Motivations For a 100 TeV pp-collider

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First + Foremost
* It's the **OBVIOUS FUTURE**

* BIG physics ideas, BIG ambitions and BIG machines are the lifeline 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 LHCb results.

But in every scenario I can imagine, we will need the 100 TeV pp machine.
My remarks will mostly be preliminary and must be further sharpened and quantified—they indicate a plan for more serious work which is being undertaken.
Ultimate Fate of "Naturalness"
Triumph of 20th Century

QM + Relativity

\[ \downarrow \]

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"

Why are we all pointed in same direction?

"fine-tuning"
No new physics so far @ LHC is putting broad idea of Naturalness under pressure....
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 CCP? 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 ~ l% level "accidents"

Two neutrons not bound by 60 keV!

Low Quadrupole of CMB power

Moon eclipsing the sun

Adding "EWSB" to this list from LHC would be fascinating, but not knockout
How will we know?

- Higher Energy, DUT
  - Find Something! $\Rightarrow$ End of discussion!
  - Find Nothing $\Rightarrow$ Tuning $\times E_{\text{machine}}^2$

- Rare processes
  \[ \Rightarrow \text{Indirect, Linear gain in tuning} \]

- Precision measurements
* Tuning probe $\propto E_n^{2/3}$

* Higgs + nothing else @ 100 TeV

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

* Never seen this level of tuning in particle physics
* In my view, this "worst-case scenario" would be a 100 x more shocking + dramatic than no Higgs @letic 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:

\[ \sim 10 \text{ TeV scale} \]

\[ H_2 \sim 1 \text{ TeV} \]

\[ H_1 \sim 125 \text{ GeV} \]

* 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
Minimally Split SUSY

\[ 100\text{ s} \rightarrow 1000\text{ s} \text{ TeV} \]

Reason for splitting:
fermions carry R-symmetry,
scalars don't

Scalars, Higgsinos

Unification \checkmark

Dark Matter \checkmark

\[ \tilde{g}, \tilde{w}, \tilde{b} \]

\(~ \alpha^{-1} \text{ Splitting Happens Generically}~\)
Higgs Mass

Could easily have $3 \text{ TeV} \lesssim m_H \lesssim 20 \text{ TeV}$, compatible with DM, out of LHC reach, accessible to $100 \text{ TeV}$; 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 $\rightarrow$ scale $\approx 10^2 \text{ TeV}$!

LOOK FOR MODERATE DISPLACED DECAYs
* Say we produce \( \sim 3 \text{ TeV} \)
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:

\[ \tilde{\omega} \rightarrow b h \]
\[ \tilde{\omega} \rightarrow b \tilde{\tau} \rightarrow \tau Z \]

\[ \text{dominates} \]
\[ \text{Br} \sim 10^{-4} \text{ for } \mu \sim 10 \text{ TeV} \]

Need rate to see it!
What if LHC discovers (relatively) natural spectrum?
* What we already know from LHC makes it implausible that we'll see whole spectrum of new physics, even if it's relatively natural:

\[ m_{\tilde{t}} \sim 600 \text{GeV} \]

\[ m_{\tilde{\chi}_1^\pm} \sim 5 \text{TeV} \]

\[ \text{EDM bounds} \]

\[ \text{e.g. natural SUSY} \]

LHC no way, 100 TeV piece of cake
*How can we conclusively establish new physics addresses the hierarchy prob?*

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

<table>
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<th>$y_{\tilde{t}\tilde{h}}/y_{\tilde{t}\bar{h}}^{MSSM}$</th>
<th>$\sigma(pp \to \tilde{t}\tilde{t}\bar{h}\tilde{h})$ [fb]</th>
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<td>7.5</td>
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<tr>
<td>1</td>
<td>28.8</td>
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<tr>
<td>2</td>
<td>114</td>
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Alive spectrum today will be seen by LHC

Can distinguish @ $\sim 5 \sigma$ with a lab of data
Robust probe of up to a few TeV electroweak particles.

\[ \text{WIMPS could very easily be here — LHC not ideal "DM factory" } \]
For the first time, rich and alive possibilities for Collider Flows and Flows.
* 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!