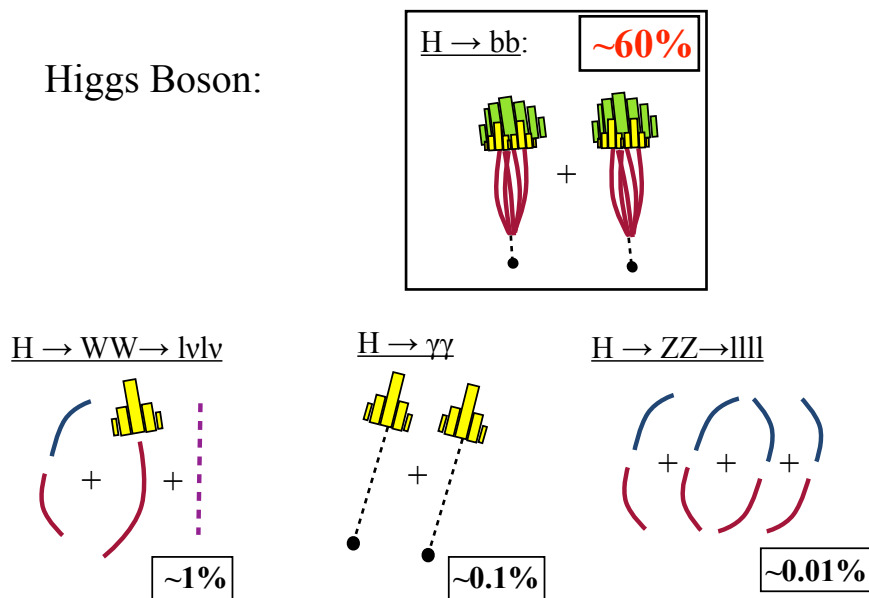


## Lecture 25

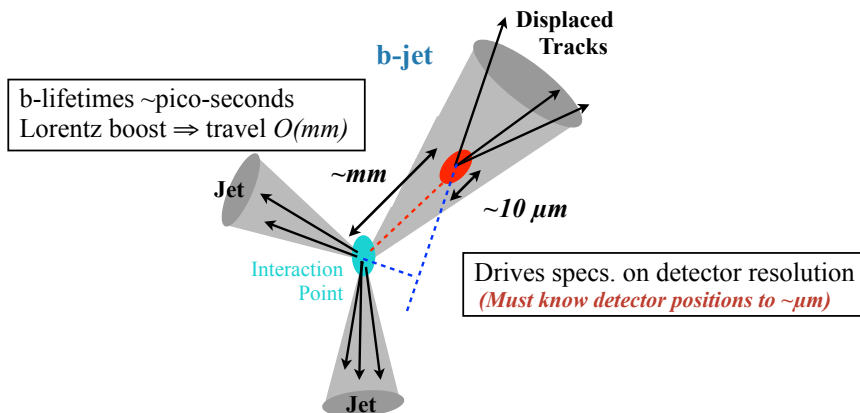
Higgs Boson:



47

## b-jet Identification (*b-Tagging*)

Critical as b-jet ubiquitous in higgs final states.



52

# 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.

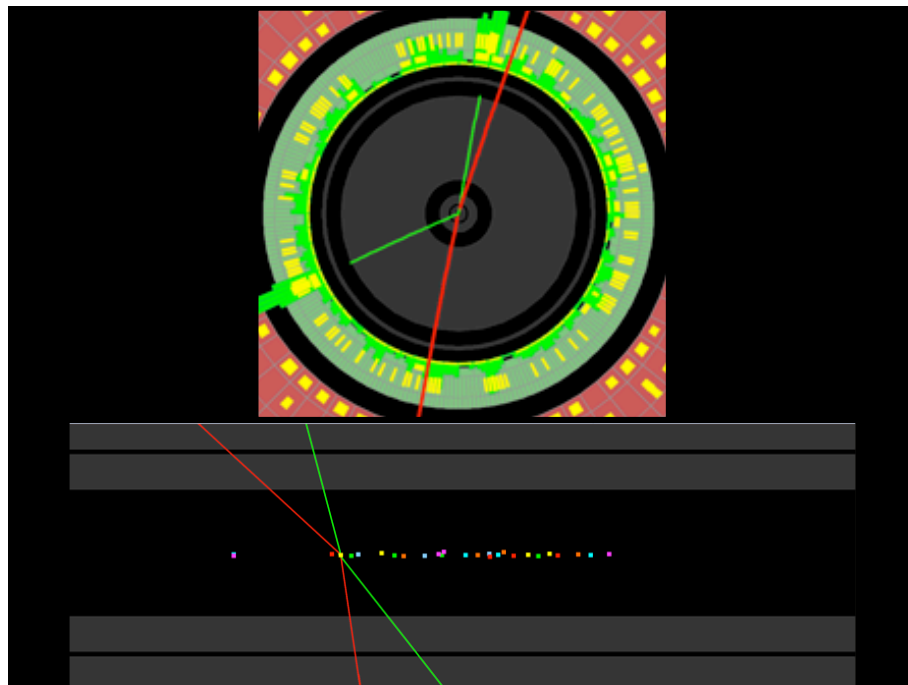
## Triggering at the LHC:

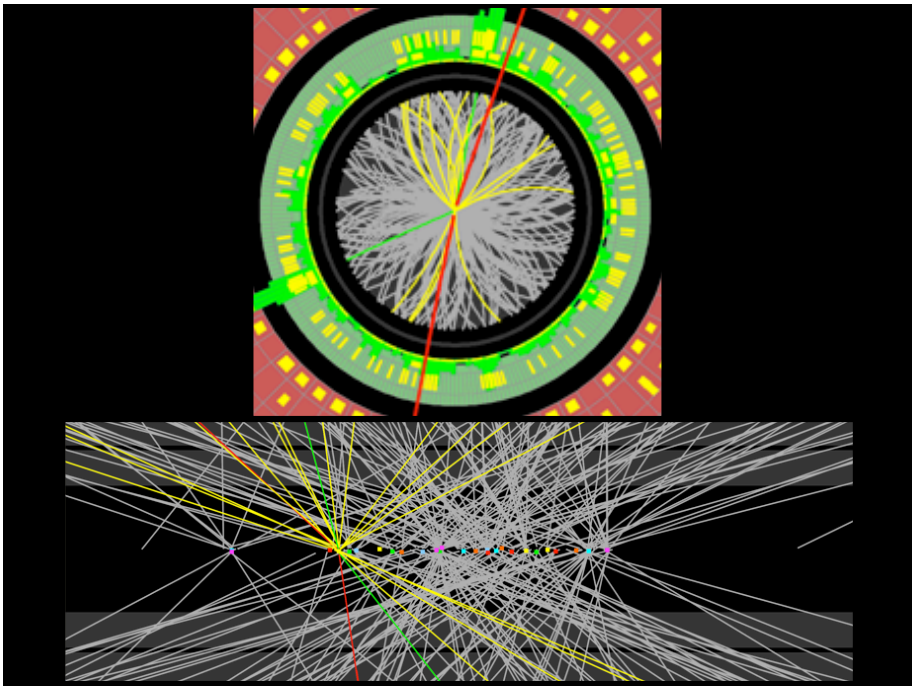
- Custom Electronics + Commodity CPU
- Fast processing of images (micro-seconds / seconds)
- Events rate from 40 MHz  $\rightarrow$  1kHz.
- Data rate from 80 TBs (!)  $\rightarrow$  2 GB/s

---

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

Significantly complicates analysis of events





## Vacuum Fluctuations

QM+Spacetime  $\Rightarrow$  Anti-particles  $\Rightarrow$  Vacuum is interesting place.

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

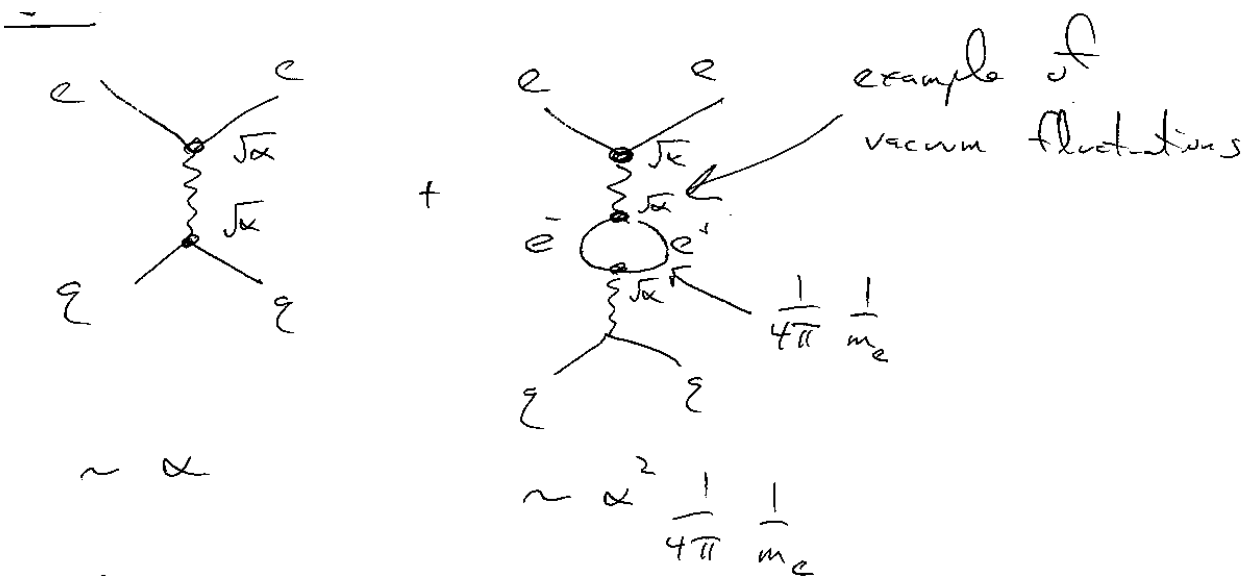
$$E \cdot t \sim E \cdot x \sim 1 \Rightarrow \text{Small distances} \Rightarrow \text{large } E$$

If  $E \gg 2m_e$  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 existence:

No meaningful sense in which the vacuum is empty.

### Example 1



### Example 2

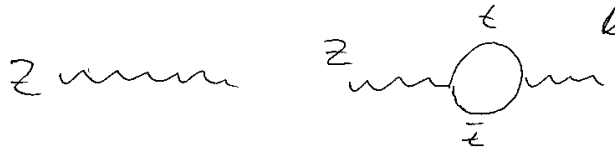
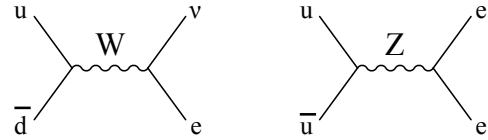


Diagram gives a correction to the mass of the Z-boson from the top quark

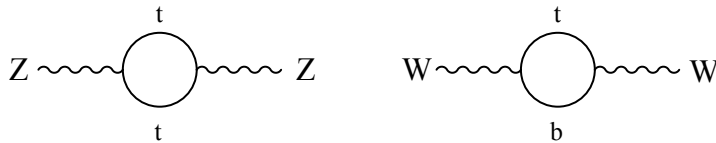
# History of Prediction and Discovery

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

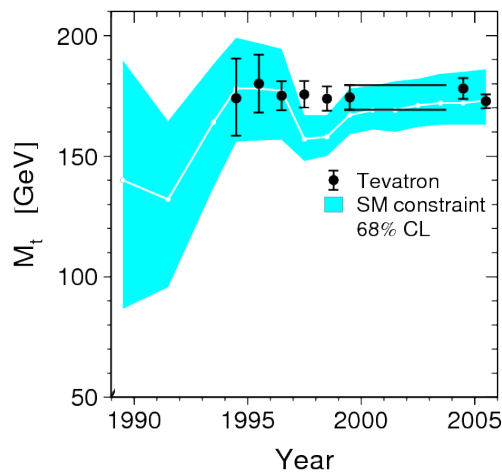
1983: W/Z discovered at CERN



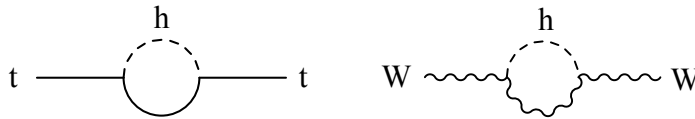
Early 90s: W/Z used to predict top mass



1995: top quark discovered at Fermilab

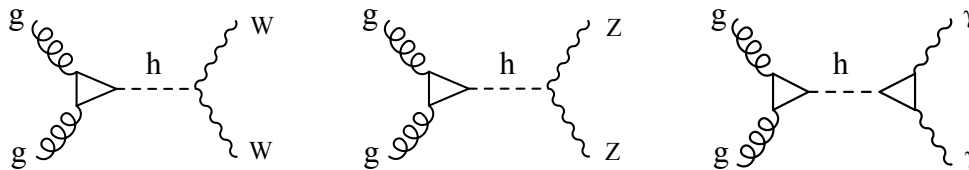


2000s: W/top quark and used to predict the higgs:  $50 < m_H < 150 \text{ GeV}$  (95%)



2012: Higgs discovered at CERN:

$m_H = 125 \text{ GeV}$



These “Quantum Corrections” (Vacuum fluctuations) have observable physical consequences.

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

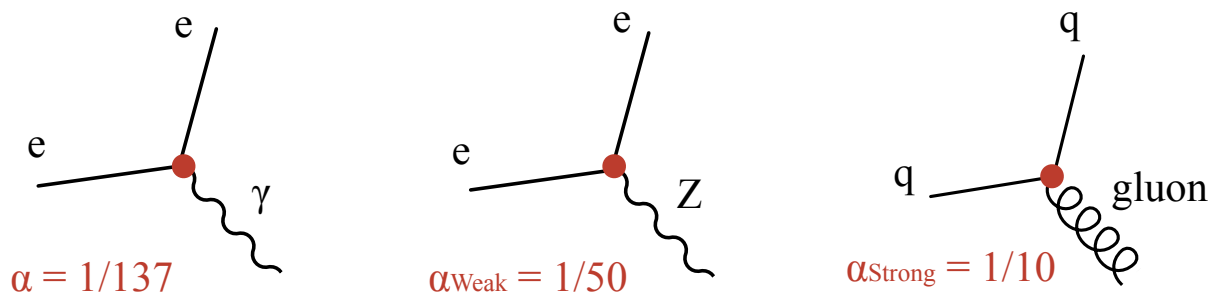
---

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!**

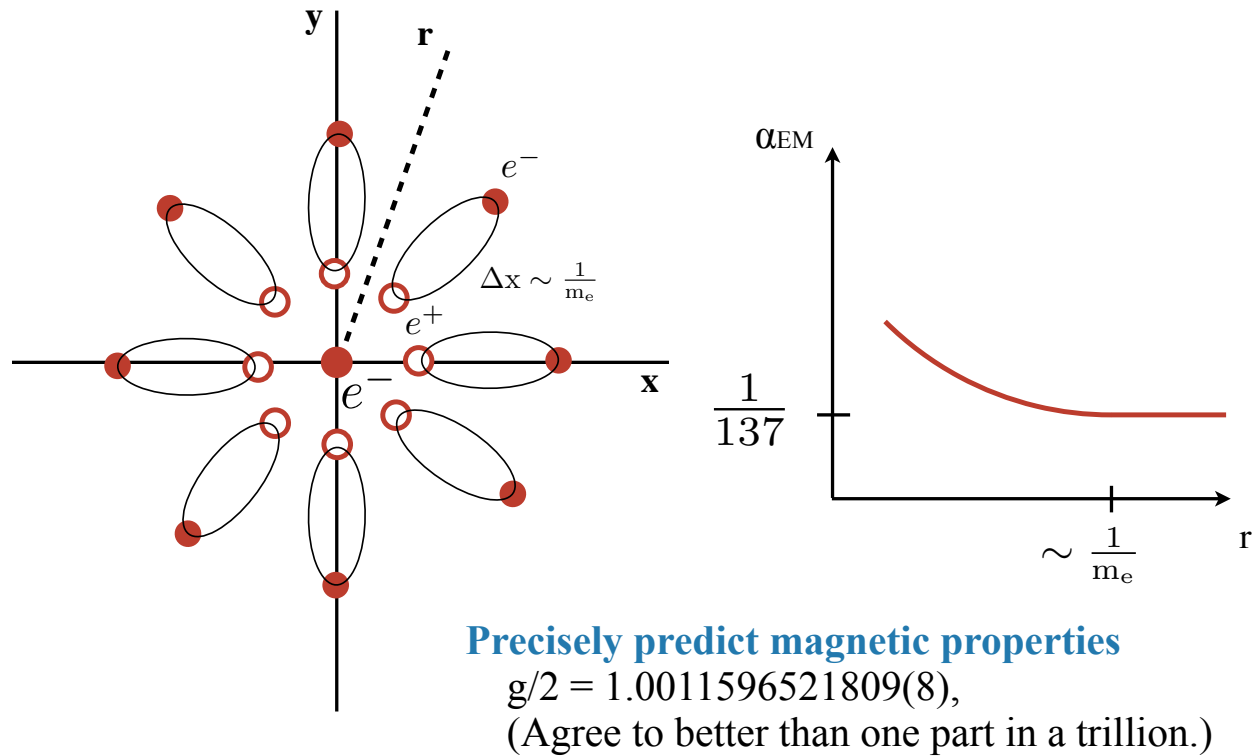
This is the real reason we build colliders! See basic underlying symmetry.

We already talked about this for the weak interaction. ( $m_W$  and  $m_Z \gg 0$  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



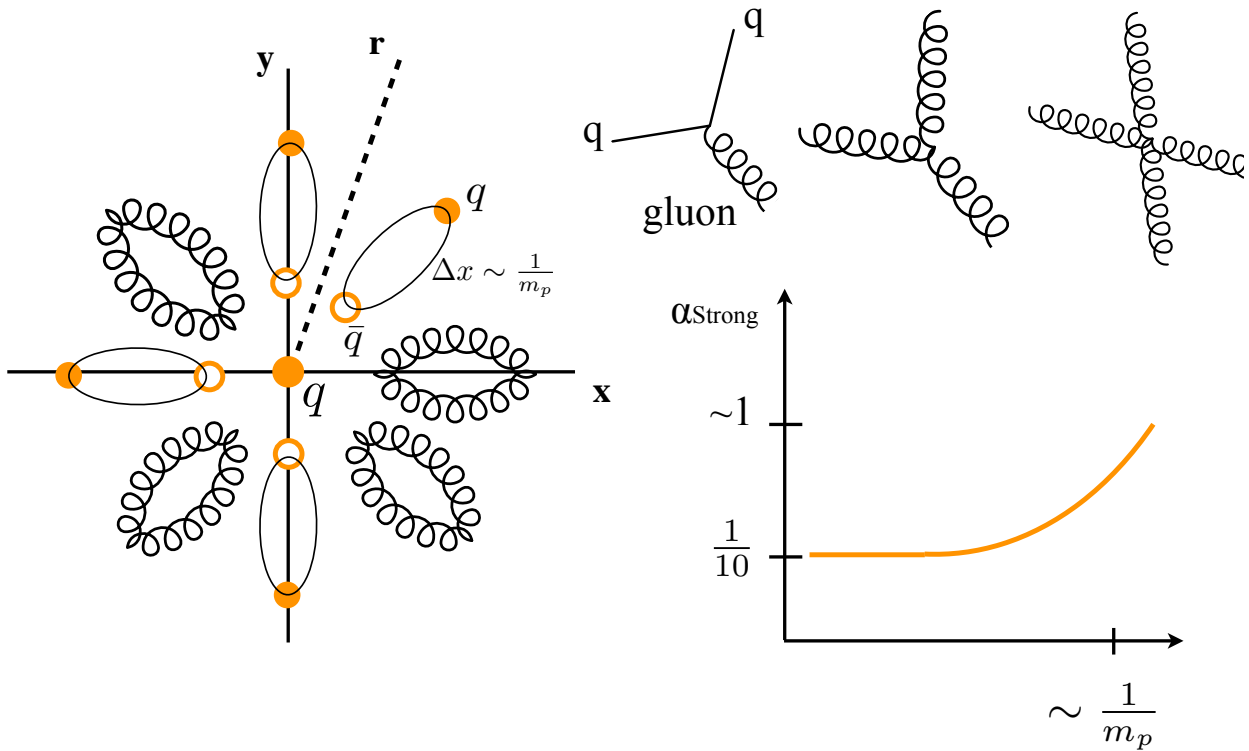
$\alpha$  increases because you are “seeing” more of the bare electron charge.

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Same game with the Strong Interaction

## Strong Interaction w/Distance

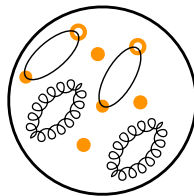
Unlike photons, gluons can self interact.



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

Interaction become very strong  $\sim 1/m_p$

Proton:



B/c force grows with distance:

- Cant pull them out of the proton
- $q$  and gluons “confined”

Sets the size of protons (neutrons)