Higgs + Jet angular and p_T distributions : MSSM versus SM

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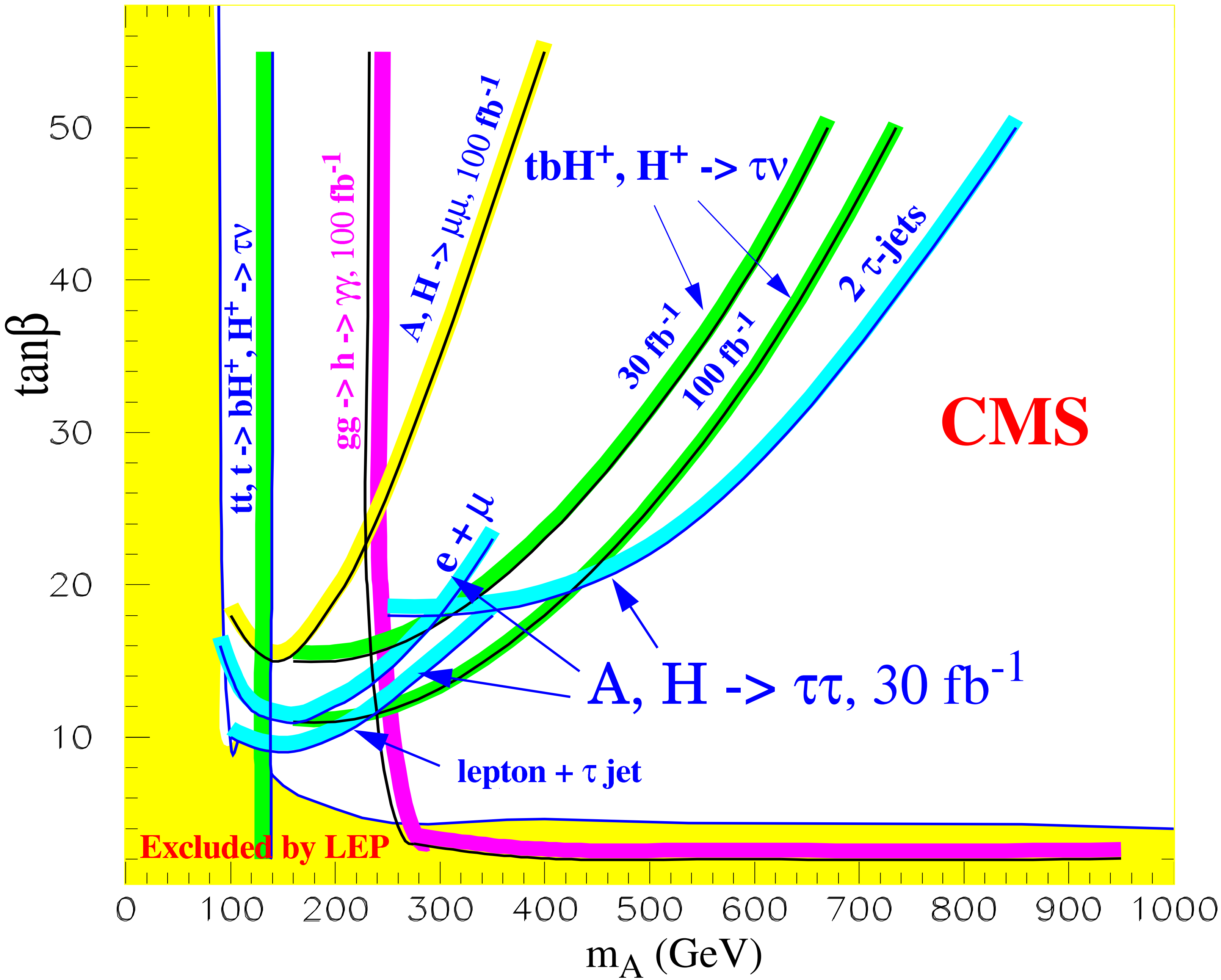
outline :

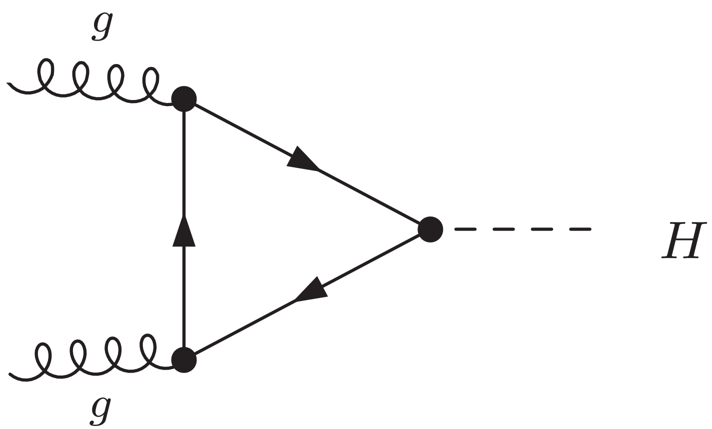
- Higgs + jet in the Standard Model
  - Higgs production @ the LHC
  - Higgs + jet
- Higgs + jet in the MSSM
  - differences to the SM
  - Feynman graphs
- MSSM results
  - total hadronic cross section @ LHC ($\sqrt{S} = 14\,\text{TeV}$)
  - differential hadronic cross section

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.
  → better S/B ratio
  → allows for refined cuts

disadvantage:

* lower rate than inclusive Higgs production

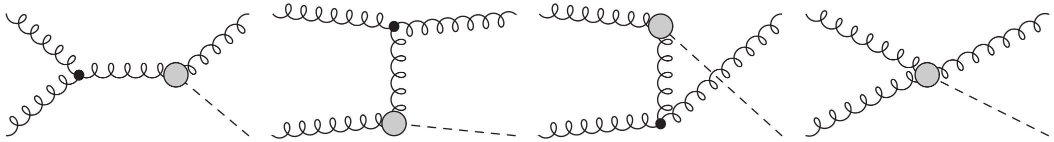
(*) NLO signal prediction has still sizable theoretical uncertainty ($\approx$ 20%)

(*) background only partly known at NLO accuracy

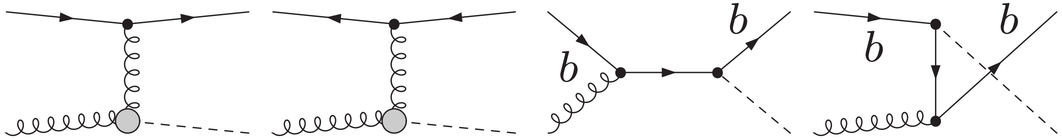
→ theoretical uncertainties larger than in the fully inclusive case (so far)

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

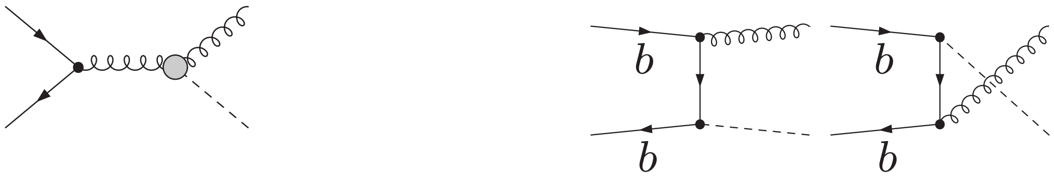
- $gg \longrightarrow Hg$ (≈ 50 - 70 % of total rate)



- $qg \longrightarrow Hq, \bar{q}g \longrightarrow H\bar{q}$ (≈ 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 $pp \to H + \text{jet}$
  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 $pp \to H + X$

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

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

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

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

$\rightarrow$ change of overall rate

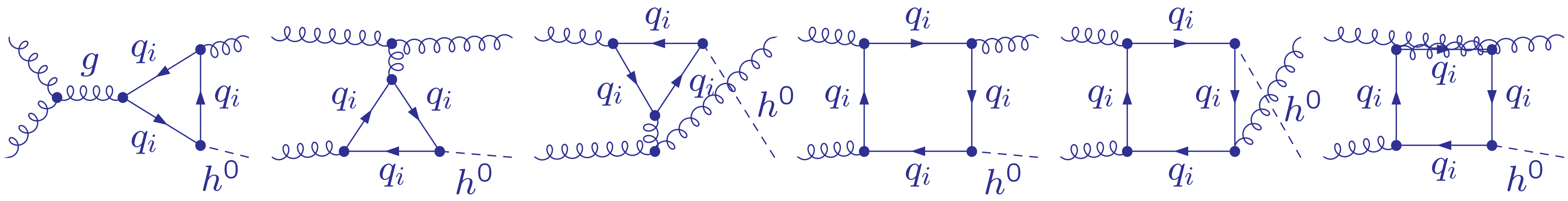
* additional superpartner-loops (even additional topologies)

$\rightarrow$ also angular distribution changed

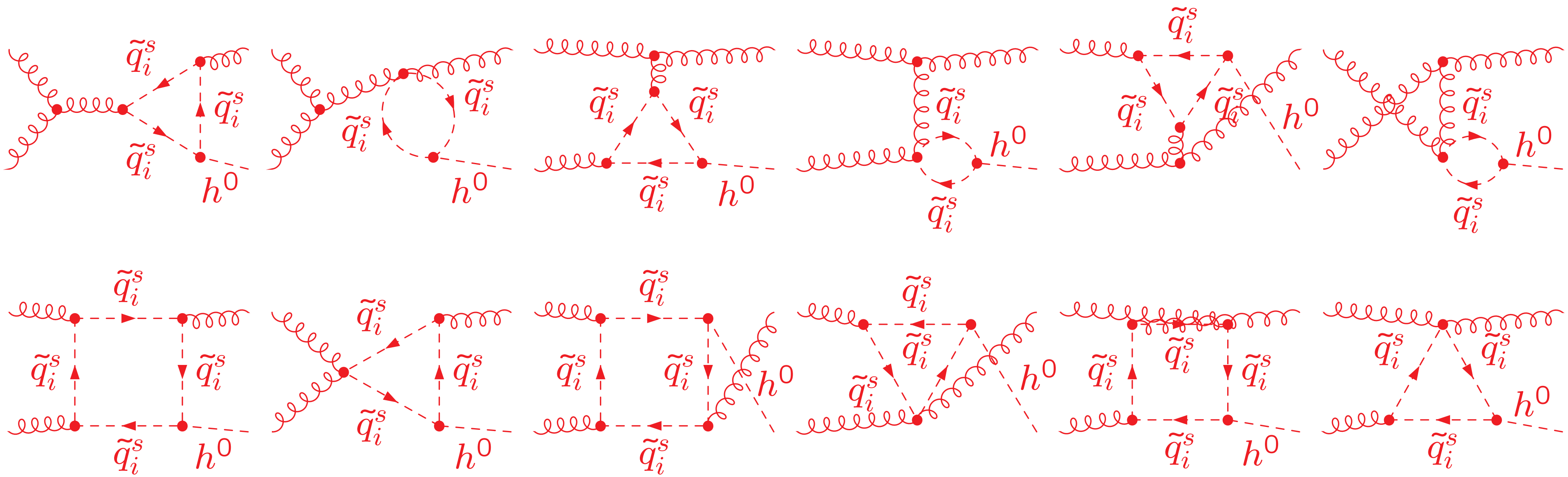
– Feynman graphs [Field et al.'03; Langenegger et al. '06] (only quark loops)

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

quark loops

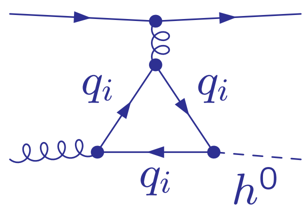


superpartner loops

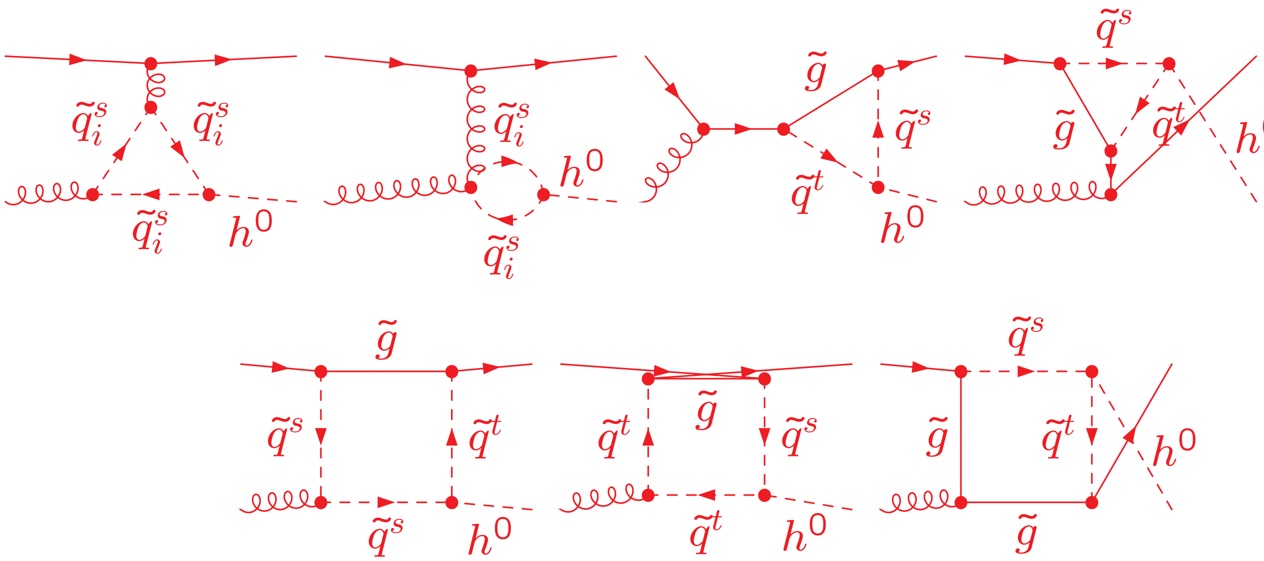


quark-gluon scattering, $qg \to h^0 q$

quark loops

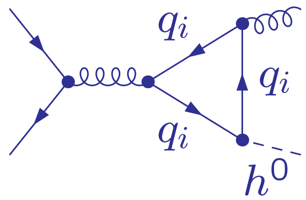


superpartner loops

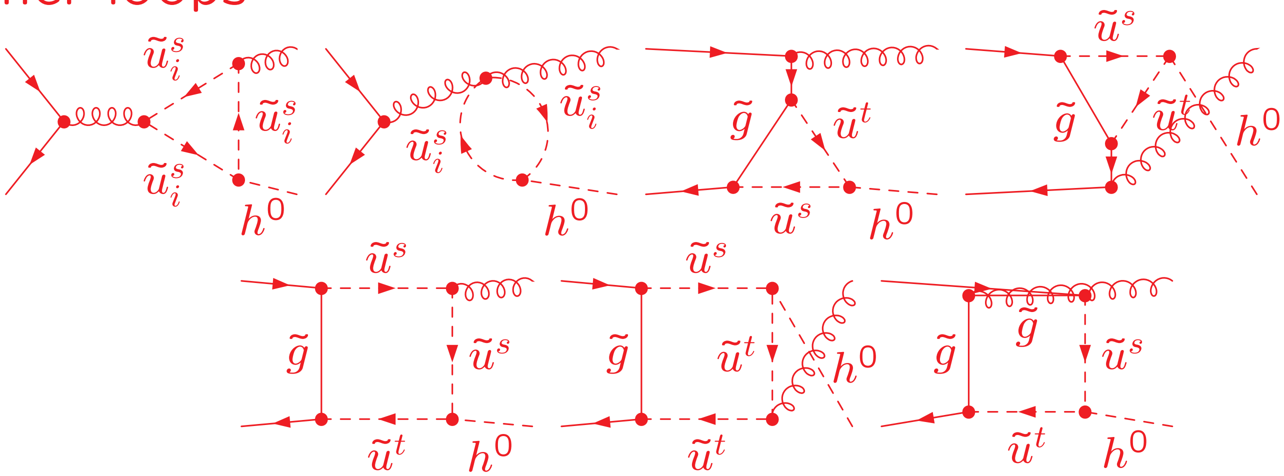


quark-antiquark annihilation, $q\bar{q} \to h^0 g$

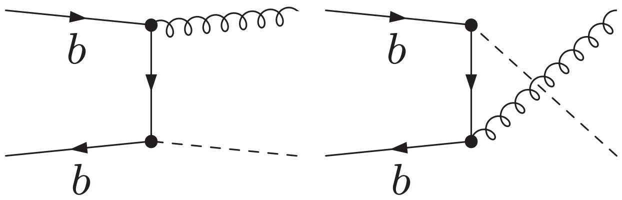
quark loops



superpartner loops



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



• MSSM results

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

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

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

with the parton luminosity

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

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.

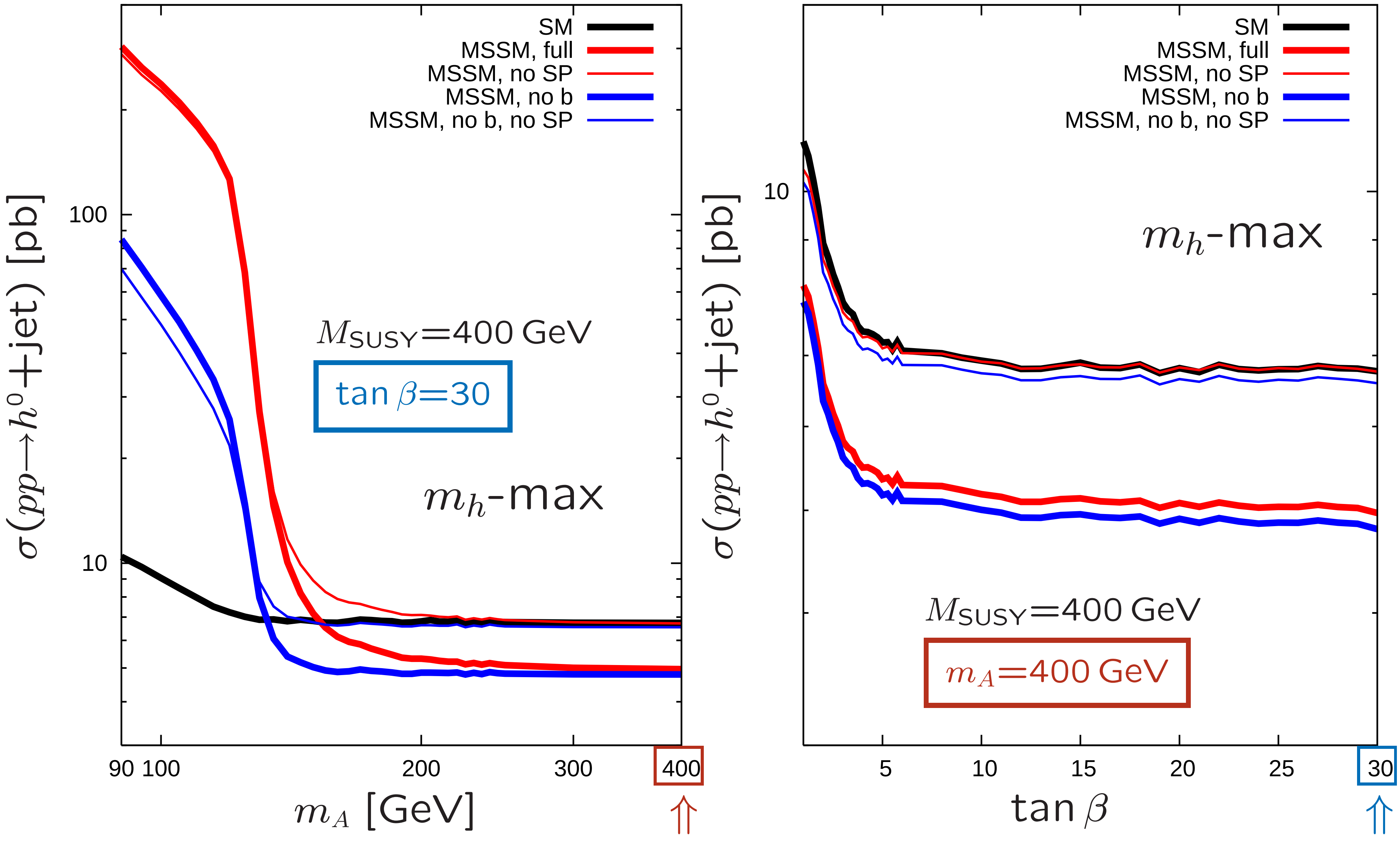
The results shown are for the MSSM m_h^{max} benchmark scenario with common squark mass scale M_{SUSY}.

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

[MSSM results, total hadronic cross section]

m_A- and $\tan\beta$-dependence

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



$M_{\rm SUSY}$-dependence

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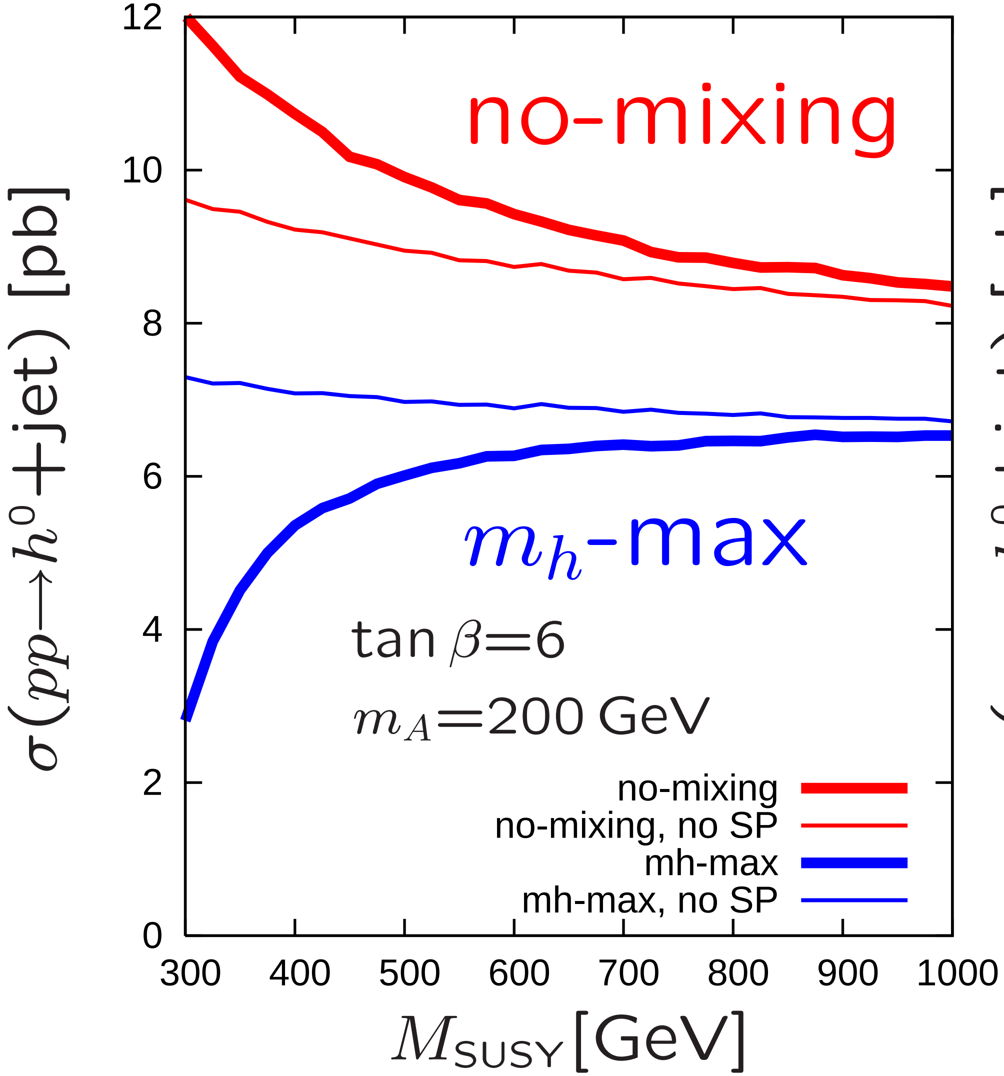
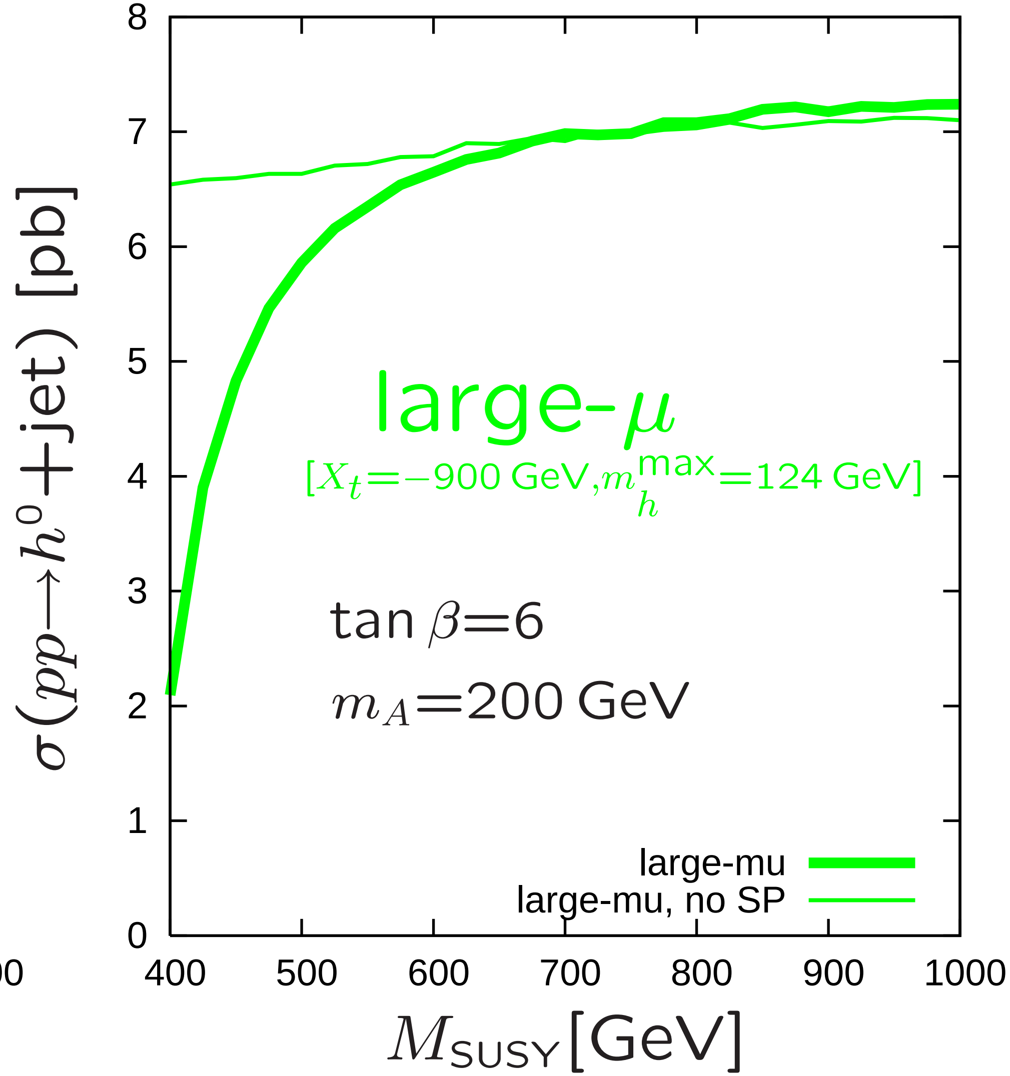
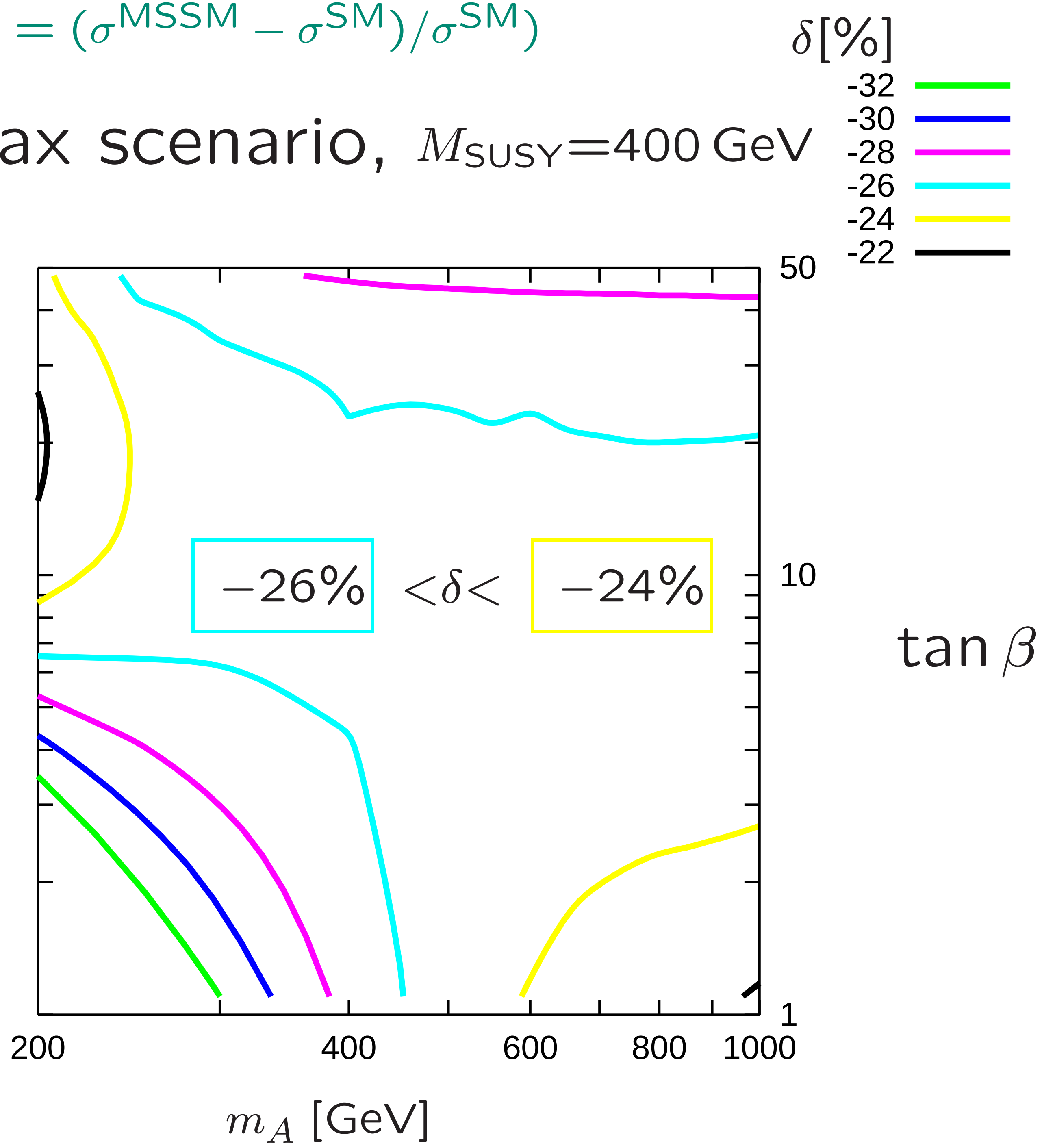




relative difference $\delta = (\sigma^{\text{MSSM}} - \sigma^{\text{SM}})/\sigma^{\text{SM}})$

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



– differential hadronic cross section

$$\frac{d\sigma(S,p_T)}{dp_T} = \sum_{\{n,m\}} \int_{\tau_0}^{1} d\tau \frac{d\mathcal{L}_{nm}^{AB}}{d\tau} \frac{d\hat{\sigma}_{nm}(\hat{s}=\tau S, p_T)}{dp_T}$$

$$\frac{d\sigma(S,y_{\text{jet}}^{\text{lab}})}{dy_{\text{jet}}^{\text{lab}}} = \sum_{\{n,m\}} \int_{\tau_0}^{1} d\tau \int_{\tau}^{1} \frac{dx}{x} \left\{ \frac{f_{n/A}(x) f_{m/B}(\frac{\tau}{x})}{1+\delta_{nm}} \frac{d\hat{\sigma}_{nm}(\hat{s}=\tau S, \hat{y}_{\text{jet}})}{d\hat{y}_{\text{jet}}} \Bigg|_{\hat{y}_{\text{jet}}=Y(y_{\text{jet}}^{\text{lab}},\tau,x)} + \frac{f_{m/A}(x) f_{n/B}(\frac{\tau}{x})}{1+\delta_{nm}} \frac{d\hat{\sigma}_{nm}(\hat{s}=\tau S, \hat{y}_{\text{jet}})}{d\hat{y}_{\text{jet}}} \Bigg|_{\hat{y}_{\text{jet}}=-Y(y_{\text{jet}}^{\text{lab}},\tau,x)} \right\}$$

with

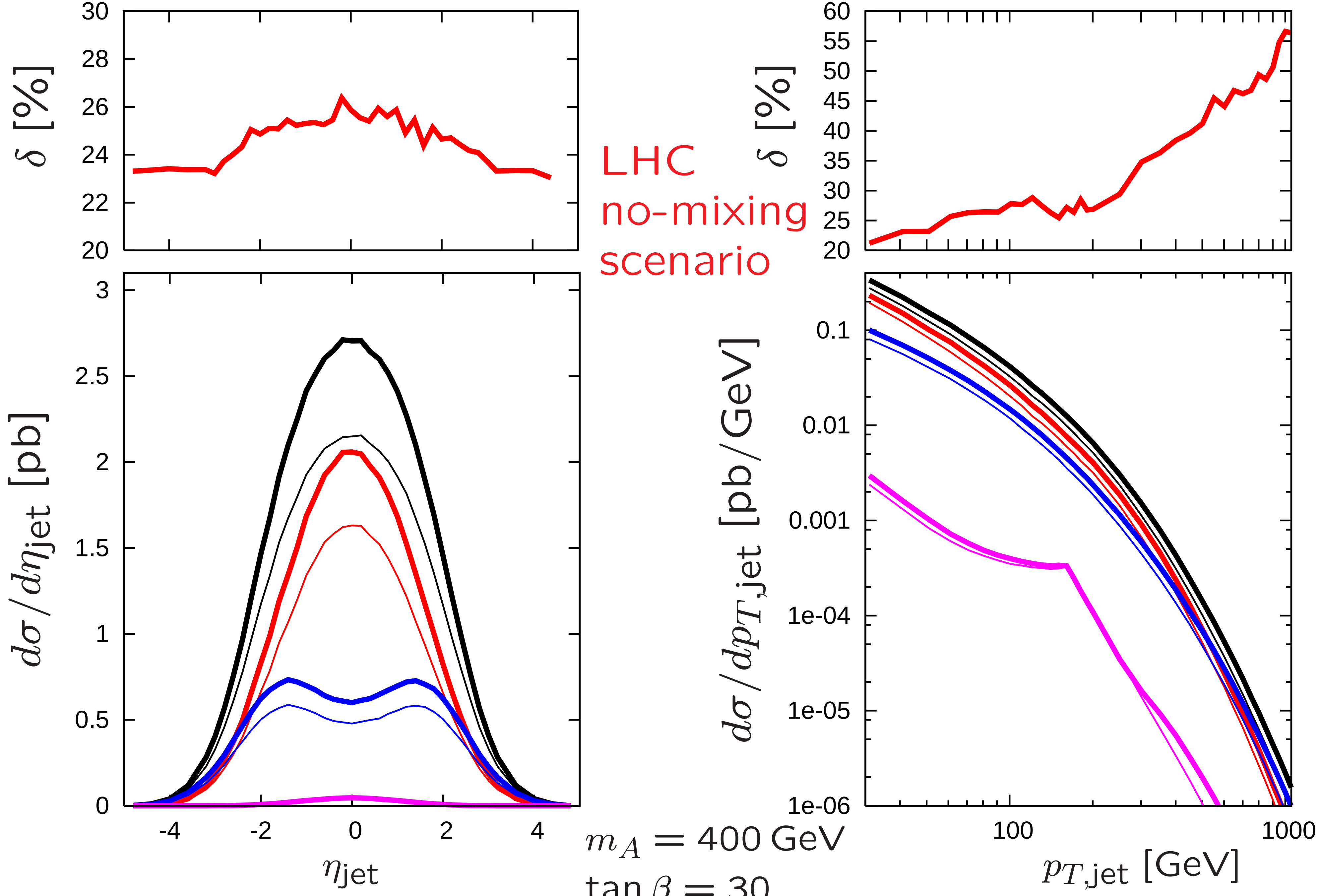
$$Y(y_{\text{jet}}^{\text{lab}},\tau,x) = y_{\text{jet}}^{\text{lab}} + \tanh\left(\frac{\tau - x^2}{\tau + x^2}\right).$$

Also here, the cuts, $p_{T,\text{jet}} \geq 30\,\text{GeV}$, $|\eta_{\text{jet}}| \leq 4.5$ have been applied.

Note that the pseudo-rapidity $\eta_{\text{jet}} = y_{\text{jet}}^{\text{lab}}$ for the massless outgoing parton.

$p_{T,\text{jet}}$- and y_{jet}-dependence :

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



$m_A = 400$ GeV

$\tan\beta = 30$

[MSSM results, differential hadronic c. s.]

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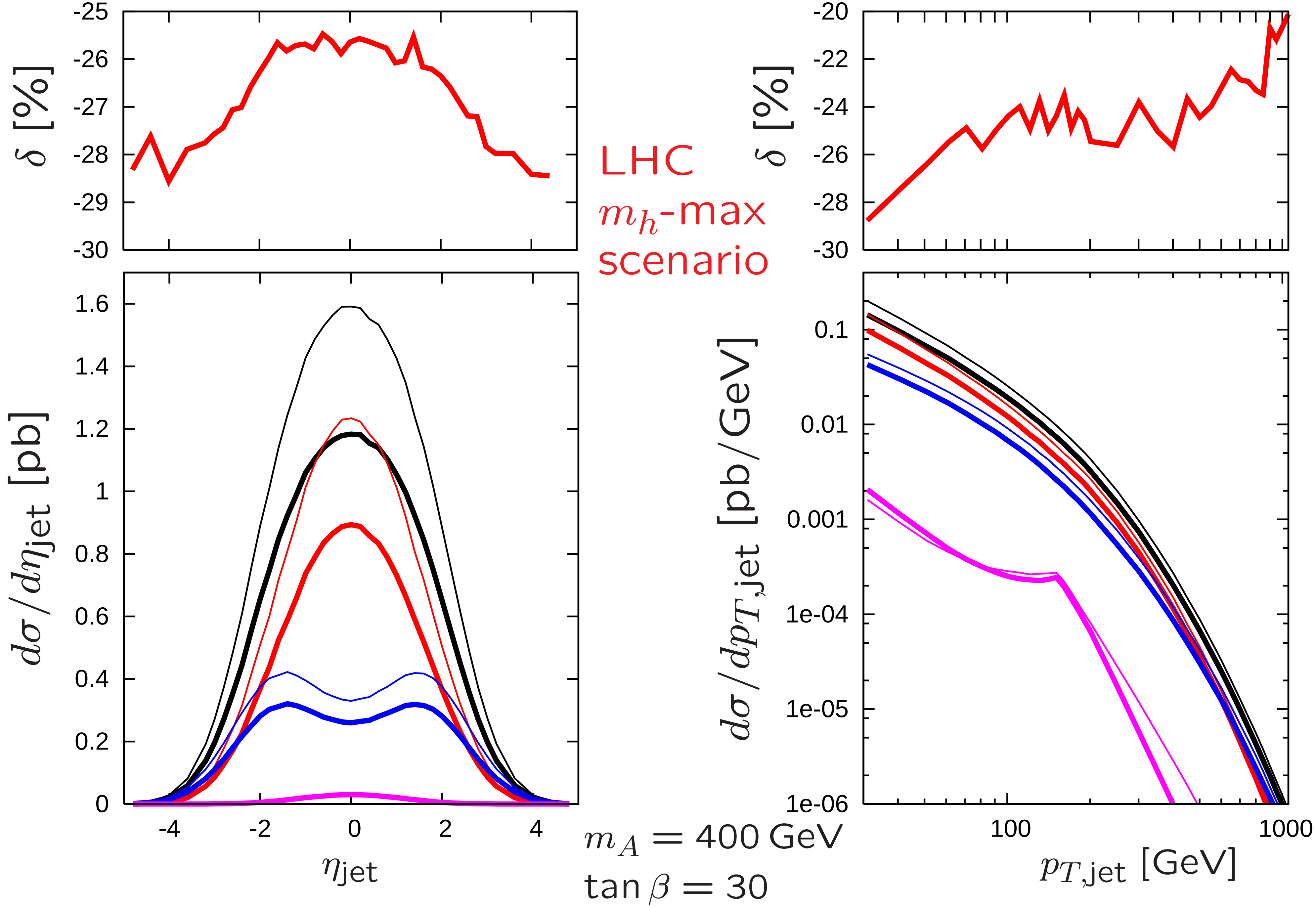

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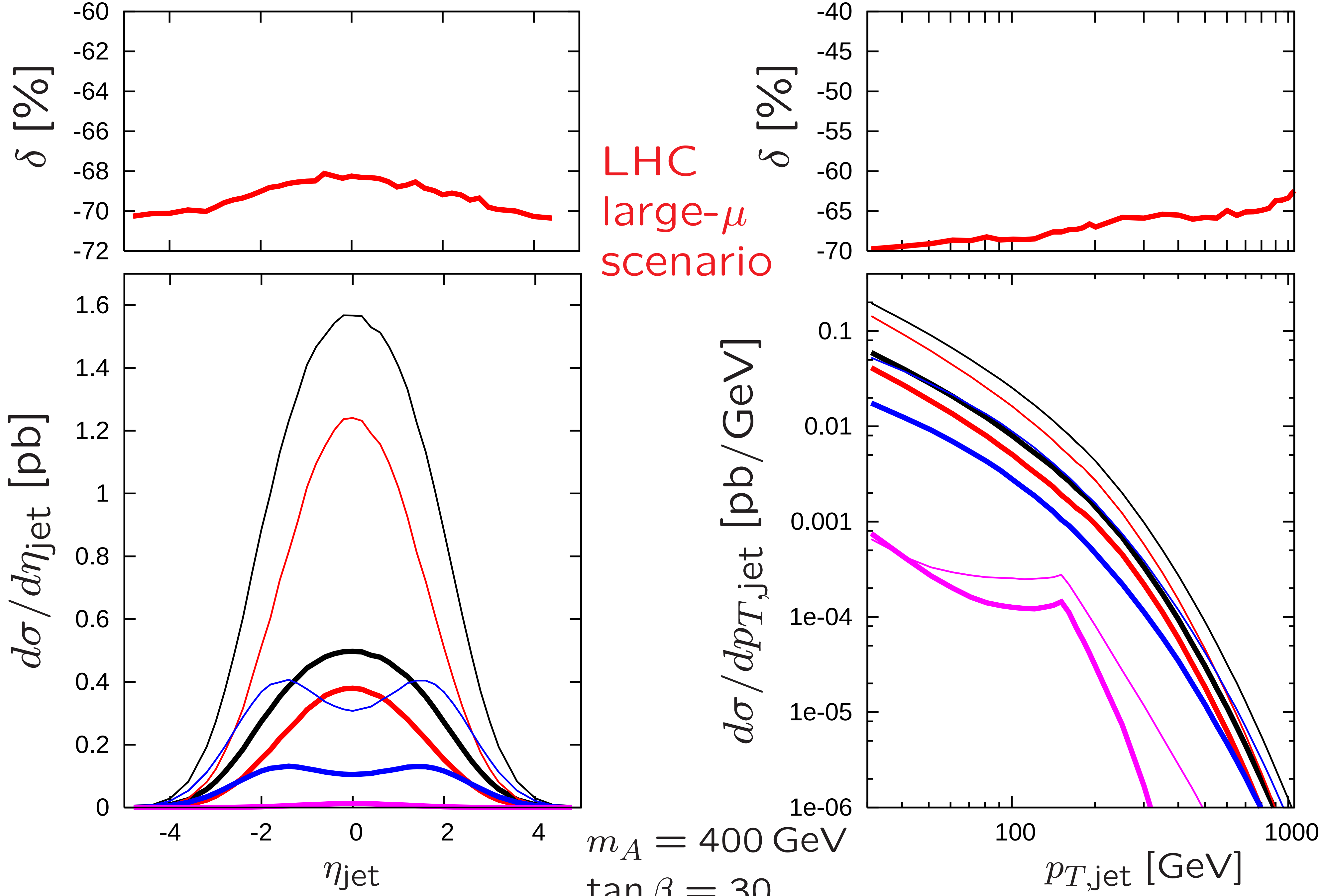

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summary

- 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,

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

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

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

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

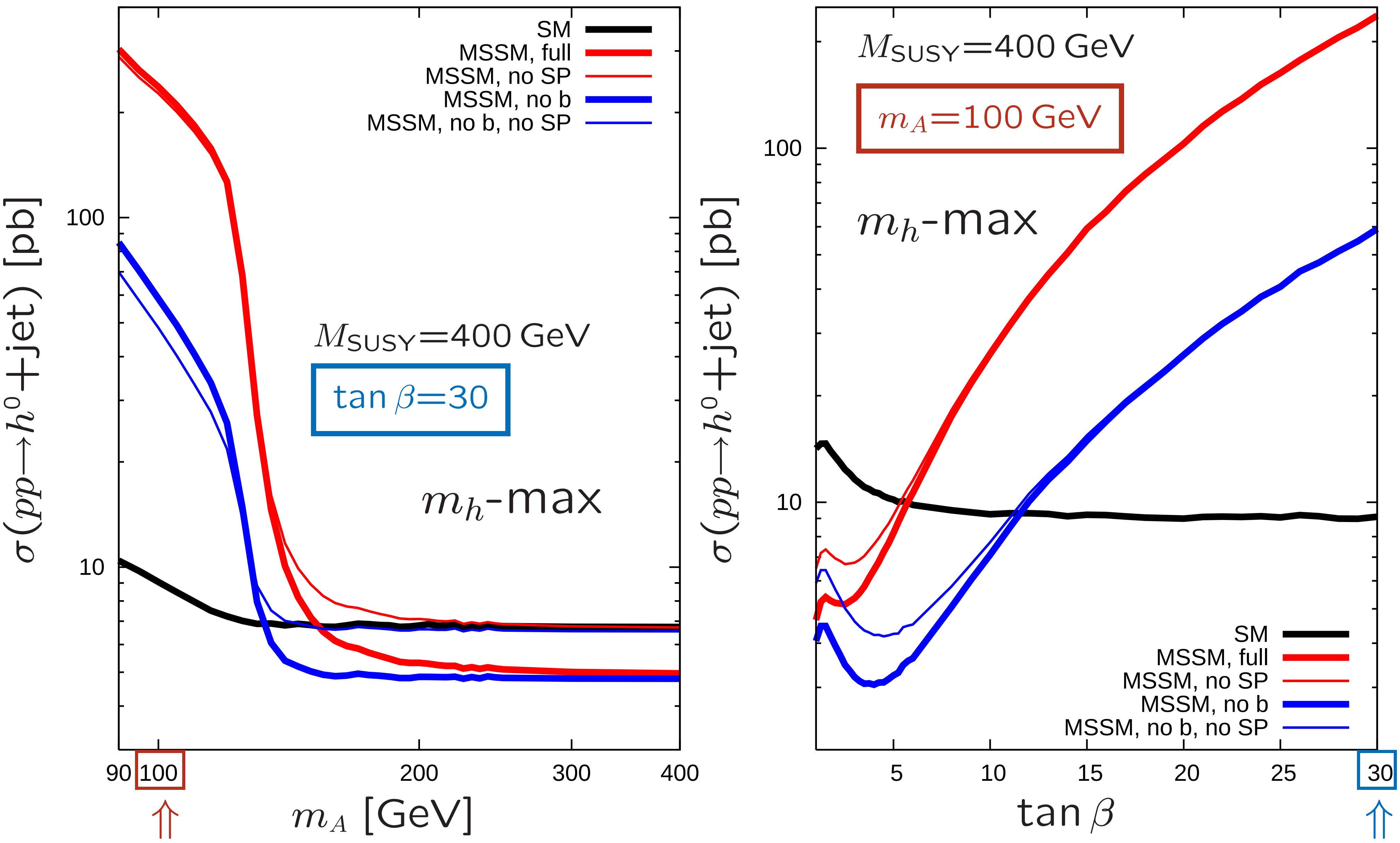
$$\frac{d\hat{\sigma}_{\text{partonic}}}{d\Omega}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{d\hat{t}}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{dy_{\text{jet}}}, \quad \frac{d\hat{\sigma}_{\text{partonic}}}{dp_{T,\text{jet}}},$$

is available on request $\longrightarrow$ oliver.brein@durham.ac.uk

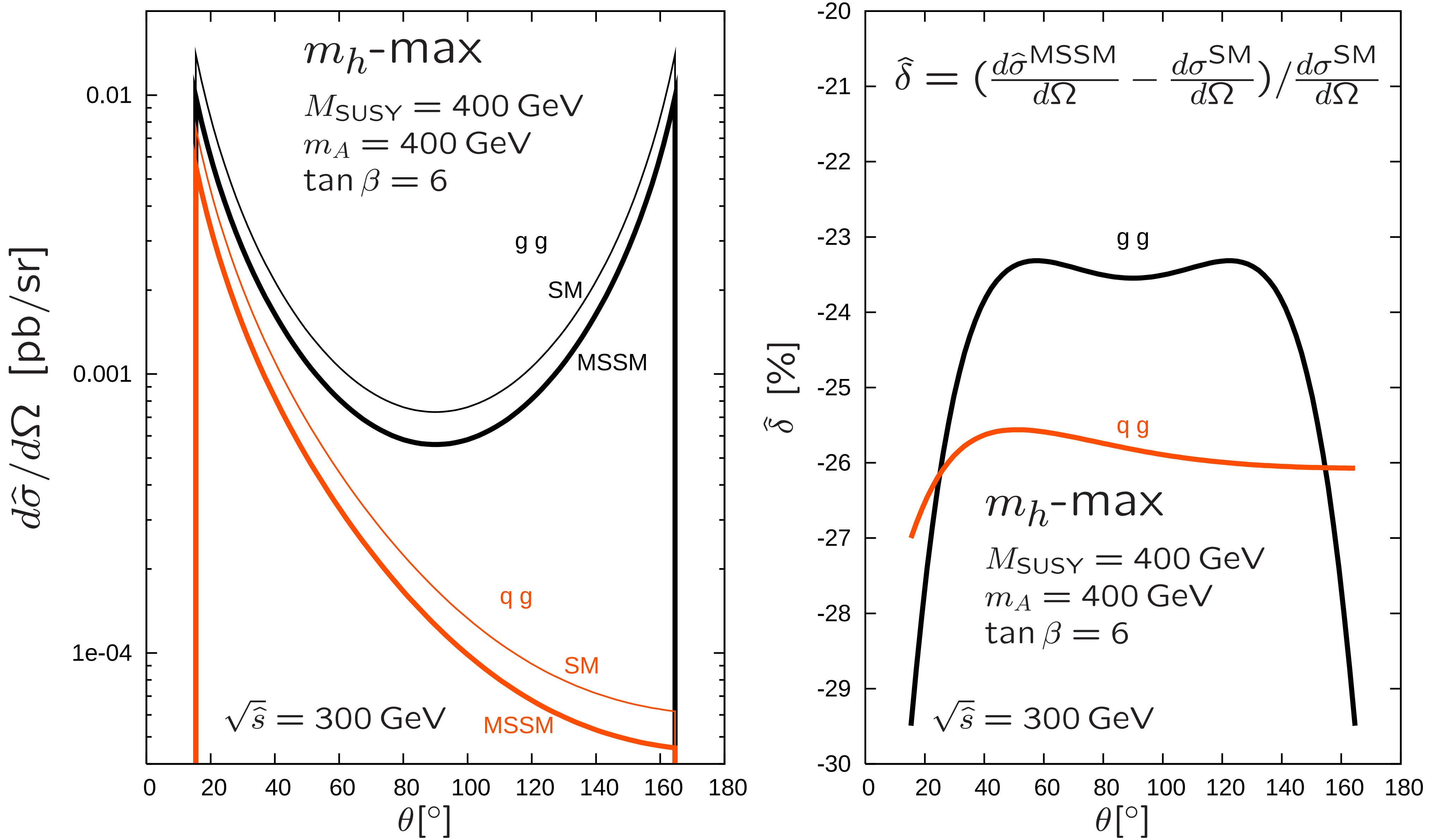
Backup

m_A- and $\tan\beta$-dependence

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



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



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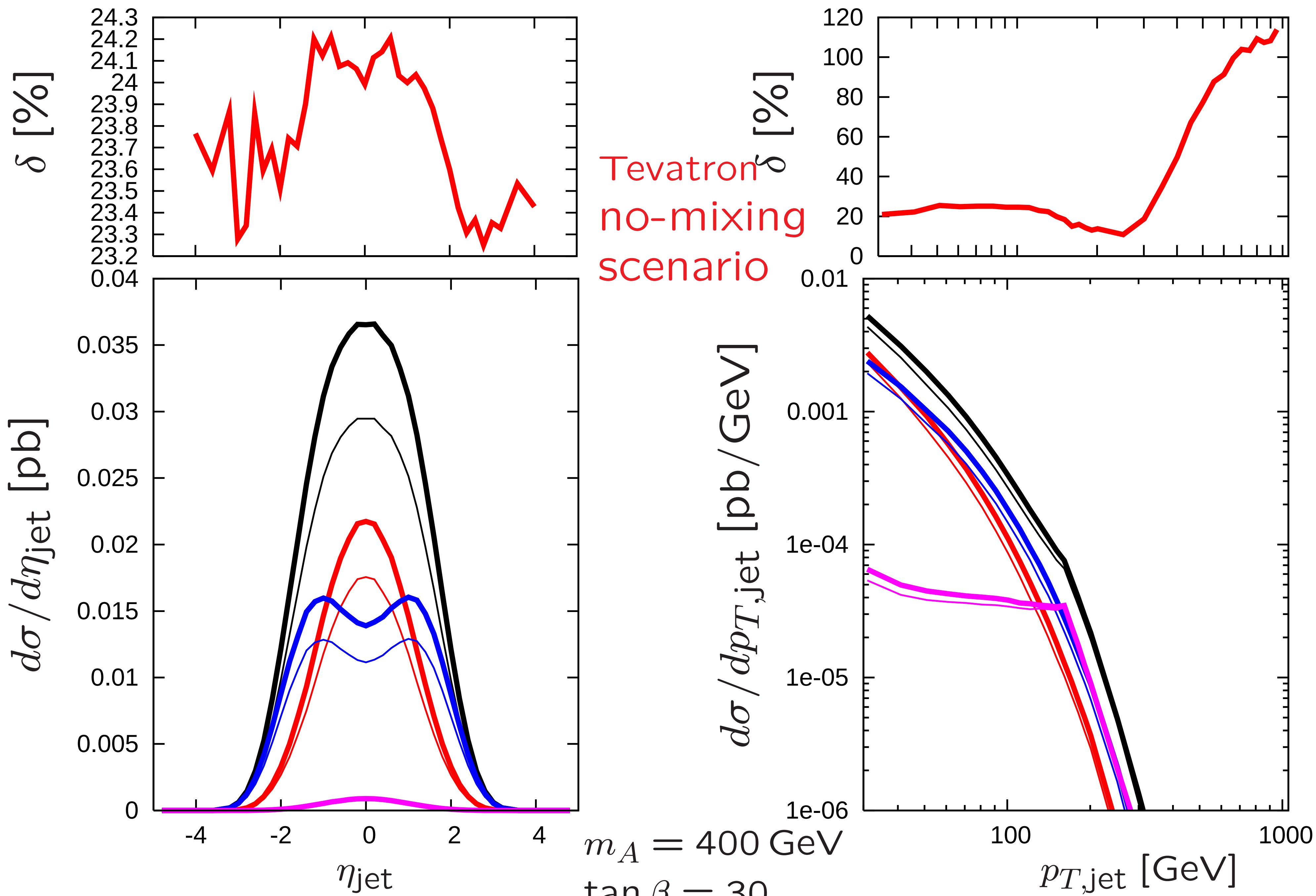

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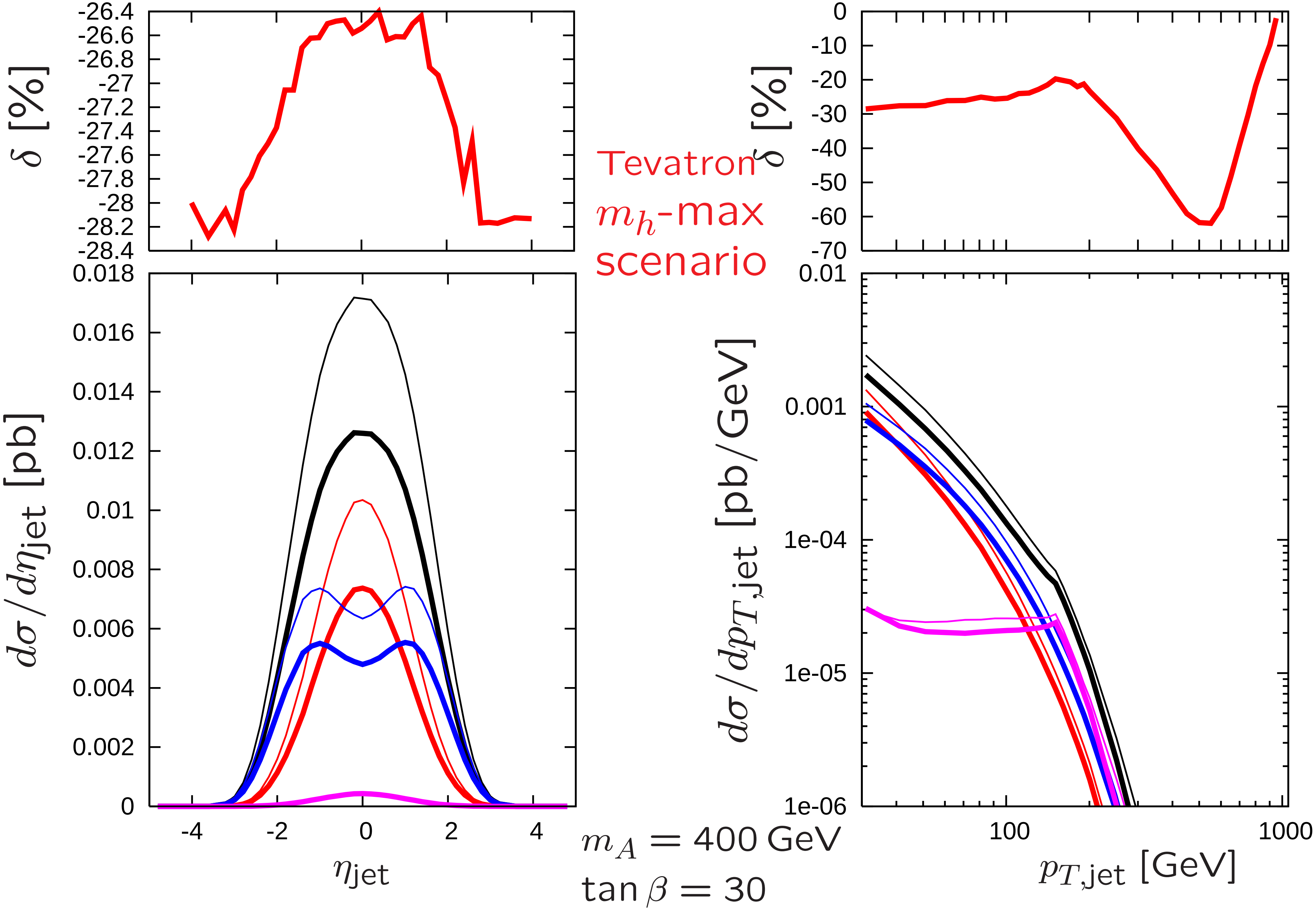

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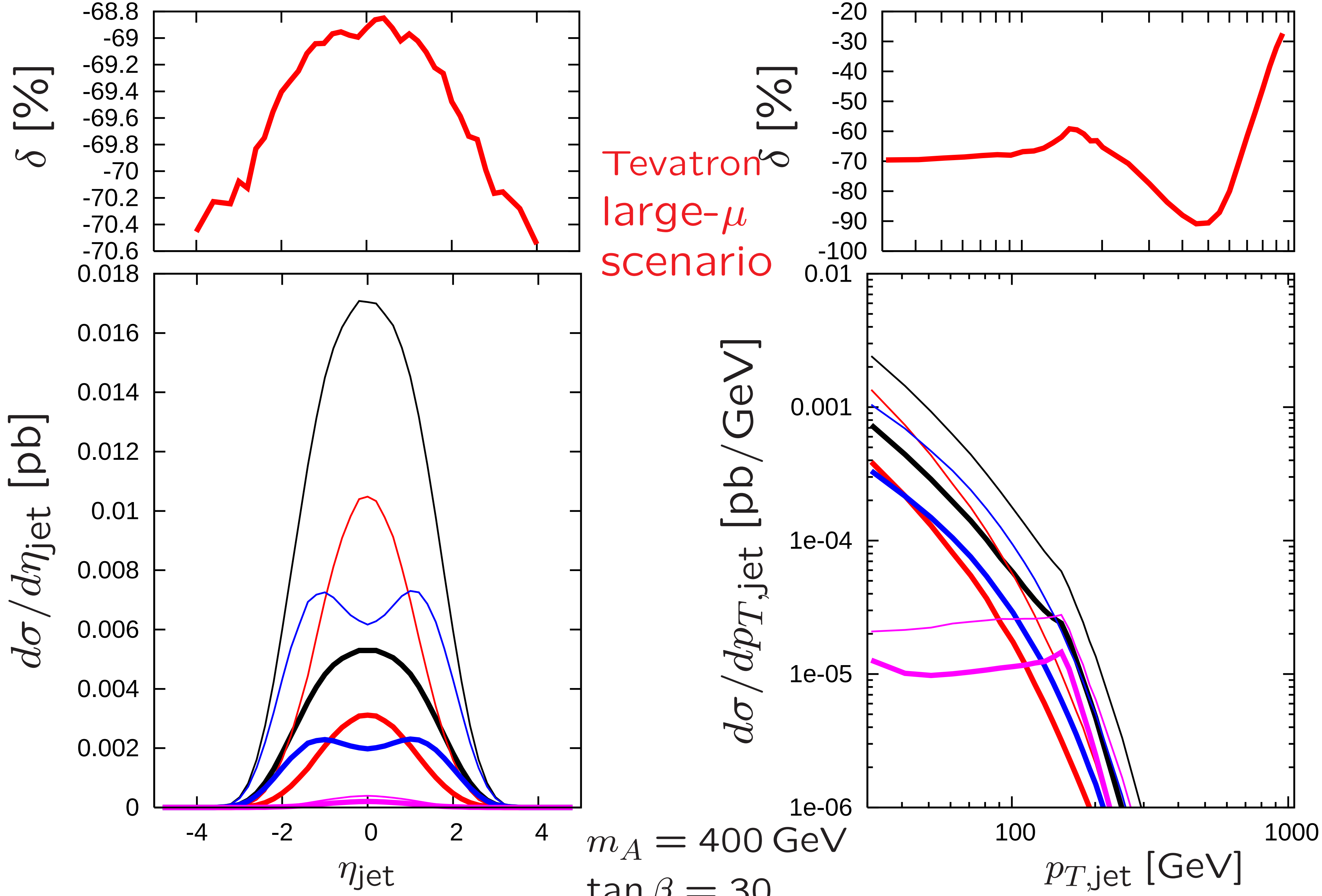

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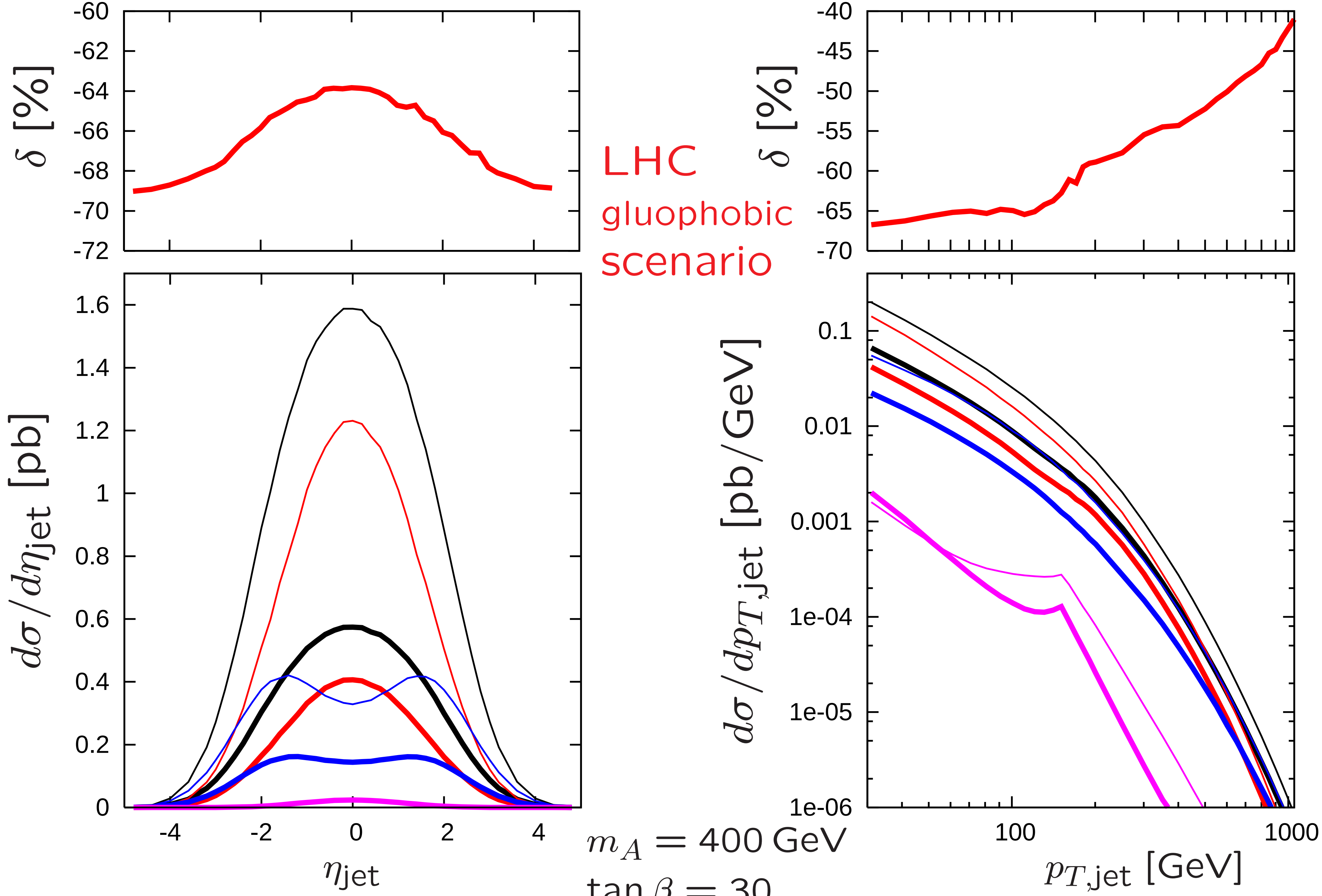

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