Prague Analysis of TB2008: Methods and Comments

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Contents

- **Gains and „large scale” corrections**
- **Simulations**
- **From tracking resolutions to hit reconstruction**

This talk is based on the materials presented by Peter Kodyš in his overview of results. It adds some focus on methods, open questions, and plans.

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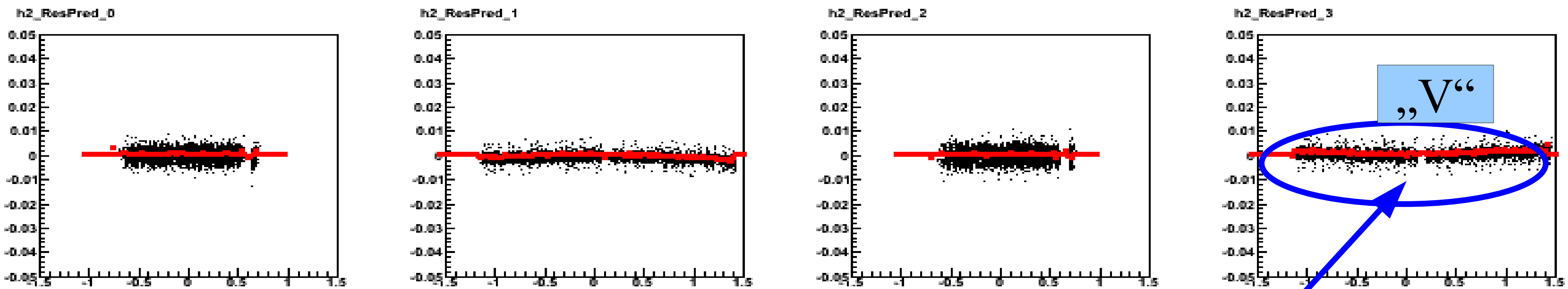
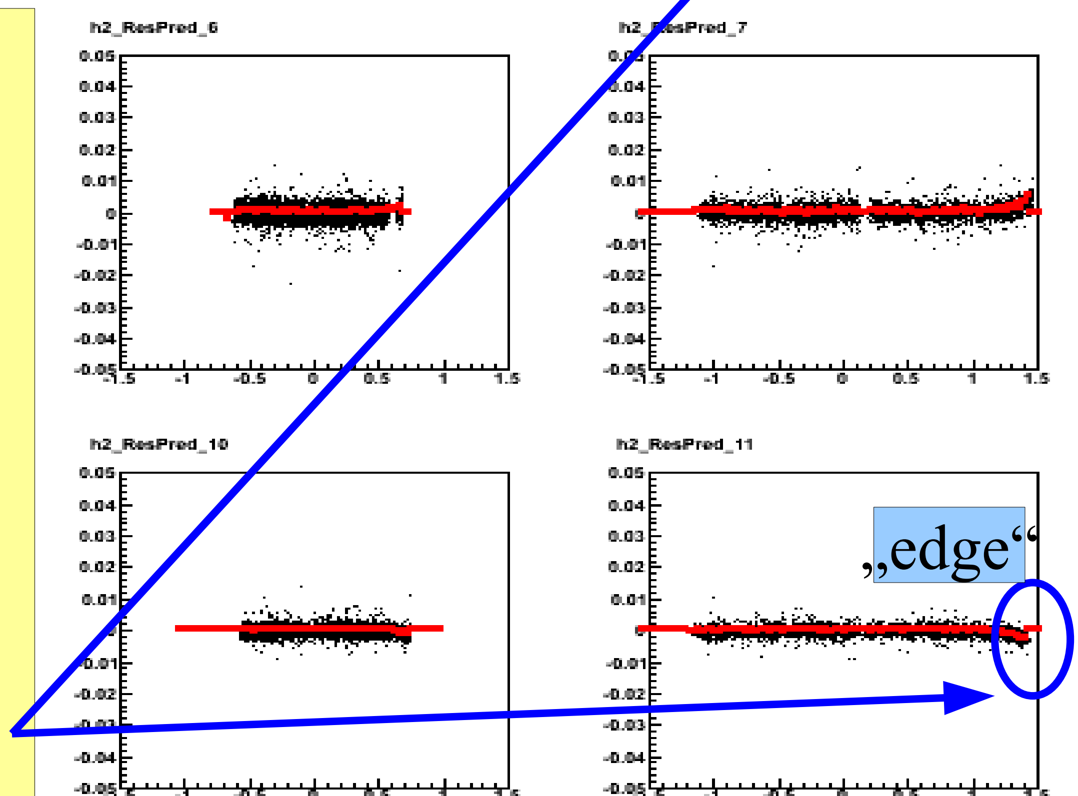
1. Gains and “large scale” corrections



- We have shown such plots first time in Valencia last year.
- These are residuals plotted against position
- The plots indicate that there are position-dependent differences between hit positions reported by tracking and by the detector.
- There are several patterns of these differences



1. Gains and „large scale“ corrections

What we know:

- Edge distortions are independent of edge voltage
- The distortions do not visibly change between runs
- They can be largely corrected using testbeam data, but a correction based on source test or laser is preferable

What we don't know:

- We don't understand the origin.
- Some distortions (“V“ and “modulo 4”) can be attributed to pixel gain variations (== they disappear by gain equalization), but some do not.
-

1. Gains and „large scale“ corrections: Pixel gain equalization

Goal: Estimate gains of individual pixels and equalize them.

Requirements:

- Do it precisely:
  1% error in gain gives up to 0.5% error in position, which reads 0.5% of pitch – that is, tenths of microns, which is measurable. So we need ~10^4 signals when equalizing means or medians.
- Proper equalization requires equal signal distributions.

Testbeam data do not comply with either of the two requirements:

- Distributions (and pixel statistics) differ due to different occupancy of pixels. As a rule, gains in purely irradiated pixels can not be reliably estimated.
- Seed signals have more similar distributions, but pixels with larger gains „steel“ seeds from neighbours, so iteration is necessary. Also, the statistics is smaller, we don't have enough seeds even in long runs like 1318.

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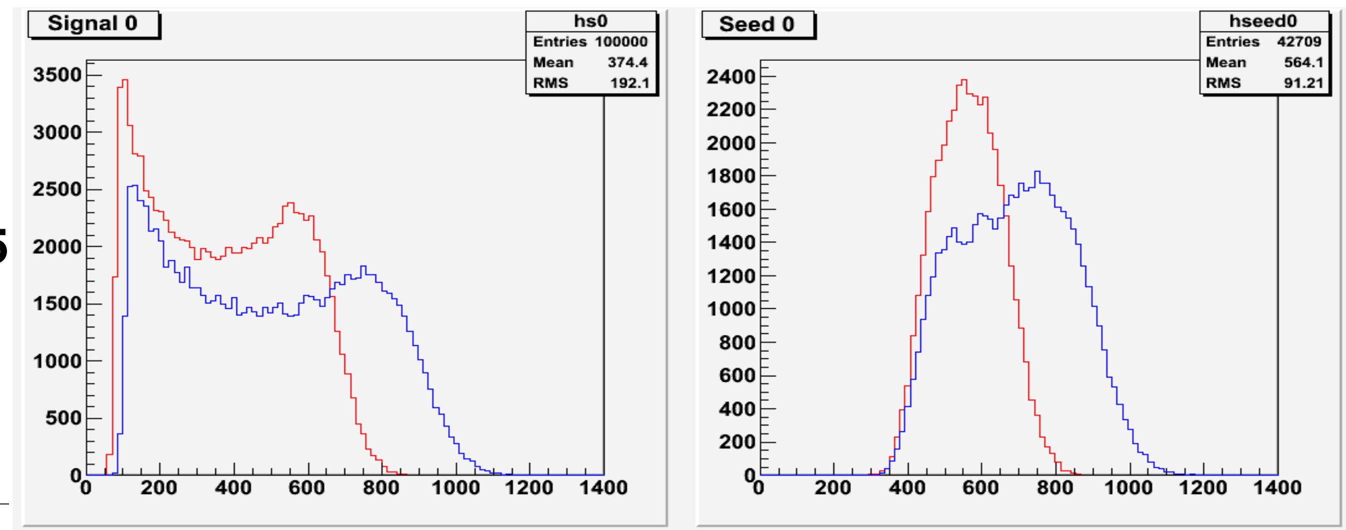
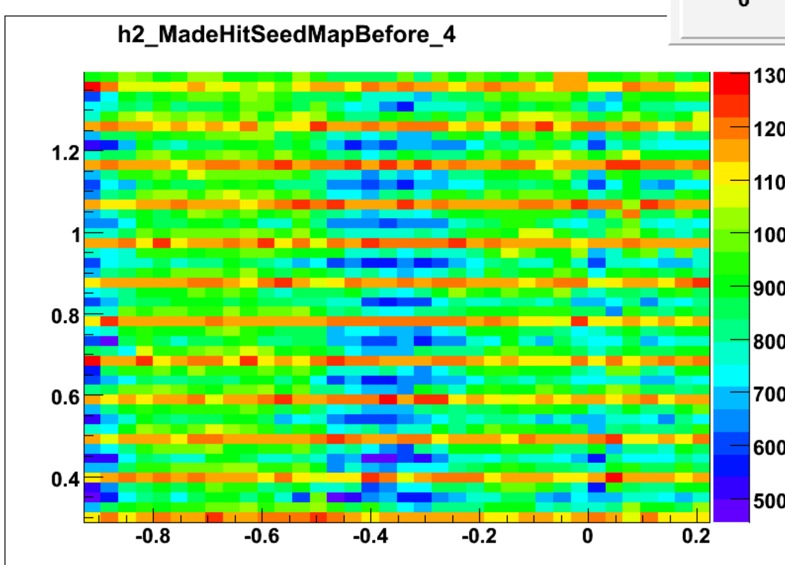
1. Gains and „large scale“ corrections: Pixel gain equalization (cont'd)

Solution: Estimate row and column gains. Try to cope with „cross“ effects.

Distributions of all signals (left) and seeds (right) for two pixels with different gains (0.75 – red, 1.0 – blue). The pixel with higher gain „steels“ seeds from the other pixel.





„Cross“ effects in detector 4 (seed map):

The „modulo 4“ row patterns cannot be corrected by row and column corrections, because the gains are ~ constant for row# mod 4 = 0, and vary for other rows. This can be fixed by using different column corrections dependent on row# mod 4.

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1. Gains and „large scale“ corrections: Pixel gain equalization (cont'd)

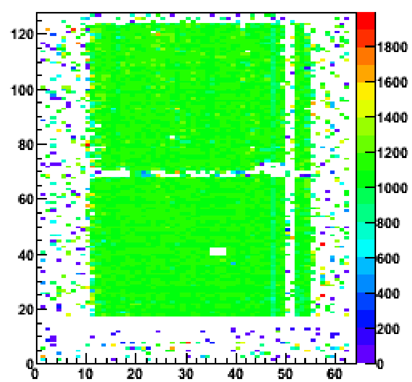
Prague gain correction:

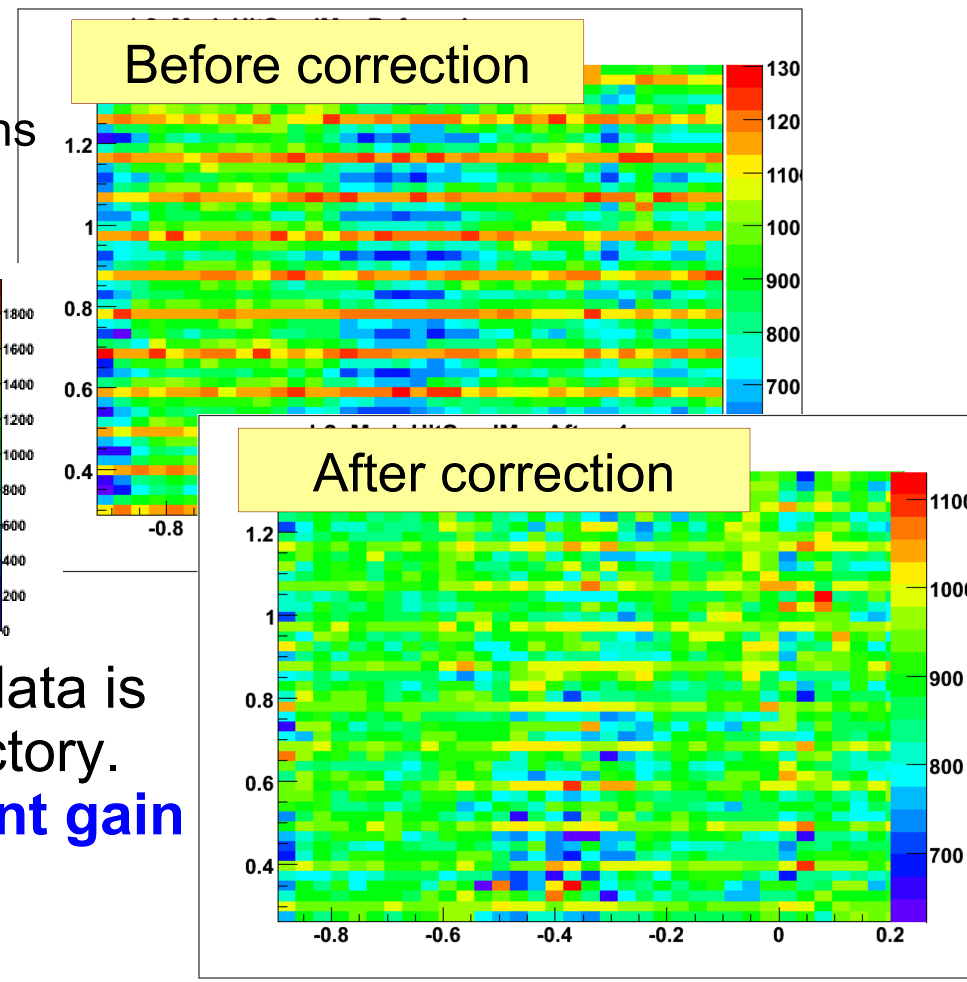
- Use seeds to calculate row and column gains. Use 4 column gains to correct rows with row# mod 4 = i separately.

- Iterate:

1. Calculate trimmed (10% on each tail) means
2. Equalize
3. Recalculate seeds
4. Repeat.

Hitmap (detector 0) shows large areas with low occupancy (white) where gain corrections cannot be reliably calculated.





Gain correction based on tracking data is difficult and the result is not satisfactory. **For tracking, we need independent gain information.**

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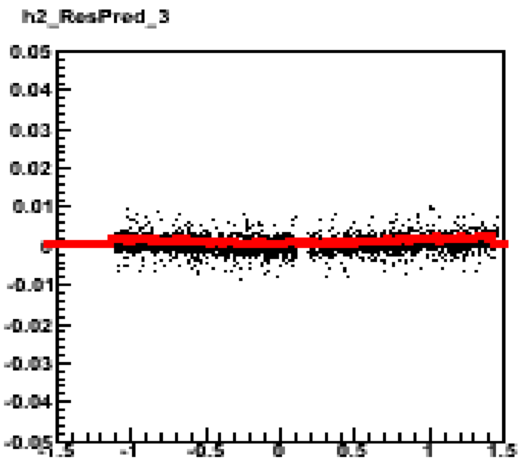
1. Gains and „large scale“ corrections: Large scale response corrections

LSR corrections are based on the residuals-vs-position plots.

- Calculate tracking residuals
- Plot them agains position
- Use the trendline of the plot to correct positions reported by the detector.

LSR can achieve the same effect as row / column gain equalization. It can be calculated over a smaller statistics, because it combines information from all detectors.



LSR correction (red line) is based on plots of residuals vs. position.

Open question:
Are there „pure“ LSR corrections? That is, are there distortions that cannot be corrected by gain equalization?
Presently, we are not able to correct some distortions in residual plots by gain equalization, but this may change once we have good gain measurements based on source / laser

2. Simulations

What we have:

- Geant4 simulations of particle tracks in the detector setup.

  True multiple scattering, detector resolutions are simulated by Gaussian smearing. These are routinely used to validate the analysis: we show that our analysis gives resolutions close to MC-true resolutions.

- Toy simulations

  Multiple scattering modelled by Gaussians with Moliérian widths, resolutions by Gaussian smearing. This we use to study the effects of non-Gaussian tails on the analysis. We have seen no such effects.

In development:

- Toy digitization

  Simulation of pixel signals based on the distribution of a prototype charge cloud, to validate hit reconstruction and local resolutions

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3. From tracking resolutions to hit reconstruction: Overview

Detector resolution ≡ RMS error of position measurement in the detector

Notes:
- „Mean“ square here also means averaging over the detector surface or its part
- Detector resolution is NOT the best position error we can achieve – if we have a track going through several detectors, we can obtain position estimates with errors smaller than the resolutions of individual detectors.

We calculate detector resolutions from the covariance matrix of fit residuals.
Each fit residual is a linear combination of detector measurement errors and multiple scattering deflections => residual covariance is a linear combination of measurement error covariance and multiple scattering covariance.

$$cov\left(\hat{\mathbf{u}}^c\right) \equiv \left\langle \left(\mathbf{u}^c - \hat{\mathbf{u}}^c\right)\left(\mathbf{u}^c - \hat{\mathbf{u}}^c\right)^T \right\rangle = \mathbf{H}\left(\mathbf{G}\boldsymbol{\Sigma}^2\mathbf{G}^T + \boldsymbol{\Delta}^2\right)\mathbf{H}$$

u are local hit cooridnates

G describes the geometry of multiple scattering

Σ and Δ are diagonal matrices of MS scatt.deflections and squared detector resolutions

H is a projector to the residual space

3. From tracking resolutions to hit reconstruction: Overview (cont'd)

$$cov\left(\hat{\mathbf{u}}^c\right) \equiv \left\langle \left(\mathbf{u}^c - \hat{\mathbf{u}}^c\right)\left(\mathbf{u}^c - \hat{\mathbf{u}}^c\right)^T \right\rangle = \mathbf{H}\left(\mathbf{G}\Sigma^2\mathbf{G}^T + \Delta^2\right)\mathbf{H}$$

(This is the same formula as on the previous slide.)

RMS multiple scattering deflections can be calculated using the Moliere formula, so we can express detector resolutions in terms of residual correlations and RMS multiple scattering deflections.

The procedure is complicated by the fact that H doesn't have full rank: its rank is 2 x (number of points on the track) – 4. We use some matrix algebra to express the resolutions in terms of pseudonverses of HH, which is equivalent to a least-squares fit to the covariance matrix.

We have tested a new resolution estimator using the full covariance matrix (rather than just the diagonal), but to-date it doesn't seem to be decisively better.

We used toy simulations to check the effect of the non-Gaussian tails of the MS distribution.

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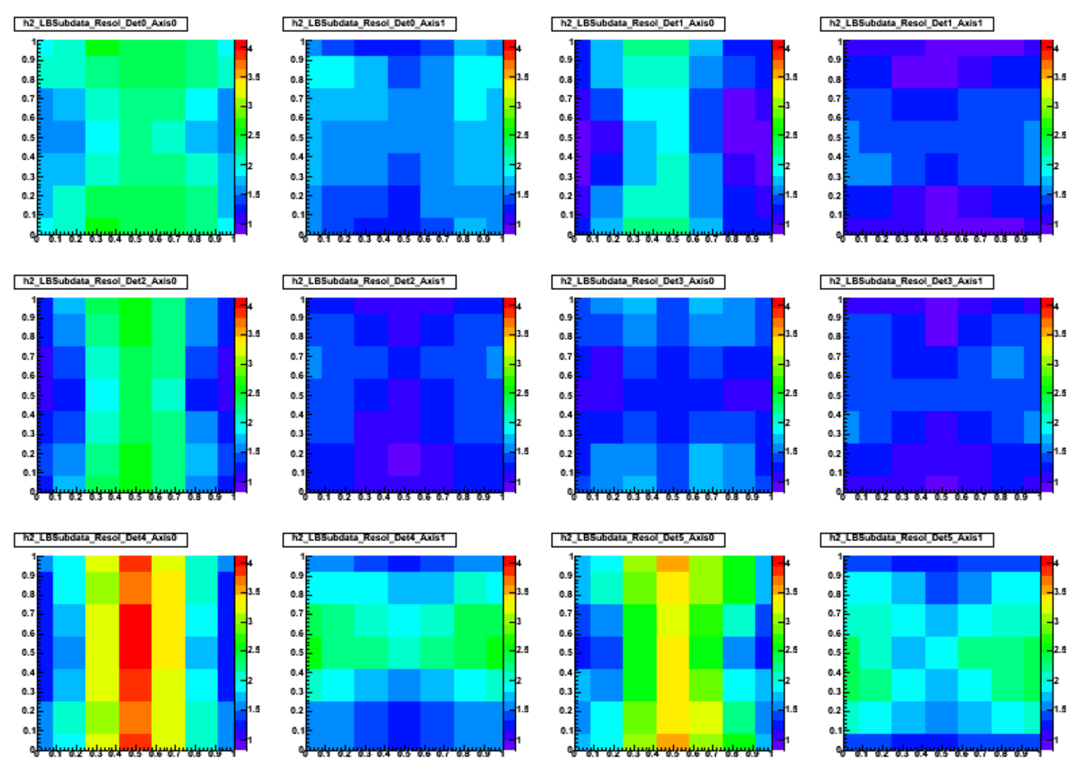
3. From tracking resolutions to hit reconstruction: Local resolutions

With sufficient statistics, we can easily calculate „local“ resolutions by looking only at residuals from tracks passing a selected region of a detector – for example, a selected position in (any) detector pixel.

This can be used to validate the predicted errors of cluster reconstruction, which is important for applications of the detectors.

Observations:

1. This way we can only obtain a smoothed „resolution map“ of detector pixels: the minimum width of the smoothing kernel is given by the error of tracking predictions (that is, by telescope error)
2. We have to revisit hit reconstruction and estimation of hit reconstruction errors – there will soon be a DEPFET note from us on this matter.



Thanks for your attention.

Backup slides

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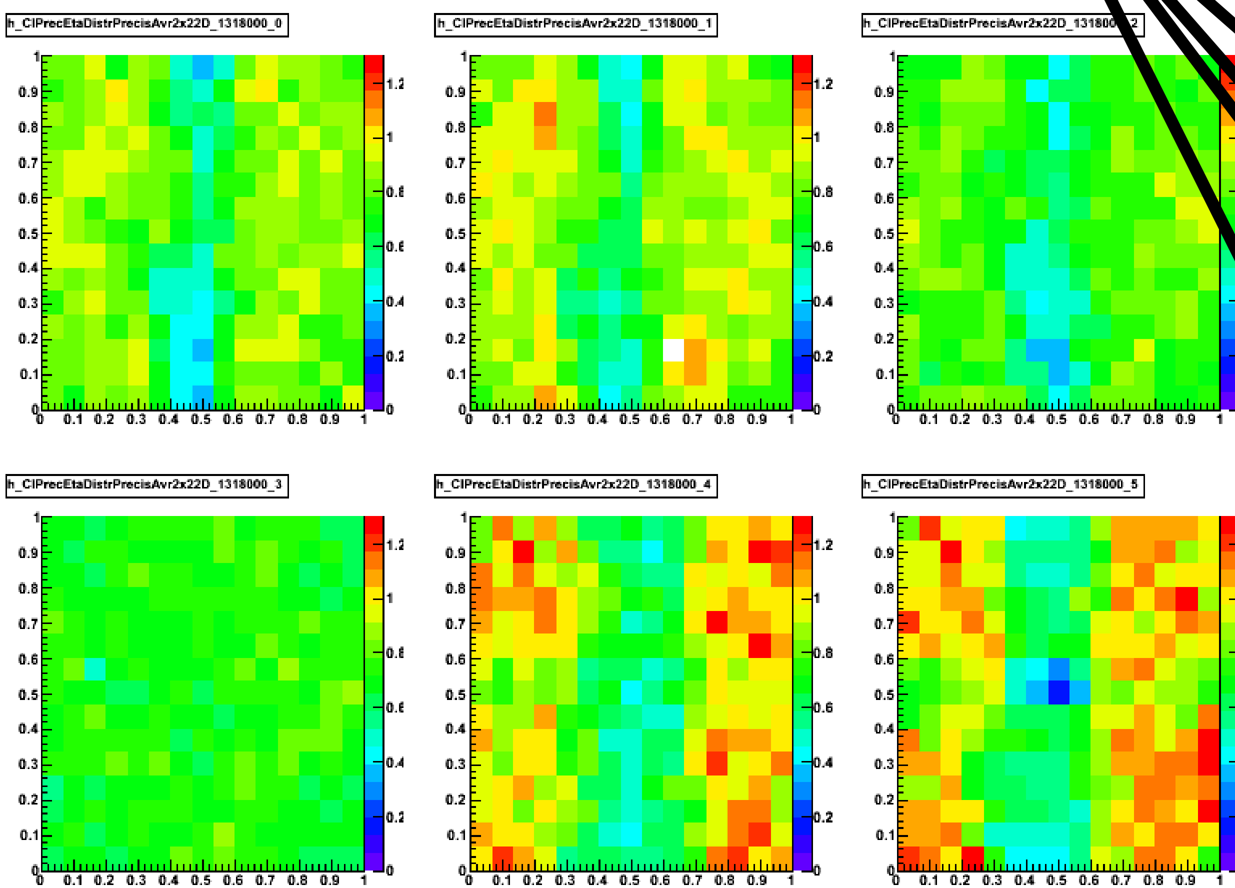
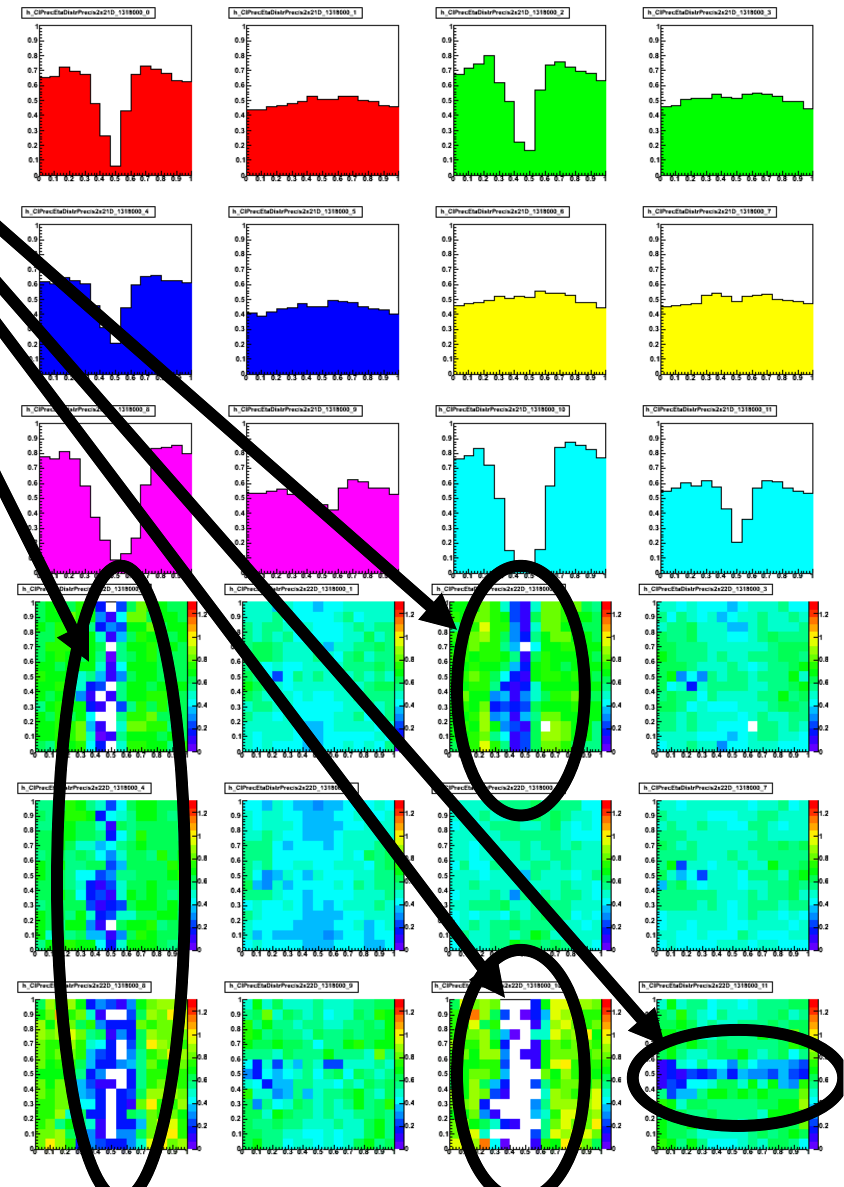
Residuals and resolution results on example scan

- Cluster COG analysis: from signals there is minimal possible resolution based on noise and cluster cut level, signals on pixels and cluster size.
- There is area of single pixel cluster size





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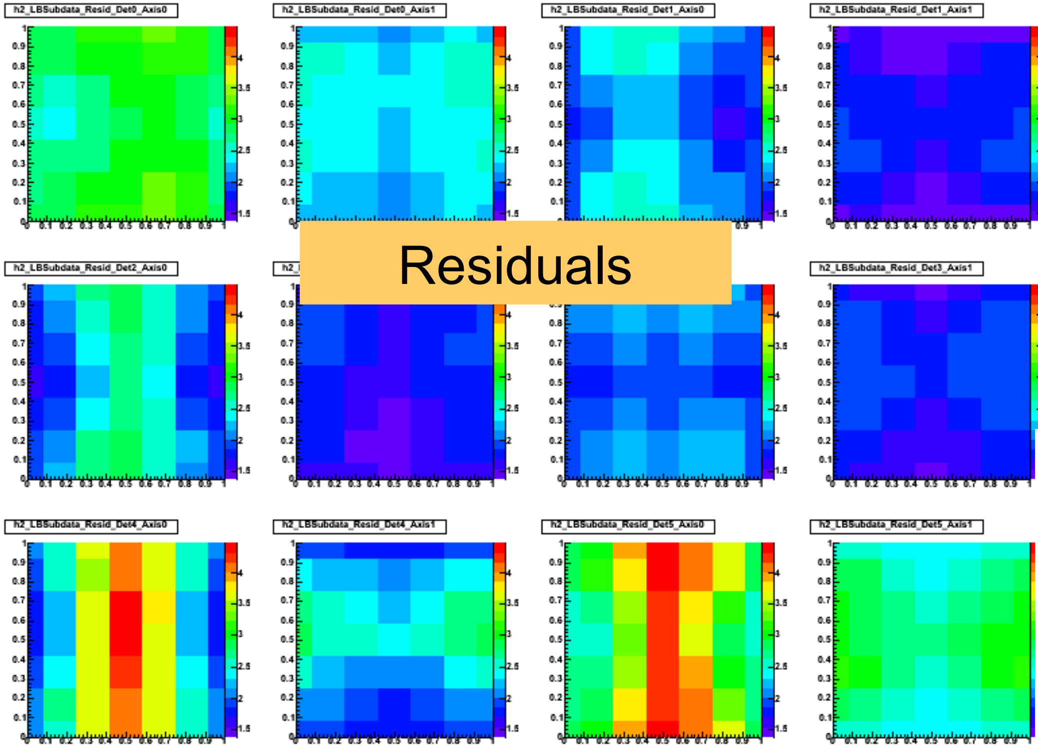
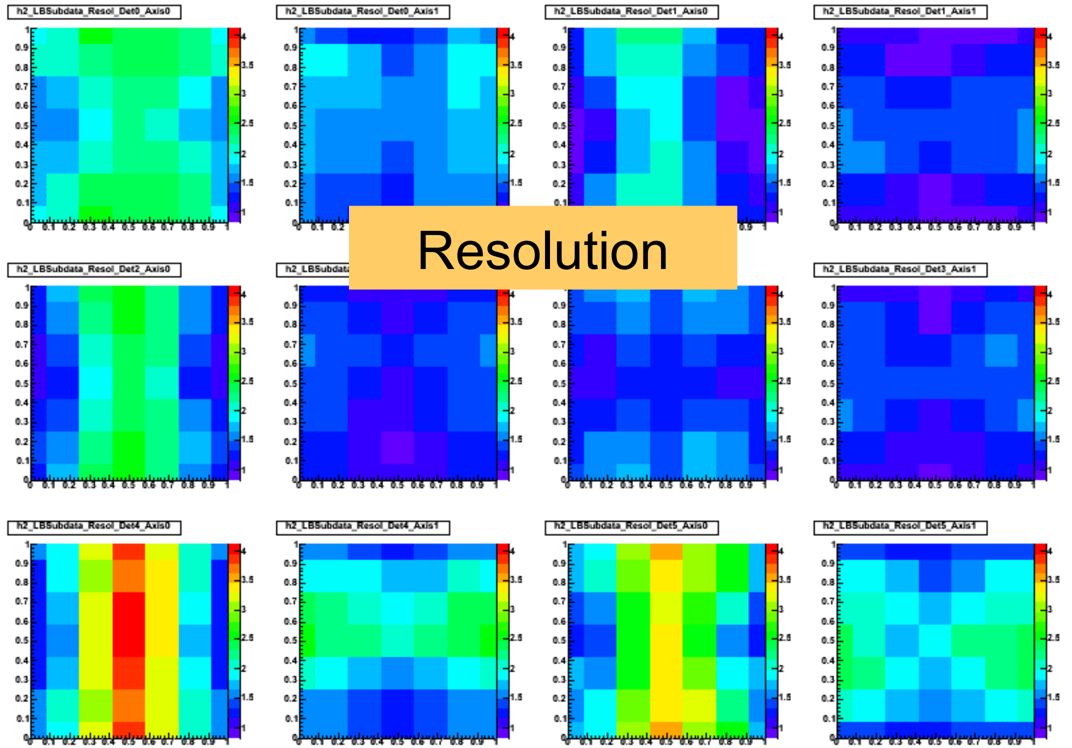
Residuals and resolution results on example scan

- Sub pixel analysis from tracks, resolution plots:





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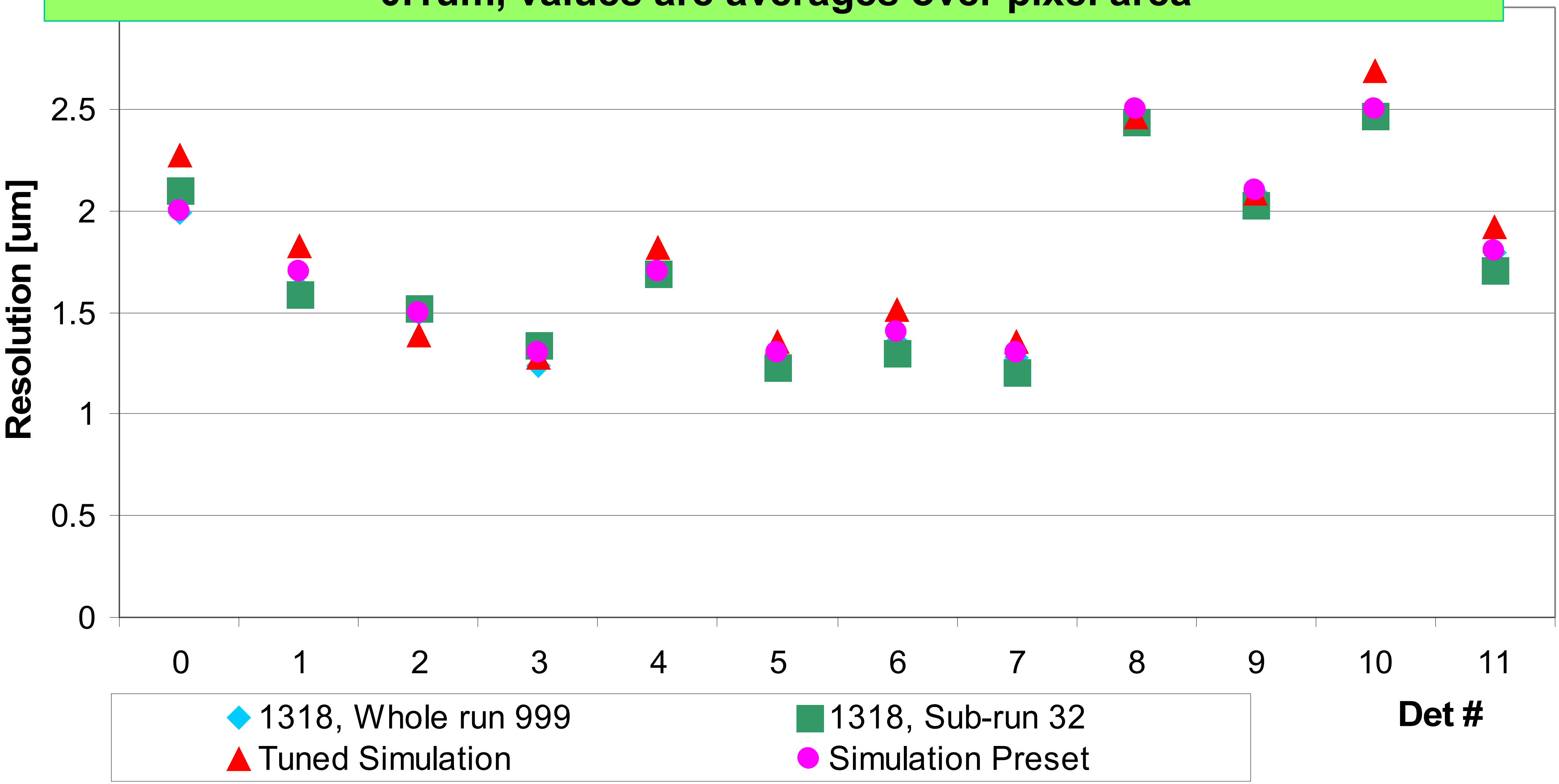
Description of analysis from Residuals to Resolution
Determining resolutions

The plot shows resolutions reproduced from analysis of simulated data for best estimates from the real TB 2008 data. Errors in resolutions are ~0.1um, values are averages over pixel area



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Residuals and resolution results on example scan

Final results of residuals and resolutions – average values in tables, direction x:

X residual [μm]	Module 0 CCGME-S90K02 32x24 μm	Module 1 CCGME-90K02 32x24 μm	Module 2 SIMCME-S90K00 32x24 μm	Module 3 CCGME-S90I03 24x24 μm	Module 4 CCGME-S90I00 32x24 μm	Module 5 CCGME-90I00 32x24 μm
TIPP09: PRG, 1318, EdgeCut, Eta, LSR	2.8	2.1	2.1	2.0	3.0	3.4
VLC, 1318	2.1	2.3	3.3(*)	2.9(*)	2.3	2.9
Bonn, 1273	1.9	1.8	2.2	2.4	2.2	2.2
PRG, 1318, best (Gain, EdgeCut, Eta, LSR)	2.9	2.2	2.3	2.0	3.1	3.4
PRG, 1318, Gain, Eta, LSR	3.0	2.3	2.4	2.0	3.3	3.5
PRG, 1318, Eta, LSR	3.0	2.3	2.5	2.0	3.2	3.5
PRG, 1318, Gain, Eta, LSR	2.9	2.1	2.0	2.0	3.1	3.4
PRG, 1318, Gain, EdgeCut, Eta	2.8	2.0	2.0	2.0	3.0	3.4
PRG, simulation	2.8	2.1	2.2	2.0	3.0	3.4
Net Tracking Error	1.7	1.4	0.9	1.2	1.5	2.1
Multiple Scattering	1.2	0.4	0.9	0.9	0.4	1.2
Blue: unrealistically low, Red: unrealistically high, Green: in good agreement, black: for discussion						

X resolution [μm]	Module 0 CCGME-S90K02 32x24 μm	Module 1 CCGME-90K02 32x24 μm	Module 2 SIMCME-S90K00 32x24 μm	Module 3 CCGME-S90I03 24x24 μm	Module 4 CCGME-S90I00 32x24 μm	Module 5 CCGME-90I00 32x24 μm
TIPP09: PRG, 1318, EdgeCut, Eta, LSR	2.0	1.5	1.7	1.4	2.5	2.5
PRG, 1318, best (Gain, EdgeCut, Eta, LSR)	2.1	1.6	1.9	1.3	2.6	2.4
PRG, 1318, Gain, Eta, LSR	2.1	1.7	2.0	1.3	2.8	2.4
PRG, 1318, Eta, LSR	2.2	1.7	2.1	1.3	2.8	2.4
PRG, 1318, Gain, Eta, LSR	2.1	1.5	1.5	1.4	2.7	2.3
PRG, 1318, Gain, EdgeCut, Eta	2.0	1.5	1.5	1.3	2.5	2.4
PRG, Cluster analysis - minimum limit	0.7	0.7	0.6	0.5	0.8	0.8
PRG, Cluster analysis - recalculate	2.1	2.2	1.9	1.5	2.4	2.4
PRG, simulation	2.3	1.4	1.8	1.5	2.5	2.7
Net Tracking Error	1.7	1.4	0.9	1.2	1.5	2.1
Multiple Scattering	1.2	0.4	0.9	0.9	0.4	1.2

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Residuals and resolution results on example scan

Final results of residuals and resolutions – average values in tables, direction y:

Y residual [µm]	Module 0 CCGME-S90K02 32x24 µm	Module 1 CCGME-90K02 32x24 µm	Module 2 SIMCME-S90K00 32x24 µm	Module 3 CCGME-S90I03 24x24 µm	Module 4 CCGME-S90I00 32x24 µm	Module 5 CCGME-90I00 32x24 µm
TIPP09: PRG, 1318, EdgeCut, Eta, LSR	2.4	1.7	1.7	1.8	2.4	2.8
VLC, 1318	1.3	1.7	2.0	1.9	1.9	2.0
Bonn, 1273	1.9	1.8	2.1	2.2	3.1	2.2
PRG, 1318, best (Gain, EdgeCut, Eta, LSR)	2.3	1.7	1.7	1.7	2.2	2.6
PRG, 1318, Gain, Eta, LSR	2.5	1.8	1.8	1.8	2.2	2.7
PRG, 1318, Eta, LSR	2.5	1.8	1.8	1.8	2.4	2.8
PRG, 1318, Gain, Eta, LSR	2.5	1.9	1.9	2.0	2.7	2.9
PRG, 1318, Gain, EdgeCut, Eta	2.4	1.7	1.7	1.8	2.7	2.8
PRG, simulation	2.4	1.8	1.7	1.8	2.4	2.7
Net Tracking Error	1.2	1.0	0.7	0.8	1.1	1.5
Multiple Scattering	1.2	0.4	0.9	0.9	0.4	1.2
Blue: unrealistically low, Red: unrealistically high, Green: in good agreement, black: for discussion						

Y resolution [µm]	Module 0 CCGME-S90K02 32x24 µm	Module 1 CCGME-90K02 32x24 µm	Module 2 SIMCME-S90K00 32x24 µm	Module 3 CCGME-S90I03 24x24 µm	Module 4 CCGME-S90I00 32x24 µm	Module 5 CCGME-90I00 32x24 µm
TIPP09: PRG, 1318, EdgeCut, Eta, LSR	1.7	1.3	1.3	1.3	2.1	1.8
PRG, 1318, best (Gain, EdgeCut, Eta, LSR)	1.5	1.3	1.2	1.2	1.8	1.7
PRG, 1318, Gain, Eta, LSR	1.8	1.3	1.3	1.3	1.8	1.8
PRG, 1318, Eta, LSR	1.8	1.3	1.3	1.3	2.0	1.9
PRG, 1318, Gain, Eta, LSR	1.8	1.4	1.4	1.5	2.5	1.6
PRG, 1318, Gain, EdgeCut, Eta	1.6	1.3	1.2	1.3	2.4	1.6
PRG, Cluster analysis - minimum limit	0.5	0.5	0.5	0.5	0.6	0.6
PRG, Cluster analysis - recalculate	1.5	1.6	1.4	1.5	1.8	1.8
PRG, simulation	1.8	1.3	1.4	1.4	2.1	1.9
Net Tracking Error	1.2	1.0	0.7	0.8	1.1	1.5
Multiple Scattering	1.2	0.4	0.9	0.9	0.4	1.2

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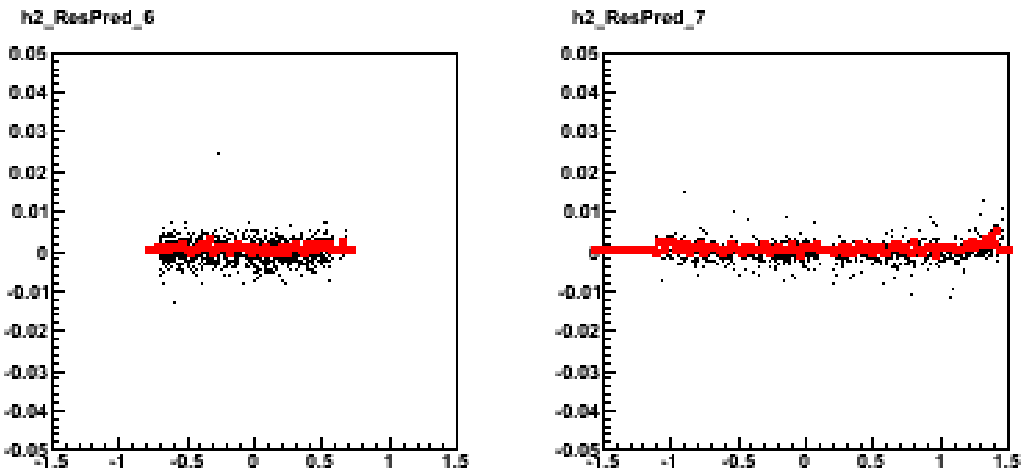
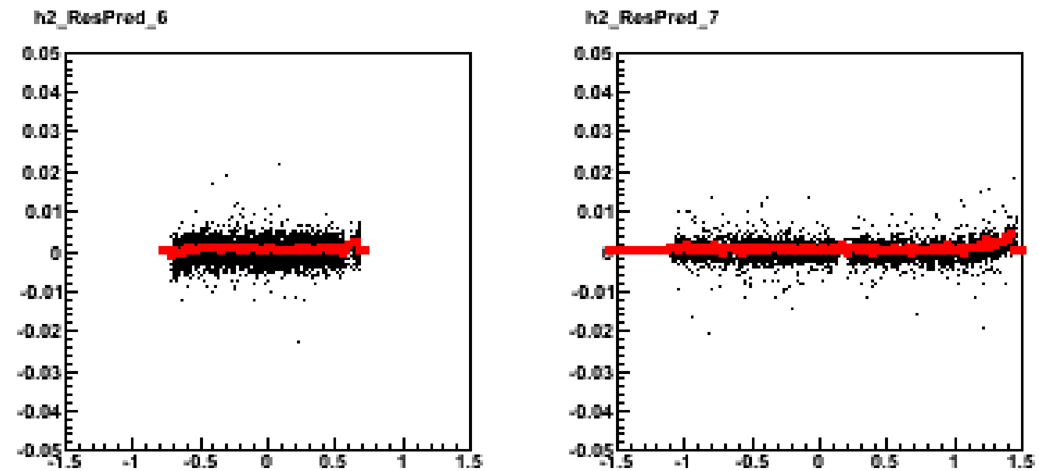
Resolution on edge scan

- Edge scan seems shows no significant changes on edge effect in LSR

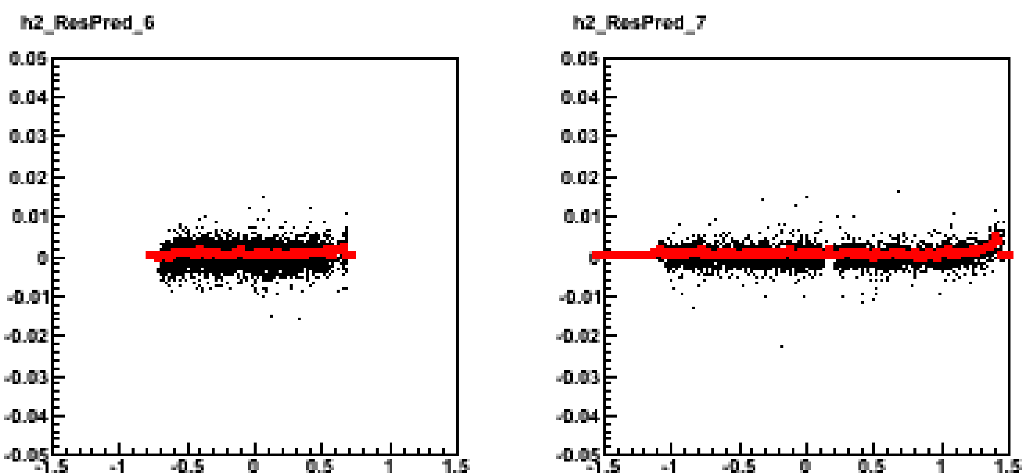
Edge offset: 0V



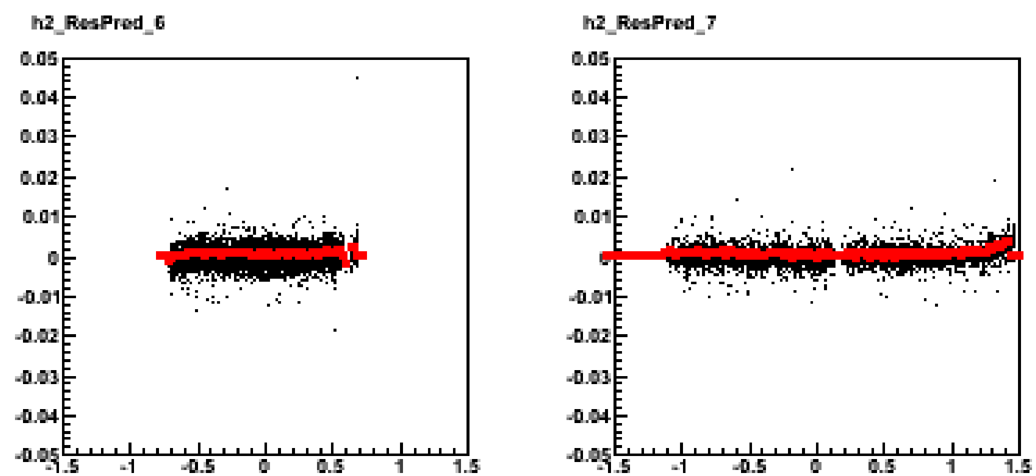
Edge offset: 2V



Edge offset: 1V



Edge offset: 3V



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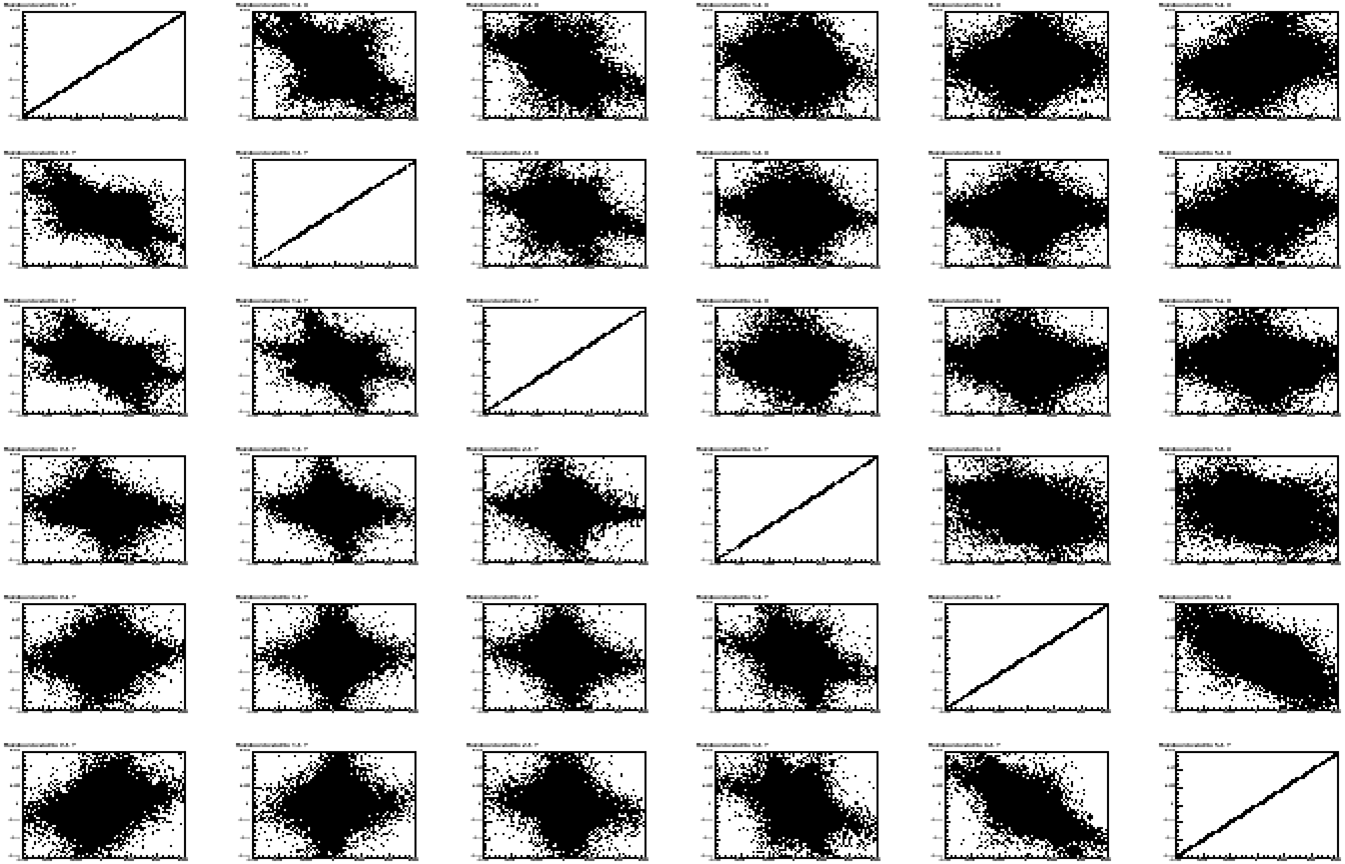
Residuals and resolution results on example scan

- Correlation matrix, non-diagonal correlations shows effects from different area of pixel and non-Gaussian effect influence.



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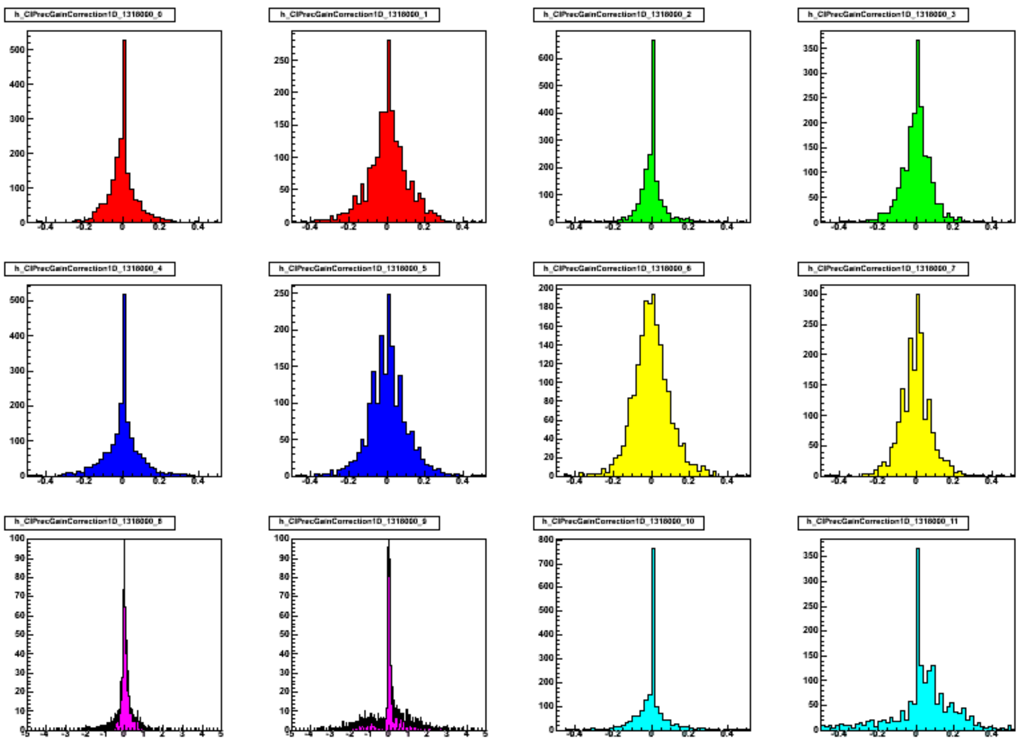
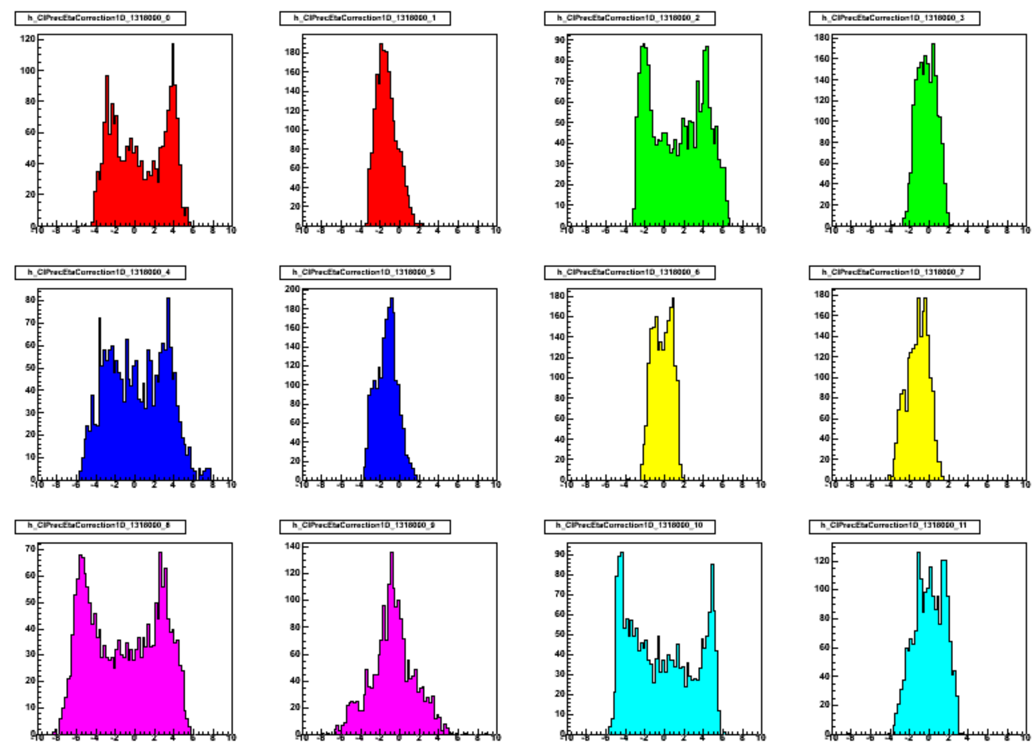
Residuals and resolution results on example scan

- Corrections influence to impact point position: gain correction (upper plot) and eta correction (button plot)



gain correction: X-range is in +- 0.5μm, module 4 have range 10x higher

eta correction: X-range is in +- 10μm



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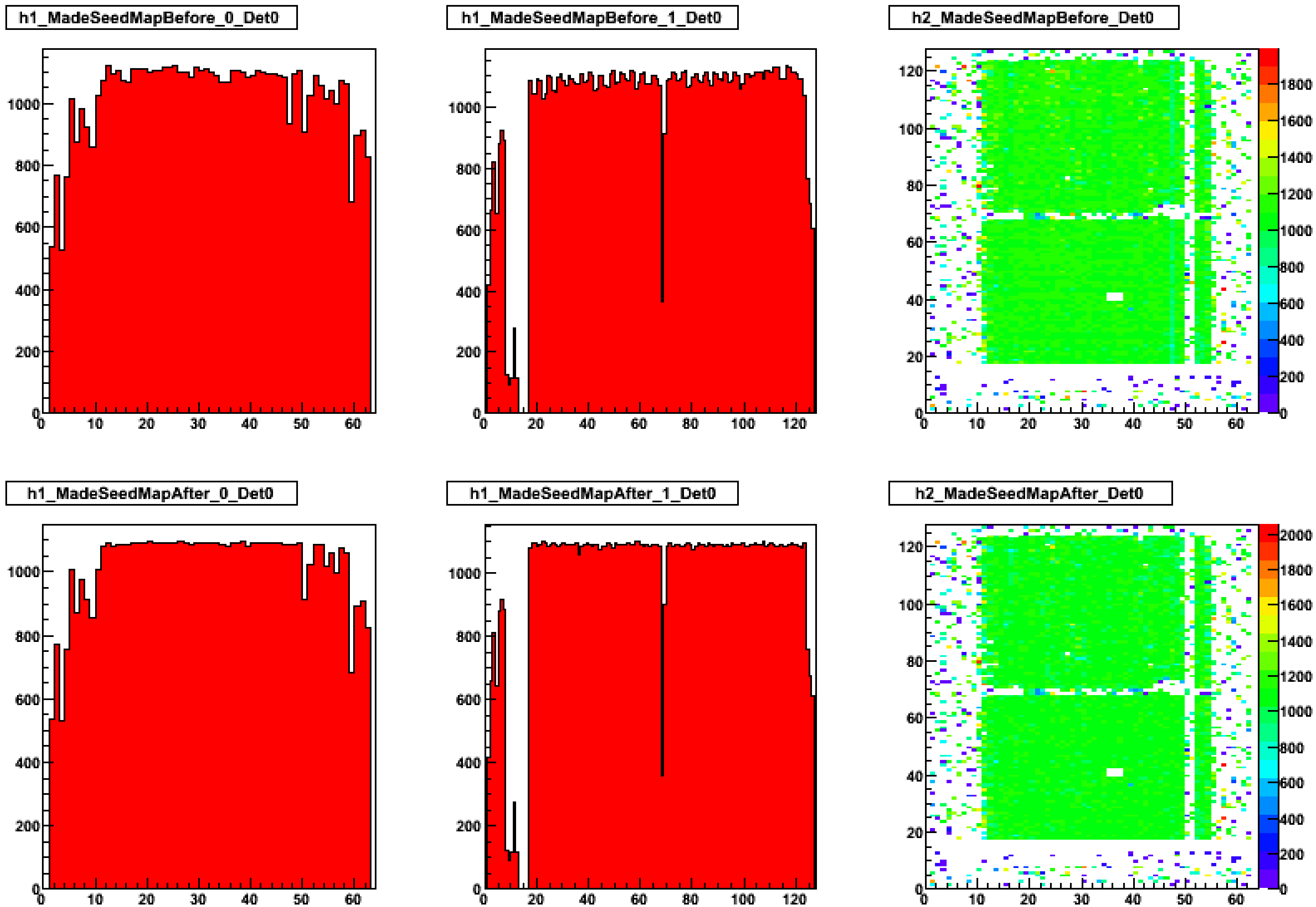
Residuals and resolution results on example scan

- Gain correction, final correction, module 0, small periodical structure was observed



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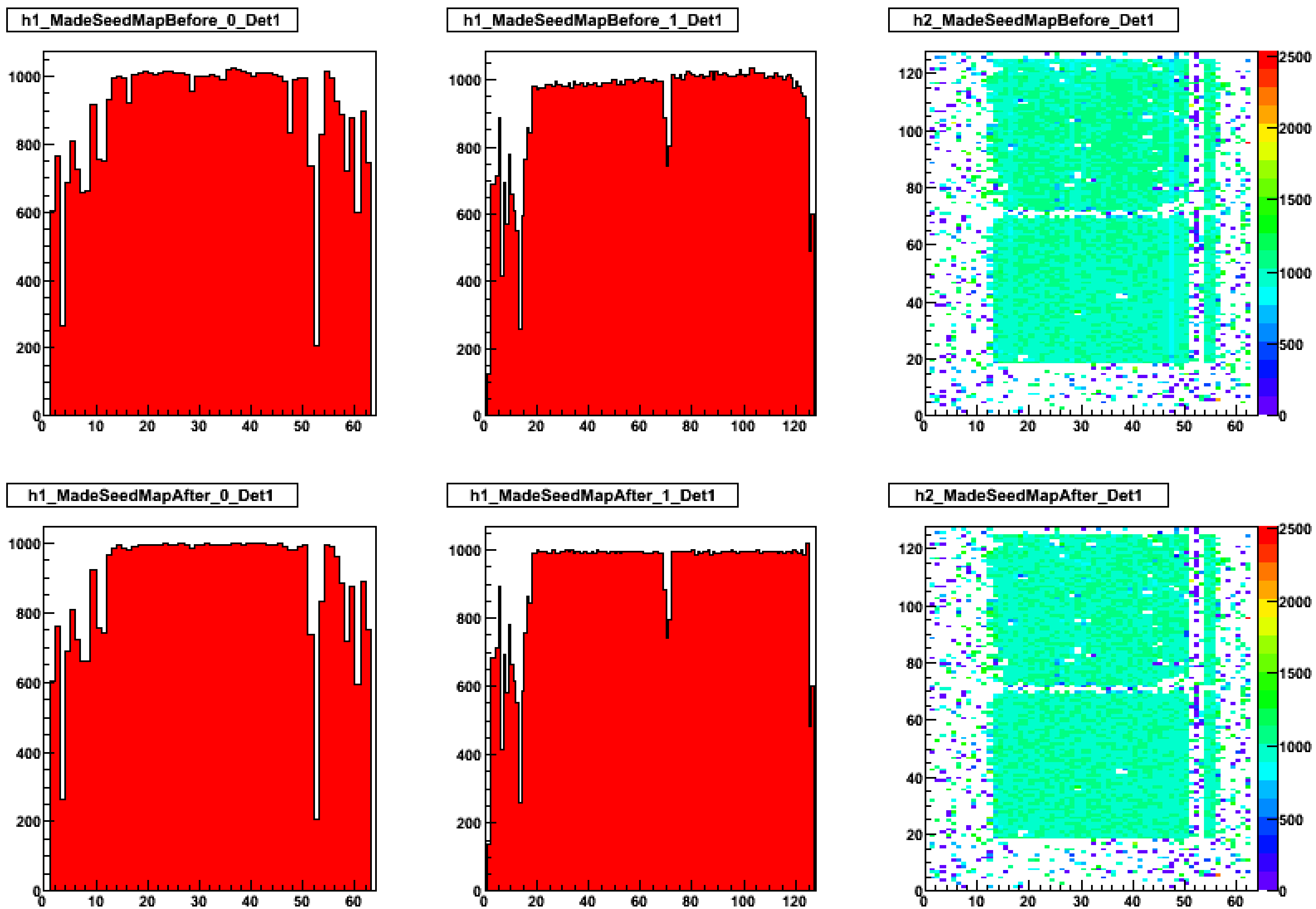
Residuals and resolution results on example scan

- Gain correction, final correction, module 1, no periodical structure was observed



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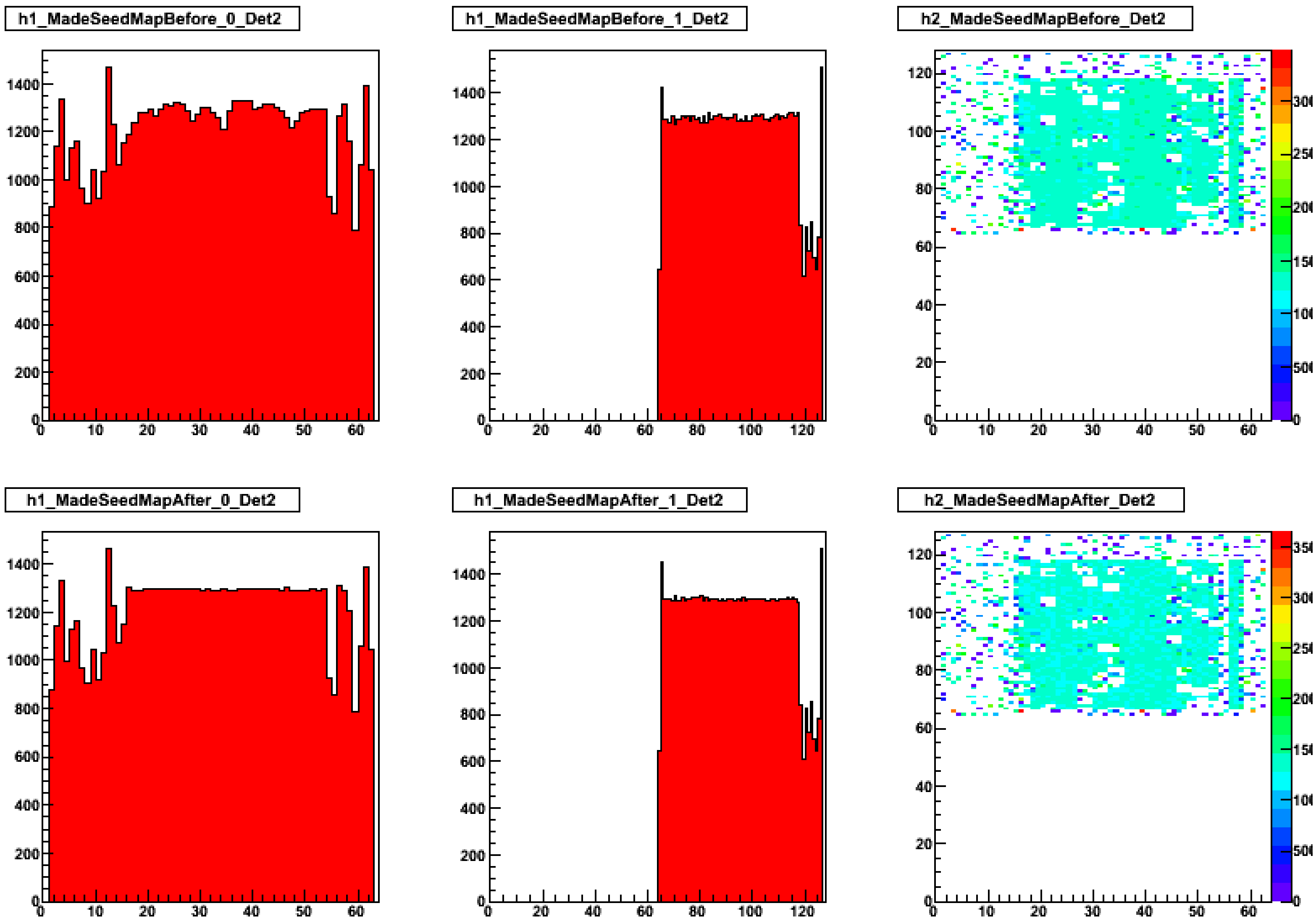
Residuals and resolution results on example scan

- Gain correction, final correction, module 2, no periodical structure was observed



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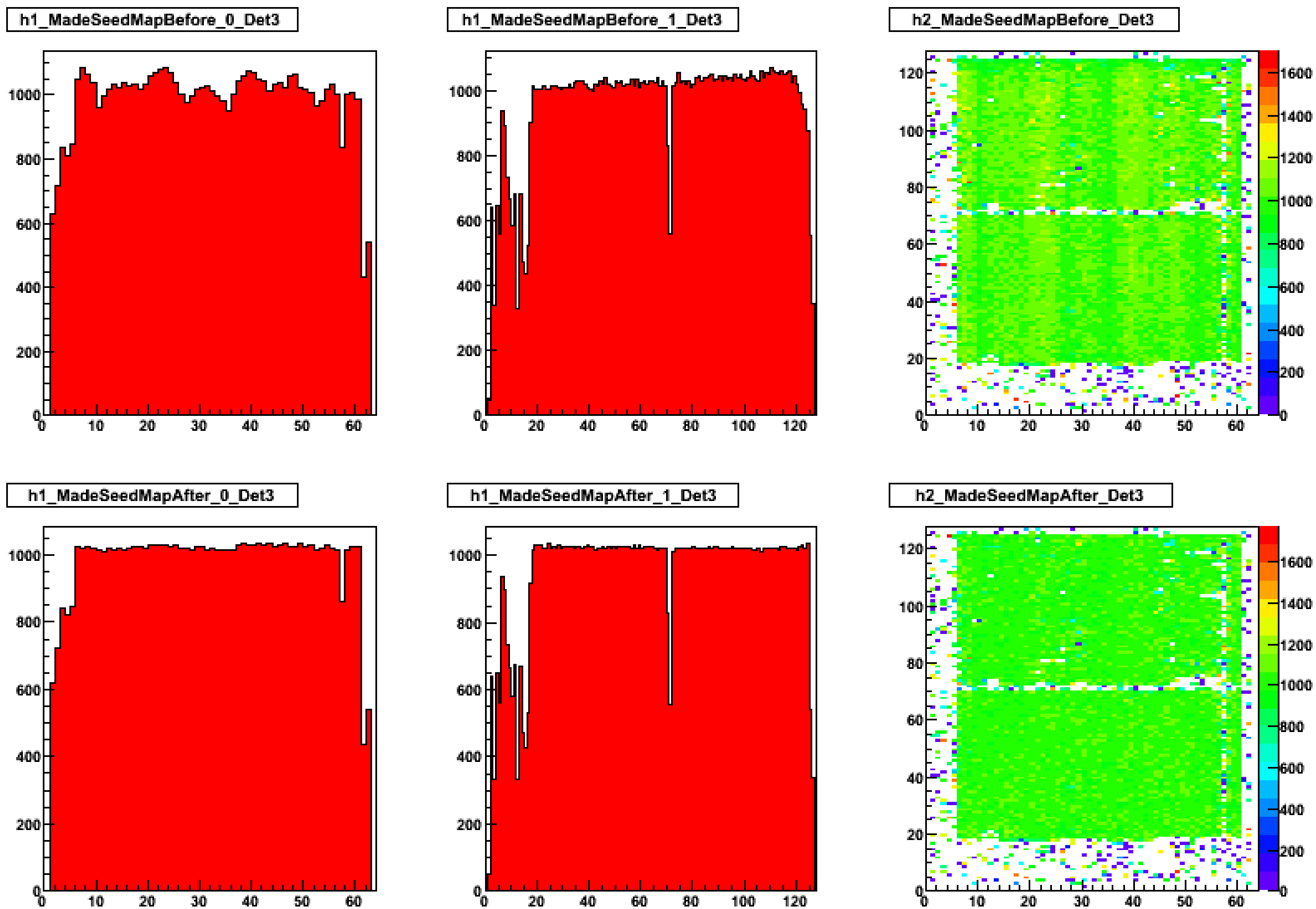
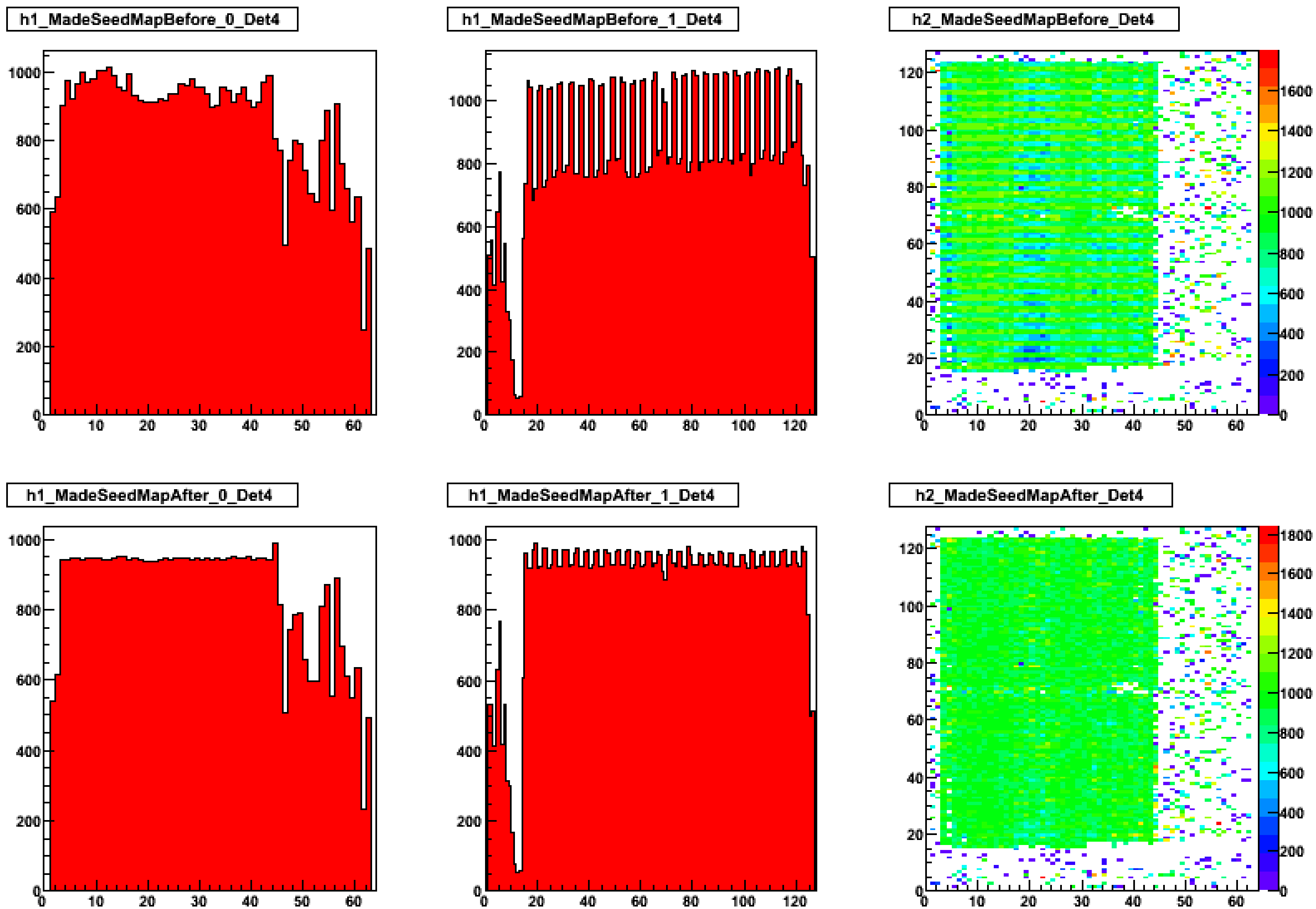
Residuals and resolution results on example scan

- Gain correction, final correction, module 3, no periodical structure was observed



Residuals and resolution results on example scan

- Gain correction, final correction, module 4, big periodical structure was observed



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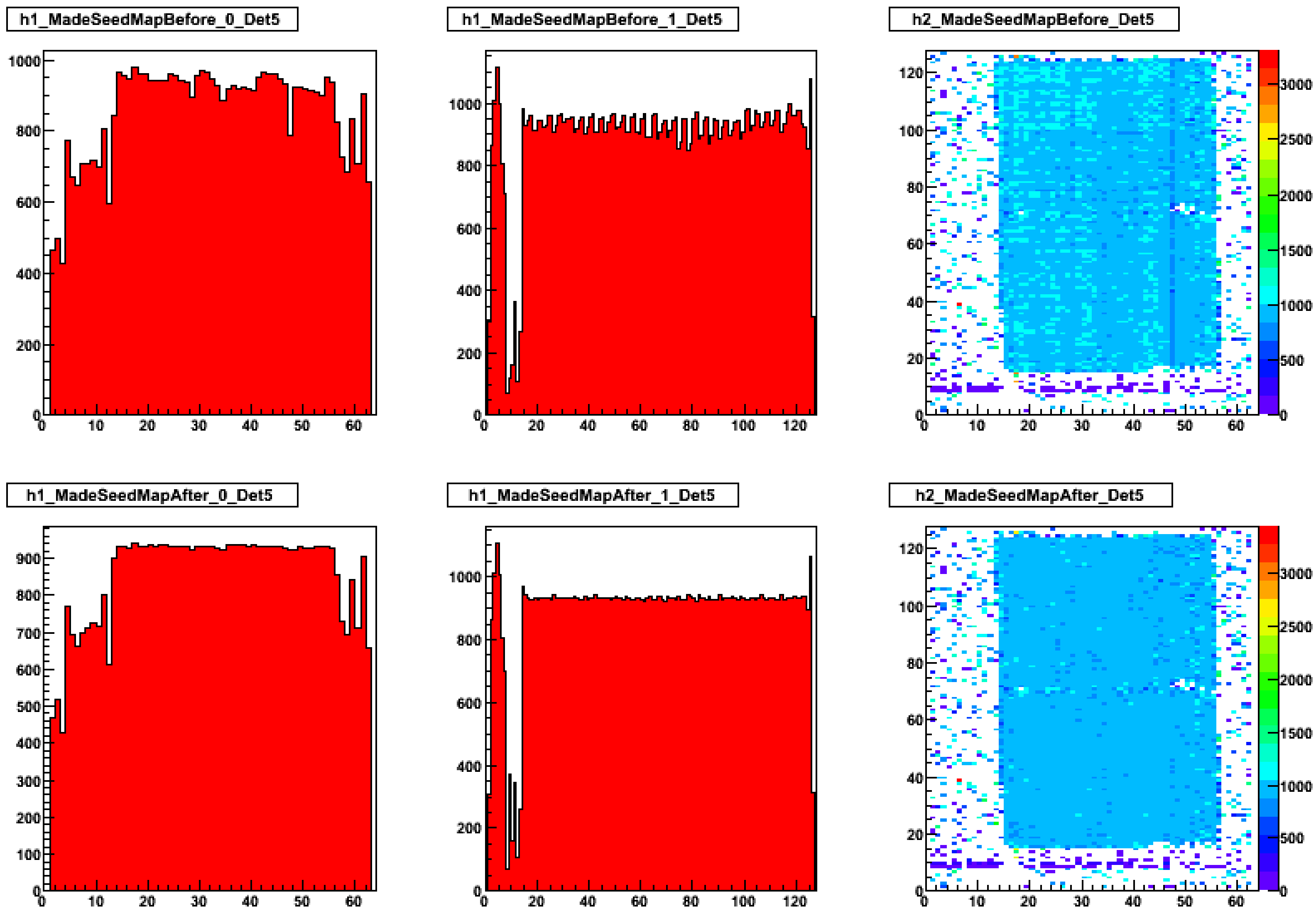
Residuals and resolution results on example scan

- Gain correction, final correction, module 5, small periodical structure was observed



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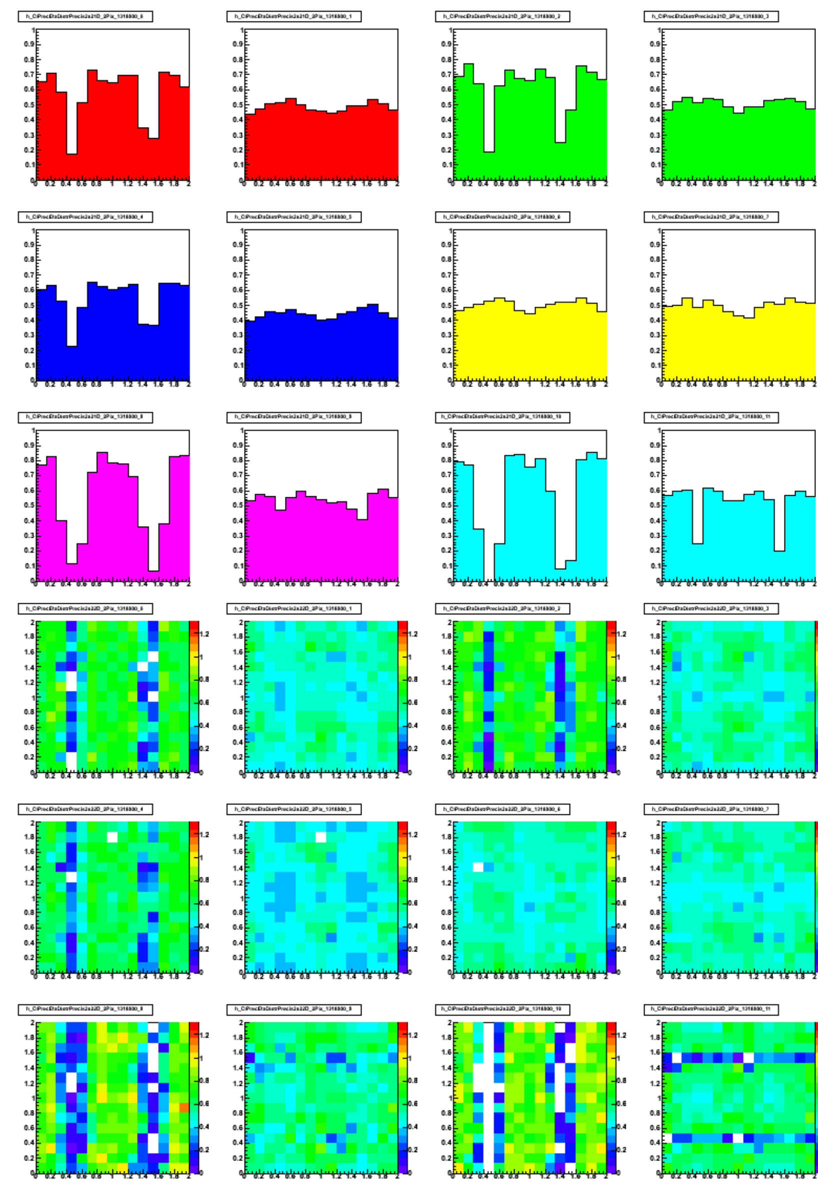
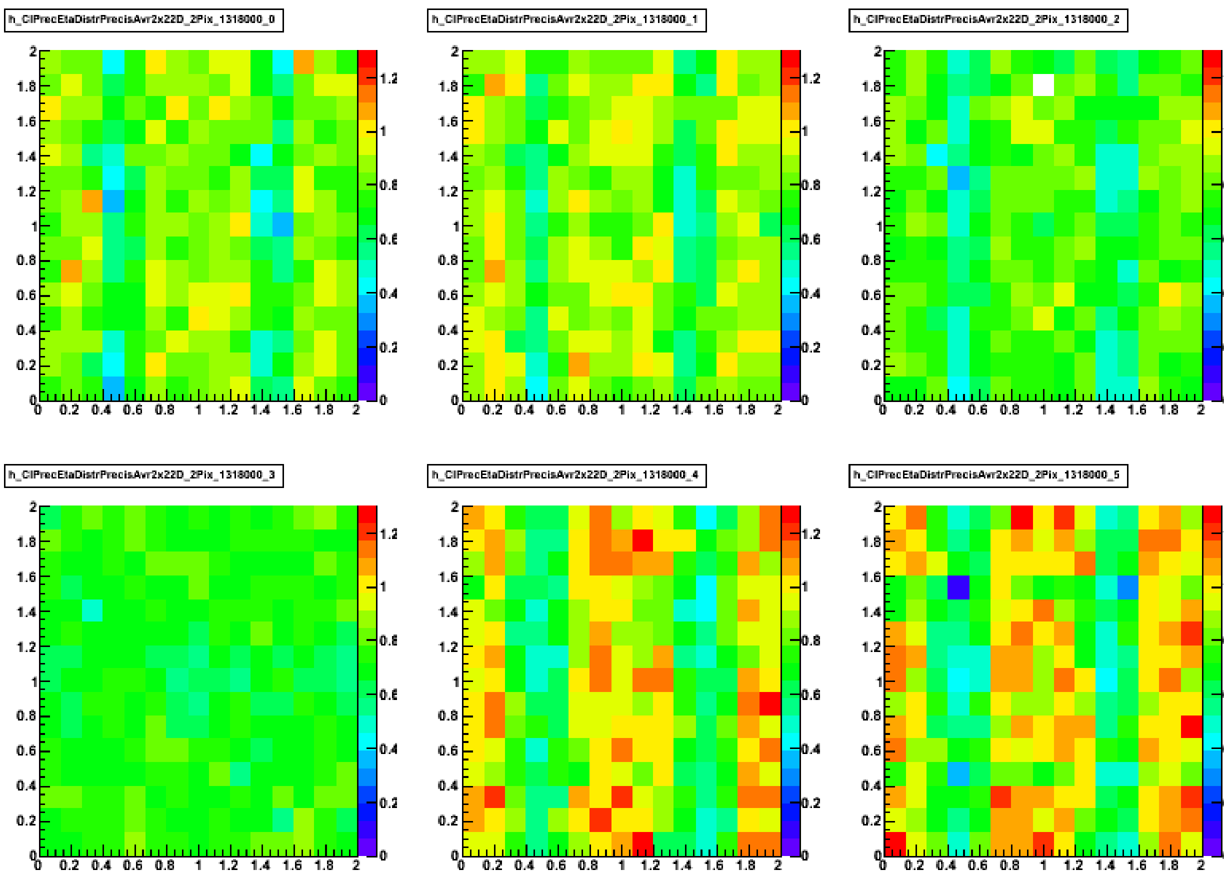
Residuals and resolution results on example scan

- Cluster COG analysis: from signals there is minimal possible resolution based on noise and cluster cut level, signals on pixels and cluster size.
- There is area of single pixel cluster size
- Plots are on period of 2 pixels





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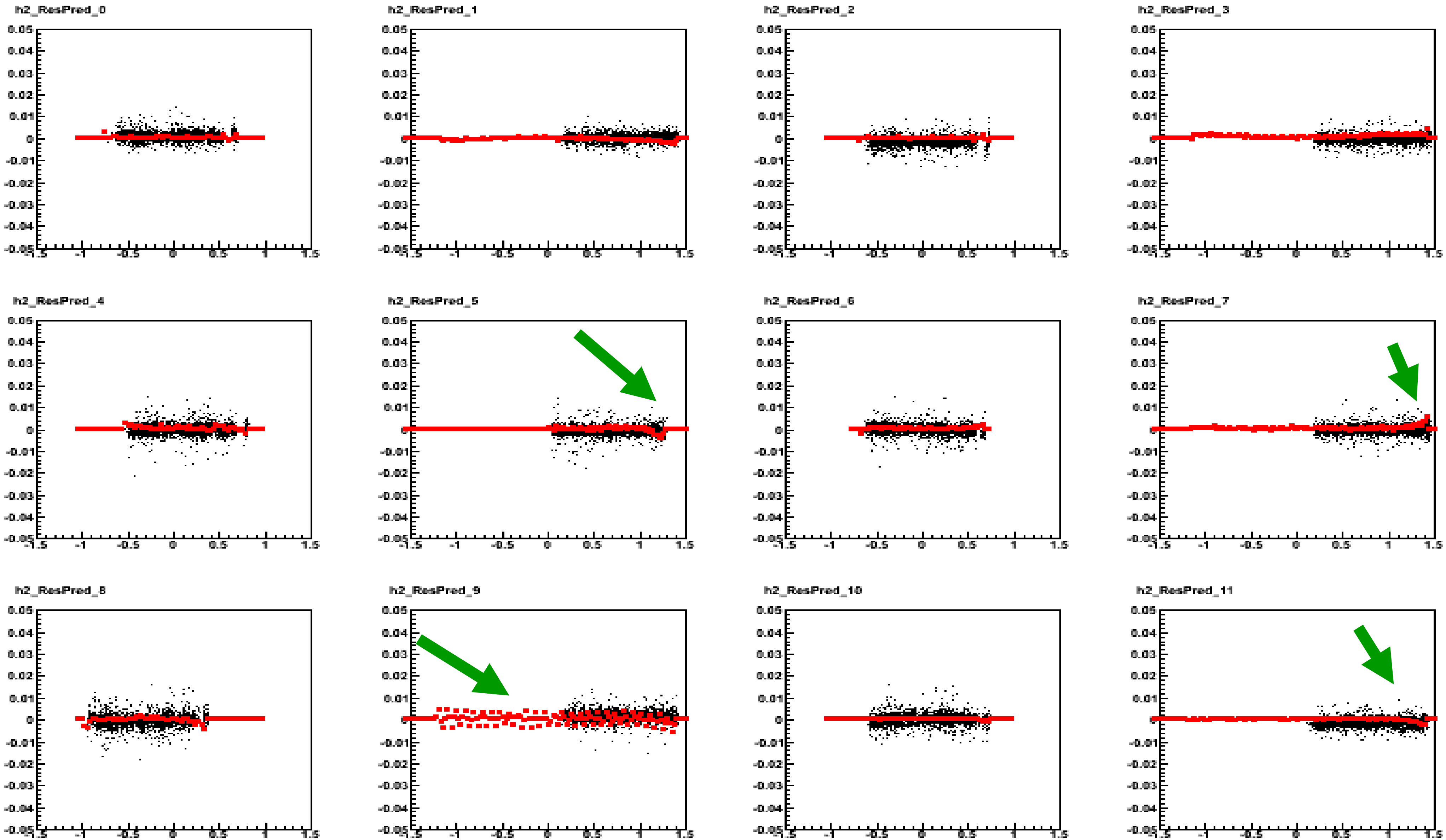
Description of analysis from Residuals to Resolution
Example of LSR corrections, Det#4



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Description of analysis from Residuals to Resolution
Collected results presented on TIPP09 in Tsukuba (Japan)

	Detector 0		Detector 1		Detector 2		Detector 3		Detector 4		Detector 5	
	Axis x	Axis y	Axis x	Axis y	Axis x	Axis y	Axis x	Axis y	Axis x	Axis y	Axis x	Axis y
Pixel size [µm]	32	24	32	24	32	24	24	24	32	24	32	24
Signal [ADU]	1599		1453		1884		1614		1259		1213	
Noise [ADU]	13.7		13.0		14.8		13.0		13.7		13.7	
S/N Ratio	117		112		127		124		92		88	
Cluster Size	3.9		3.9		4.1		4.5		3.3		3.2	
Seed [ADU]	1111		1028		1315		1050		958		928	
Residuals σ [µm]	2.8	2.4	2.1	1.7	2.1	1.7	2.0	1.8	3.0	2.4	3.4	2.8
Resolutions σ [µm]	2.0	1.7	1.5	1.3	1.7	1.3	1.4	1.3	2.5	2.1	2.5	1.8