Electroweak and Bottom Quark Contributions to Higgs + Jet Production

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

outline :

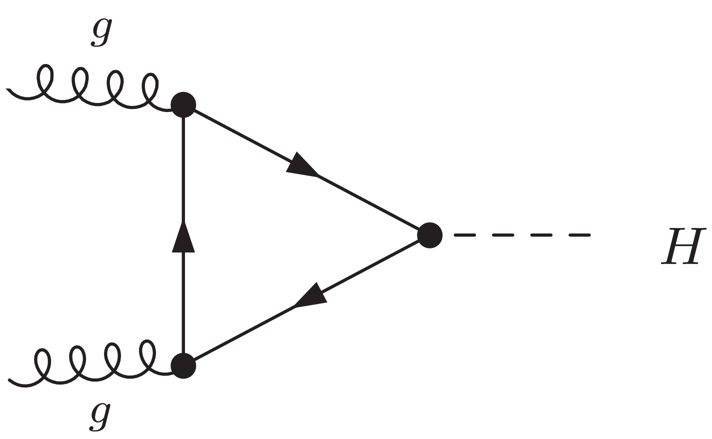
- Higgs + Jet in the Standard Model
- LO Contributions to Higgs + Jet
- Numerical Results

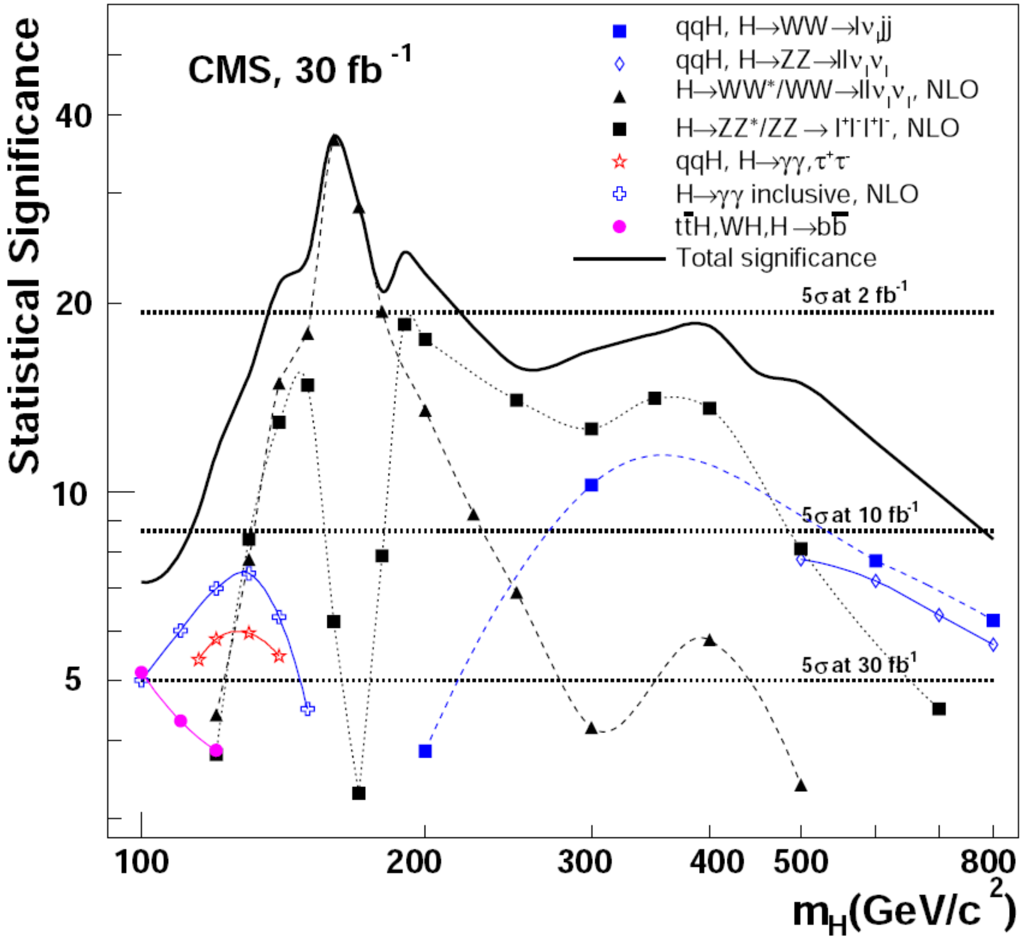
- Higgs + Jet in the Standard Model

• 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 $H \to \gamma\gamma$.

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

LO QCD $\mathcal{O}(\alpha_S^3\alpha)$: [van der Bij et al. '87; Baur, Glover '89]

NLO QCD $\mathcal{O}(\alpha_S^4\alpha)$: [de Florian, Grazzini, Kunszt '99]

+ NLL soft gluon threshold resummation: [de Florian, Kulesza, Vogelsang '05]

advantages:

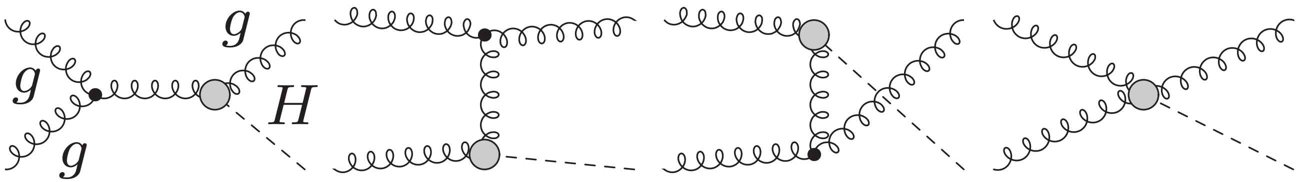
* richer kinematical structure compared to inclusive Higgs production.
  - $\rightarrow$ allows for refined cuts
  - $\rightarrow$ better signal significance $(S/\sqrt{B})$

* background predictions e.g. for $H \rightarrow \gamma\gamma$ under better theoretical control

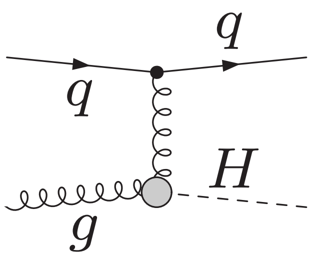
disadvantage:

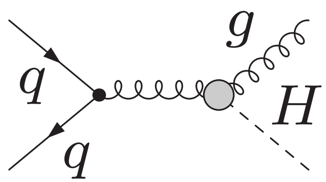
* lower rate than inclusive Higgs production

SM H+jet, partonic processes ($\mathcal{O}(\alpha_S^3\alpha)$, mainly via top loops):



$gg \longrightarrow Hg$ (≈ 60 - 75 % of total rate)





$qg \longrightarrow Hq$ (≈ 25 - 40 %) $q\bar{q} \longrightarrow Hg$ (rate small)

simulations: $pp \to H + \text{jet}, H \to \gamma\gamma$ [Abdullin et al. '98 & '02; Zmushko '02]

$pp \to H + \text{jet}, H \to \tau^+\tau^- \to l^+l^-\not{p}_T$ [Mellado et al. '05]

show: $H + \text{jet}$ 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: SM:

- Higgsjet [de Florian, Grazzini, Kunszt '99]
  NLO QCD cross section for $pp \to H +$ jet (large m_t approx.)
  also: soft gluon resummation [de Florian, Kulesza, Vogelsang '05]
- HqT [Bozzi, Catani, de Florian, Grazzini '03 & '06]
  p_T-distribution for $pp \to H + X$ (large m_t approx.)
  including resummation at $NLL + LO$ and $NNLL + NLO$ QCD accuracy
- MC@NLO [Frixione, Webber '02; Frixione, Nason, Webber '05]
  contains $pp \to H + X$ event generation at NLO QCD accuracy
  (large m_t approx.)
- FEHiP [Anastasiou, Melnikov, Petriello '05]
  NNLO QCD differential cross section for $pp \to H + X$ (large m_t approx.)
- HPro [Anastasiou, Bucherer, Kunszt '09]
  corrects large m_t approx. NNLO QCD differential predictions
  by finite m_t/m_b terms from NLO QCD

NNLO QCD accuracy $\propto 10\%$ (scale variation)
$\to$ further improvements need to consider other 10%-ish effects

available codes: MSSM:

- HJET 1.3 [OBr, Hollik '03; '07]
  LO QCD full MSSM (no approximations)
  & LO QCD SM (no approximations):

$$\sigma^{\text{total}}_{\text{hadronic}}, \; \frac{d\sigma_{\text{hadronic}}}{d\sqrt{\hat{s}}}, \; \frac{d\sigma_{\text{hadronic}}}{dp_{T,\text{jet}}}, \; \frac{d\sigma_{\text{hadronic}}}{d\eta_{\text{jet}}}, \; \frac{d^2\sigma_{\text{hadronic}}}{dp_{T,\text{jet}}\, d\eta_{\text{jet}}}, \; \ldots$$

- LO Contributions to Higgs + Jet

• LO Contributions to Higgs + Jet

This work was triggered by a recent theoretical study of SM Higgs + high-p_T jet production [Keung, Petriello '09] which looked at:

1. finite quark mass (m_t, m_b) effects on the p_T distribution
   $\rightarrow$ already included in our calculation [OBr, Hollik '03; '07]

2. electroweak loop effects on the p_T distribution

– 5-flavour scheme

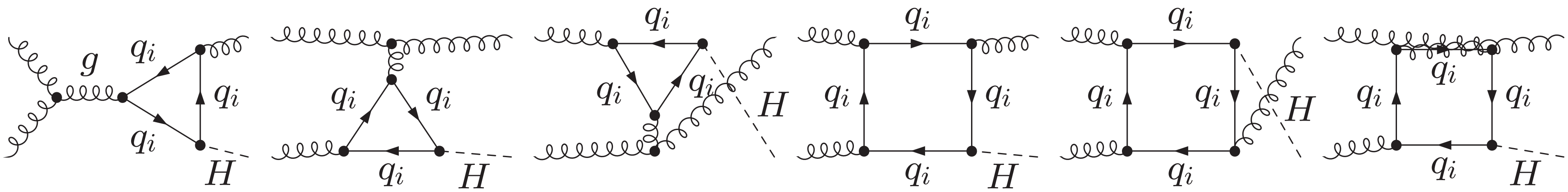
The Higgs + *one* high-p_T jet final state suggests :

use a 5-flavour scheme

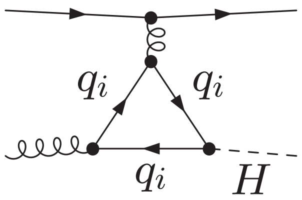
i.e. to consider bottom quarks as distributed in the proton.

– Gluon & Light Quark (u, d, s, c) QCD Contribution : $\mathcal{O}(\alpha_S^3 \alpha)$

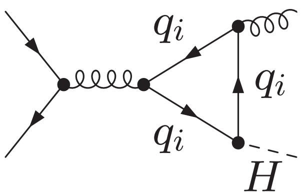
gluon fusion, $gg \rightarrow Hg$



quark gluon scattering, $qg \rightarrow Hq$

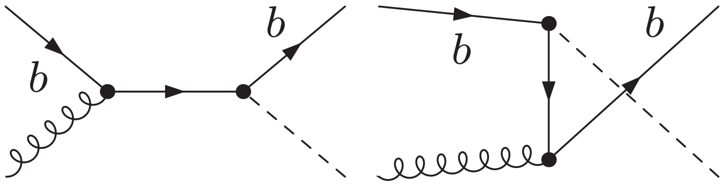


quark anti-quark annihilation, $q\bar{q} \rightarrow Hg$

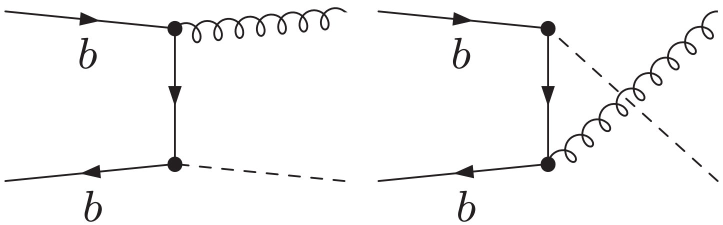


– Bottom Quark QCD Contribution : $\mathcal{O}(\alpha_S \alpha)$

quark gluon scattering, $bg \to Hb$



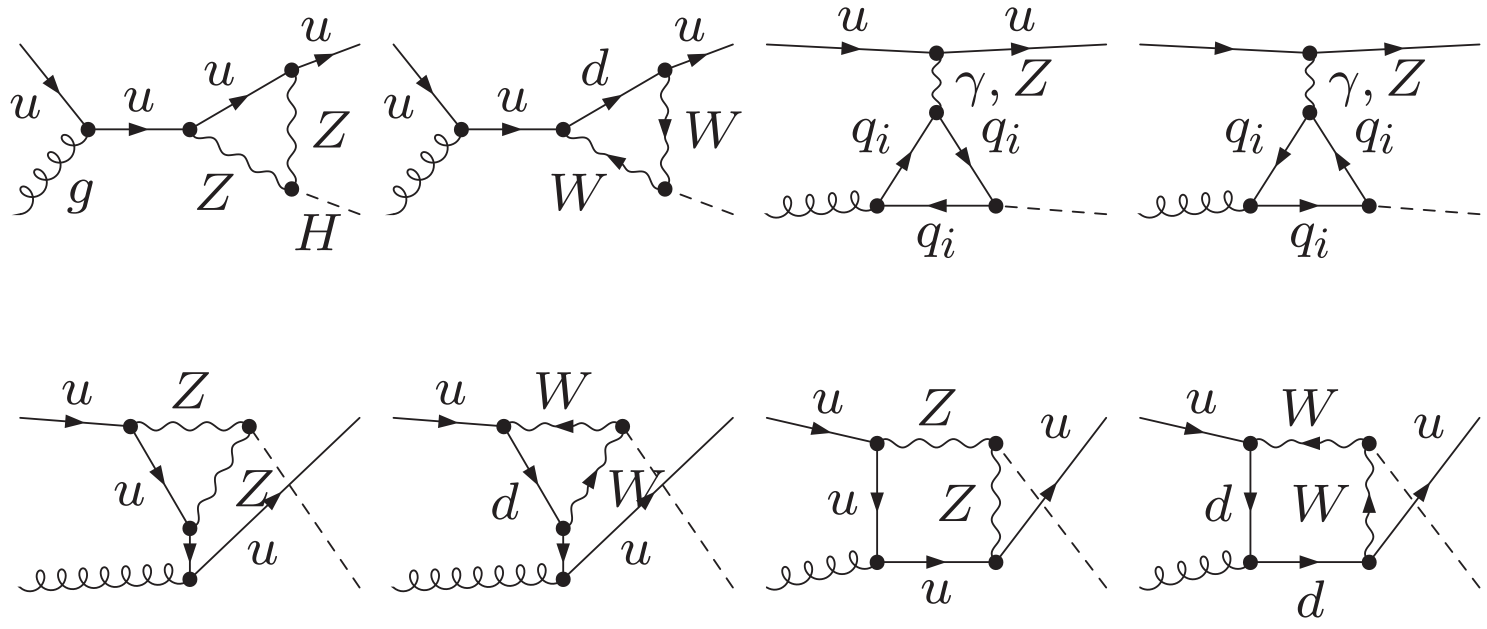
quark anti-quark annihilation, $b\bar{b} \to Hg$



– Light Quark (u, d, s, c) EW Contribution : $\mathcal{O}(\alpha_S \alpha^3)$

[Mrenna, Yuan '96; Keung, Petriello '09]

quark gluon scattering, $qg \longrightarrow Hq$



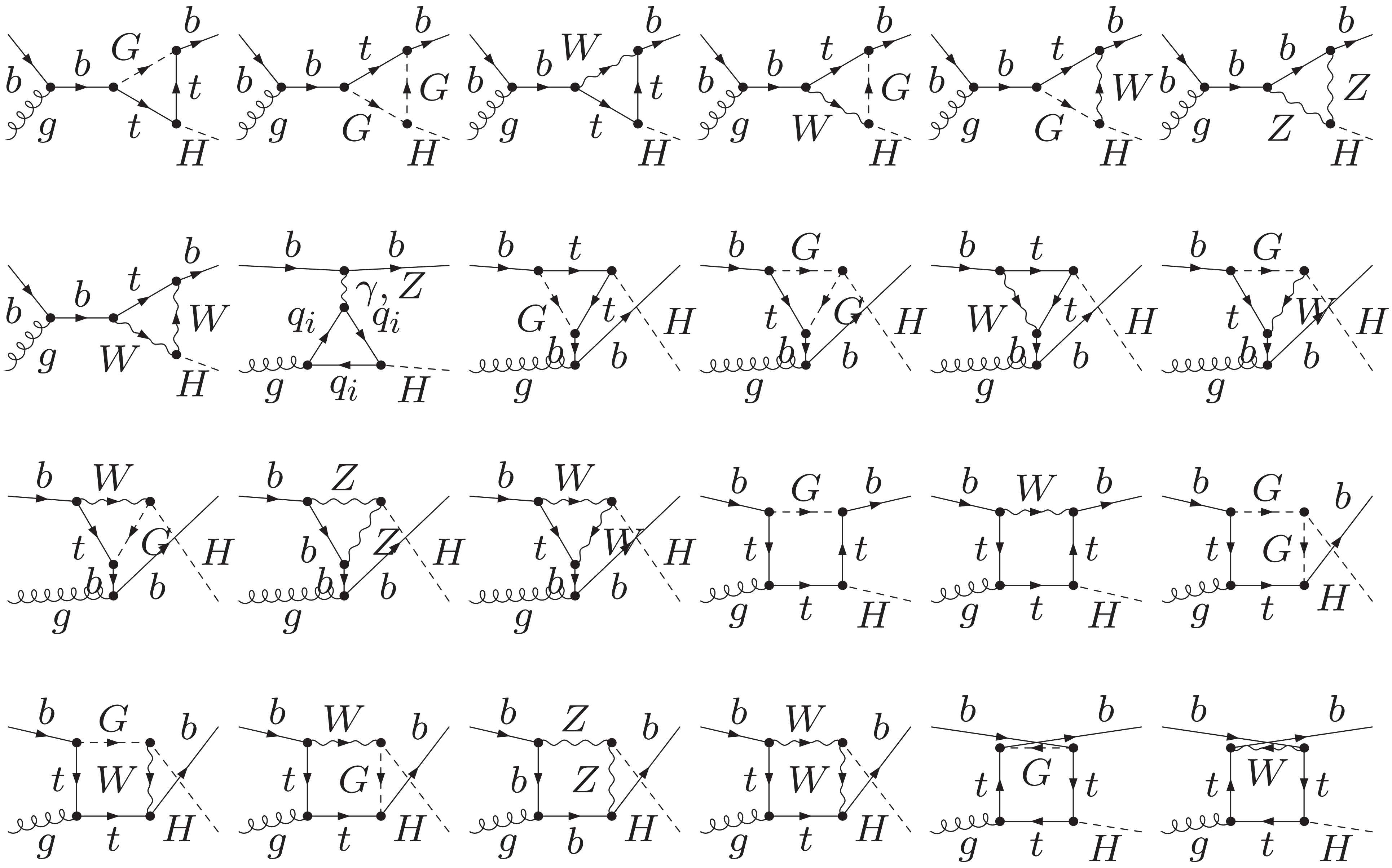
quark anti-quark annihilation, $q\bar{q} \longrightarrow Hg$

crossed diagrams

– Bottom Quark EW Contribution : $\mathcal{O}(\alpha_S \alpha^3)$

[Mrenna, Yuan '96]

quark gluon scattering, $bg \to Hb$



quark anti-quark annihilation, $b\bar{b} \to Hg$: crossed diagrams

- Numerical Results

– LHC

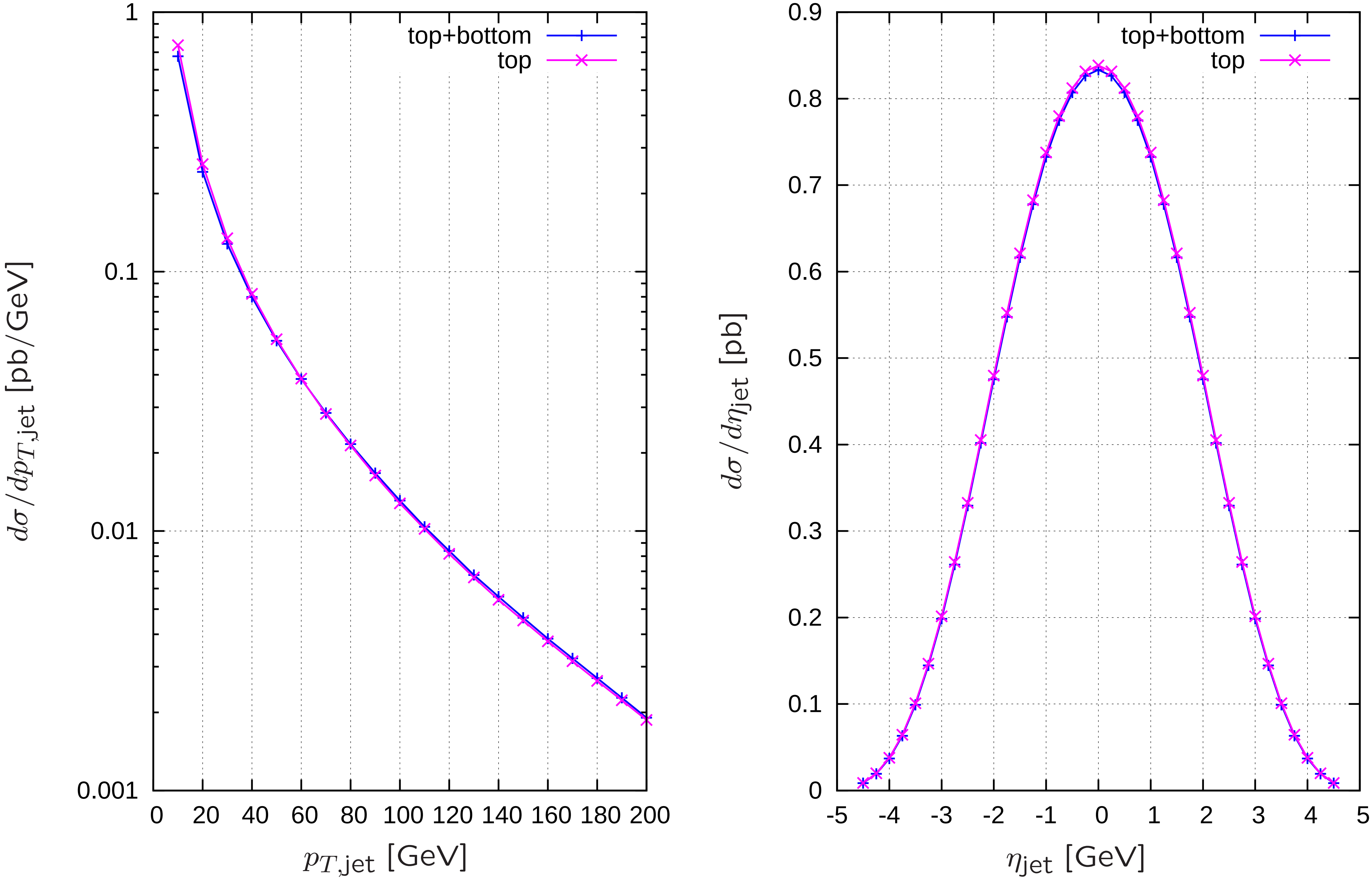
differential hadronic cross sections for $\sqrt{S} = 10\,\text{TeV}$

$$\frac{d\sigma(S,p_{T,\text{jet}})}{dp_{T,\text{jet}}},\ |\eta_{\text{jet}}| < 4.5$$

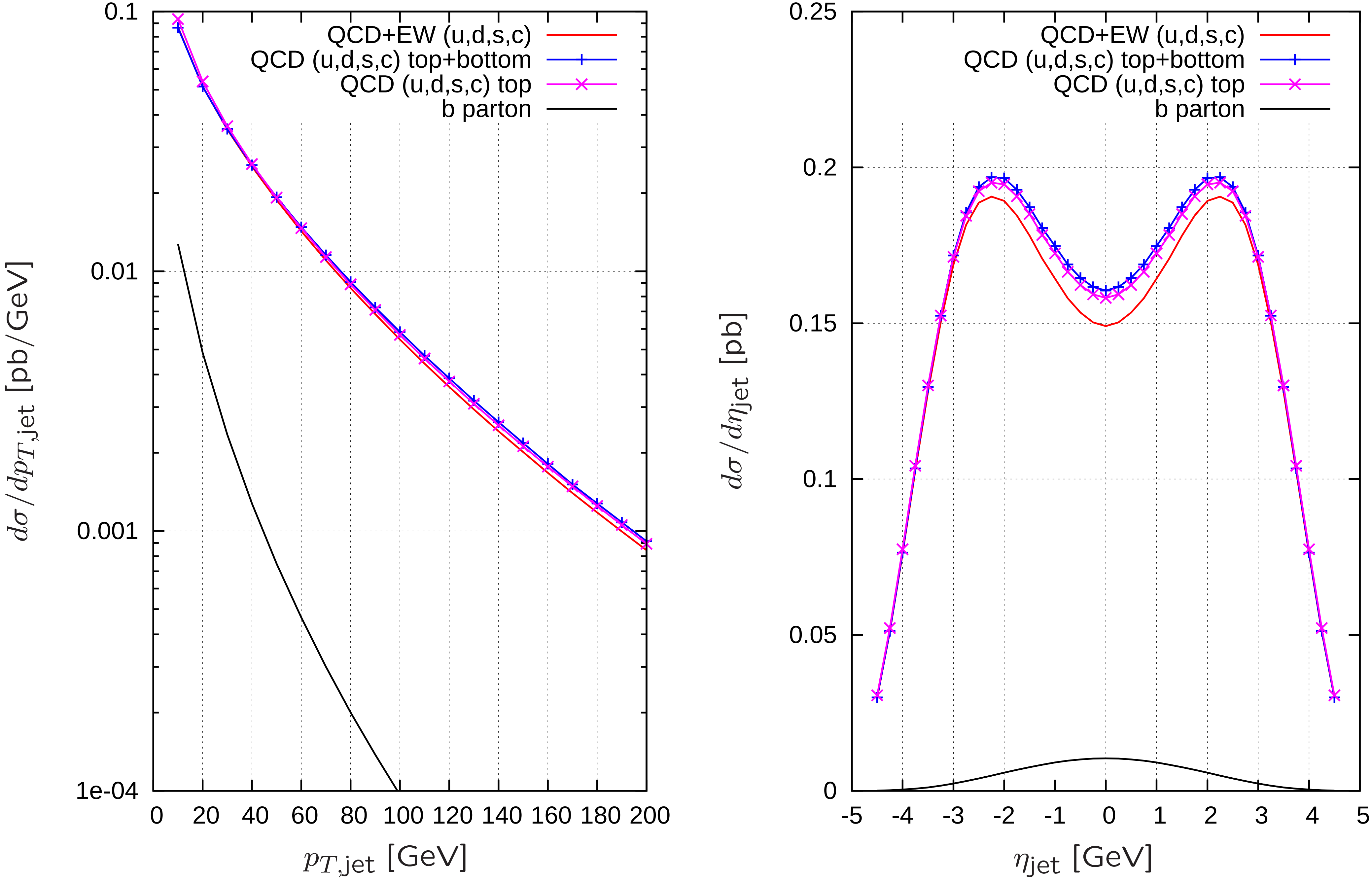
$$\frac{d\sigma(S,\eta_{\text{jet}})}{d\eta_{\text{jet}}},\ p_{T,\text{jet}} > 30\,\text{GeV}$$

[Numerical Results, LHC]

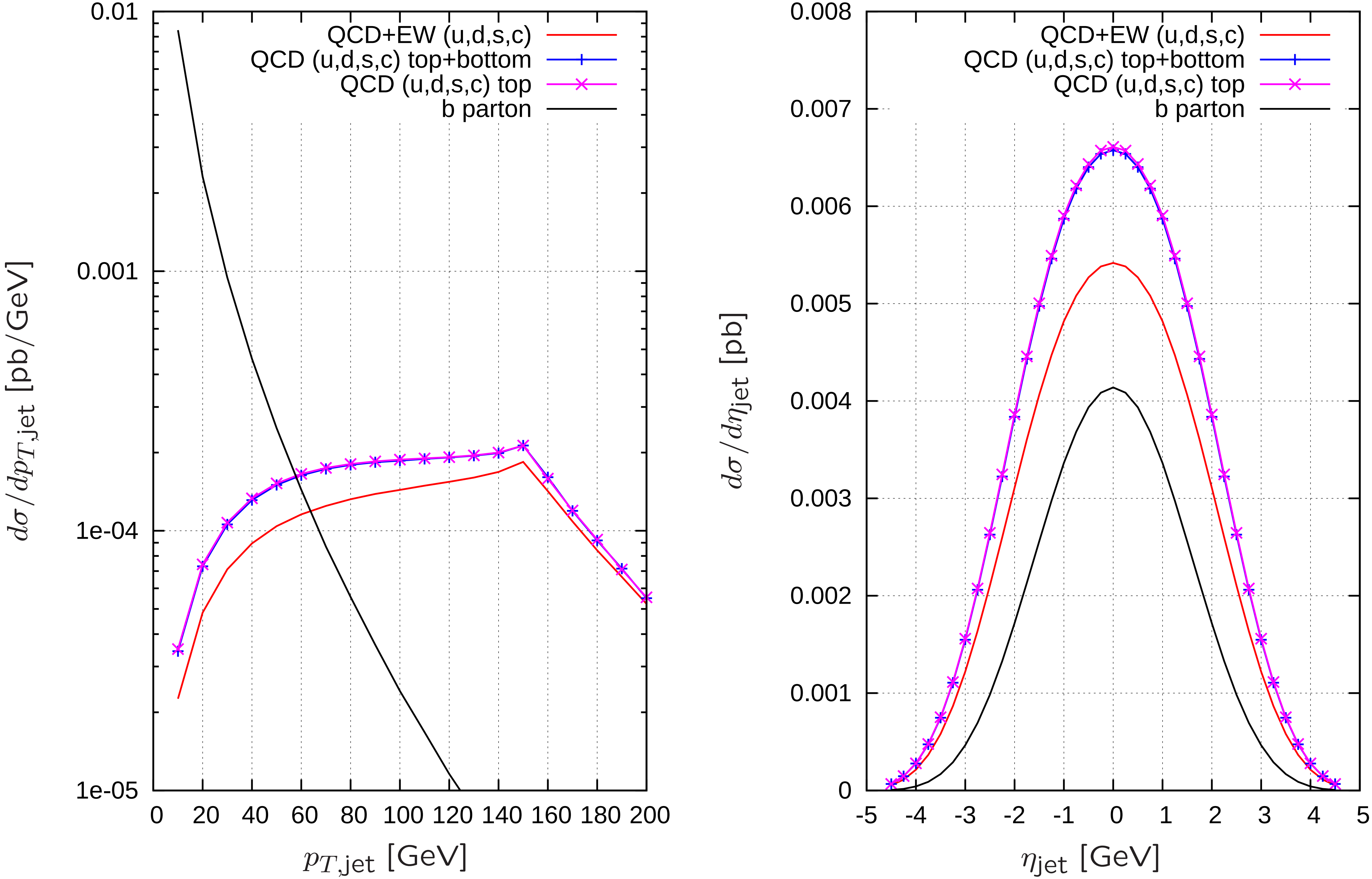
$p_{T,\text{jet}}$- and η_{jet}-distributions : gluon fusion $(m_H = 120\,\text{GeV})$



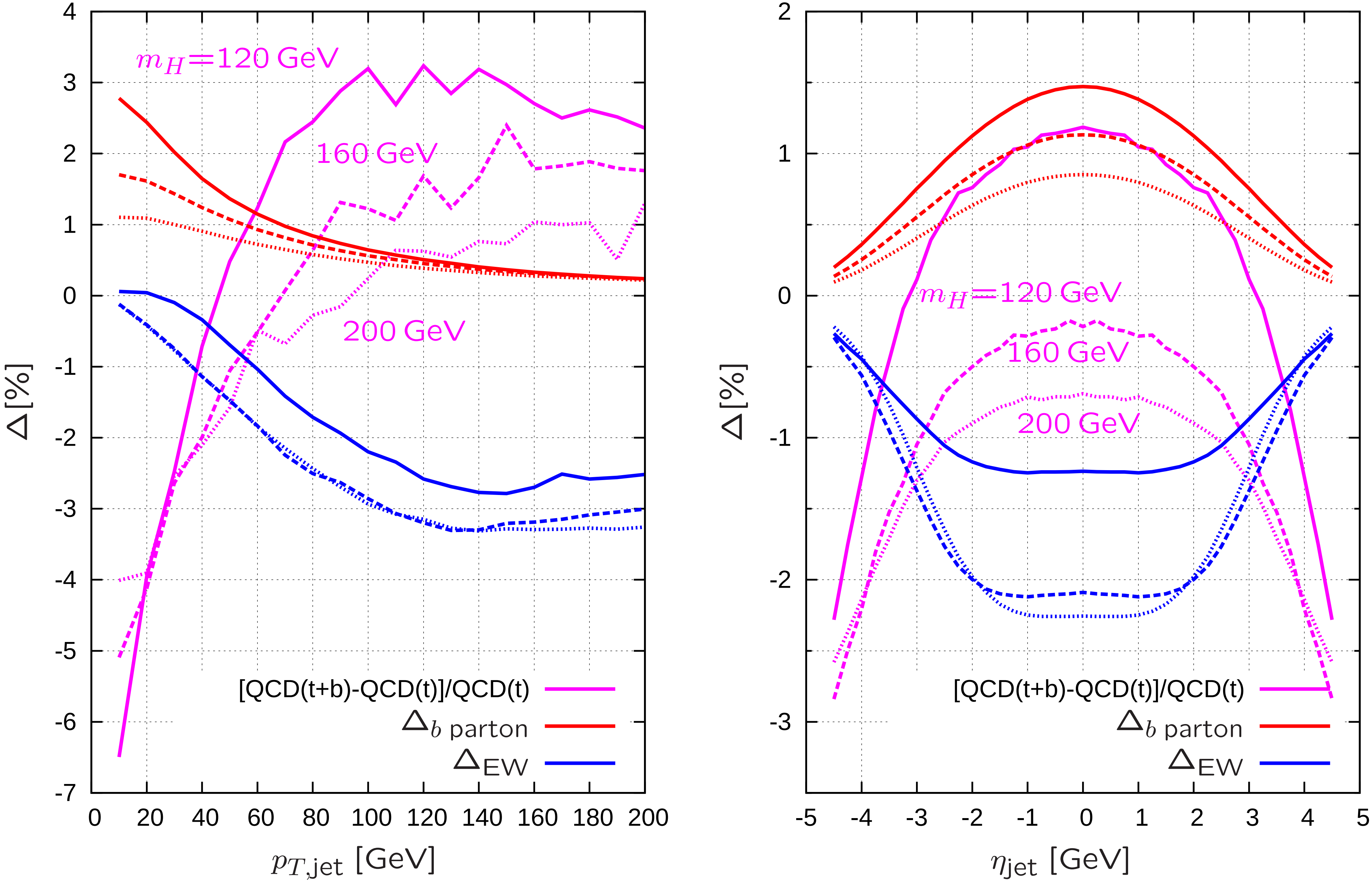
$p_{T,\mathrm{jet}}$- and η_{jet}-distributions : quark-gluon scattering ($m_H = 120\,\mathrm{GeV}$)



$p_{T,\text{jet}}$- and η_{jet}-distributions : $q\bar{q}$ scattering $(m_H = 120\,\text{GeV})$



relative differences in $p_{T,\text{jet}}$- and η_{jet}-distributions : $(m_H = 120\ \text{GeV})$



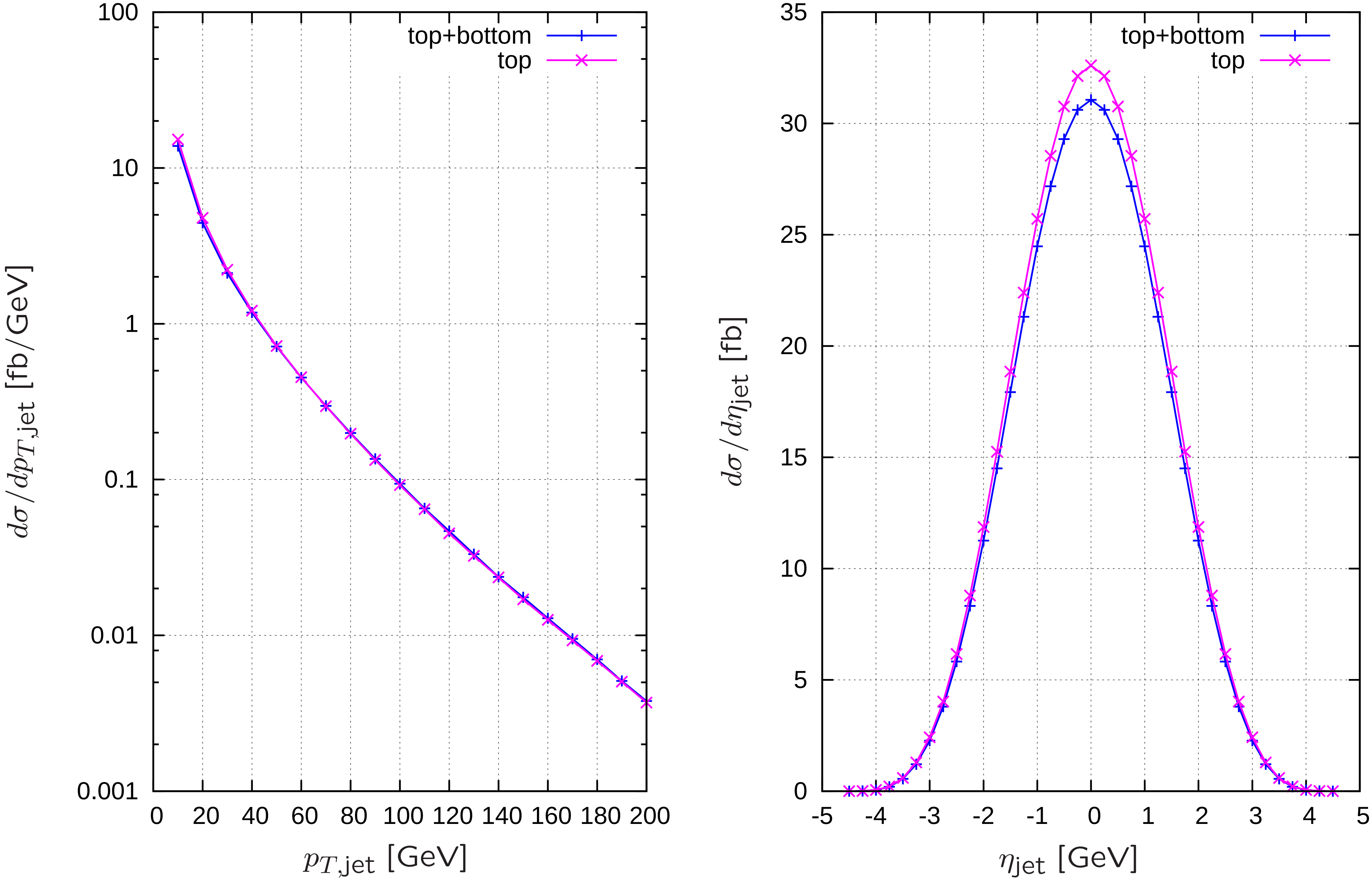
– Tevatron

differential hadronic cross sections for $\sqrt{S} = 1.96\,\text{TeV}$

$$\frac{d\sigma(S, p_{T,\text{jet}})}{dp_{T,\text{jet}}}, \; |\eta_{\text{jet}}| < 2.5$$

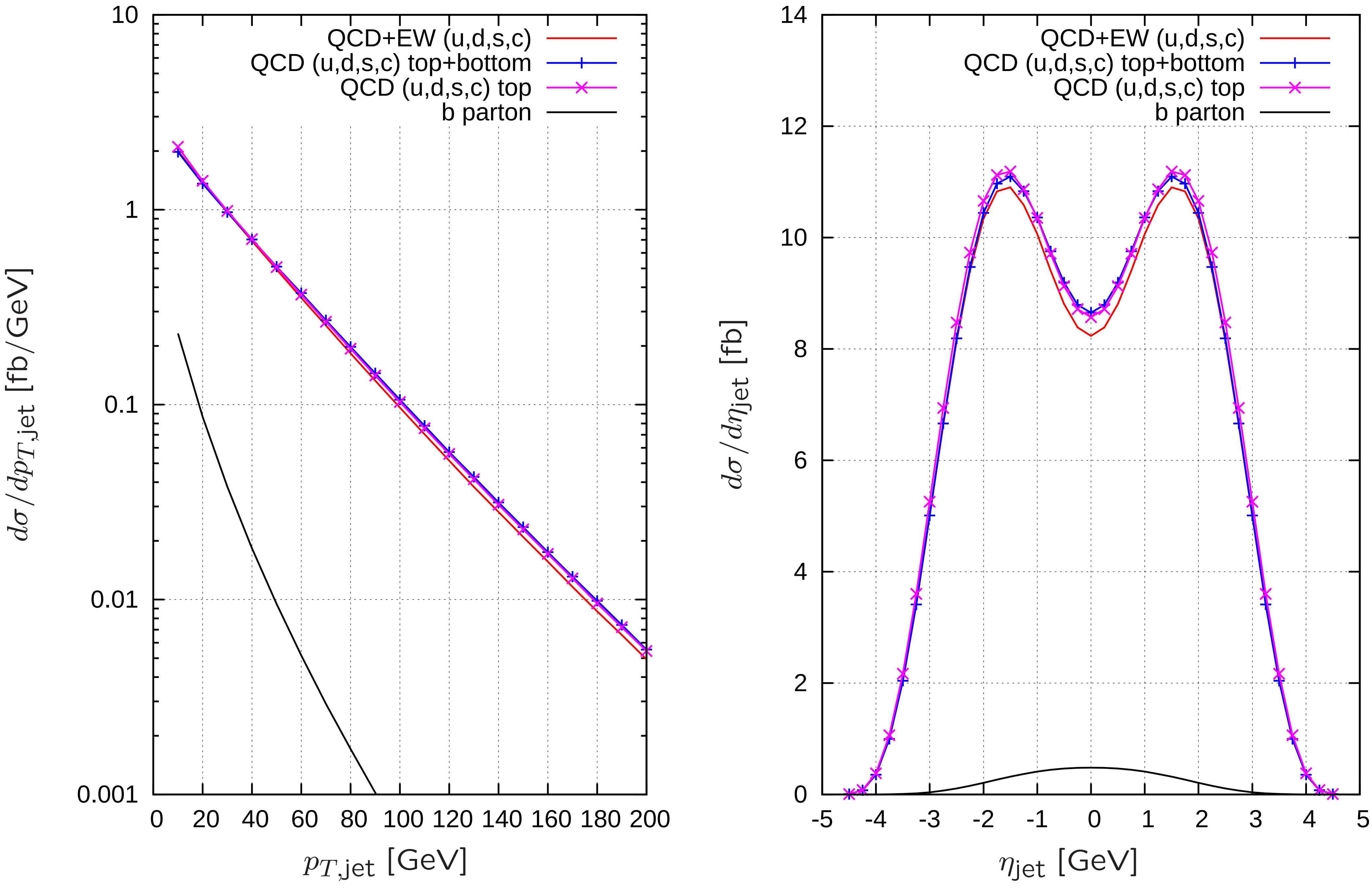
$$\frac{d\sigma(S, \eta_{\text{jet}})}{d\eta_{\text{jet}}}, \; p_{T,\text{jet}} > 15\,\text{GeV}$$

$p_{T,\mathrm{jet}}$- and η_{jet}-distributions : gluon fusion $(m_H = 120\,\mathrm{GeV})$

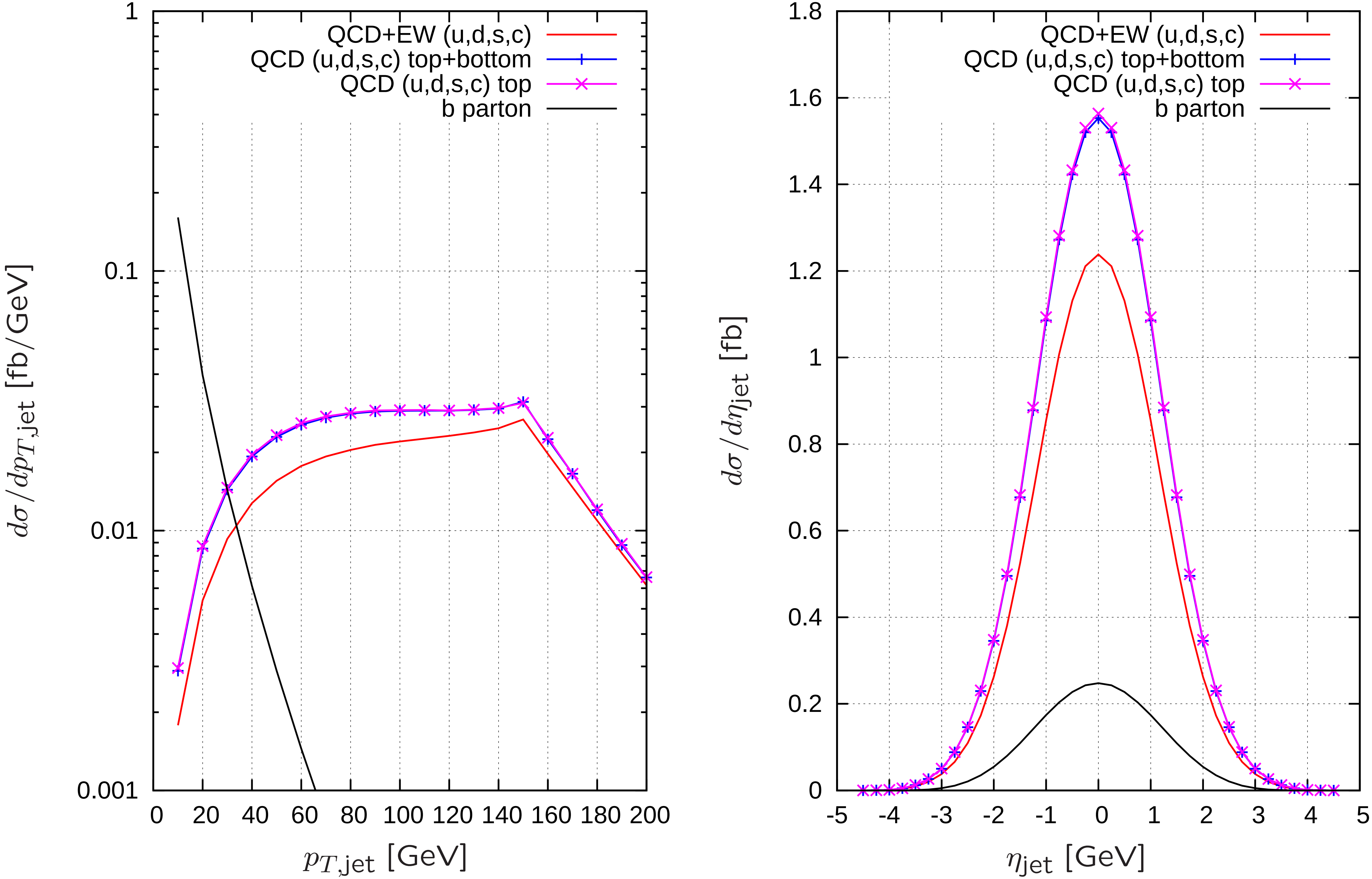


[Numerical Results, Tevatron]

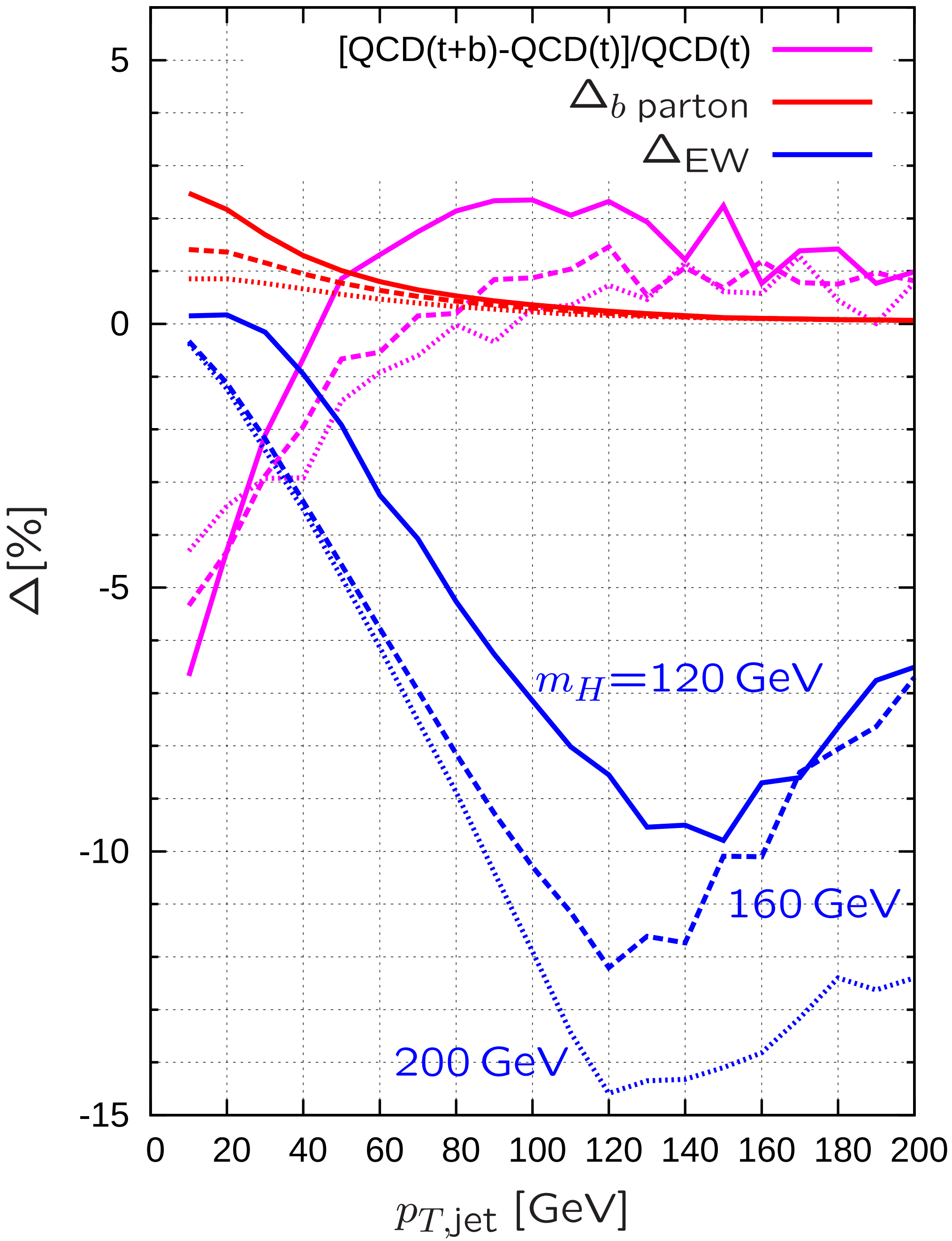
$p_{T,\text{jet}}$- and η_{jet}-distributions : quark-gluon scattering ($m_H = 120\,\text{GeV}$)

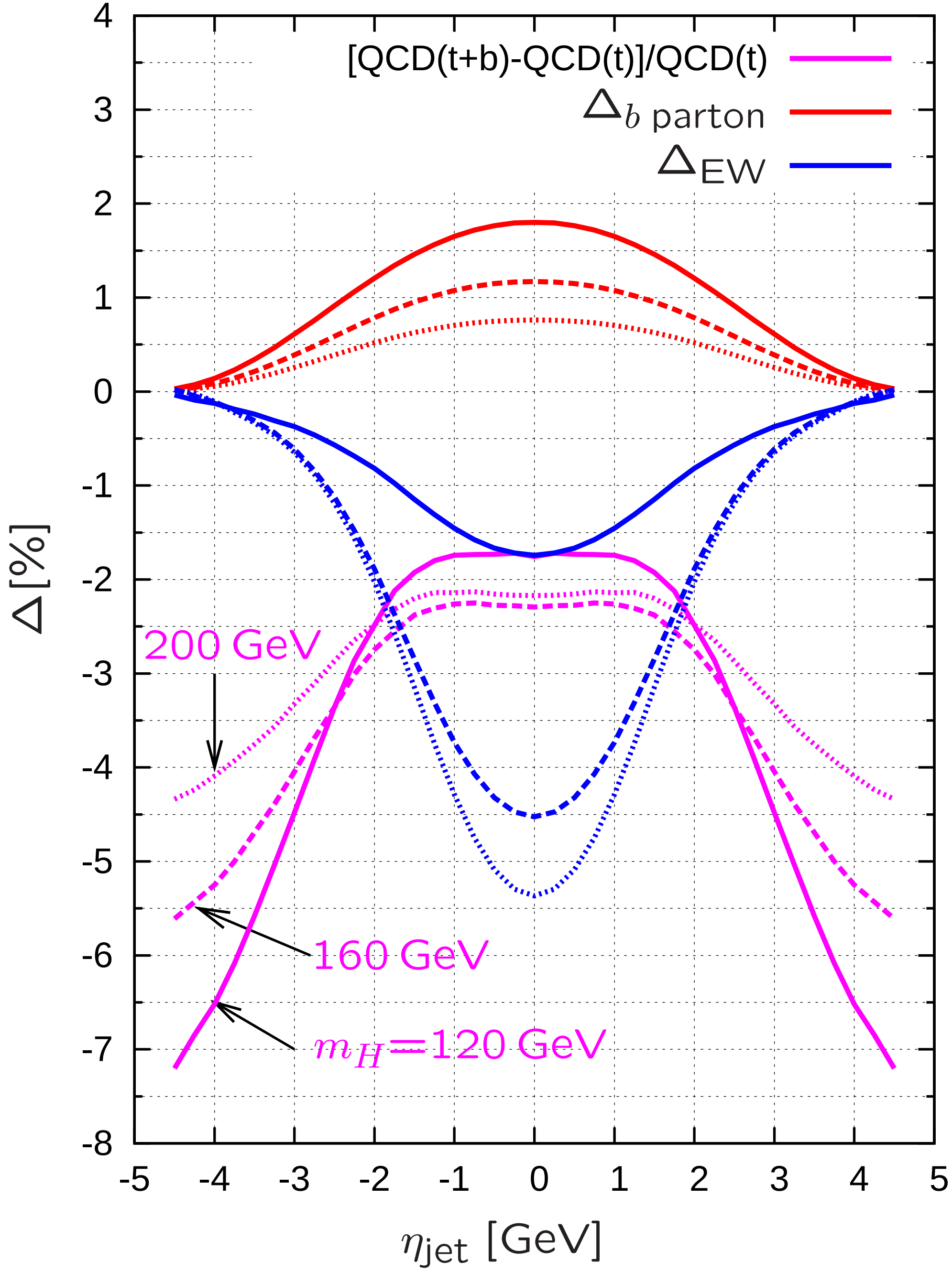


$p_{T,\mathrm{jet}}$- and η_{jet}-distributions : $q\bar{q}$ scattering $(m_H = 120\,\mathrm{GeV})$



relative differences in $p_{T,\text{jet}}$- and η_{jet}-distributions : $(m_H = 120\,\text{GeV})$





summary

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

- Improvements over the present NLO QCD accuracy for the H + jet final state, require the consideration of:
  - electroweak one-loop contributions
  - all bottom quark contributions

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