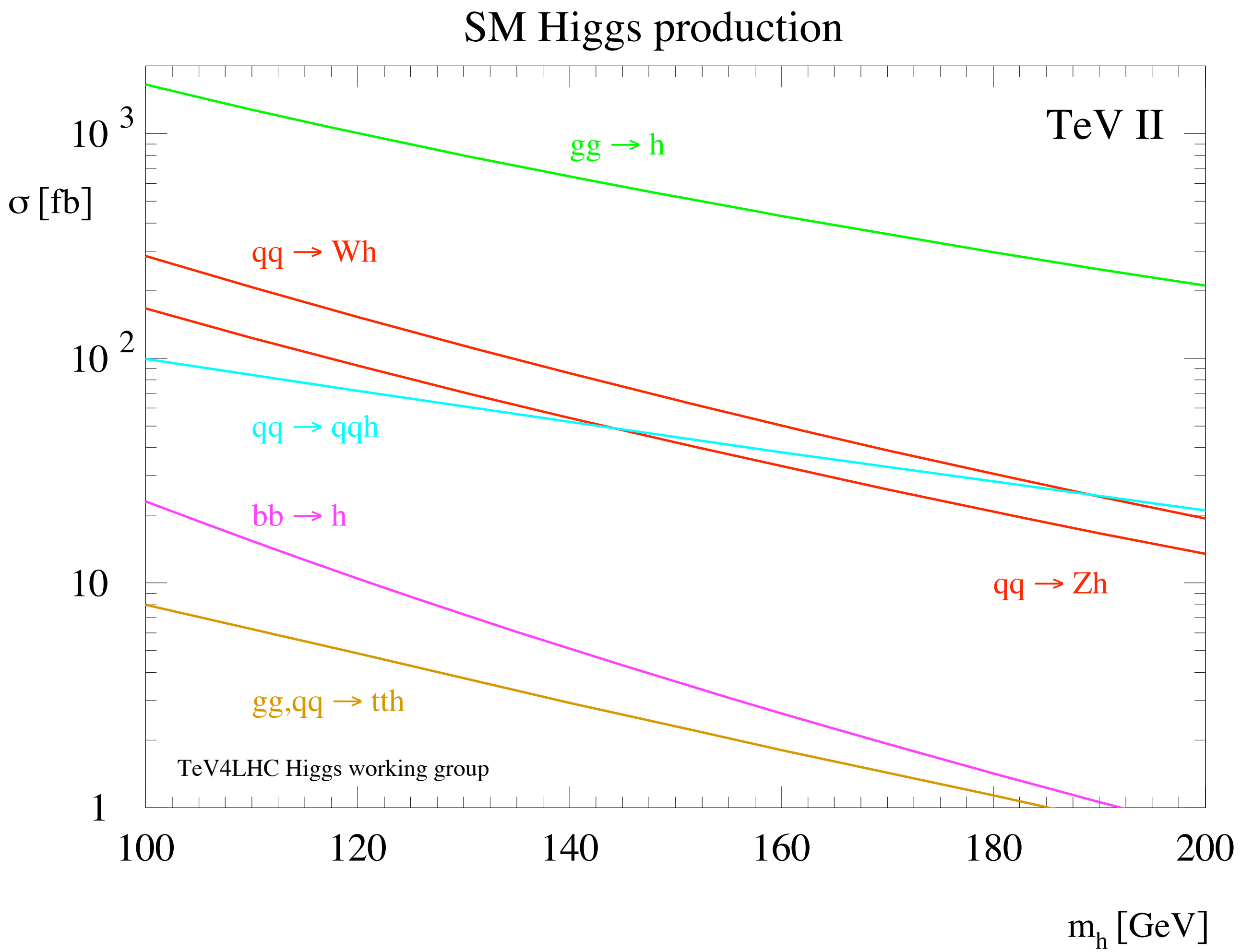
Higgs Production at LHC

Vittorio Del Duca
INFN Torino

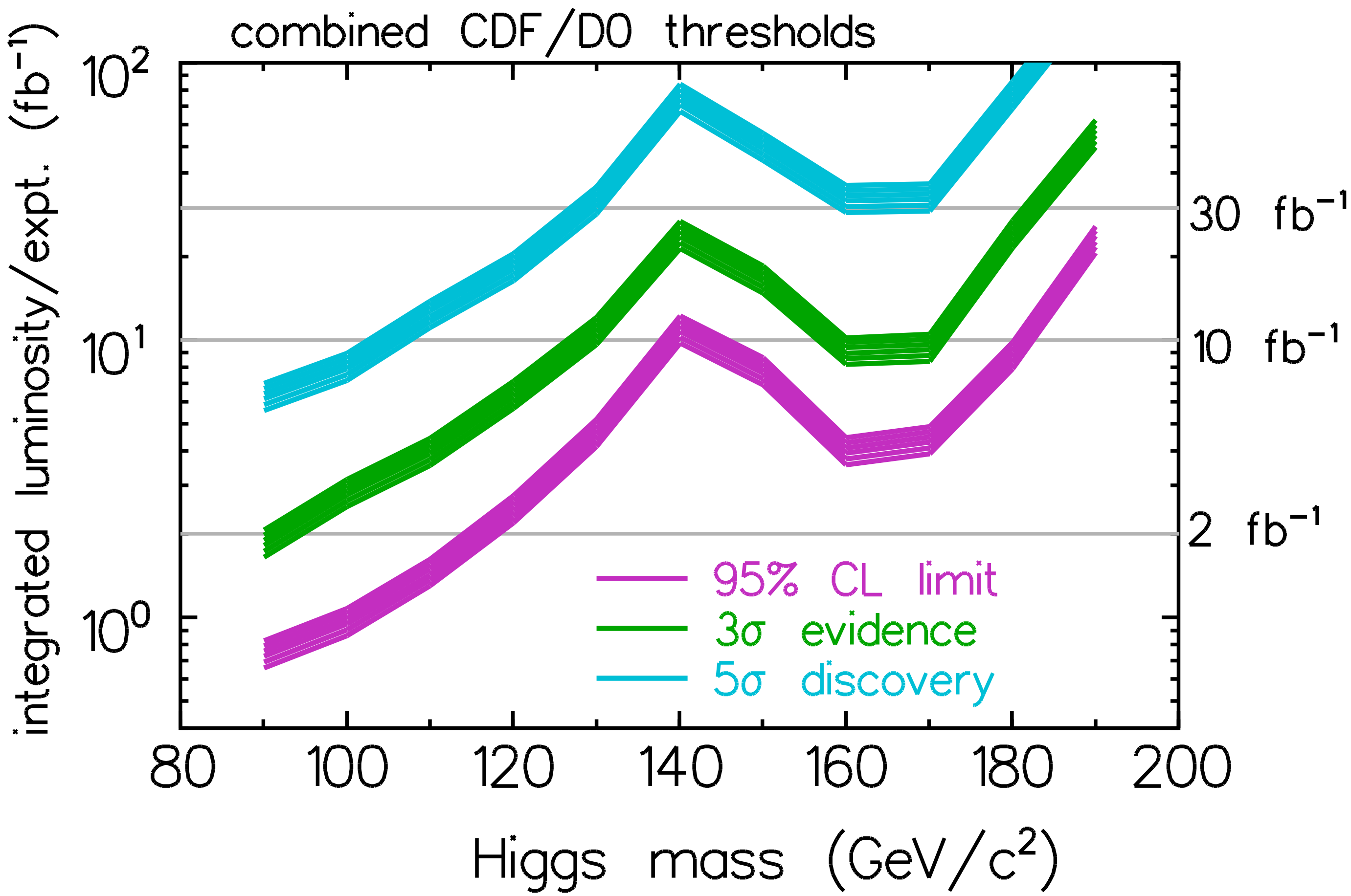
Getting ready for the LHC Madrid 26 October 2006

Higgs production at Tevatron Run-II



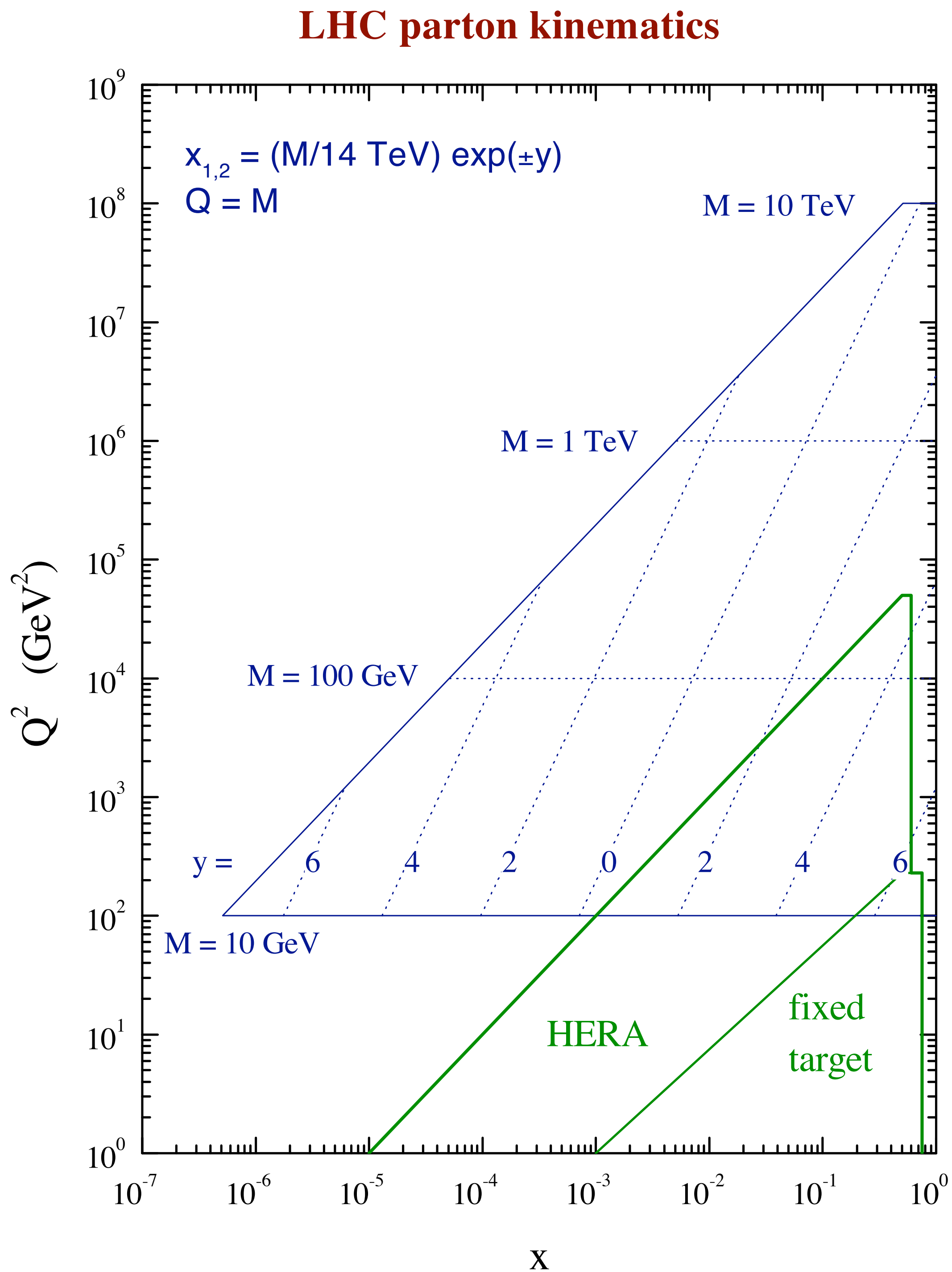
- in the intermediate Higgs mass range $M_H \sim 100 - 200$ GeV
  - gluon fusion cross section is ~ 0.2 – 2 pb
  - *WH, ZH* yield cross sections of ~ 10 – 300 fb
  - WBF cross section is ~ 20 - 100 fb

Higgs search - Tevatron reach



- Tevatron has collected so far about 2 fb^{-1}
- Although it cannot collect enough integrated luminosity to claim discovery above the LEP exclusion limit (114.4 GeV), it could collect enough to hint at some evidence for a signal

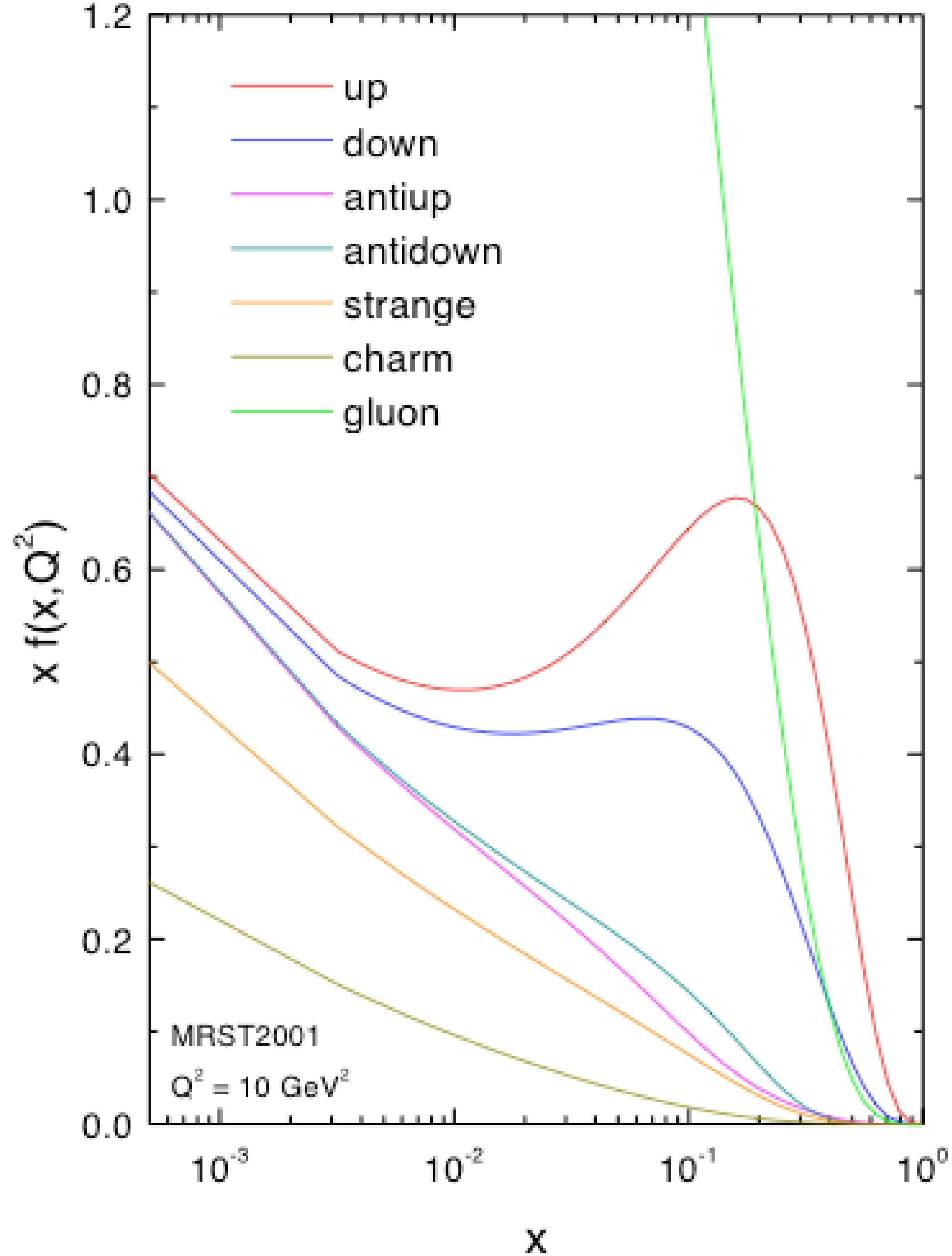
LHC kinematic reach



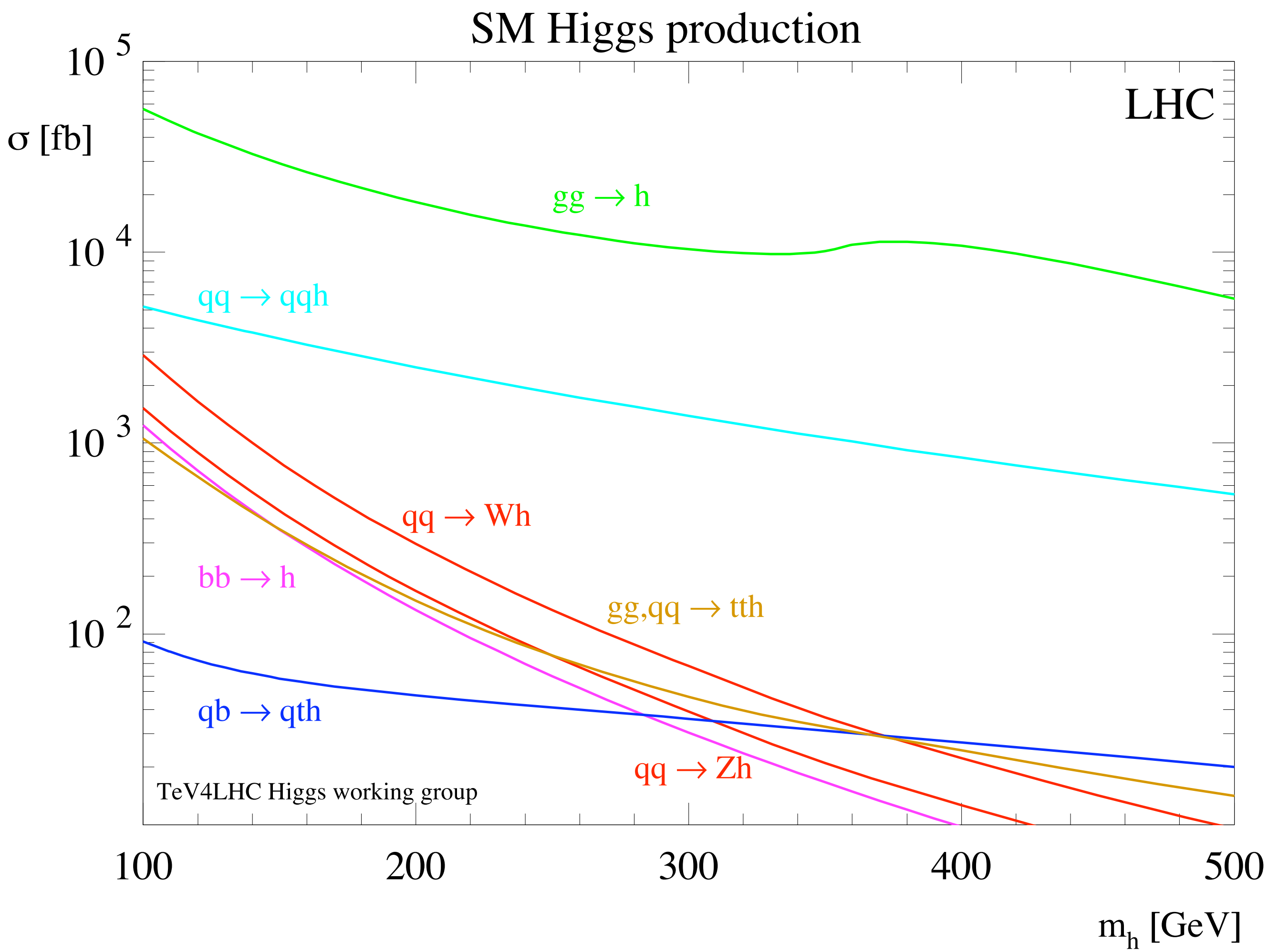
J. Stirling

LHC opens up a new kinematic range

MRST 2001 PDF's



Higgs Production at LHC

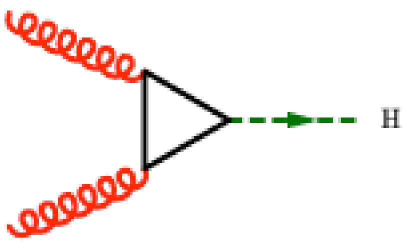


- in the intermediate Higgs mass range $M_H \sim 100 - 200\ \mathrm{GeV}$
  - gluon fusion cross section is $\sim 20 - 60\ \mathrm{pb}$
  - WBF cross section is $\sim 3 - 5\ \mathrm{pb}$
  - $WH, ZH, t\bar{t}H$ yield cross sections of $\sim 0.2 - 3\ \mathrm{pb}$

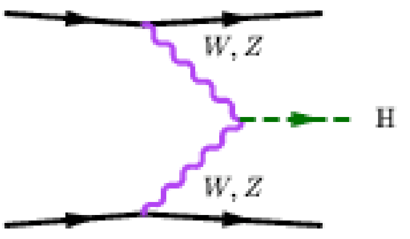
Higgs Production Modes at LHC

In proton collisions at 14 TeV, and for $M_H > 100$ GeV the Higgs is produced mostly via

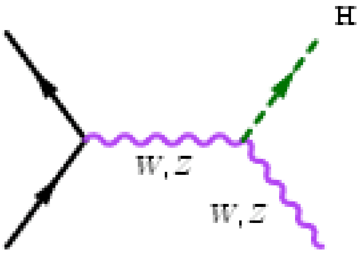
- gluon fusion $gg \to H$
  - largest rate for all M_H
  - proportional to the top Yukawa coupling y_t



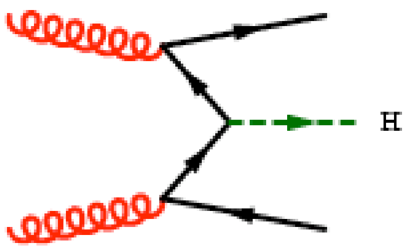
- weak-boson fusion (WBF) $qq \to qqH$
  - second largest rate (mostly $u\,d$ initial state)
  - proportional to the WWH coupling



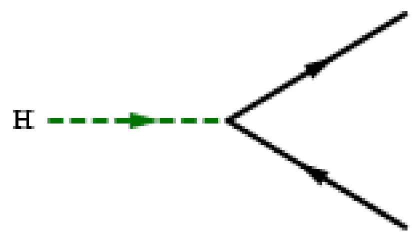
- Higgs-strahlung $q\bar{q} \to W(Z)H$
  - third largest rate
  - same coupling as in WBF



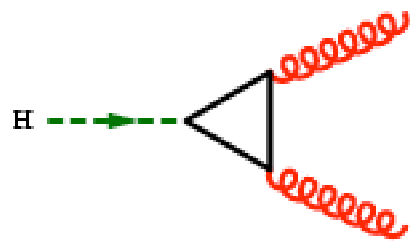
- $t\bar{t}(b\bar{b})H$ associated production
  - same initial state as in gluon fusion, but higher x range
  - proportional to the heavy-quark Yukawa coupling y_Q



Higgs Decay Modes at LHC

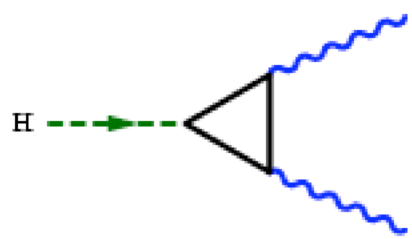


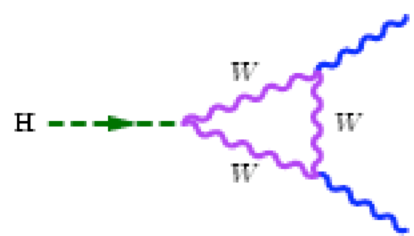
proportional to the Yukawa coupling squared, and thus to m_f^2



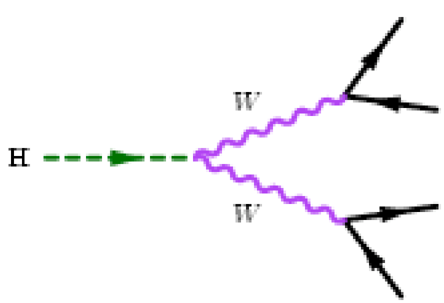
proportional to m_f^4/m_H^4

but dominated by top quark Yukawa coupling





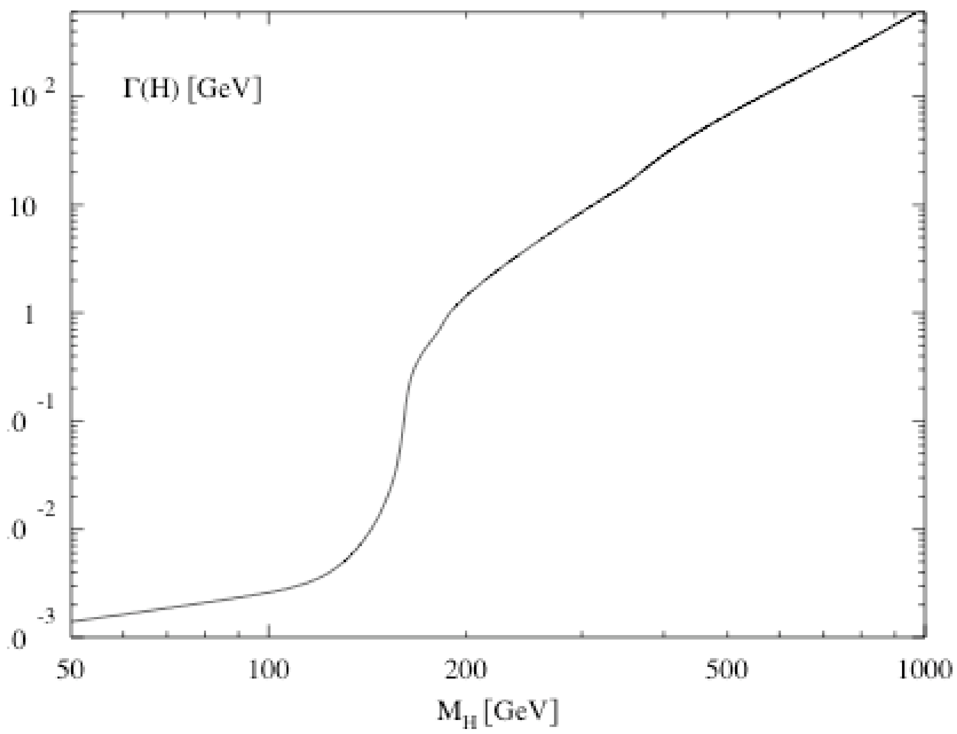
dominated by EW coupling

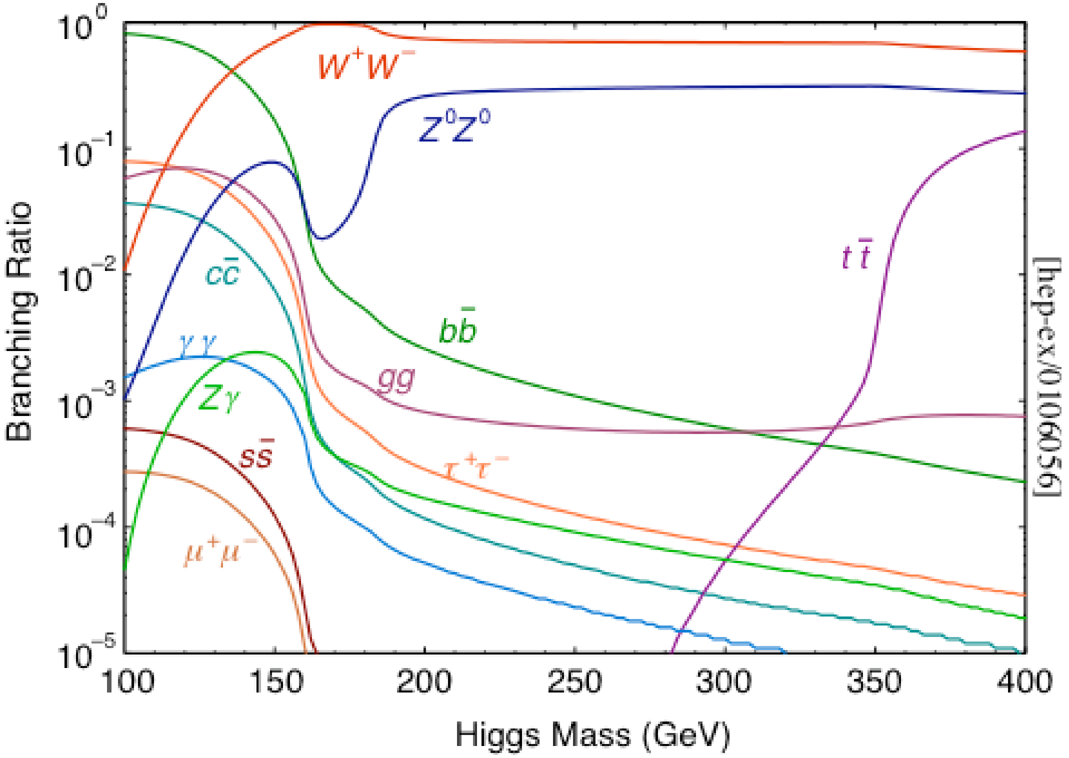


proportional to α_W

Decay width into W^*W^* plays a significant role

HIGGS DECAY AT LHC

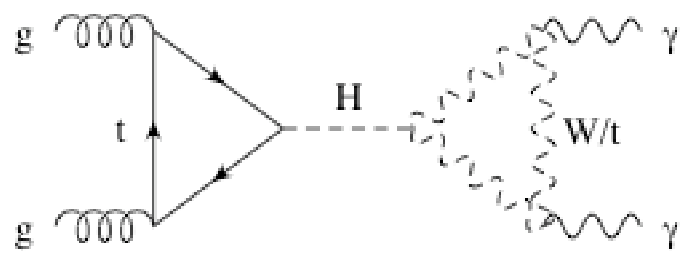


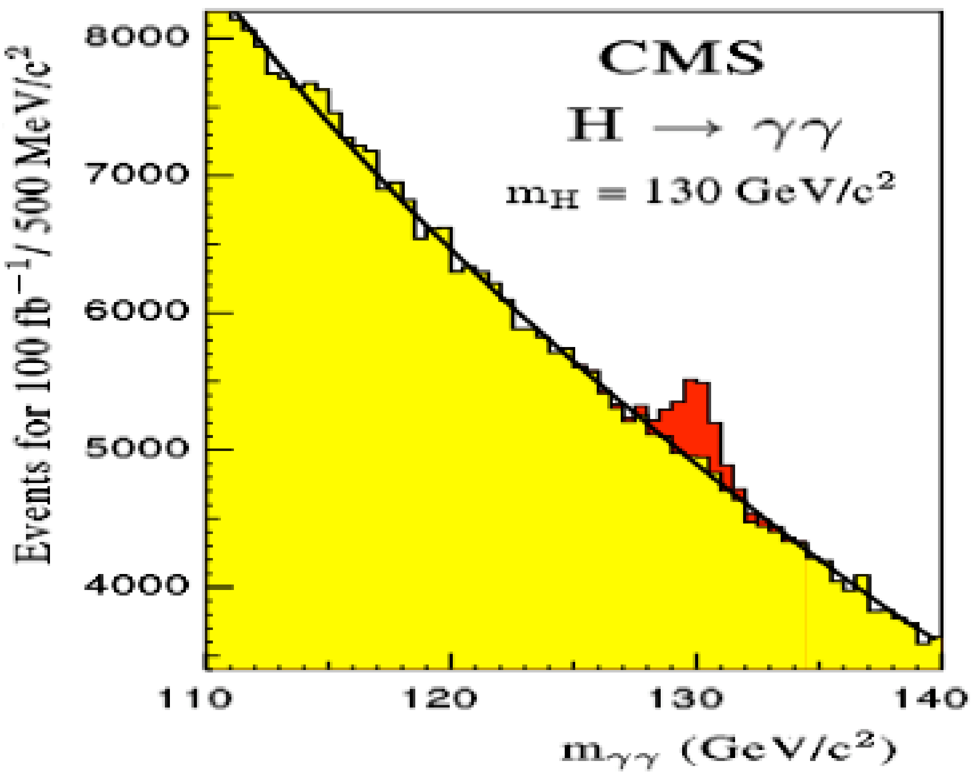


total width

branching fractions

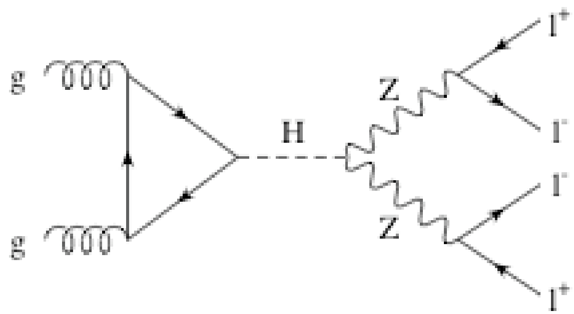
Inclusive searches: $H \to \gamma\gamma$

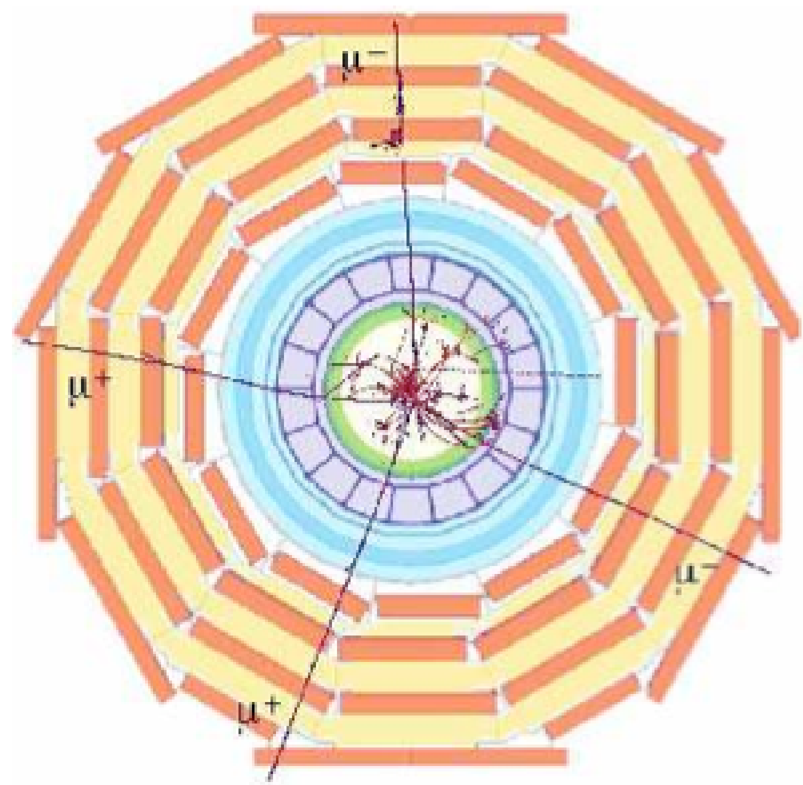




- Small BR: $\approx 10^{-3}$
- Large backgrounds from $pp \to \gamma\gamma$
- CMS and ATLAS have very good photon-energy resolution: $\mathcal{O}(1\%)$
- Search for a narrow $\gamma\gamma$ invariant mass peak, with $m_H < 150$ GeV
- Background is smooth: extrapolate it into the signal region from the sidebands

INCLUSIVE SEARCHES: $H \to ZZ \to l^+l^-l^+l^-$

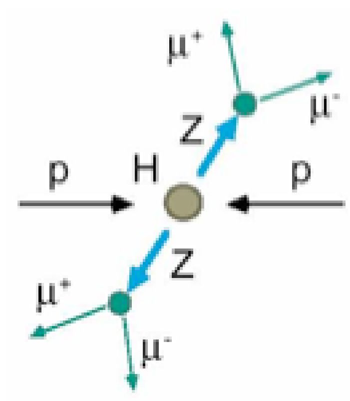


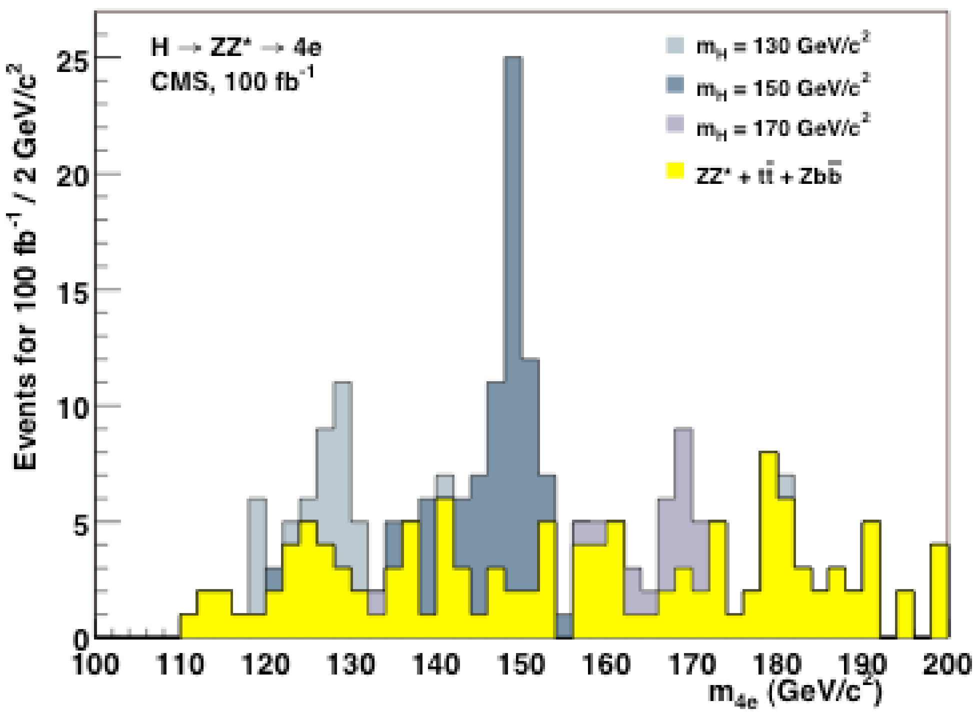


- Gold-plated mode: cleanest mode for $2m_Z < m_H < 600$ GeV
- Smooth, irreducible background from $pp \to ZZ$
- Small BR: $\mathrm{BR}(H \to ZZ)$ is a few $\%$ at threshold

INCLUSIVE SEARCHES: $H \to ZZ \to l^+l^-l^+l^-$

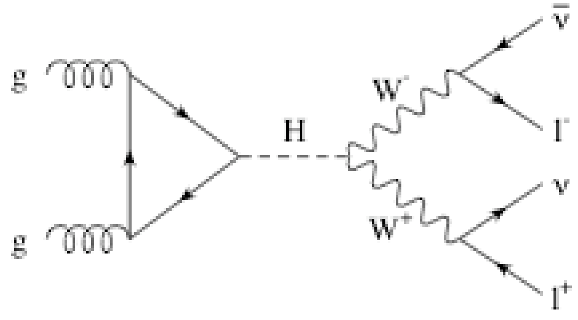
- Fully reconstructed invariant mass of the leptons



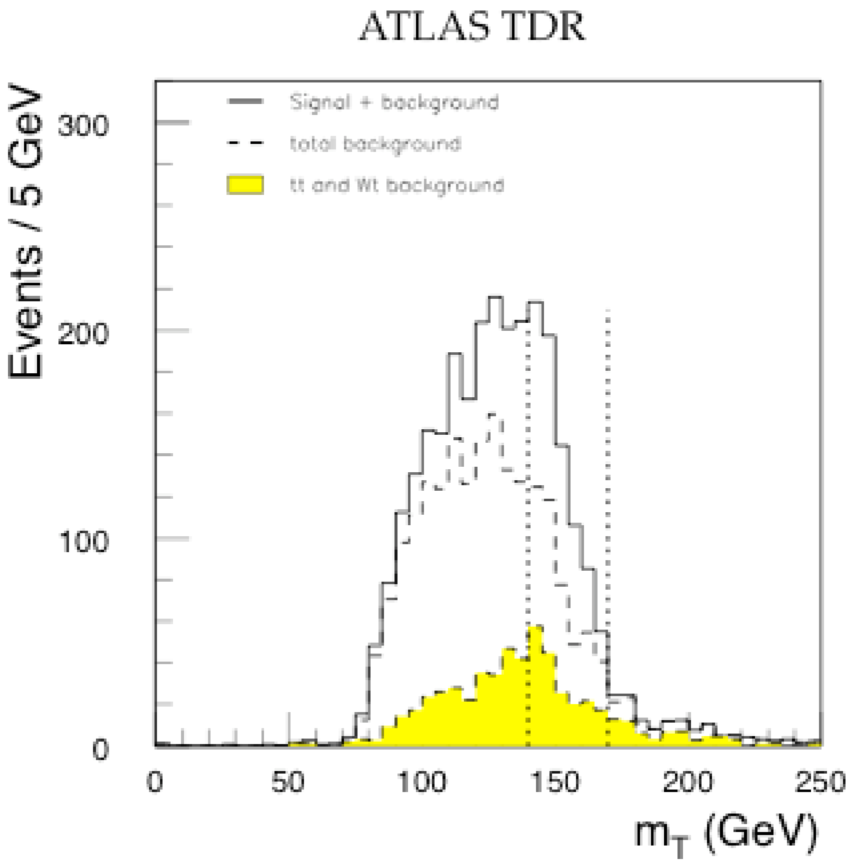


- Silver-plated mode $H \to ZZ \to l^+l^-\nu\bar{\nu}$ useful for $m_H \approx 0.8 - 1$ TeV

INCLUSIVE SEARCHES: $H \to WW \to l^+\nu l^-\bar{\nu}$



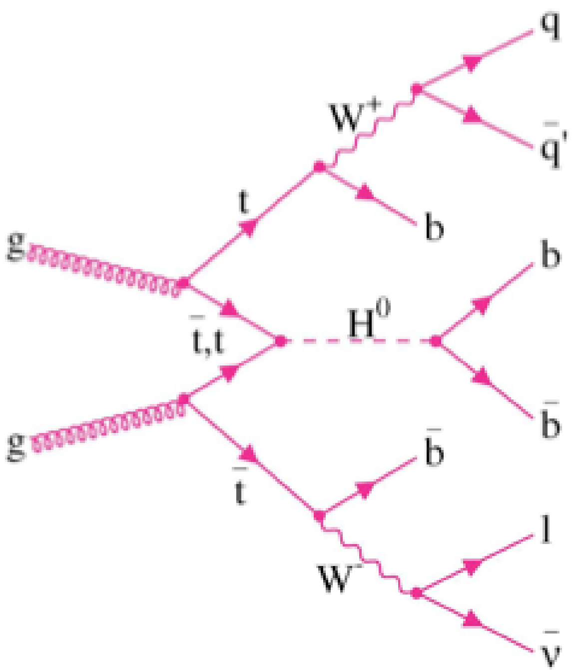
- Exploit l^+l^- angular correlations
- Signal and background have similar shapes: must know background normalisation well

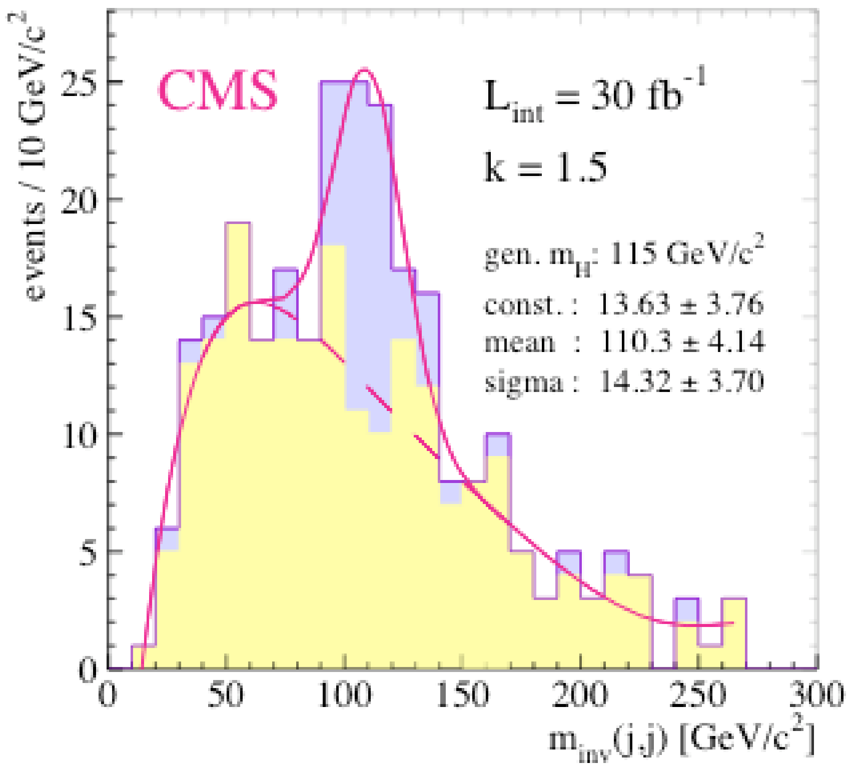


$m_H = 170$ GeV

integrated luminosity: $20\ \text{fb}^{-1}$

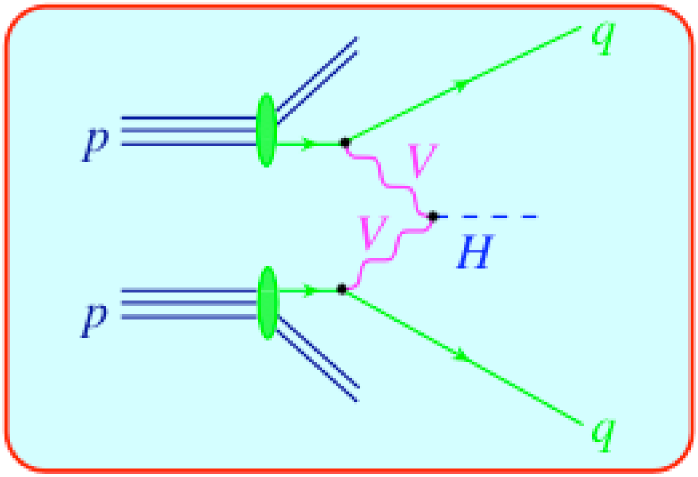
ASSOCIATED PRODUCTION: $Ht\bar{t} \to t\bar{t}b\bar{b}$

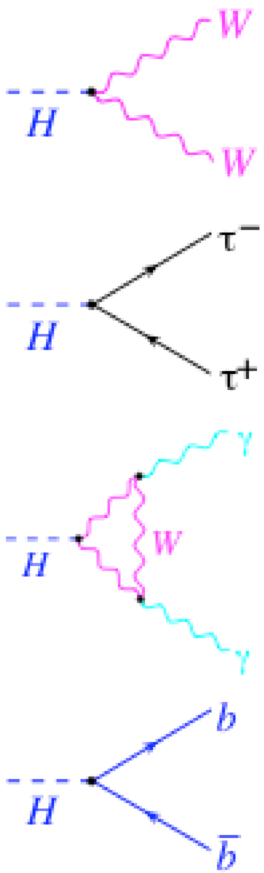




- Search channel for $m_H = 120 - 130$ GeV
- Measure h_t^2 BR$(H \to b\bar{b})$ with $h_t = Ht\bar{t}$ Yukawa coupling
- must know background normalisation well

WEAK BOSON FUSION: $qq \longrightarrow qqH$





$m_H > 120$ GeV

$m_H < 140$ GeV

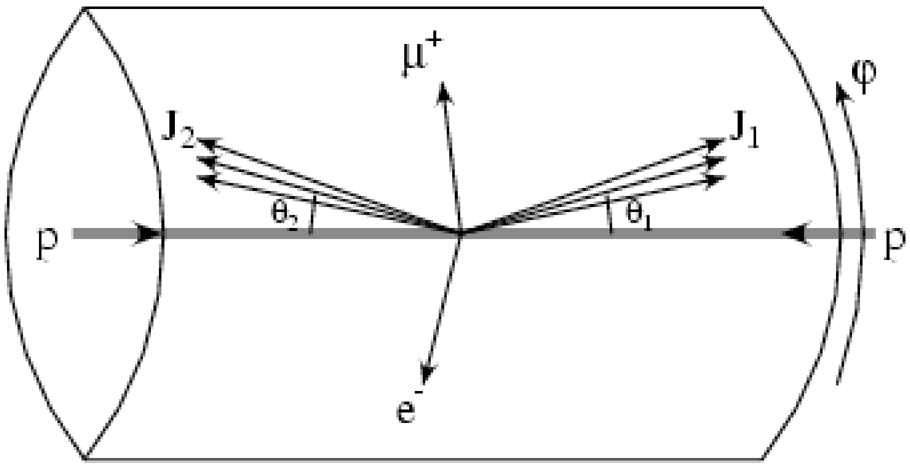
$m_H < 150$ GeV

$m_H < 140$ GeV

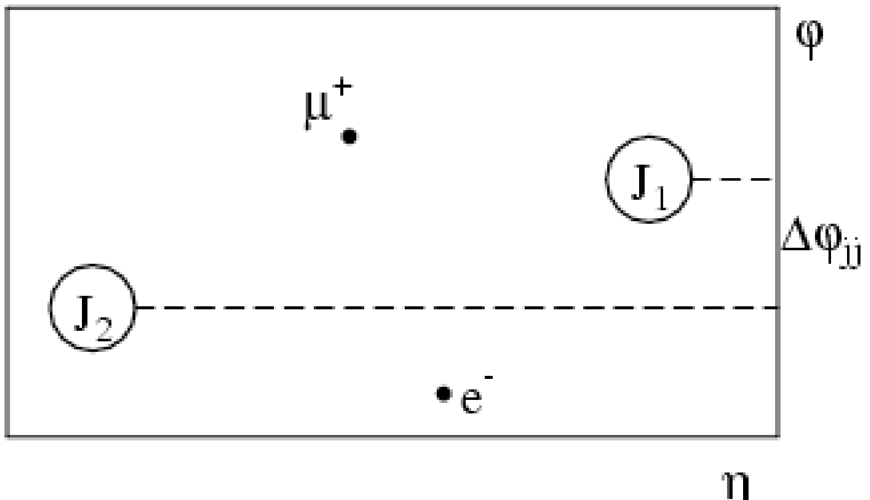
- WBF can be measured with good statistical accuracy: $\sigma \times \mathrm{BR} \approx \mathcal{O}(10\%)$

Weak Boson Fusion

A WBF event



Lego plot

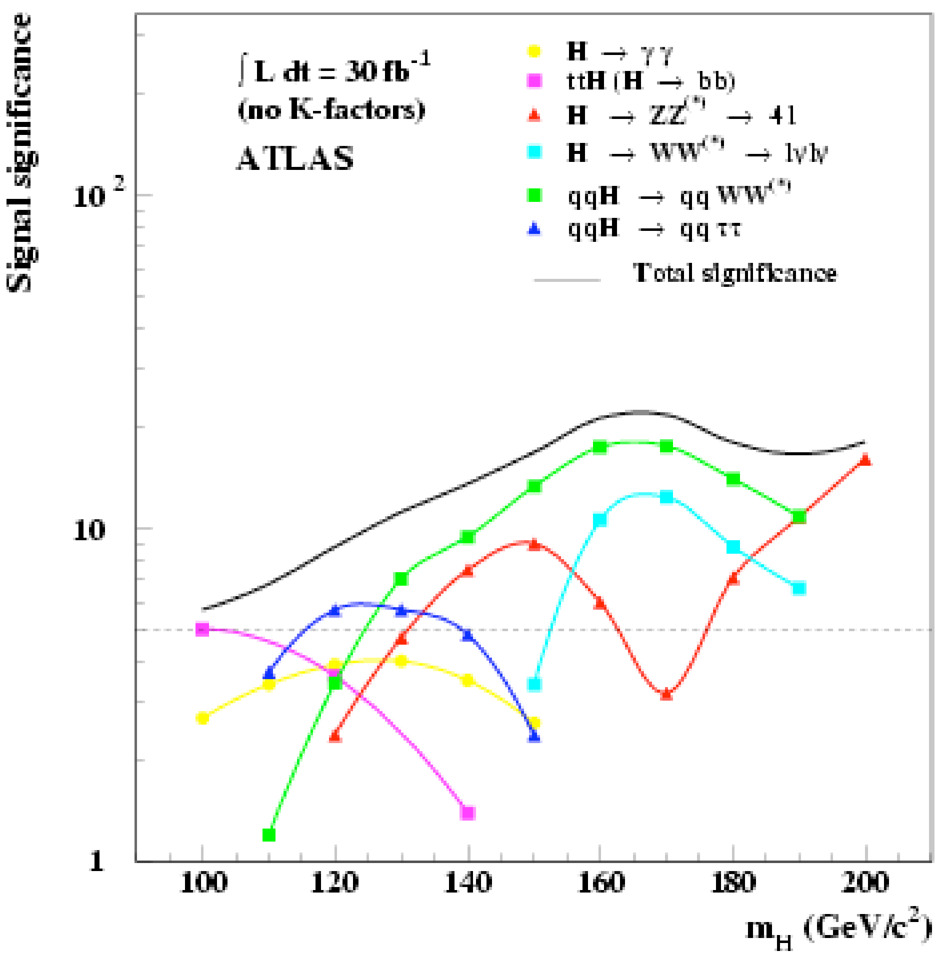


$$\eta = \frac{1}{2} \ln \frac{1+\cos\theta}{1-\cos\theta}$$

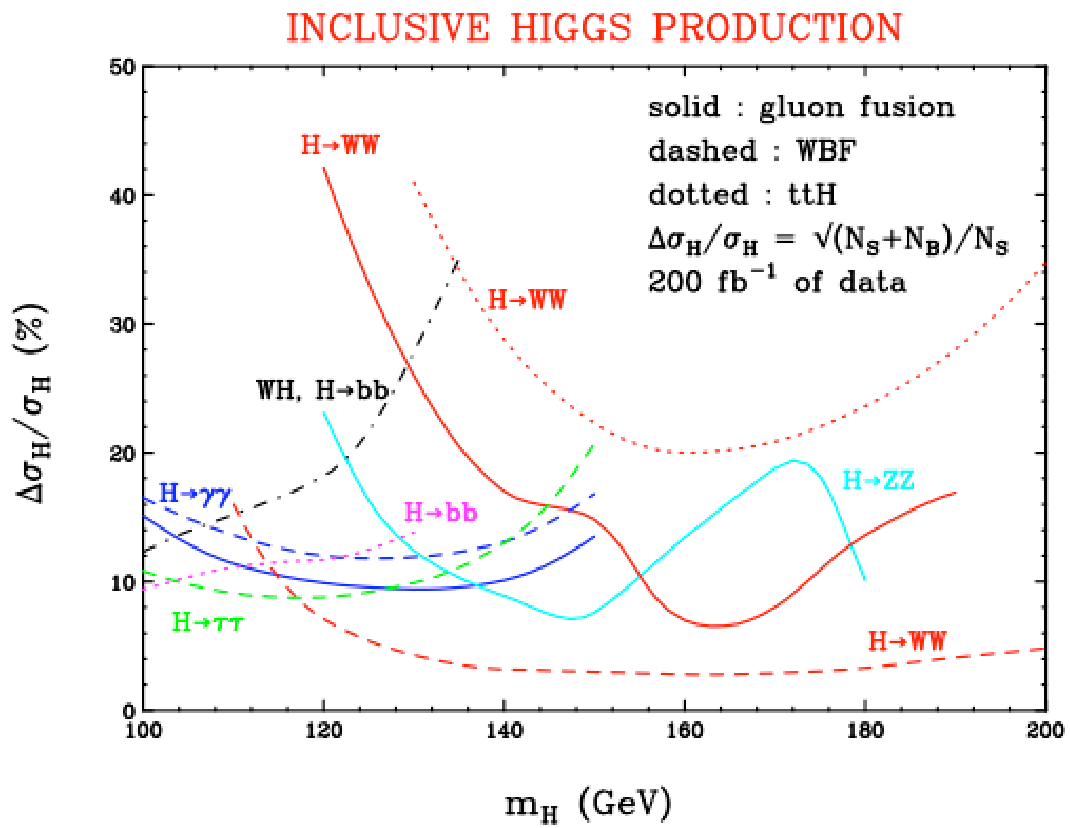
- WBF features
  - energetic jets in the forward and backward directions
  - Higgs decay products between the tagging jets
  - sparse gluon radiation in the central-rapidity region, due to colourless W/Z exchange
  - NLO corrections increase the WBF production rate by about $10\,\%$, and thus are small and under control

Campbell, Ellis; Figy, Oleari, Zeppenfeld 2003

Signal significance and (stat + syst) error



hep-ph/0402254



hep-ph/0203187

Statistical significance: $\dfrac{N_S}{\sqrt{N_S + N_B}}$

QCD/p.d.f. uncertainties:

$\mathcal{O}(5\%)$ for WBF

$\mathcal{O}(20\%)$ for gluon fusion

luminosity uncertainties: $\mathcal{O}(5\%)$

Higgs Couplings and Quantum Numbers

The properties of the Higgs-like resonance are its

- couplings: gauge, Yukawa, self-couplings
- quantum numbers: charge, colour, spin, CP

Duehrssen et al.'s analysis hep-ph/0406323

- use narrow-width approx for Γ (fine for $m_H < 200$ GeV)
- production rate with H decaying to final state xx is

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

branching ratio for the decay is $\mathrm{BR}(H \to xx) = \frac{\Gamma_x}{\Gamma}$

observed rate determines $\frac{\Gamma_p \Gamma_x}{\Gamma}$

- WBF and gluon-fusion rates yield measurements of combinations of partial widths

$$\frac{\Gamma_W \Gamma_\gamma}{\Gamma} \quad \text{from} \quad qq \to qqH,\ H \to \gamma\gamma$$

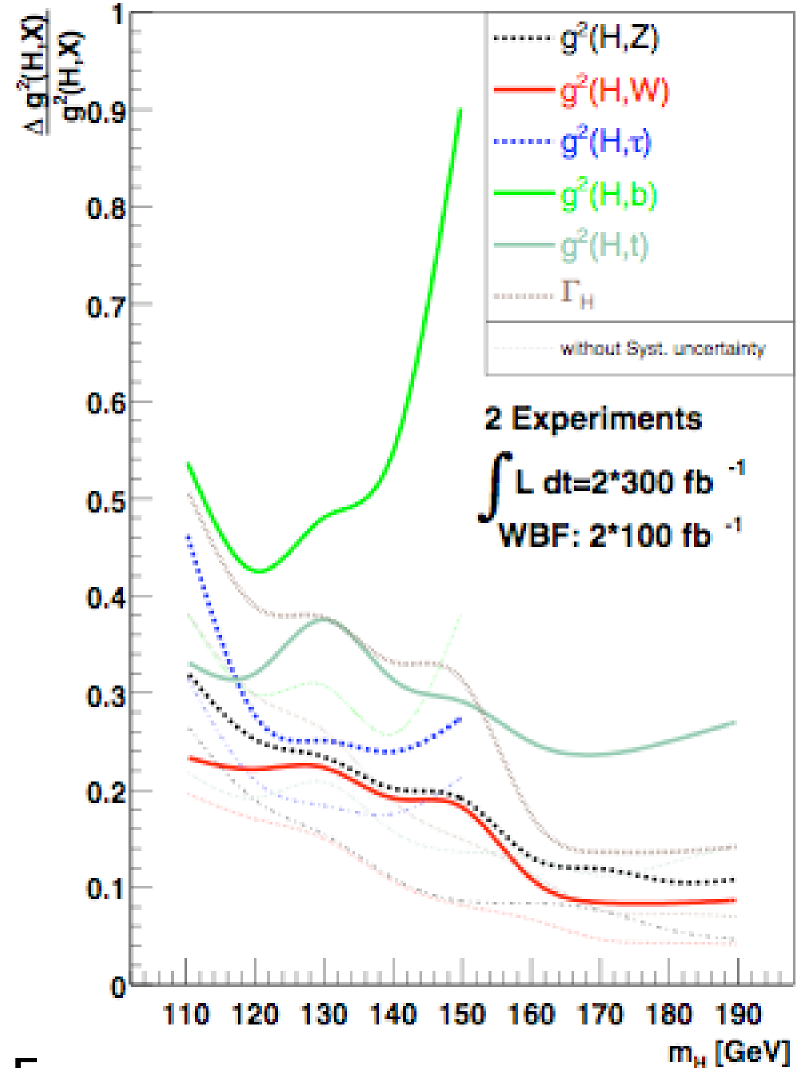
$$\frac{\Gamma_W \Gamma_\tau}{\Gamma} \quad \text{from} \quad qq \to qqH,\ H \to \tau\tau$$

$$\frac{\Gamma_W^2}{\Gamma} \quad \text{from} \quad qq \to qqH,\ H \to WW^*$$

$$\frac{\Gamma_g \Gamma_\gamma}{\Gamma} \quad \text{from} \quad gg \to H \to \gamma\gamma$$

$$\frac{\Gamma_g \Gamma_Z}{\Gamma} \quad \text{from} \quad gg \to H \to ZZ^*$$

$$\frac{\Gamma_g \Gamma_W}{\Gamma} \quad \text{from} \quad gg \to H \to WW^*$$



- Note that Γ can be estimated:

  direct observation of *H* yields lower bound on Γ

  assume $\Gamma_V \leq \Gamma_V^{\rm SM} \qquad V = W, Z$

  (true in any model with arbitrary # of Higgs doublets ⇒ true in MSSM)

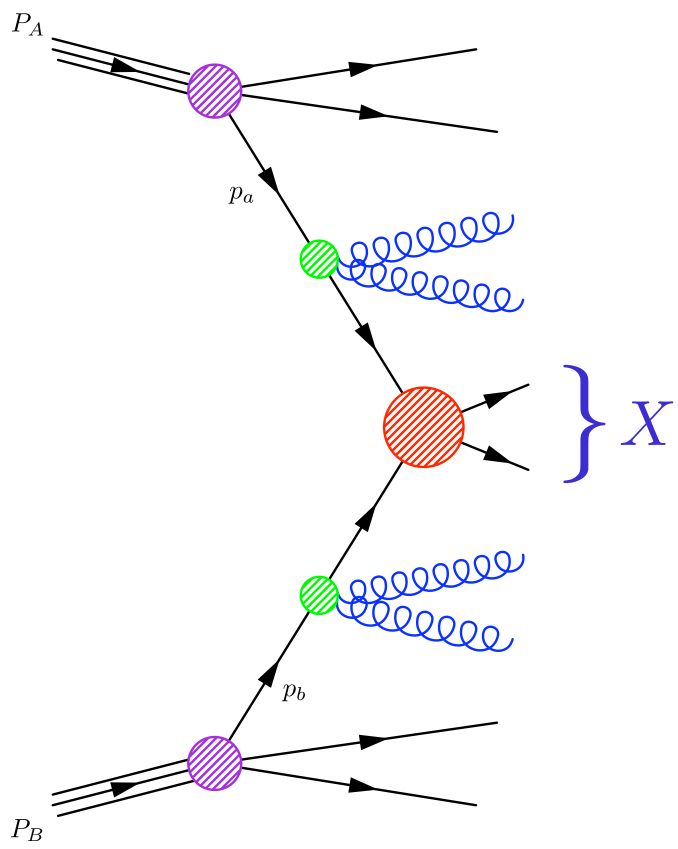
  combine $\Gamma_V \leq \Gamma_V^{\rm SM}$ with measure of Γ_V^2/Γ from $H \to VV$

  obtain upper bound on Γ

Higgs Couplings and Quantum Numbers

The gauge coupling has also CP properties and a tensor structure. Info on that can be obtained by analysing the final-state topology of Higgs + 2 jet events
(more on this later)

Cross sections at high Q^2



separate the short- and the long-range interactions through factorisation

$$\sigma_X = \sum_{a,b} \int_0^1 dx_1 dx_2\, f_{a/A}(x_1, \mu_F^2)\, f_{b/B}(x_2, \mu_F^2)$$
$$\times\ \hat{\sigma}_{ab\to X}\left(x_1, x_2, \{p_i^\mu\}; \alpha_S(\mu_R^2), \alpha(\mu_F^2), \frac{Q^2}{\mu_R^2}, \frac{Q^2}{\mu_F^2}\right)$$

$$X = W, Z, H, Q\bar{Q}, \text{high-}E_T\text{jets}, \ldots$$

$\hat{\sigma}$ is known as a fixed-order expansion in α_S

$$\hat{\sigma} = C\alpha_S^n(1 + c_1\alpha_S + c_2\alpha_S^2 + \ldots)$$

$c_1 =$ NLO $\quad c_2 =$ NNLO

or as an all-order resummation

$$\hat{\sigma} = C\alpha_S^n[1 + (c_{11}L + c_{10})\alpha_S + (c_{22}L^2 + c_{21}L + c_{20})\alpha_S^2 + \ldots]$$

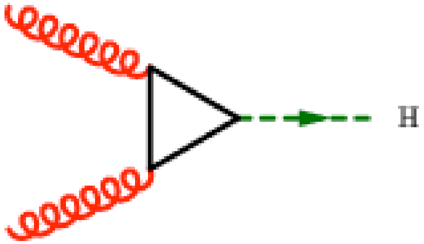
where $L = \ln(M/q_T), \ln(1-x), \ln(1/x), \ln(1-T), \ldots$

$c_{11}, c_{22} =$ LL $\quad c_{10}, c_{21} =$ NLL $\quad c_{20} =$ NNLL

HIGGS PRODUCTION VIA GLUON FUSION

LEADING ORDER

$\mathcal{O}(\alpha_s^2)$ $gg \to H$

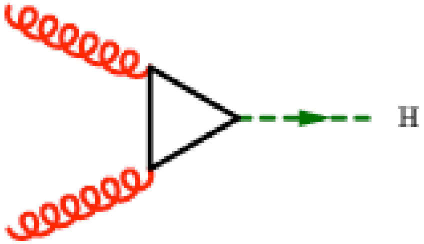


☛ energy scales: $\hat{s} = M_{\mathrm{H}}^2$ and M_t^2

Higgs Production via Gluon Fusion

Leading Order

$\mathcal{O}(\alpha_s^2)$ $gg \to H$

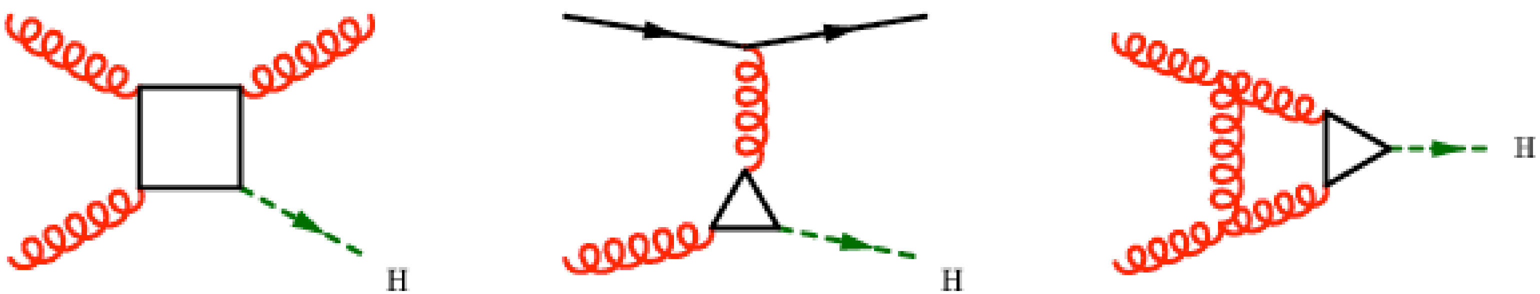


☛ energy scales: $\hat{s} = M_{\rm H}^2$ and M_t^2

NLO corrections

$\mathcal{O}(\alpha_s^3)$

- 2-loop $gg \to H$
- 1-loop $gg \to gH$ $qg \to qH$ $+$ crossings

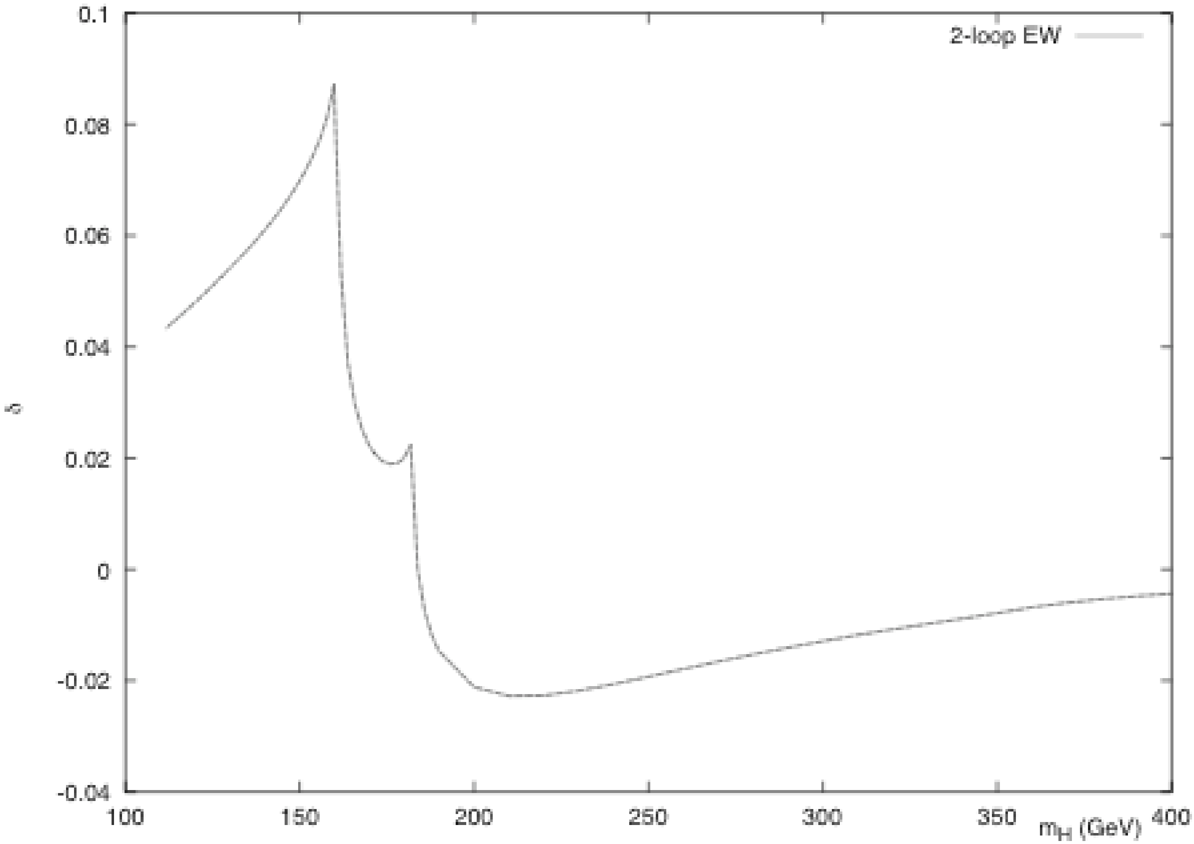


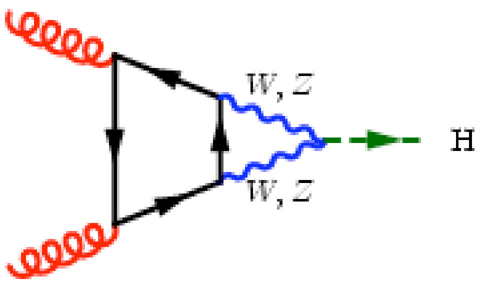
Djouadi, Graudenz, Spira, Zerwas, '93-'95

☛ large K factor: $\sigma^{\rm NLO} = K^{\rm NLO}\,\sigma^{\rm LO}$ $\mathcal{O}(40-100\%)$

EW CORRECTIONS

a QCD loop + an EW loop $\mathcal{O}(\alpha_S^2 \alpha_W^2)$



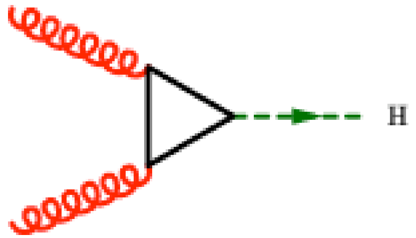


Aglietti Bonciani Degrassi Vicini 04
(light fermion loop)

Degrassi Maltoni 04
(heavy fermion loop)

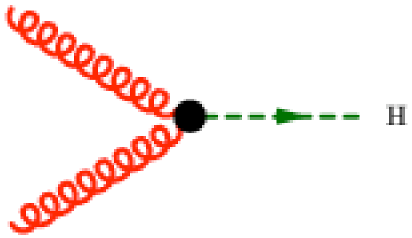
- Relative corrections to production and decay through gluon fusion (with light fermion loop)
- For $115\,\mathrm{GeV} \leq M_H \leq 2M_W$ the total electroweak corrections are 5 to 8 % of leading order

The Large Top-mass Limit

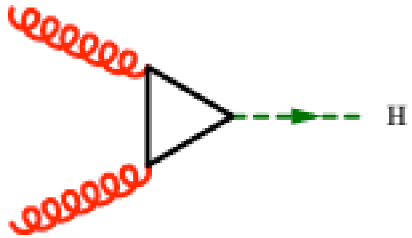


$$M_{\rm H} \ll 2M_t$$

$$\longrightarrow$$

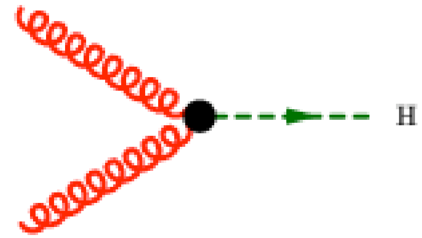


THE LARGE TOP-MASS LIMIT

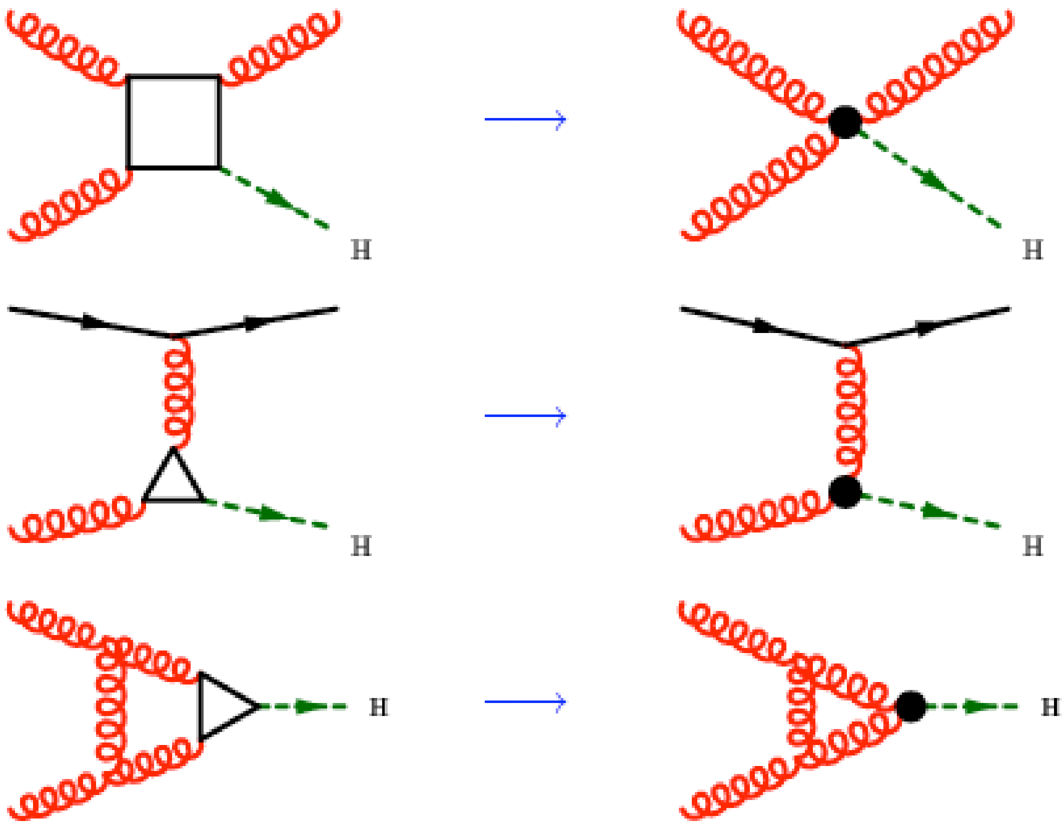


$M_{\mathrm{H}} \ll 2M_t$

$\longrightarrow$



NLO CORRECTIONS



K factor in the large M_t limit

$$K_\infty = \lim_{M_t \to \infty} K$$

NLO rate in the large M_t limit

$$\sigma_\infty^{\mathrm{NLO}} = K_\infty^{\mathrm{NLO}}\, \sigma^{\mathrm{LO}}$$

$\sigma_\infty^{\mathrm{NLO}}$ is within 10% of σ^{NLO} for $M_{\mathrm{H}} \lesssim 1$ TeV

$gg \to H$ in the large M_t Limit

NNLO corrections

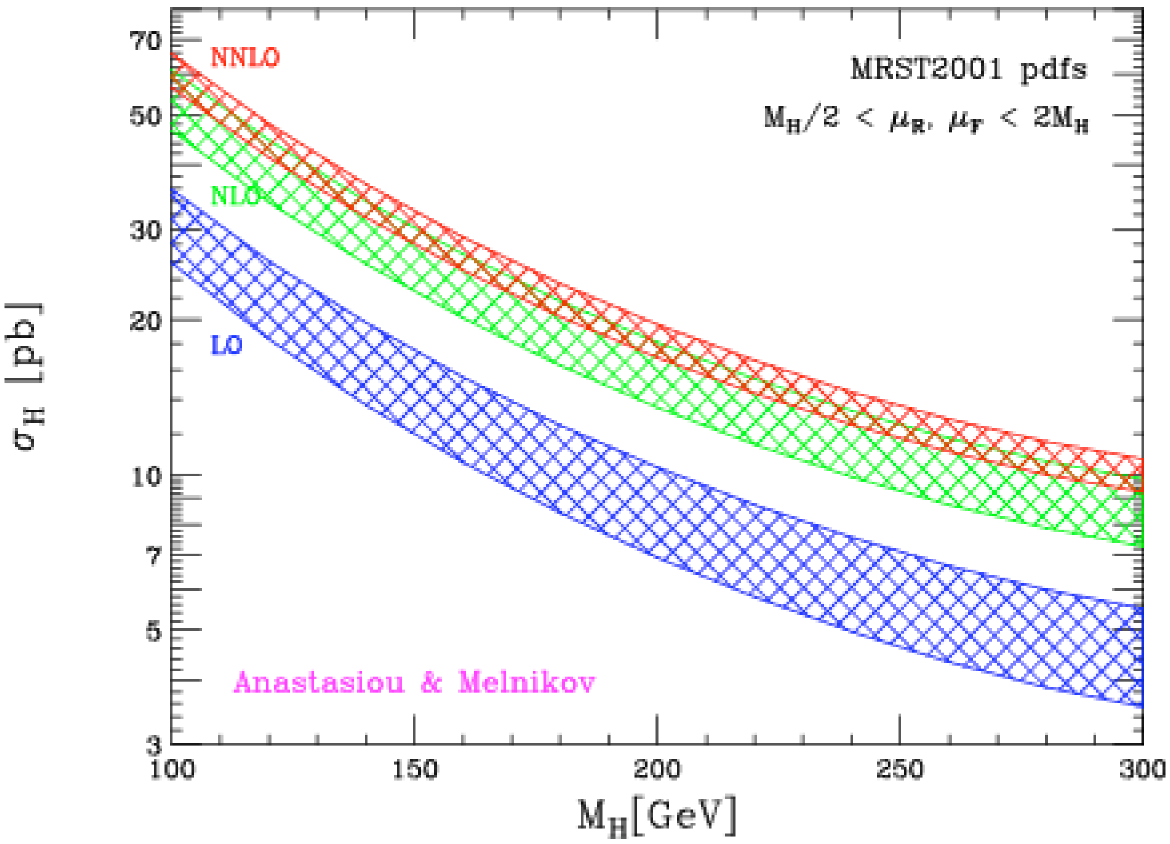
$\mathcal{O}(\alpha_S^4)$

2-loop $gg \to H$

1-loop $gg \to gH \quad qg \to qH \quad +$ crossings

tree $gg \to ggH \quad qg \to qgH \quad qQ \to qQH \quad +$ crossings

R. Harlander hep-ph/0007289



total cross section for inclusive Higgs production at LHC

Harlander Kilgore 02
Anastasiou Melnikov 02
Ravindran Smith van Neerven 03

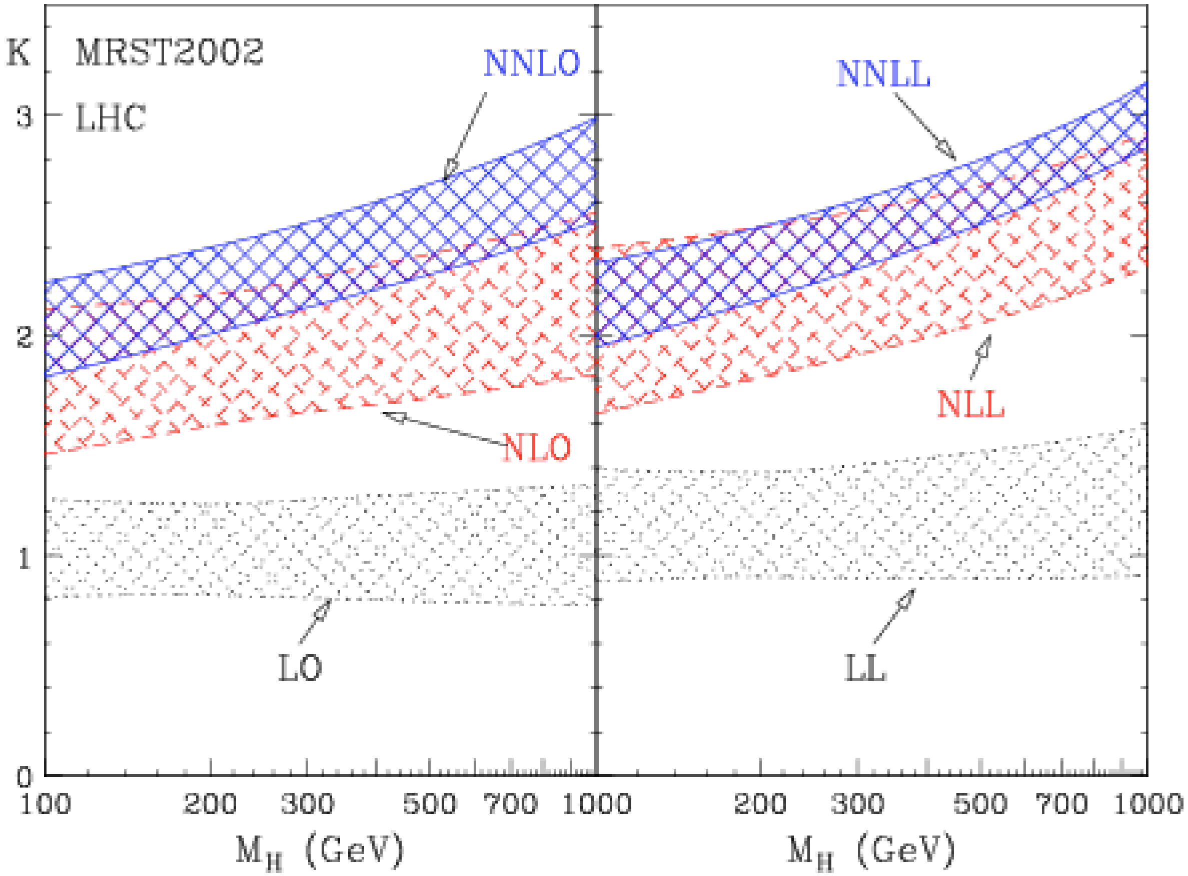
The band contours are

lower $\mu_R = 2M_H \quad \mu_F = M_H/2$

upper $\mu_R = M_H/2 \quad \mu_F = 2M_H$

NNLO CORRECTIONS + NNLL RESUMMATION

- Threshold resummation of soft gluon radiation

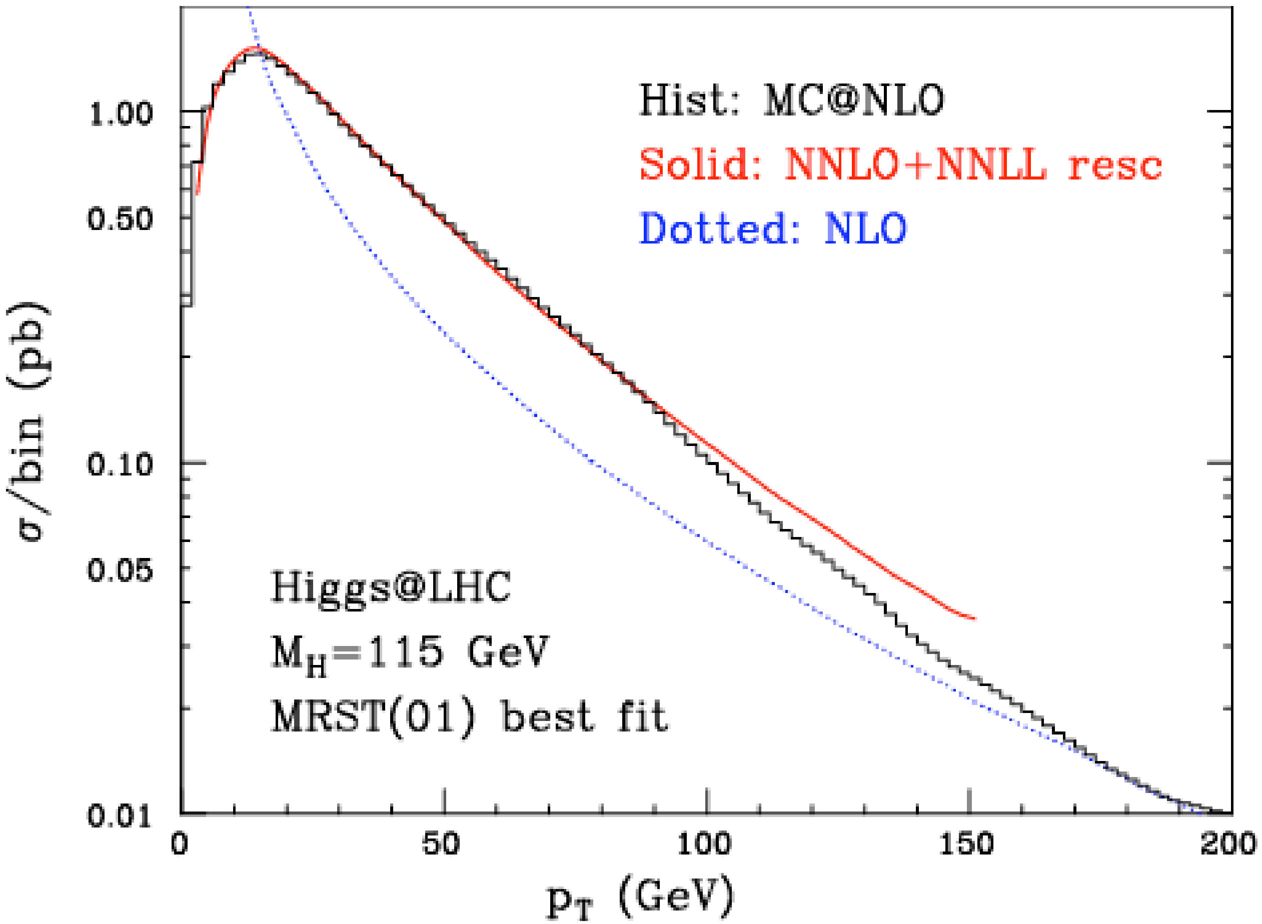


Catani, de Florian
Grazzini, Nason
hep-ph/0306211

- K factor is computed wrt to σ^{LO} at $\mu_R = \mu_F = M_{\mathrm{H}}$
  band contours have $\mu_{R(F)} = \chi_{R(F)} M_{\mathrm{H}}$ and $1/2 \leq \chi_{R(F)} \leq 2$ but $1/2 \leq \chi_R/\chi_F \leq 2$
- NNLL increases NNLO by about 6%
- scale uncertainty at NNLL of about 8% (at NNLO of about 10%)

NNLO + NNLL versus MC@NLO

Higgs p_T distribution



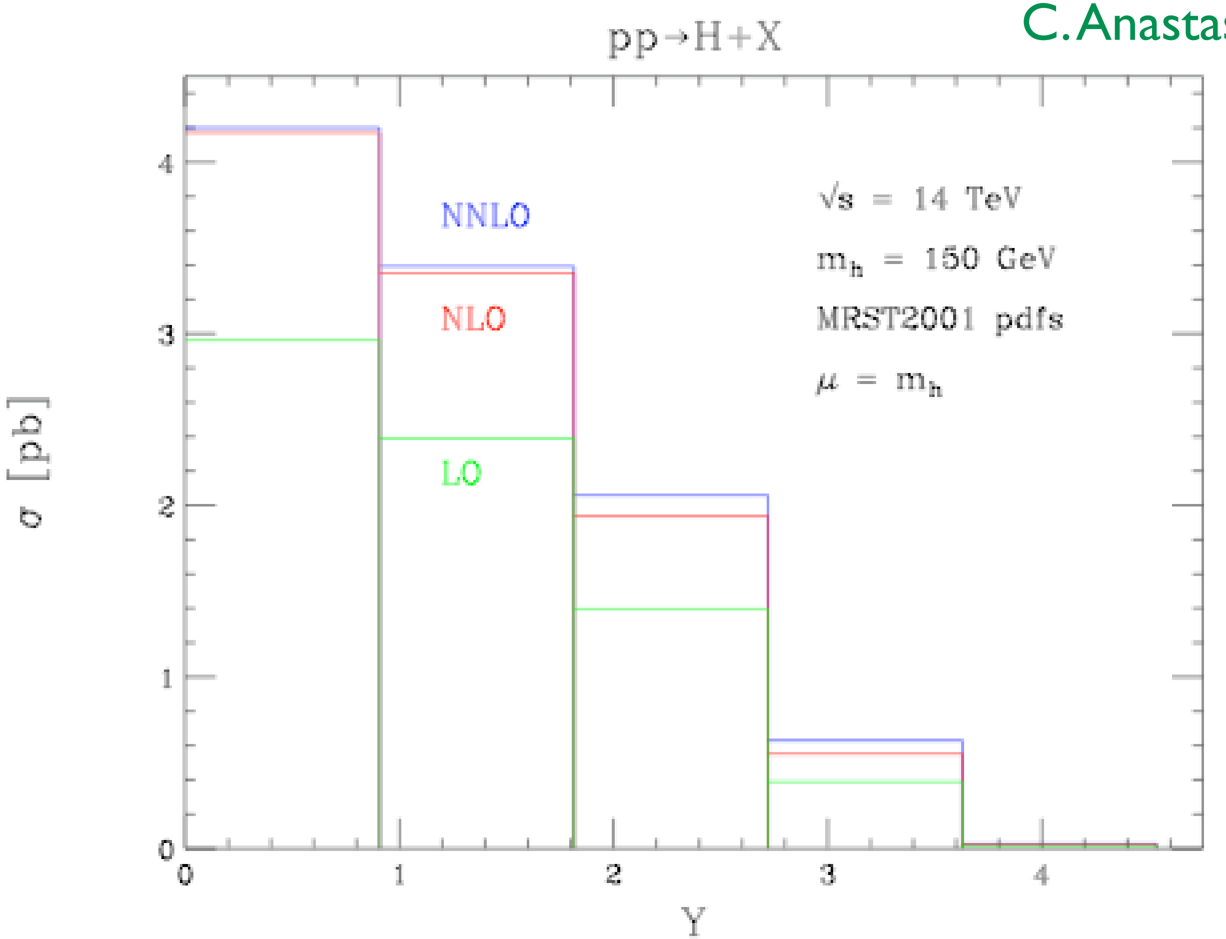
difference at large p_T is due to different default $\mu = \mu_R = \mu_F$ scale $\mu^2 = M_H^2$ for NNLO + NNLL, $\mu^2 = M_H^2 + p_T^2$ for MC@NLO

S. Frixione hadron collider wksp MSU 2004

NNLO corrections

a fully differential cross section:
bin-integrated rapidity distribution, with a jet veto

C. Anastasiou K. Melnikov F. Petriello 2004



jet veto: require

$R = 0.4$

$|\mathbf{p}_T^j| < p_T^{veto} = 40 \text{ GeV}$

for 2 partons

$R_{12}^2 = (\eta_1 - \eta_2)^2 + (\phi_1 - \phi_2)^2$

if $R_{12} > R$

$|\mathbf{p}_T^1|, |\mathbf{p}_T^2| < p_T^{veto}$

if $R_{12} < R$

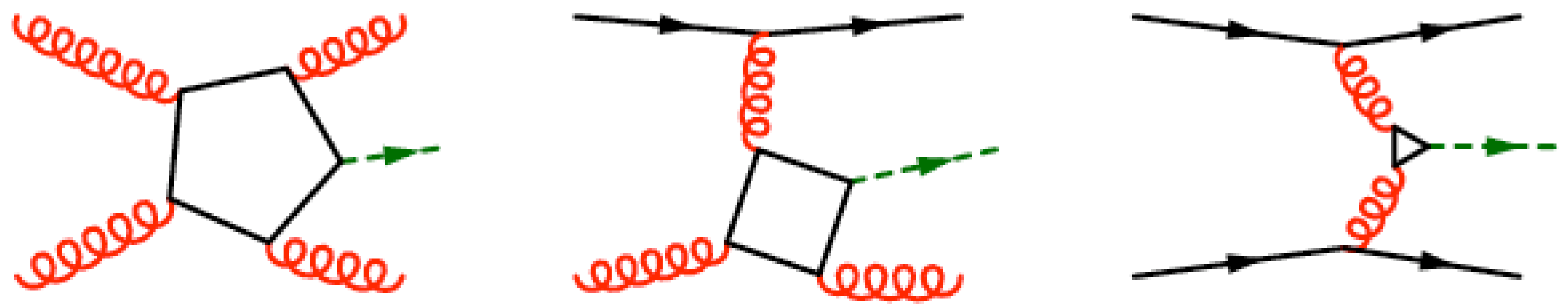
$|\mathbf{p}_T^1 + \mathbf{p}_T^2| < p_T^{veto}$

- $M_H = 150 \text{ GeV}$ (jet veto relevant in the $H \to W^+W^-$ decay channel)
- K factor is much smaller for the vetoed x-sect than for the inclusive one: average $|\mathbf{p}_T^j|$ increases from NLO to NNLO: less x-sect passes the veto

Higgs + 2 Jets via Gluon Fusion

Leading Order

$\mathcal{O}(\alpha_s^4)$

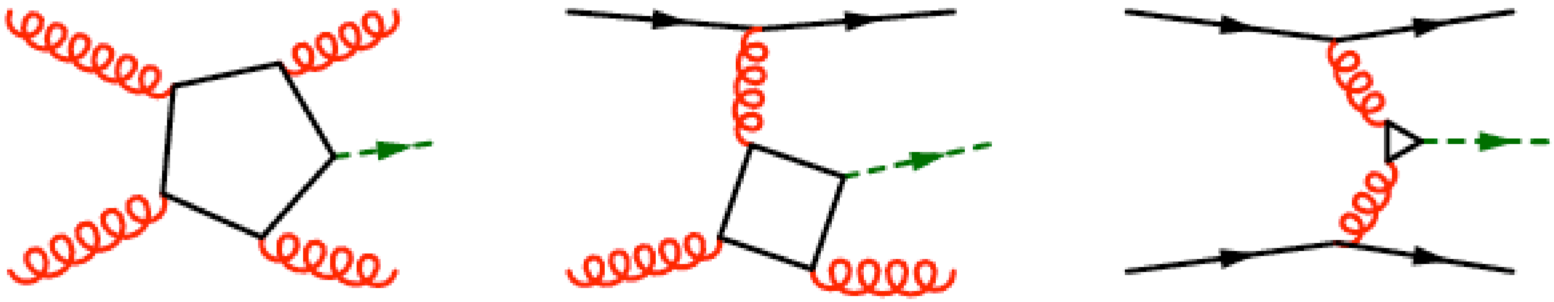


- tree $gg \to ggH$ $qg \to qgH$ $qQ \to qQH$ + crossings
- energy scales: $\hat{s}\,, s_{j_1 \mathrm{H}}, s_{j_2 \mathrm{H}}, s_{j_1 j_2}, M_{\mathrm{H}}^2, M_t^2$, with $\hat{s} = s_{j_1 j_2} + s_{j_1 \mathrm{H}} + s_{j_2 \mathrm{H}} - M_{\mathrm{H}}^2$

Higgs + 2 Jets via Gluon Fusion

Leading Order

$\mathcal{O}(\alpha_s^4)$

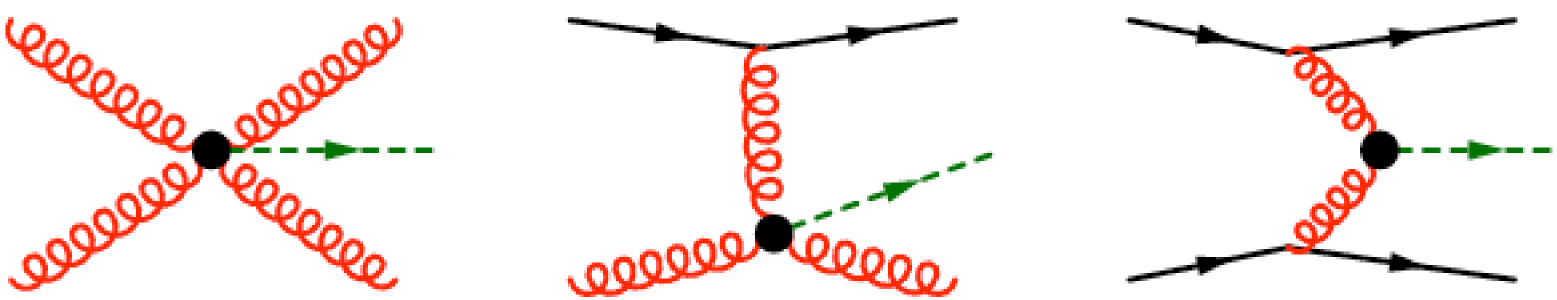


- tree $gg \to ggH \quad qg \to qgH \quad qQ \to qQH \quad +$ crossings
- energy scales: $\hat{s}\,, s_{j_1 \mathrm{H}}, s_{j_2 \mathrm{H}}, s_{j_1 j_2}, M_{\mathrm{H}}^2, M_t^2$, with $\hat{s} = s_{j_1 j_2} + s_{j_1 \mathrm{H}} + s_{j_2 \mathrm{H}} - M_{\mathrm{H}}^2$

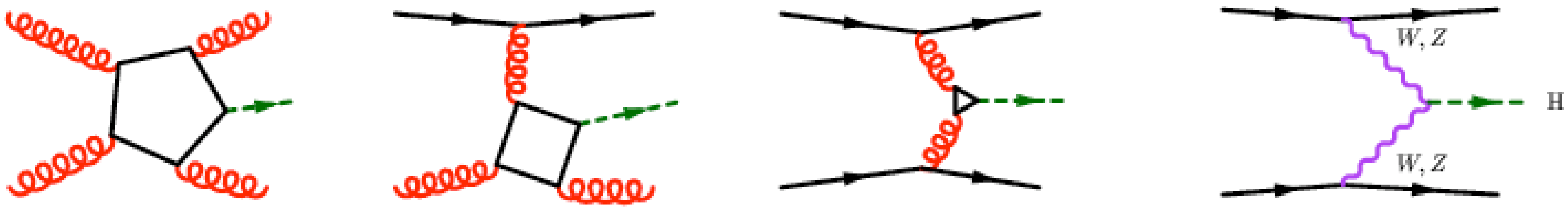
Large M_t limit

is accurate if $M_{\mathrm{H}} \ll 2M_t$ and $p_{j_1 \perp}, p_{j_2 \perp}, p_{\mathrm{H}\perp} \ll M_t$

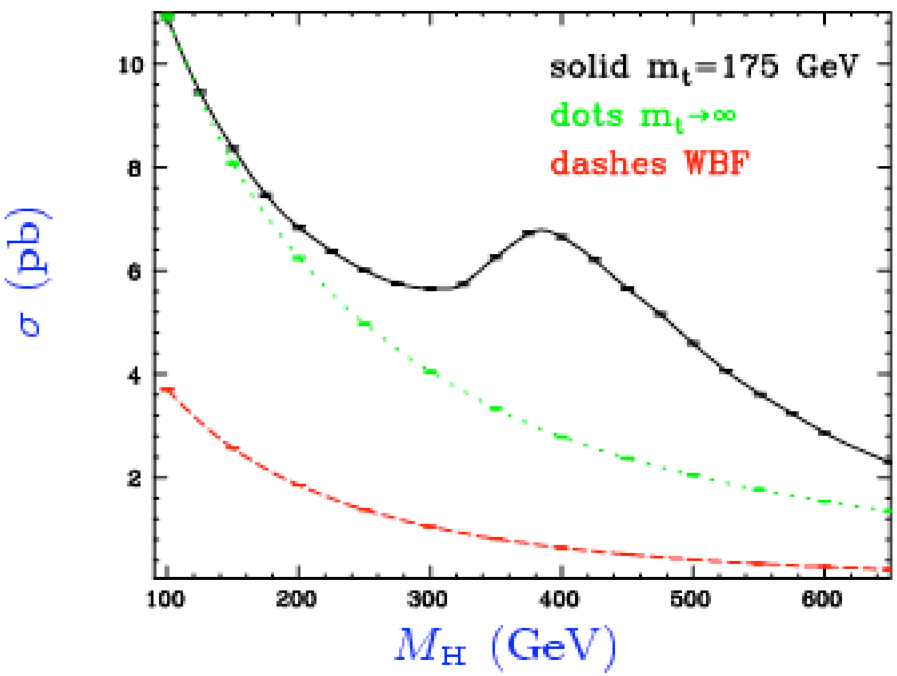
is valid even when $s_{j_1 j_2}, s_{j_1 \mathrm{H}}, s_{j_2 \mathrm{H}} \gg M_t^2$

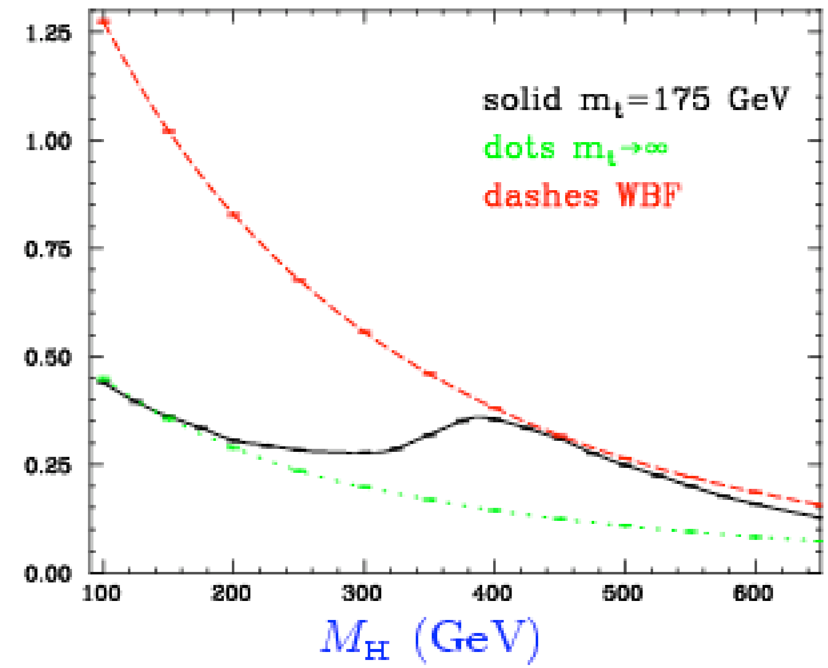


$H+$ 2 JETS RATE as a function of M_H



$\mu_F = \sqrt{p_{j_1\perp} p_{j_2\perp}}\,, \mu_R = M_Z$ Kilgore, Oleari, Schmidt, Zeppenfeld, VDD hep-ph/0105129





inclusive cuts: $\begin{cases} p_{j\perp} > 20 \text{ GeV} \\ |\eta_j| < 5 \\ R_{jj} > 0.6 \end{cases}$

WBF cuts: incl. + $\begin{cases} |\eta_{j_1} - \eta_{j_2}| > 4.2 \\ \eta_{j_1} \cdot \eta_{j_2} < 0 \\ \sqrt{s_{j_1 j_2}} > 600 \text{ GeV} \end{cases}$

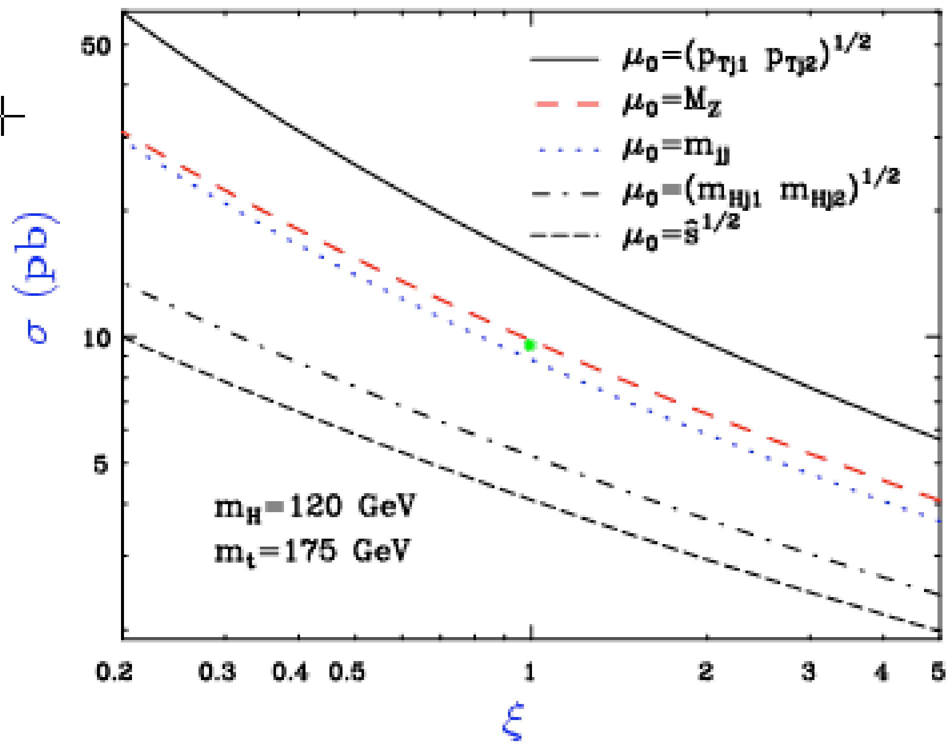
☛ WBF cuts enhance WBF wrt gluon fusion by a factor 10

Scale dependence

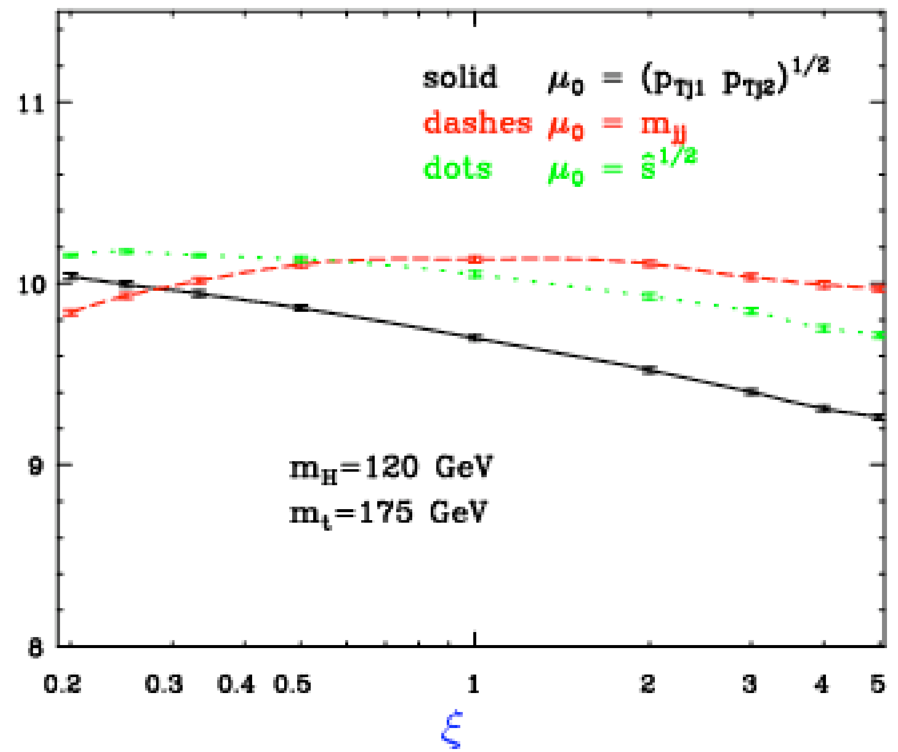
renormalisation μ_R & factorisation μ_F scales

Kilgore, Oleari, Schmidt, Zeppenfeld, VDD hep-ph/0108030

$\mu_R = \xi\mu_0,\ \mu_F = \sqrt{p_{j_1\perp}p_{j_2\perp}}$



$\mu_F = \xi\mu_0,\ \mu_R = M_Z$

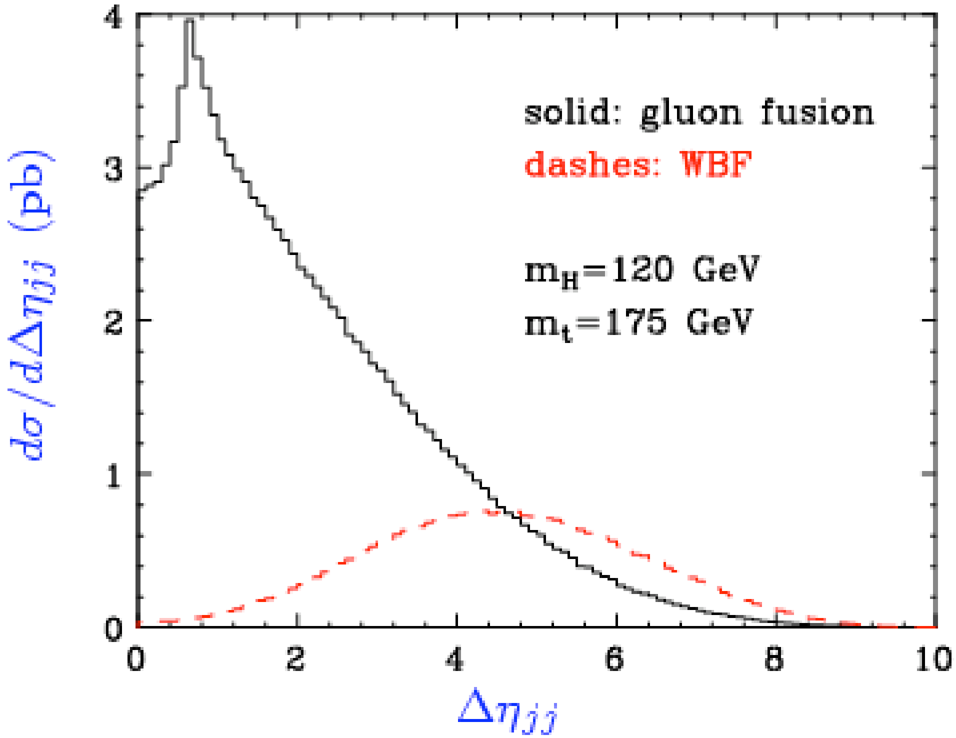


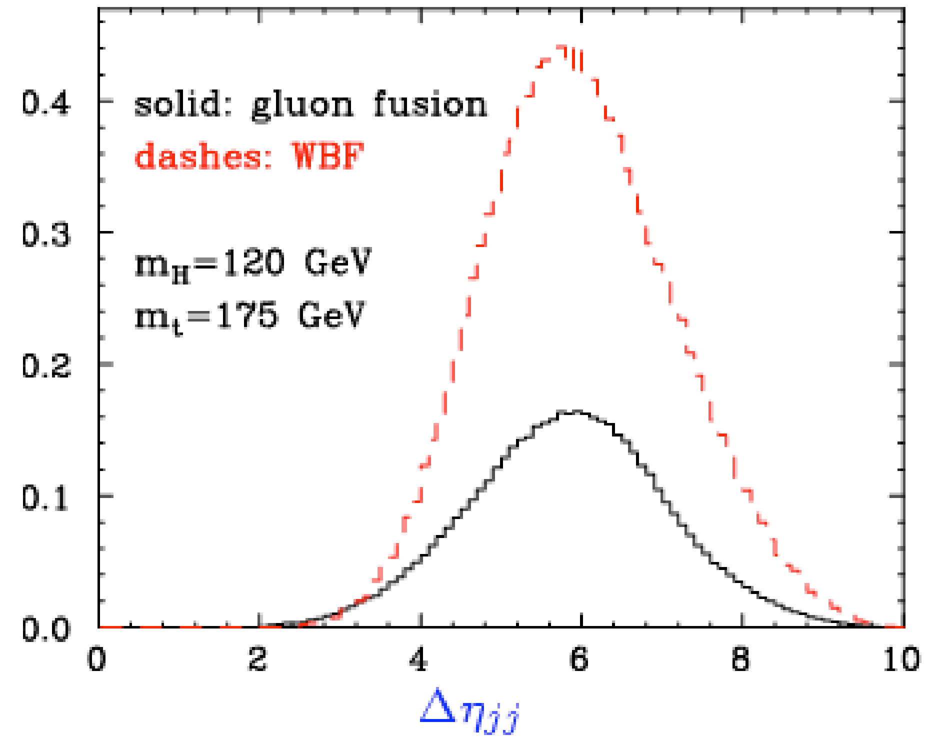
- strong μ_R dependence: the calculation is LO and $\mathcal{O}(\alpha_s^4)$
  - a natural scale for α_s ?

    high energy limit suggests $\alpha_s^4 \to \alpha_s(p_{j_1\perp})\alpha_s(p_{j_1\perp})\alpha_s^2(M_H)$
    - σ varies by a factor 2.5 for $\mu_0/2 < \mu_R < 2\mu_0$
- mild μ_F dependence: $\mathcal{O}(10\%)$ over the $\mu_0/5 < \mu_R < 5\mu_0$ range

Rapidity distributions

+ $\Delta\eta_{jj}$: rapidity difference between the two jets





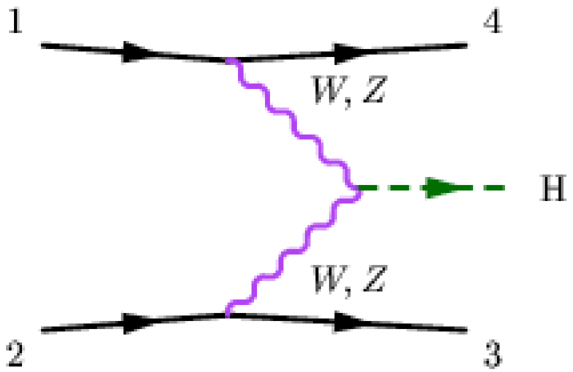
inclusive cuts: $\begin{cases} p_{j\perp} > 20 \text{ GeV} \\ |\eta_j| < 5 \\ R_{jj} > 0.6 \end{cases}$

WBF cuts: incl. + $\begin{cases} \eta_{j_1} \cdot \eta_{j_2} < 0 \\ \sqrt{s_{j_1 j_2}} > 600 \text{ GeV} \end{cases}$

- WBF events spontaneously have a large $\Delta\eta_{jj}$
- dip in gluon fusion at low $\Delta\eta_{jj}$ is unphysical: $R_{jj} = \sqrt{\Delta\eta_{jj} + \Delta\phi_{jj}} > 0.6$

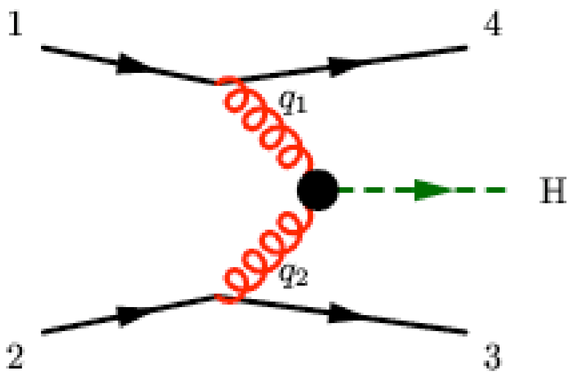
Azimuthal angle correlations

$\Delta\phi_{jj} \equiv$ the azimuthal angle between the two jets



$$\mathcal{A}_{WBF} \sim \frac{1}{2p_1 \cdot p_4 - M_W^2} \frac{1}{2p_2 \cdot p_3 - M_W^2} \hat{s} m_{jj}^2$$

➥ a flat $\Delta\phi_{jj}$ distribution



gluon fusion in the large M_t limit

$$\mathcal{L}_{eff} = \frac{1}{4} A\ H\ G^a_{\mu\nu} G^{a\,\mu\nu} \quad A = \frac{\alpha_s}{3\pi v}$$

$$\mathcal{A}_{gluon} \sim J_1^\mu (q_1^\nu q_2^\mu - g^{\mu\nu} q_1 \cdot q_2) J_2^\nu$$

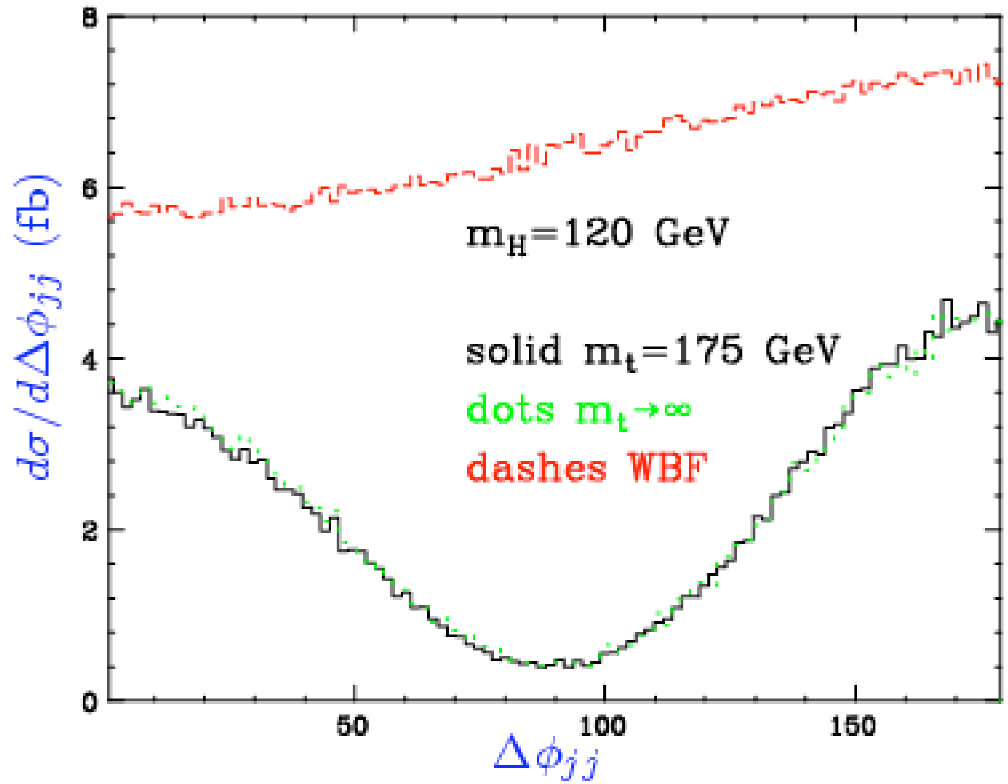
$J^\mu \equiv$ quark-gluon current

for $|p_i{}^z| \gg |p_i{}^{x,y}| \quad i = 3, 4$: forward jets

$$\mathcal{A}_{gluon} \sim (J_1^0 J_2^0 - J_1^3 J_2^3)\ p_{3\perp} \cdot p_{4\perp}$$

➥ zero at $\Delta\phi_{jj} = \frac{\pi}{2}$

Azimuthal angle distribution

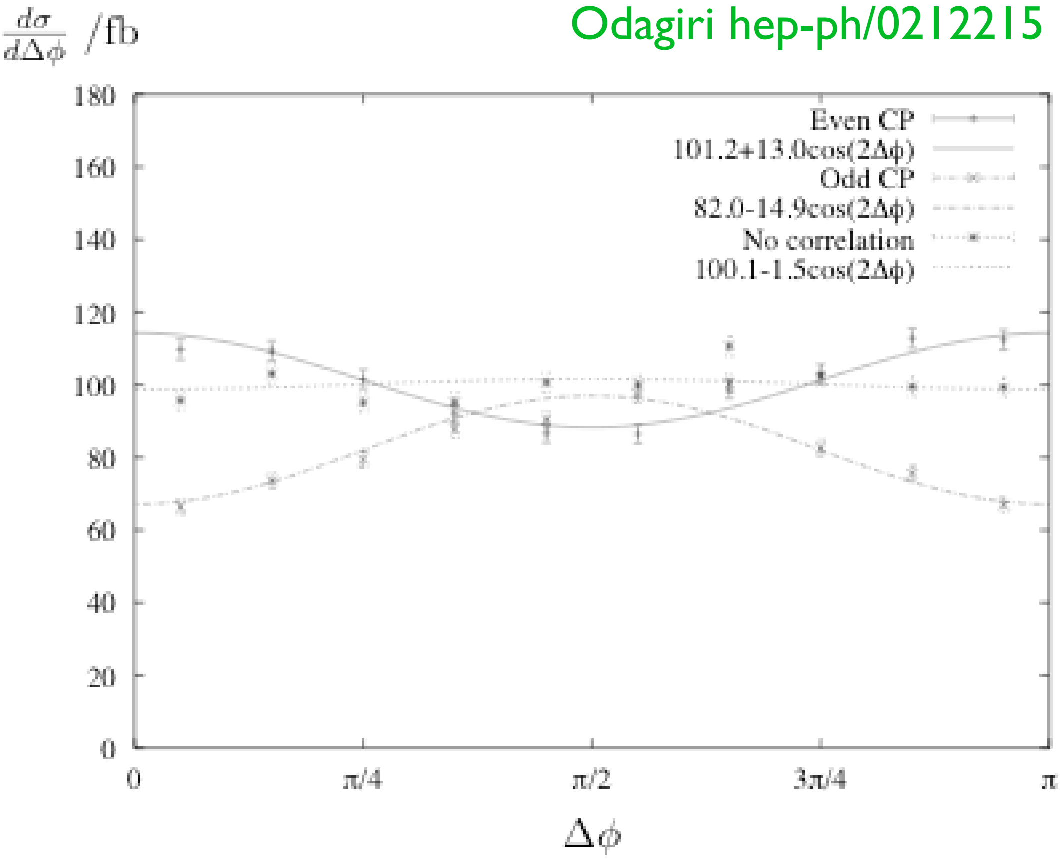


$$\text{WBF cuts:} \quad \begin{cases} p_{j\perp} > 20 \text{ GeV} \\ |\eta_j| < 5 \\ R_{jj} > 0.6 \end{cases} + \begin{cases} \eta_{j_1} \cdot \eta_{j_2} < 0 \\ |\eta_{j_1} - \eta_{j_2}| > 4.2 \\ m_{jj} > 600 \text{ GeV} \end{cases}$$

- the azimuthal angle distribution discriminates between WBF and gluon fusion
- note that the large M_t limit curve approximates very well the exact curve

Including parton showers and hadronisation through HERWIG, Odagiri finds much less correlation between the jets, but the plot has been obtained by generating also the jets through the showers

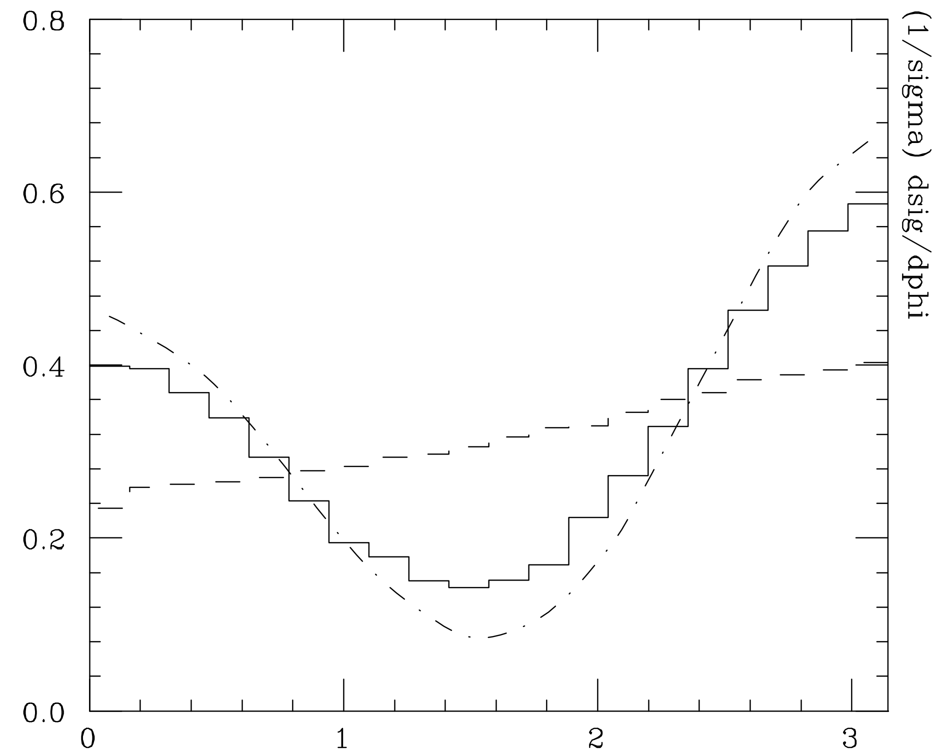
Odagiri hep-ph/0212215



Azimuthal angle distribution

- ALPGEN: H + 2 jets at parton level + parton shower by HERWIG

Klamke Mangano Moretti Piccinini Pittau Polosa Zeppenfeld VDD 2006



dash: VBF
solid: gluon fusion w/ PS
dot-dash: ditto w/o PS

A_ϕ: a quantity that characterises how deep the dip is

A_ϕ	parton level	shower level
$ggH + 2$ jets	0.474(3)	0.357(3)
$VBF + 2$ jets	0.017(1)	0.018(1)

$$A_\phi = \frac{\sigma(\Delta\phi < \pi/4) - \sigma(\pi/4 < \Delta\phi < 3\pi/4) + \sigma(\Delta\phi > 3\pi/4)}{\sigma(\Delta\phi < \pi/4) + \sigma(\pi/4 < \Delta\phi < 3\pi/4) + \sigma(\Delta\phi > 3\pi/4)}$$

$\Delta\Phi$ is the azimuthal angle between the tagging jets

WWH Coupling

- the azimuthal angle $\Delta\phi_{jj}$ between the jets can be used as a tool to investigate the tensor structure of the WWH coupling

Plehn, Rainwater, Zeppenfeld hep-ph/0105325

- take a gauge-invariant effective Lagrangian with dim. 6 operators (CP even and CP odd) describing an anomalous WWH coupling

$$\mathcal{L}_6 = \frac{g^2}{2\Lambda^2_{e,6}} \left(\Phi^\dagger \Phi\right) V_{\mu\nu} V^{\mu\nu} + \frac{g^2}{2\Lambda^2_{o,6}} \left(\Phi^\dagger \Phi\right) \widetilde{V}_{\mu\nu} V^{\mu\nu}$$

- expand Φ about the vev (get dim. 5 (D5) operators)

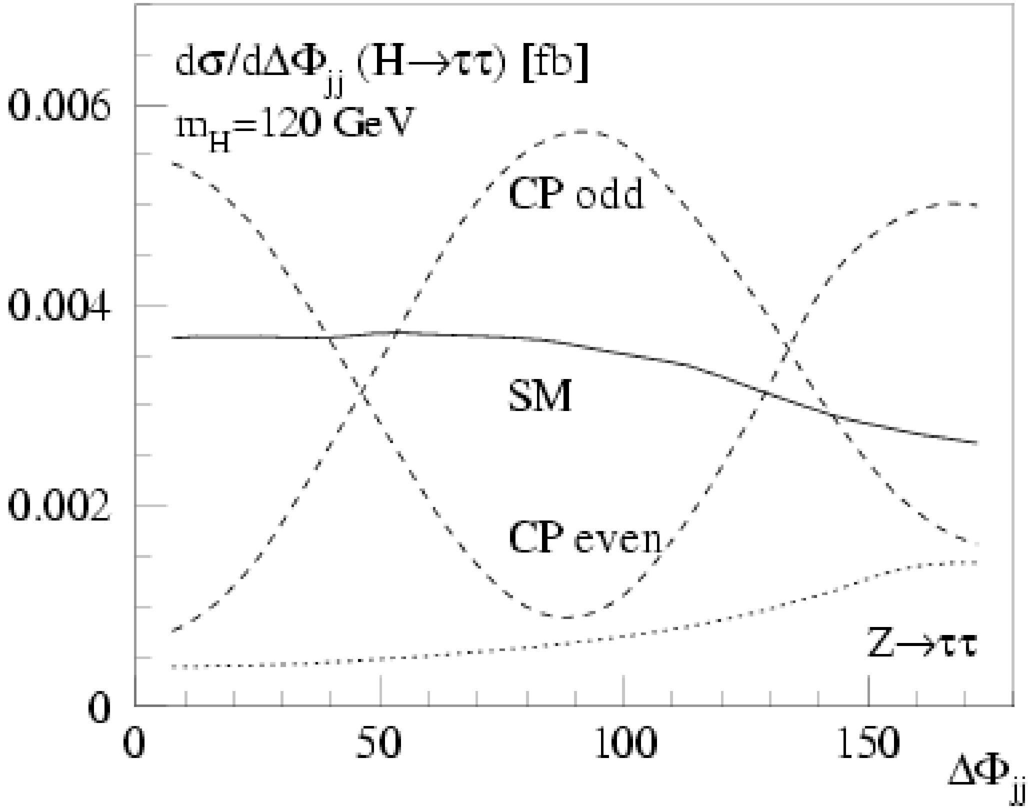
$$\mathcal{L}_5 = \frac{1}{\Lambda_{e,5}} H\, W^+_{\mu\nu} W^{-\mu\nu} + \frac{1}{\Lambda_{o,5}} H\, \widetilde{W}^+_{\mu\nu} W^{-\mu\nu} \quad \text{with} \quad \frac{1}{\Lambda_5} = \frac{g^2 v}{\Lambda^2_6}$$

- CP odd D5 operator: $\epsilon^{\mu\nu\alpha\beta}$ tensor in the coupling
  - ➡ zero at $\Delta\phi_{jj} = 0, \pi$
- CP even D5 operator is like the effective ggH coupling

$$\mathcal{A}_{\text{CP even}} \sim \frac{1}{\Lambda_{e,5}} J_1^\mu \left(q_1^\nu q_2^\mu - g^{\mu\nu} q_1 \cdot q_2\right) J_2^\nu \quad \Rightarrow \quad \text{zero at } \Delta\phi_{jj} = \frac{\pi}{2}$$

Azimuthal angle distribution for WWH couplings

- assume a Higgs-like scalar signal is found at LHC at the SM rate (for D5 operators: $\Lambda_5 \sim 500$ GeV)



WBF cuts:

$p_{j\perp} > 20$ GeV

$|\eta_j| < 5$

$R_{jj} > 0.6$

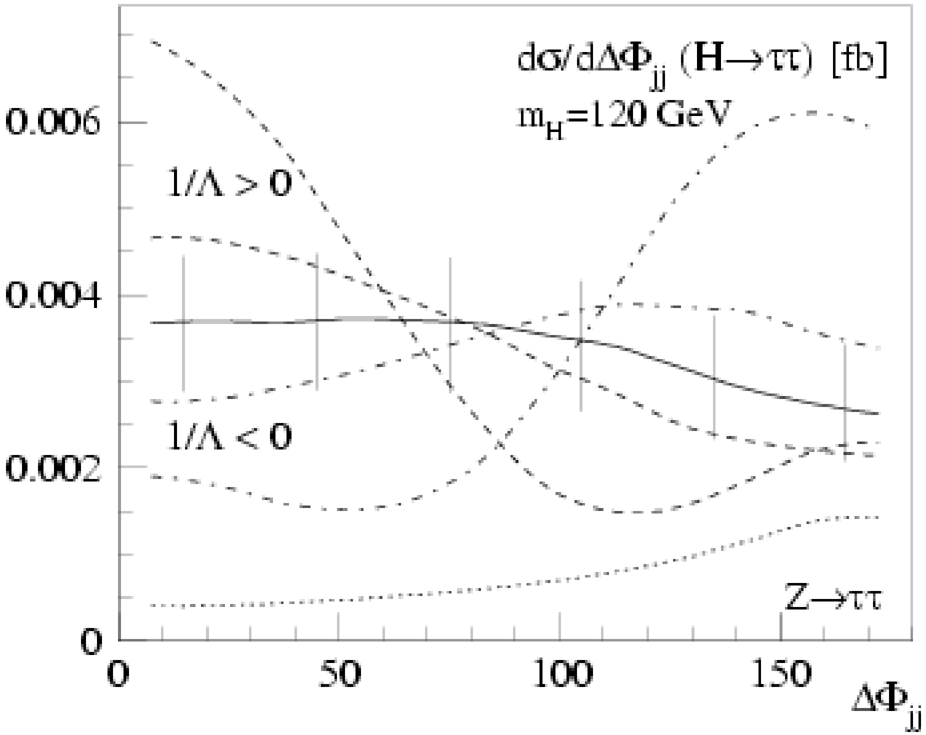
$\eta_{j_1} \cdot \eta_{j_2} < 0$

$|\eta_{j_1} - \eta_{j_2}| > 4.2$

- the $\Delta\phi_{jj}$ distribution
  - ☛ discriminates between different WWH couplings
  - ☛ is independent of the particular decay channel and the Higgs mass range

Interference effects in the $\Delta\phi_{jj}$ distribution

- assume a Higgs candidate is found at LHC with a predominantly SM $g^{\mu\nu}$ coupling. How sensitive are experiments to any D5 terms ?
- no interference between SM and CP odd D5 operator



$\Delta\phi_{jj}$ distribution for the SM and interference with a CP even D5 coupling. The two curves for each sign of the operator correspond to values $\sigma/\sigma_{\rm SM} = 0.04, 1.0$. Error bars correspond to an integrated luminosity of 100 fb^{-1} per experiment, distributed over 6 bins, and are statistical only

- interference between SM and CP even D5 operator: $|\mathcal{A}|^2 = |\mathcal{A}_{\rm SM} + \mathcal{A}_{e,5}|^2$
  - ☛ all terms, but $|\mathcal{A}_{\rm SM}|^2$, have an approximate zero at $\Delta\phi_{\rm jj} = \pi/2$
  - ☛ systematic uncertainty induced by $H + 2$ jet rate from gluon fusion
    - ➡ $HG_{\mu\nu}G^{\mu\nu}$ is a CP even D5 operator

The Central Jet Veto

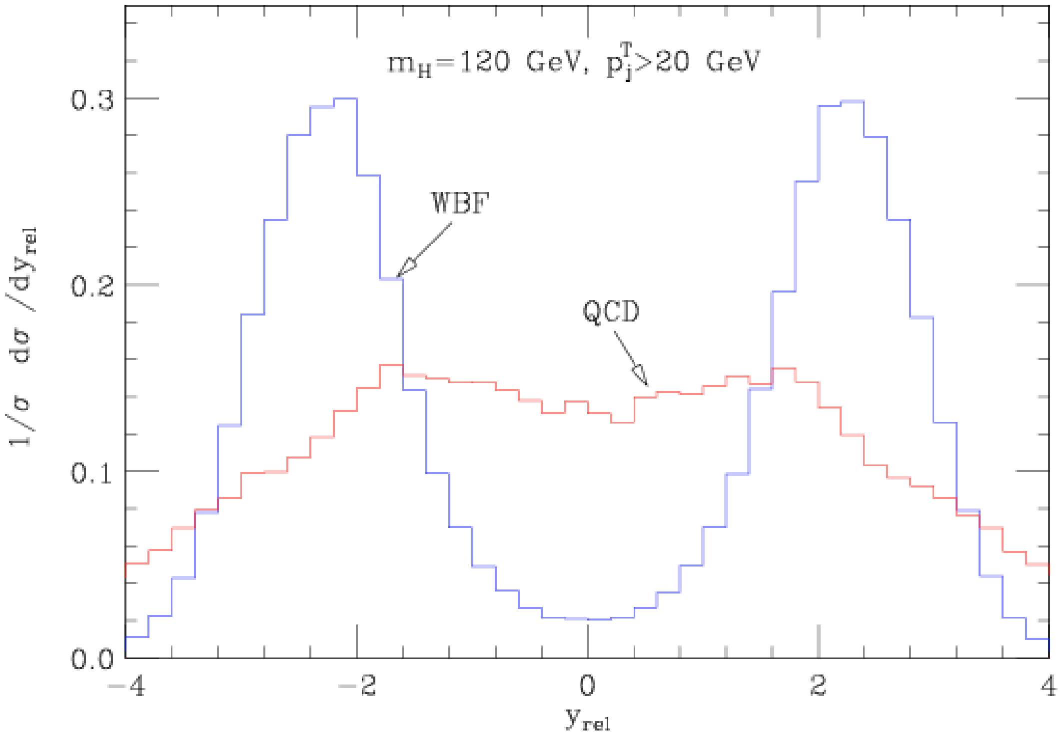
- In WBF no colour is exchanged in the t channel

- The central-jet veto is based on the different radiation pattern expected for WBF versus its major backgrounds, i.e. $t\bar{t}$ production and WW + 2 jet production

  Barger, Phillips & Zeppenfeld hep-ph/9412276

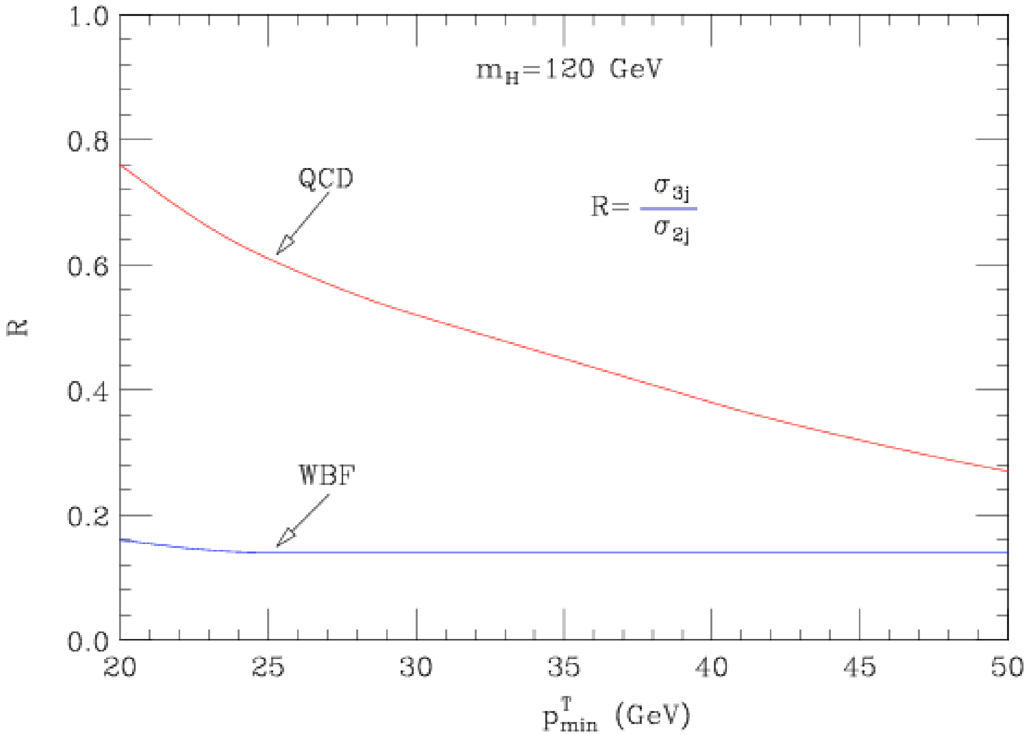
- The central-jet veto can also be used to distinguish between Higgs production via gluon fusion and via WBF

Frizzo, Maltoni, VDD hep-ph/0404013



Distribution in rapidity of the third jet wrt to the rapidity average of the tagging jets

Ratio of Higgs + 3 jet to Higgs + 2 jet production as a function of p^T_{min}



Conclusions

- If a Standard Model Higgs is there, LHC will see it

- Once the Higgs is found, we shall want to study its couplings and quantum numbers

- In Higgs + 2 jets, the azimuthal angle correlation between the two jets can be used as a tool to distinguish between WBF and gluon fusion, and to investigate the tensor structure of the WWH coupling

- Because of the characteristic final-state topology induced by WBF production large-rapidity cuts can be used to deplete gluon fusion wrt WBF