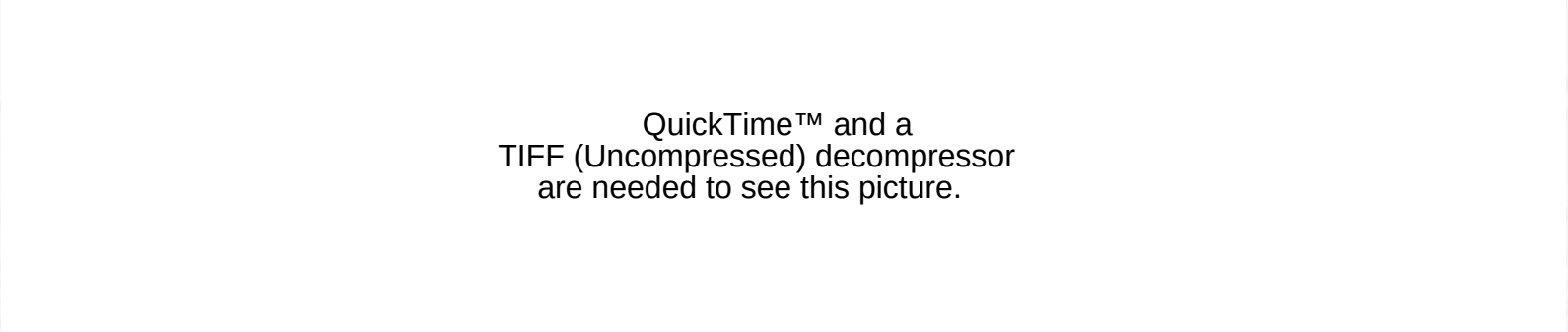
Particle Physics Experiments



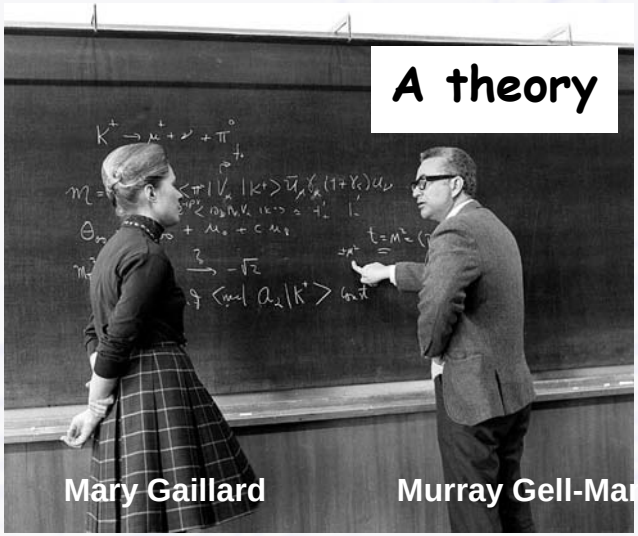
HEP Detectors and their Technologies

Silvia Schuh
CERN

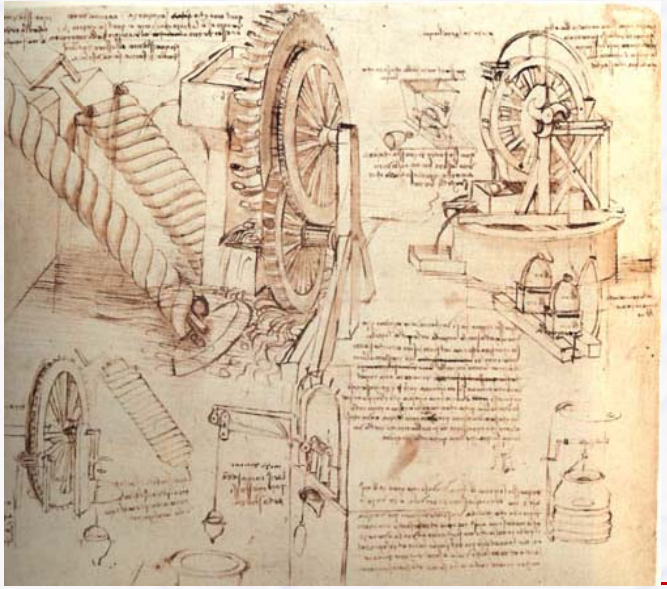
Overview

- Introduction and Concepts
- Properties of Particles
  - Which are measurable? How?
- Particle Interactions
- Particle Detectors in HEP
  - Tracking Detectors
  - Energy Measurement
  - Particle Identification
  - Infrastructure
  - Existing Particle Detectors

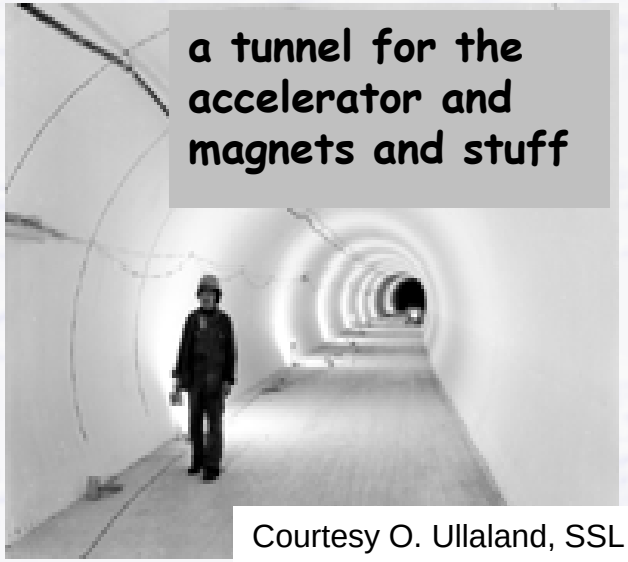
For a HEP Experiment one needs…



a cafeteria



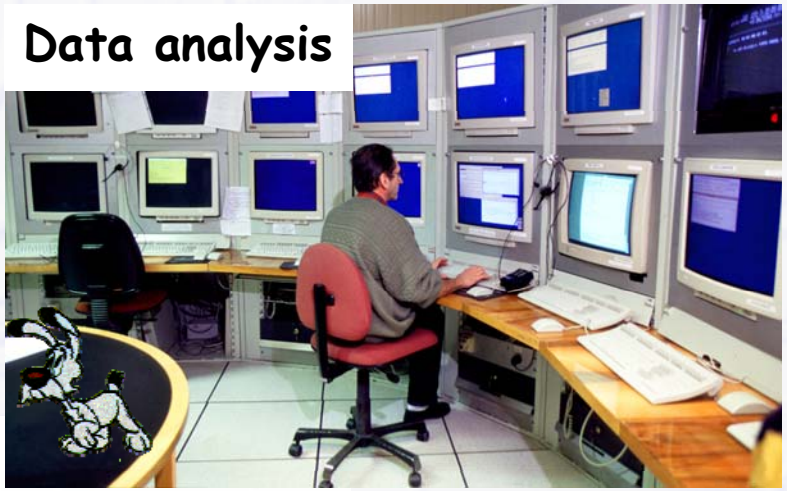
Clear and easy to understand drawings



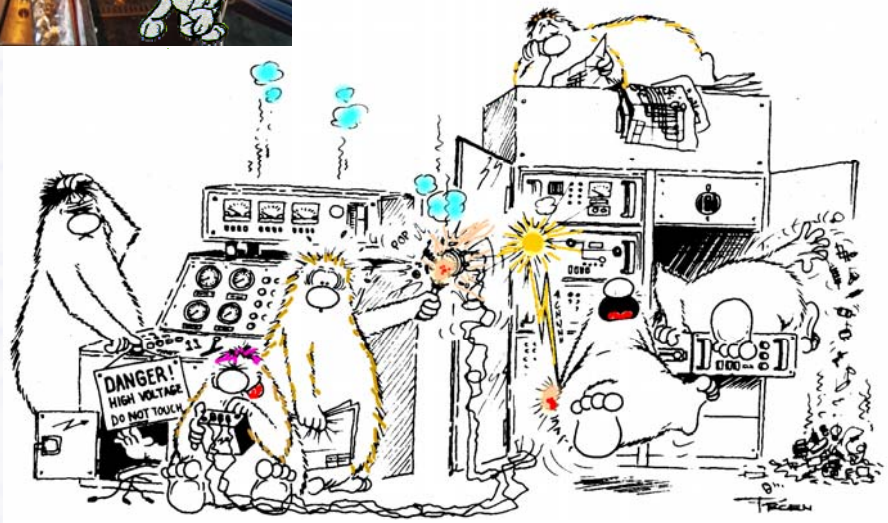
Courtesy O. Ullaland, SSL 2006

… and also …

Data analysis



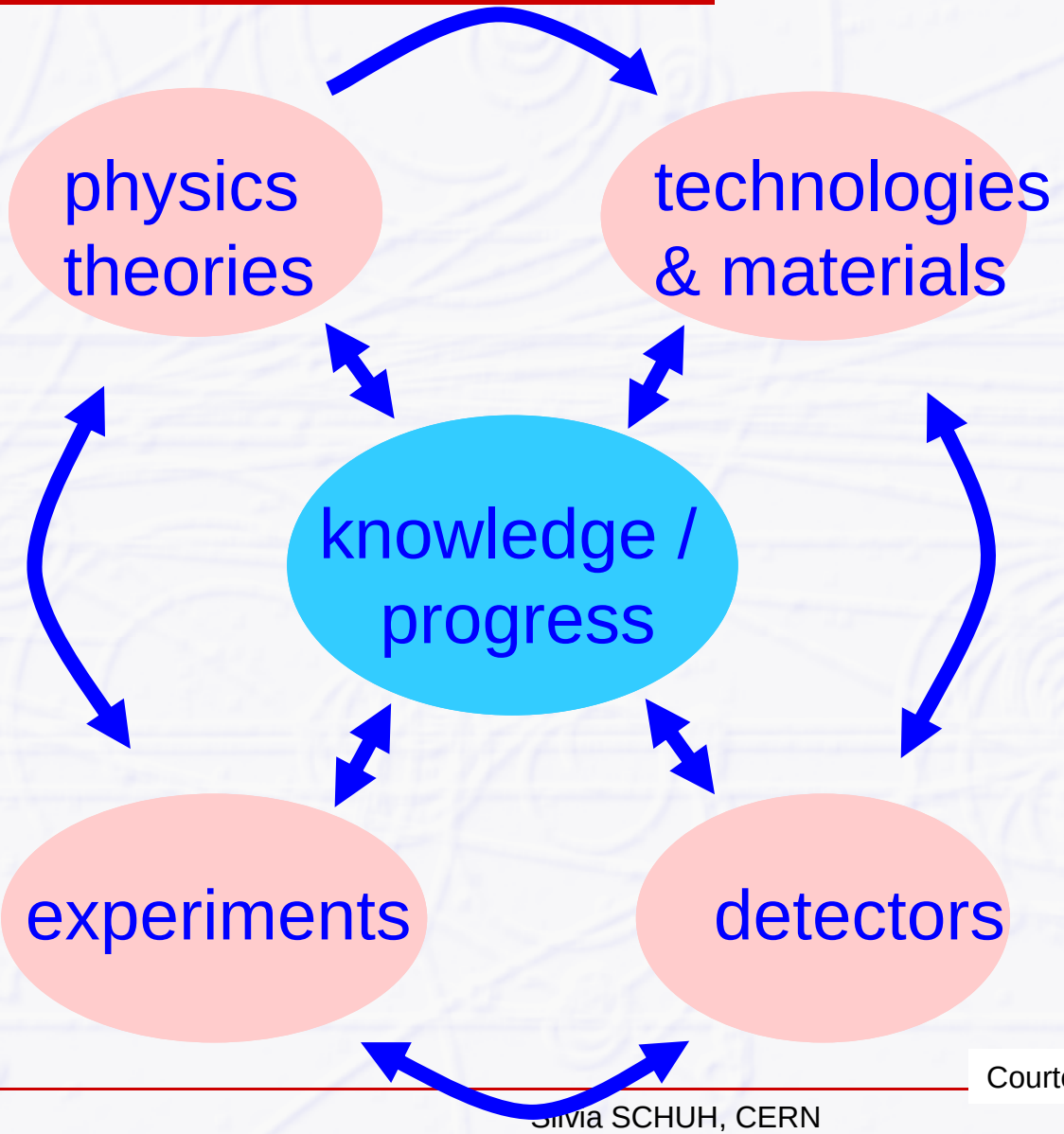
BUT:



We will just concentrate on the detectors

Courtesy O. Ullaland, SSL 2006

Progress Cycle



Courtesy C. Joram, SSL 2003

Useful units & relations

$$E^2 = p^2c^2 + m_0^2c^4$$

energy E: measured in eV
momentum p: measured in eV/c
mass m_0 : measured in eV/c^2

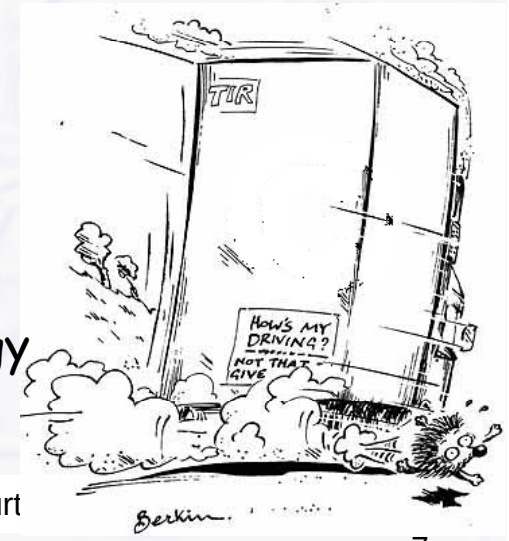
$$p = \left.\begin{pmatrix} p_1 \\ p_2 \\ p_3 \end{pmatrix}\right\} \begin{matrix} E \\ \end{matrix} \qquad \begin{pmatrix} E \\ p \end{pmatrix}$$

$$\beta = \frac{v}{c} \qquad (0 \le \beta < 1) \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}} \qquad (1 \le \gamma < \infty)$$

$$E = m_0\gamma c^2 \qquad p = m_0\gamma\beta c \qquad \beta = \frac{pc}{E}$$

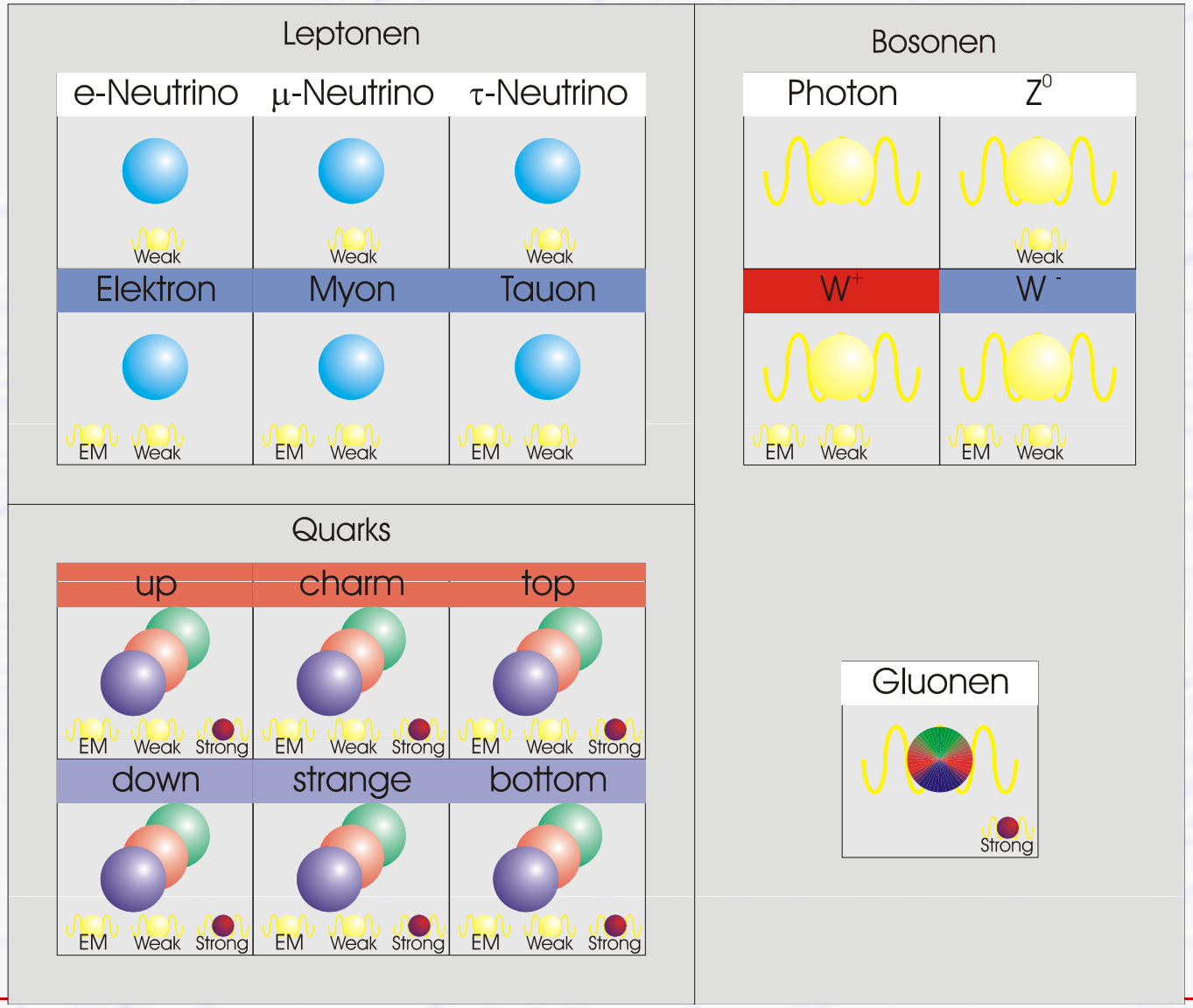
1 eV is a small energy:
1 eV = $1.6 \cdot 10^{-19}$ J
m_{bee} = 1g = $5.8 \cdot 10^{32}$ eV/c^2
v_{bee} = 1 m/s $\rightarrow E_{bee} = 10^{-3}$ J = $6.25 \cdot 10^{15}$ eV
$E_{LHC} = 14 \cdot 10^{12}$ eV

However, LHC has total stored beam energy
10^{14} protons $\times\ 14 \cdot 10^{12}$ eV $\cong 10^8$ J
or, one 100t truck at 100 km/h

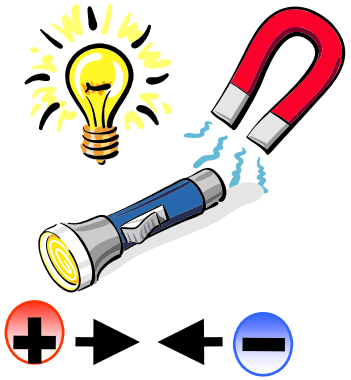


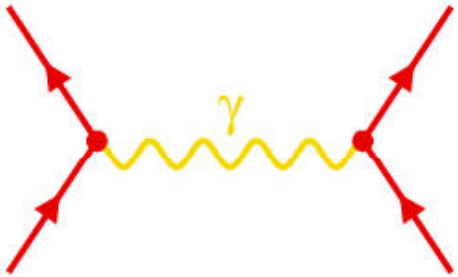
Court

Elementary Particles

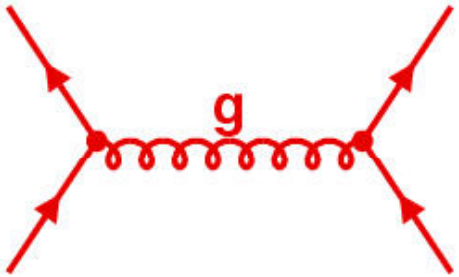


Fundamental Forces

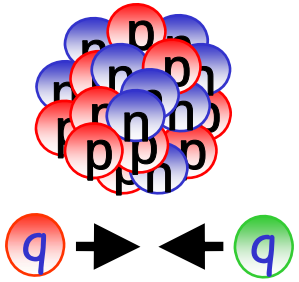


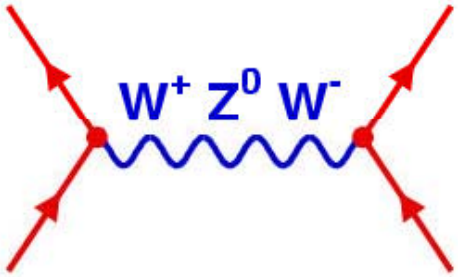


Electromagnetic force

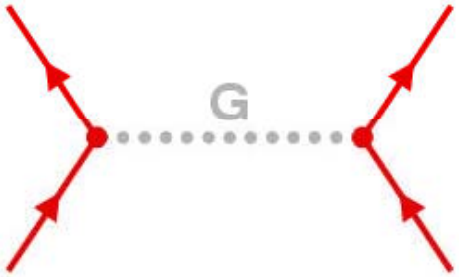


Strong force

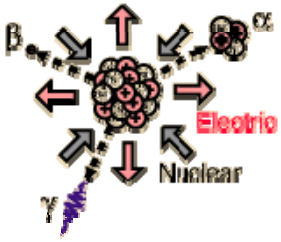




Weak force



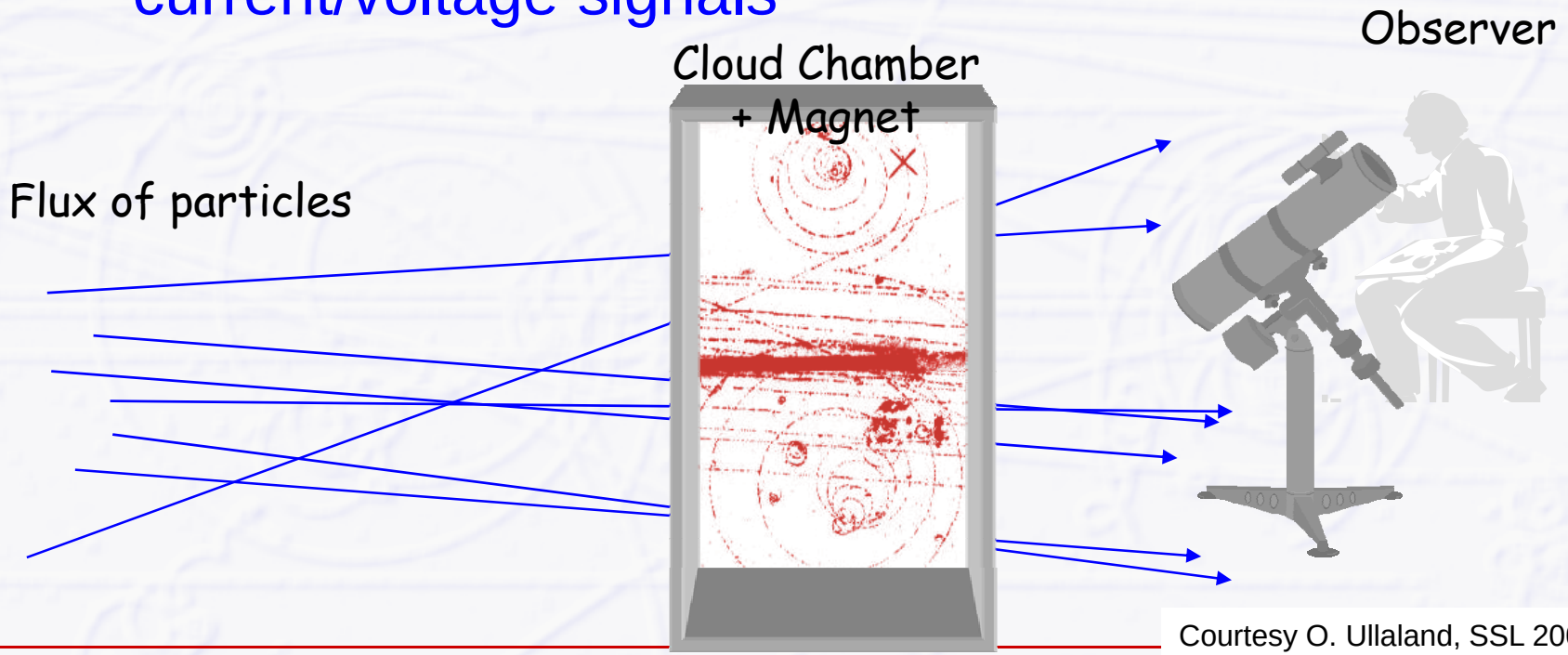
Gravitation



weakest 'force':
in microcosm
insignificant

Particle Detection

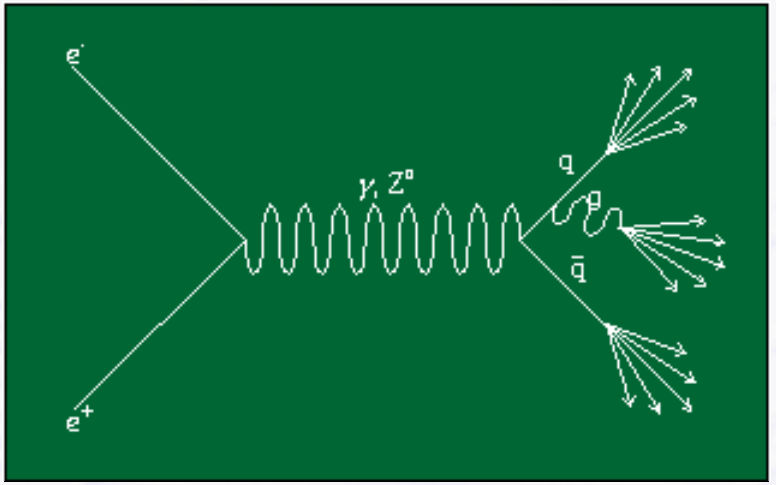
- Particles cannot be seen/measured “directly”
  - Measurement occurs via interaction with matter ⊕ magnetic fields
  - Observation → Conversion into optical images or current/voltage signals



Courtesy O. Ullaland, SSL 2006

Studying Interactions

- via scattering
- via annihilation

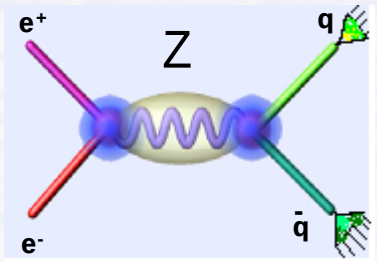


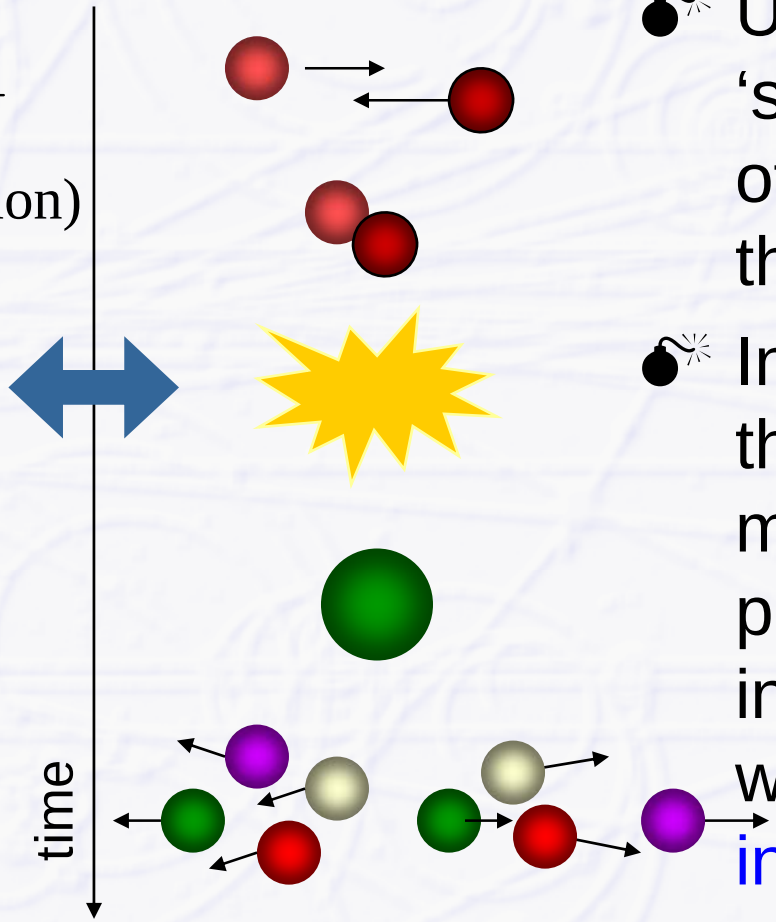
- via the production of new particles
- all interactions are produced in
  - Colliding Beam Experiments or
  - Fixed Target Experiments

Colliding particles - an artists view

$$e^+ + e^- \rightarrow Z^0 \rightarrow q\bar{q}$$

$$(+\text{hadronization})$$





- Usually we can only 'see' the end products of the reaction, but not the reaction itself.
- In order to reconstruct the reaction mechanism and the properties of the involved particles, we want the maximum information about the end products !

Courtesy C. Joram, SSL 2003

Ideal Detectors?

- In an ideal detector, one could record 100% of any interaction, capture and measure perfectly all properties of all emerging particles, and by this reconstruct the complete event.

- This would give us the power to compare the interaction directly to theoretical predictions without most uncertainties.

- NB: (In)Efficiency
  - not all particles are detected, some leave the detector without any trace (neutrinos), some escape through not sensitive detector areas (holes, cracks for e.g. water cooling and gas pipes, cables, electronics, mechanics)

Particle Properties

- Which properties does a particle have?
  - energy
  - momentum
  - charge
  - ~~mass~~
  - life time
  - ~~spin~~
  - decay modes

- And which of those are measurable?

Particle Properties

$$p = \left.\begin{pmatrix} E \\ p_1 \\ p_2 \\ p_3 \end{pmatrix}\right\} \begin{pmatrix} E \\ p \end{pmatrix}$$

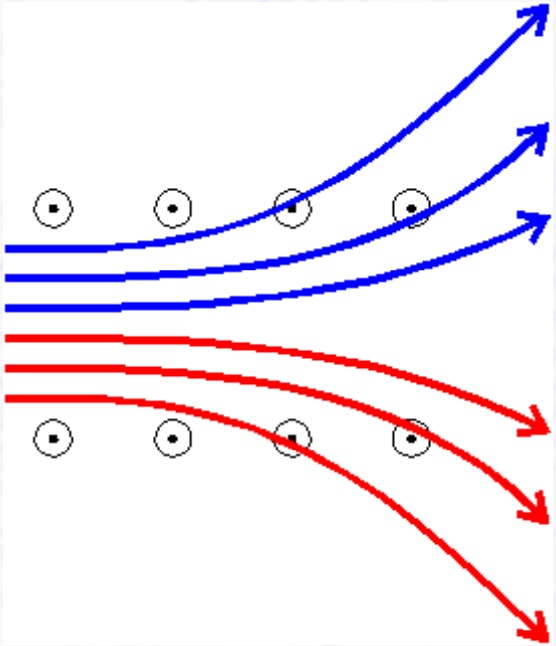
- Which properties can we derive?
  - Mass

$$E^2 = m^2 \cdot c^4 + p^2 c^2 \Rightarrow m = \frac{\sqrt{E^2 - p^2 c^2}}{c^2}$$

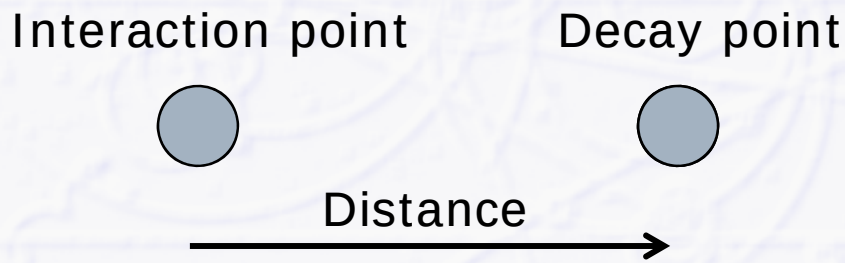
  - Spin
    - A bit more abstract from angular distributions

Particle Properties

- charge

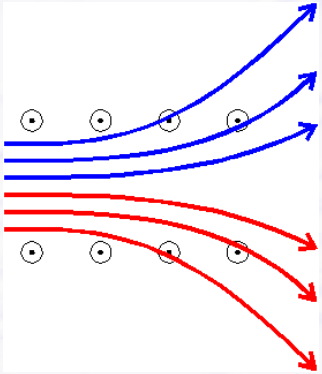


- lifetime



Measuring Particle Properties

- momentum



$$F = q \cdot v \cdot B = m \cdot \frac{v^2}{R}$$

$$\Rightarrow q \cdot B \cdot R = m \cdot v = |p|$$

- velocity
  - time of flight
  - RICH
- energy
  - calorimeter

Which particles can be detected?

- Charged Particles

$$e^+, e^-, p, \pi^\pm, \mu^\pm$$

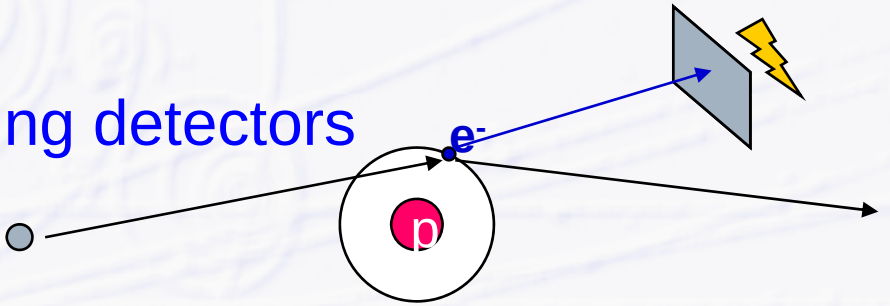
- Neutral Particles

$$\gamma, n, \pi^0, \nu$$

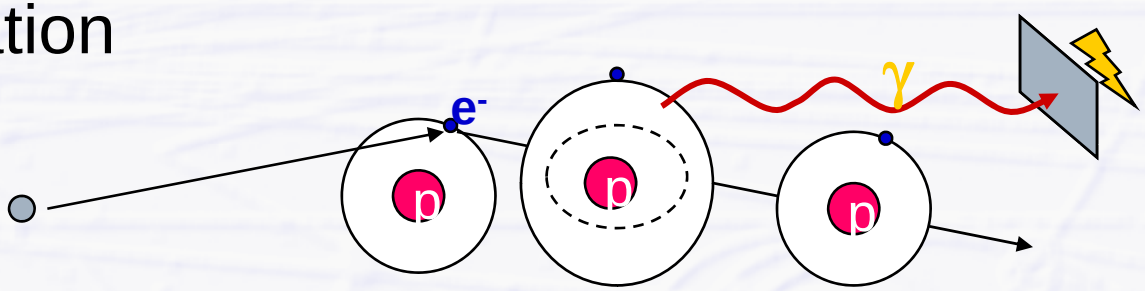
- Different particle types interact very differently with the detector material.

Particle Interactions - charged particles

- Ionization
  - Basic mechanism in tracking detectors



- Excitation/Scintillation

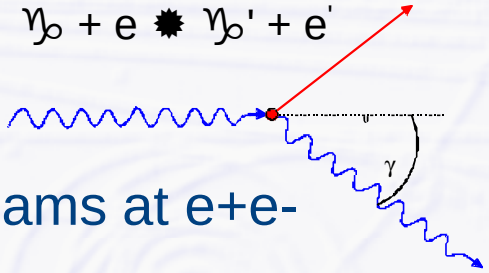


- (Multiple) elastic scattering w/ atoms of detector material
  - Unwanted, changes initial direction
- Photon radiation
  - Bremsstrahlung (accelerated charge radiates photons), Cherenkov light (faster than light in medium), Transition radiation

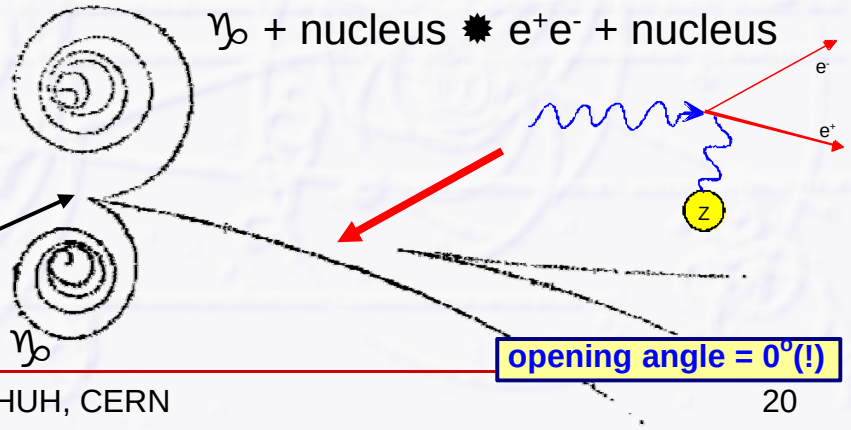
Particle Interactions - photons

- Photo effect
  - photo detectors: knock-out electrons on photo cathodes (vacuum and gas) or at semi conductors (surface)
    - Photo Multiplier Tubes (PMT), photo diodes

- Compton scattering (e-γ scattering)
  - not used for particle detection
    - used for polarization measurement of beams at e+e- machines

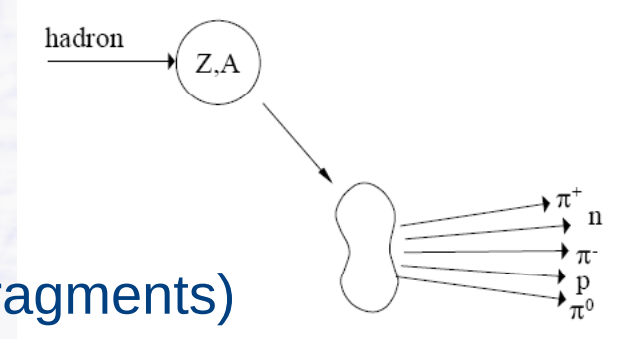


- Pair production ($\gamma \rightarrow$e+e-)
  - initiates electromagnetic shower in calorimeters, unwanted in tracking detectors



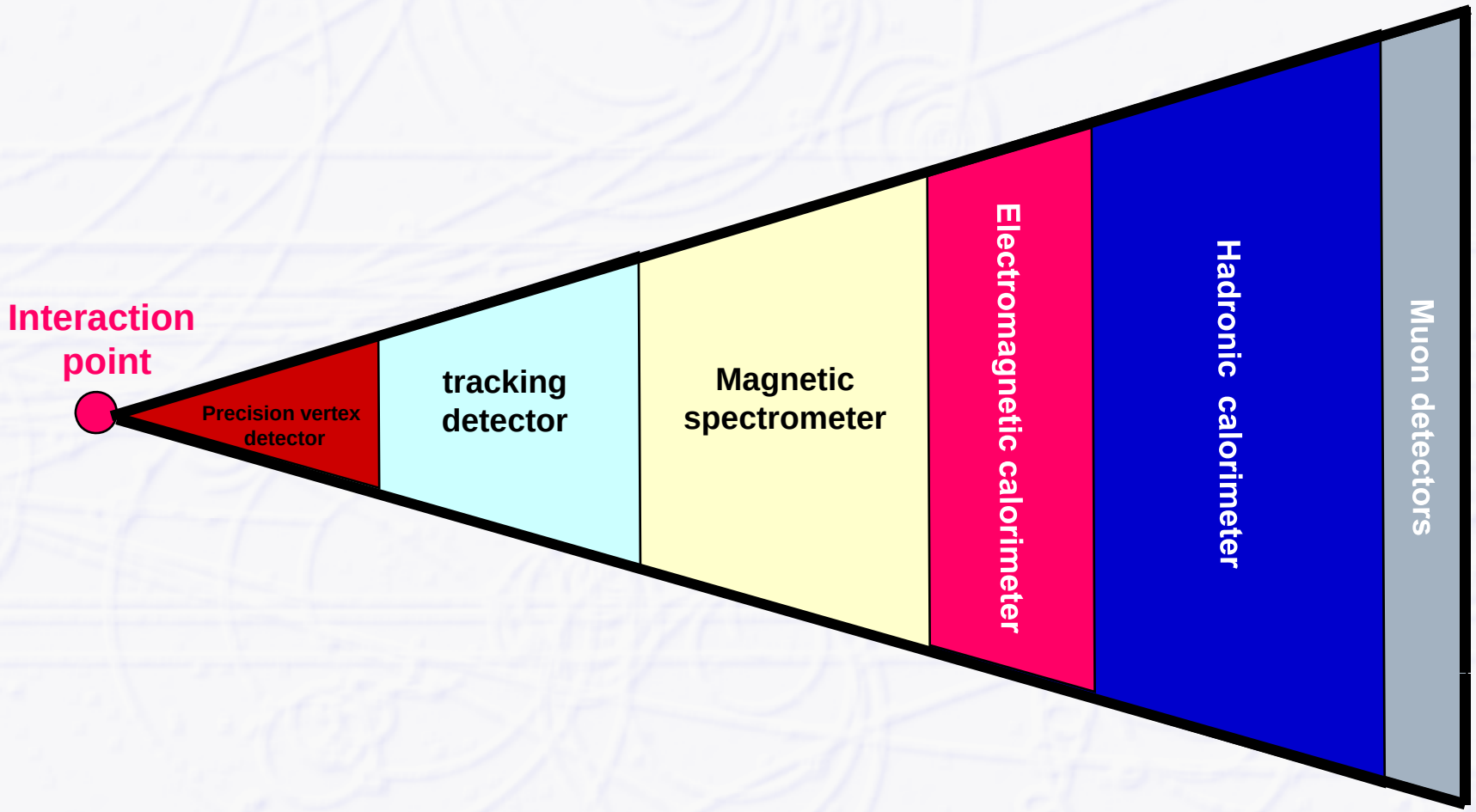
Particle Interactions - other

- Hadronic Particles
  - Strong Force – Inelastic nuclear interaction
    - Charged and uncharged hadrons (p, K, π, n ...)
    - Result: nuclear fragments (really measured are charged fragments)

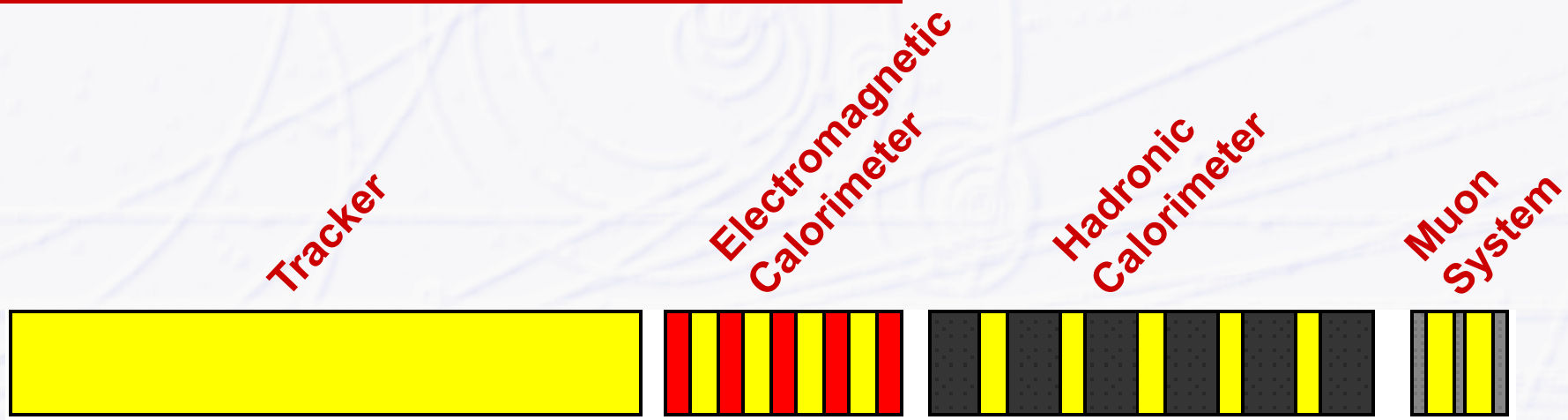


- Neutrinos
  - „No“ interaction in particle detectors at accelerators
  - Signature: Missing Energy

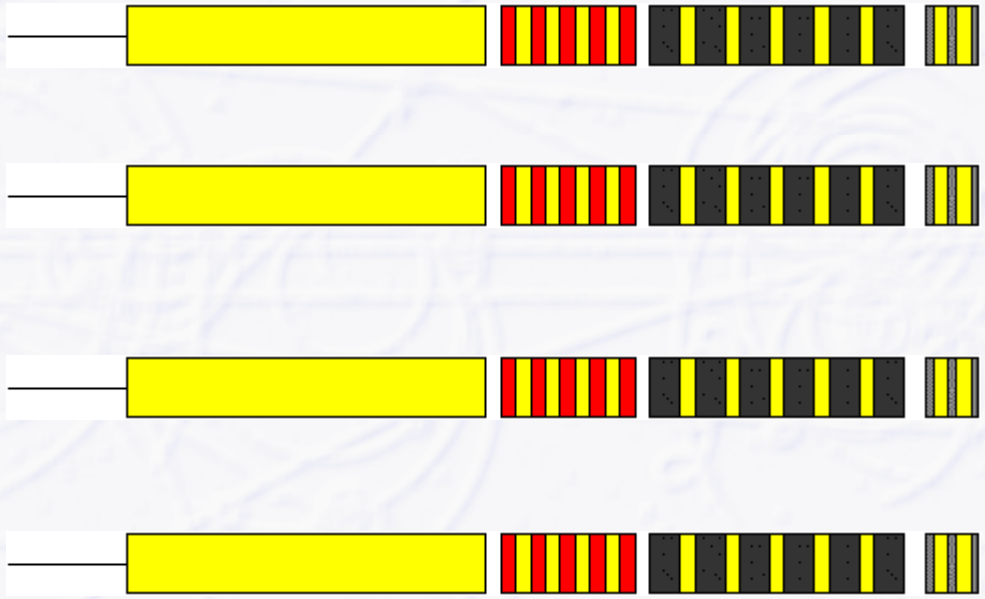
A Typical Detector Concept



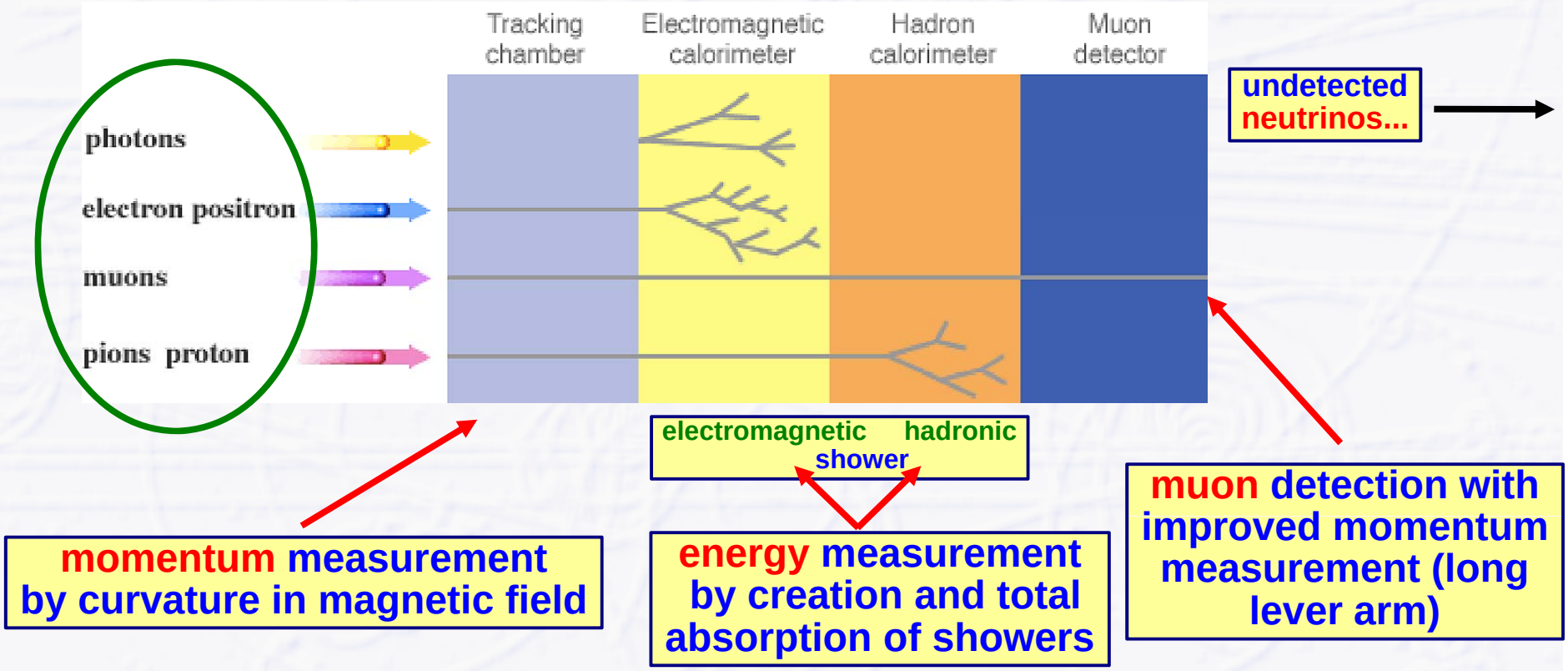
Passage of Particles - Ingredients



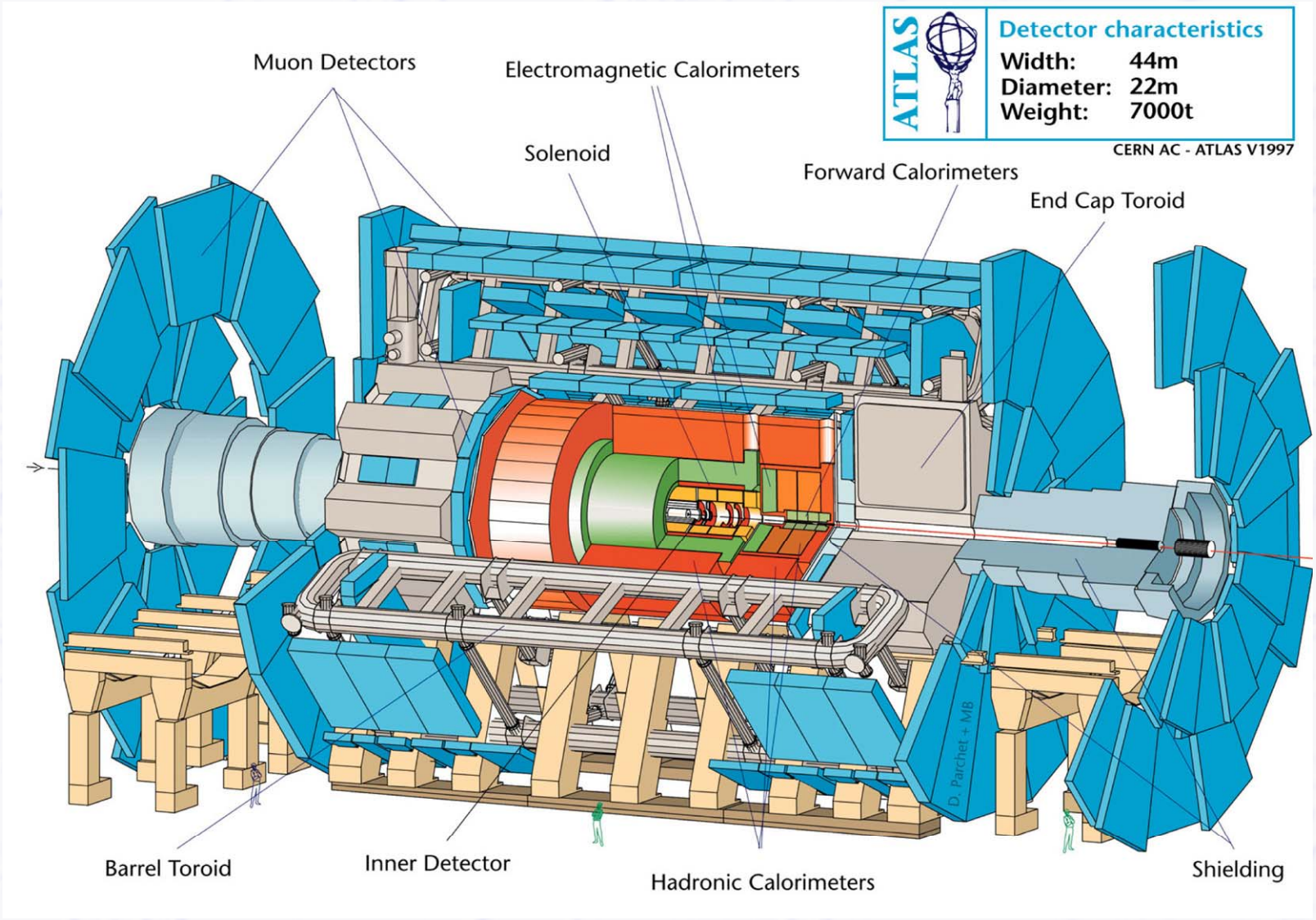
- Electrons
- Photons
- Hadrons
- Muons



Passage of particles - summary



… and in real life… ATLAS



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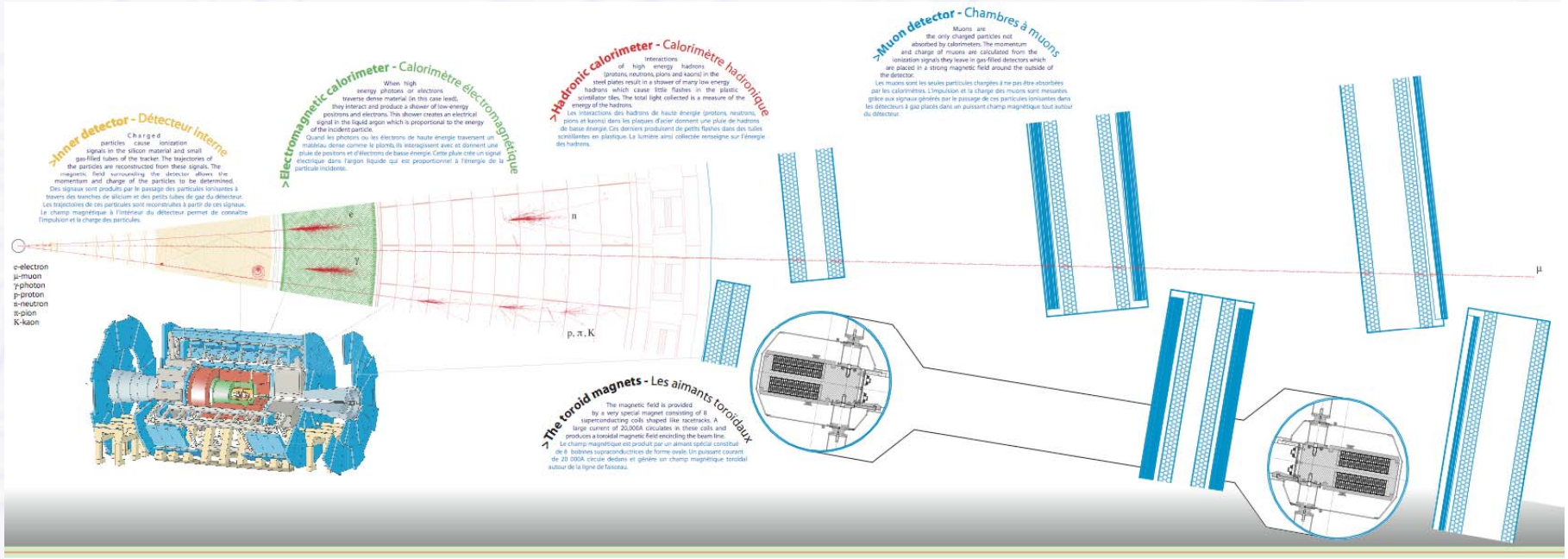

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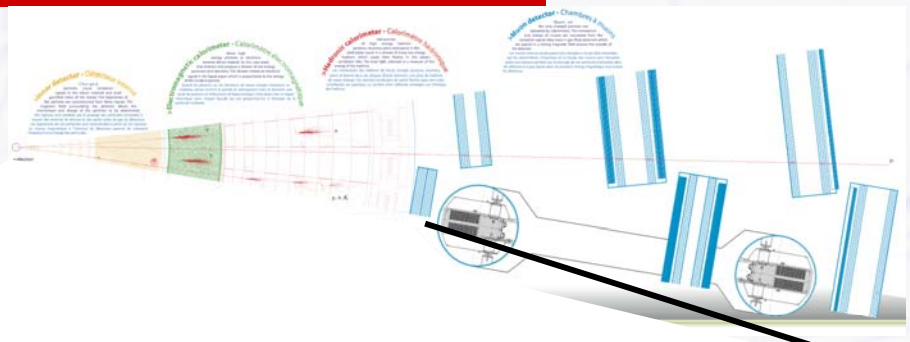
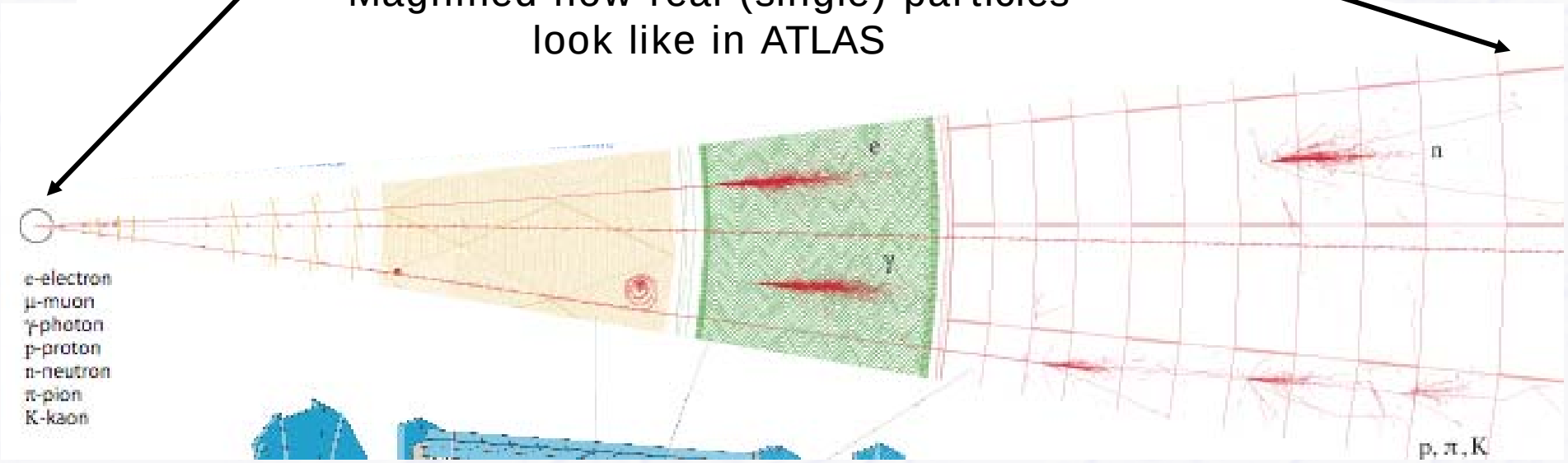


Magnified how real (single) particles look like in ATLAS



End of Day 1