Les Houches, 2007

Higgs Working Group:

Theory Summary, S. Dawson

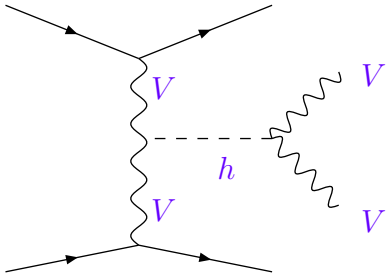
THANKS TO THE ORGANIZERS!

Understanding QCD Corrections to Rates

- Tremendous effort in Standard Model
  - SM Higgs productions rates known at NLO & some at NNLO and/or with resummation of large logarithms (see Grazzini talk)
  - Emphasis now on implementing corrections in useful programs (not just cross sections, but distributions)
  - Understanding theory assumptions (and communicating them!)
  - Including electroweak corrections
  - Precision calculations of Higgs properties in Non-SM theories (development of tools)

Important Channel for Higgs Production is Vector Boson Fusion

- Clean experimental signature with high p_T jets in forward and backward regions
- Large rapidity gap between jets



- Jet tagging and central jet veto suppress QCD backgrounds

- Important for Higgs discovery
- Allows precise measurements of hWW, hZZ, hff couplings
- Experimental accuracy on $\sigma \cdot B \sim 5\text{-}10\%$

QCD Uncertainties in VBF Well Understood

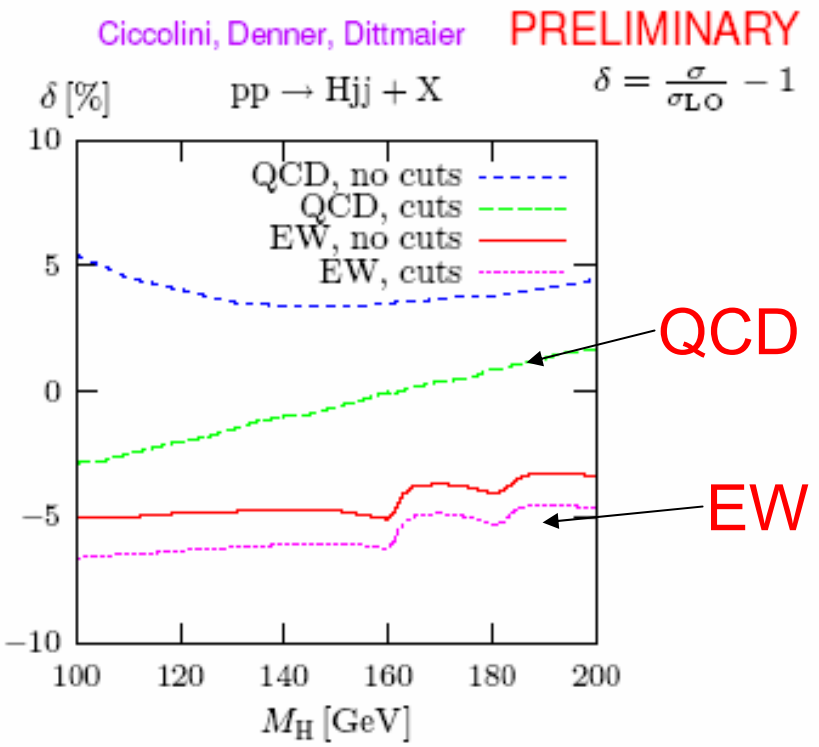
- ***VBFNLO*** is NLO parton level Monte Carlo for VBF and dominant backgrounds
  - Includes Hjj, WWjj, ZZjj, Wjj, Zjj at NLO with decays
  - http://www-itp-physik.uni-karlsruhe.de/~vbfnloweb/
- Input arbitrary experimental cuts/scale choices/PDFs
- Output arbitrary differential distributions
- Can include:
  - Anomalous HVV couplings
  - Anomalous WWW couplings

} Resource for BSM group

Zeppenfeld et al

Vector Boson Fusion and EW Corrections

- Electroweak corrections to vector boson fusion are of similar size as QCD corrections (-4% , -7%)
- Partial cancellation between EW & QCD
- How do EW corrections affect distributions?



Stay tuned…

Comparison between VBF QCD Calculations

- Excellent agreement between QCD corrections from Denner (et al) and Zeppenfeld (et al) for pp→hjj at LO and NLO QCD
- CTEQ6L1 PDFs for LO σ's, CTEQ6M for NLO σ's, VBF cuts

Cross Section for pp→hjj in fb

Process	Denner et al	VBFNLO	Ratio-1
M_h=120 GeV, LO	1647	1650	-0.17 ± 0.10%
M_h=120 GeV, NLO	1745	1740	0.27 ± 0.13%
M_h=160 GeV, LO	1299	1300	-0.14 ± 0.07%
M_h=160 GeV, NLO	1398	1397	0.05 ± 0.1%
M_h=200 GeV, LO	1035	1035	0.04 ± 0.06%
M_h=200 GeV, NLO	1131	1128	0.26 ± 0.10%

$gg \to H \to \gamma\gamma$ at NNLO

Use cuts as in CMS TDR

$$p_T^{\min} > 35 \text{ GeV} \qquad |y| < 2.5$$
$$p_T^{\max} > 40 \text{ GeV}$$

Photons should be isolated: total transverse energy in a cone of radius R=0.3 should be smaller than 6 GeV

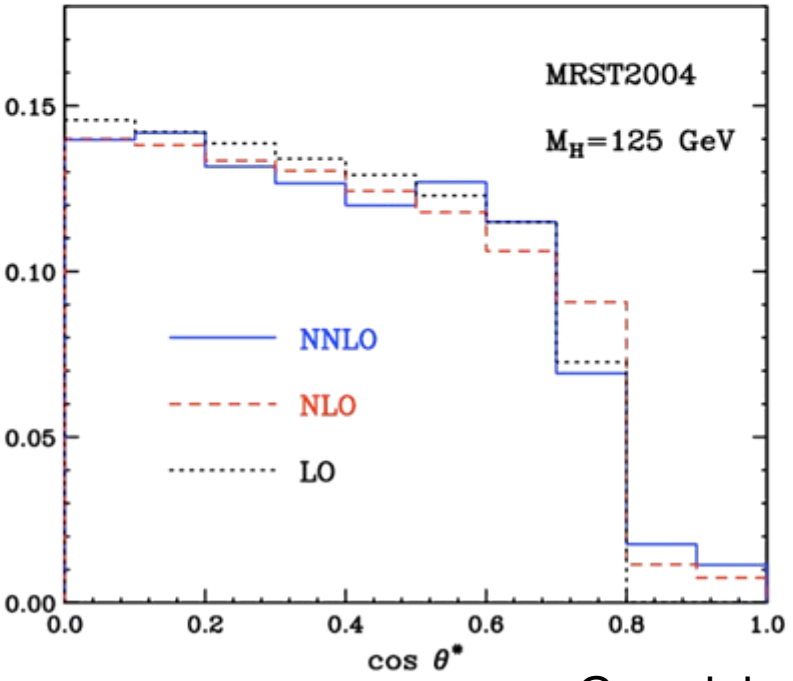
Define $\cos\theta^*$ distribution

θ^* **polar angle of one of the photons in the Higgs rest frame (used by ATLAS: thanks to Suzanne Gascon and to Markus Schumacher)**

Note upper bound on $\cos\theta^*$ at LO

➡ Again perturbative instability beyond LO !

PRELIMINARY



Grazzini

Moving Beyond the SM

- Much effort on MSSM
- Higgs models beyond MSSM
  - NMSSM as example
    - Generically, this model has 3 neutral Higgs bosons, 2 pseudoscalars, and couplings altered from MSSM couplings
    - New signatures / mass patterns
    - In most of parameter space Higgs sector looks like MSSM!
  - Light Higgs boson can be allowed by LEP results
    - Identify benchmark points

Benchmark Scenarios for NMSSM

- Two classes of scenarios:
  - Lightest scalar is pseudo-scalar a_1
    - $h_1 \rightarrow a_1\, a_1$ with branching ratio near 1
    - $a_1 \rightarrow \tau^+\tau^-$
    - $a_1 \rightarrow b\bar{b}$
  - Decays to a_1 not allowed kinematically, but BR's and/or production rates different than MSSM

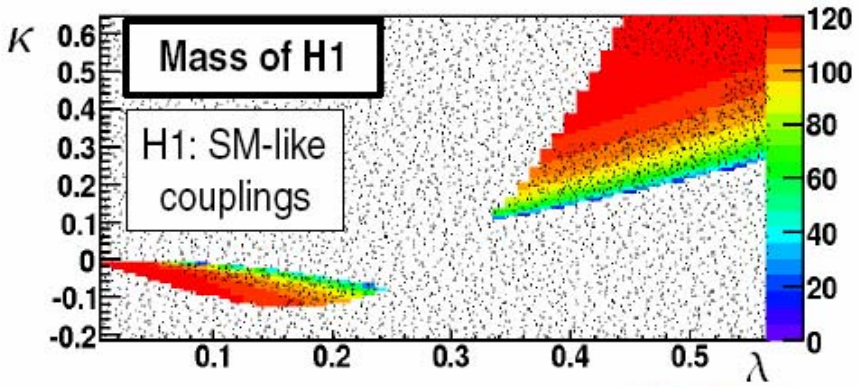
Require benchmark points not be excluded by LEP searches and theoretical consistency

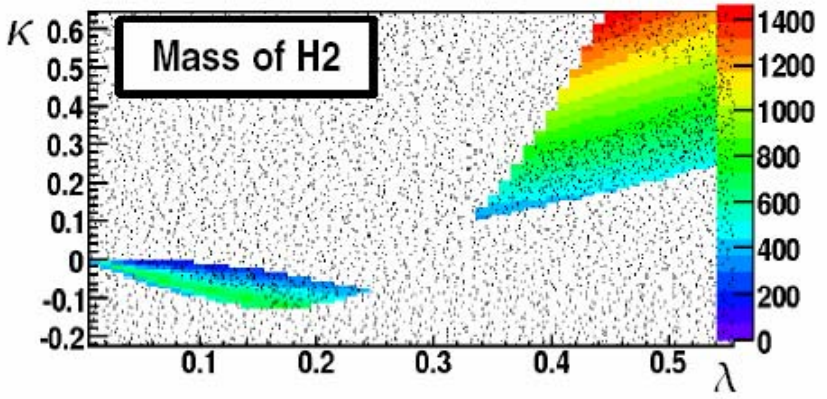
Two Interesting NMSSM Scenarios as Possible Benchmarks

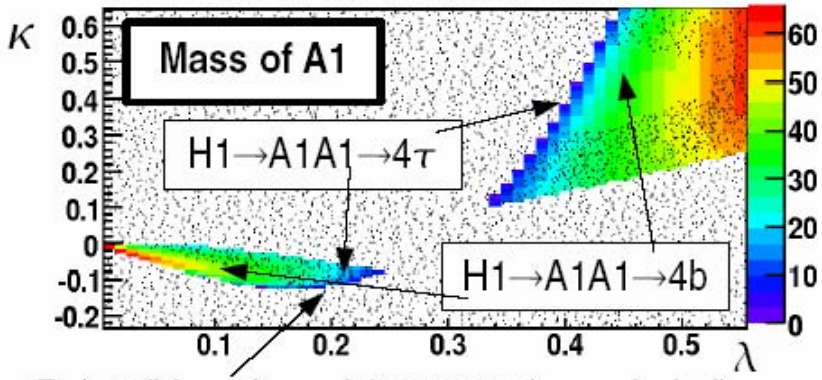
I. Rottländer, A. Djouadi, R. Godbole, M. Schumacher

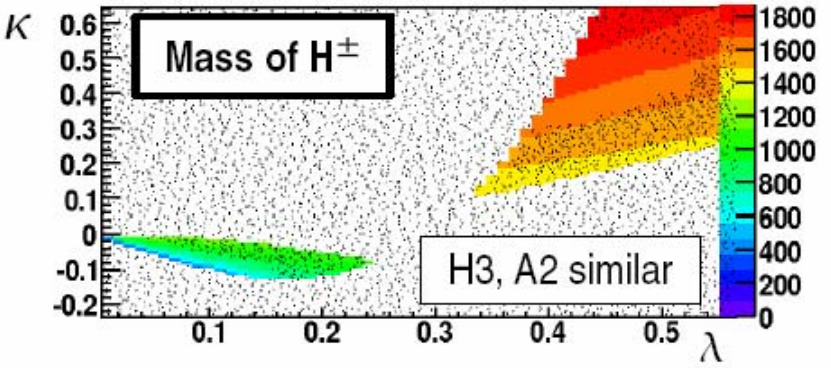
Goal: Define typical or challenging scenarios for evaluation of the discovery potential of the six NMSSM Higgs bosons (H1, H2, H3, A1, A2, $H^{\pm}$) at the LHC

Scenario 1: μ_{eff}= -520 GeV, Aλ= -580 GeV, Aκ= -2.8 GeV, tanβ = 5.0, λ, κ varied









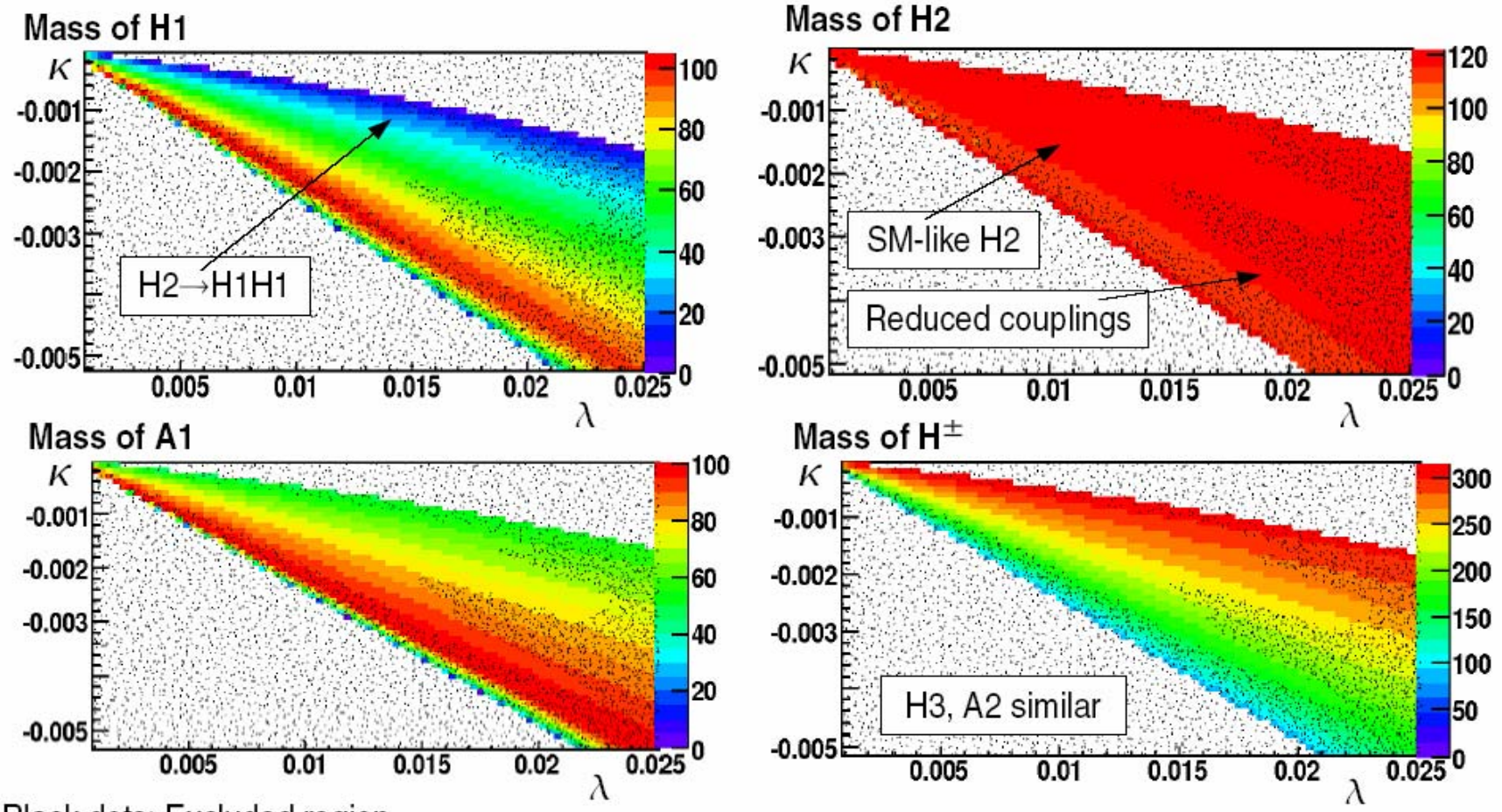
"Point 1" from hep-ph/0503203 (unexcluded)

Black dots: Excluded region

Scenario 2: μ_{eff} = -284 GeV, Aλ = -70 GeV, Aκ = -54 GeV, tanβ = 5.7

λ, κ varied (very small)

All six Higgs bosons relatively light (< ~300 GeV)!



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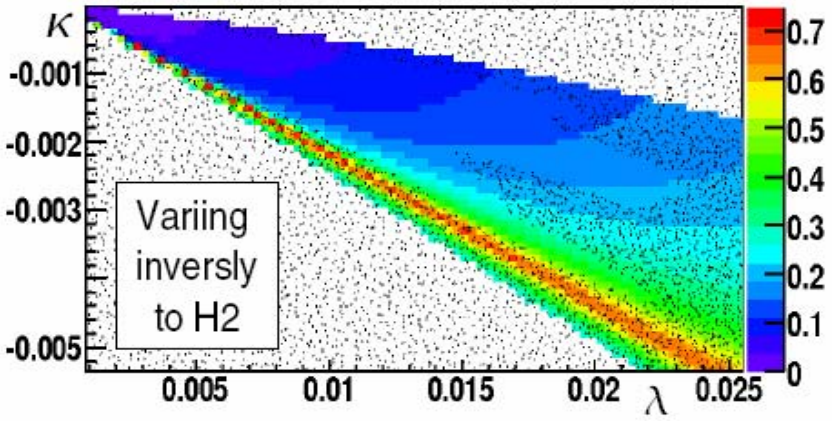
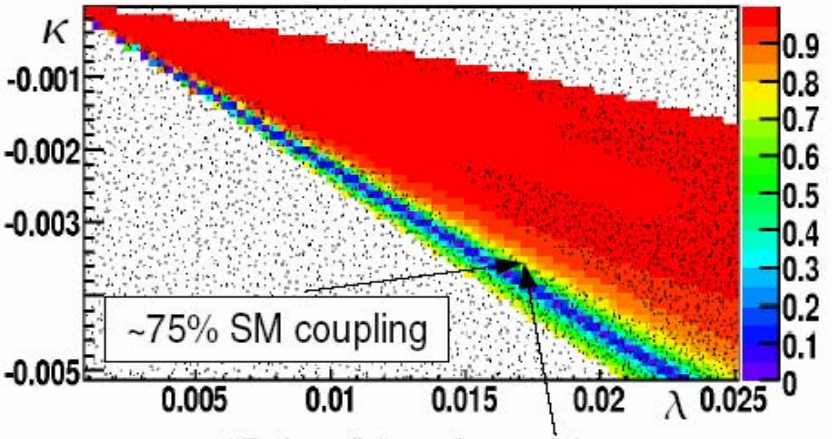
Scenario 2: μ_{eff} = -284 GeV, Aλ = -70 GeV, Aκ = -54 GeV, tanβ = 5.7, λ, κ varied

Vector boson coupling of H1



Top & gluon couplings vary similarly
H2 b-coupling enhanced

Vector boson coupling of H2



"Point 0" from hep-ph/0503203:
Lowest LHC significance w/o H/A→H/A decays

General remark: Interesting part of parameter space seems to be often in marginal regions of larger "SM-like" regions or narrowly confined by constraints

Conclusion: Cover regions with the four different kinds of phenomenology typical to the NMSSM (reduced couplings, H1→A1A1→4τ/4b, light H1) with two scans!

Some more details:

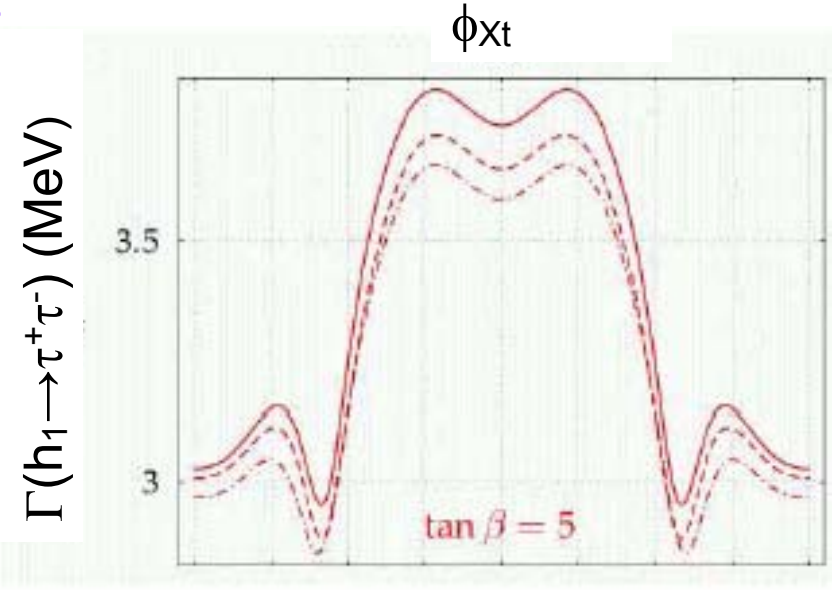
NMHDECAY, m_{top}=172 GeV, Ren. scale=1000 GeV, no WMAP constraints considered

M_1 = 500 GeV, M_2 = 1 TeV, M_3 = 3 TeV, M_{Susy} = 1 TeV, A_t=A_b=A_τ=1.5 TeV

Including higher order effects in MSSM

- FeynHiggs 2.6 (new version)
  - Includes full 1-loop evaluation of Higgs mass matrix with complex phases
  - Inclusion of $O(\alpha_s\ \alpha_t)$ effects
  - Phases give 5-10% effect

http://www.feynhiggs.de



Hahn, Heinemeyer, Hollik, Rzehak, Weiglein

SUSY Particle Decays in MSSM

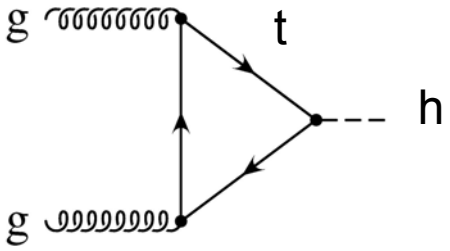
- SUSY-HIT
  - SUSY spectrum with any spectrum code in SLHA format
  - MSSM Higgs Decays:
    - Includes decays to SUSY particles
    - Higher order corrections, off-shell decays
    - New: Includes SLHA format
  - MSSM particle decays:
    - QCD corrections to colored 2-body decays

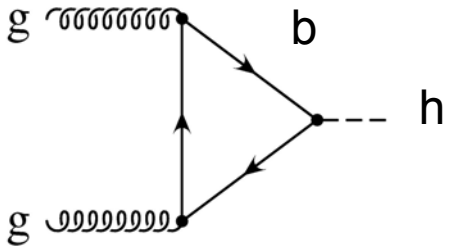
http://lappweb.in2p3.fr/~muehlleitner/SUSY-HIT

Djouadi,Muhlleitner, Spira

Rescaling NLO Corrections in Non-SM Scenarios

- ***Requires great care***
- Dominant Higgs production mechanism at LHC is gg → h
  - Many NLO QCD corrections done in $M_t \to \infty$ limit
  - Doesn't work in MSSM: can't just rescale SM corrections





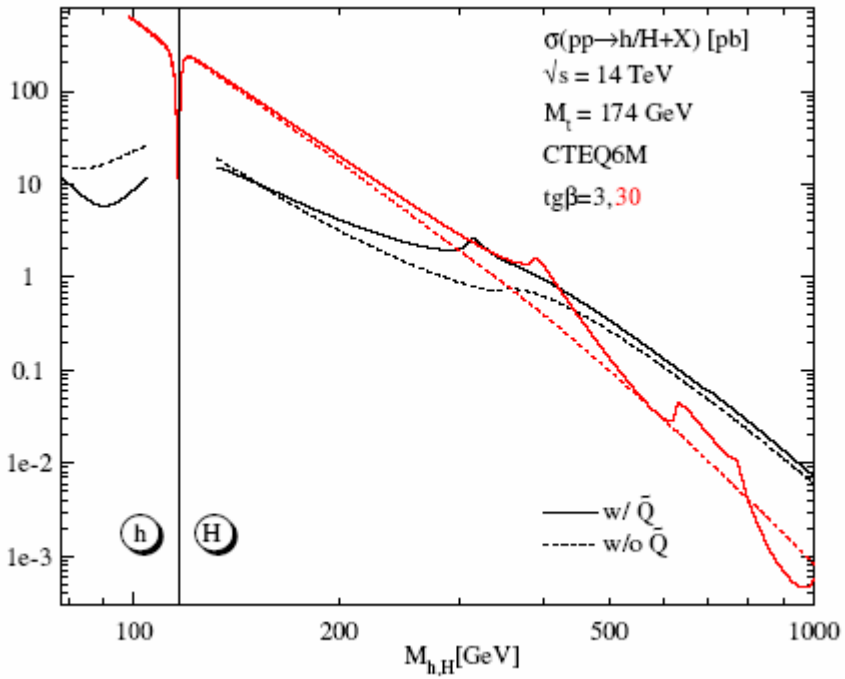
- Independent of M_t in large M_t limit
- tth coupling ~cot β

- ~ tan β $(M_b/M_h)^2$ ln(M_h/M_b)
- Dominant contribution for tan β > 7

QCD Corrections to MSSM Higgs Production

- gg→h
  - Important effects from b-quark loops at large tan β and squark loops when M_{squark}< 400 GeV

NLO Cross Sections



Muhlleitner, Spira

Conclusions

- Theorist's Homework:
  - Keep calculating higher order effects to Higgs production and backgrounds
  - Include calculations in programs useful for experimentalists
  - COMMUNICATE assumptions/limits of programs
  - Develop tools for Higgs models beyond SM and MSSM