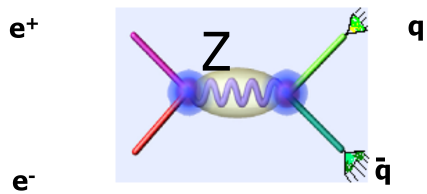
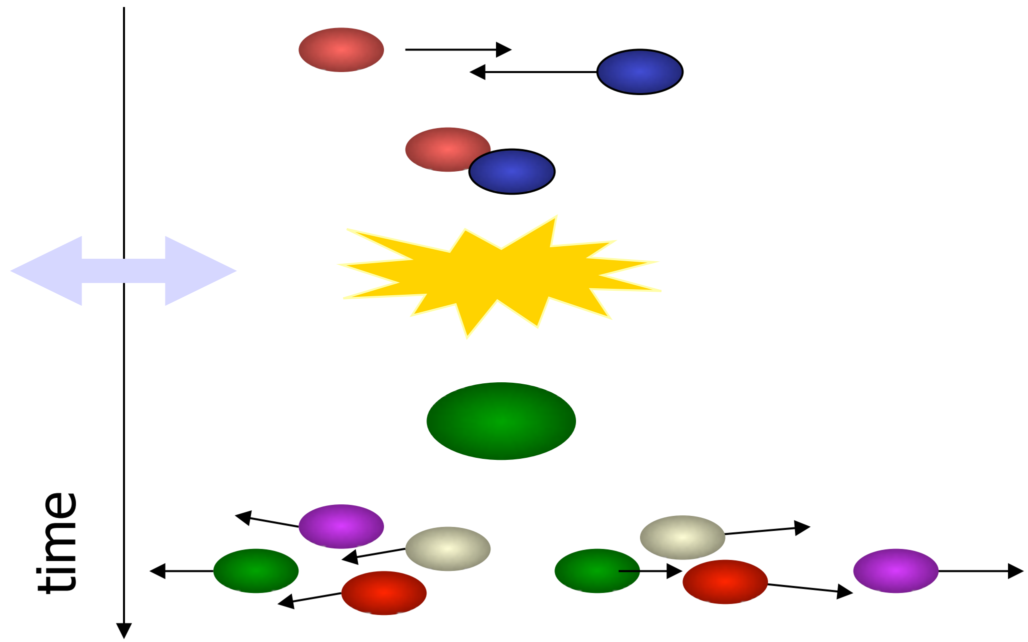
Lecture 17

Idealistic views of an elementary particle reaction

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

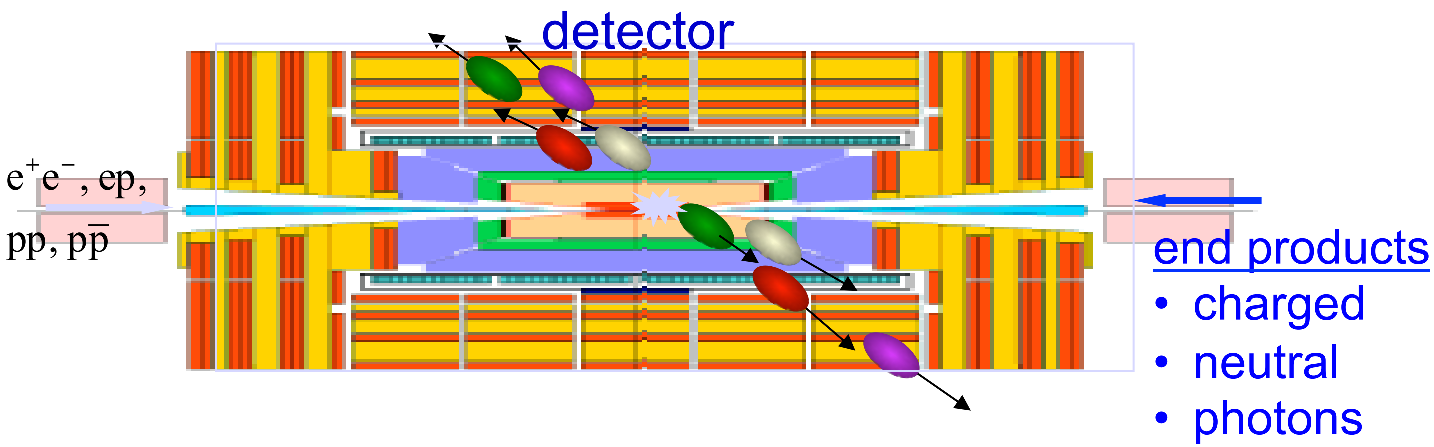
$$(+\,\text{hadronization})$$





- 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 !

The ‘ideal’ particle detector should provide…



- **coverage of full solid angle (no cracks, fine segmentation**
- **measurement of momentum and/or energy**
- **detect, track and identify all particles**
- **fast response, no dead time**

☝ **practical limitation**: **Particles are detected via their interaction with matter.**

Many different principles are involved (mainly of electromagnetic nature).

Finally we will always observe ionization and excitation of matter.

Most frequent "stable" particles ($c\tau > 500$ μm) are:

electrons	e	mass = 0.511 MeV
muons	μ	mass = 105.7 MeV
photons	γ	mass = 0 MeV
pions	π	mass = 139.6 MeV
kaons	K	mass = 493.7 MeV
protons	p	mass = 938.3 MeV
neutrons	n	mass = 939.6 MeV

The difference in mass, charge and interaction are used to identify the particle species.

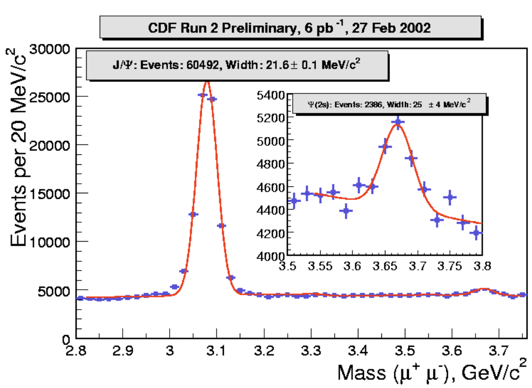
How can detect existence of particles with undetectable flight path?
Unstable particle → reconstruct the mass from the parameters of its decay products. Mass is an invariant quantity i.e., its value is the same in the rest frame.

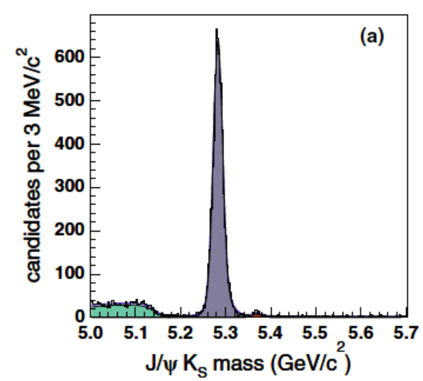
$$m^2 = (E_1 + E_2)^2 - (p_1 + p_2)^2$$

$$E = E_1 + E_2$$

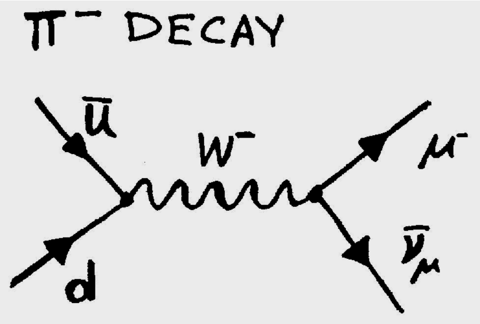
$$\vec{p} = \vec{p}_1 + \vec{p}_2$$

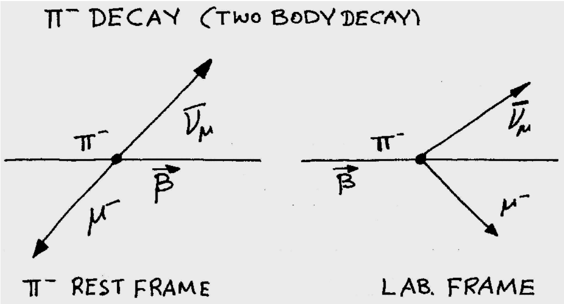
This can be done in sequential steps. In a typical e+e- collision there are ~10 charged particles in the final state. Not all are produced directly in the initial interaction. After reconstruction of decays $J/\Psi \rightarrow \mu^+ \mu^-$ and $K^0 \rightarrow \pi^+ \pi^-$ we can look for B meson in its decay $B \rightarrow J/\Psi\, K^0$





Kinematics of two-body decay: $\pi^- \rightarrow \mu^- \nu_\mu$





Two-body decay in the rest frame of parent particle must conserve momentum i.e., decay products are back-to-back.
For decays **in flight** one must apply Lorentz transformation.

Design of the particle detector
(wishes and constraints)

Definitions and units

$$E^2 = \vec{p}^{\,2}c^2 + m_0^2 c^4$$

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

- E - energy measured in eV
- p - momentum measured in eV/c
- m_o - mass measured in eV/c^2

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

To find short lived object we must know momenta and masses of its decay products

1 eV is small 1 eV = $1.6\cdot10^{-19}$ J

m_{bee} = 1g = $5.8\cdot10^{32}$ eV/c^2

v_{bee}= 1m/s → E_{bee} = 10^{-3} J ≈ $6.25\cdot10^{15}$ eV

E_{LHC} = $14\cdot10^{12}$ eV

To rehabilitate LHC…

Total stored beam energy: 10^{14} protons * $14\cdot10^{12}$ eV ≈ $1\cdot10^{8}$ J

this corresponds to a

m_{truck} = 100 T

v_{truck} = 120 km/h

Definitions and units

The concept of cross sections

Cross sections s or differential cross sections ds/dW are used to express the probability of interactions between elementary particles.

Example: 2 colliding particle beams

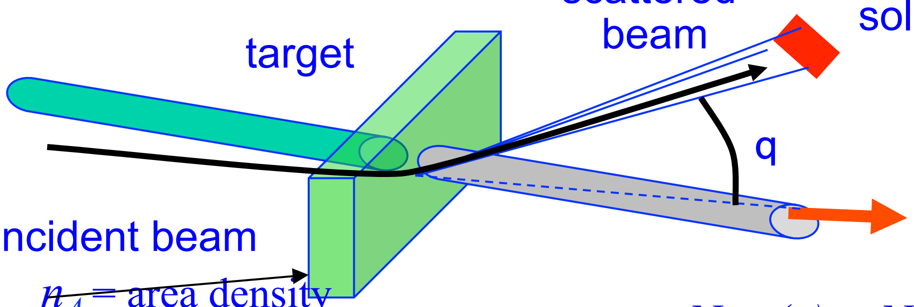
$F_1 = N_1/t$ $F_2 = N_2/t$

What is the interaction rate $R_{int.}$?

$$R_{int} \approx \underbrace{N_1 N_2 / (A \cdot t)}_{\text{Luminosity } L \ [cm^{-2}\ s^{-1}]} = s \cdot L$$

> s has dimension as an area !
>
> Practical unit:
>
> 1 barn (b) = 10^{-24} cm^2

Example: Scattering from target

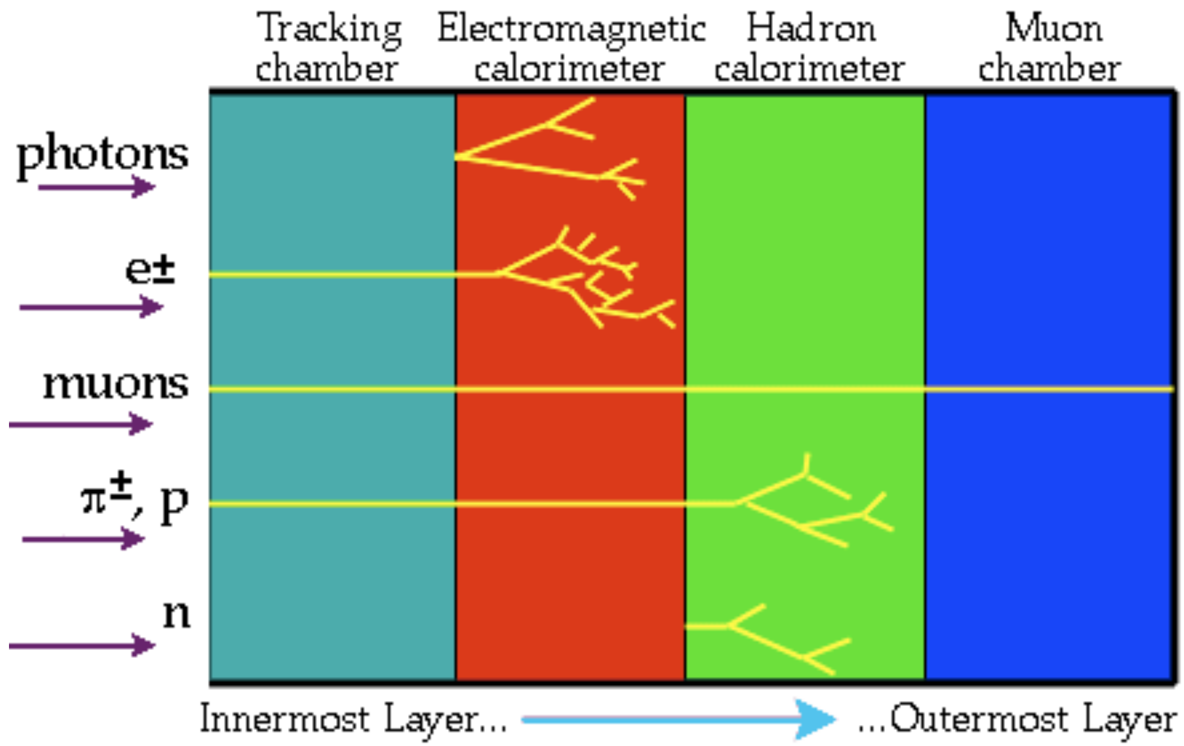


n_A = area density of scattering centers in target

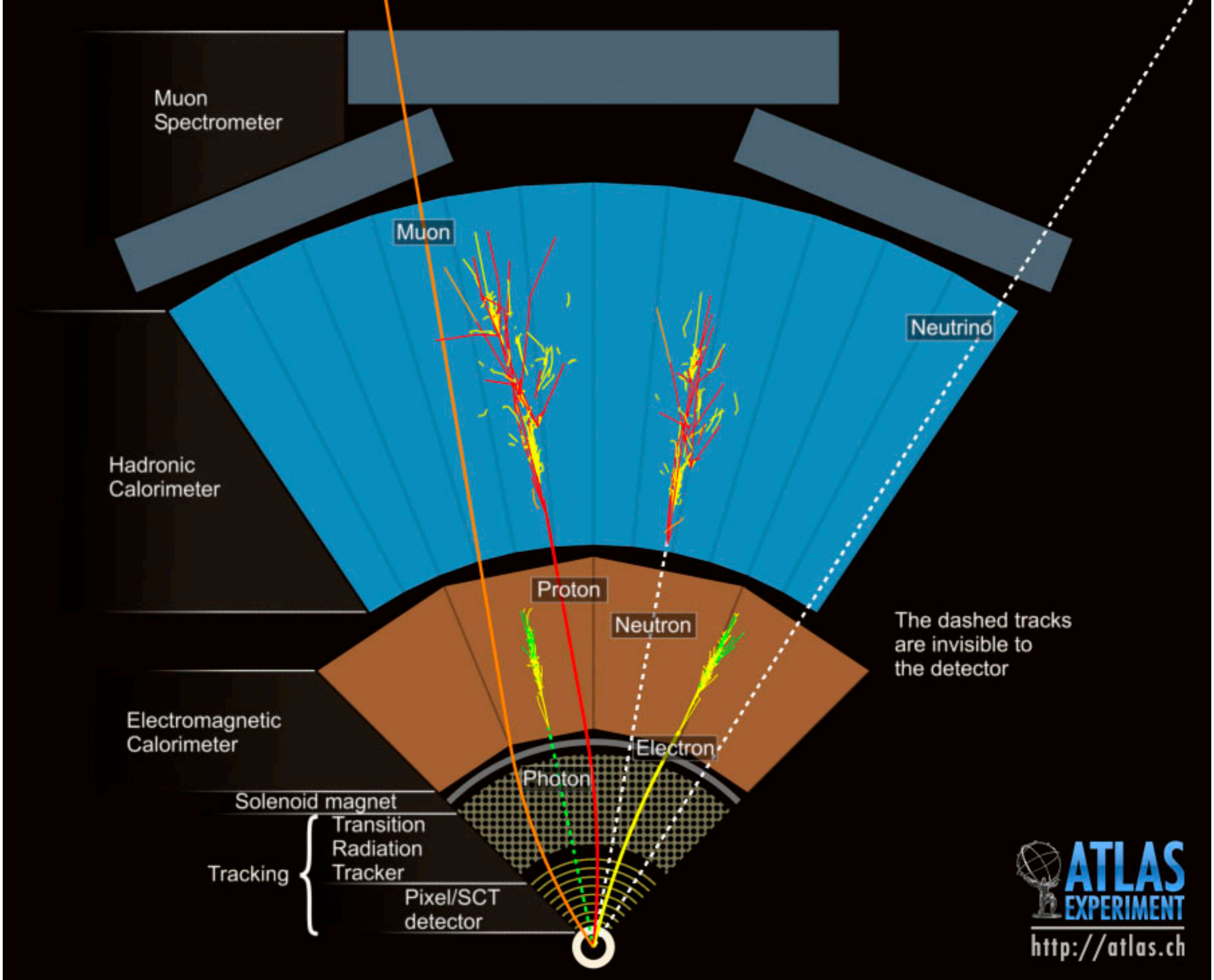
$$N_{scat}(q) \approx N_{inc} \cdot n_A \cdot dW$$

$$= ds/dW(q) \cdot N_{inc} \cdot n_A \cdot dW$$

Components of a generic collider detector



electrons - ionization + bremsstrahlung
photons - pair production in high Z material
charged hadrons - ionization + shower of secondary interactions
neutral hadrons - no ionization but shower of secondary interactions
muons - ionization but no secondary interactions



Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Transition Radiation Tracker
Tracking
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch

Optimization

- Which kind of "particle" we have to detect?
- Which "property" of the particle we have to know?

– position

– lifetime

– quantum numbers

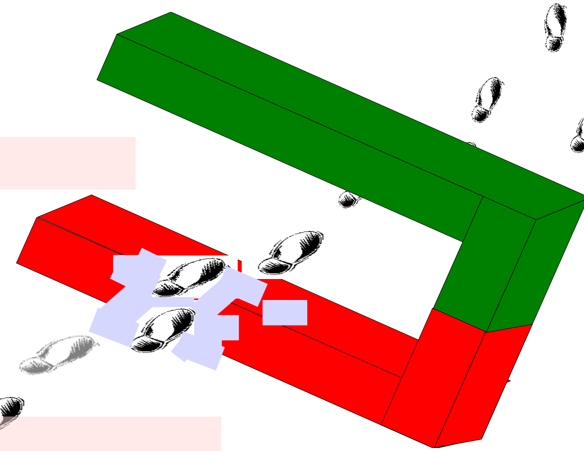
– energy

– charge

- What is the maximum count rate?
- What is the "time distribution" of the events?
- What is the required measurement resolution ?
- What is the dead time?

Tracking

- Momentum measurement
- Multiple scattering
- Bethe-Bloch formula / Landau tails
- Ionization of gases
- Wire chambers

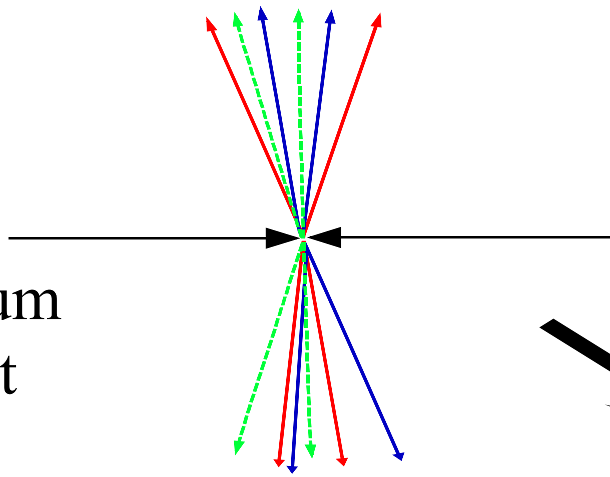


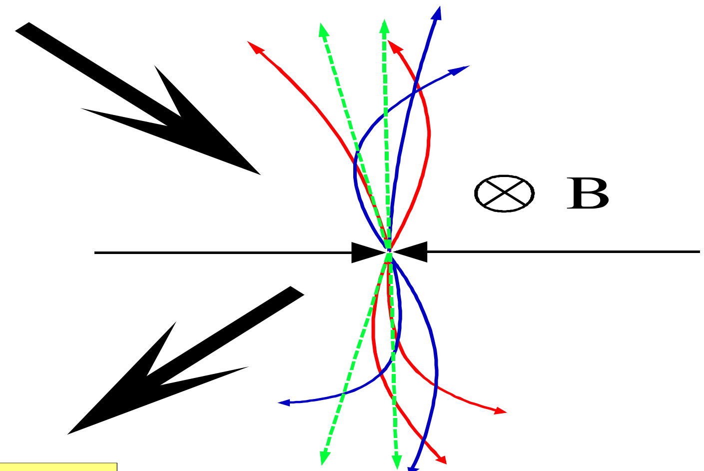
- Drift and diffusion in gases
- Drift chambers
- Micro gas detectors
- Silicon as a detection medium
- Silicon detectors strips/pixels

Momentum measurement

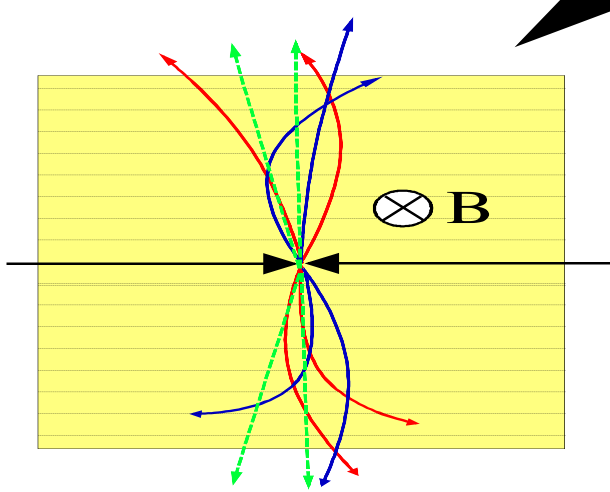
$p = 0.3\ B\ \rho$

No momentum measurement





Momentum component transverse to B can be measured



particle trajectory should not be distorted by sequential scattering -> low mass