

# **Prospects of Close Range Digital Photogrammetry in large physics installations**

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- MAIN FEATURES OF THE CERN EQUIPMENT**
- TESTS VALIDATION AND APPLICATIONS**
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## INTRODUCTION

- digital photogrammetry specially since the LHC project
- CERN Positioning Metrology Group since last February ...
- a DCS 460 non metric digital camera plus 18 mm and 24 mm lenses,
- the Rollei DPA / CDW software package.



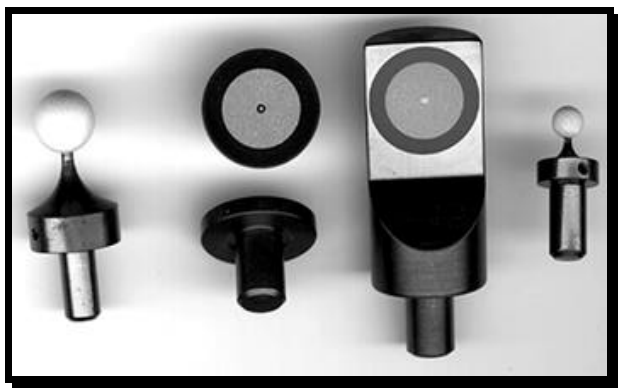
## MAIN FEATURES OF THE CERN EQUIPMENT

### The image recording system

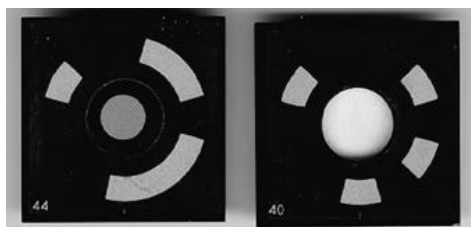


- Nikon N90 camera body,
- CCD full-frame imager 18.4 mm \* 27.6 mm (2036 \* 3060 pixels) - each image 6Mbytes,
- elements arranged very precisely, no expedient for flattening - pixel = 9 microns,
- two images 1.6 seconds, subsequent images at intervals of approximately 8 seconds,
- calibration: principal point and principal distance also lens distortion and affine data,
- image measurement accuracy ... 1/40 pixel.

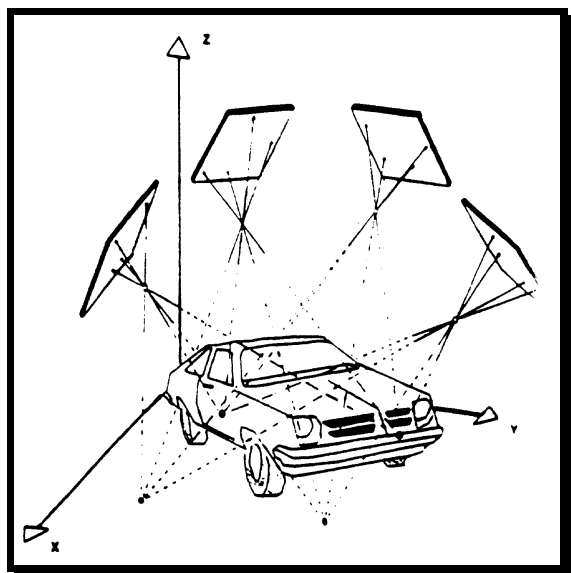
### The image analysis



- the measured variables are the 2D image coordinates of the projected object points,
- image analysis based on detection of object structures (discrete and unique points, edges retro-reflecting targets): gray values → edges,
- exposure time and aperture optimized for best possible point imaging and a suitable contrast: low and high - pass filters (digital image covers at least 5 pixels),
- coded targets enable fast and automated image measurement (ring with code surrounding 'buttons' when space available).



## The multi-photo orientation and the bundle adjustment software



- the software → the base for the 3D object coordinates from the 2D image coordinates measurements,
- the reconstruction in an oriented block by spatial ray intersection,
- in addition to image measurements, geometrical observations: known distances and heights and/or given control point coordinates (additional observations),
- shape derived from pure photogrammetric information,
- size and location from additional observations information (object space).

## THE MULTI-PHOTO GIVES THE INITIAL VALUES OF CAMERA STATIONS AND THE OBJECT COORDINATES

### THE BUNDLE INCLUDES ...

$$\begin{bmatrix} x_{ij} - x_H - dx \\ y_{ij} - y_H - dy \end{bmatrix} = \frac{-c}{Z_{ij}^*} \cdot \begin{bmatrix} X_{ij}^* \\ Y_{ij}^* \end{bmatrix}$$

$$\begin{bmatrix} X_{ij}^* \\ Y_{ij}^* \\ Z_{ij}^* \end{bmatrix} = D(\omega_j, \varphi_j, \kappa_j) \begin{bmatrix} X_i - X_{oj} \\ Y_i - Y_{oj} \\ Z_i - Z_{oj} \end{bmatrix}$$

- camera data interior orientation (image system):  $c$  focal length,  $x_H$ ,  $y_H$  principal point coordinates,  $dx$ ,  $dy$  systematic image errors,
- camera station exterior orientation (object system):  $X_{oj}$ ,  $Y_{oj}$ ,  $Z_{oj}$  perspective center coordinates, axis, tilt and swing of camera,
- $x_{ij}$ ,  $y_{ij}$  point coordinates (image system),  $X_{ij}^*$ ,  $Y_{ij}^*$ ,  $Z_{ij}^*$  point coordinates (parallel to image system) and  $X_i$ ,  $Y_i$ ,  $Z_i$  (object system),
- $D(\omega_j, \varphi_j, \kappa_j)$  rotation matrix from object into position parallel to the auxiliary system.

### THIS FUNCTIONAL RELATION ALLOWS ...

- ↳ self-calibration with simultaneous multi-photo orientation (convergent images, strong network),
- ↳ systematic radial symmetric/asymmetric and tangential lens distortion and sensor affine parameters ... as well as.

**Observations supplémentaires sur la définition du système**

Coordonnées

Paramètres des coordonnées

N° de 3001 X 99.9474 ☒ Y -3 ☒ Z 10.0095 ☒

| N° de p. | X       | Y   | Z       | ALT      | XYZ   |
|----------|---------|-----|---------|----------|-------|
| 3001     | 99.9474 | -3. | 10.0095 | 1        | 1 1 1 |
| 3003     | ---     | --- | ---     | 0        | 1 1 1 |
| 3011     | ---     | --- | ---     | 159.9889 | 0 0 1 |

☐ Régler tous sur actif

Copier Effacer Nouveau Imprimer

Distances

Paramètres de distance

N° de 3001 N° de 3003 Obs. 299.939 ☒ Calculer la distance

| N° de p. | N° de p. | Obs.    | ALT |
|----------|----------|---------|-----|
| 3001     | 3003     | 299.939 | 1   |
| 3301     | 3303     | ---     | 0   |
| 3101     | 3501     | ---     | 0   |

☐ Régler tous sur actif

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Importer des coordonnées OK Annuler Aide

**Réglages de base, mesure de points d'image**

Points

☐ Naturel

☒ Signalisé

☒ Clair ☐ Sombre

☐ Incrément de point 1

Opérateurs

☒ Centre de gravité Par. de centre de gravité

☒ Ellipses Paramètres d'ellipse

☒ Marques codées Par. pour le codage

↳ every point measured in at least 3 images taken from different camera stations with the best possible conditions of intersection,

↳ if starting values for all camera stations and object points unknown first two images at least 7 common points, all successive images preferably 5 points in common with the preceding one, system fixing minimum,

↳ if no starting values for the camera stations and object points unknown; first two images at least 7 common points, all successive images at least 6 points in common with the preceding one, at least 4 full control points required.

- camera stations and object points computation in a 'first two camera stations local system' and relative orientation for the first image pair,
- computation of camera stations of the 3<sup>rd</sup> to nth image by spatial resection and computation of further object points by intersection,
- transformation of the object points into the defined co-ordinate system and multi-image orientation in the specified system: computation of the camera stations of the 1<sup>st</sup> to nth image by spatial resection and computation of improved new point coordinates by intersection,
- robust error detection (L1-norm with balanced observations - minimization of absolute values of residuals.)

### THE BUNDLE COMPUTATION CAN BE SET ...

- camera calibration data are used or to be re-calibrated by the bundle,
- *Free network* function if the system with object points marked as datum.

**Résultats**

| EOR | BNr | KNr | X       | Y        | Z       |
|-----|-----|-----|---------|----------|---------|
| < > | 1   | 460 | -92.703 | -490.142 | 289.617 |

| IOR | K n | Réseau | ck       | xH     | yH      |
|-----|-----|--------|----------|--------|---------|
| < > | 460 | -460   | -24.4293 | 0.4714 | -0.4062 |

| OBC | Point n | X       | Y       | Z      | s X  |
|-----|---------|---------|---------|--------|------|
| < > | 1       | 350.115 | 264.780 | 83.554 | 0.24 |

| PHC | Image | Point n | v X     | v Y    | CODE | ACT |
|-----|-------|---------|---------|--------|------|-----|
| < > | 1     | 1       | -0.0003 | 0.0005 | 33   | 1   |

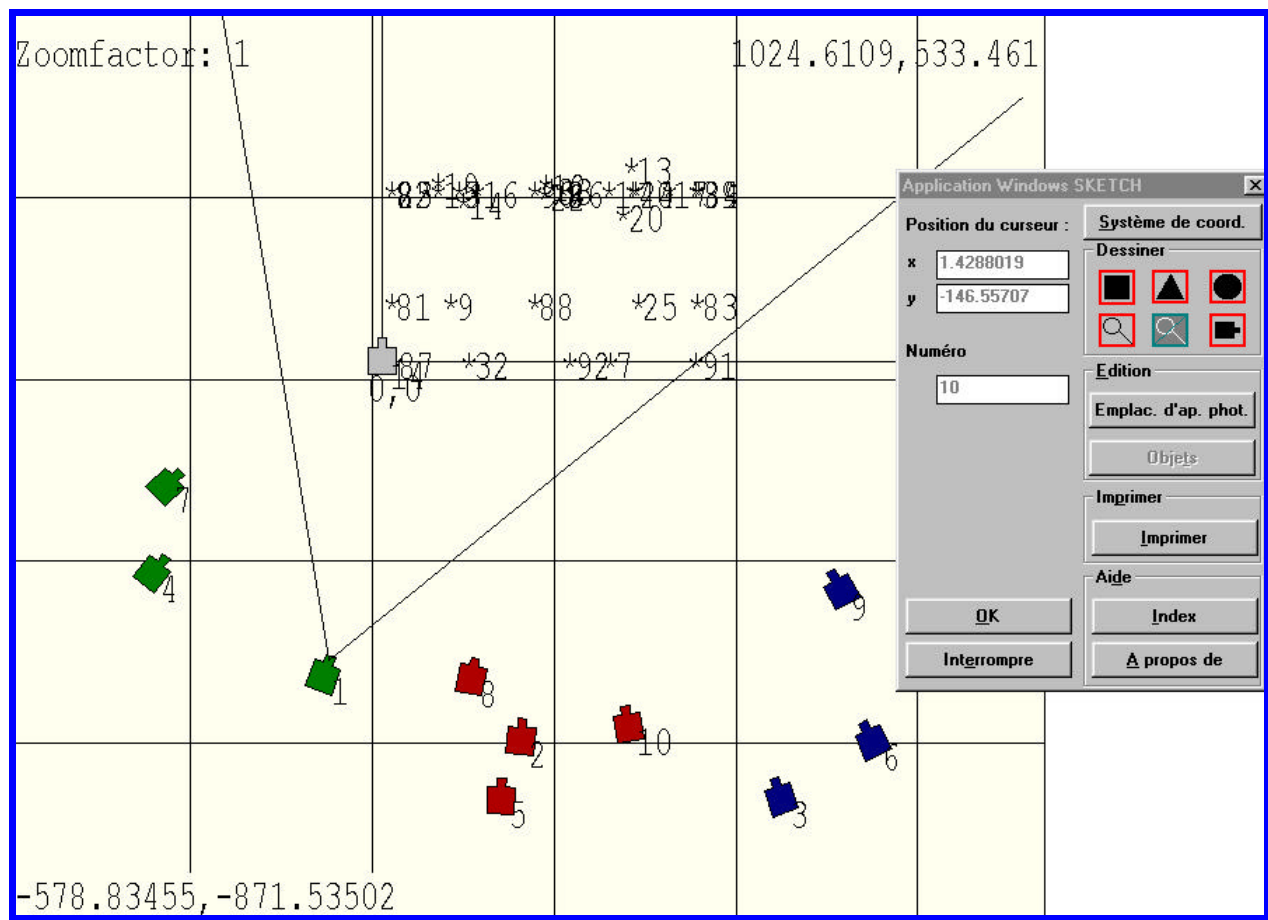
| Test | Image | Point n | X     | Y      |
|------|-------|---------|-------|--------|
| < >  | 1     | 7       | 9.265 | -3.797 |

| AOB | Ken. | n    | UK. | Obs.   |
|-----|------|------|-----|--------|
| < > | 1    | 3001 | 1   | 99.947 |

Buttons: Sauvegarder, Terminer, Continuer, Aide, Résultat

- PROMPT based on the L2-norm,
- results ↪ EOR camera, OBC object, PHC image,
- $v_x$ ,  $v_y$  between the measured and the computed co-ordinate of the determined point (if in multi-photo,  $v_x$  and  $v_y > 0.1\text{mm}$  ↪ gross errors),
- automatic point image correction  $< 0.001\text{ mm}$ .

## A SKETCH FUNCTION ...

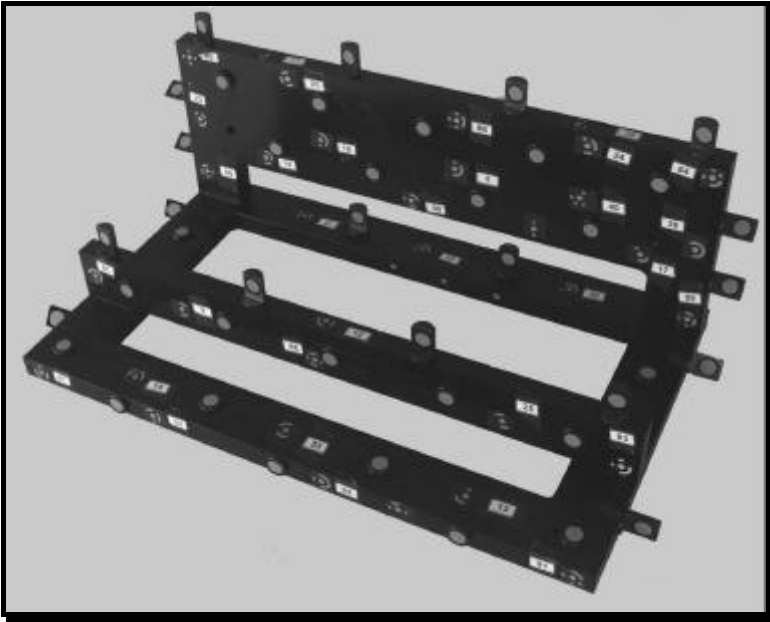


- a computer-aided shooting on the monitor,
- network configuration,
- camera stations in red if not computed, green if single or multi-photo orientation computed, blue if computed by the bundle,
- any computed station activated ↗ position, axis, tilt and swing are edited,
- starting values of camera stations can be extracted from the sketch,
- additional camera stations can be added at any step of the project.

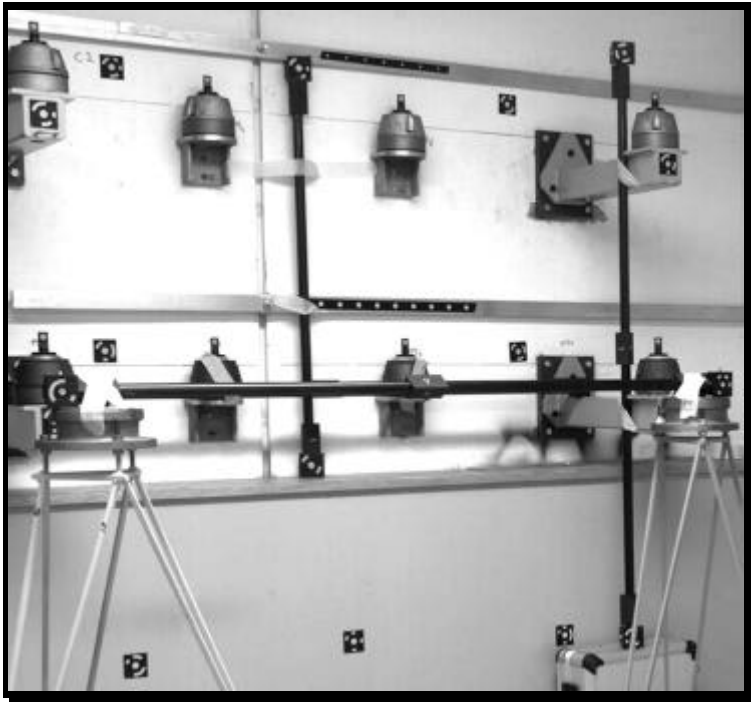


## TESTS VALIDATION AND APPLICATIONS

### TESTS VALIDATION BENCHES ...

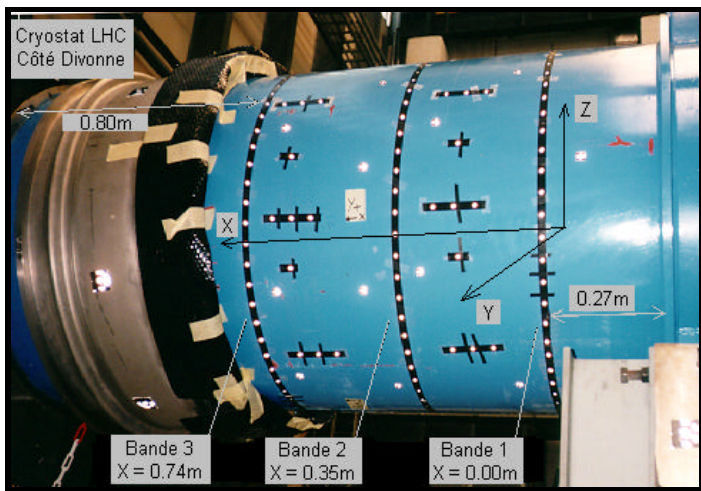
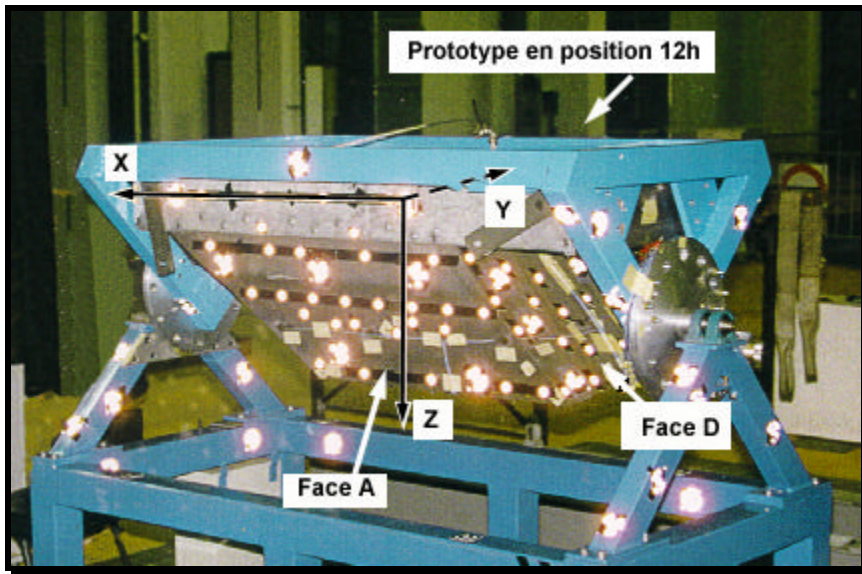


- 0.5m\*0.3m\*0.2m,
- 13 camera stations,
- 1533 observations,
- 13 CMM distances 5 $\mu$ m as additional observations,
- Sigma0 0.3  $\mu$ m,
- $S_{XYZ}$  r.m.s 7 $\mu$ m,
- addit. distances r.m.s 8 $\mu$ m.

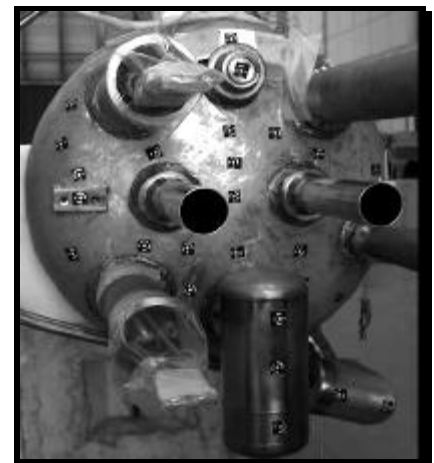


- 3m\*3m \* 2.2m, 22 Cern sockets,
- minimum 80 retro and coded targets, 45 camera stations, 4200 observations,
- 20 interferometer/leveling as additional observations 5/20 $\mu$ m,
- Sigma0 0.2  $\mu$ m,
- $S_{XYZ}$  r.m.s 20  $\mu$ m,
- addit. distances r.m.s. 18 $\mu$ m,
- coded rings around retro-buttons

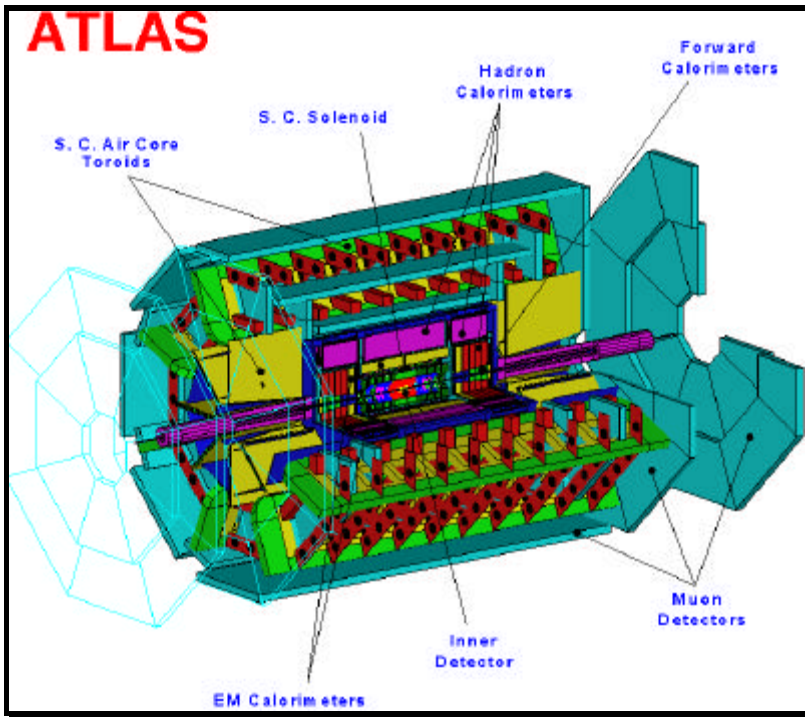




- LHC cold mass, only coded targets
- 10 stations ...  $\cong 1$  h altogether.



## TOWARDS THE PHYSICS INSTALLATIONS IN LHC ...



- Q.A.P, 20  $\mu\text{m}$  200 $\mu\text{m}$ , digital system a major measuring device,

- X/Z object plane parallel to image plane, obj. accuracy  $\sigma_X$ ,

- photo scale mb, focal length c, image accuracy  $\sigma_X'$ ,  $\sigma_Y'$ ,

- 2<sup>nd</sup> image depth Y,  $\sigma_Y$  photo base b/recording distance s,

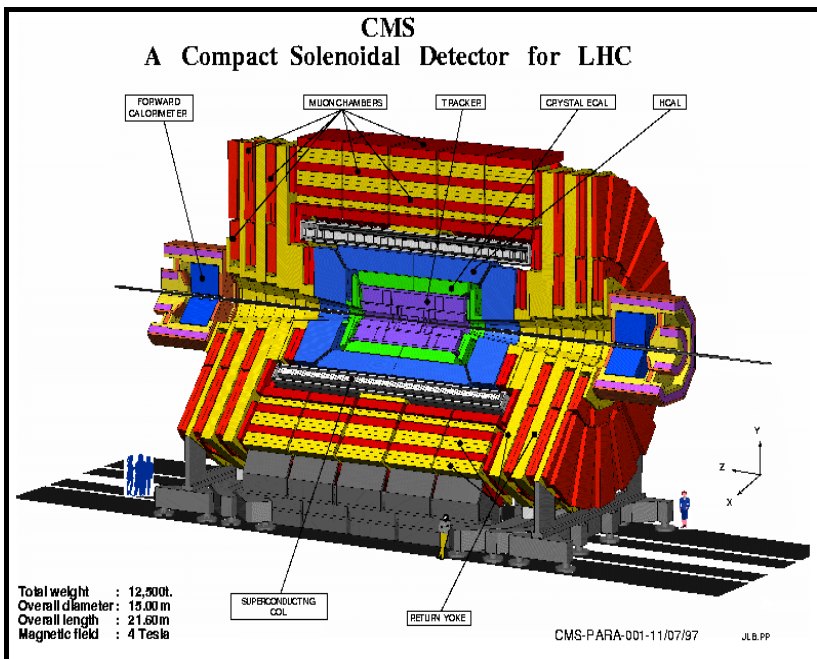
- $\sigma_X \cong \sigma_X' * mb \cong \sigma_Y' * mb$ ,  
 $\sigma_Y \cong \sigma_X' * mb * s / b$ ,

- $mb \cong \text{obj.dist./same image dist.}$

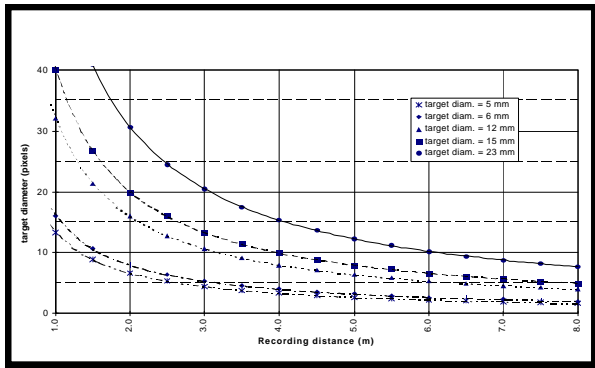
- object 20  $\mu\text{m}$ , image 0.25  $\mu\text{m}$ ,  
 $mb \cong 20/0.25 \cong 80$ , 24 mm c,  
 $s \cong mb * c$ ,  $s \cong 1.92$  m,

- max. object size (18.4\*27.6)  
1.47 m V, 2.21 m H

- 200  $\mu\text{m}$  and 18 mm lens ...  
 $mb \cong 800$ ,  $s \cong 14.4$  m ,  
14.7 m V, 22.1m H ...

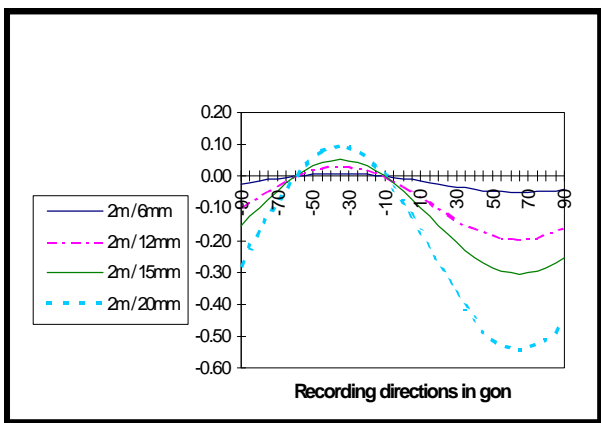


- ⇒ network configuration,
- ⇒ targets design,
- ⇒ minimal AND maximal target diameter  $D$  in object space estimated,
- ⇒ coarse estimation of global accuracy in object space ...



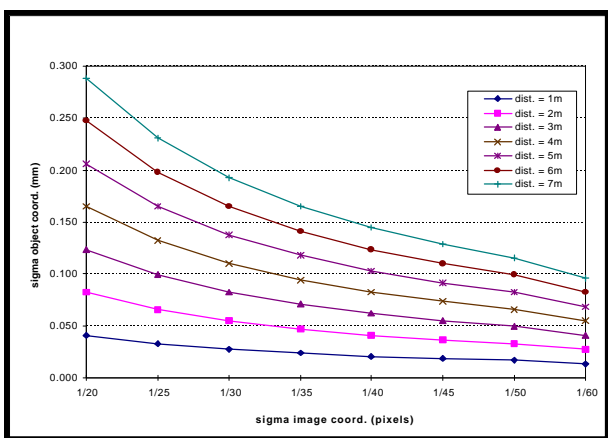
- minimal target diameter object  $D$ , minimal image  $p_n$  (5 pixels,  $45 \mu\text{m}$ ), recording distance  $s$ , focal length  $c$ ,  $D \geq p_n * s / c$ ,

- 3.6 mm for '20  $\mu\text{m}$ ' project (24 mm lens),
- 36.0 mm for '200  $\mu\text{m}$ ' project (18 mm lens),



- maximal target diameter specially on very close range,

- image accuracy of  $0.3 \mu\text{m}$ , target  $>10 \text{ mm}$  not to be used for 2 m.



- 'on the spot' accuracy object coordinates,
- ex: 24 mm lens, various target diameters,
- various recording distances.

## CONCLUSION



- short time on-site nearly independent from the number of object points,
- possibility to choose the recording stations in a very flexible way,
- procedure with high measuring accuracy for voluminous objects in situ,
- new product ... Q<sup>16</sup> Metric camera from Rollei (4096\*4096 pixels),

‘CONVENTIONAL TRIANGULATION METHOD’ ...

‘HIGH ACCURATE DIGITAL METRIC UNIQUE CAMERA TRIANGULATION METHOD ... ‘