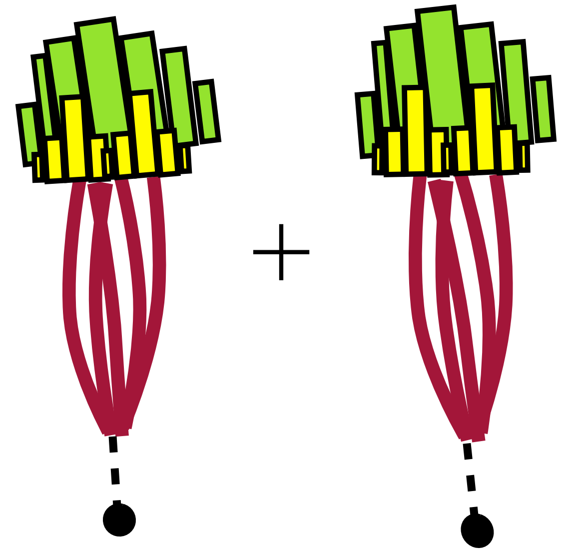
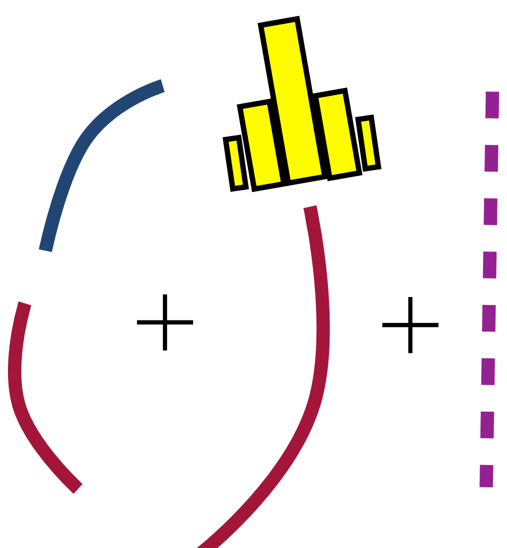
Higgs Boson:

<u>H → bb:</u> **~60%**

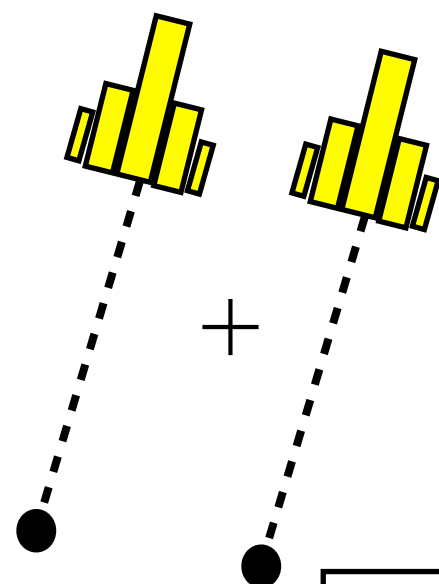


<u>H → WW→ lνlν</u>



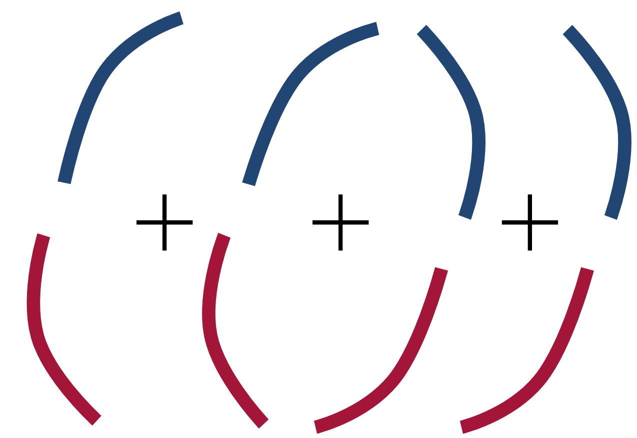
~1%

<u>H → γγ</u>



~0.1%

<u>H → ZZ→llll</u>

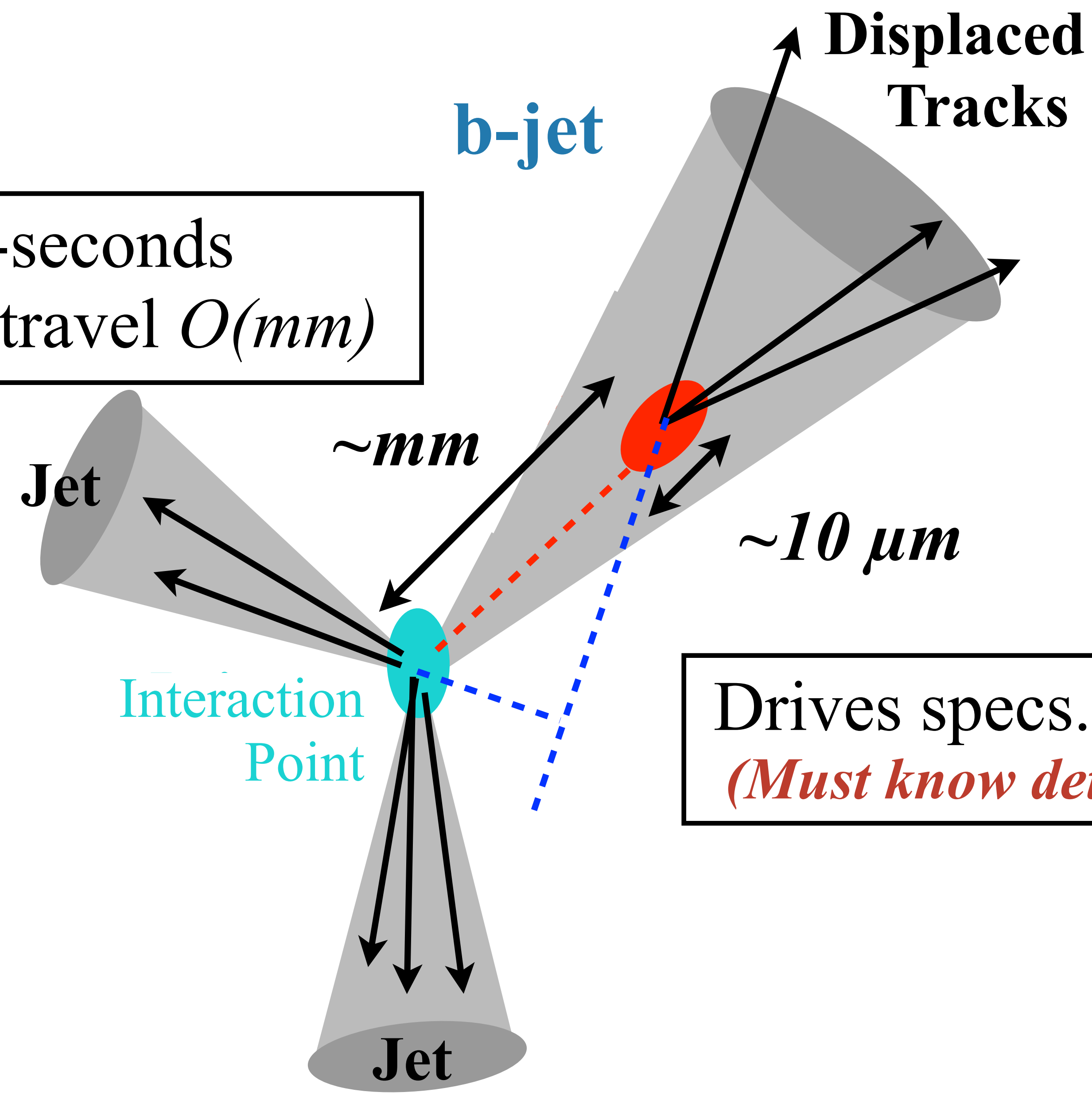


~0.01%

b-jet Identification *(b-Tagging)*

Critical as b-jet ubiquitous in higgs final states.

b-lifetimes ~pico-seconds
Lorentz boost ⇒ travel *O(mm)*



Drives specs. on detector resolution
(Must know detector positions to ~μm)

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.

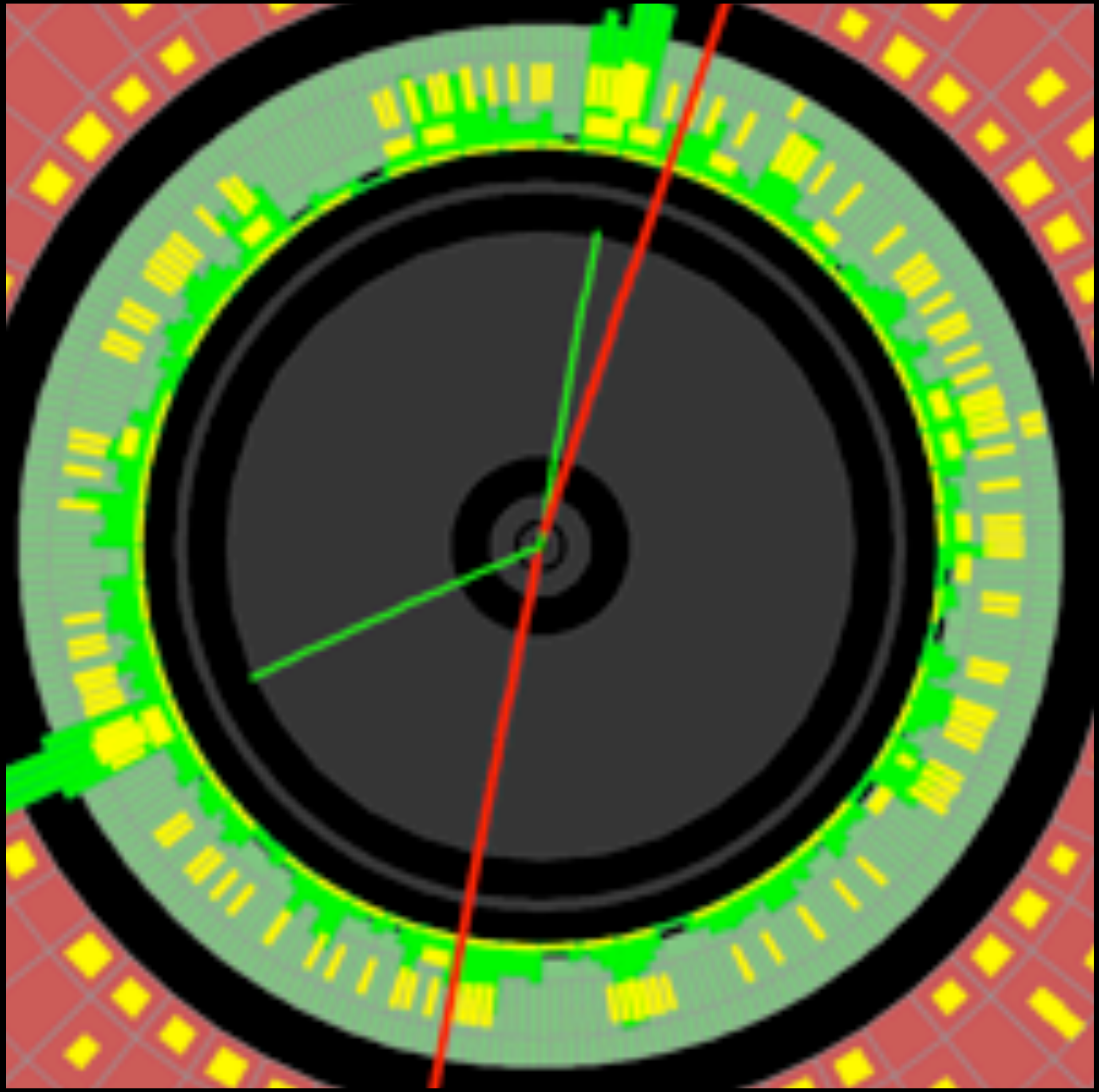
Triggering at the LHC:

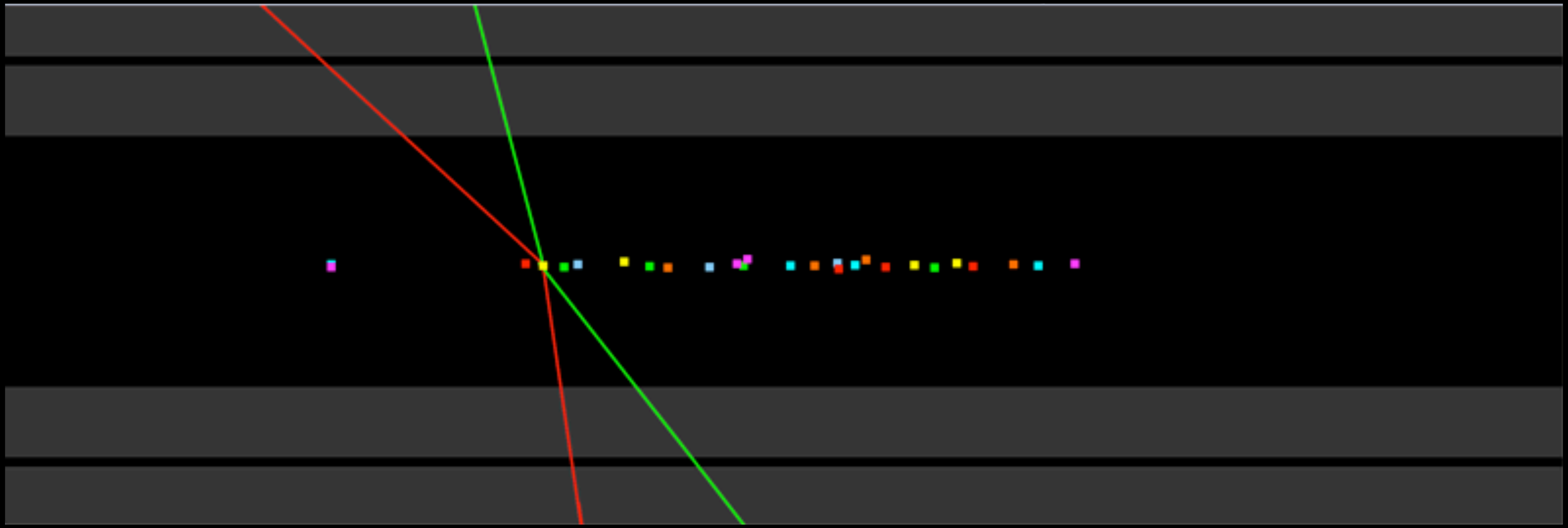
- Custom Electronics + Commodity CPU
- Fast processing of images (micro-seconds / seconds)
- Events rate from 40 MHz → 1kHz.
- Data rate from 80 TBs **(!)** → 2 GB/s

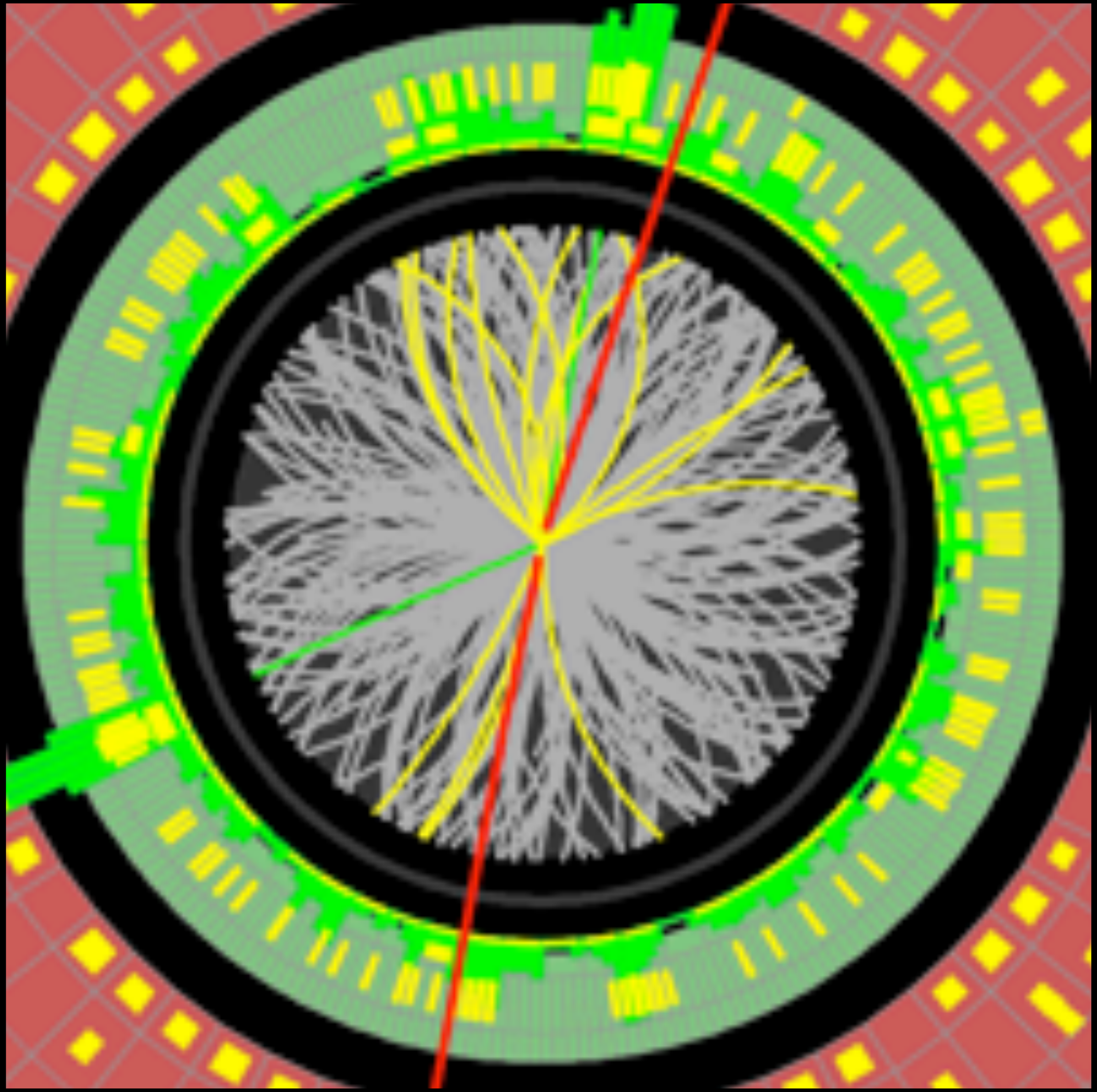
Pile-Up

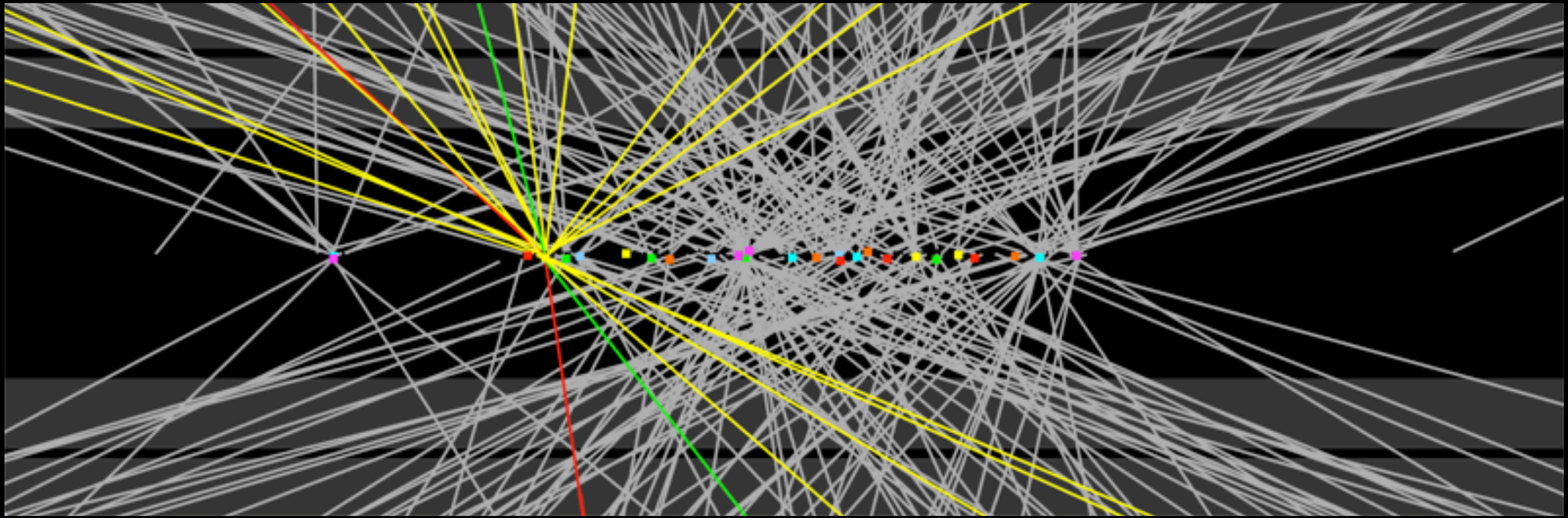
To collect data faster, each picture (“Event”) has multiple proton collisions.

Significantly complicates analysis of events









- Vacuum fluctuations

QM + Spacetime $\Rightarrow$ Antiparticles $\Rightarrow$ Vacuum is interesting place.

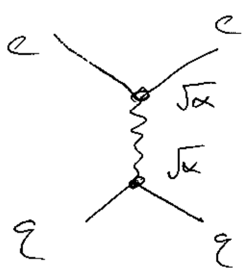
B/c QM need to put in Energy to probe small distances

$E \cdot t \sim E\, x \sim 1 \Rightarrow$ Small distances $\Rightarrow$ large E

if $E \gg 2m_e$ nothing stops you from making e^+e^- pairs.

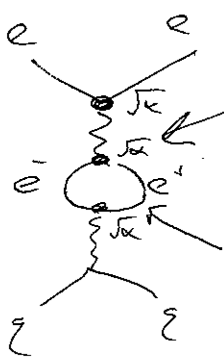
So operationally, should think of the vacuum as full of particle - anti particle pairs constantly coming in and out of existence: No meaningful sense in which the vacuum is empty.

eg: 1 example



$\sim \alpha$

+



example of vacuum fluctuations

$\frac{1}{4\pi}\frac{1}{m_e}$

$\sim \alpha^2 \frac{1}{4\pi}\frac{1}{m_e}$

example 2

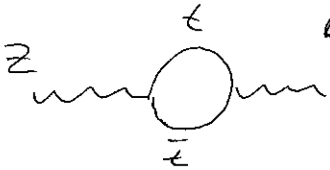
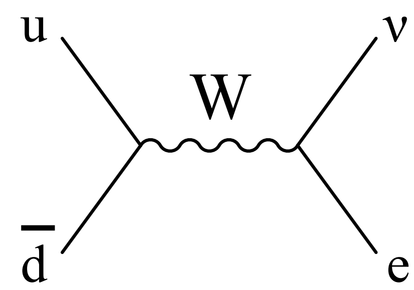


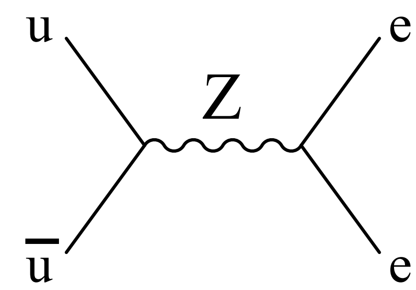
diagram gives a correction to the mass of the Z-boson from the top Quark.

History of Prediction and Discovery

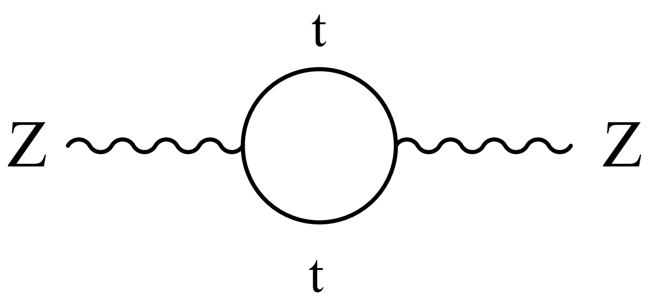
Late 60s: Standard Model takes modern form. Predicts W/Z bosons

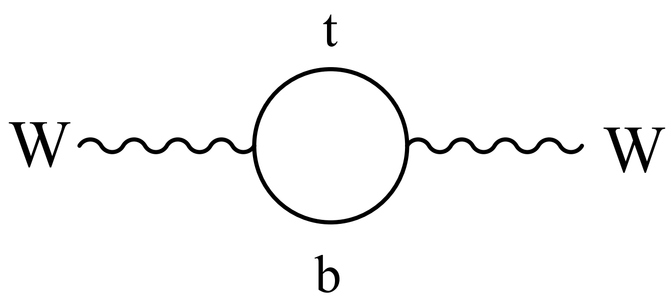
1983: W/Z discovered at CERN





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





1995: top quark discovered at Fermilab

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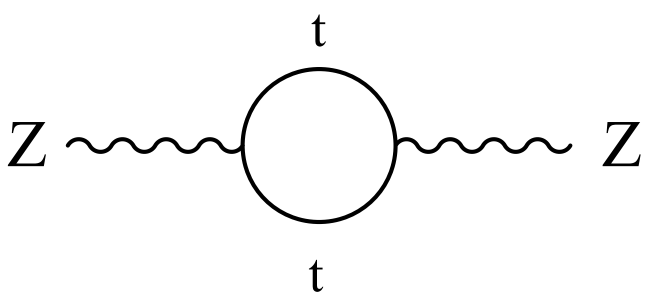
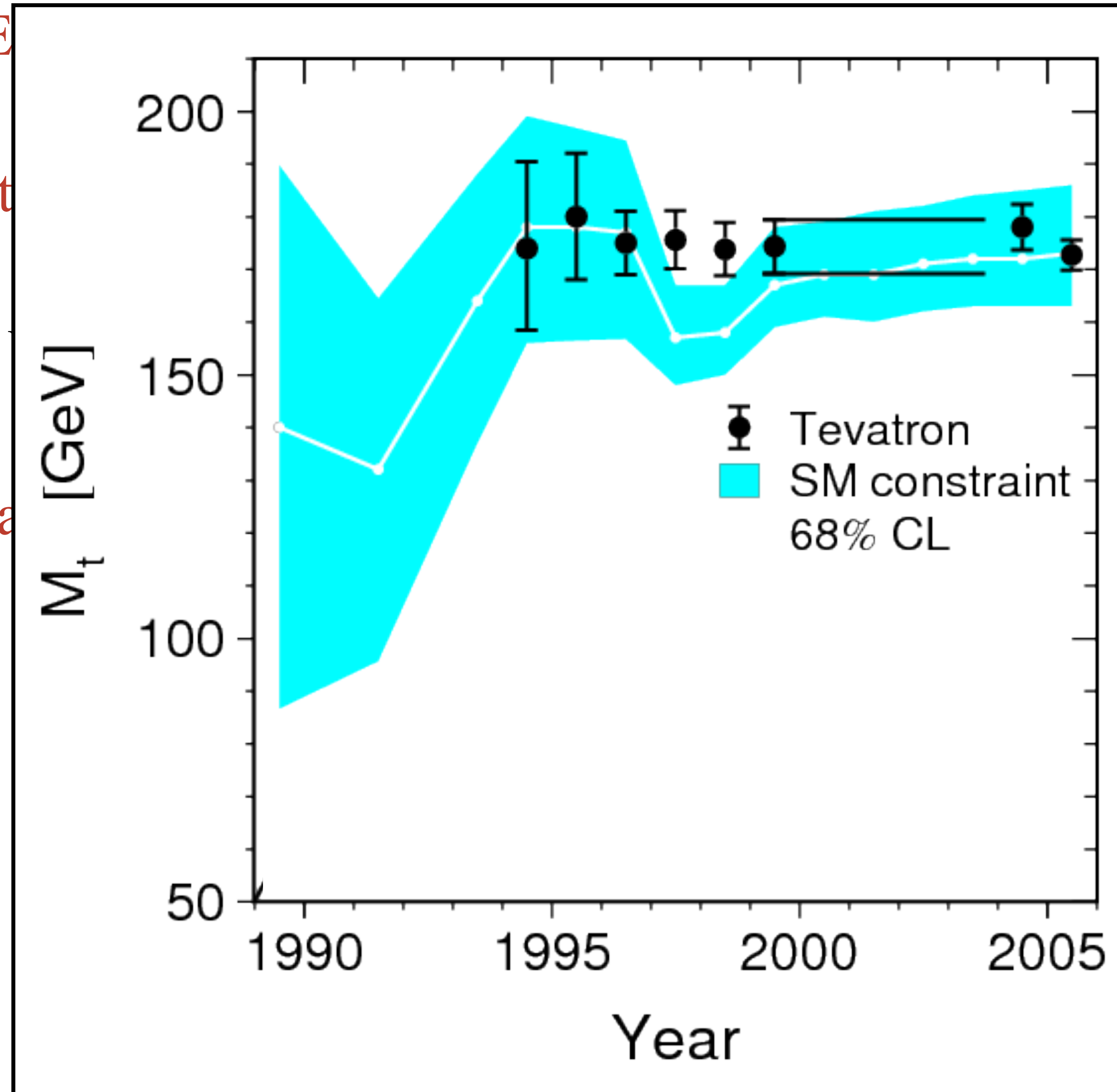
Early 90s: W/Z used to predict t



1995: top quark discovered a



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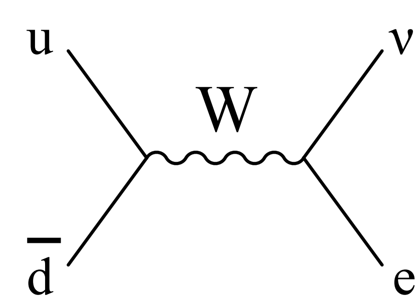

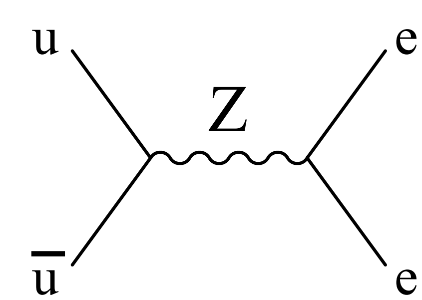

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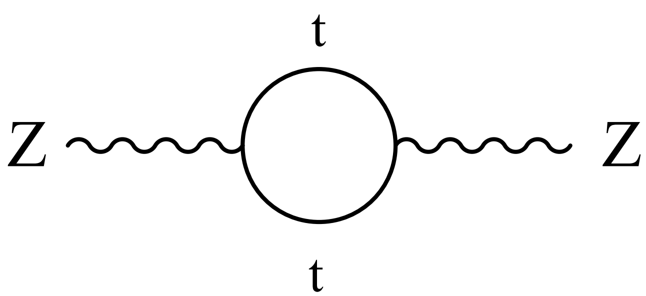
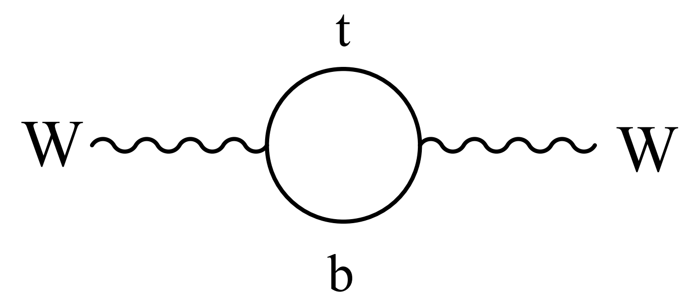
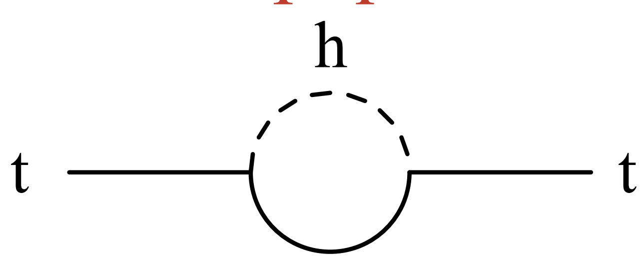
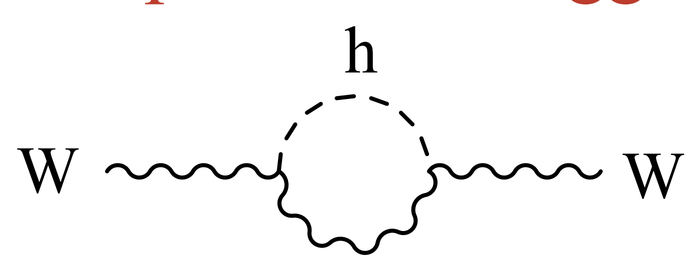




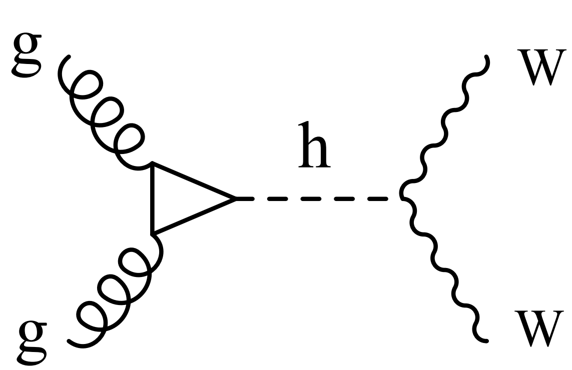
1995: top quark discovered at Fermilab

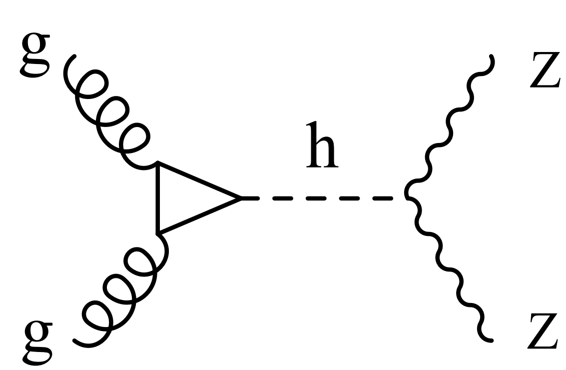
2000s: W/top quark and used to predict the higgs: **$50 < m_H < 150$ GeV** (95%)

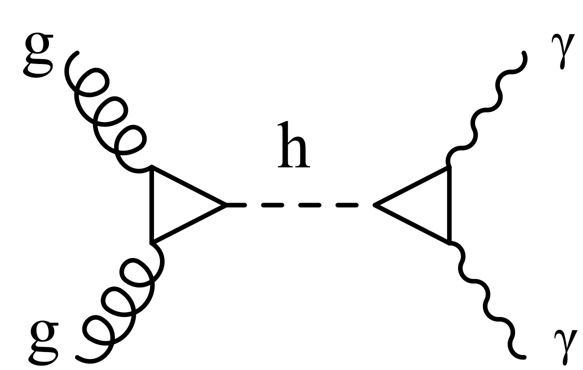




2012: Higgs discovered at CERN: **$m_H = 125$ GeV**





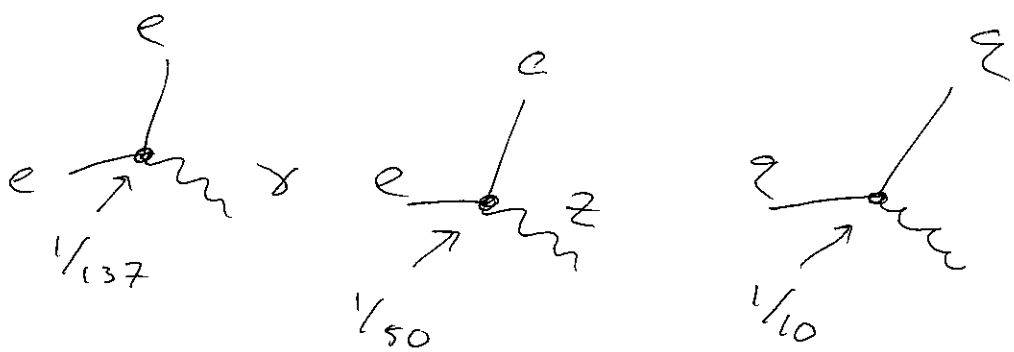


these "Quantum Corrections" (Vacuum fluctuation)
have <u>observed</u> physical consequences

Predicted the mass of the top quark 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



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

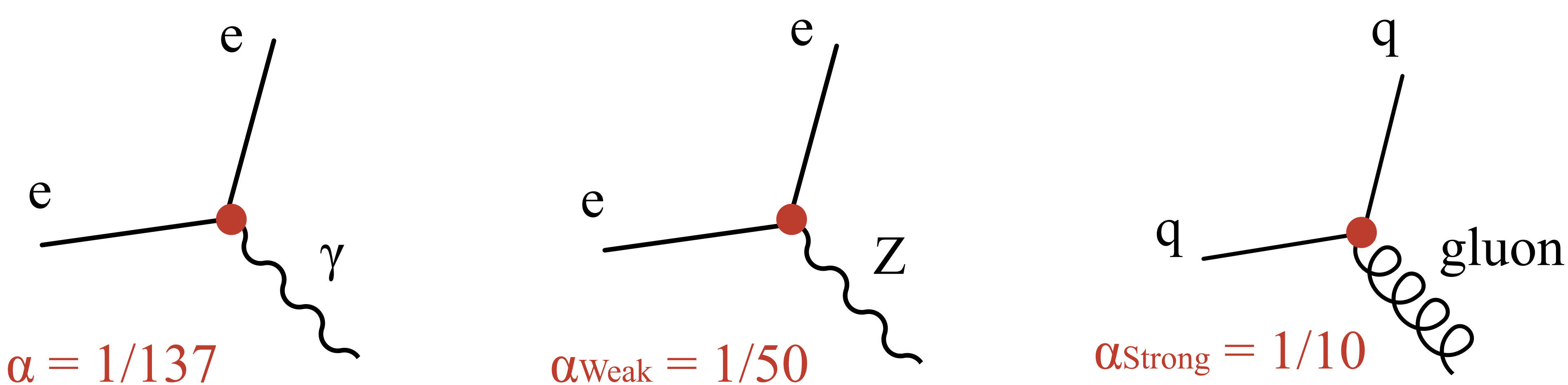
The fact that they look different to us is a long distance illusion.

We already talked about this for the weak interaction
m_W & $m_Z \gg 0$
Cut off the range

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

Forces Common Language

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



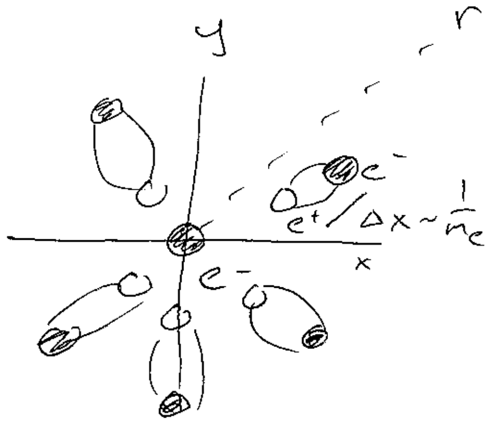
Forces look very different to us… **is a long distance illusion!**

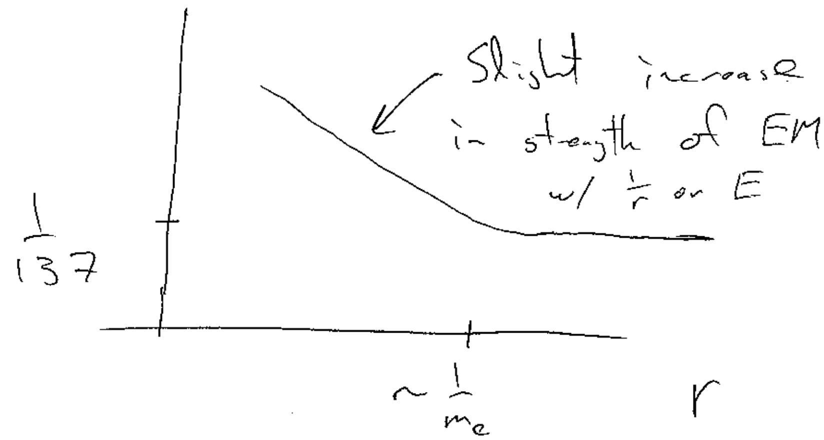
- Strong force: anti-screening / confinement
- Weak force: massing force carriers

At short distance (~1/mZ) all look the forces start to look the same

This is the reason we build colliders! Unity at small scales.

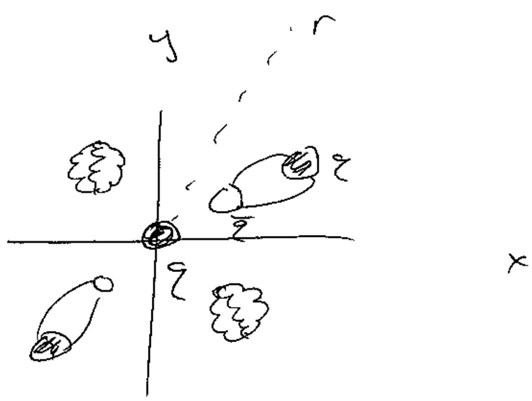
Imagine you wanted to measure the EM Strength vs distance



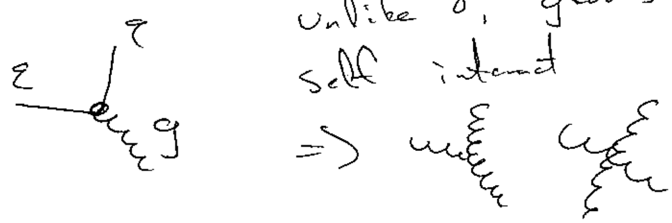


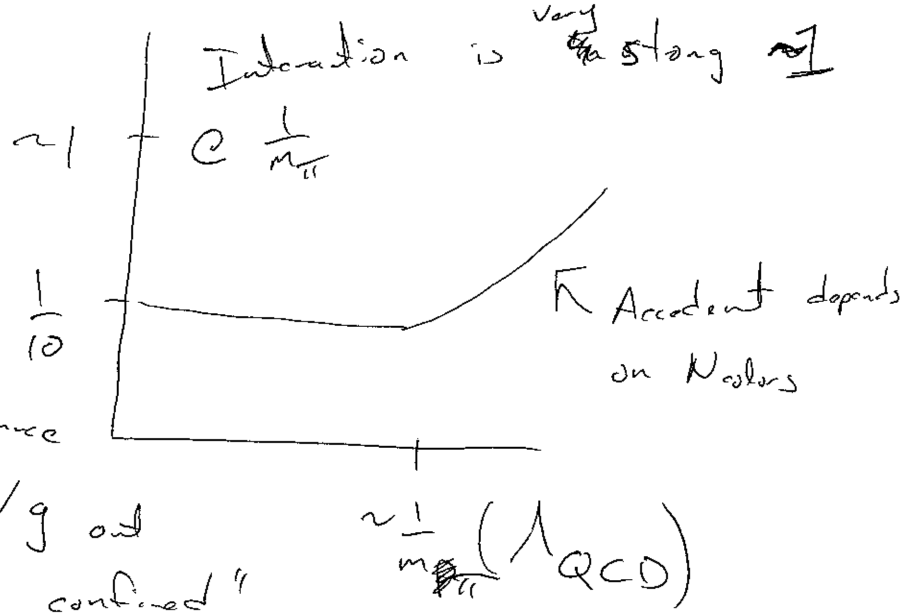
α increases B/c you are "seeing" more of the bare electron charge.

Same game w/ Strong Interaction

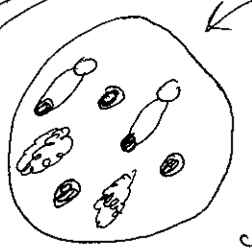


Unlike γ, gluons can self interact





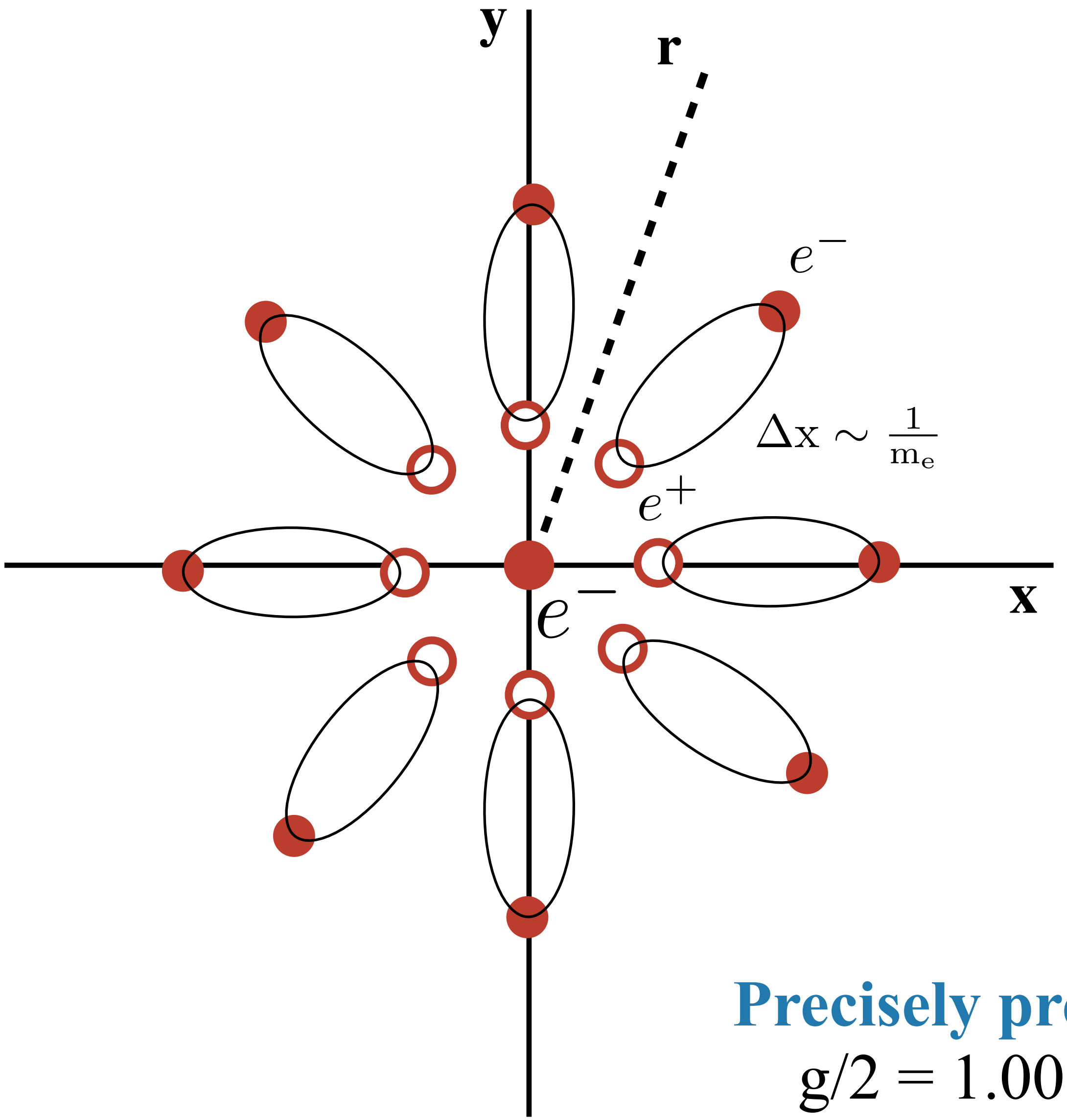
<u>Proton</u>

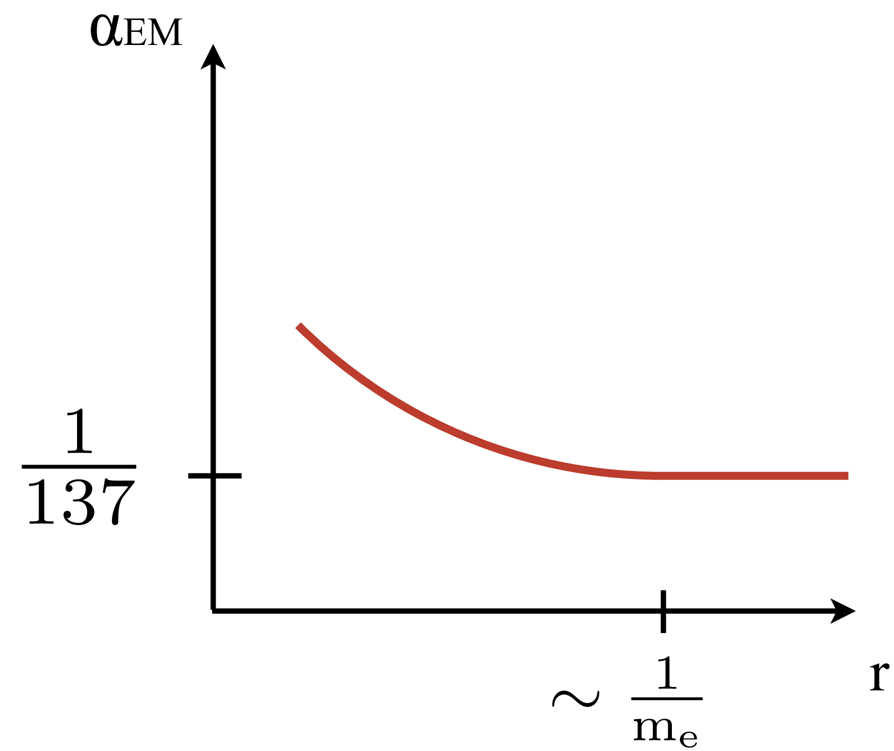


B/c force grows w/ distance Can't pull q/g out of proton => "q confined"

Λ_{QCD} sets size of hadrons.

EM Strength w/Distance





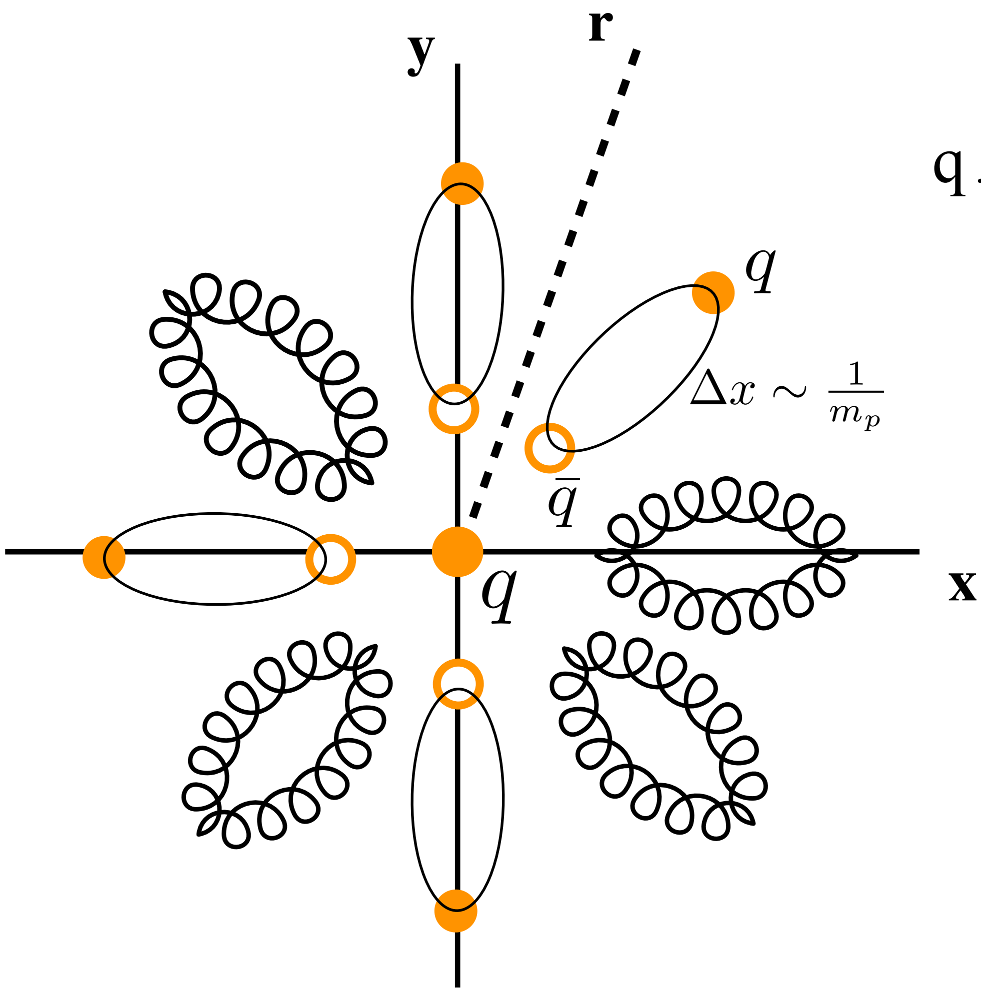
Precisely predict magnetic properties

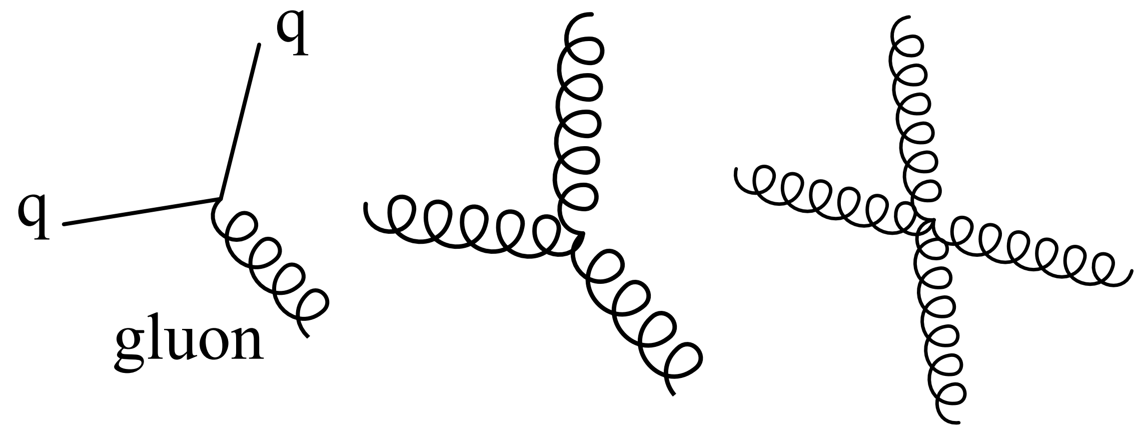
g/2 = 1.0011596521809(8),

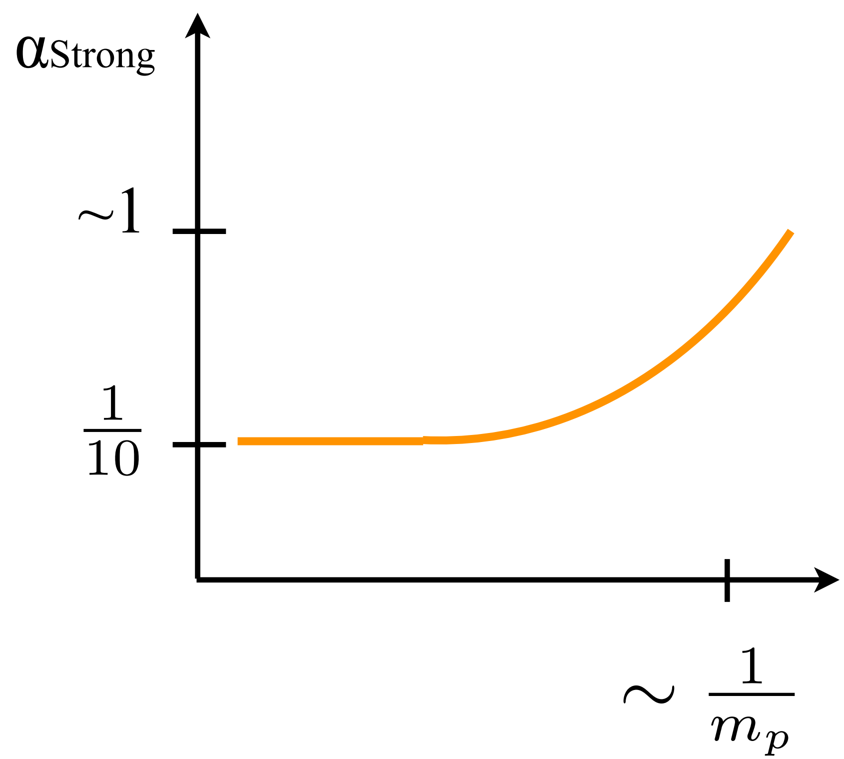
(Agree to better than one part in a trillion.)

Strong Interaction w/Distance

Unlike photons, gluons can self interact.







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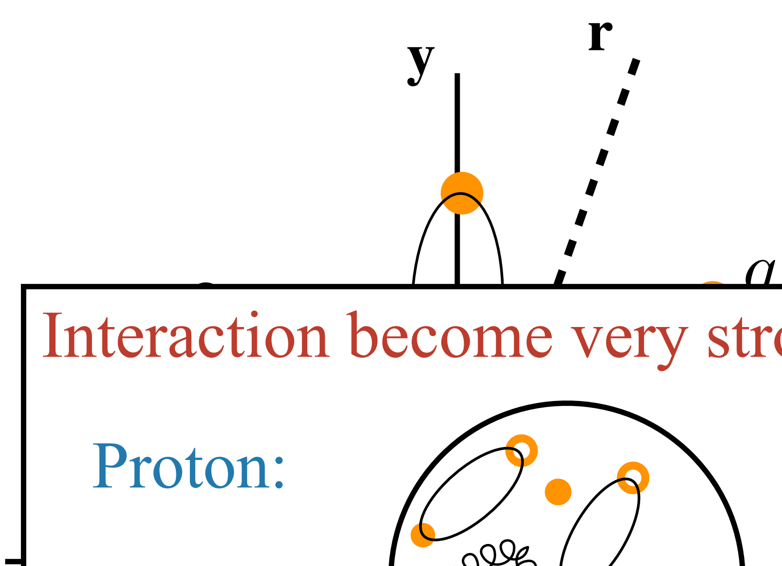
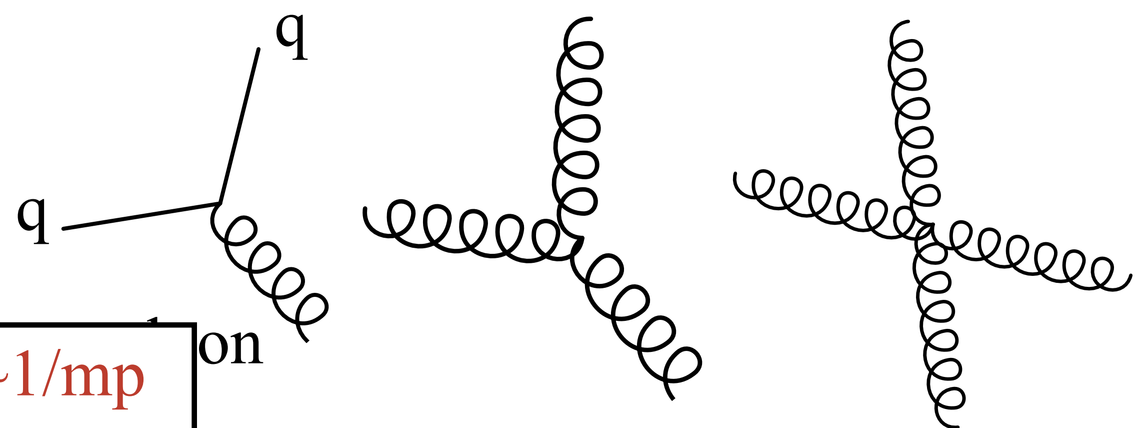
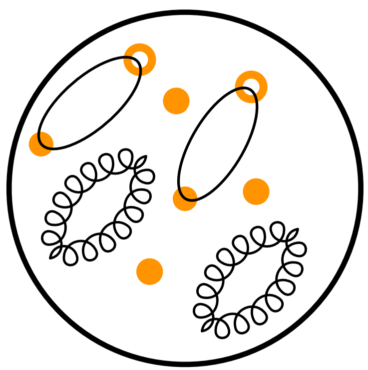




Interaction become very strong ~1/mp

Proton:



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

Sets the size of protons (neutrons)