THE TOP-HIGGS CONNECTION

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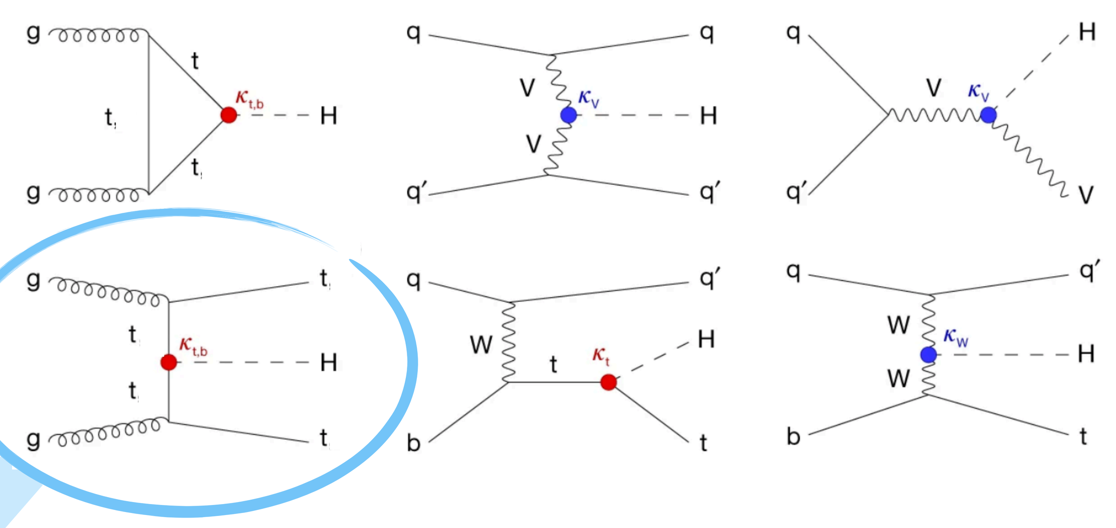
- The **Standard Model** of Particle Physics is the theoretical framework describing the elementary particles and their interactions through the strong, weak and electromagnetic forces.
- In order to give mass to the Standard Model particles, it is necessary to assume the existence of a scalar field, permeating the whole space-time, called **Higgs field**.
- The vacuum excitation of the Higgs field is called **Higgs boson** and it was discovered in **2012** at the Large Hadron Collider (LHC).
- This incredible discovery opened the doors to ten years of searches and measurements which allowed to further test the validity of the Standard Model.
- The Large Hadron Collider has collected a large wealth of data, but **no direct signal of New Physics** beyond the Standard Model has been unveiled so far.
- Searches for New Physics signals must proceed by looking for **tiny deviations** in Standard Model processes: **precision is the keystone** of new physics searches.

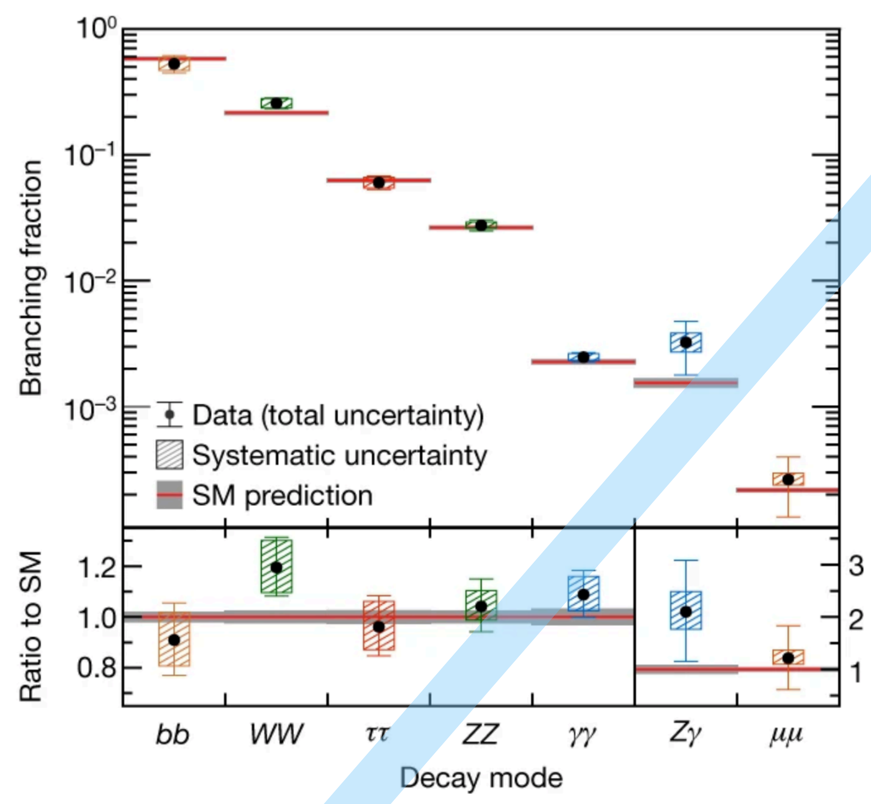
A. HIGGS BOSON

- It is a scalar (spin 0) field with mass $m_H = 125$ GeV.
- It is electrically neutral and colourless: it cannot couple directly to gluons and photons.
- It generates the mass term for the electroweak bosons via the so called **Brout-Englert-Higgs (BEH) mechanism**, proposed in 1964.
- It gives mass to fermions through **Yukawa-type** interactions.
- The Higgs couplings to fermions and bosons are proportional to the mass of the respective particle: the larger is the mass, the stronger is the coupling to the Higgs boson!

Production and decay mechanisms:

- There are **4 possible production modes** in proton-proton collisions: gluon fusion (87%), vector boson fusion (7%), Higgs strahlung (4%) and Higgs production in association with one or two top quarks ($\sim$1%).
- The dominant mechanism is gluon fusion where two gluons, one from each incident proton, fuse via a top quark quantum loop.



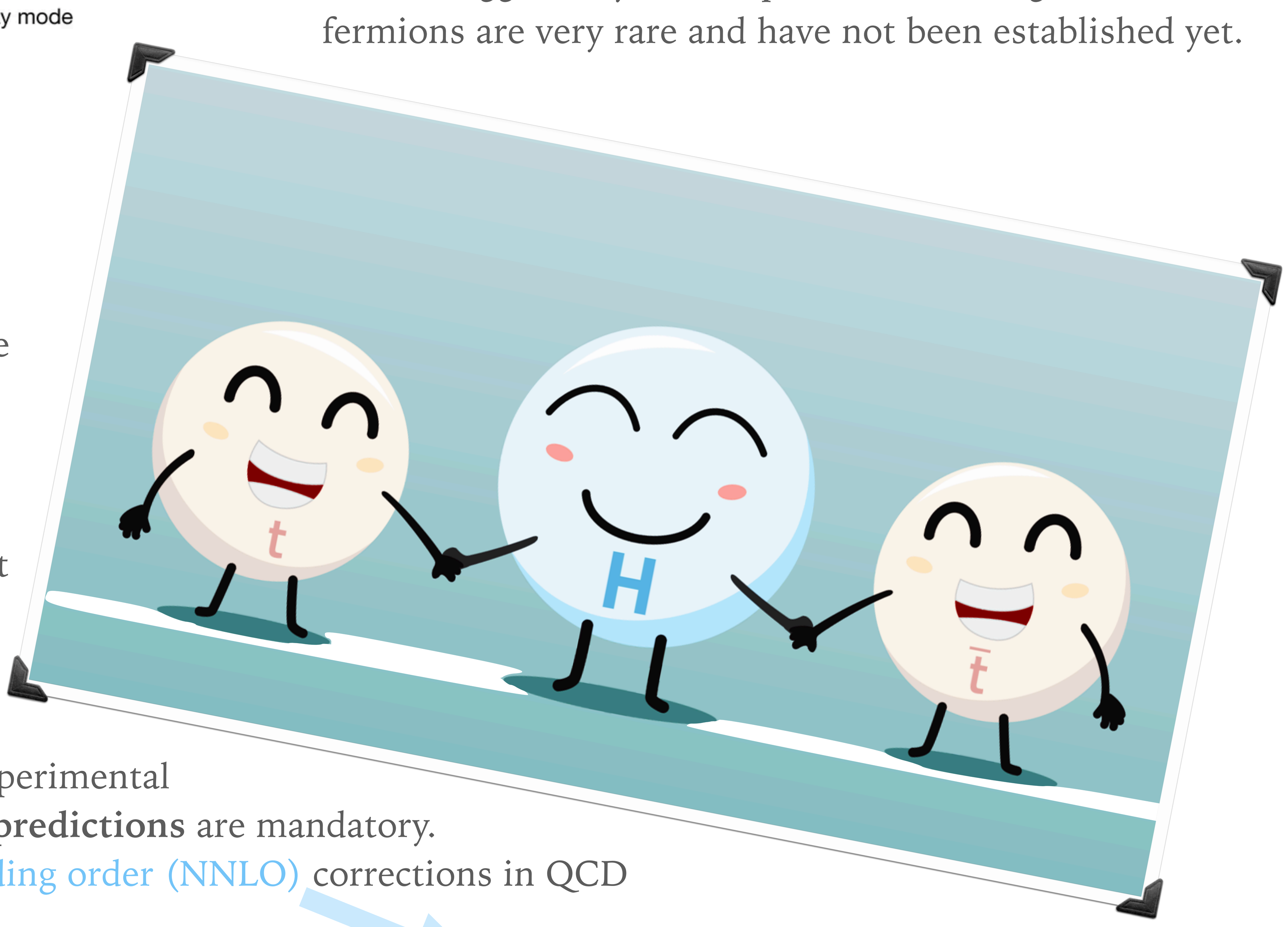


- Concerning the **decay modes**, the Higgs boson can decay into a pair of vector bosons or fermions.
- The discovery channels in 2012 were $H \to ZZ \to 4l$, usually called "4-lepton channel", and $H \to \gamma\gamma$ (via a top-quark or a W-boson loop).
- The huge amount of data collected by the LHC during these ten years allowed to measure the branching fractions of $H \to \tau^+\tau^-$ and $H \to b\bar{b}$.
- The Higgs decays into a pair of 1st or 2nd generation fermions are very rare and have not been established yet.

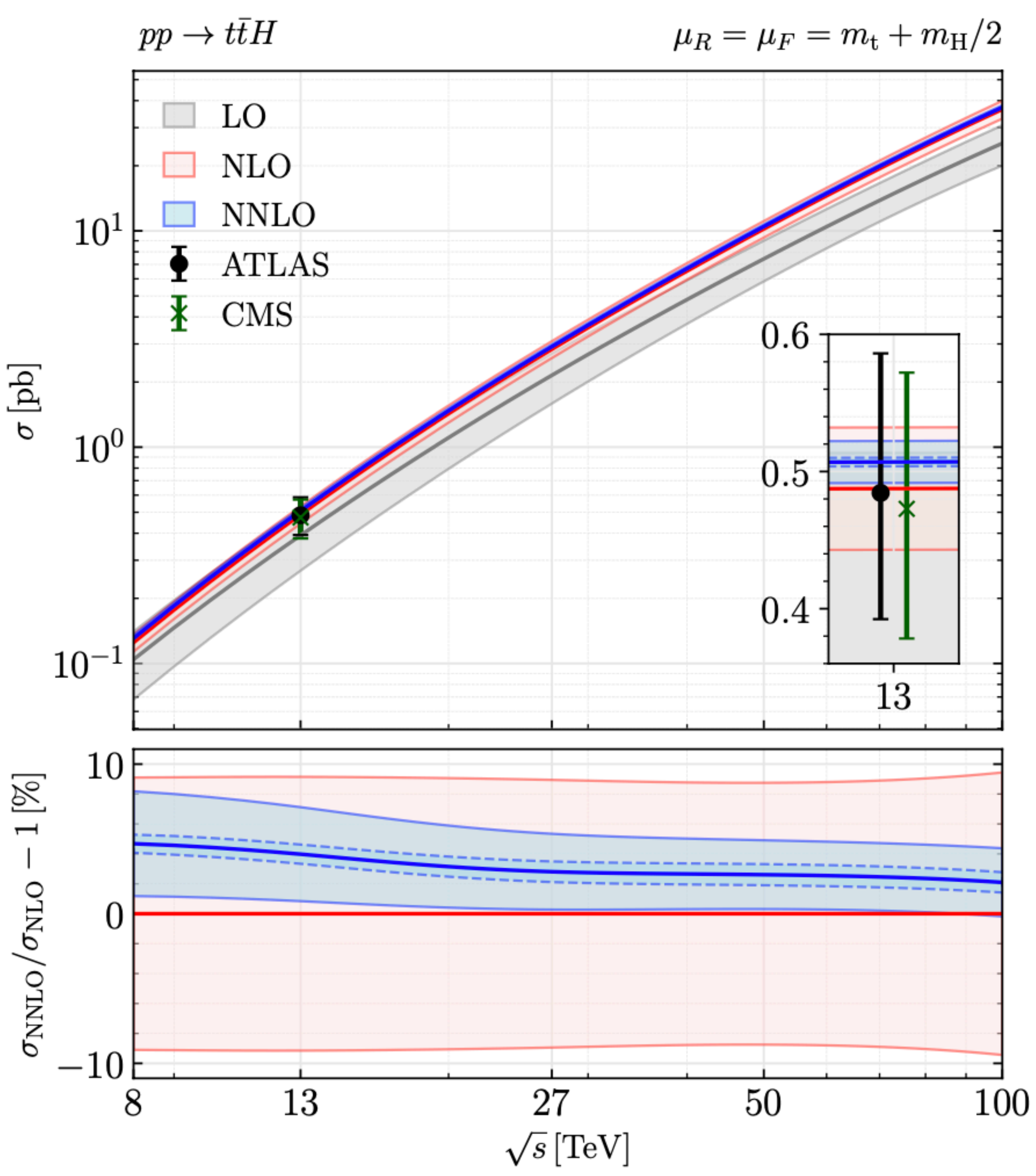
B. TOP-QUARK

- It is the **heaviest fermion** known up to date, with a mass close to the Higgs vacuum expectation value ($m_t = 173$ GeV).
- It is the SU(2) partner of the bottom quark, with an electric charge equal to +2/3 .
- The top quark has a short life and weakly decays into a W-boson and a bottom quark, before hadronising.
- Being the heaviest Standard Model particle, it **couples strongly** with the Higgs boson.

C. ASSOCIATE HIGGS-TOP PRODUCTION



- The top quarks are not evanescent quantum fluctuations as in gluon fusion but they are instead produced as short-lived real particles and detected together with the Higgs.
- For this reason, this production mode is particularly relevant allowing for a direct measurement of the **top-Yukawa coupling**!
- The experimental accuracy on the cross section measurement is currently $\mathcal{O}(20\%)$ but it is expected to go down to $\mathcal{O}(2\%)$ in the next years, with more data collected.



- In order to match the expected experimental accuracy, **more precise theoretical predictions** are mandatory. The inclusion of next-to-next-to-leading order (NNLO) corrections in QCD perturbation theory is needed:

$$\sigma = \sigma_{LO} + \Delta\sigma_{NLO} + \Delta\sigma_{NNLO} + \dots$$

- The main bottleneck in the theoretical computation is represented by the **two-loop virtual amplitudes**, which are at the frontier of current technologies.
- To overcome this problem, in a recent work, we developed a **soft-Higgs boson approximation** ($p_H \to 0$) and we properly extended it to account for a physical Higgs.
- This approximation allowed us to compute the NNLO cross section with a residual uncertainty of less than 1%, obtaining **the most advanced perturbative prediction up to date**!

σ [pb]	$\sqrt{s} = 13$ TeV	$\sqrt{s} = 100$ TeV
σ_{LO}	$0.3910^{+31.3\%}_{-22.2\%}$	$25.38^{+21.1\%}_{-16.0\%}$
σ_{NLO}	$0.4875^{+5.6\%}_{-9.1\%}$	$36.43^{+9.4\%}_{-8.7\%}$
σ_{NNLO}	$0.5070\,(31)^{+0.9\%}_{-3.0\%}$	$37.20(25)^{+0.1\%}_{-2.2\%}$

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