Precision Higgs Physics: Theory Status

Robert Harlander

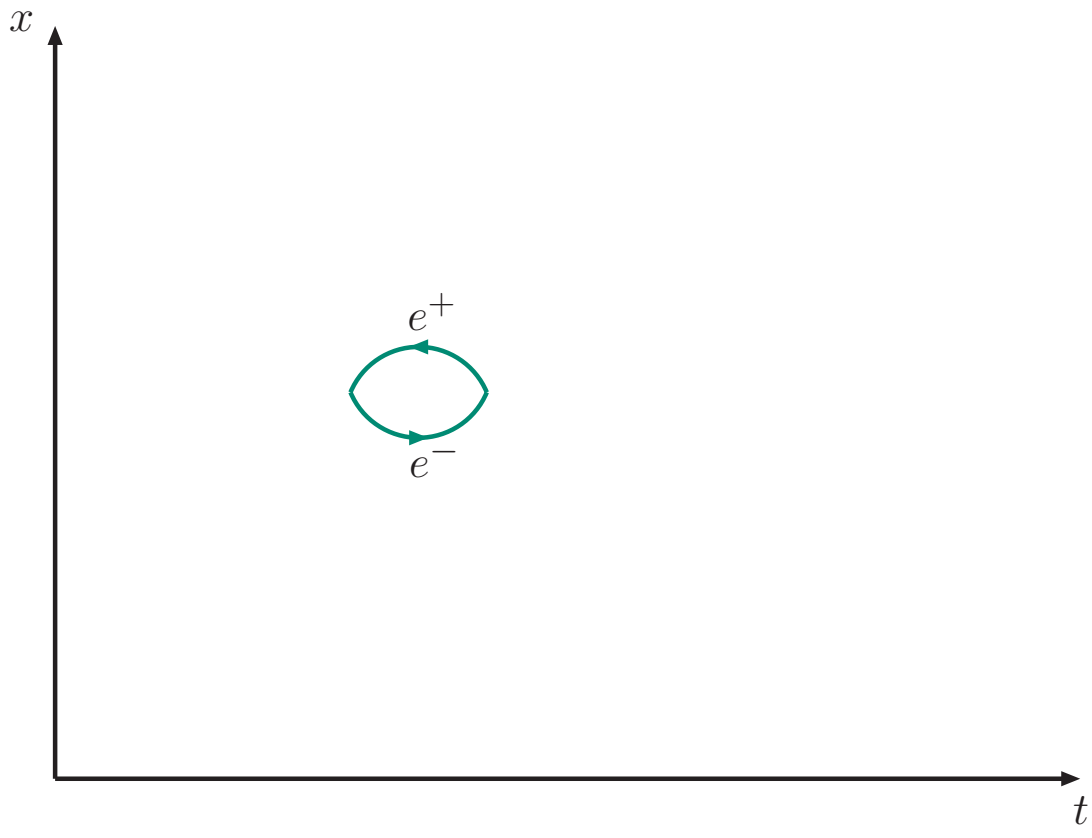
Bergische Universität Wuppertal

UK HEP Forum

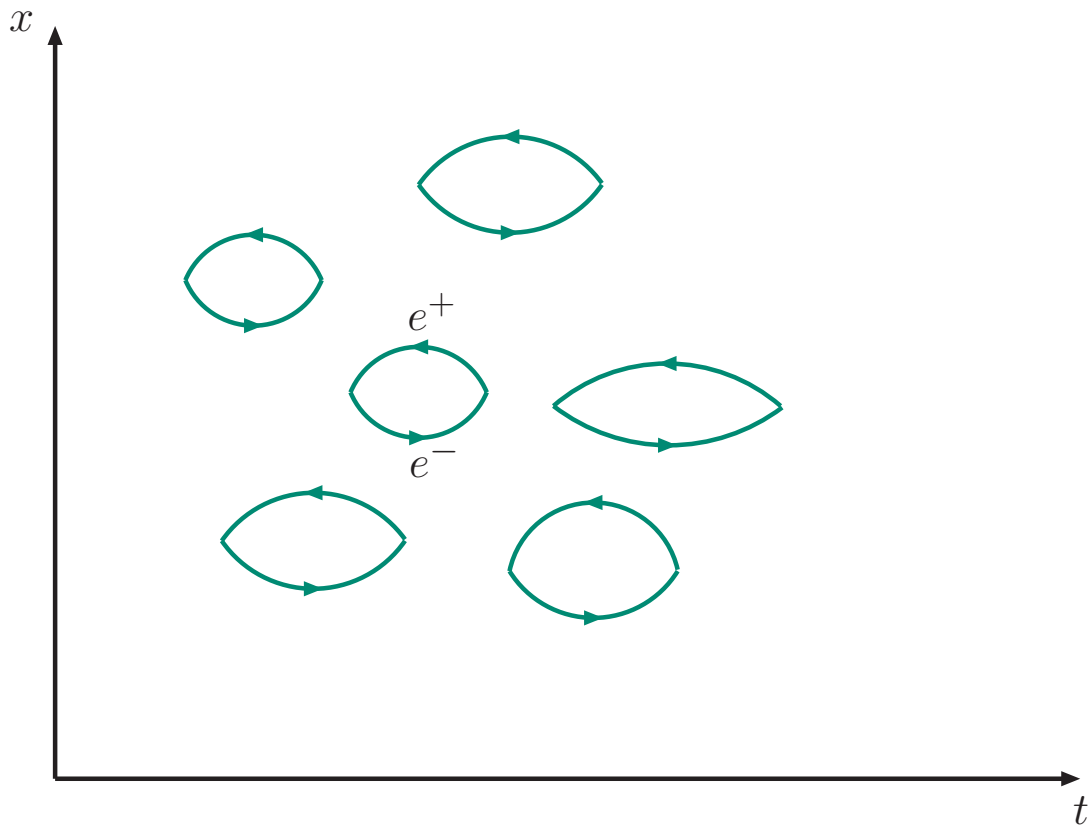
Cosener's House, 7-8 May 2009

Vacuum

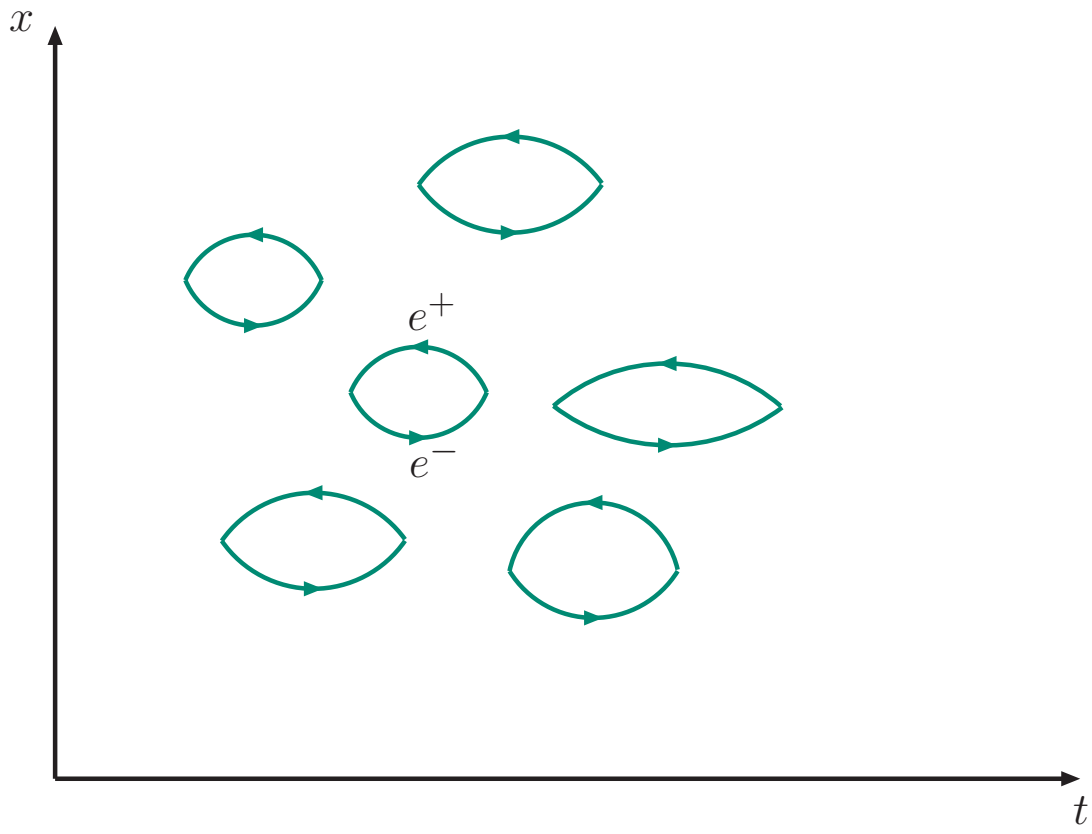
Vacuum



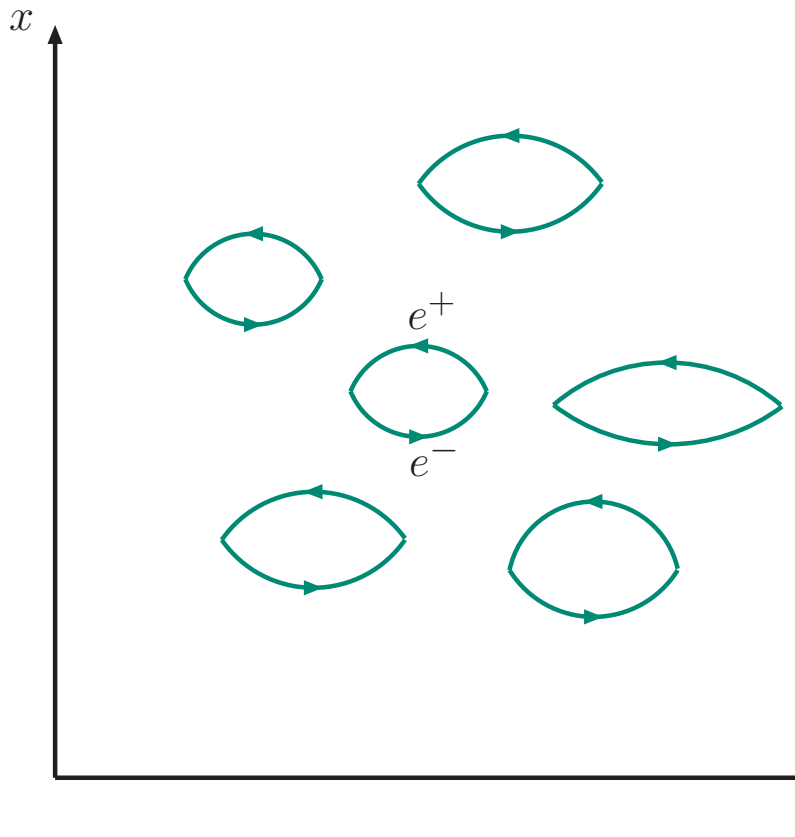
Vacuum

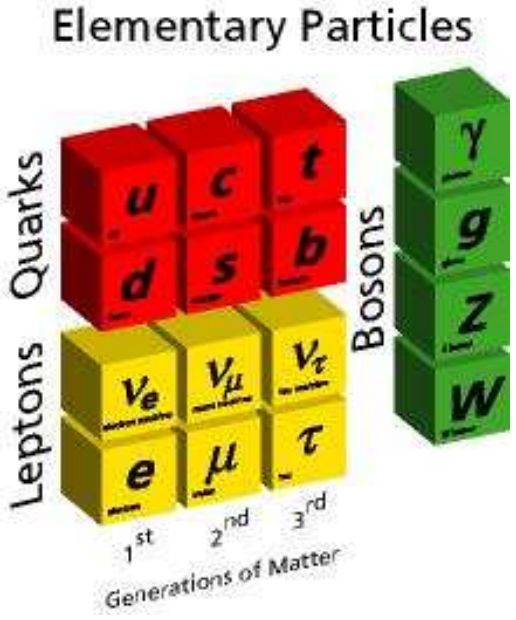


Vacuum fluctuations

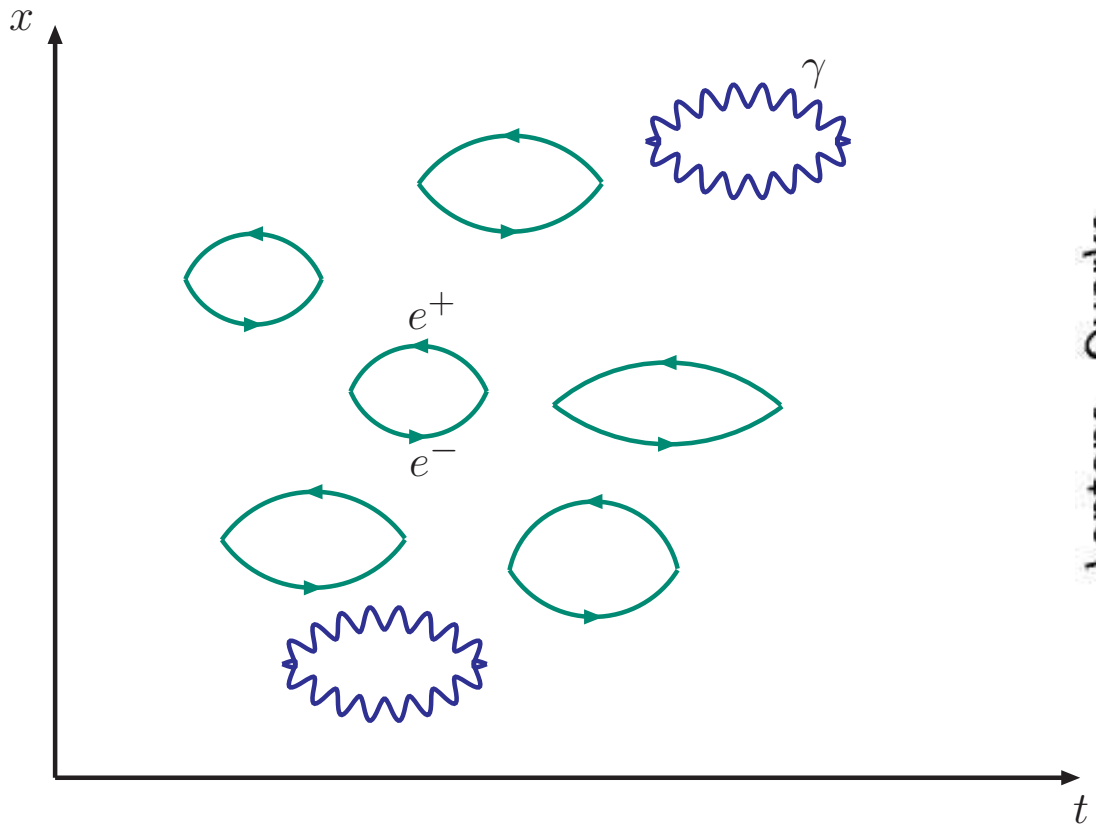


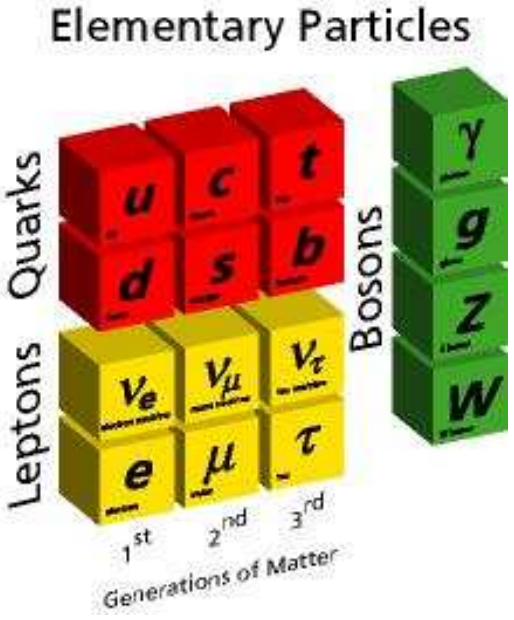
Vacuum fluctuations



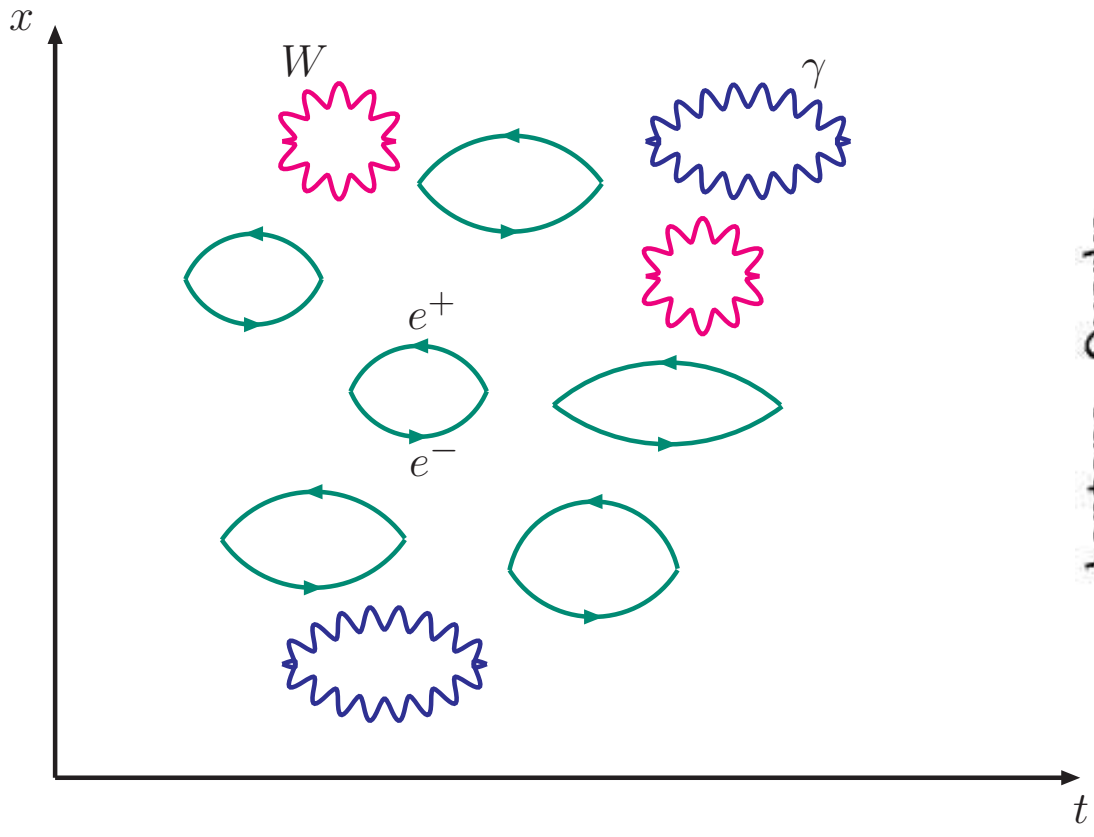


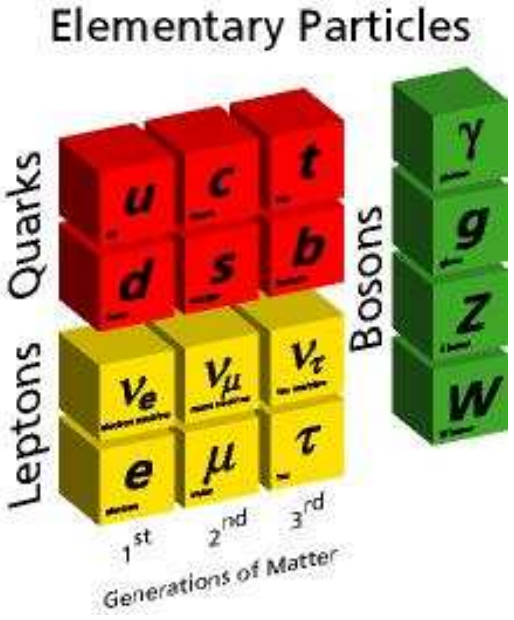
Vacuum fluctuations



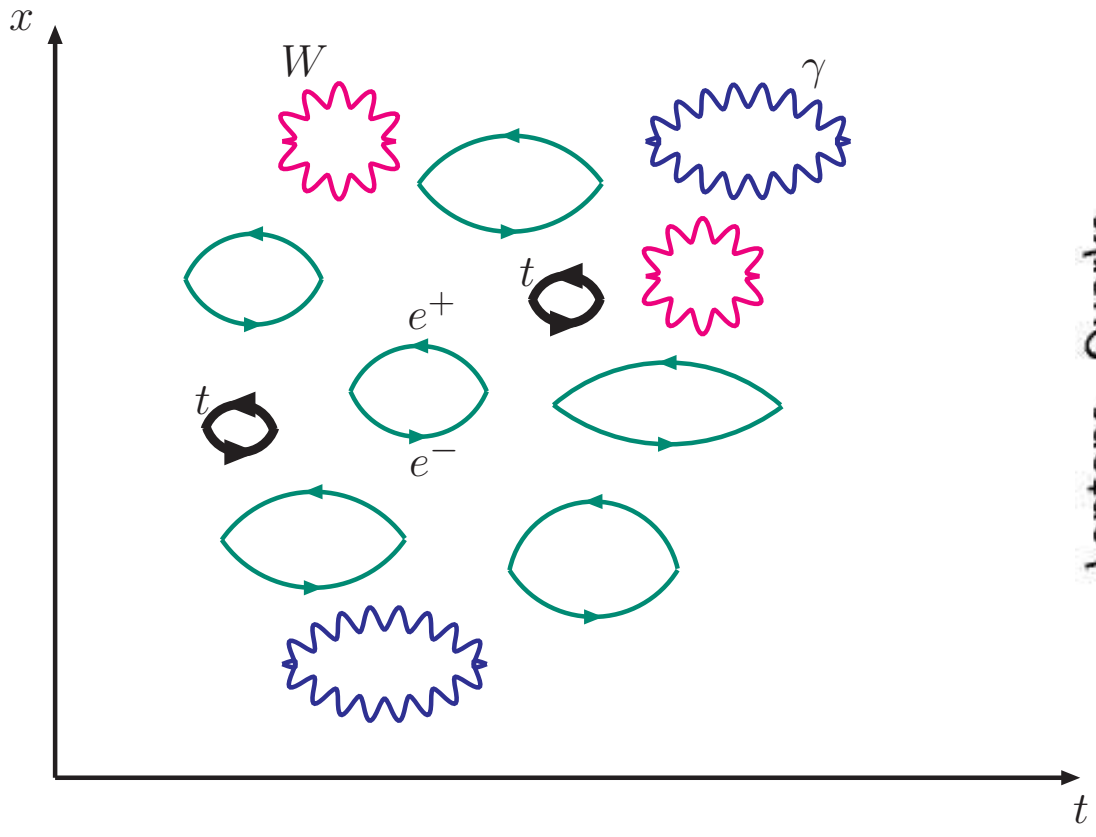


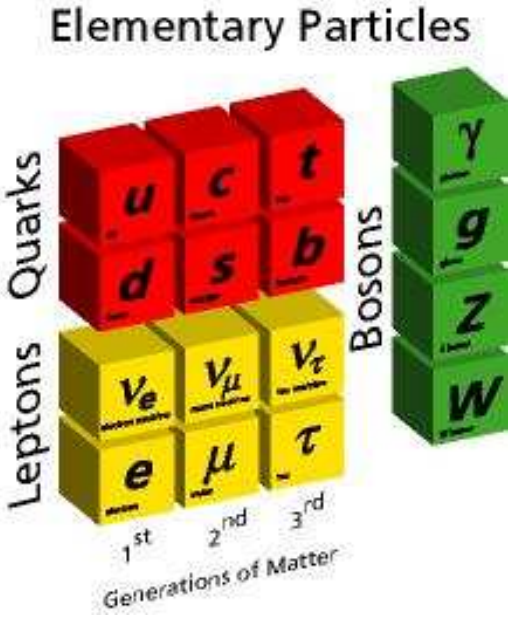
Vacuum fluctuations



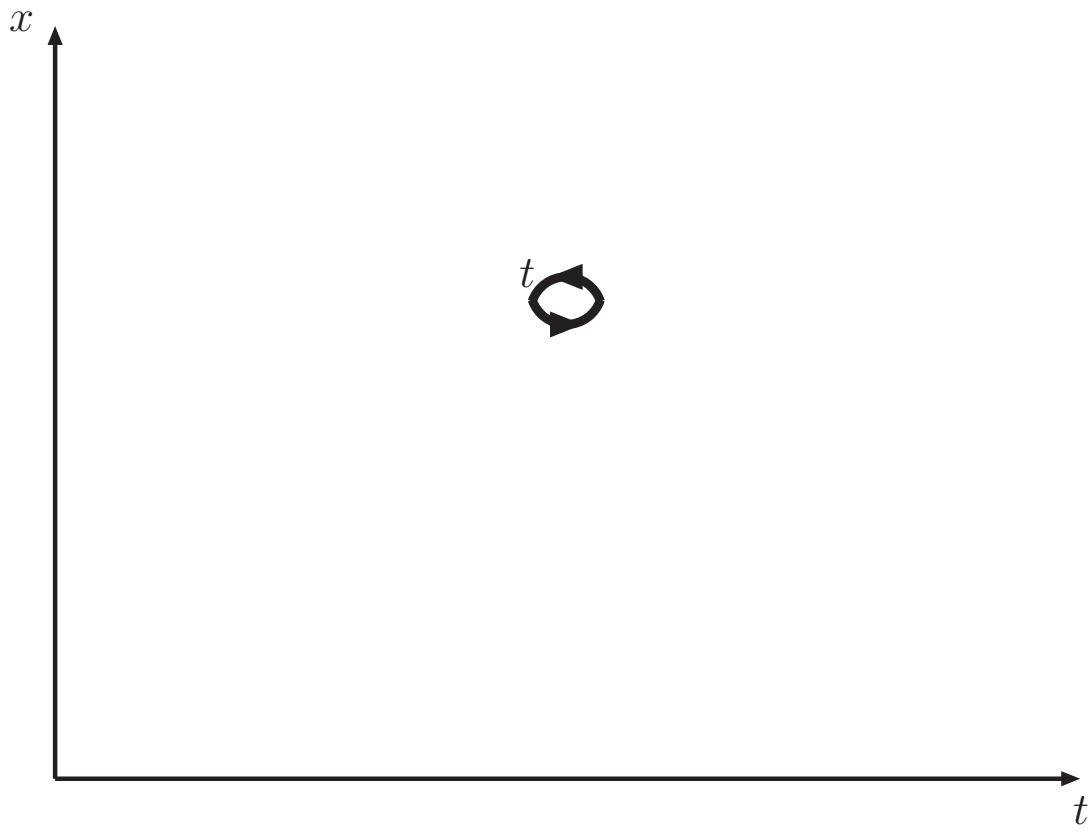


Vacuum fluctuations

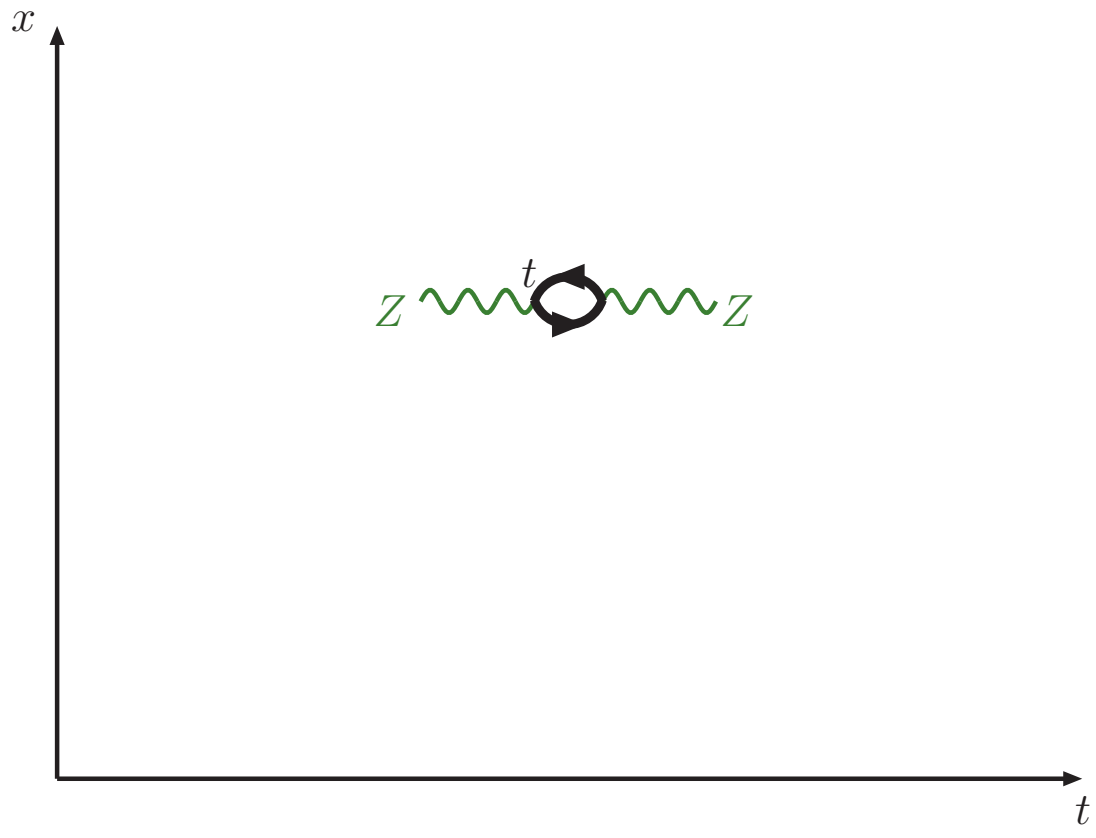




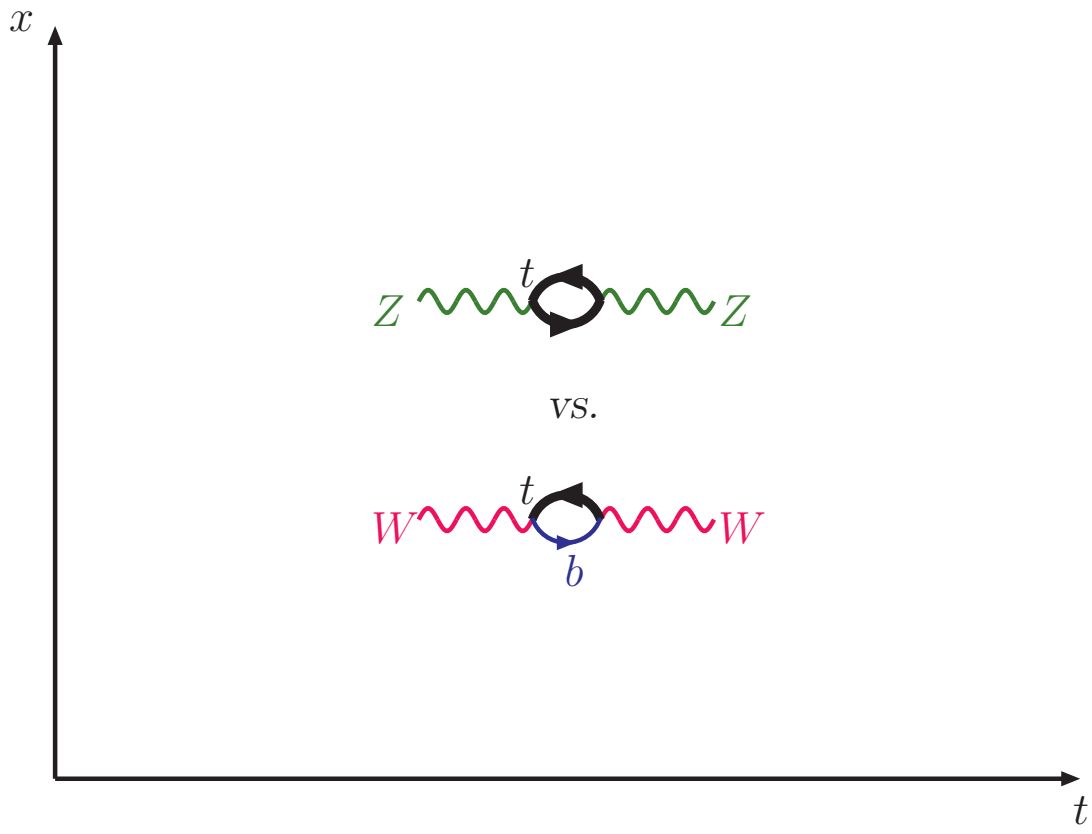
ρ parameter



ρ parameter

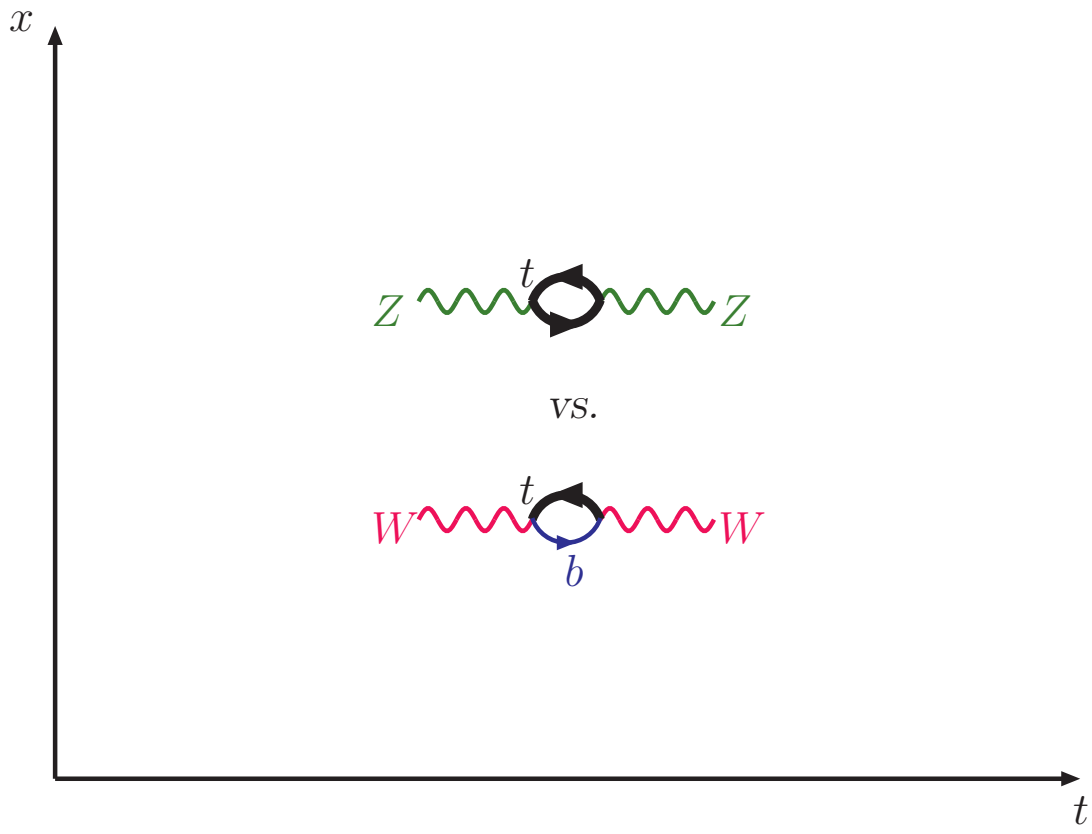


ρ parameter



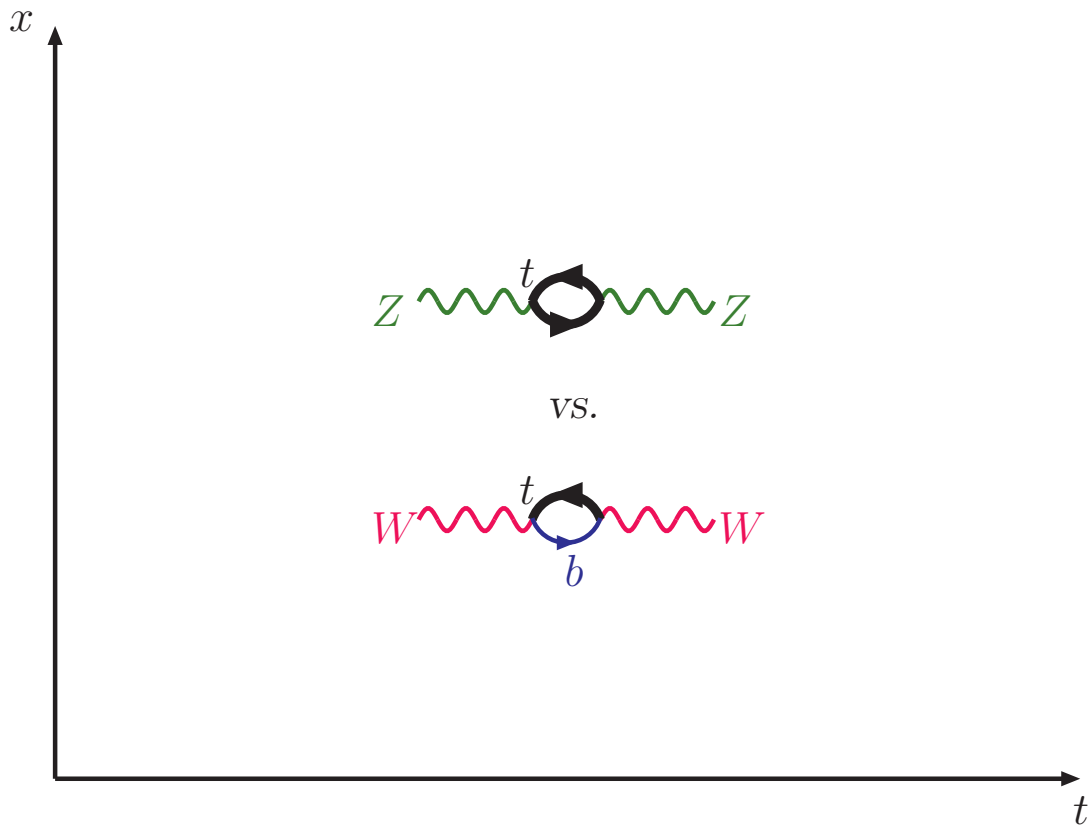
$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} = \frac{g'^2}{g^2 + g'^2}$$

ρ parameter



$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} = \frac{g'^2}{g^2+g'^2}\left(1 - \frac{c_W^2}{s_W^2}\Delta\rho\right)$$

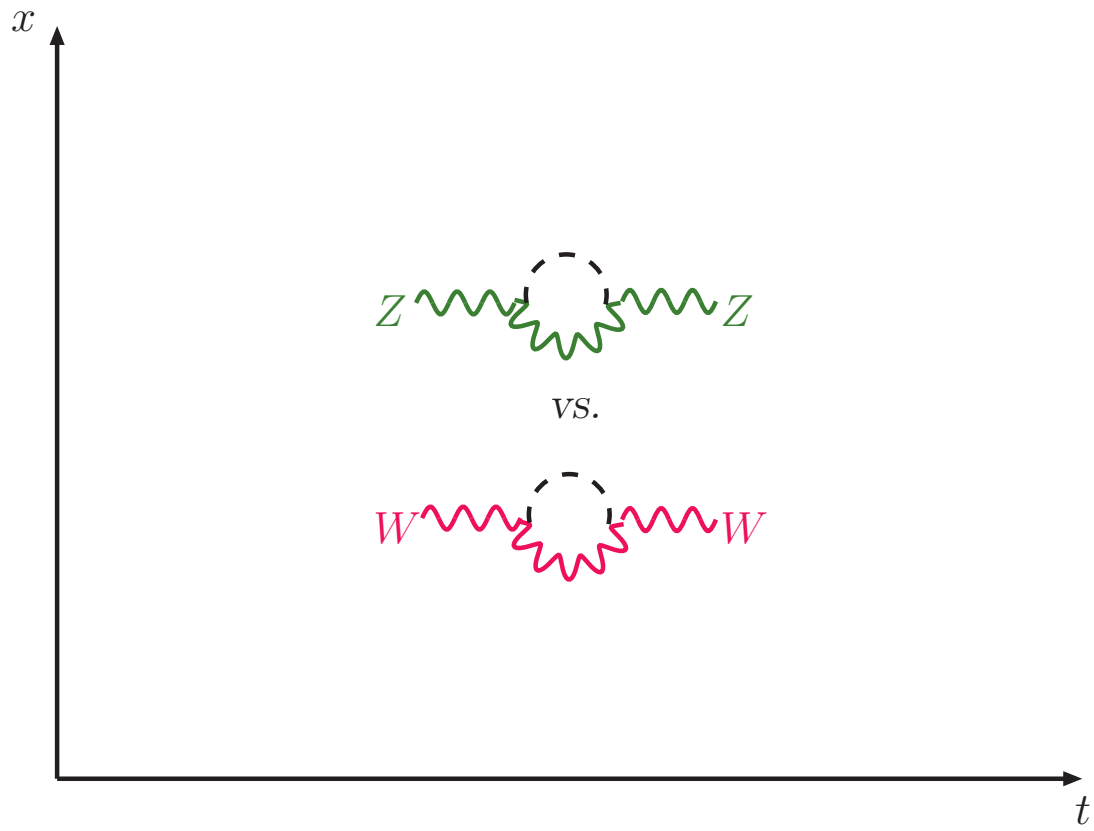
ρ parameter



$$\Delta\rho \sim m_t^2$$

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} = \frac{g'^2}{g^2+g'^2}\left(1 - \frac{c_W^2}{s_W^2}\Delta\rho\right)$$

ρ parameter

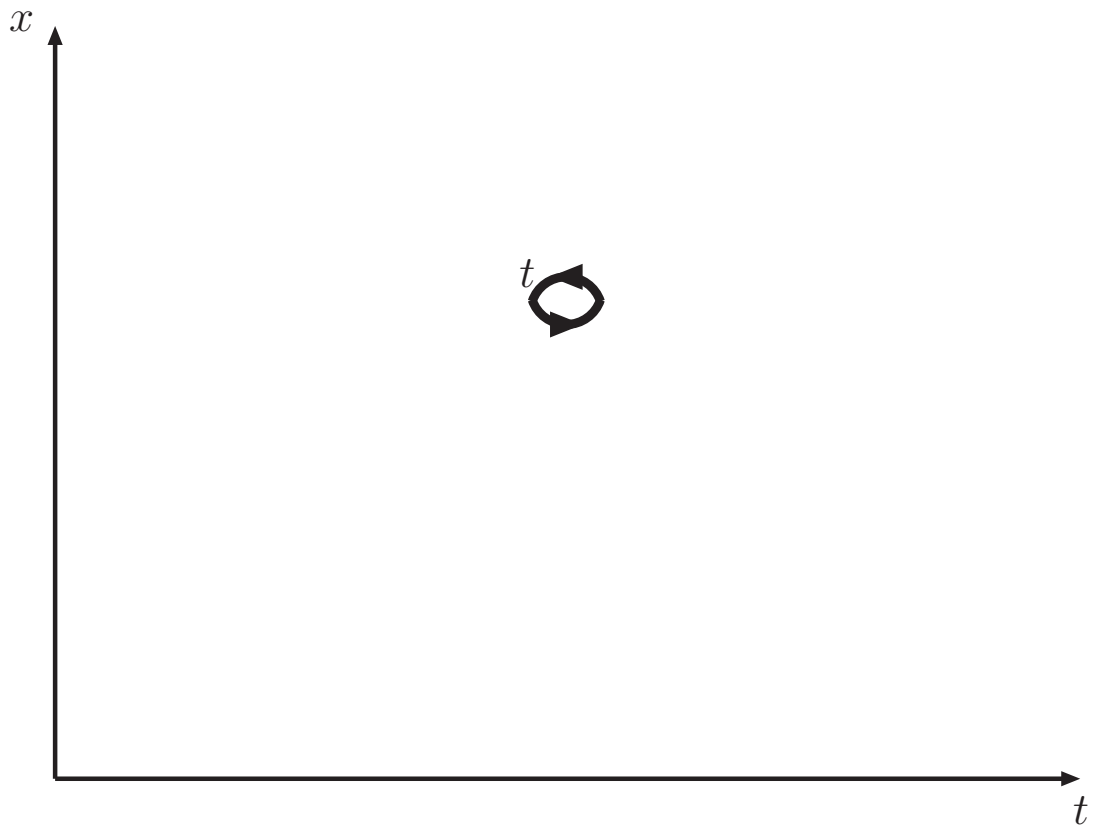


$$\Delta\rho \sim m_t^2$$

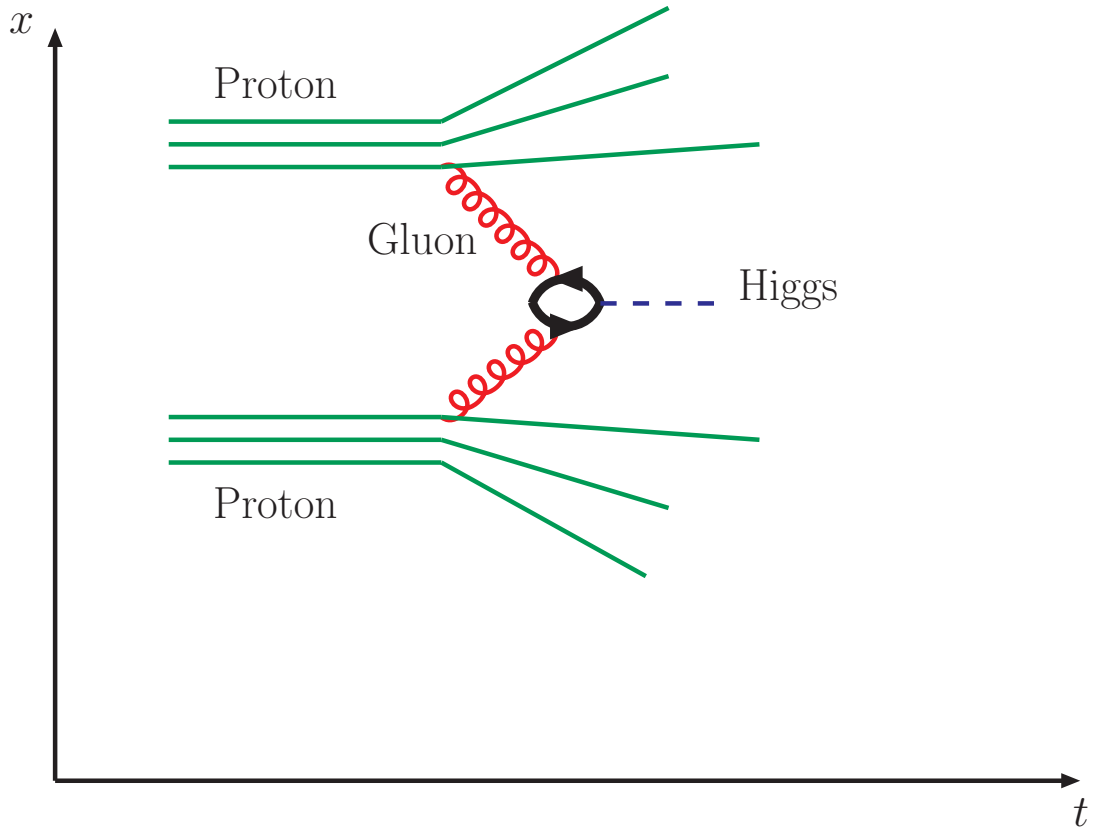
$$\Delta\rho \sim \ln M_H^2$$

$$\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2} = \frac{g'^2}{g^2+g'^2}\left(1 - \frac{c_W^2}{s_W^2}\Delta\rho\right)$$

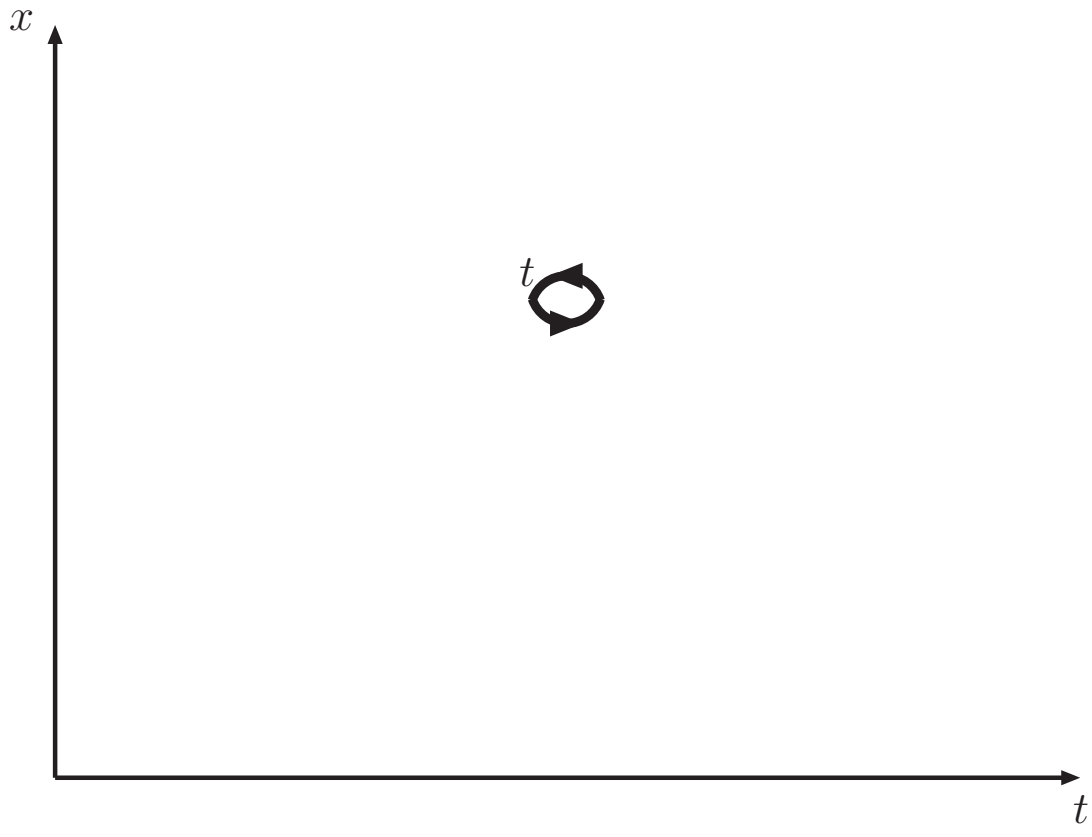
Higgs production



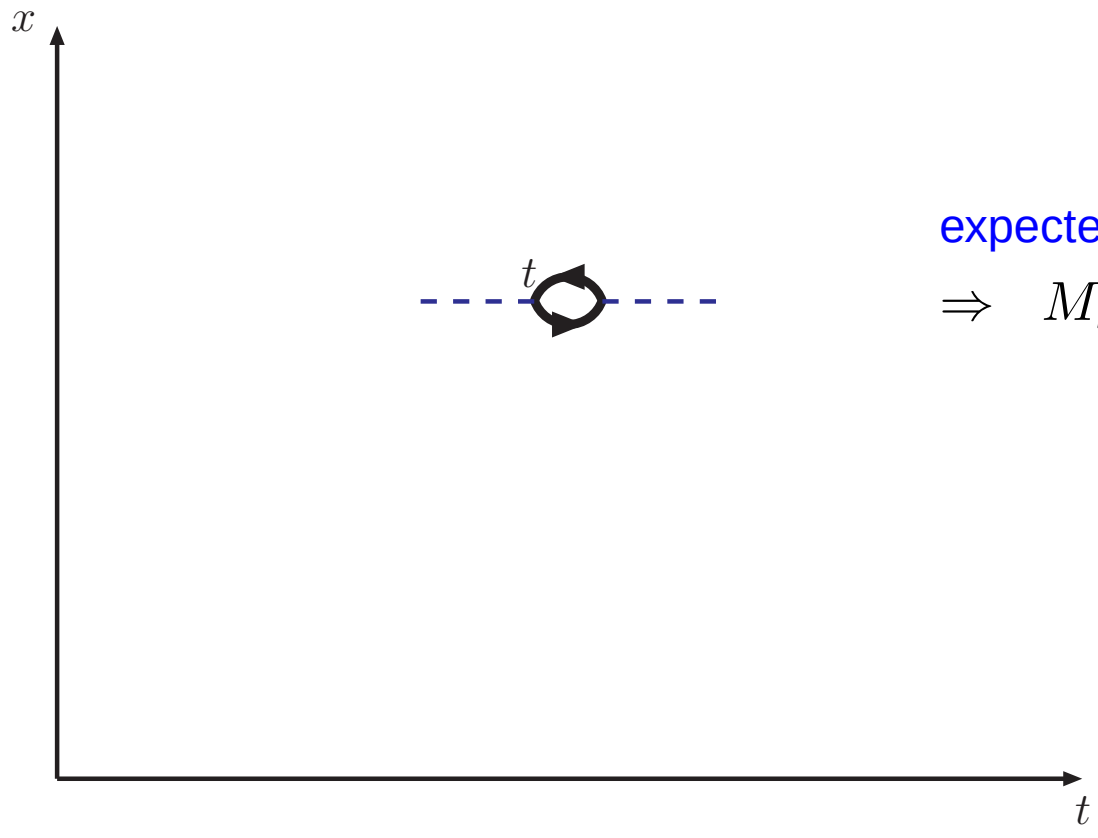
Higgs production



Example: Higgs mass



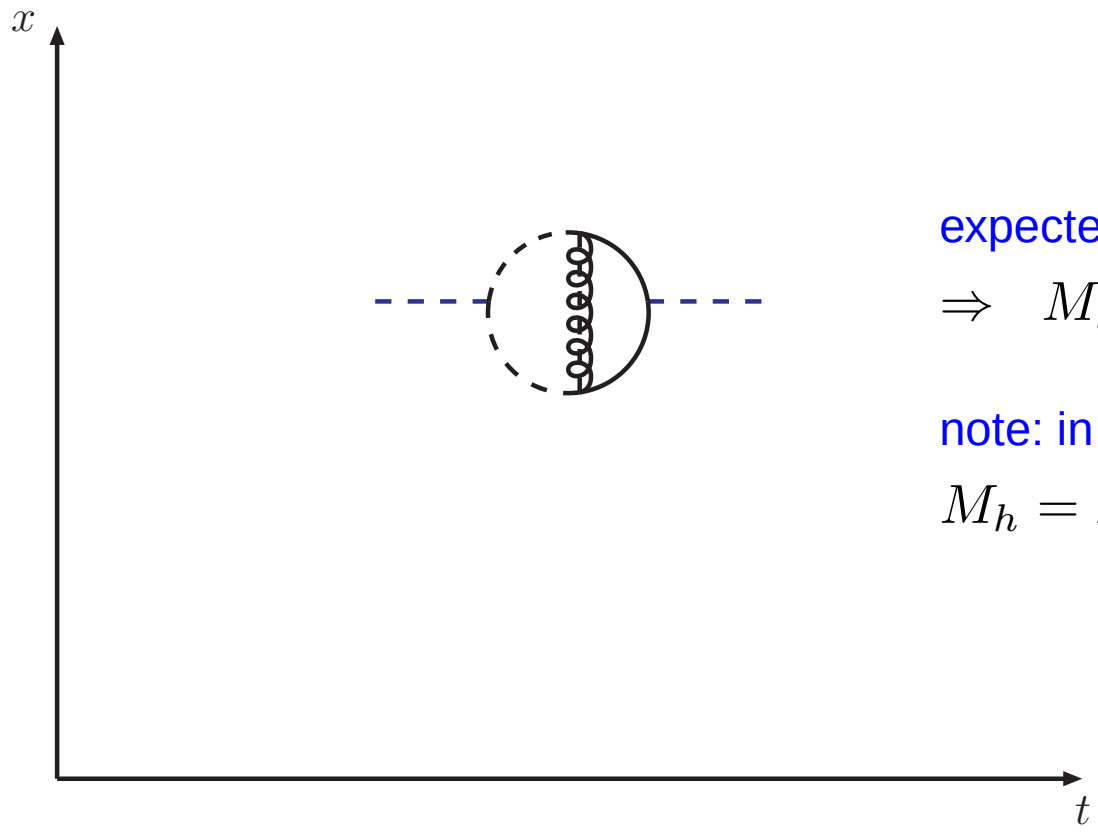
Example: Higgs mass



expected: $\Delta M_h^{\rm exp} \sim \mathcal{O}(0.1\%)$

$\Rightarrow$ M_h will be precision quantity

Example: Higgs mass



expected: $\Delta M_h^{\rm exp} \sim \mathcal{O}(0.1\%)$

$\Rightarrow$ M_h will be precision quantity

note: in SUSY

$M_h = M_h(M_A, \tan\beta, \ldots)$

Example: Higgs mass

$$M_h = M_h(M_A, \tan\beta, \ldots)$$

1-loop:

[Ellis, Ridolfi, Zwirner '91], [Okada, Yamaguchi, Yanagida '91], [Haber, Hempfling 91], [Chankowski, Pokorski, Rosiek '92], [Brignole '92], [Dabelstein '95], [Pierce, Bagger, Matchev, Zhang '97]

2-loop logarithmic:

[Carena, Espinosa, Quiros, Wagner '95], [Espinosa, Navarro '01], [Haber, Hempfling, Hoang '97]

2-loop:

[Hempfling, Hoang '94], [Heinemeyer, Hollik, Weiglein '98], [Zhang '99], [Espinosa, Zhang '00], [Brignole, Degrassi, Slavich, Zwirner '02]

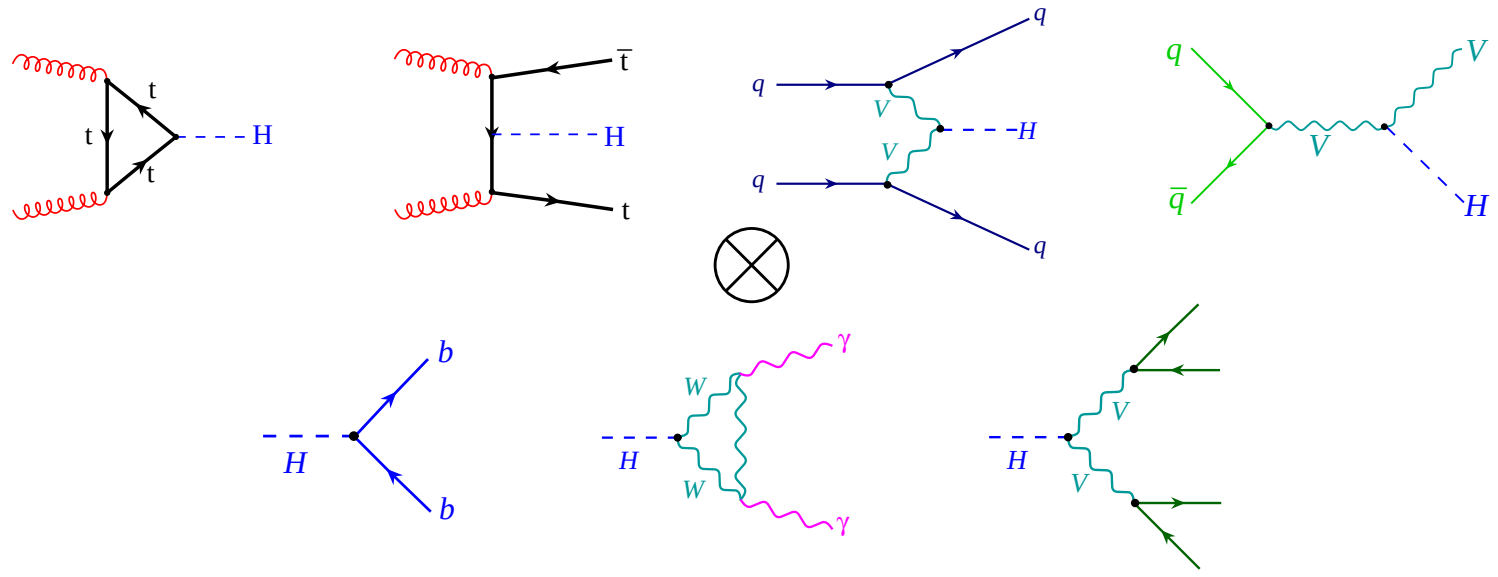
3-loop logarithmic:

[Martin '03]

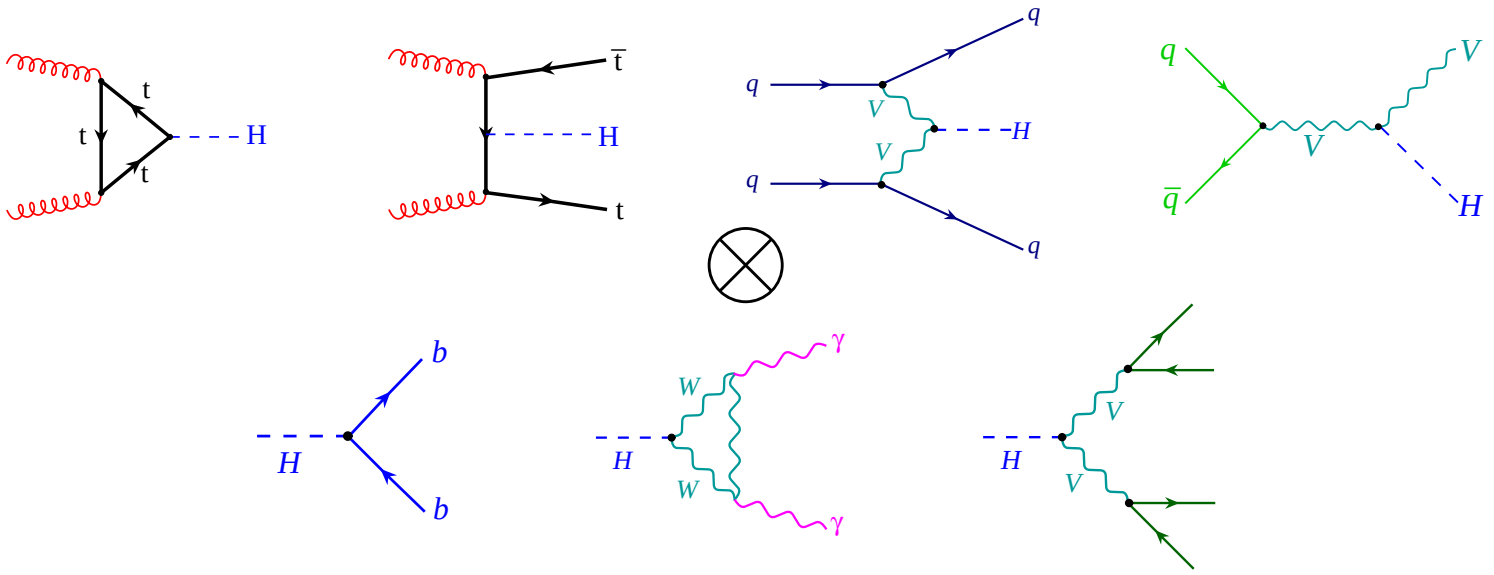
3-loop:

[R.H., Kant, Mihaila, Steinhauser '08] $O(1\text{GeV})$-effect!

Higgs couplings



Higgs couplings



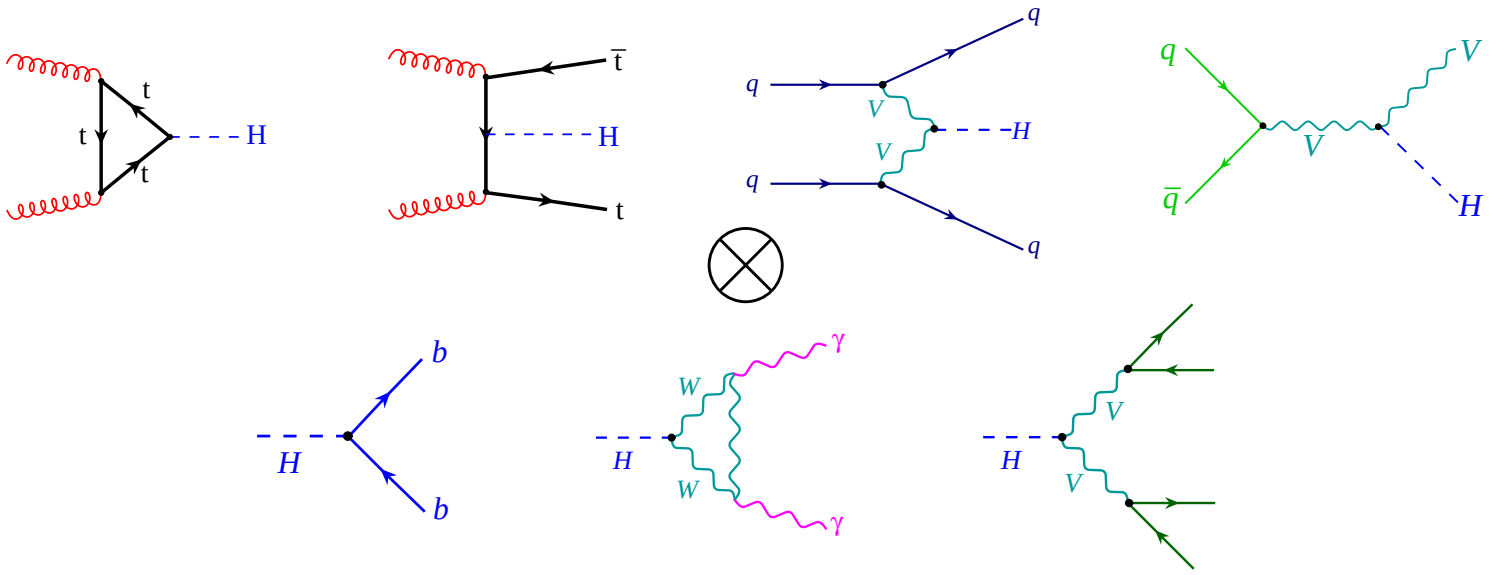
$$\Rightarrow \quad \frac{\Gamma_g \Gamma_\gamma}{\Gamma}, \quad \frac{\Gamma_g \Gamma_V}{\Gamma}, \quad \frac{\Gamma_V \Gamma_V}{\Gamma}, \quad \frac{\Gamma_V \Gamma_\tau}{\Gamma}, \quad \text{etc.}$$

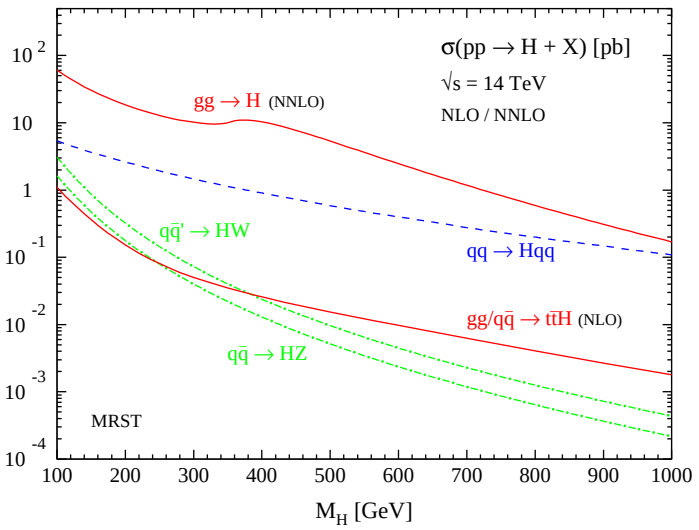
$$\Rightarrow \quad \frac{\Gamma_V}{\Gamma}\left(\Gamma_g + \Gamma_V + \Gamma_\tau + \ldots\right) = \Gamma_V$$

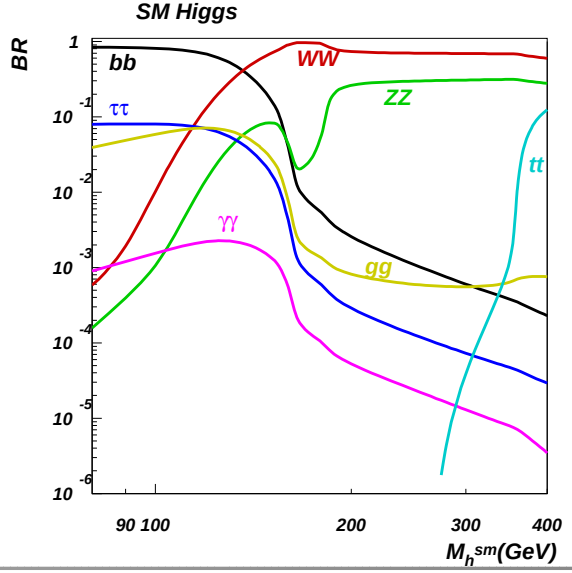
$$\Rightarrow \quad \Gamma_\gamma \, , \Gamma_g \, , \text{etc.}$$

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

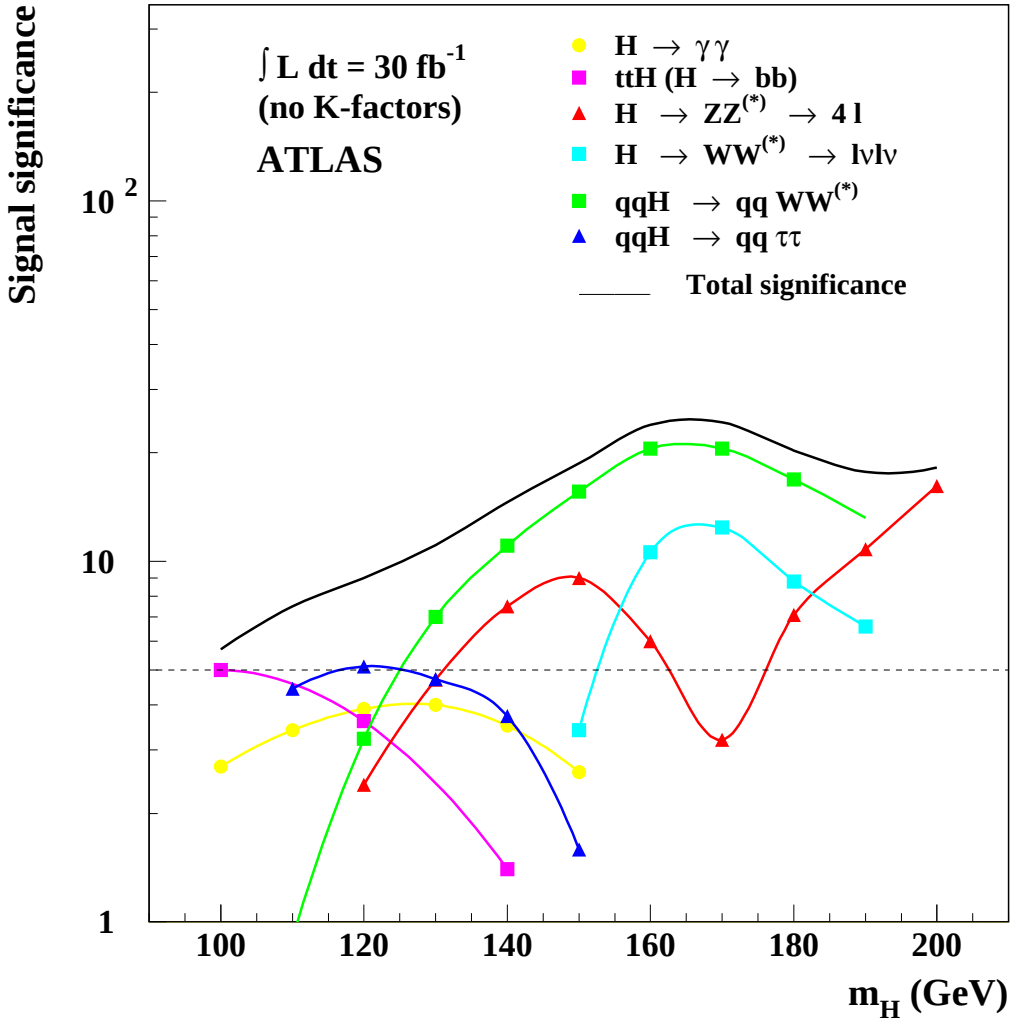
$pp \longrightarrow H$ at 14 GeV

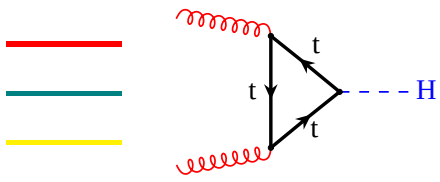




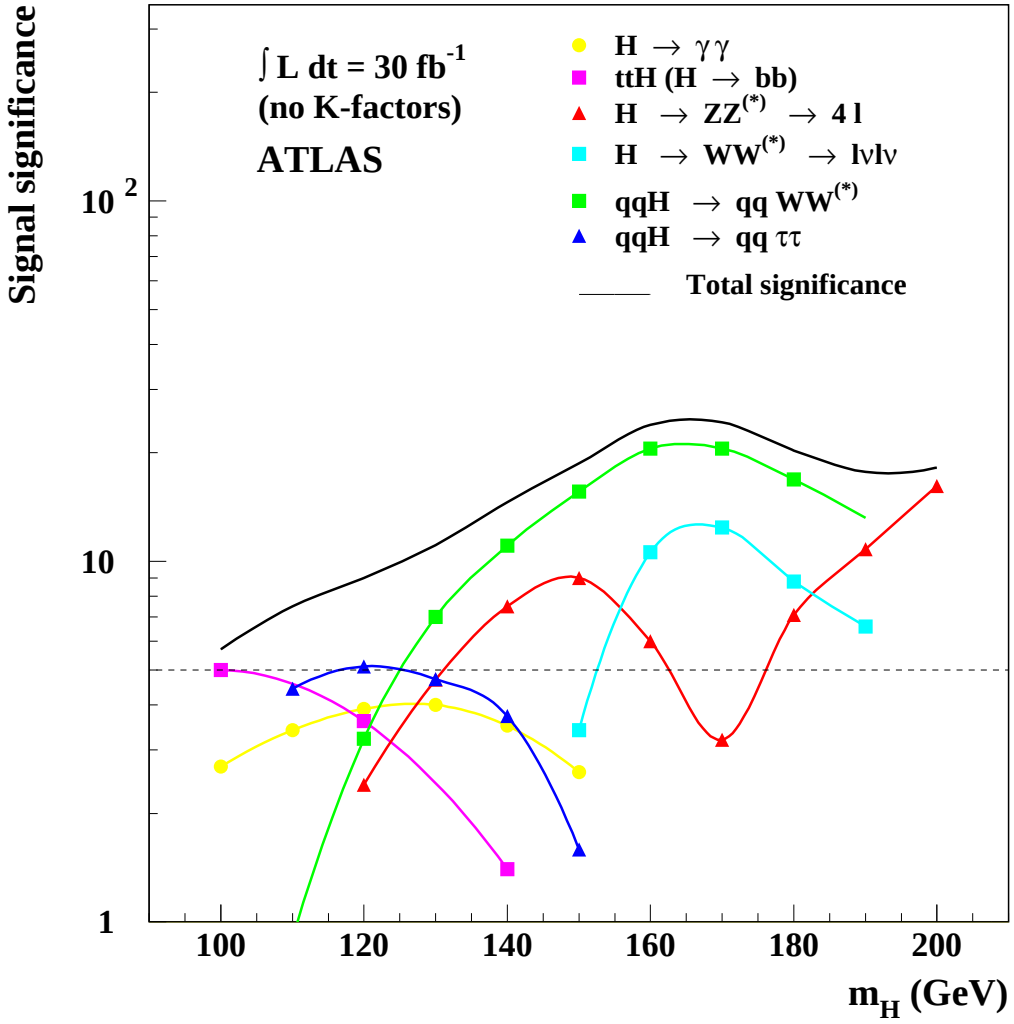


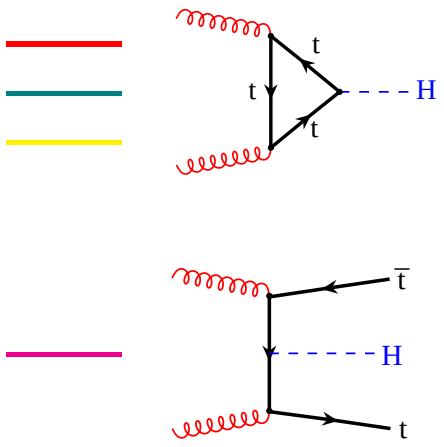
Discovery Potential



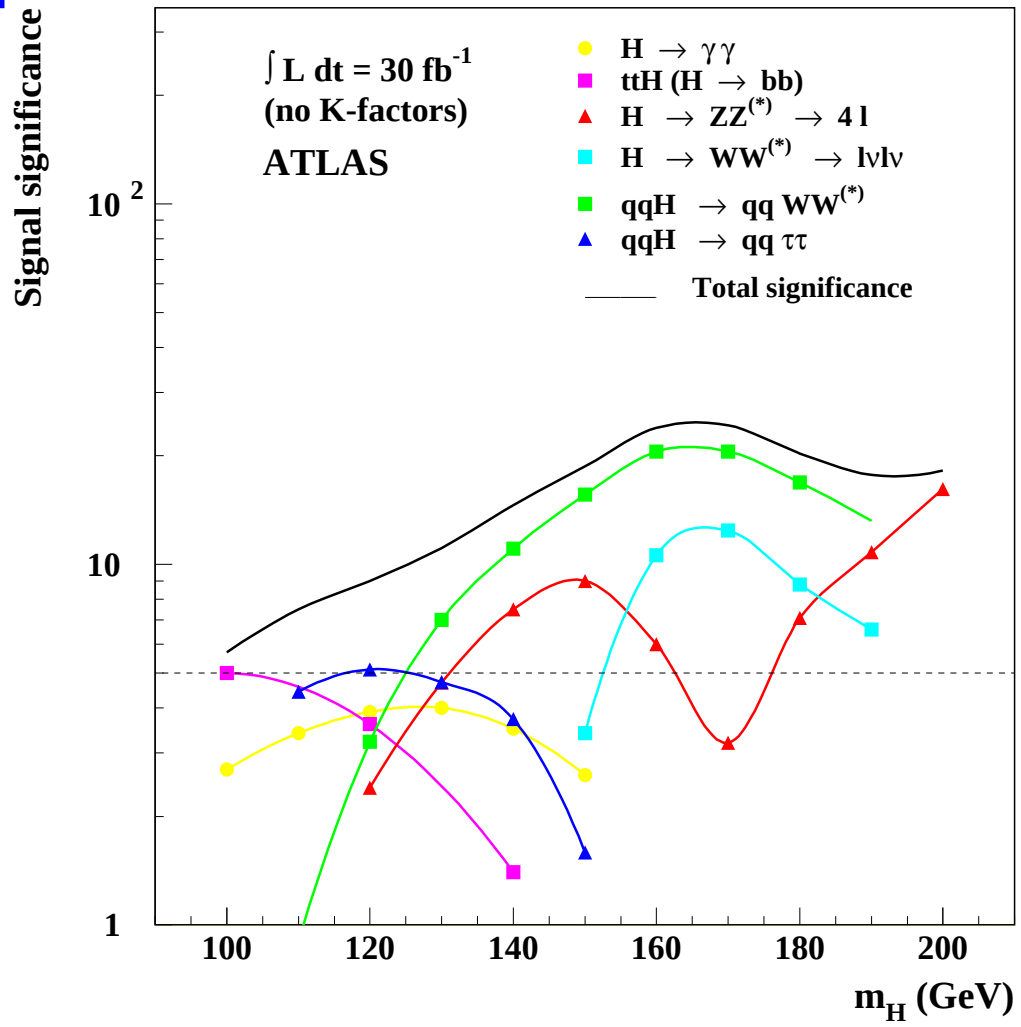


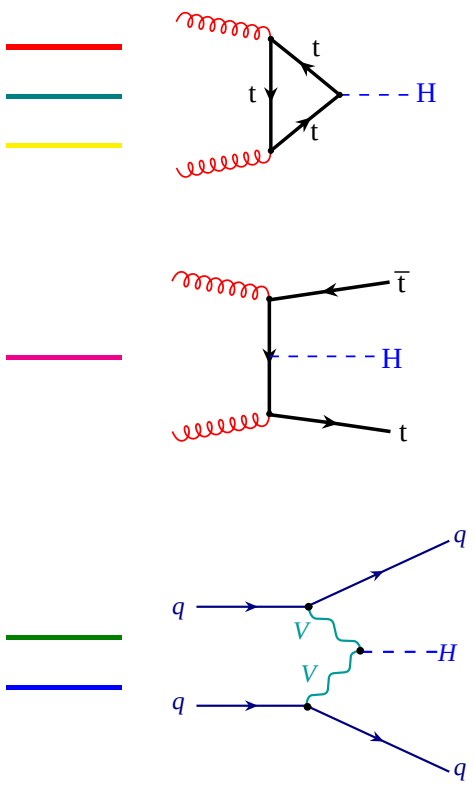
Discovery Potential



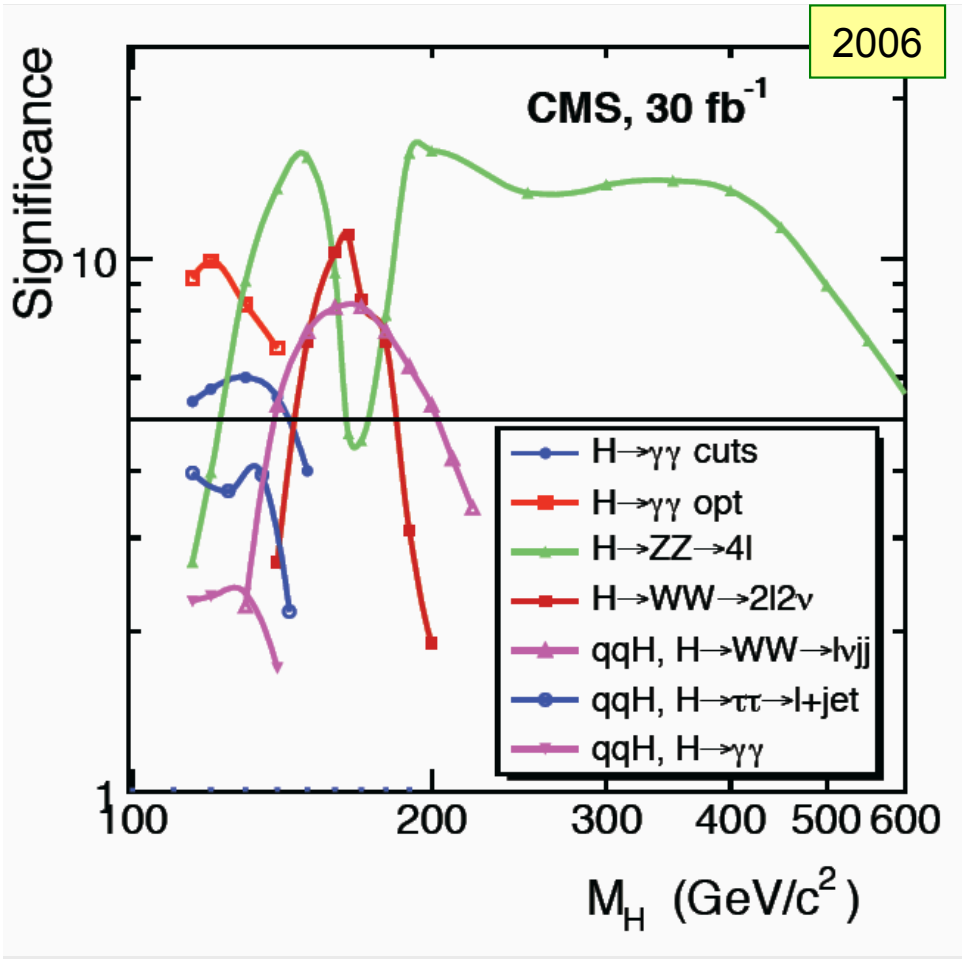


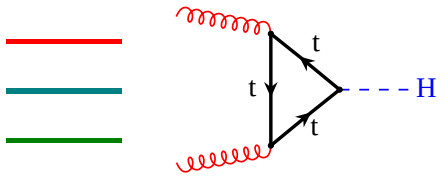
Discovery Potential

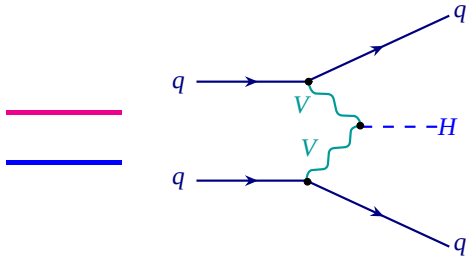




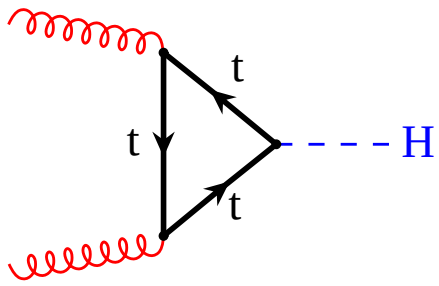
Disovery Potential





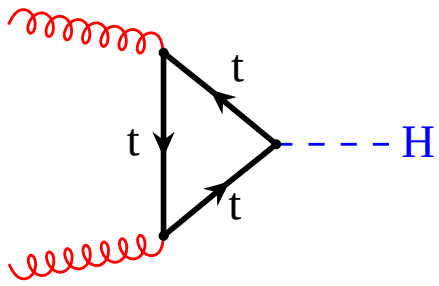


Gluon Fusion



- dominant production mode
- sensitive to heavy particle spectrum

Gluon Fusion

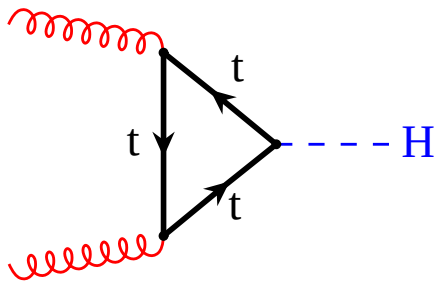


- dominant production mode
- sensitive to heavy particle spectrum

but

- $H \to b\bar{b}$ decay mode not usable for discovery
- LO is 1-loop $\longrightarrow$ radiative corrections difficult
- depends on Yukawa coupling

Gluon Fusion



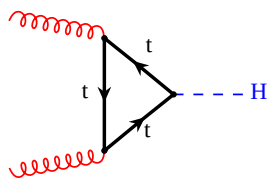
- dominant production mode
- sensitive to heavy particle spectrum

but

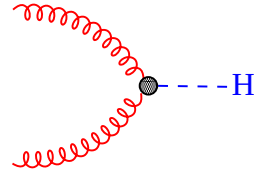
- $H \to b\bar{b}$ decay mode not usable for discovery
- LO is 1-loop $\to$ radiative corrections difficult — really?
- depends on Yukawa coupling

Gluon fusion

- effective theory for $m_t \gg M_H$:

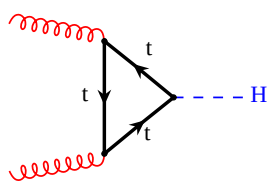


$$\xrightarrow{m_t \gg M_H} \quad C(m_t, \alpha_s) \times$$

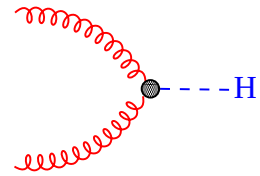


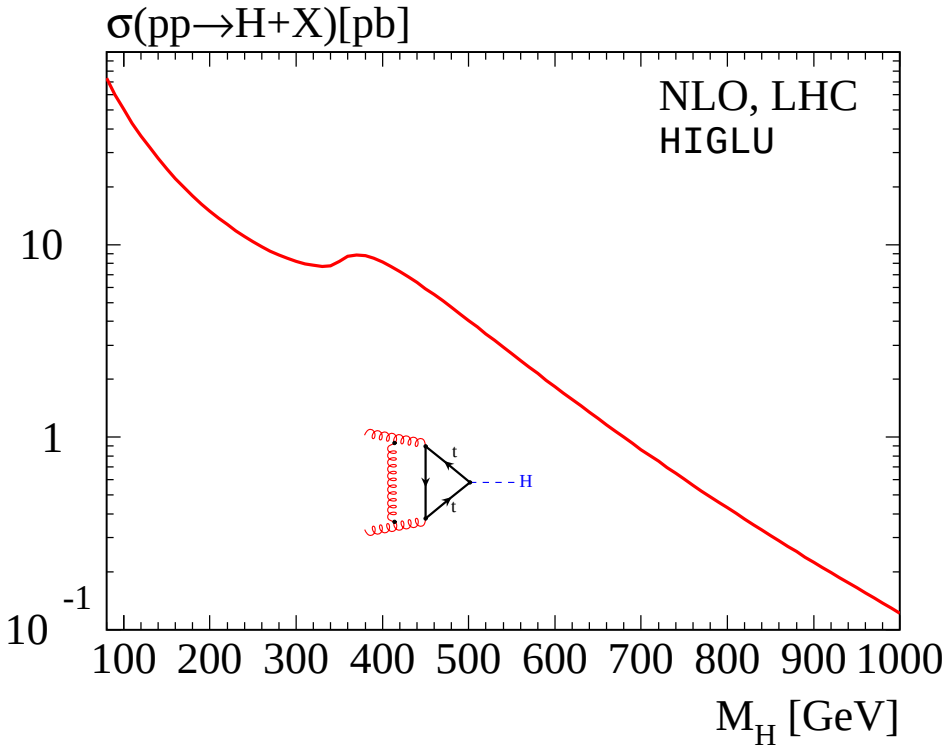
Gluon fusion

effective theory for $m_t \gg M_H$:



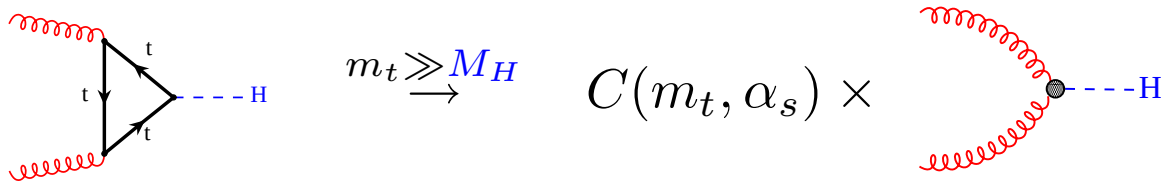
$$\xrightarrow{m_t \gg M_H} \quad C(m_t, \alpha_s) \times$$

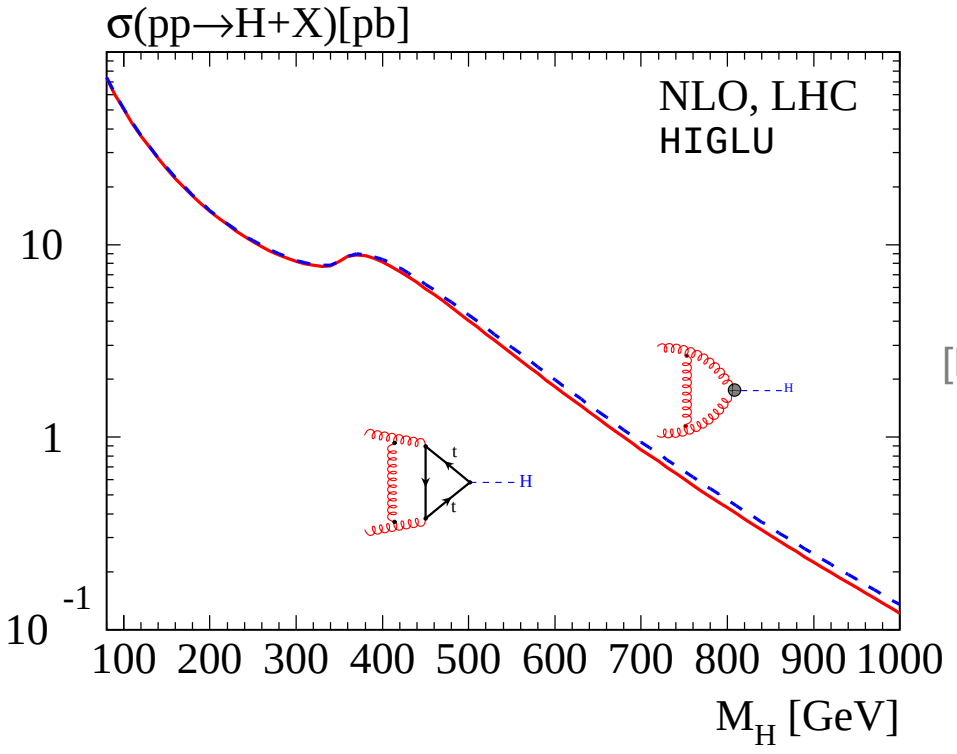




Gluon fusion

- effective theory for $m_t \gg M_H$:

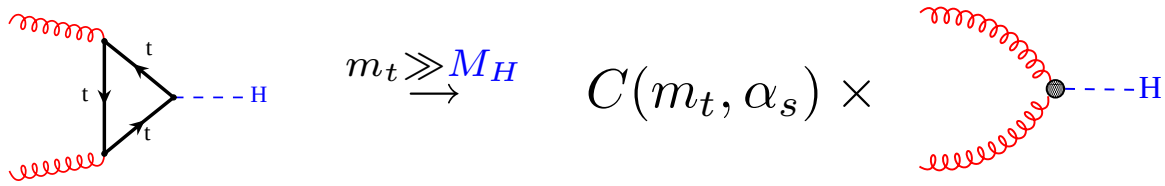


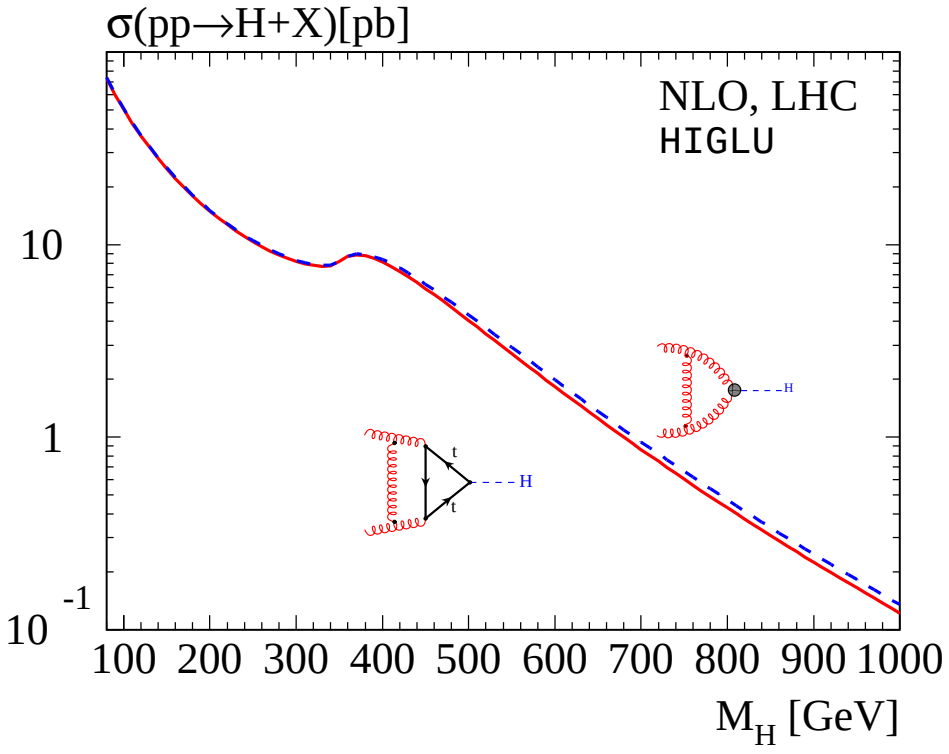


[Krämer, Laenen, Spira '96]

Gluon fusion

- effective theory for $m_t \gg M_H$:

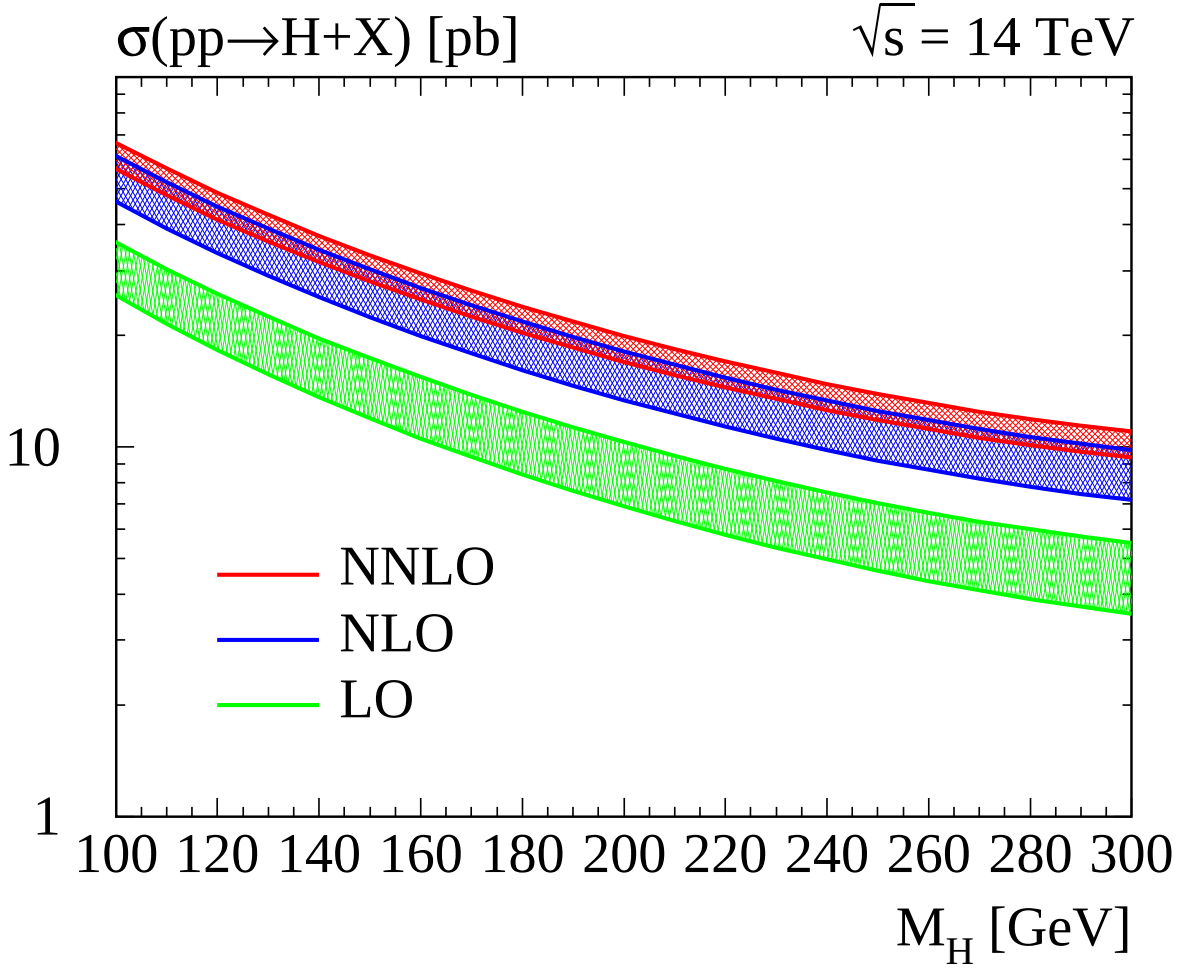




Holds also at NNLO?

see, e.g., [Marzani *et al.* '08]

Gluon fusion at NNLO

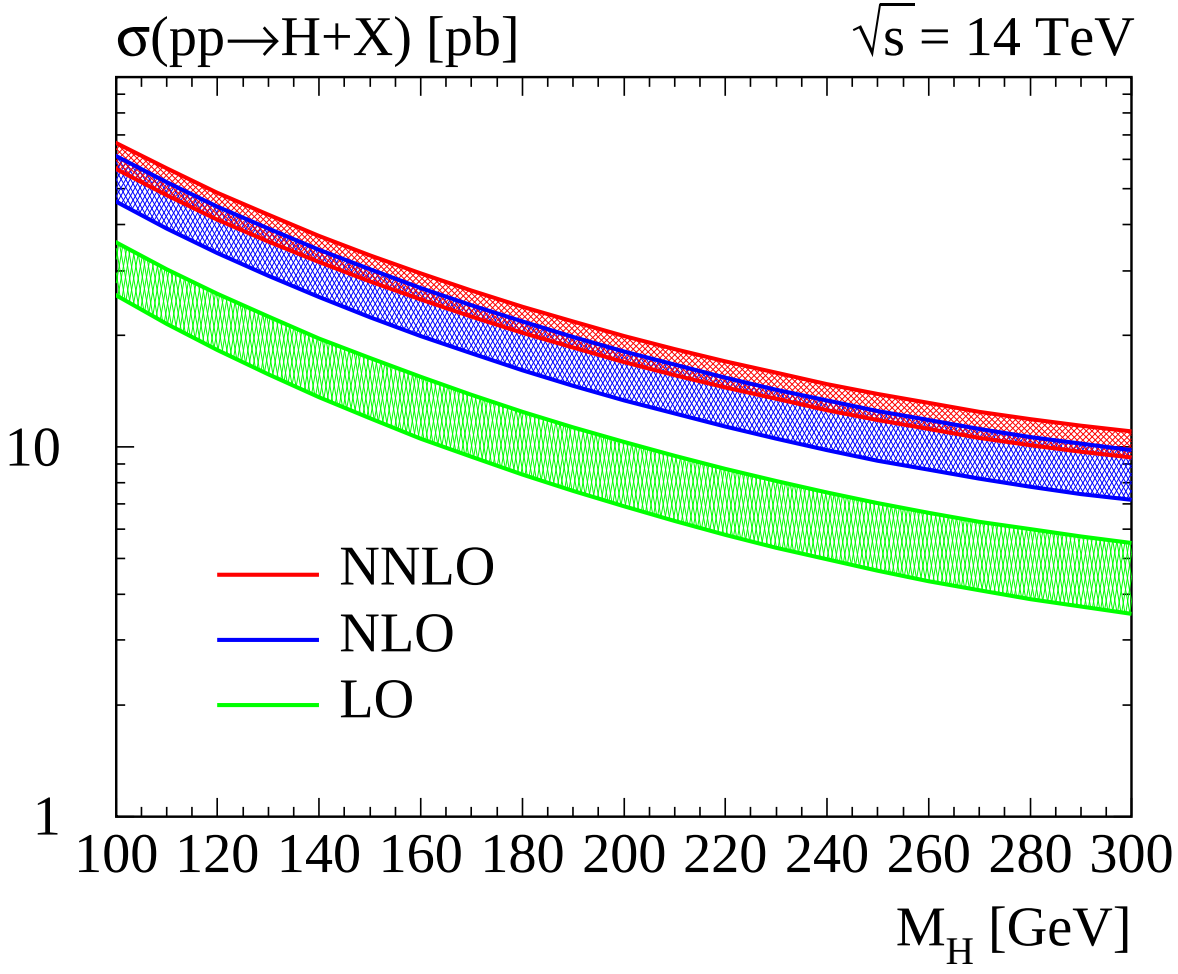


[R.H., Kilgore '02]
[Anastasiou, Melnikov '02]
[Ravindran, Smith, Neerven '03]

[Spira, Djouadi, Graudenz, Zerwas '91/'93]

[Dawson '91]

Gluon fusion at NNLO



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

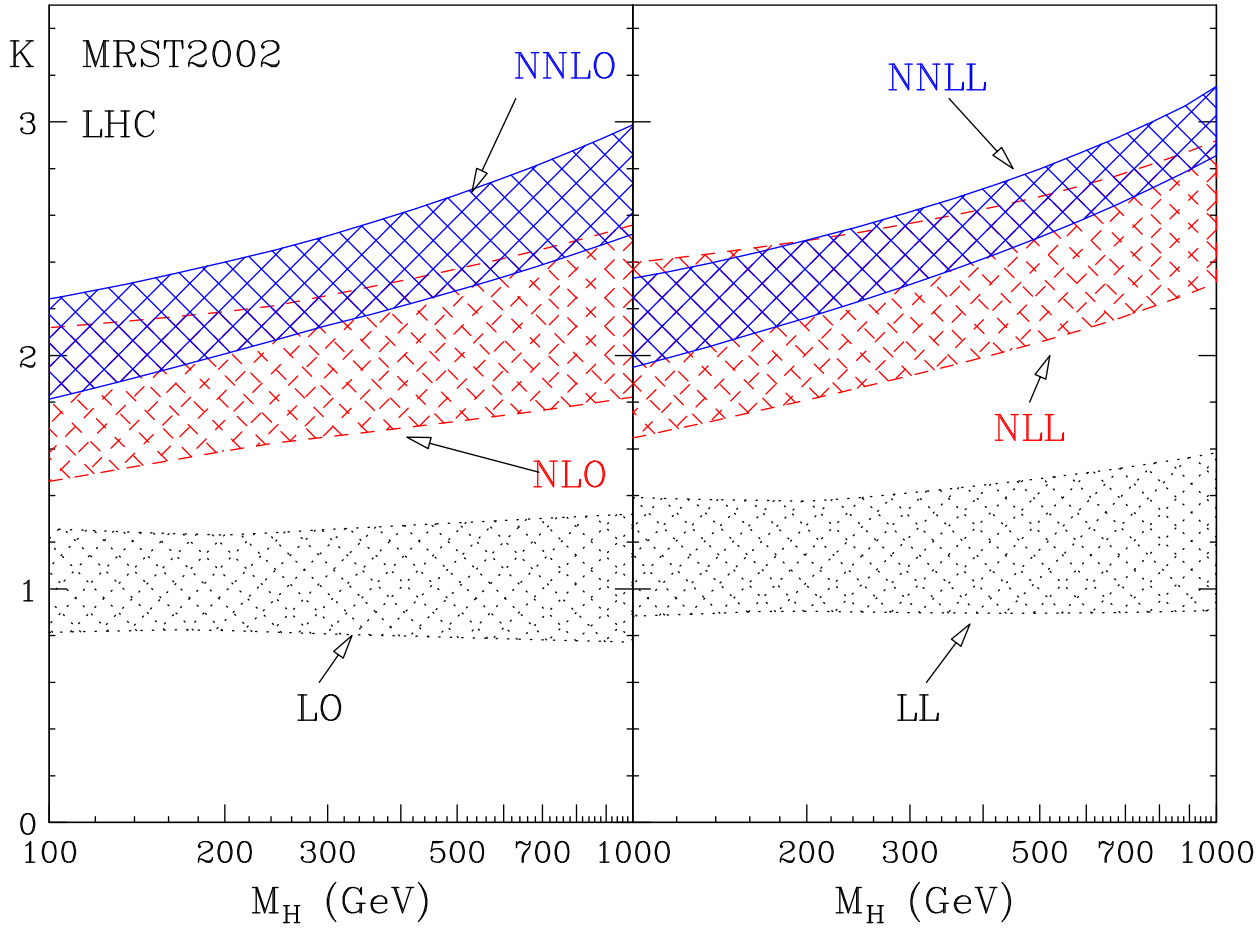
[Spira, Djouadi, Graudenz, Zerwas ’91/’93]

[Dawson ’91]

Why so large?

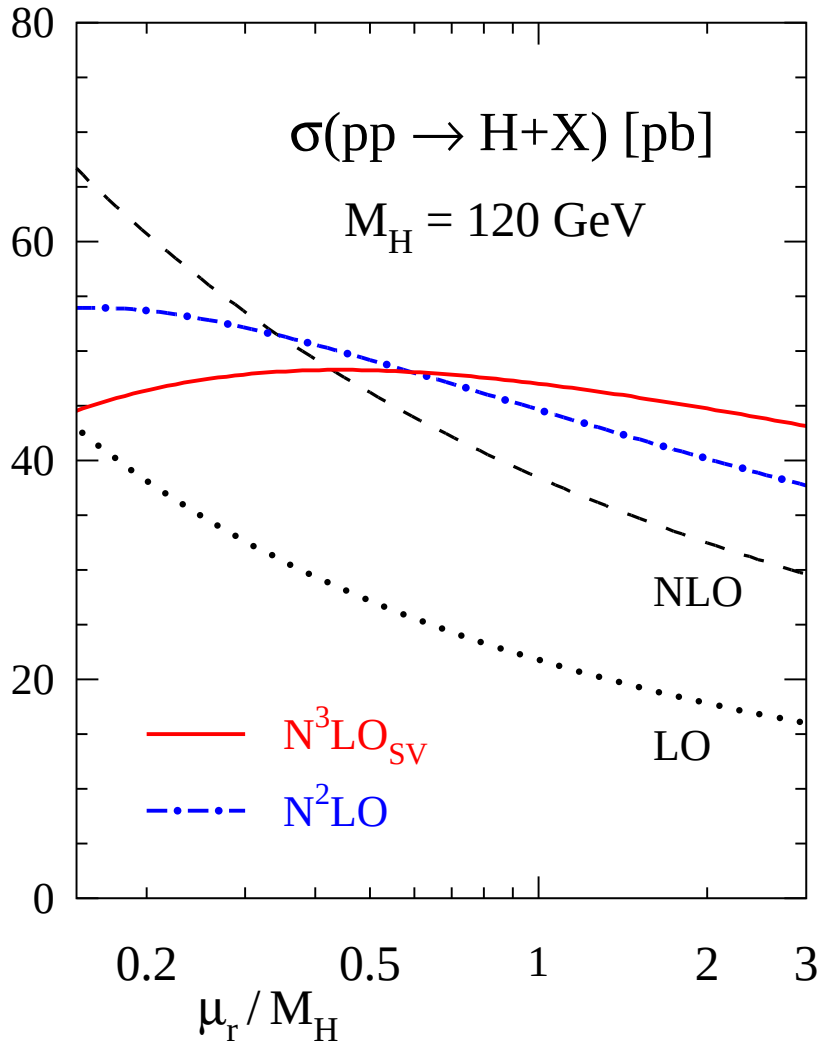
Gluon fusion – beyond NNLO

- soft resummation $\hat{s} \to M_H^2$ [Catani, Grazzini, de Florian, Nason '03]



Gluon fusion – beyond NNLO

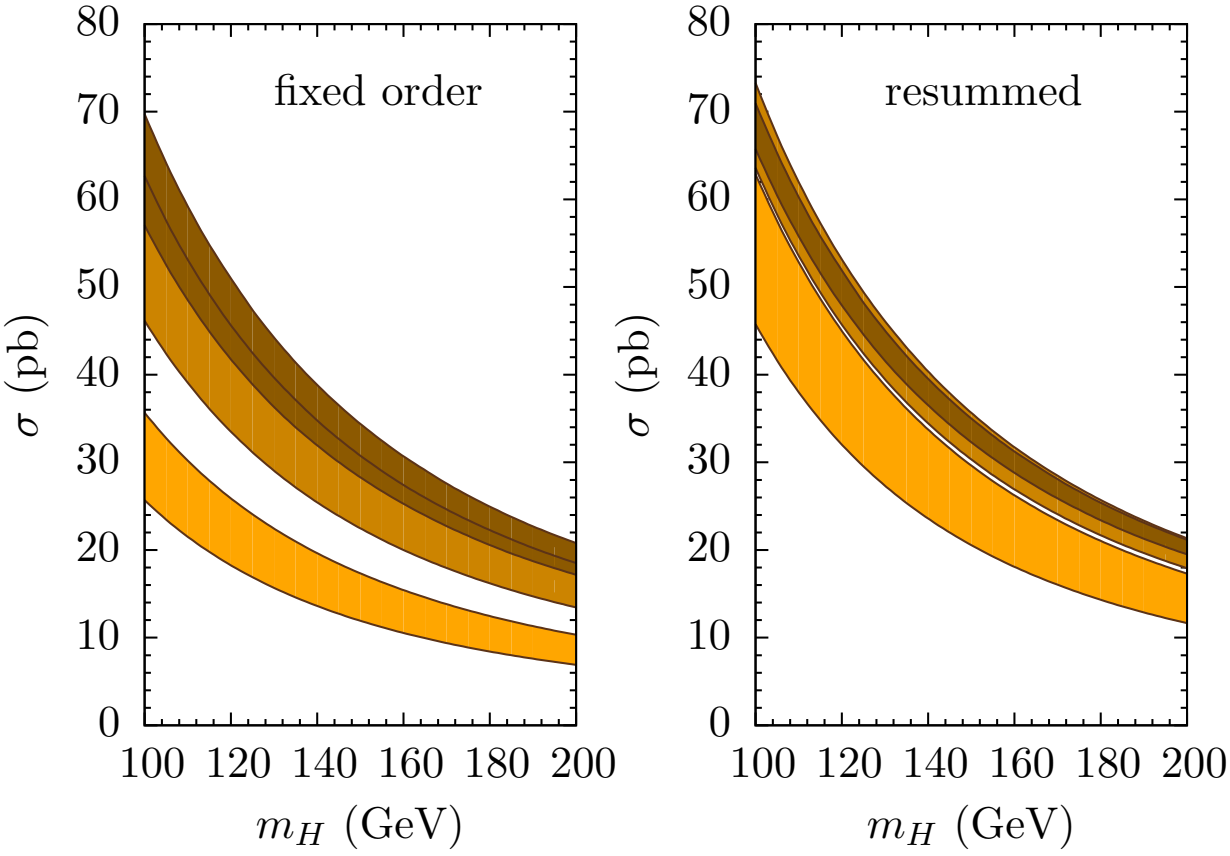
- N^3LO soft



[Moch, Vogt '05]
[Laenen, Magnea '05]
[Ravindran '05]
[Kidonakis '05]
[Idilbi, Ju, Yuan '06]

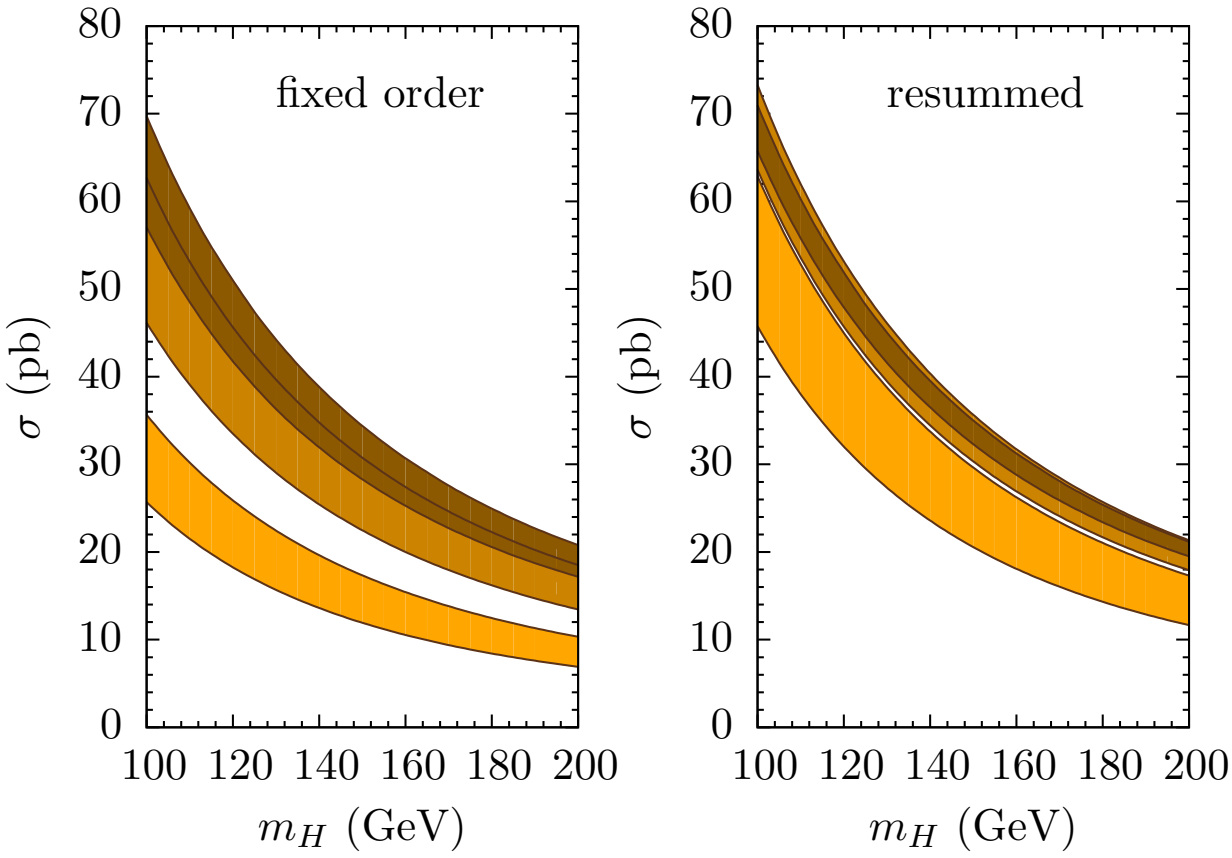
Latest developments

Resumming $(C_A \pi \alpha_s)^n$ from $\ln(-q^2) = \ln q^2 - i\pi$



Latest developments

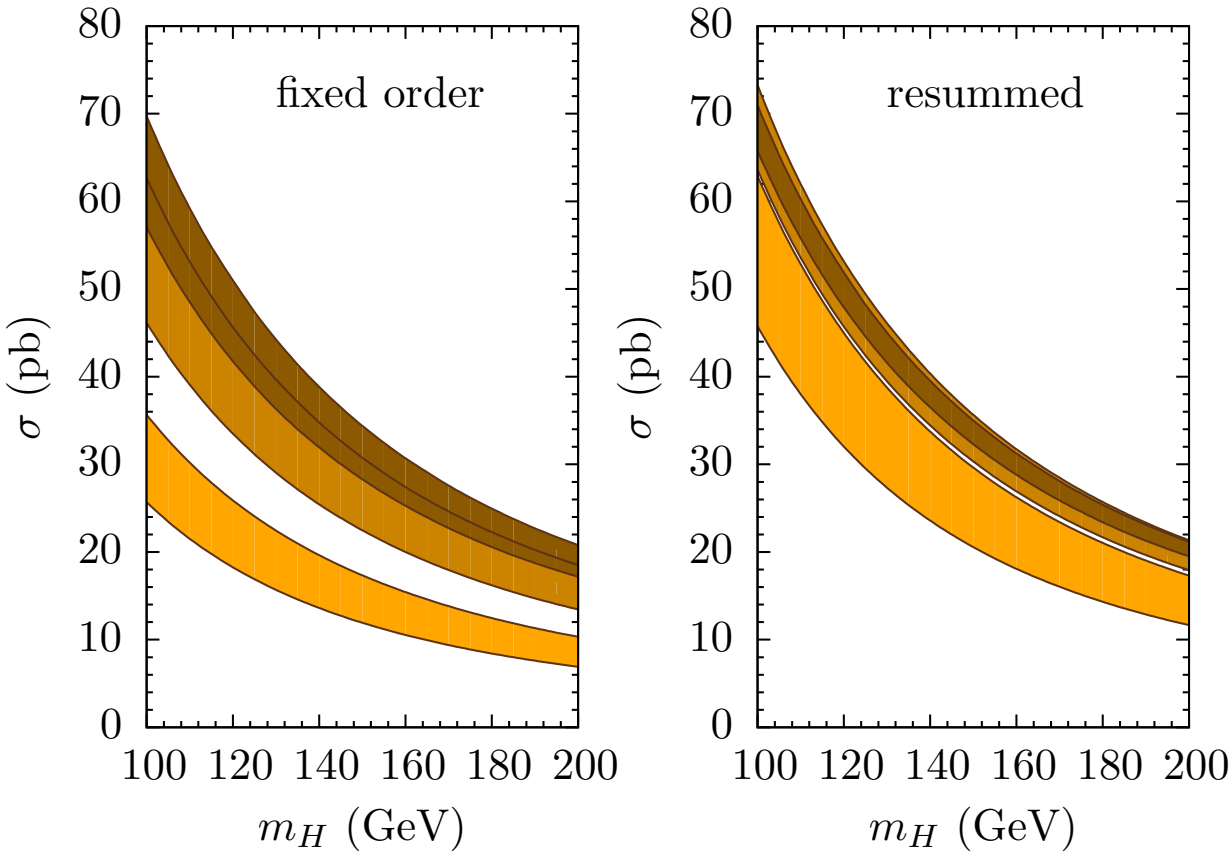
Resumming $(C_A \pi \alpha_s)^n$ from $\ln(-q^2) = \ln q^2 - i\pi$



Message: π^2 is large

Latest developments

Resumming $(C_A \pi \alpha_s)^n$ from $\ln(-q^2) = \ln q^2 - i\pi$



Message: π^2 is large but some π^2's are larger than others...

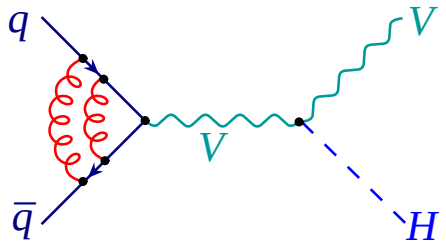
Gluon fusion

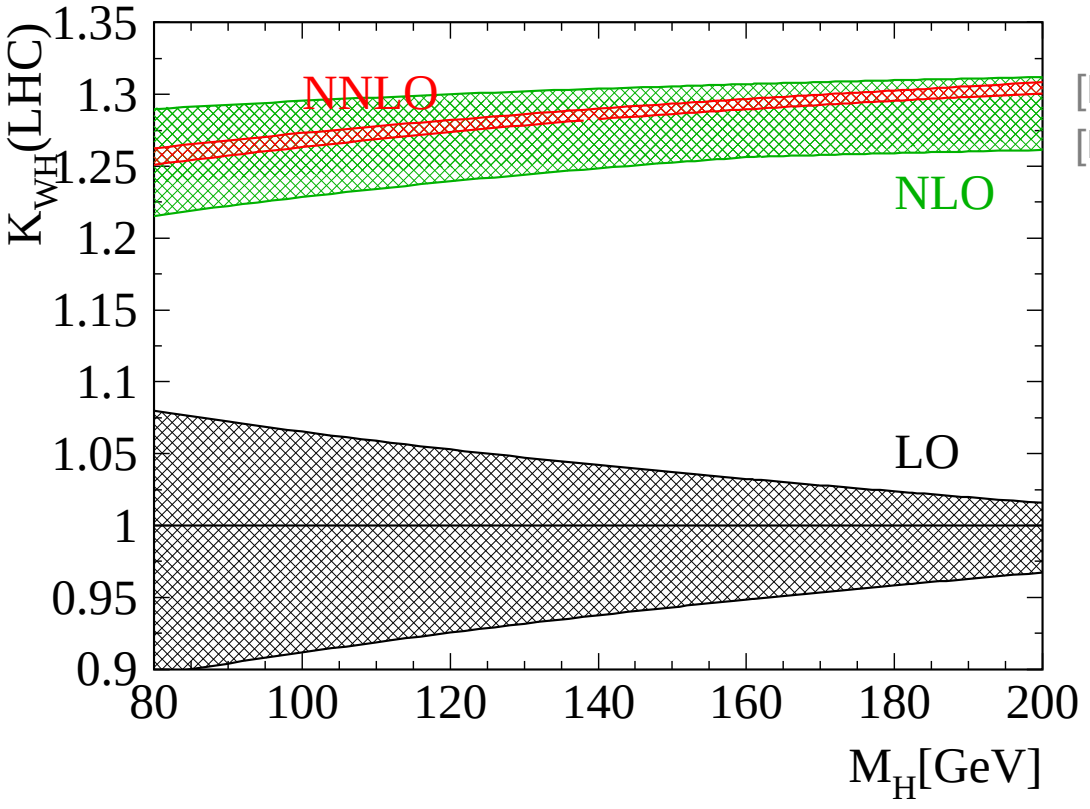
- QCD corrections
  - under good control, but
  - final word on origin of large corrections (probably) not spoken
  - better understanding more important than full N^{3}LO

Gluon fusion

- QCD corrections
  - under good control, but
  - final word on origin of large corrections (probably) not spoken
  - better understanding more important than full N^{3}LO
- Electro-weak corrections
  - can be large at LHC due to “Sudakov” $\ln^2(\hat{s}/M_W^2)$
  - in fact:
    - Higgs-Strahlung [Ciccolini, Dittmaier, Krämer ’03]

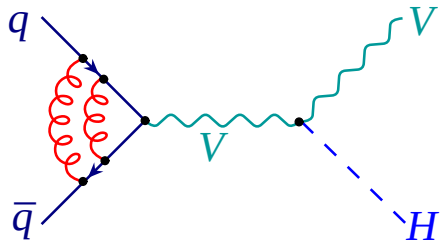
Higgs Strahlung

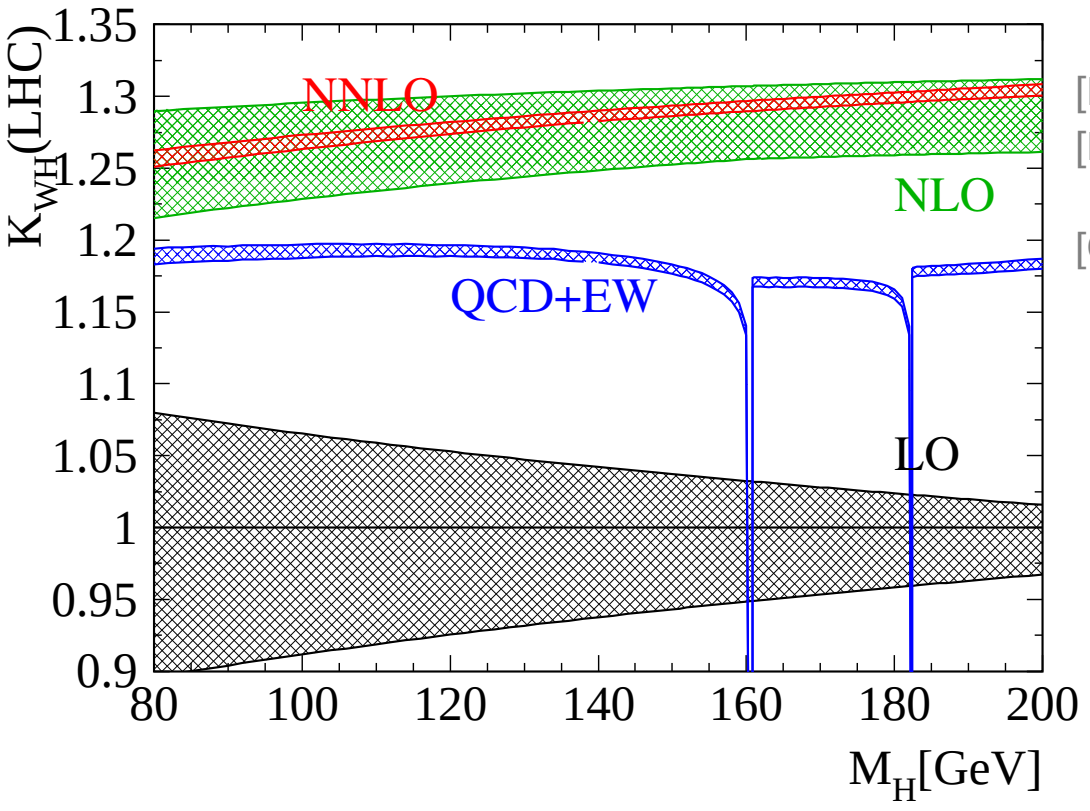




[Brein, Djouadi, R.H. '03]
[Han, Willenbrock '90]

Higgs Strahlung





[Brein, Djouadi, R.H. '03]
[Han, Willenbrock '90]

[Ciccolini, Dittmaier, Krämer '03]

Gluon fusion

- QCD corrections
  - under good control, but
  - final word on origin of large corrections (probably) not spoken
  - better understanding more important than full N^{3}LO
- Electro-weak corrections
  - can be large at LHC due to “Sudakov” $\ln^2(\hat{s}/M_W^2)$
  - in fact:
    - Higgs-Strahlung [Ciccolini, Dittmaier, Krämer ’03]

Gluon fusion

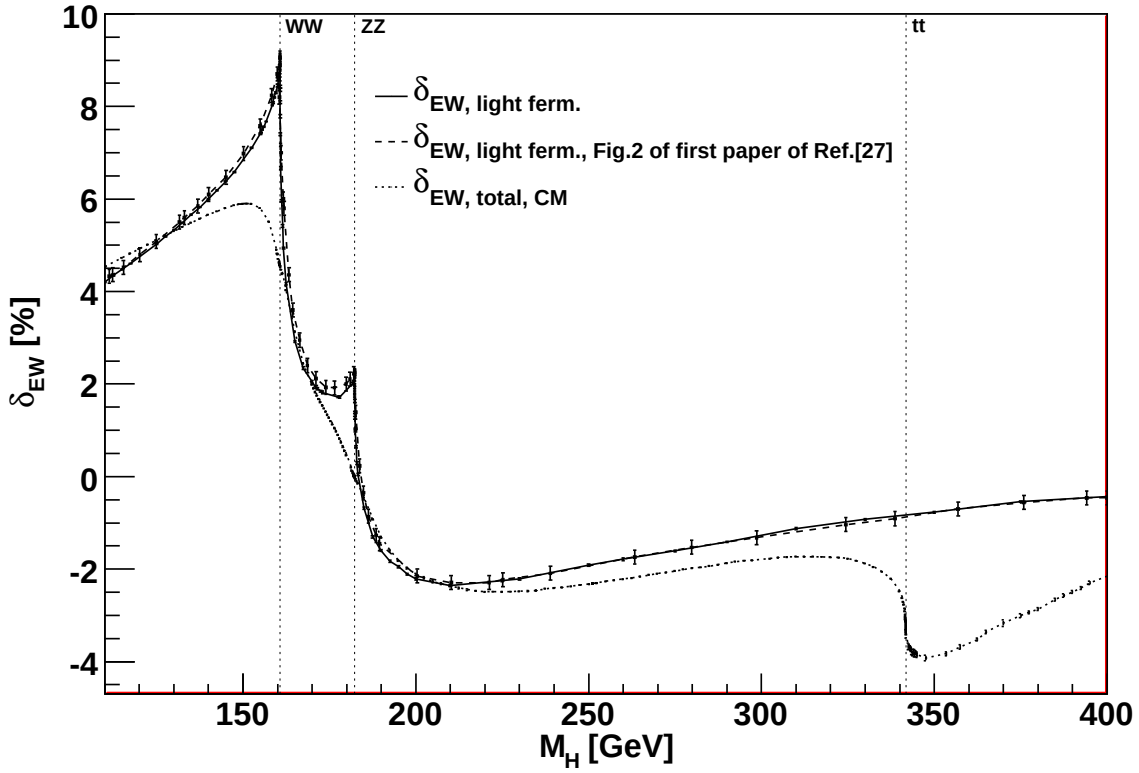
- QCD corrections
  - under good control, but
  - final word on origin of large corrections (probably) not spoken
  - better understanding more important than full N^{3}LO
- Electro-weak corrections
  - can be large at LHC due to “Sudakov” $\ln^2(\hat{s}/M_W^2)$
  - in fact:
    - Higgs-Strahlung [Ciccolini, Dittmaier, Krämer ’03]
    - WBF [Ciccolini, Denner, Dittmaier ’08] $\longrightarrow$ later

Gluon fusion

- QCD corrections
  - under good control, but
  - final word on origin of large corrections (probably) not spoken
  - better understanding more important than full N^{3}LO
- Electro-weak corrections
  - can be large at LHC due to “Sudakov” $\ln^2(\hat{s}/M_W^2)$
  - in fact:
    - Higgs-Strahlung [Ciccolini, Dittmaier, Krämer ’03]
    - WBF [Ciccolini, Denner, Dittmaier ’08] $\longrightarrow$ later
    - gluon fusion

Gluon fusion

- electro-weak corrections:



[Actis, Passarino, Sturm, Uccirati '08]

partial:

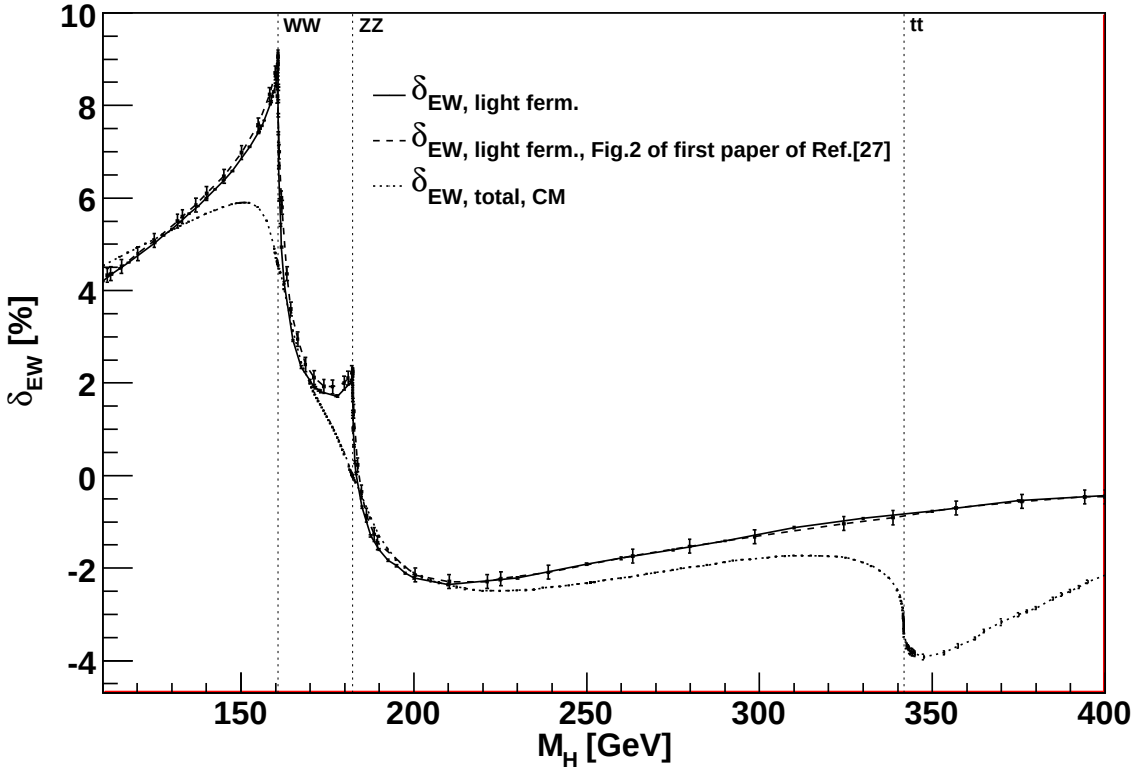
[Aglietti, Bonciani, Degrassi, Vicini '04]

[Degrassi, Maltoni '04]

[Djouadi, Gambino '94]

Gluon fusion

- electro-weak corrections:



[Actis, Passarino, Sturm, Uccirati '08]

partial:

[Aglietti, Bonciani, Degrassi, Vicini '04]

[Degrassi, Maltoni '04]

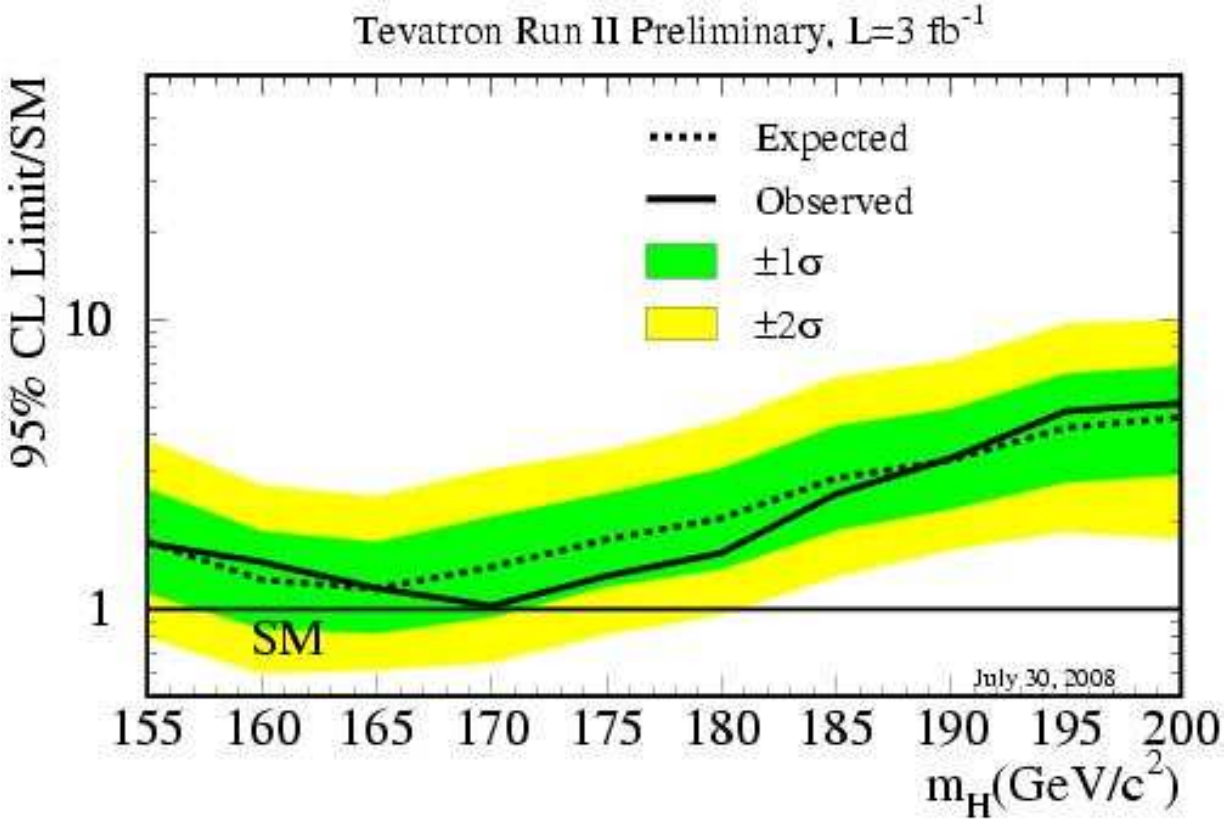
[Djouadi, Gambino '94]

- mixed EW/QCD? (remember LEP?)

  → do they factorize? [Anastasiou, Boughezal, Petriello '08]

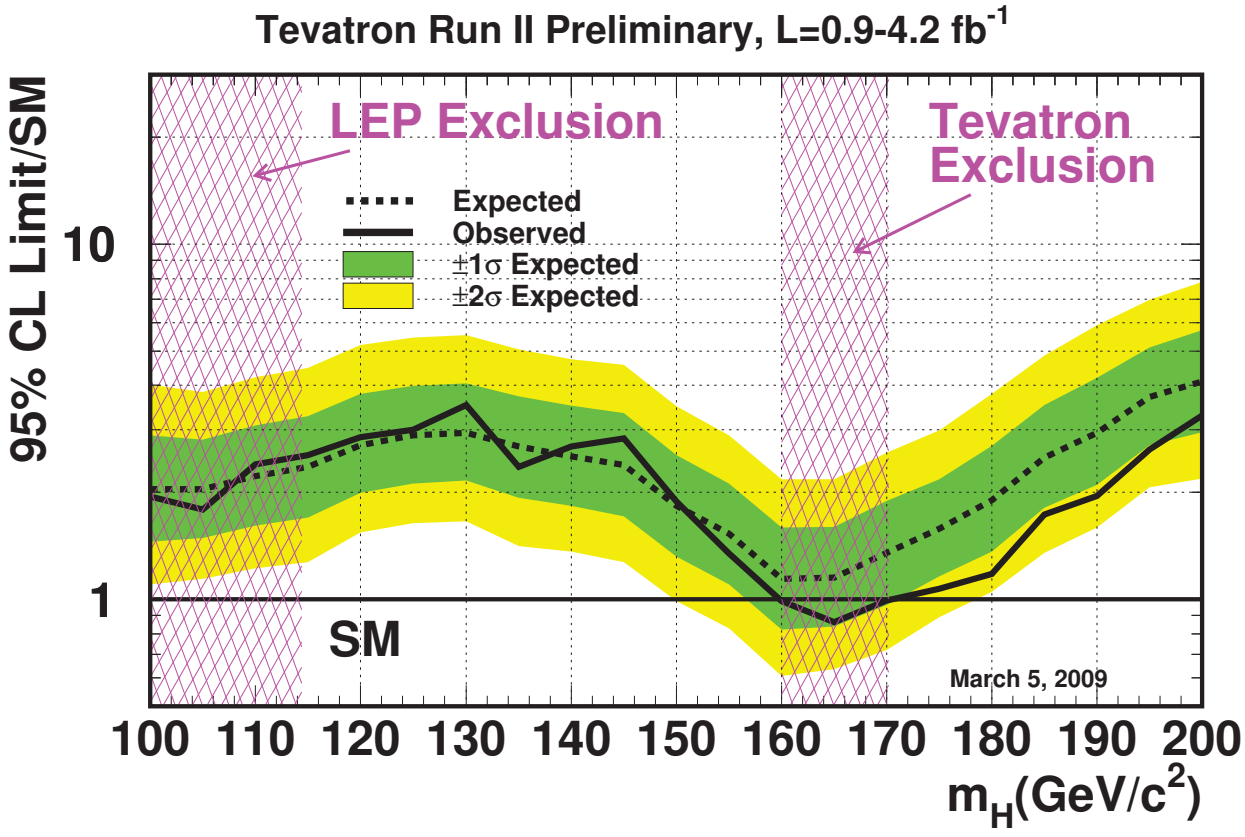
Putting things together...

Compared to



$\mathcal{O}(10\%)$ increase

Putting things together…

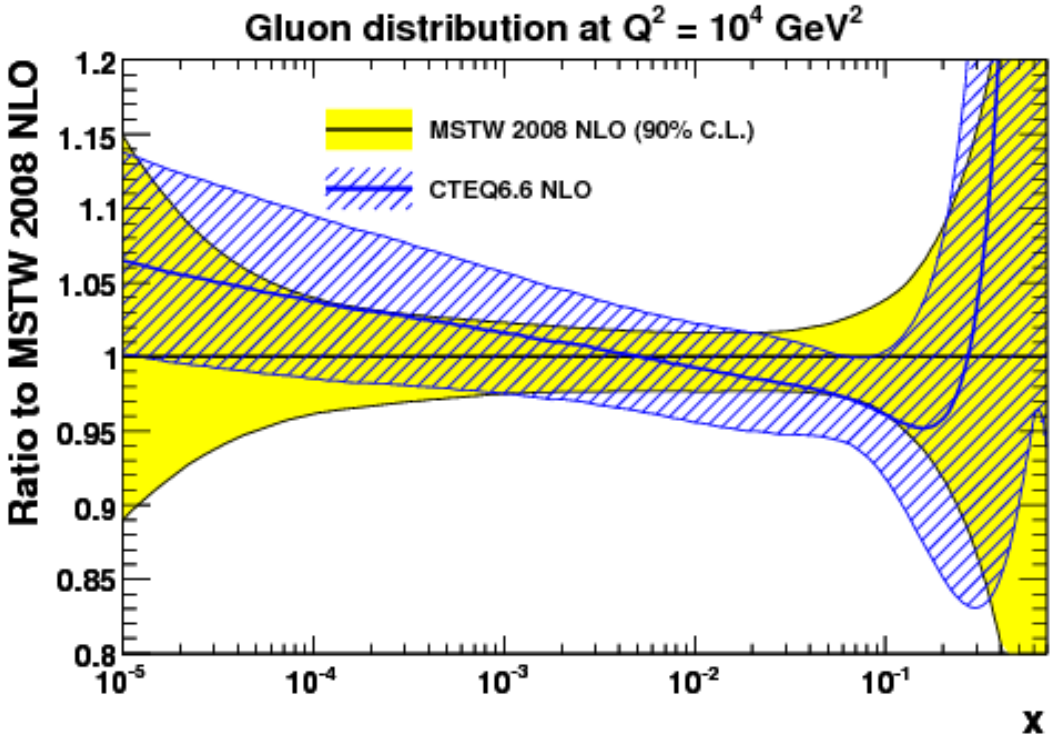


but note: change `MRST2006` → `MSTW2008` leads to $\mathcal{O}(10\%)$ decrease!

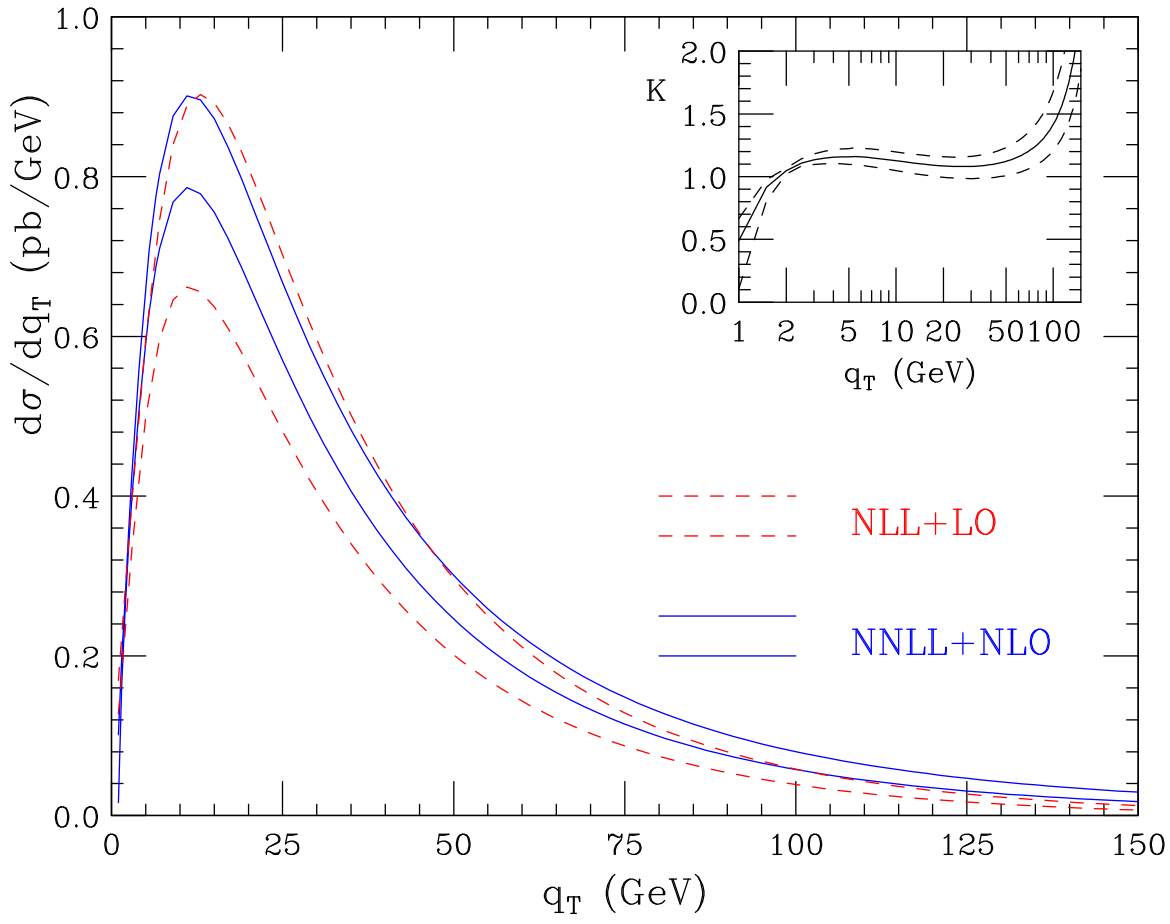
[de Florian, Grazzini '09], [Anastasiou, Boughezal, Petriello '08]

PDF uncertainty?

- MSTW 2008 [cf. talk by J. Stirling]

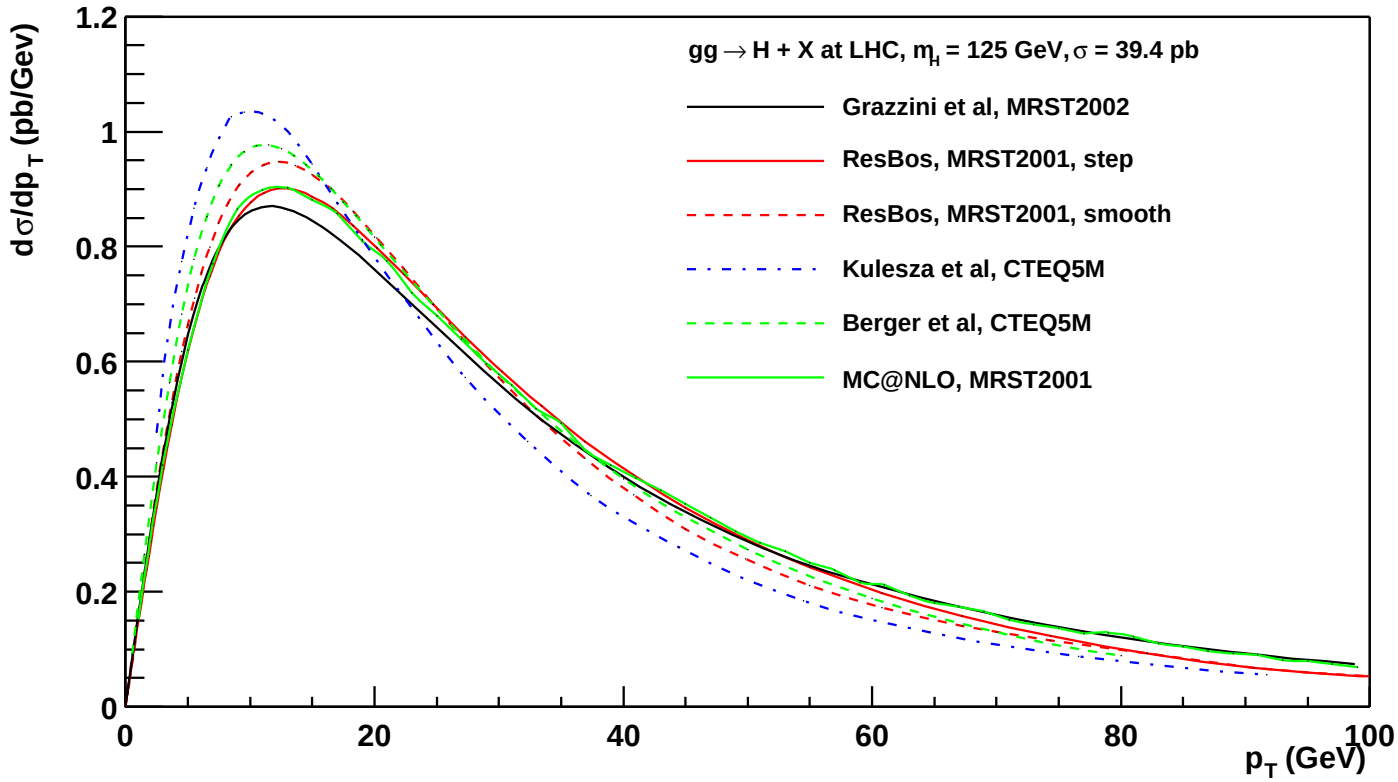


Distributions



[Bozzi, Catani, de Florian, Grazzini '05]

Distributions

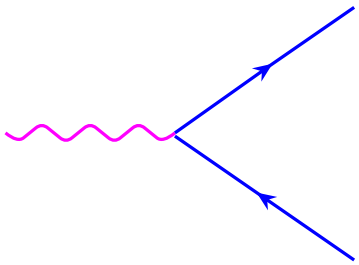


from [hep-ph/0403052]

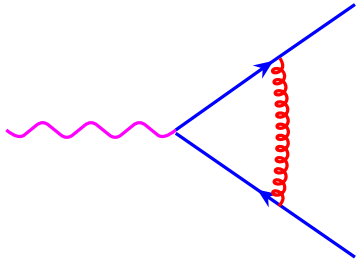
Higher orders with Cuts

Consider $Z \to 2$ jets: inclusive

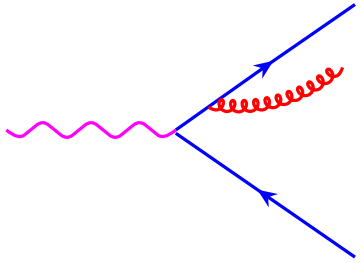
LO:



NLO:



$+ \int$

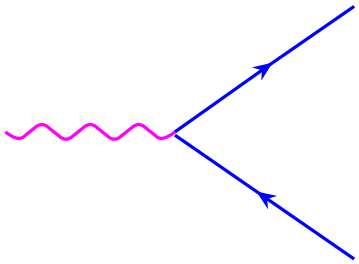


$$\frac{A}{\epsilon} + B \qquad -\frac{A}{\epsilon} + C \qquad = \qquad B + C$$

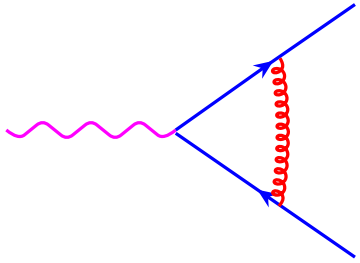
Higher orders with Cuts

Consider $Z \to 2$ jets: exclusive

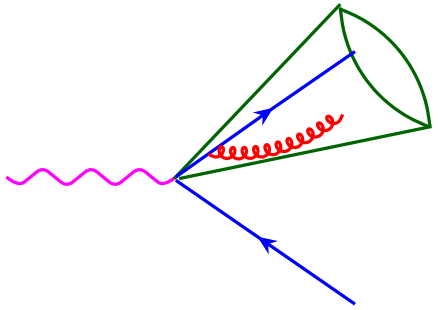
LO:



NLO:

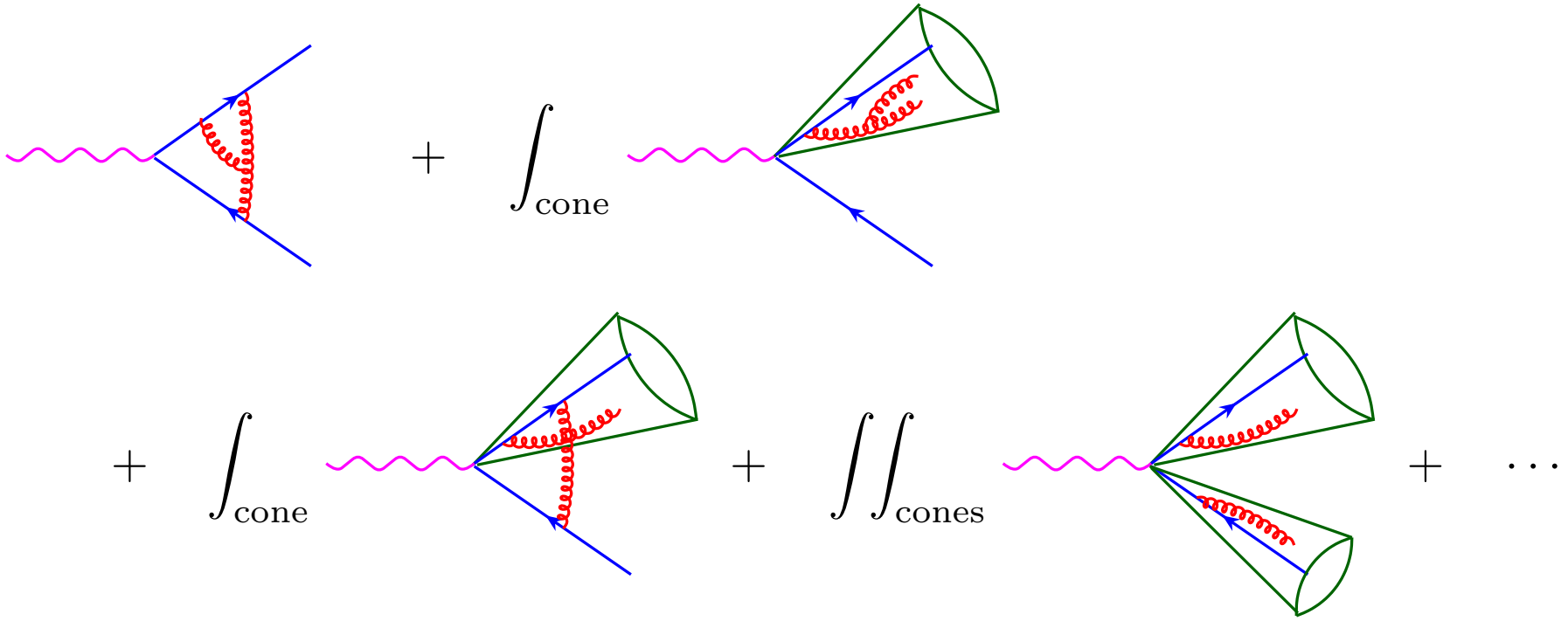


$+ \int_{\text{cone}}$



$$\frac{A}{\epsilon} + B \qquad -\frac{A}{\epsilon} + C_{\text{cut}} \qquad = \qquad B + C_{\text{cut}}$$

Exclusive at NNLO



[Anastasiou, Melnikov, Petriello], [Gehrmann, G.-de Ridder, Glover],
[Grazzini, Frixione], [Kilgore], [Kosower], [Somogyi, Trocsanyi, Del Duca], [Weinzierl]

Exclusive at NNLO

- $e^+e^- \to 2$ jets

  [Anastasiou, Melnikov, Petriello '04]

  using sector decomposition [Binoth, Heinrich]

- $e^+e^- \to 3$ jets

  [Gehrmann-De Ridder, Gehrmann, Glover, Heinrich '08]

  [Weinzierl '08]

  using antenna subtraction [Gehrmann-De Ridder, Gehrmann, Glover]

- $q\bar{q} \to V$

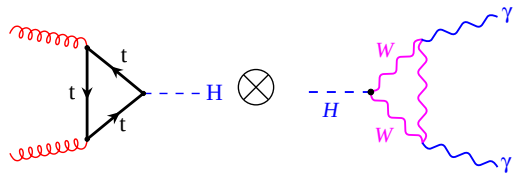
  [Melnikov, Petriello '06]

- $gg \to H$

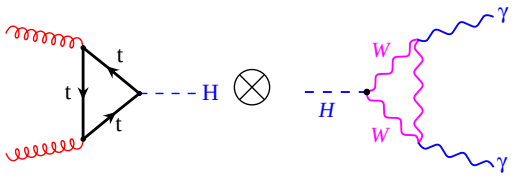
  FEHIP: [Anastasiou, Melnikov, Petriello '04]

  HNNLO: [Catani, Grazzini '07] subtraction method

NNLO with cuts



NNLO with cuts

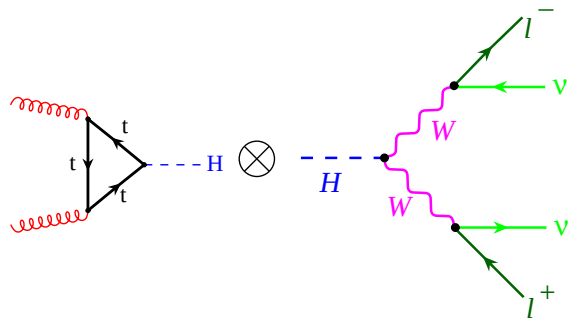


m_h	$\sigma^{\rm cut}_{\rm NNLO}/\sigma^{\rm inc}_{\rm NNLO}$	$K^{(2)}_{\rm cut}/K^{(2)}_{\rm inc}$
110	0.590	0.981
115	0.597	0.968
120	0.603	0.953
125	0.627	0.970
130	0.656	1.00
135	0.652	0.98

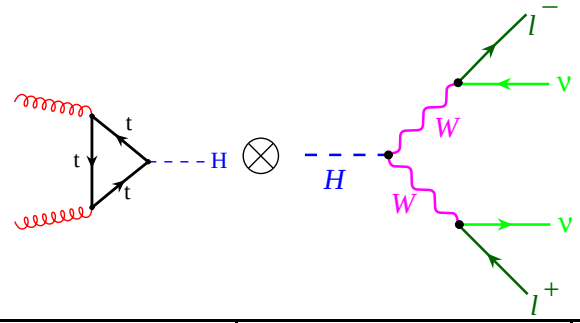
[Anastasiou, Melnikov, Petriello '05]

see also [Grazzini '07]

NNLO with cuts



NNLO with cuts

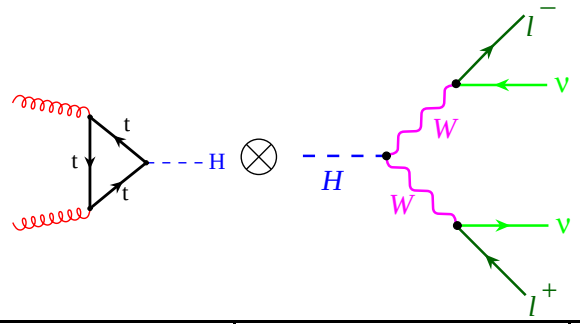


$\sigma[fb]$	LO	NLO	NNLO
$\mu = M_h/2$	21.002 ± 0.021	22.47 ± 0.11	18.45 ± 0.54
$\mu = M_h$	17.413 ± 0.017	21.07 ± 0.11	18.75 ± 0.37
$\mu = 2M_h$	14.529 ± 0.014	19.50 ± 0.10	19.01 ± 0.27

[Anastasiou, Dissertori, Stöckli '07]

see also [Grazzini '08]

NNLO with cuts



$\sigma[fb]$	LO	NLO	NNLO
$\mu = M_h/2$	21.002 ± 0.021	22.47 ± 0.11	18.45 ± 0.54
$\mu = M_h$	17.413 ± 0.017	21.07 ± 0.11	18.75 ± 0.37
$\mu = 2M_h$	14.529 ± 0.014	19.50 ± 0.10	19.01 ± 0.27

[Anastasiou, Dissertori, Stöckli '07]

see also [Grazzini '08]

Questions:

- can one understand the size of the radiative corrections (with cuts)?
- are the cuts sensitive to heavy top limit?
- effect of "π^2-resummation" ?

Including soft radiation

- match NLO calculation with parton shower

  without double counting

Including soft radiation

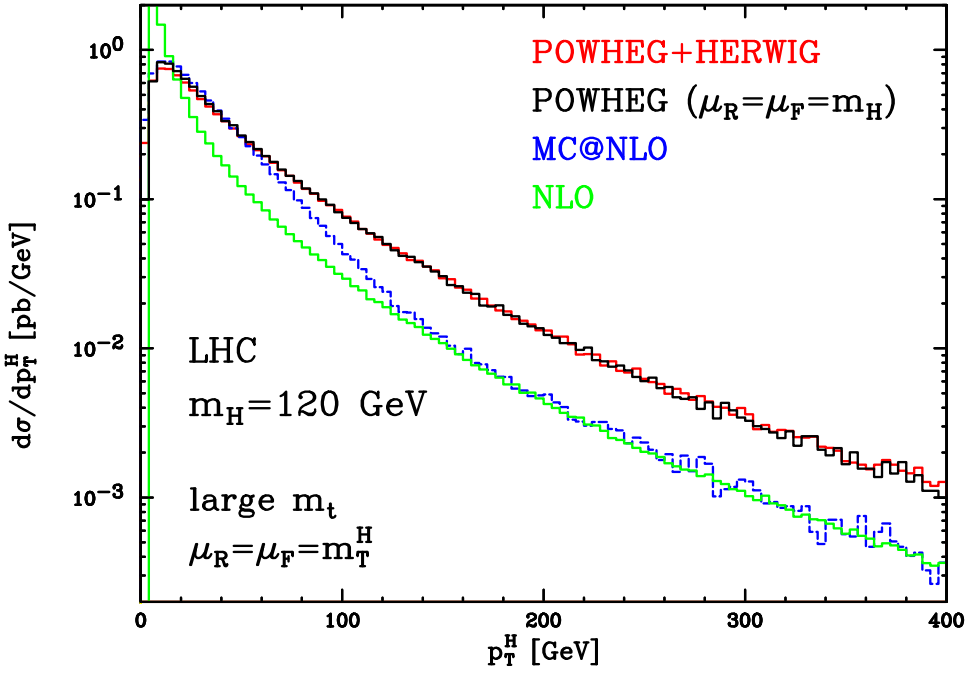
- match NLO calculation with parton shower

  without double counting

- two successful approaches so far:
  - MC@NLO [Frixione, Nason, Webber '03]
  - POWHEG [Frixione, Nason, Oleari '07]

Including soft radiation

- match NLO calculation with parton shower
  without double counting
- two successful approaches so far:
  - MC@NLO [Frixione, Nason, Webber '03]
  - POWHEG [Frixione, Nason, Oleari '07]



[Alioli, Nason, Oleari, Re '08]

[Hamilton, Richardson, Tully '09]

Including soft radiation

- approximate solutions:

Including soft radiation

- approximate solutions:
  - ME $\oplus$ PS

    CKKW [Catani, Kuhn, Krauss, Webber] $\longrightarrow$ SHERPA [Gleisberg et al.]

    AlpGen [Mangano]

Including soft radiation

- approximate solutions:
  - ME $\oplus$ PS

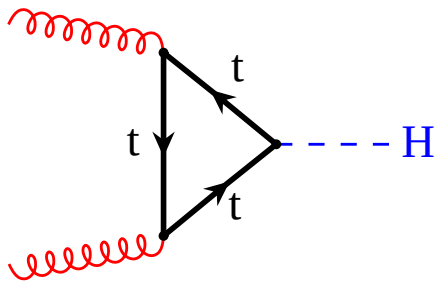
    CKKW [Catani, Kuhn, Krauss, Webber] $\longrightarrow$ SHERPA [Gleisberg et al.]

    AlpGen [Mangano]
  - differential re-weighting of LO MC

    e.g. reweight Pythia by FEHIP

    [Davatz *et al.* '04,'06]

Gluon Fusion

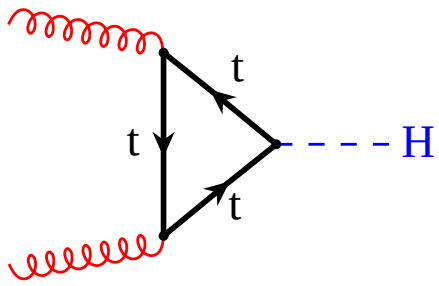


- dominant production mode
- sensitive to heavy particle spectrum

but

- $H \to b\bar{b}$ decay mode not usable for discovery
- LO is 1-loop $\longrightarrow$ radiative corrections difficult
- depends on Yukawa coupling

Gluon Fusion



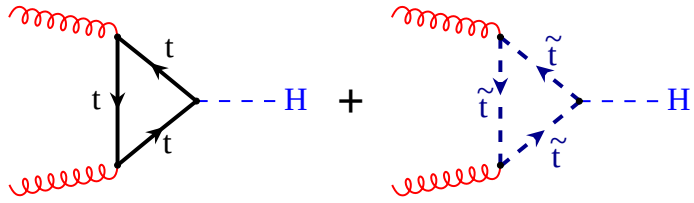
- dominant production mode
- sensitive to heavy particle spectrum

but

- $H \to b\bar{b}$ decay mode not usable for discovery
- LO is 1-loop $\longrightarrow$ radiative corrections difficult
- depends on Yukawa coupling

Effects of SUSY

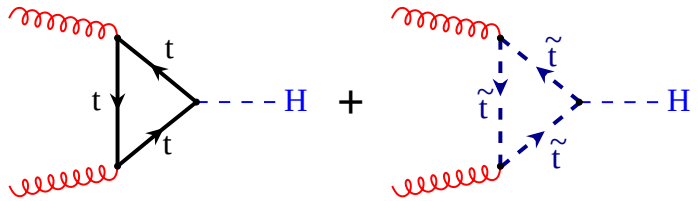
[Djouadi 98], [Carena *et al.* 99]



may interfere destructively!

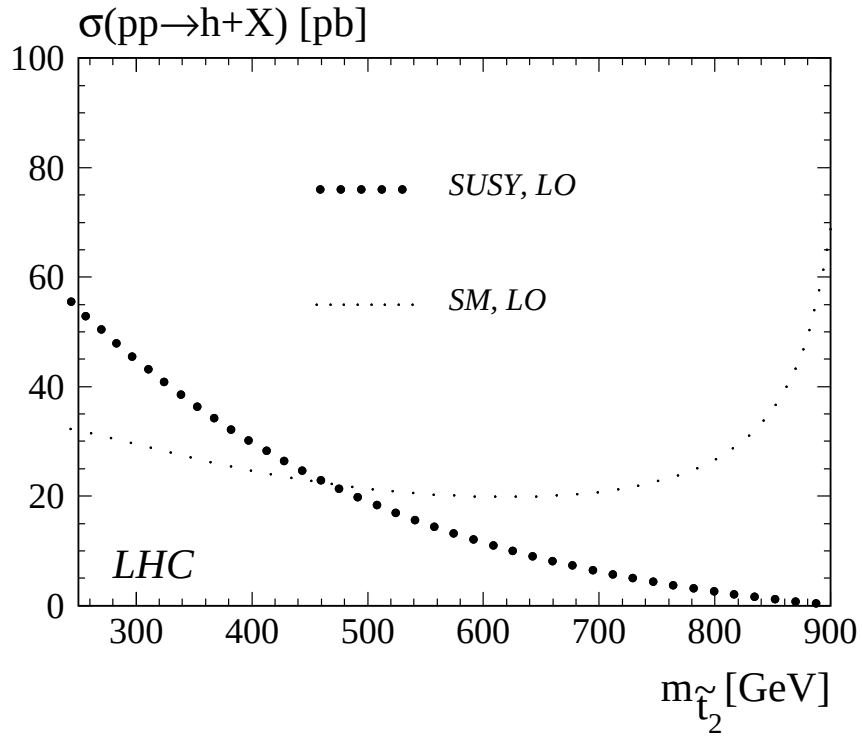
Effects of SUSY

[Djouadi 98], [Carena *et al.* 99]



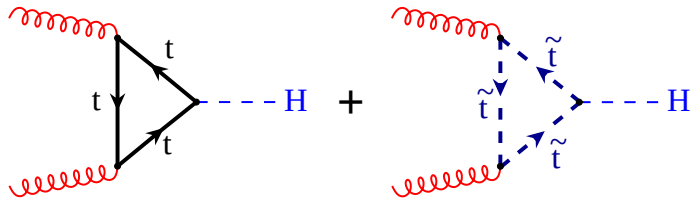
may interfere destructively!

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



Effects of SUSY

[Djouadi 98], [Carena *et al.* 99]



may interfere destructively!

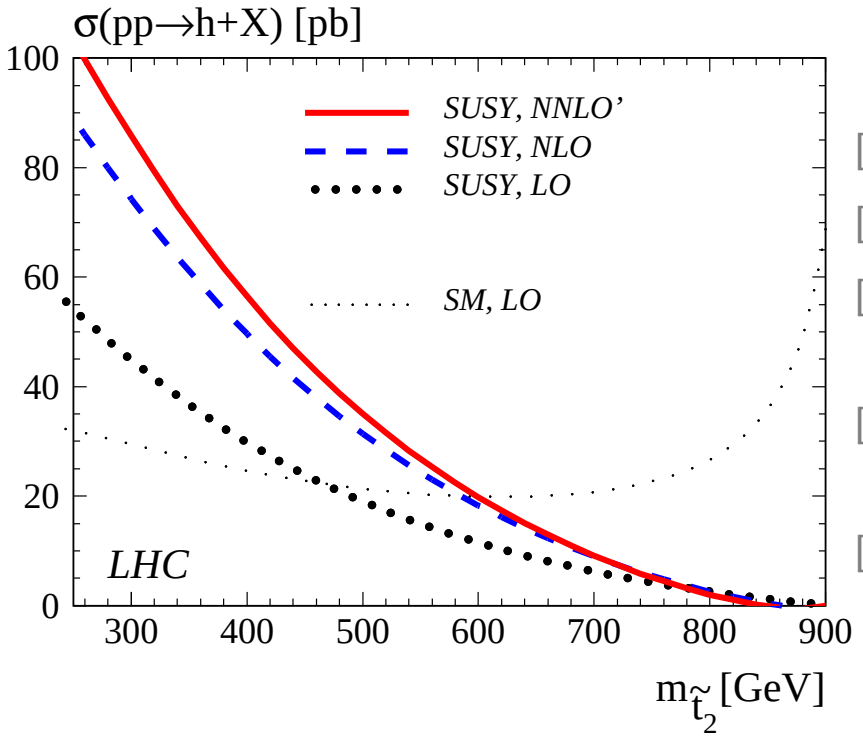
$m_{\tilde{t}_1} = 200\,\text{GeV}$

$m_{\tilde{g}} = 1\,\text{TeV}$

$\tan\beta = 10\,,$

$\alpha = 0\,,$

$\theta_t = \frac{\pi}{4}$



[R.H., Steinhauser '04],

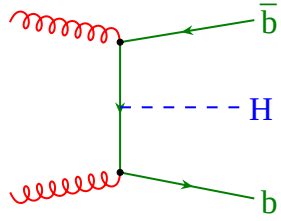
[Anastasiou *et al.* '06/'08]

[Mühlleitner, Rzehak, Spira '07/'08]

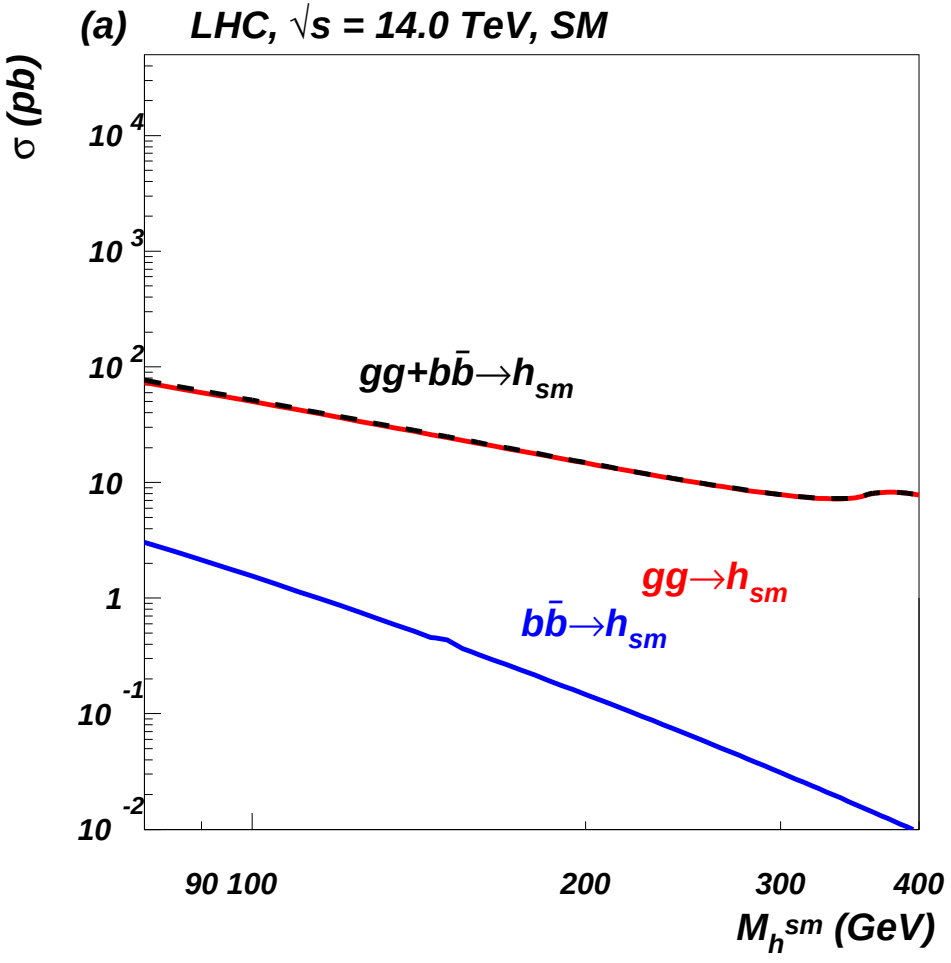
[Aglietti, Bonciani, Degrassi, Vicini '06]

[Degrassi, Slavich '08]

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

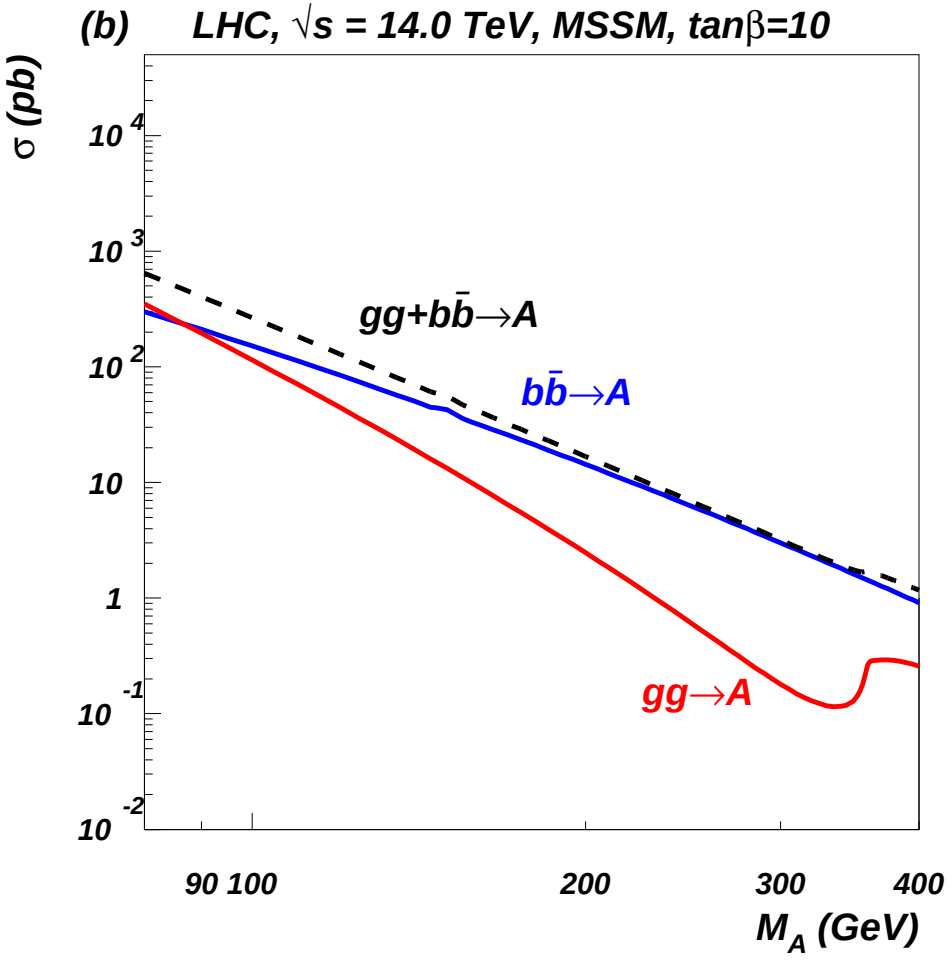


Numerical relevance



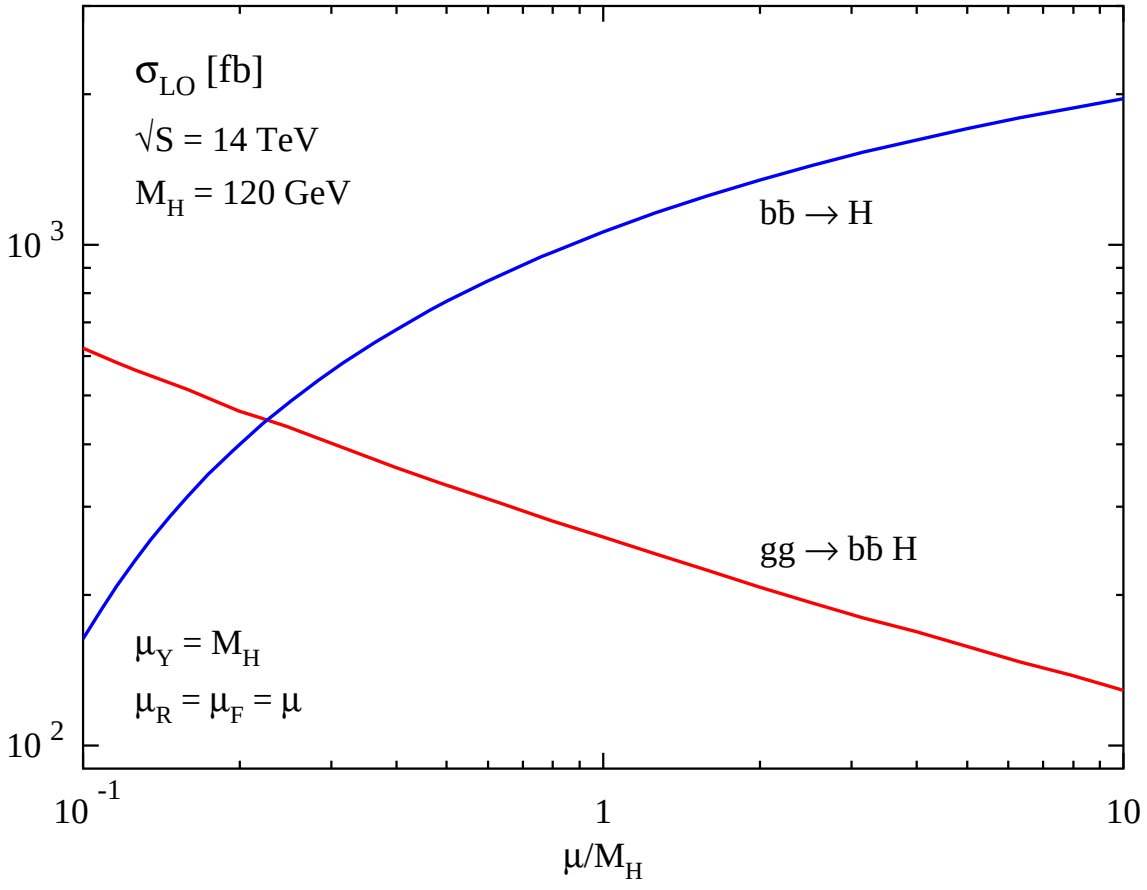
from [Belyaev et al., '05]

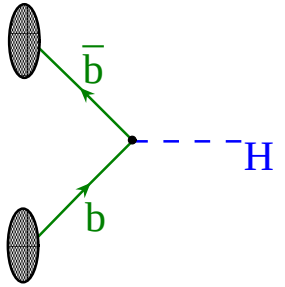
Numerical relevance

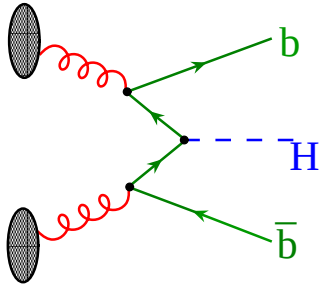


from [Belyaev et al., '05]

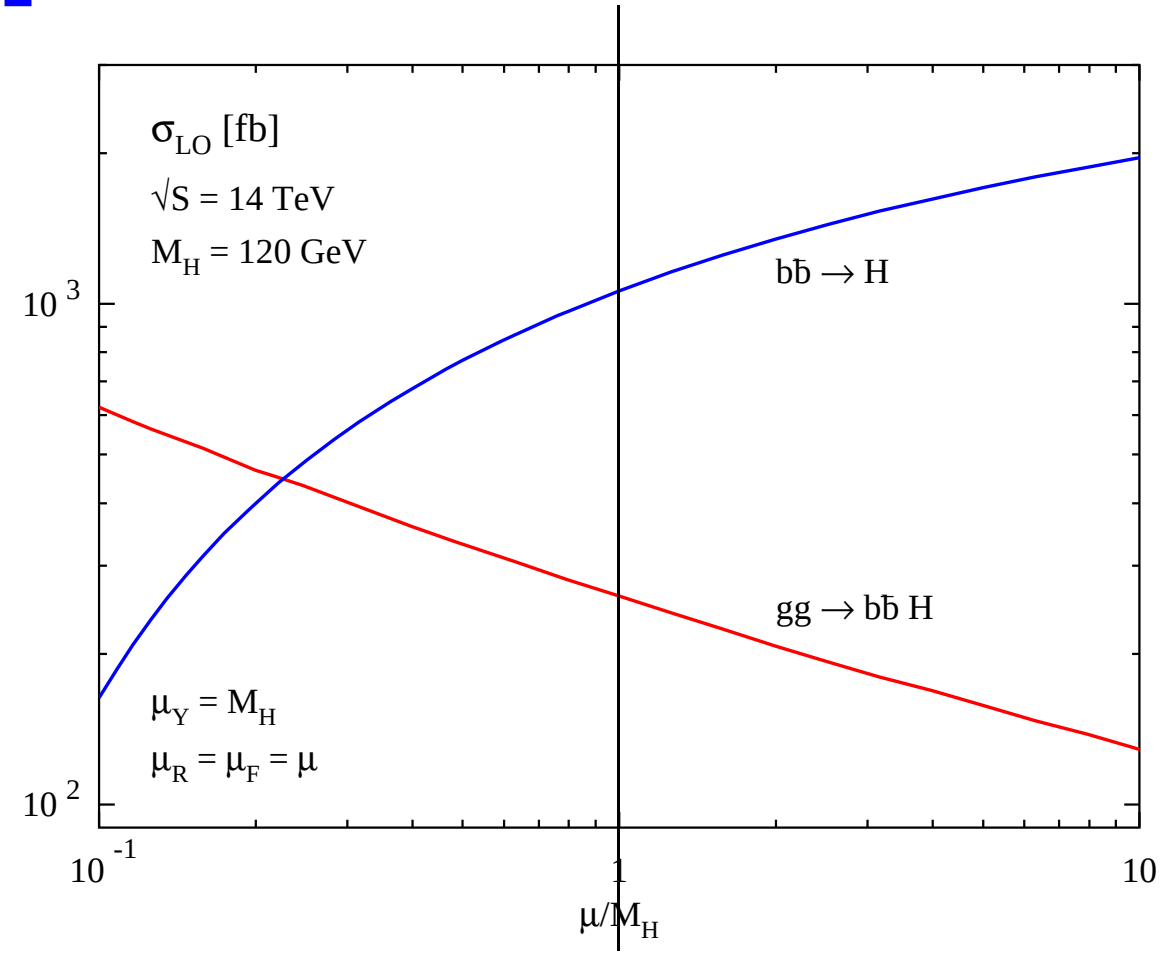
4-FNS vs. 5-FNS

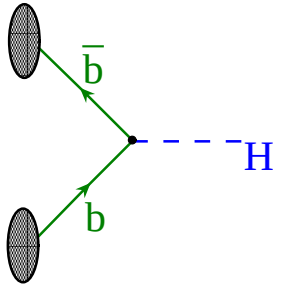

σ_LO [fb]
√S = 14 TeV
M_H = 120 GeV
bb̄ → H
gg → bb̄ H
μ_Y = M_H
μ_R = μ_F = μ
10 3
10 2
10 -1
1
10
μ/M_H

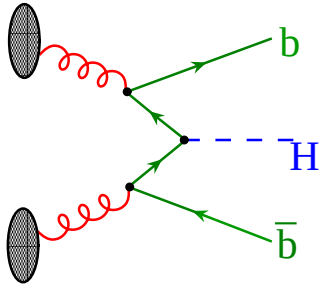

b̄
b
H


b
H
b̄

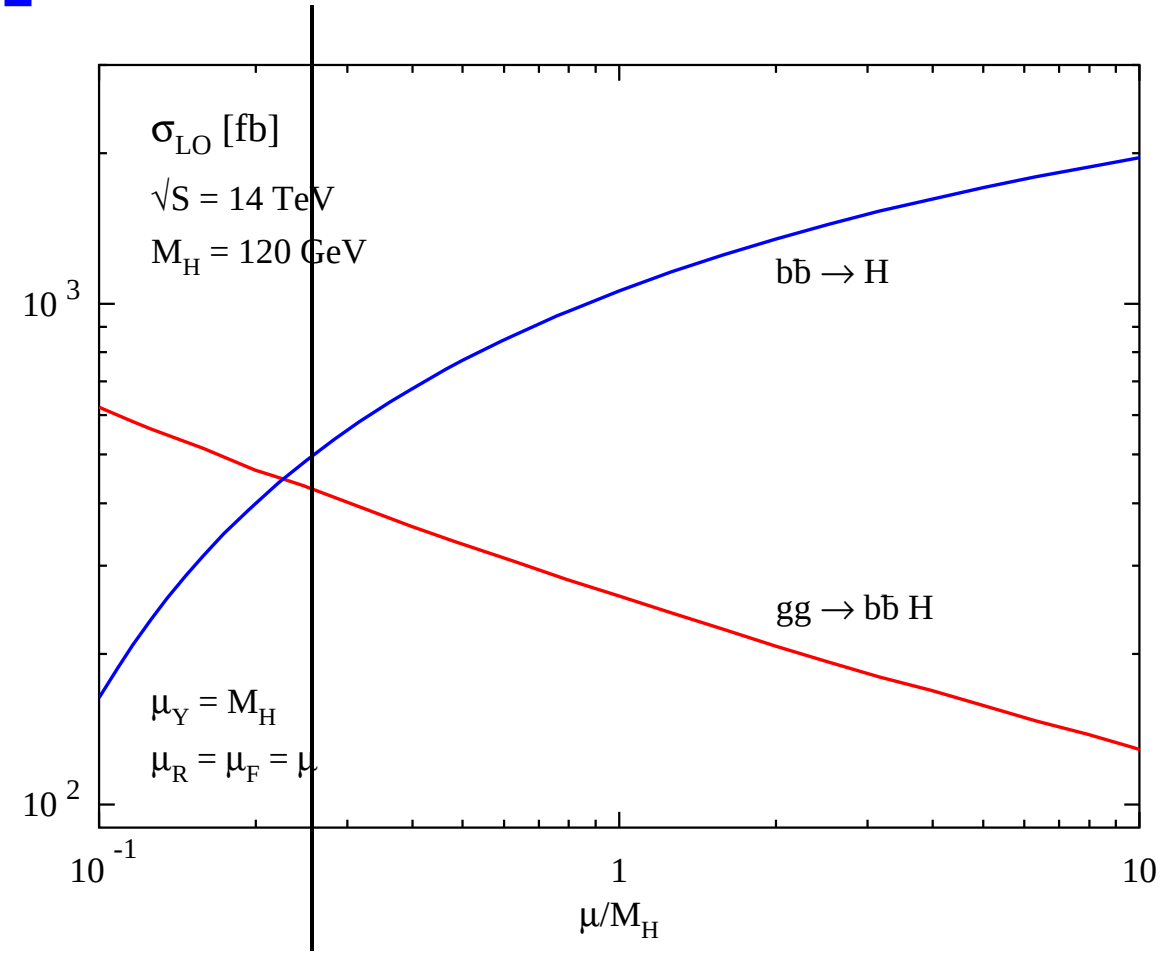
4-FNS vs. 5-FNS

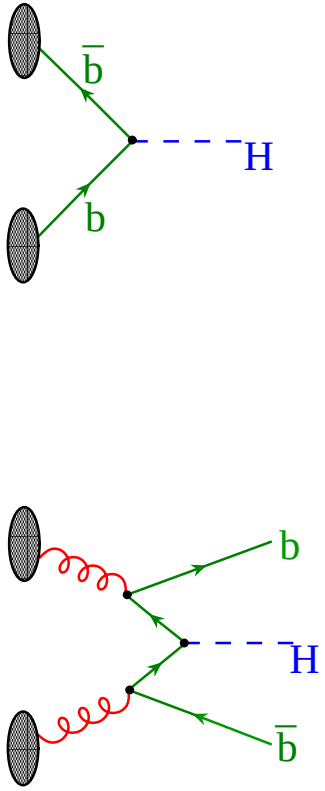

σ_LO [fb]
√S = 14 TeV
M_H = 120 GeV
bb̄ → H
gg → bb̄ H
μ_Y = M_H
μ_R = μ_F = μ
10 3
10 2
10 -1
1
10
μ/M_H


b̄
b
H

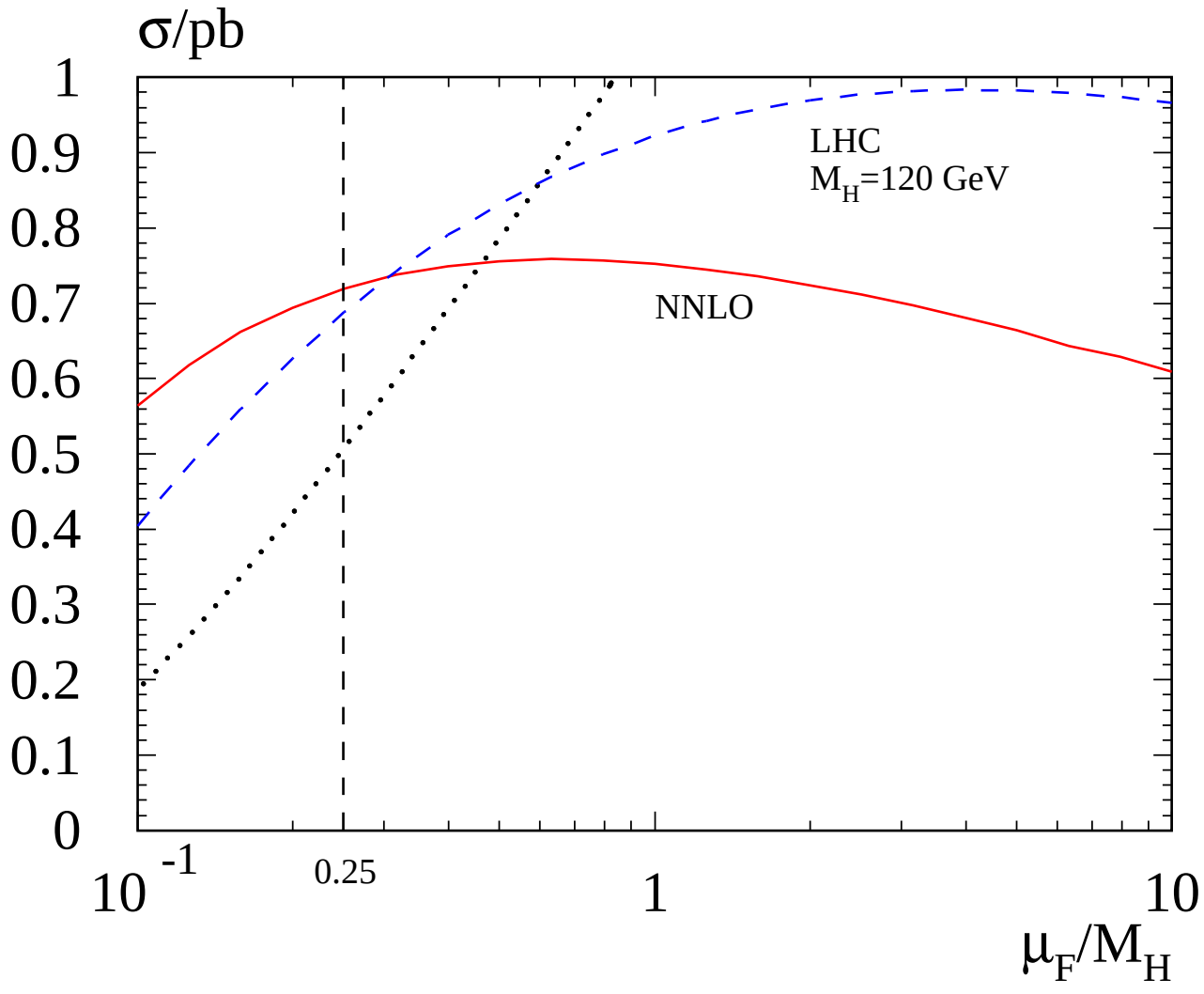

b
H
b̄

4-FNS vs. 5-FNS

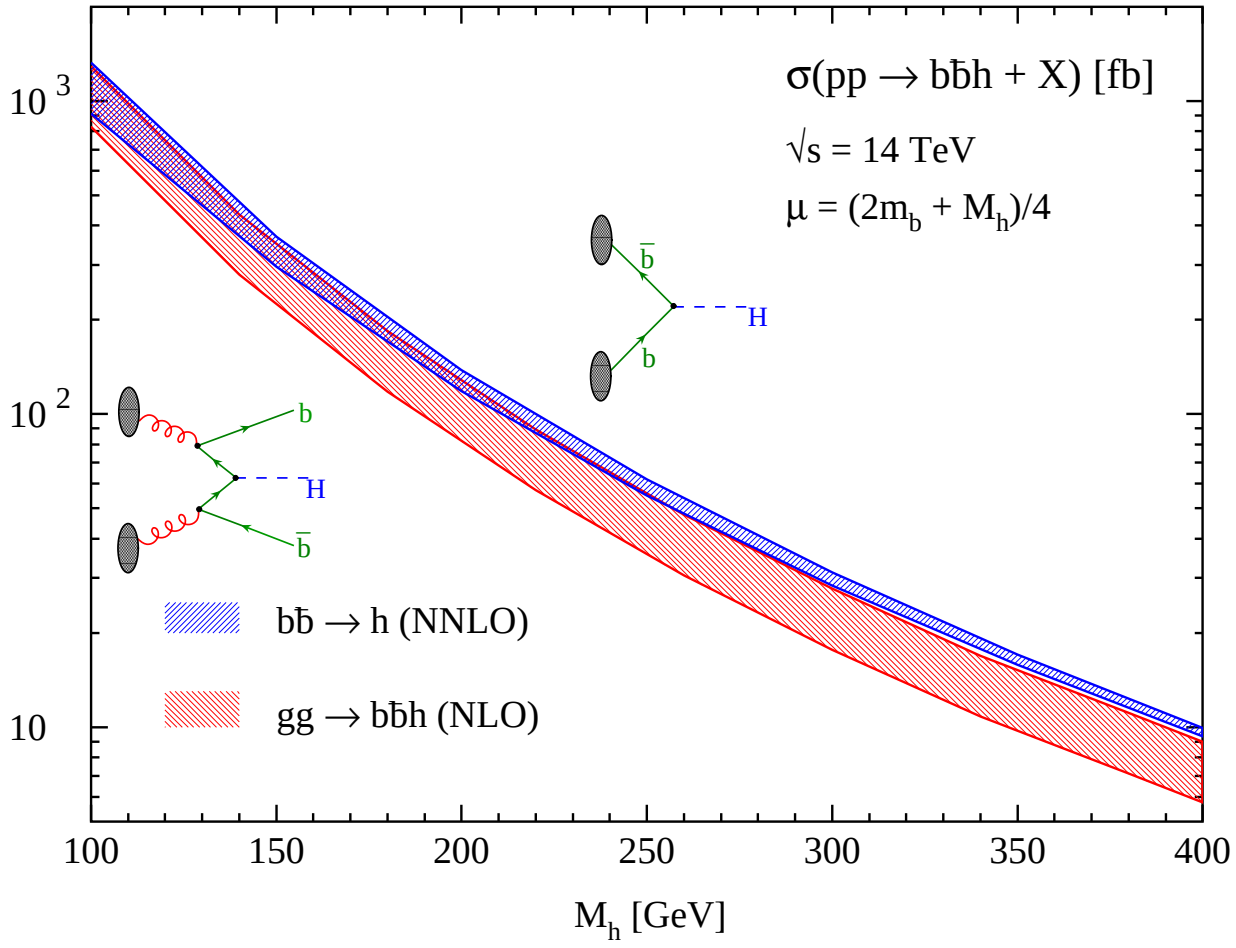

σ_LO [fb]
√S = 14 TeV
M_H = 120 GeV
bb̄ → H
gg → bb̄ H
μ_Y = M_H
μ_R = μ_F = μ
10 3
10 2
10 -1
1
10
μ/M_H


b̄
b
H
b
H
b̄

5-FNS at NNLO


σ/pb
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LHC
M_H=120 GeV
NNLO
10^-1
0.25
1
10
μ_F/M_H

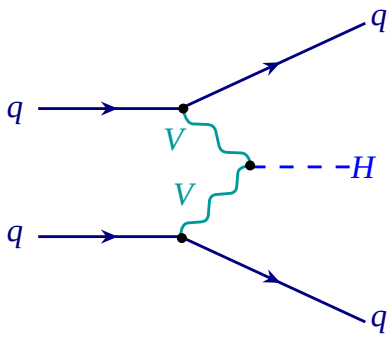
$pp \to H + b\bar{b}$

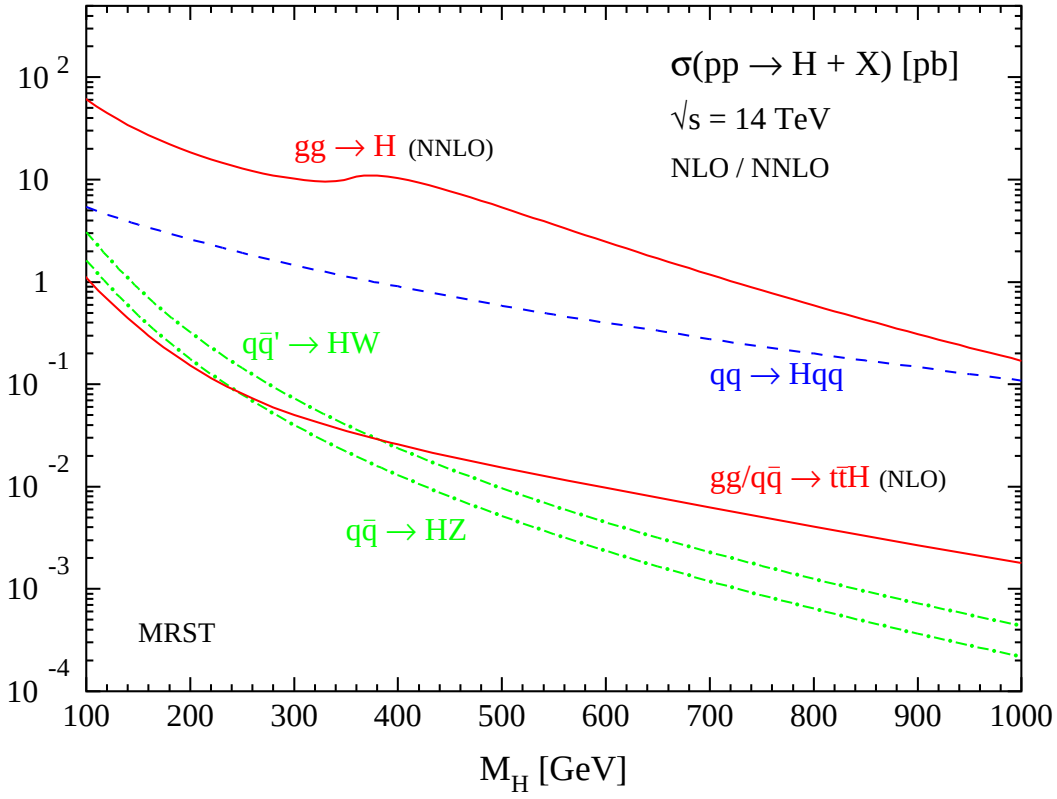


meanwhile also electro-weak corrections available

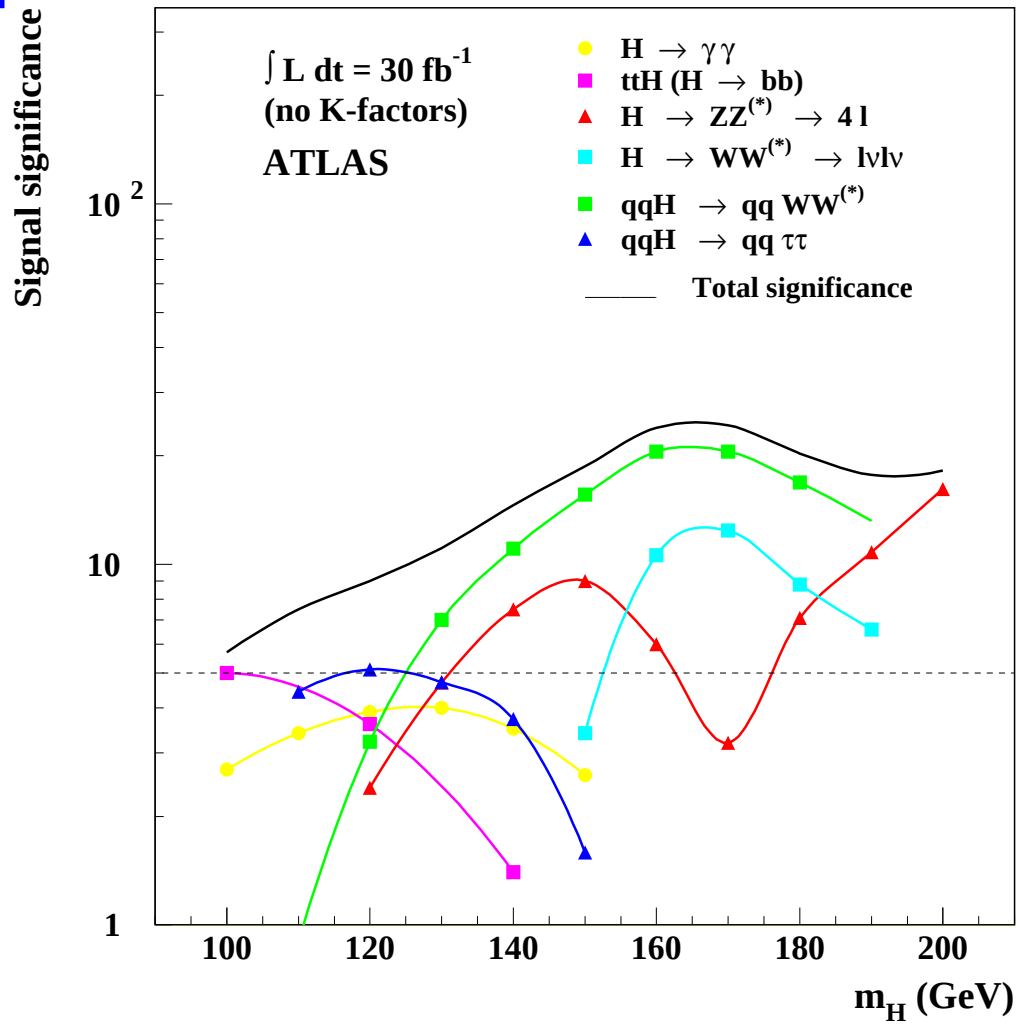
[Dittmaier, Krämer, Mück, Schlüter '06]

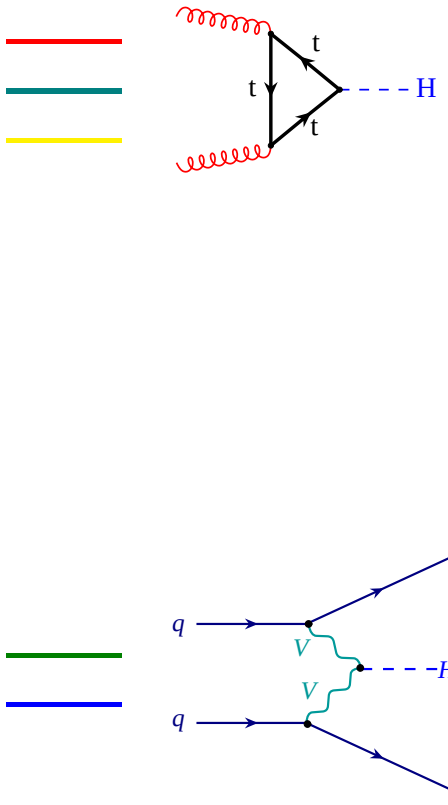
Weak Boson Fusion



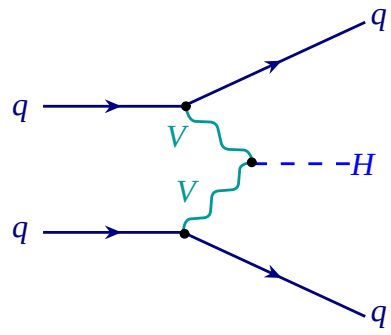


Discovery Potential

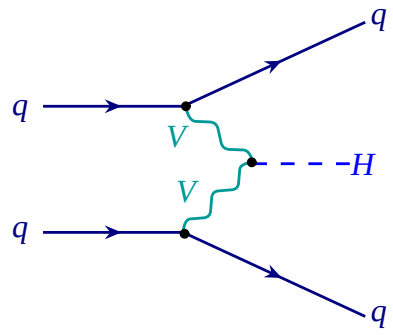


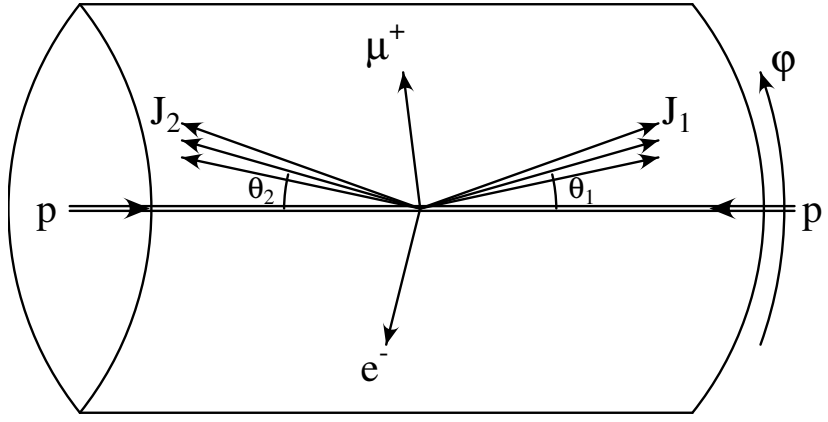


WBF Signature

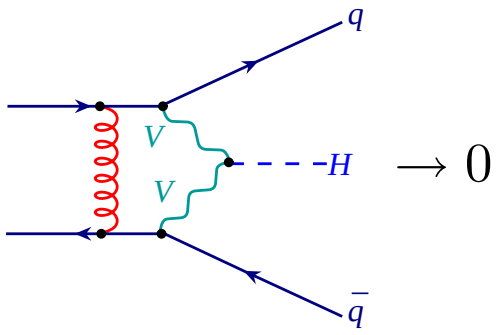


WBF Signature

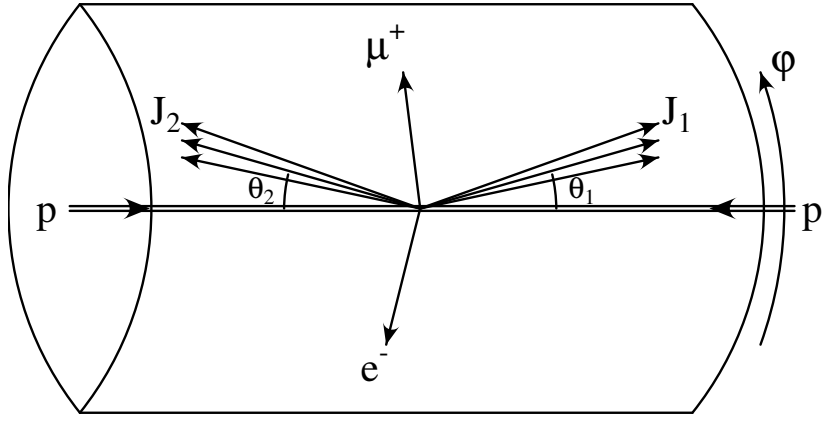




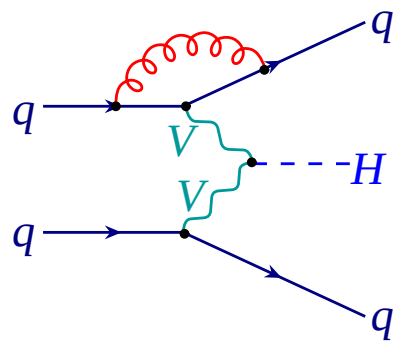
WBF Signature

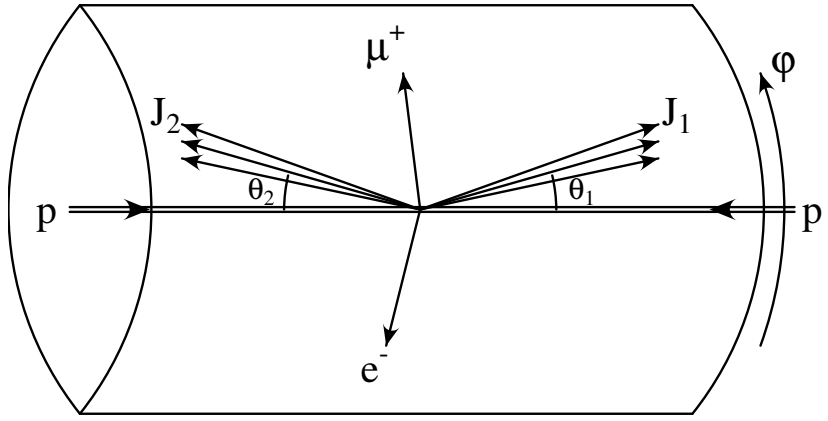


$\longrightarrow 0$



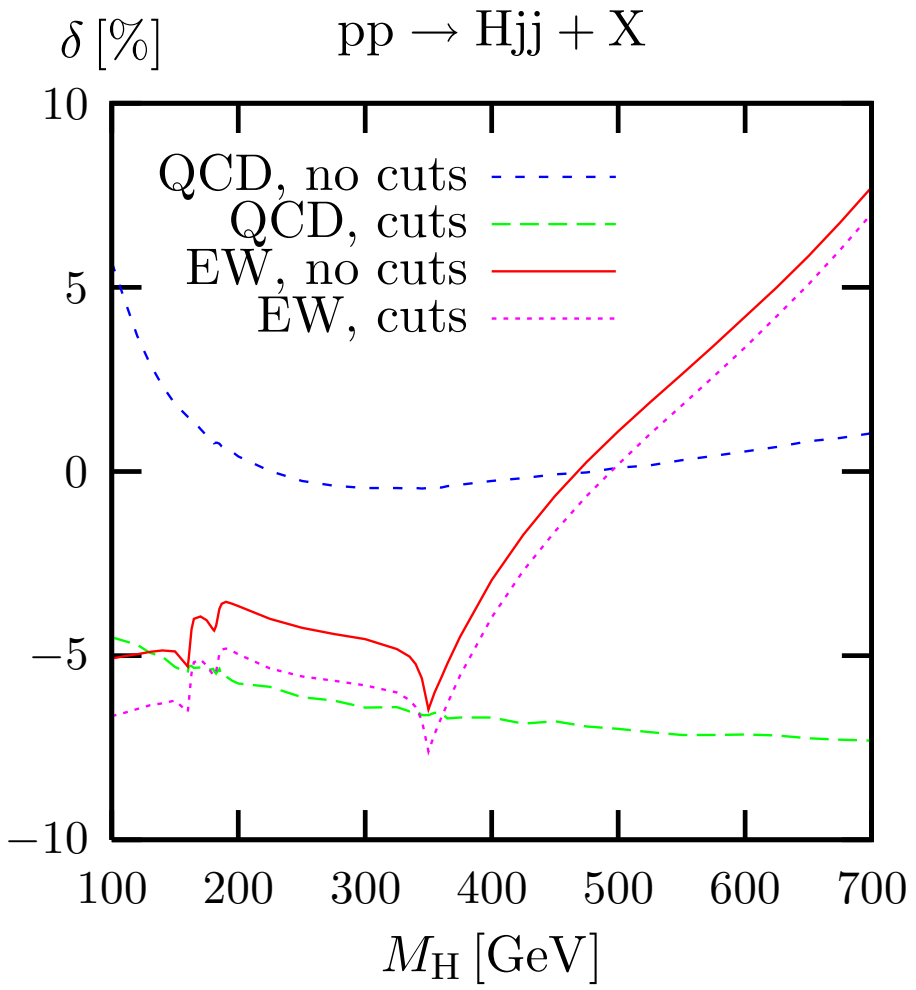
WBF Signature





NLO QCD: [Figy, Oleari, Zeppenfeld '03] + EW: [Ciccolini, Denner, Dittmaier '08]

WBF: QCD+EW corrections

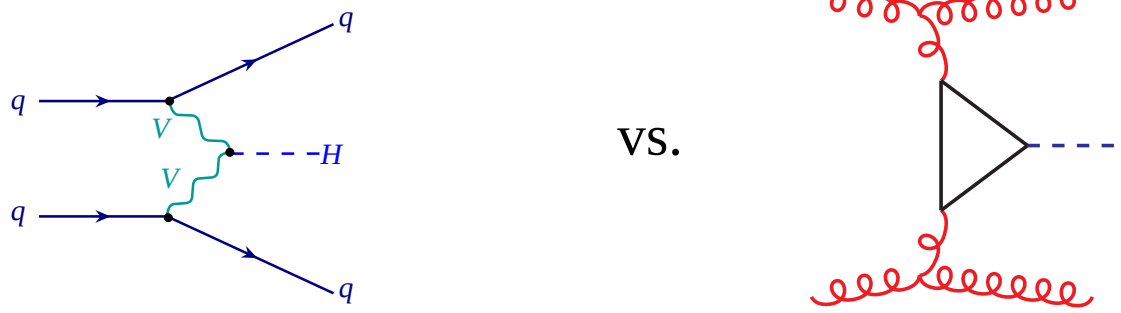


[Ciccolini, Denner, Dittmaier '08]

WBF: other corrections

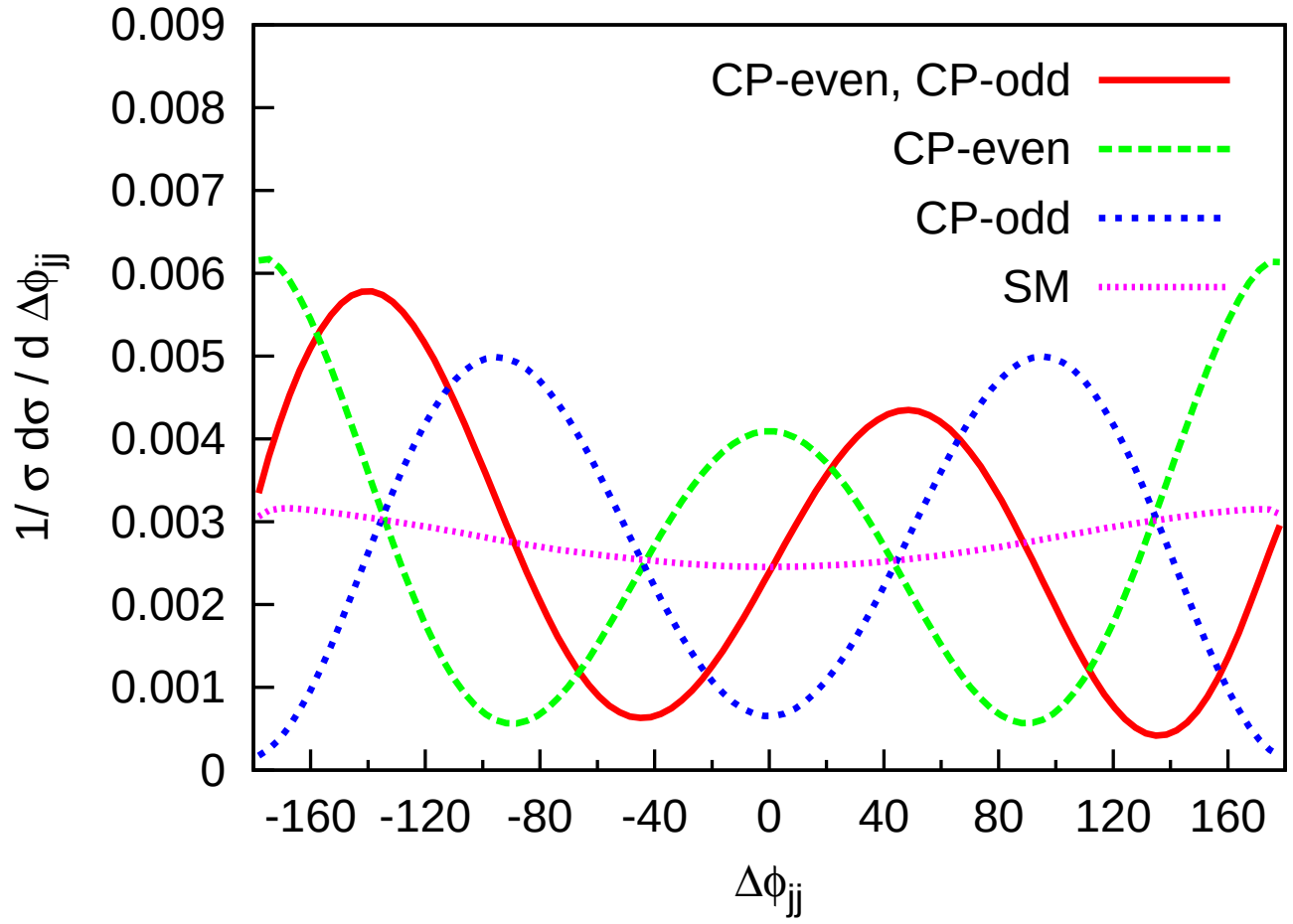
- mixed QCD/EW [Bredenstein, Hagiwara, Jäger '08]
- gluon fusion/WBF interference [Andersen, Binoth, Heinrich, Smillie '07]
- gluon induced WBF [R.H., Vollinga, Weber '08]

Weak Boson Fusion



- $gg \to H$+2 jets: [Del Duca, Kilgore, Oleari, Schmidt, Zeppenfeld '01]
- NLO for $m_t \to \infty$: [Campbell, Ellis, Zanderighi '06]
- $gg \to H + n$ jets: [Andersen, Del Duca, White '08]
- appropriate cuts allow distinction

Measure CP


0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1/ σ dσ / d Δφjj
CP-even, CP-odd
CP-even
CP-odd
SM
-160
-120
-80
-40
0
40
80
120
160
Δφjj

General theory progress

- 1-loop multileg
  - “classical” approach

    [Passarino, Veltman ’79], [Davydychev ’91],
    [Giele, Glover ’04], [Ellis, Giele, Zanderighi ’05], [Denner, Dittmaier ’05],
    [v. Hameren, Vollinga, Weinzierl ’05], [Binoth *et al.* ’08]

General theory progress

- 1-loop multileg
  - “classical” approach

    [Passarino, Veltman ’79], [Davydychev ’91],
    [Giele, Glover ’04], [Ellis, Giele, Zanderighi ’05], [Denner, Dittmaier ’05],
    [v. Hameren, Vollinga, Weinzierl ’05], [Binoth *et al.* ’08]

  - generalized unitarity

    [Bern, Dixon, Dunbar, Kosower ’94],
    [Britto, Cachazo, Feng ’05], [Berger, Bern, Dixon, Forde, Kosower ’06],
    [Ossola, Papadopoulos, Pittau ’08], [Giele, Kunszt, Melnikov ’08],
    [Giele, Zanderighi ’08], [Ellis, Giele, Kunszt, Melnikov, Zanderighi ’08]

Background processes: Les Houches '05 wishlist

Reaction	background for	existing calculations
$pp \to VVj$	$t\bar{t}H$, new physics	WWj: Dittmaier, Kallweit, Uwer '07 WWj: Campbell, R.K.Ellis, Zanderighi '07 WWj: Binoth, Guillet, Karg, Kauer, Sanguinetti (in progress)
$pp \to t\bar{t}b\bar{b}$	$t\bar{t}H$	this talk
$pp \to t\bar{t}jj$	$t\bar{t}H$	–
$pp \to VVb\bar{b}$	VBF$\to H \to VV$, $t\bar{t}$, NP	–
$pp \to VVjj$	VBF$\to H \to VV$	VBF: Jäger, Oleari, Zeppenfeld '06 + Bozzi '07
$pp \to Vjjj$	new physics	amplitudes: Berger et al. '08, R.K.Ellis et al. '08
$pp \to VVV$	SUSY trilepton signal	ZZZ: Lazopoulos, Melnikov, Petriello '07 WWZ: Hankele, Zeppenfeld '07 VVV: Binoth, Ossola, Papadopoulos, Pittau '08

- NLO for $2 \to 3$ processes established
- very few calculations for $2 \to 4$, no complete calculation for pp process

  $e^+e^+ \to 4f$ (EW) Denner et al. '05 , $e^+e^+ \to HH\nu\bar{\nu}$ (EW) Boudjema et al. '05

  $\gamma\gamma \to t\bar{t}b\bar{b}$ (QCD) Lei et al. '07, $u\bar{u} \to s\bar{s}b\bar{b}$ (QCD) Binoth et al. '08

Open questions

- perturbative calculations become more and more precise – beware of the non-perturbative factors:
  - take pdf variations serious
  - underlying event models? $\longrightarrow$ VBF central jet veto!
- to what extent do we need (N)NLO MC's?
- can we put CKKW, MLM on a more solid ground?