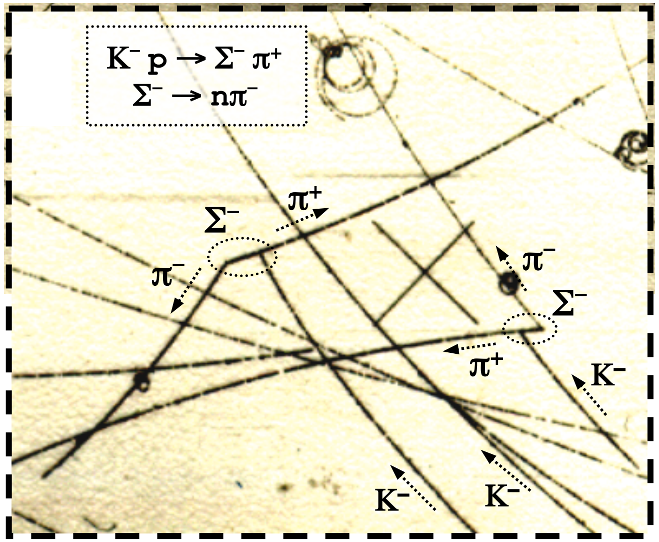
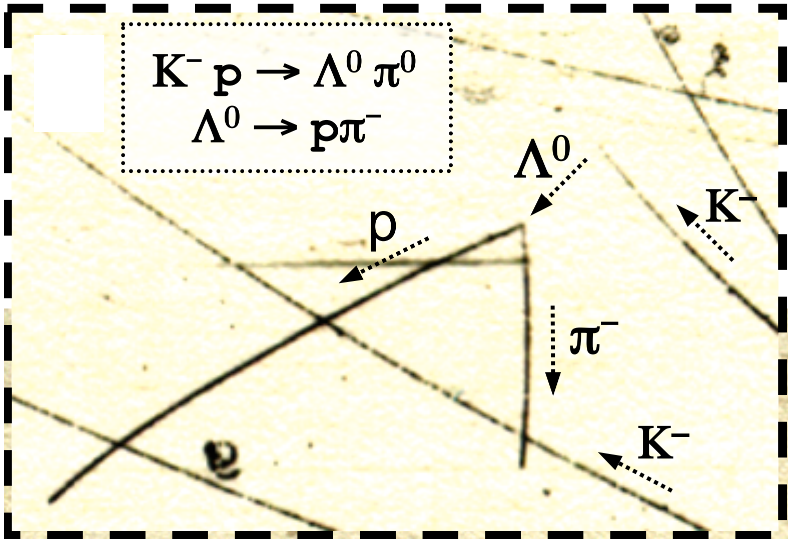
PHY20004 Particle Physics Class 4:

Particle Physics Experiments

In this class we'll learn about particle physics experiments with beams, colliders and detectors such as bubble chambers

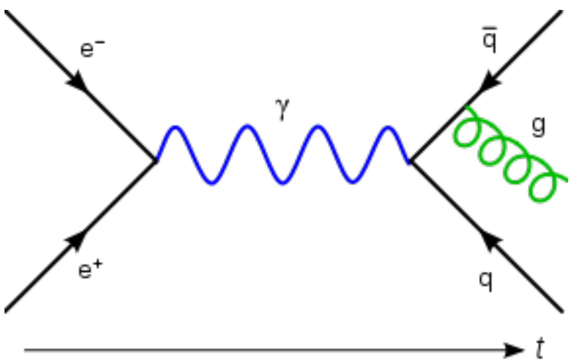


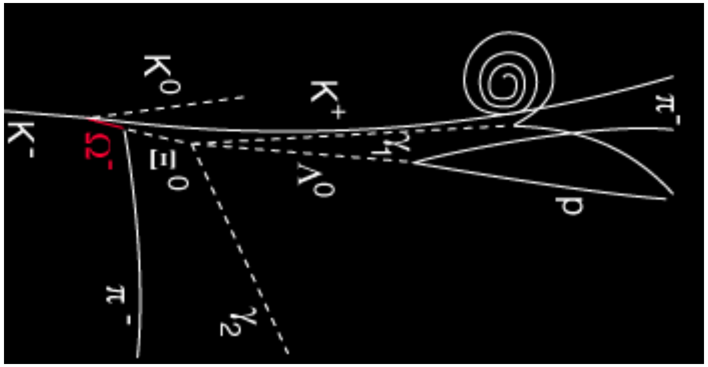


The development of particle physics

- Particle physics has advanced through an interplay of **theoretical ideas** and **unexpected experimental discoveries**

Theoretical ideas ⟷ **Experimental discoveries**





- Development of quark model
- Unification of electromagnetic and weak interactions
- Quantum field theory of strong interaction

- Discovery of different baryons and mesons containing quarks
- Discovery of 3 generations of leptons
- Discovery of quark masses

How do we test particle physics?

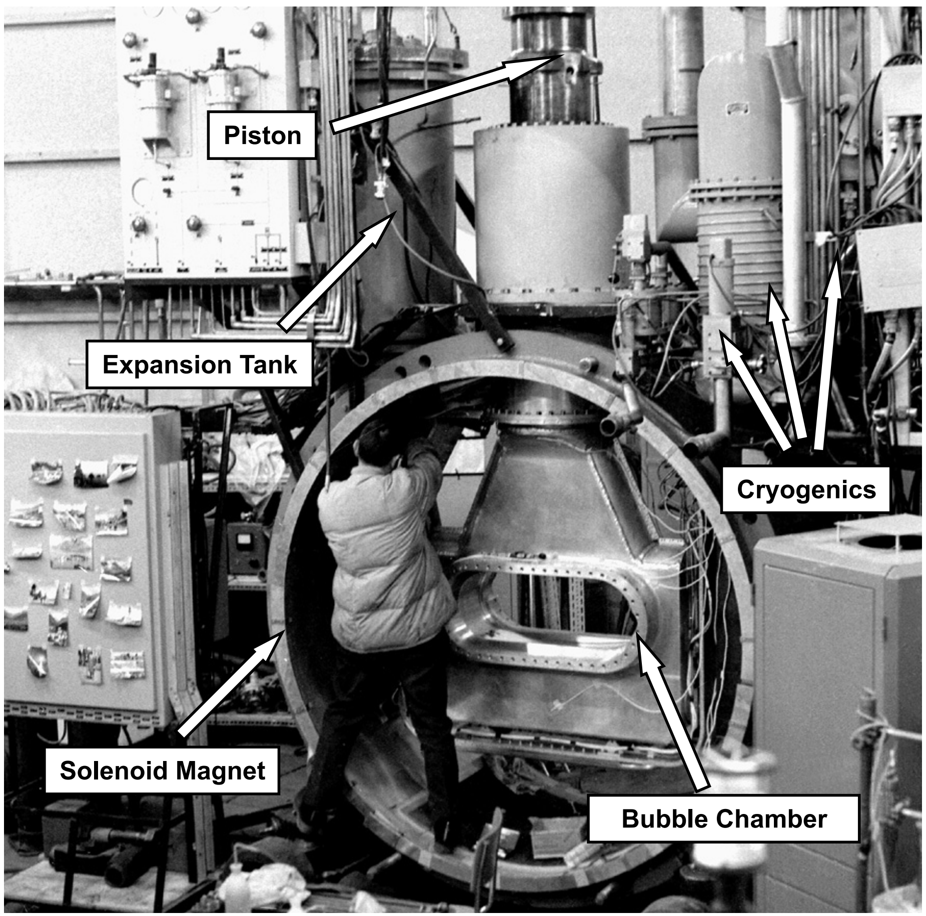
- To test particle physics we need to **generate** different types of decays and reactions, and **measure the tracks** and properties of their products using detectors
- Decays and reactions can be “encouraged” using high-energy beams and particle colliders!

Credit: CERN

Bubble chambers

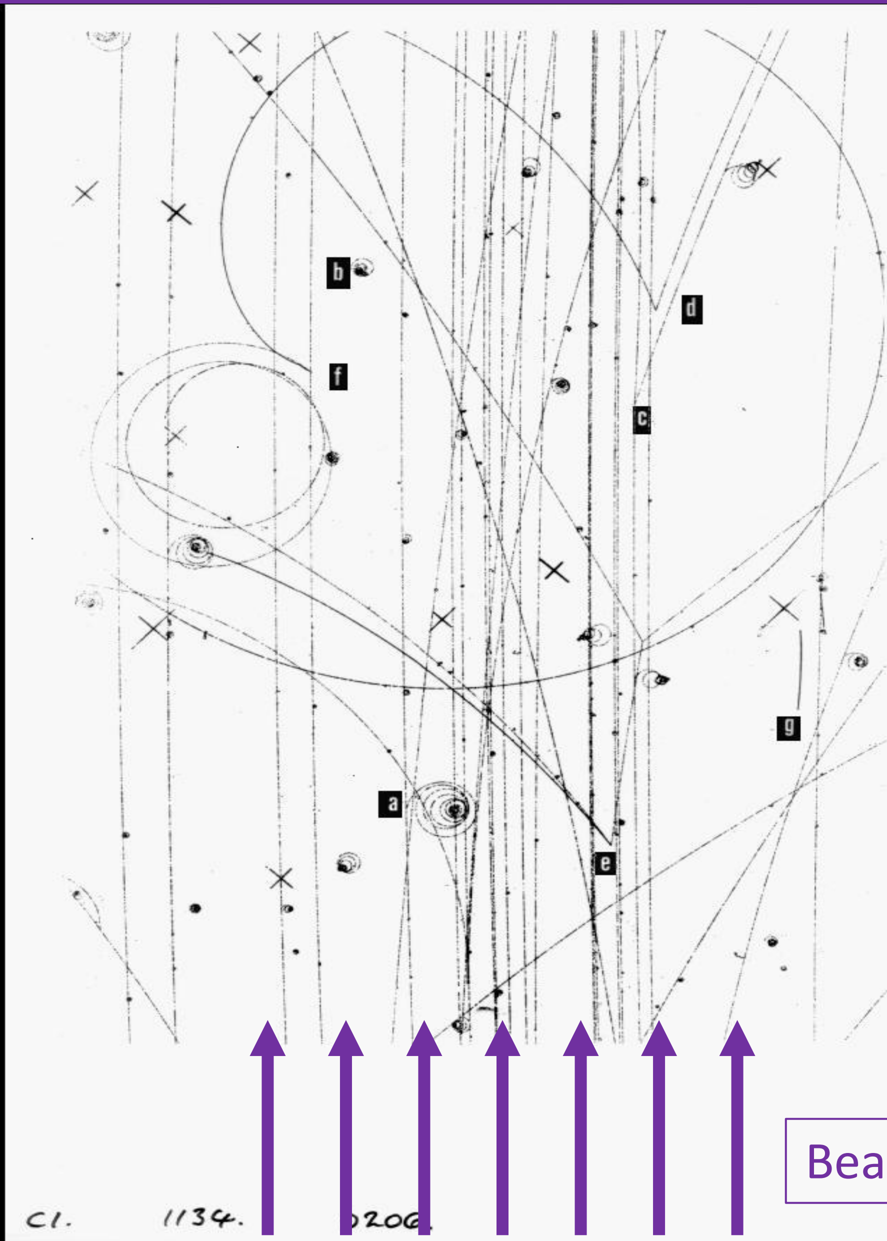
- **Bubble chambers** are a beautiful example of a particle physics experiment, responsible for several major discoveries

Saclay 81cm Bubble Chamber



- A bubble chamber is a pressurized vessel containing **liquid hydrogen** close to its boiling point
- As a beam of particles is directed into the chamber, a piston releases the pressure, and the hydrogen becomes **super-heated**
- Charged particles passing through the chamber leave **ionization trails** (“bubbles”) where the liquid boils
- The bubbles are **photographed**, revealing the particle trajectories

Bubble chambers



Here's an example bubble chamber photograph. A **magnetic field** has been applied, directed into the page. Positive/negative charges curve to the left/right!

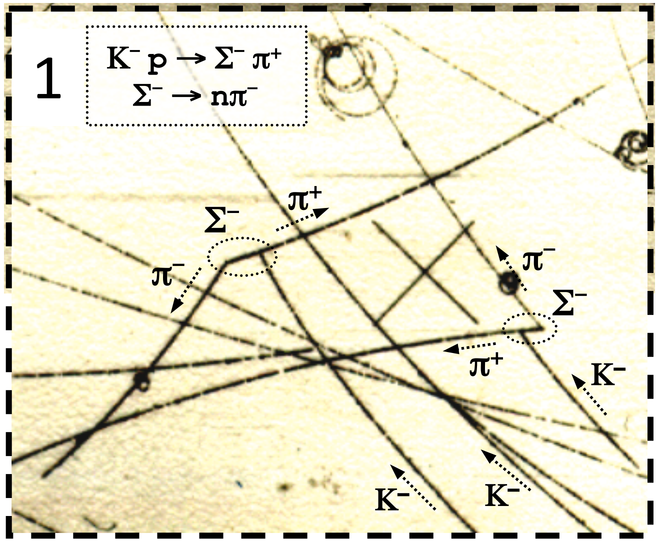
The kaons interact with hydrogen atoms in the chamber, causing various reactions!

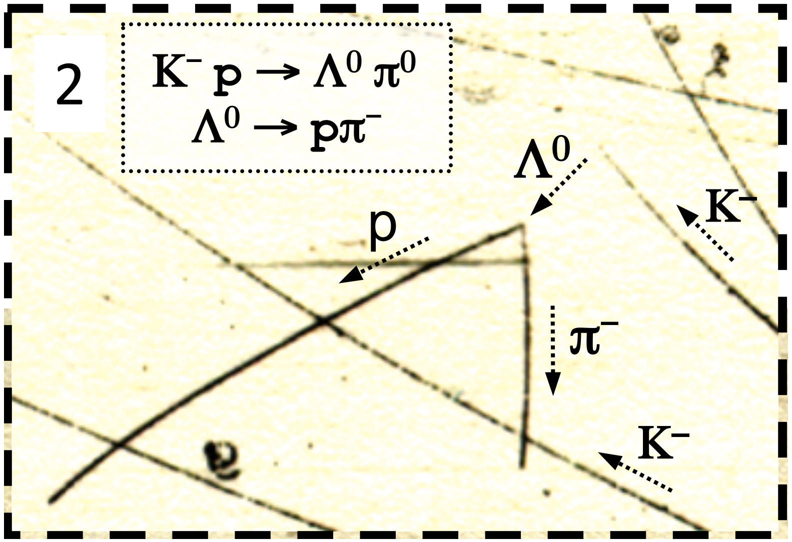
- Scattering ("billiard ball") **collisions** releasing protons and electrons
- **Creation** of new particles (hyperons)
- **Decay** of those particles into pions and other particles

Beam of negatively-charged kaons (K^-)

Bubble chambers

- Here are a couple of examples of reactions that can occur in a bubble chamber *(we'll see a lot more in the Worksheet!)*





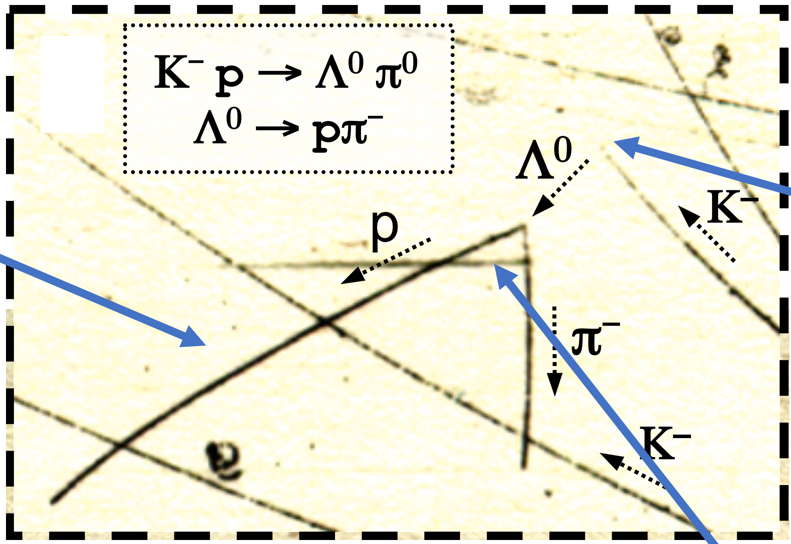
- The kaon and proton produce a Σ^- hyperon and charged pion (π^+)
- The Σ^- decays into a neutron and pion (π^-) – the neutron has no charge so can't be seen!

- The kaon and proton produce a Λ^0 hyperon and neutral pion (π^0)
- The Λ^0 decays into a proton and pion (π^-) – the Λ^0 has no charge so can't be seen!

Bubble chambers

- Bubble chambers are a nice physics showcase because they involve **all the fundamental interactions**!

The ionization trails for charged particles are produced by the ***electromagnetic interaction****, as are electrons spiralling in the magnetic field!*



The particle creations are produced by the ***strong interaction****, conserving quark numbers*

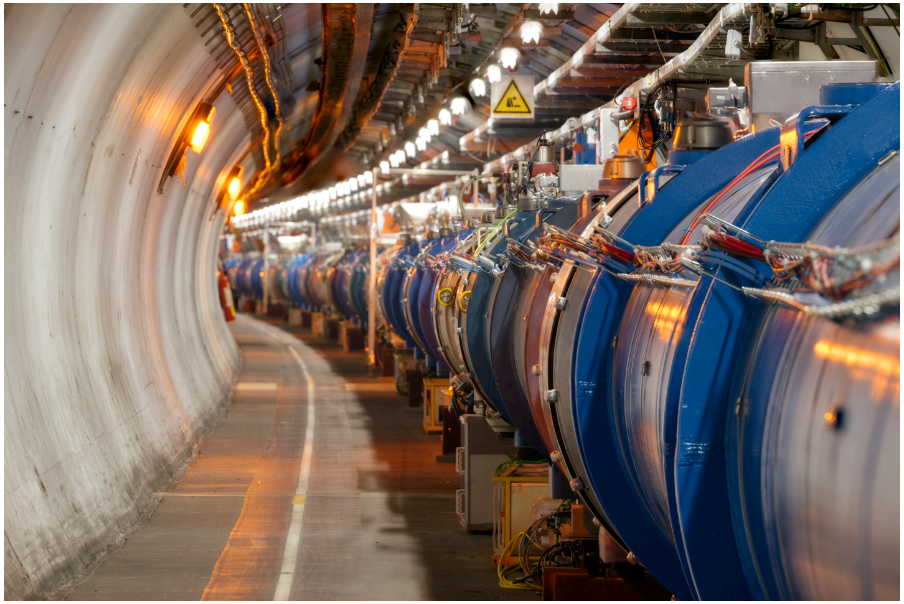
The resulting decays are ***weak interactions****, in which changes of quark flavour occur*

Modern particle accelerators

- Modern particle accelerators and colliders are designed to reach **ever-greater energies**, in the quest for new particles

High-voltage **linear design**, e.g. Stanford Linear Accelerator (SLAC)

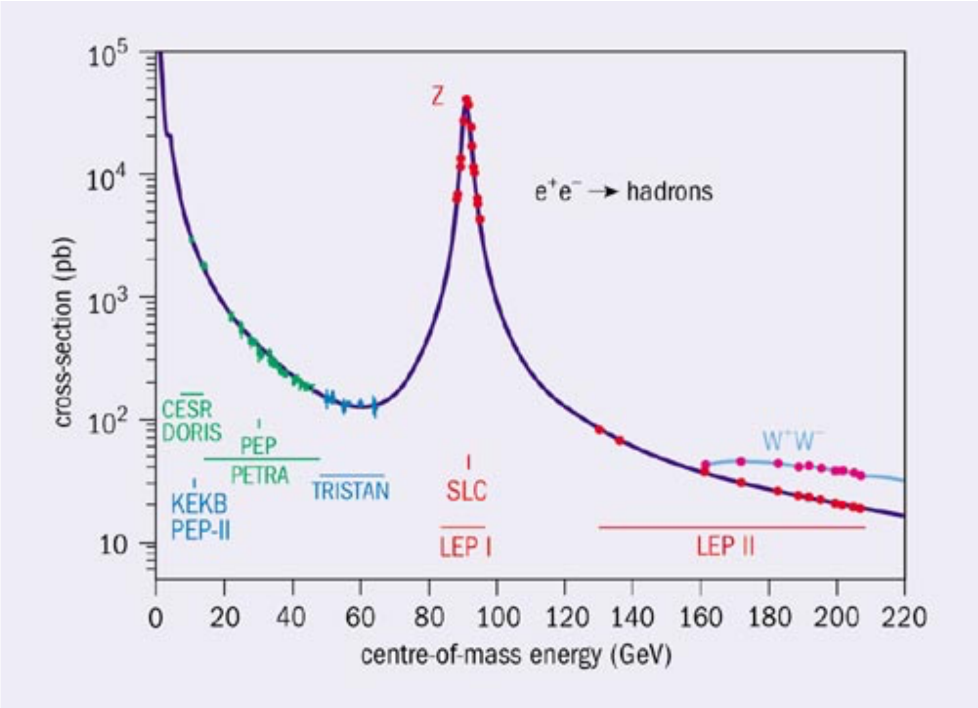
Circular design involving high-power magnets, e.g. Large Hadron Collider (LHC)



Modern particle accelerators

- Modern particle accelerators and colliders are designed to reach **ever-greater energies**, in the quest for new particles

- Increasing beam energy allows the creation of particles with increasing rest mass via **energy resonances**

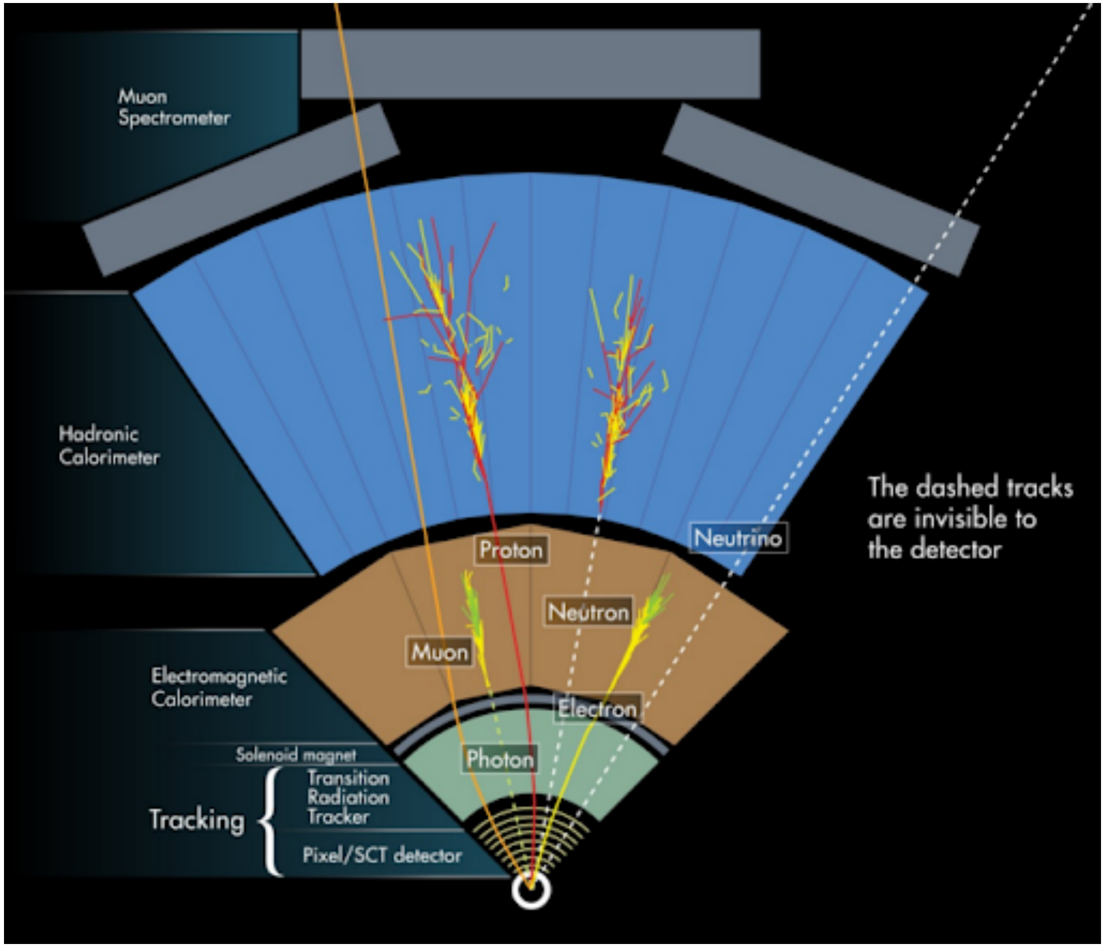


*A good example is the interaction cross-section for **electron-positron collisions**. This has a significant spike at $\sim 90\ GeV$ because the Z^0 particle can then form. The Z^0 then decays into hadrons*

Credit: https://cerncourier.com

Modern particle accelerators

- Detector technology has also advanced in comparison to bubble chambers!



The detector is composed of a number of different layers, which detect particles of different types (this example is from the ATLAS experiment at the LHC)

Credit: http://collider.physics.ox.ac.uk

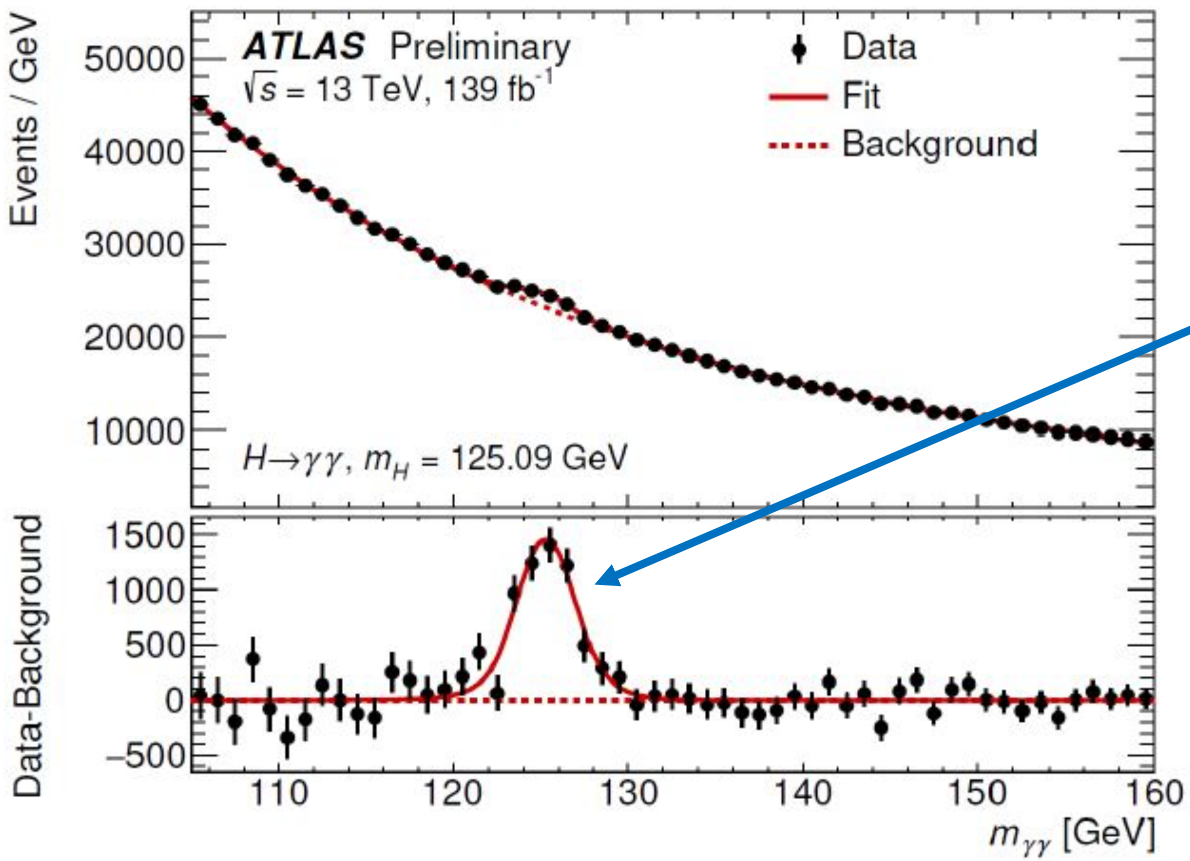
Particle discoveries

Year	Particle	Notes
1964	Quarks	The quark theory is proposed as a mathematical model, initially consisting of 3 quarks (up, down, strange)
1964	Ω^- particle	A baryon consisting of 3 strange quarks is discovered
1974	J/ψ particle	A 4th quark: charm-anticharm meson independently discovered by 2 groups. Many other mesons follow.
1976	Tau lepton	A third generation of leptons is unexpectedly discovered at SLAC; the standard model takes shape
1977	Bottom quark	A 5th quark, the bottom quark, is discovered at Fermilab
1983	W and Z bosons	Observed in proton-antiproton collisions at CERN
1995	Top quark	CDF and D0 experiments at Fermilab finally discover the top quark at an unexpectedly high mass
2012	Higgs boson	Part of a mechanism by which fundamental particles gain mass; discovered by the ATLAS and CMS experiments at CERN

See https://particleadventure.org/other/history/smt.html for more information!

Particle discoveries

- Of course, the most recent exciting discovery was the **Higgs boson** by the Large Hadron Collider *(we'll discuss this more in the next class!)*



Recent data from the ATLAS experiment at the LHC, showing the decay of the Higgs boson into photons

Key take-aways

- The timeline of particle physics has seen an interplay of **theoretical ideas** and **experimental discoveries**
- **Bubble chambers** are a particle experiment which analyses reactions and decays through the tracks of charged particles
- The reactions and decays seen in a bubble chamber can be understood using **conservation laws** of particle physics
- Modern beams, colliders and detectors access higher energies through linear or circular designs; new particles can be created through **energy resonances**
- Discoveries in the past couple of decades using this method have included the **top quark** (1995) and **Higgs boson** (2012)