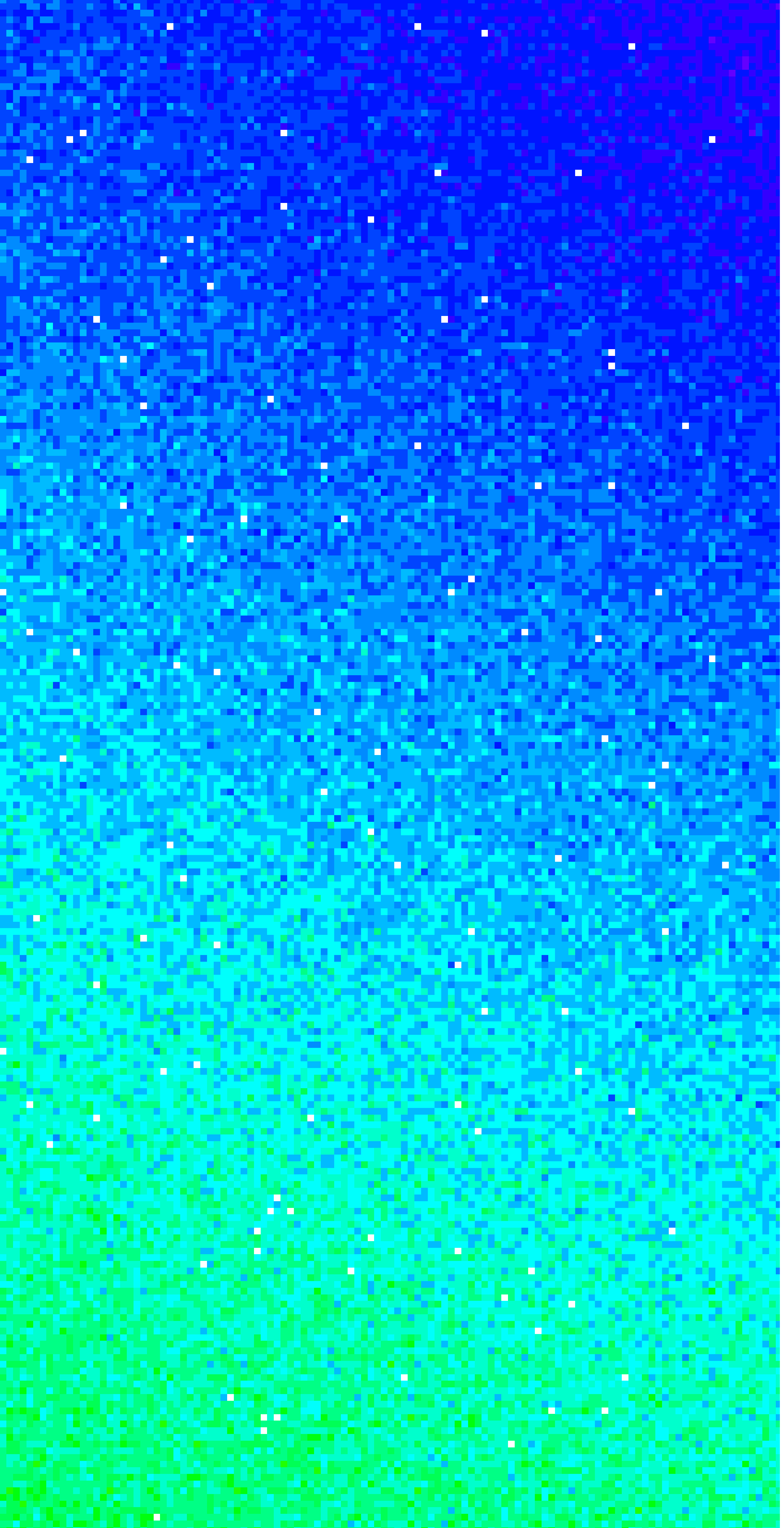
Timepix calibration, simulation and test-beam data analysis

Sophie Redford - CLIC workshop - 02.06.15

with thanks to the LCD vertex group



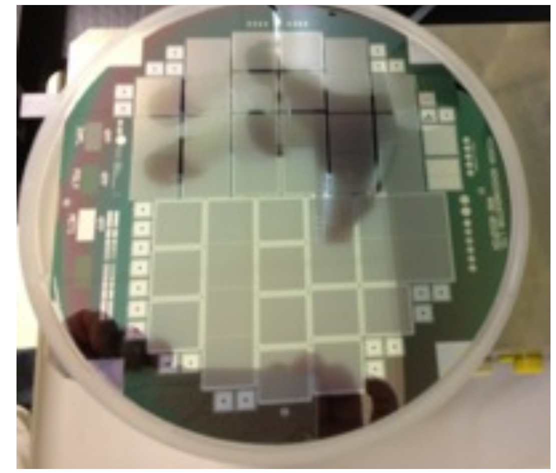
Outline

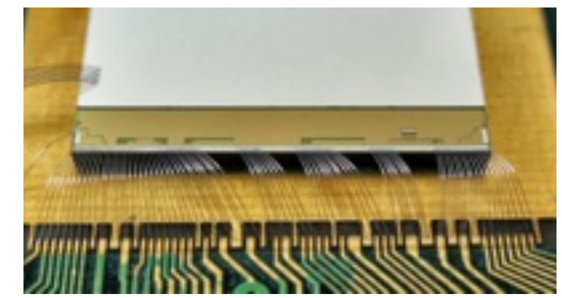
1. Motivation & the six Timepix assemblies
2. Introduction to calibration
3. Where do the photons come from?
4. Data reconstruction
5. Available statistics
6. Peak finding with KDE & most likely TOT values
7. Threshold measurements
8. Surrogate fit global & pixel by pixel
9. Temperature dependence
10. Application to test-beam data & simulation validation

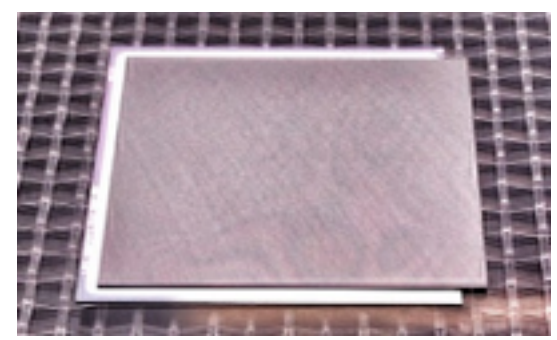
Motivation

Why calibrate six Timepix assemblies?

1. to find out about the assemblies
   - global calibration parameters
   - pixel calibration - uniformity
2. to apply to test-beam data
   - to calculate depletion voltage
   - to calculate single-hit resolution
   - to validate simulation







The six assemblies:

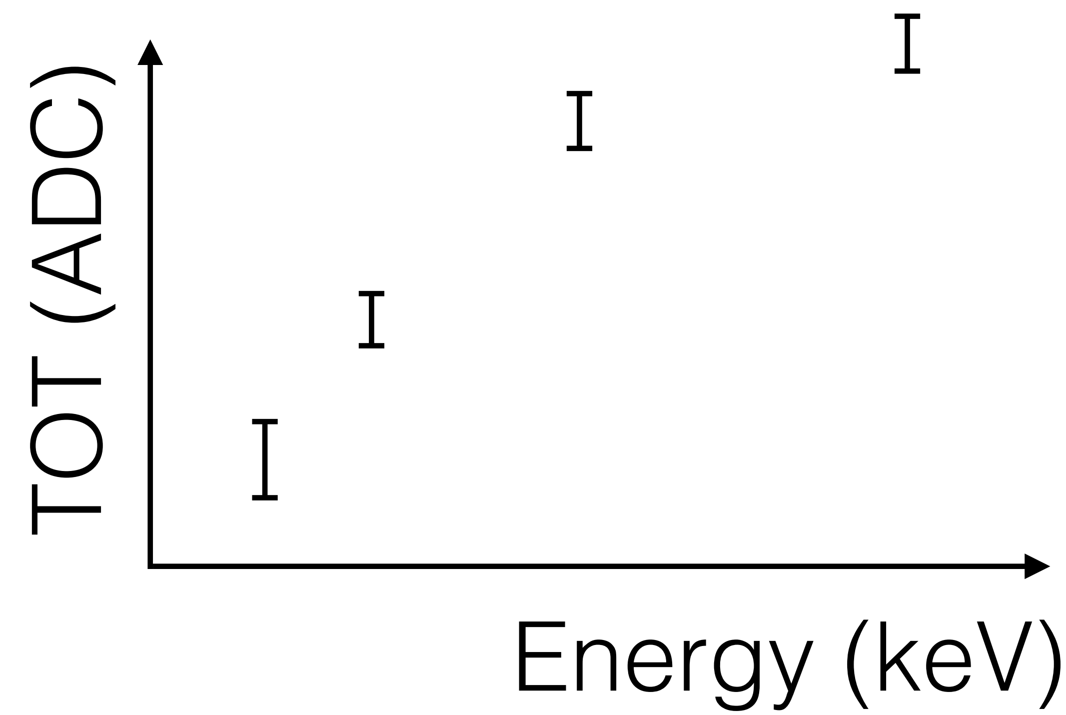
Assembly	Sensor thickness (μm)	V_{Bias} (V)
A06-W0110	50	15
B06-W0125	200	-50
B07-W0125	300	40
C04-W0110	50	15
D09-W0126	100	35
L04-W0125	100	35

Introduction to calibrating

Using photons of known energy to measure the response of the assemblies

All about two numbers:

- the energy of the photons (known)
- the most likely TOT (?)



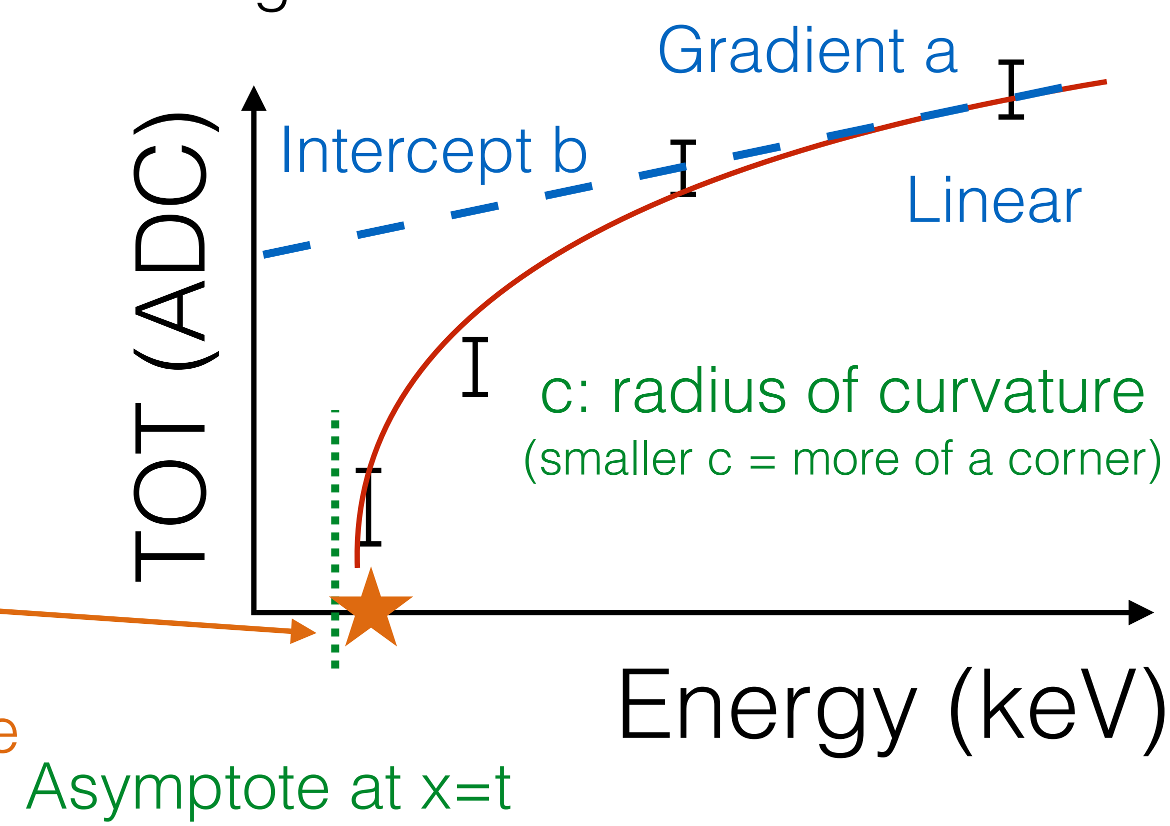
From data points to a parametrisation: the surrogate function:

$$y = \boxed{ax + b} - \boxed{\frac{c}{x - t}}$$

High x — Low x

The threshold (in energy):

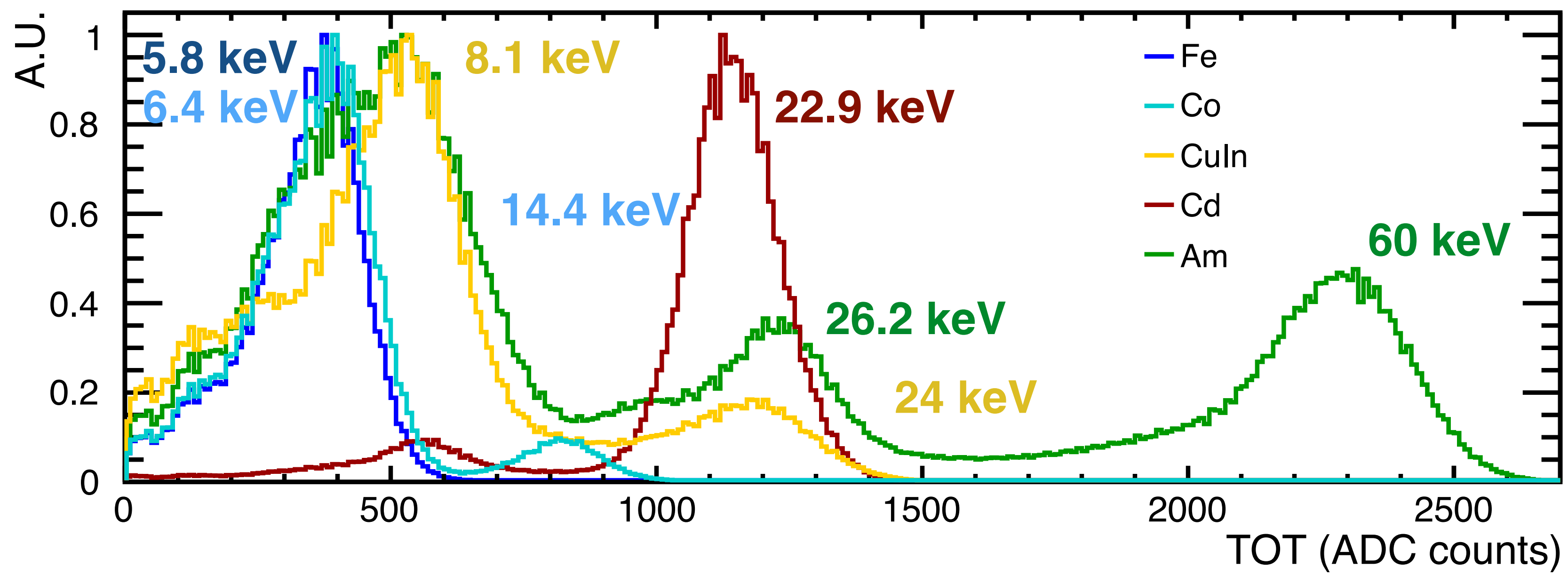
- should be positive
- not the same as t
- can be determined in counting mode



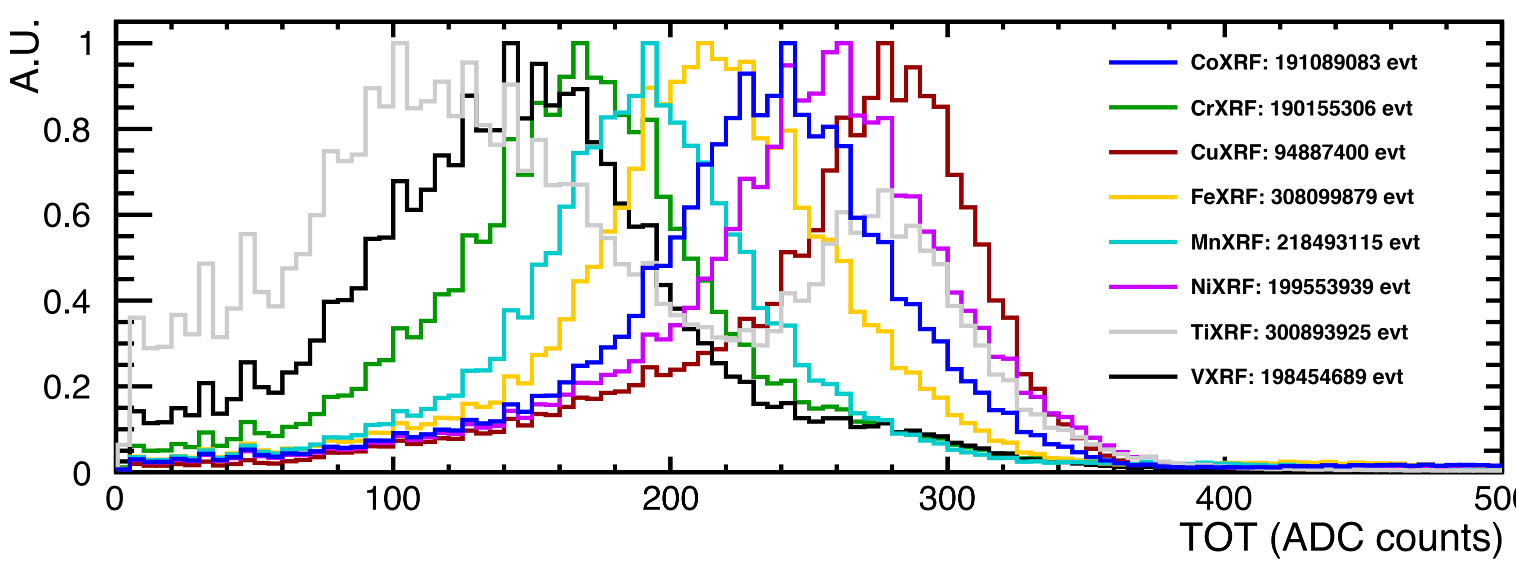
Where do the photons come from?

1. Radioactive sources
   - at CERN
   - in TOT mode

Source	Energy (keV)	Lab	Mode
^{241}Am	26.3 & 59.5	CERN	TOT
^{109}Cd	22.1	CERN	TOT
^{57}Co	6.4 & 14.4	CERN	TOT
^{55}Fe	5.9	CERN	TOT



2. X-ray fluorescence
   - at CERN and LNLS
   - in TOT and counting mode



Target	Energy (keV)	Lab	Mode
CuIn	8.0 & 24.2	CERN	TOT
Co	6.9	LNLS	TOT
Cr	5.4	LNLS	TOT
Cu	8.0	LNLS	TOT
Fe	6.4	LNLS	TOT
Mn	5.9	LNLS	TOT
Ni	7.5	LNLS	TOT
Ti	4.5	LNLS	TOT
V	5.0	LNLS	TOT
Cu	8.0	CERN	Counting
In	24.2	CERN	Counting
Pd	21.2	CERN	Counting
Zr	15.8	CERN	Counting

Data reconstruction

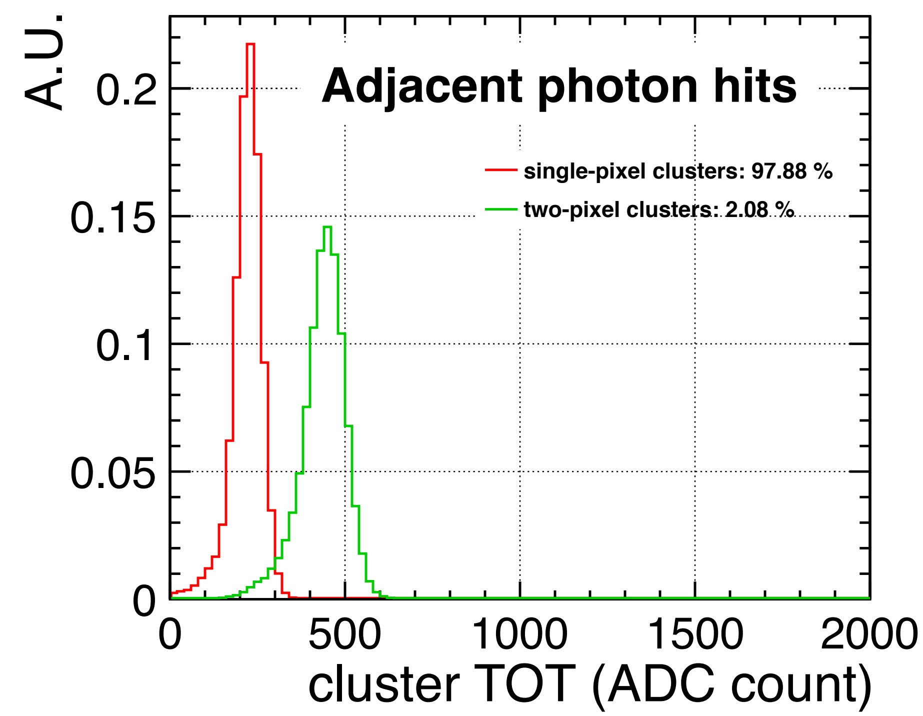
We need to detect the whole photon energy in one pixel

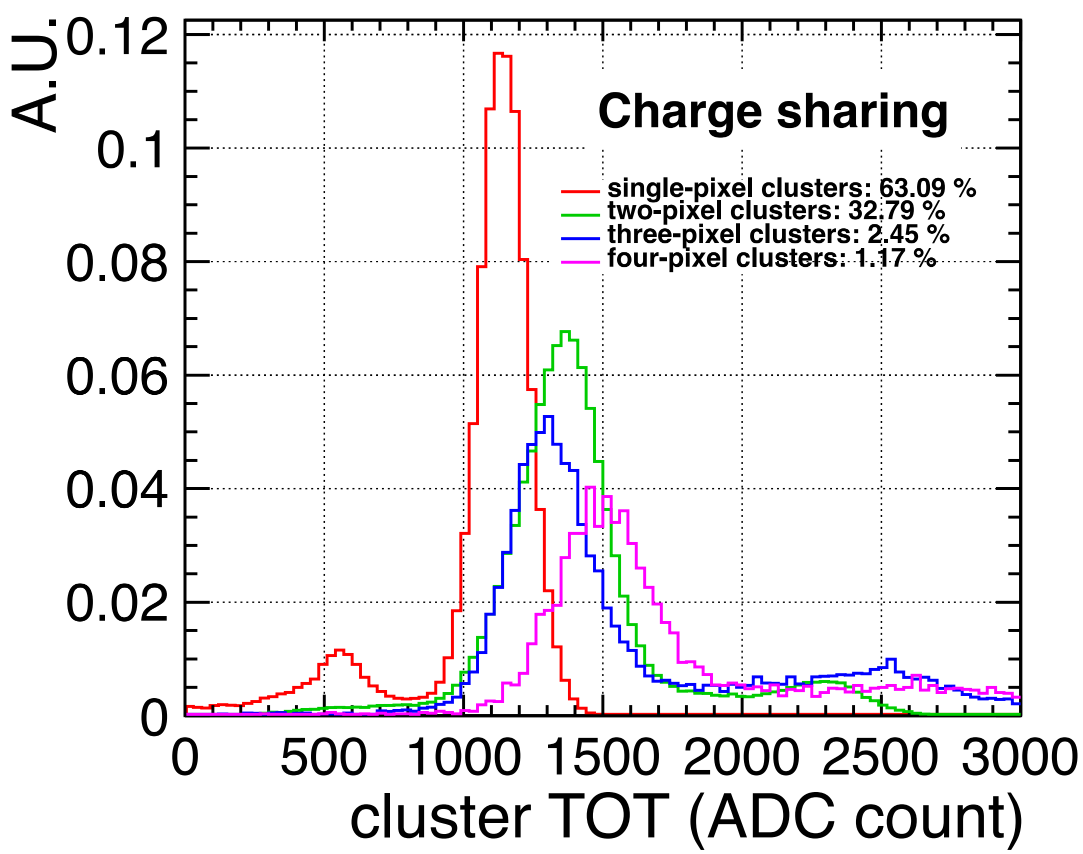
Therefore we require single-pixel clusters

Multi-pixel clusters can be formed by:

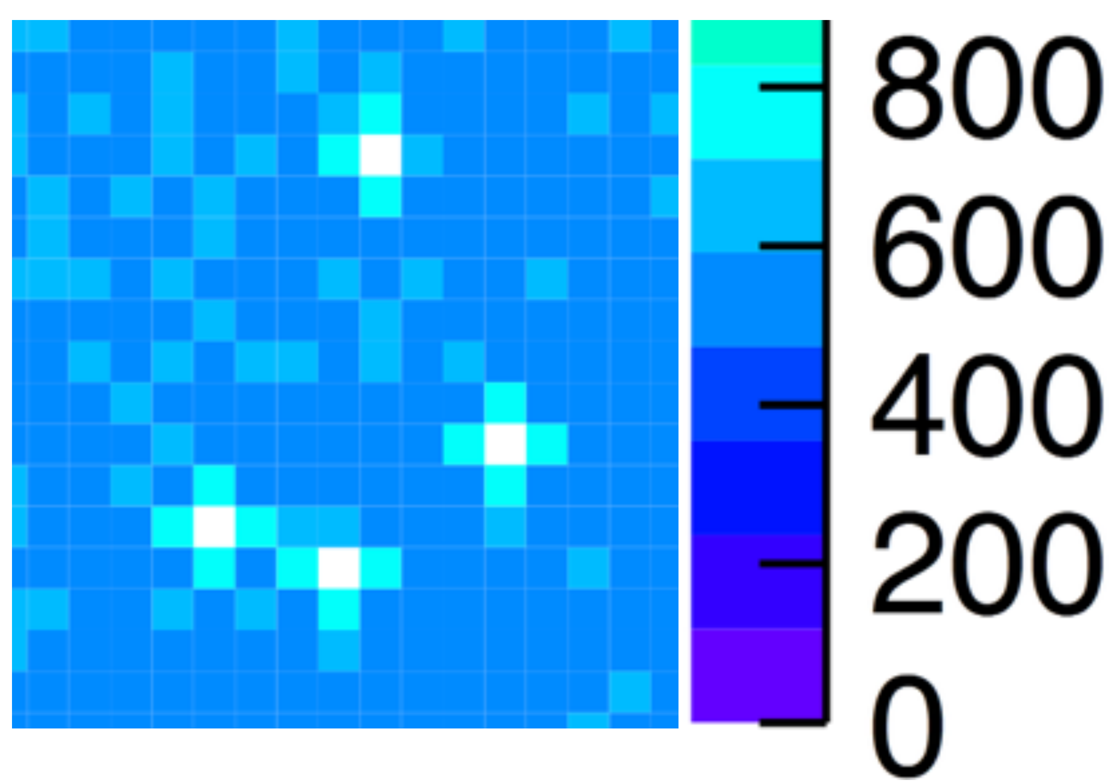
1. adjacent photon hits
2. charge sharing

In data we expect and find evidence of both

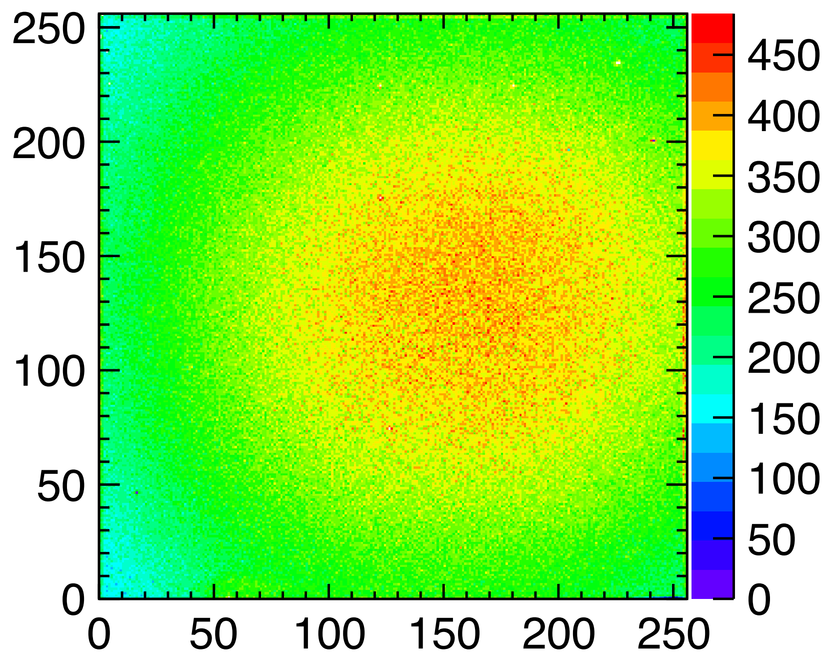




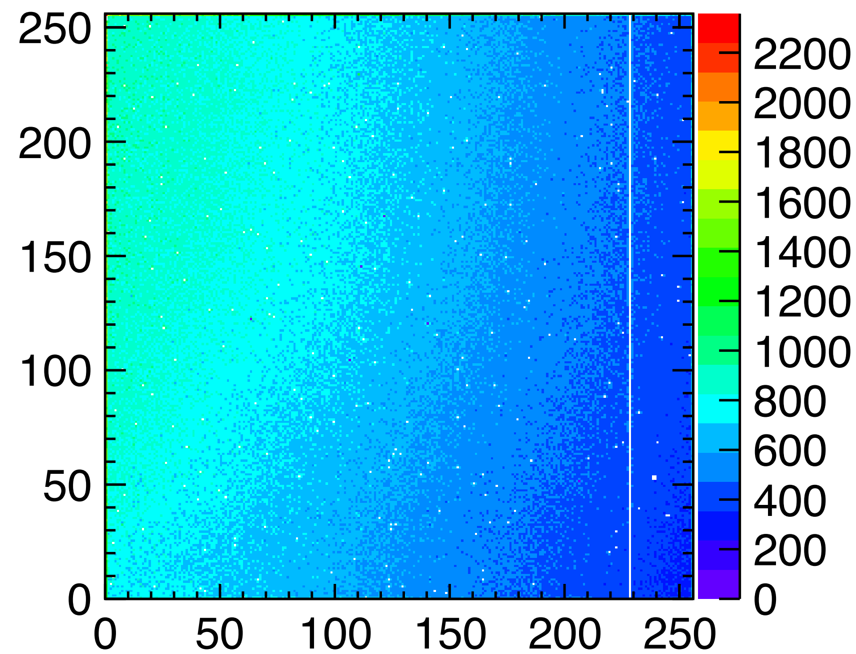
Hits per pixel: pattern due to undetected charge sharing with a masked pixel



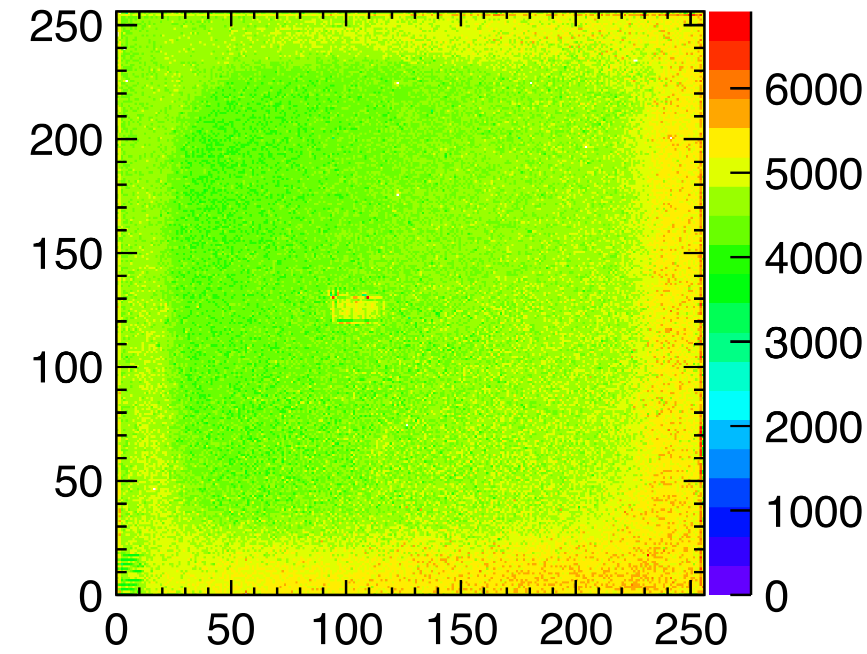
Available statistics



Hit map
A06-W0110 Cd



Hit map
C04-W0110 Am



Hit map
A06-W0110 FeXRF

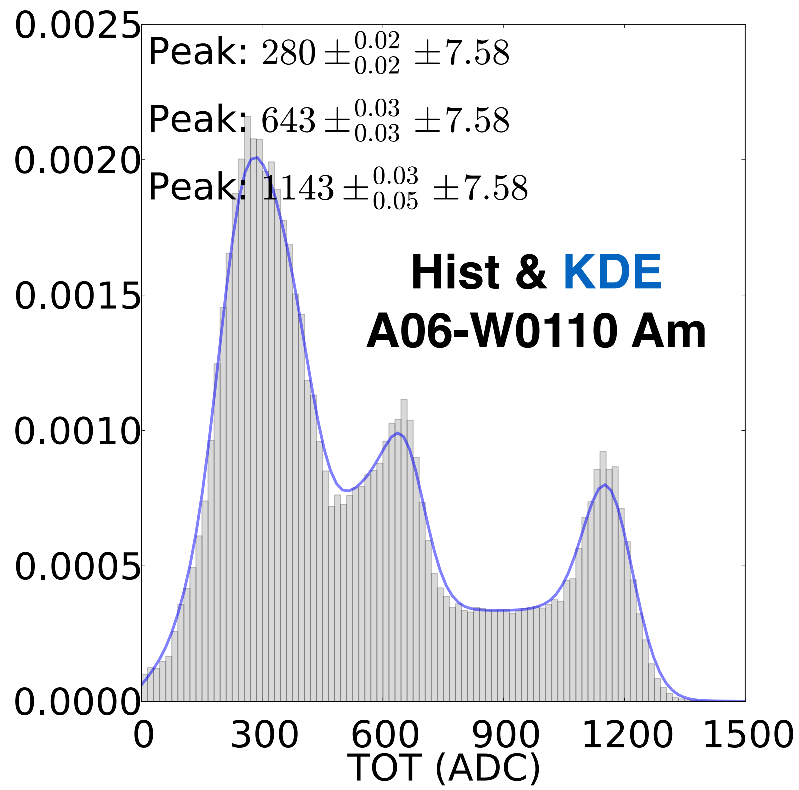
1. Hit maps show good illumination of assemblies
2. Hits per pixel drops very low for certain sources/assemblies

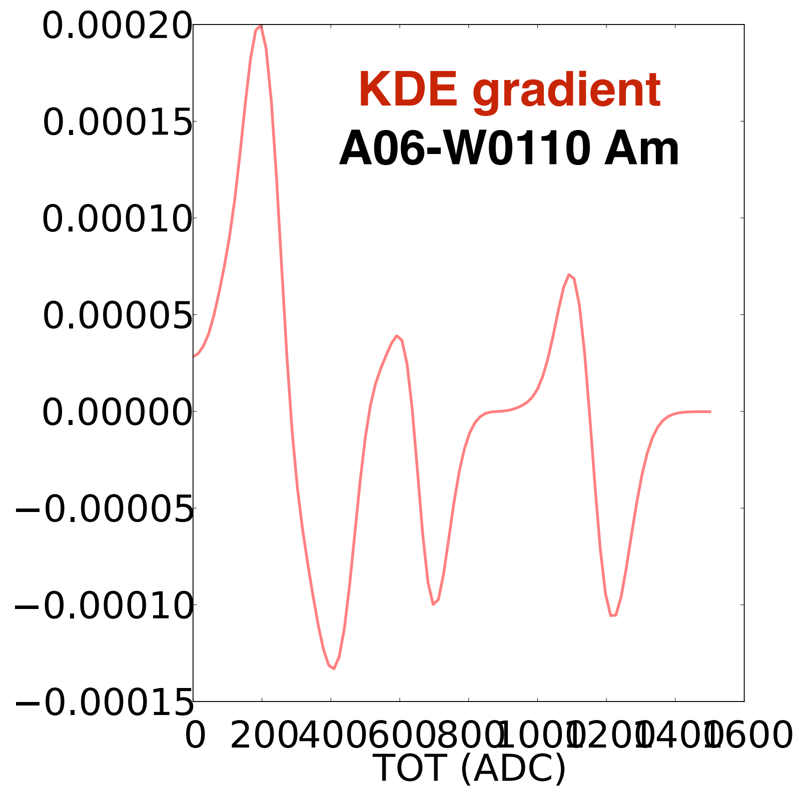
Average number of hits per pixel

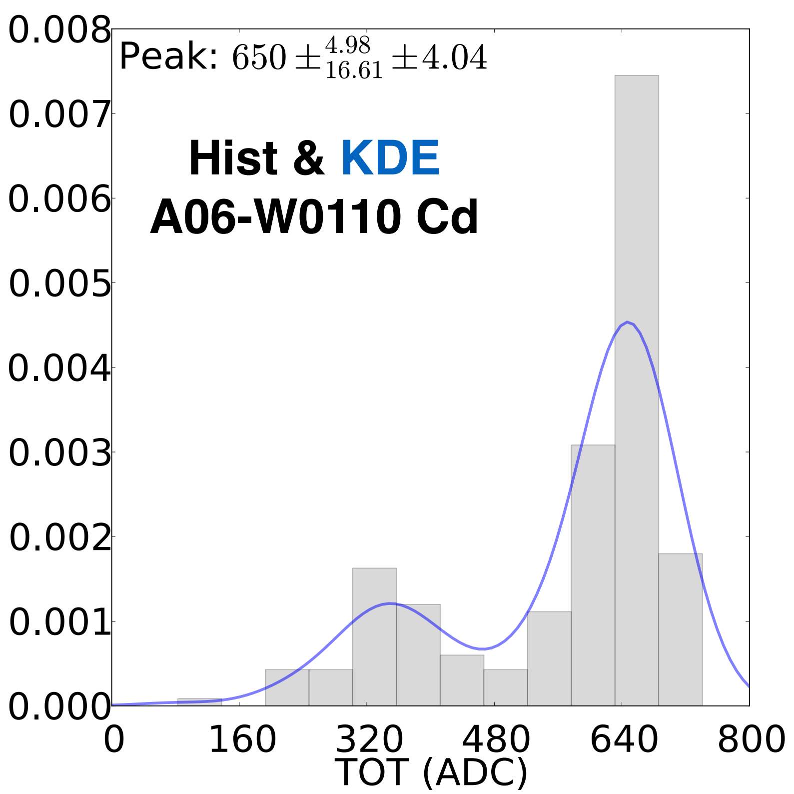
Assembly	^{55}Fe	^{57}Co	^{109}Cd	CuIn (XRF)	^{241}Am
A06-W0110	963	9	307	17	944
B06-W0125	1226	404	81	442	765
B07-W0125	1114	9	223	9	642
C04-W0110	1383	298	110	53	638
D09-W0126	900	20	109	14	976
L04-W0125	1741	310	171	14	1432

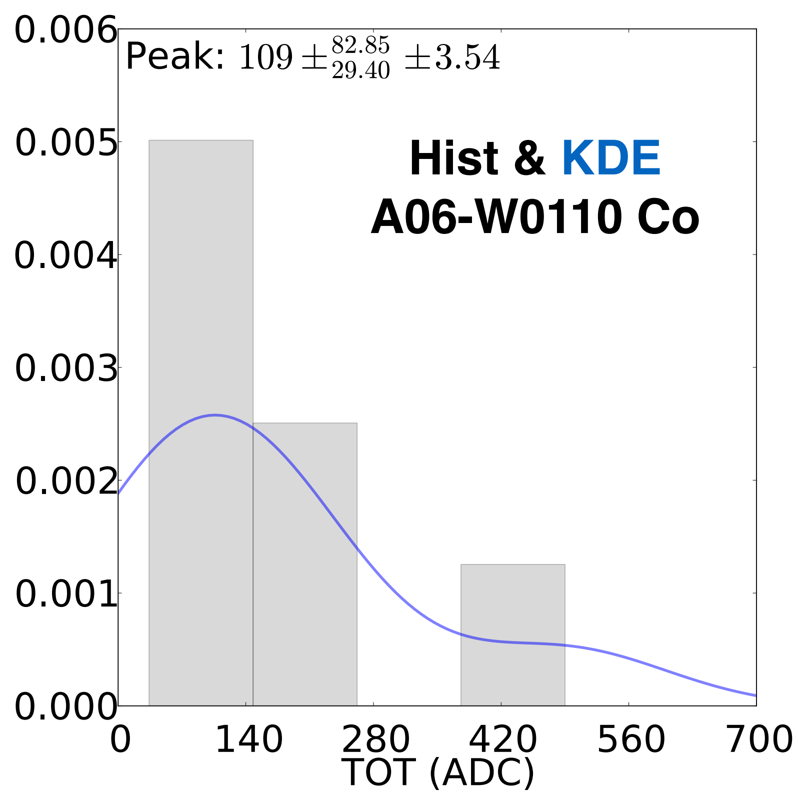
Peak finding with KDE

1. Kernel density estimation to find the most-likely TOT value(s)
2. Use gradient of KDE to identify peak(s)
   - peak: zero and falling





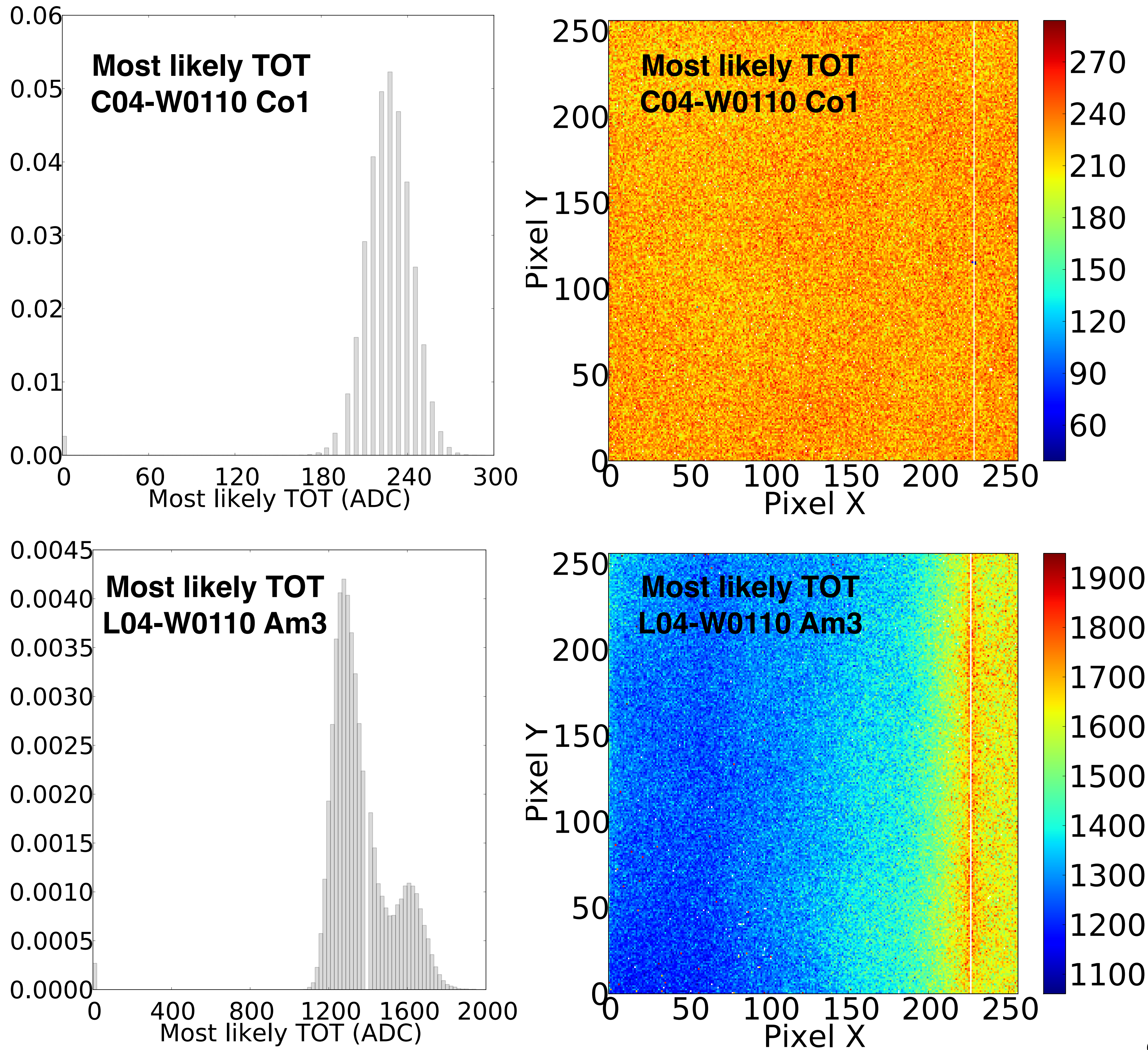




- Same method works at all levels of statistics, global and pixel by pixel (varying bandwidth)
- But peaks can be lost at low statistics

Most likely TOT per pixel

- Already gives indication on assembly uniformity
- Most assemblies seem uniform (like C04-W0110)
- L04-W0125 the most non-uniform



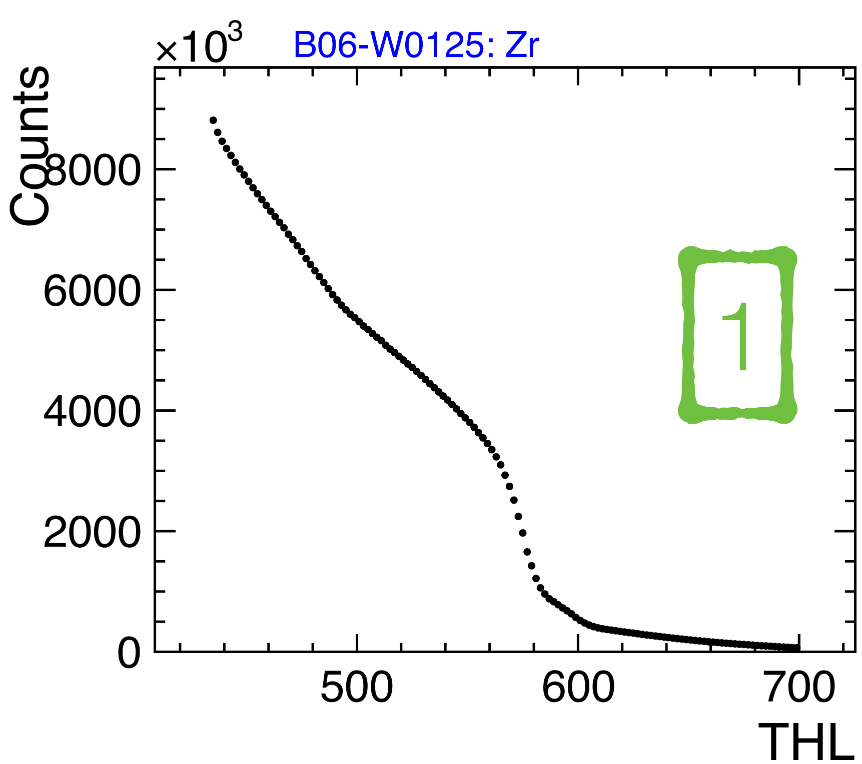
Threshold measurements

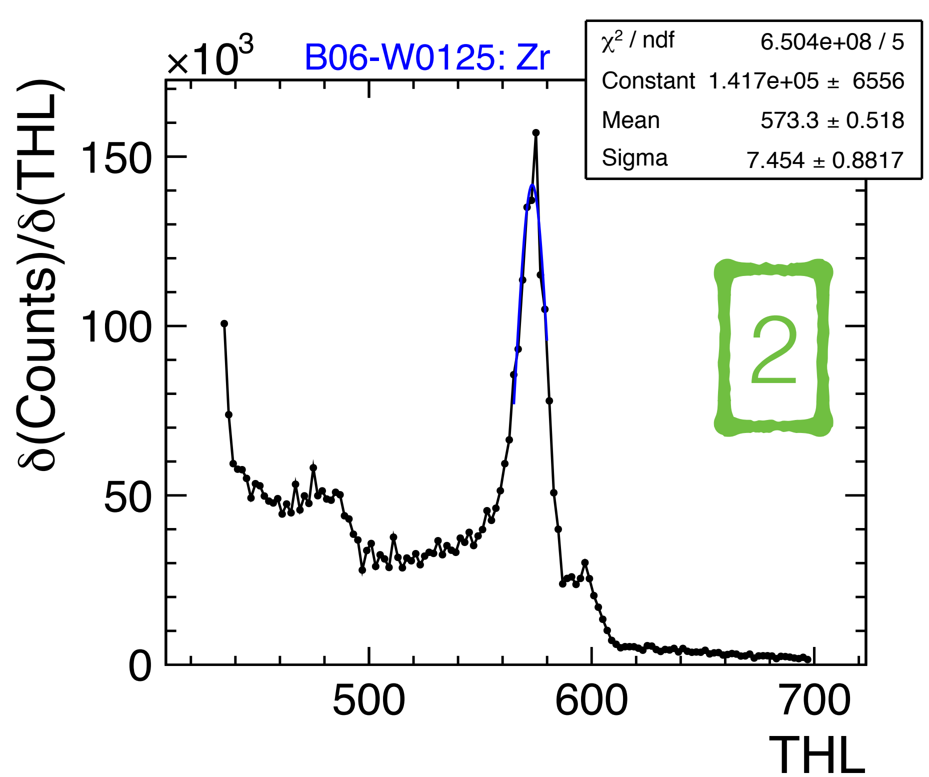
Performed in counting mode with X-ray fluorescence measurements at CERN

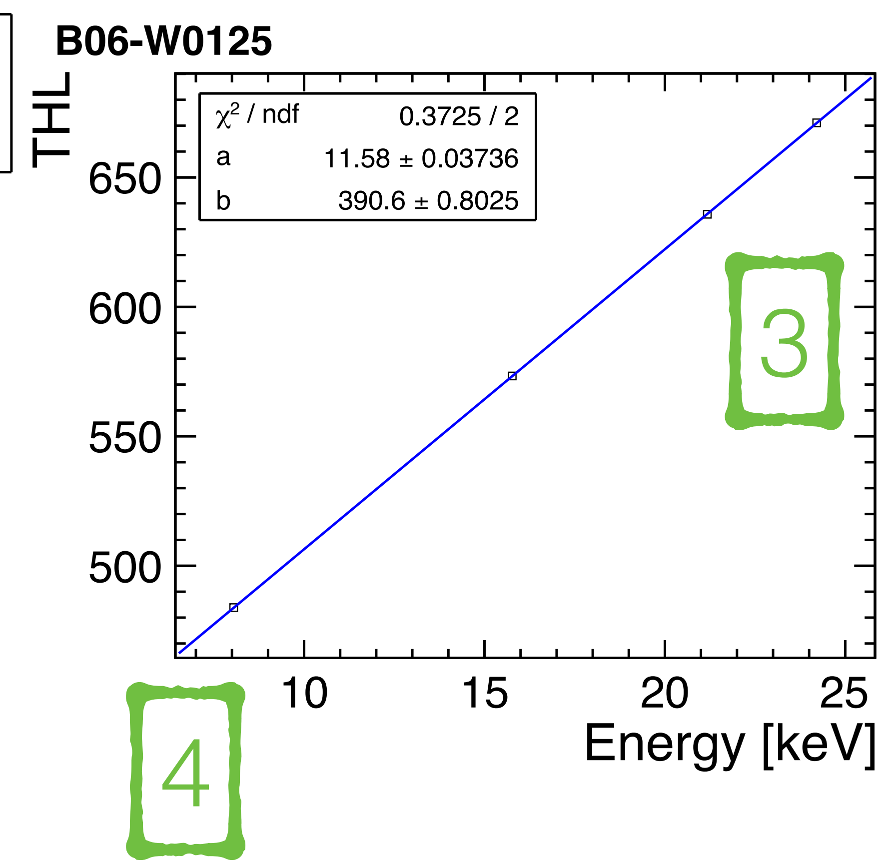
1. Count hits per frame whilst threshold is varied
2. Take derivative of count as a function of threshold, peak position

(Repeat for other photon sources)

3. Fit straight line to peak positions
4. Extrapolate to zero energy to find threshold in energy

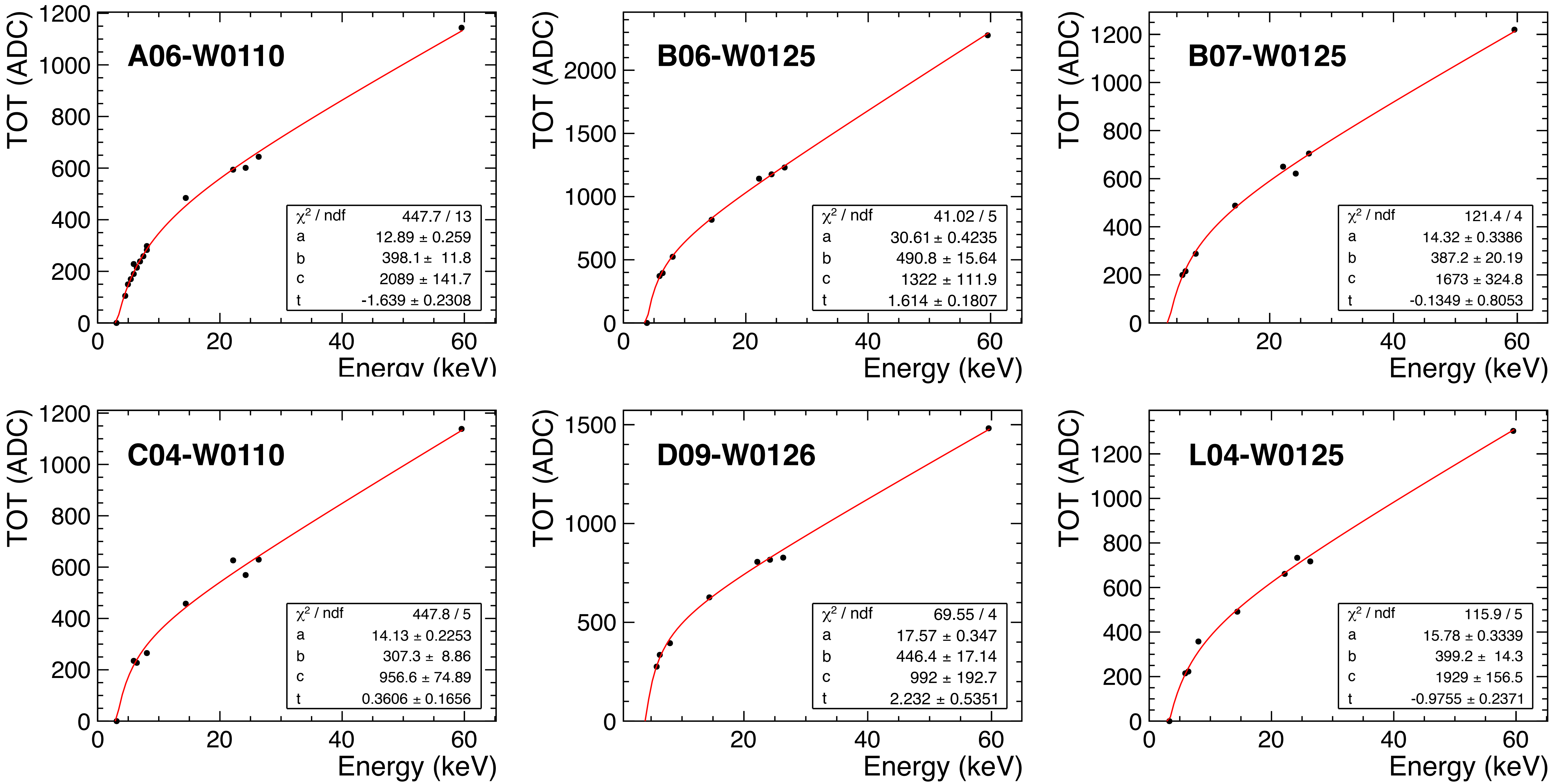






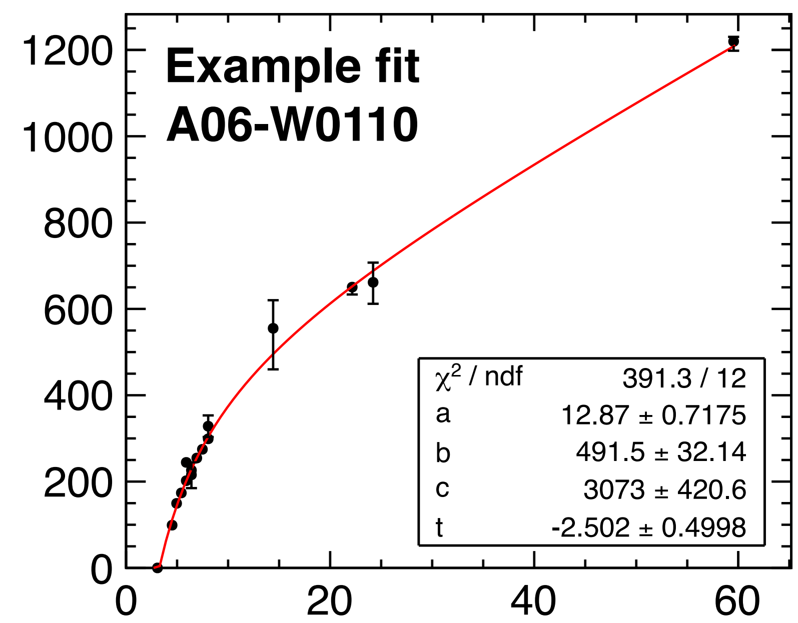
Surrogate fit - global

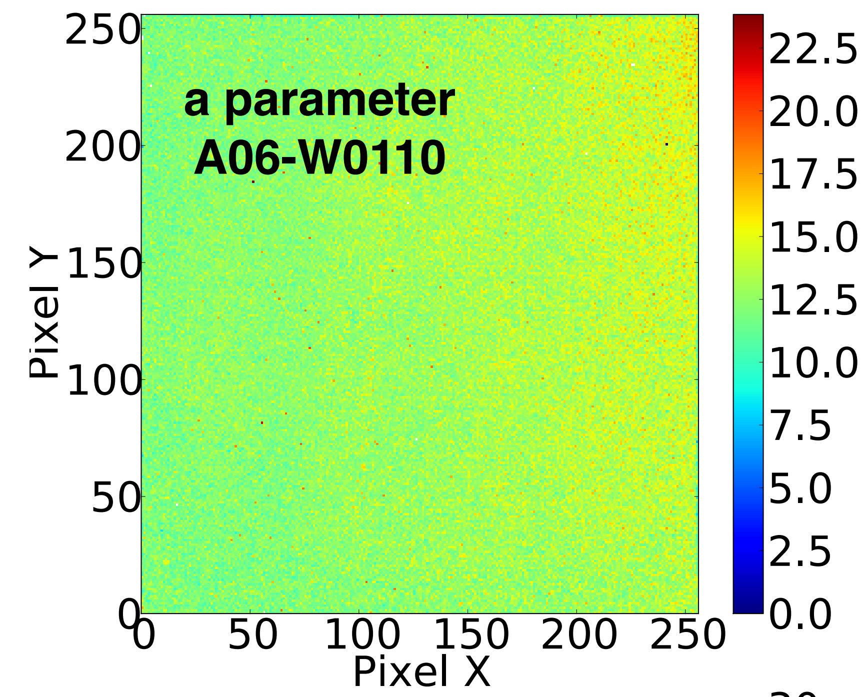
1. Global data points statistically extremely accurate
2. Systematics relevant

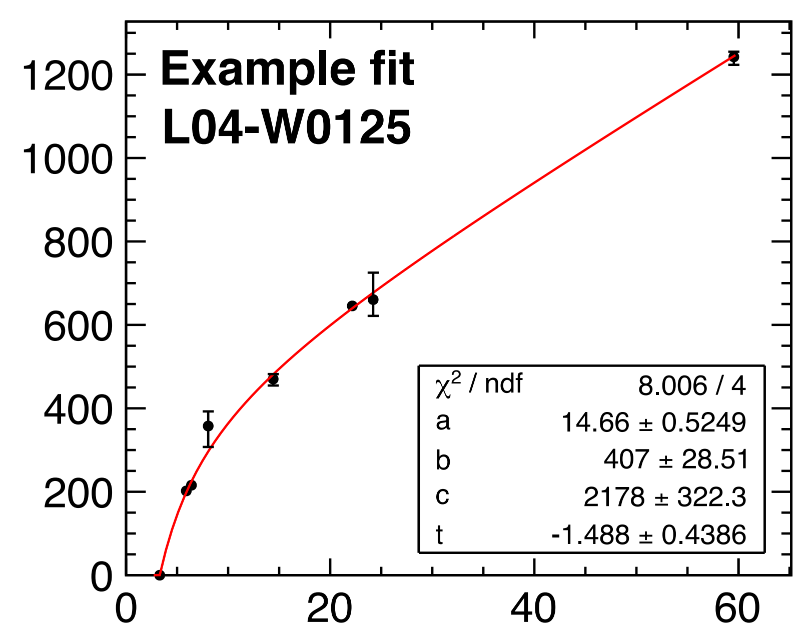


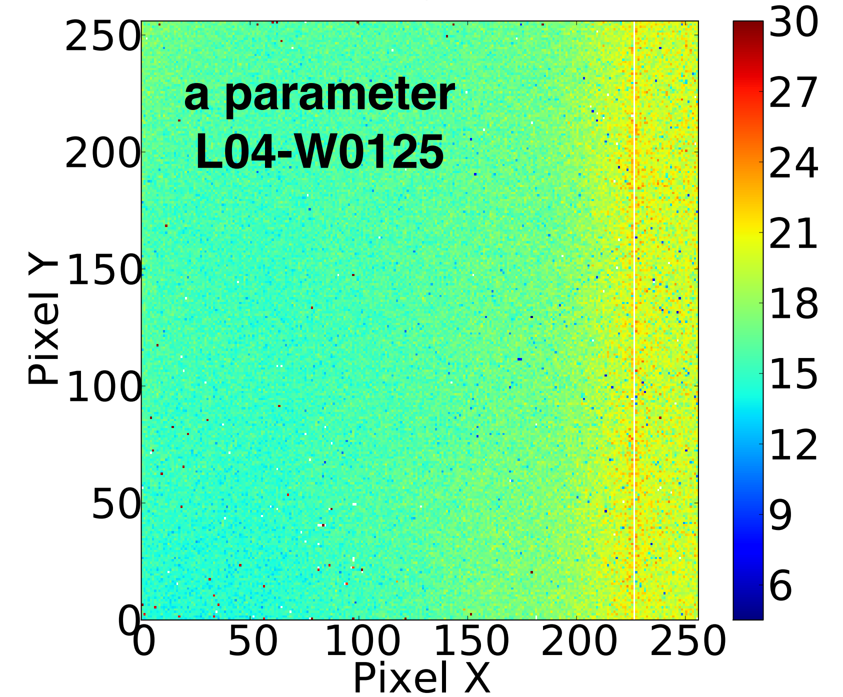
Surrogate fit - pixel

- The surrogate function has four degrees of freedom - a, b, c, t
- We require 5 data points to make the fit
- Maps of fitted parameters show assembly uniformity
- Still to come: a check to remove badly fit pixels (use χ^2/ndf, will need systematic uncertainties)







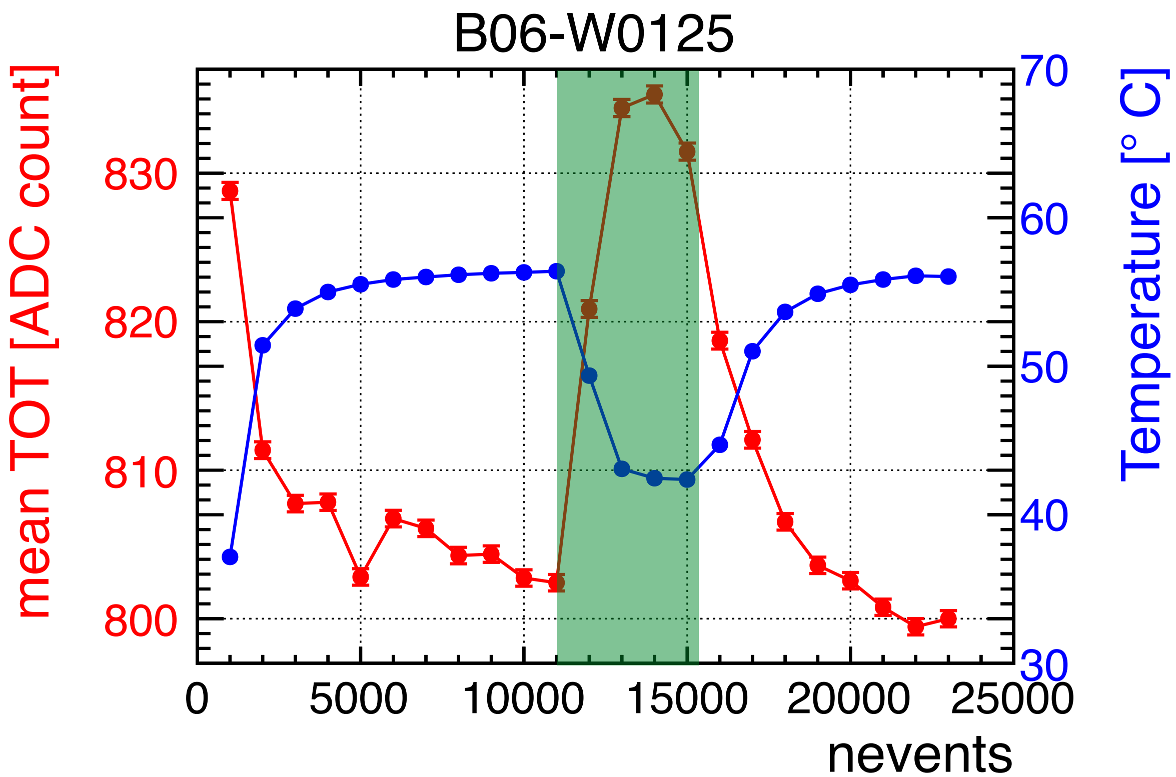


Number of pixels:

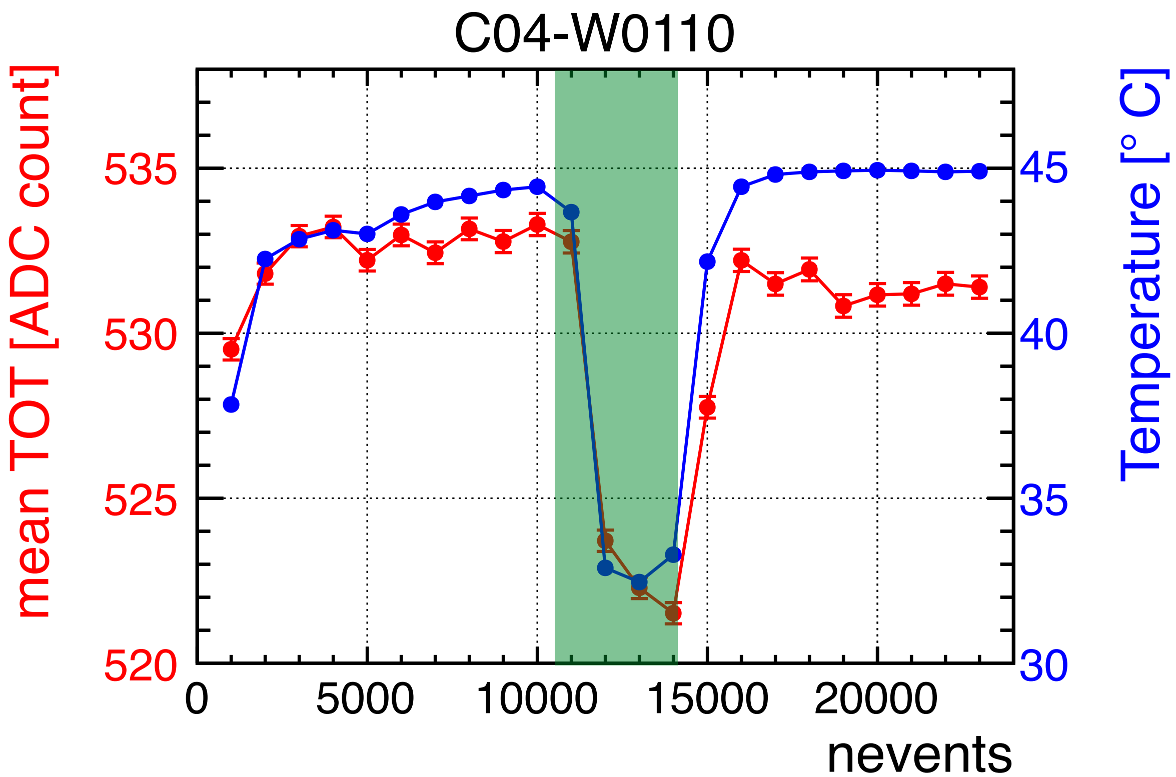
	A06-W0110	B06-W0125	B07-W0125	C04-W0110	D09-W0126	L04-W0125
Masked	8	789	394	493	293	344
No fit	14	789	549	500	315	344
Bad fit	still to come					

Temperature dependence

- Peak positions found to depend on time - due to temperature change
- Took data with fan on/off: ~12°C change means 2-3% change in TOT
  - in test-beam: no fan. lower occupancy might mean lower temperature
- What is the temperature (and it's variation) in test beam?
  - no fan, lower occupancy might mean lower temperature
  - temperature extraction from log files ongoing
  - might lead to systematic? scaling?



Cooling fan on

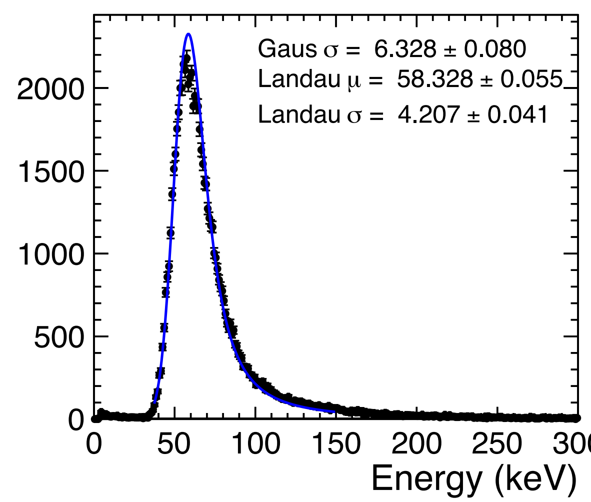


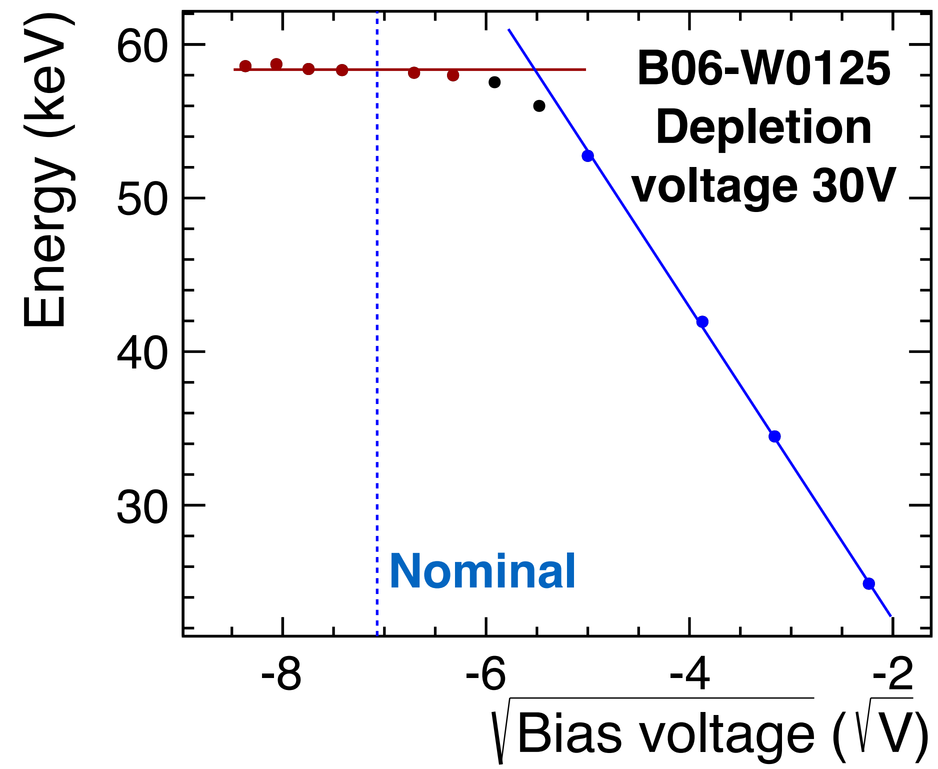
Cooling fan on

Application to test-beam

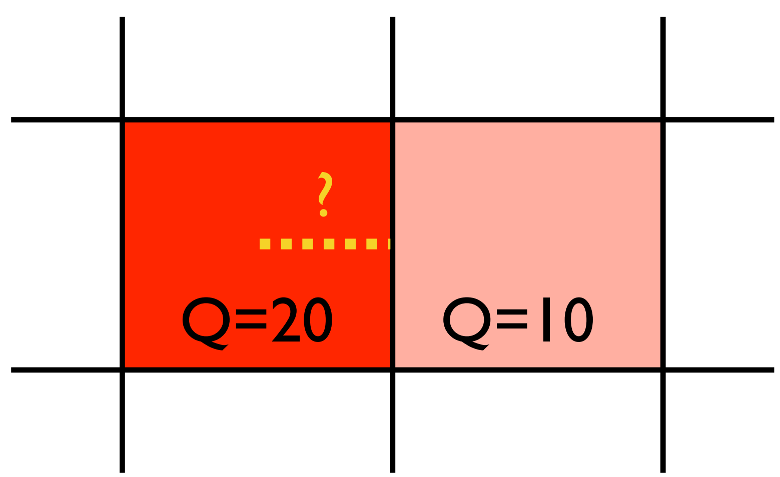
Once the calibration is finalised it will be applied to test-beam data in order to calculate:

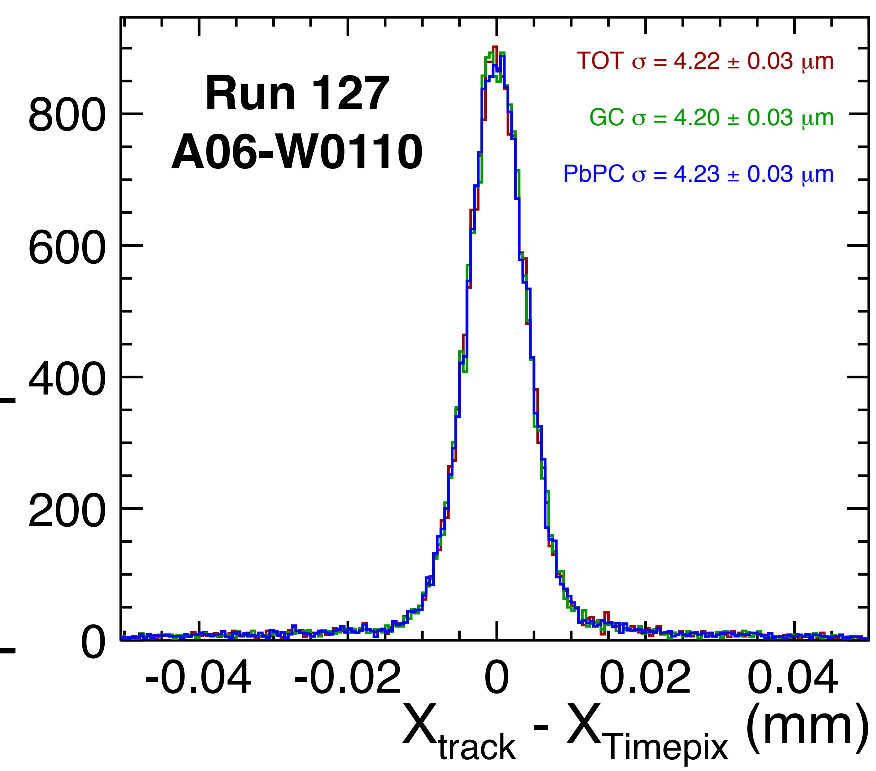
1. sensor depletion voltage
    - TOT to energy
    - Landau peak position
    - with varying bias V
    - plateau marks
      fully depleted region





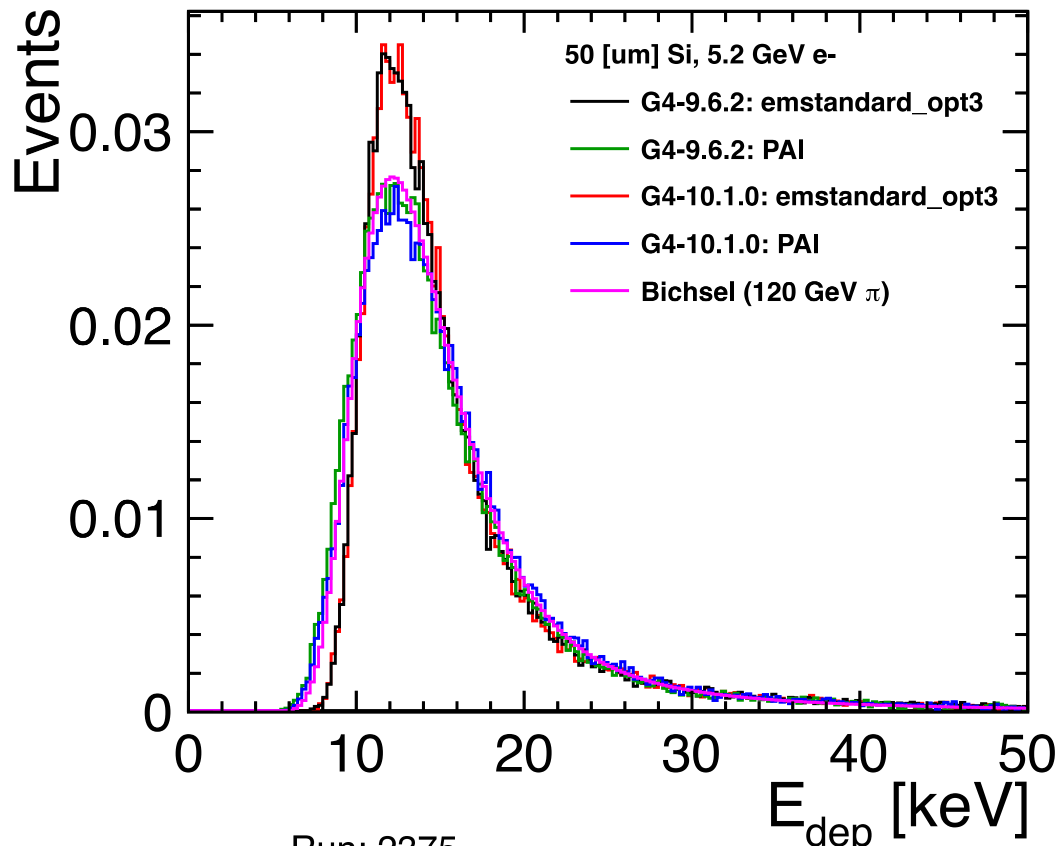
2. single-point resolution from energy
    - eta correction method uses ‘charge’
    - can use TOT or energy
    - calibrated energy
      might improve
      resolution

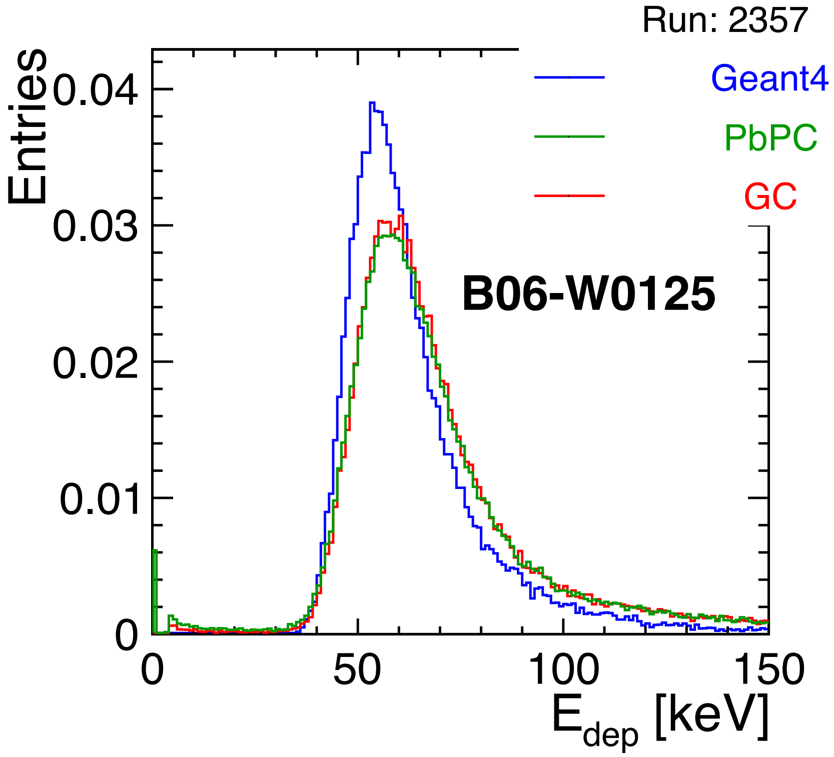


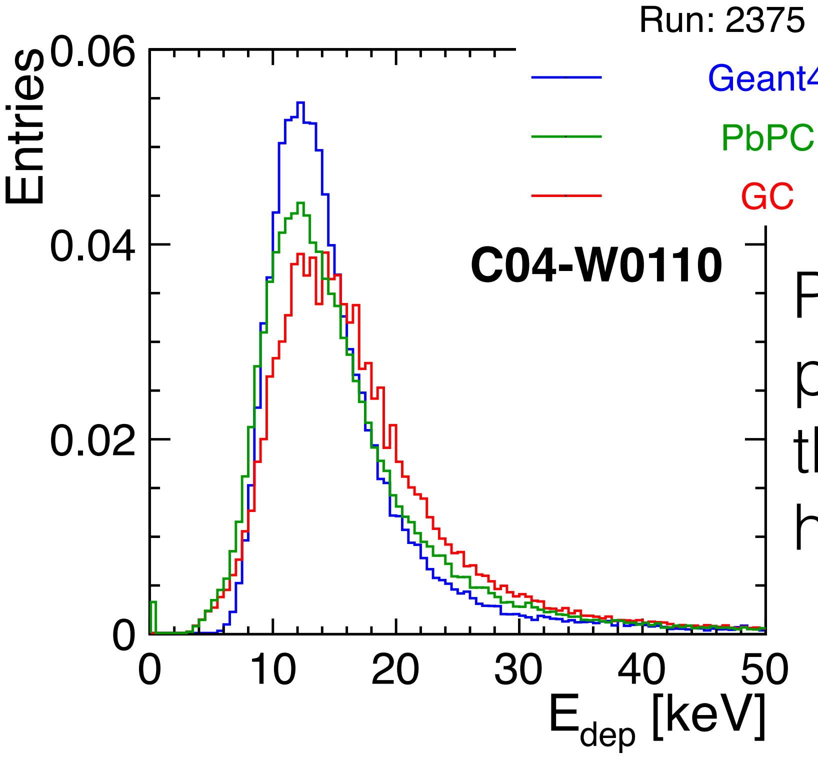


Simulation validation

1. Compare different models for the calculation of energy deposition in thin silicon sensors
   - GEANT4 PAI (Photoabsorption Ionization) model does the best
2. Comparison with data:
   - all clusters in data
   - no charge sharing or noise in GEANT4



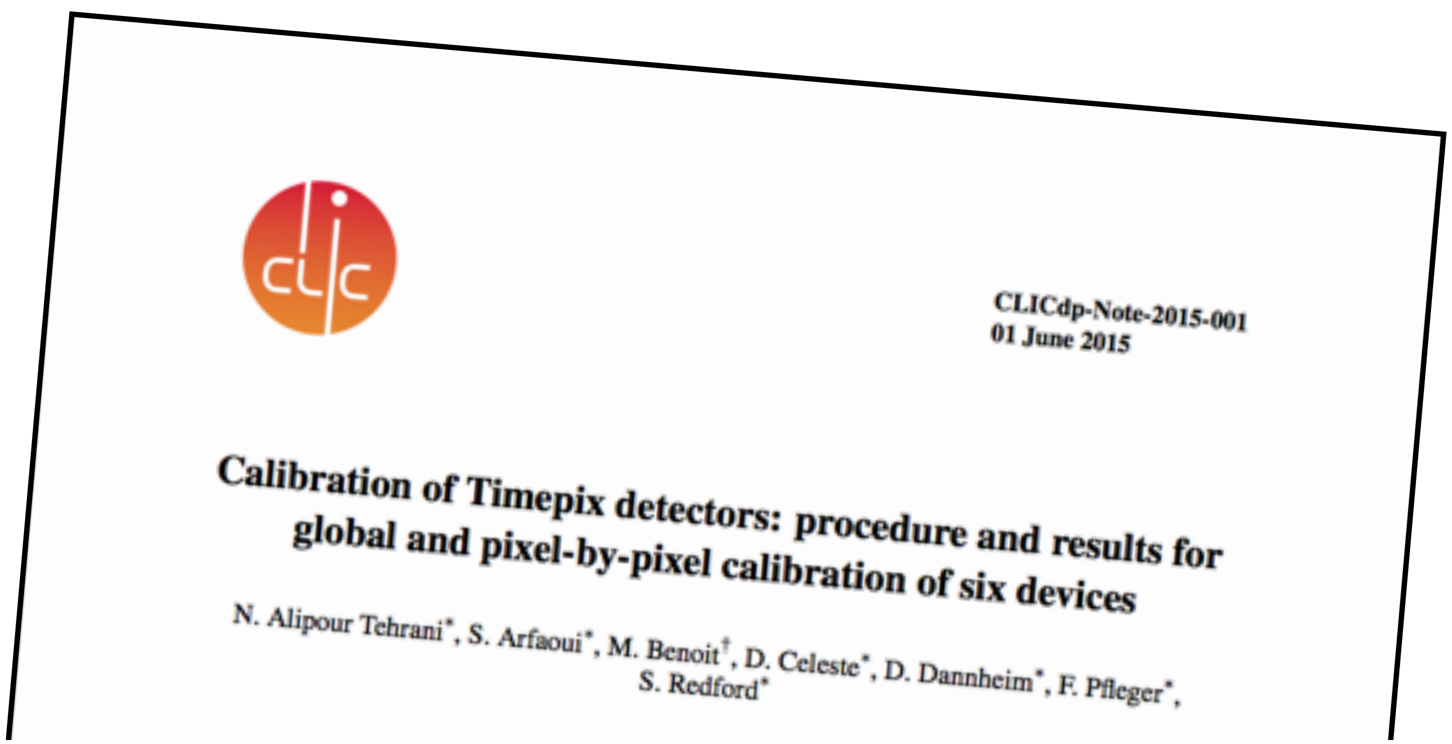




PbPC improves the peak position as well as the FWHM (full-width-half-maximum) of C04

Summary

- Six Timepix assemblies → data recorded → analysed **Thanks team!**
- Source and X-ray fluorescence measurements **from CERN and LNLS**
- Peak finding method **with Kernel Density Estimation**
- Threshold measurements **derived**
- Parametrisation of calibration **from Surrogate function fit**
- Assemblies **sometimes uniform, sometimes less so**
- **What's left:** systematics (temperature), then finalise test-beam, simulation
- **See for yourself:**
  https://svnweb.cern.ch/trac/clicdet/browser/trunk/doc/Timepix_Calibration/
  https://github.com/LCDsoft/TimepixCalibration


CLICdp-Note-2015-001
01 June 2015

Calibration of Timepix detectors: procedure and results for global and pixel-by-pixel calibration of six devices

N. Alipour Tehrani*, S. Arfaoui*, M. Benoit†, D. Celeste*, D. Dannheim*, F. Pfleger*, S. Redford*

Thanks for your attention!