Lectures 7 and 8 – Accelerators, Colliders, Detectors and Detector Physics

Read M & S Chapter 4 for these lectures - this is distributed with this handout
– Read Section 4.2 for Lecture 7
– Read Section 4.3 and 4.4 for Lecture 8
– Read Section 4.5 in advance of Lecture 9

Sources of high energy collisions – Natural and Artificial

Cosmic rays

- Advantages
  (Fill in during lecture)

- Disadvantages

Particle Accelerators

- Fixed target vs Colliding beam experiments

- Linear vs Circular accelerators
Linear Accelerators / Colliders of note

- SLAC – Stanford Linear Accelerator Center / SPEAR – Stanford Positron Electron Asymmetric Ring;

- International Linear Collider

Circular accelerators/ Synchrotrons

[Note: Radius of curvature of charged particle in magnetic field is in proportion to momentum]

Synchrotron radiation

Energy radiated per turn: $\Delta E = \frac{4\pi q^2 \beta^3 \gamma^4}{3e_0 r}$ and thus $\Delta E \propto \frac{1}{m^2}$ !!

Circulator Accelerators / Colliders

- 1st generation of devices were cyclotrons

- SPS – Synchrotron Proton Source – protons / SppS – later proton anti-proton CM Energies:

- LEP – Large Electron Positron – electrons / LHC – Large Hadron Collider – protons CM Energies:

- HERA – Hadron Electron Ring Accelerator, Hamburg – only ever hadron-lepton collider. Energies:

- TeVatron – Fermilab – main experiments CDF, D0 CM Energies:
CERN accelerators – LEP and LHC

**LEP:** - collisions of $e^+$ and $e^-$

4 experiments – OPAL, DELPHI, L3 and ALEPH

CERN Accelerators

![Diagram of CERN accelerators: LEP, SPS, PS, LHC, OPAL, DELPHI, L3, ALEPH]
LHC: - collisions of p and p

Experiments – ATLAS, CMS, LHCb, LHCf, ALICE

Detectors at the LHC – multi-purpose or specific purpose

- ATLAS (visit [http://atlas.ch](http://atlas.ch))
- CMS
- ALICE
- LHCb
- LHCf

Particles in use at accelerators – built for a purpose

- PEP-II & BaBar;
- RHIC,
- HERA,
- K2K, BELLE,
- BOONE, miniBOONE
Accelerator characteristics – s and luminosity

- Center of mass energy available

Luminosity is the key characteristic of a colliding beam experiment and must be increased for higher reaction rates / events.

Luminosity in a particle beam is given by: \( L = JN \)

- \( J \) = flux; \( N \) number of particles per bunch

The reaction rate \( R \) is then given by: \( R = \sigma L \)

Units of \( L \) – inverse area per second

The cross section for a given transition is thus: \( \sigma_{if} = \frac{R_{i\rightarrow f}}{J} \)

Total number of reactions is related to the integrated luminosity: \( \mathcal{L} \equiv \int Ldt \)

Measured experimental cross section for an event: \( \sigma_{if} = \frac{N_{i\rightarrow f}}{\mathcal{L}} \)

Need large integrated luminosity over time (measured as inverse cross-section) to generate a statistically significant number of low probability events.

See M & S Appendix B.1, B.2 and B.3 as necessary for tutorial problem example for LEP data.

Example of measured cross-sections

Plot of cross section for electron-positron collisions – data from LEP and other sources

\( \sigma \ e^+e^- \rightarrow \) hadrons or leptons, \( s \) at various different values of \( s \).
Particle detector Physics and Practice

Revision guidelines:

Read Handout of M & S Sections 4.3 and 4.4

Principles of particle detectors:

Particle interaction with matter M&S 4.3
Short range interactions with nuclei M&S 4.3.1
Ionization energy losses M&S 4.3.2
Radiation energy losses M&S 4.3.3
Interaction of photons in matter M&S 4.3.4
Ranges and interaction lengths M&S 4.3.5
Transition Radiation See ATLAS video on transition radiation tracker

Constituents of particle detectors:

Particle detectors M&S 4.4
Gas detectors M&S 4.4.2
Semiconductor detectors M&S 4.4.3
Scintillation counters M&S 4.4.4
Cerenkov counters M&S 4.4.5
Calorimeters M&S 4.4.6

Complete detector system – ATLAS as an example:

Visit [http://atlas.ch/detector-overview/index.html](http://atlas.ch/detector-overview/index.html) for the ATLAS detector subcomponent videos

Make note of the physical principles above that are employed at ATLAS.

Notes on ATLAS systems -

Register and participate in HiggsHunters.org and use the knowledge above to good effect to help identify events from the ATLAS detector in a “citizen-science” project.