COCOA

Cms Object-Oriented Code for Optical Alignment

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Outline

- Optical alignment
  - The CMS optical alignment system
  - The problem of optical alignment and how to solve it
  - COCOA
- Effect of misalignment in the reconstruction
- Alignment with tracks
- Commonalities and difference of the several alignment softwares

The problem

SIMULATION:

You are designing a new optical alignment system and you want to:

- **Propagate errors:**
  - Calculate how much the errors of the calibrated parameters and the measurements affect the errors of the parameters we want to measure
- **Study redundancies:**
  - How much errors changes if some measurement disappears
- **Study range:**
  - When a measurement will get out of the range of the measuring device is some objects move

The problem (II)

RECONSTRUCTION:

• Optical system takes measurements (2D sensors, 1D sensors, tiltmeters, distancemeters)

$\Rightarrow$ results are not what expected by extrapolating measured and calibrated parameters. **Why?**

- Wrong rotation / position of some objects
- Wrong internal calibration of some objects
    - wedge of a splitter
    - internal calibration of a distancemeter
    - deviation when traversing a sensor
    - ...

- **Software is the same for Simulation and Reconstruction**
    - Only difference: for Simulation measurement is ideal, for Reconstruction measurement is real

How to solve it

- Get the equations of how each measurement depends on all those parameters
  - positions, rotations, internal parameters

$M_1 = f_1(p_1, p_2,\ldots, p_m)$

$M_2 = f_2(p_1, p_2,\ldots, p_m)$ $\quad$ *$M_1,\ldots, M_n$ = Measurments*

… $\quad$ *$p_1,\ldots,p_m$ = parameters (known and unknown)*

$M_n = f_n(p_1, p_2,\ldots, p_m)$ $\quad$ f_i are non linear equations

- You know the measurements and some calibrated parameters, need to know the missing ones

$\Rightarrow$ Solve the system of equations: **Non-linear least squares fit**

- **To solve a system of equations, you do not have to know the equations**

How to solve it (II)

- **Only the derivatives are needed**

⇒ Get the derivatives with a numerical method

- Reproduce a measurement with initial parameters (e.g. propagate a laser until the sensor)
- Move a parameter and see how the measurement value changes
- Repeat n times moving $1/2^i$, until it converges

Total CMS alignment system: 30000 parameters ⇒ **big and sparse matrices ⇒ sparse matrix library (meschach C library)**

COCOA

♦ General purpose software to simulate and reconstruct optical alignment systems composed of any combination of

laser, x-hair laser, source, lens, pinhole, mirror, plate splitter, cube splitter, rhomboid prism, optical square, sensor2D, sensor1D, COPS, distancemeter, distance target, tiltmeter, 'user defined'

• Each object has internal parameters (planarity of a mirror, wedge between plates of a plate splitter, internal calibration of COPS...)

• User can define its own object: *Tell COCOA how much the light ray will be shifted and deviated for each measurement*

➢ Reconstructs positions, angles or internal parameters of each object from the measurement values

➢ Propagates the errors of the measurements and calibrations (including correlations)

COCOA

COCOA

- ♦ System description in simple files
  - Simple text files
  - XML (CMS format)
  - Tool available to trasalate automatically ASCII-XML
- ♦ Interface with DAQ measurements
  - Currently from text files
  - Soon from POOL-ORACLE database
- ♦ Interactive 3D view
  - VRML (Virtual Reality Modeling Language)
  - IGUANA visualisation of XML files

- Scan of a parameter and analysis of results

- Randomization of a parameter

COCOA

- **Documentation:**
  - Primer
  - User’s Guide
  - Advanced User’s Guide
  - Two examples explained with detail
  - dOxygen documentation

COCOA

- **How it works:**
  - Describe the system in an input ASCII file
  - Select which parameters are unknown and which are known
  - For the known one write the values
  - Input the measurements

  ➢ software provides **best values for unknown parameters** (positions/rotations/internal parameters) compatible with measurements and **propagate the errors** from the measurements and the known parameters

An example input file

```
// system composed of one laser, one periscope that
holds a plate splitter and a mirror and two 2D
sensors.

GLOBAL_OPTIONS
report_verbose 2
save_matrices 0
length_error_dimension 2
angle_error_dimension 2

PARAMETERS
pos_laser 0
posZ_periscope 1
posZ_sensor 1.1
err_pos 100
err_ang 100
prec_sens2D 5

SYSTEM_TREE_DESCRIPTION
object system laser periscope 2 sensor2D
object periscope plate_splitter mirror
```

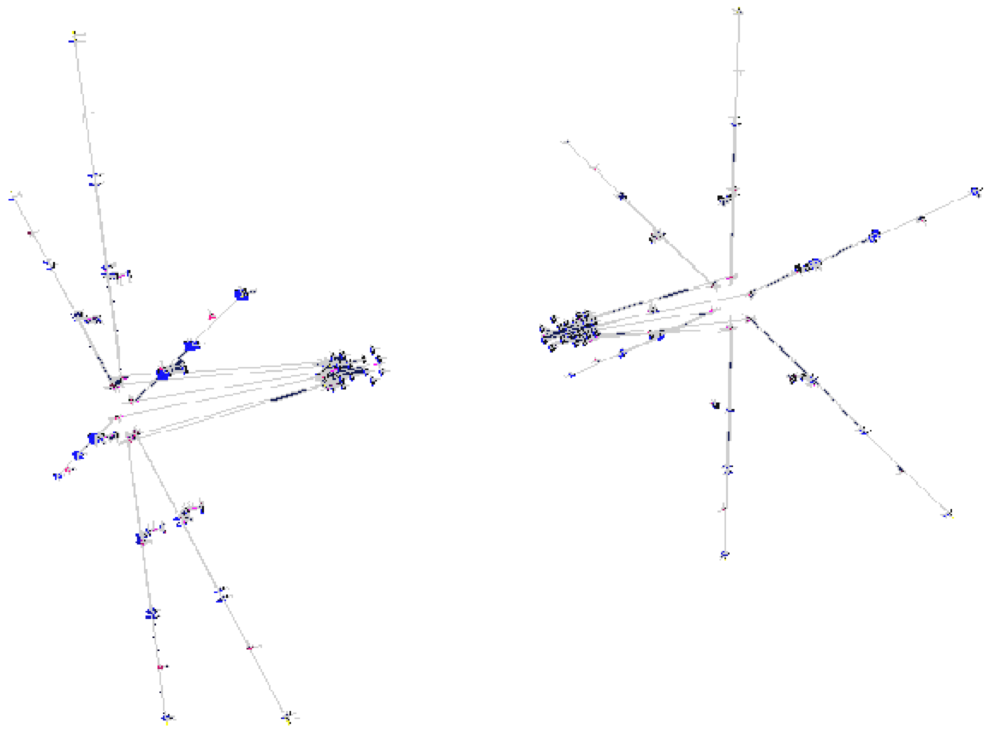
```
SYSTEM_TREE_DATA
system s
 laser laser // this is the laser
  centre
   X  pos_laser 1000  unk
   Y  pos_laser 1000  unk
   Z  pos_laser 0.    fix
  angles
   X   0  err_ang  unk
   Y   0  err_ang  unk
   Z   0  err_ang  cal
 periscope peri
  centre
   X   0  err_pos  cal
   Y   0.25  err_pos  cal
   Z posZ_periscope err_pos  cal
  angles
   X   0   err_ang  cal
   Y   0   err_ang  cal
   Z   0   err_ang  cal
```

```
plate_splitter spli
    ENTRY {
      length shiftX 0. 0. fix
      length shiftY 10. 0. fix
      angle wedgeX 0.0001 10 cal
      angle wedgeY 0.0001 10 cal
}
    centre
      X   0   err_pos  cal
      Y -0.25 err_pos  cal
      Z   0.  0.       cal
    angles
      X   0   err_ang  cal
      Y   0   err_ang  cal
      Z   0   err_ang  cal
  mirror mirr
    ENTRY {
      none planarity 0.1 0. cal
     }
    centre
      X   0   err_pos  cal
      Y 0.25  err_pos  cal
      Z   0.  err_pos  cal
    angles
      X   0  err_ang  cal
      Y   0  err_ang  cal
      Z   0  err_ang  cal
```

```
// now the two sensors
  sensor2D sens1
    centre
      X   0  err_pos  cal
      Y   0  err_pos  cal
      Z posZ_sensor err_pos  cal
    angles
      X   0  err_ang  cal
      Y   0  err_ang  cal
      Z   0  err_ang  cal
  sensor2D sens2
   centre
      X   0  err_pos  cal
      Y  0.5 err_pos  cal
      Z   0  err_pos  cal
    angles
      X   0  err_ang  cal
      Y   0  err_ang  cal
      Z   0  err_ang  cal

MEASUREMENTS
SENSOR2D
  s/laser & s/peri/spli:T & s/sens1
  H  0.1   prec_sens2D
  V -0.1   prec_sens2D
SENSOR2D
  s/laser & s/peri/spli:D & s/peri/mirr & s/sens2
  H  0.2   prec_sens2D
  V -0.1   prec_sens2D
```

Use of COCOA



- Several test benches

- Several design studies

- Simulation of full CMS Link alignment system (3000 parameters)

- Simulation of full CMS Muon Endcap align. system (6500 parameters)

- Reconstruction of ISR test: one full CMS muon alignment halfplane (3000 parameters)

- To be used for the reconstruction of displacements at the CMS Magnet Test (May 2006)

The CMS optical alignment system

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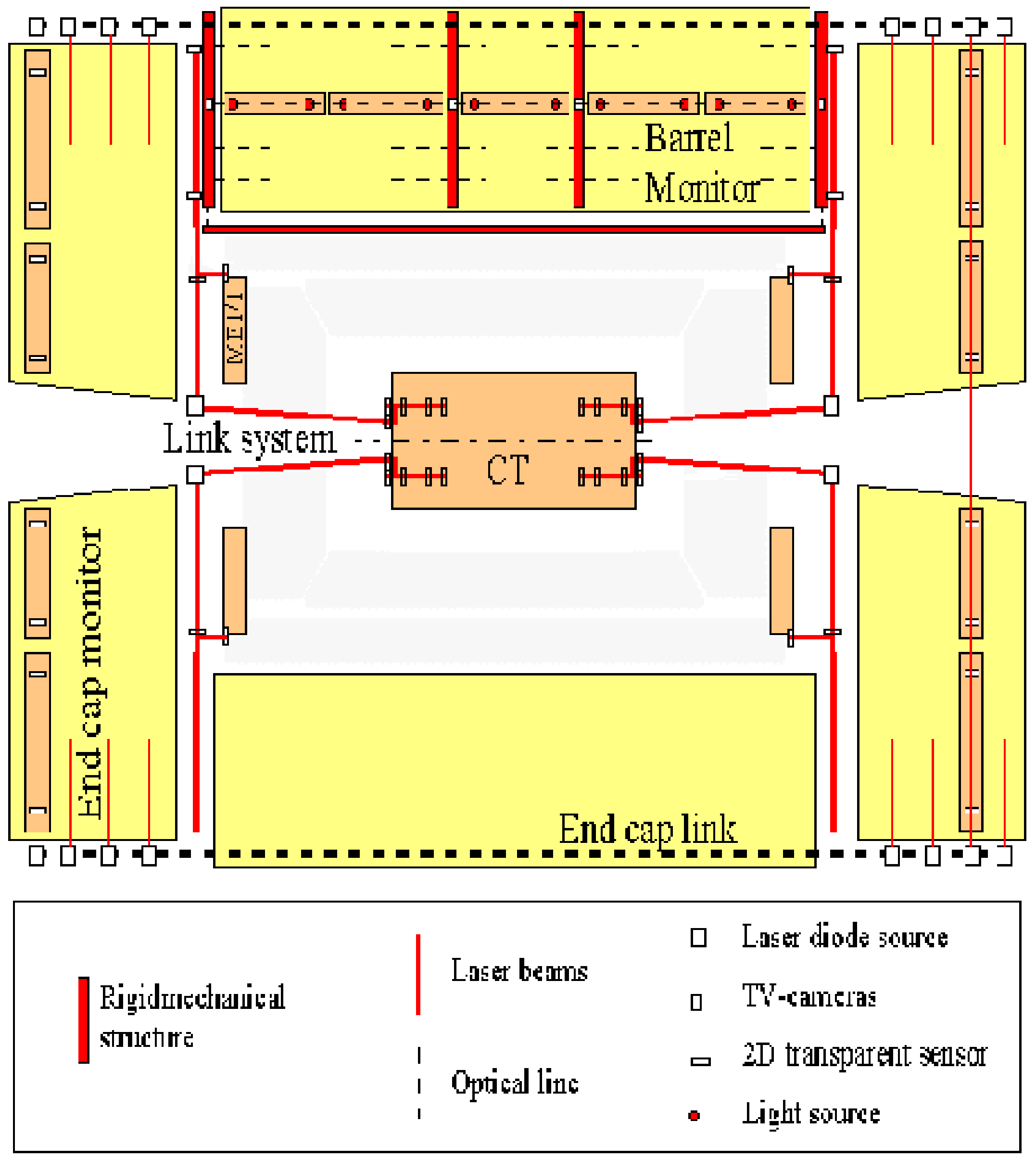
Muon Chambers suffer movements and deformations from magnetic field, gravity and temperature
(≈ several mm)

⇒ Monitor Muon Chambers position relatively among them and with respect to the central Tracker
(≈ 150 µm)

***4 subsystems* with quite different hardware**

- Align. internal Muon Barrel
- Align. internal Muon Endcap
- Align. Muon ⇔ Tracker
- Align. Internal Tracker

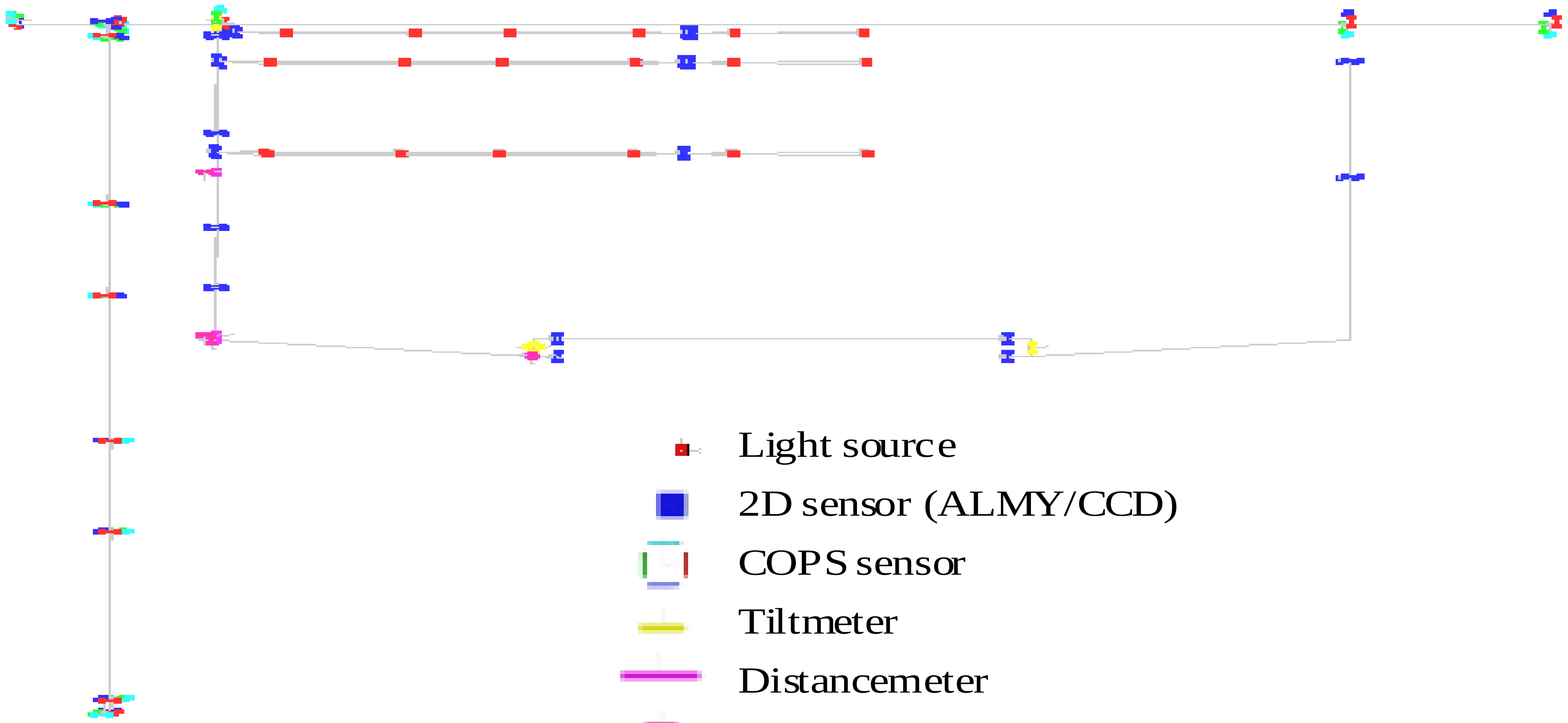


Reconstruction of ISR test

- ‘Proof of concept’ test of CMS alignment system: one full half-plane
  - Barrel
    - 18 forks (4 light sources each)
    - 3 double cameras
    - 3 single cameras on MAB+z
    - 120 measurements
  - Endcap
    - 2 x-hair lasers
    - 7 COPS
    - transfer plate with 2 COPS
    - 1 COPS on MAB +Z
    - 1 COPS on fake MA -Z
    - 47 measurements
  - Link
    - 2 laserboxes
    - laser level
    - 10 2D sensors
    - 2 tubes
    - 4 distancemeters
    - 4 tiltmeters
    - 312 measurements

- Input object parameters from calibrations
- Input object positions from survey
- Input measurements collected during August and September 2003

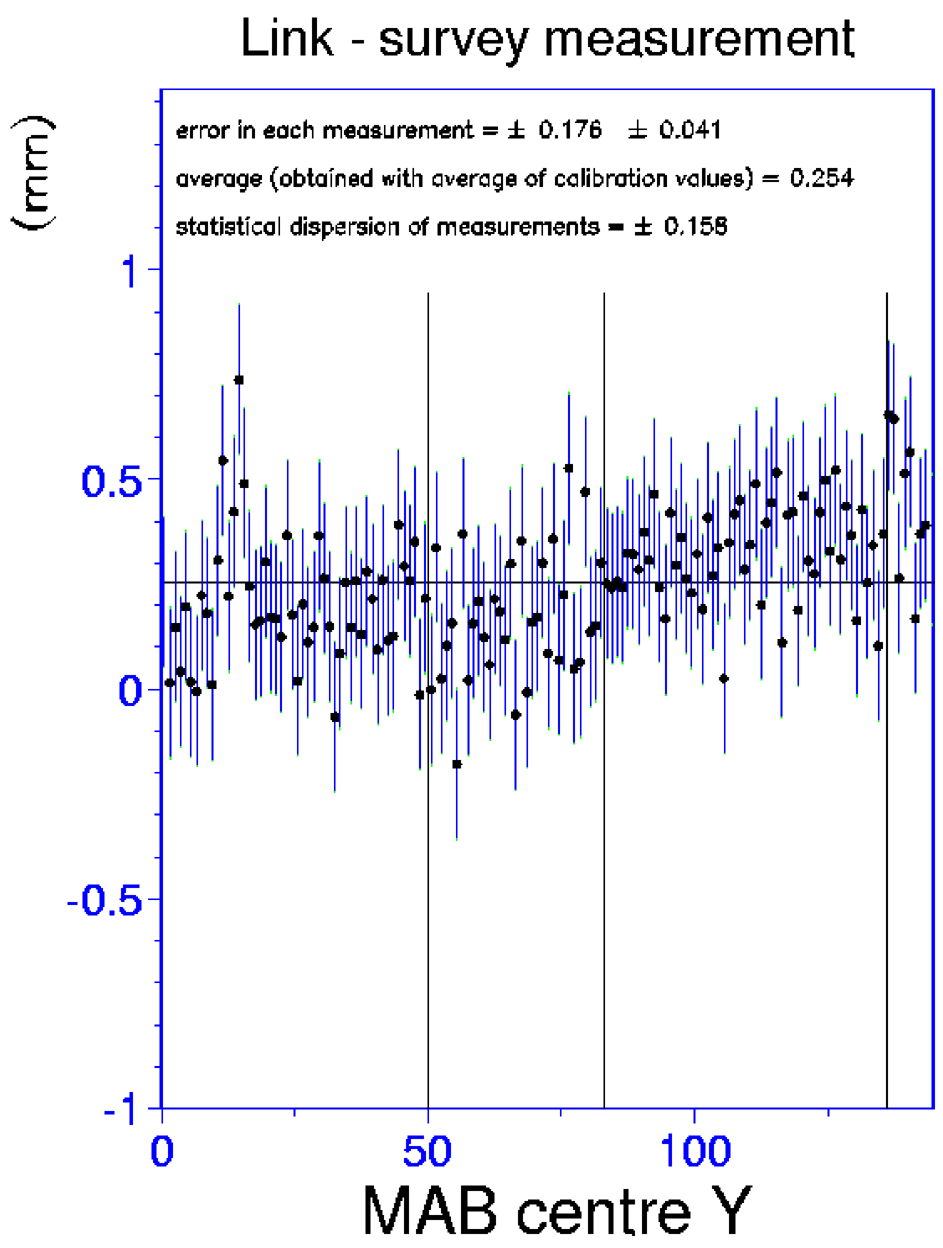
Full ISR setup in COCOA
(interactive 3D VRML view)



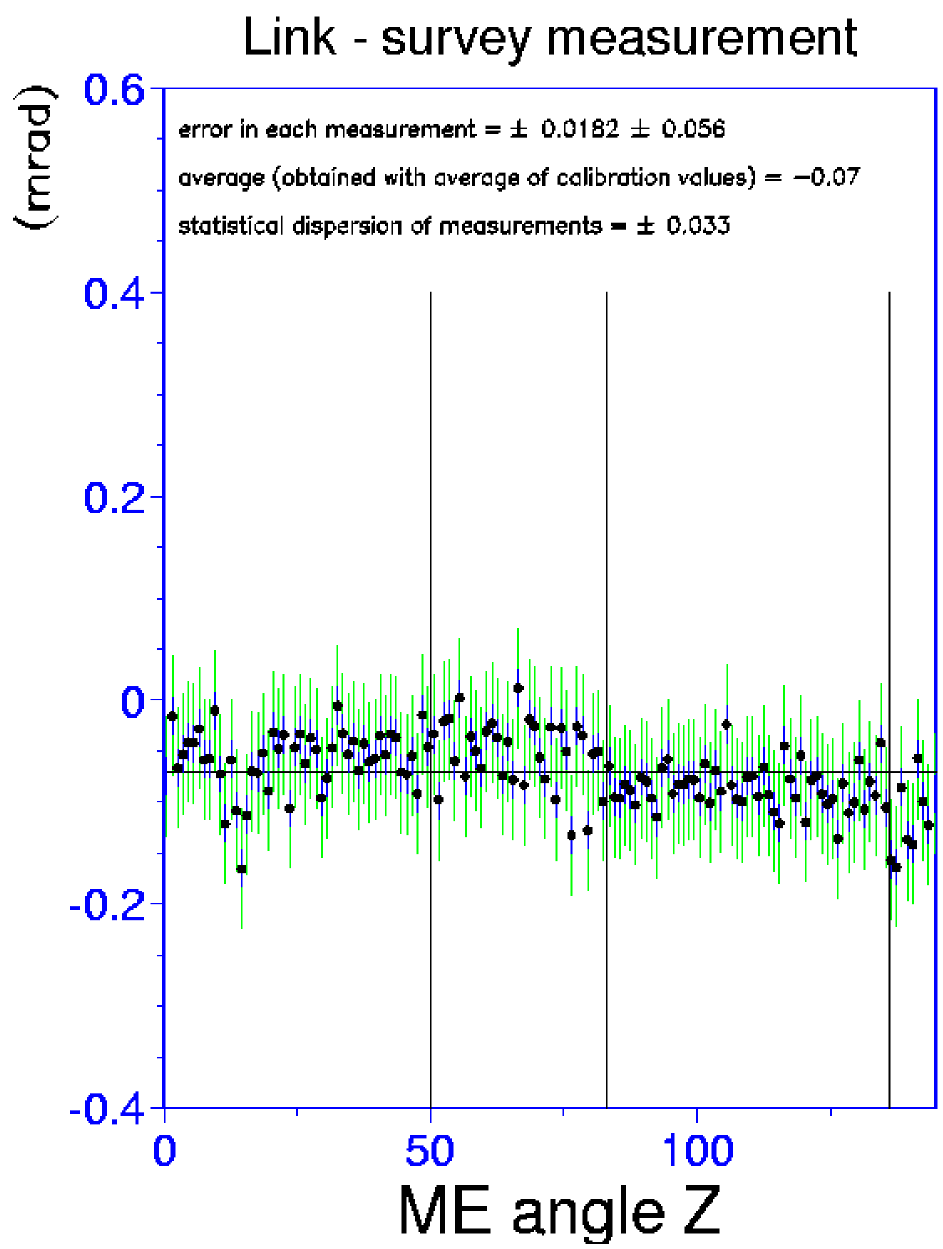
🟥	Light source
🟦	2D sensor (ALMY/CCD)
▢	COPS sensor
▬	Tiltmeter
▬	Distancemeter
🟥	Distance target

06/06/01

August



September



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Time and memory consumption

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Full CMS Link alignment system (2865 parameters):

- **20 minutes** in Athlon 1.3 GHz
- Memory: **590 Mb**
  - Due to the size of matrices (long double precision)
- Time and memory scales as ~(#param)^2 !

$\Rightarrow$ we cannot simulate full CMS (40k params)

- **Split the system in N parts**
  - Time and memory will diminish by a factor N
  - COCOA gives you the correlations and you can input the correlations for the next job
- **Diminish the number of parameters**
  - Many parameters have a negligible effect in the final result
  - Needs a thorough testing to avoid biasing
- **Try other sparse matrix libraries**
  - Many parameters have a negligible effect in the final result

Summary

- Optical alignment systems are used in several experiments
- Need a flexible software to simulate and reconstruct:
  - Design ideas
  - Design prototypes
  - Test benches
  - Full system

- COCOA is a general purpose alignment software developed as a Software Engineering project
  - User just describes its system in ASCII files
  - COCOA reconstructs the unknown parameters and propagate the errors

- COCOA soundness has been stressed during several years of use in CMS