# Higgs Physics

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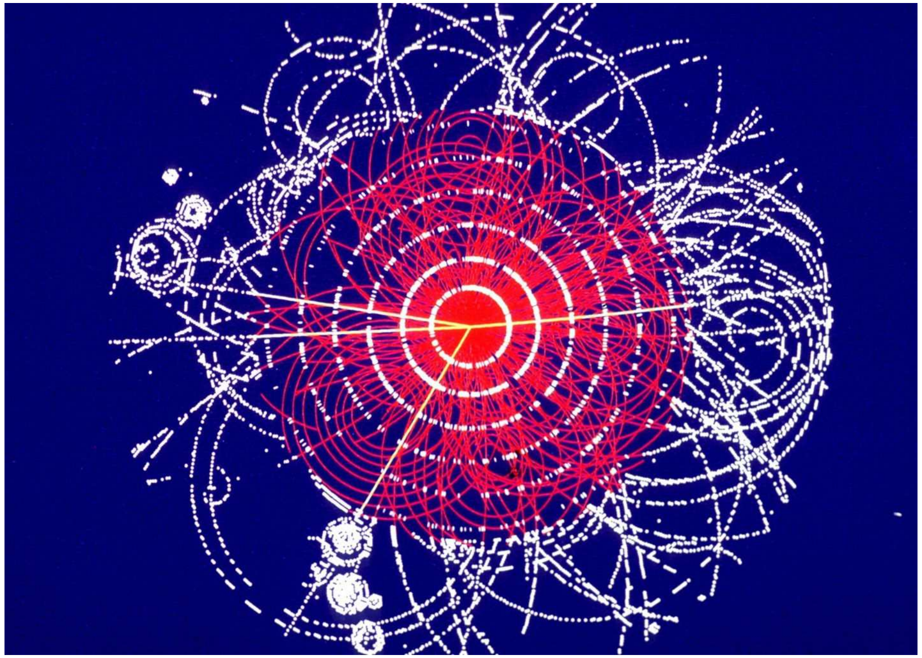
- Introduction
- Higgs Theory
- Search Channels at the LHC
- H coupling measurements
- QCD corrections
- Conclusions



# The Standard Model of particle physics

Interactions are described by gauge theory with gauge group

$$SU(3) \quad x \quad SU(2)\ x\ U(1)$$

Strong interactions: **QCD**

$SU(3)$ 8 massless gluons

Electroweak interactions:

$SU(2)\ x\ U(1)$ $\gamma$ massless

$W^{\pm}, Z$ massive

$W$ and $Z$ masses violate $SU(2)xU(1)$ gauge symmetry.

# Fermion fields of the SM and gauge quantum numbers

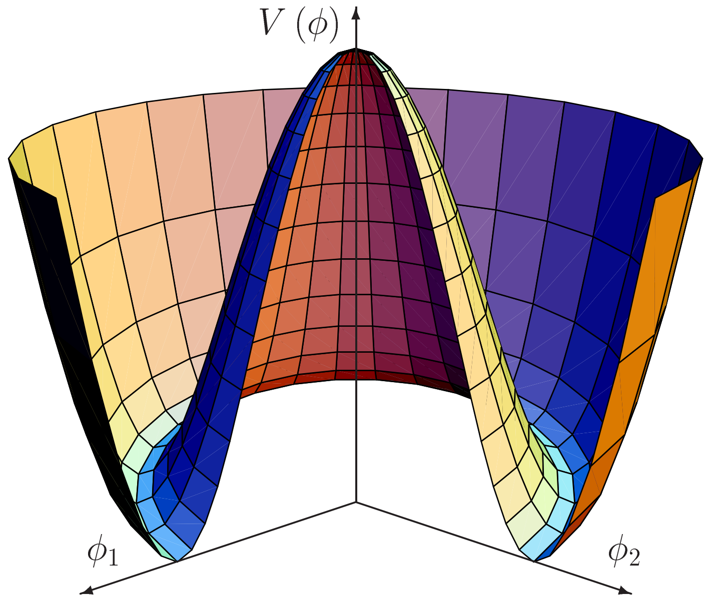
| | | | | $SU(3)$ | $SU(2)$ | $U(1)_Y$ |
|---|---|---|---|---|---|---|
| $Q_L^i =$ | $\begin{pmatrix} u_L \\ d_L \end{pmatrix}$ | $\begin{pmatrix} c_L \\ s_L \end{pmatrix}$ | $\begin{pmatrix} t_L \\ b_L \end{pmatrix}$ | 3 | 2 | $\frac{1}{6}$ |
| $u_R^i =$ | $u_R$ | $c_R$ | $t_R$ | 3 | 1 | $\frac{2}{3}$ |
| $d_R^i =$ | $d_R$ | $s_R$ | $b_R$ | 3 | 1 | $-\frac{1}{3}$ |
| $L_L^i =$ | $\begin{pmatrix} \nu_{eL} \\ e_L \end{pmatrix}$ | $\begin{pmatrix} \nu_{\mu L} \\ \mu_L \end{pmatrix}$ | $\begin{pmatrix} \nu_{\tau L} \\ \tau_L \end{pmatrix}$ | 1 | 2 | $-\frac{1}{2}$ |
| $e_R^i =$ | $e_R$ | $\mu_R$ | $\tau_R$ | 1 | 1 | $-1$ |
| $\nu_R^i =$ | $\nu_{eR}$ | $\nu_{\mu R}$ | $\nu_{\tau R}$ | 1 | 1 | 0 |

# Spontaneous symmetry breaking

Experimentally, the weak bosons are massive. The Standard Model gives mass to gauge bosons and fermions via the Higgs mechanism:

Postulate existence of a complex scalar doublet

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \begin{pmatrix} 0 \\ \frac{v+H}{\sqrt{2}} \end{pmatrix} + \text{Goldstone terms},$$




$$\mathcal{L}_{\text{Higgs}} = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V\left(\Phi^\dagger \Phi\right)$$

$$D^\mu = \partial^\mu - igW_i^\mu \frac{\sigma^i}{2} - ig' \frac{Y_\Phi}{2} B^\mu$$

$$V\left(\Phi^\dagger \Phi\right) = \lambda \left(\Phi^\dagger \Phi - \frac{v^2}{2}\right)^2$$

$V\left(\Phi^\dagger \Phi\right)$ is $SU(2)_L \times U(1)_Y$ symmetric.

# Higgs coupling to gauge bosons

Kinetic energy term of Higgs doublet field:

$$(D^\mu \Phi)^\dagger (D_\mu \Phi) = \frac{1}{2}\partial^\mu H \partial_\mu H + \left[ \left(\frac{gv}{2}\right)^2 W^{\mu +} W^-_\mu + \frac{1}{2}\frac{(g^2 + g'^2)\, v^2}{4} Z^\mu Z_\mu \right] \left(1 + \frac{H}{v}\right)^2$$

- $W, Z$ mass generation: $m_W^2 = \left(\frac{gv}{2}\right)^2$, $m_Z^2 = \frac{(g^2+g'^2)v^2}{4}$
- $WWH$ and $ZZH$ couplings are generated
- Higgs couples propotional to mass: coupling strength $= 2\, m_V^2/v$ $(= g^2 v/2$ for W)

Measurement of $WWH$ and $ZZH$ couplings is essential for identification of $H$ as agent of symmetry breaking: Without a v.e.v. such a trilinear coupling is impossible at tree level

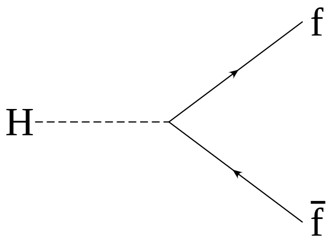
# Fermion masses and couplings to the Higgs boson

Fermion masses arise from Yukawa couplings via $\Phi^\dagger \rightarrow (0, \frac{v+H}{\sqrt{2}})$

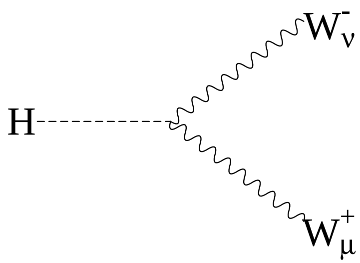
$$
\begin{aligned}
\mathcal{L}_{\text{Yukawa}} &= -\Gamma_d \bar{Q}_L \Phi d_R - \Gamma_d^* \bar{d}_R \Phi^\dagger Q_L + \ldots \\
&= -\Gamma_d \, (\bar{u}_L, \bar{d}_L) \begin{pmatrix} 0 \\ \frac{v+H}{\sqrt{2}} \end{pmatrix} d_R + \ldots \\
&= -\Gamma_d \, \frac{v+H}{\sqrt{2}} \, \bar{d}_L \, d_R + \ldots \\
&= -\sum_f m_f \, \bar{f} f \left(1 + \frac{H}{v}\right)
\end{aligned}
$$

- Test SM prediction: $\bar{f} f H$ Higgs coupling strength $= m_f / v$
- Observation of $H f \bar{f}$ Yukawa coupling is no proof that v.e.v exists

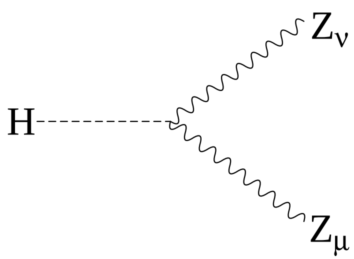
# Feynman rules




$$-i\frac{m_f}{v}$$




$$i g\, m_W\, g_{\mu\nu}$$




$$i\, g\, \frac{1}{\cos\theta_W}\, m_Z\, g_{\mu\nu}$$

Verify tensor structure of $HVV$ couplings. Loop induced couplings lead to $HV_{\mu\nu}V^{\mu\nu}$ effective coupling and different tensor structure: $\quad g_{\mu\nu} \quad \longrightarrow \quad q_1 \cdot q_2\, g_{\mu\nu} - q_{1\nu} q_{2\mu}$

# The MSSM Higgs sector

The SM uses the conjugate field $\Phi_c = i\sigma_2\Phi^*$ to generate down quark and lepton masses. In supersymmetric models this must be an independent field

$$\begin{aligned} \mathcal{L}_{\text{Yukawa}} &= -\Gamma_d \bar{Q}_L \Phi_1 d_R - \Gamma_e \bar{L}_L \Phi_1 e_R + \text{h.c.} \\ &\quad -\Gamma_u \bar{Q}_L \Phi_2 u_R + \text{h.c.} \end{aligned}$$

Two complex Higgs doublet fields $\Phi_1$ and $\Phi_2$ receive mass and v.e.v.s $v_1, v_2$ from generalized Higgs potential. Mass eigenstates constructed out of these 8 real fields are

Neutral sector:
2 CP even Higgs bosons: $h$ and $H$
1 CP odd Higgs boson: $A$
1 Goldstone boson: $\chi_0$

Charged sector:
charged Higgs bosons: $H^\pm$
charged Goldstone boson: $\chi^\pm$

Goldstone bosons absorbed as longitudinal degrees of freedom of $Z, W^\pm$

# Couplings of the MSSM Higgses

## Fermions

Two doublet fields mix, two v.e.v's $v_1 = v\cos\beta, \quad v_2 = v\sin\beta$:

$$\begin{aligned}
\mathcal{L}_{\text{Yuk.}} &= -\Gamma_b \bar{b}_L \Phi_1^0 b_R - \Gamma_t \bar{t}_L \Phi_2^0 u_R + \text{h.c.} \\
&= -\Gamma_b \bar{b}_L \frac{v_1 + H\cos\alpha - h\sin\alpha + iA\sin\beta}{\sqrt{2}} b_R - \Gamma_t \bar{t}_L \frac{v_2 + H\sin\alpha + h\cos\alpha + iA\cos\beta}{\sqrt{2}} t_R + \dots
\end{aligned}$$

Expressed in terms of masses the Yukawa Lagrangian is

$$\mathcal{L}_{\text{Yuk.}} = -\frac{m_b}{v}\bar{b}\left(v + H\frac{\cos\alpha}{\cos\beta} - h\frac{\sin\alpha}{\cos\beta} - i\gamma_5 A\tan\beta\right) b - \frac{m_t}{v}\bar{t}\left(v + H\frac{\sin\alpha}{\sin\beta} + h\frac{\cos\alpha}{\sin\beta} - i\gamma_5 A\cot\beta\right) t$$

$\Longrightarrow$ coupling factors compared to SM $hff$ coupling $-i\, m_f/v$

## Gauge Bosons

extra coupling factors for $hVV$ and $HVV$ couplings as compared to SM

$$hVV \sim \sin(\beta - \alpha) \qquad\qquad HVV \sim \cos(\beta - \alpha)$$

# Goals of Higgs Physics

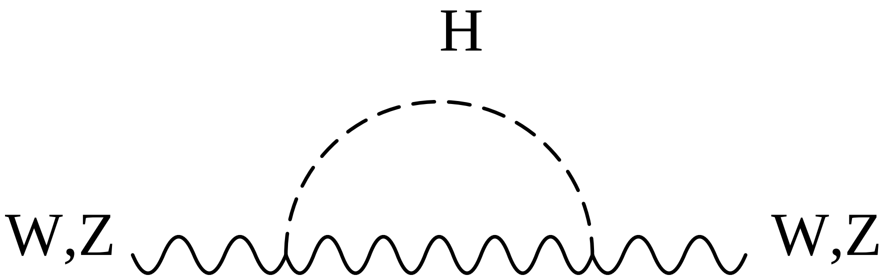
Higgs Search = search for dynamics of $SU(2) \times U(1)$ breaking

- Discover the Higgs boson
- Measure its couplings and probe
  mass generation for gauge bosons and fermions

# Clues to the Higgs boson mass: SM case

Higgs mass is largely unconstrained by theory $\Longrightarrow$ need experimental input

Electroweak precision data from LEP, SLC, $m_W$, $m_t$, ...




SM predictions for observables depend logarithmically on Higgs mass

$$\sim \frac{\alpha}{\pi} \log \frac{m_H^2}{m_W^2}$$

Data require small such contribution

$$\Longrightarrow m_H \approx \text{ order } m_Z$$

# SM Higgs mass fit to EW precision data

$$m_H = 87^{+36}_{-27}\ \text{GeV}$$

Including theory uncertainty

$$m_H < 160\ \text{GeV} \quad (95\%\ \text{CL})$$

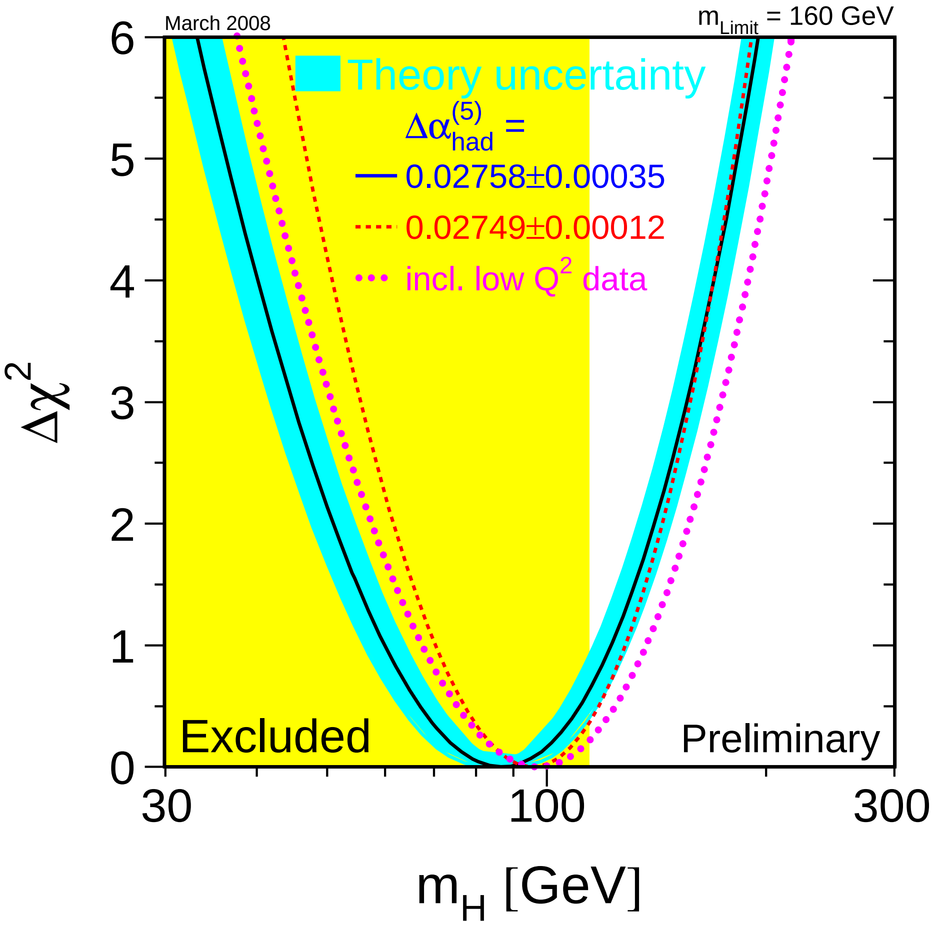
Does not include

Direct search limit from LEP

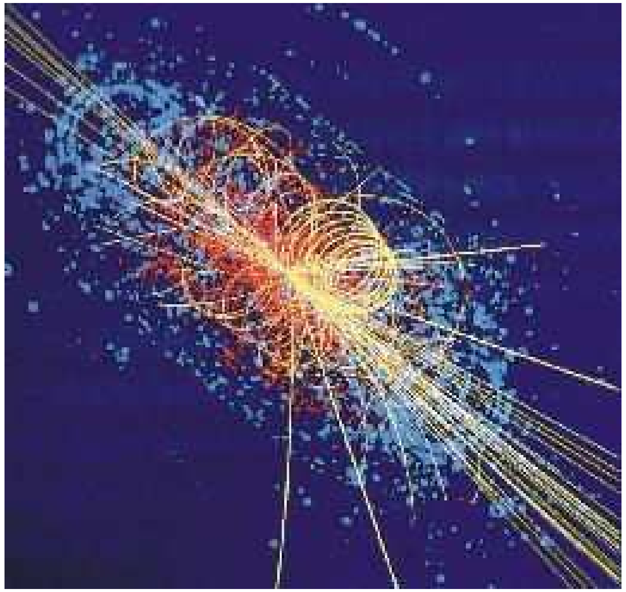
$$m_H > 114\ \text{GeV} \quad (95\%\ \text{CL})$$

Renormalize probability for $m_H > 114$ GeV to 100%:

$$m_H < 190\ \text{GeV} \quad (95\%\ \text{CL})$$



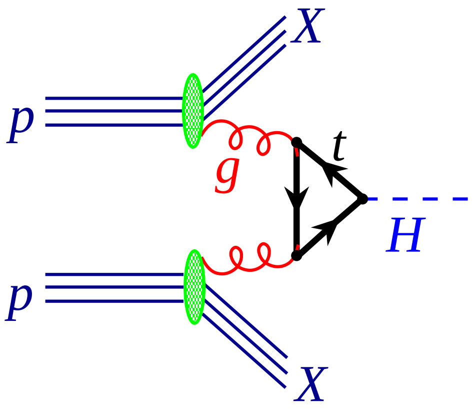
# Higgs boson search at the LHC



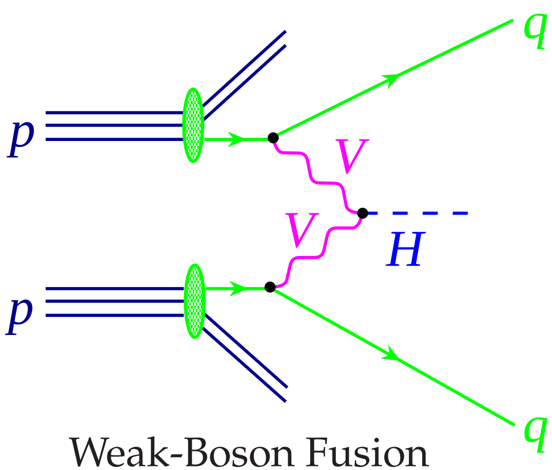
Two steps

- Production of the Higgs boson
- Detection of the decay products of the Higgs boson and identification of the events

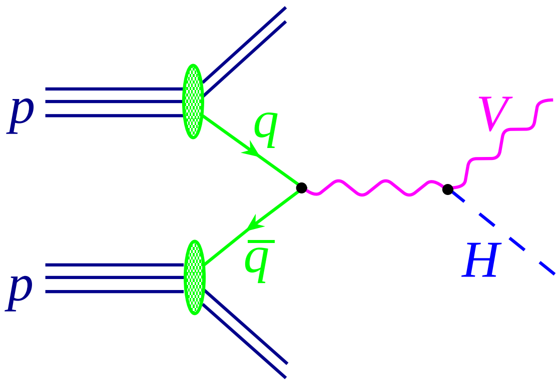
# Higgs Production Channels at the LHC



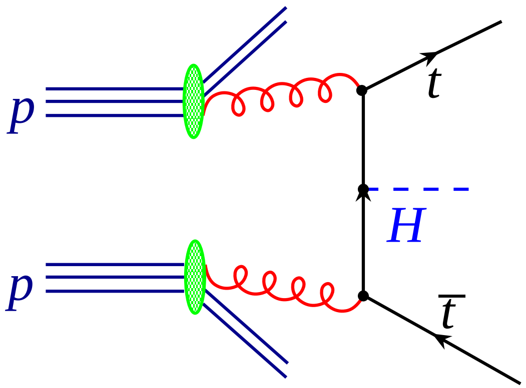

Gluon fusion




Weak-Boson Fusion

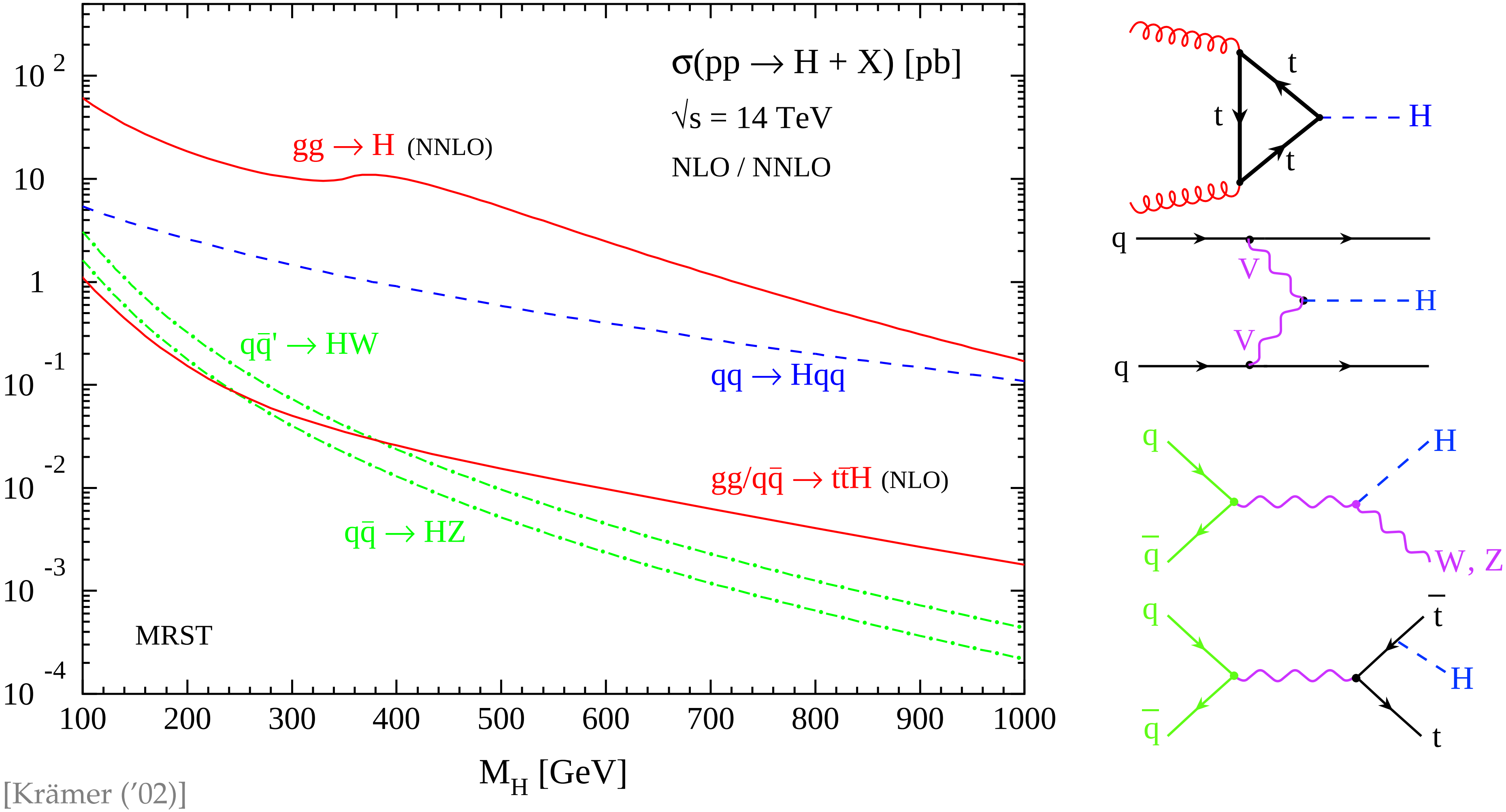



Higgs Strahlung




$t\bar{t}H$

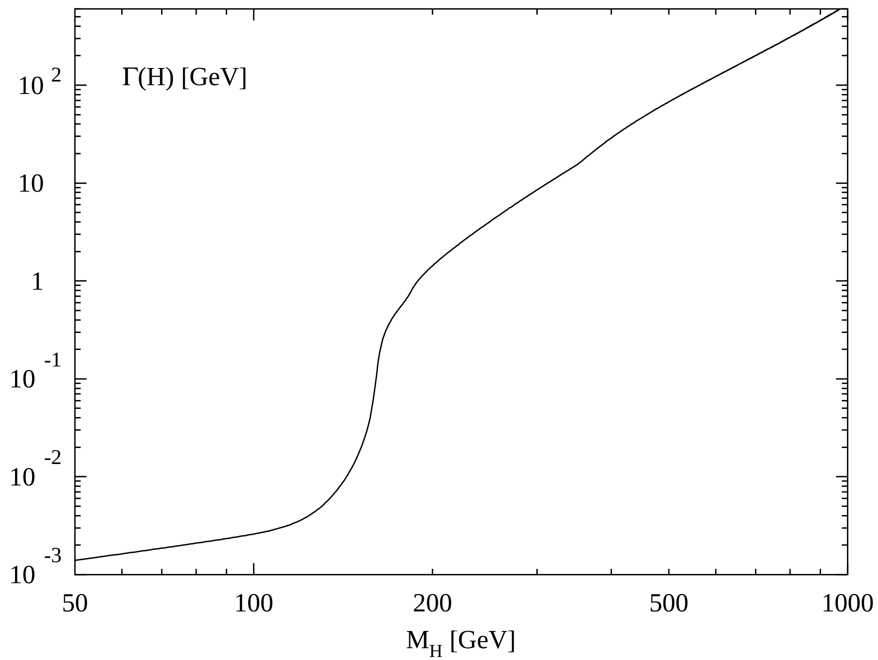
# Total cross sections at the LHC

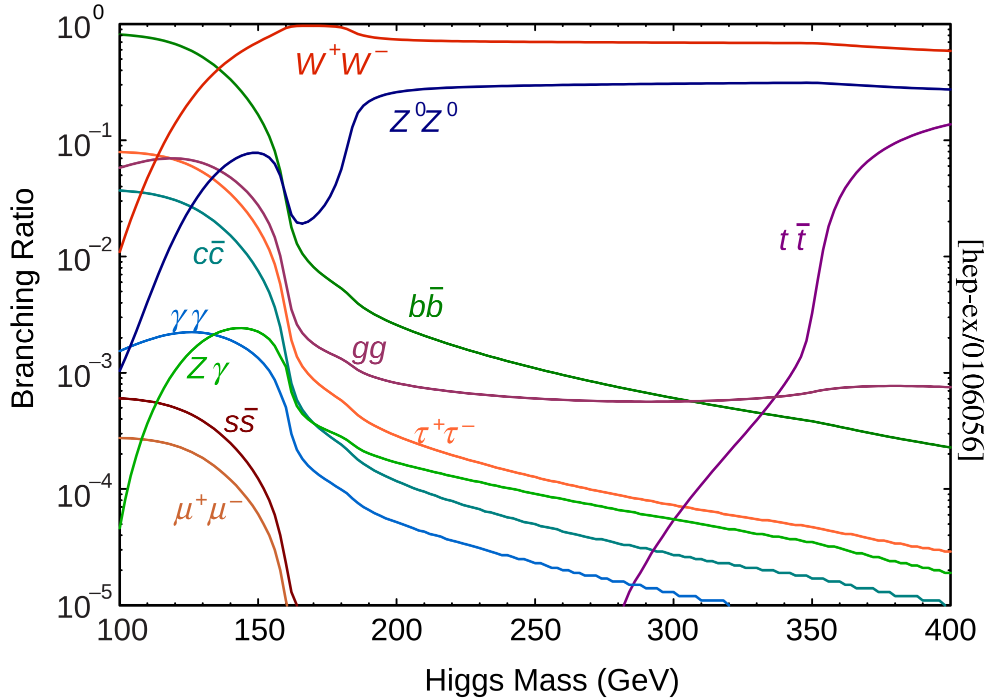



[Krämer ('02)]

# Decay of the SM Higgs

Higgs decay width and branching fractions within the SM



# Inclusive search channels

- inclusive search for

$$H \to \gamma\gamma$$

invariant-mass peak, for $m_H < 150$ GeV

- inclusive search for

$$H \to ZZ^* \to \ell^+\ell^-\ell^+\ell^-$$

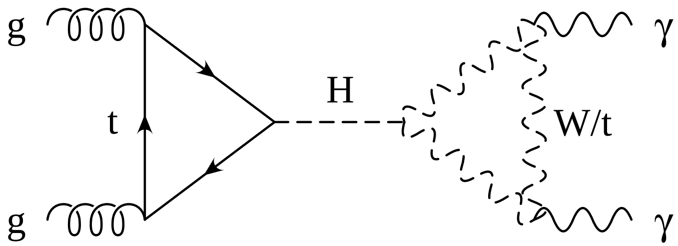
for $m_H \geq 130$ GeV and $m_H \neq 2m_W$.

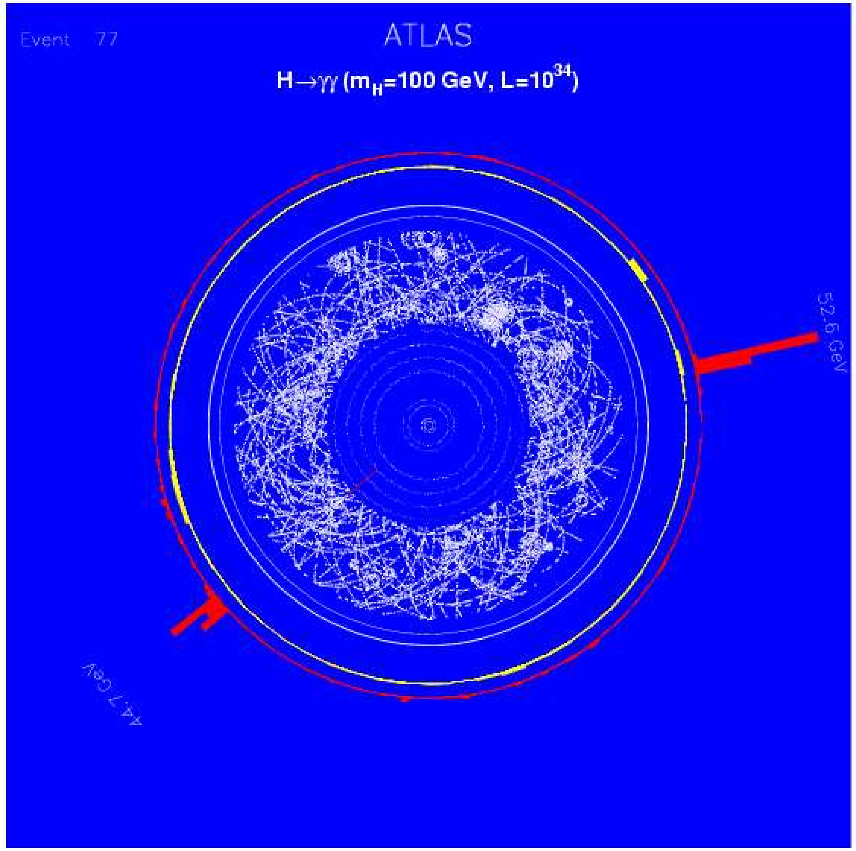
- inclusive search for

$$H \to W^+W^- \to \ell^+\bar{\nu}\ell^-\nu$$

for $140 \text{ GeV} \leq m_H \leq 200$ GeV

# $H \to \gamma\gamma$



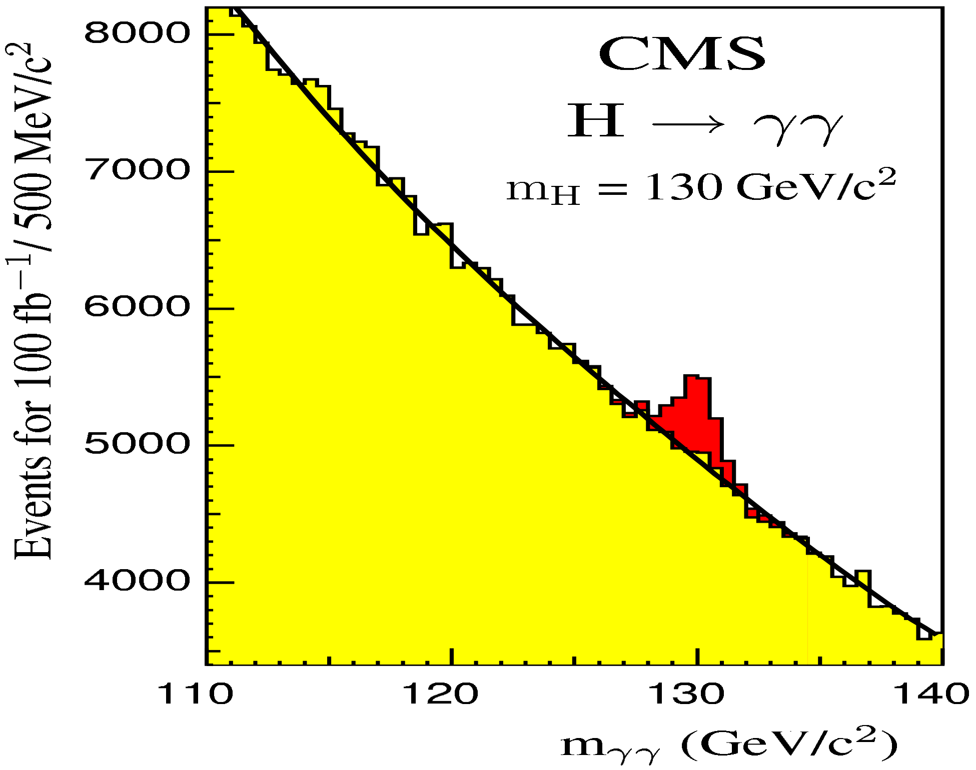




- ✗ $\text{BR}(H \to \gamma\gamma) \approx 10^{-3}$
- ✗ large backgrounds from $q\bar{q} \to \gamma\gamma$ and $gg \to \gamma\gamma$
- ✓ but CMS and ATLAS will have excellent photon-energy resolution (order of 1%)

Look for two isolated photons.

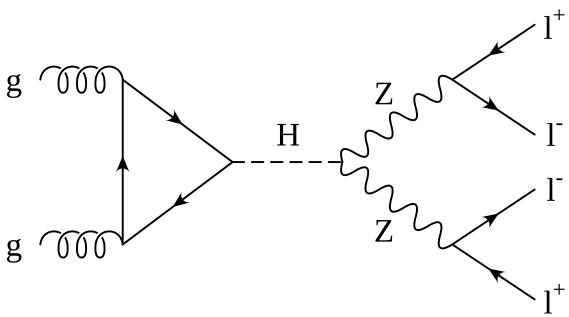
## $H \to \gamma\gamma$

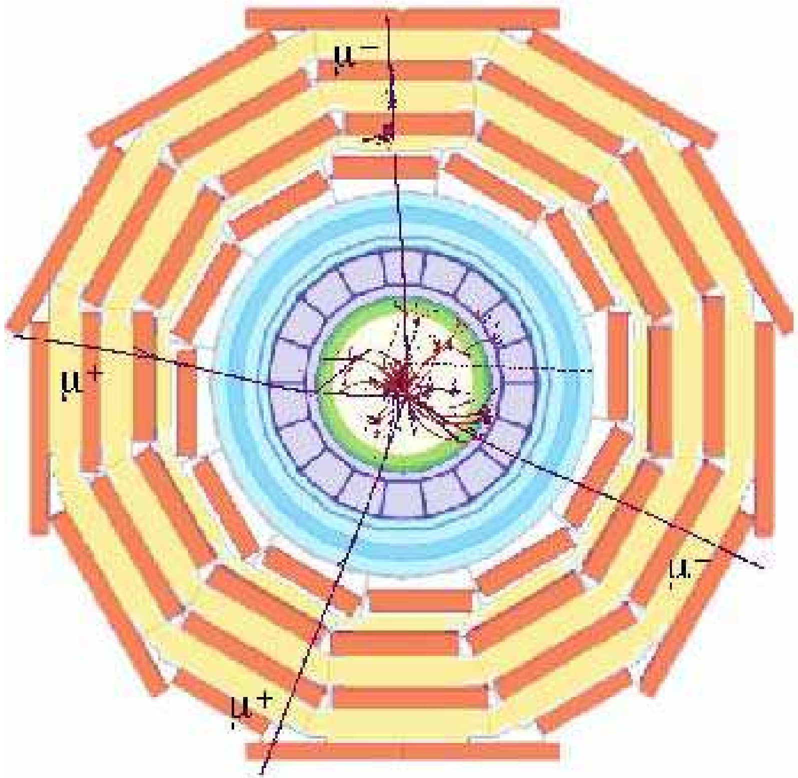
- ✓ Look for a narrow $\gamma\gamma$ invariant mass peak
- ✓ extrapolate background into the signal region from sidebands.



# $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$

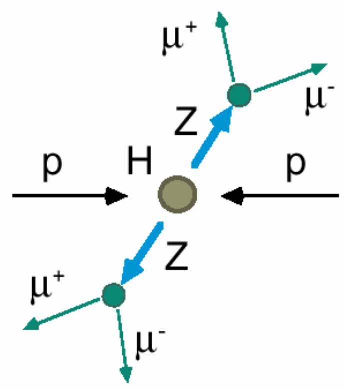
The gold-plated mode

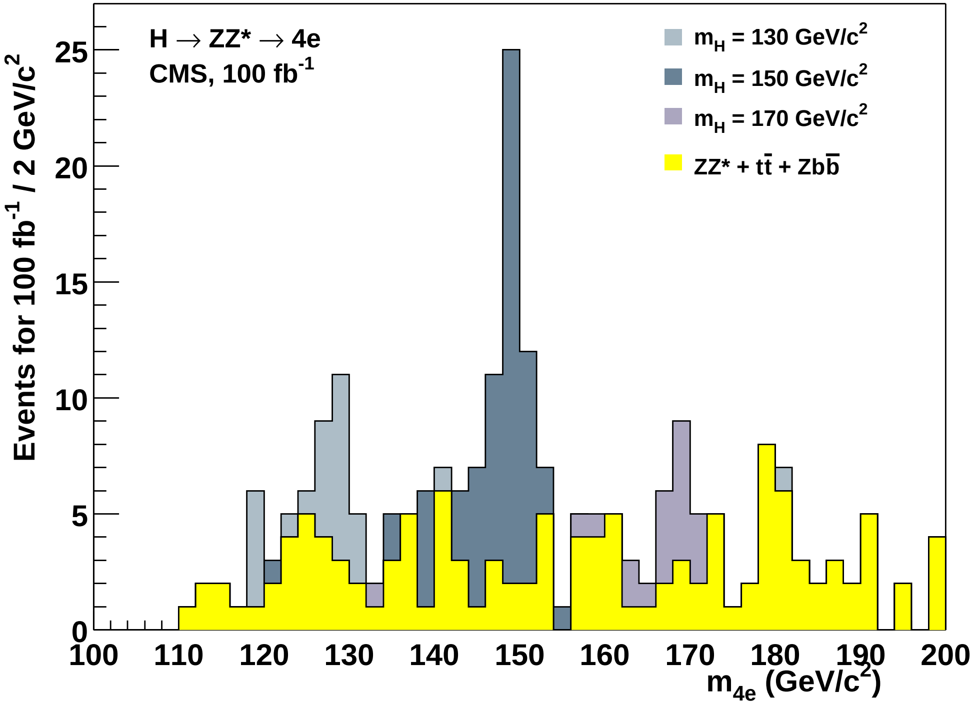



- ✓ This is the most important and clean search mode for $2m_Z < m_H < 600$ GeV.
- ✓ continuum, limited, irreducible background from $q\bar{q} \to ZZ$
- ✗ small BR$(H \to \ell^+\ell^-\ell^+\ell^-) \approx 0.15\%$ (even smaller when $m_H < 2m_Z$)

# $H \to ZZ \to \ell^+\ell^-\ell^+\ell^-$



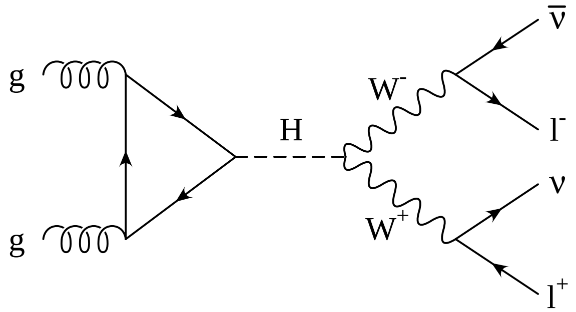

✓ invariant mass of the charged leptons fully reconstructed

For $m_H \approx 0.6$–$1$ TeV, use the "silver-plated" mode $H \to ZZ \to \nu\bar{\nu}\ell^+\ell^-$

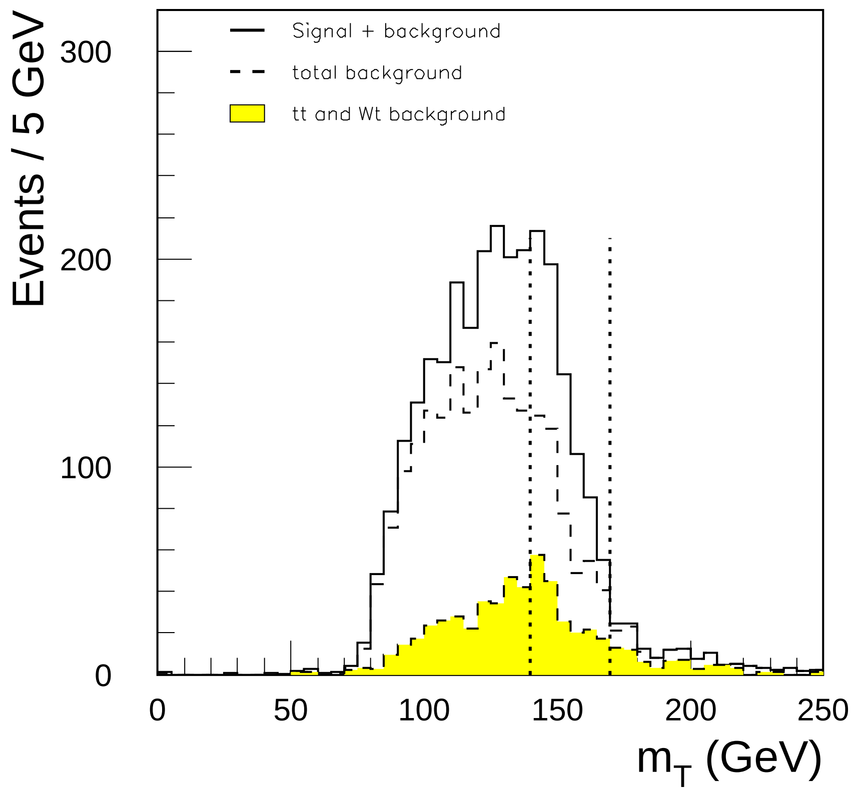
✓ $\mathrm{BR}(H \to \nu\bar{\nu}\ell^+\ell^-) = 6\ \mathrm{BR}(H \to \ell^+\ell^-\ell^+\ell^-)$

✓ the large $E_T$ missing allows a measurement of the transverse mass

# $H \longrightarrow WW \longrightarrow \ell^+ \bar{\nu} \ell^- \nu$




ATLAS TDR




- ✓ Exploit $\ell^+\ell^-$ angular correlations
- ✓ measure the transverse mass with a Jacobian peak at $m_H$

$$m_T = \sqrt{2\, p_T^{\ell\ell}\, \not{E}_T \,(1 - \cos(\Delta\Phi))}$$

- ✗ background and signal have similar shape $\Longrightarrow$ must know the background normalization precisely

$m_H = 170\,\text{GeV}$

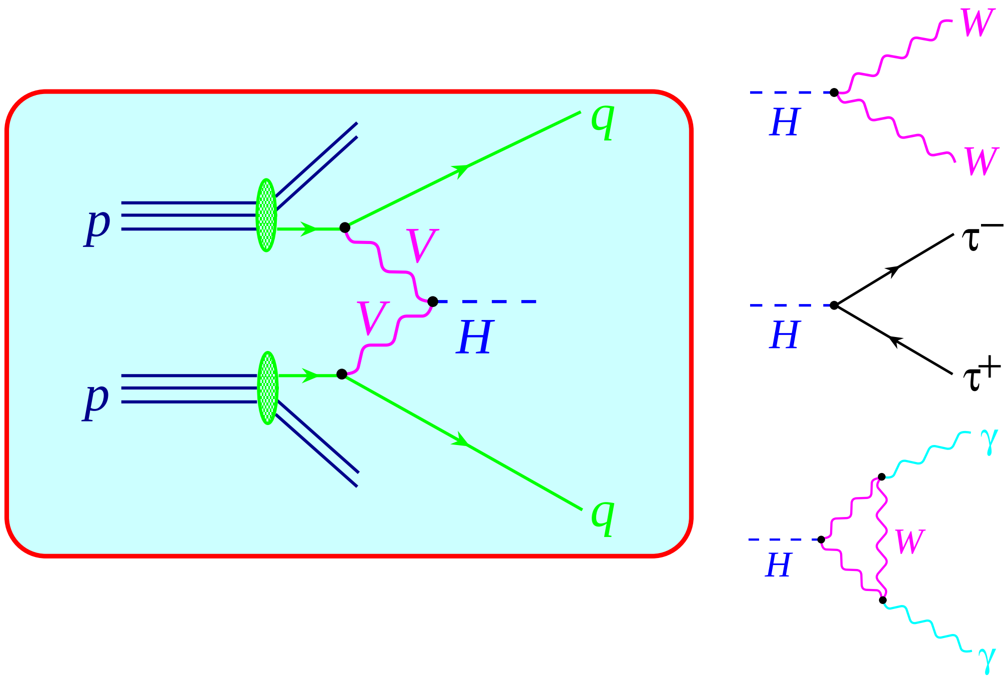
integrated luminosity = 20 fb$^{-1}$

# Associated production search channels

- $pp \to t\bar{t}H \to t\bar{t}b\bar{b}$
  for $m_H < 120$–$130$ GeV
- $q\bar{q} \to WH\ ,\ ZH$
  with Higgs decay $H \to b\bar{b}$

The leptons from $W$ or $Z$ decay produced in association with the Higgs boson serve to trigger the event.

# Vector Boson Fusion




$m_H > 120$ GeV

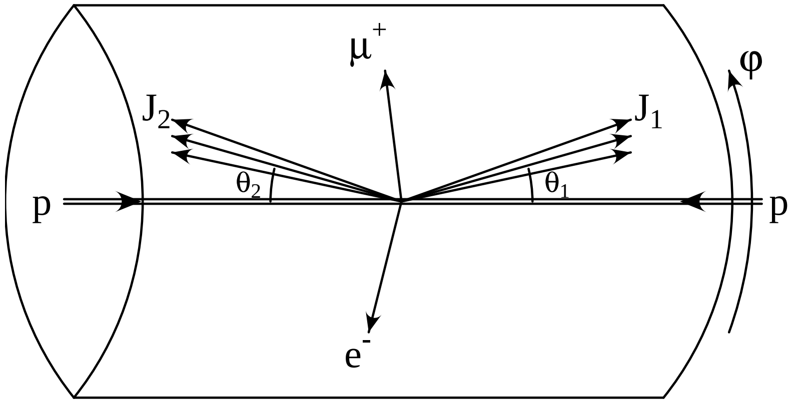
$m_H < 140$ GeV

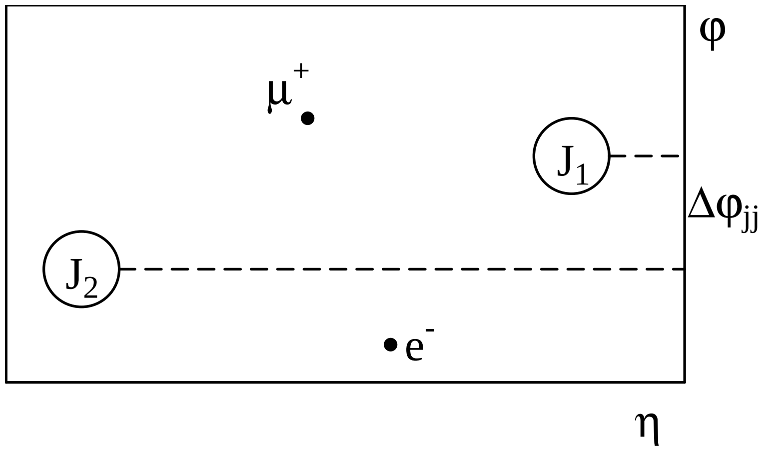
$m_H < 150$ GeV

[Eboli, Hagiwara, Kauer, Plehn, Rainwater, D.Z. . . . ]

Most measurements can be performed at the LHC with statistical accuracies on the measured cross sections times decay branching ratios, $\sigma\times$ BR, of order 10% (sometimes even better).

# VBF signature

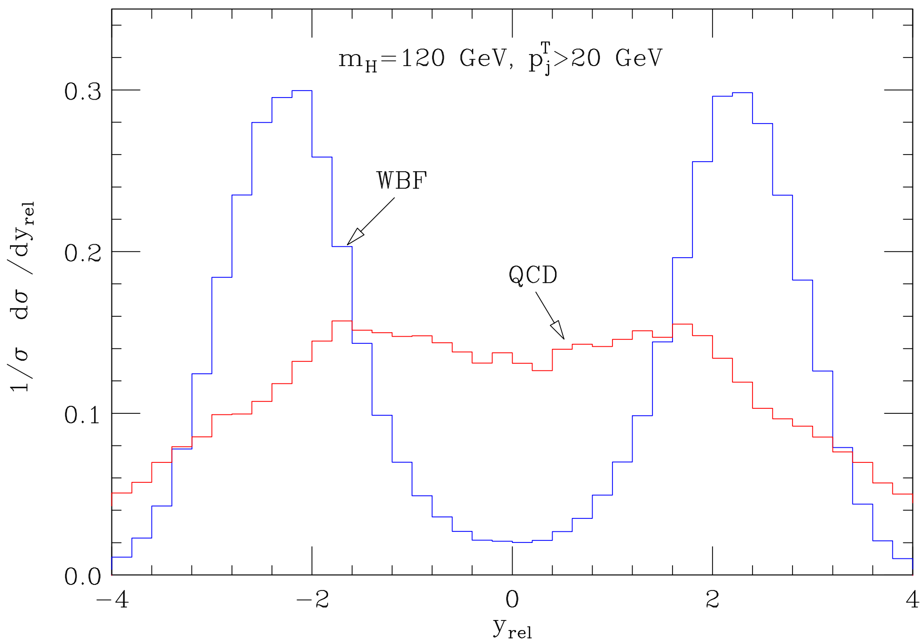


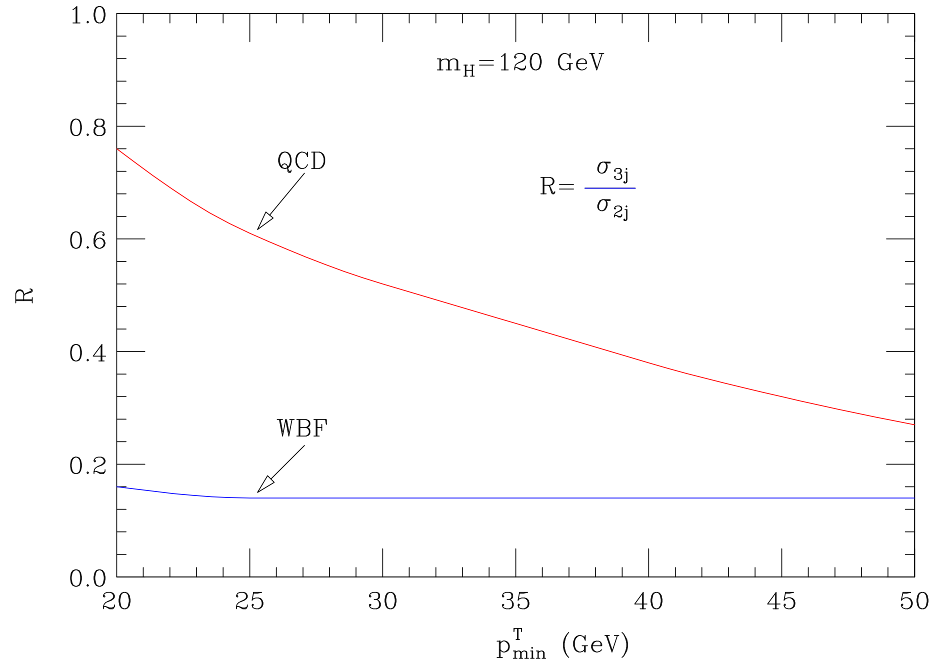




Characteristics:

- energetic jets in the forward and backward directions ($p_T > 20$ GeV)
- large rapidity separation and large invariant mass of the two tagging jets
- Higgs decay products between tagging jets
- Little gluon radiation in the central-rapidity region, due to colorless $W/Z$ exchange (central jet veto: no extra jets with $p_T > 20$ GeV and $|\eta| < 2.5$)

# Central Jet Veto: $Hjjj$ from VBF vs. gluon fusion




[ Del Duca, Frizzo, Maltoni, JHEP 05 (2004) 064]

- A distinguishing feature of VBF is that at LO no color is exchanged in the t-channel.
- The central-jet veto is based on the different radiation pattern expected for VBF versus its major backgrounds [hep-ph/9412276, hep-ph/0012351]
- Central jet veto can be used to distinguish Higgs production via GF from VBF

# Example: Parton level analysis of $H \to WW$

Near threshold: $W$ and $W^*$ almost at rest in Higgs rest frame $\Longrightarrow$ use $m_{ll} \approx m_{\nu\nu}$ for improved transverse mass calculation:

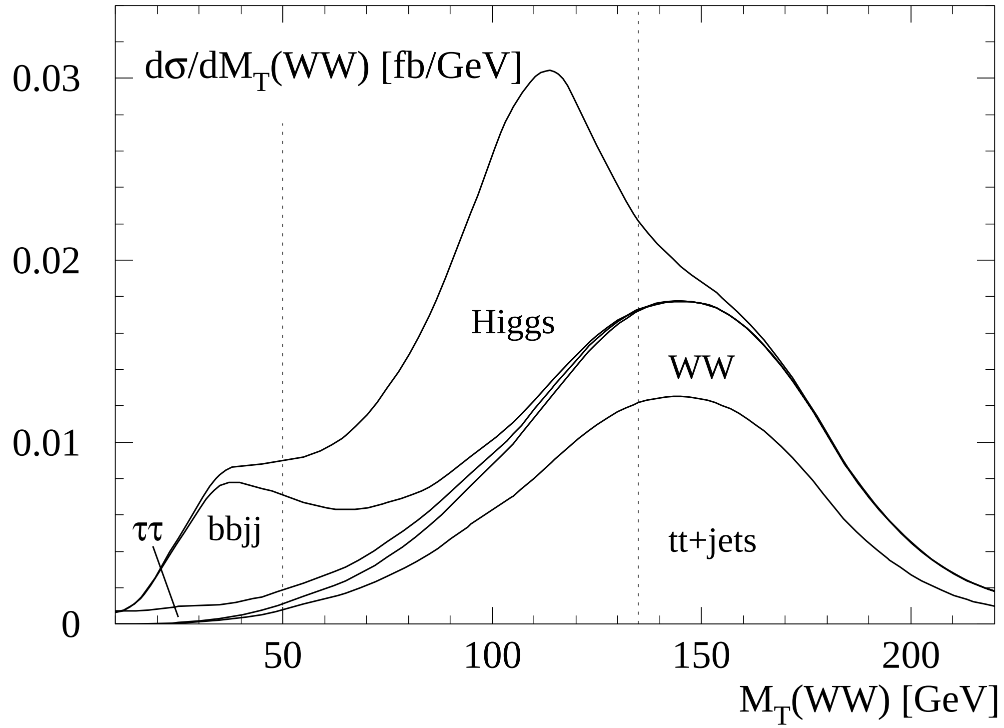
$$E_{T,ll} = \sqrt{\mathbf{p}_{T,ll}^2 + m_{ll}^2}$$

$$\not{E}_T = \sqrt{\not{\mathbf{p}}_T^2 + m_{\nu\nu}^2} \approx \sqrt{\not{\mathbf{p}}_T^2 + m_{ll}^2}$$

$$M_T = \sqrt{(\not{E}_T + E_{T,ll})^2 - (\mathbf{p}_{T,ll} + \not{\mathbf{p}}_T)^2}$$

Observe Jacobian peak below $M_T = m_H$

Kauer, Plehn, Rainwater, D.Z. hep-ph/0012351

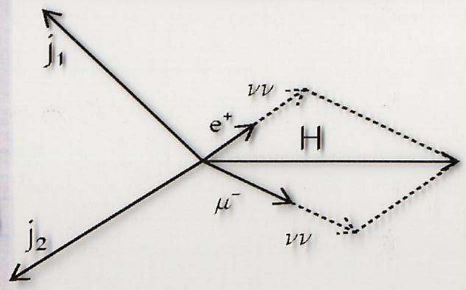


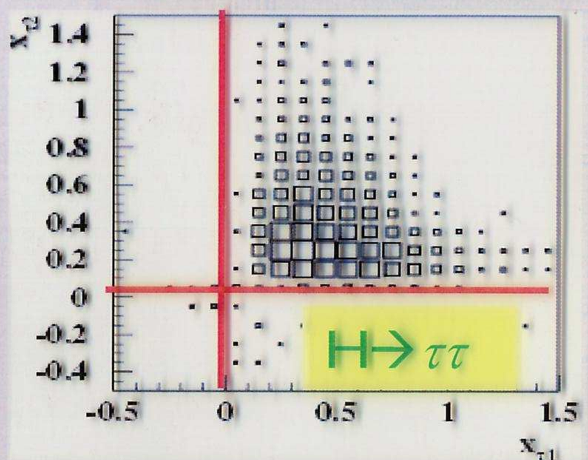

Transverse mass distribution for $m_H =$ 115 GeV and $H \to WW^* \to e^{\pm}\mu^{\mp}\not{p}_T$

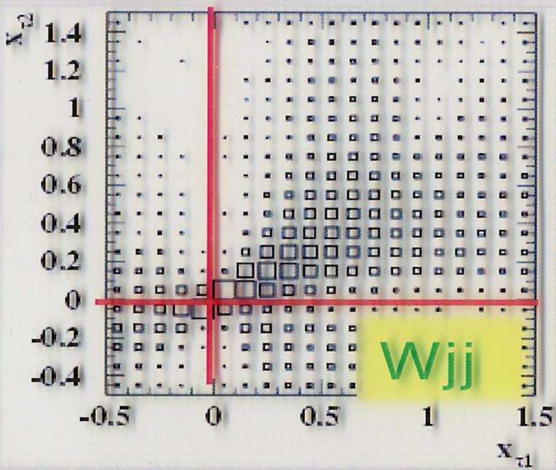
# Weak Boson Fusion: $H \rightarrow \tau\tau$

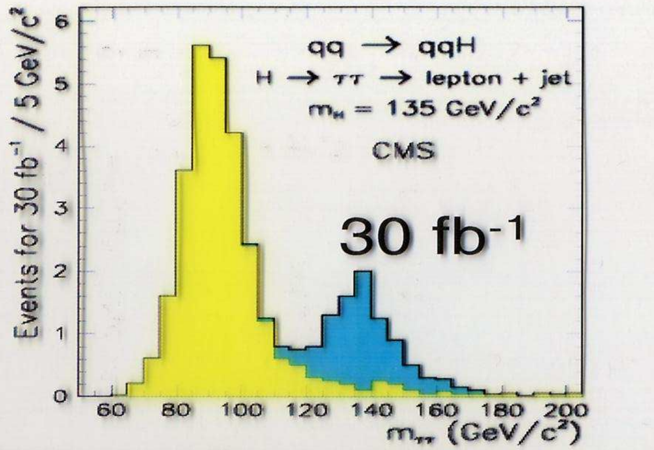
Mass can be reconstructed in collinear approximation

$x_\tau$ = momentum fraction carried by tau decay products



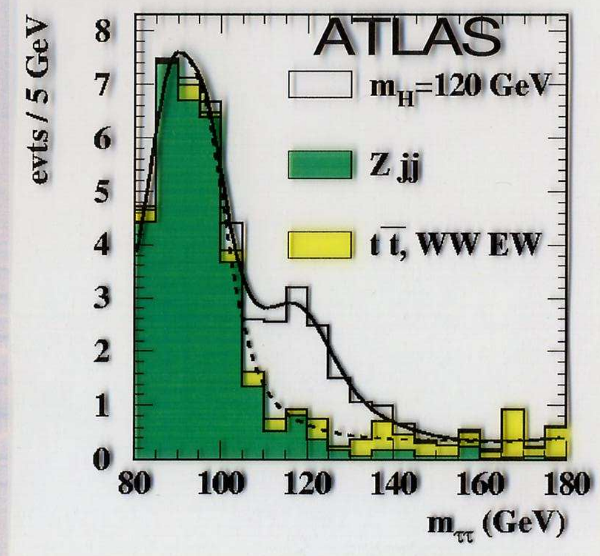

$\sigma_M$ = 11 to 12 GeV

★ significance > 5 for 30 $fb^{-1}$ and $M_H$=110 to 140 GeV ($\tau\tau \rightarrow e\mu$, $\tau\tau \rightarrow ll$, $\tau\tau \rightarrow l$ had)

★ background estimate: ~10%

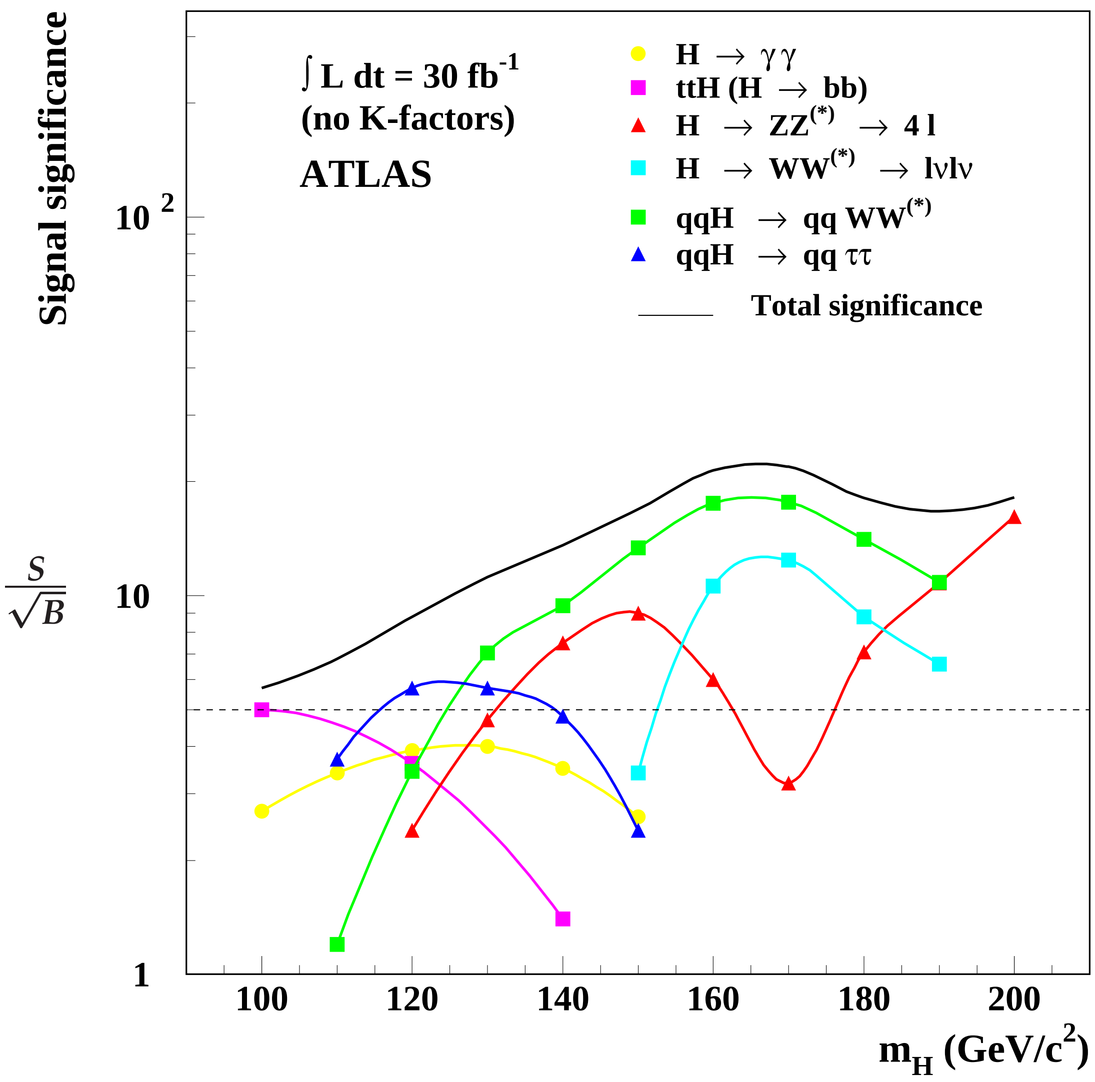
for $M_H$>125 GeV from side bands

for $M_H$>125 GeV from normalisation of $Z \rightarrow \tau\tau$ peak




$H \rightarrow \tau\tau \rightarrow e\mu$ 30 $fb^{-1}$

# Higgs discovery potential



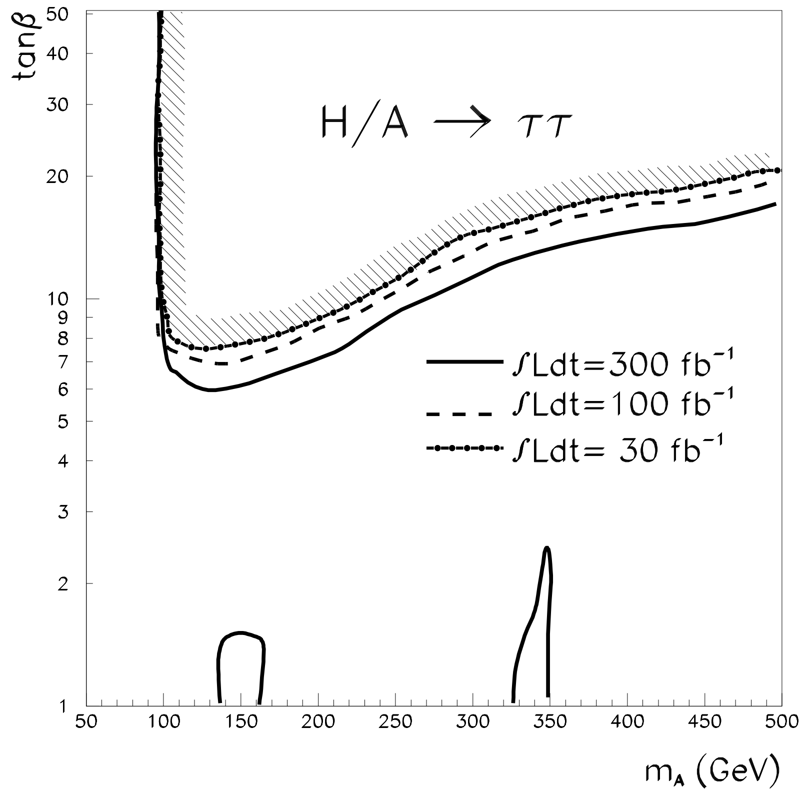
# Reach for H/A discovery within MSSM

Enhancement of
*Hbb* and *Abb* coupling
by factor $\tan\beta$
compared to SM Higgs

⟹ large production cross section for $pp \to \bar{b}bH/A$

⟹ decay dominated by $H/A \to \bar{b}b,\ \tau^+\tau^-$

ATLAS TDR




$5\sigma$ discovery contours

# Reach for $H^{\pm}$ discovery within MSSM

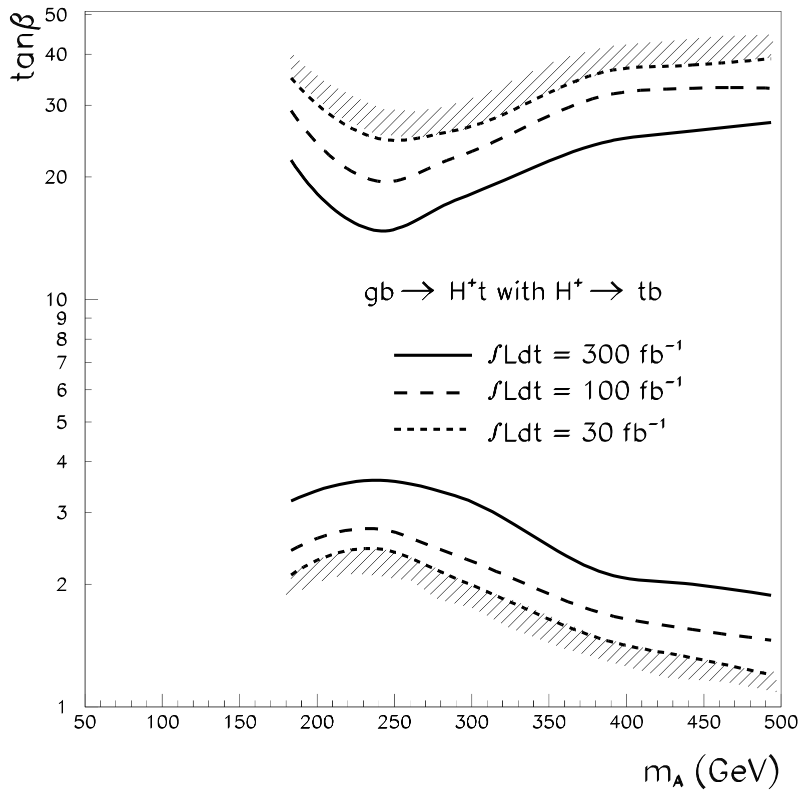
- For $m_{H^{\pm}} > m_t + m_b$ expect $H^{\pm} \to tb$ decay
- Dominant production process

$$gg \to H^{\pm} tb$$

b-quark has low $p_T$: $gb \to H^{\pm} t$ is dominant subprocess

- Main background from $\bar{t}t(+\text{jets})$ production

ATLAS TDR




$5\sigma$ discovery contours

# Measuring Higgs couplings at LHC

LHC rates for partonic process $pp \to H \to xx$ given by $\sigma(pp \to H) \cdot BR(H \to xx)$

$$\sigma(H) \times \mathrm{BR}(H \to xx) = \frac{\sigma(H)^{\mathrm{SM}}}{\Gamma_p^{\mathrm{SM}}} \cdot \frac{\Gamma_p \Gamma_x}{\Gamma},$$

Measure products $\Gamma_p \Gamma_x / \Gamma$ for combination of processes ($\Gamma_p = \Gamma(H \to pp)$)

Problem: rescaling fit results by common factor $f$

$$\Gamma_i \to f \cdot \Gamma_i, \qquad \Gamma \to f^2 \Gamma = \sum_{obs} f \Gamma_i + \Gamma_{rest}$$

leaves observable rate invariant $\Longrightarrow$ no model independent results at LHC

Loose bounds on scaling factor:

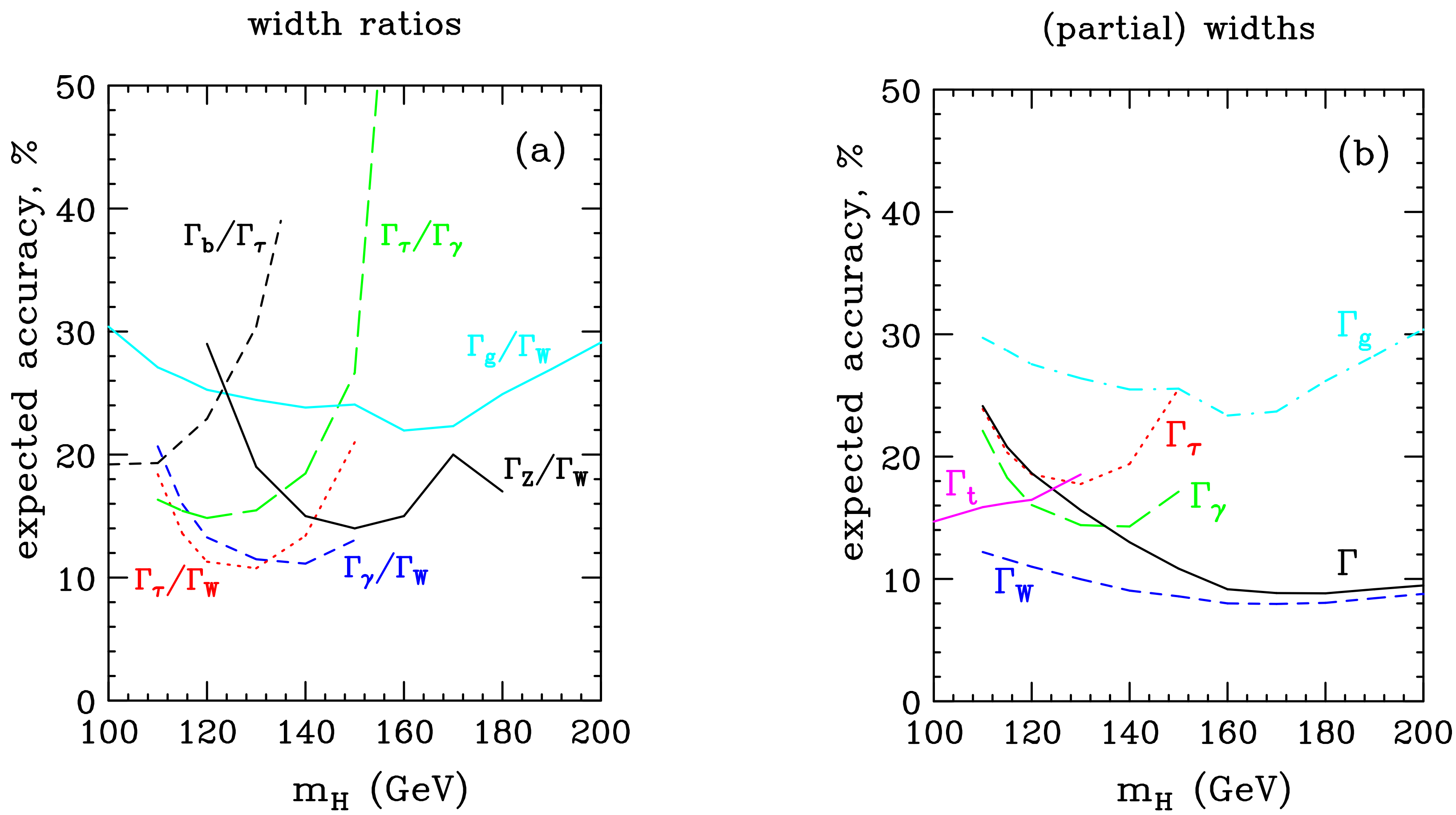
$$f^2 \Gamma > \sum_{obs.} f \Gamma_x \qquad \Longrightarrow \qquad f > \sum_{obs.} \frac{\Gamma_x}{\Gamma} = \sum_{obs.} BR(H \to xx) (= \mathcal{O}(1))$$

Total width below experimental resolution of Higgs mass peak ($\Delta m = 1 \ldots 20$ GeV)

$$f^2 \Gamma < \Delta m \qquad \Longrightarrow \qquad f < \sqrt{\frac{\Delta m}{\Gamma}} < \mathcal{O}(10 - 40)$$

# Fit LHC data within constrained models

- $\frac{g_{H\tau\tau}}{g_{Hbb}}$ = SM value
- $\frac{g_{HWW}}{g_{HZZ}}$ = SM value
- no exotic channels




With 200 fb$^{-1}$ measure partial width with 10–30% errors, couplings with 5–15% errors

# Distinguishing the MSSM Higgs sector from the SM

Alternative: compare data to predictions of specific models

Example: $m_H^{max}$ scenario of LEP analyses

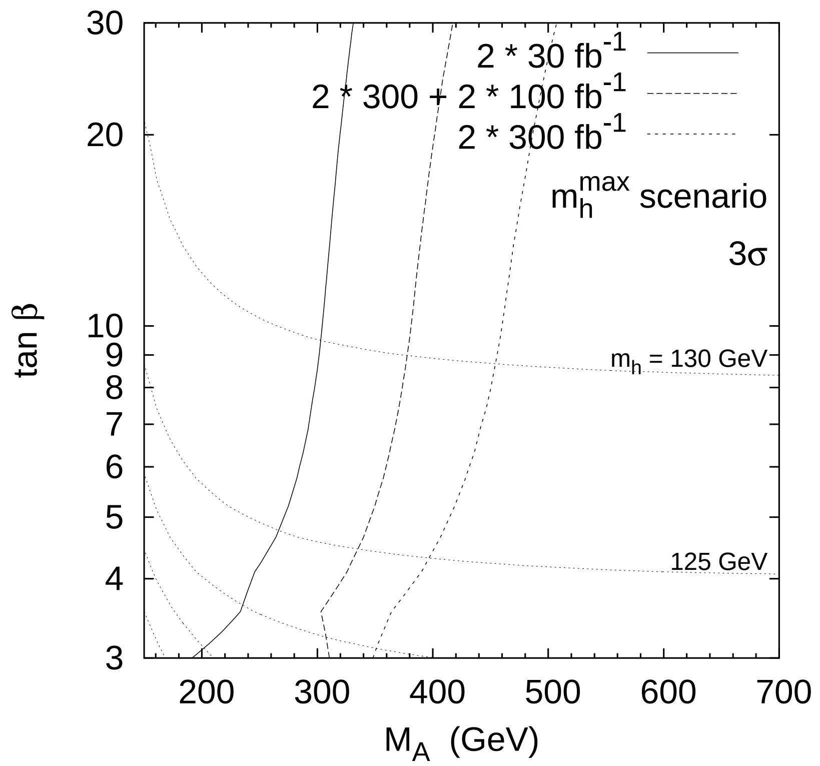
Consider modest $m_A$:

- decoupling almost complete for $hWW$ and $h\gamma\gamma$ (effective) vertices
- enhanced $hbb$ and $h\tau\tau$ couplings compared to SM increases total width of $h$

$\Longrightarrow$

- $\approx$ SM rates for $h \to \tau\tau$ in VBF
- suppressed $h \to \gamma\gamma$ and $h \to WW$ rates in VBF

3$\sigma$-effects or more at small $m_A$



## Corrections for Higgs production cross sections

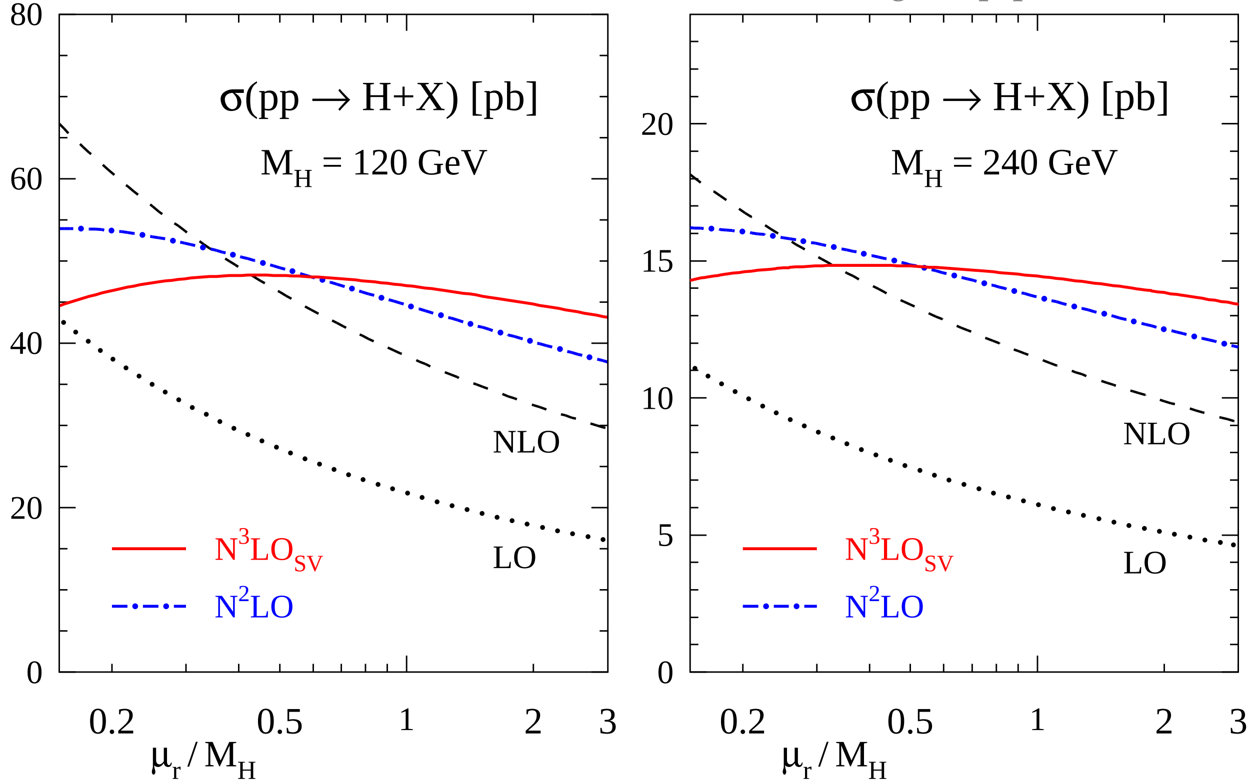
Measurement of partial widths at 10–20% level or couplings at 5–10% level requires predictions of SM production cross sections at 10% level or better

$\Longrightarrow$ need QCD corrections to production cross sections. Much progress in recent years

- $gg \to H$ (all but NLO in $m_t \to \infty$ limit)
  - NLO for finite $m_t$: Graudenz, Spira, Zerwas (1993)
  - NNLO: Harlander, Kilgore (2001); Anastasiou, Melnikov (2002); Ravindran, Smith, van Neerven (2003)
  - $N^3LO$ in soft approximation: Moch, Vogt (2005)
- $Hjj$ by gluon fusion at NLO: Campbell, Ellis, Zanderighi (2006)
- weak boson fusion
  - total cross section at NLO: Han, Willenbrock (1991)
  - distributions at NLO: Figy, Oleari, D.Z (2003); Campbell, Ellis, Berger (2004)
  - 1-loop EW corrections: Ciccolini, Denner, Dittmaier (2007)
- $\bar{t}tH$ associated production at NLO: Beenakker et al.; Dawson, Orr, Reina, Wackeroth (2002)
- $\bar{b}bH$ associated production at NLO: Dittmaier, Krämer, Spira; Dawson et al. (2003)

# QCD corrections to $gg \to H$

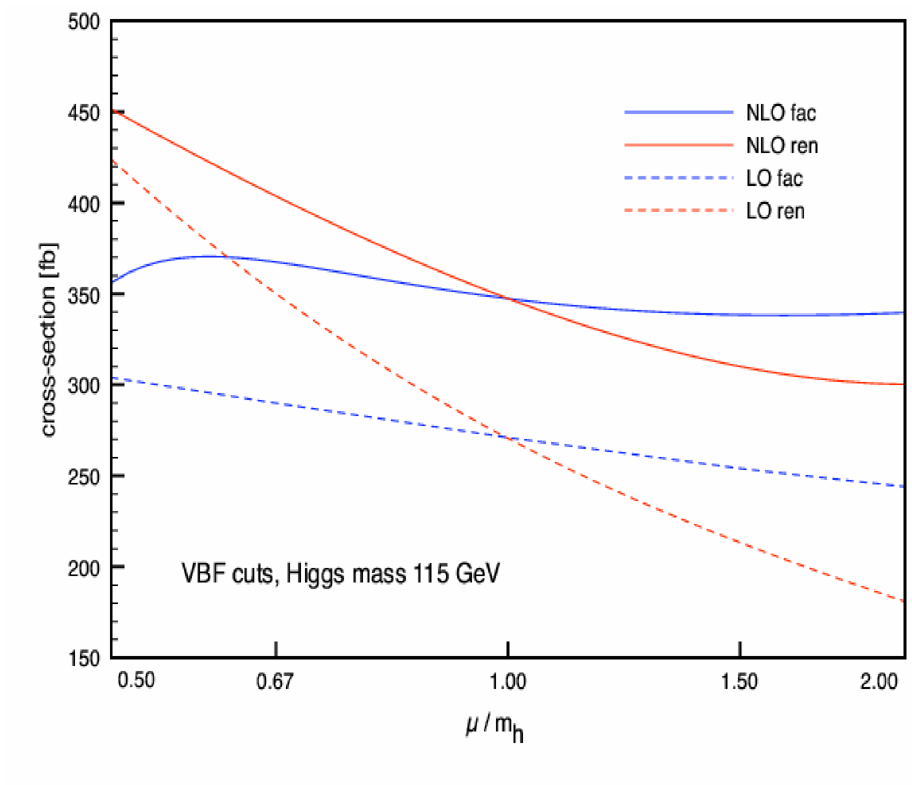


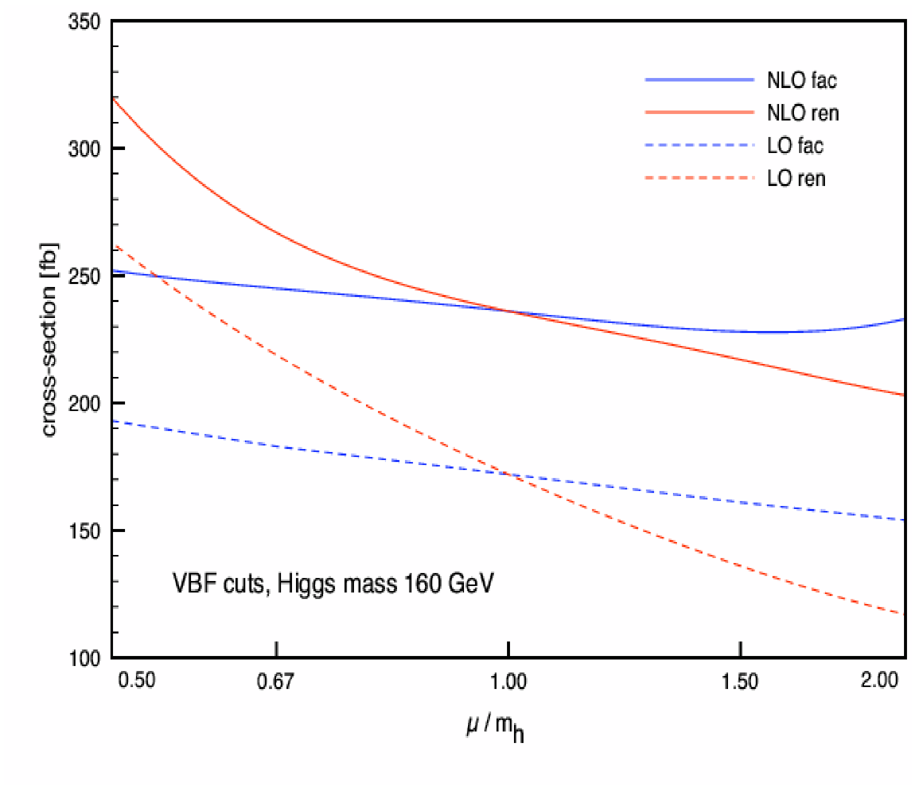



- ✓ Huge improvement in recent years
- ✓ Remaining scale uncertainty below 10%
- ✓ Uncertainty from gluon pdf $\approx 4-7\%$
- ✗ What is K-factor for cross section with cuts? Most problematic: central jet veto against $\bar{t}t$ background for $H \to WW$ search

# $Hjj$ cross section for gluon fusion

Calculation of $Hjj$ cross section at NLO in $m_t \to \infty$ limit by Campbell, Ellis, Zanderighi, hep-ph/0608194

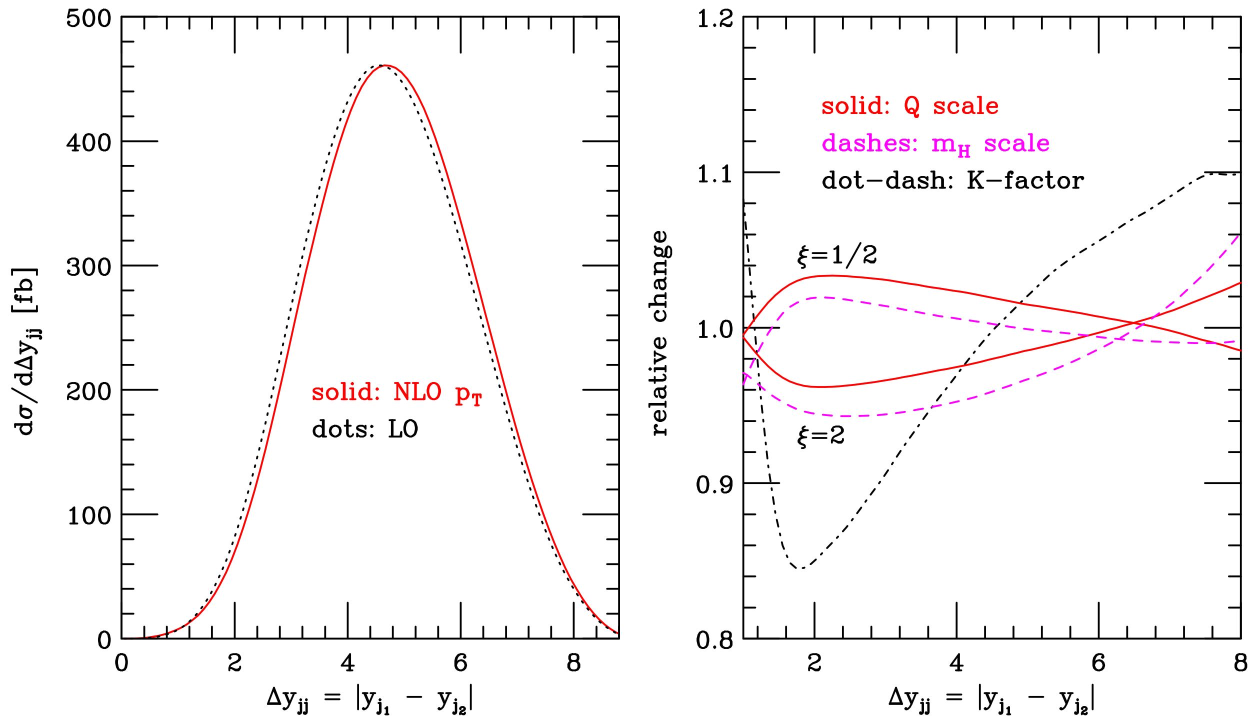



- Modest increase of cross section at 1-loop: K-factor of order 1.2 - 1.4
- Reduced scale dependence at NLO: remaining scale uncertainty $\approx \pm 20\%$

# NLO QCD corrections to VBF

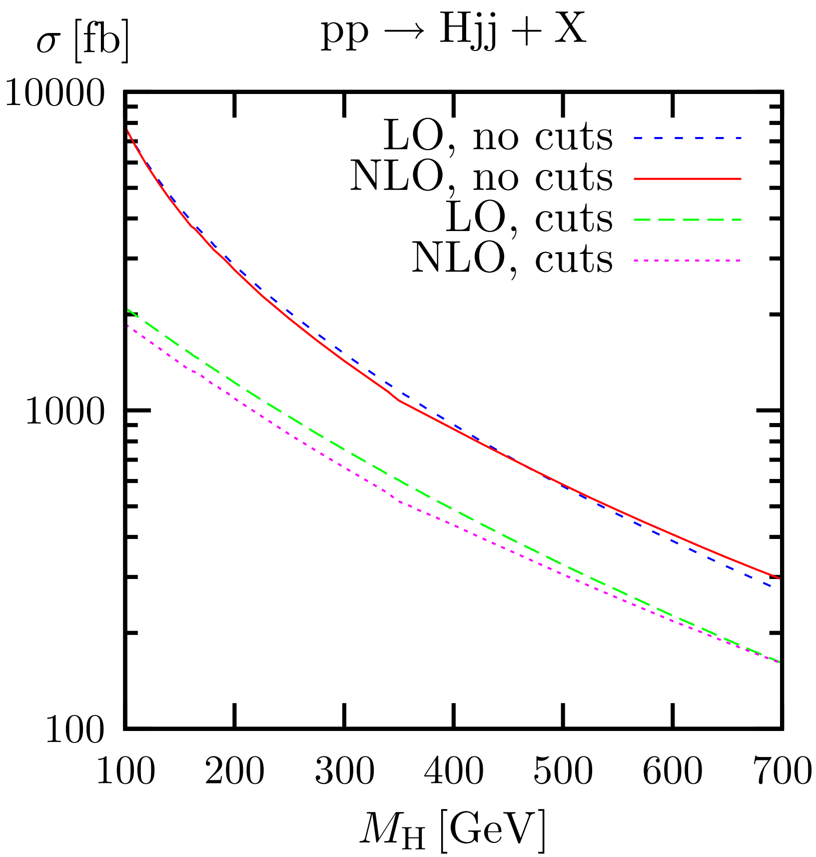
- ✓ Small QCD corrections of order 10%
- ✓ Tiny scale dependence of NLO result
  - $\pm 5\%$ for distributions
  - $< 2\%$ for $\sigma_{\text{total}}$
- ✓ K-factor is phase space dependent
- ✓ QCD corrections under excellent control
- ✗ Need electroweak corrections for 5% uncertainty

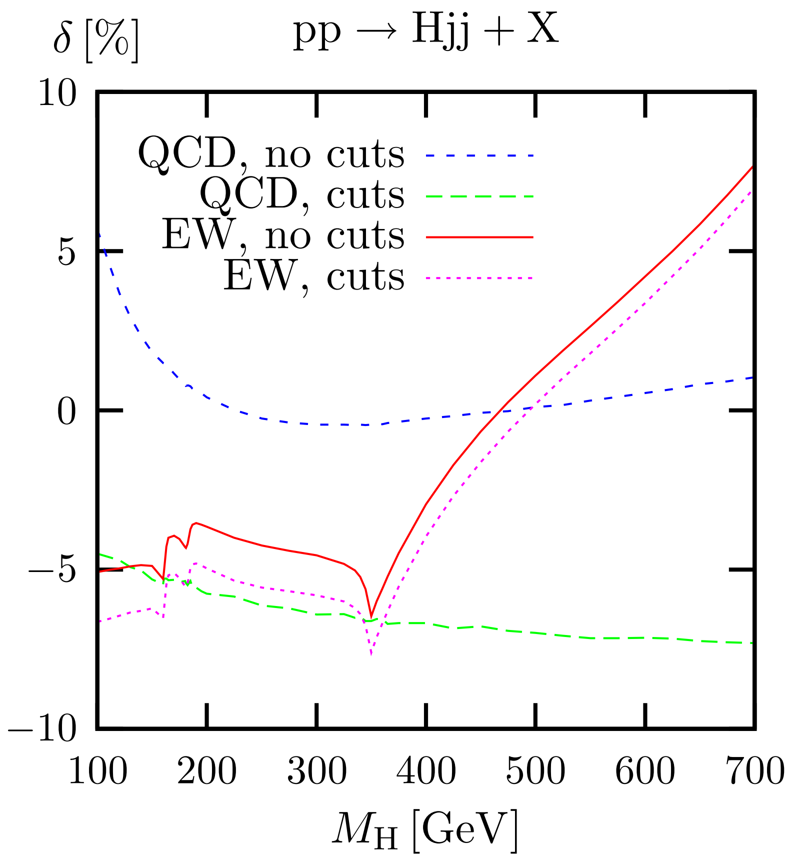



$m_H = 120\,\text{GeV}$, typical VBF cuts

# QCD + EW corrections to Hjj production

Cross sections without and with VBF cuts: $p_T(j) > 20$ GeV $\quad |y_{j_1} - y_{j_2}| > 4, \;\; y_{j_1} \cdot y_{j_2} < 0$



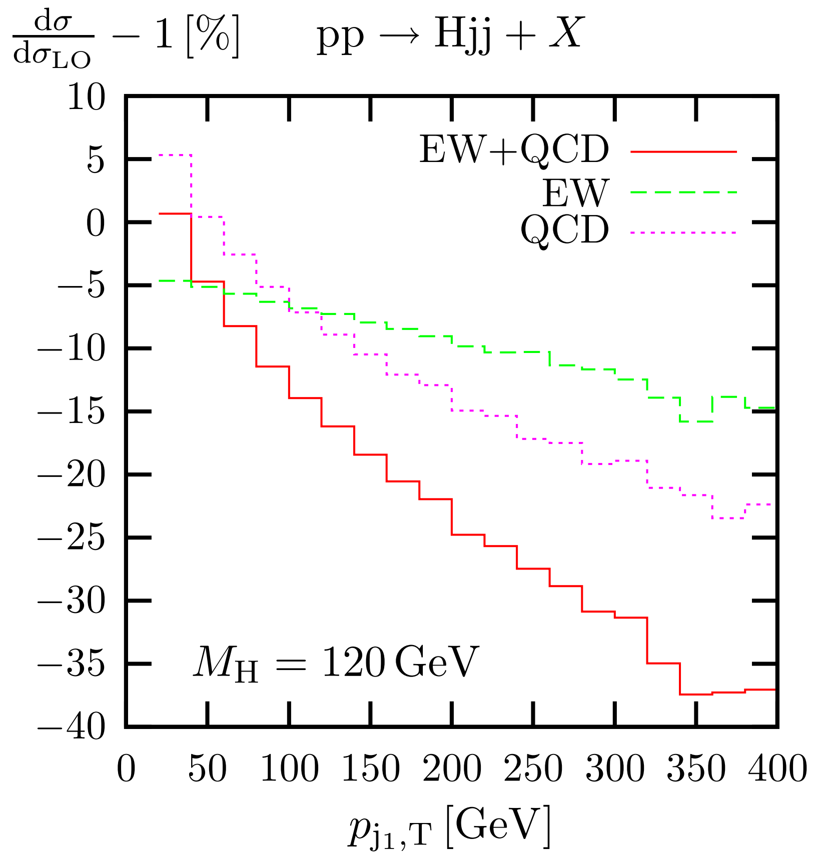




Ciccolini, Denner, Dittmaier, arXiv:0710.4749

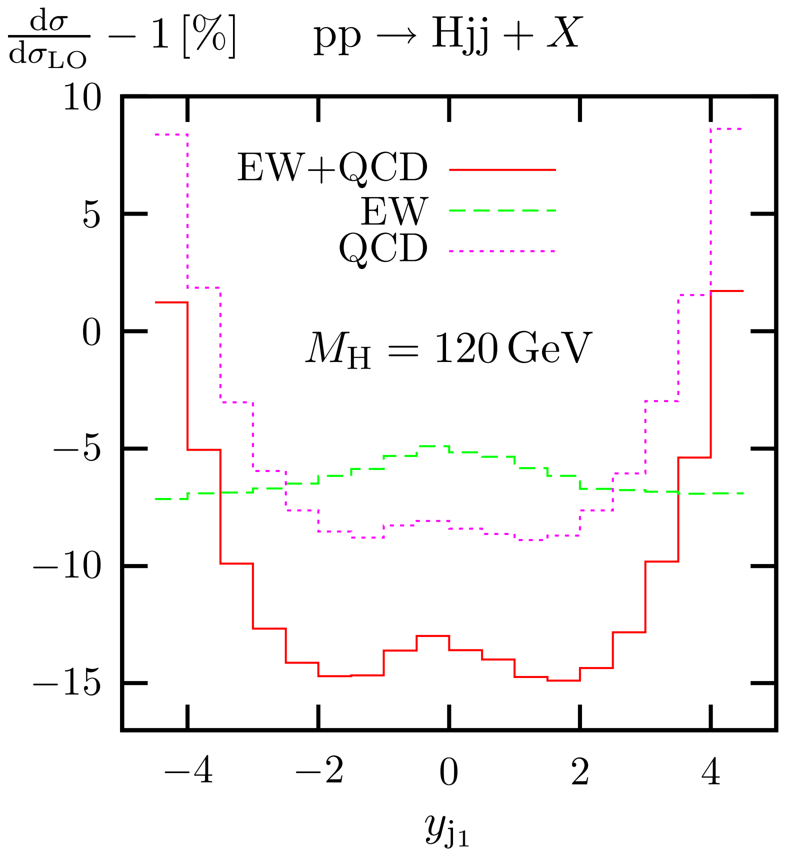
# Relative size of 1-loop corrections

Consider distributions of hardest jet in the event:

$p_T$ distribution



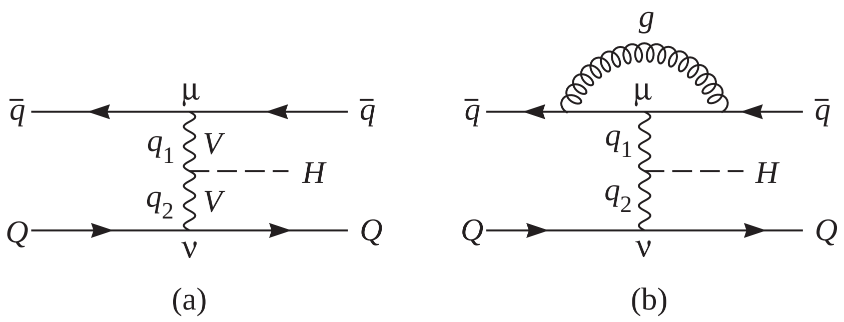

rapidity distribution




strong shape changes by QCD corrections, EW corrections affect mostly normalization

# Tensor structure of the $HVV$ coupling

Most general $HVV$ vertex $T^{\mu\nu}(q_1, q_2)$




$$T^{\mu\nu} = a_1\, g^{\mu\nu} + a_2\,\left(q_1 \cdot q_2\, g^{\mu\nu} - q_1^{\nu} q_2^{\mu}\right) + a_3\, \varepsilon^{\mu\nu\rho\sigma}\, q_{1\rho} q_{2\sigma}$$

The $a_i = a_i(q_1, q_2)$ are scalar form factors

Physical interpretation of terms:

SM Higgs $\quad \mathcal{L}_I \sim H V_\mu V^\mu \longrightarrow a_1$

loop induced couplings for neutral scalar

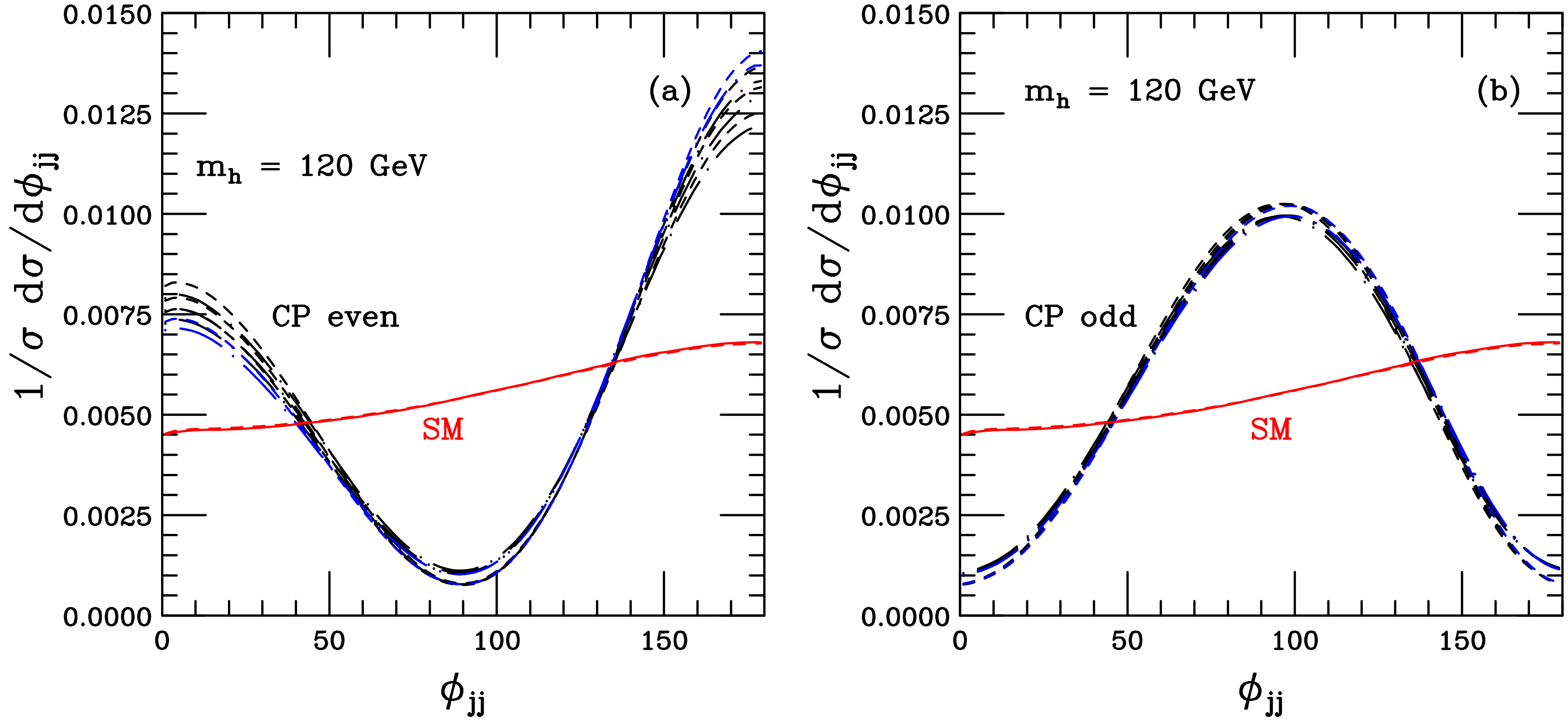
CP even $\quad \mathcal{L}_{eff} \sim H V_{\mu\nu} V^{\mu\nu} \longrightarrow a_2$

CP odd $\quad \mathcal{L}_{eff} \sim H V_{\mu\nu} \tilde{V}^{\mu\nu} \longrightarrow a_3$

Must distinguish $a_1$, $a_2$, $a_3$ experimentally

# Azimuthal angle correlations

Tell-tale signal for non-SM coupling is azimuthal angle between tagging jets




Dip structure at 90° (CP even) or 0/180° (CP odd) only depends on tensor structure of $HVV$ vertex. Very little dependence on form factor, LO vs. NLO, Higgs mass etc.

# Conclusions

- The LHC will tell us how electroweak symmetry breaking is realized in nature.
- LHC will observe a SM-like Higgs boson in multiple channels, with $5 \ldots 20\%$ statistical errors
  $\Longrightarrow$ great source of information on Higgs couplings
- Extraction of couplings at the LHC requires knowledge of NLO QCD corrections for signal and important backgrounds
- Higgs boson CP properties from jet-angular correlations in VBF and gluon fusion
- LHC starts serious data taking this year. Eciting times ahead of us!