MSSM Higgs Boson Production via Weak Boson Fusion

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in coll. with:

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based on:

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Outline

- Weak boson fusion:

  Standard Model (SM)

  vs

  Minimal Supersymmetric Standard Model (MSSM)

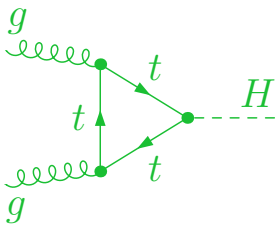
- Corrections from the Higgs sector

- SUSY contributions: Results

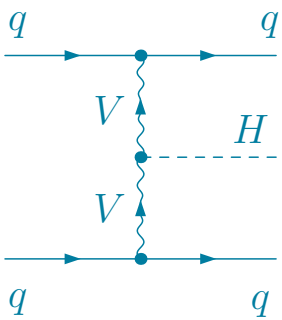
Higgs Production in the Standard Model

Different production channels:

- Gluon fusion:

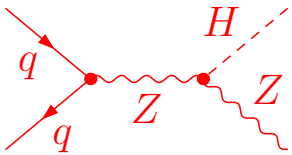


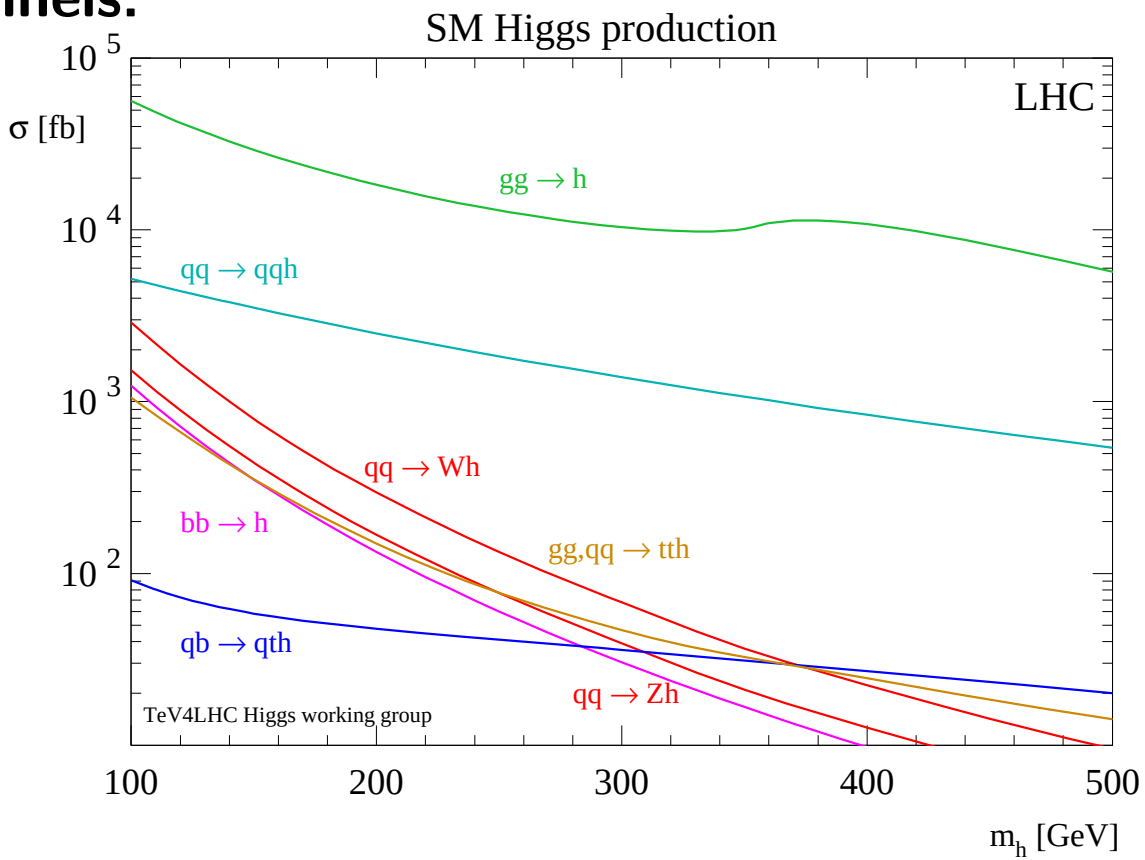
- Weak boson fusion:



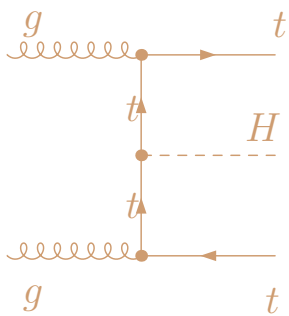
clear exp. signature (two jets in forward region)

- Associated production with a gauge boson



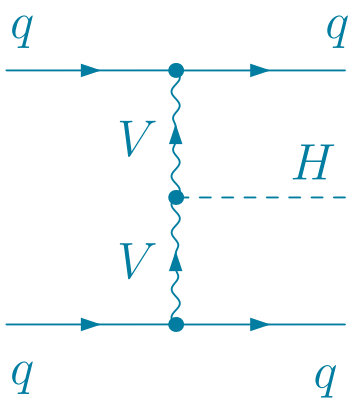


- Associated production with a heavy top-antitop pair

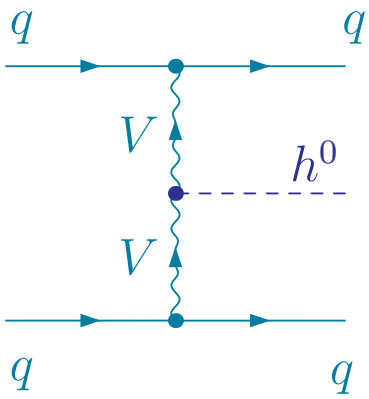


Weak Boson Fusion at the Born Level

Standard Model (SM):



MSSM:



$V = \{W, Z\}$

$\text{coupling}_{VVH} \sin(\beta - \alpha) = \text{coupling}_{VVh^0}$

$\Rightarrow \quad \sigma_{\text{SM}} \sin^2(\beta - \alpha) = \sigma_{\text{MSSM}}$

$\alpha =$ mixing angle of CP-even MSSM Higgs bosons

$\tan\beta =$ ratio of MSSM Higgs vacuum expect. values

$\sigma =$ cross section

For large parts of the parameter space:

$$\sin(\beta - \alpha) \approx 1$$

$\Rightarrow$ Difference between SM and MSSM?

Consider: NLO contributions

Weak Boson Fusion at Higher Orders

Known contributions:

Standard Model:

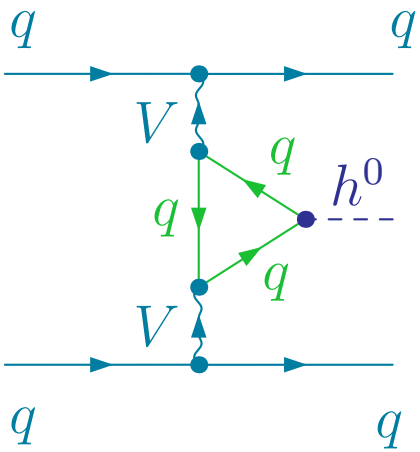
- NLO QCD corrections [Han, Valencia, Willenbrock; Spira; Figy, Oleari, Zeppenfeld; Berger, Campbell]
- NLO QCD and NLO electroweak corrections [Ciccolini, Denner, Dittmaier]
- Estimate of the size of the NNLO QCD corrections [Harlander, Vollinga, Weber]
- Interference effects of gluon and weak boson fusion are negligible [Andersen, Binoth, Heinrich, Smillie; Bredenstein, Hagiwara, Jäger]

MSSM:

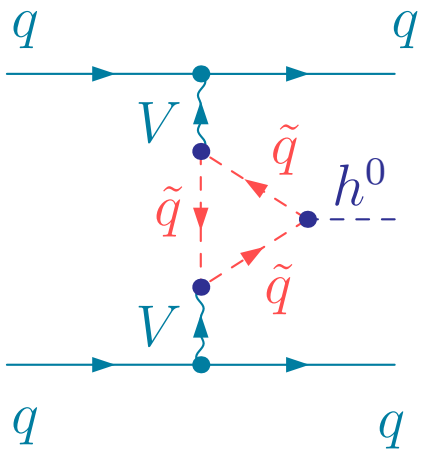
- NLO SUSY QCD vertex corrections with degenerate squark masses [Djouadi, Spira]
- Complete NLO SUSY contributions [Hollik, Plehn, Rauch, H.R.]

NLO Corrections in the MSSM

Standard Model like:



SUSY like:



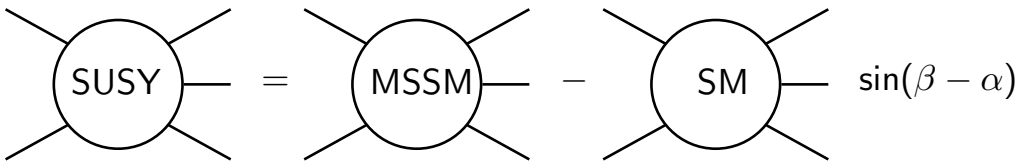
In the loop: either **Standard Model** or **SUSY** type particles (R-parity)

Standard Model NLO contributions known

$\Rightarrow$ only calculate SUSY contributions

Problem: MSSM Higgs sector differs from the Standard Model one

Solution: Generate MSSM and Standard Model amplitude and subtract:



Corrections with Origin in the Higgs Sector

At Born level: Mass of the lightest Higgs boson: $M_{h^0} \leq M_z \approx 91$ GeV
With quantum corrections: $M_{h^0} \lesssim 135$ GeV

$\Rightarrow$ Large quantum corrections to the Higgs mass
$\Rightarrow$ have to be taken into account (large kinematical effect)

Also: Higgs couplings get corrections:

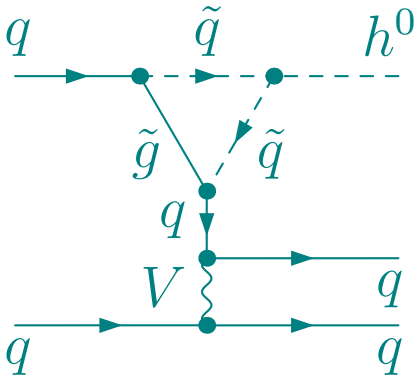
- finite momentum effects $\longrightarrow$ Feynman diagrams: `FeynHiggs` [Hahn, Heinemeyer,Hollik, H.R., Weiglein]
- self consistent couplings $\longrightarrow$ effective potential: `SubH` [Carena, Espinosa, Quiros, Wagner]

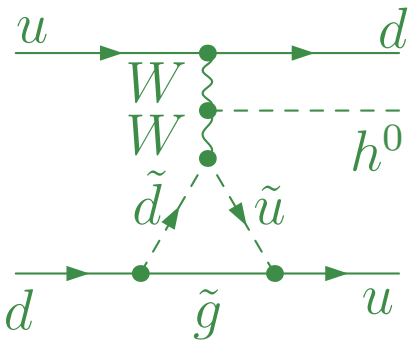
small corrections, small uncertainty

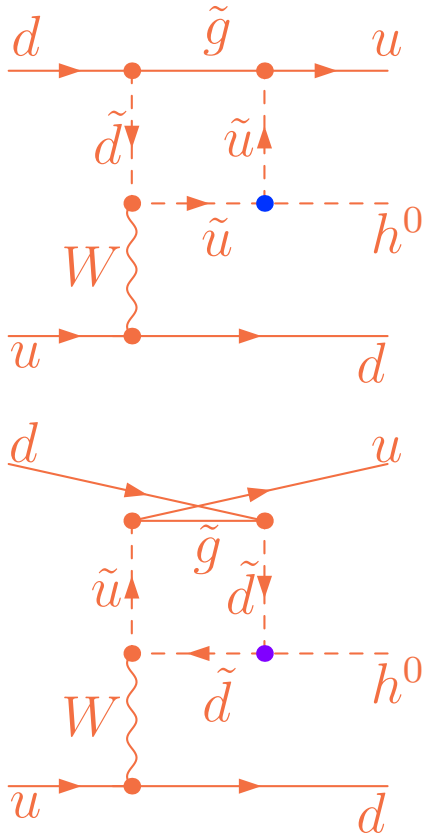
	$\Delta\sigma/\sigma(ud \to udh)$	$(\sigma_{\alpha_{\text{eff}}} - \sigma_{\text{full}})/\sigma$
effective theory		
α_{eff}	-0.389 %	-0.122 %
full	-0.266 %	
Feynman diagrams		
α_{eff}	-0.393 %	-0.076 %
full	-0.317 %	
Feynman diagrams, loop-improved Z_{FH}		
α_{eff}	-0.343 %	-0.115 %
full	-0.228 %	

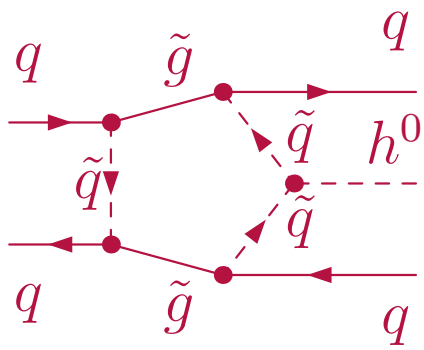
SPS1a

SUSY-Corrections: SUSY-QCD-Contributions







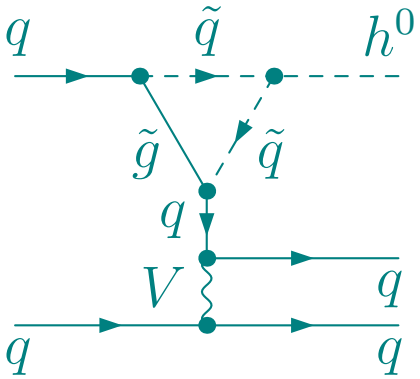


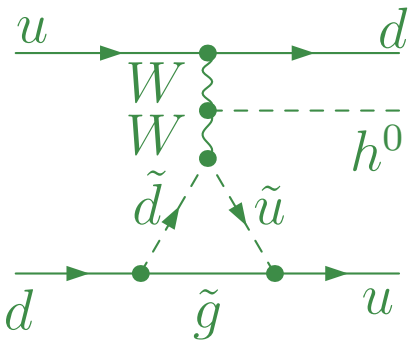
– W-coupling lefthanded
– Quarks approx. massless
$\Rightarrow$ no chirality flip
$\Rightarrow$ no gluino mass insertion
only terms $\sim \frac{M_{h^0}}{2}$

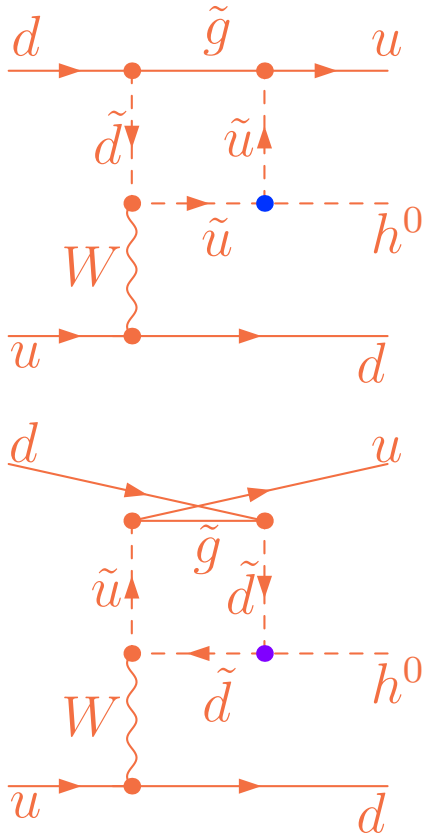
coupling$_{\tilde{u}\tilde{u}h^0}$
$\approx -$coupling$_{\tilde{d}\tilde{d}h^0}$
$\sim (T_3 - Qs_w)$
$\Rightarrow$ cancellations

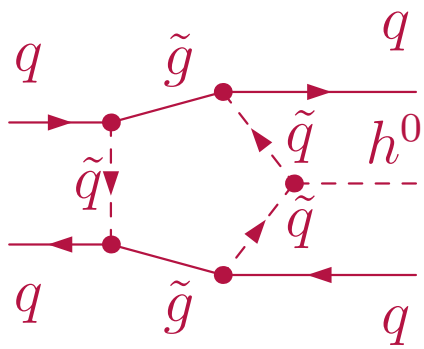
contribution of $\mathcal{O}(\alpha_s^2\alpha^2)$
with $\alpha_s^2 \approx \alpha$:
same order
as tree-level
BUT: different kinemat. structure, large loop masses

SUSY-Corrections: SUSY-QCD-Contributions









In total:
SUSY QCD
contributions
are tiny.

– W-coupling lefthanded
– Quarks approx. massless
⇒ no chirality flip
⇒ no gluino mass insertion
only terms $\sim \frac{M_{h^0}}{2}$

coupling$_{\tilde{u}\tilde{u}h^0}$
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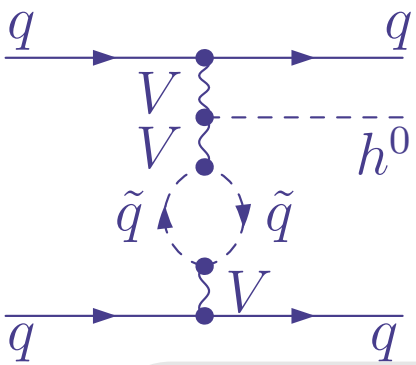
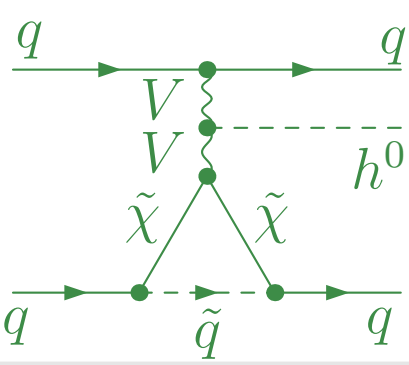
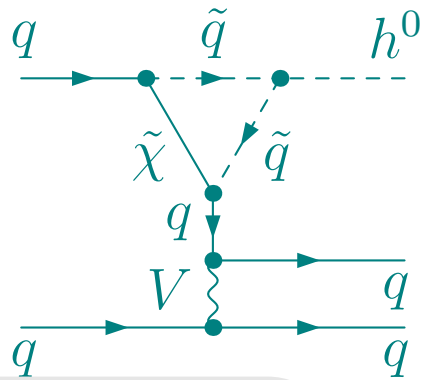
contribution of
$\mathcal{O}(\alpha_s^2\alpha^2)$
with $\alpha_s^2 \approx \alpha$:
same order
as tree-level
BUT: different
kinemat. structure,
large loop masses

SUSY-Corrections: Different Contributions







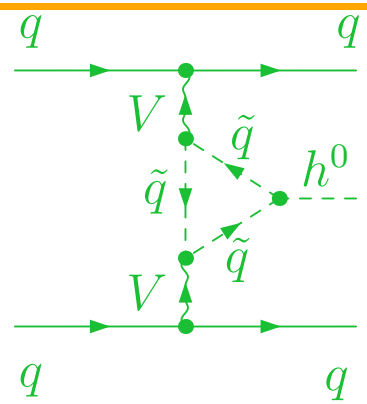
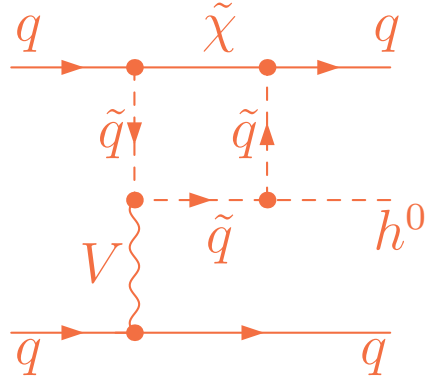
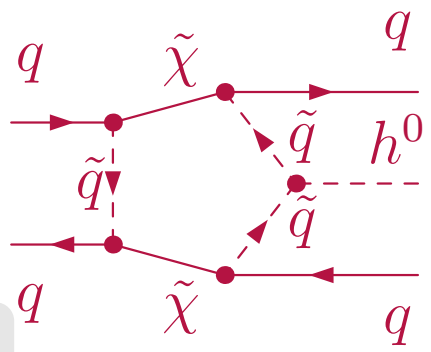


diagram	$\Delta\sigma/\sigma$ [%]	diagram	$\Delta\sigma/\sigma$ [%]
$\Delta\sigma \sim \mathcal{O}(\alpha)$		$\Delta\sigma \sim \mathcal{O}(\alpha_s)$	
self energies	0.199		
$qqW + qqZ$	-0.392	$qqW + qqZ$	-0.0148
qqh	-0.0260	qqh	0.00545
$WWh + ZZh$	-0.329		
box	0.0785	box	-0.00518
pentagon	0.000522	pentagon	-0.000308

sum of all $\Delta\sigma/\sigma = -0.484$ %





SPS1a

- SUSY-QCD corrections are tiny.
- SUSY-electroweak corrections are dominant.

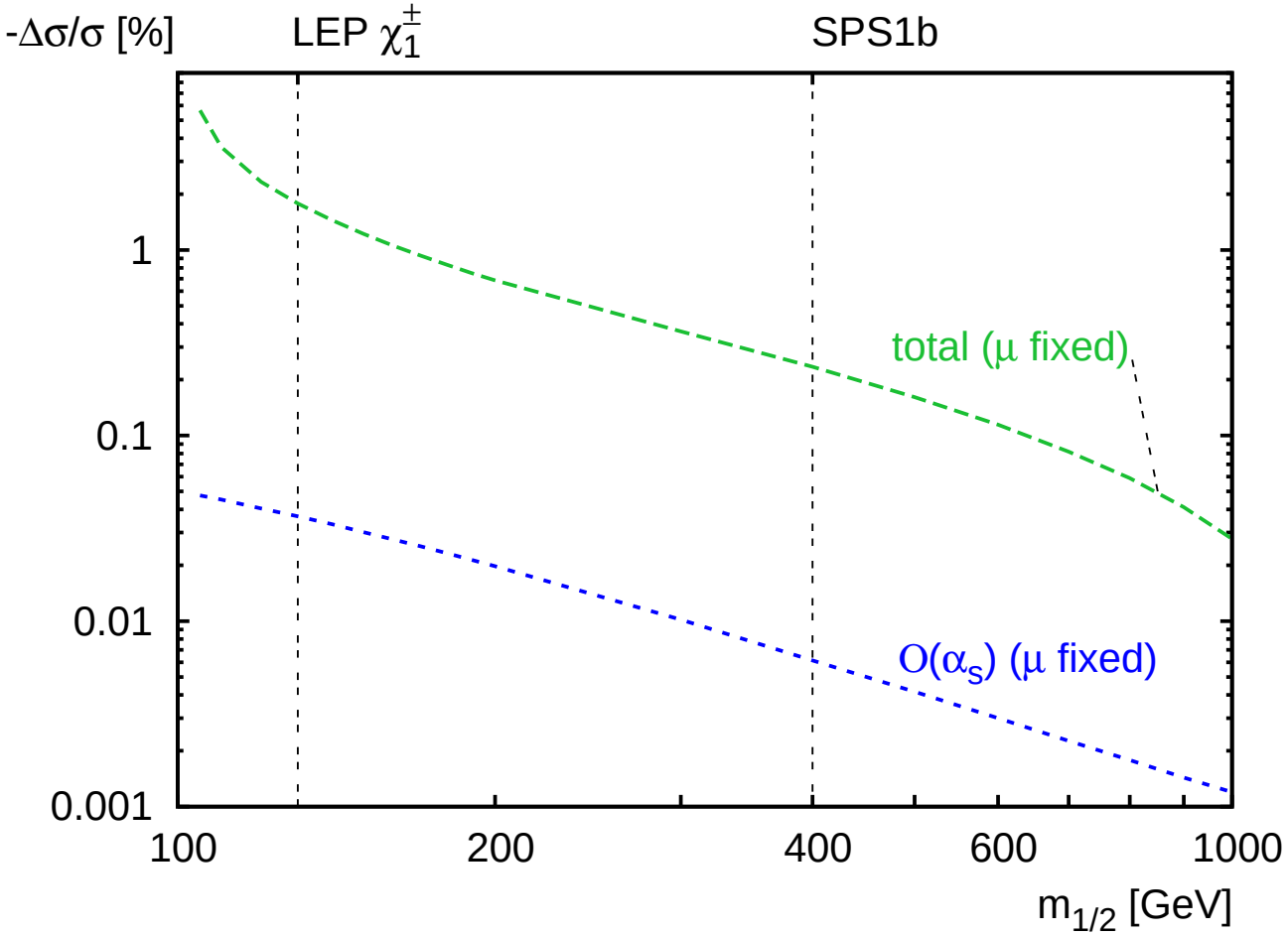
SUSY-Corrections: SPS Points

$(\sigma^{\text{one-loop}} - \sigma^{\text{BORN}})/\sigma^{\text{BORN}}$ [%]

	$WWh + ZZh$	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha_s)$	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

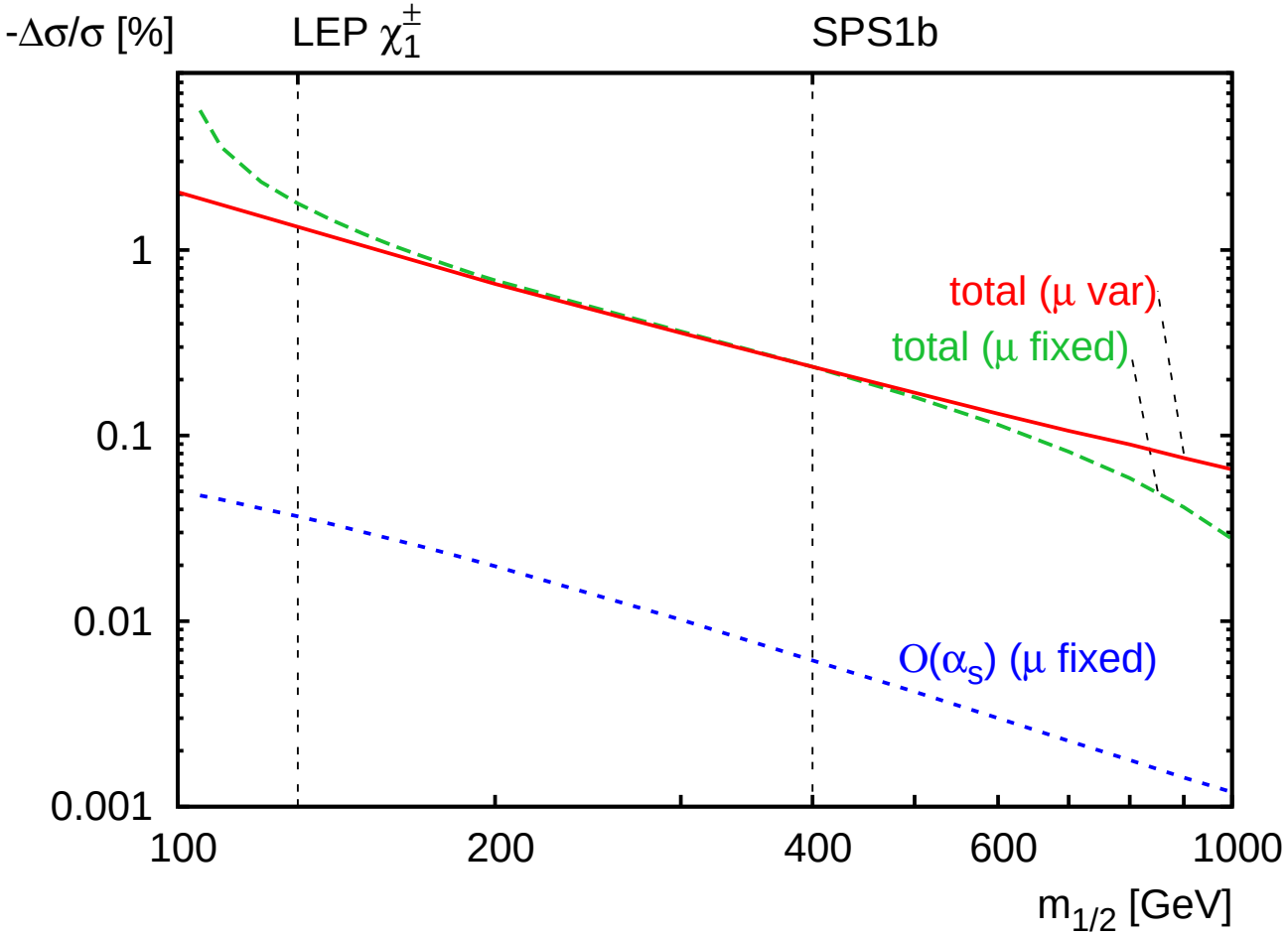
- Again: SUSY QCD corrections are tiny,
  SUSY electroweak corrections are dominant.
- Typical size: less or around 1 %

SUSY-Corrections: $m_{1/2}$-Dependence



- Maximum size of corrections at the LEP2 chargino limit: -2%.
  (For parameter points allowed by direct SUSY searches:
  one can find up to 4 %.)
- Again: SUSY QCD corrections are very tiny.

SUSY-Corrections: $m_{1/2}$-Dependence



- Maximum size of corrections at the LEP2 chargino limit: -2%.
  (For parameter points allowed by direct SUSY searches:
  one can find up to 4 %.)
- Again: SUSY QCD corrections are very tiny.

Conclusions

- Higgs production via weak boson fusion is an important discovery mode for a Higgs boson.
- At the loop level: SUSY particles occur in the MSSM.
- SUSY QCD corrections are very tiny.
- SUSY electroweak corrections are at the percent level.

Corrections with Origin in the Higgs Sector

Higgs self couplings, mixing angle and masses for parameter point SPS1a:

	effective theory [Carena, Espinosa, Quiros, Wagner]		Feynman diagrams [Hahn, Heinemeyer, Hollik, R, Weiglein]		
	α_{eff}	full	α_{eff}	full	
λ_{HHH}	0.208	0.198	0.210	0.210	triple Higgs couplings without $\frac{-3em_W}{2c_w^2 s_w}$
λ_{HHh}	−0.285	−0.275	−0.284	−0.279	
λ_{Hhh}	−0.216	−0.219	−0.220	−0.257	
λ_{hhh}	0.952	1.503	0.950	1.276	
α_{eff}	−0.1132		−0.1158		mix. angle
m_h	109.8 GeV		111.0 GeV		masses
m_H	391.5 GeV		391.6 GeV		

- α_{eff}: Mixing angle α in the Born coupling is replaced by α_{eff}.
- full: Also, genuine loop-corrections to the couplings are included.