Development of Data Correction for the 1M Large Pixel Detector at the EuXFEL

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On behalf of the LPD collaboration

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- The calibration problem
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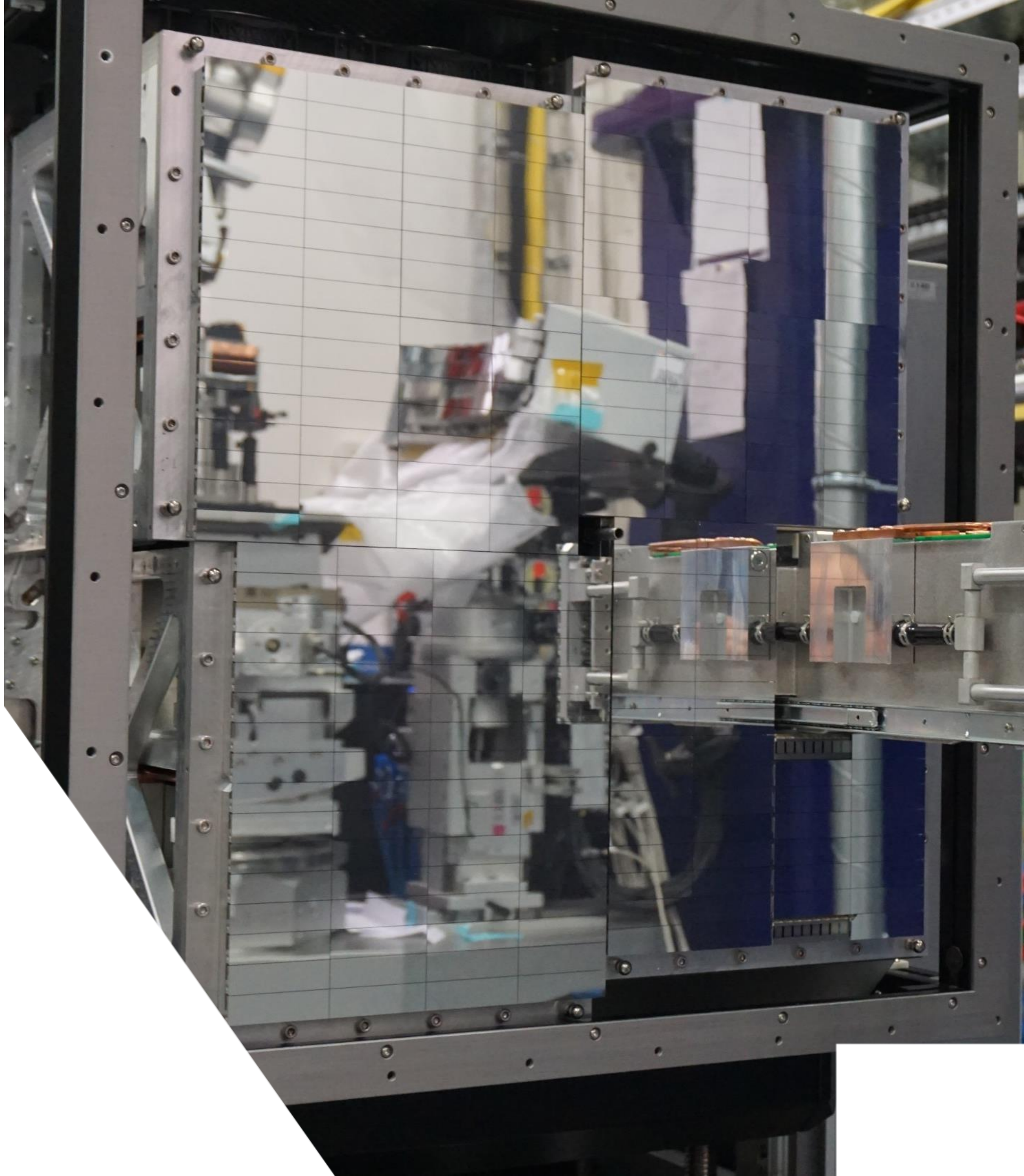

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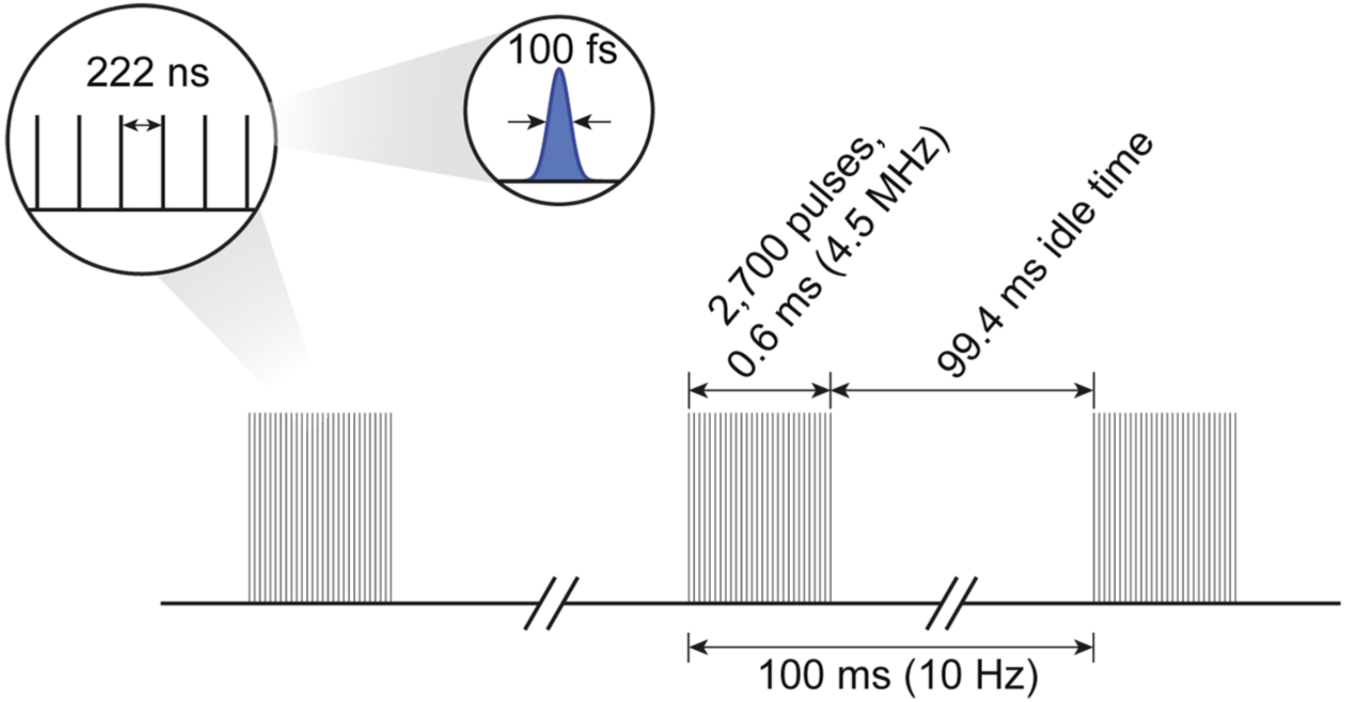
FXE at EuXFEL

- Ultra-fast laterally coherent pulsed x-ray source
- Operating pulse rate of 4.5MHz
- Pump-probe studies
- Areas of research include: absorption, emission and scattering studies of highly dynamic processes

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Scientific instrument Femtosecond X-ray Experiments (FXE): instrumentation and baseline experimental capabilities[1]

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The Large Pixel Detector (LPD)

- Developed by STFC for EuXFEL
- Housed on the FXE instrument
- Delivered September 2017
- High dynamic range facilitated by three parallel gain stages

LPD - General Detector Properties	
Sensor material	500 μm thick Hammamatsu silicon tiles
Pixel size	500 μm x 500 μm
No. Pixels	>1 million (1024 x 1024)
Max Dynamic Range	10^5 photons/pixel @ 12keV
Frame Rate	4.5 MHz
Images per train	510

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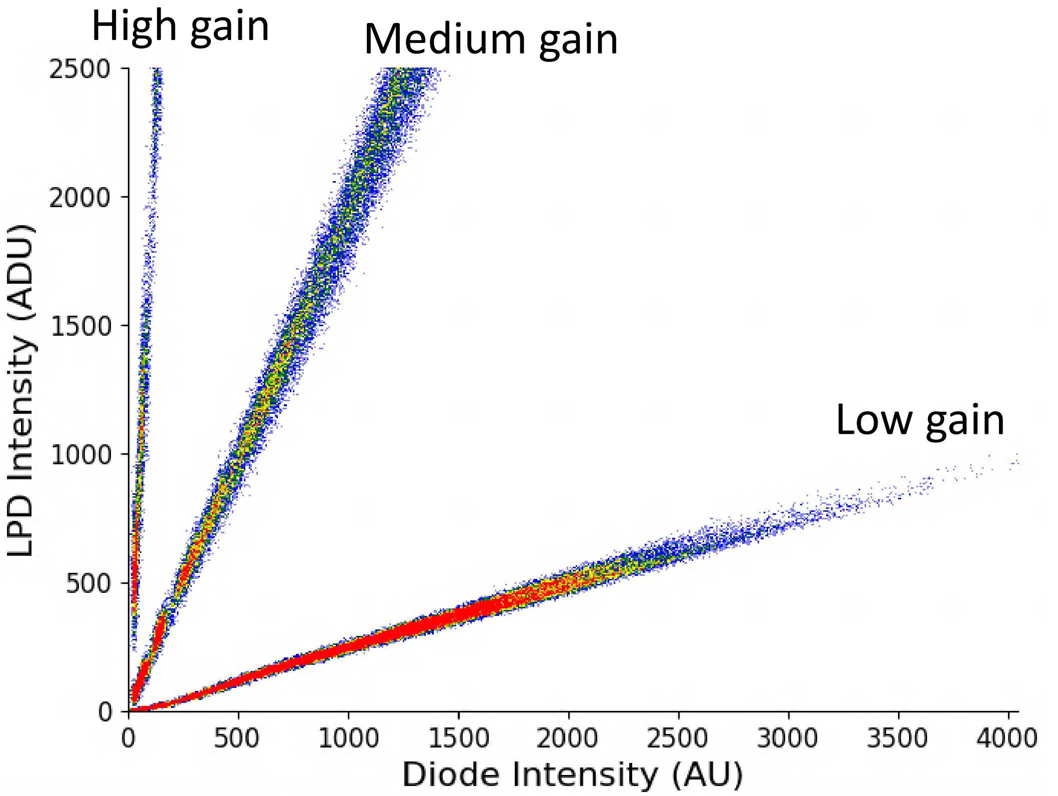
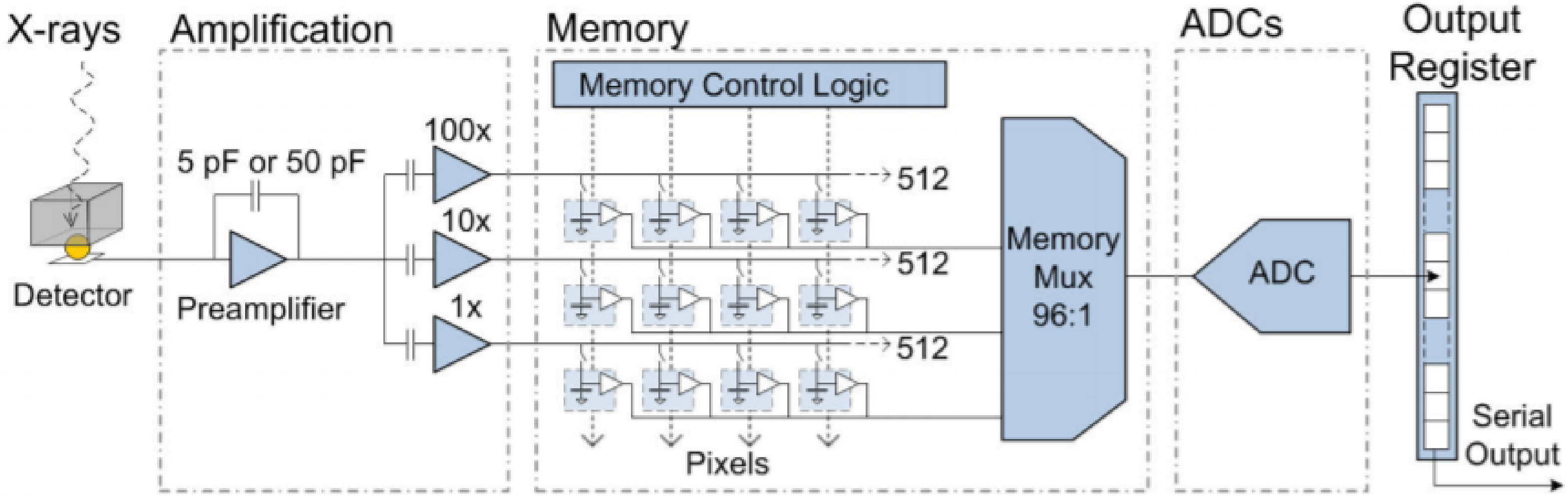
Parallel Gain Stages

- Unlike contemporary adaptive gain control using feedback loops, LPD readouts all three gains in parallel, with the appropriate gain saved to memory

- We can override the gain selection and operate in either fixed gain or parallel gain mode





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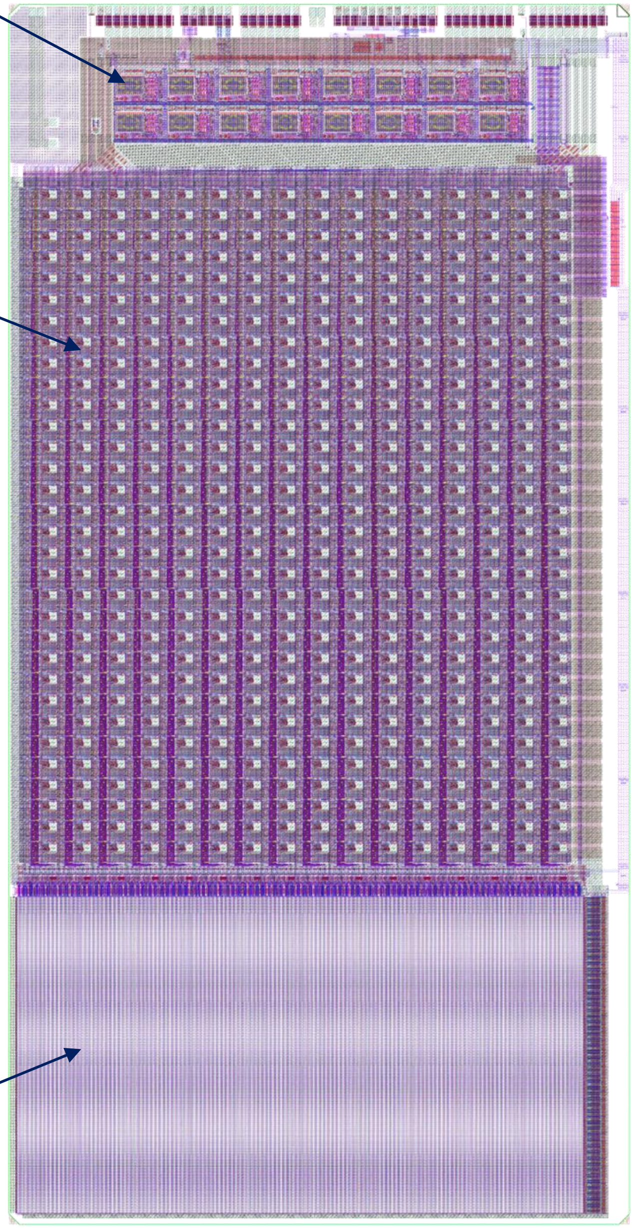
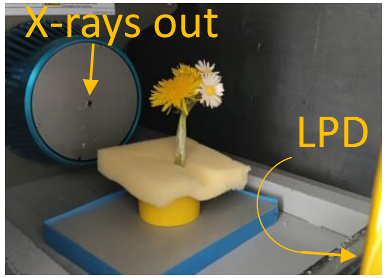
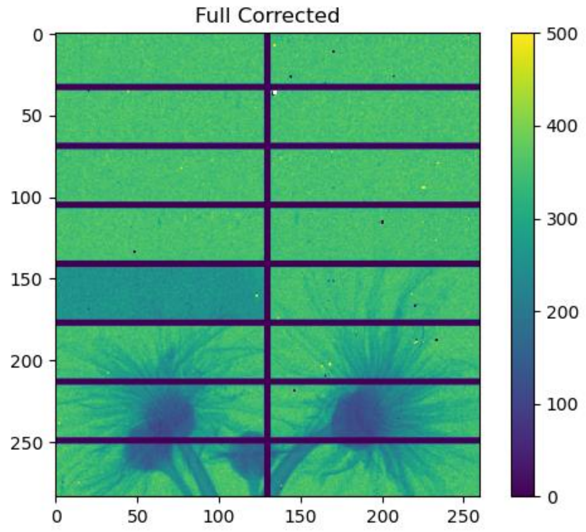
Detector Calibration Challenge

- > 1 million pixels (1024 x 1024)
- 512 memory cells and 3 gain stages per pixel
- → more than 1 billion individual correction coefficients required
- Standard x-ray set gain corrections are a simple but do not transfer well for use in the high speed settings experienced at EuXFEL.
  - 4.5MHz → 220ns for integration of charge and reset
  - 90ns for integrating of signal, remainder dedicated to reset.
  - So that's integrating 10^6 photons per single ASIC and 10^{10} across the entire 1M in just 90ns
- Dedicated calibration beamtimes are essential







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Calibration Data Acquisition

- Fluorescence image from irradiation of target with 9.3 keV beam
- Data acquired from an attenuation sweep
- LPD as a function of a reference (I_0) Si PIN diode or APD
- Fixed duration at each intensity before changing beam attenuating filters
- Capture in parallel gain mode for complete calibration data

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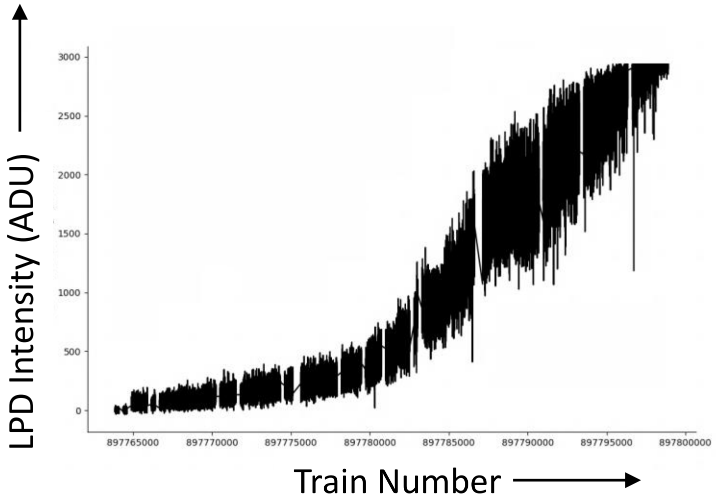
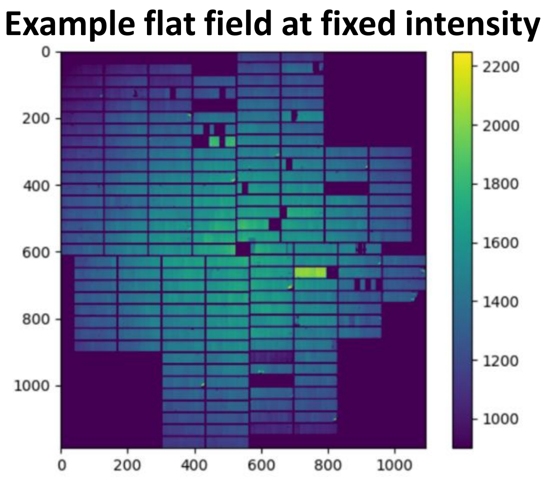
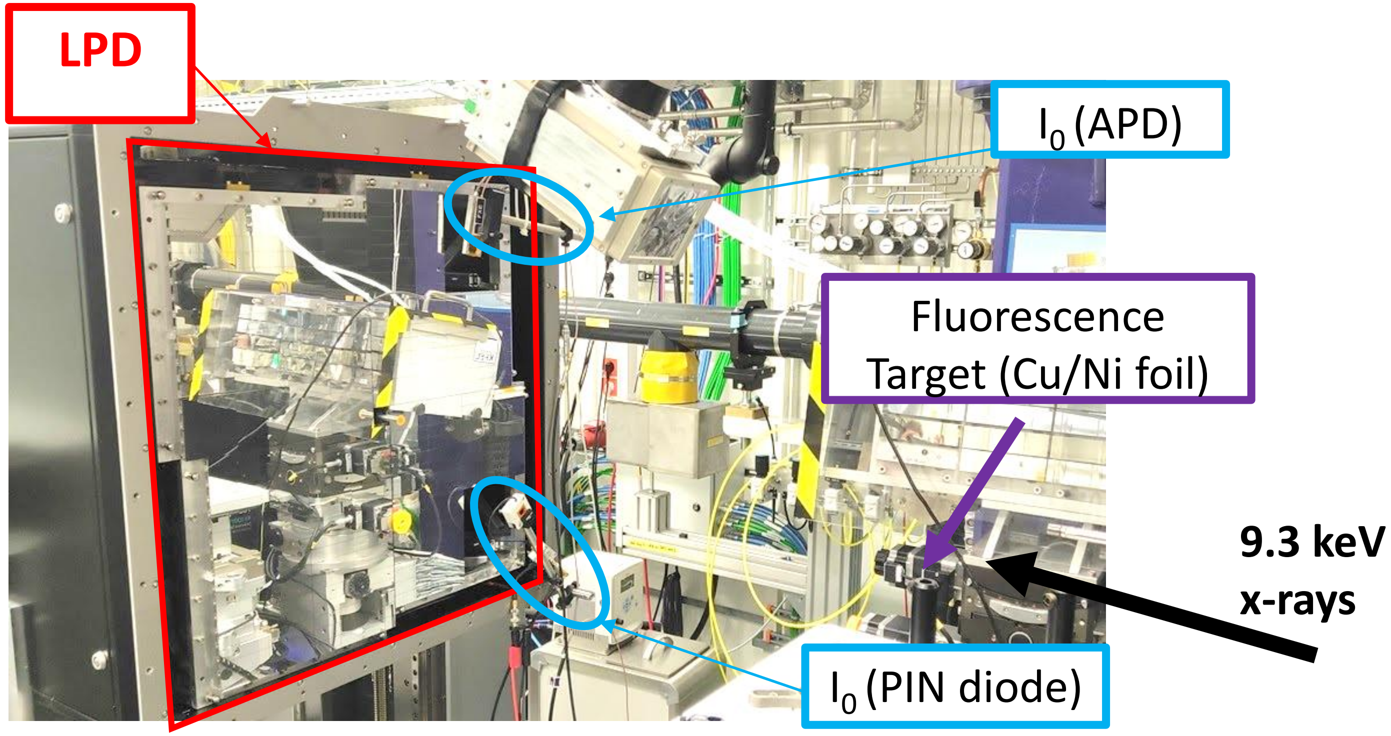
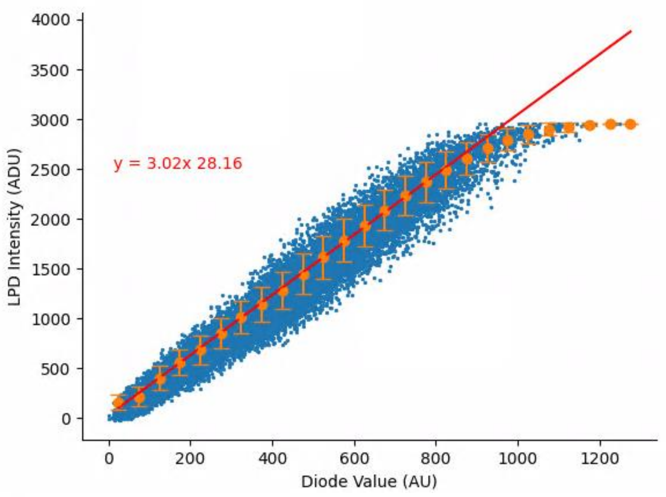




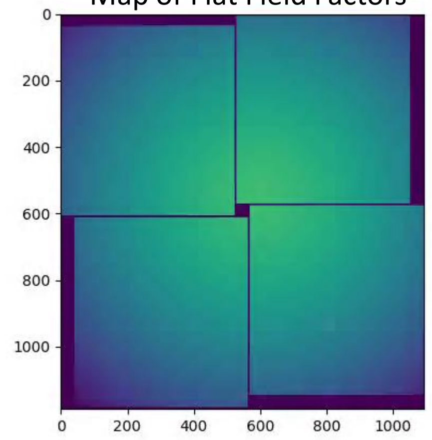


Generating the Correction Maps

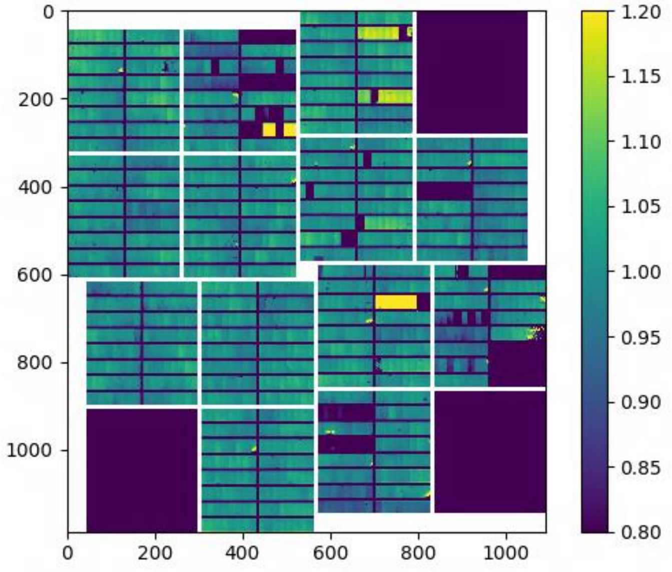
- Per memory cell pixel corrections for high and medium gain stages



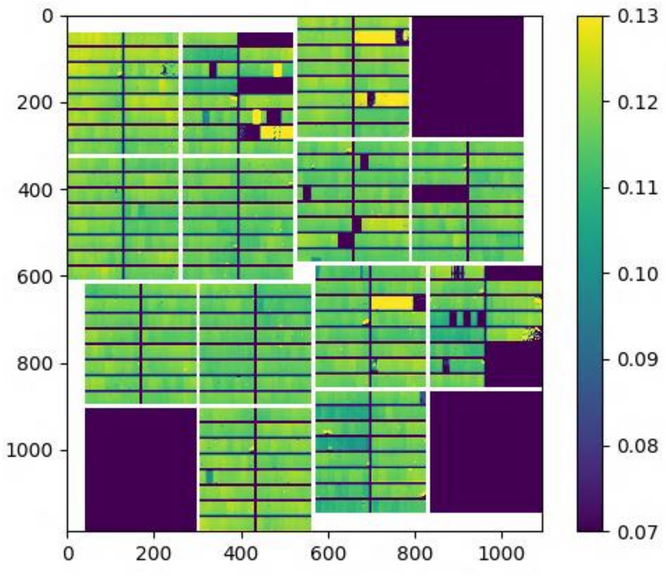
Map of Flat Field Factors



Gain Map (High gain)



Gain Map (Medium gain)



- Gain maps have been normalised in order to keep corrected LPD values in approximately ADU units
- The flatness of the gain maps indicates the corrections are independent to the shape of the incident field

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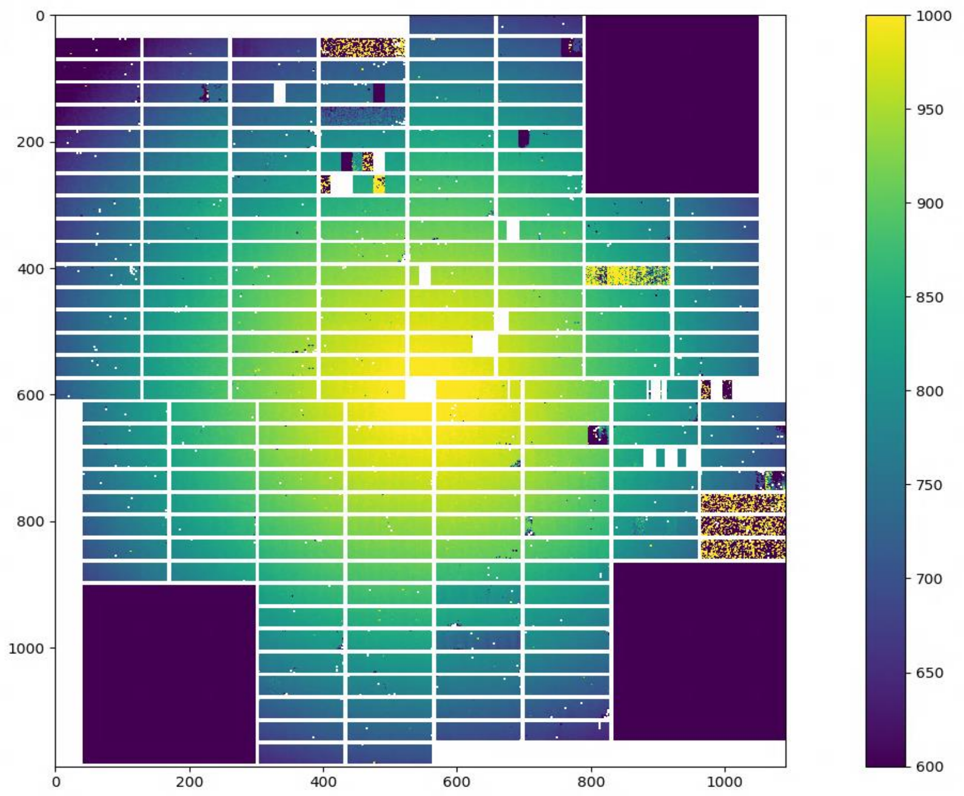
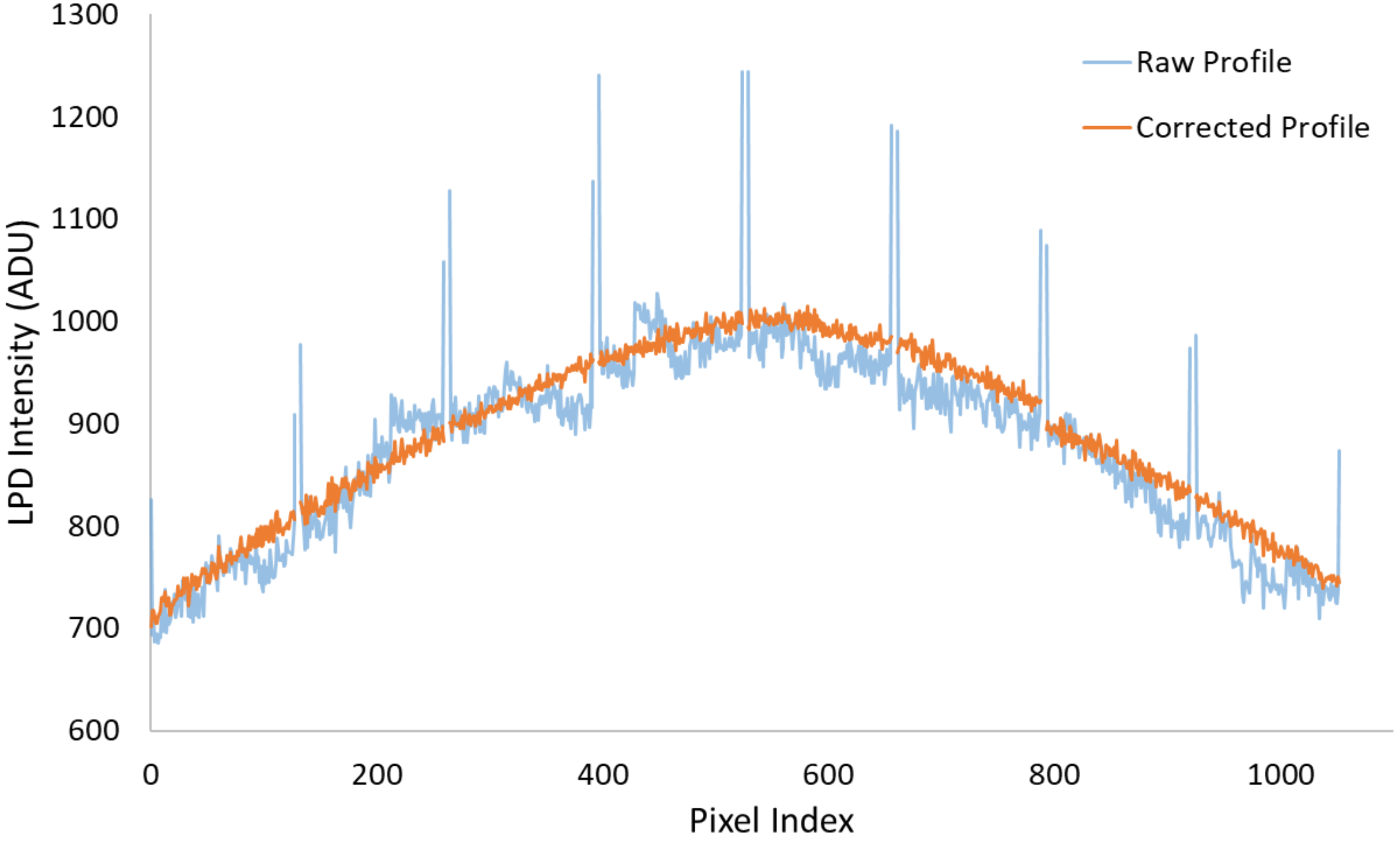
Applying the Correction – flat field





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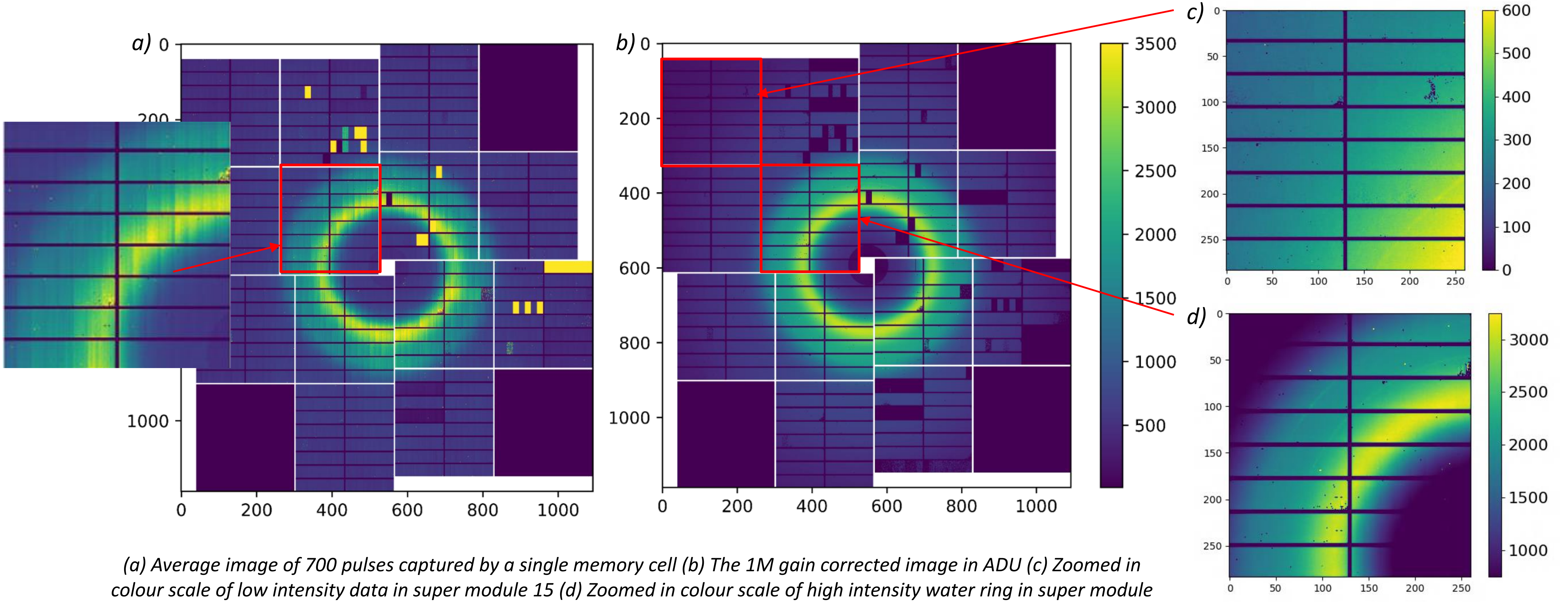
Applying the Correction – water scatter ring



(a) Average image of 700 pulses captured by a single memory cell (b) The 1M gain corrected image in ADU (c) Zoomed in colour scale of low intensity data in super module 15 (d) Zoomed in colour scale of high intensity water ring in super module 13. The raw data was acquired in LPD's autogain mode at 4.5MHz with an incident beam energy of 16.6keV that pushed both the high and medium gain stages.

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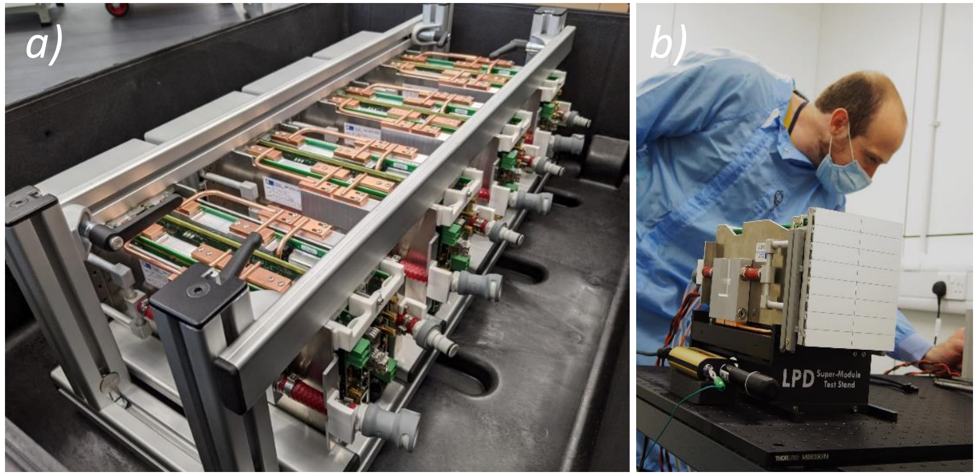
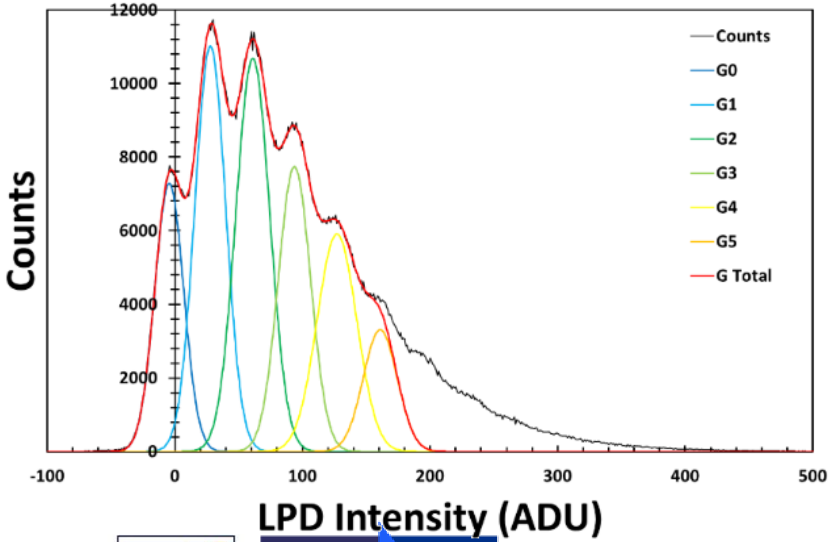
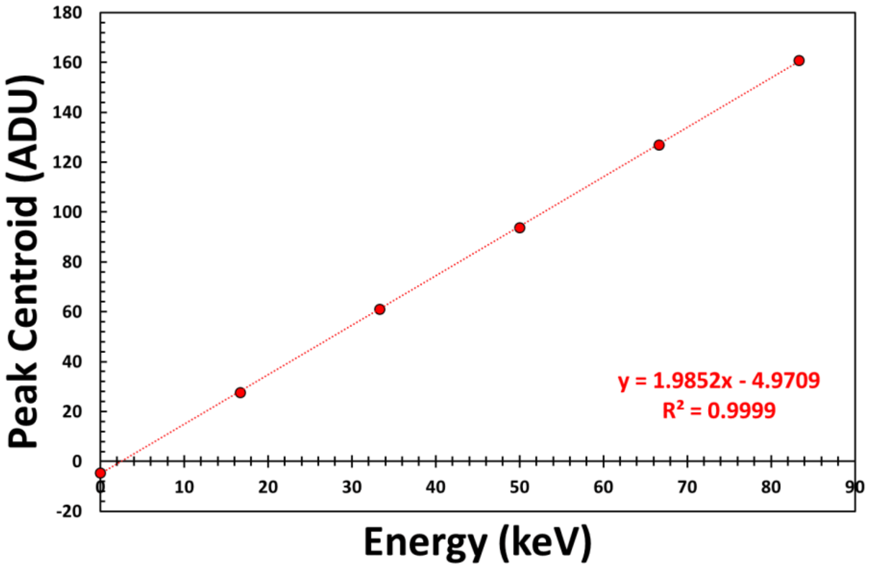
Future Work

- So far presented a correction aligning LPDs pixels on a common axis. Next step is to provide an energy calibration.
- photon peak counting with LPD is possible, however only achievable in the high gain stage
- Plan to use photon peak counting to calibrate a 'golden pixel'



a) new LPD supermodules ready to be shipped and b) testing completed supermodules in lab





4 additional SMs have been delivered to EuXFEL, will now integrate these into the calibration enabling imaging with the complete 1M detector

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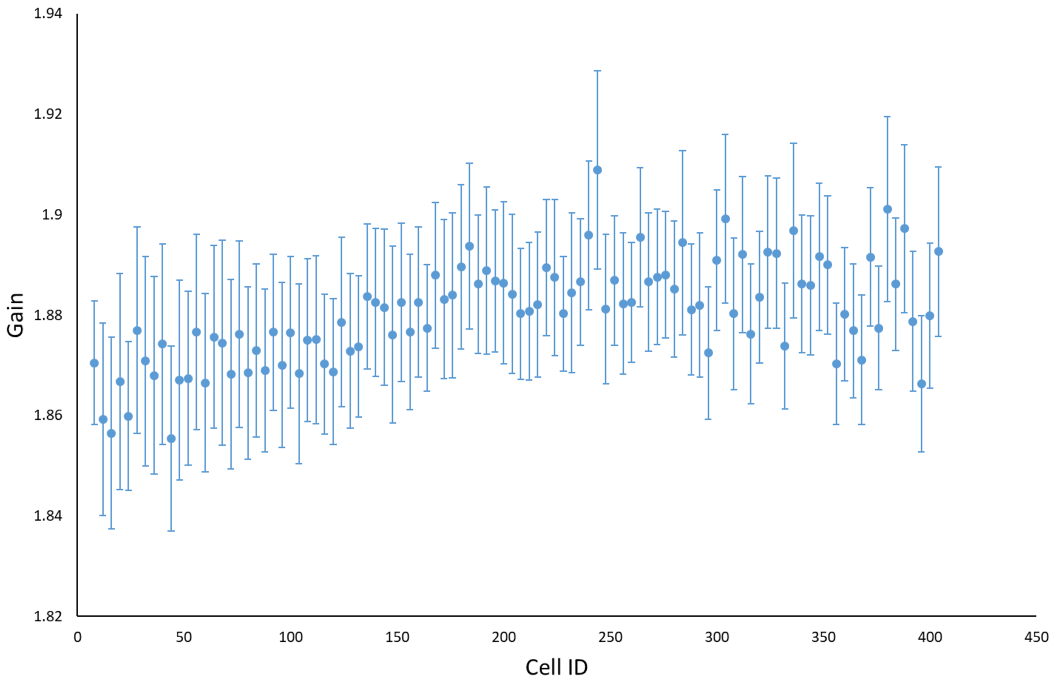
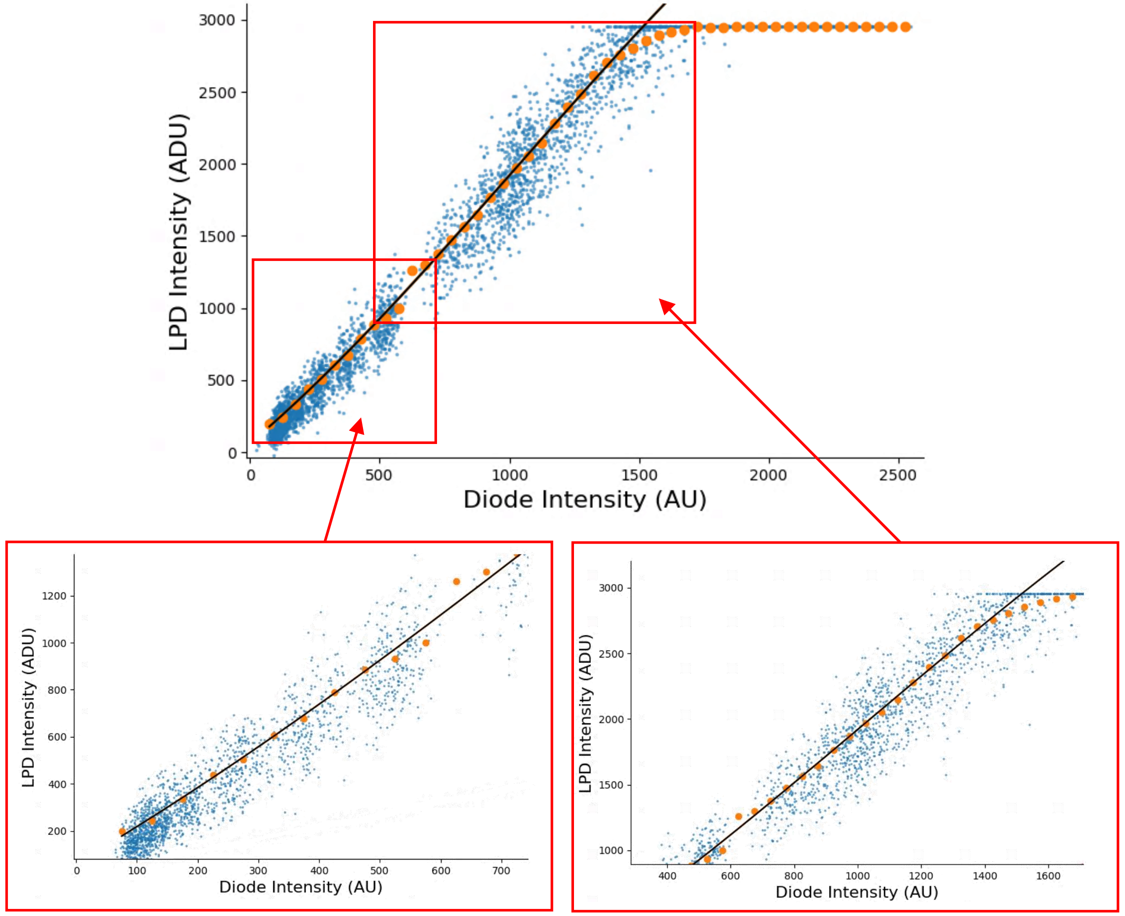
Future Work

- Rolling out of the correction across all memory cells where as this presentation focusses on the analysis of a single memory cell.



- The correction maps presented here are based on linear fits. Now implementing non-linear fits beginning with 3 degree polynomials.



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Conclusion

- From an attenuation sweep of a fluorescence data we have developed a linear correction and applied this to the high and medium gain stages on a per memory cell basis
- Currently investigating the application of non-linear correction techniques
- Will use photon peak analysis in order to perform the final energy calibration
- Have successfully delivered four new LPD super modules to FXE

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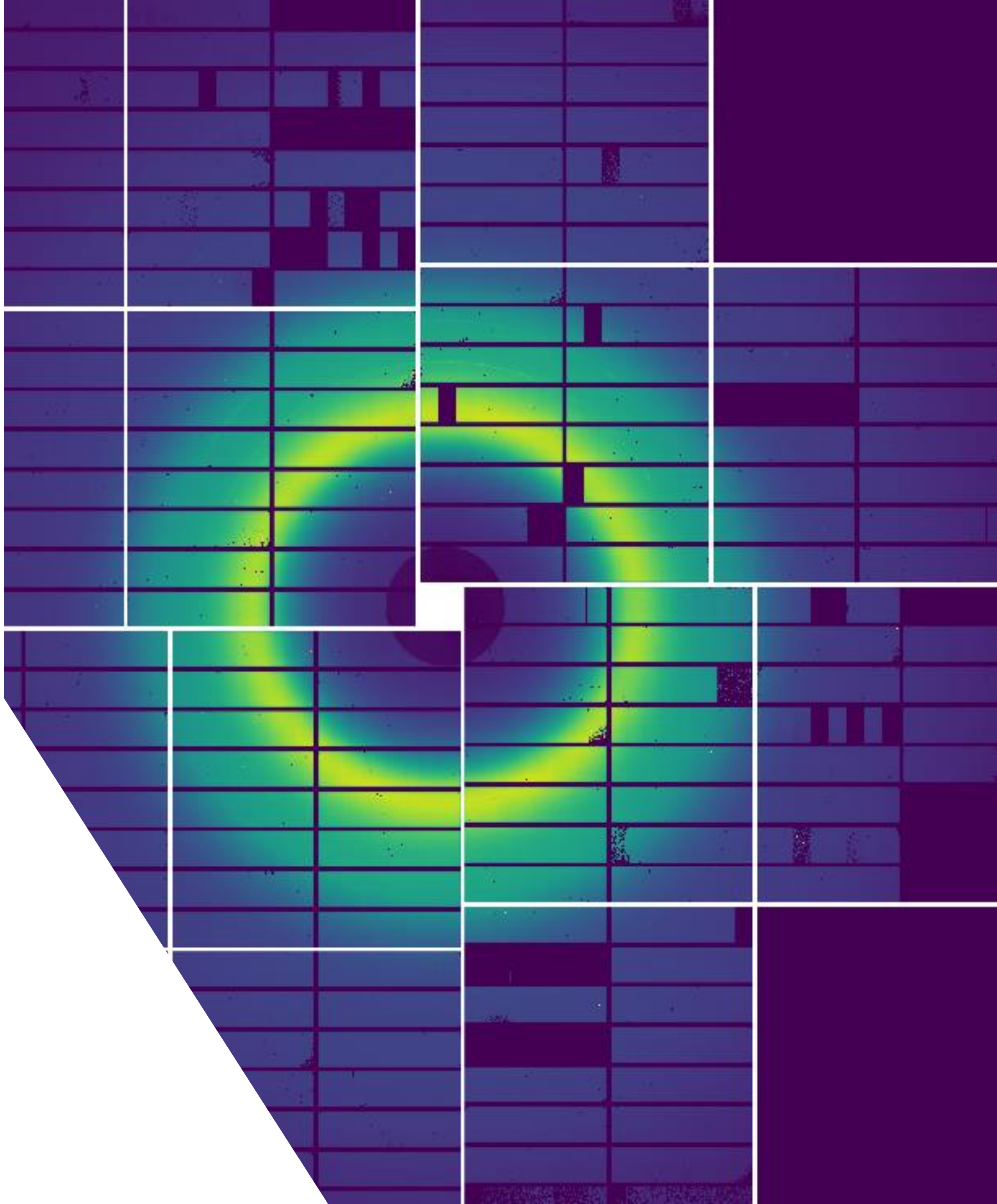

Thank you for your attention

Any Questions?

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Techniques for Quantifying Corrections

- **Structural Similarity Index**
- Mean Square Error
- Signal to Noise Ratio

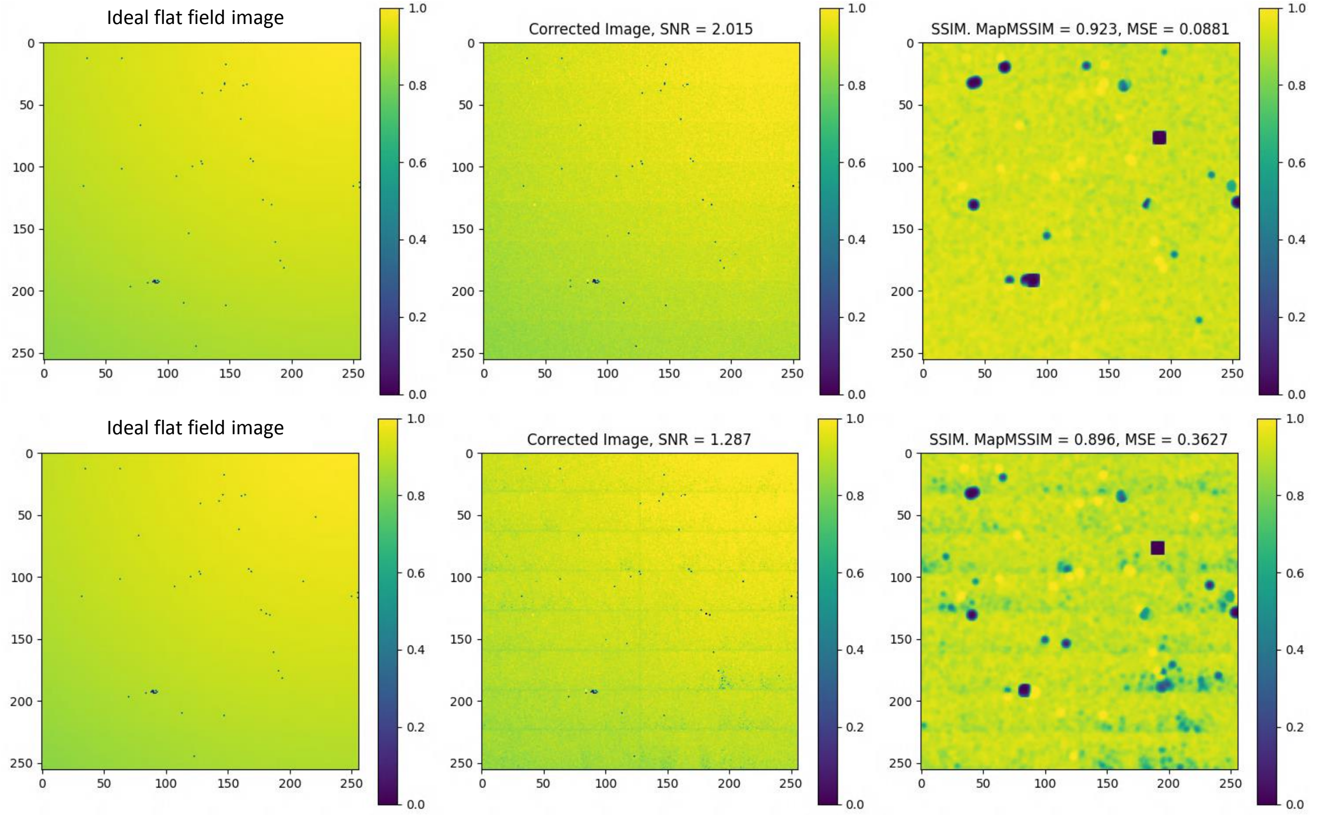
IEEE TRANSACTIONS ON IMAGE PROCESSING, VOL. 13, NO. 4, APRIL 2004 1

Image Quality Assessment: From Error Visibility to Structural Similarity

Zhou Wang, *Member, IEEE,* Alan C. Bovik, *Fellow, IEEE*
Hamid R. Sheikh, *Student Member, IEEE,* and Eero P. Simoncelli, *Senior Member, IEEE*

Fig. 2. Comparison of "Boat" images with different types of distortions, all with MSE = 210. (a) Original image (8bits/pixel; cropped from 512×512 to 256×256 for visibility); (b) Contrast stretched image, MSSIM = 0.9168; (c) Mean-shifted image, MSSIM = 0.9900; (d) JPEG compressed image, MSSIM = 0.6949; (e) Blurred image, MSSIM = 0.7052; (f) Salt-pepper impulsive noise contaminated image, MSSIM = 0.7748.

All images have MSE = 210



Comparison of two corrections: 3 degree polynomial fitting (top) and linear fitting (bottom)

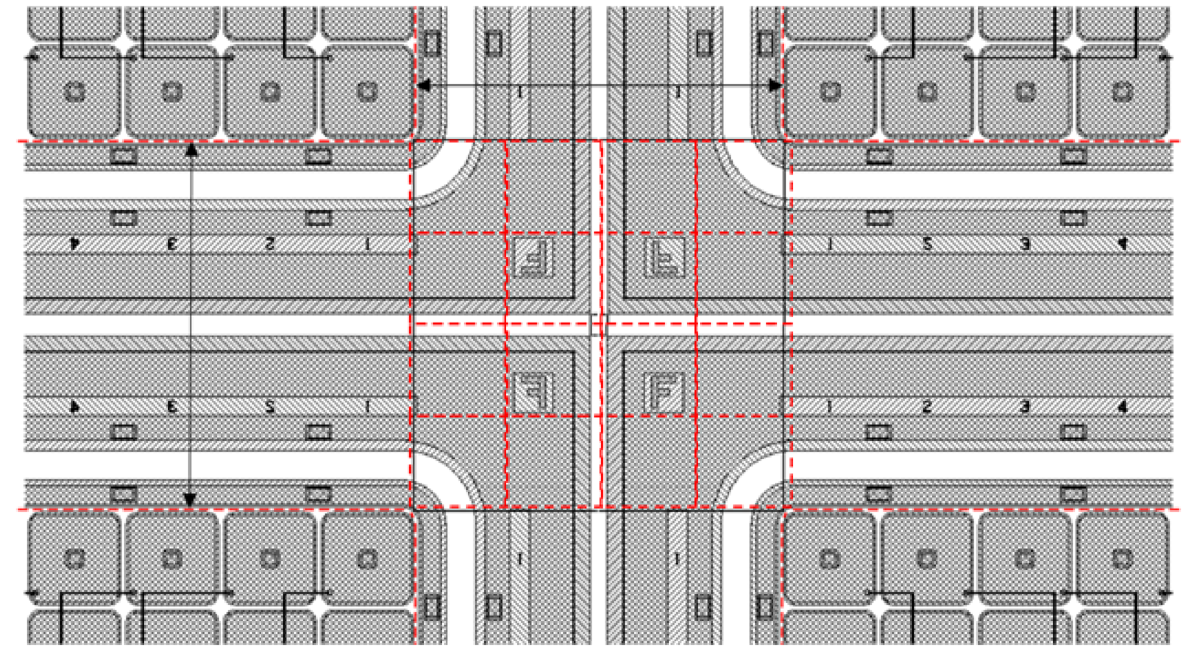


Figure 1: Detector tiles on the LPD system have the above metallisation at the edges of the sensors. There is a grounded guard band and then a gap to a HV bias distribution layer. This layer was part of the original plan to feed the sensor HV from the back side. This was replaced by ribbon bonds, but the layout in the sensor remains.
This means that despite the gap between sensors being on a few hundred microns. The gap between active pixels is 2mm or 4 pixels.
On any given super-module the mechanics of LPD were designed such that the position is known to +/-25um. In reality 30um is typically achieved and 100um a worst case situation.
This means that within a super-module you can assume the 4 pixel gap between tiles is the best positional information to use.

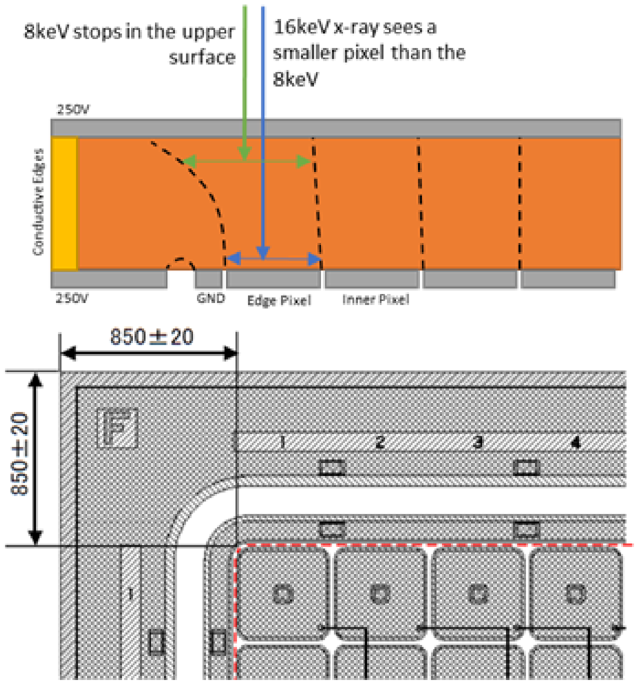


Figure 2: Regarding edge pixels the metallisation that forms the pixels is exactly the same as all the others. We understand that the apparent increase in sensitivity of these pixels is due to the way the effective pixel volume and electric fields are distorted by the other metallisation and potentials present at the edges.
Since this is dependent on depth it is clear the sensitivity of edge pixels will be energy dependent.