HEPSummerDays Workshop
CMS Projects in SYSU

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15 July, 2022

Physics:

1. Search for Extra yukawa coupling
2. Tri-boson measurement
3. new structures in the $J/\psi J/\psi$ mass spectrum

Others

1. Detector
2. Generator

- In SM, t → ch only happens in loop-level, is highly suppressed, $BR(t \to ch) \sim 10^{-15}$, and even smaller for t → uh

- In 2HDM I/II (with Z2 symmetry), loop-level, $BR(t \to ch) \sim 10^{-5}$ (or 10^{-4}), no evidence

- In 2HDM III (without Z2 symmetry), tree-level t → ch (FCNC) is possible (BR at percent level). But lots of results have put strong constraints on the FCNC, fortunately, in 2HDM, the coupling of $hq_j\bar{q}_i \sim sqrt(m_j m_i)$, which effectively evade the low energy FCNC   arXiv:2012.05735v1

- In 2HDM, 5 Higgs boson, 2 CP-even, 1 CP-odd, 2 charged. Without Z2 symmetry,

$$V(\Phi, \Phi') = \mu_{11}^2 \Phi^2 + \mu_{22}^2 \Phi'^2 - (\mu_{12}^2 \Phi^\dagger \Phi' + \text{h.c.}) + \frac{\eta_1}{2}\Phi^4 + \frac{\eta_2}{2}\Phi'^4$$

$$+ \eta_3 \Phi^2 \Phi'^2 + \eta_4 \Phi^\dagger \Phi'^2 + \left\{ \frac{\eta_5}{2}(\Phi^\dagger \Phi')^2 + \left[\eta_6 \Phi^2 + \eta_7 \Phi'^2\right]\Phi^\dagger \Phi' + \text{h.c.}\right\}.$$

Mass of two charge Higgs and CP-odd:

$$m_{H\pm}^2 = \mu_{22}^2 + \frac{1}{2}\eta_3 v^2,$$

$$m_A^2 = \mu_{22}^2 + \frac{1}{2}(\eta_3 + \eta_4 - \eta_5)v^2.$$

Mass matrix of two CP-even (one of them is h(125))

$$M_{\text{even}}^2 = \begin{bmatrix} \eta_1 v^2 & \eta_6 v^2 \\ \eta_6 v^2 & m_A^2 + \eta_5 v^2 \end{bmatrix},$$

$$R_\gamma^T M_{\text{even}}^2 R_\gamma = \begin{bmatrix} m_H^2 & 0 \\ 0 & m_h^2 \end{bmatrix}, \quad R_\gamma = \begin{bmatrix} c_\gamma & -s_\gamma \\ s_\gamma & c_\gamma \end{bmatrix}, \quad \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} = \begin{pmatrix} c_\beta & s_\beta \\ -s_\beta & c_\beta \end{pmatrix} \begin{pmatrix} \Phi_1 \\ \Phi_2 \end{pmatrix}$$

RunI alignment: the 125 GeV boson resemble rather SM higgs -> very small mixing angle between h-H (or H1-H2), if let 125 GeV Higgs boson to be h, then

$$c_\gamma \cong \frac{\eta_6 v^2}{m_H^2 - m_h^2}, \qquad \sim 0$$

(if let 125 GeV Higgs boson to be H, then $c_\gamma \sim 1$)

Yukawa coupling of 2HDM without Z2 symmetry:

Phys. Rev. D 72, 035004 (2005), Phys. Lett. B 751,135 (2015), Phys. Lett. B 725, 378 (2013)

$$-\frac{1}{\sqrt{2}} \sum_{f=u,d,\ell} \bar{f}_i \Big[\big(-\lambda_i^f \delta_{ij} s_\gamma + \rho_{ij}^f c_\gamma \big) h + \big(\lambda_i^f \delta_{ij} c_\gamma + \rho_{ij}^f s_\gamma \big) H - i \, \mathrm{sgn}(Q_f) \rho_{ij}^f A \Big] R f_j$$
$$-\bar{u}_i \big[(V\rho^d)_{ij} R - (\rho^{u\dagger} V)_{ij} L \big] d_j H^+ - \bar{\nu}_i \rho_{ij}^\ell R \ell_j H^+ + h.c., \tag{5}$$

t→ ch(125) is searched right after the higgs(125) discovery, currently best limits @95% CL is from ATLAS,

$$\mathcal{B}(t \to ch) < 1.1 \times 10^{-3}, \qquad (\text{ATLAS } 36 \text{ fb}^{-1}, \ 2019)$$

From formula.5, it's possible that t->ch is difficult to search is not due to the small coupling rho_ij but the small alignment c_γ

For H, the coupling is not hidden behind the c_γ, so we move to the A/H search

- Low mass (< ~700 GeV) extra higgs bosons may exist with additional Yukawa couplings hidden by fermion mass-mixing hierarchy.
- Such Higgs bosons may be searched for in different channels but currently we focus on the ttc(bar) channel: **two same-sign leptons, MET, 2 b-jets, 1 c-jet**.
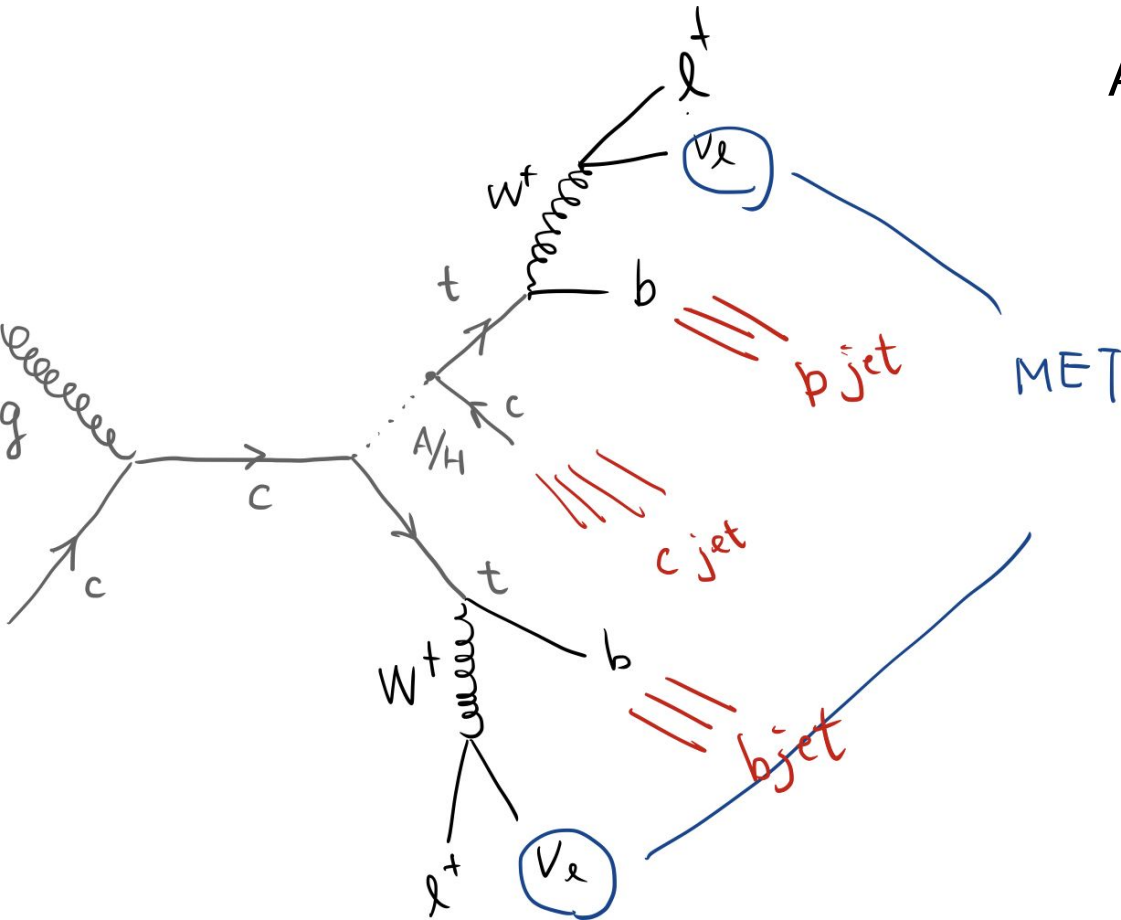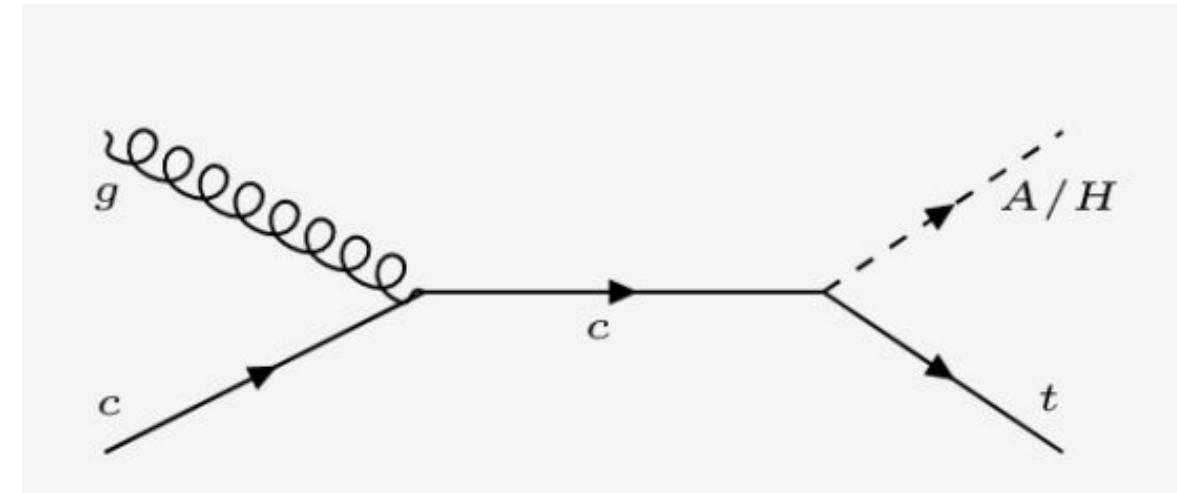
A few of the main pheno references:
- PLB 798 (2019) 134953, PLB 786 (2018) 212 George W.-S. Hou, M. Kohda, Tanmoy Modak.
- George W.-S. Hou et al., e.g. arXiv:1910.08002, Chin. J. Phys. 77 (2022) 432.
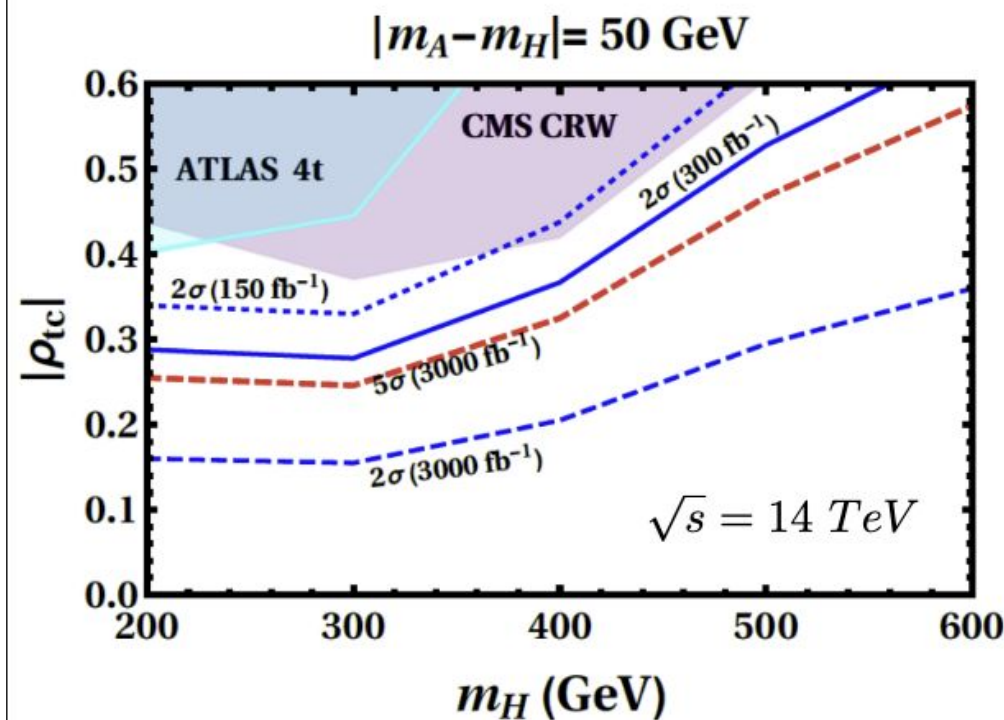
G. W.S. Hou, T. Modak, arXiv:2012.05735.

→ Possible to observe or exclude some region of the phase-space for extra yukawa couplings through the ttc(bar) process.

Cross section of tri-boson processes are small, good probe to potential new physics. EFT interpretation of BSM is model-independent,

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{n=5}^{\infty} \frac{f_n}{\Lambda^{n-4}} \mathcal{O}_n$$

	WWWW	WWZZ	ZZZZ	WWAZ	WWAA	ZZZA	ZZAA	ZAAA	AAAA
$O_{S,0}, O_{S,1}$	√	√	√						
$O_{M,0}, O_{M,1}, O_{M,6}, O_{M,7}$	√	√	√	√	√	√	√		
$O_{M,2}, O_{M,3}, O_{M,4}, O_{M,5}$		√	√	√	√	√	√		
$O_{T,0}, O_{T,1}, O_{T,2}$	√	√	√	√	√	√	√	√	√
$O_{T,5}, O_{T,6}, O_{T,7}$		√	√	√	√	√	√	√	√
$O_{T,8}, O_{T,9}$			√	√		√	√	√	√

Currently working on channels with photon, corporate with PKU group, e.g.,
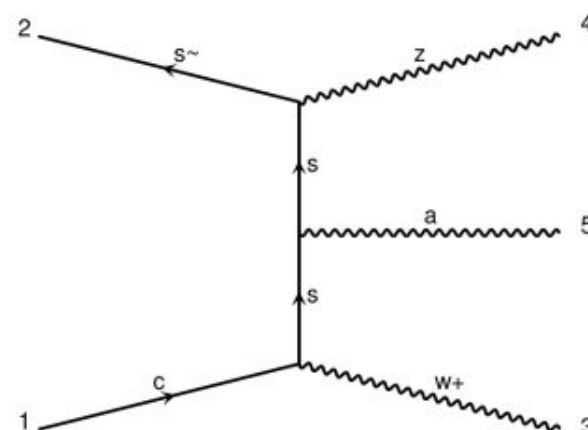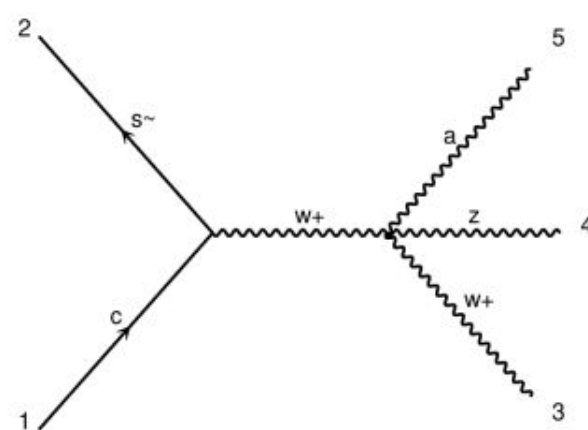
As introduced in Prof. Zhen Hu talk, very exciting results, highlight in ICHEP2022.

Xining Wang (SYSU -> TSinghua) contribute to this work actively. Corporate with Tsinghua and Nanjing Normal University.

- CERN Summer Student Programme
- Thesis award of undergraduate student

GEM: GE2/1 assembly and test.
SYSU with PKU and Tsinghua group
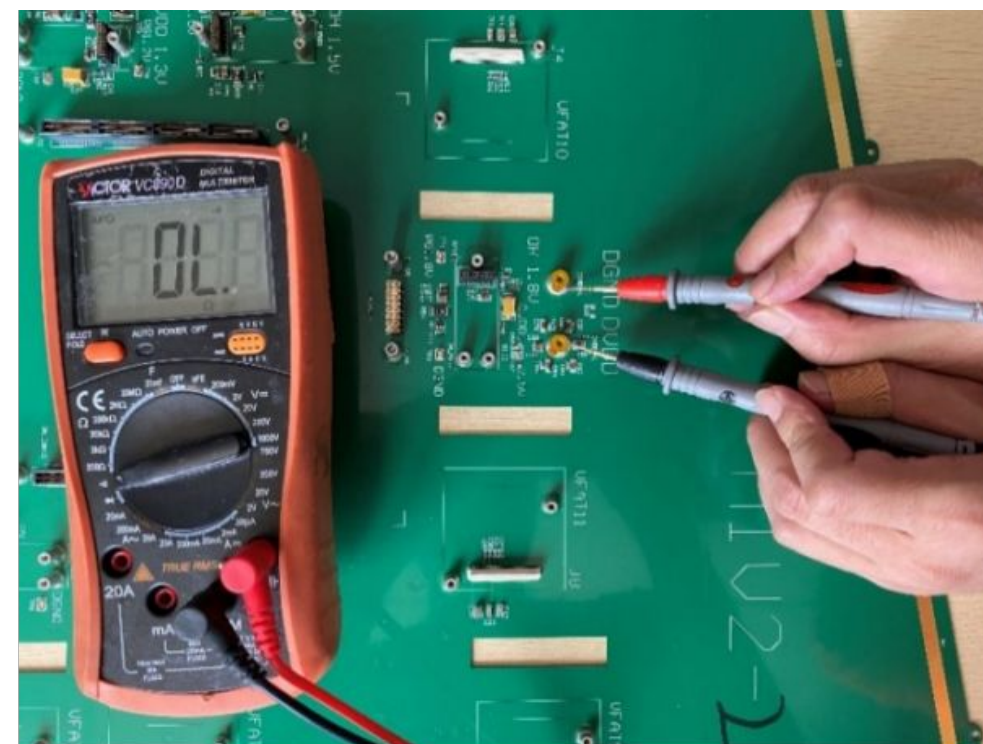
Several students and postdoc work in Generator group:

Active in generator validation (Wanyue Wang), sample production (Zhaoyang Yuan, MC contact) and sample management (Meng Lu, GEN L2).

Manpower at SYSU:
- Faculty: 尤郑昀
- Postdoc: 卢梦
- Students: 袁朝阳, 李静舒, 蔡洵业, 李志军, 宋天资
  王晰宁, 汪莞悦, 郭蒙

Physics:
- SUSY has started the extra yukawa coupling search with Taiwan group and it's on a good shape
- SYSU works on triboson measurement corporate with PKU group
- Student from SYSU contribute to the discovery and evidence of new structures in the 4c mass spectrum
- There are also other projects in progress which are still in preliminary status

Others:
- SYSU has join the detector development for Phase2
- Active contribution in CMS generator group