

New physics effects in Higgs cross sections

Robert Harlander

Bergische Universität Wuppertal

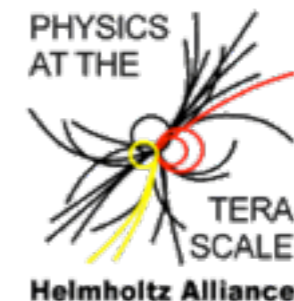
ERC Workshop Nov 2014, Mainz

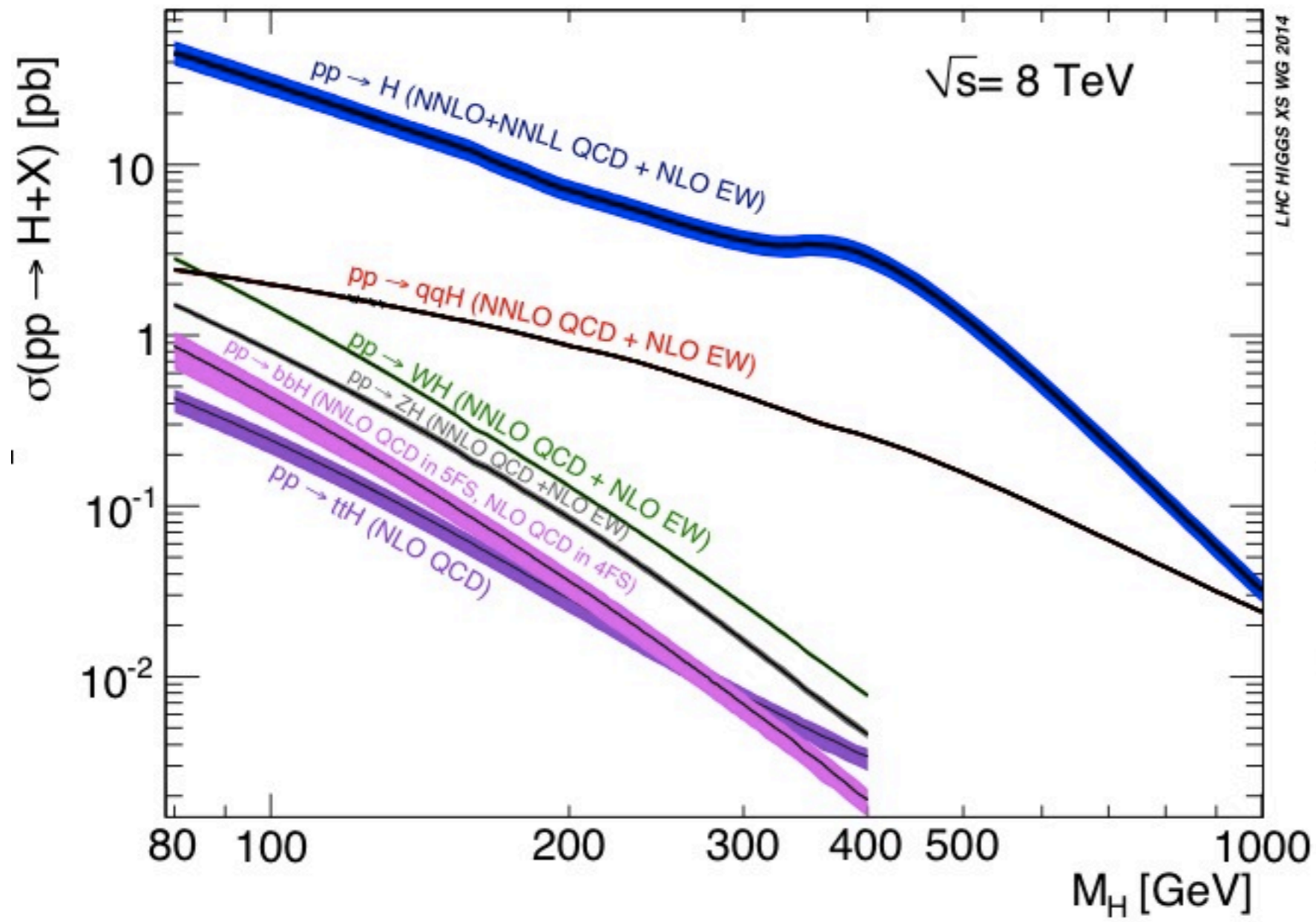
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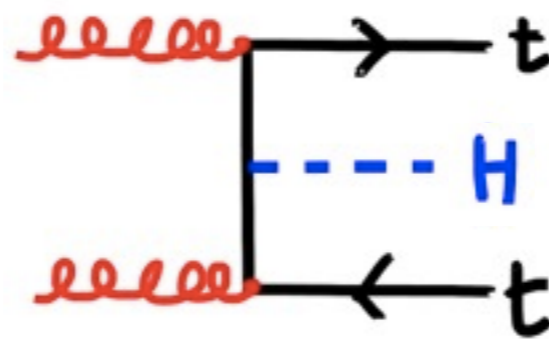
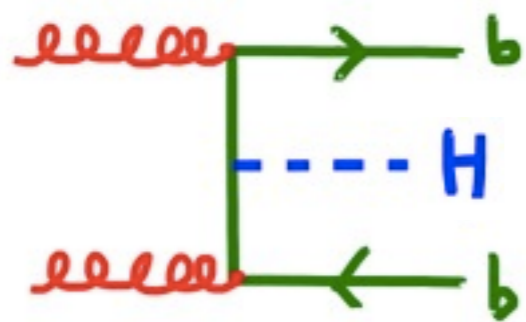
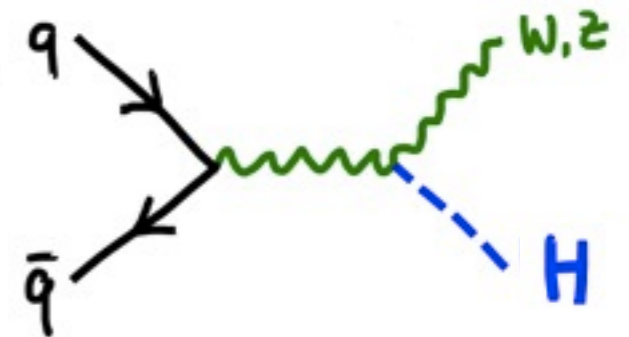
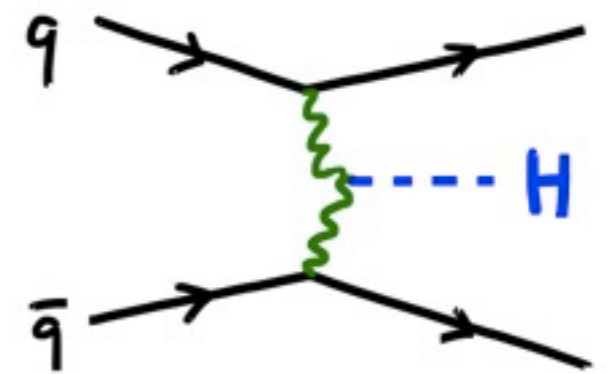
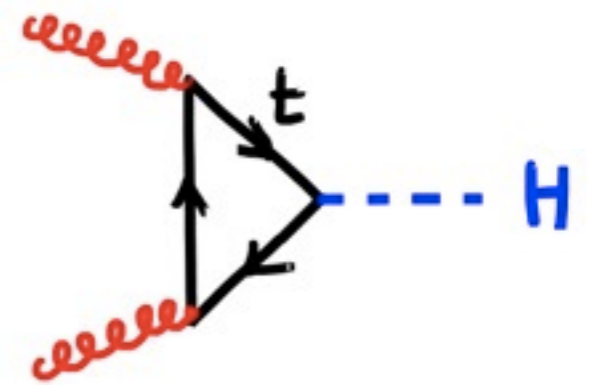


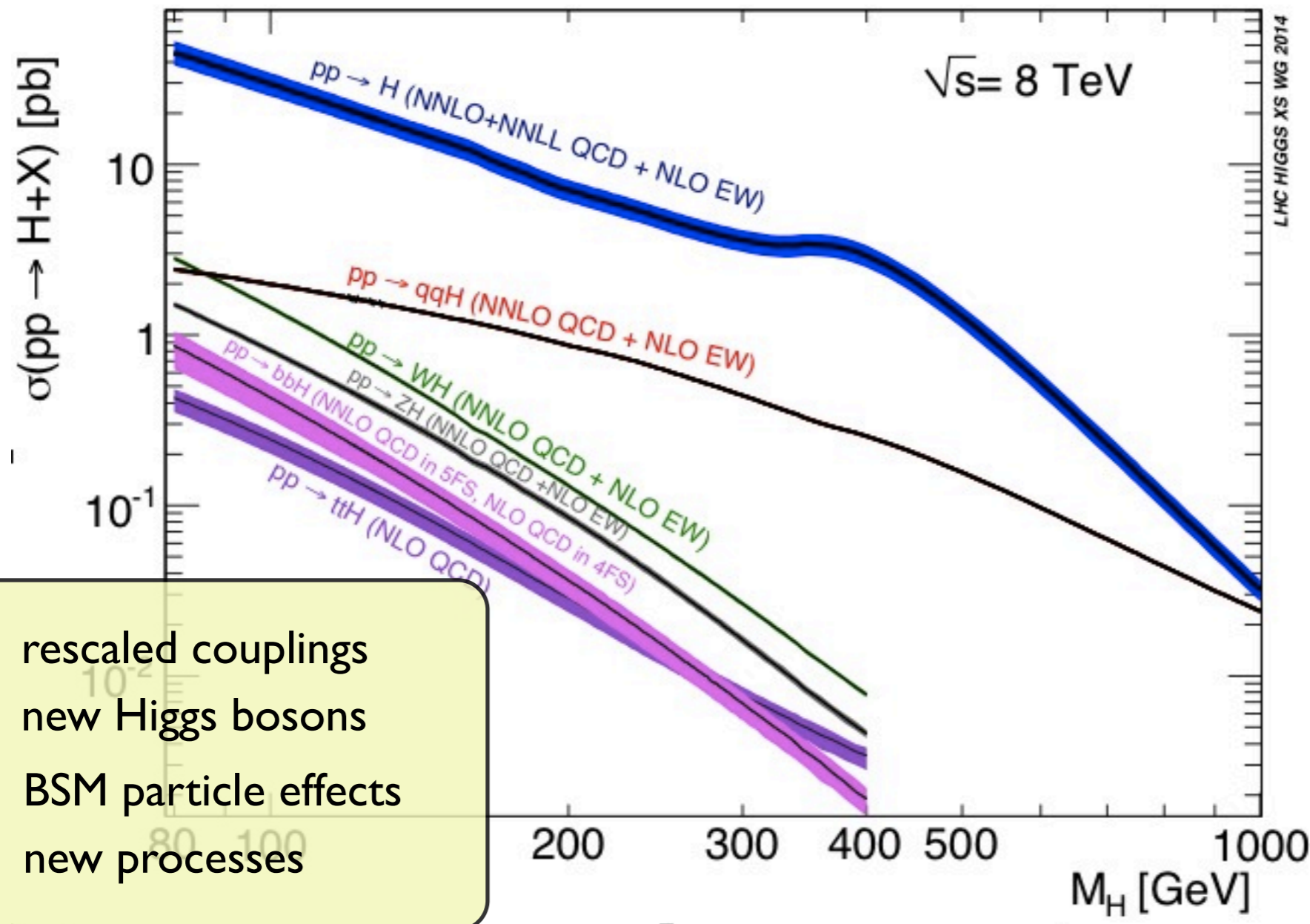
Bundesministerium
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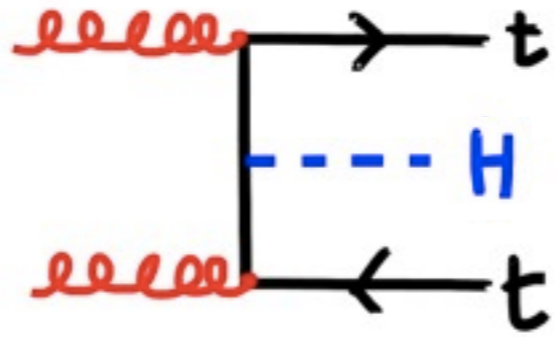
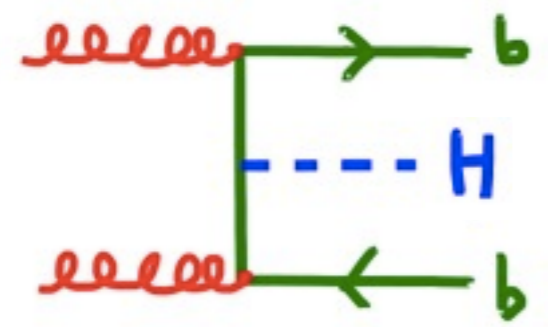
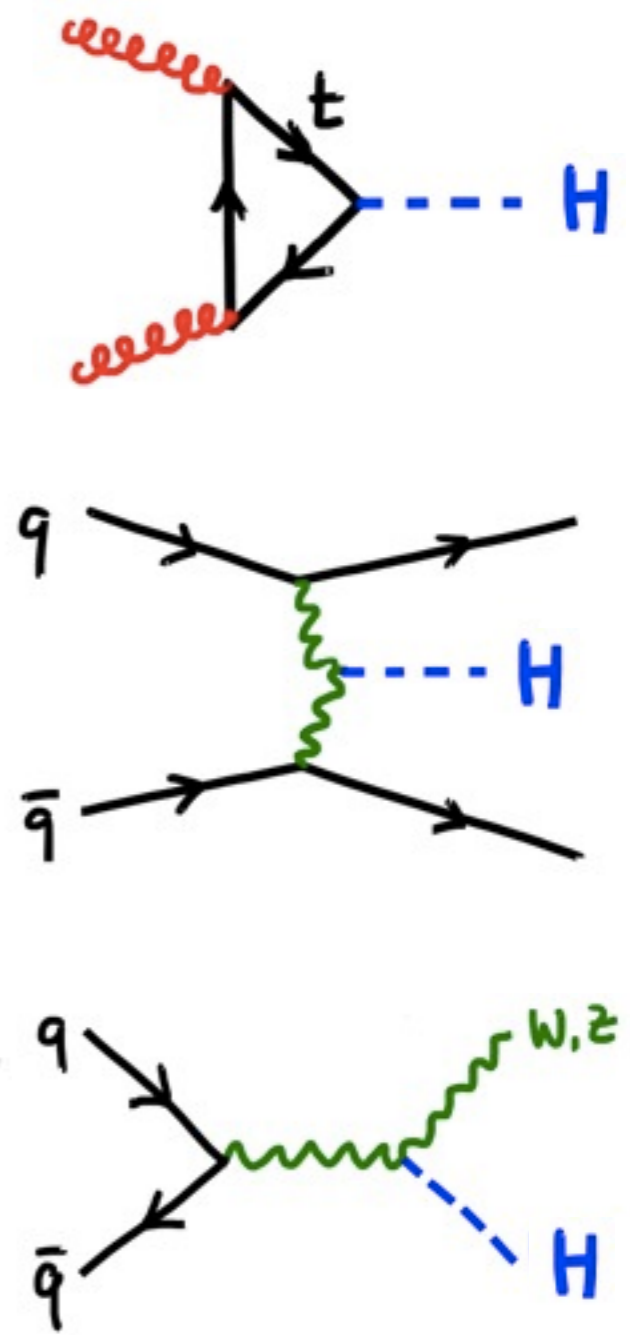
LHC HIGGS XS WG 2014



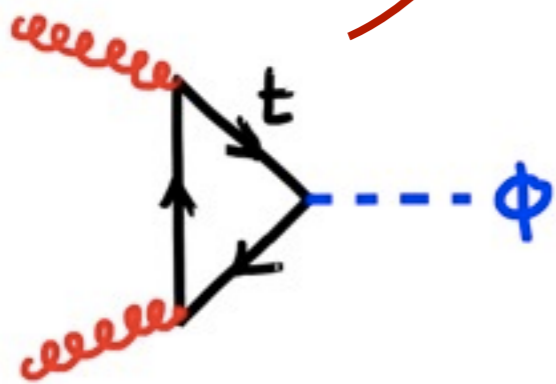
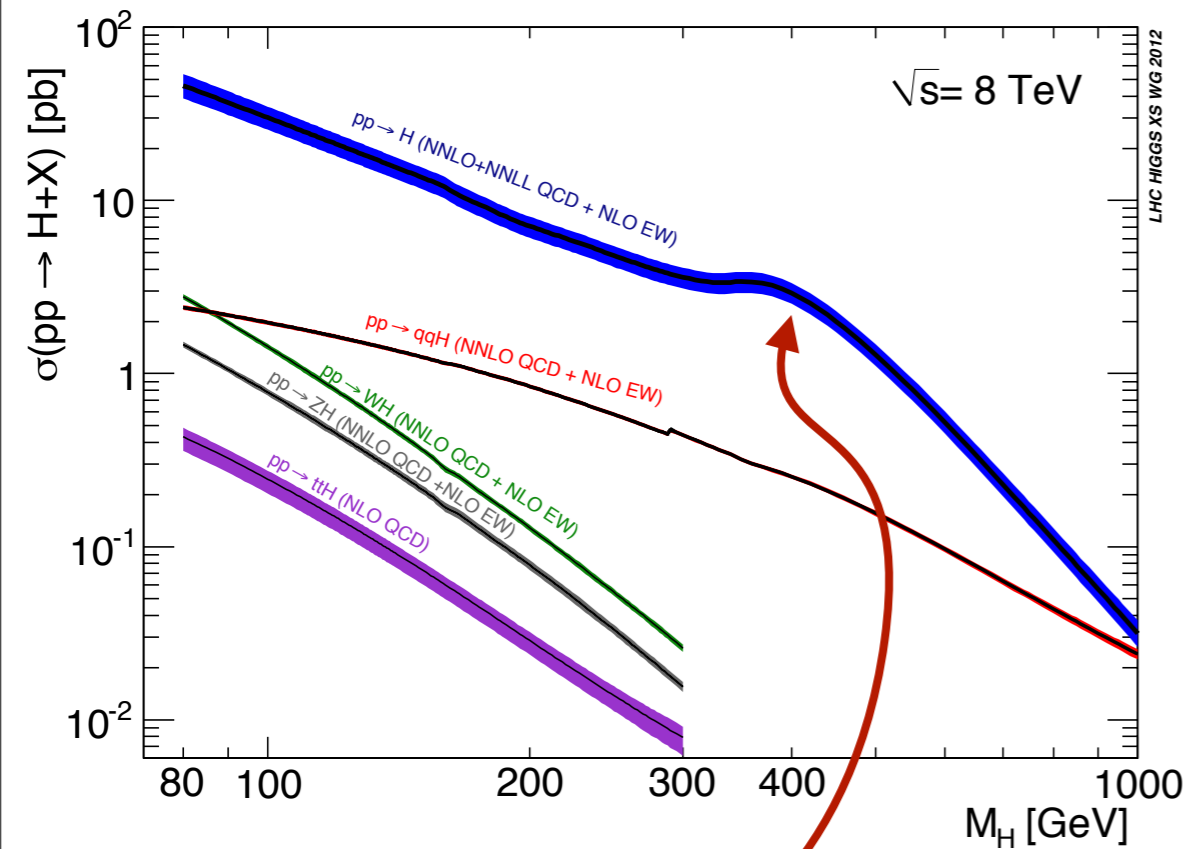


LHC HIGGS XS WG 2014

rescaled couplings
 new Higgs bosons
 BSM particle effects
 new processes



Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91 **~80%**

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02 **~30%**
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08 **~10%**

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94 **~5%**

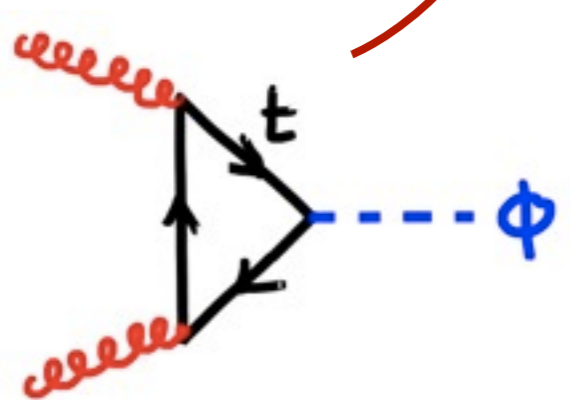
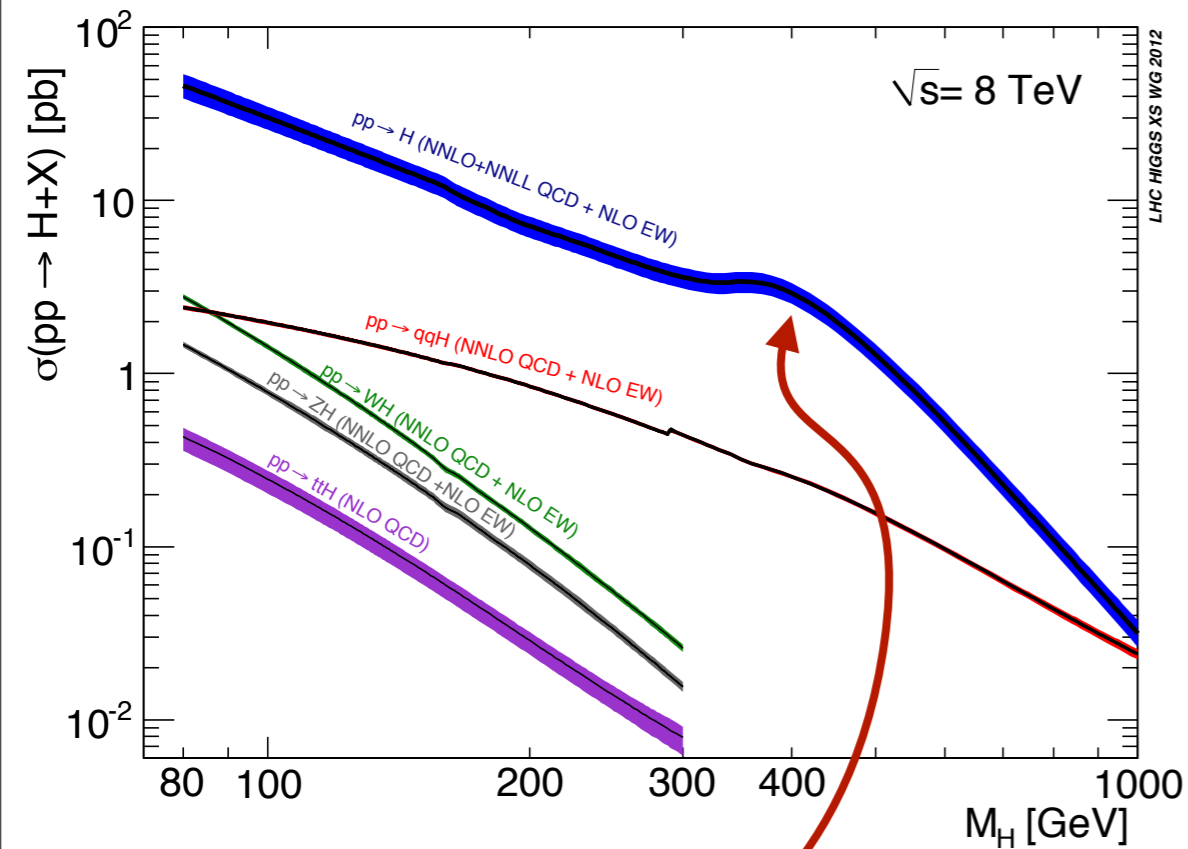
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

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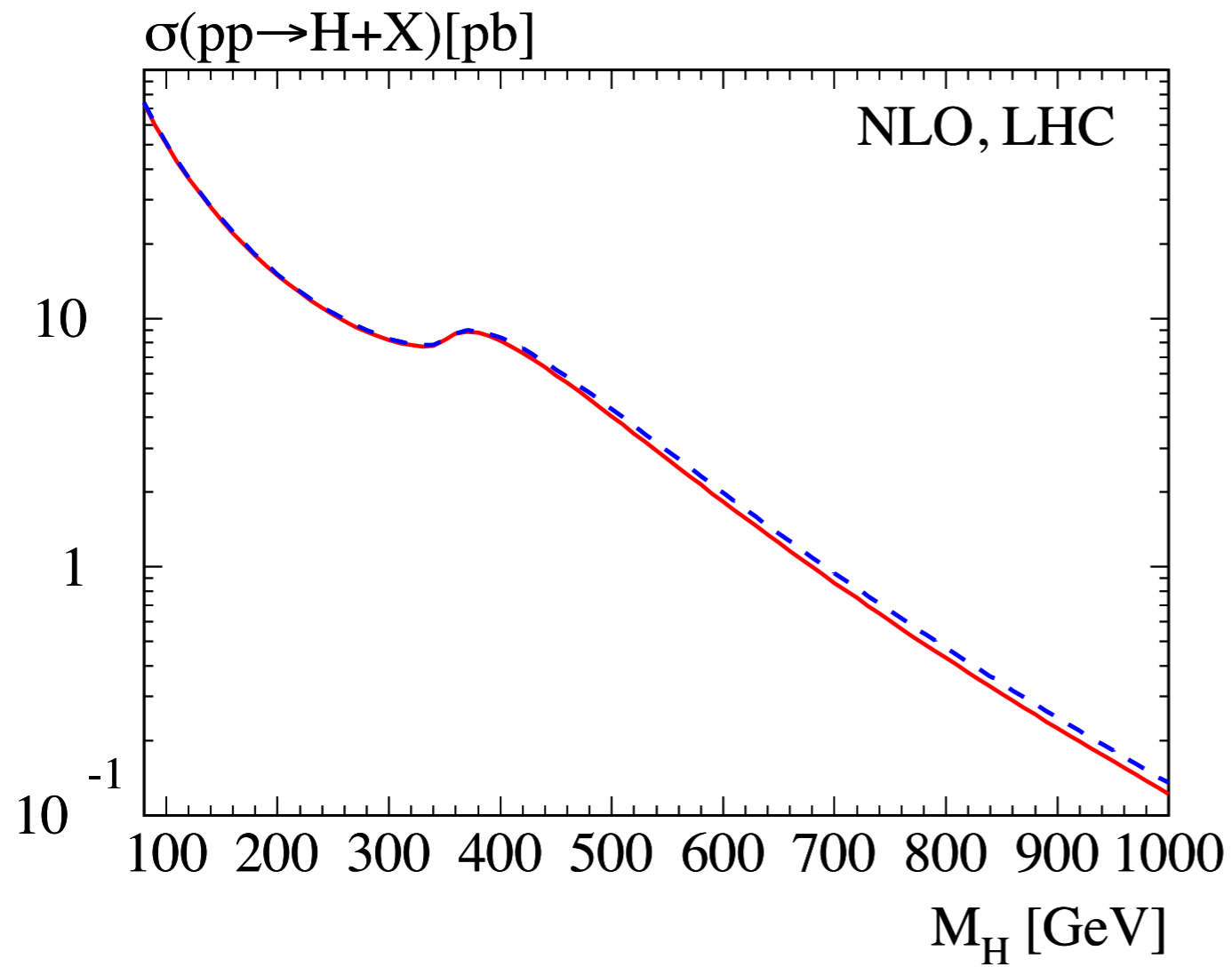
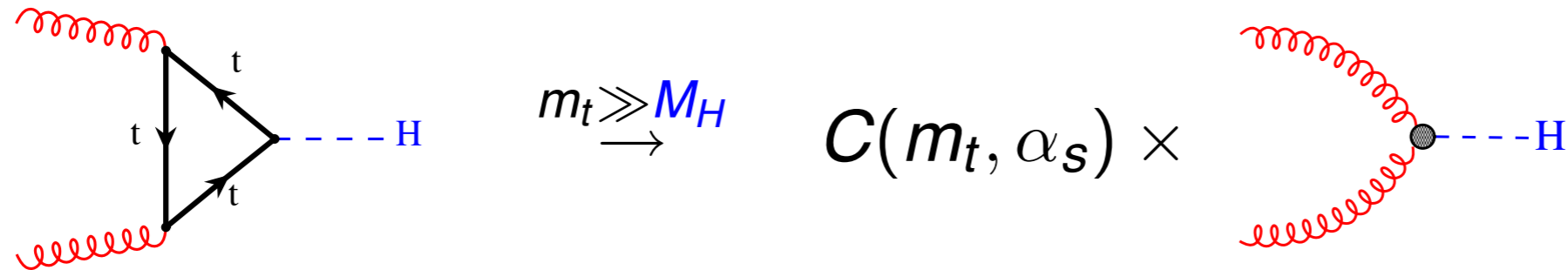
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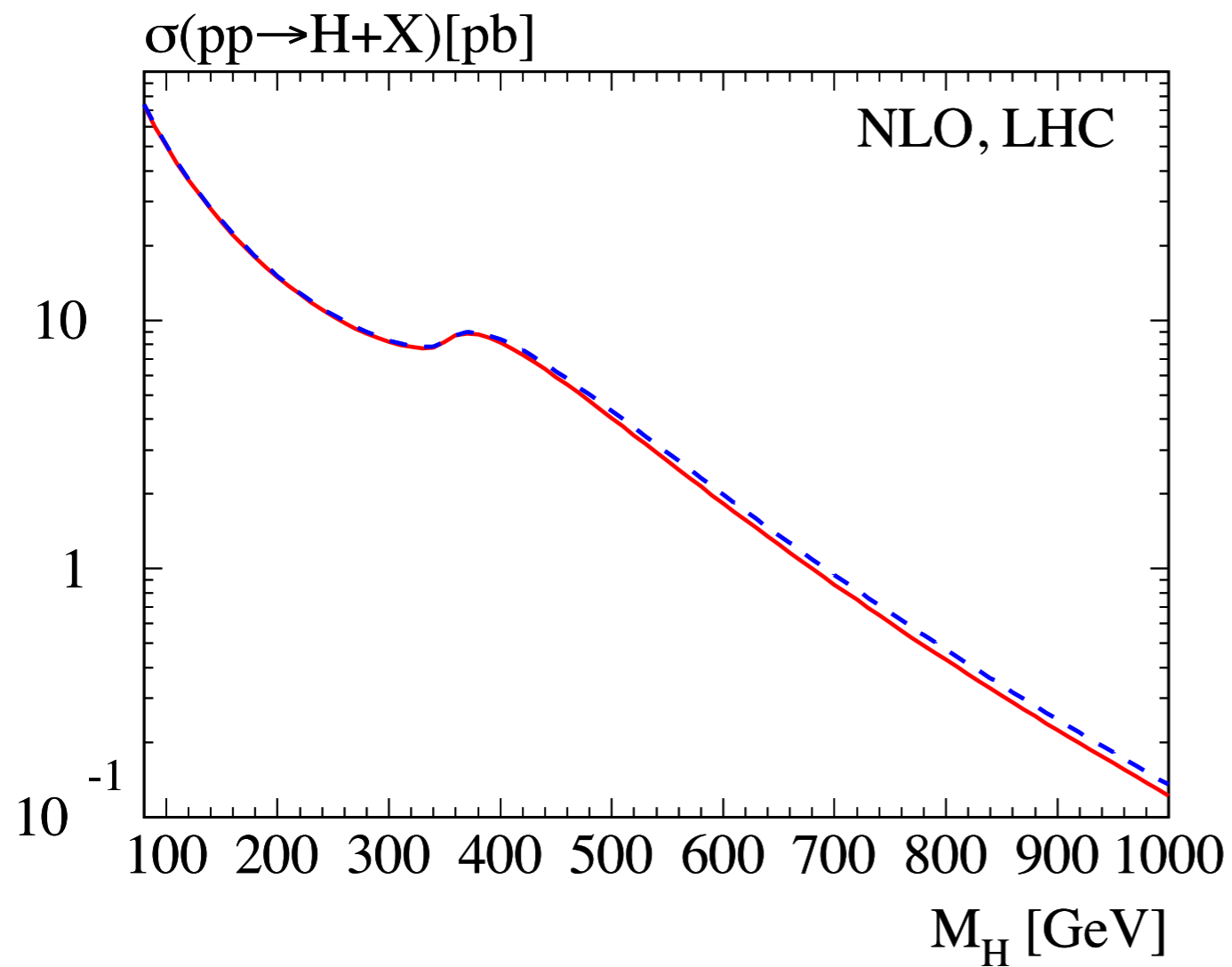
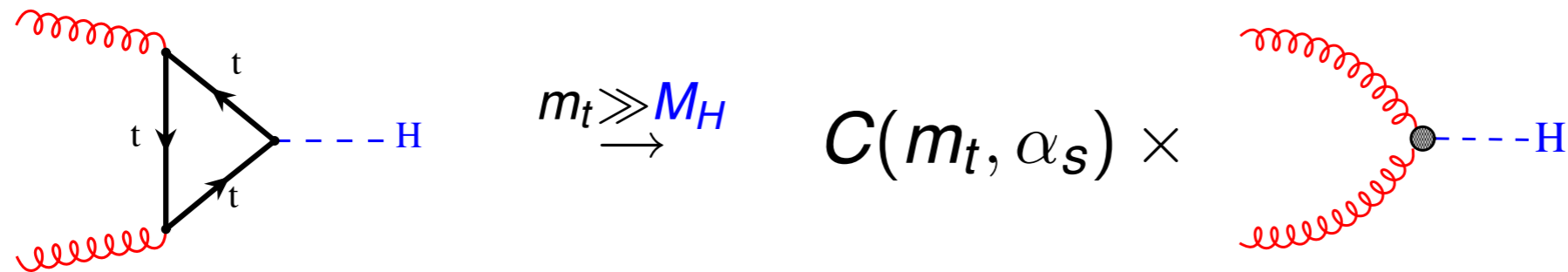
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heavy-top limit!

heavy-top effective theory:

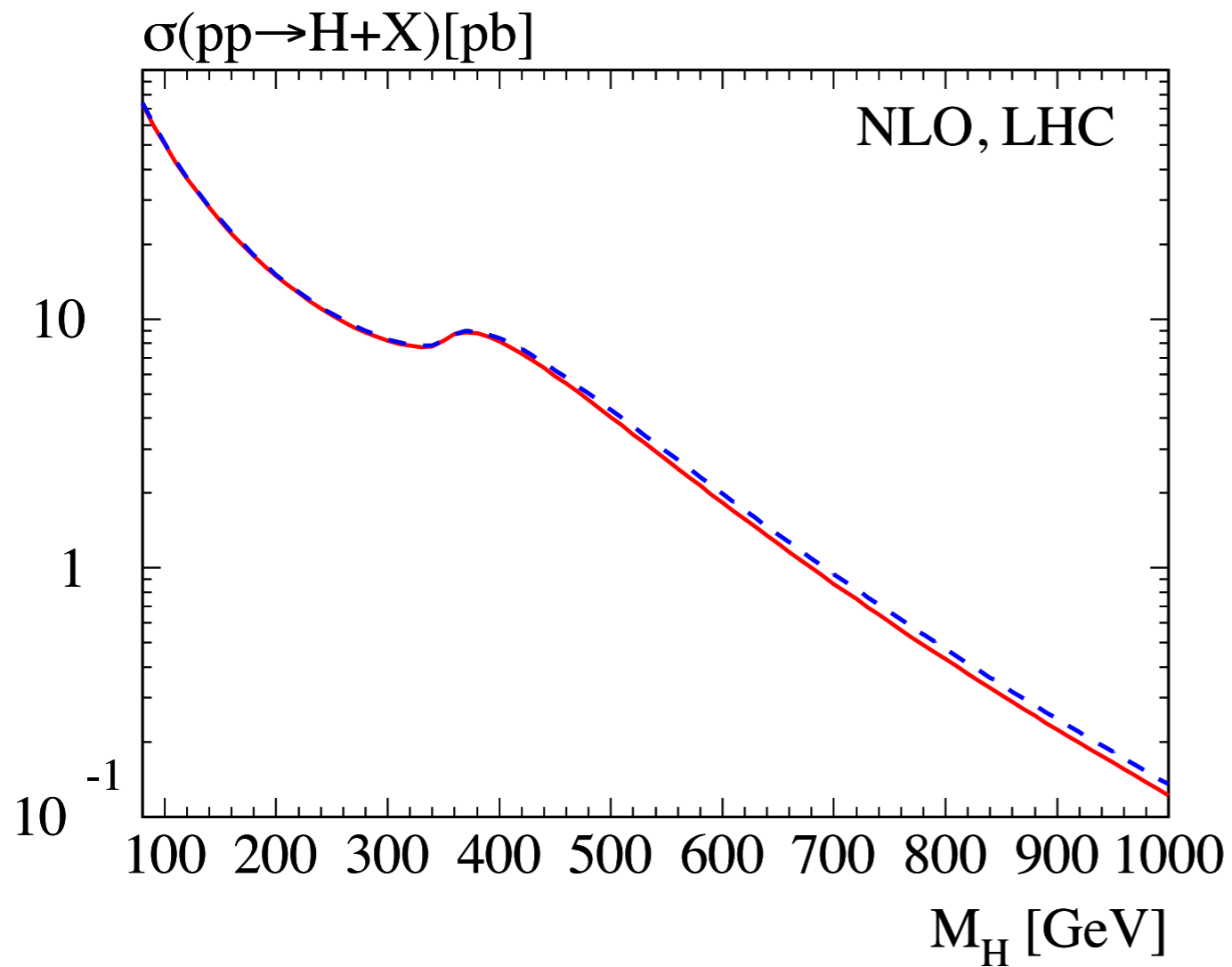
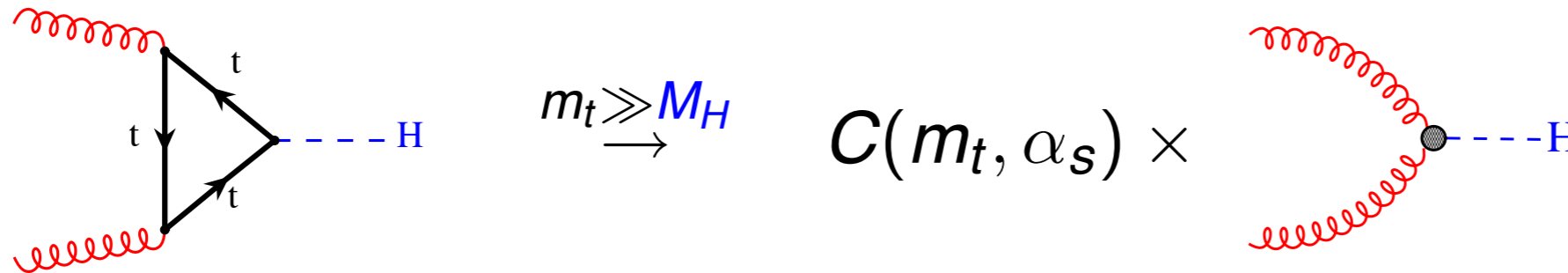


heavy-top effective theory:



$$\sigma_{\infty}^{\text{HO}} \equiv \sigma^{\text{LO}}(m_t) \left(\frac{\sigma^{\text{HO}}}{\sigma^{\text{LO}}} \right)_{m_t \rightarrow \infty}$$

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what about higher orders?

Heavy-top limit:

$$\sigma_{\infty}^{\text{HO}}(\mathbf{s}, m_H, m_t) \equiv \sigma^{\text{LO}}(m_t, m_H) \left(\frac{\sigma^{\text{HO}}(\mathbf{s}, m_H)}{\sigma^{\text{LO}}} \right)_{m_t \rightarrow \infty}$$

Honest expansion:

$$\sigma^{\text{HO}}(\mathbf{s}, m_H, m_t) = \sum_n \left(\frac{m_H^2}{4m_t^2} \right)^n \sigma_n^{\text{HO}}(\mathbf{s}, m_H)$$

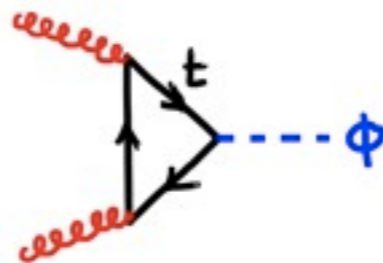
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ok for virtual:



$$\sigma(\mathbf{s}, m_H) = \sigma(m_t^2, m_H)$$

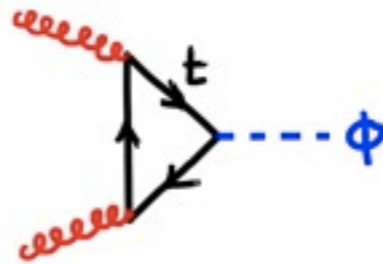
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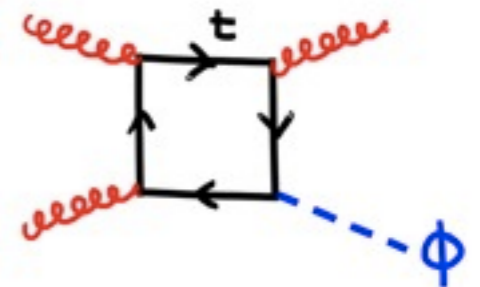
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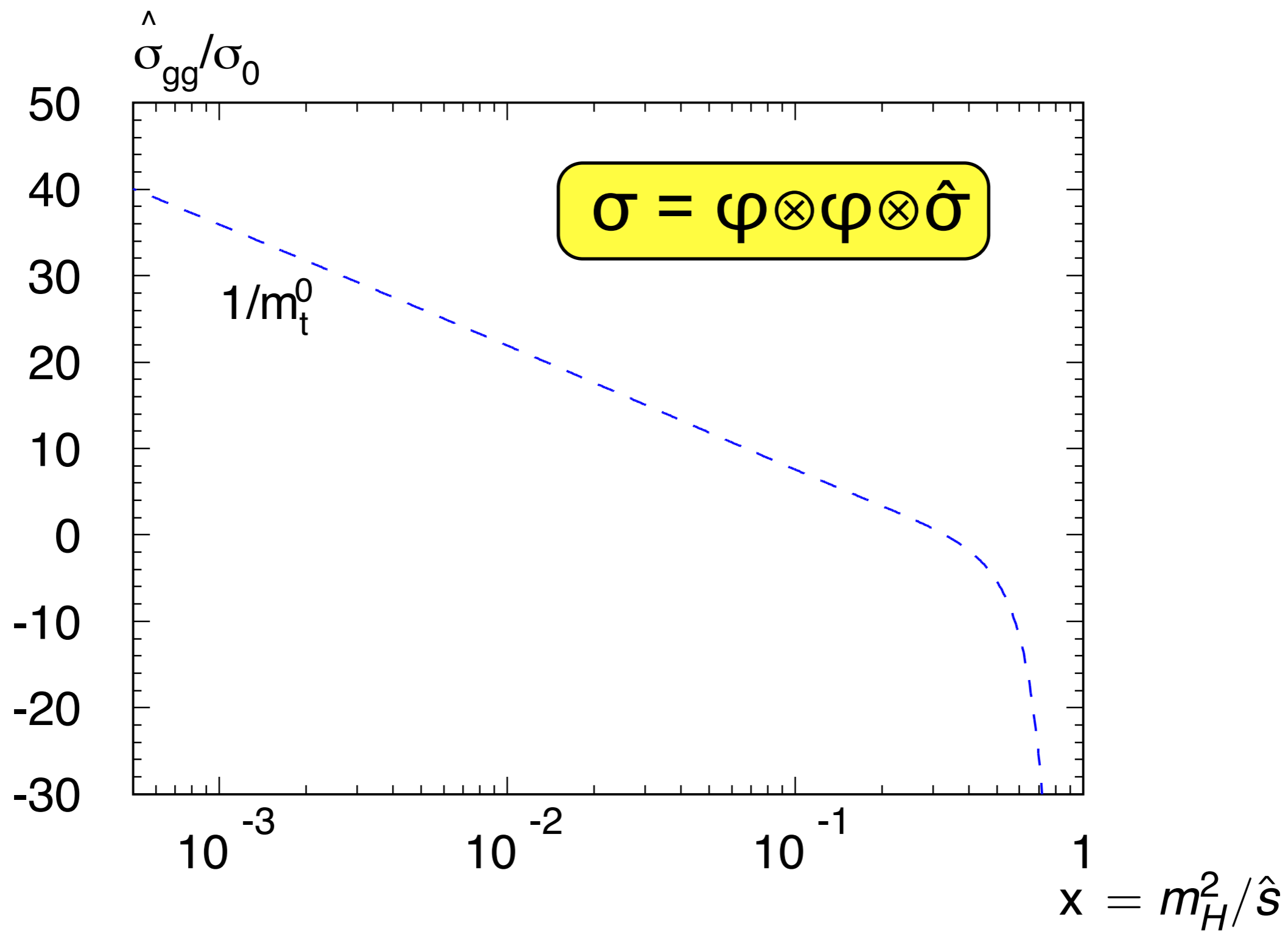


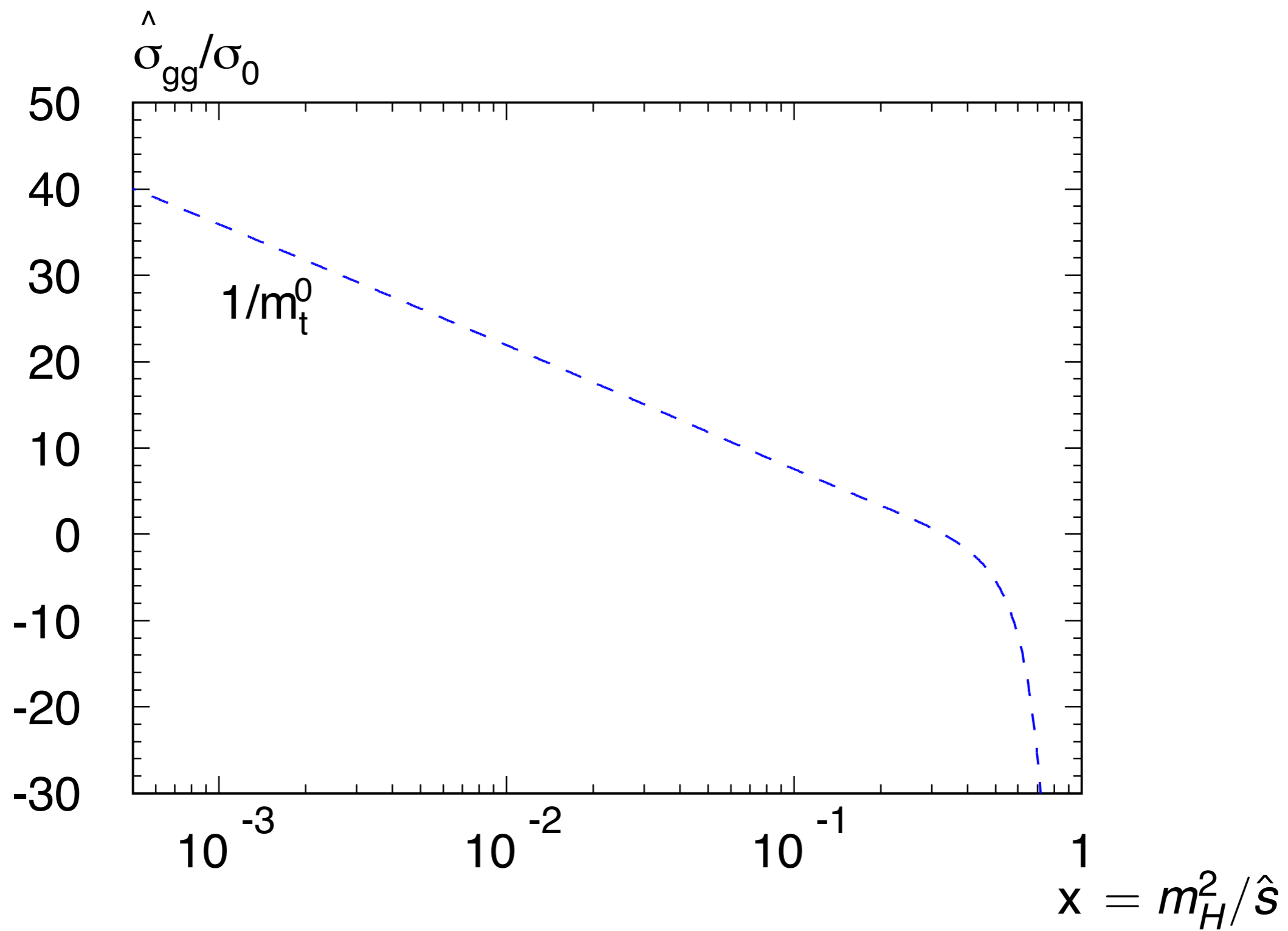
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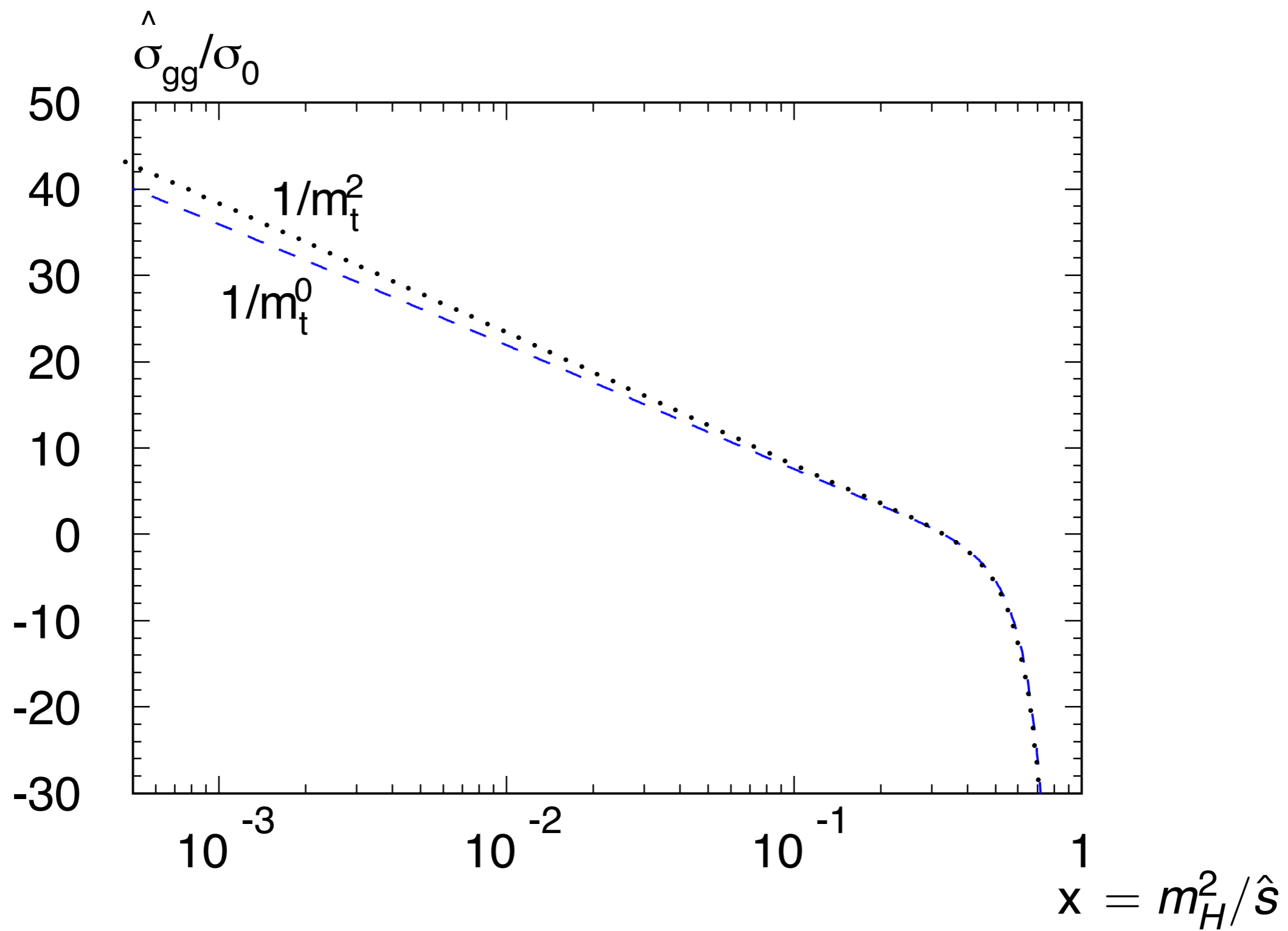
problem for real, because $s > 4 m_t^2$ possible:

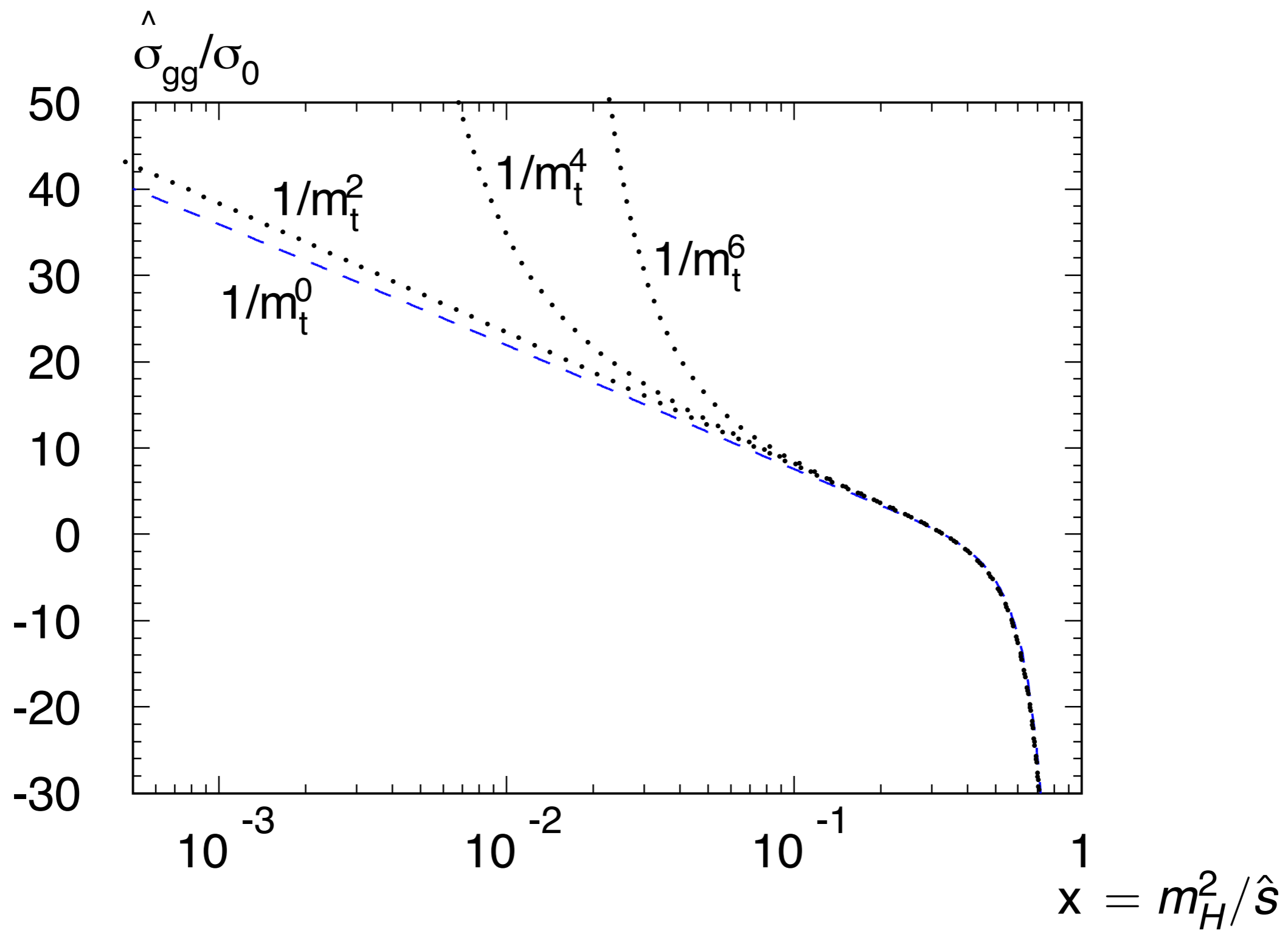


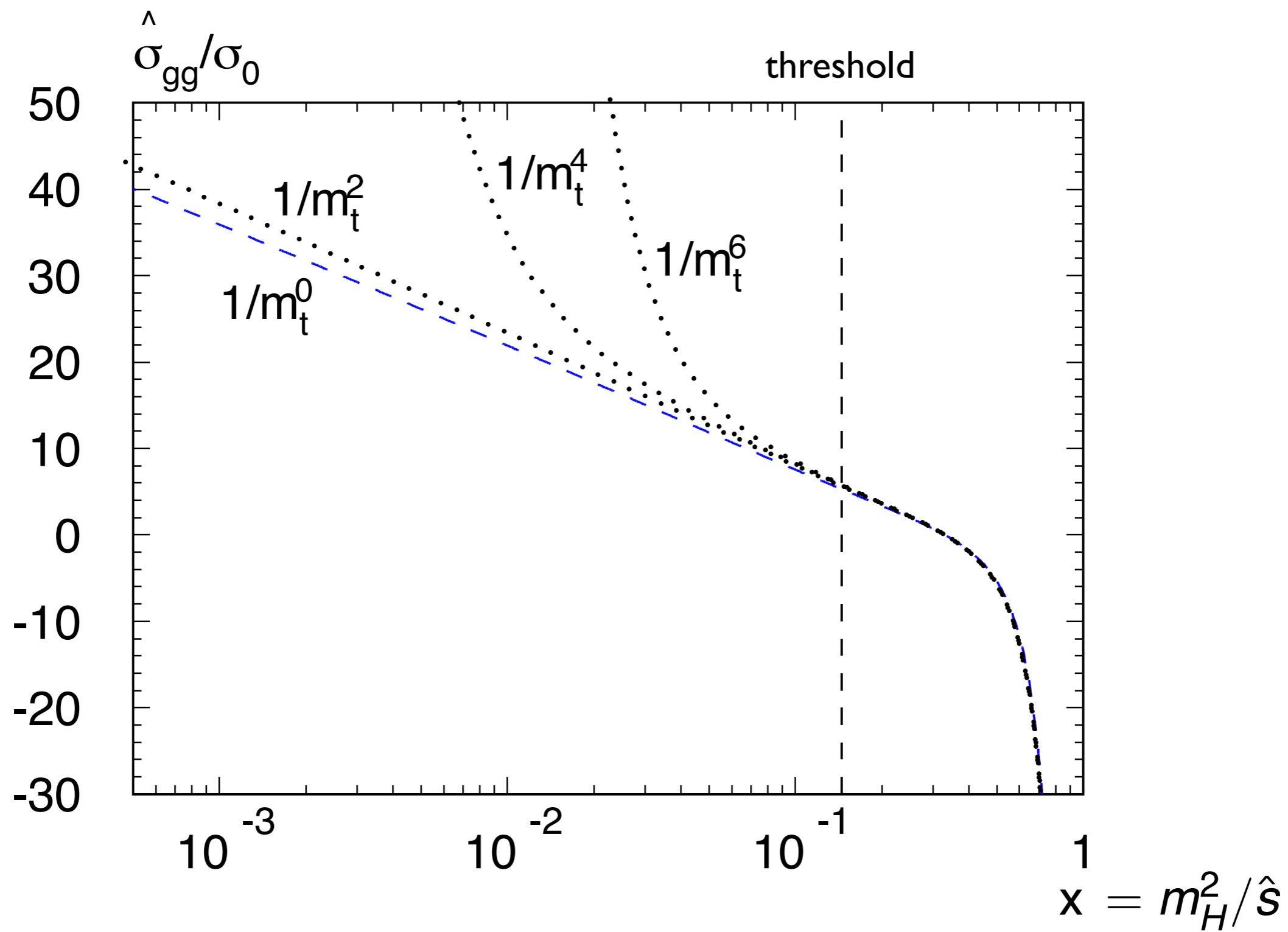
$$\frac{s}{m_t^2} = \frac{m_H^2}{m_t^2} \cdot \frac{s}{m_H^2}$$

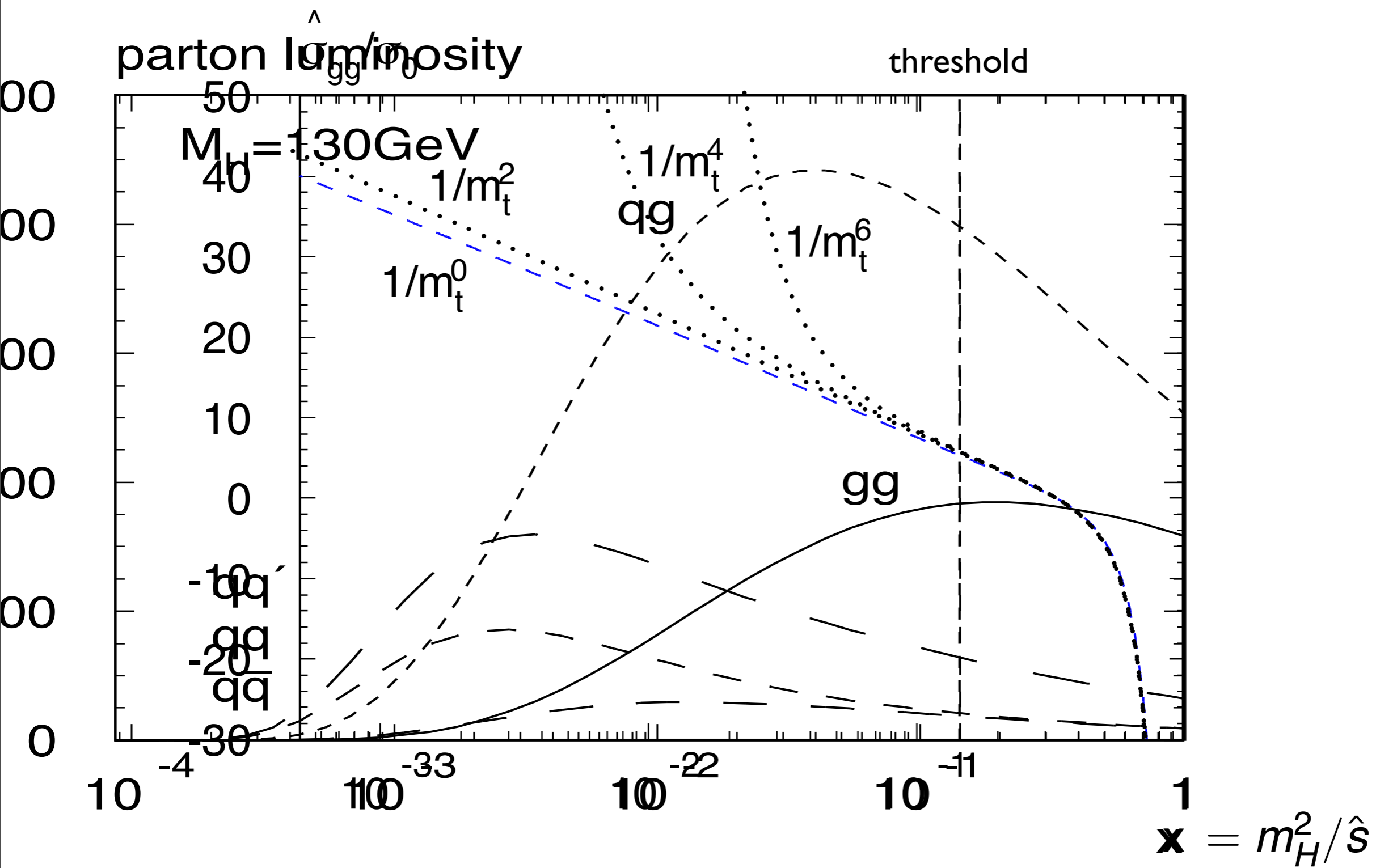


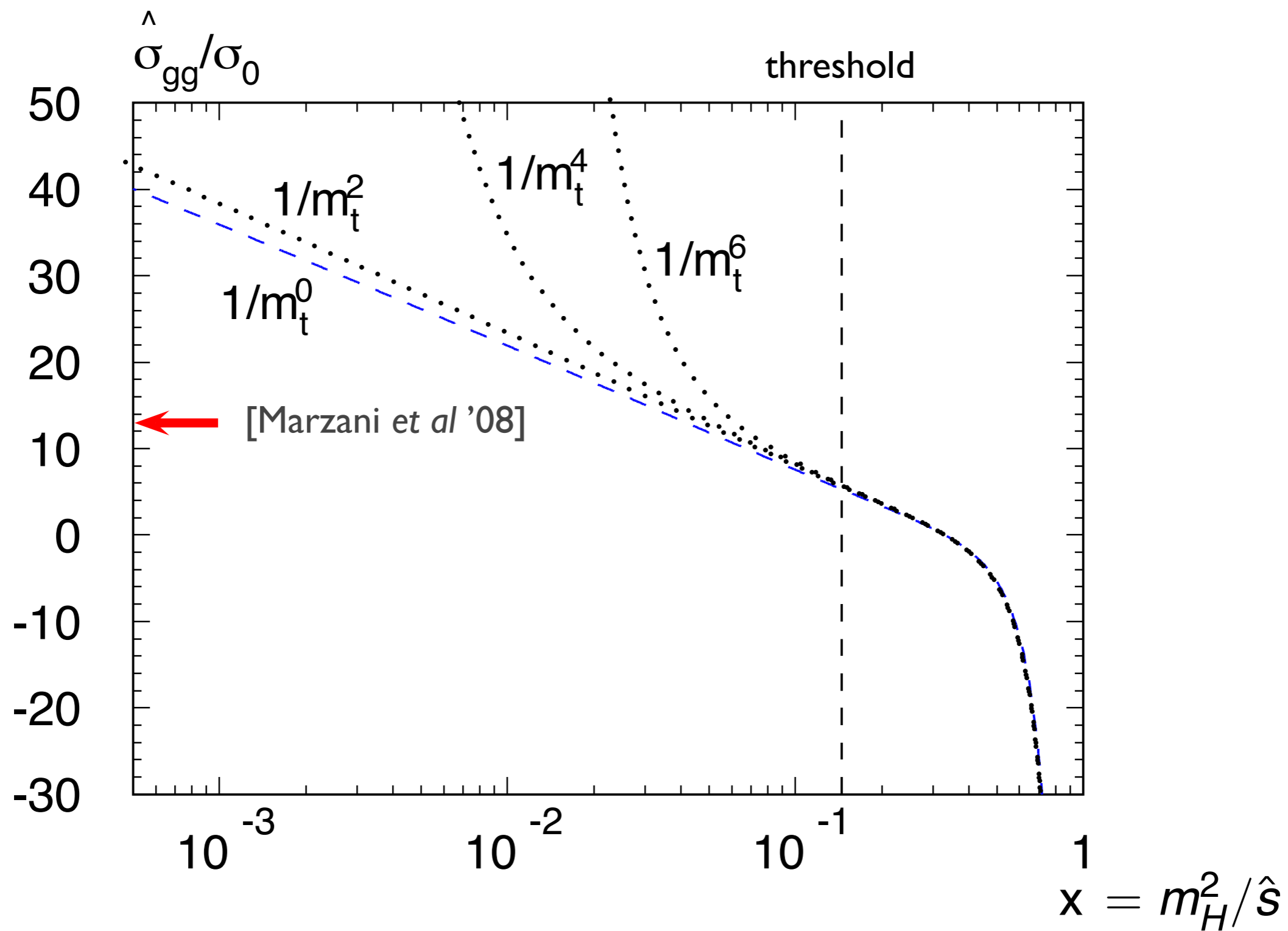


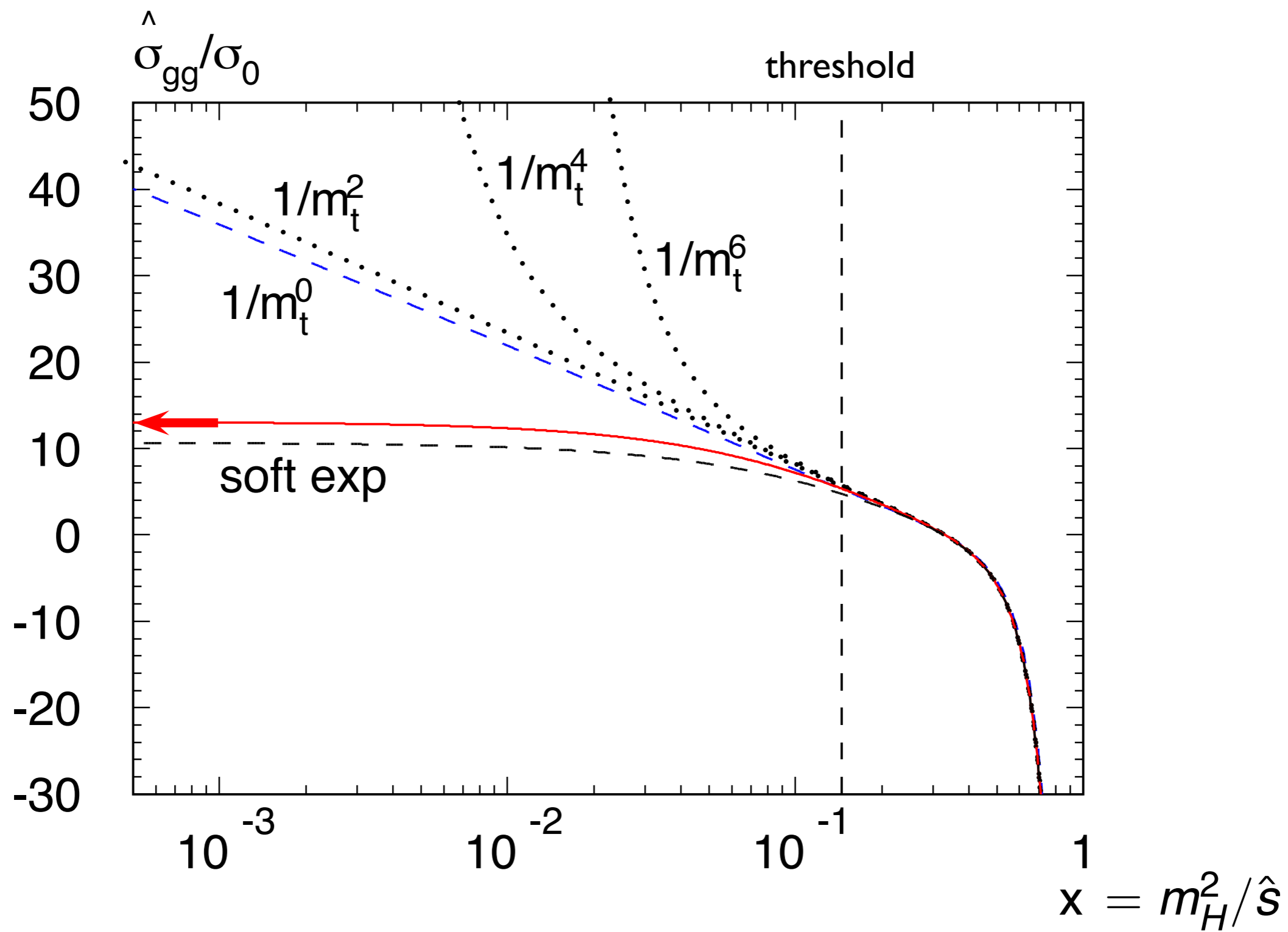


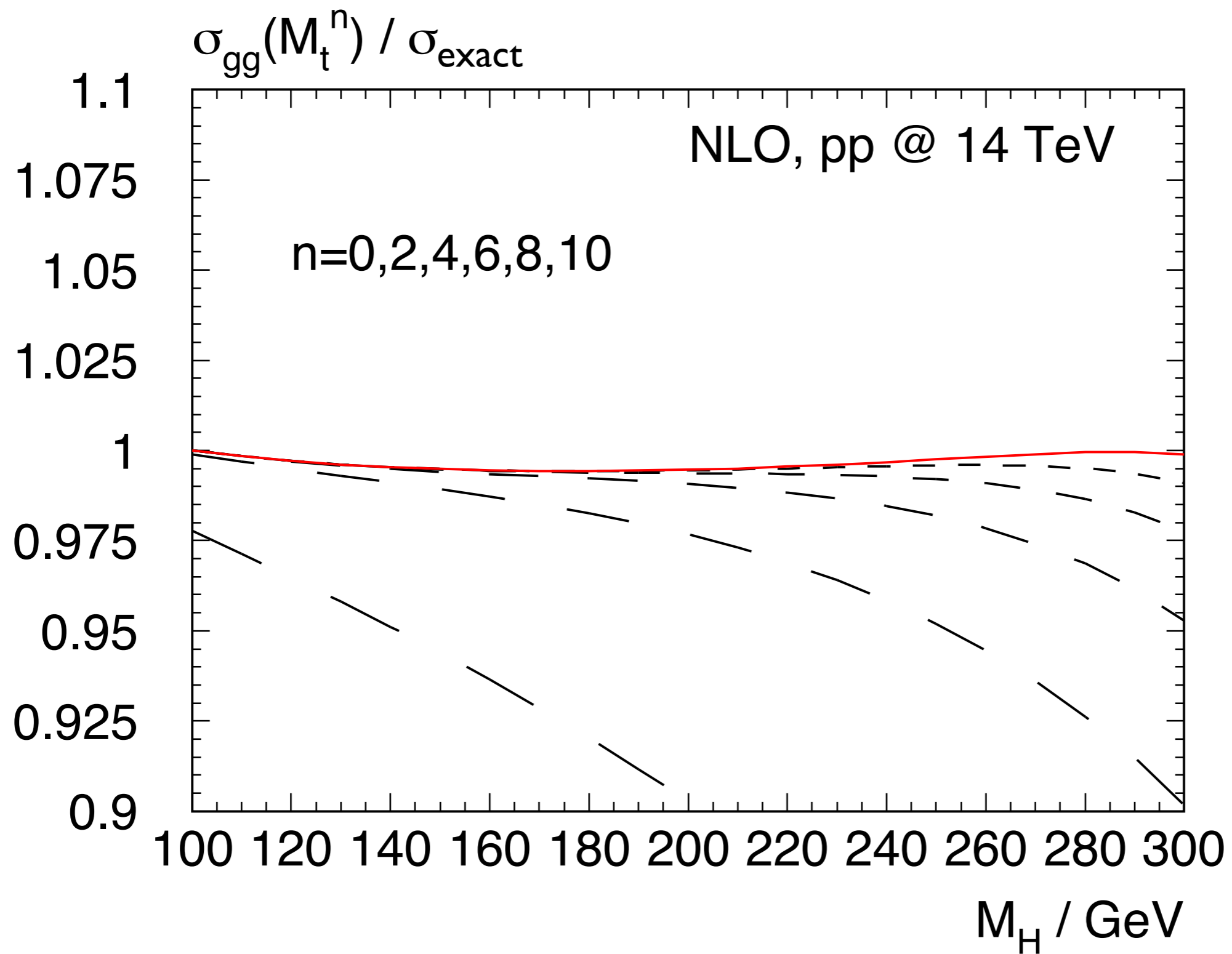


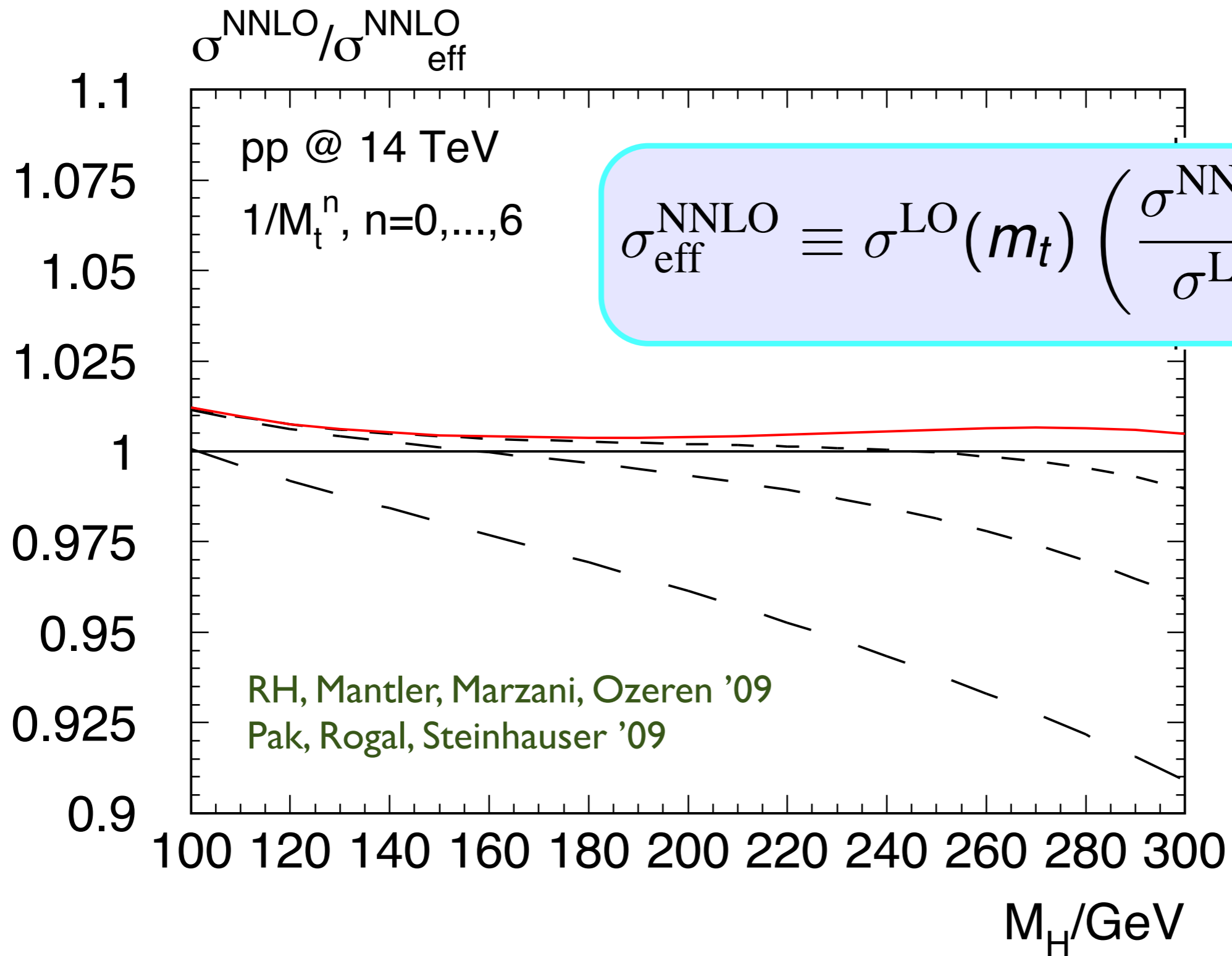






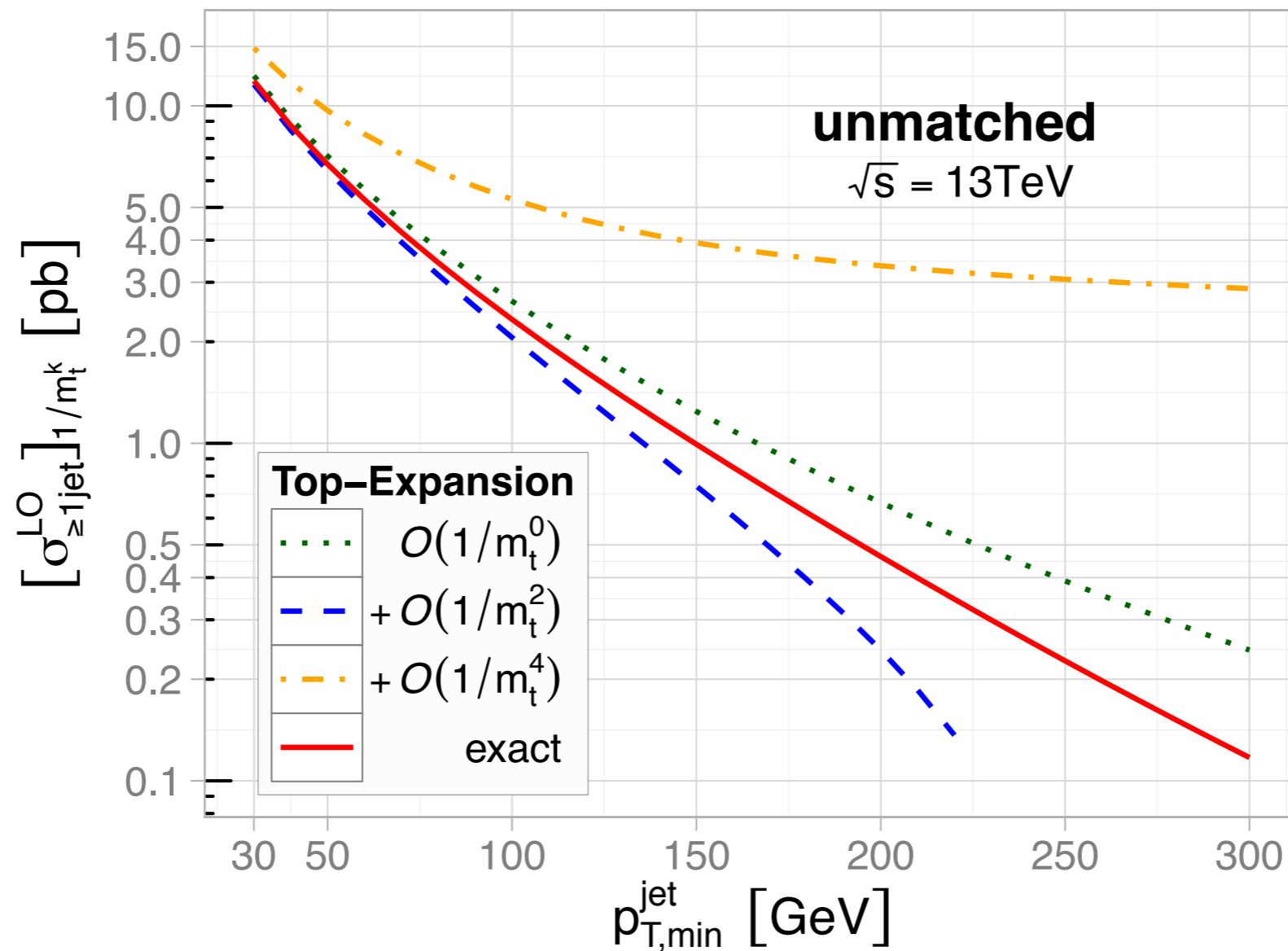
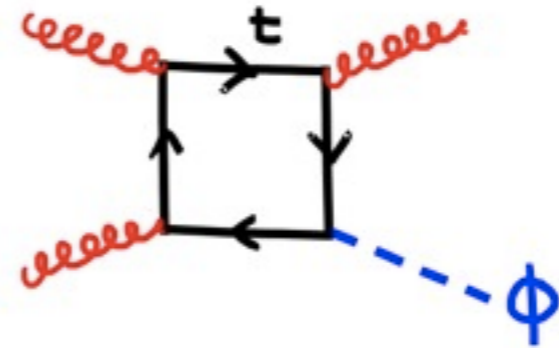






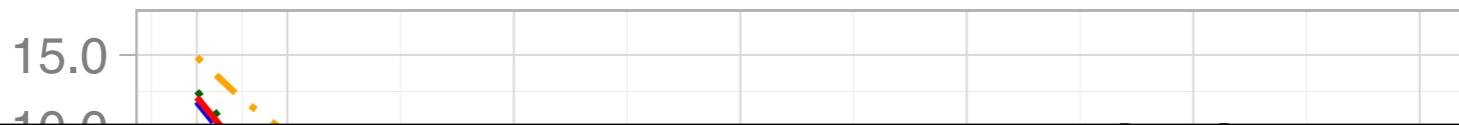
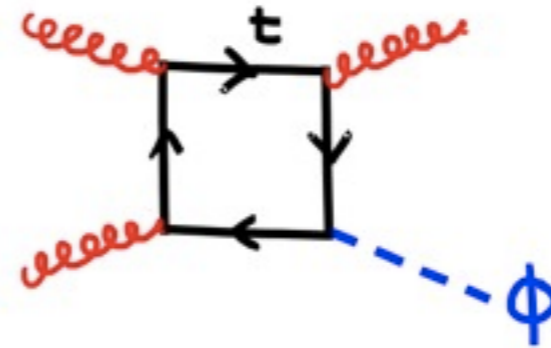
Differential

e.g. inclusive H+jet:



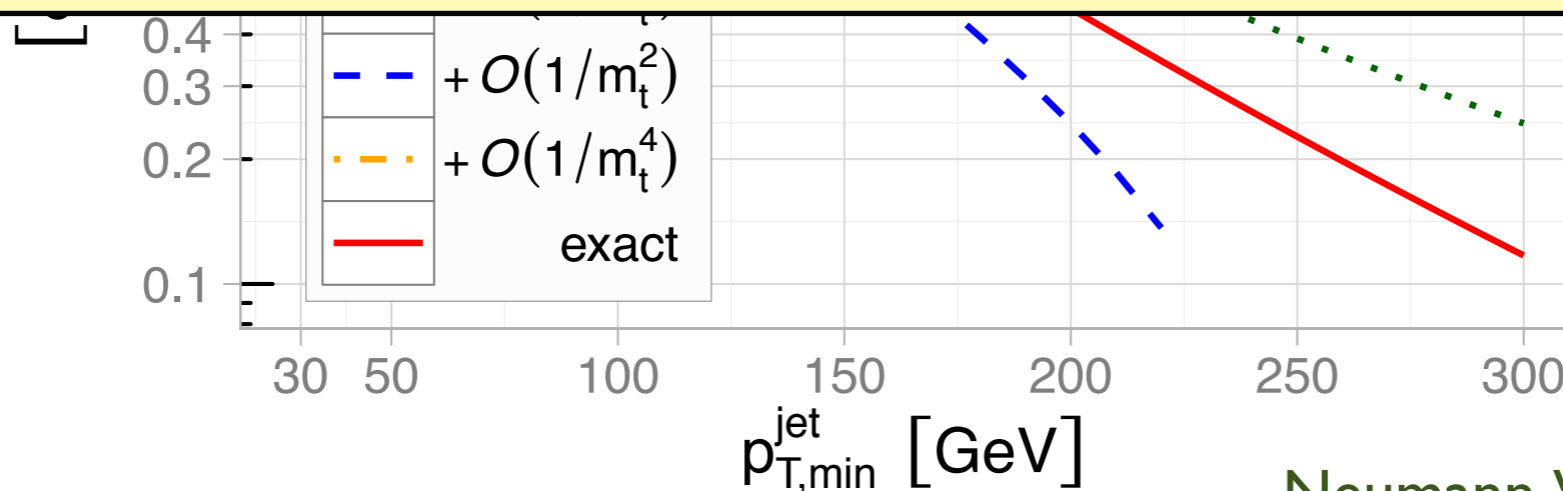
Differential

e.g. inclusive H+jet:



$$\left[\sigma_{\text{tot, matched}} \right]_{m_t^k} - \left[\sigma_{\text{tot, unmatched}} \right]_{m_t^k} = \left[\sigma_{\geq 1\text{-jet, matched}} \right]_{m_t^k} - \left[\sigma_{\geq 1\text{-jet, unmatched}} \right]_{m_t^k}$$

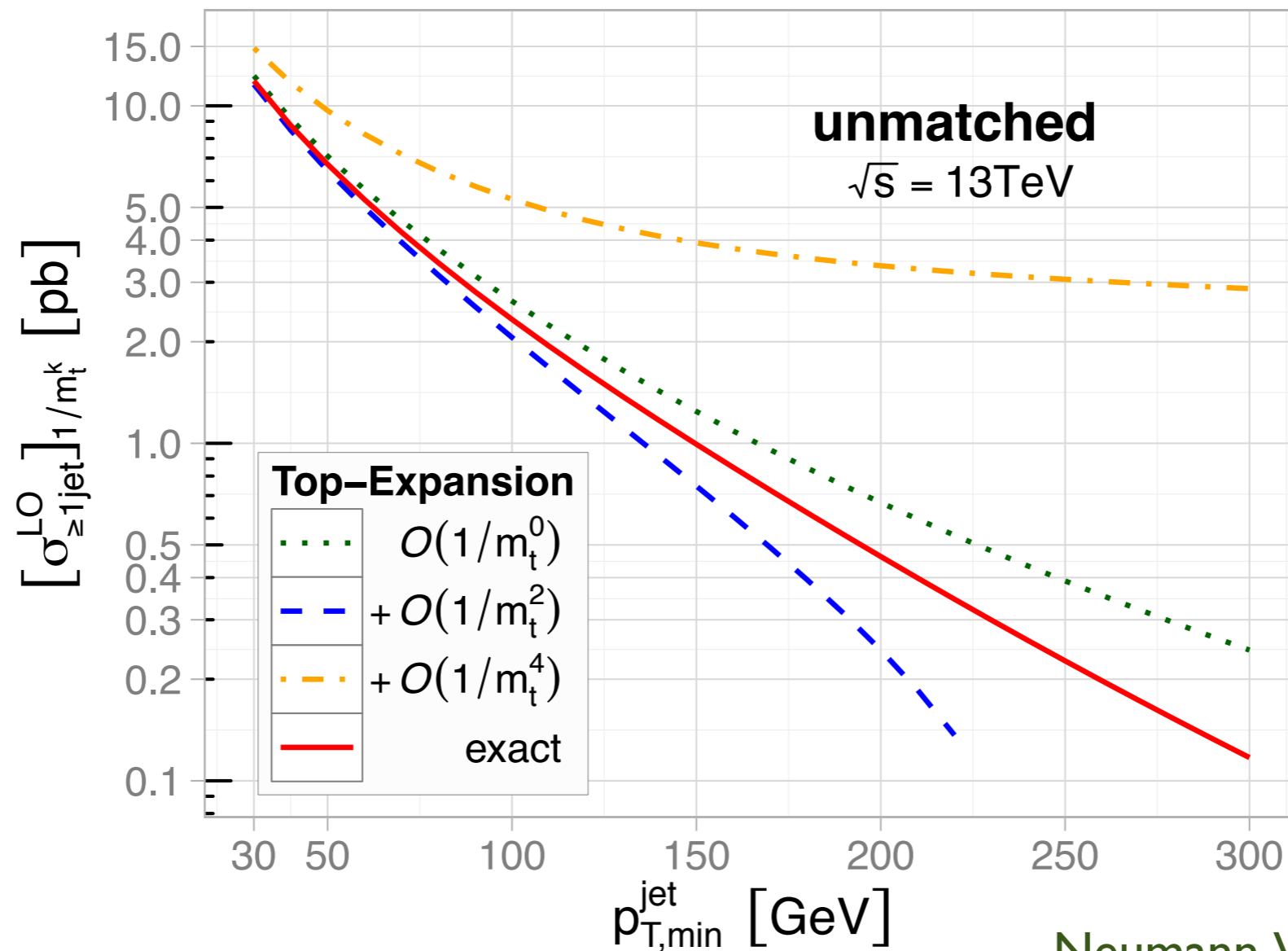
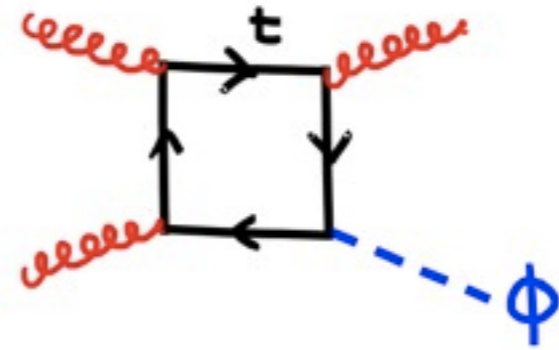
$$\left[\sigma_{\geq 1\text{-jet, matched}} \right]_{m_t^k} \equiv \left[\sigma_{\geq 1\text{-jet, unmatched}} \right]_{m_t^k} + \left[\sigma_{\text{tot, matched}} \right]_{m_t^k} - \left[\sigma_{\text{tot, unmatched}} \right]_{m_t^k}$$



Neumann, Wiesemann '14

Differential

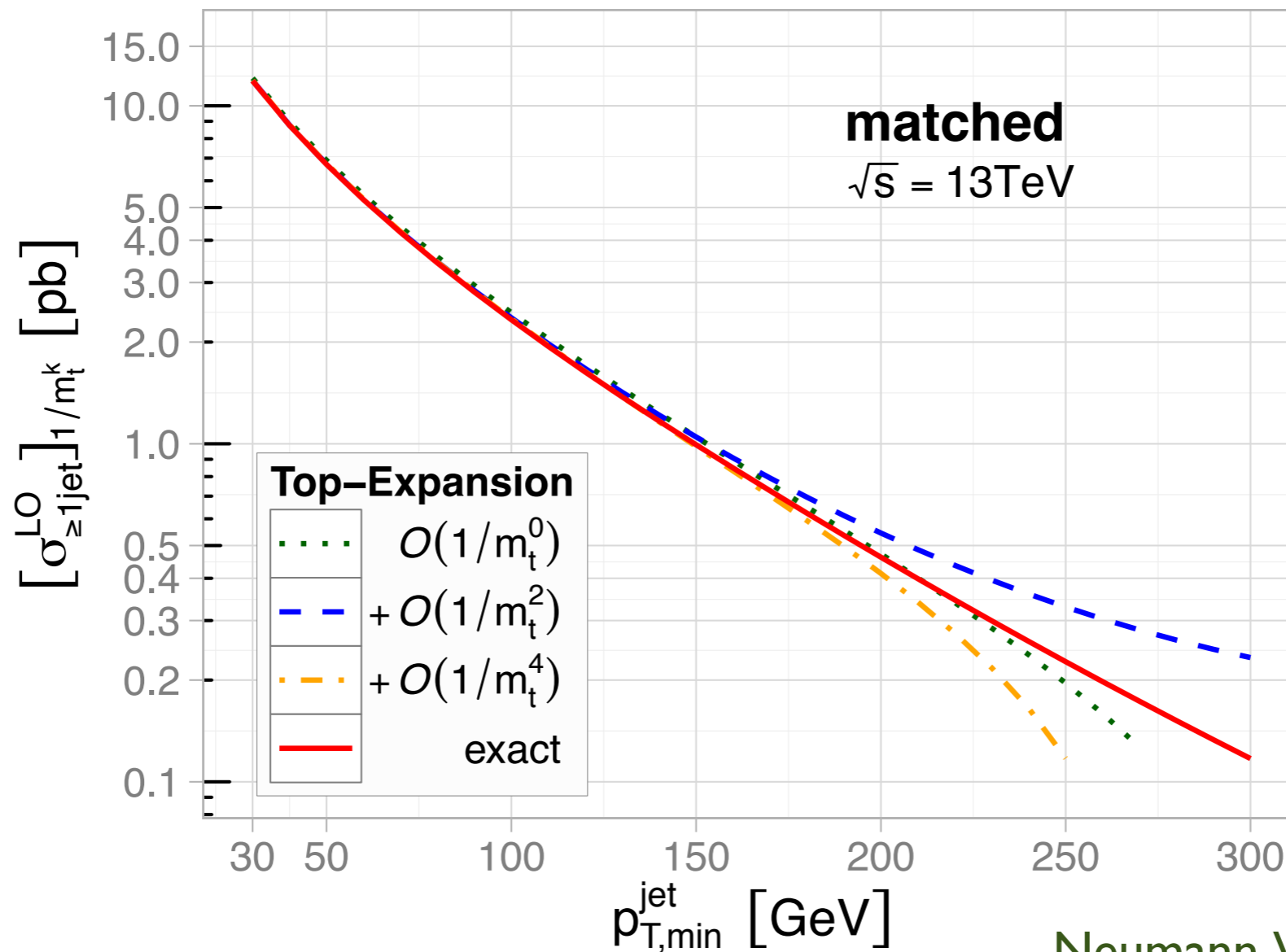
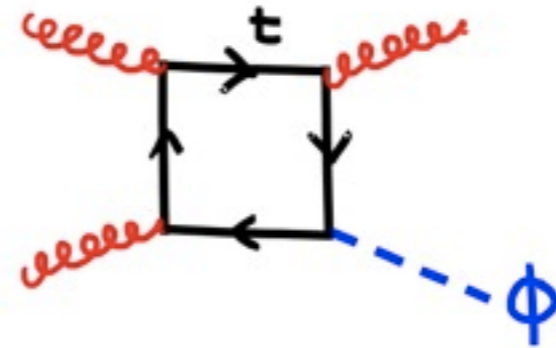
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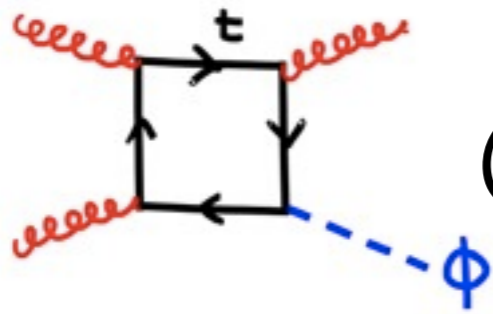
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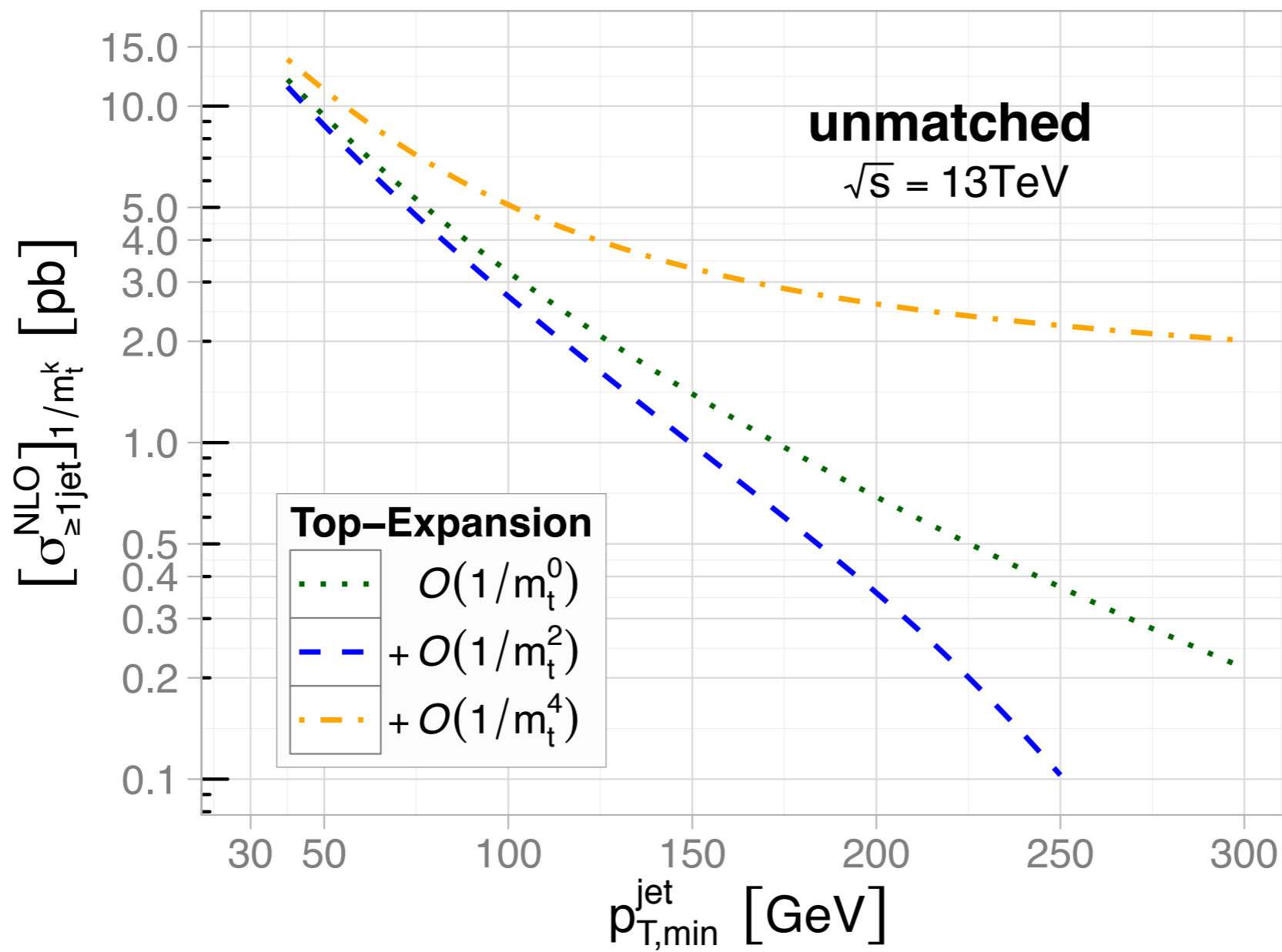
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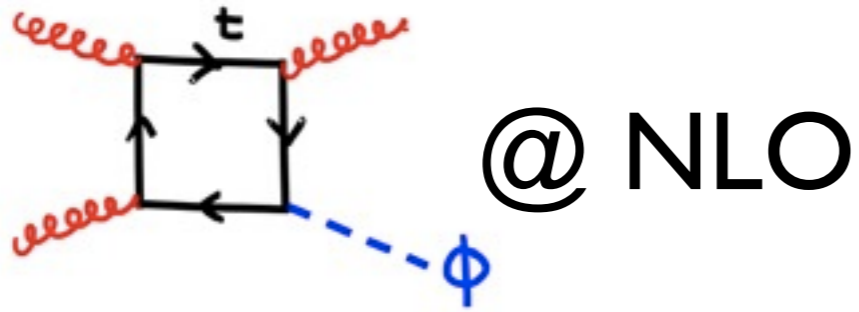


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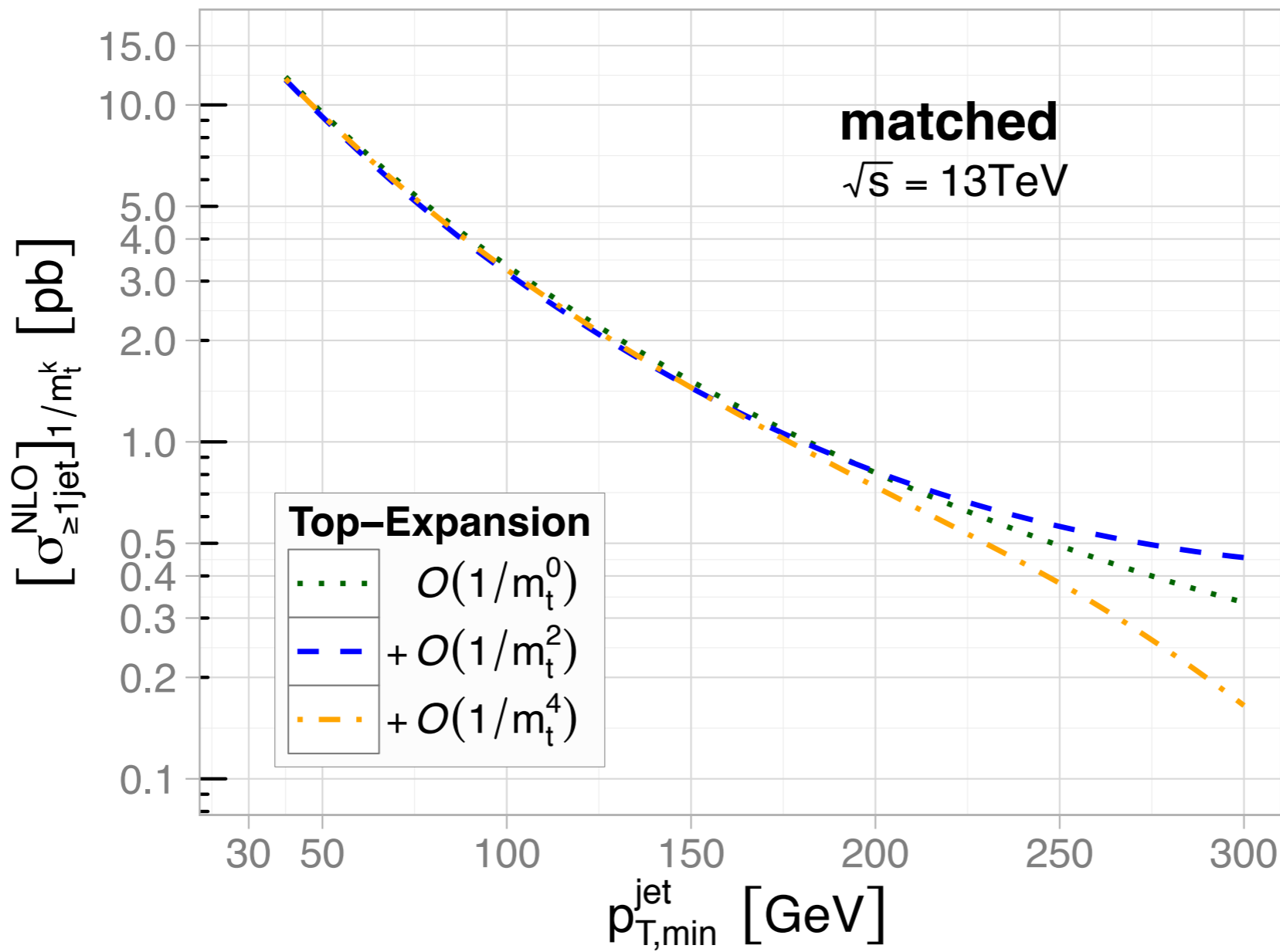


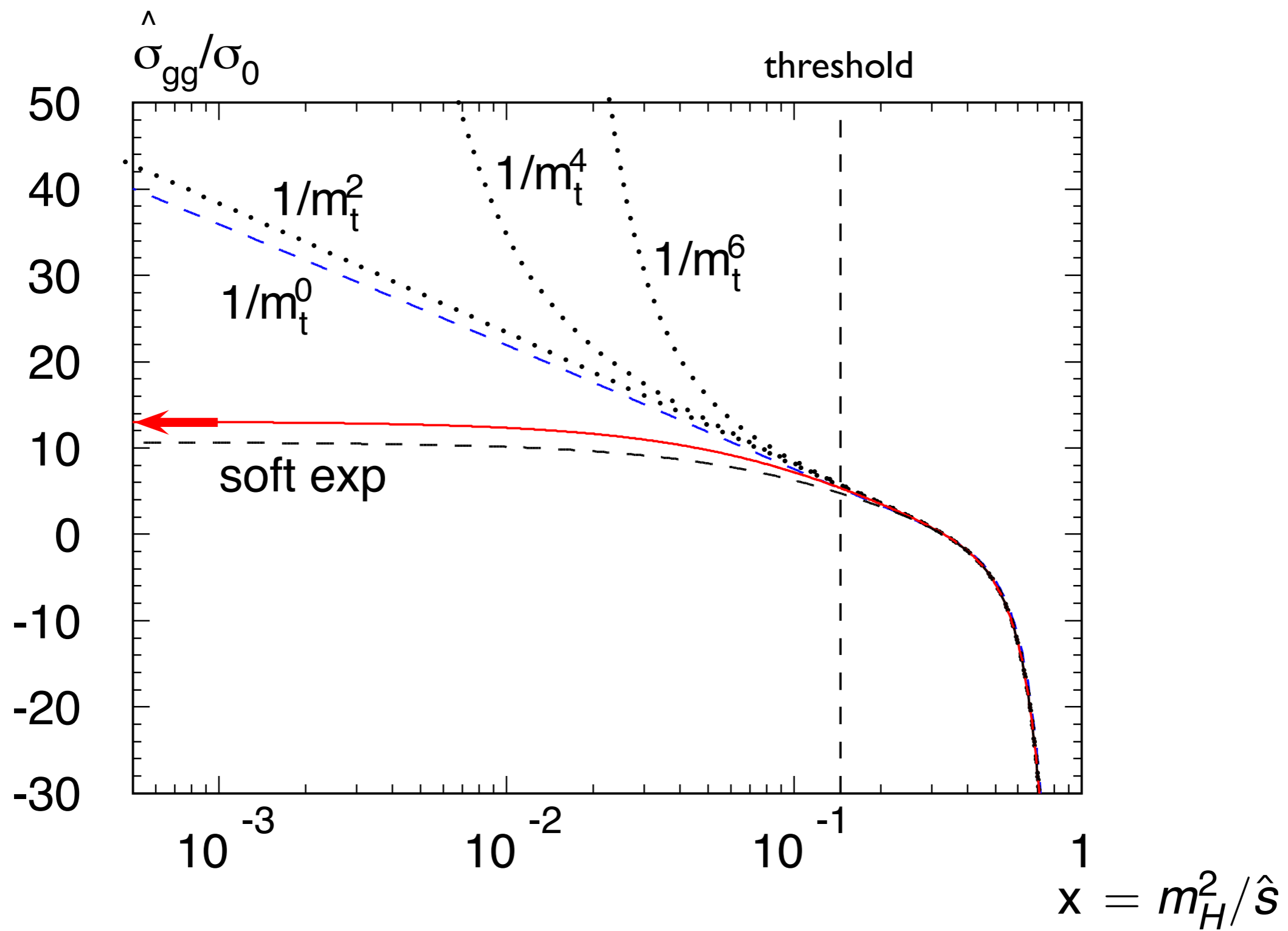
@ NLO

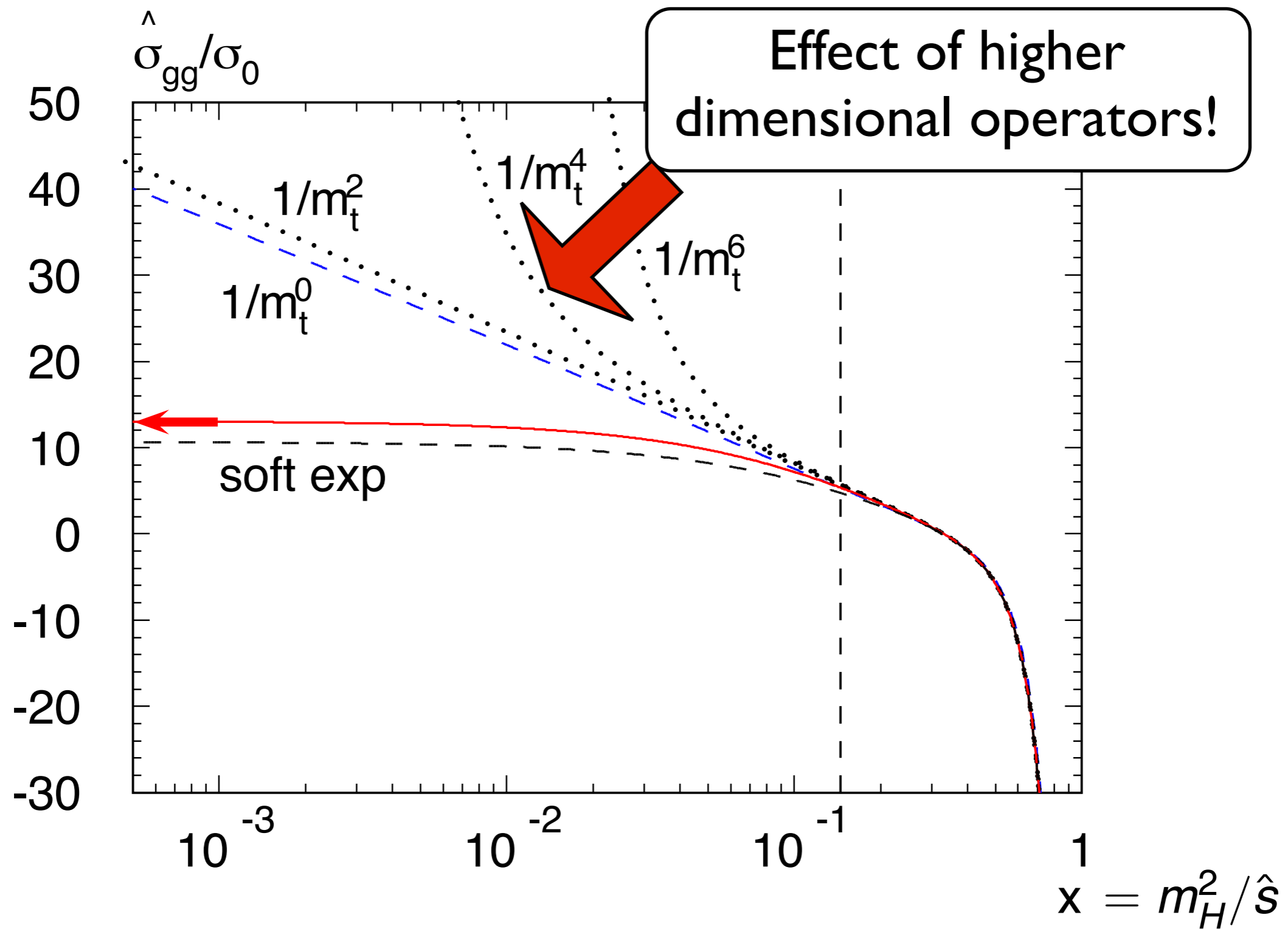




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Consider extreme case:

- Higgs does not couple to top quark
- gluon-Higgs coupling mediated by $\Lambda \gg M_H$

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$$\mathcal{L} = \frac{C_1}{\Lambda} \mathcal{O}_1 + \sum_{n=2}^5 \frac{C_n}{\Lambda^3} \mathcal{O}_n$$

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measurement of total cross section

\Rightarrow at least one of the C_n must be large!

expect very different p_T spectrum

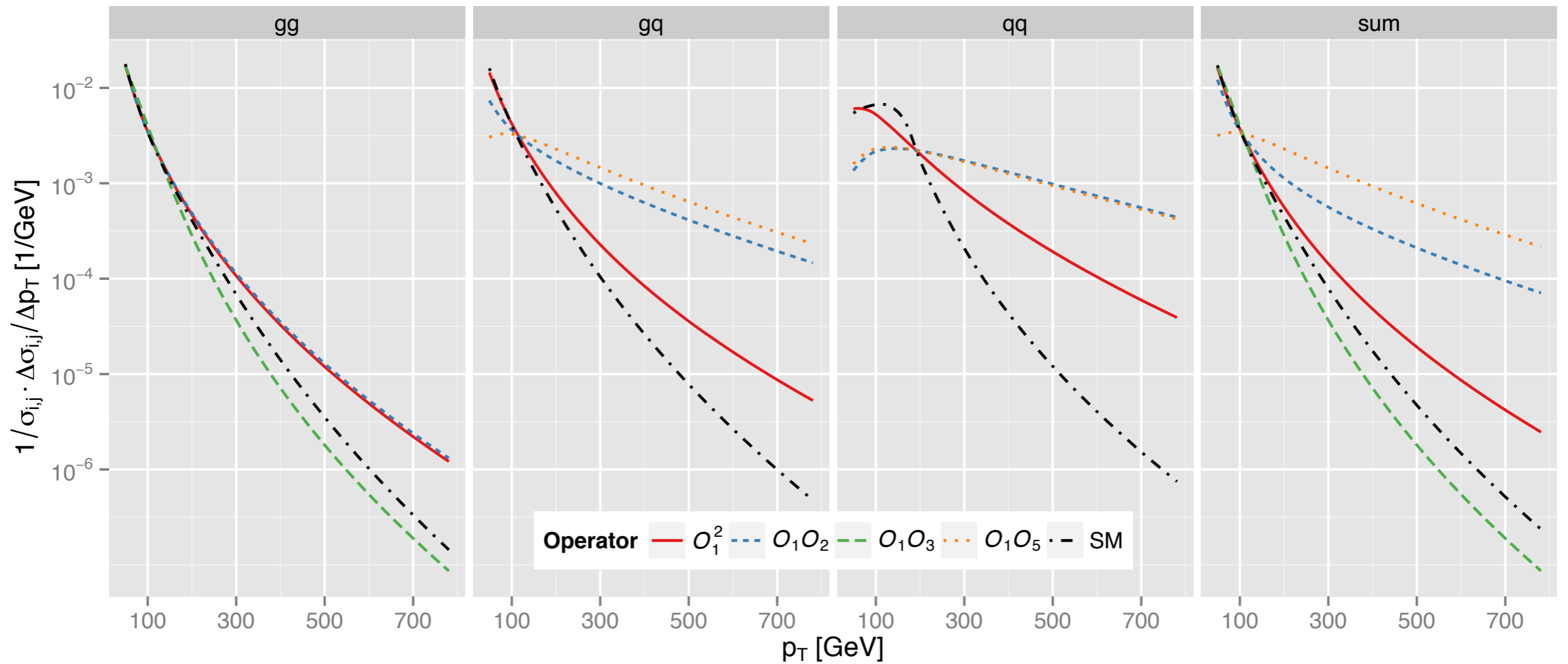
RH, Neumann '13

see also: Banfi, Martin, Sanz '14

Azatov, Paul '14

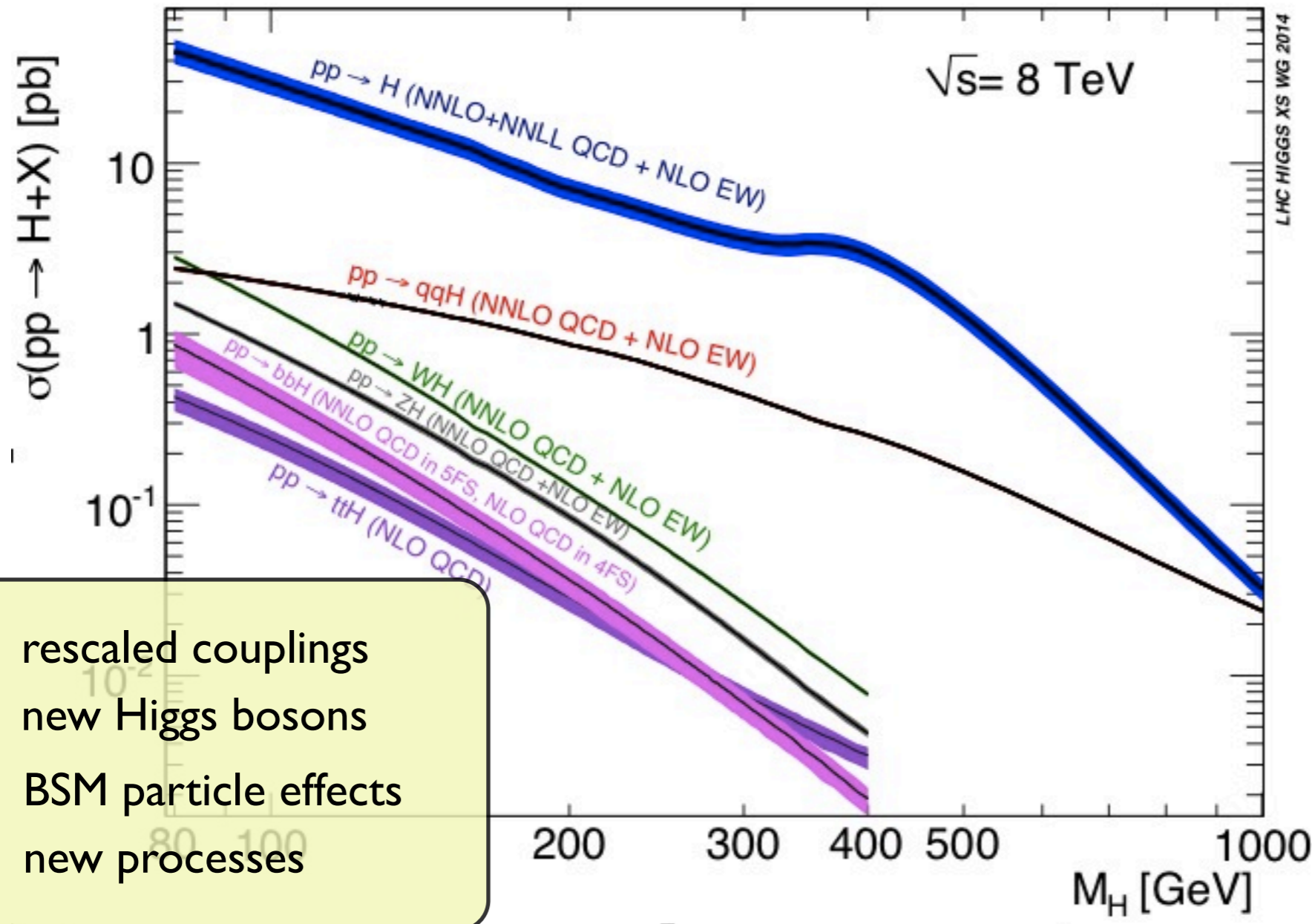
Grojean, Salvioni, Schlaffer, Weiler '14

p_T -shape for higher operators:



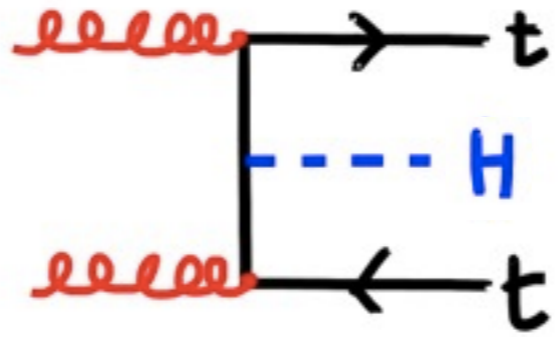
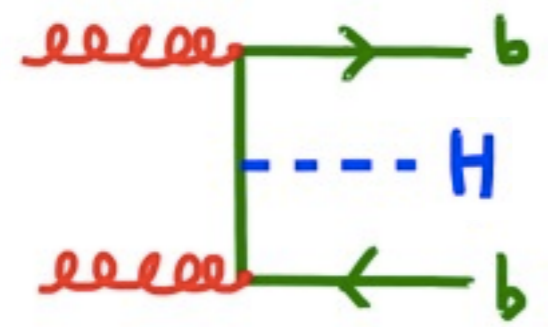
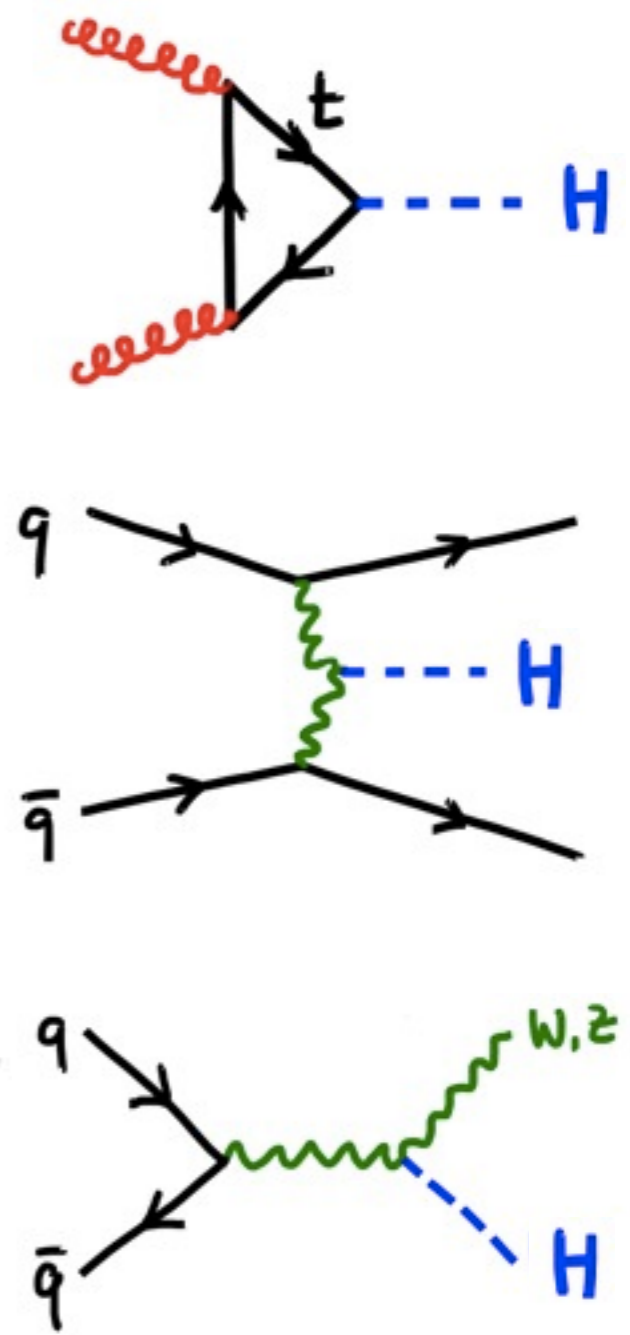
RH, Neumann '13

NLO: Dawson, Lewis, Zeng '14

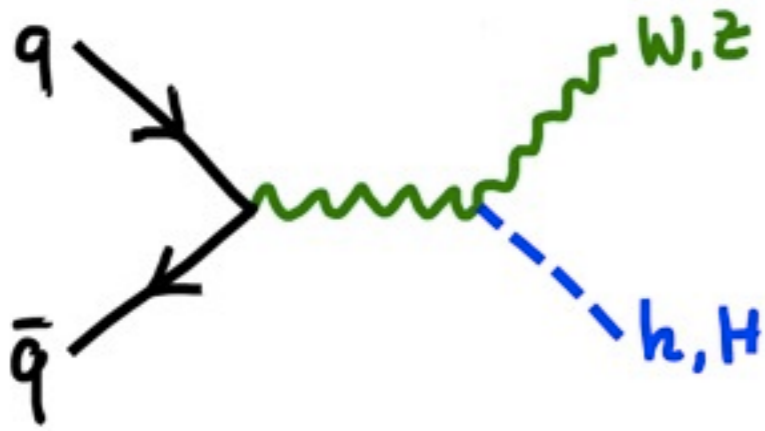


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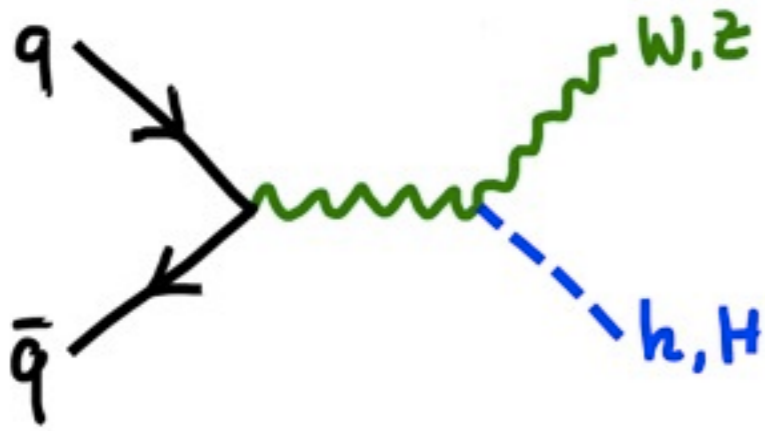
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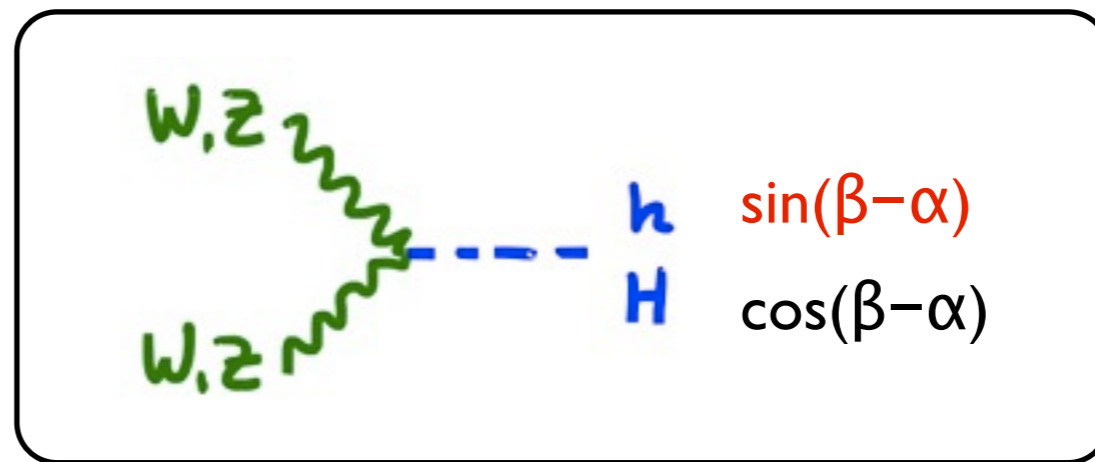
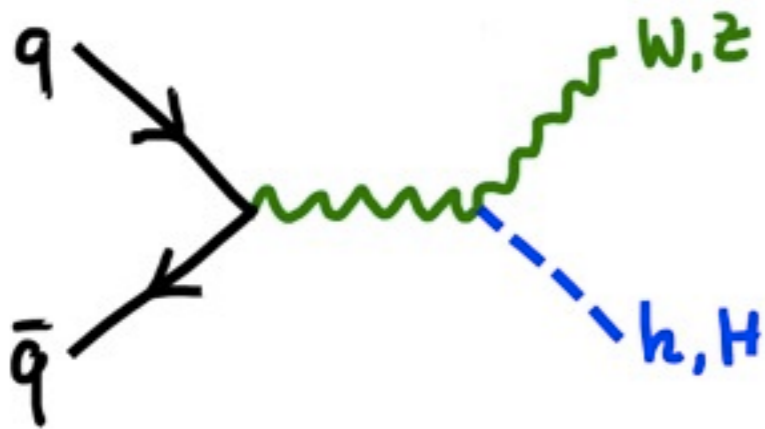
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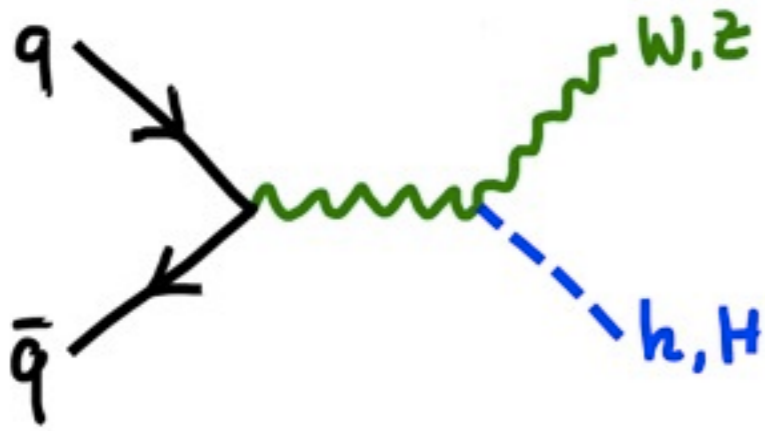
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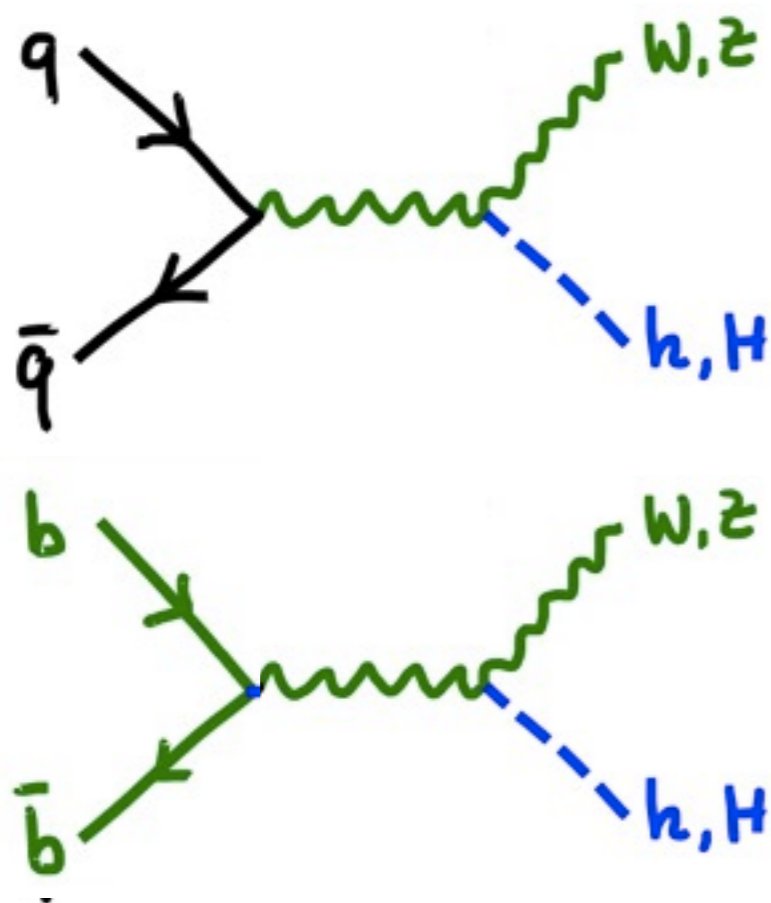
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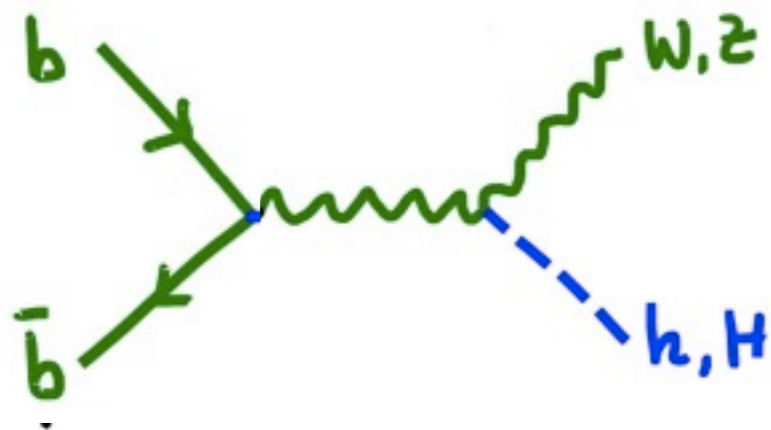
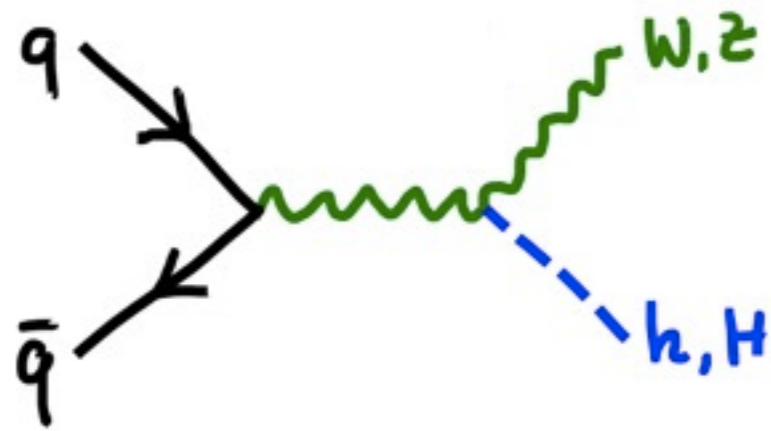
Effects due to new Higgs bosons:



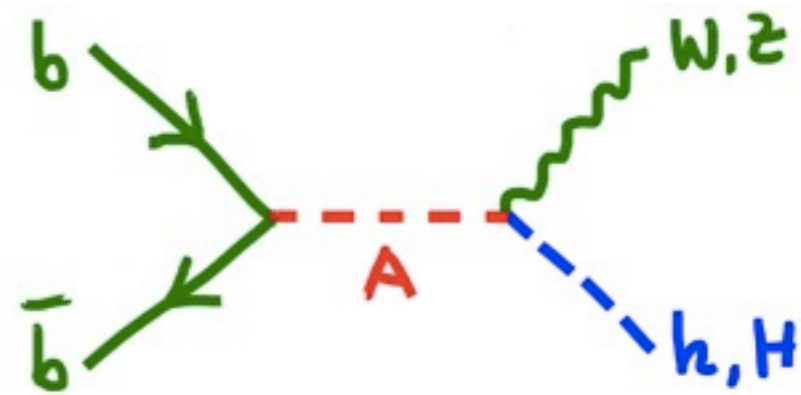
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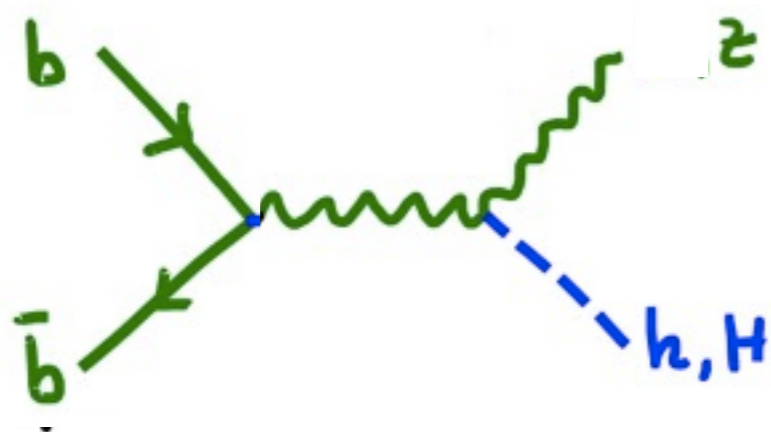
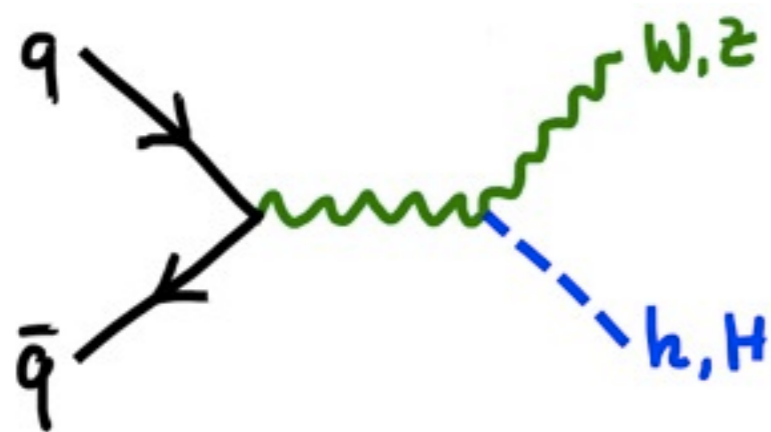


small, but:

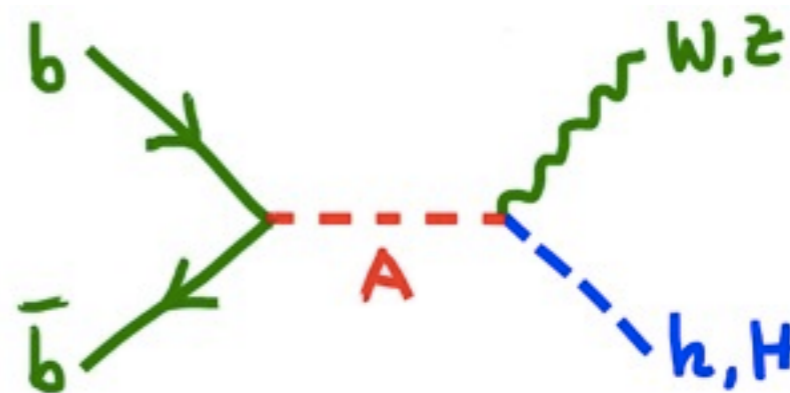


new s-channel contribution!

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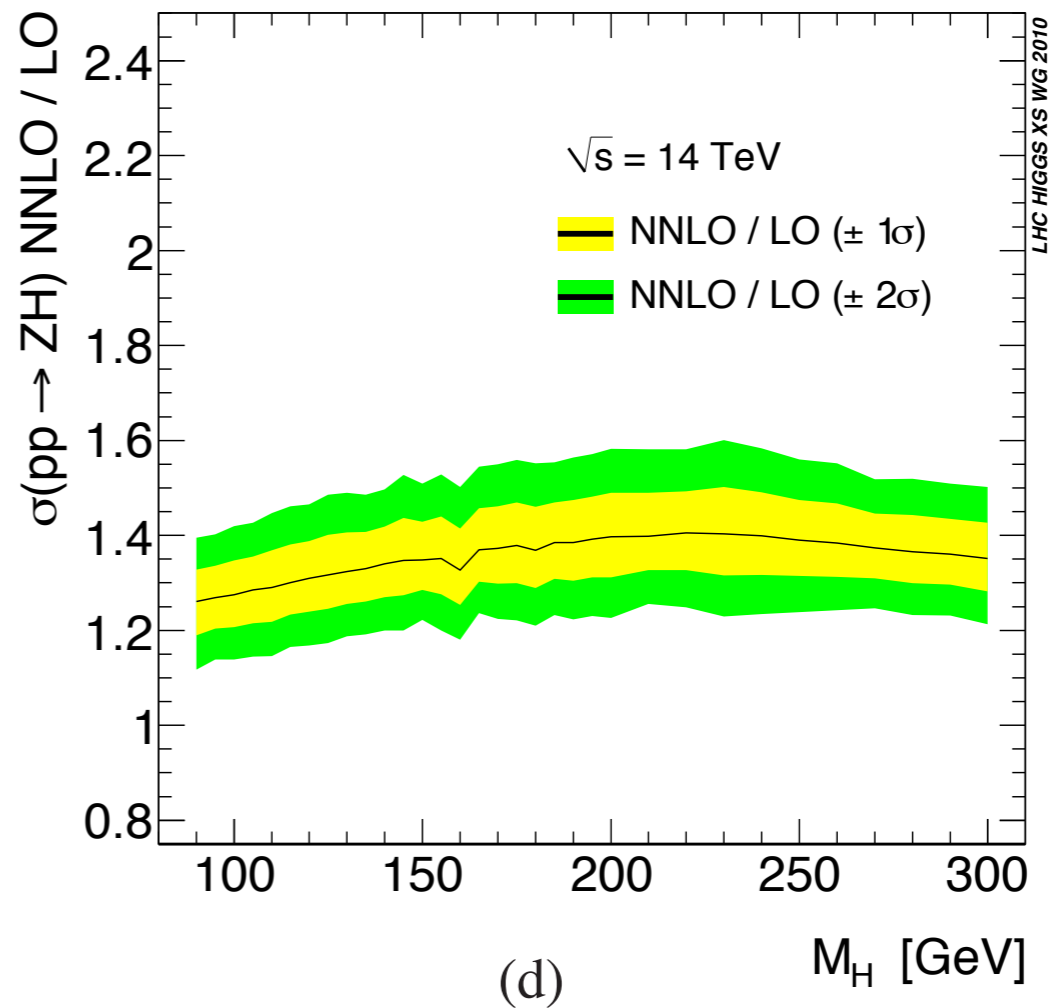
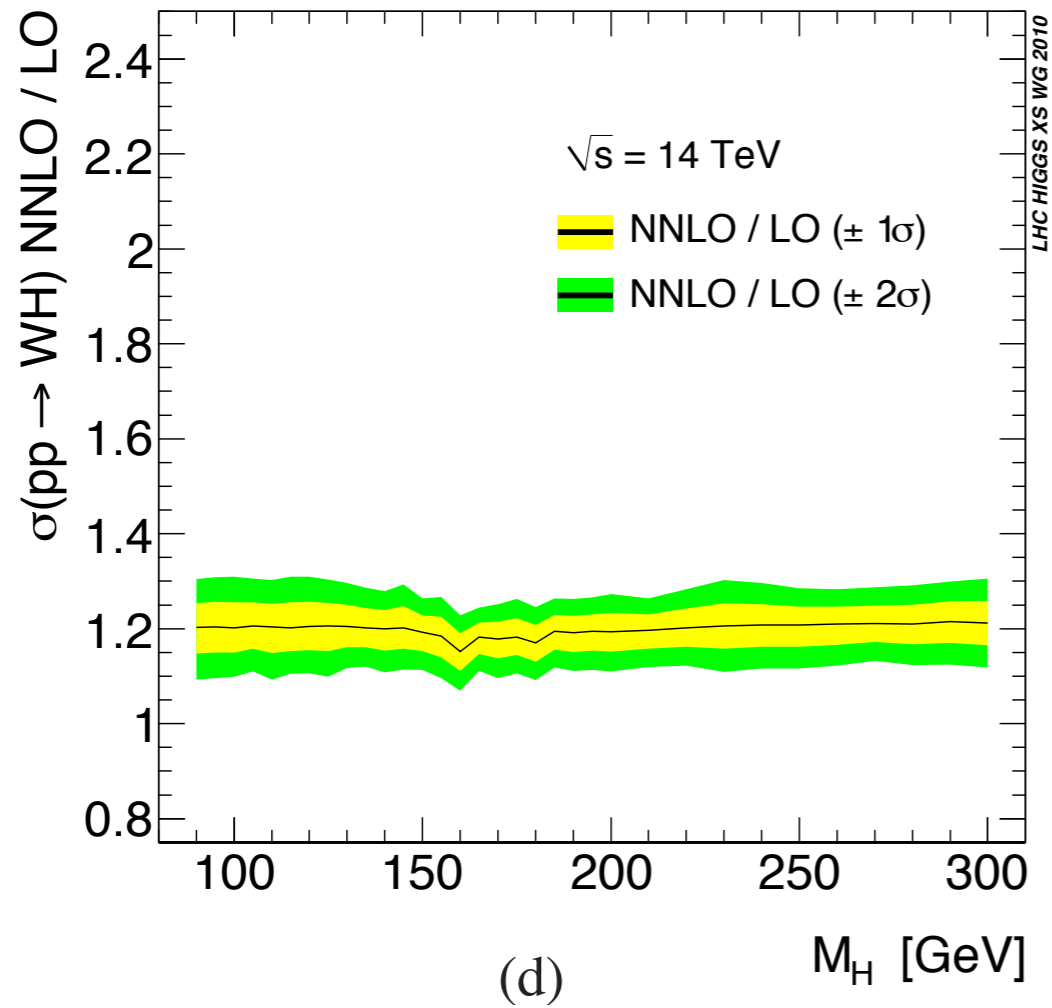
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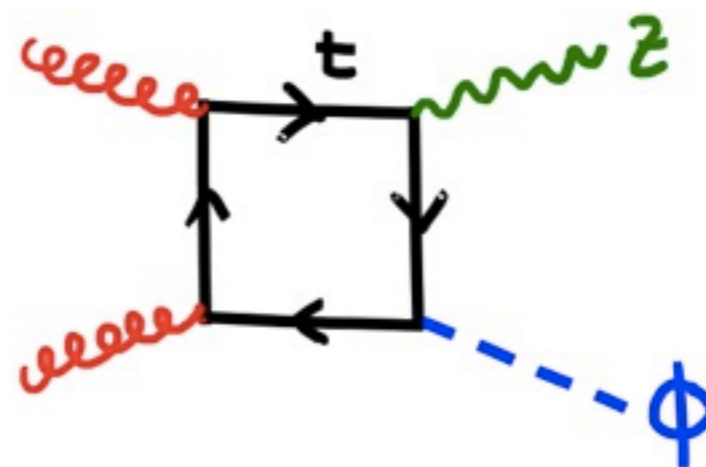
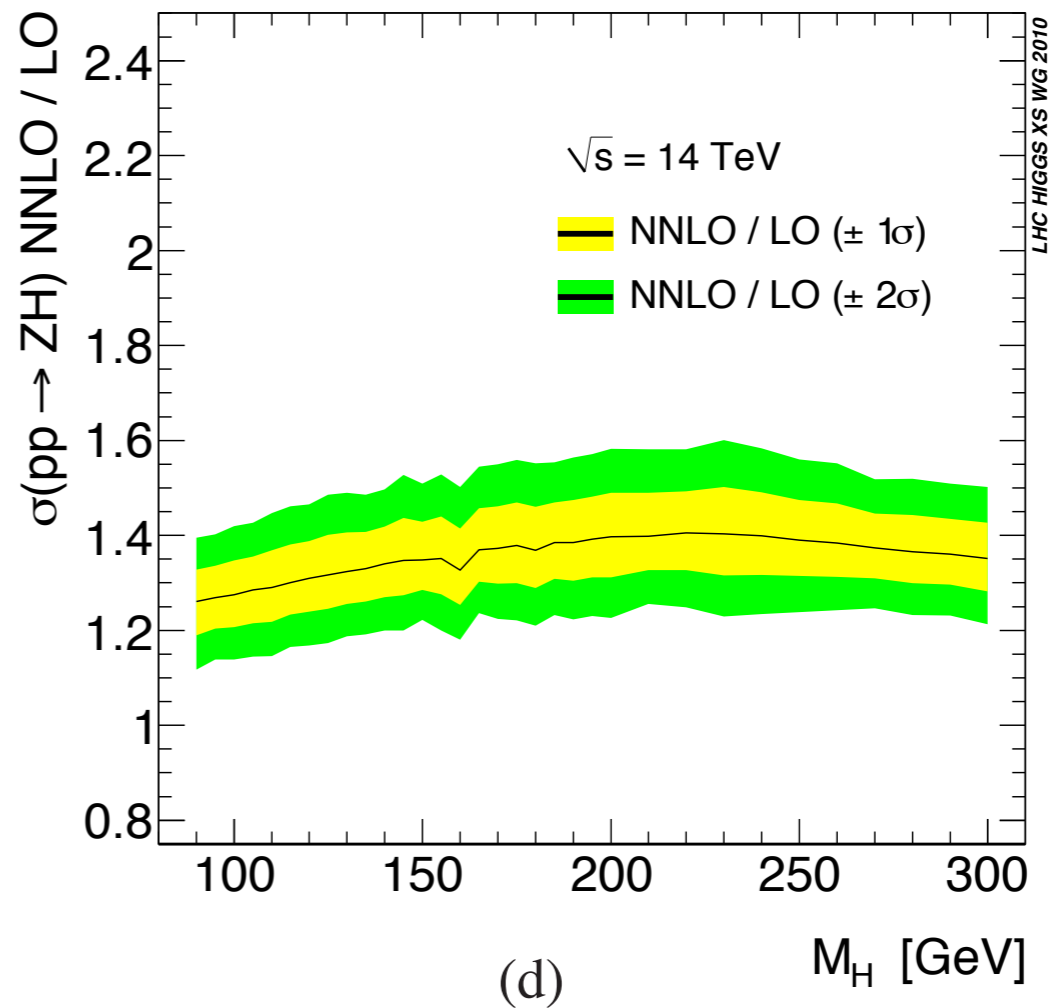
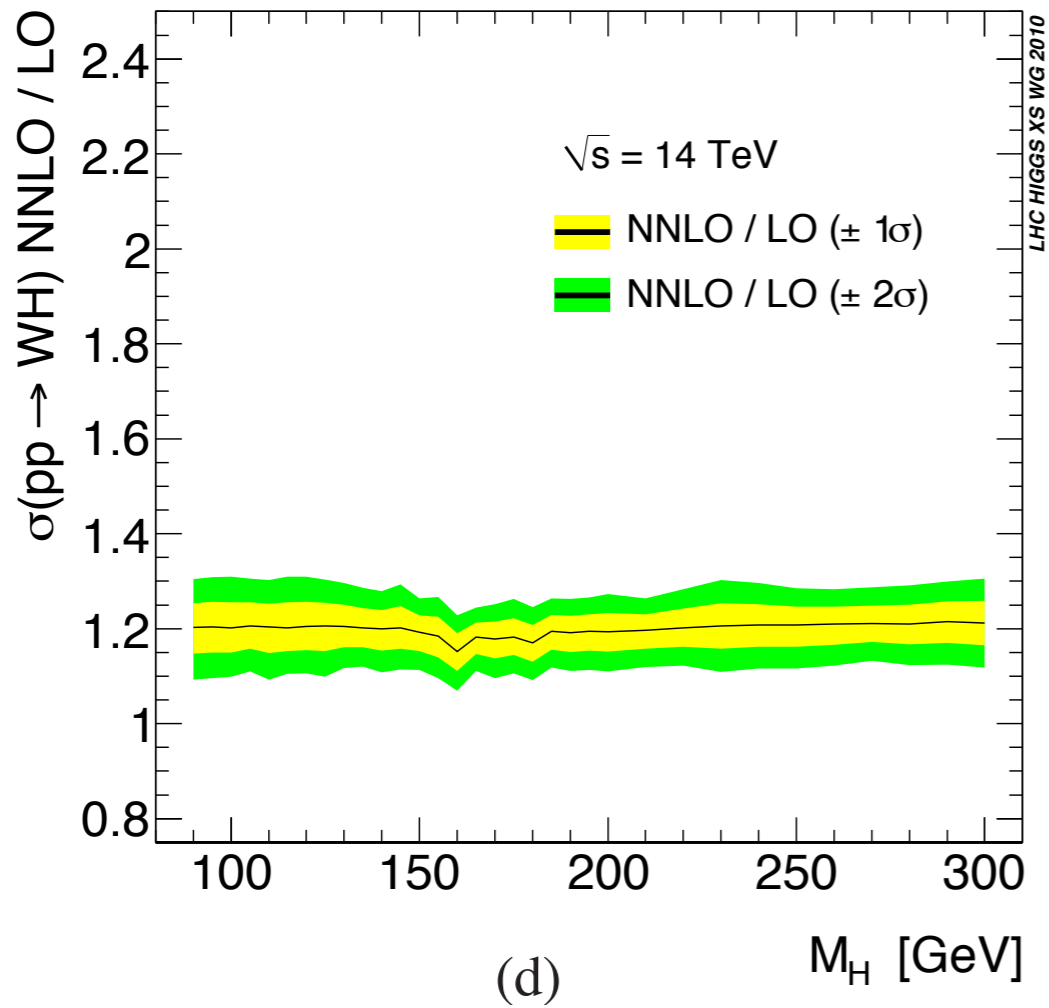
new s-channel contribution!

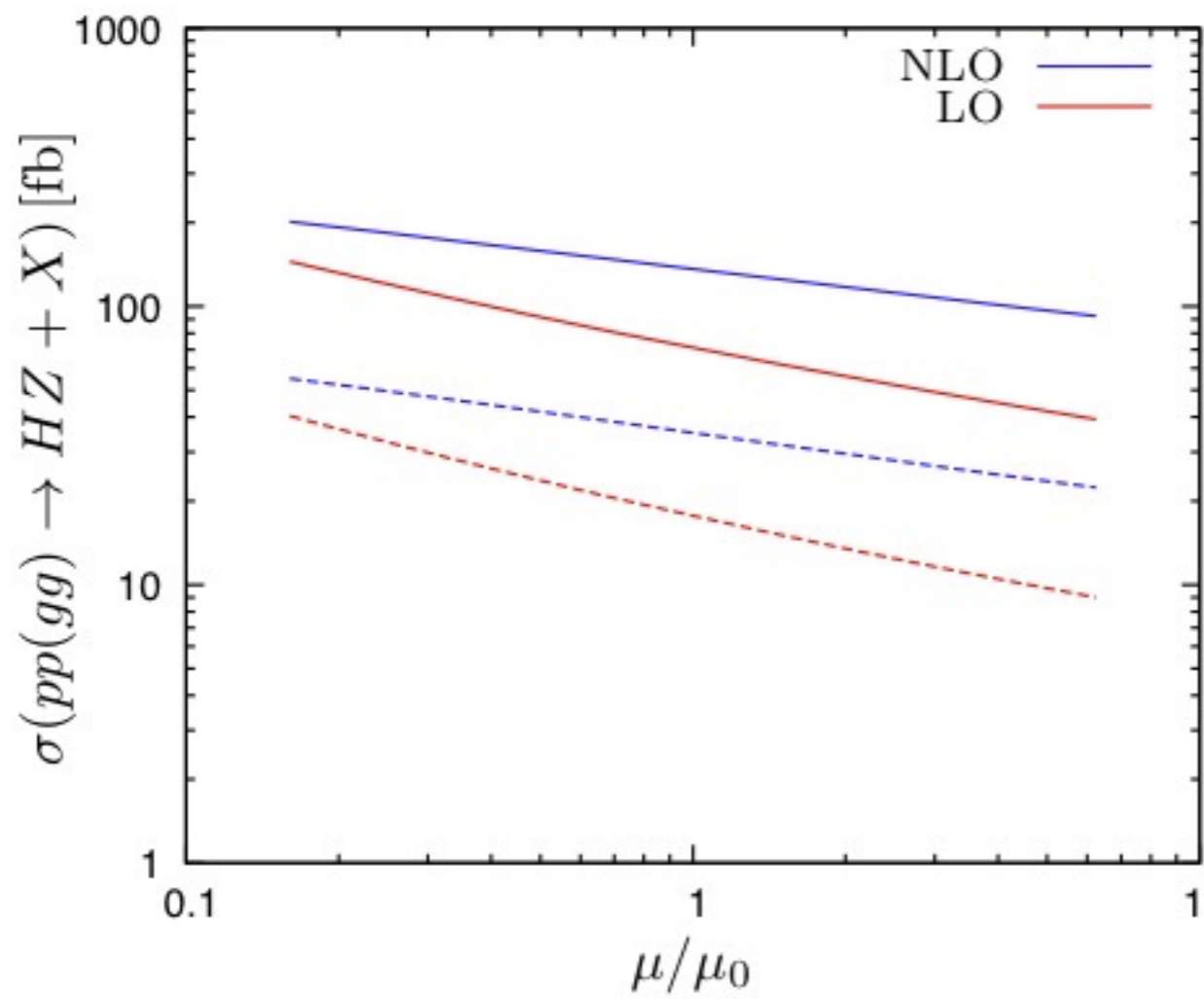
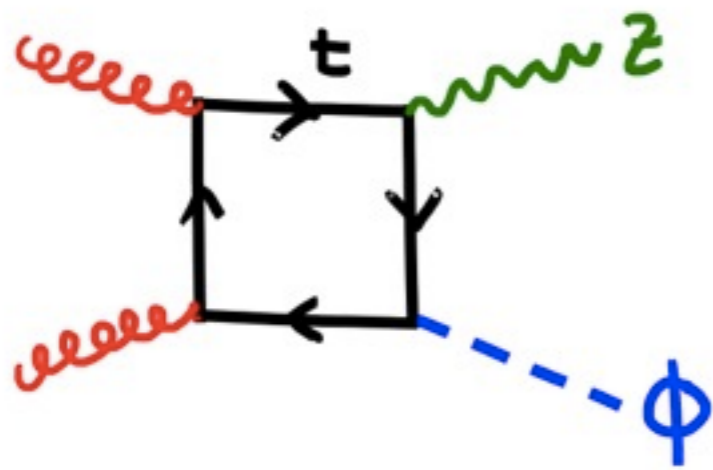
only for ZH, not WH!

WH vs. ZH in the SM:

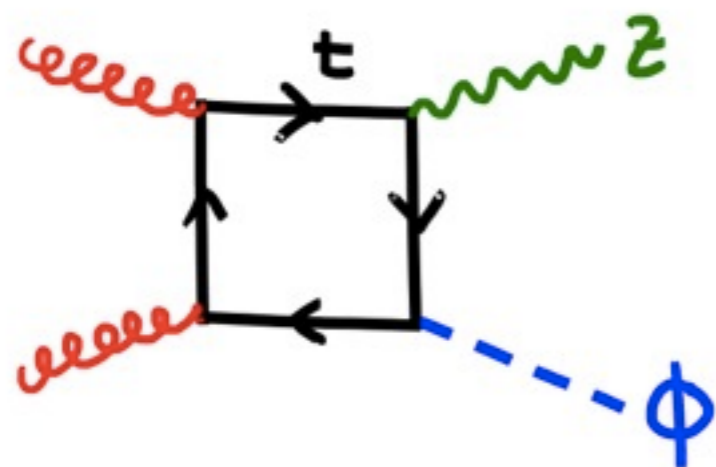


WH vs. ZH in the SM:

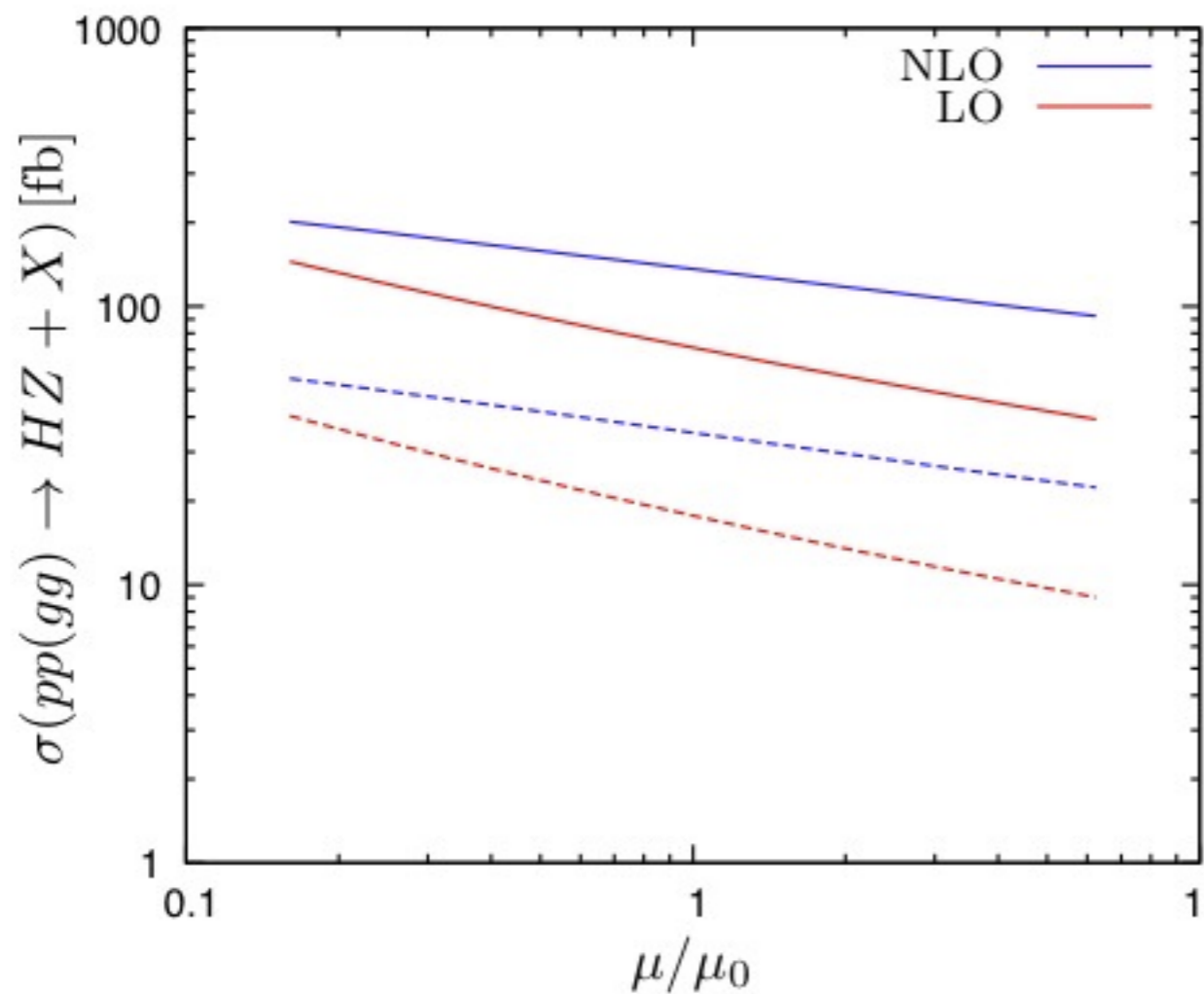




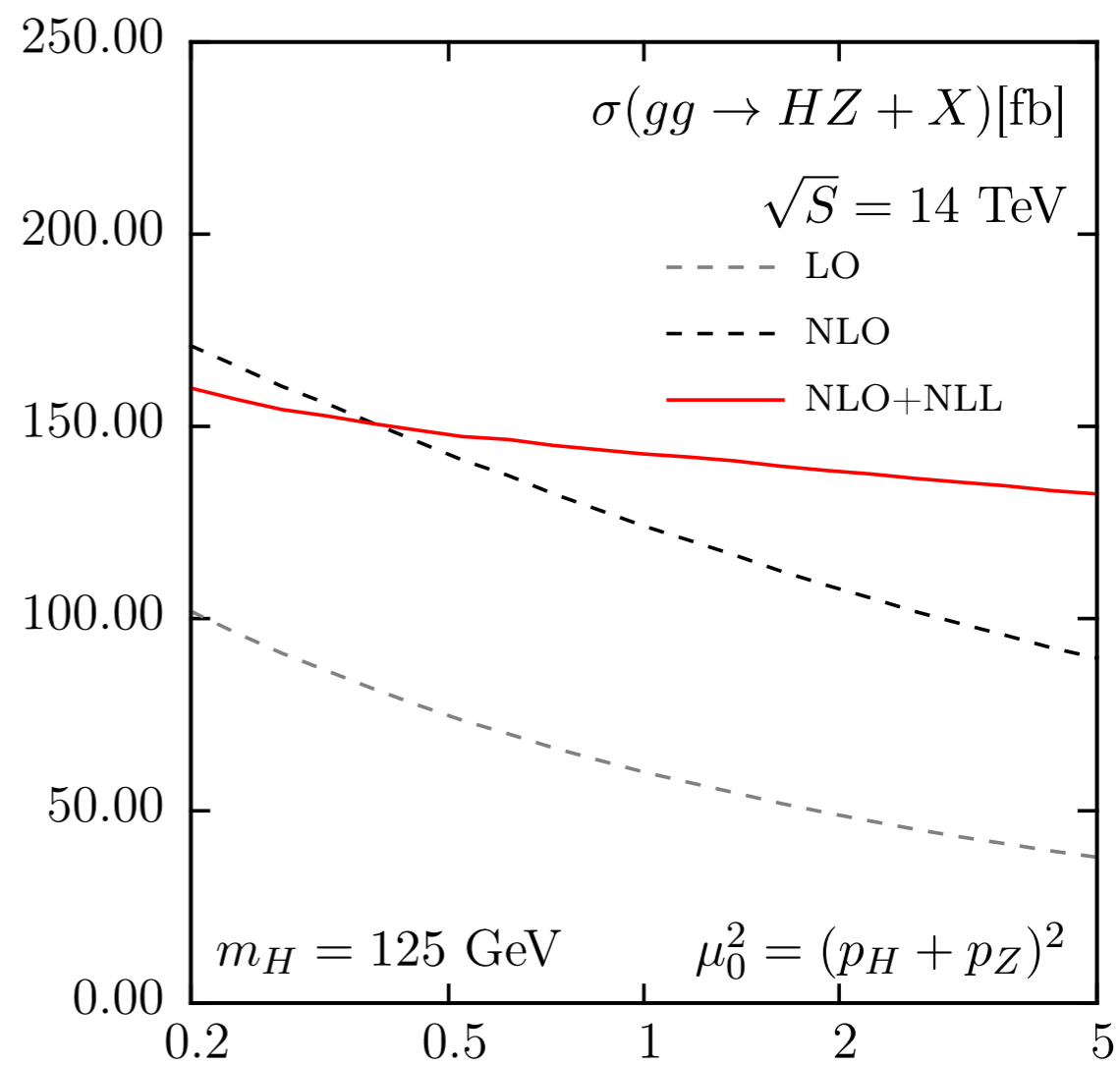
NLO: Altenkamp, Dittmaier, RH, Rzehak, Zirke '12



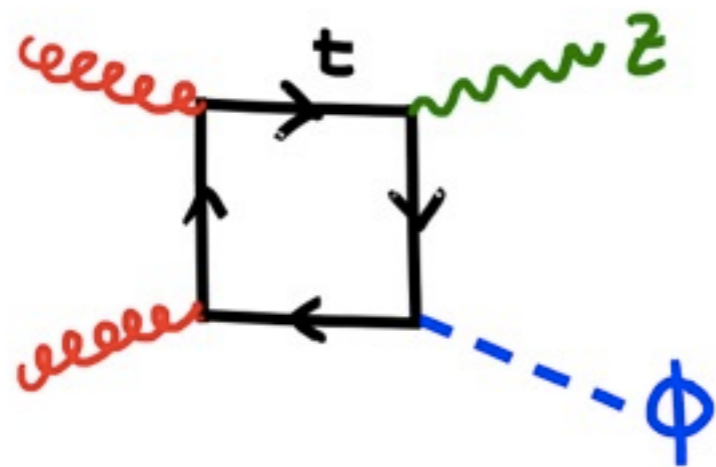
at NLO:



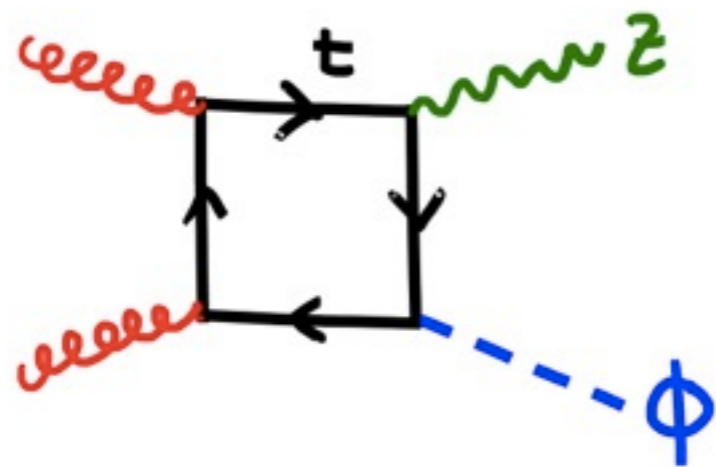
NLO: Altenkamp, Dittmaier, RH, Rzehak, Zirke '12



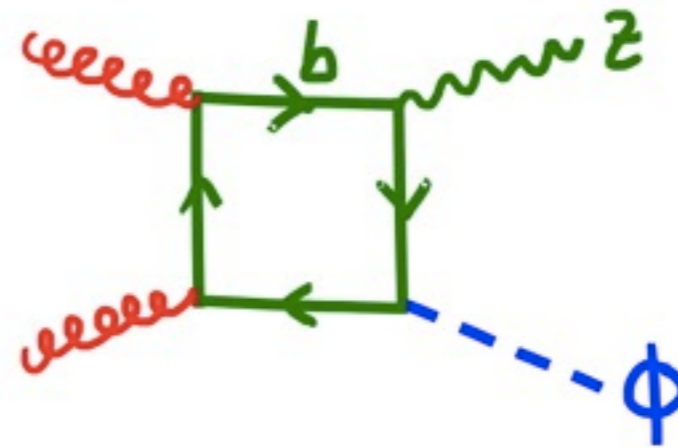
NLO+NLL:
RH, Kulesza, Theeuwes, Zirke '14



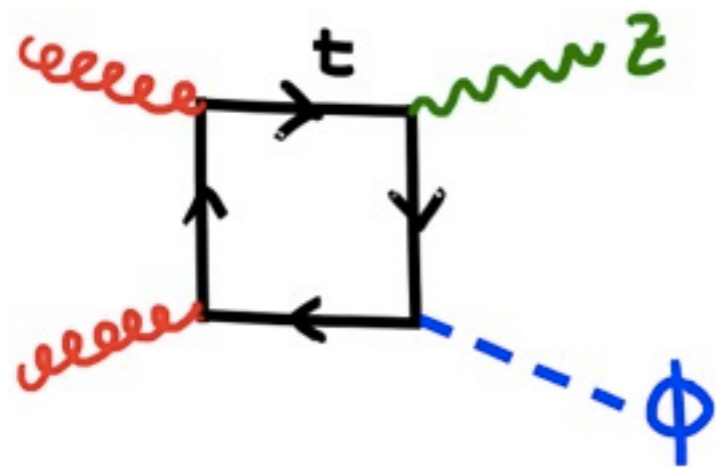
in SUSY?



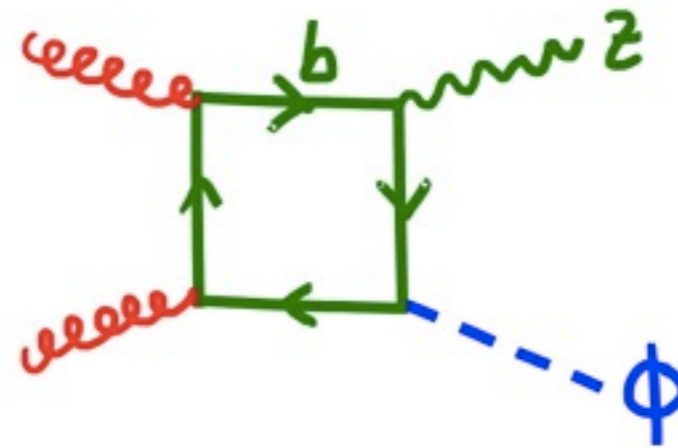
in SUSY?



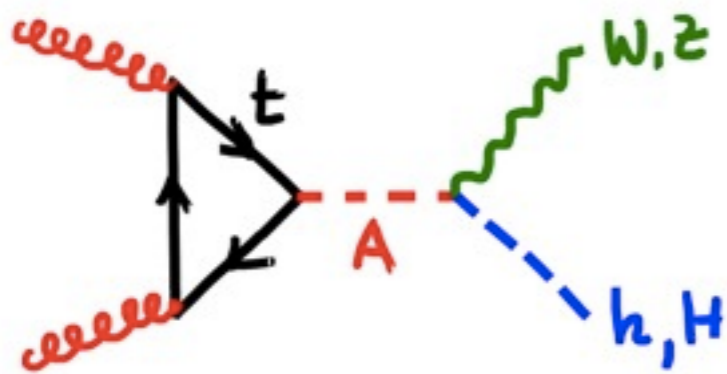
enhancement
by $\tan\beta$

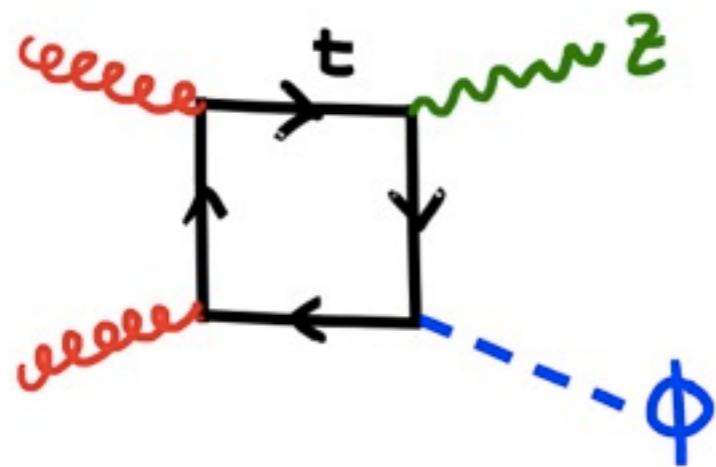


in SUSY?

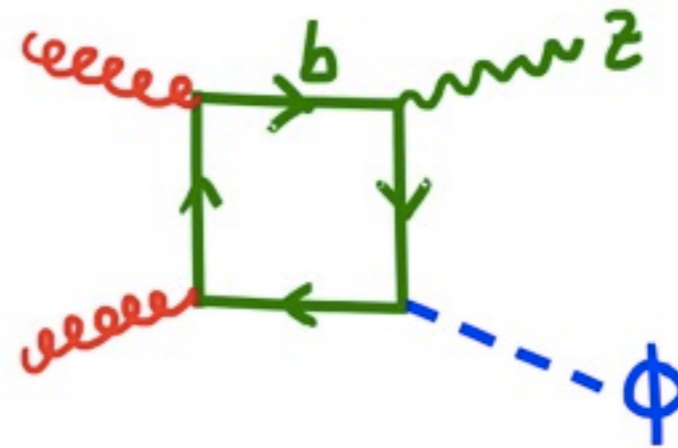


enhancement
by $\tan\beta$

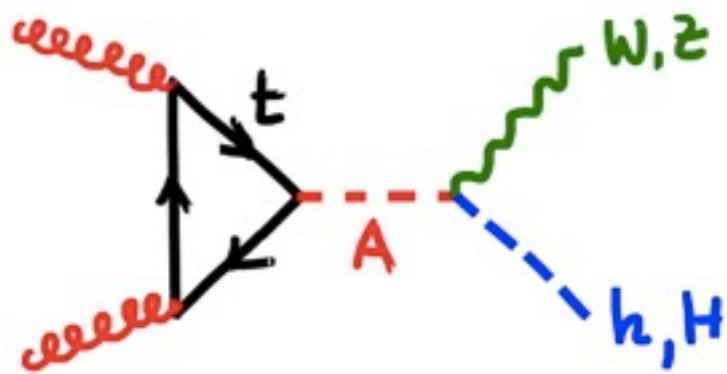




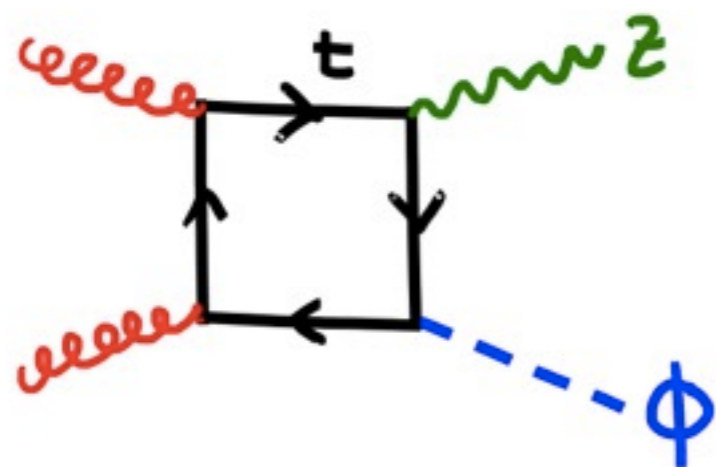
in SUSY?



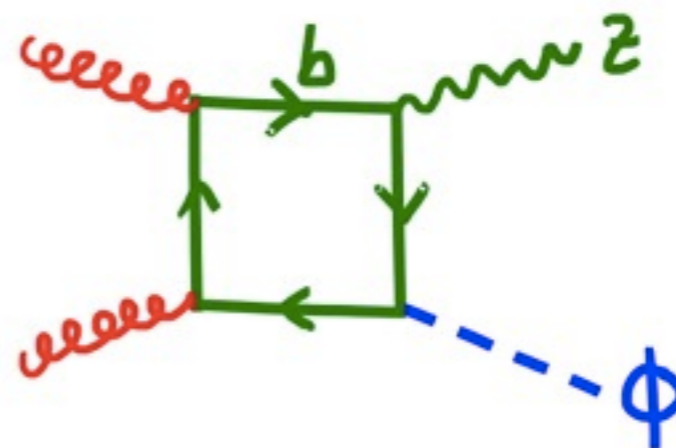
enhancement
by $\tan\beta$



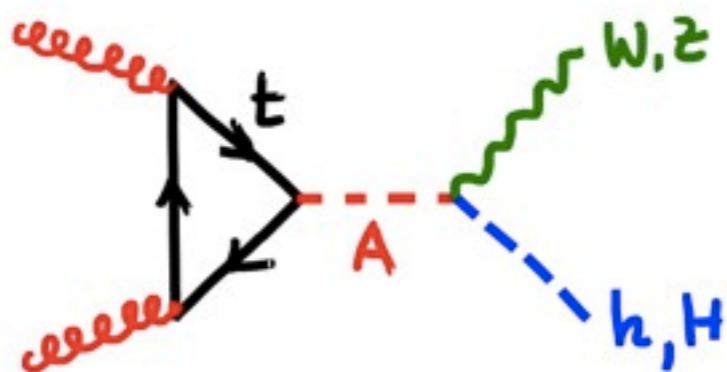
Squarks?



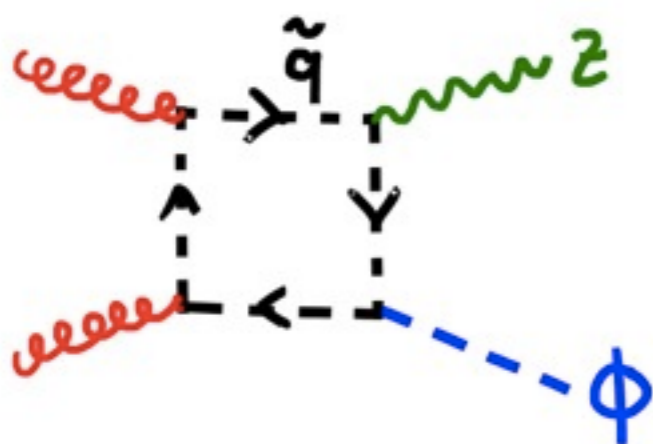
in SUSY?



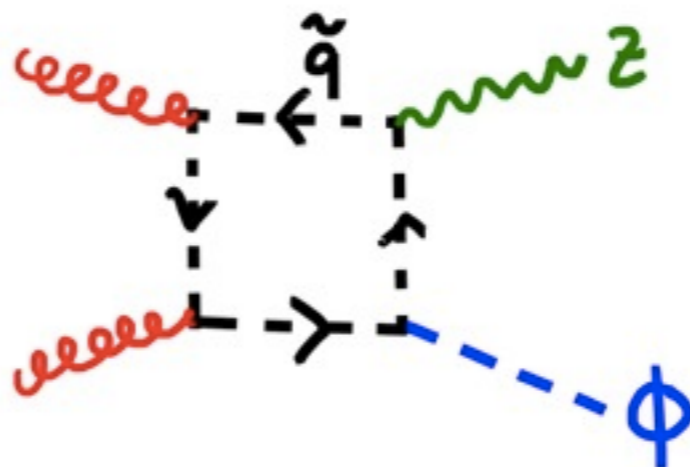
enhancement
by $\tan\beta$



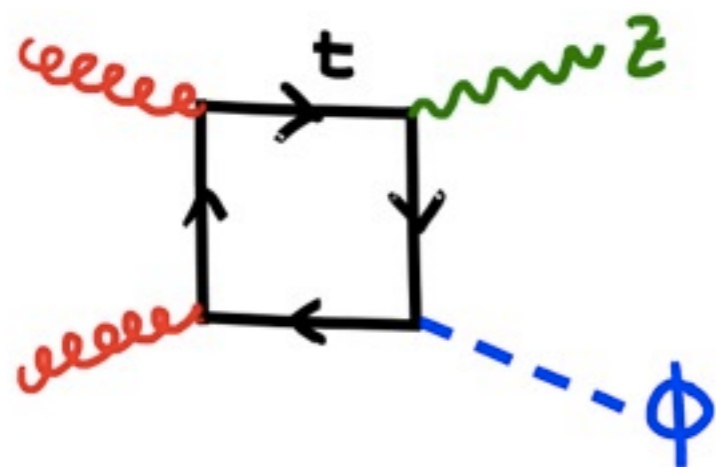
Squarks?



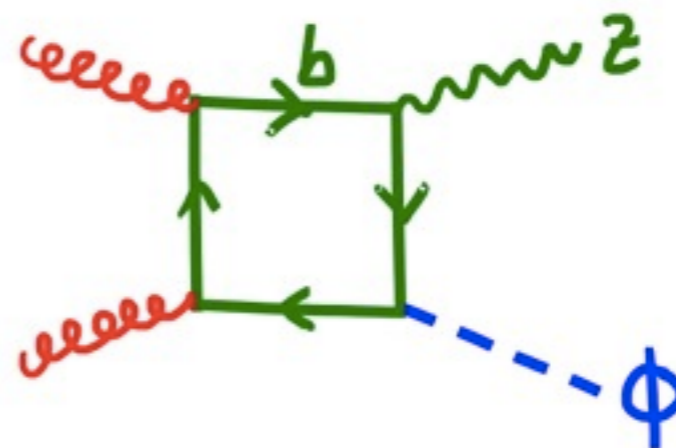
+



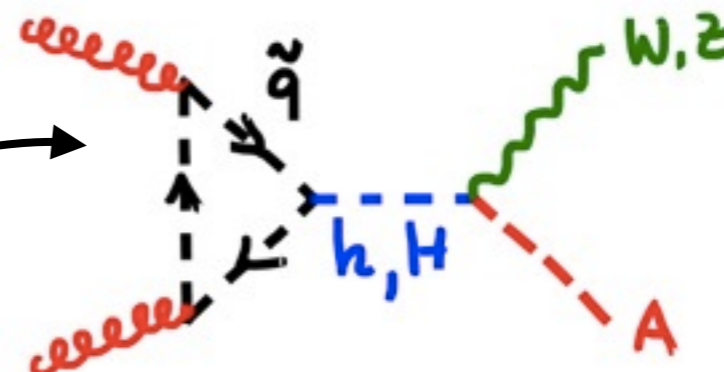
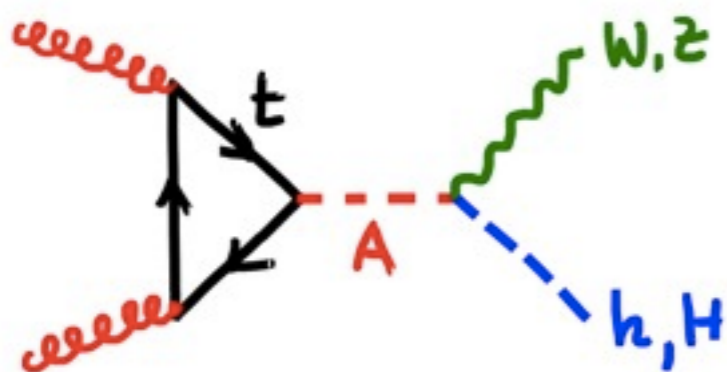
= 0



in SUSY?

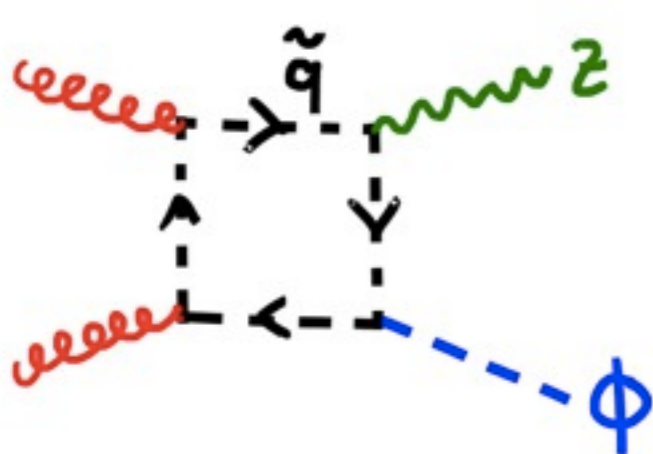


enhancement
by $\tan\beta$

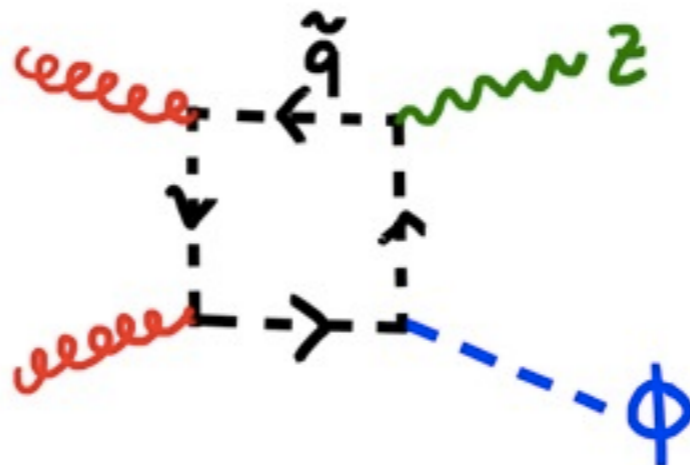


only

Squarks?



+



= 0

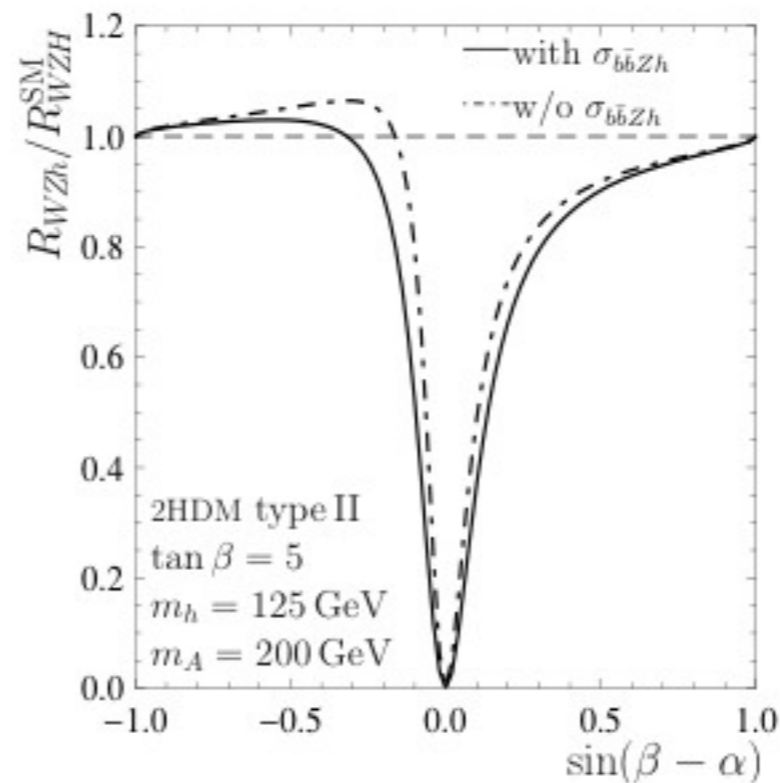
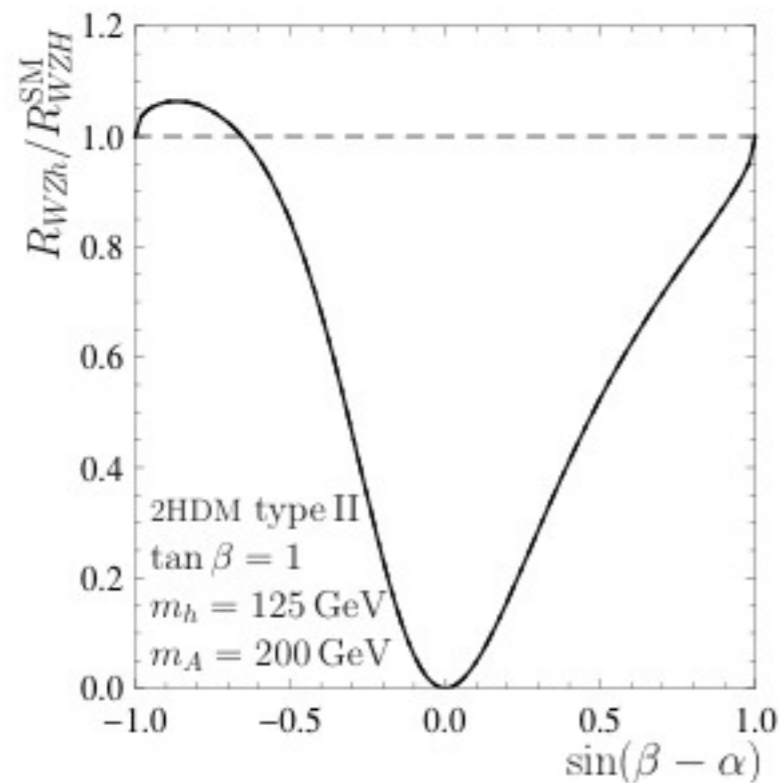
consider ratio: σ_{WH}/σ_{ZH}

consider ratio: σ_{WH}/σ_{ZH}

- very weak dependence on PDFs
- very weak dependence on α_s
- reduced experimental uncertainties

consider ratio: σ_{WH}/σ_{ZH}

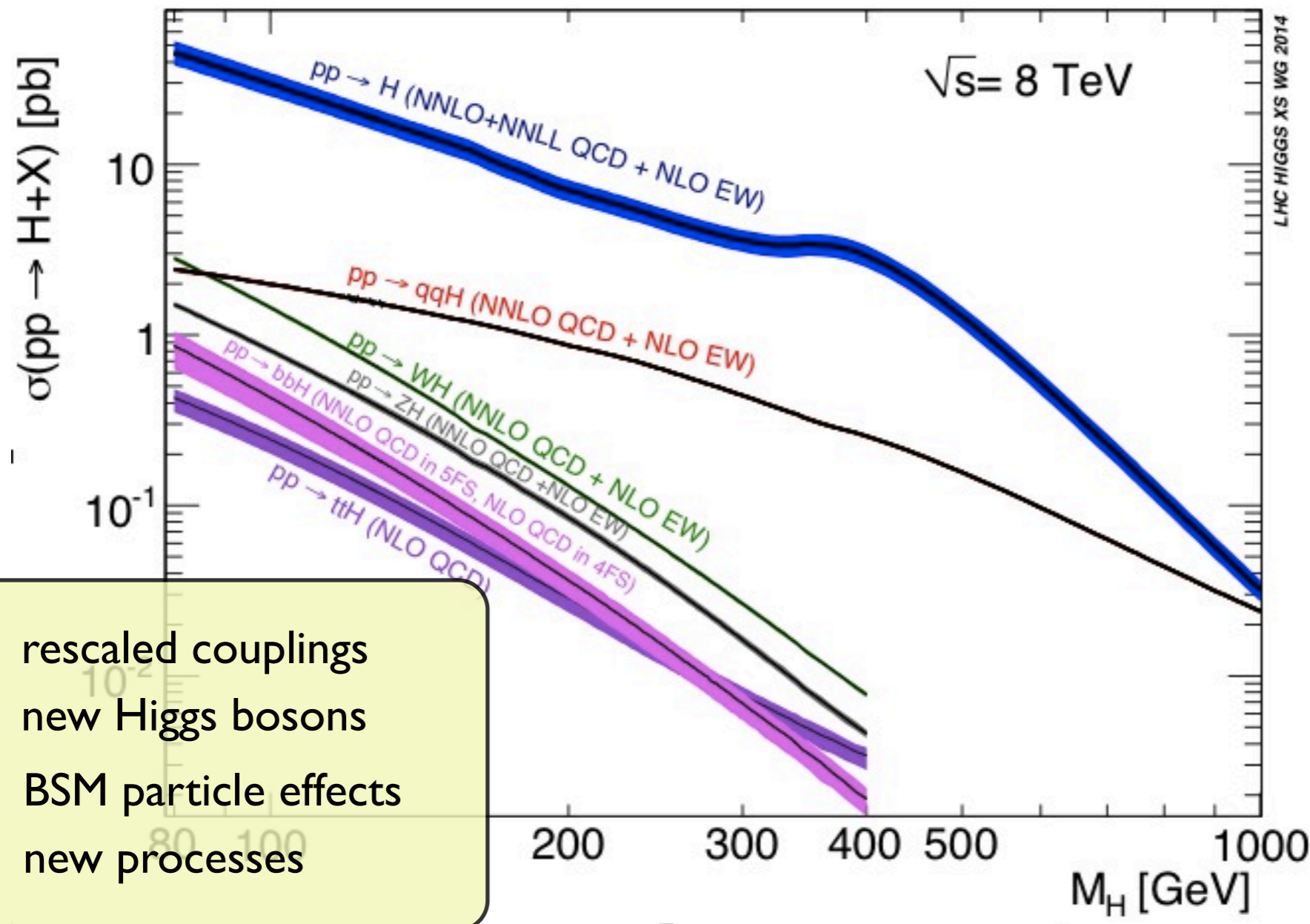
- very weak dependence on PDFs
- very weak dependence on α_s
- reduced experimental uncertainties



2HDM

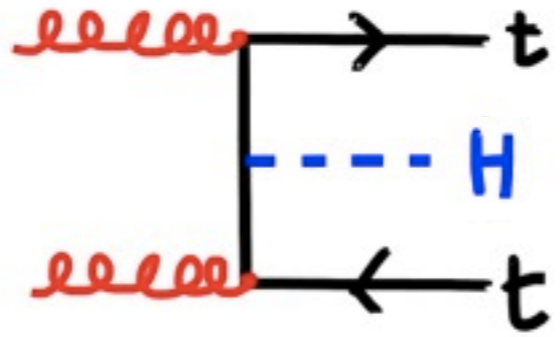
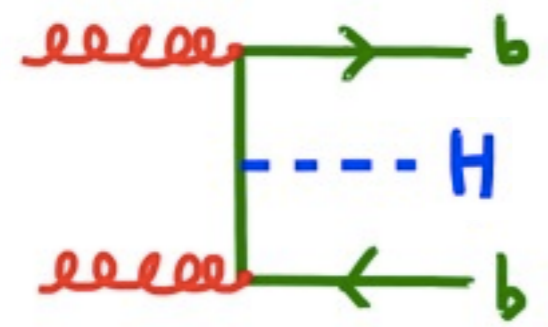
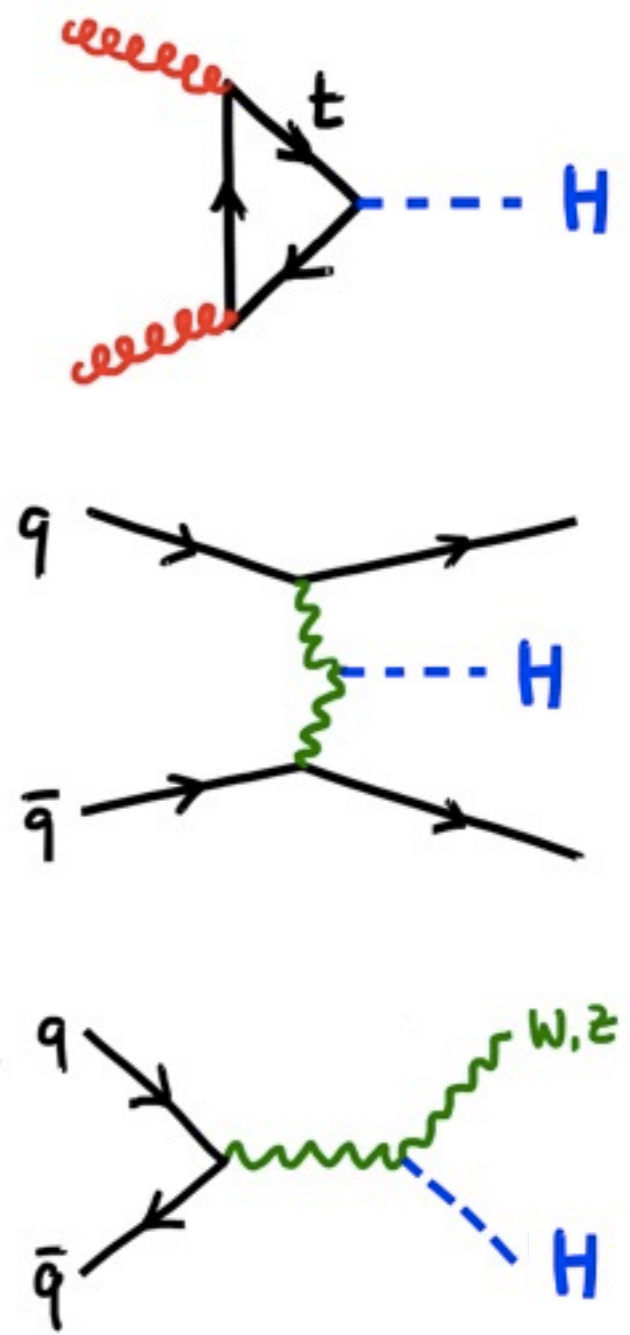
RH, Liebler, Zirke '13

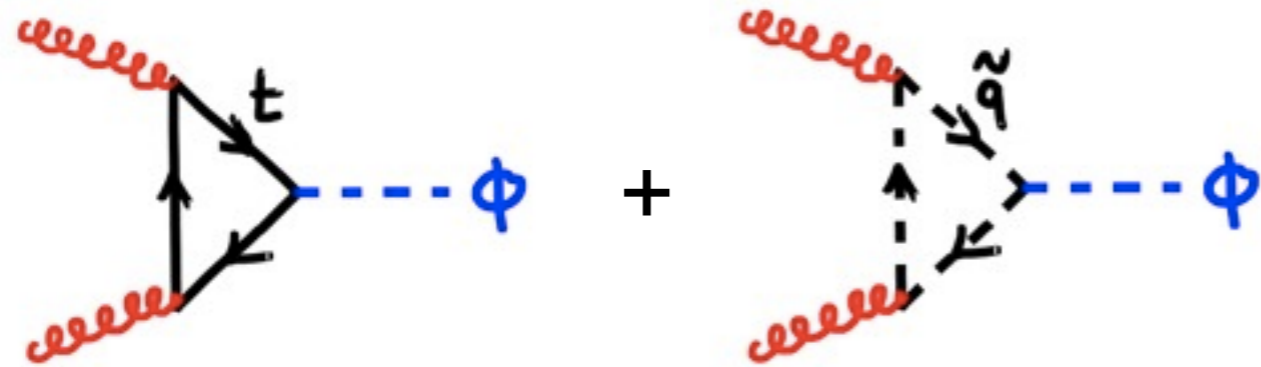
see also: Englert, McCullough, Spannowsky '13

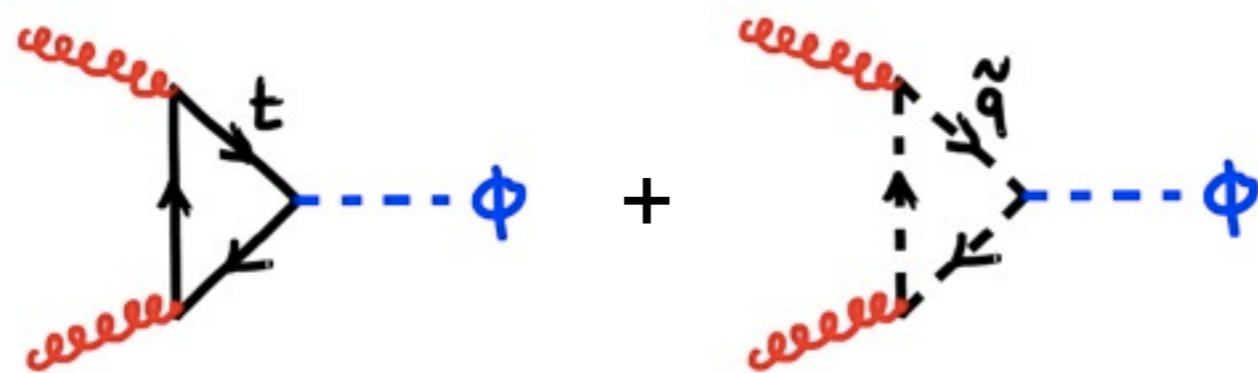


LHC HIGGS XS WG 2014

rescaled couplings
 new Higgs bosons
 BSM particle effects
 new processes








can interfere destructively (gluophobic Higgs)

Djouadi '98

- [SusHi](#)
- [Changelog](#)
- [Manual](#)
- [Examples](#)
- [Contact](#)
- [Download](#)
- [MoRe-SusHi](#)



Download

 [Follow @sushi4physics](#)

Version 1.4.1 (05.11.2014) is available here: [Download Manual for Version 1.4.1](#)

After providing the corresponding links in the Makefile, we recommend for fans of the MSSM:

to link SusHi to [FeynHiggs \(FH\)](#) by `./configure; make predef=FH`!

to link SusHi to [HiggsBounds/HiggsSignals+FH](#) by `./configure; make predef=HB` or `HS`!

fans of the 2HDM:

to link SusHi to [2HDMC](#) by `./configure; make predef=2HDMC`!

More features/add-ons to SusHi:

- **New code MoRe-SusHi for analytically resummed transverse momentum distributions!**

[https://github.com/mreiter/SusHi](#)

- SusHi
- Changelog
- Manual
- Examples
- Contact
- Download
- MoRe-SusHi



Download

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Version 1.4.1 (05.11)
 Manual for Version 1.4.1
 After providing the c
fans of the MSSM:
 to link SusHi to FeynHiggs
 to link SusHi to Higgs
fans of the 2HDM:
 to link SusHi to 2HDMC

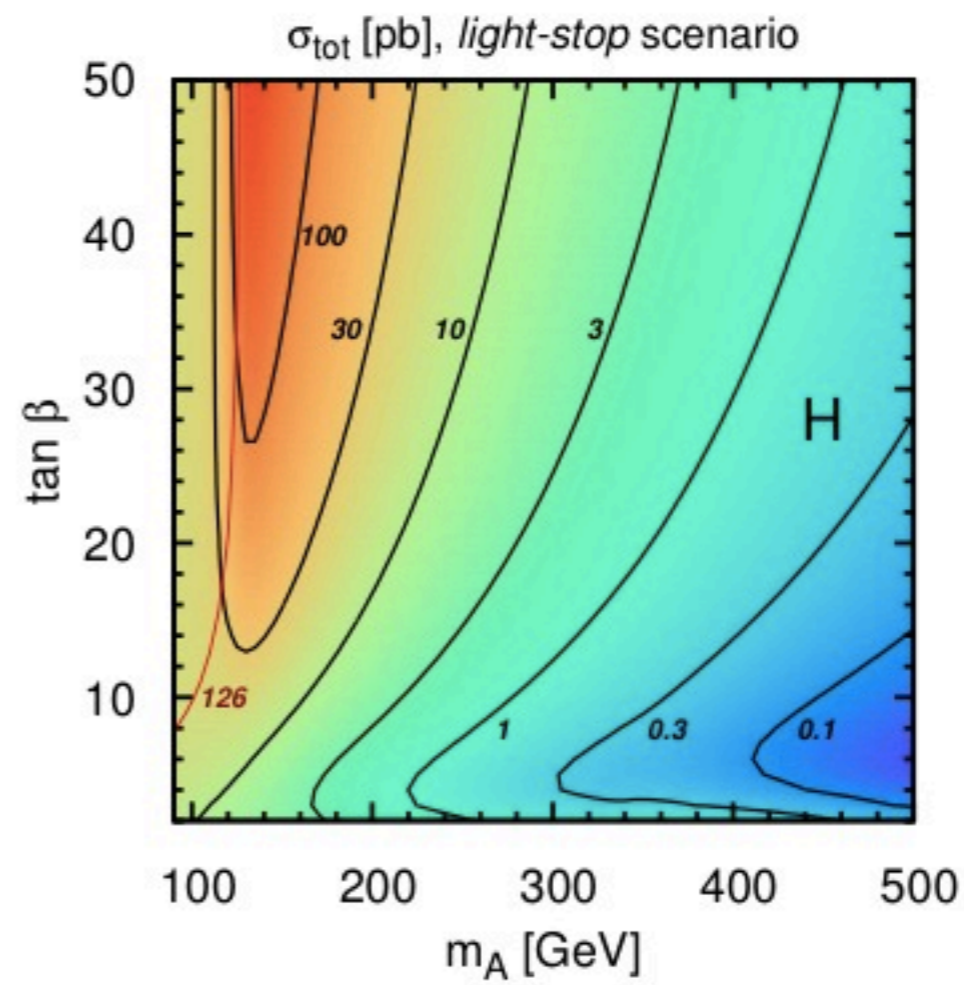
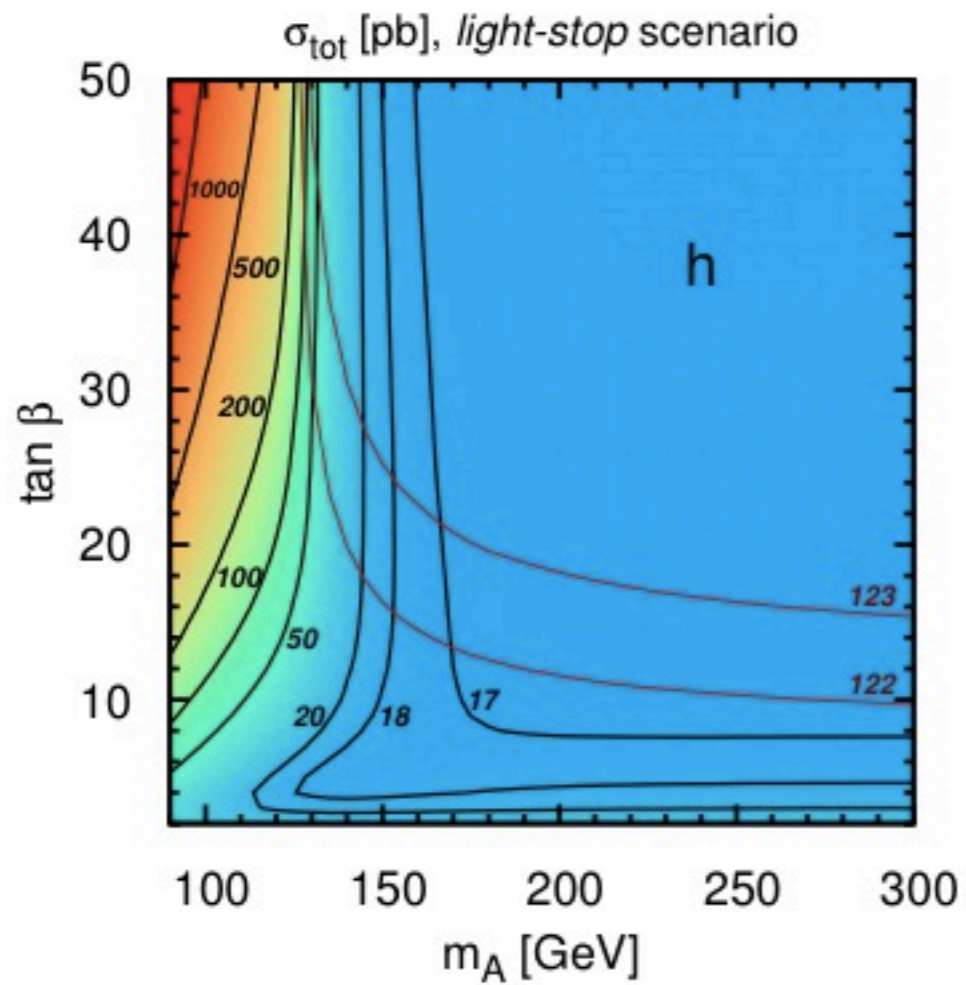
More features/add-on

- **New code MoRe**
transverse momentum distributions!

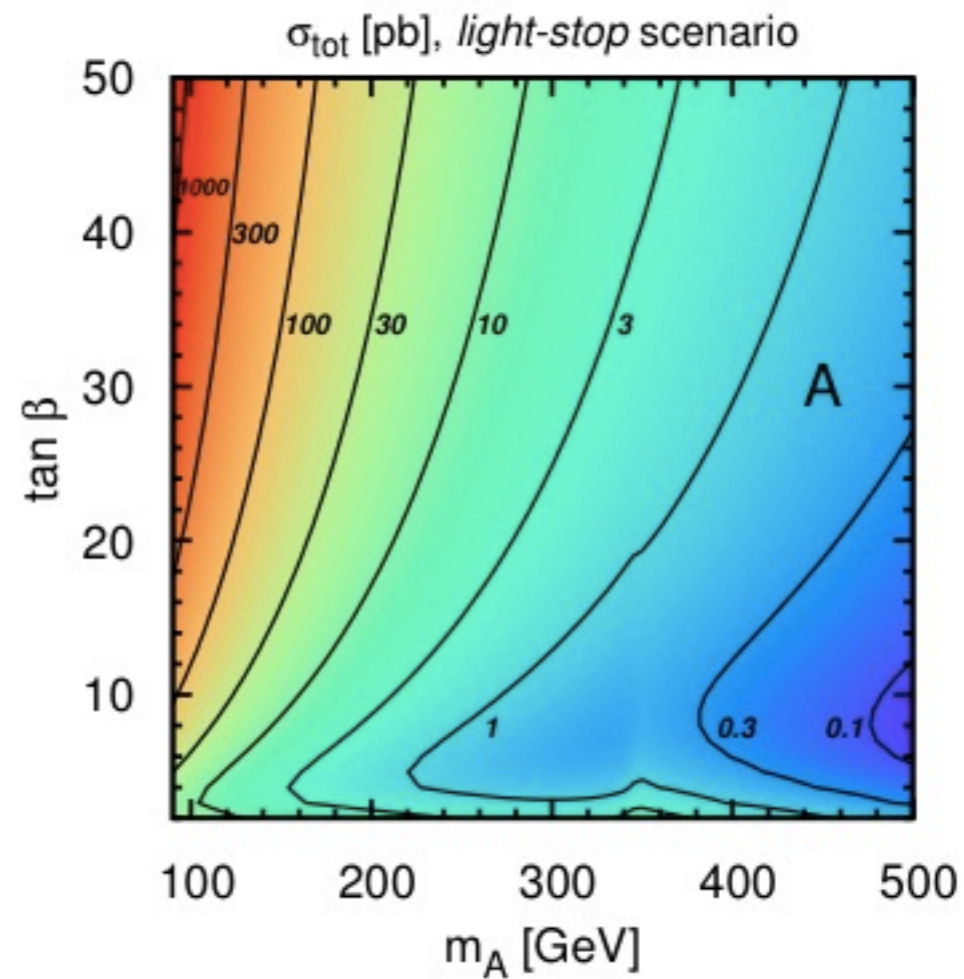
- full MSSM @ NLO
- SM @ NNLO
- 2HDM
- bbh
- various ren. schemes
- link to FeynHiggs
- link to LHAPDF
- link to 2HDMC
- ...

RH, Liebler, Mantler '12

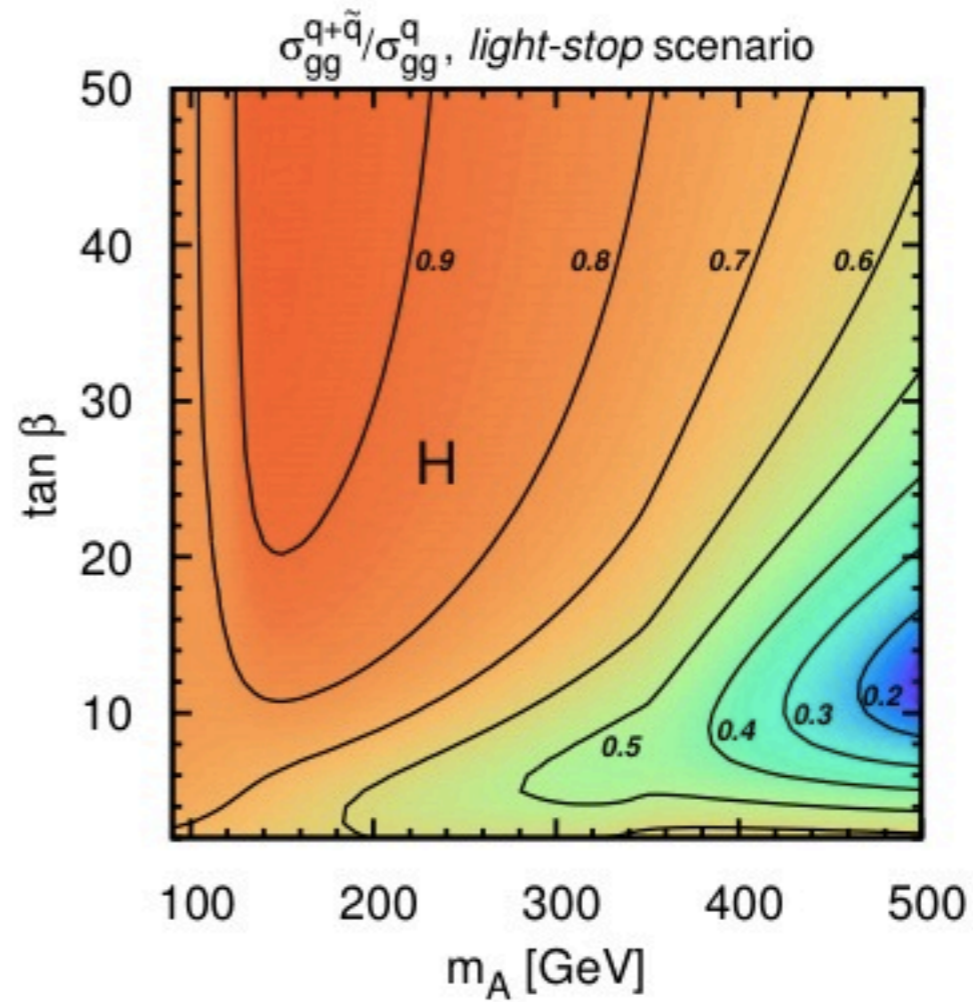
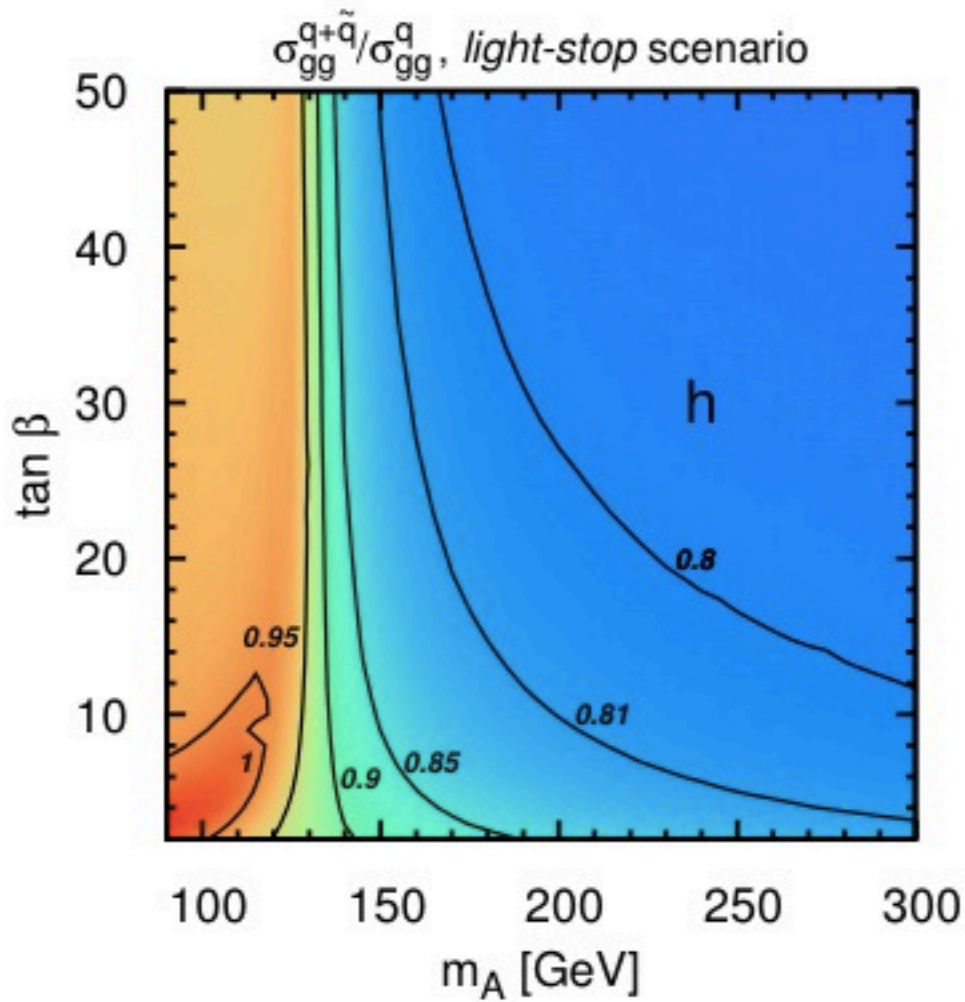
HB" or "HS"!



σ_{tot} [pb]

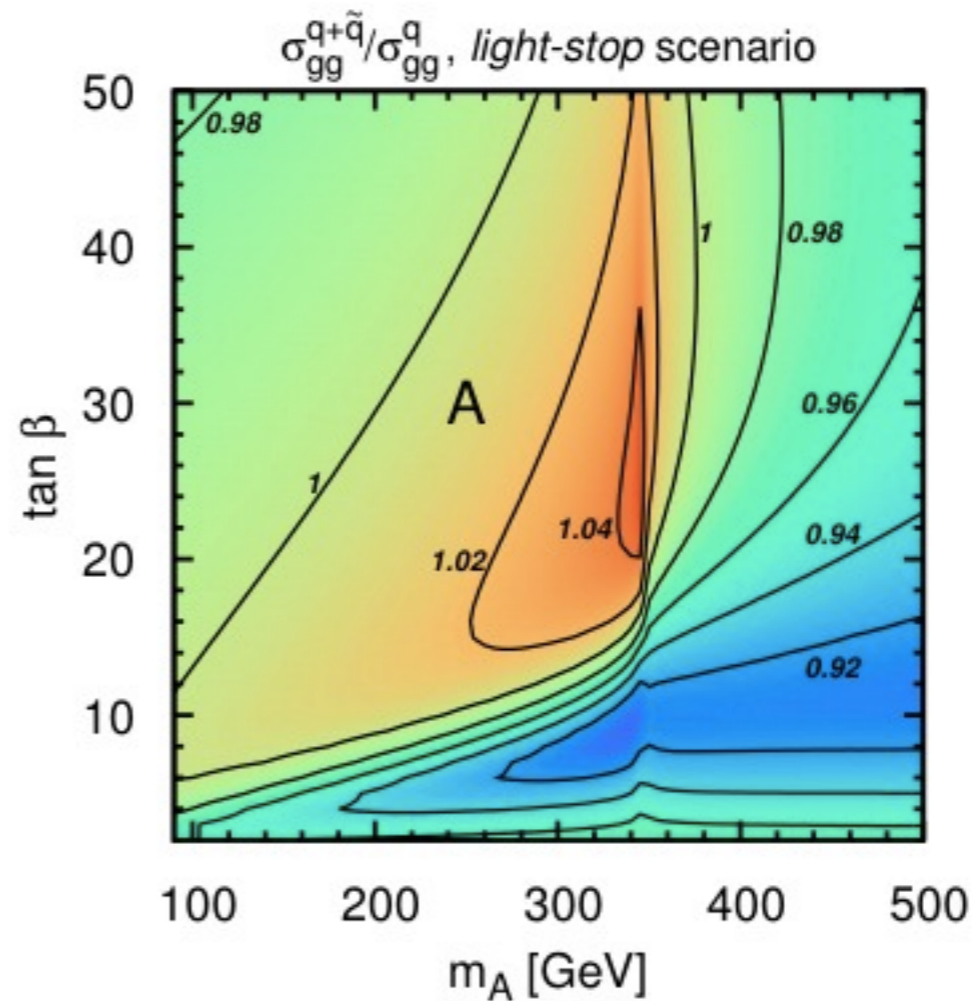


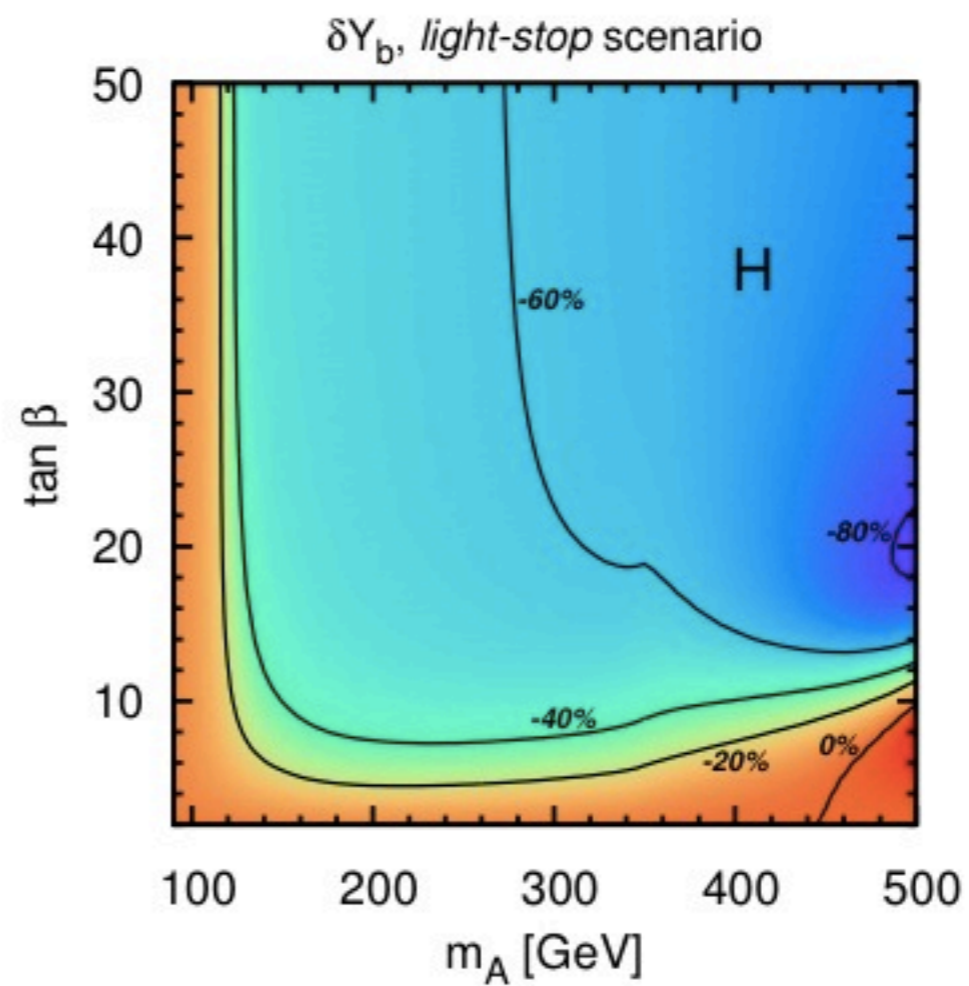
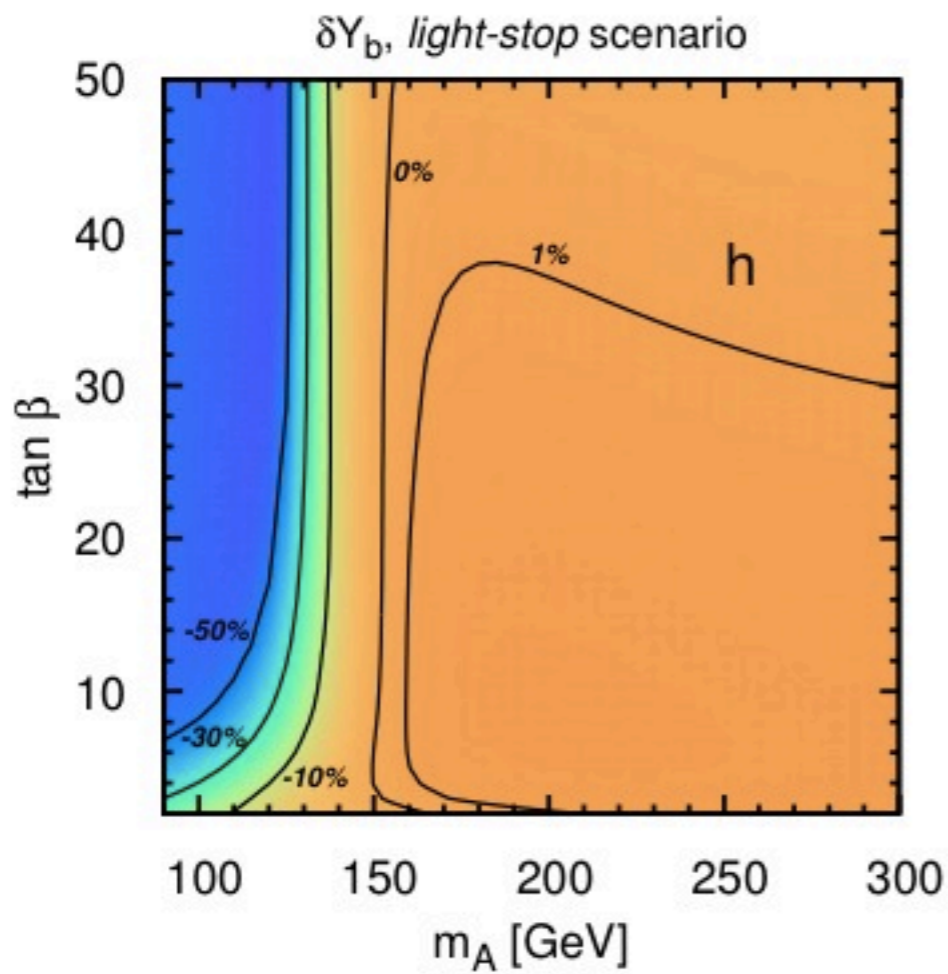
Bagnaschi, RH, Liebler, Mantler, Slavich, Vicini '14



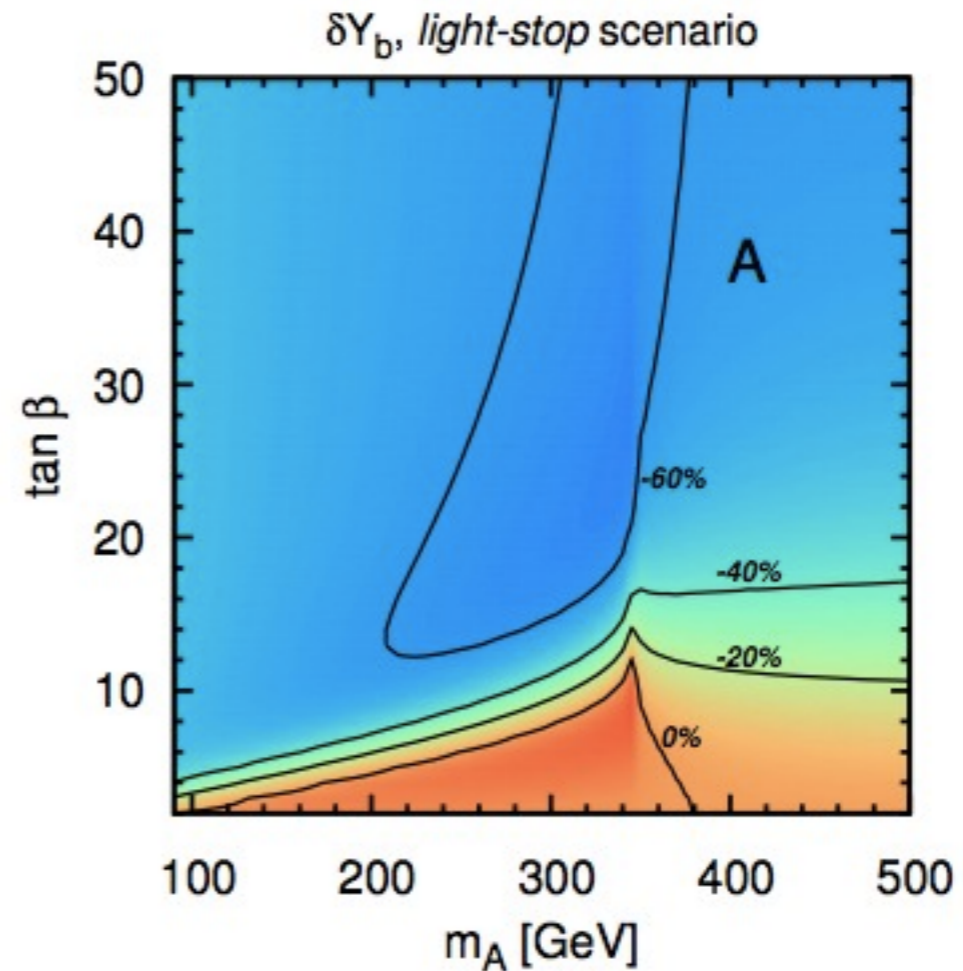
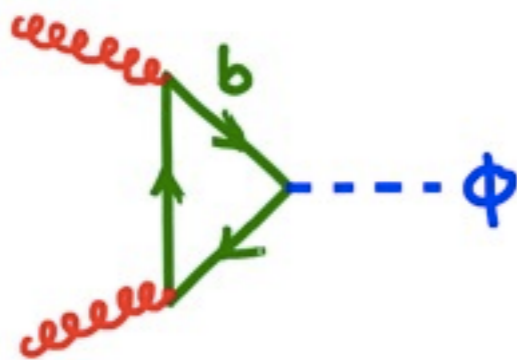
squark effects:

$$\sigma_{gg}^{q+\tilde{q}}/\sigma_{gg}^q$$

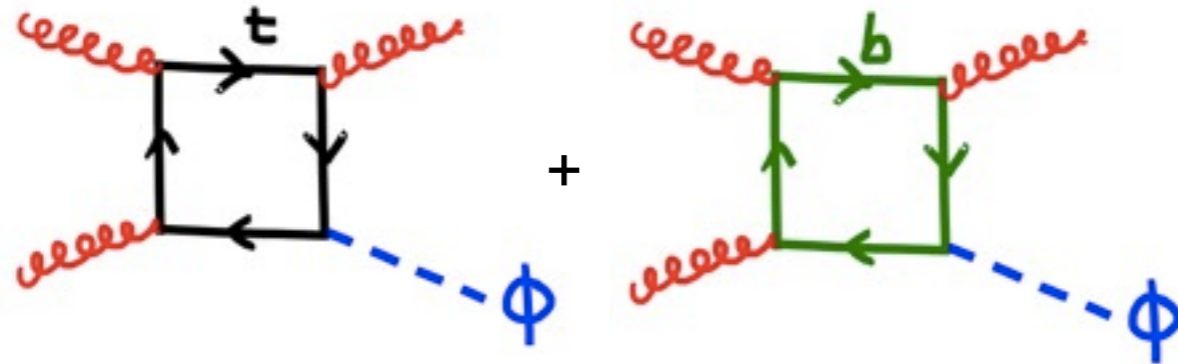




$m_b(M_H/2)$ vs. $m_b(\text{pole})$
in Yukawa coupling

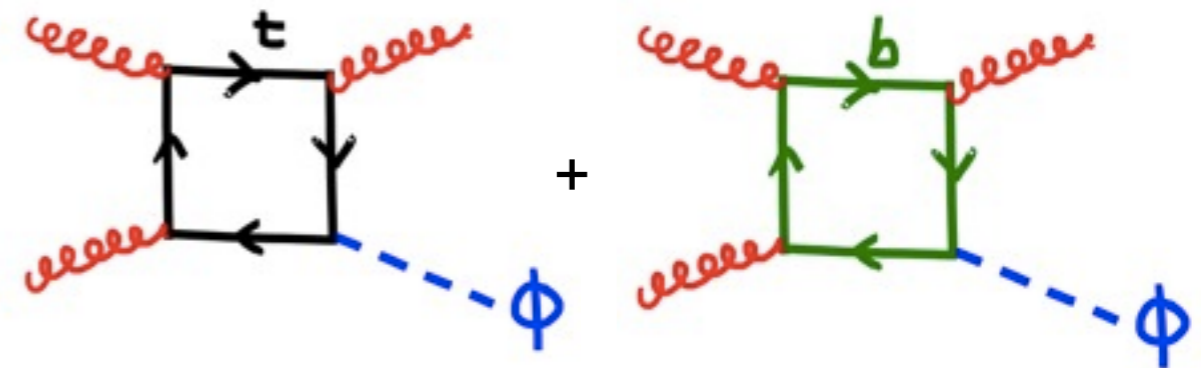
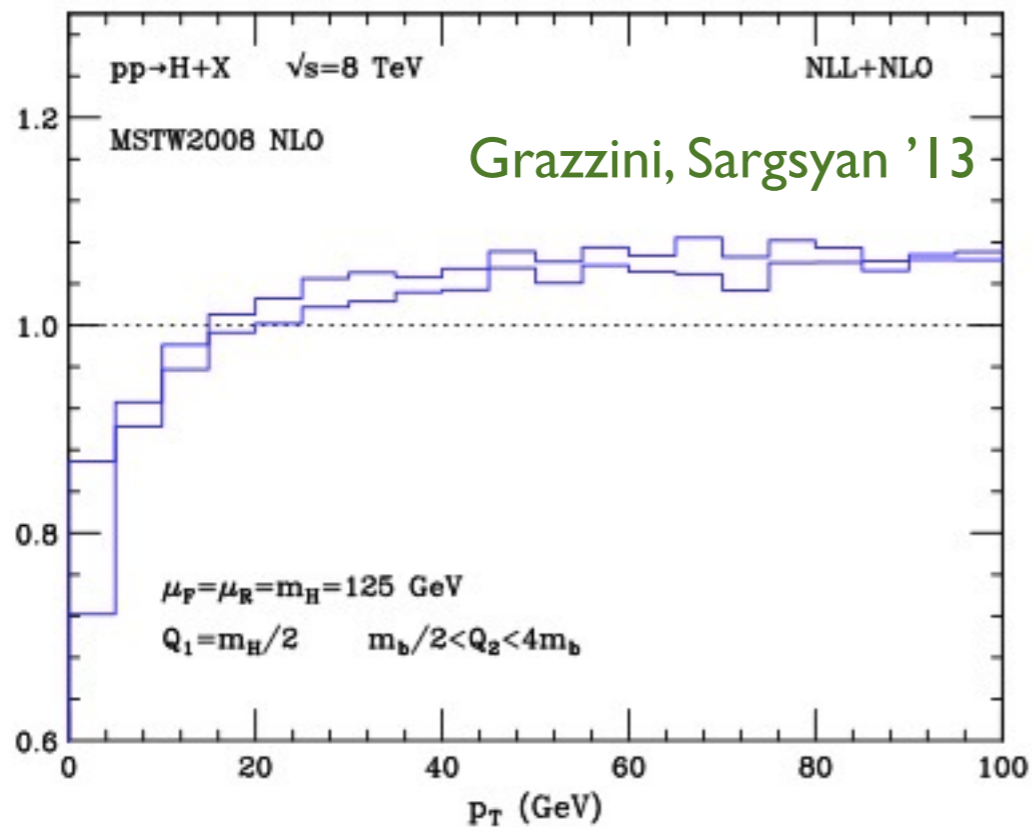
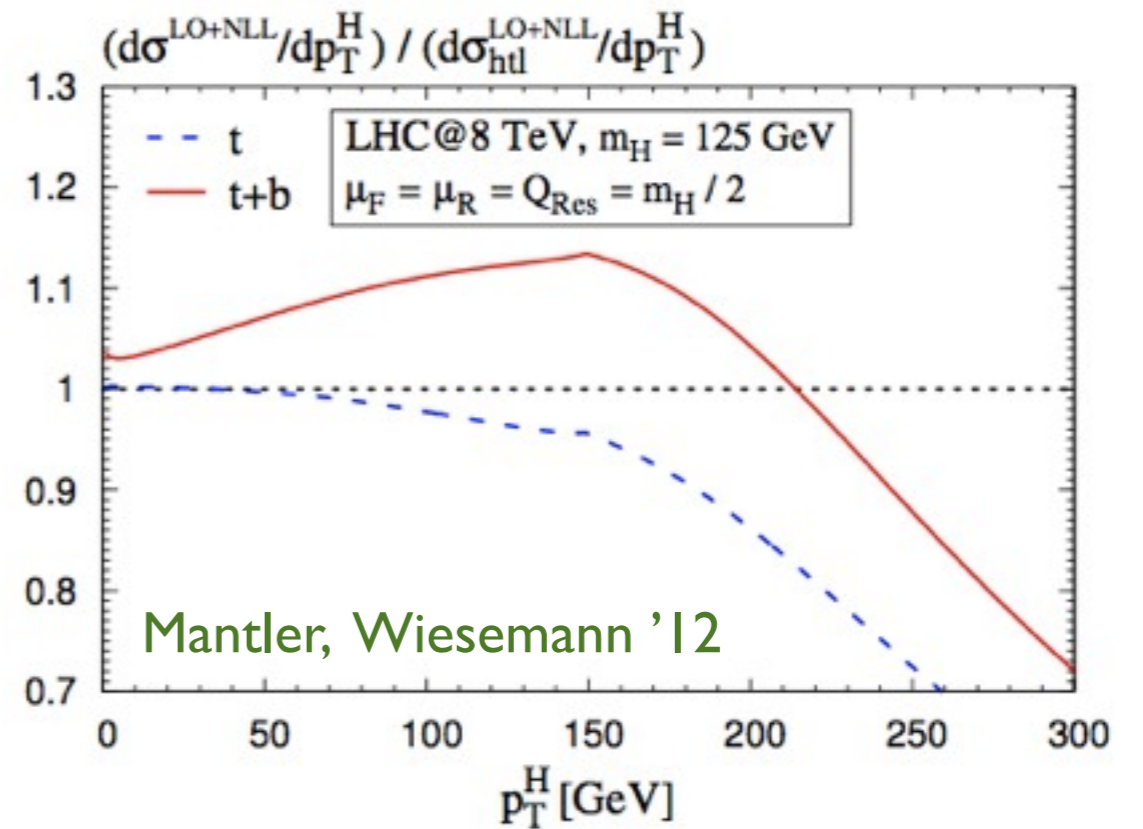
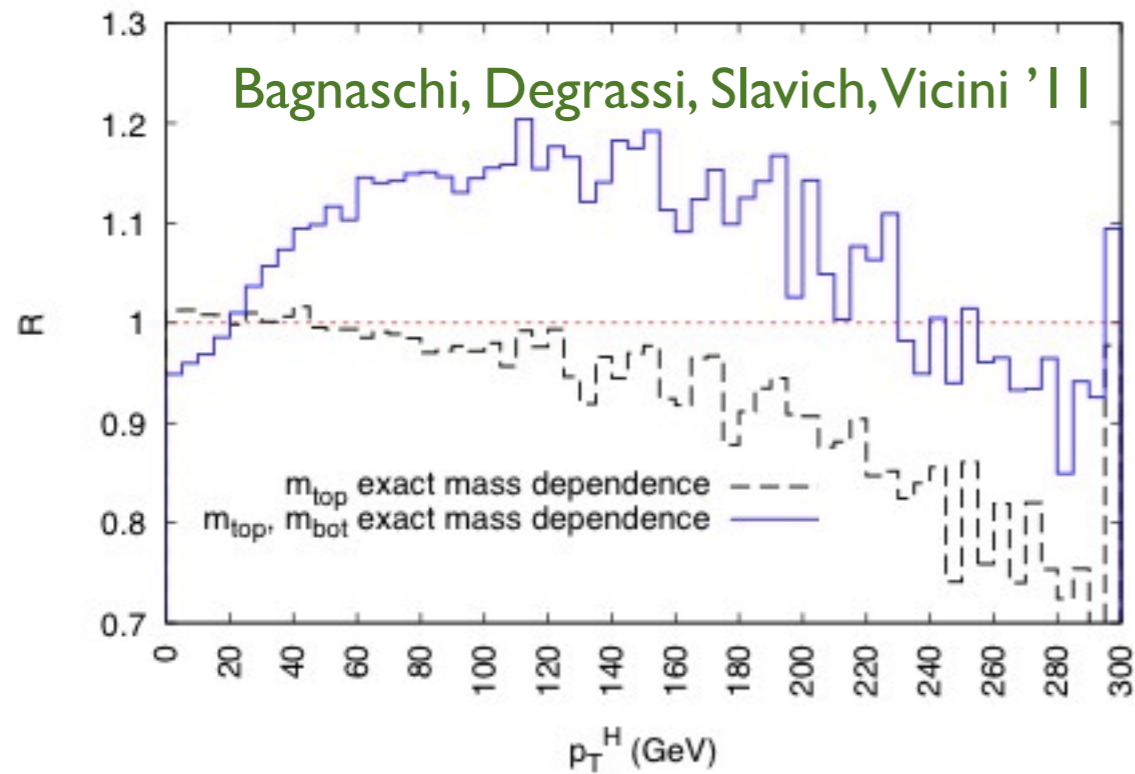


Transverse momentum distribution:

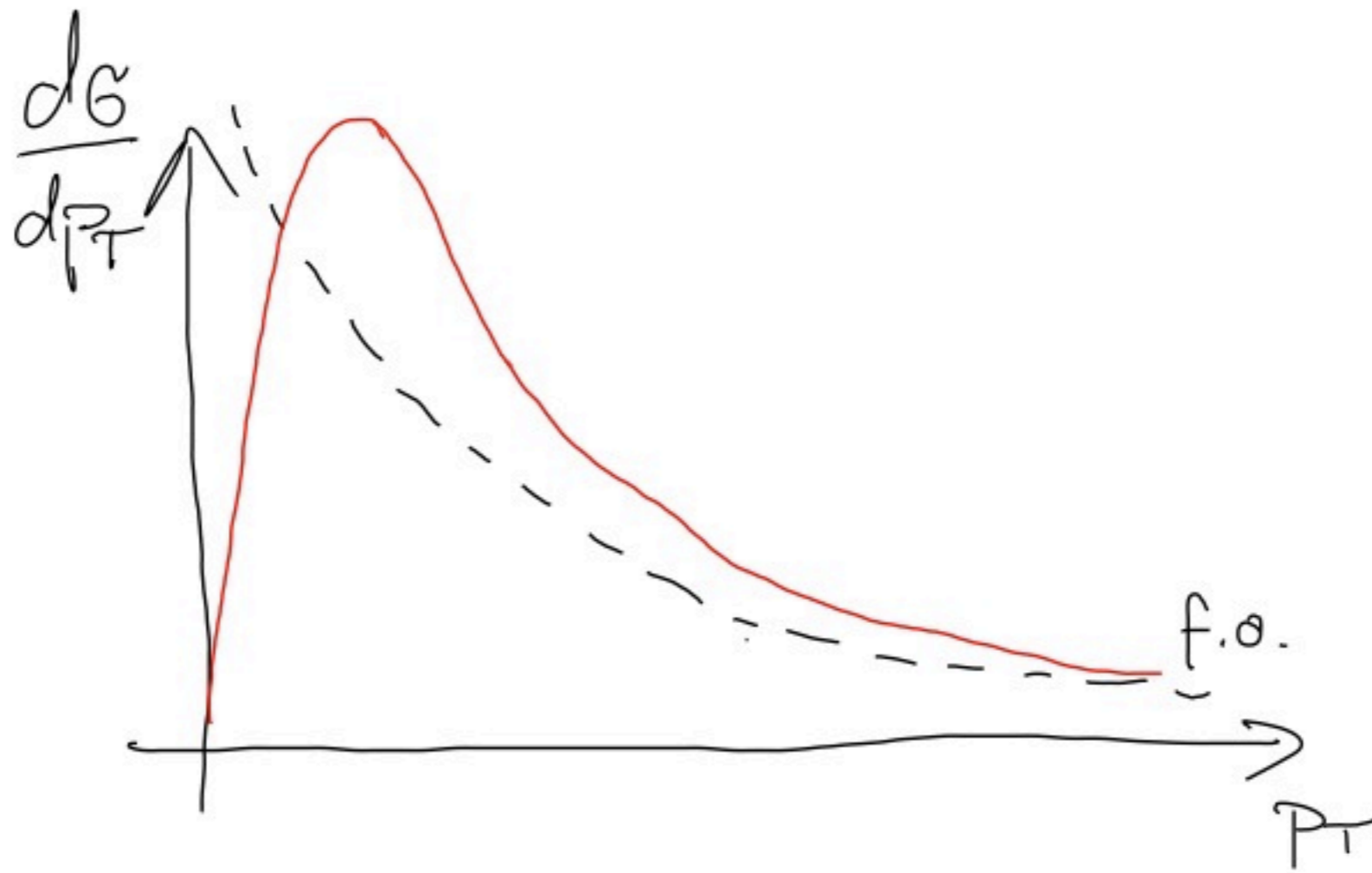


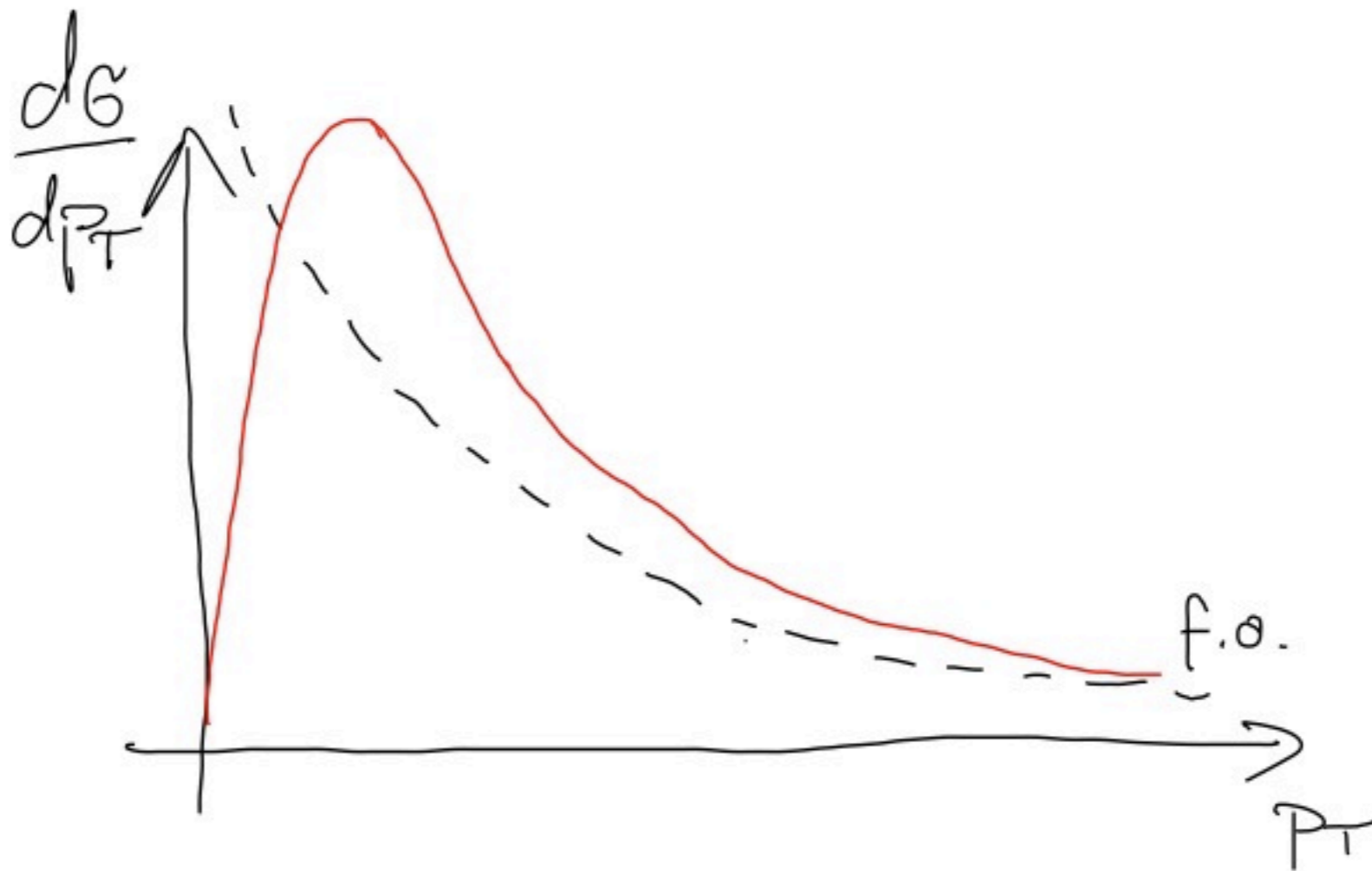
small p_T region: factorization for $p_T > m_b$?

Transverse momentum:



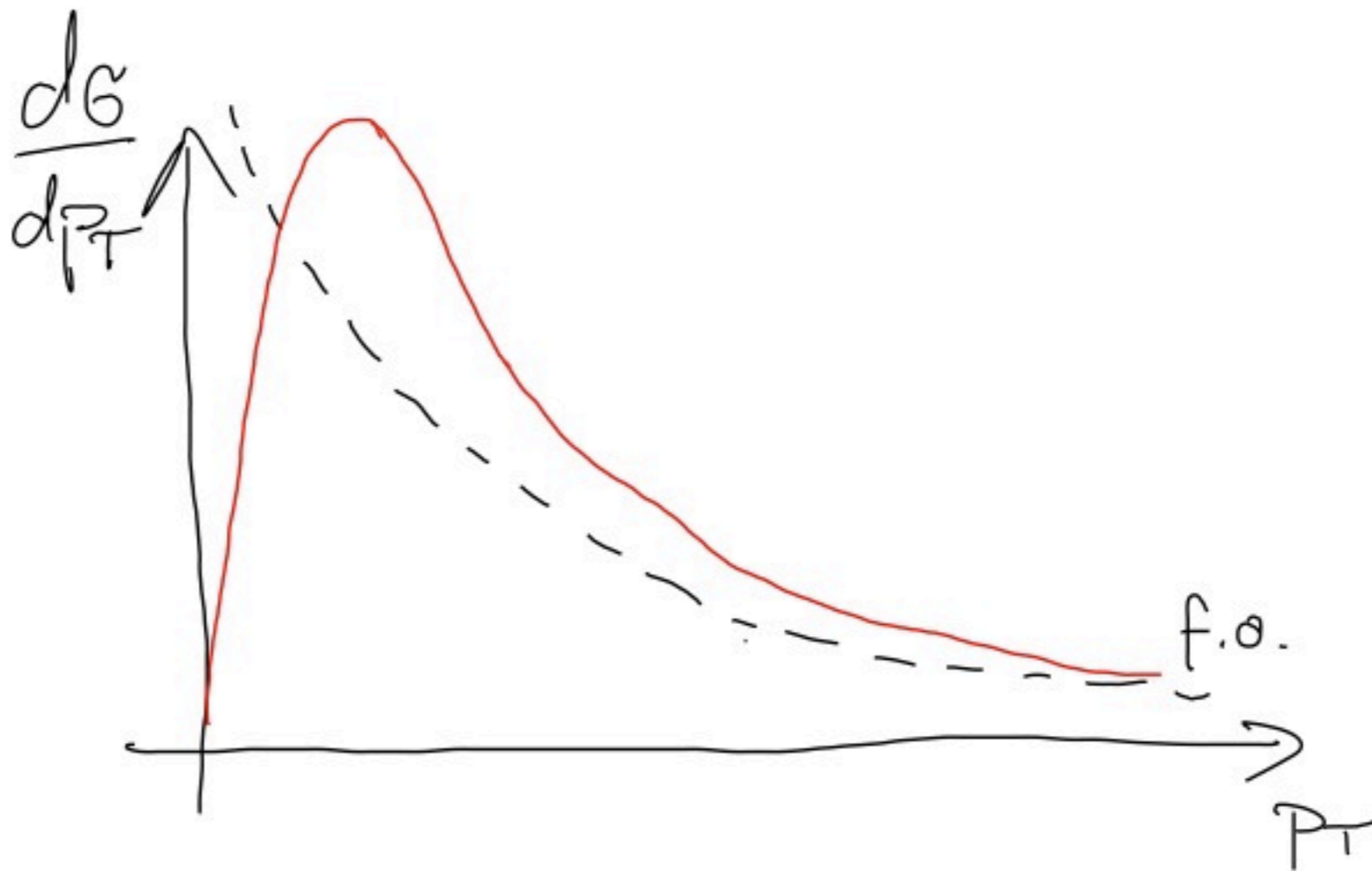
see also: Banfi, Monni, Zanderighi '14





$$\int dp_T^2 \left[\frac{d\sigma}{dp_T^2} \right]_{\text{f.o.}+\text{l.a.}} \equiv [\sigma_{\text{tot}}]_{\text{f.o.}}$$

Bozzi, Catani, de Florian, Grazzini '14

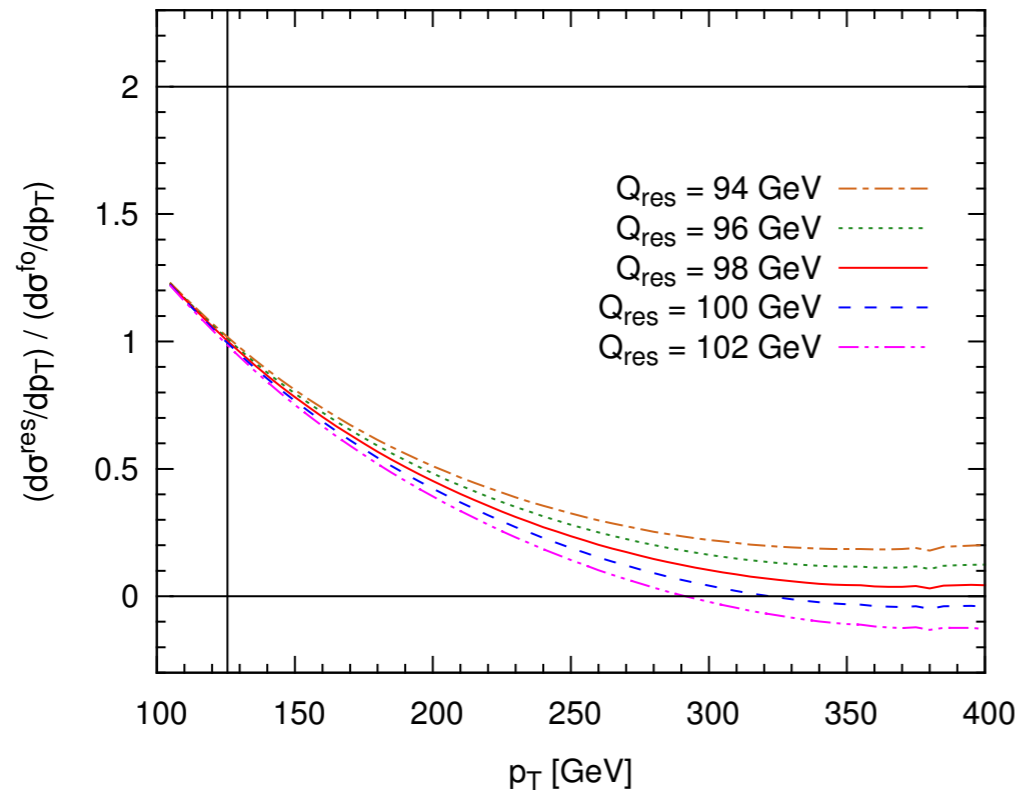


$$\int dp_T^2 \left[\frac{d\sigma}{dp_T^2} \right]_{\text{f.o.}+\text{l.a.}} \equiv [\sigma_{\text{tot}}]_{\text{f.o.}}$$

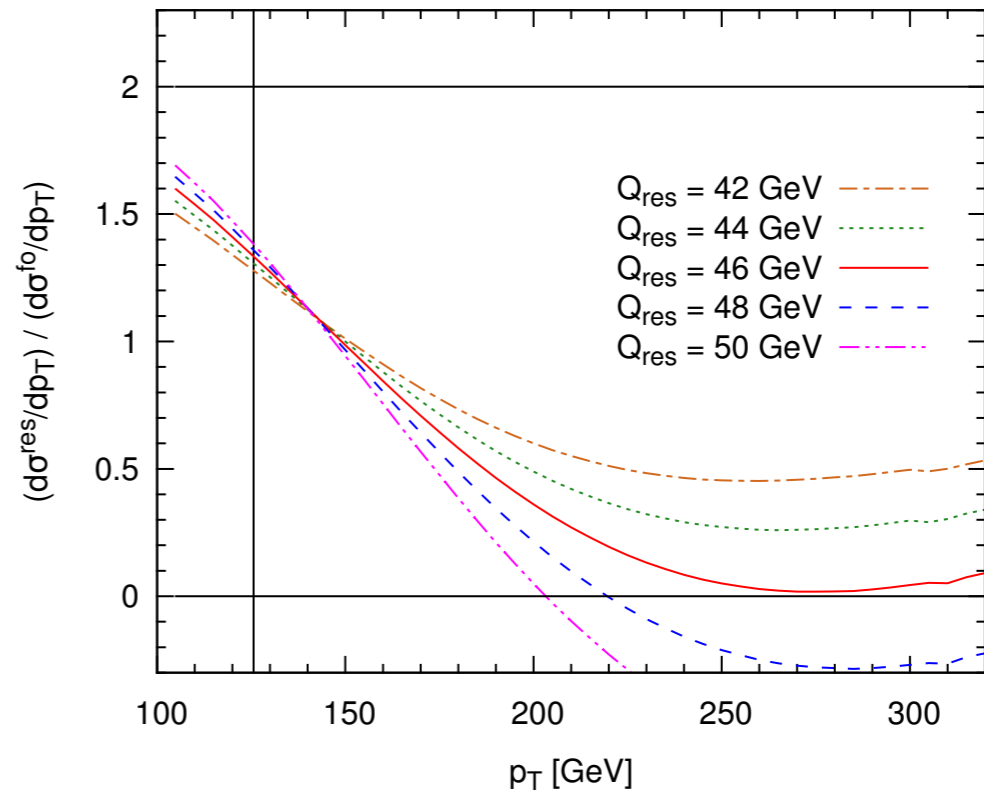
Bozzi, Catani, de Florian, Grazzini '14

may lead to

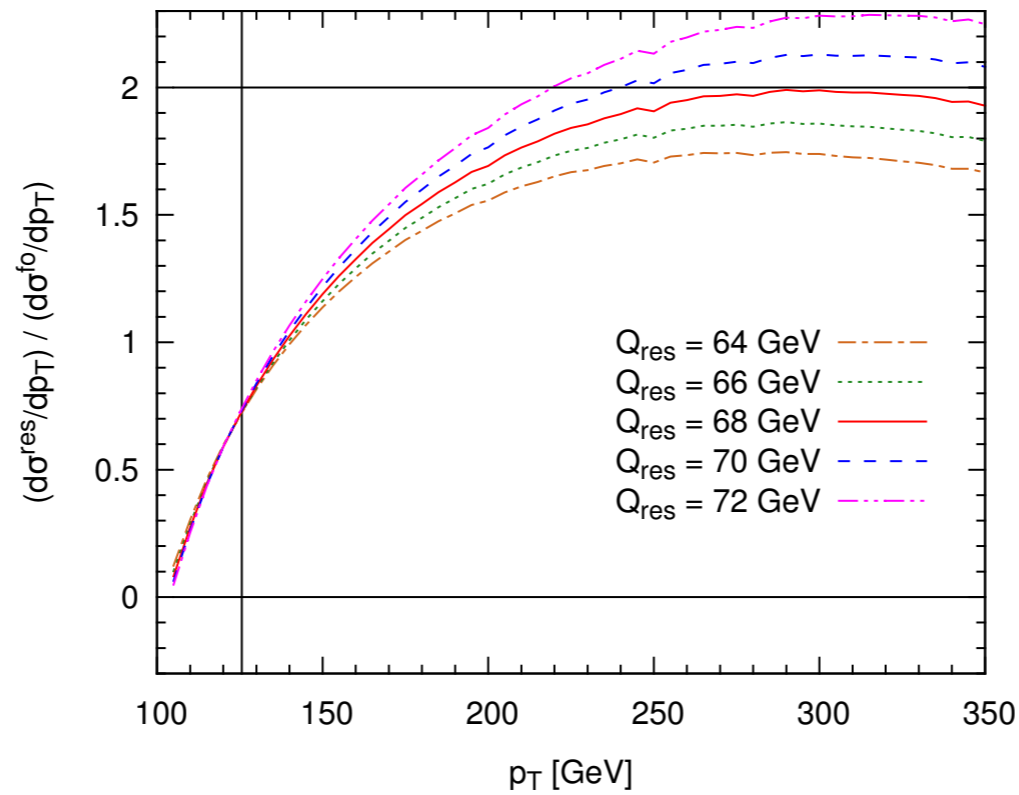
$$d\sigma/dp_T \neq d\sigma/dp_T|_{\text{fixed order}} \quad \text{at large } p_T$$



(a)

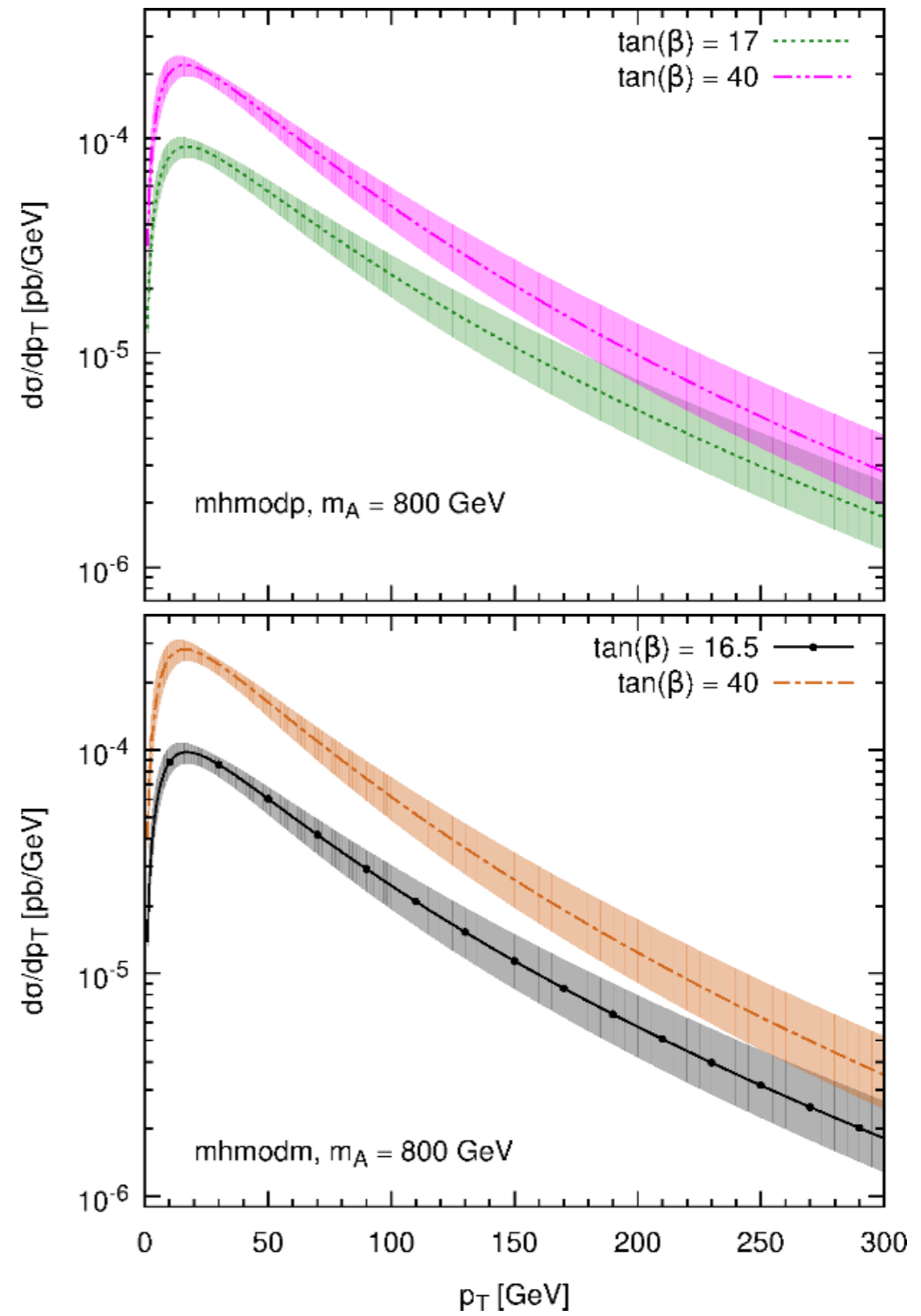
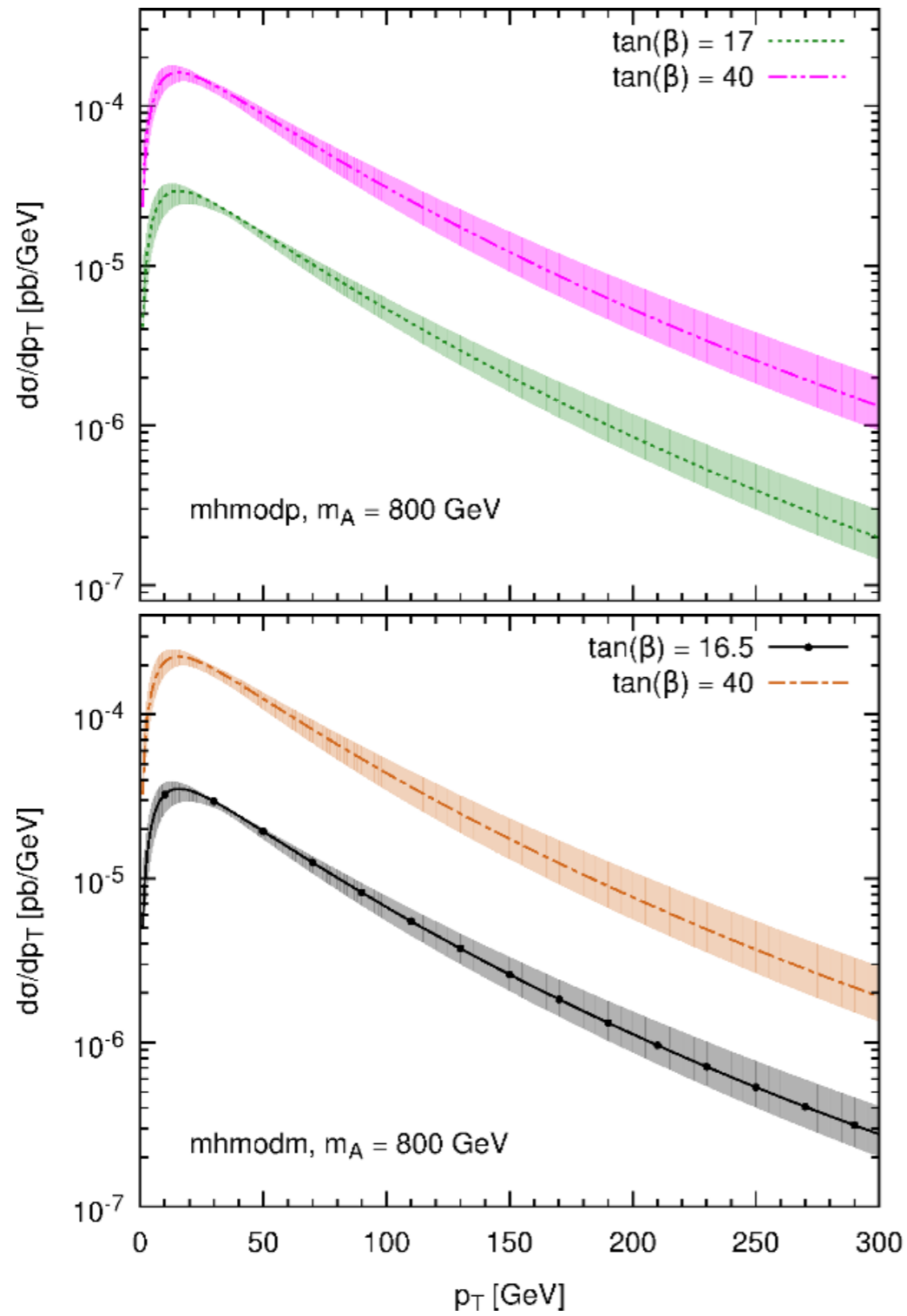


(b)

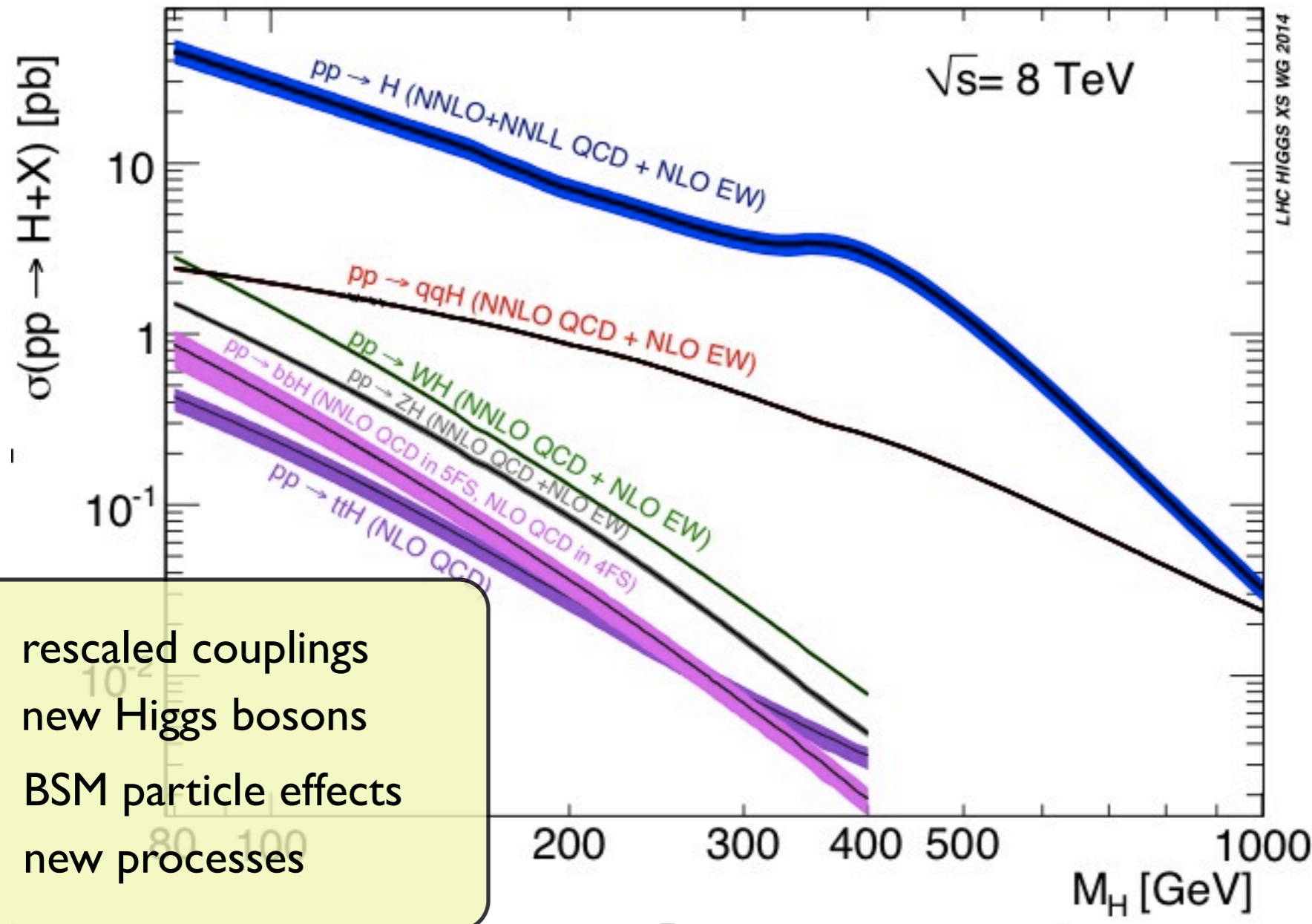


(c)

RH, Mantler, Wiesemann '14

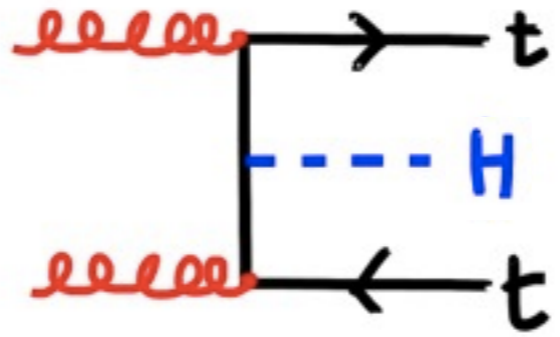
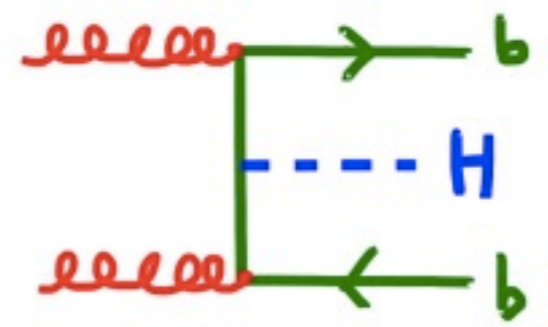
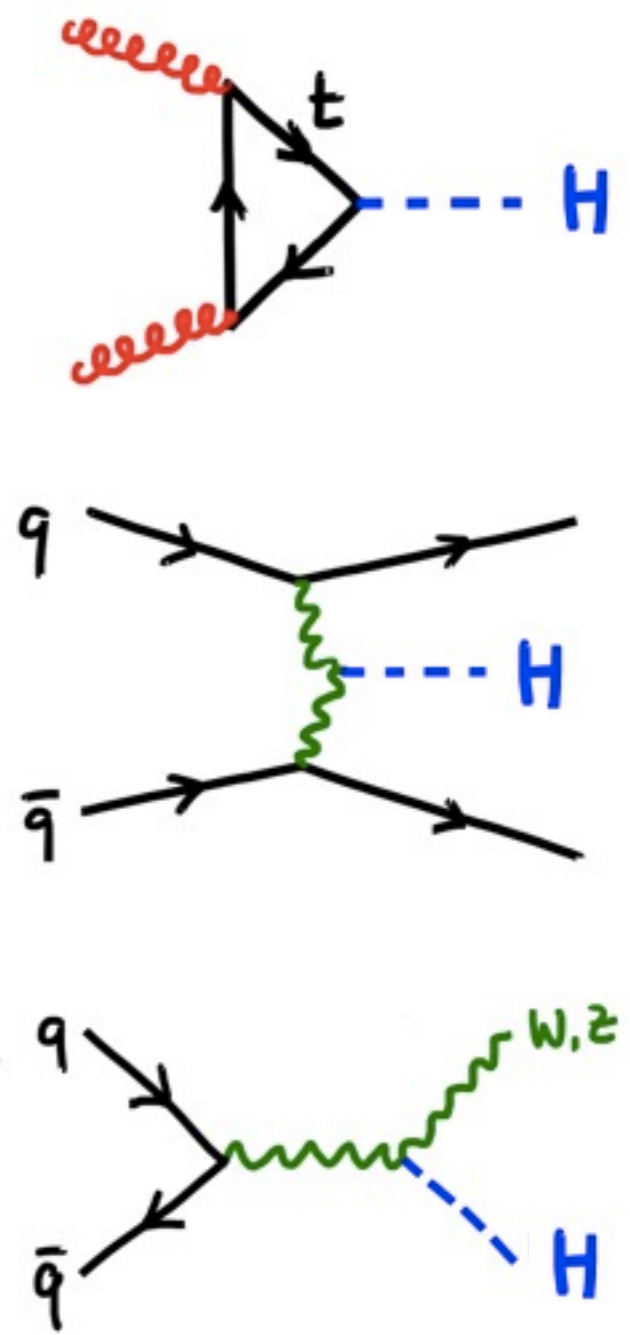


RH, Mantler, Wiesemann '14

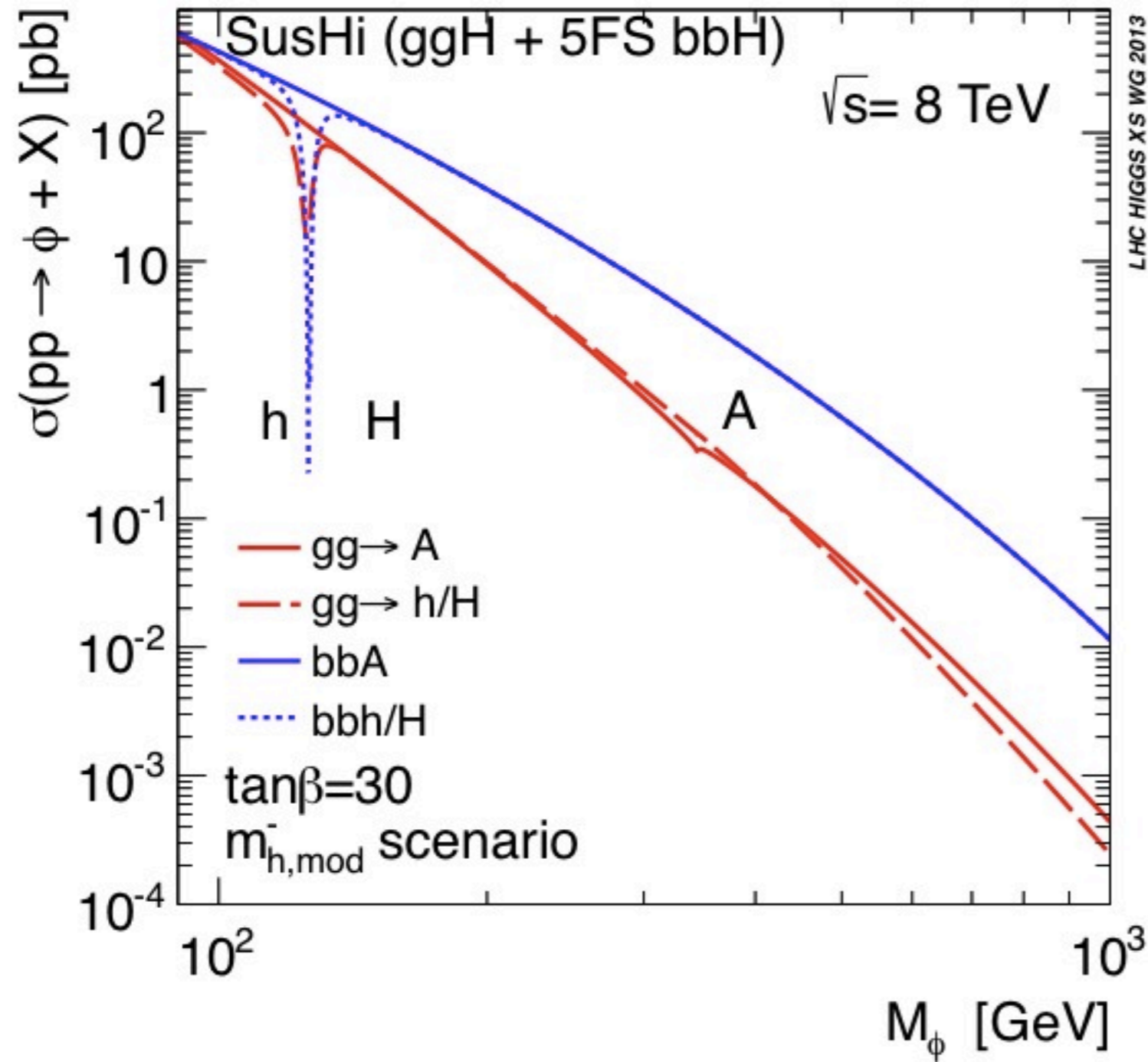


LHC HIGGS XS WG 2014

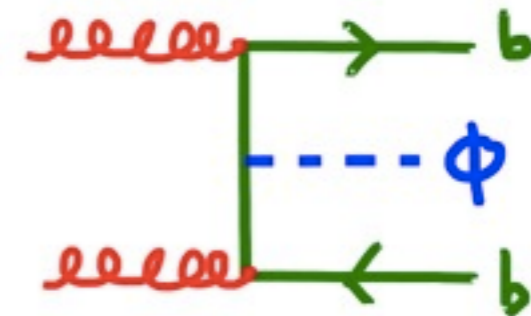
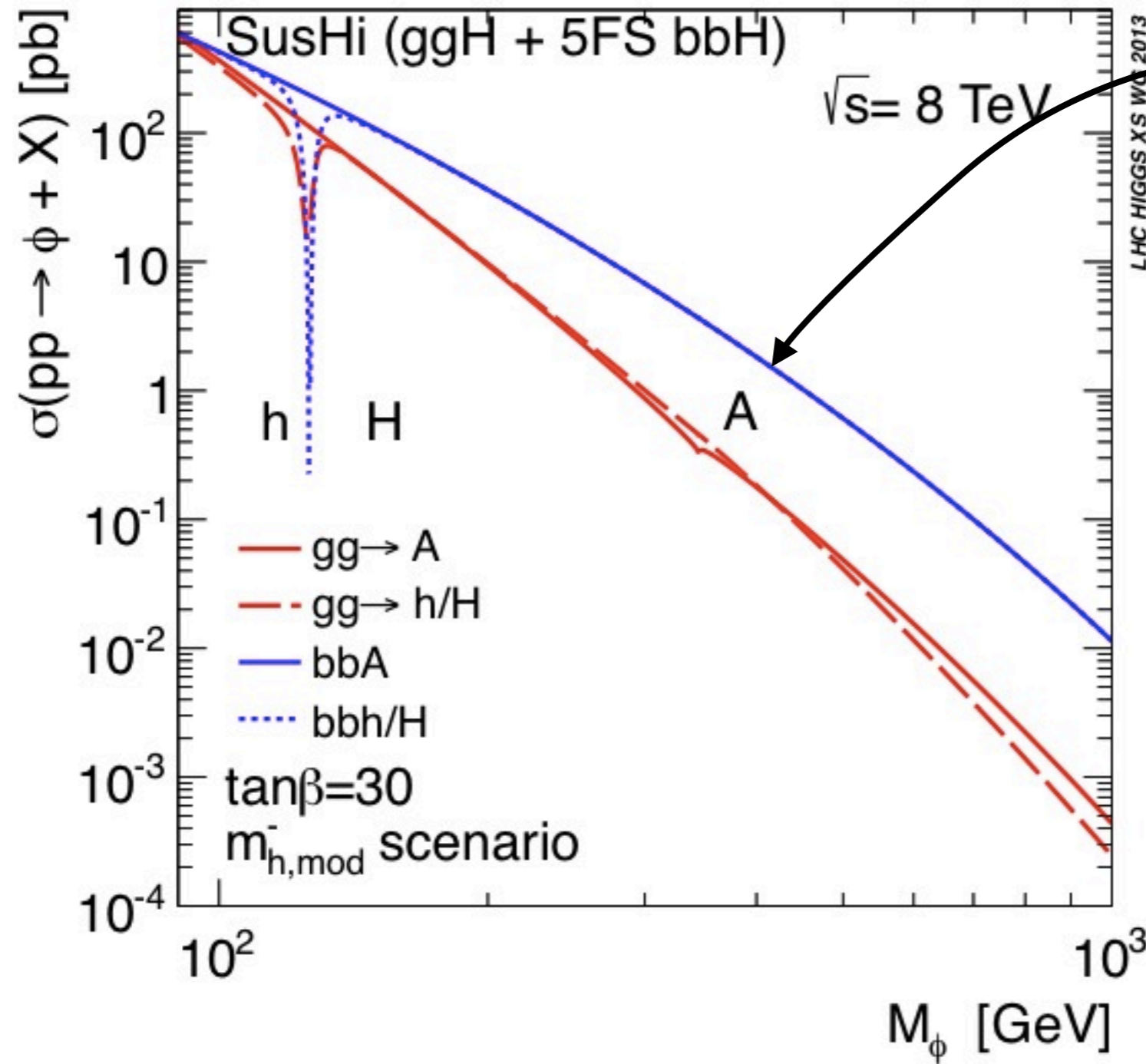
rescaled couplings
 new Higgs bosons
 BSM particle effects
 new processes



“New” production modes:

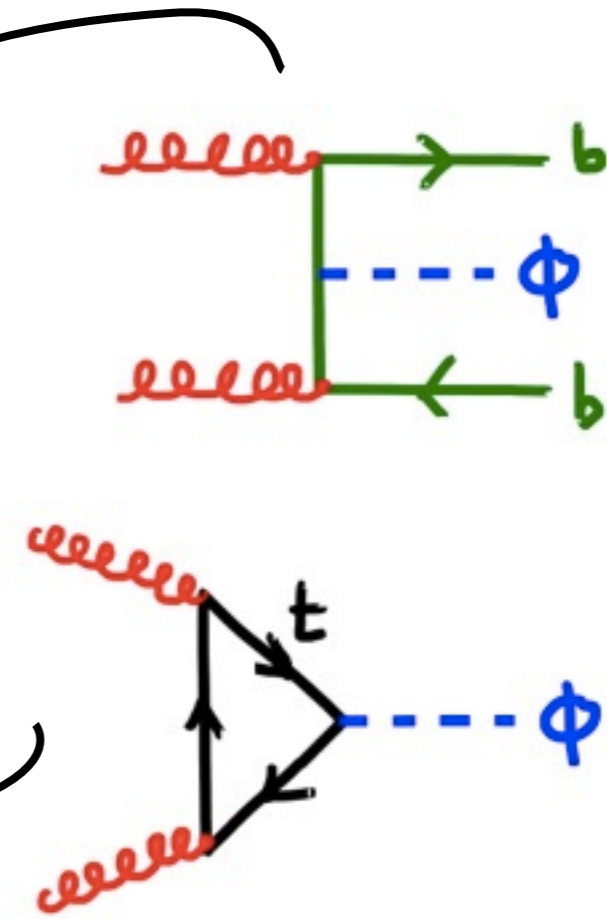
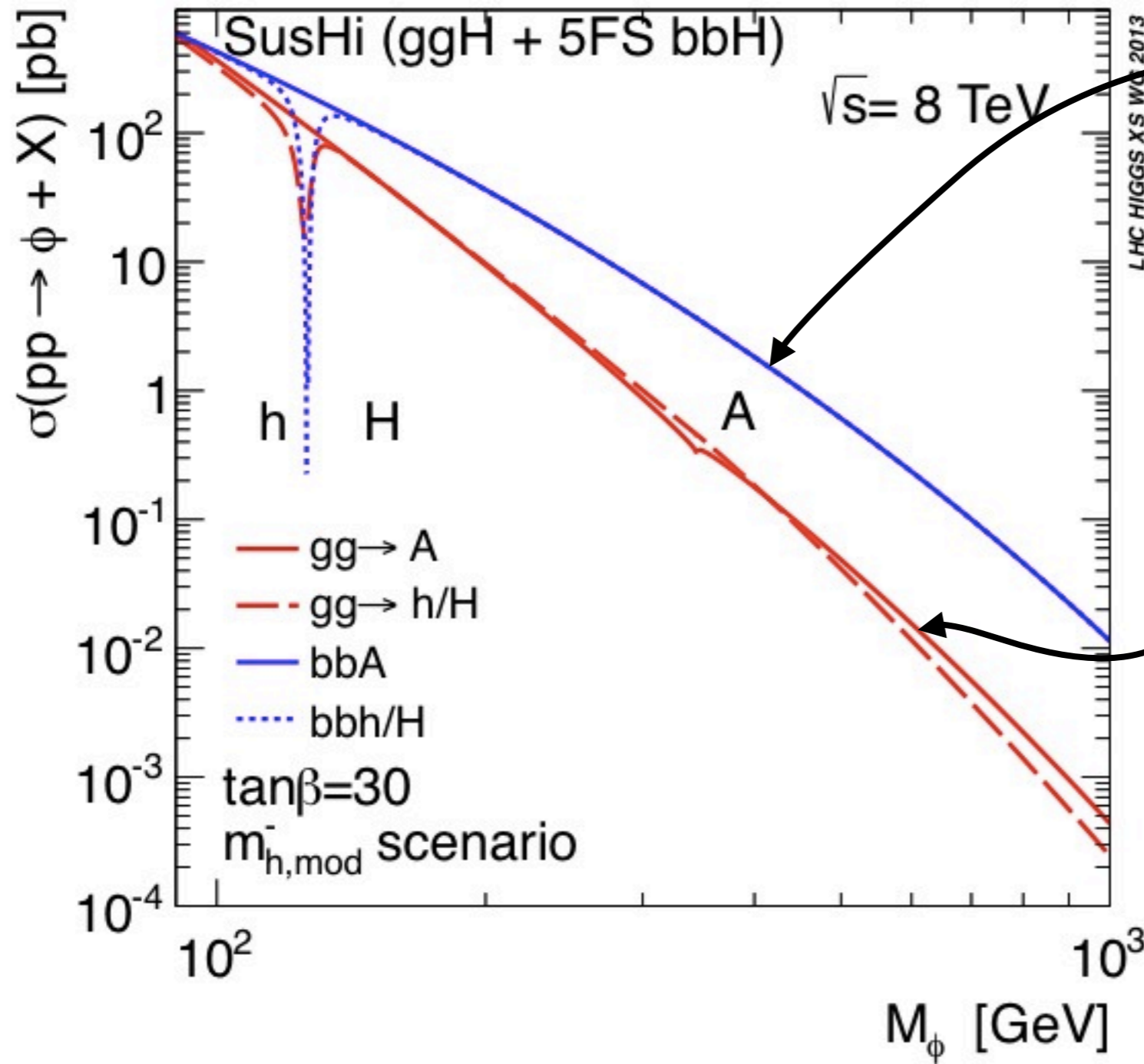


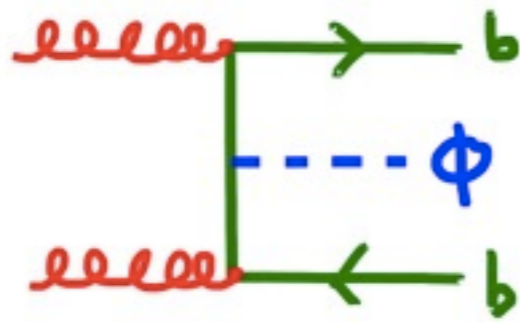
“New” production modes:



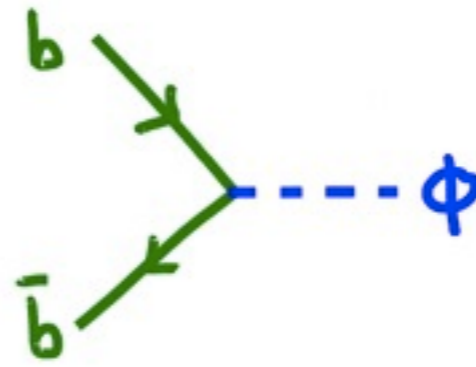
LHC HIGGS XS WG 2013

“New” production modes:

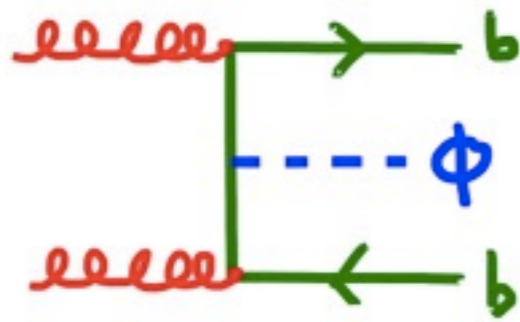




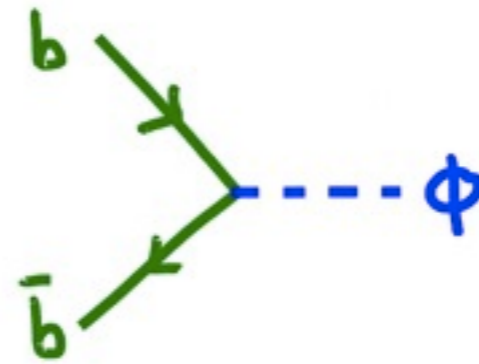
4FS: through NLO



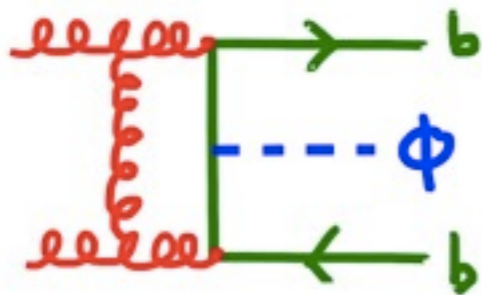
5FS: through NNLO



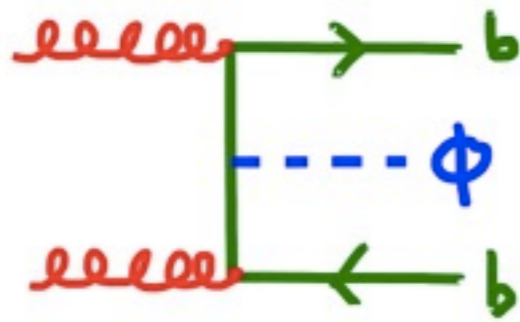
4FS: through NLO



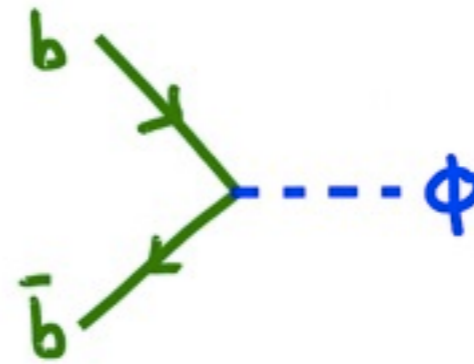
5FS: through NNLO



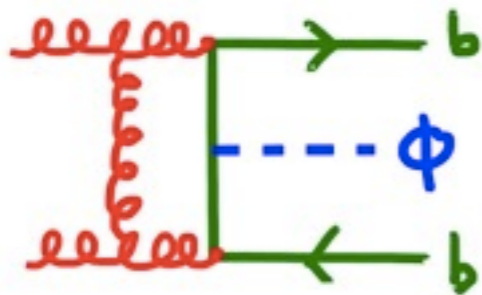
not in 5FS NNLO!



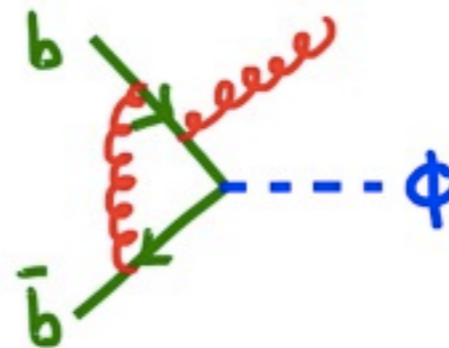
4FS: through NLO



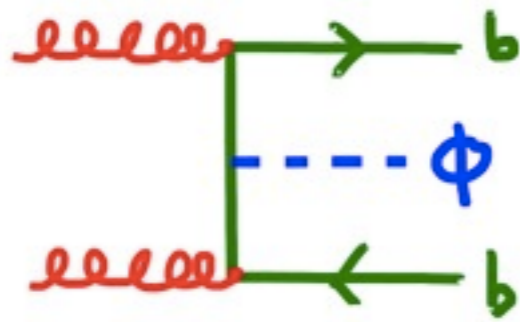
5FS: through NNLO



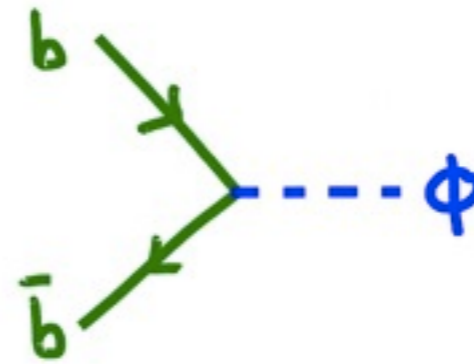
not in 5FS NNLO!



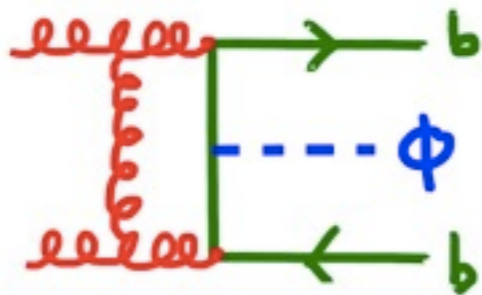
not in 4FS NLO!



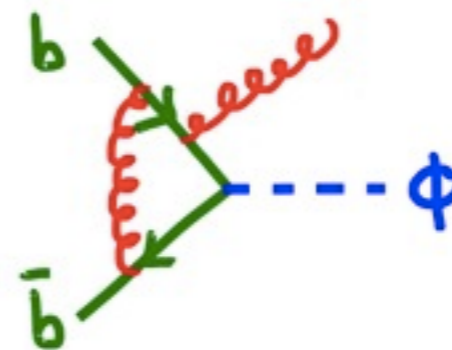
4FS: through NLO



5FS: through NNLO



not in 5FS NNLO!



not in 4FS NLO!

$$\sigma^{\text{matched}} = \frac{\sigma^{4\text{FS}} + w \sigma^{5\text{FS}}}{1 + w}$$

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

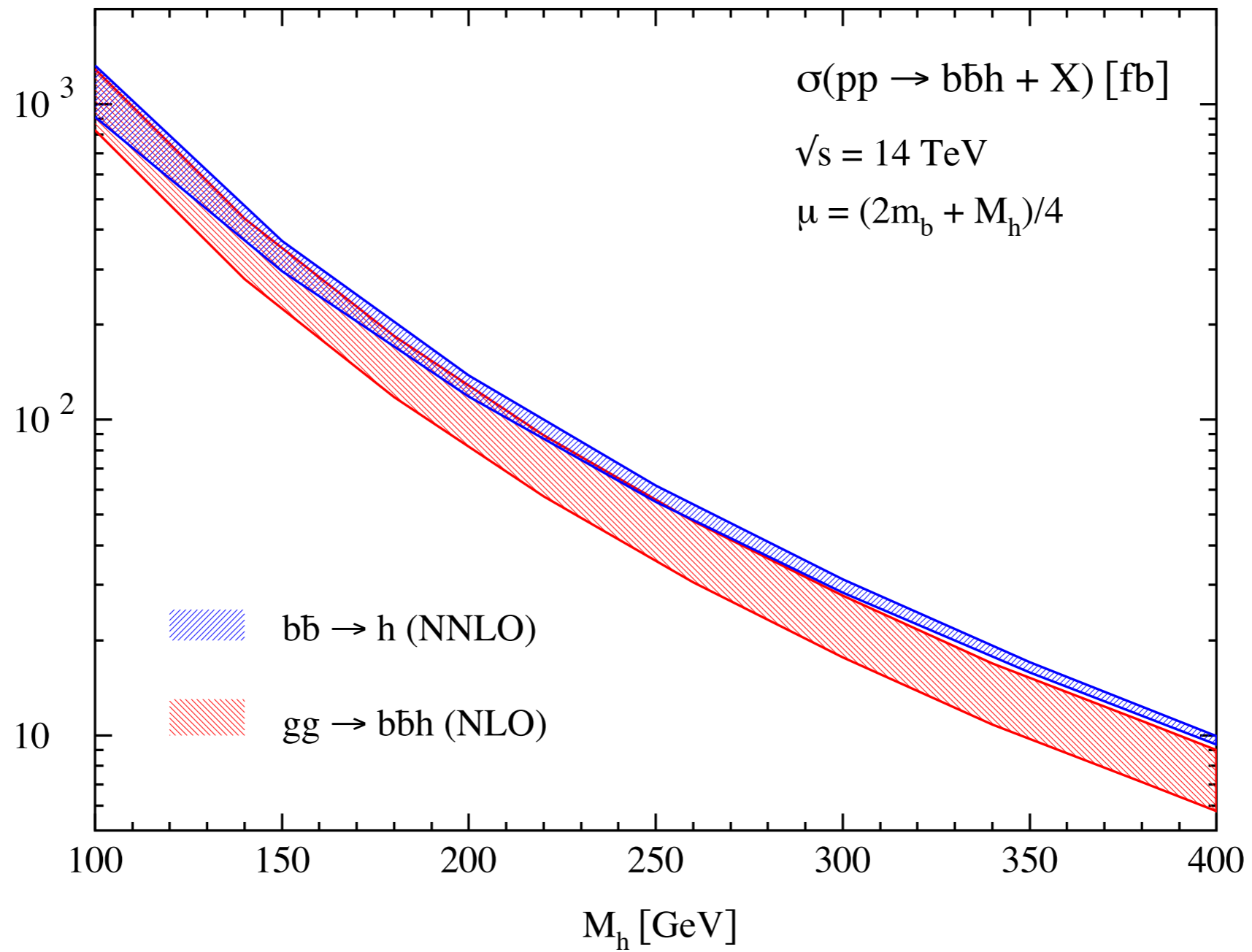
Santander matching

RH, Krämer, Schumacher '11

see also: Maltoni, Ridolfi, Ubiali '12

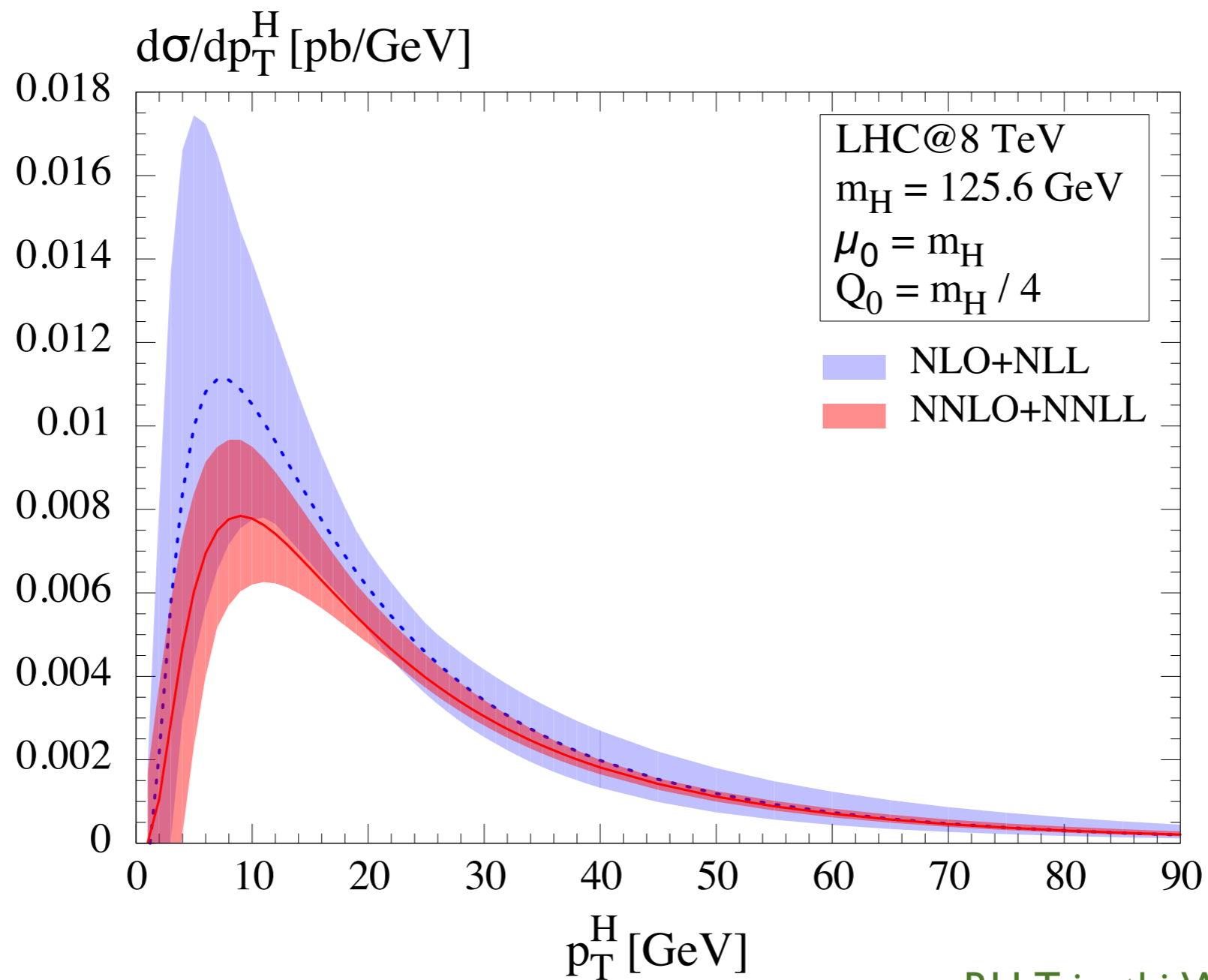
Wiesemann et al. '14

Total cross section:

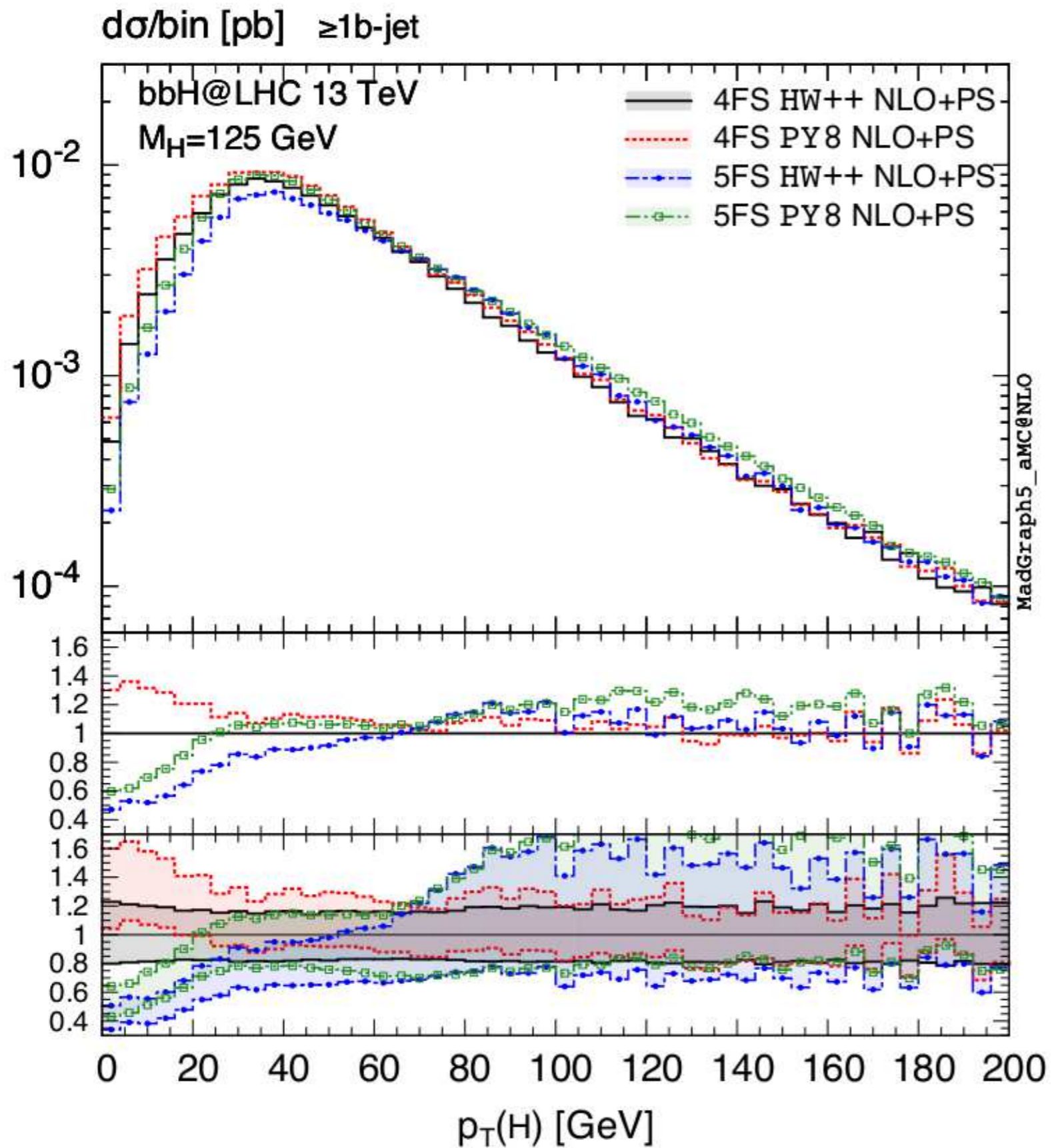


Les Houches 2003

p_T distribution at NNLO+NNLL in 5FS:



RH, Tripathi, Wiesemann '14



4FS vs. 5FS

M. Wiesemann^a, R. Frederix^b, S. Frixione^b, V. Hirschi^c, F. Maltoni^d, P. Torrielli^{ae}

2014

4FS vs. 5FS

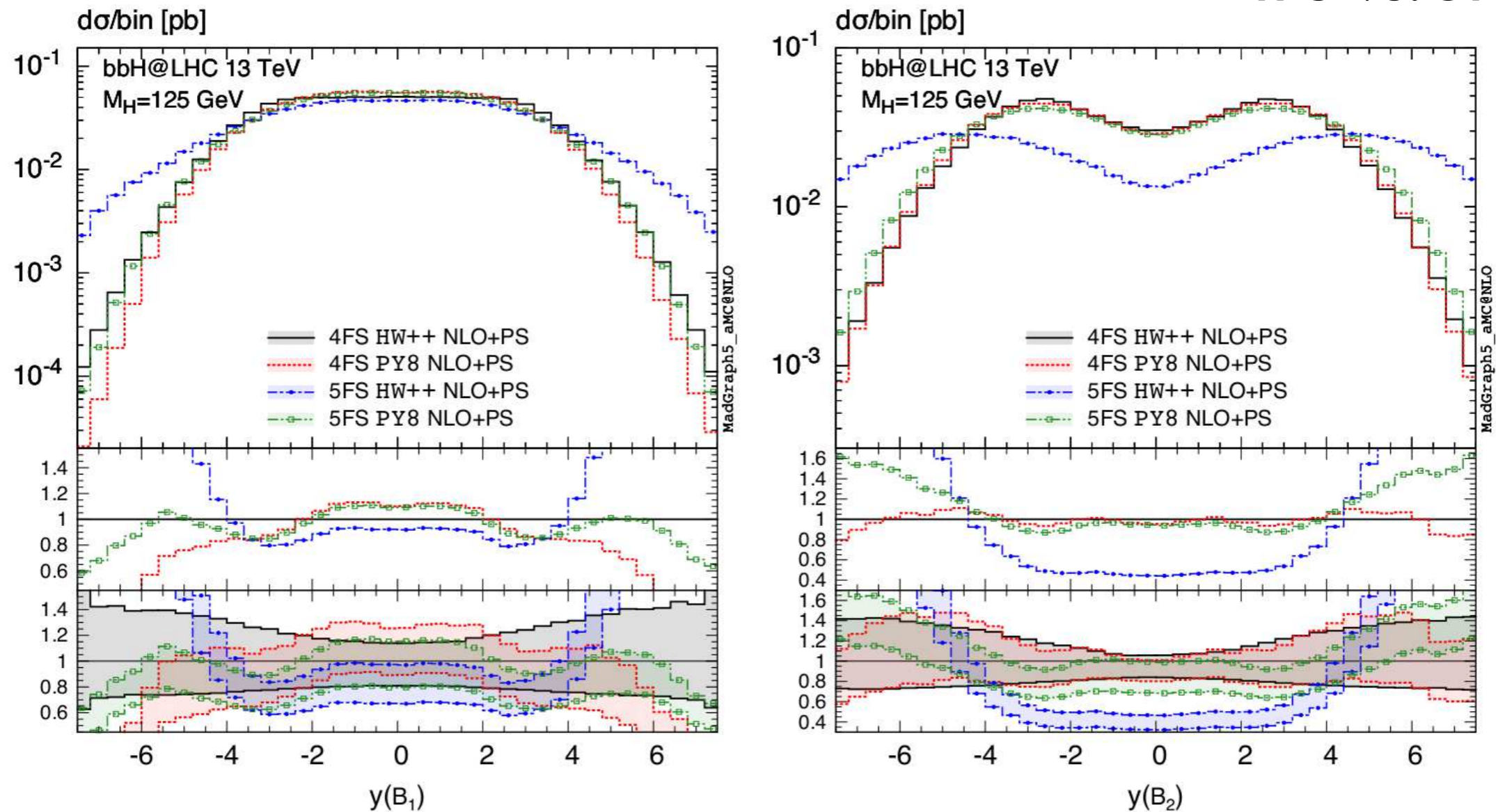


Figure 15: Rapidity of the hardest (left panel) and second-hardest (right panel) B hadron, in the 4FS and 5FS at the NLO+PS accuracy, as predicted by HERWIG++ and PYTHIA8. All histograms have been normalised so that their integrals are equal to one.

M. Wiesemann^a, R. Frederix^b, S. Frixione^b, V. Hirschi^c, F. Maltoni^d, P. Torrielli^{ae}

2014

Conclusions

- SM results often allow trivial estimate of BSM effects
- dedicated BSM cross section predictions require fast and flexible tools
 - [SusHi](#) for gluon fusion for SUSY
- Higgs Strahlung: high potential due to WH vs. ZH
- 4FS vs. 5FS (6FS??) may become very relevant
- very promising: differential quantities