Higgs Theory Overview

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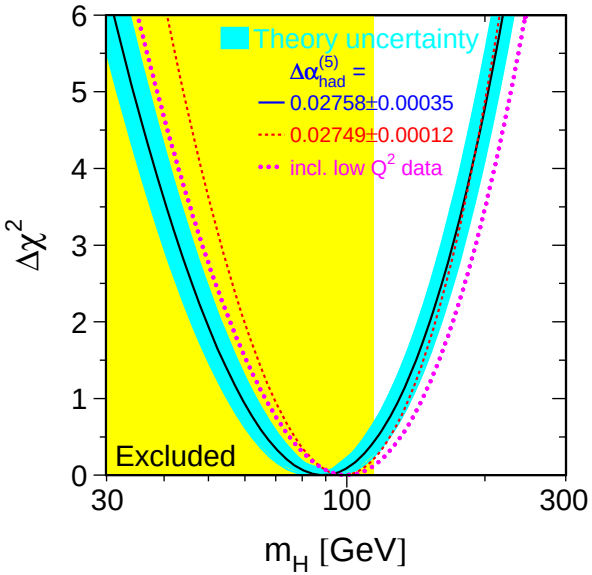
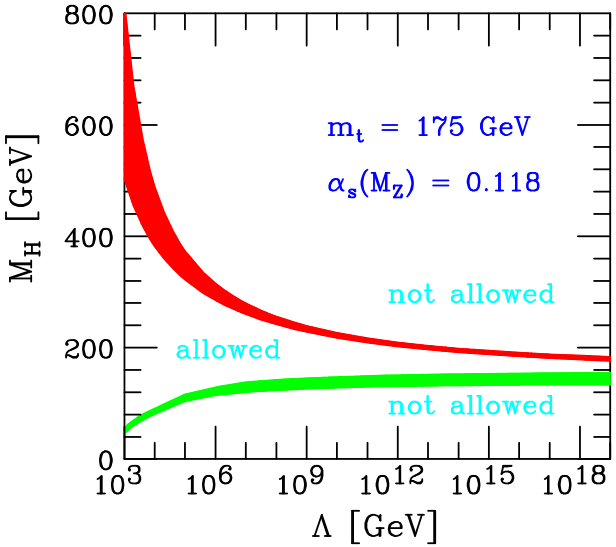
Physics at LHC, Cracow, July 2006

- Higgs physics – why theory?
- inclusive cross sections
- exclusive cross sections – status
- supersymmetry

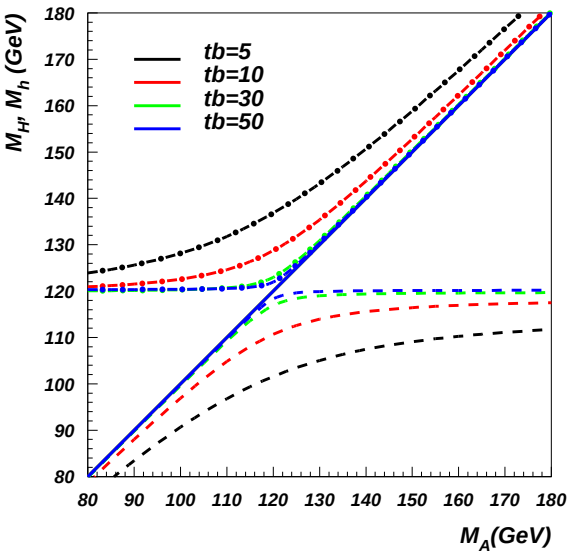
Where is the Higgs boson?





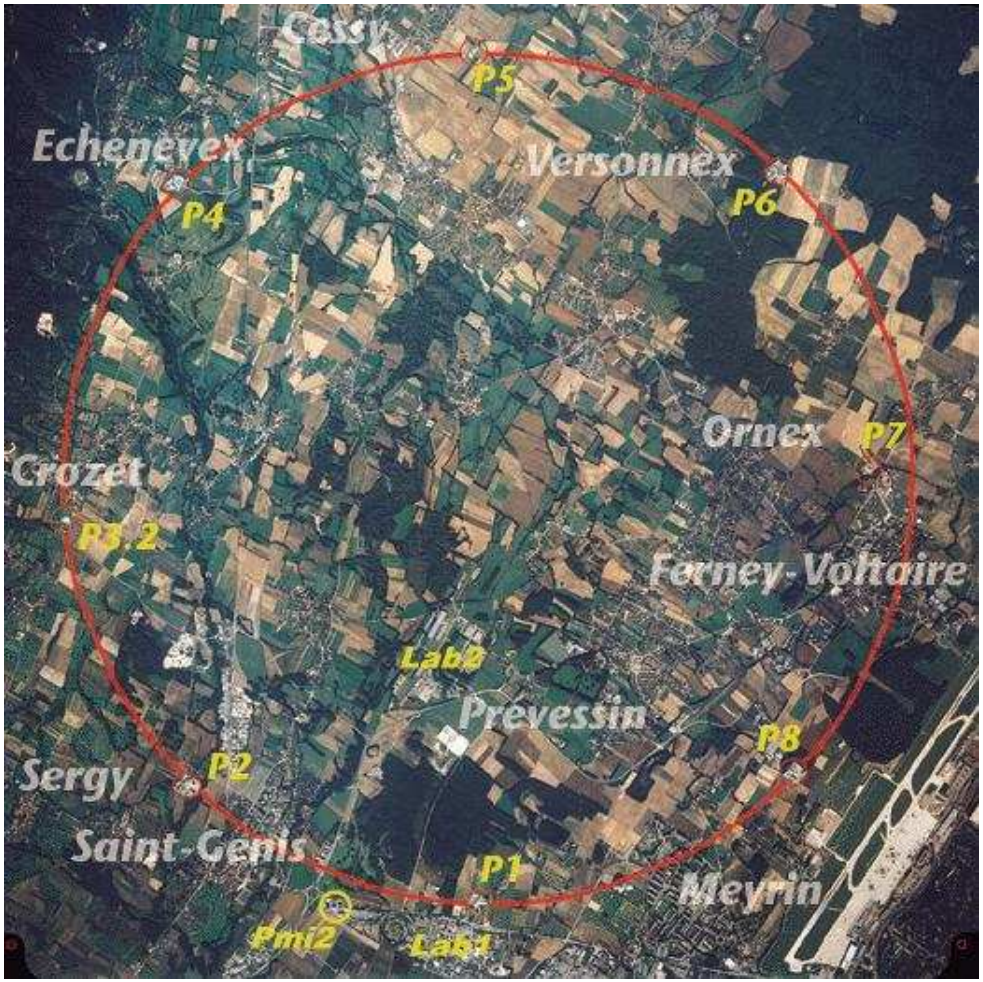
$$M_H = 89^{+42}_{-30}\,\text{GeV}$$

$$M_H < 207\,\text{GeV}$$

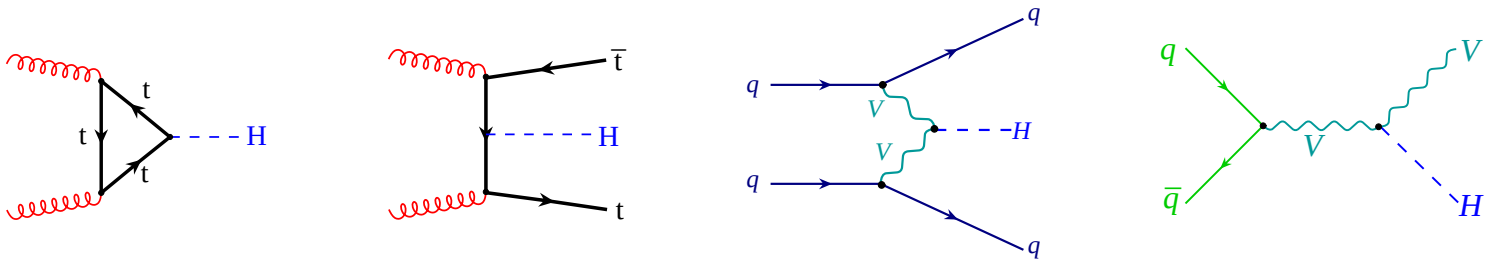


Large Hadron Collider

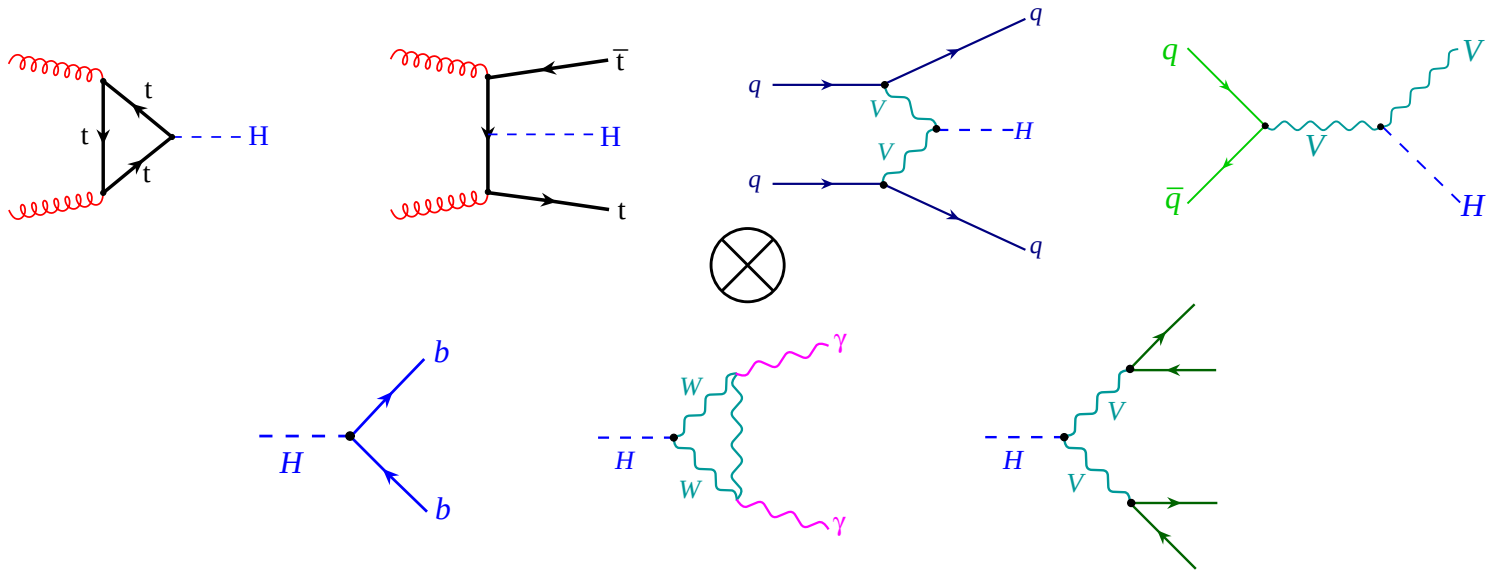
proton →← proton



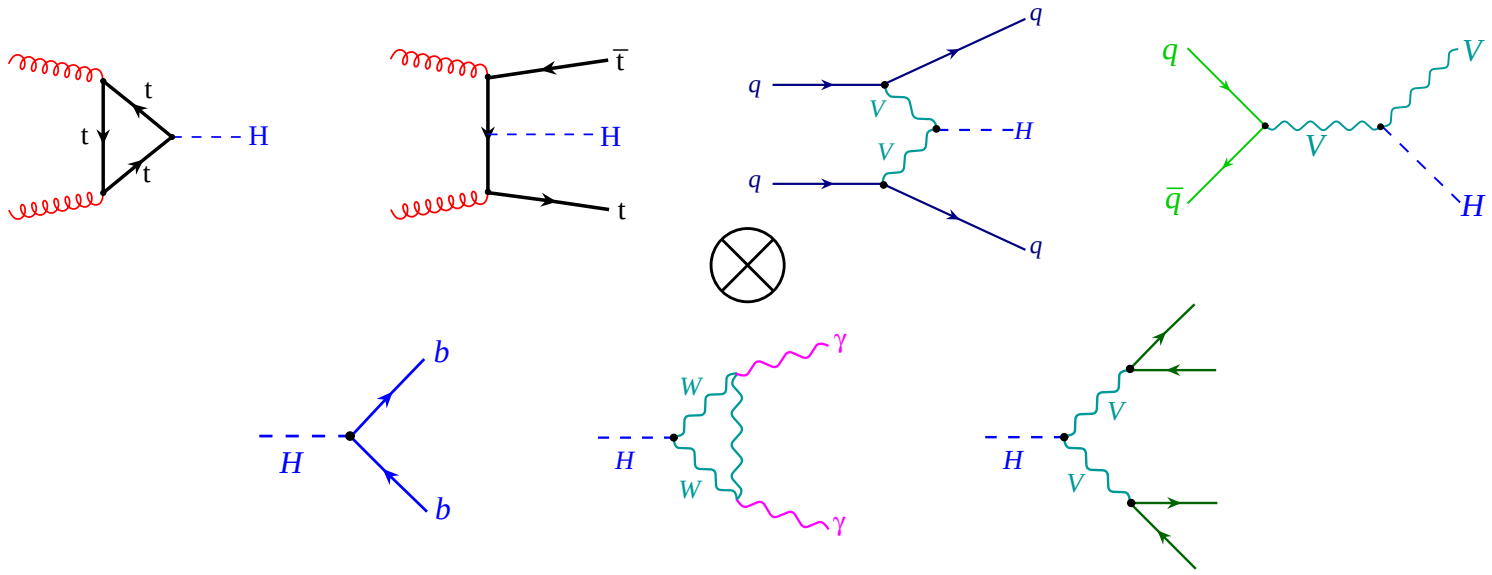
$pp \longrightarrow H$ at 14 GeV

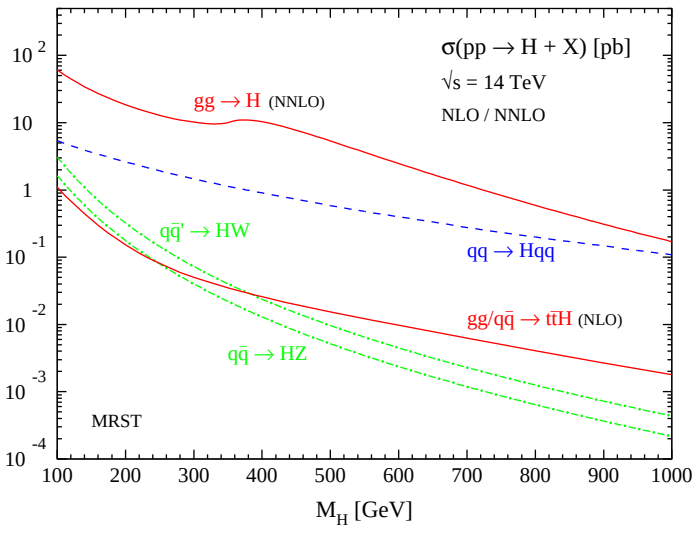


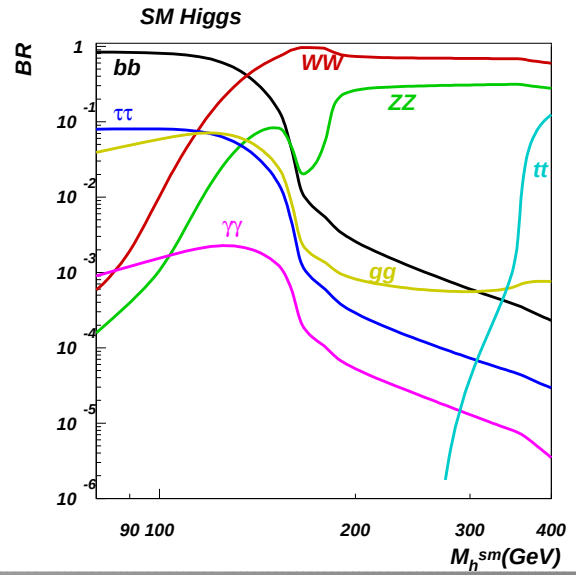
$pp \longrightarrow H$ at 14 GeV



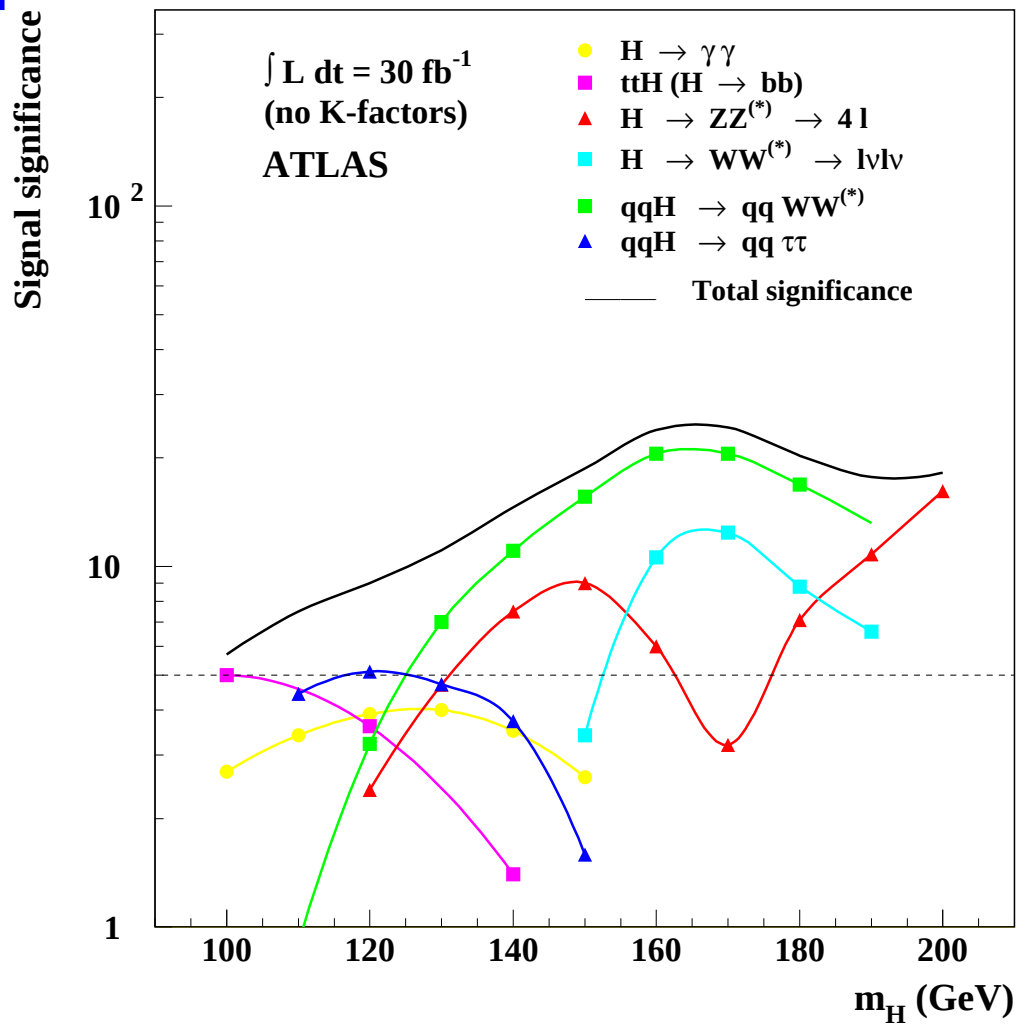
$pp \longrightarrow H$ at 14 GeV

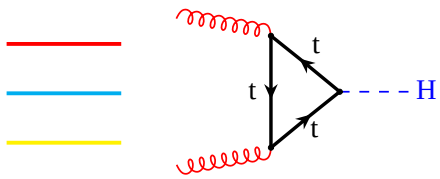




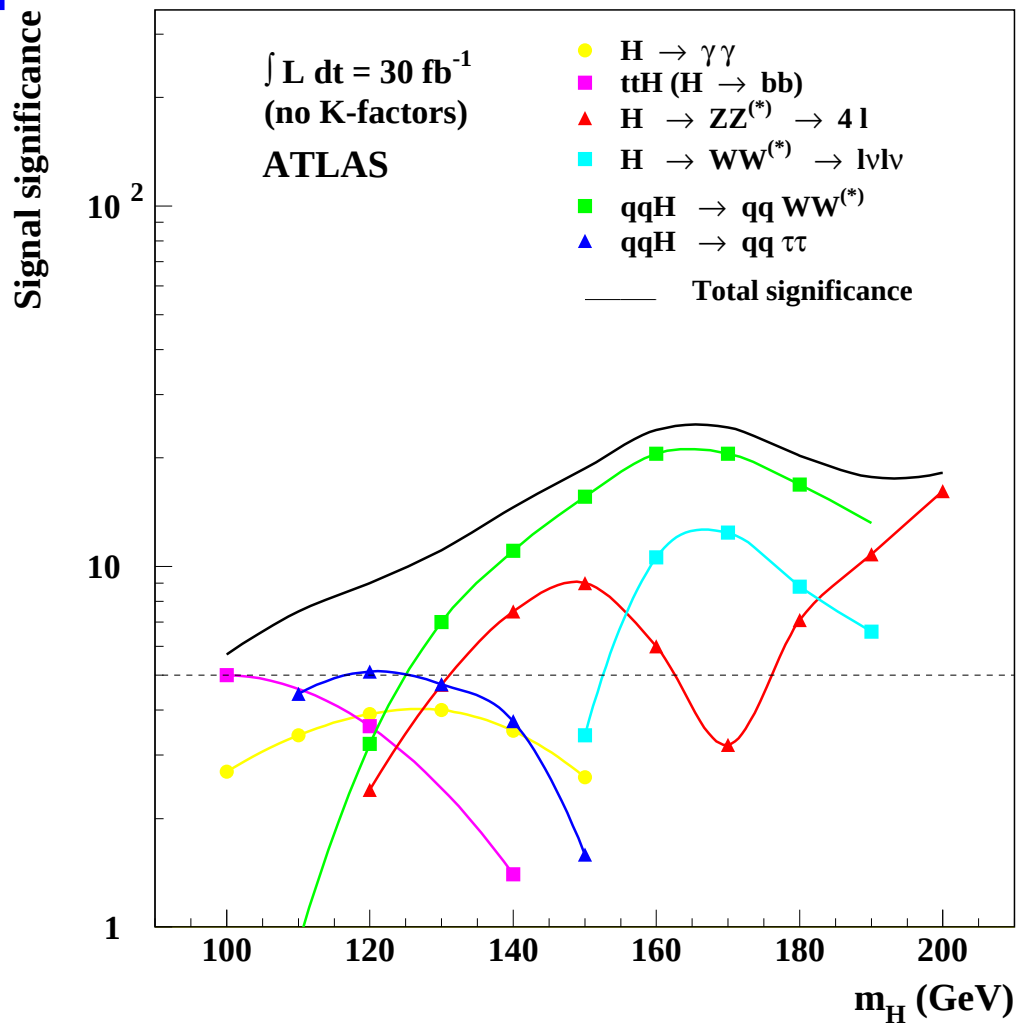


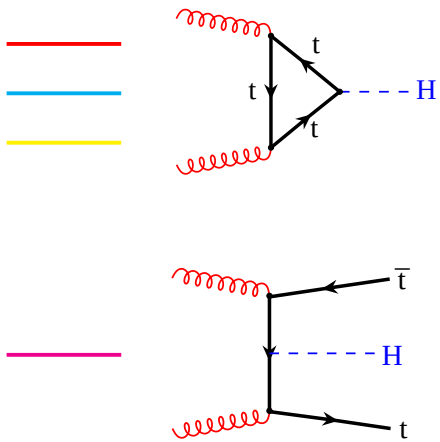
Discovery Potential



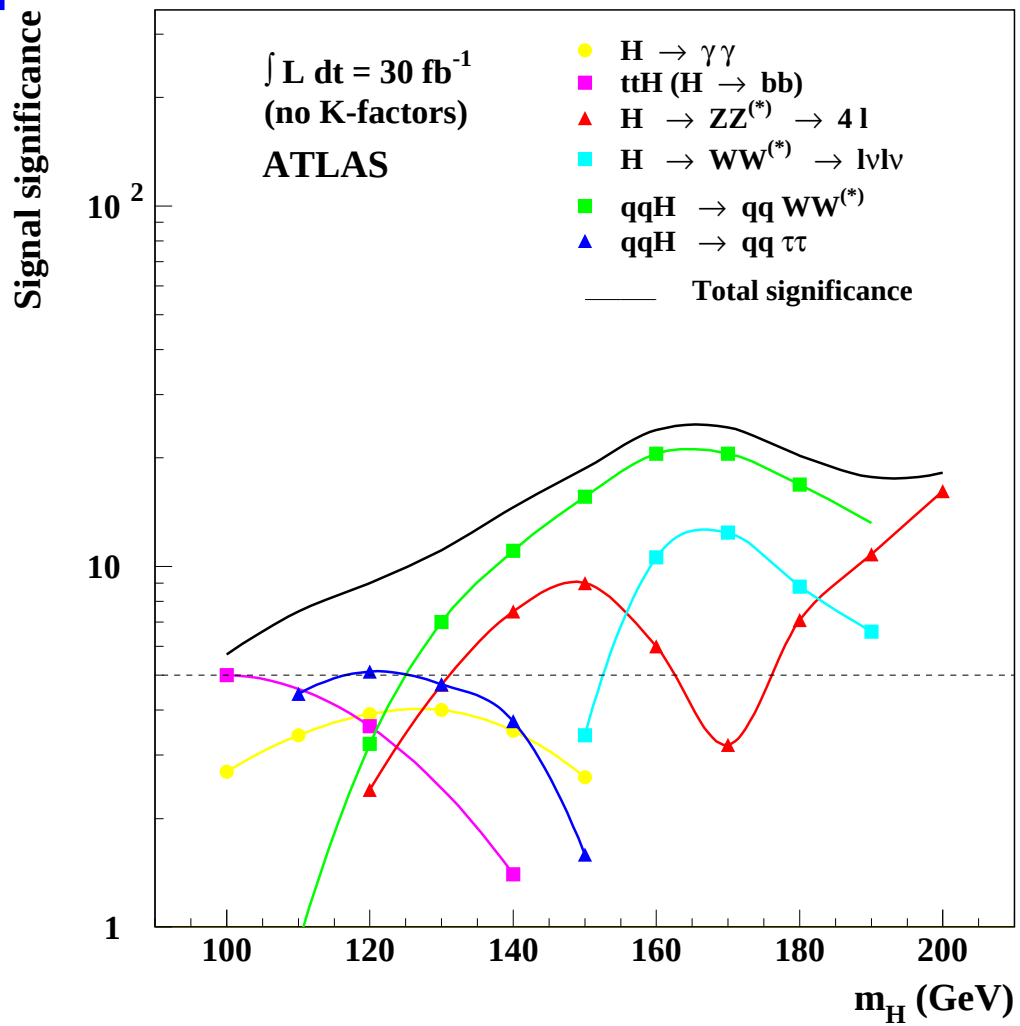


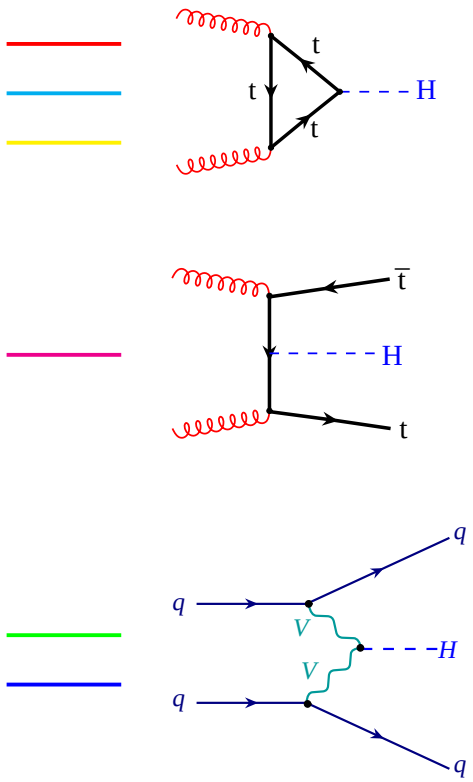
Discovery Potential



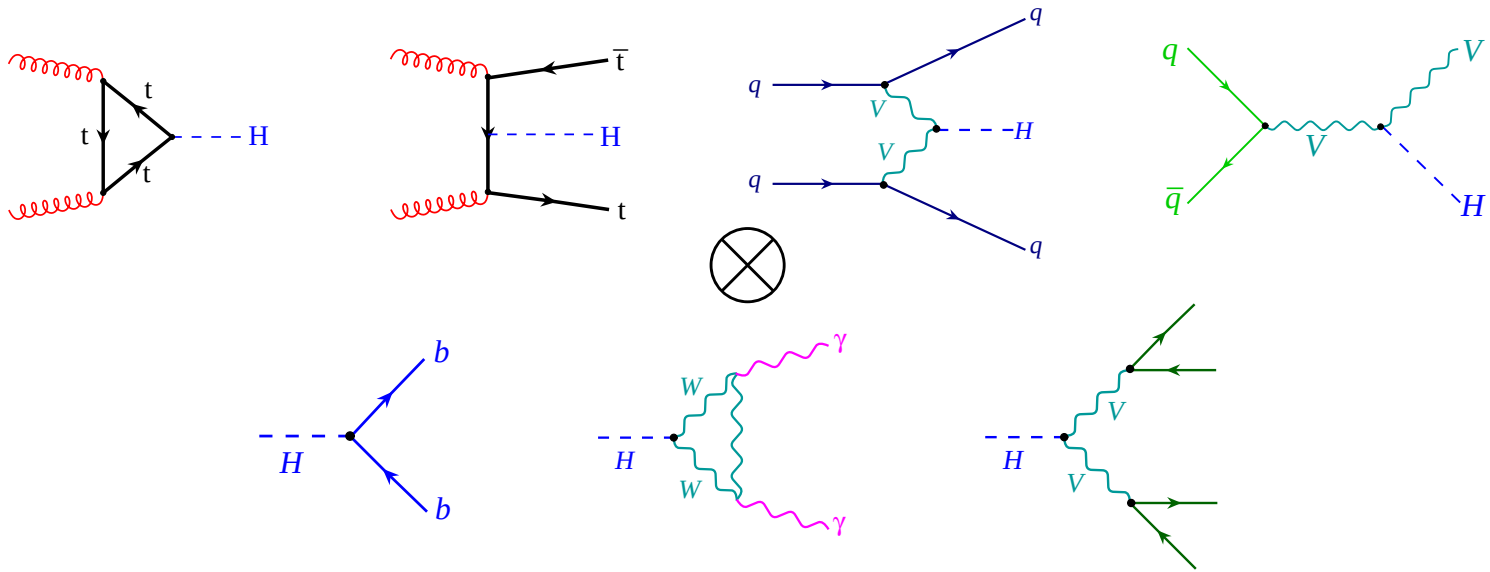


Discovery Potential

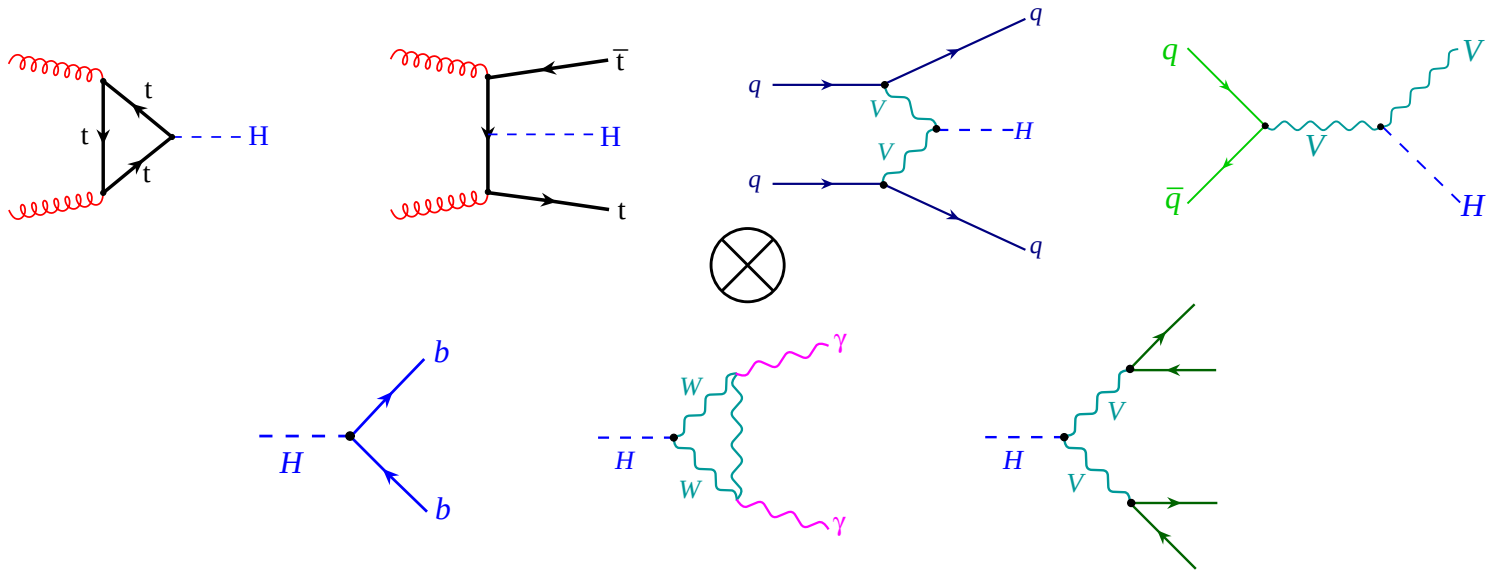




Coupling measurement



Coupling measurement



$$\Rightarrow \quad \frac{\Gamma_g \Gamma_\gamma}{\Gamma}, \quad \frac{\Gamma_g \Gamma_V}{\Gamma}, \quad \frac{\Gamma_V \Gamma_V}{\Gamma}, \quad \frac{\Gamma_V \Gamma_\tau}{\Gamma}, \quad \text{etc.}$$

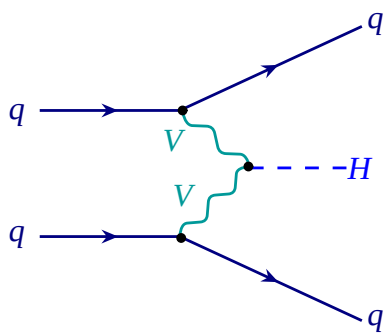
$$\Rightarrow \quad \frac{\Gamma_V}{\Gamma}\left(\Gamma_g + \Gamma_V + \Gamma_\tau + \ldots\right) = \Gamma_V$$

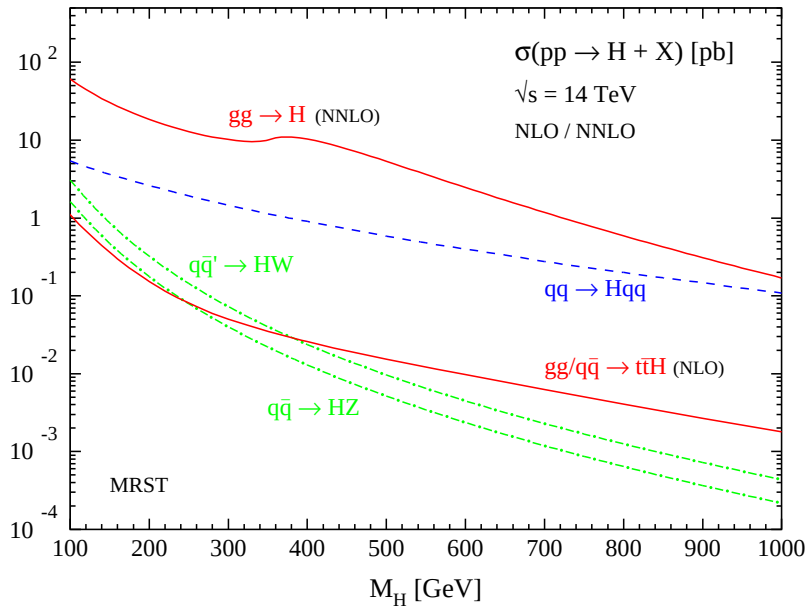
$$\Rightarrow \quad \Gamma_\gamma\,, \Gamma_g\,, \text{etc.}$$

[Zeppenfeld *et al.*], [Dührssen *et al.*]

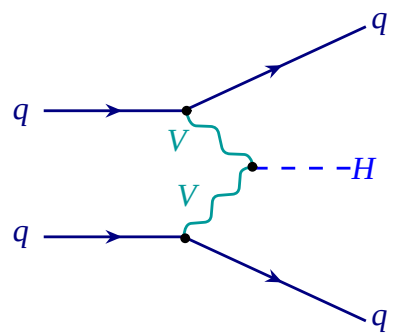
$\rightarrow$ couplings to 5-15% ($\mathcal{L}$=200 fb^{-1})

Weak Boson Fusion





Weak Boson Fusion



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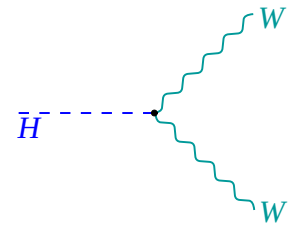
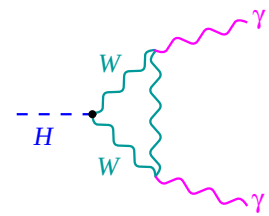
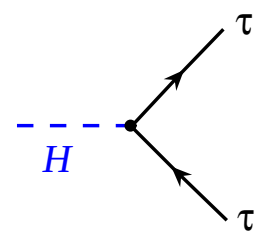


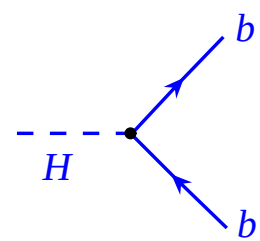
$M_H > 120\,\mathrm{GeV}$



$M_H < 150\,\mathrm{GeV}$



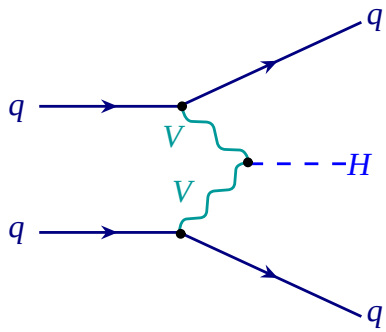
$M_H < 140\,\mathrm{GeV}$



$M_H < 140\,\mathrm{GeV}$

[Rainwater, Zeppenfeld; Eboli, Hagiwara, Kauer, Plehn, . . .]
[Mangano, Moretti, Piccinini, Pittau, Polosa ('03)]

WBF Signature



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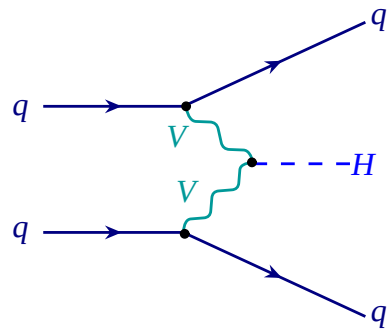

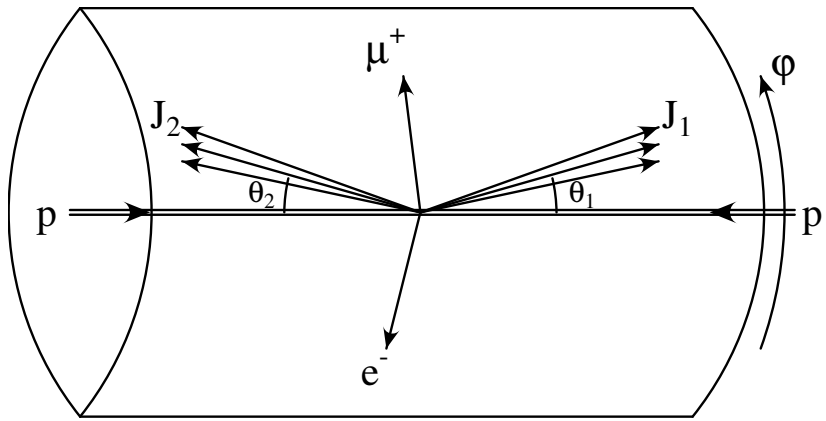

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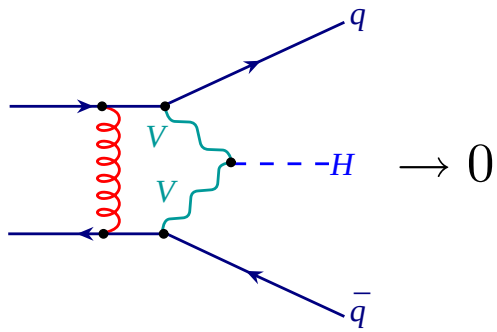

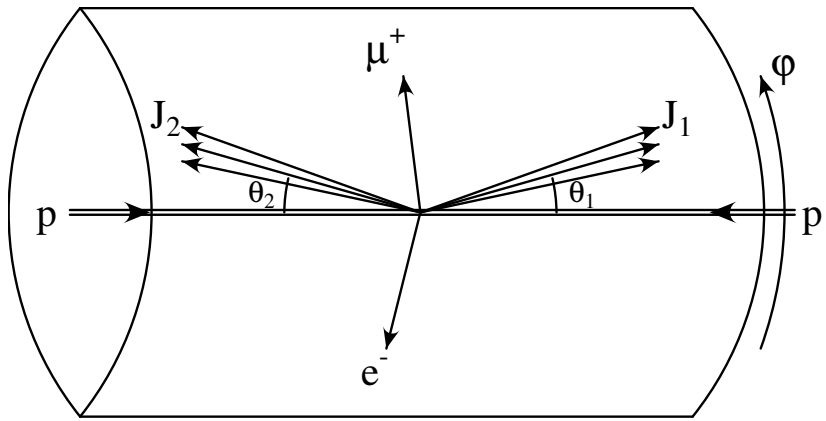

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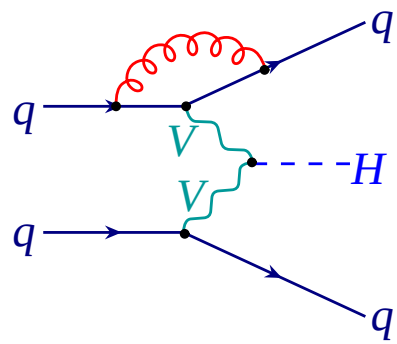
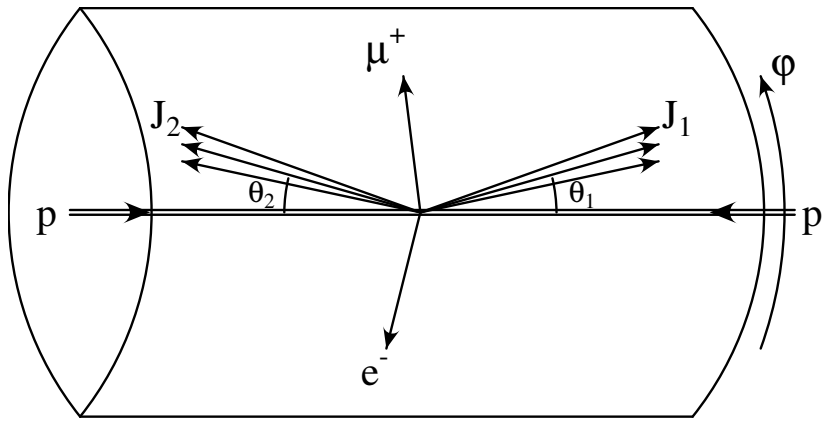
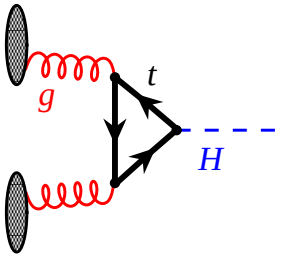


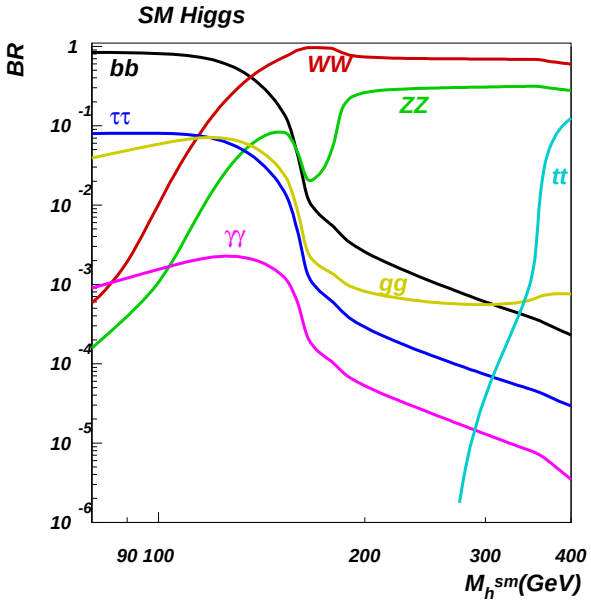


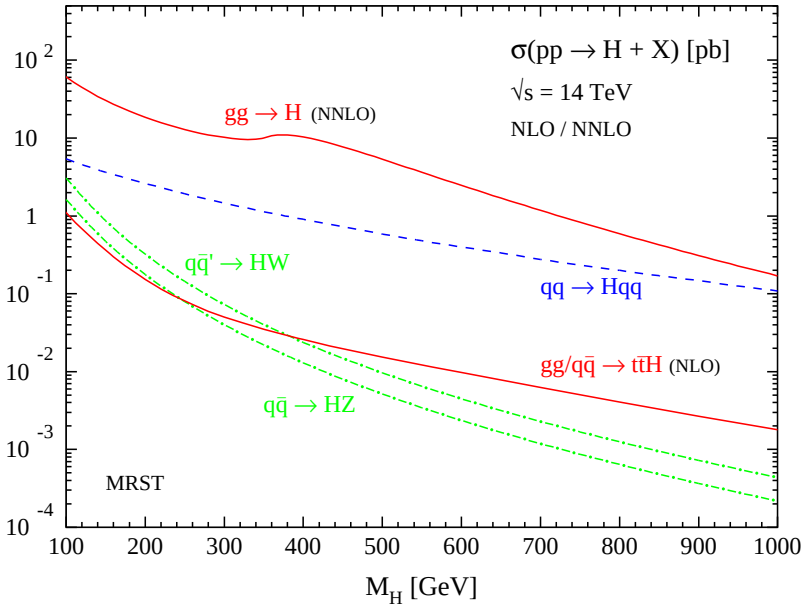
NLO: [Figy, Oleari, Zeppenfeld ('03)]

→ talk by B. Jäger

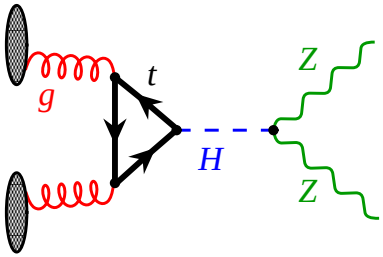
Gluon fusion

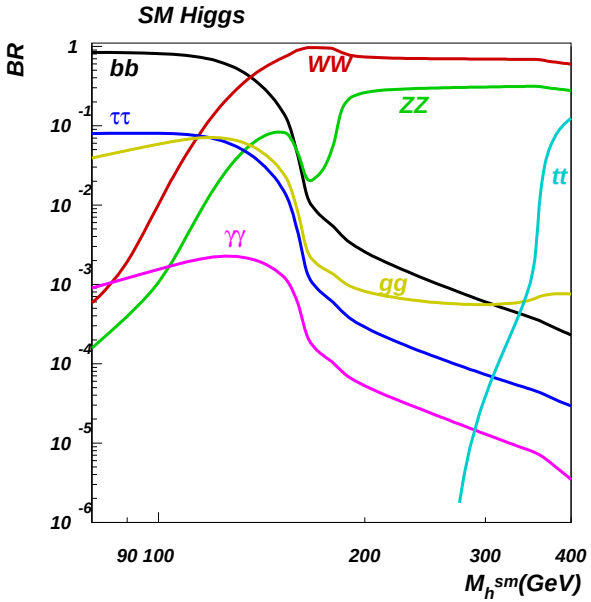


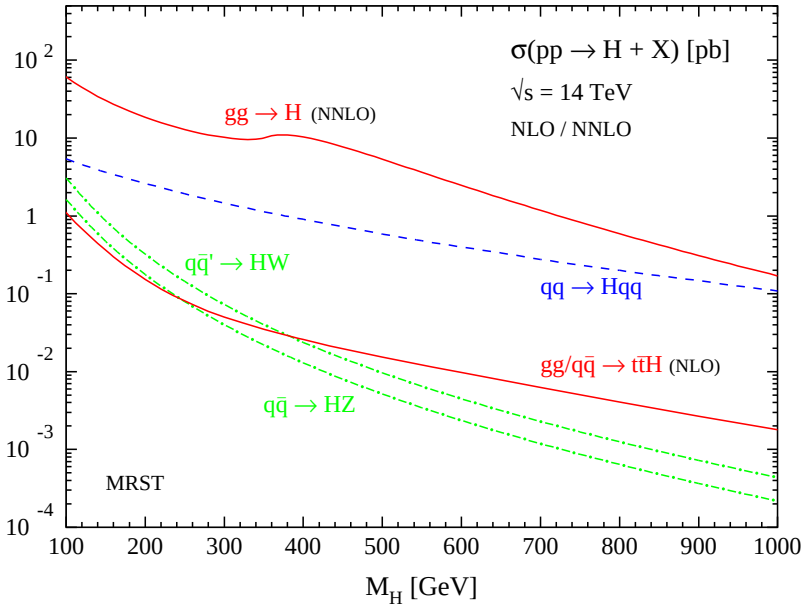




Gluon fusion







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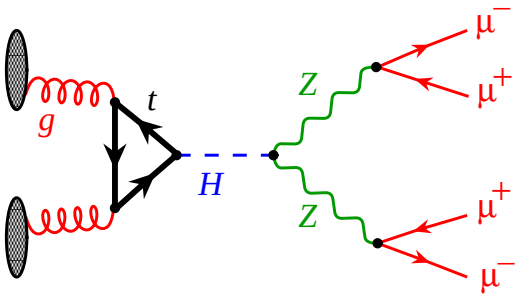
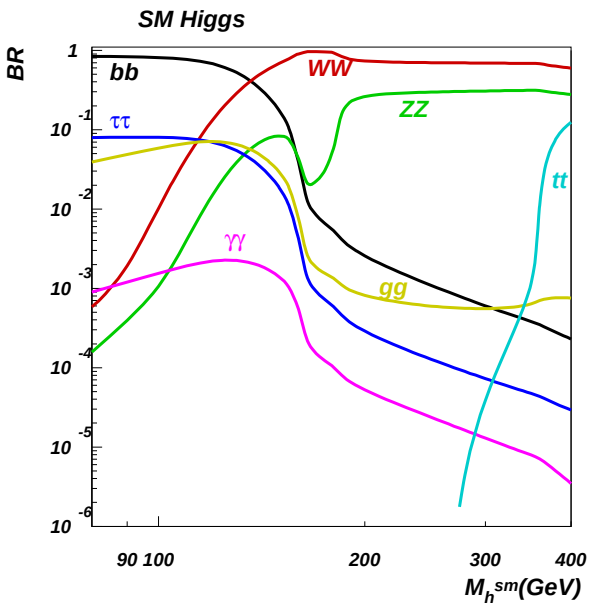
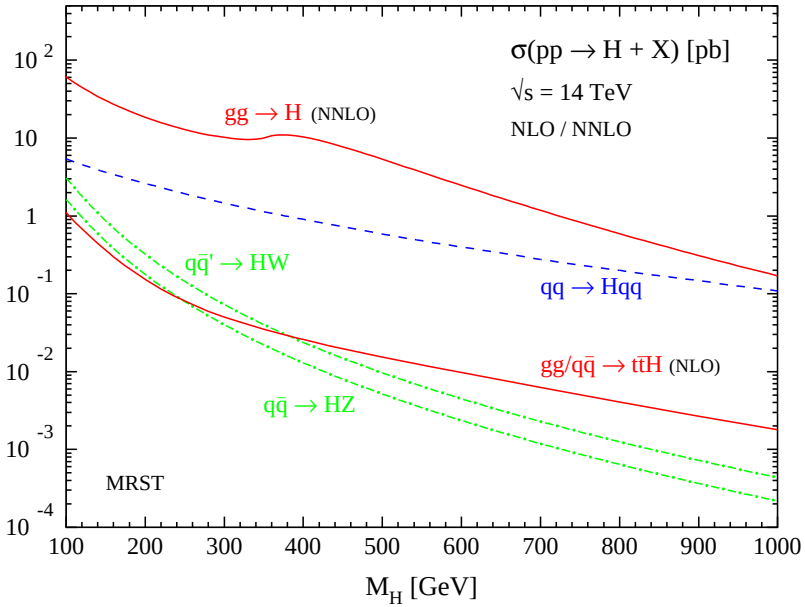
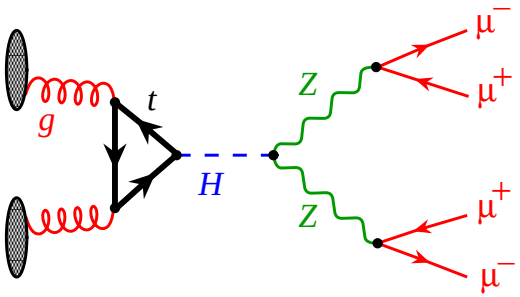
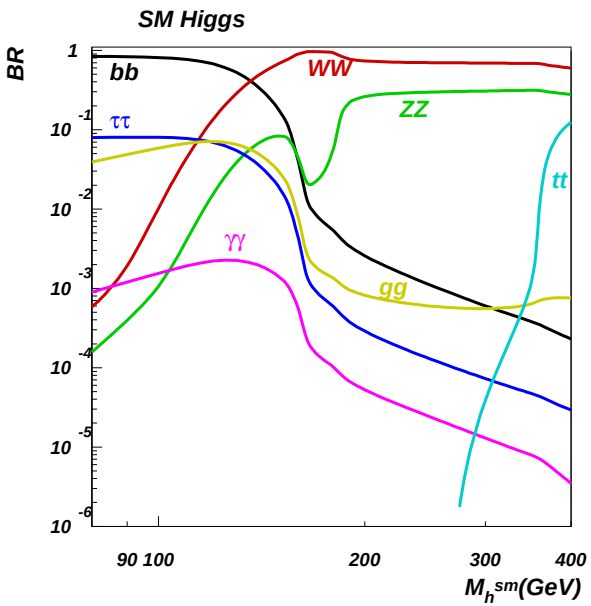


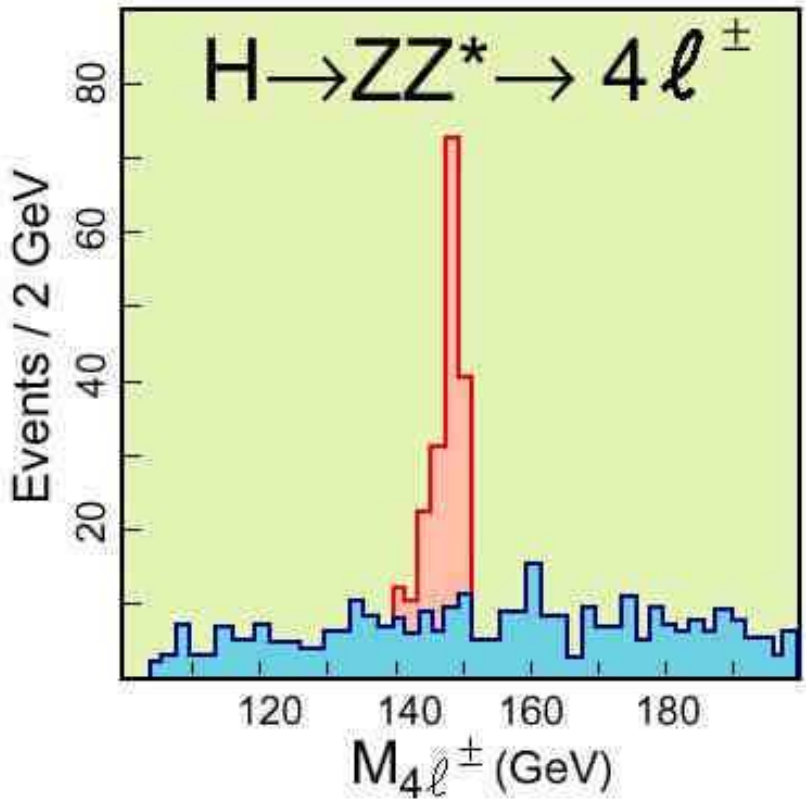




Gluon fusion







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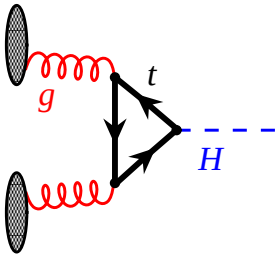

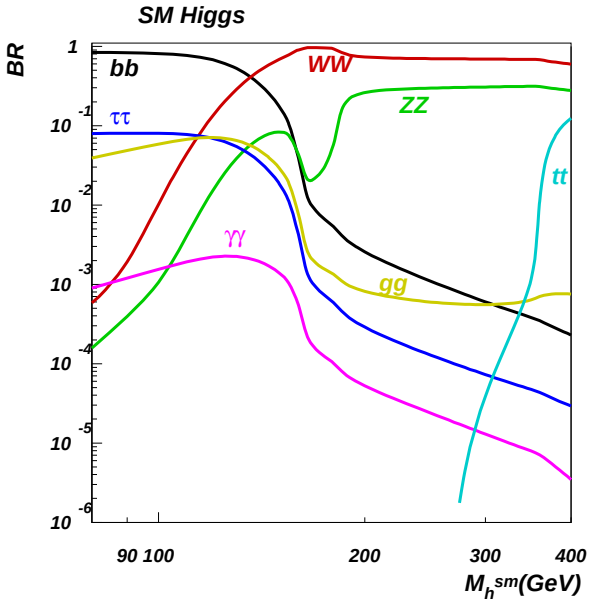

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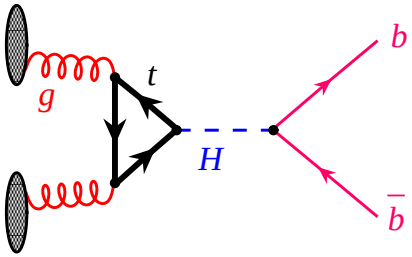

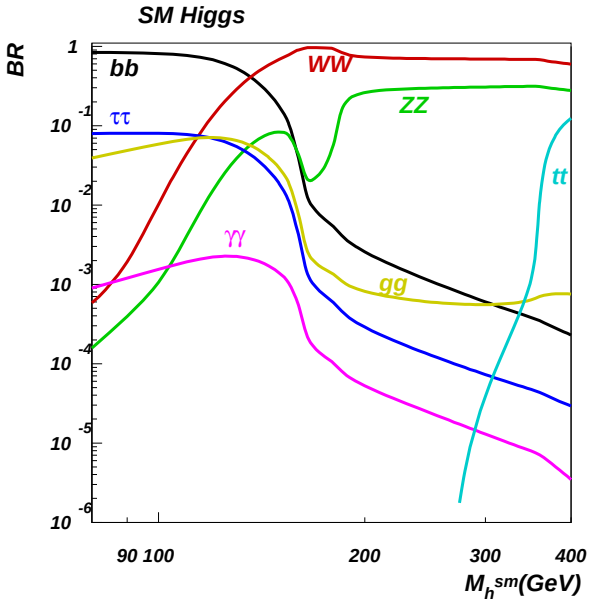

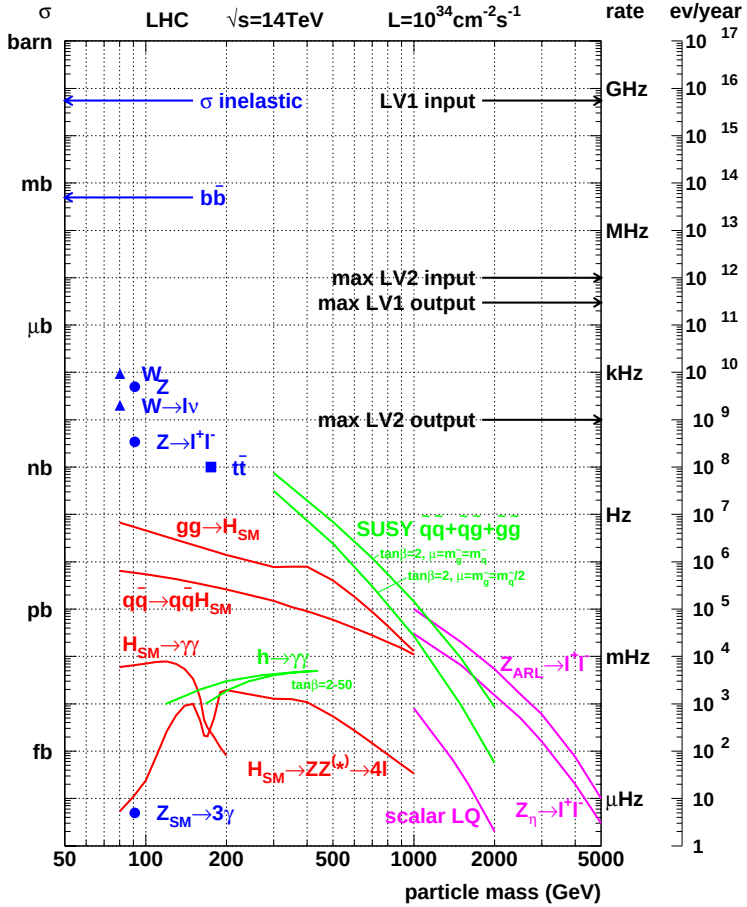

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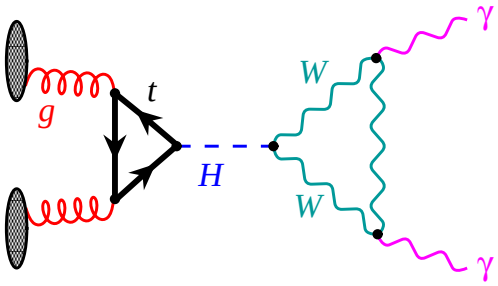
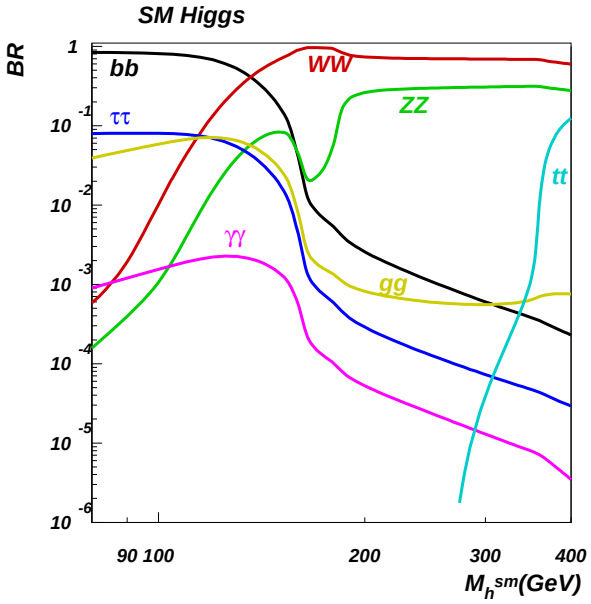
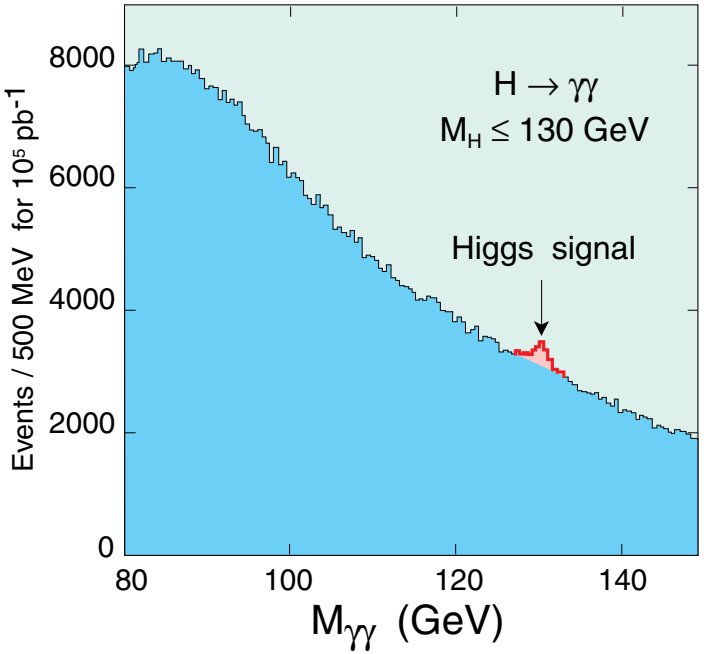
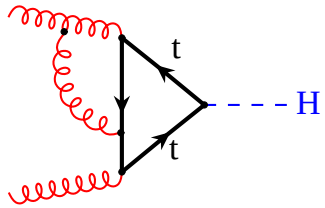
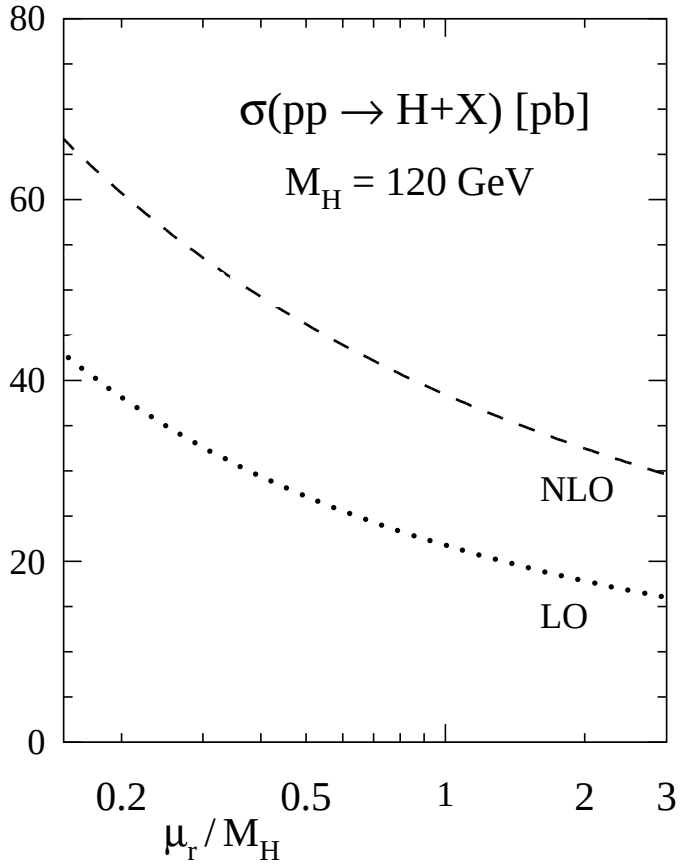






Gluon fusion

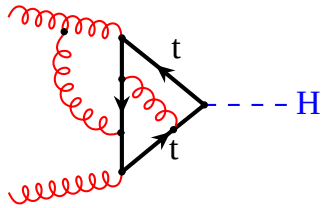


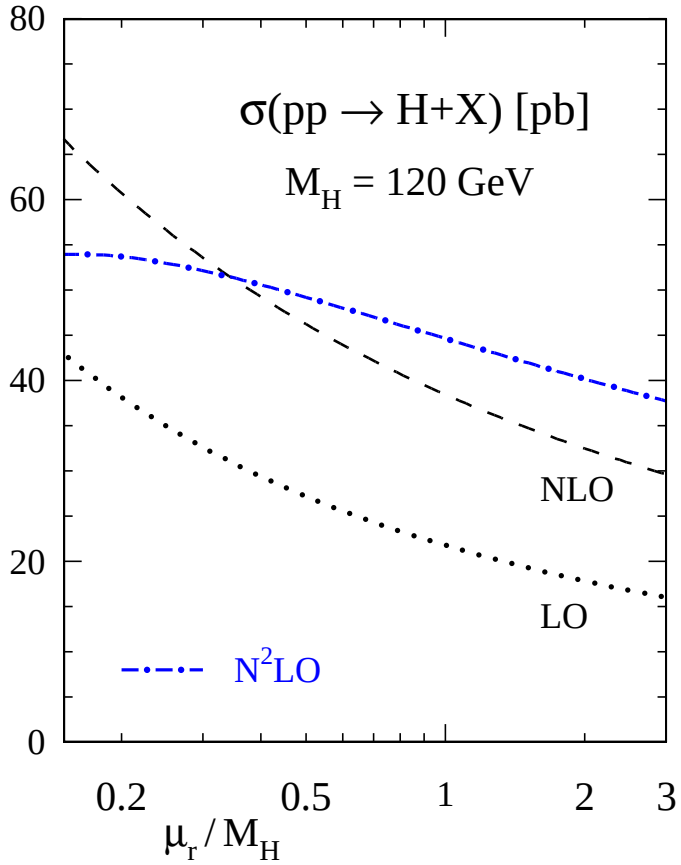


[Dawson ’91]

[Djouadi, Graudenz, Spira, Zerwas ’91,’93]

Gluon fusion

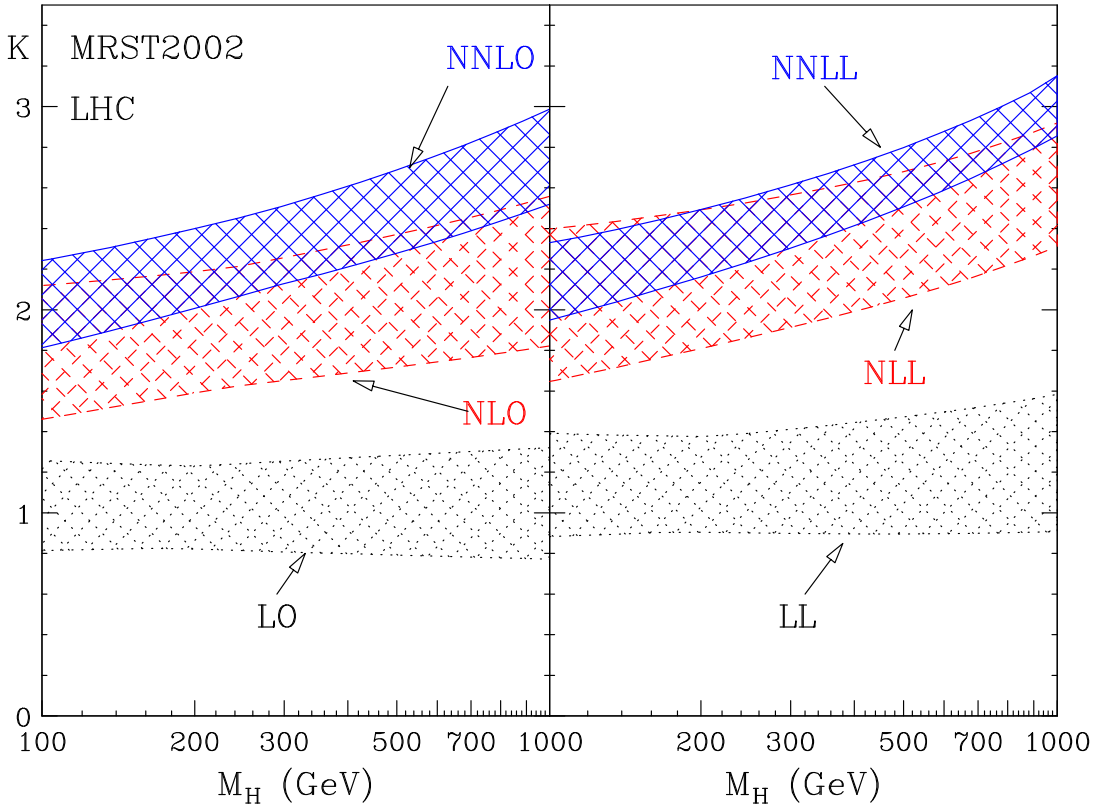




[R.H., Kilgore ’02]
[Anastasiou, Melnikov ’02]
[Ravindran, Smith, v.Neerven ’03]

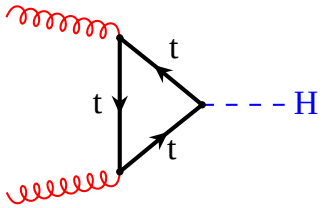
[Dawson ’91]
[Djouadi, Graudenz,
Spira, Zerwas ’91,’93]

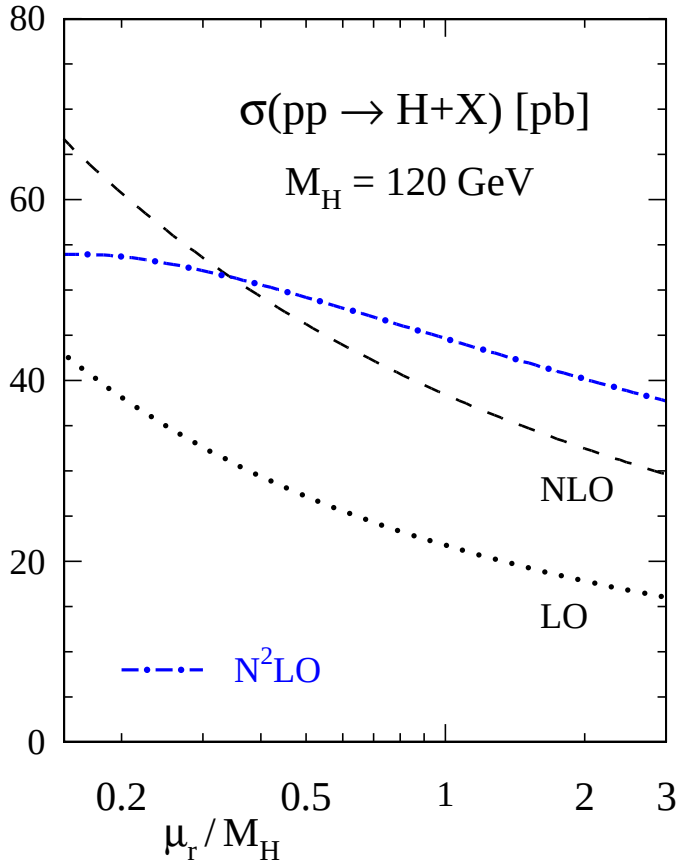
Resummation



[Catani, de Florian, Grazzini, Nason '03]

Gluon fusion





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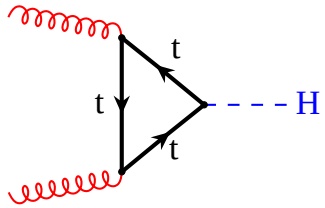
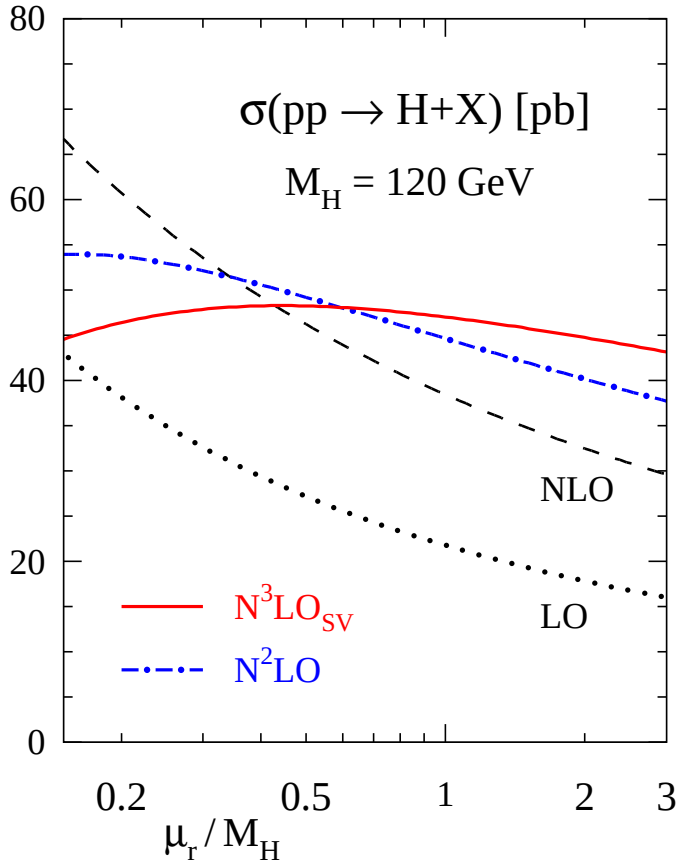
[Anastasiou, Melnikov ’02]
[Ravindran, Smith, v.Neerven ’03]

[Dawson ’91]
[Djouadi, Graudenz,
Spira, Zerwas ’91,’93]

Gluon fusion





[Moch, Vogt ’05]

[R.H., Kilgore ’02]
[Anastasiou, Melnikov ’02]
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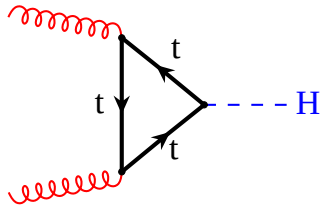
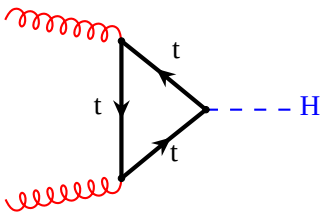


Electro-weak effects: max. $5 - 8\%$

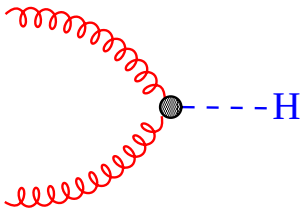
[Djouadi, Gambino ('94)]
[Aglietti, Bonciani, Degrassi, Vicini ('04)]
[Degrassi, Maltoni ('04)]

Side remark

- effective theory for $m_t \gg M_H$:



$\xrightarrow{m_t \gg M_H}$ $C(m_t, \alpha_s) \times$



$C(m_t, \alpha_s)$: [Chetyrkin, Kniehl, Steinhauser '96]
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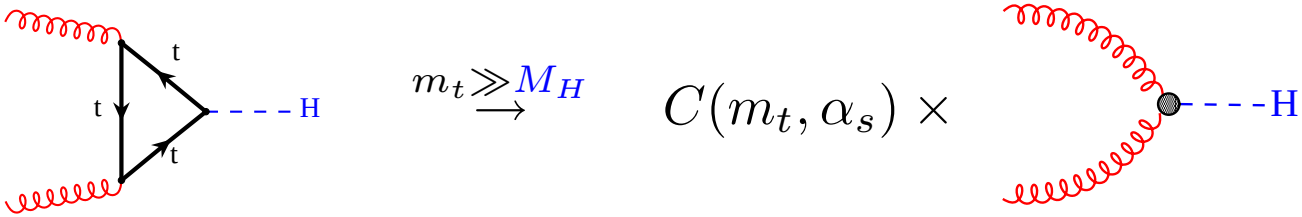

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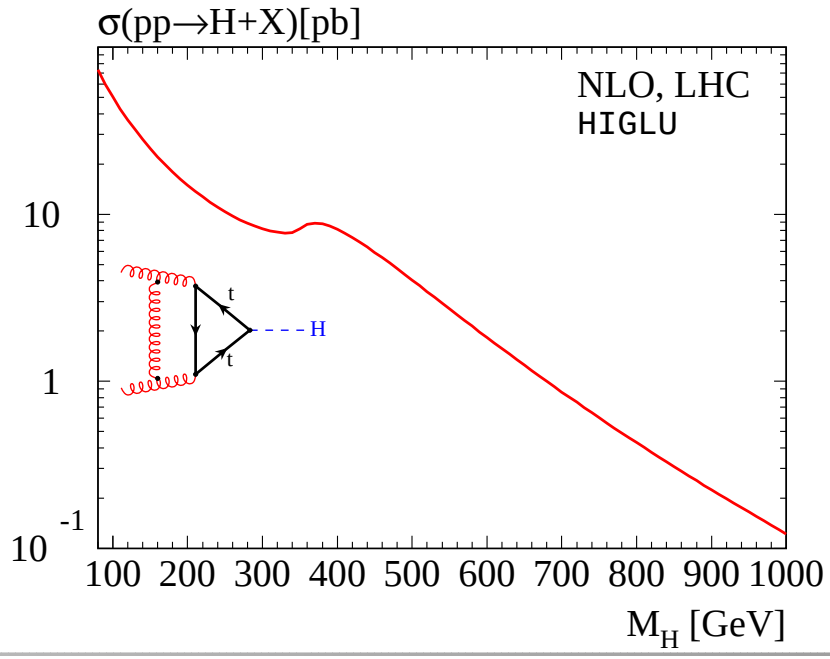

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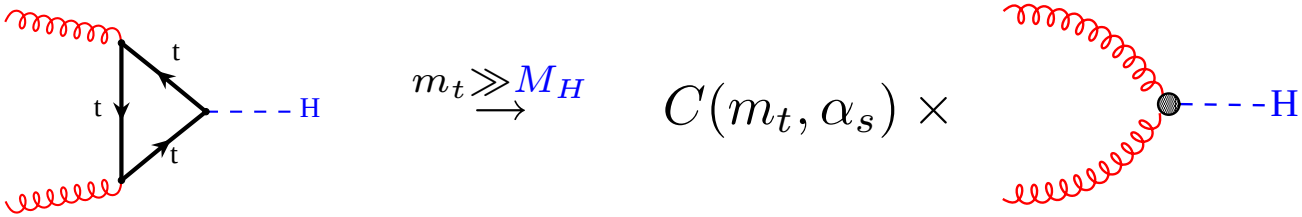

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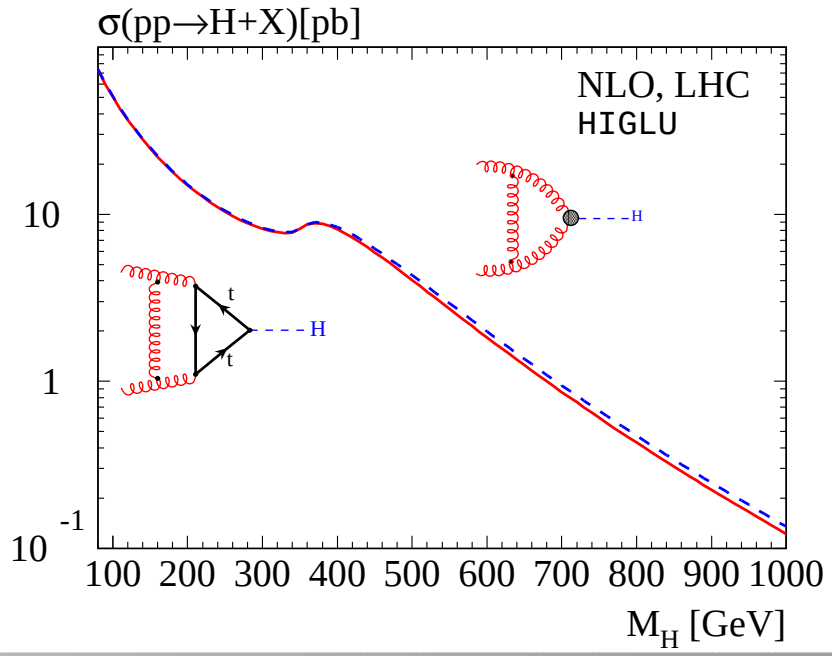

[Spira, Djouadi, Graudenz, Zerwas ('95)]

[S.Dawson ('91)]

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Importance of higher orders

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  $\longrightarrow$ scale dependence

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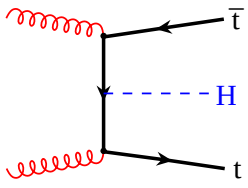

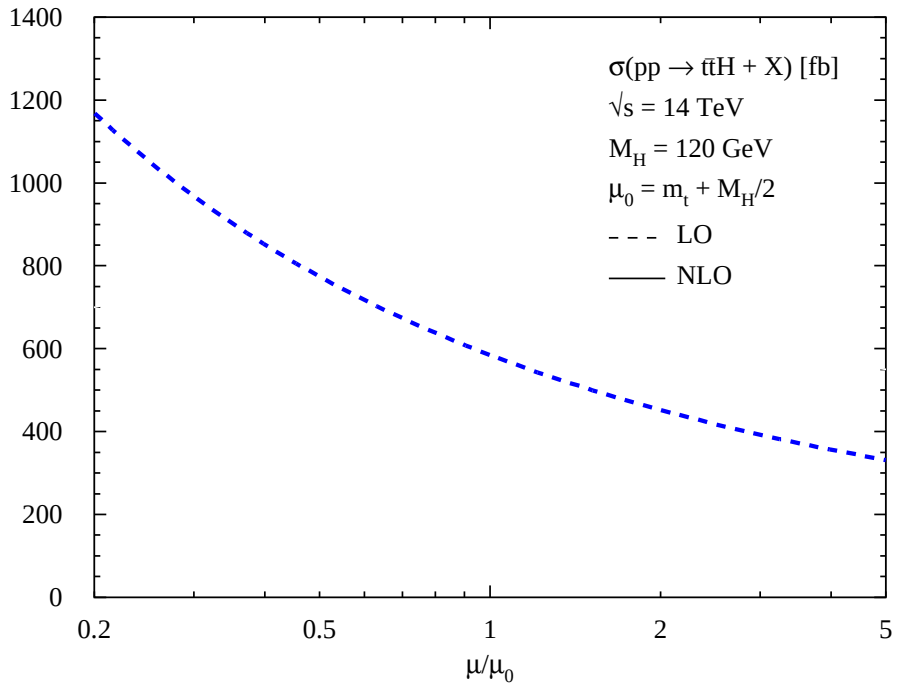

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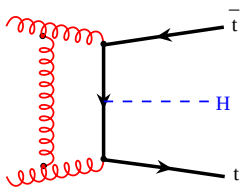

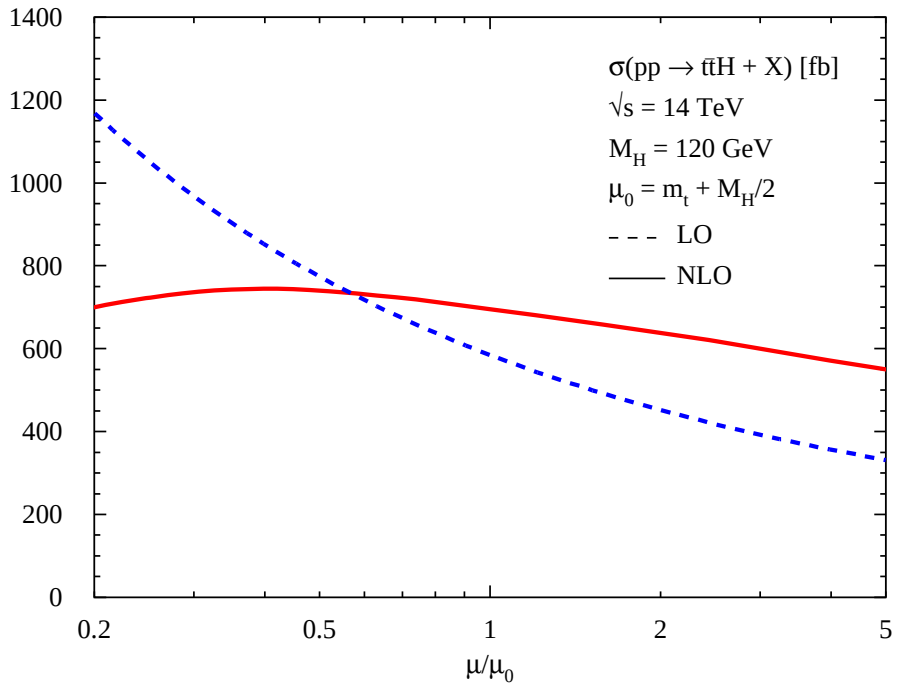

[Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas ’01]

[Dawson, Reina, Wackeroth, Orr, Jackson ’01-’03]

Distributions and Cuts

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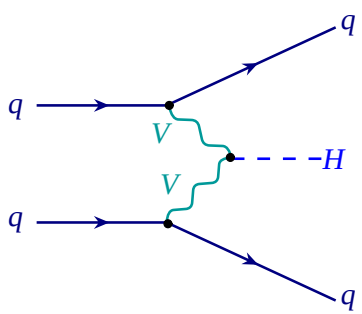

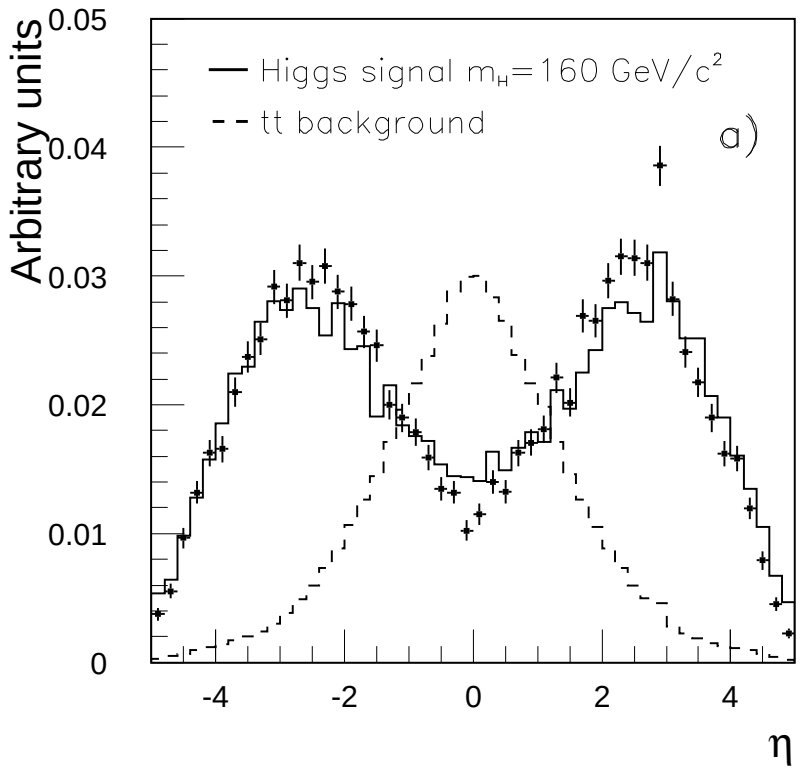

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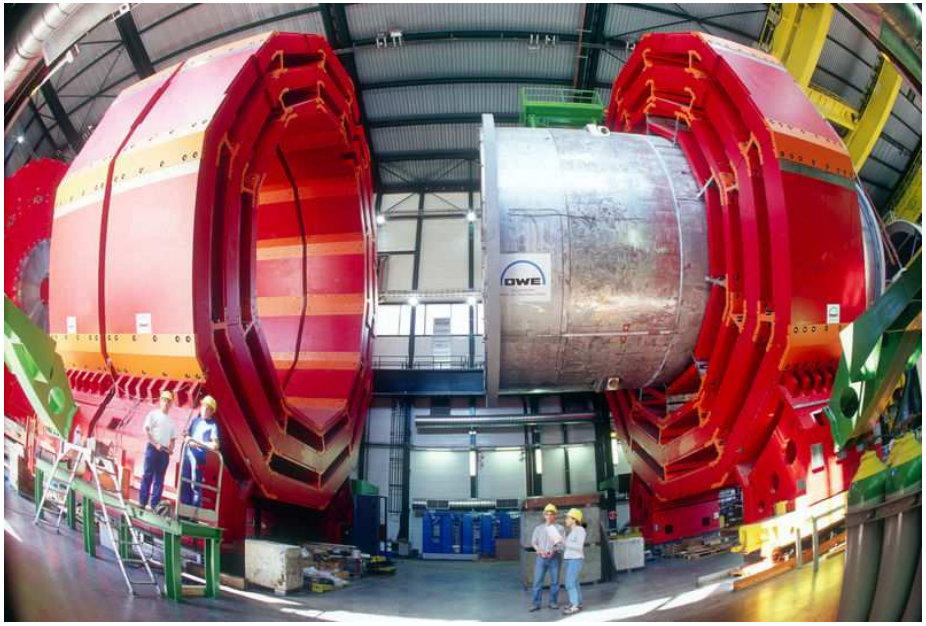
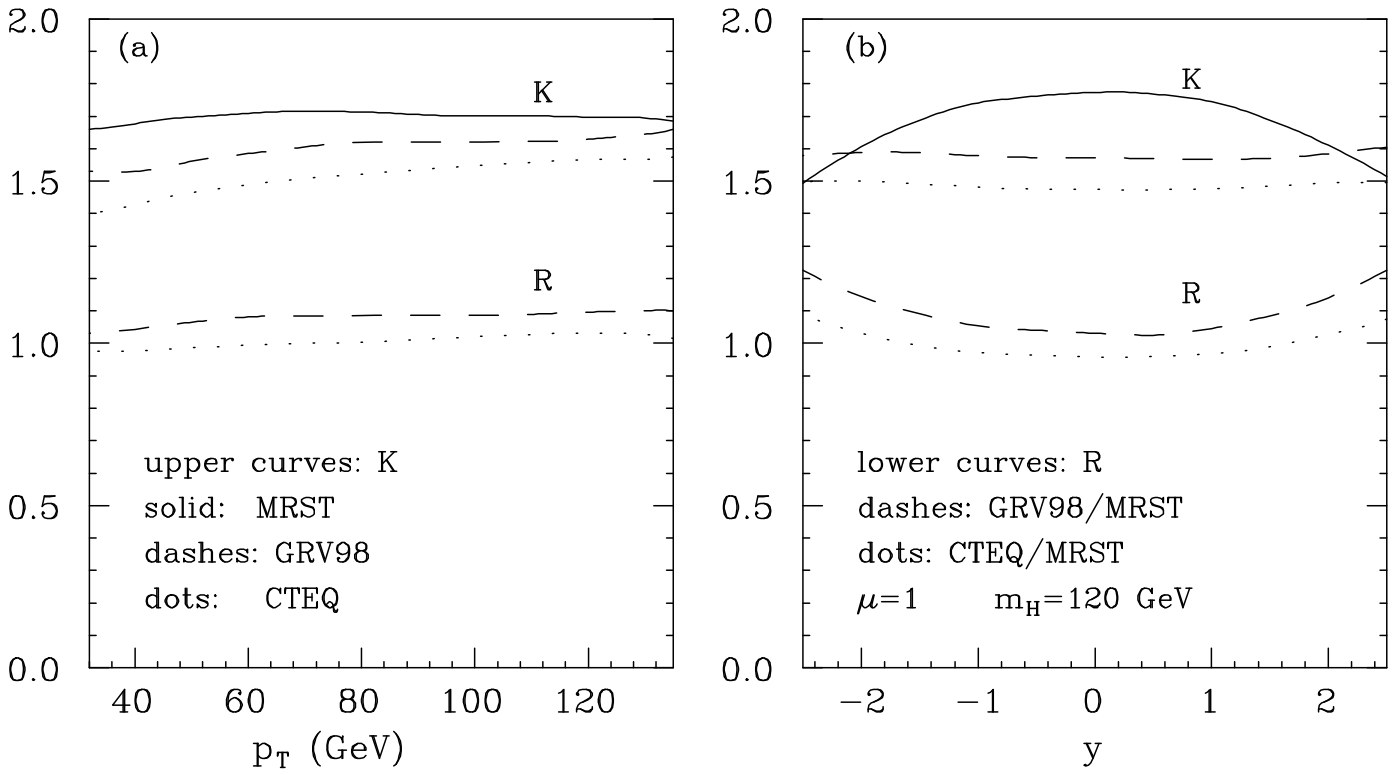
- there are no 4π detectors!



$K(p_T, y) \approx K_{\text{tot}}$?

$M_H = 120\,\text{GeV}$ from [de Florian, Grazzini, Kunszt '99]



see also [Glosser, Schmidt '02]
[Ravindran, Smith, v.Neerven '02]

Higher orders with Cuts

Consider $Z \to 2\,\text{jets}$: inclusive

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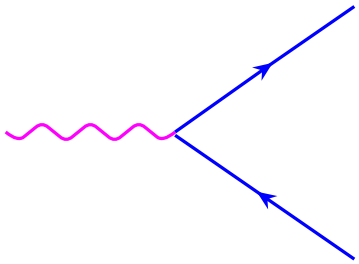
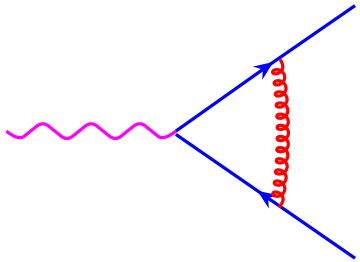
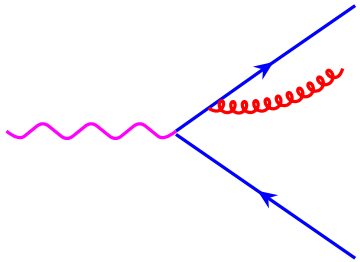


NLO:



$+ \int$



$$\frac{A}{\epsilon} + B \qquad -\frac{A}{\epsilon} + C \qquad = \qquad B + C$$

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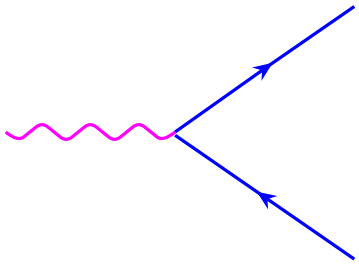

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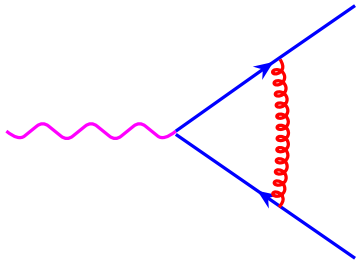
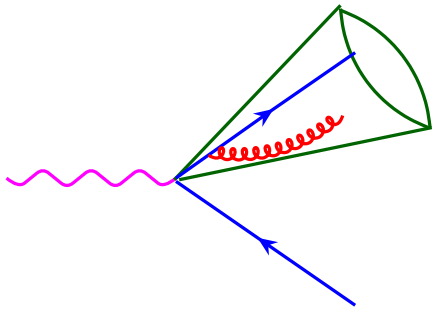


$+ \int_{\text{cone}}$



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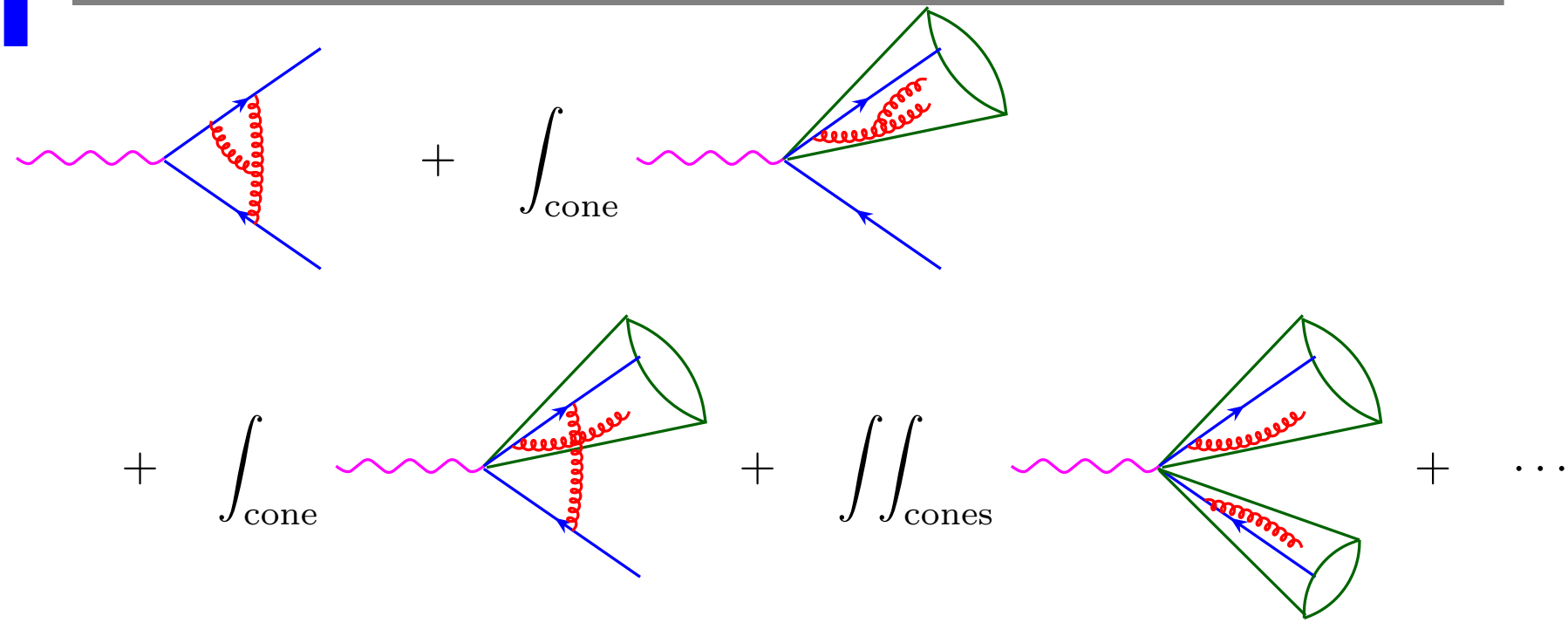
Exclusive at NNLO

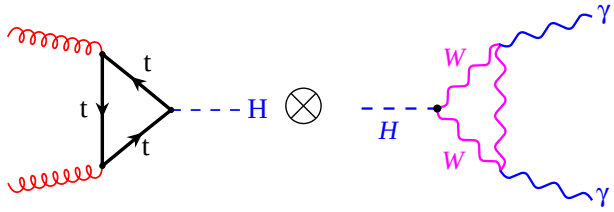


Very active field:

[Anastasiou, Melnikov, Petriello], [Gehrmann, G.-de Ridder, Glover],

[Grazzini, Frixione], [Kilgore], [Kosower], [Somogyi, Trocsanyi, Del Duca], [Weinzierl]

NNLO with cuts



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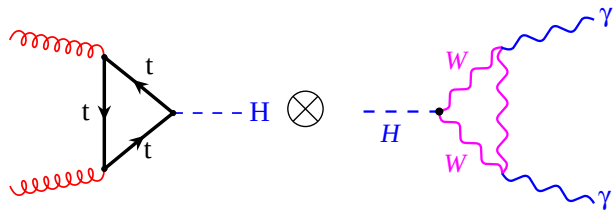

m_h	$\sigma^{\text{cut}}_{\text{NNLO}}/\sigma^{\text{inc}}_{\text{NNLO}}$	$K^{(2)}_{\text{cut}}/K^{(2)}_{\text{inc}}$
110	0.590	0.981
115	0.597	0.968
120	0.603	0.953
125	0.627	0.970
130	0.656	1.00
135	0.652	0.98

[Anastasiou, Melnikov, Petriello '05]

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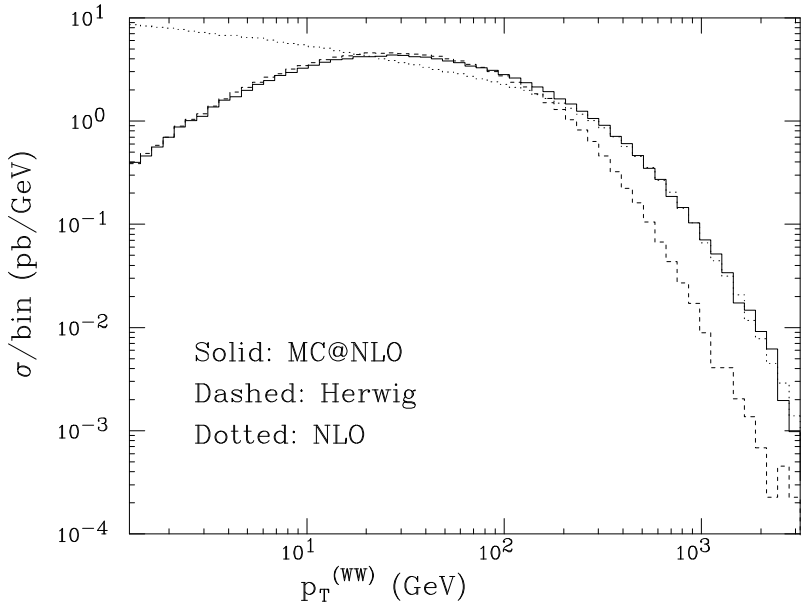

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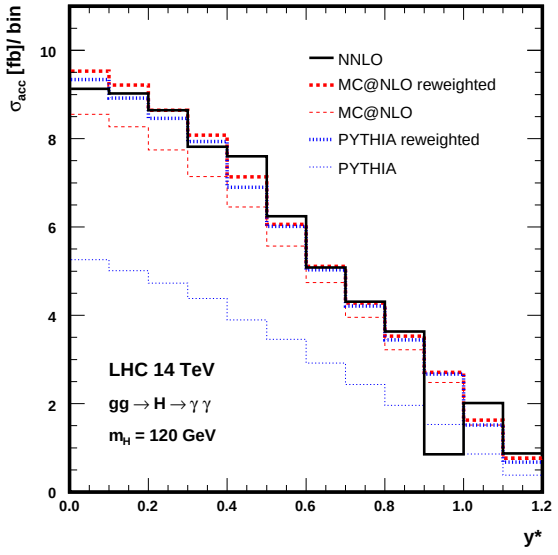

Decays

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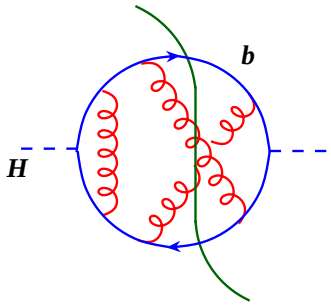

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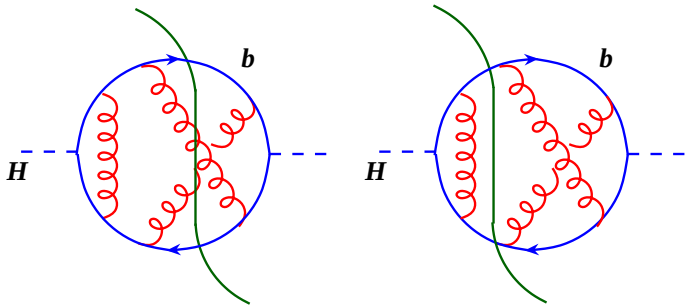

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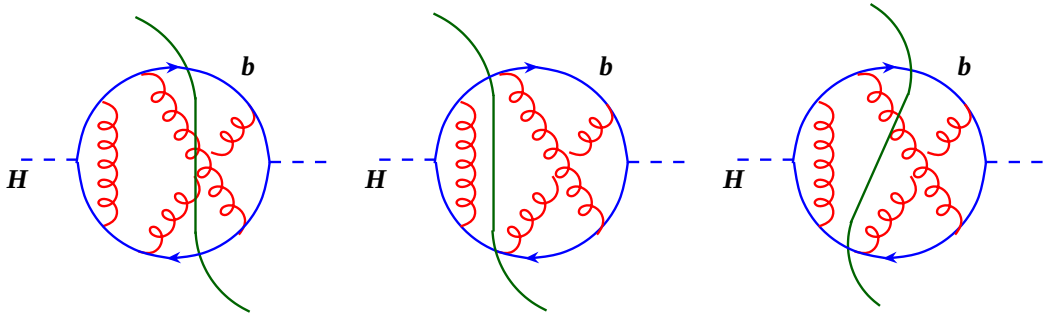

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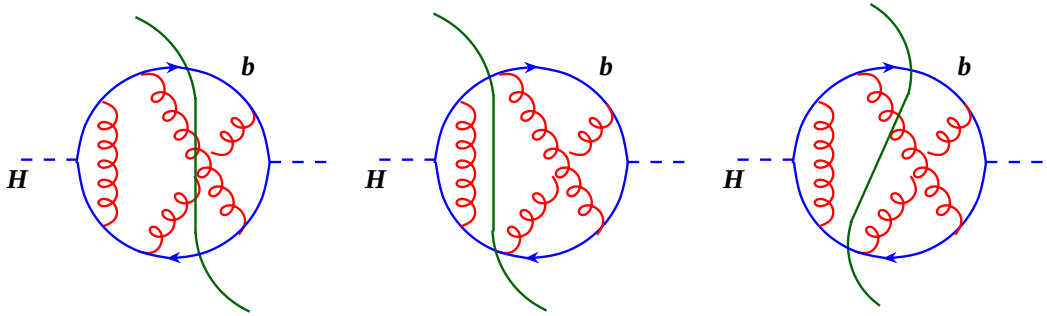

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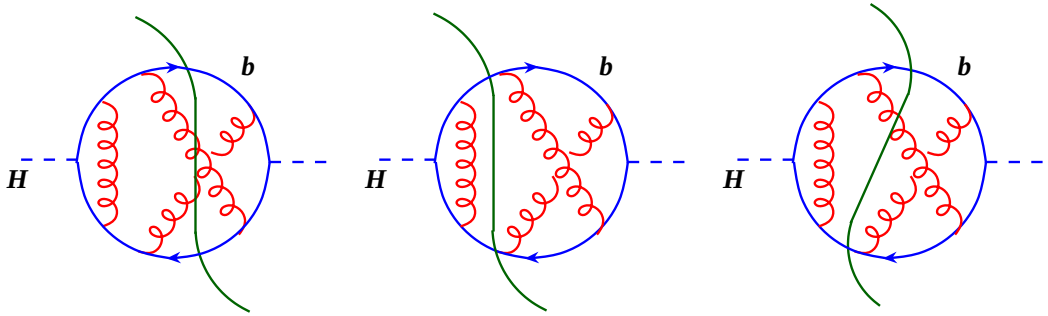

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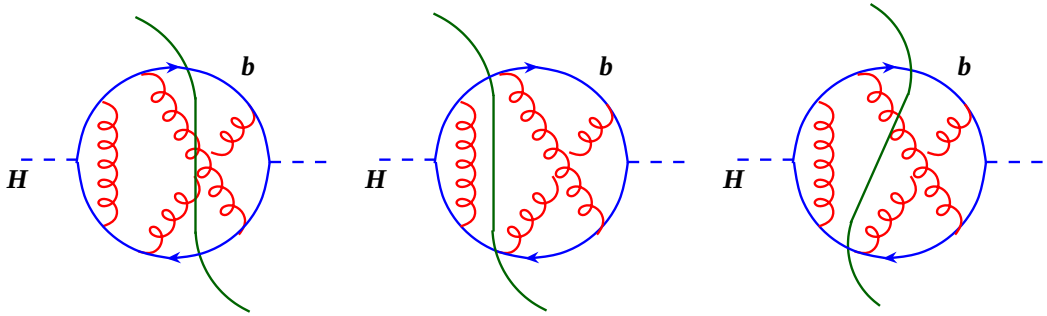

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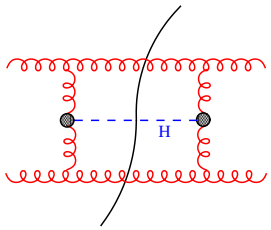
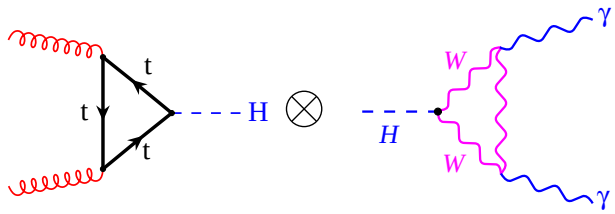
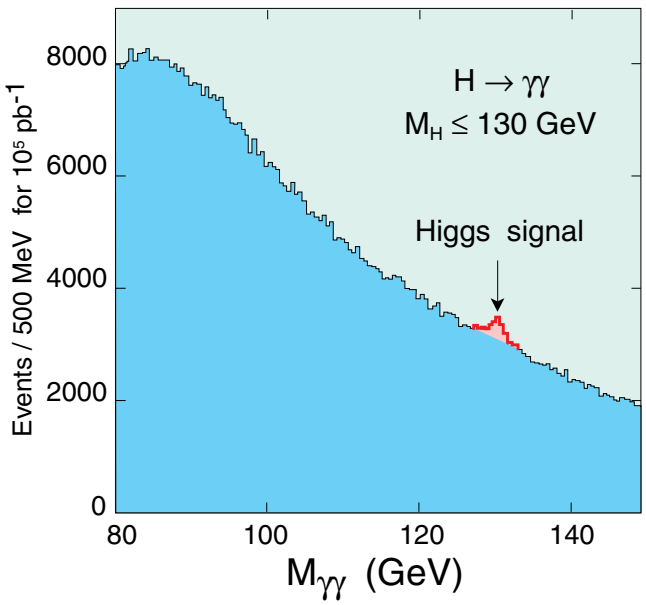
- remark: 

$$\delta(p^2 - m^2) \to \frac{1}{2\pi i}\left[\frac{1}{p^2 - m^2 - i\epsilon} - \frac{1}{p^2 - m^2 + i\epsilon}\right]$$

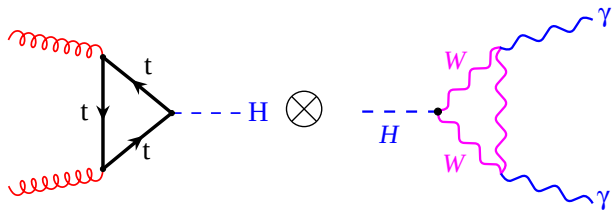
$\longrightarrow$ use multi-loop techniques for phase space integrals! [Anastasiou, Melnikov]

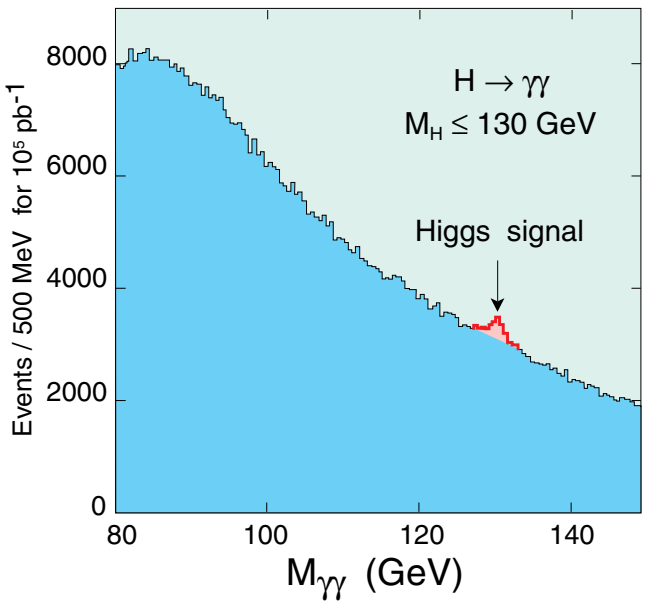
Backgrounds



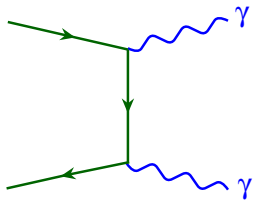


Backgrounds





VS.



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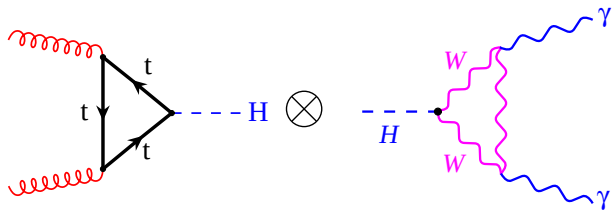

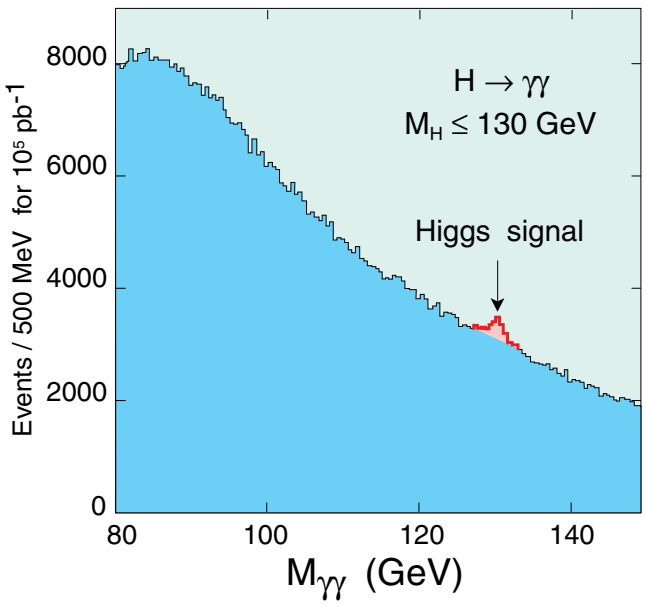

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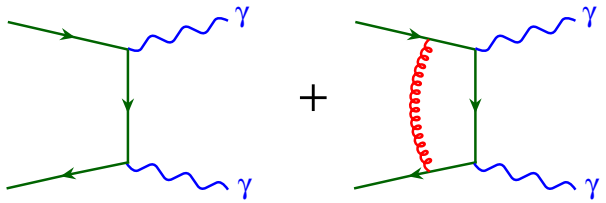
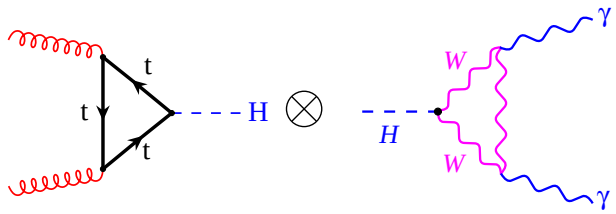
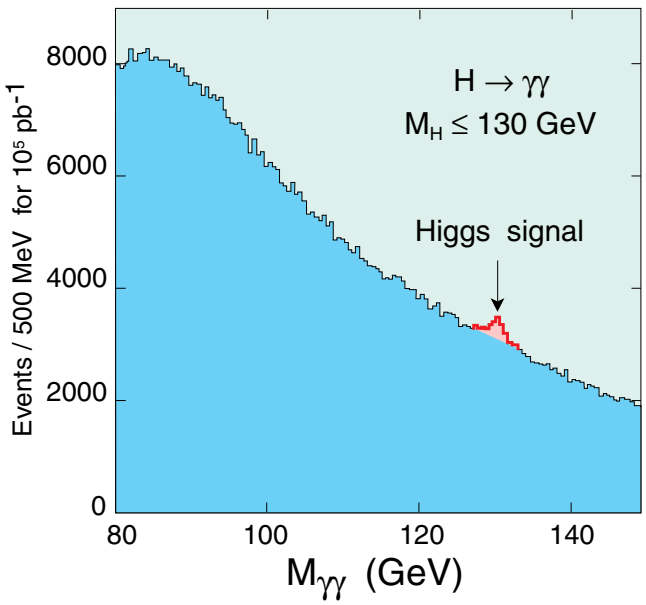


[Binoth, Guillet, Pilon, Werlen ’00]

Backgrounds





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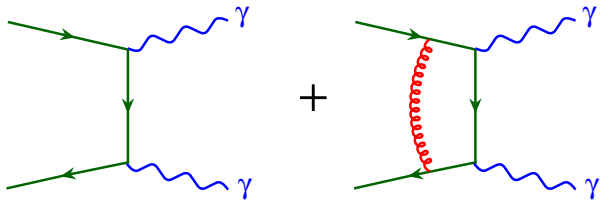
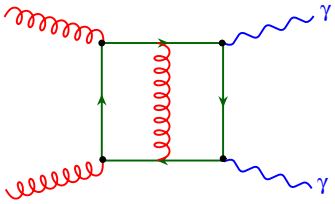
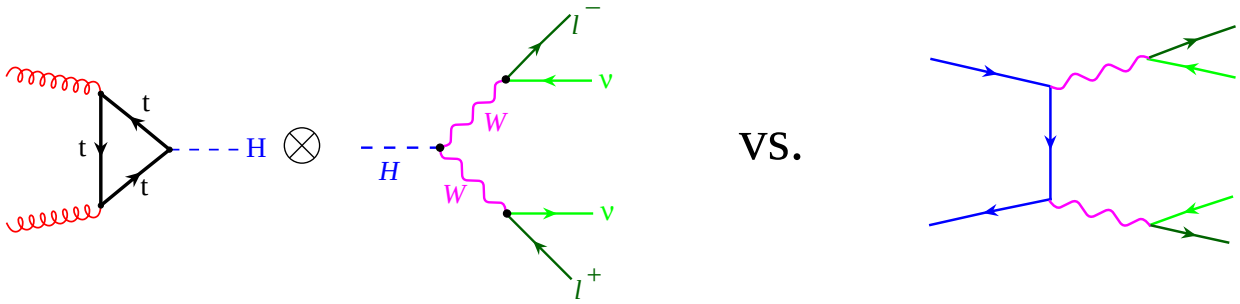


[Binoth, Guillet, Pilon, Werlen ’00]



[Bern, Dixon, Schmidt ’02]

Backgrounds



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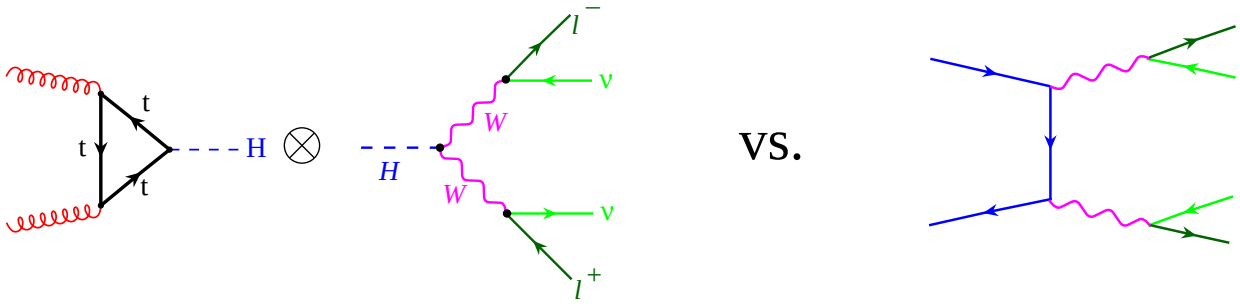

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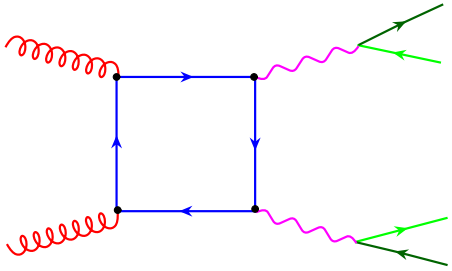

up to 30% of NLO $q\bar{q}$

[Binoth, Cicciolini, Kauer, Krämer '05]
[Dührssen, Jakobs, Marquard, v.d. Bij '05]

→ talk by N. Kauer

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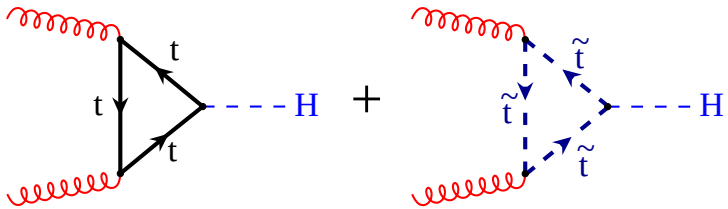

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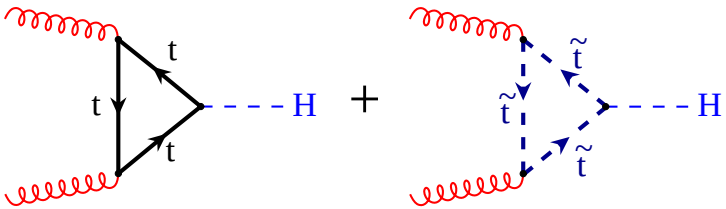
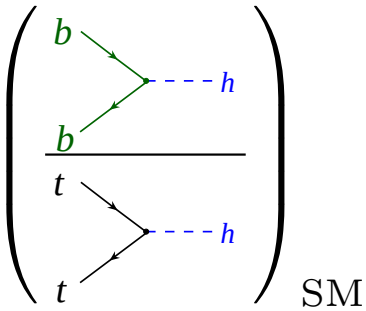
- 

- 

$\mathrm{SM} \quad = \dfrac{m_b}{m_t}$

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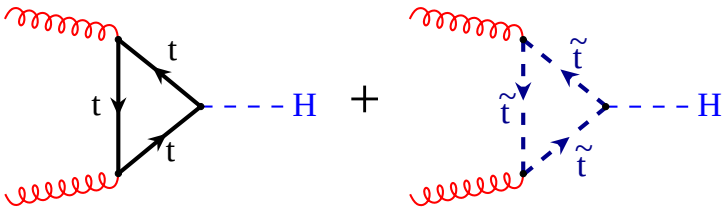
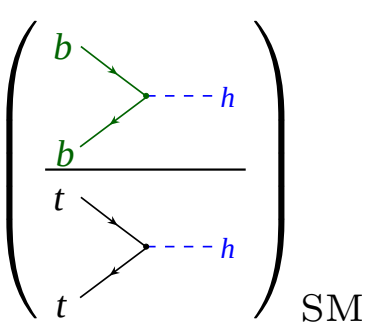
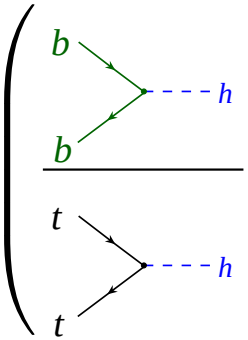
- 

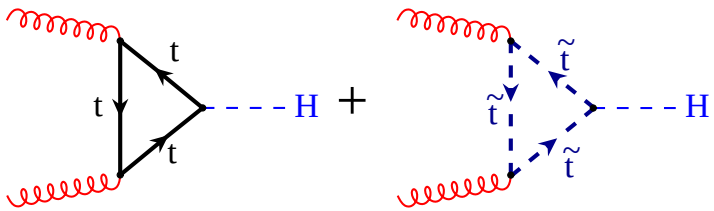
- 

$_{\text{SM}} = \dfrac{m_b}{m_t}$, 

$_{\text{MSSM}} = \dfrac{m_b}{m_t} \cdot \tan\beta$

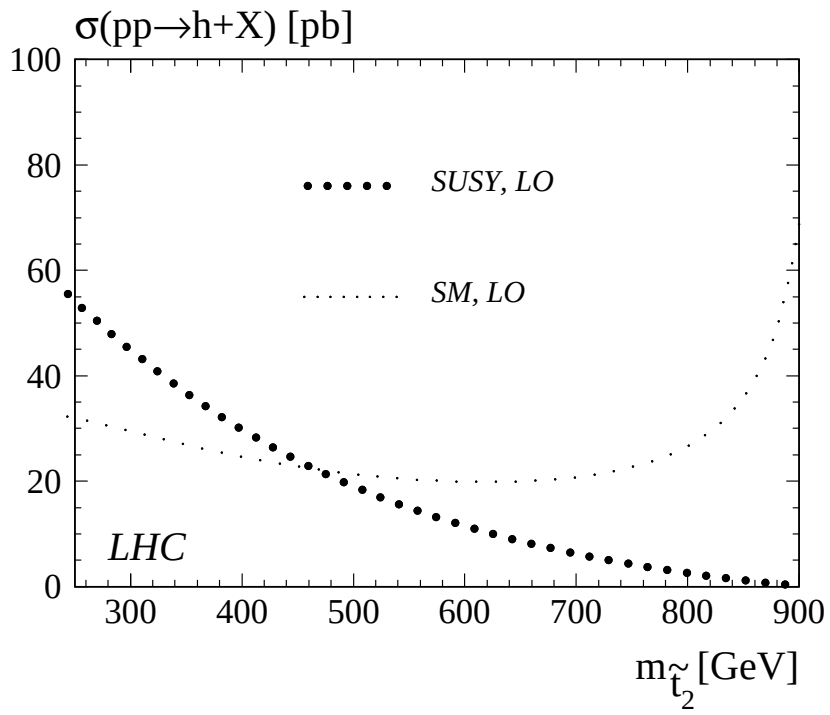
Example: “gluophobic Higgs”

[Djouadi ’98], [Carena *et al.* ’99]



may interfere destructively!

$$m_{\tilde{t}_1} = 200\,\text{GeV}$$
$$m_{\tilde{g}} = 1\,\text{TeV}$$
$$\tan\beta = 10\,, \quad \alpha = 0\,,$$
$$\theta_t = \frac{\pi}{4}$$



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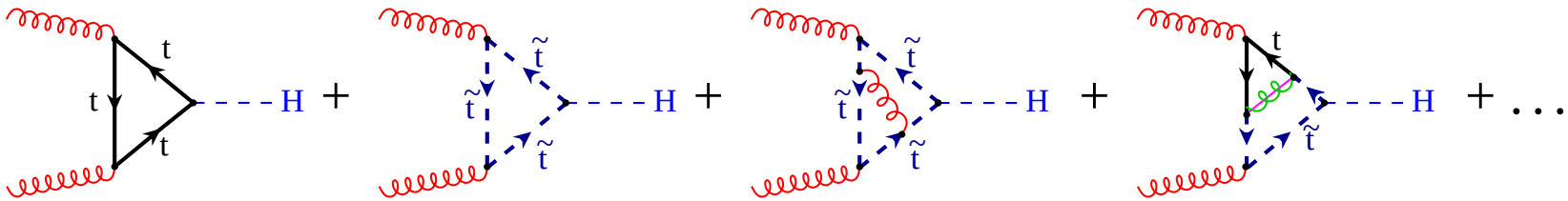

[R.H., Steinhauser ’04]

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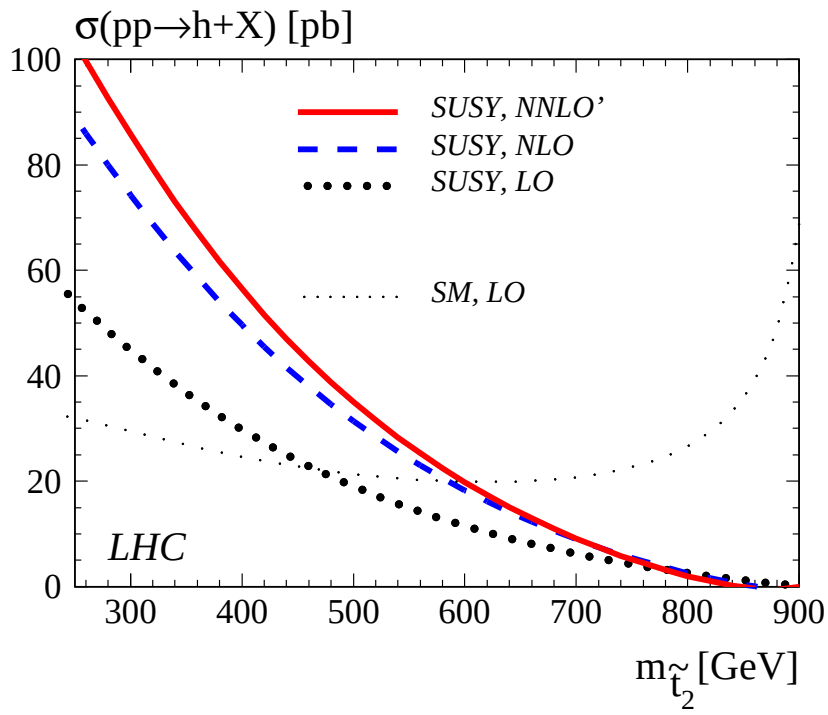

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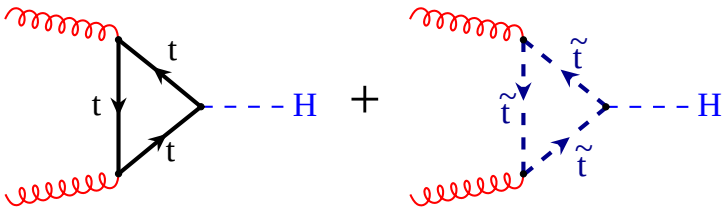
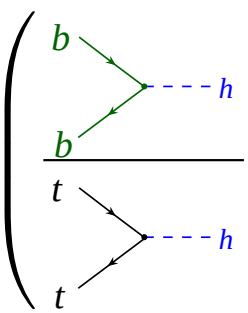
- 

- 

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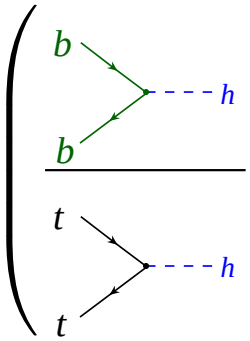

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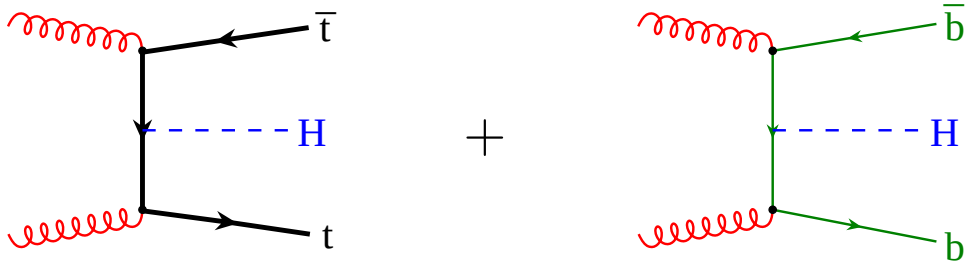

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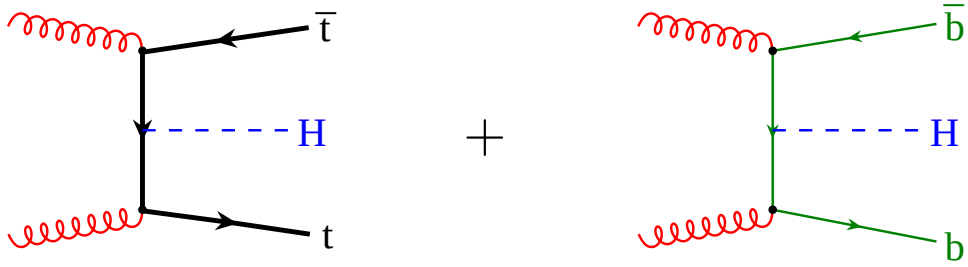

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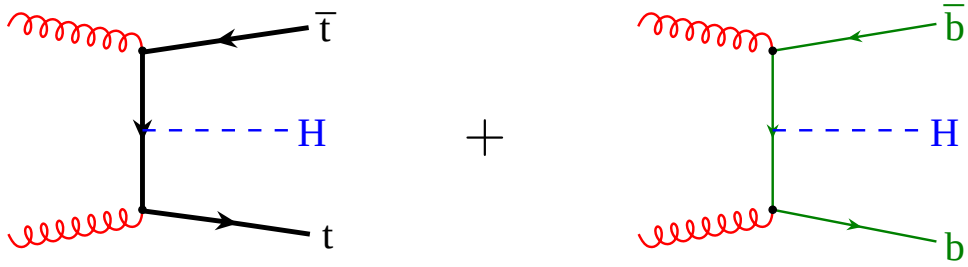

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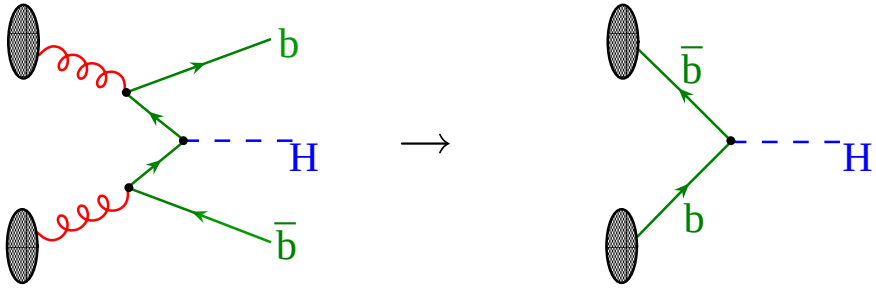
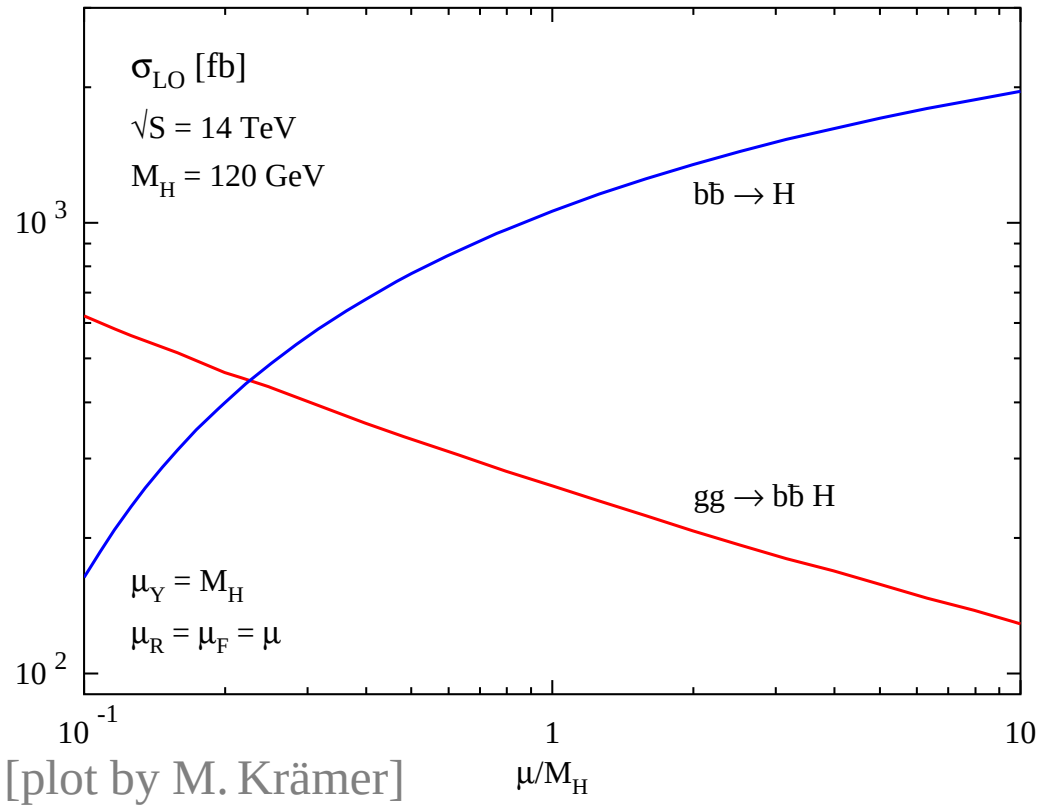
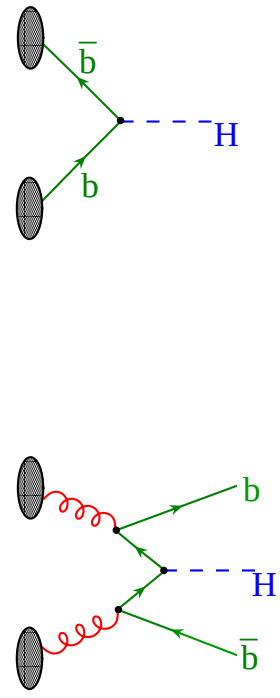
- resummation: bottom quarks as partons



$b\bar{b} \longrightarrow h$ vs. $gg \longrightarrow b\bar{b}h$



[plot by M. Krämer]



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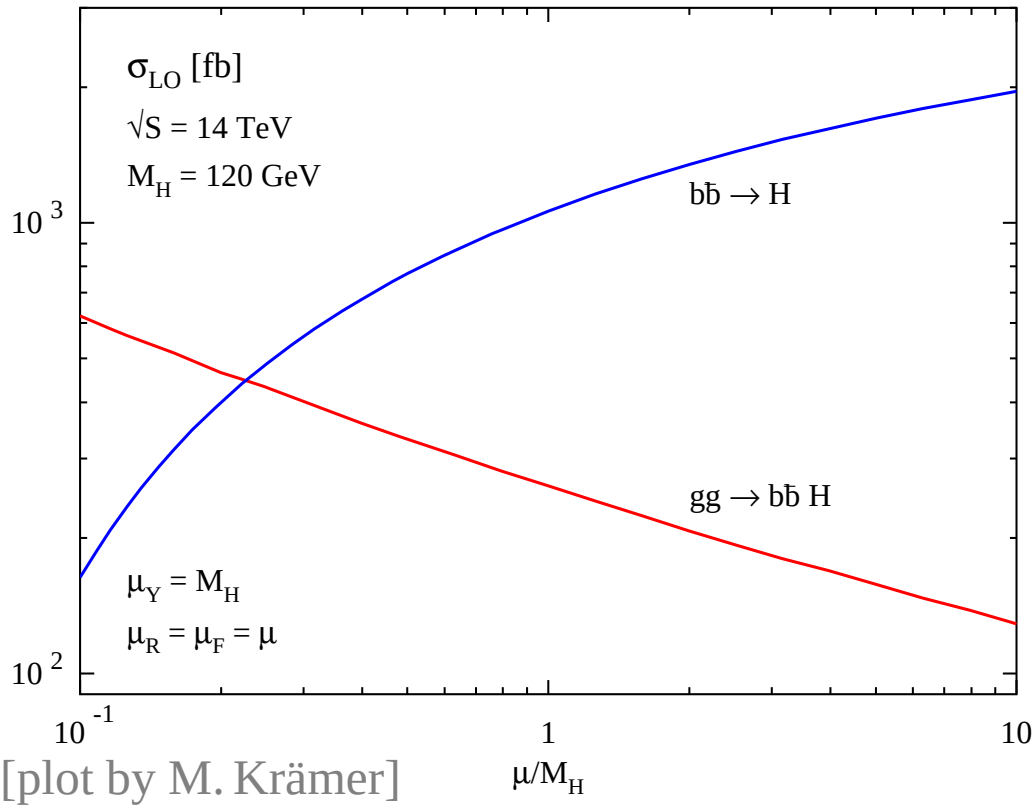

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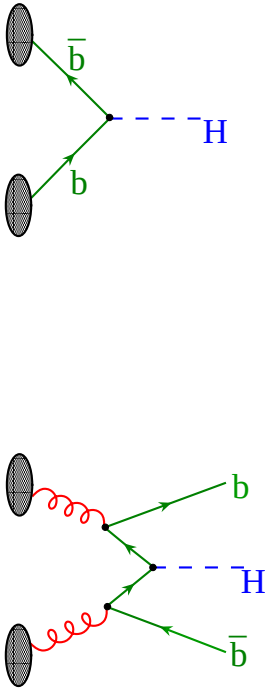
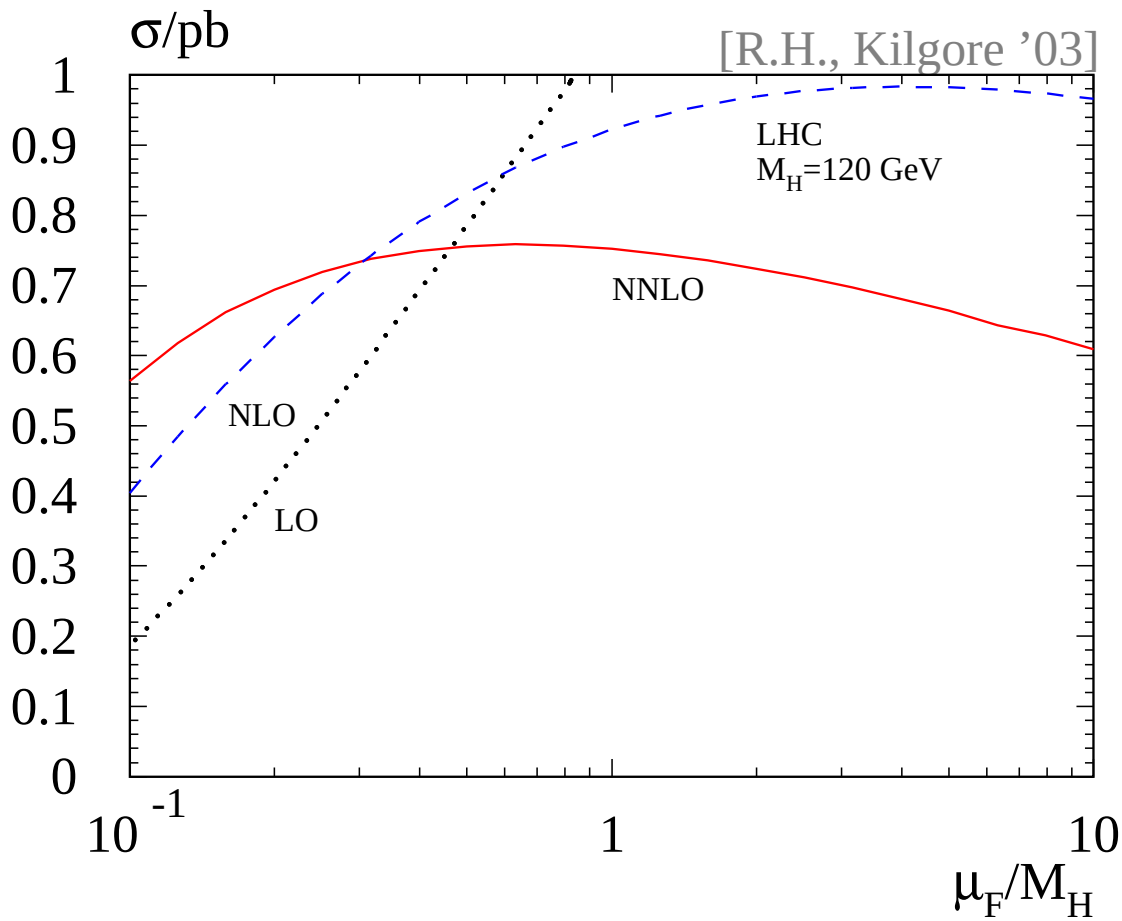


$$\mu_F = M_H/4?$$

[Boos, Plehn '04] [Maltoni, Sullivan, Willenbrock '03]

$b\bar{b} \longrightarrow H$ at NNLO



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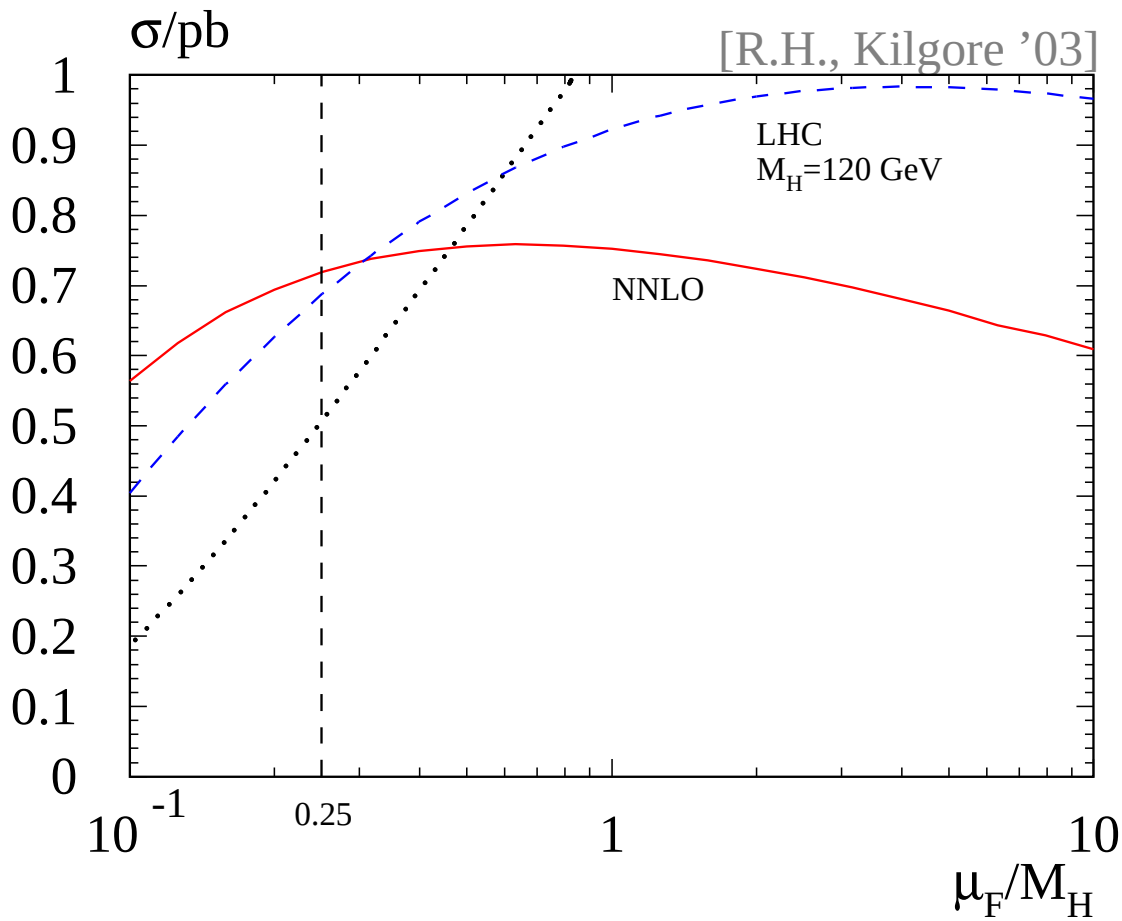

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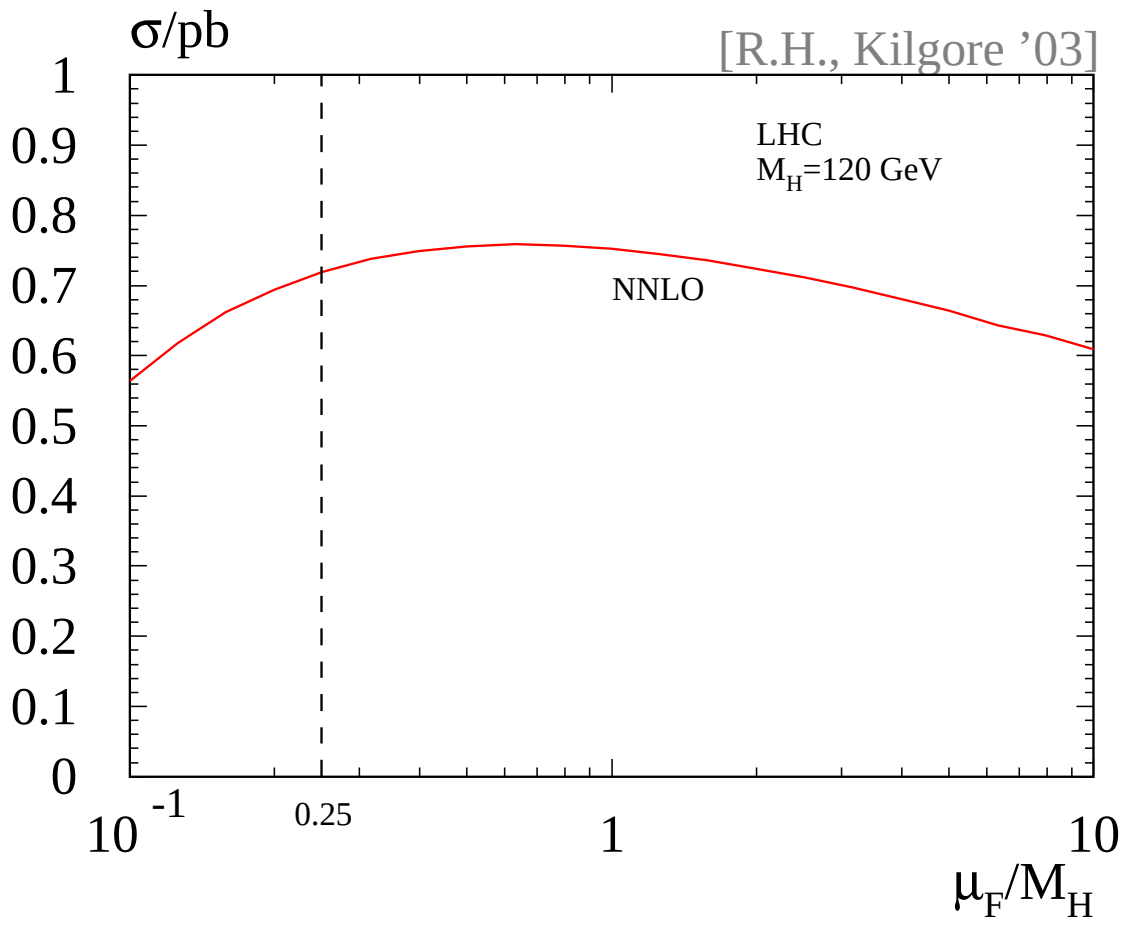

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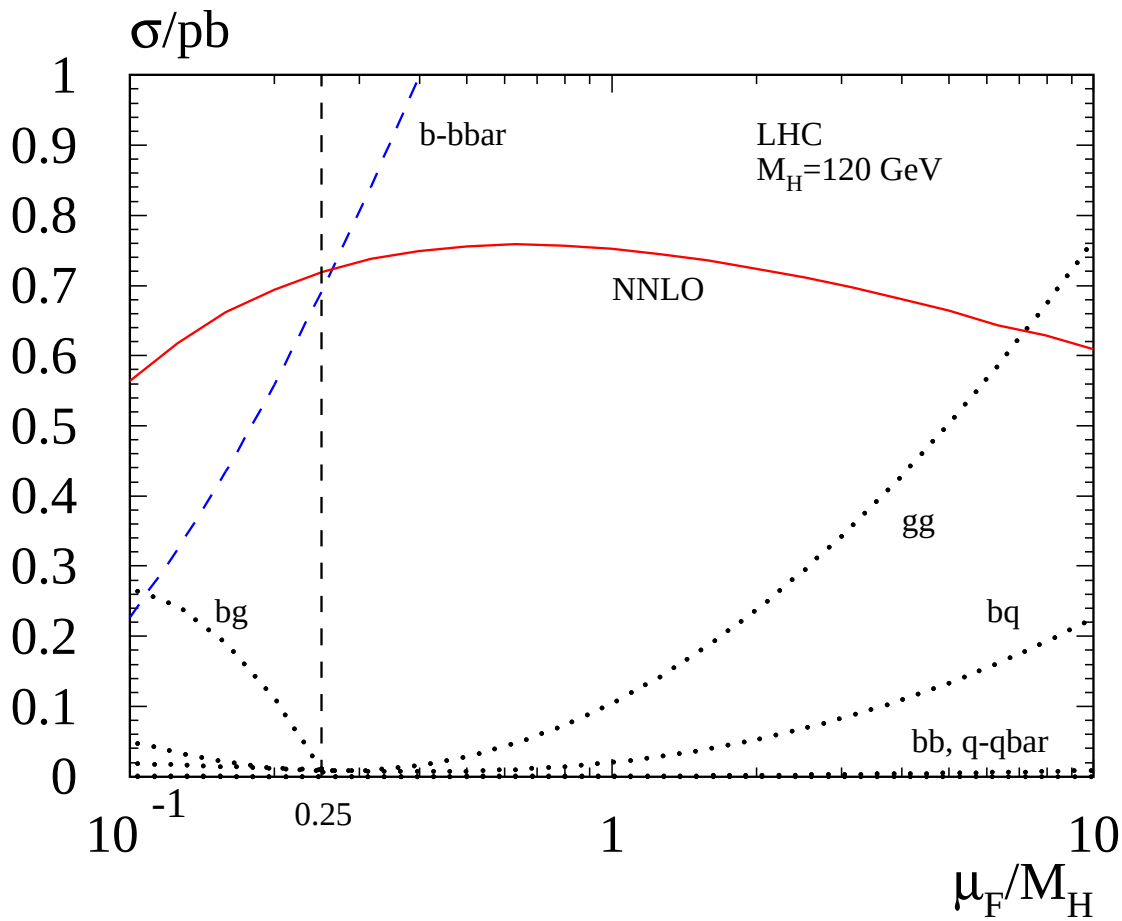

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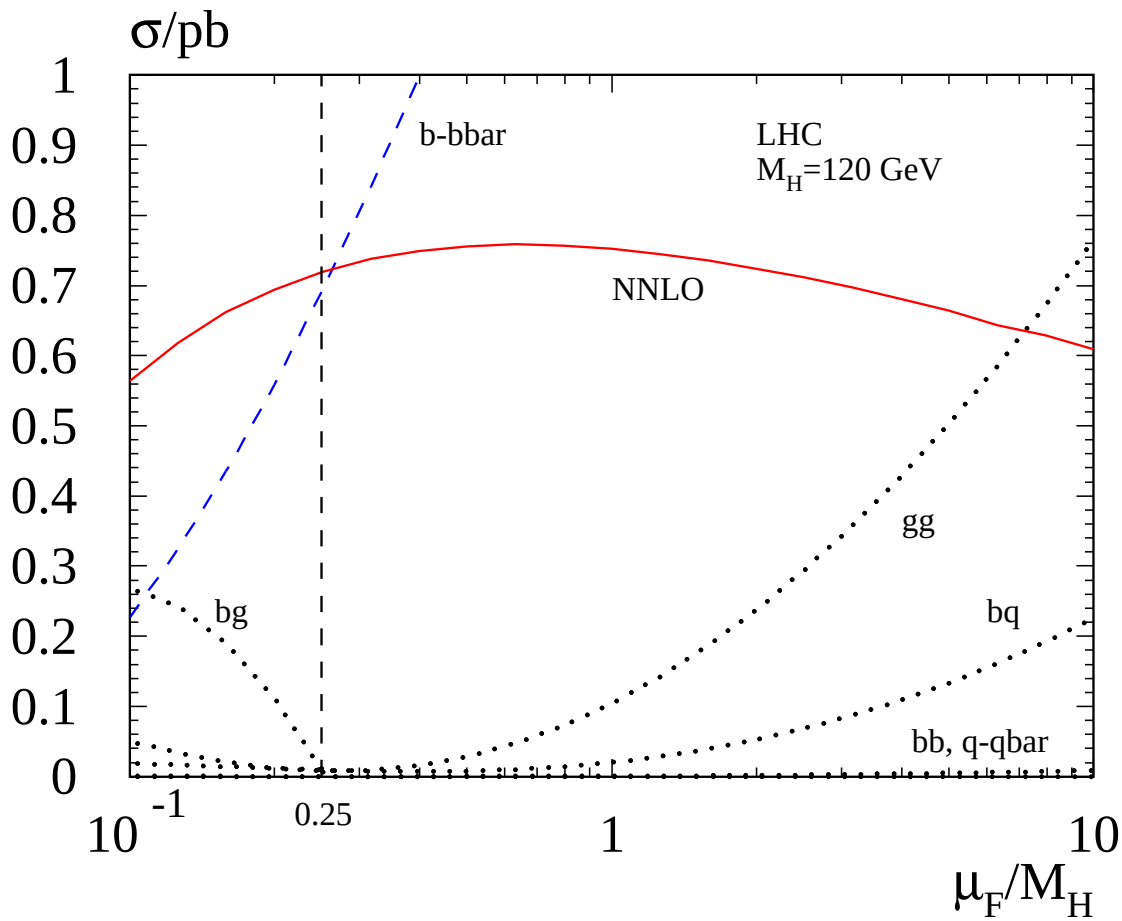

test: $b\bar{b} \to Z$ at Tevatron [Maltoni, McElmurry, Willenbrock '05]

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- exciting times ahead of us

  $\rightarrow$ (N)NLO era at hadron colliders has begun!

  $\rightarrow$ Higgs physics with data!