ALIGNMENT OF THE ATLAS-ALFA DETECTORS*

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The experimental data-based alignment procedure of the Absolute Luminosity for ATLAS (ALFA) detectors is discussed. The procedure is heavily based on the symmetry properties of the elastic proton–proton scattering. The detectors operate in the vicinity of the LHC beams during dedicated running periods. Each time they are moved towards data-taking position, their alignment must be determined independently for each insertion into the accelerator beam pipe.

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1. Introduction

The elastic proton–proton scattering is one of the processes measured by the ATLAS detector [1]. It is a binary process in which the protons interact through nuclear and Coulomb forces. At the LHC energies for the four-momentum transfer $|t| < 10^{-4}$ GeV^2, the Coulomb interactions dominate, while for $|t| > 10^{-2}$ GeV^2, the nuclear interactions take over. The interval around 10^{-3} GeV^2 is referred to as the Coulomb-nuclear interference region. The process kinematics can be described using two variables (the four-momentum conservation): ϕ — the azimuthal angle and θ — the scattering angle. Owing to its azimuthal symmetry, the colliding protons are not polarised, the dynamics of the *pp* elastic scattering is described using only the scattering angle, which at small θ has a simple relation to t, $|t| \sim \theta^2$. Investigations of the elastic *pp* scattering provide information on the inner structure of a proton and the long-range QCD domain [2].

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The fits to the differential cross-section data deliver values of σ_{total} and ρ. The total cross section, σ_{total}, is determined using the optical theorem and proportional to the imaginary part of the forward nuclear amplitude

$$\sigma_{\text{total}} \propto \operatorname{Im} F_{\mathrm{N}}(t \to 0)\,, \tag{1}$$

while the ρ parameter represents the ratio of the real-to-imaginary parts of the forward nuclear amplitude

$$\rho \equiv \frac{\operatorname{Re} F_{\mathrm{N}}(t \to 0)}{\operatorname{Im} F_{\mathrm{N}}(t \to 0)}\,. \tag{2}$$

2. The experimental set-up of ALFA detector

The ALFA detector [3] consists of four stations, two on the left and two on the right side of the interaction point, approximately 240 meters away. Each station comprises two Roman pots, and each Roman pot contains one main detector and two overlap detectors placed on the main detector sides. The Roman pots for allow the insertion of the detectors into the beam pipe along the vertical direction and separate them from the ultra-high vacuum. The main detector is used for physics studies, while the overlap detector is employed in the detector alignment procedure.

The detectors use square scintillating fibres with a side length of 0.5 mm. The main detector consists of twenty planes of fibres arranged orthogonally at angles $\pm 45^\circ$ w.r.t. the y-axis (u, v directions). There are 64 fibres in each plane and they are staggered by multiples of 1/10 of the fibre size. The spatial resolution is about 30 μm per u and v coordinates. Each overlap detector contains three layers of 30 fibres staggered by 1/3 of the fibre size. Its spatial resolution is $\sim$ 50 μm. The fibres are read out by 64-channel multi-anode photomultipliers.

In total, the ALFA system comprises eight detectors labelled 1 through 8. Two elastic arms are introduced, due to the back-to-back topology of elastic events: detectors 1, 3, 6, and 8 belong to arm1, while detectors 2, 4, 5, and 7 to arm2, see Fig. 1. The signal signature is that protons hit all detectors in arm1 or arm2. Events with protons hitting all upper or all lower detectors are coming from a beam background. The latter includes the beam-halo particles, the single diffractive, and double Pomeron exchange events.

In addition to the position measurement, the ALFA detectors provide the scattering angles of the scattered proton trajectory. If there were no LHC quadrapoles, the local angles, which are angles measured by ALFA, and scattering angles would be the same. However, due to the presence of the LHC magnetic lattice, the two angles are related by a linear relation.

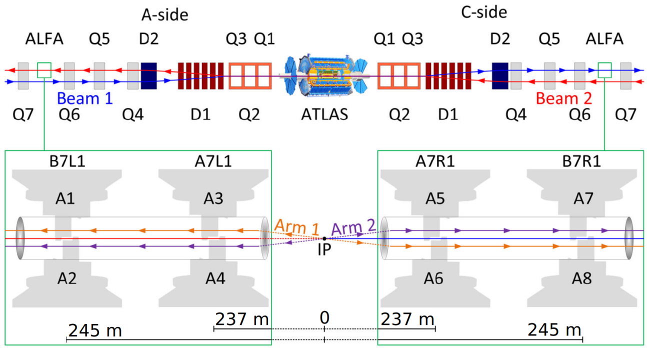

Fig. 1. Layout of the ALFA detectors [3]. The lower panel shows the definition of the arms, see the text.

3. ALFA alignment parameters

Alignment of the ALFA detector transforms the detector coordinates into the beam coordinates by adjusting the D, Δy, Δx, and θ_{z} parameters such that the elastic pattern is symmetric in the beam coordinate system, *c.f.* Fig. 2. Here, D is the distance between the upper and lower main detectors, Δy is the vertical offset — a shift of the origin along the y-axis, Δx is the horizontal offset, and θ_z is the rotation angle around the z-axis (the nominal beam axis).

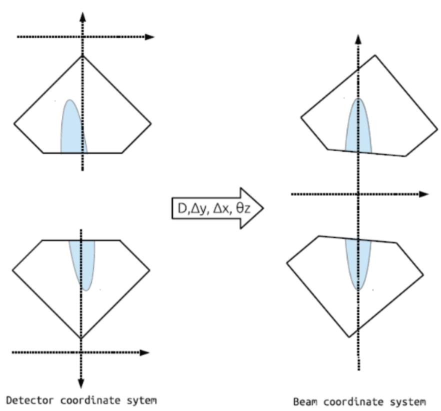

Fig. 2. A schematic view of the alignment procedure.

4. Distance measurement

The overlap detector measures the vertical position of beam-halo protons that have left the bunch structure of the beam but are still contained within the beam pipe. The halo proton hits fibres in the upper and lower overlap detectors at the same vertical position, Fig. 3. This allows for measuring the $D_{\rm up}$ and $D_{\rm low}$, and since $d_{\rm up}$ and $d_{\rm low}$ are already known, formula $d = D_{\rm up} + D_{\rm low} - d_{\rm up} - d_{\rm low}$ can be used to determine the d distance between the upper and lower main detectors.

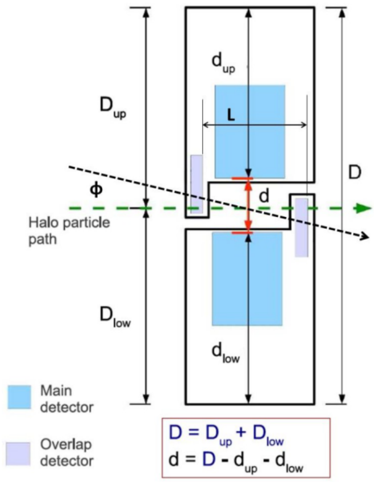

Fig. 3. The principle of the vertical distance measurement.

5. Horizontal alignment

The horizontal alignment shifts the origin of the coordinate system along the x-axis to achieve symmetry in the pattern of elastic scattering events, which are selected based on the correlations, which are present in the events and originate from conservation laws. In the implementation phase, the x distribution of elastic protons in each detector is considered. Its mean is used as a correction factor, see Fig. 4. After a few iterations, when the correction becomes sufficiently small, the detector is considered to be horizontally aligned.

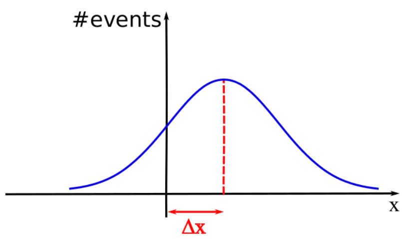

Fig. 4. The "measured" distribution of the elastic proton x-position. The horizontal offset is indicated by Δx.

6. Vertical alignment

As previously stated, the goal of vertical alignment is to adjust the origin of the coordinate system along the y-axis to attain symmetry of the observed elastic pattern. The vertical alignment originates from the beam offset relative to the center of the y-axis, and it cannot be determined during distance measurement between two detectors. The procedure steps are sketched in Fig. 5. In the first step, the distribution of events as a function of the y-coordinate is constructed for the upper (y_{upper}) and lower ($-y_{\text{lower}}$) detectors of each station. Next, the ratio of the distributions is calculated and a linear fit is performed, see Fig. 5 (a). If the y_{upper}-value is fixed and $-y_{\text{lower}}$ is shifted by Δy, a slope-shift plot can be generated (*c.f.* Fig. 5 (b)). Then, a line is fitted to the slope-shift plot as well. By using the root of the fitted formula as a correction, after a few iterations, when the correction becomes sufficiently small, the station is considered vertically aligned. Eventually, the line fitted to the ratio of the upper and lower distributions will be parallel to the horizontal axis, and the root of the fitting line in the slope-shift plot will be very close to zero.

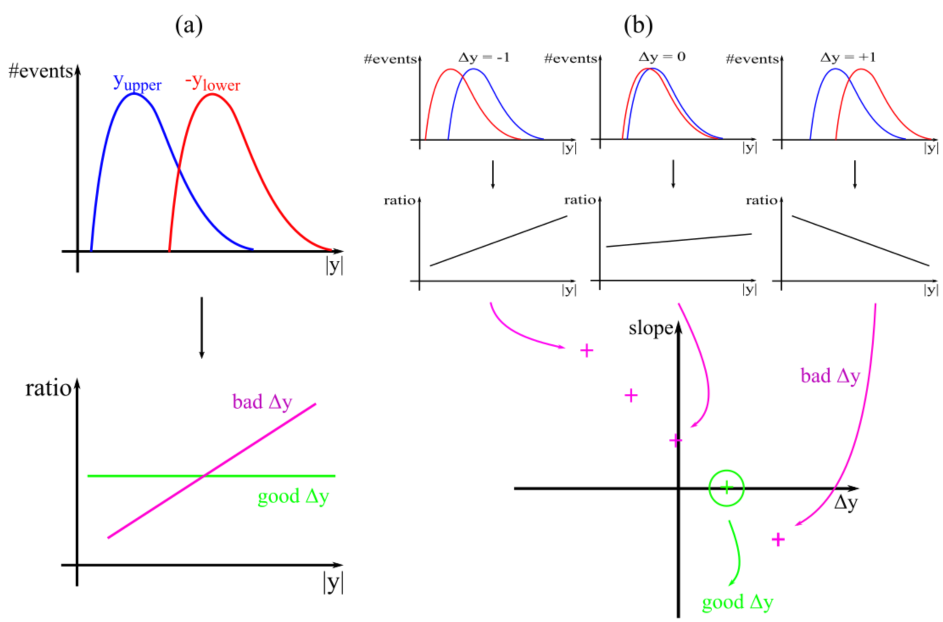

Fig. 5. (a) The ratio distribution (see the text), and (b) the slope-shift plot.

7. Rotational alignment

In the execution stage, the distribution of $\langle x \rangle$ as a function of y is constructed and a straight line is fitted to it, see Fig. 6. The rotation angle around the z-axis is related to the slope given by the linear fit, $\theta_z = \arctan(\text{slope})$. By using the obtained θ_z-value as a correction factor, after a few iterations, when the correction becomes sufficiently small, the detector may be considered rotationally aligned. As a result, $\theta_z \approx 0$ and the (x, y) distribution of the elastic protons will be symmetric w.r.t. the y-axis.

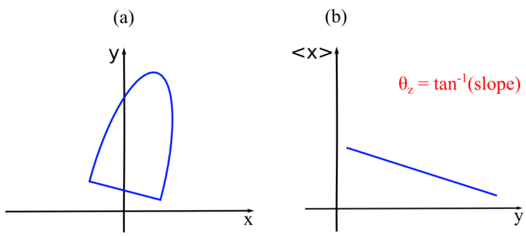

Fig. 6. (a) The (x, y) distribution of the observed elastic pattern, and (b) the correlation between $\langle x \rangle$ and y of elastic protons.

8. Summary

The experimental set-up of the ATLAS-ALFA detector system was briefly sketched. The procedure of horizontal, vertical, and rotational alignment of the detector was presented.

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