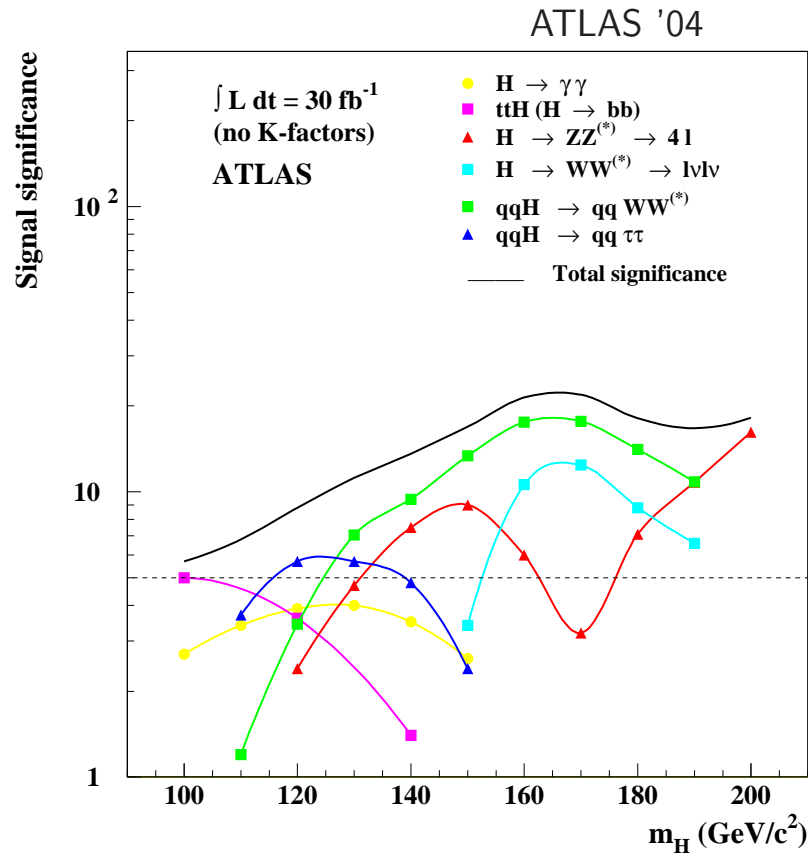


# Contributions to Higgs production in Vector Boson Fusion at $\mathcal{O}(\alpha_s^2\alpha^3)$

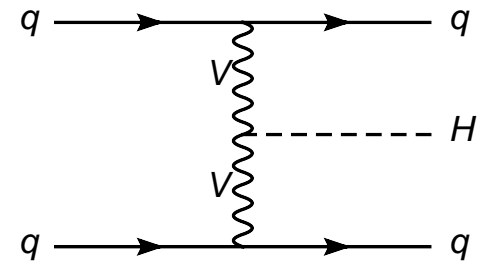
Marcus Weber  
SUNY at Buffalo

in collaboration with  
Robert Harlander

## Higgs discovery at LHC



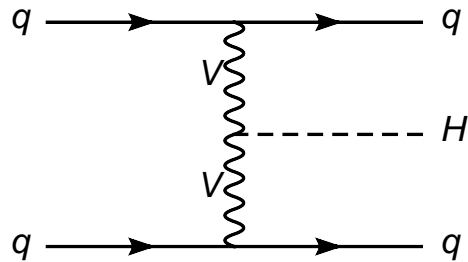
### Vector Boson Fusion: $qq' \rightarrow qq'H$



- important Higgs discovery mode at LHC
- allows measurement of  $HVV$  couplings

→ precise predictions for VBF necessary

# Vector Boson Fusion



## VBF characteristics

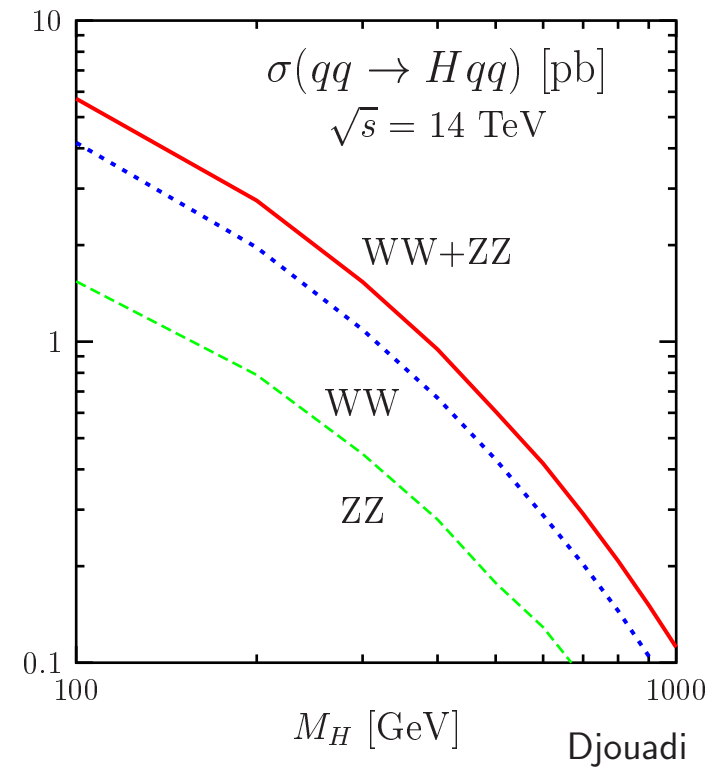
- t-channel  $W/Z$  exchange  
→ 2 jets at high rapidities
- no color exchange  
no central hadronic activity
- $H$  decay products at low rapidities

## QCD background

- much jet activity in central detector region

→ suppression of VBF background possible

leading order cross section at LHC

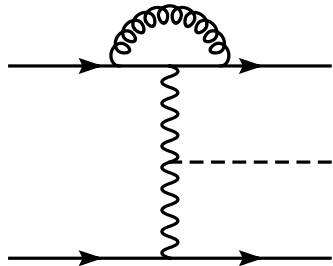


# Vector Boson Fusion at NLO

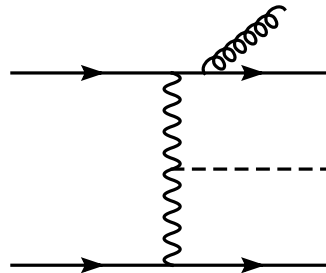
## QCD corrections

- total rates [Han, Valencia, Willenbrock '92] [Djouadi, Spira '00]
- distributions [Figy, Oleari, Zeppenfeld '03] [Barger, Campbell '04]

virtual corrections



real corrections

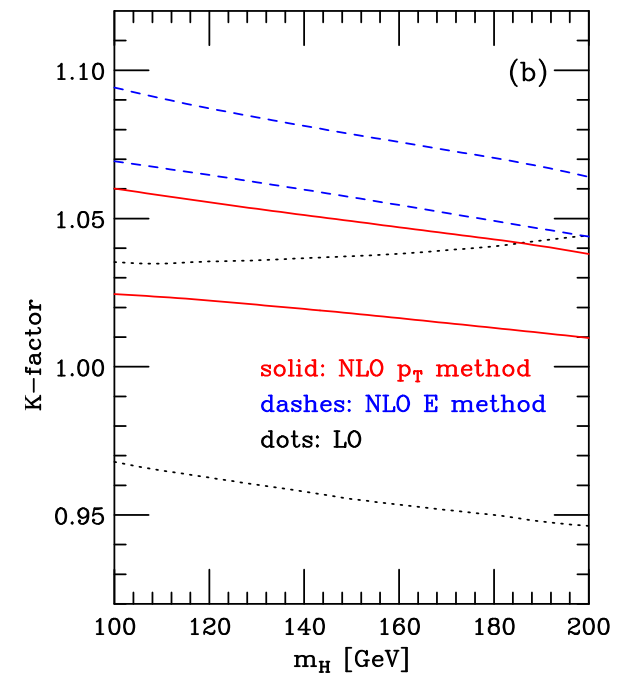


- **no color exchange**
  - only corrections to structure functions
  - read radiation in forward/backward region

⇒ distinctive kinematics not changed at NLO

- size: +5...10%
- scale uncertainty  $\sim 2\%$

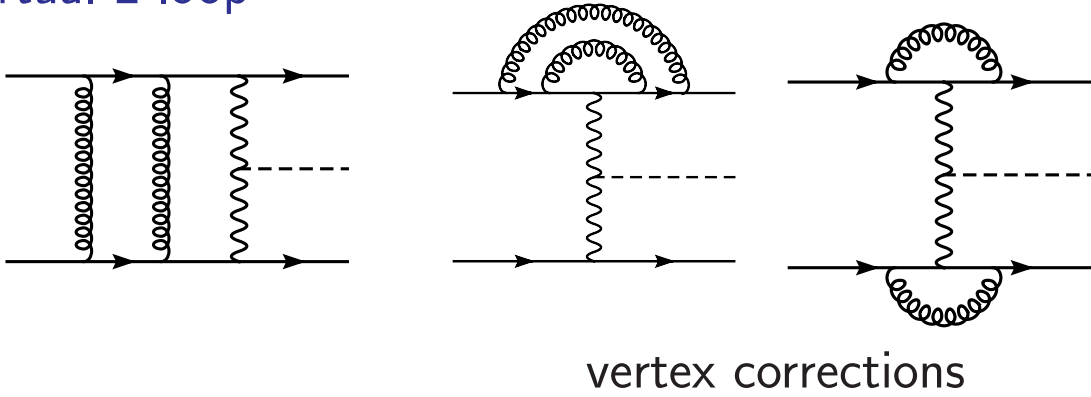
NLO K-factor at LHC



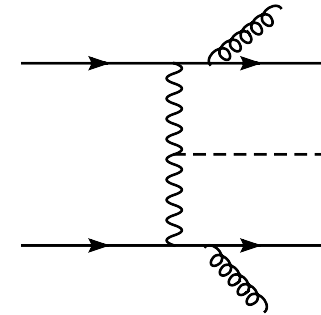
Figy, Oleari, Zeppenfeld

# Vector Boson Fusion at NNLO

virtual 2-loop

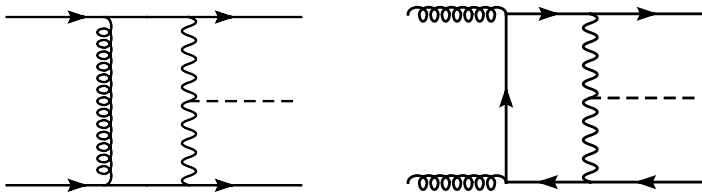


real radiation



→ no color exchange

$(1\text{-loop})^2$



→ color exchange

gluon induced processes  $gg \rightarrow q\bar{q}H$

leading order, loop induced

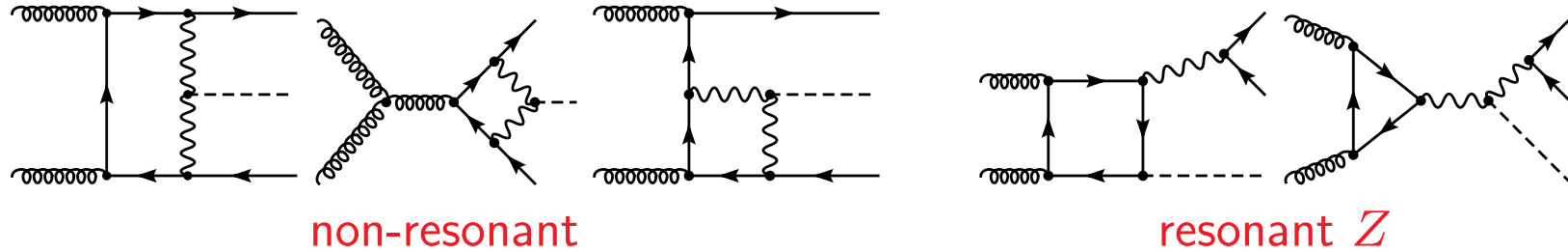
finite, gauge invariant

→ this talk

# $gg \rightarrow q\bar{q}H$

consider:  $gg \rightarrow q\bar{q}H$  and crossed processes ( $q\bar{q} \rightarrow ggH$  and  $qg \rightarrow qgH$ )

sample diagrams for  $gg \rightarrow q\bar{q}H$



external quarks: sum over 5 light flavours, taken as massless

diagrams with resonant  $Z$  boson

- resonant and nonresonant diagram sets separately gauge invariant
- resonant diagrams:  $gg \rightarrow HZ^* \rightarrow Hq\bar{q}$ 
  - NNLO corrections to Higgsstrahlung
  - suppressed by VBF cuts on invariant jet-jet mass
  - exclude, use only non-resonant diagrams

initial state radiation diagrams

amplitude diverges for soft or collinear final state quarks

→ real corrections to  $\bar{q}g \rightarrow \bar{q}H$

require 2 non-collinear well separated hard jets using cuts → finite cross section

# Calculation

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- 't Hooft-Feynman gauge
  - generation by FeynArts
  - evaluation using Mathematica / FormCalc
    - standard matrix elements and coefficients containing tensor loop integrals
    - translation to C++ code for numerical evaluation
  - tensor loop integrals
    - 3/4 point integrals: Passarino-Veltman reduction
    - 5 point integrals:
      - numerical instabilities from inverse Gram determinants in tensor reduction
      - alternative reduction avoiding leading inverse Gram determinants
- using loop integral library by A. Denner
- phase space integration: VEGAS
    - distributions possible

[Denner, Dittmaier '02]

## checks of the calculation

- finiteness
  - no UV, IR, collinear divergences in full amplitude

- gauge invariance

matrix element:  $\mathcal{M} = \epsilon_\mu(k_1)\epsilon_\nu(k_2)\mathcal{M}^{\mu\nu}$

gauge invariance requires:

$$k_{1\mu}\epsilon_\nu(k_2)\mathcal{M}^{\mu\nu} = \epsilon_\mu(k_1)k_{2\nu}\mathcal{M}^{\mu\nu} = 0$$

→ checked numerically

## phase space cuts

### minimal cuts

$$p_{Tj} > 20 \text{ GeV}, \quad |\eta_j| < 5, \quad R > 0.6$$

$$R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$$

→ 2 well separated hard jets

### additional VBF cuts

$$|\Delta\eta| > 4.2, \quad \eta_1 \cdot \eta_2 < 0$$

$$m_{jj} > 600 \text{ GeV}$$

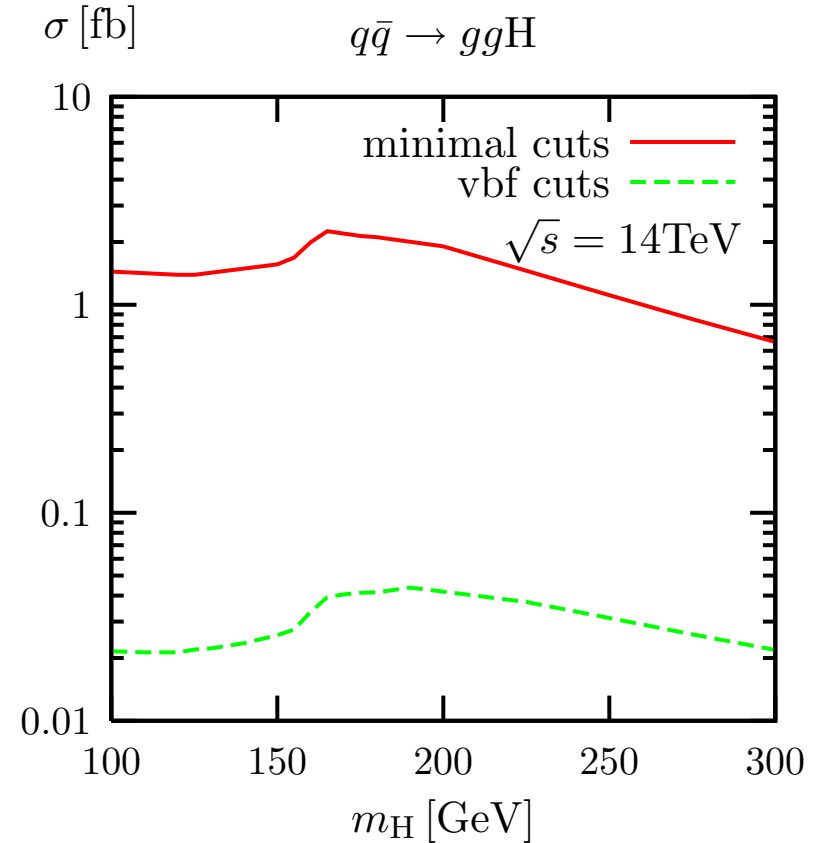
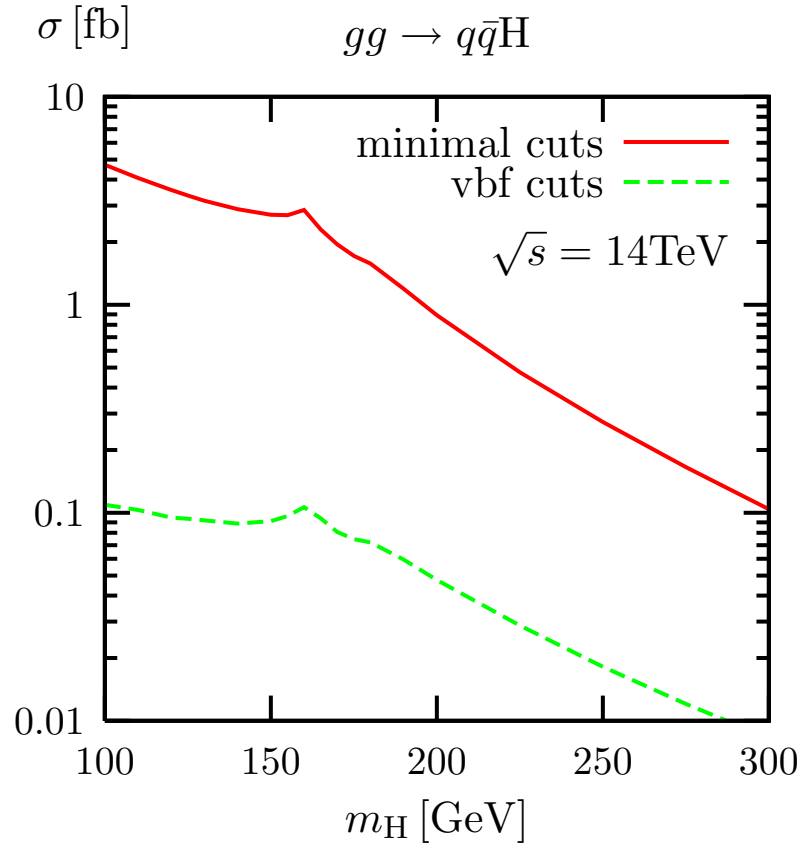
→ separation of VBF process from background

# Results for LHC: total cross section

parton densities: MRST nnlo

$$gg \rightarrow q\bar{q}H$$

$$q\bar{q} \rightarrow ggH$$

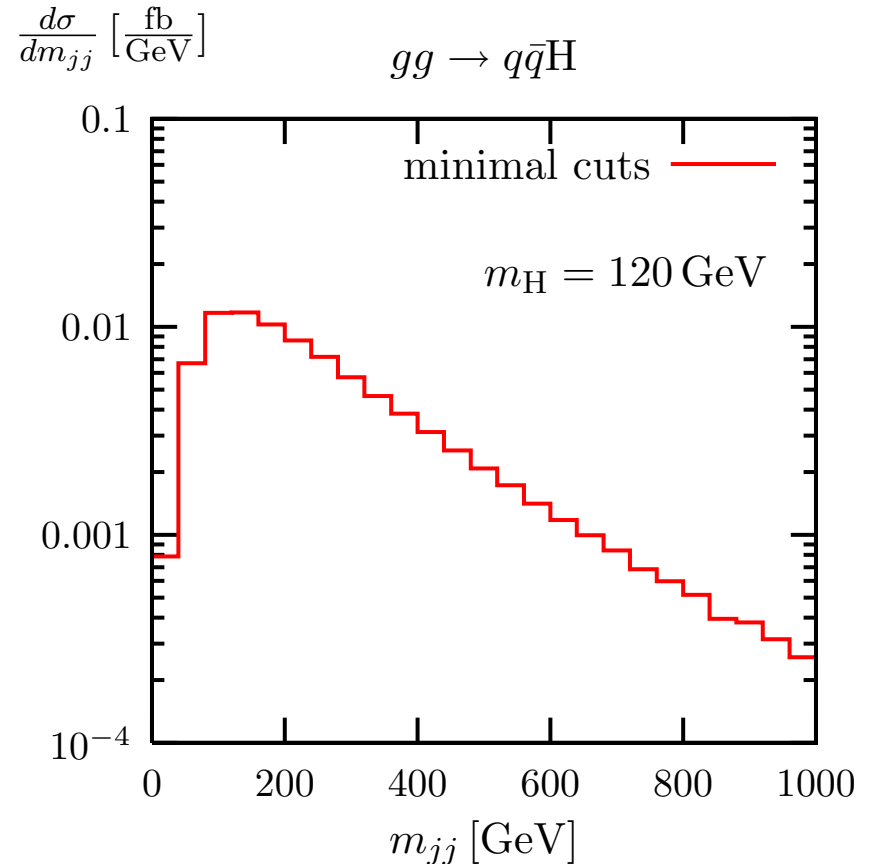
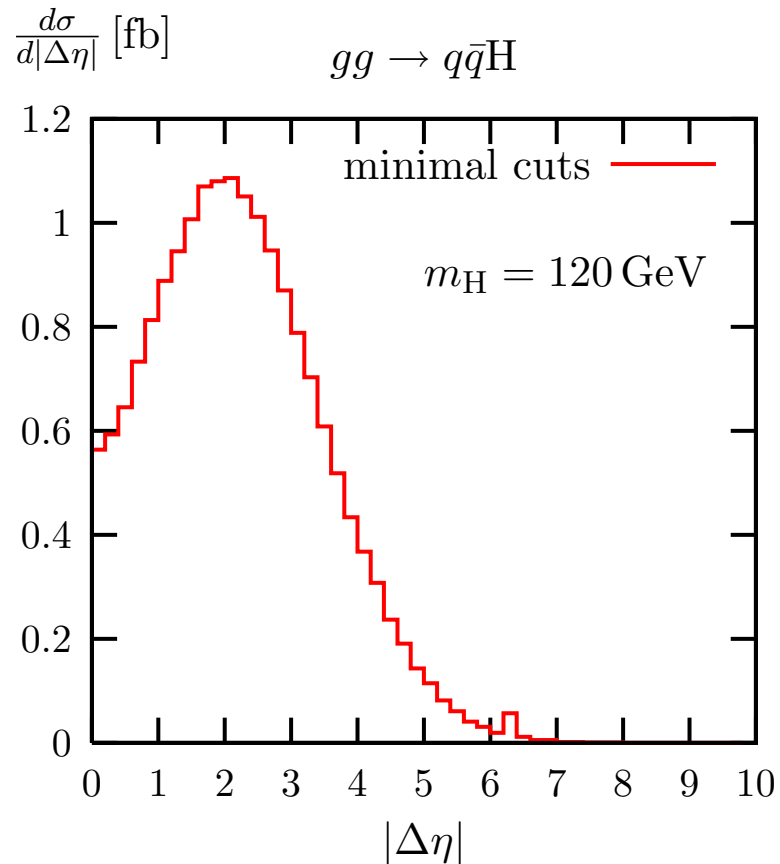


VBF LO:  $\sigma \approx 1$  pb with vbf cuts

- $W$  threshold in loops visible
- VBF cuts: strong suppression

# Results for LHC: distributions

$m_H = 120 \text{ GeV}$ , minimal cuts



- rapidity gap: smaller than for vector boson fusion (peak at  $\Delta\eta \approx 4..5$ )
- dijet invariant mass: rapid falloff

# conclusions

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- vector boson fusion important Higgs production channel at LHC
- no color exchange at LO and NLO  
color exchange contributions only at NNLO
- $gg \rightarrow q\bar{q}H$  and crossed processes  
finite, gauge invariant subset of NNLO corrections  
with color exchange
- $\sigma \sim 5 \text{ fb}$  for 100 GeV Higgs with minimal cuts  
strong suppression by additional VBF cuts