ϕ^* distributions in the MSSM

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3rd HiggsTools YRM

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The MSSM: Higgs sector

The Higgs sector is enlarged w.r.t. the SM, featuring two SU(2) doublet (super)fields. Therefore, one is left with 3 neutral physical states: 2 CP-even (H, h) and 1 CP-odd (A).

- From data: h should be SM-ish; $m_h \sim 125$ GeV.
- H preferably heavy ($m_H > 300$ GeV)
- $m_h = 125$ GeV is good for (thanks to?) SUSY!
- Main production channel for h at the LHC: gluon fusion.

$$H_d = \begin{pmatrix} (v_d + \phi_d^0 + i\chi_d^0/\sqrt{2}) \\ \phi_d^- \end{pmatrix}, \quad H_u = \begin{pmatrix} \phi_u^+ \\ (v_u + \phi_u^0 + i\chi_u^0/\sqrt{2}) \end{pmatrix} \tag{1}$$

$$v^2 = v_d^2 + v_u^2 = 4M_W^2/g^2 = (246\text{GeV})^2, \quad \tan\beta = \frac{v_u}{v_d} \tag{2}$$

The MSSM: The squark sector

We focus only on third generation (s)quarks. For each Dirac fermion we have 2 complex scalar superpartners.
The interaction eigenstates $\tilde{q}_{L,R}$ are not diagonal;

$$\mathcal{L}_{\tilde{q}} = (\tilde{q}_L^\dagger, \tilde{q}_R^\dagger)\mathcal{M}^2_{\tilde{q}}(\tilde{q}_L, \tilde{q}_R) \qquad (3)$$

$$\mathcal{M}^2_{\tilde{q}} = \begin{pmatrix} m^2_{Q_L} + m_q^2 + D_L & m_q X_q \\ m_t^2 X_q & m_{Q_R} + m_q^2 + D_R \end{pmatrix} \qquad (4)$$

with

$$D_L = M_Z^2 \cos 2\beta (T_{3q} - Q_q s_W^2), \quad D_R = M_Z^2 \cos 2\beta Q_q s_W^2 \qquad (5)$$

the mass eigenstates $m_{\tilde{q}_{1,2}}$ are obtained diagonalizing the mass matrix $\rightarrow$ they are admixtures of the weak states.

Why are stops important? Higgs mass and Higgs ggF production at the LHC.

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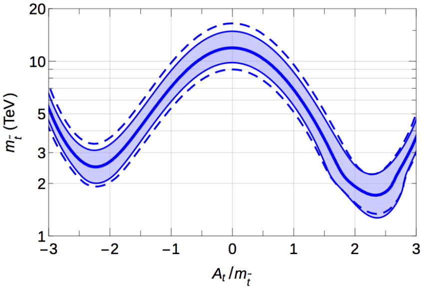
The MSSM: the Higgs mass

SUSY protects the Higgs mass of quadratic divergences that arise in the SM (fine tuning problem). In the MSSM, the Higgs mass is bounded by:

$$M_h^2 \lesssim M_Z^2 + \frac{3m_t^4}{4\pi^2 v^2}\left(\ln\left(\frac{m_T^2}{m_t^2}\right) + \frac{A_t^2}{m_T^2}\left(1 - \frac{A_t^2}{12m_T^2}\right)\right) \quad (6)$$

with $m_T^2 \equiv \frac{1}{2}(m_{\tilde{t}_1^2} + m_{\tilde{t}_2^2})$, $A_t \sim X_t$.

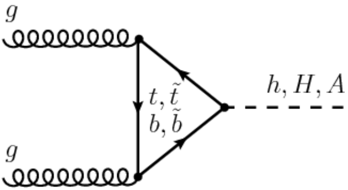


- Mass gap between top-stops give rise to sizeable (large??) corrections to the M_h^2.
- Large stops masses → reintroduce a naturalness problem.

higgstools

The MSSM: ggF Higgs production

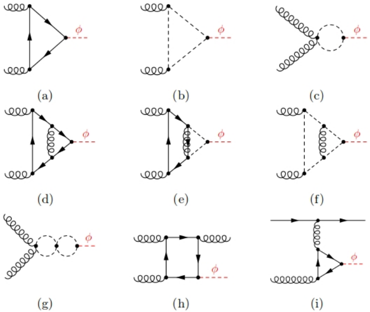
- Total cross section known at N3LO for the SM in the infinite top mass approximation.
- Known at NLO with full quark mass dependence (both in SM and MSSM).
- Who is running in the loop? mainly tops, *and stops* (and to a less extent bottom quarks and sbottoms).
- $\tilde{t}_{1,2}$ generally leads to a suppression in the total cross section: depend on the stops masses and mixings.



At leading order, the Higgs is produced with 0 p_T, i.e. it doesn't leave the beam axis.

The MSSM: h p_T distribution

pT is produced by the recoil with a gluon . Thus, the pT of the higgs produced in ggF is a beyond-LO effect.



- All the NLO diagrams amplitudes for the SM and (N)MSSM are implemented in the publicly available code SusHi, including contributions of SUSY particles.
- For arbitrarily low pT one finds divergences, different methods exist to deal with them: *Ressumation*: (references here), *NLO+PS*: (references here)

What happens when there are NP particles in the loop? what do we expect for the pT distribution?

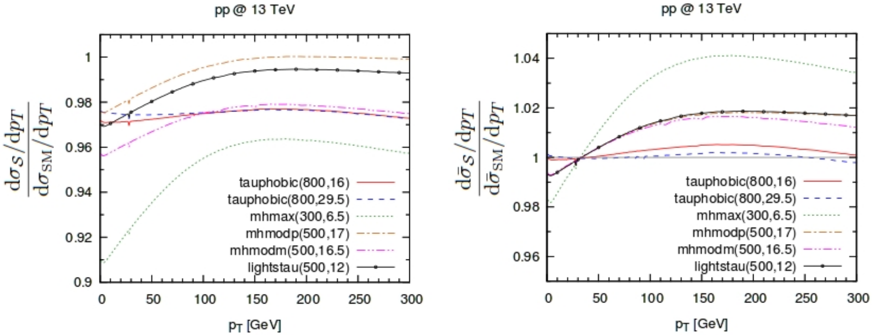


Figure : Ressumed p_T distribution in various scenarios (from HXSWG normalized to the SM distribution. [R.V.Harlander, H. Mantler, M. Wiesemann, 1409.0531]

Very little impact, of order <4% for almost all scenarios

What about the stops? $\tilde{t}$ with large mixing can alter the total cross section and the shape of the pT distributions of h. Current bounds $\tilde{t} \gtrsim 400$ GeV; we expect its effects to be **noticeable at the high pT tail** (refer to shruti results)

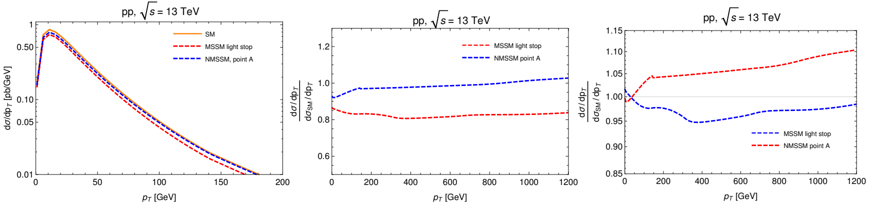


Figure : Ressumed p_T distributions, obtained with the code MoRe-SusHi [R.V.Harlander, H. Mantler, M. Wiesemann, 1409.0531].

MSSM light stop scenario:

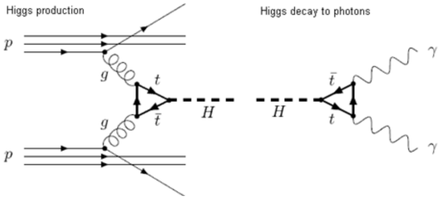
$$\tan\beta = 20, \quad A_t = 1\text{TeV}, \mu = 350\text{GeV}, \quad m_{\tilde{t}_1} = 350\text{GeV} \tag{7}$$

NMSSM point A

$$\lambda = 0.65, \quad \tan\beta = 2, \quad A_t = 1\text{TeV} \quad, \mu = 200\text{GeV}, \quad m_{\tilde{t}_1} = 700\text{GeV} \tag{8}$$

ϕ^*: definition in the diphoton channel

We consider the diphoton channel for a ggF produced Higgs.



The variable ϕ^* is defined as:

$$\phi^* \equiv \tan\left(\frac{\phi_{acopl}}{2}\right) \cdot \sin(\theta^*_\eta) \qquad (9)$$

with,

$$\phi_{acopl} \equiv \pi - \Delta\phi(\gamma\gamma), \qquad (10)$$

$$\cos(\theta^*_\eta) \equiv \tanh\left(\frac{\eta^{\gamma_1} - \eta^{\gamma_2}}{2}\right) \qquad (11)$$

.

- At low $p_T \Rightarrow \phi^* \approx 2p_t m_{\gamma\gamma}$ (see Juan's talk)
- Proposed for studying low p_T^Z region for Drell-Yan process, due to better experimental resolution.
- at high p_T, ϕ^* is not trivially related to p_T (actually ϕ^* has no theoretical upper bound).
- **How ϕ^* affected by NP? What happens at large ϕ^*?**

Obtaining the ϕ^* distribution

We used the code aMC_SusHi to generate Higgs events produced in ggF at NLO QCD, for the *SM and the MSSM*.
[H.Mantler, M. Wiesemann, 1504.06625; S. Liebler, H.Mantler, M. Wiesemann, 1608.02949]

- aMC@NLO approach through MadGraph5_aMC@NLO.
- Linked to the Fortran code SusHi for the computation of SM and SUSY amplitudes (R. Harlander, S.Liebler, H. Mantler, 1212.3249)
- NLO matched to Parton Shower events; arbitrary low p_T.
- MadGraph5 automatically linked to Pythia for showering events.

Obtaining the ϕ^* distribution

The set up: generation

- We use the MSTW2008NLO PDF
- dynamical scale choice;

$$\mu_R = \mu_F = \frac{1}{2}\sqrt{m_h^2 + p_T^2} \tag{12}$$

- We generate 500k events for each scenario (SM, MSSM light stop), equivalent to $\mathcal{L} \sim 7300\ \text{fb}^-1$ (taking $\epsilon \approx 100\%$), at $\sqrt{s} = 13$ TeV.

ϕ^* distributions: Results

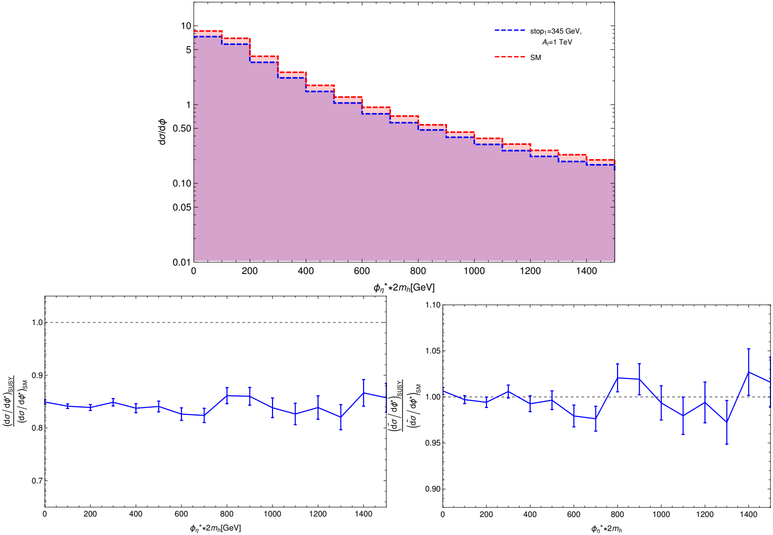
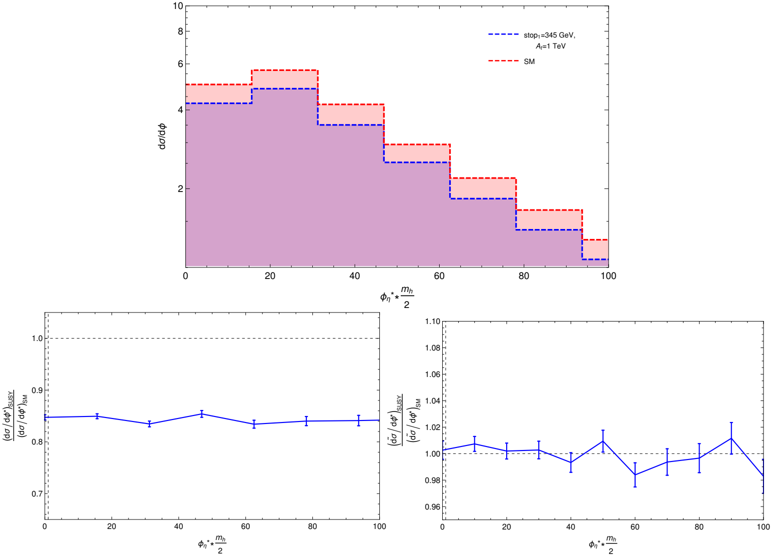


Figure : ϕ^* distribution for the SM and the MSSM light stop scenario ($m_{\tilde{t}_1} = 345$ GeV, $A_t = 1$ TeV).

ϕ^* distributions: Results. Low ϕ^*



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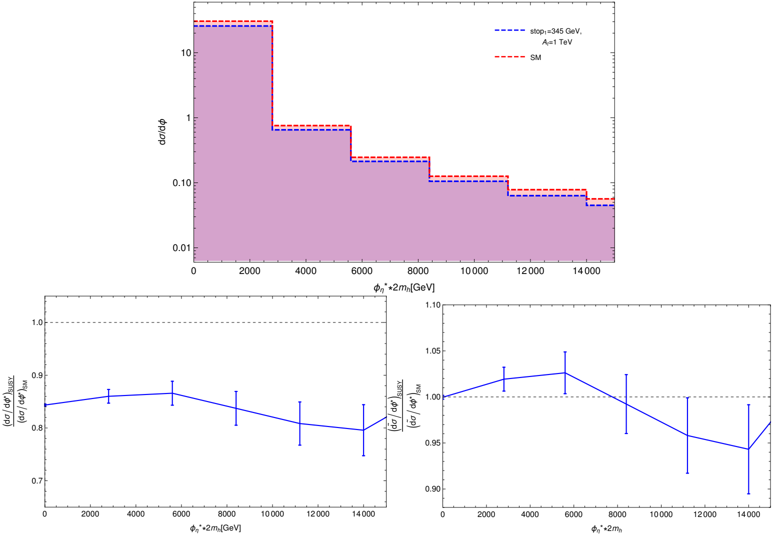

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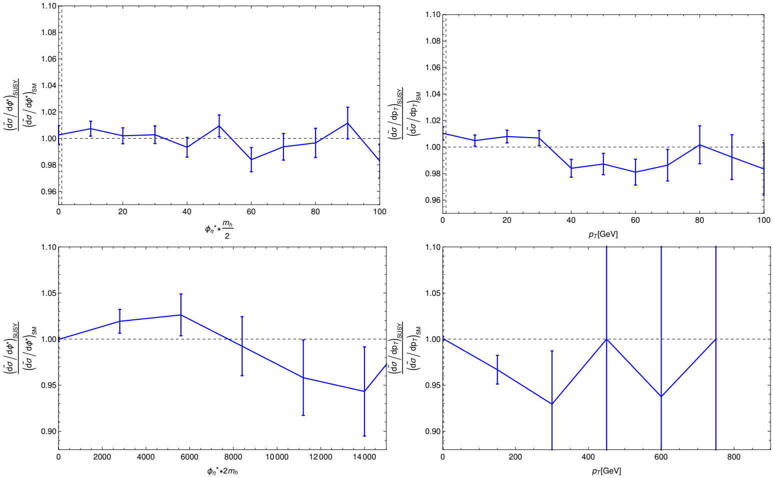
ϕ^* distributions: Results. Comparing ϕ^* and $p_T^{\gamma\gamma}$



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Summary

- We defined the ϕ^* observable for the ggF$\rightarrow h \rightarrow \gamma\gamma$ process.
- We obtained the p_T and ϕ^* distributions for the SM and the 'most optimistic' MSSM light stop scenario. Deviations from the SM are expected at large $p_T \Rightarrow$ also at large ϕ^*?
- Within the reach of the HL-LHC, ϕ^* does not offer a better discrimination power for discovering NP in this process

Thanks for your attention!

Backup

Limits on stops mass