New physics searches in top sector at LHC

Michihisa Takeuchi (Kavli IPMU)

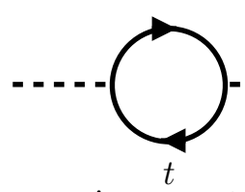
Motivation

2 big problems in particle physics

both problems indicate new particles at TeV scale!

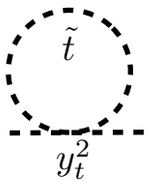
hierarchy problem

$$m_h^2 = m_{h,0}^2 + \delta m_h^2 \sim 125^2\mathrm{GeV}^2 \sim 10^4\mathrm{GeV}^2$$

$\delta m_h^2 \sim$  $\sim -\frac{3}{4\pi} y_t^2 \Lambda_{\rm SM}^2 \sim 10^6\mathrm{GeV}^2 (\Lambda_{\rm SM} = 1\mathrm{TeV})$

Higgs mass receives quantum corrections of the order of highest mass scale

⇒ **partner particle loop cancels the divergence**

SUSY 

new particle, same coupling by symmetry

can be a fermion partner T in composite type models

dark matter

Obviously, SM not enough to describe Universe

– What is dark matter?

WIMP (Weakly interacting massive particle)?

$\Omega_{\rm cdm} h^2 = 0.113 \rightarrow m_\chi \sim 1$ TeV ⇒ new particle in TeV?

LHC : TeV collider — best place for TeV new physics searches

various search strategies at LHC

direct productions, loop effects, flavor signatures etc.

especially new physics expected in top sector

tops are copiously produced at LHC, open precision top physics

new particle production

arxiv:1604.03938 [D. Goncalves, K. Sakurai, MT]

New particles production: typically 1fb ~ 1pb

Large SM BG: lots of known SM particles are produced W,Z ~ 10^2 nb, tt ~ 1nb

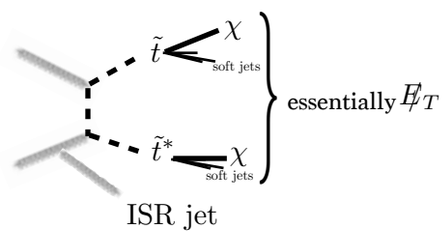
How to reduce the overwhelming SMBG is always the challenge at LHC

handles — missing momentum $\not{E}_T$, jets, leptons, photon, b-tag

light stop search

usual signal: 2 tops + $\not{E}_T$ sensitive when $m_{\tilde{t}} \gg m_\chi$

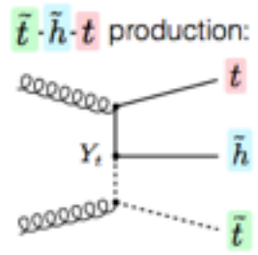
difficult case : $m_{\tilde{t}} \sim m_\chi$ degenerate case — monojet searches sensitive



Good	whatever particles probed robust prediction based on QCD
Bad	we don't know what produced no information on DM

We propose SUSY ttH production

$\tilde{t}$-$\tilde{h}$-t production:



mono-top signature: without top flavor violation

we can access DM nature

$\sigma(\tilde{t}_1 t \chi^0_{1(2)}) \propto \mathcal{R}\sigma_{\tilde{h}}$ depend on neutralino mixing not on stop mixing

higgsino measure: $\mathcal{R} \simeq \frac{|N_{14}|^2 + |N_{24}|^2}{\sin^2\beta}$

sensitivity at LHC up to 380 GeV sensitive cf.) monojet: up to 500 GeV

access also stop mixing through different decay distributions

ℓ : forward b : backward relative to polarization

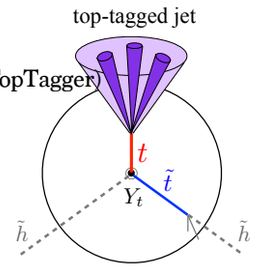
combine mono-jet and mono-top allow to access both *stop mass* $m_{\tilde{t}}$ and *higgsino measure* $\mathcal{R}$

hadronic mode

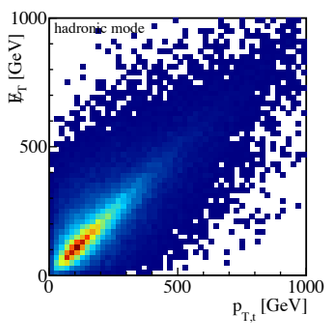
large Emiss, large boost needed -> Top Tagging (HEPTopTagger)

obvious advantage of hadronic mode

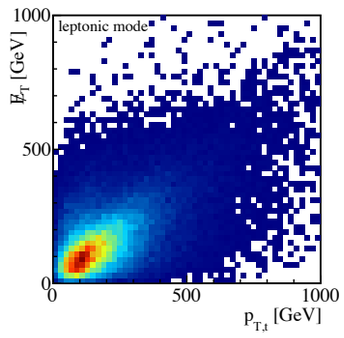
larger branching ratio ~ 67%

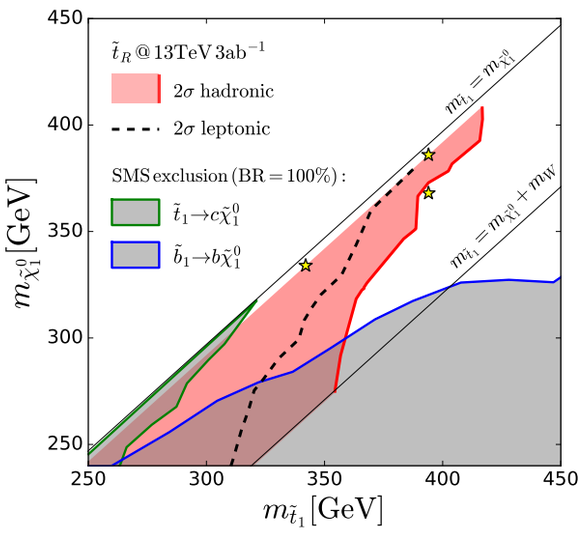


hadronic mode:
$\not{E}_T$ fully usable



leptonic mode:
partly cancel by ν

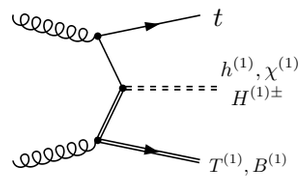


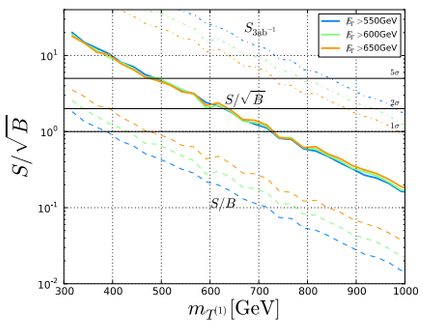


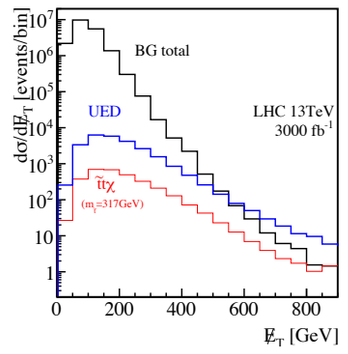
hadronic mode sensitivity higher than leptonic mode

it would be more true at 100 TeV collider, boosted objects help a lot !

Fermionic partner (UED)







in general, larger cross sections

higher mass scale sensitive

both for mono-jet, mono-top

mono-jet: colored partners

mono-top: colored partners &

relative importance depends on the mass spectrum

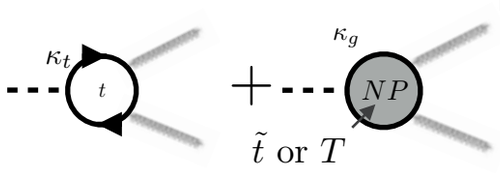
differential distributions

Large SM particles production at LHC: W,Z ~ 10^{11} , tt ~ 10^9, H ~ 10^8

differential distributions can be measured precisely

→ sensitive to new physics effects

Eur.Phys.J. C74 (2014) no.10, 3120 [M. Schlaffer, M. Spannowsky, MT, A. Weiler, C. Wymant]

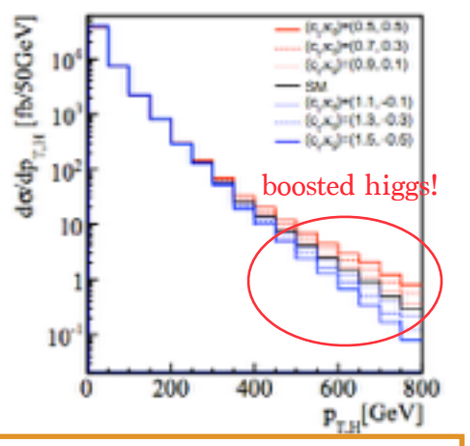


$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \kappa_t \frac{m_t}{v} \bar{t}th + \kappa_g^{NP} \frac{\alpha_s}{12} \frac{h}{v} G^a_{\mu\nu} G^{\mu\nu a}$$

inclusive $\sigma^{\rm inc}(H)$ is $\propto (\kappa_g^{\rm eff})^2$ $\qquad \kappa_g^{\rm eff} = \kappa_t + \kappa_g^{NP}$

new particle modify the SM couplings via loop effects

$p_{T,H}$ distribution sensitive to the couplings



alternative method to probe the top yukawa and top partner effects

flavor signature

With high energy of LHC ~ 10^9 top pair produced

observing rare decay processes very promising

→ new particles induce non-standard decays

In the SM: $t \to bW$ almost 100% | **top flavor changing decay $t \to ch$** | new physics signature!

top-specific 2HDM

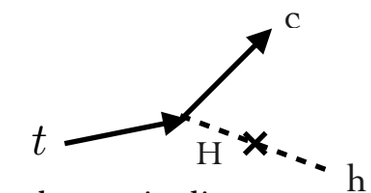
JHEP 1511 (2015) 057

motivated for solving strong CP, domain wall problems (Variant Axion model)

only top quark couples with the other Higgs doublet

$$L^u = -\Phi_1 \overline{u}_{Ra} [Y_{u1}]_{ai} Q_i - \Phi_2 \overline{u}_{R3} [Y_{u2}]_i Q_i + \text{h.c.}$$

$$Y_{u1} = \begin{pmatrix} * & * & * \\ * & * & * \\ 0 & 0 & 0 \end{pmatrix}, \quad Y_{u2} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ * & * & * \end{pmatrix}$$



yukawa mis-alignment

predicts flavor violation

Flavor Changing effect proportional to a and m_{f_L}

$a \equiv (\tan\beta + \cot\beta)\cos(\beta - \alpha)$.

Large

$$\mathcal{L}_{tc} = -\frac{a}{2v_{\rm SM}} h \, (\bar{c}_R \quad \bar{t}_R) \begin{pmatrix} m_c(1-\cos\rho) & m_t \sin\rho \\ m_c \sin\rho & m_t(\cos\rho - 1) \end{pmatrix} \begin{pmatrix} c_L \\ t_L \end{pmatrix} + \text{h.c.}$$

Small

interesting parameter space just starts probed by top rare decays

exciting future progress in top flavor physics

Top quark couples the most strongly to the Higgs, and plays a special role for EWSB

At LHC huge number of Top quark pair produced — open a new era of precision top physics

LHC is the powerful tool for searching for new physics especially in top sector