# ALICE alignment challenge

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**Abstract**

ALICE physics goals and the characteristics of the ALICE detector essential to achieve them are briefly described. The reconstruction precision for ALICE physics is presented and commented upon from the point of view of the alignment quality. The strategic choices to cope with the alignment challenges are briefly developed.

## 13.1 ALICE experimental programme

The main goal of ALICE is to study the role of chiral symmetry in the generation of mass in composite particles (hadrons) using heavy-ion collisions, in order to attain high-energy densities over large volumes and long time scales [1]. In addition, the aim is to study the physics of parton densities close to phase-space saturation, and parton collective dynamical evolution towards hadronization (confinement) in a dense nuclear environment. In this way, one expects to gain a deeper insight into the structure of the QCD-phase diagram and the properties of the QGP (Quark Gluon Plasma) phase. The nucleon–nucleon centre-of-mass energy for collisions of the heaviest ions at the LHC (PbPb, $\sqrt{s} = 5.5$ TeV) exceeds that available at RHIC by a factor of about 30, opening up a new physics domain. The successful completion of the heavy-ion programme requires the study of pp, pA and lighter A–A collisions in order to establish the benchmark processes under the same experimental conditions. Moreover, these measurements are interesting *per se* as ALICE has a unique ability to study both soft and hard aspects of such interactions. A list of the main heavy-ion observables in ALICE follows:

- particle multiplicities,
- particle spectra,
- particle correlations (flow, HBT),
- event-by-event fluctuations,
- jets,
- direct photons,
- dileptons,
- heavy-quarks and quarkonia.

These observables, studied as a function of collision centrality, form a basis for accessing the physics goals of ALICE. The possibility of reaching them and the number of events needed in order to obtain satisfactory significance levels will depend on the performance of the detectors and on the precision of their calibration and alignment. [2]. In general, the number of collected events depends on the nature and the energy of the beam, the luminosity, and the running time. For completeness let us mention that the overall success of the ALICE physics programme will depend, as for the other LHC experiments, on the background conditions of the LHC. ALICE will take its first data with pp collisions because the LHC will be commissioned with proton beams, and also because pp physics is an integral part of the ALICE programme.

ALICE will in fact require pp running throughout its operation; during the initial years longer periods to both commission the detector and to take pp physics data, and later in the programme, shorter periods to start up and calibrate/align the detector prior to each heavy-ion period. The very first data will be most probably taken with the cosmics which enable initial precious information to be obtained concerning the mechanical precision of most of the ALICE detectors. Later on cosmic events will be collected in parallel with the normal data-taking in the framework of the standard running scheme, both for physics and alignment.

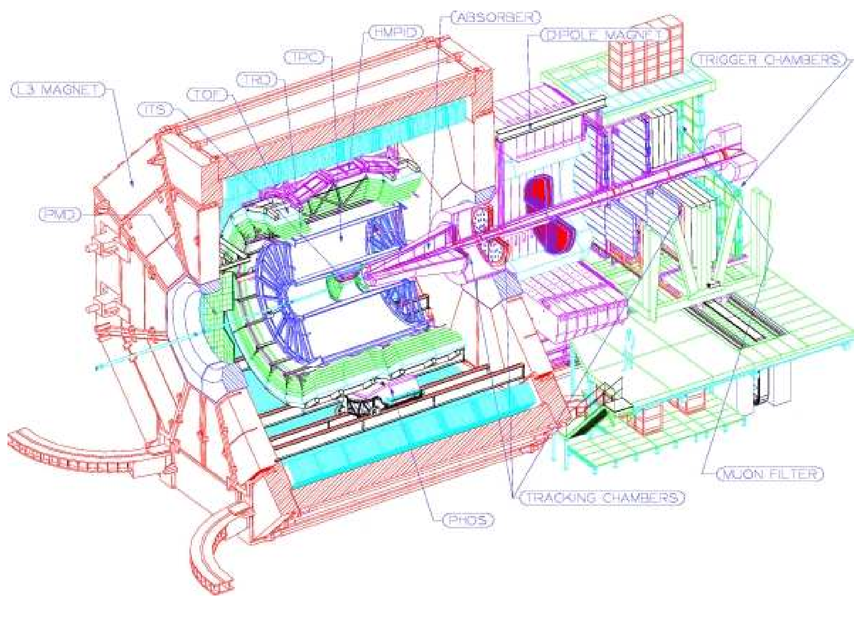

**Fig. 13.1:** Longitudinal view of the ALICE detector

## 13.2 ALICE detectors

The ALICE detector sub-systems are described in detail in the Technical Design Reports (TDRs). A list of these TDRs (not exhaustive) is given in the bibliography at the end of this report. A general view of the ALICE detector is shown in Fig. 13.1. ALICE is a general-purpose experiment whose detectors measure and identify mid-rapidity hadrons, leptons, and photons produced in the interaction [3].

A unique design, with very different optimization from the one selected for the dedicated pp experiments at the LHC, has been adopted for ALICE. This results from the requirements to track and identify particles from very low ($\sim$100 MeV/$c$) up to fairly high ($\sim$100 GeV/$c$) $p_{\rm t}$, to reconstruct short-lived particles such as hyperons, D and B mesons, and to perform these tasks in an environment with large charged-particle multiplicity, up to 8000 per unit of rapidity at mid-rapidity. The detection and identification of muons is performed with a dedicated spectrometer (including a large warm dipole magnet), covering a domain of large rapidities ($-4.0 \leq \eta \leq -2.4$). Hadrons, electrons and photons are detected and identified in the central rapidity region ($-0.9 \leq \eta \leq 0.9$) by a complex system of detectors immersed in a moderate (0.5 T) magnetic field. Tracking relies on a set of high granularity detectors: an inner tracking system (ITS) [4] consisting of six layers of silicon detectors (see Fig. 13.2), a large-volume Time-Projection Chamber (TPC) [5] (see Fig. 13.3), and a Transition-Radiation Detector (TRD) [6].

Particle identification in the central region is performed by measuring energy loss in the tracking detectors, transition radiation in the TRD, time of flight (TOF) [7] with a high-resolution array, Cherenkov radiation with a High-Momentum Particle Identification Detector (HMPID) [8], and energy of photons with a crystal Photon Spectrometer (PHOS) [9]. A large acceptance Electromagnetic Calorimeter (EMCAL) [10] will enforce progressively the photon detection subsystem. Additional detectors located at large rapidities complete the central barrel system to characterize the event (collision centrality) and to provide the interaction trigger. In order to be able to cope with events of very high multiplicities a choice was made to build a large TPC as the main tracking device. A consequence of this choice is a modest speed of DAQ (due to a maximum drift time of about 90 $\mu$s) thus limiting the usable luminosity with pp collisions, in order to keep the pile-up at a tolerable level. With Pb–Pb running the foreseen luminosity ($10^{27}$ cm$^{-2}$ s$^{-1}$) will match well the TPC data-taking speed, taking full advantage of its multiparticle detection performance.

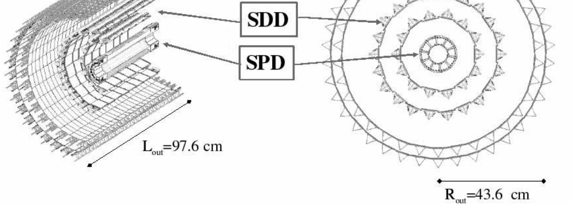

**Fig. 13.2:** Layout of the ITS

The Inner Tracking System (ITS) consists of six layers of silicon detectors located at radii: $r$ = 4, 7, 15, 24, 39 and 44 cm. It covers the rapidity range of $|\eta| \leq 0.9$ for all vertices located within the length of the interaction diamond ($\pm 1\sigma$), i.e. $\sim$11.4 cm along the beam direction. The number, position and segmentation of the layers are optimized for efficient track finding and high impact-parameter resolution.

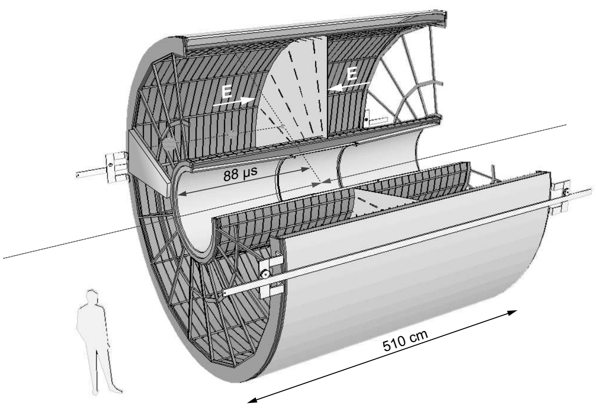

**Fig. 13.3:** TPC schematic layout

In particular, the ITS outer radius is determined by the necessity of matching ITS track segments with those from the TPC, and the inner radius is the minimum allowed by the radius of the beam pipe (3 cm).
Because of the high particle density, up to 80 particles per cm$^2$, and in order to achieve the required impact particle resolution (well below 100 $\mu$m for high momentum tracks), pixel detectors have been chosen for the two innermost layers, and silicon drift detectors for the following two layers. The outer two layers, where the track densities are below one particle per cm$^2$, are equipped with double-sided silicon micro-strip detectors. With the exception of the pixels, all other detectors have analog readout for particle identification via d*E*/d*x* measurement in the non-relativistic ($1/\beta^2$) region. This gives the ITS a stand-alone capability as a low-$p_\mathrm{t}$ particle measurement device.

The principal tasks of the ITS are:

- to localize the primary vertex with a resolution (multiplicity dependent) better than 100 $\mu$m,
- to reconstruct the secondary vertices from decays of hyperons and D and B mesons,
- to track and identify particles with momentum below 100 MeV/$c$ (not reaching the TPC),
- to improve the angular (impact parameter) and momentum resolution for the higher $p_\mathrm{t}$ particles traversing also the TPC.

The values of momentum and impact parameter resolution for particles with small transverse momenta are dominated by multiple scattering effects in the material of the detector. Therefore the amount of material in the active volume has to be reduced to a minimum (the 0.8 mm Be pipe has a negligible effect here). However, the silicon detectors used to measure ionization densities (drifts and strips) must have a minimum thickness of approximately 300 $\mu$m to provide reasonable signal-to-noise ratio. In addition, detectors must overlap ($\sim 2\%$) to cover entirely the solid angle, which is anyway beneficial for the alignment procedures. Taking into account the incidence angles of tracks, the detectors effective thickness amounts to $\sim 0.4\%$ of $X_0$. The thickness of additional material in the active volume is limited to a comparable effective thickness.
The main parameters of the ITS detectors are summarized in Table 13.1.

**Table 13.1:** Parameters of the various ITS detector types. A module represents a single sensor element.

| Parameter | | Silicon pixel | Silicon drift | Silicon strip |
|---|---|---|---|---|
| Spatial precision r$\varphi$ | ($\mu$m) | 12 | 38 | 20 |
| Spatial precision $z$ | ($\mu$m) | 100 | 28 | 830 |
| Two track resolution r$\varphi$ | ($\mu$m) | 100 | 200 | 300 |
| Two track resolution $z$ | ($\mu$m) | 850 | 600 | 2400 |
| Cell size | ($\mu$m$^2$) | $50 \times 425$ | $150 \times 300$ | $95 \times 40000$ |
| Active area per module | (mm$^2$) | $12.8 \times 69.6$ | $72.5 \times 75.3$ | $73 \times 40$ |
| Readout channels per module | | 40 960 | $2 \times 256$ | $2 \times 768$ |
| Total number of modules | | 240 | 260 | 1698 |
| Total number of readout channels | (k) | 9 835 | 133 | 2608 |
| Total number of cells | (M) | 9.84 | 23 | 2.6 |
| Average occupancy (inner layer) | (%) | 2.1 | 2.5 | 4 |
| Average occupancy (outer layer) | (%) | 0.6 | 1.0 | 3.3 |
| Power dissipation in barrel | (W) | 1500 | 1060 | 1100 |
| Power dissipation end-cap | (W) | 500 | 1750 | 1500 |

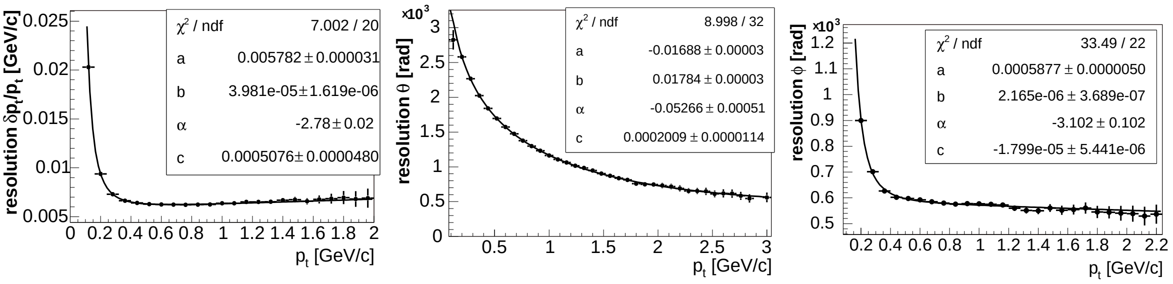

**Fig. 13.4:** Single-particle momentum resolution in terms of $\delta p_\mathrm{t}/p_\mathrm{t}$, $\delta\theta$, and $\delta\varphi$, as a function of the transverse momentum

## 13.3 ALICE design physics performance

The ALICE detector and its physics performance is described in detail in Ref. [3]. The design of the tracking system has primarily been driven by the requirement of efficient and robust track finding in the high multiplicity events. The detectors use mostly three-dimensional hit information and continous tracking with many points, in a moderate magnetic field (0.5 T). The field strength is a compromise between momentum resolution, acceptance at low momentum, and tracking and trigger efficiency. The main track resolution parameters are displayed in Fig. 13.4. The momentum cut-off is kept as low as possible ($\leq$ 100 MeV/$c$), in order to study collective effects associated with large scales (identical-particle interferometry) and to detect the decay products of low-$p_\mathrm{t}$ hyperons. In this respect the ITS plays an important role enabling, owing to its excellent double-hit resolution, the separation of tracks with close momenta.

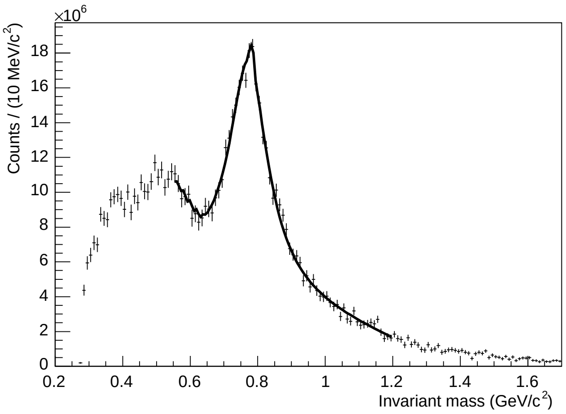

**Fig. 13.5:** Fit of $\rho$ Breit-Wigner, $\omega$ and background to $\pi^+\pi^-$ invariant mass spectrum after like-sign subtraction for $10^6$ central Pb–Pb events. The fitted width of the $\rho$ peak is $0.162 \pm 0.008$ GeV/$c^2$.

For the study of the resonance production ($\rho, \omega$ and $\phi$), and in particular the behaviour of the mass and the width of the mesons in a dense medium, the momentum resolution is a key requirement. Precision of mass measurement must be comparable to, or better than, the natural width of the resonances in order to observe possible changes of their parameters induced by the predicted chiral symmetry restoration. In Fig. 13.5, the invariant mass of the reconstructed $\rho$ resonance produced in central Pb–Pb events is shown (MC-generated events).

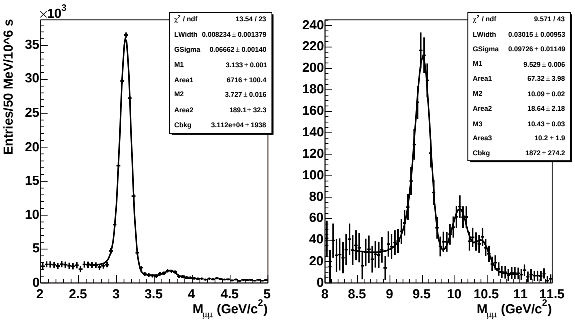

**Fig. 13.6:** Fit of the dimuon spectra for the 1st centrality class in the J/Ψ (left) and $\Upsilon$ (right) mass regions. The solid lines are the results of the fits.

At high momentum, a reasonably good resolution up to 100 GeV/$c$ is essential for jet-quenching studies, since it has to be adequate to measure the leading particles of jets up to jet momenta above a few hundreds of GeV/$c$. The resolution must also be sufficient to separate the different states of the $\Upsilon$ family (both in the central barrel and in the Muon Spectrometer — see Fig. 13.6).

The requirement on angular resolution is determined by the need to measure precisely the position of the primary and secondary vertices. The ITS design has been optimized mainly to provide accurate measurement of the track impact parameter (see Fig. 13.7), enabling the identification of secondary vertices of charm and beauty mesons.

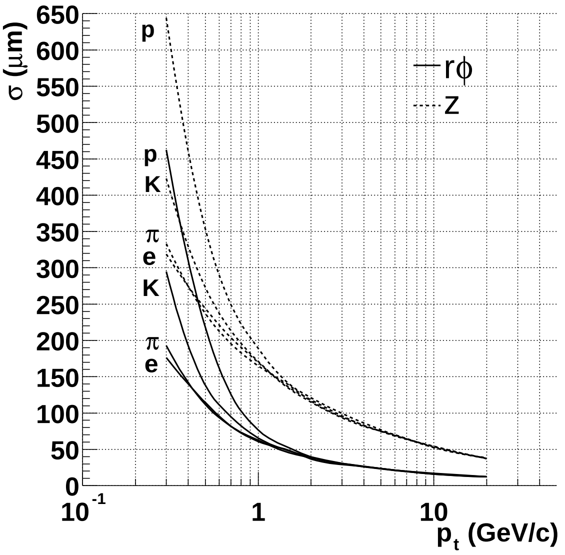

**Fig. 13.7:** Impact Parameter resolutions in central Pb–Pb collisions for electrons, pions, kaons and protons as a function of the transverse momentum

## 13.4 General ALICE alignment aspects

All the ALICE physics performance figures shown above refer to the ideal situation of perfect calibration and alignment. As the first physics with ALICE will be devoted mainly to the soft physics sector, the effects related to imperfect knowledge of alignment parameters can be expected to play a secondary role, as the reconstruction precision will be mainly limited by multiple scattering. This helps one to understand why the ALICE study on the influence of misalignment on physics has started relatively late. It has been checked, for example, whether the multiplicity measurement using only the pixel detectors of the ITS system is not affected significantly, up to the highest, realistic level of the geometrical misalignment. An investigation has also been made concerning the influence of the alignment precision in the Muon Spectrometer on the feasibility of separating members of the $\Upsilon$ family — a topic which is discussed in a separate ALICE contribution [11].

After the first data-taking the main interest will move progressively to the topics relying more strongly on the detailed knowledge of the detector alignment, which will be gained using mainly the cosmics and pp data. ALICE is a heterogeneous system of different detector types which also differ from the point of view of the required alignment precision. For example, the PHOS detector will need to be aligned with a precision of only 1 mm, which can easily be satisfied by a standard survey measurement after installation of the detector. With the drift-type tracking detectors there is a strong interplay between calibration and alignment (mainly in TPC and SDD), that will require the use of special methods (lasers, charge injectors) to get them properly calibrated first. The TPC in particular will need a careful study to disentangle the misalignment from the E×B effects, which could be quite important due to the large drift distance (up to 250 cm). To provide high structural integrity of the TPC against gravitational and thermal loads whilst keeping the material budget low, composite materials were chosen. Hence the mechanical stability and precision is guaranteed to be about 250 $\mu$m. The strongest demand on the detector alignment precision comes from the ITS detector, which follows from the previous discussion of its role in the ALICE physics programme. For this reason the greatest possible care is taken to respect the construction precision requirements, enumerated in the ITS Technical Design Report (see Ref. [4]). This precision, depending on the structure level in the system, ranges from 20 to 100 $\mu$m and will need to be improved using tracks, down to a 10 $\mu$m level.

The Muon Spectrometer has a dedicated hardware alignment monitoring system [12] (multipoint optical Geometrical Monitoring System), ensuring the alignment precision of about 50 $\mu$m. This is complemented by a software alignment based on the Millepede algorithm [13].

ALICE regularly performs large-scale MC simulations in order to stress the offline infrastructure (AliRoot) for the data flow, reconstruction, and analysis [14].

The year 2006 Physics Data Challenge (PDC06) has, for the first time, included the generation of events with two levels of misalignment: the one left after applying the full re-alignment hardware and software procedures (so-called *residual misalignment*), and the one expected at day-1 as a result of the mechanical detector imprecision (so-called *full misalignment*).

Analysis of these data is at present in progress and is expected to give an answer to the question of the impact of misalignment on the numerous observables enumerated at the beginning of this contribution.

## 13.5 Inner Tracking System (ITS) alignment challenge

Without any doubt, the most challenging detector from the point of view of alignment is the Inner Tracking System. Its main parameters are given in Table 13.1. The total number of modules is 2198 which corresponds to 13188 degrees of freedom (plus a few global degrees of freedom) — a modest value compared to the ATLAS and/or CMS equivalent numbers, but an order of magnitude higher than in the RHIC heavy ion experiment STAR. The general layout of the ITS mechanical structure has been developed in order to respect the main physics requirements of the experiment and to ensure reliable long-term operation. This implies, amongst other requirements, a high-precision positioning of the modules and a thermo-mechanical stability of the system. For the support structure the type of carbon fibre was chosen in order to maximize stiffness and minimize thermal expansion. Finite Element Analysis (FEA) simulations were performed in order to find the best configuration and the relative orientation of the carbon-fibre layers.

Given that the tracking is based on both TPC and ITS (see Fig. 13.8), there is a strong requirement of an accurate relative alignment of the ITS and the TPC.

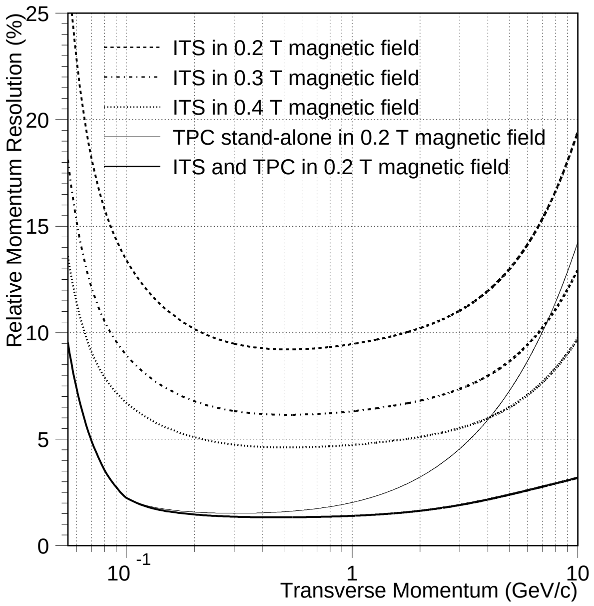

**Fig. 13.8:** Relative momentum resolution for pions using only the ITS as a function of transverse momentum, compared with the resolution using both ITS and TPC, and TPC stand-alone

For this reason the relative position of the two subdetectors will not only be tuned by alignment software procedures with tracks, but will also be monitored by a dedicated optical system ITSAMS (ITS Alignment Monitoring System). In addition to some unpredictable random misalignments at the level of single modules and support structures, some global ITS distortions (as shown in Fig. 13.9) are possible, making the alignment procedure more complex. Thanks to a limited total weight of the system (including cooling and cabling) of ∼1000 N, the collective modes related to sagging are not expected to dominate the overall misalignment. Re-alignment aligorithms, based on local residual minimization [15], are still at an early stage of development and need intense debugging and testing on the MC events. Another option envisaged is using the Millepede algorithm, already adapted to the AliRoot environment by the Muon Spectrometer group (AliMillepede). The final choice will depend on the MC tests of the local, iterative approach. As previously mentioned, the two innermost ITS layers are composed of Silicon Drift Detectors, which will need careful calibration before being included in the realignment process. For this reason a conservative solution is envisaged in which the pixel detectors are aligned in a stand-alone mode using cosmic muons and then used as a reference detector to align the outer detectors. In the case of pp data, a main vertex position, easily reconstructed using only the pixel clusters or tracklets, can be used as an additional track point.

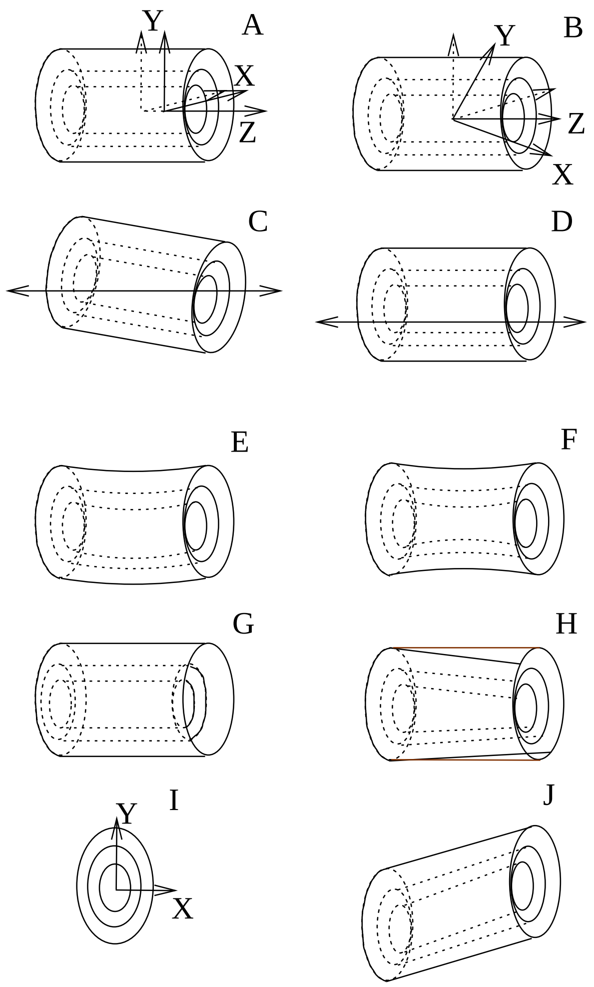

**Fig. 13.9:** Different types of global (A–D), and collective displacements of the ITS. A: Translation in $z$. B: Rotation about the cylinder axis $\varphi$. C: Rotation about an axis perpendicular to $z$. D: Translation in $y$ and/or $y$ of the beam. E: Sag in the ladders. F: Bulge in the ladders. G: An $r$-dependent shift in the $z$ position of the ladders. H: Twist or torsion in the ITS. I: Systematic scale change in the ITS radii. J: Rack or a displacement of the end-cones in the plane orthogonal to the beam axis.

## 13.6 Summary

ALICE is a unique LHC heavy-ion dedicated experiment, exceeding in size and complexity all past and present heavy-ion experiments. Alignment requirements of its subdetectors are quite heterogeneous, demanding a full range of different hardware and software methods of re-alignment. The ALICE offline framework AliRoot [14] and the ALICE alignment framework [16] have been developed in a way to make this task relatively easy and straightforward. At present the main effort is being put on adapting and testing different standard algorithms and strategies of alignment, the most challenging being the Inner Tracker System. The goal in this case is to reach an alignment precision of $\sim 10\,\mu$m.

The exchange of information during this Workshop has greatly contributed towards a deeper assessment of the different mathematical and practical aspects of the detector alignment process. This gives an additional guarantee of the successful realization of the difficult and ambitious physics programme of the ALICE experiment.

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