Gluon induced W-boson pair production as SM Higgs boson discovery background at the LHC

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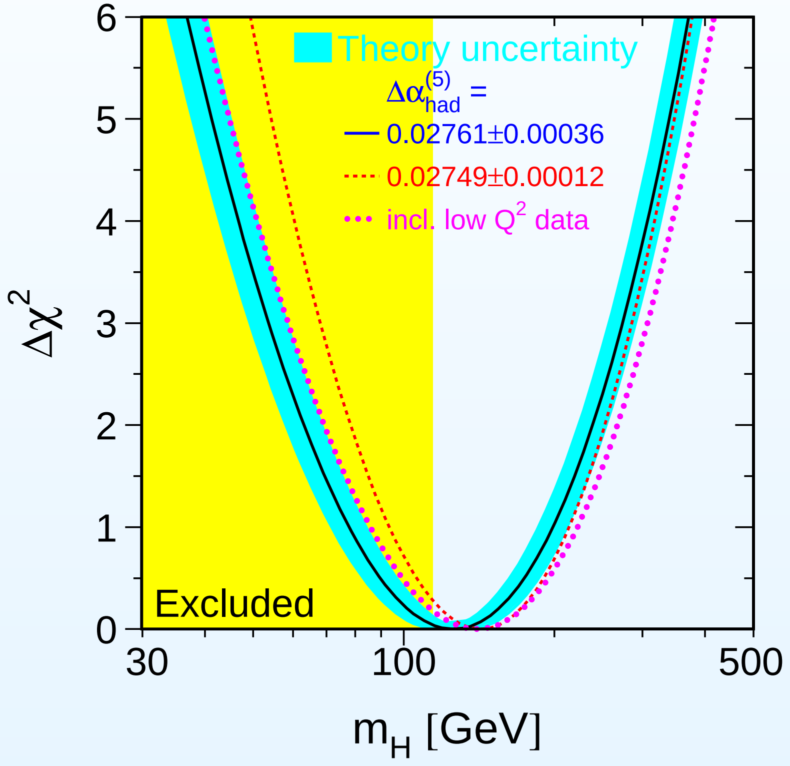
Outline

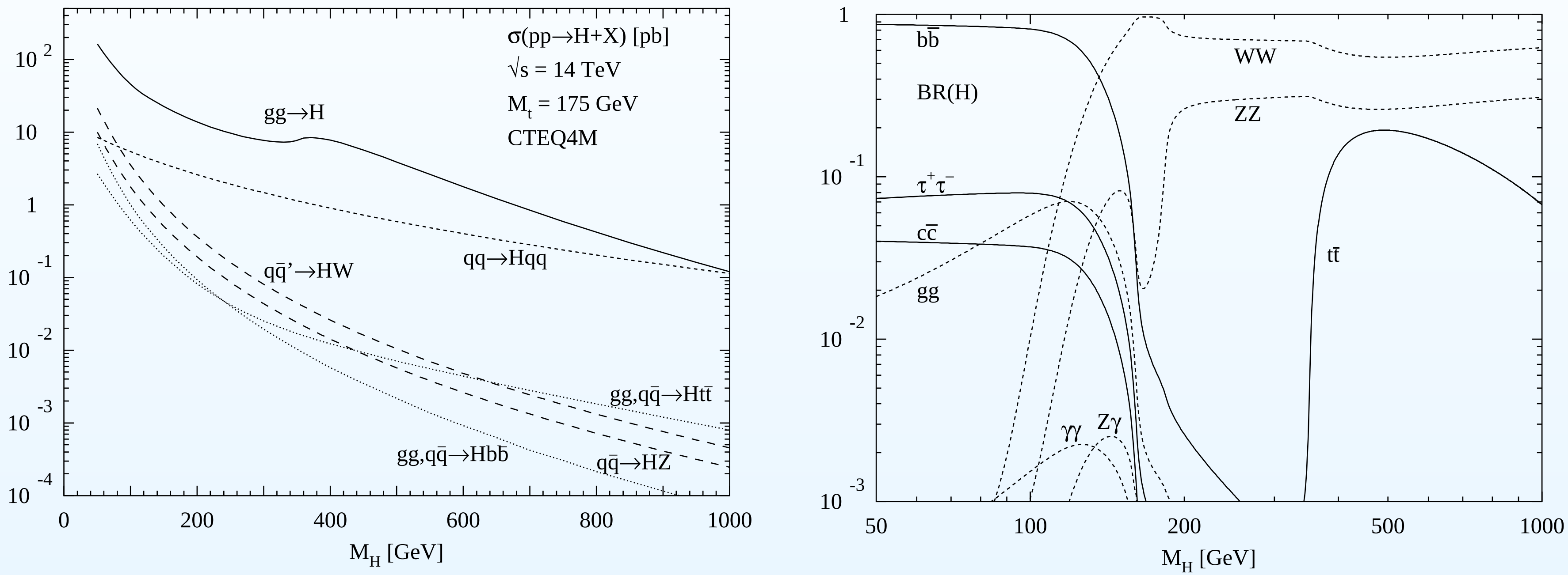
- SM Higgs boson
  - Mass constraints
  - Production and decay
  - Search channels at the LHC
- $gg \rightarrow W^-W^+ \rightarrow \ell\bar{\nu}_\ell\,\bar{\ell}'\nu_{\ell'}$
  - Motivation
  - Calculation details
  - Results
  - `gg2WW` code
  - Recent developments
- Conclusions

SM Higgs boson: Mass constraints



- Precision EW data (LEP EWWG) :
  - $M_H = 126^{+73}_{-48}$ GeV (68% $C.L.$)
  - $M_H < 280$ GeV (95% $C.L.$)
- LEP direct searches (LEP HWG) :
  - 114.4 GeV $< M_H$ (95% $C.L.$)

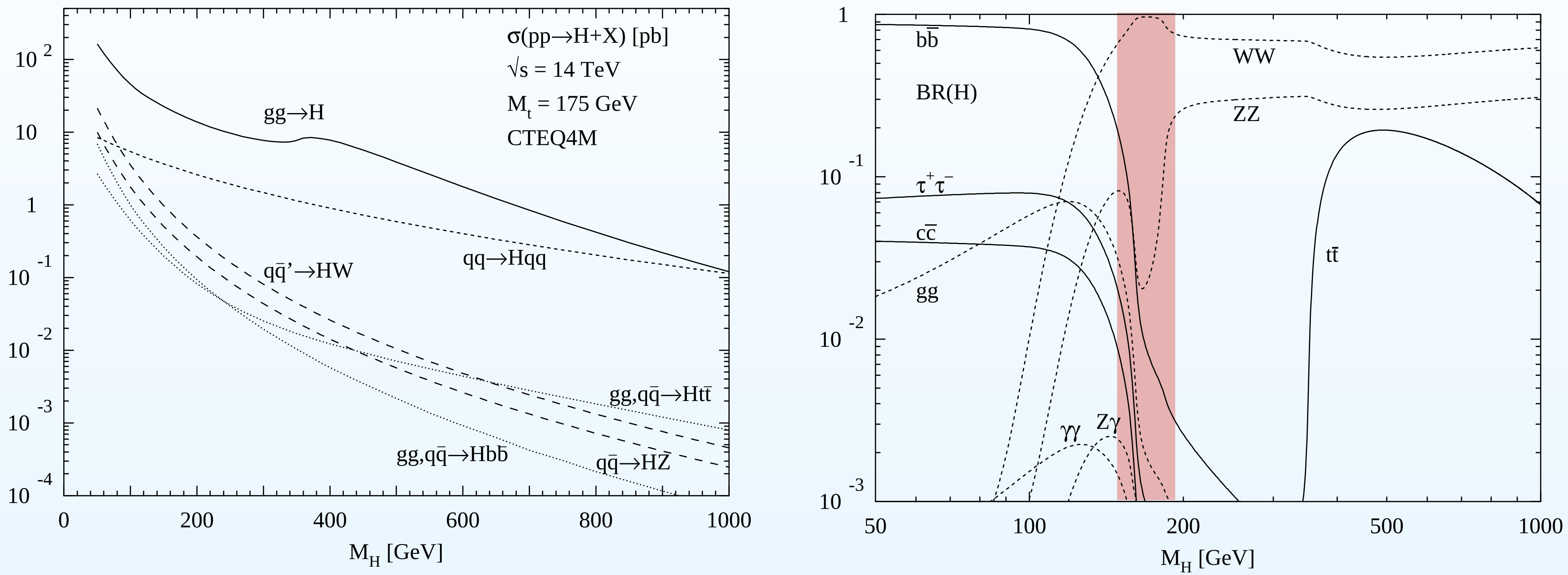
SM Higgs: Production and decay



M. Spira

- Largest cross section: $gg \to H$ and $qq \to Hqq$

SM Higgs: Production and decay

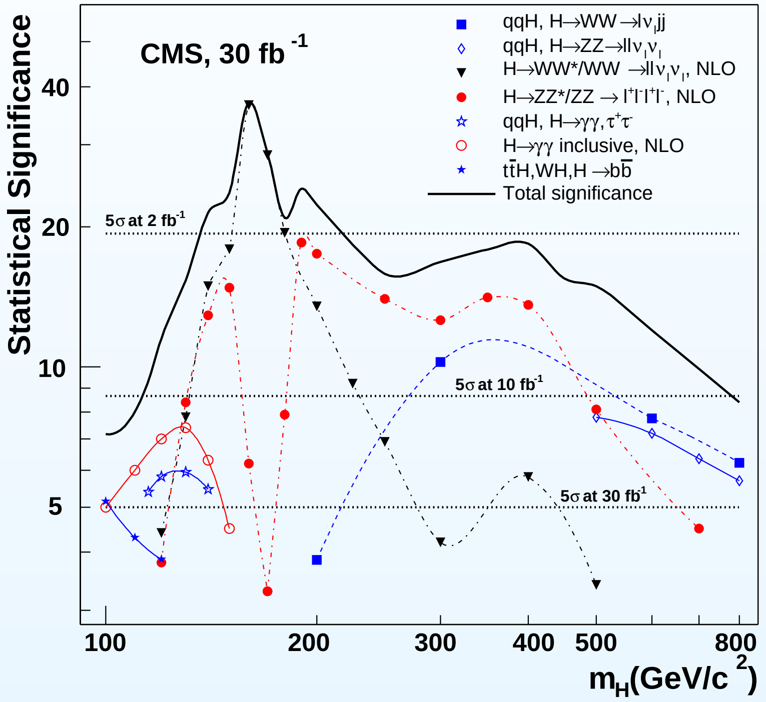


M. Spira

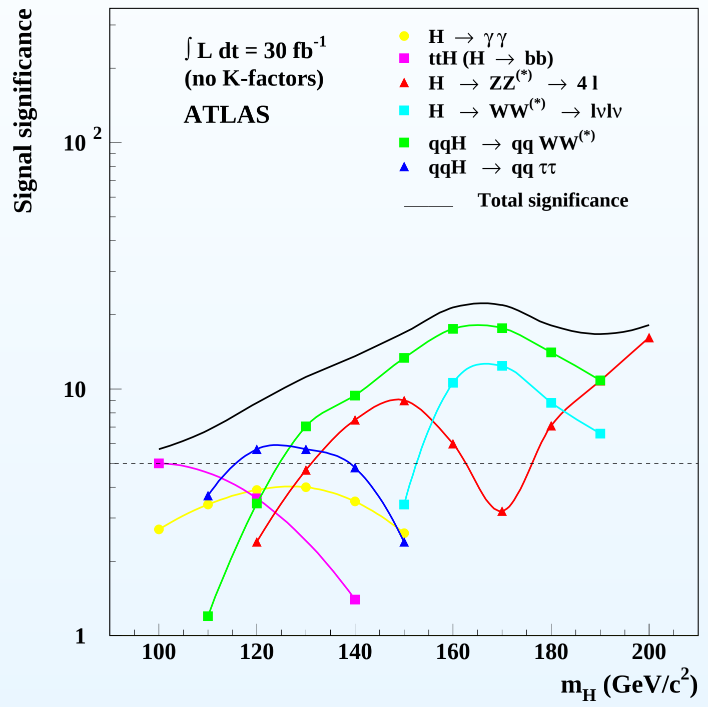
- Largest cross section: $gg \to H$ and $qq \to Hqq$
- Focus on $140\ \mathrm{GeV} < M_H < 180\ \mathrm{GeV}$

SM Higgs: LHC search channels

LHC discovery potential



CMS-Note-2003-33



Asai et al. (2004)

SM Higgs: LHC search channels

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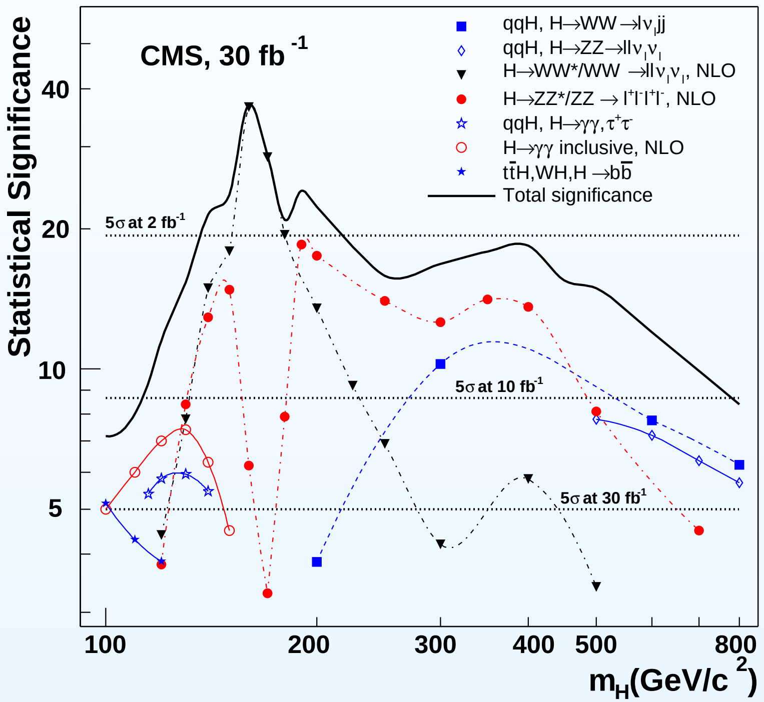

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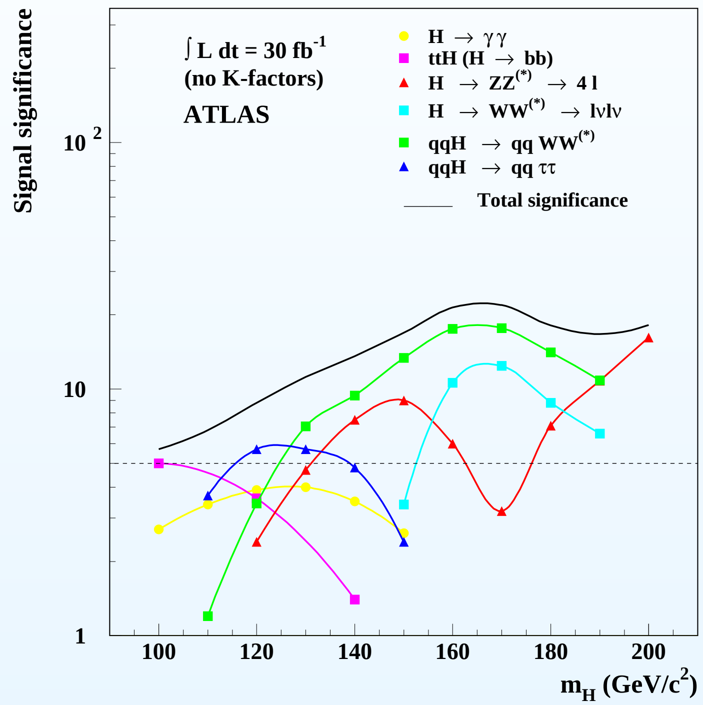
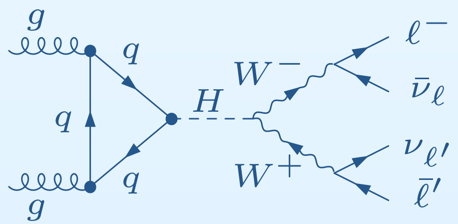


Asai et al. (2004)

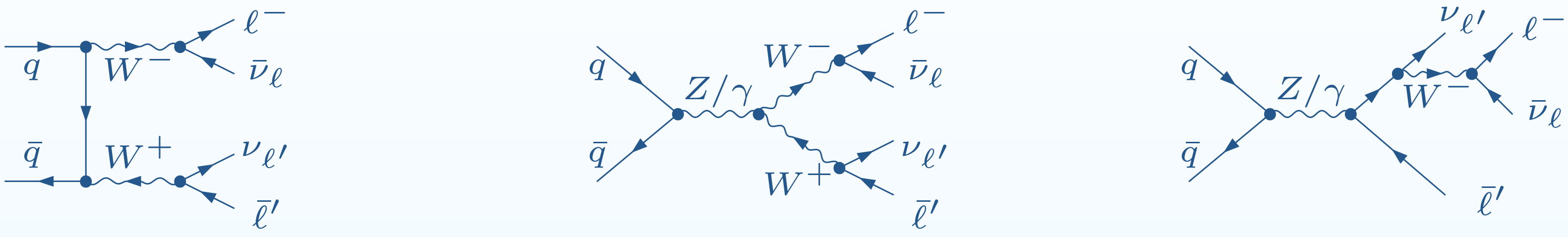
Signal

- $H \to W^-W^+ \to \ell\,\bar{\nu}\;\bar{\ell}'\,\nu_{\ell'}$:



Hadronic W-pair production status

- LO (J. M. Campbell, R. K. Ellis) :



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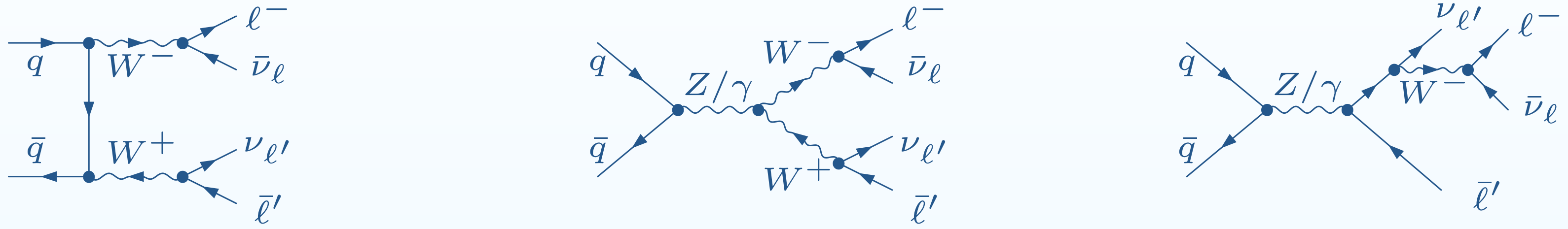

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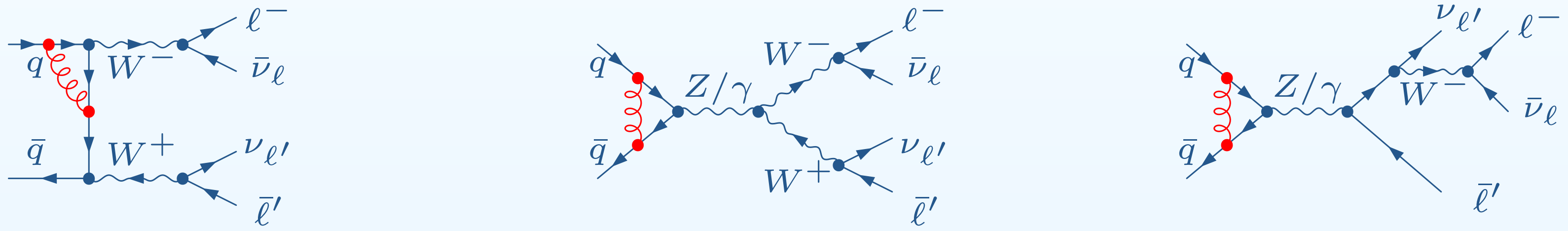

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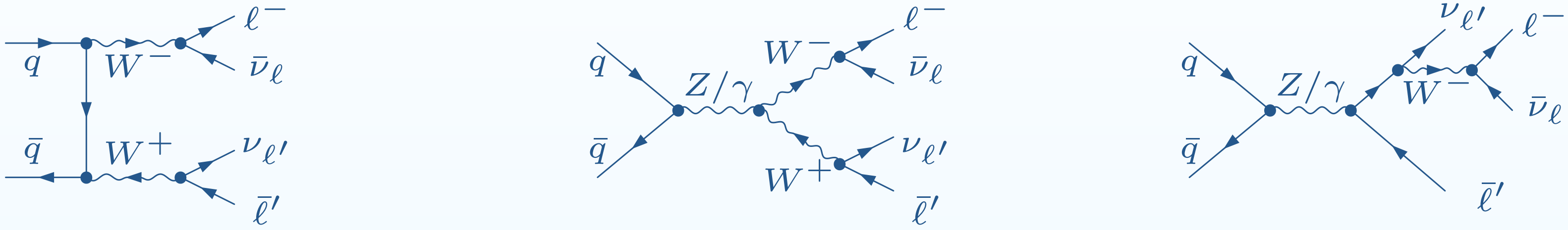

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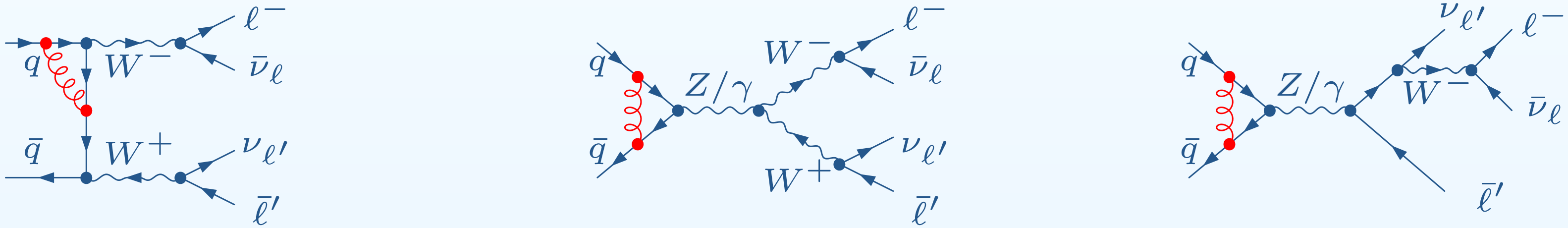

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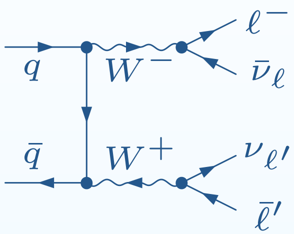

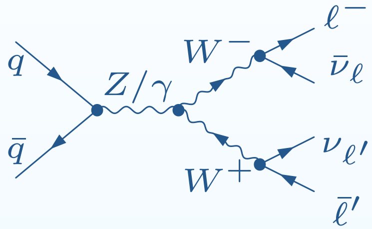

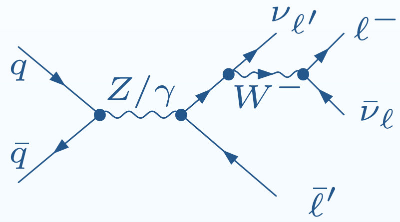

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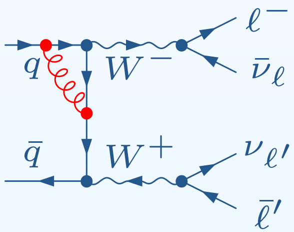

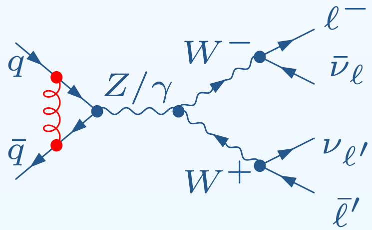

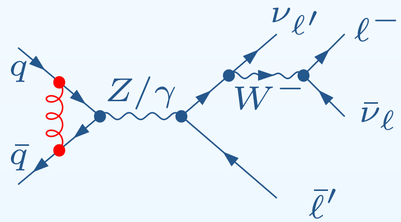

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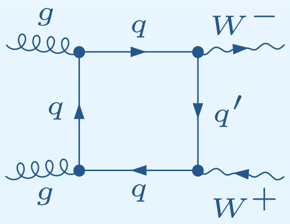

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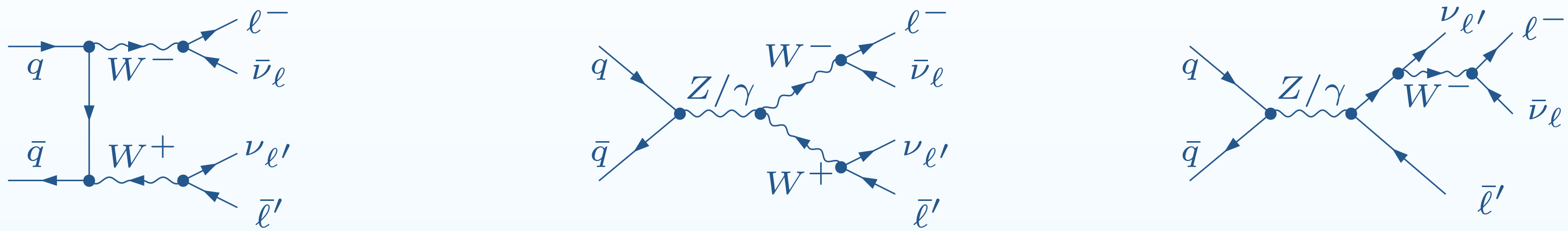

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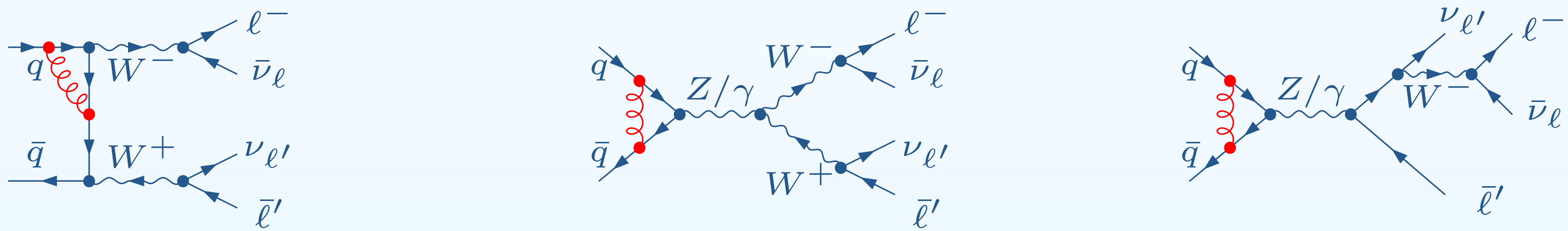

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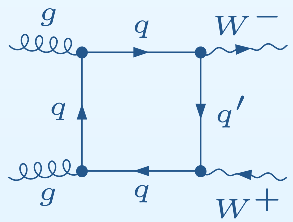

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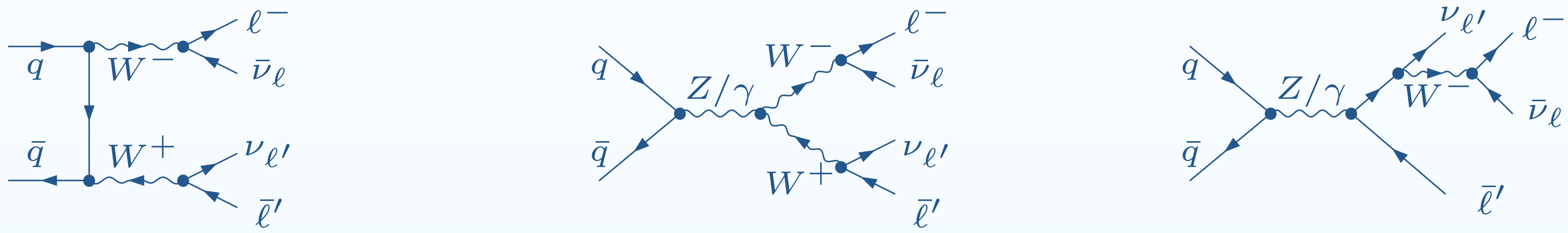

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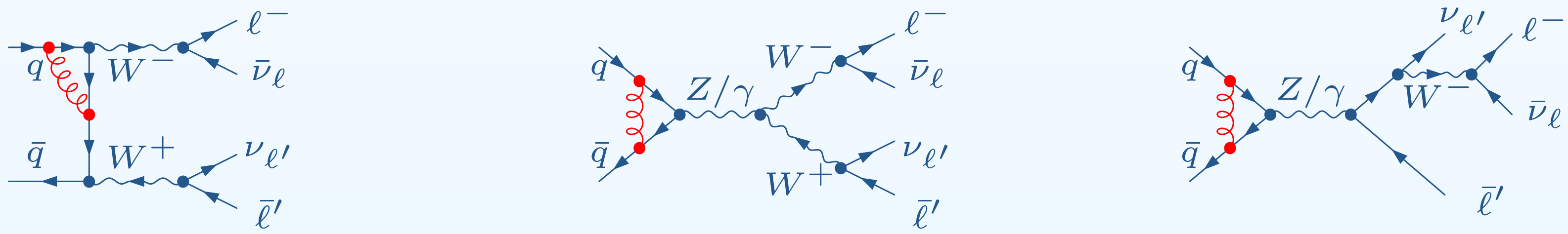

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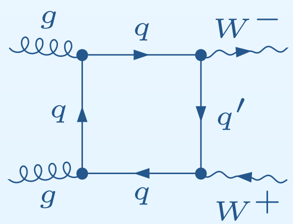


- $gg \to Z^* Z^*$ (C. Zecher, T. Matsuura, J. J. van der Bij)
- Tree level $gg \to W\, Z/\gamma\, q\bar{q}$ (K. L. Adamson, D. de Florian, A. Signer)

Search strategy

Details (M. Dittmar, H. K. Dreiner)

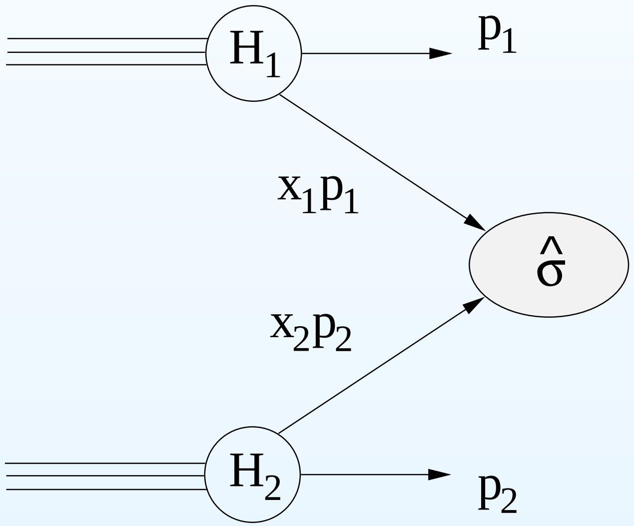
- Signal: $gg \to H \to W^- W^+ \to l\,\bar{\nu}_l\,\bar{l}'\,\nu_{l'}$, $140\ \mathrm{GeV} < M_H < 180\ \mathrm{GeV}$
- Basic cuts:
  - Cuts selecting dileptons events from vector boson decays
  - Cuts suppressing single Z production
  - Jet veto
- W-signal related cuts:
  - Transverse opening angle cut (spin angle correlation)
  - Polar angle cut (background is boosted)
- $5\sigma - 10\sigma$ detection with $5\ \mathrm{fb}^{-1}$

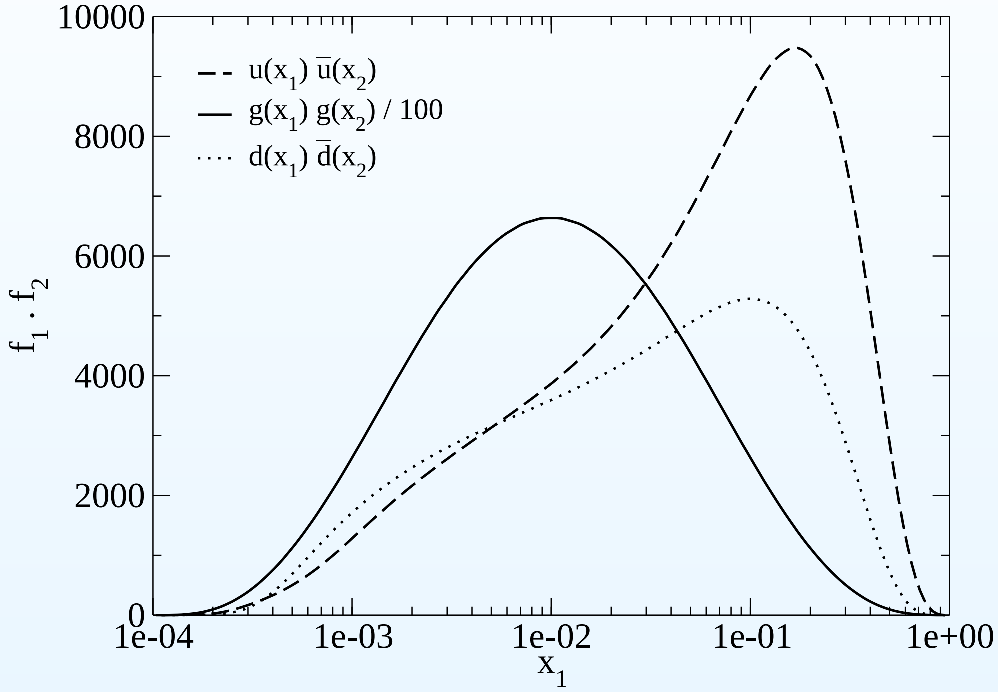
Spin angle correlation (C. Nelson; E. W. N. Glover, J. Ohnemus, Scott S. D. Willenbrock)

- H is a scalar $\Rightarrow W^\pm$ helicities related
- $W^\pm$ decay leptons are related to vector boson helicity
- Signal $\Rightarrow$ small lepton opening angle

Search strategy

Background boost





- Hadron cross section:

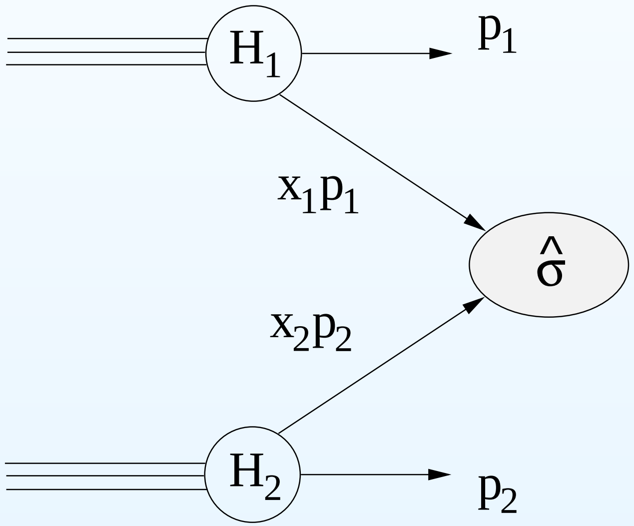
$$\sigma = \int dx_1 \, dx_2 \, f_1(x_1) \, f_2(x_2) \, \hat{\sigma}(x_1, x_2)$$

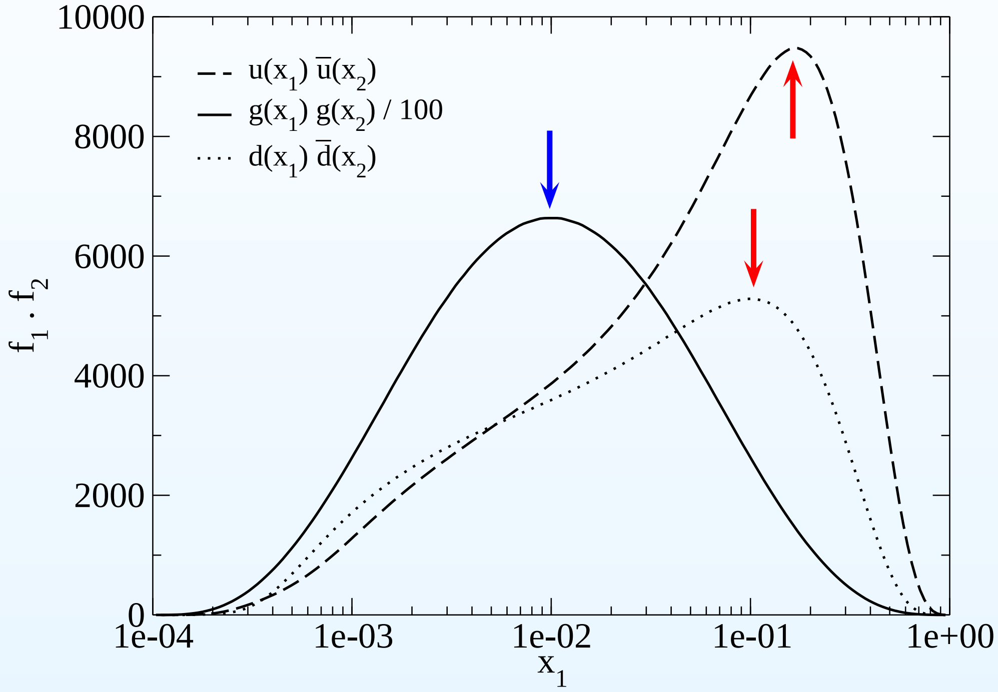
- PDFs product:

$$x_1 x_2 \sim \frac{M_{WW}^2}{s} \sim \frac{M_H^2}{s} \, , \quad v = \frac{|x_1 - x_2|}{x_1 + x_2}$$

Search strategy

Background boost





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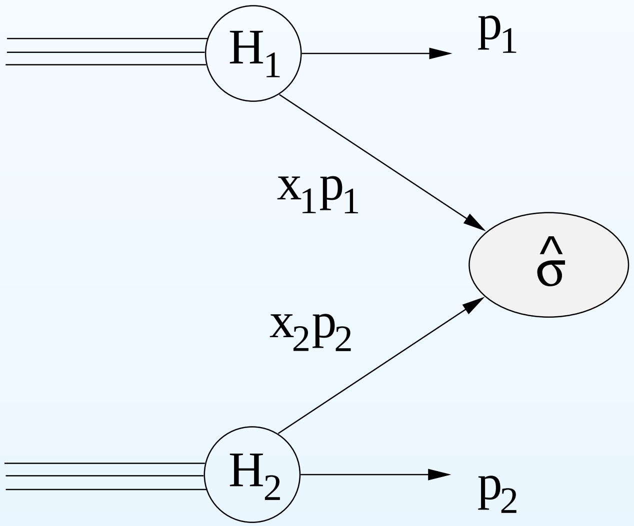

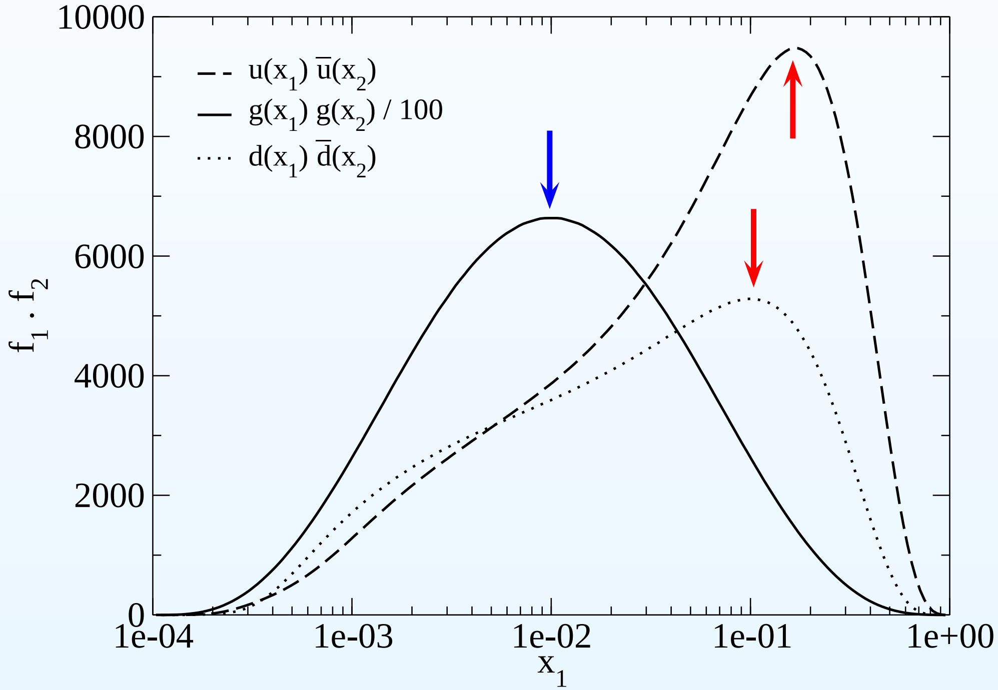

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- $$v_{gg} \simeq 0$$
  $$v_{qq} \simeq 0.98$$

$gg \to WW$ contribution

Different analyses

- M. Dittmar and H. K. Dreiner (1996-1997)
- K. Jakobs and T. Trefzger (2000)
- D. Green, *et al.* (2000)
- G. Davatz, G. Dissertori, M. Dittmar, M. Grazzini and F. Paus (2004)

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$gg \to WW$ motivation

- Is this contribution important?
  - Contribution $\sim \alpha_s^2$
  - However:
    - High gluon luminosity at the LHC
    - Experimental cuts effects (cf. polar angle cut)
- High precision needed for
  - SM Higgs search
  - SM non-abelian structure testing
  - New physics probes

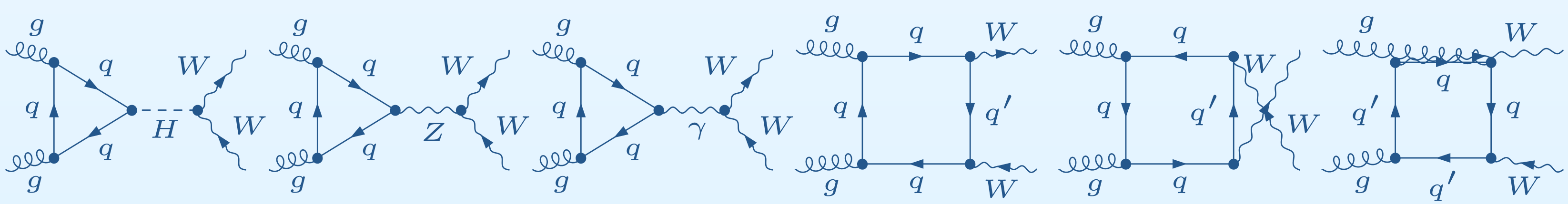
Calculation details

- Offshell W-bosons
- Internal fermions massless, except b and t
- External fermions massless

Amplitude structure

$$
\begin{aligned}
\mathcal{M} &= \mathcal{M}^{\mu_1\mu_2\mu_3\mu_4}\,\varepsilon_{1,\mu_1}\varepsilon_{2,\mu_2}P_{\mu_3\nu_3}(p_3,M_W)P_{\mu_4\nu_4}(p_4,M_W)J_3^{\nu_3}J_4^{\nu_4}\\
J_3^{\mu_3} &= \bar{u}(p_6)\gamma^{\mu_3}\,\tfrac{1}{2}(1-\gamma_5)v(p_5)\\
J_4^{\mu_4} &= \bar{u}(p_8)\gamma^{\mu_4}\,\tfrac{1}{2}(1-\gamma_5)v(p_7)\\
P^{\mu\nu}(p,M_W) &= \frac{g^{\mu\nu}}{p^2-M_W^2+i\,M_W\Gamma_W}
\end{aligned}
$$

Feynman Diagrams



Calculation details

$$\mathcal{M}^{\mu_1\mu_2\mu_3\mu_4} = \sum_{j,k} \mathcal{T}_j^{\mu_1\mu_2\mu_3\mu_4}\,\mathcal{I}_k\,\mathcal{C}_{jk}$$

$$\mathcal{T}_j^{\mu_1\mu_2\mu_3\mu_4} \longrightarrow \text{Tensor Structures}$$

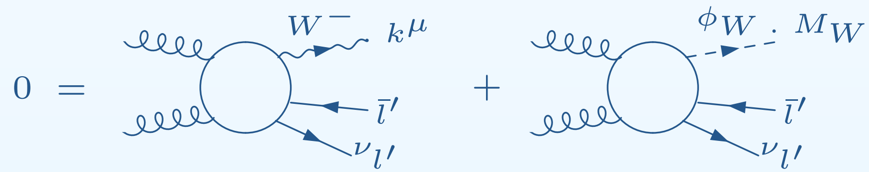
$$\mathcal{I}_k \longrightarrow \text{Scalar Integrals}$$

$$\mathcal{C}_{jk} \longrightarrow \mathcal{C}_{jk}(\hat{s}, \hat{t}_{ij}, \hat{u}, w_1^2, w_2^2)$$

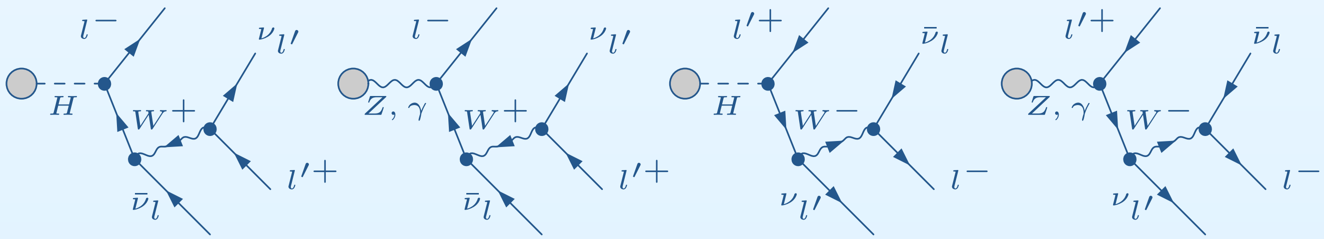
- Expressions manipulation and simplification: MAPLE and FORM.
- Tensor integral reduction: Binoth et al. and Passarino, Veltman.
- Gram determinants
- MAPLE $\longrightarrow$ FORTRAN
- Two indepent calculations compared symbolically and numerically

Calculation Details

- Dimensional Regularization (BM formalism)
  - UV-finite
  - IR-safe
- Gauge invariance
  - Ward Identity



  - Single-resonant contributions



Numerical Evaluation

- $gg \to W^*W^*$ processes: FORTRAN implementation, using VEGAS / DVEGAS
- Parameters:
  - $$\begin{array}{llll} M_W & = 80.419 \text{ GeV} & M_Z & = 91.188 \text{ GeV} \\ \Gamma_W & = 2.06 \text{ GeV} & \Gamma_Z & = 2.49 \text{ GeV} \\ G_\mu & = 1.16639 \times 10^{-5} \text{ GeV}^{-2} & V_{\text{CKM}} & = \mathbb{1} \end{array}$$
  - G_μ-scheme
  - PDFs: CTEQ6
  - QCD scales
    - Central: $\Lambda_{\text{fact}} = \mu_{\text{ren}} = M_W$
    - Variations: independent in $\left[\frac{M_W}{2}, 2M_W\right]$
- Reproduce onshell results (J. J. van der Bij, E. W. N. Glover)
- $q\bar{q} \to W^*W^*$ processes: evaluated at LO and NLO with MCFM

Results

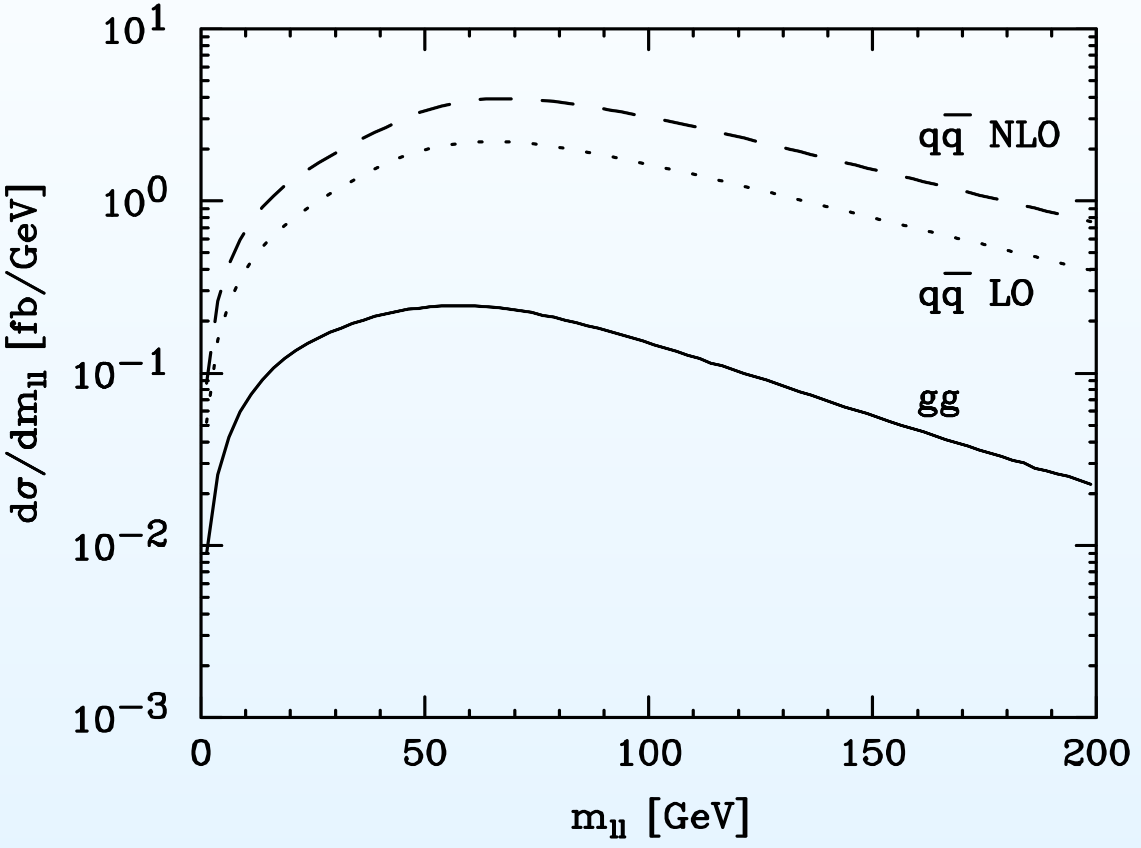
	gg	$q\bar{q}$ LO	$q\bar{q}$ NLO	$\frac{\sigma_{\rm NLO}}{\sigma_{\rm LO}}$	$\frac{\sigma_{\rm NLO+gg}}{\sigma_{\rm NLO}}$
	$\sigma(pp \to W^*W^* \to \ell\bar{\nu}\bar{\ell}'\nu')$ [fb]				
σ_{tot}	$53.61(2)^{+14.0}_{-10.8}$	$875.8(1)^{+54.9}_{-67.5}$	$1373(1)^{+71}_{-79}$	1.57	1.04
σ_{std}	$25.89(1)^{+6.85}_{-5.29}$	$270.5(1)^{+20.0}_{-23.8}$	$491.8(1)^{+27.5}_{-32.7}$	1.82	1.05
σ_{bkg}	$1.385(1)^{+0.40}_{-0.31}$	$4.583(2)^{+0.42}_{-0.48}$	$4.79(3)^{+0.01}_{-0.13}$	1.05	1.29

Phase space cuts

- No Cuts (σ_{tot})
- Standard LHC cuts (σ_{std})
  - $20\ {\rm GeV} < p_{T,\ell}$
  - $|\eta_\ell| < 2.5$
  - $25\ {\rm GeV} < \not{p}_T$
- Higgs search cuts (σ_{bkg}) †
  - $\Delta\phi_{T,\ell\ell} < 45°$
  - $M_{\ell\ell} < 35$ GeV
  - 25 GeV $< p_{T,\min}$ and 35 GeV $< p_{T,\max} < 50$ GeV
  - $20\ {\rm GeV} < p_{T\,\rm jet}$ and $|\eta_{\rm jet}| < 3$

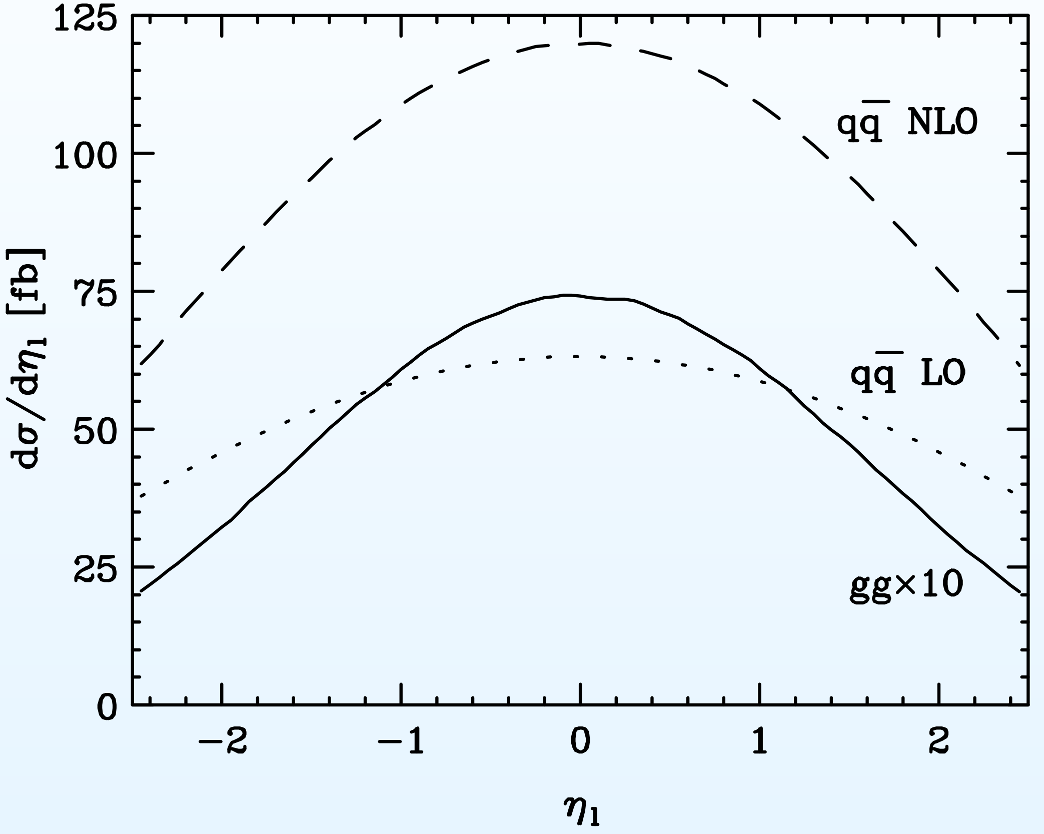
† (M. Dittmar, H. Dreiner, G. Davatz, G. Dissertori, M. Grazzini, F. Pauss)

Results: m_{ll}

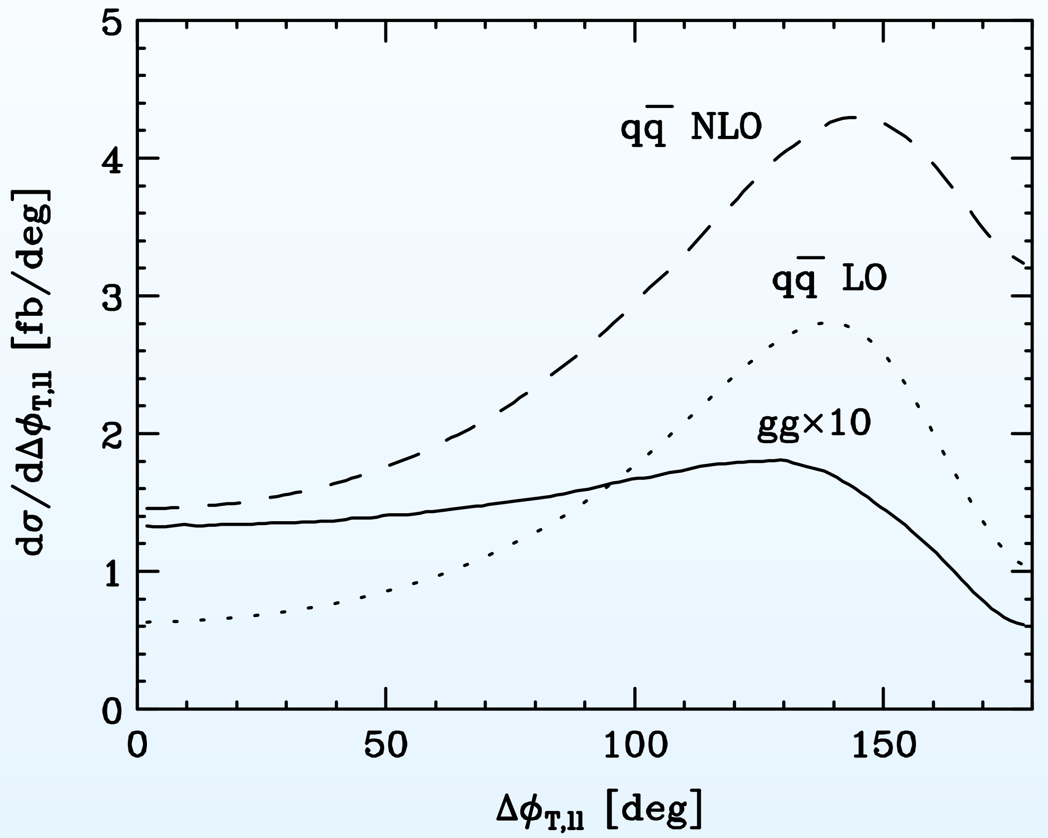


10^1
10^0
10^-1
10^-2
10^-3
dσ/dm_ll [fb/GeV]
qq̄ NLO
qq̄ LO
gg
0
50
100
150
200
m_ll [GeV]

Results: η_{l^-}



Results: $\Delta\phi_{ll}$



`gg2WW` *code*

- $gg \rightarrow W^-W^+ \rightarrow l\bar{\nu}_l\,\bar{l}'\nu_{l'}$
- Features:
  - Full spin decay angle correlation and offshell effects
  - Adaptive MC with DVEGAS
  - Easily modified cuts specification and histogram generation
  - Parallel processing
  - Amplitude in double or quadruple precision
  - LHAPDF
  - Event generation in LHA format
- Contact persons:
  - M. C. (`Mariano.Ciccolini@psi.ch`)
  - N. Kauer (`kauer@physik.rwth-aachen.de`)
- Official Distribution at

`http://prdownloads.sourceforge.net/hepsource/gg2WW-1.0.0.tar.gz?download`

Latest Analyses

Using gg2WW

- G. Davatz et al. (CMS)
  - $200\,000$ unweighted events
  - Showering with Pythia 6.2 with and without ISR
- B. Quayle et al. (Atlas)
  - Inclusion of $gg \to WW$ effects into $WW + 0j$ analysis
  - Herwig for showering/hadronization
  - Control sample contribution 5%
  - Signal-like region 13%
  - Different cuts
    - $\Delta\phi_{ll} < 1.5$
    - $20 \text{ GeV} < M_{ll} < 64 \text{ GeV}$

Independent Result

- M. Dührssen, K. Jakobs, J. J. van der Bij, P. Marquard

Conclusions

- $gg \to H \to W^-W^+ \to l\,\bar{\nu}_l\,\bar{l}'\,\nu_{l'}$ important Higgs search channel
- W-boson pair production: main background
- Gluon induced offshell W-boson pair production calculation
- $gg \to W^-W^+$ contribution:
  - No cuts: 5%
  - Higgs selection cuts: 30%
- Gluon induced contribution must be taken into account.
- `gg2WW` code
- Future Work
  - Massive b and t loops
  - Incorporate modifications into `gg2WW` code
  - Implement the ZZ mediated process into `gg2WW` (`gg2VV`?)