Probing the Top Yukawa with $h \to 4\ell$ Decays

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The Top Yukawa Sector

- Top Yukawa an important parameter in SM and BSM with fundamental implications for hierarchy problem
- Could be modified in solutions to hierarchy problem

$$\mathcal{L}_t \supset \frac{m_t}{v} h\bar{t}(y_t + i\tilde{y}_t\gamma^5)t$$

($y_t = 1$ and $\tilde{y}_t = 0$ in SM)

- May be a potential source of CP violation in BSM
- Important to have probes of magnitude and CP phases

Probing Top Yukawa with Rates

- Can probe Top Yukawa with rate measurements
  - $h \to \gamma\gamma$ and $h \to Z\gamma$ two body decays
  - $gg \to tth$ production (also $gg \to h$ production)

$\mathcal{L}$	$\mu(tth)$	$\mu(h \to \gamma\gamma)$	$\mu(h \to Z\gamma)$
Current	2.8 ± 1.0 [5]	1.14 ± 0.25 [103]	NA
300 fb^{-1}	1.0 ± 0.55 [105]	1.0 ± 0.1 [104]	1.0 ± 0.6 [106]
3000 fb^{-1}	1.0 ± 0.18 [105]	1.0 ± 0.05 [104]	1.0 ± 0.2 [106]

TABLE I. Values of current constraints and future projections on the relative signal strength $\mu_i = \sigma/\sigma_{SM}$ (or BR/BR_{SM})

- Only probe sum of couplings squared of CP even/odd couplings
- Need interference effects to probe CP properties
  - Proposals include differential spectra in $tth, th, ZH, tHW + ...$

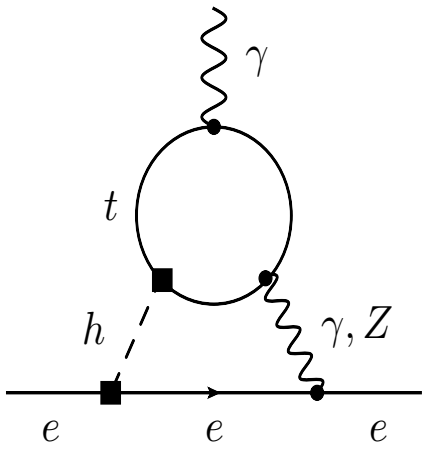
    (see for example: 0007298, 1311.2028, 1312.5736, 1406.1961, 1504.00611)
  - Challenging measurements requiring various assumptions

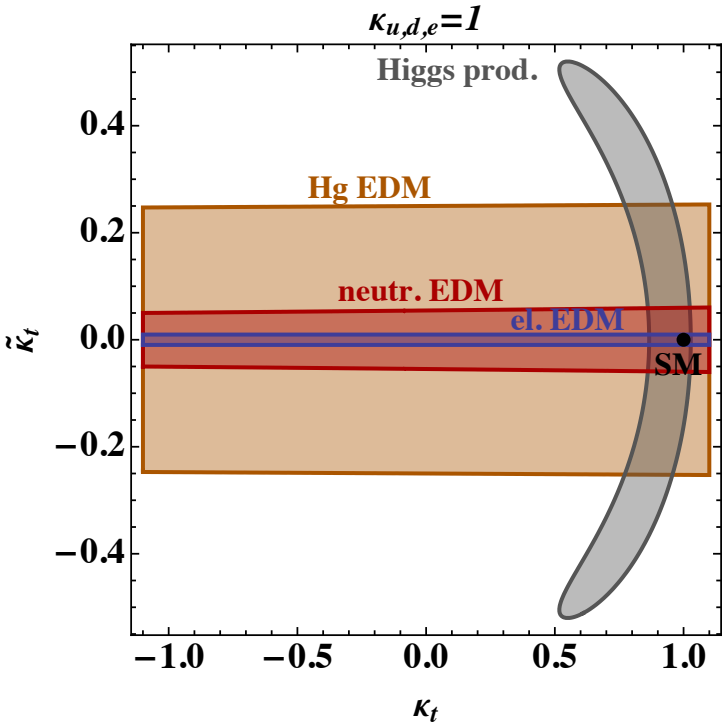
Probing CP Violation Top Yukawa with EDMs

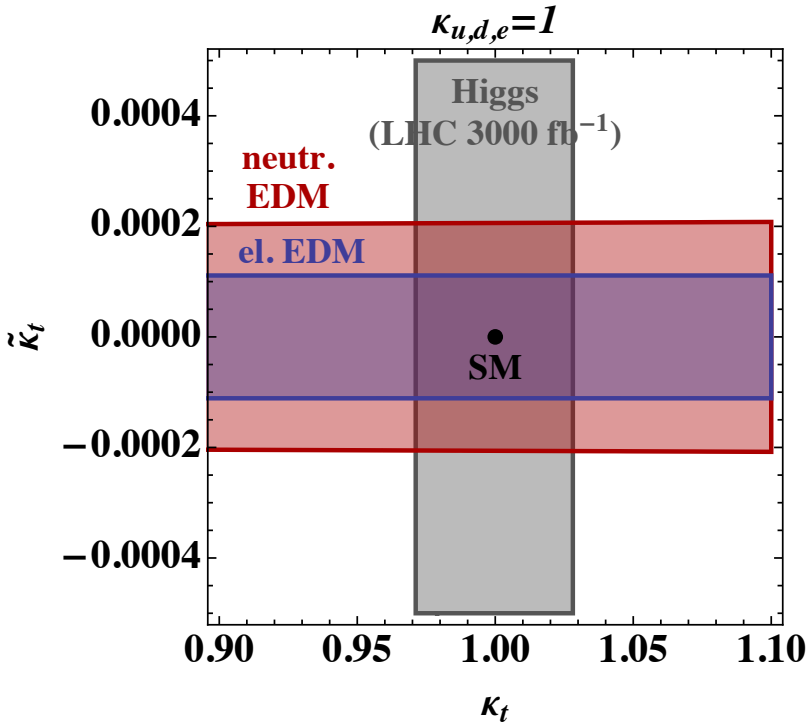
- Strong indirect constraints on CPV from EDMs

  (J. Brod, U. Haisch, J Zupan: 1310:1385)

- Requires assumptions about Higgs coupling to electrons

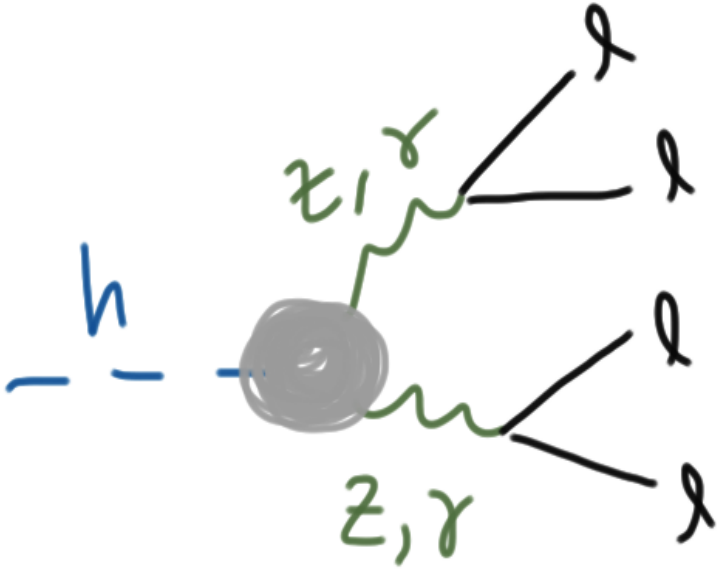






- Useful to have CP sensitive probe free of these assumptions

Effective Higgs Couplings in $h \to 4\ell$



- We consider fully differential Higgs to four leptons decays as a probe of top Yukawa
- Much work using MEM has been done to study hVV effective couplings

(see CMS $h \to 4\ell$ study in 1411.3441)

$$\mathcal{L} = \frac{h}{4v}\Big(2m_Z^2 A_1^{ZZ} Z_\mu Z^\mu$$

Background

$$+ A_2^{ZZ} Z_{\mu\nu} Z^{\mu\nu} + A_3^{ZZ} Z_{\mu\nu} \tilde{Z}^{\mu\nu}$$

Signal

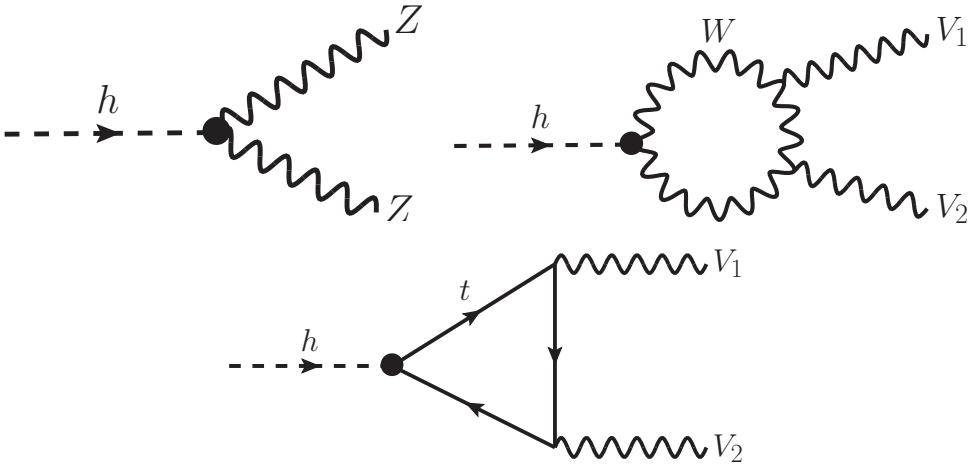
$$+ A_2^{\gamma\gamma} F_{\mu\nu} F^{\mu\nu} + A_3^{\gamma\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$+ 2A_2^{Z\gamma} Z_{\mu\nu} F^{\mu\nu} + 2A_3^{Z\gamma} Z_{\mu\nu} \tilde{F}^{\mu\nu}\Big)$$

- Effective couplings generated by underlying loop effects

Loop effects in Higgs to four lepton decays

- Dominated by tree level hZZ mediated amplitude
- The W and top loops contribute at 1-loop to effective hVV couplings



- Can study the nature of top and W couplings to the Higgs

  (see Y. Chen, J. Lykken, M. Spiropulu, D. Stolarski, RVM: 1608.02159 for study of W couplings)

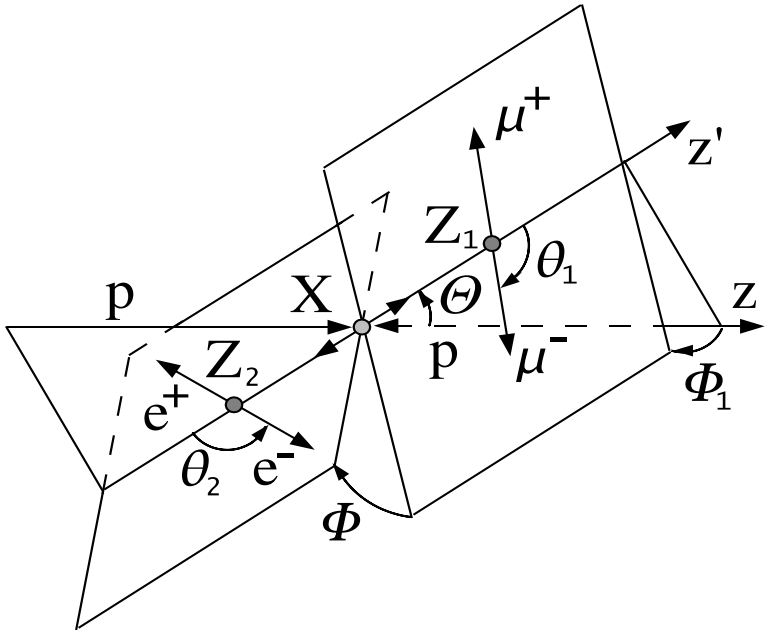
$$\mathcal{L}_{ZW} \supset \frac{h}{v}\left(g_Z m_Z^2 Z^\mu Z_\mu + 2 g_W m_W^2 W^{\mu +} W_\mu^-\right)$$

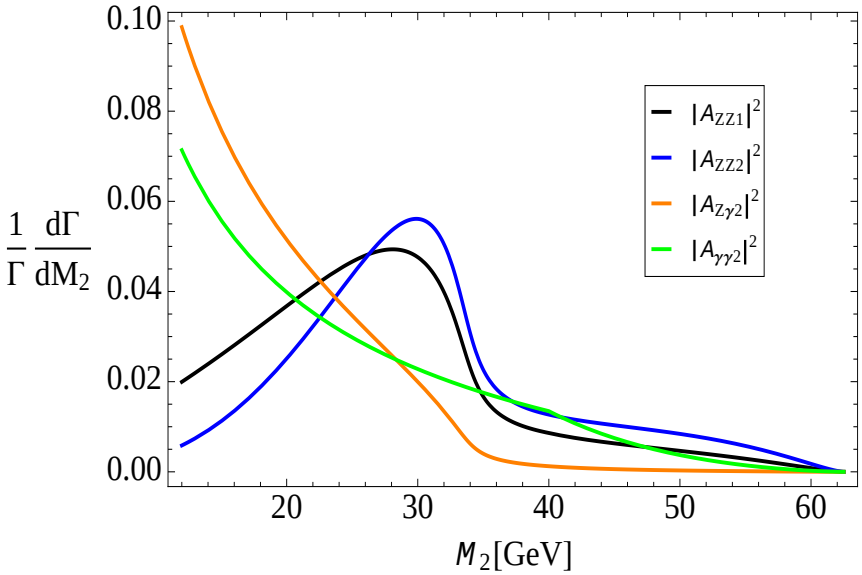
$$\mathcal{L}_t \supset \frac{m_t}{v} h \bar{t}(y_t + i\tilde{y}_t \gamma^5) t$$

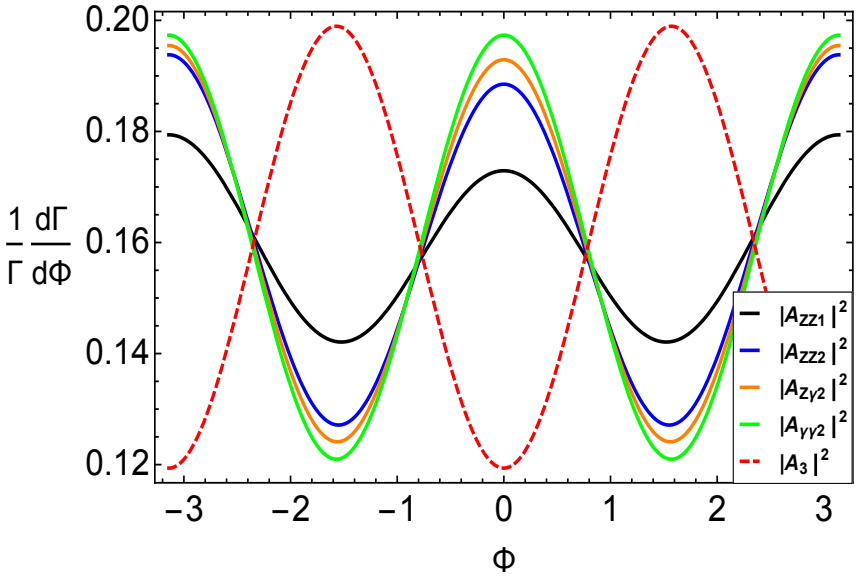
- Interference between tree level hZZ amplitude and loop diagrams allows us to probe CP properties and phases

ID-ing the Higgs with Kinematic Distributions

- Sensitivity to Higgs couplings and underlying loop effects comes from the many kinematic observables
- Contain information about CP properties and tensor structure of Higgs couplings



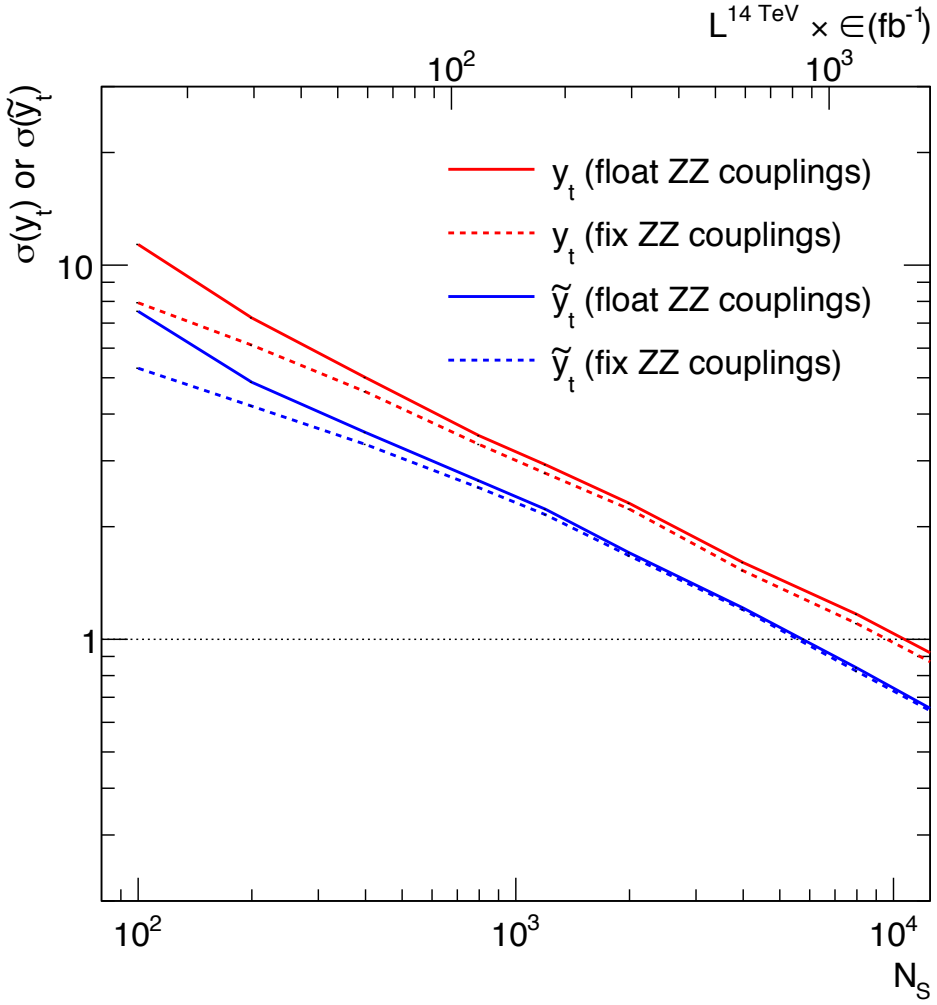




Sensitivity Curves for Top Yukawa

(Y. Chen, D. Stolarski, RVM: 1505:01168)

- Sensitivity to magnitude is statistics limited at the LHC

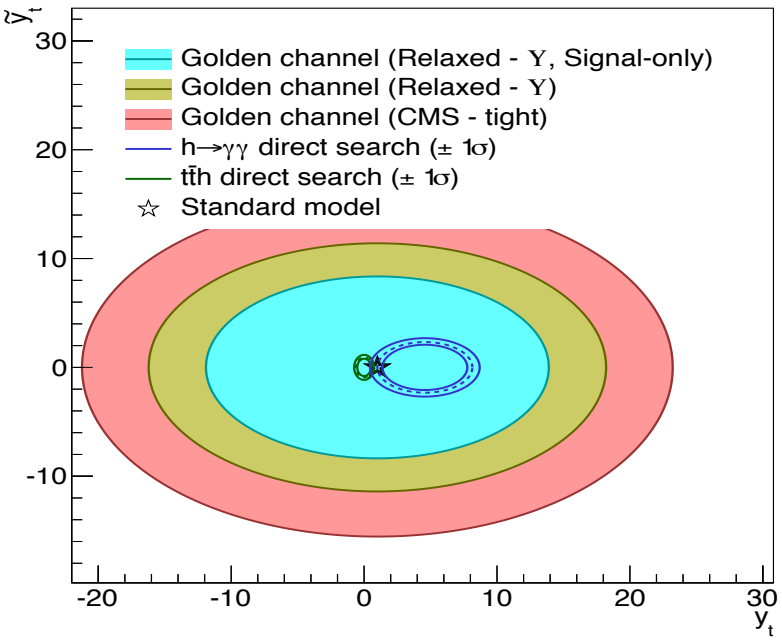


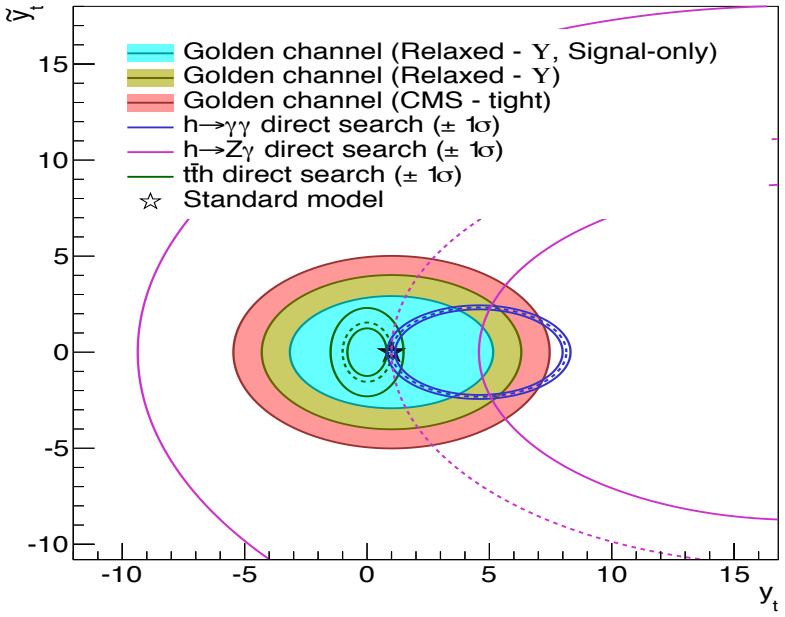
- Can still say something useful about CP properties

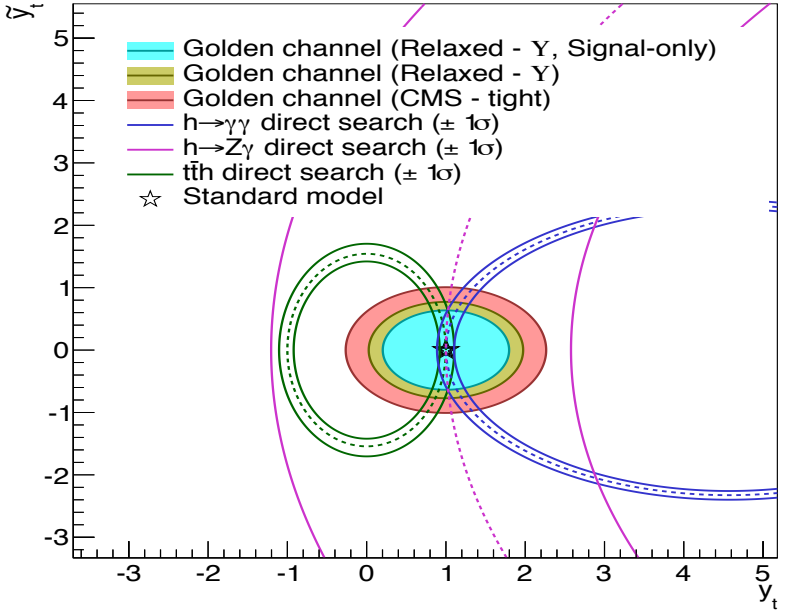
Probing Top Yukawa CP Properties in $h \to 4\ell$

(Y. Chen, D. Stolarski, RVM: 1505:01168)

- Compare with other probes: $h \to \gamma\gamma$, $h \to Z\gamma$, and tth







- Not yet sensitive, but should be at high luminosity LHC
- Qualitatively different probe of top Yukawa CP properties

THANKS!