

Outline of Summary

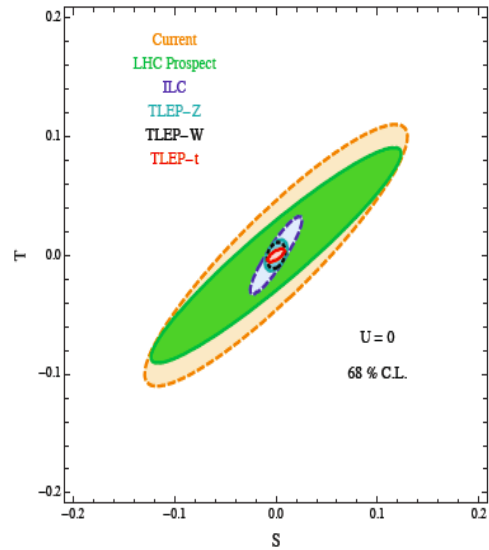
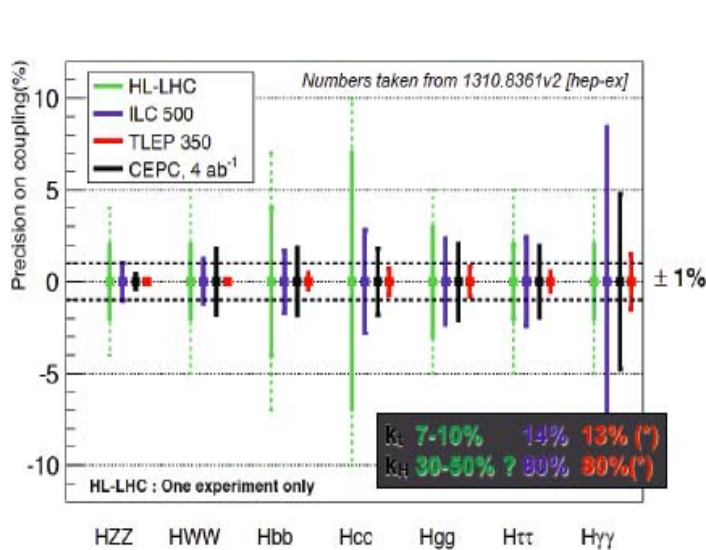


- (0) New Machines for a New Frontier
- (1) The Ewk Phase Transition
- (2) Naturalness + deep origin of EWSB
- (3) Dark Matter(s)
- [(4) New world of Flavor + CP]

New Machines for the

New Frontier

\* CEPC: Huge Leap in Precision



Higgs Factory

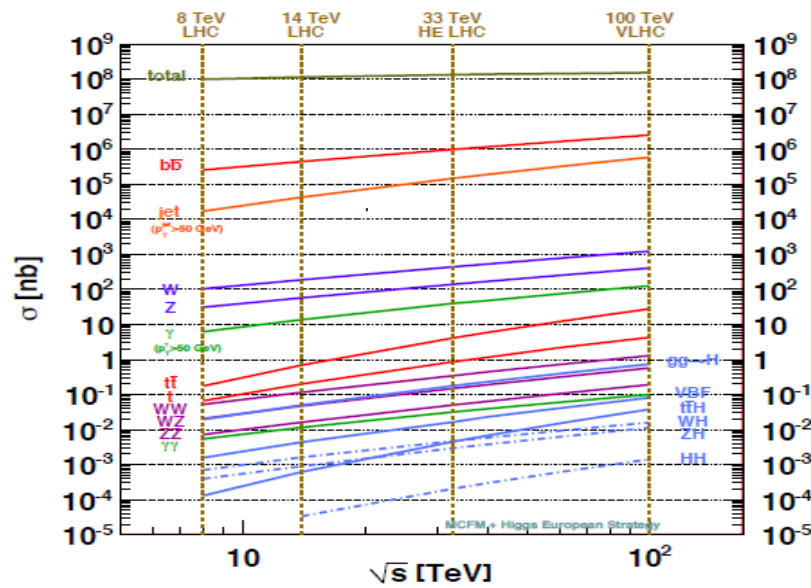
Z factory

\* Invisible + Exotic Higgs decays

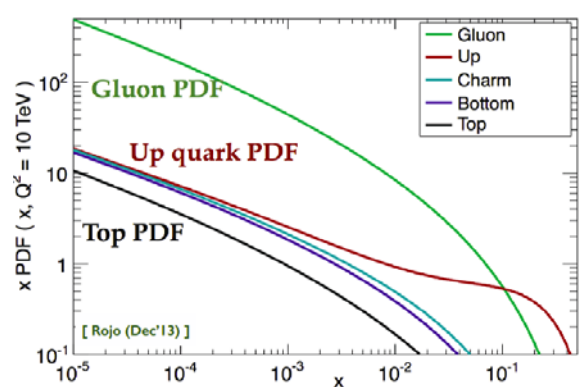
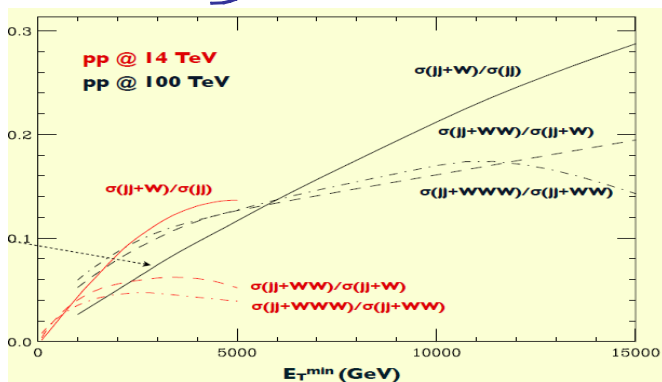
\* CPV in Higgs couplings

\* SPPC: Huge Leap in Energy

• Enormous Rates

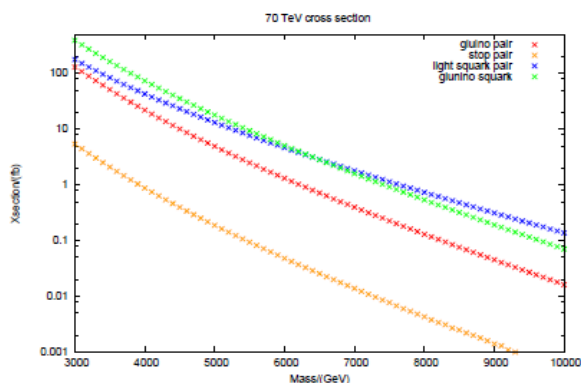


• Finally see SM in massless limit!

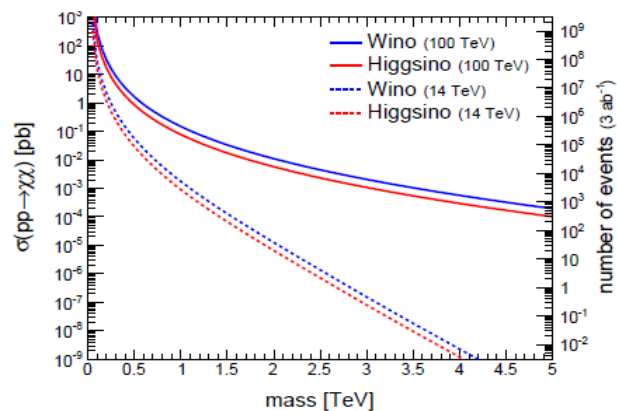


# \* Illustrative Reach for New Physics

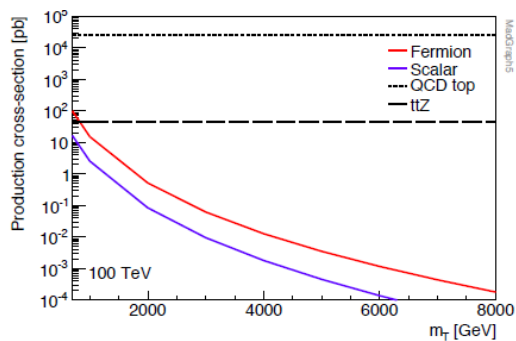
## Colored Pairs



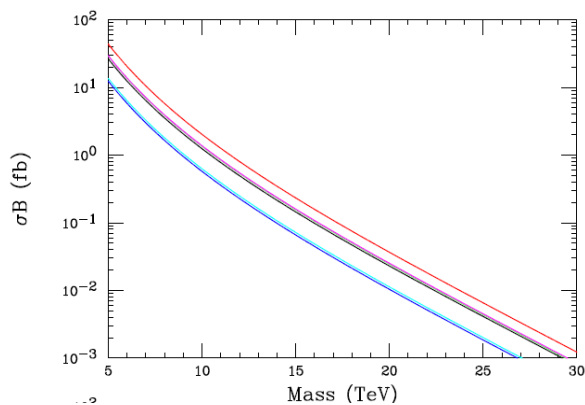
## Ewk Pairs



## \* Vector-Like Fermions



## \* $W'/Z'$



# \* Powerful + Complementary probes of Higgs couplings

$[126]$  :  $[\partial h^\dagger h]^2$ ,  $h^\dagger h h f f^c$ ,  $h^\dagger h F^2$   $\leftarrow$  CEPC

$(h^\dagger h)^3$   $\leftarrow$  SPPC  $\left\{ \begin{array}{l} \text{Totally} \\ \text{Generic} \end{array} \right.$

$(h^\dagger D^\mu h)^2$ ,  $h^\dagger W_{\mu\nu} B_{\mu\nu} h$ ,  $h^\dagger D_\mu h \bar{f} \gamma^\mu f$

$\uparrow$  .1 TeraZ

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

Phase Transition

"No Lose"

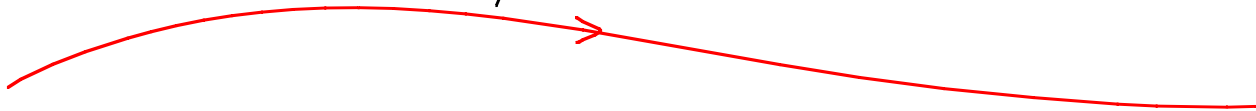
DM

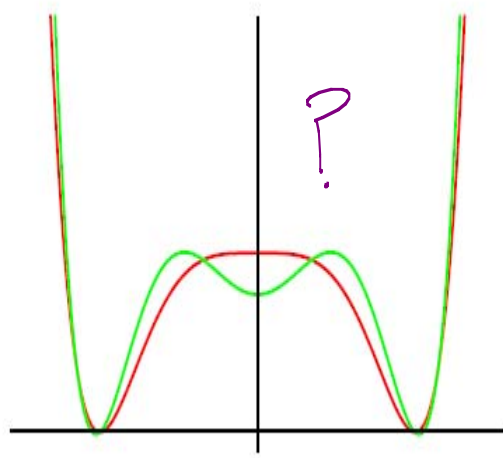
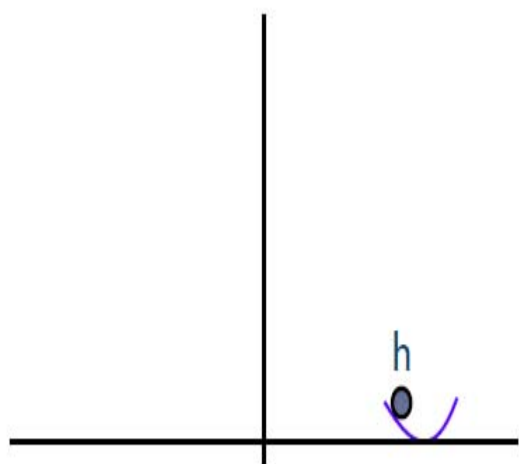
See or Rule out  
Simplest possibilities

Naturalness

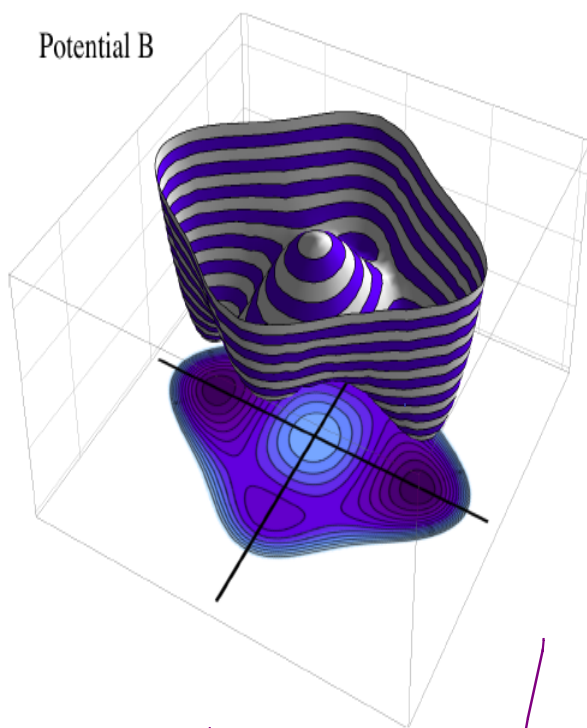
NO LOSE

The Electroweak Transition





or  
even



?

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

$$* \quad \Delta \mathcal{L} = \frac{(h^\dagger h)^3}{\Lambda^2} + \frac{(\partial_\mu h^\dagger h)^2}{\Lambda^2} + \dots$$

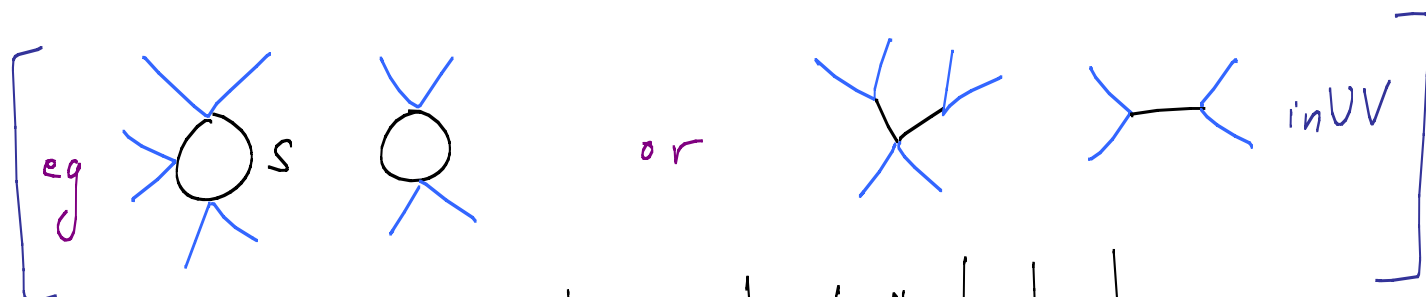
directly  
affects  
transition  
( $h^3$  coupling)

SPRC/CEPC

identical  
symmetries

( $\mathbb{Z}_2$ )

CEPC

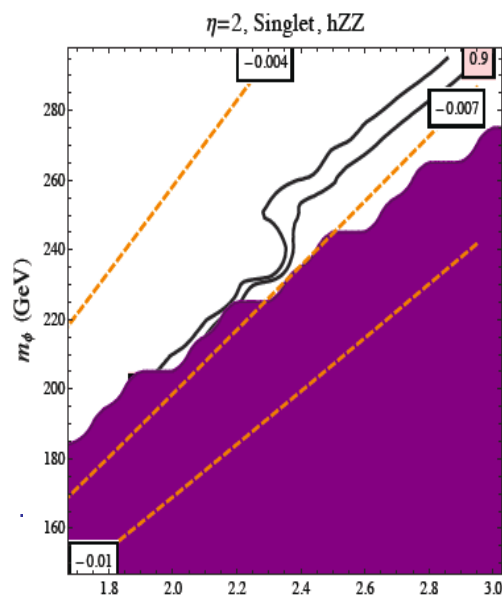
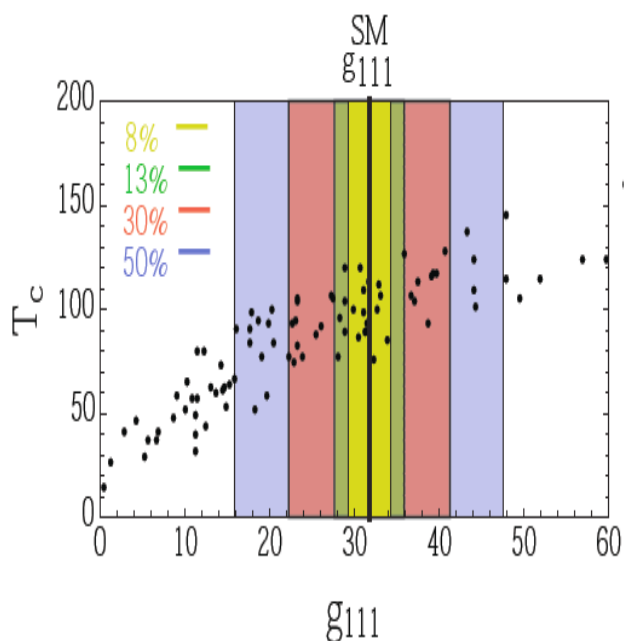


\* S may even be so light that it changes transition more qualitatively

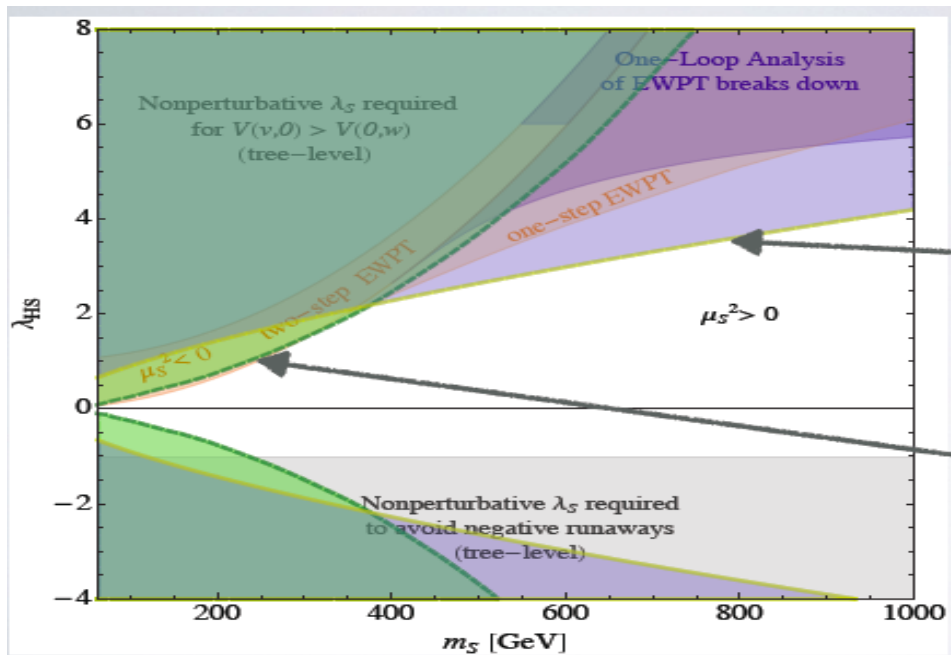
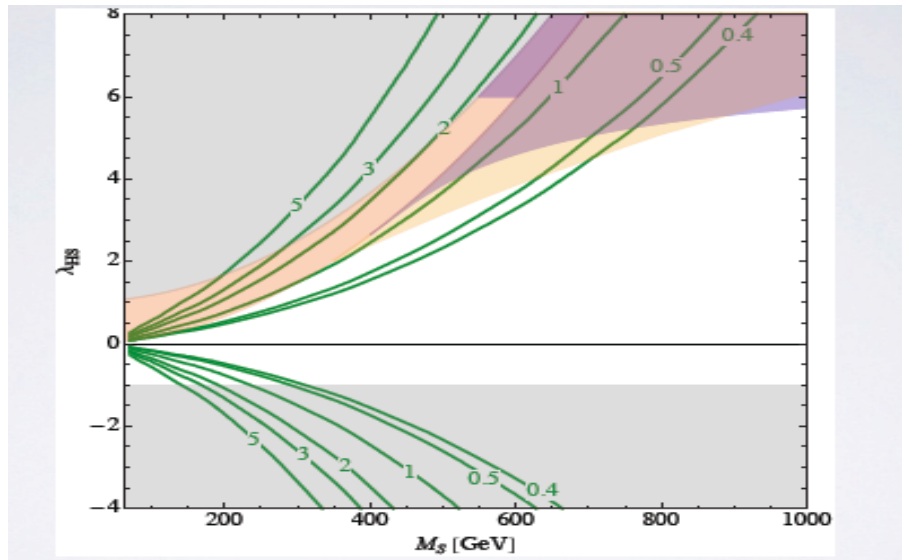
\* Easy cases can be spectacular:

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!

$$\left\{ \begin{array}{l} \text{Diagram: } h \text{ (dashed line) connected to a circle loop with } t \text{ (top) and } t^c \text{ (bottom), which is then connected to } h \text{ (dashed line).} \\ \propto \left( \frac{3\lambda_t^2}{8\pi^2} \right) \Lambda^2 \end{array} \right.$$

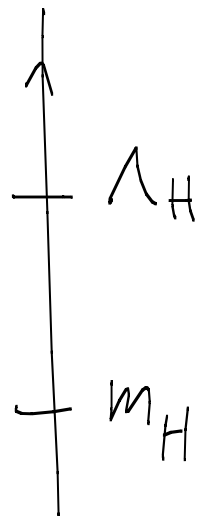
$\uparrow$   
 Just reflects MODEL  
 not THEORY

\* Higgs is SIMPLEST PARTICLE  
we've ever seen

\*  $m_H^2 H^\dagger H$  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

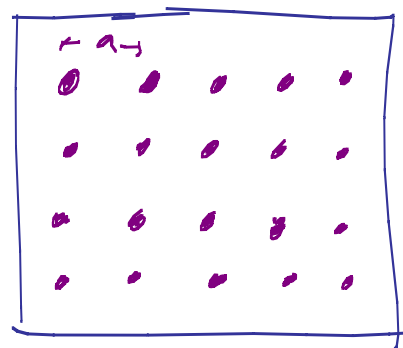
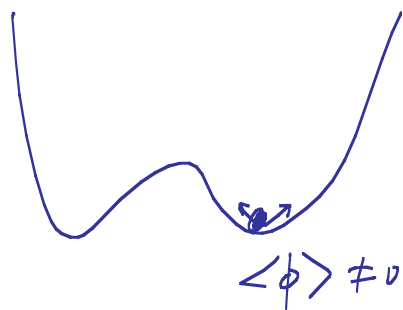
$$m_H^2 = a \Lambda_H^2 + b \left( \frac{\Lambda_H^2}{8\pi^2} \right) \Lambda_H^2 + \dots$$

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

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

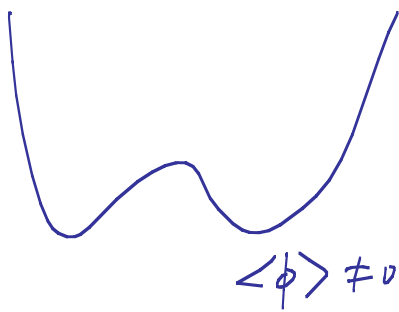
Borne out by all known examples,  
both theoretically, as well as experimentally!

# A Famous Example

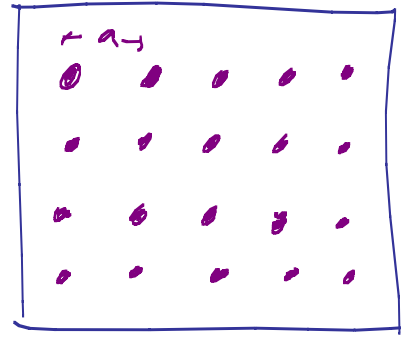


Still no understanding  
of  $m_Y^2 \ll 1/a^2$ !

# An Example We've Seen



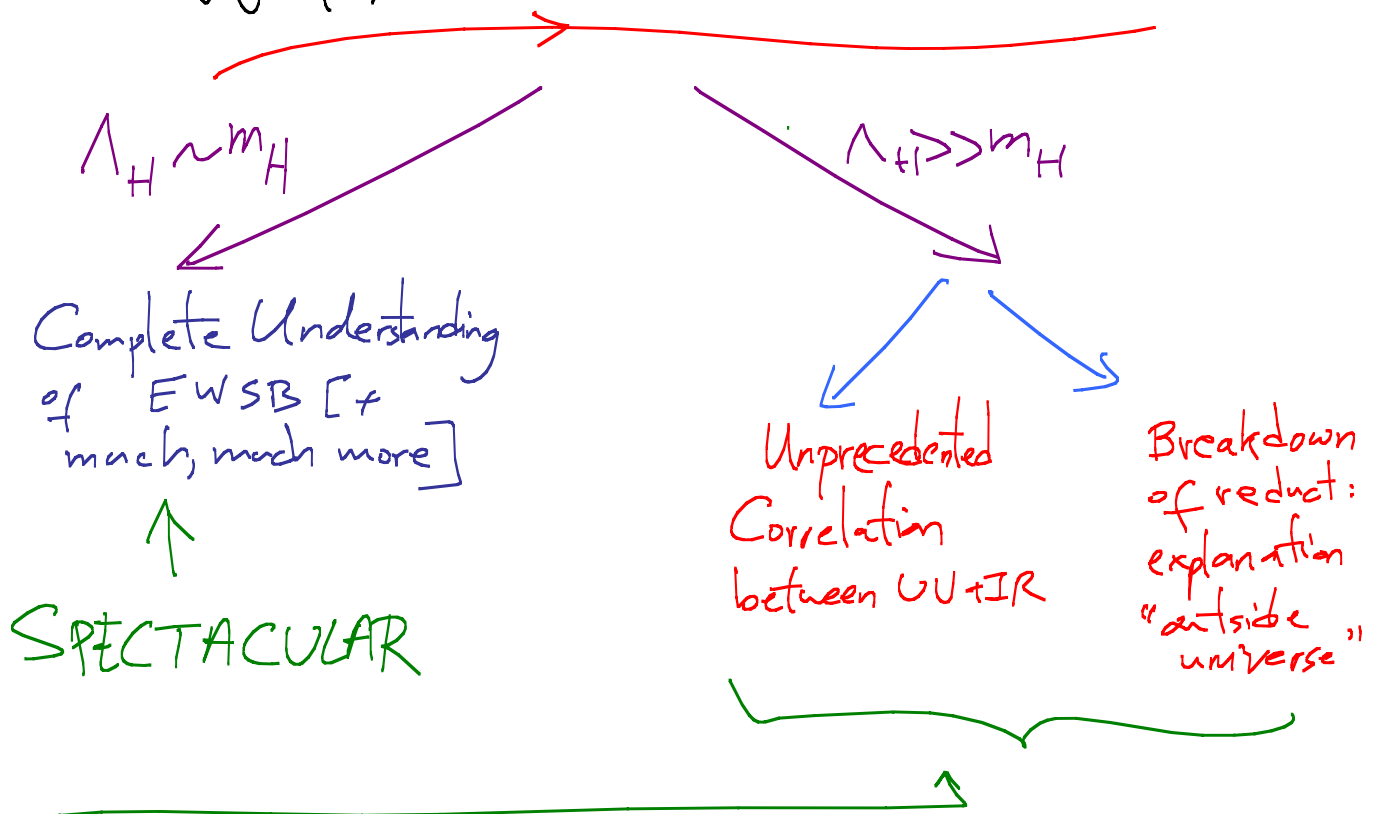
UV  $\rightarrow$



Explanation not  
in UV, but  
OUTSIDE SYSTEM!

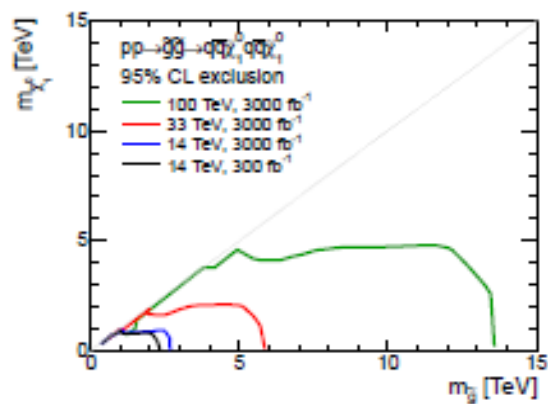
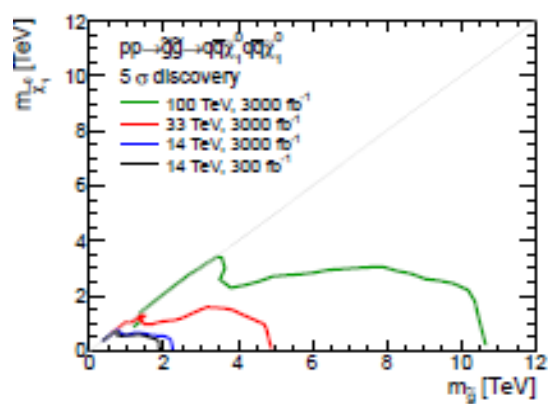
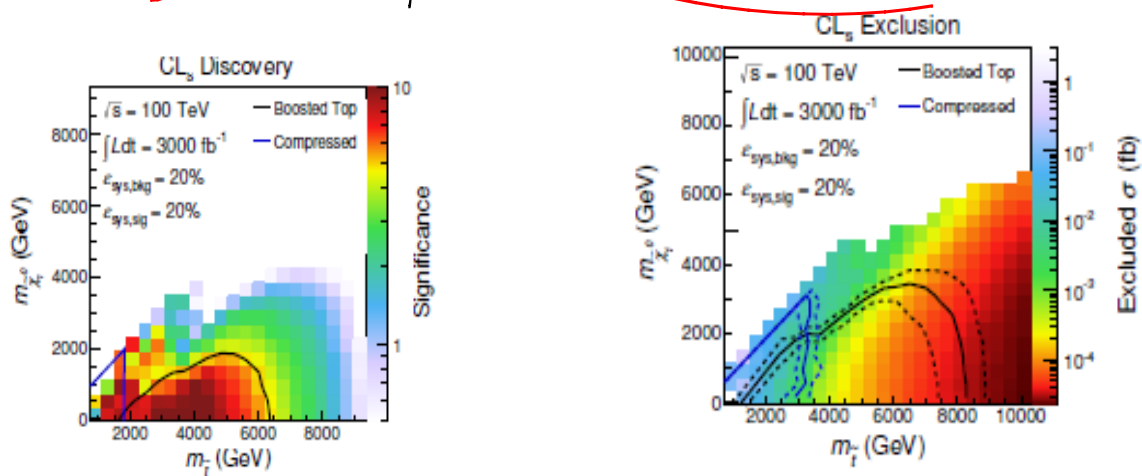
- \* Here: "fine-tuning"
- \* Breakdown of reductionism for this system!

# WIN-WIN-WIN

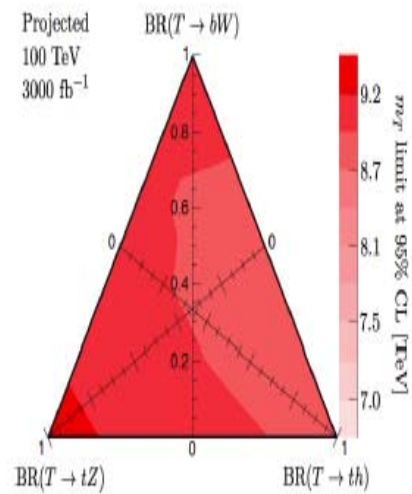
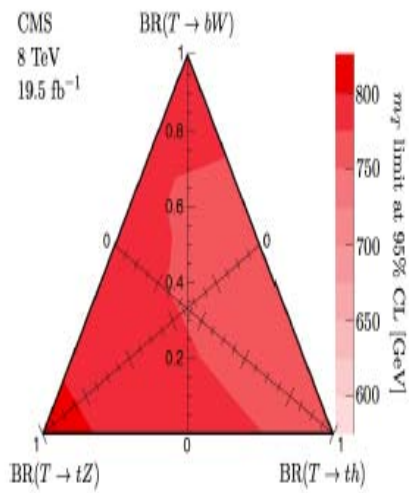
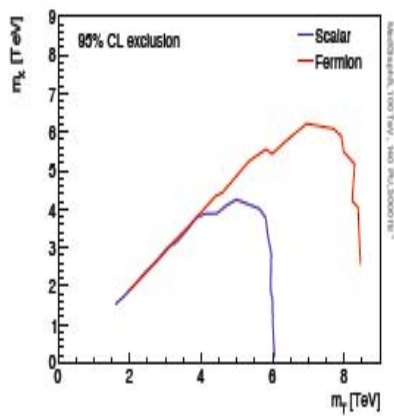


Won't know which, but, REVOLUTIONARY either way.  
Epochal change in direction of Fundamental Physics

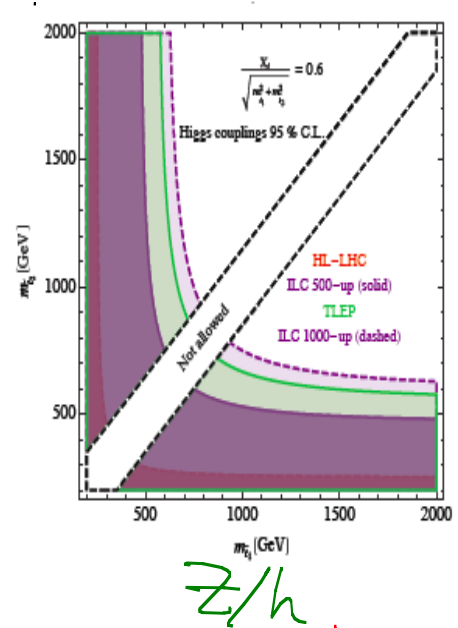
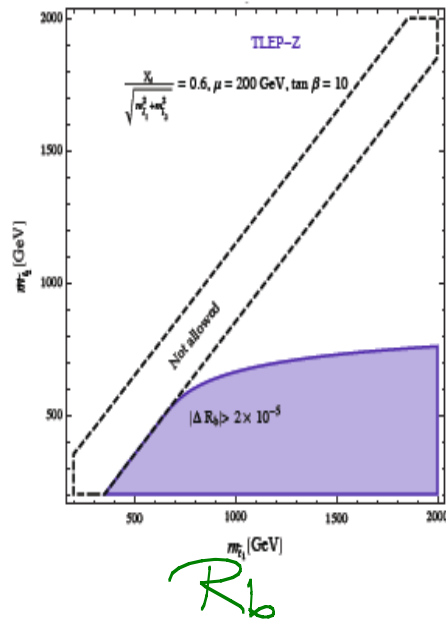
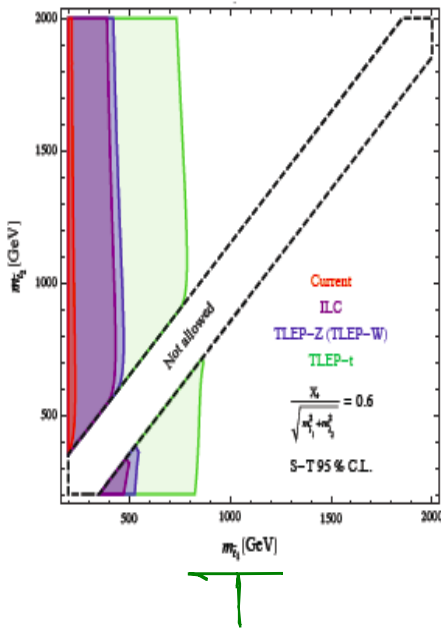
# Stops + Gluinos



# Top Partners



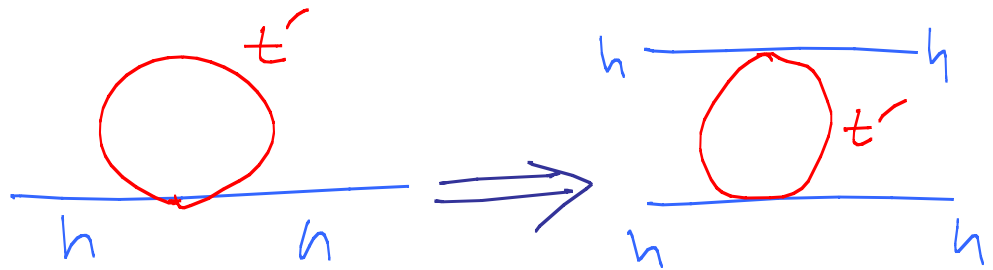
# Stop is affecting Z/H @ CEPC



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"?

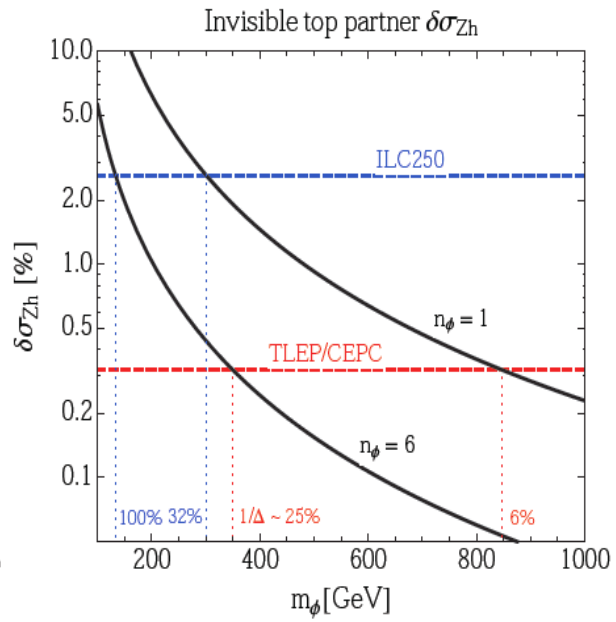
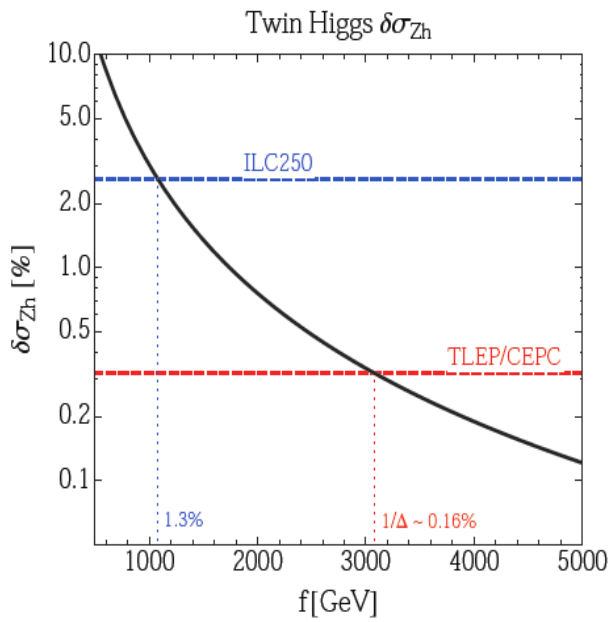
NO!



Uncolored top  
partners

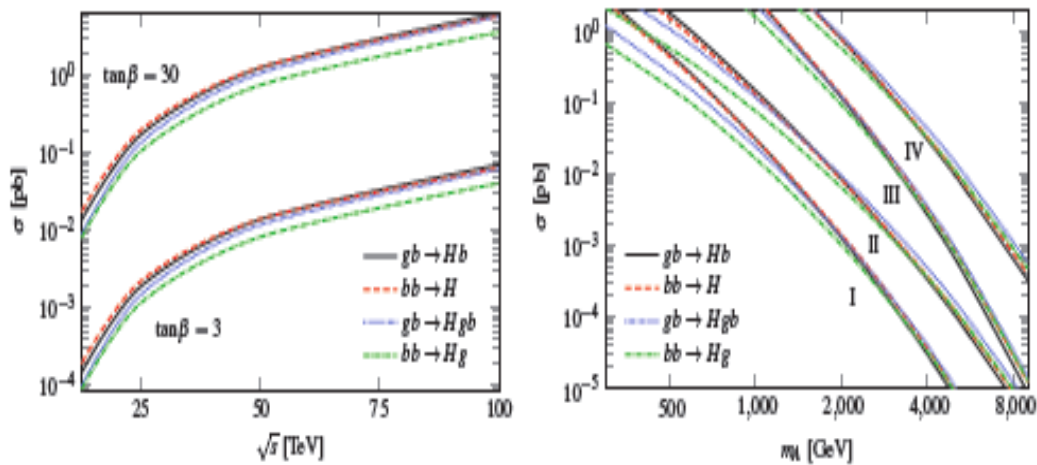
inevitable  
Z/h shift

# Naturalness "No-Lose" Thm



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

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

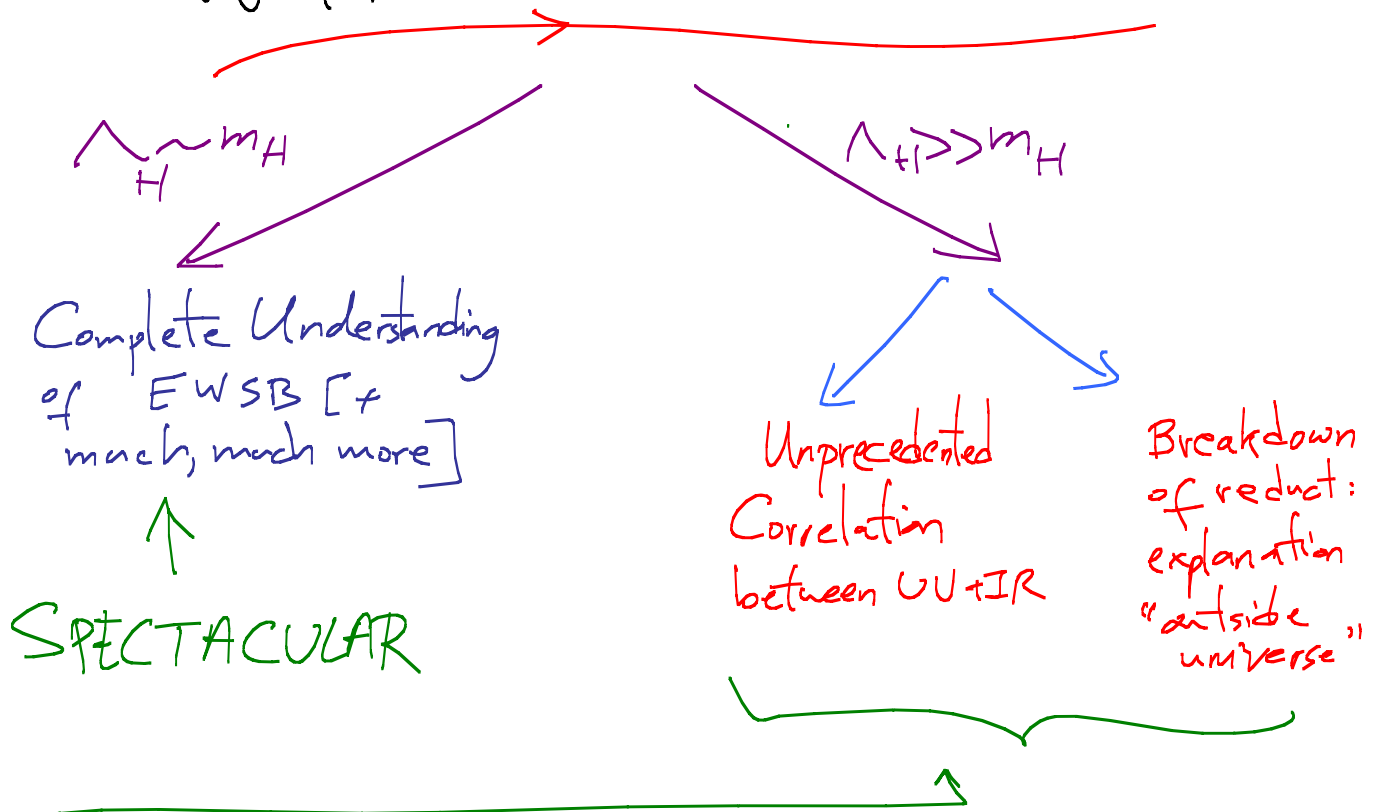


\* Of course if we do  
see new physics @ LHC  
[e.g.  $2\text{ TeV } \tilde{g}'$ ], we won't  
produce with enough rate to  
learn what they are trying to tell us!  
[e.g. is it a gluino?]

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

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

# WIN-WIN-WIN



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

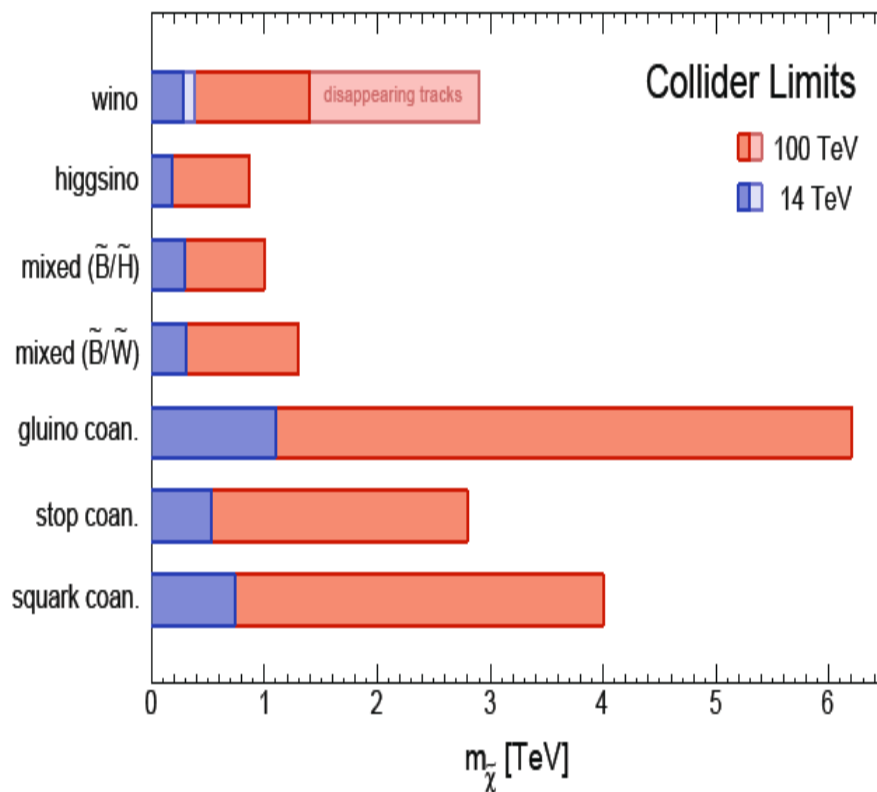
Dark Matter(s)



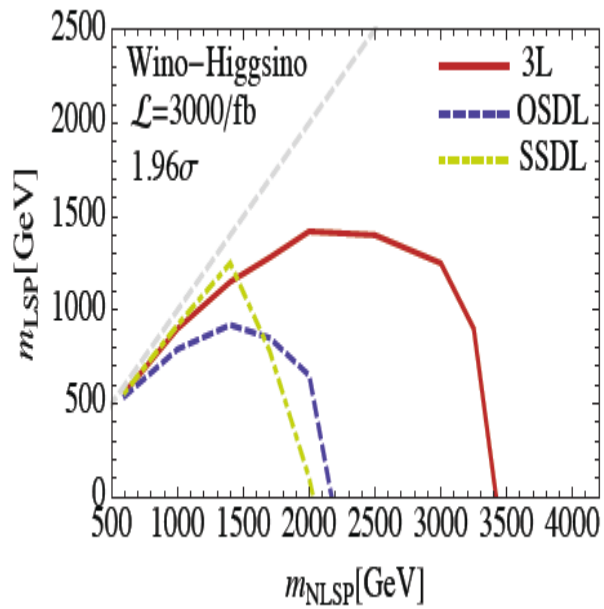
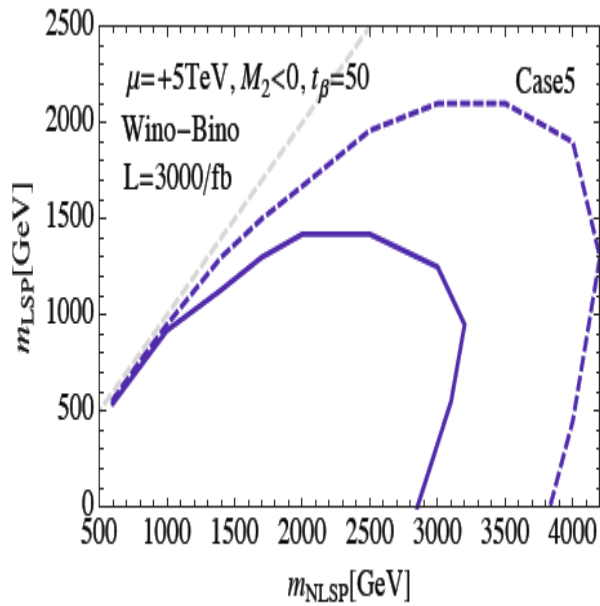
• WIMPS are, still, the only calculable models of dark matter we have

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

# Rock-Bottom Case: Monojets



# Reach for EWK Cascades



Phase Transition

"No Lose"

DM

See or Rule out  
Simplest possibilities

Naturalness

NO LOSE

[Countering]

Common Objections

"There's no point  
to planning ahead before  
we get LHC 13/14 results"

"If only Higgs @ LHC,  
we can't guarantee  
discoveries, won't convince  
politicians to build machines"

" If Higgs Factory / 100 TeV ✓

doesn't see new physics,

it will be a big  
waste / failure "

"The Machines are too  
Hard - can't get Z,  
Indicously expensive, ..."

"Instead of building  
bigger accelerators, shouldn't  
we wait to develop revolutionary  
new methods + do it cheap?"

"Maybe particle physics isn't  
the royal road to fundamental  
physics — what about cosmology,  
don't we have much more powerful  
accelerator in the sky?"

Our Case I<sub>s</sub>

Amazingly Strong

The scientific issues  
at stake are the most  
difficult + profound ones we  
have faced since 1930's

The scale of our vision  
+ ambition must be  
commensurate with what  
the science demands: **BE  
MORE, NOT LESS AGGRESSIVE  
IN PURSUING IT**

\* I look forward to  
seeing updated drafts from  
WG's

\* Making good progress on summary.

\* Plan to put everything together  
for version 1 NEXT WEEK