exciting new physics at future e^+e^- colliders

Jiayin Gu

DESY/IHEP

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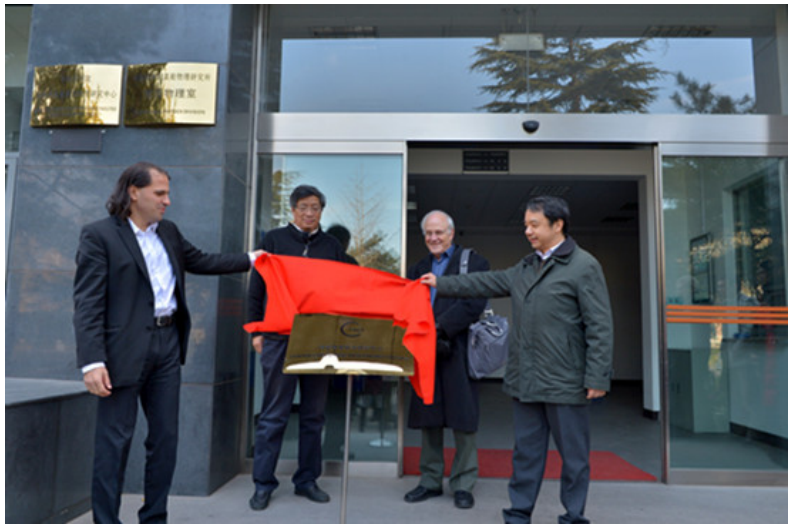
introducing myself (and where I came from) ...

- I ...
  - did my PhD at UC Davis (2009-2014, advisor: Hsin-Chia Cheng).
  - was (am) a postdoc at the Center for Future High Energy Physics (CFHEP), Institute of High Energy Physics , Chinese Academy of Sciences (2014 - ??).
  - came to DESY under the "China-Germany postdoc exchange program" (March 2016 - February 2018).

- CFHEP
  - was founded to facilitate the theory study of China's future collider program.
  - has a visitors program!
  - http://cfhep.ihep.ac.cn/



Future e^+e^- colliders

- Circular colliders
  - The Circular Electron-Positron Collider (CEPC) in China[1]
  - The Future Circular Collider (FCC-ee) at CERN
  - Possible runs at $240\,\text{GeV}$ (Higgs factory), Z-pole, and $350\,\text{GeV}$.
  - Large luminosity
  - The tunnel can be used for a hadron collider of $\sim 100\,\text{TeV}$ center of mass energy in the future!

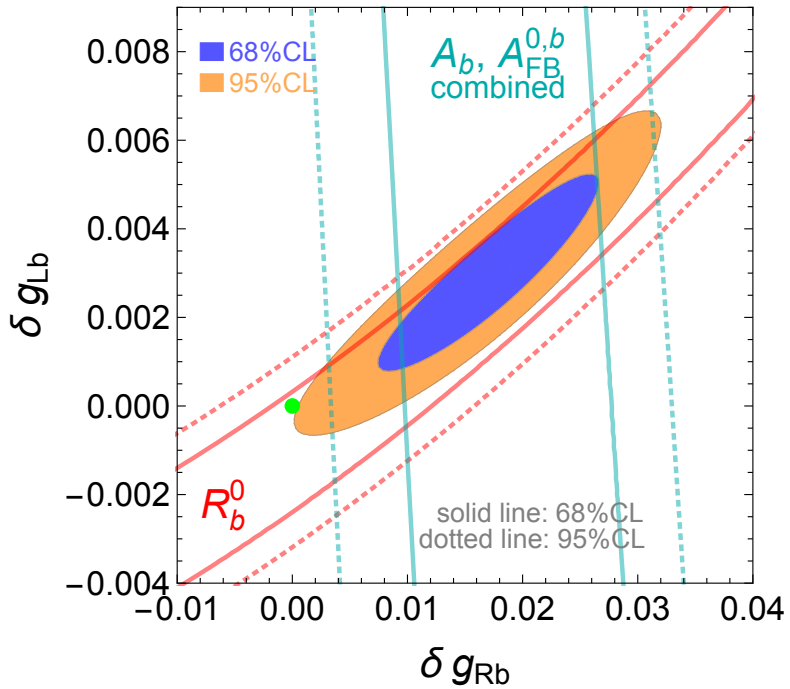
- Linear collider
  - The International Linear Collider (ILC) in Japan
  - Smaller luminosity, but can achieve a much larger center of mass energy (500 GeV, and possibly 1 TeV)!
  - Longitudinal beam polarization.

[1] pre-CDR available at http://cepc.ihep.ac.cn/preCDR/volume.html

what a e^+e^- machine can do and what I have worked on

- Higgs Factory at 240-$250\,\text{GeV}$
  - Precision Higgs measurements in $e^+e^- \to hZ$ (and also $e^+e^- \to \nu\bar{\nu}h$).
  - Angular distributions in HZ production can provide additional information. [1512.06877] N. Craig, JG, Z. Liu, K. Wang
  - It can also collect a large amount of data of $e^+e^- \to WW$, which has a cross section of $\sim 100\times$ the one of $e^+e^- \to hZ$. (Buy one get one free!)
  - Towards a global fit of SMEFT with all the measurements above. current work with Christophe, Gauthier and Kechen
- Z-pole (a better version of LEP)
  - Oblique corrections (S and T parameters).
  - Non-oblique corrections, e.g. the $Zb\bar{b}$ coupling. [1508.07010] S. Gori, JG, L.-T. Wang
- Run at higher energies (350 GeV, 500 GeV...)
- I've also worked on Stop searches at the LHC! (current work with Haipeng An and Lian-Tao Wang)

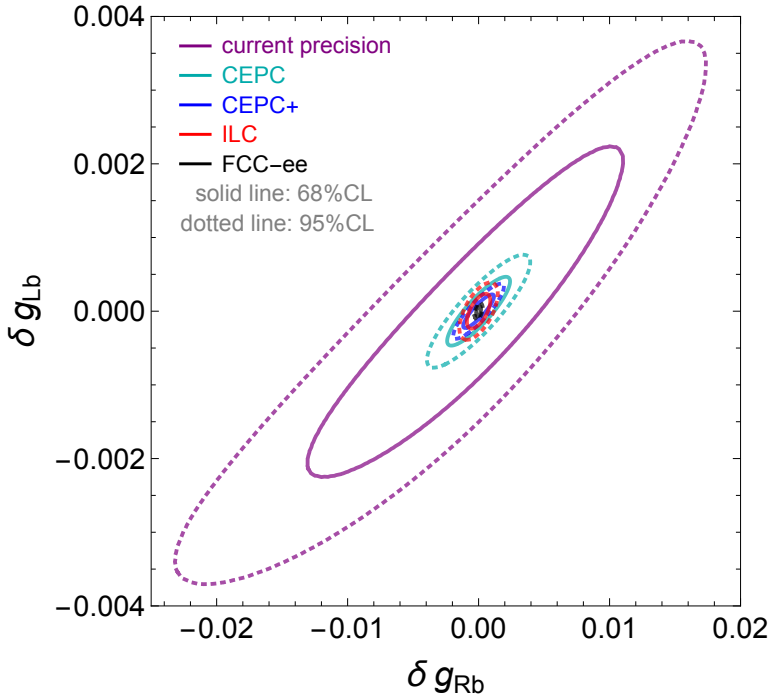
Why is $Zb\bar{b}$ interesting?

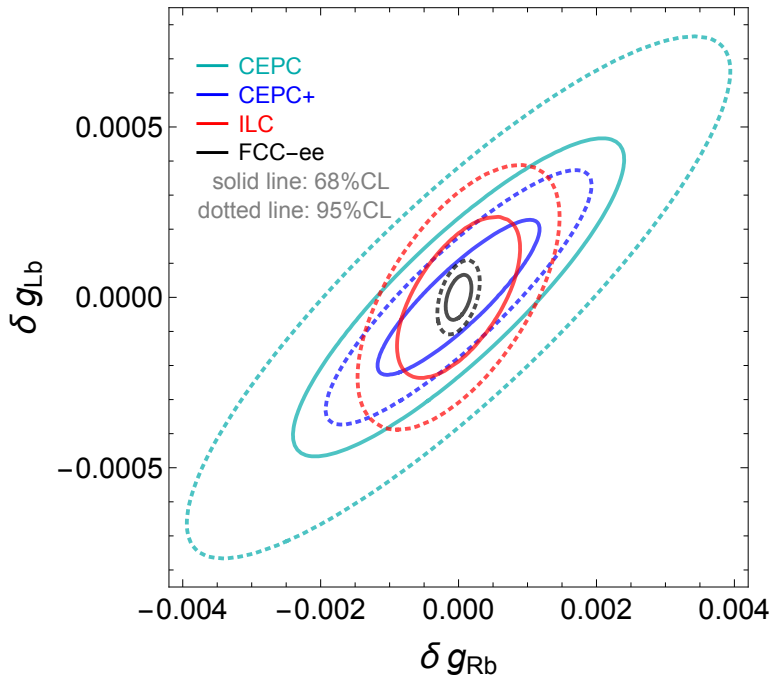


- Global fit with SM+(S, T, δg_{Lb} , δg_{Rb}).

- The $Zb\bar{b}$ couplings (g_{Lb} and g_{Rb}) are directly probed by three observables, R_b, $A_{\rm FB}^{0,b}$(LEP) and $\mathcal{A}_b$(SLC).
- Theory side: many new physics models predict a sizable correction to the $Zb\bar{b}$ couplings.
- Experiment side: $\sim 2.5\,\sigma$ discrepancy between the LEP $A_{\rm FB}^{0,b}$ measurement and its SM prediction (requires a sizable modification to the $Zb_R\bar{b}_R$ coupling).

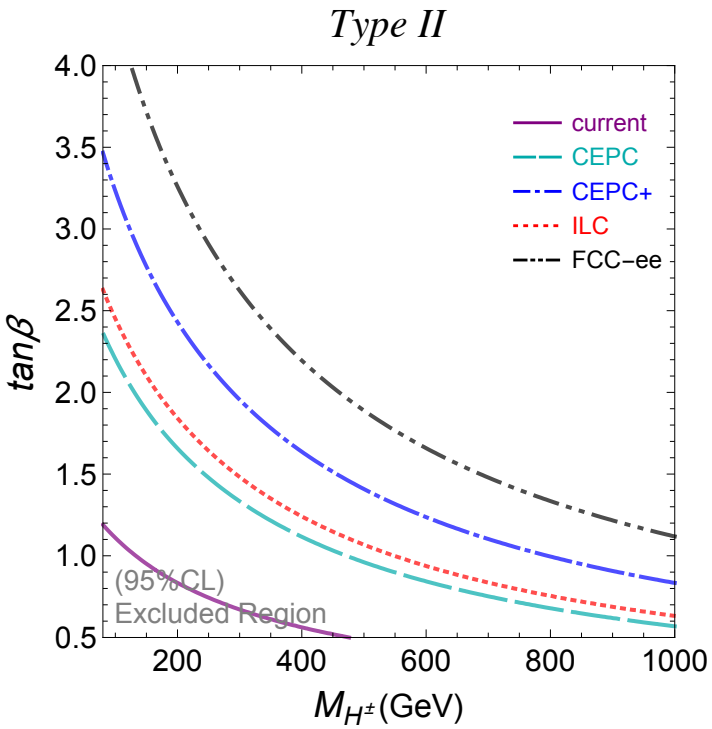
precision reach in future colliders

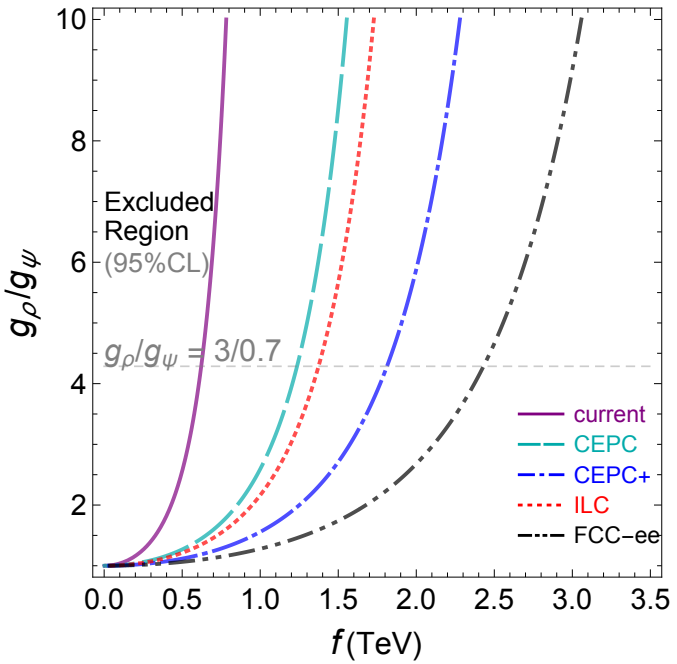




- Assuming the results are SM-like.
- Estimation strongly depends on the assumptions on systematic uncertainties.
- CEPC with $\sim 2 \times 10^9$ Zs and conservative estimations of systematics is already much better than LEP.

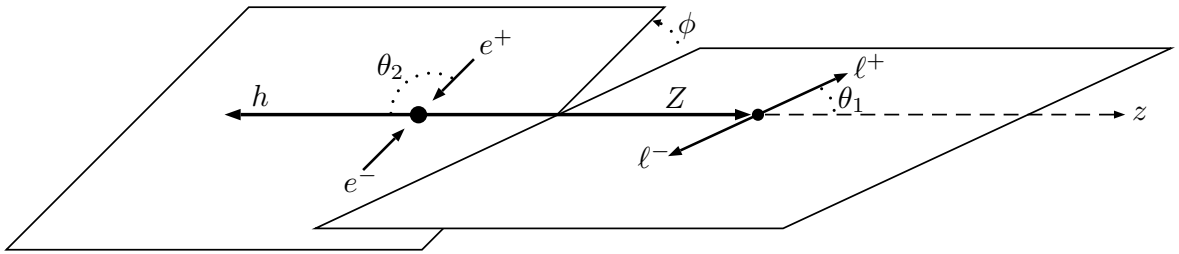
Model Implications





- Left: Type II 2HDM
- Right: Minimal composite Higgs models with custodial protection. (Contribution from fermion loops estimated in: [1306.4655] Grojean, Matsedonskyi, Panico)

Angular Observables in HZ production



- Angular distributions in HZ production can provide information in addition to the rate measurement alone.
- EFT calculations have been done in *e.g.* 1406.1361(Beneke, Boito, Wang).
- 6 independent asymmetry observables

$$\mathcal{A}_{\theta_1}\ ,\quad \mathcal{A}_{\phi}^{(1)}\ ,\quad \mathcal{A}_{\phi}^{(2)}\ ,\quad \mathcal{A}_{\phi}^{(3)}\ ,\quad \mathcal{A}_{\phi}^{(4)}\ ,\quad \mathcal{A}_{c\theta_1,c\theta_2}\ .$$

- Focusing on leptonic decays of Z (good resolution, small background, statistical uncertainty dominates).

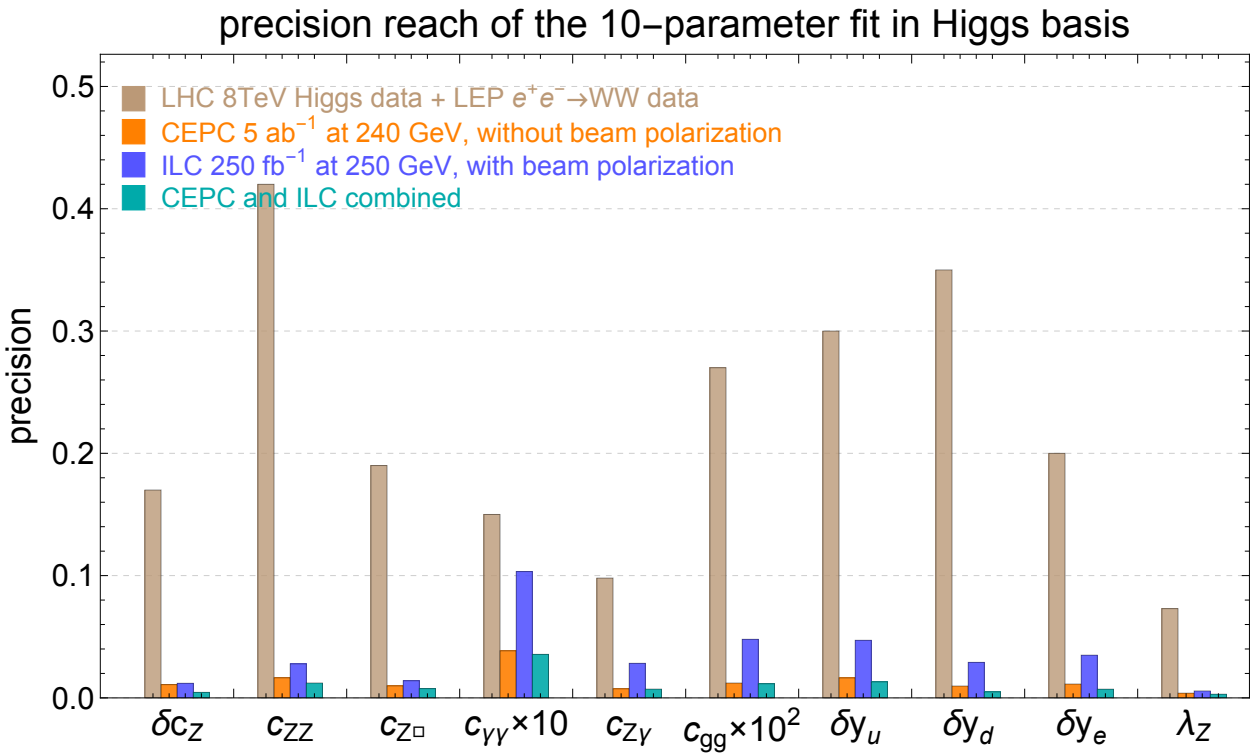
Global fit at a Higgs factory

- Global fit from a combination of all possible measurements at a Higgs factory ($\sqrt{s} \sim 240$ or $250\,\text{GeV}$).
  - $e^+e^- \to hZ$ (production, decay, angular asymmetries)
  - $e^+e^- \to \nu\bar{\nu}h$ (WW fusion)
  - $e^+e^- \to WW$ (TGC)
- Assuming new physics is CP-even, flavor universal.
- Assuming no corrections to Z-pole observables and W mass. (good assumptions?)
- We are left with 10 operators, parameterized in the Higgs basis by:

$$\delta c_Z\,, \quad c_{ZZ}\,, \quad c_{Z\Box}\,, \quad c_{\gamma\gamma}\,, \quad c_{Z\gamma}\,, \quad c_{gg}\,, \quad \delta y_u\,, \quad \delta y_d\,, \quad \delta y_e\,, \quad \lambda_Z\,.$$

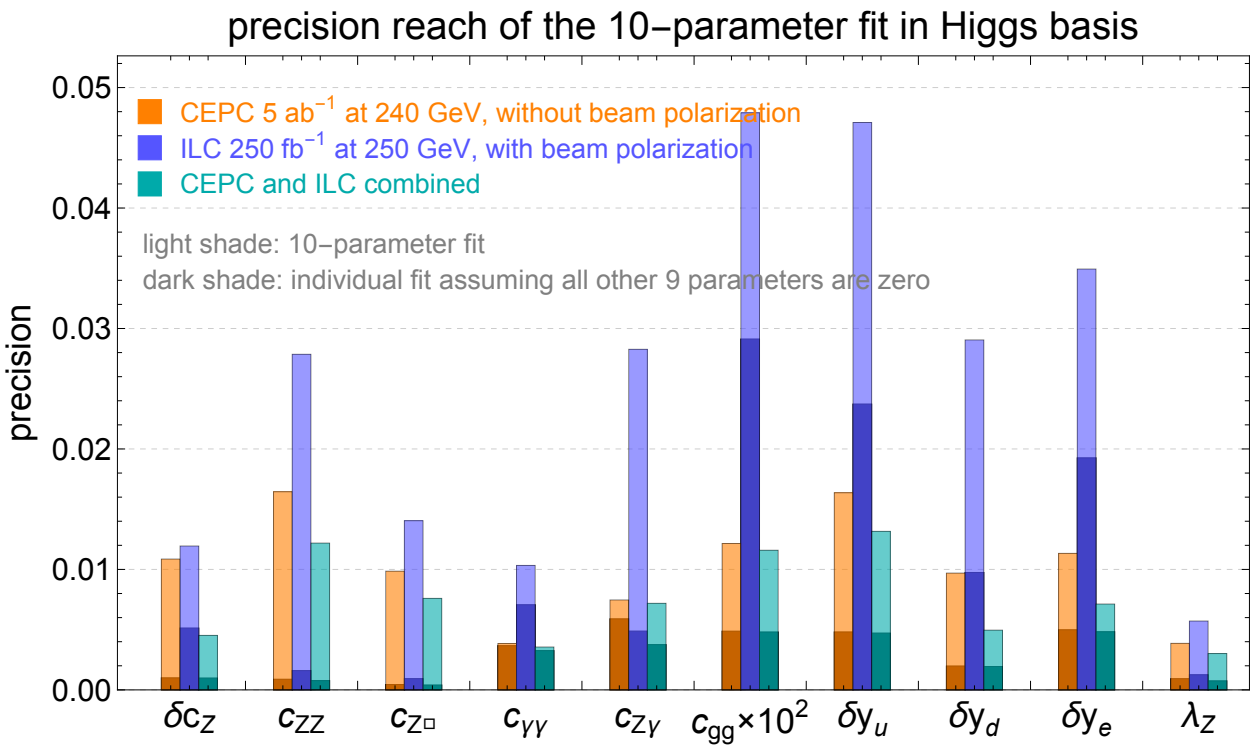
- Strong independent constraints can be obtained for all 10 coefficients!

some preliminary results...



- Much better than the current results! (Taken from [1508.00581] Falkowski, Gonzalez-Alonso, Greljo, Marzocca, obtained from LHC 8 TeV Higgs data and LEP $e^+e^- \to WW$ data.)
- haven't compared with HL-LHC data yet...

some preliminary results...



- CEPC: circular collider, large luminosity
- ILC: linear collider, beam polarization (60% of total Luminosity goes to $P(e^-, e^+) = (-0.8, +0.3)$, 40% goes to $P(e^-, e^+) = (+0.8, -0.3)$.)
- Complementarity!

Conclusion

- After the discovery of Higgs at the LHC, an plausible "next step" is to build an e^+e^- collider to perform Higgs precision measurements.
- Several plans have already been proposed (CEPC, ILC, FCC-ee).
- Many other important measurements can also be performed (Z-pole measurements, $e^+e^- \to WW$, ...)
- Theoretical studies play a crucial role in terms of determining the goal and potential of these colliders.
- Still a lot of work to be done!

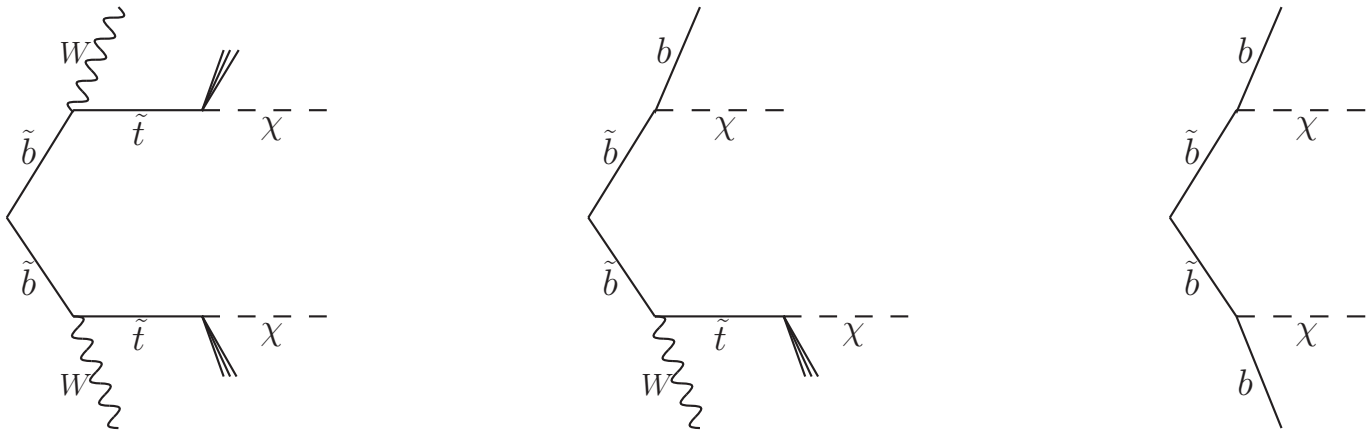
Conclusion

ASK NOT WHAT
BIG CIRCULAR COLLIDERS
CAN DO FOR YOU, ASK
WHAT YOU CAN DO FOR
BIG CIRCULAR COLLIDERS!

- Nima Arkani-Hamed

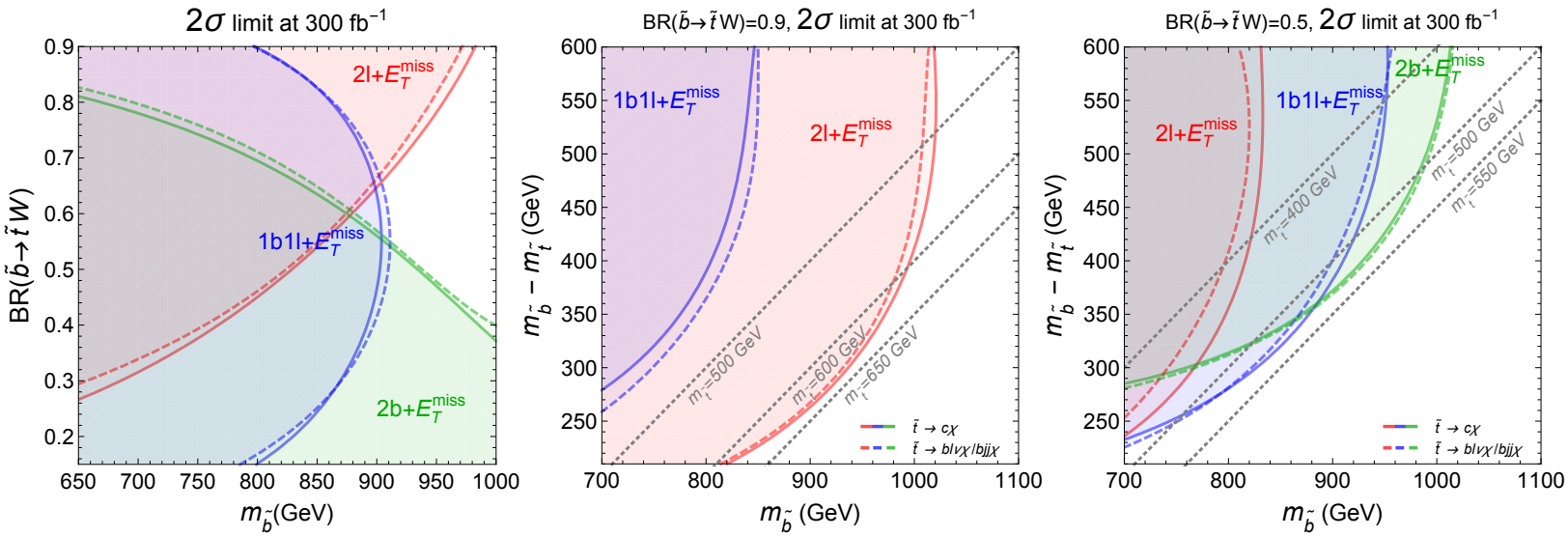
backup slides

Searching the hidden stop from sbottom decays



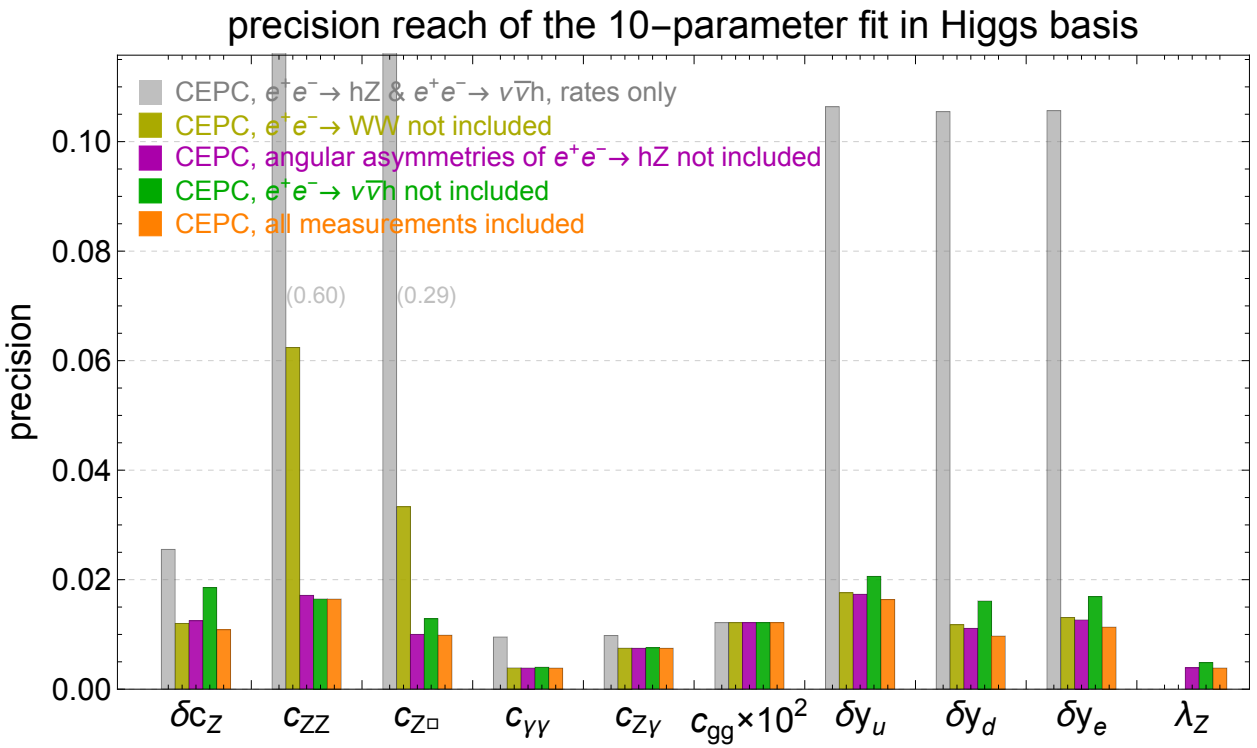
- Stop could be hidden at the LHC (*e.g.* if $m_{\tilde{t}} \approx m_{\chi}$)!
- Seaching the hidden stop from sbottom decay could potentially provide the best reach.
- Killing two birds with one stone! (stop and sbottom)

Searching the hidden stop from sbottom decays



- $m_{\tilde{t}} - m_{\chi} = 30\,\text{GeV}$, 13 TeV LHC with $300\,\text{fb}^{-1}$ data.
- Left: $m_{\tilde{b}} - m_{\tilde{t}} = 400\,\text{GeV}$. Middle: $\text{BR}(\tilde{b} \to \tilde{t}W) = 0.9$. Right: $\text{BR}(\tilde{b} \to \tilde{t}W) = 0.5$.
- If $m_{\tilde{b}} \lesssim 1\,\text{TeV}$ and the decay $\tilde{b} \to \tilde{t}\,W$ has a significant branching ratio, a stop almost degenerate with neutralino can be excluded up to about 500–600 GeV at the 13 TeV LHC with $300\,\text{fb}^{-1}$ data. (The mono-jet search needs $\sim 3000\,\text{fb}^{-1}$ to reach the same bound.)

some preliminary results...



some preliminary results...