High precision prediction of the lightest Higgs boson mass in the MSSM

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in collaboration with

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Higgs boson at the LHC

- Higgs mass:

  ATLAS: $M_h = 125.5 \pm 0.2 \pm 0.5$ GeV

  CMS: $M_h = 125.7 \pm 0.3 \pm 0.3$ GeV

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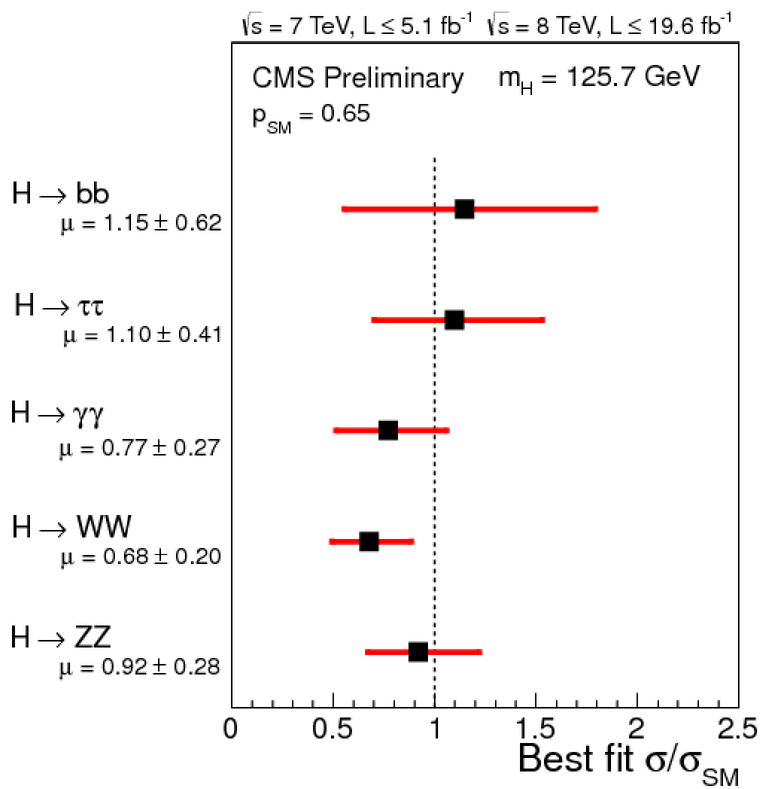
- Higgs couplings: experimental data consistent with SM predictions



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- Sensitivity of $Br(h \to ZZ^*)$ and $Br(h \to WW^*)$ to BSM physics

Higgs boson mass in Supersymmetry

- Minimal Supersymmetric Extention of SM: 2 Higgs doublets
- Lightest Higgs boson mass:
  - Predicted by theory ($M_{h,\mathrm{Born}} < M_Z$)
  - Very sensitive to quantum corrections

    $$M_h^2 = M_{h,\mathrm{Born}}^2 + \Delta M_h^2(M_{\mathrm{top}}, M_{\mathrm{susy}}, \ldots)$$
  - Parametric uncertainties $\simeq\ \mathcal{O}(1\,\mathrm{GeV})$
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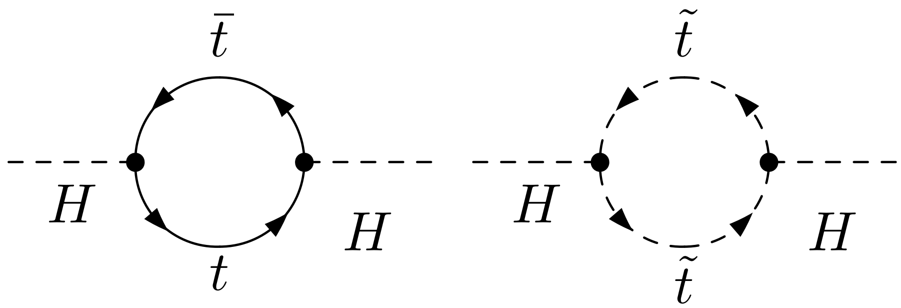
- Theory goals:
  - bring ΔM_h^{th} to $\mathcal{O}(1\,\mathrm{GeV})$ level
  - extend validity range for heavy SUSY masses
    $\Rightarrow$ resummation of large logs $\ln(M_{\mathrm{top}}/M_{\mathrm{SUSY}})$

Calculation of the Higgs boson mass

- 1st order perturbation theory (1-loop): $\Delta M_h = \mathcal{O}(20 - 40\ \text{GeV})$



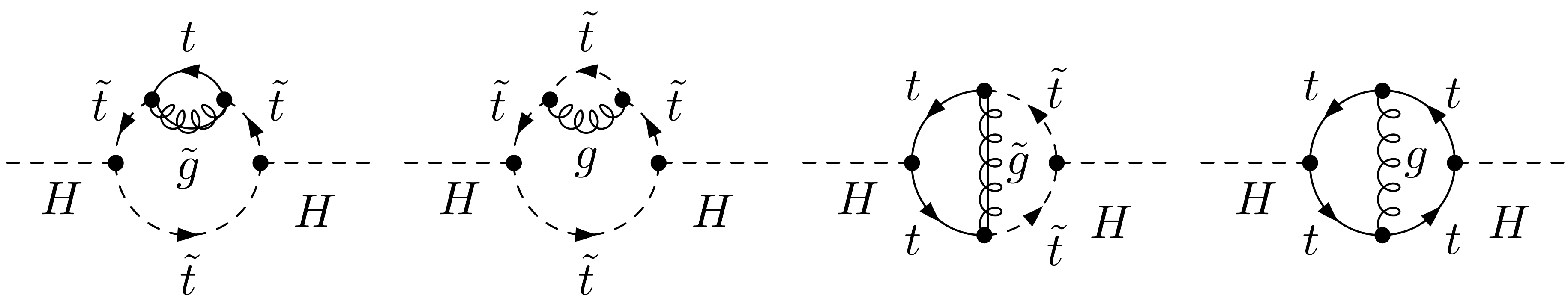
$$M_h^2 = M_{h,\text{Born}}^2 + \frac{3M_t^4}{4\pi^2 v^2 \sin\beta^2} \ln\frac{M_{\text{susy}}^2}{M_{\text{top}}^2} + \ldots$$

[J.Ellis, Ridolfi, Zwirner '91], [Okada, Yamaguchi,Yanagida '91], [Haber, Hempfling '91]

exact 1-loop: [Chankowski, Pokorski and Rosiek '92], [Brignole '92], [Dabelstein '94]

Calculation of the Higgs boson mass

- 2nd order perturbation theory (2-loop): $\Delta M_h = \mathcal{O}(5 - 10\ \mathrm{GeV})$



[Haber, Hempfling, Hoang '96], [Heinemeyer, Hollik and Weiglein '98], [Degrassi, Slavich, Zwirner '01],

[Espinosa and Zang '00], [Brignole, Degrassi, Slavich, Zwirner '02] , [Carena et al '00] ,

[S. Martin '03], [S. Martin '05], [Heinemeyer et al '05], . . ., [S. Borowka et al '14]

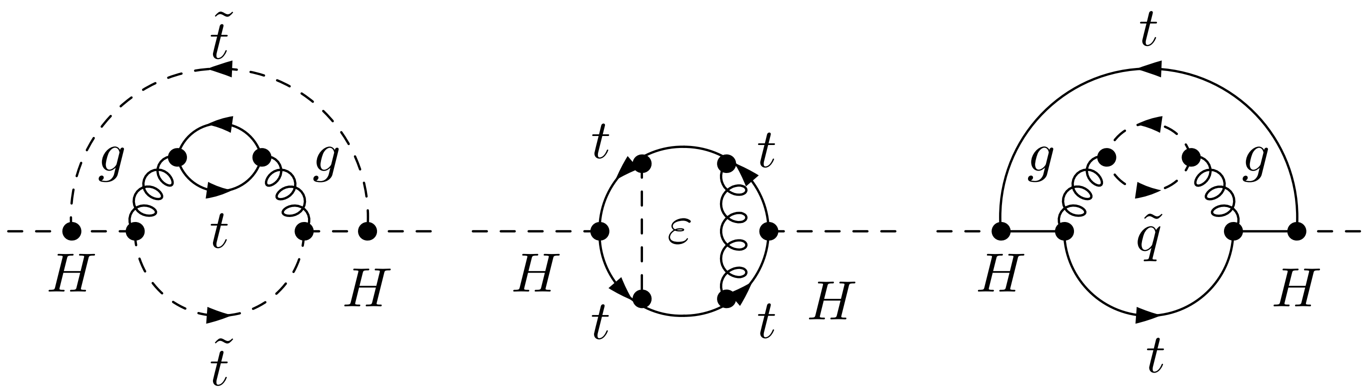
Computer codes: `FeynHiggs` [Heinemeyer et al]

`CPSuperH` [Lee et al]

. . .

Calculation of the Higgs boson mass

- 3rd order perturbation theory (3-loop): $\Delta M_h = \mathcal{O}(2 - 5\ \text{GeV})$
- SUSY-QCD corrections [Harlander, Kant, L. M., Steinhauser '08, '10]



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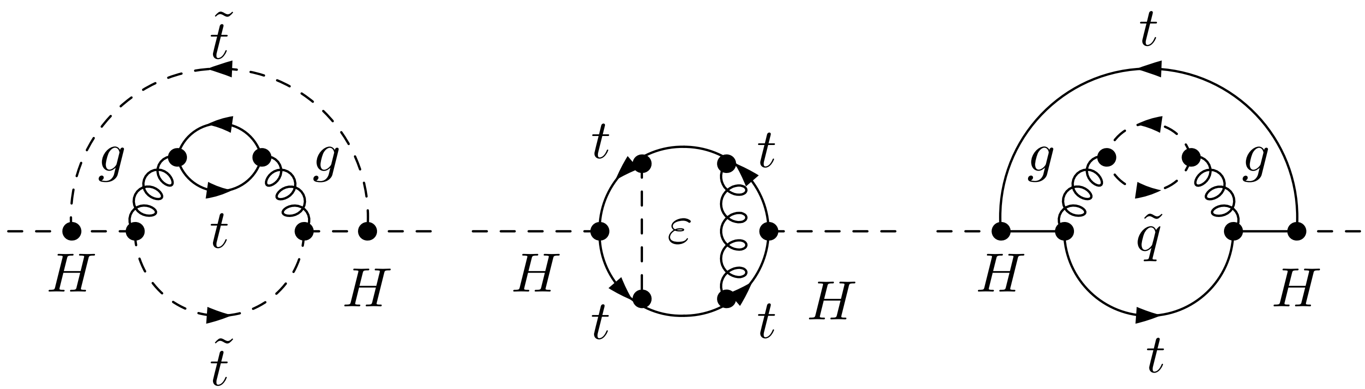

- LL and NLL [S. Martin '07], [Hahn '13] and NNLL [Draper '13] and their resummation
- This talk: resummation of LL, NLL and NNLL on top of 3-loop SUSY-QCD result

Cancellation of logs

- **LL** and **NLL**, etc.

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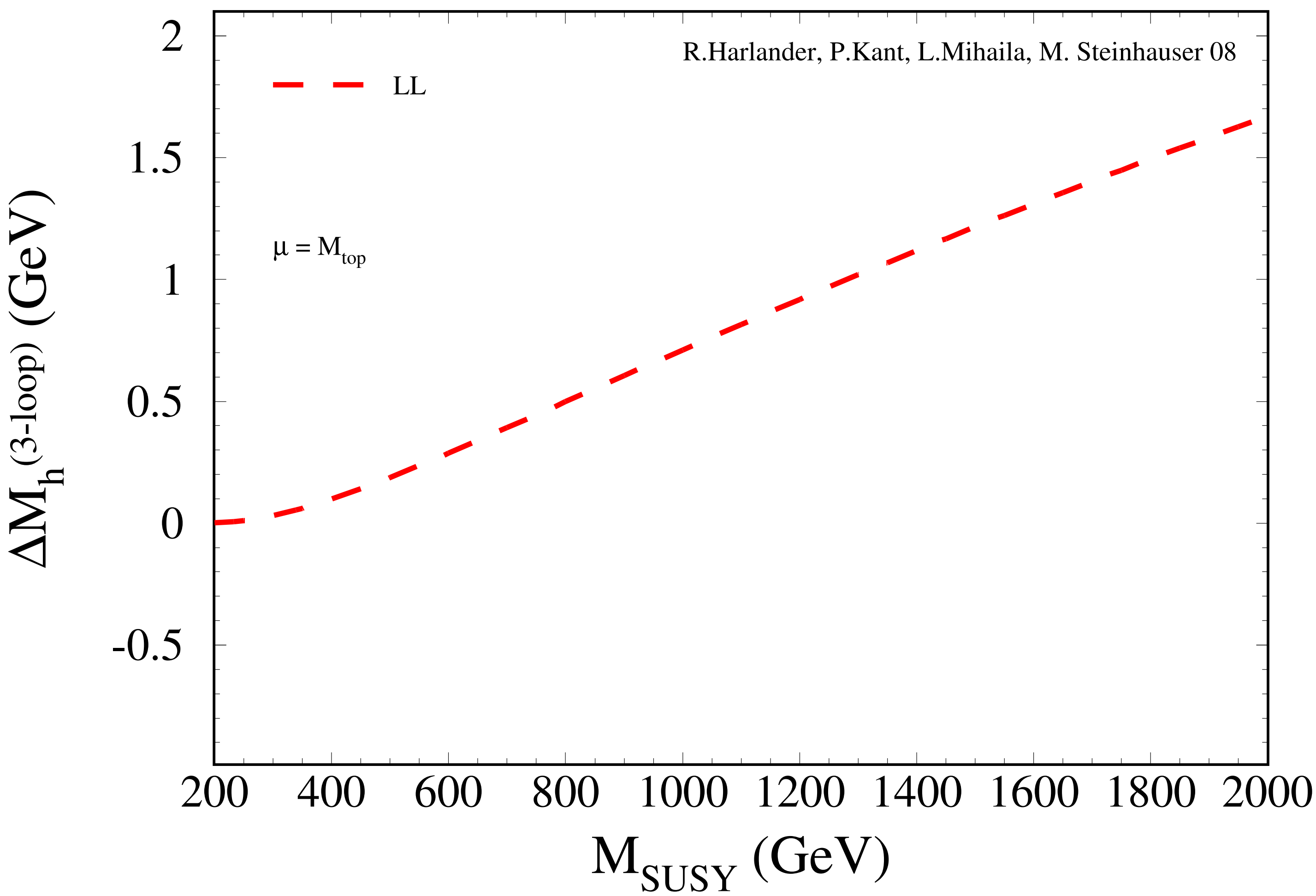

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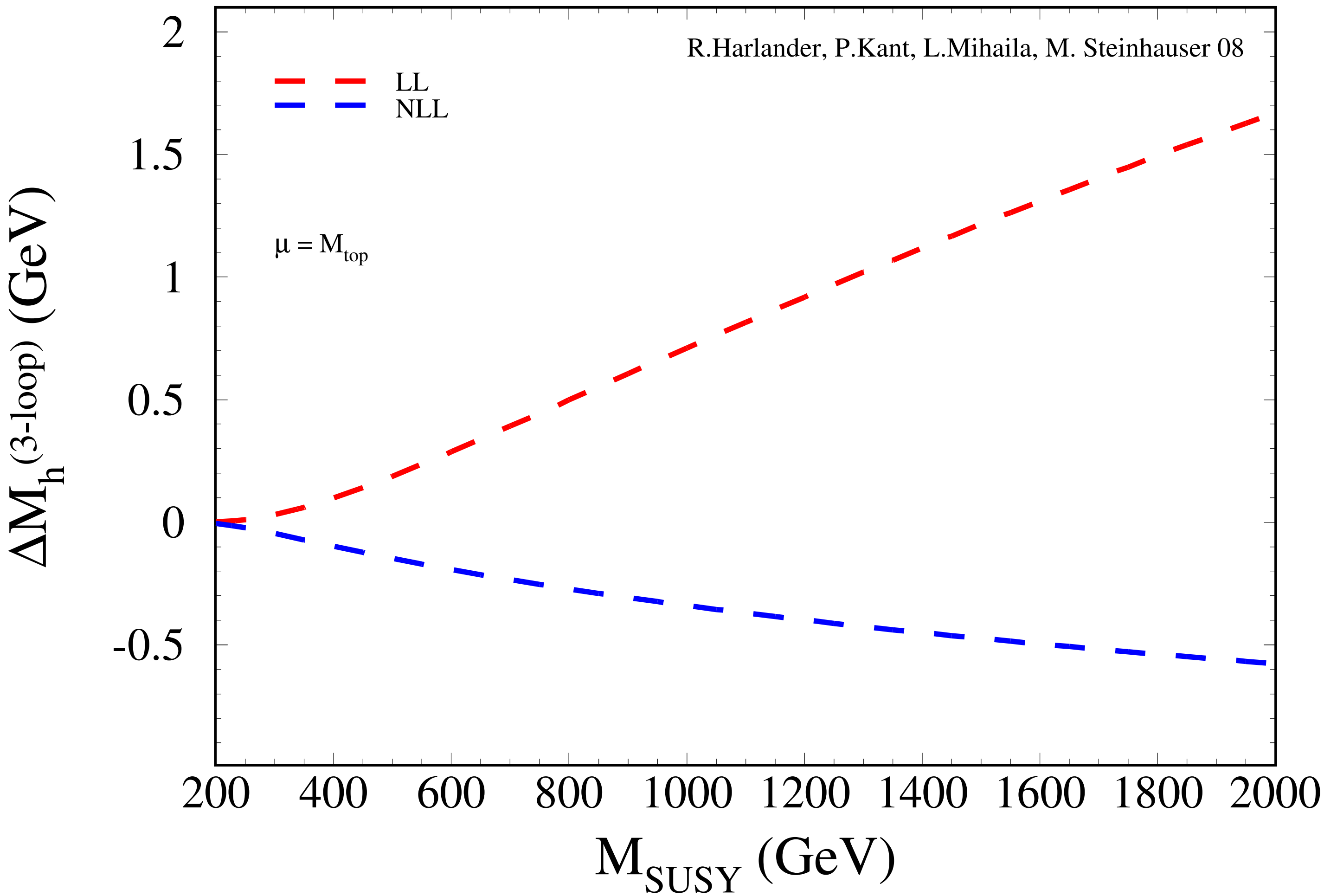

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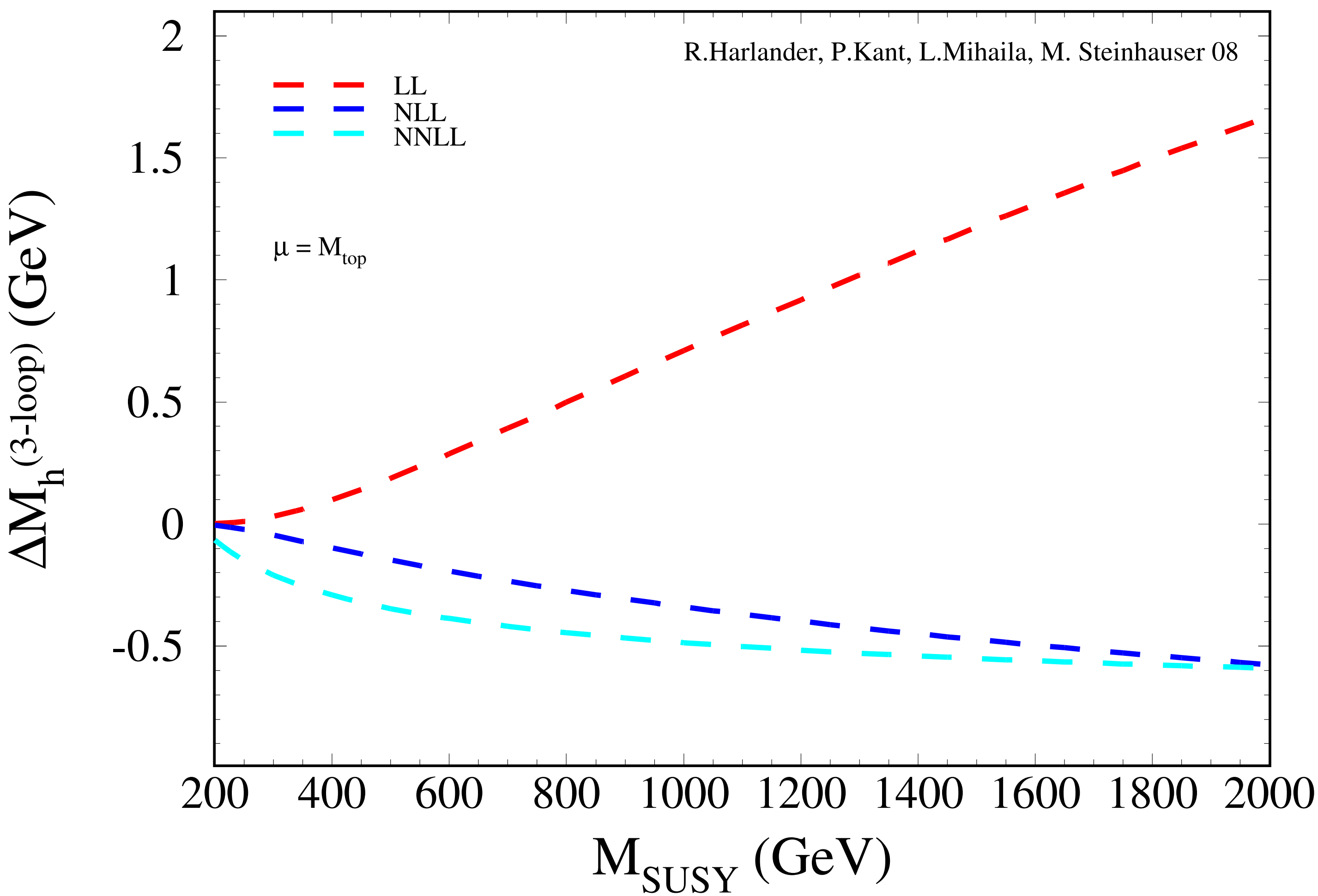

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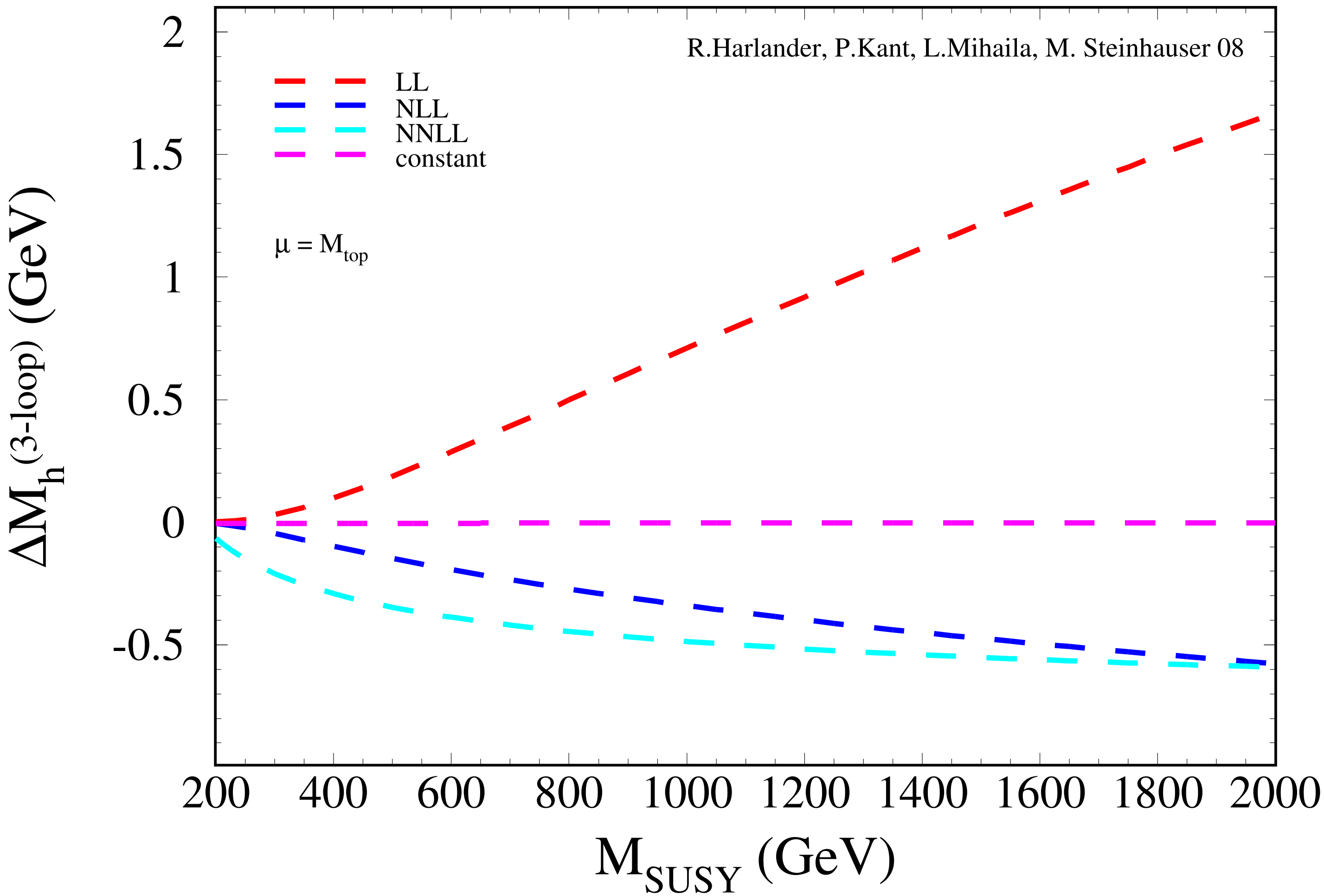

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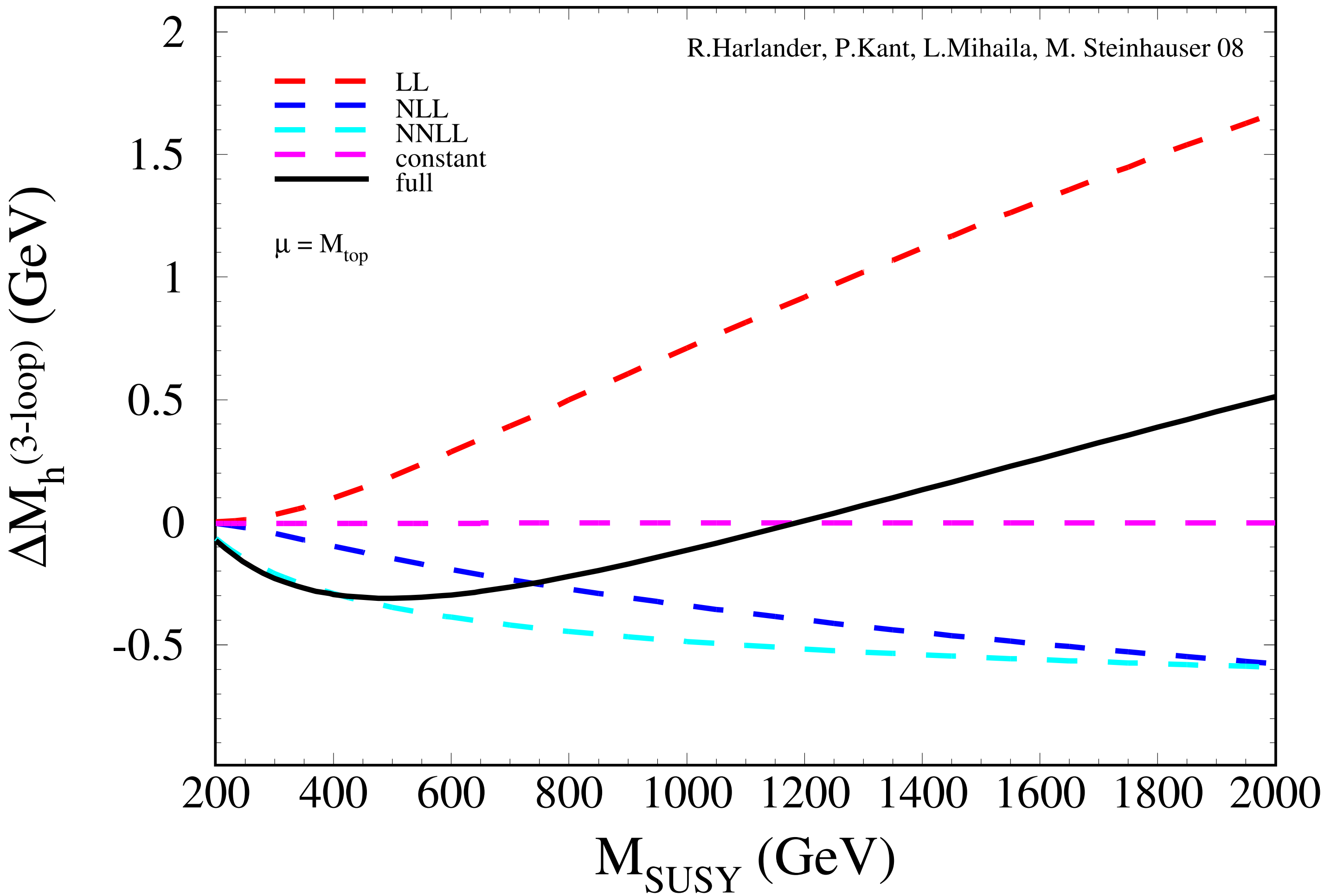
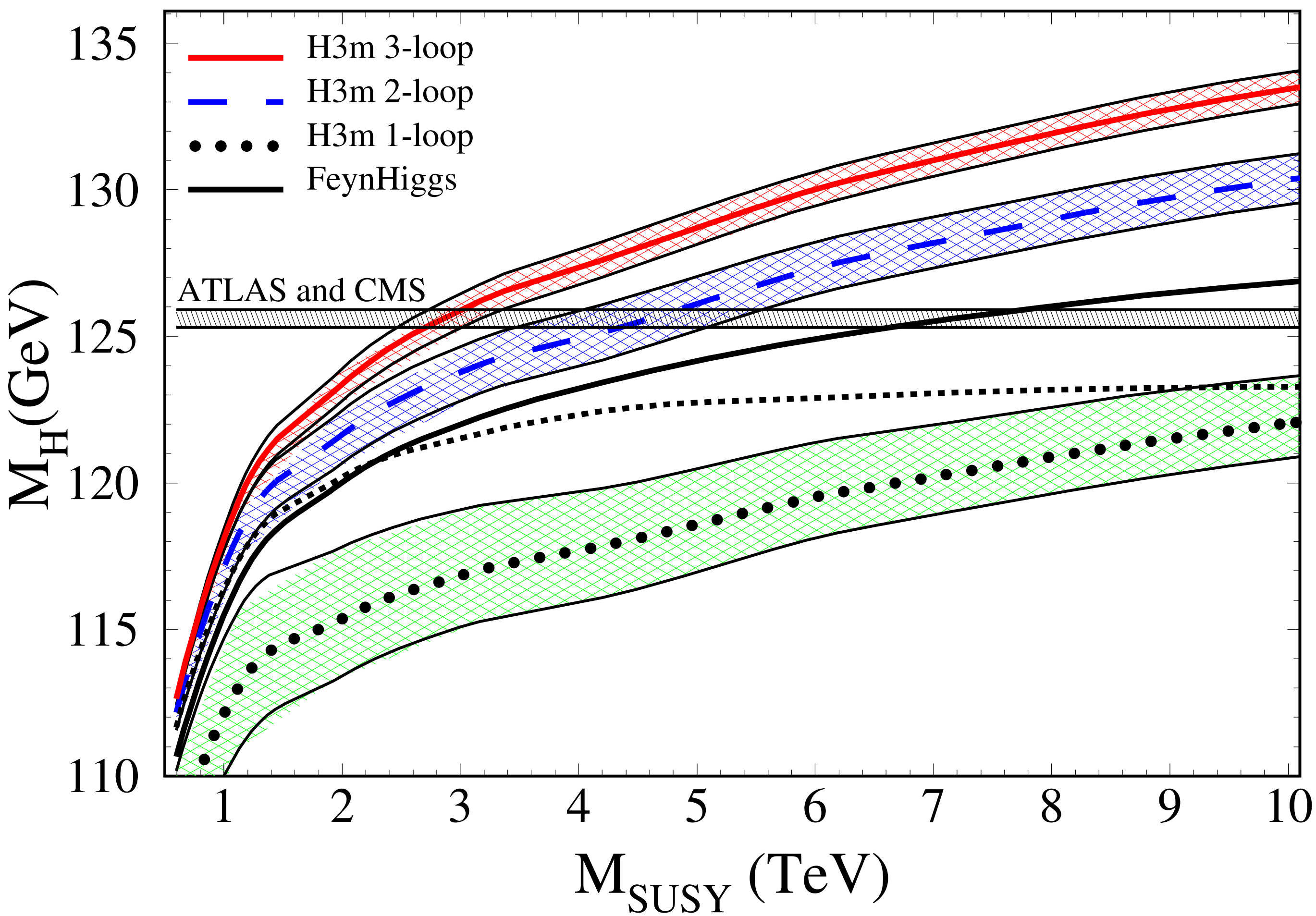


Results (2)

[Kunz, L.M., Zerf '14]



[H3m: Kant, Harlander, L.M., Steinhauser '10]

Running Top-Yukawa Coupling

- $\alpha_t(\mu) \sim m_{\rm top}(\mu)$ [Hempfling and Kniehl '94]

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  - $m_{\text{top}}^{\text{MSSM}}(\mu)/M_{\text{top}}^{\text{OS}}$ at 2 loops [S. Martin '04]
    $\Rightarrow$ TSIL code [Martin and Robertson '05]

Large logs: $\ln\left(\frac{M_{\text{SUSY}}^2}{M_{\text{top}}^2}\right)$

ΔM_{top}	SM	MSSM ($M_{\text{SUSY}} = 6$ TeV)
1 loop	9.8 GeV	42.3 GeV
2 loops	1.7 GeV	8.2 GeV
3 loops	0.5 GeV	???

To be compared to $\Delta M_{\text{top}}^{\text{exp}} \approx 1$ GeV

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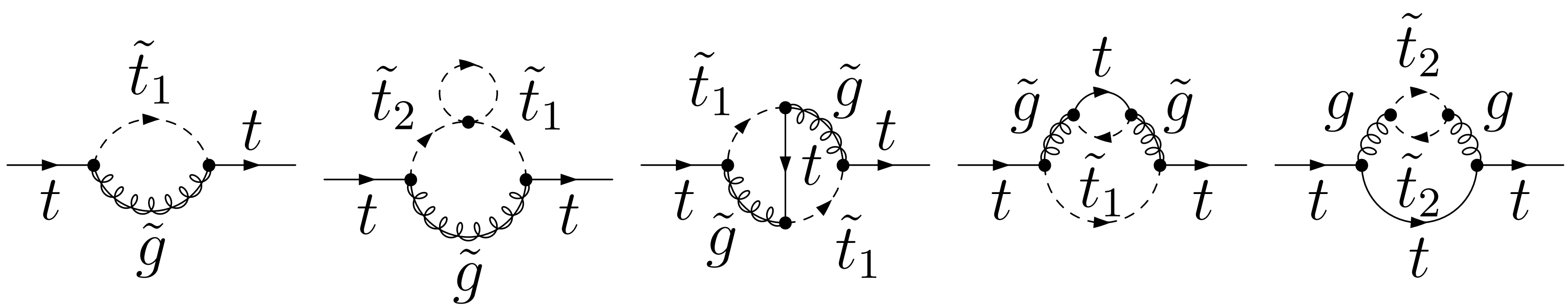
- Direct calculation of $m_{\text{top}}^{\text{MSSM}}(\mu \approx M_{\text{SUSY}} > 1\ \text{TeV})$
- Indirect calculation: resummation of large logs
  - SM = effective theory derived from MSSM

$$m_{\text{top}}^{\text{SM}}(\mu_{\text{dec}}) \quad = \quad m_{\text{top}}^{\text{MSSM}}(\mu_{\text{dec}}) \cdot \zeta_{m_t}(M_{\text{SUSY}}, \mu_{\text{dec}})$$

$\zeta_{m_t}(M_{\text{SUSY}}, \mu)$: reduction to 2-loop tadpole MI



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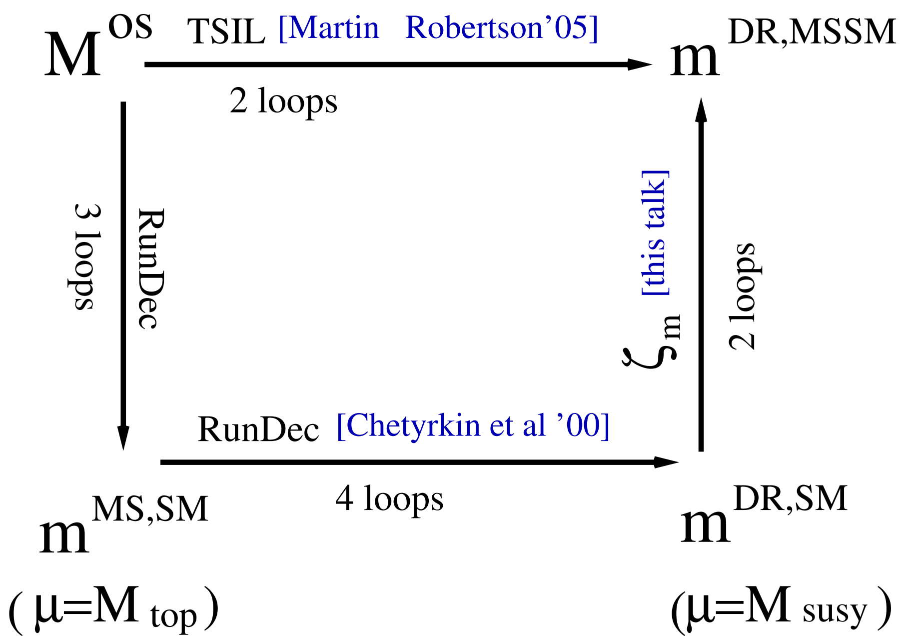
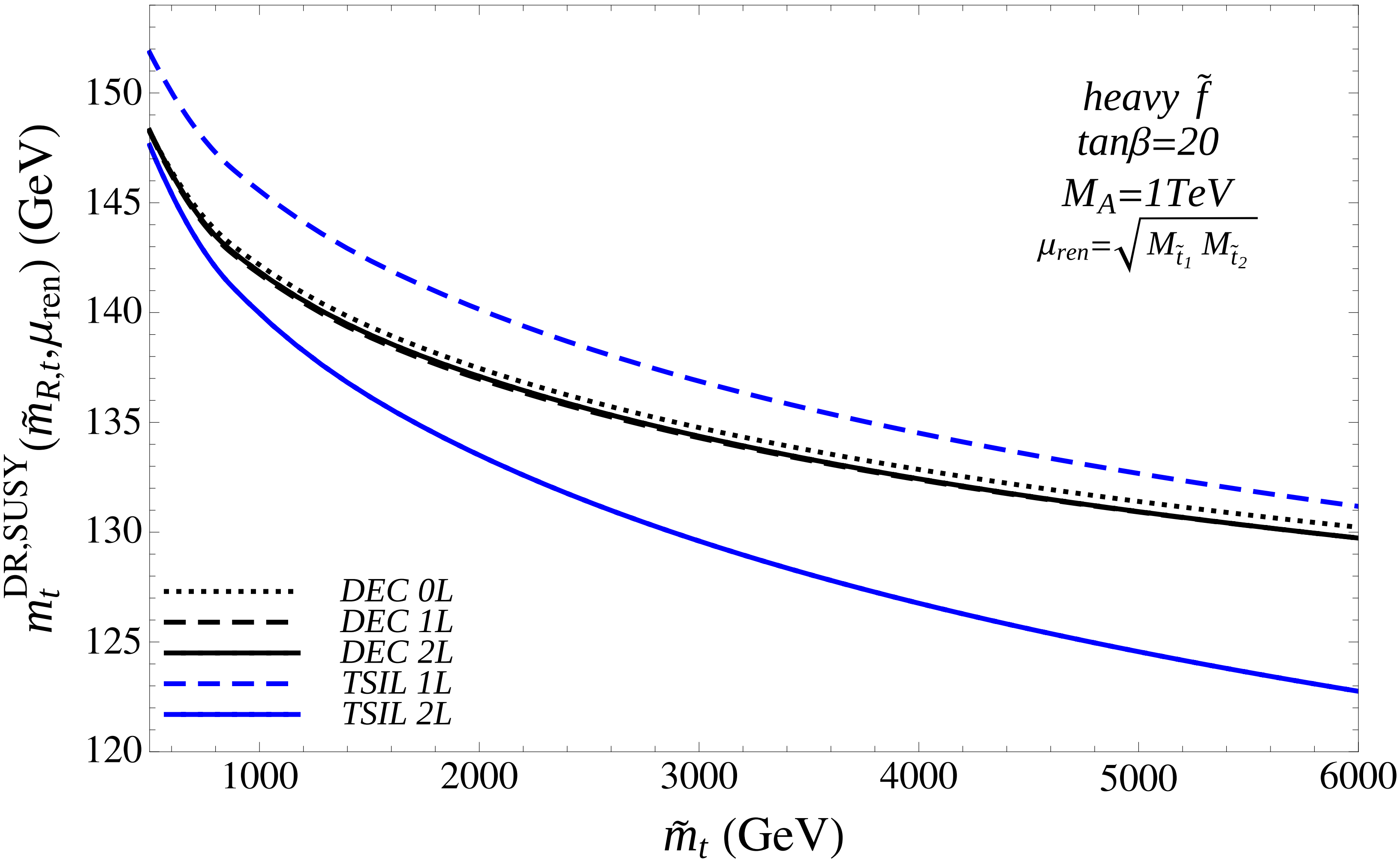


$$\Delta m_{\text{top}}^{\text{MSSM}}(\mu = 6\text{ TeV}) = 0.4\text{ GeV}$$

Numerical Results: $m_{\rm top}^{\rm MSSM}(\mu)$

[Kunz, L.M., Zerf '14]



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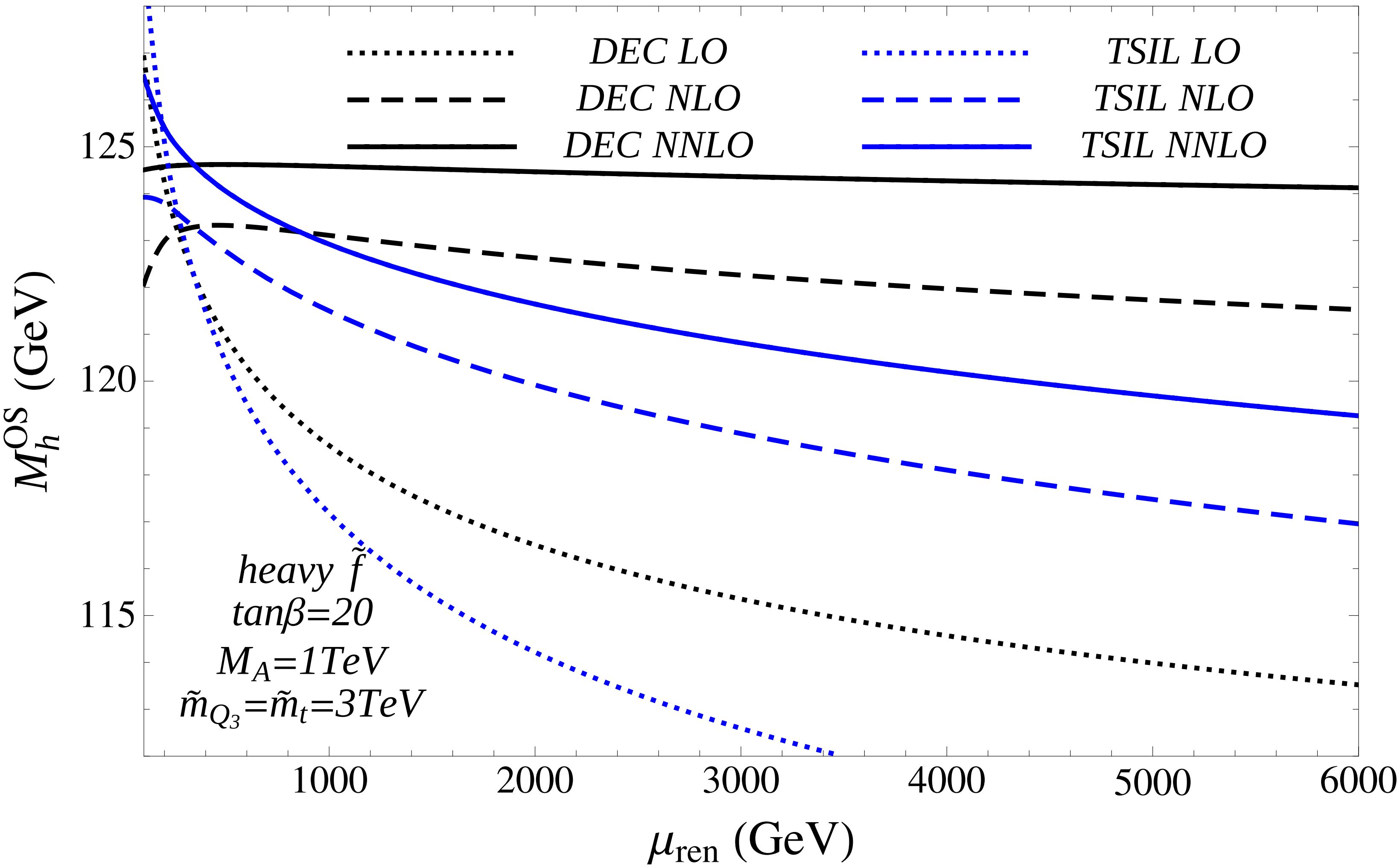

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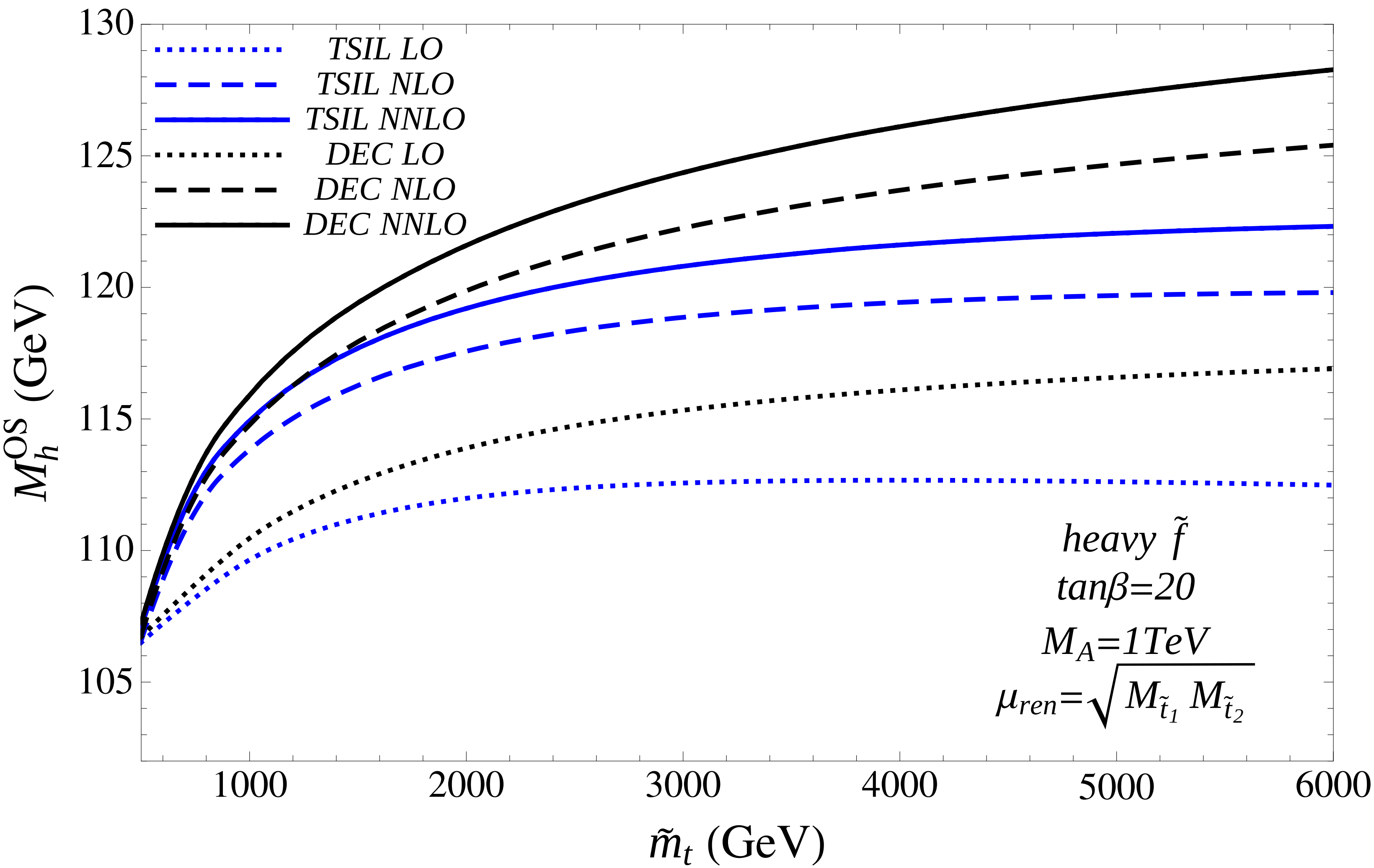

Conclusions

- Precise determination of M_h and M_{top} needed for BSM
- M_h affected by large radiative corrections in SUSY theories
- Resummation of large logarithms for heavy SUSY particles required
- Still a lot of work to be done on theory side !!!