Production of Neutral Higgs + Jet in the MSSM

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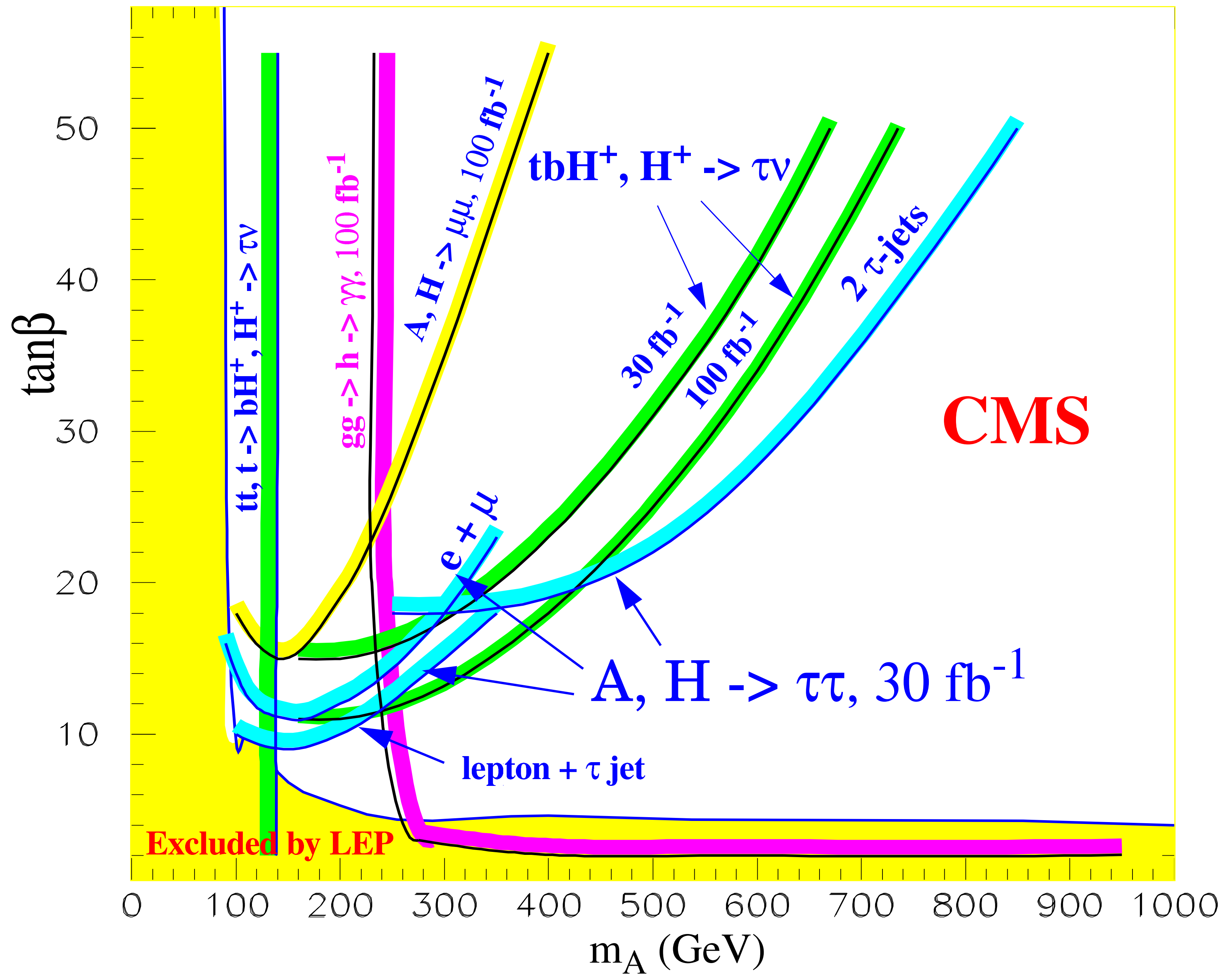
outline :

- Higgs + jet in the Standard Model
  - Higgs production @ the LHC
  - Higgs + jet
- Higgs + jet in the MSSM
  - differences to the SM
  - Feynman graphs
- MSSM Results
  - hadronic cross section @ LHC ($\sqrt{S} = 14\,\mathrm{TeV}$)
  - m_A- and $\tan\beta$-dependence
  - M_{SUSY} -dependence
  - relative difference $\delta = (\sigma^{\mathrm{MSSM}} - \sigma^{\mathrm{SM}})/\sigma^{\mathrm{SM}})$
  - angular dependence

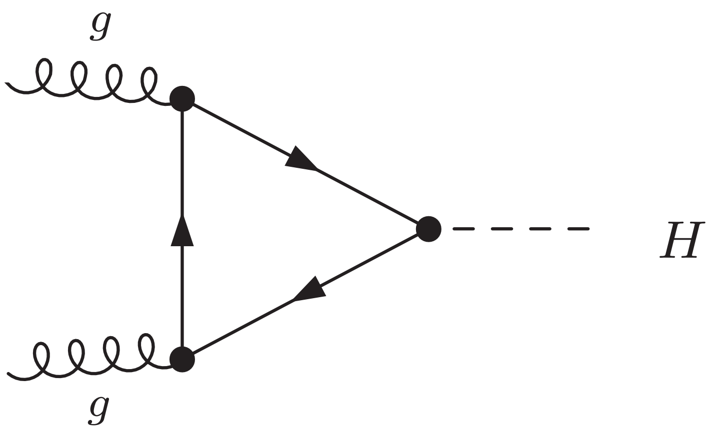
Quickstart

LHC/CMS 5σ discovery contours for the MSSM Higgs bosons



– Higgs production @ the LHC

SM Higgs production @ LHC mainly via gluon fusion:



Detection ($m_H \approx 100 - 140$GeV): mainly via the rare decay $H \to \gamma\gamma$.

$\longrightarrow$ difficult ! huge background

– Higgs + jet [R.K. Ellis et al. '87; Baur, Glover '89] (LO)
[de Florian, Grazzini, Kunszt '99] (NLO QCD)

suggestion: study Higgs events with a high-p_T hadronic jet

advantage:

* richer kinematical structure compared to inclusive Higgs production.
  $\rightarrow$ better S/B ratio
  $\rightarrow$ allows for refined cuts

disadvantage:

* lower rate than inclusive Higgs production

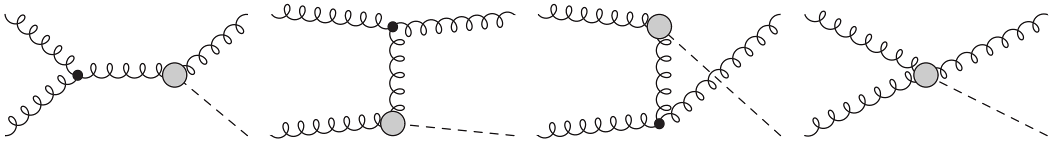
(*) NLO signal prediction has still sizable theoretical uncertainty ($\approx 20\%$)

(*) background only partly known at NLO accuracy

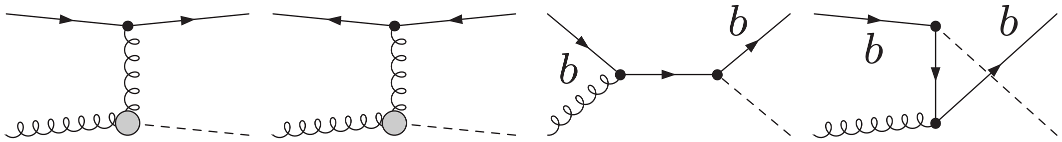
$\rightarrow$ theoretical uncertainties larger than in the fully inclusive case (so far)

SM H+jet, partonic processes (mostly loop-induced):

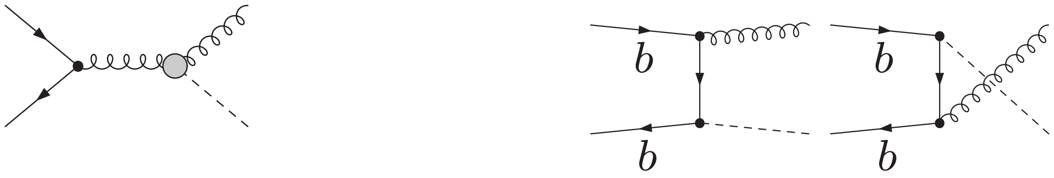
- $gg \longrightarrow Hg$ (≈ 50 - 70 % of total rate)



- $qg \longrightarrow Hq, \bar{q}g \longrightarrow H\bar{q}$ (≈ 30 - 50 % of total rate)



- $q\bar{q} \longrightarrow Hg$ (rate small)



recently simulated: $pp \longrightarrow H + \text{jet}, H \longrightarrow \gamma\gamma$ [Abdullin et al. '98 & '02]
$pp \longrightarrow H + \text{jet}, H \longrightarrow \tau^+\tau^- \longrightarrow l^+l^-\not{p}_T$ [Mellado et al. '05]

result: $H + \text{jet}$ production (e.g. with $p_{T,\text{jet}} \geq 30\,\text{GeV}$, $|\eta_{\text{jet}}| \leq 4.5$)
is a promising alternative (supplement)
to the inclusive SM Higgs production
for $m_H \approx 100 - 140\text{GeV}$.

available codes:

- Higgsjet [de Florian, Grazzini, Kunszt '99]
  NLO QCD cross section for $pp \to H + \text{jet}$

- HqT [Bozzi, Catani, de Florian, Grazzini '03 & '06]
  p_T-distribution for $pp \to H + X$
  at $NLL + LO$ and $NNLL + NLO$ QCD accuracy
  (large effects at small p_T resummed)

- MC@NLO [Frixione, Webber '02; Frixione, Nason, Webber '05]
  contains $pp \to H + X$ event generation at NLO QCD accuracy

- FEHiP [Anastasiou, Melnikov, Petriello '05]
  NNLO QCD differential cross section for $pp \to H + X$

but the LHC calls for further improvement of the theoretical predictions

• Higgs + jet in the MSSM

[OBr, Hollik '03]

Motivation:

* promising simulation results in the SM case
* MSSM prediction for h^0 + jet not known yet
* process loop-induced $\rightarrow$ potentially large effects from virtual particles

– differences to the SM

partonic processes similar to the SM:

gluon fusion	$gg \rightarrow h^0 g$,
quark-gluon scattering	$q(\bar{q})g \rightarrow h^0 q(\bar{q})$,
$q\bar{q}$ annihilation	$q\bar{q} \rightarrow h^0 g$

but: * different Higgs Yukawa-couplings

$$g^{\mathrm{SM}}_{q\bar{q}H} = \frac{e}{2s_W}\frac{m_q}{m_W} \longrightarrow g^{\mathrm{MSSM}}_{q\bar{q}h^0} = \frac{e}{2s_W}\frac{m_q}{m_W} f_q(\alpha,\beta),$$

$$f_{u_I}(\alpha,\beta) = \cos\alpha/\sin\beta$$

$$f_{d_I}(\alpha,\beta) = -\sin\alpha/\cos\beta$$

$\rightarrow$ change of overall rate

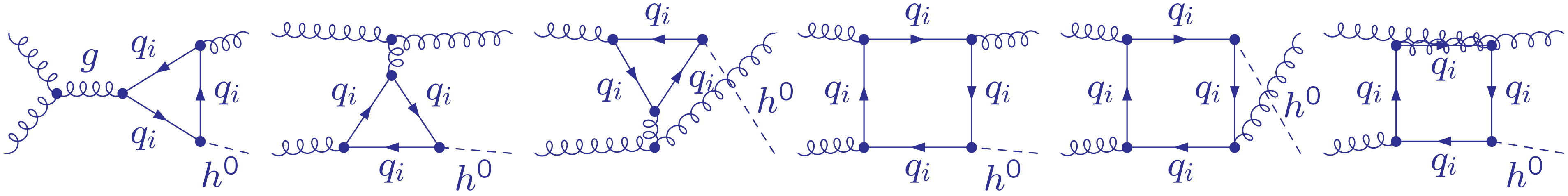
* additional superpartner-loops (even additional topologies)

$\rightarrow$ also angular distribution changed

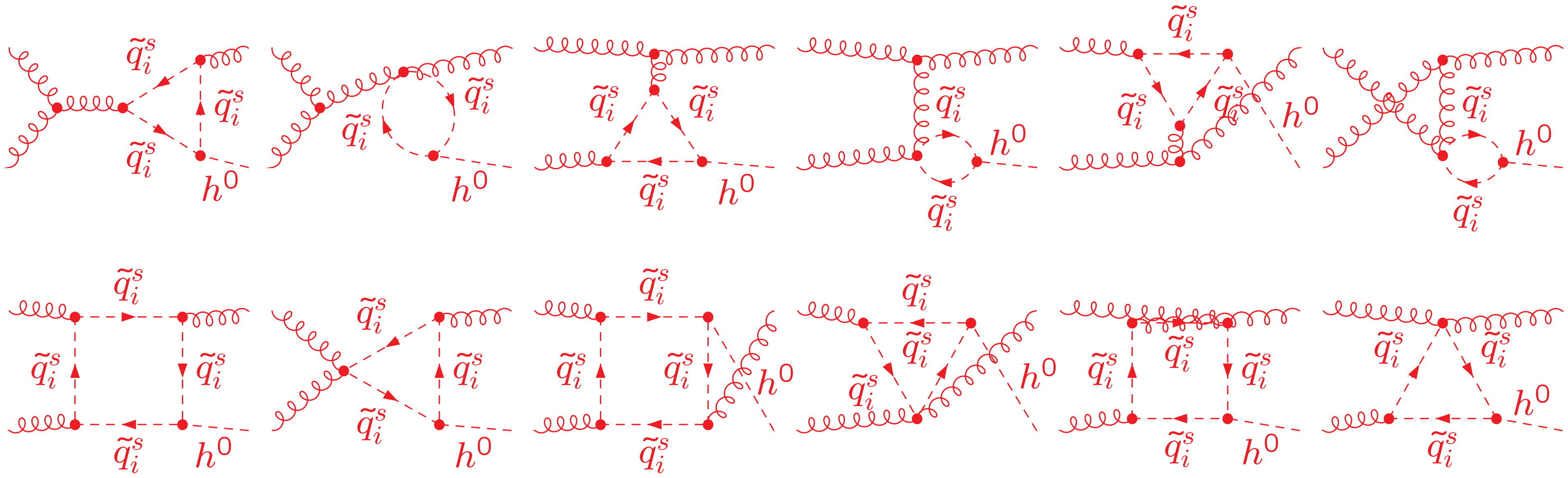
– Feynman graphs

gluon fusion, $gg \to h^0 g$

quark loops

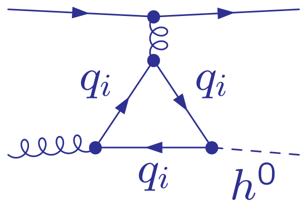


superpartner loops

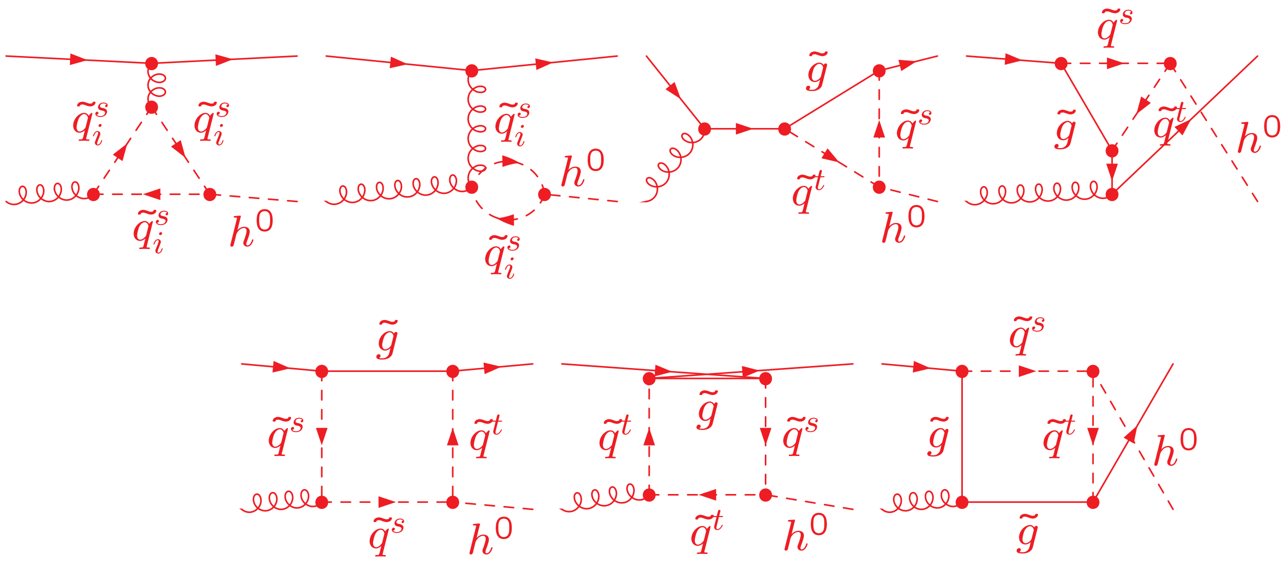


quark-gluon scattering, $qg \to h^0 q$

quark loops

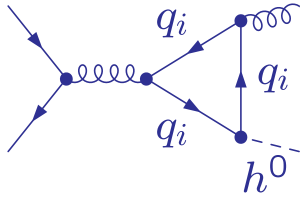


superpartner loops

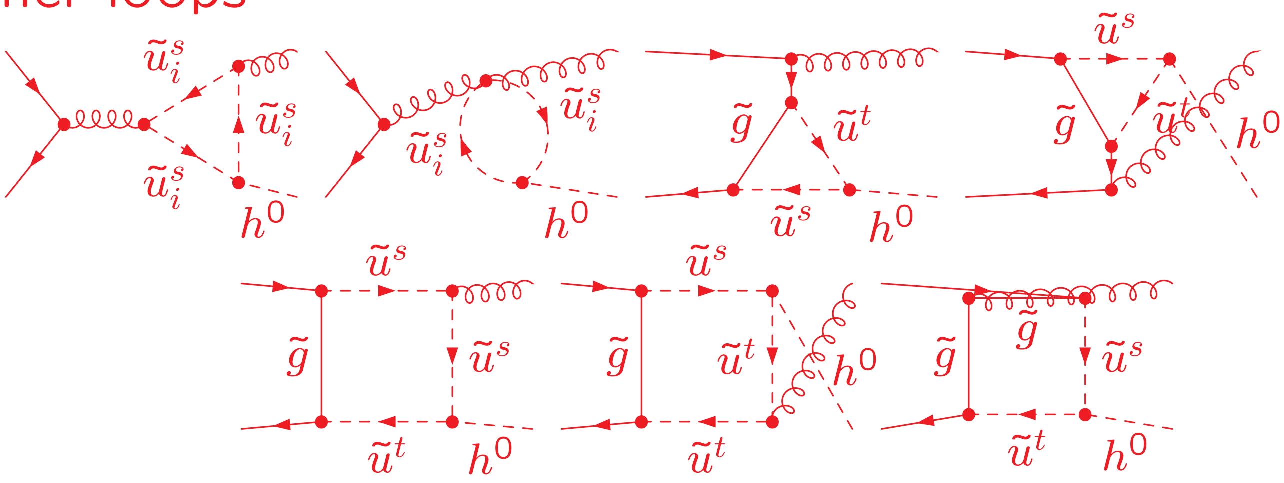


quark-antiquark annihilation, $q\bar{q} \longrightarrow h^0 g$

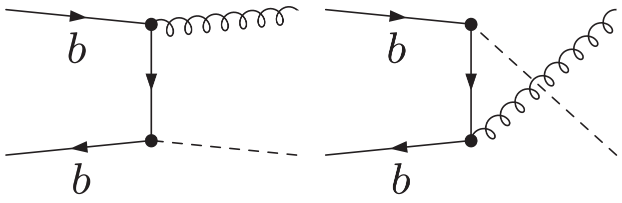
quark loops



superpartner loops



$b\bar{b}$ annihilation, $b\bar{b} \longrightarrow h^0 g$



• MSSM Results

– hadronic cross section @ LHC ($\sqrt{S} = 14\,\text{TeV}$)

$$\sigma(pp \to h^0 + \text{jet} + X) =$$

$$\int_{\tau_0}^{1} d\tau \left(\frac{d\mathcal{L}^{pp}_{gg}}{d\tau}\, \hat{\sigma}_{gg\to gh^0}(\hat{s}) + \sum_q \frac{d\mathcal{L}^{pp}_{qg}}{d\tau}\, \hat{\sigma}_{qg\to qh^0}(\hat{s}) + \sum_q \frac{d\mathcal{L}^{pp}_{q\bar{q}}}{d\tau}\, \hat{\sigma}_{q\bar{q}\to gh^0}(\hat{s}) \right)\Bigg|_{\hat{s}=\tau S}$$

with the parton luminosity

$$\frac{d\mathcal{L}^{AB}_{nm}}{d\tau} = \int_{\tau}^{1} \frac{dx}{x} \frac{1}{1+\delta_{nm}} \left[f_{n/A}(x) f_{m/B}(\frac{\tau}{x}) + f_{m/A}(x) f_{n/B}(\frac{\tau}{x}) \right].$$

The cuts $p_{T,\text{jet}} \geq 30\,\text{GeV}$ and $|\eta_{\text{jet}}| \leq 4.5$
determine τ_0 and the angular integration limits.

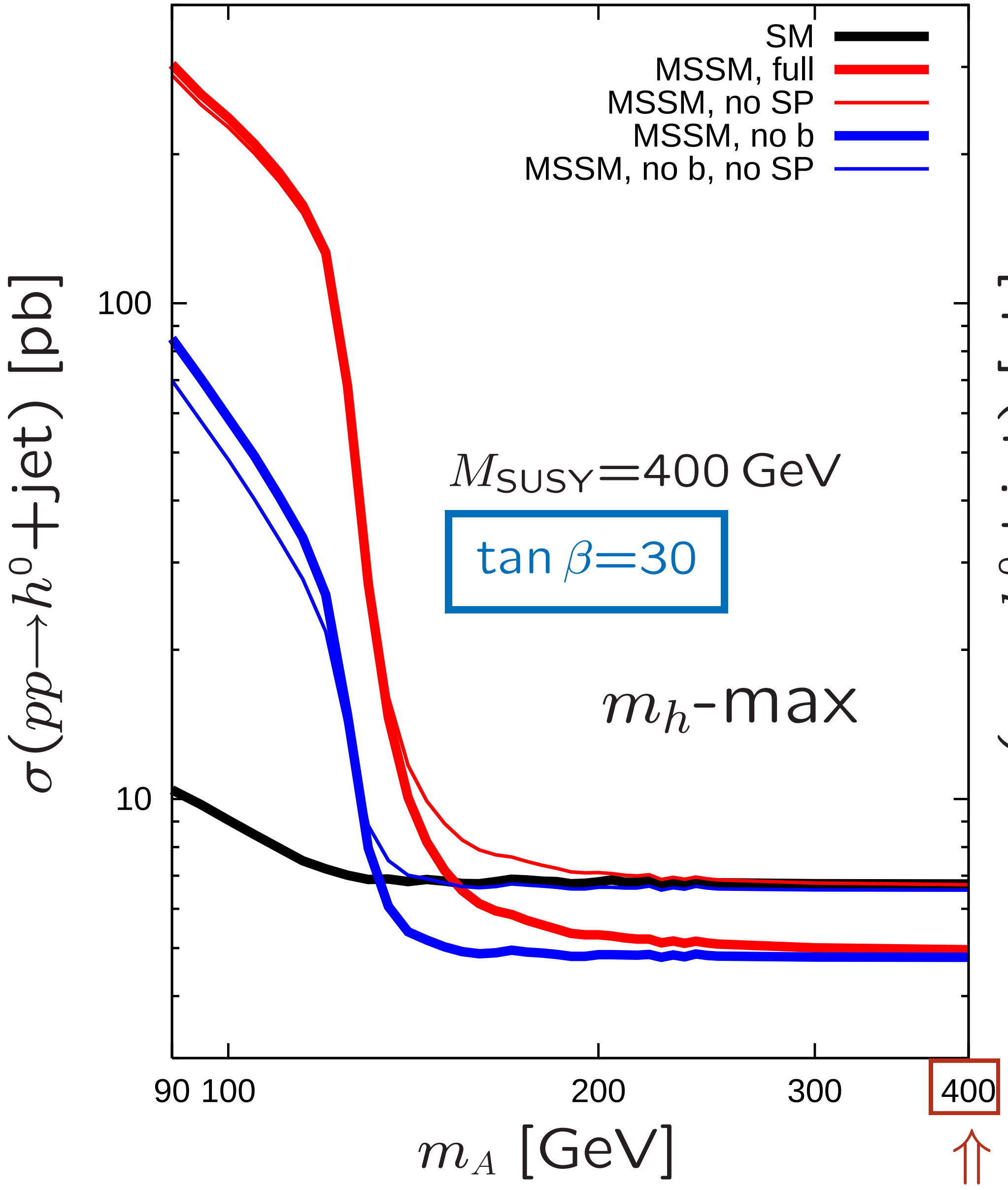
The results shown are for the MSSM m_h^{max} benchmark scenario
with common squark mass scale M_{SUSY}.

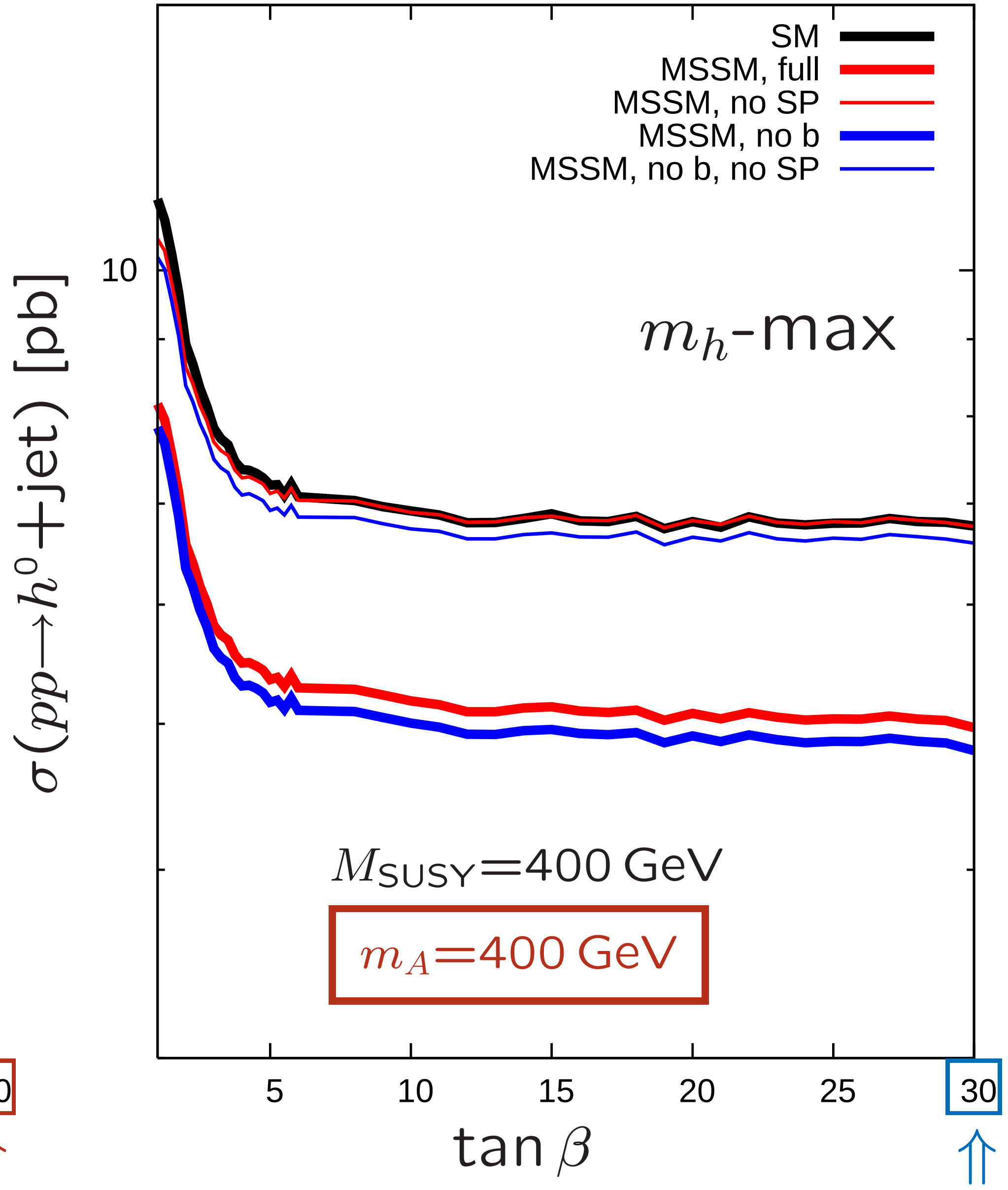
[partonic processes calculated using FeynArts/FormCalc, see : www.feynarts.de]

[MSSM Results]

– m_A- and $\tan\beta$-dependence

(cuts: $p_{T,\text{jet}} \geq 30$ GeV , $|\eta_{\text{jet}}| \leq 4.5$)





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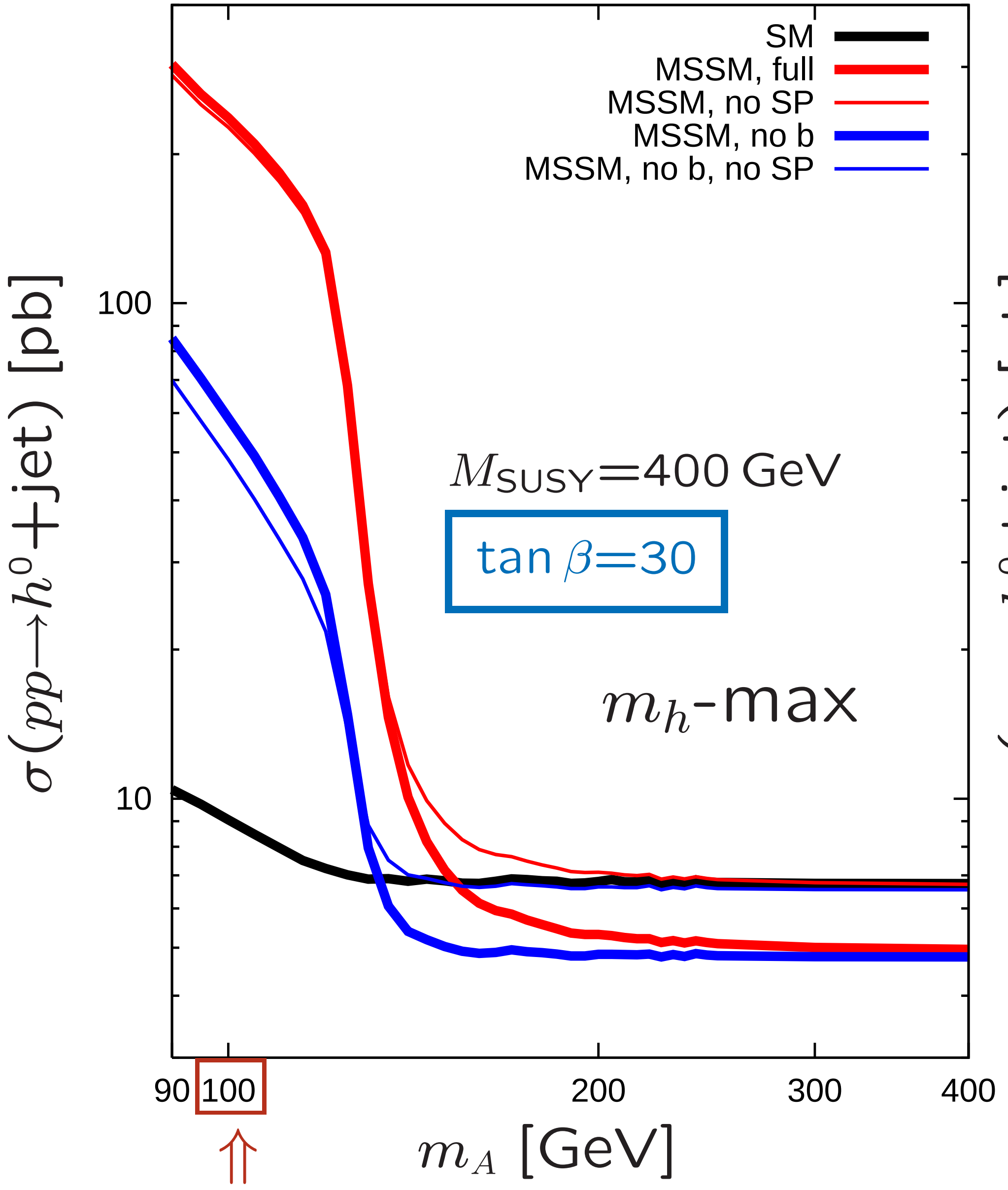
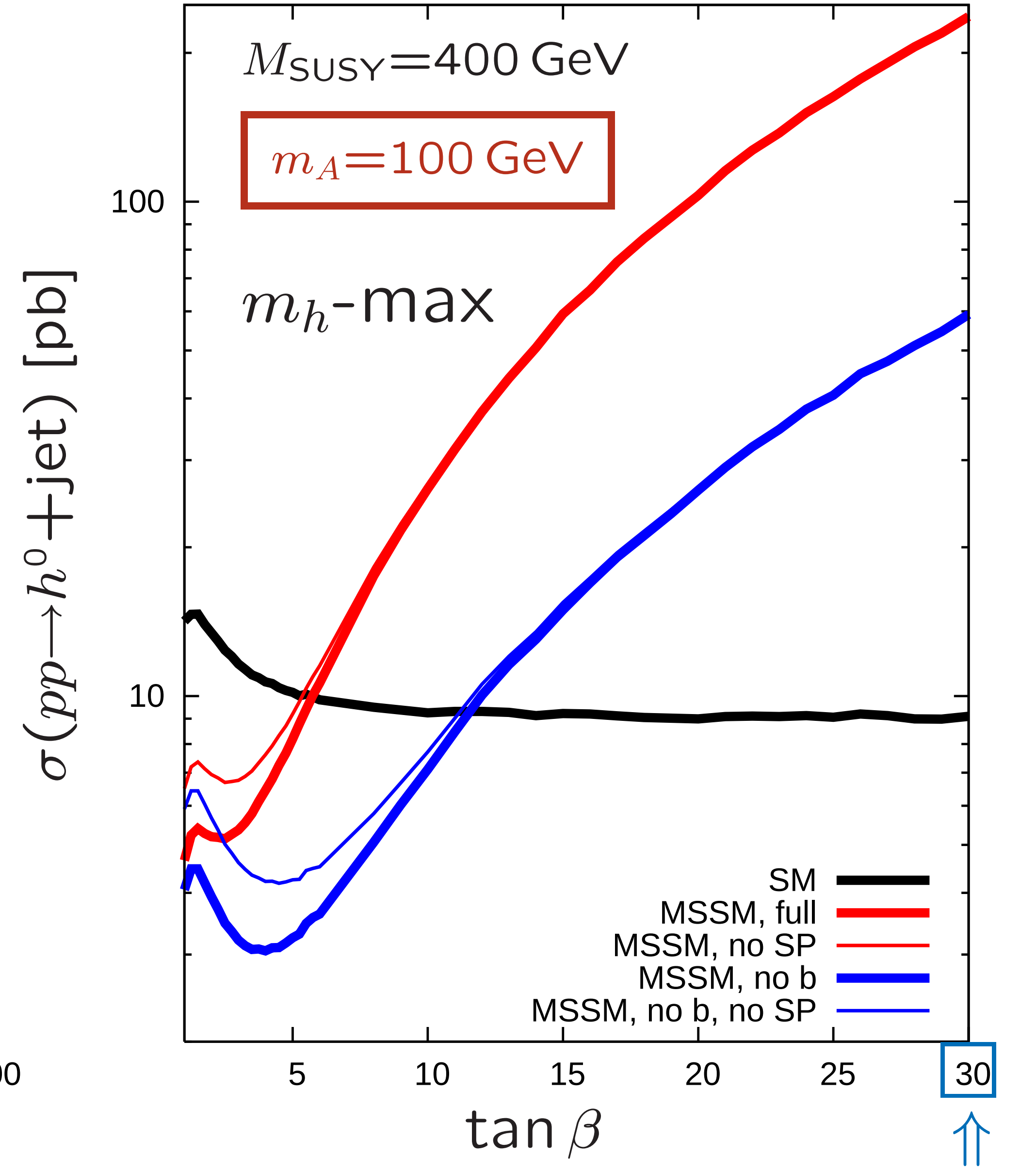
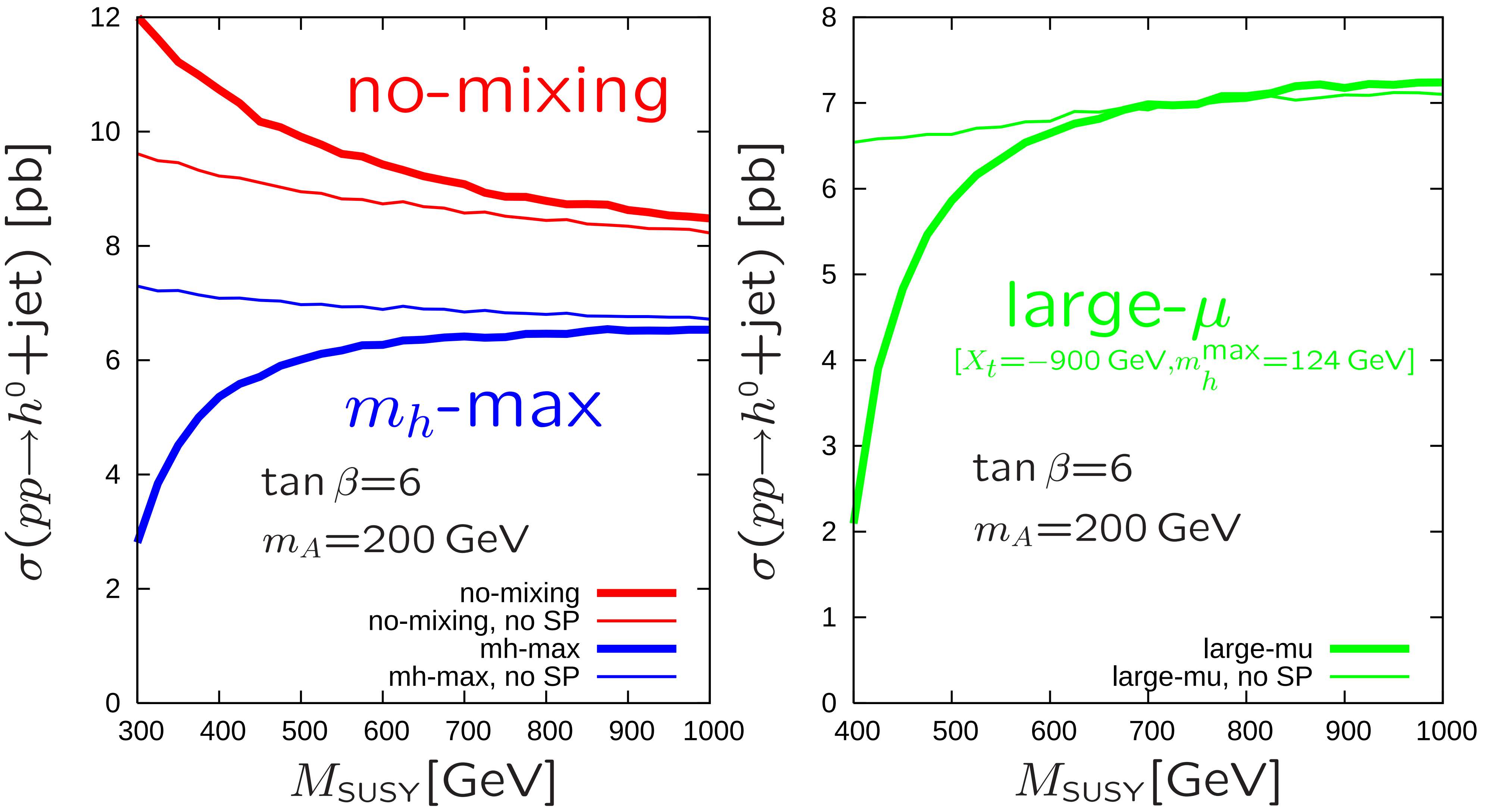


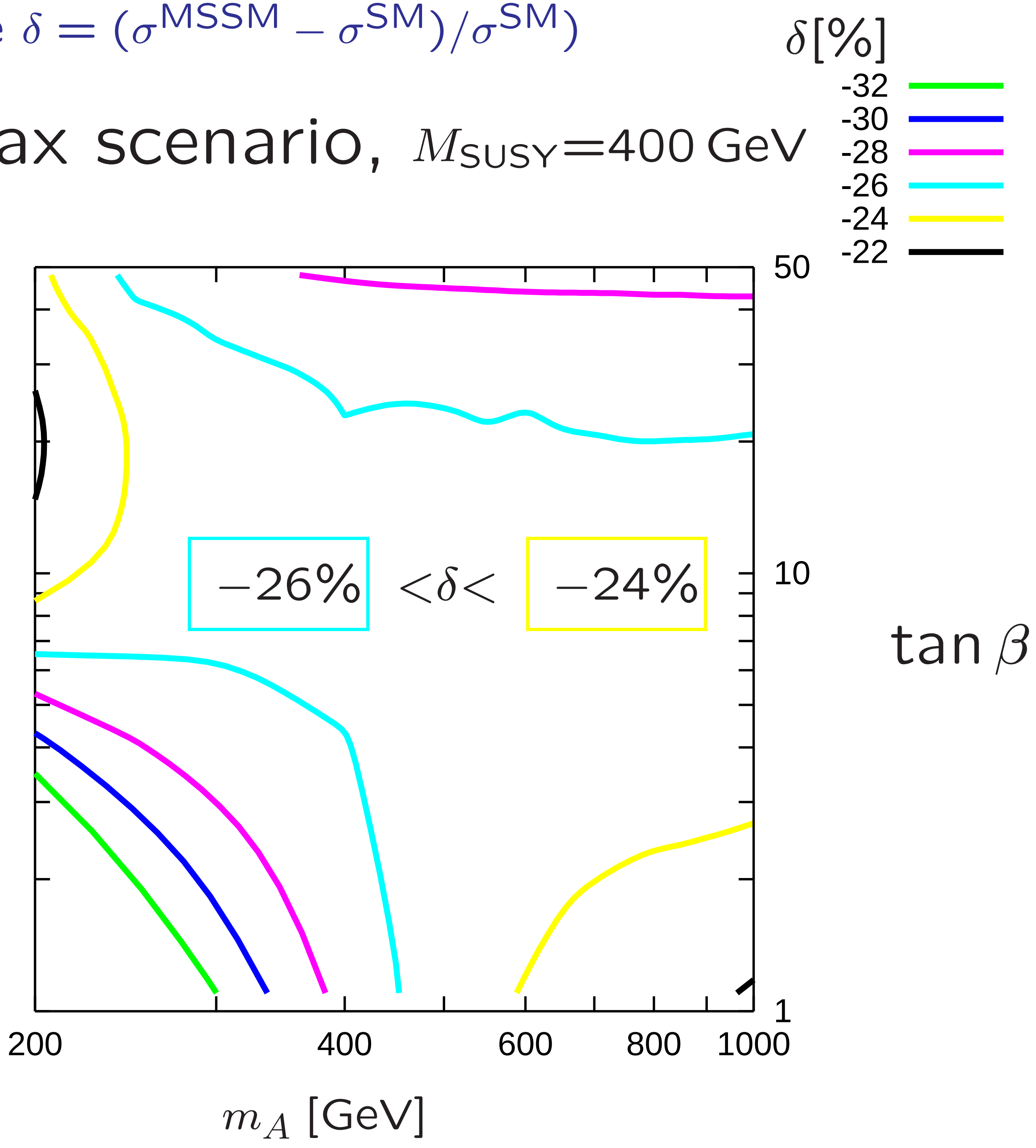


– M_{SUSY} -dependence (cuts: $p_{T,\text{jet}} \geq 30$ GeV , $|\eta_{\text{jet}}| \leq 4.5$)



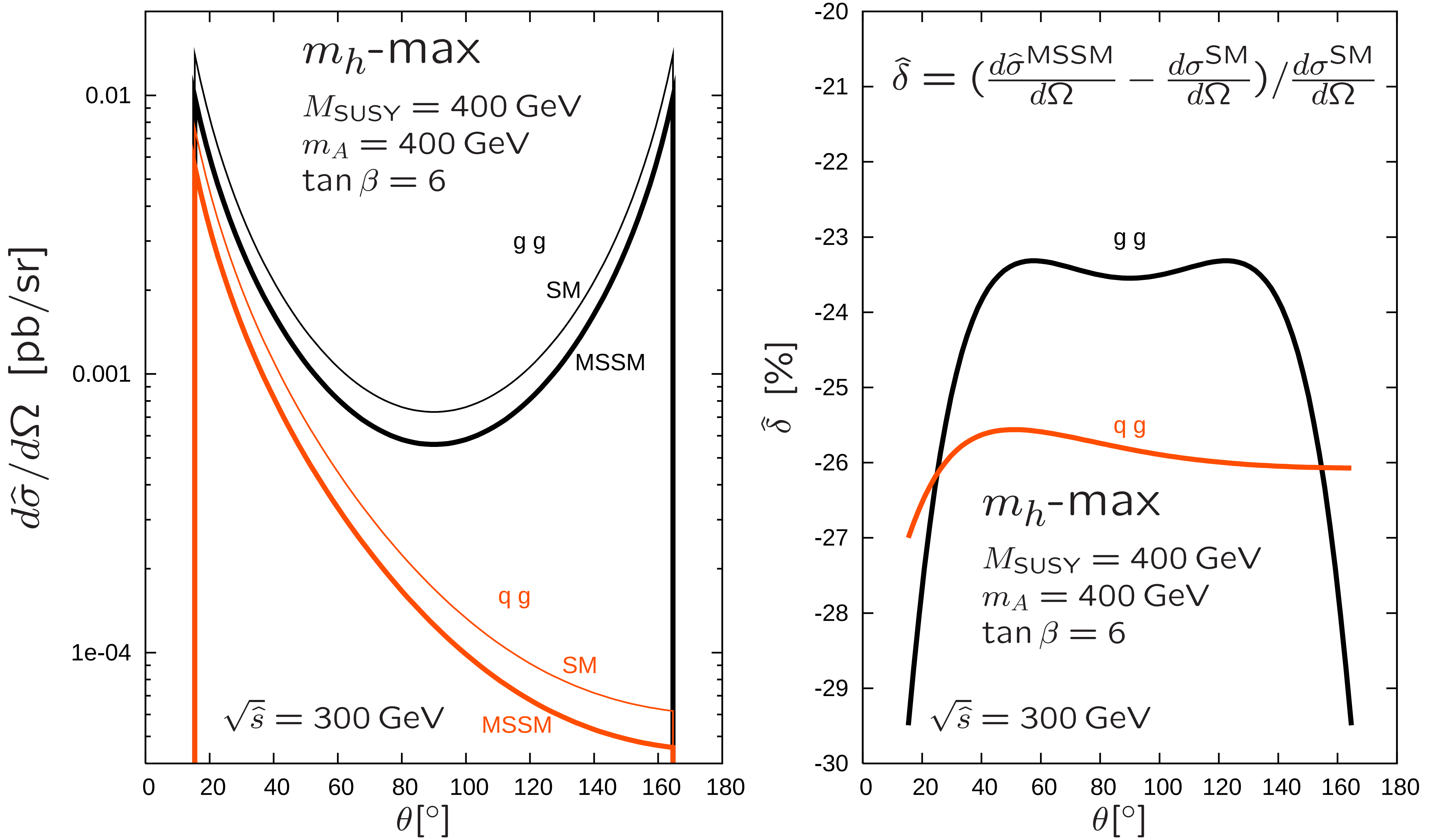
– relative difference $\delta = (\sigma^{\mathrm{MSSM}} - \sigma^{\mathrm{SM}})/\sigma^{\mathrm{SM}}$

m_h-max scenario, M_{SUSY}=400 GeV



– angular dependence

(cuts: $p_{T,\mathrm{jet}} \geq 30$ GeV , $|\eta_{\mathrm{jet}}| \leq 4.5$)



summary

- SM simulations show: Higgs + high-p_T jet production is a promising alternative to the inclusive production.

- LO MSSM prediction shows large effects due to virtual squarks.
  (processes loop-induced)
  – sizeable differences between SM and MSSM expectations can occur
  – angular distributions are changed at the $\approx$ 5% level

- more precise predictions are needed in order to be useful for experimental analyses at the LHC.

FORTRAN code HJET to calculate the MSSM (and SM) cross sections is available on request $\longrightarrow$ oliver.brein@durham.ac.uk