Constraints on new physics using Higgs pT STXS measurements with H1jet and HiggsSignals

Alexander Lind

with Emanuele Bagnaschi, Henning Bahl, Thomas Biekötter, Sven Heinemeyer, and Georg Weiglein

INFN Istituto Nazionale di Fisica Nucleare
LNF LABORATORI NAZIONALI DI FRASCATI

IRN Terascale @ Montpellier

25 November 2025

Constraints on new physics using Higgs pT STXS measurements with H1jet and HiggsSignals

Alexander Lind

with Emanuele Bagnaschi, Henning Bahl, Thomas Biekötter, Sven Heinemeyer, and Georg Weiglein

Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DI FRASCATI

Feel free to ask me about the LNF Spring School!

IRN Terascale @ Montpellier
25 November 2025

Quick overview

Quick scanning over BSM parameter space

BSM → H1jet → Predictions → HiggsSignals → Statistical test

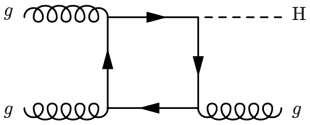
Higgs predictions compared to experimental measurements

H1jet

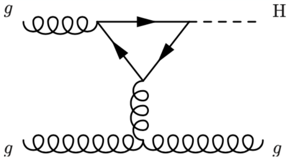
A fast and easy-to-use tool to compute transverse momentum distributions

$$\mathcal{L}_{\text{eff.}} \subset -\kappa_t \frac{m_t}{v} t\bar{t}H + \kappa_g \frac{\alpha_s}{12\pi}\frac{H}{v} G^a_{\mu\nu} G^{\mu\nu\, a}$$

$$\frac{\sigma(\kappa_t, \kappa_g)}{\sigma^{\text{SM}}} \propto (\kappa_t + \kappa_g)^2$$



(a) Box diagram.



(b) Triangle diagram.

Loops: SM top + BSM top-partner

Meant for theorists and quick scans over BSM parameter spaces

Published in 2011.04694 and h1jet.hepforge.org

H1jet — The method

Processes $2 \to 1$ and $2 \to 2$ but can be extended

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} = \frac{p_T}{8\pi} \int_{-\eta_M}^{\eta_M} \mathrm{d}\eta \sum_{i,j} \left[\frac{|\mathcal{M}_{ij}(\hat{s}, \hat{t}, \hat{u})|^2}{E_X \hat{s}^{3/2}} \mathcal{L}\left(\frac{\hat{s}}{s}, \mu_F\right) \right]$$

$$\eta_M = \ln\left(x_M + \sqrt{x_M^2 - 1}\right)$$

$$x_M = \frac{s - m_X^2}{2p_T\sqrt{s}}$$

$$\hat{s} = \left(p_T \cosh\eta + \sqrt{m_X^2 + p_T^2 \cosh^2\eta}\right)^2$$

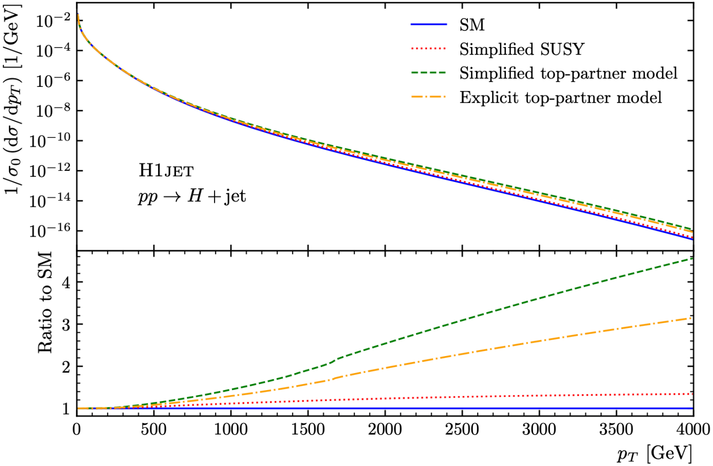
$$\hat{t} = -p_T e^{-\eta}\sqrt{\hat{s}}$$

$$\hat{u} = -p_T e^{\eta}\sqrt{\hat{s}}$$

1D integration done using adaptive Gaussian quadrature

Code interfaced with CHAPLIN and HOPPET

H1jet — Built-in models and BSM interface



Possibility to add any number of given top-partners by specifying mass, κ, and whether fermion or scalar

HiggsTools

Comparison of a wide class of BSM models to available Higgs signal rate measurements

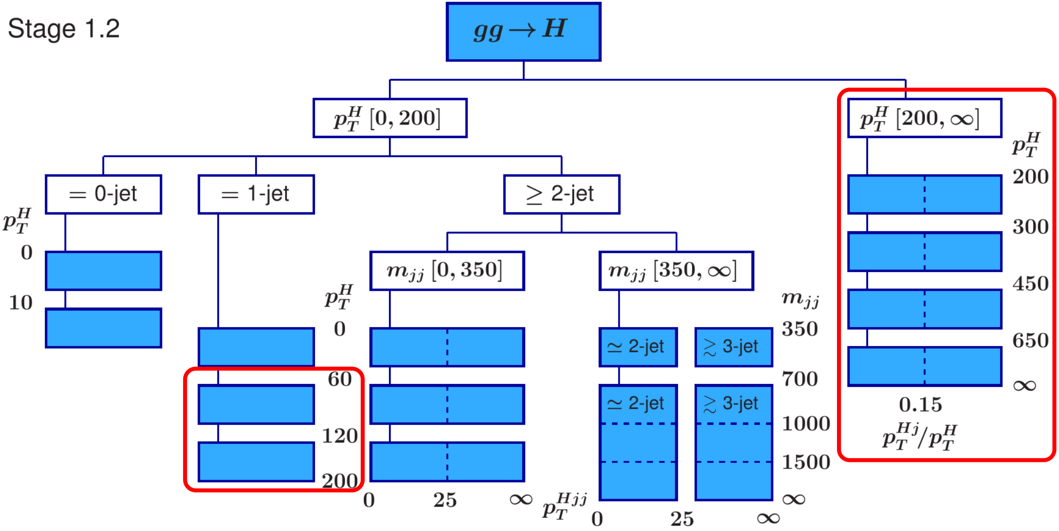
- HiggsPredictions
- HiggsBounds
- HiggsSignals

gitlab.com/higgsbounds/higgstools

2012.09197 [hep-ph]

2210.09332 [hep-ph]

STXS bin definitions



HiggsSignals input

Using modification factors in HiggsSignals:

$$\text{mod. factor} = r = \frac{\sigma^{\mathrm{BSM}}(\mathrm{bin})/\sigma_0^{\mathrm{BSM}}}{\sigma^{\mathrm{SM}}(\mathrm{bin})/\sigma_0^{\mathrm{SM}}} = \frac{\sigma^{\mathrm{BSM}}(\mathrm{bin})}{\sigma^{\mathrm{SM}}(\mathrm{bin})} \times \frac{\sigma_0^{\mathrm{SM}}}{\sigma_0^{\mathrm{BSM}}}$$

where:

$\sigma(\mathrm{bin})$ = integrated cross-section in the STXS bin

σ_0 = inclusive cross-section

HiggsSignals provides a χ^2 value for each model point

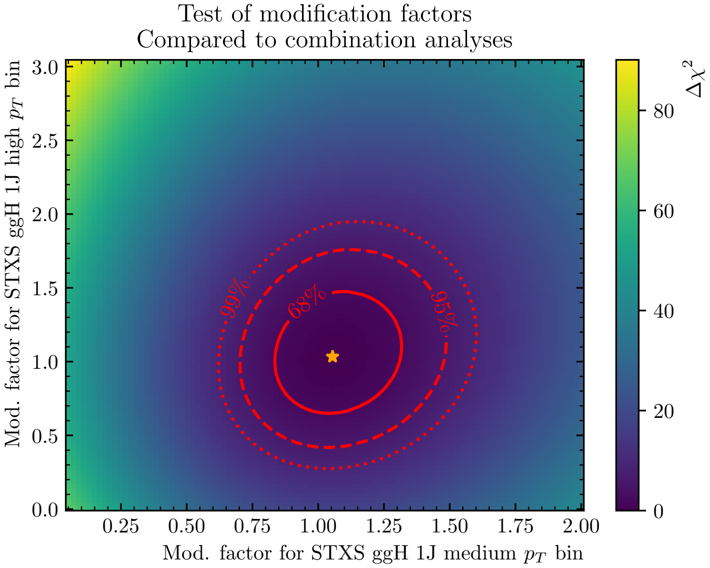
$$\Delta\chi^2 = \chi^2 - \chi^2_{\mathrm{min}}$$

HiggsSignals datasets

HiggsSignals datasets: hsdataset on GitLab

Datasets implemented in HiggsSignals that includes STXS bin measurements:

- CMS 2103.06956
  `gamgam_STXS_LHC13_CMS_137.json`
- ATLAS 2207.00348
  `gamgam_STXS_LHC13_ATLAS_139.json`
- CMS 2204.12957
  `tautau_CMS_STXS_139ifb_LHC13_CMS_138.json`
- CMS 2103.04956
  `ZZ_4l_STXS_LHC13_CMS_137.json`
- ATLAS 2004.03447
  `ZZ_4l_STXS_LHC13_ATLAS_139.json`


Test of modification factors
Compared to combination analyses
Mod. factor for STXS ggH 1J high p_T bin
Mod. factor for STXS ggH 1J medium p_T bin
$\Delta\chi^2$
68%
95%
99%
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
80
60
40
20
0

Simplified SUSY

Simplified SUSY model with two stops $\tilde{t}_1$ and $\tilde{t}_2$

Model described in hep-ph/0207010 and 1806.05598

Free parameters: $m_{\tilde{t}_1}$, Δm, $\theta_{\tilde{t}}$, $\tan\beta$

$$m_{\tilde{t}_2} = \sqrt{m_{\tilde{t}_1}^2 + (\Delta m)^2}$$

Stop Yukawa coupling factors

$$\kappa_{\tilde{t}_1} = \frac{m_t^2}{m_{\tilde{t}_1}^2}\left[\alpha_1 \cos^2\theta_{\tilde{t}} + \alpha_2 \sin^2\theta_{\tilde{t}} + 2 - \frac{(\Delta m)^2}{2m_t^2}\sin^2(2\theta_{\tilde{t}})\right]$$

$$\kappa_{\tilde{t}_2} = \frac{m_t^2}{m_{\tilde{t}_2}^2}\left[\alpha_1 \sin^2\theta_{\tilde{t}} + \alpha_2 \cos^2\theta_{\tilde{t}} + 2 + \frac{(\Delta m)^2}{2m_t^2}\sin^2(2\theta_{\tilde{t}})\right]$$

$$\alpha_1 = \frac{m_Z^2}{m_t^2}\cos(2\beta)\left[1 - \frac{4}{3}\sin^2\theta_W\right]$$

$$\alpha_2 = \frac{4}{3}\frac{m_Z^2}{m_t^2}\cos(2\beta)\sin^2\theta_W$$

Simplified SUSY

The simplified SUSY model here considers only the stop squark sector of the MSSM in the decoupling limit, $M_A \gg m_Z$

Furthermore, we assume the only scalars running in the loop are $\tilde{t}_1$ and $\tilde{t}_2$, i.e. we neglect the sbottom squarks – their contribution may be non-negligible if $\tan\beta$ is large enough

Additionally, higher-order diagrams involving gluinos are neglected

Beyond the $h\tilde{t}_1\tilde{t}_1$ and $h_0\tilde{t}_2\tilde{t}_2$ couplings, there is also the mixed $h\tilde{t}_1\tilde{t}_2$ coupling, but this is not included as it does not contribute to the $pp \to h$ and $pp \to h + \mathrm{jet}$ cross-sections at leading-order

Simplified SUSY

Top squark contribution to inclusive cross-section $gg \to h$

$$\frac{\sigma_0^{\mathrm{SUSY}}}{\sigma_0^{\mathrm{SM}}} = \kappa_g^2 \simeq \left(1 + C_g \frac{F_g^{\mathrm{SUSY}}}{F_g^{\mathrm{SM}}}\right)^2$$

with ratio of effects from higher-order QCD corrections

$$C_g = 1 + \frac{25\alpha_s}{6\pi}$$

and gluon fusion form factors $\left(\tau_i = \frac{m_h^2}{4m_i^2}\right)$

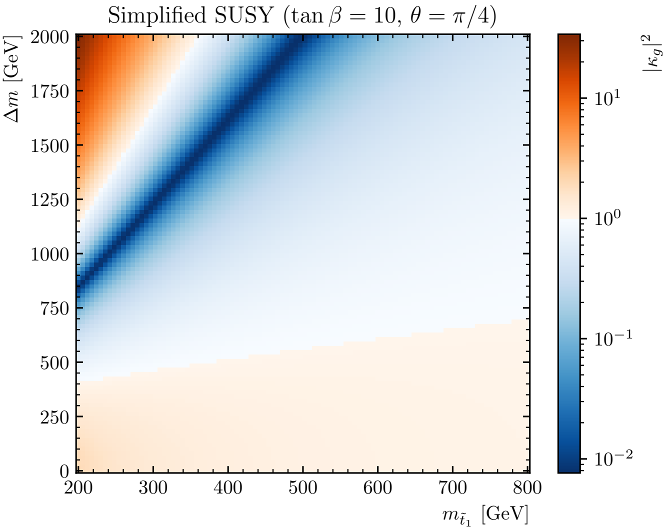
$$F_g^{\mathrm{SM}} = \sum_{i=t,b} F_{1/2}(\tau_i)\left(1 + \frac{11\alpha_s}{4\pi}\right) \qquad F_g^{\mathrm{SUSY}} = \sum_{i=\tilde{t}_1,\tilde{t}_2} \frac{1}{2}\kappa_{\tilde{t}_i} F_0(\tau_i)$$

If $m_{\tilde{t}_1}, m_{\tilde{t}_2} \gg m_h$ then

$$F_g^{\mathrm{SUSY}} \simeq -\frac{1}{6}\sum_{i=\tilde{t}_1,\tilde{t}_2} \kappa_{\tilde{t}_i} = -\frac{1}{3}\left[\frac{m_t^2}{m_{\tilde{t}_1}^2} + \frac{m_t^2}{m_{\tilde{t}_2}^2} - \frac{1}{4}\sin^2(2\theta_{\tilde{t}})\frac{(\Delta m)^4}{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}\right]$$

Simplified SUSY

Benchmark point: $\tan\beta = 10$, max. mixing angle, $\theta_{\tilde{t}} = \pi/4$, $\sin^2(2\theta_{\tilde{t}}) = 1$



Simplified SUSY

Two slices of the parameter space $(m_{\tilde{t}_1}, \Delta m, \theta_{\tilde{t}})$ where we see cancellation, $\kappa_g^2 \to 1$

- $F_g^{\mathrm{SUSY}} = 0$
- $C_g F_g^{\mathrm{SUSY}} / F_g^{\mathrm{SM}} = -2$

The first one due to $F_g^{\mathrm{SUSY}} = 0$ happens if

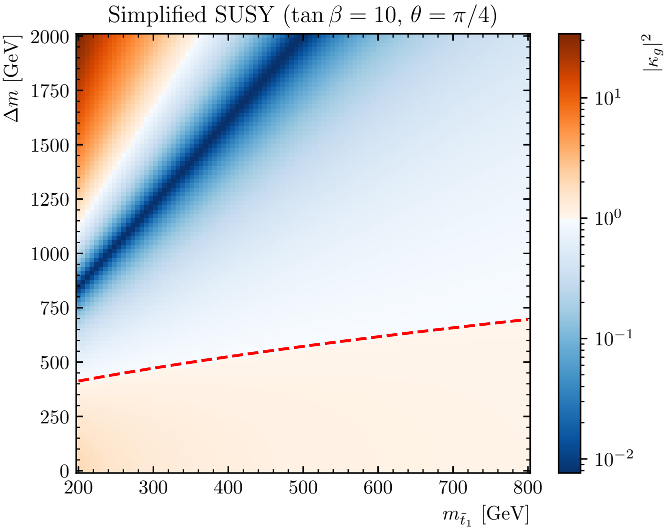
$$(\Delta m)^2 = \frac{2m_t^2}{\sin^2(2\theta_{\tilde{t}})} \left(1 \pm \sqrt{1 + 2\frac{m_{\tilde{t}_1}^2}{m_t^2} \sin^2(2\theta_{\tilde{t}})} \right)$$

For $\sin^2(2\theta_{\tilde{t}}) = 1$ and $m_{\tilde{t}_1} \gg m_t$ we get

$$\Delta m \simeq \sqrt{2m_t^2 \left(1 + \sqrt{2}\frac{m_{\tilde{t}_1}}{m_t} \right)} \approx 256\sqrt{1 + 0.008\, m_{\tilde{t}_1}}$$

Simplified SUSY

Plotting the $\Delta m \simeq 256\sqrt{1 + 0.008\, m_{\tilde{t}_1}}$ line with reduced sensitivity



Simplified SUSY

We see reduced BSM sensitivity, $\kappa_g^2 \to 1$, if $C_g \frac{F_g^{\rm SUSY}}{F_g^{\rm SM}} = -2$

In this region of parameter space, $\tilde{t}_1$ and t dominates over $\tilde{t}_2$ and b

$$\kappa_{\tilde{t}_1} F_0(\tau_{\tilde{t}_1}) \simeq -4 \frac{\left(1 + \frac{11\alpha_s}{4\pi}\right)}{\left(1 + \frac{25\alpha_s}{6\pi}\right)} F_{1/2}(\tau_t)$$

In the approximation $\tau_t \ll 1$ and $\tau_{\tilde{t}_1} \ll 1$ we get

$$F_{1/2}(\tau_t) \simeq -\frac{4}{3} \qquad\qquad F_0(\tau_{\tilde{t}_1}) \simeq -\frac{1}{3}$$

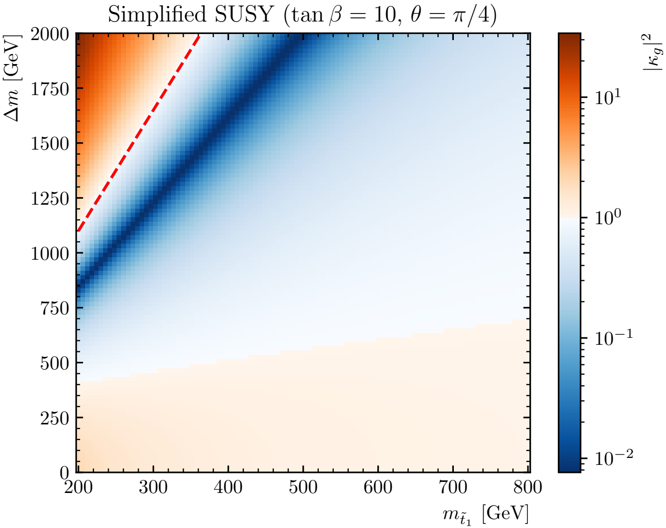
When taking $\Delta m, m_{\tilde{t}_2} \gg m_{\tilde{t}_1}, m_t$

$$\frac{(\Delta m)^2}{2m_{\tilde{t}_1}^2} \sin^2(2\theta_{\tilde{t}}) \simeq \frac{\left(1 + \frac{11\alpha_s}{4\pi}\right)}{\left(1 + \frac{25\alpha_s}{6\pi}\right)} \frac{48}{3}$$

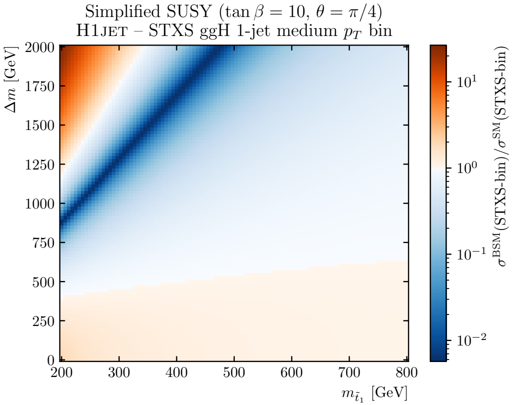
For $\sin^2(2\theta_{\tilde{t}}) = 1$ and $\alpha_s \approx 0.118$, we have

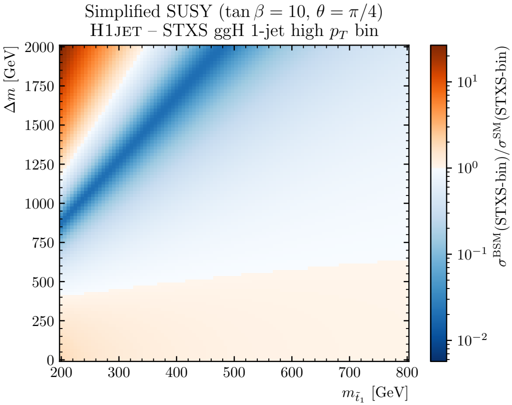
$$\Delta m \simeq 5.5 \times m_{\tilde{t}_1}$$

Plotting the $\Delta m \simeq 5.5 \times m_{\tilde{t}_1}$ line with reduced sensitivity



The ratio of cross-sections in two of the STXS $gg \to H$ 1-jet bins





Simplified SUSY

The differential cross-section for $pp \to H+$jet has similar behaviour for $p_T \ll m_t, m_{\tilde{t}_1}, m_{\tilde{t}_2}$ as the inclusive cross-section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} \sim |\mathcal{M}|^2 \sim \left(-\frac{4}{3} + F_g^{\mathrm{SUSY}}\right)^2$$

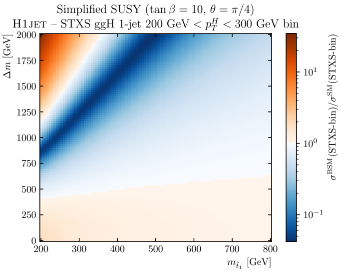
Hence, for the STXS $gg \to H$ 1-jet bins where $p_T \leq 200$ GeV, we will see the same deviation as in the inclusive cross-section assuming $m_{\tilde{t}_1}, m_{\tilde{t}_2} > m_t, m_h$

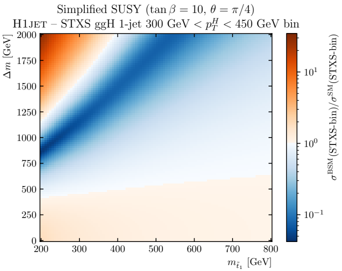
For high p_T we get a kinematical term

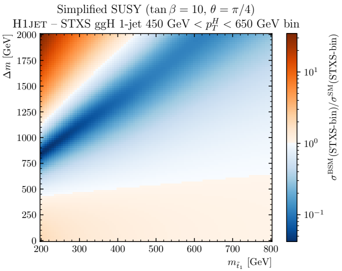
$$\frac{\mathrm{d}\sigma}{\mathrm{d}p_T} \sim |\mathcal{M}|^2 \sim \frac{\kappa_{\tilde{t}}^2}{p_T^2}\left[A_0 + A_1 \ln\left(\frac{p_T^2}{m_{\tilde{t}}^2}\right) + A_2 \ln^2\left(\frac{p_T^2}{m_{\tilde{t}}^2}\right)\right]$$

Which may apply to the STXS bins with $p_T > 200$ GeV but they suffer from lower experimental statistics

The ratio of cross-sections in the STXS $gg \to H$, $p_T^H > 200$ GeV bins

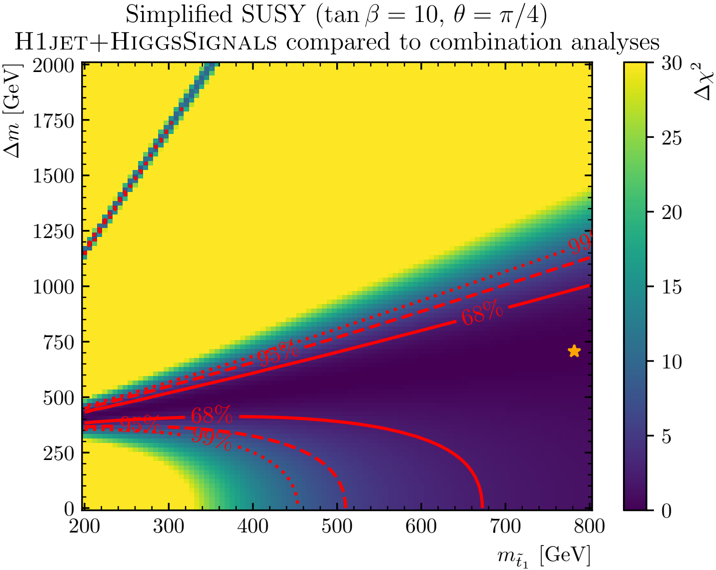






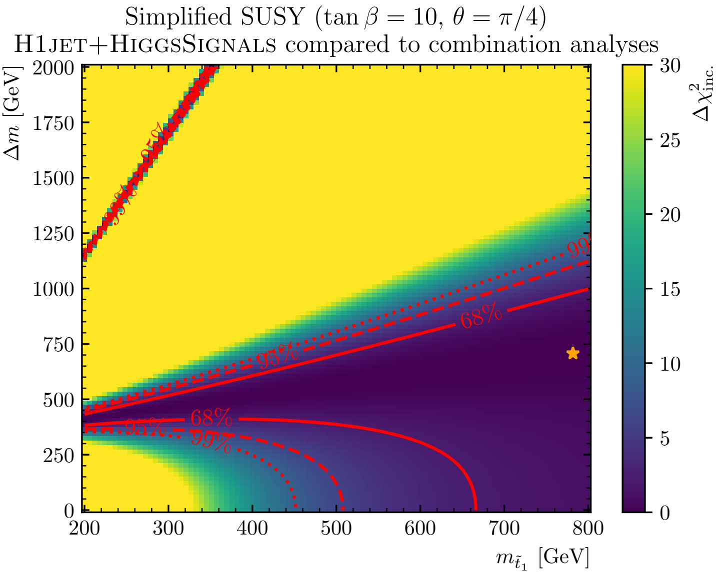
Simplified SUSY

Minimum point: $(m_{\tilde{t}_1}, \Delta m) \approx (782 \text{ GeV}, 707 \text{ GeV})$



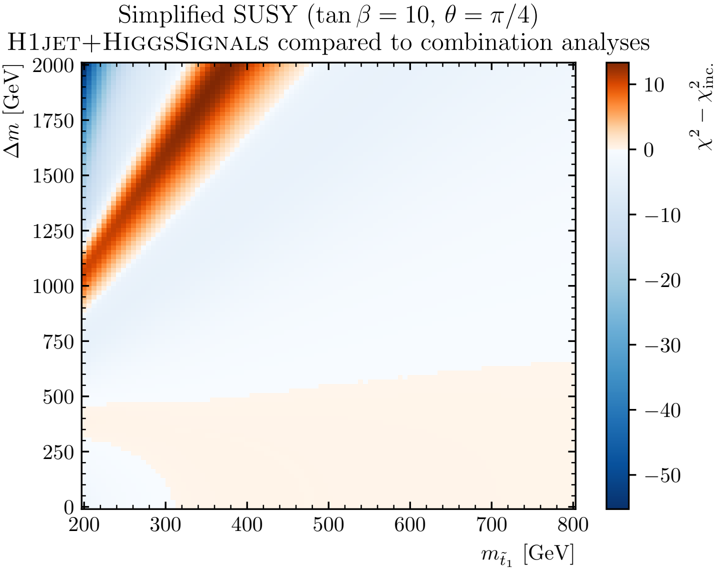
Simplified SUSY

Inclusive cross-section only



Simplified SUSY

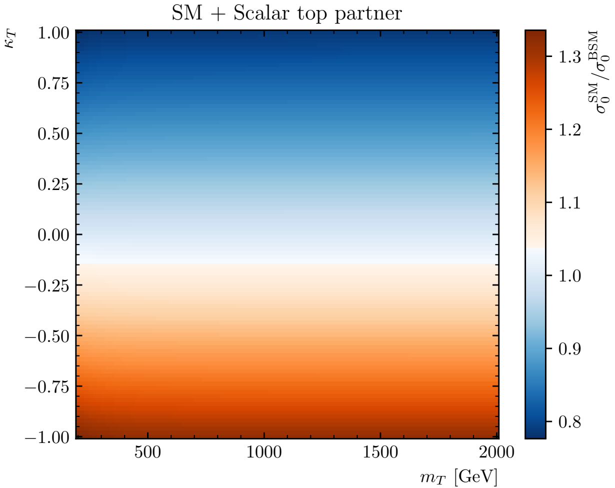
Difference in χ^2 when including inclusive rate and p_T bins vs. including only inclusive rate



Generic scalar top partner

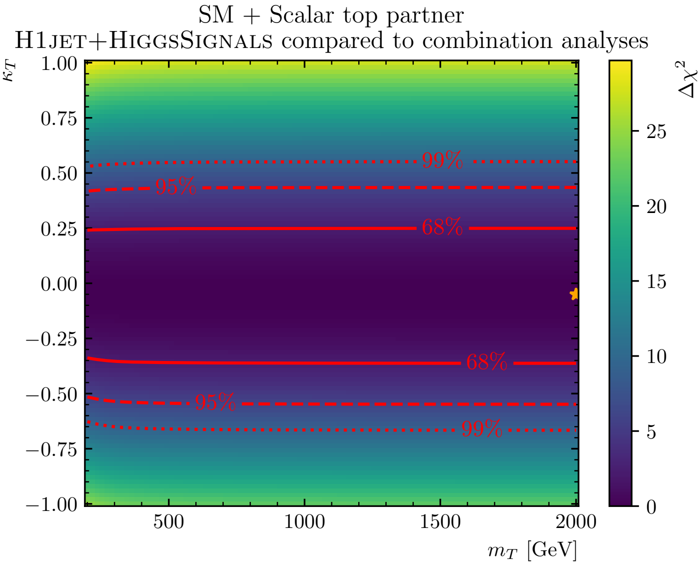
Inclusive cross-section only sensitive to κ_T

$$\sigma_0^{\mathrm{BSM}}/\sigma_0^{\mathrm{SM}} = \kappa_g^2 \simeq 1 + \kappa_T F_0(\tau_T) \sim 1 - \frac{\kappa_T}{3}$$

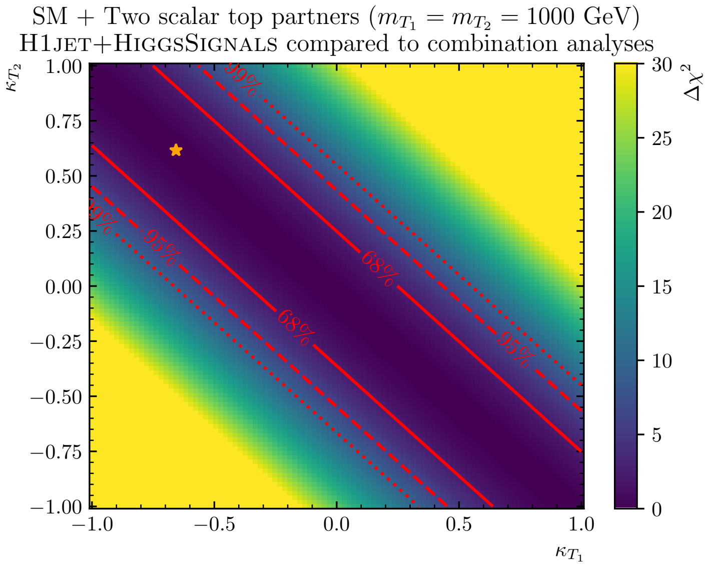


Generic scalar top partner

Minimum point at $\kappa_T \approx 0$, i.e. closest to SM



Two scalar top partners



Summary and outlook

Summary:

- Presented new interface between H1jet and HiggsSignals
- Statistical test of several BSM models against STXS measurements
- Generic models onto which BSM models can be mapped

Outlook:

- Interface to FeynHiggs for full MSSM
- Dimension-8 operators for Higgs
- Additional experimental analyses in HiggsSignals
- Projections for HL-LHC


Many thanks!
La Gazette