Important open questions for (circular) $e^+ e^-$ colliders

Contribution to panel discussion

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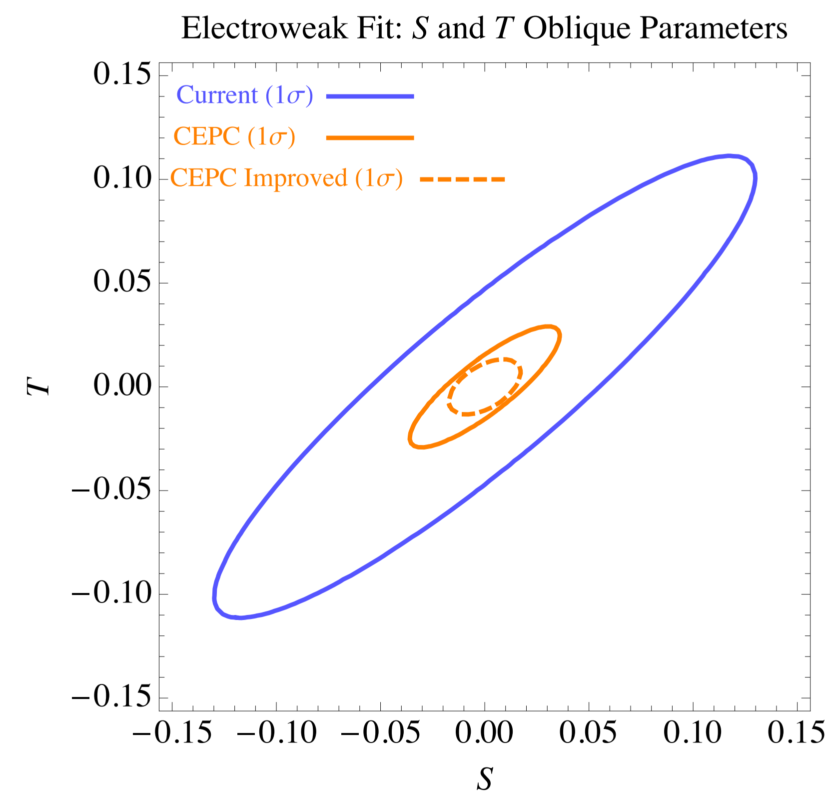
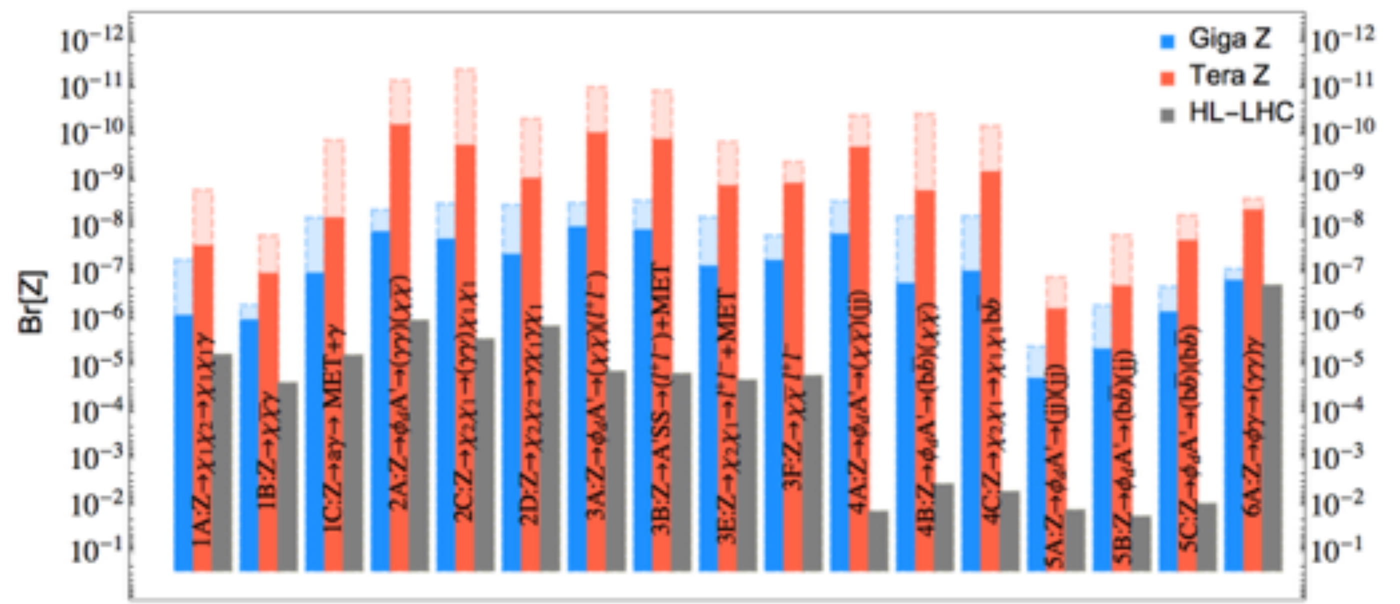
How many Zs? Giga-Z vs Tera-Z

- Oblique S and T: O(10) improvement with Giga-Z.
  - Need to improve other systematics: m_W , m_t etc to improve further.

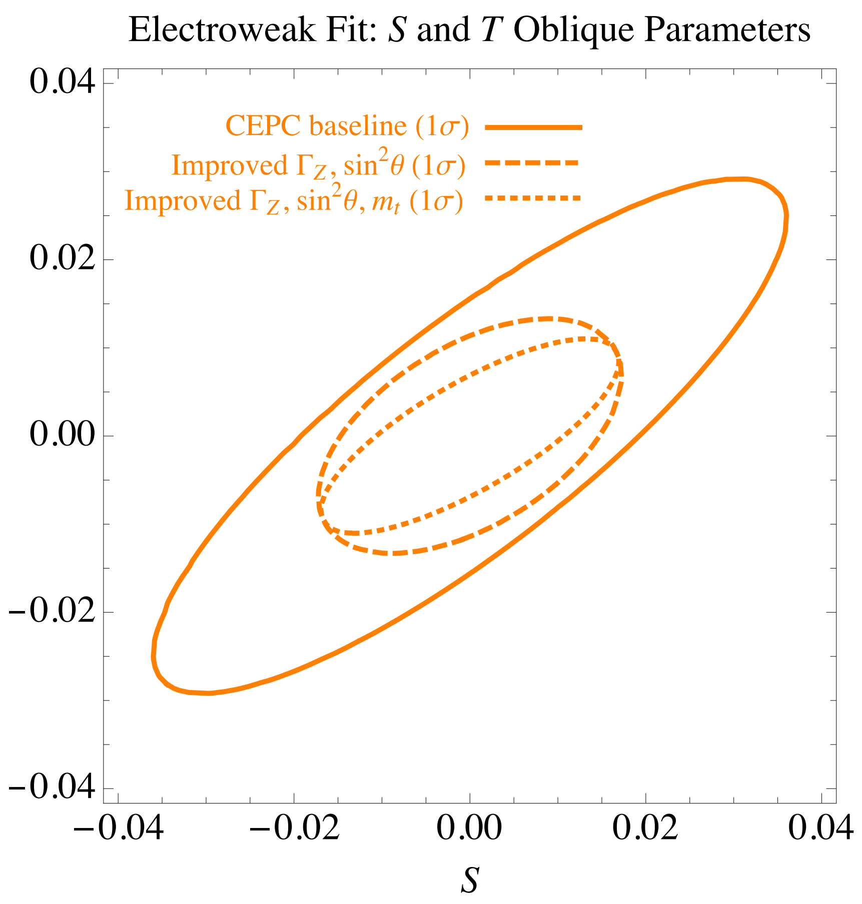


- More Zs can do more:
  - rare Z decay
  - Flavor.



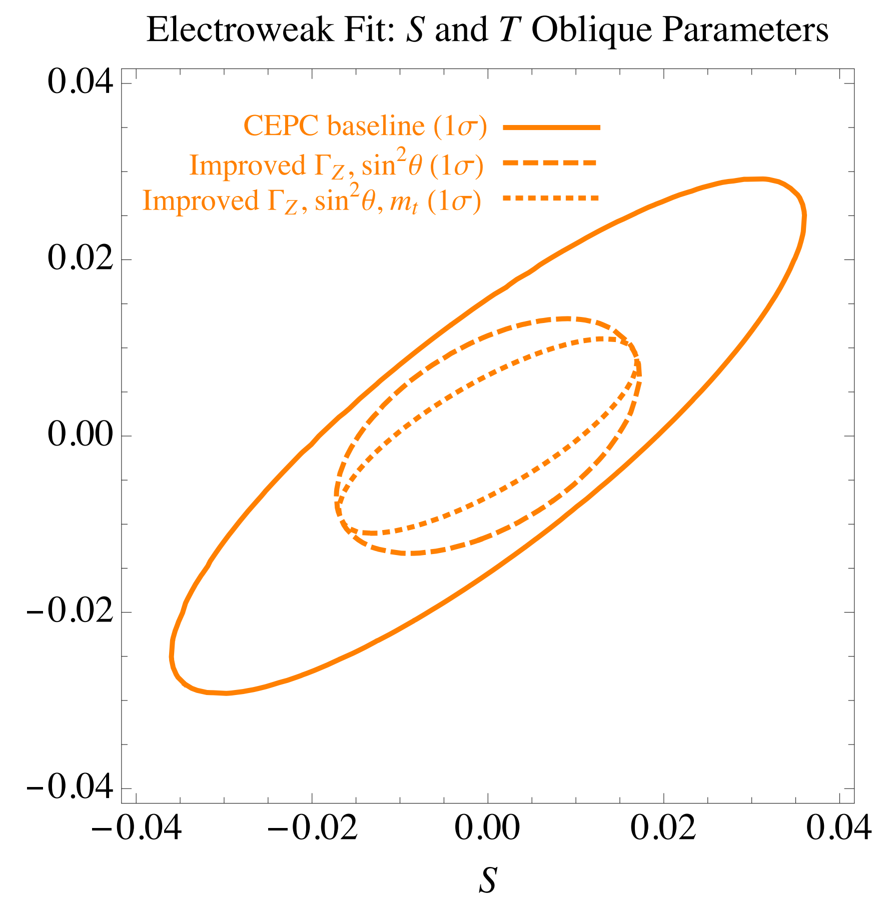
J. Liu, X. Wang 1712.07237

Higher E, ttbar threshold?



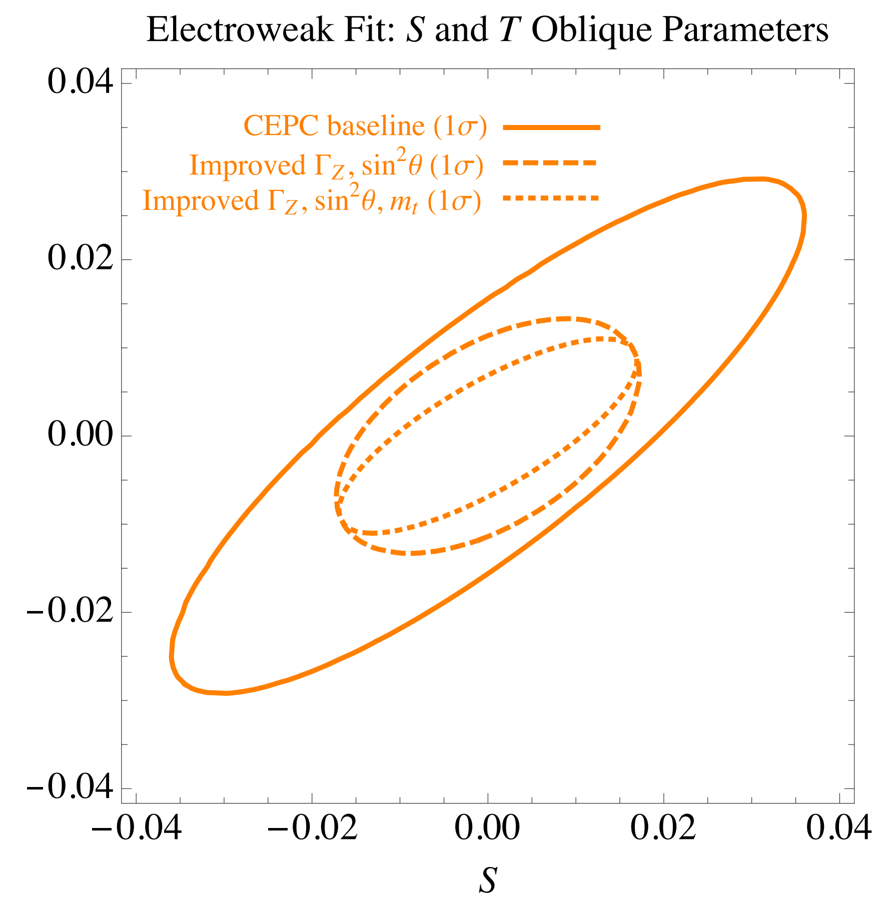
Higher E, ttbar threshold?

- This alone only a small improvement for the fit to S and T.
  - Need many other improvements as well.

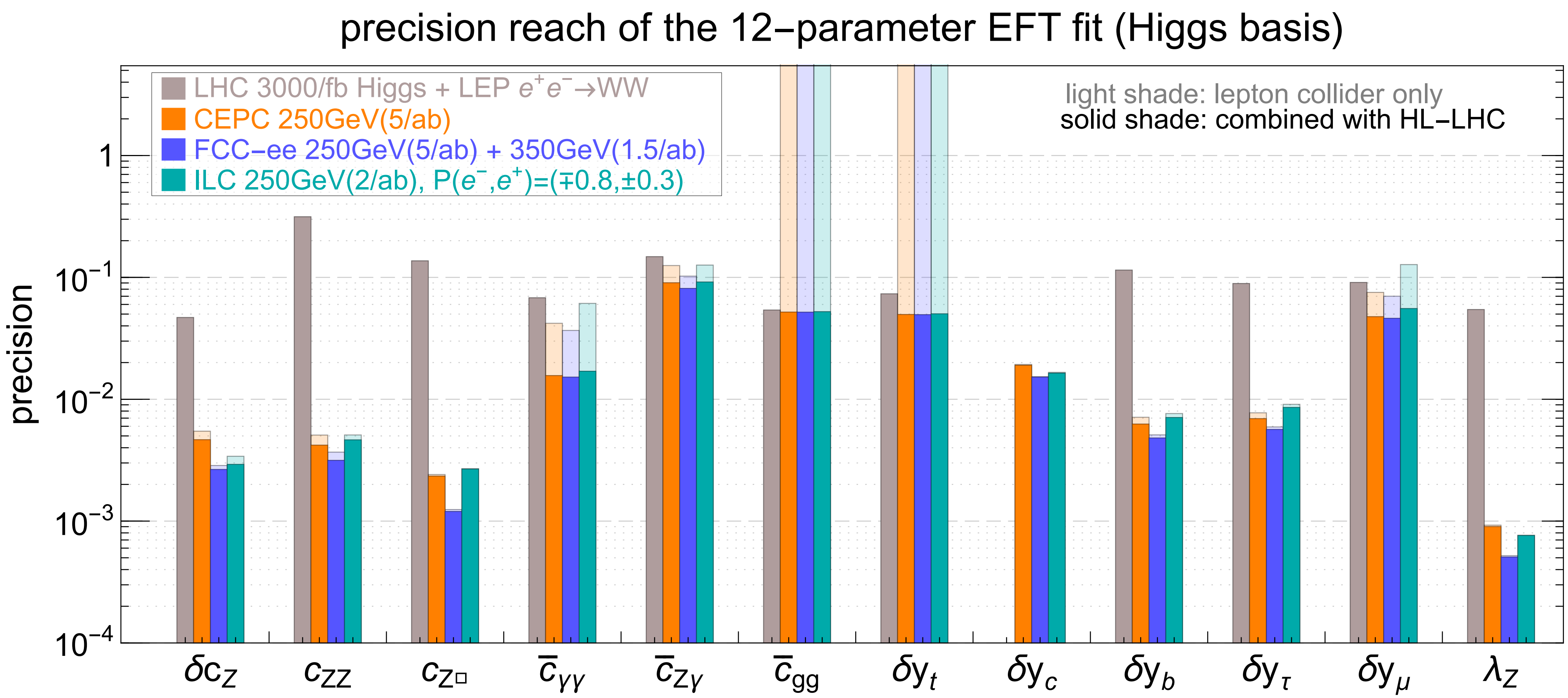


Higher E, ttbar threshold?

- This alone only a small improvement for the fit to S and T.
    - Need many other improvements as well.
- However, higher energy can improve sensitivity to new physics.
    - 100 TeV pp may cover some of these as well. Needs more studies.



For Higgs measurement:



- Big step beyond the LHC
- Both 350 and polarization could help.
  - Complementary in places, not qualitatively different.

Scenarios

Basic CEPC-like version:

5 ab^{-1} on 250, 1 million Higgs. 1 yr on Z-pole, Giga-Z

FCC-ee:

FCC-ee possible operation model

working point	luminosity/IP [10^{34} $cm^{-2}s^{-1}$]	total luminosity (2 IPs)/ yr	physics goal	run time [years]
Z first 2 years	100	26 ab^{-1}/year	**150 ab^{-1}**	**4**
Z later	200	52 ab^{-1}/year		
W	32	8.3 ab^{-1}/year	**10 ab^{-1}**	**1**
H	7.0	1.8 ab^{-1}/year	**5 ab^{-1}**	**3**
machine modification for RF installation & rearrangement: **1 year**				
top 1st year (350 GeV)	0.8	0.2 ab^{-1}/year	**0.2 ab^{-1}**	**1**
top later (365 GeV)	1.5	0.38 ab^{-1}/year	**1.5 ab^{-1}**	**4**

Scenarios

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5 ab^{-1} on 250, 1 million Higgs. 1 yr on Z-pole, Giga-Z

Something in between?

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My personal ordered wish-list

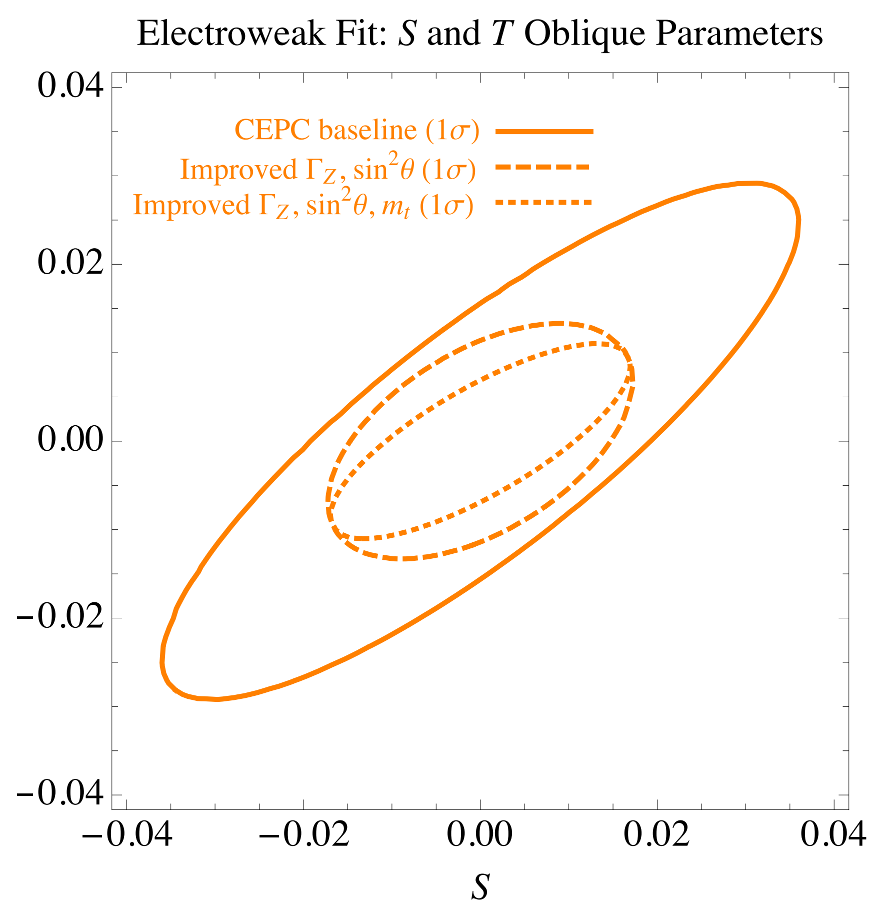
- After 1 million Higgs, move on to 100 TeV pp as soon as possible.

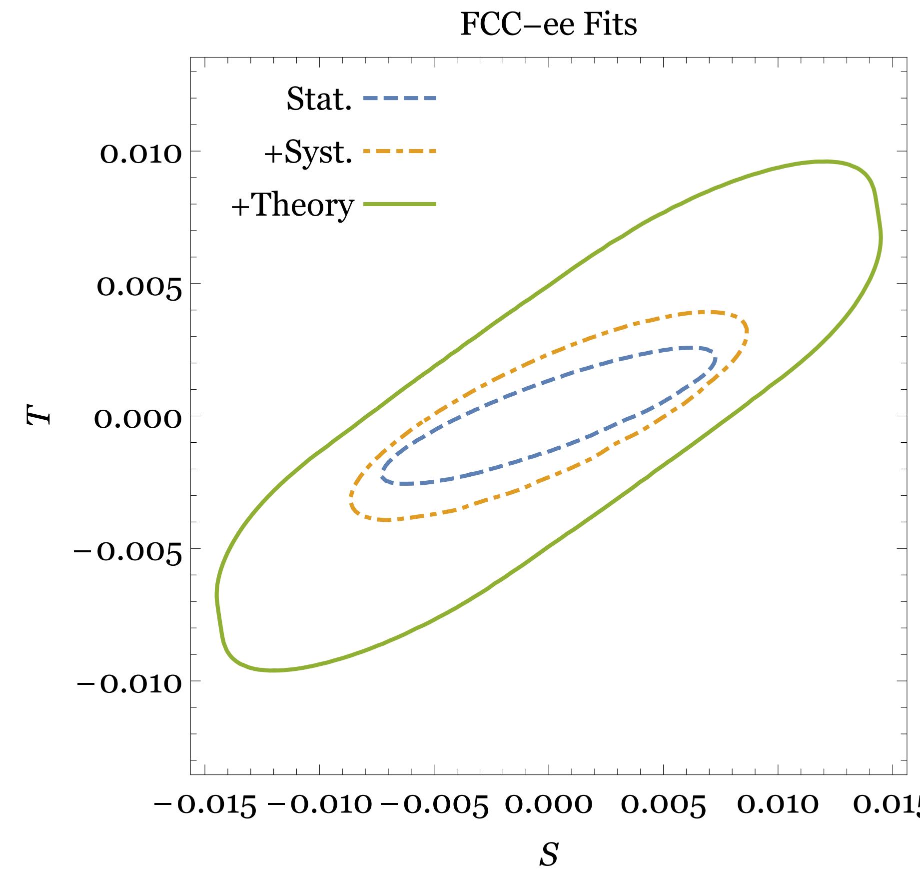
- ttbar threshold, perhaps a little bit higher for better measurement of top couplings.

- Tera-Z for rare decay, flavor physics.

extra

Ultimate precision?





M. Reece. Stat and Syst based on "First look" paper

	TLEP-Z	TLEP-W	TLEP-t
$\alpha_s(M_Z^2)$	$\pm 1.0 \times 10^{-4}$ [37]	$\pm 1.0 \times 10^{-4}$ [37]	$\pm 1.0 \times 10^{-4}$ [37]
$\Delta\alpha_{\rm had}^{(5)}(M_Z^2)$	$\pm 4.7 \times 10^{-5}$	$\pm 4.7 \times 10^{-5}$	$\pm 4.7 \times 10^{-5}$
m_Z [GeV]	$\pm 0.0001_{\rm exp}$ [2]	$\pm 0.0001_{\rm exp}$ [2]	$\pm 0.0001_{\rm exp}$ [2]
m_t [GeV] (pole)	$\pm 0.6_{\rm exp} \pm 0.25_{\rm th}$ [23]	$\pm 0.6_{\rm exp} \pm 0.25_{\rm th}$ [23]	$\pm 0.02_{\rm exp} \pm 0.1_{\rm th}$ [2, 23]
m_h [GeV]	$< \pm 0.1$	$< \pm 0.1$	$< \pm 0.1$
m_W [GeV]	$(\pm 8_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$ [23, 40]	$(\pm 1.2_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$ [20, 40]	$(\pm 1.2_{\rm exp} \pm 1_{\rm th}) \times 10^{-3}$ [20, 40]
$\sin^2\theta_{\rm eff}^{\ell}$	$(\pm 0.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$ [20, 40]	$(\pm 0.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$ [20, 40]	$(\pm 0.3_{\rm exp} \pm 1.5_{\rm th}) \times 10^{-5}$ [20, 40]
Γ_Z [GeV]	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$ [2, 26]	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$ [2, 26]	$(\pm 1_{\rm exp} \pm 0.8_{\rm th}) \times 10^{-4}$ [2, 26]

FCC-ee projections, based on "First look" paper