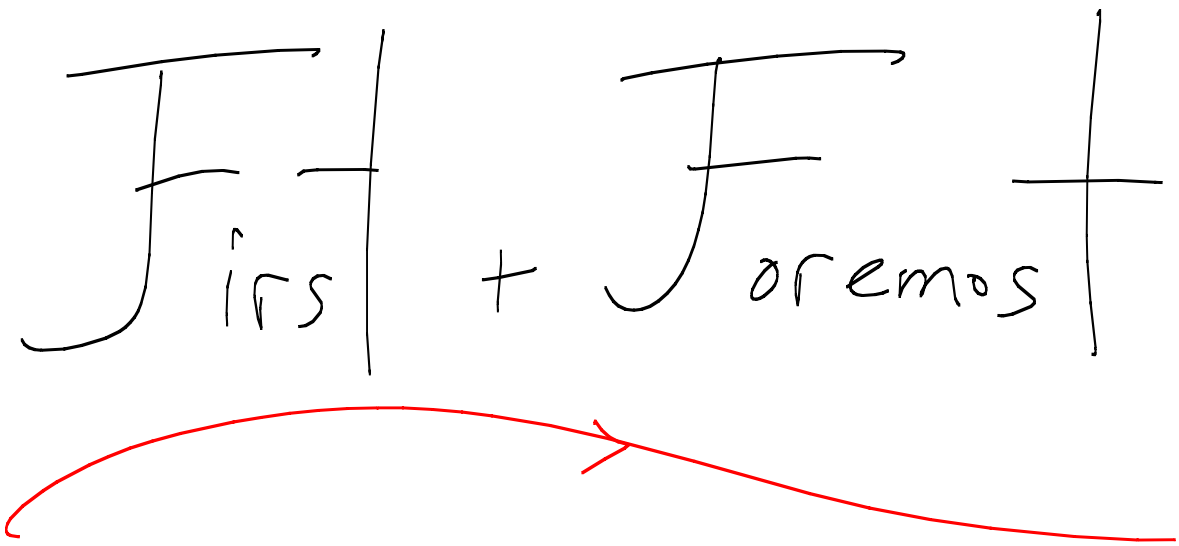
Motivations For a 100 TeV pp-collider

Nima Arkani-Hamed


First + Foremost

* It's the OBVIOUS FUTURE

* BIG physics ideas, BIG ambitions and BIG machines are the lifeblood of our field. It's how we've attracted the best minds on the planet to work on the hardest, most fundamental, most long-term problems in all of Science.

INSANE TO

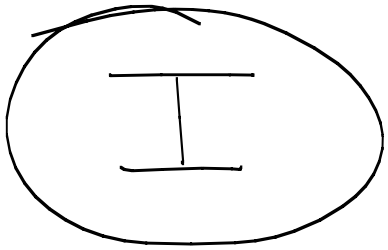
DROP THE

BALL NOW

Obviously, how to proceed will depend on first LHC 13 results.

But in every scenario I can imagine, we will need the 100 TeV pp machine

My remarks will mostly be preliminary + must be further sharpened + quantified - they indicate a plan for more serious work which is being undertaken



Ultimate Fate of "Naturalness"

Triumph of 20th Century

QM + Relativity

↓

Universe is Inevitable

Central Drama of 21st Century

QM + Relativity

↓

Universe (seems) Impossible

Higgs Discovery Crucial

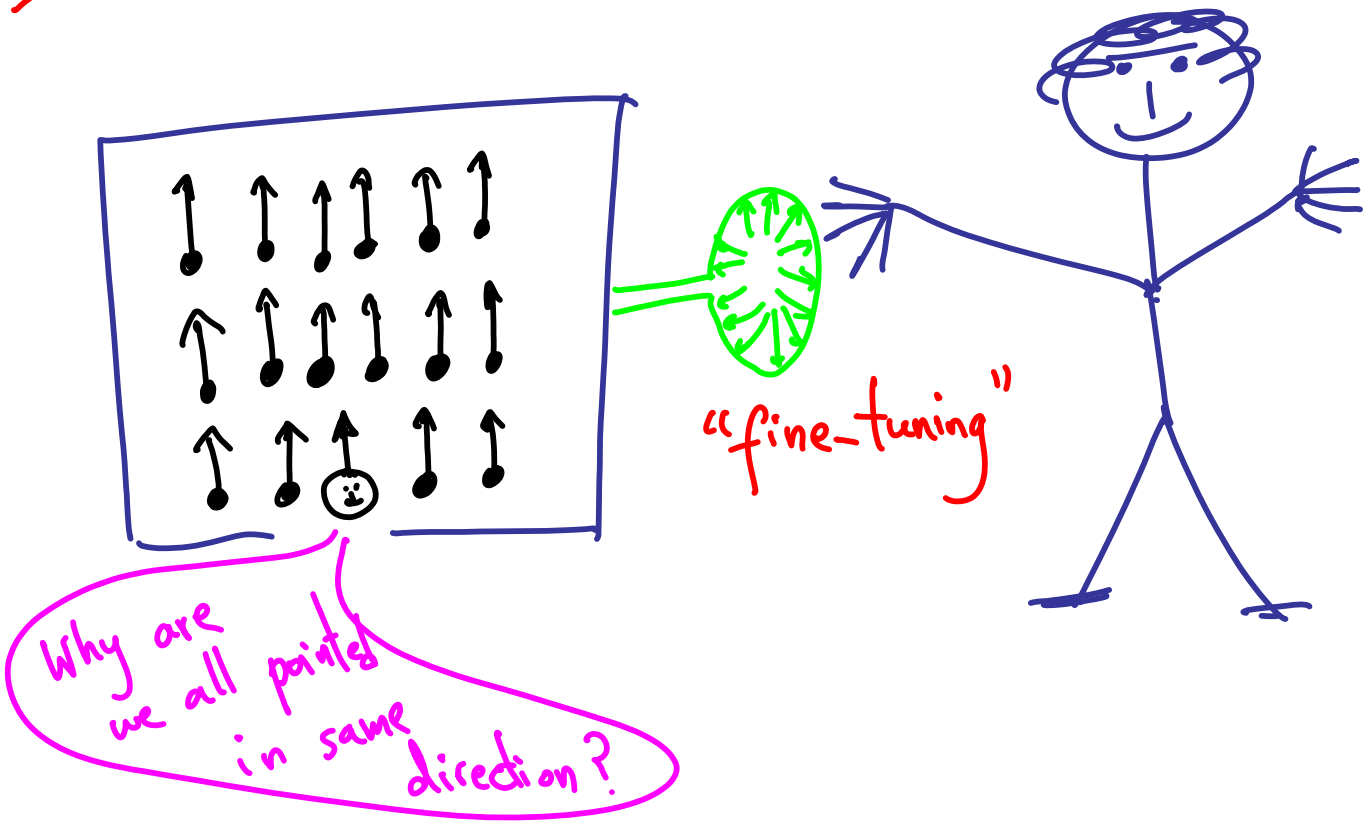
Light Higgs

↓

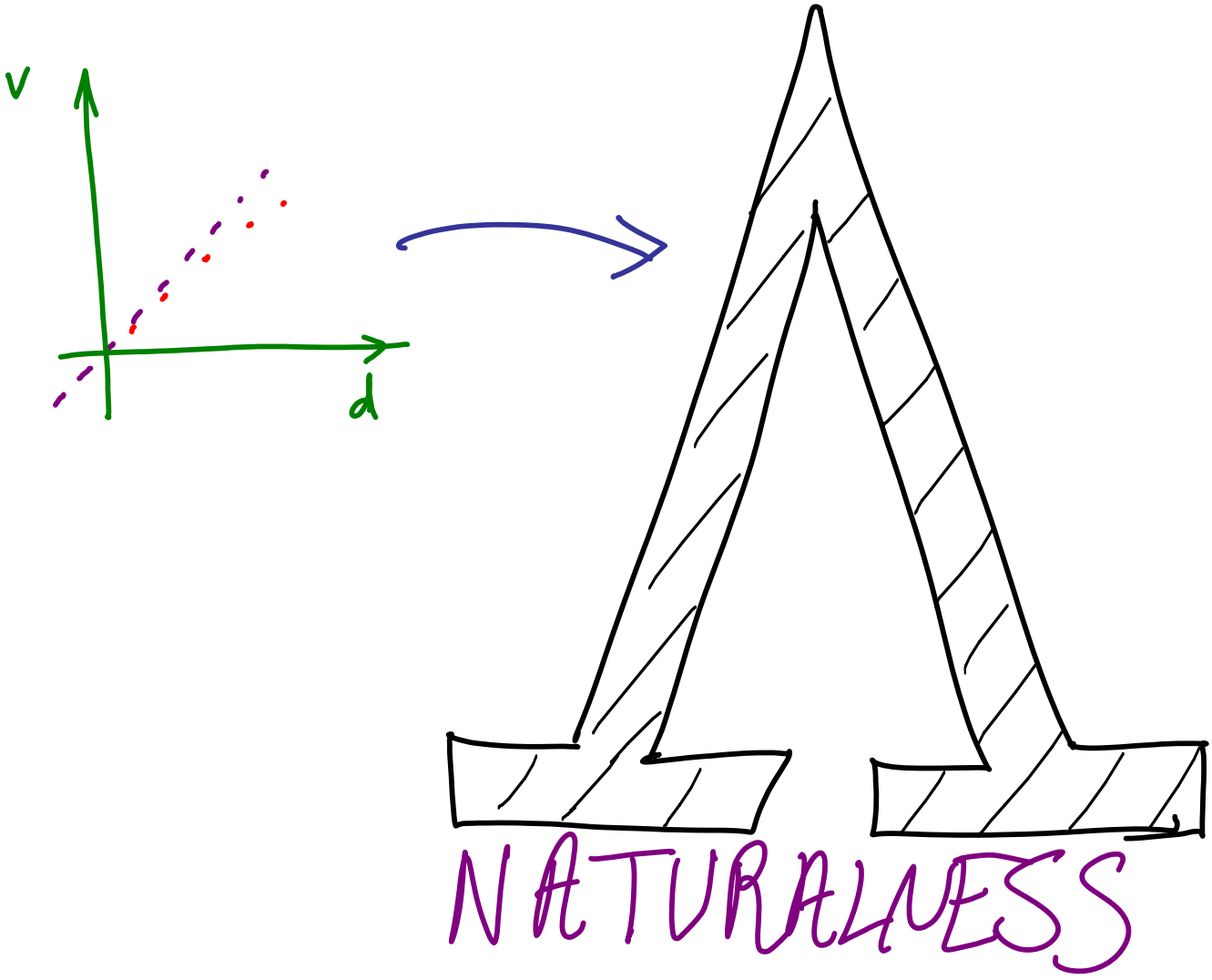
Our Vacuum is Qualitatively Different than Random C.M. System

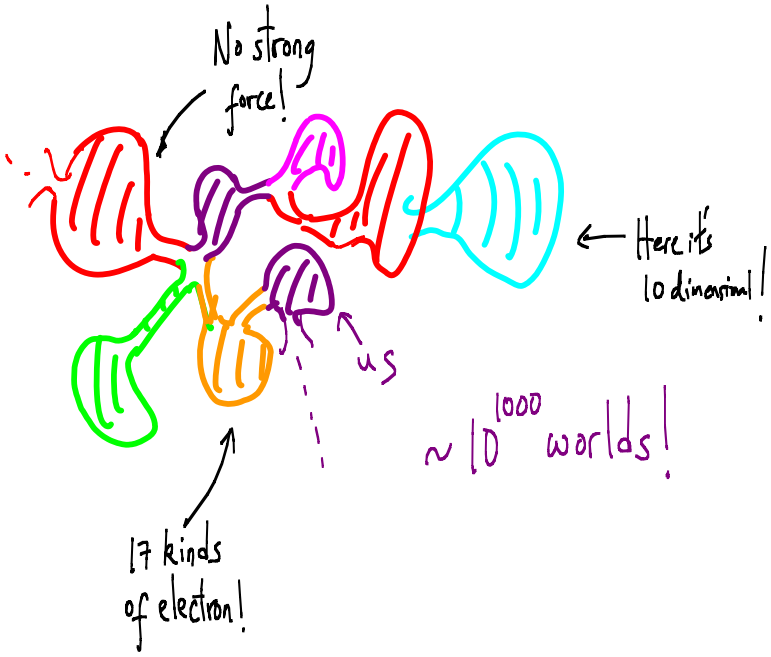
[AKA "Crappy Metal"]

Never seen before in "state of nature"

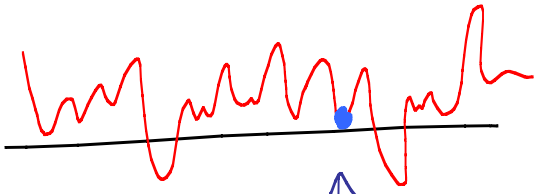


No new physics so far @ LHC is putting broad idea of Naturalness under pressure....


v
d
NATURALNESS



$\sim 10^{1000}$ worlds!



Everywhere Lethal + Empty except ...

Here, accidentally, Universe not empty

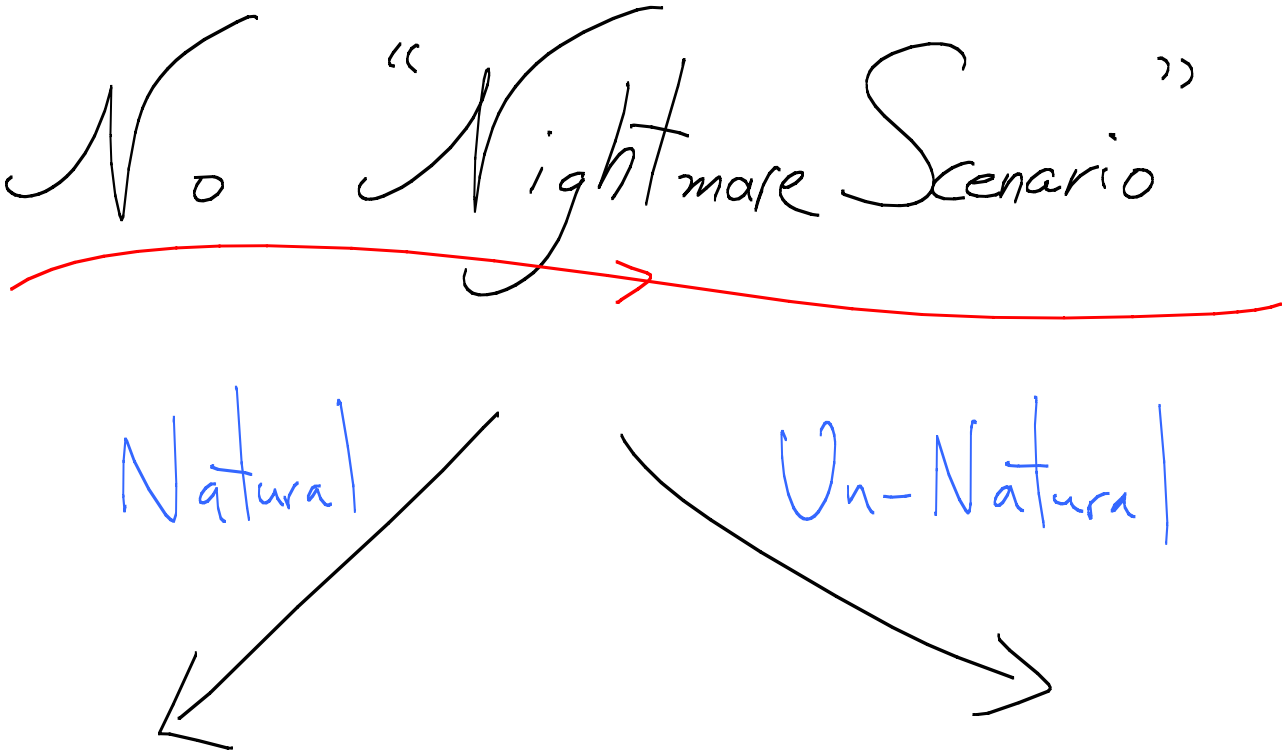
We could be getting circumstantial evidence, + more of a push towards this radical picture

Is Weak Scale Natural?

HUGE STAKES

BIFURCATORY MOMENT

IN HISTORY OF THE FIELD


No "Nightmare Scenario"
Natural
Un-Natural
BIG NEW PRINCIPLES
BIGGER PARADIGM SHIFT:
Like CC?
How Tuned?

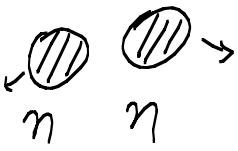
Higgs + Nothing Else@LHC?

A Fine-tuning of at least 1% for weak scale

CONVINCING?

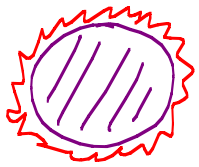
[I'LL need more evidence!]

There are many ~1% level "accidents"



Two neutrons not bound by 60 keV!

Low Quadrupole of CMB power



Moon eclipsing the sun

Adding "EWSB" to this list from L.H.C would be fascinating, but not KNOCKOUT

How will we know?

- Higher Energy, DUH
  - * Find Something! → End of discussion!
  - * Find Nothing → Tuning $\propto E^{2}_{machine}$
- Rare processes
- Precision measurements

} Indirect, Linear gain in tuning

* tuning probe $\propto E_{CM}^2$

* Higgs + nothing else @ 100 TeV

$\Longrightarrow \sim 10^{-4}$ tuning!

* Never seen this level of tuning in particle physics

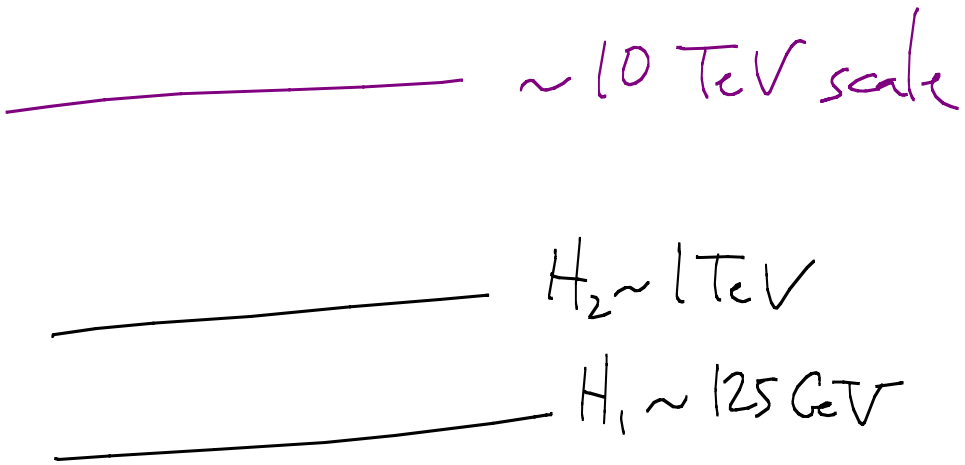
* In my view, this "worst-case scenario" would be ~ 100 X more shocking + dramatic than no Higgs @ LHC

NAIL IN COFFIN OF NATURALNESS

This alone fully justifies the march to 100 TeV, in my view

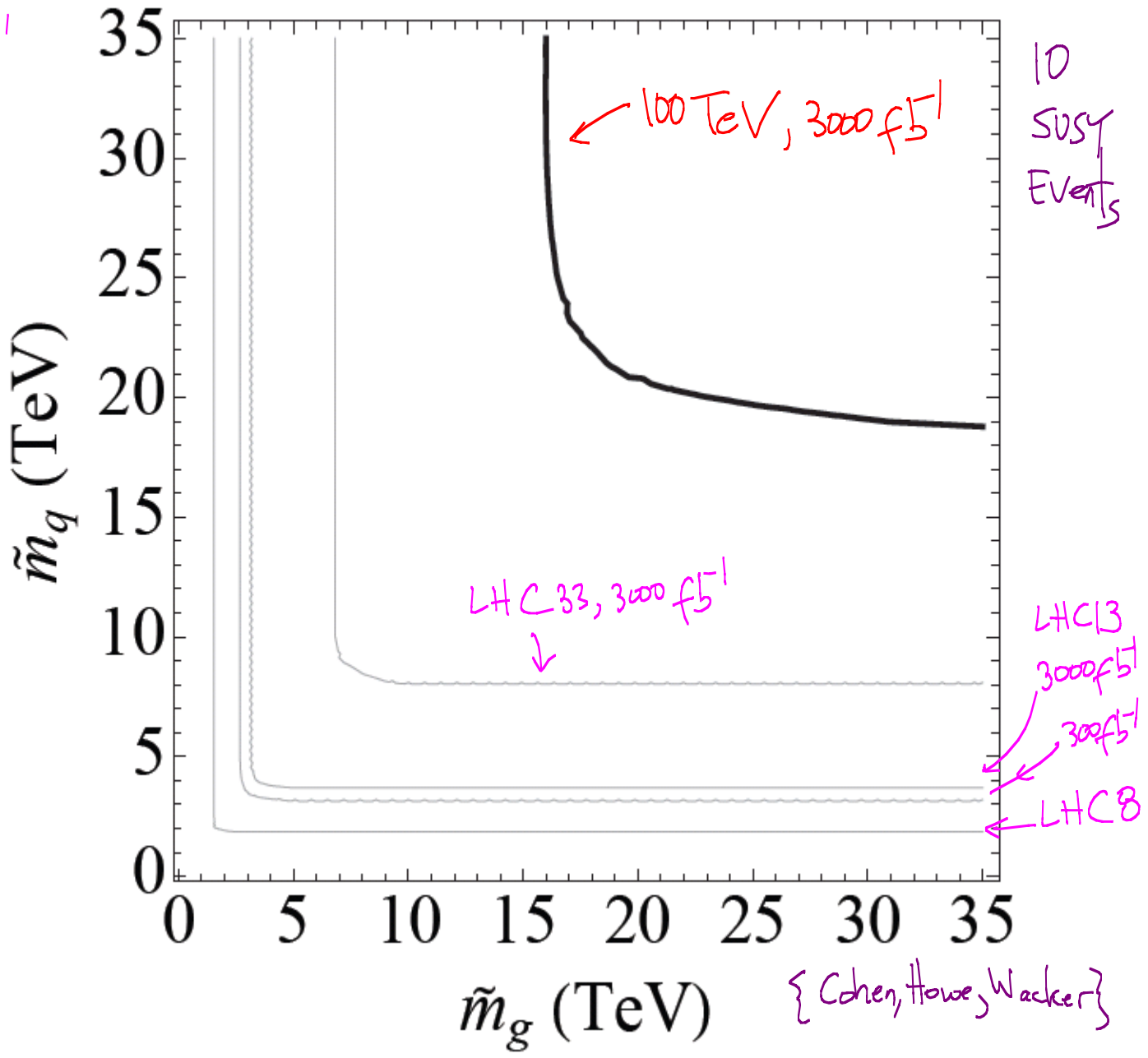
[Tera-Z @ TLEP plays very important complementary role]

Even more shocking things could be found:

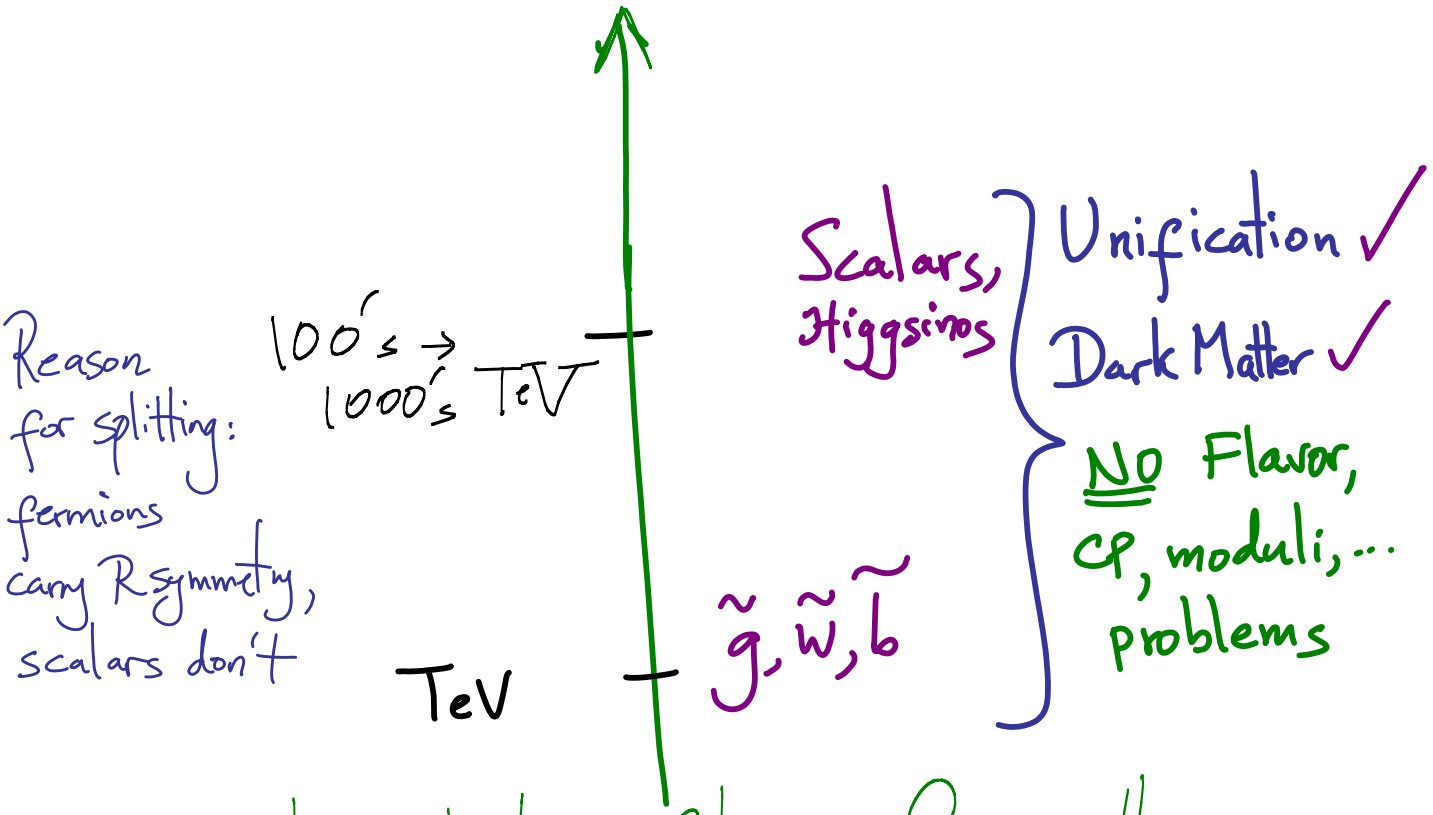


* Tuning $\sim (10^{-4}) \times (10^{-2}) \sim 10^{-6}$!
* Kills all "anthropic" explanations (I know of)

- If instead, we are "just" ~1% unlucky, LHC could still miss everything, but 100 TeV pp will catch the new physics

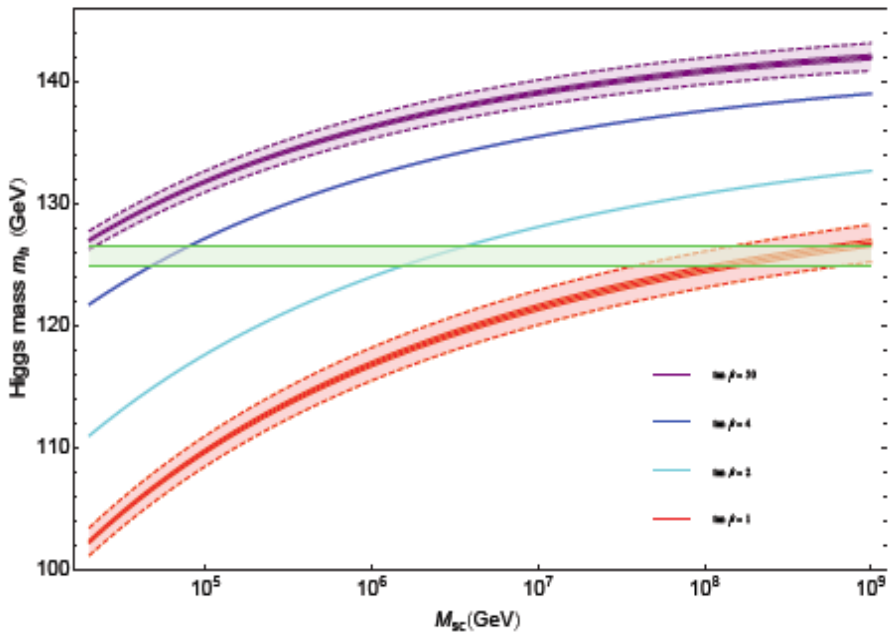

35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
$\tilde{m}_q$ (TeV)
$\tilde{m}_g$ (TeV)
100 TeV, 3000 fb^{-1}
10 SUSY Events
LHC33, 3000 fb^{-1}
LHC13
3000 fb^{-1}
300 fb^{-1}
LHC8
{Cohen, Howe, Wacker}

Minimally Split SUSY



$\sim \alpha^{-1}$ Splitting Happens Generically

Higgs Mass



$\tilde{g}$ 6TeV
$\tilde{W}$ 3TeV
$\tilde{h}$ 1TeV

Could easily have 3TeV $\lesssim m_{\tilde{g}} \lesssim$ 20TeV, compatible with DM, out of LHC reach, accessible to 100TeV; heavier $\tilde{g}$'s problematic

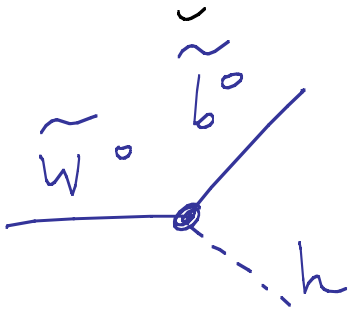
With $\tilde{g}, \tilde{W}, \tilde{b}$ as only new particles – their decays can only proceed through higher-dimension operators!

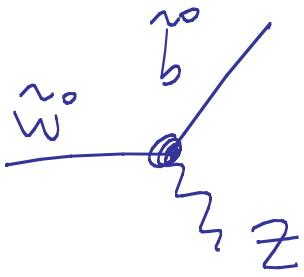
Inside detector $\longrightarrow$ scale $\gtrsim 10^2$ TeV!

LOOK FOR MODERATE DISPLACED DECAYS

* Say we produce ~ 3 TeV gluino in LHC ; 100 TeV is gluino factory, precision on decay patterns + displacement, big clues/constraints on heavy scale

e.g. direct probe of heavy higgsinos:





dominates

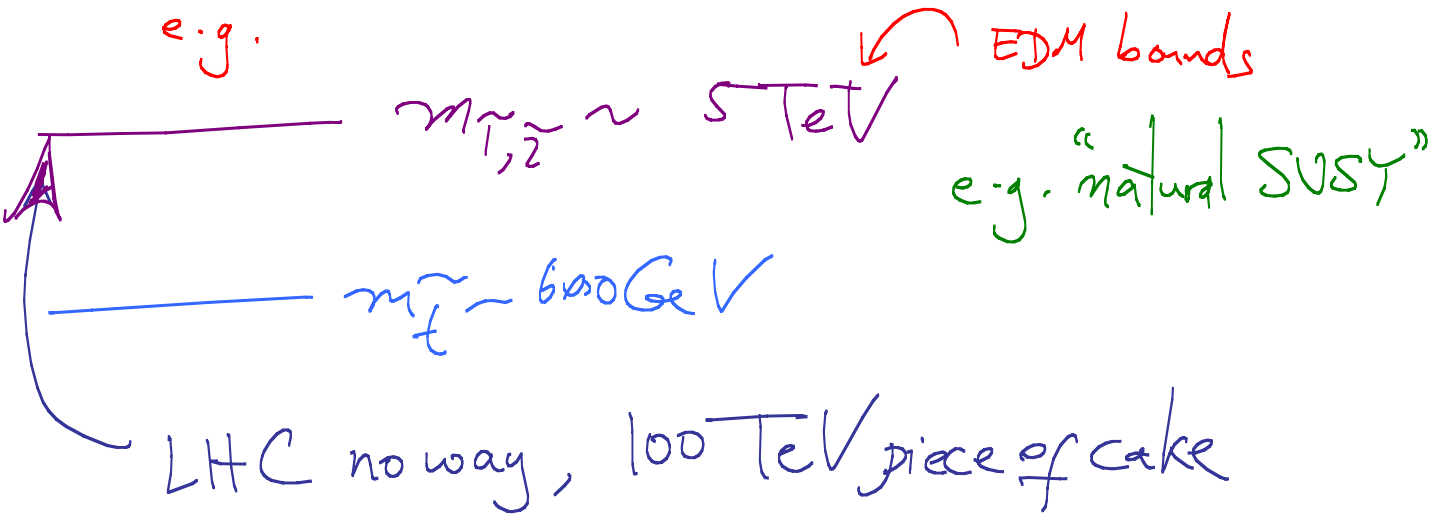
$Br \sim 10^{-4}$ for $\mu \sim 10$ TeV

Need rate to see it!

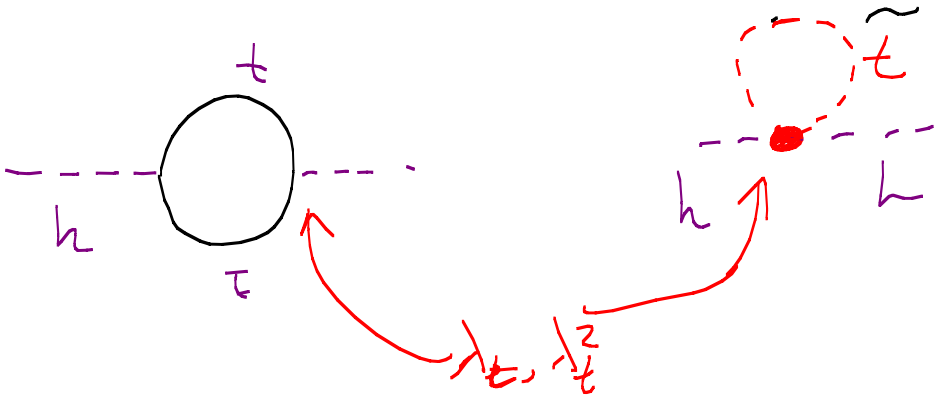
What if L.H.C discovers

(relatively) Natural Spectrum?

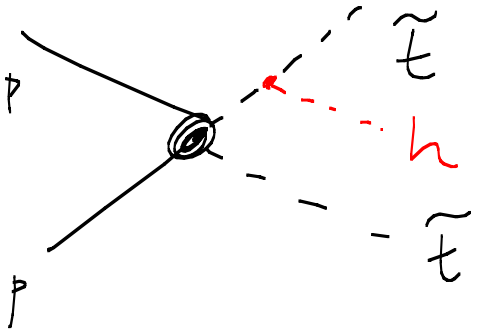
* What we already know from LHC makes it implausible that we'll see whole spectrum of new physics, even if its relatively natural:



* How can we conclusively establish new physics addresses the hierarchy prob?



Crucial "SUSY relation" between couplings



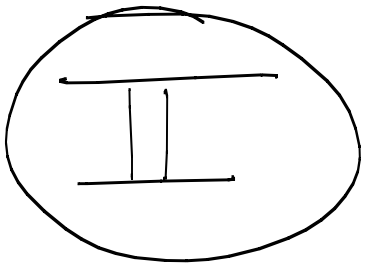
{Craig, Krohn, Wang}

Alive spectrum today, will be seen by LHC13

Table 4: Total cross section for $pp \to t\bar{t}\tilde{N}\tilde{N}h$ at $\sqrt{s} = 100$ TeV for $m_{\tilde{t}} = 500$ GeV, $m_{\tilde{N}} = 250$ GeV and various values of the stop-stop-higgs coupling relative to the supersymmetric value.

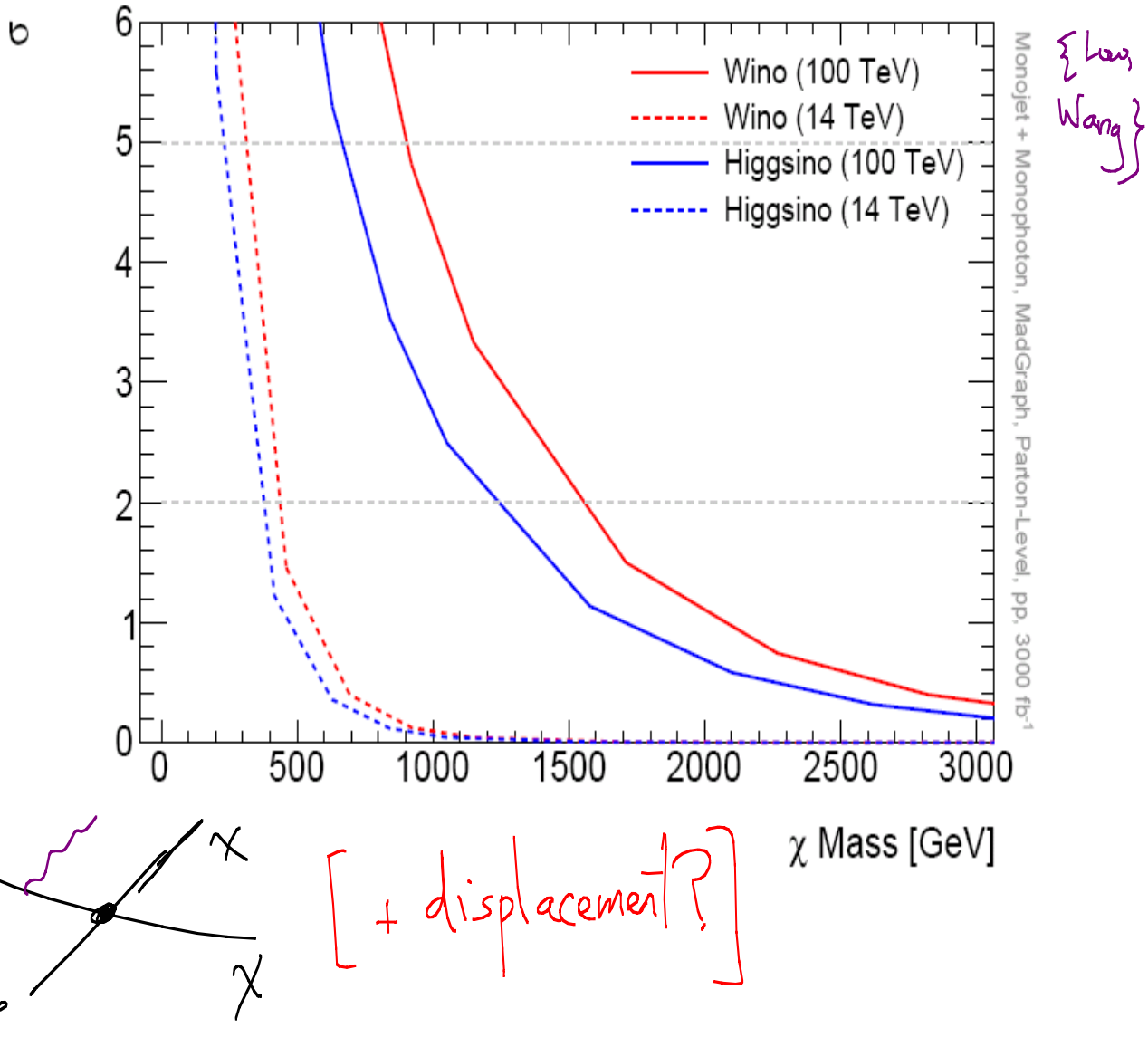
$y_{\tilde{t}\tilde{t}h}/y_{\tilde{t}\tilde{t}h}^{MSSM}$	$\sigma(pp \to t\bar{t}\tilde{N}\tilde{N}h)$ [fb]
0	0.3
1/2	7.5
1	28.8
2	114

Can distinguish @ $\sim 5\sigma$ with $\sim 1\,ab^{-1}$ of data

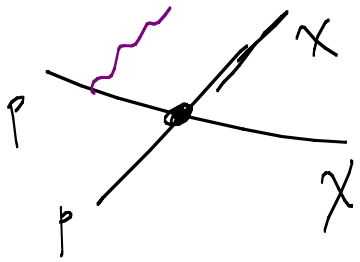


Robust probe of up to ~ few TeV electroweak particles.

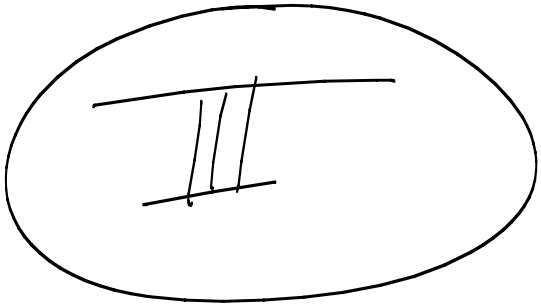
{WIMPS could very easily be here — LHC not ideal "DM factory"}



{Low, Wang}



[+ displacement?]

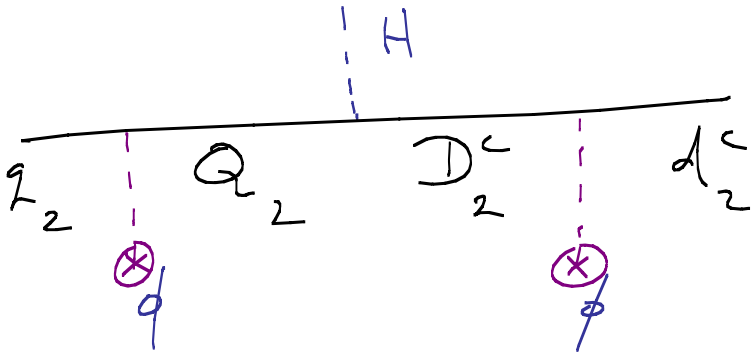


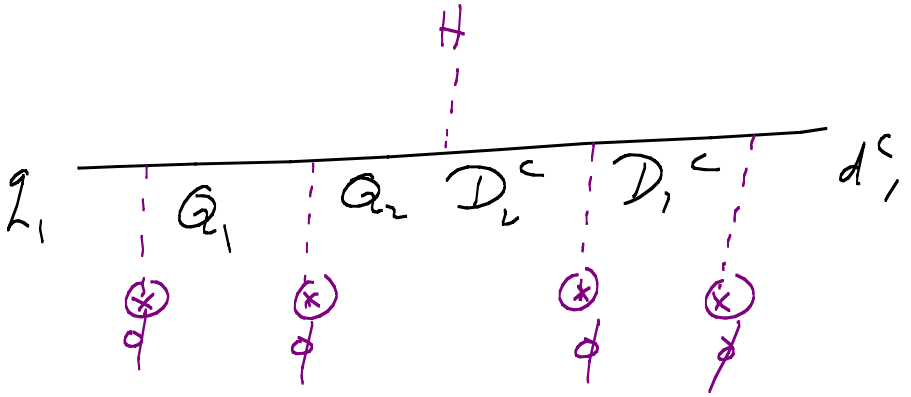
For the first time, rich + alive possibilities for Collider Flavor Picks.

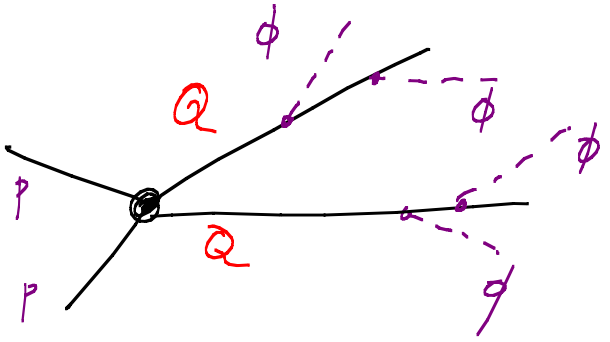
* Not possible to generate flavor @ ~ TeV scale + not be dead by FCNC's ⟹ no flavor collider physics @ LHC.

* Not so already if new physics @ 10 TeV...

e.g.







Long cascade decays w/ fingerprint of flavor symmetry structure.


We Can
We Must

* EVERY student/post-doc/person with a pulse (esp. under 35) I know is ridiculously excited by even a glimmer of hope for a 100 TeV pp collider

These people don't suffer from SSC PTSD

There is a huge pool of dedicated, talented people ready to be unleashed on this physics, and willing to work on every front to help make it happen!