The LHCb detector

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1 The LHC

- 27km circumference proton-proton collider located 100m underground on Swiss-French border
- Design energy of $\sqrt{s} = 14$ TeV

$$s = (p_1 + p_2)^2$$

- Design luminosity of $10^{34}\text{cm}^{-2}s^{-1}$

$$R = \mathcal{L} \cdot \sigma$$

$$L = \int \mathcal{L} dt$$

- Home to 4 main experiments: ATLAS, CMS, LHCb, ALICE
  - ATLAS, CMS general purpose detectors
  - ALICE dedicated to heavy-ion physics
  - LHCb dedicated b-physics experiment

What are the difficulties associated with proton-proton colliders as opposed to electron-positron colliders?

2 The LHCb detector

- LHCb is a single-arm forward spectrometer unlike other 4π detectors
- LHCb deliberately does not exploit the full luminosity of the LHC to avoid **pile-up**
- Main physics goal to measure CP violation parameters through decays of b-hadrons
- $b\bar{b}$ pairs are produced in same forward or backward cone through gluon-gluon fusion

Why is LHCb a different shape to the other 3 detectors?

3 Detecting particles

- Detectors measure parameters of particles via their energy loss in the detector material
  - Ionisation/excitation
  - Pair production
  - Strong interaction
  - Bremsstrahlung
  - Cherenkov radiation
  - Multiple coulomb scatterings

From other lecture courses, can you briefly describe each of these?

4 Selecting b-decays

- b-hadrons fly $\approx$ 1cm before decaying through the weak force
- Secondary vertices displaced from Primary Vertex (PV) are key signature of a b-decay
- Key discriminating variables: Impact parameter (IP), DIRA angle, b-hadron flight distance significance. Requires very precise vertexing close to the collision

In the decay $B^+ \to K^+\mu^+\mu^-$ the kaon is known as the bachelor particle. Does it have a large or small IP with respect to the PV?

5 The VELO

- Precise vertexing is vital for LHCb to be able to select b-decays from background events
- The VELO is the closest subdetector to the beam at the LHC
- Semicircles of silicon detectors can retract to 35mm during beam injection and ramp up and contract to 7mm from the beam in stable conditions (Vertexing will be dealt with in detail in ALICE lectures)

Why must the VELO be retracted during beam injection and ramp up?

6 Dipole magnet

- Dipole magnet creates magnetic field perpendicular to beamline with an integrated field of 4 Tm
- Charged particles follow curved trajectory in a magnetic field due to the Lorentz force
- Radius of curvature of a charged particle in a magnetic field is related to its momentum

$$r[\mathrm{m}] = \frac{p[\mathrm{GeV/c}] \cdot \sin\theta}{0.3zB[\mathrm{T}]}$$

The magnet periodically reverses polarity. Why?

7 RICH subdetector

- Decays of b-hadrons often involve multiple kaons, pions and protons
- RICH subdetectors vital for PID of hadrons
- Charged particles undergo Cherenkov radiation when passing through a medium faster than light in that medium
- Opening angle of the cone of photons determines velocity of particle

$$\cos\theta_c = \frac{c}{n \cdot v}$$

- Along with a momentum measurement from the curved trajectory through the magnetic field the mass of a particle (and its identity) can be determined
- LHCb has two RICH subdetectors covering complementary momentum ranges. RICH 1 uses C_4F_{10} (n=1.03). RICH 2 uses CF_4 (n=1.0005)

RICH 1 covers a lower momentum range than RICH 2. Why must it be before the magnet?

8 Calorimeters

- LHCb has an ECAL and HCAL to measure energies of neutral particles (and for some level of PID)
  (Calorimetry will be handled in detail in the ATLAS lectures)

Do we want calorimeters with many or few radiation/nucelar interaction lengths?

9 Muon stations

- Muons experience minimal interaction with the detector material before the muon stations
- Five multiwire proportional chambers interleaved with 80cm thick planes of iron that stop any other type of particles
- Muons must register hits in all 5 muon stations for a positive ID

Why do only muons make it all the way to the back of the LHCb detector?

10 Trigger

- At LHCb interactions occur at a rate of 13MHz
- The whole LHCb detector can only be read out at 1MHz and not all events are interesting for our analyses
- A trigger system is used to select the interesting events to further process
- LHCb employs a hardware and a software trigger
  - L0 hardware trigger - runs synchronously with bunch crossings. Particles from b-hadron decays tend to have high p_T - use information from calorimeters or muon chambers which have very short latency
  - Software HLT1 - runs asynchronously, whole detector read out and vertices reconstructed. Selects events with tracks with eg. large IP
  - Software HLT2 - whole event reconstructed. Events selected using high level reconstructed objects such as flight distances

How fast must the L0 trigger decide whether to keep or discard an event?

11 Simulation

- Monte Carlo simulation data is crucial to physics analyses for evaluating efficiencies, optimising selection criteria and creating fit templates
- LHCb MC has 3 stages: PYTHIA, EVTGEN, GEANT

Simulated data is very good for modeling the kinematic parameters of particles but not good at modelling the PID of particles. Why?

12 Accessing data for analysis

- Even after the trigger the dataset is too large for individual analysts to process
- The data is stripped (loose, analysis specific selection criteria applied centrally) and streamed (split into different data files)

Analysts do not have access to the raw data (direct output of the subdetectors), only the reconstructed data (higher-level reconstructed objects like tracks and vertices). Why does LHCb have re-stripping campaigns?