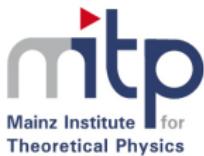


Supersymmetric Corrections to Top Quark Production at Threshold

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High precision fundamental constants at the TeV scale
March 20th 2014



Overview

1 Motivation

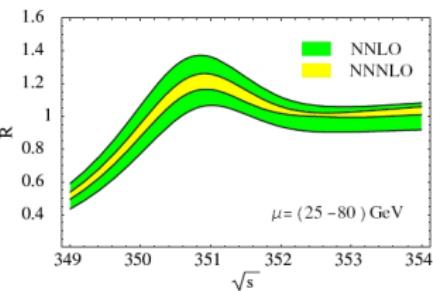
2 Ingredients & Synthesis

3 Old & New Results

4 Summary



Motivation



A precise theoretical prediction of $\sigma_{tot}^{t\bar{t}}$ at threshold:

→ accurate measurement α_s, m_t, Γ_t at ILC. [talk by J. Fuster]

Future theory predictions with 3% uncertainty in σ :

→ $\Delta m_t = \pm 27_{\text{exp}} \pm 9_{\text{th}} \text{ MeV } 10 \text{ fb}^{-1}$ pp!! [Seidel, Simon, Tesar, Poss 2013]

Todays (SM) predictions (NNLL): [Hoang, Stahlhofen 13]

$\delta\sigma/\sigma \approx \pm 5\%$ uncertainty

→ NNNLO in progress [talk by J. Piclum]

- ➔ What happens with the total cross section when we use the MSSM as underlying theory?
- ➔ How big can the contributions from SUSY particles become?

Cross Section via Optical Theorem

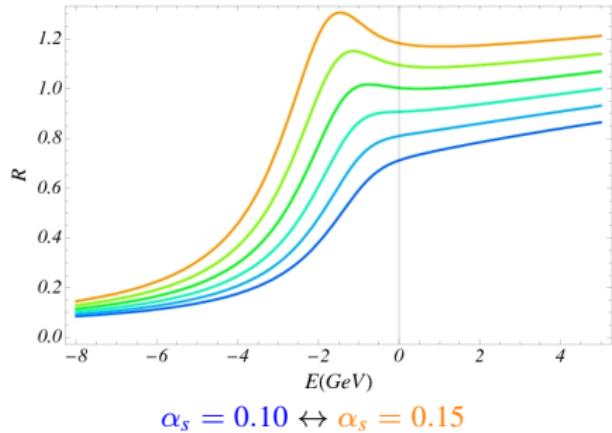
$$\sigma_{tot}(e^+e^- \rightarrow t\bar{t}) \propto \frac{1}{s} Im[\textcolor{red}{C}^2 G(E + i\Gamma_t)].$$

1 G

- ▶ 2-point Greens function of the Top Quark pair in S_1^3 -state.
- ▶ Top quarks are very slow after creation.
→ Calculated in (p/v)**Non Relativistic QCD**.
- ▶ Contains resummed potential, soft and ultra soft QCD modes.

Cross Section via Optical Theorem

$$\sigma_{tot}(e^+ e^- \rightarrow t\bar{t}) \propto \frac{1}{s} Im[\textcolor{red}{C}^2 G(E + i\Gamma_t)].$$



$$R = \frac{\sigma_{tot}(e^+ e^- \rightarrow t\bar{t})}{\sigma_{tot}(e^+ e^- \rightarrow \mu^+ \mu^-)}, E = \sqrt{s} - 2m_t.$$

Cross Section via Optical Theorem

$$\sigma_{tot}(e^+e^- \rightarrow t\bar{t}) \propto \frac{1}{s} Im[\textcolor{red}{C}^2 G(E + i\Gamma_t)].$$

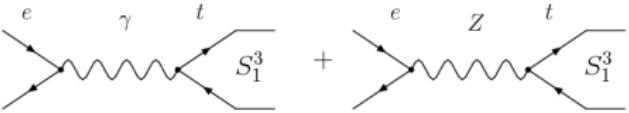
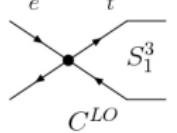
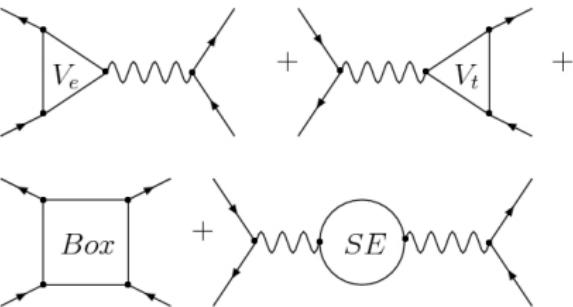
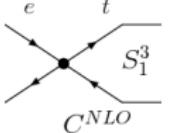
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2 C

- ▶ Matching Coefficient of the creation and annihilation operator for S_1^3 Top Quark pairs in NRQCD.
- ▶ Matches the NRQCD vector current to the full theory (SM or MSSM).
- ▶ Contains all hard modes $\sim m_t$.
→ SUSY enters here.

Extracting the Matching Coefficient in Full Theory

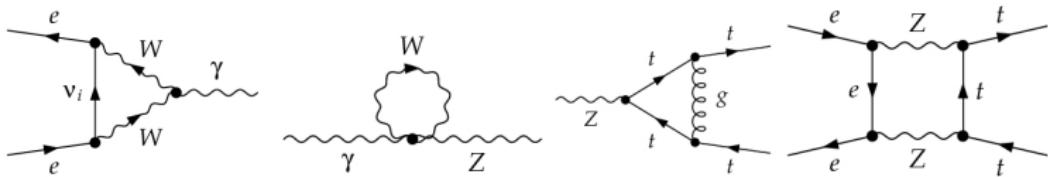
Order	Full Theory	NRQCD
LO		
NLO		



$$C_{SM}^{LO} = C_{MSSM}^{LO}.$$



C can be understood as effective charge.



EW Contributions to C^{1L} are known. [Guth,Kühn 92],[Hoang,Reißer 06]
We reproduced the results (in t'Hooft Feynman Gauge). ✓

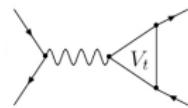
- Divergences are regularized with Dimensional REGularization (DREG) renormalized in On-Shell-Scheme.
- The pure 1L QCD contribution is well known:

$$C_{\text{QCD}}^{\text{NLO}} = -\frac{8}{3} \frac{\alpha_s}{\pi} \times C^{LO}$$

($C_{\text{QCD}}^{\text{NNNLO}}$ calculated (up to singlet contribution)!!
[Marquard,Piclum,Seidel,Steinhauser 2014]).

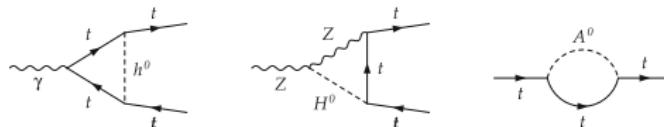
Known Parts of MSSM

1-Loop contribution to $\gamma t\bar{t}$ - and $Z t\bar{t}$ -vertex:



+ Higgs sector of MSSM \leftrightarrow THDM Type II.

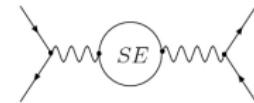
→ calculated in **DREG** ($m_b = 0$, CKM = 1) [Denner, Guth, Kühn 92]. ✓



+ SUSY QCD Contributions are known [Su, Wise 01]. ✓



1-Loop Vector Boson SE Corrections:



+ Calculated for $\sigma_{\text{tot}}^{\text{NLO}}$ above threshold in **DREG** [Hollik, Schappacher 98]. ✓

New parts of MSSM



MSSM: Super symmetric theory.

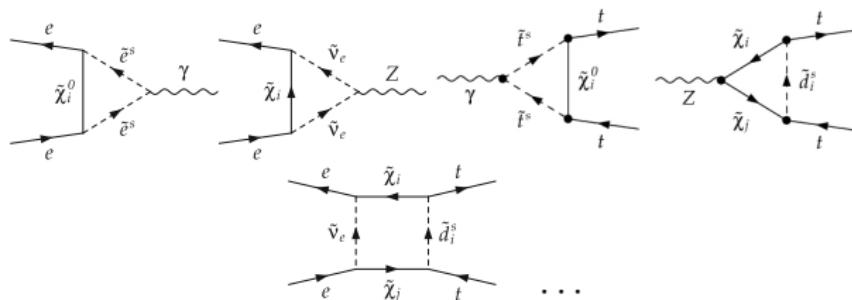
Use Dimensional **RED**uction for regularization!



SM processes @ 1L: $C(\text{OS}, \text{DRED}) = C(\text{OS}, \text{DREG})$. ✓



Contribution of EW SUSY-particles in $e^- e^+ / t\bar{t}$ -vertex and box diagrams:



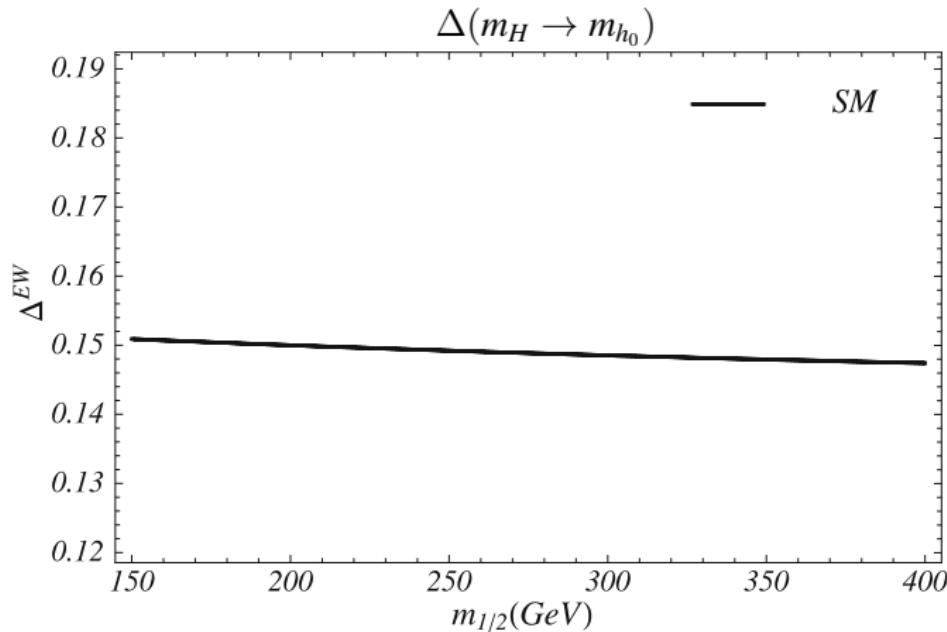
Synthesis:

- MATHEMATICA package TQPAT.M.
- Numerical analysis using mSUGRA scenarios. [Kiyo,Steinhauser,NZ 09]

Correction to the Cross Section

$$\Delta = \frac{\sigma_{\text{tot}}^{\text{1L}}}{\sigma_{\text{tot}}^{\text{tree}}} \Big|_{s=4m_t^2} .$$

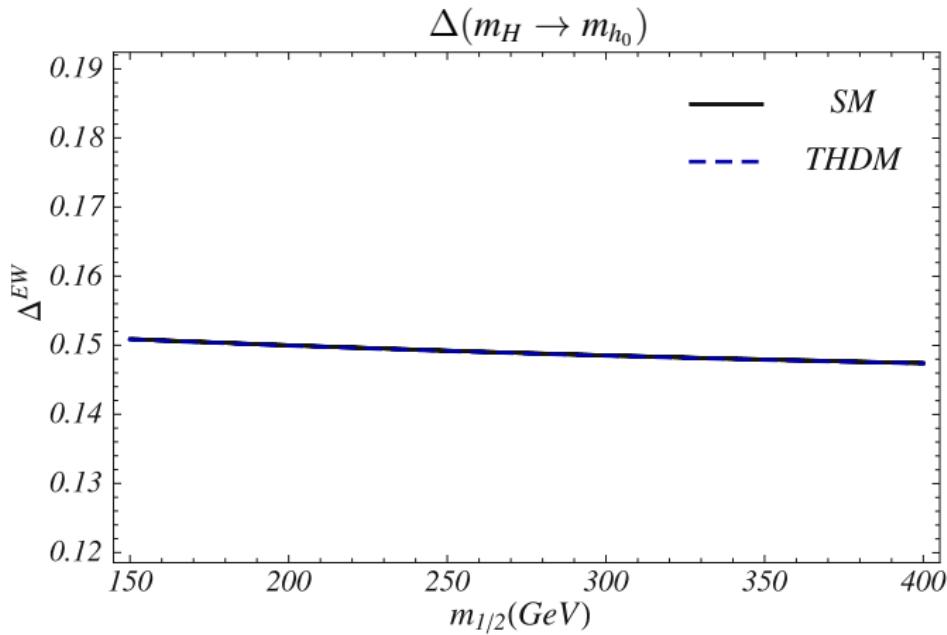
- mSUGRA Scenario SPS2 Slope.



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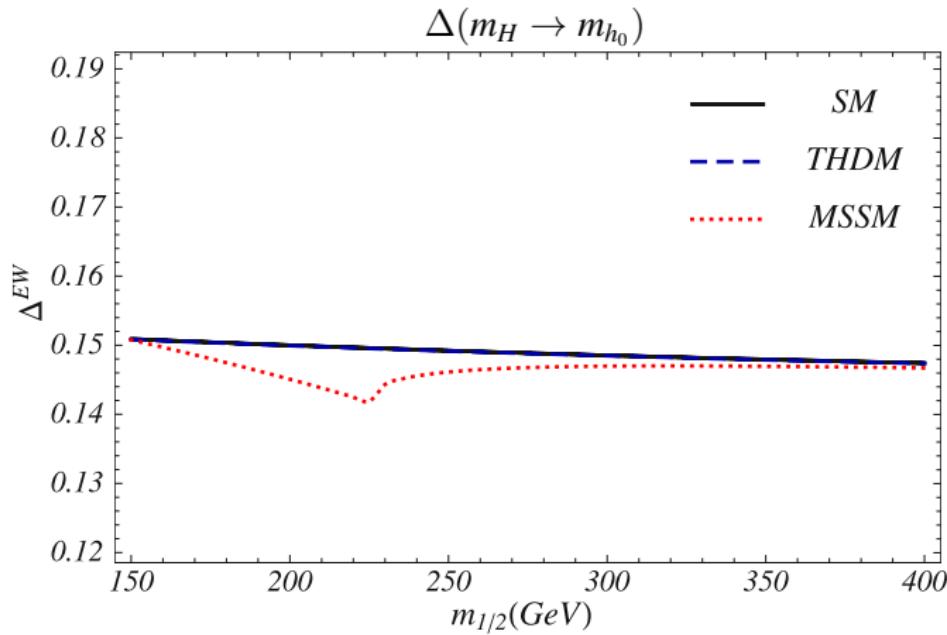
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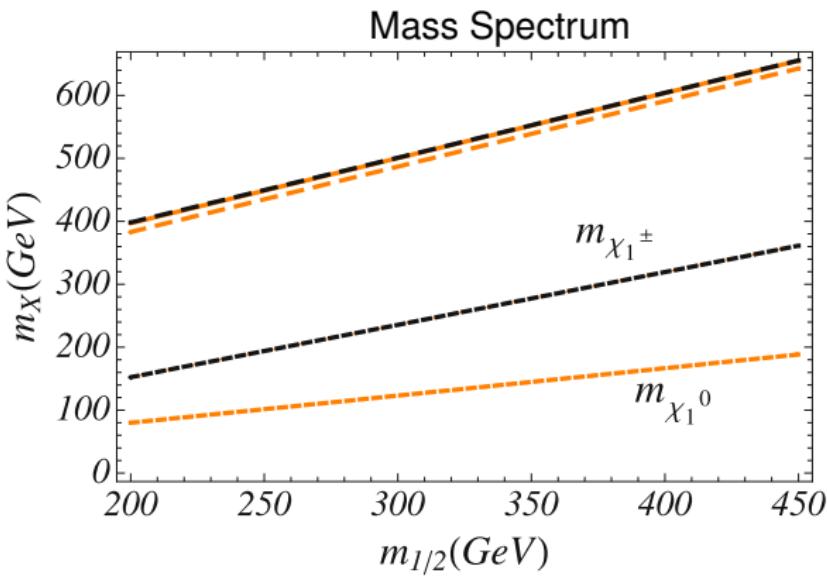
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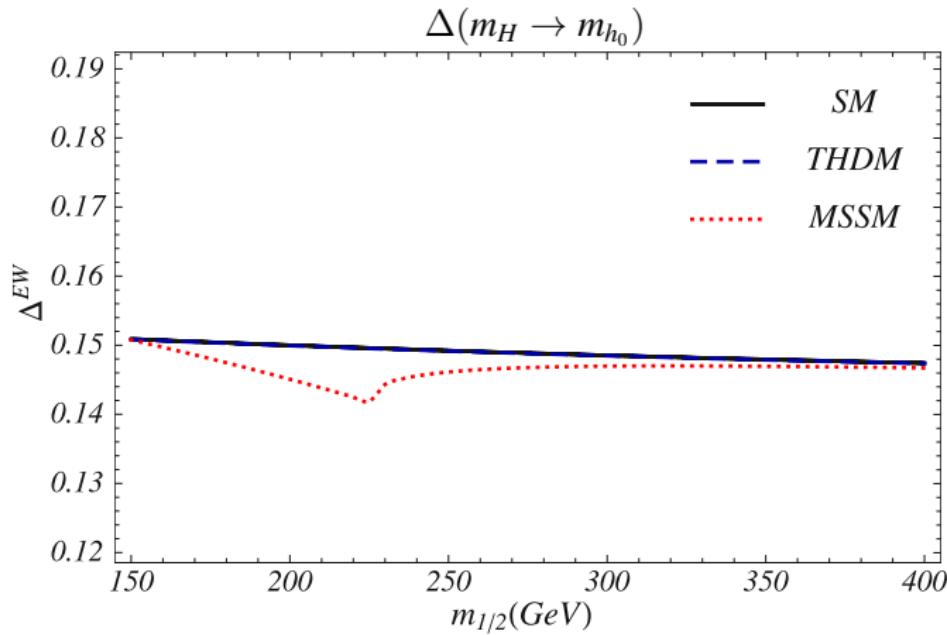
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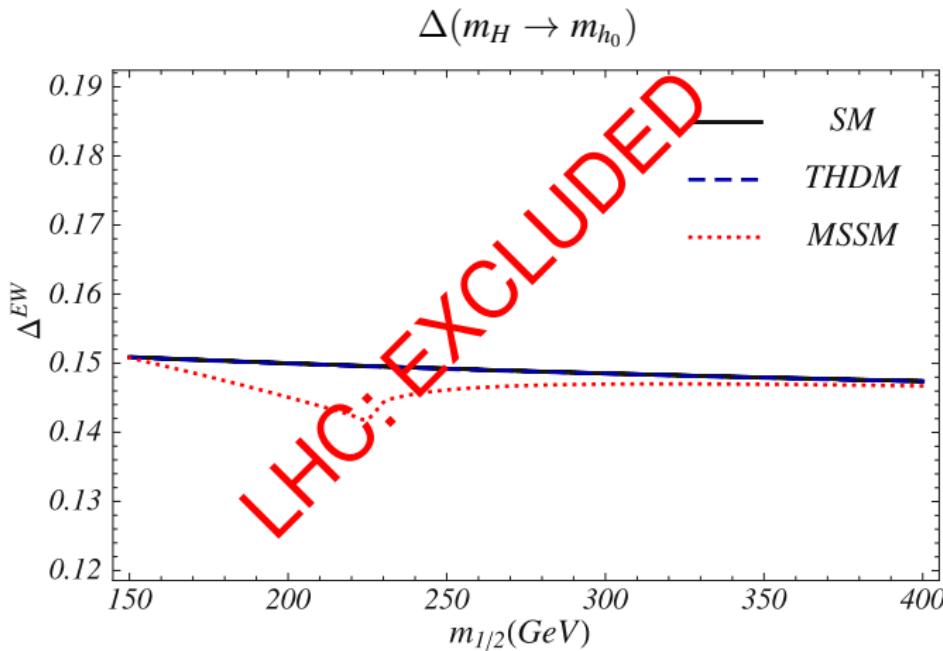
- mSUGRA Scenario SPS2 Slope.



Correction to the Cross Section

$$\Delta = \frac{\sigma_{\text{tot}}^{1\text{L}}}{\sigma_{\text{tot}}^{\text{tree}}} \Big|_{s=4m_t^2} .$$

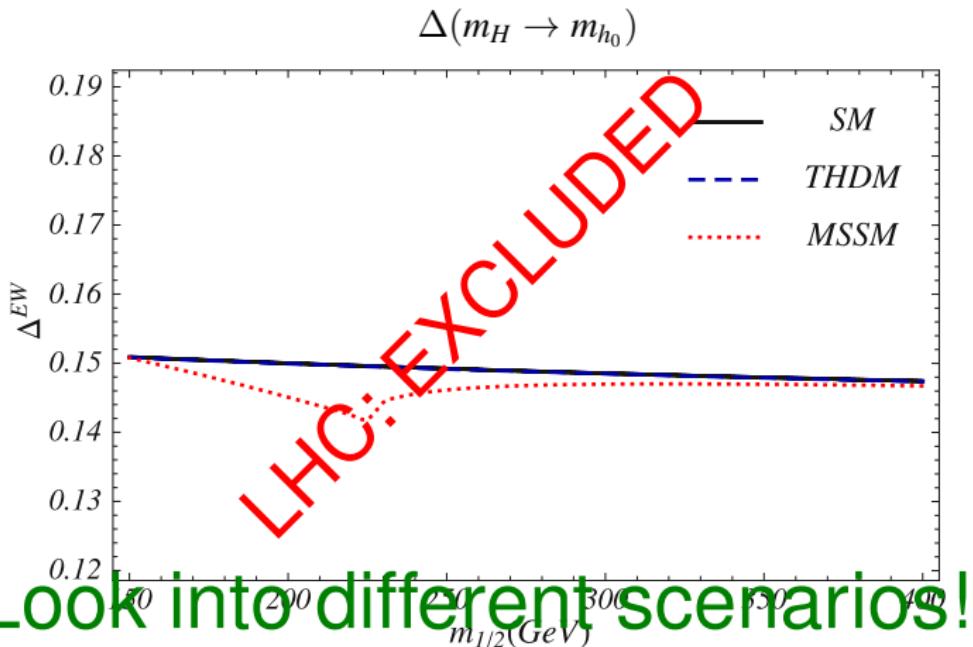
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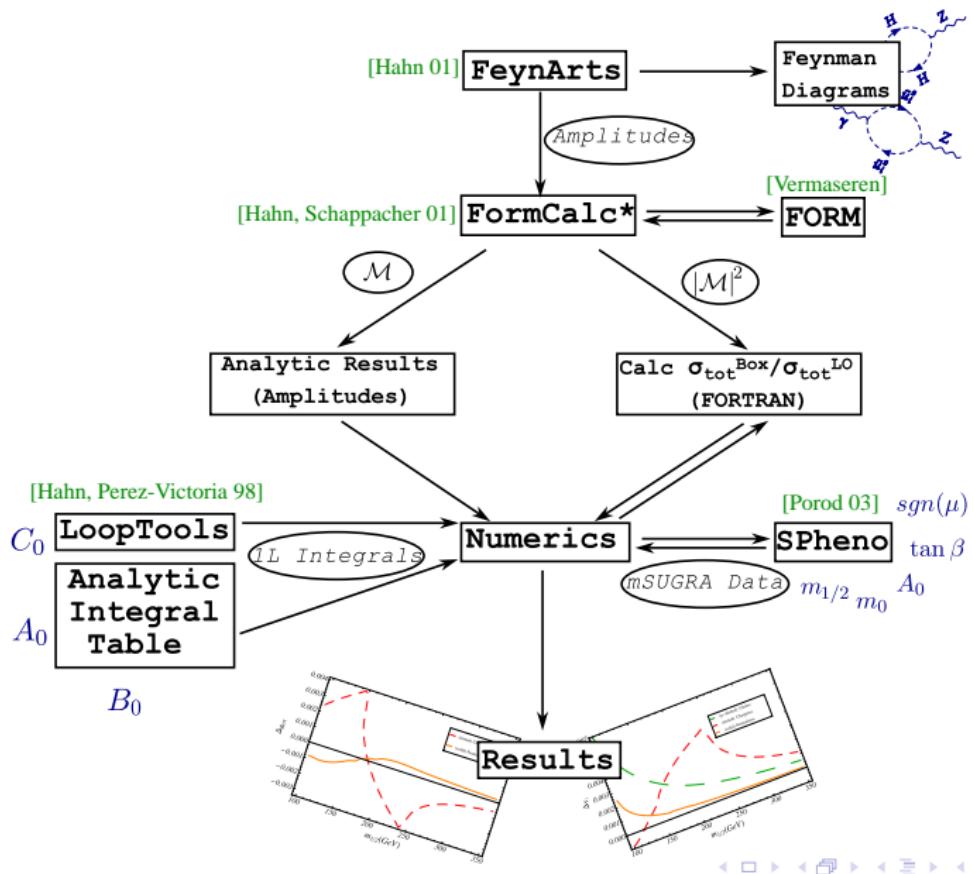
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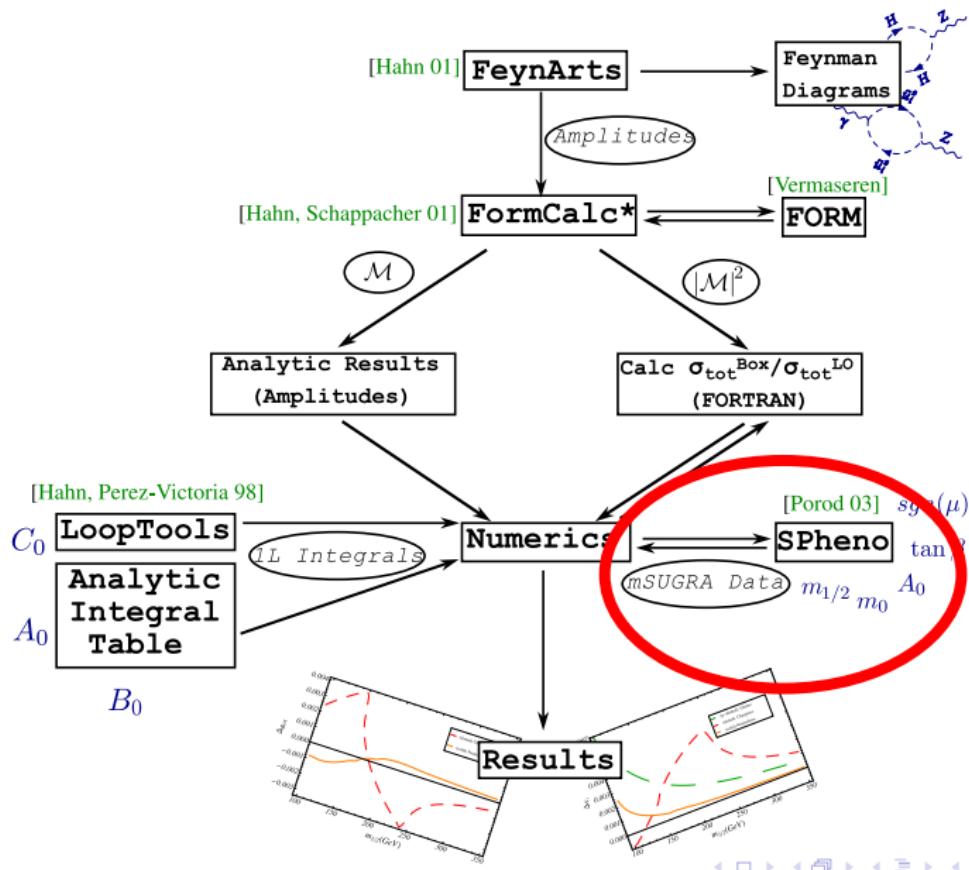
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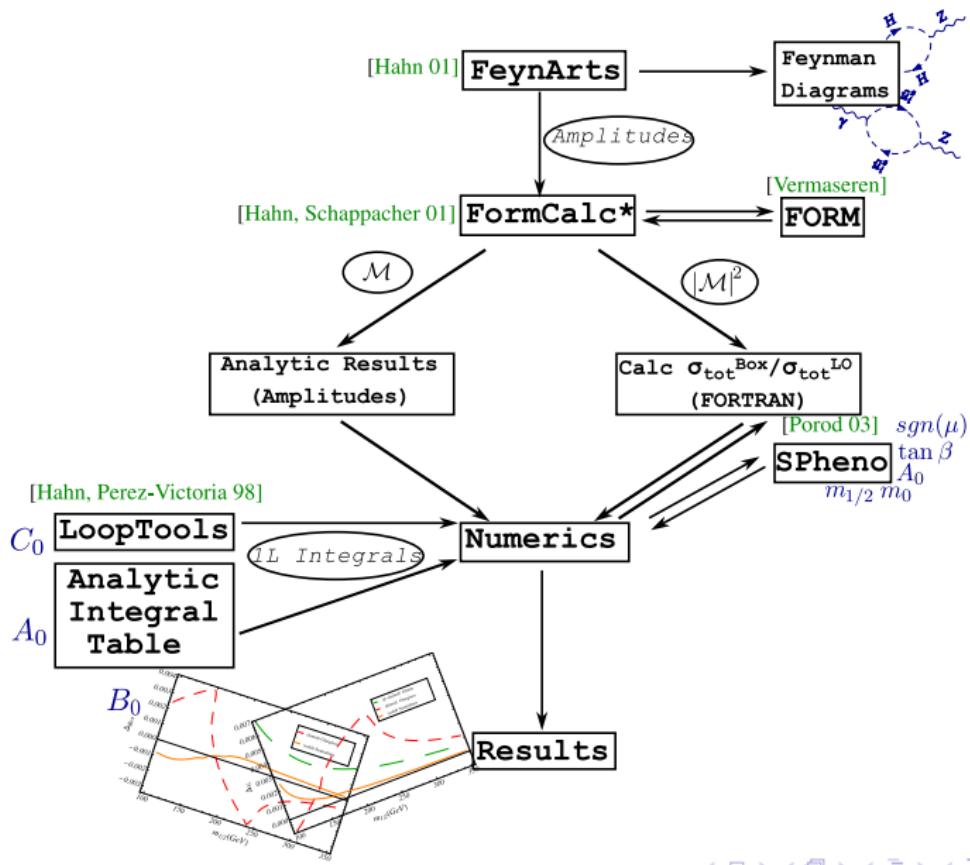
Work on TQPAT.m @ MITP



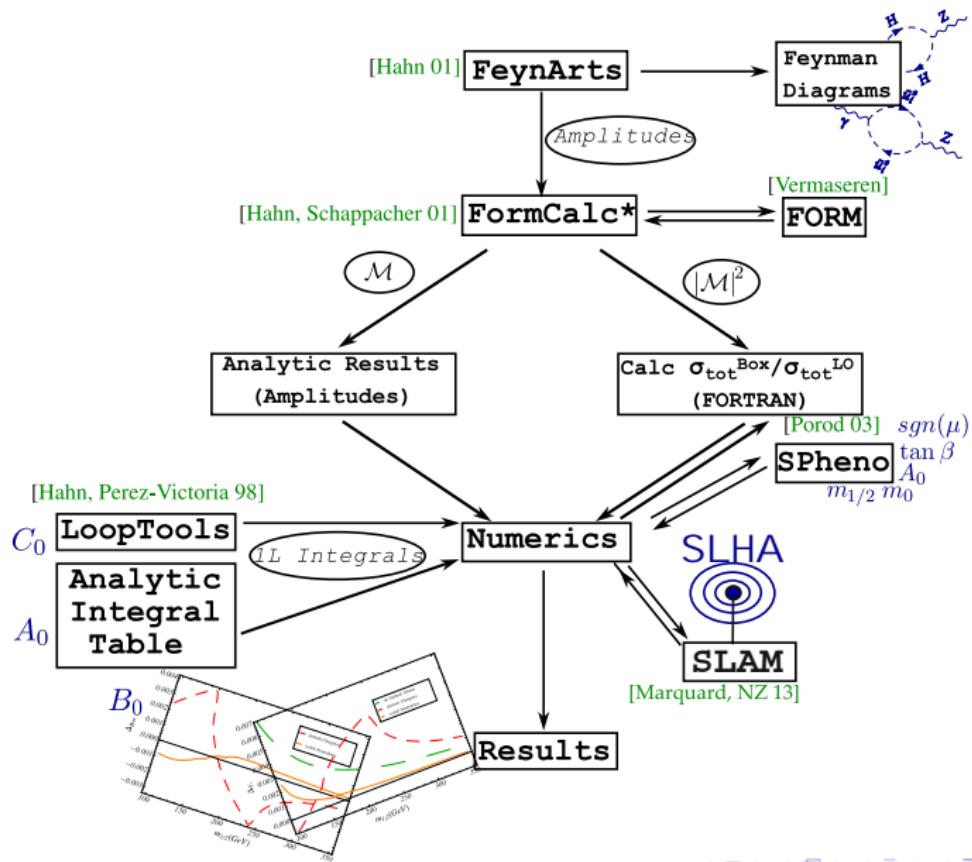
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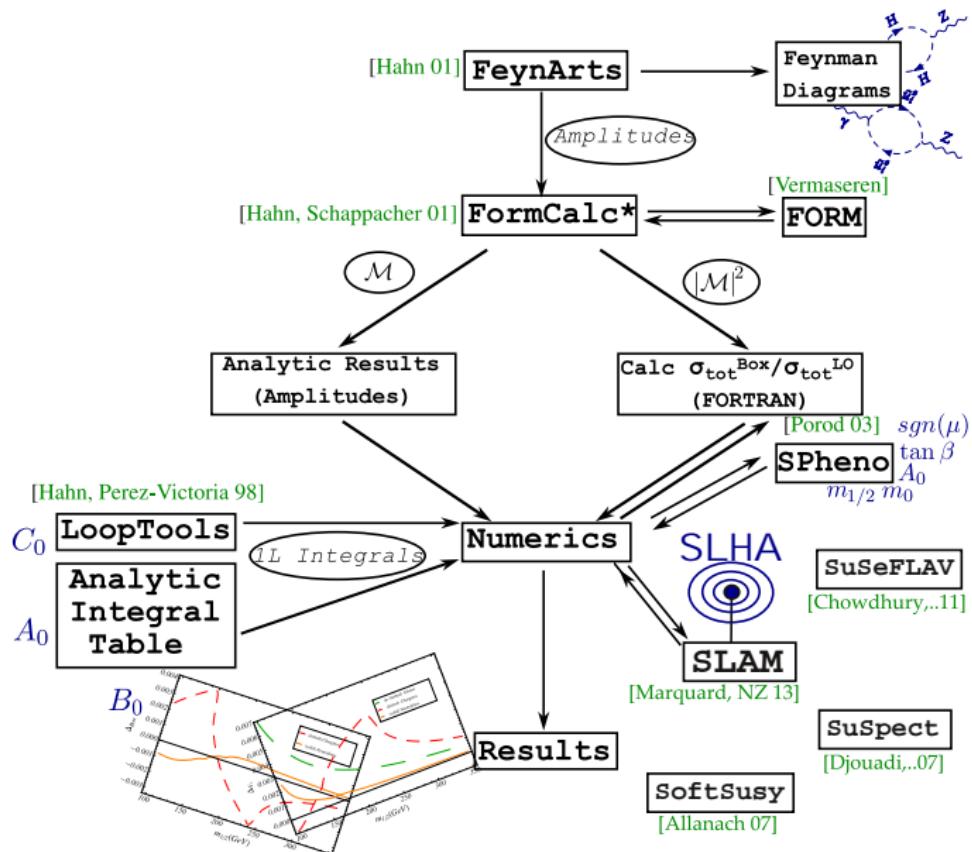
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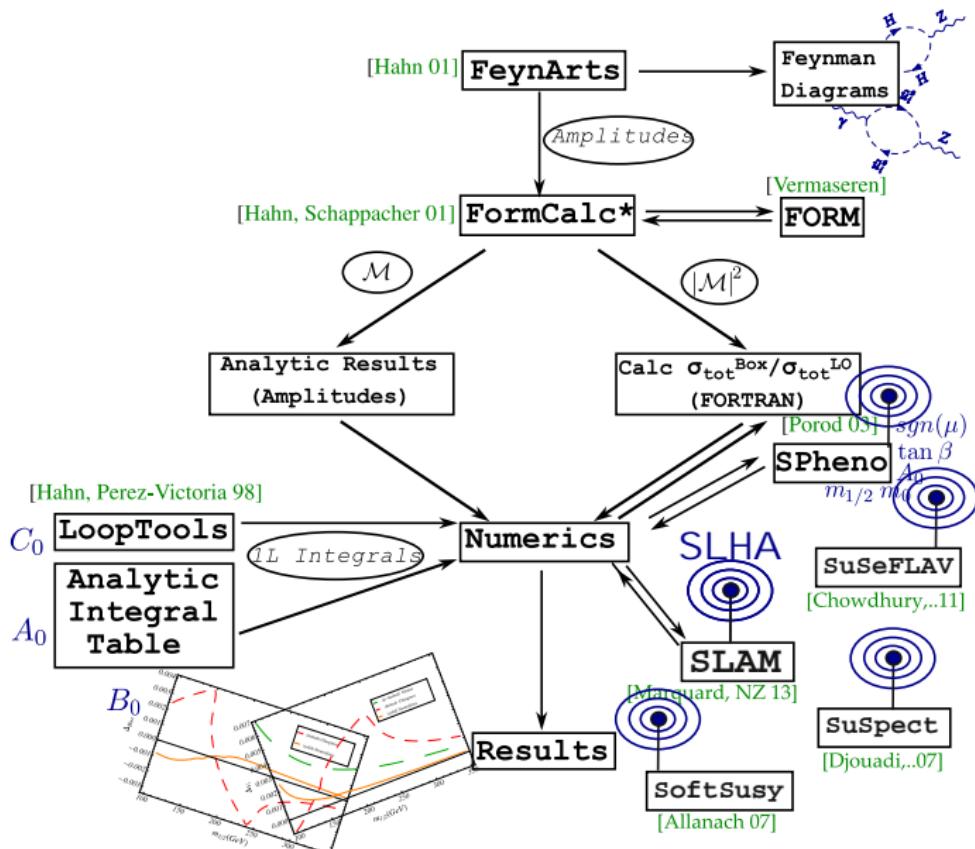
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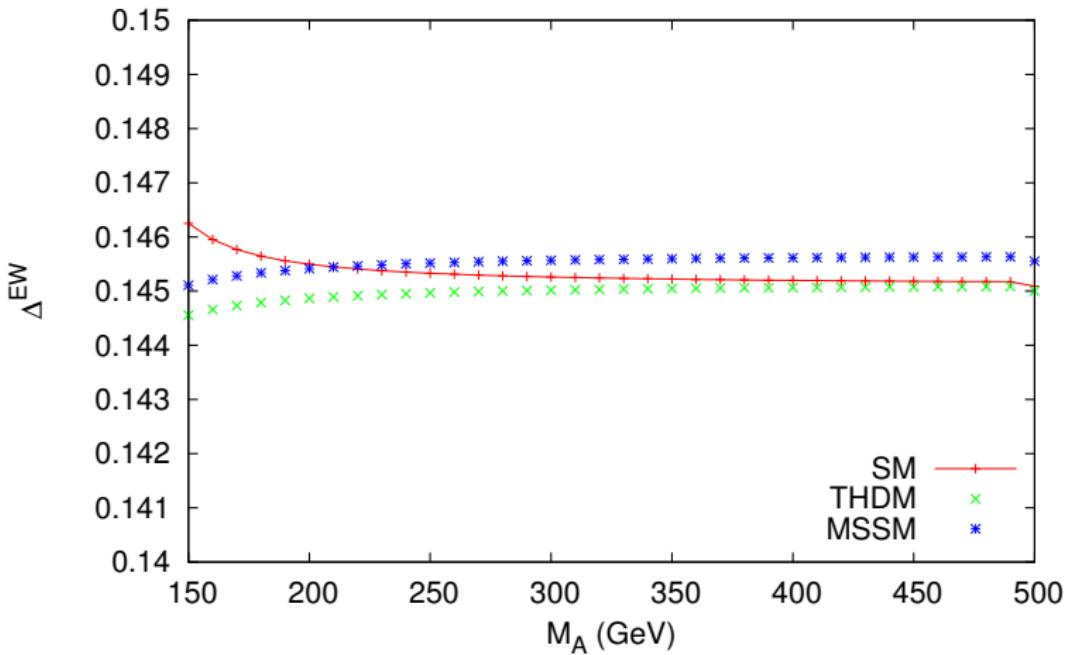
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New Results

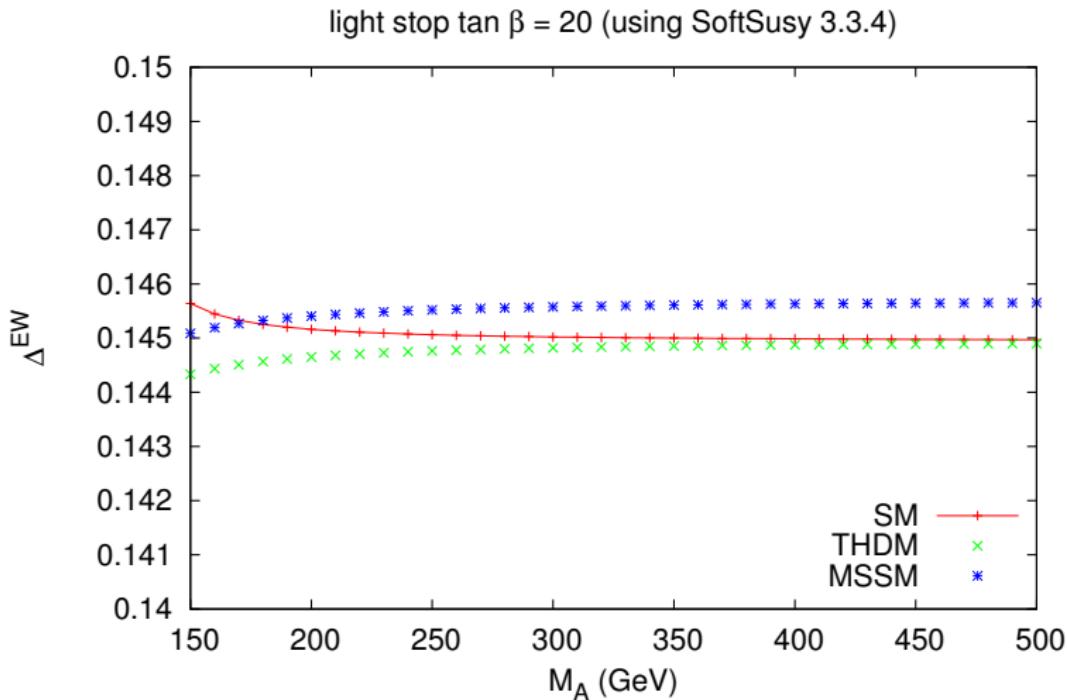
- Light \tilde{t} -Scenario [Carena, Heinmeyer, Stal, Wagner, Weiglein 13]

light stop $\tan \beta = 15$ (using SoftSUSY 3.3.4)



New Results

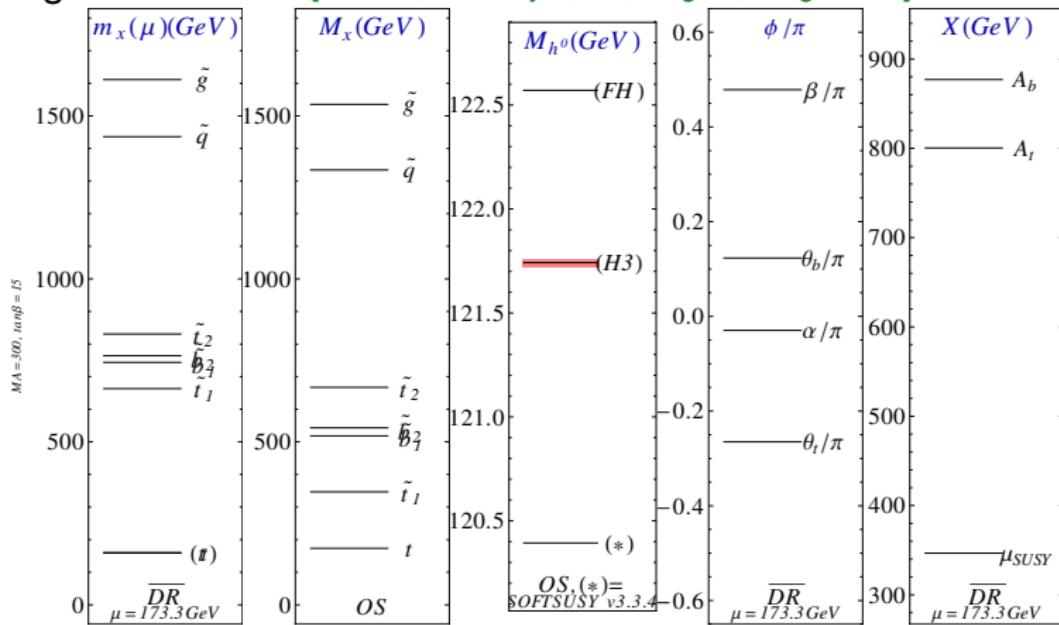
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New Results

PRELIMINARY

- Light \tilde{t} -Scenario [Carena, Heinmeyer, Stal, Wagner, Weiglein 13]



$$\tan \beta = 15, M_A = 300 \text{ GeV}$$

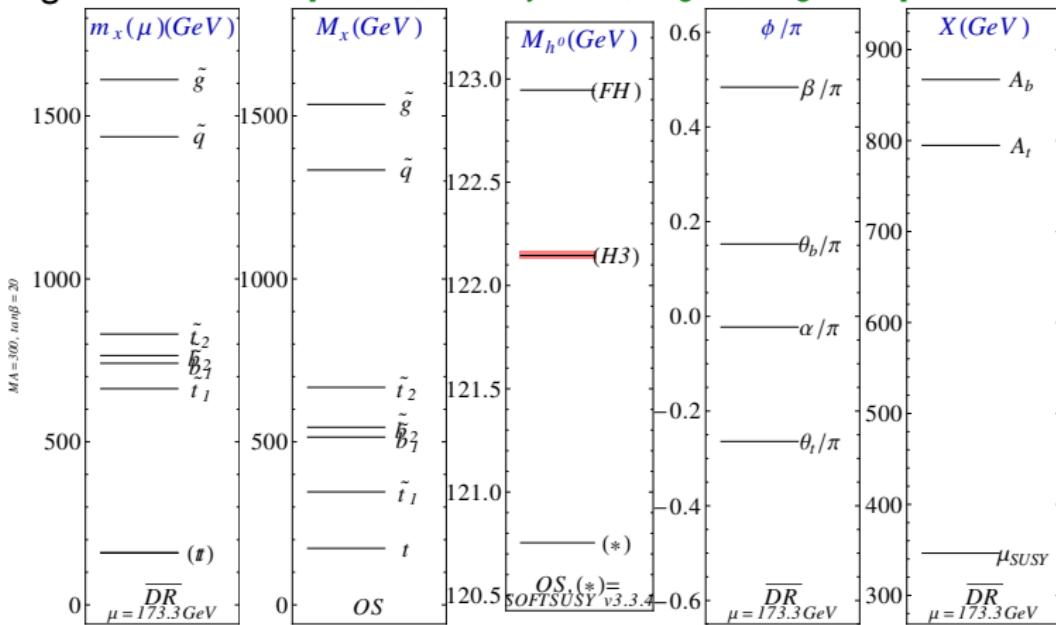
PRELIMINARY

New Results

PRELIMINARY

PRELIMINARY

- Light \tilde{t} -Scenario [Carena, Heinmeyer, Stal, Wagner, Weiglein 13]



$$\tan \beta = 20, M_A = 300 \text{GeV}$$

Summary

- ① Hard 1L corrections (C^{1L}) for $e^+e^- \rightarrow t\bar{t}$ -Pair Production at threshold in SM, THDM and MSSM are available. [Kiyo,Steinhauser,NZ 09]
Known results:

$$\Delta_{\text{EW}}^{\text{SM}}(\alpha = 137^{-1}) \approx +14\%, \quad \Delta_{\text{QCD}}^{\text{SM}} \approx -17\%,$$

$$\Delta_{\text{QCD}}^{\text{SUSY}} \lesssim 1\%.$$

- ② Observation for mSUGRA SPSx ($m_H \rightarrow m_{h_0}$):

$$\Delta_{\text{EW}}^{\text{SUSY}} = \Delta_{\text{EW}}^{\text{MSSM}} - \Delta_{\text{EW}}^{\text{THDM}} \lesssim 1\%.$$

- ③ Small SUSY effects $\lesssim 1\%$ expected (pathologic cases?).



Outlook

- ▶ Numerical analysis for up-to-date MSSM scenarios
- ▶ SUSY parameter space scan

Summary End

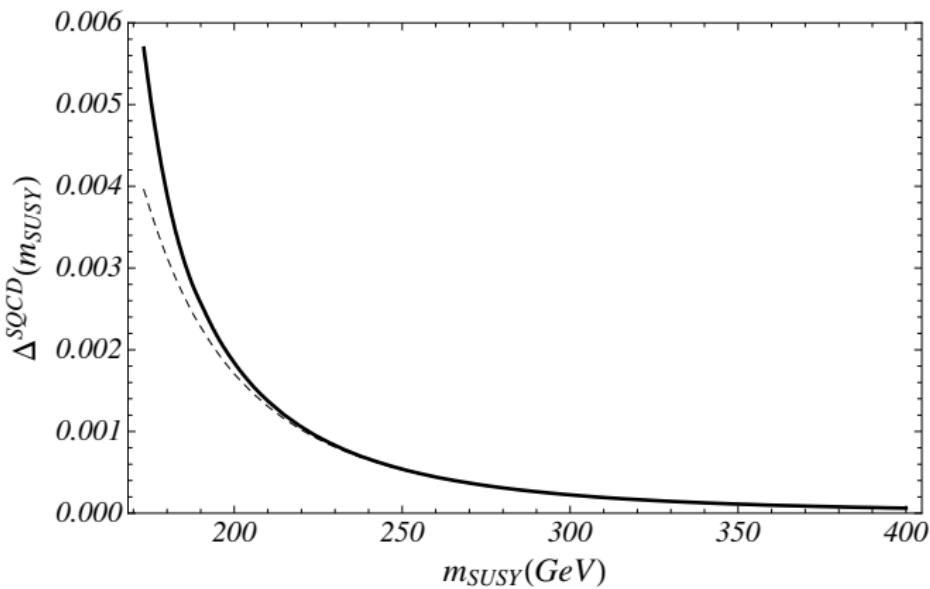
$$\Delta(C_A, C_V)$$

$C_A \propto$ leptonic axial vector current.

$C_V \propto$ leptonic vector current.

$$\Delta = 2\text{Re} \frac{C_A^{(0)} C_A^{(1)} + C_V^{(0)} C_V^{(1)}}{(C_A^{(0)})^2 + (C_V^{(0)})^2}.$$

SUSYQCD-Effects



SUSYQCD-Effects

