


Next Steps

A red arrow is drawn below the text, starting under the word 'Next' and pointing towards the word 'Steps'.

CFHEP → CHEP

(P)<sup>2</sup> Pre CDR → (Pre) CDR

# Schedule Guideline for CEPC pre-CDR

August – December 2014

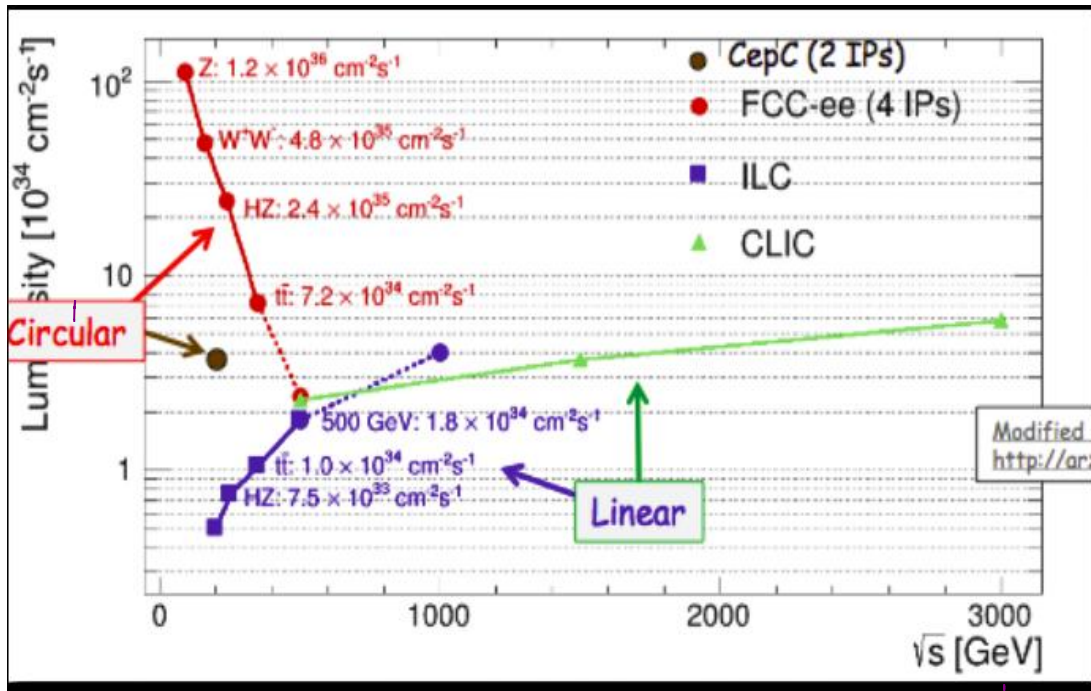
Questions? Please contact Xinchou Lou (xinchou@ihep.ac.cn)

August 1-15	August 16-31	September 1-15	September 16-30	October 1-15	October 16-31	November 1-15	November 16-30	December 1-15	December 16-31
		<p>← RESPECTABLE IN ~ 2 WKS</p> <p>(1) pre-CDR draft version 0 from each (sub-)group (with all required elements, some contents may be missing); (2) identify loose ends &amp; address them at the (sub)group level.</p>							
			<p>(1) external reviewers identified and invitations sent out during first period; (2) additions and revisions being worked on; (3) formation of editorial board at SJTU workshop; (4) internal reviews within (sub-)groups.</p>						
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							<p>(1) final edition (including <b>Introduction &amp; Summary</b>) in English; (2) translation of pre-CDR into Chinese completed and reviewed.</p>		
								<p>(1) proof; (2) print and release to CAS and public.</p>	

August 5, 2014


# Standardize (Range of) Machines

\* CEPC :  $\mathcal{L}_{TLEP} \mathcal{L}_{TLEP/10}$  [4 IPs]




\* SPPC 100 TeV  $3 \text{ ab}^{-1}$   
[50 TeV ?]

Outline of Summary




- (0) New Machines for a new Frontier
  - (1) The Ewk Phase Transition
  - (2) Naturalness + deep origin of EWSB
  - (3) Dark Matter(s)
  - [ (4) New world of Flavor + CP ]
- { Throughout: interplay with LHC }

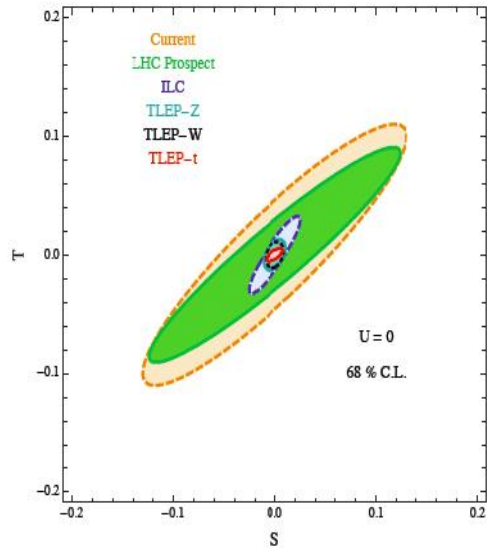
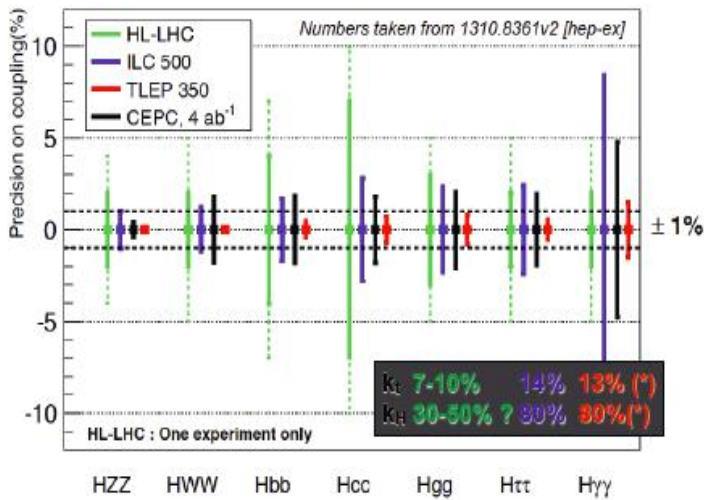
New Machines for the



New Frontier



# \* CEPC: Huge Leap in Precision



Higgs Factory

Z factory

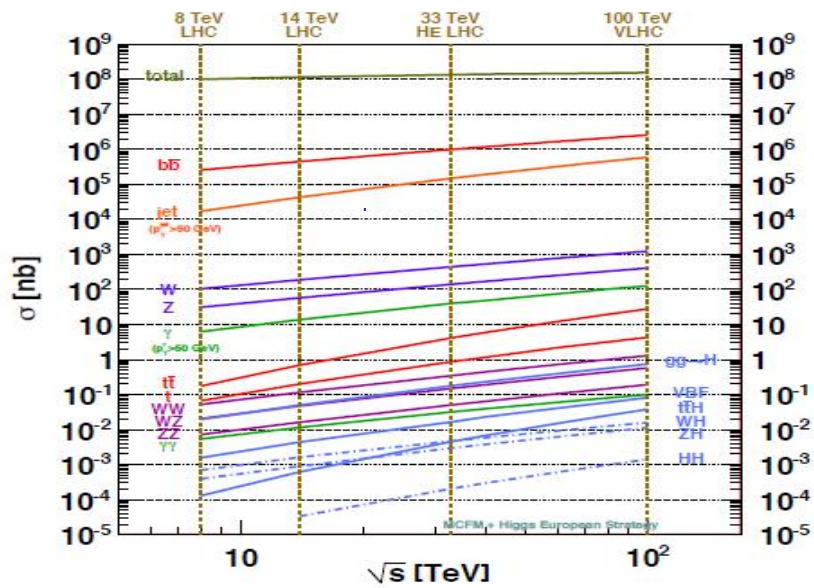
\* Invisible + Exotic Higgs decays

\* CPV in Higgs couplings

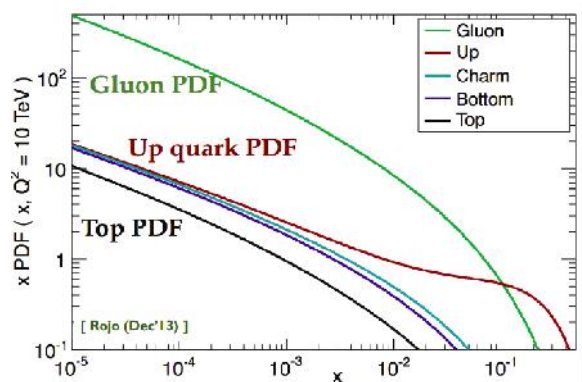
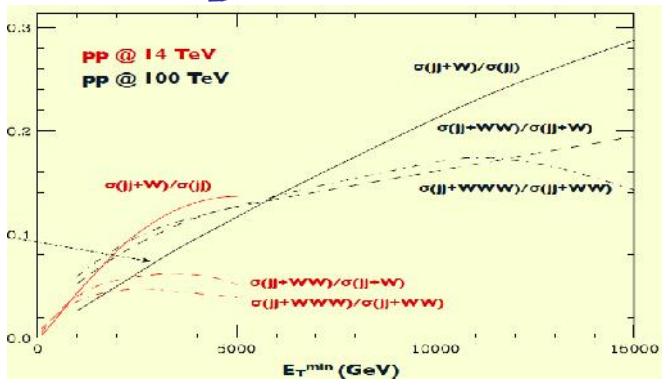


# \* SPPC: Huge Leap in Energy

- Enormous Rates

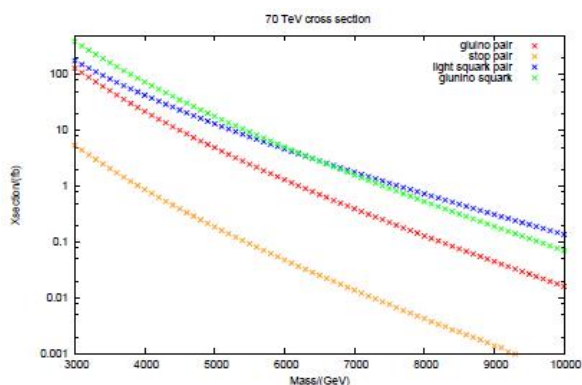


- Finally see SM in massless limit!

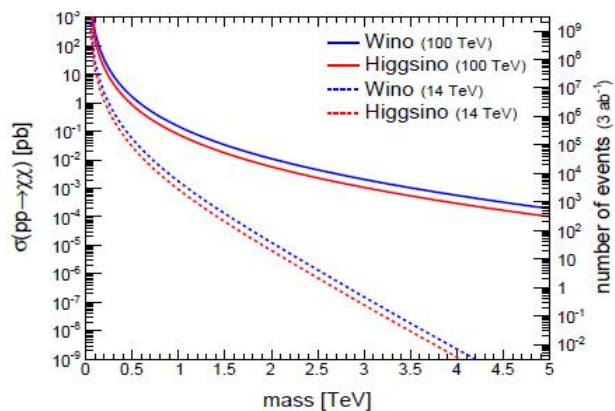


# \* Illustrative Reach for New Physics

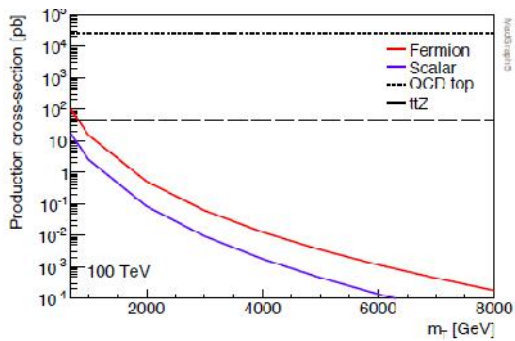
## Colored Pairs



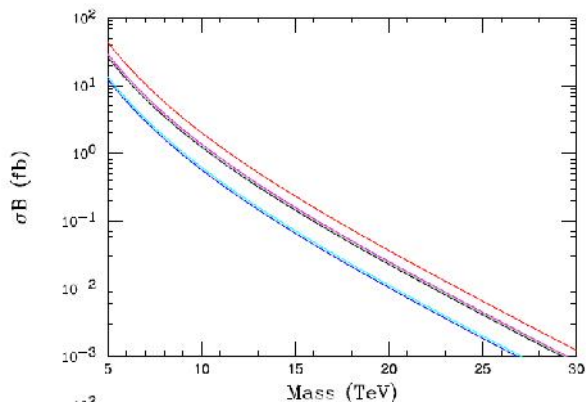
## Ewk Pairs



## \* Vector-Like Fermions



## \* $W/Z$



# \* Powerful + Complementary probes of Higgs couplings

$[N_{\alpha_6}]^2 : [\partial h^\dagger h]^2, h^\dagger h h f f^c, h^\dagger h F^2$   
 $(h^\dagger h)^3$

← CEPC  
← SPPC } Totally Generic

$(h^\dagger D^\mu h)^2, h^\dagger W_{\mu\nu}^a h, h^\dagger D_\mu h F^{\mu\nu} f$

← .1 TeraZ

$\Delta$  probed to (multi-)TeV scale

Phase Transition

“No Lose”

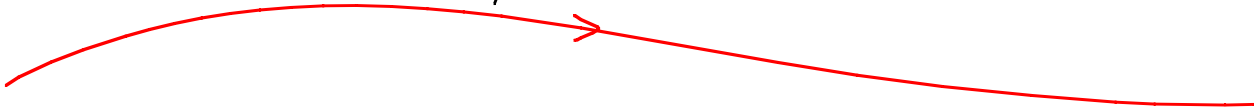
DM

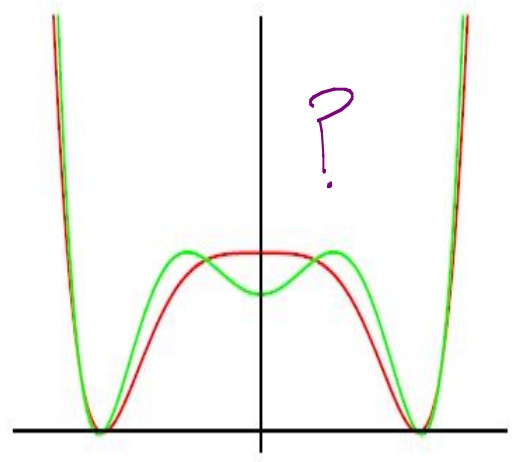
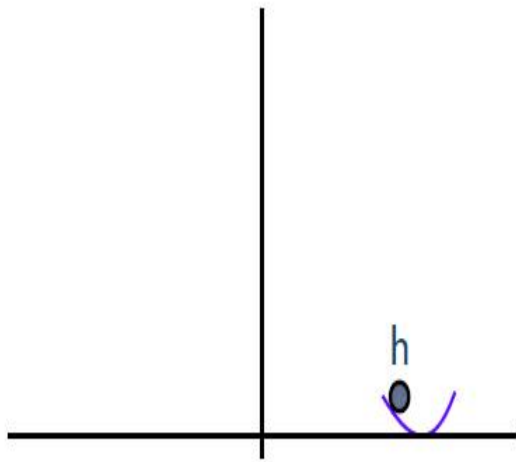
Naturalness

See or Rule out  
Simplest possibilities

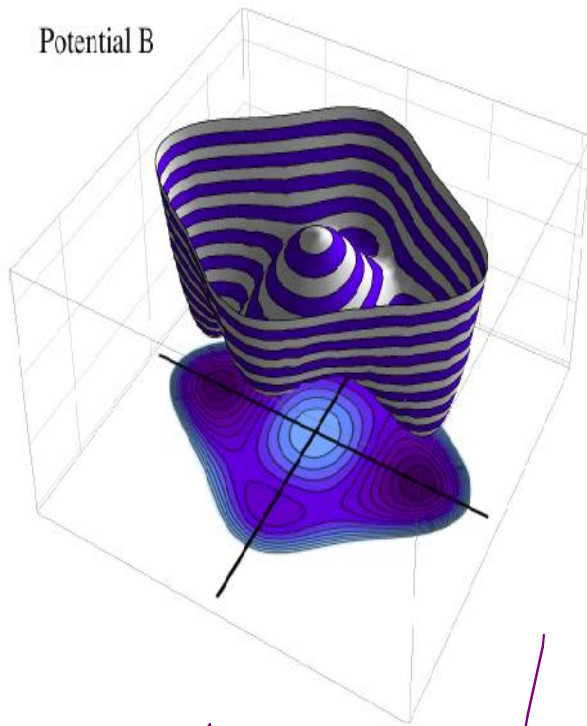
NO LOSE

# The Electroweak Transition





Potential B



or  
even

?

\* LHC won't come close to settling this  
 \* Perfect for CEPC/SPPC!

$$* \quad \Delta Z = \frac{(h^{\dagger}h)^3}{\Lambda^2} + \frac{(\partial \cdot h^{\dagger}h)^2}{\Lambda^2} + \dots$$

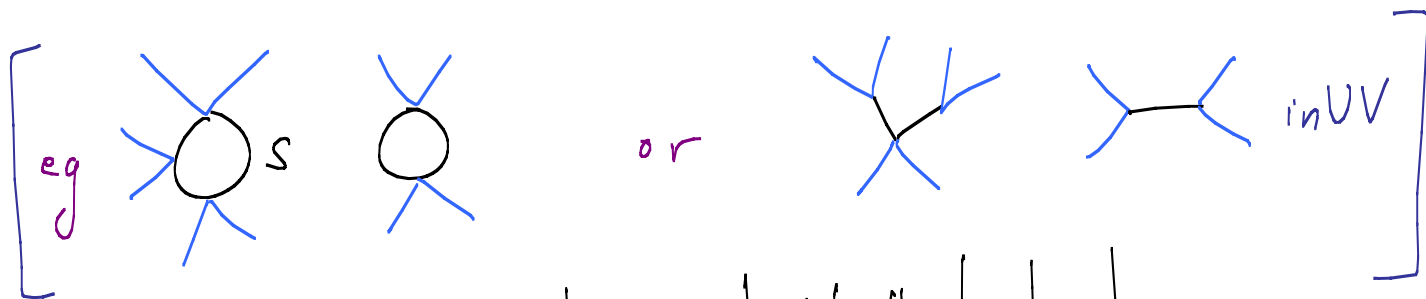
directly  
affects  
transition  
( $h^3$  coupling)

SPPC/CEPC

identical  
symmetries

( $Zh$ )

CEPC

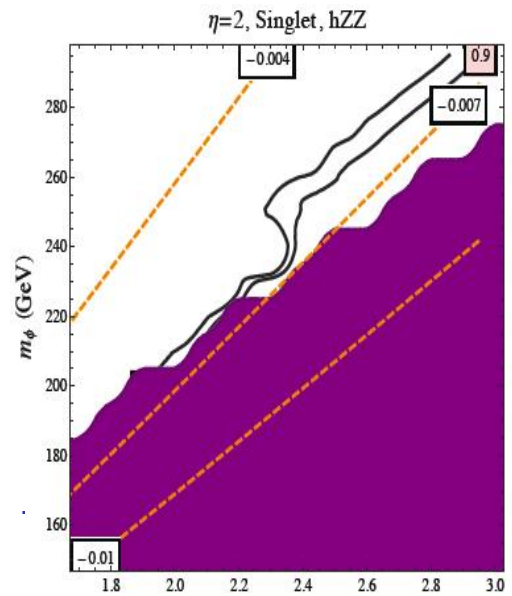
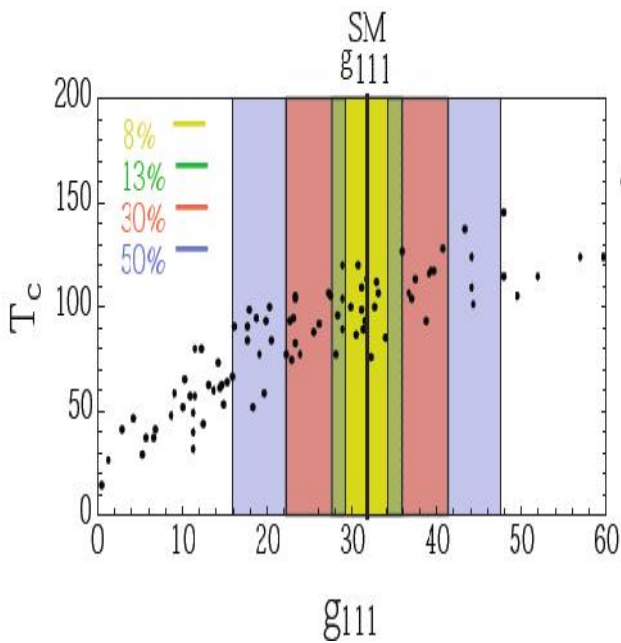


\* S may even be so light that it changes transition more qualitatively

\* Easy cases can be spectacular:

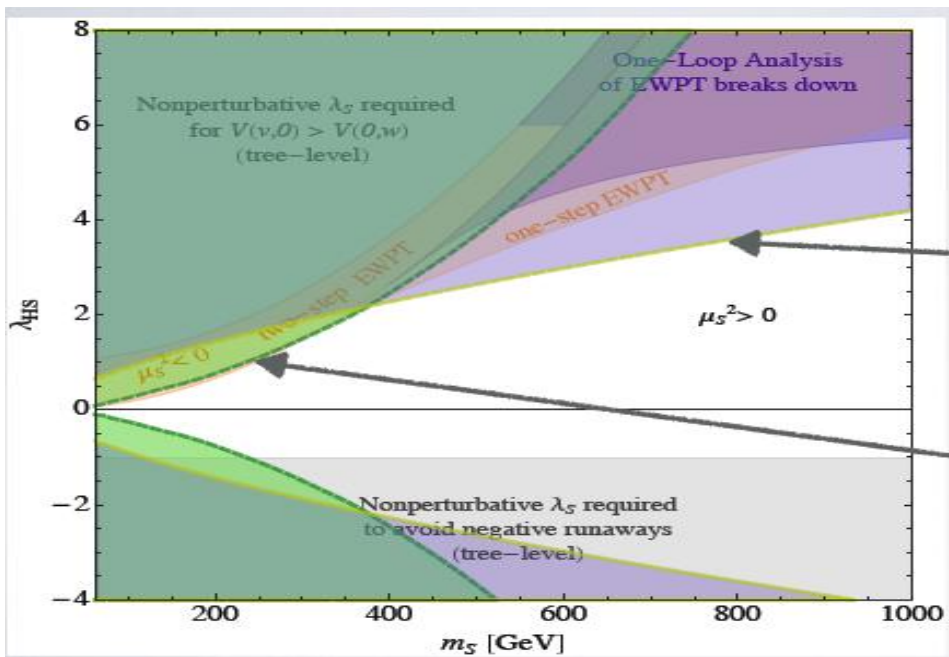
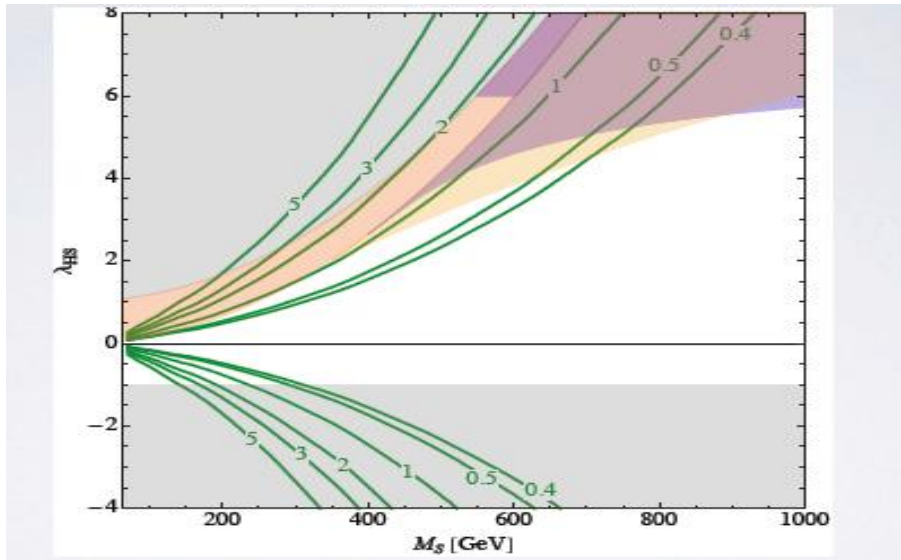
e.g.  $m_S < m_{H/2}$

but even toughest cases can't hide





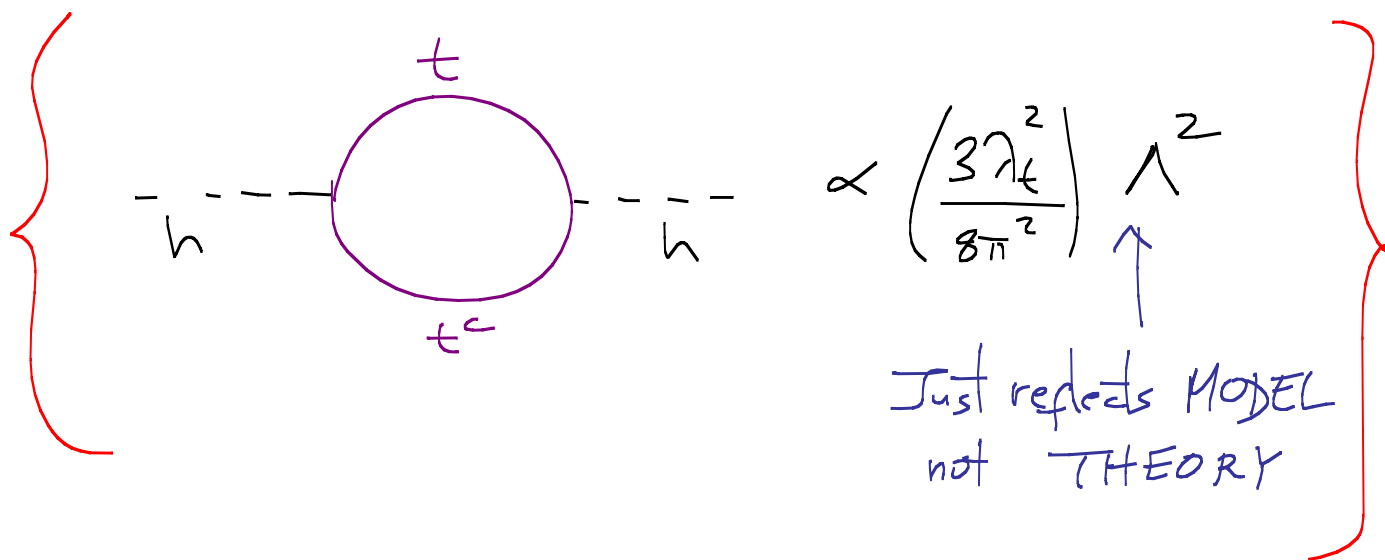
+ Direct production @ SPPC :



Origin + Naturalness of  
Electroweak Scale

The Standard Model is aptly named... it is a phenomenological **MODEL**, not a deep **THEORY**, of EWSB.

$M_h^2$  is a parameter, not predicted, but fitted by experiment!



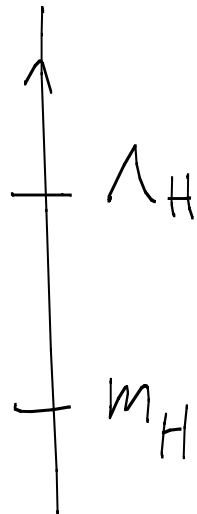
\* Higgs is SIMPLEST PARTICLE  
we've ever seen

\*  $m_H^2 t t^\dagger H$  is SIMPLEST

PARAMETER in particle physics,  
and the most relevant @ low E!

\* Quest for THEORY starts here  
— especially since it turns out to  
be the most mysterious of all of them!

# [400-yr] Reductionist Paradigm



← scale where Higgs THEORY is revealed,  $m_H$  becomes calculable

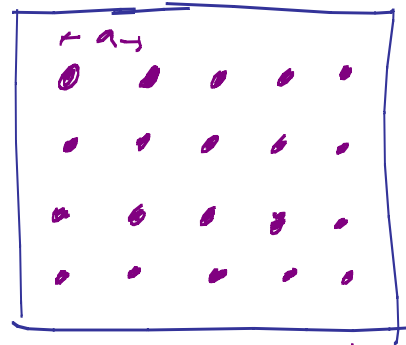
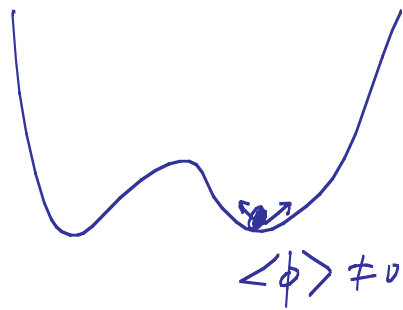
$$m_H^2 = a \Lambda_H^2 + b \left( \frac{\Lambda_H^2}{8+2} \right) \Lambda_H^2 + \dots$$

$\Lambda_H \sim m_H$  : "Natural"  
Complete Understanding

$\Lambda_H \gg m_H$  : Needs extreme correlation  
between UV + IR  
physics (POSSIBLE, NEVER SEEN  
BEFORE)

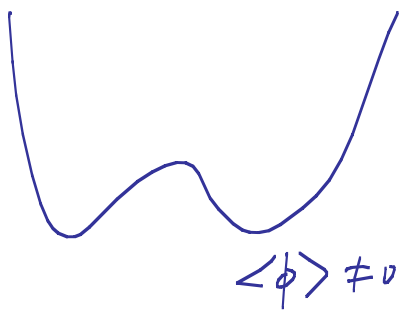
Borne out by all known examples,  
both theoretically, as well as experimentally!

# A Famous Example

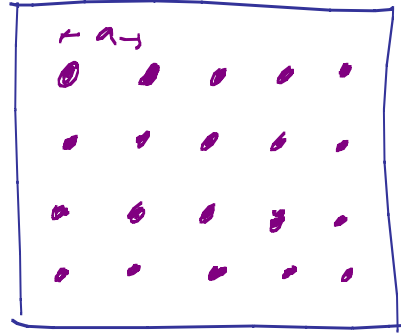


Still no understanding  
of  $m^2 \ll 1/a^2$ !

# An Example We've Seen



UV  $\rightarrow$

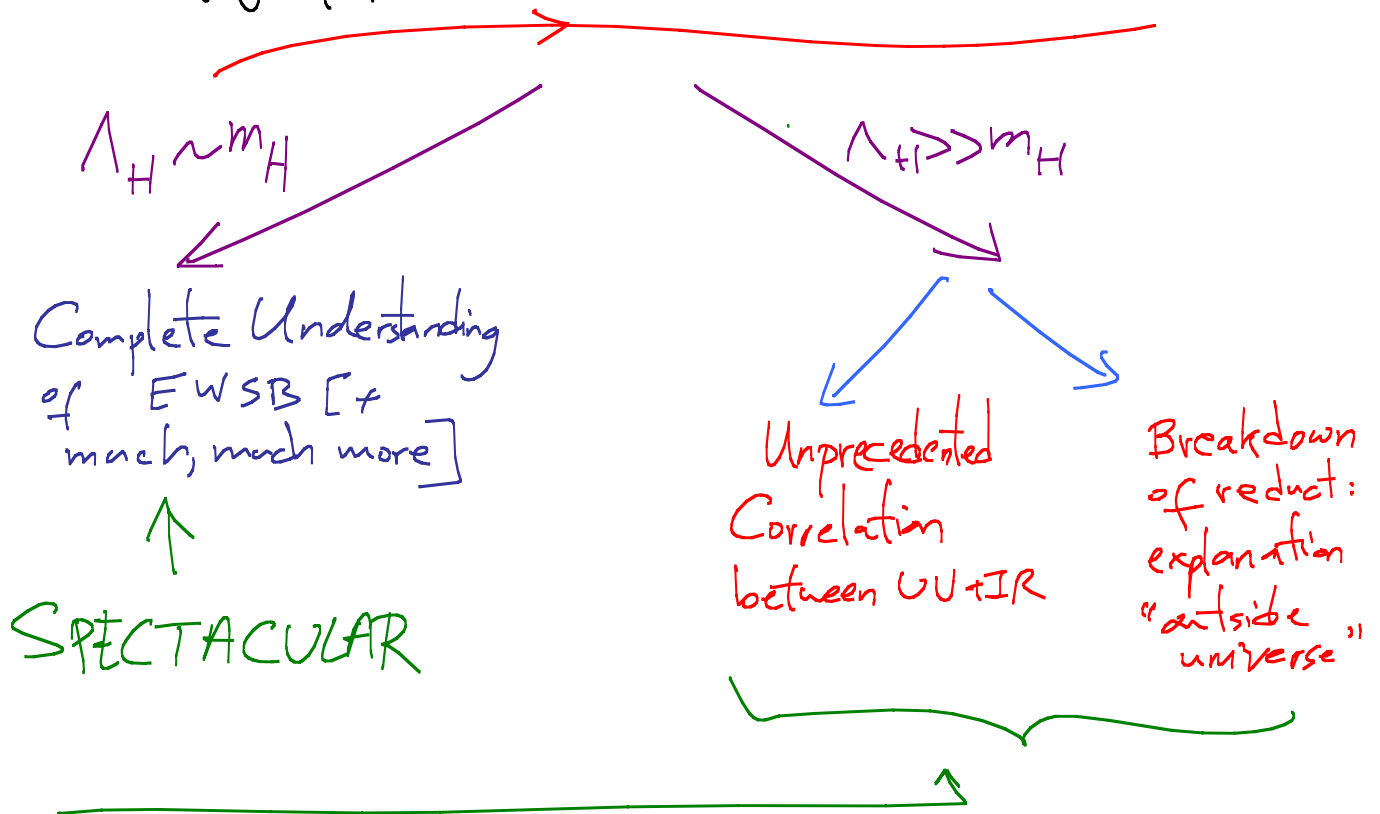


Explanation not  
in UV, but  
OUTSIDE SYSTEM!

- \* Here: "fine-tuning"
- \* Breakdown of reductionism for this system!

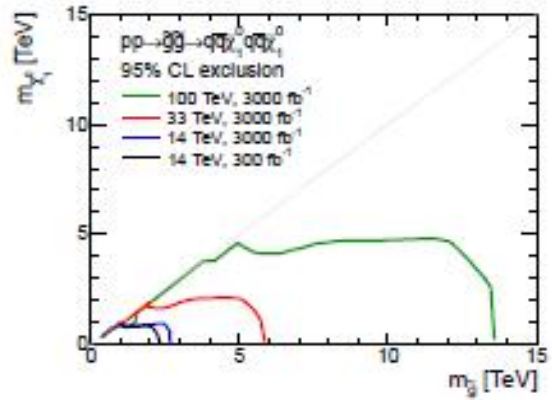
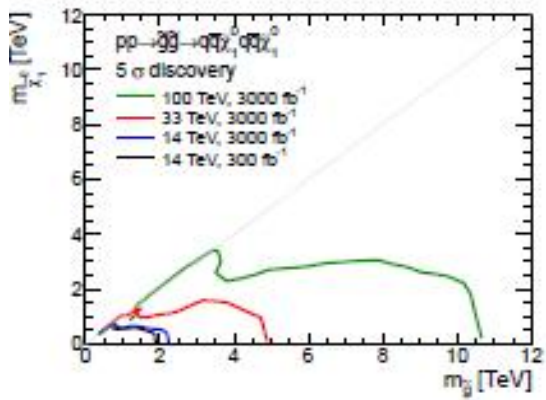
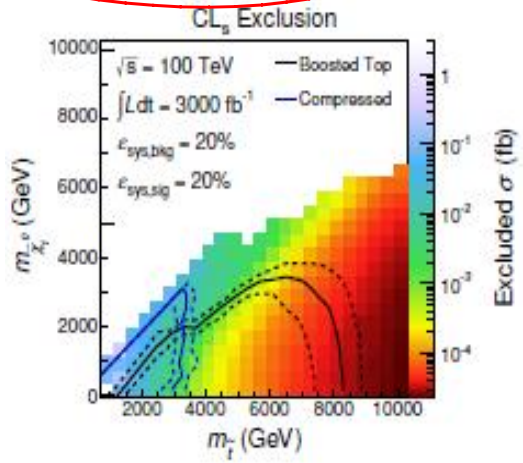
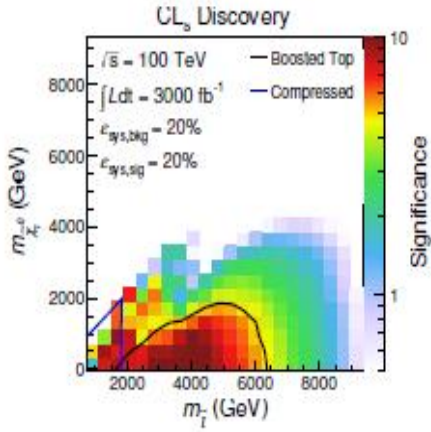


# WIN-WIN-WIN

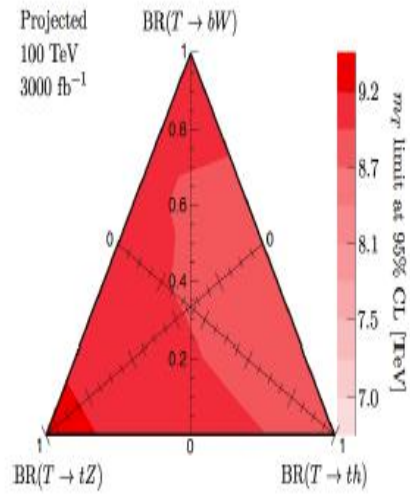
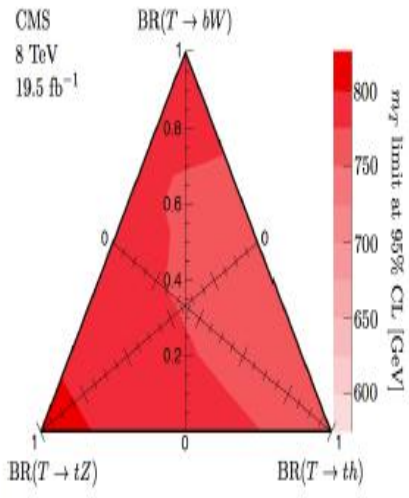
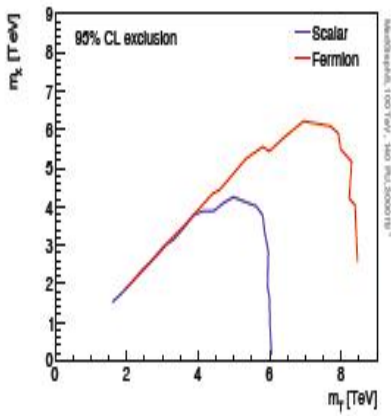


Won't know which, but, REVOLUTIONARY either way.  
Epochal change in direction of Fundamental Physics

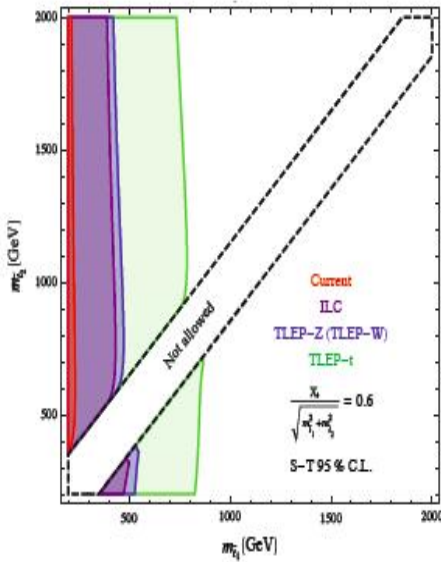
# Stops + Gluinos



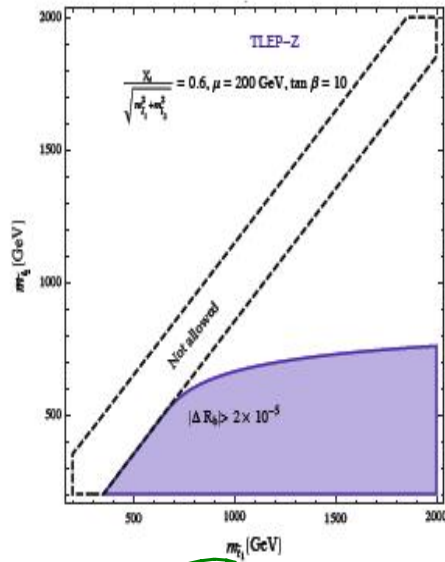
# Top Partners



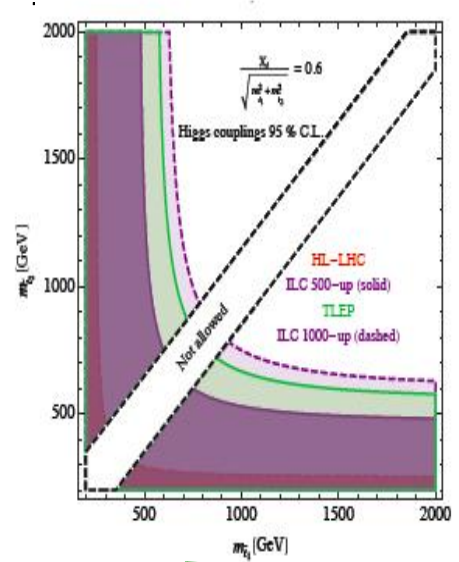
# Stops affecting Z/H @ CEPC



T



R<sub>b</sub>

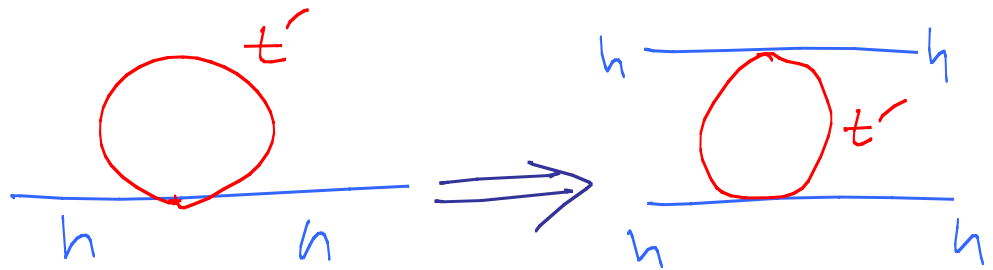


Z/h

Can + hide Natural Stops no matter how buried it is @ hadron colliders

\* Say no new physics @ LHC -  
 is it really true this already  
 means  $\sim 1\%$  "tuning"?

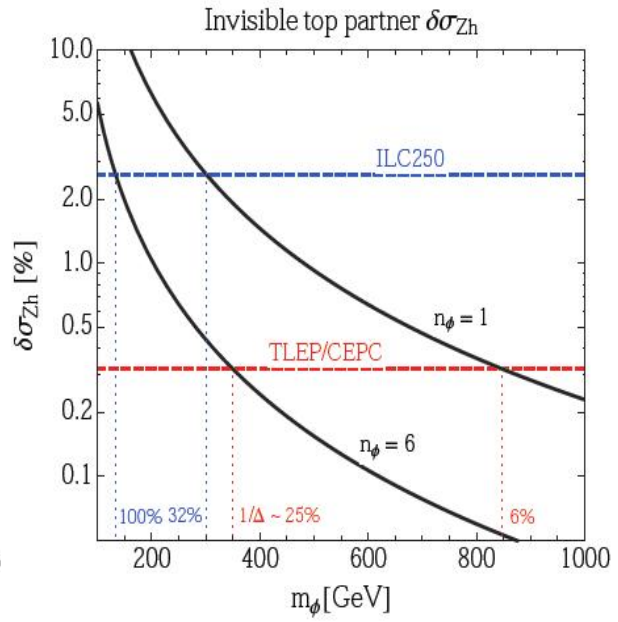
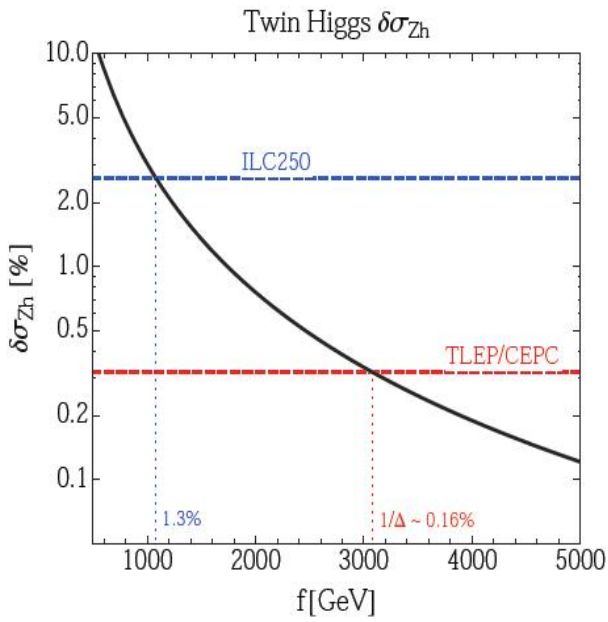
NO!  
 ~~~~~



Uncolored top  
 partners

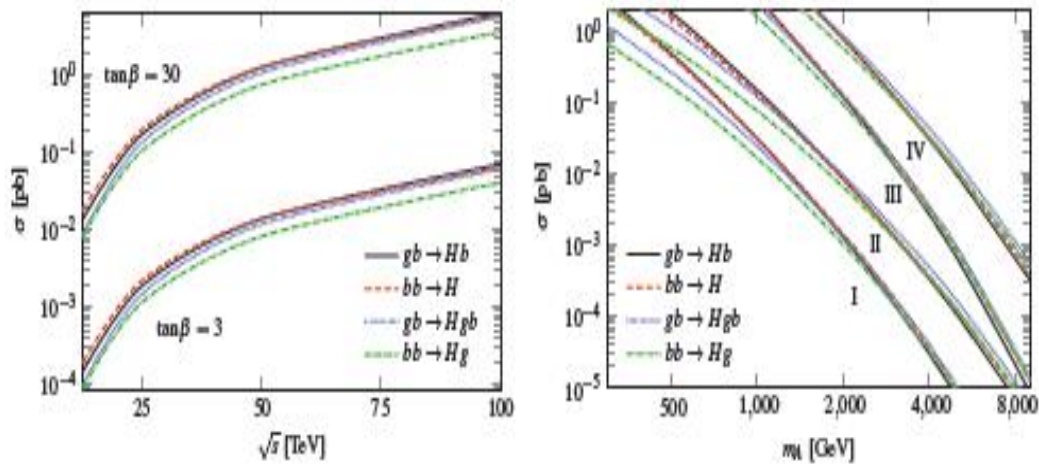
inevitable  
 $Z/h$  shift

# Naturalness "No-Lose" Thm



\* Scalars are weird — are there any more of them?

#### 5.4 Probing Heavy New Higgs States at SPPC



\* Of course if we do  
see new physics @ LHC  
[e.g. 2 TeV  $\tilde{g}'$ ], we won't  
produce with enough rate to  
learn what they are trying to tell us!  
[e.g. is it a gluino?]

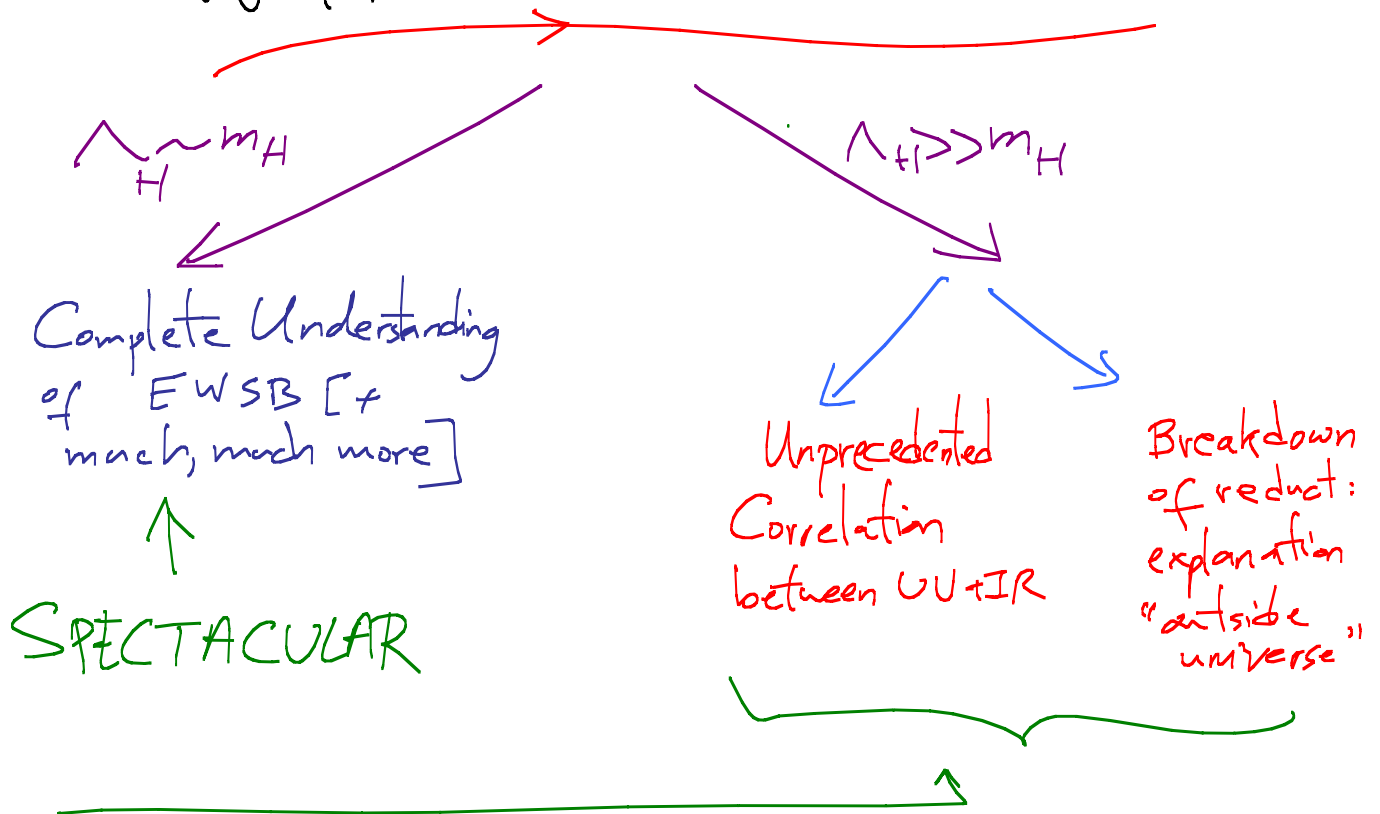


• And it's very unlikely  
we will see full spectrum

[ "Rattazzi's Thm" ]

• e.g. natural SUSY, could have  
 $\tilde{f}_{1,2}$  up to  $\sim 10$ 's TeV —  
can make  $\tilde{L}/\tilde{g}$  associated production

# WIN-WIN-WIN



Won't know which, but, REVOLUTIONARY either way.  
Epochal change in direction of Fundamental Physics

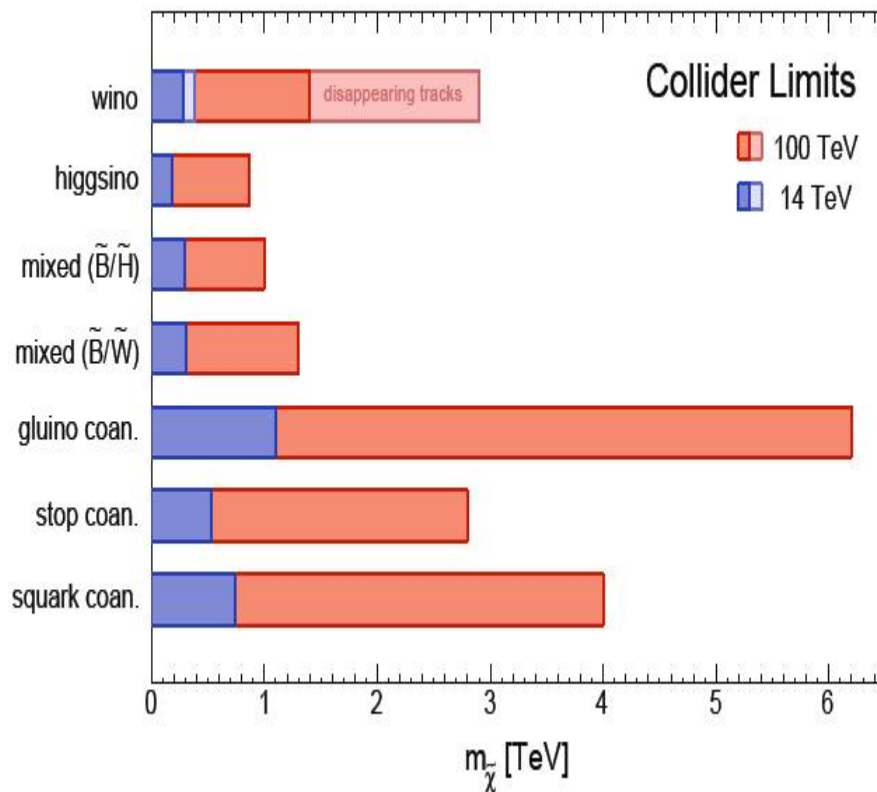
Dark Matter(s)



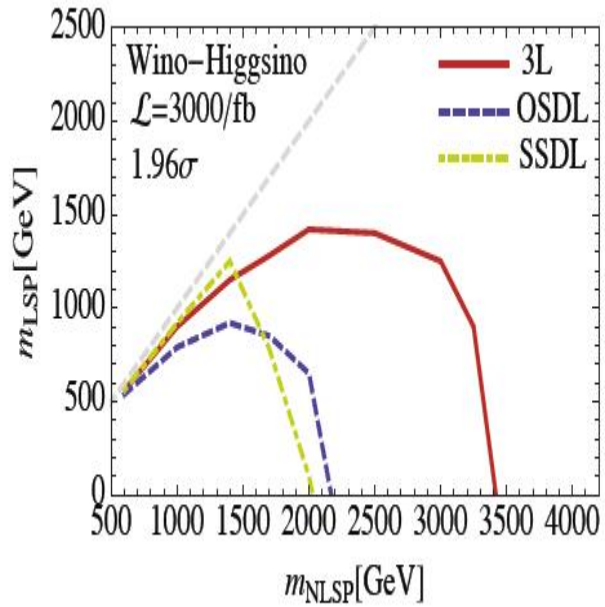
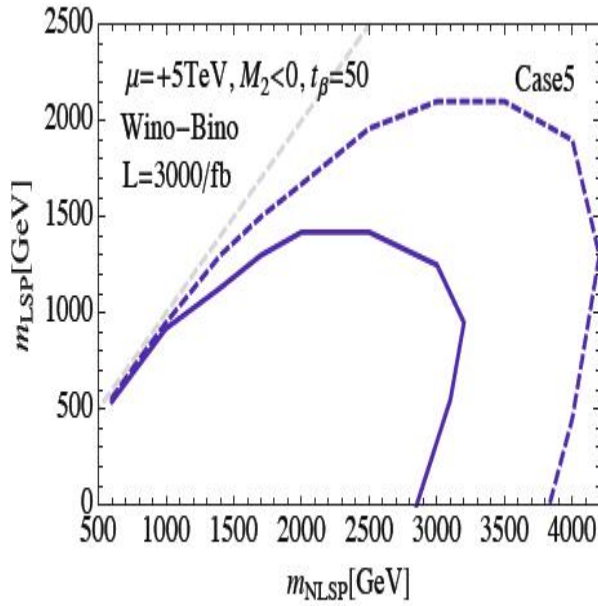
• WIMPS are, still, the only calculable models of dark matter we have

• If "W" = "eWeak" —  
could easily be  $\sim$  few TeV, +  
inaccessible @ LHC. [Even more likely  
now, after LHC 8]

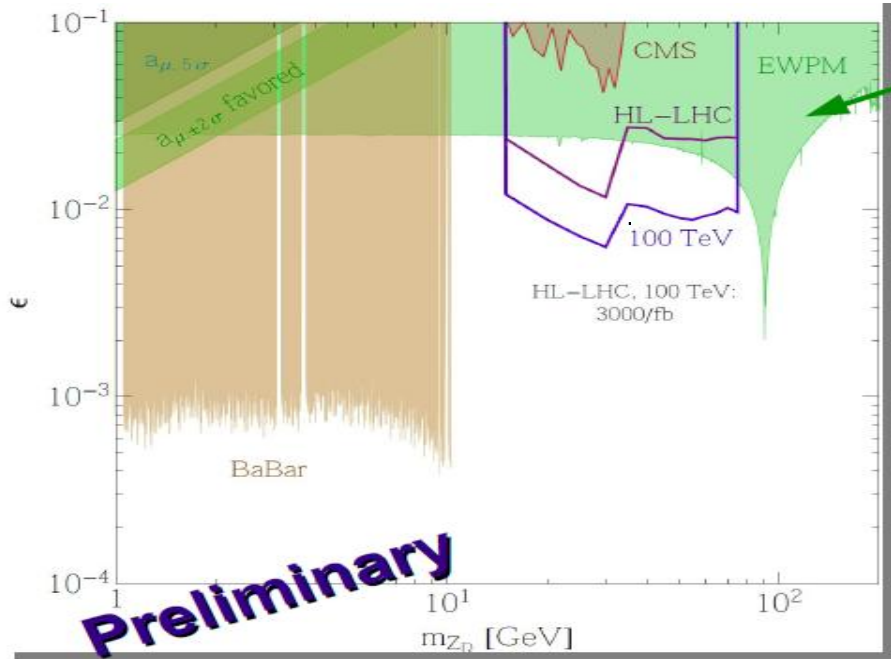
# Rock-Bottom Case: Monojets



# Reach for EWK Cascades



# Higgs Decays to Dark Sectors



Phase Transition

“No Lose”

DM

Naturalness

See or Rule out  
Simplest possibilities

NO LOSE



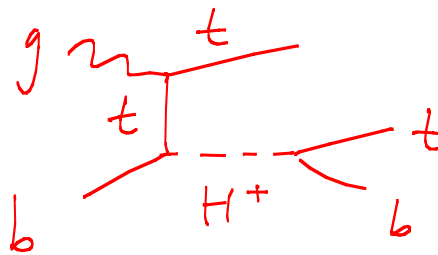
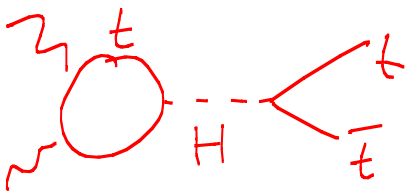
Concrete Requests to WGs



# Higgs

\* What is the actual story for  $h^3$  sensitivity @ CLTC [60%, 30%, 15%]

\* Standard 2HDM reach @ SPAC



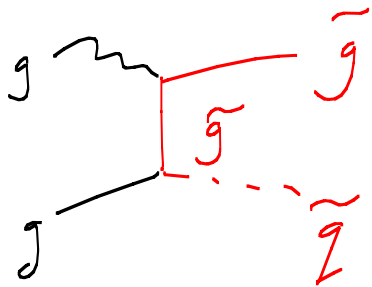
# BSM Non-SUSY



- \* Top partners CTEPC/SPPC
- \*  $W'$  reach SPPC
- \*  $t \rightarrow c$  @ SPPC,  $\tau \rightarrow \mu$  @ CTEPC

# SUSY

\*



say  $\tilde{g} @ 2 \text{TeV}$ ,

reach for  $\tilde{q} (\sim 40 \text{TeV}?)$

\* Heavy Higgs reach @ SPPC

\* Probing gauge-Yukawa coupling of  $\tilde{g}/\tilde{q}$ , for both  $\sim \text{TeV}$

# Cosmology

\* How robustly do we understand 1st order transition requirement?

[ $\Delta h^3$  seems to range from  $\mathcal{O}(100\%)$  to  $\mathcal{O}(20\%)$  across various studies]

\* Direct reach on  $S$  in  $(S_{k^+k^-})_{\text{model}}$   
@ SPPC

\* Probes of  $CP$  in  $S/H$  decays  
@ SPPC

# MC + SM Groups



- \* Co-ordinate mutual activities,  
also with experimentalists
- \* Interface with currently  
established groups

Case is Amazingly Strong

+

Easy to Explain

The discovery of the Higgs boson at the Large Hadron Collider (LHC) completed our understanding of 20th century physics. Fundamental physics now finds itself at one of the most exciting crossroads in its history. The central questions today are the most profound ones that have been posed in decades, related to the ultimate origins of the elementary particles and of space-time itself. Many of these questions are intimately connected with the Higgs particle, which is unlike any elementary particle we have seen before, appearing to be far more point-like than naturally expected on theoretical grounds.

Major new input from experiments is needed for progress. The future of fundamental physics on the 20-50 year timescale hinges on starting a huge new accelerator complex that can take us at least one order of magnitude beyond the ultimate reach of the LHC.

A remarkable proposal from China is to house a huge new accelerator in an approximately 100 km circular tunnel. In the first stage, the machine would collide electrons and positrons, thereby producing millions of Higgs particles and measuring its properties to fantastic sub-percent level precision, providing vital clues to its microscopic structure. In the second stage, the machine would collide protons at energies almost 10 times more powerful than the LHC. This will allow us to hunt for new fundamental particles 10 times heavier than we can possibly produce with the LHC, and new particles the LHC may produce in small numbers will be produced with a 1000 times higher rate, giving us a powerful window into the quantum-mechanical vacuum of our universe with 100 times greater sensitivity than ever before.

It would be a boon for physics to actively engage the ocean of Chinese talent into the field. The scientific and engineering challenges involved in building the machine would be a major stimulus to the development of Chinese science and technology- work in this subject is the ideal training ground for learning to attack difficult, long-term problems in technical fields, fostering skills sure to be of paramount importance in the coming decades. At the same time, thousands of the world's most talented physicists and engineers would flock to China to enthusiastically join in the effort.

Over the centuries, the quest to understand the laws of Nature at the deepest level has been one of the noblest and most consequential aspirations of humanity. By building this "Great Collider", China will catapult into global leadership of fundamental physics in the 21st century.









We have a Challenging +  
Exciting ~ 2 months  
ahead of us!

# Schedule Guideline for CEPC pre-CDR

August – December 2014

Questions? Please contact Xinchou Lou (xinchou@ihep.ac.cn)

| August<br>1-15                                                                                                                                                                                                                                                     | August<br>16-31 | September<br>1-15                                                                                                                                             | September<br>16-30 | October<br>1-15 | October<br>16-31                                                                   | November<br>1-15                                                                                                                                             | November<br>16-30                                                                    | December<br>1-15                                                                      | December<br>16-31 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-----------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|-------------------|
|                                                                                                                                                                                                                                                                    |                 |  <span style="color: red; font-size: 1.2em;">← RESPECTABLE IN ~ 2 WKS</span> |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |                                                                                       |                   |
| <p>(1) pre-CDR draft version 0 from each (sub-)group (with all required elements, some contents may be missing); (2) identify loose ends &amp; address them at the (sub)group level.</p>                                                                           |                 |                                                                                                                                                               |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |                                                                                       |                   |
|                                                                                                                                                                                                                                                                    |                 |                                                                              |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |                                                                                       |                   |
| <p>(1) external reviewers identified and invitations sent out during first period; (2) additions and revisions being worked on; (3) formation of editorial board at SJTU workshop; (4) internal reviews within (sub-)groups.</p>                                   |                 |                                                                                                                                                               |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |                                                                                       |                   |
|                                                                                                                                                                                                                                                                    |                 |                                                                                                                                                               |                    |                 |                                                                                    |  <span style="color: red; font-size: 1.2em;">← AWESOME IN ~ 2 MONTHS</span> |                                                                                      |                                                                                       |                   |
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|                                                                                                                                                                                                                                                                    |                 |                                                                                                                                                               |                    |                 |  |                                                                                                                                                              |                                                                                      |                                                                                       |                   |
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|                                                                                                                                                                                                                                                                    |                 |                                                                                                                                                               |                    |                 |                                                                                    |                                                                                                                                                              |  |                                                                                       |                   |
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|                                                                                                                                                                                                                                                                    |                 |                                                                                                                                                               |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |  |                   |
| <p>(1) proof; (2) print and release to CAS and public.</p>                                                                                                                                                                                                         |                 |                                                                                                                                                               |                    |                 |                                                                                    |                                                                                                                                                              |                                                                                      |                                                                                       |                   |

August 5, 2014

