

# Precision Electroweak Tensions and a Wide Dark Photon

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with Aaron Pierce and Keisuke Harigaya

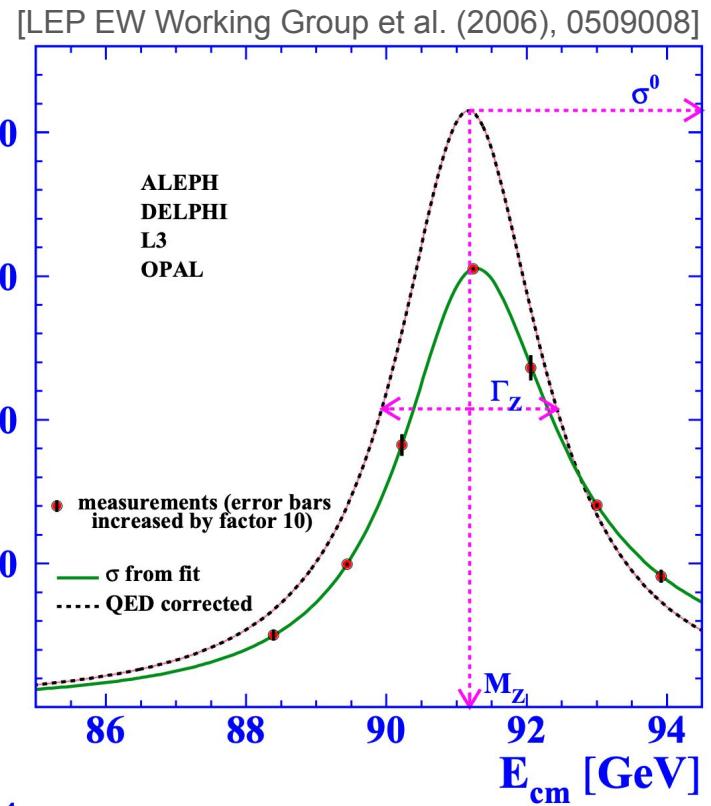
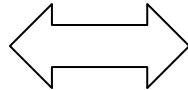
# Outline

- Precision Electroweak (PEW) Analysis
  - Oblique Parameters STU
- Kinetic Mixing and the Dark Photon
- Results

# The Precision Electroweak Fit

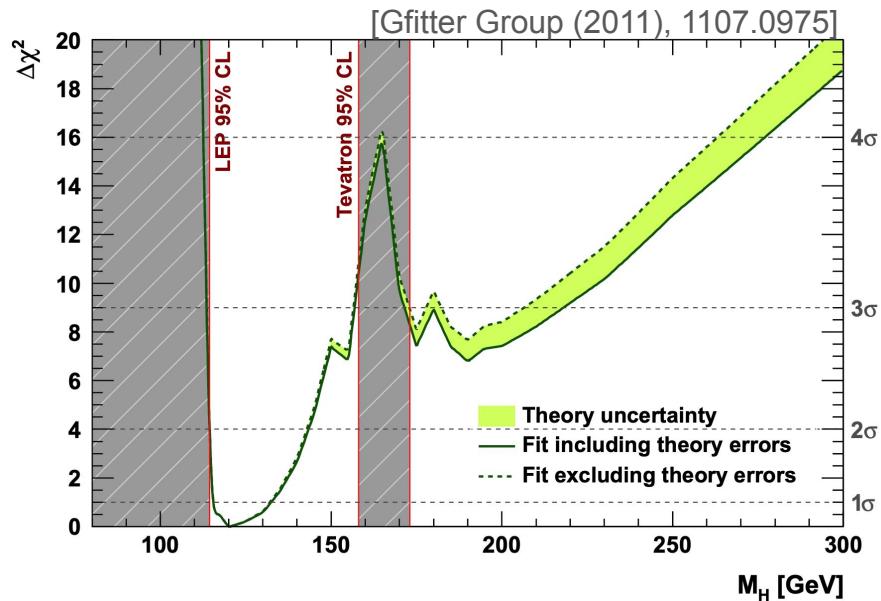
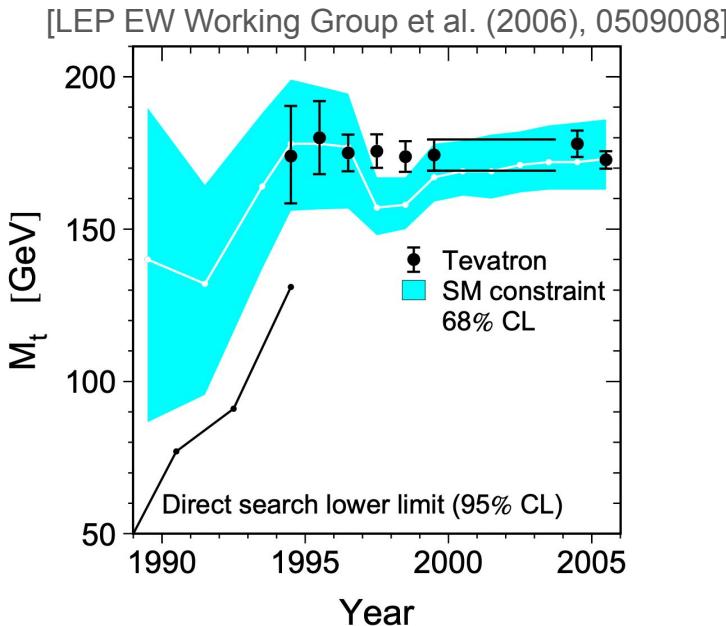
- Precision Measurements
- Computation of observables
- Fit tells us:
  - If the model works
  - Values for parameters

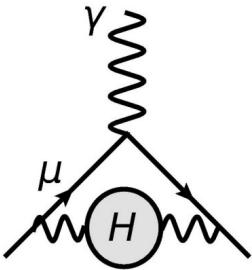
$$\mathcal{O} = \mathcal{O}(M_z, M_h, M_t, \alpha_s, \Delta\alpha_{had}^{(5)})$$



# The Precision Electroweak Fit - Successes

- Successful predictions of the top and higgs masses

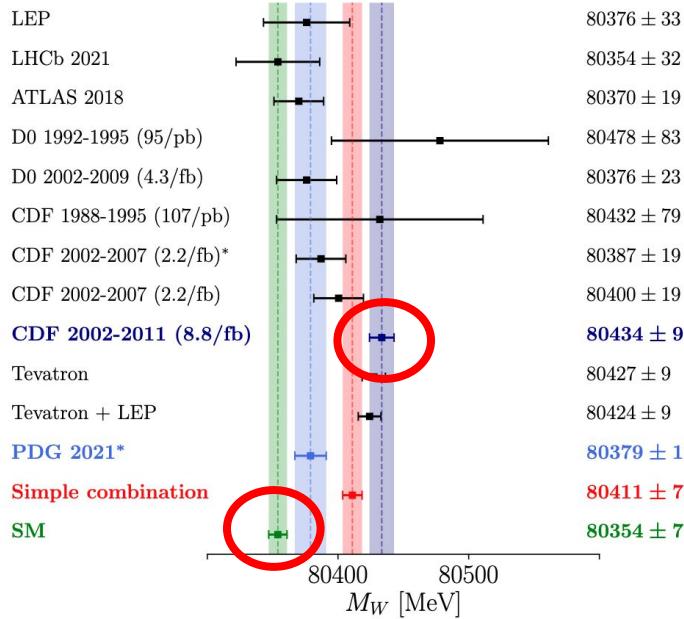




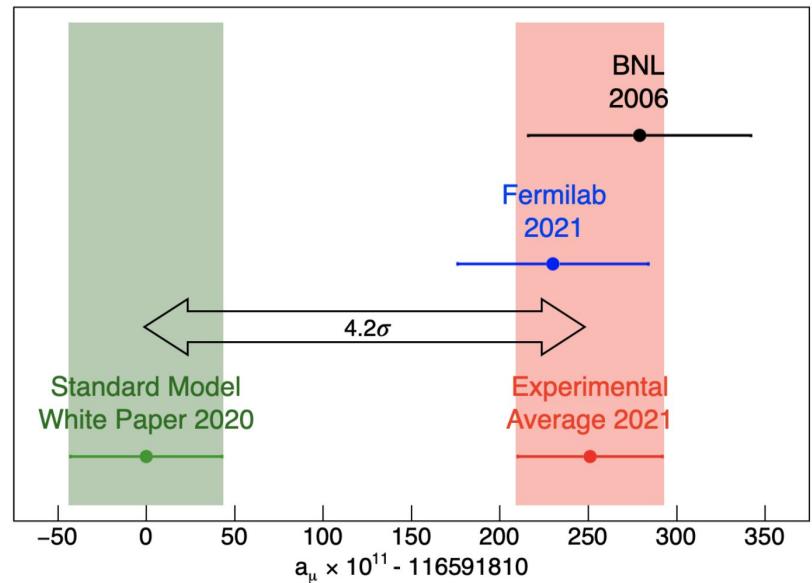
# Precision Electroweak Fit - Tensions

- Things look pretty good, but a few tensions remain

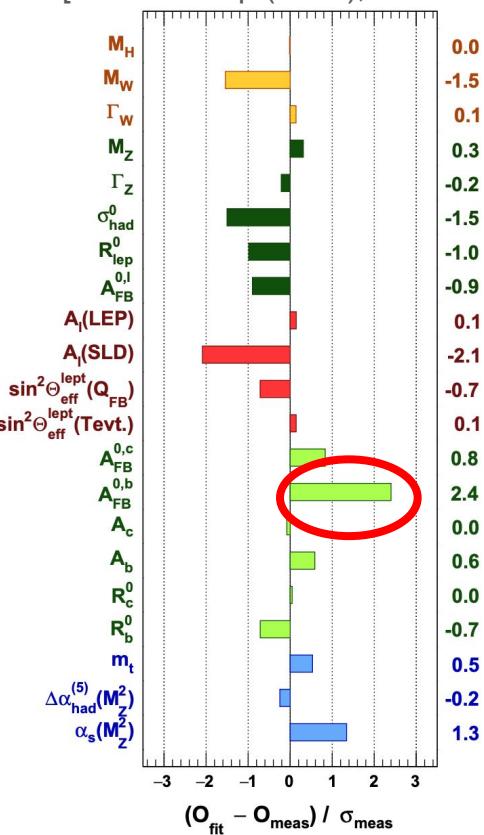
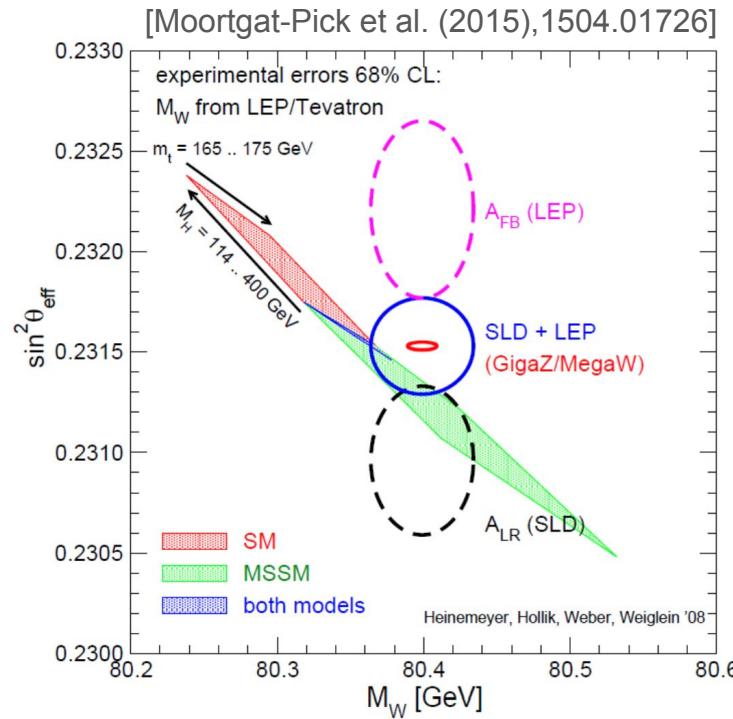
[Athron, Fowlie, Lu, Wu, Wu, Zhu (2022), 2204.03996]



[Keshavarzi, Khaw, Yoshioka (2021), 2106.06723]



# Precision Electroweak Fit - Tensions (2)



# Precision Electroweak Analysis + BSM Physics

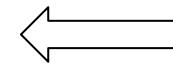
- One Option: Modify SM and recompute all observables
  - Problem: Not very efficient
- Better Option: Find a generic way to parameterize BSM effects
  - Oblique Parameters - Capture modifications to gauge boson propagators
    - S, T, U

$$S \leftrightarrow (h^\dagger \sigma^a h) W_{\mu\nu}^a B^{\mu\nu}$$

[Peskin, Takeuchi (1990) PRL;  
Peskin, Takeuchi (1992) PRD]

$$T \leftrightarrow (h^\dagger D^\mu h)(D_\mu h^\dagger h)$$

$$U \leftrightarrow (h^\dagger W^{a\mu\nu} h)(h^\dagger W_{\mu\nu}^a h)$$

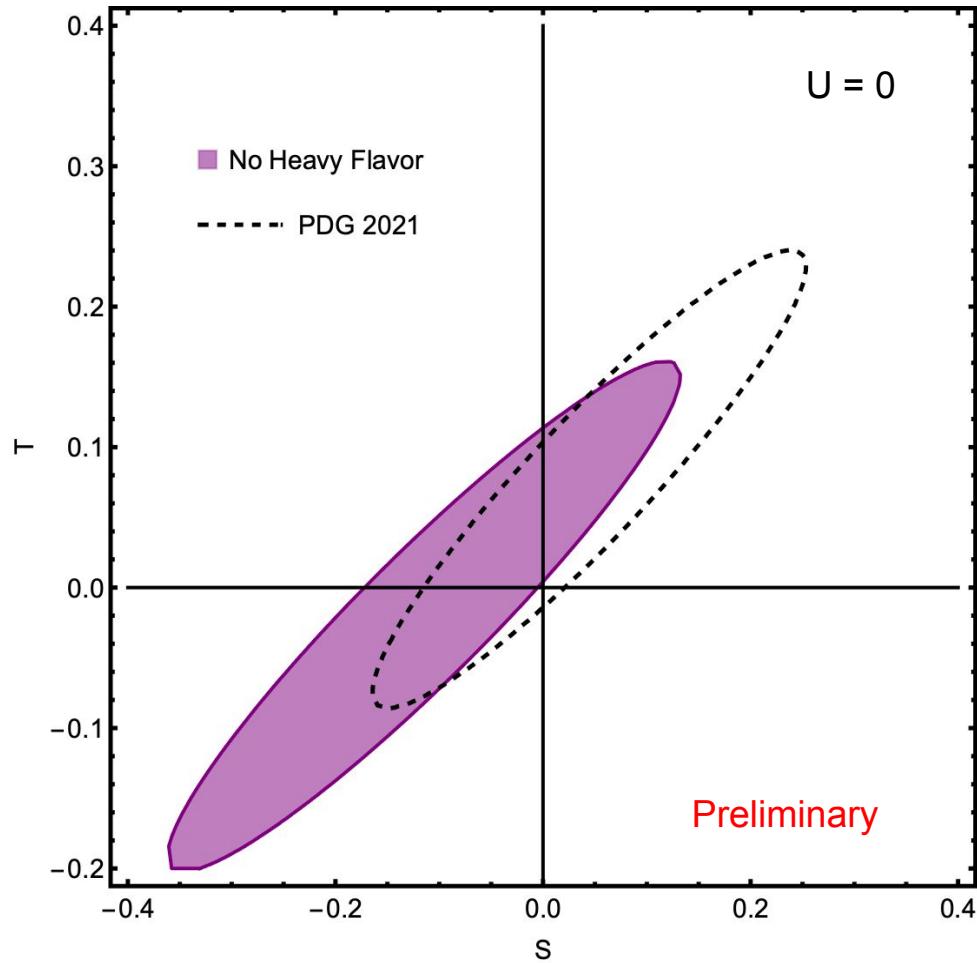


Dim 8

# Oblique Fits

$$\chi^2(\theta = M_z, M_h, M_t, \alpha_s, \Delta\alpha_{had}^{(5)}, S, T)$$

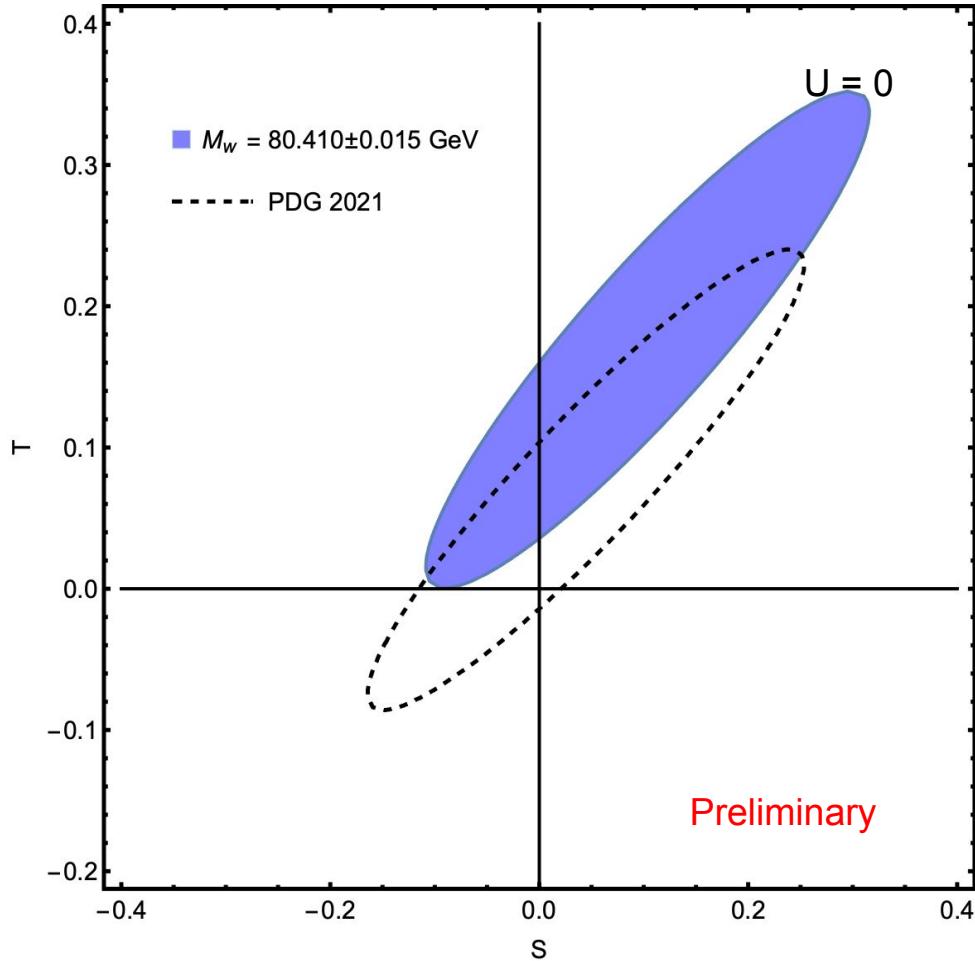
$$= (\mathbf{y} - \boldsymbol{\mu}(\theta))^T V^{-1} (\mathbf{y} - \boldsymbol{\mu}(\theta))$$



# Oblique Fits

$$\chi^2(\theta = M_z, M_h, M_t, \alpha_s, \Delta\alpha_{had}^{(5)}, S, T)$$

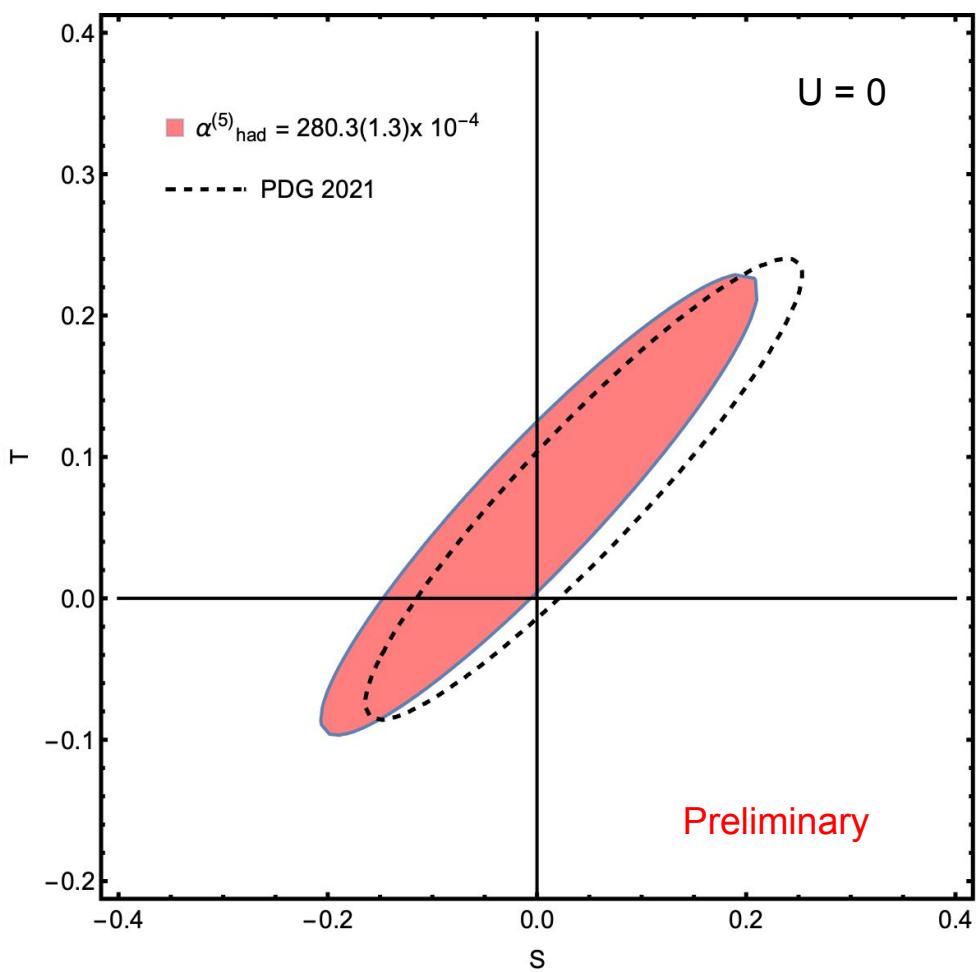
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# Oblique Fits

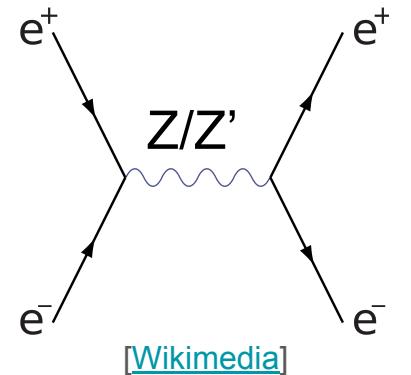
$$\chi^2(\theta = M_z, M_h, M_t, \alpha_s, \Delta\alpha_{had}^{(5)}, S, T)$$

$$= (\mathbf{y} - \boldsymbol{\mu}(\theta))^T V^{-1} (\mathbf{y} - \boldsymbol{\mu}(\theta))$$



# Kinetic Mixing

- Add a new spontaneously broken U(1) symmetry
  - “Dark Photon”, “Dark Z”, “Z”
- Simple and well-motivated extension to the SM



$$\mathcal{L} \supset -\frac{1}{4}\hat{B}_{\mu\nu}\hat{B}^{\mu\nu} - \frac{1}{4}\hat{Z}_{D\mu\nu}\hat{Z}_D^{\mu\nu} + \boxed{\frac{\epsilon}{2\cos\theta_w}\hat{Z}_{D\mu\nu}\hat{B}^{\mu\nu}} + \frac{1}{2}M_{D,0}^2\hat{Z}_{D\mu}\hat{Z}_D^\mu$$

$$\alpha S = 4\xi c_w^2 s_w \eta$$

$$\alpha T = \xi^2 \left( \frac{M_{Z_2}^2}{M_{Z_1}^2} - 1 \right) + 2\xi s_w \eta$$

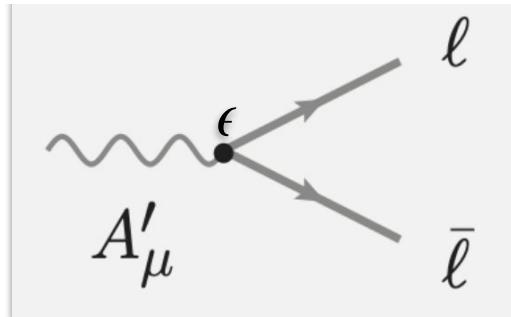
$$\eta \equiv \frac{\epsilon/c_w}{\sqrt{1 - \frac{\epsilon^2}{c_w^2}}}$$

[Babu, Kolda, March-Russell (1998) PRD; Curtin, Essig, Gori, Shelton, (2014), 1412.0018]

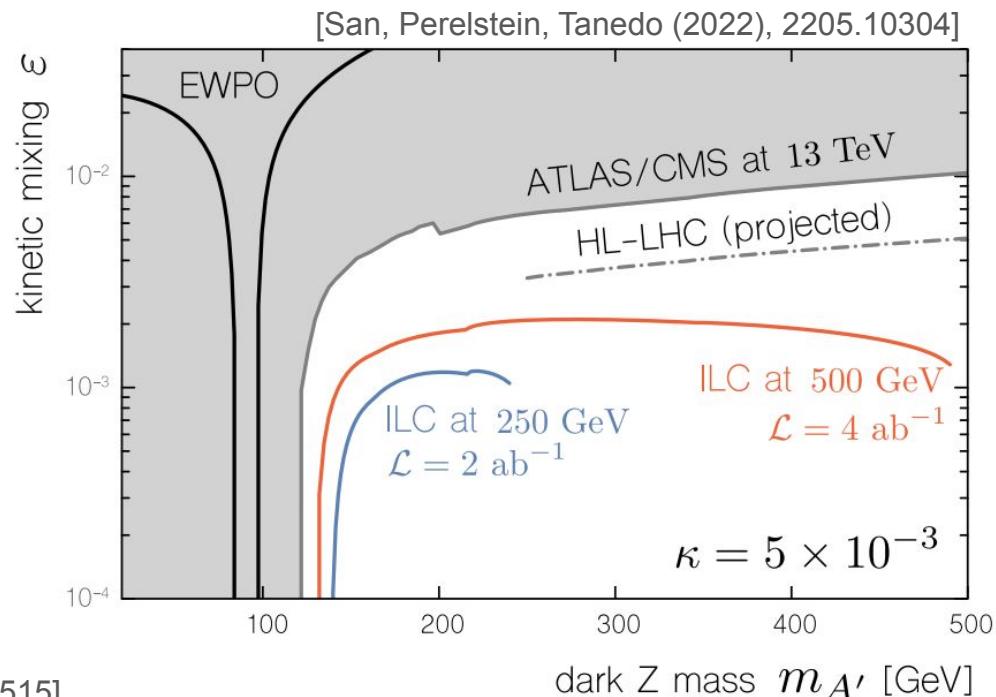
# Kinetic Mixing - Collider Bounds and Width Effects

$$\sigma(q\bar{q} \rightarrow l^+l^-) \sim \epsilon^2$$

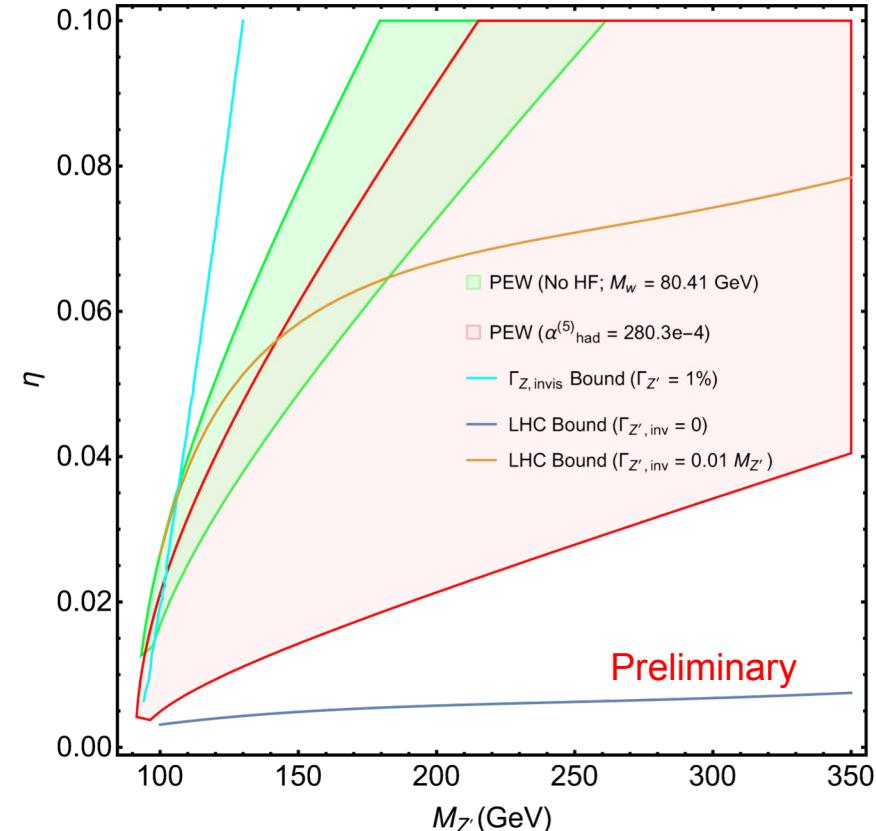
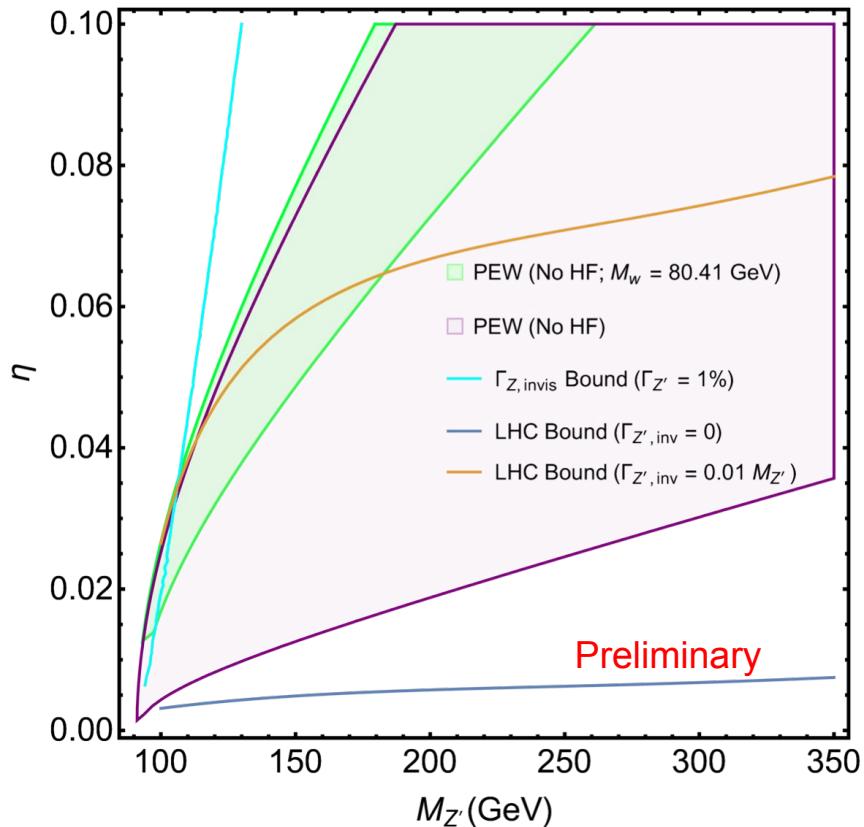
$$\Gamma(Z' \rightarrow \text{SM}) \sim \epsilon^2$$



[Fabbrichesi, Gabrielli, Lanfranchi, (2020), 2005.01515]



# Dark Photon Parameter Space



# Summary

- Existing tensions motivate the exploration of different data combinations in the PEW fit
- S-T preferred region for different data combinations
- Connection to kinetic mixing
  - Complementarity between PEW and collider bounds
  - Interesting target for future LHC searches

# Thank You!

# Backup Slides

# Oblique Parameters

$$\begin{aligned}
 T &\equiv \frac{1}{\alpha(m_Z)} \left( \frac{\Pi_{WW}(0)}{m_W^2} - \frac{\Pi_{ZZ}(0)}{m_Z^2} \right) = \frac{\rho - 1}{\alpha(m_Z)} \\
 S &\equiv \frac{4c^2 s^2}{\alpha(m_Z)} \left( \frac{\Pi_{ZZ}(m_Z^2) - \Pi_{ZZ}(0)}{m_Z^2} - \frac{c^2 - s^2}{cs} \frac{\Pi_{Z\gamma}(m_Z^2)}{m_Z^2} - \frac{\Pi_{\gamma\gamma}(m_Z^2)}{m_Z^2} \right) \\
 U &\equiv \frac{4s^2}{\alpha(m_Z)} \left( \frac{\Pi_{WW}(m_W^2) - \Pi_{WW}(0)}{m_W^2} - \frac{c}{s} \frac{\Pi_{Z\gamma}(m_Z^2)}{m_Z^2} - \frac{\Pi_{\gamma\gamma}(m_Z^2)}{m_Z^2} \right) - S
 \end{aligned}$$

$$\begin{aligned}
 \mathcal{L}_{\text{eff}} &= \mathcal{L}_{SM}(\tilde{e}_i) + \hat{\mathcal{L}}_{\text{new}}, & \alpha S &= 4s_w^2 c_w^2 \left( A - C - \frac{c_w^2 - s_w^2}{c_w s_w} G \right), \\
 \hat{\mathcal{L}}_{\text{new}} &= -\frac{A}{4} \hat{F}_{\mu\nu} \hat{F}^{\mu\nu} - \frac{B}{2} \hat{W}_{\mu\nu}^\dagger \hat{W}^{\mu\nu} - \frac{C}{4} \hat{Z}_{\mu\nu} \hat{Z}^{\mu\nu} + \frac{G}{2} \hat{F}_{\mu\nu} \hat{Z}^{\mu\nu}, & \alpha T &= w - z, \\
 &\quad - w \tilde{m}_w^2 \hat{W}_\mu^\dagger \hat{W}^\mu - \frac{z}{2} \tilde{m}_z^2 \hat{Z}_\mu \hat{Z}^\mu. & \alpha U &= 4s_w^4 \left( A - \frac{1}{s_w^2} B + \frac{c_w^2}{s_w^2} C - 2 \frac{c_w}{s_w} G \right).
 \end{aligned}$$

[Burgess, Godfrey, König, London, Maksymyk, (1994), 9312291;  
 Peskin, Takeuchi (1990) PRL; Peskin, Takeuchi (1992) PRD]