LHC2FC summary on SLHC physics opportunities

James Wells
CERN TH & MCTP

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What is LHC2FC?

Institute/Workshop sponsored by TH Group.

“Goals of this TH Institute will be (i) to discuss recent physics developments, (ii) to anticipate near-term capabilities of Tevatron, LHC and other experiments, and (iii) to have discussions on the most effective ways to be prepared for giving science input to plans of the post-LHC era.”

Significant interactions between theorists and experimentalists during this Institute.

Future Colliders Overview Series

Interlaced throughout the Institute was a series of talks dedicated to the physics case and technology issues of future colliders: LHC/SLHC, ILC, CLIC, muon collider, and Tevatron status.

For SLHC:

Feb 10th: L. Evans, "LHC accelerator status and upgrade plans"

Feb 20th: M. Mangano, "Physics opportunities with the sLHC"

Many other talks talks & discussions that touch upon SLHC:
http://indico.cern.ch/conferenceTimeTable.py?confId=40437

SLHC Physics

Basic viewpoint: All things equal, higher luminosity is always good.

Detailed cases can be made for benefit of much higher luminosity for many scenarios that could be discovered at the LHC.

Partial List: many discussed at LHC2FC…

- Detecting composite Higgs via high-energy WW scattering
- Detecting rare decays of the Higgs boson
- Precision measurements of Higgs boson couplings
- Determination of the Higgs self-coupling

- Extending the reach of superpartner masses
- Precision measurements of susy spectrum and couplings

- Extending the reach of quark substructure probes
- Extending the reach of Z’ and W’ gauge bosons
- Discerning small deviations in triple gauge boson vertices
- Probing rare decays of the top quark

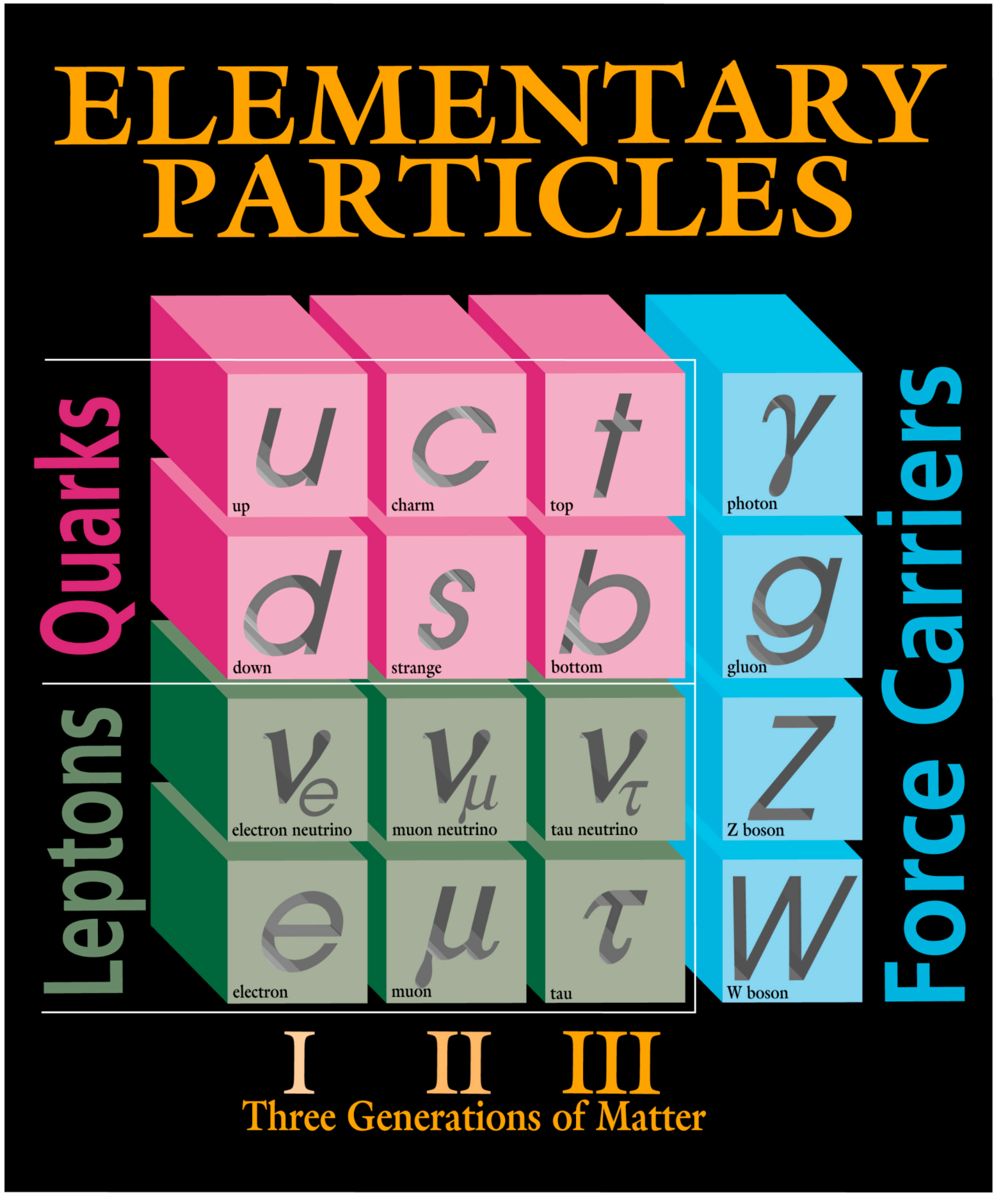
- Finding evidence for a hidden/singlet sector
- Extending the reach for smaller extra dimensions
- ….

Even with modest assumptions…

The potential payoffs can be enormous even under very modest eventualities.

Let us focus on the Higgs boson discovery. First, a little background.

Building Blocks



Fermilab 95-759

Complications

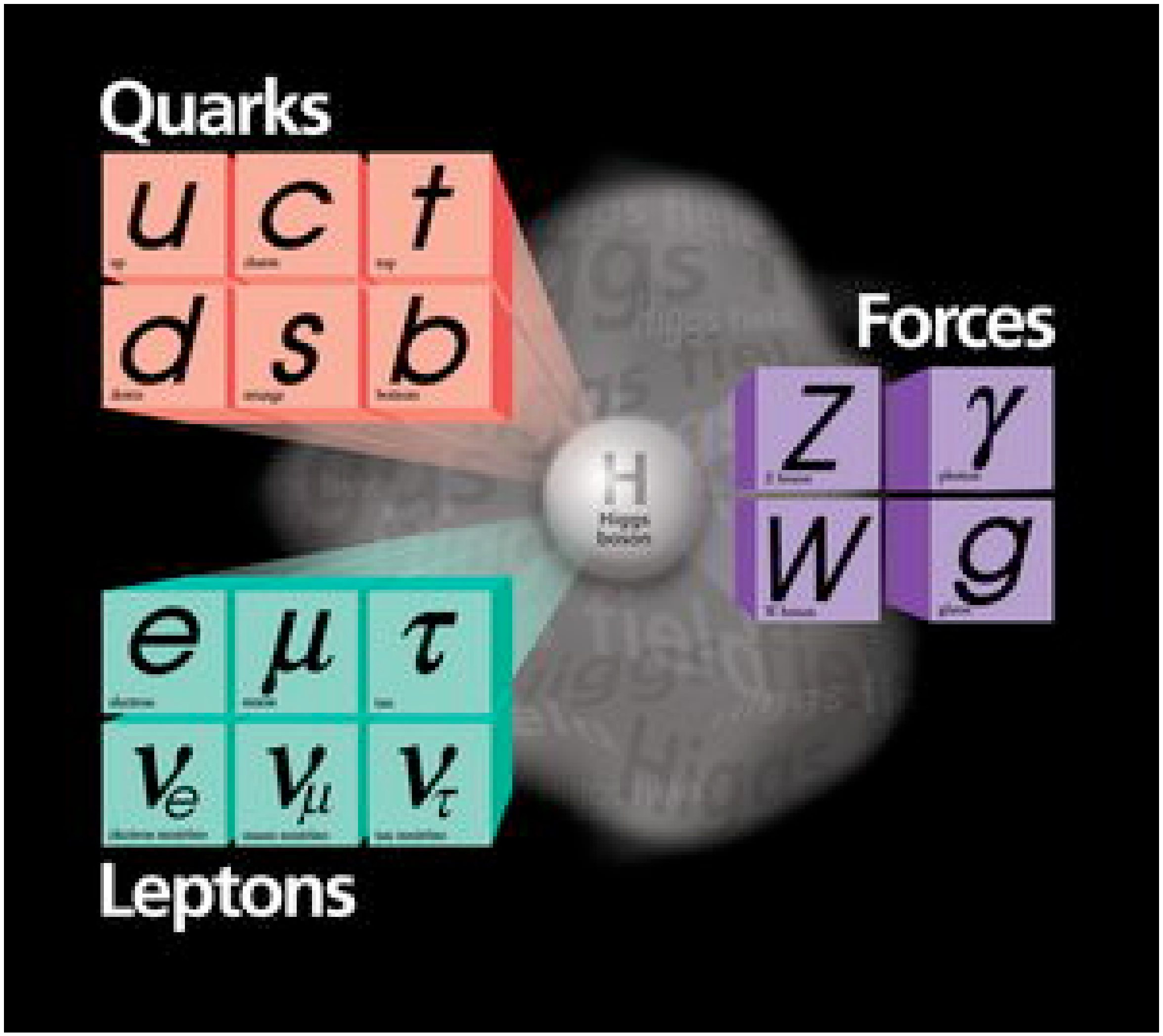
The W and Z gauge bosons have mass.

The matter particles (top, bottom, electron, etc.) have mass.

Symmetry properties of the weak force do not allow this.

“Break” the symmetry to allow mass. New particle does this: the Higgs boson.

Higgs Boson

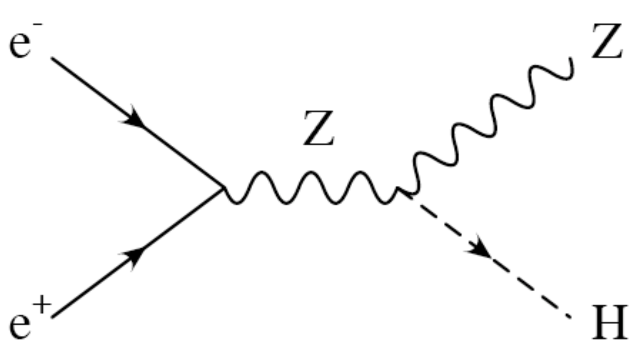


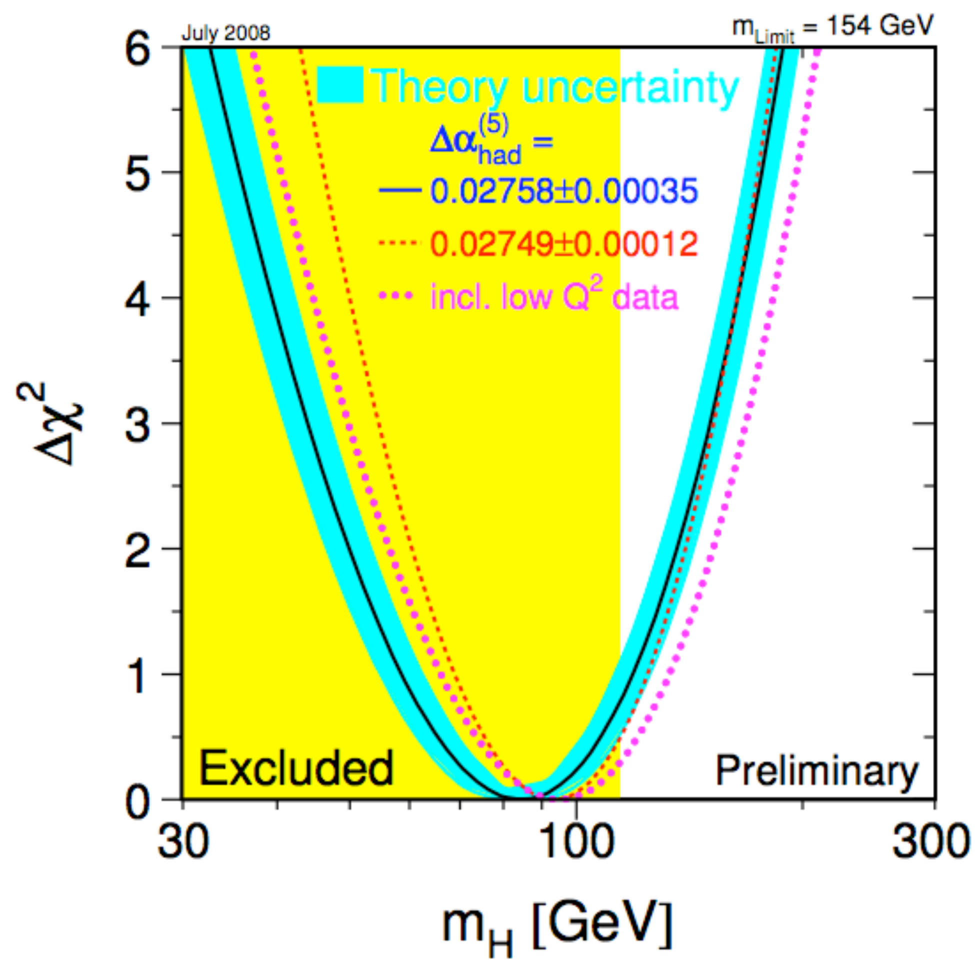
physorg.com

Higgs mass limits

Higgs boson mass upper limit (95% CL) from precision Electroweak is about 200 GeV.

Lower limit from lack of direct signal at LEP 2 is about 115 GeV.

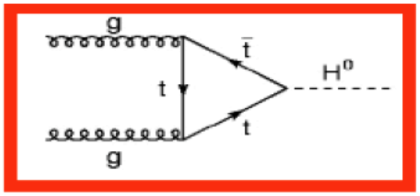




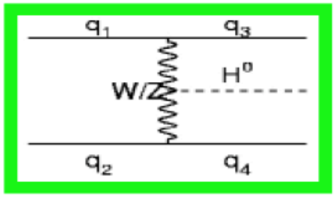
LEPEWWG

Experiment: 115 GeV < m_h < ~200 GeV

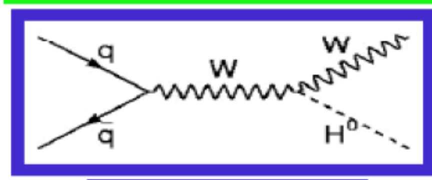
LHC will find it



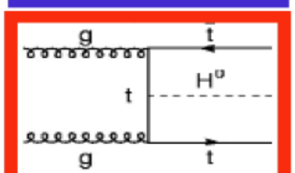
GF $H \rightarrow WW, ZZ, \gamma\gamma$



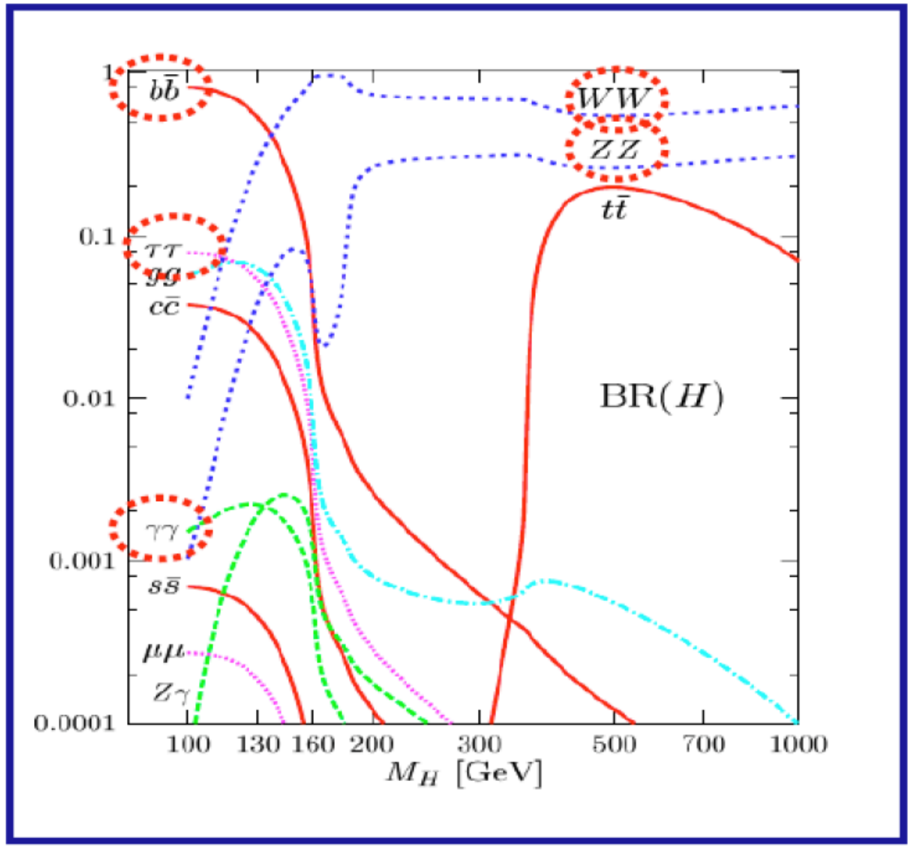
VBF $H \rightarrow WW, \gamma\gamma, \tau\tau$



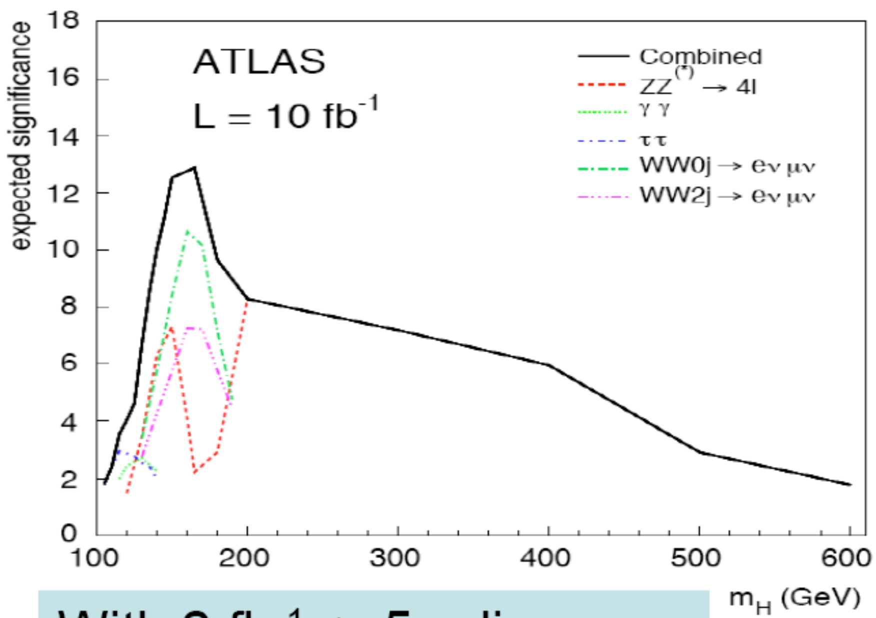
$H \rightarrow WW, \gamma\gamma$

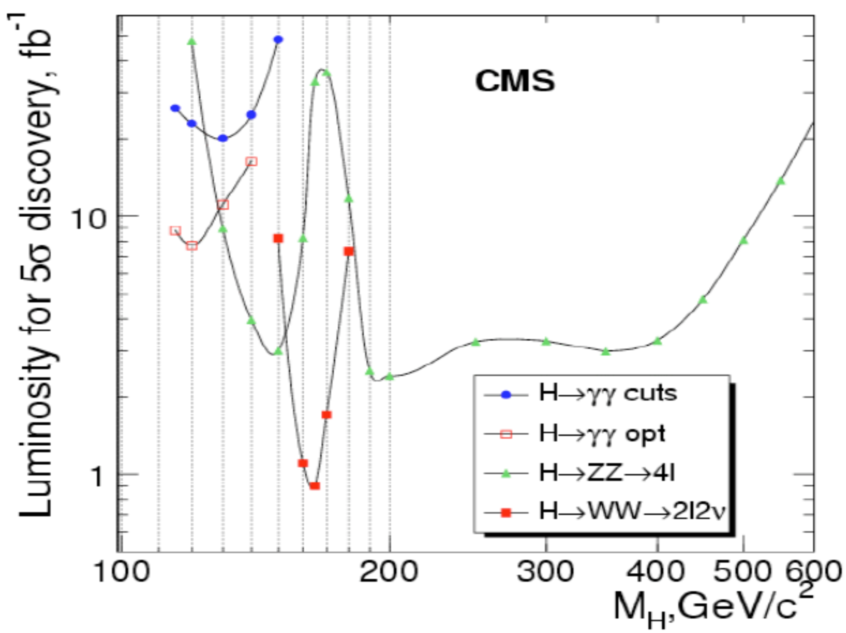


$H \rightarrow WW, \gamma\gamma, bb$



Many channels explored!
All the mass range is covered!





With 2 fb^{-1}, > 5σ discovery in 143 < m_H(GeV) < 179

- Full mass range can already be covered after a few years at low luminosity
- Similar performance in ATLAS
- Several channels available over a large range of masses
  Vector boson fusion channels play an important role at low mass !

Important changes w.r.t. previous studies:

- **H → γγ** sensitivity of ATLAS and CMS comparable
- **ttH → tt bb** disappeared in both ATLAS and CMS studies

Higgs Boson at the LHC

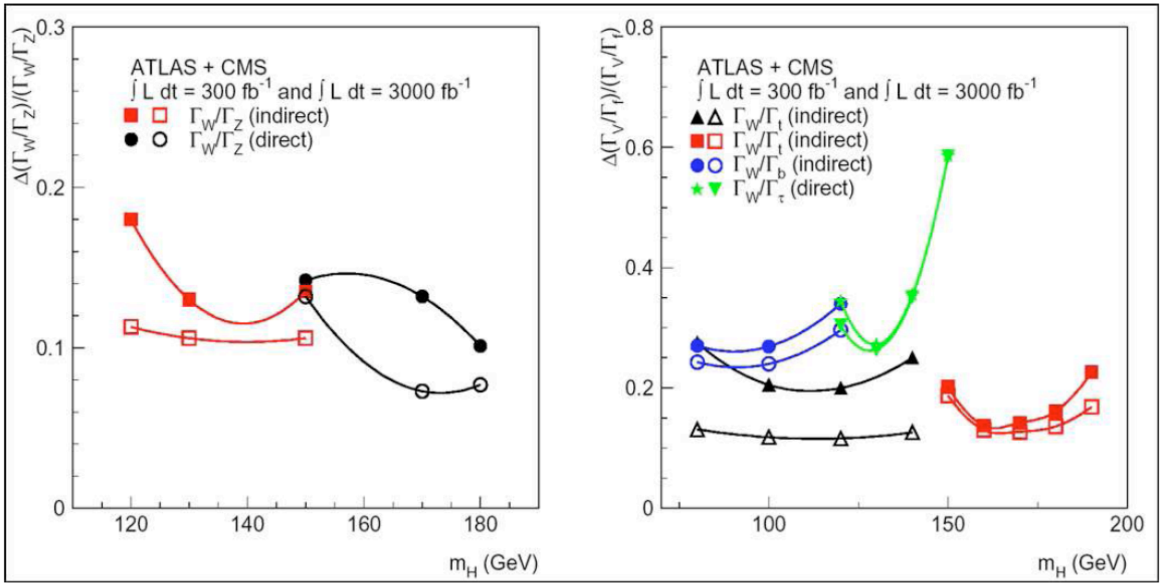
We expect much more than this. But …

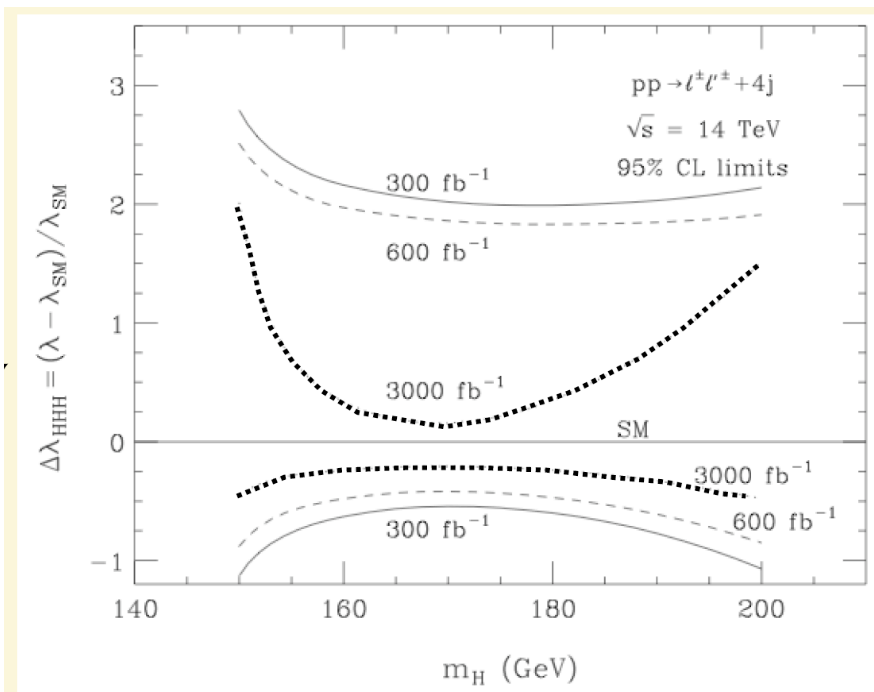
… suppose: After years of LHC running, we find a Standard Model Higgs boson and nothing else.

This would be exciting. A revolutionary discovery by any definition.

What benefits regarding Higgs boson physics could there be to SLHC upgrades?

Tests of Higgs Couplings





hep-ph/0204087 & M. Mangano SLHC talk.

	$600\ fb^{-1}$	$6000\ fb^{-1}$
$H \to Z\gamma$	3.5 σ	11 σ
$H \to \mu^+\mu^-$	< 3.5 σ	~ 7 σ

m[H] ~ [110-140] GeV

Han, McElrath, hep-ph/0201023

Hidden world effects at high luminosity?

"There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy." -Hamlet

The SM is merely a description of the particles that make up our bodies, and copies of those particles, and the forces between those particles.

Copernicus (NASA photo)

Copernicus Monument in Toruń
by Christian Friedrich Tieck (1853)

Why at our scale?

There is a definite scale in nature whose origin we do not understand: M_Z.

No strong reason to believe that SM is alone at that mass scale.

How can “hidden world” couple to us?

Consider the SM lagrangian plus the following:

$$\mathcal{L}_\Phi = |D_\mu \Phi_{SM}|^2 + |D_\mu \Phi_H|^2 + m^2_{\Phi_H}|\Phi_H|^2 + m^2_{\Phi_{SM}}|\Phi_{SM}|^2 \\ -\lambda|\Phi_{SM}|^4 - \rho|\Phi_H|^4 - \kappa|\Phi_{SM}|^2|\Phi_H|^2. \quad (3)$$

Standard Model Higgs very special:

Gauge invariant and Lorentz invariant all by itself with dim<4.

Higgs boson is the window to new worlds.

Narrow Trans-TeV Higgs Boson

Within 10% errors, the lighter Higgs boson looks just like the SM Higgs in this example.

When the mixing is small, the heavy Higgs has smaller cross-section (bad), but more narrow (good).

Mixing proportional to κ → s_ω^2

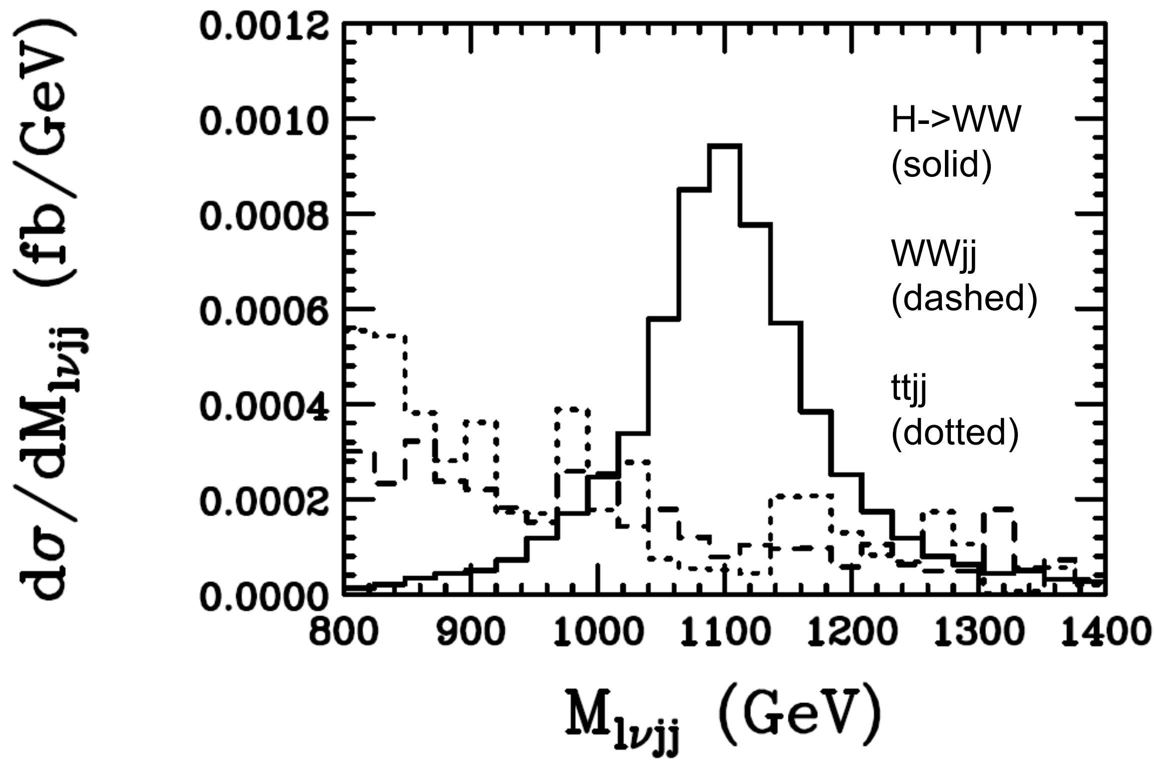
Two mass eigenstates → m_h, m_H

	Point A	Point B	Point C
s_ω^2	0.40	0.31	0.1
m_h (GeV)	143	115	120
m_H (GeV)	1100	1140	1100
$\Gamma(H \to hh)$ (GeV)	14.6	4.9	10
$BR(H \to hh)$	0.036	0.015	0.095

Investigate Point C example

H->WW->jjlν

Techniques: Atlas & CMS TDRs and Iordanidis, Zeppenfeld, '97



Between 1.0 & 1.3 TeV 13 signal events in 100 fb^{-1} vs. 7.7 bkgd

Similar kind of analysis for H->ZZ->ll$\nu\nu$ yields even more challenging result:
In 500 fb^{-1} 3.9 signal vs. 1.4 bkgd

Does Analysis Scale to SLHC?

Analysis relies on forward tagged jets ($\eta>2.0$) from vector boson fusion.

Can this technique work at 10^{35} cm^{-2} s^{-1} luminosity?

Pile-up can wreak havoc on high-rapidity tags such as this.

From the Gianotti, Mangano, Virdee et al. report (hep-ph/0204087) some strategies were identified that might help:

- Reduce jet cone size ($\Delta R<0.2$) to limit pile-up effects
- "Increase the calorimeter and trigger granularity in the forward regions"
- "Reduce the pile-up noise in the calorimeters by using optimal filtering techniques."
- Develop algorithms that could "distinguish between incoherent pile-up of energy and QCD jets."

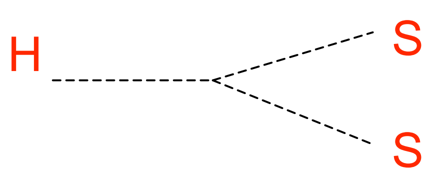
If these strategies do not work, then must rely on new topologies becoming applicable due to high luminosity to search for very weakly coupled hidden states.

Sources of Invisible Decay

Many ideas lead to invisible Higgs decays -- possible connections to dark matter. Joshipura et al. '93 ; Binoth, van der Bij, '97, etc.

Simplest of all is the addition of a real scalar field with Z_2.

$$\mathcal{L} = \frac{M_S^2}{2} S^2 + \lambda S^2 |\Phi_{SM}|^2 + \cdots$$



Branching fraction into invisible final state depends on λ.

SM Higgs decay competition

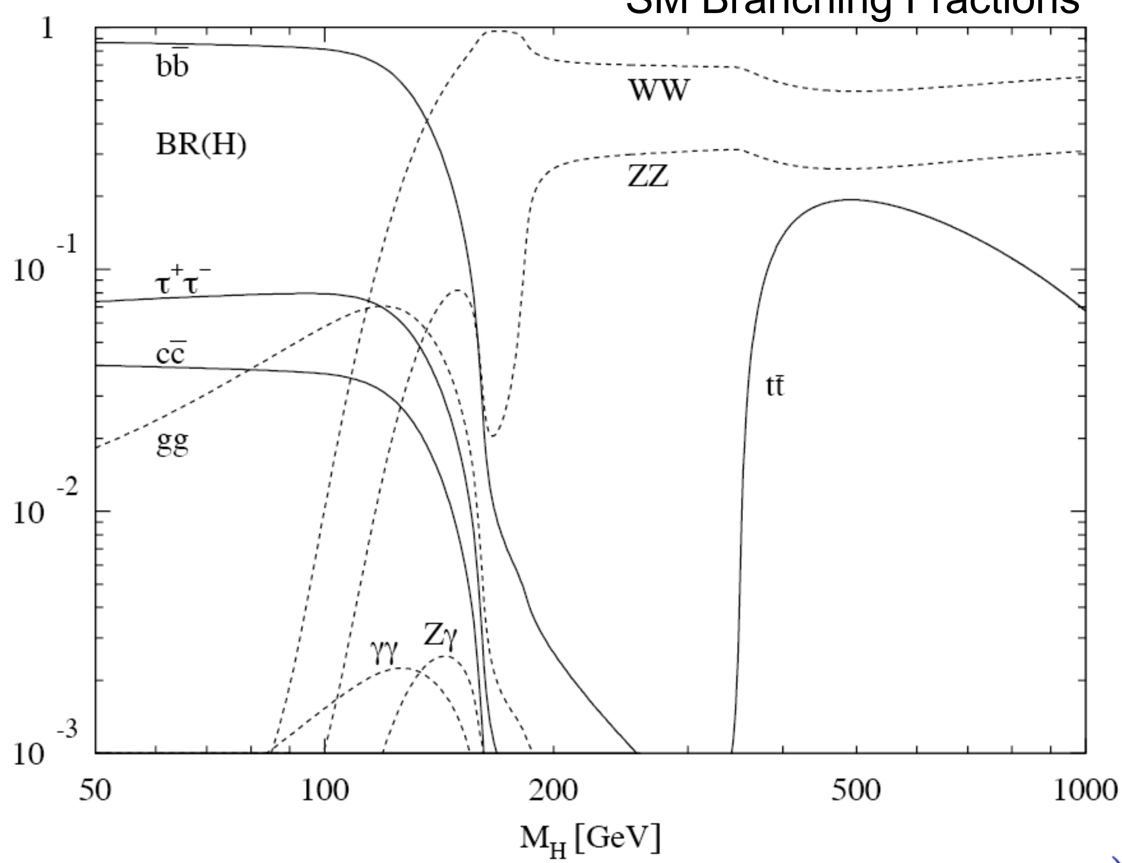
Expectations:

If $m_h<2m_W$
Invisible width could be anything.

If $m_h>2m_W$
Invisible width likely small.

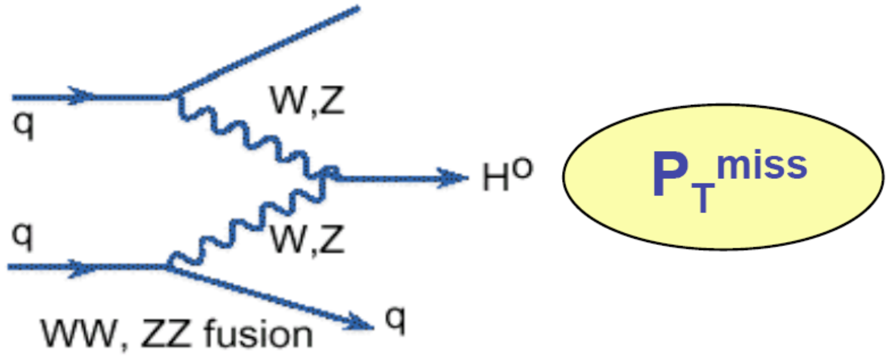
Focus on B(inv)<<B(SM).
[If B(inv) >> B(SM) Interesting SLHC studies to determine B(SM)]

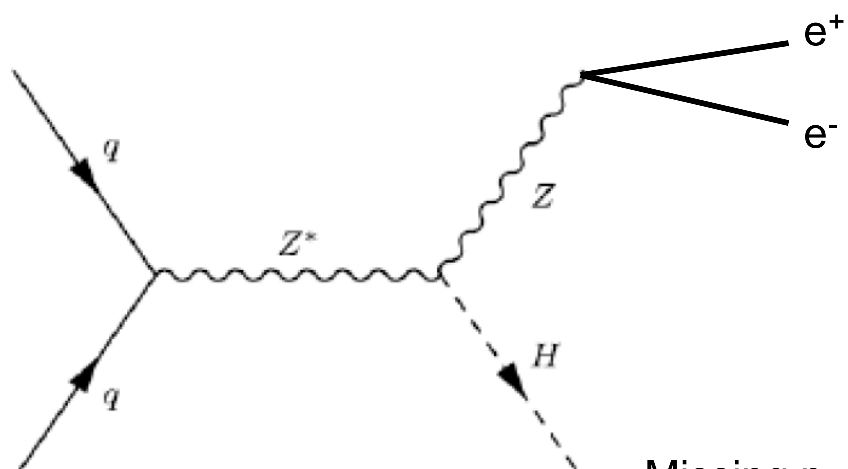
SM Branching Fractions



(M. Spira, Fortsch.Phys. 46 (1998) 203)

Two Approaches to Finding Invisibly Decaying Higgs Boson





Missing p_T

Figs from K. Assamagen talk

ATLAS CSC Study

$$\xi^2 = BR(H \to inv.) \frac{\sigma_{BSM}}{\sigma_{SM}}$$

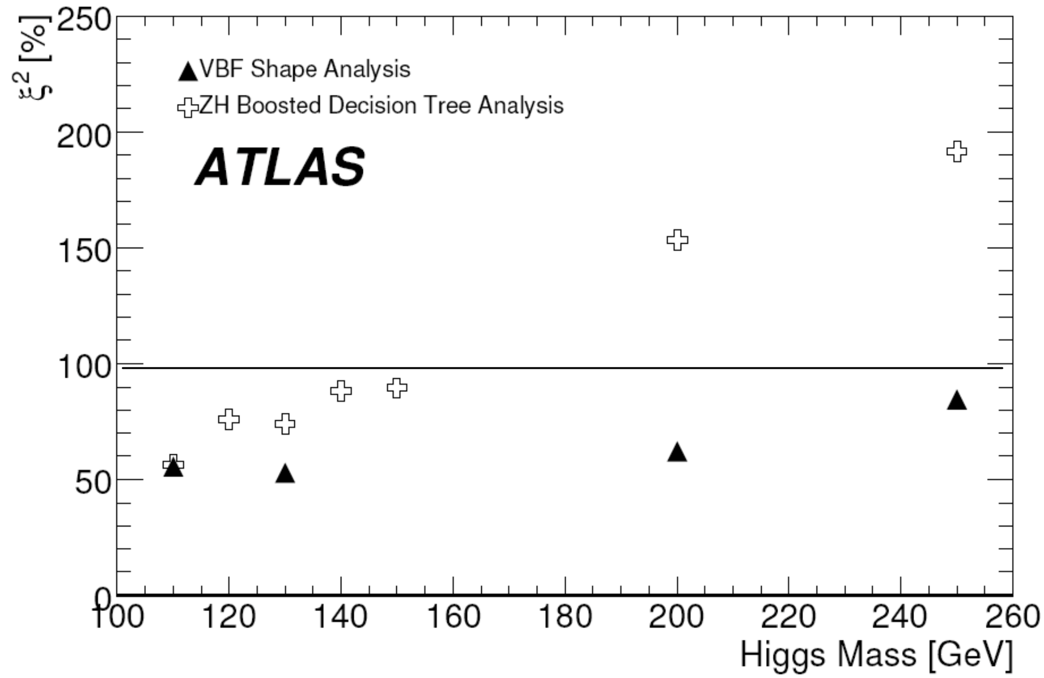


Figure 13: Sensitivity to an invisible Higgs boson with ATLAS for both the VBF and *ZH* channels with 30 fb^{-1}of data assuming only Standard Model backgrounds. The open crosses show the sensitivity for the *ZH* analysis and the solid triangles show the sensitivity for the VBF shape analysis for 95 % CL. Both these results include systematic uncertainties.

At SLHC the ZH mode might do better than VBF mode.

ZH->llνν is a counting experiment. Largest background is ZZ and largest systematic error is knowing total SM rate.

Bkgd measurable at SLHC? E.g., normalize ZZ->llνν to ZZ->4l. (At LHC, only ~12 events survive all BDT cuts in 30 fb^{-1}.)

Conclusions

All things equal, higher luminosity of SLHC is surely to be wanted under any eventuality.

Two broad categories:

Study the New Physics better that was discovered at the LHC:
Superpartner masses, Z' couplings, Higgs boson(s) couplings including self coupling, etc.

Make New Discoveries by virtue of higher luminosity:
Heavier Z' bosons, triple gauge boson vertex deviations, superpartner mass reach, $W_L W_L$ deviations, weakly coupled exotic states, invisible states from Higgs boson decays, etc.

Even the "Higgs boson only" scenario can greatly benefit from SLHC.