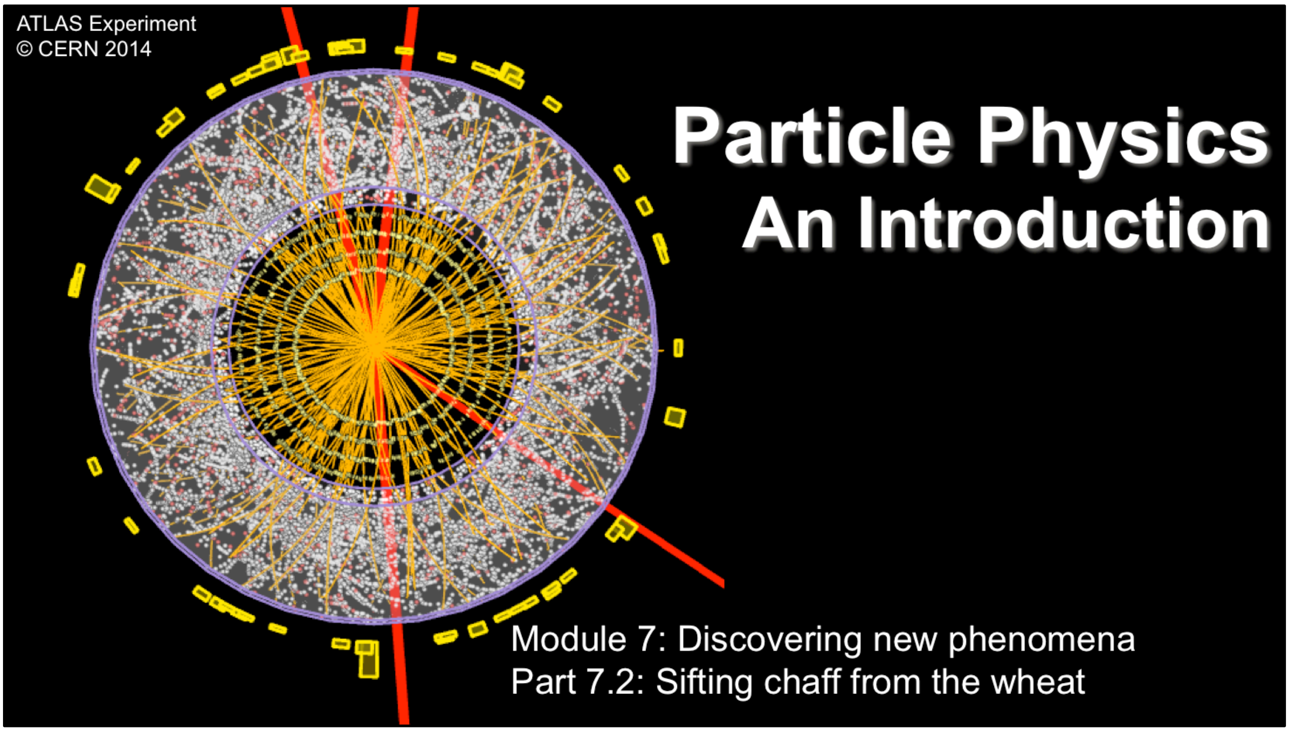


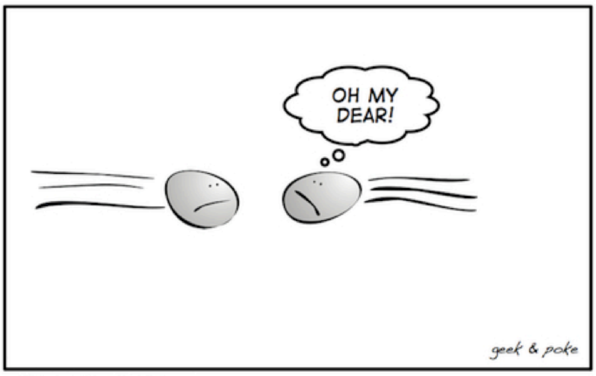
In this module we discuss searches for new phenomena, beyond the known ones described by the standard model.

In this video we will talk about the lifecycle of a collision event; from the time the event is produced in the heart of a detector until when it gets ready to be processed in a physics analysis.

After watching this video you will know:

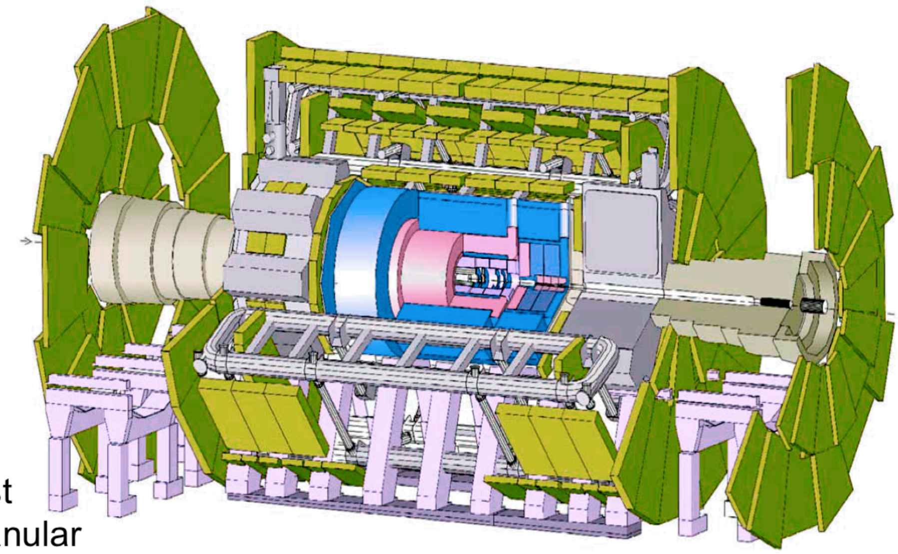
- Why we trigger on physics events in the collider experiments;
- How we translate the analogue and digital signals of the detectors to physical objects that we associate with Standard Model particles, for the events we have triggered on; and
- How we deal with the large amounts of data that are produced in the collider experiments.

All that, in connection to what we need to search for new physics.



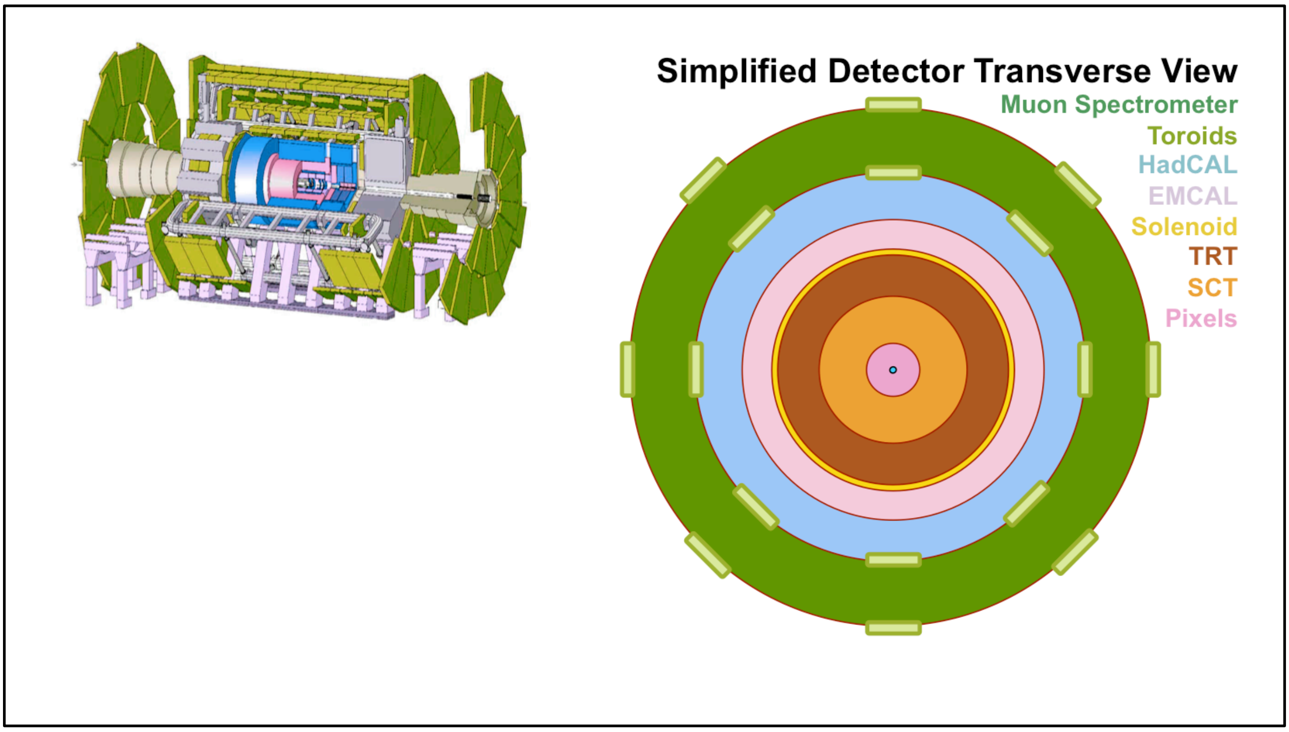
LATELY INSIDE THE LHC:
2 PROTONS 0.0000000000000000001 SEC BEFORE THE COLLISION

As you already learned in Module 3, proton bunches, each containing hundreds of millions of protons, collide at the LHC in collision points where experiments are installed.

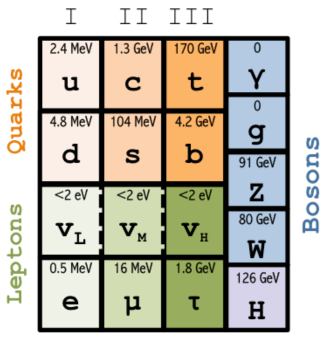


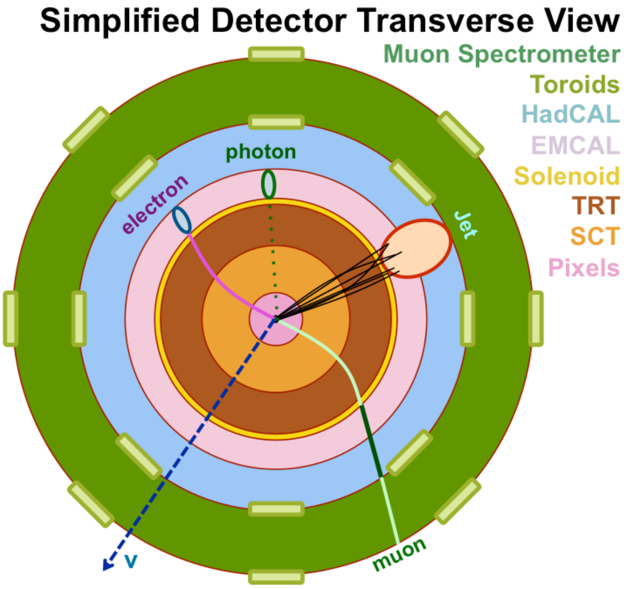
✓ Fast
✓ Granular
✓ Resistant to radiation

This is one of the general-purpose detectors of the LHC, the ATLAS detector. We have alredy gone through its elements and their functions in video 3.10a.

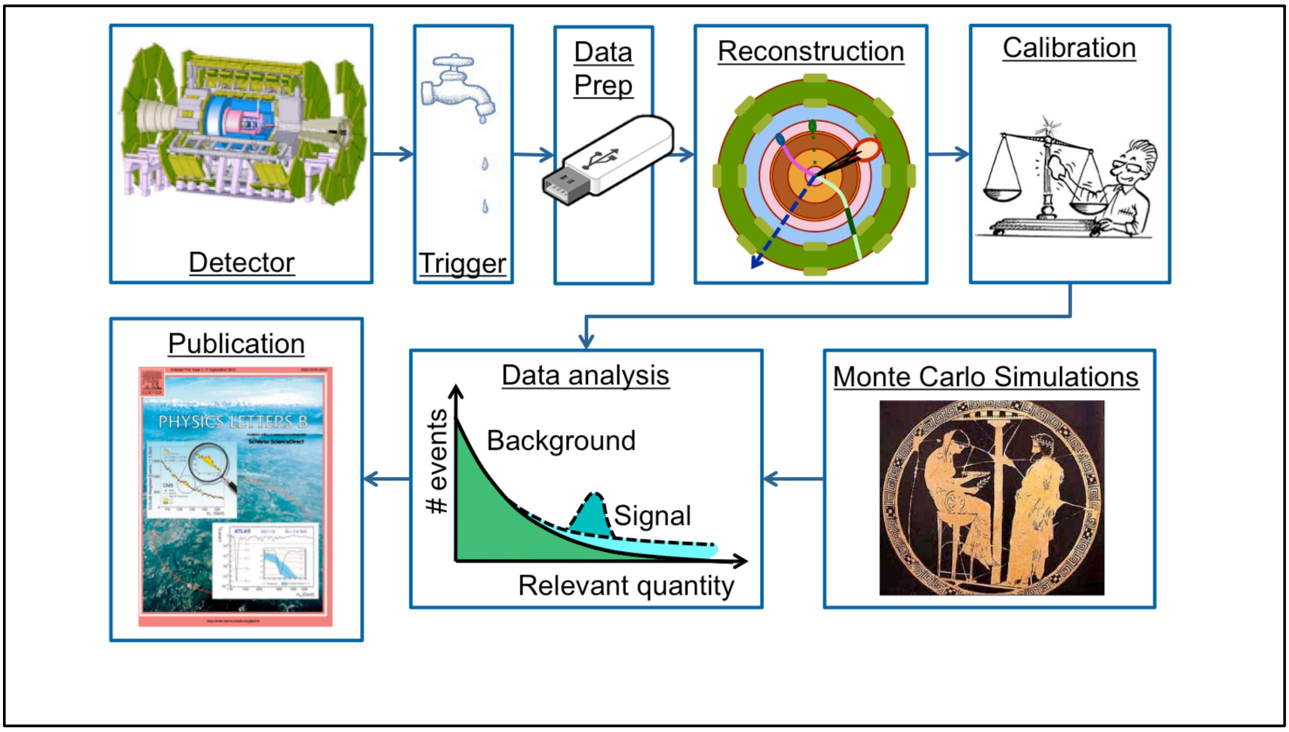


If we take a look at a transverse view of the detector, we will see that it has an onion structure: it’s made up of various layers of different detectors.
An inner detector, inside a solenoid, used for tracking charged particles, calorimeters for electromagnetic and hadronic shower measurements, and a muon spectromenter in toroidal magnetic field, for muon momentum measurements.





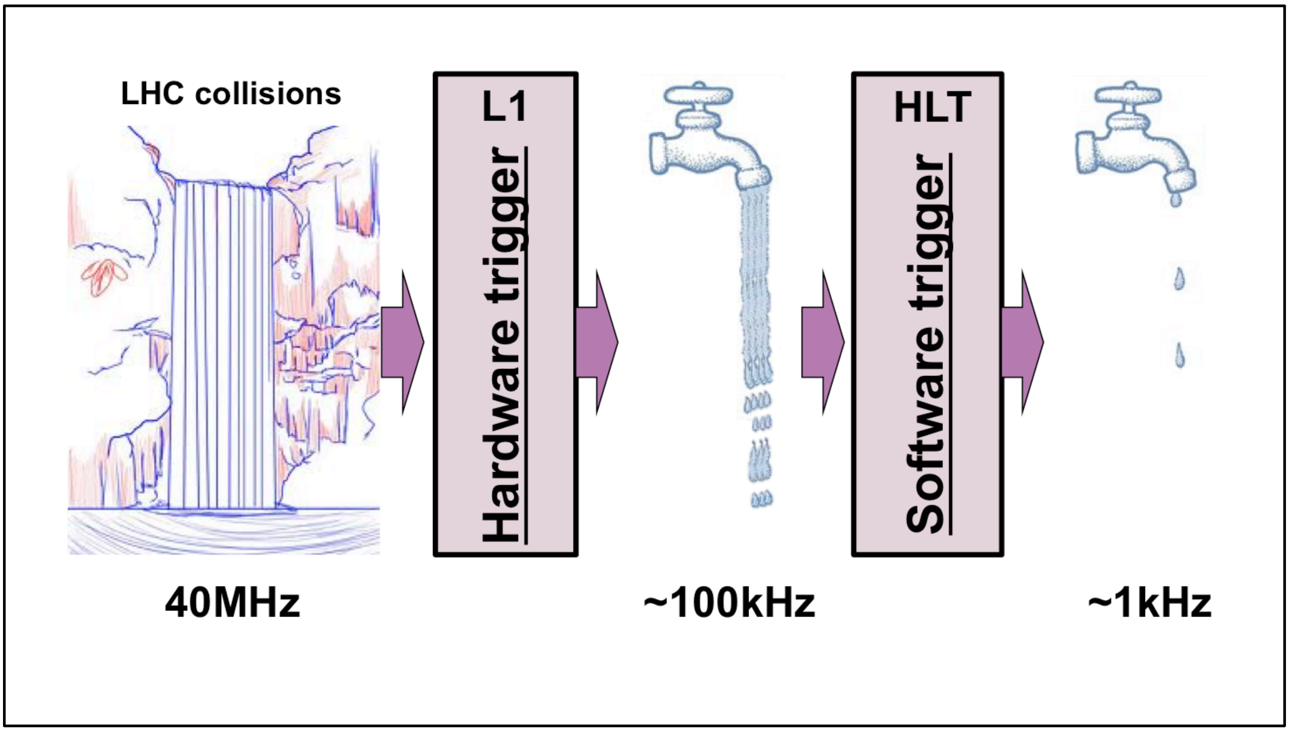
Proton-proton collisions result in many particles, which decay to the lightest elementary particles compatible with their quantum numbers. These leave their signatures in the detector as digital and analogue signals, which we reconstruct as objects that we associate with the elementary particles. So the particles we reconstruct in the detector are electrons and photons and muons, and quarks and gluons as particle jets. Details about the detector response to various particle types are given in video 3.10a.



Events that contain sufficiently interesting features to be further analysed are triggered on and stored for further processing. These events go through event reconstruction. To ensure an accurate measurement of the properties of the reconstructed objects, a calibration procedure is applied. Calibrated objects are now ready for analysis.

In our analyses, we need to compare our data to theoretical calculations. To achieve this, event simulations, called "Monte Carlo simulations" are performed, which create artificial events based on a specific theoretical assumption. With these components in place – reconstructed and calibrated data on one hand and data simulated according to theoretical predictions on the other hand – we are ready to search for new physics in our data.

But let's first understand these components better. And let's start from the trigger; what does this actually do?



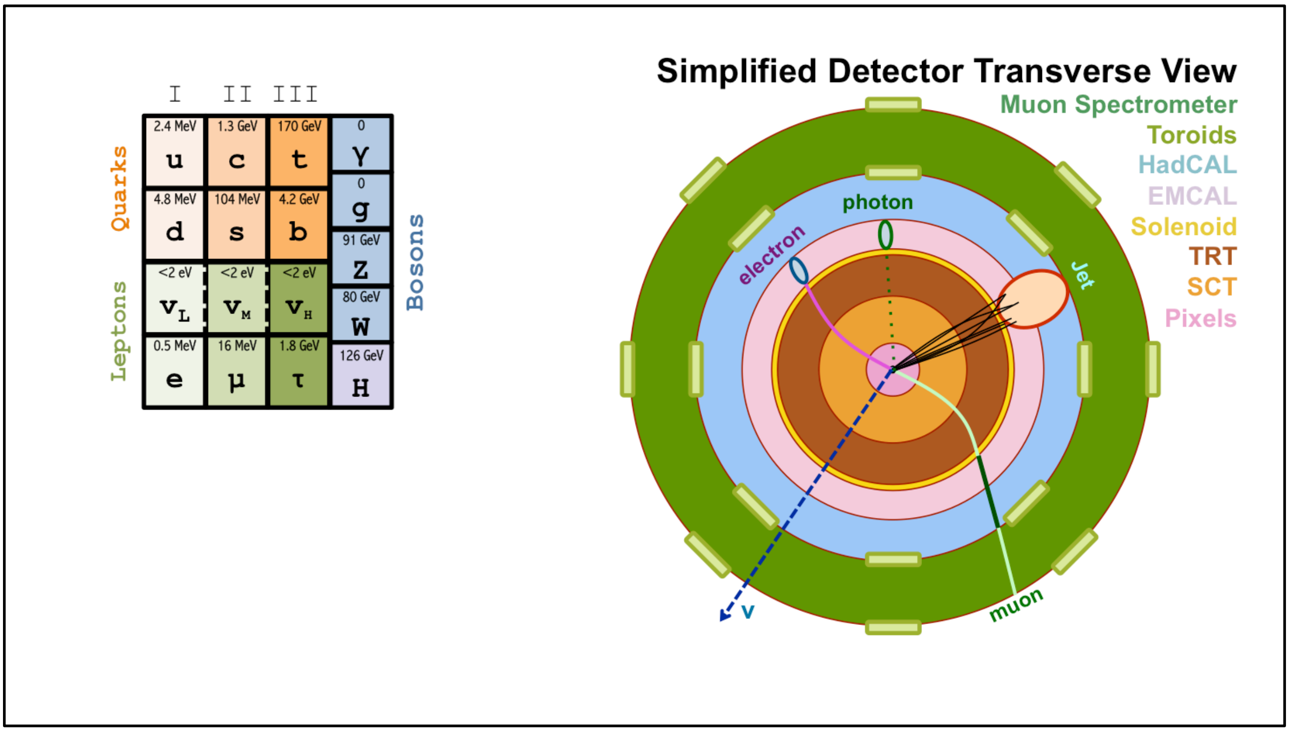
The LHC is colliding proton bunches with a maximum rate of 40MHz. Each event recorded by the experiments, containing all digital and analog information from the detector, has a data size of about 1MByte. So saving all events would lead to about 40 TeraBytes of data per second.

This is a huge amount of data to store but also to process. Furthermore, most of these events only contain known physics, so we need to select which of them to keep. This is where the trigger system comes in.

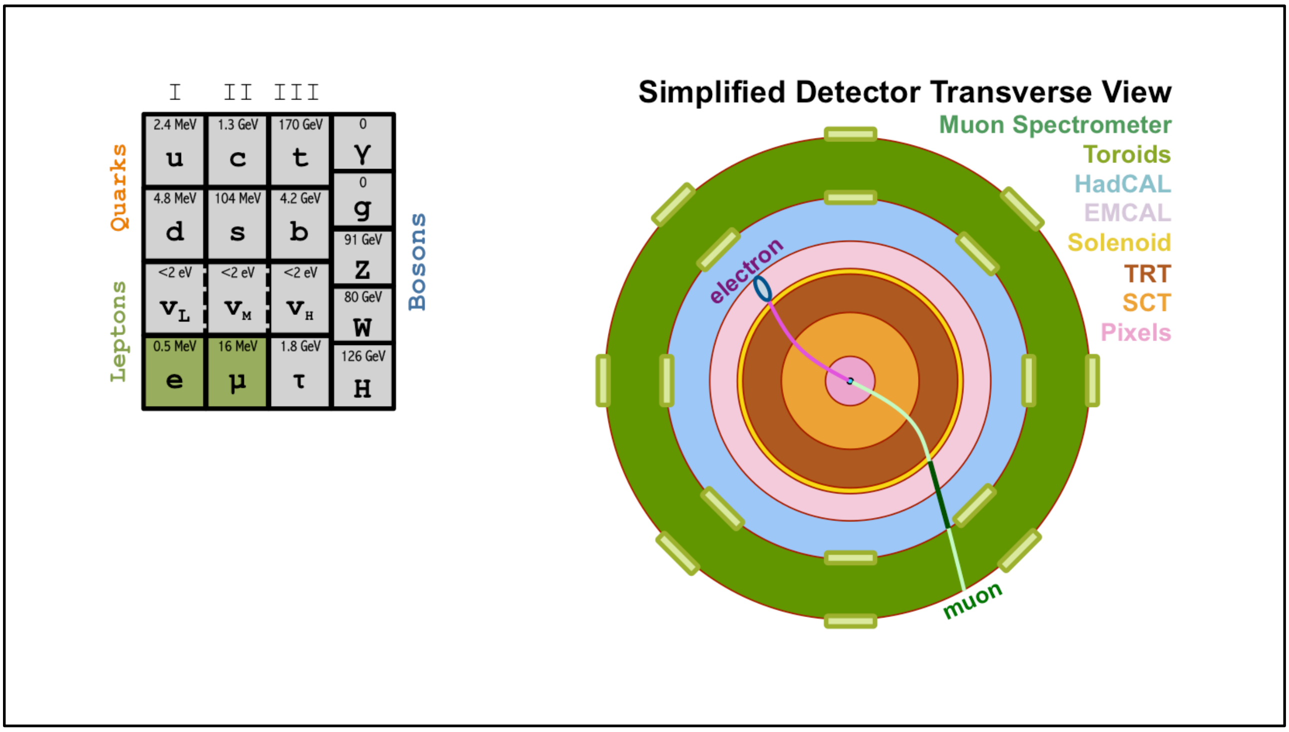
The trigger system of the large multi-purpose experiments consists of 2 main components, a hardware-based one, and a software-based one. The trigger system is built to be extremely robust and fast as it needs to take a reliable decision in a very short time.

The trigger helps the selection of interesting events, but also applies upper limits in the number of events we can select at each of its steps.

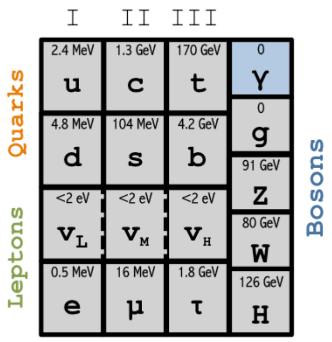
Triggering on events that contain new phenomena is an extremely big challenge; we don't know a-priori how these events will look like, we therefore have to built our trigger selections generic enough to ensure we don't loose anything interesting. As events we don't trigger on are simply lost for ever.

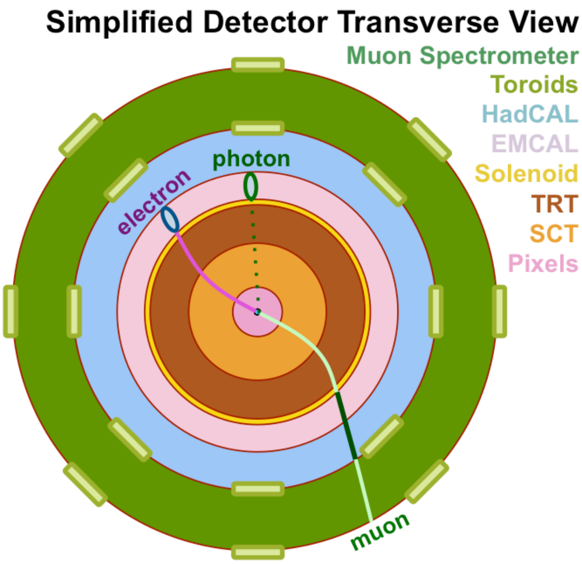


For events that were triggered, the detector tells us about the elementary particles that were created in the collision process, as well as their properties. Typically most of these particles are relevant in the searches for new physics, and we will see why in the following videos of this module. An overview is given in video 3.10a, here we summarize the detector response to the main types of particles.

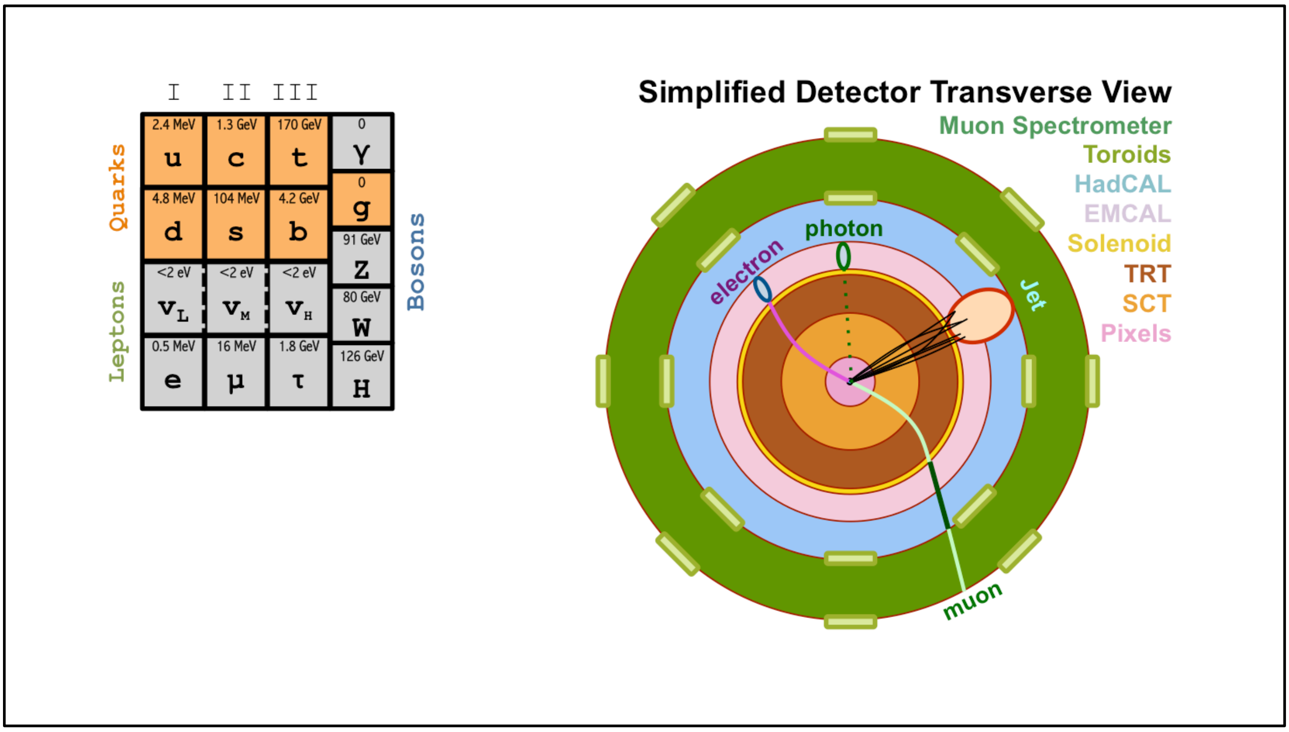


Electrons and muons both leave tracks in the Inner Detector. The electrons are reconstructed by matching this track with an electromagnetic shower. For muons the Inner Detector track is matched to a muon track in the muon spectrometer.

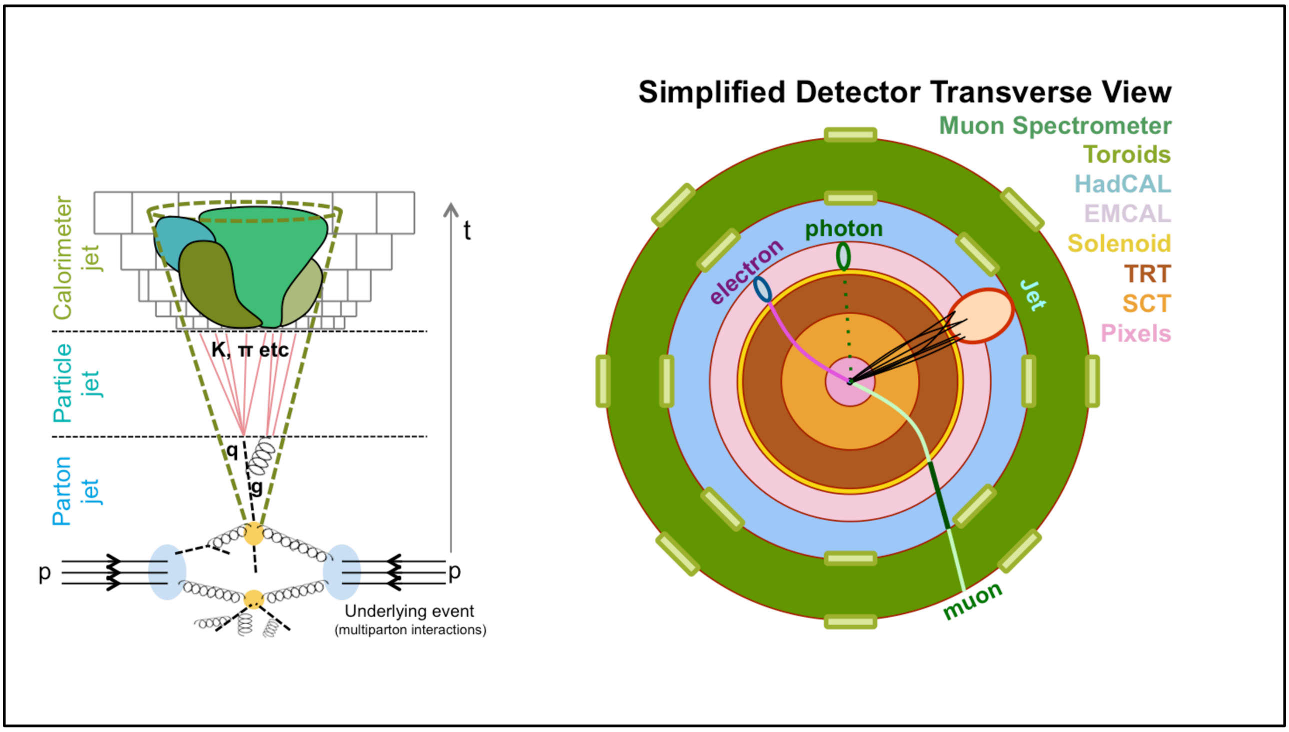




Photons, being neutral, leave no tracks in the Inner Detector and are therefore associated to an electromagnetic shower with no track pointed to it. We have discussed electromagnetic showers in video 3.6.

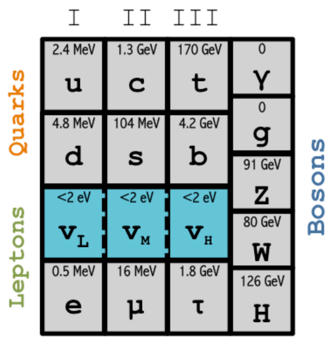


Quarks and gluons are much more complicated objects to reconstruct.
Quarks and gluons can't live by themselves but have to exist in bound states, as was already explained in Module 5.



They hadronize and are therefore reconstructed in the calorimeter as a hadronic shower.

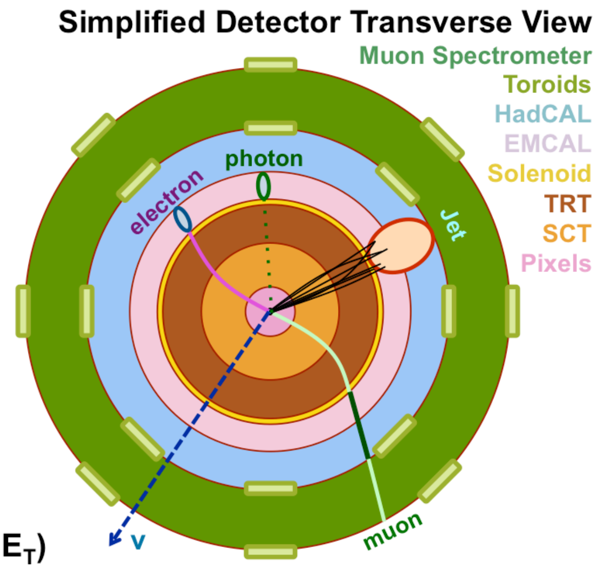
Algorithms scan the calorimeter data in order to identify the most significant energy depositions corresponding to quarks or gluons. The resulting objects are the jets. It's worth pointing out that the dominant process resulting from a proton-proton interaction is the production of gluons or quarks, therefore jets dominate the detected final states.



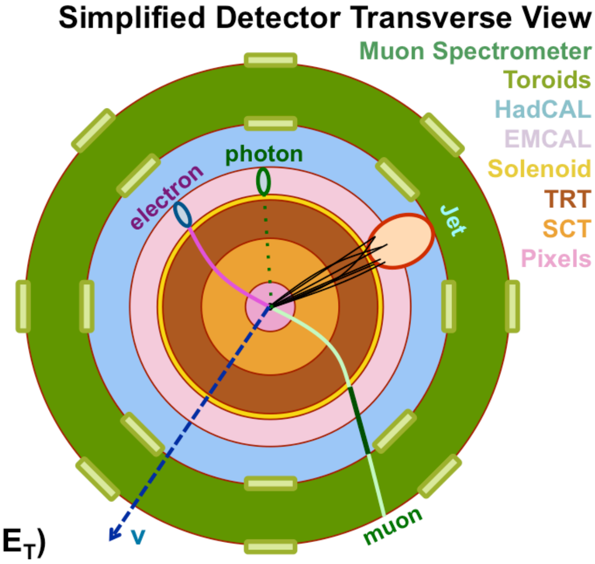
In the transverse plane:

$$\sum \vec{\mathrm{p}}_{\mathrm{T}} = 0$$

Missing Transverse Momentum (ME_T)



Neutrinos don't interact with the detector and therefore escape undetected. However, we can get information about neutrinos using the knowledge that in the transverse plane, because of conservation of momentum, the vector sum of the momenta of all the objects has to be zero. So neutrinos are associated with the missing momentum in the transverse plane.

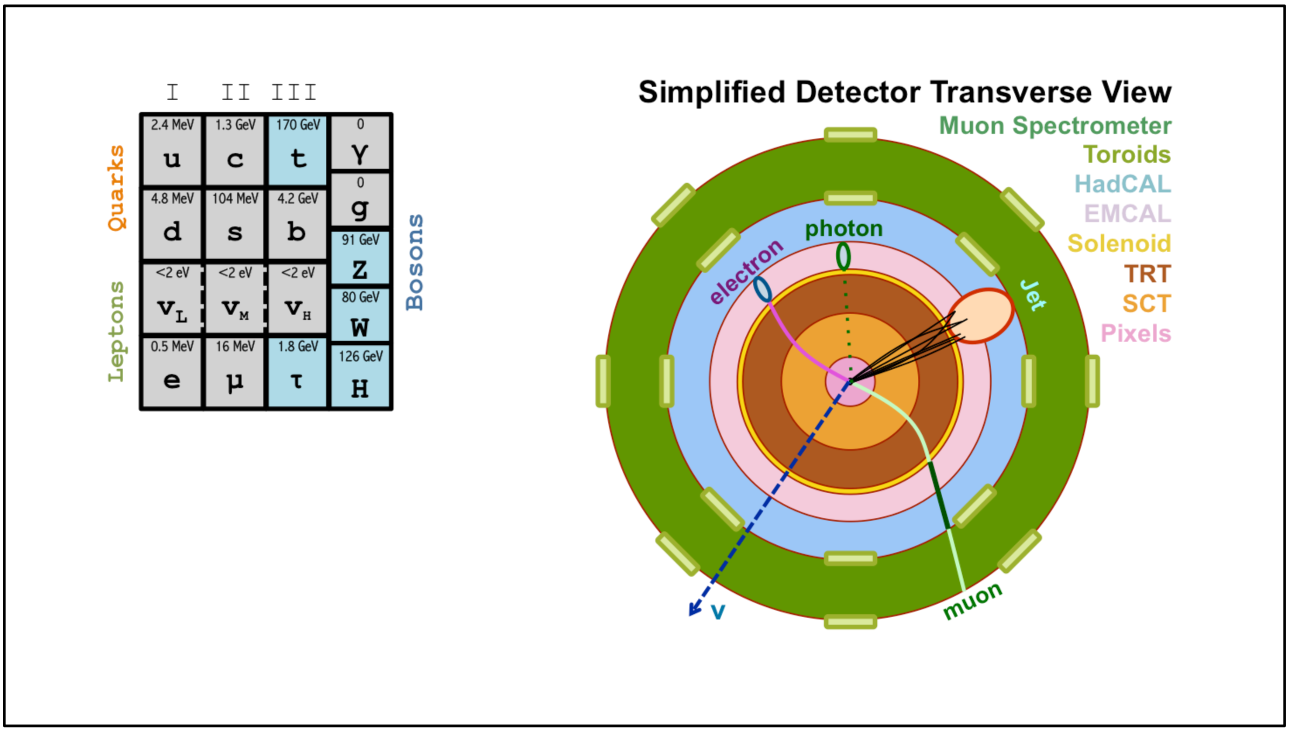


In the transverse plane:

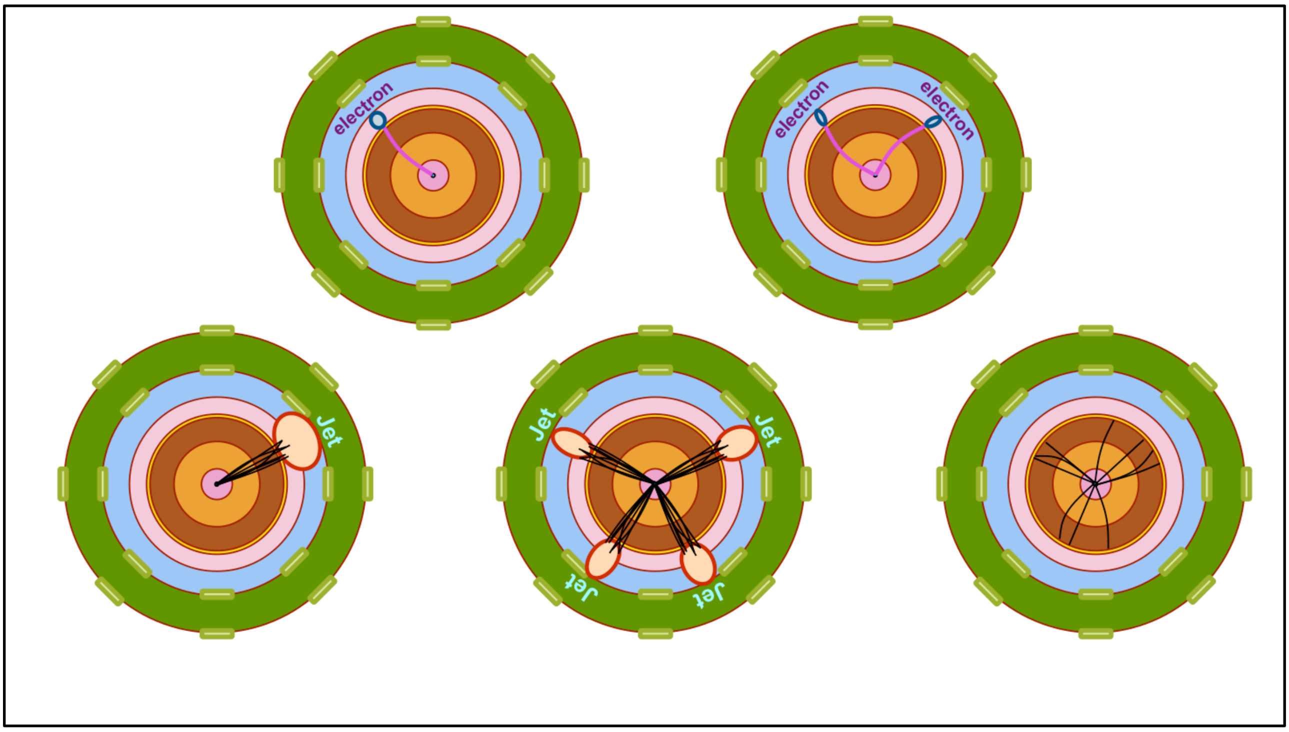
$$\sum \vec{p}_T = 0$$

Missing Transverse Momentum (ME_T)

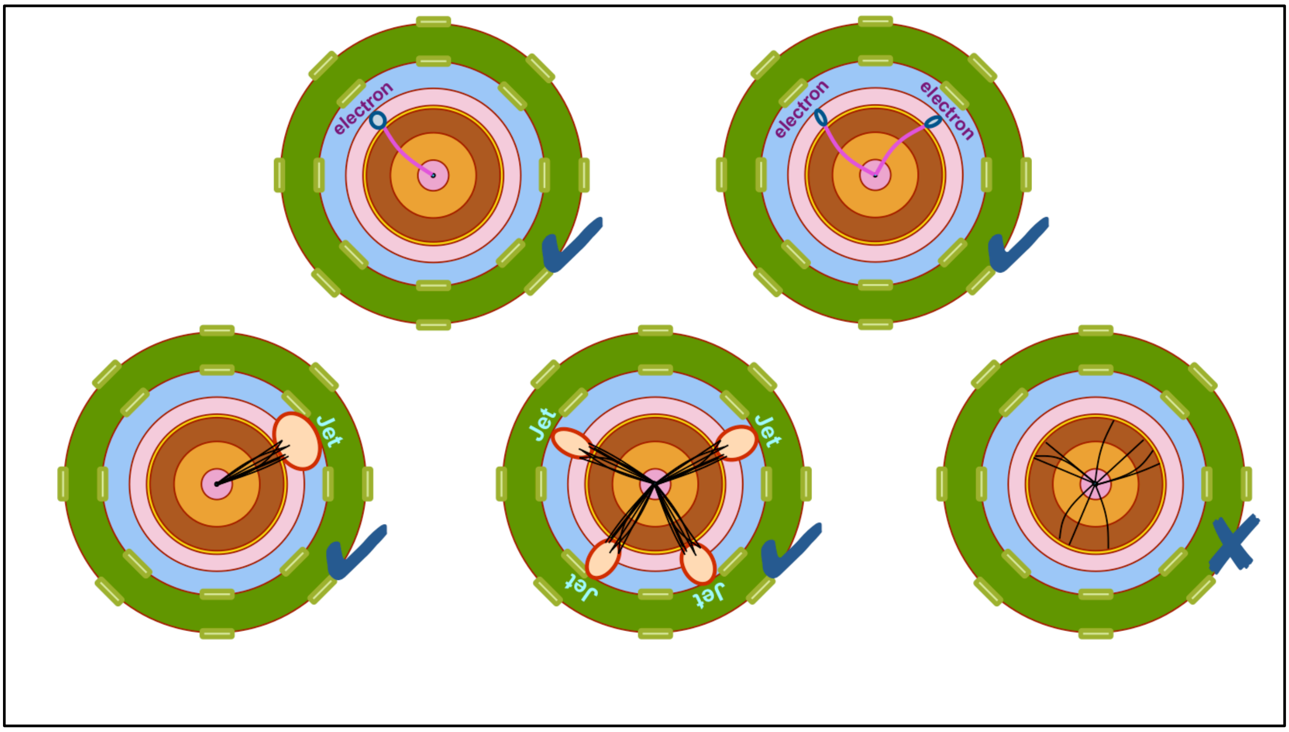
Any neutral and weakly interacting particle, such as dark matter candidates, will in fact behave like neutrinos and will be identified as missing transverse momentum in the detector. Missing transverse momentum is extremely important in our searches for new physics.



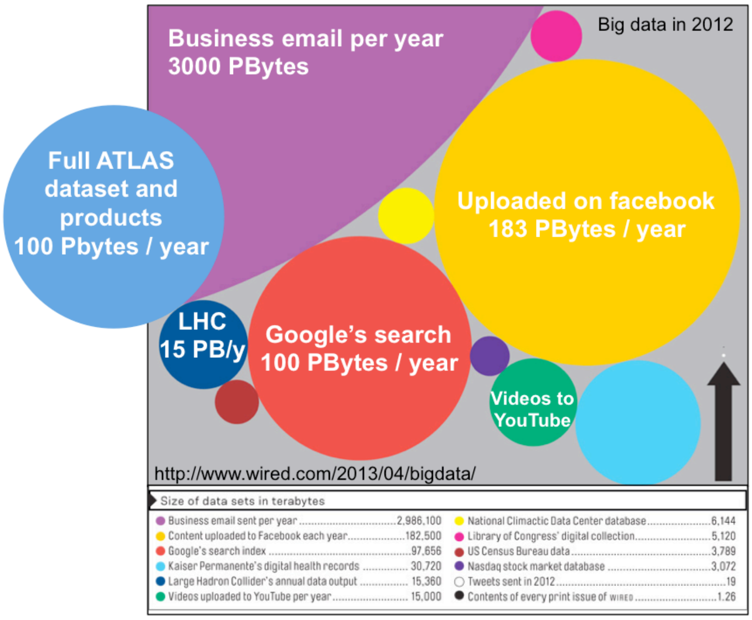
W, Z, H bosons, top quarks and tau leptons decay immediately to elementary matter particles and we reconstruct them using their decay products.



In a detector we can therefore observe various event topologies and based on their characteristics we can classify the events. This is in fact what we are doing already at trigger level; we are running algorithms that perform simplified reconstruction and based on the characteristics of the events we accept or discard the events.



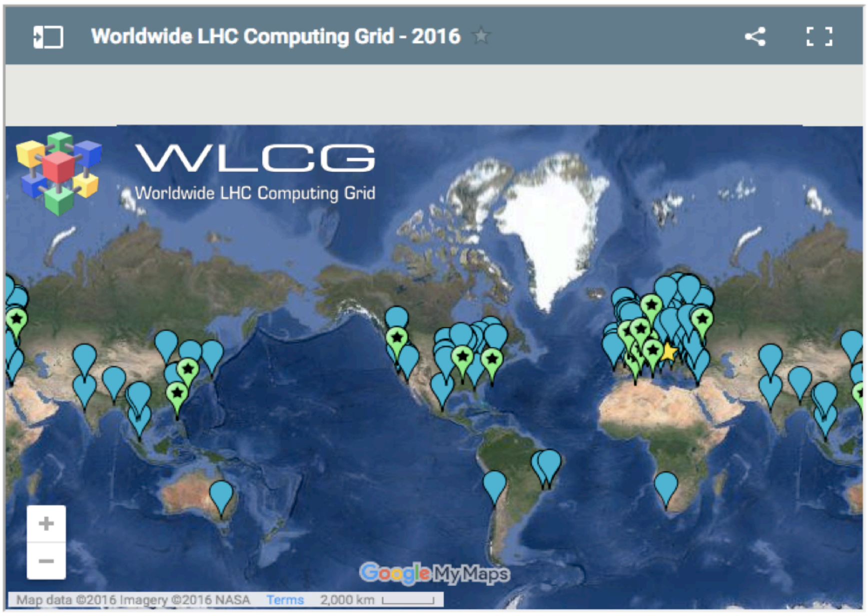
For example, events with high-momentum objects or large multiplicity of objects are accepted by the trigger for further processing. Events with only low energy particles are not generally accepted as these are of no general interest, since they correspond to low q^2 processes. It would also be impossible to store and process those as they are the most common ones.



Despite the fact that we are finding ways to reduce the amount of data we need to process, we are still generating incredibly large amounts of data. Such large amounts are needed to ensure that the rarest processes will be produced and saved in our data; such would be processes coming from new physics.

These data get reconstructed and calibrated, as we said. It is the products of this process we are eventually using, without ever discarding the original data, since we often need to reprocess them, to e.g. improve reconstruction or calibration.

In order to make the best use of the large amount of data, we use sophisticated methodologies, such as machine learning techniques and other statistical methods, which are often CPU-intensive. This adds to the computing needs of the LHC experiments; it's not only data and simulation storage we need, but also processing power. This is a combination that creates a great challenge.



This challenge is being addressed using major innovations in computing, such as the computing grid. Numerous computing centers in universities all over the world are interconnected forming a computing grid. They receive copies of the data and give the capability to scientists to run their analysis processes on this grid in an automatic and transparent way. Research and development in the computing domain is in active progress, and a task always extremely challenging and rewarding at the same time.

This concludes this lecture. In the next video, we will talk about a specific type of searches, the so-called “bump” searches.