Approach for Large Scale Metrology for Physics Detectors

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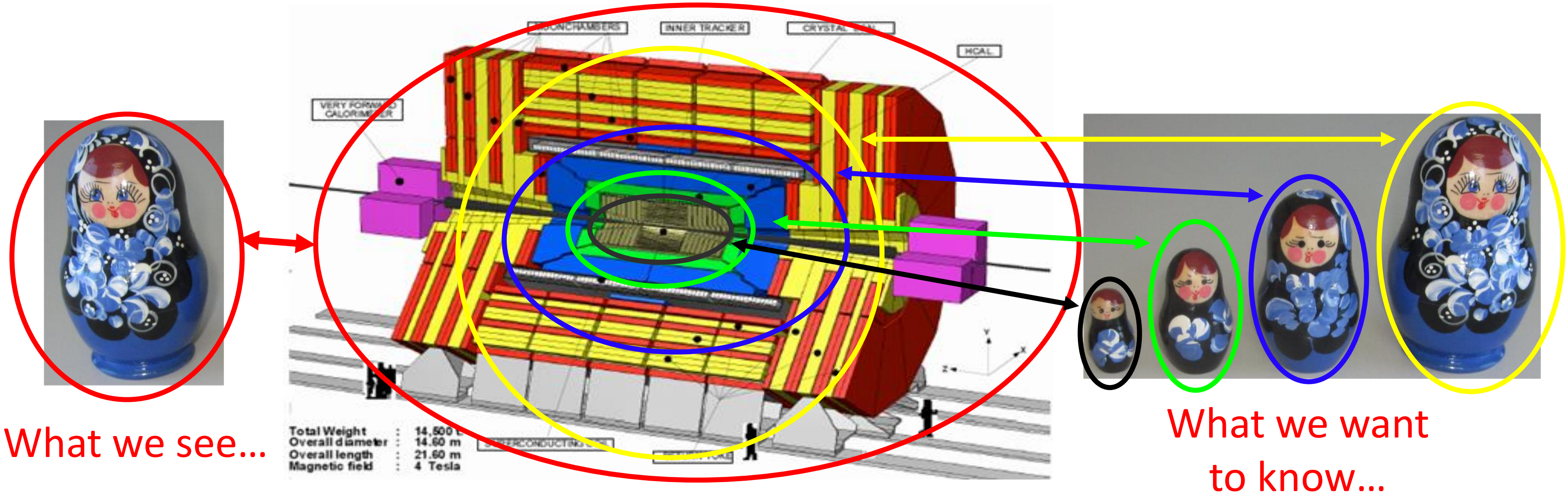
Geodetic Metrology group (BE-GM)

Mandate of Experiment Surveying and Alignment (ESA) section:

- The geometrical infrastructure for the detector installation
- Detector metrology for assembly and alignment on the beam lines
- The as-built measurements following with the installation phases

This includes entire lifetime of the detector:

Prototypes, deformation tests, quality control, (pre-)assembly, alignment, maintenance



Pre-Discussion

Discussion with physicist/engineer/designer for each tasks

- Define precisely the needs for geometrical control / alignment / survey
- Define all stages when survey will be needed
- Find reasonable solutions
- Include alignment to the design (references and space)
- Define local coordinate system
- We have to adapt to the experimental schedules

Typically provided measurement precision (1 sigma)

Detector control at manufacturing before assembly	0.02-0.30 mm (max. 0.50 mm)
Deformation of detectors under special conditions	~ 0.02-0.10 mm
Relative position of detectors wrt other detectors	< 0.30 mm
Absolute position of detectors wrt accelerator geometry	< 1.0 mm

Preparation

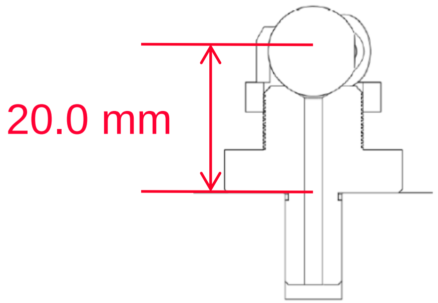
Survey reference points

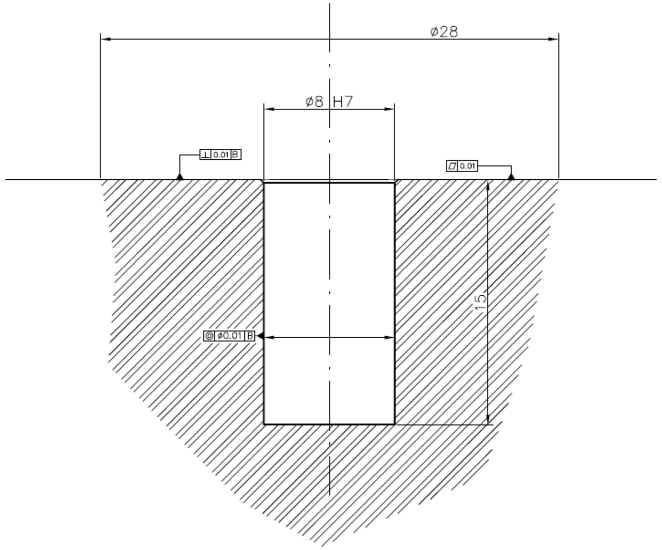
- Different survey targets have to be placed on object
- 3D – survey reference hole

  ➔ best solution, highest flexibility

- Define survey reference holes on detector
  - Already early in the design phase
  - Reference hole accessible and visible during ALL phases
  - Position on stable support
  - On individual detector elements as later on assembled groups
  - For total station, laser tracker or photogrammetry
  - Coordinates are given for centre of survey target
  - Sensitive elements are referred to reference holes by constructor

WARNING: the values are given as indications
Every new values must be discussed and agreed!



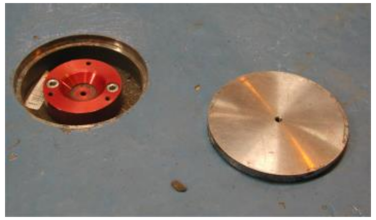


8H7 reference hole
28 mm contact surface
15 mm depth

Additional survey requirements

Local network:

- Stable floor for theodolite or laser tracker measurements (concrete)
- Supports permanently fixed on walls / stable pillars
- Tripods bolted to the floor or brackets on walls
- Temporary network points glued around detector (nests 1.5”)
- Access to detector for temporary installation of survey target
- Line of sight between instrument station and points
- Constant temperature for significant results for dimension



Survey Toolbox

SU software

Total stations TS60/TC2002

Photogrammetry

TOOLBOX
Experiment metrology

Optical levels
NA2/N3

Commercial software

Laser Trackers
AT401/402/403

Laser scanner
Z+F IMAGER® 5016

➔ **Line of sight between instrument and object required!**

Photogrammetry

Image acquisition needs no stable station

- Photos taken on platform, scaffolding or cherry-picker

Mobile System with ‘high’ precision

- Off-site interventions in factory or institutes
- Clean rooms, assembly halls and experimental caverns
- Inner detector components < 1m (1 sigma < 50 microns)

Limited measurement time for large amount of points

- Short interruption for installation, production process

Camera system

- PC (Windows 11)
- Nikon D3X - 24MP, Canon EOS 5DS - 50MP
- Different lenses (17-28 mm)
- Top flash, ring flash

Software: Hexagon AICON 3D Studio V. 12.00.18 – DPA PRO

Photogrammetry

References for scale

- Carbon fibre scale bars (max. 1.5 m)
  - Calibration on CMM
- Geodetic measurements
  - Laser tracker AT401/402
  - Total station TC2002

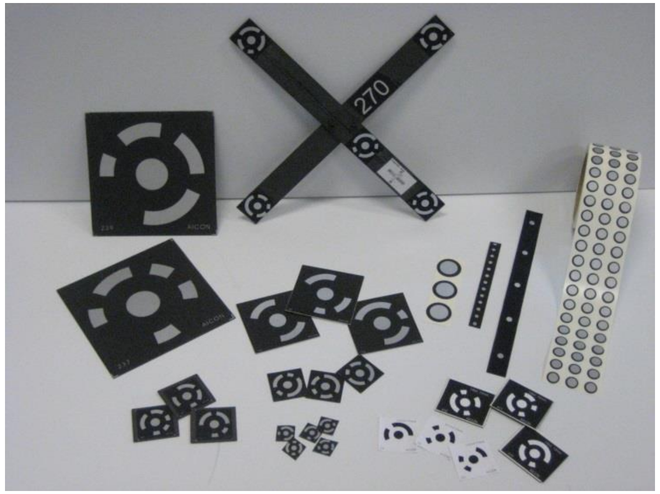
Targets

- Coded / non-coded
- Retroreflective / non-retroreflective
- Button targets Hubbs / GMS / Aicon
- Sticker targets of different types

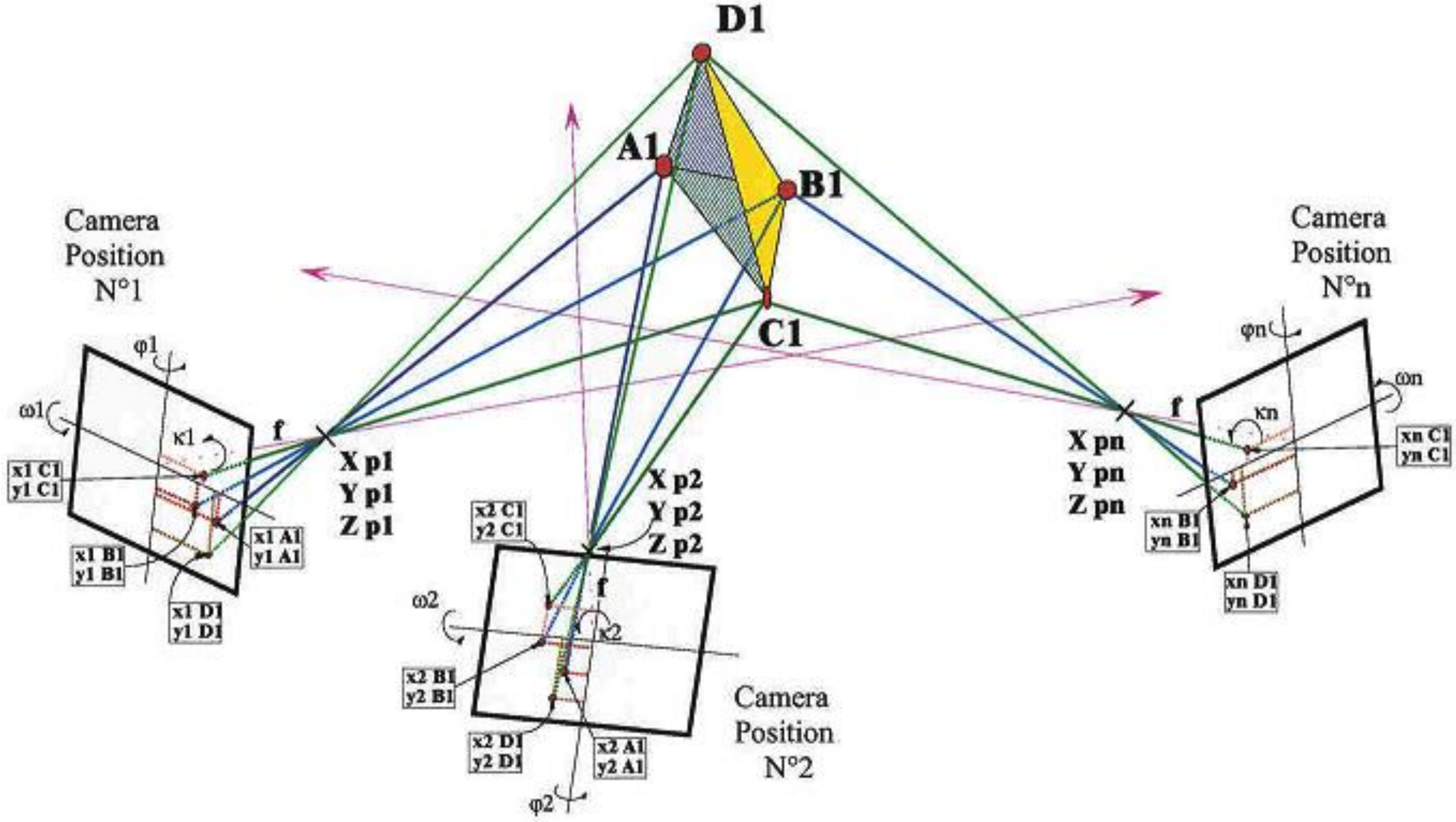
Our system is optimized for:

- **measurement of signalized points to get the highest precision**

➔ We must have access and touch the detector



Photogrammetry principle



Laser Tracker - Leica AT401/402/403

As flexible and light as a Total Station

Measures on special prisms

For flexible volumes as

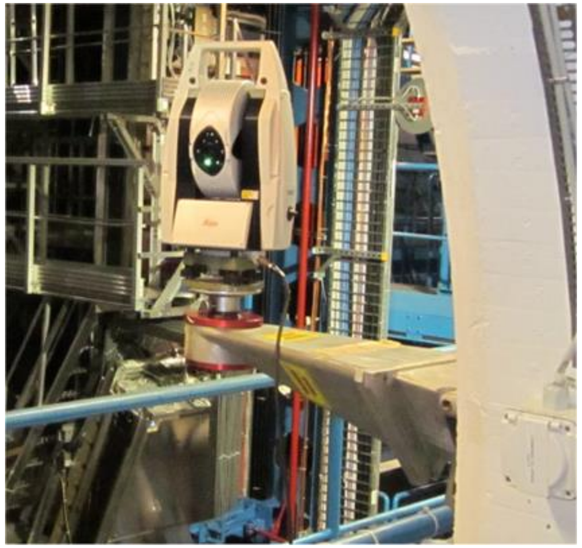
- experimental cavern network
- individual detectors
- Max. +- 80 m

Instrument can be remote controlled

➔ automation possible (ALARA)

Instrument has same support as Total Station

➔ compatible with existing survey infrastructure



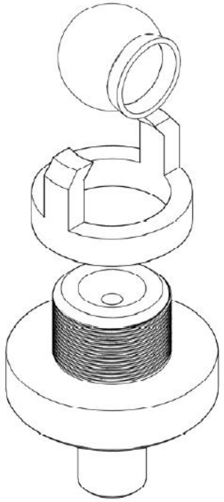
Specifications for precision

15µm + 6µm/m MPE
7.5µm + 3µm/m typical
➔ Precision at 10m distance < 0.05mm typical (1 sigma)

Leica AT401/402/403

Targets are prisms with 3.5”, 1.5” and 0.5” diameter and adapters

Interchangeable tooling to photogrammetric and total station targets available for survey reference holes



Efficient combination of precision, time and human resources!

Total Stations and Optical Levels

Total stations measure polar coord. (Hz, Vz, Dist.)

- TS60/TC2002 is measuring with precision of:
  - 0.3 mm for distances (spec 1.0 mm)
  - Measures on retro-stickers
  - < 5.0 cc for angles (spec 1.5 cc)
- Surveying targets are balls (angles) and prisms (distance)
- Measurement is manual (operator needed)

- Optical level measures height (1D) wrt horizontal pane
- NA2/N3 precision is < 0.05 mm for individual measurement
- Levelling rod can directly touch surface

Laser Scanning

Scan data can bring as-built dimensions into the 3D CAD model to have most accurate of CAD models for future integration, upgrades etc.

Scanners exist for different precisions from µm to cm level

- Level for integration at 3-5 mm

Special properties for surfaces to get good quality:

- Not transparent (glass, resin)
- Not completely black or complementary colour of scanner laser
- Not too reflective (no mirrors, polished or shiny surfaces)
  - => Surface could be prepared with spray, adhesive tape, paint etc.

Geo-referencing necessary to link the scan to coordinate system of object or to global reference system

- by known targets distributed in object space
- transformation of point clouds (only relative)

Treatment of scan data

Different steps for point cloud treatment:

- Data acquisition and transfer in the field
- Pre-treatment
  - Assembly of scan stations
  - Referencing to survey coordinate system
  - Removal of obvious parasite measurements
  - Reduce point data to keep parts of interest
  - Export point cloud (xyz files)
- Meshing has been performed (point cloud => triangular mesh)
- Mesh has been cleaned; small holes filled up
- (Creation of surfaces – reverse engineering)
- Export to CAD

GM-ESA

???

You can find point clouds everywhere BUT very few final models!!!

There is a reason why…

Laser Scanner Z+F 5016 imager®

Up to 1 100 000 points/sec

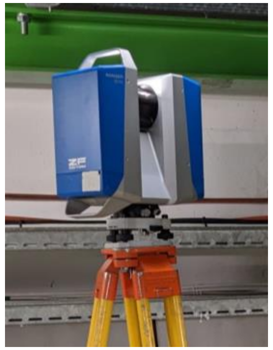
Point accuracy at 10m = +-2 mm

Spot size = 5.0mm @ 10m

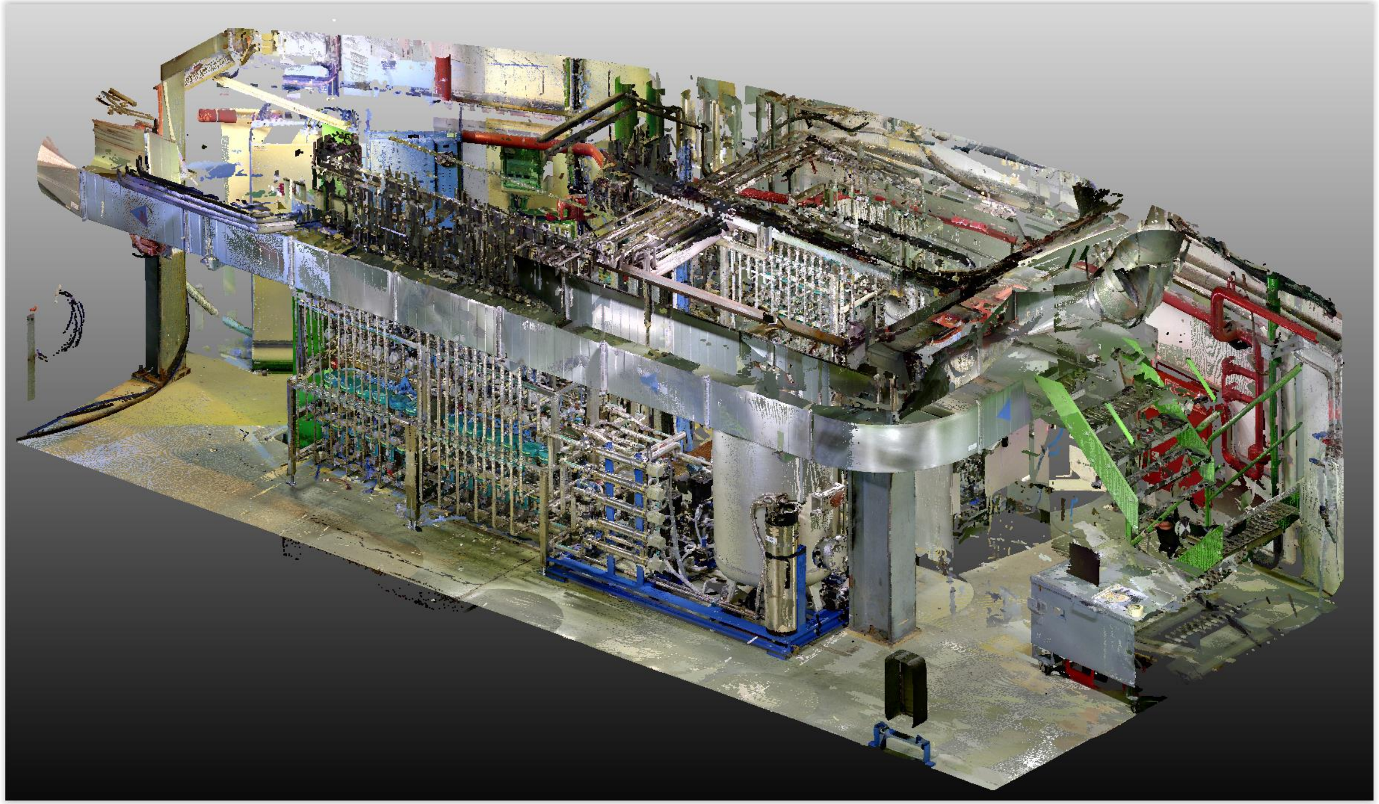
Field of view: 360° x 320°

Colour texture by HDR photos

Textured point cloud as result



3D Scanning of the new cooling plant inside the Alice Cavern (Measurement and processing)



Conclusion

- BE-GM-ESA can be implicated in survey requests for detector installation and maintenance
  - Design
  - Validation / test phase
  - Construction
  - Installation
- Photogrammetry and Laser Tracker are well adapted tools
- We are flexible in method and can adapt it to working conditions

➔ BE-GM-ESA decides as function of the constraints the optimal method

- Precision wrt. machine geometry has to cope with long term deformations at civil engineering level
- Mechanical adjustment systems need to be integrated
- Permanent contact between BE-GM-ESA and detector responsible

➔ BE-GM participation at early stages – integration of references, assembly procedures

… for new projects as SHiP etc.

Define carefully the control and alignment needs

- What has to be measured? With respect to what? At what stage? Where?
- What is the required precision / error budget?

Definition of reference holes and special equipment (adapter…) needed by BE-GM-ESA

First fiducialisation of sensitive elements at construction site

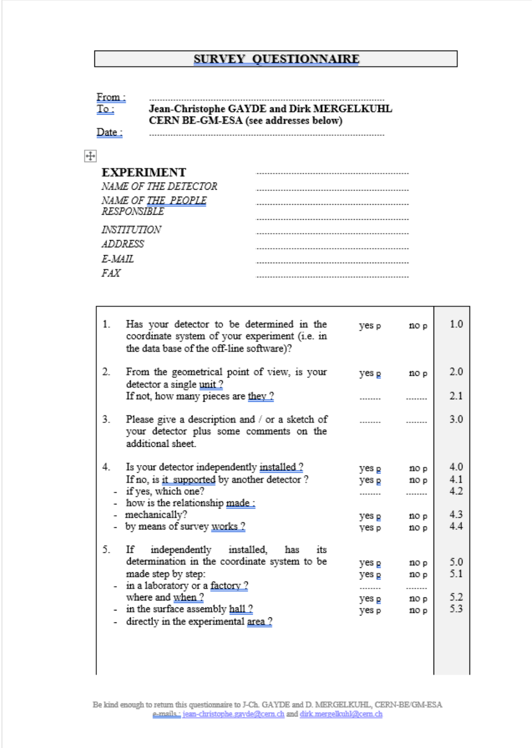
➔ **As the references carry the detector geometry information**

If there are NO references, there is a high risk that NO precise survey can be performed!

No detailed as-built model is available for the experiments (services etc.)

➔ **An early discussion for each individual detector is necessary**

➔ **Questionnaire can be found at: https://edms.cern.ch/document/1074957**



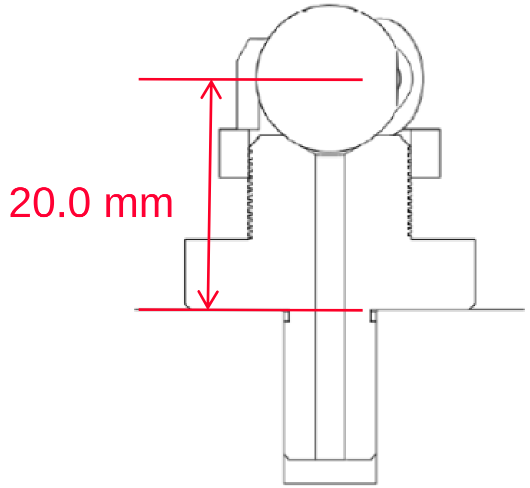
SURVEY QUESTIONNAIRE

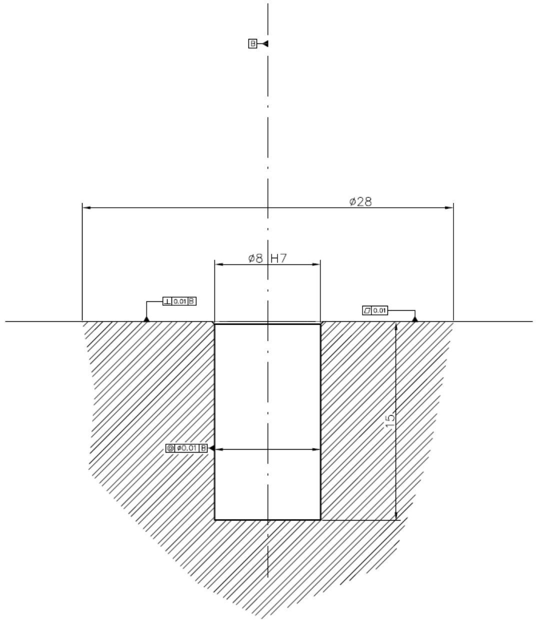
From : ....
To : **Jean-Christophe GAYDE and Dirk MERGELKUHL**
CERN BE-GM-ESA (see addresses below)
Date : ....

EXPERIMENT ....
NAME OF THE DETECTOR ....
NAME OF THE PEOPLE RESPONSIBLE ....
INSTITUTION ....
ADDRESS ....
E-MAIL ....
FAX ....

1.	Has your detector to be determined in the coordinate system of your experiment (i.e. in the data base of the off-line software)?	yes p	no p	1.0
2.	From the geometrical point of view, is your detector a single unit ?	yes p	no p	2.0
	If not, how many pieces are they ?	....	....	2.1
3.	Please give a description and / or a sketch of your detector plus some comments on the additional sheet.	....	....	3.0
4.	Is your detector independently installed ?	yes p	no p	4.0
	If no, is it supported by another detector ?	yes p	no p	4.1
	- if yes, which one?	....	....	4.2
	- how is the relationship made :			
	- mechanically?	yes p	no p	4.3
	- by means of survey works ?	yes p	no p	4.4
5.	If independently installed, has its determination in the coordinate system to be	yes p	no p	5.0
	made step by step:	yes p	no p	5.1
	- in a laboratory or a factory ?	....	....	
	where and when ?	yes p	no p	5.2
	- in the surface assembly hall ?	yes p	no p	5.3
	- directly in the experimental area ?			

Be kind enough to return this questionnaire to J-Ch. GAYDE and D. MERGELKUHL, CERN-BE/GM-ESA
e-mails : jean-christophe.gayde@cern.ch and dirk.mergelkuhl@cern.ch





8H7 reference hole
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15 mm depth

Thanks for your attention!

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BEAMS DEPARTMENT

Geodetic Metrology GROUP

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