

Survey-based alignment of the pixel barrel detector using Millepede-II

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Overview

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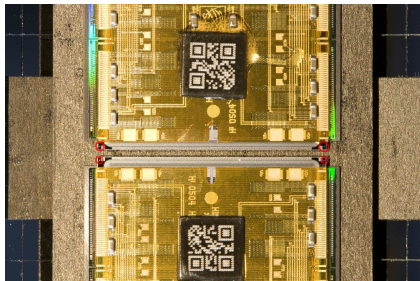
χ^2 and degrees of freedom

Conclusions and open issues

Backup

How the survey was done

- ▶ Done using a digital camera (Canon EOS 400D with macro lens)
- ▶ Photos covering two adjoining modules along ladders
- ▶ On some ladders view was obstructed, tf. not surveyed



The red circles highlight the fiducial points on the sensor module.

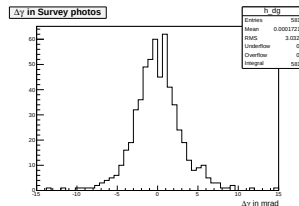
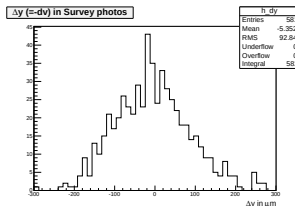
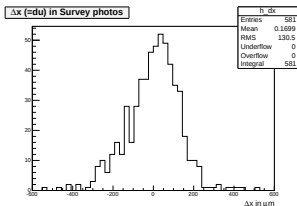
The position of the marks on the sensor are known to better than $0.2 \mu\text{m}$ – and so the distance of the marks on one sensor. The resolution is about 0.18 pixels.

Details see presentation by Hans-Christian Kästli (10.7.08)¹

¹<http://indico.cern.ch/sessionDisplay.py?sessionId=2&confId=36388>

What we see from the survey

The following histograms show just what we get from the images using simple geometry:



If $\Delta x > 0$, module in lower z direction is shifted more in u direction

Modules are closer than design if $\Delta y < 0$

$\Delta \gamma > 0$:  $\Delta \gamma < 0$: 
Upper module in lower z direction

Parametrization – local fit

In one image we have 4 markers resulting in 8 measurements. An image may be shifted and rotated among its center and the scale needs to be fixed:²

$$\begin{pmatrix} x_i \\ y_i \end{pmatrix}^{\text{meas}} = \begin{pmatrix} a_0 \\ a_1 \end{pmatrix} + \begin{pmatrix} a_2 & a_3 \\ -a_3 & a_2 \end{pmatrix} \begin{pmatrix} u_i \\ v_i \end{pmatrix}^{\text{marker}} \quad (1)$$

where the parameters a_2 and a_3 get their meaning as scale S and rotation angle ϕ like

$$S = \sqrt{a_2^2 + a_3^2} \quad (2)$$

$$\phi = \arctan \frac{a_3}{a_2} \quad (3)$$

Therefore we have $8 - 4 = 4$ degrees of freedom.

²coordinates in local CMS frame: $\begin{pmatrix} u \\ v \end{pmatrix}$ in cm, local image frame: $\begin{pmatrix} x \\ y \end{pmatrix}$ in px

Parametrization – global fit

To connect the information of an image to the detector, we use

$$\begin{pmatrix} u_i \\ v_i \end{pmatrix}^{\text{marker}} = \begin{pmatrix} u \\ v \end{pmatrix}^{\text{sensor}} + \begin{pmatrix} \cos \gamma & -\sin \gamma \\ \sin \gamma & \cos \gamma \end{pmatrix} \begin{pmatrix} u_i \\ v_i \end{pmatrix}^{\text{marker,nom}} \quad (4)$$

Doing this for **one ladder** (8 modules = 7 images) we get the following balance of *ndof*:

Measurements:	7×8	= 56
Local parameters:	7×4	= 28
Global parameters:	8×3	= 24
Net ndof :		4

We surveyed 83 ladders (out of 96) and therefore we assume 332 *ndof* in the global fit. To be proven...

Parametrization – fit constraints

In order to make the solution unique, we use the following (natural) constraints per ladder:

$$\sum u_i = 0 \quad \sum v_i = 0 \quad \sum \gamma_i = 0 \quad (5)$$

Toy setup

In order to simulate surveys, functionality to create stochastic toy surveys has been added. It uses a start geometry (global tag, sqlite file plus possible misalignment).

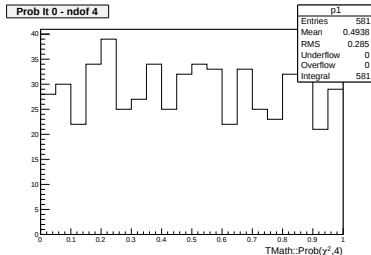
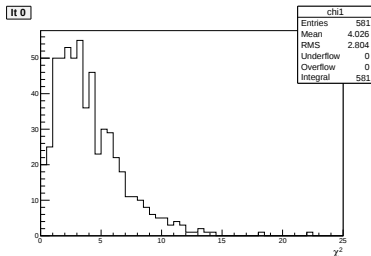
The parameters have been chosen to match what we have in the real survey:

Parameter	Mean	Gaussian σ
a_0	1880 px	100 px
a_1	2420 px	100 px
S	1150 px/cm	100 px/cm
ϕ	0 mrad	0.02 mrad

The measurements were smeared with a width of 0.175 px, corresponding to the precision of $1.5 \mu\text{m}$ obtained in reference given earlier.

Toy survey – Local fit

First a look at the fit quality

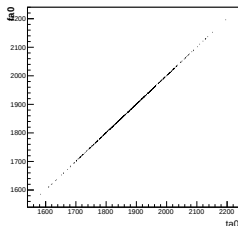


The χ^2 distribution looks fine, $\langle \chi^2 \rangle$ is 4.026 and the probability distribution seems to be reasonable flat.

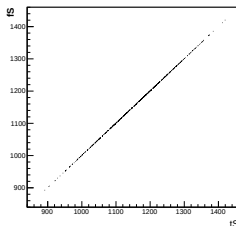
Toy survey – Local fit

How well do we find the local parameters?

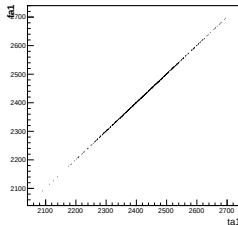
fa0:ta0



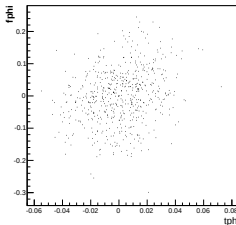
fs:ts



fa1:ta1



fphi:tphi

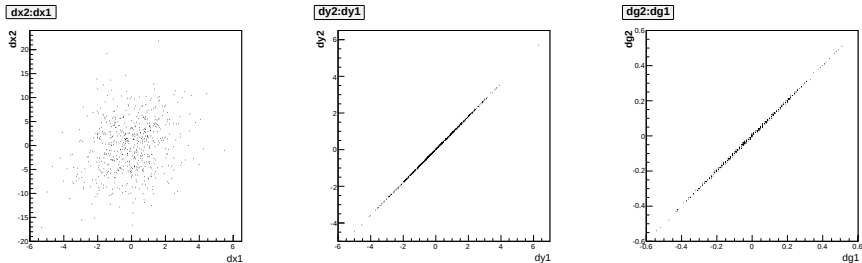


Shown are the fit results versus the truth for a_0 , a_1 , S and ϕ . Except for ϕ the correlations are excellent.

But a quick calculation shows that the width chosen for smearing ϕ lies slightly below the resolution of the images. So this is no surprise.

Toy survey – Global fit

Below I compare the geometrically determined values from the images on the ordinate with the fit result on the abscissa (x and y in μm , γ in mrad):



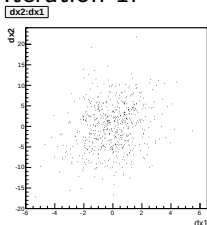
This is a surprise. In x (u) no correlation visible, in y (v) with an slope of about 0.88 (estimated from the plot, observe different scales of the axes) and only γ is ok.

The χ^2 is 571.55. Do we need to iterate?

Toy survey – Global fit

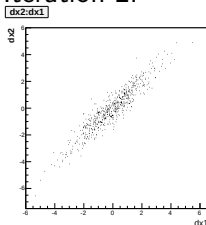
Now let us see what iterations do³. Shown are the results in x compared with the truth values:

Iteration 1:



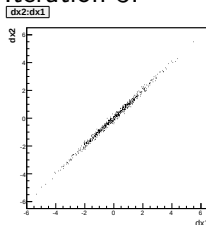
χ^2 : 571.55

Iteration 2:



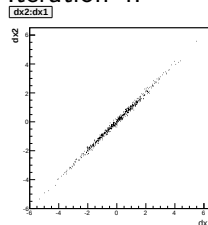
χ^2 : 571.54

Iteration 3:



χ^2 : 571.45

Iteration 4:



χ^2 : 571.47

So, we recover. The other coordinate (y) as well (see backup slides).

³For the experts: pede uses 2 internal iterations. Requesting more doesn't change this. Forcing the recalculation of the matrix does not improve the results.

Toy survey – revising degrees of freedom

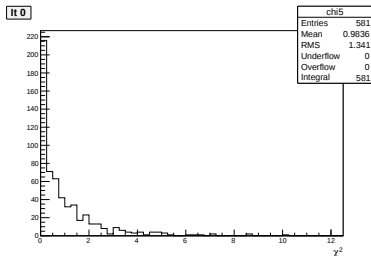
Do we understand the χ^2 ? In the global fit it stays more or less the same among iterations. Every time I iterate the local fit is calculated once more:

Iteration	local χ^2
0	4.026
1	14.34
2	1.120
3	0.985
4	0.984

This seems to be strange — but not really. The first local fit before the first global one is compatible with 4 degrees of freedom. After a succesful global fit, a lower χ^2 seems natural. The local fit can't move the global variables, the global one can.

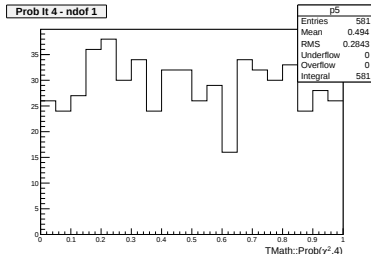
Toy survey – revising degrees of freedom

The distribution of the χ^2 and its probabilities show the following:



The χ^2 distribution looks fine and is compatible with 1 *ndof*.

But does this make any sense?



Toy survey – revising degrees of freedom

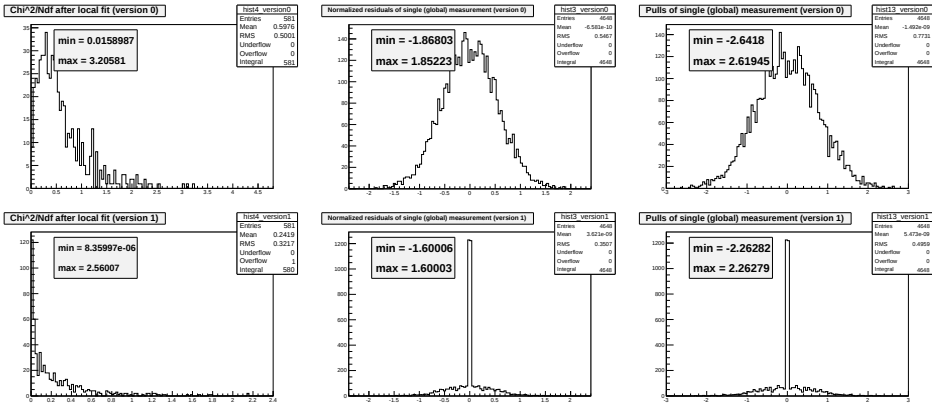
Some facts about the fit:

- ▶ One image has 8 measurements
- ▶ One image needs 4 local parameters
- ▶ We have 4 degrees of freedom left
- ▶ In every image I choose a reference frame, the one of the module in lower z position⁴
- ▶ 3 global parameters define the position of the other module in the image
- ▶ 1 degree of freedom is left
- ▶ This means $ndof$ 7 per ladder, 581 per barrel (83 ladders)
- ▶ Compatible with the global χ^2 of $571.5/581=0.984$

⁴Possible room for enhancement: only one frame per ladder instead of one per image, but lot harder to implement

Toy survey – Plots from pede

Shown are the plots from the first iteration (full CMSSW run).



The distribution of the pulls and the normalized residuals after the first pede internal iteration look strange. Expert advice needed.

Conclusions

- ▶ The implementation works with a toy setup
- ▶ The parameters can be recovered nicely (except the angle ϕ in the local fit, but below resolution)
- ▶ Distributions from pede not yet understood
- ▶ First results with real data are underway
- ▶ The next important step is to see if we can detect wrong data (accidentally swapped images, moving of modules over time)

Backup: Toy survey, global fit

Results in global parameter recovery after the 4th iteration:

