Group 3 - Particle Detectors

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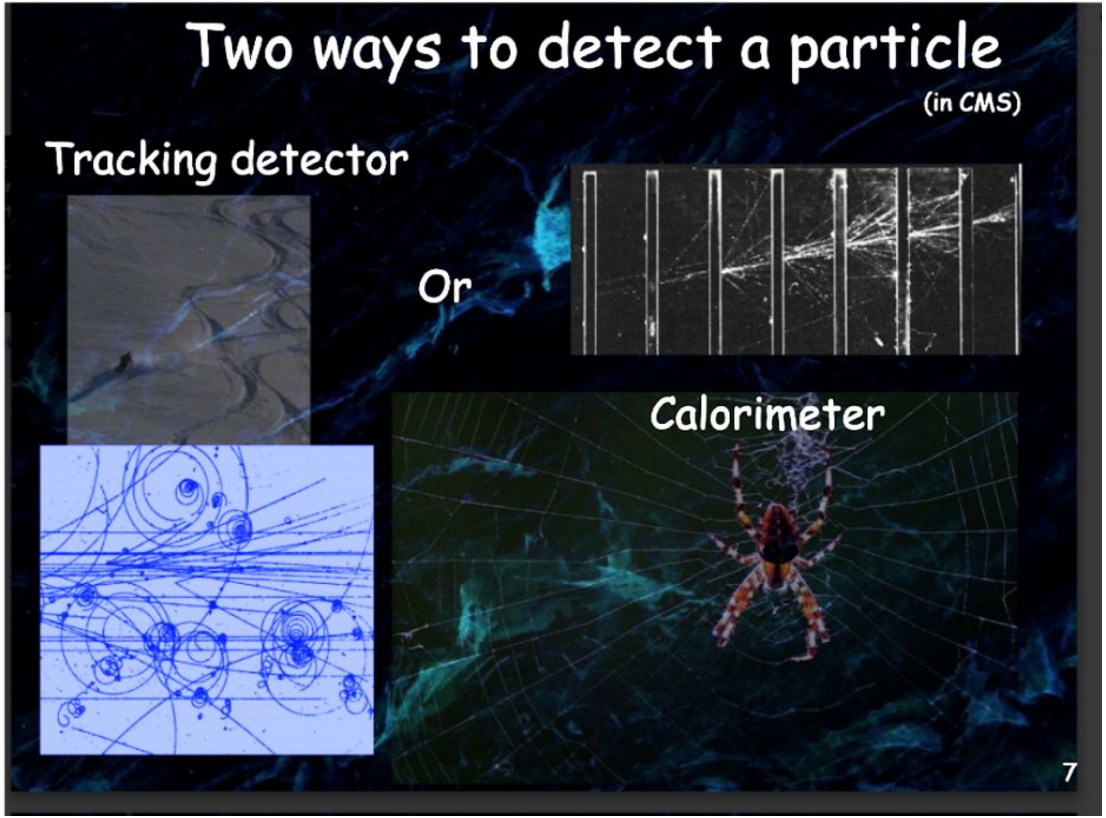
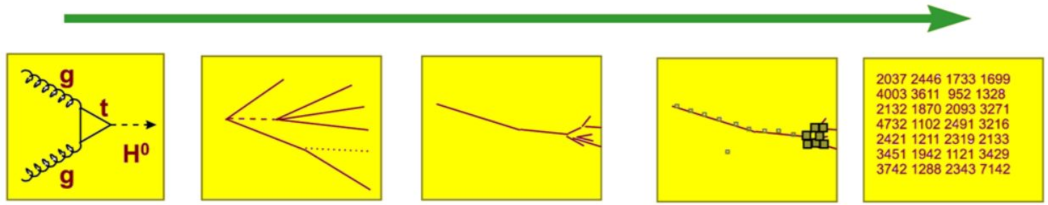
Just as hunters can identify animals from tracks in mud or snow, physicists identify subatomic particles from the traces they leave in detectors.



From Physics to Raw Data



Basic physics

Collision Point

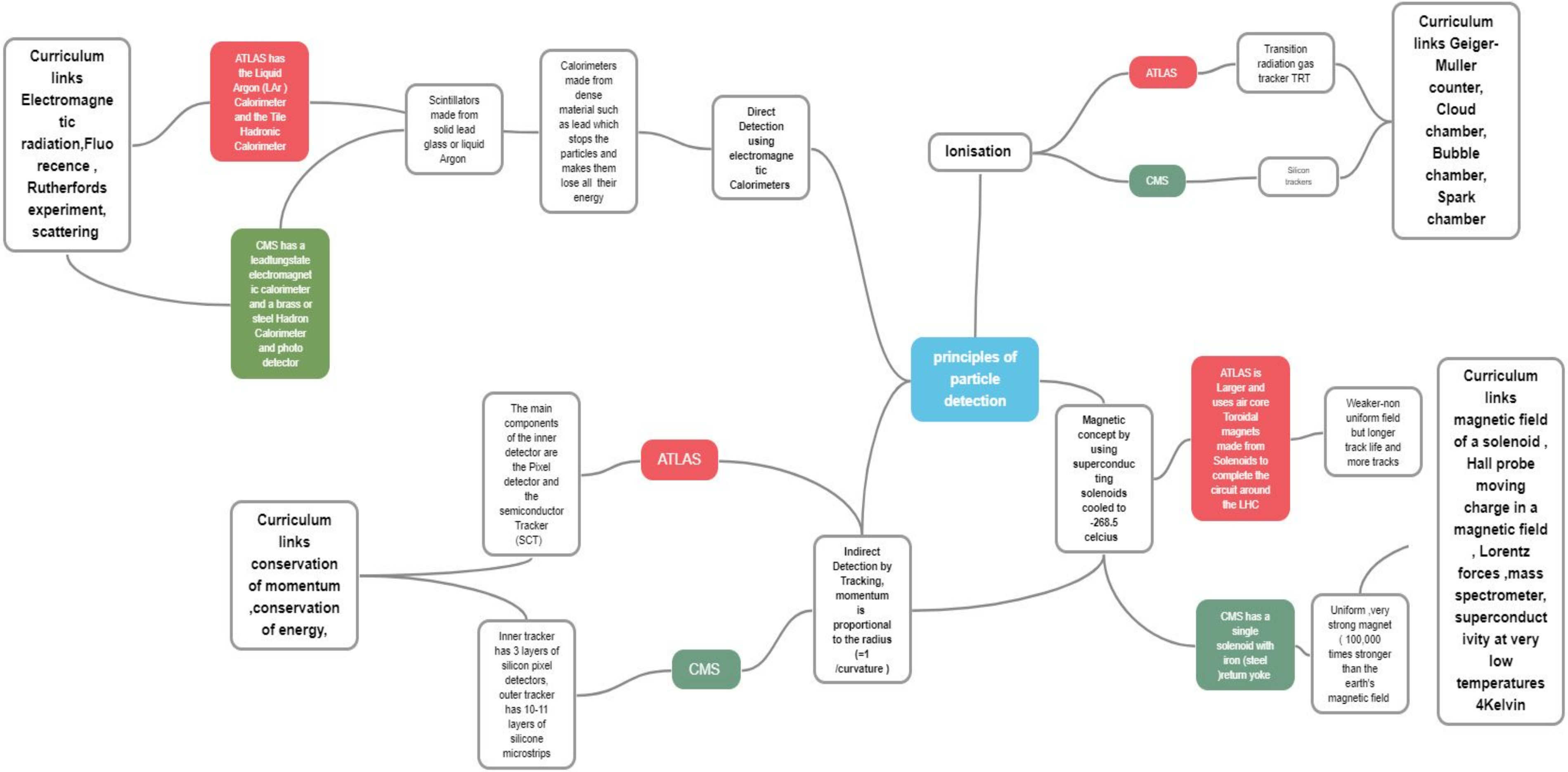
Fragmentation, Decay

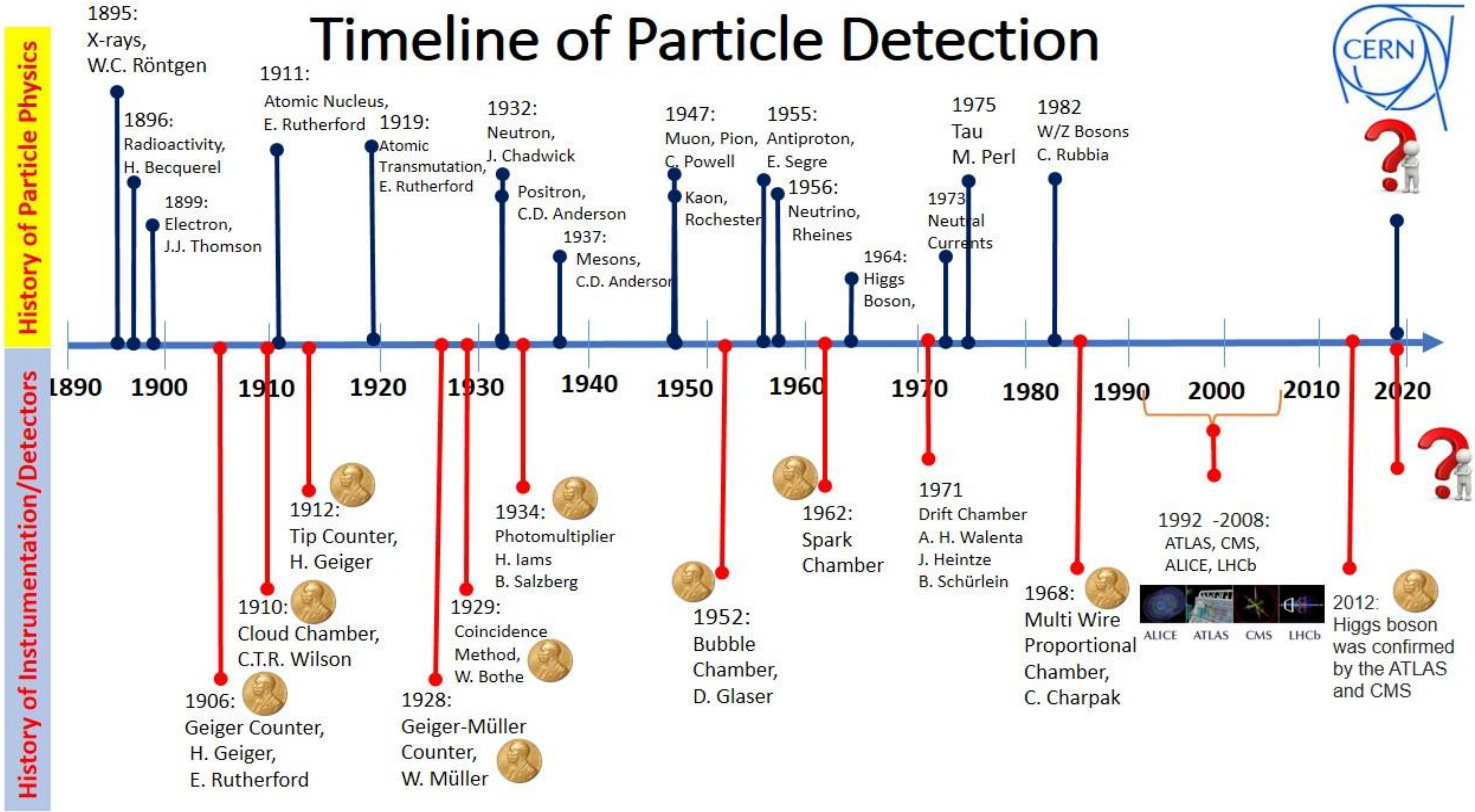
Interaction with detector material
Multiple scattering, interactions

Detector response
Noise, pile-up, cross-talk, inefficiency, ambiguity, resolution, response function, alignment

Raw data
Read-out addresses, ADC, TDC values, Bit patterns

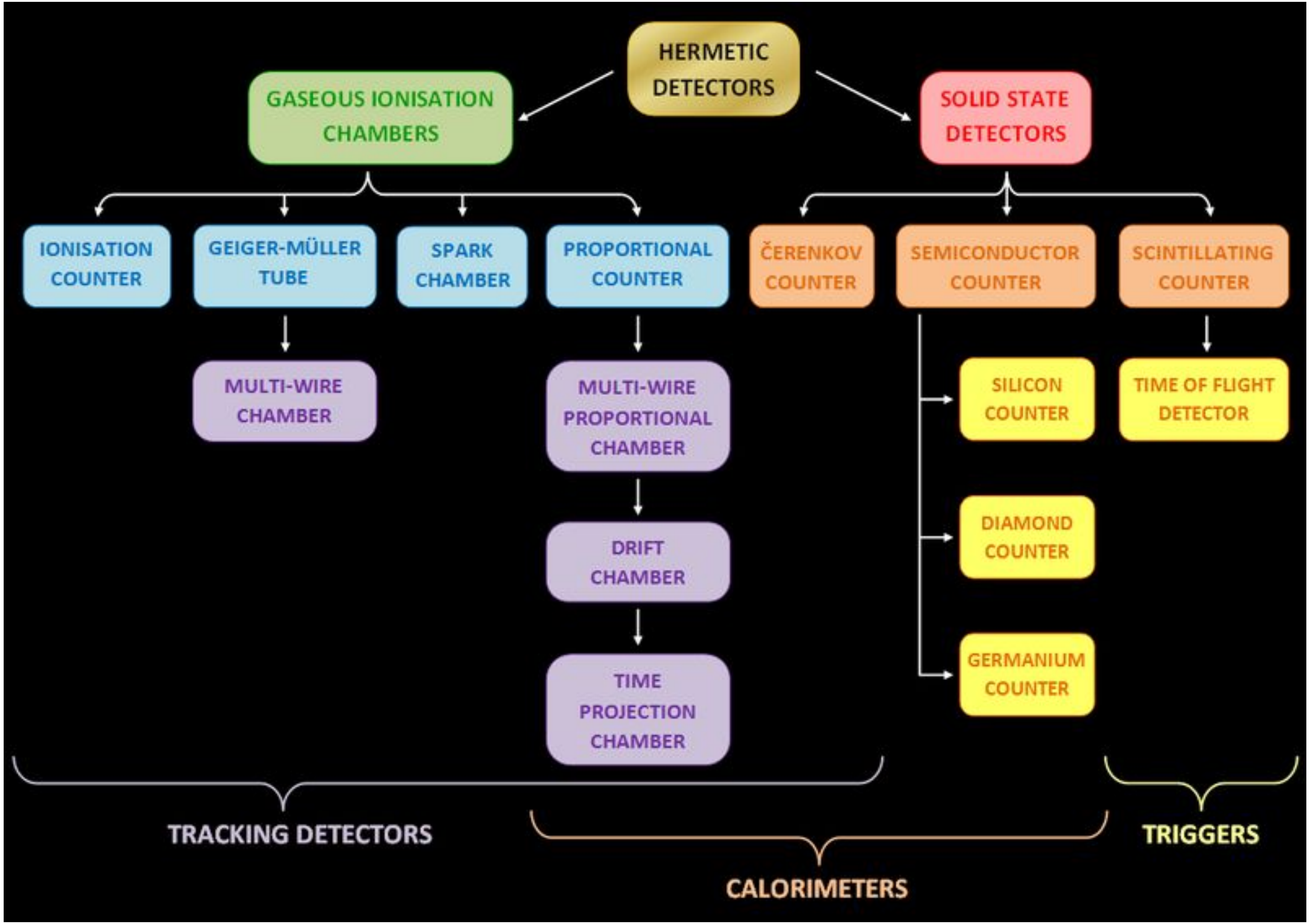
- **Actually recorded are raw data with ~1 GB/s for ATLAS/CMS**
  - mainly electronics numbers
    - e.g. number of a detector element where the ADC (Analog-to-Digital converter) saw a signal with x counts...


principles of particle detection
Direct Detection using electromagnetic Calorimeters
Calorimeters made from dense material such as lead which stops the particles and makes them lose all their energy
Scintillators made from solid lead glass or liquid Argon
ATLAS has the Liquid Argon (LAr) Calorimeter and the Tile Hadronic Calorimeter
CMS has a leadtungstate electromagnetic calorimeter and a brass or steel Hadron Calorimeter and photo detector
Curriculum links Electromagnetic radiation,Fluorecence , Rutherfords experiment, scattering
Ionisation
ATLAS
Transition radiation gas tracker TRT
CMS
Silicon trackers
Curriculum links Geiger-Muller counter, Cloud chamber, Bubble chamber, Spark chamber
Magnetic concept by using superconducting solenoids cooled to -268.5 celcius
ATLAS is Larger and uses air core Toroidal magnets made from Solenoids to complete the circuit around the LHC
Weaker-non uniform field but longer track life and more tracks
CMS has a single solenoid with iron (steel)return yoke
Uniform ,very strong magnet (100,000 times stronger than the earth's magnetic field
Curriculum links magnetic field of a solenoid , Hall probe moving charge in a magnetic field , Lorentz forces ,mass spectrometer, superconductivity at very low temperatures 4Kelvin
Indirect Detection by Tracking, momentum is proportional to the radius (=1 /curvature)
ATLAS
The main components of the inner detector are the Pixel detector and the semiconductor Tracker (SCT)
CMS
Inner tracker has 3 layers of silicon pixel detectors, outer tracker has 10-11 layers of silicone microstrips
Curriculum links conservation of momentum ,conservation of energy,



Timeline of Particle Detection
CERN
History of Particle Physics
History of Instrumentation/Detectors
1895: X-rays, W.C. Röntgen
1896: Radioactivity, H. Becquerel
1899: Electron, J.J. Thomson
1911: Atomic Nucleus, E. Rutherford
1919: Atomic Transmutation, E. Rutherford
1932: Neutron, J. Chadwick
Positron, C.D. Anderson
1937: Mesons, C.D. Anderson
1947: Muon, Pion, C. Powell
Kaon, Rochester
1955: Antiproton, E. Segre
1956: Neutrino, Rheines
1964: Higgs Boson,
1973 Neutral Currents
1975 Tau M. Perl
1982 W/Z Bosons C. Rubbia
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
1906: Geiger Counter, H. Geiger, E. Rutherford
1910: Cloud Chamber, C.T.R. Wilson
1912: Tip Counter, H. Geiger
1928: Geiger-Müller Counter, W. Müller
1929: Coincidence Method, W. Bothe
1934: Photomultiplier H. Iams B. Salzberg
1952: Bubble Chamber, D. Glaser
1962: Spark Chamber
1971 Drift Chamber A. H. Walenta J. Heintze B. Schürlein
1968: Multi Wire Proportional Chamber, C. Charpak
1992 -2008: ATLAS, CMS, ALICE, LHCb
ALICE
ATLAS
CMS
LHCb
2012: Higgs boson was confirmed by the ATLAS and CMS

The detector zoo

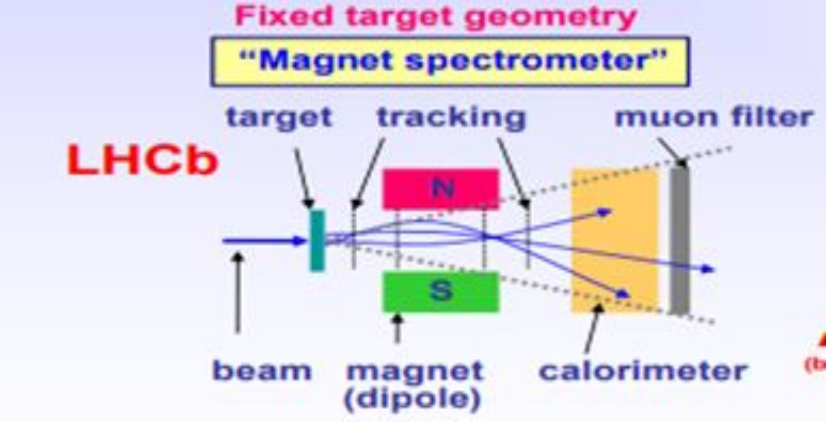


Basic principles of particle detection

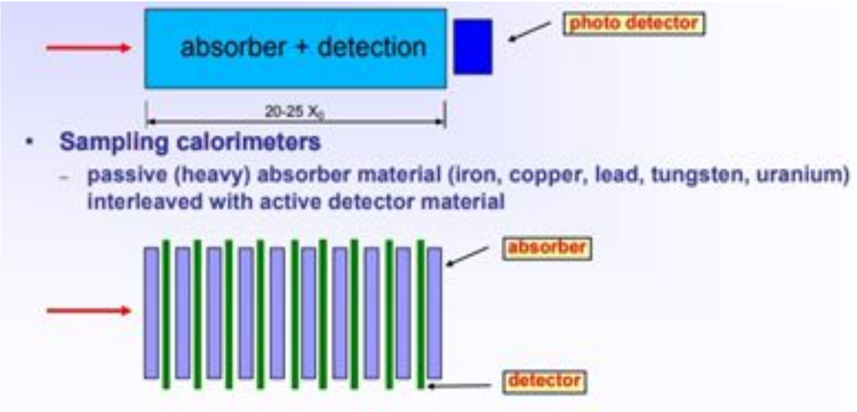
The information obtained on a particle like speed, mass, and electric charge help physicists to work out the identity of a particle. The detectors are made up of strong magnetic field (4T) with operating temperature of about 4K and an electric current of 20KA for bending the highly energetic particles, The detectors like CMS have 3 main types of sub-detector. Tracking device,Calorimeters and Particle identification detector.
A particle normally travels in a straight line, but in the presence of a magnetic field around the particle detector, its path is bent into a curve, the curvature of the path helps to calculate the momentum and hence identify its type. Particles with very high momentum travel in almost straight lines, whereas those with low momentum move forward in tight spirals inside the detector.

Tracking devices

In particle physics, **tracking** is the process of reconstructing the trajectory (or **track**) of electrically charged particles in a particle detector known as a **tracker**. Tracking devices reveal the paths of electrically charged particles through the trails they leave behind/ as they pass through, the modern tracking devices do not make the tracks of particles directly visible. Instead, they produce tiny electrical signals that a computer program can reconstructs the patterns of tracks recorded by the detector, and displays them on a screen. The tracker has layers made up of silicon



Calorimeters and Particle identification detectors



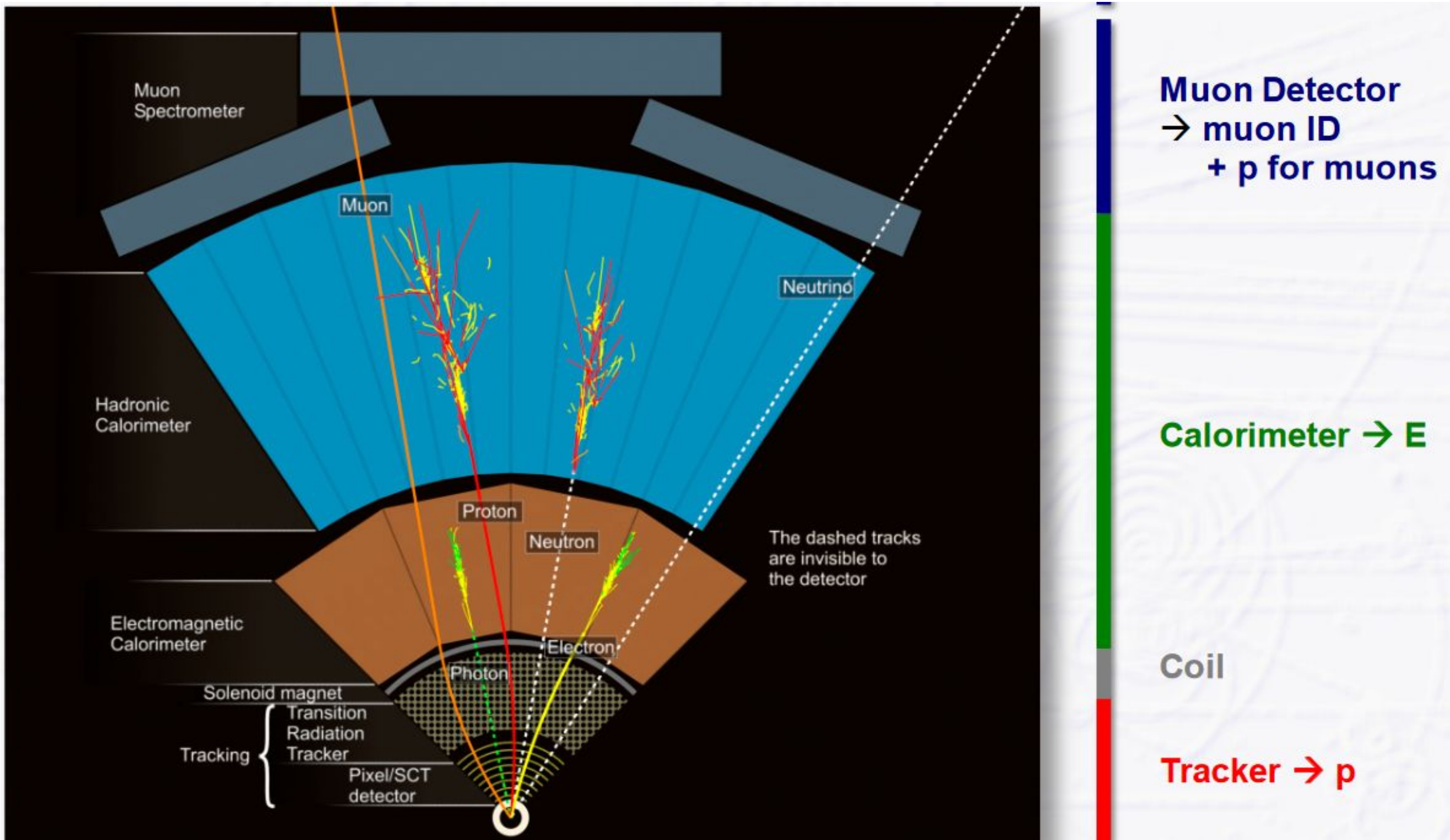
A calorimeter measures the energy of a particle by stopping or absorbing its energy.the particle are, forced to deposit all of their energy within the detector. Calorimeters consist of layers of “passive” (heavy) or “absorbing”material,e.g iron, copper, tungsten, lead – interleaved with layers of an “active” medium such as solid lead-glass or liquid argon. Calorimeters such as Electromagnetic calorimeters (ECAL), measure the energy of light particles like electrons and photons as they interact with the electrically charged particles in matter while Hadronic calorimeters (HCAL), samples the energy of hadrons (particles containing quarks, such as protons and neutrons) as they interact with atomic nuclei.

Calorimeters can stop most known particles except muons and neutrinos, muons interacts very little with matter – it can travel through metres of dense material before it is stopped. For this reason, muon chambers – tracking devices are specialized to be the outermost layer of a detector.

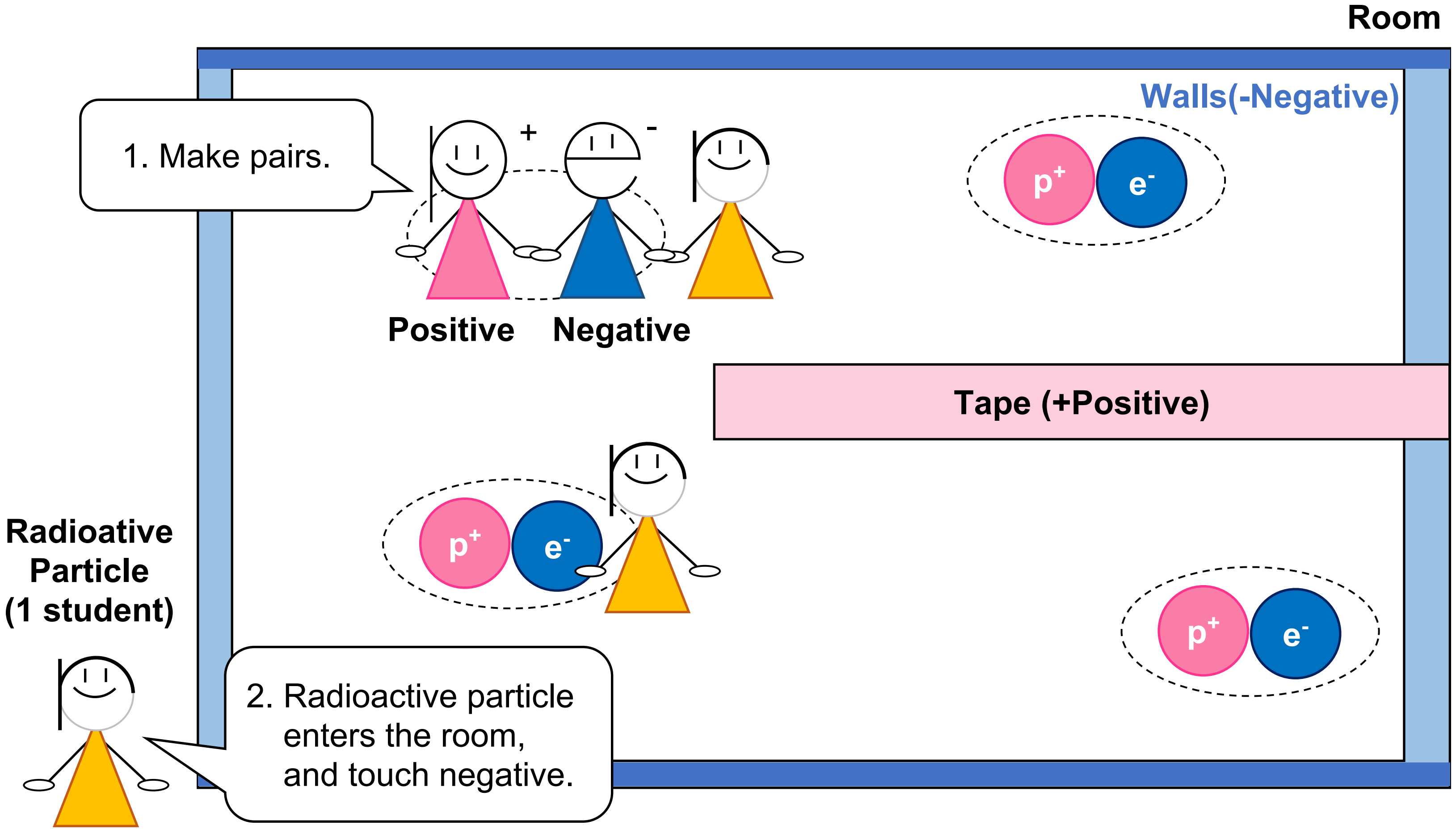
Particle-identification detectors: Once a particle has passed through the tracking devices and the calorimeters, the rest task is to identity. The method work by detecting radiation emitted by charged particles.This is done through:-

- Cherenkov radiation: this is light emitted when a charged particle travels faster than the speed of light through a given medium. The light is given off at a specific angle according to the velocity of the particle. Combined with a measurement of the momentum of the particle, the velocity can be used to determine the mass and hence to identify the particle.
- Transition radiation: this radiation is produced by a fast charged particle as it crosses the boundary between two electrical insulators with different resistances to electric currents. The phenomenon is related to the energy of a particle and distinguishes different particle types.

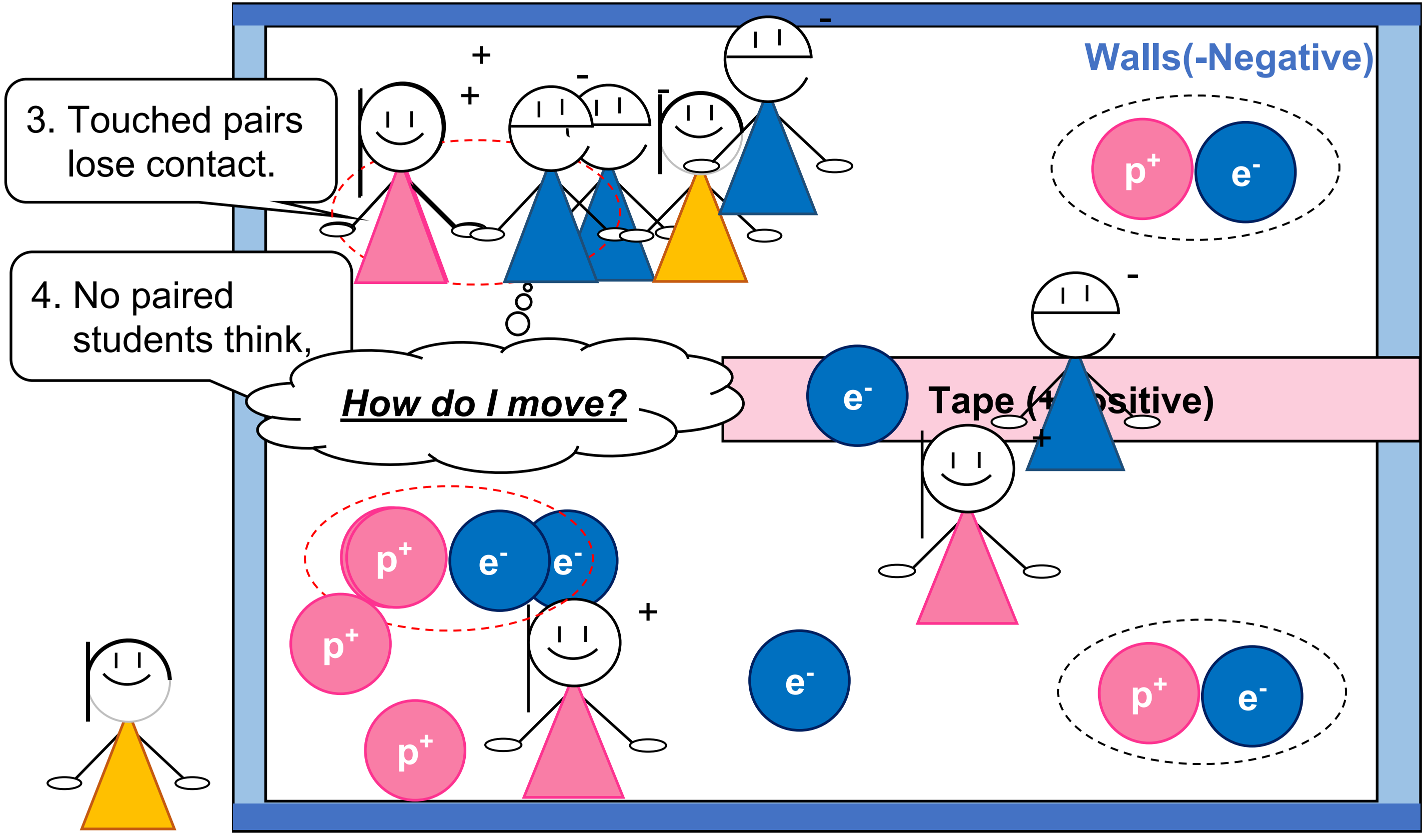
Particle identification detector



Activities: Ionisation - Game



Activities: Ionisation - Game



Rule

- In case negative students are touched, they have to lose contact with partner.

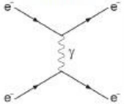
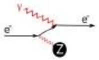
Aim

- Learn mechanisms of ionisation and Geiger-Müller-counter.
- Think movements of positive, negative and radioactive particles.

Interactive simulation:
http://www.gigaphysics.com/gmtube_lab.html

Tracking particles with a cloud chamber

Tracks of the particles in cloud chamber

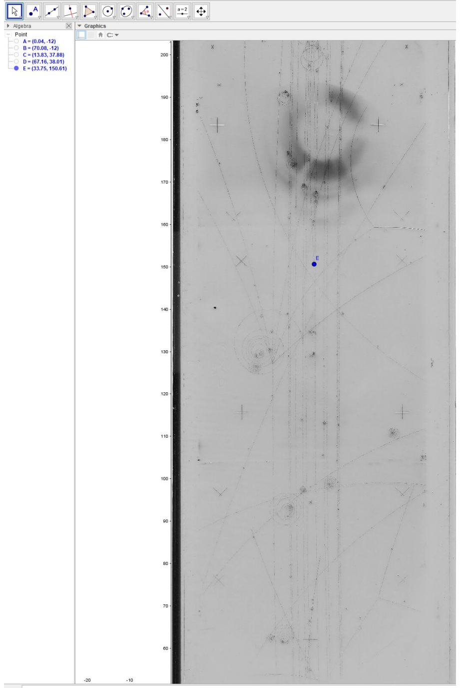
Pictures © Karlsruher Institut für Technologie (KIT)	Particle	Explanation
	**muon or anti-muon**	Thin straight tracks - fast particles with high kinetic energy - they ionise molecules without scattering - high energy muons, electrons or their corresponding anti-particles - source: secondary cosmic particles
	**electron or positron**	
	**α particle system**	Thick straight tracks (approx. 5 cm): - alpha particle systems (2p2n) - massive particle systems with high “ionisation density” (for alpha: 1 MeV/cm) - source: Radon-222 gas, natural radiation
	**electron** 	Curly / curved tracks: - slow electrons scatter with other electrons via electromagnetic interaction - the lower the momentum of a particle, the easier it scatters - Photoelectrons are low energy electrons set free by high energy photons (via Photoelectric effect) - Source: muon transformation, beta emitters, photoelectric effect
	**photoelectron** 	

Benefits of an old-fashioned detector - The bubble chamber

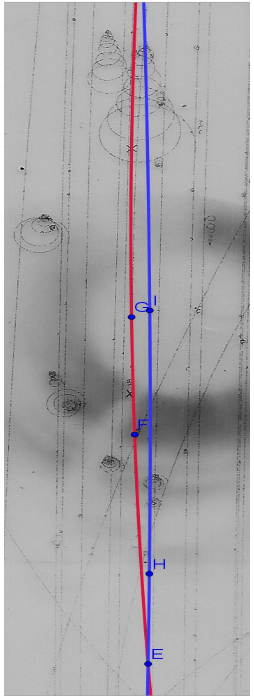
- What are those very different lines?
  Misconception: “*We see particles…*”
  Misconception: *The students think, what they see is the path of the particle rather than it’s projection in 2D.*
- What can we learn from right- (left-) curved traces?
  Chance: *Revision of Right/Left-Hand-rule / Lorentz-Force*
- Can we do more with such pictures?
  Chance: *Introduction of weak charge in addition to el. charge.*
  Chance: *Calculating momentum and energy by measuring the radius.*
  Therefore: *use geogebra!*
  Problem: *2D-projection, missing z-component of momentum.*

<u>Transformation</u> of a neutral particle - Example in ggb

1.) Import to geogebra and scale.



2.) construct circles and measure radii.



3.) Calculate projections of momentum of each particle and calculate total momentum.

$$F_Z = F_L$$

$$m \cdot \frac{v^2}{r} = e \cdot v \cdot B$$

$$\rightarrow p = m \cdot v = e \cdot B \cdot r$$

4.) Calculate energy of every new particle and calculate total energy.

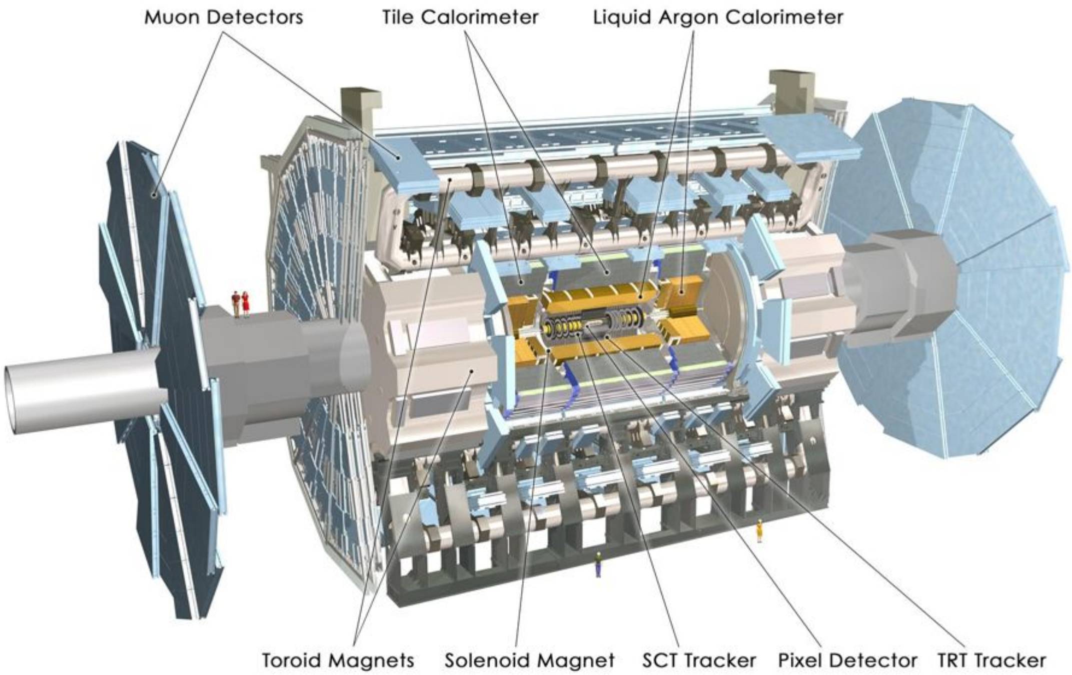
$$E^2 = (m_0 \cdot c^2)^2 + (p \cdot c)^2$$

5.) Calculate invariant mass.

$$m_0^2 = \left(\frac{E}{c^2}\right)^2 - \left(\frac{p}{c}\right)^2$$

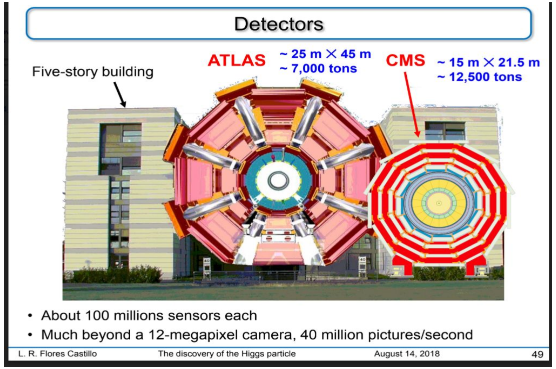
To make it easy: Prepare excel-sheet and work with units of eV, eV/c, eV/c²...

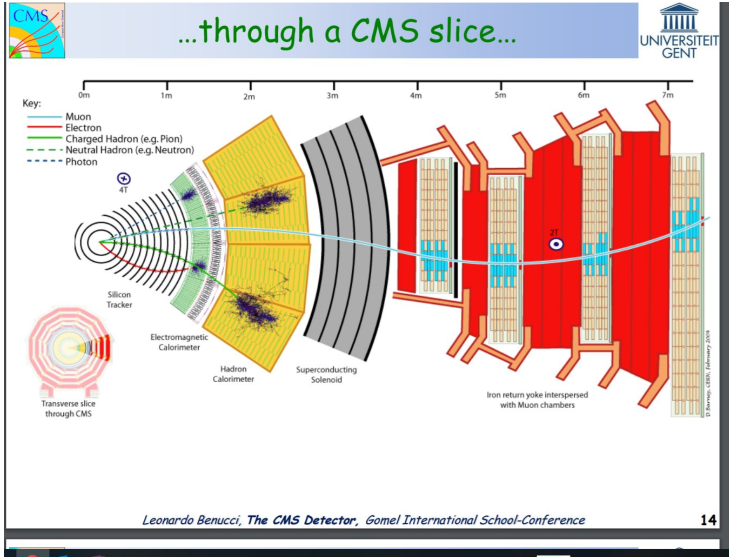
Activity: ATLAS-Detector and parts

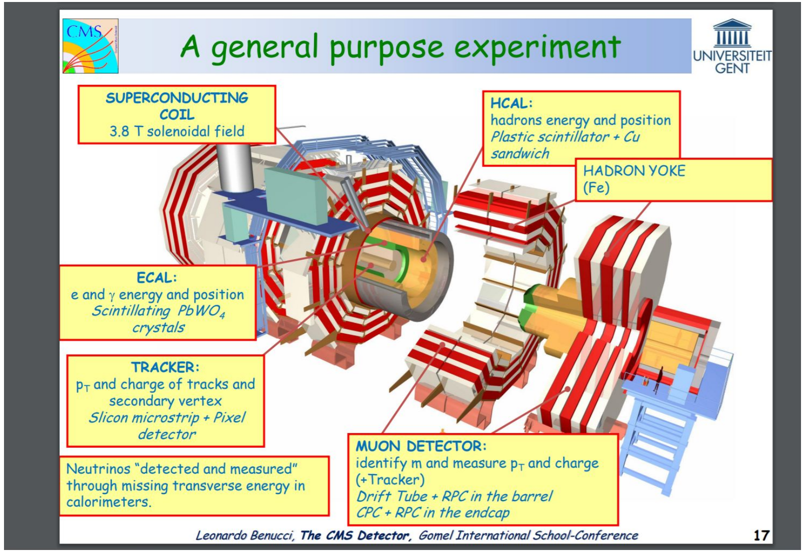


Identifying particles animation
https://kjende.web.cern.ch/kjende/en/wpath_teilchenid1.htm

The CMS Detector







References

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(2)https://indico.cern.ch/event/43007/contributions/1065007/attachments/927851/1313682/HistoryInstrumentation.pdf

(3)http://users.sch.gr/papandre/cern/?page_id=286

(4) http://gomelschool.hep.by/Talks/29.07_1_CMSDetector_LBenucci.pdf

(5) https://atlas.cern/discover/detector/inner-detector

(6)https://indico.cern.ch/event/425968/contributions/1913125/attachments/905691/1278148/marc.weber.milano.atlastracker3.pdf

(7) https://en.wikipedia.org/wiki/Particle_detector

Un hommage à la ITW2018