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MSSM Higgs Boson Production via Gluon Fusion

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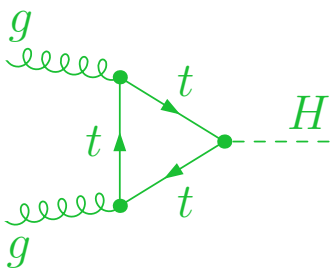
SUSY10, 26 August 2010

Outline

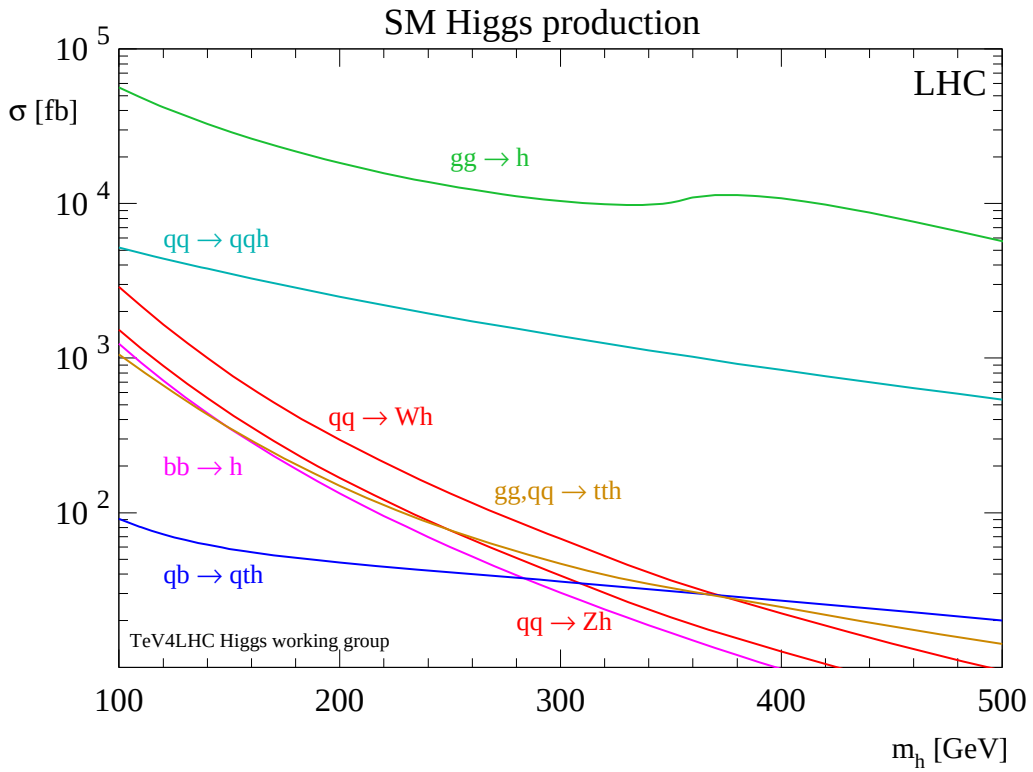
- Higgs boson production via gluon fusion
- Decoupling of gluinos
- Genuine SUSY QCD contributions

Standard Model Higgs Boson Production

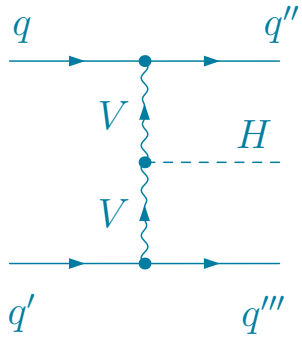
Gluon fusion:



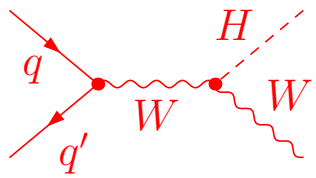
Largest cross section!



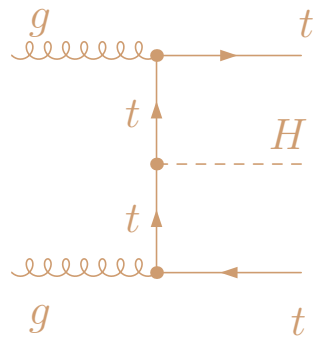
Weak boson fusion:



Higgs-strahlung:



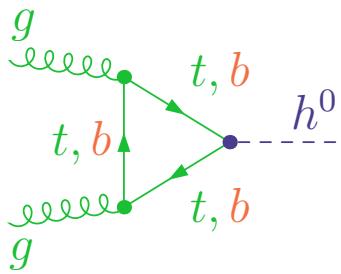
Heavy quark fusion:



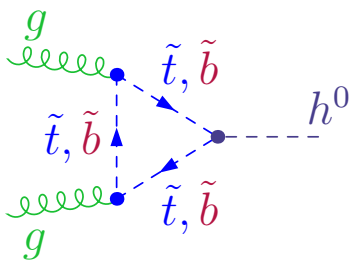
MSSM Higgs Production via Gluon Fusion

- Higgs production via gluon fusion with subsequent decay

  ▷ into photons: $gg \to h^0 \to \gamma\gamma$
  Possible discovery channel for
  Higgs boson masses $M_{h^0} \sim 120$ GeV [CMS 06, ATLAS 09]

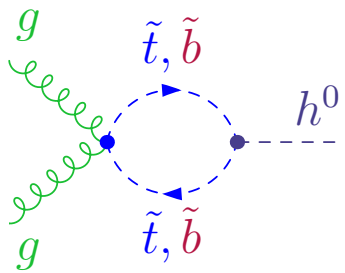


  ▷ into photons or other particles:
  Useful for coupling measurements



  $\Rightarrow$ Need to know the cross section of $gg \to h^0$

- Coupling of gluons, g, to the Higgs bosons is mediated via quarks and their superpartners squarks.
  (here: h^0, lightest MSSM Higgs boson)

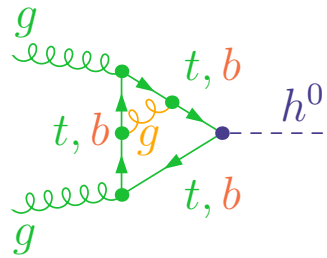


Pure QCD Corrections

- Pure QCD (only gluons) corrections to quark and squark loops with full mass dependence

  $\Rightarrow$ increase of the cross section of 100%.

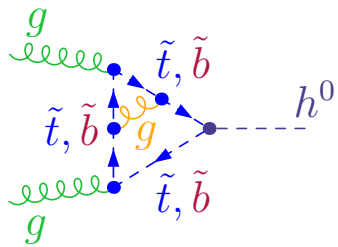
  [Spira, Djouadi, Graudenz, Zerwas 92, 95; Graudenz, Spira, Zerwas 93; Anastasiou, Beerli, Bucherer, Daleo, Kunszt 07; Aglietti, Bonciani, Degrassi, Vicini 07; Bonciani, Degrassi, Vicini 07; Mühlleitner, Spira 08]



- Pure QCD corrections can be approximated by very heavy top quarks and squarks with 20 – 30 % accuracy for small $\tan\beta$ (large $\tan\beta$: bottom quark and squark contributions are important).

  $\tan\beta =$ ratio of Higgs vacuum expectation values

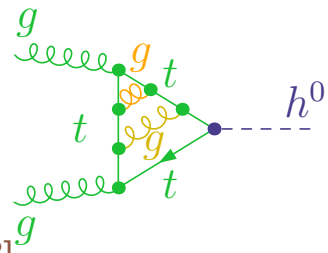
  [Djouadi, Spira, Zerwas 91; Dawson 91; Kauffman, Schaffer 94; Dawson, Kauffman 94; Dawson, Djouadi, Spira 96; Krämer, Laenen, Spira 98]



Pure QCD Corrections

- NNLO QCD corrections in the heavy top quark limit
  (no squarks included)
  $\Rightarrow$ increase of the cross section by 20 – 30 %.

  [Harlander, Kilgore 02, 02; Anastasiou, Melnikov 02, 03; Ravindran, Smith, van Neerven 03]



- Finite top quark mass effects at NNLO (no squarks)
  $\Rightarrow$ below the scale uncertainty.

  [Harlander, Ozeren 09, 09; Pak, Rogal, Steinhauser 09, 09; Harlander, Mantler, Marzani, Ozeren 09]

- Estimates of N^3LO corrections (no squarks)
  $\Rightarrow$ improved convergence

  [Catani, de Florian, Grazzini, Nason 07; Moch, Vogt 05; Ravindran 06, 06]

- Soft gluon resummation: $\sim$ 10% effects

  [Catani, de Florian, Grazzini, Nason 07]

- Electroweak contributions: $\sim$ 5% effects

  [Degrassi, Maltoni 04, Aglietti, Bonciani, Degrassi, Vicini 06,
  Actis, Passarino, Sturm, Uccirati 08, Anastasiou, Boughezal, Petriello 09]

Supersymmetric (SUSY) QCD Contributions

- (SUSY) QCD (gluons and gluinos) contributions in the heavy top quark/squark and gluino limit:

  Next term in the mass expansion indicates:

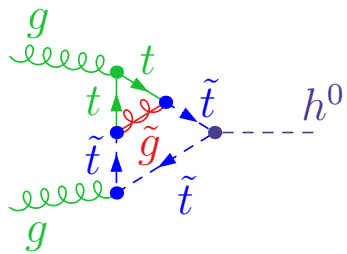
  Approximation: Good for the lightest MSSM Higgs boson and small and moderate tan β values.

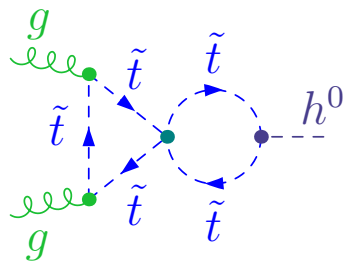
  [Harlander, Steinhauser 03,03, 04, Harlander, Hoffmann 06, Degrassi, Slavich 08]

- (SUSY) QCD contribution including the mass dependence of all particles (bottom quark/squark contributions included):

  - ▷ The heavy mass limit approximation: Good for small and moderate tan β.
  - ▷ Contributions from squark quartic couplings and gluinos can be sizeable.

    [Anastasiou, Beerli, Daleo 08]





Conceptual problem

On the one hand: Keeping supersymmetric relations between parameters intact

$\Rightarrow$ gluinos do not decouple

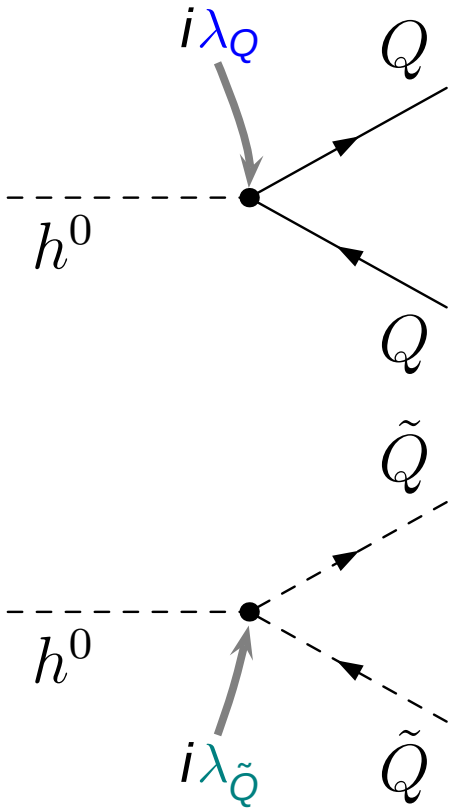
(For heavy gluinos: Result depends logarithmically on the gluino mass $M_{\tilde{g}}$.)

On the other hand: Decoupling theorem: [Appelquist, Carrazzone 75]

Heavy fields decouple at low momenta (except for renormalization effects).

Decoupling of the Gluinos

Simplified scenario: no mixing, degenerate squark masses:



$$\lambda_Q = g\,\frac{m_Q}{v}$$

$$\lambda_{\tilde{Q}} = 2\,g\,\frac{m_Q^2}{v} = 2\frac{v}{g}\lambda_Q{}^2$$

SUSY relation

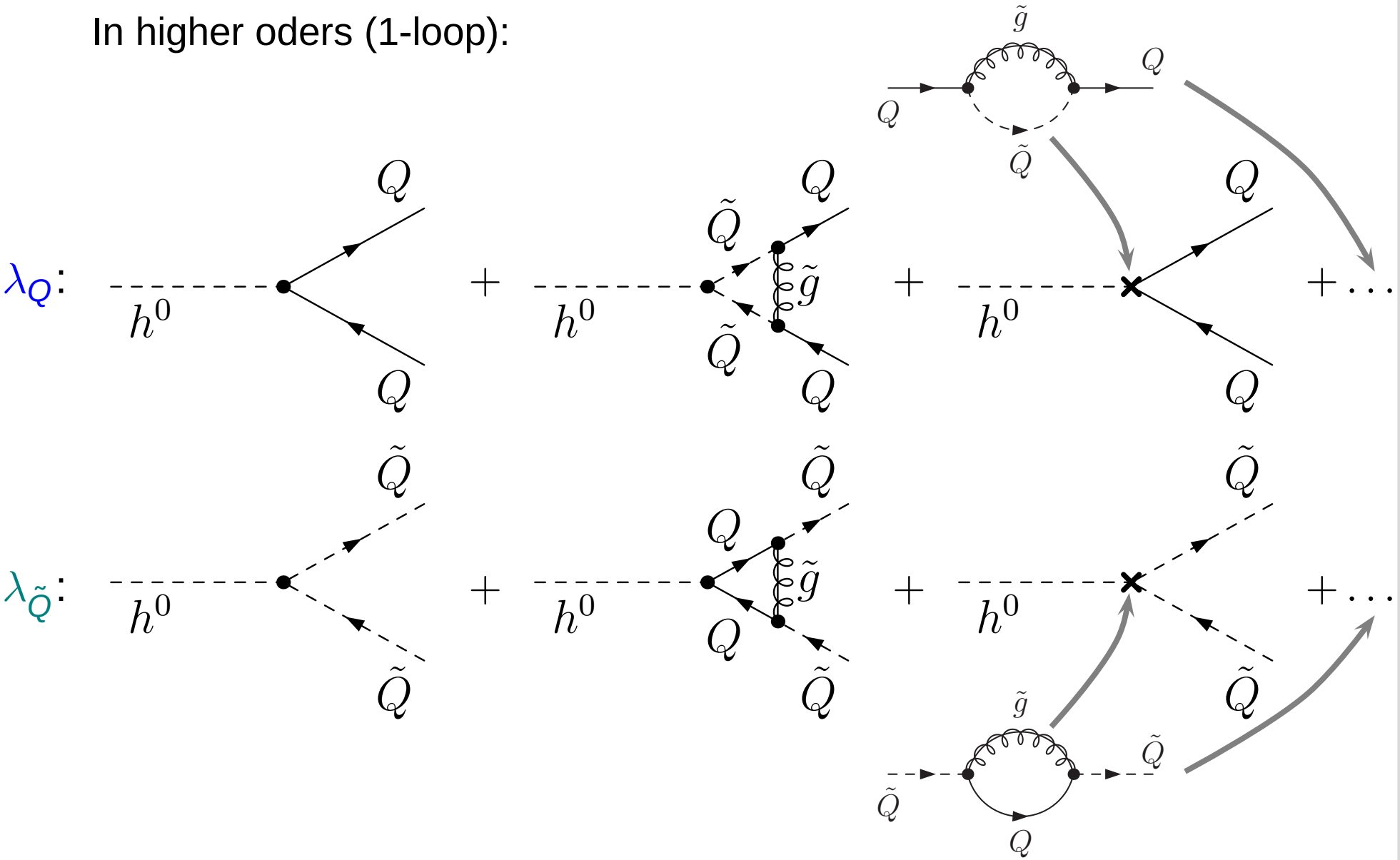
m_Q = quark mass;

$v = (v_1^2 + v_2^2)^{\frac{1}{2}} \approx 246$ GeV, v_i = Higgs vacuum expectation value;

g = norm. factor of the Higgs coupling to a quark pair with respect to the SM

Decoupling of the Gluinos

In higher oders (1-loop):



Decoupling of the Gluinos

Scales above $M_{\tilde{g}}$: $\mu_R > M_{\tilde{g}}$	Scales below $M_{\tilde{g}}$: $\mu_R < M_{\tilde{g}}$
• Renormalization scheme: $\overline{\text{MS}}$ (only divergent parts in counterterms)	• Renormalization scheme: momentum subtraction (MO) (for decoupling of the gluino)
• RGE: **(Renormalization group equations)** same for $\lambda_{\tilde{Q}}$ and $2\frac{v}{g}\lambda_Q^2$	• RGE: differ for $\lambda_{\tilde{Q}}$ and $2\frac{v}{g}\lambda_Q^2$
• Symmetry relation between λ_Q and $\lambda_{\tilde{Q}}$ intact	• Symmetry relation between λ_Q and $\lambda_{\tilde{Q}}$ broken

Matching at scale $M_{\tilde{g}}$: $\mu_R = M_{\tilde{g}}$:

- Threshold contributions

Taking into account the mismatch of the couplings λ_Q and $\lambda_{\tilde{Q}}$ for $\mu_R < M_{\tilde{g}}$:

$\Rightarrow$ Gluino decouples from the theory [Mühlleitner, HR, Spira 08]

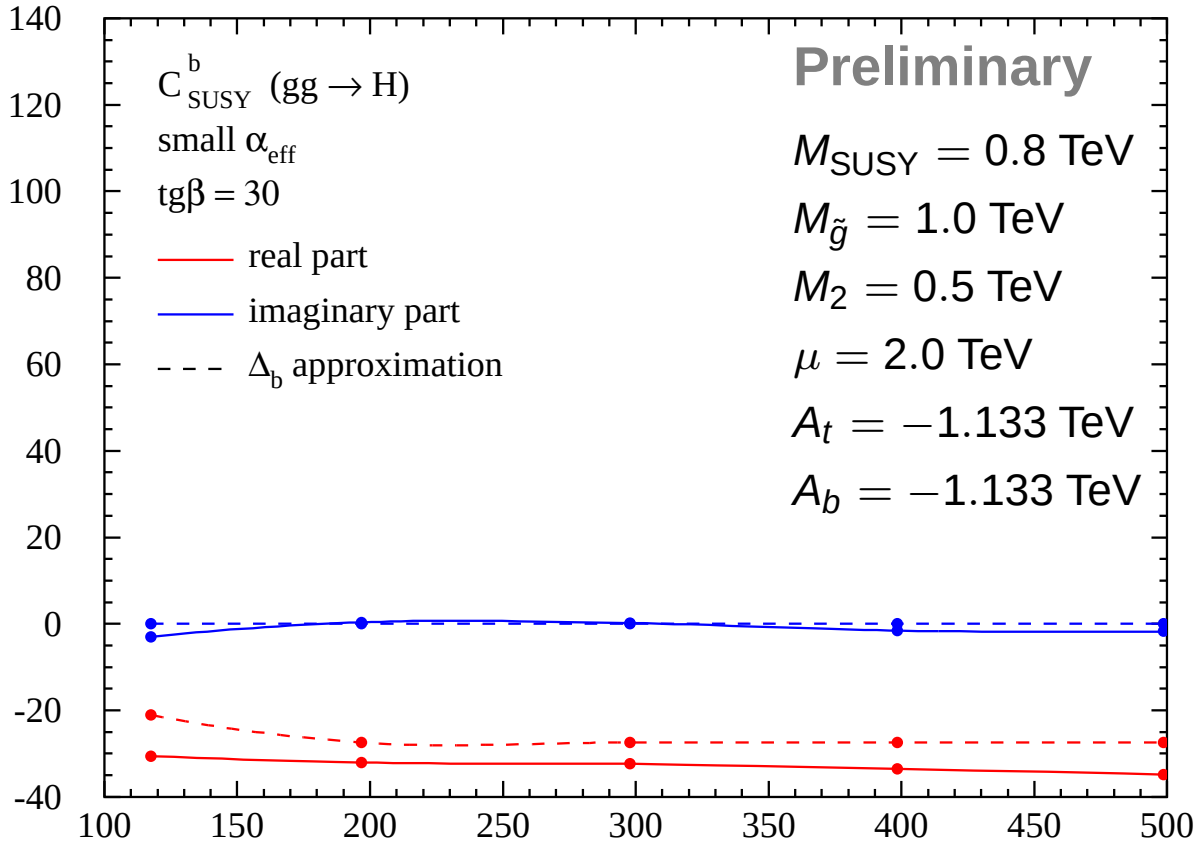
Genuine SUSY QCD contributions

to the bottom quark/squark amplitude (with full mass dependence):

As form factor C^b_{SUSY}:

$$F_b^{Higgs}\left(1 + C^b_{SUSY}\frac{\alpha_s}{\pi}\right)$$

F_b^{Higgs}: bottom quark form factor



- Careful choice of renormalization scheme:
  Here: A_b in $\overline{MS}$ scheme [Mühlleitner, HR, Spira]
  Other: A_b defined via vertex [Degrassi, Slavich 10]
- Δ_b approximation (corrected bottom Yukawa coupling): Rough approx.

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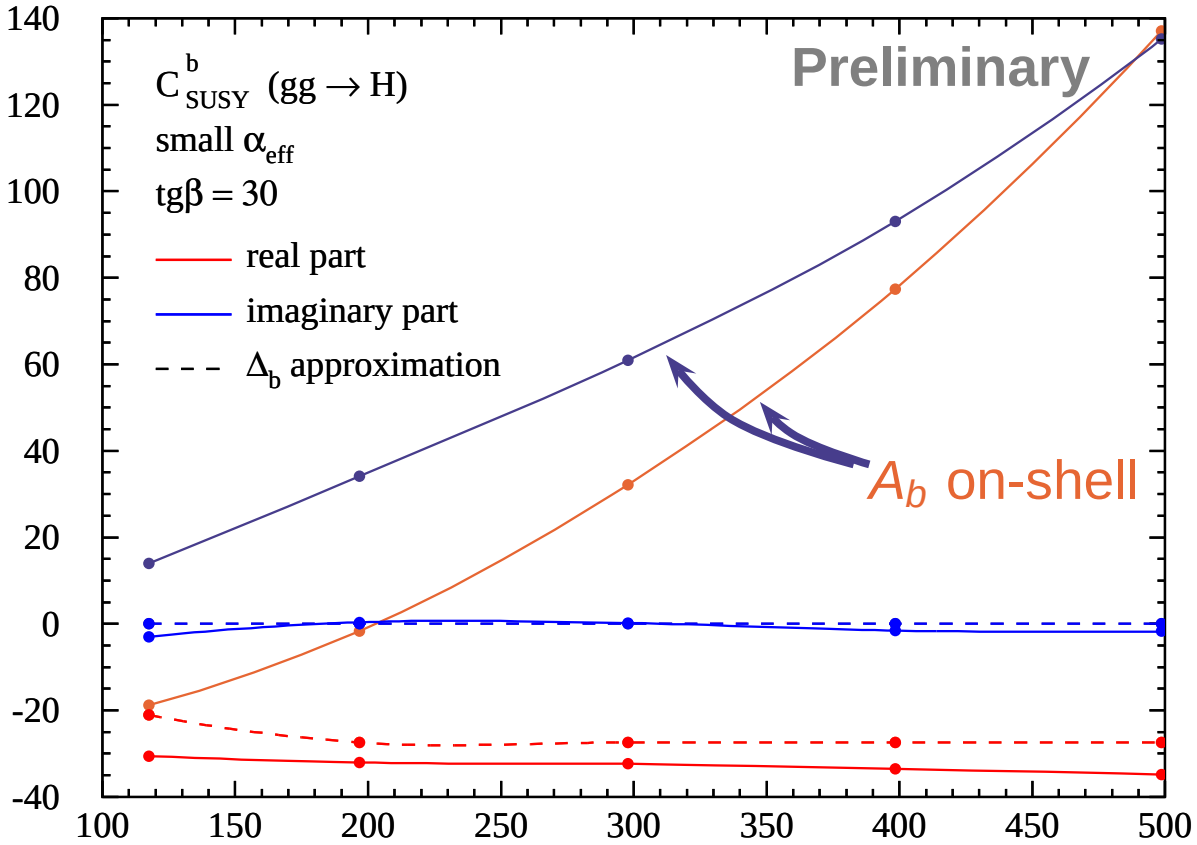
F_b^{Higgs}: bottom quark form factor



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Conclusions

- Gluon fusion:
  - A loop-induced Higgs boson production mechanism
  - Large cross section
- Cross section in the MSSM:
  - Pure QCD corrections: Large
  - SUSY QCD corrections: Sizeable
- For scales below the gluino mass:
  - Symmetry relation between Higgs couplings to quarks and to squarks: Broken
  - Gluino decouples
- Genuine SUSY QCD contributions:
  - Sizeable
  - Δ_b approximation works roughly.