LHCb Outer Tracker

recent results prototype tests

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Abstract

The LHCb experiment aims to make precision studies of CP asymmetries in the B-meson systems at the LHC at CERN. LHCb is a single-arm spectrometer with a forward angular coverage from ~10mrad upto ~300mrad. Due to the small branching ratios and large background involved in most decay channels, a precise momentum measurement is required.

The main task of the LHCb tracking system is to provide efficient reconstruction of charged-particles and precise measurement of their momenta. The tracking system consists of 11 stations. Each station is divided into an Inner and Outer Tracker. The Inner Tracker is used for the high particle density regions around the beam pipe. The Outer Tracker covers the remaining part of the LHCb acceptance.

The requirement of low occupancies over a large area in the Outer Tracker can be met by using drift tubes with a straw tube geometry in combination with a fast drift gas. First results of tests with prototype chambers with 5mm cell size are presented. The chambers were tested with various gas mixtures. The effect of a magnetic field upto 1.4 Tesla was also tested. These measurements are compared with simulations of the drift behaviour (with the simulation program Garfield).

CP violation & B mesons

Since its discovery, CP violation has been detected only in kaon decays. The B-meson system offers many more decay modes, furthermore it gives theoretical more accurate predictions. This makes it a very attractive place to study CP-violation.

In the Standard Model CP violation is accommodated by a complex phase in the quark mixing matrix, i.e. the CKM matrix;

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

The required unitarity of the CKM-matrix gives 9 equations. Two of these equations are particulary relevant for the B-meson systems:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$
$$V_{tb}V_{ub}^* + V_{ts}V_{us}^* + V_{td}V_{ud}^* = 0$$

They can be drawn as triangles in the complex plane (see fig. 1). Here λ is the sine of the Cabibbo angle.

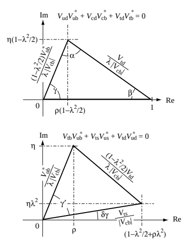


Fig.1: Unitary triangle in the Wolfenstein's parametrisation up to $\mathcal{O}(\lambda^5)$.

The angles α, β, γ and $\delta\gamma$ can be determined indirectly by measuring the lengths of the sides of the triangles. Within the Standard Model the angles can also be directly measured from CP asymmetries of B-meson decays. Well known examples are;

$$\begin{array}{ll} \beta: & B_d \to J/\psi K_S \\ \alpha: & B_d \to \pi^+\pi^- \quad \text{(penguins!)} \\ \gamma: & B_d \to DK \\ \gamma - 2\delta\gamma: & B_s \to D_s^{\pm}K^{\mp} \\ \delta\gamma: & B_s^0 \to J/\psi\phi \end{array}$$

LHCb Performance

Because of its high $b\bar{b}$ cross section ($\sim 500\mu b$) and high luminosity the LHC will produce a variety of B-hadrons at a high rate. The LHCb detector is specially designed to make precision studies of CP asymmetries in the B-meson system and to measure rare B-decays. LHCb aims to operate at a relatively modest LHC luminosity of $2 \times 10^{32} cm^{-2}s^{-1}$. At this luminosity most of the bunch crossings produce a single pp interaction thus avoiding the analyses of overlapping events. Furthermore detector occupancies are low and radiation damage limited. At this luminosity $\sim 10^{12} b\bar{b}$ pairs are produced in one year (10^7 s) of data taking. Table 1 shows the expected number of various reconstructed B decays in one year.

Decay Mode	Visible Br. fraction	Offline Reconstr.
$B_d^0 \to \pi^+\pi^-$ + tag	0.7×10^{-5}	6.9 k
$B_d^0 \to K^+\pi^-$	1.5×10^{-5}	33 k
$B_d^0 \to \rho^+\pi^-$ + tag	1.8×10^{-5}	551
$B_d^0 \to J/\psi K_S$ + tag	3.6×10^{-5}	56 k
$B_d^0 \to \bar{D}^0 K^{*0}$	3.3×10^{-7}	337
$B_d^0 \to K^{*0}\gamma$	3.2×10^{-5}	26 k
$B_s^0 \to D_s^- \pi^+$ + tag	1.2×10^{-4}	35 k
$B_s^0 \to D_s^- K^+$ + tag	8.1×10^{-6}	2.1 k
$B_s^0 \to J/\psi\phi$ + tag	5.4×10^{-5}	44 k

Table 1: Expected numbers of events reconstructed offline in one year (10^7 s of data taking) for some channels.

LHCb Detector

LHCb is a single arm spectrometer with a forward angular coverage from $\theta_{min} \sim 15mrad$ upto $\theta_{max} \sim 300mrad$. This geometry is chosen because b and $\bar{b}$-hadrons are mostly produced in the same forward cone as can be seen from figure 2. LHCb comprises a vertex detector, a tracking system, RICH counters, preshower-, EM- and hadron-calorimeter and a muon detector.

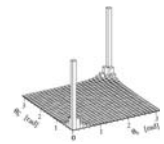


Fig.2: Polar angles of the b- and $\bar{b}$-hadrons produced at LHCb.

The layout of the proposed LHCb detector is shown below (fig. 3).

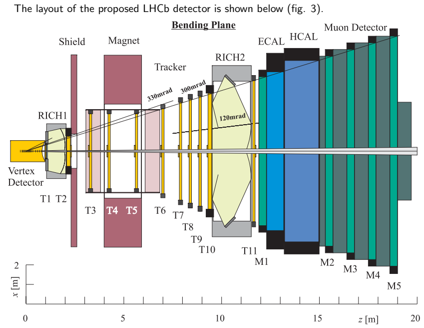


Fig.3: Topview (i.e. bending plane) of the LHCb detector.

- Vertex system
  - Si $r-\phi$ strip detector, single sided, $150\mu m$ thick, analogue readout
- Tracking system
  - Inner: Micro Strip Gas Chamber with GEM or Micro Cathode Strip Chamber
  - Outer: Drift chambers with (straw)tube technology
- RICH system
  - RICH-1: Aerogel ($n = 1.03$) C_4F_{10} ($n = 1.0014$)
  - RICH-2: CF_4 ($n = 1.0005$)
  - Photon detector: Hybrid Photon Diodes
- Calorimeter system
  - Preshower: Single layer Pb/Si(14/10mm)
  - ECAL: Shashlik type, depth $= 25X_0$, $\sigma(E)/E = 10\%/\sqrt{E} \oplus 1.5\%$
  - HCAL: scintillator tiles embedded in iron, depth $= 7.3\lambda$, $\sigma(E)/E = 80\%/\sqrt{E} \oplus 5\%$
- Muon system
  - Multigap Resistive Plate Chambers
  - Cathode Pad Chambers (high flux region)

Most of the detector systems have evolved since the Technical Proposal. In this poster we concentrate on the (developments) in the Outer Tracker system.

LHCb Outer Tracker

The main purpose of the tracking system is to provide efficient reconstruction of charged particles and precise measurements of their momenta. On a less detailed level it also provides input to other detector systems. For the RICH it provides the measurements of track direction (needed for pattern recognition in the RICH). Furthermore, tracking hits are used in the Level-1 and Level-2 triggers.

The tracking system can be divided in the Inner and Outer tracker. The Inner Tracker is used for the high particle density regions around the beam pipe. The Outer Tracker covers the remaining part of the LHCb acceptance.

The tracking system consists of 11 stations. They are situated between the Vertex Detector and the calorimeters (see fig. 3). The stations (T1-T11) can be grouped according to there principal functionality:

- T1-T2:
  - link between Vertex Detector & Main Trackers track(segments)
  - RICH: measurements of track entry and exit points
- T3-T6: 'track following'
  - measurement of track curvature, i.e. momentum
- T7-T10: 'track finding'
  - finding track seeds in magnetic field 'free' region
- T11:
  - RICH: measurement of track entry and exit points (with T10)
  - link between Main Trackers & muon chambers track(segments) (+ calorimeters)

The proposed dipole magnet (design has recently been changed) provides a vertical magnetic field of upto ~ 1.8 Tesla. In order to accurately measure the momentum of a particle the highest track precision has to be achieved in the bending (X, Z) plane. Therefore the tracking stations uses vertical wires (Outer Tracker) and strips (Inner Tracker). Detection layers under stereo angles ($\pm 5°$) are used to achieve three dimensional track information.

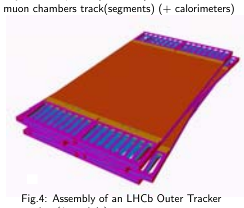


Fig.4: Assembly of an LHCb Outer Tracker station (1 module).

To cover the large area of the Outer Tracker the relatively cheap detection technology of drift tube chambers is chosen. A 'standard' Outer Tracker station (i.e. T3-T9) is made out of 4 detection planes. Each plane contains 2 staggered layers of drift cells (see fig. 5).

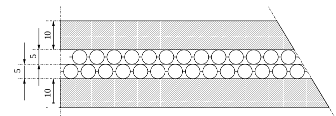
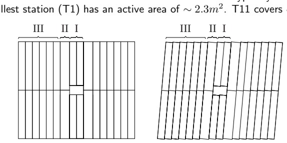


Fig.5: Cross section of an Outer Tracker detection plane.

A full plane is assembled out of several smaller modules of typically 32 cells (see fig. 6). The smallest station (T1) has an active area of $\sim 2.3m^2$. T11 covers $\sim 43m^2$.



(a) Vertical Wires (b) Stereo Wires

Fig.6: Modularity of Outer Tracker detector planes.

Extensive research has been done (and is ongoing) to determine the optimal cell shape, cell material and drift gas. Single cell (tube) requirements:

- occupancy $< 10\%$
- total signal propagation time within 2 bunch crossings (50ns)
- efficiency near 100%
- cope with high (inhomogeneous) magnetic field
- resolution $150 - 200\mu m$

The default option:

- cell shape: 5mm straw tube (6mm pitch)
- cell material: Kapton-XC
- gas mixture: Ar/CF4/CO2 based

This cell size results in a total of ~135k read out channels.

Tracking Performance

- average occupancy $\sim 5\%$ (max 10% in hottest regions)
- $\left(\frac{\delta p}{p}\right)^2 = (0.0024 \cdot p)^2 + (0.36\%)^2$
- momentum resolution multiple scattering dominated
- position resolution more than adequate
- $\Rightarrow$ good invariant mass resolution
  - e.g. $B \to \pi\pi$: $15.2{\rm MeV/C}^2$

Drift cell simulations

Simulations with the computer program Garfield have been done to study the electric properties of drift cells. Garfield can perform detailed simulations of drift chambers taking into account electric & magnetic field, diffusion, avalanches and attachement. It calculates field maps, electron/ion drift lines (see fig. 7), x(t)-relations, etc...

We studied various design parameters of the Outer Tracker:

- cell shape and size
- gas mixture
- (inhomogeneous) magnetic field

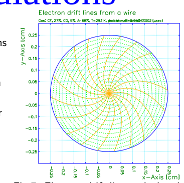


Fig.7: Electron drift lines calculated by Garfield(5mm straw tube, ArCF4CO2: 682705).

B_y (Tesla)	B_z (Tesla) 0.0	0.5	1.0	1.2	1.4
0.0	27				
0.5	26				
0.8	30	32			
1.0	32	34	38		
1.2	35	36	40	42	
1.4	39	39	43	44	47
1.6	43	43	46	47	49
1.8	48	47	49	50	52
2.0	54	52	52	53	55
2.2	62	57	56	57	59

Table 2: Simulated T_{max} (in ns) for a 5mm straw tube in ArCF4CO2:682705 for magnetic field in Y (vertical) as well as Z direction.

Table 2 shows the simulated maximum drift time for various magnetic fields in a 5mm straw tube using the gas mixture Ar/CF4/CO2:68/27/5. In the field free region the requirement of a maximum total signal propagation time of 50ns is clearly met. The chambers in the magnet have a wire length of ~ 150cm corresponding to a maximum of ~ 7.5ns drift in the wire. According to Garfield the maximum allowed B-field is thus 1.6 Tesla for these chambers and gas mixture.

Prototype test results

Outer Tracker prototype modules have been build and are being tested. Modules of 5mm straw tube have recently (June 1999) been placed in a 10GeV π beam. The modules operated without problems. Figure 8 shows a TDC spectrum of a single cell. Extracting the maximum drift time from these spectra gives:

B_y (Tesla)	T_{max} (ns)
0.0	28 $\pm$1
1.0	32 $\pm$1
1.4	37 $\pm$2

A first attempt to calculate the cell efficiency gives: eff $> 90\%$.

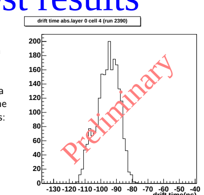


Fig.5: Measured drift time spectrum for a single 5mm straw tube in ArCF4CO2:682705.

Conclusions and Outlook

- Tracking system:
  - average occupancy $\sim 5\%$ (max 10% in hottest regions)
  - $\left(\frac{\delta p}{p}\right)^2 = (0.0024 \cdot p)^2 + (0.36\%)^2$
- June'99 Outer Tracker test-beam:
  - working OT prototype (5mm straw tubes, ArCF4CO2: 68/27/5, 30 cm long)
    - $T_{max} < 45$ns (up to B < 1.6 Tesla)
    - efficiency $> 90\%$
  - results agree with Garfield simulation
  - advanced analyses started (RT-relations (via autocalibration), efficiency vs R (within cell), resolution, ...)
- To be done for OT design:
  - scale prototypes (modules up to ~ 3.5m long)
  - determine optimal gas mixture

Presented during the SLAC summer institute 1999. Enquiries to Rutger.van.der.Eijk@cern.ch