The physics of the LHC

outcome of your discussions ....

What you learned

- Why it is important to find the Higgs.
- What is fundamental and what is not.
- Why we think there are exactly three neutrinos.
- Why we are searching for “unification theory”.
- An understanding of what progress is in science.
- Asking the why questions and not just how and what?
- That we don’t know what mass is!

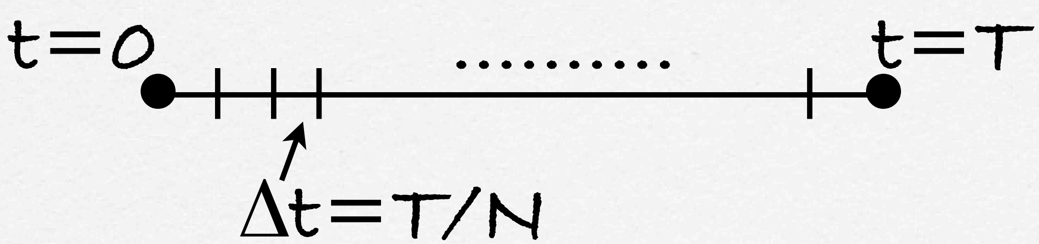
What you concluded you can use in class:

- The first 14 slides – roughly.
- The animation of why light slows down in a medium.
- The relation between lifetimes and decay channels.
- Everything can be tracked back to the fundamental forces: Michelangelos example with the wind.
- The stability of the neutron in the nucleus
- The purpose of proton-proton collider versus e-/e+
- We can now tell the students the reason why they have built LHC
- We can now explain qualitatively how the Higgs field works
- We can explain an example of virtual particles

Particles don't age

The properties of a particle are independent of its "age".
A proton produced today cannot be distinguished from a proton produced during the big bang.

E.g.: The probability that ($n \to p\, e\, \nu$) in the time interval Δt is independent of the time that the neutron has already lived.



$P(n \to p\, e\, \nu \text{ in } \Delta t) = \Gamma\, \Delta t$ $\qquad$ $P(n \text{ stable after } \Delta t) = 1 - \Gamma\, \Delta t$

$$P(n \text{ decays after } T) = (1 - \Gamma\, \Delta t)^N = (1 - \Gamma T/N)^N \xrightarrow{N \to \infty} \exp(-\Gamma T)$$

Questions

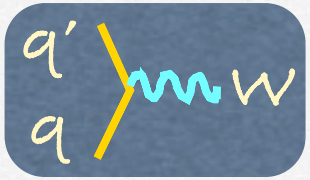
- How is the upper limit of the Higgs boson known?
  - This is complicated and takes time. I'll explain it at the end if there is time left
- Is it possible to find the Higgs boson in the Tevatron?
  - YES, but only if it is light and if the Tevatron can accumulate enough data
- Are particles beyond the Standard Model expected?
  - YES, because we need new phenomena to explain Dark Matter, neutrino masses, and few other puzzles left unanswered by the Standard Model
- Why was λ=1 for the top quark?
  - It is an experimental fact, we still don't have a "why" explanation. This is adeep mystery, but it could also be just a numerical coincidence

Questions

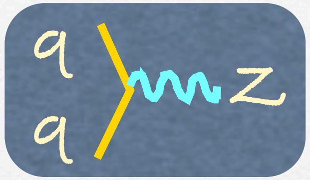
- Can you solve the “dark matter” problem at the LHC?
  - In principle YES. For example, if the DM particle is the lighest particle of supersymmetry, which we expect to produce it at the LHC.
- Why is the graviton a tensor boson and not a vector boson?
  - The photon is a vector because it couples to the electric current, which is a vector. The electric current is a vector because the electric charge is a scalar. The charge of gravity is “energy”, which is the time component of a 4-dimensional vector. Its current is therefore a 2-index tensor, and the graviton, which couples to it, must be the same
- Is it possible to have many (2,3,...) Higgs?
  - YES. This is true, e.g., in supersymmetry. One Higgs field gives mass to up-type quarks, the other to down-type quarks. If so, the LHC will hopefully see both Higgs bosons!

Questions

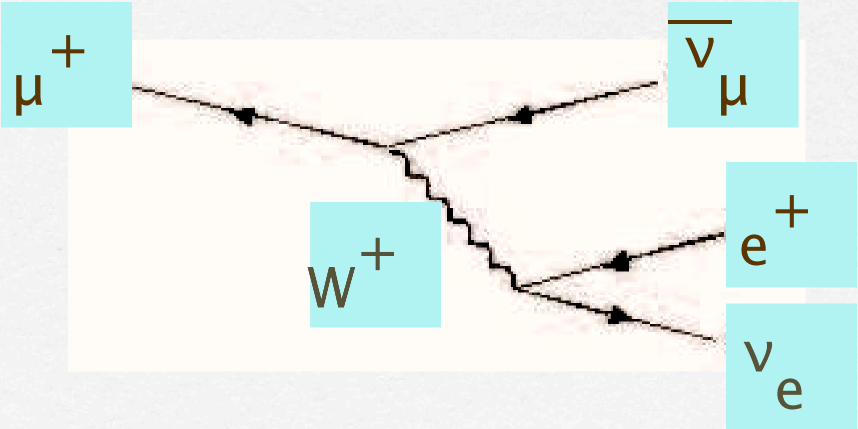
- Can quarks interact with the weak field?



→nuclear β decay

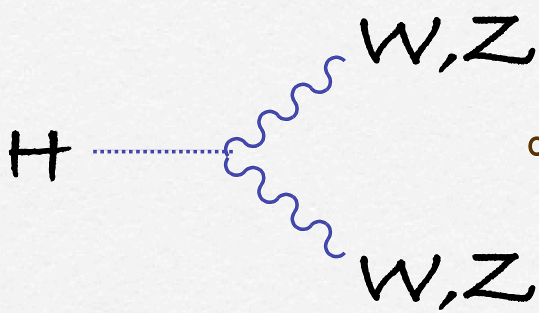


- Could you comment on the directions on the arrows on the diagram in slide 17? (We haven't heard a lot about Feynman diagrams).

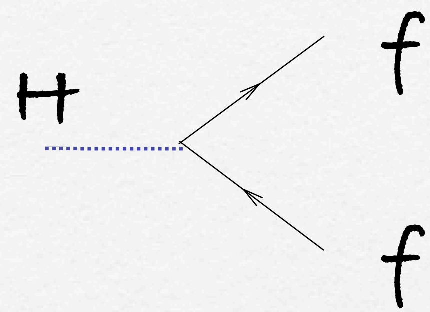


Questions

- How do we know that the Higgs will decay into 2 Z particles?

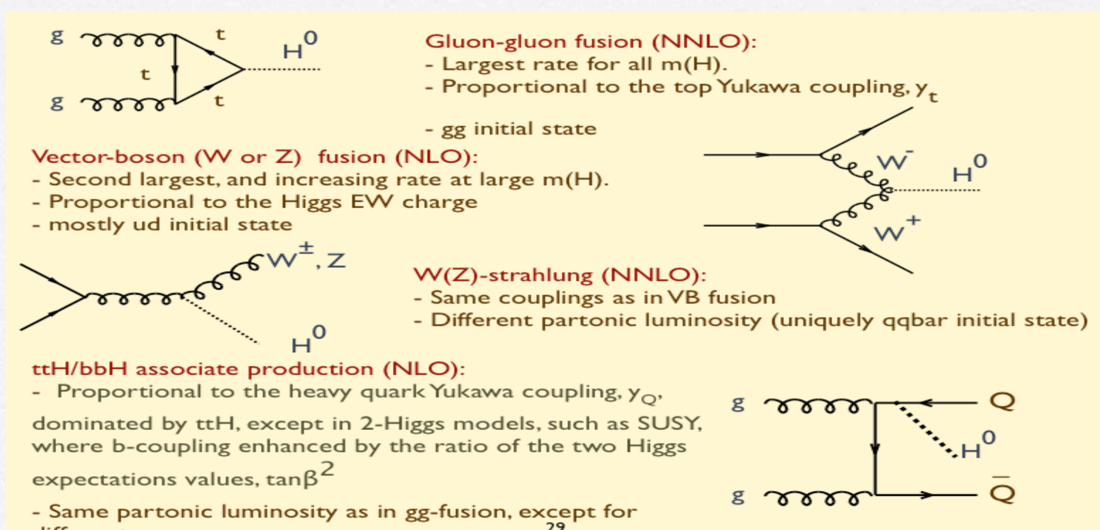


$\propto m_{W,Z}$



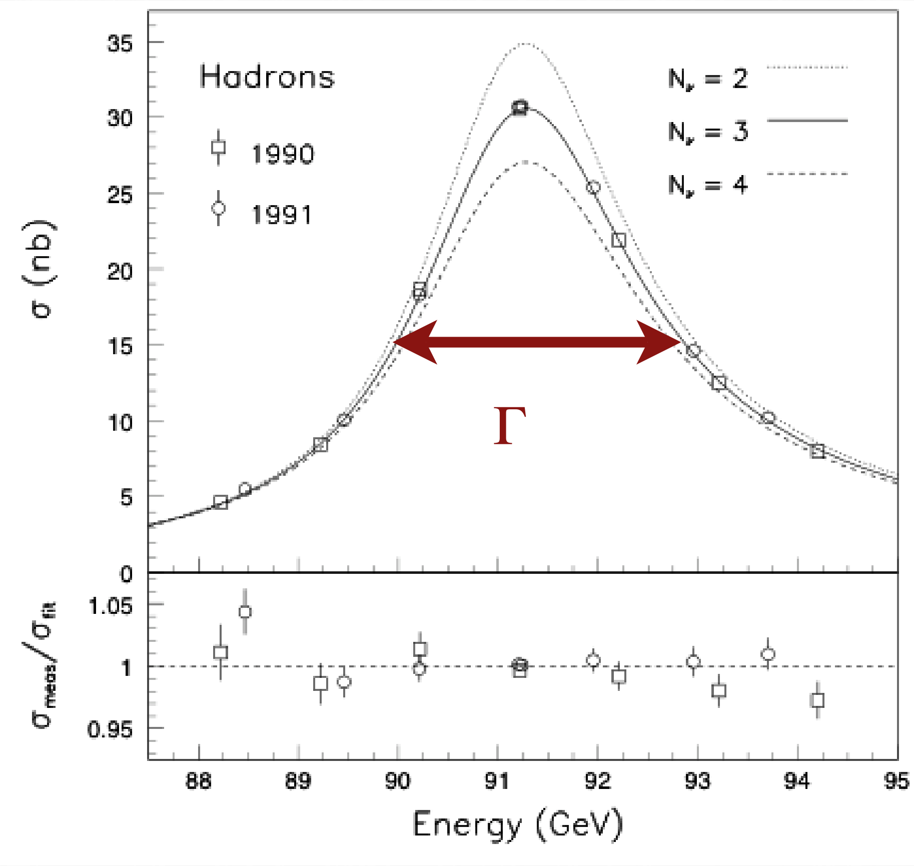
$\propto m_f$ $f=q,l$

- What are the 4 production mechanisms at LHC?



Questions

- Clarify the figure on slide 19 – you said the width grows with the number of neutrinos – yet in the figure it seems to narrow with the number of neutrinos?



You are right, but the width is defined at half the height of the peak. With more neutrinos the peak is reduced more quickly, and the width at half-peak increases.

One can also prove that the peak height is inversely proportional to the width,

$$\sigma_{peak} \propto M_Z / \Gamma$$

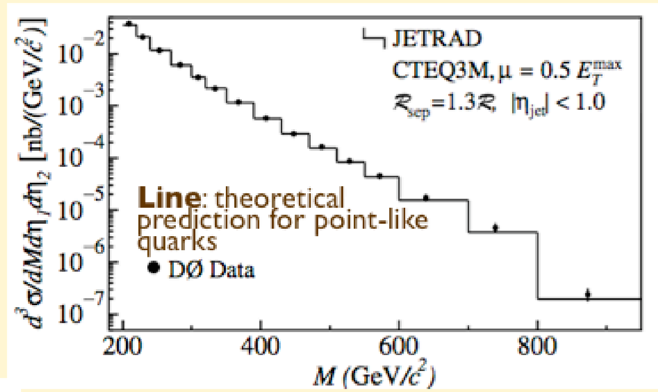
so the decrease in the peak is itself a sign that the width is increasing

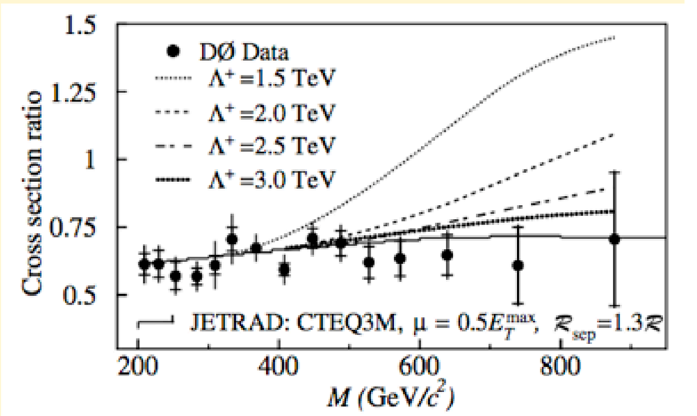
Questions

- Could you recap the physics behind slide 22? What do we want to prove with it?

Real data (Tevatron) vs theoretical expectations

If quarks had a substructure apparent at a distance scale equal to $1/\Lambda$, this would lead to deviations from the theoretical curve





⇒ the data exclude Λ < 2.4 TeV

Existing date prove that quarks are pointlike at least down to **10^{-17} cm**

The LHC will probe distances a factor of 10 smaller!!

Questions

- Is the Higgs field the modern version of the ether? Why not?
- What would happen if the Higgs is not found?
- Are there any restrictions on "virtual" particles inside a proton? Please clarify.