Probing P and T Violation in The Higgs Sector

Michael Park

in collaboration with

Scott Thomas

Rutgers University

May 7, 2013

Motivation

Existence of Higgs now beyond reasonable doubt

As of now, no compelling evidence for BSM physics

Weak scale new physics could give percent level deviations to SM Higgs observables

Thus far, work has focused on straw men discrimination between discrete possibilities

Precision measurements as a probe of new physics

Symmetries of the interactions should be measured

The Golden Channel

The "Golden Channel" provides an ideal platform for precision measurements

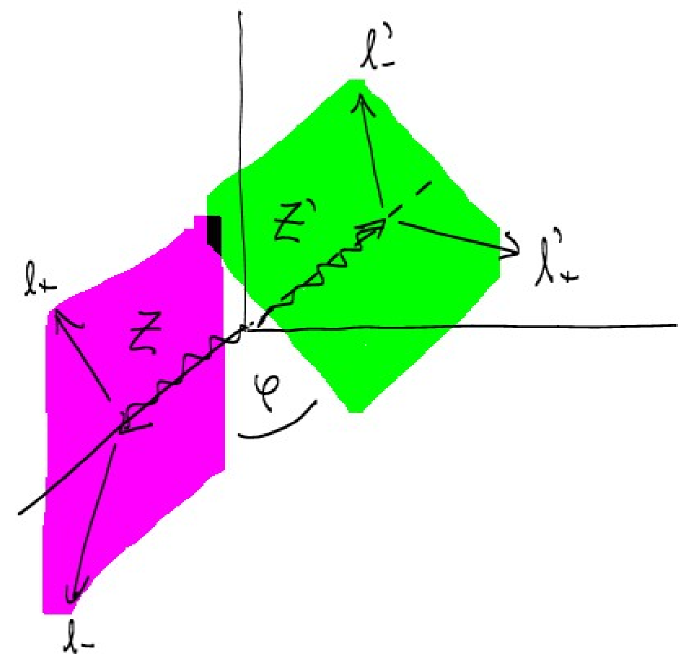
$$pp \to h \to ZZ' \to l_+ l_- l'_+ l'_-$$

Pros:

- **Preserves all kinematic information**
- **Highest accuracy of measurements**

Cons:

- **Low statistics**



An EFT Approach

In the Standard Model, the contributing operator is

$$\mathcal{O}_h = \frac{m_Z^2}{v} h Z^\mu Z_\mu$$

Many contributing d=6 operators

After EWSB, relevant for the golden channel are

$$\mathcal{O}_+ = \frac{g_Z^2 S_{ZZ}}{16\pi v} h Z^{\mu\nu} Z_{\mu\nu}$$

$$\mathcal{O}_- = \frac{g_Z^2 \widetilde{S}_{ZZ}}{16\pi v} h Z^{\mu\nu} \widetilde{Z}_{\mu\nu}$$

Kinematic Structures

Different operators transmit different kinematic properties to decay products

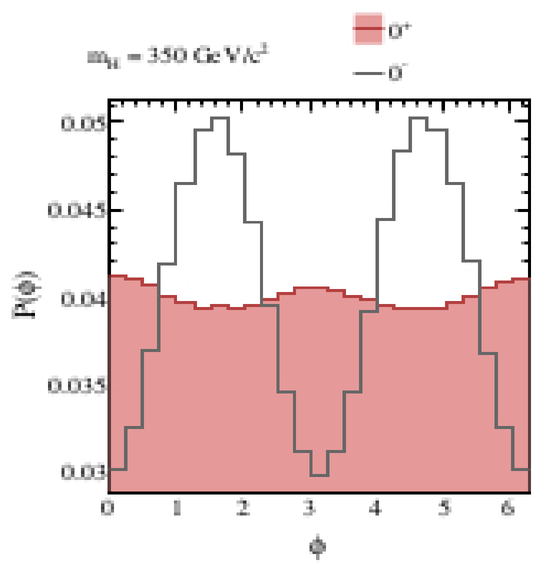
$$Z^\mu Z_\mu \sim \epsilon_Z \cdot \epsilon_{Z'}$$

$$Z^{\mu\nu} Z_{\mu\nu} \sim (p_Z \cdot p_{Z'})(\epsilon_Z \cdot \epsilon_{Z'}) - (p_Z \cdot \epsilon_{Z'})(p_{Z'} \cdot \epsilon_Z)$$

$$Z^{\mu\nu} \widetilde{Z}_{\mu\nu} \sim \epsilon_{\mu\nu\rho\sigma} p_Z^\mu \epsilon_Z^\nu p_{Z'}^\rho \epsilon_{Z'}^\sigma$$

The plane angle is sensitive to the gauge boson polarization

$$\epsilon^\mu \overline{\psi} \gamma_\mu \psi$$



T Violation

T violation should show up as an interference effect

In principle spin measurements could be used

For four body finals states, the plane angle is sensitive to violations of T (Kaon systems)

Photon conversions in Higgs decays to diphoton

Detectors can really only measure 4-vectors

T-odd Observable

The unique T-odd observable for this four body final state is given by

$$\tau \equiv \frac{\epsilon_{\mu\nu\rho\sigma} p^{\mu}_{l_+} p^{\nu}_{l_-} p^{\rho}_{l'_+} p^{\sigma}_{l'_-}}{m_h^4}$$

It is related to the plane angle by

$$\sin\varphi = -\frac{1}{2}\tau \frac{\lambda^{1/2}(m_h^2, m_Z^2, m_{Z'}^2)}{\sqrt{m_Z^2 m_{Z'}^2 (p_{l_+}\cdot p_{Z'})(p_{l_-}\cdot p_{Z'})(p_{l'_+}\cdot p_Z)(p_{l'_-}\cdot p_Z)}}$$

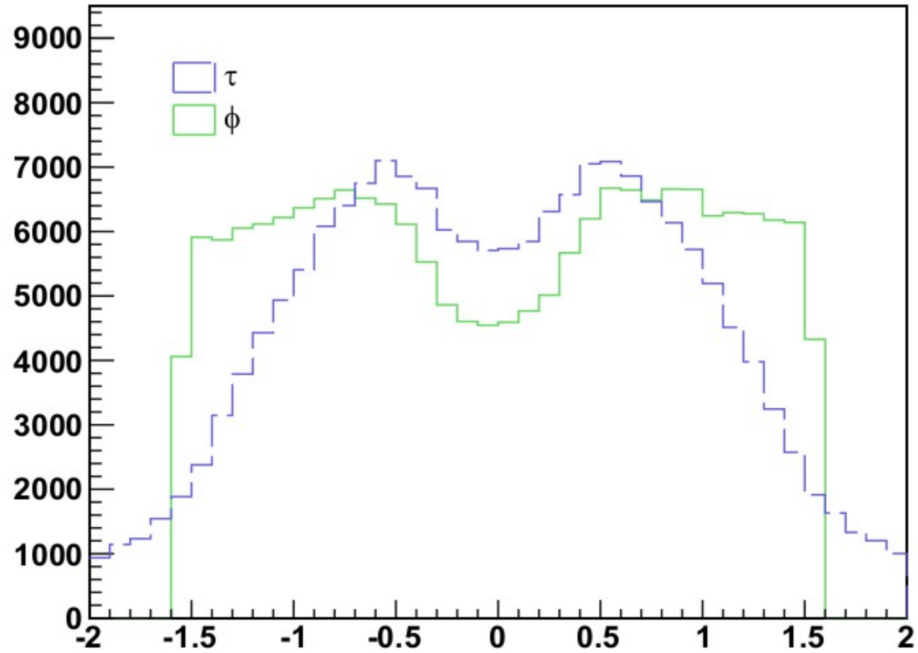
Interference effect, vanishes for pure scalar or pure pseudo-scalar coupling

T-odd Observable

Plotting this variable shows almost no noticeable asymmetry

Maybe the asymmetry is too small

Give up?



Matrix Elements

$$|\mathcal{M}_{total}|^2 = |\mathcal{M}_h|^2 + |\mathcal{M}_-|^2 + \mathcal{M}_h^*\mathcal{M}_- + h.c.$$

Explicit matrix element numerators elucidate kinematic structure

$$|\mathcal{M}_h|^2 \sim \frac{32 m_Z^4 (g_V^2 + g_A^2)^2}{v^2}[(p_{l_+}\cdot p_{l'_+})(p_{l_-}\cdot p_{l'_-}) + (p_{l_+}\cdot p_{l'_-})(p_{l_-}\cdot p_{l'_+})]$$

$$|\mathcal{M}_-|^2 \sim \frac{g_Z^4 \widetilde{S}_{ZZ}^2 (g_V^2 + g_A^2)^2}{8\pi^2 v^2}\Big[8\tau^2 + 2m_Z^2 m_{Z'}^2[(p_{l_+}\cdot p_{Z'})(p_{l_-}\cdot p_{Z'}) + (p_{l'_+}\cdot p_Z)(p_{l'_-}\cdot p_Z)] - m_Z^4 m_{Z'}^4\Big]$$

Interference term should be proportional to tau

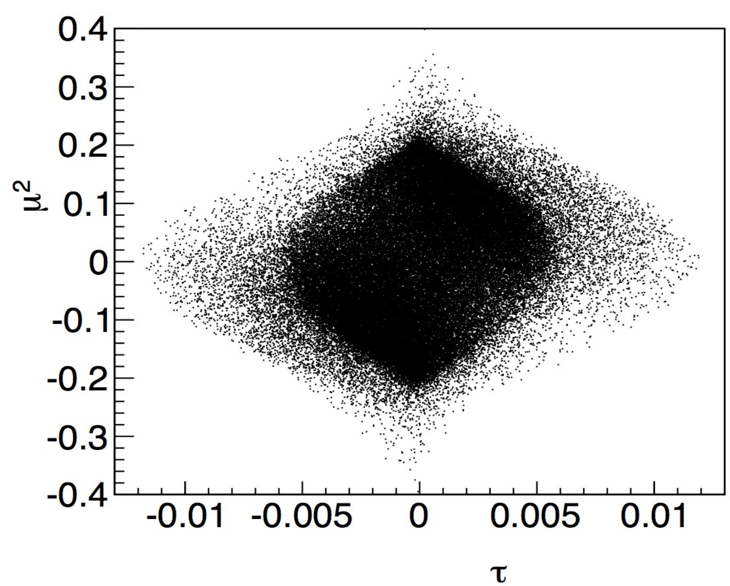
$$\mathcal{M}_h^*\mathcal{M}_- + h.c. \sim \frac{4 g_Z^2 \widetilde{S}_{ZZ} m_Z^2 (g_V^2 + g_A^2)^2}{\pi v}\tau (p_{l_+} - p_{l_-})^\mu (p_{l'_+} - p_{l'_-})_\mu$$

Enhancing the Asymmetry

$$\mathcal{M}_h^*\mathcal{M}_- + h.c. = \frac{4g_Z^2\widetilde{S}_{ZZ}m_Z^2(g_V^2+g_A^2)^2}{\pi v}\tau(p_{l_+}-p_{l_-})^\mu(p_{l'_+}-p_{l'_-})_\mu$$

Asymmetry obscured by momentum structure of matrix element

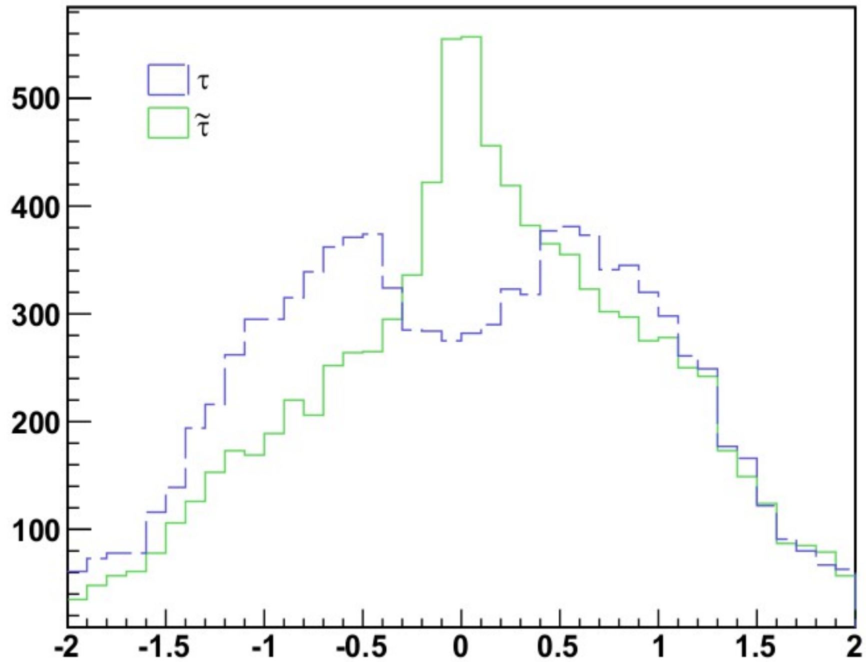
$$\tilde{\mu} \equiv \frac{(p_{l_+}-p_{l_-})^\mu(p_{l'_+}-p_{l'_-})_\mu}{m_h^2} = \frac{m^2_{l_+l'_+} - m^2_{l_+l'_-} - m^2_{l_-l'_+} + m^2_{l_-l'_-}}{m_h^2}$$



Enhancing the Asymmetry

Define a new observable that untangles the asymmetry

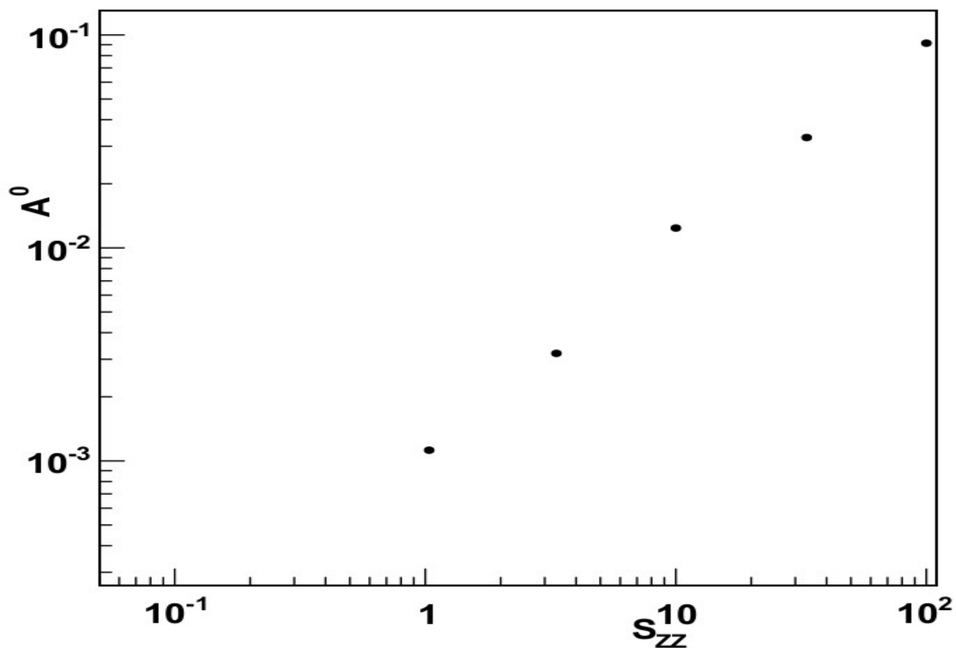
$$\widetilde{\mathcal{T}} \equiv \tau\tilde{\mu} = \frac{\epsilon_{\mu\nu\rho\sigma} p^{\mu}_{l_+} p^{\nu}_{l_-} p^{\rho}_{l'_+} p^{\sigma}_{l'_-} \left(m^2_{l_+l'_+} - m^2_{l_+l'_-} - m^2_{l_-l'_+} + m^2_{l_-l'_-}\right)}{m_h^6}$$



Quantifying the Asymmetry

The simplest way to quantify the asymmetry is

$$\mathcal{A}^{(\theta)}_{\widetilde{\mathcal{T}}} = \int d\widetilde{\mathcal{T}}\ \left(\theta(\widetilde{\mathcal{T}}) - \theta(-\widetilde{\mathcal{T}})\right)\ \frac{d\mathcal{P}(h \to \ell^+\ell^-\ell'^+\ell'^-)}{d\widetilde{\mathcal{T}}}$$



Bounds from EDM's

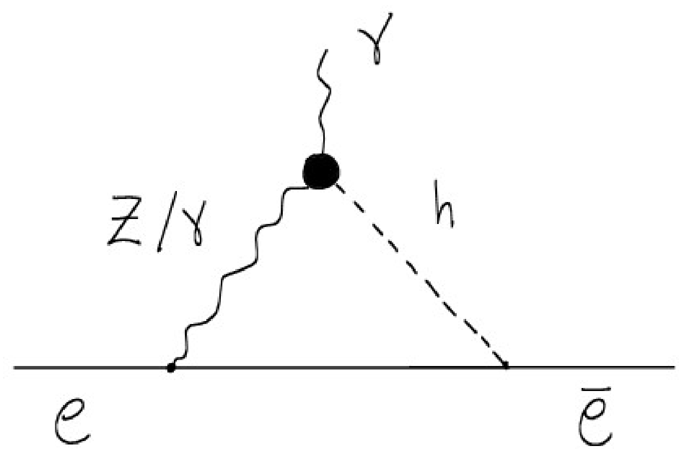
Electric dipole of electron comes from the operator

$$\mathcal{O}_{EDM} = \frac{d_e}{2}\overline{\Psi}\sigma^{\mu\nu}\Psi\widetilde{A}_{\mu\nu}$$

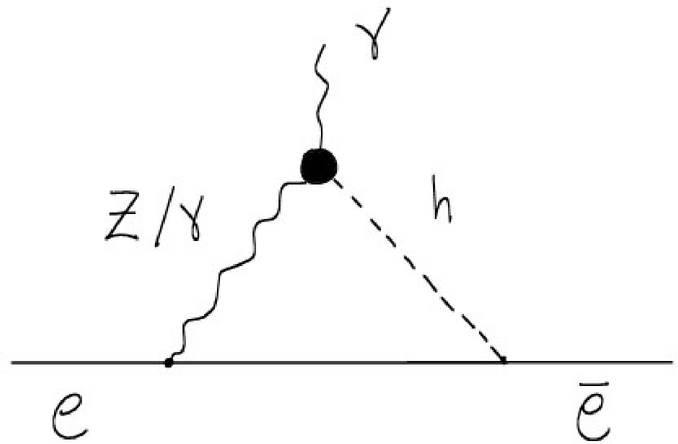
At one loop, contributions to the moment could come from

$$\mathcal{O}_-^{AA} = \frac{g^2\widetilde{S}_{AA}}{16\pi v}hA^{\mu\nu}\widetilde{A}_{\mu\nu}$$

$$\mathcal{O}_-^{AZ} = \frac{gg_Z\widetilde{S}_{AZ}}{16\pi v}hZ^{\mu\nu}\widetilde{A}_{\mu\nu}$$



Bounds from EDM's



Really it is a specific linear combination that is bounded by the EDM

$$\frac{d_e}{e} = \frac{\alpha}{32\pi^2}\frac{m_e}{v^2}\left[\widetilde{S}_{AA}\log\left(1+\frac{\Lambda^2}{m_h^2}\right) - \frac{1-4s_W^2}{2s_W^2c_W^2}\widetilde{S}_{AZ}\frac{m_h^2\log\left(1+\frac{\Lambda^2}{m_h^2}\right) - m_Z^2\log\left(1+\frac{\Lambda^2}{m_Z^2}\right)}{m_h^2-m_Z^2}\right]$$

$$\frac{d_e}{e} < 1\times 10^{-26}$$

Conclusion

The era of precision Higgs measurements has begun

A novel evaluation of discrete symmetries in Higgs interactions

The measurement of a new coupling

Ridiculous integrated luminosity needed to beat bounds from EDM (fine tuning?)

Yet still an interesting probe of T-violation in the Higgs sector