Distributions for Higgs + Jet at Hadron Colliders: MSSM vs SM

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[see also 0705.2744 [hep-ph]; hep-ph/0305321]

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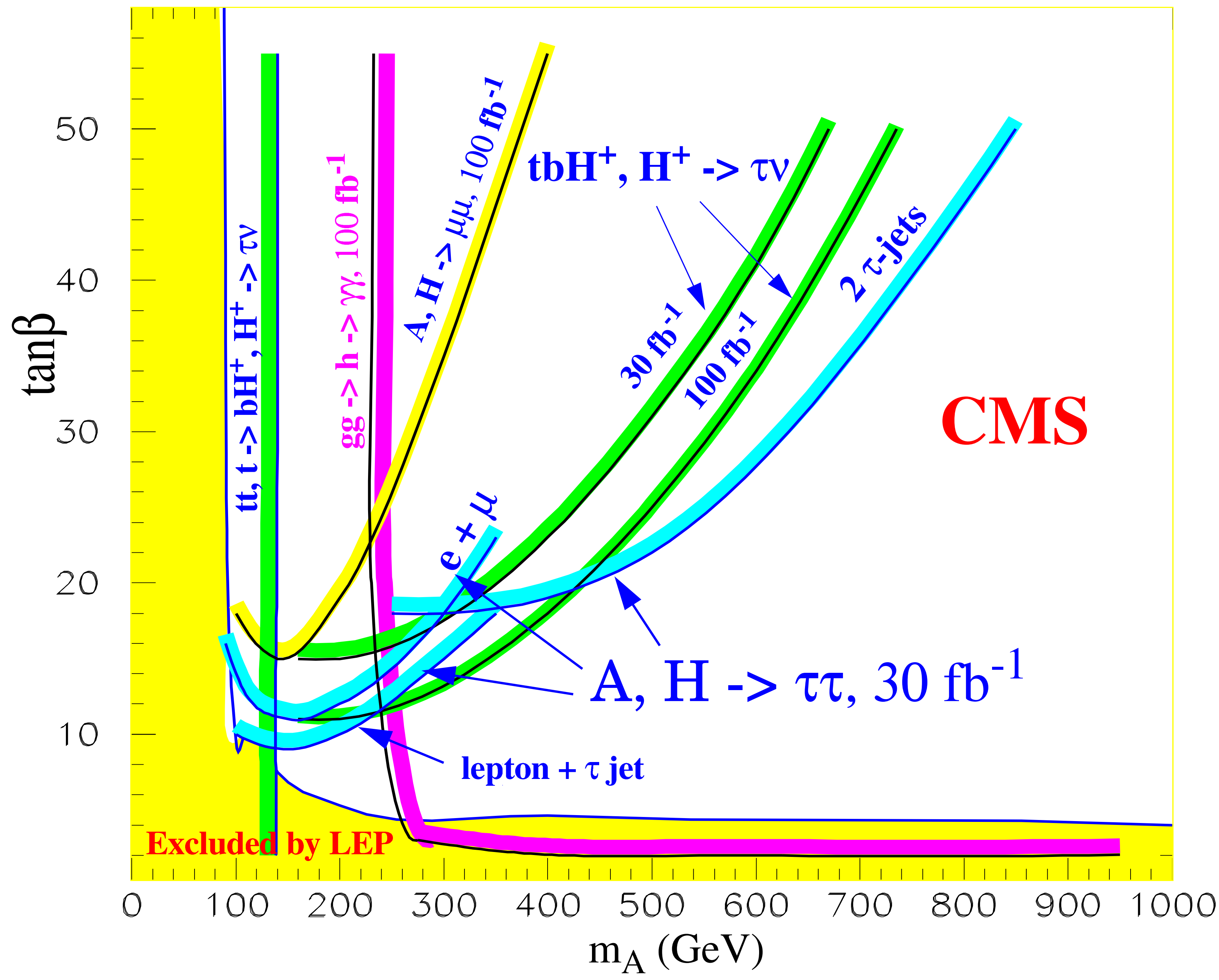
outline :

- Higgs + jet in the Standard Model
- Higgs + jet in the MSSM
- MSSM results

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

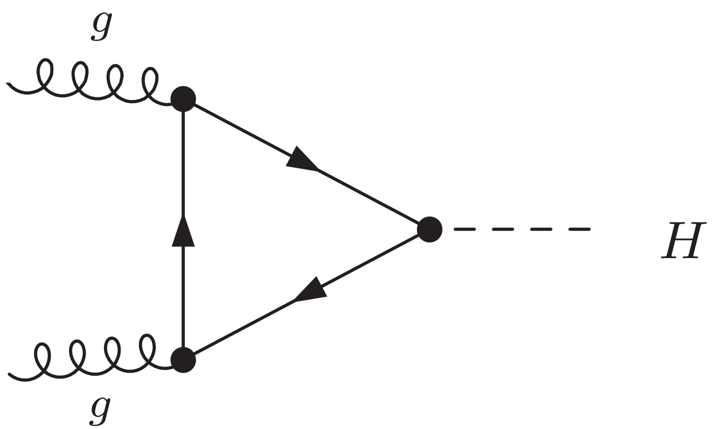


- Higgs + jet in the Standard Model

• Higgs + jet in the Standard Model

– 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

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

[R.K. Ellis et al. '87; Baur, Glover '89] (LO)

[de Florian, Grazzini, Kunszt '99] (NLO QCD)

advantage:

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

disadvantage:

* lower rate than inclusive Higgs production

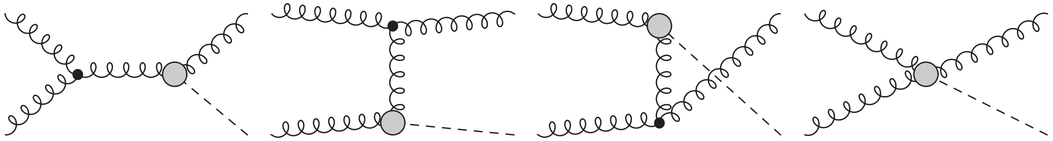
(*) NLO signal prediction has still sizable theoretical uncertainty ($\approx 20\%$)

(*) background only partly known at NLO accuracy

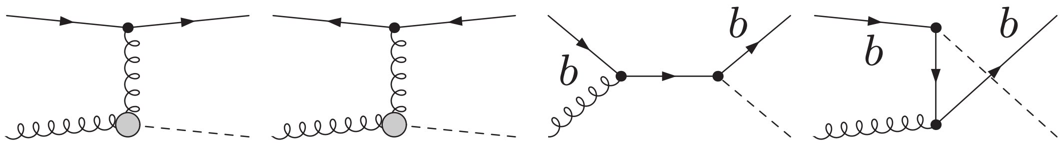
→ theoretical uncertainties larger than in the fully inclusive case (so far)

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

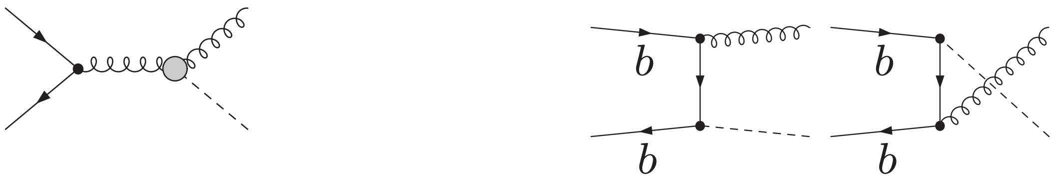
- $gg \longrightarrow Hg$ (≈ 50 - 70 % of total rate)



- $qg \longrightarrow Hq, \bar{q}g \longrightarrow H\bar{q}$ (≈ 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; Zmushko '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 $pp \to H +$ jet
  also: soft gluon resummation [de Florian, Kulesza, Vogelsang '05]

- 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 $pp \to H + X$

- Higgs + jet in the MSSM

• Higgs + jet in the MSSM

[OBr, Hollik '03; '07] (full MSSM), [Field, Dawson, Smith '04] (MSSM, no superpartners), [Langenegger et al. '06] (MSSM with soft-gluon resummation, no superpartners)

– differences to the SM

Motivation:

* promising simulation results in the SM case

* process loop-induced → potentially large effects from virtual particles

partonic processes similar to the SM:

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

but: * different Higgs Yukawa-couplings

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

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

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

→ change of overall rate

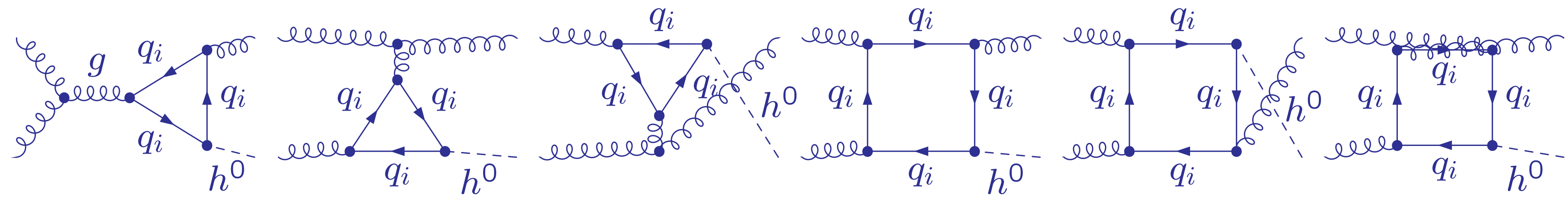
* additional superpartner-loops (even additional topologies)

→ also angular distribution changed

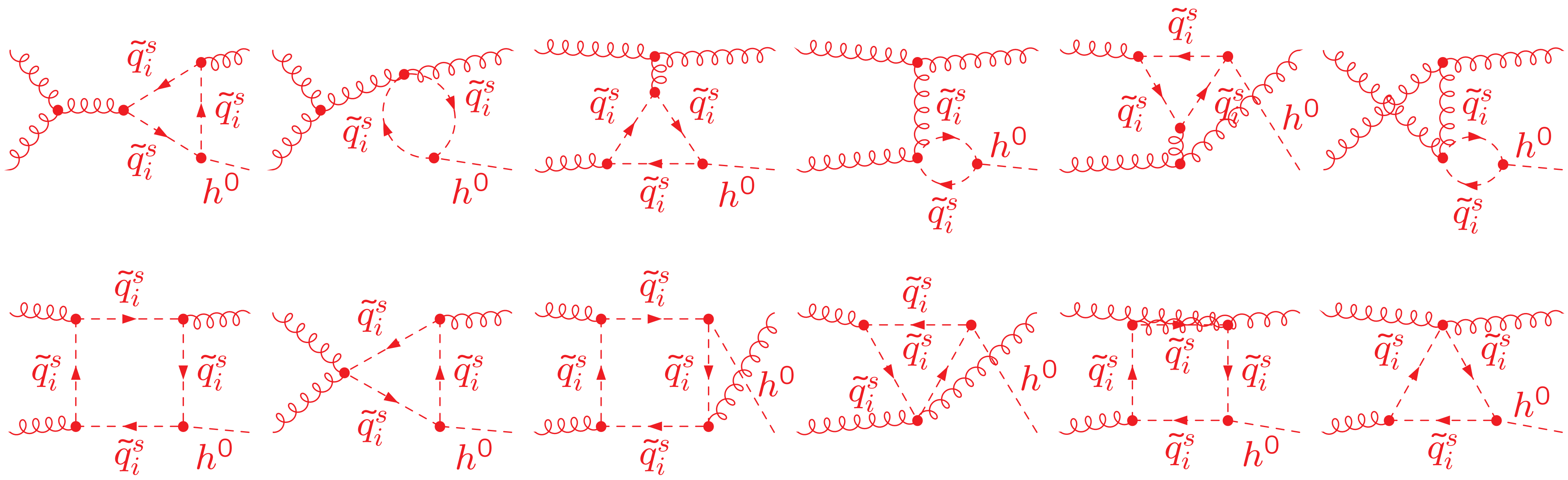
– Feynman graphs

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

quark loops

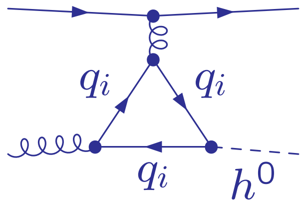


superpartner loops

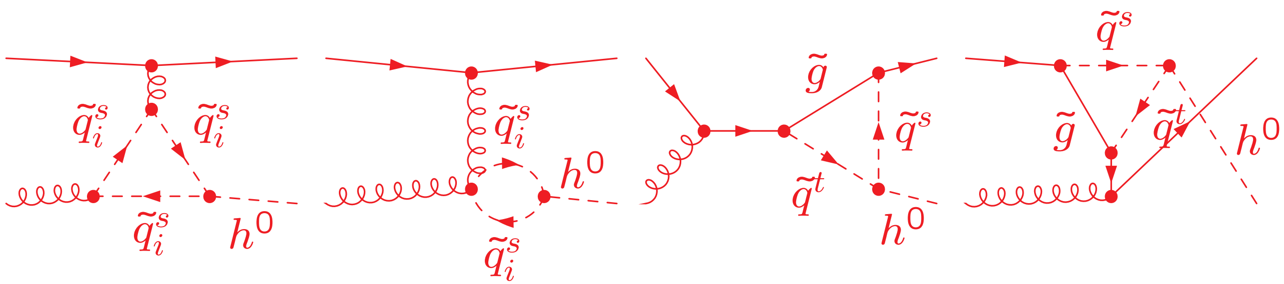


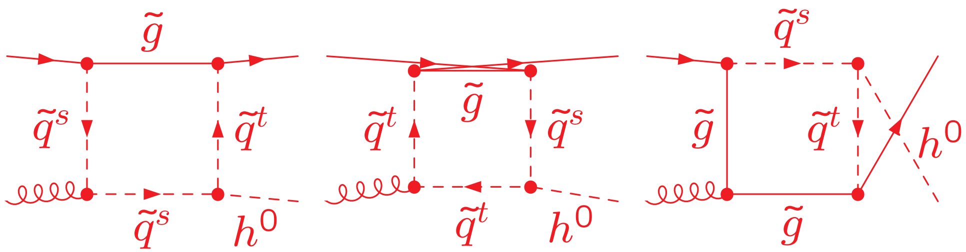
quark gluon scattering, $qg \to h^0 q$

quark loops



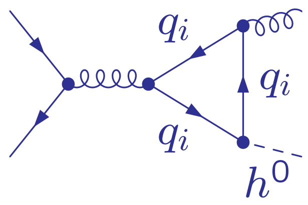
superpartner loops



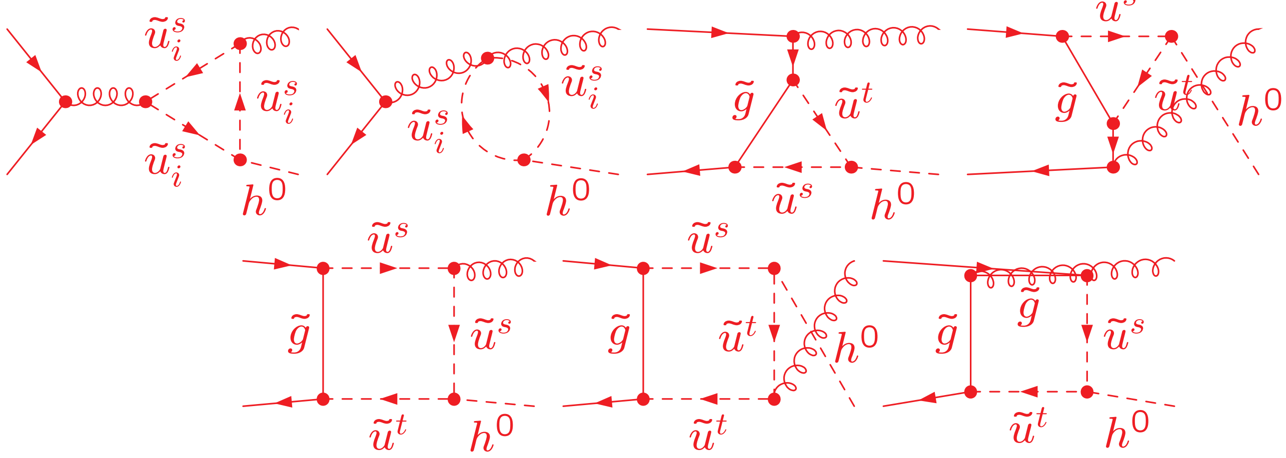


quark anti-quark annihilation, $q\bar{q} \longrightarrow h^0 g$

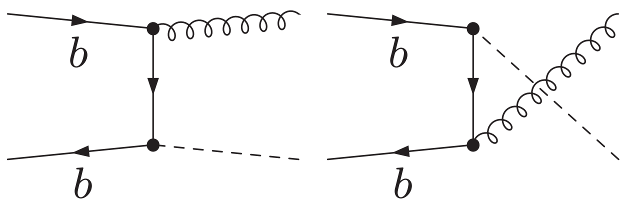
quark loops



superpartner loops



b-quark processes: bg scattering, $bg \longrightarrow h^0 b$,
$b\bar{b}$ annihilation, $b\bar{b} \longrightarrow h^0 g$



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

- MSSM results

– total cross section

total hadronic cross section @ LHC

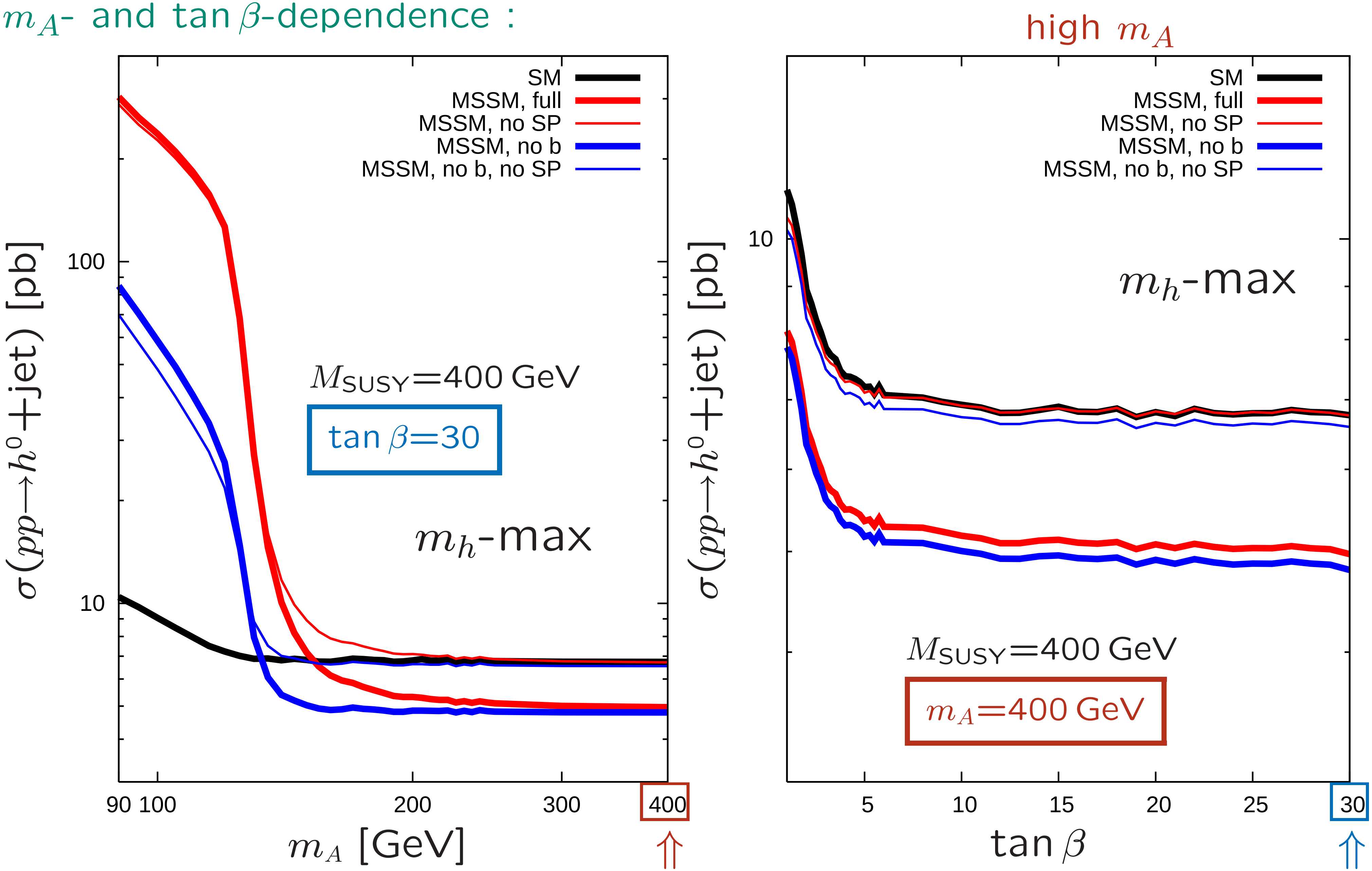
$$\sigma(pp \to h^0 + \text{jet} + X)$$

applying the cuts

$p_{T,\text{jet}} \geq 30\,\text{GeV}$ and $|\eta_{\text{jet}}| \leq 4.5$

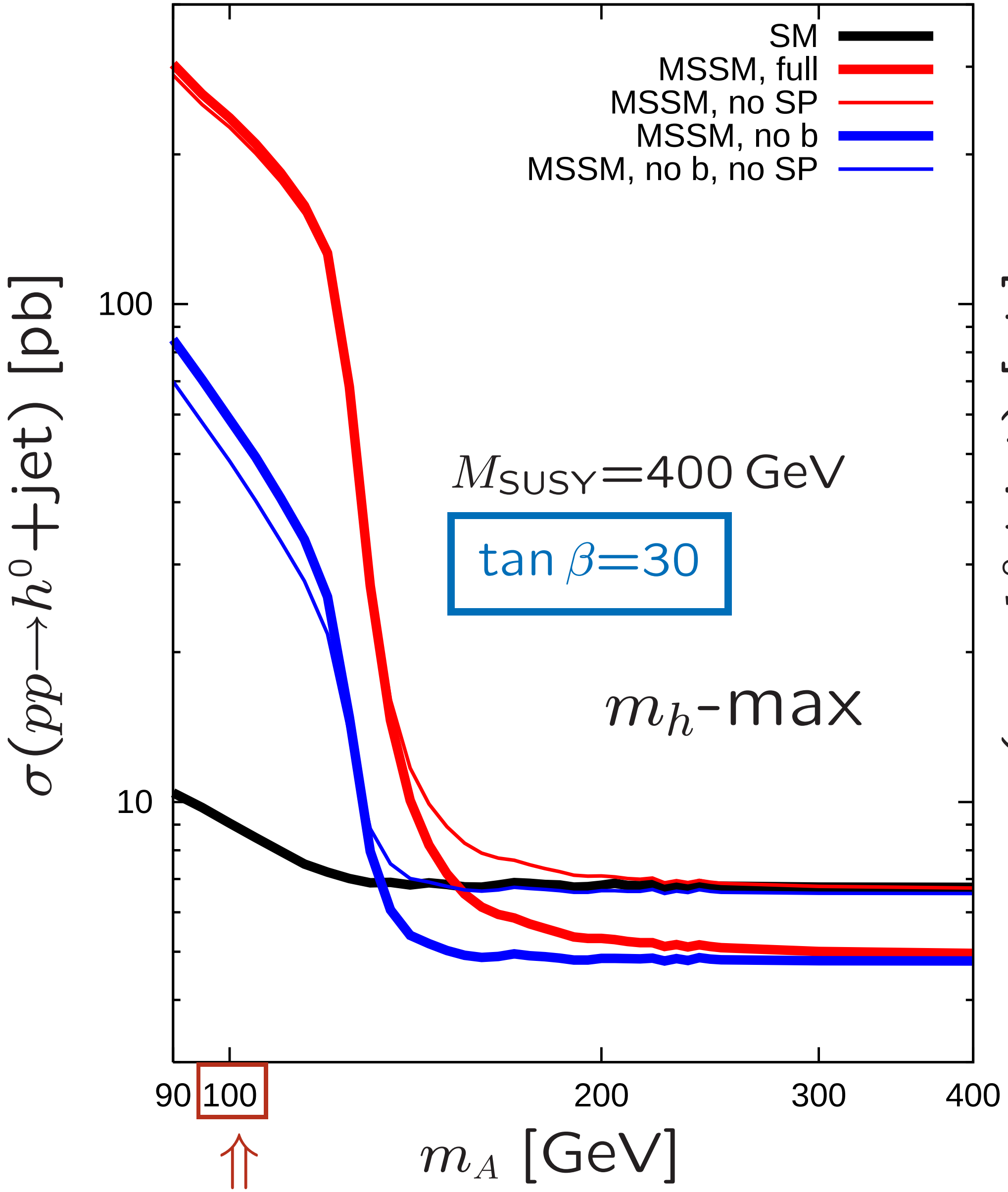
[MSSM results, total cross section]

m_A- and $\tan\beta$-dependence :

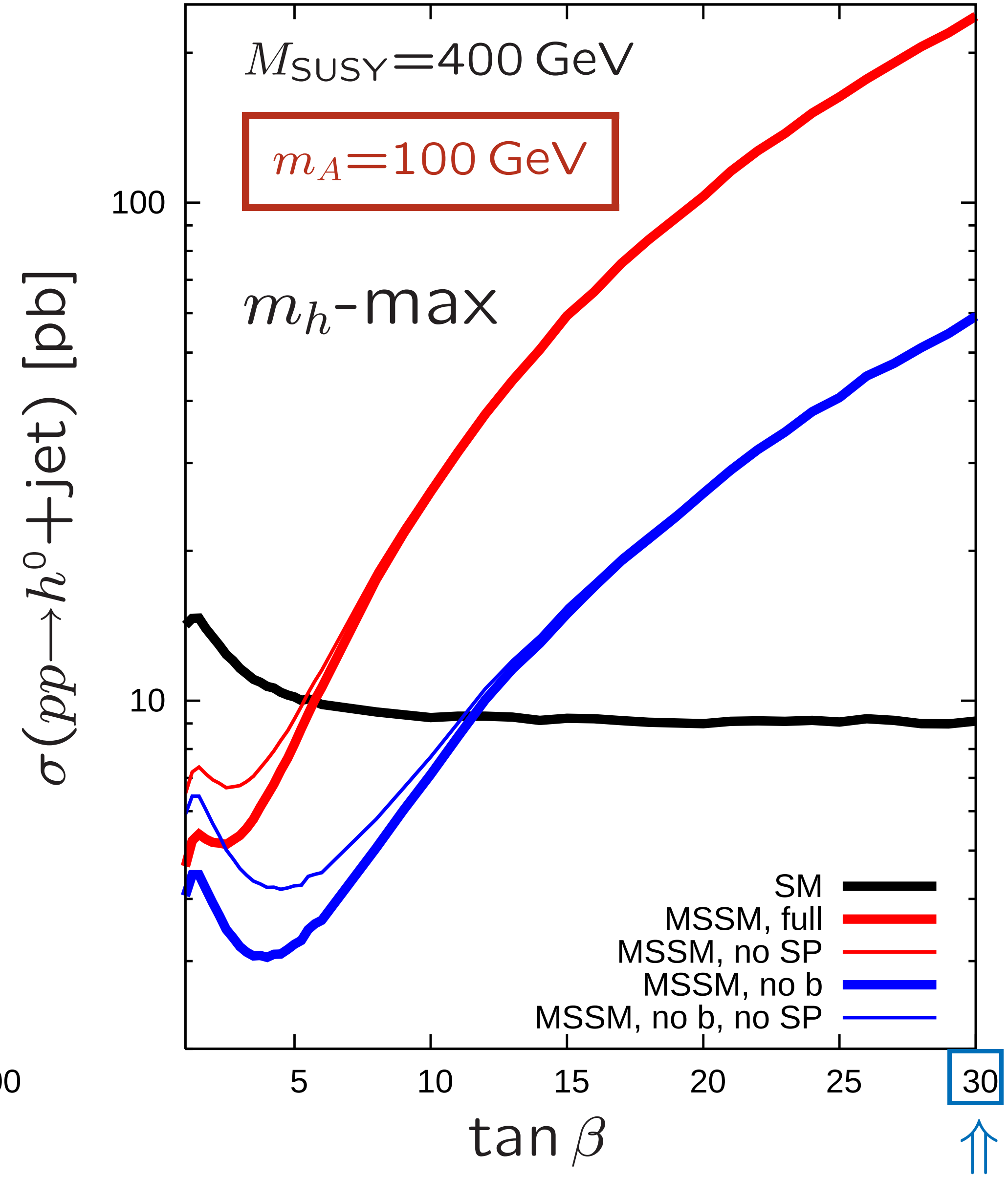


[MSSM results, total cross section]

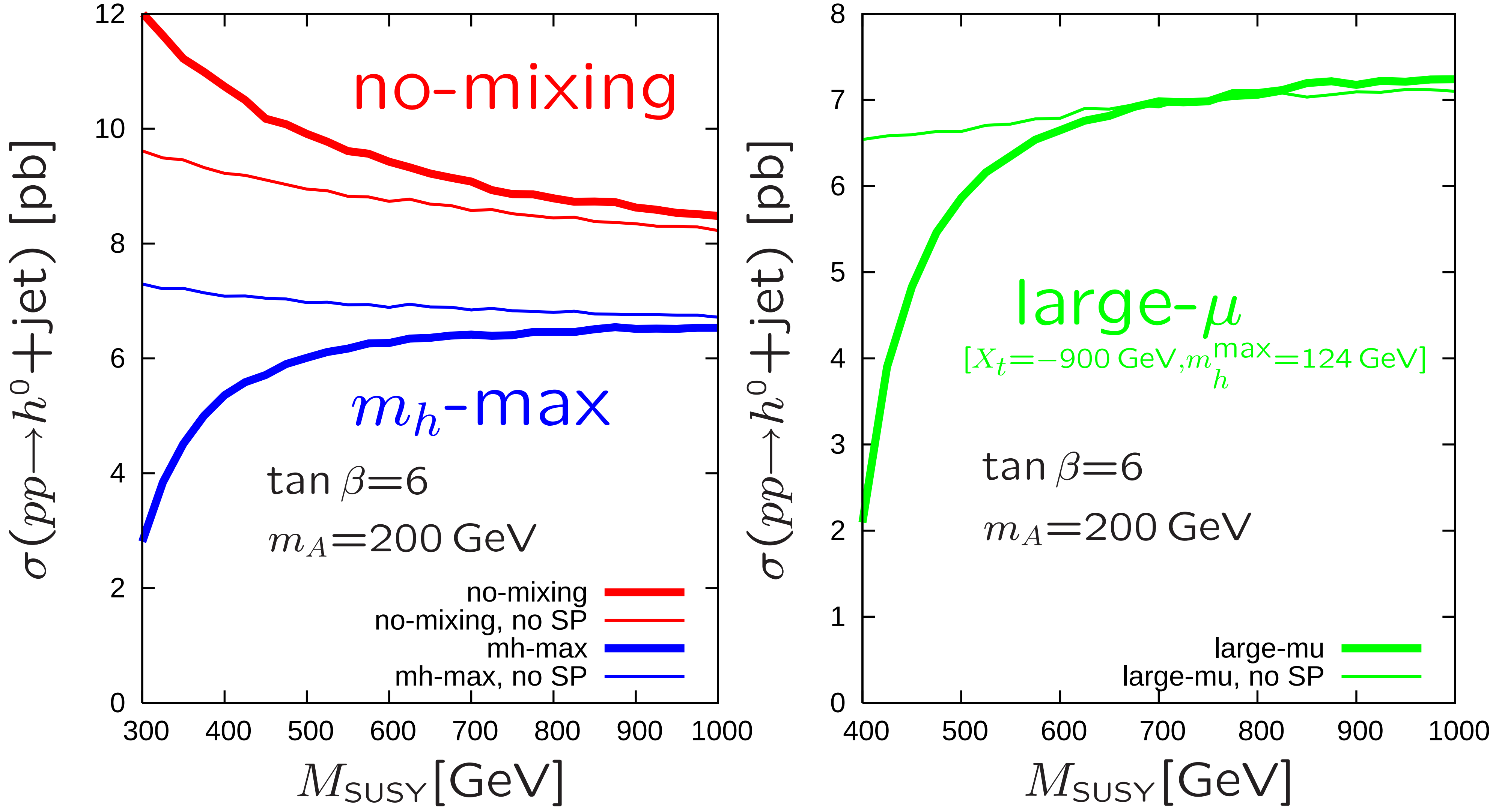
m_A- and $\tan\beta$-dependence :



low m_A

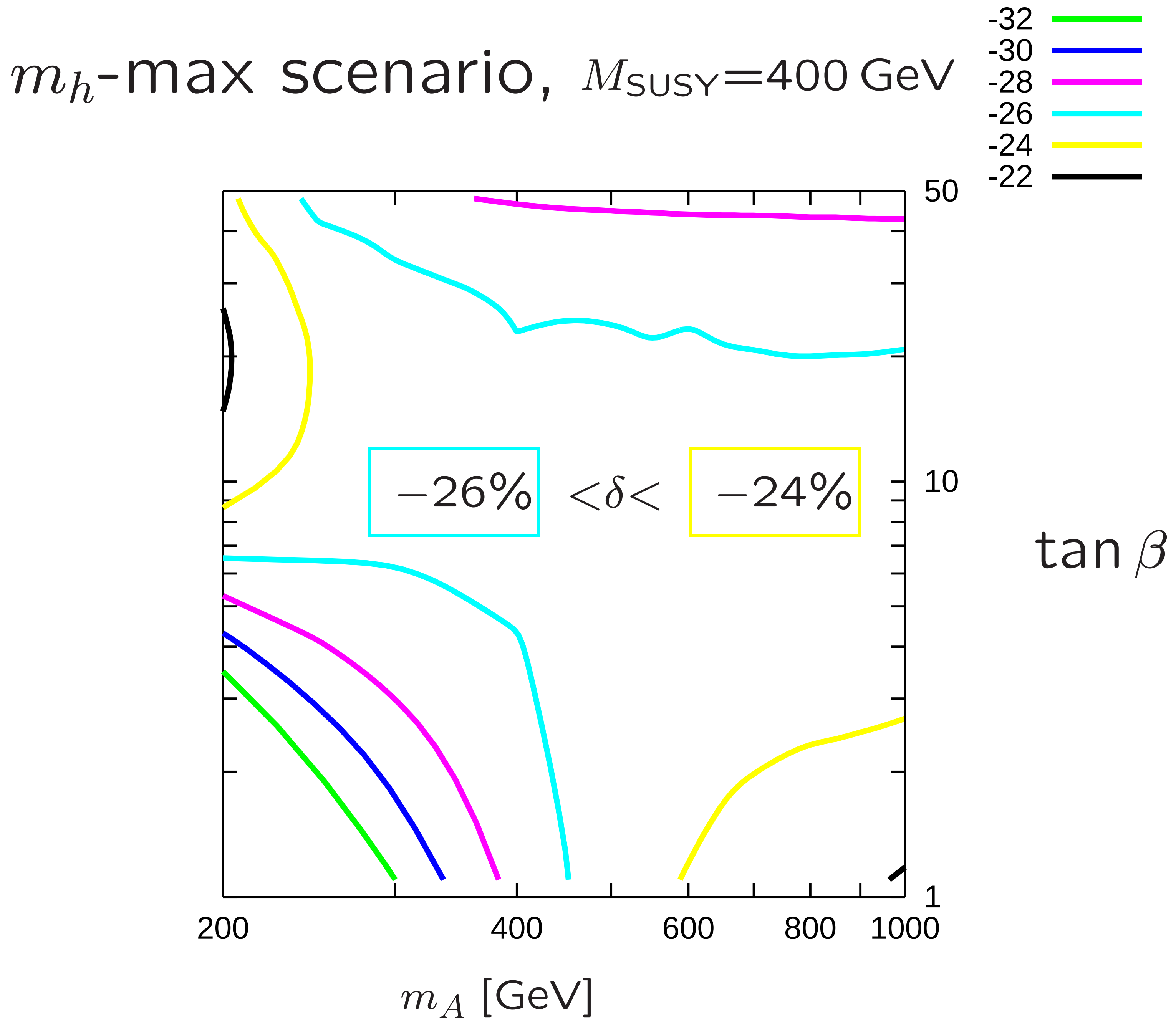


M_{SUSY} -dependence :



[MSSM results, total cross section]

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



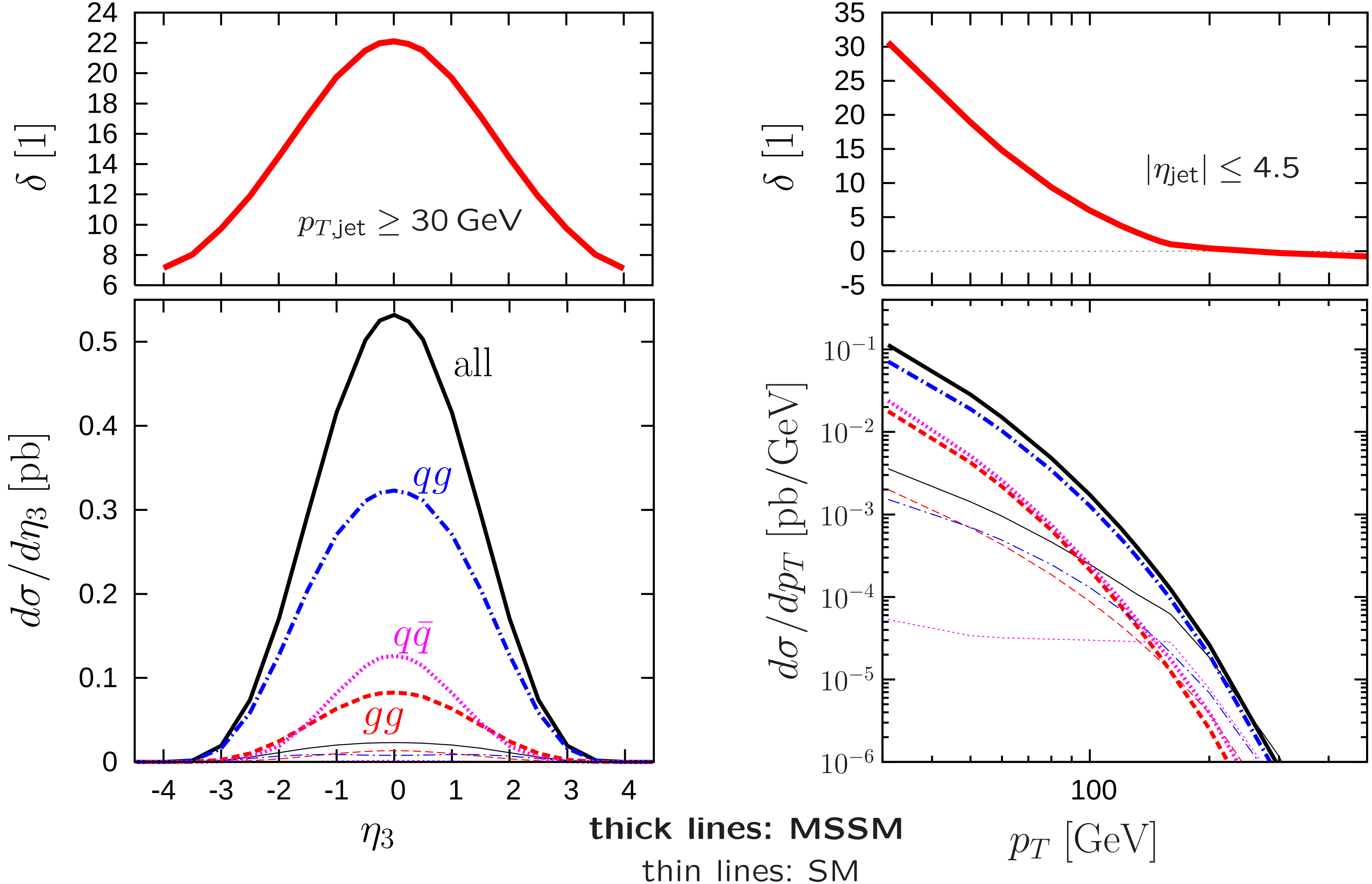
– differential cross section

differential hadronic cross sections @ LHC/Tevatron

$$\frac{d\sigma(S,p_{T,\text{jet}})}{dp_{T,\text{jet}}},\quad \frac{d\sigma(S,\eta_{\text{jet}})}{d\eta_{\text{jet}}},\quad \frac{d^2\sigma(S,p_{T,\text{jet}},\eta_{\text{jet}})}{dp_{T,\text{jet}}\,d\eta_{\text{jet}}}$$

$p_{T,\text{jet}}$- and η_{jet}-dependence, low-m_A case

Tevatron, m_h-**max scenario**, $M_{\text{SUSY}} = 400$ **GeV**, $m_A = 110$ **GeV**, $\tan\beta = 30$

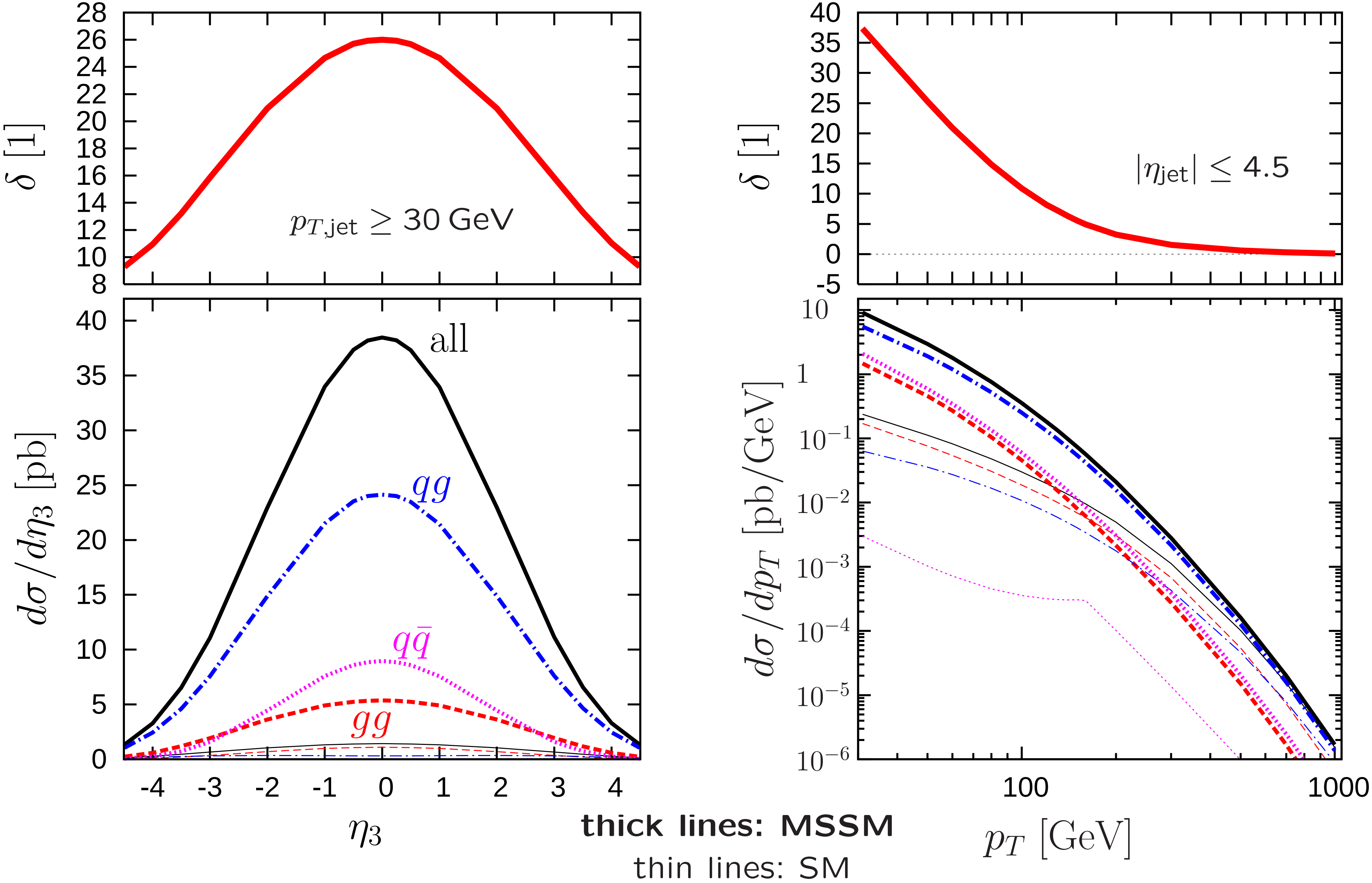


thick lines: MSSM

thin lines: SM

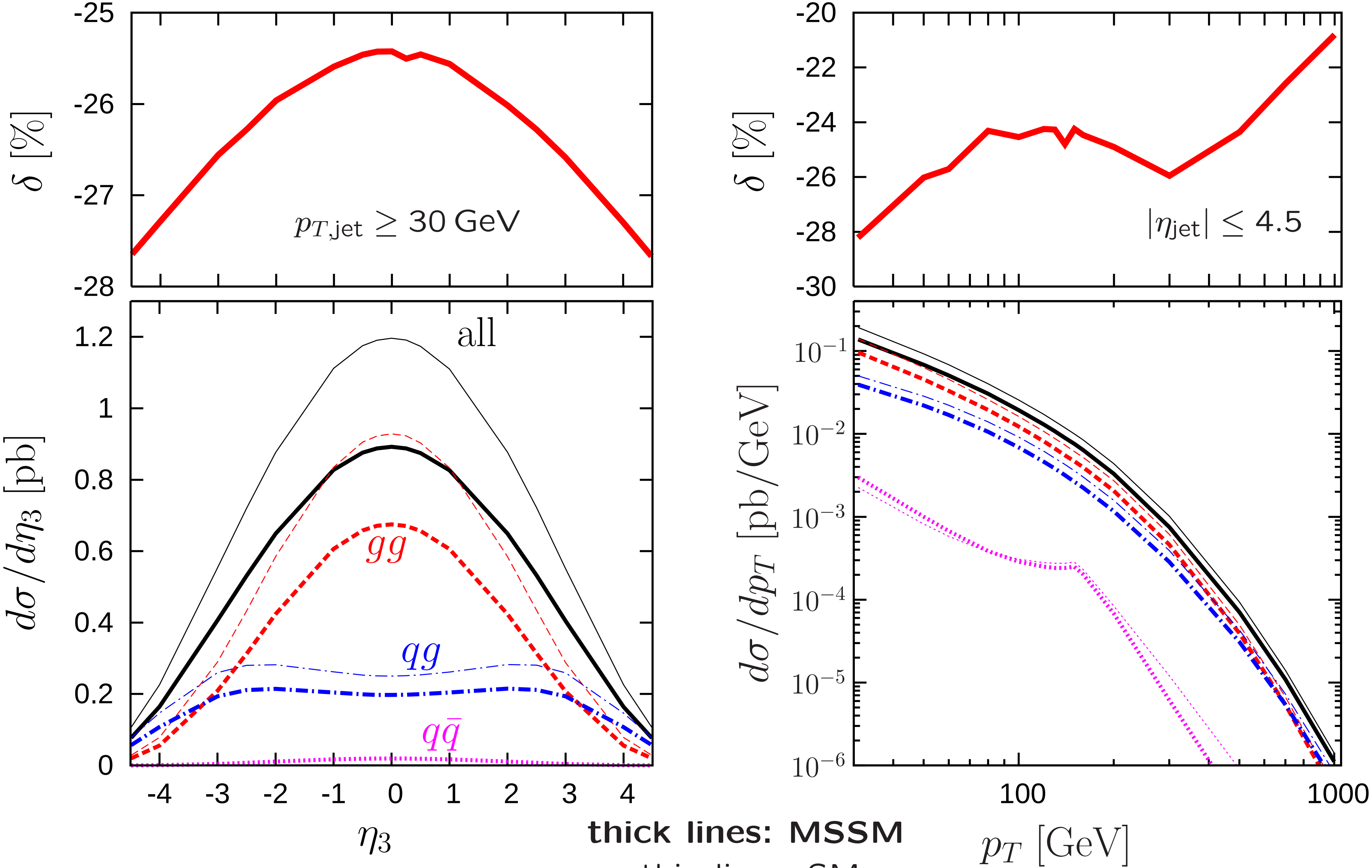
$p_{T,\text{jet}}$- and η_{jet}-dependence, low-m_A case

LHC, m_h-**max scenario**, $M_{\text{SUSY}} = 400$ **GeV**, $m_A = 110$ **GeV**, $\tan\beta = 30$



$p_{T,\text{jet}}$- and η_{jet}-dependence, high-m_A case

LHC, **m_h-max scenario**, $M_{\text{SUSY}} = 400$ **GeV**, $m_A = 400$ **GeV**, $\tan\beta = 30$

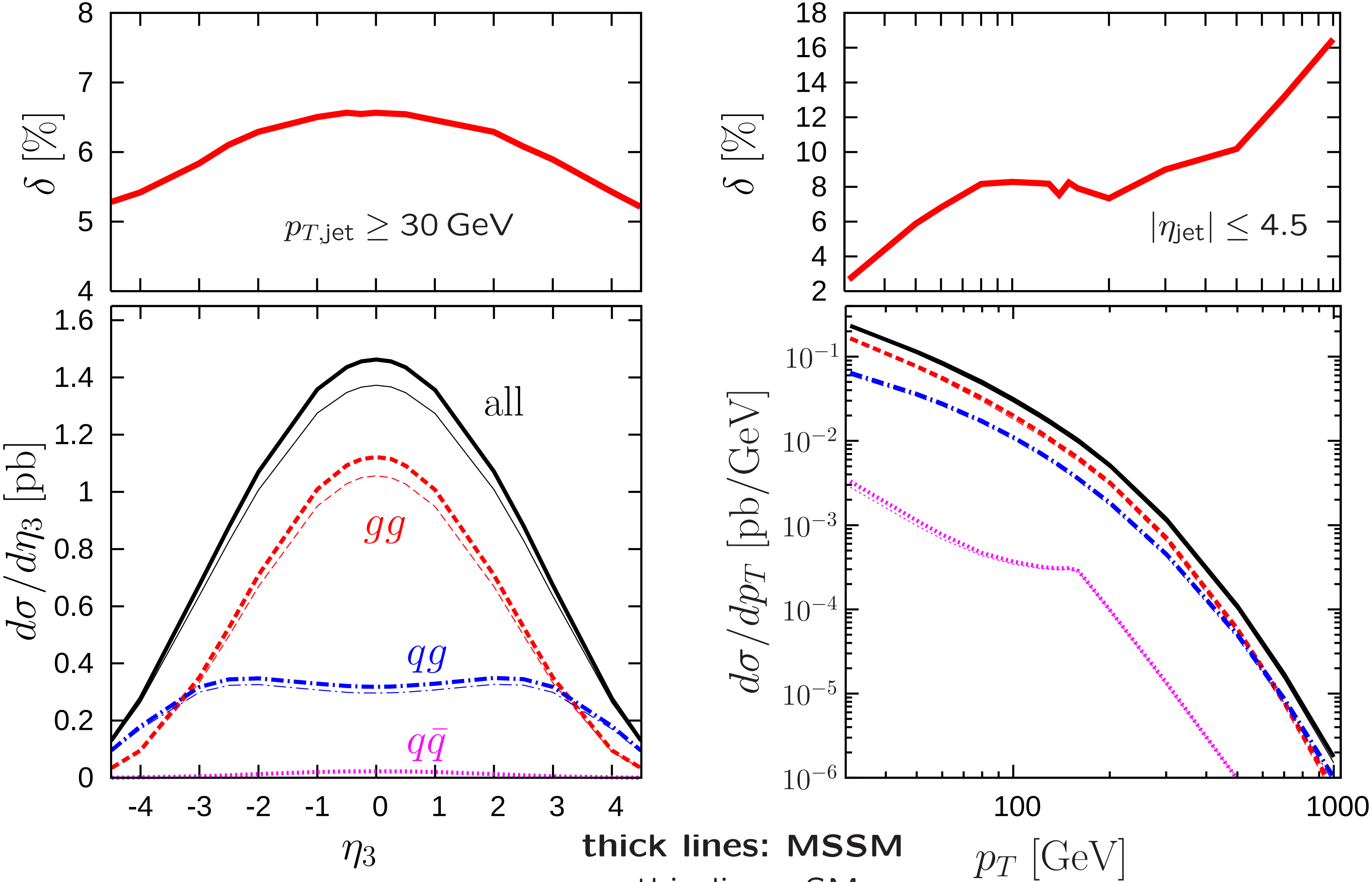


thick lines: MSSM

thin lines: SM

$p_{T,\text{jet}}$- and η_{jet}-dependence, high-m_A case

LHC, no-mixing(700) scenario, $M_{\text{SUSY}} = 700$ **GeV,** $m_A = 500$ **GeV,** $\tan\beta = 35$

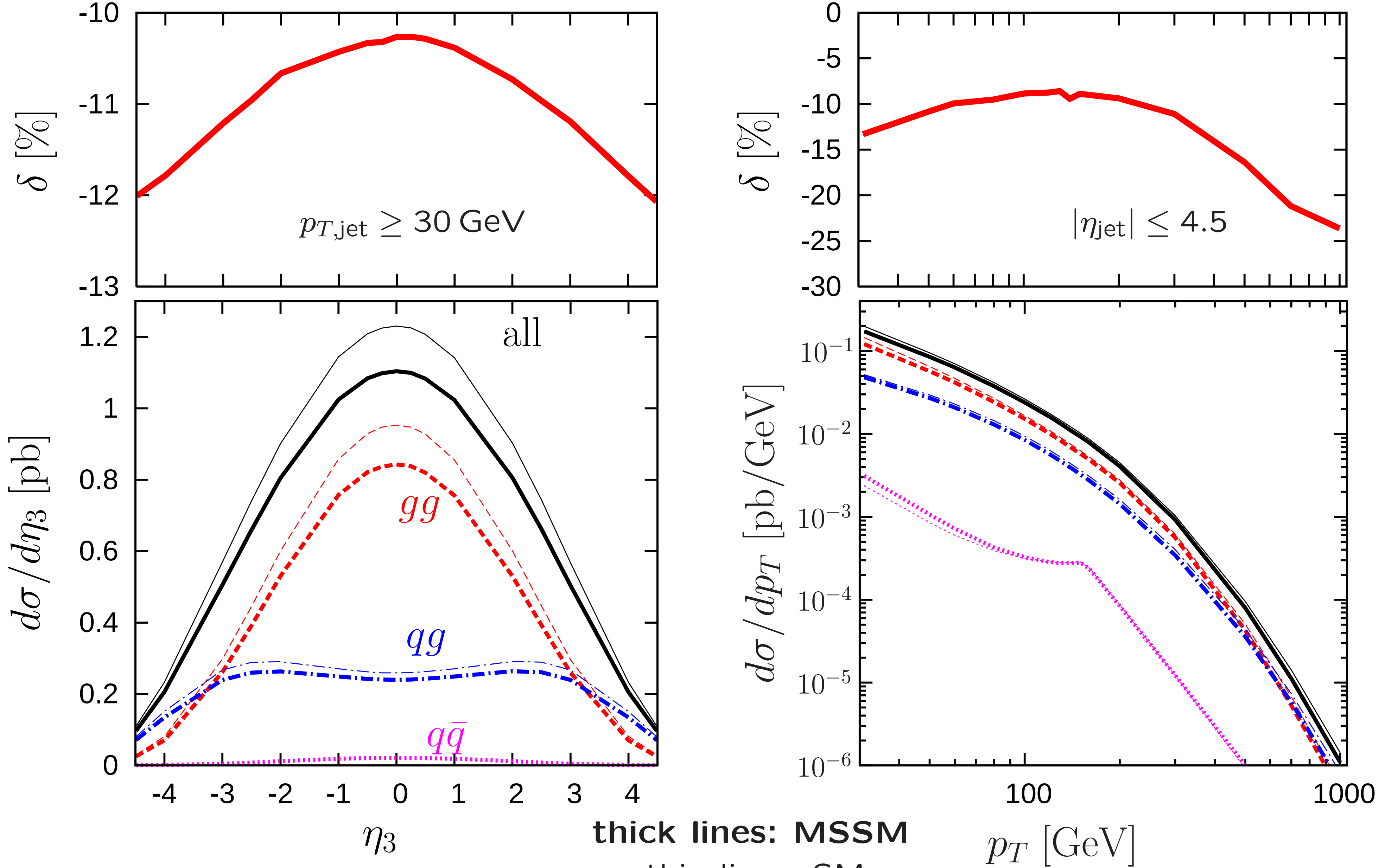


thick lines: MSSM
thin lines: SM

[MSSM results, differential cross section]

$p_{T,\text{jet}}$- and η_{jet}-dependence, high-m_A case

LHC, **small-α_{eff} scenario**, $m_A = 400\,$**GeV**, $\tan\beta = 30$



thick lines: MSSM

thin lines: SM

1st Question : Can we detect such 2 %-ish differences
in the η or p_T distribution ? $\longrightarrow$ No !
$\longrightarrow$ absolute cross section measurement :
systematic uncertainties too large !

2nd Question : Can we do better than that ? $\longrightarrow$ Yes
$\longrightarrow$ larger differences occur in the η-p_T plane
$\longrightarrow$ define suitable ratios of cross sections

LHC, $\frac{d^2\sigma}{dp_{T,\mathrm{jet}}d\eta_{\mathrm{jet}}}$: MSSM − SM relative and absolute difference

relative difference in % :

contour lines ——

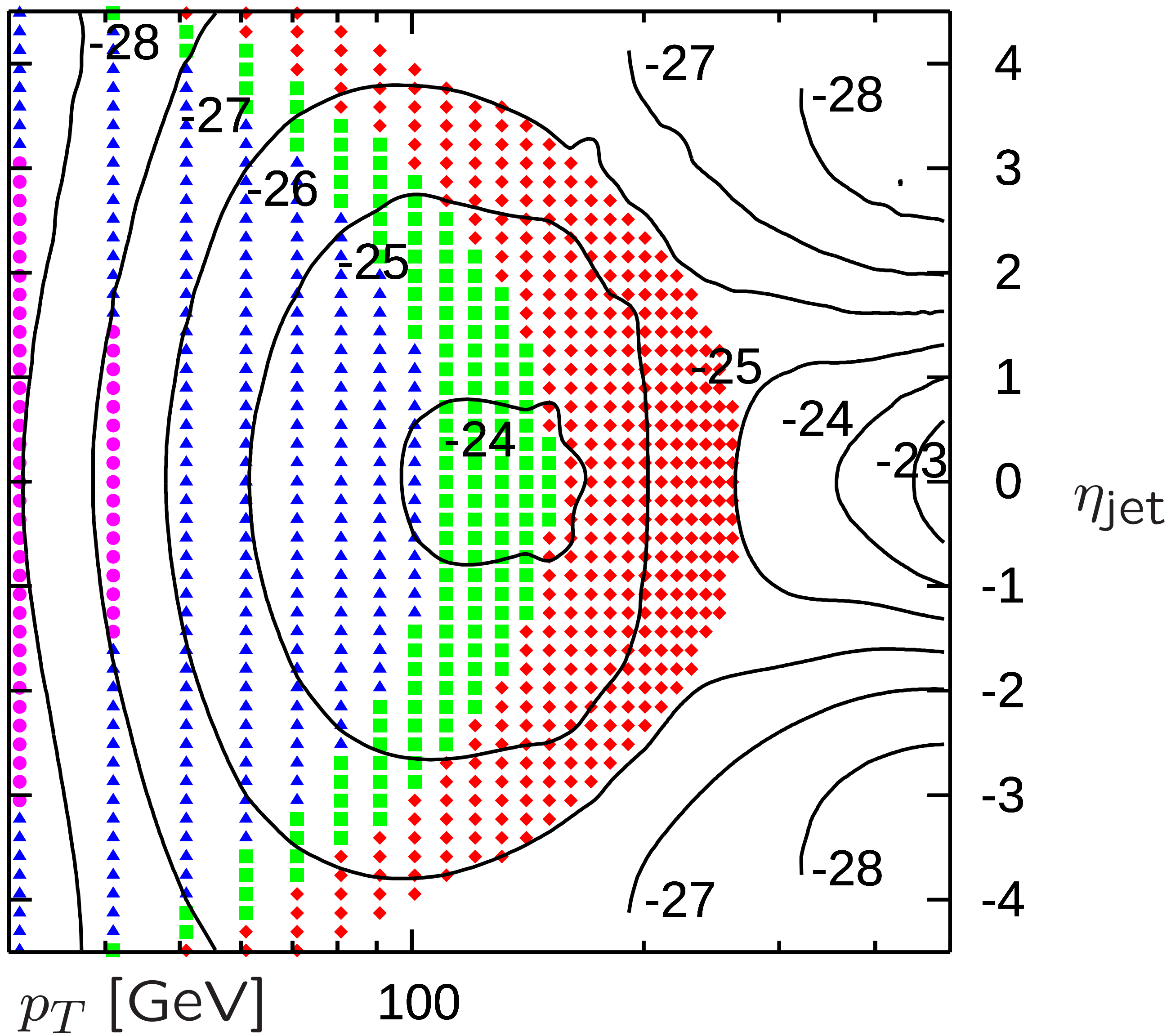
absolute difference :

● : 5 - 10 fb/GeV

▲ : 1 - 5 fb/GeV

■ : 0.5 - 1 fb/GeV

♦ : 0.1 - 0.5 fb/GeV



LHC, m_h-max scenario, $M_{\mathrm{SUSY}} = 400$ GeV, $m_A = 400$ GeV, $\tan\beta = 30$

LHC, $\frac{d^2\sigma}{dp_{T,\text{jet}}d\eta_\text{jet}}$: MSSM − SM relative and absolute difference

relative difference in % :

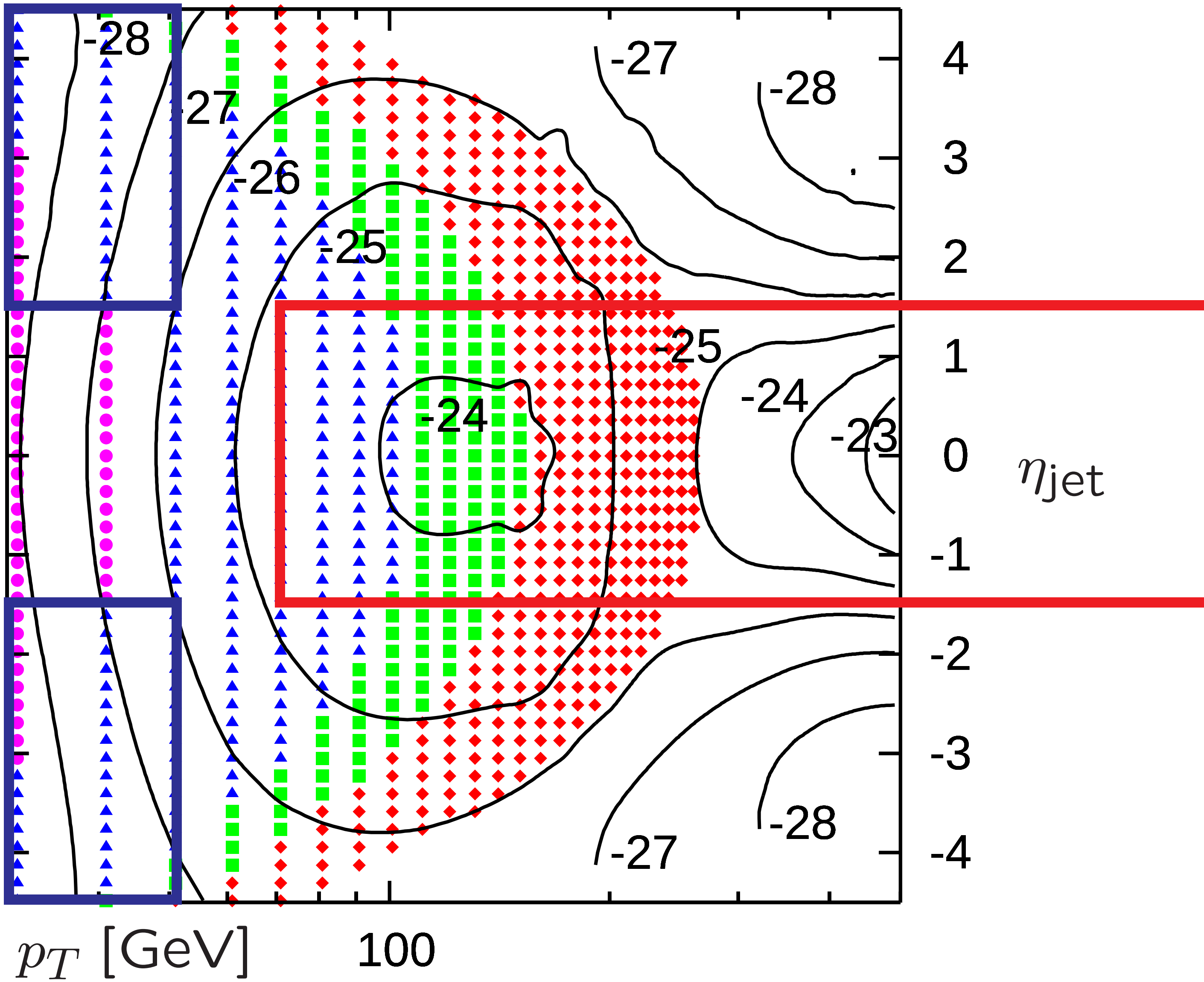
contour lines ——

absolute difference :

- ● : 5 - 10 fb/GeV
- ▲ : 1 - 5 fb/GeV
- ■ : 0.5 - 1 fb/GeV
- ♦ : 0.1 - 0.5 fb/GeV

→ consider ratio :

$$R = \frac{\sigma\left(\begin{array}{c} p_T > 70\ \text{GeV} \\ |\eta| < 1.5 \end{array}\right)}{\sigma\left(\begin{array}{c} p_T \in [30, 50]\ \text{GeV} \\ |\eta| > 1.5 \end{array}\right)}$$



LHC, m_h-max scenario, $M_\text{SUSY} = 400$ GeV, $m_A = 400$ GeV, $\tan\beta = 30$

[MSSM results, differential cross section]

example: ratio $R = \dfrac{\sigma\left(\boxed{|\eta| < 1.5,\ p_T > 70\ \text{GeV}}\right)}{\sigma\left(\boxed{|\eta| > 1.5,\ p_T \in [30, 50]\ \text{GeV}}\right)}$

for the above m_h-max scenario at the LHC ($m_A = 400$ GeV, $\tan\beta = 30$):

quantity	SM	MSSM
$\sigma\left(\boxed{|\eta| < 1.5, p_T > 70\ \text{GeV}}\right)$	1.448 pb	1.096 pb
$\sigma\left(\boxed{|\eta| > 1.5, p_T \in [30, 50]\ \text{GeV}}\right)$	1.419 pb	1.031 pb
R	1.020	1.063

$$\rightarrow \Delta = \frac{R_{\text{MSSM}} - R_{\text{SM}}}{R_{\text{SM}}} = 4.2\%$$

FORTRAN code HJET to calculate the MSSM (and SM) cross sections,

$$\sigma^{\text{total}}_{\text{hadronic}},$$

$$\frac{d\sigma_{\text{hadronic}}}{d\sqrt{\hat{s}}}, \quad \frac{d\sigma_{\text{hadronic}}}{dp_{T,\text{jet}}}, \quad \frac{d\sigma_{\text{hadronic}}}{d\eta_{\text{jet}}},$$

$$\frac{d^2\sigma_{\text{hadronic}}}{dp_{T,\text{jet}}\, d\eta_{\text{jet}}}$$

$$\hat{\sigma}^{\text{total}}_{\text{partonic}},$$

$$\frac{d\hat{\sigma}_{\text{partonic}}}{d\Omega}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{d\hat{t}}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{dy_{\text{jet}}}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{dp_{T,\text{jet}}},$$

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summary

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

- difference between MSSM and SM Higgs + jet production also extends to the shapes of differential distributions.
  - if b-quark processes dominate (low m_A):
    - * much larger cross sections and softer p_T spectrum
  - if loop-induced processes dominate (high m_A):
    - * large effect on total cross section due to (rather light) virtual squarks
    - * mild but possibly measurable deviations in differential distributions with non-trivial variation in the whole η-p_T plane

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