Higgs production in bottom quark annihilation

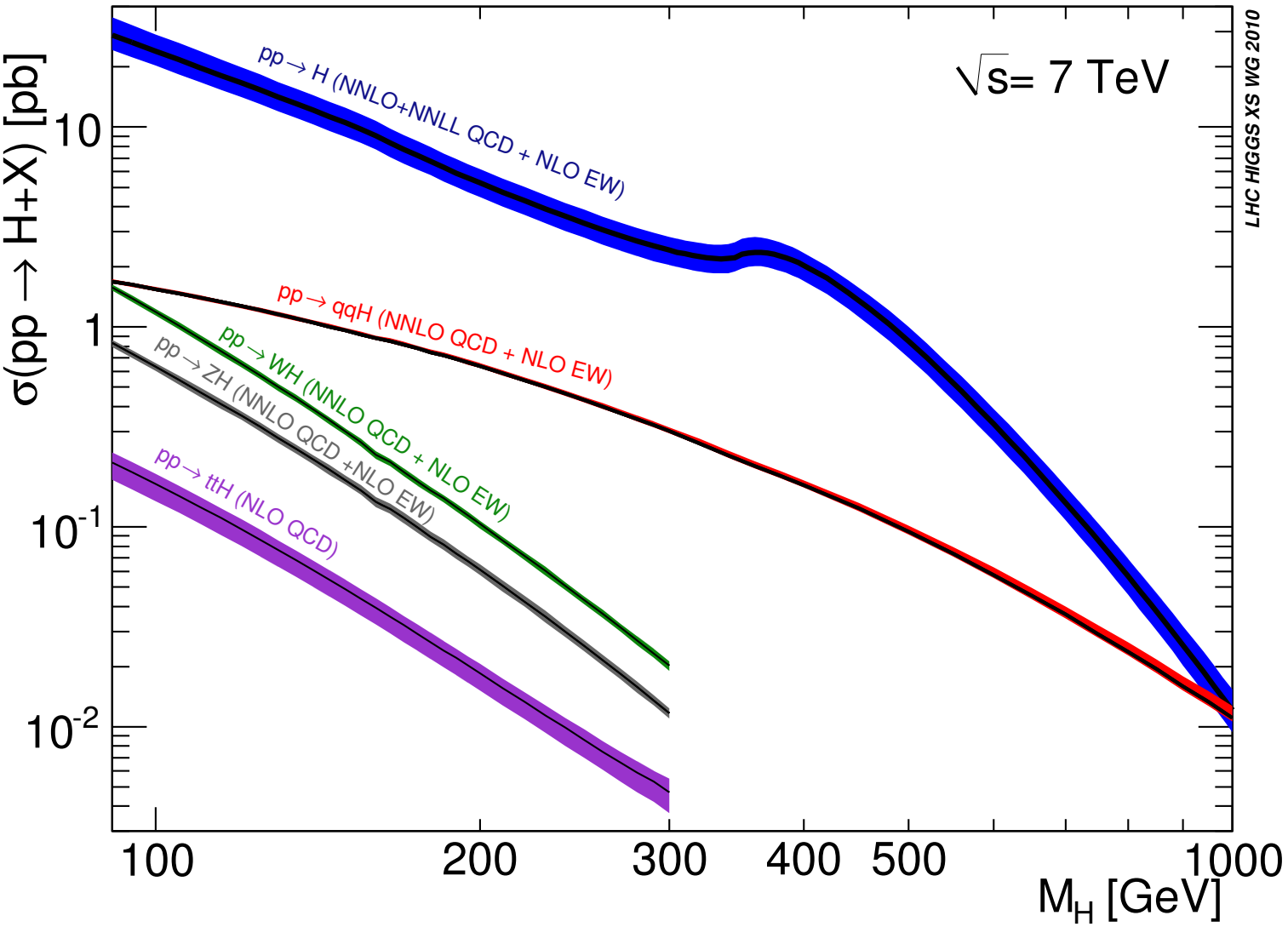
Robert Harlander

BU Wuppertal

Loops and Legs 2012

Wernigerode
15-20 April 2012

Introduction



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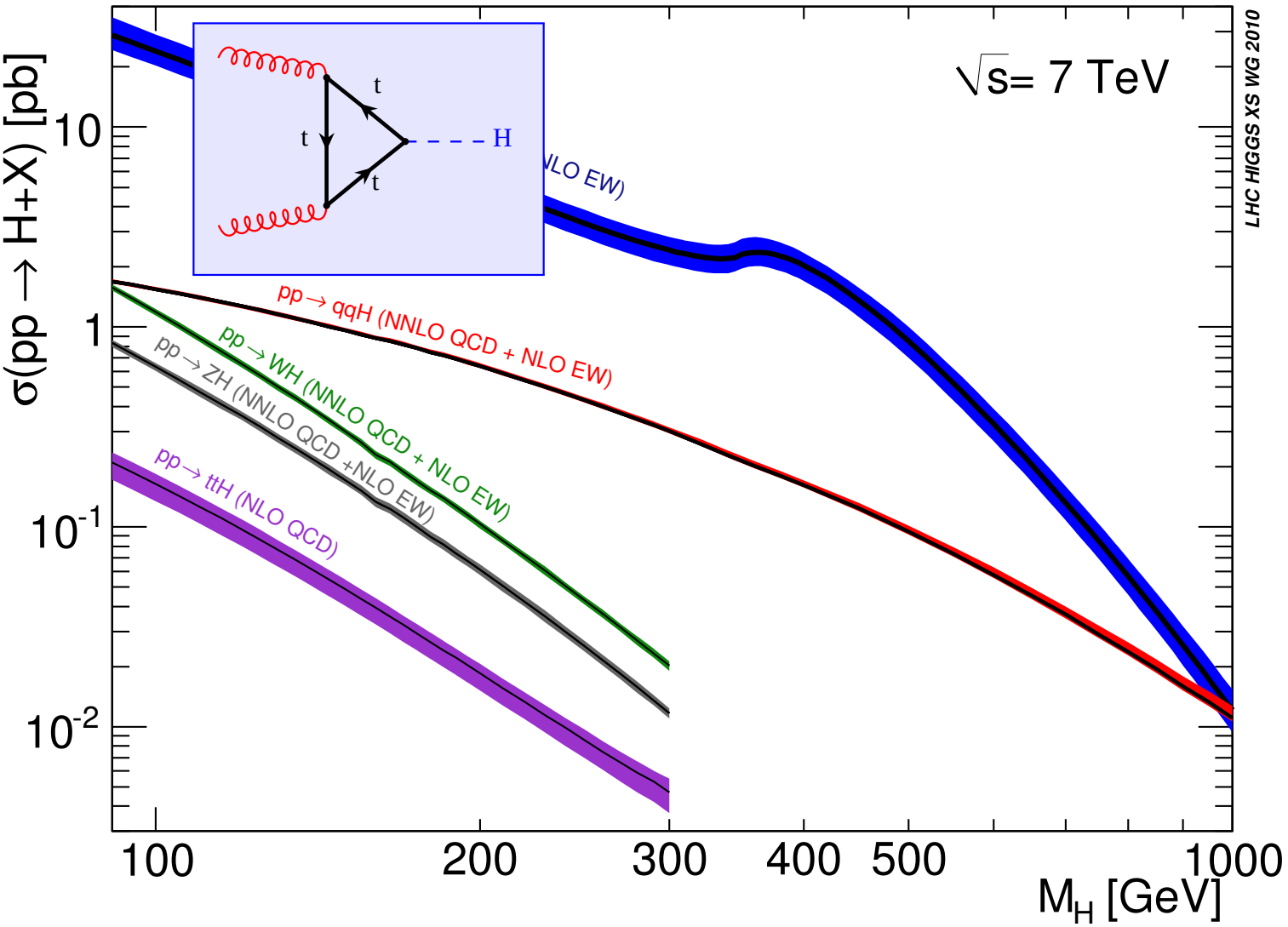

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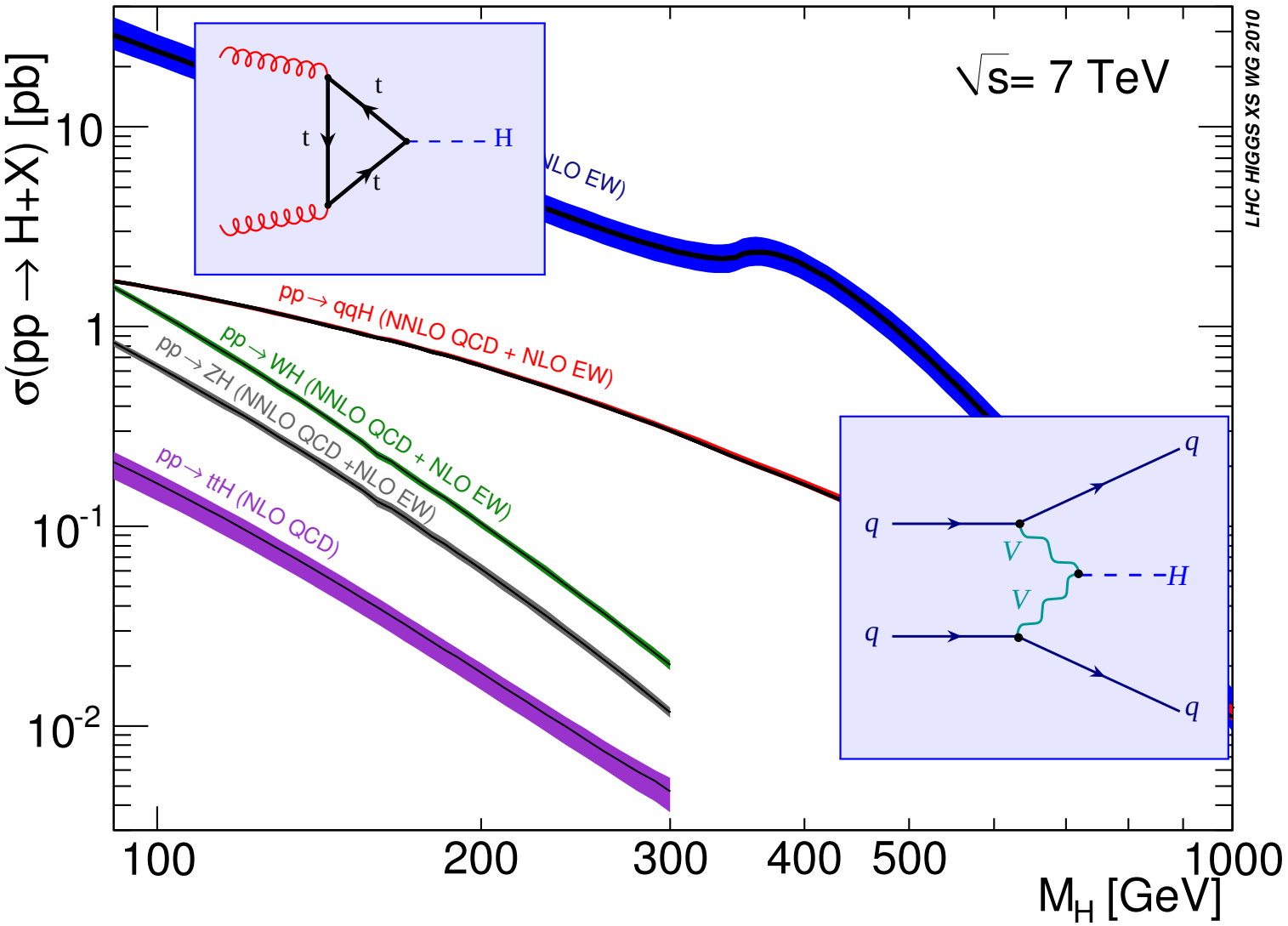

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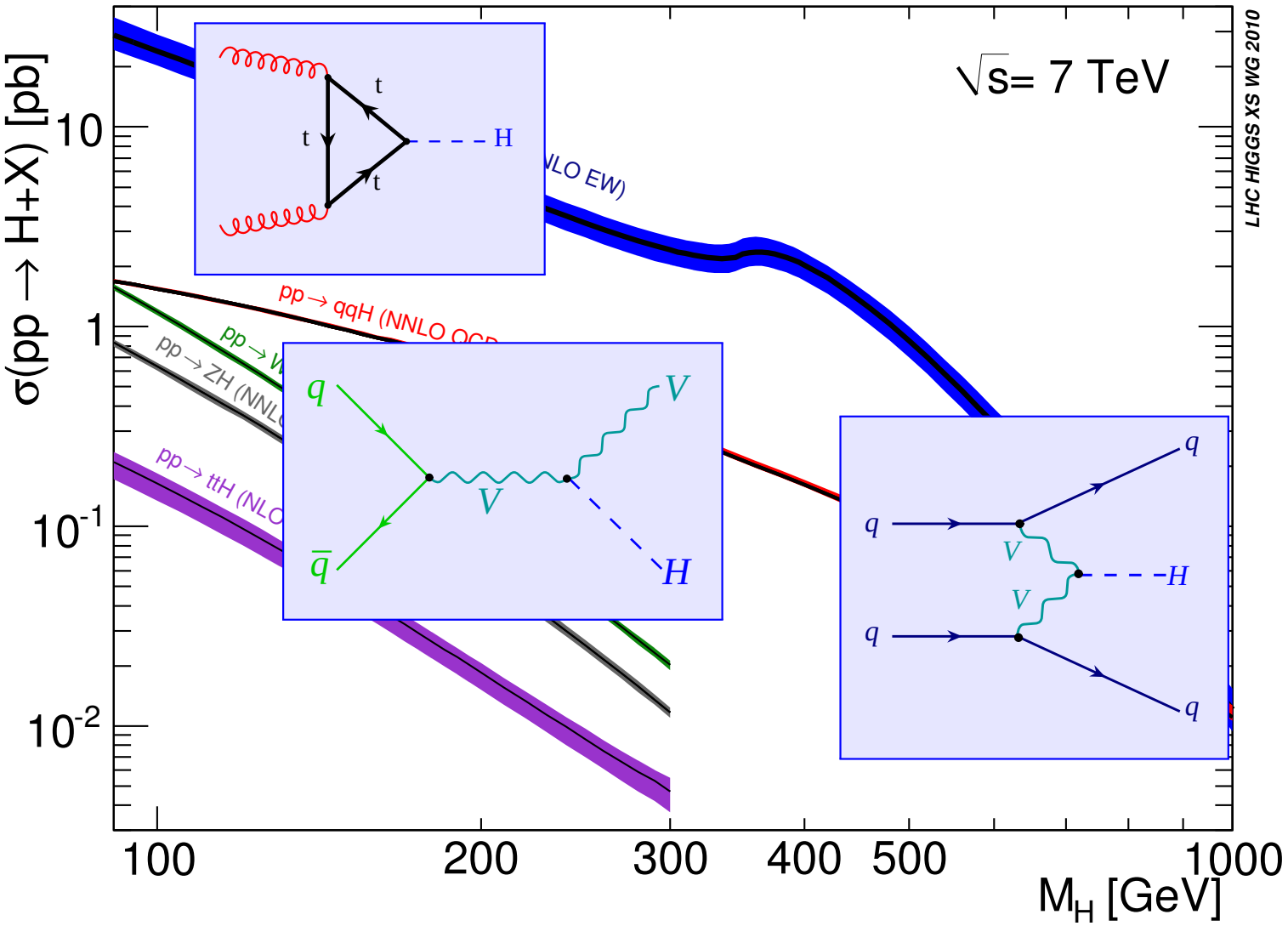

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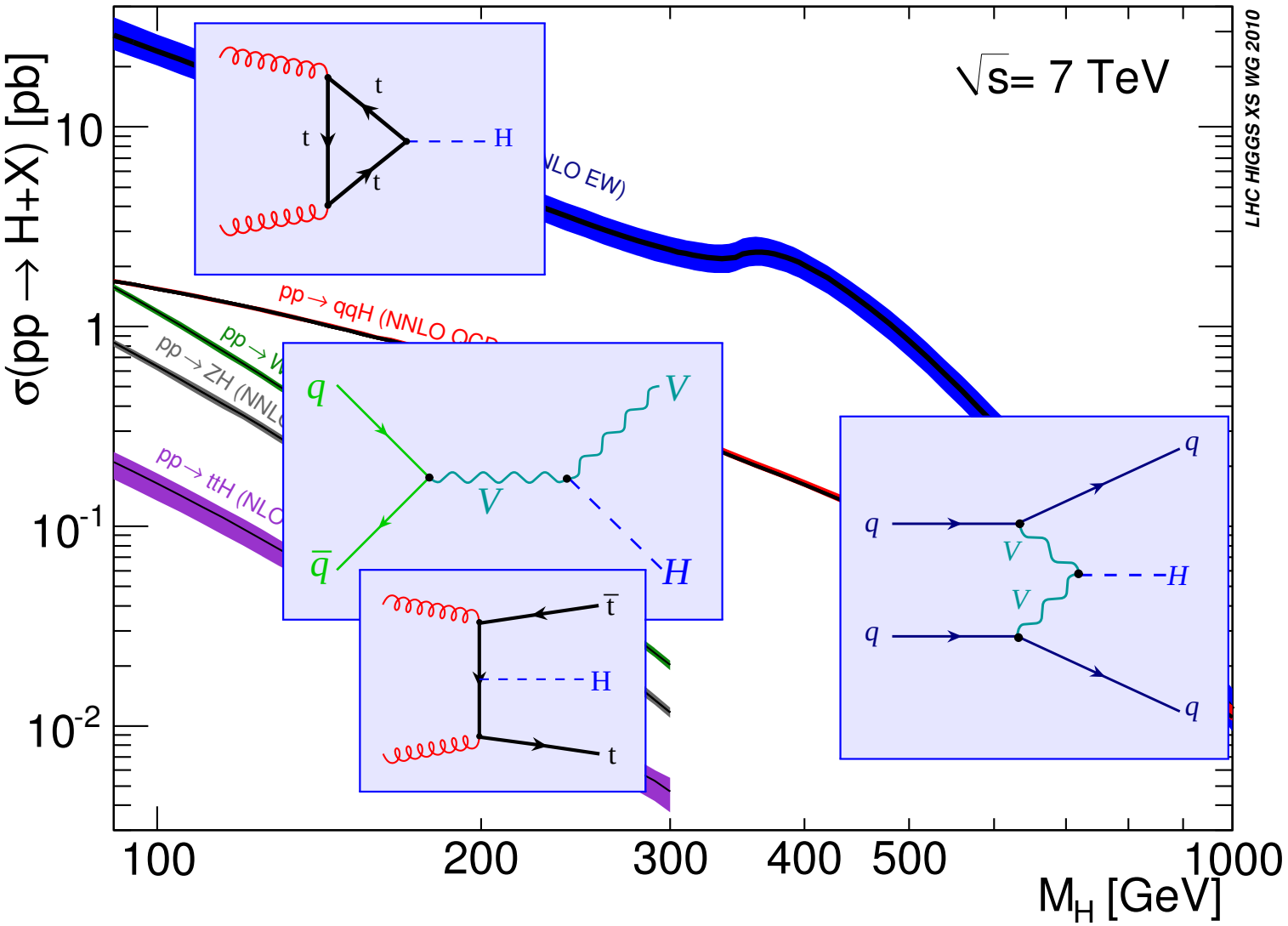

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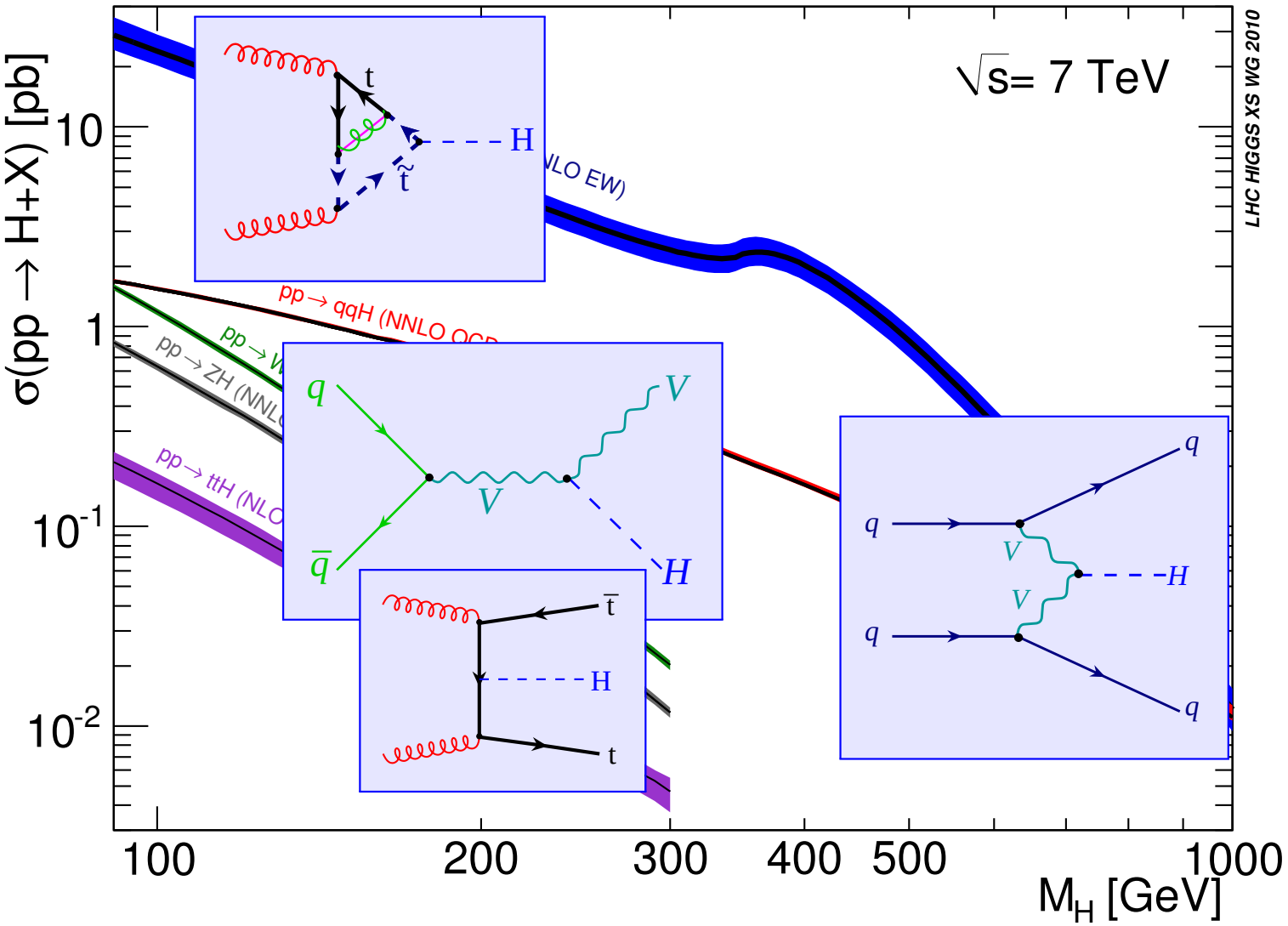

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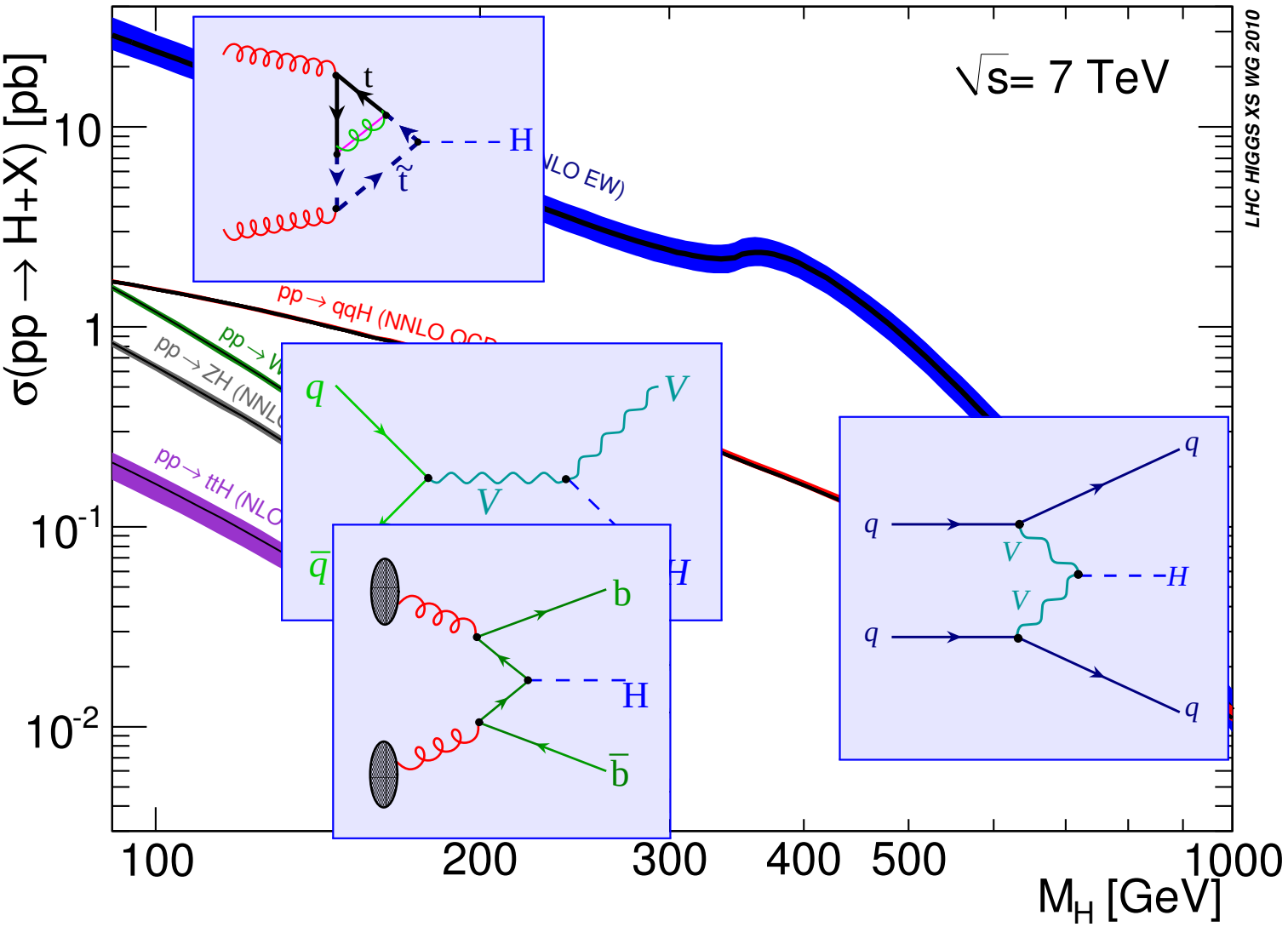
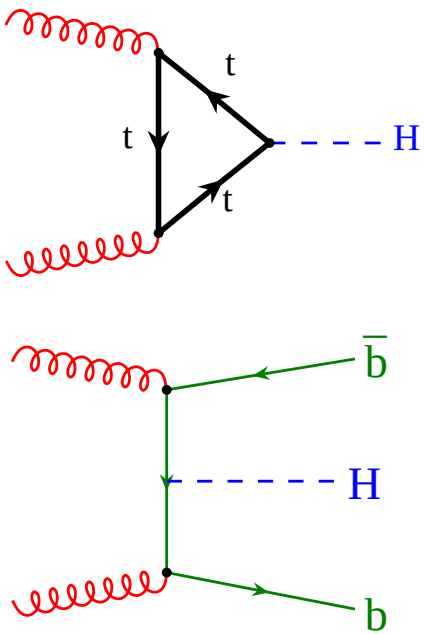
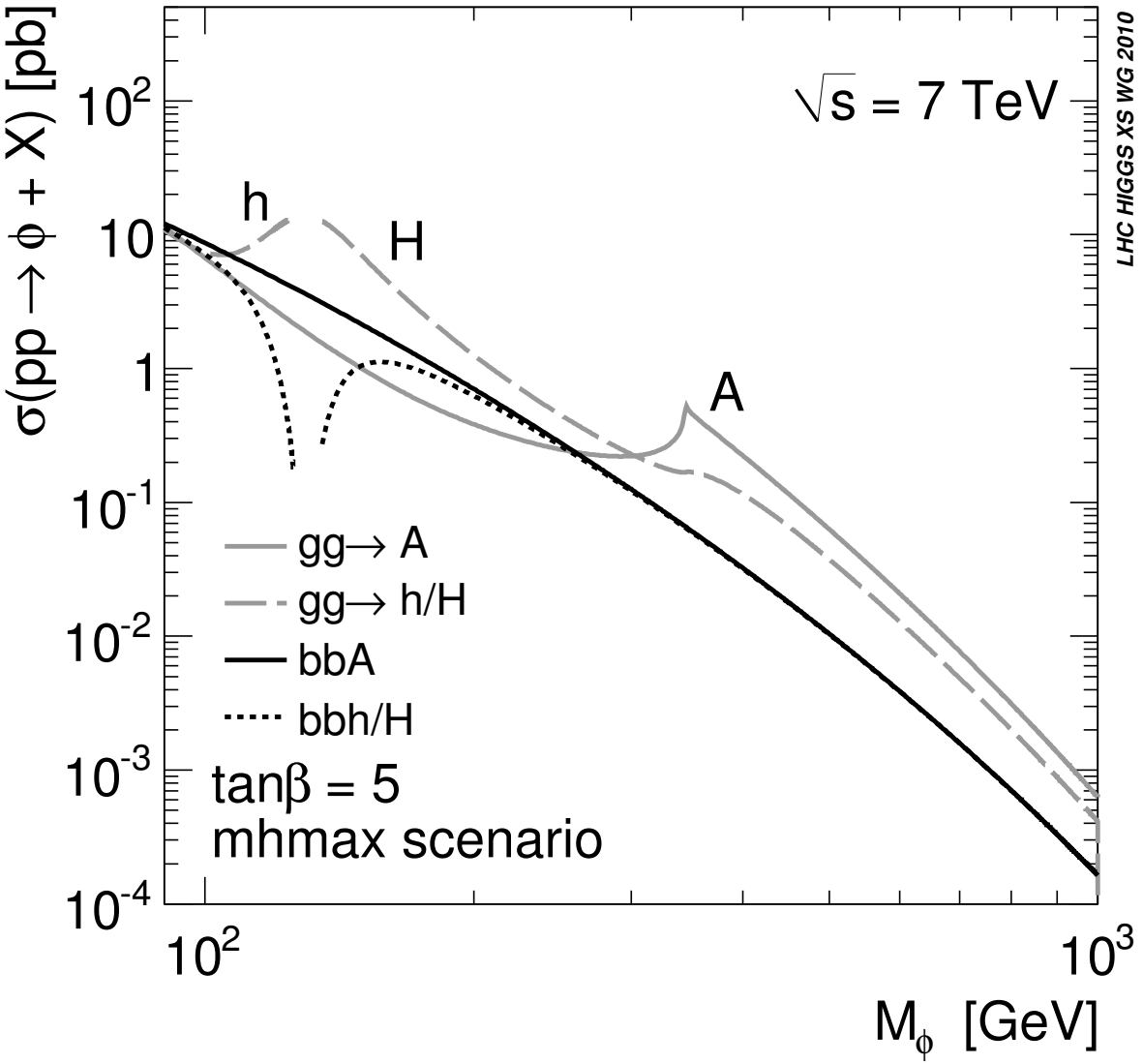
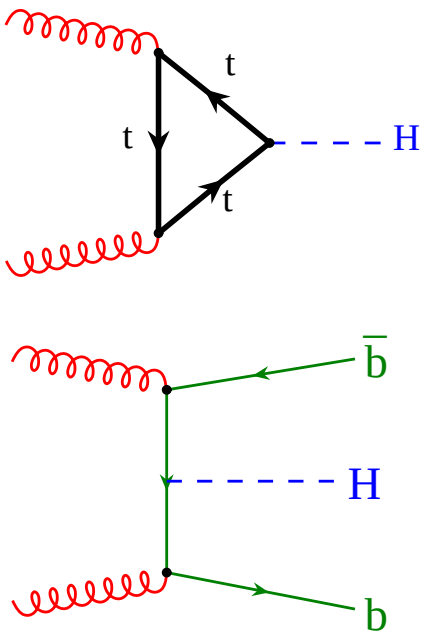


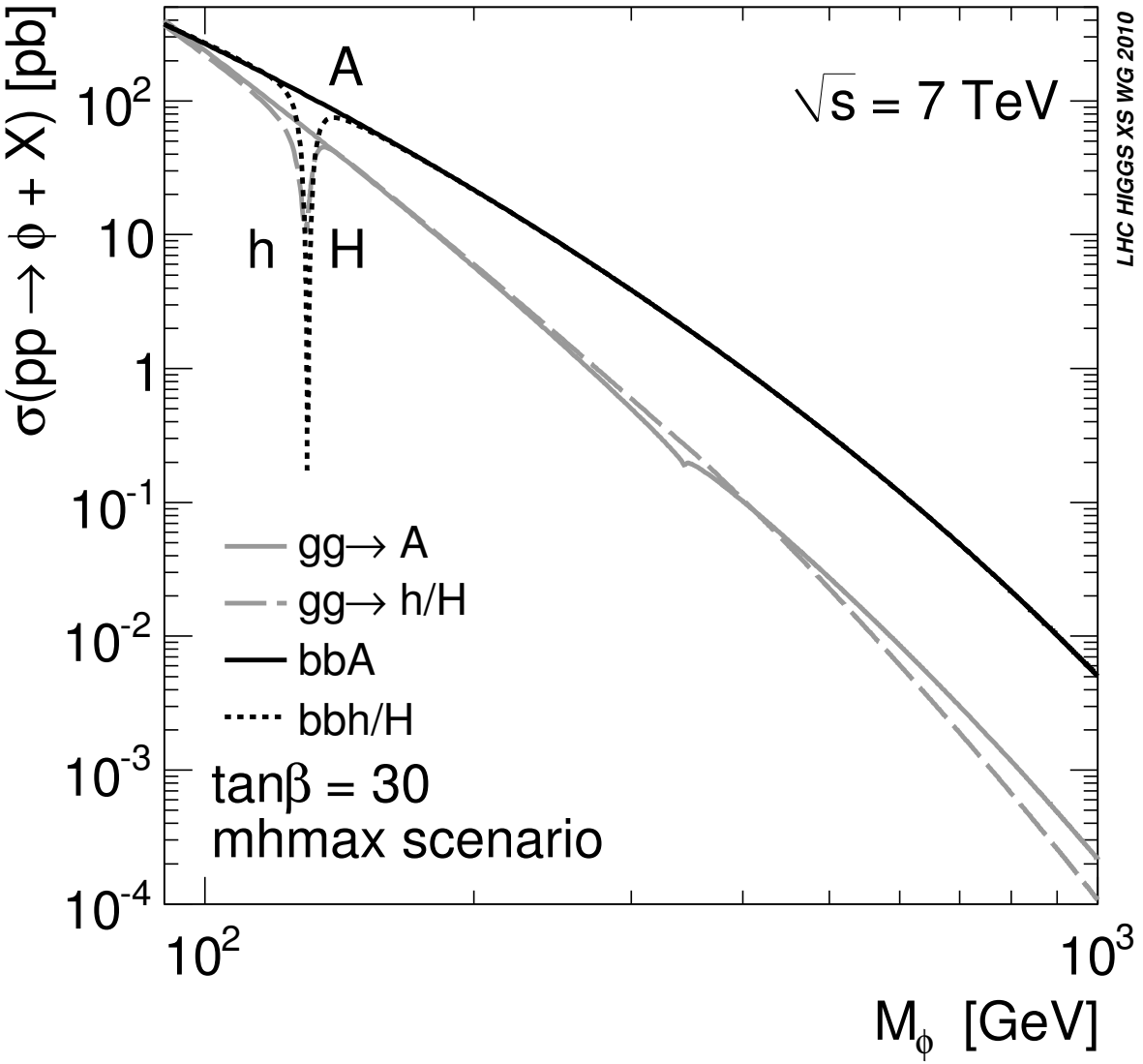
Higgs XS, tan $\beta = 5$



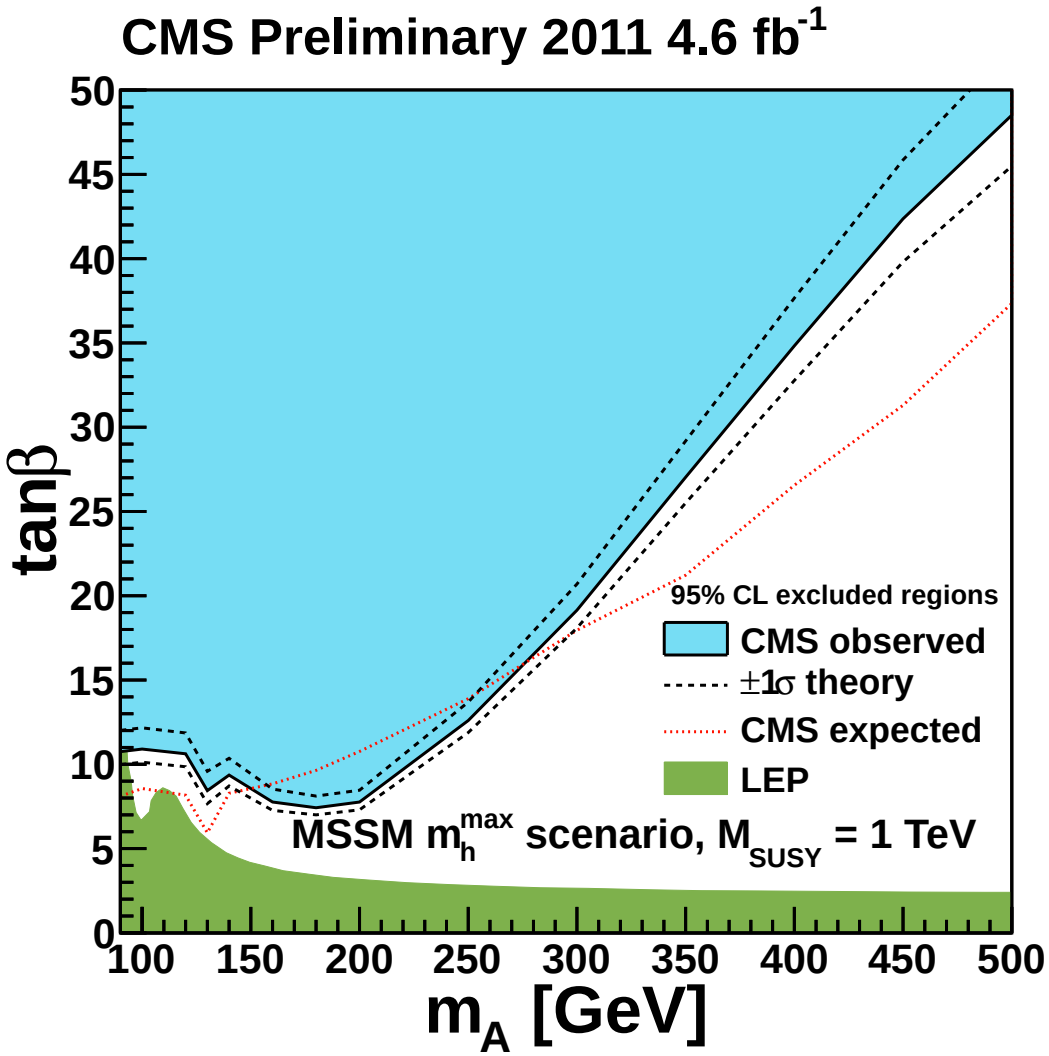


Higgs XS, tan $\beta = 30$

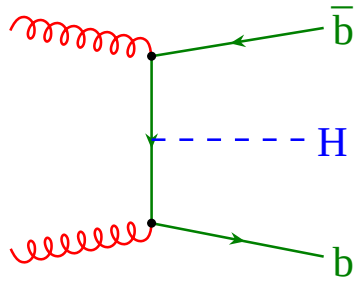




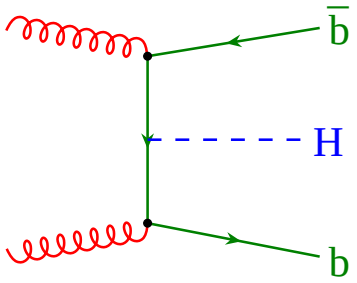
$b\bar{b} \to \Phi$


CMS Preliminary 2011 4.6 fb-1
tanβ
mA [GeV]
95% CL excluded regions
CMS observed
±1σ theory
CMS expected
LEP
MSSM mhmax scenario, MSUSY = 1 TeV

$H/A + b\bar{b}$

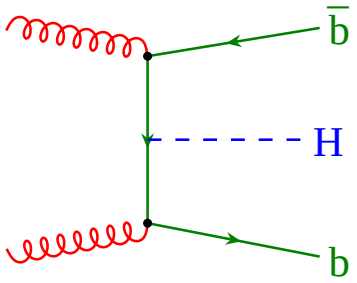


$H/A + b\bar{b}$

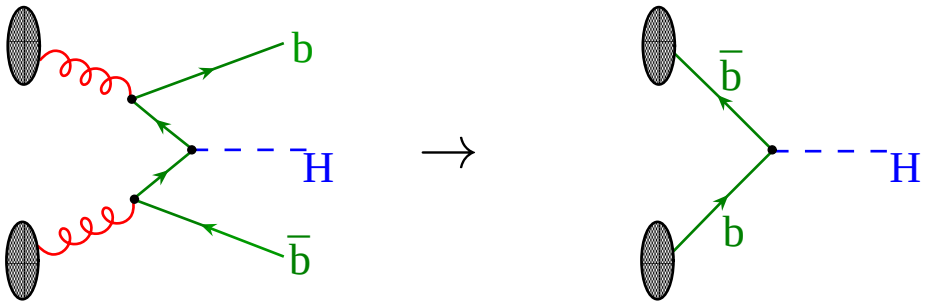


- collinear logarithms: $\sim \alpha_s \ln(m_b/M_H) \sim \alpha_s \ln(4/100)$

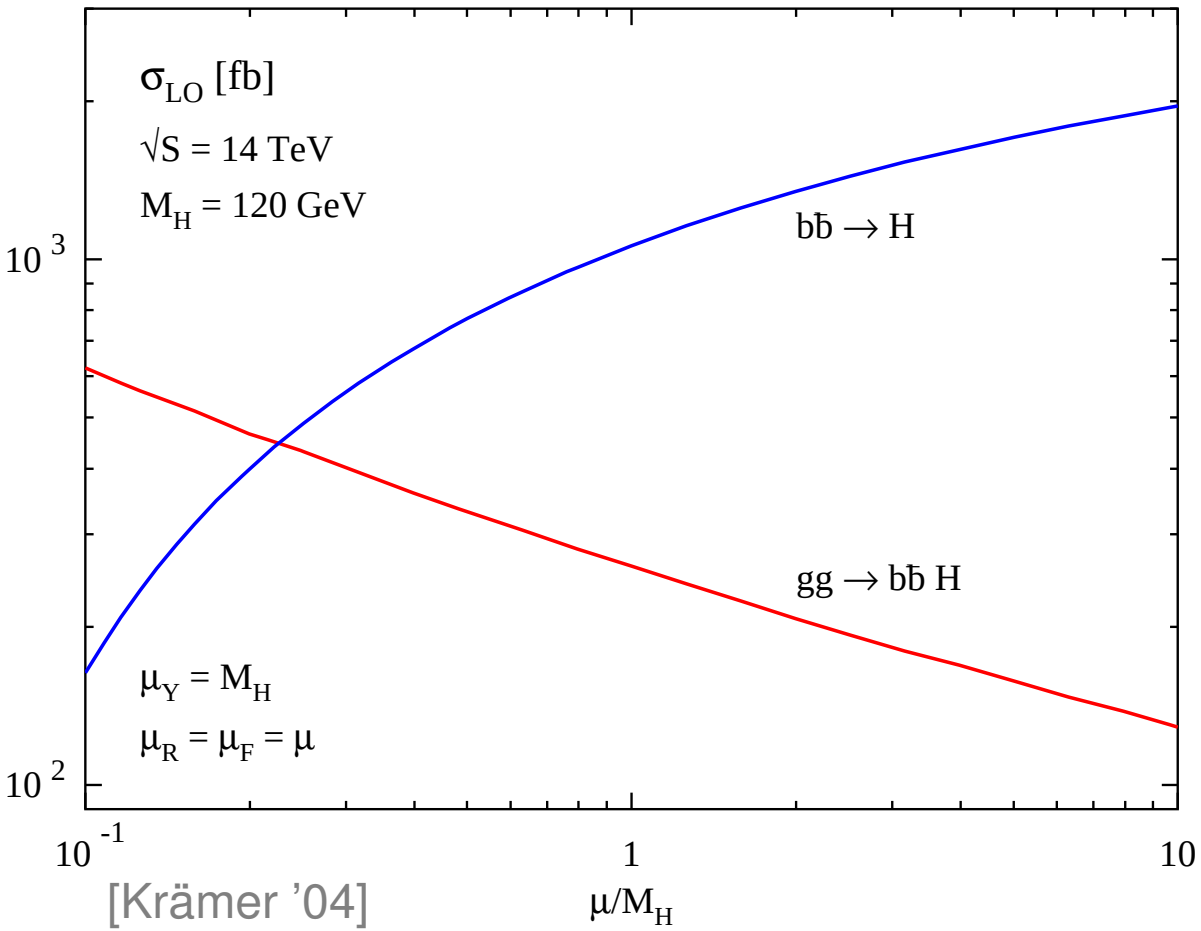
$H/A + b\bar{b}$



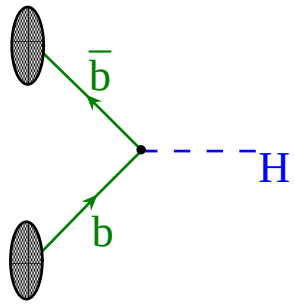
- collinear logarithms: $\sim \alpha_s \ln(m_b/M_H) \sim \alpha_s \ln(4/100)$
- resummation: bottom quarks as partons

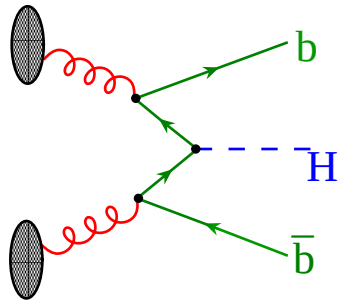


4-FNS vs. 5-FNS (LO)

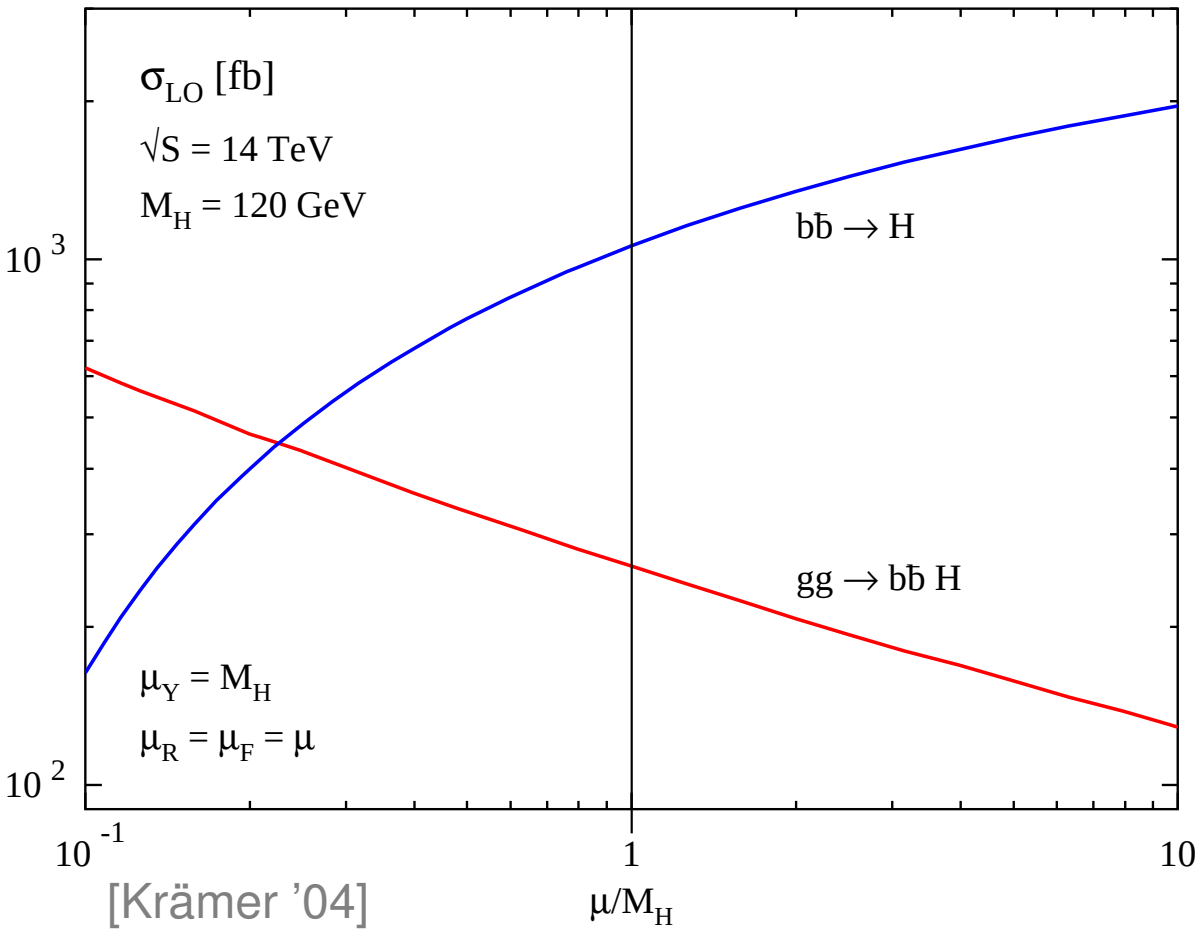


[Krämer '04]

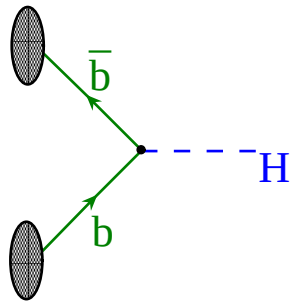


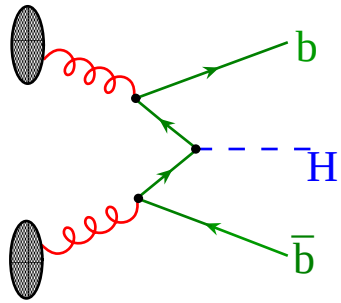


4-FNS vs. 5-FNS (LO)



[Krämer '04]





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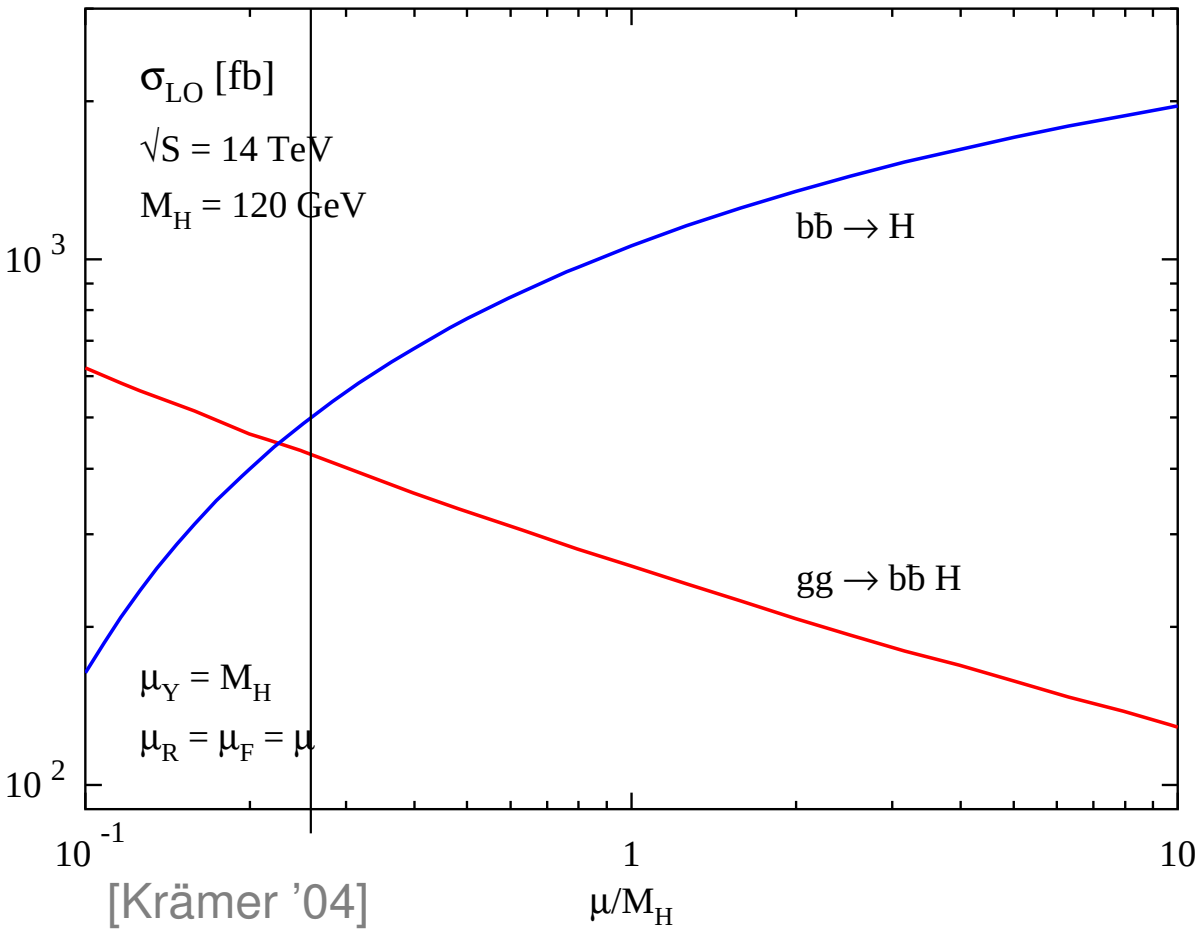

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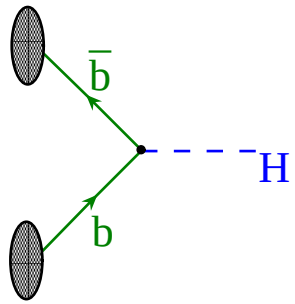
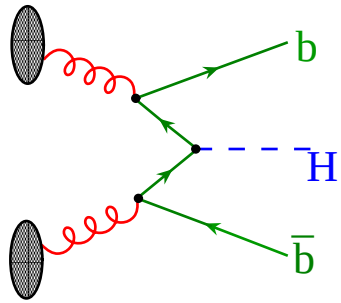
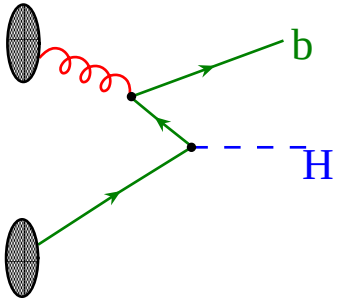




The “right” factorization scale

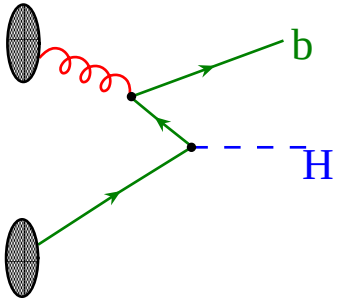
restrict use of bottom PDF to collinear region:



collinear region: $\dfrac{\mathrm{d}\sigma}{\mathrm{d}t} \sim \dfrac{1}{t}$

The “right” factorization scale

restrict use of bottom PDF to collinear region:



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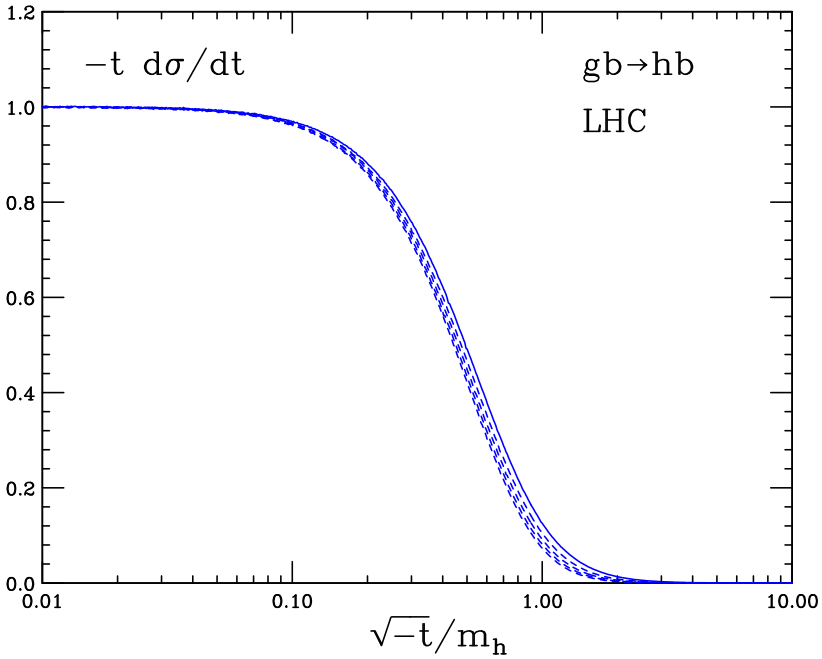

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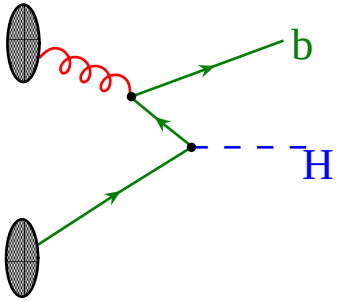

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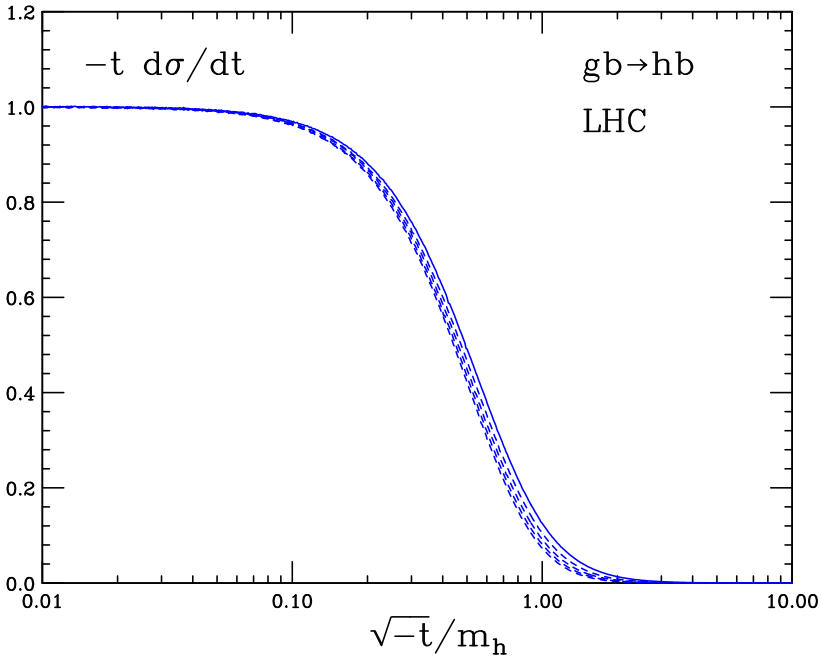
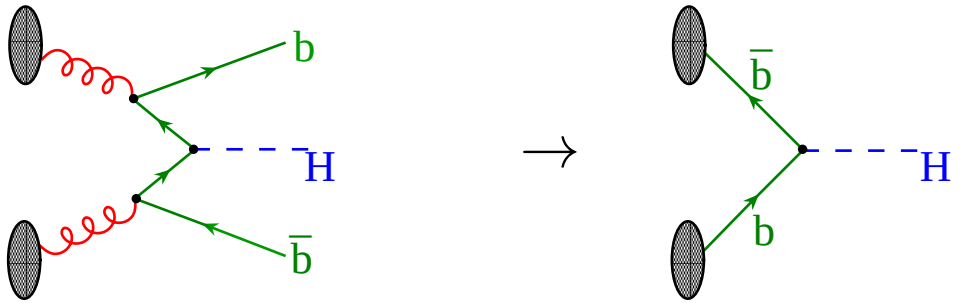


$\Rightarrow$ choose $\mu_F \approx m_h/4$

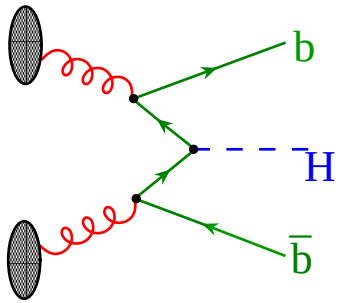
[Plehn ’02], [Plehn, Boos ’03]
[Maltoni, Willenbrock, Sullivan ’03]
[Spira, Rainwater, Zeppenfeld ’03]

Higher orders: NLO



$$\alpha_s^2 \left(c_{02} l_b^2 + c_{01} l_b + c_{00} \right) \qquad \sum_{n=2}^{\infty} (\alpha_s l_b)^n$$

Higher orders: NLO



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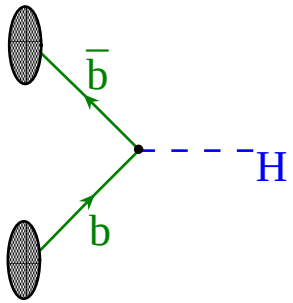

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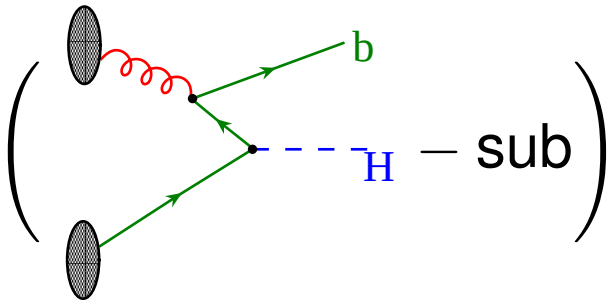
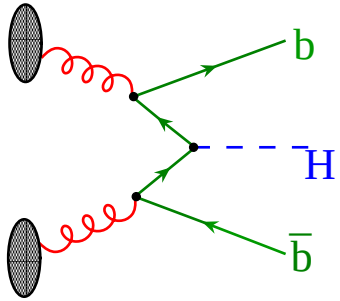


$$\alpha_s^2 \left(c_{02} l_b^2 + c_{01} l_b + c_{00} \right) \qquad \sum_{n=2}^{\infty} (\alpha_s l_b)^n \qquad \sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \frac{1}{l_b}$$

Higher orders: NLO



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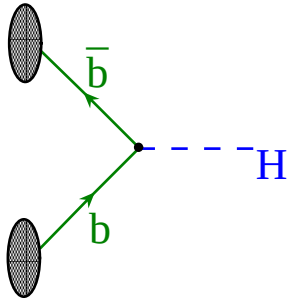

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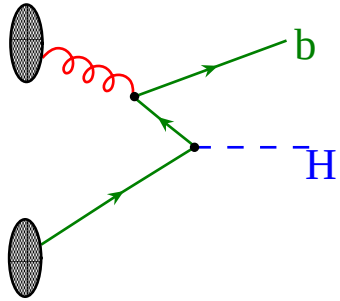
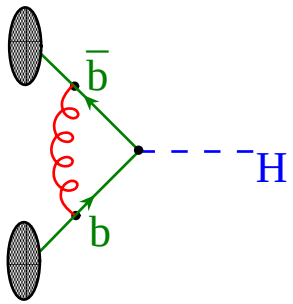


$- \text{sub}\Big)$

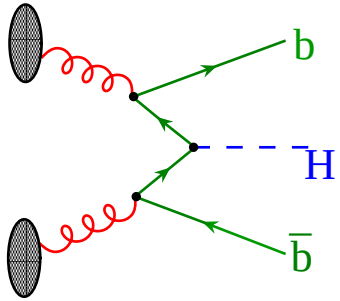
$$\alpha_s^2 \left(c_{02} l_b^2 + c_{01} l_b + c_{00}\right) \qquad \sum_{n=2}^{\infty} (\alpha_s l_b)^n \qquad \sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \frac{1}{l_b}$$

$+$



$$\sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \alpha_s$$

Higher orders: NLO



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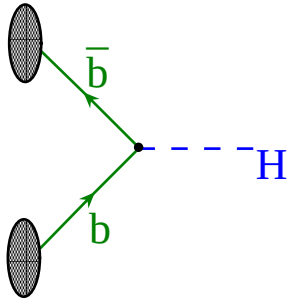

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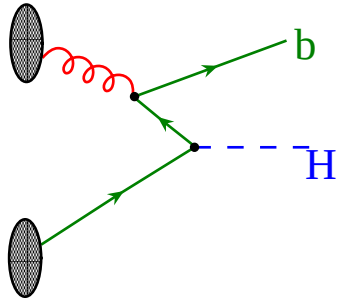
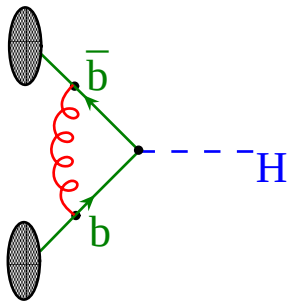


$- \text{sub}$

$\alpha_s^2 \left(c_{02} l_b^2 + c_{01} l_b + c_{00} \right)$ $\quad \sum_{n=2}^{\infty} (\alpha_s l_b)^n$ $\quad \sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \frac{1}{l_b}$

$+$

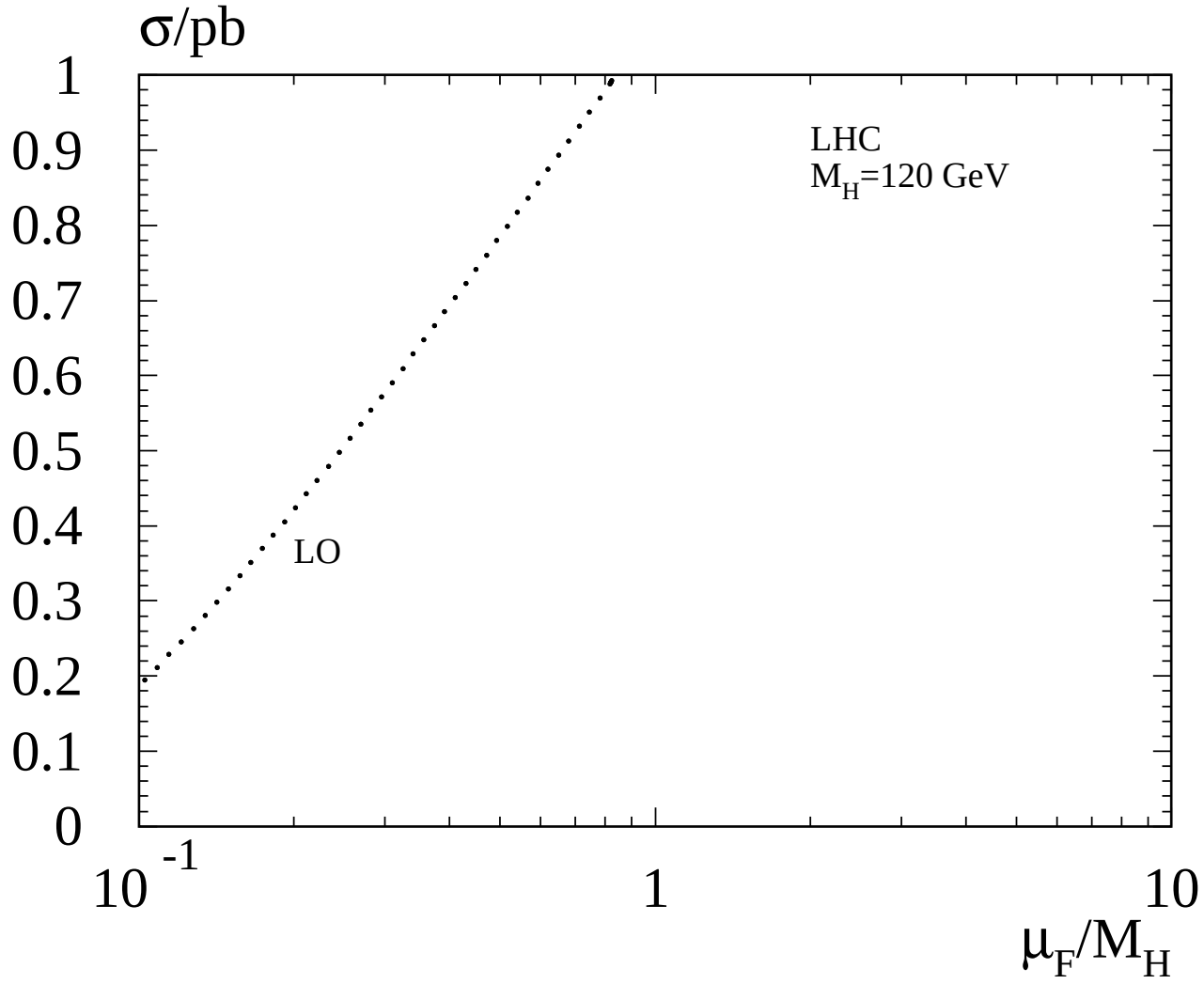


$\sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \alpha_s$

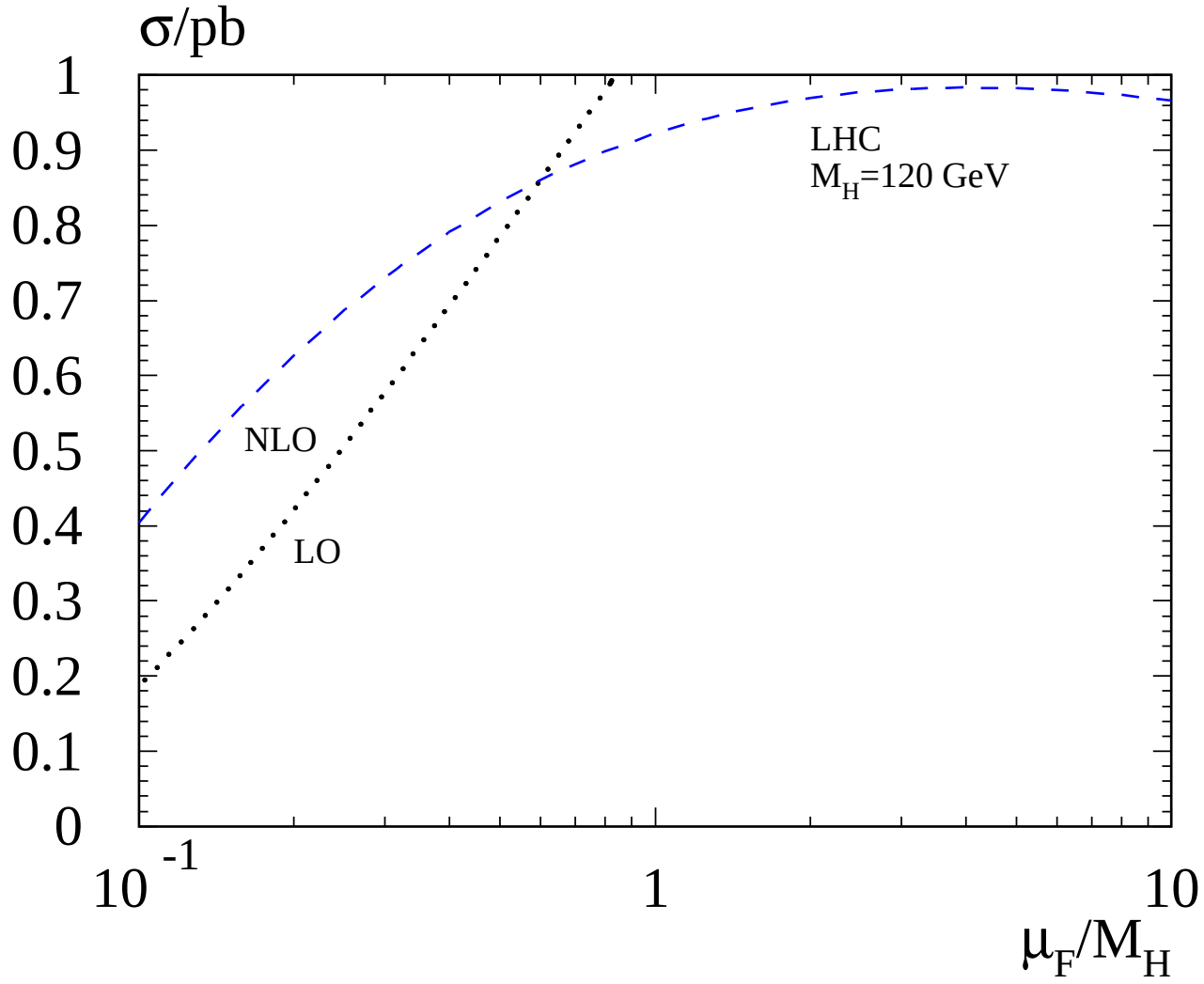
$$\text{NLO:} \quad \sigma(b\bar{b} \rightarrow H) = \sum_{n=0}^{\infty} (\alpha_s l_b)^n \, \alpha_s^2 \left[\; c_{n2} \, l_b^2 \; + \; c_{n1} \, l_b \right]$$

[Maltoni, Sullivan, Willenbrock '03]

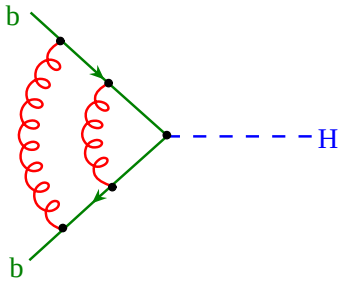
$b\bar{b} \to H$ at NLO



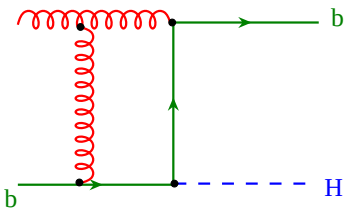
$b\bar{b} \to H$ at NLO



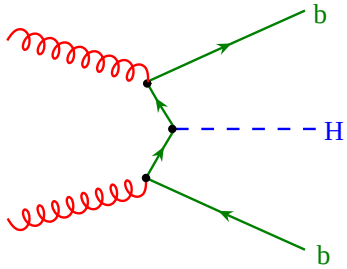
Higher orders: NNLO



$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \alpha_s^2$$

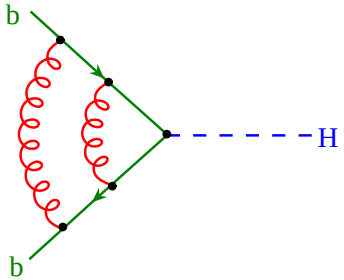


$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \alpha_s \frac{1}{l_b}$$



$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \frac{1}{l_b^2}$$

Higher orders: NNLO



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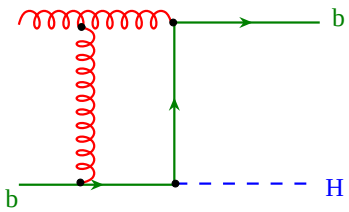
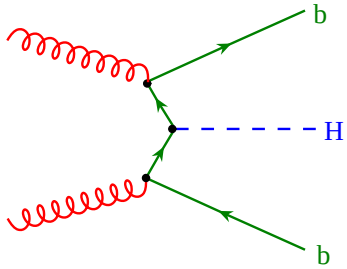


$$\sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \alpha_s \frac{1}{l_b}$$

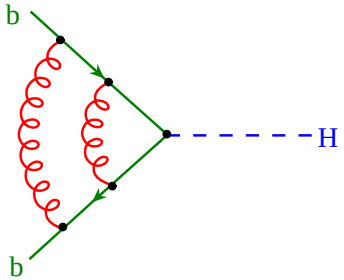


$$\sum_{n=2}^{\infty} (\alpha_s l_b)^n \cdot \frac{1}{l_b^2}$$

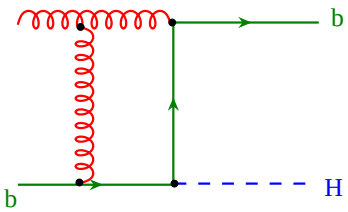
NNLO: $$\sigma(b\bar{b} \to H) = \sum_{n=0}^{\infty} (\alpha_s l_b)^n \, \alpha_s^2 \left[c_{n2} \, l_b^2 + c_{n1} \, l_b + c_{n0} \right]$$

[R.H., Kilgore '03]

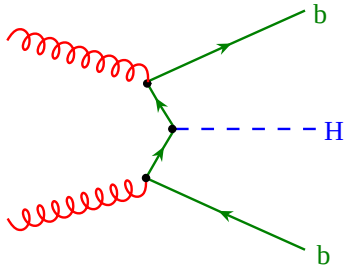
Higher orders: NNLO



$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \alpha_s^2$$



$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \alpha_s \frac{1}{l_b}$$



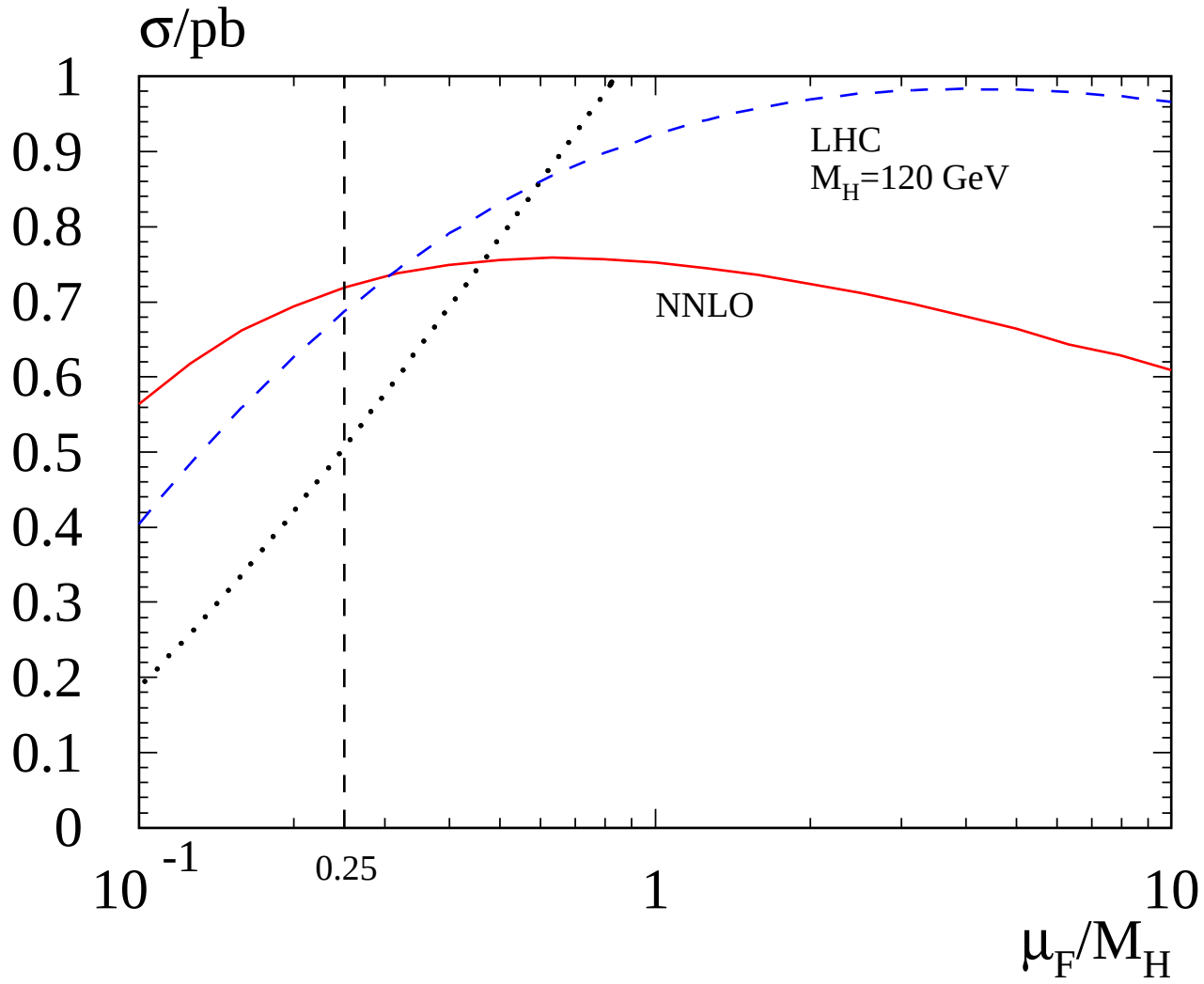
$$\sum_{n=2}^{\infty}(\alpha_s l_b)^n \cdot \frac{1}{l_b^2}$$

NNLO: $$\sigma(b\bar{b} \to H) = \sum_{n=0}^{\infty} (\alpha_s l_b)^n \, \alpha_s^2 \Big\{ \Big[\; c_{n2} \, l_b^2 \; + \; c_{n1} \, l_b \; + \; c_{n0} \Big]$$

[R.H., Kilgore '03]

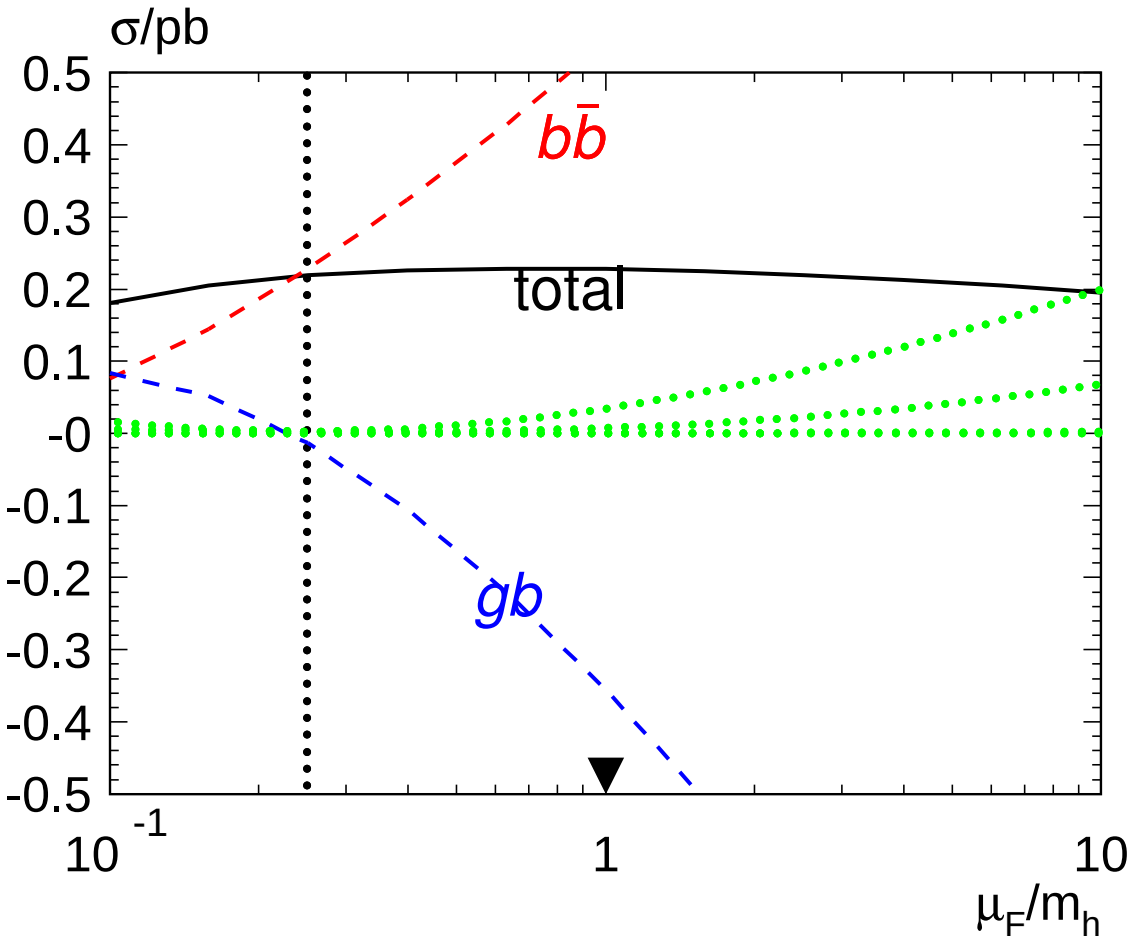
higher orders: $$+ \, d_{n3}\alpha_s^3 + d_{n4}\alpha_s^4 + \ldots \Big\}$$

5-FNS at NNLO



`bbh@nnlo`: [RH, Kilgore '03]

Sub-channels: μ-dependence



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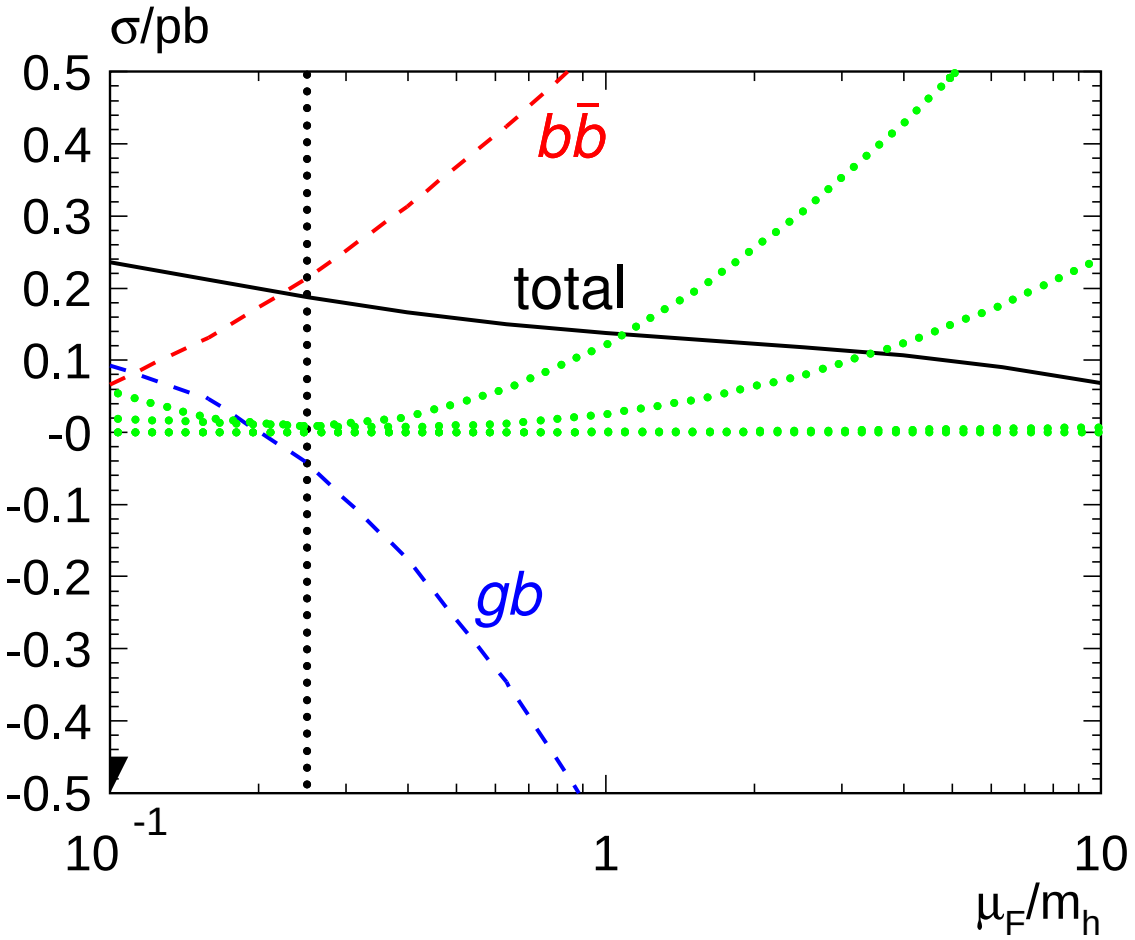

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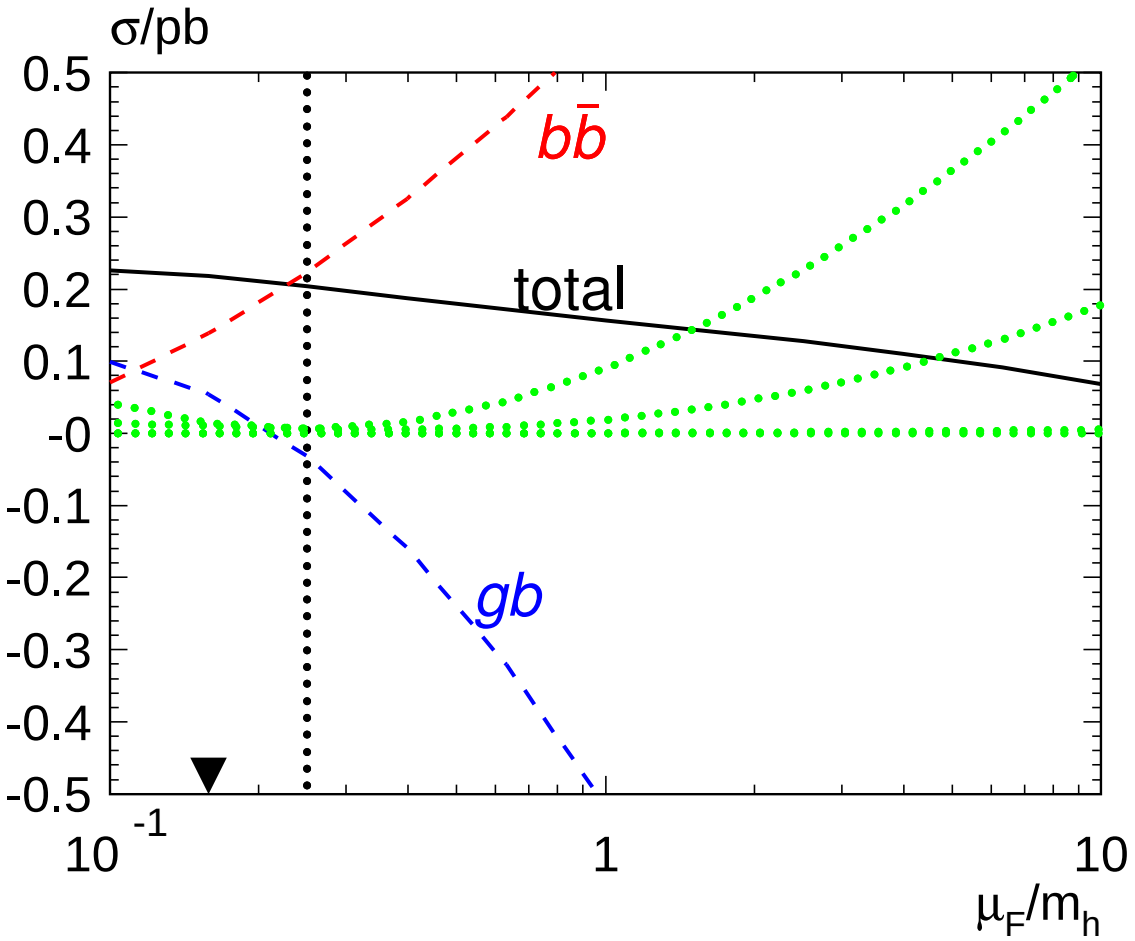

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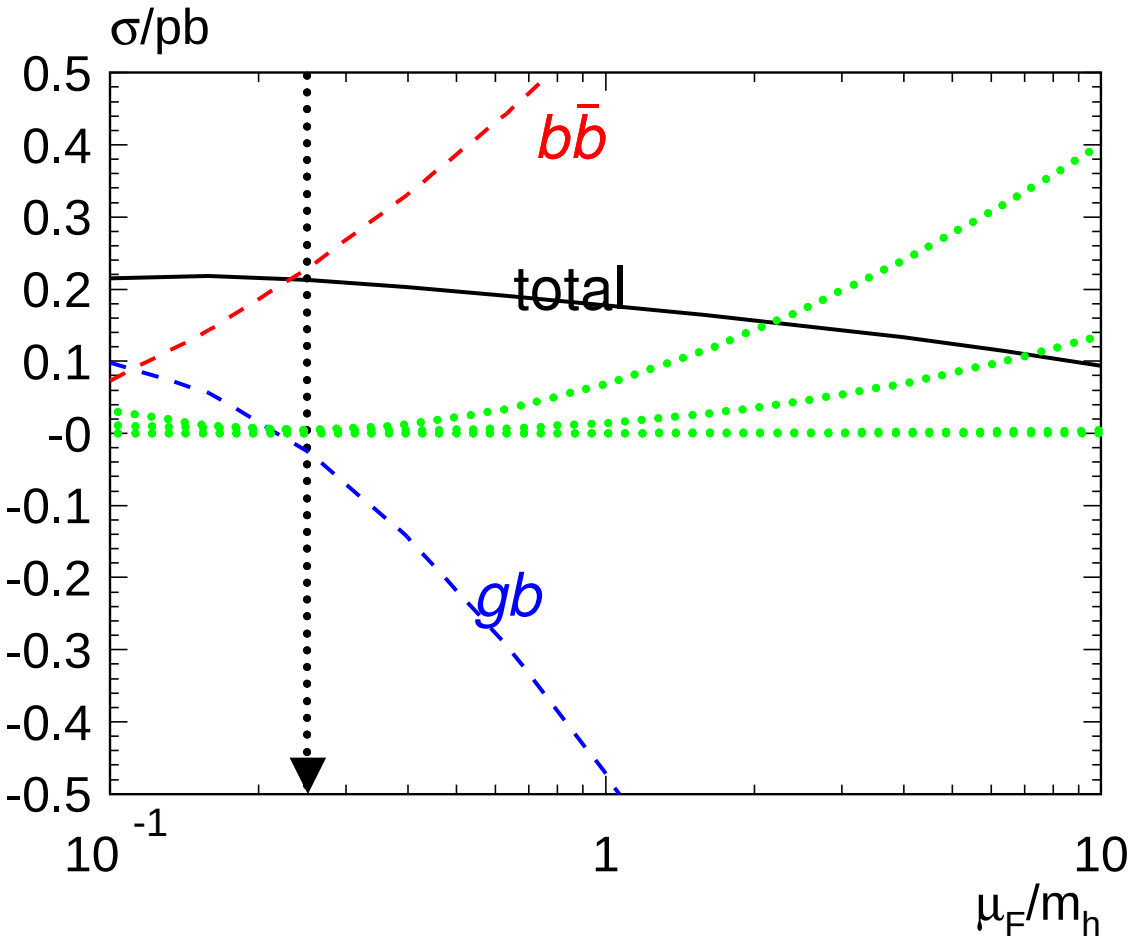

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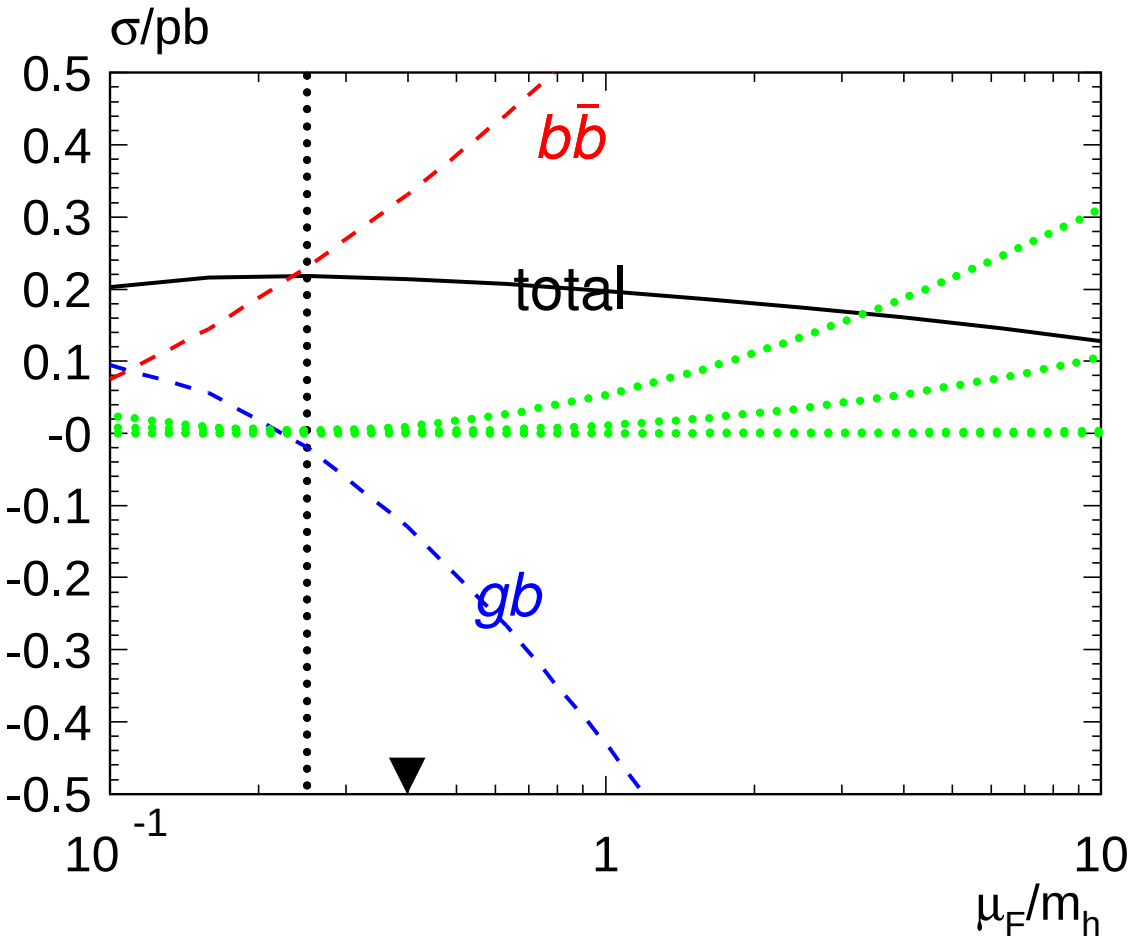
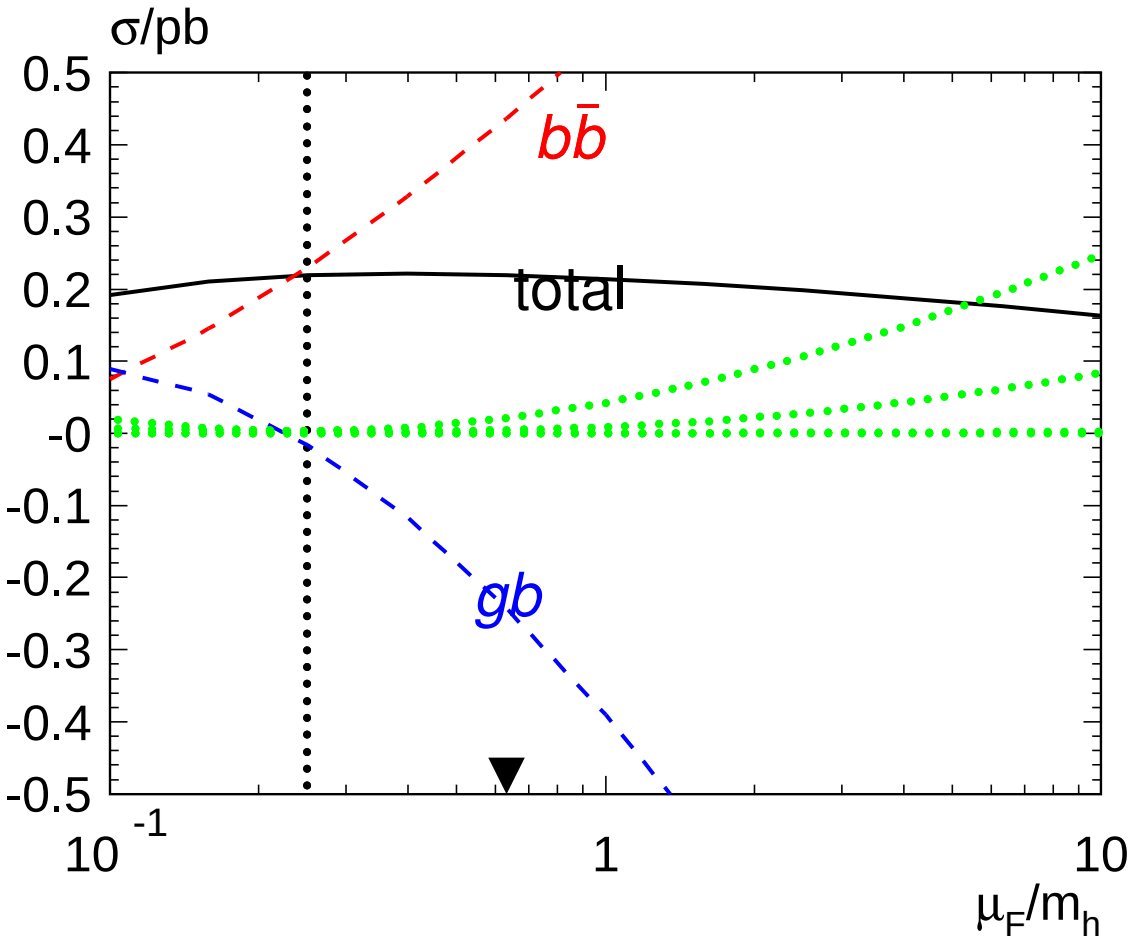
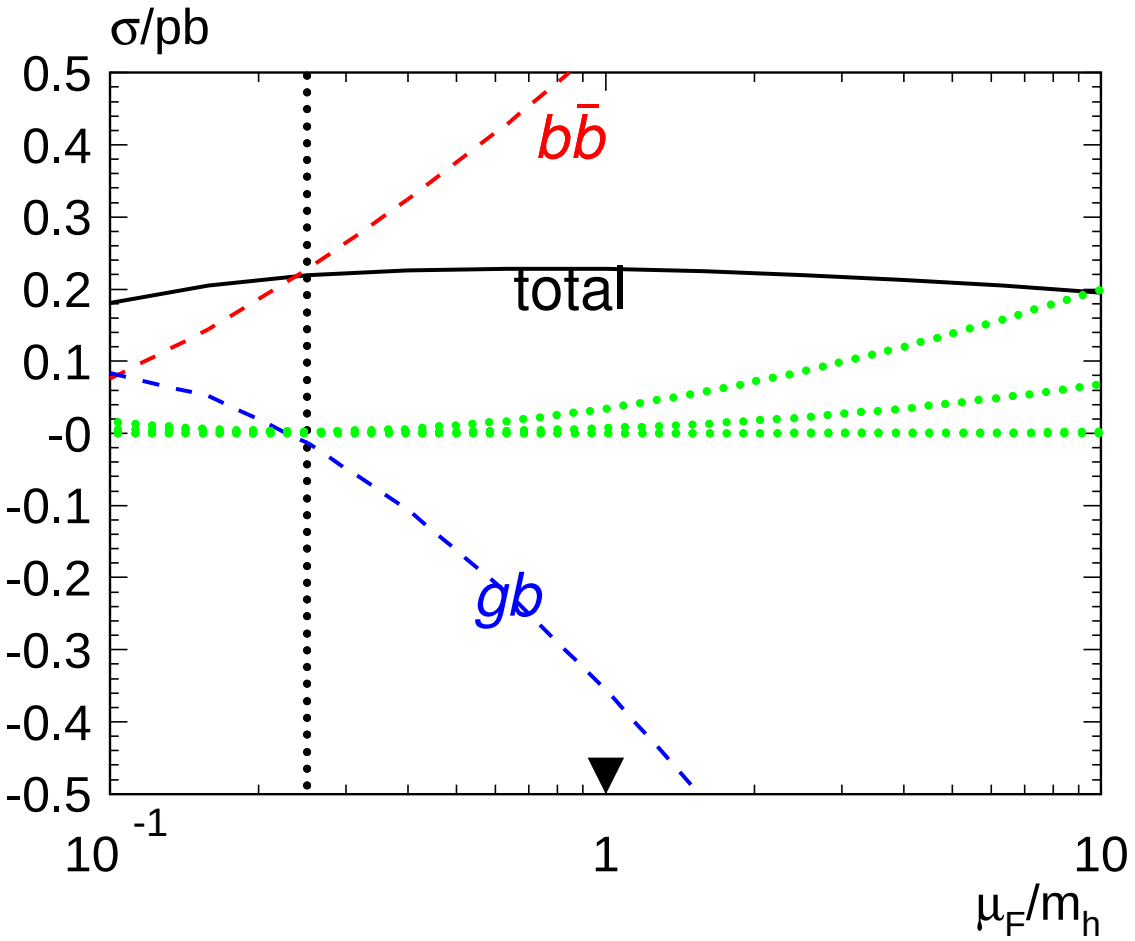


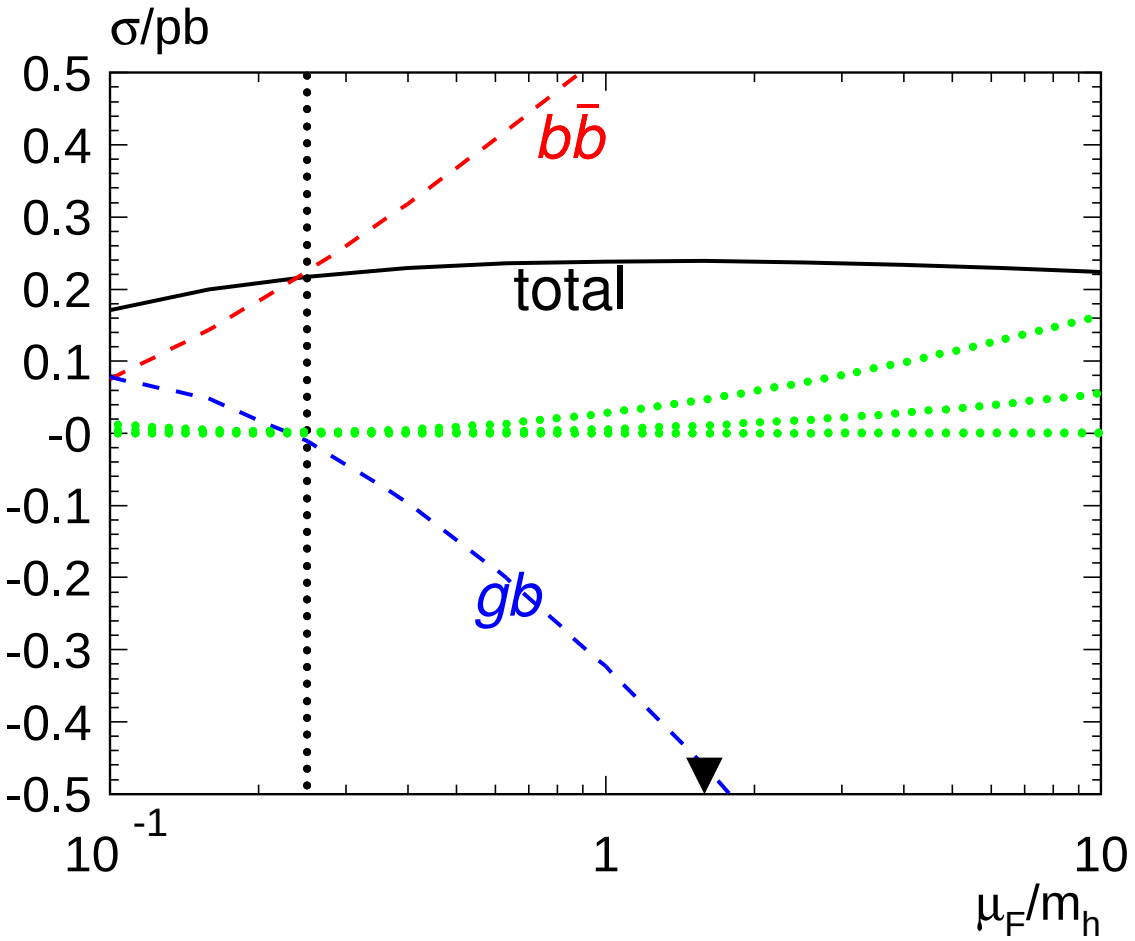
Sub-channels: μ-dependence



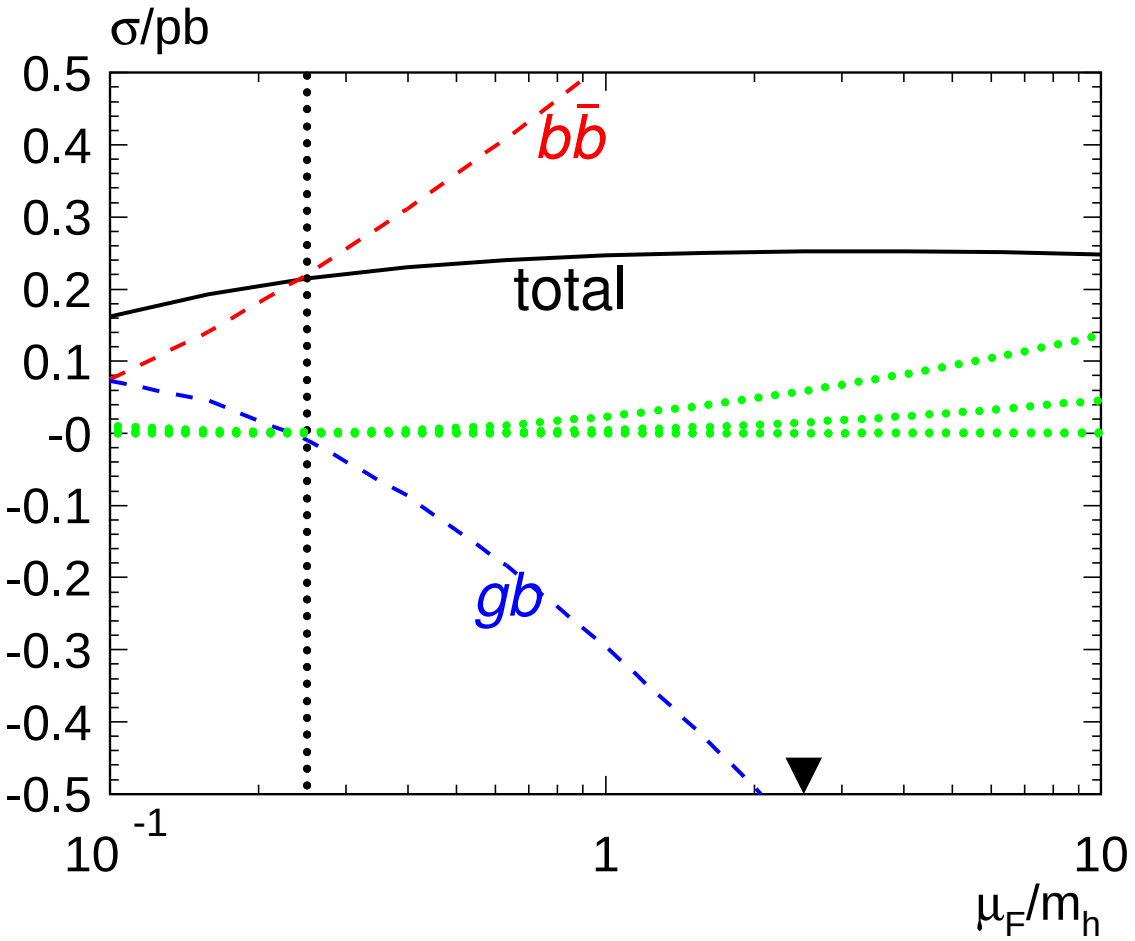
Sub-channels: μ-dependence



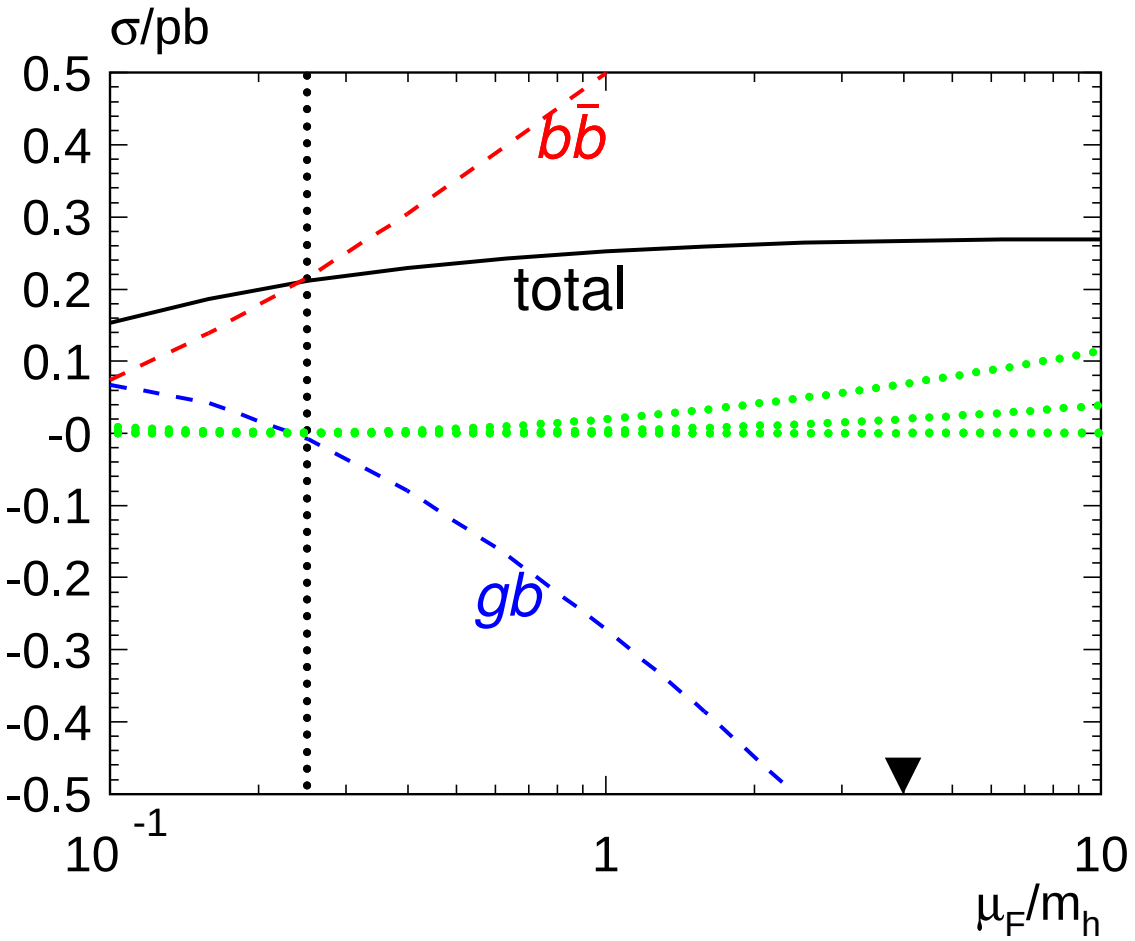
Sub-channels: μ-dependence



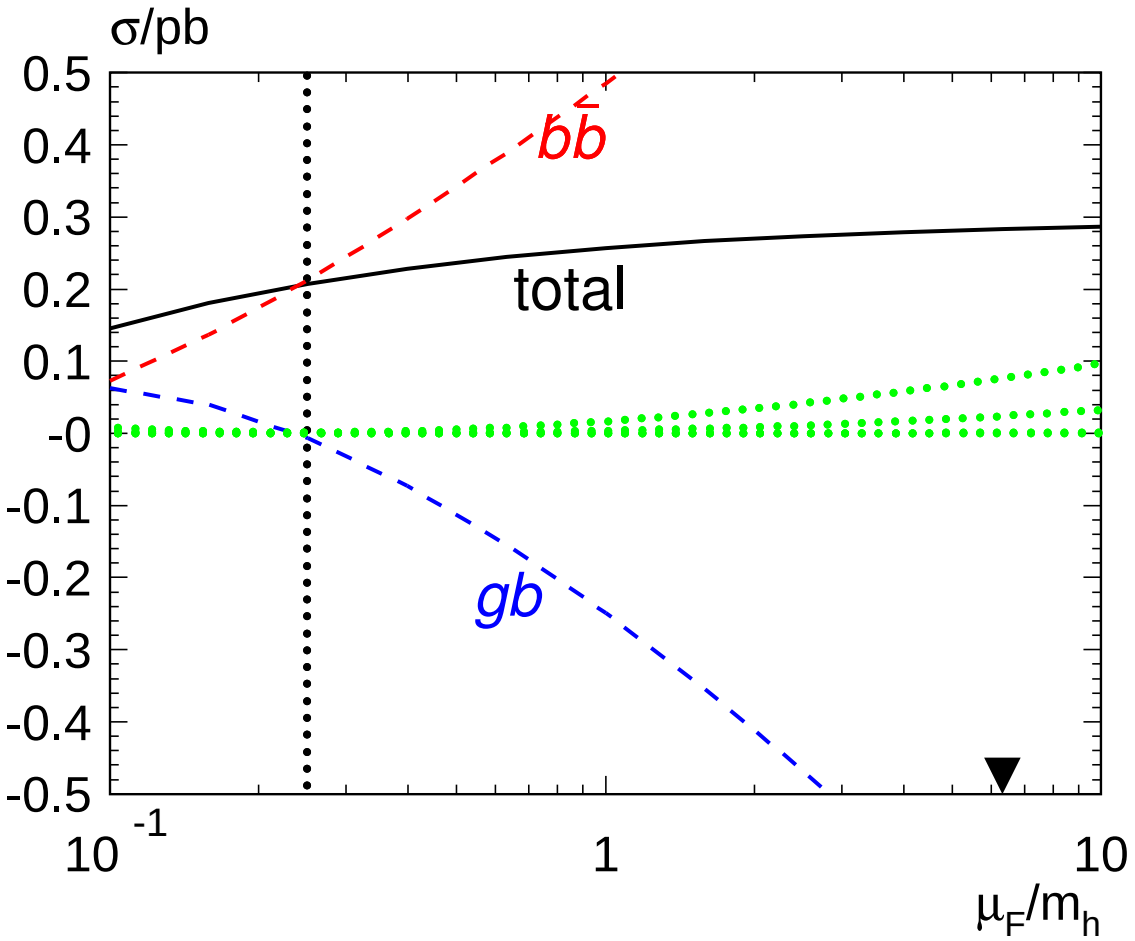
Sub-channels: μ-dependence



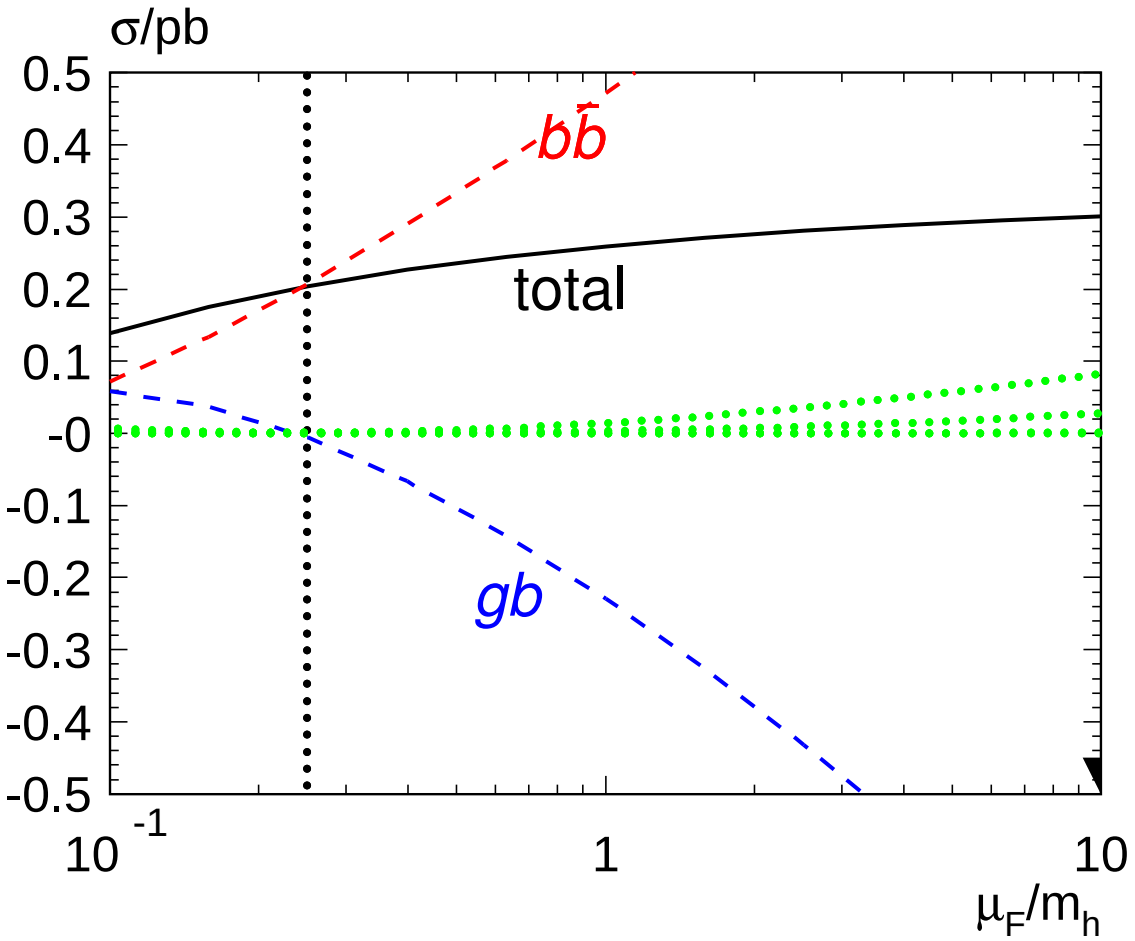
Sub-channels: μ-dependence



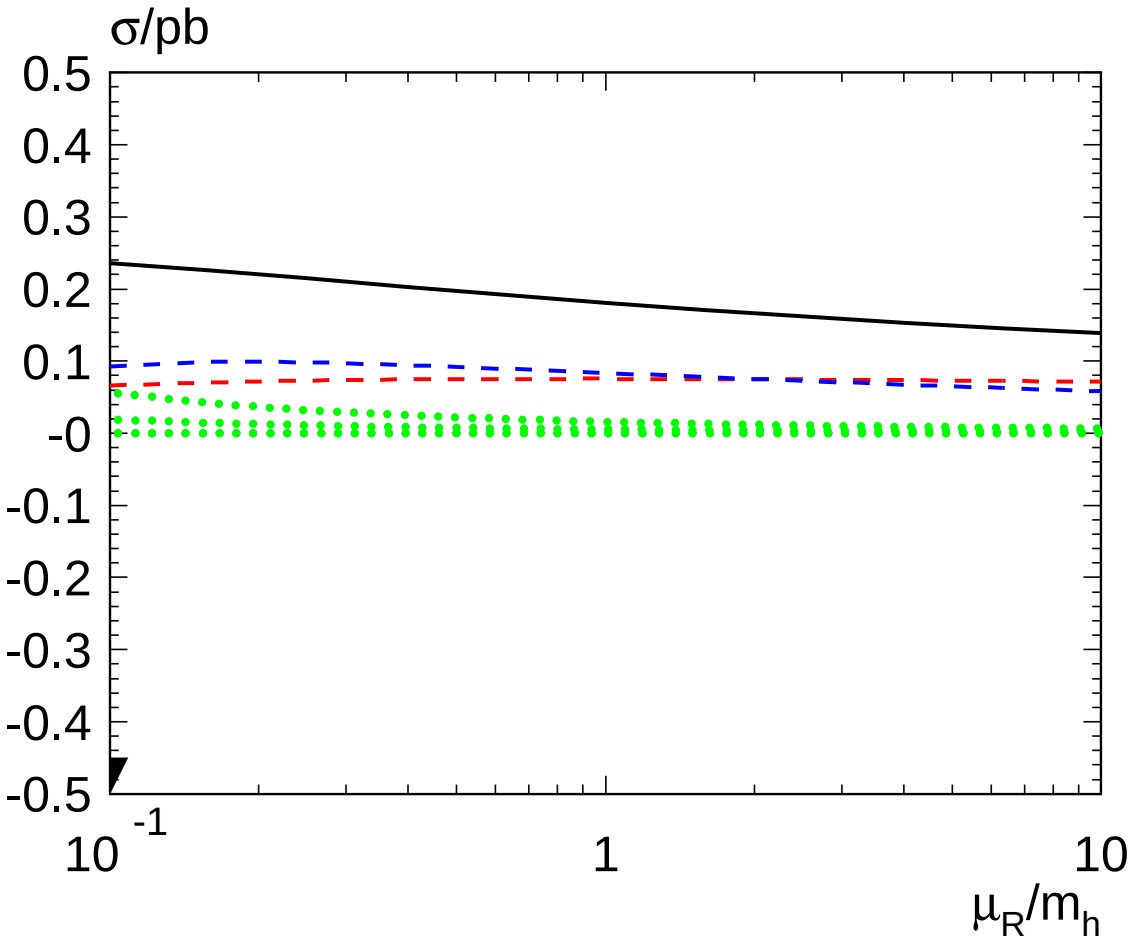
Sub-channels: μ-dependence



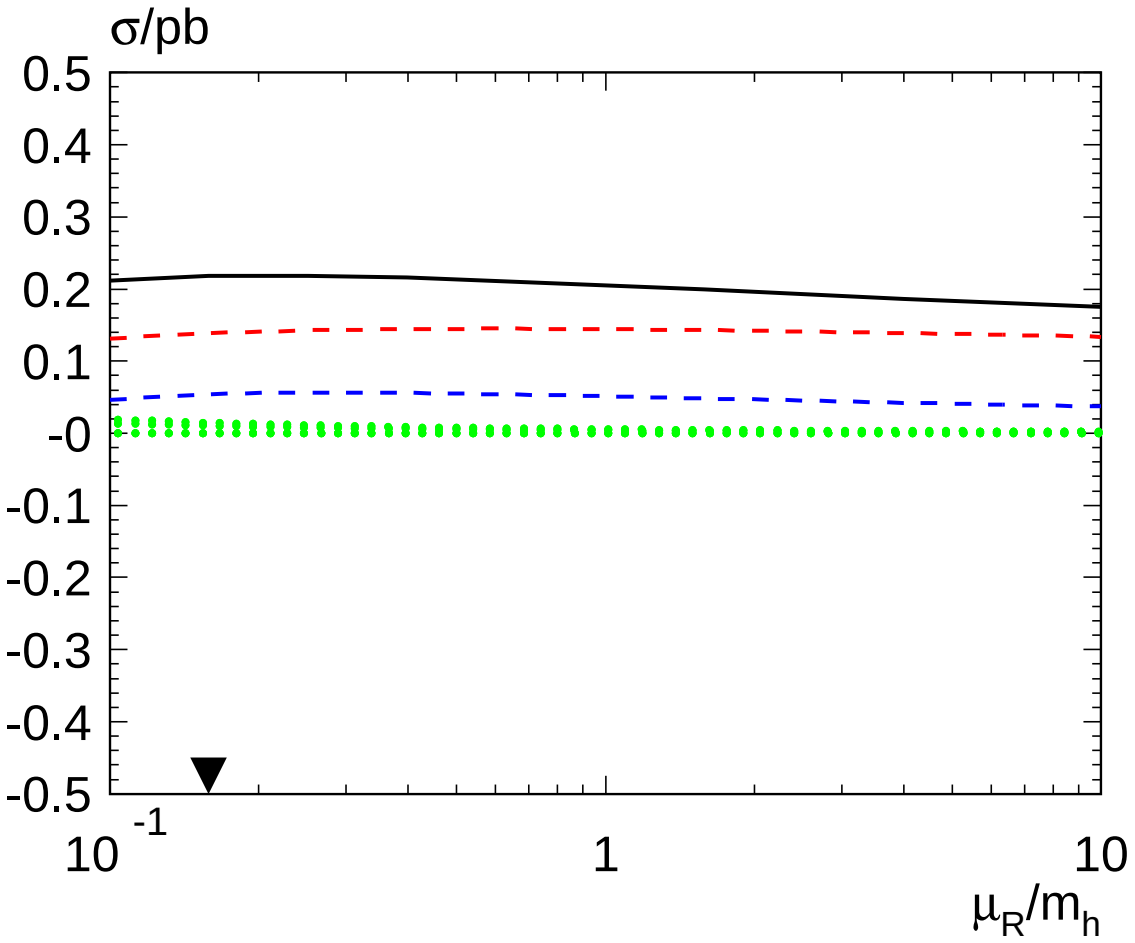
Sub-channels: μ-dependence



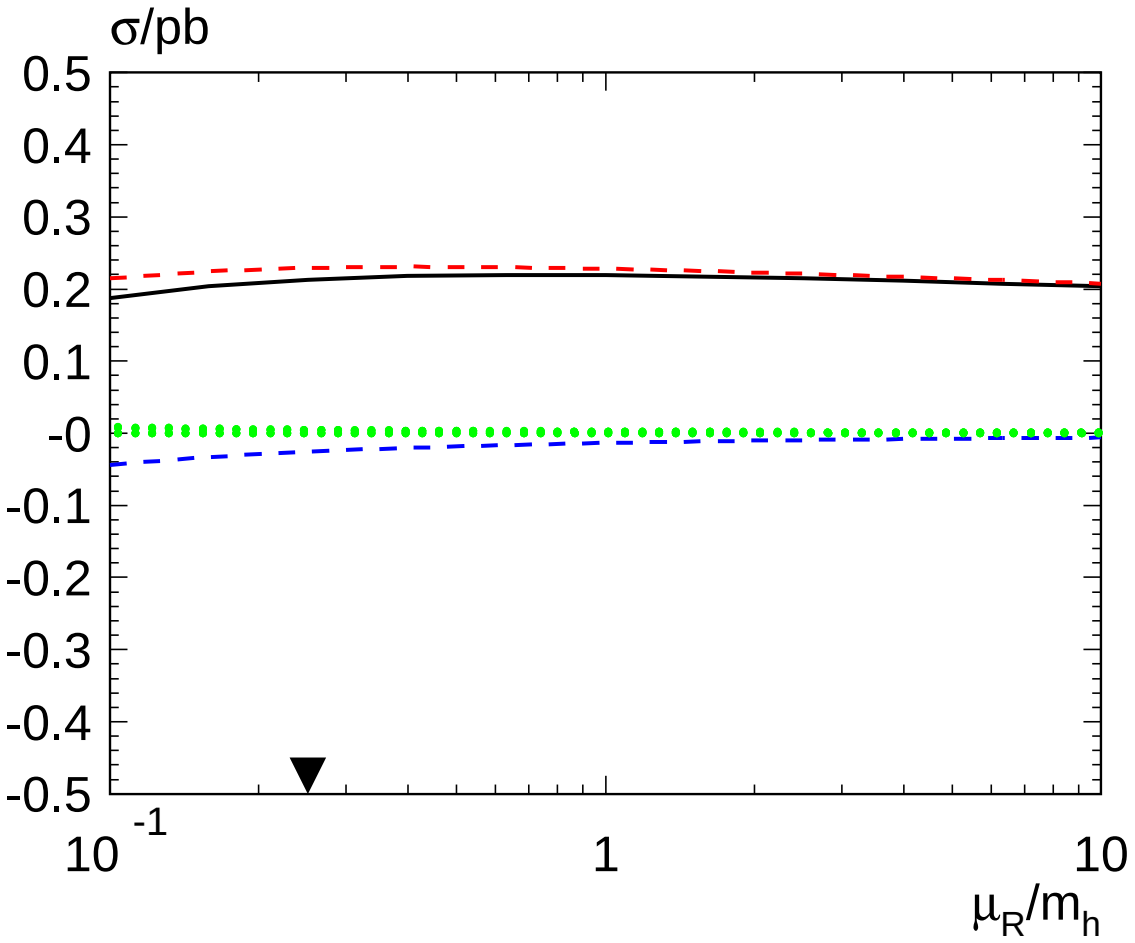
Sub-channels: μ-dependence



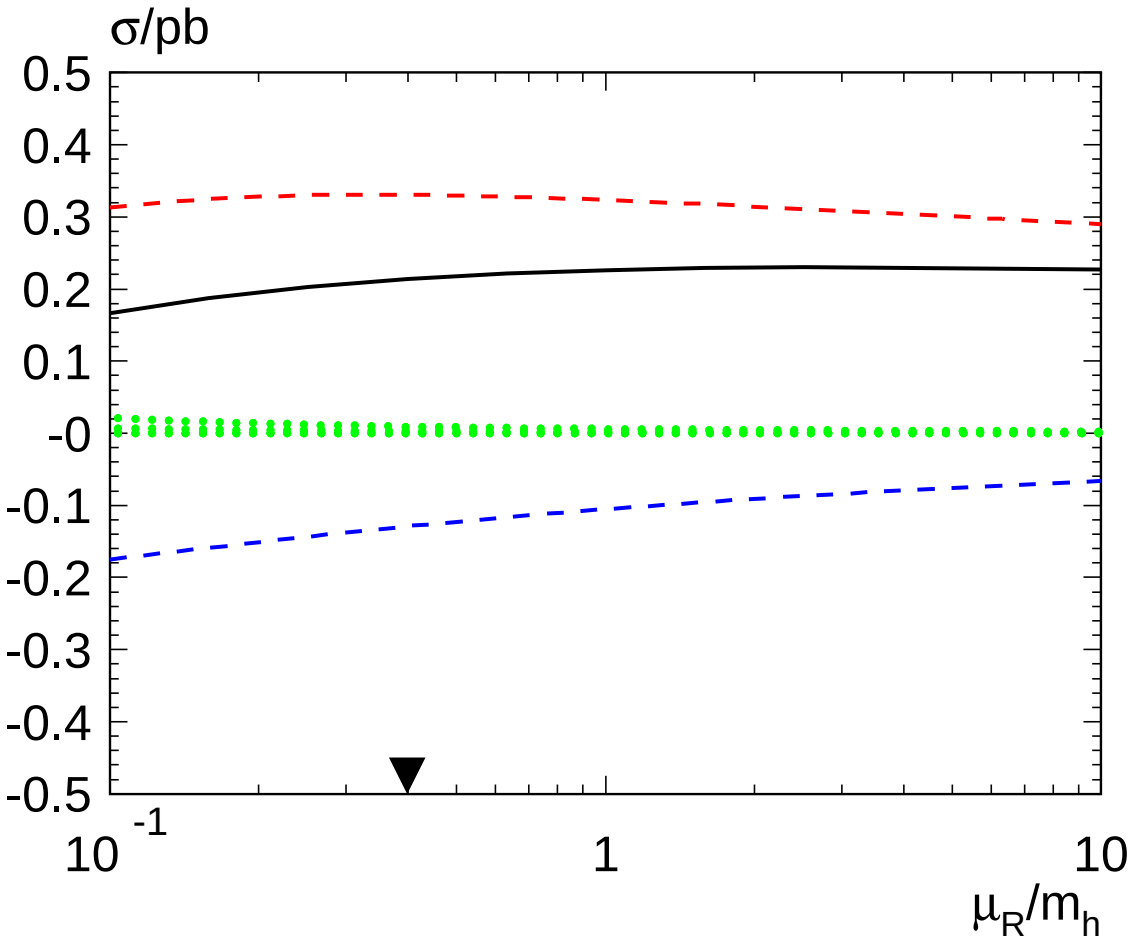
Sub-channels: μ-dependence



Sub-channels: μ-dependence



Sub-channels: μ-dependence



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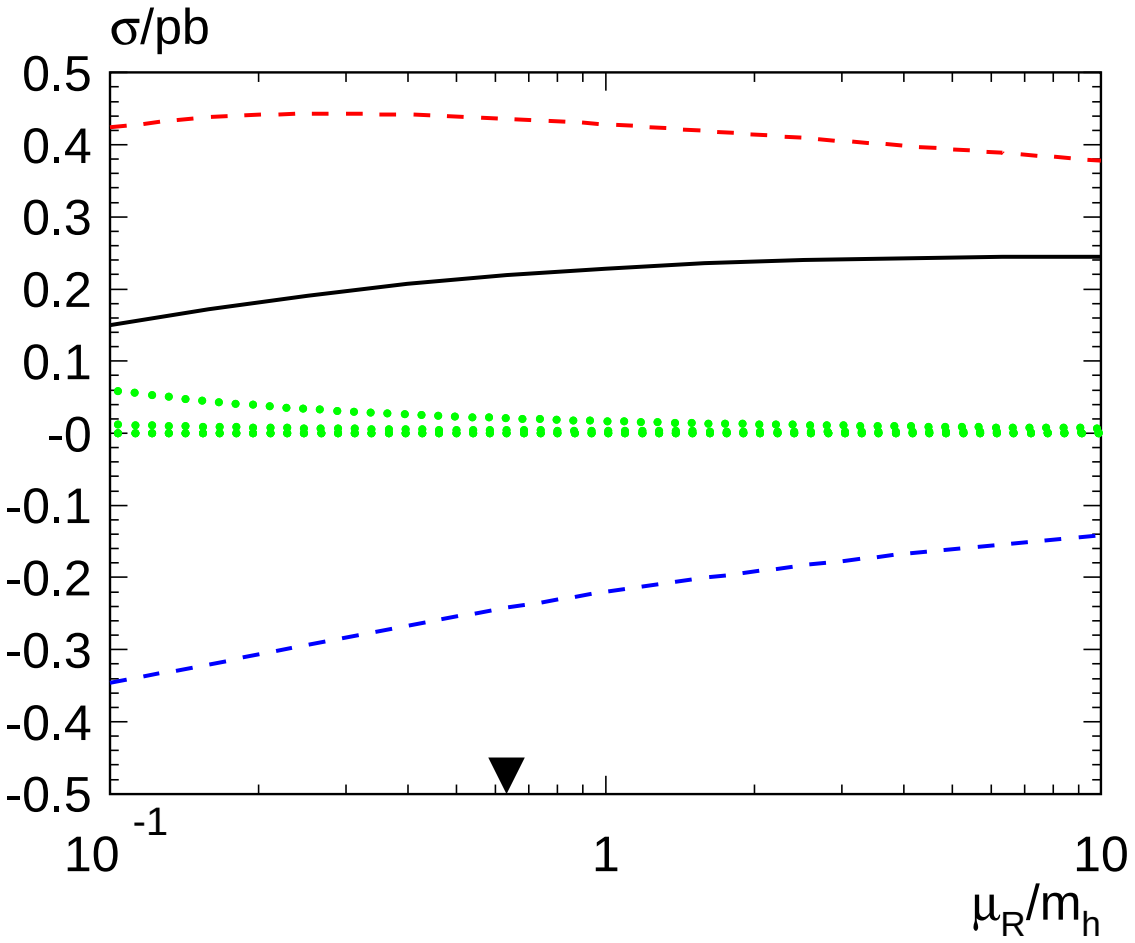
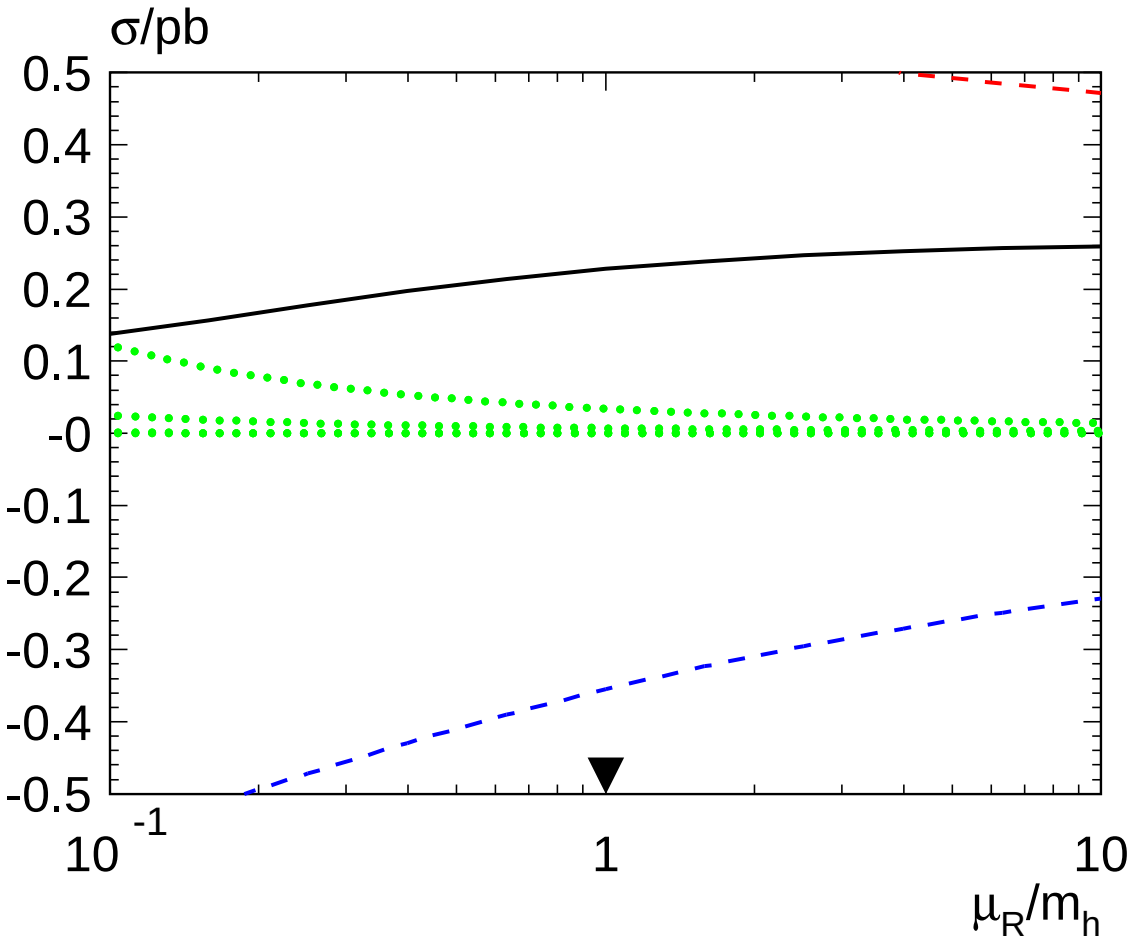


Sub-channels: μ-dependence



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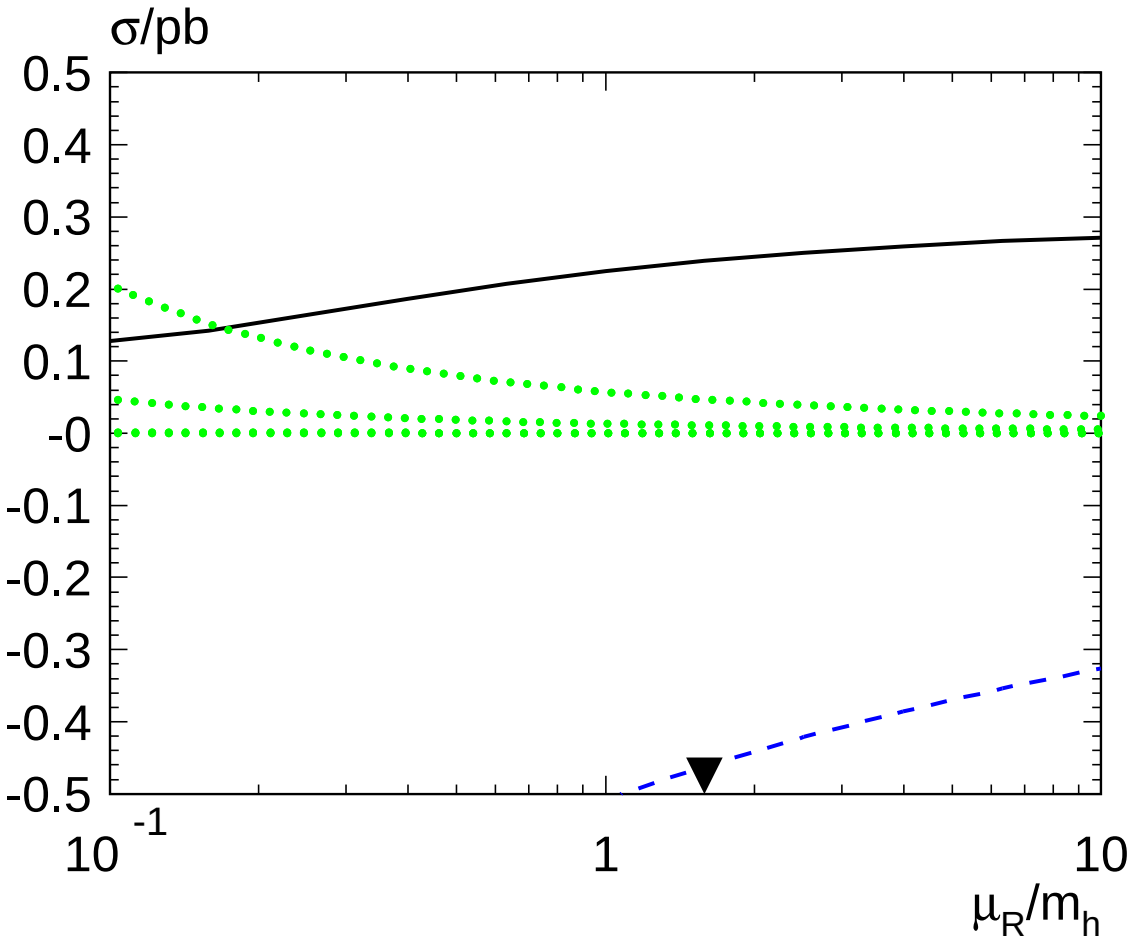

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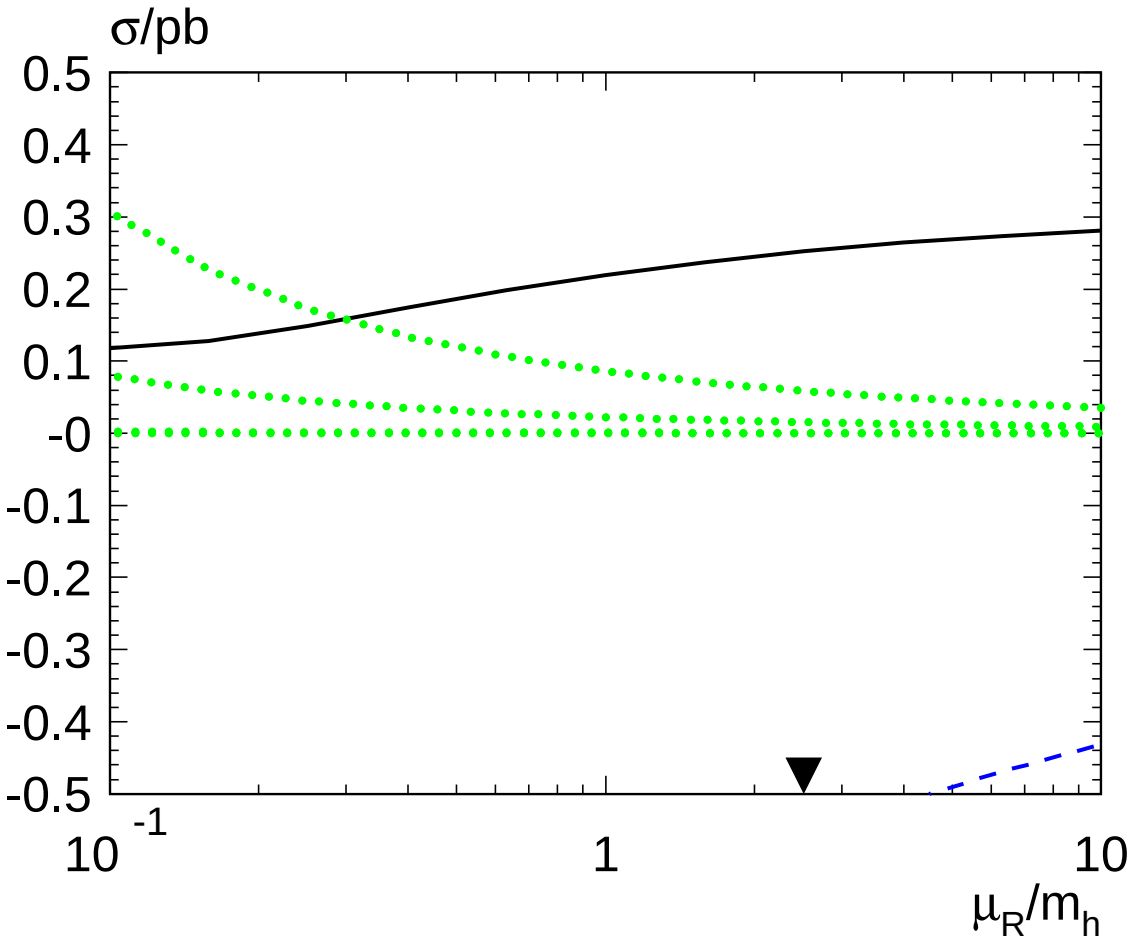
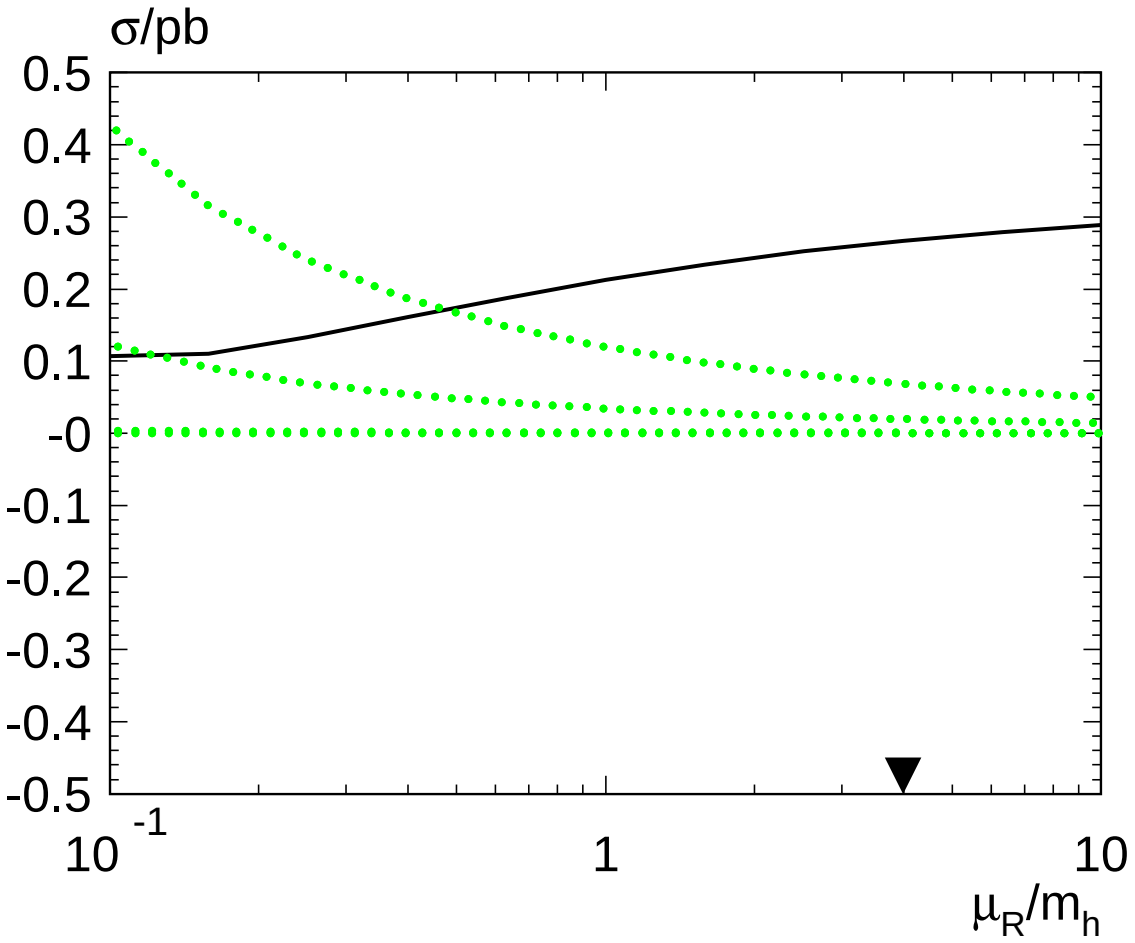


Sub-channels: μ-dependence



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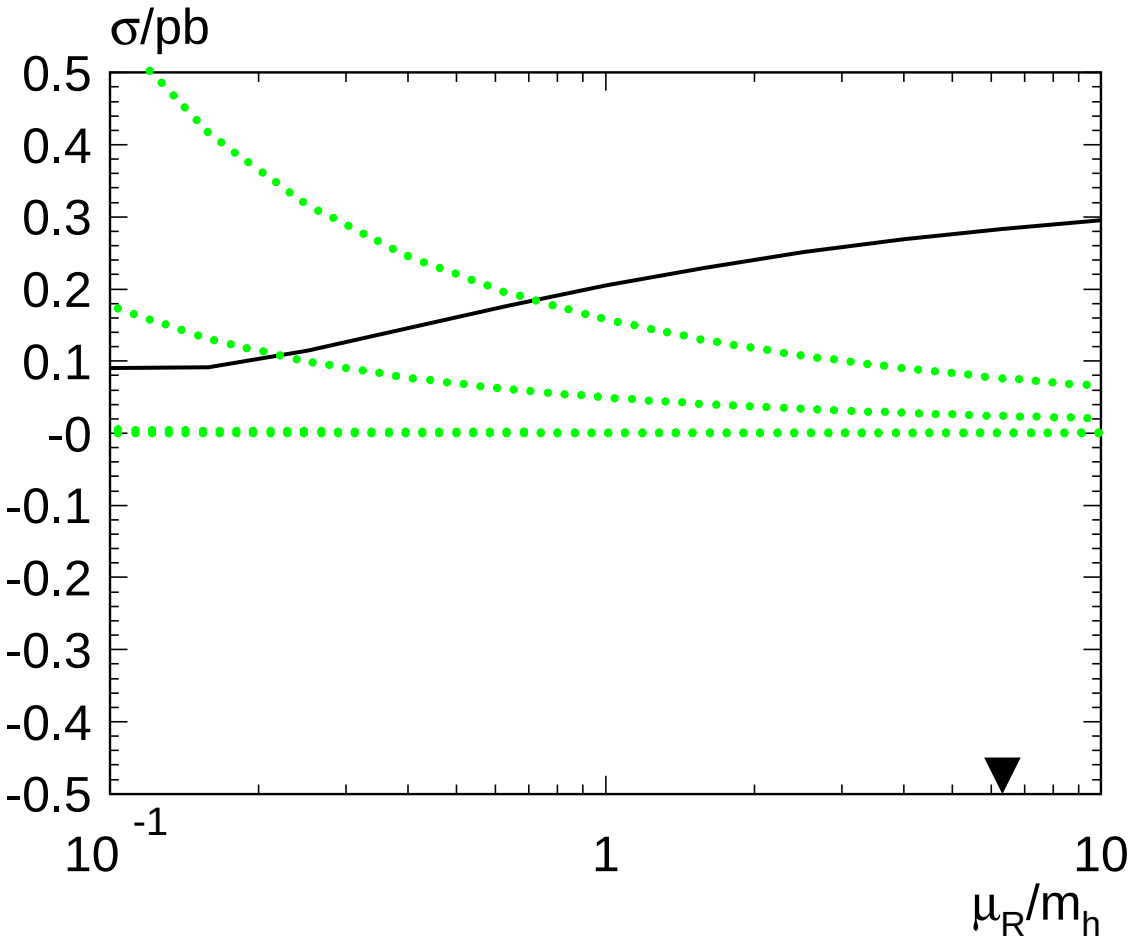
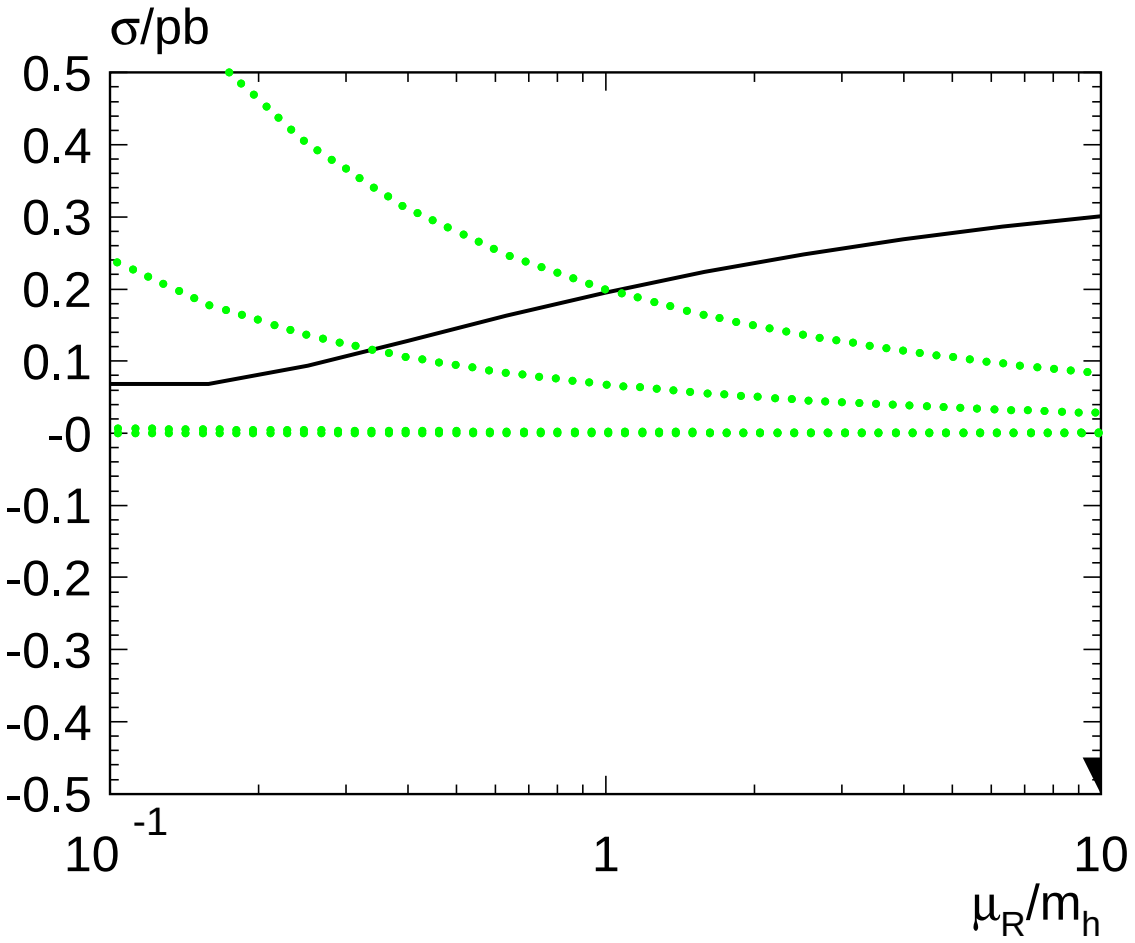
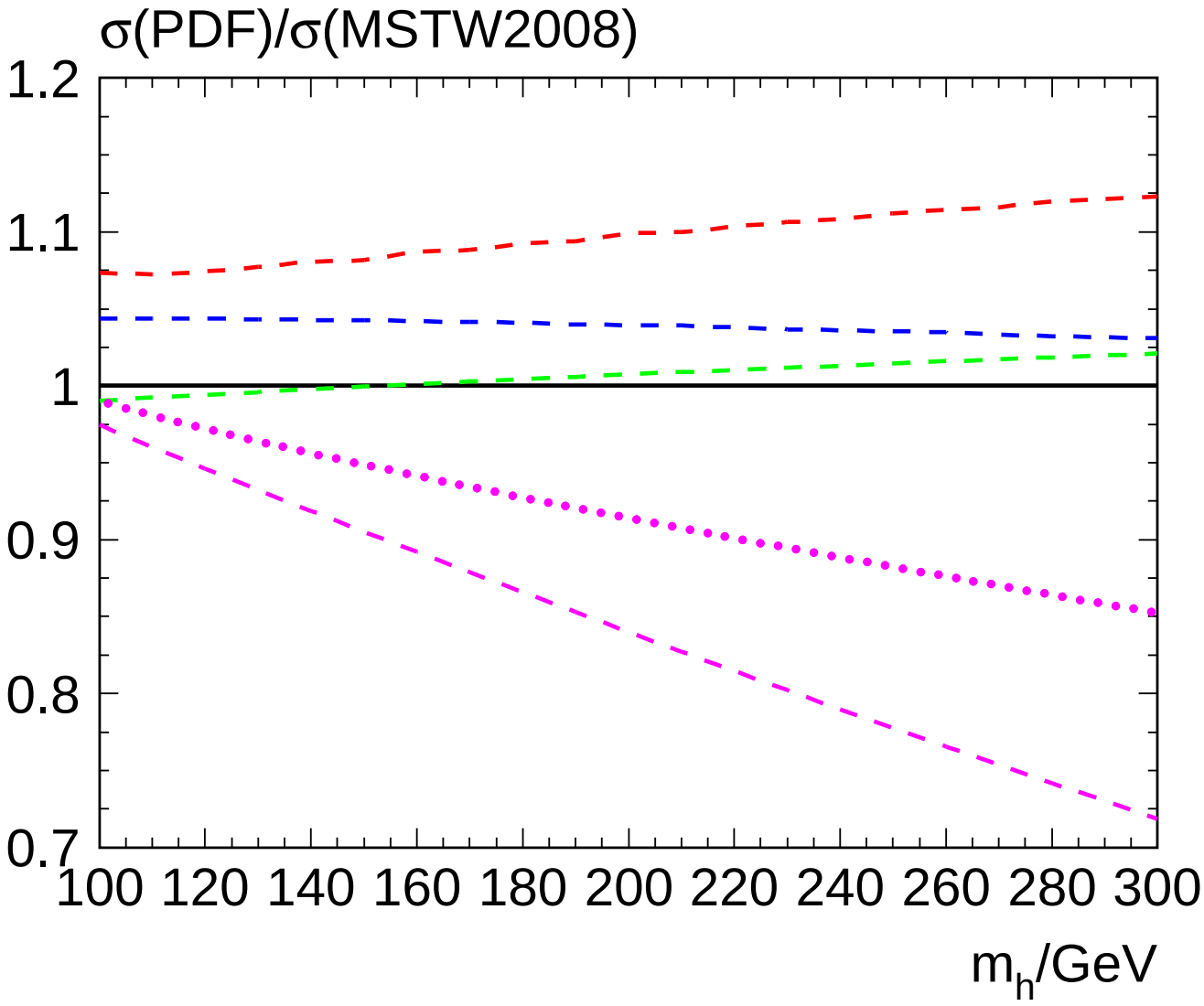


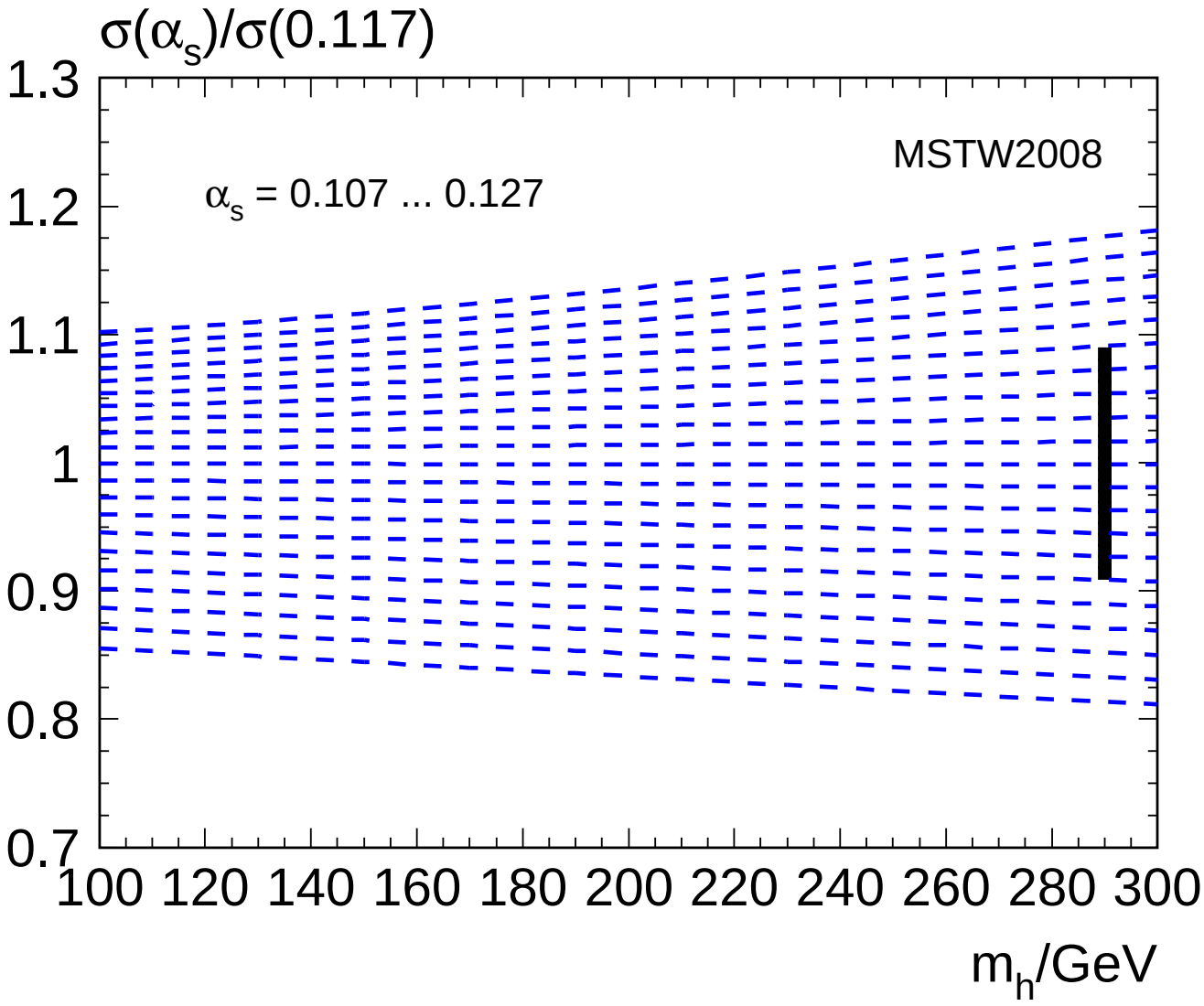
Sub-channels: μ-dependence



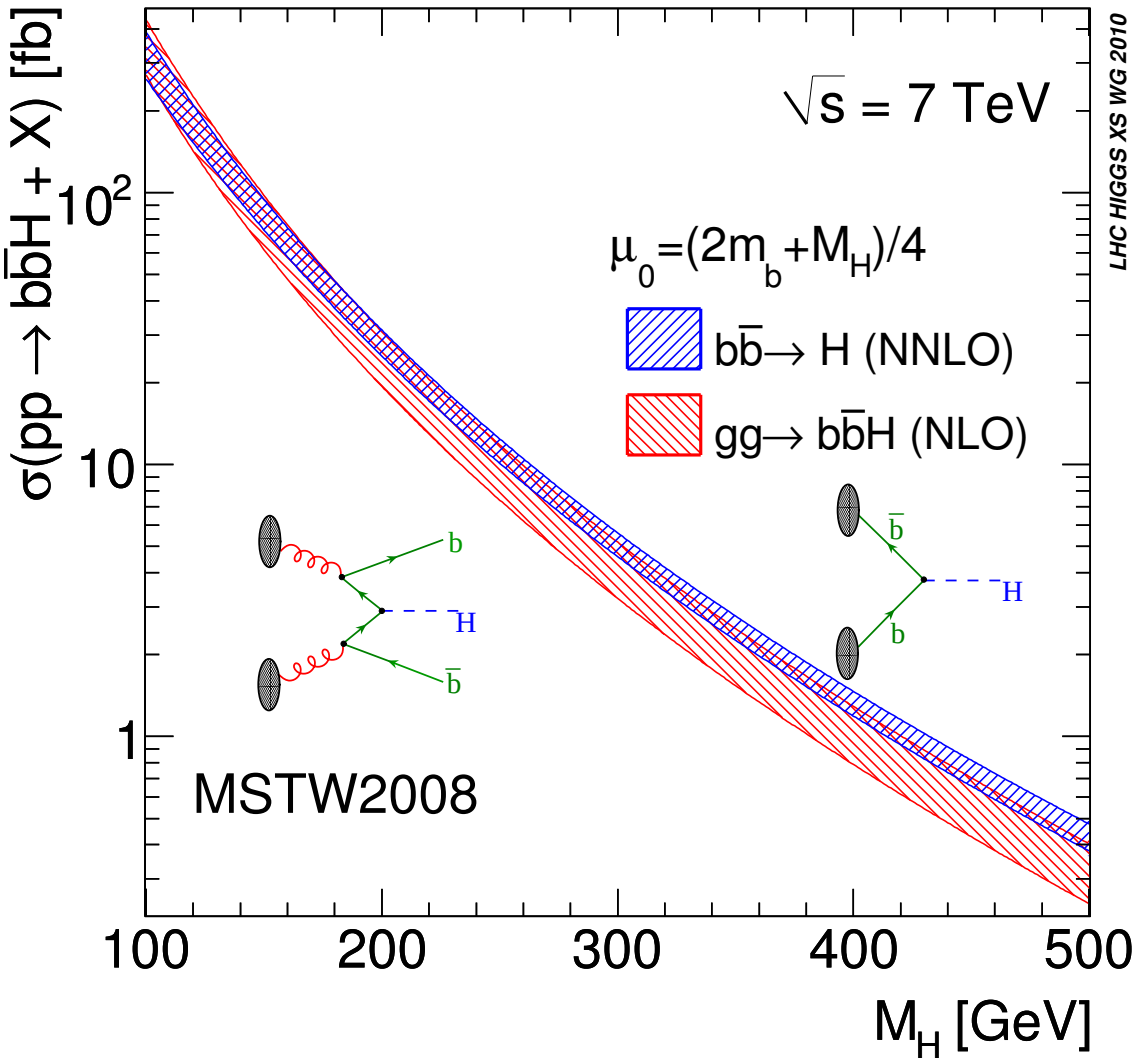
PDF dependence



α_s dependence



$pp \to H + b\bar{b}$



[RH, Kilgore '03]

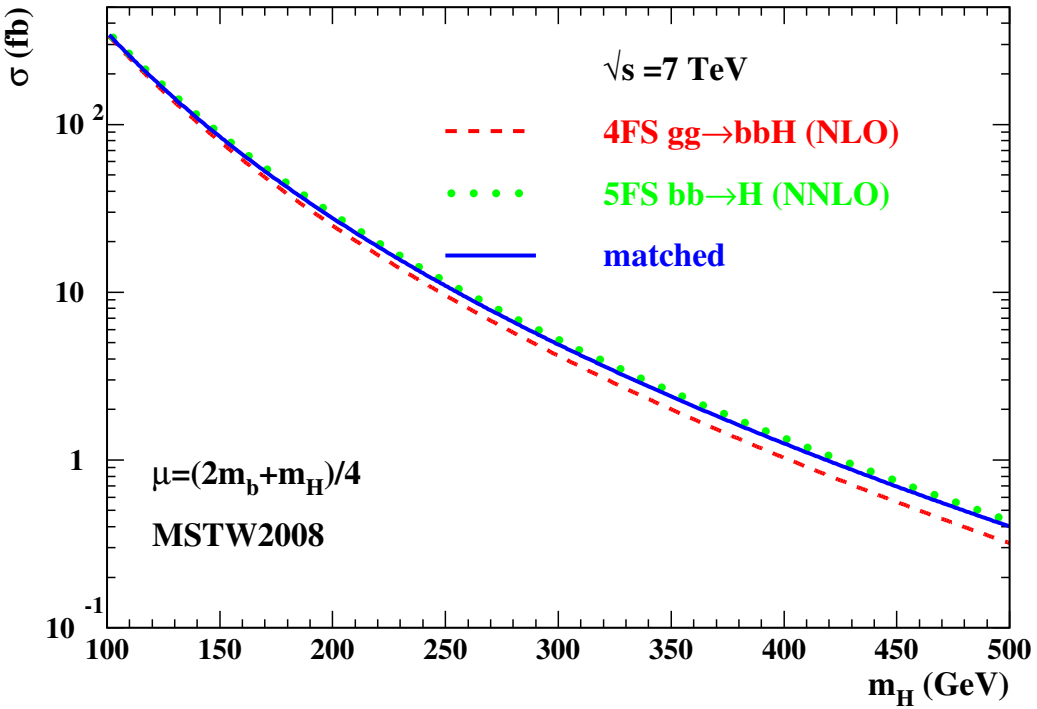
[Dittmaier, Krämer, Spira '04]

[Dawson, Jackson, Reina, Wackeroth '04]

electro-weak:

[Dittmaier, Krämer, Mück, Schlüter '06]

Santander matching



[R.H., Krämer, Schumacher '11]

$$\sigma = \frac{\sigma_{4\mathrm{FS}} + w\sigma_{5\mathrm{FS}}}{1+w}$$

$$\Delta\sigma = \frac{\Delta\sigma_{4\mathrm{FS}} + w\Delta\sigma_{5\mathrm{FS}}}{1+w}$$

$$w = \ln\frac{m_H}{m_b} - 2$$

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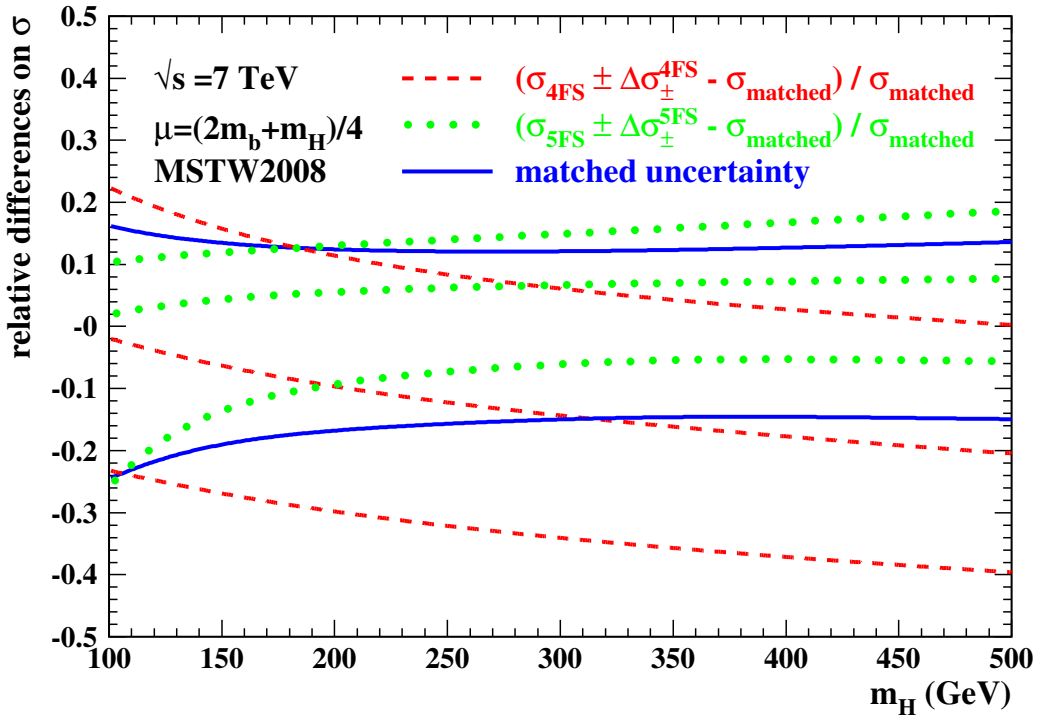

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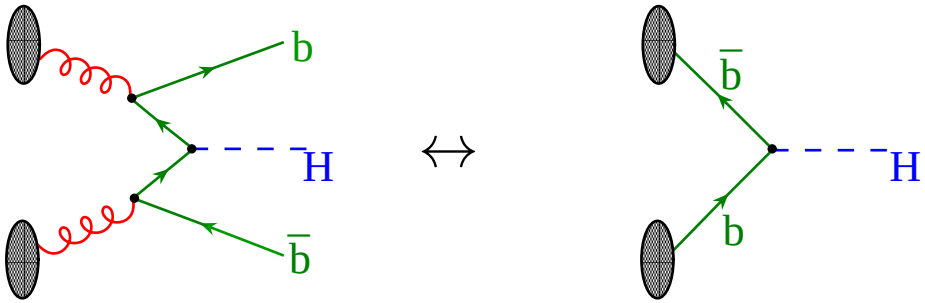
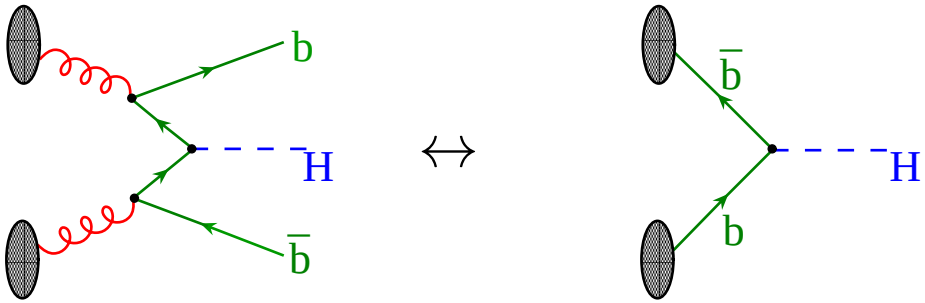
Distributions



- 5FS specifically suitable for inclusive cross section

Distributions



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- what about distributions?
- so far: $H + b$

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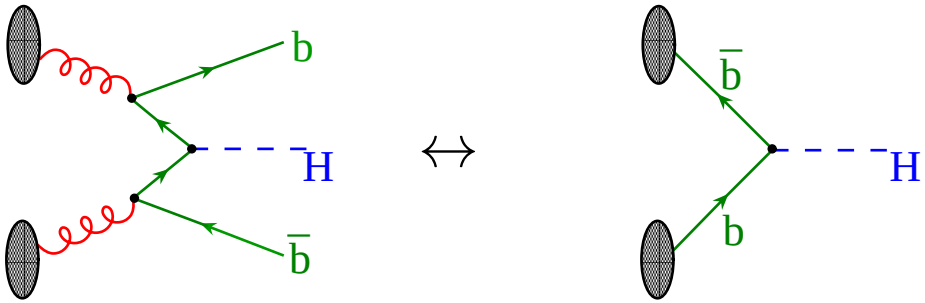

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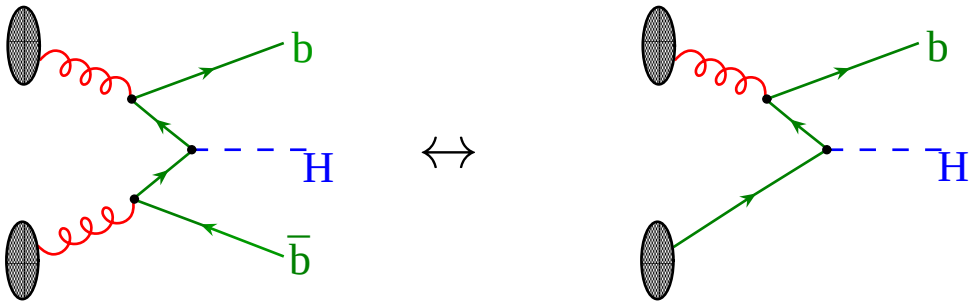
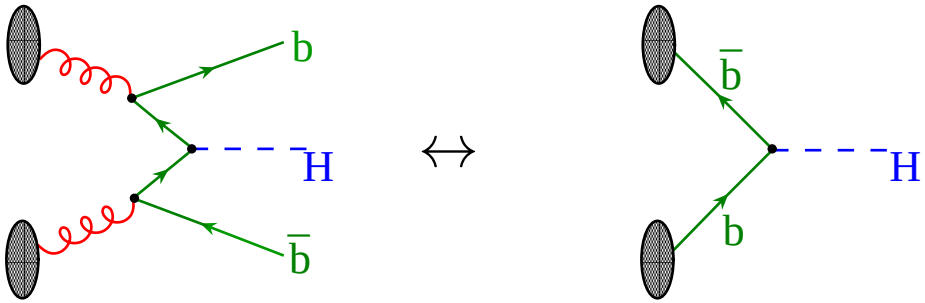


NLO:

[Campbell *et al.* '03]

Distributions



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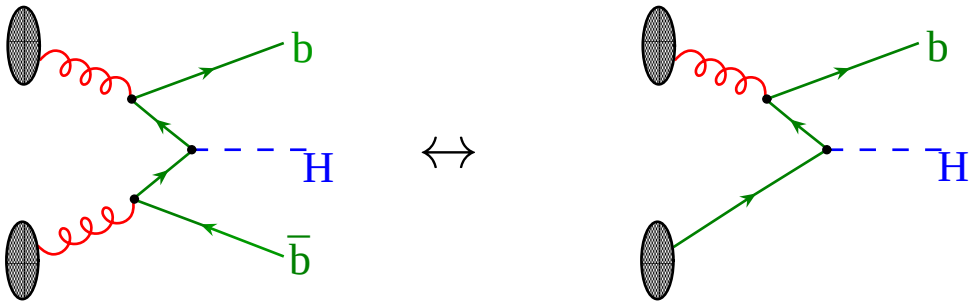


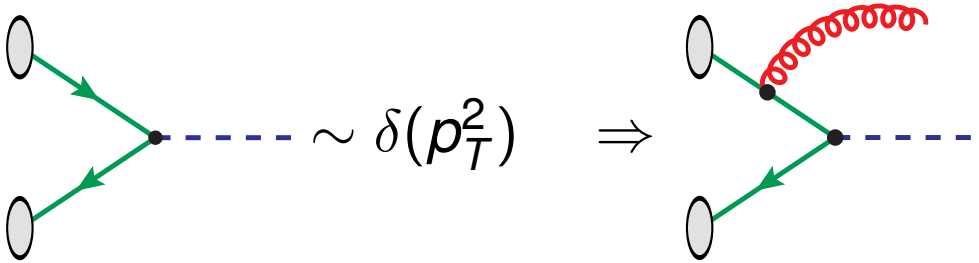
NLO:

[Campbell *et al.* '03]

- here: more general $H + X$

Distributions

- first step: Higgs transverse momentum $\Leftrightarrow$ H+jet



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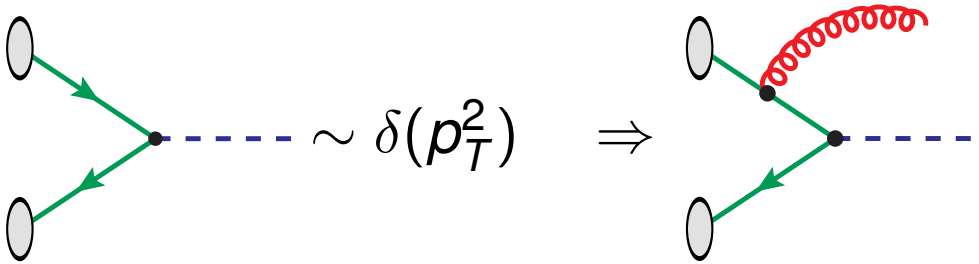
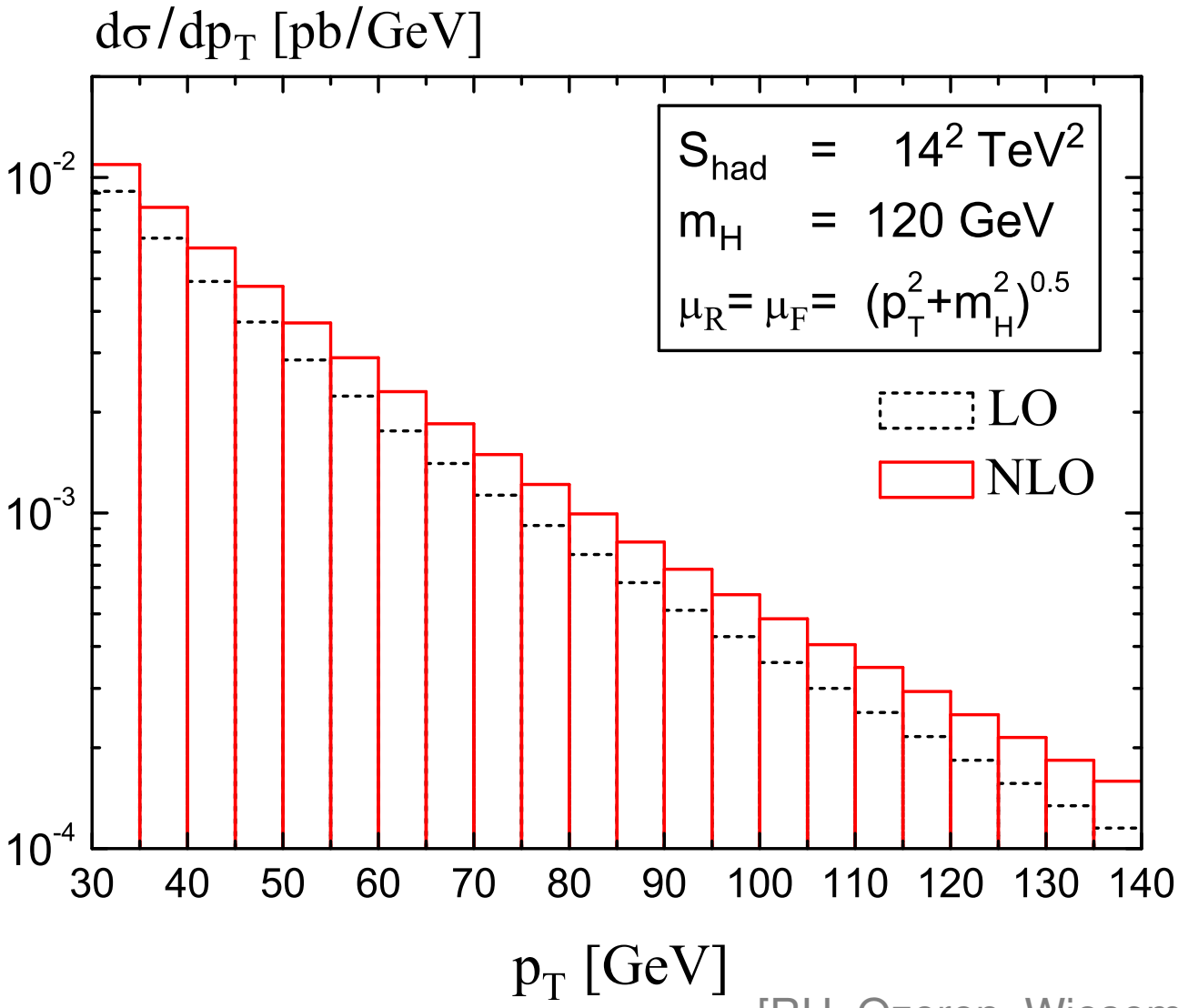


- consistent treatment requires NLO

Distributions



[RH, Ozeren, Wiesemann '10]

Jet veto

- in analogy to gluon fusion [Catani, Grazzini, de Florian '02]:

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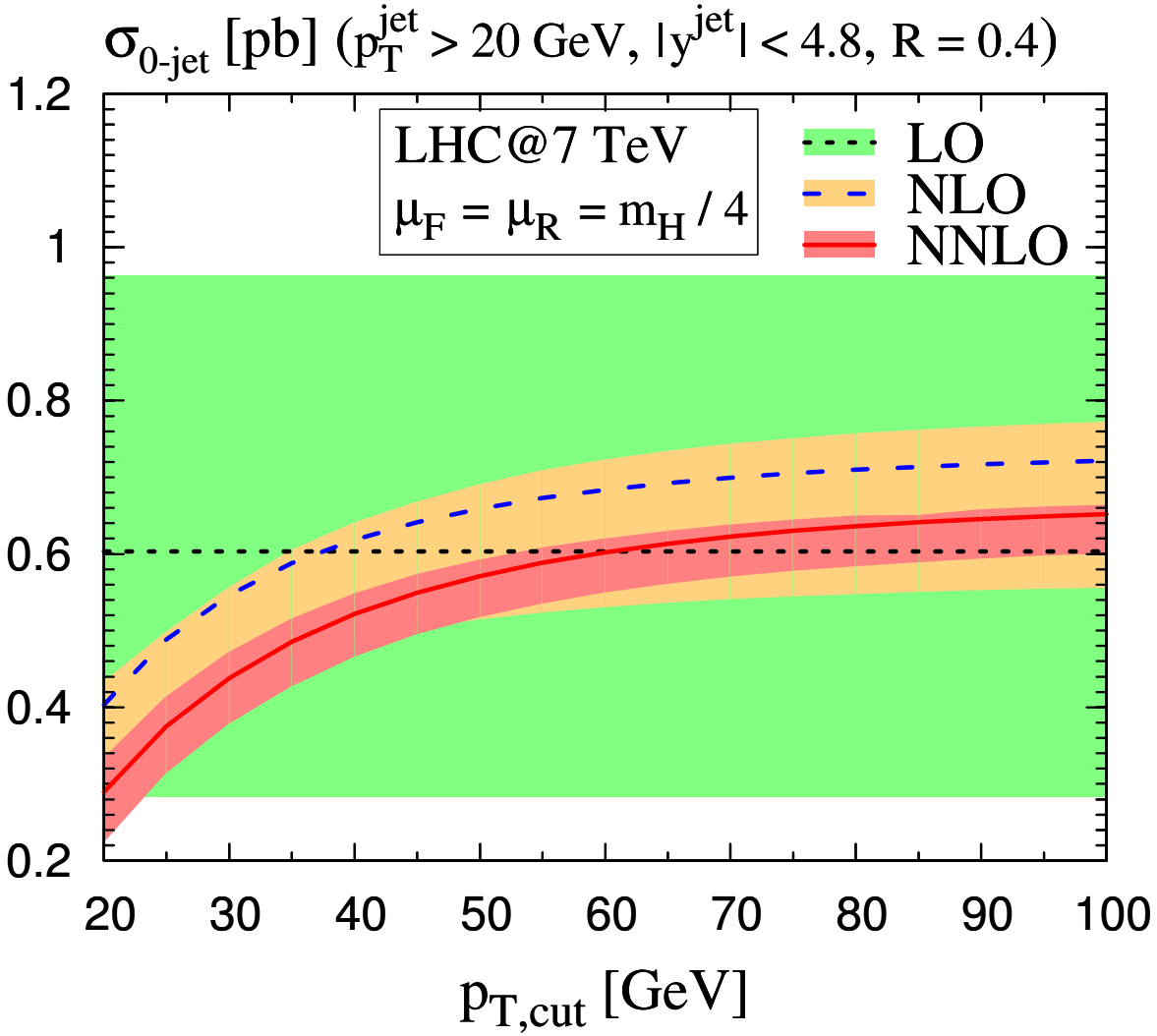
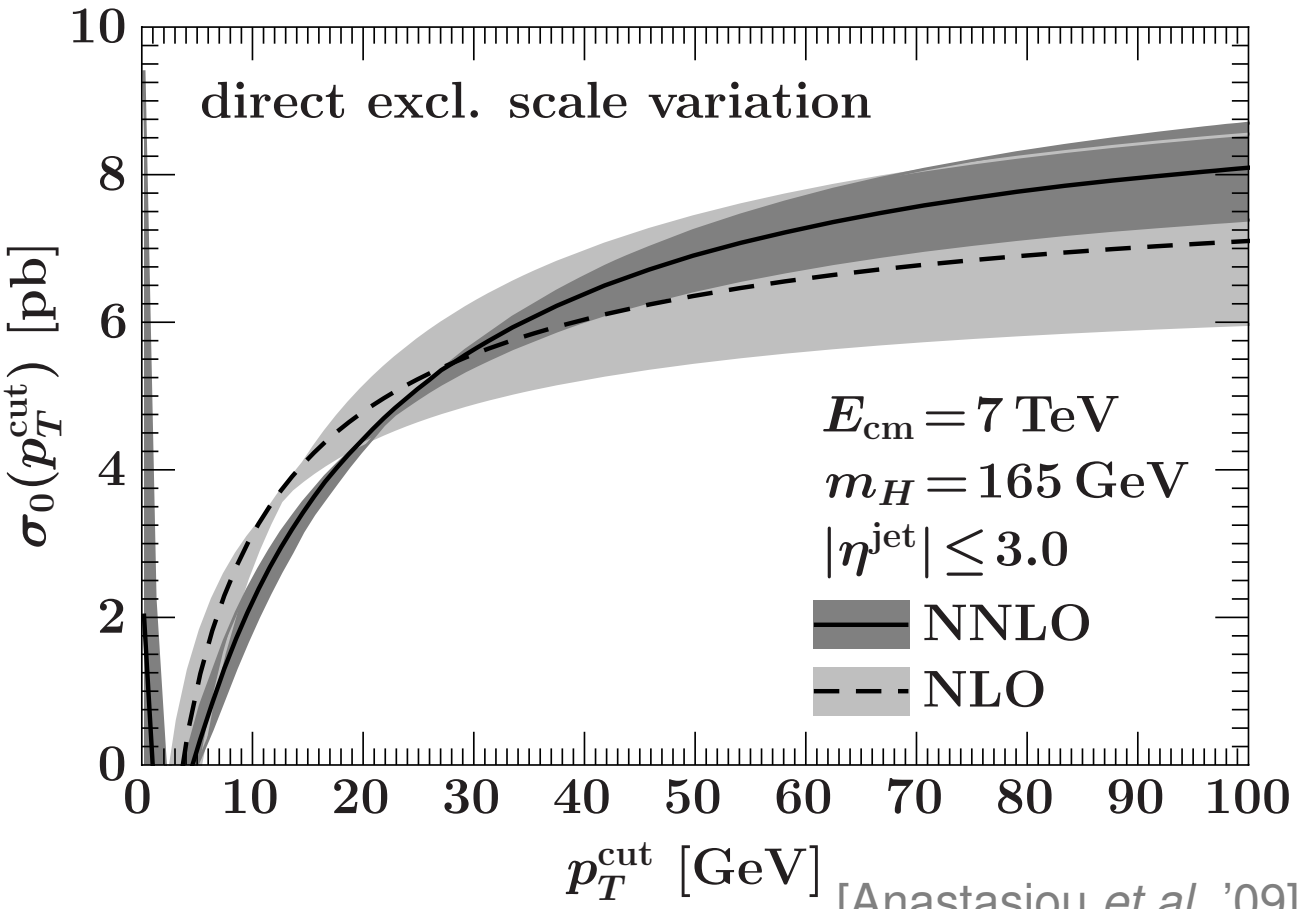
p_T veto



[RH, Ozeren, Wiesemann '10]

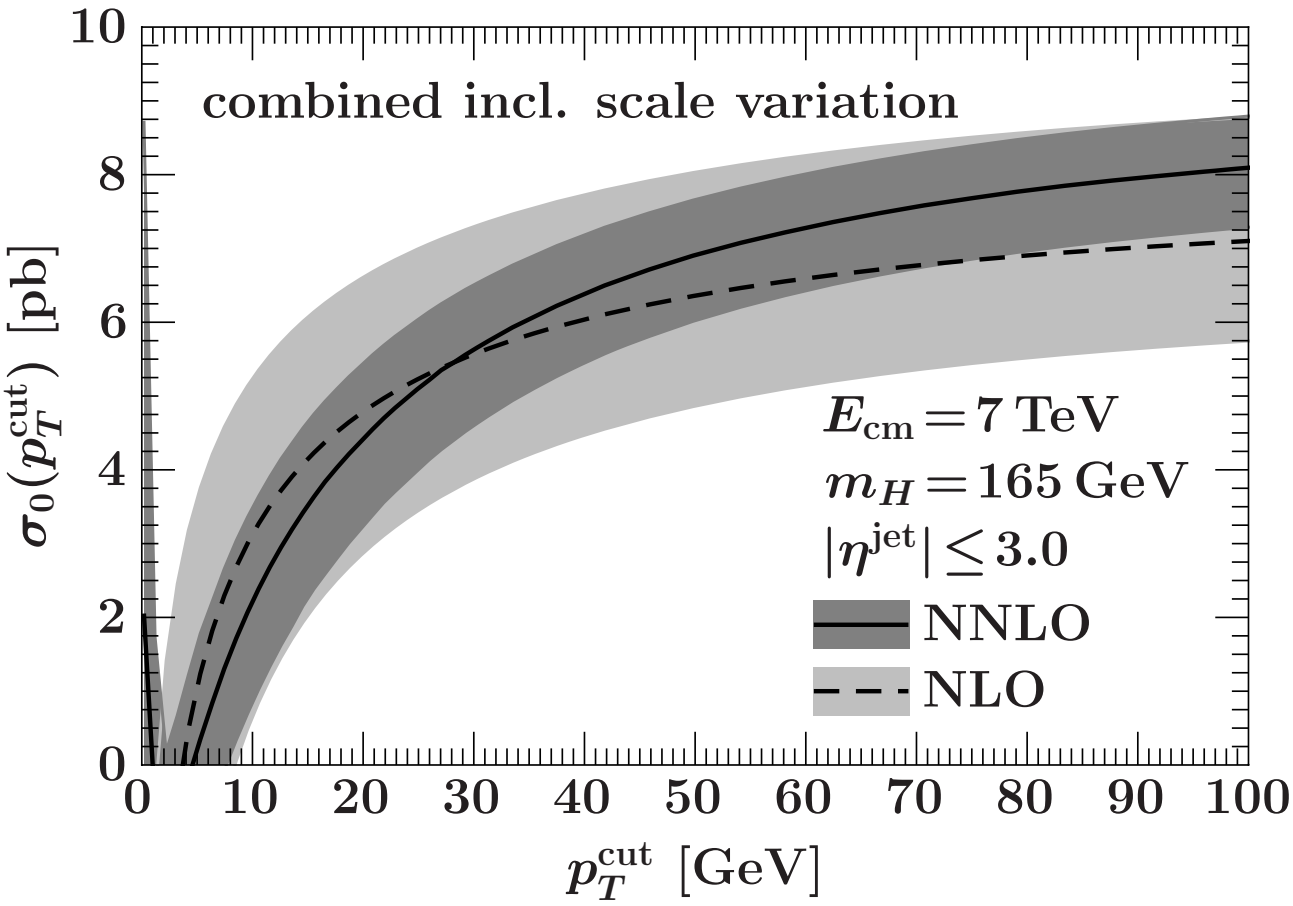
p_T veto – gluon fusion



[Anastasiou *et al.* '09]

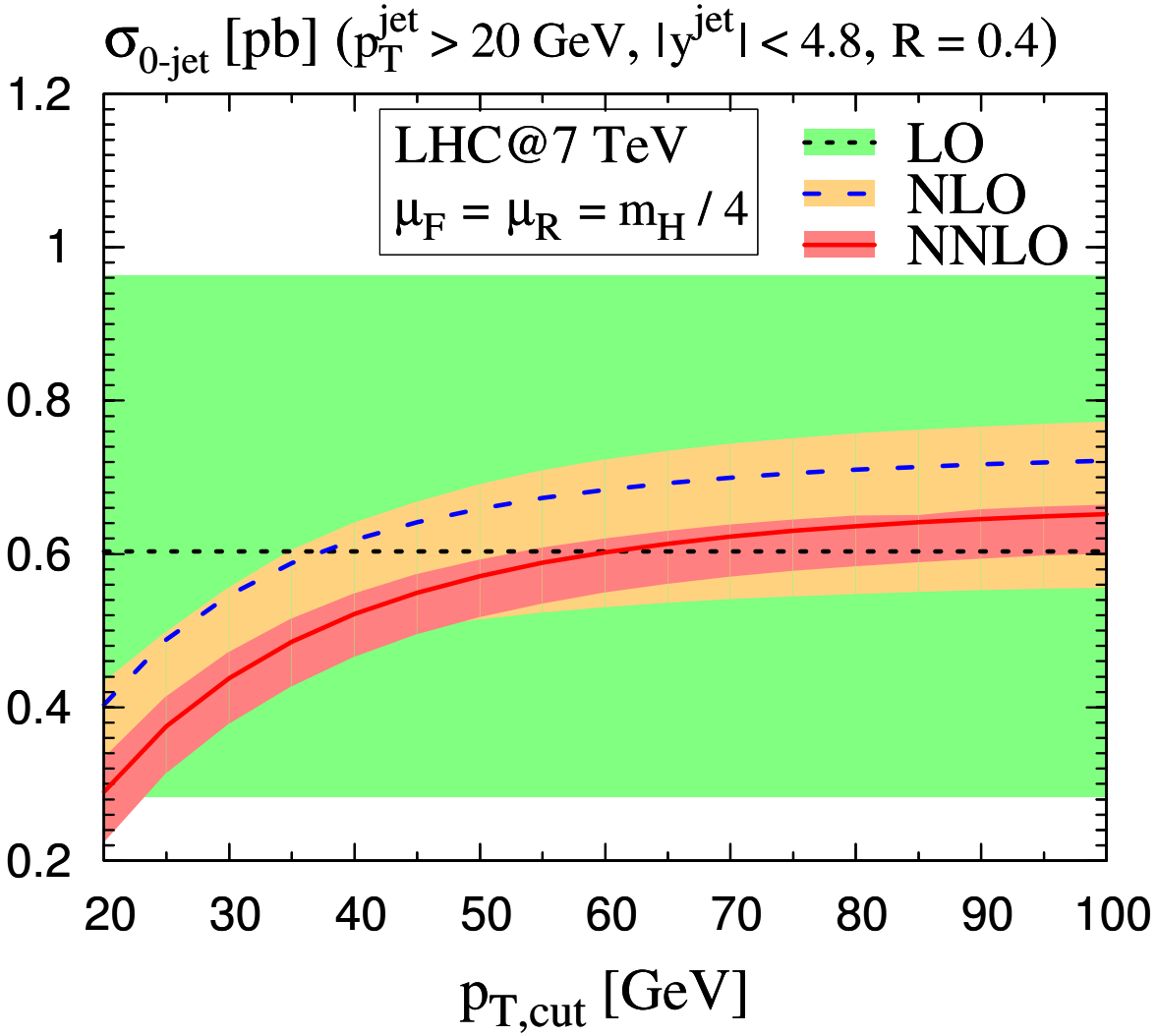
from: [Tackmann, Stewart '11]

p_T veto – gluon fusion



[Tackmann, Stewart '11]

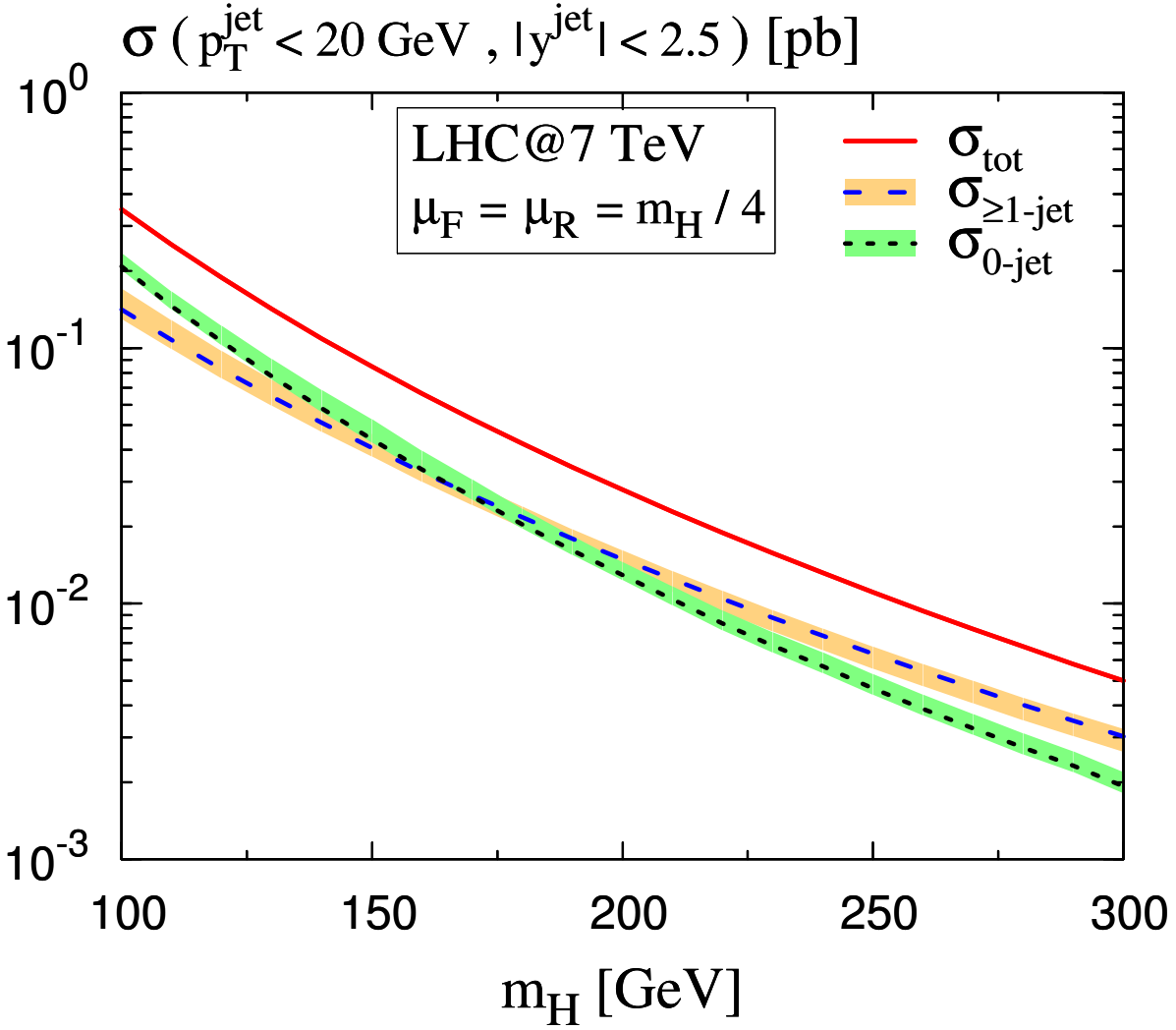
p_T veto



[RH, Ozeren, Wiesemann '10]

$b\bar{b} \to H$+jet

Results

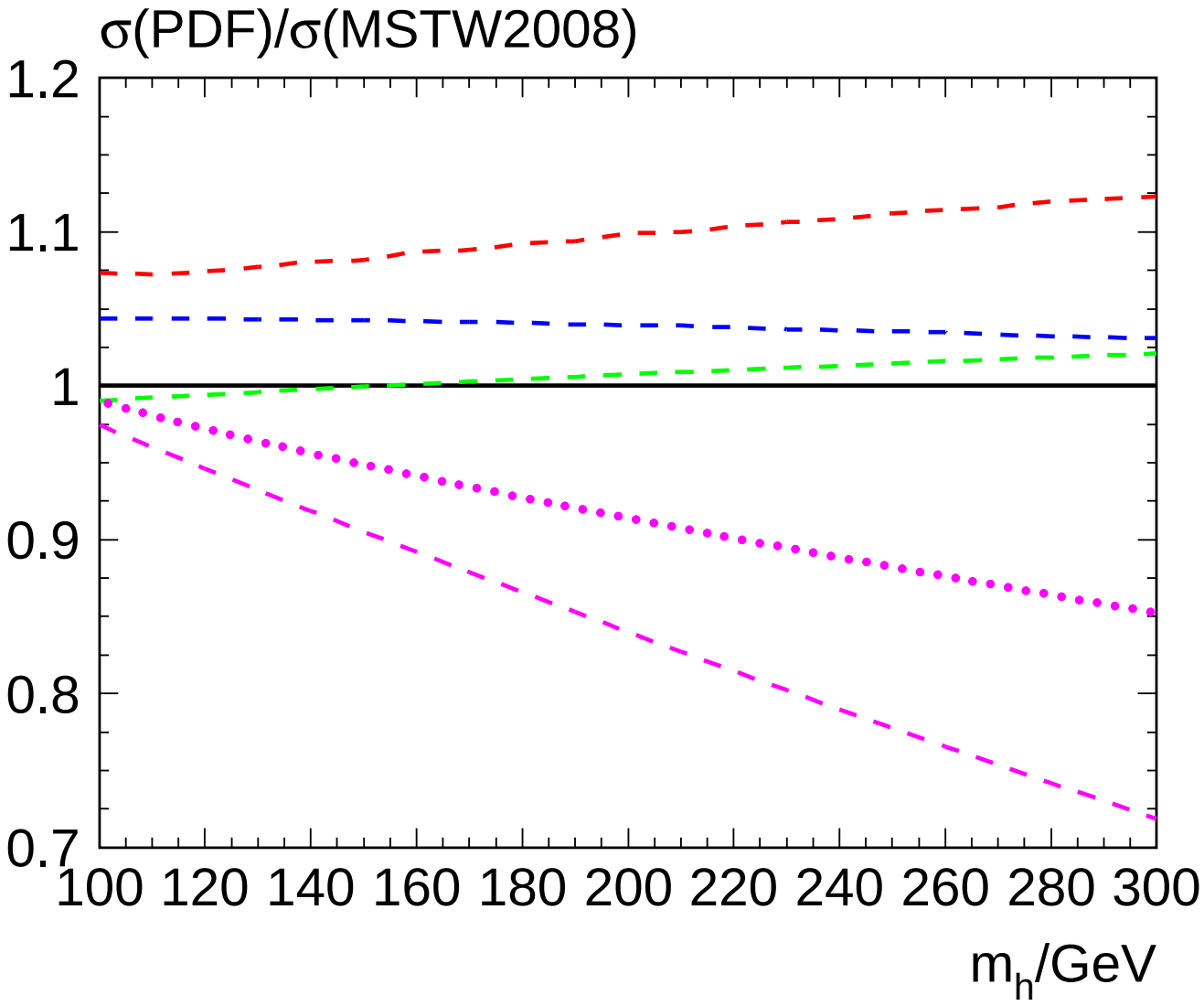


[RH, Wiesemann '11]

Conclusions

- $b\bar{b}H$ is interesting channel for SUSY Higgs production
- 5-flavor scheme vs. 4-flavor scheme
  most recent study: [Maltoni, Ridolfi, Ubiali '12]
- inclusive cross section in good shape
  `bbh@nnlo`, `iHixs`
- here: p_T and y distributions in 5-flavor scheme
- next step: fully differential cross sections / p_T resummations / ...

PDF dependence



PDF dependence