33 vs. 100 TeV Discussion

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Plan A or Plan B?

- **There are no doubts that a 100 TeV machine is better than a 33 TeV one:**
  - "It's better to be rich and healthy than poor and sick"
- **However, is this the machine the world (and CERN) could afford?**
  - N.B. At a cost of ~CHF 25B, we need to start saving ~CHF 1B/year *NOW* to be able to build it! This is 1/3 of the world's HEP budget.
- **Is it also the machine worth four decades to wait?**
- **Given that, would a 33 TeV machine be a good Plan B?**
  - Could it also be a Plan A?

Plan A and Plan B!

Consider two scenarios:

- **LHC Run 2 and HL-LHC do not find new physics**
  - The measurement of the Higgs boson couplings becomes the raison d'être for the HL-LHC
  - After ~1/ab (~2030) still have fairly good detectors, but are facing diminishing return
  - If the high-field magnet technology is ready, stop the HL-LHC and upgrade to run at 33 TeV in ~2035 (less than 20 years from now!)
  - Get ~3/ab @ 25ns with the HL-LHC pileup and ATLAS+CMS Phase II detectors, with the focus on the Higgs boson self-coupling measurement
- **Possibly the only machine we could afford in this scenario**
  - If HE-LHC finds new physics (or CEPC points to a concrete energy scale), go for ~100 TeV machine and reuse the HE-LHC magnets (1/3 of the full number needed for the FCC)

- **LHC Run 2 finds new physics (e.g., X(750))**
  - The scope of the program shifts toward study of its properties
  - Almost all the models predict other partners, which may very well be reachable at 33 TeV
  - Do not want to wait 35 years for the new machine - want to build it as soon as possible
- **Possibly revolutionize the field and break the spell of a flat funding**
  - Consider a 33 TeV machine to be a 30% demonstrator of the FCC at a ~10% cost
  - N.B. cost(33) ~ (cost(100) - CHF 10B)/3 ~ 5B [10B = tunnel + 2 detectors]

Technical Challenge

- **It's not easy to go up a factor of ~7 in energy in a single shot!**
- **Memento LHC:**
  - Original plan to start at 13 TeV in 2008
  - Took an incident and 7 years to reach this energy, and learned a lot in the process
- **Going up by a factor of 2-3 twice appears to be a more adiabatic way, with an ability to steer the ultimate energy according to the findings at 33 TeV/CEPC**
- **Keeps the field very much alive for the next 50 years, without a major gap between the machines (HL-LHC program lasts till 2035, and there is nothing to cover the gap to ~2050 when the FCC could start)**
  - Build most of the FCC infrastructure while operating HE-LHC
  - Train generations of accelerator physicists and experimentalists
  - Continuos stream of results for theoretical community to ponder on

Some Benchmarks

- **Double Higgs boson production @33 TeV is x6.1 that of 14 TeV: ~30% uncertainty on λ can be reduced to ~12%**
  - N.B. This is an ~8σ measurement vs. ~3σ evidence at the HL-LHC

	N_{100}	N_{100}/N_8	N_{100}/N_{14}
$gg \to H$	16×10^9	4×10^4	110
VBF	1.6×10^9	5×10^4	120
WH	3.2×10^8	2×10^4	65
ZH	2.2×10^8	3×10^4	85
$t\bar{t}H$	7.6×10^8	3×10^5	420

N33	N33/N14	N100/N33
5.4×10^8	3.5	30
0.47×10^8	3.8	34
1.4×10^7	2.9	22
0.9×10^7	3.3	24
1.3×10^7	7.3	58

Assume 3 ab^{-1} @ 33 TeV [existing detectors, 10 years of running with the HL-LHC luminosity]
N.B. a factor of 7 in the N100/N33 is due to higher integrated luminosity

Building a Physics Case

- **Taking a 33 TeV machine as a necessary step toward an "ultimate" pp machine is a good argument to bring up**
  - People and funding agencies like "demonstrators" and proof of feasibility
  - It also helps "safety" arguments [prove that a 100 TeV machine won't destroy the world - barely did this for the LHC!]
    - No serious studies have been done since the Higgs boson discovery, and the time is ripe to make this happen
- **Many of the FCC physics studies made available in the last year can be directly propagated to the 33 TeV machine**
  - Clearly the reach is not going to be as impressive, but there is good physics to be done, particularly if one takes into account funds saved by cutting the HL-LHC program short
  - In fact, this will be a HL-HE-LHC, combining the best of both options