The Active Prealignment of the CLIC Components

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CERN is studying the feasibility of building a high energy e+e- linear collider: the Compact LInear Collider CLIC. One of the challenges of such a collider is the prealignment tolerance on the transverse positions of the components which is ten micrometers over a sliding window of 200 m, along the 14 km of each linac. This paper reviews the solutions proposed and the progress made in the study of the active prealignment of the CLIC components.

1. INTRODUCTION

Over the last 50 years at CERN, there has been a succession of particle colliders each larger and more powerful than the last and their alignment has proved to be a permanent challenge for the surveyors. Thus, in 1959, the tolerances of alignment of the magnets of the Synchrotron with Protons (PS) were ± 0.3 to 0.6 mm in the radial plane and 0.6 to 1.2 mm in the vertical plane [1]. At the present time, this tolerance after smoothing in the LHC is ± 0.3mm (3σ). This evolution, exposed numerically, hardly appears impressive. However, in 50 years, one has passed from an accelerator of 630 m circumference of a hundred elements, with the LHC, of 29.7 km of circumference and its more than 1230 dipoles and 470 quadrupoles, requiring more sophisticated systems of measurement for the automation of measurements, more complex calibrations, with more sophisticated geodetic works considering the dimensions involved.

CLIC (Compact LInear Collider) is a study for a future linear collider of particles e-/e+, allowing collisions going from 0.5 to 5 TeV. The tolerance necessary for the alignment of the components of this collider is of ±10 μm (3σ) on 200 m. It is still a challenge to be met but different from those that preceded. Indeed until now smoothing took place in two phases: the determination of the relative position of each element and the calculation of its smoothed position, then the manual displacement of the jack's supports concerned. In the case of the CLIC, prealignment will have to be active and of a micrometric precision.

This paper, after a description of the CLIC and the challenge of its alignment, describes the orientations taken as well as the progress made in the study of the active prealignment of CLIC components.

2. THE CLIC STUDY AND THE ALIGNMENT

2.1. Overview of CLIC

CLIC is a study for a future linear accelerator e+/e- whose power in the centre of mass could reach 5 TeV, optimized for energy in the centre of mass of 3 TeV. It is based on a technology known as "two beam acceleration". The idea is to accelerate the beam using high frequency structures (CAS) (30 GHz) subjected to a strong accelerating field (150 MV/m). RF power necessary to these structures comes from other structures (Power ExTraction Structure known as PETS) being used for deceleration of another beam parallel with the first one (see Figure 1).

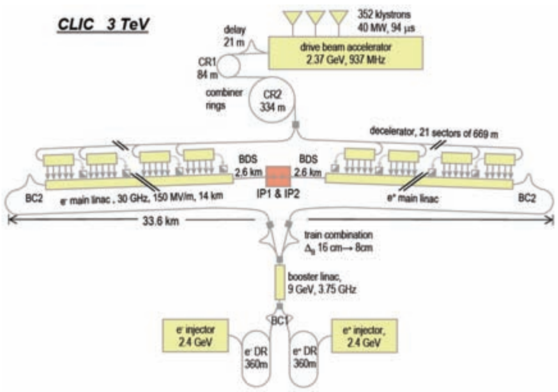

Figure 1: Overall layout of CLIC for a centre of mass of 3 TeV

In the case of a configuration of 3 TeV, the two main beams respectively accelerating electrons and positrons measure 13.75 km each. The beam is then focused before the collision to reach a section of 43 nm in the horizontal plane and 1nm in the vertical plane. One disadvantage of this technology is that higher CLIC RF frequency makes the scheme more sensitive to alignment errors and ground stability.

2.2. CLIC module overview

To introduce the constraints of alignment, it is necessary to explain the assembly of the CLIC components. The CLIC is composed of two parallel beams: the main beam, or “Main linac” and the decelerated beam, or “Drive linac”. The whole is divided into 2 m length modules (see Figure 2).

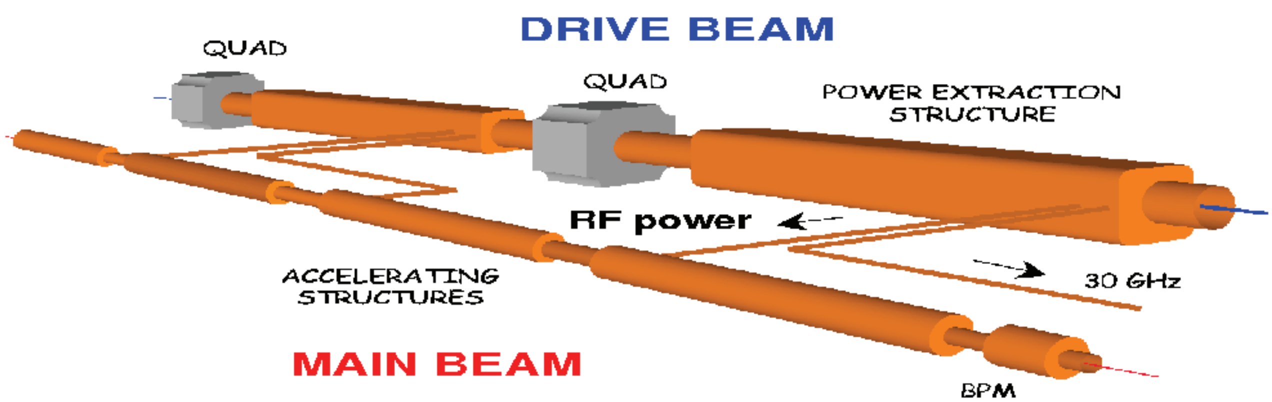

Figure 2: CLIC module layout

Each module is composed of 4 accelerating structures CAS, themselves composed of 4 assembled and prealigned HDS quadrant cells. In order to simplify the alignment of these components in the tunnel, four CAS components are aligned on the same girder with one Beam Position Monitor (BPM), within a precision of ±3 μm. This operation will have to be carried out in clean room, so that the references of alignment associated with the girders and the elements are determined perfectly, following a procedure which remains to be defined. In the same way, concerning the drive linac, the PETS components will be prealigned on the girders. Concerning the quadrupoles of the main and drive linac, they have to be completely independent of the girders from the point of view of alignment. These will be laid on their own support, the design of which will have to be optimized taking into account their great sensitivity to the vibrations.

Studies on the active prealignment of the CLIC, which started in 1989, arrived at an innovating solution concerning the mechanics of the supporting girders [3]. Two consecutive girders are connected by a mechanical system, equivalent to an articulation point, able to be regulated by 3 degrees of freedom, to some extent guaranteeing a natural mechanical smoothing of adjacent girders.

2.3. The alignment of CLIC

The geodetic network proves to be the spinal column which links the linacs and the detectors. Different steps described in [2] will allow the determination of the geodetic network in the tunnel, for example the installation and the determination of a geodetic surface network, or the transfer of the references in the tunnel. These steps are common to any linear accelerator of equivalent length.

The various girders on which rest the accelerating cavities and their associated BPM, as well as the supports of the quadrupoles with their associated BPM, will have to be the subject of an active prealignment along the main linac, in order to be located in the measurement range of the BPM, and to allow the beam to circulate. The tolerance given for this transverse prealignment is ± 10 µm on a sliding window of 200m along the 14 km of linac. This paper will concern this step of the CLIC alignment.

Thanks to the introduced pilot beam, information resulting from measurements of the BPM makes it possible to set up the “beam based alignment” in order to optimize the position of the accelerating cavities and the quadrupoles. The procedure to align these elements for an optimum trajectory of the beam will not be detailed in this document.

2.4. The active pre alignment of CLIC

The prealignment of CLIC will have to guarantee a tolerance on the transverse positions of the girders of ± 10 µm on a sliding window of 200m. Such a tolerance cannot be obtained and preserved by a static alignment performed before the startup. With such a tolerance, the effects induced by the human activity and the ground movements can no longer be put aside: it becomes necessary to set up an active system - in this case an automated process where the association of sensors and actuators makes it possible to align the girders in real time closest to their theoretical position. Moreover, micrometric precision necessary for this prealignment, associated to the fact that it is active, imply the use of new alignment systems. Indeed, standard metrology instrumentation, being used for the LHC alignment (tacheometers, levels, laser tracker) is completely unable to ensure even one of these aspects.

However, alignment systems answering these criteria exist and have been used for more than 10 years by the surveyors at CERN for specific tasks such as the monitoring of large physics experiments [4], micrometric alignments in radioactive areas [5]. They are measurement systems based on a capacitive technology, such as Hydrostatic Leveling System (HLS), Wire Positioning System (WPS) or inclino-accelerometers Tilt Meter System (TMS). The Red Alignment System from NIKHEF (RASNIK) system, developed by the National Institute for Nuclear Physics and High Energy Physics in Amsterdam (NIKHEF) was also used in the LEP experiments and will be used quite extensively in the LHC experiments [6]

The study of the CLIC active prealignement system was initiated in 1988 by I. Wilson, W. Coosemans and W. Schnell. Many mock ups, facilities, calculations, prototypes were carried out before proposing the following strategy for the active prealignment:

- A simplification of the problem by prealigning a number of components of each linac on girders, which comes to align the girders instead of aligning each of the components

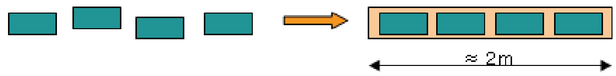

Figure 3: Prealignment of components on girders

- A simplification of the alignment by linking all the adjacent girders by a common articulation point. The alignment then consists in aligning each articulation point according to three degrees of freedom.

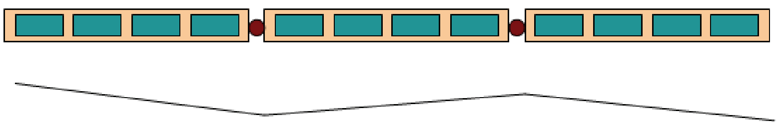

Figure 4: Adjacent girders linked by a common articulation point

- To each articulation point, are associated the sensors of a first metrological network, named "proximity network", allowing a high precision alignment between adjacent girders. This proximity network is composed by low cost sensors providing a few micrometers precision over 10m.

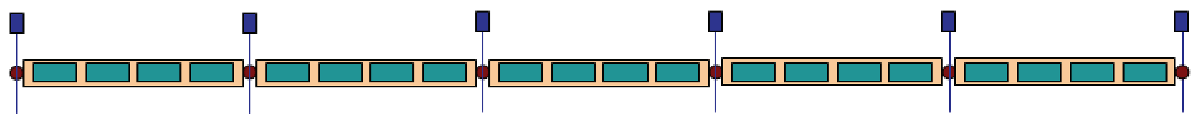

Figure 5: Proximity network

- Every x articulation point, a second metrological network is associated to the articulation point. This network will allow precision propagation on long distances, made of reference frames of more than 100m long, overlapping on half of the length.

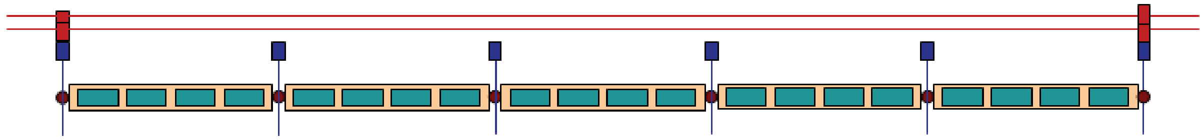

Figure 6: Propagation network

Concerning the proximity network, the measurement system used would be the RASNIK system. The measurement uncertainty for this three points alignment system (source of light, lens and camera CCC) is about ± 1 µm on a distance from 5m between the transmitter and the receiver.

Concerning the propagation network, it is undoubtedly in this part of the alignment of the CLIC that resides the true challenge. Indeed, to ensure a micrometric precision on a few meters is not simple, but the solutions exist. On the other hand, to ensure this same order of precision on several hundred meters imposes a much more complex device. The idea is to have a precise system of measurement with some micrometers over lengths greater than 100 m. To propagate the precision on the 13 km of each linac, the two systems are then put in parallel with shifted origins.

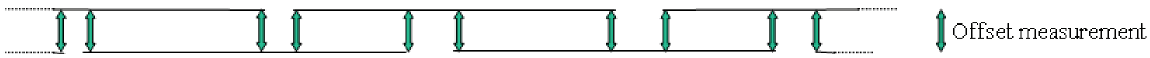

Figure 7 : Overlapping alignment systems

Two systems of measurement are planned to fulfill this role: WPS system, composed of wire stretched over more than 100 m, and RASCLIC system, under development in collaboration with NIKHEF institute. The measurement of one articulation point every x modules has to be carried out with the propagation system in order to link both propagation and proximity networks. The quadrupoles, independent of the girders, are directly attached to the propagation network.

3. SITUATION OF THE STUDIES ON THE ACTIVE PREALIGNMENT

3.1. Studies context

As mentioned previously, the studies on the CLIC active prealignment started in 1988, taking into account the challenge of attaining reachable tolerances. A first global solution was presented in 2003, foreseeing that a solution was possible, although a certain number of points still remained to be validated. The studies were then stopped between 2003 and 2005, because of a lack of means and personnel; they have started again gradually since one year, with the arrival of a person working full-time for these studies.

The main objectives of CLIC studies are recalled in this general definition: “the CLIC study is a site independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron-positron linear collider in the post-LHC era for physics up to the multi-TeV center of mass colliding beam energy range (0.5 to 5 TeV)”. If this definition is translated to the CLIC alignment, we must understand that we need to probe the feasibility of the prealignment before 2010, while remaining within a reasonable budget. It is around these two points that are focused the current studies. We are at the feasibility stage, and therefore are not calling into question all the solutions put forward previously, but trying to find solutions or alternatives to the points which remained outstanding, while trying to reduce the costs. Before detailing the studies in progress and the orientations considered, let us recall the solution proposed in 2003.

3.2. Active pre alignment solution in 2003

The solution put forward in 2003 is based on a proximity network composed of RASNIK sensors providing redundant information of position. These components are attached to each articulation point linking two adjacent girders. Every 5 modules, an articulation point is connected to the network of propagation, made of stretched wires overlapping over the half of their length over a distance of more than 100 m, and thus propagating the precision. Metrological plates are positioned all the 50 m, supporting WPS sensors from starting and arrival of wires and the WPS located at the level of the sag of the parallel wire. In order to model the wire into the vertical plane, all the plates are equipped with a HLS sensor and a clino-accelerometer.

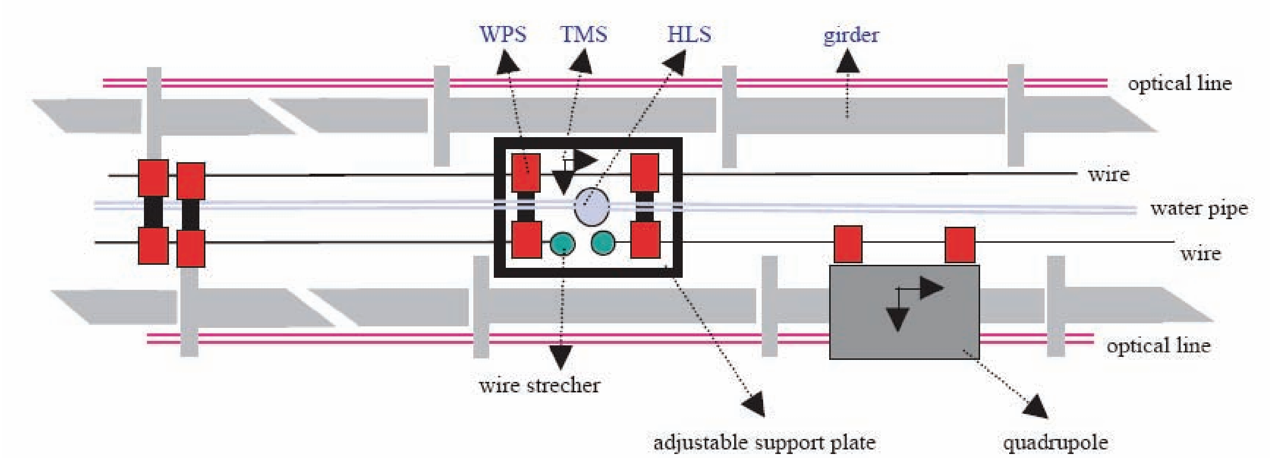

Figure 8 : Schematic plan view of the two geometrical reference networks [7]

The simulations based on this configuration gave very encouraging results with an uncertainty on relative alignment ranging between 8 and 14 µm on 200 m, at the same time in planimetry and altimetry, and of uncertainties of positioning girder to girder of about 5 micrometers.

The greatest interrogation point relates to the use of stretched wires for the vertical alignment. The stretched wires are modelized using HLS sensors, providing a reference linked to the geoid. To model a wire precisely, it is necessary to know the difference in height in three points along the wire. The superposition of HLS sensors on WPS sensors provides this reference with a margin of a few micrometers. However the CLIC must follow a straight “laser” line, which requires a thorough knowledge of the geoid of a precision such as has never been sought by the various organizations in charge of gravimetry, or to find an alternative to model the stretched wire. Another solution, more radical still, would be to replace WPS system by an optical measurement system, almost insensitive to gravity.

3.3. Orientation of the studies in 2006

It is of primary importance to conclude first on the feasibility of an active prealignment, by focusing the studies on the following points:

- The determination of the maximum achievable precision regarding the definition of the geoid, in relation with the Federal Office of Topography of Switzerland.
- The search for another method of modeling a stretched wire (with an uncertainty in the determination of a few micrometers).
- The development of a laser solution, in collaboration with NIKHEF, named RASCLIC using the “TT1” test stand, whose length is approximately 140m. This test facility and its associated alignment system are described in chapter §3.

- The validation of the assumptions made on the uncertainties of the alignment systems measurements, used during simulations concerning the global prealignment reachable precision

It will be then necessary to validate the solution adopted in a real environment: the two beam test area, belonging to the CLIC Test Facility 3 CTF3, whose goal is to demonstrate all the remaining CLIC specific key issues to show the feasibility of the CLIC scheme.

It is also important to propose a solution at a realistic and affordable cost, which also requires studies in parallel, such as:

- Increasing the length of a stretched wire. The use of a wire stretched on 500 m would not only make it possible to increase the precision of propagation, but also to reduce the costs. It implies the validation of the stability of the measurements carried out on a wire of such a length, to find an interesting solution to effectively protect the wire from the ventilation, and to set up a method of installation of the wire appropriate to such distances. These tests will take place at the end of the year in a CERN tunnel.
- The NIKHEF Institute is studying a low-cost solution for the RASNIK system if this is to be installed every two meters along 34 km.
- A collaboration is being set up with University UNMDP of Mar del Plata in Argentina, in order to upgrade the solution of control of the sensors and actuators, developed and tested 10 years ago.

4. THE RASCLIC ALIGNMENT SYSTEM AND THE TT1 TEST FACILITY

4.1. The RASCLIC alignment system

NIKHEF has proposed adaptation of its RASNIK system to long distance observation, i.e. to develop a new alignment system providing the transverse positions of several targets distributed along more than 100 m, with a measurement uncertainty superior to ±5 µm.

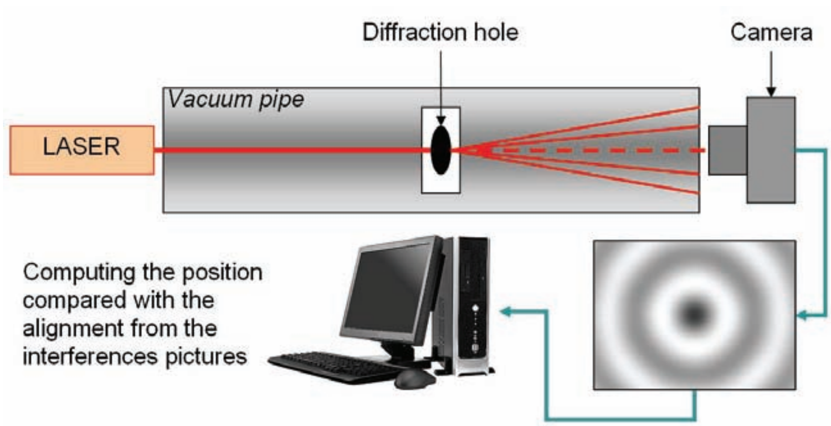

Figure 9: RASCLIC overview

The straight line reference is defined by a laser beam under vacuum, between the emitter and the detector. A first idea consists in using targets with a hole and in determining the center of the model of diffraction on the detector (in fact a CCD camera).

The RASCLIC is currently under development. The first tests are being carried out on the TT1 test facility. They consist in testing various diffraction patterns (one or more holes, various diameters, etc) on a total distance of 90 m. One of the great constraints of this solution will be to find adequate mechanics allowing the quick and precise lowering and raising of the various targets along the beam.

4.2. The TT1 test facility

This test facility is located in tunnel TT1 of an old particle accelerator of the CERN: ISR. The layout of TT1 facility is very close to the layout of the CLIC active prealignment proposal of 2003, where the propagation network is made up of two parallel lines of stretched wires over a distance of 100 m, overlapping in the middle of the distance. In that layout, each plate is equipped with one HLS sensor, with one to three WPS sensors, and with one component of the RASCLIC system. Each plate is laid on moveable supports allowing displacements along the three directions.

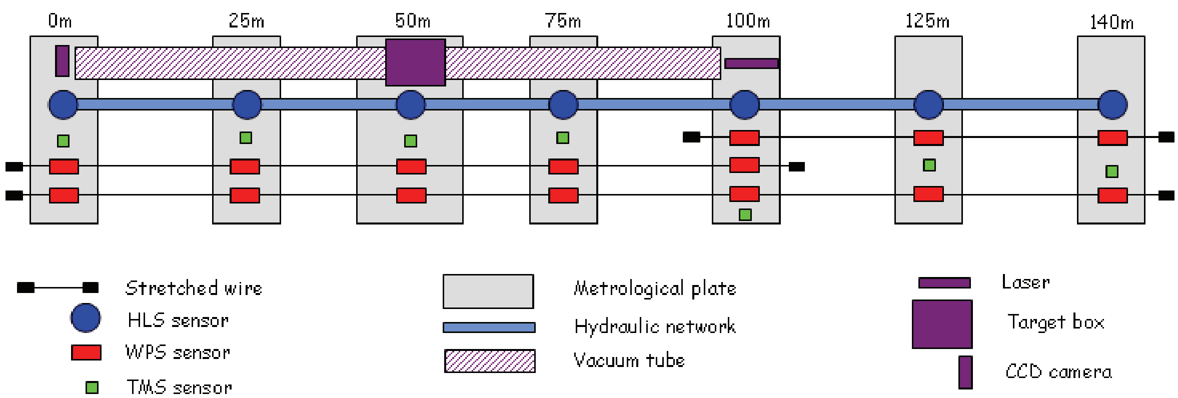

Figure 10: Schematic plan view of TT1 facility

This test facility must fulfill the following objectives:

- To study the WPS alignment system, in particular the problems of wire protection, the effects of the wire length on its modelization and on the quality of measurements, as well as other influences such as the temperature and the disturbances due to gravity
- To study the optical RASCLIC system suggested by NIKHEF, with in particular the diffraction due to air fluctuations, diaphragm not perpendicular to the beam or loss of coherence of the laser, the choice of the targets or patterns, the reflection in the tube, the instability of the laser, other influences such as temperature
- To carry out a comparison between WPS, HLS and RASCLIC systems.

Such a configuration of sensors will allow validating the a prior*i* accuracy used for the previous simulations, which were:

- A priori accuracy of the measurements of an horizontal offset from a wire: $\sigma = \pm 5$ µm
- A priori accuracy of the measurements of a vertical offset from a wire: $\sigma = \pm 8$ µm
- A priori accuracy of leveling measurements: $\sigma = \pm 7$ µm

Only stability measurements have been carried out for the moment, showing promising results. A very good correlation is obtained for example between measurements of HLS and WPS sensors located on the same metrological plates, which makes it possible to show the precision of these alignment systems.

Regarding the RASCLIC system, in spite of the absence of vacuum, useful data in the form of image frames could be collected for several positions of the zone lens showing a position resolution, in terms of image position on sensor, of 2 μm in horizontal and 4μm in vertical. [8]

5. CONCLUSION

The alignment of a linear collider on 34km, with a tolerance of ± 10 μm over a sliding window of 200 m is a challenge. Since 1989, a team of CERN surveyors showed that it is not a Utopia: WPS, HLS, RASNIK alignment systems, tested and developed at the time, are now used for multiple applications at CERN. In addition to the aspects relating to the space required by these systems and their cost, a major point remains: the use of these same alignment systems to carry out a straight alignment along such distances. Various solutions are currently being studied (local gravimetric measurements, new method of modeling of a stretched wire) or alternatives (development of a new optical alignment system: the RASCLIC), in order to prove the feasibility of this alignment for 2010.

Acknowledgments

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