Midterm Report on Decadal Mission: Towards the New Physics Higgs/Flavor Era

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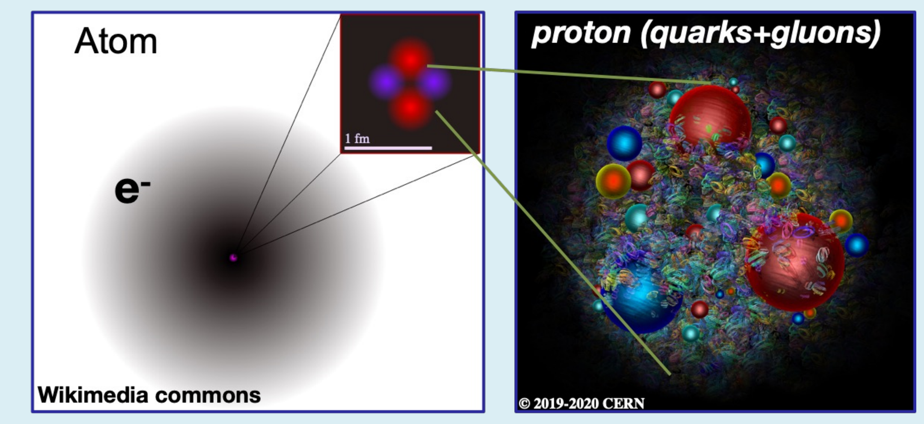
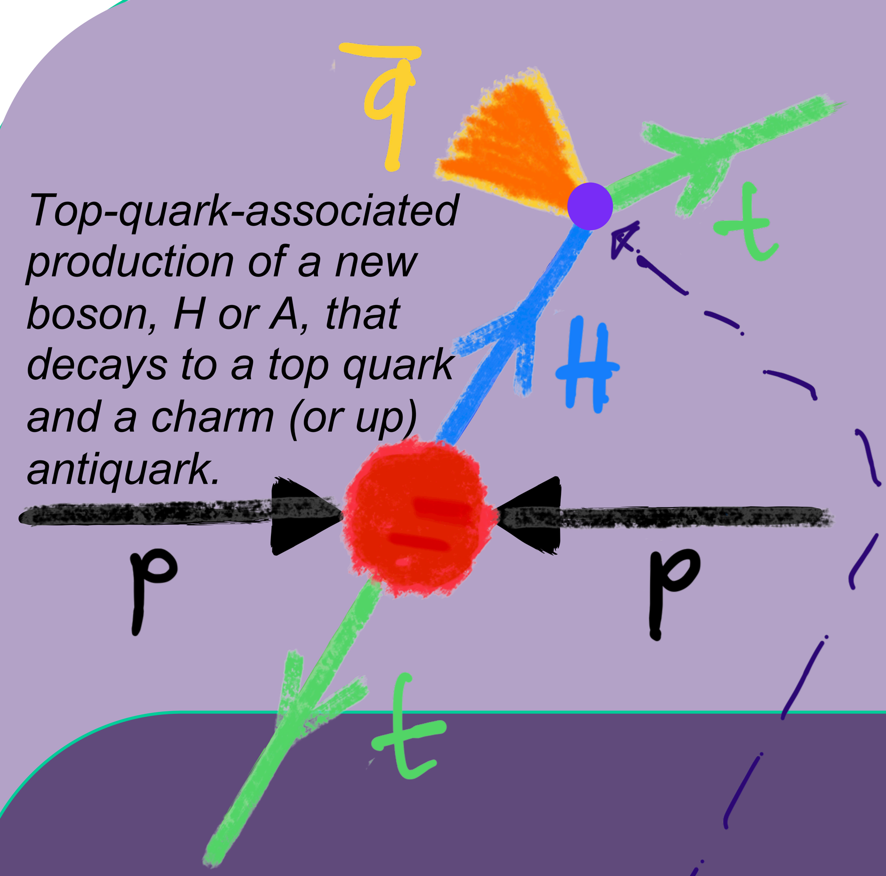
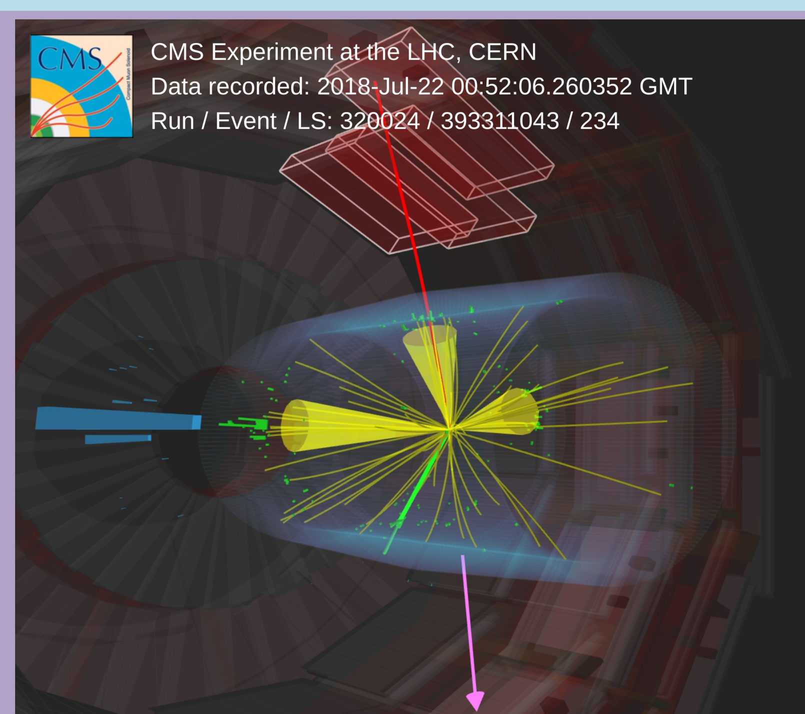
- Higgs and Englert received the Nobel Prize in Physics after the 2012 **discovery of the Higgs boson** with a mass of 125 GeV by ATLAS and CMS.
- Provided evidence of predicted **'Higgs field' that pervades the universe** and provides the **mechanism that gives mass to the fundamental building blocks of nature**.
- **If Higgs field didn't exist**, then electrons would be massless and they would not bind to the nucleus! The electromagnetic attraction between protons and electrons would not be sufficient to bind them → **we wouldn't have atoms, molecules, plants, animals, planets or stars**. The entire universe would look very different!



- No hints of new physics beyond Standard Model (SM) to understand unexplained phenomena: **matter-antimater imbalance in the Universe, dark matter, heaviness of the top quark.**
- No limitations in the SM that prevent the existence of more than one «Higgs boson».
- ***We believe energy scales best suited for LHC, and rare processes that we could still probe haven't been exhausted*** → Look for extra Higgs bosons and their couplings **[t-c-H]** at ~500 GeV mass scale in two independent processes (shown by violet disks connected by a dashed line in the diagrams below), and rare decays exploring processes we understand well theoretically and measure precisely experimentally $[B_s^0(B^0) \rightarrow \mu^+\mu^-]$.

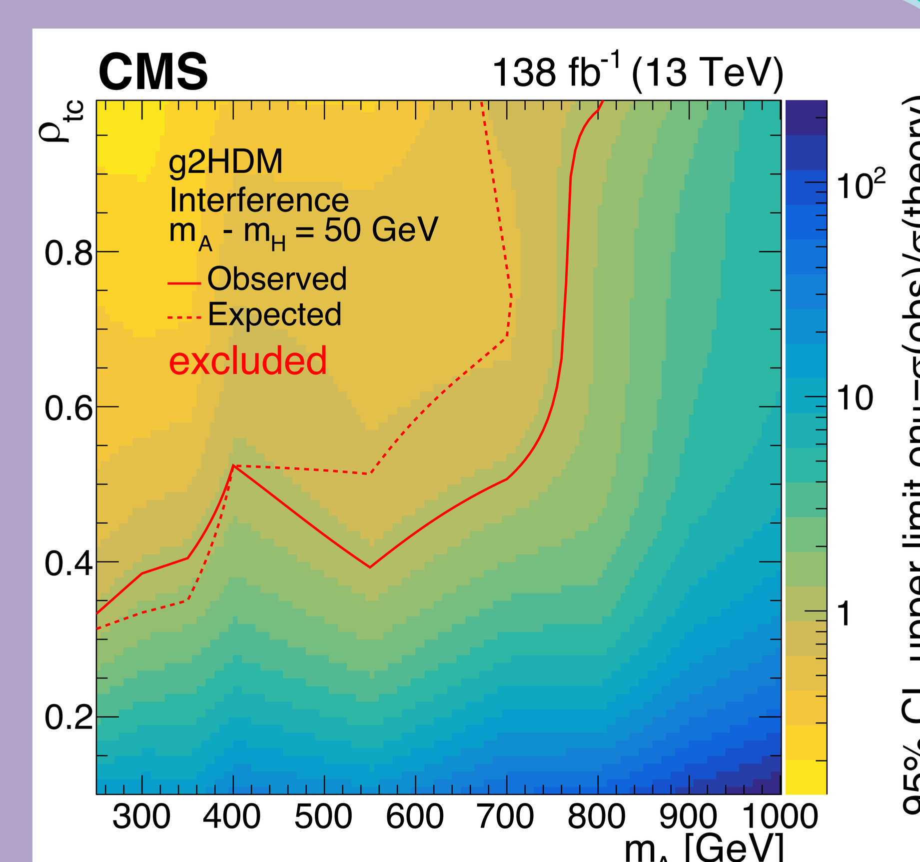


Top-quark-associated production of a new boson, H or A, that decays to a top quark and a charm (or up) antiquark.

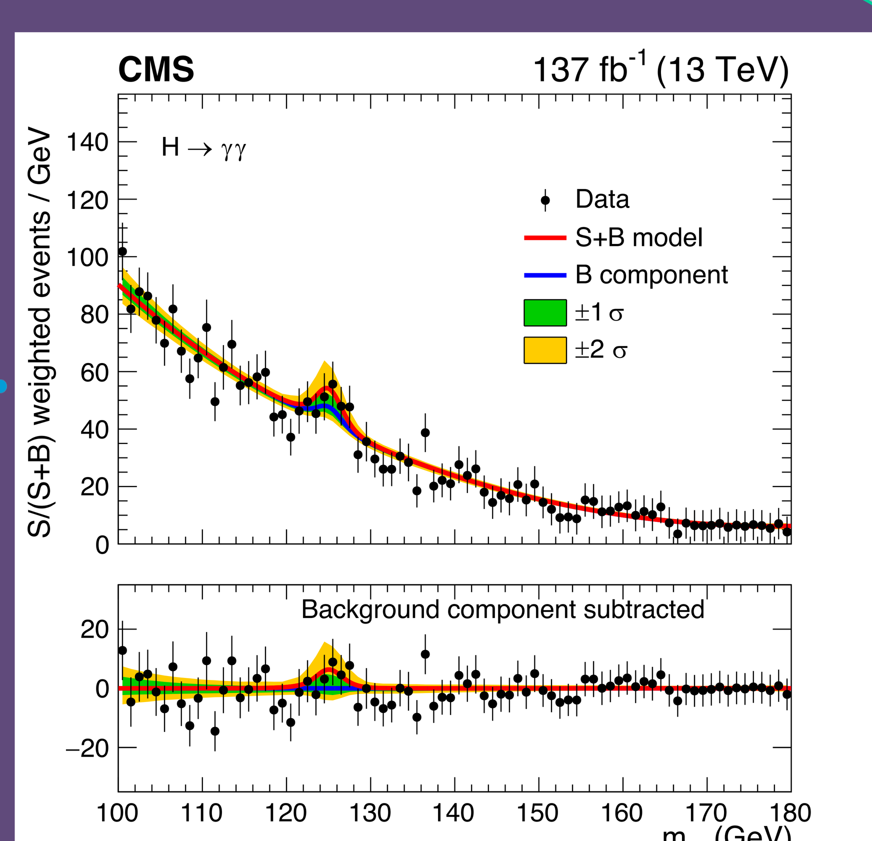


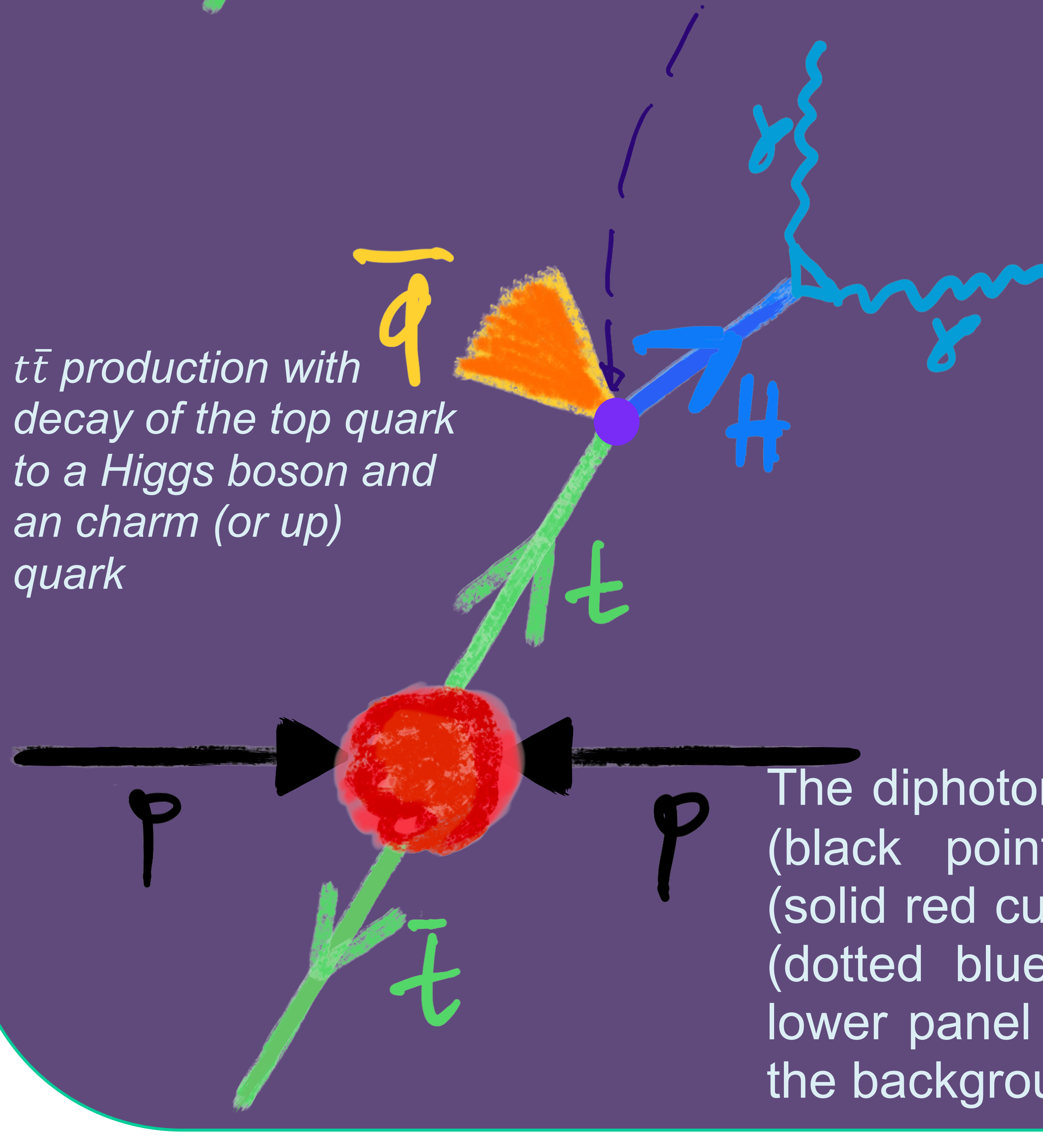
A candidate signal event recorded by the CMS detector [1]. Signature is similar to a top-quark-associated A/H production where both top quarks decay to leptons.

Characterized by two leptons (here a muon and an electron) with the same electric charge, two b jets from decay of top quarks, and a third jet from A/H decay. Muon is shown by red line, electron by green line, and jets by yellow cones.



Observed upper limits for the ratio between the measured signal production cross section and that expected from the theory, as a function of the mass of the neutral Higgs boson A, and the strength of its interaction with the top quark and charm antiquark, or with the top antiquark and charm quark [2].

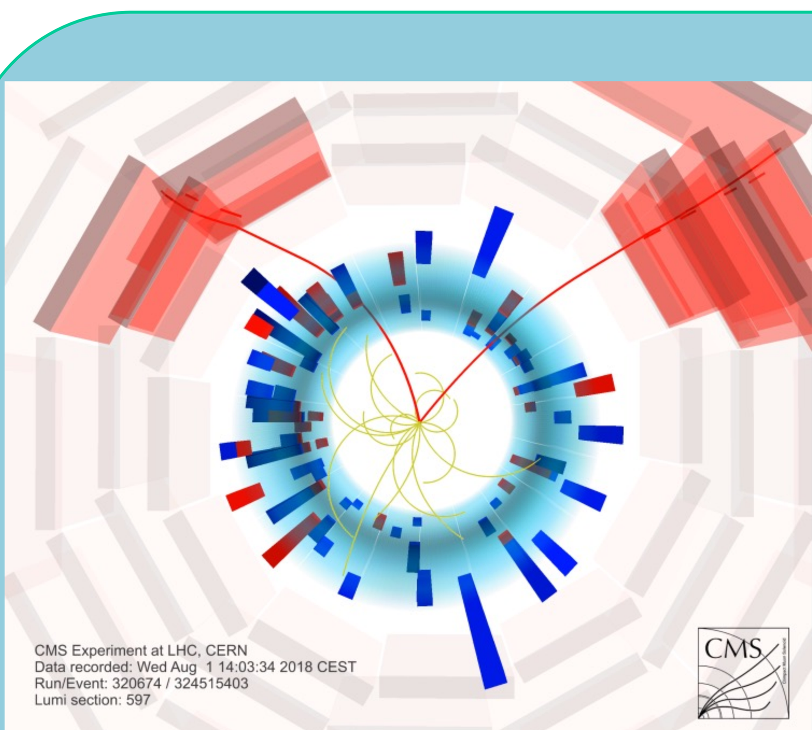




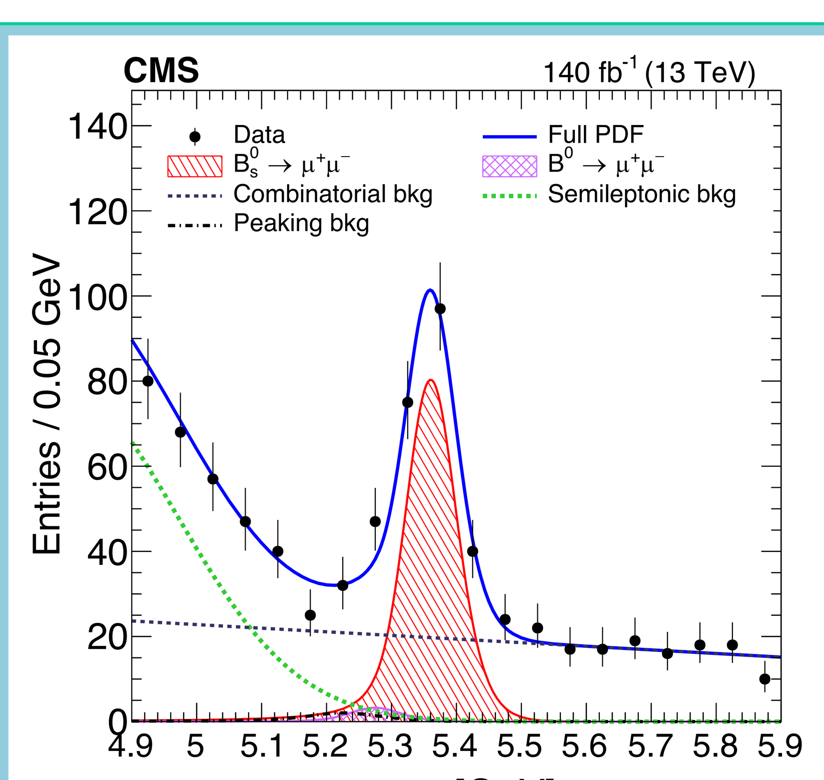
$t\bar{t}$ production with decay of the top quark to a Higgs boson and an charm (or up) quark

The diphoton invariant mass distribution from data (black points), and signal+background models (solid red curve), and the background model alone (dotted blue curve), for $t \rightarrow Hc$ interactions. The lower panel shows the same information, but with the background component subtracted [3].

- No significant excess above SM predictions observed for sub-TeV new Higgs bosons with ~1 extra Yukawa couplings from these two measurements.
- **We are exploring other signatures not explored before that provides new handles.**
- Looking for extra Higgs bosons in different final states with different experimental signatures increase our chance to find hints of extra Higgs bosons.



A candidate event for $B_s^0(B^0) \rightarrow \mu^+\mu^-$ decay as reconstructed in the CMS detector [4].



Dimuon mass distribution for high signal purity B_s^0 meson events. Blue curve represents the projection of the final fit model [5].

- $B_s^0 \rightarrow \mu^+\mu^-$ measured decay probability: **3.8±0.4 per billion**. Despite this very convincing observation, we still see no evidence of the B^0 meson decay (rate < 2 per 10 billion).
- Observed B_s decay rate and lifetime (1.8±0.2 picoseconds) are very close to theoretical predictions decreasing the overall tension in the present B decay anomalies. **This result marks a new milestone in our quest in understanding possible flavour anomalies recently reported by several experiments.**
- Further studies of these rare decays continue to be of great interest. With the $B_S \rightarrow \mu^+\mu^-$ decay firmly established and measured with high precision, our sights shift on the ultimate process: $B^0 \rightarrow \mu^+\mu^-$ decay. With the large data sets anticipated in the next few years of the LHC Run 3, **we might catch the first glimpse of this extremely-rare process and learn more about the puzzling anomalies and the physics beyond the standard model.**

References

[1] CMS Collaboration, https://cms.cern/news/hunting-higgs-boson-siblings-top-quarks
[2] CMS Collaboration, Phys. Lett. B 850 (2024) 138478
[3] CMS Collaboration, Phys. Rev. Lett. 129 (2022) 032001
[4] CMS Collaboration, https://cms.cern/news/new-study-rare-b-meson-decays-two-muons
[5] CMS Collaboration, Phys. Lett. B 842 (2023) 137955

We thank the support of the Academic Summit Program of *National Science and Technology Council of Taiwan (NSTC)*, as well as the *National Taiwan University (NTU) President's Fund*.