``11th International Workshop on Top Quark Physics (TOP2018)”
Sept. 2018, Bad Neuenahr, Germany

TOP - HIGGS INTERFACE
— RARE/EXOTIC PRODUCTIONS

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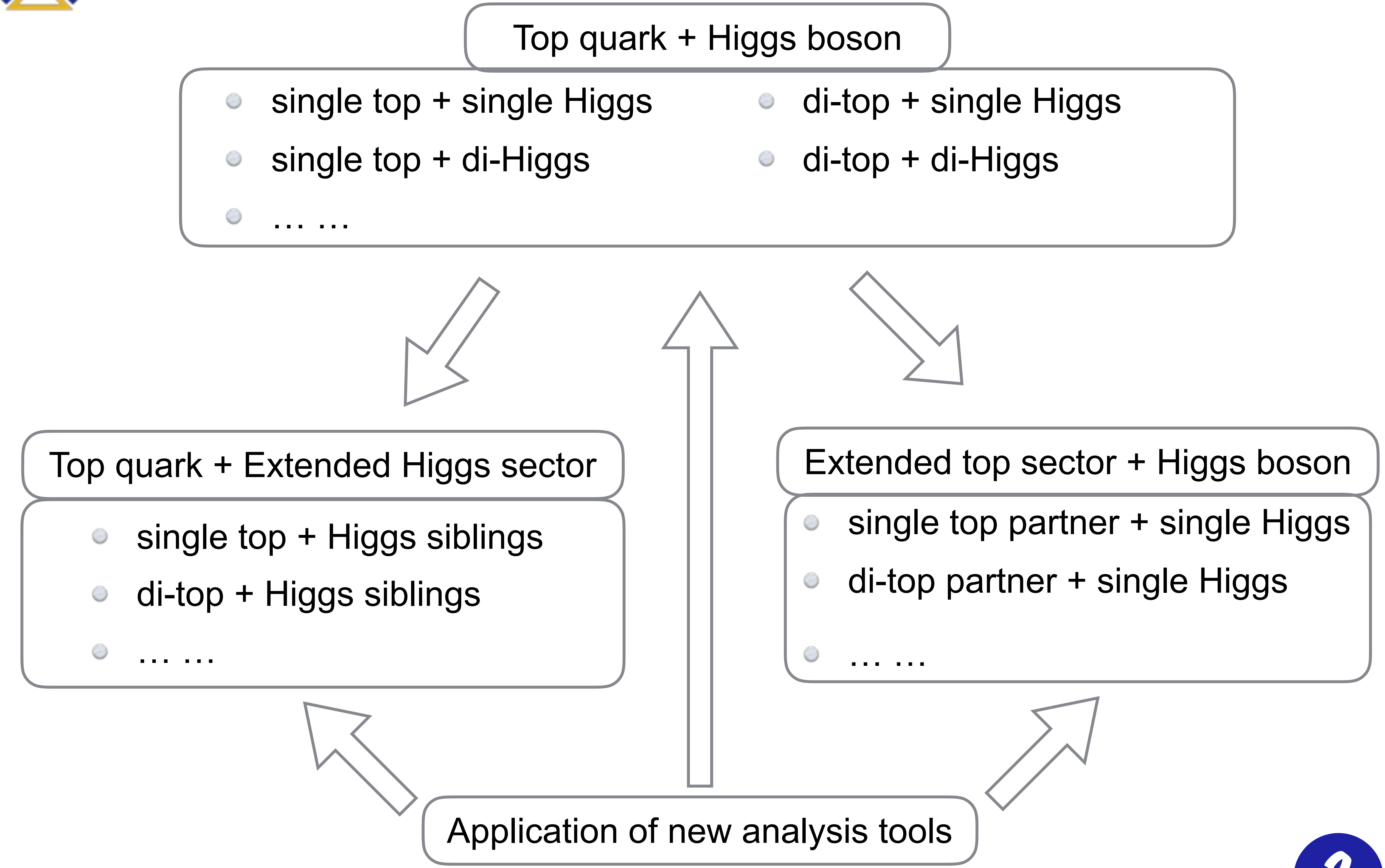
Top-Higgs Interface



Top quark + Higgs boson

- single top + single Higgs
- single top + di-Higgs
- … …
- di-top + single Higgs
- di-top + di-Higgs

Top quark + Extended Higgs sector

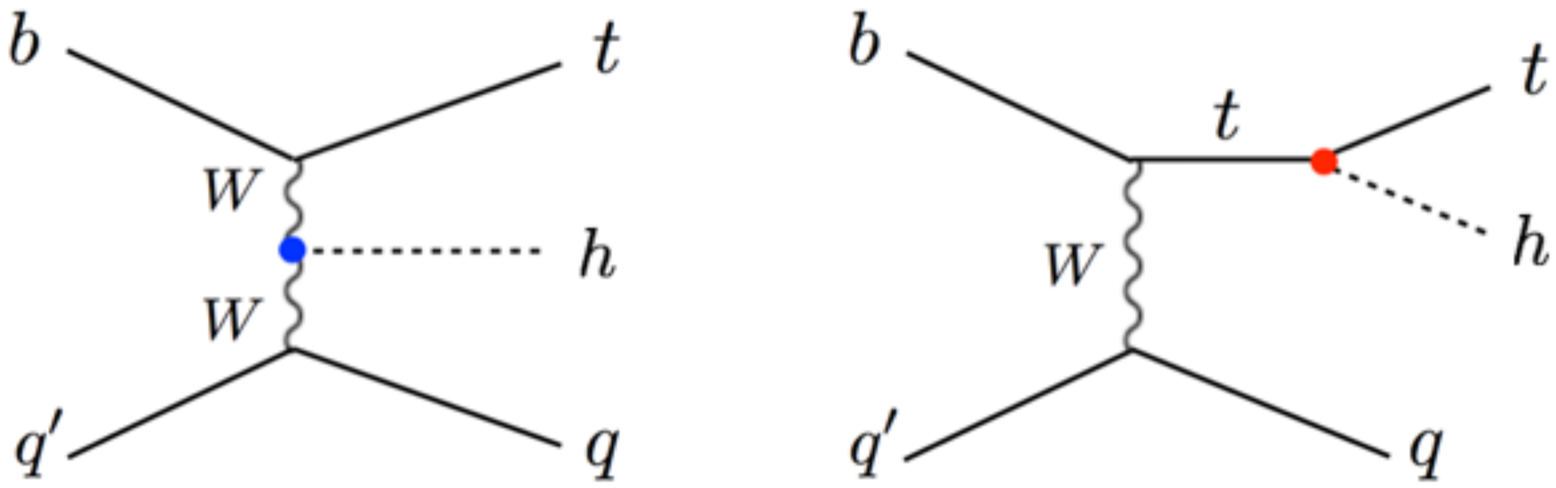
- single top + Higgs siblings
- di-top + Higgs siblings
- … …

Extended top sector + Higgs boson

- single top partner + single Higgs
- di-top partner + single Higgs
- … …

Application of new analysis tools

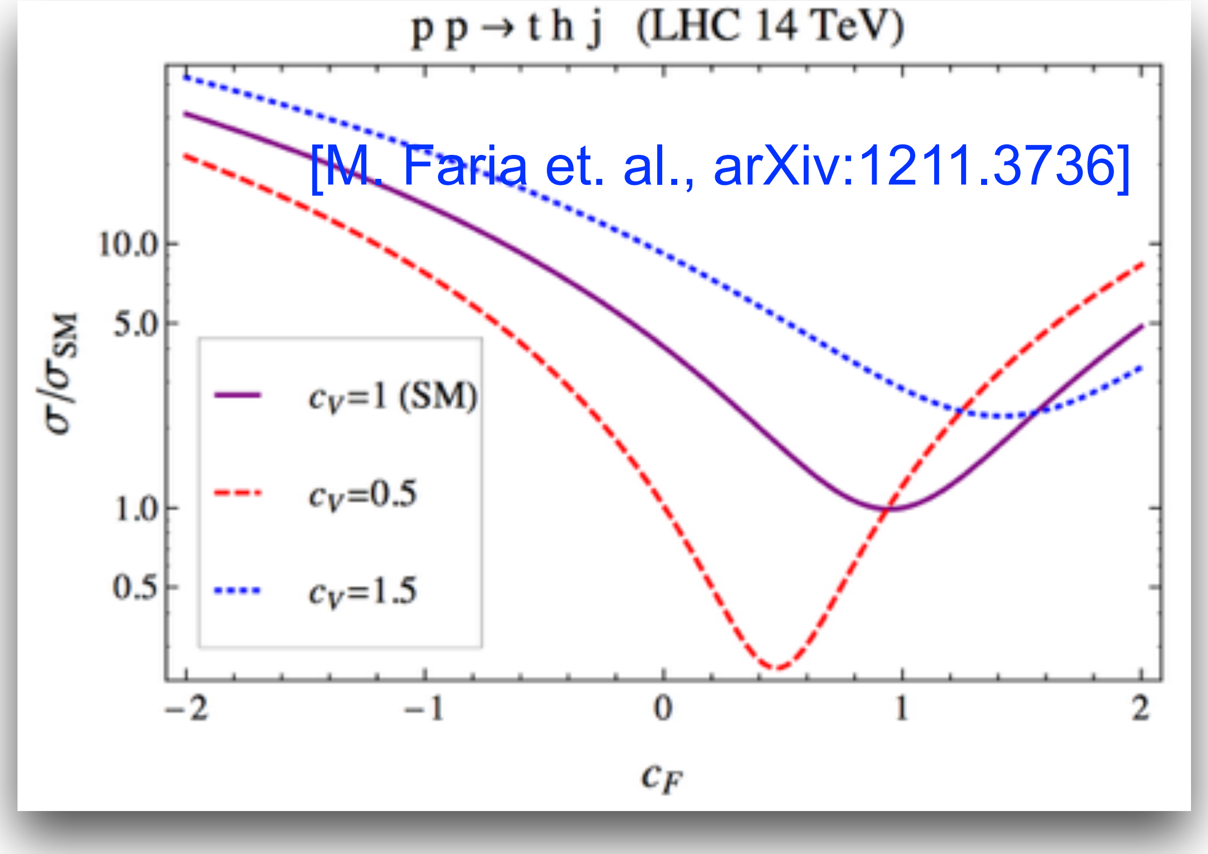
Single Top + Single Higgs



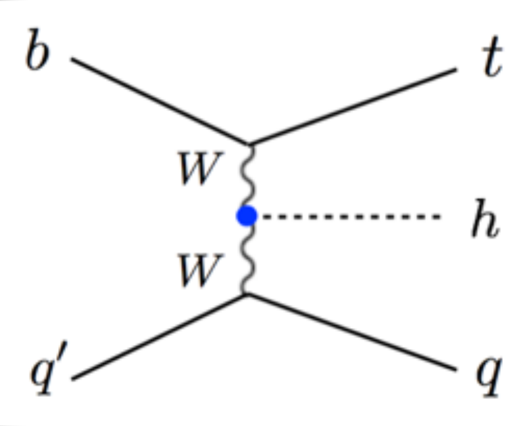
Single Top + Single Higgs

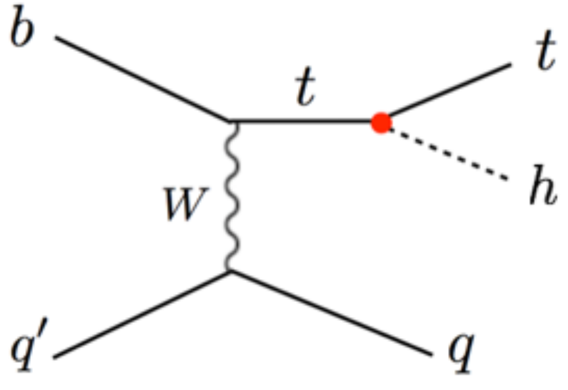
Probing the sign of the Higgs - top coupling

[T. Tait and C.-P. Yuan, hep-ph/0007298]



[M. Faria et. al., arXiv:1211.3736]



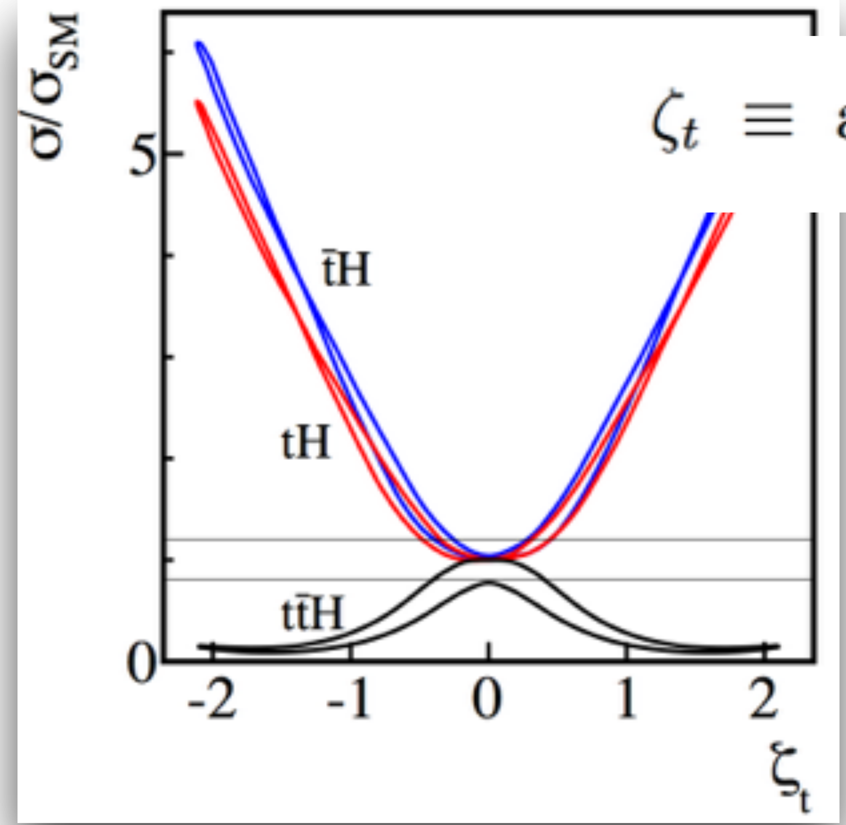


- Determine the sign of top Yukawa coupling, utilizing interference effect

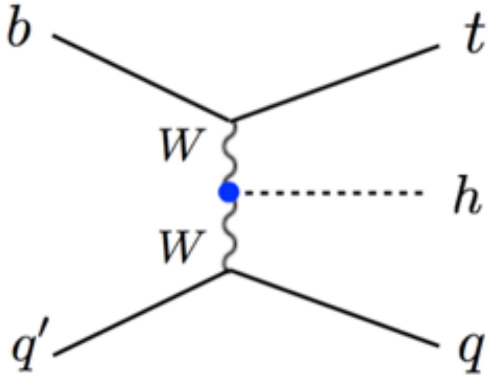
Single Top + Single Higgs

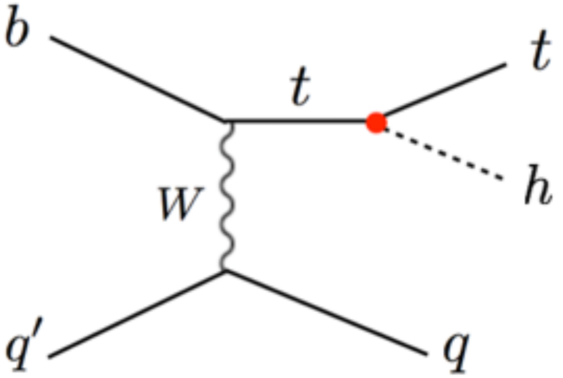
Decoding the CP-structure of Higgs - top coupling

$$\mathcal{L}_t = -\frac{m_t}{v}(\kappa_t \bar{t}t + i\tilde{\kappa}_t \bar{t}\gamma_5 t)h$$



$$\zeta_t \equiv \arctan\left(\frac{\tilde{\kappa}_t}{\kappa_t}\right)$$





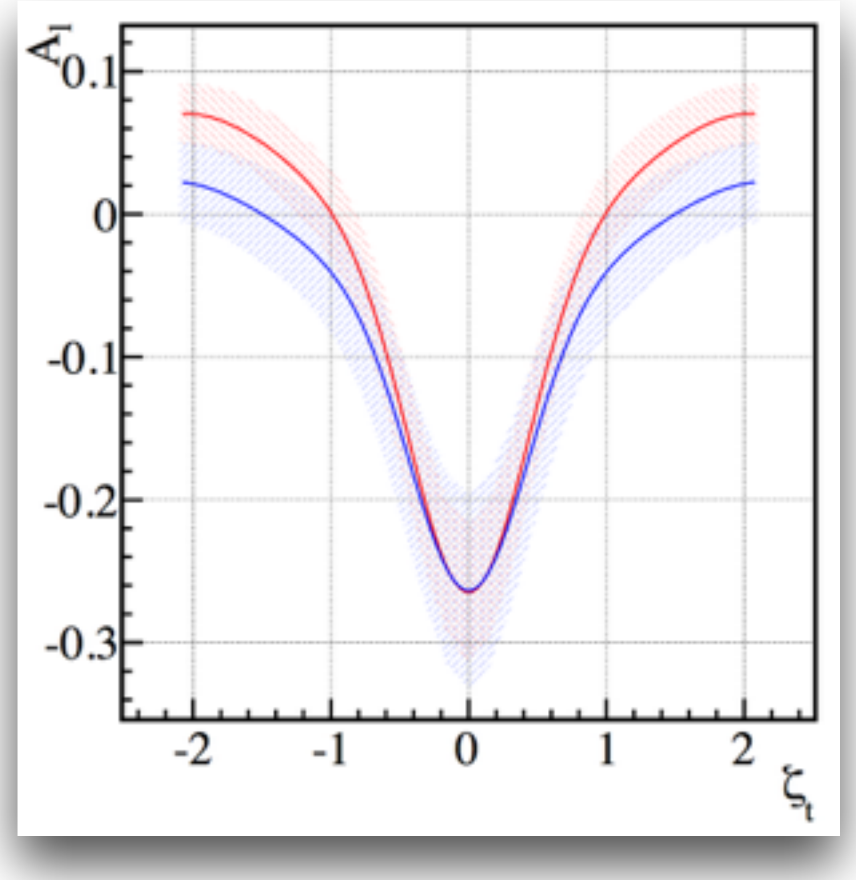
[J.Ellis et. al., arXiv:1312.5736]

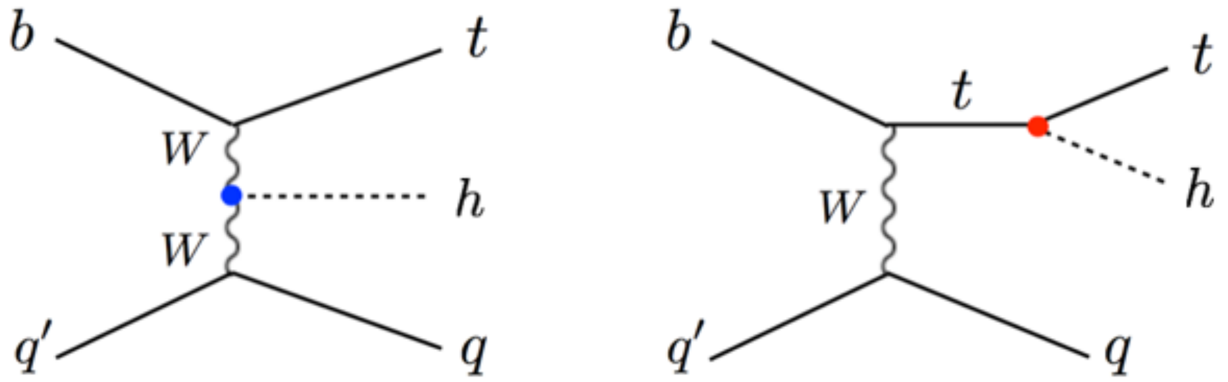
- Similar idea can be applied to probe the CP-structure of the Higgs-top coupling

Single Top + Single Higgs

Decoding the CP-structure of Higgs - top coupling

$$\mathcal{L}_t = -\frac{m_t}{v}(\kappa_t \bar{t}t + i\tilde{\kappa}_t \bar{t}\gamma_5 t)h$$





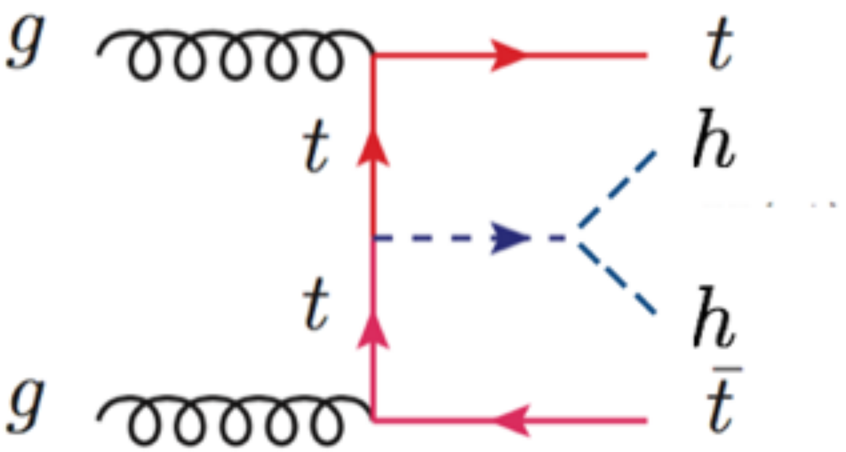
$$\zeta_t \equiv \arctan\left(\frac{\tilde{\kappa}_t}{\kappa_t}\right)$$

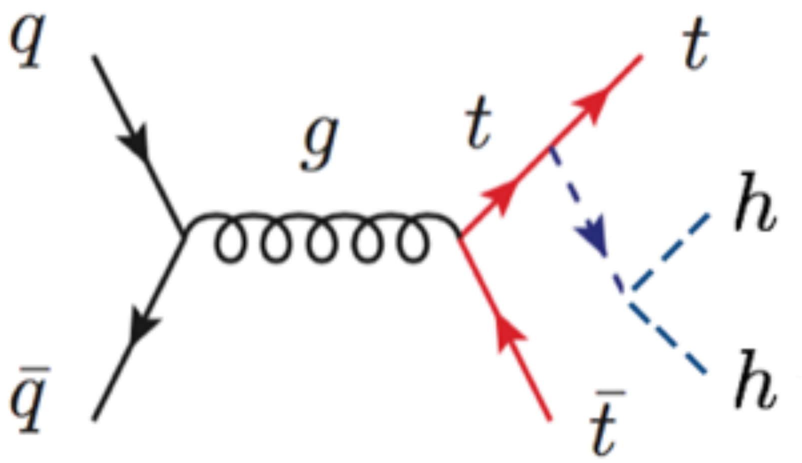
$$A_\ell = \frac{N(\cos\theta_\ell > 0) - N(\cos\theta_\ell < 0)}{N(\cos\theta_\ell > 0) + N(\cos\theta_\ell < 0)}$$

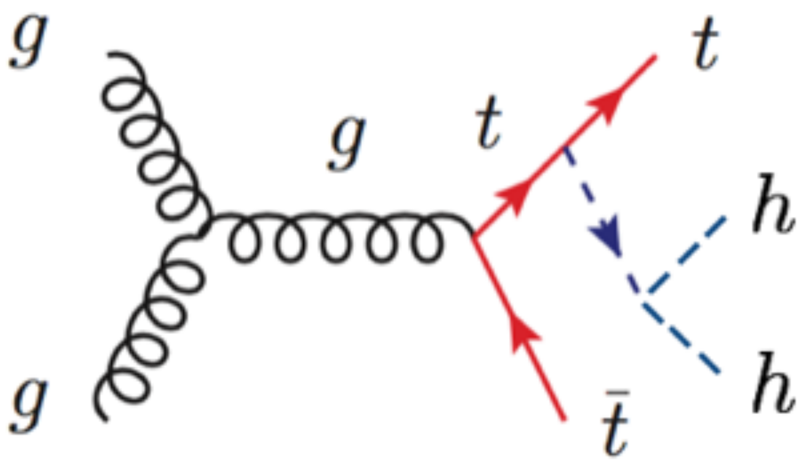
[J.Ellis et. al., arXiv:1312.5736]

- W couples to left-chiral top only, whereas the Higgs-top coupling modifies top polarization depending on its CP-structure

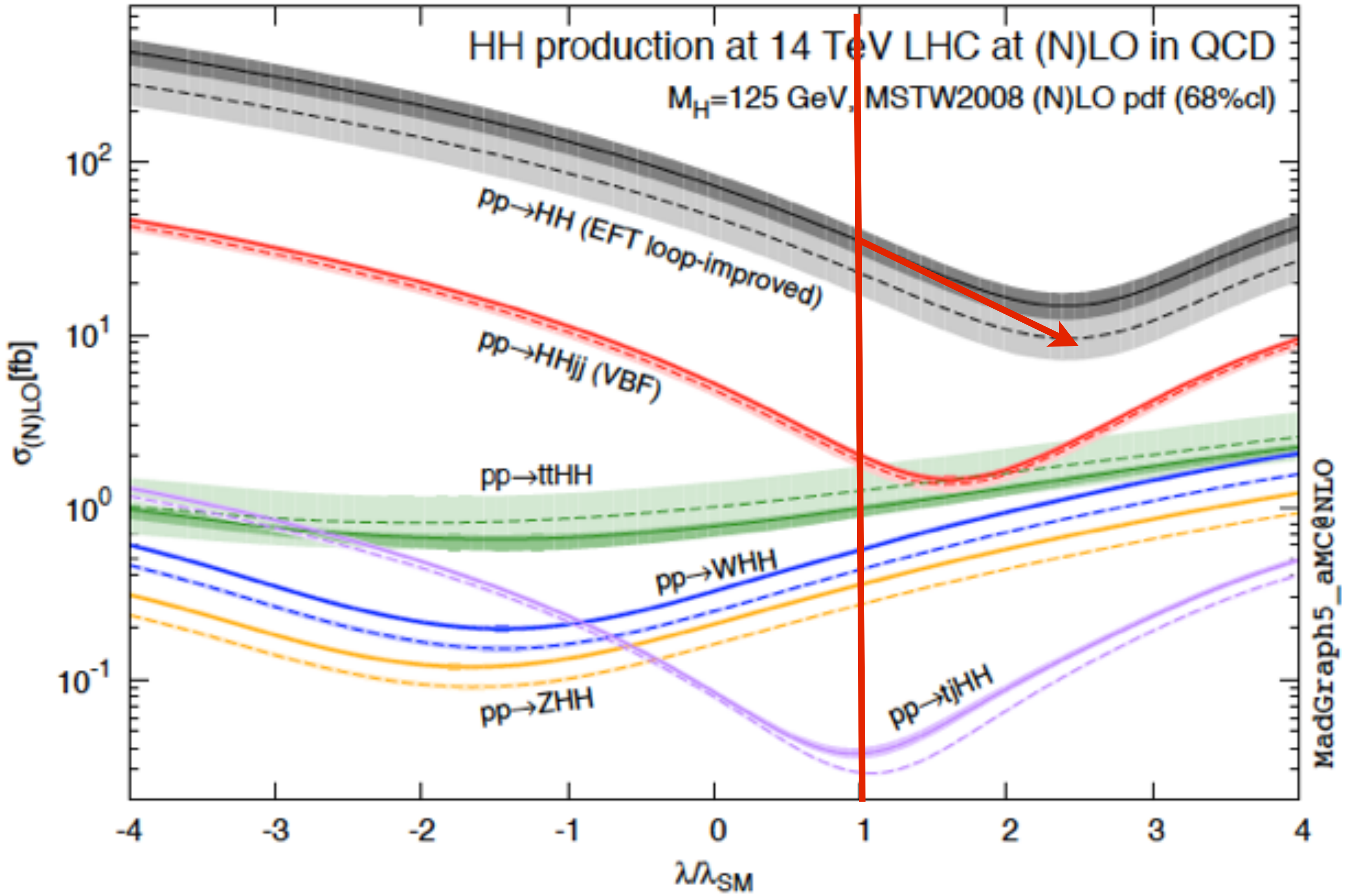
Di-Top + Di-Higgs

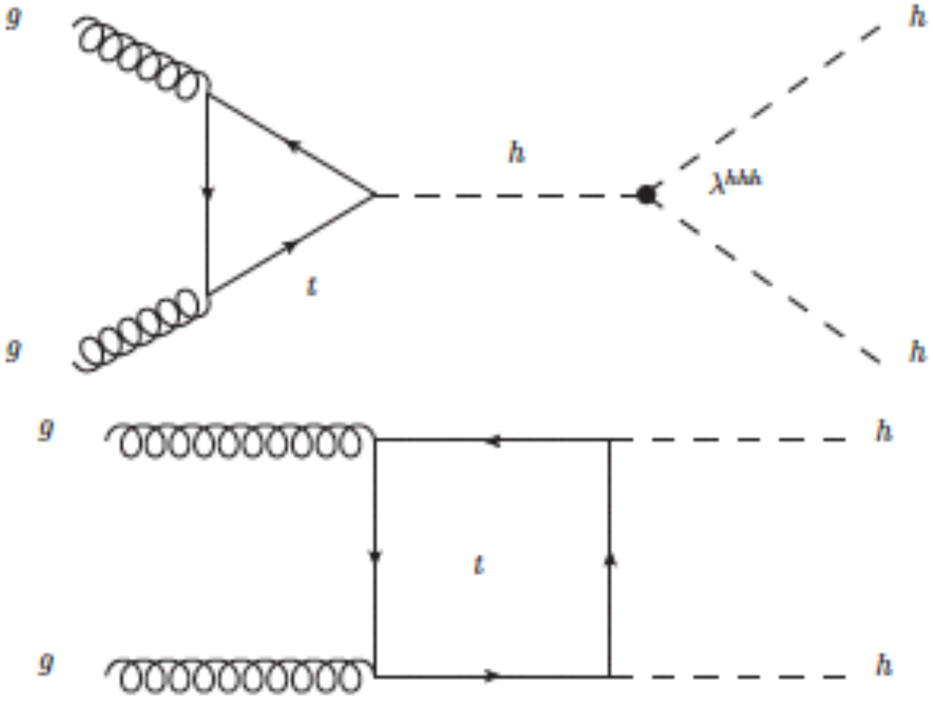






pp → tthh vs. pp → hh

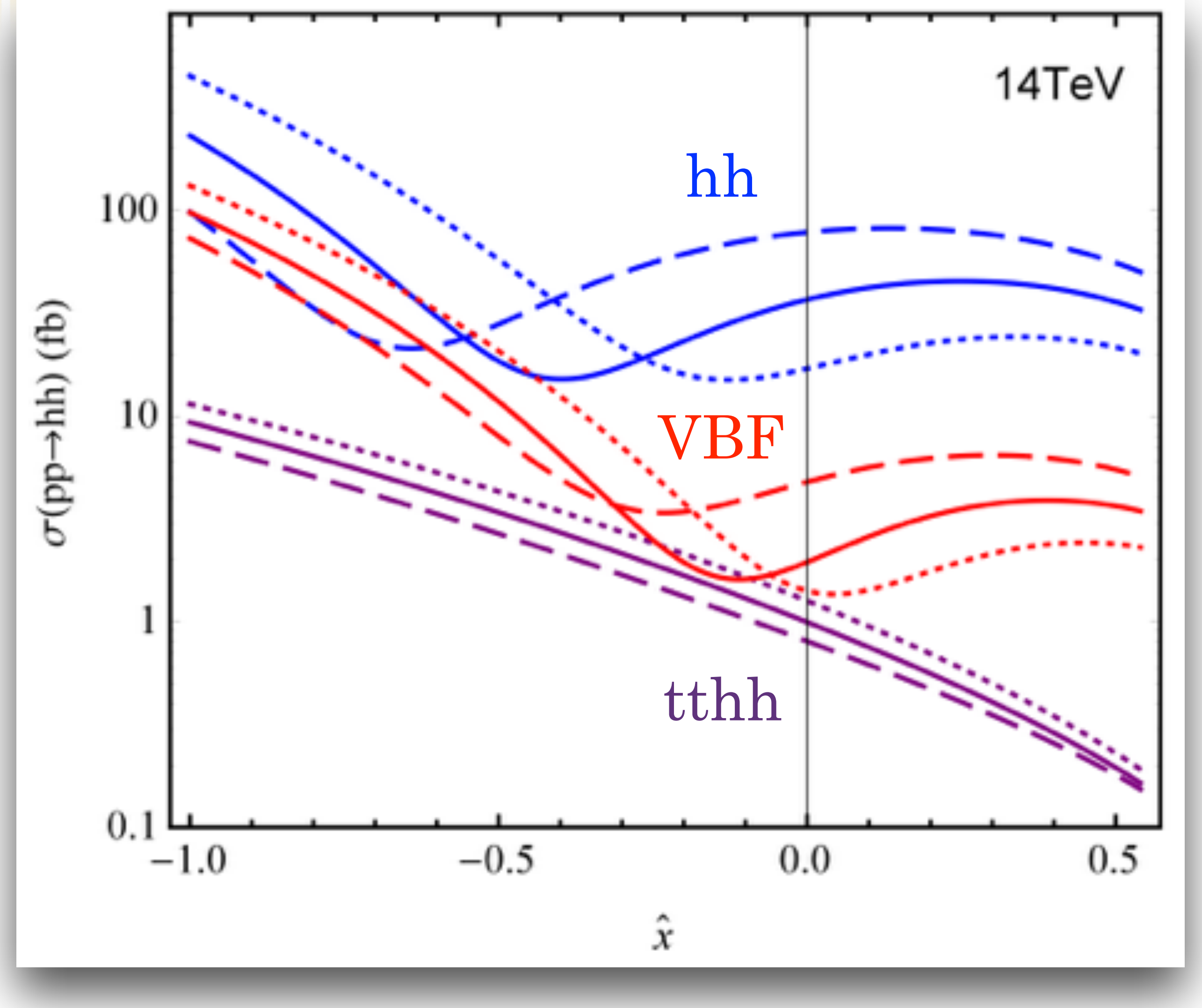




[R. Frederix et. al., arXiv:1401.7340]

- Gluon fusion: simple topology, large xsection
- tthh: despite relatively small xsecion, background reduced by extra top pair, and no big pay for BR (if consider tthh -> ttbbbb)
- Complementarity: destructive interference (gluon fusion) + constructive interference (tthh)

pp → tthh vs. pp → hh



[H. He, J. Ren, W. Yao, arXiv: 1506.03302]

$$\mathcal{O}_{\Phi,2} = \frac{1}{2}\partial^{\mu}(H^{\dagger}H)\partial_{\mu}(H^{\dagger}H)$$

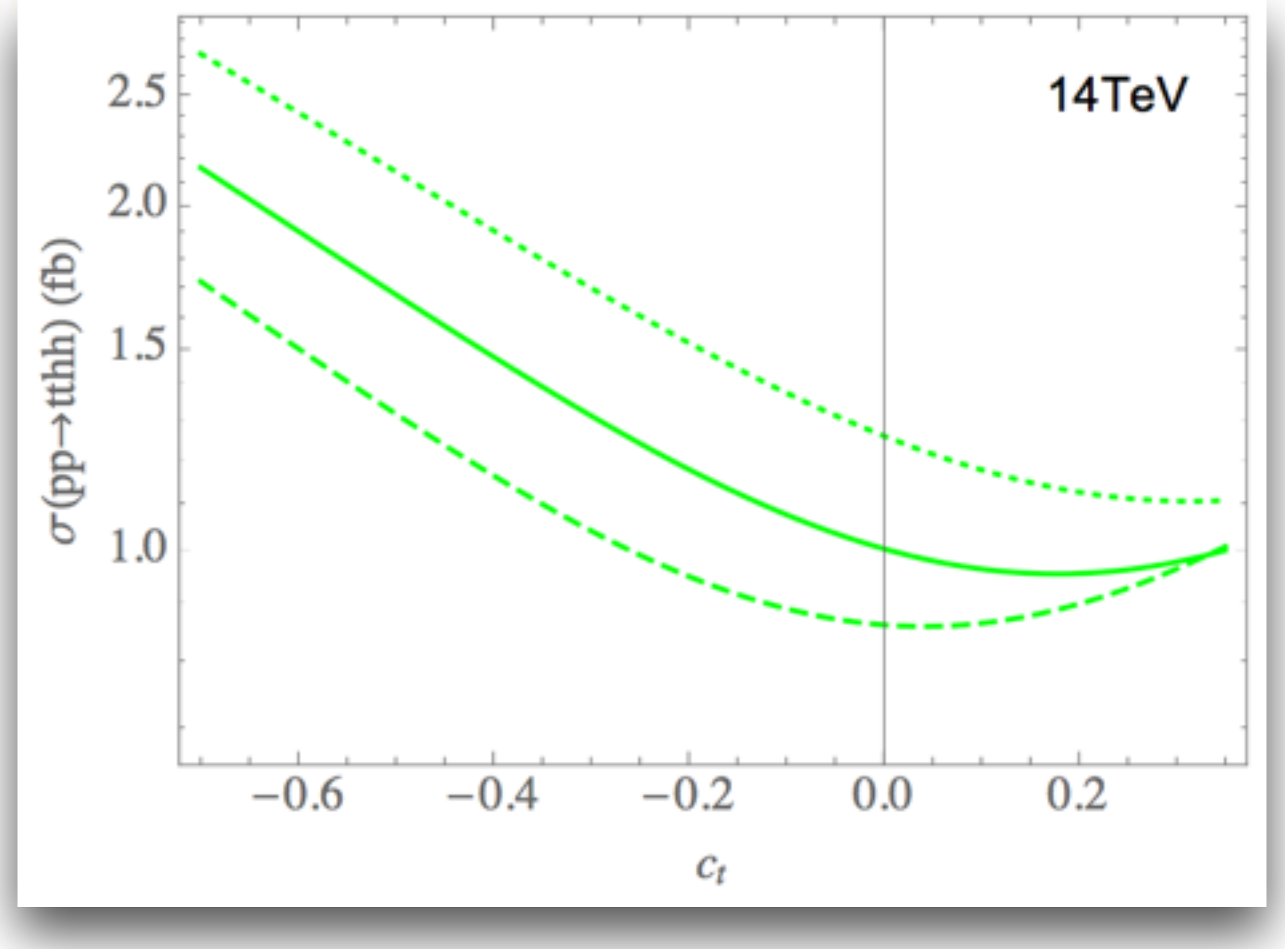
$$\mathcal{O}_{\Phi,3} = \frac{1}{3}(H^{\dagger}H)^{3}$$

$$\widehat{x} \equiv x_2\,\zeta^2 \qquad \widehat{r} \equiv -x_3\,\zeta^2\,\frac{2v^2}{3M_h^2}$$

$$\zeta \equiv (1+x_2)^{-\frac{1}{2}}$$

$$\left.\frac{\sigma(pp\to\bar{t}thh)}{\sigma(pp\to\bar{t}thh)_{\rm sm}}\right|_{\rm 14TeV} = (1-\widehat{x})^2\left(1+0.23\,\widehat{r}-0.73\,\widehat{x}+0.04\,\widehat{r}^2+0.60\,\widehat{x}^2-0.26\,\widehat{r}\,\widehat{x}\right)$$

The tthh Operator



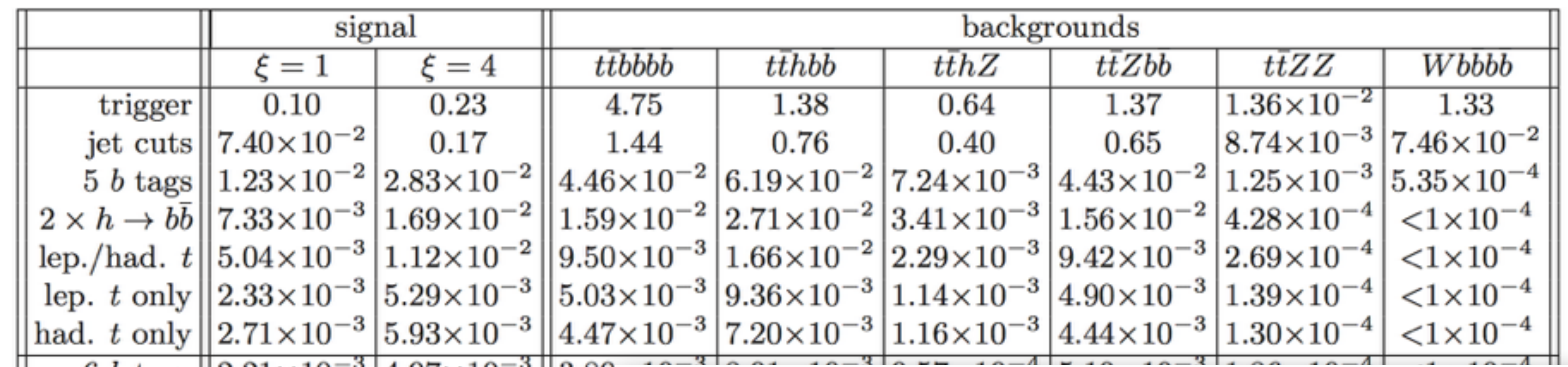
[Provided by J. Ren]

- Can receive contributions from the tthh operator (induced by 6D top-Yukawa operator)
- pp -> tthh can serve a probe for this operator / the measurement of the cubic Higgs coupling could be contaminated by this operator

$$\Gamma(hhh) = i\lambda_{sm}(1+\kappa_3) \qquad \Gamma(tthh) = i\frac{c_t}{v}$$

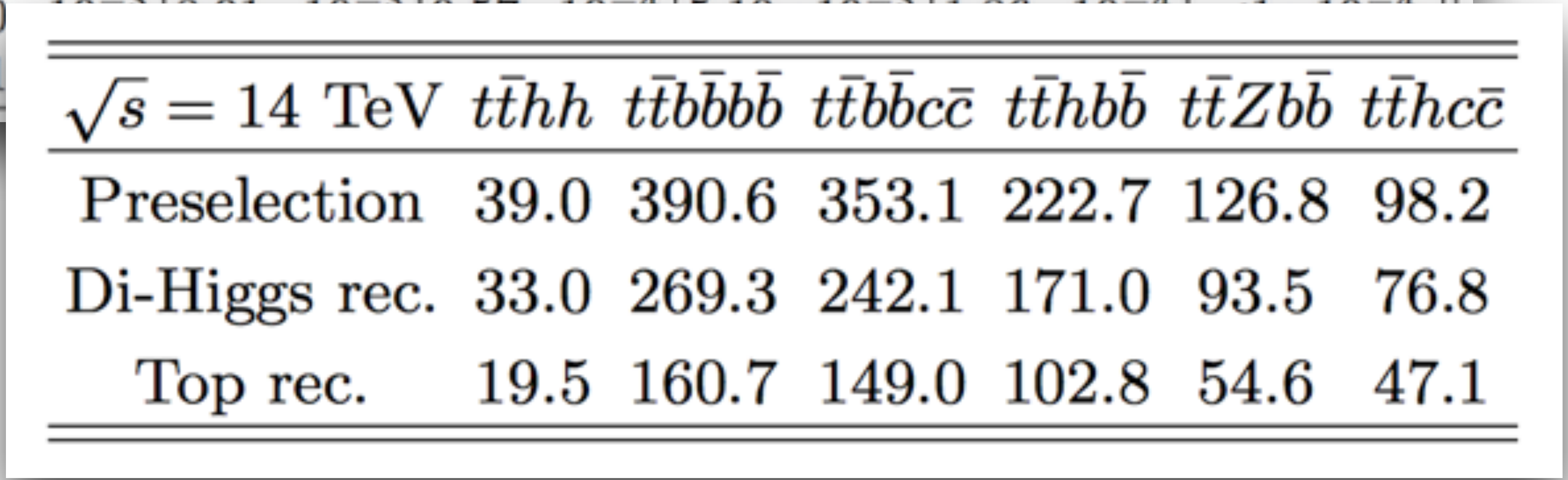
$$\left.\frac{\sigma(pp\to tthh)}{\sigma(pp\to tthh)_{sm}}\right|_{14\text{TeV}} = 1 + 0.20\kappa_3 - 0.56c_t + 0.06\kappa_3^2 + 1.6c_t^2 - 0.43\kappa_3 c_t$$

Sensitivities at HL-LHC (Cut-Based)



	signal		backgrounds					
	$\xi = 1$	$\xi = 4$	$t\bar{t}b\bar{b}b\bar{b}$	$t\bar{t}hb\bar{b}$	$t\bar{t}hZ$	$t\bar{t}Zb\bar{b}$	$t\bar{t}ZZ$	$Wb\bar{b}b\bar{b}$
trigger	0.10	0.23	4.75	1.38	0.64	1.37	1.36×10^{-2}	1.33
jet cuts	7.40×10^{-2}	0.17	1.44	0.76	0.40	0.65	8.74×10^{-3}	7.46×10^{-2}
5 b tags	1.23×10^{-2}	2.83×10^{-2}	4.46×10^{-2}	6.19×10^{-2}	7.24×10^{-3}	4.43×10^{-2}	1.25×10^{-3}	5.35×10^{-4}
$2\times h \to b\bar{b}$	7.33×10^{-3}	1.69×10^{-2}	1.59×10^{-2}	2.71×10^{-2}	3.41×10^{-3}	1.56×10^{-2}	4.28×10^{-4}	$<1\times10^{-4}$
lep./had. t	5.04×10^{-3}	1.12×10^{-2}	9.50×10^{-3}	1.66×10^{-2}	2.29×10^{-3}	9.42×10^{-3}	2.69×10^{-4}	$<1\times10^{-4}$
lep. t only	2.33×10^{-3}	5.29×10^{-3}	5.03×10^{-3}	9.36×10^{-3}	1.14×10^{-3}	4.90×10^{-3}	1.39×10^{-4}	$<1\times10^{-4}$
had. t only	2.71×10^{-3}	5.93×10^{-3}	4.47×10^{-3}	7.20×10^{-3}	1.16×10^{-3}	4.44×10^{-3}	1.30×10^{-4}	$<1\times10^{-4}$
6 b tags	2.21×10^{-3}	4.97×10^{-3}	3.80					
$2\times h \to b\bar{b}$	1.81×10^{-3}	5.94×10^{-3}	2.01					

[C. Englert, F. Krauss, M. Spannowsky, J. Thompson, arXiv:1409.8074]

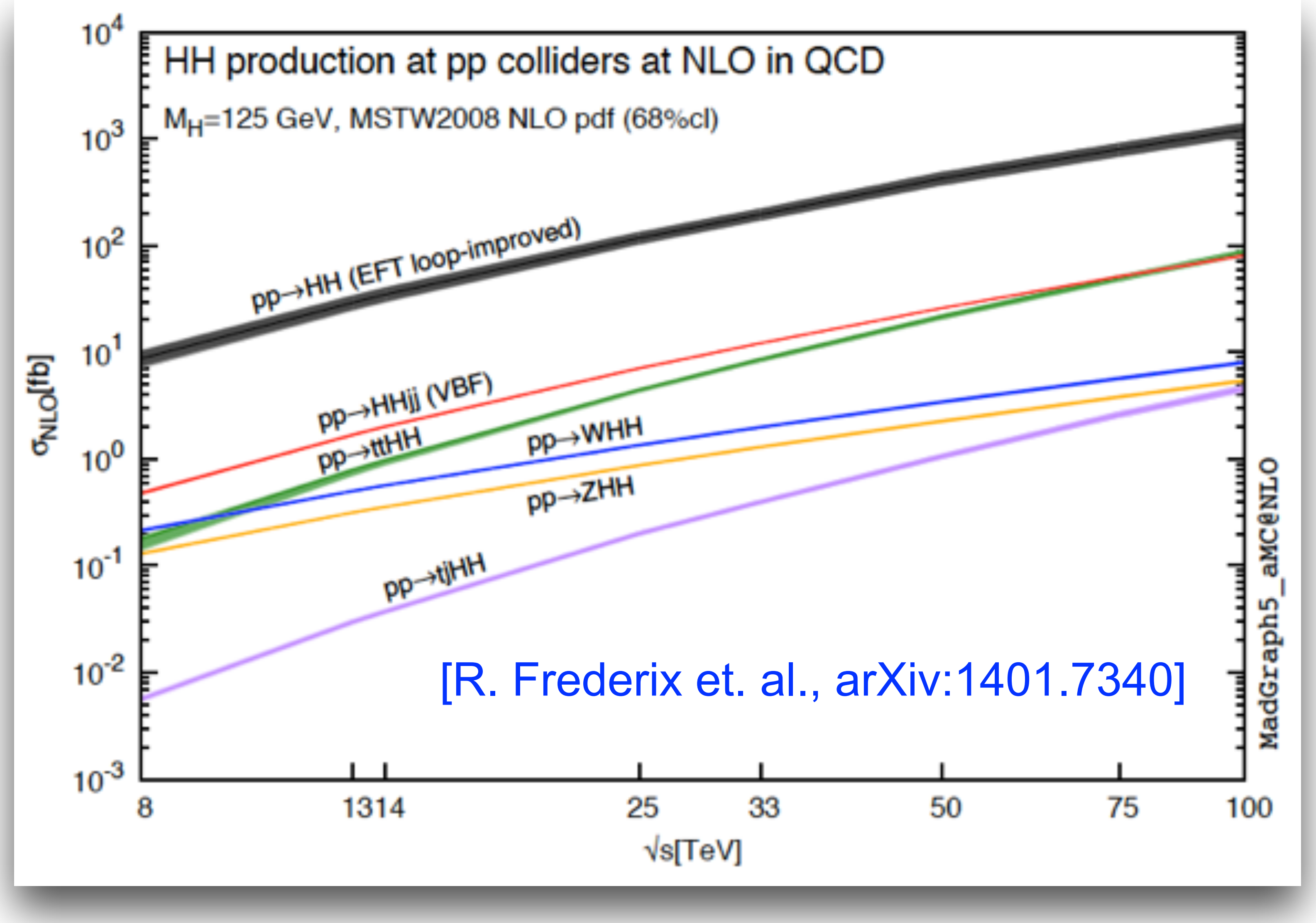


$\sqrt{s} = 14$ TeV	$t\bar{t}hh$	$t\bar{t}b\bar{b}b\bar{b}$	$t\bar{t}b\bar{b}c\bar{c}$	$t\bar{t}hb\bar{b}$	$t\bar{t}Zb\bar{b}$	$t\bar{t}hc\bar{c}$
Preselection	39.0	390.6	353.1	222.7	126.8	98.2
Di-Higgs rec.	33.0	269.3	242.1	171.0	93.5	76.8
Top rec.	19.5	160.7	149.0	102.8	54.6	47.1

[TL, H. Zhang, arXiv:1410.1855]

- Luminosity of 3/ab => $S/\sqrt{B} \sim 1 - 2\sigma$
- A subsequent analysis [ATL-PHYS-PUB-2016-023] => $S/\sqrt{B} \sim 0.35\sigma$

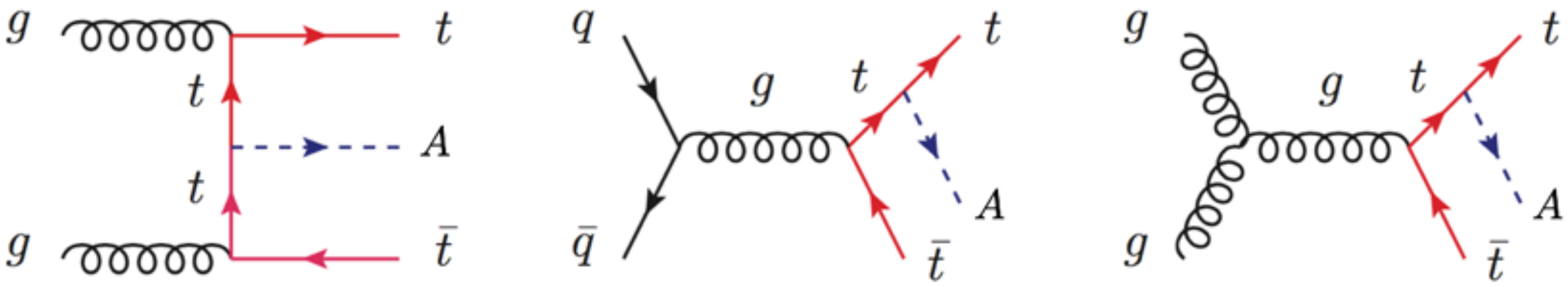
Comments



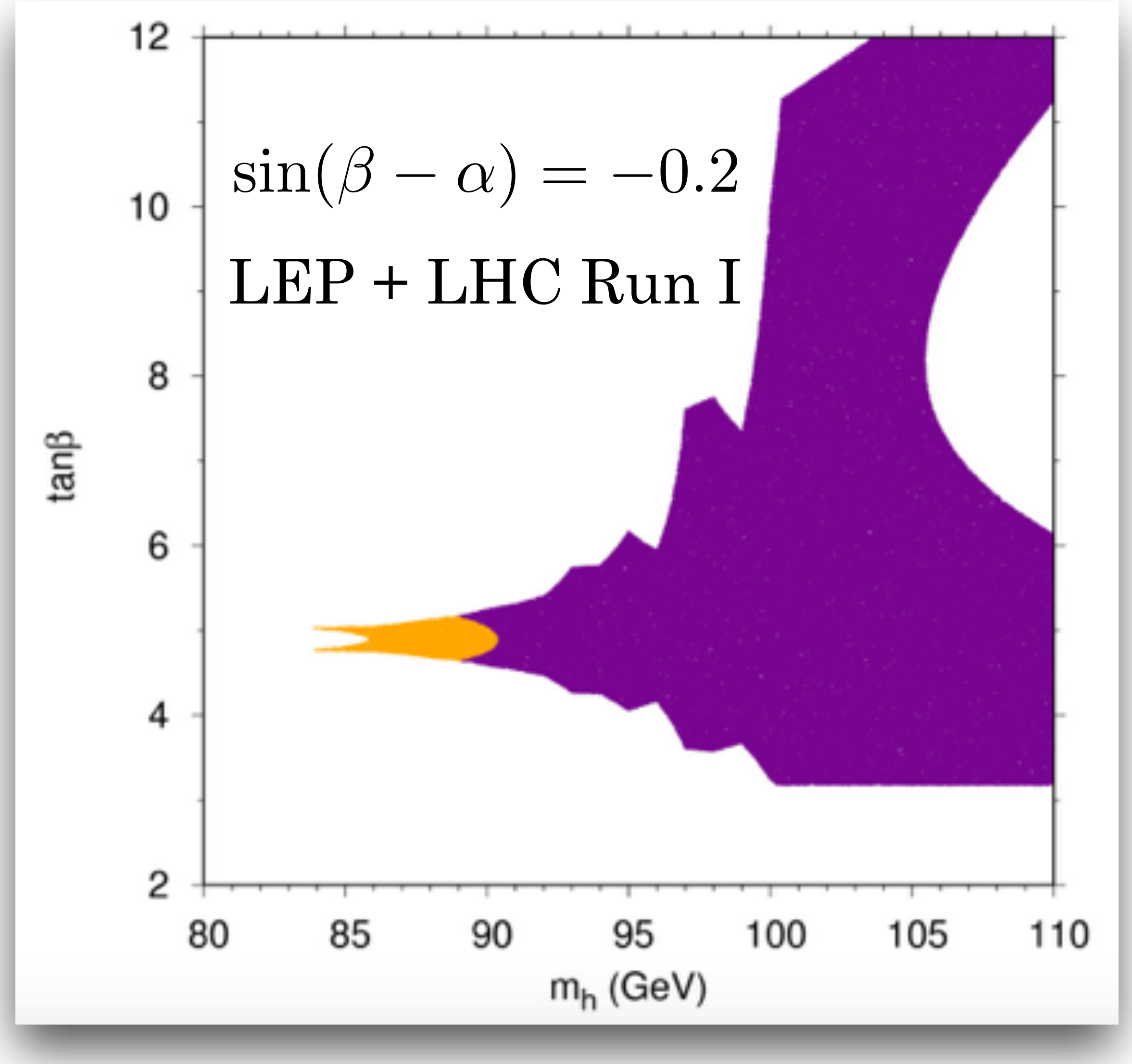
[R. Frederix et. al., arXiv:1401.7340]

- New analysis tools: ML (BDT, DNN)
- New decay modes, e.g., tthh -> ttbbWW: loss in signal rate, gain from same-sign di-leptons
- Gain from higher beam energy: two-order increase in section from 14TeV to 100TeV

Di-Top + Light Neutral Higgs



Sub-EW Scale Scalar and Pseudoscalar



[G. Cacciapaglia et. al., arXiv:1607.08653]

- Sub-EW scale scalar (2HDM): strongly constrained by LEP measurements
- Sub-EW scale pseudoscalar (2HDM): interacts with WW, ZZ via higher dimensional operator => weakly constrained by LEP and LHC data

The Probe of Exotic Higgs Decays

arXiv.org > hep-ph > arXiv:1312.4992

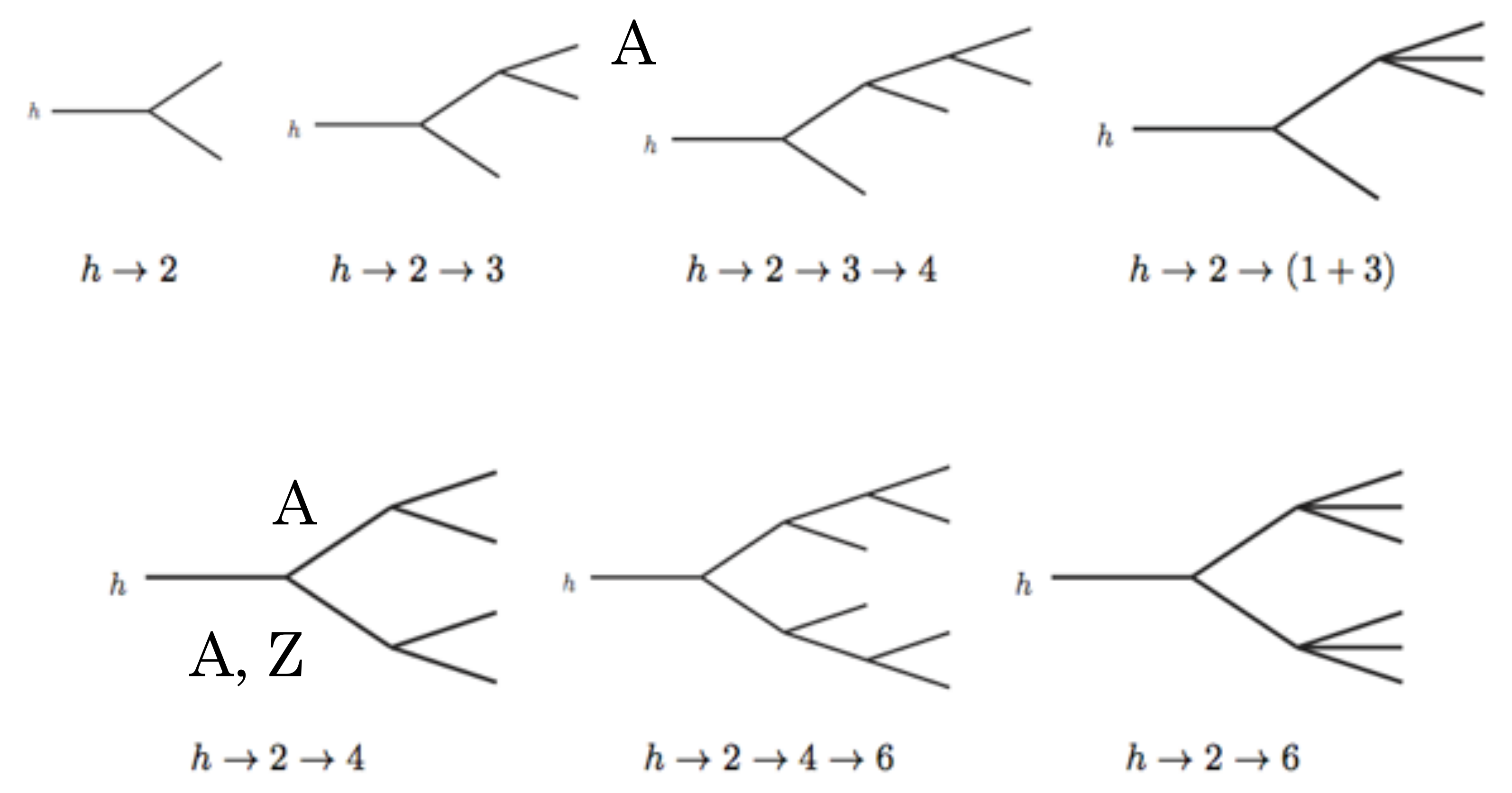
Search or

High Energy Physics - Phenomenology

Exotic Decays of the 125 GeV Higgs Boson

David Curtin, Rouven Essig, Stefania Gori, Prerit Jaiswal, Andrey Katz, Tao Liu, Zhen Liu, David McKeen, Jessie Shelton, Matthew Strassler, Ze'ev Surujon, Brock Tweedie, Yi-Ming Zhong

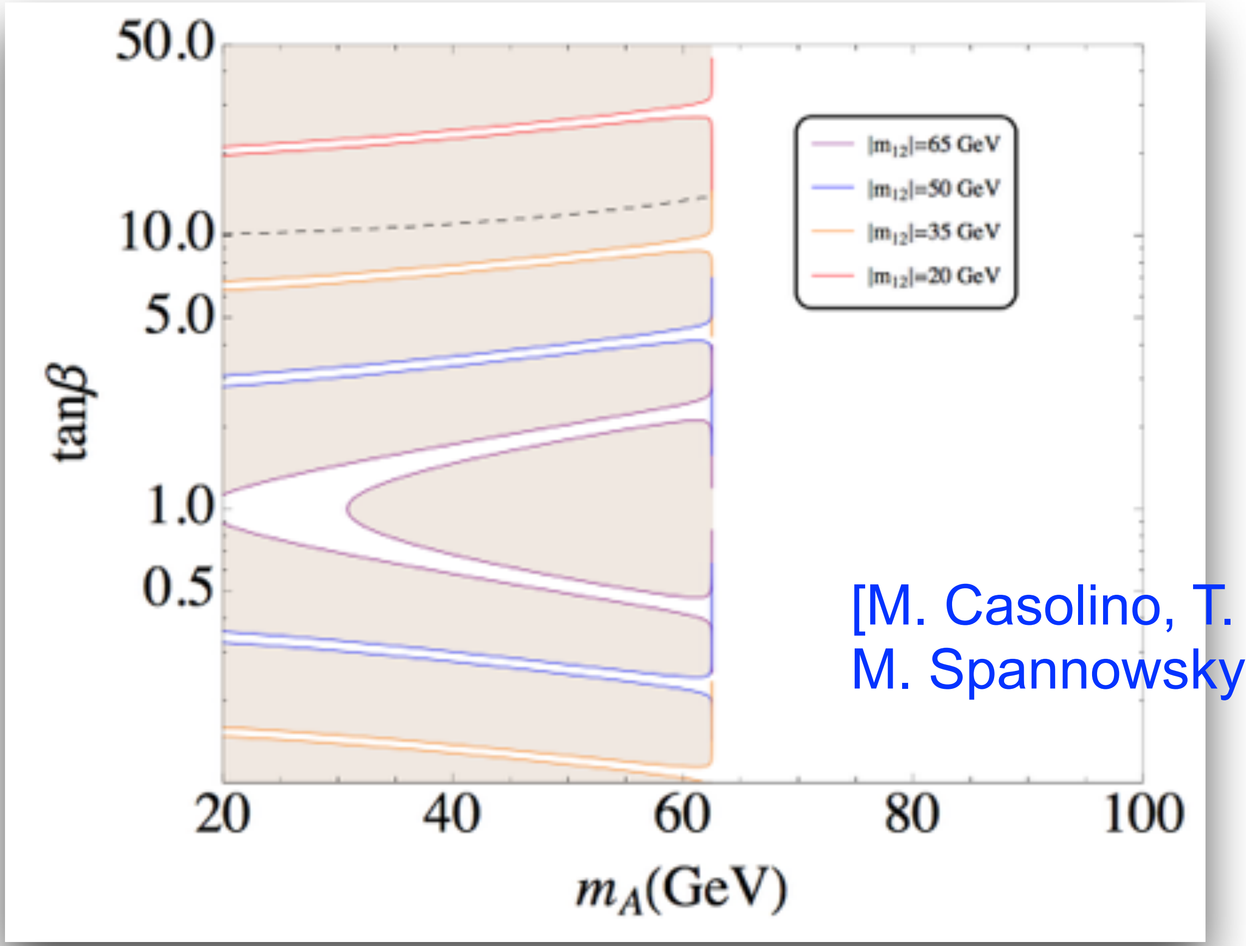
(Submitted on 17 Dec 2013 (v1), last revised 2 Sep 2015 (this version, v5))



Limitations of Exotic Higgs Decays

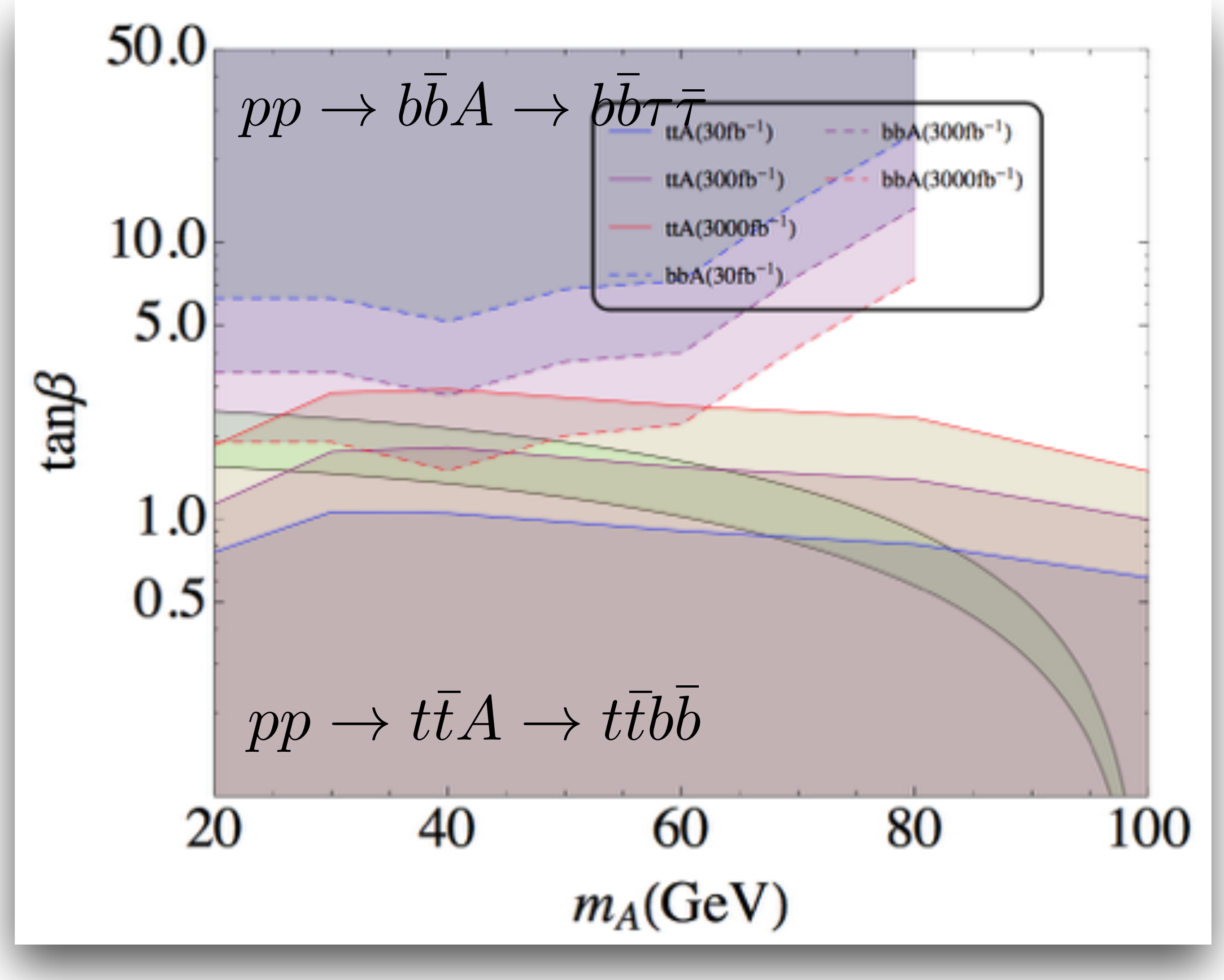
- Phase space availability, e.g. mA > mh/2
- Accidental suppression of the coupling g_hAA and hence Br(h -> AA) [J. Bernon et. al., arXiv:1412.3385]

$$g_{hAA} = -\frac{2m_A^2 + m_h^2 - 2m_{12}^2 \sec\beta \csc\beta}{v}$$



[M. Casolino, T. Farooque, A. Juste, TL,
M. Spannowsky, arXiv: 1507.07004]

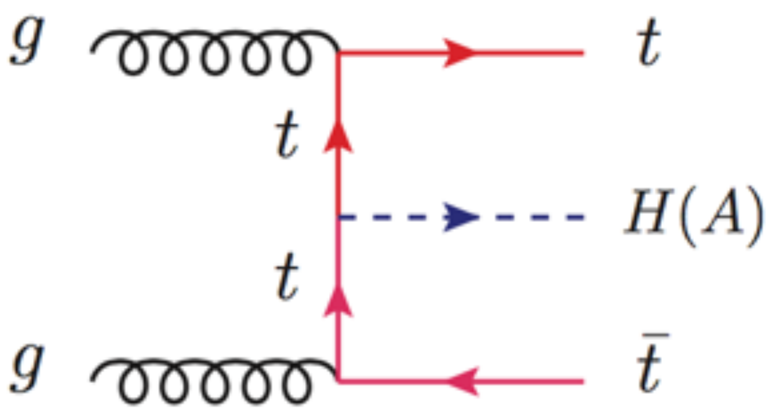
Complementary Approach

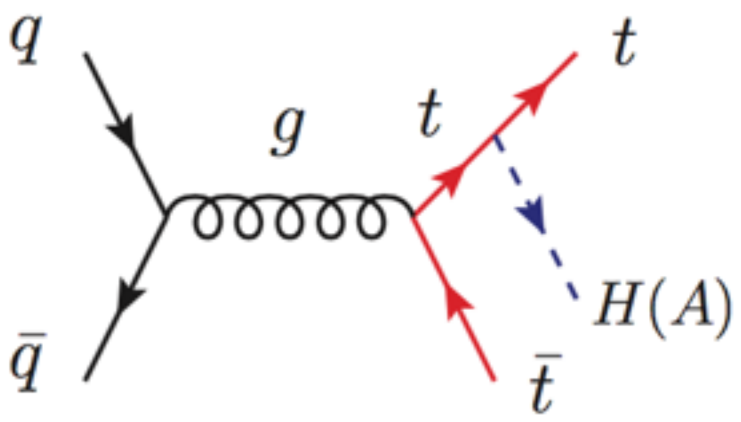


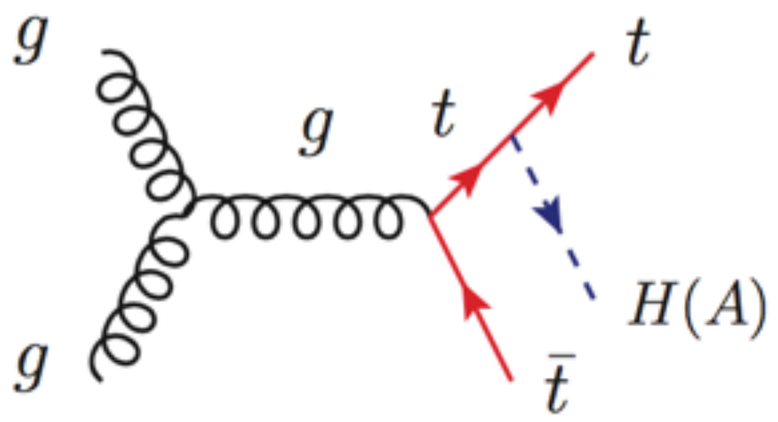
[M. Casolino, T. Farooque, A. Juste, TL, M. Spannowsky, arXiv: 1507.07004]

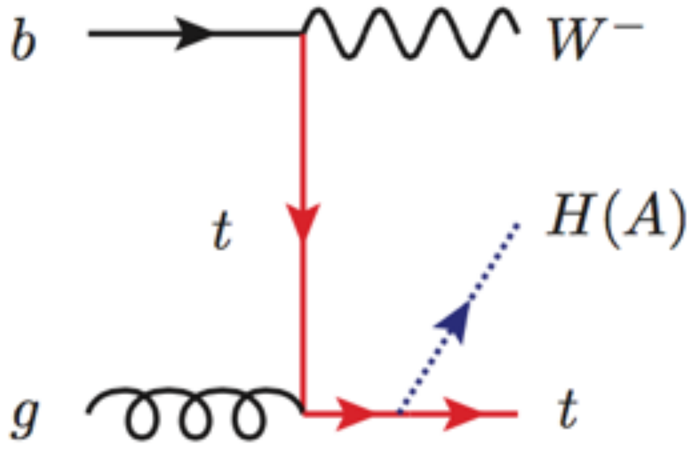
- To fully probe the low mass region => a combined search of bbA and ttA productions
- A coverage below 100 GeV could be achieved at HL-LHC for type II 2HDM, except a ``wedge'' region

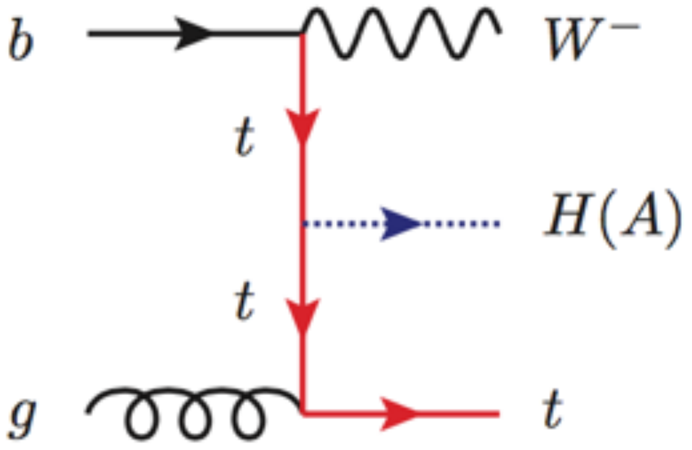
Single /Di-Top + Heavy Neutral Higgs



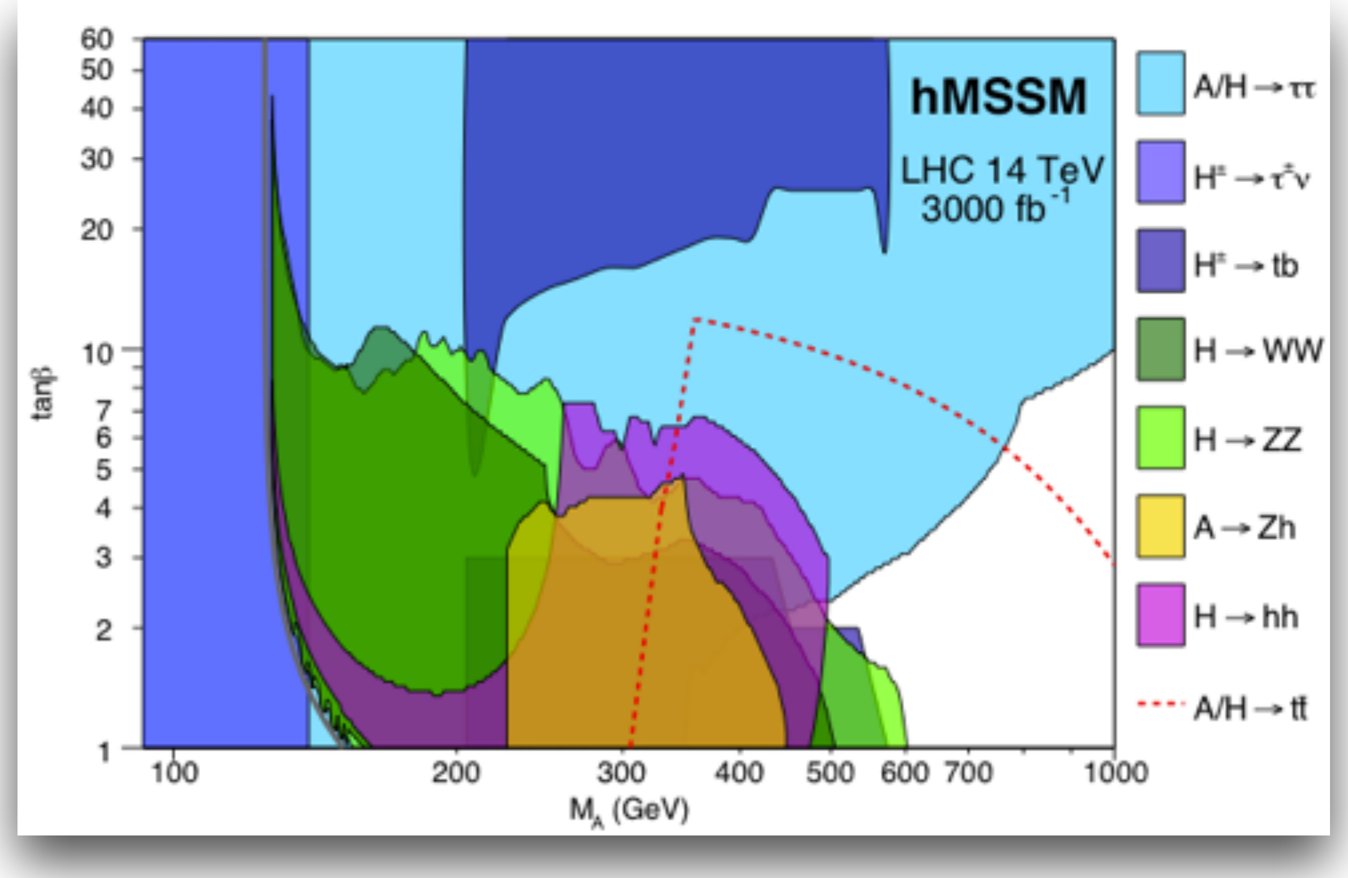








MSSM Higgs Bosons at HL-LHC

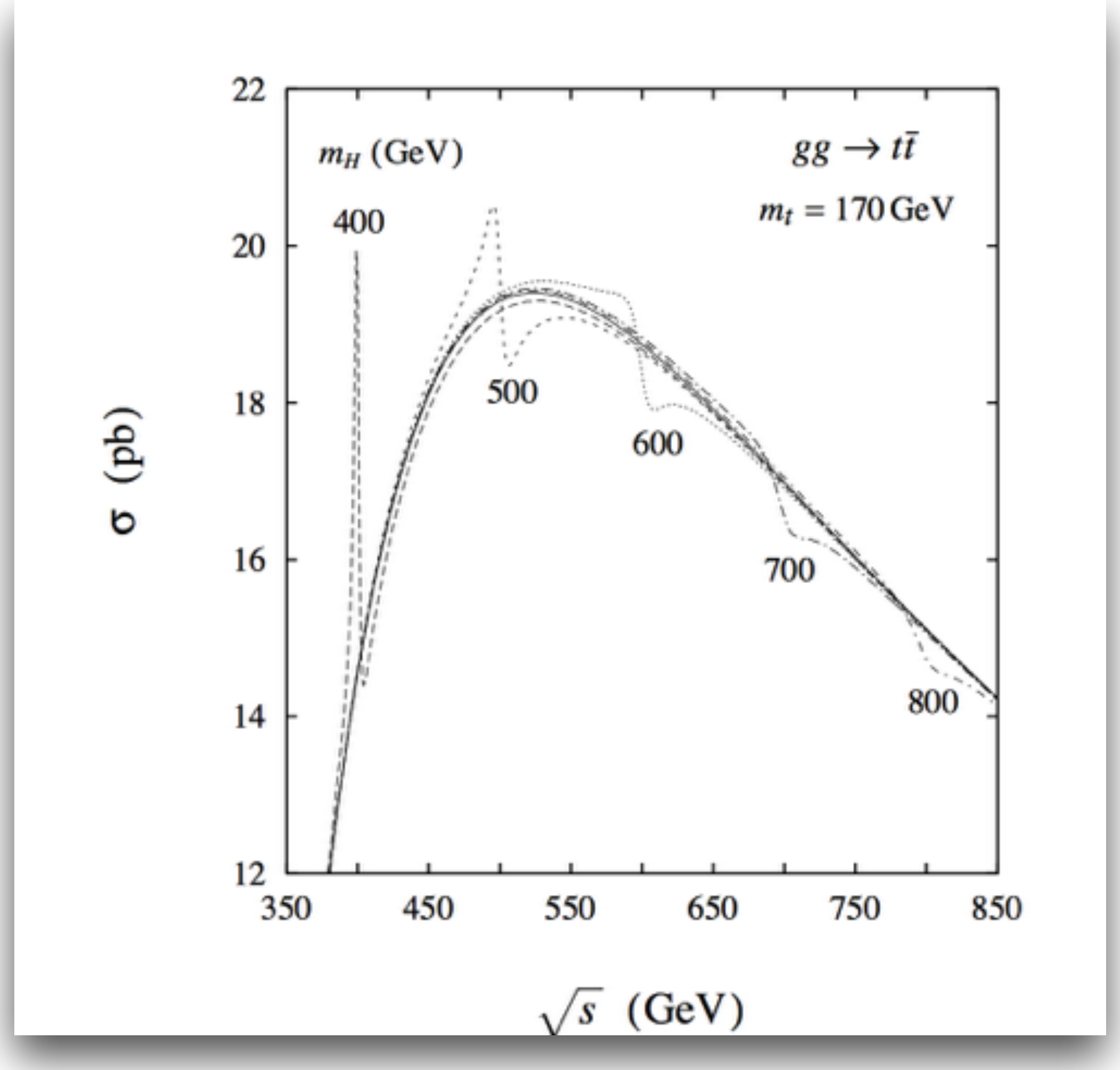


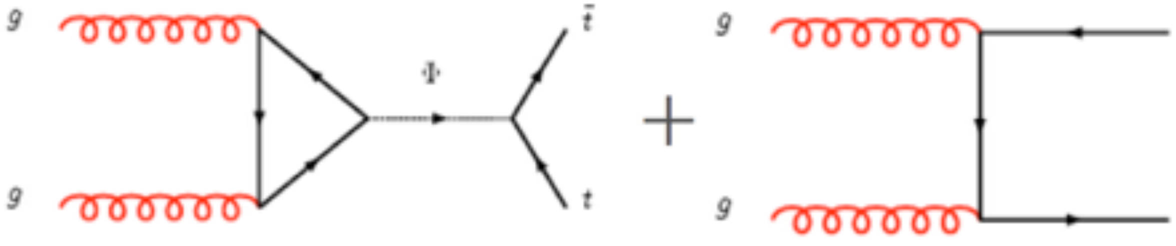
[Djouadi et. al.’arXiv:1502.05653]

$$g_{HVV} = g_{hZA} = g_{hW^{\mp}H^{\pm}} \propto \cos(\beta - \alpha) \to 0$$

- Decoupling limit (type II 2HDM): tt mode dominates H/A decays in moderate and low $\tan\beta$ region
- However, gg -> H/A -> tt is challenging to measure

Difficulty in Gluon-fusion Channel

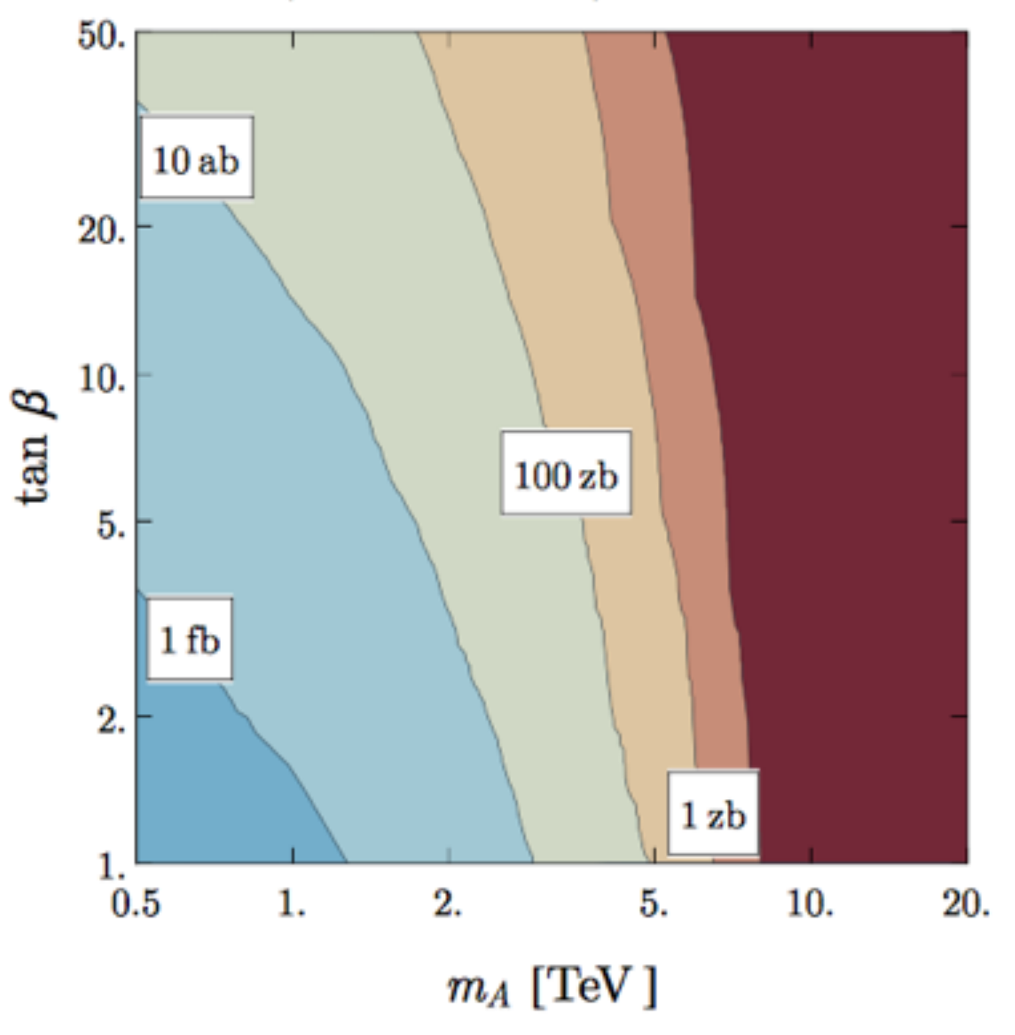




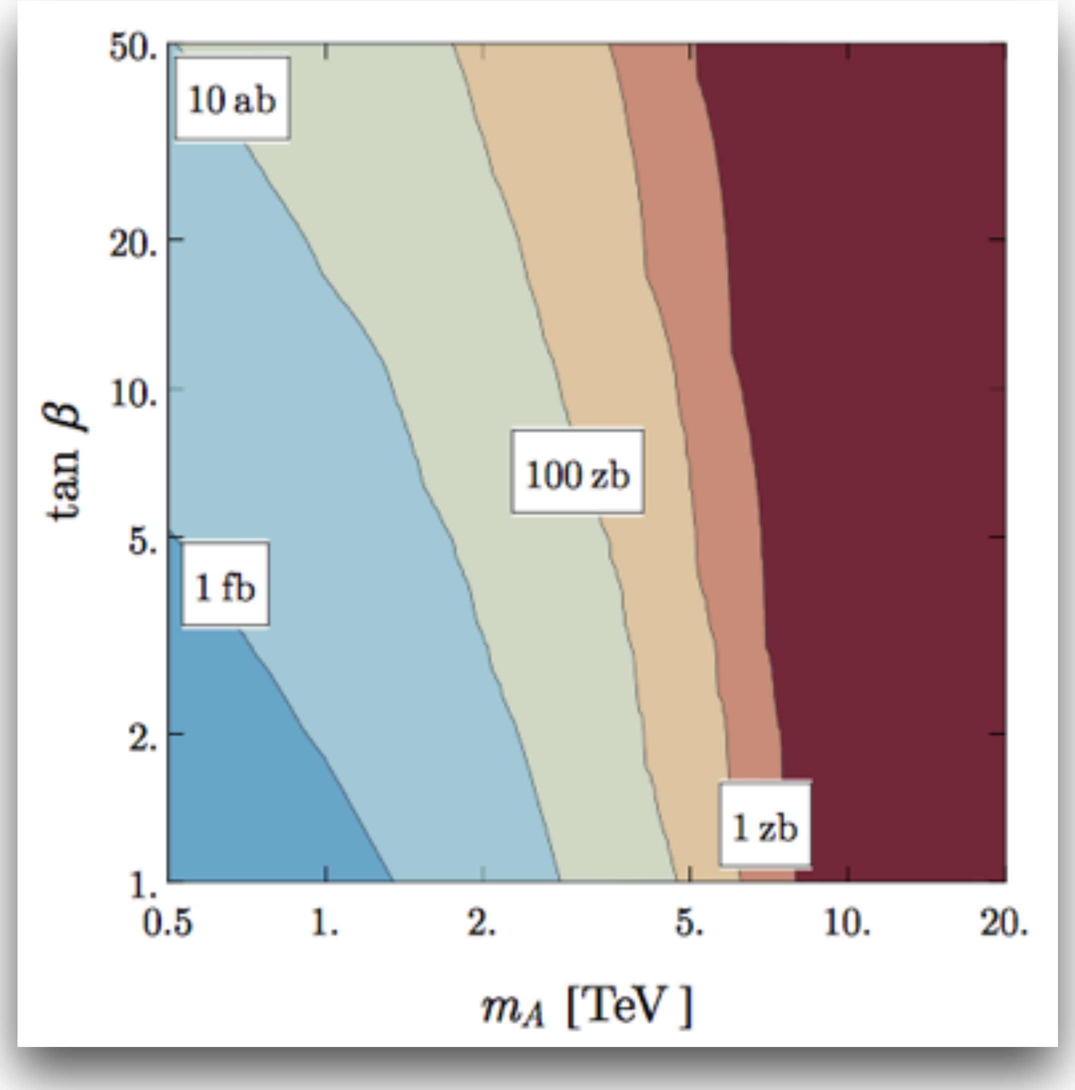
- Interference with QCD tt => resonance structure of peak, dip or nothing

[D. Dicus et. al., hep-ph/9404359]

Single /Di-Top + Heavy Neutral Higgs



$\sigma\left(pp \to (H+A)tW^{\pm}\right)$ at 14 TeV

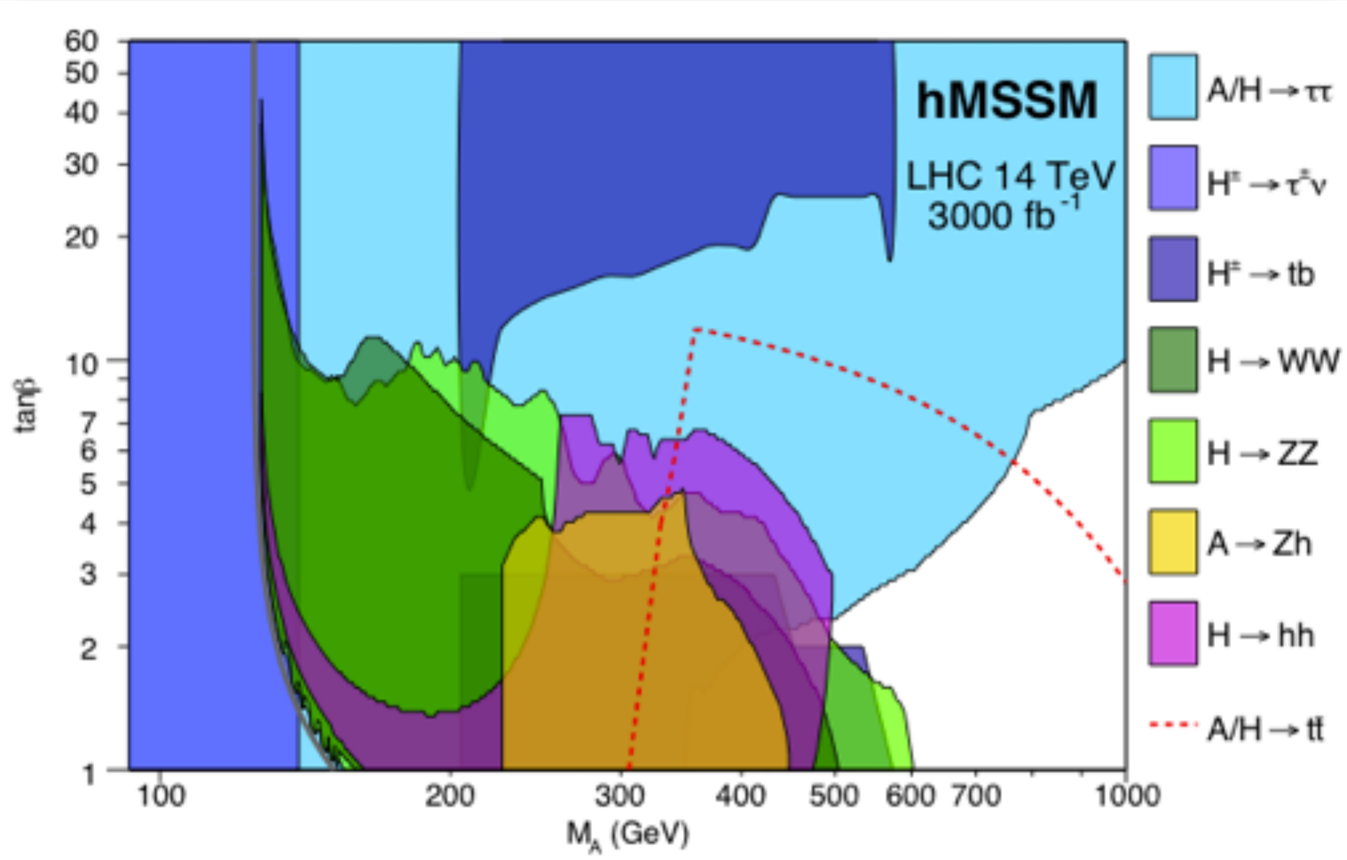


$\sigma\left(pp \to (H+A)t\bar{t}\right)$ at 14 TeV

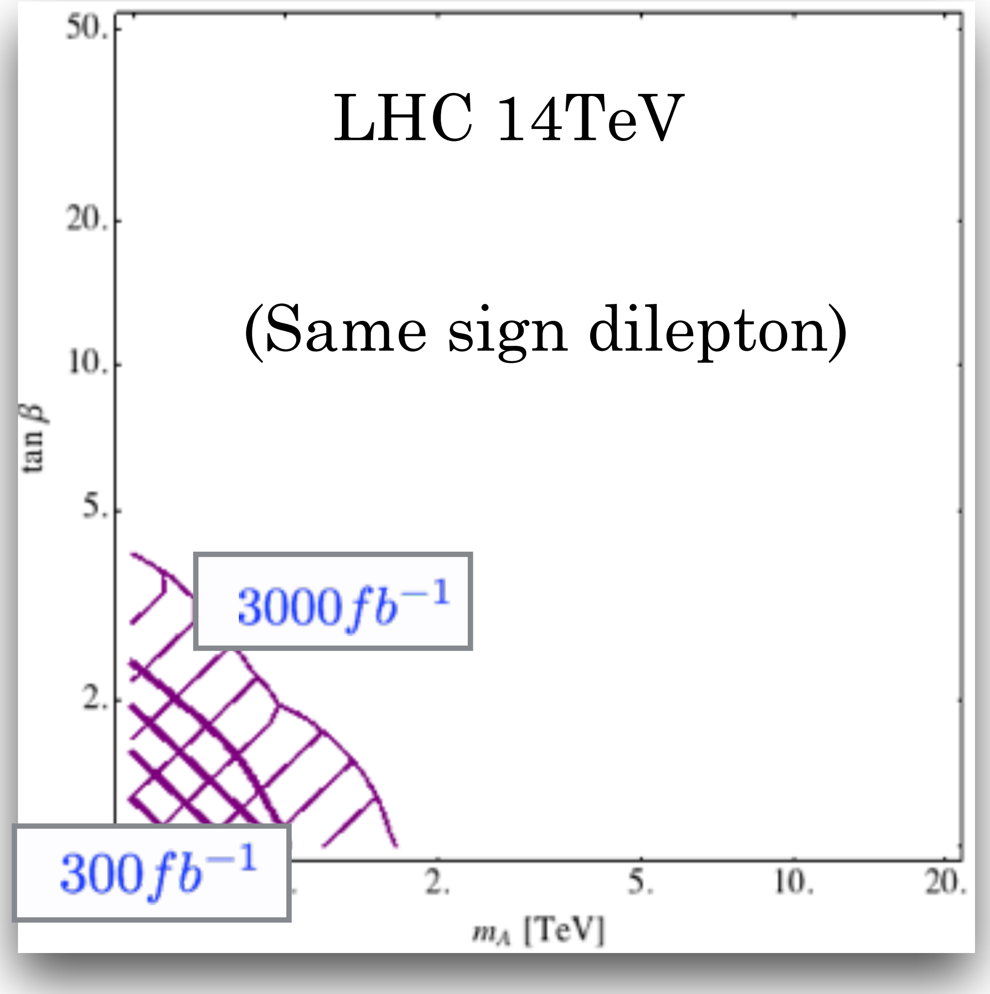
[N. Craig, J. Hajer, Y.-Y. Li, TL, H. Zhang, arXiv: 1605.08744]

- Xsections are comparable for tWH/A and ttH/A at 14 TeV

Decoupling Limit at LHC



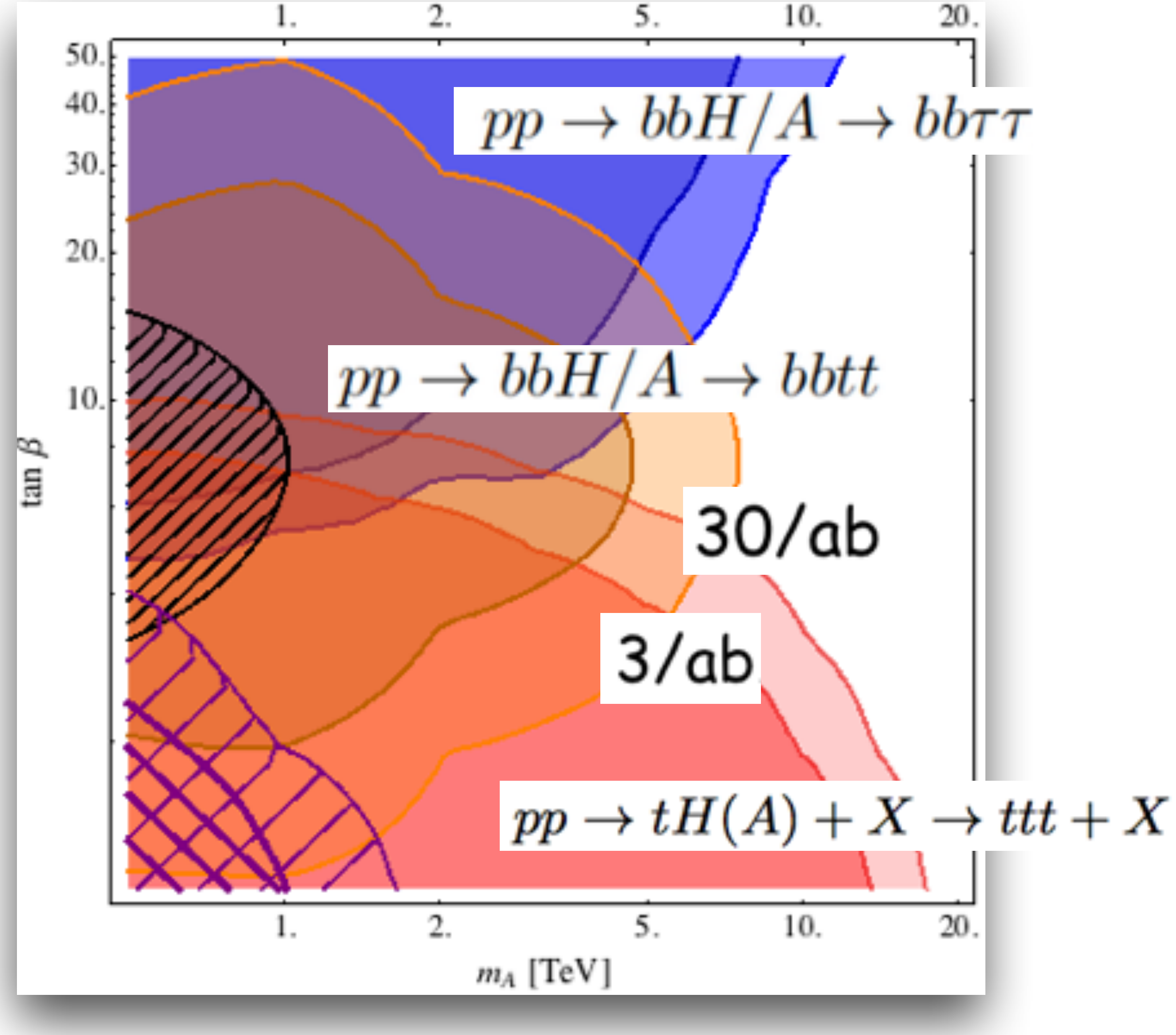
[Djouadi et. al.'arXiv:1502.05653]



[N. Craig, J. Hajer, Y.-Y. Li, TL, H. Zhang, arXiv:1605.08744]

- A combination of both allows to probe the blank region up to ~1 TeV at HL-LHC

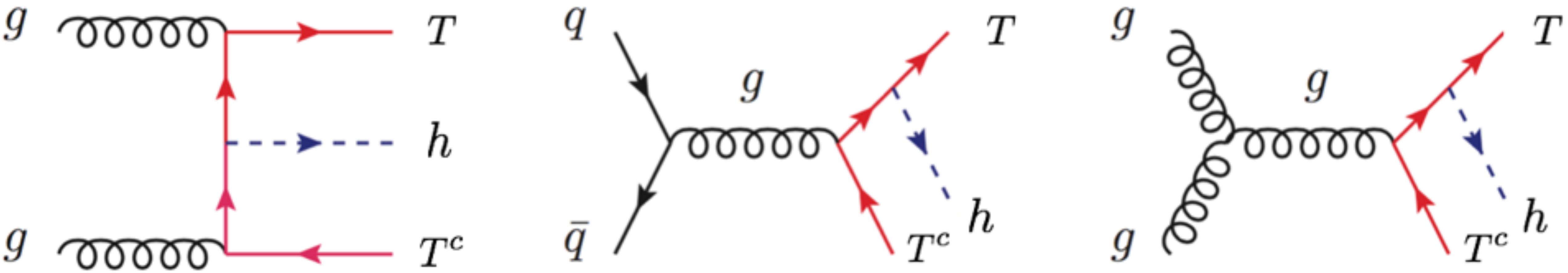
Decoupling Limit: from LHC to 100 TeV



[N. Craig, J. Hajer, Y.-Y. Li, TL, H. Zhang, arXiv: 1605.08744]

- Large $\tan\beta$: bbH -> bbtautau continues to be significant
- Moderate $\tan\beta$: exclude mA up to ~8TeV via bbH/A -> bbtt (semi-leptonic tt).
- Low $\tan\beta$: cover up to ~15TeV via tH/A + X -> ttt + X and ttH/A -> tttt

Di-Top Partners + Single Higgs



Why TTh?

- Fermion top partners extensively exist in BSM theories, such as the ones addressing ``naturalness'' like little Higgs models [see D. Shih's talk]

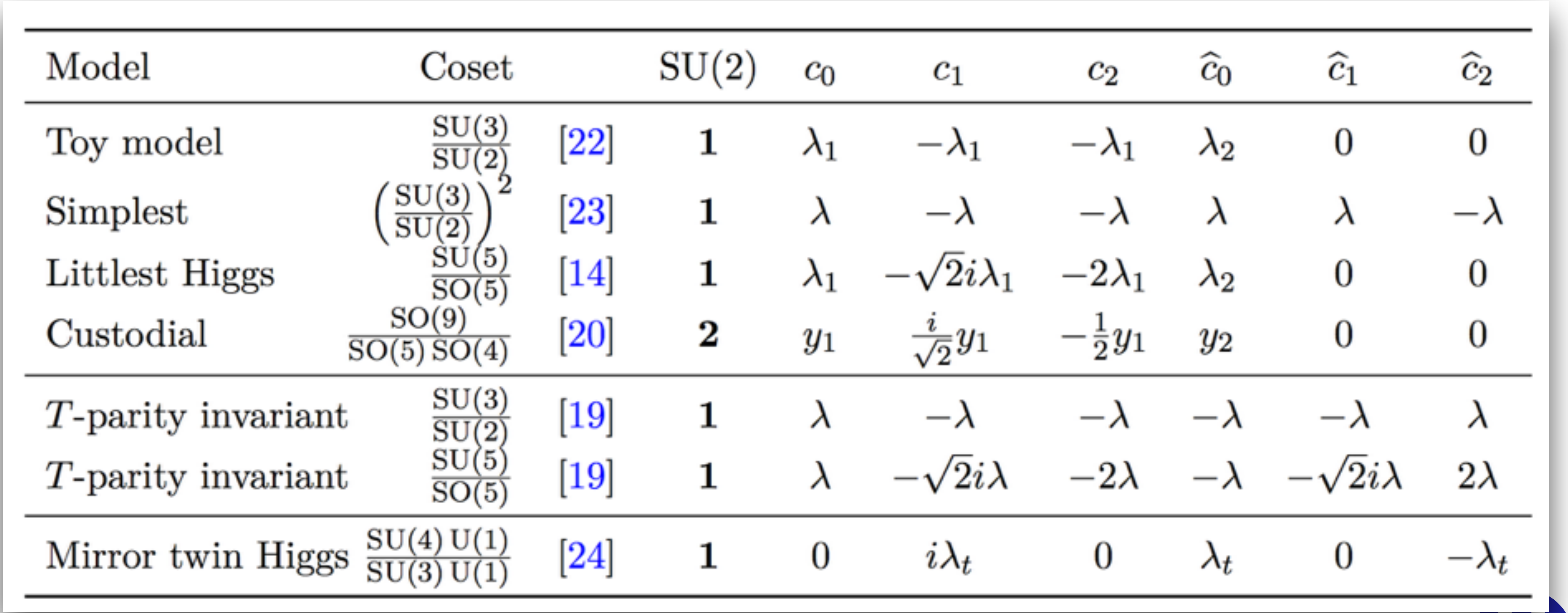
- Question: why is TTh relevant, given that TT or single T productions may have a better sensitivity in their searches? [see L. Serkin's talk]

- Answer: the theories of ``naturalness'' are not the only ones predicting the existence of such partner particles. Generically, the partner particles predicted by ``natural'' theories need to interact with the Higgs boson following some symmetry-protected sum rule.

Little Higgs / Twin Higgs Models

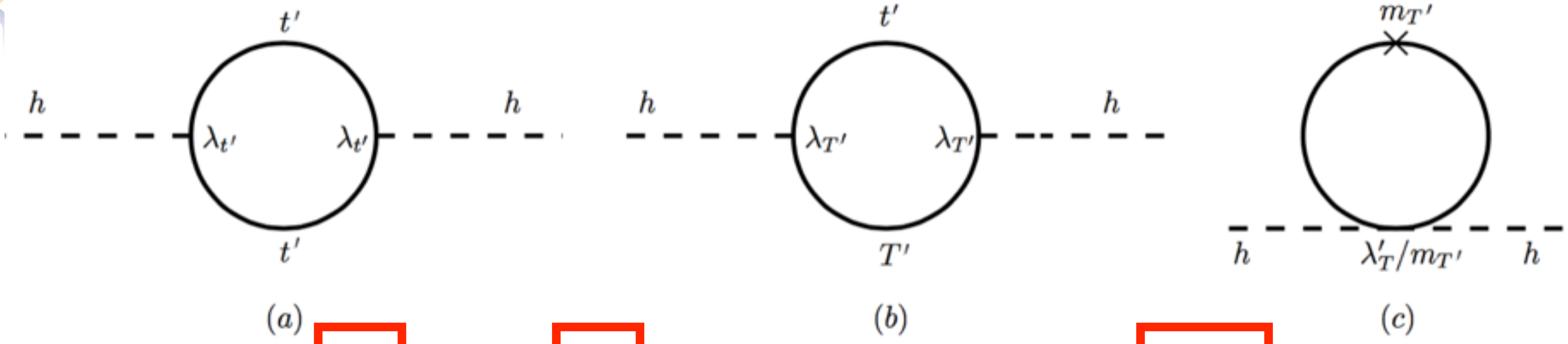
SM + one pair of vector-like (weak isospin singlet) top partners

$$\begin{aligned}\mathcal{L}_U = {} & u_3^c\left(c_0 f U + c_1 H q_3 + \frac{c_2}{f} H^2 U + \ldots\right) \\ & + U^c\left(\hat{c}_0 f U + \hat{c}_1 H q_3 + \frac{\hat{c}_2}{f} H^2 U + \ldots\right) + \text{h.c.}\ .\end{aligned}$$



Model	Coset		SU(2)	c_0	c_1	c_2	$\hat{c}_0$	$\hat{c}_1$	$\hat{c}_2$
Toy model	$\frac{SU(3)}{SU(2)}$	[22]	$\mathbf{1}$	λ_1	$-\lambda_1$	$-\lambda_1$	λ_2	0	0
Simplest	$\left(\frac{SU(3)}{SU(2)}\right)^2$	[23]	$\mathbf{1}$	λ	$-\lambda$	$-\lambda$	λ	λ	$-\lambda$
Littlest Higgs	$\frac{SU(5)}{SO(5)}$	[14]	$\mathbf{1}$	λ_1	$-\sqrt{2}i\lambda_1$	$-2\lambda_1$	λ_2	0	0
Custodial	$\frac{SO(9)}{SO(5)\,SO(4)}$	[20]	$\mathbf{2}$	y_1	$\frac{i}{\sqrt{2}}y_1$	$-\frac{1}{2}y_1$	y_2	0	0
T-parity invariant	$\frac{SU(3)}{SU(2)}$	[19]	$\mathbf{1}$	λ	$-\lambda$	$-\lambda$	$-\lambda$	$-\lambda$	λ
T-parity invariant	$\frac{SU(5)}{SO(5)}$	[19]	$\mathbf{1}$	λ	$-\sqrt{2}i\lambda$	-2λ	$-\lambda$	$-\sqrt{2}i\lambda$	2λ
Mirror twin Higgs	$\frac{SU(4)\,U(1)}{SU(3)\,U(1)}$	[24]	$\mathbf{1}$	0	$i\lambda_t$	0	λ_t	0	$-\lambda_t$

Little Higgs / Twin Higgs Models



$$\mathcal{L}_{T'} = m_{T'} T'^c T' + \boxed{\lambda_{t'}} H t'^c t' + \boxed{\lambda_{T'}} H T'^c t' + \frac{\alpha_{t'}}{2m_{T'}} H^2 t'^c T' + \boxed{\frac{\alpha_{T'}}{2m_{T'}}} H^2 T'^c T' + \frac{\beta_{t'}}{6m_{T'}^2} H^3 t'^c t' + \frac{\beta_{T'}}{6m_{T'}^2} H^3 T'^c t' + \mathcal{O}\left(H^4\right) + \text{h.c.}$$

$$\boxed{\alpha_{T'} = -\left|\lambda_{T'}\right|^2 - \left|\lambda_{t'}\right|^2}$$

The sum rule, protected by underlying bosonic symmetries which are broken collectively or accidentally less strongly, ensures the stability of Higgs mass at one-loop level.

Post the discovery of any top partner-like particle, a must-be-done task will be testing the sum rule in the top sector. But, how?

Sum Rule - Mass Basis After EWSB

$$\mathcal{L}_T = m_T T^c T + \lambda_t v t^c t + \boxed{\frac{\lambda_t}{\sqrt{2}}} h t^c t + \frac{\lambda_T}{\sqrt{2}} h T^c t + \frac{a_t v}{\sqrt{2} m_T} h t^c T + \boxed{\frac{a_T v}{\sqrt{2} m_T}} h T^c T$$

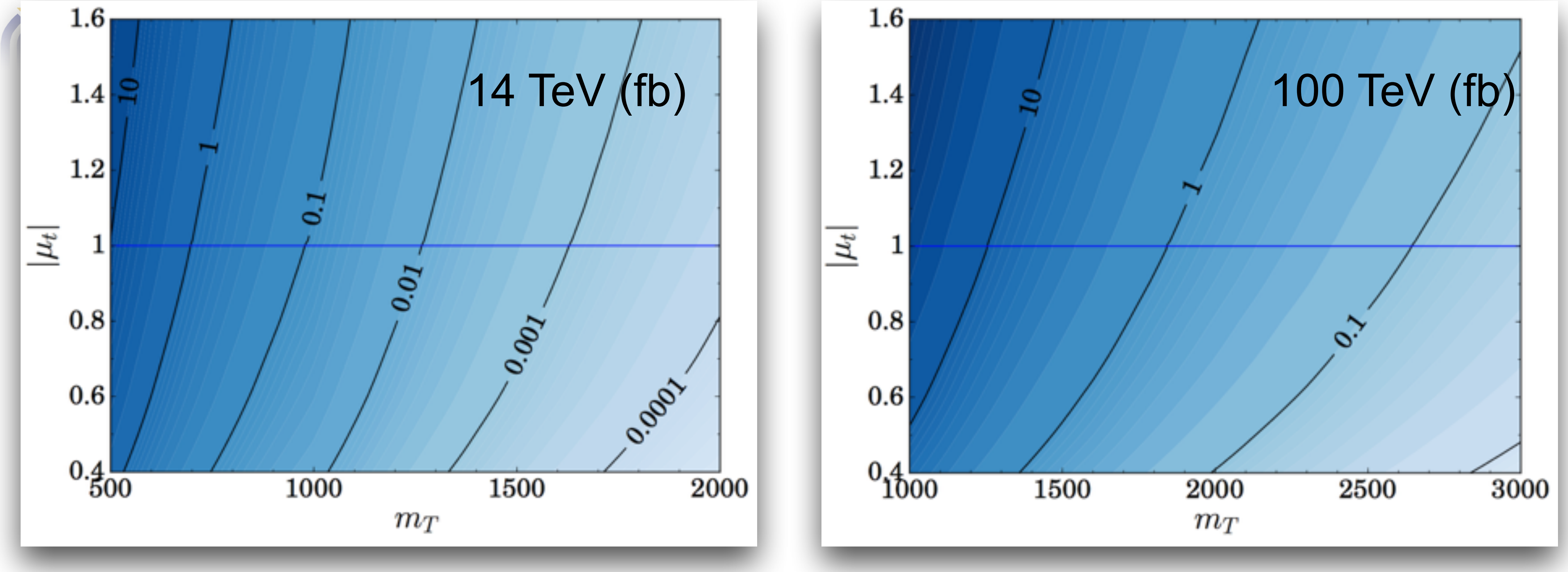
$$+ \frac{\alpha_t}{4 m_T} h^2 t^c T + \frac{\alpha_T}{4 m_T} h^2 T^c T + \frac{b_t v}{4 m_T^2} h^2 t^c t + \frac{b_T v}{4 m_T^2} h^2 T^c t + \mathcal{O}\left(h^3, \frac{v^2}{m_T^2}\right) + \text{h.c.}$$

$$\boxed{\alpha_{T'} = -|\lambda_{T'}|^2 - |\lambda_{t'}|^2} \quad \Rightarrow \quad \boxed{a_T = -|\lambda_t|^2 + \mathcal{O}\left(\frac{v^2}{m_T^2}\right)}$$

- At leading order, the sum rule involves flavor-diagonal Yukawa couplings only
- => Guideline to test the sum rule of the top sector: measuring all flavor-diagonal Yukawa couplings => the TTh production becomes relevant!

[C. Chen, J. Hajer, TL, I. Low and H. Zhang, arXiv: 1705.07743]

TTh Production in Little Higgs Model

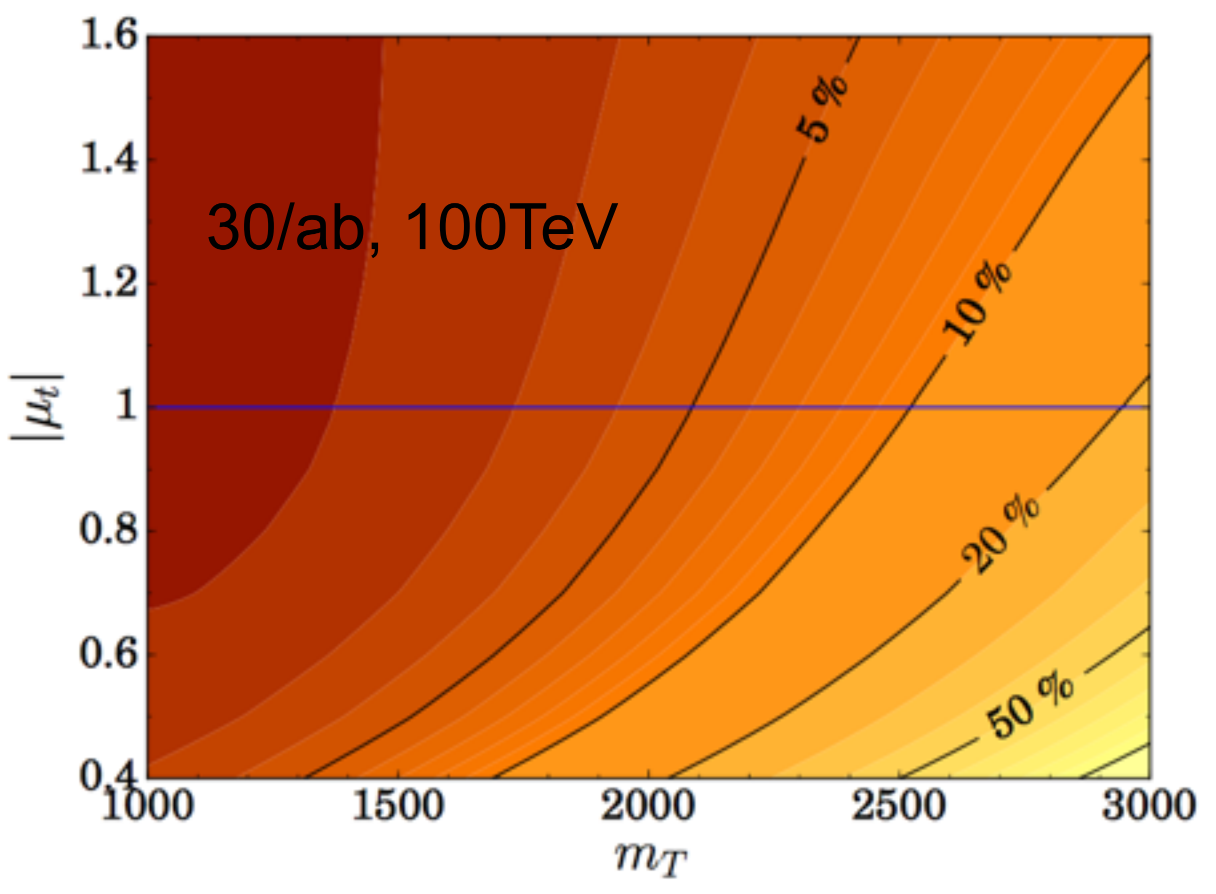


[C. Chen, J. Hajer, TL, I. Low and H. Zhang, arXiv: 1705.07743]

Naturalness parameter: $$\mu_t = -\frac{a_T}{|\lambda_t|^2} + \mathcal{O}\left(\frac{v^2}{m_T^2}\right) \qquad \mu_t|_{\text{natural}} = 1$$

- The test of sum rule <=> The measurement of μ_t value

Precision of Measuring Naturalness Parameter at 100 TeV



[C. Chen, J. Hajer, TL, I. Low and H. Zhang, arXiv: 1705.07743]

- $\mathrm{BR}(T \to th) \simeq \mathrm{BR}(T \to tZ) \simeq \frac{1}{2}\mathrm{BR}(T \to Wb) \simeq 25\,\%$ is assumed for TTh measurements
- A precision of 10(20)% in measuring μ_t could be achieved up to ~ 2.5(3)TeV for little higgs models without T-parity, at 100 TeV

$$\delta\mu = \sqrt{\left(-\frac{1}{\lambda_t^2}\delta a_T\right)^2 + \left(2\frac{a_T}{\lambda_t^3}\delta\lambda_t\right)^2}$$

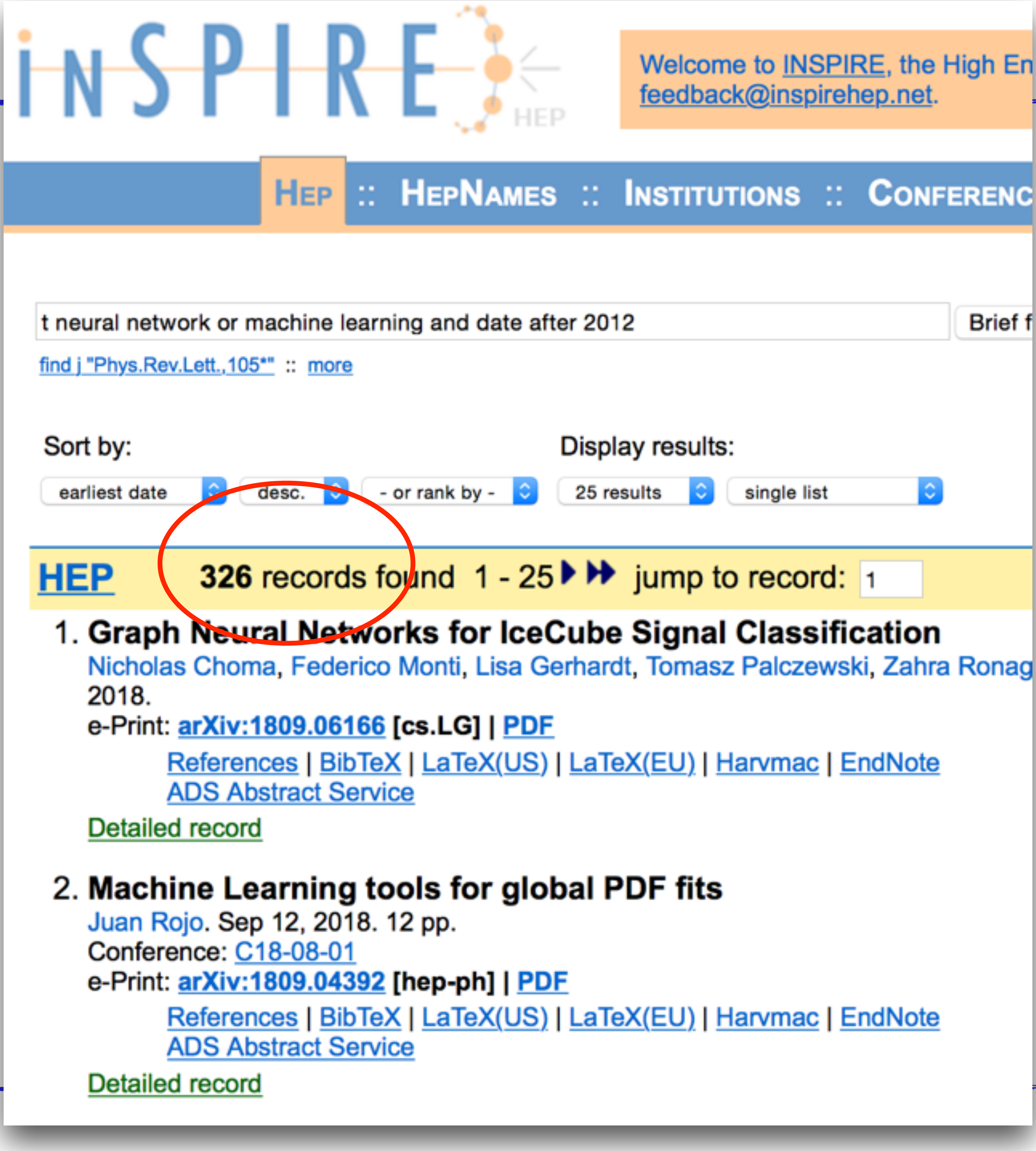
(30/ab, 100TeV)

$$\delta\lambda_t \sim 1\%$$

[M. Mangano, T. Plehn, et. al., arXiv: 1507.08169]

Application of New Analysis Tools

[Also see D. Shih’s talk]



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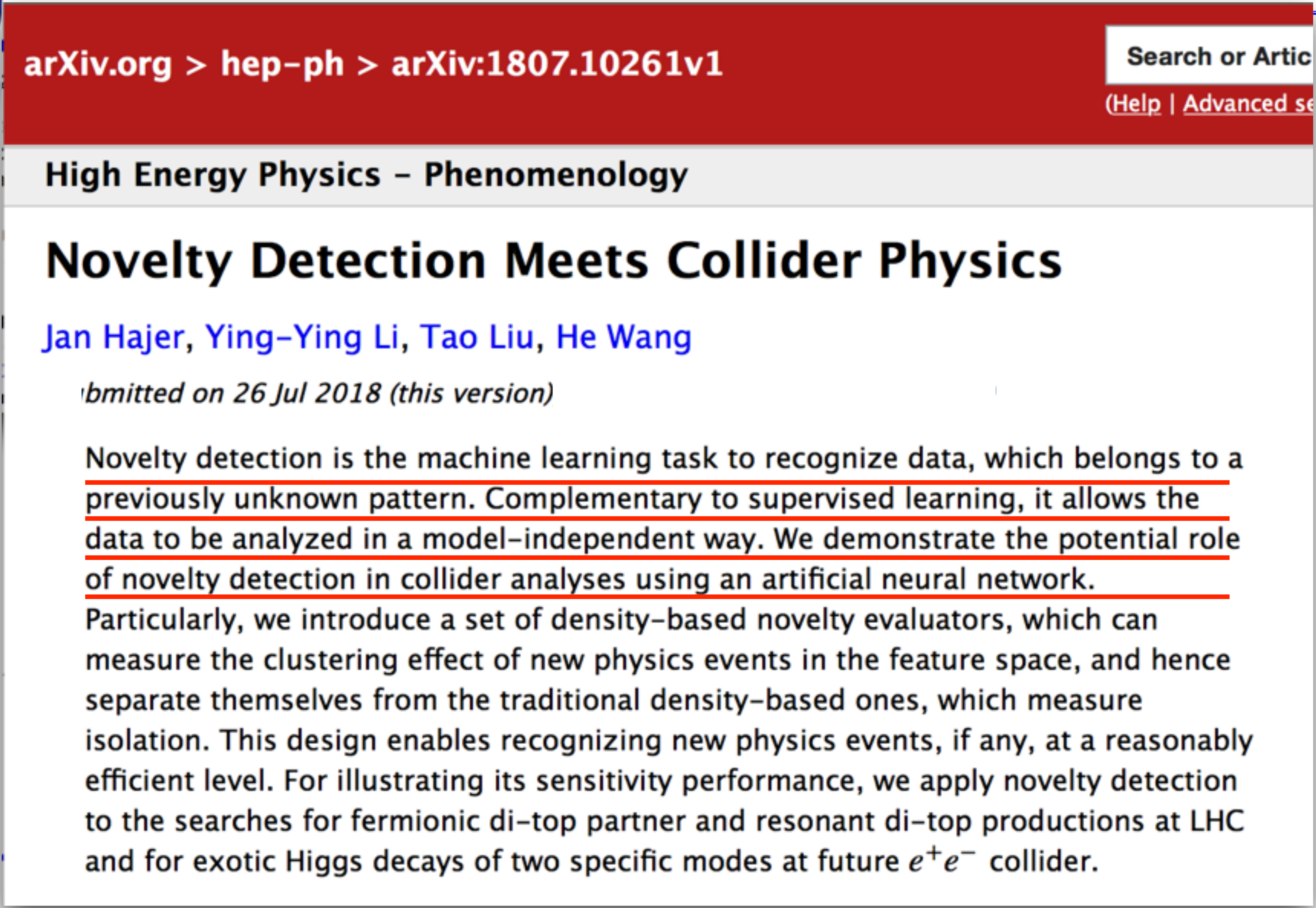


arXiv.org > hep-ph > arXiv:1807.10261v1

High Energy Physics – Phenomenology

Novelty Detection Meets Collider Physics

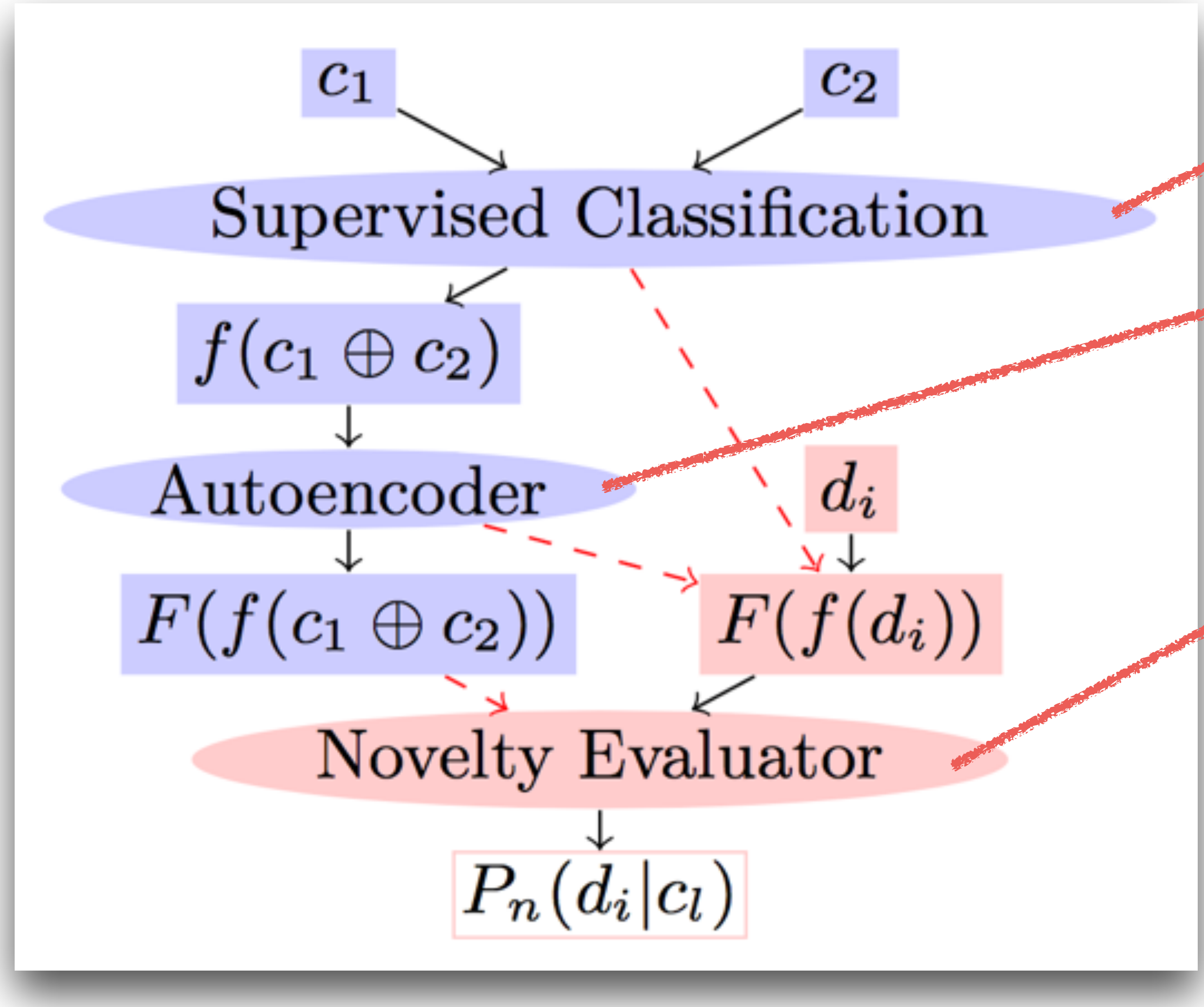
Jan Hajer, Ying-Ying Li, Tao Liu, He Wang

bmitted on 26 Jul 2018 (this version)

Novelty detection is the machine learning task to recognize data, which belongs to a previously unknown pattern. Complementary to supervised learning, it allows the data to be analyzed in a model-independent way. We demonstrate the potential role of novelty detection in collider analyses using an artificial neural network. Particularly, we introduce a set of density-based novelty evaluators, which can measure the clustering effect of new physics events in the feature space, and hence separate themselves from the traditional density-based ones, which measure isolation. This design enables recognizing new physics events, if any, at a reasonably efficient level. For illustrating its sensitivity performance, we apply novelty detection to the searches for fermionic di-top partner and resonant di-top productions at LHC and for exotic Higgs decays of two specific modes at future e^+e^- collider.

Novelty (Anomaly) Detection - Algorithm

[J. Hajer, Y.-Y. Li, TL and H. Wang, arXiv: 1807.10261]
(For relevant studies, also see [Heimel et. al., 1808.08979; Farina et. al., 1808.08992])

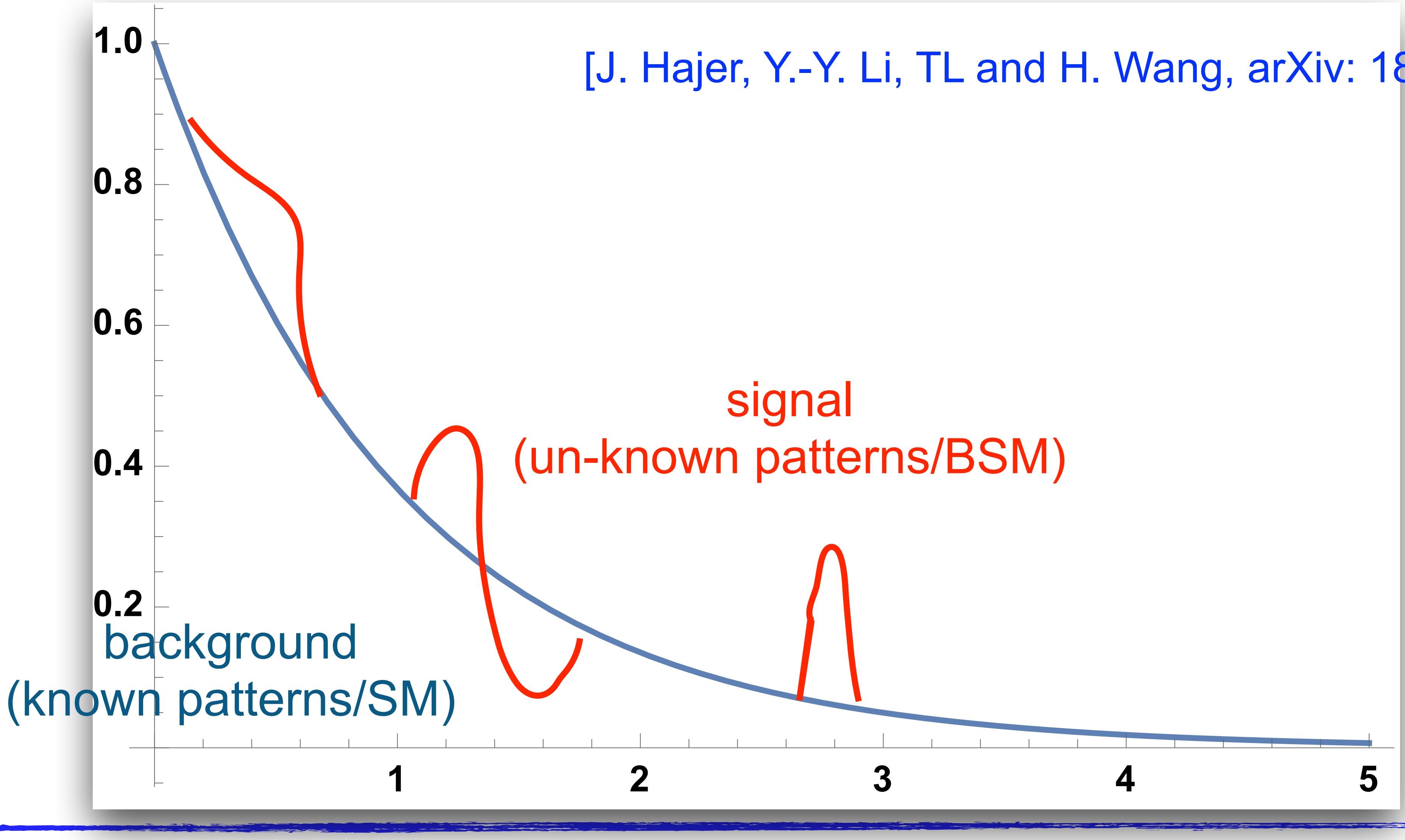


- Step 1: (SM/background) feature learning
- Step 2: dimension reducing of feature space (auto-encoder)
- Step 3: novelty evaluating of testing data
- Analyze detection sensitivity based on novelty response of testing data

With such algorithms, new physics can be searched for without a priori knowledge!

Novelty (Anomaly) Detection - Novelty Evaluator

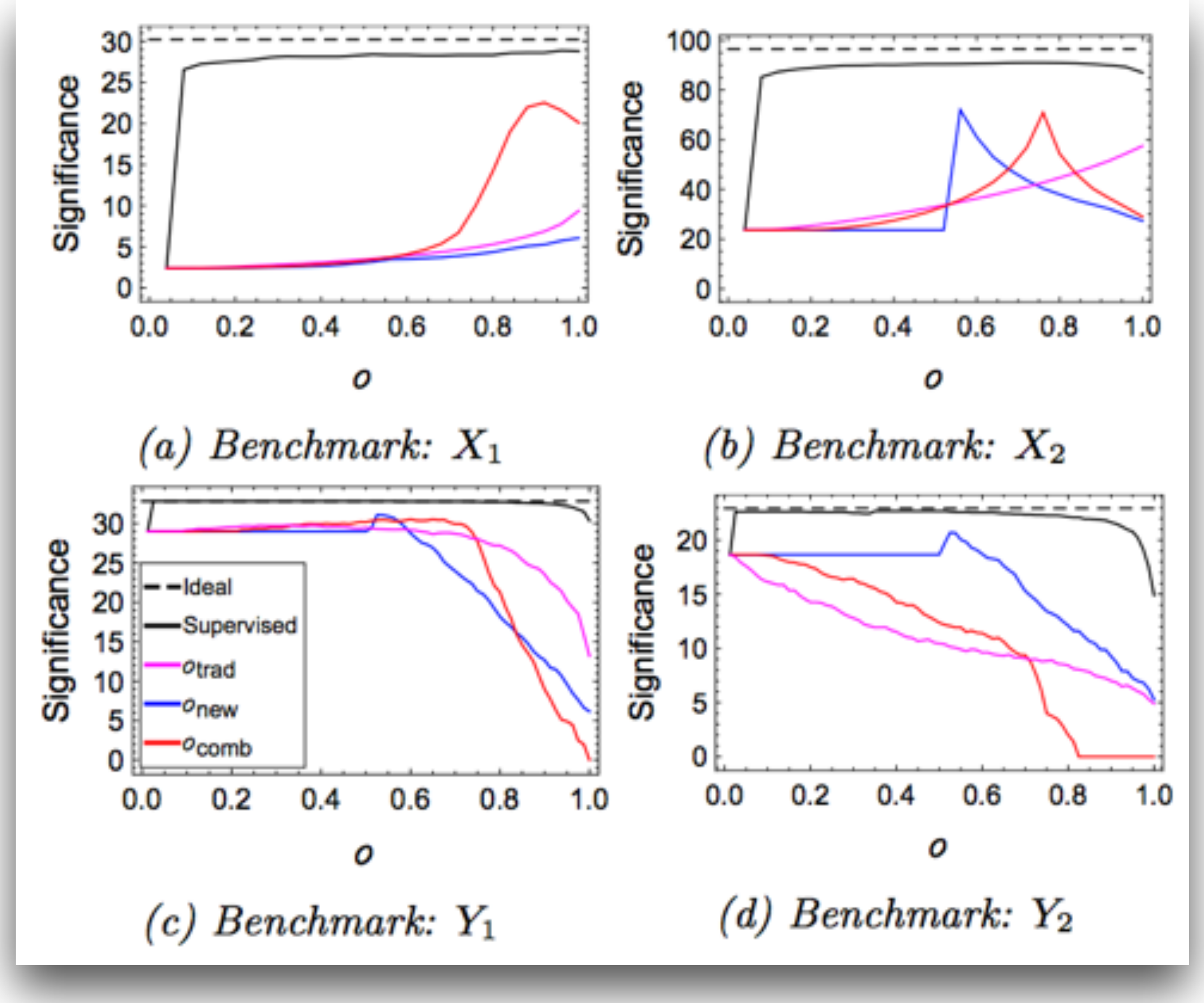
- Novelty evaluators determine to what extent the information carried by data distributions in the feature space can be utilized for sensitivity analysis.
- Therefore novelty evaluators sensitive to the clustering of the signal/BSM events in the feature space (such as peak, dip, shape, etc.) are developed.



[J. Hajer, Y.-Y. Li, TL and H. Wang, arXiv: 1807.10261]

Parton-level Benchmark Study

[J. Hajer, Y.-Y. Li, TL and H. Wang, arXiv: 1807.10261]



(a) Benchmark: X_1 (b) Benchmark: X_2

(c) Benchmark: Y_1 (d) Benchmark: Y_2

- Analysis one: di-top (leptonic) production at LHC (the SM Xsections have been scaled by a factor 1/2000, for simplification).

$$\mathbf{X_1}: \; pp \to \overline{T}T \to W_l^+ W_l^- \bar{b}b$$

$$\mathbf{X_2}: \; pp \to Z' \to \bar{t}t$$

- Analysis two: $Zh \to llbb + MET$ at future e+e- collider

$$\mathbf{Y_1}: \; h \to \tilde{\chi}_1 \tilde{\chi}_2 \to \tilde{\chi}_1 \tilde{\chi}_1 a.$$

$$\mathbf{Y_2}: \; h \to Za$$

- Sensitivities achieved are not far below the ones based on supervised learning

The follow-up project in collaboration with experimentalists at ATLAS is on-going, to fill up the gap between proof of concept and real applications

Thank you!

Novelty Evaluators - Traditional Wisdom

$$\Delta_{\text{trad}} = \frac{d_{\text{train}} - \langle d'_{\text{train}} \rangle}{\langle d'^2_{\text{train}} \rangle^{1/2}} \qquad \mathcal{O} = \frac{1}{2}\left(1 + \operatorname{erf}\left(\frac{c\Delta}{\sqrt{2}}\right)\right)$$

Novelty measure: range unnormalized

Novelty evaluator: $0 \leq \mathcal{O} \leq 1$

- d_{train} : mean distance of a testing data point to its k nearest neighbors
- $\langle d'_{\text{train}} \rangle$: average of the mean distances defined for its k nearest neighbors
- $\langle d'^2_{\text{train}} \rangle^{1/2}$: standard deviation of the latter
- All quantities are defined wrt the training dataset

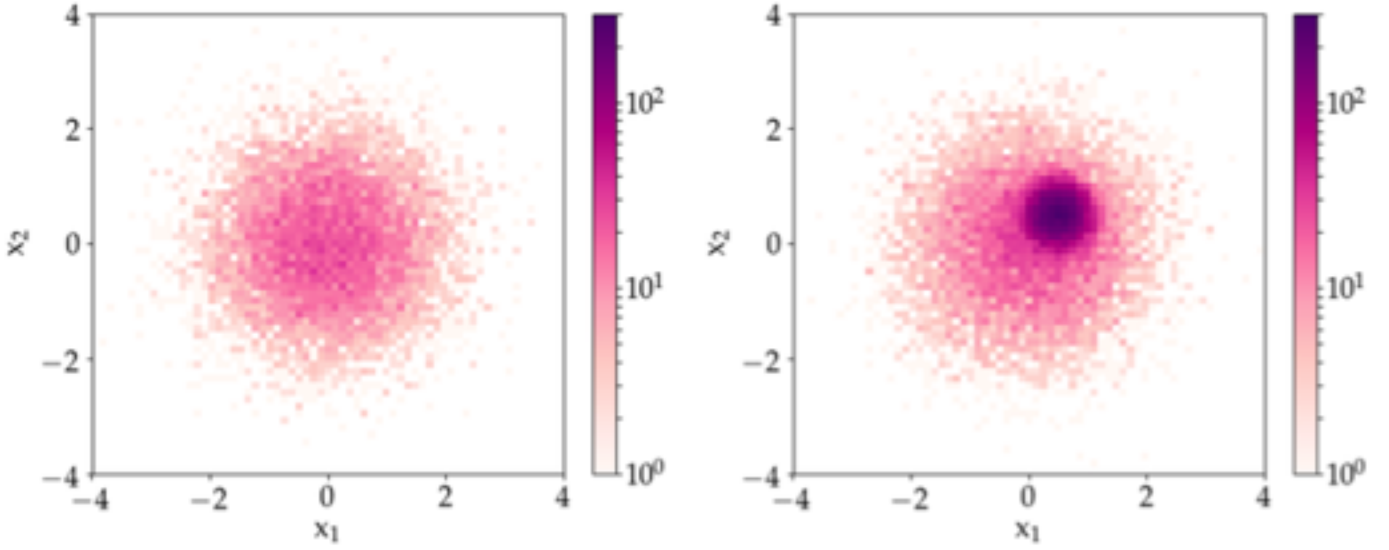
[H. Kriegel, P. Kroger, E. Schubert, and A. Zimek, 2009]
[R. Socher, M. Ganjoo, C. D. Manning, and A. Ng , 2013]

Novelty Evaluators - New Input

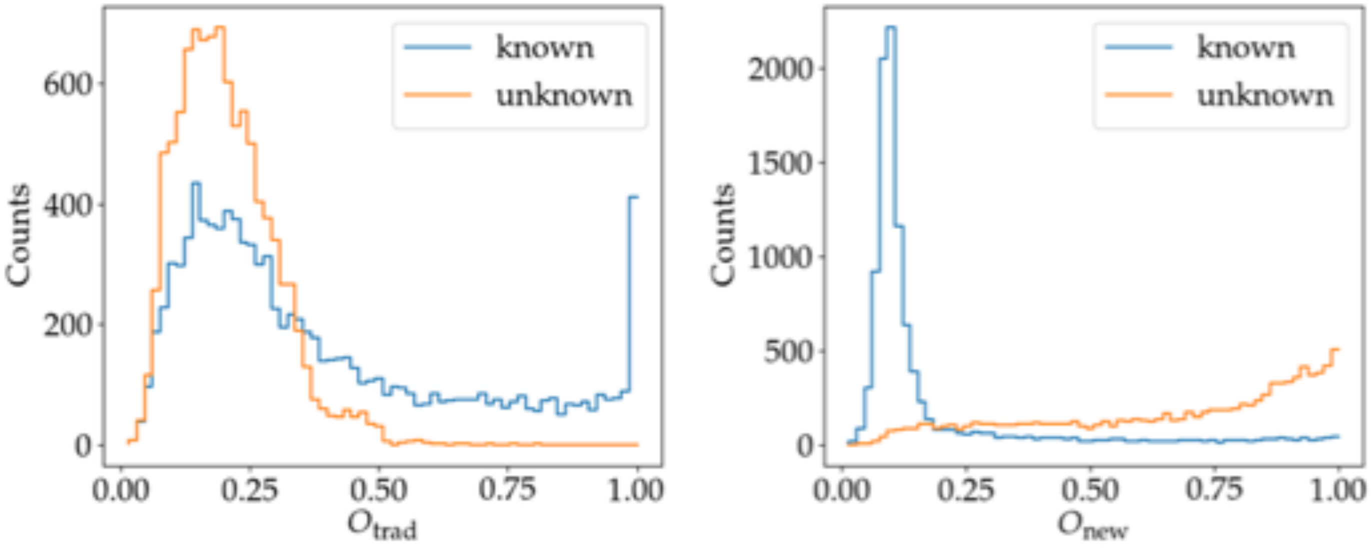
$$\Delta_{\mathrm{trad}} = \frac{d_{\mathrm{train}} - \langle d'_{\mathrm{train}} \rangle}{\langle d'^2_{\mathrm{train}} \rangle^{1/2}} \qquad \Delta_{\mathrm{new}} = \frac{d_{\mathrm{test}}^{-m} - d_{\mathrm{train}}^{-m}}{d_{\mathrm{train}}^{-m/2}}$$

- d_{train}: mean distance of a testing data point to its k nearest neighbors in the training dataset
- d_{test} : mean distance of a testing data point to its k nearest neighbors in the testing dataset
- m: dimension of the feature space
- Novelty is evaluated by comparing local densities of the testing point in the training and testing datasets
- Approximately statistical interpretation : $\Delta_{\mathrm{new}} \propto \left.\frac{S}{\sqrt{B}}\right|_{\mathrm{local\ bin}}$

Novelty Evaluators: Performance Comparison



(a) Training data. *(b) Testing data.*



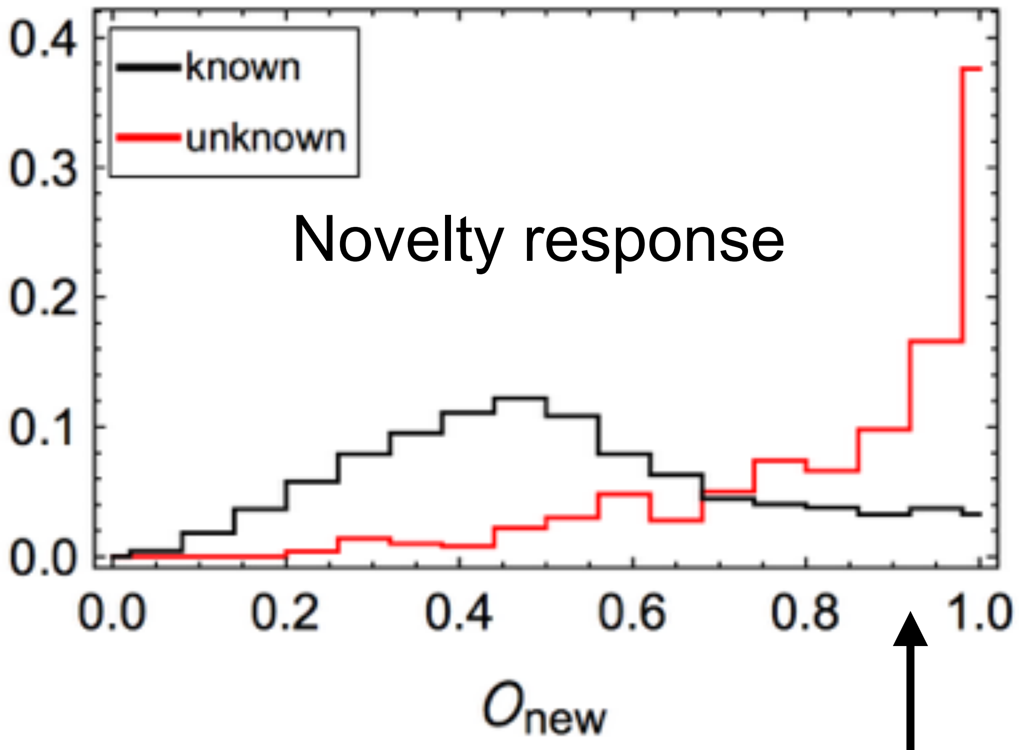
(c) $\mathcal{O}_{trad}$ performance. *(d) $\mathcal{O}_{new}$ performance.*

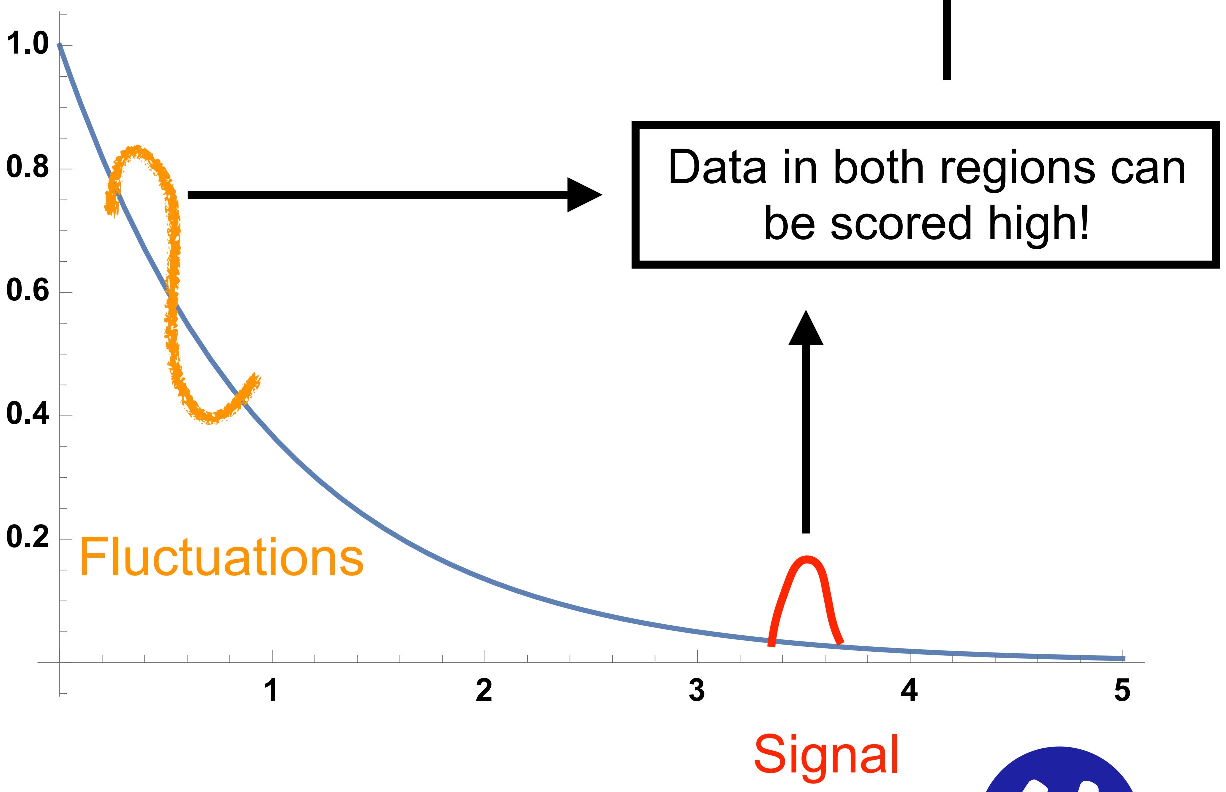
- Consider 2D Gaussian samples
- Training dataset: known pattern only
- Testing dataset: known + unknown patterns
- Compared to O_trad, the novelty response of unknown-pattern data is much stronger for O_new
- => A well-separation between the known- and unknown-pattern data distributions

``Look Elsewhere Effect''

$$\Delta_{\text{new}} = \frac{d_{\text{test}}^{-m} - d_{\text{train}}^{-m}}{d_{\text{train}}^{-m/2}}$$

Without a priori knowledge on the BSM physics, novelty detection generically suffers from ``Look Elsewhere Effect (LEE)'', given the size of the parameter space to be searched.



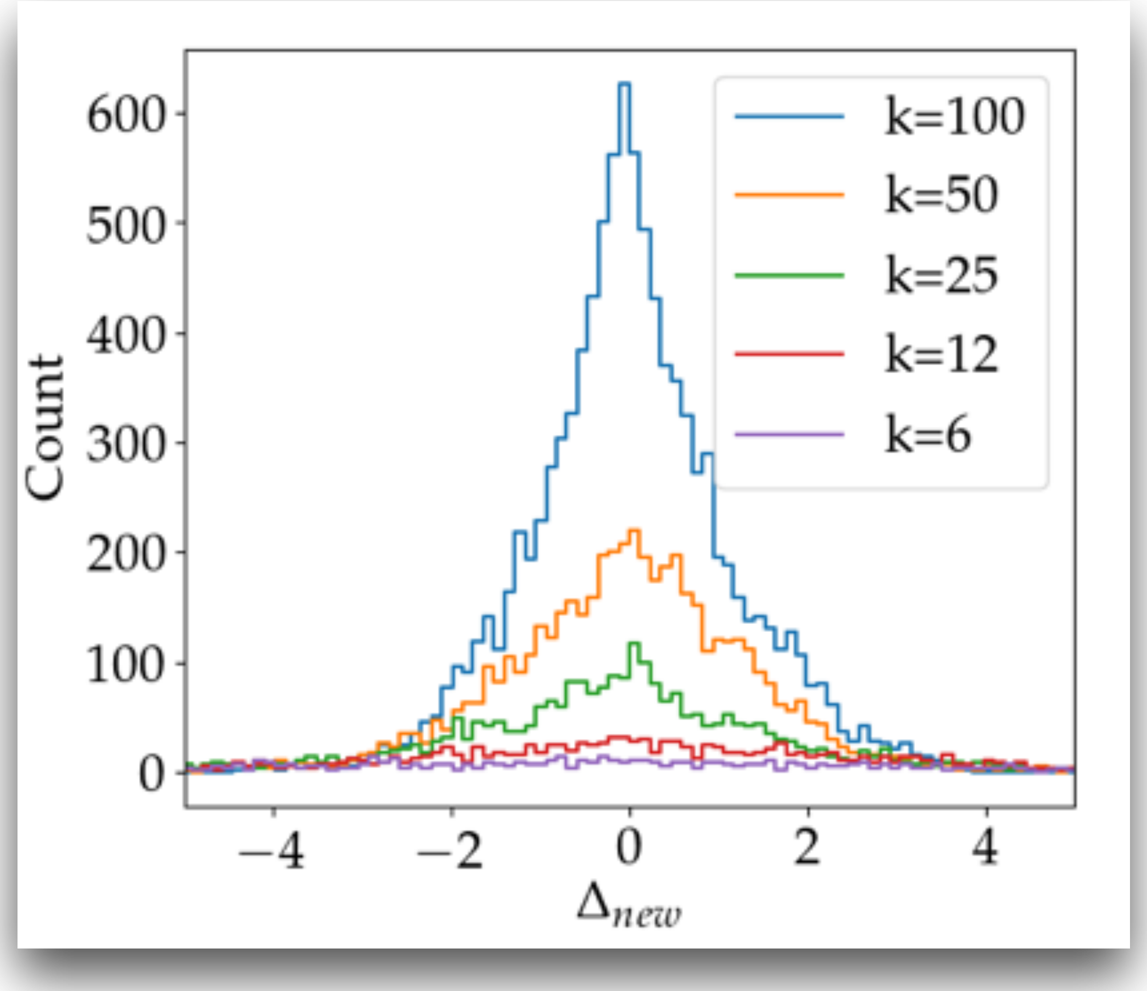


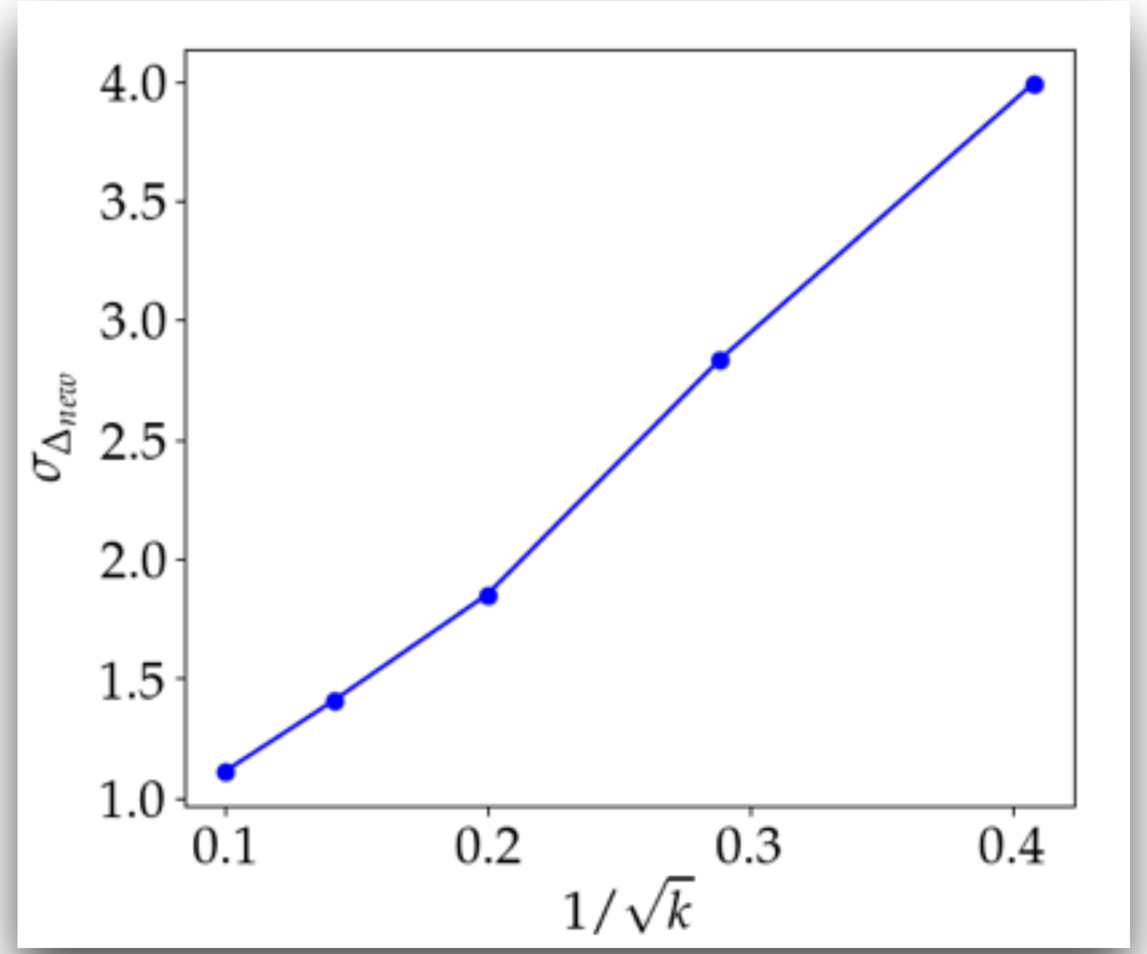
Data in both regions can be scored high!

``Look Elsewhere Effect'' - Central Limit Theorem

Central Limit Theorem

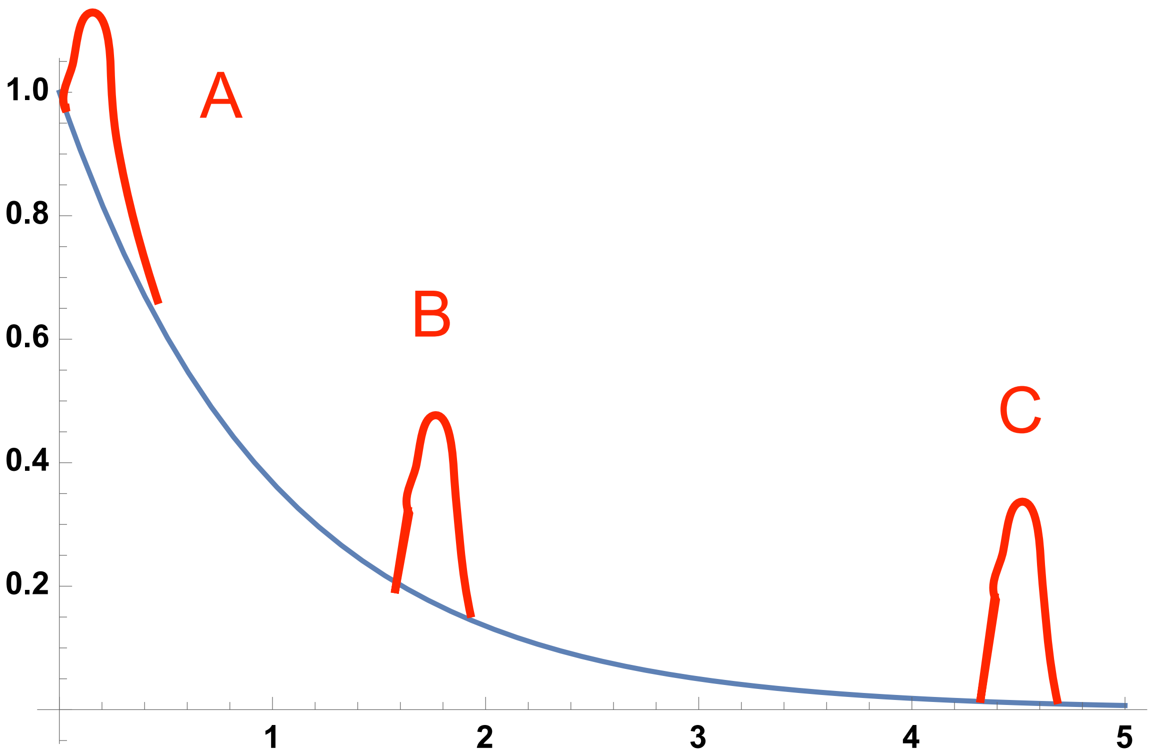
The standard deviation of the Delta_new response scales with 1/sqrt{k} or 1/sqrt{L}, for the testing data with known patterns only.

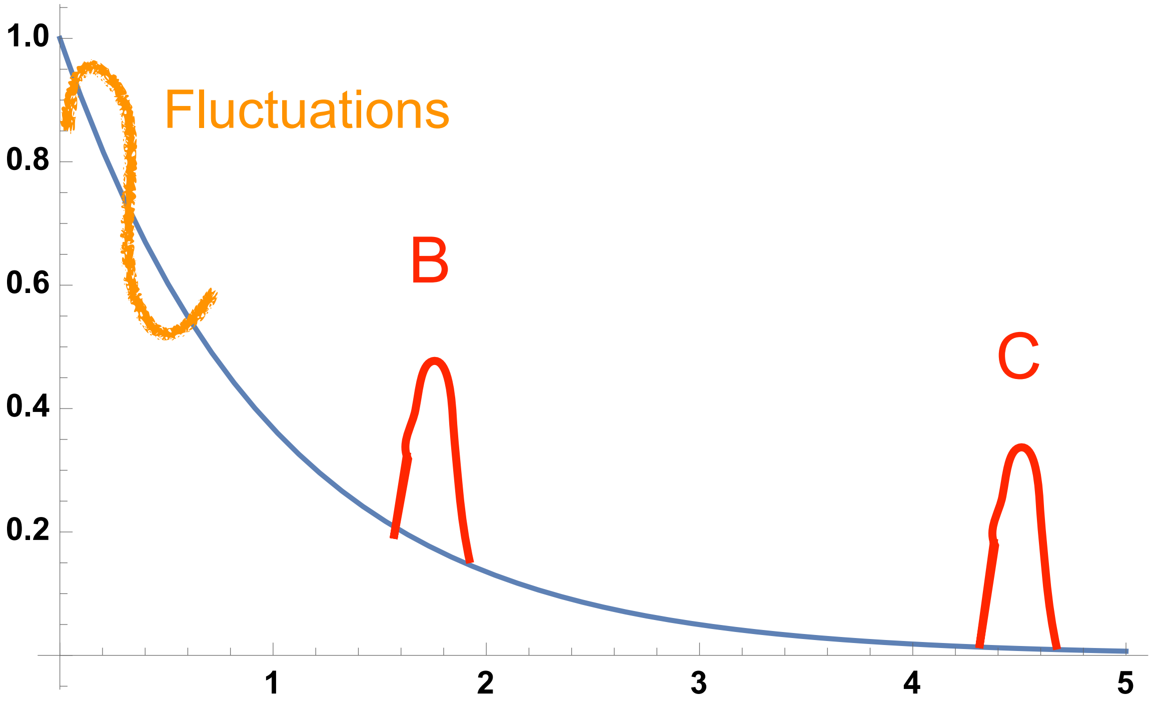




Strategy to Address Large LEE

Given the fixed number of background and signal events, which cases have a worse LEE among A, B, C?





To compensate for high-scoring of known-pattern data from high-density region

=> $\mathcal{O}_{\text{comb}} = \sqrt{\mathcal{O}_{\text{trad}}\mathcal{O}_{\text{new}}}$