 : 25-50%
- Gauge Boson
 - g_z^2 : 10-30%
 - g_w^2 : 10-25%
- Total Width : 15-50%

Discrimination between SM and MSSM

- Use only event rates of Higgs to distinguish the SM from a specific MSSM scenario. [hep-ph/0407190 -> no-mixing scenario]

- $3\sigma : M_A < 350 \text{ GeV}$, $5\sigma : M_A < 250 \text{ GeV}$.
 - hbb and $h\tau\tau$ are enhanced in this region.
 - We also expect observations of multi Higgs.

Summary

- Present experimental data prefers Light Higgs ($M_H < 200\text{GeV}$) to Heavy.
- Light Higgs is interesting from a point of view of both **discovery** and **parameter determination**.
 - Thanks to observations with multi modes.
- ATLAS can discover a Higgs boson with **10fb^{-1} or less**.
 - We are working very hard to establish how to calibrate/estimate/evaluate what we need (if possible) using the real data.
- In the low mass region, couplings and the total width can be determined with the accuracy of **a several 10% using (2 x) 300fb^{-1}** of data at LHC.
- **Real (14TeV) physics run will start in 2008.**

Backup

SM Higgs mass

- From the precision measurements:

$$m_H = 91^{+45}_{-32} \text{ GeV}$$

Including theory uncertainty:

$$m_H < 186 \text{ (95\% CL)}$$

Direct search of LEP:

$$m_H > 114 \text{ GeV (95\% CL)}$$

Renormalize probability for

$m_H > 114 \text{ GeV}$ to 100%:

$$m_H < 219 \text{ GeV (95\% CL)}$$

We put the SM Higgs into a corner. LHC can discover the SM Higgs.

Summary of Studies for SM Higgs

Combination of production and decay

Production	Decay	Mass region and purpose	
Gluon Fusion	$H \rightarrow \gamma\gamma$	110-140GeV	Discovery , Mass
	$H \rightarrow ZZ \rightarrow 4l$	140-1000 GeV	Discovery , Mass, spin, coupling
	$H \rightarrow WW$	130-170 GeV	Discovery
Vector Boson Fusion	$H \rightarrow \tau\tau$	110-140GeV	Discovery , Mass, coupling
	$H \rightarrow WW$	130-200GeV	Discovery , W coupling
	$H \rightarrow \gamma\gamma$	110-140GeV	Discovery , Mass
	$H \rightarrow bb$	110-140GeV	Yb coupling (need study of trigger)
ttH	$H \rightarrow bb$	110-130GeV	Yt coupling
	$H \rightarrow \tau\tau$	110-130GeV	
	$H \rightarrow WW$	130-180GeV	
WH	$H \rightarrow WW$	140-170GeV	Discovery , W coupling

MSSM Higgs Sensitivity for 5σ -discovery

MSSM Higgs bosons

2HDM $\rightarrow$ 4 Higgs : $h, H^0, A^0, H^{\pm}$

- 4 Higgs observable
- 3 Higgs observable
- 2 Higgs observable
- 1 Higgs observable

We can observe two or more Higgs over most of parameter space.

“Only h ” and
 “ $h \sim$ SM Higgs”
 $\rightarrow$ How to disentangle SM/MSSM?