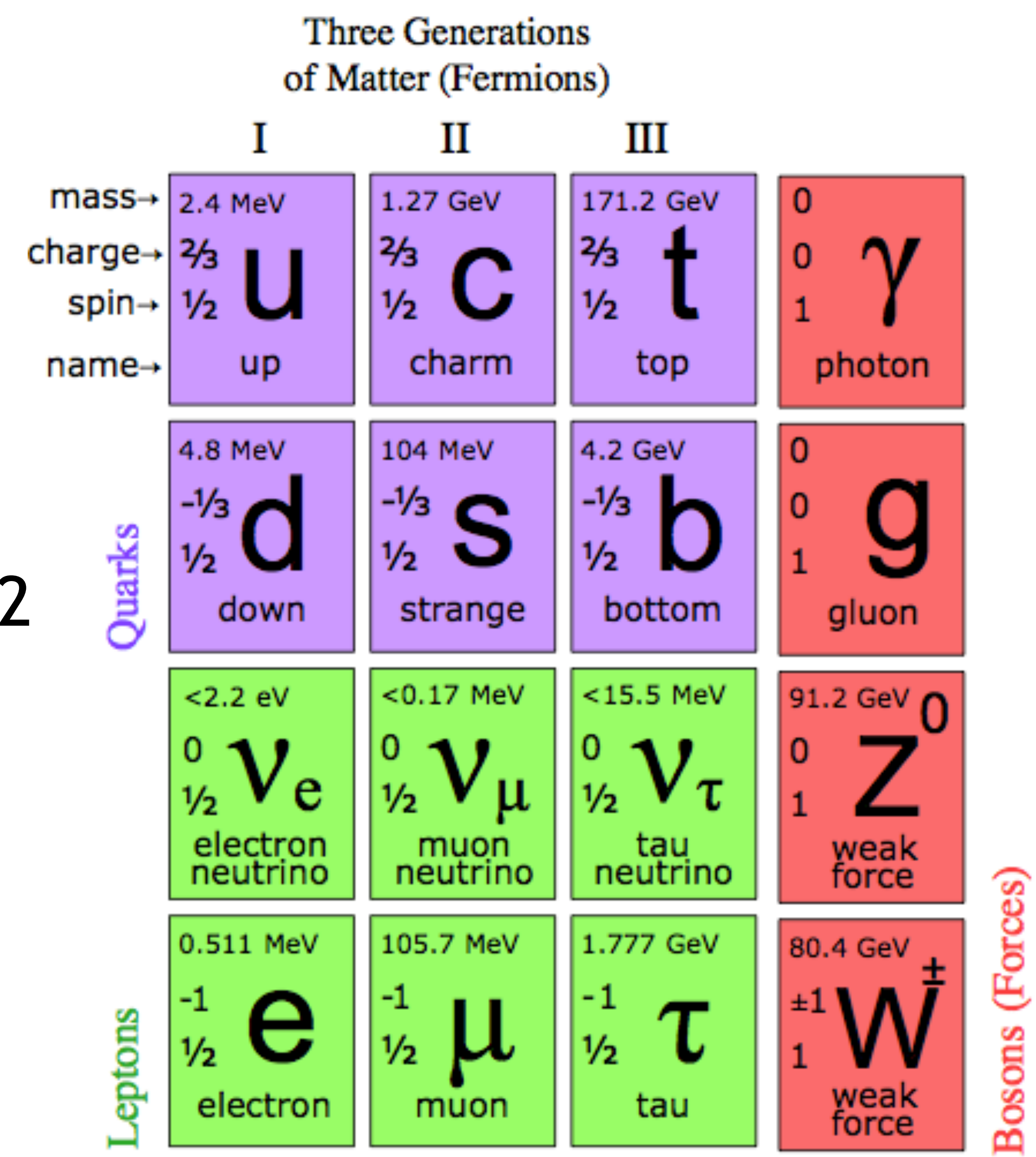
From Tuesday: Summary

- Summary: the Standard Model is our current model for particle physics. But it doesn't explain all observations.

Highly suggested reading:

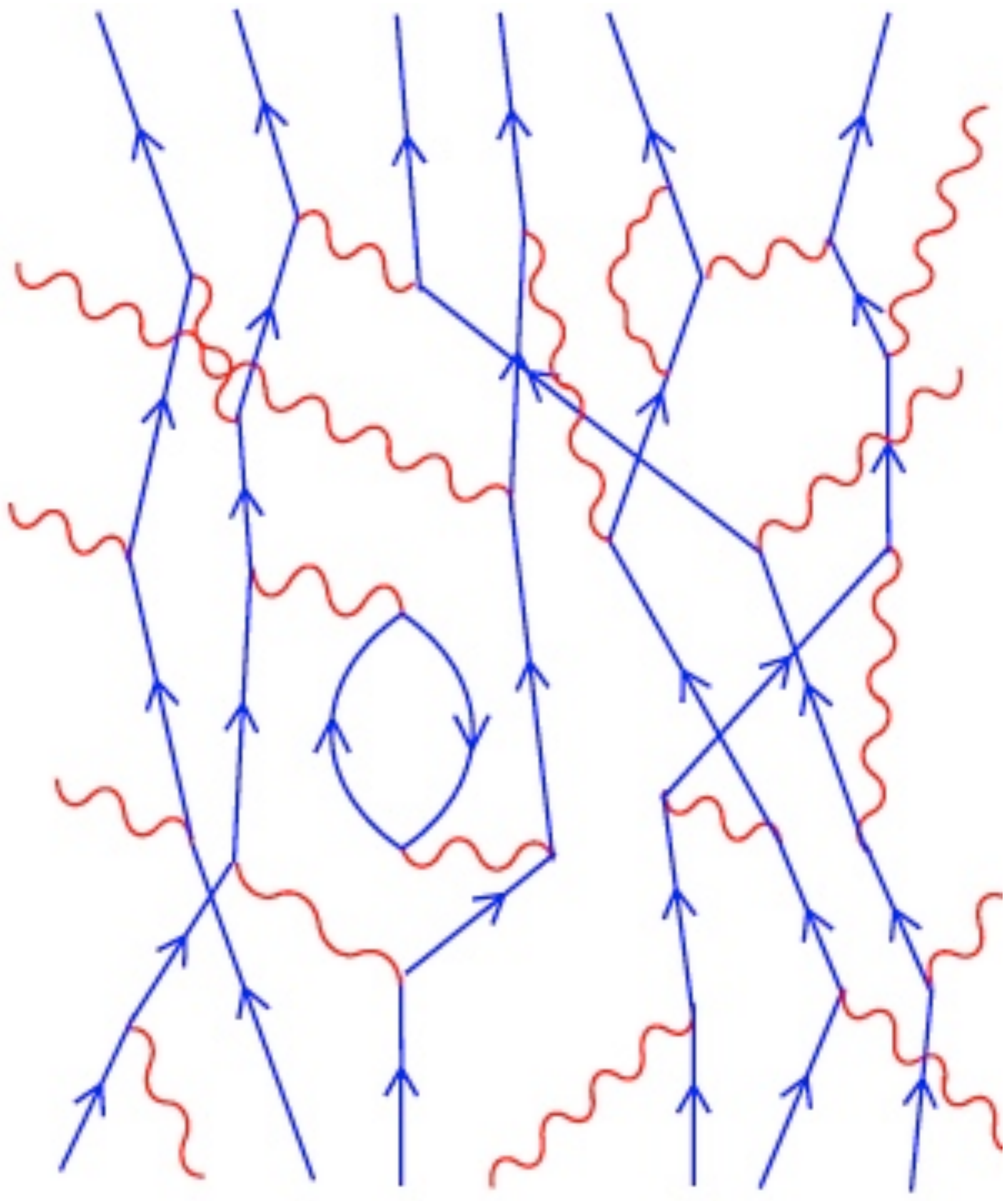
- Tuesday's lecture: Griffiths 1.1 -1.5
- Today's Lecture: Griffiths chapters 2 & 6



Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 2: Feynman Diagrams

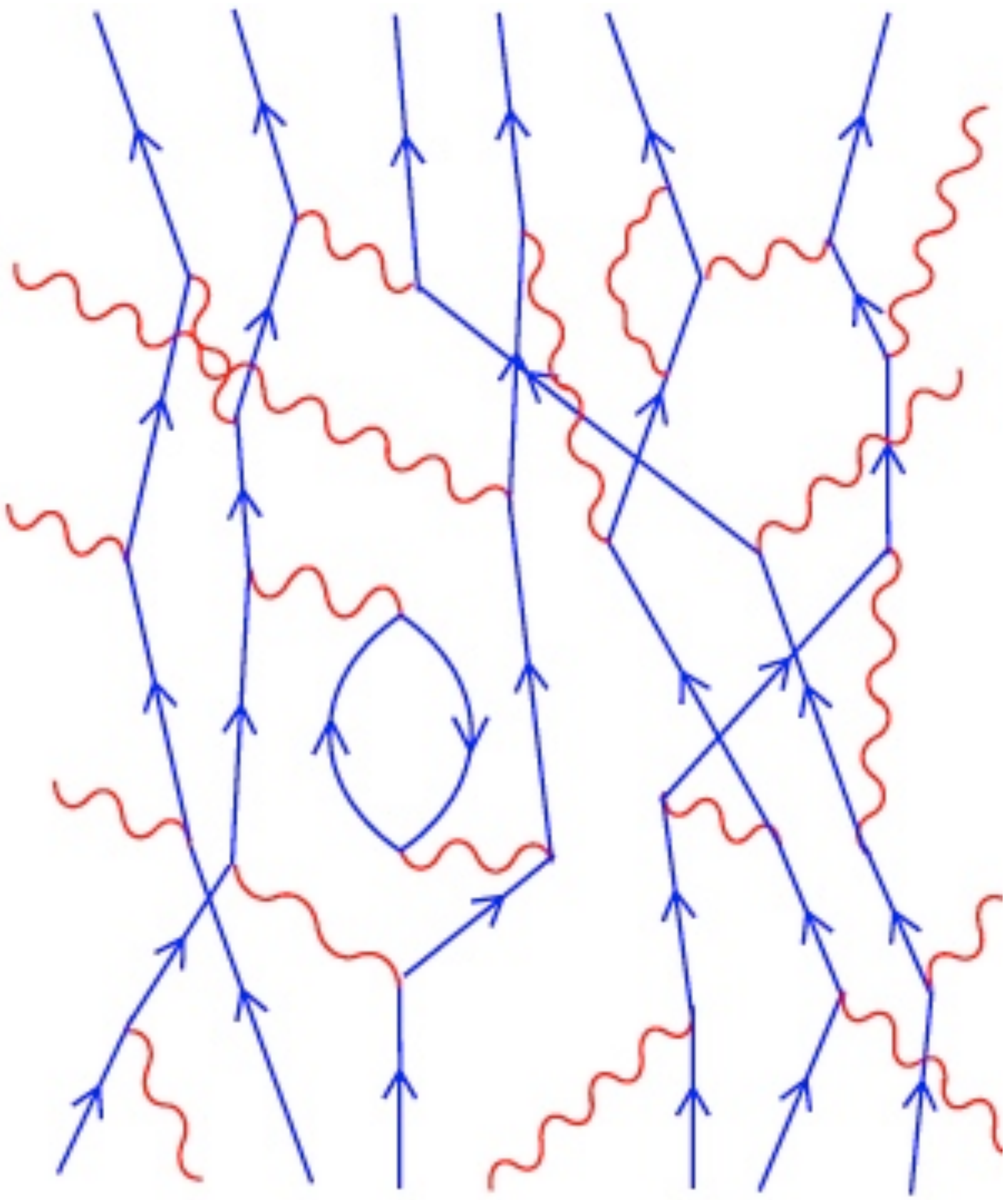


The Plenum in Particle QED

Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 2: Feynman Diagrams



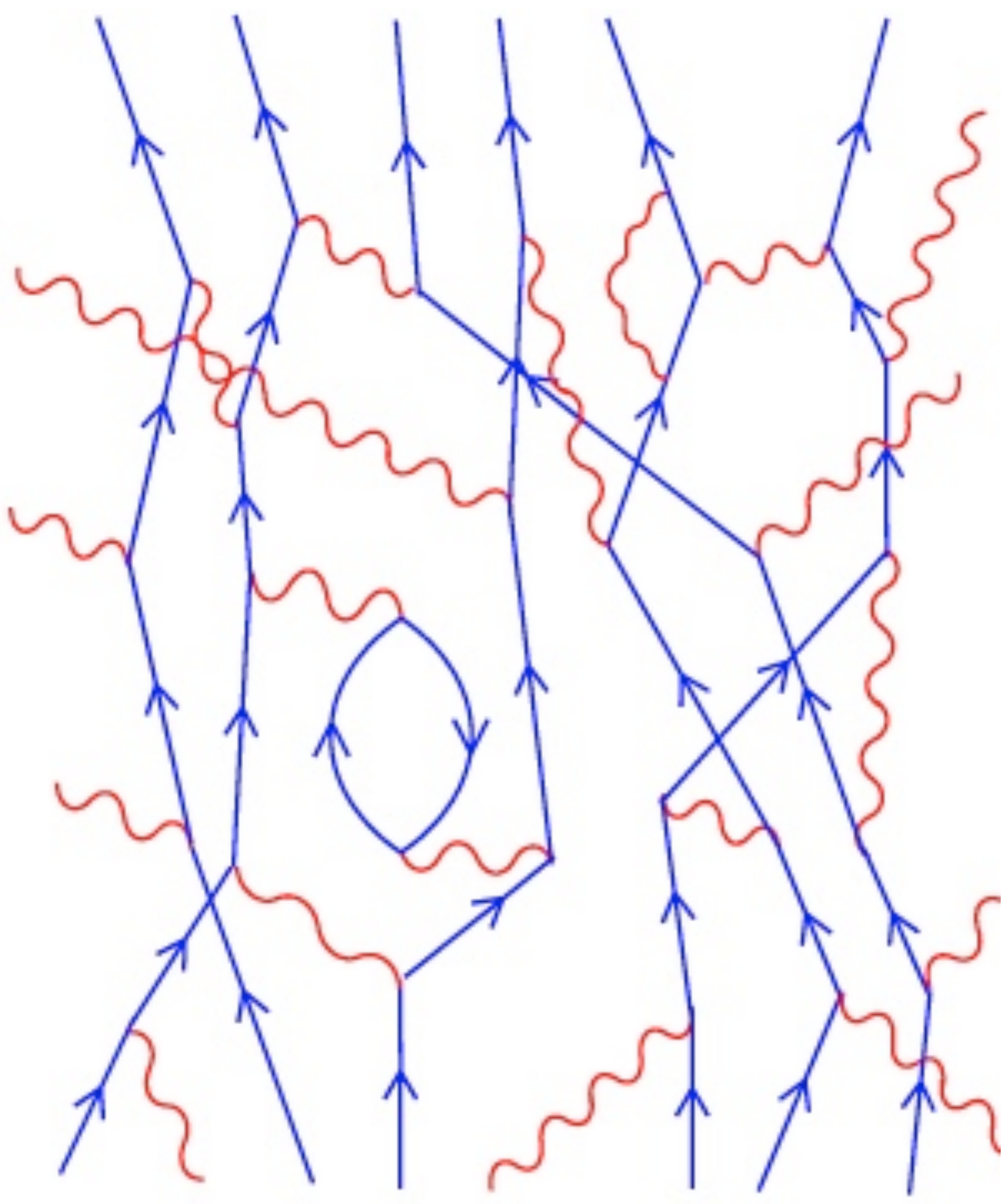
The Plenum in Particle QED

★2012 highlights

Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 2: Feynman Diagrams



The Plenum in Particle QED

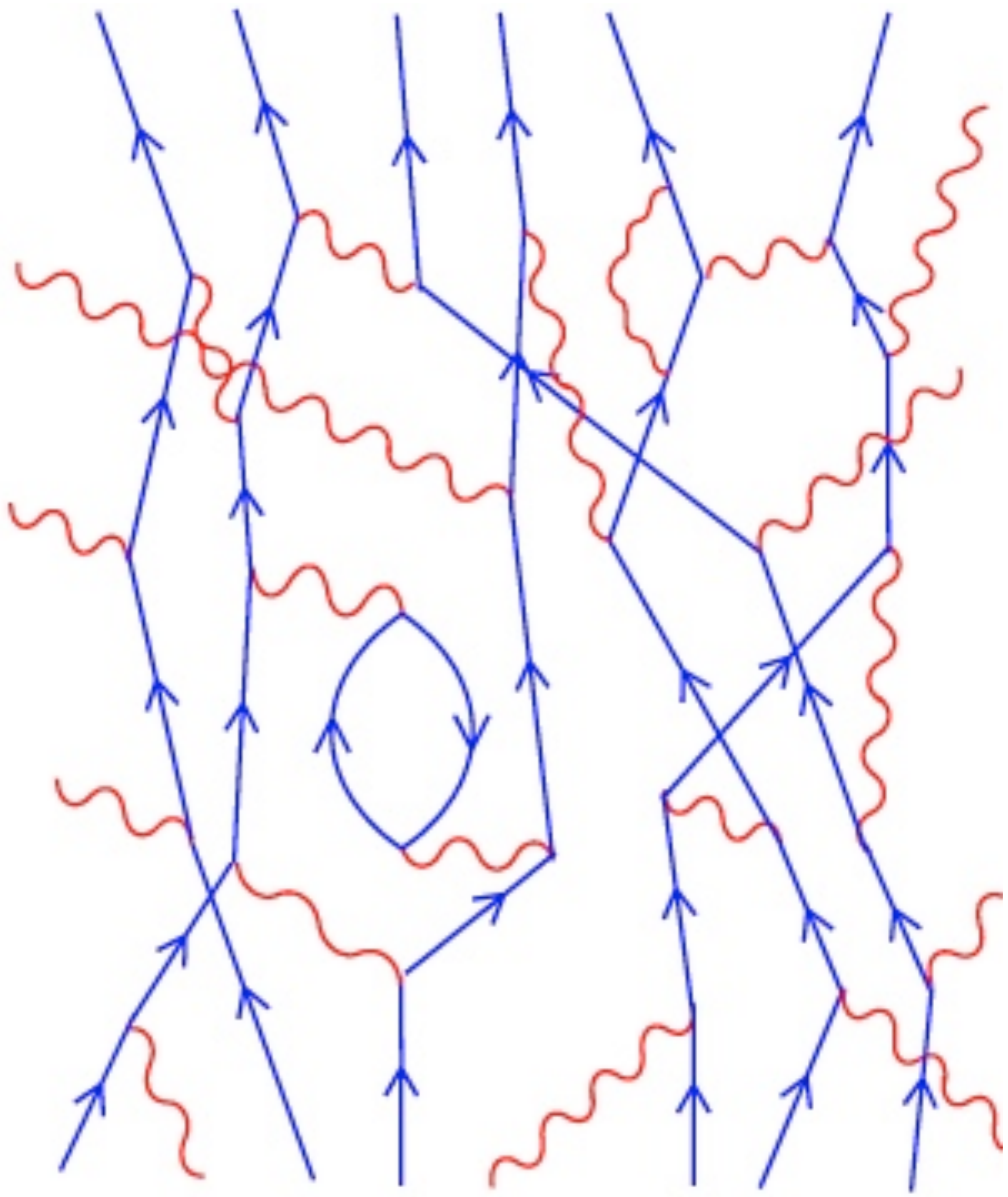
★2012 highlights

★Decays and Scatterings

Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 2: Feynman Diagrams



The Plenum in Particle QED

★2012 highlights

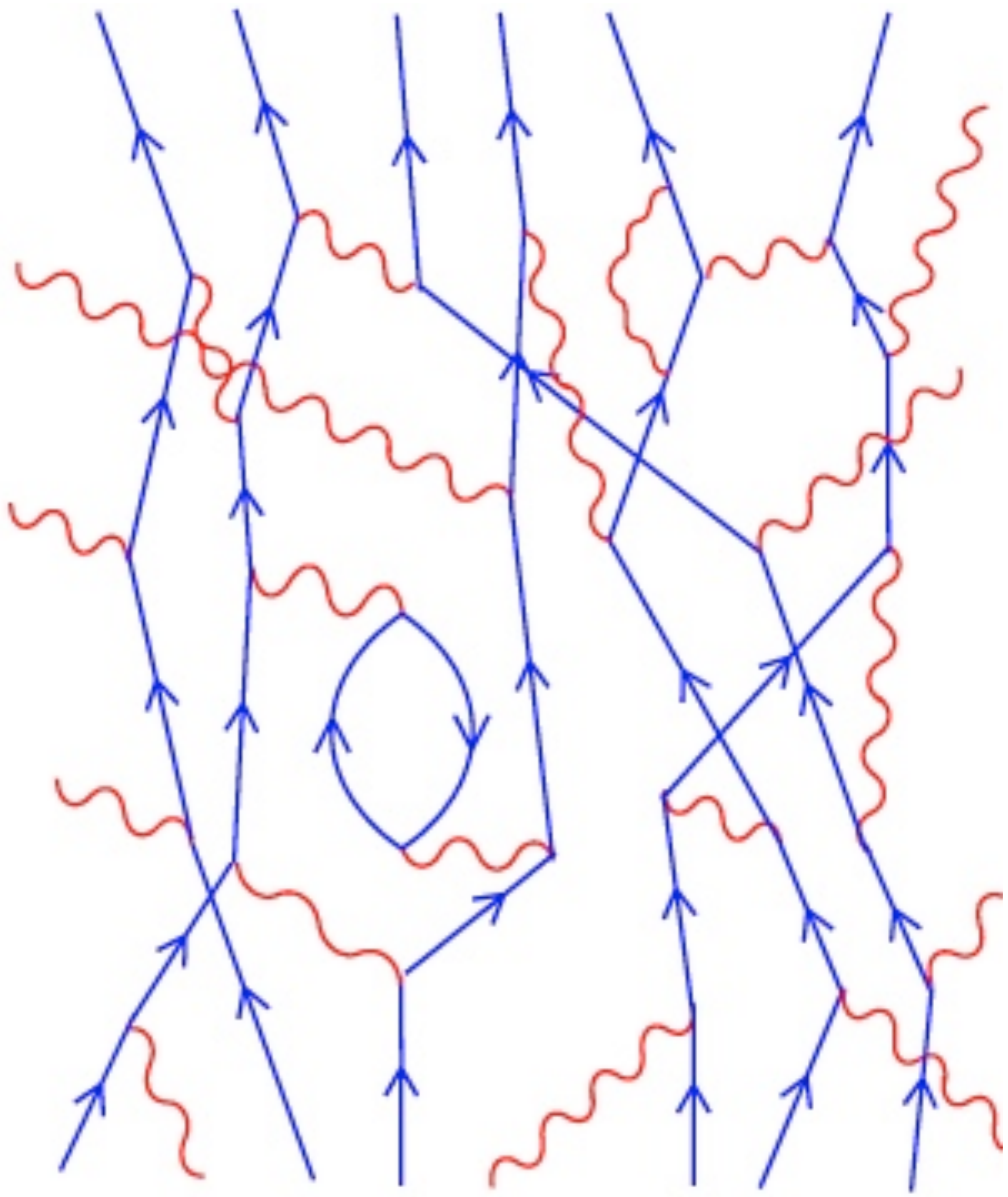
★Decays and Scatterings

★Feynman Diagrams

Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 2: Feynman Diagrams



The Plenum in Particle QED

★2012 highlights

★Decays and Scatterings

★Feynman Diagrams

★Fermi's Golden Rule

Particle Physics in 2012

Three big results of the year were:

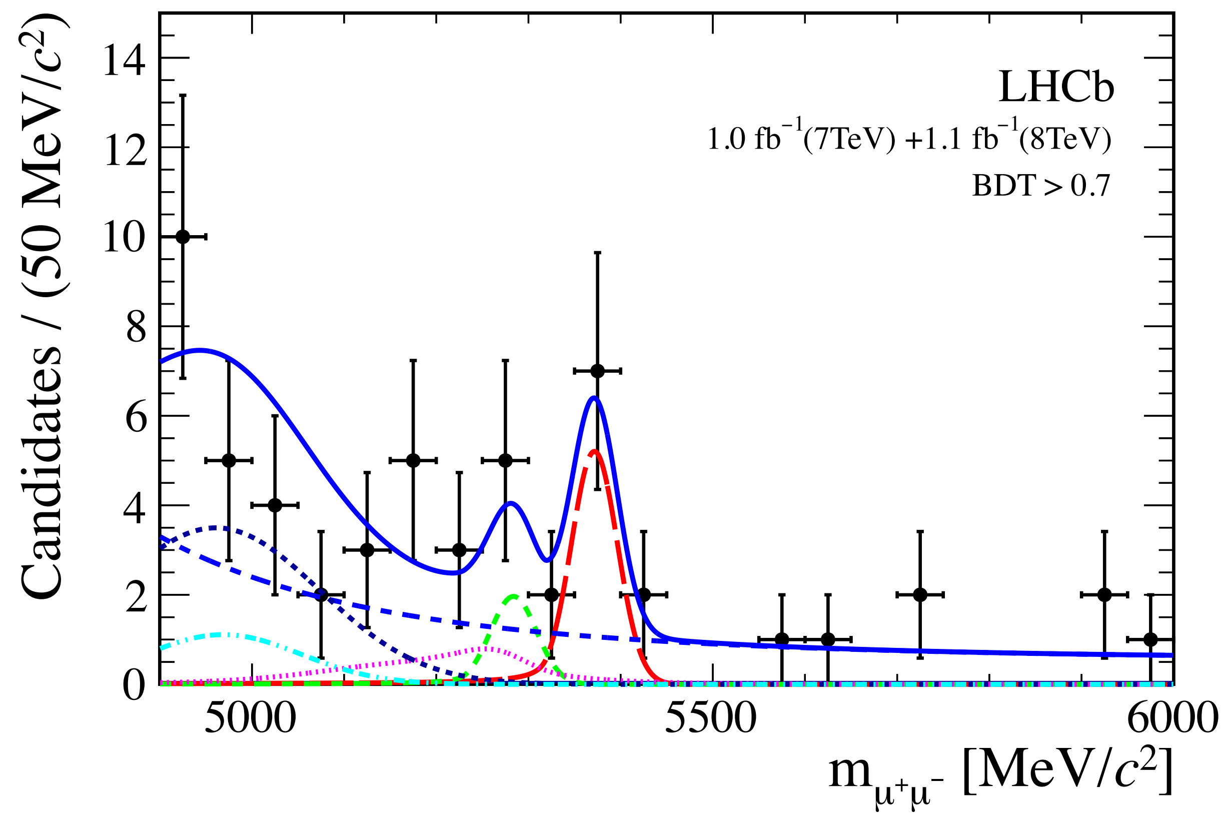
★Discovery of a new boson, very probably the Higgs boson!

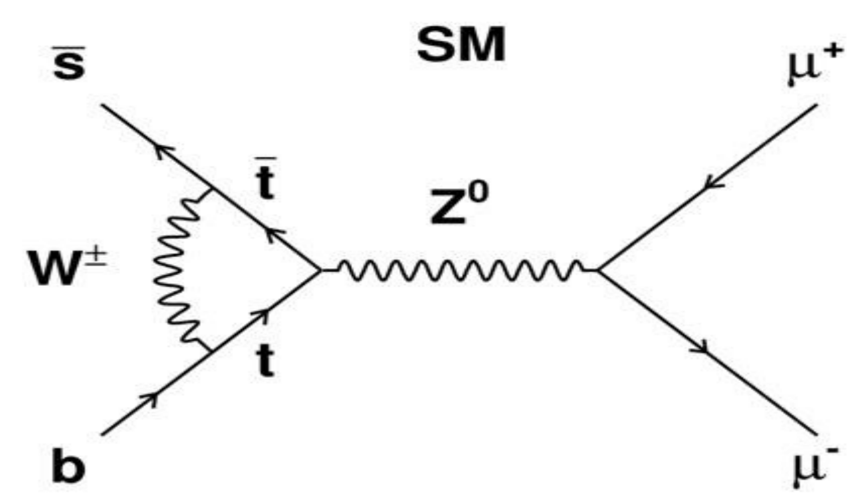
★A first measurement of $B_S \to \mu^+\mu^-$

★A measurement of neutrino mixing angle $\sin\theta_{13}$

Observation of $B_S \to \mu^+\mu^-$

- By LHCb experiment at CERN
- Measured Branching Ratio is
  $\mathbf{BR(B_S \to \mu^+\mu^-) = (3.2 \pm^{1.5}{}_{1.2}) \times 10^{-9}}$
- Compatible with the prediction of the Standard Model
- Better measurements could limit the contributions from non-Standard Model processes

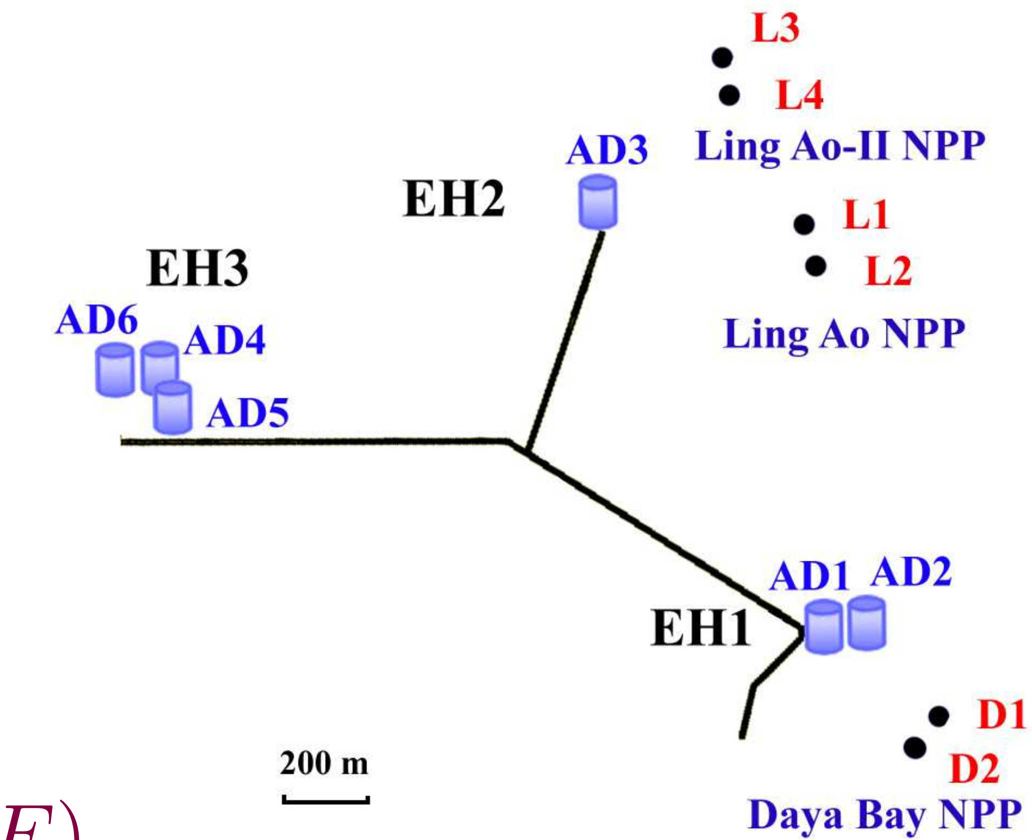




reference: http://arxiv.org/abs/1211.2674

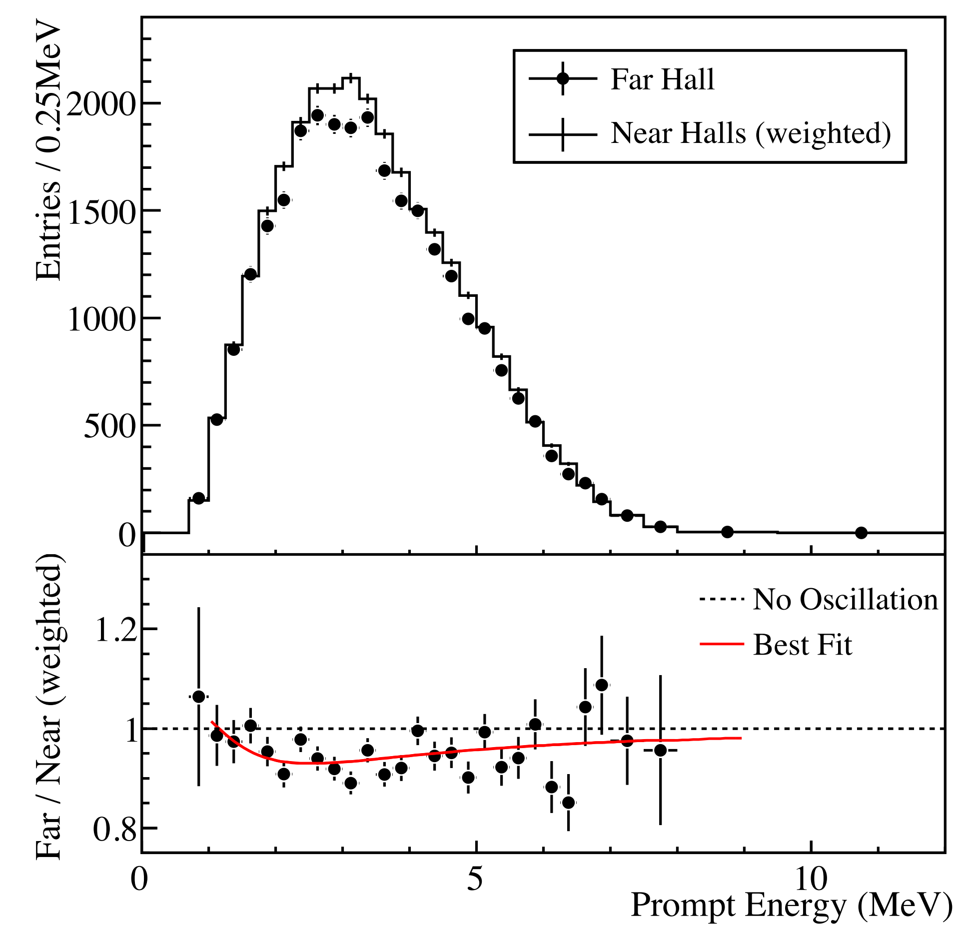
Electron Neutrino Disappearance

- Day Bay experiment in South China
- Sensitive to electron anti-neutrinos ($\bar{\nu}_e$) from six nuclear reactors (**D**, **L**) detected by six detectors (**AD**).
- Look at difference between detection rates between near (**EH1, EH2**) and far (**EH3**) detectors.



$$P_{\text{survival}} \approxeq 1 - \sin^2 2\theta_{13} \sin^2(1.267\Delta m_{31}^2 L/E)$$

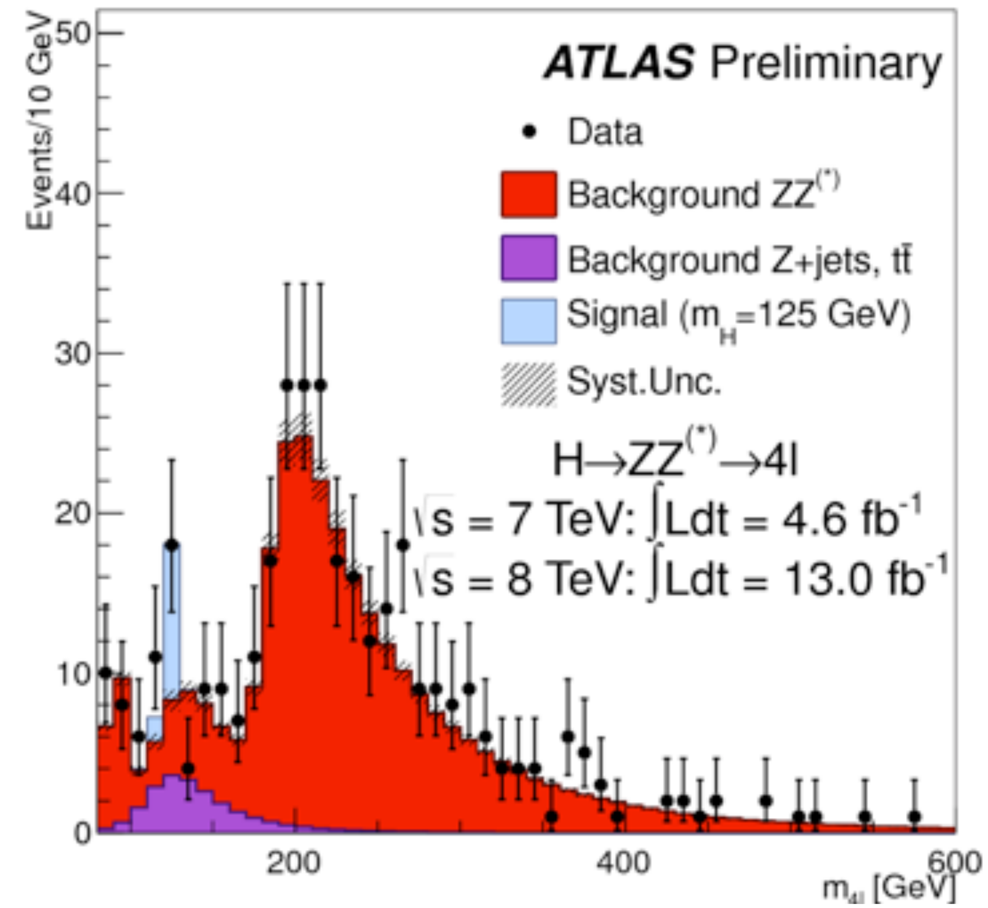
- $\Delta m_{31}^2 = 2.23 \pm {}^{0.12}_{0.08}$ **meV**^{2} measured from the atmospheric reactions
- E is the energy of $\bar{\nu}_e$ in **MeV**
- L is the distance of between detectors in metres.
- Measurement is $\sin^2\theta_{13} = 0.0089 \pm 0.0011$

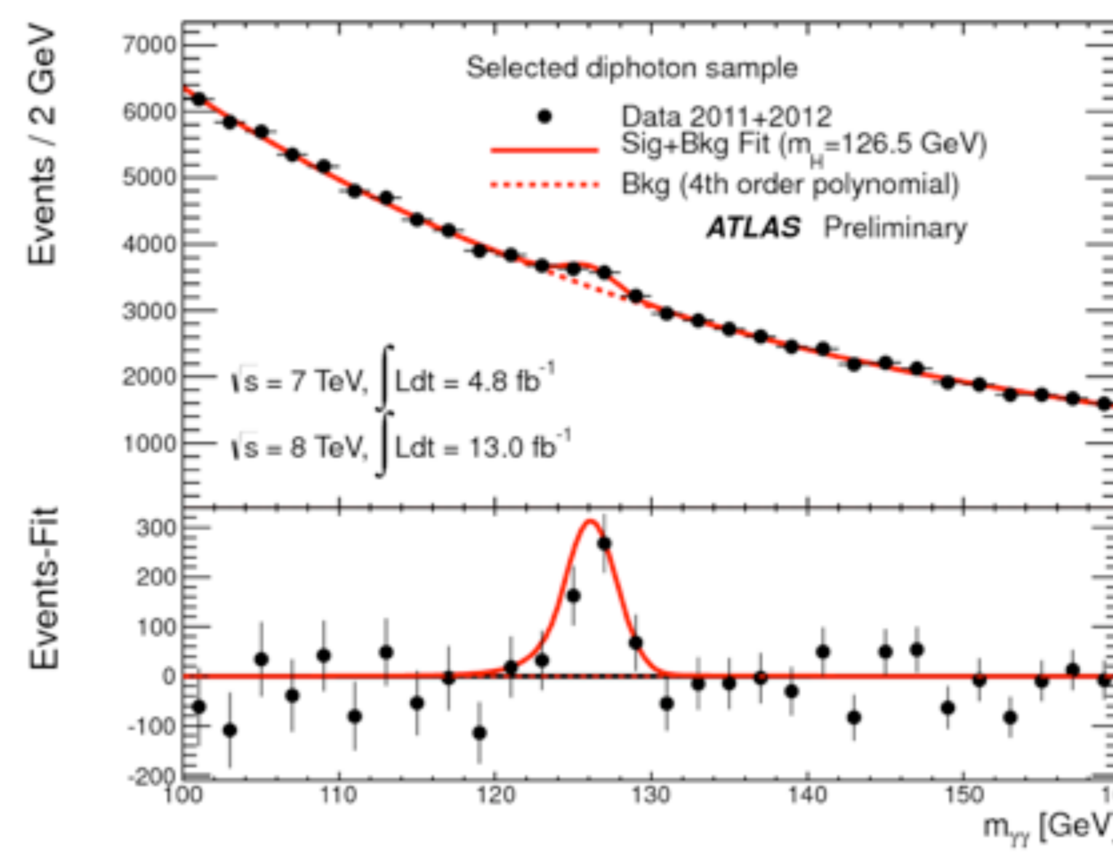


reference: http://arxiv.org/abs/1210.6327

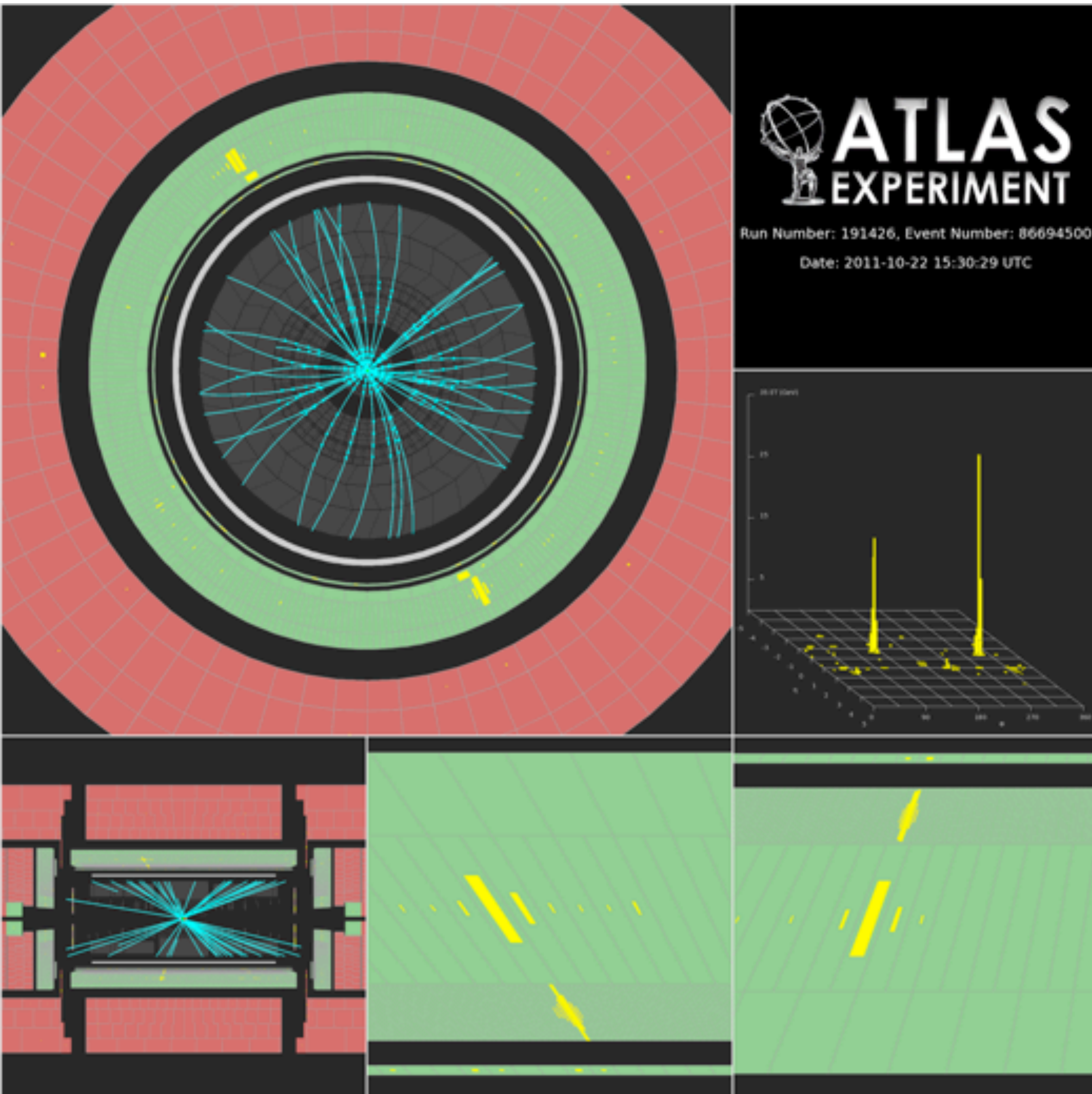
Discovery of the Higgs Boson

- ATLAS and CMS experiments at CERN
- "Bumps" observed in invariant mass at **m ≈ 125 GeV** in:
  - ➡ $\gamma\gamma$
  - ➡ $\ell^+\ell^-\ell^+\ell^-$ $(\ell=\{e,\mu\})$
- Consistent with $H\rightarrow\gamma\gamma$ and $H\rightarrow ZZ\rightarrow 4\ell$ production
- Statistical significance of the excess is now 7 σ from ATLAS alone!



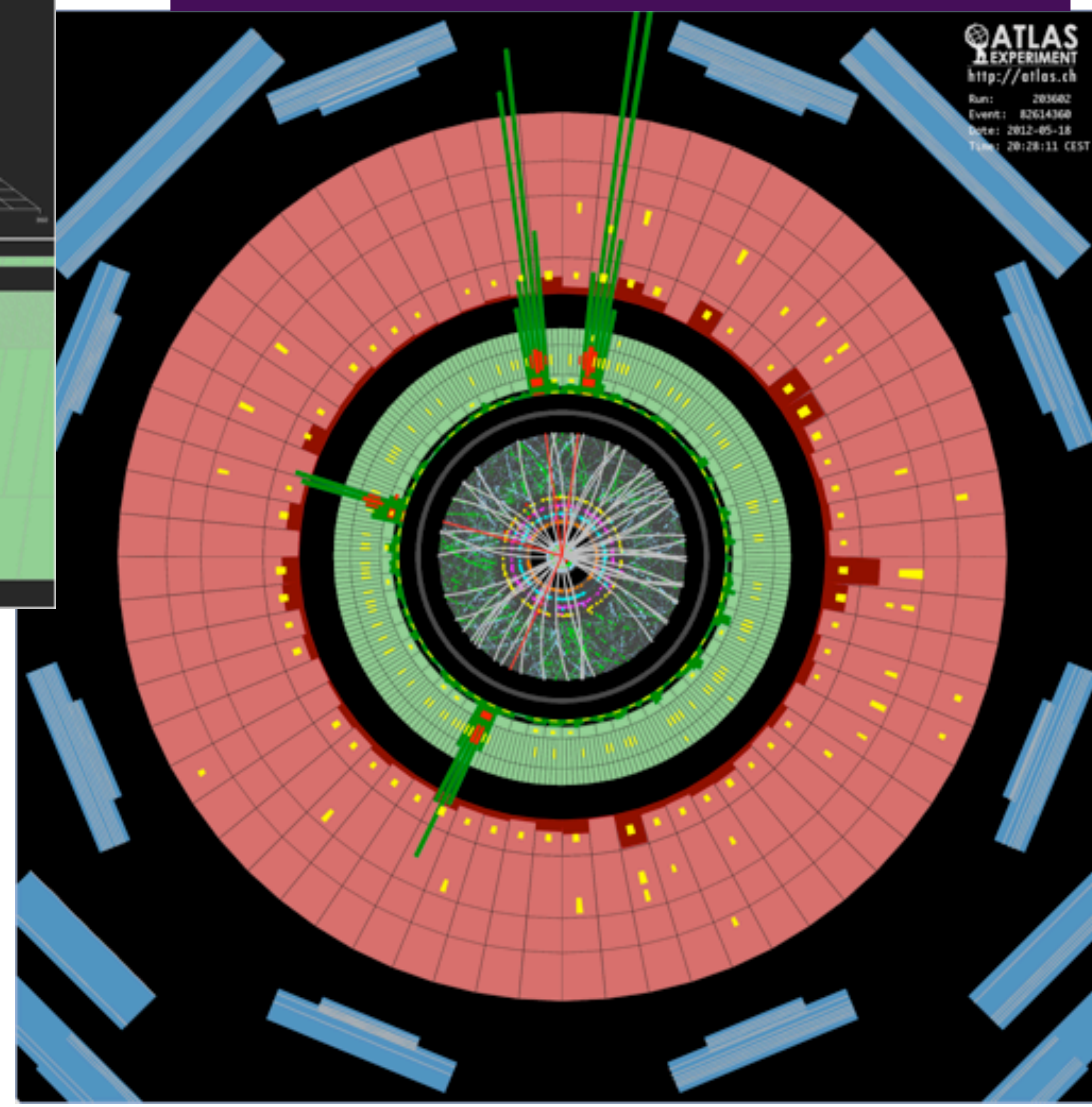


References: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-170/, ATLAS-CONF-2012-169/, ATLAS-CONF-2012-168/



$H \to \gamma\gamma$ candidate event

$H \to ZZ \to 4e$ candidate event

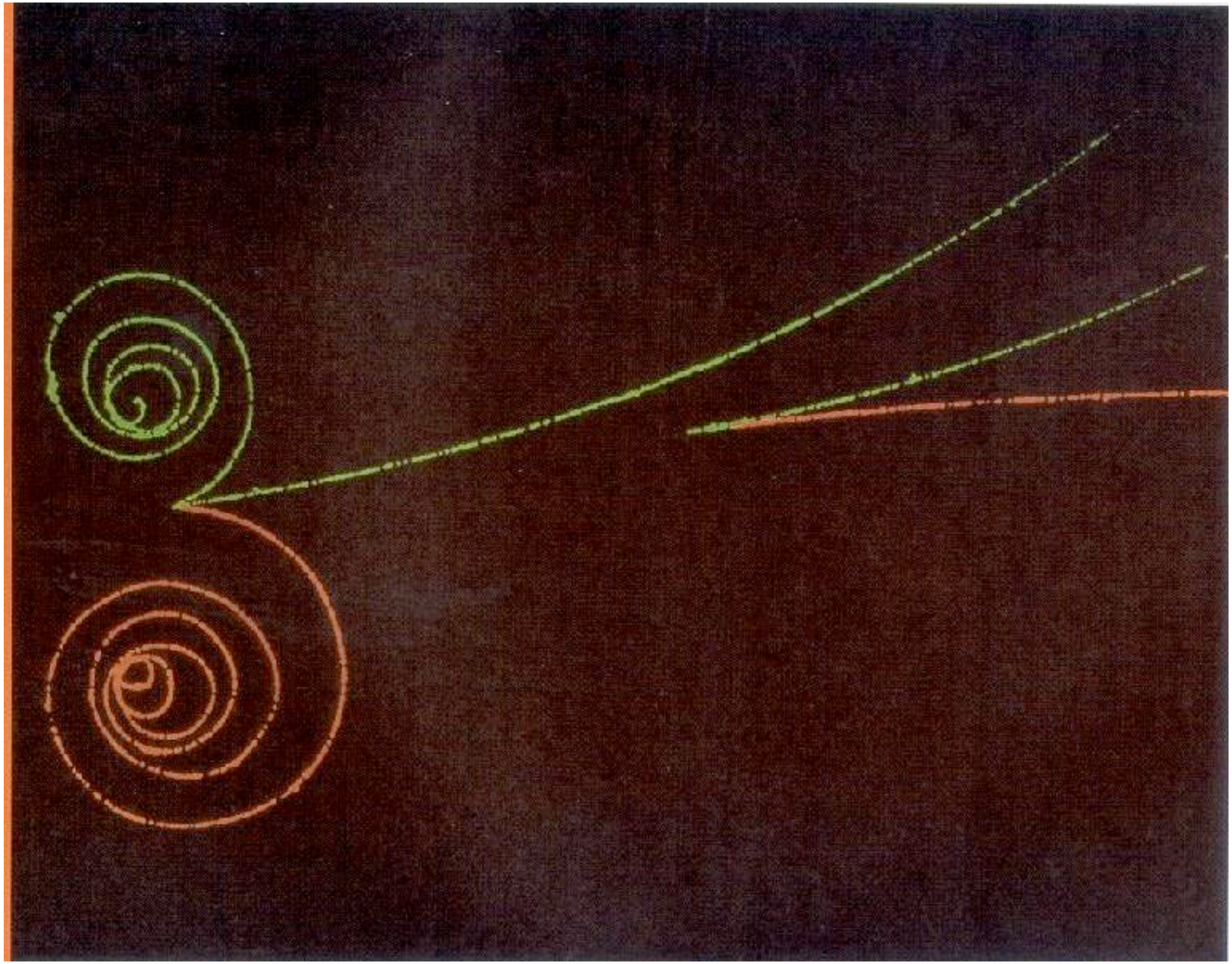


December 2012

- Fabiola Gianotti is named Time magzine Person of the Year 2012, runner up
- Higgs boson is particle of year 2012.
- Professor Higgs awarded Membership of the Order of the Companions of Honour by Queen Elizabeth II
- Alan Walker is awarded an MBE for services to science engagement and science education in Scotland.

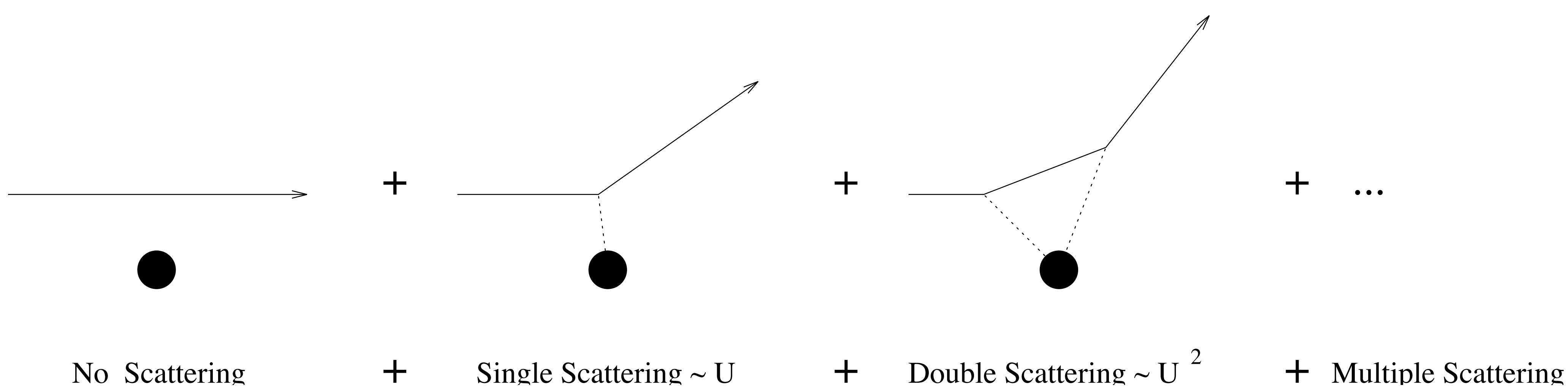
http://www.ph.ed.ac.uk/news/new-years-honours-2013-08-01-13

Prof Higgs visits ATLAS



Scattering Theory

- Consider the interactions between **elementary particles.**
- Review from Quantum Physics, Lecture 12, 13: Quantum Scattering Theory & the Born Approximation
- Born Series: we can think of a scattering in terms of series of terms

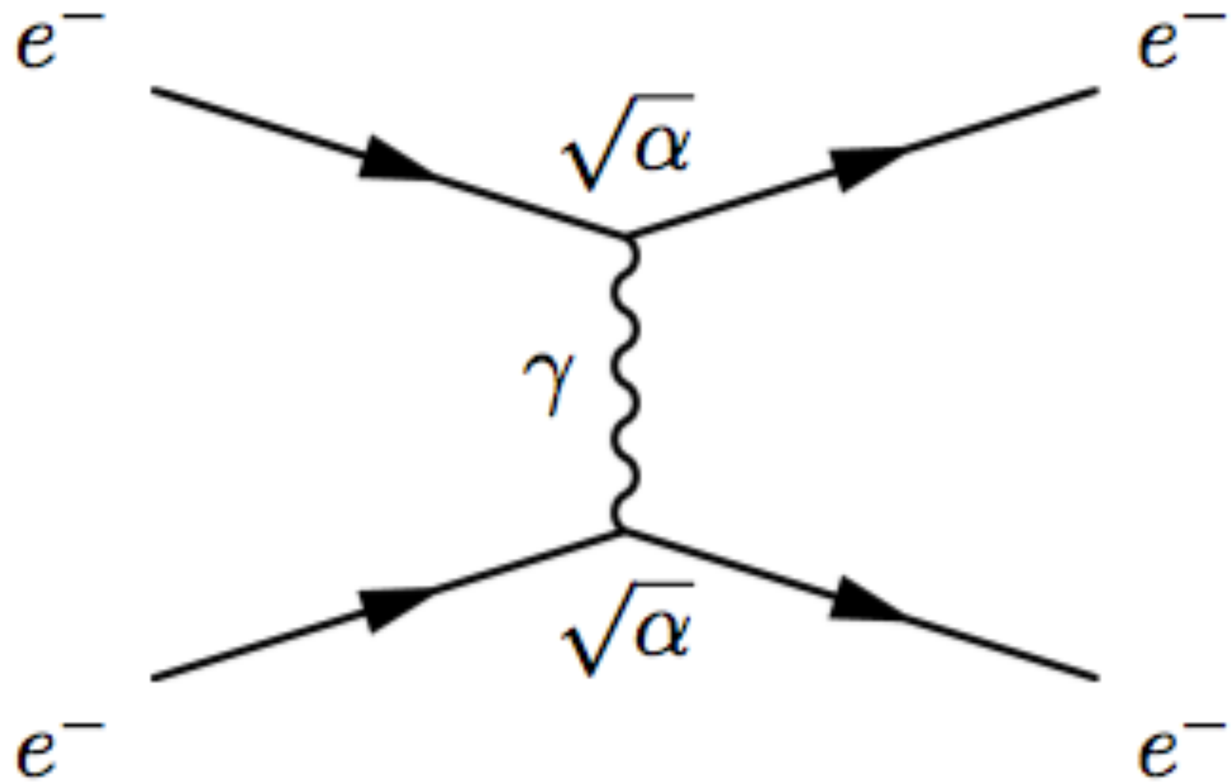


- 1 boson exchange is more probable than 2 boson exchange which is more probable than 3 boson exchange…
- The total probability is the sum of all possible numbers of boson exchange

$$\mathcal{M}_{\rm tot} = \mathcal{M}_1 + \mathcal{M}_2 + +\mathcal{M}_3 \ldots$$

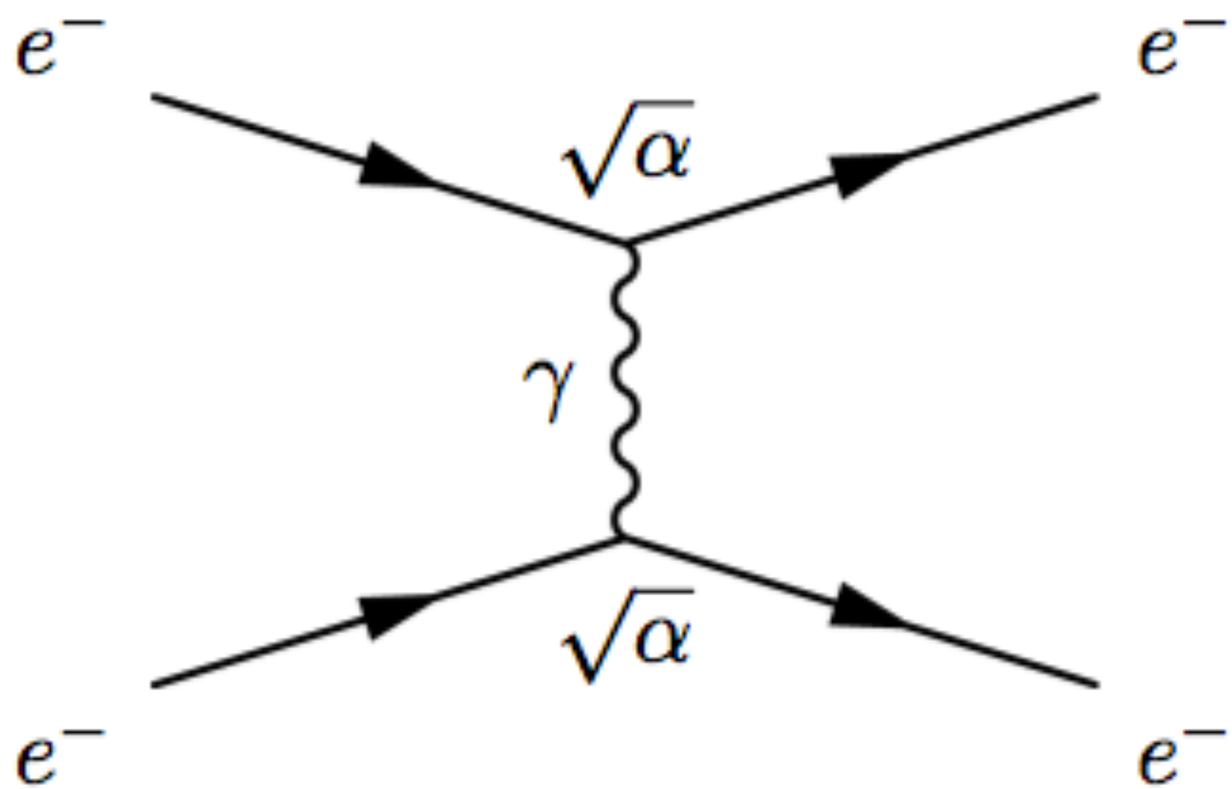
- Feynman diagrams make use of the Born series to calculate the individual **matrix elements** $\mathcal{M}_i$

Drawing Feynman Diagrams



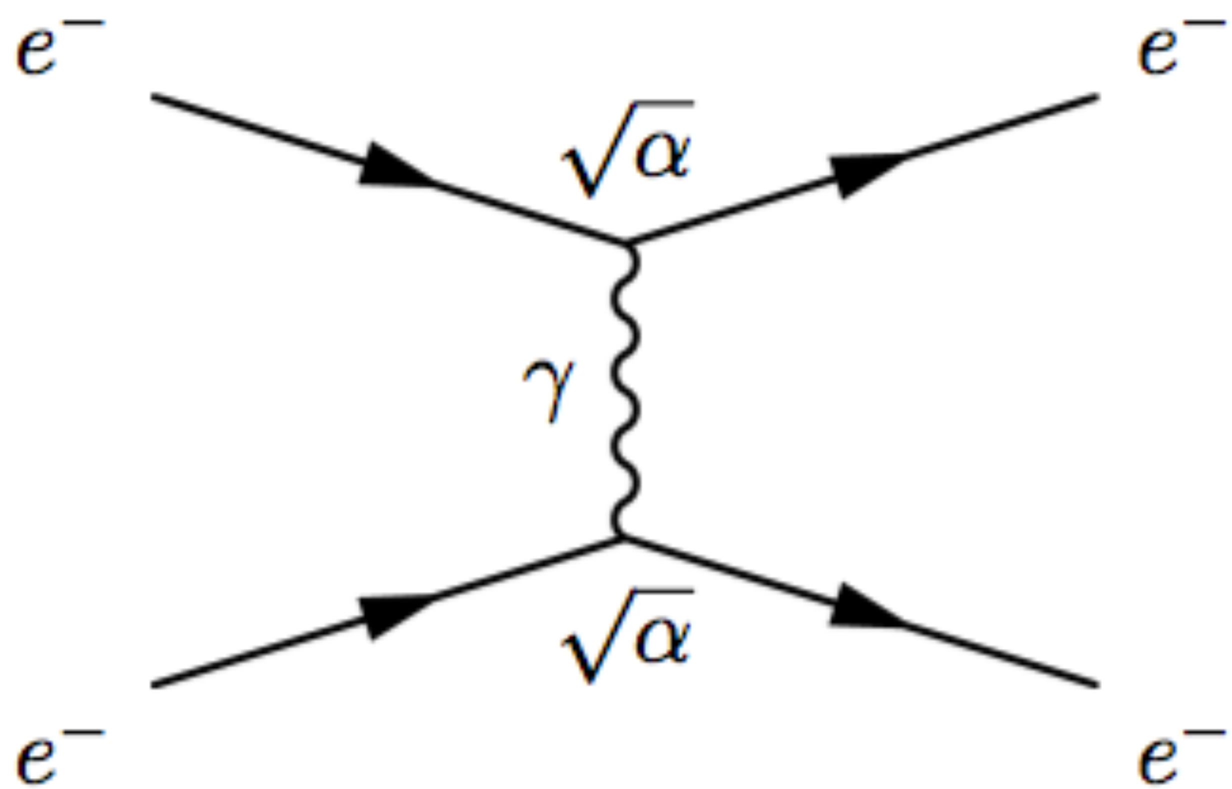
Drawing Feynman Diagrams

Initial state particles on the left



Drawing Feynman Diagrams

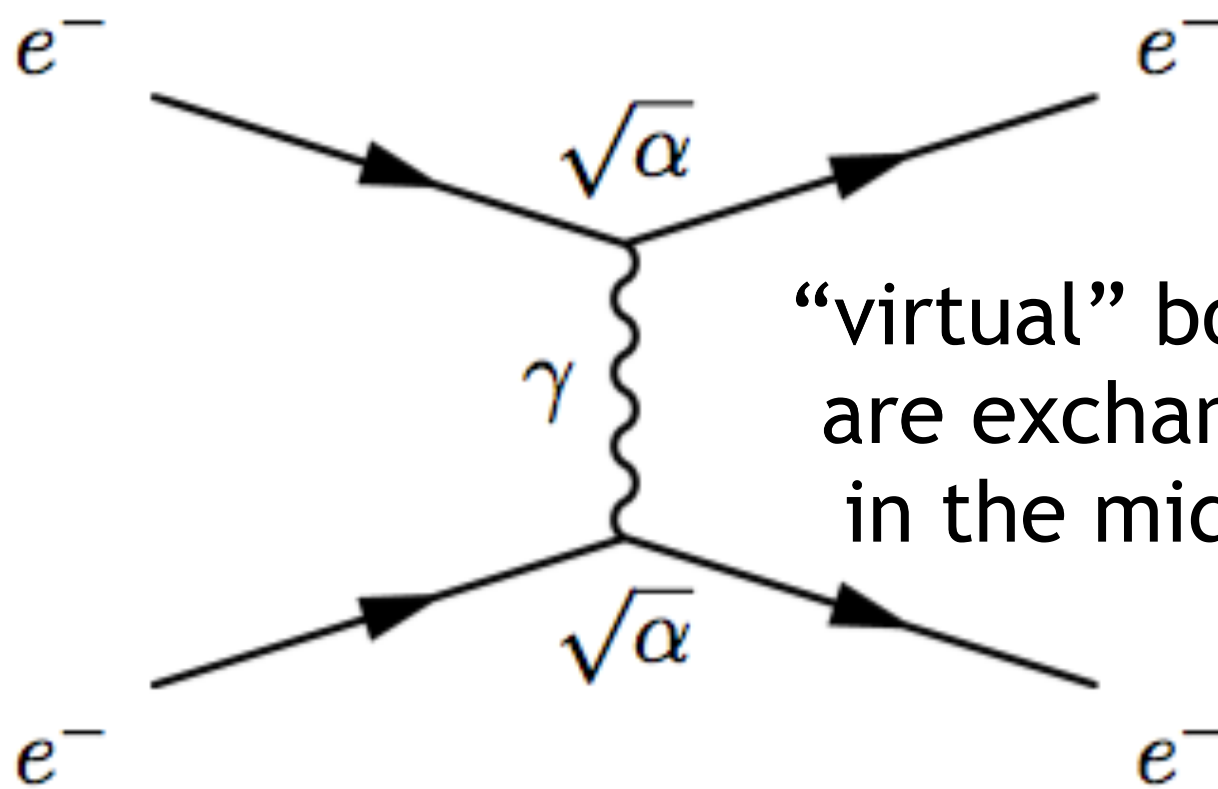
Initial state particles on the left



Final state particles on the right

Drawing Feynman Diagrams

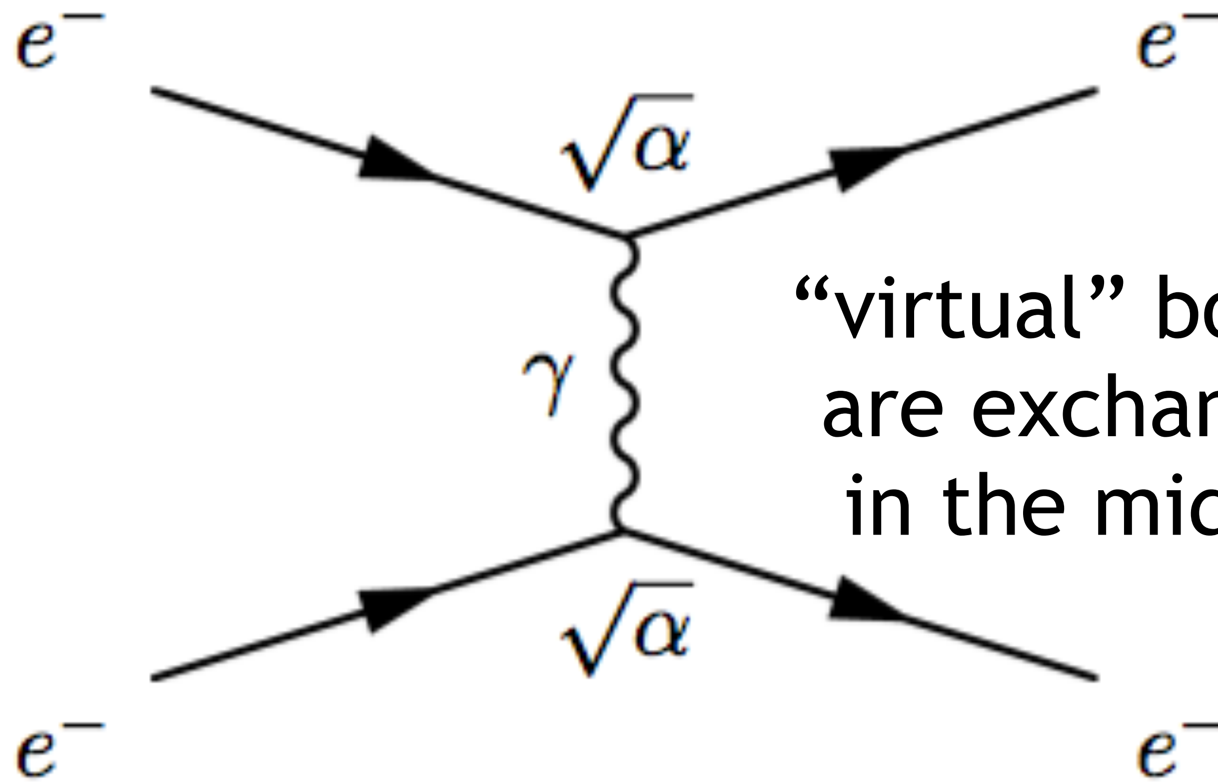
Initial state particles on the left



"virtual" bosons are exchanged in the middle

Final state particles on the right

Drawing Feynman Diagrams



Initial state particles on the left

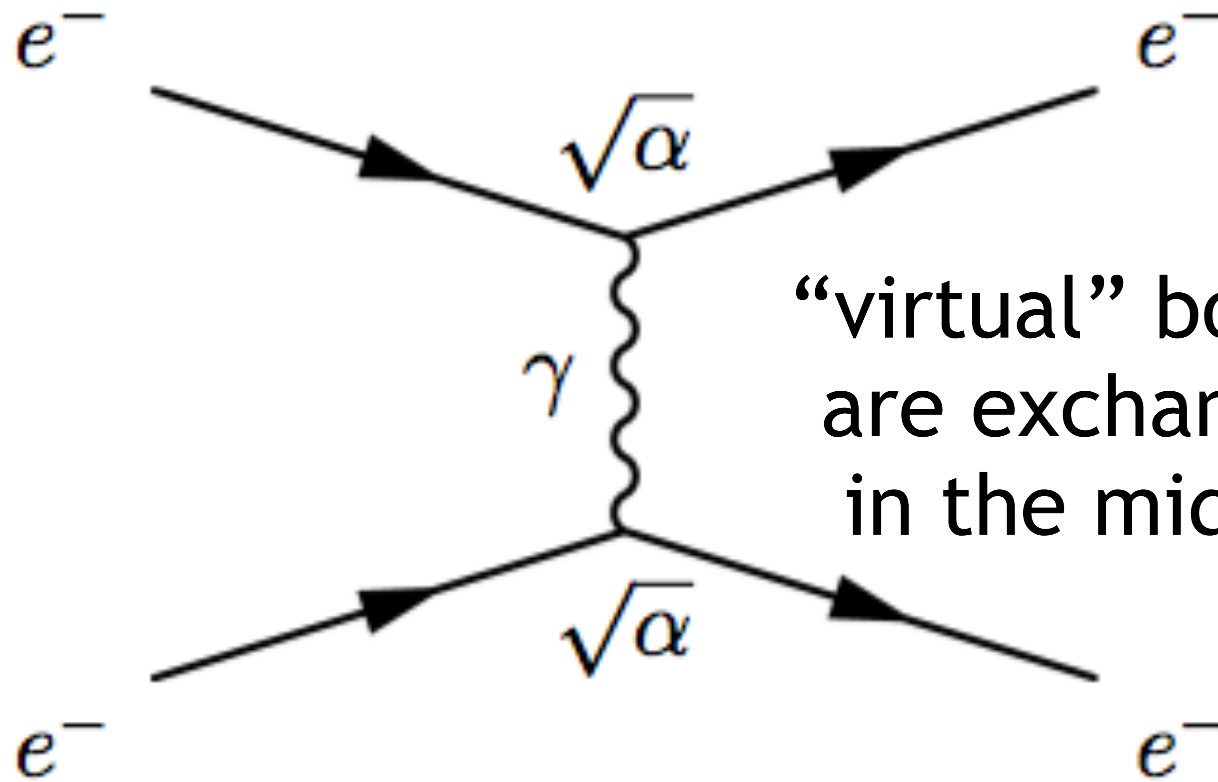
"virtual" bosons are exchanged in the middle

Final state particles on the right

Each interaction vertex has a coupling constant

Drawing Feynman Diagrams

Initial state particles on the left



Final state particles on the right

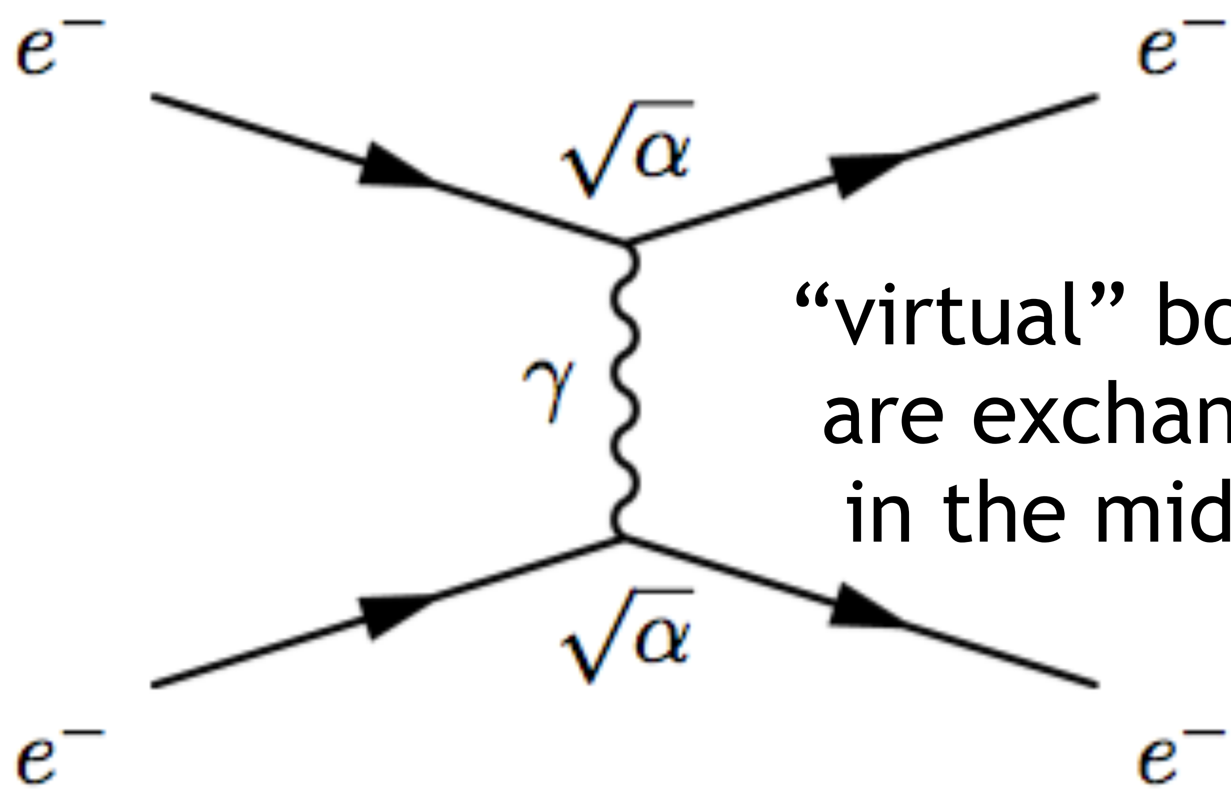
"virtual" bosons are exchanged in the middle

Each interaction vertex has a coupling constant

fermions | antifermions | photons, ***W*, *Z*** bosons | gluons | ***H*** bosons

Drawing Feynman Diagrams

Initial state particles on the left



Final state particles on the right

"virtual" bosons are exchanged in the middle

Times flows from left to right

Each interaction vertex has a coupling constant

fermions | antifermions | photons, ***W*, *Z*** bosons | gluons | ***H*** bosons