HIGGS PHYSICS AT THE LHC

Tilman Plehn

MPI & Edinburgh

- Higgs potential and corrections
- how we will find the Higgs at LHC
- will work: Higgs decay to tau pairs
- will not work: Higgs decay to bottom quarks
- might work: Higgs self coupling
- would be great: Higgs couplings analysis

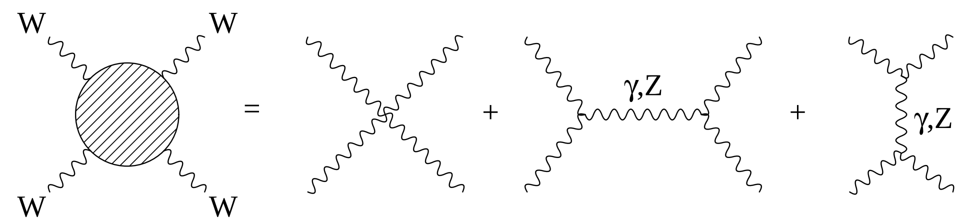
STANDARD–MODEL HIGGS SECTOR: 1

Theory of W, Z bosons

– start with SU(2) gauge theory [like QED with massless W, Z]

– include measured masses $\mathcal{L} \sim -m_{W,Z} A_\mu A^\mu$

$\Rightarrow$ not gauge invariant, not renormalizable, so what?



Unitarity

– test theory in WW $\to$ WW scattering
$\to \mathcal{A} \propto G_F E^2$ just like Fermi's theory, not unitary above 1.2 TeV [barely LHC energy]
$\to$ postulate additional scalar Higgs boson to conserve unitarity
$\to$ fixed coupling $g_{WWH} \propto m_W$

– add fermions and test WW $\to f\bar{f}$
$\to$ fixed coupling $g_{ffH} \propto m_f/m_W$

– test new theory in WW $\to$ WWH
$\to$ fixed coupling $g_{HHH} \propto m_H^2/m_W$

– final test: WW $\to$ HHH
$\to$ fixed coupling $g_{HHHH} \propto m_H^2/m_W^2$

$\Rightarrow$ all Higgs couplings non-negotiable

Higgs potential

- remember Lagrangian invariant under $SU(2) \times U(1)$
- break symmetry through vacuum: SU(2) doublet with vev
- minimize Higgs potential $\Phi = \left(0, (v + H)/2\right)$ [v = 246 GeV known from W, Z masses]

⇒ first attempt: renormalizable Higgs potential [does all we want]

$$\mathcal{L}_{\text{Higgs}} = |D_\mu \Phi|^2 - V$$
$$V = \lambda \left(|\Phi|^2 - \frac{v^2}{2} \right)^2 = \mu^2 |\Phi|^2 + \lambda |\Phi|^4 + \text{const}$$

⇒ not the whole story with new scale Λ [fi rst-order EW phase transition: hep-ph/0407019]

$$V = \sum_{n=0} \frac{\lambda_n}{\Lambda^{2n}} \left(|\Phi|^2 - \frac{v^2}{2} \right)^{2+n}$$

⇒ gauge–invariant D6 Higgs operators $\mathcal{L}'_{\text{Higgs}} = \sum f_i/\Lambda^2 \, \mathcal{O}_i$ [hep-ph/0301097]

$$\mathcal{O}_{\text{kin}} = \frac{1}{2} \partial_\mu (\Phi^\dagger \Phi) \partial^\mu (\Phi^\dagger \Phi)$$
$$\mathcal{O}_{\text{pot}} = -\frac{1}{3} (\Phi^\dagger \Phi)^3$$

LHC Searches

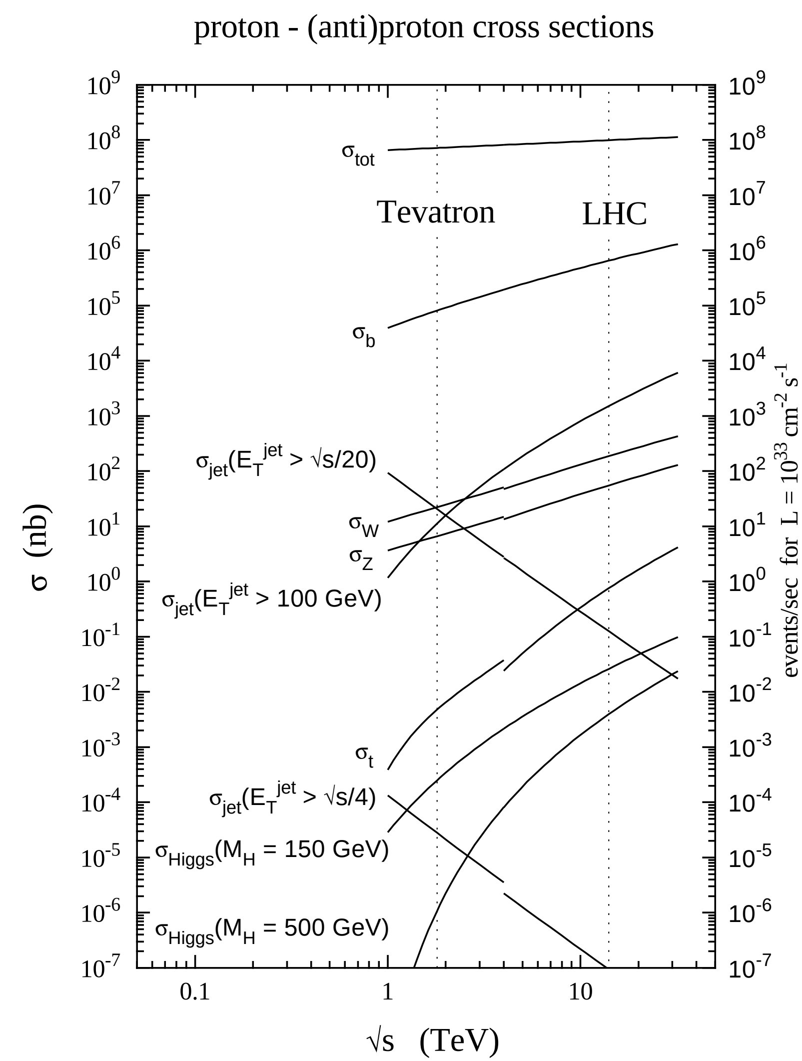
Conversion of beam energy into particle mass

– search for new particles easier if particle produced
  $\longrightarrow$ highest possible energies required

– clean e^+e^- colliders:
  LEP: Z pole
  LEP2: 206 GeV for e.g. ZH
  ILC/CLIC: 1...4 TeV in future

– powerful hadron colliders:
  Tevatron: $p\bar{p}$ with 2 TeV [valence quarks]
  LHC: pp with 14 TeV [gluons]

– LHC mass reach $\sim$ 3 TeV [win by luminosity]



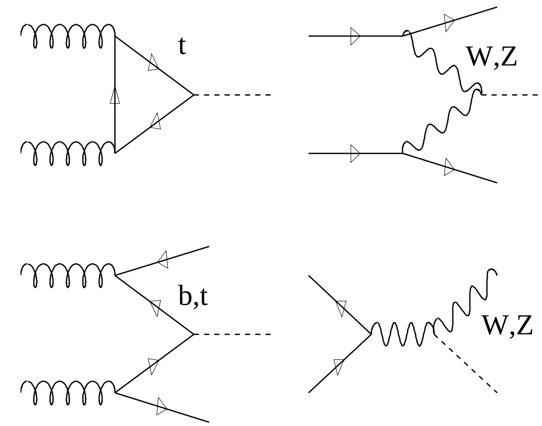
New physics at hadron colliders

– what is a jet and what is inside? [b, τ tag]

– trigger: ‘no leptons — no data’

– backgrounds pp $\rightarrow$ jj or pp $\rightarrow$ WZ+jets

– Gaussian statistics: $S/\sqrt{B} > 5$ discovery



Design Higgs searches for the LHC

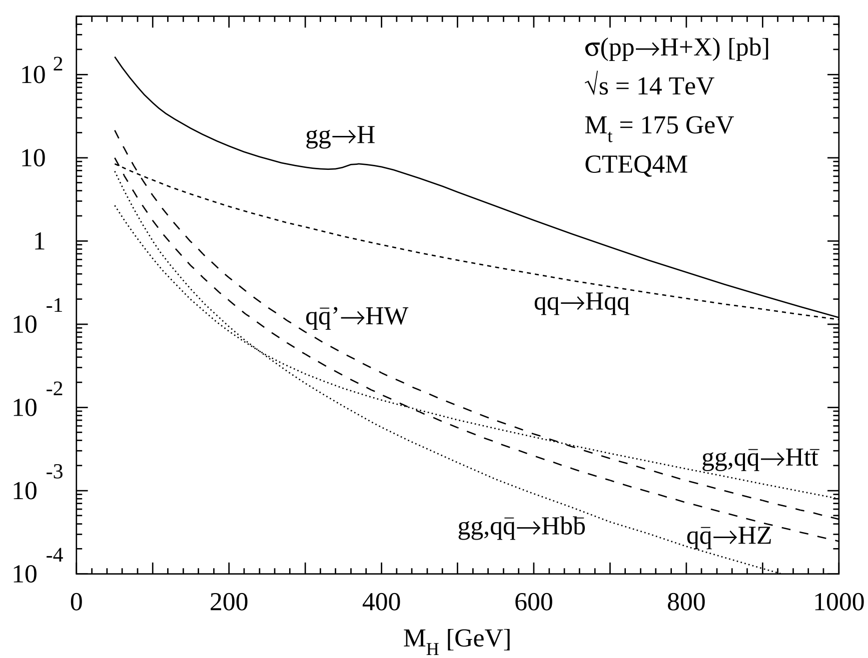
– (a) unitarity limit: $m_H < 1$ TeV
  (b) electroweak precision tests: $m_H \lesssim 250$ GeV

– production and decay of light Higgs

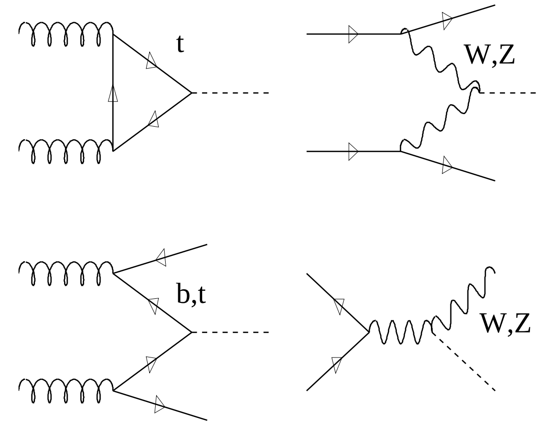
gg → H qq → qqH gg → $t\bar{t}$H $q\bar{q}'$ → WH	↔	signal × trigger backgrounds systematics $S/\sqrt{B}$ vs. S/B mass resolution...	↔	H → $b\bar{b}$ H → WW H → $\tau^+_{\ell h}\tau^-_{\ell}$ H → $\gamma\gamma$ H → $\mu\mu$...

Production rates

[luminosity 30-300 fb^{-1}]



HIGGS PRODUCTION AND DECAY: 1



Design Higgs searches for the LHC

– (a) unitarity limit: $m_H < 1$ TeV
  (b) electroweak precision tests: $m_H \lesssim 250$ GeV

– production and decay of light Higgs

$gg \to H$
$qq \to qqH$
$gg \to t\bar{t}H$
$q\bar{q}' \to WH$

$\leftrightarrow$

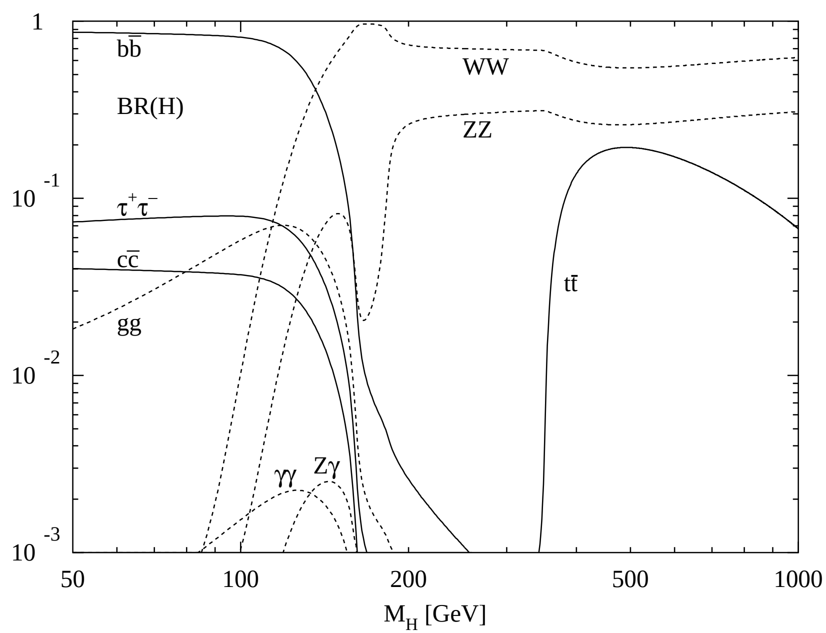
signal $\times$ trigger
backgrounds
systematics
$S/\sqrt{B}$ vs. S/B
mass resolution...

$\leftrightarrow$

$H \to b\bar{b}$
$H \to WW$
$H \to \tau^{+}_{\ell h}\tau^{-}_{\ell}$
$H \to \gamma\gamma$
$H \to \mu\mu$...

Branching fractions

[up to 10^6 events]



HIGGS PRODUCTION AND DECAY: 2

Some numbers behind it

- gluon-fusion production and $H \to ZZ \to 4\mu$ no-brainer

  ['golden channel' above 140 GeV, mass resolution excellent]

- $H \to WW$ only slightly harder, but no mass peak

  [above 150 GeV, off-shell still not clear, $gg \to WW$ background only recently]

- 6 million light Higgses in gluon fusion: $gg \to H \to \gamma\gamma$

  [mass resolution $\Delta m_H / m_H \sim \Gamma / \sqrt{S} < 0.5\%$]

- backgrounds smaller in WW fusion: $qq \to qqH \to qqWW$

  [works off-shell down to $m_H < 120$ GeV]

- light Higgs: $qq \to qqH \to qq\tau\tau$ [will discuss later]

- more challenging strategies:

  $gg \to t\bar{t}H \to t\bar{t}b\bar{b}$ [also later]

  $gg \to t\bar{t}H \to t\bar{t}WW$ [likely to work]

  $gg \to t\bar{t}H \to t\bar{t}\tau\tau$ [yet unclear]

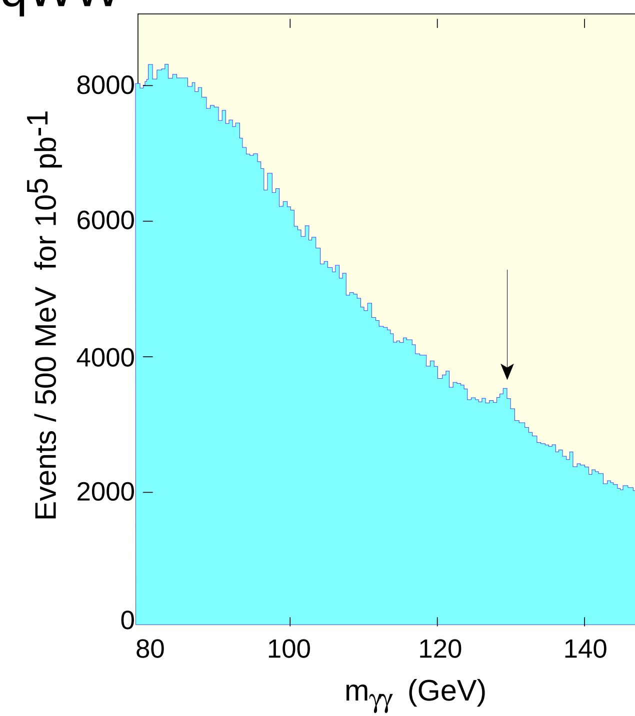
  $q\bar{q}' \to WH \to Wb\bar{b}$ [killer QCD backgrounds]

  $qq \to qqH \to qqb\bar{b}$ [no ATLAS trigger]

  $qq \to qqH \to qq\mu\mu$ [remember Kyle Cranmer's coll.]

$\Rightarrow$ Very cool, just $H \to b\bar{b}$ a sad story...

$H_{SM} \to \gamma\gamma$



Higgs Production and Decay: 2

Some numbers behind it

– gluon-fusion production and $H \to ZZ \to 4\mu$ no-brainer

['golden channel' above 140 GeV, mass resolution excellent]

– $H \to WW$ only slightly harder, but no mass peak

[above 150 GeV, off-shell still not clear, $gg \to WW$ background only recently]

– 6 million light Higgses in gluon fusion: $gg \to H \to \gamma\gamma$

[mass resolution $\Delta m_H / m_H \sim \Gamma/\sqrt{s} < 0.5\%$]

– backgrounds smaller: $qq \to qqH \to qqWW$

[works off-shell down to $m_H < 120$ GeV]

– light Higgs: $qq \to qqH \to qq\tau\tau$ [will discuss later]

– more challenging strategies:

$gg \to t\bar{t}H \to t\bar{t}b\bar{b}$ [also later]

$gg \to t\bar{t}H \to t\bar{t}WW$ [likely to work]

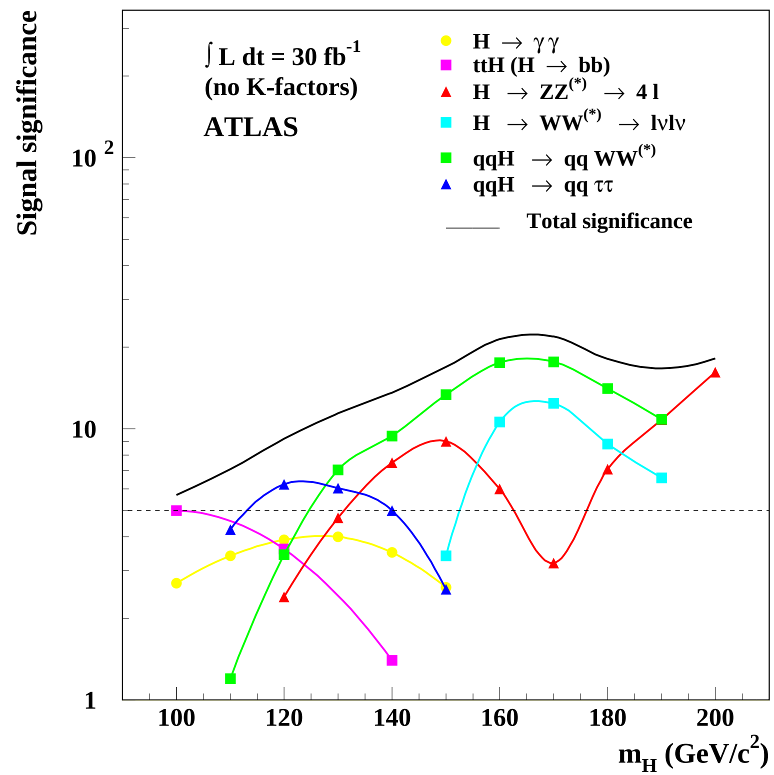
$gg \to t\bar{t}H \to t\bar{t}\tau\tau$ [yet unclear]

$q\bar{q}' \to WH \to Wb\bar{b}$ [killer QCD backgrounds]

$qq \to qqH \to qqb\bar{b}$ [no ATLAS trigger]

$qq \to qqH \to qq\mu\mu$ [remember Kyle Cranmer's coll.]

$\Rightarrow$ Very cool, just $H \to b\bar{b}$ a sad story...



WBF Higgs Production: 1

two hard, isolated leptons
missing transverse momentum
two forward tagging jets
90 GeV$<$ $m_{\tau\tau}^{\text{coll}}$ $<$160 GeV

Signal: $pp \to qqH,\ H \to \tau\tau \to e^{\pm}\mu^{\mp}4\nu$

– $\tau \to \ell\bar{\nu}_\ell\nu_\tau$ not reconstructable

– τ from Higgs decay strongly boosted

[lepton ($\vec{k}$) and τ ($\vec{p}$) approximately collinear: momentum fraction x]

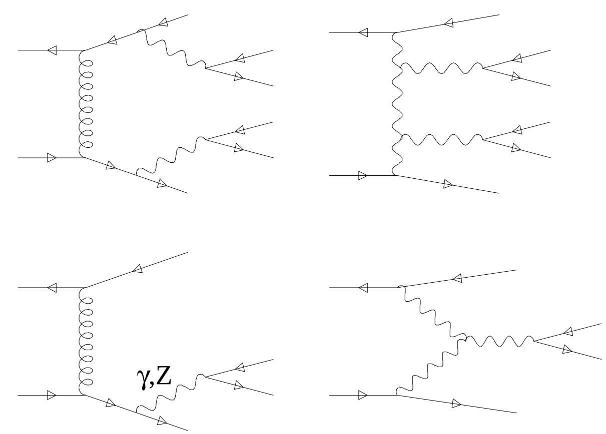
$\Rightarrow$ solve eqs: $\vec{k}_{T,1}/x_1 + \vec{k}_{T,2}/x_2 = \vec{p}_{T,1} + \vec{p}_{T,2} = \vec{k}_{T,1} + \vec{k}_{T,2} + \vec{p}_{T,\text{miss}}$

$\Rightarrow$ obtain $m_{\tau\tau}^{\text{coll}} \sim 2(k_1 \cdot k_2)/(x_1 x_2)$

$\Rightarrow$ mass measurement $\Delta m_H/m_H \sim 15\,\text{GeV}/\sqrt{S} \sim 5\,\text{GeV}$

After acceptance cuts

2.2 fb	signal $pp \to H_{SM} + jj$ [$m_H = 120$ GeV]
1230 fb	$pp \to t\bar{t} + \text{jets}$ [tagging jet either $t \to bW$ or additional jet]
1050 fb	$pp \to b\bar{b} + jj$ [with $b \to \ell\nu c$]
4.9 fb	$pp \to W^+W^- + jj$ (QCD) [with $W \to \ell\nu$]
3.3 fb	$pp \to W^+W^- + jj$ (EW)
57 fb	$pp \to \tau\tau + jj$ (QCD)
2.3 fb	$pp \to \tau\tau + jj$ (EW)
	$pp \to H_{SM} + jj \to W^+W^- + jj$



WBF Higgs Production: 1

Signal: $pp \to qqH,\ H \to \tau\tau \to e^{\pm}\mu^{\mp}4\nu$

– $\tau \to \ell\bar{\nu}_\ell\nu_\tau$ not reconstructable

– τ from Higgs decay strongly boosted

[lepton ($\vec{k}$) and τ ($\vec{p}$) approximately collinear: momentum fraction x]

two hard, isolated leptons
missing transverse momentum
two forward tagging jets
90 GeV< $m_{\tau\tau}^{coll}$ <160 GeV

$\Rightarrow$ solve eqs: $\vec{k}_{T,1}/x_1 + \vec{k}_{T,2}/x_2 = \vec{p}_{T,1} + \vec{p}_{T,2} = \vec{k}_{T,1} + \vec{k}_{T,2} + \vec{p}_{T,miss}$

$\Rightarrow$ obtain $m_{\tau\tau}^{coll} \sim 2(k_1 \cdot k_2)/(x_1 x_2)$

$\Rightarrow$ mass measurement $\Delta m_H/m_H \sim 15\,\text{GeV}/\sqrt{S} \sim 5\,\text{GeV}$

Background suppression cuts

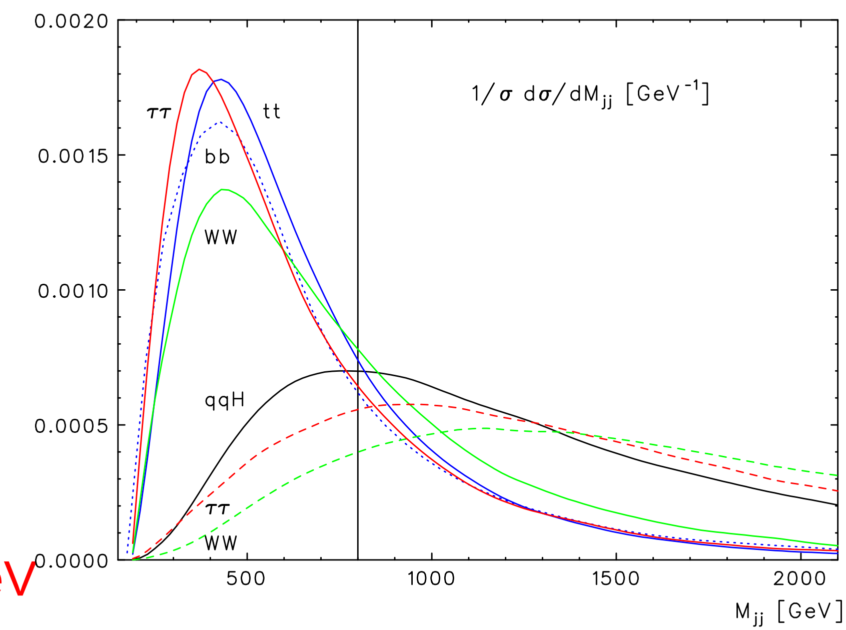
– veto central $p_{T_b} > 20$ GeV [$t\bar{t}$+jets down to 72 fb]

– $p_T^{miss} > 30$ GeV [soft $b\bar{b}jj$ gone]

– $m_{jj} > 800$ GeV [anti-QCD: gluons with low m_{jj}]

– non-τ rejection [anti-W]

$\Rightarrow$ S/B=1/6, or S/B=1/1 for $m_H = 120 \pm 10$ GeV



WBF Higgs Production: 1

Signal: $pp \to qqH,\ H \to \tau\tau \to e^\pm \mu^\mp 4\nu$

– $\tau \to \ell \bar{\nu}_\ell \nu_\tau$ not reconstructable

– τ from Higgs decay strongly boosted

[lepton ($\vec{k}$) and τ ($\vec{p}$) approximately collinear: momentum fraction x]

two hard, isolated leptons
missing transverse momentum
two forward tagging jets
90 GeV$< m_{\tau\tau}^{coll} <$160 GeV

$\Rightarrow$ solve eqs: $\vec{k}_{T,1}/x1 + \vec{k}_{T,2}/x2 = \vec{p}_{T,1} + \vec{p}_{T,2} = \vec{k}_{T,1} + \vec{k}_{T,2} + \vec{p}_{T,miss}$

$\Rightarrow$ obtain $m_{\tau\tau}^{coll} \sim 2(k_1 \cdot k_2)/(x_1 x_2)$

$\Rightarrow$ mass measurement $\Delta m_H/m_H \sim 15\,\text{GeV}/\sqrt{S} \sim 5\,\text{GeV}$

Background suppression cuts

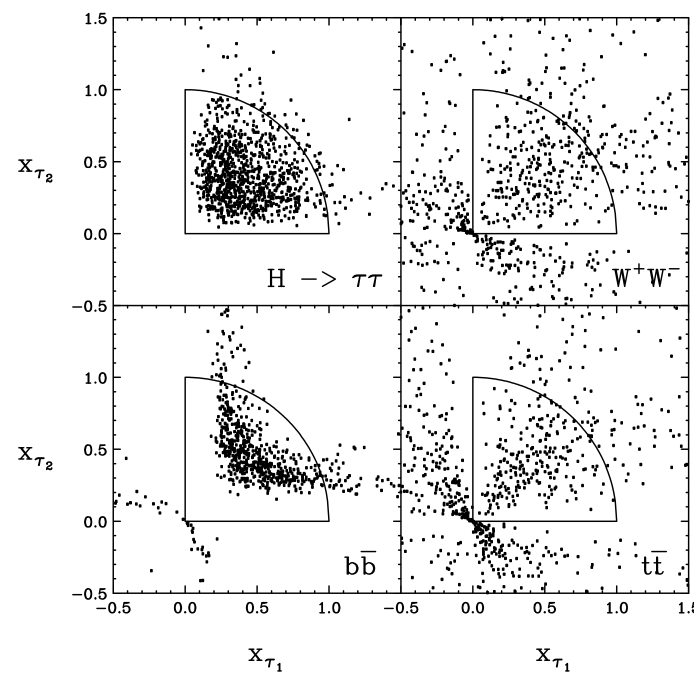
– veto central $p_{T_b} > 20$ GeV [$t\bar{t}$+jets down to 72 fb]

– $p_T^{miss} > 30$ GeV [soft $b\bar{b}jj$ gone]

– $m_{jj} > 800$ GeV [anti-QCD: gluons with low m_{jj}]

– non-τ rejection [anti-W]

$\Rightarrow$ S/B=1/6, or S/B=1/1 for $m_H = 120 \pm 10$ GeV



WBF Higgs Production: 2

More anti-QCD: central mini-jet veto

– additional jet emission cross section large (e.g. $t\bar{t}$, $t\bar{t}j$, $t\bar{t}jj$)

$$\sigma_2 \lesssim \sigma_{2+j} \equiv \int_{p_{T,min}}^{\infty} d\sigma_{2+j} \qquad \text{for} \quad p_{T,min} \sim 10\,\text{GeV (WBF)} \qquad p_{T,min} \sim 40\,\text{GeV (QCD)}$$

⇒ veto $p_{T_j} > 20$ GeV and $\eta_{j,min} < \eta_j < \eta_{j,max}$ to suppress QCD

– theoretical treatment difficult, efficiencies likely to be measured

⇒ S/B=2.8/1 for $m_H = 120 \pm 10$ GeV

Both $\tau\tau$ channels with safe margins [Standard Model with 60fb^{-1}]

M_H[GeV]	100	110	120	130	140	150
$\epsilon \cdot \sigma_{sig}$ (fb)	0.62	0.58	0.50	0.37	0.23	0.11
S	37.4	35.0	30.0	22.3	13.7	6.5
B	67.5	27.0	10.8	6.7	5.7	5.3
S/B	0.6	1.3	2.8	3.3	2.4	1.2
σ_{Gauss} (dual leptonic)	4.2	5.7	6.9	6.2	4.4	2.3
σ_{Gauss} (lepton-hadron)		5.7	7.4	6.3	4.7	2.6

WBF Higgs Production: 2

More anti-QCD: central mini-jet veto

– additional jet emission cross section large (e.g. $t\bar{t}$, $t\bar{t}j$, $t\bar{t}jj$)

$$\sigma_2 \lesssim \sigma_{2+j} \equiv \int_{p_{T,min}}^{\infty} d\sigma_{2+j} \qquad \text{for} \quad p_{T,min} \sim 10\,\text{GeV (WBF)} \qquad p_{T,min} \sim 40\,\text{GeV (QCD)}$$

⇒ veto $p_{T_j} > 20$ GeV and $\eta_{j,min} < \eta_j < \eta_{j,max}$ to suppress QCD

– theoretical treatment difficult, efficiencies likely to be measured

⇒ S/B=2.8/1 for $m_H = 120 \pm 10$ GeV

General features of WBF production

– cross section $10 \cdots 3$ pb for $m_H < 200$ GeV

– forward jet tagging, central Higgs decay products, central mini-jet veto

⇒ $(H \to \gamma\gamma)$@50 fb^{-1} for $m_H = 110 \cdots 145$ GeV [$\gamma\gamma$ mass resolution]

$(H \to \tau\tau)$@60 fb^{-1} for $m_H = 100 \cdots 140$ GeV [lepton-hadron and dual lepton]

$(H \to WW)$@5 fb^{-1} for $m_H = 140 \cdots 200$ GeV

ASSOCIATED HIGGS PRODUCTION

What about $H \to b\bar{b}$ for a light Higgs?

– what about the 90% of Higgses decaying to $b\bar{b}$?

– gluon-fusion: killed by background

– WBF fusion: no trigger

– WH production: killed by low rate and NLO background

– $\sigma(t\bar{t}H) \sim 100$ fb

$t\bar{t}H, H \to b\bar{b}$ for a light Higgs [ATL-PHYS-2003-24]

– trigger: one $t \to bW^+ \to b\ell^+\nu$

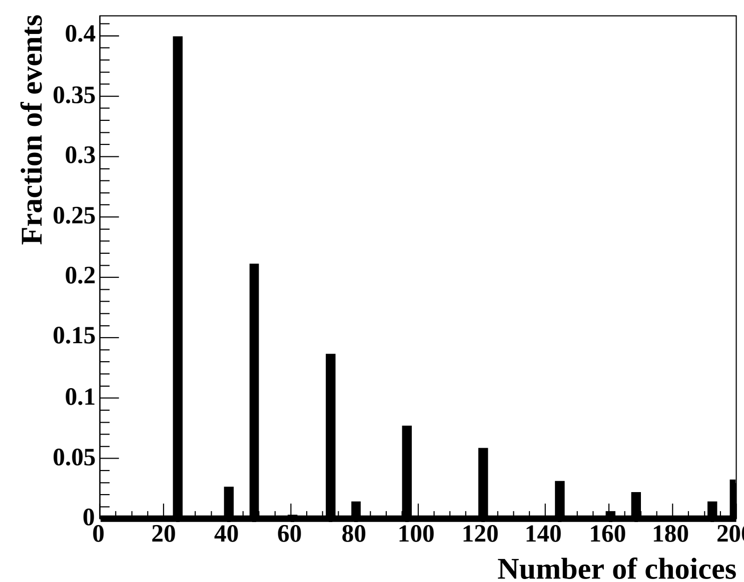
– reconstruction and rate: one $t \to bW^+ \to bjj$

– continuum background $t\bar{t}b\bar{b}, t\bar{t}jj$ [weighted by b-tag]

⇒ reconstruct m_H in $pp \to t\bar{t}H \to 4b_{tag}\ 2j\ \ell\nu$

⇒ higher lumi means poorer b-tag, no-win

⇒ likely to be ‘challenging’



What about $H \to b\bar{b}$ for a light Higgs?

– what about the 90% of Higgses decaying to $b\bar{b}$?

– gluon-fusion: killed by background

– WBF fusion: no trigger

– WH production: killed by low rate and NLO background

– $\sigma(t\bar{t}H) \sim 100$ fb

$t\bar{t}H, H \to b\bar{b}$ for a light Higgs [ATL-PHYS-2003-24]

– trigger: one $t \to bW^+ \to b\ell^+\nu$

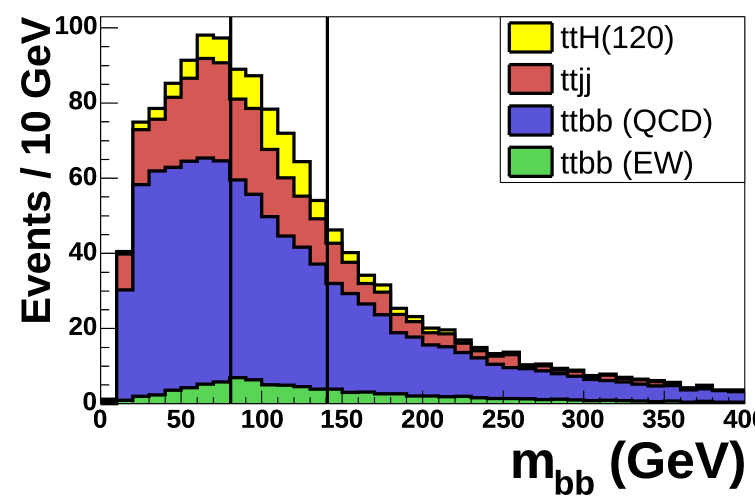
– reconstruction and rate: one $t \to bW^+ \to bjj$

– continuum background $t\bar{t}b\bar{b}, t\bar{t}jj$ [weighted by b-tag]

$\Rightarrow$ reconstruct m_H in $pp \to t\bar{t}H \to 4b_{tag}\ 2j\ \ell\nu$

$\Rightarrow$ higher lumi means poorer b-tag, no-win

$\Rightarrow$ likely to be ‘challenging’



What about $H \to b\bar{b}$ for a light Higgs?

– what about the 90% of Higgses decaying to $b\bar{b}$?

– gluon-fusion: killed by background

– WBF fusion: no trigger

– WH production: killed by low rate and NLO background

– $\sigma(t\bar{t}H) \sim 100$ fb

$t\bar{t}H, H \to b\bar{b}$ for a light Higgs [ATL-PHYS-2003-24]

– trigger: one $t \to bW^+ \to b\ell^+\nu$

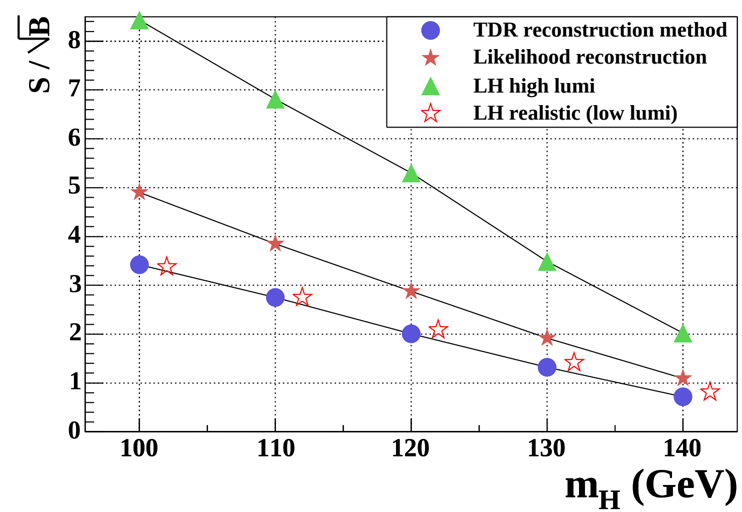
– reconstruction and rate: one $t \to bW^+ \to bjj$

– continuum background $t\bar{t}b\bar{b}, t\bar{t}jj$ [weighted by b-tag]

⇒ reconstruct m_H in $pp \to t\bar{t}H \to 4b_{tag}\ 2j\ \ell\nu$

⇒ higher lumi means poorer b-tag, no-win

⇒ likely to be ‘challenging’



HIGGS COUPLING EXTRACTION: 1

Coupling extraction at the LHC

– motivation: e.g. little Higgs axions vs. radion vs. Higgs?

– measure: $\mathrm{gg}: \mathrm{H} \to \mathrm{ZZ}, \mathrm{WW}, \gamma\gamma$
$\mathrm{VV}: \mathrm{H} \to \mathrm{ZZ}, \mathrm{WW}, \gamma\gamma, \tau\tau$
$\mathrm{t\bar{t}H}: \mathrm{H} \to \mathrm{WW}, \mathrm{b\bar{b}}...$
$\to$ light Higgs: 8 good $\sigma \cdot$ BR plus $\mathrm{H} \to \mathrm{b\bar{b}}$

– extract: couplings to $\mathrm{W}, \mathrm{Z}, \mathrm{t}, \mathrm{b}, \tau, \mathrm{g}, \gamma$, invisible
$\to$ most complete: 8 parameters

$\Rightarrow$ trick: cancel uncertainties
$(\mathrm{WBF}: \ \mathrm{H} \to \mathrm{WW})/(\mathrm{WBF}: \ \mathrm{H} \to \tau\tau)$
$(\mathrm{WBF}: \ \mathrm{H} \to \mathrm{WW})/(\mathrm{gg}: \ \mathrm{H} \to \mathrm{WW})$...

– goals: Higgs vs. scalars? SM vs MSSM? doublet vs. general Higgs?

$\Rightarrow$ unwanted: $g_{\mathrm{WWH}} \leftrightarrow g_{\mathrm{ZZH}}$ via SU(2)
unwanted: $g_{\mathrm{bbH}} \leftrightarrow g_{\tau\tau\mathrm{H}}$ via down-type Yukawa

HIGGS COUPLING EXTRACTION: 2

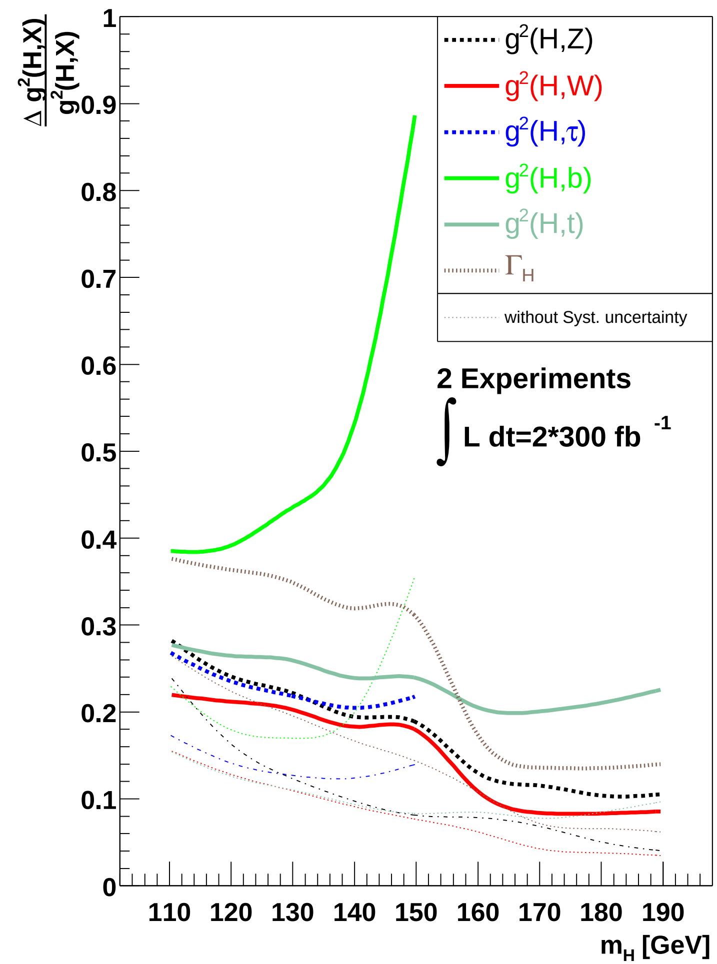
Coupling extraction at the LHC

– motivation: e.g. little Higgs axions vs. radion vs. Higgs?

– measure: $gg : H \to ZZ, WW, \gamma\gamma$
$VV : H \to ZZ, WW, \gamma\gamma, \tau\tau$
$t\bar{t}H : H \to WW, b\bar{b}...$
$\to$ light Higgs: 8 good $\sigma \cdot$ BR plus $H \to b\bar{b}$

– extract: couplings to $W, Z, t, b, \tau, g, \gamma$, invisible
$\to$ most complete: 8 parameters

$\Rightarrow$ trick: cancel uncertainties
$(WBF : H \to WW)/(WBF : H \to \tau\tau)$
$(WBF : H \to WW)/(gg : H \to WW)...$



Include total width

– degeneracy: $\sigma\, BR \propto (g_p^2/\sqrt{\Gamma_H})\ (g_d^2/\sqrt{\Gamma_H})$

[from $(WBF : WW/\tau\tau)$ measure $g_{WWH}/g_{\tau\tau H}$]

– additional constraint: $\sum \Gamma_i(g^2) < \Gamma_H \Rightarrow \Gamma_H|_{min}$

– $WW \to WW$ unitarity: $g_{WWH} \lesssim g^{SM}_{WWH} \Rightarrow \Gamma_H|_{max}$

$\Rightarrow$ couplings and width extraction great but hard

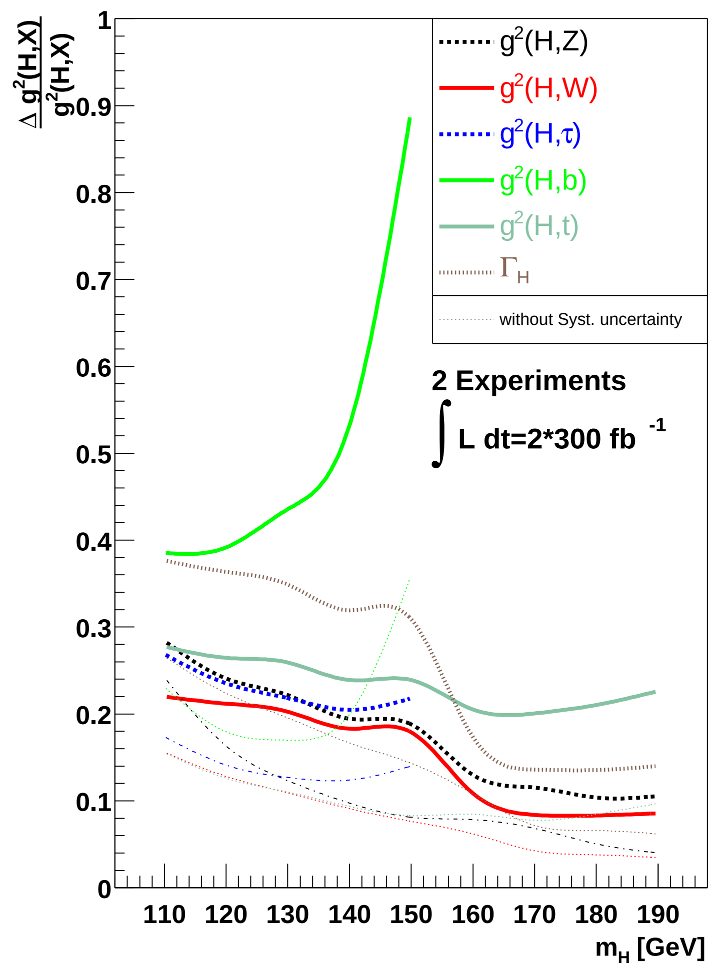
Coupling extraction at the LHC

– motivation: e.g. little Higgs axions vs. radion vs. Higgs?

– measure: $\text{gg} : \text{H} \to \text{ZZ}, \text{WW}, \gamma\gamma$
$\text{VV} : \text{H} \to \text{ZZ}, \text{WW}, \gamma\gamma, \tau\tau$
$\text{t}\bar{\text{t}}\text{H} : \text{H} \to \text{WW}, \text{b}\bar{\text{b}}...$
$\to$ light Higgs: 8 good $\sigma \cdot \text{BR}$ plus $\text{H} \to \text{b}\bar{\text{b}}$

– extract: couplings to $\text{W}, \text{Z}, \text{t}, \text{b}, \tau, \text{g}, \gamma$, invisible
$\to$ most complete: 8 parameters

$\Rightarrow$ trick: cancel uncertainties
$(\text{WBF} : \text{H} \to \text{WW})/(\text{WBF} : \text{H} \to \tau\tau)$
$(\text{WBF} : \text{H} \to \text{WW})/(\text{gg} : \text{H} \to \text{WW})...$



In future

– fit to more observables

– error on mass measurement [SM vs. SUSY?]

– cancel more errors [universal logs in σ and Γ?]

– compute higher-order corrections

$\Rightarrow$ warning: underestimating errors now will bite us later!

HIGGS POTENTIAL AND SELF COUPLINGS

Higgs self coupling

– scalar with Yukawa couplings to fermions, so what?

– renormalizable SM potential: $\mu^2 = -\lambda v^2$ with $\lambda = m_H^2/(2v^2)$
and self couplings $\lambda_{3H}/\lambda_{4H} = v$

– MSSM: $\lambda_{3h}/\lambda_{4h} = v \sin(\beta+\alpha)/\cos 2\alpha$ and m_h à la 2nd floor

– D6 operator: $\mu^2/v^2 = -\lambda_0 + 3\lambda_1 v^2/(4\Lambda^2)$ and $\lambda = \lambda_0 - 3\lambda_1 v^2/(2\Lambda^2)$.

Higgs pair production

– HH $\to$ 4W: serious detector simulation needed, not hopeless
[use observable m_{vis} to determine λ_{HHH}, need NLO $\sigma(t\bar{t}j)$]

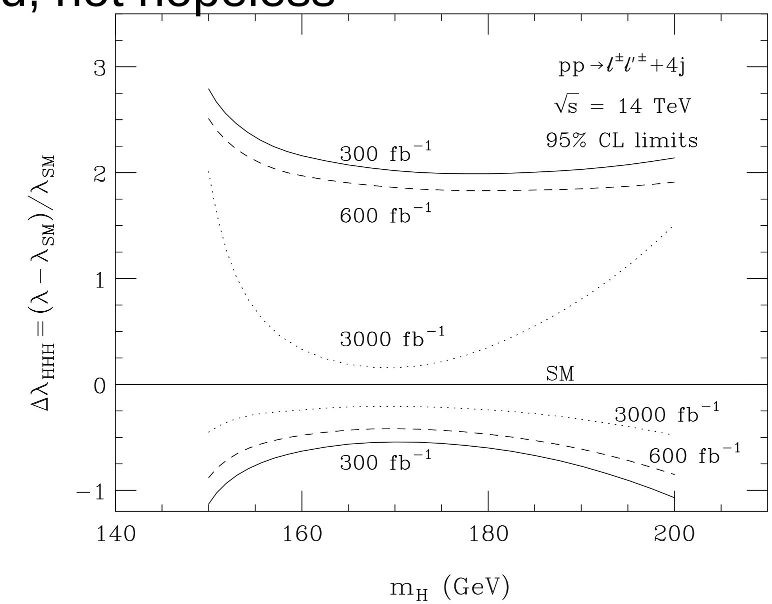
– HH $\to b\bar{b}\tau\tau$: miracle required

– HH $\to$ 4b: several major miracles mandatory
[ILC in better shape]

– HH $\to b\bar{b}\mu\mu$: small miracle would be helpful
[might come out of $\mu\mu$ mass resolution]

– HH $\to b\bar{b}\gamma\gamma$: some enhancement needed

$\Rightarrow$ serious challenge to detectors and machine



OUTLOOK

Standard-Model Higgs at the LHC

– we will find it in more than one channel for all m_H

– we will measure many properties more or less well:

set of couplings and width
self coupling (only λ_{HHH})
CP properties and WWH coupling structure
invisible decays
Higgs to muons (2nd generation Yukawa)
former stealth models...

– hardly anything still correct in Higgs chapter of Atlas TDR

$\Rightarrow$ for WBF we need to understand central jet veto [or give up and measure it]

$\Rightarrow$ for some measurements we need NLO backgrounds

$\Rightarrow$ it is a disgrace that we will miss $H \to b\bar{b}$

$\Rightarrow$ if SM then higher-dimensional operators mandatory [absolutely nothing done yet]