Supersymmetric Higgs Production via Vector-Boson Fusion

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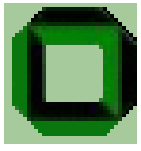

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(in collaboration with W. Hollik, T. Plehn, H. Rzehak)

Supersymmetry

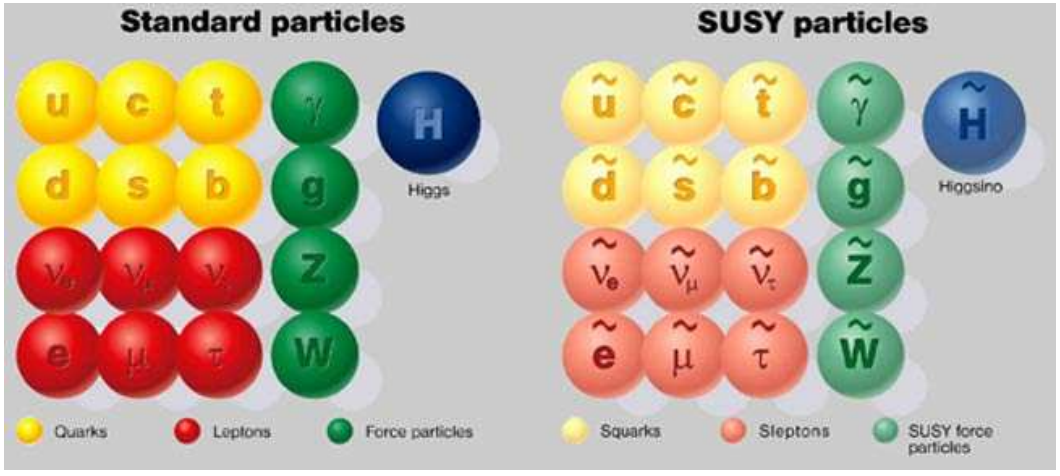
Symmetry between bosons and fermions:

$$Q\,|\text{boson}\rangle = |\text{fermion}\rangle\,; \qquad Q\,|\text{fermion}\rangle = |\text{boson}\rangle$$

Q: Supersymmetry Operator

Simplest model:
Minimal Supersymmetric Standard Model (MSSM)

- Supersymmetric partner to each Standard Model particle
- Two Higgs doublets $\Rightarrow$ 5 Higgs bosons (h^0,H^0,A^0,$H^\pm$)
- Particles with same quantum numbers mix
  (e.g. Zino, Photino, 2 Higgsino $\rightarrow$ 4 Neutralino)



MSSM Higgs Sector

Two Higgs doublets:

$$H_1 = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}\left(\phi_1^0 - i\chi_1^0\right) \\ -\phi_1^- \end{pmatrix}_{(Y=-1)}, \quad H_2 = \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}\left(\phi_2^0 + i\chi_2^0\right) \end{pmatrix}_{(Y=+1)}$$

Physical spectrum:

h^0, H^0: light and heavy CP-even neutral Higgs boson

A^0: CP-odd neutral Higgs boson

$H^\pm$: charged Higgs boson

Two free parameters:

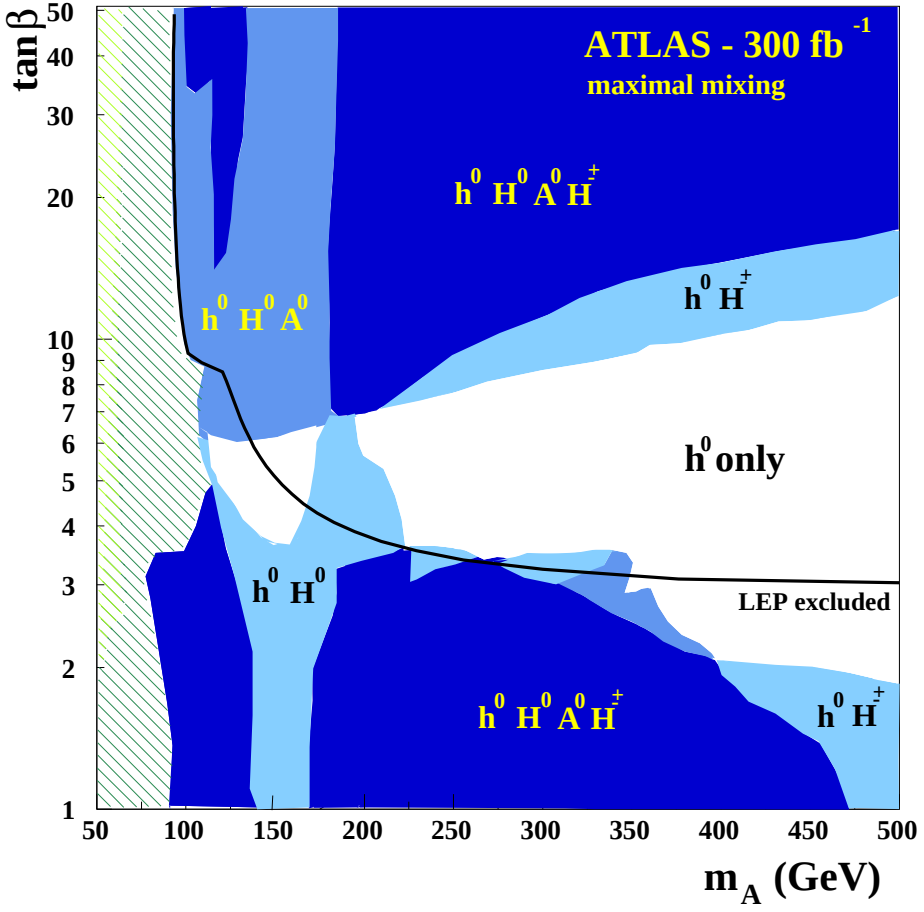
m_A: mass of the CP-odd Higgs boson

$\tan(\beta) = \frac{v_2}{v_1}$: ratio of the Higgs vevs

Prediction: $m_{h^0} \lesssim 140$ GeV

LHC Higgs Discovery Potential

[Atlas TDR 1999]



Significant region where only one Higgs boson can be found

Which model if $m_H \lesssim 140$ GeV and coupling SM-like?

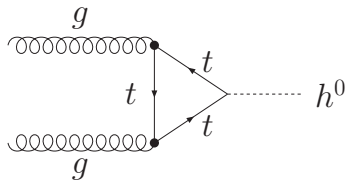
Can we distinguish SM from MSSM in the Higgs sector by other means?

$\Rightarrow$ Loop corrections to Higgs production processes

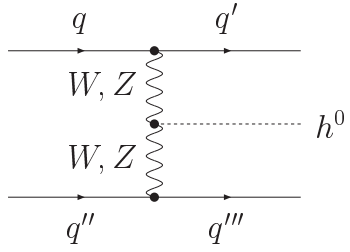
Production Modes

Main (MSSM-)Higgs-boson production modes:

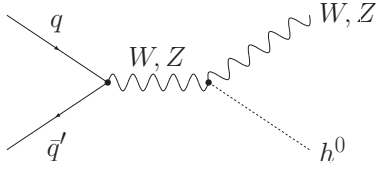
- Gluon-Gluon Fusion



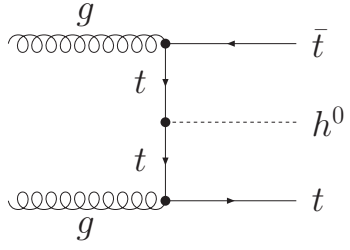
- Vector-Boson Fusion

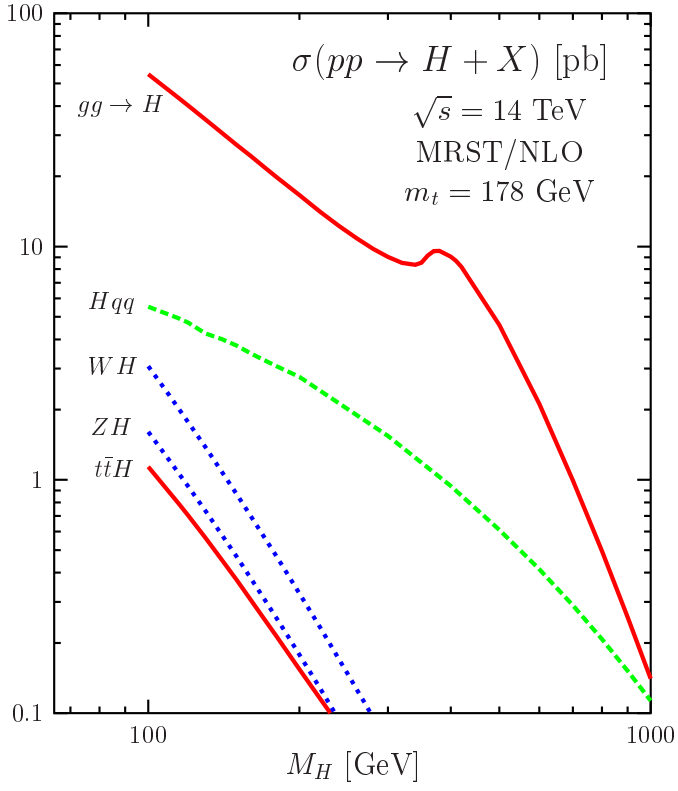


- Associated Production with a Gauge Boson



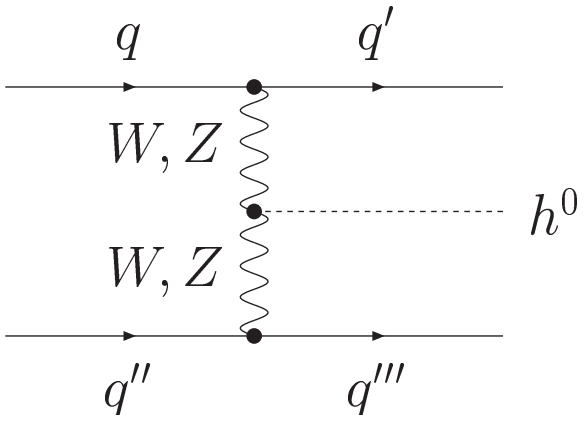
- Associated Production with Top-Quark–Antiquark Pair

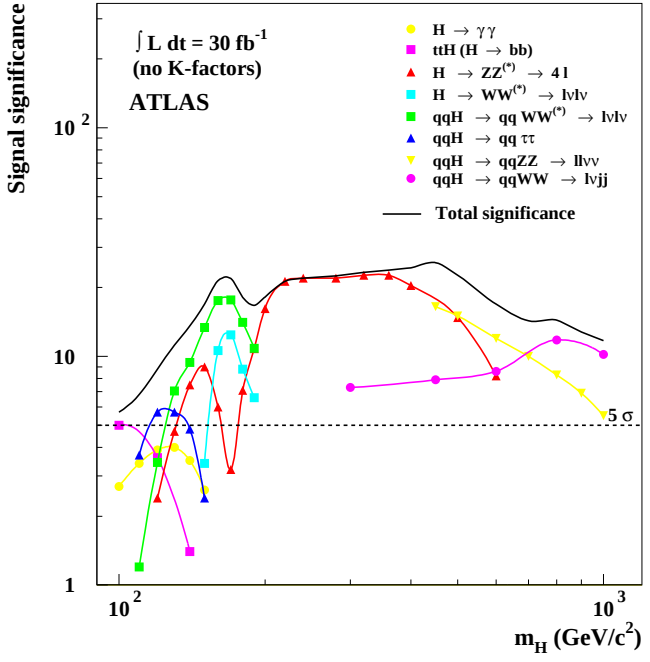




Higgs Production via Vector Boson Fusion

- Second-largest production cross section of Higgs bosons at the LHC (after gluon-gluon fusion)
- Distinct kinematic properties:
  - 2 jets in forward regions of the detector
  - Reduced jet activity in central region
  - central Higgs boson
- Most promising channel for early discovery of the Higgs with $h^0 \longrightarrow \tau^+\tau^-$ decay
- SM-NLO corrections completely known:
  $\mathcal{O}(\alpha_s) \sim 5 - 10\%$, $\mathcal{O}(\alpha) \sim 5\%$
  [Djouadi, Spira, Zerwas; Han, Valencia, Willenbrock]
  [Figy, Oleari, Zeppenfeld; Berger, Campbell]
  [Ciccolini, Denner, Dittmaier]
- Vector-boson-fusion–gluon-gluon interference
  [Andersen, Binoth, Heinrich, Smillie; Bredenstein, Hagiwara, Jäger]
  and gluon-induced contributions [Harlander, Vollinga, Weber] negligible

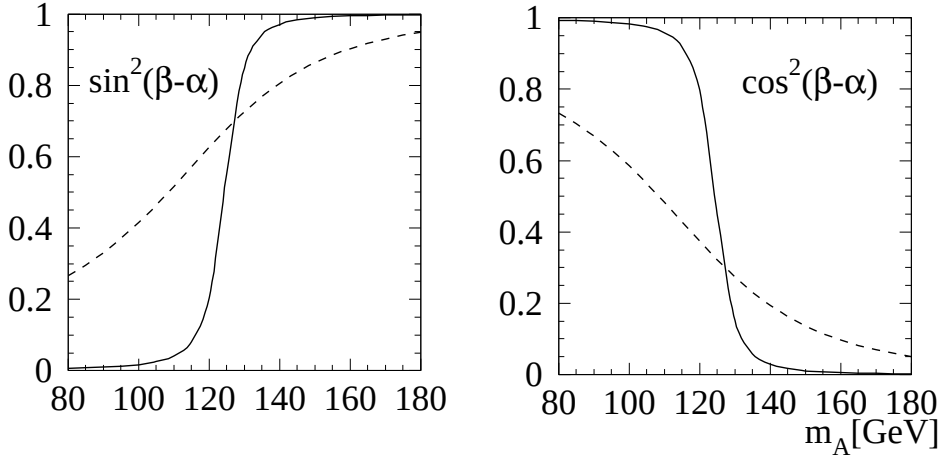




Corrected Tree-level Result

Conversion from the known SM result to the MSSM:

- Replace SM-Higgs boson with (SM-like) MSSM h^0-Boson
- Vector-Boson–Vector-Boson–Higgs coupling modified by
  $\Gamma^{MSSM}_{WWh^0,ZZh^0} = \Gamma^{SM}_{WWH,ZZH} \cdot \sin(\beta - \alpha)$
- Therefore change of total cross section as
  $\sigma^{MSSM} = \sigma^{SM} \cdot \sin(\beta - \alpha)^2$



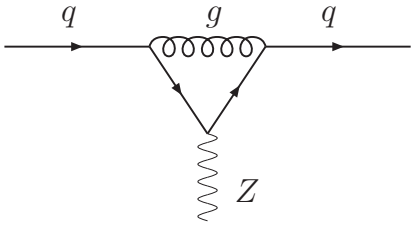
$$\tan\beta = \begin{cases} 4 & \text{dashed} \\ 30 & \text{solid} \end{cases}$$

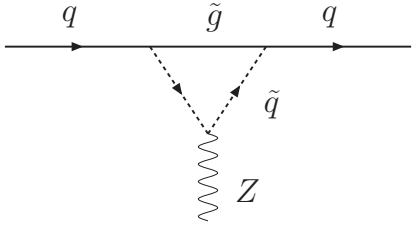
[Plehn, Rainwater, Zeppenfeld 1999]

- $\sin(\beta - \alpha)^2$ close to 1 for large parts of the parameter space
- $\Rightarrow$ Couplings of the h^0 SM-like
- Loop corrections induced by SUSY particles?
- Additional contributions to cross sections

Additional Loop Corrections

- SM is subsector of the full MSSM
- $\Rightarrow$ SM loop corrections form part of the full MSSM set
- R-parity conservation allows separation of SM and SUSY part at one-loop level

(loop consists either of SM 

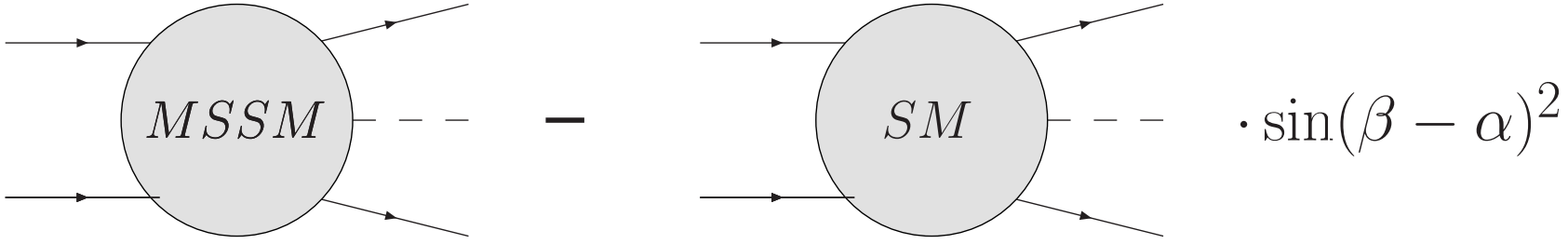
or SUSY 

particles)

- Not completely true in the Higgs sector:
  - MSSM is a (type-II) Two-Higgs doublet model (THDM)
  - Some THDM parameters fixed by SUSY relations
    (e.g. m_{h^0} not a free parameter any longer)
  - Renormalisation in the Higgs sector requires both SM and SUSY part so that divergencies cancel
    (depending on renormalization scheme)
- Split between SM and additional SUSY contribution more difficult

SUSY=MSSM-SM

- SM part (QCD and EW) already calculated
- Simple transfer to MSSM by $\sigma^{SM(MSSM)} = \sigma^{SM} \cdot \sin(\beta - \alpha)^2$
- In the end want one-loop corrections for complete MSSM
- $\Rightarrow$ Subtract SM part from MSSM to obtain additional SUSY contribution

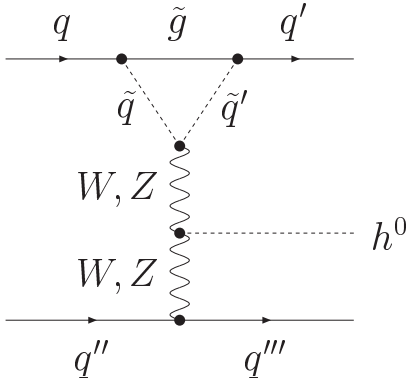


using $m_H^{SM} = m_{h^0}^{MSSM}$

- Subtraction performed on amplitude level
- Cross-check that for non-Higgs couplings this corresponds to just omitting the SM particles

Strong Corrections

Strong ($\mathcal{O}(\alpha_s)$) corrections:



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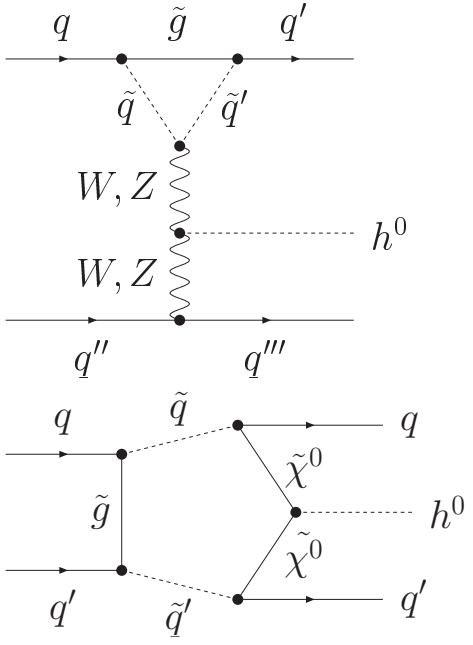

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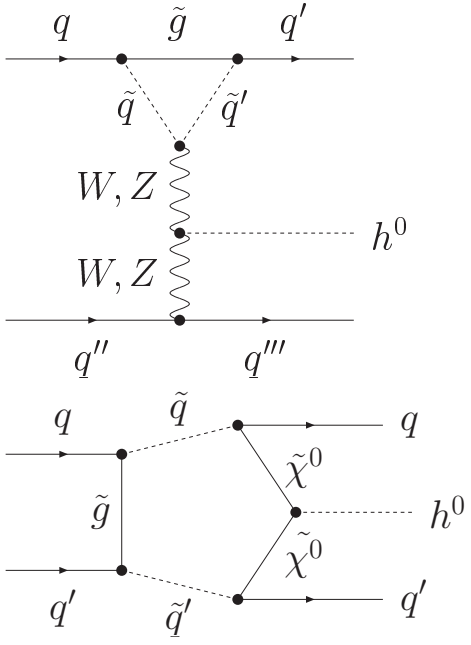

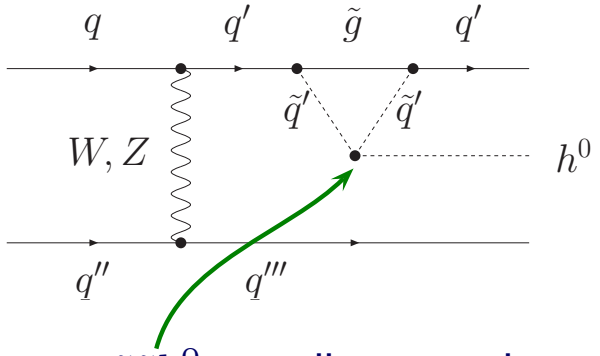

$\tilde{q}\tilde{q}h^0$-coupling contains gauge part (from D-terms)

$\Rightarrow$ Does not vanish even if neglecting Yukawa coupling

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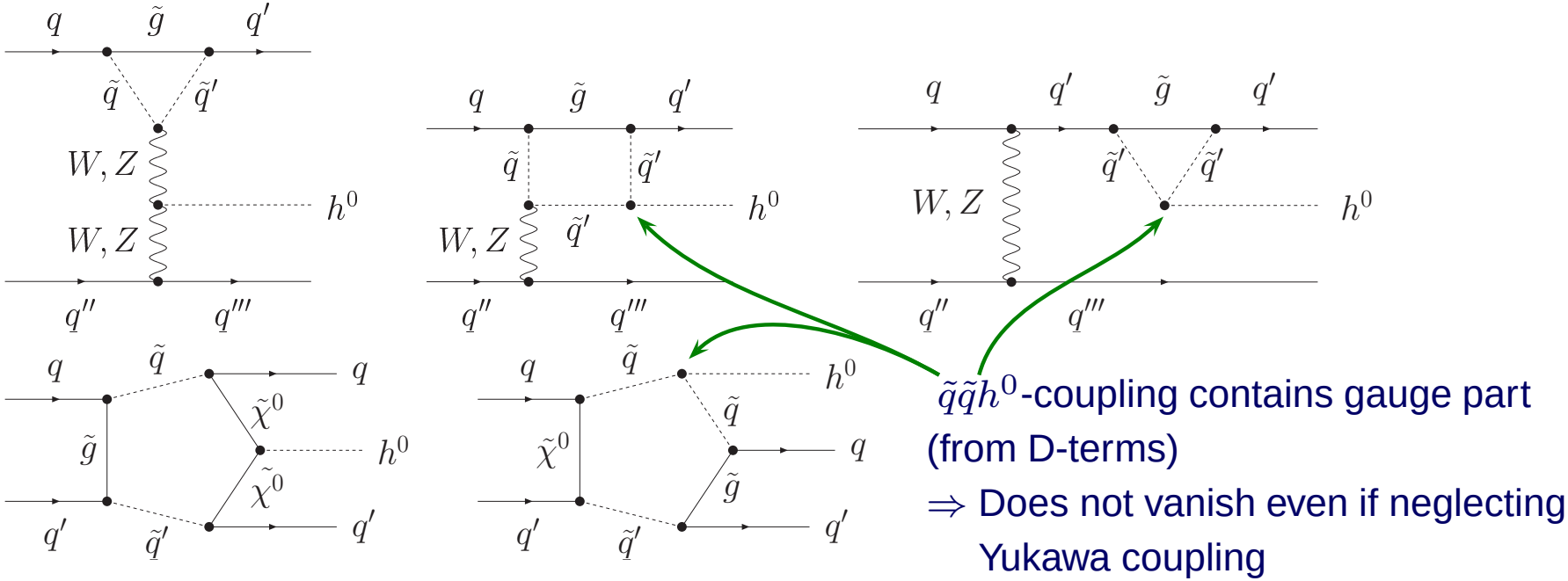

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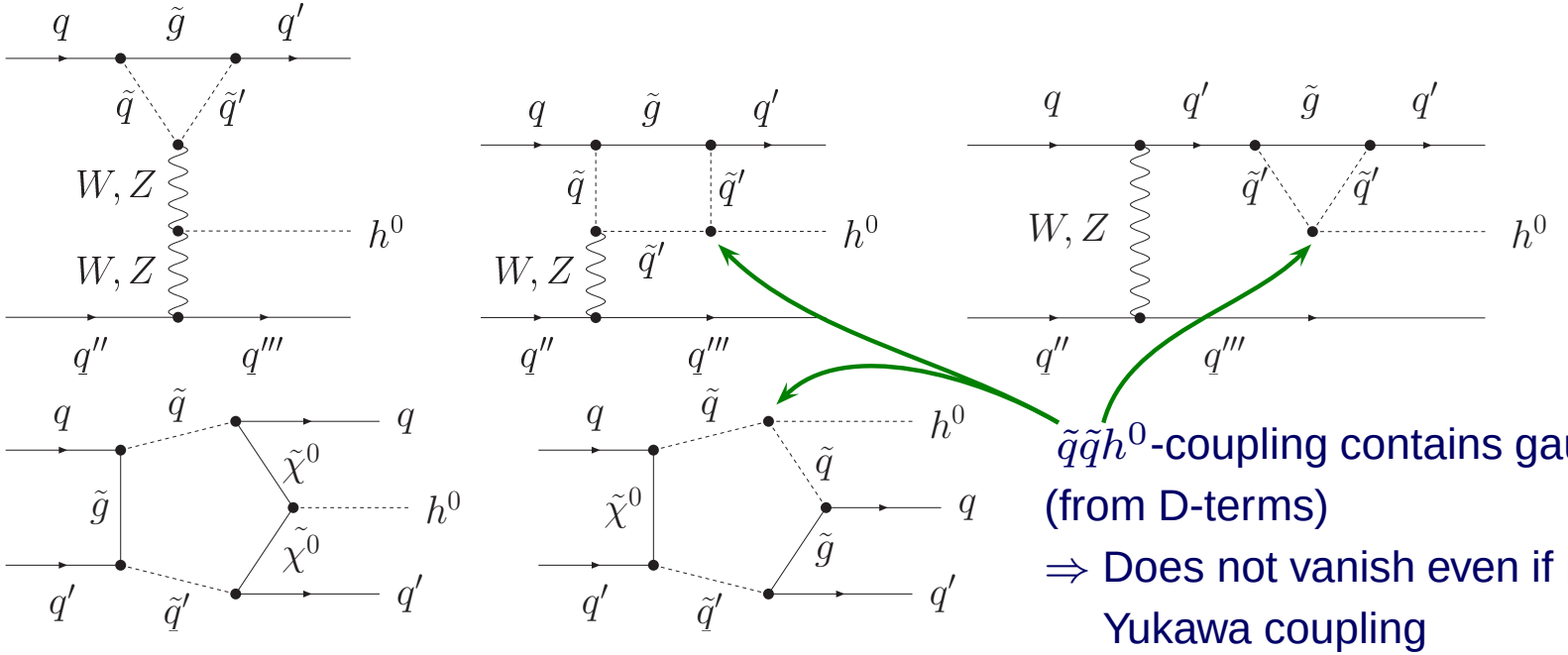

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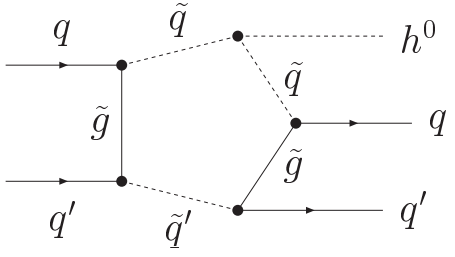
Additional possibility for pentagon diagrams:



$\propto \alpha_s^2 \alpha^2$

Using $\alpha_s^2 \sim \alpha$ same order as tree-level

However, not same kinematic structure as tree-level diagram

$\Rightarrow$ Greatly reduced by kinematic cuts

Suppressions

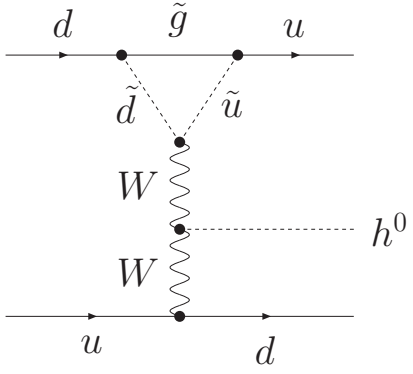
Size of the strong corrections (Parameter point SPA):

	$(\sigma^{\text{one-loop}} - \sigma^{\text{born}})/\sigma^{\text{born}}$	
Vertex corrections	$-1.2 \cdot 10^{-2}\%$	[Djouadi, Spira 2000]
effective qqh^0-Vertex	$4.9 \cdot 10^{-3}\%$	
Box diagrams	$-4.7 \cdot 10^{-3}\%$	
LO Pentagon diagrams	$-1.7 \cdot 10^{-4}\%$	
$\mathcal{O}(\alpha_s)$ Pentagon diagrams	$1.9 \cdot 10^{-5}\%$	
total SUSY-QCD corrections	$-1.2 \cdot 10^{-2}\%$	

$\Rightarrow$ Large suppressions

Why are the corrections so small:

Vertex Corrections:



- W-coupling purely left-handed
- Quarks approximately massless
- $\Rightarrow$ Trace over fermion line cannot yield $m_{\tilde{g}}$, only kinematic term $\sim m_{h^0}/2$.

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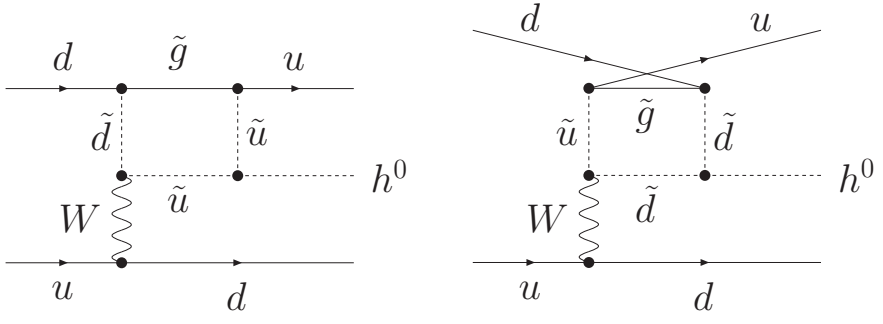


$\Gamma_{\tilde{u}^\dagger \tilde{u} h^0} \sim -\Gamma_{\tilde{d}^\dagger \tilde{d} h^0}$

$\Gamma_{\tilde{u}^\dagger \tilde{d} W^+} = \Gamma_{\tilde{d}^\dagger \tilde{u} W^-}$

$\Gamma_{\bar{u} d W^+} = \Gamma_{\bar{d} u W^-}$

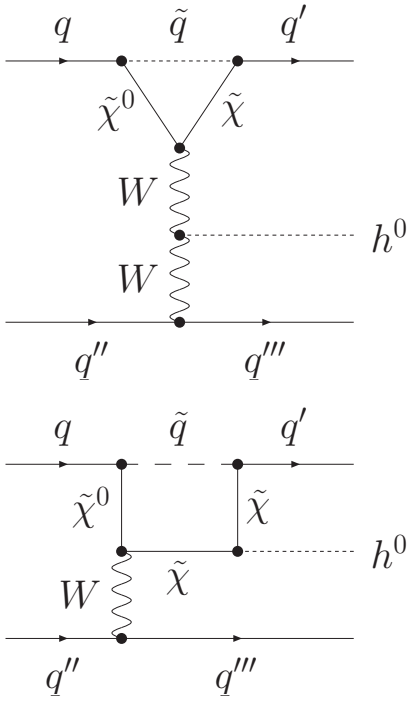
$\Rightarrow$ Contributions cancel

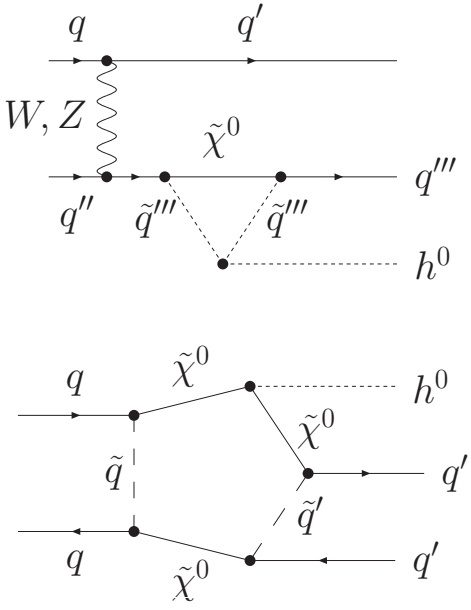
(up to differences between $\tilde{u}$- and $\tilde{d}$ masses, which are small in common SUSY-breaking scenarios).

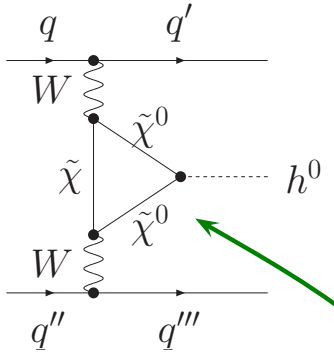
Electro-weak Corrections

Electro-weak ($\mathcal{O}(\alpha)$) corrections:

Any strong diagram with replacement $\tilde{g} \to \tilde{\chi^0}$ $+$







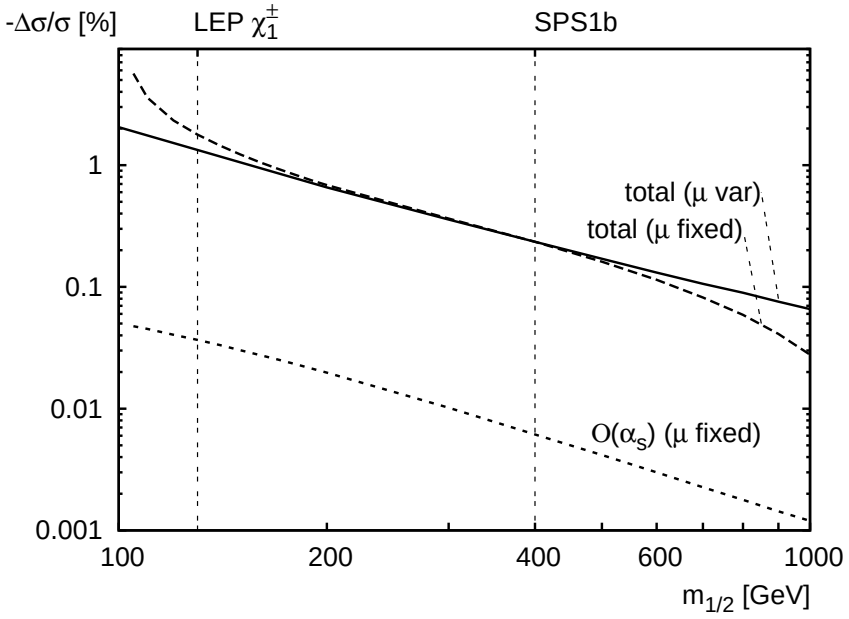
Also corrections to VVh vertex appear

$\Rightarrow$ Additional diagrams lead to more natural size of corrections

Numerical Results

Size of the supersymmetric corrections:

(SPS: Set of reference points
which probe “typical” parts of the
supersymmetric parameter space)



	$\Delta\sigma/\sigma$ [%]			
	WWh $+ZZh$	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha_s)$	all
SPS1a	-0.329	-0.469	-0.015	-0.484
SPS1b	-0.162	-0.229	-0.006	-0.235
SPS2	-0.147	0.129	-0.002	-0.131
SPS3	-0.146	-0.216	-0.006	-0.222
SPS4	-0.258	-0.355	-0.008	-0.363
SPS5	-0.606	-0.912	-0.010	-0.922
SPS6	-0.226	-0.309	-0.010	-0.319
SPS7	-0.206	-0.317	-0.006	-0.323
SPS8	-0.157	-0.206	-0.004	-0.210
SPS9	-0.094	-0.071	-0.003	-0.074

$\Rightarrow$ Typical corrections at or below 1%

$\Rightarrow$ Can reach up to 4% for parameter points still allowed

$\Rightarrow$ Need to be considered for a precision analysis of the Higgs sector

Conclusions

- Higgs-boson production via Vector Boson Fusion important discovery mode for the Higgs boson and to study electroweak symmetry breaking

- Supersymmetric diagrams can lead to additional effects beyond simple tree-level factor $\sin(\beta - \alpha)^2$

- Supersymmetric QCD corrections strongly suppressed

- Supersymmetric electro-weak corrections modify cross section on the percent level