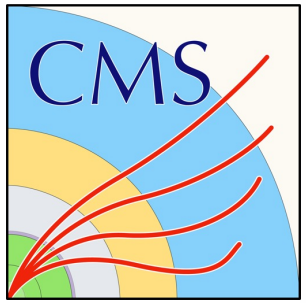
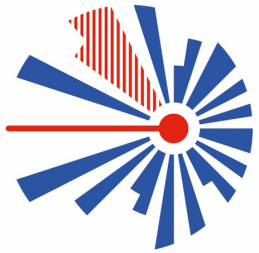
Probing new forces among 3rd generation quarks at the CMS experiment

13 May 2024

Maryam Shooshtari





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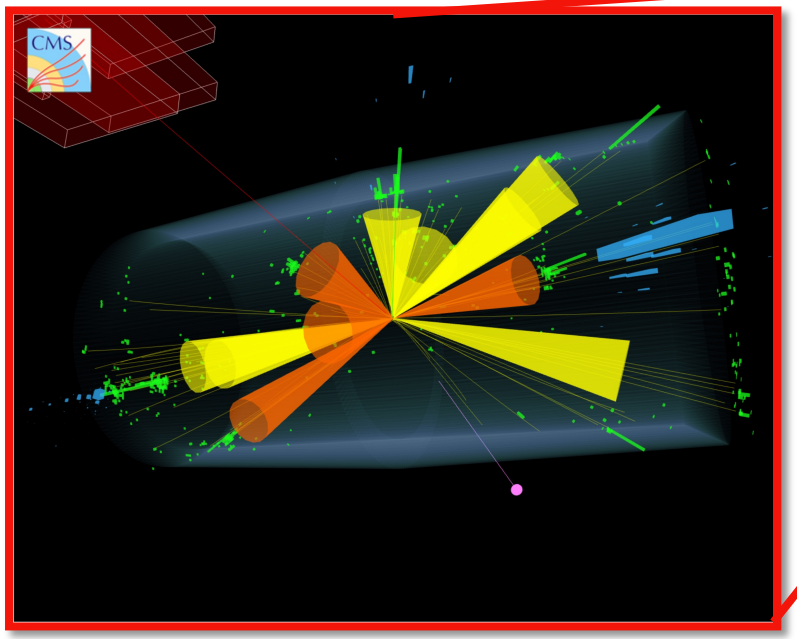
LHC as a top factory

- LHC is the only collider currently capable of producing top quarks
- They are studied at high precision in CMS

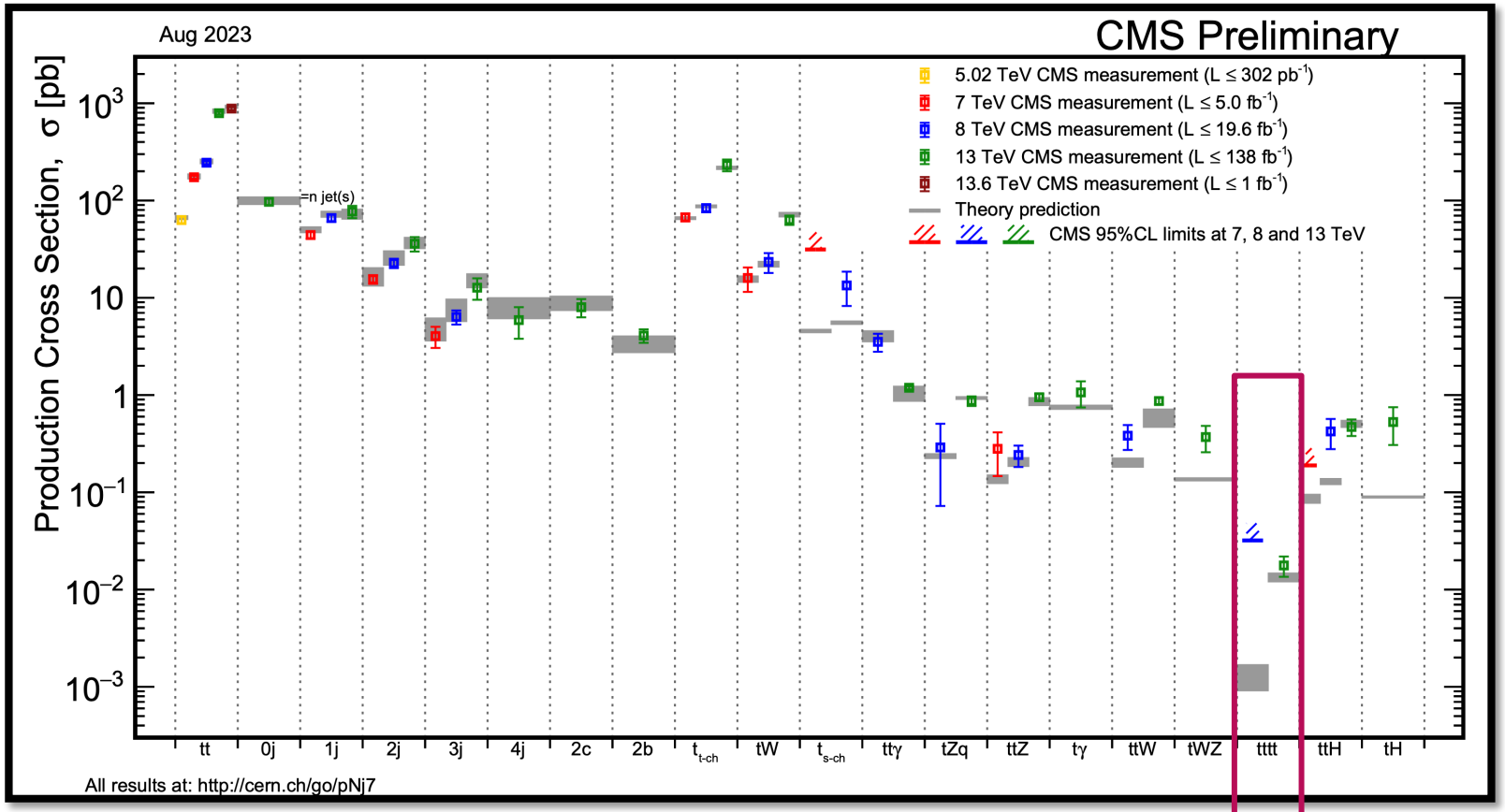


Top quarks

- Top quark is the heaviest SM Particle $m_t \approx 172.5\ GeV$
- with a substantial Yukawa coupling $y_t = \sqrt{2}\, m_t/v \approx 1$
- They are extremly short-lived
  - They decay before bound states are formed
  - So we can study top-quark properties through its decay produc

Top quarks at CMS

- Most energetic SM production ever observed
- are extremely rare under the SM assumptions
- can probe four-fermion operators within a SMEFT framework

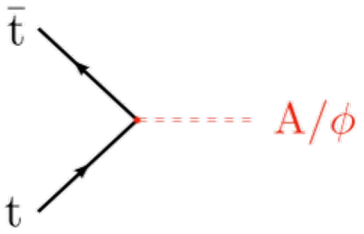


This talk is focused on $t\bar{t}t\bar{t}$

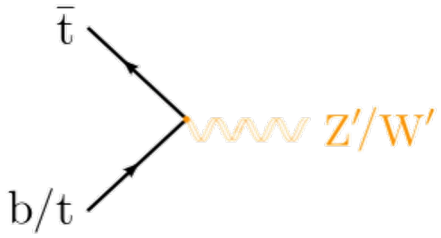
- can be affected through top-philic new physics scenarios
- are sensitive to many new physics scenarios, such as composite Higgs models and supersymmetry

How could heavy quarks feel new forces?

- Extended scalar sectors "two Higgs doublet models" from SUSY or other BSM physics [review]



- High-mass force carriers similar to the W and Z bosons : Z′ and W′ bosons [review]



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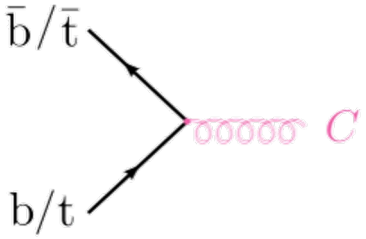

- Composite sector whose bound states mix with the SM particles: (right-handed) top-quark and/or Higgs compositness [review]

- Hypothetical UV models

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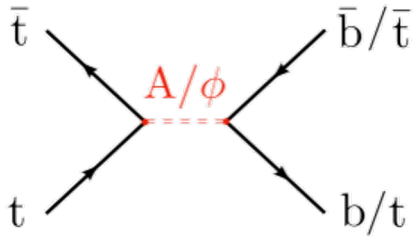

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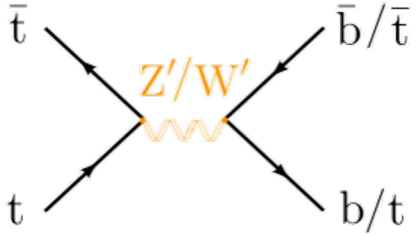

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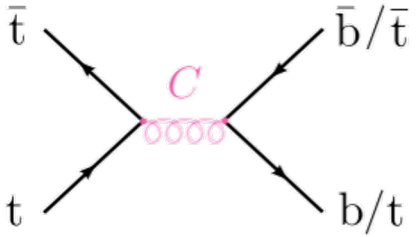

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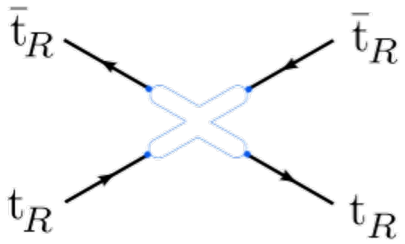

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  - predict force-carrier exchange

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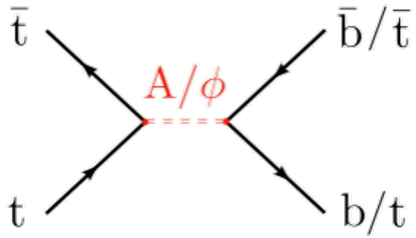

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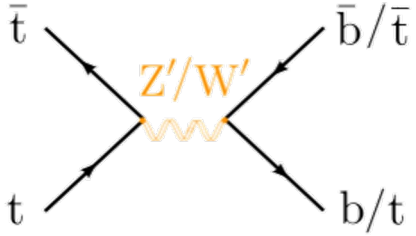

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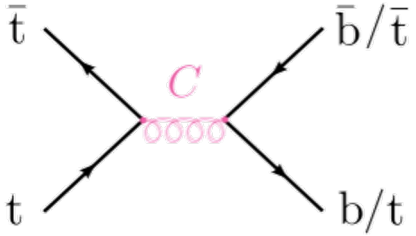

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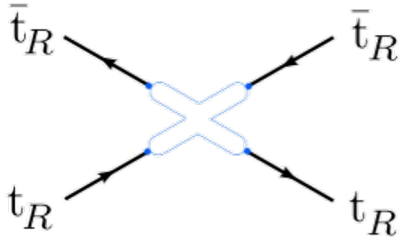

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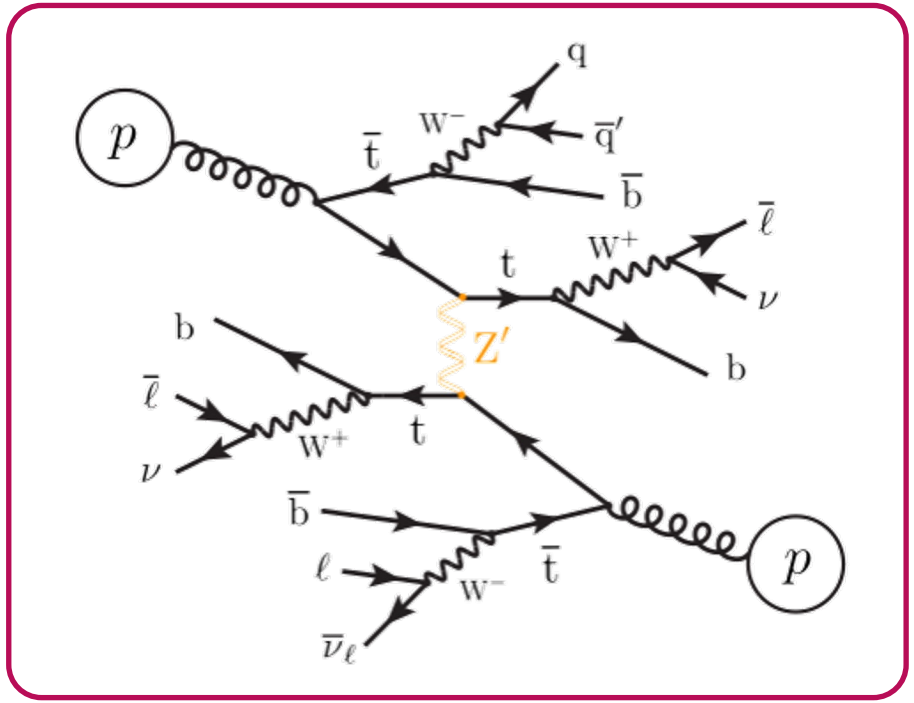
  - modify predictions for LHC processes



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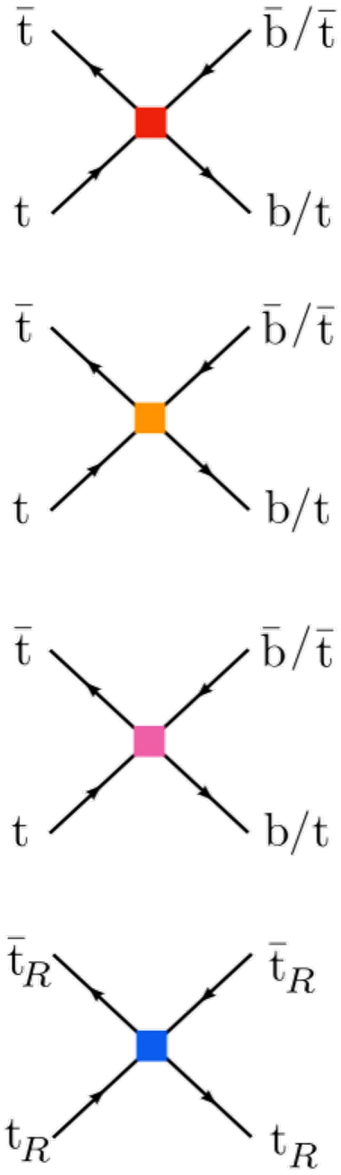
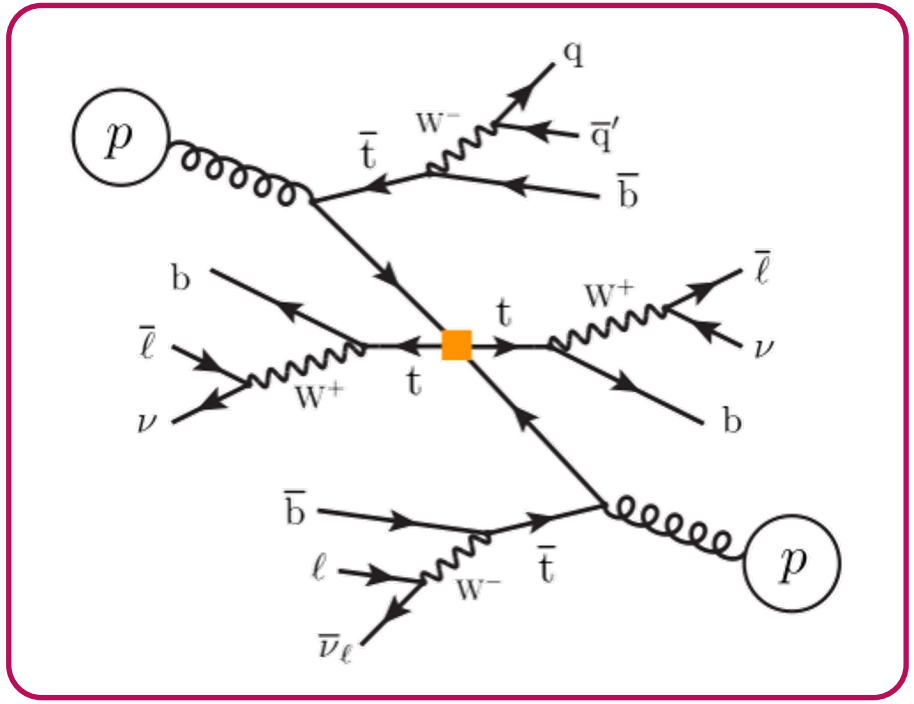


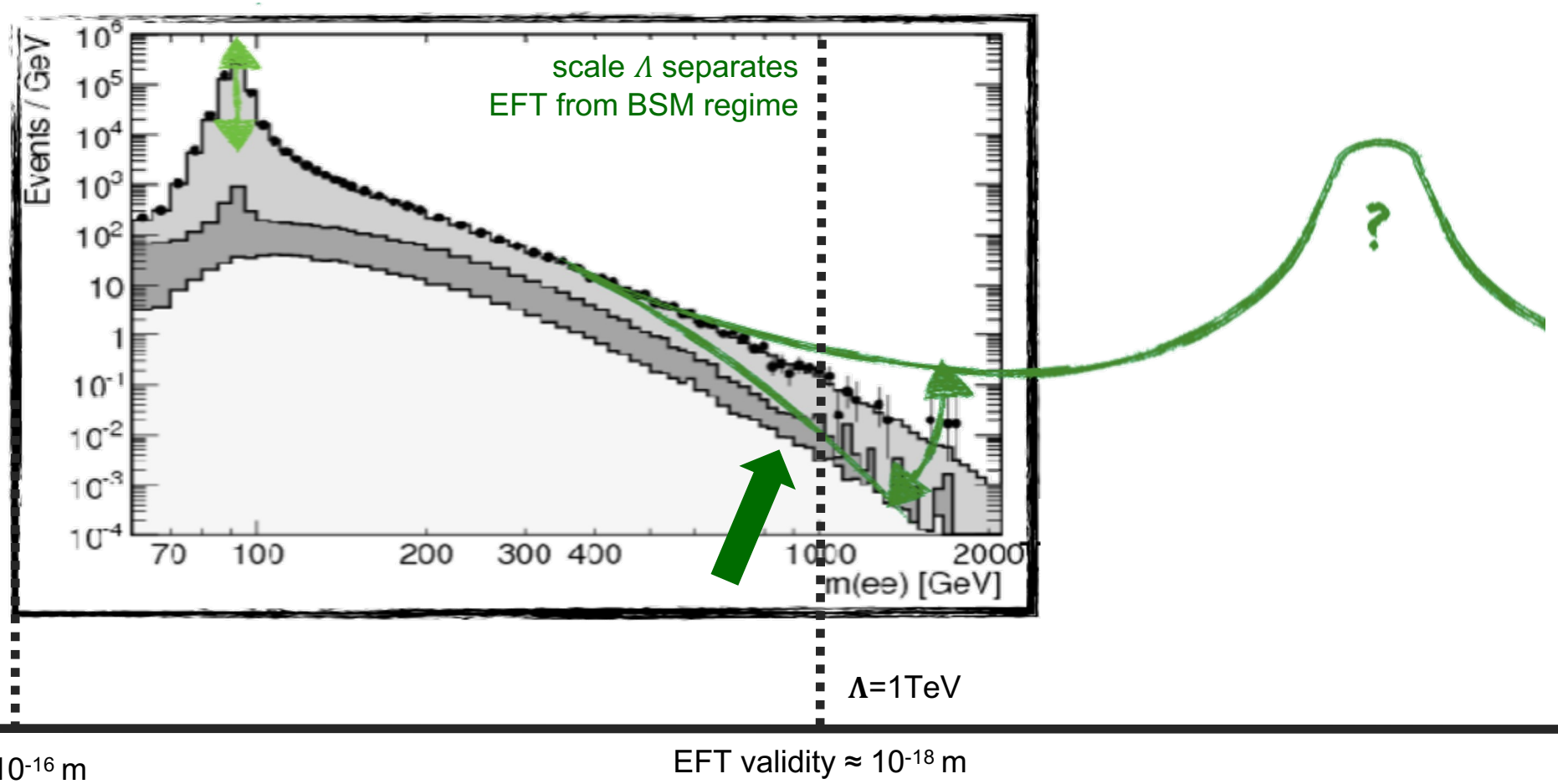
- Hypothetical UV models
  - predict force-carrier exchange
  - modify predictions for LHC processes
  - look for them in LHC data using an "effective theory"



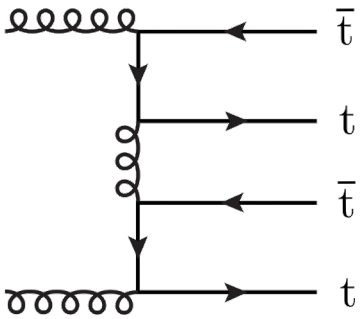
- Combine t vs. t & t vs. b

BSM at the tail of distribution

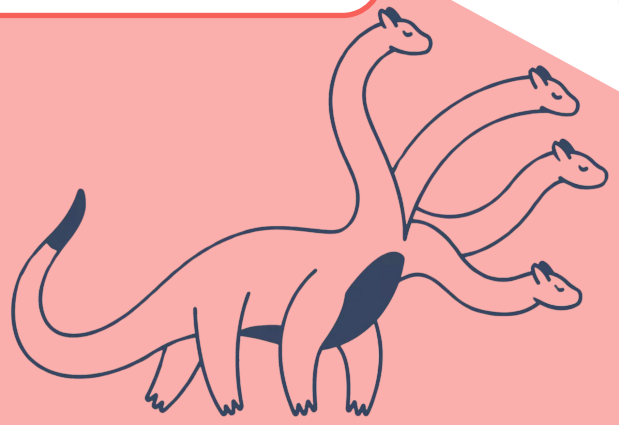
- BSM physics at high energies could change the shape of the tail of the distribution

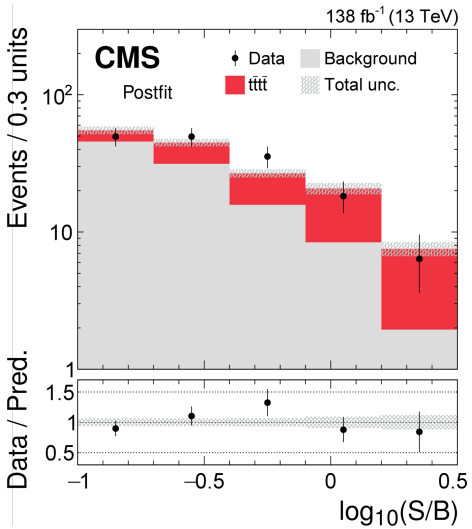


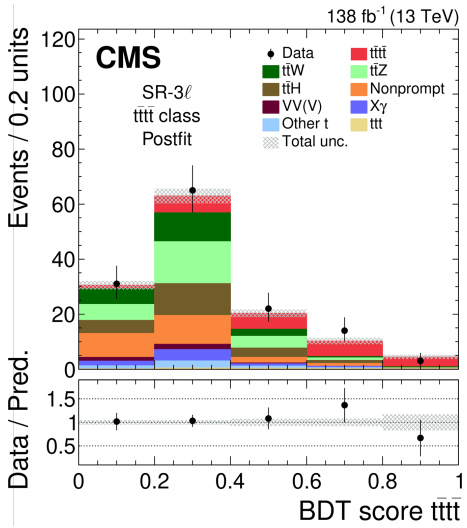
SM $t\bar{t}t\bar{t}$

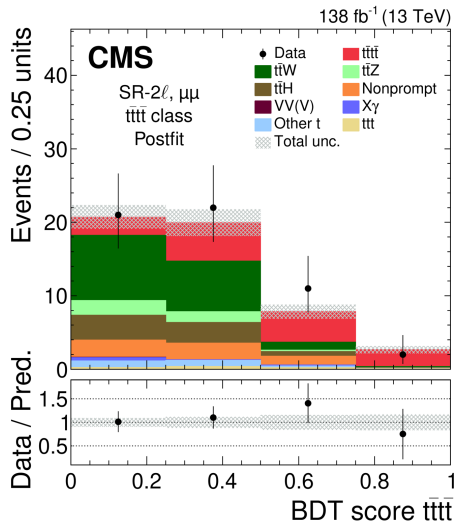


$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(4)}$$

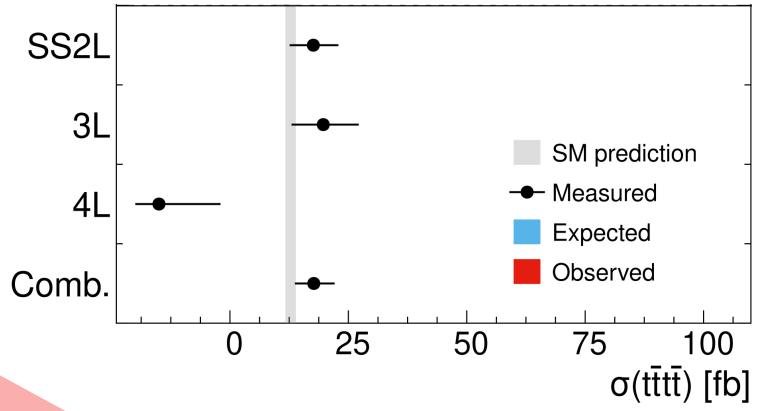


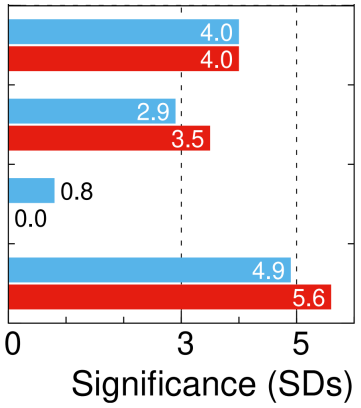






xsec: 17.7 ± 4.2 fb
32% higher than SM

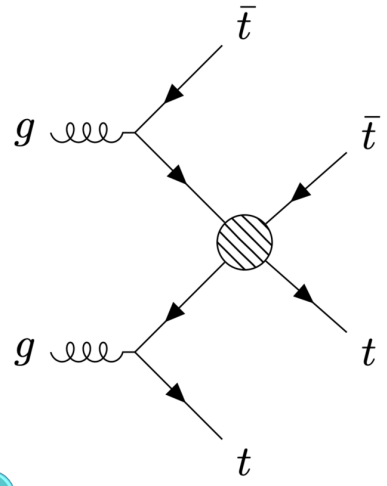




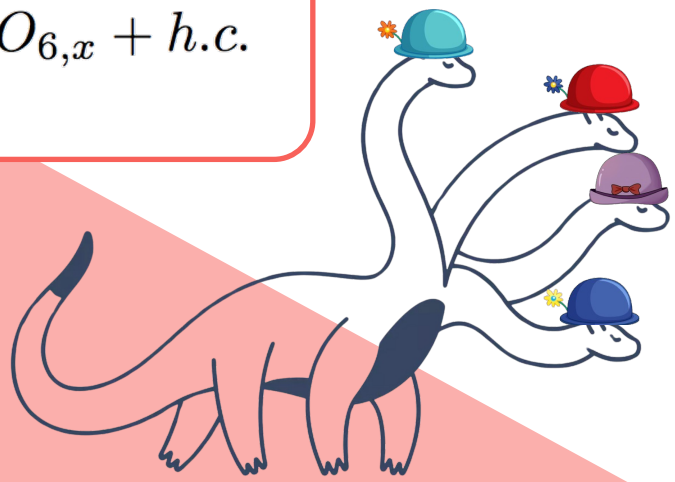
- We first have to understand this process at SM level
- 4-top xsec was measured at SM by CMS at 5.6σ [2305.13439]

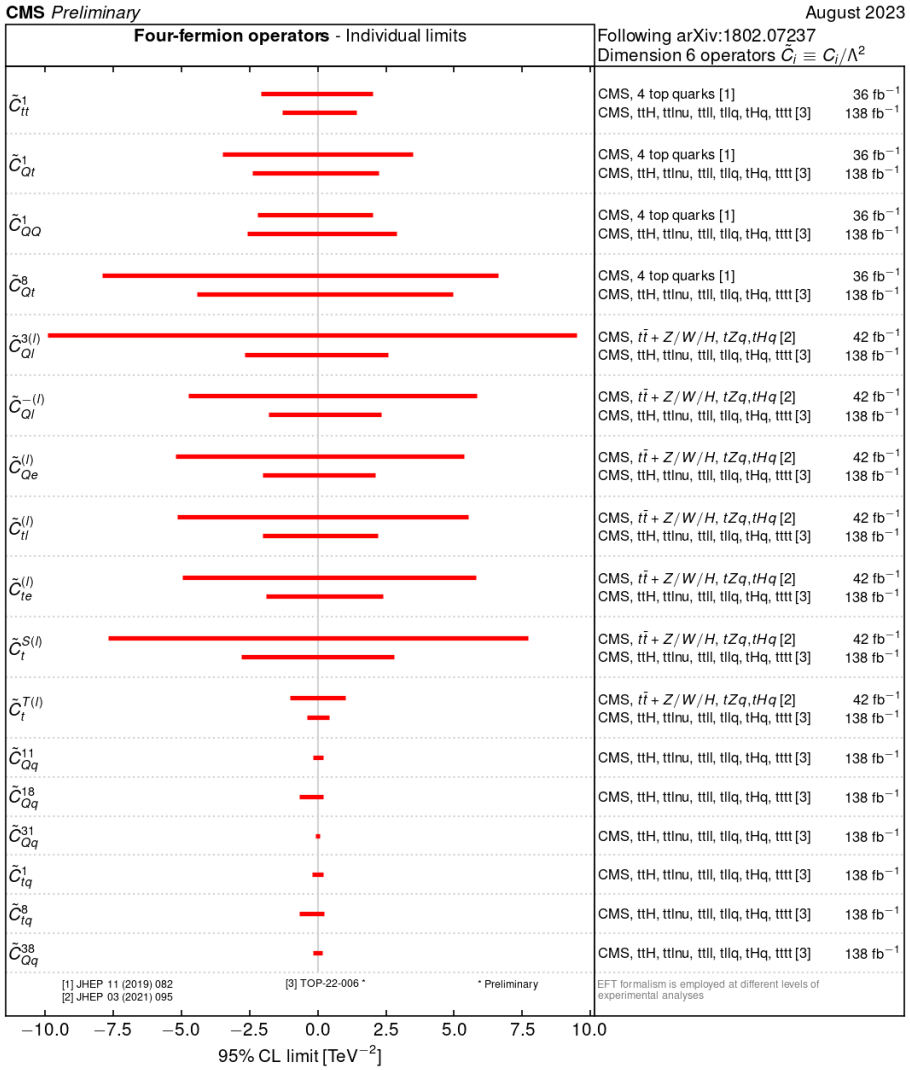
and by ATLAS at 6.1σ [2303.15061]

EFT $t\bar{t}t\bar{t}$



$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(4)} + \sum \frac{C_x}{\Lambda^2} O_{6,x} + h.c.$$



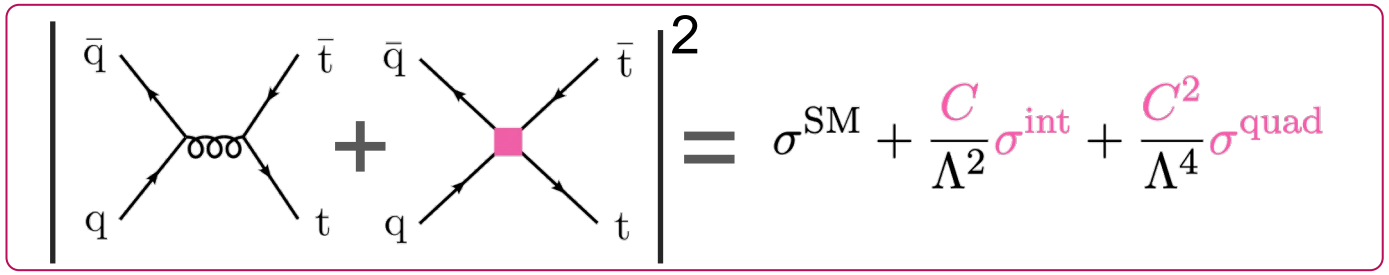


- BSM physics at energy scale Λ may alter cross-sections and kinematics
- One way of parametrizing it is SMEFT : as a function of dimension-6 operators O_x with coefficient c_x
- In this work we focus on four-heavy-quark operators

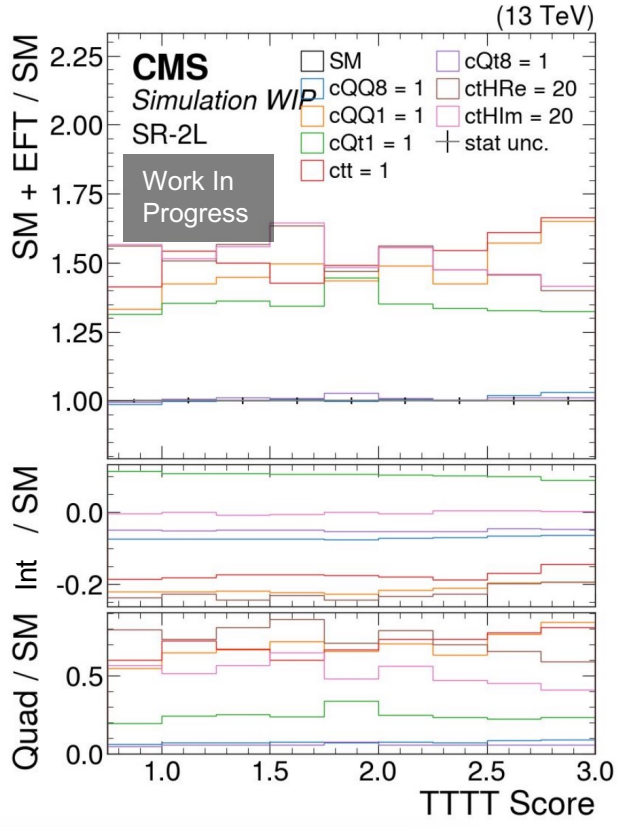
[2208.04962]

Measuring EFT in CMS

- Possible deviations from the SM show up in the x-section in the form :

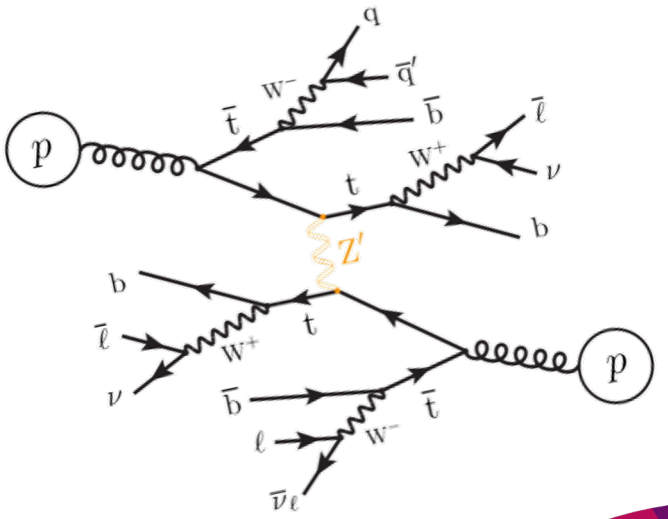


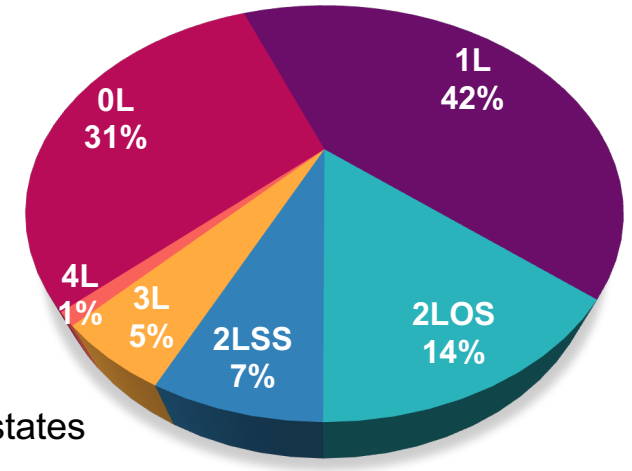
- For each operator, add the relative diagrams to standard model to the simulation
  - Observe the effect in kinematic variables and in x-section



$t\bar{t}t\bar{t}$ topology

- Four top production leads to large object multiplicity final states. Each top decays to Wb, so the detector signature is characterized by
  - 4 b-quarks leading to jets
  - the decay products of 4 W bosons
- We analyse events w/ 2LOS, 2LSS, or 3L final states

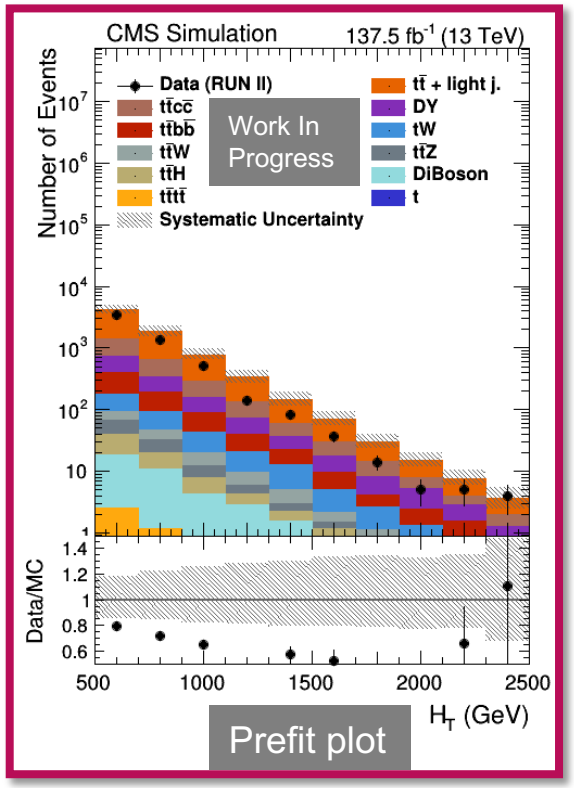


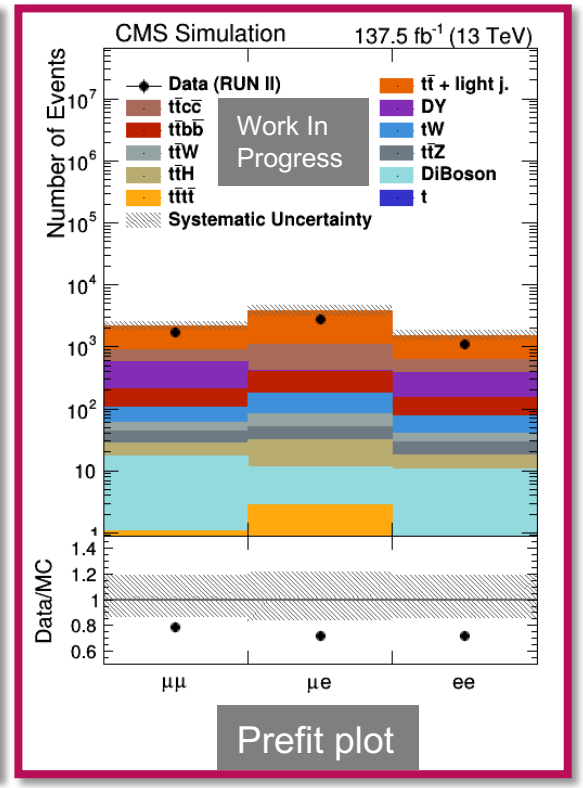


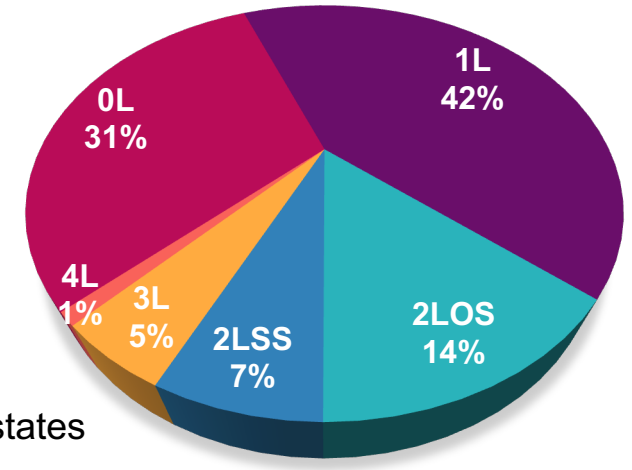
Fraction of tttt final states

$t\bar{t}t\bar{t}$ topology

- 2LOS channel is categorised by jets, b-jets w/ low (b-)jet categories as CRs
- Main challenge in OS : estimation/suppression of dominating tt+jets background







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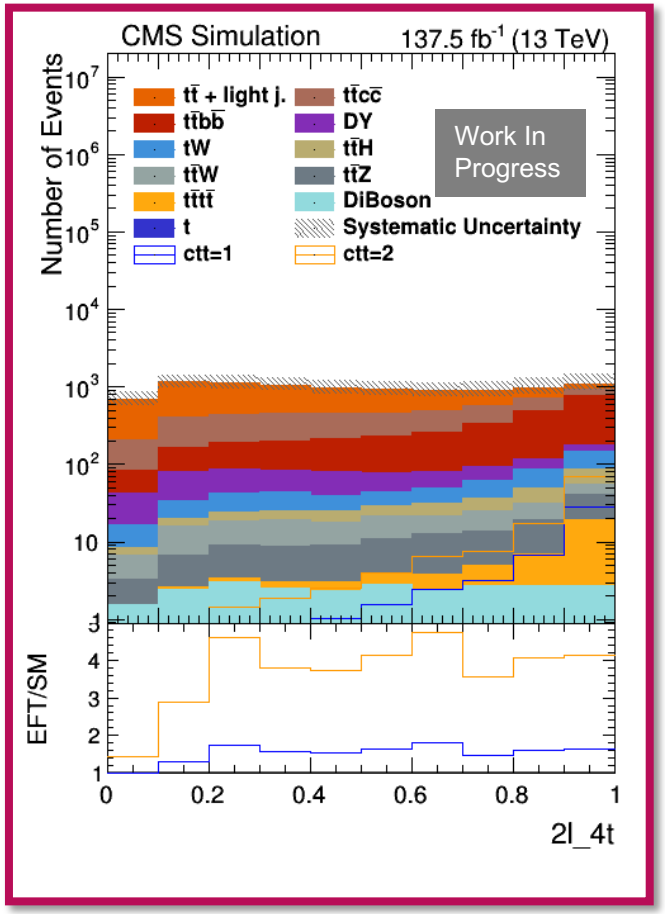
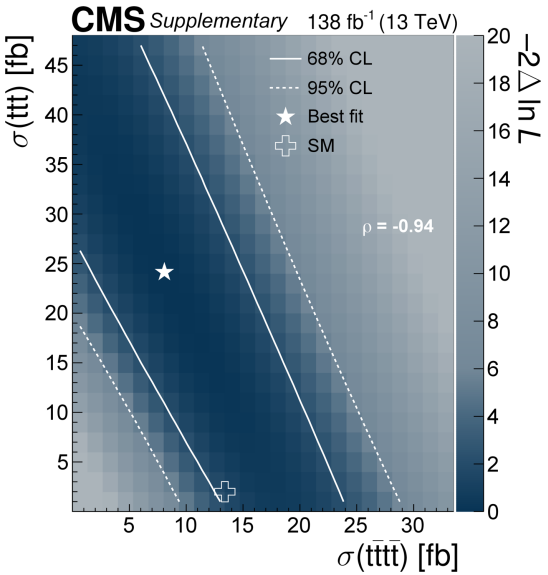
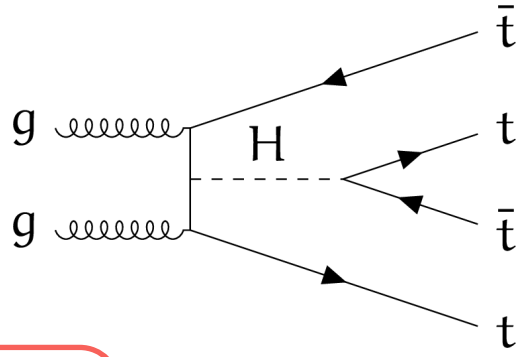
- Main challenge in OS : estimation/suppression of dominating tt+jets background
  - Multivariable classification MVA and Resolved top tagger used in 2LOS (see Cristina's talk)
- Variation of TTTT events for the operator O_{tt}^{1} with wc set to 1 and 2 are clearly visible
- Overlap with 3-top events

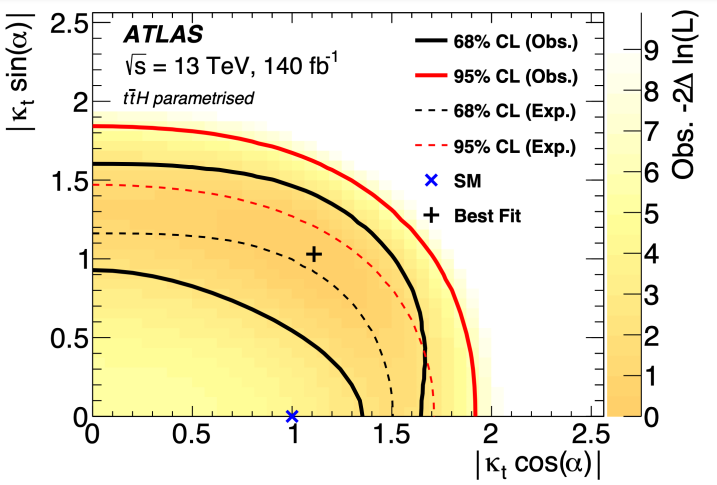


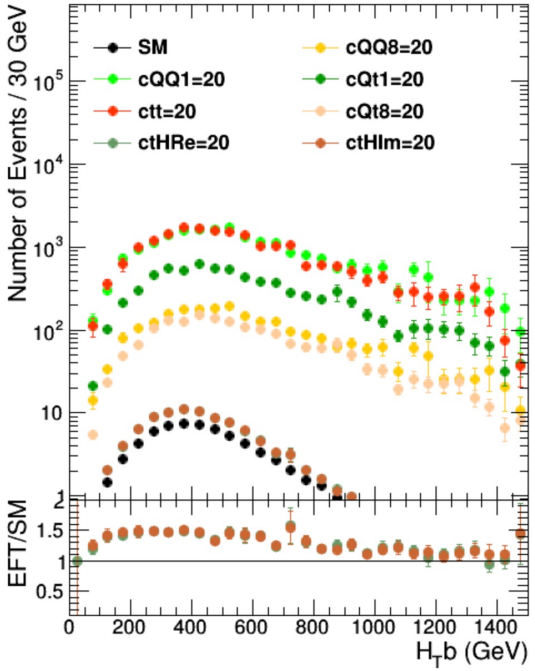


Top Yukawa coupling



$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(4)} + \bar{Q}_L Y_t t\varphi + \bar{Q}_L Y_b b\tilde{\varphi} + h.c.$$

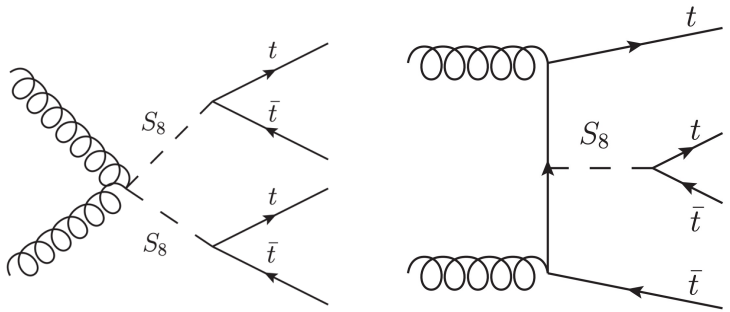




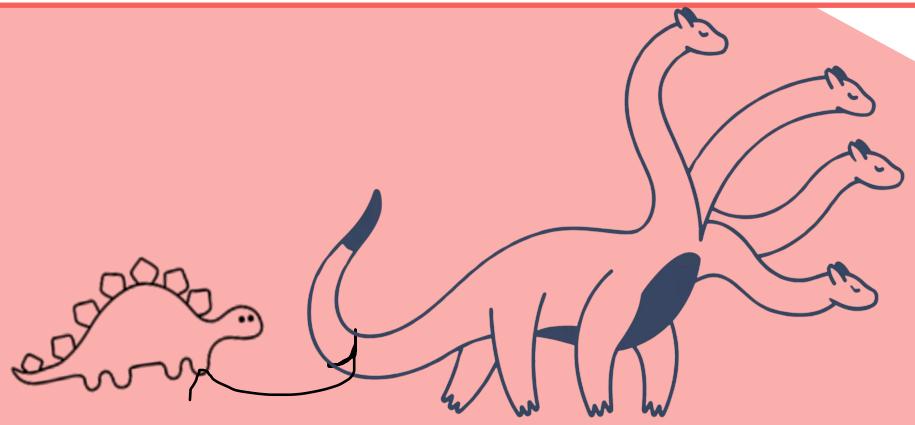
- Top quark is a window on the microscopic origin of the EWSB with its large Y_t.
- First step : EFT operator O_{tH}
- Next : identify phase space of EW $t\bar{t}t\bar{t}$ production and construct observable that improves sensitivity to Yukawa extraction

[1602.01934]

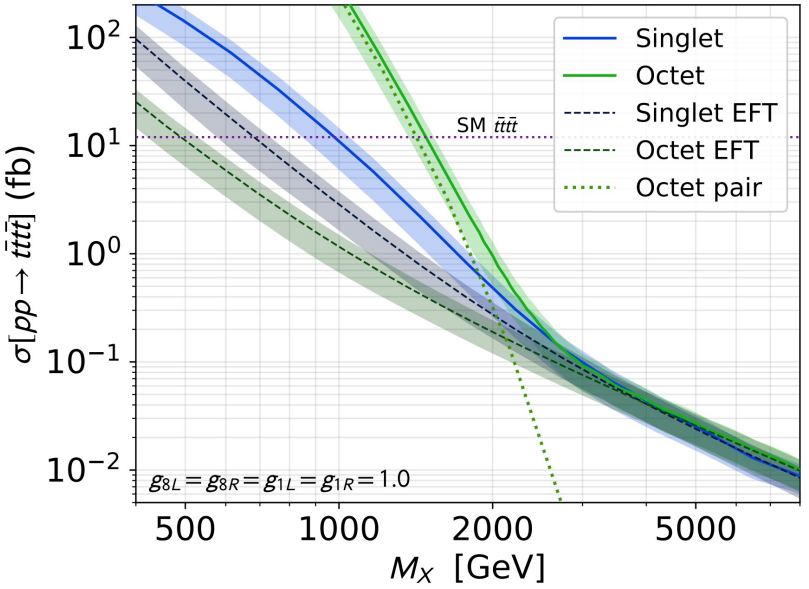
Top philic resonances

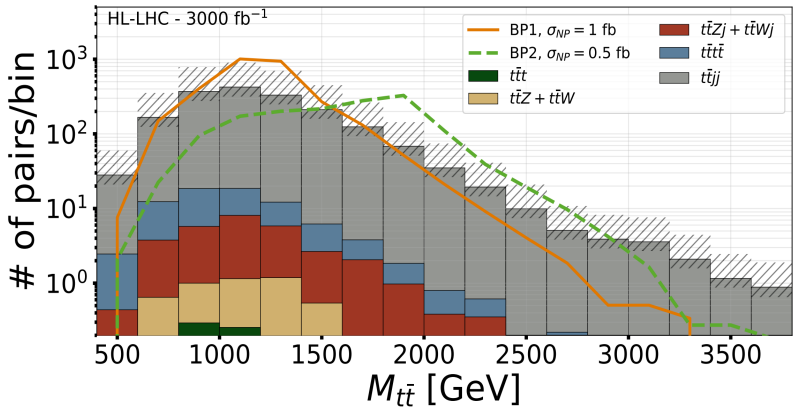


$$\mathcal{L}_{eff} = \mathcal{L}_{SM}^{(4)} + \frac{1}{2}\partial_\mu S_1 \partial^\mu S_1 - \frac{1}{2} m_{S_1}^2 S_1^2 + y_{1S} \bar{t}\, S_1\, t$$
$$+ \frac{1}{2} D_\mu S_8^A D^\mu S_8^A - \frac{1}{2} m_{S_8}^2 S_8^A S_8^A + y_{8S} \bar{t}\, T^A S_8^A\, t$$



- New BSM heavy resonances decaying to top quark pairs
- a color-singlet scalar S_1 or, a color-octet scalar S_8





[2104.09512]
[2404.14482]

Summary

- There are many challenges and opportunities in $t\bar{t}t\bar{t}$ final states
- Distinguish backgrounds like three-top and tt+X
- Signal modelling for different BSM models is in process
    - Yukawa coupling
    - BSM resonances
    - EFT operators
- Develop tools and methods to optimize the analysis
- The hunt continues!