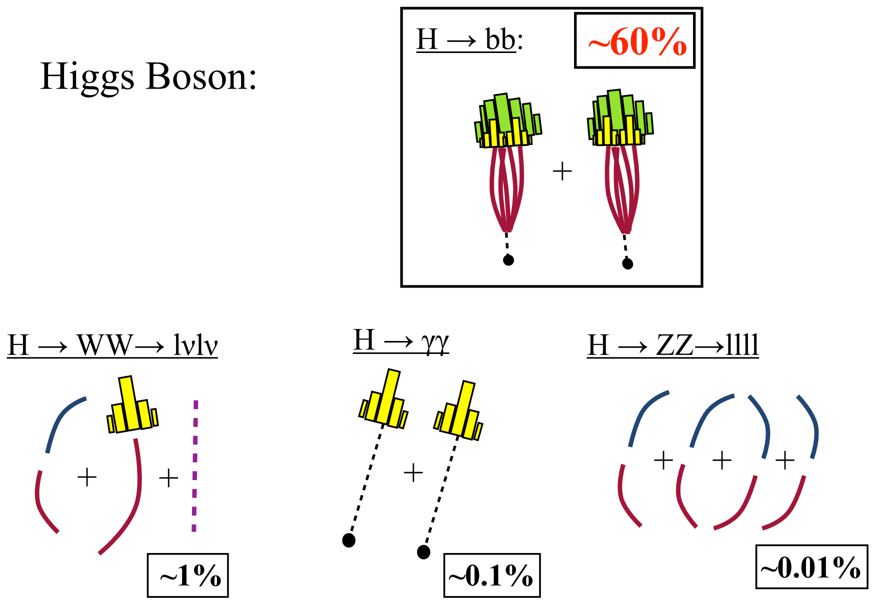
Lecture 25

Higgs Boson:



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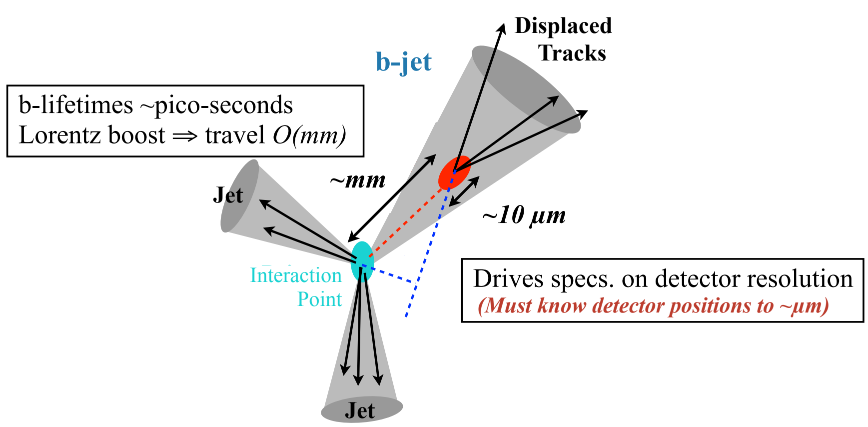
b-jet Identification *(b-Tagging)*

Critical as b-jet ubiquitous in higgs final states.



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Triggering

- LHC provides orders of magnitude more collisions than we can save to disk.
  - Can only keep 1 out of 40,000 events / Discarded data lost forever
- Interesting physics is incredibly rare:
  ~1 Higgs per billion events / ~1 Di-Higgs per trillion events

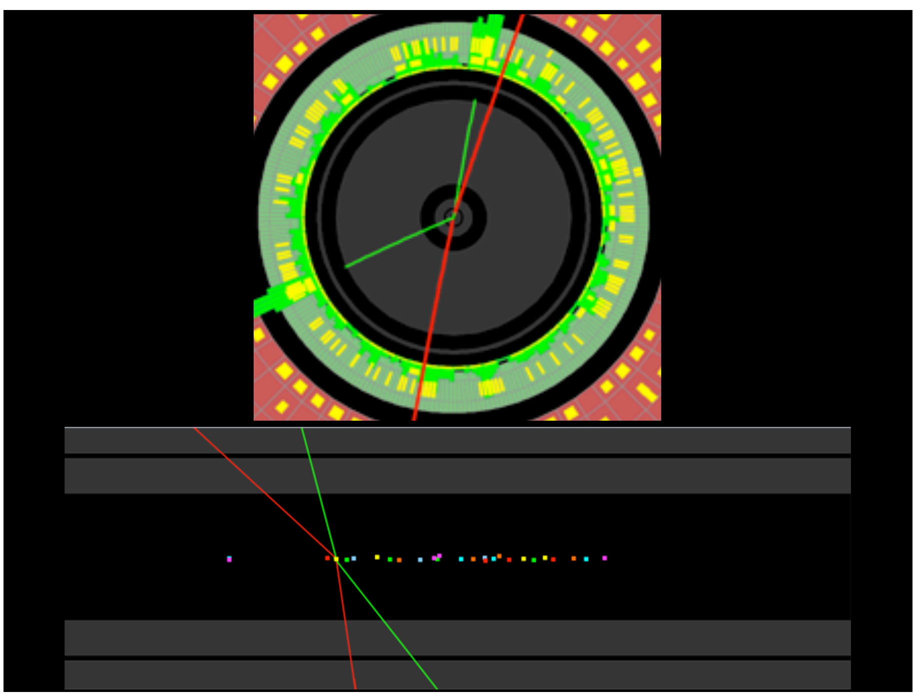
Triggering: Process of selecting which collisions to save for further analysis.

Triggering at the LHC:

- Custom Electronics + Commodity CPU
- Fast processing of images (micro-seconds / seconds)
- Events rate from 40 MHz → 1kHz.
- Data rate from 80 TBs **(!)** → 2 GB/s

To collect data faster, each event has multiple proton collisions.

Significantly complicates analysis of events



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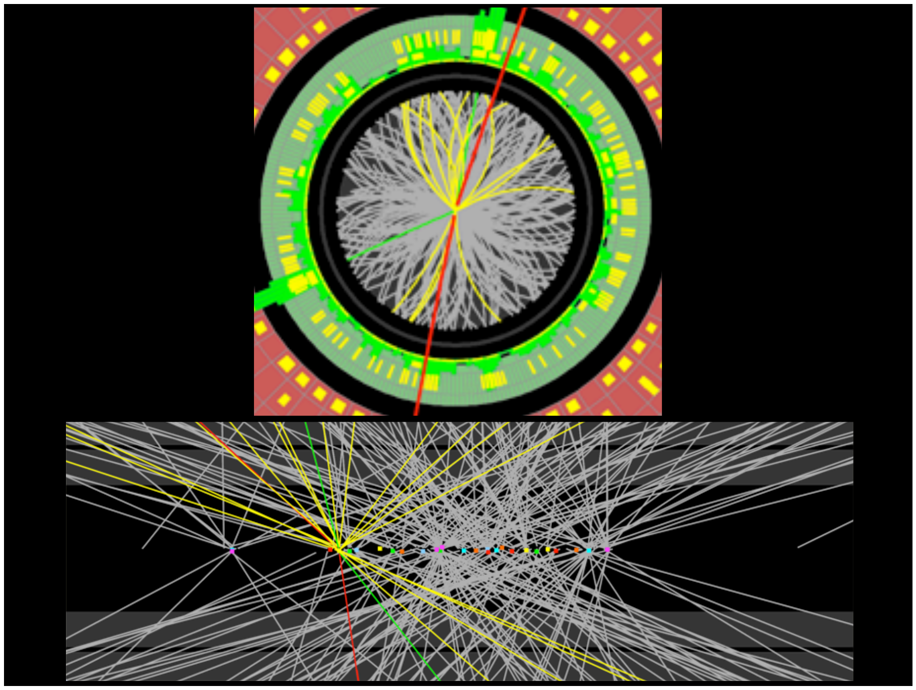


Vacuum Fluctuations

QM+Spaceetime ⇒ Anti-particles ⇒ Vacuum is interesting place.

Because of QM, need to put in Energy to probe smaller distances.

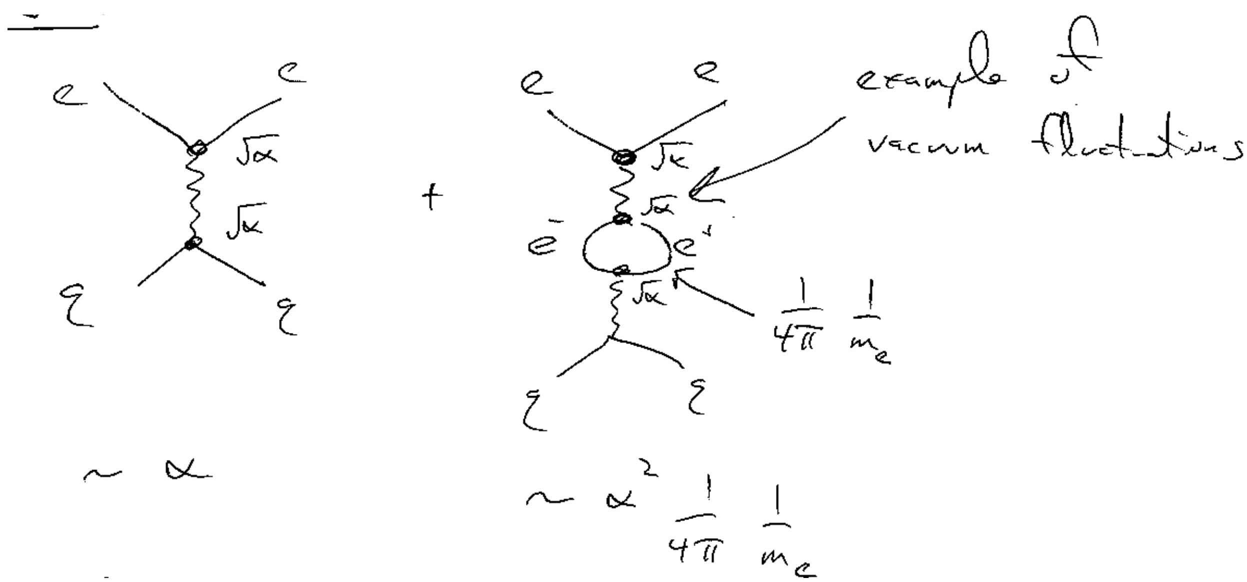
$$E \cdot t \sim E \cdot x \sim 1 \Rightarrow \text{Small distances} \Rightarrow \text{large E}$$

If $E >> 2m_2$ nothing stops you from making e^+e^- pairs.

So operationally, should think of the vacuum as filled of particle-anti-particle pairs constantly coming in and out of existance:

No meaningful sense in which the vacuum is empty.

Example 1



Example 2

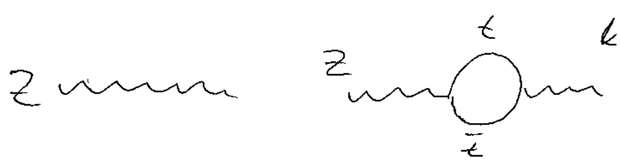
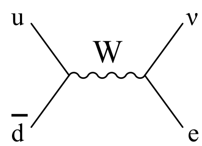


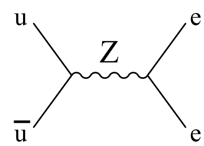
Diagram gives a correction to the mass of the Z-boson from the top quark

History of Prediction and Discovery

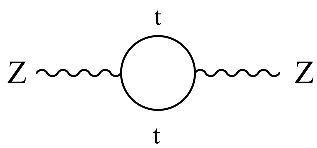
Late 60s: Standard Model takes modern form. Predicts W/Z bosons

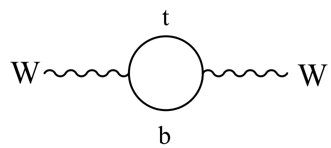
1983: W/Z discovered at CERN



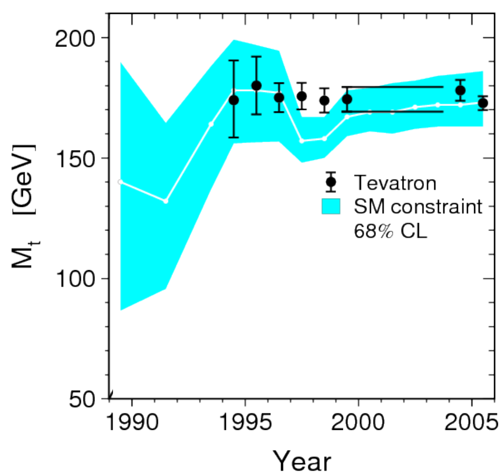


Early 90s: W/Z used to predict top mass

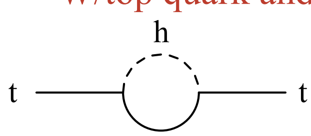


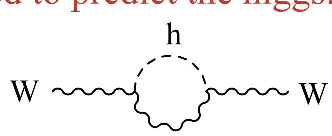


1995: top quark discovered at Fermilab

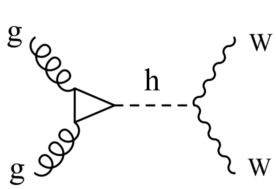


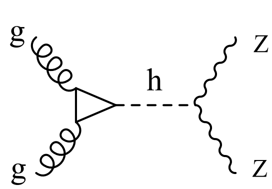
2000s: W/top quark and used to predict the higgs: **50 < m_H < 150 GeV** (95%)

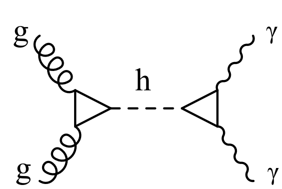




2012: Higgs discovered at CERN: **m_H = 125 GeV**







These "Quantum Corrections" (Vacuum fluctuations) have <u>observable</u> physical consequences.

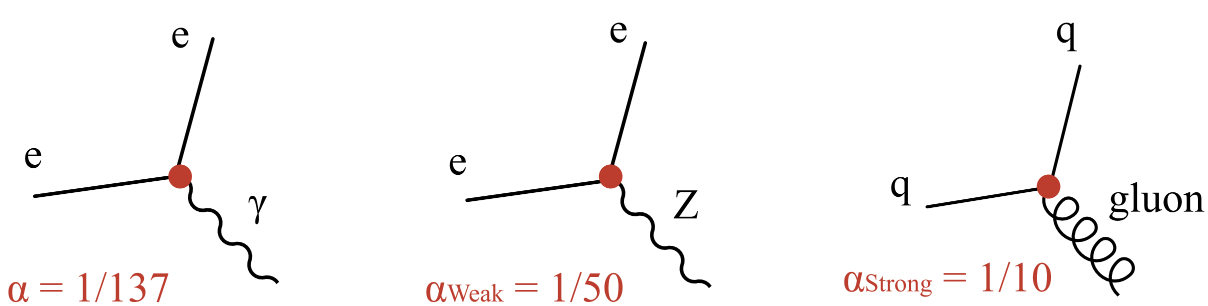
Predicted the mass of the top quark and higgs boson before it was discovered.

Forces all expressed in common language.

At high energy $E \gtrsim m_{W,Z}$, first time we see that all forces described in same basic way.

Forces Common Language

First time that we see that all forces described in same basic way.



Forces look very different to us… **is a long distance illusion!**

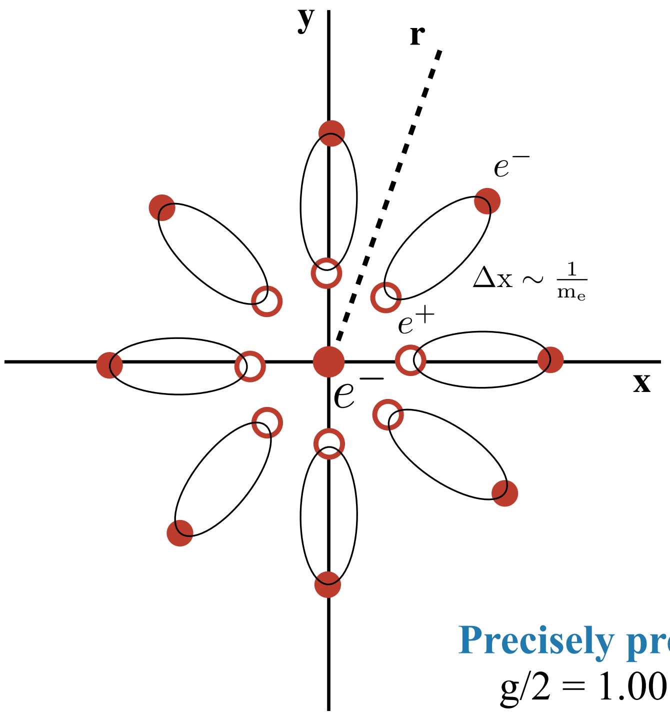
This is the real reason we build colliders! See basic underlying symmetry.

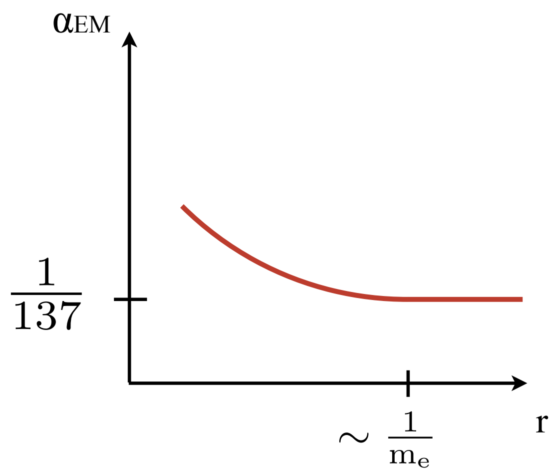
We already talked about this for the weak interaction. (m_W and $m_Z >> 0$ cuts of the range of the force)

Now lets look at why the strong interaction looks so different...

Imagine you wanted to measure the EM strength vs distance.

EM Strength w/Distance





Precisely predict magnetic properties

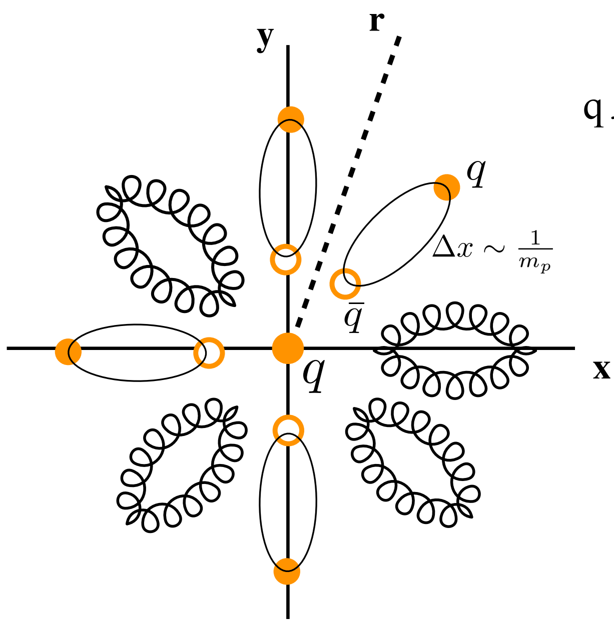
g/2 = 1.0011596521809(8),

(Agree to better than one part in a trillion.)

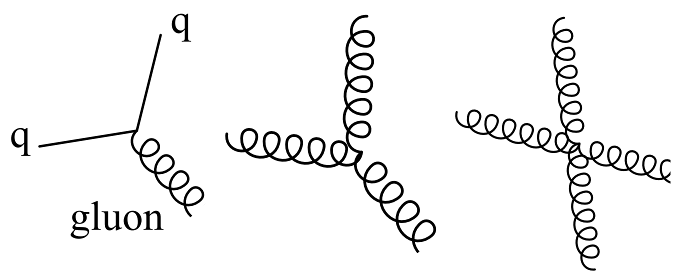
α increases because you are "seeing" more of the bare electron charge.

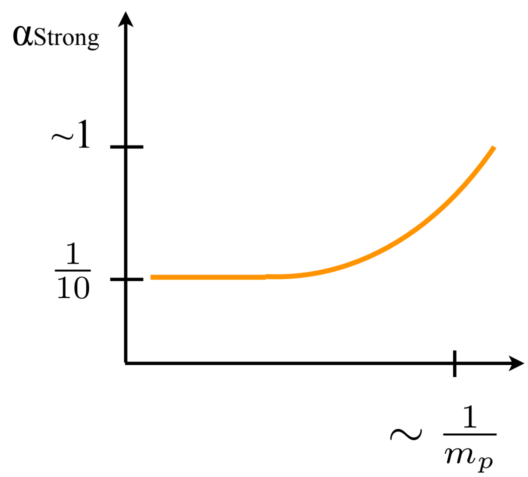
Same game with the Strong Interaction

Strong Interaction w/Distance



Unlike photons, gluons can self interact.

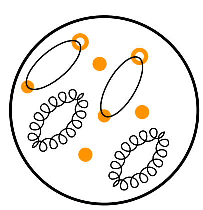




Increase is an “accident” depends on the number of colors, the number of quarks and gauge group.

Interaction become very strong ~1/mp

Proton:



B/c force grows with distance:
- Cant pull them out of the proton
- q and gluons “confined “

Sets the size of protons (neutrons)