Pixel TPC: Analysis of the 2015 & 2014 Test Beam data

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Based on results presented in the PixelTPC meeting nr 22 on10 March, and 23 on 21 April

https://agenda.linearcollider.org/event/7063/

Introduction: questions

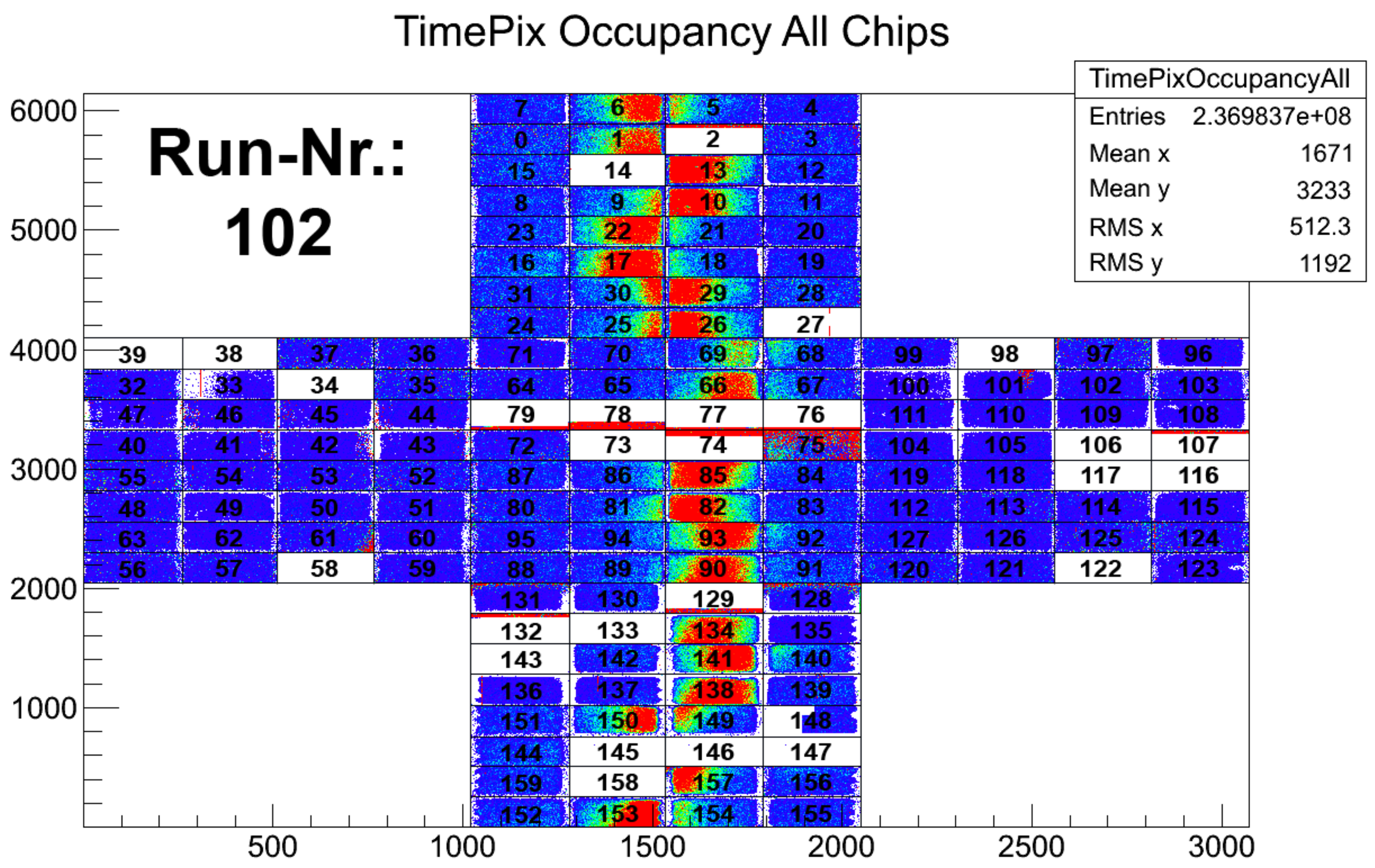
- Study the performance of the test beam data
  - Octoboards modules (96 chips) 2015 data
  - Octopuce 2014 (only 8 chips) data
- Can we reach the design resolution?
- What is the size of deformations?
  - What is their source and how do we control them
- Learn lessons on how to build the next module

- The reason for discussing not only the 2015 but also the 2014 data is that in the last data set we can show that we can reach the design resolution on a small scale

Test beam data (B=0) 2015

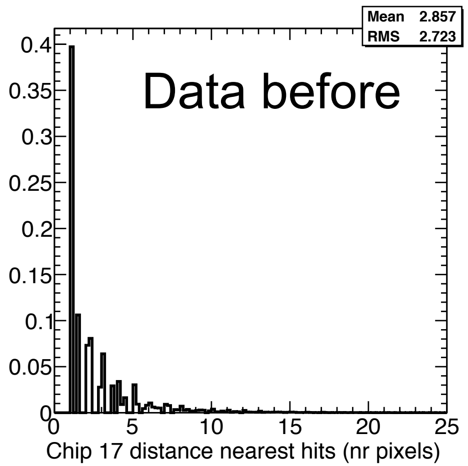
- Analysis of the pixel test beam data
- Description of the setup (picture next slide)
  - 10 octoboards consisting of 2 x 4 chips
  - Geometry y along radius of the TPC: x orthongonal
  - z from time measurement 25 nsec clock
- Start by a zero B field run: straight tracks
- Run 000102_150402 offset z is 6 cm
- Typically track crosses 2 x 10 Chips
- Cannot align all chips in an octoboard because only 2/8 are illuminated by the beam
- Use of new "rotated flipped" GEAR geometry file

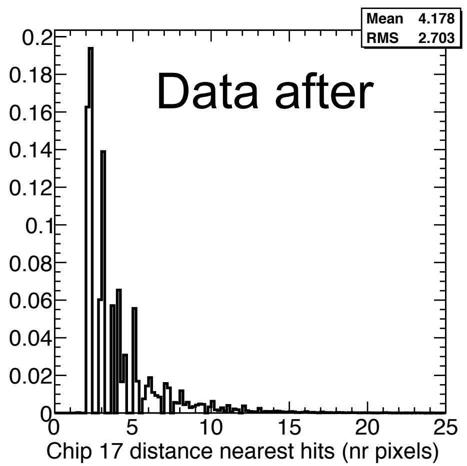
Chip layout in the test beam

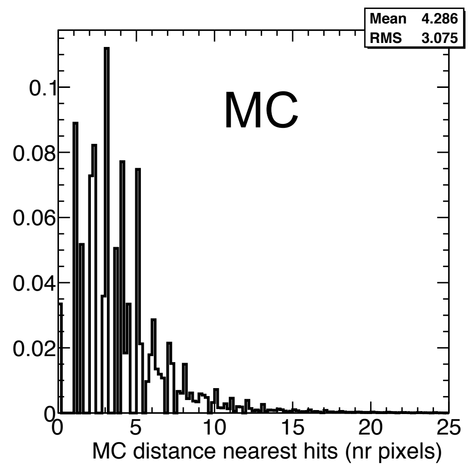


Neighbor hits in Chips

- To reach the design resolution a hit should not be double counted or fire neighbor pixels.
- In the "raw" test beam data we plotted the distance between the hits and found a large spike at low distances
- These hits are not evenly distributed over the chip and have to be removed. Choose hit with largest charge deposit







Data selection & cleaning

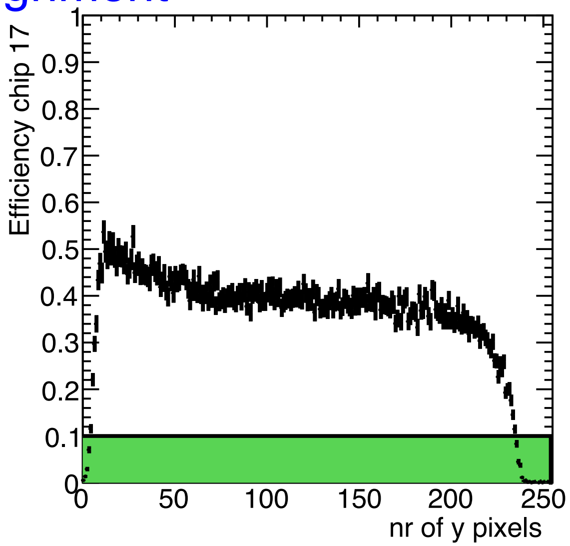
Method and selections (B field 0 run)

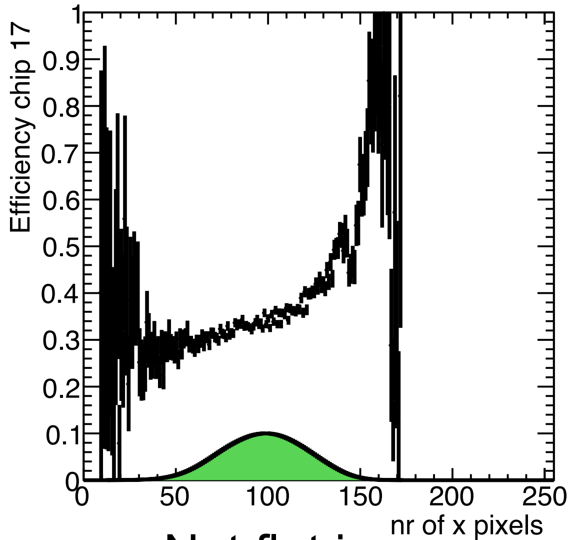
- Select a track through chip 17 and 141 with more than 100 hits. For these ref. chips the beam is far from the edges. NB tracks near edges give a large biases on residuals.
- Reject chips tracks that cross the x edges within plus or minus 3 s.d. (0.8 mm) So keeping only chips where all the expected hits should be found.
- Select only clean tracks with cuts on delta phi, z0 and d0. Reject double tracks with too many hits.
- From the track parameters I calculate the expected beam profile on the chip assuming a Gaussian of 0.8 mm This gives the expected nr hits on the chip in pixel units. - The hits that are actually found are also stored - The relative efficiency is the division of the found/expected.

Chip 17 relative efficiencies

The best chip = reference 1
Starting point for alignment

In green
beam profile:
flat in y and
multiple
gaussians x

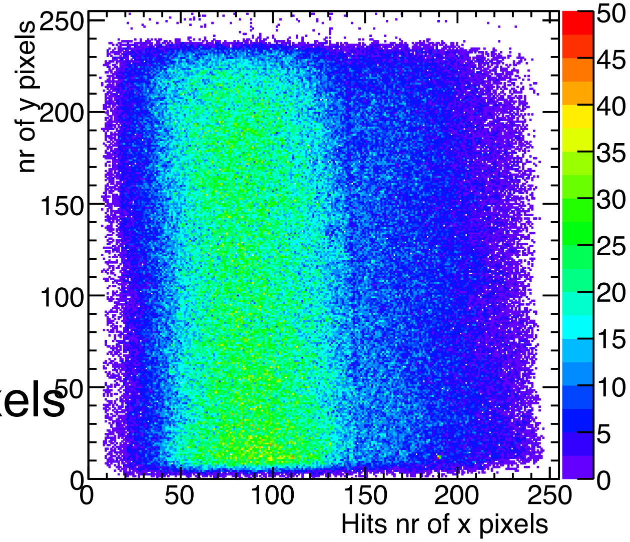


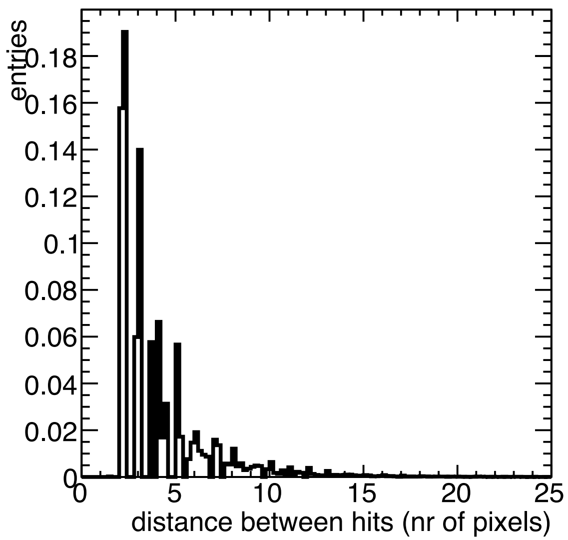


drop 220-256 pixels
drop 0 -10 pixels

Not flat in x

Raw hits



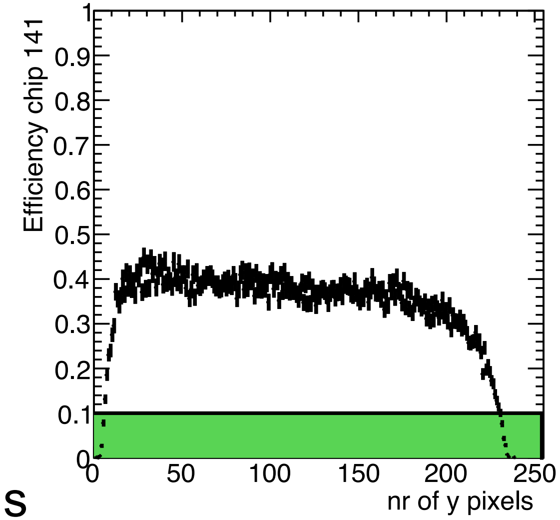


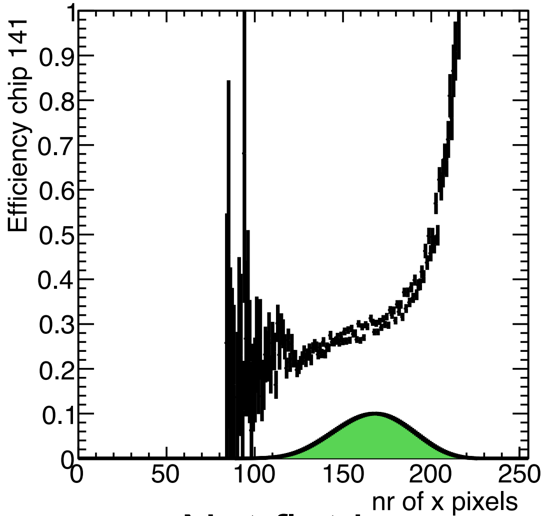
Dead zones:
Dike 6 pixels
Guard ring in y 15 pixels

Chip 141 relative efficiencies

Reference chip 2
Starting point for alignment

In green beam profile: flat in y and multiple gaussians x



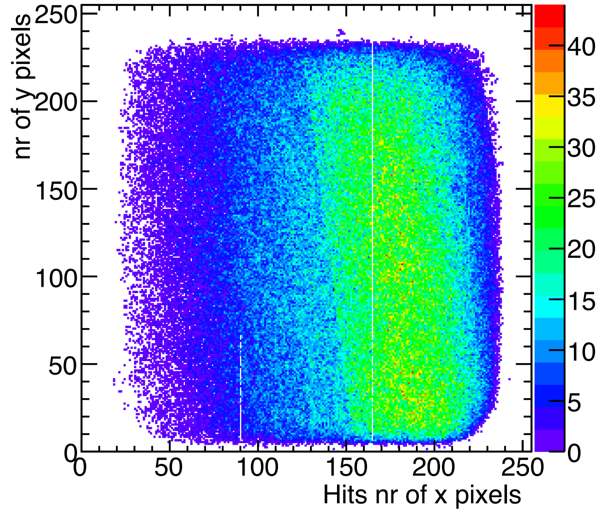


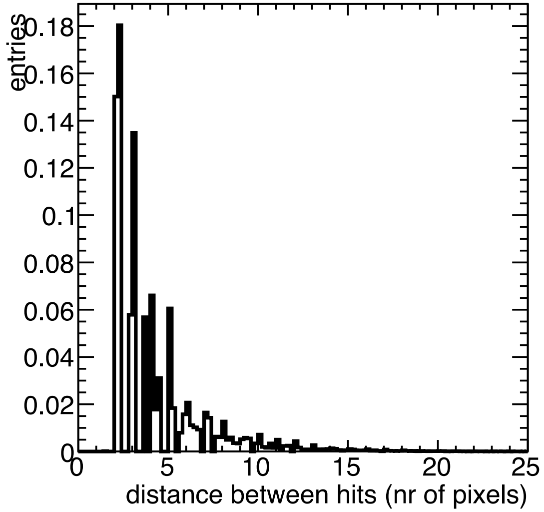
Not flat in x

drop 220-256 pixels
drop 0 -10 pixels

Raw hits

Right bottom round edge

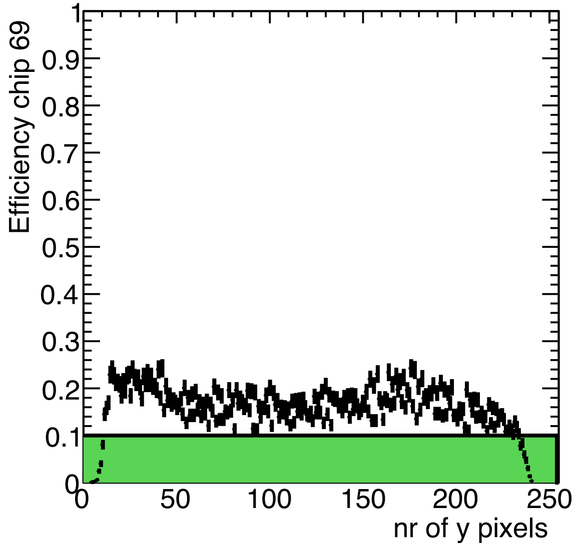


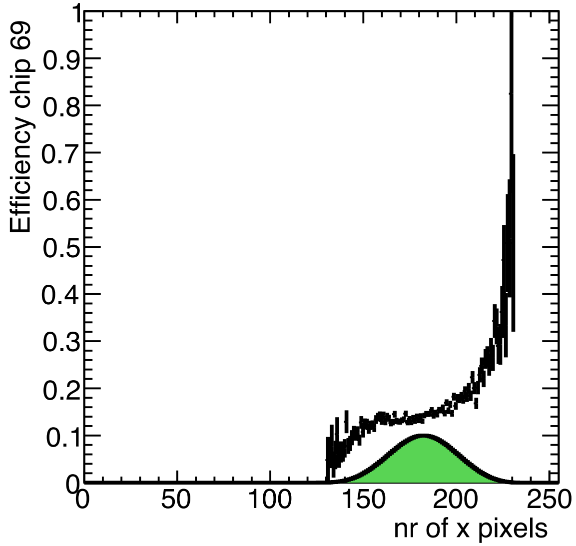


Chip 69 relative efficiencies

Bad low efficiency chip

In green beam profile: flat in y and multiple gaussians x

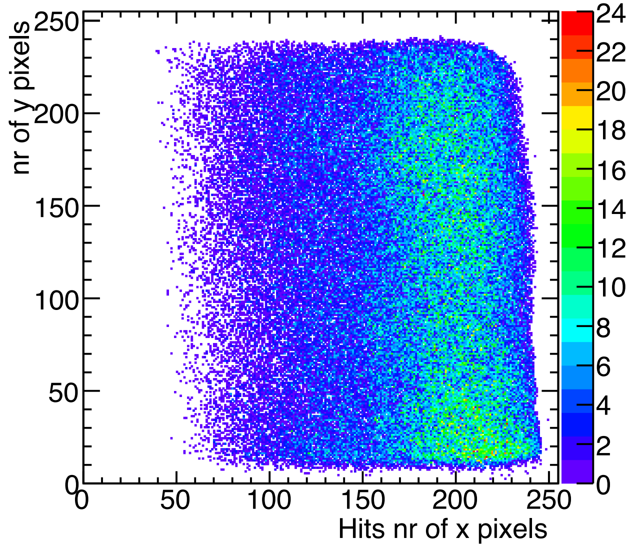


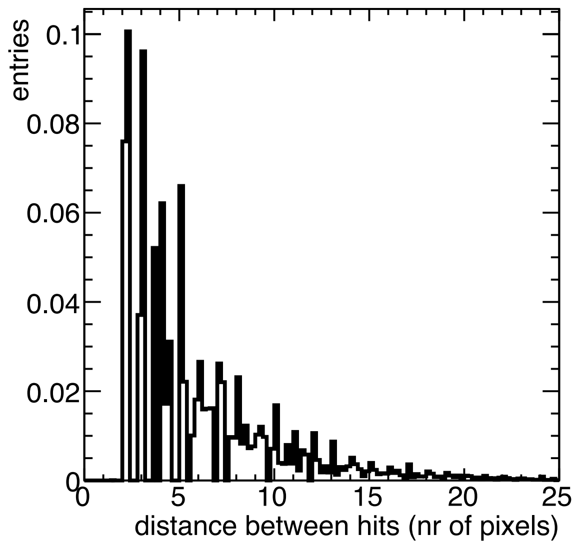


drop 220-256 p
drop 0 -10 pixe

Raw hits

Right bottom round edge



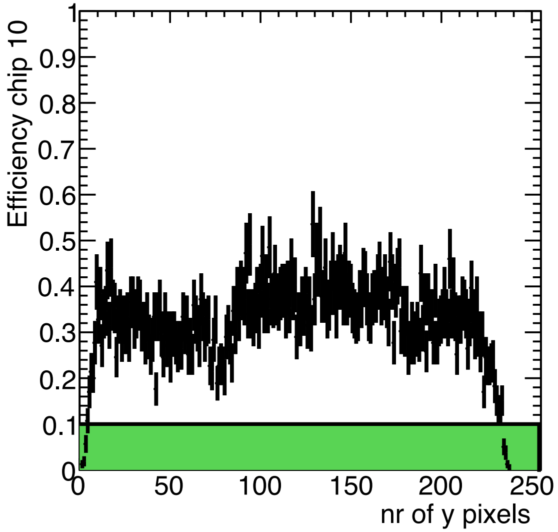


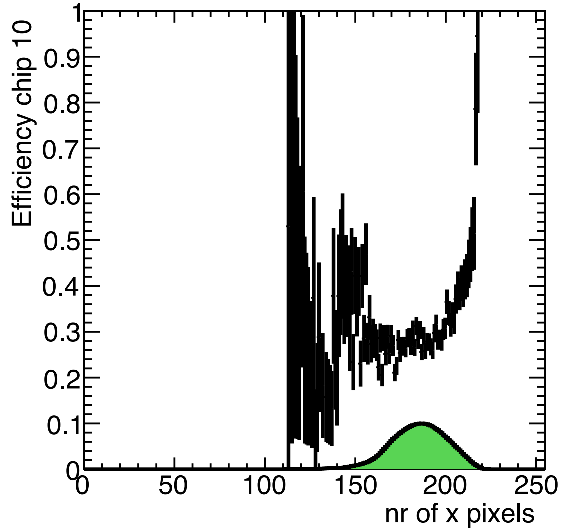
Chip 10 relative efficiencies

Bumpy efficiency chip

In green beam profile: flat in y and multiple gaussians x

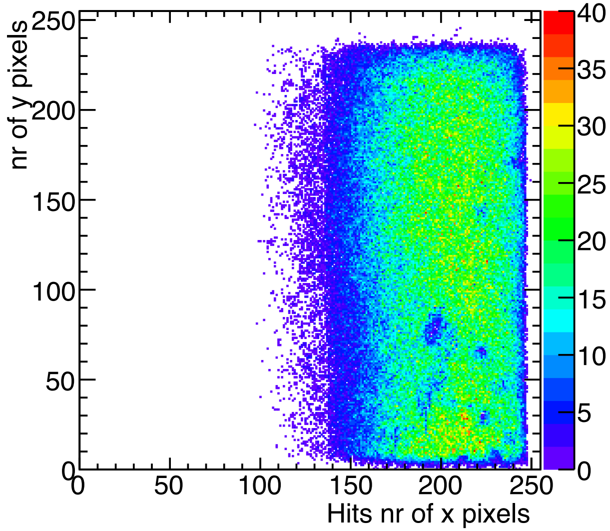
drop 220-256 pi
drop 0 -10 pixel

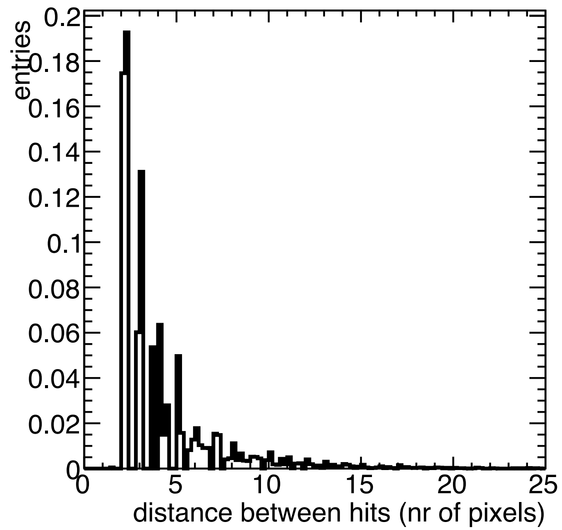




Raw hits

Right bottom round edge





Chip 153 relative efficiencies

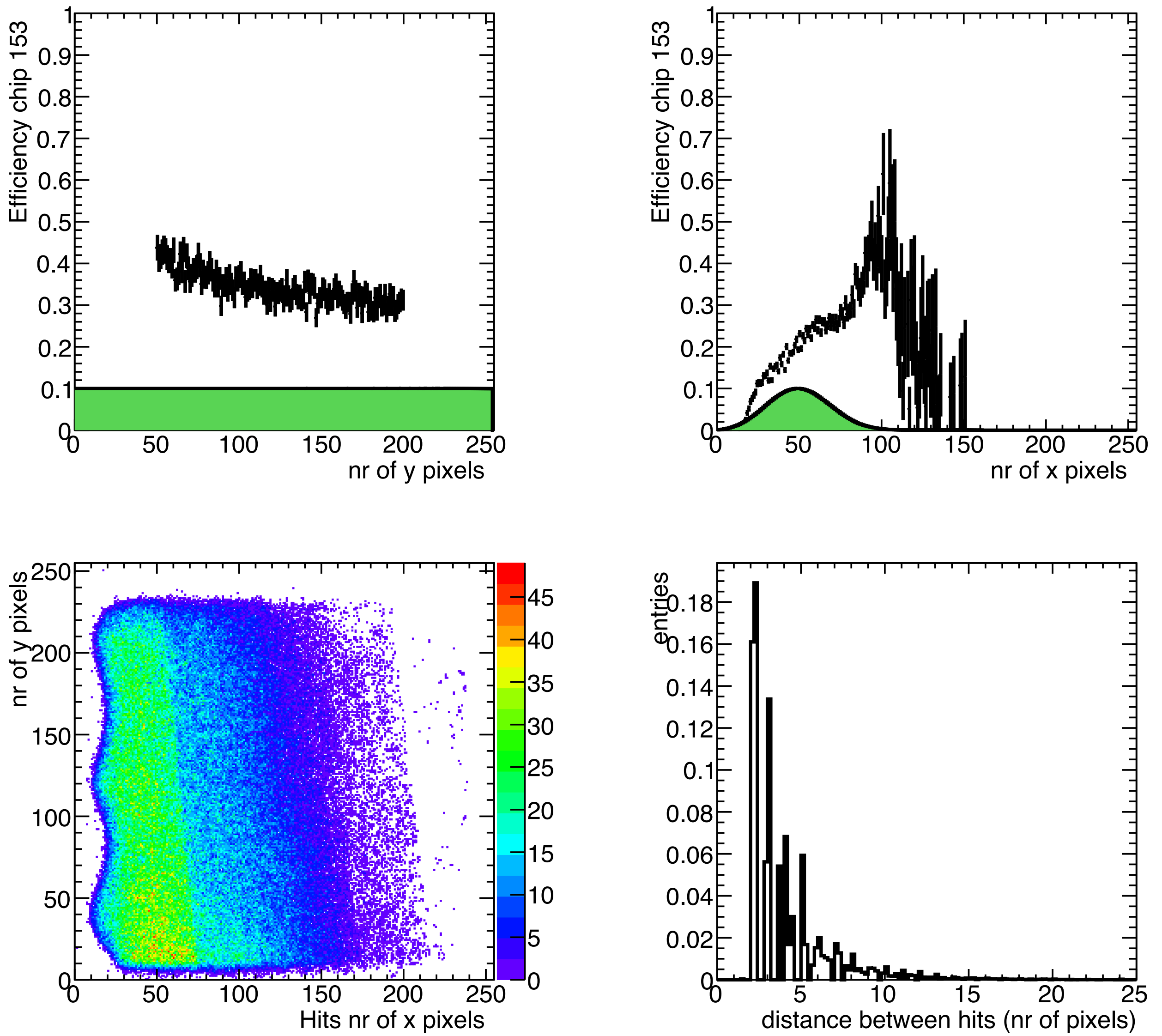
Wiggly efficiency chip

In green
beam profile:
flat in y and
multiple
gaussians x

drop 220-256 pix
drop 0 -10 pixels

Raw hits

Left wiggly
redge



Summary hits per cm

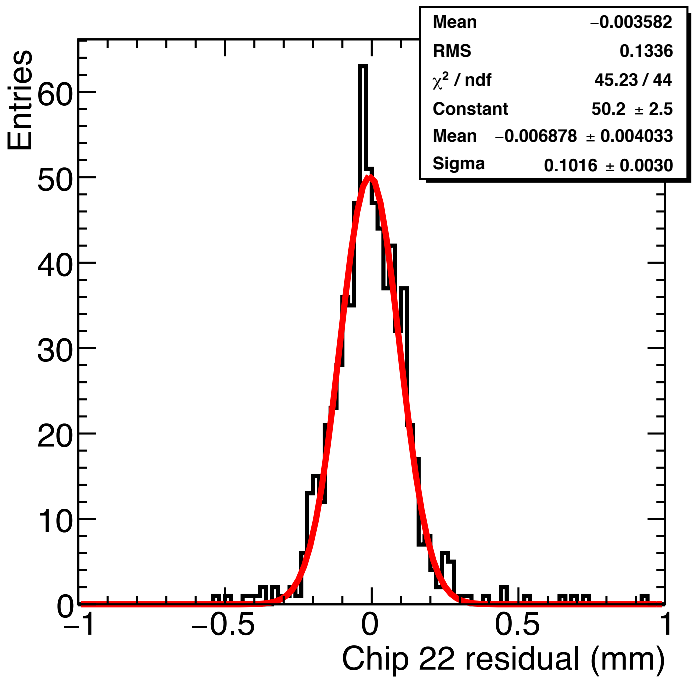
Chip	hits trunc/cm	data events
1	73.9338	69106
6	79.1688	40586
10	96.7501	12220
13	100.465	55536
17	113.648	119910
22	90.3515	86673
29	100.309	6896
66	78.1015	80896
69	49.6105	31555
82	91.9668	49731
85	89.9473	94299
90	89.5151	93416
93	89.8862	94295
134	75.3125	78250
138	88.3866	92389
141	102.99	107670
150	84.1619	5782
153	66.4043	34409

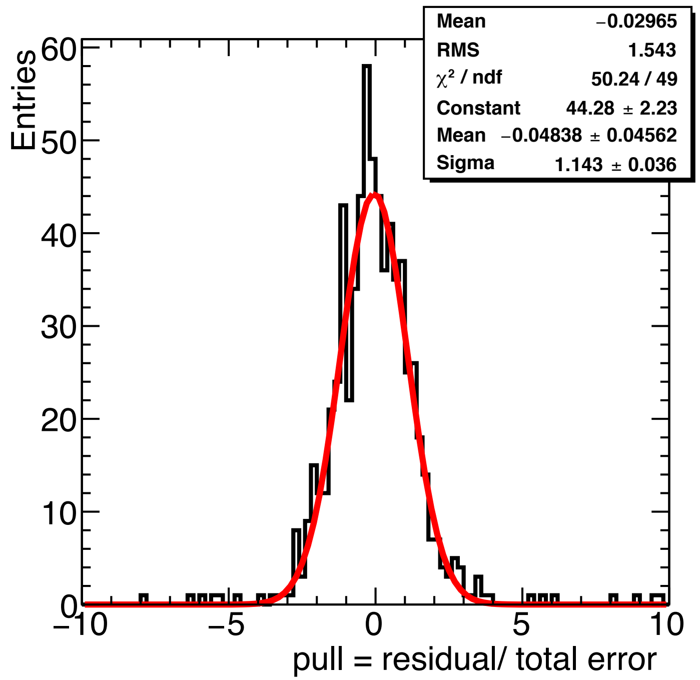
For an electron one would expect 1.4 times 100 hits/cm

Alignment and resolution per chip

Method:

- full fit through chips 17 and 141 propagate errors (assume 0.8 mm per hit)
- Fit through the reference chip ONLY
- Shift and rotate the chips (align)
- Calculate residual of reference chip wrt full fit
- Pull = residual / expected error (from full fit and chip)





Resolution per chip

0.7 mm per hit

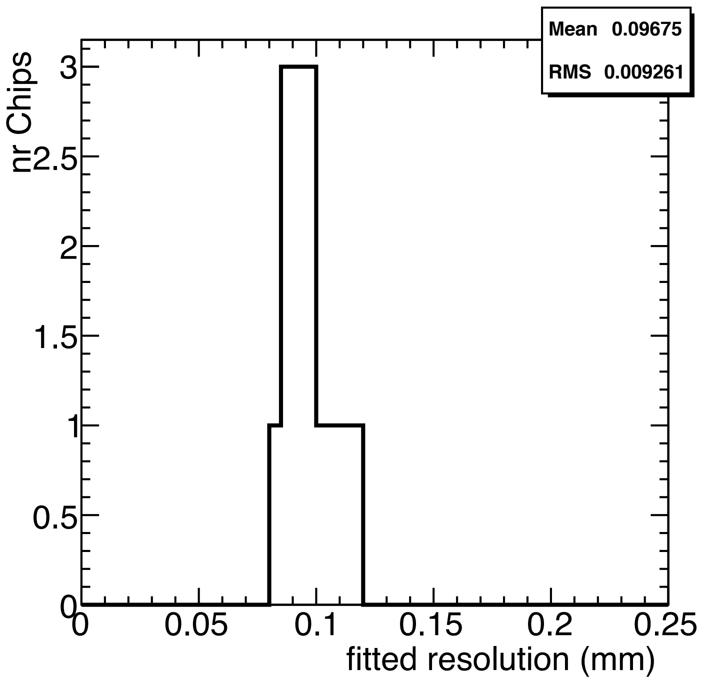
Chip	resolution(mm)	pull	
1	0.125737	1.21765	
7	0.135288	1.23106	
10	0.241599	2.37582	bumpy chip
13	0.115116	1.20874	
22	0.10159	1.14296	
66	0.104411	1.24057	
69	0.114359	1.175	
82	0.10318	1.1957	
85	0.108777	1.31491	
90	0.104571	1.37221	
93	0.109144	1.33306	
134	0.116371	1.214	
138	0.110914	1.19965	
153	0.168231	1.486	wiggly chip

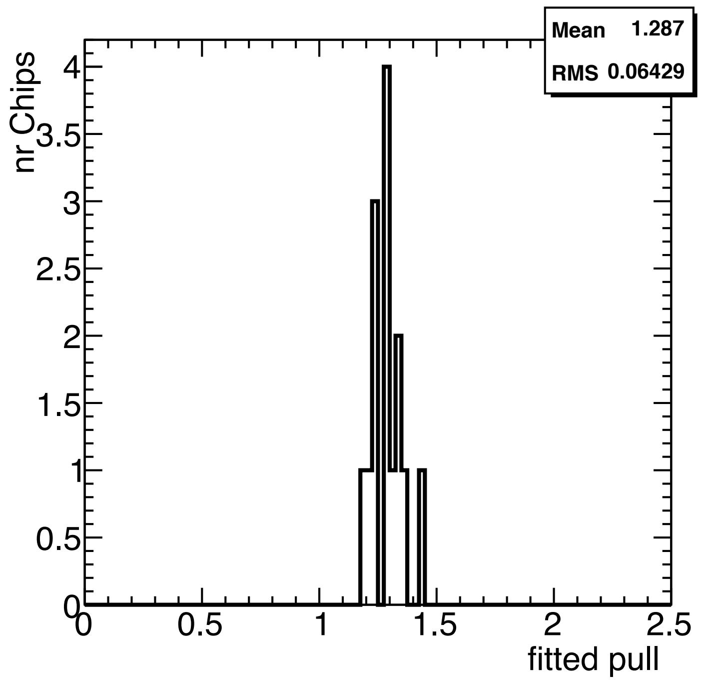
Resolution per chip using all good chips

Chip	resolution(mm)	pull	
1	0.107619	1.36837	
6	0.115158	1.31589	
13	0.0970513	1.27545	
17	0.0835968	1.27783	(was used as Ref1)
22	0.0926846	1.22985	
66	0.0908516	1.24745	
69	0.112894	1.1796	
82	0.0877	1.21932	
85	0.0936347	1.33343	
90	0.0880832	1.29956	
93	0.0886049	1.28664	
134	0.0966038	1.22604	
138	0.101433	1.3333	
141	0.0986377	1.4322	(was used as Ref2)

Improved precision use all other chips to predict position and angle in a chip

Resolution selected chips





On average the resolution per chip is 92 μm and the average pull is 1.3. The expected precision is 70 μm. This means that per chip we have a systematics per chip of 60 μm .

Sagitta analysis

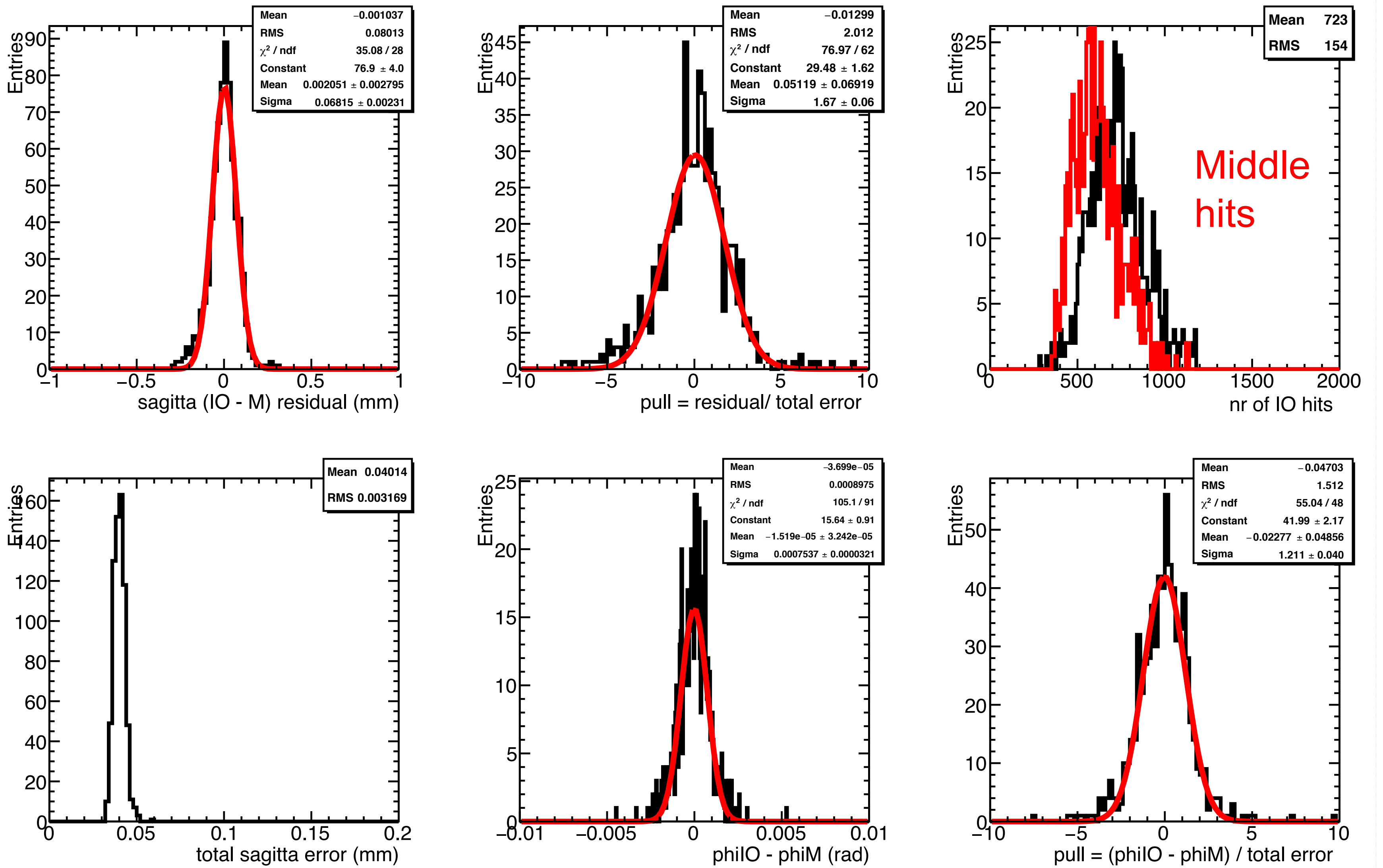
Split the tracks into three pieces according to the Modules:
Inner – Middle – Outer modules

Fit Inner + Outer -> get track parameters and errors
Fit Middle -> get track parameters and errors

The sagitta = residual at the Middle position

The sagitta shows what happens if we combine all the measurements. The pull = sagitta/expected error tells how well we do: remaining systematical errors

Sagitta analysis



Sagitta analysis results 2015

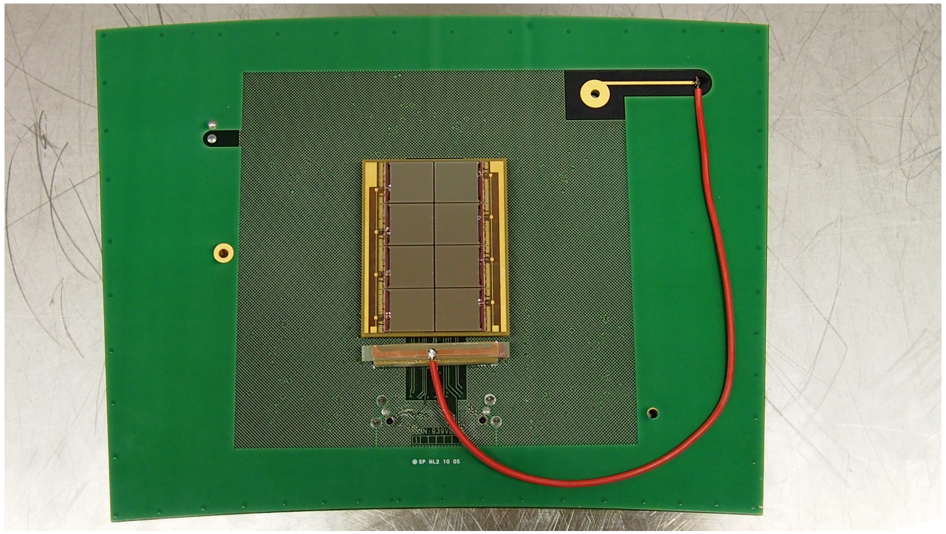
- The phi results per module are: fitted resolution 0.075 mrad expect 0.06 mrad with a fitted pull of 1.2.
  Conclude: the phi systematics is rather small: only 0.04 mrad

- The σ sagitta fitted is 67 μm; we expect 32 μm. The pull is fitted to be 1.7.
  Conclude: we have additional systematics per module of 58 μm. This is quite large.
  Note that per chip we have already a 92 μm fitted resolution. At that level there was already sign of the presence of systematics of 60 μm .

- The reason for the systematics is most likely E field deformations that affect the chip and module resolution
- Some of the deformations can be clearly seen in the hit maps
- The deformations are mostly caused by electro-mechanical imperfections

Analysis of 2014 Octopuce data

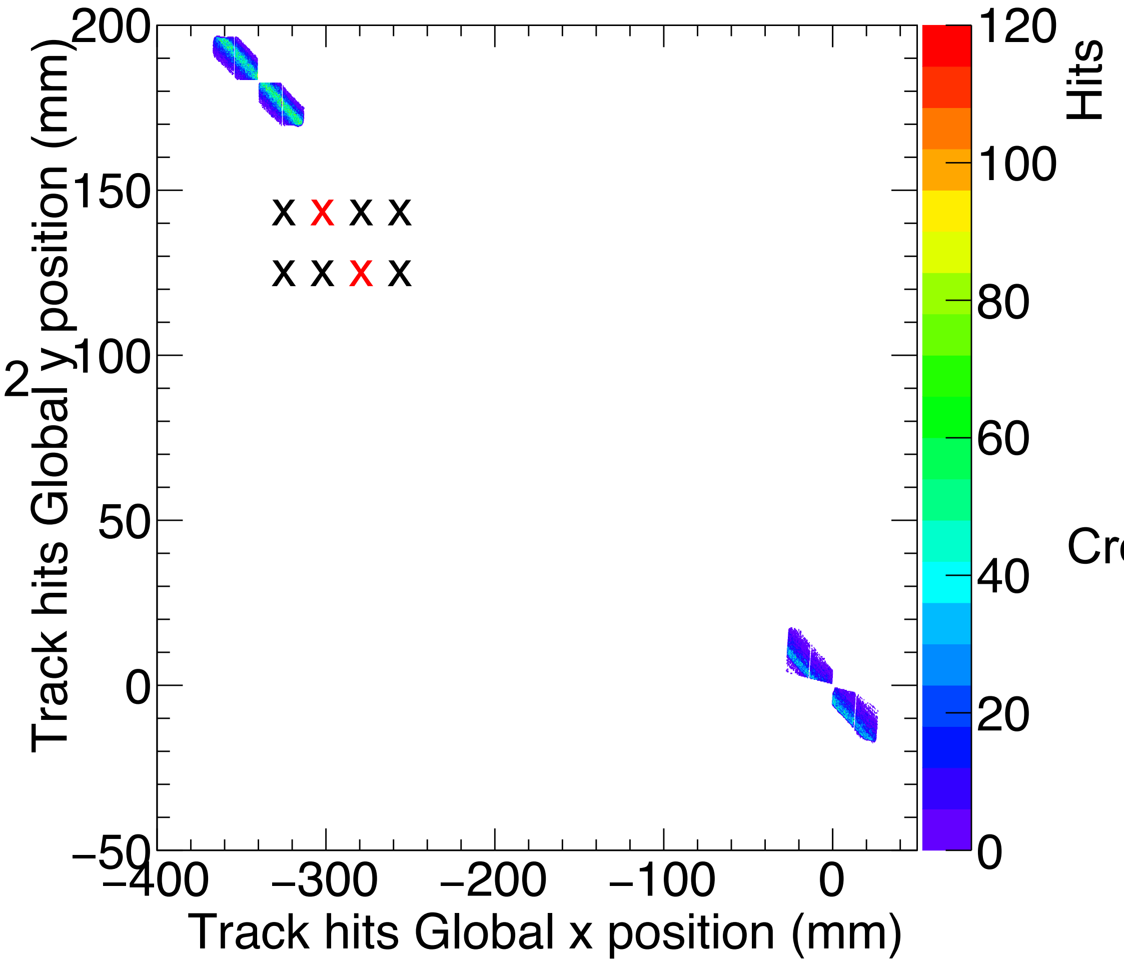
- Analysis of the pixel test beam data 2014
  - 2 octopuce boards consisting of 2 x 4 chips
  - Geometry x along radius of the TPC: y orthogonal
  - z from time measurement 25 nsec clock
- Look at B field 1 Tesla runs with z = 1cm and 2.5cm
- Runs 4178 1cm 4177 2.5cm
- Typically track crosses 2 x 4 Chips



Chip layout in the test beam

Crossed diagonally
4 chips

Nrs 13 14 11 12



Crossed diagonally
4 chips

Nrs 5 6 3 4

Chip performance

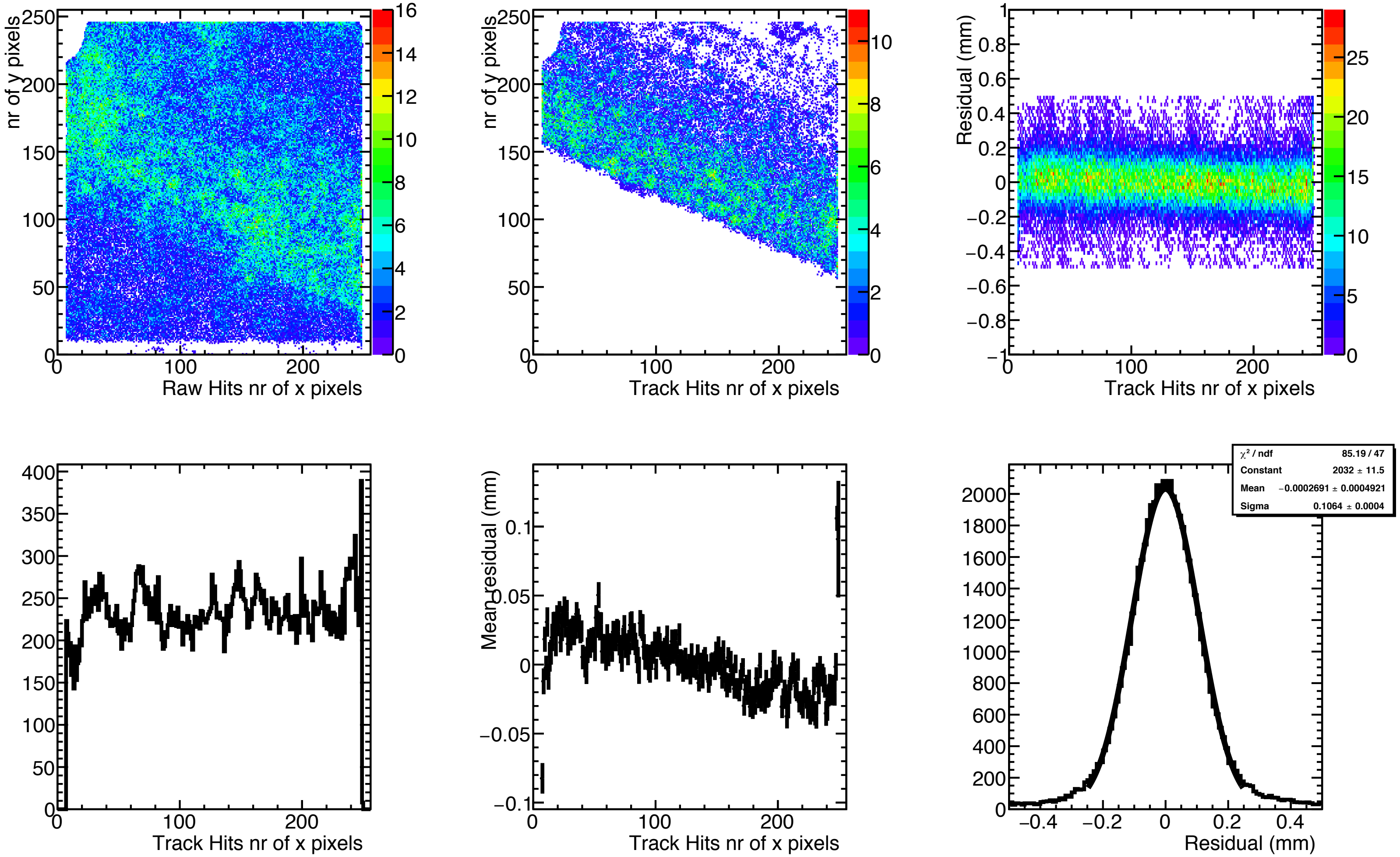
- Studied by performing a straight line fit to the hits in one octopuce board (max 8 chips in practice 4 chips)
- NB inside an octopuce board - for a 6 GeV electron - the curvature is small
- chips 1-8 "G03_W0062_H" 9-16 ="K06_W0062_H"
- Reference chips are 3, 4, 11 and 14
- Require > 25 hits in each ref chips (so e.g. 3 and 4)
- Track cleaning cut |d0| < 5 mm and |phi -2.645|<0.2
- Just shifted residuals in xy for chips 5, 6, 12 and 13

  shifts: 0.15 0.2 0.07 0.04 mm

  accounts for dead space between chips and shifts
- Residuals in xy larger than 0.5 mm are removed

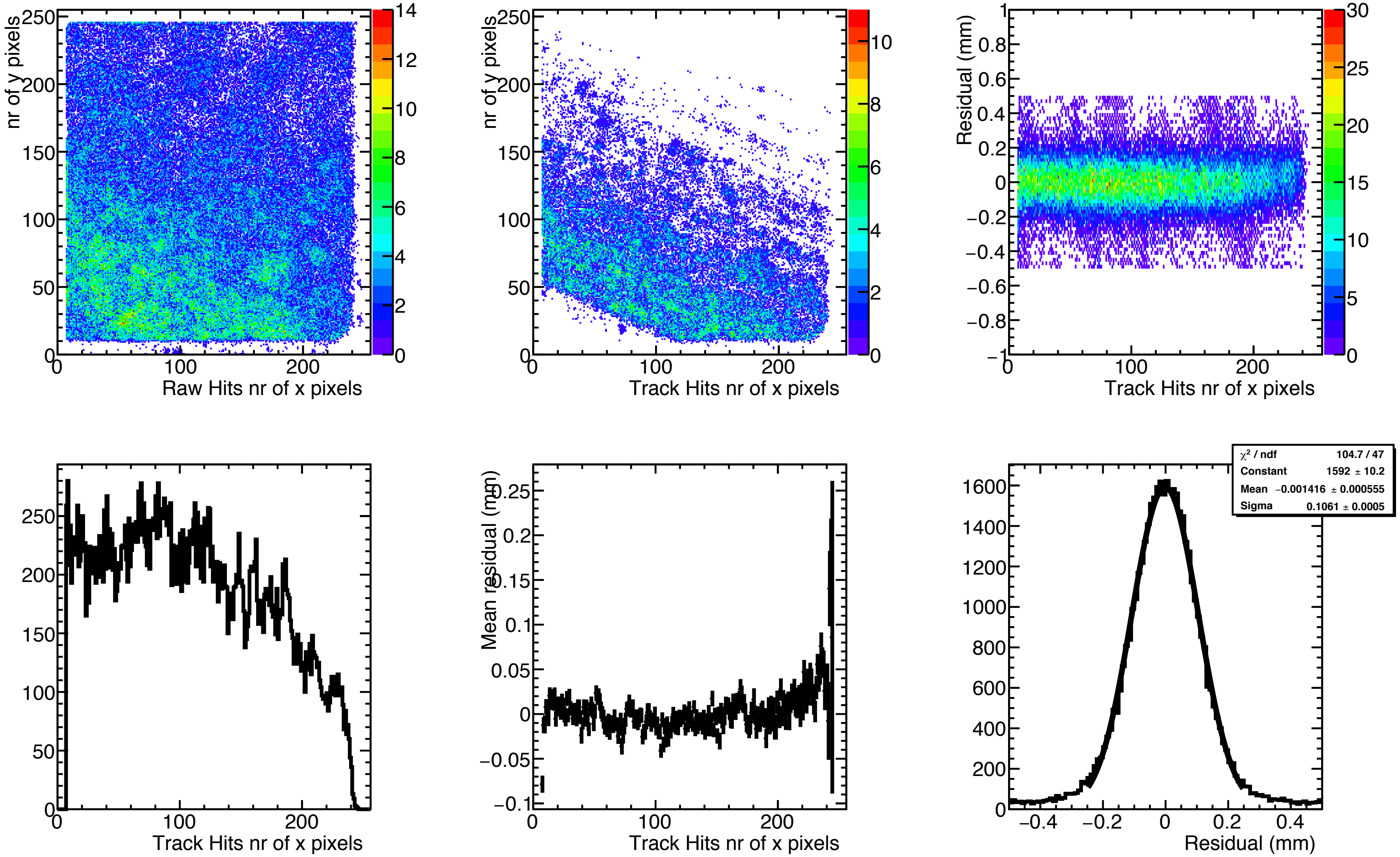
Chip 3

100 microns resolution per hit

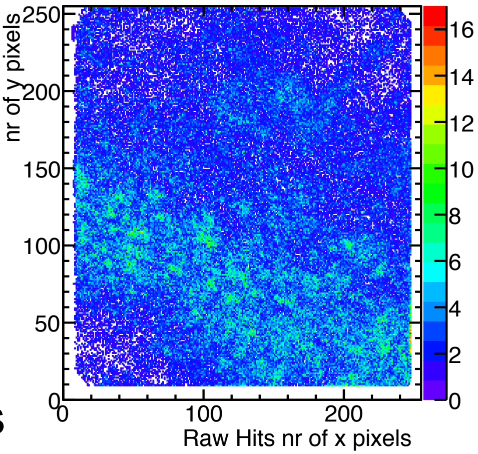


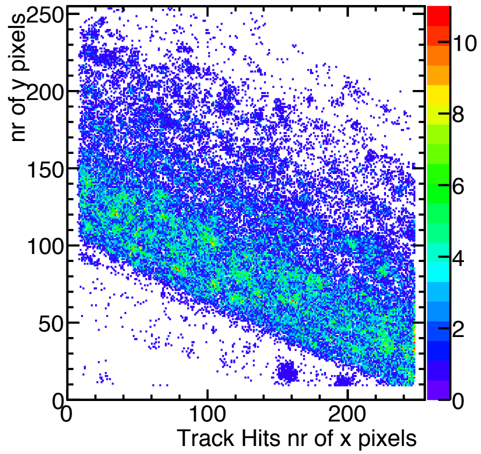
Chip 4

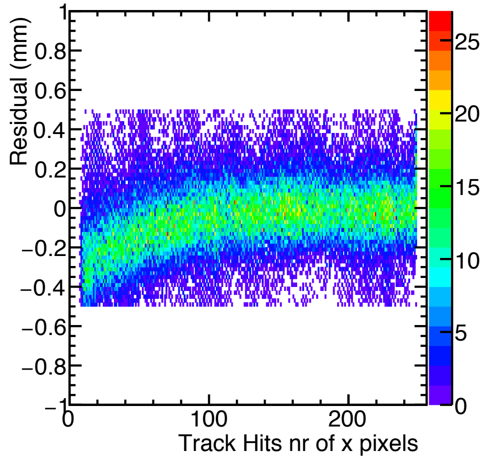
100 microns resolution per hit



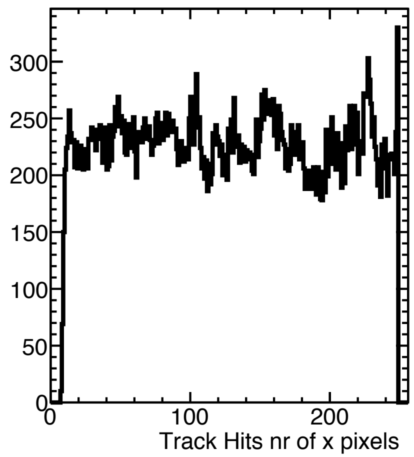
Chip 5

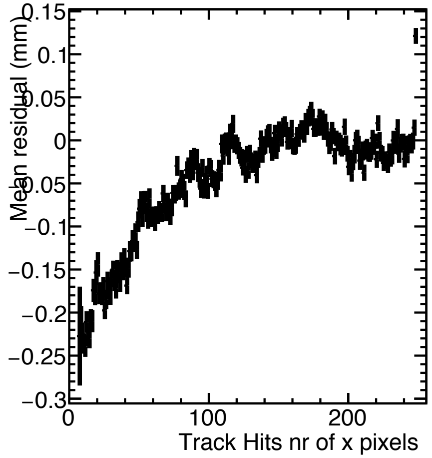


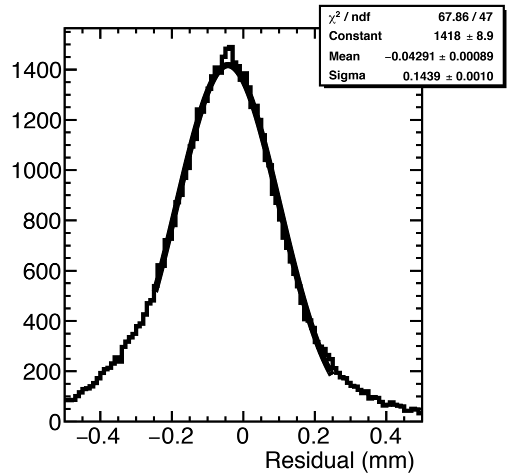




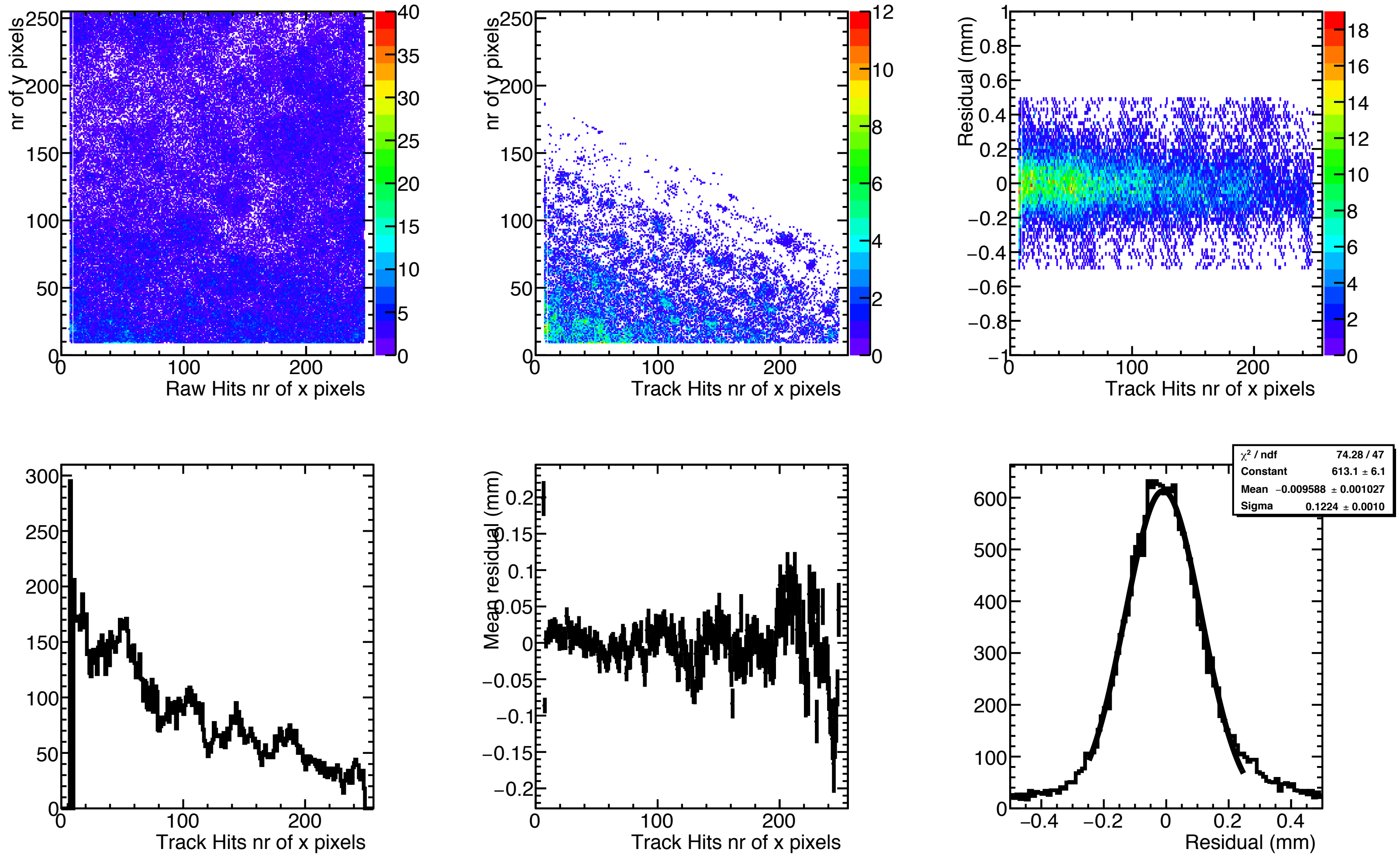
Deformations visible at edge 0.3 mm







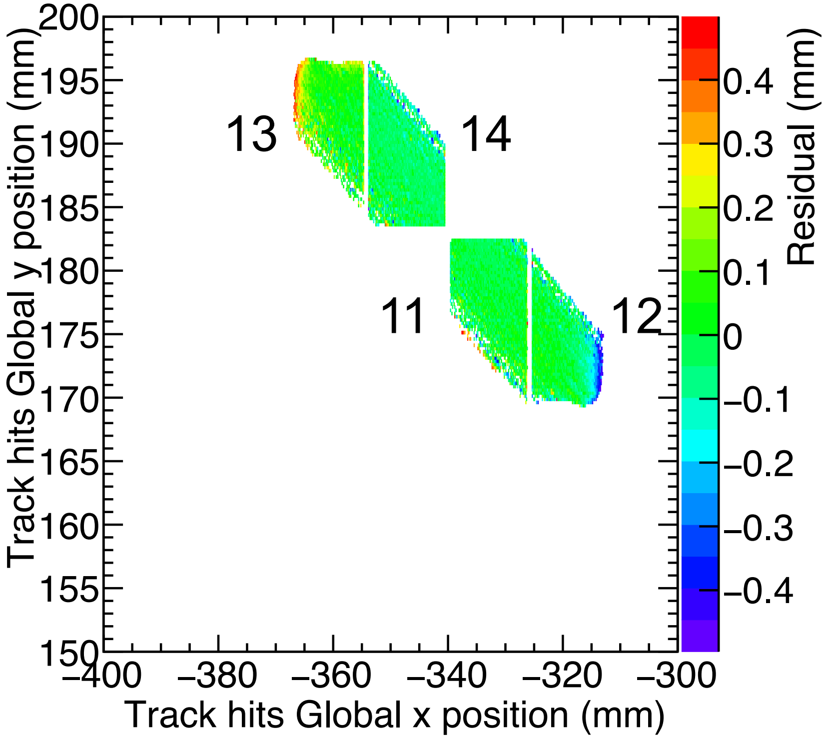
Chip 6

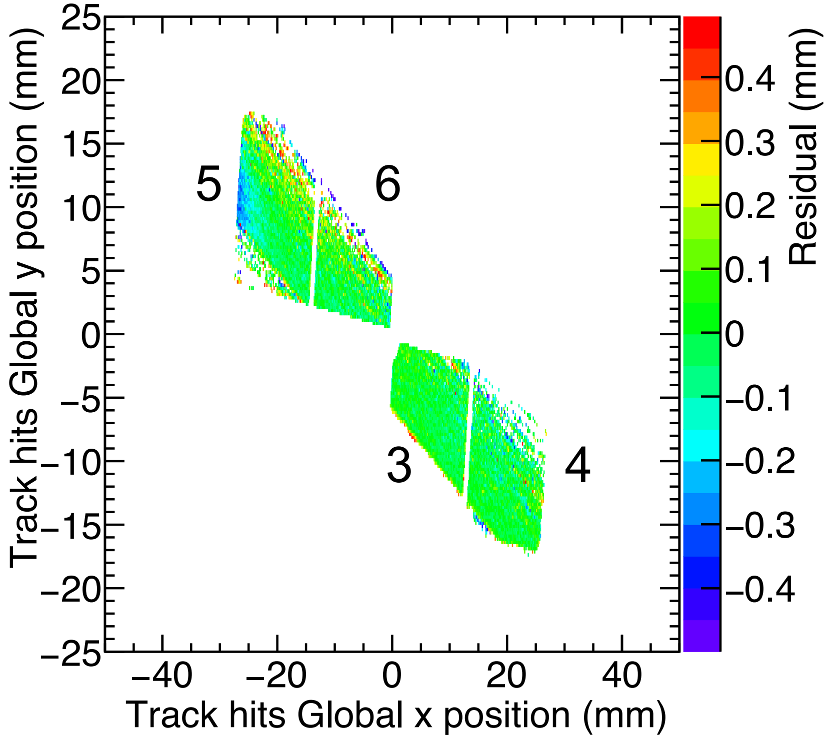


nr of y pixels
Raw Hits nr of x pixels
nr of y pixels
Track Hits nr of x pixels
Residual (mm)
Track Hits nr of x pixels
Track Hits nr of x pixels
Mean residual (mm)
Track Hits nr of x pixels
χ² / ndf 74.28 / 47
Constant 613.1 ± 6.1
Mean −0.009588 ± 0.001027
Sigma 0.1224 ± 0.0010
Residual (mm)

Where are the good and deformed zones?

Deformations on left and right side of octopuce (13,12) and left (5); right side 6 is good. Top/bottom edges 13,12 and 6 good. Chips in the middle (14,11 and 3,4) are good everywhere.

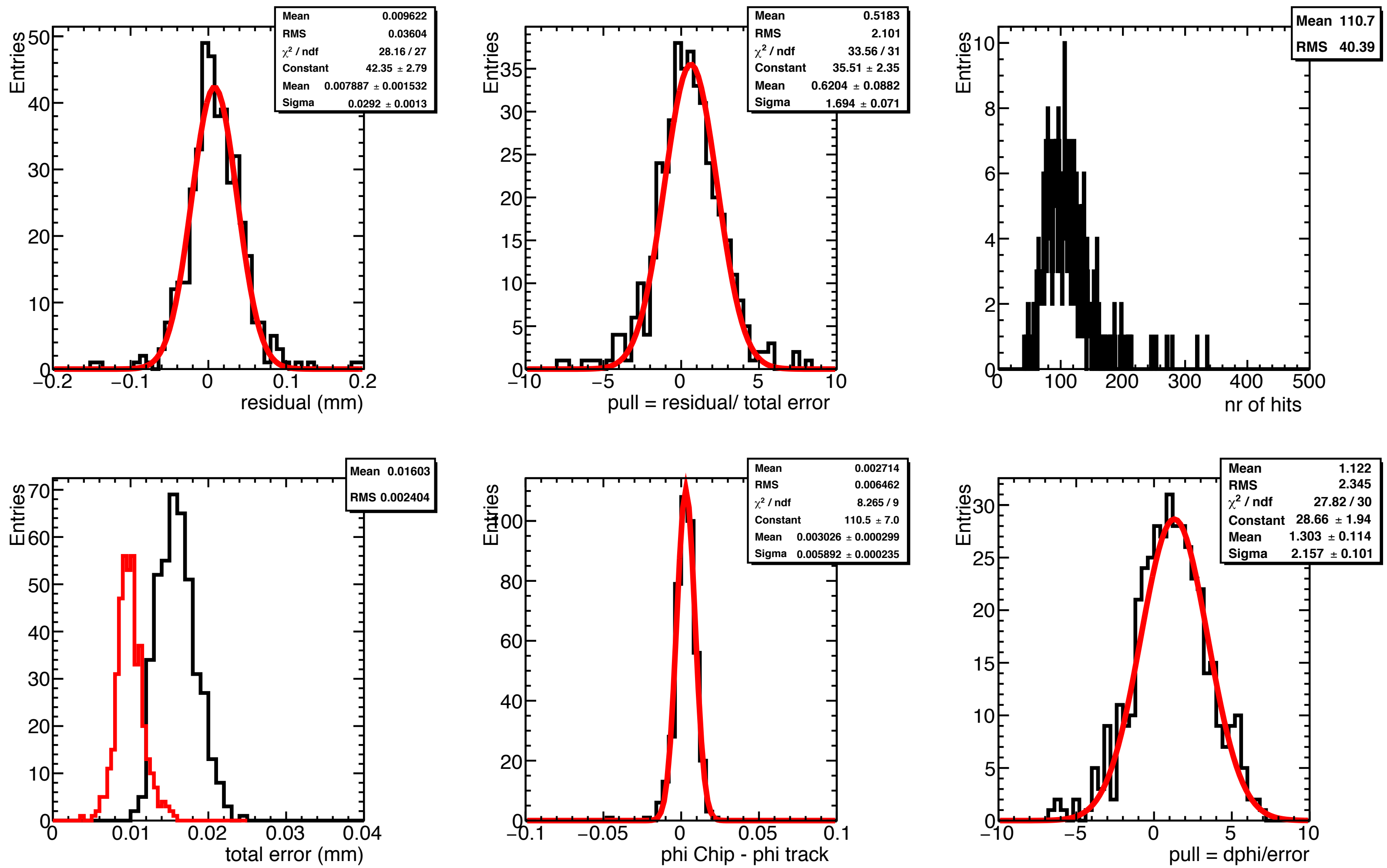




Tracking performance

- Studied by performing a straight line fit to the reference Chips 3, 4, 11 and 14 leaving out one of them:
- To study tracking the resolution we fit e.g.: chip 3 only and compare it to one fit to chips 4,11 and 14.
- Tighter track selection with cuts on two octopuce fits :
  - |d0 (xy)| < 5 mm (from 3,4 to 11,14) and vice versa.
  - |phi(3,4)-phi(11,14)|<0.012
- Residuals are corrected for shifts and phi dependence
  - res = ±30*sin(phi-2.634) shift ±0.06 0.055
- NB Residuals in xy larger than 0.5 mm are removed
- Fit can propagate errors. Require total error < 0.020 mm
- Assume 100 micron per hit

Chip 3

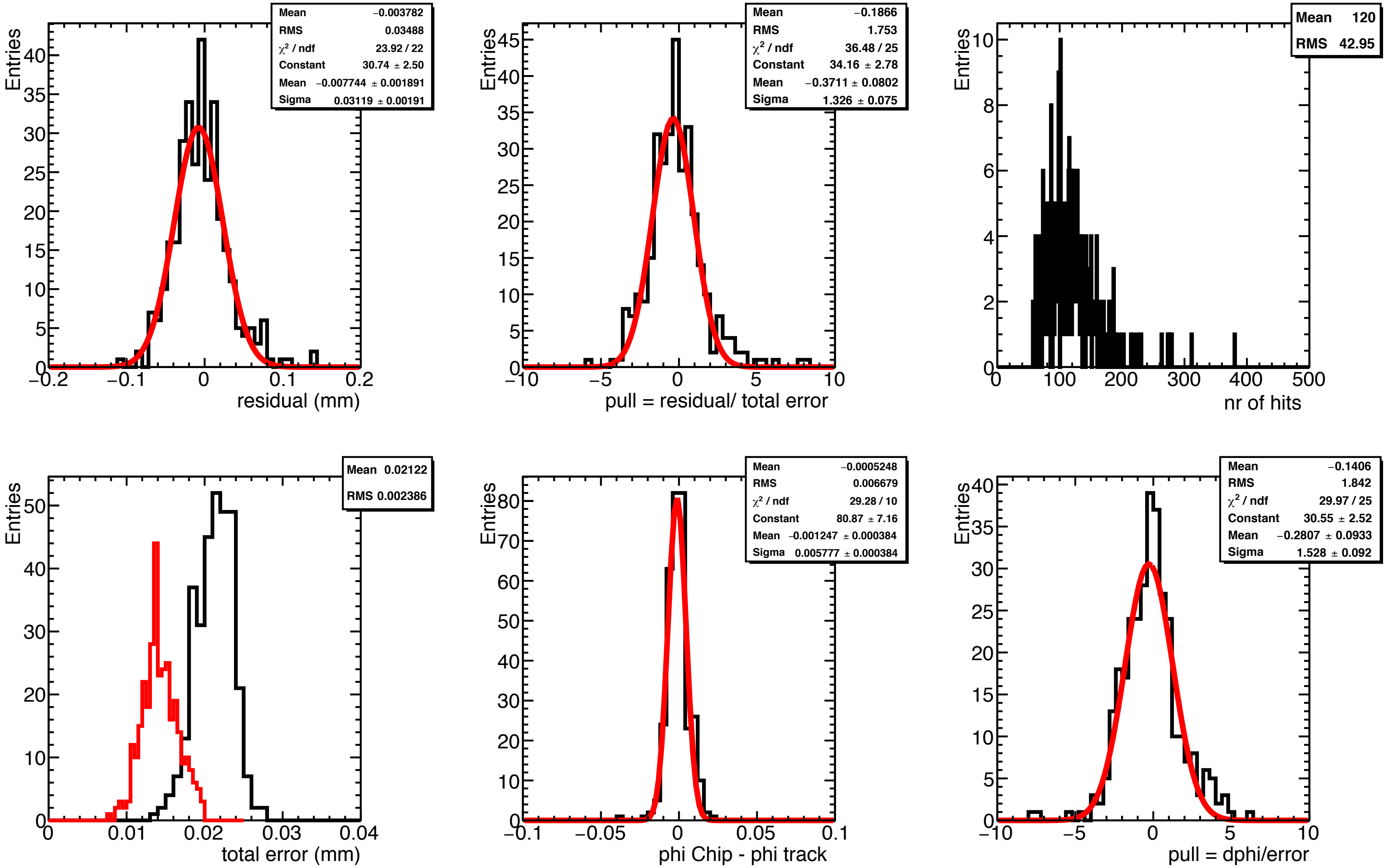

Mean 0.009622
RMS 0.03604
χ² / ndf 28.16 / 27
Constant 42.35 ± 2.79
Mean 0.007887 ± 0.001532
Sigma 0.0292 ± 0.0013
Entries
residual (mm)
Mean 0.5183
RMS 2.101
χ² / ndf 33.56 / 31
Constant 35.51 ± 2.35
Mean 0.6204 ± 0.0882
Sigma 1.694 ± 0.071
Entries
pull = residual/ total error
Mean 110.7
RMS 40.39
Entries
nr of hits
Mean 0.01603
RMS 0.002404
Entries
total error (mm)
Mean 0.002714
RMS 0.006462
χ² / ndf 8.265 / 9
Constant 110.5 ± 7.0
Mean 0.003026 ± 0.000299
Sigma 0.005892 ± 0.000235
Entries
phi Chip - phi track
Mean 1.122
RMS 2.345
χ² / ndf 27.82 / 30
Constant 28.66 ± 1.94
Mean 1.303 ± 0.114
Sigma 2.157 ± 0.101
Entries
pull = dphi/error

Tracking performance summary

chip	Resolution (mm)	pull	Phi resolution	pull
3	0.030	1.7	0.006	2.2
4	0.025	1.6	0.008	2.1
11	0.026	1.6	0.007	1.7
14	0.027	1.2	0.006	1.5

- Note correlation between residuals chip 3 and 4.
- We observe a resolution 25-30 microns where we expect on average 16 -20 micron
- Phi is a bit more off, but this has to do with the beam that has a curvature (p) distribution that must show up in |phi Chip – phi full track|

Chip 3 z = 25mm

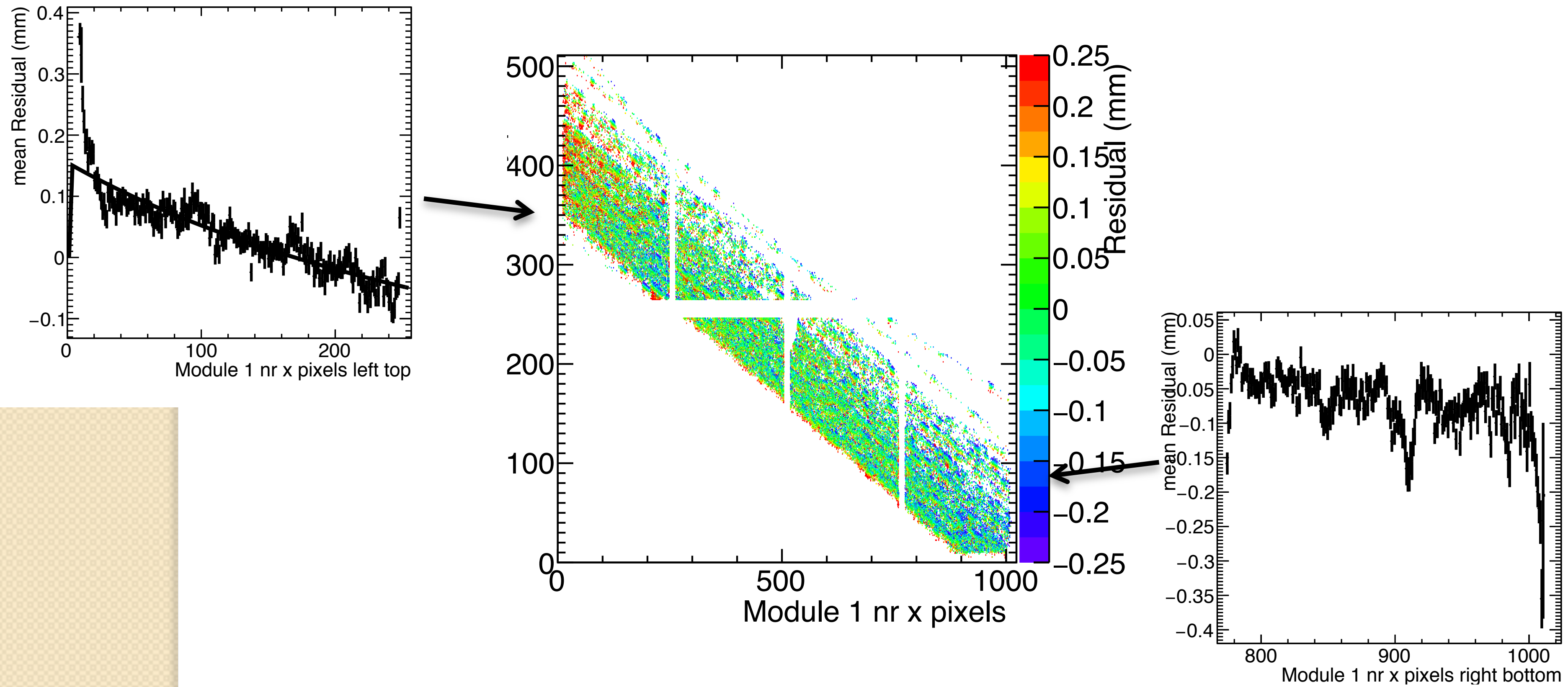

Mean -0.003782
RMS 0.03488
χ² / ndf 23.92 / 22
Constant 30.74 ± 2.50
Mean -0.007744 ± 0.001891
Sigma 0.03119 ± 0.00191
Entries
residual (mm)
Mean -0.1866
RMS 1.753
χ² / ndf 36.48 / 25
Constant 34.16 ± 2.78
Mean -0.3711 ± 0.0802
Sigma 1.326 ± 0.075
pull = residual/ total error
Mean 120
RMS 42.95
nr of hits
Mean 0.02122
RMS 0.002386
total error (mm)
Mean -0.0005248
RMS 0.006679
χ² / ndf 29.28 / 10
Constant 80.87 ± 7.16
Mean -0.001247 ± 0.000384
Sigma 0.005777 ± 0.000384
phi Chip - phi track
Mean -0.1406
RMS 1.842
χ² / ndf 29.97 / 25
Constant 30.55 ± 2.52
Mean -0.2807 ± 0.0933
Sigma 1.528 ± 0.092
pull = dphi/error

Tracking performance summary z = 25mm

chip	Resolution (mm)	pull	Phi resolution	pull
3	0.030	1.3	0.006	1.6
4	0.026	1.3	0.007	1.6
11	0.027	1.3	0.008	1.5
14	0.024	1.2	0.006	1.5

- We observe a resolution 24-30 microns where we expect on average 22 micron
- Phi is a bit more off, but this has to do with the beam that has a curvature (p)
- The expected and observed resolutions are closer than for the 1cm data. Due to the diffusion the resolution is 150 microns per hit

Module 1 performance @ 320 V no ExB field deformations!



Conclusions

- Resolution for the 1cm data 100 μ m and for 25mm 150 μ m per hit
- Per chip we observe a resolution 24-30 microns per chip (chip and track uncertainties) where we expect on average 18 (1mm) 22 (25mm) micron
- This means that deformations or remaining additional systematics per chip are typically less than 20 μ m for both data sets
- By carefully adjusting the E field (320 V data) the deformations at the edges of the board are under control and systematics per chip less than 20 μ m. Note that the "octoboard" has a syst of 58 μ m.
- The octopuce meets the design goal of our TPC.
- We need now to build a 100 chip module. For this one needs a high electro-mechanical precision: grid distance above the chip and the positioning of the chip (3D) and guard on the module.
- The basic philosophy is not to correct the ExB deformations, but to minimize them in the design.