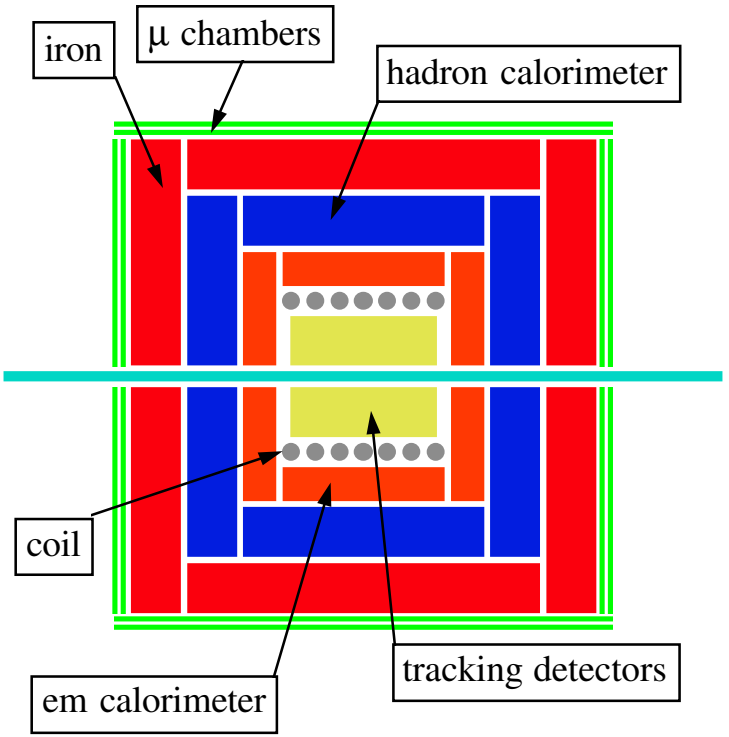
Monte Carlo Programs for Particle Physics Experiments

- Particle physics detectors
  - Tracking detectors
  - Electromagnetic calorimeters
    - » A simple shower model
  - Hadronic calorimeters
  - Muon and neutrino detection
- Why use Monte Carlo programs?
- Some references.

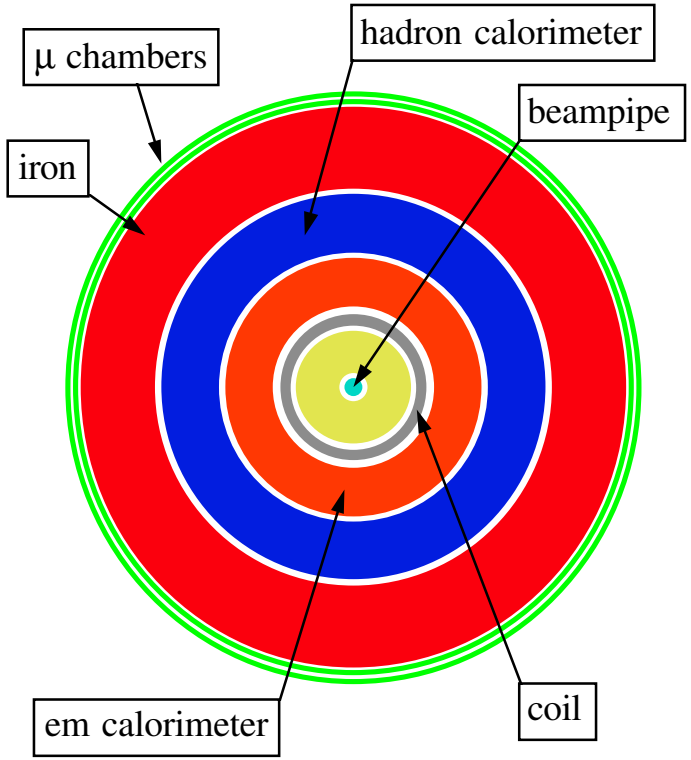
Detectors

- Many Particle Physics detectors have similar design.



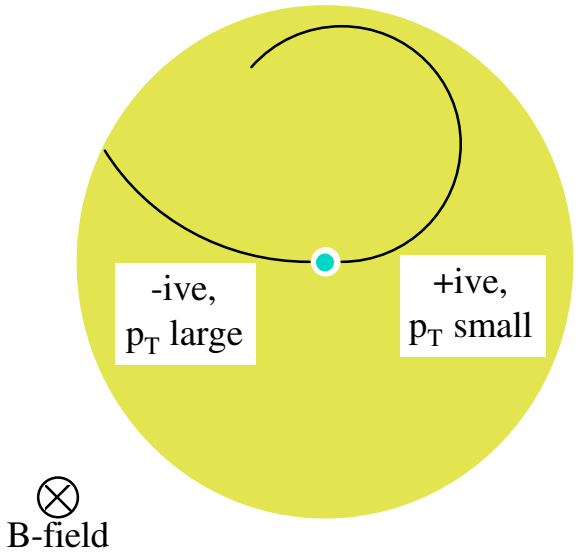
Detectors cont.

- End view

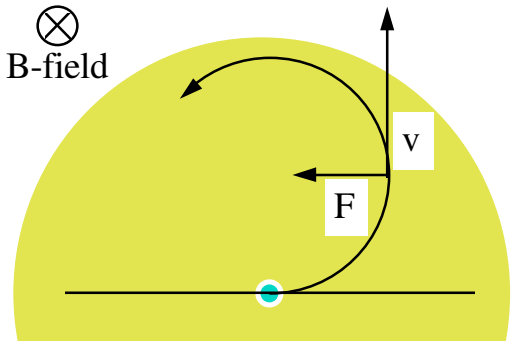


Tracking detectors

- Measure path of charged particles.
- Lorentz force due to magnetic field parallel to beam makes path helical.
- Radius of curvature gives transverse momentum.



Motion of charged particle in a magnetic field



- Charge Q, magnetic field strength B.
- Velocity v, normal to magnetic field.
- Lorentz force F, normal to directions of B and v.
- Magnitude of force $F = QvB$.
- Circular path.

Measuring momentum

- Centripetal force $F = mr\omega^2 = m\frac{v^2}{r}$.
- Equate Lorentz and centripetal forces

$$BQv = \frac{mv^2}{r}$$

$$\Rightarrow BQ = \frac{mv}{r} = \frac{p}{r}$$

hence $\boxed{p = BQr}$

An aside, units

- We have $p = BQr$ (kg m s^{-1}).
- Multiply p by c to get energy

$$pc = BQrc \text{ (J)}$$

$$= \frac{BQrc}{1.6 \times 10^{-19}} \text{ (eV)}.$$

- But Q = 1.6 x 10^{-19} C for e, μ etc.
  $pc = Brc$ (eV).
- Now c = 3 x 10^{8} m s^{-1} so:

$$pc = Br \cdot 3 \times 10^{8} \text{ (eV)}$$

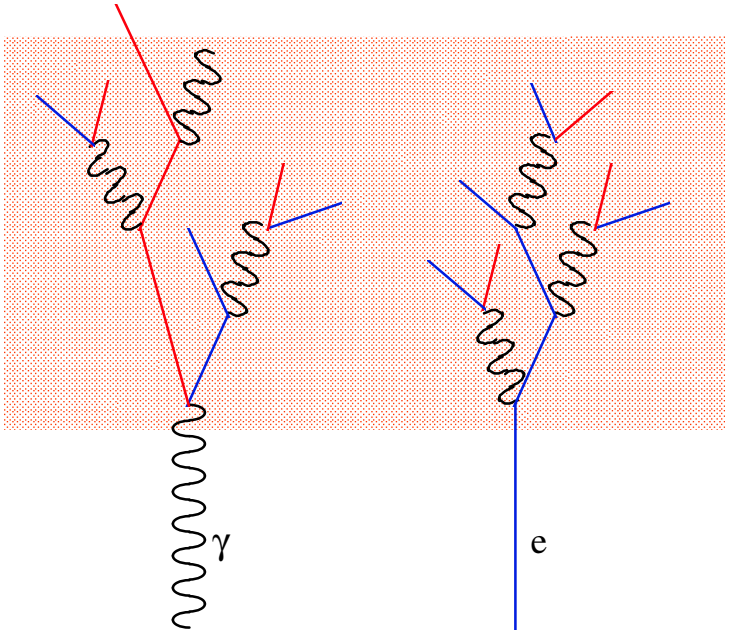
$$= \frac{Br \cdot 3 \times 10^{8}}{1 \times 10^{9}} \text{ (GeV)}$$

$$= 0.3Br \text{ (GeV)}$$

- Finally, express p in units of GeV / c
  $p = 0.3Br$ (GeV / c)

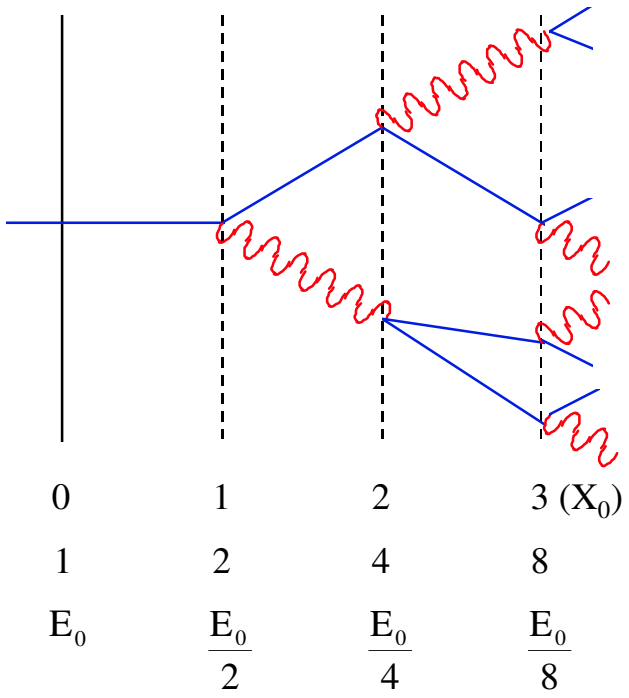
Electromagnetic calorimeters

- Electrons and photons lose all their energy in an electromagnetic shower.



A simple shower model

- Can treat EM shower approximately as follows:



Shower model cont.

- After t radiation lengths:
  - No. of particles = 2^t.
  - Energy per particle = $\frac{E_0}{2^t}$.
- Continues until energy per particle less than critical energy E_c.
- E_c is energy at which ionization energy loss equals radiation loss.
  - Approximately, $E_c = \frac{600}{Z}$ MeV.
- Find depth at which this occurs:

$$\frac{E_0}{2^{t_{max}}} = E_c \Rightarrow \frac{E_0}{E_c} = 2^{t_{max}}$$

$$\Rightarrow \ln\left[\frac{E_0}{E_c}\right] = t_{max} \ln 2$$

$$\Rightarrow t_{max} = \frac{\ln[E_0/E_c]}{\ln 2}.$$

Shower model cont.

- Number of particles at shower maximum:

$$N_{max} = 2^{t_{max}} = \exp[t_{max} \ln 2] = \frac{E_0}{E_c}.$$

- Obtain energy of initial electron by counting number of particles in shower (given approximately by $2N_{max}$).

Hadronic calorimeter

- Hadrons (particles made of quarks) lose their energy in Had shower.
- Strong interactions with nuclei.
- Typical length scale for EM shower $X_0 \sim 1$ cm.
- Typical length scale for Had shower $\lambda_I \sim 20$ cm, so Had Calo deeper than EM Calo.

Muon and neutrino detection

- Muons:
  - Visible in tracking detectors.
  - Lose little energy in EM and Had calorimeters.
  - Lose little energy in iron.
- Place muon detectors after iron.
- Only muons give signal here.
- Neutrinos lose essentially no energy in any part of detector.
- Detect via “missing momentum”.

Why use Monte Carlo programs?

- To work out what particle interactions will look like given assumptions about underlying physics.
  - The Monte Carlos that produce these “events” are called Event Generators.
- To determine influence of detector on quantities to be measured, eg:
  - How many of measured charged particles arose from photon conversions?
  - If a particle was measured to have energy E in the calorimeter, what was its original energy?

Some references

- Papers describing H1 detector:
  - Nucl. Inst. Meth A386 (1997) 310.
  - Nucl. Inst. Meth A386 (1997) 348.
- Paper describing OPAL detector:
  - Nucl. Inst. Meth. A305 (1991) 275.
- Paper describing OPAL detector simulation:
  - Nucl. Inst. Meth. A317 (1992) 47.
- Description of GEANT:
  - http://wwwinfo.cern.ch/asd/geant4/G4UsersDocuments/UsersGuides/PhysicsReferenceManual/html/index.html