ESR2

Pileup, simulations and test beams

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Outline

- Summary of research activities
- List of publications
- Pileup in hybrid pixel detectors
- Simulations of the Dosepix frontend
- High flux measurements with Dosepix
  - Count rate linearity
  - Spectral response
- Conclusions

Research activities and conferences

An overview of since the last workshop

- Developing a read out software for Dosepix
- Dosepix characterization at the ANKA Synchrotron
  - Results presented at the Medipix meeting
  - Article ready for submission
- Short secondment in Prague
- Timepix3 beam time at LANSCE Los Alamos with IEAP/CTU
  - Results partially presented by B. Bergmann
- Invited talk at the IEEE NSS Conference in Seattle
  - Characterization of CZT sensors bonded to Medipix3RX
- Invited seminar at IRA in Lausanne
- Presentations at Medipix meetings
- Argon ion test beam at SPS
- Timepix3 presentation at the Spectral X-ray Imaging Workshop at CERN

List of publications

Peer reviewed

[1] E. Frojdh et al. "Timepix3: first measurements and characterization of a hybrid-pixel detector working in event driven mode". In: *Journal of Instrumentation* 10.01 (Jan. 2015), pp. C01039–C01039. DOI: 10.1088/1748-0221/10/01/C01039.

[2] S. George, C. Severino, E. Fröjdh, F. Murtas, and M. Silari. "Measurement of an accelerator based mixed field with a Timepix detector". In: *Journal of Instrumentation* 10.03 (Mar. 2015), P03005–P03005. DOI: 10.1088/1748-0221/10/03/P03005.

[3] E. N. Gimenez et al. "Medipix3RX: Characterizing the Medipix3 Redesign With Synchrotron Radiation". In: *IEEE Transactions on Nuclear Science* 62.3 (June 2015), pp. 1413–1421. DOI: 10.1109/TNS.2015.2425227.

[4] B. Norlin, S. Reza, D. Krapohl, E. Fröjdh, and G. Thungström. "Readout cross-talk for alpha-particle measurements in a pixelated sensor system". In: *Journal of Instrumentation* 10.05 (May 2015), pp. C05025–C05025. DOI: 10.1088/1748-0221/10/05/C05025.

[5] E. Frojdh et al. "Count rate linearity and spectral response of the Medipix3RX chip coupled to a 300μm silicon sensor under high flux conditions". In: *Journal of Instrumentation* 9.04 (Apr. 2014), pp. C04028–C04028. DOI: 10.1088/1748-0221/9/04/C04028.

[6] M. D. Gaspari et al. "Design of the analog front-end for the Timepix3 and Smallpix hybrid pixel detectors in 130 nm CMOS technology". In: *Journal of Instrumentation* 9.01 (Jan. 2014), pp. C01037–C01037. DOI: 10.1088/1748-0221/9/01/C01037.

[7] A. Schübel, D. Krapohl, E. Fröjdh, C. Fröjdh, and G. Thungström. "A Geant4 based framework for pixel detector simulation". In: *Journal of Instrumentation* 9.12 (Dec. 2014), pp. C12018–C12018. DOI: 10.1088/1748-0221/9/12/C12018.

[8] R. Ballabriga et al. "The Medipix3RX: a high resolution, zero dead-time pixel detector readout chip allowing spectroscopic imaging". In: *Journal of Instrumentation* 8.02 (Feb. 2013), pp. C02016–C02016. DOI: 10.1088/1748-0221/8/02/C02016.

[9] C. Fröjdh, B. Norlin, and E. Fröjdh. "Spectral X-ray imaging with single photon processing detectors". In: *Journal of Instrumentation* 8.02 (Feb. 2013), pp. C02010–C02010. DOI: 10.1088/1748-0221/8/02/C02010.

[10] E. Frojdh et al. "Probing Defects in a Small Pixellated CdTe Sensor Using an Inclined Mono Energetic X-Ray Micro Beam". In: *IEEE Transactions on Nuclear Science* 60.4 (Aug. 2013), pp. 2864–2869. DOI: 10.1109/TNS.2013.2257851.

[11] D. Krapohl et al. "Investigation of charge collection in a CdTe-Timepix detector". In: *Journal of Instrumentation* 8.05 (May 2013), pp. C05003–C05003. DOI: 10.1088/1748-0221/8/05/C05003.

[12] E. Fröjdh et al. "Depth of interaction and bias voltage depenence of the spectral response in a pixellated CdTe detector operating in time-over-threshold mode subjected to monochromatic X-rays". In: *Journal of Instrumentation* 7.03 (Mar. 2012), pp. C03002–C03002. DOI: 10.1088/1748-0221/7/03/C03002.

[13] D. Maneuski et al. "Imaging and spectroscopic performance studies of pixellated CdTe Timepix detector". In: *Journal of Instrumentation* 7.01 (Jan. 2012), pp. C01038–C01038. DOI: 10.1088/1748-0221/7/01/C01038.

[14] S. Reza et al. "Smart dosimetry by pattern recognition using a single photon counting detector system in time over threshold mode". In: *Journal of Instrumentation* 7.01 (Jan. 2012), pp. C01027–C01027. DOI: 10.1088/1748-0221/7/01/C01027.

[15] A. Fröjdh, E. Fröjdh, G. Thungström, C. Fröjdh, and B. Norlin. "Processing and characterization of a MEDIPIX2-compatible silicon sensor with 220μm pixel size". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 633 (May 2011), S78–S80. DOI: 10.1016/j.nima.2010.06.128.

[16] E. Fröjdh, B. Norlin, G. Thungström, and C. Fröjdh. "X-ray absorption and charge transport in a pixellated CdTe detector with single photon processing readout". In: *Journal of Instrumentation* 6.02 (Feb. 2011), P02012–P02012. DOI: 10.1088/1748-0221/6/02/P02012.

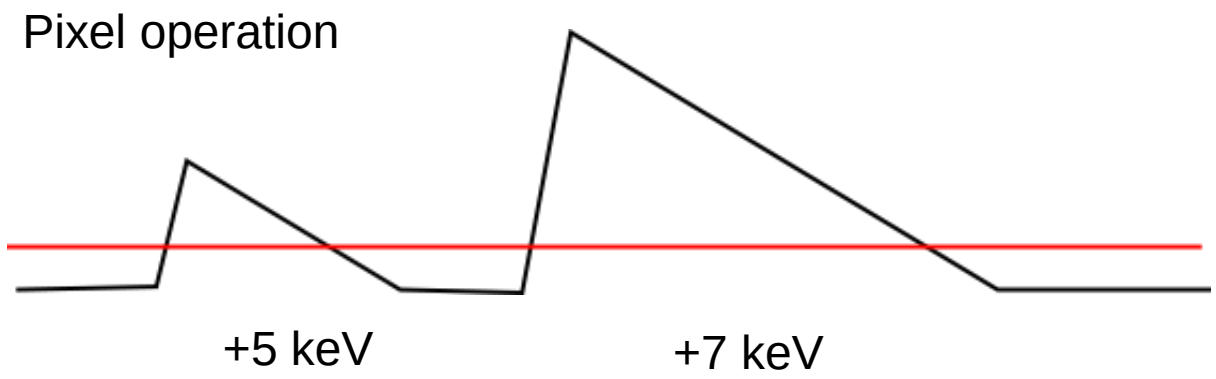
[17] E. Fröjdh, A. Fröjdh, B. Norlin, and C. Fröjdh. "Spectral response of a silicon detector with 220μm pixel size bonded to MEDIPIX2". In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 633 (May 2011), S125–S127. DOI: 10.1016/j.nima.2010.06.143.

Pulse Pileup in Hybrid Pixel Detectors

- Pileup when discussing accelerators (LHC) means several events in the same bunch crossing
  - The different events have to disentangled
- Pileup for hybrid pixel detectors is different and can be divided in two categories:
  - **Digital pileup,** the detector is not read out between events
  - **Analog pileup,** pulses from two or more particles overlap and are processed as a single pulse

Digital pileup

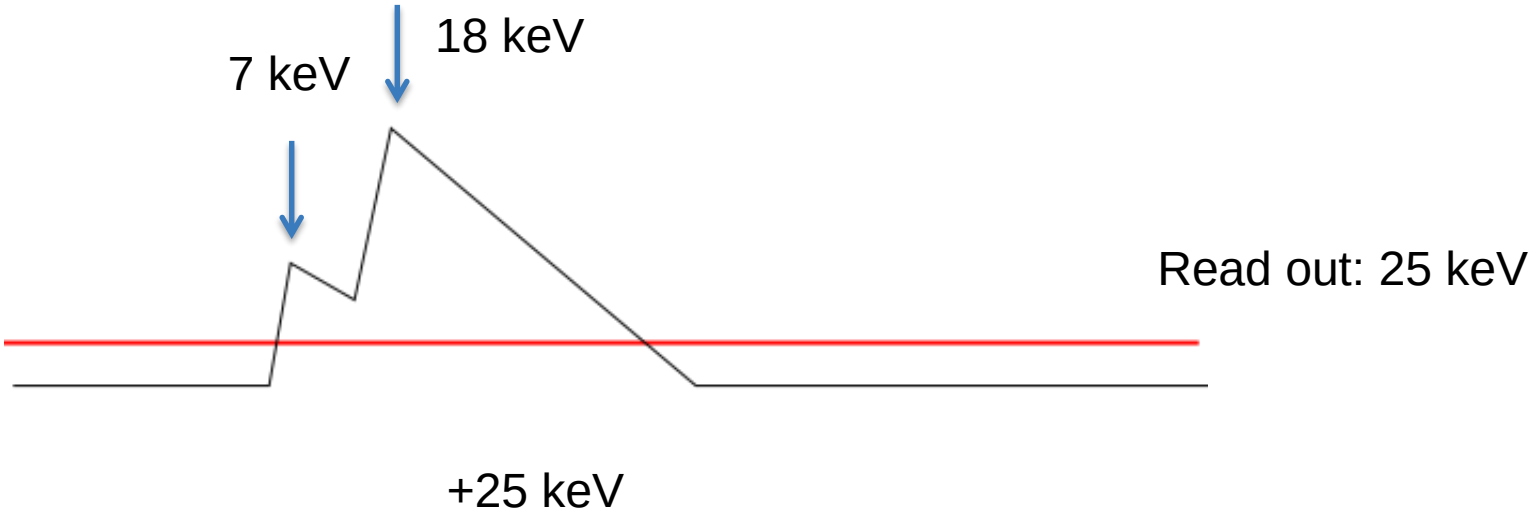
- The data from the first interaction is not read out in time and a second interaction is added to the first one
- Most common scenario for Timepix in TOT mode



Readout: 13 keV

Analogue pileup

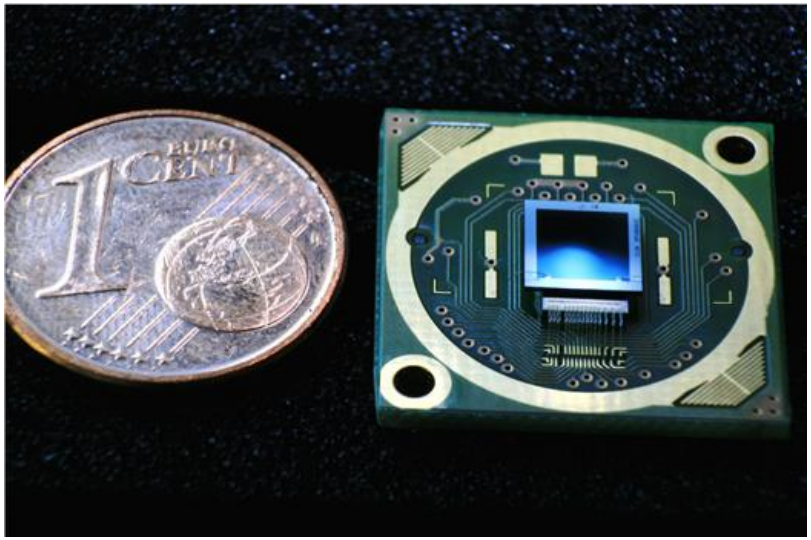
- Pileup in the analogue front end.
- Several pulses are threated as one large pulse
- Wrong amplitude because of overlap either at the tail or during the undershoot
- Most common in Medipix3RX/Dosepix during high flux applications such as X-ray imaging or tube characterization



Dosepix

- 220 x 220 μm^2 pixels size
- 16 x 16 pixels
- 4 rows of pixels with 55 x 55μm^2 sensitive area

- Energy binning mode
  - 12 bit ToT measurement @100MHz
  - 16 digital thresholds for event-by-event energy binning
  - 16x16bit counters
- Photon counting mode (8 bits)
- Integral ToT (24 bits)



Dosepix

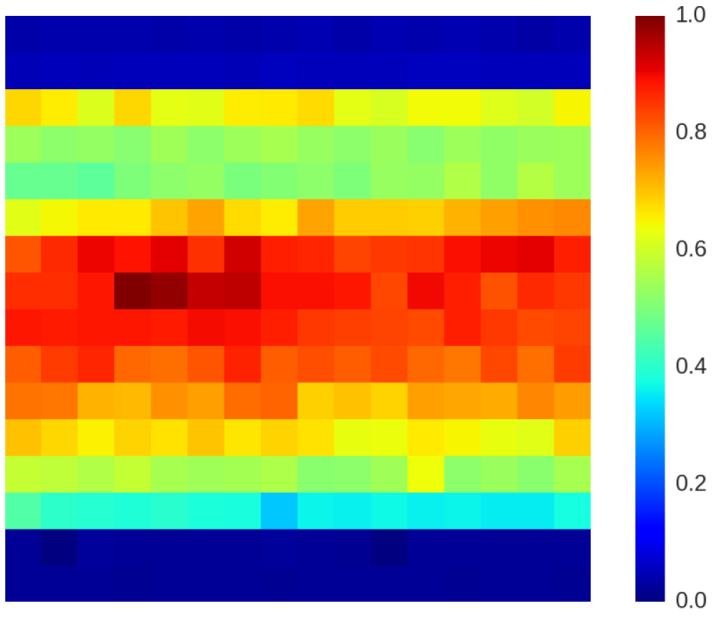
dpxctrl

- New read out software for Dosepix
- Python based
  - Linux and Windows
- High level interface
  - Data taking in PC, Binned TOT, Single hit TOT
  - Equalization
  - Calibration
- Access to low level functions
- Easy integration in measurement procedures
  - Script based or interactive
- Utilizes numpy data structures
- Compatible with DPSim fileformat
- Open source and available for Dosepix users
  - https://bitbucket.org/erikfrojdh/dpxctrl

Measurement Setup

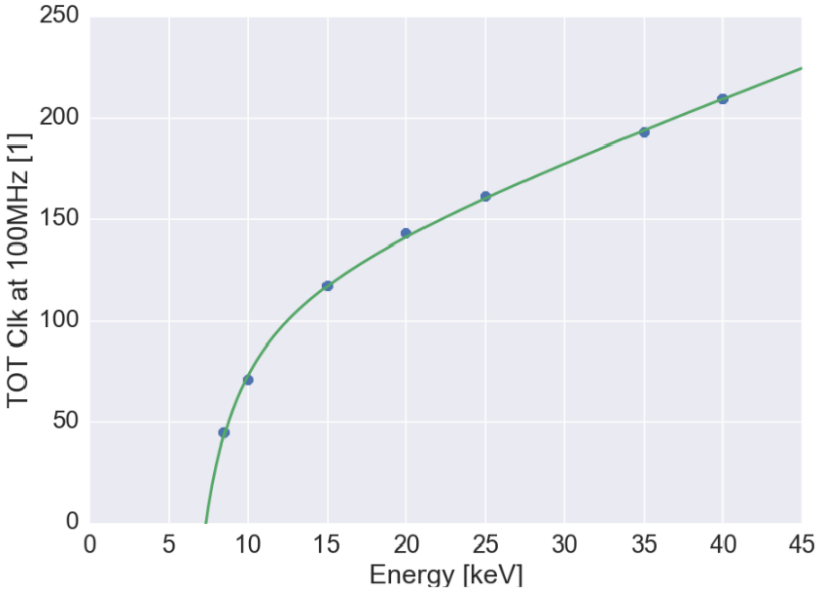
- Dosepix detector with 300 um silicon sensor
- IBA Testboard + dpxctrl software
- Monochromatic photons 8.5 – 40 keV at the ANKA synchrotron in Karlsruhe
- Intensity controlled using aluminum filters

- Energy calibration
- Count rate linearity
  - Dead time fit
- Spectral response
- Simulations

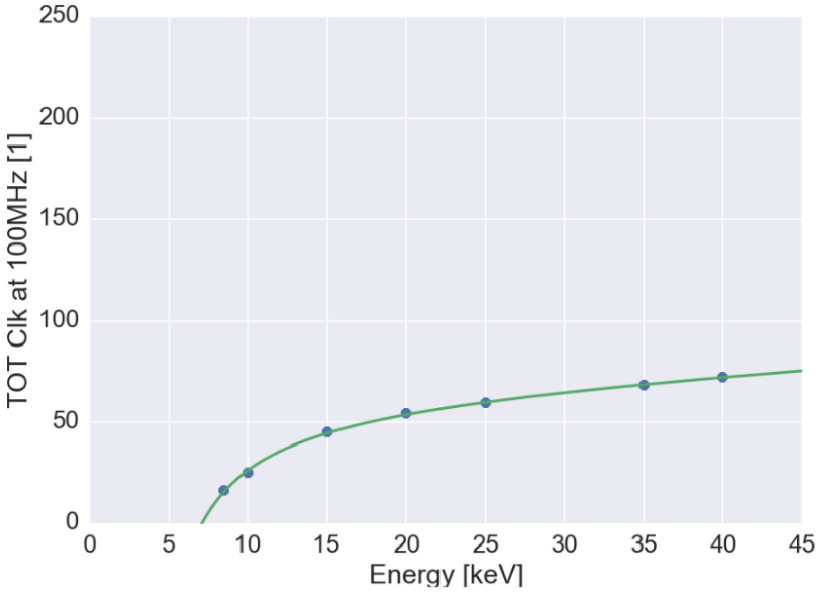


Beam profile

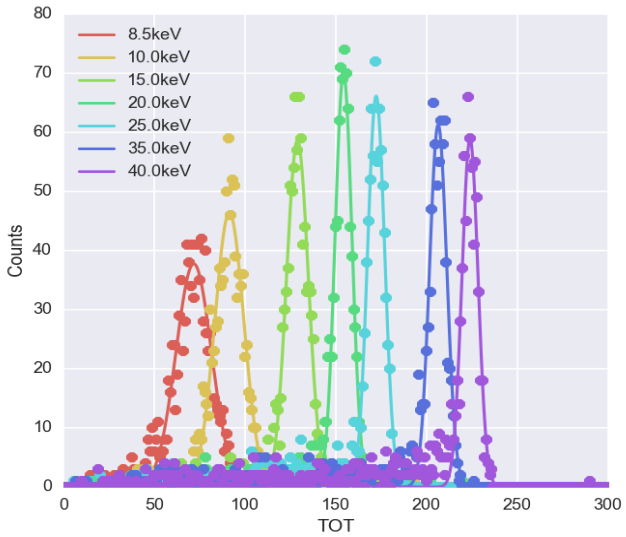
Energy Calibration

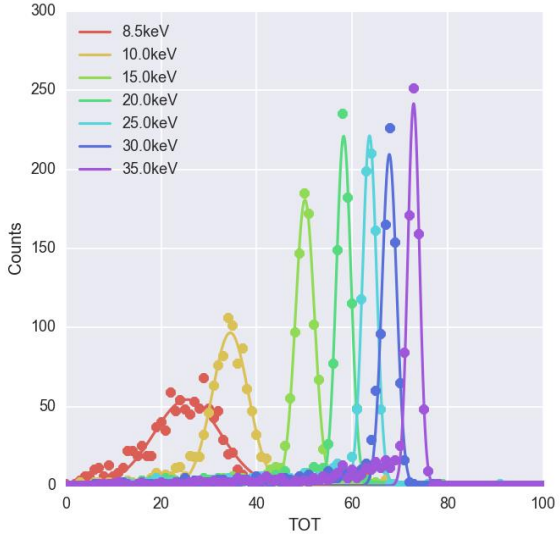


a) IKRUM = 15



b) IKRUM = 60



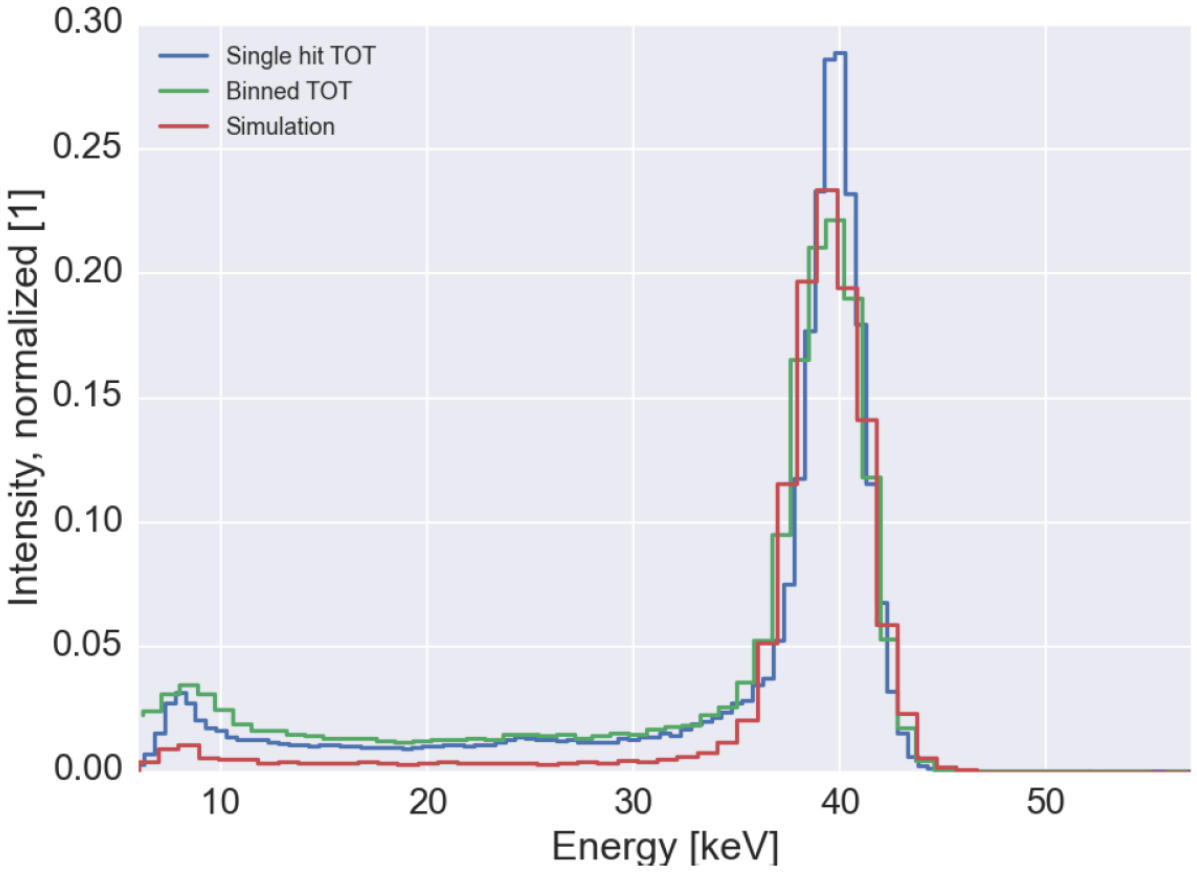


Energy Resolution

	Ikrum 15		Ikrum 60	
Energy	**keV**	**%**	**keV**	**%**
8.5	**1.43**	16.8	**2.17**	25.5
10	**1.66**	16.6	**2.17**	21.7
15	**2.40**	16.0	**2.35**	15.7
20	**2.81**	14.0	**2.91**	14.6
25	**2.90**	11.6	**3.17**	12.7
30	**-**		**-**	
35	**3.12**	8.92	**3.62**	10.3
40	**3.18**	7.95	**3.79**	9.48

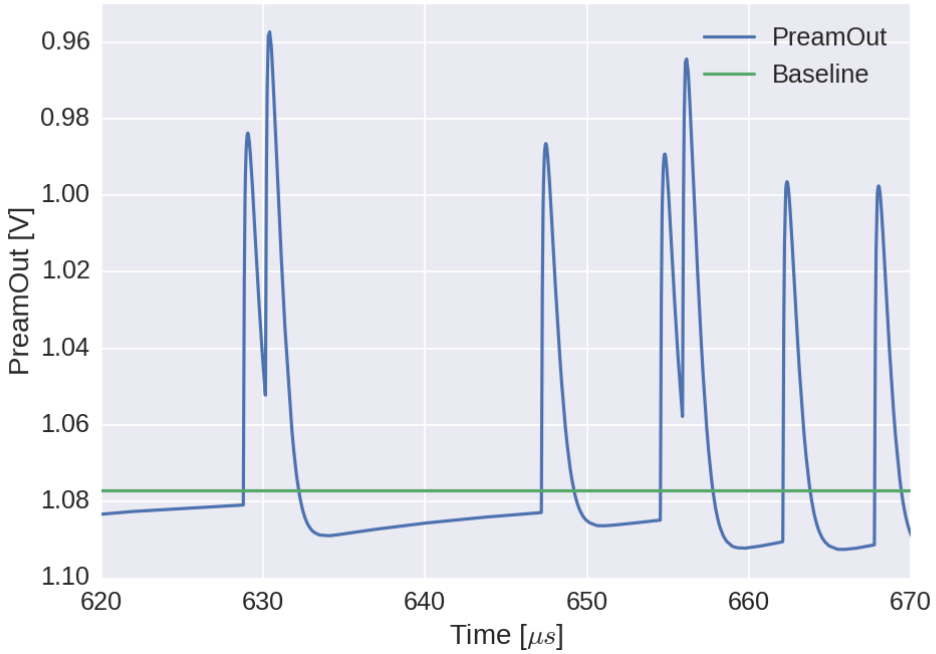
Mean single pixel energy resolution

Energy Response in Binned Mode



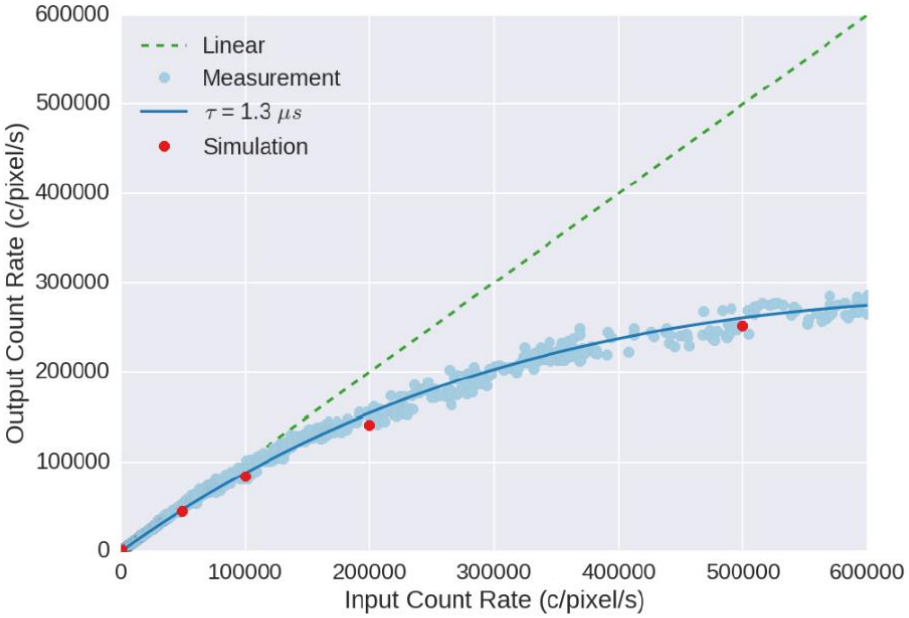
Pileup Simulations

- Dosepix circuit is simulated in Virtuoso Analog Design Environment (Winnie Wong)
- Square pulses (5 ns width) arriving randomly in time
- Using preamp output and measuring TOT applying the same data processing as for the measurement data

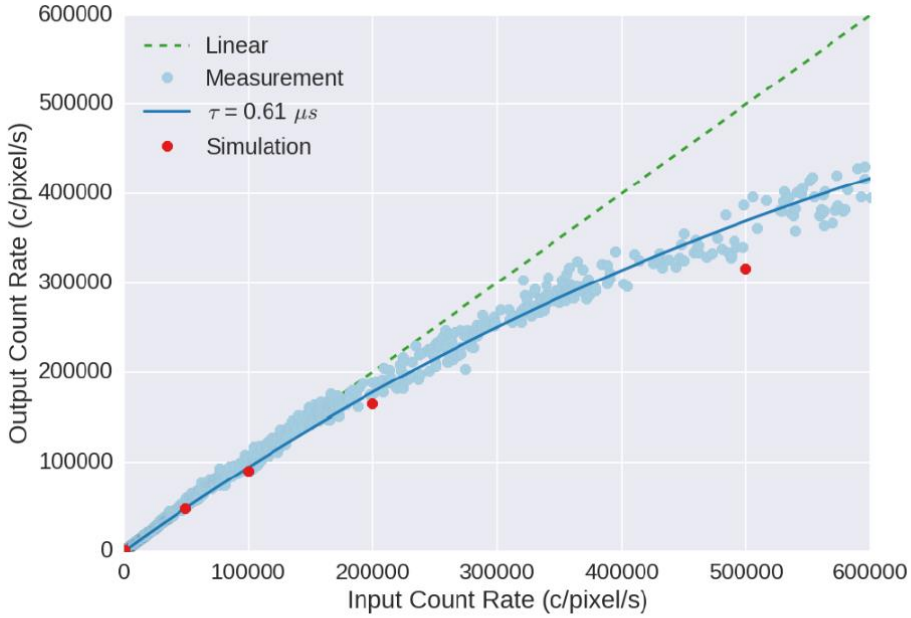


40 keV photons at 100 kHz / pixel

Pileup Measurements at 40 keV



a) IKRUM = 15



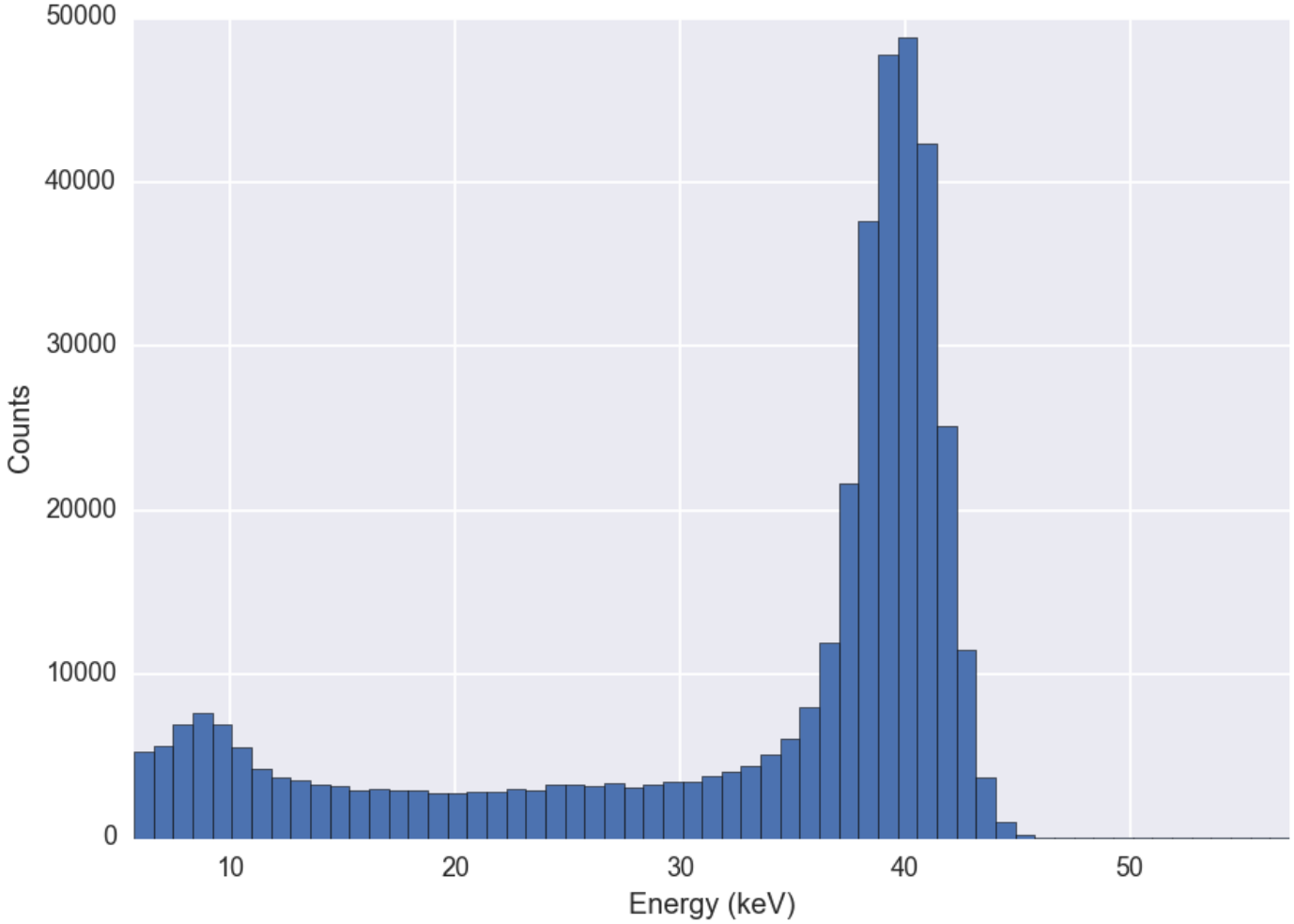
b) IKRUM = 60

Threshold: 5.5 keV

Summary of Pileup Measurements and Simulations

		Measurement with Detector			Frontend Simulation	
Energy [keV]	IKRUM [Code]	τ [μs]	$I_{0.9}$ [Mcps/mm^2]	I_{photon} [Mcps/mm^2]	τ [μs]	$I_{0.9}$ [Mcps/mm^2]
17	15	1.23	1.77	4.99	1.34	1.62
	60	0.50	4.35	12.3	0.82	2.65
	255	-	-	-	0.64	3.40
30	15	1.29	1.69	19.7	1.27	1.71
	60	0.53	4.11	47.8	0.89	2.45
	255	-	-	-	0.71	3.07
40	15	1.3	1.67	38.8	1.40	1.55
	60	0.61	3.57	83.0	0.93	2.34
	255	-	-	-	0.73	2.98

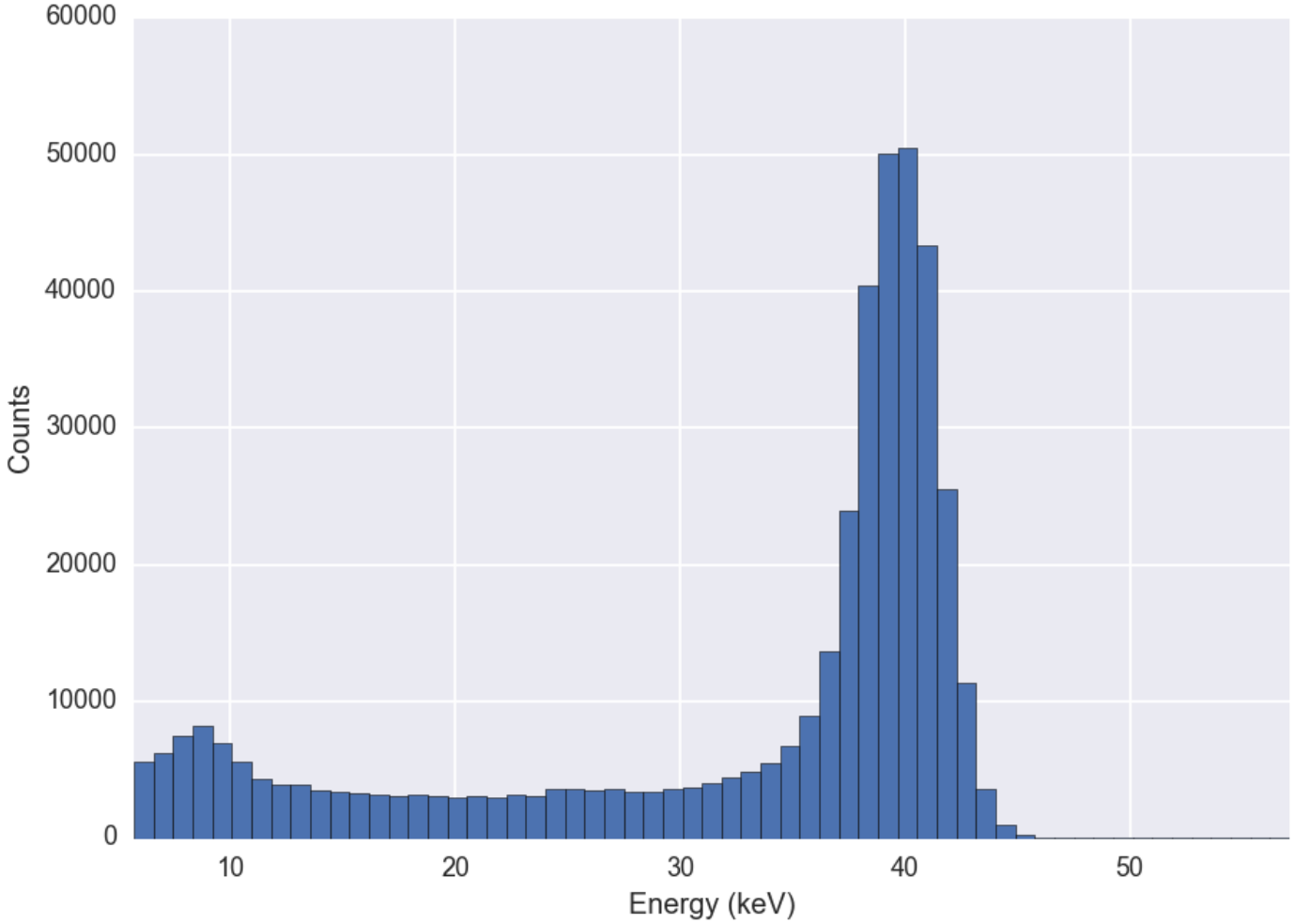
40keV



Input Count Rate 2.8 x 10^2 counts/pixel/s

5.8 x 10^3 counts/mm^2/s

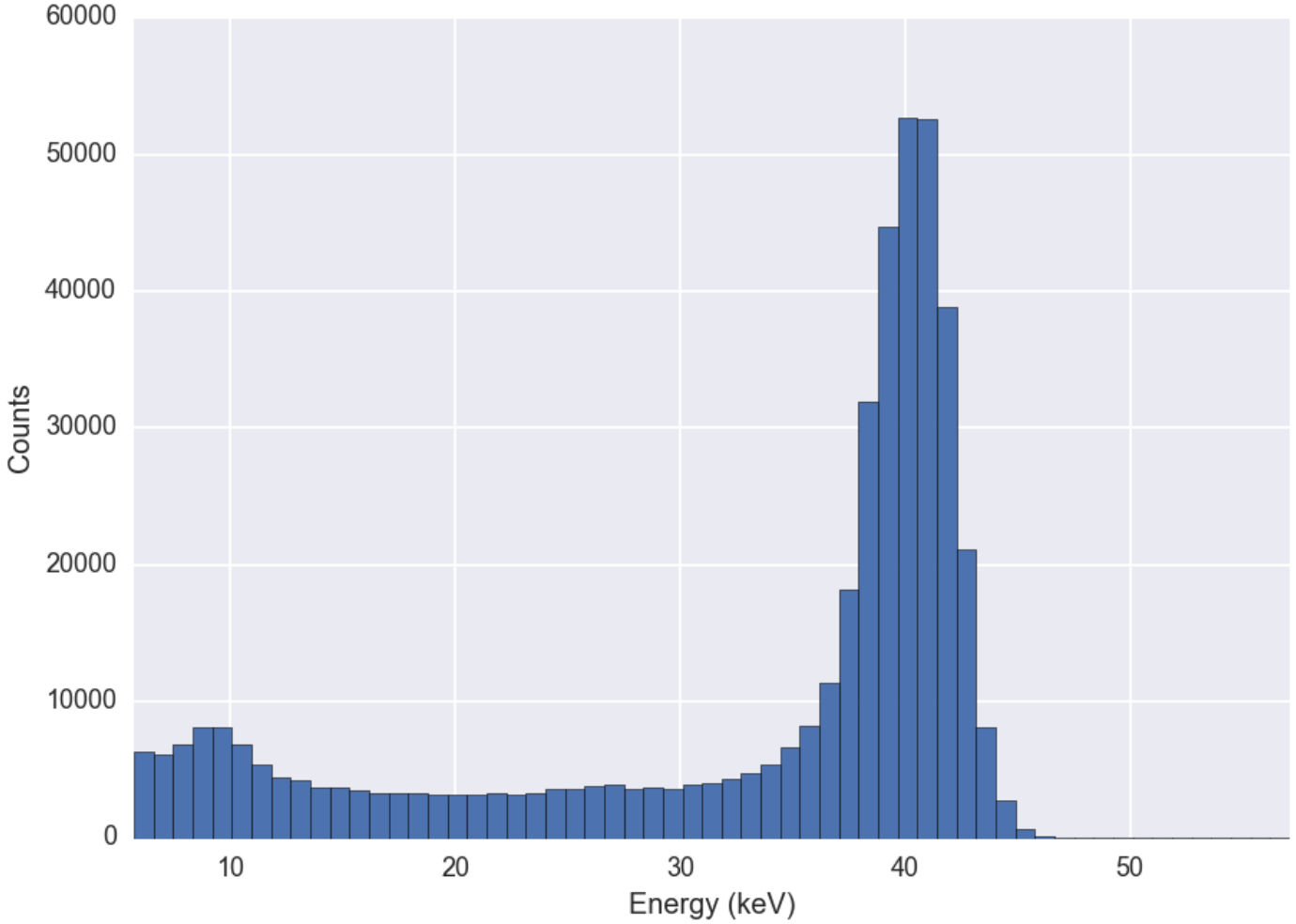
40keV



Input Count Rate 6.1 x 10^2 counts/pixel/s

1.2 x 10^4 counts/mm^2/s

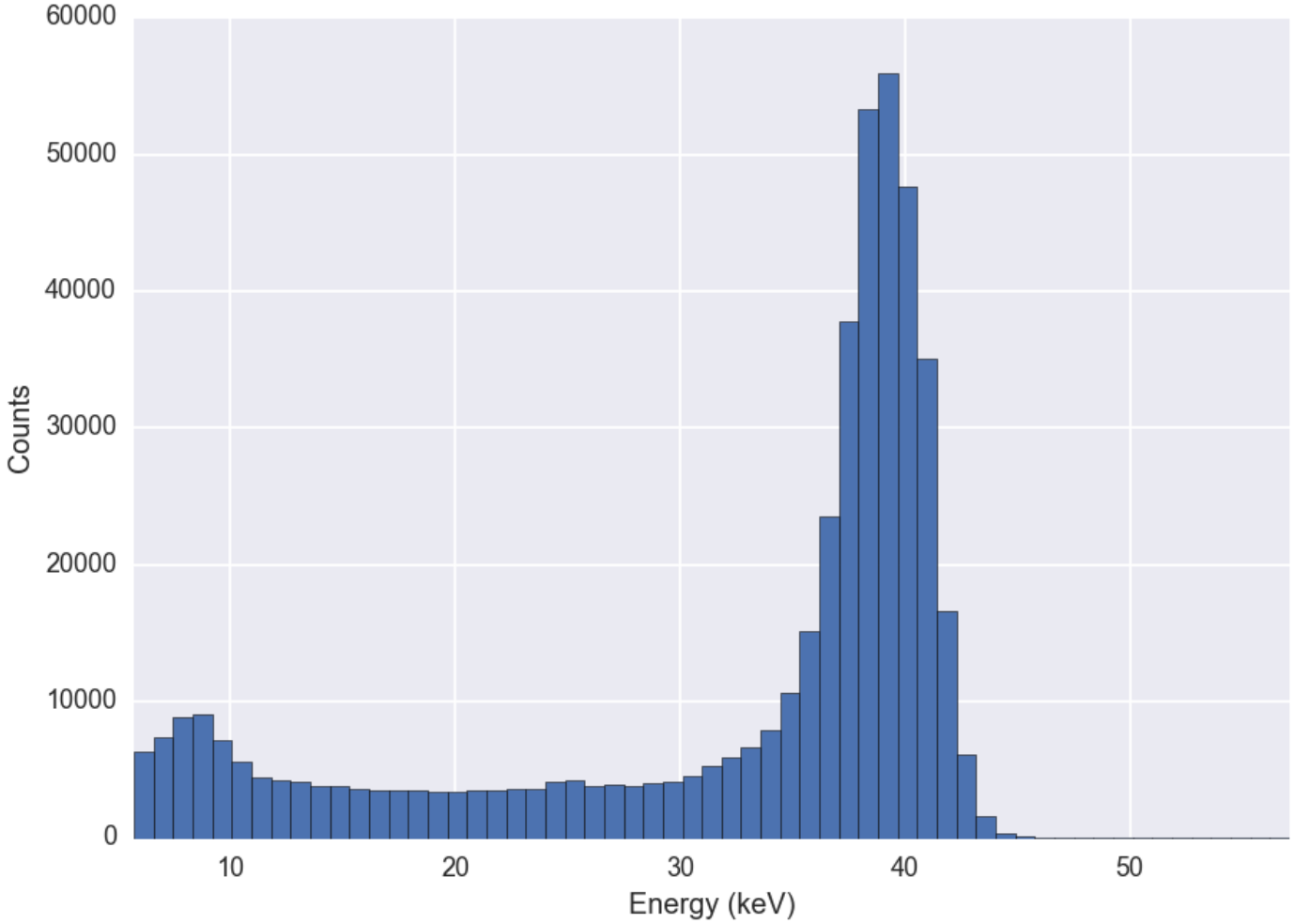
40keV



Input Count Rate 1.3 x 10^3 counts/pixel/s

2.7 x 10^4 counts/mm^2/s

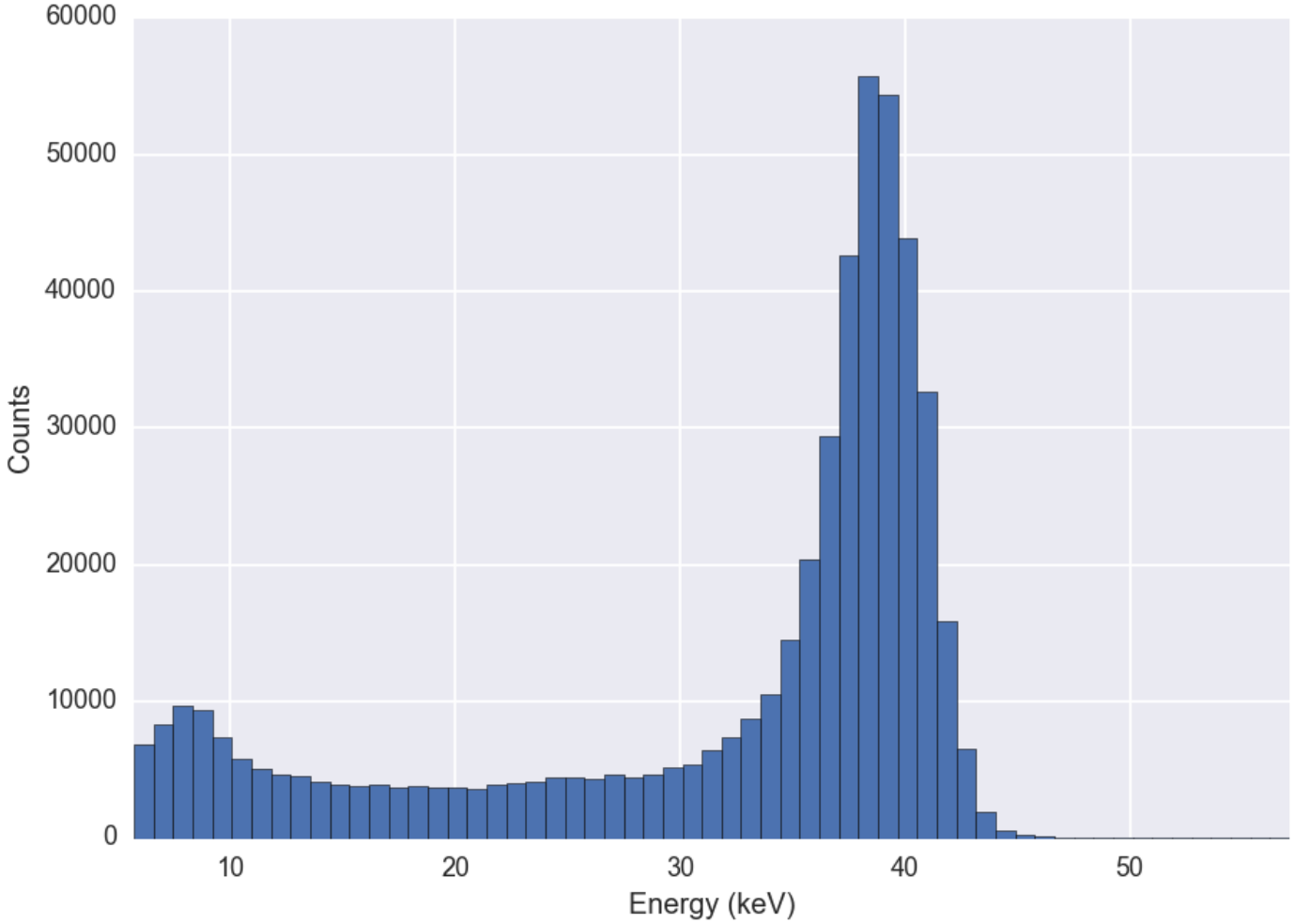
40keV



Input Count Rate 2.8×10^3 counts/pixel/s

5.8×10^4 counts/mm^2/s

40keV



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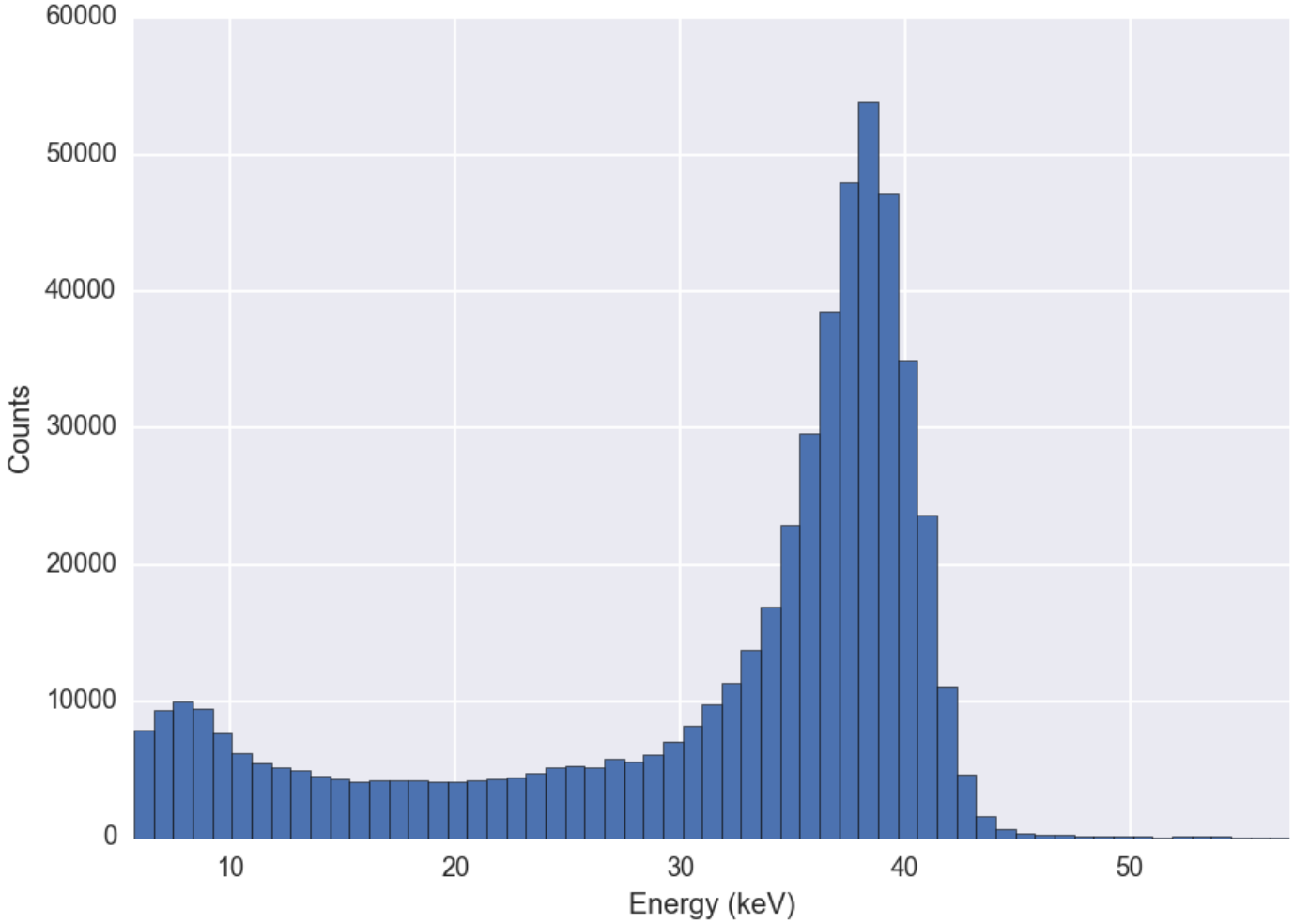
1.2 x 10^5 counts/mm^2/s

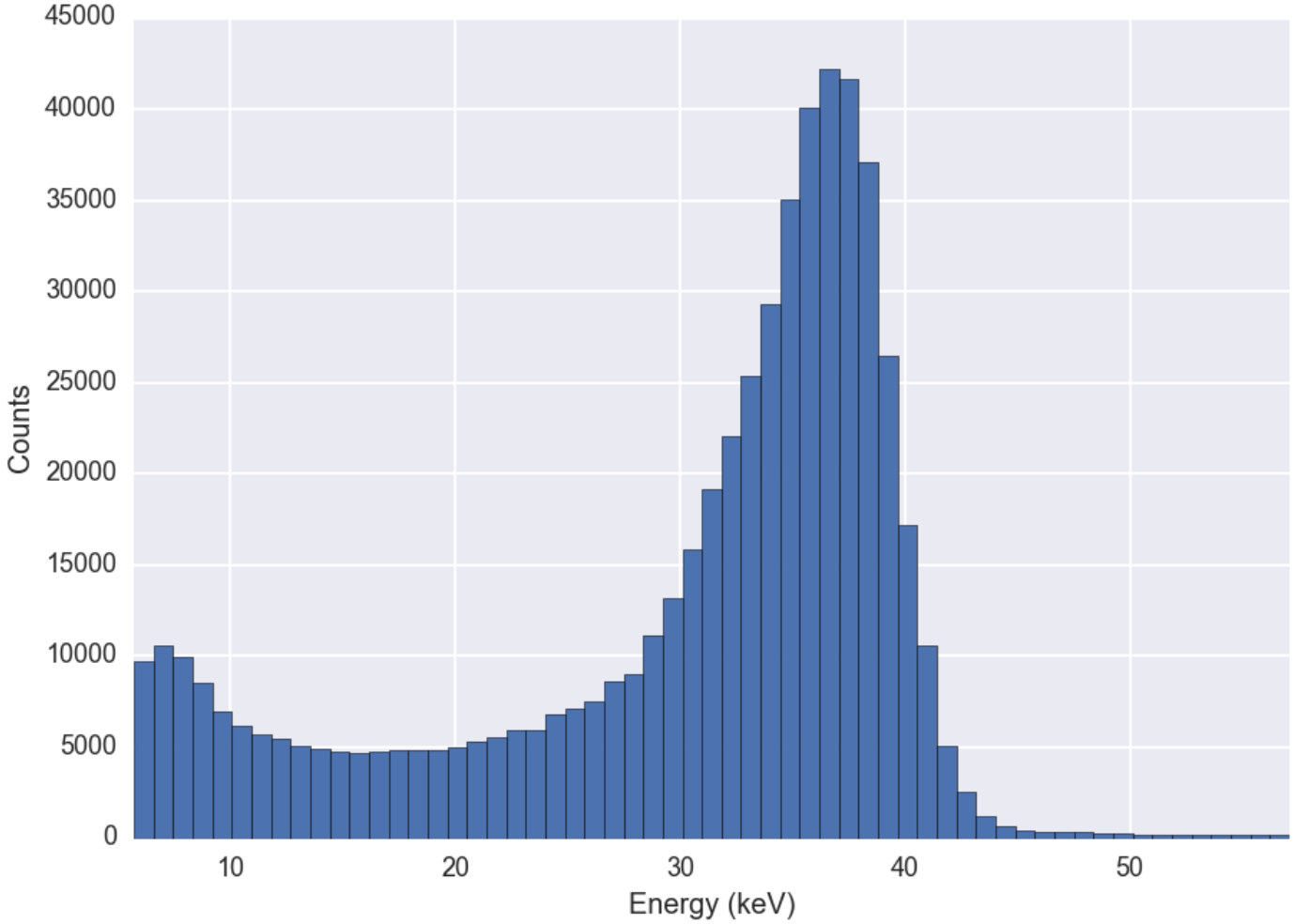
40keV



Input Count Rate 1.3 x 10^4 counts/pixel/s

2.7 x 10^5 counts/mm^2/s

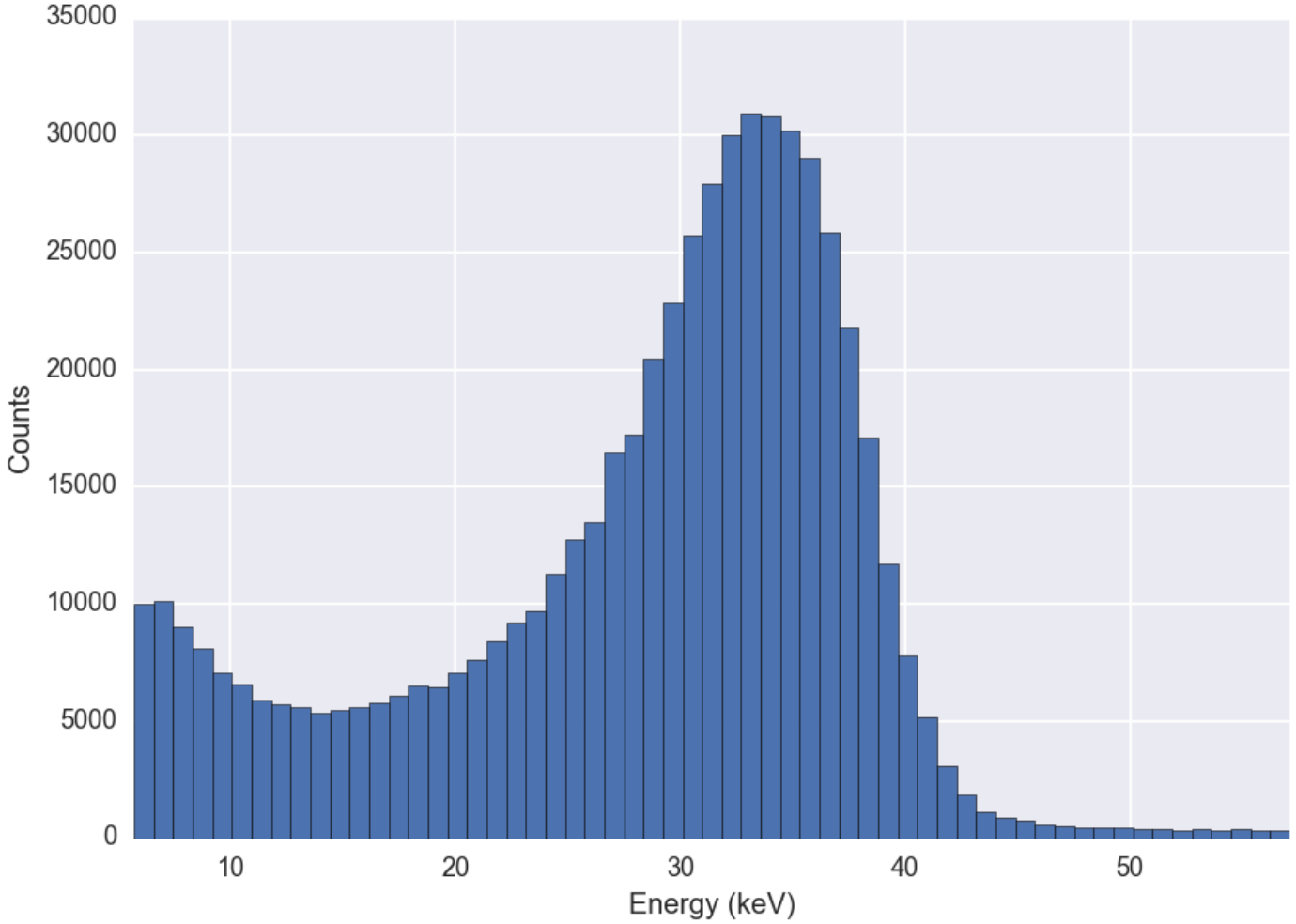
40keV



Input Count Rate 2.8 x 10^4 counts/pixel/s

5.8 x 10^5 counts/mm^2/s

40keV

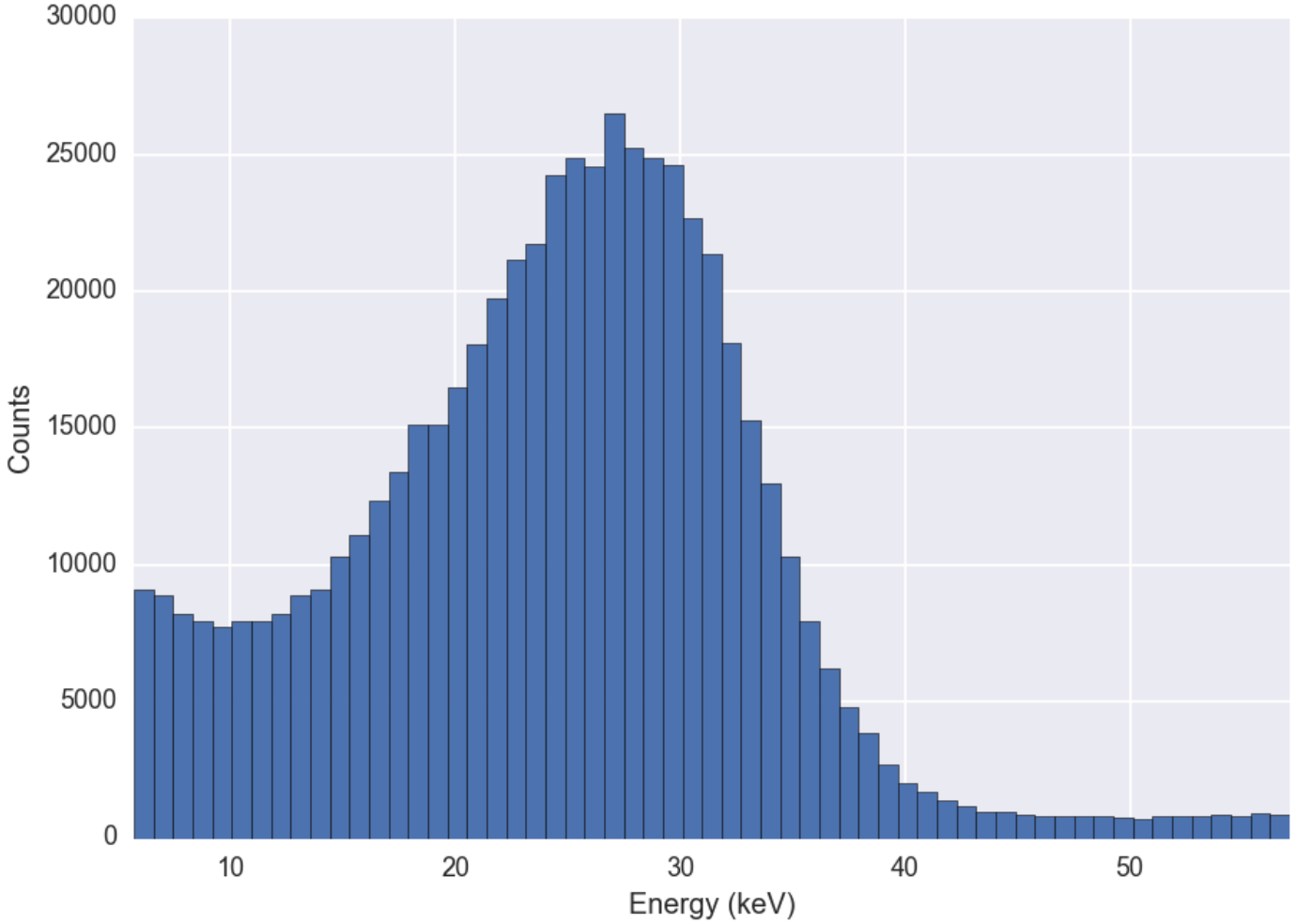


Input Count Rate

6.1 x 10^4 counts/pixel/s

1.3 x 10^6 counts/mm^2/s

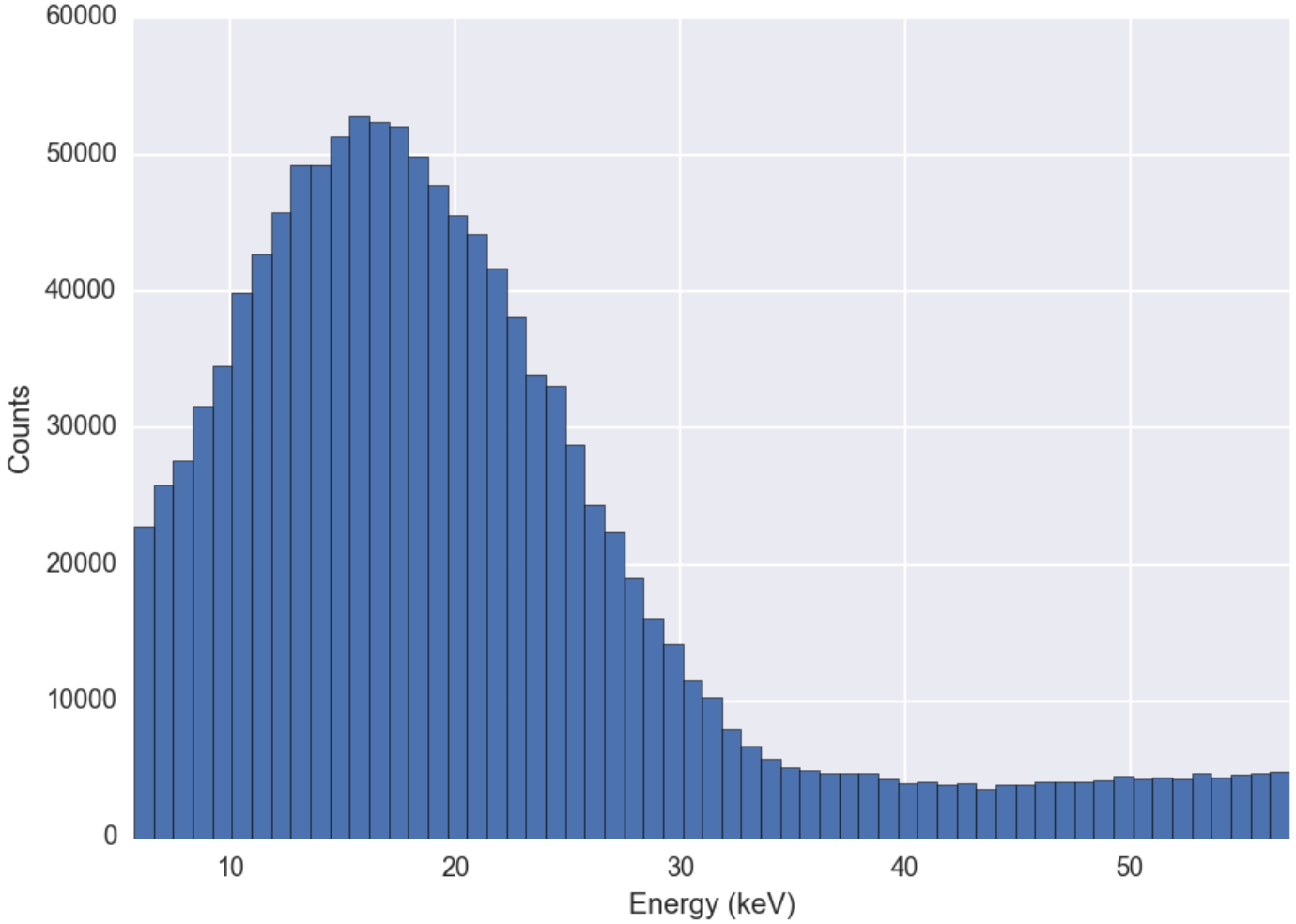
40keV



Input Count Rate 1.3 x 10^5 counts/pixel/s

2.7 x 10^6 counts/mm^2/s

40keV



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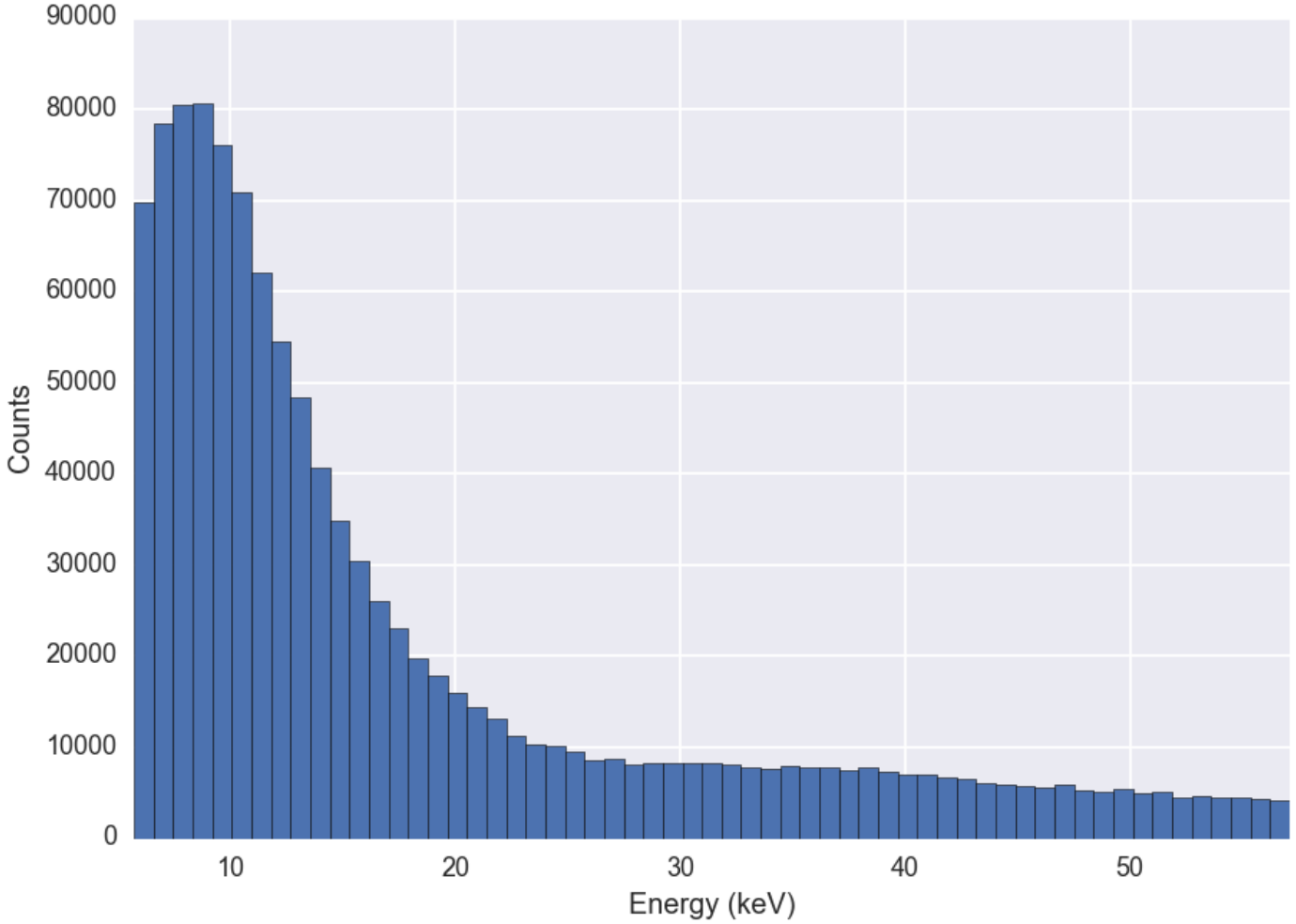
5.9 x 10^6 counts/mm^2/s

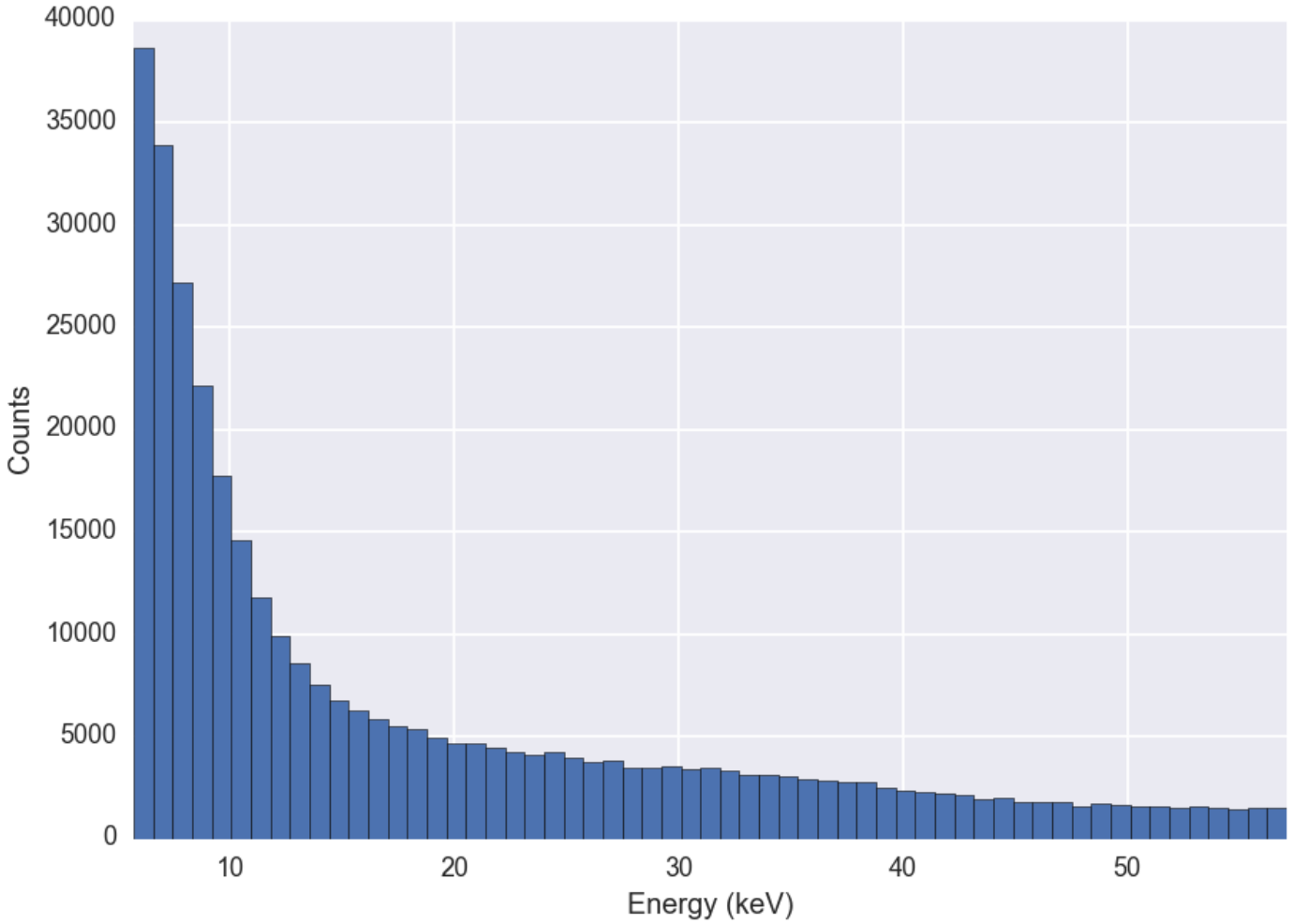
40keV



Input Count Rate 6.1 x 10^5 counts/pixel/s

1.2 x 10^7 counts/mm^2/s

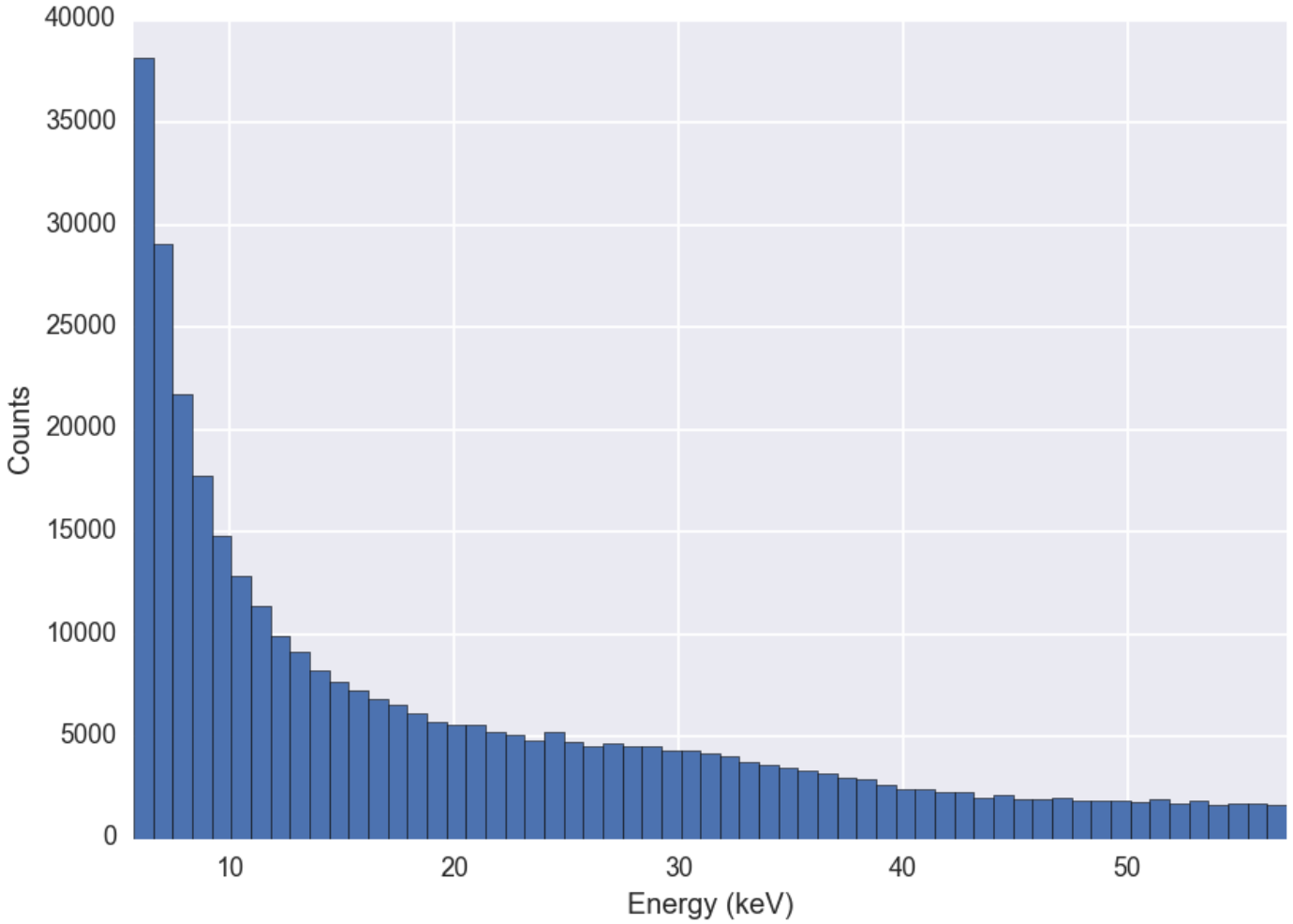
40keV



Input Count Rate 1.3 x 10^6 counts/pixel/s

2.7 x 10^7 counts/mm^2/s

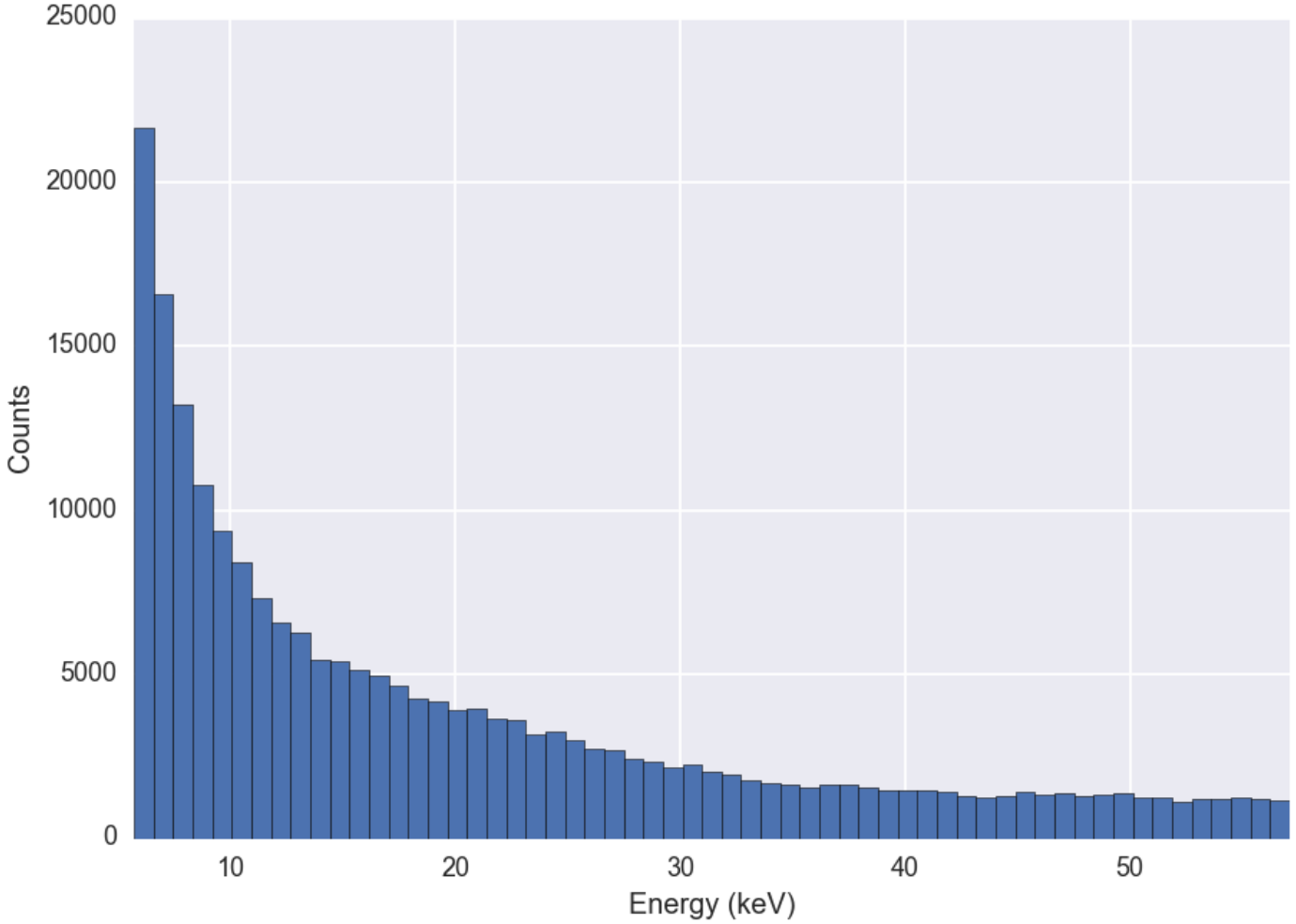
40keV



Input Count Rate 2.8 x 10^6 counts/pixel/s

5.9 x 10^7 counts/mm^2/s

40keV



Input Count Rate 6.1 x 10^6 counts/pixel/s

1.3 x 10^8 counts/mm^2/s

Conclusions

- The energy resolution of Dosepix have been measured to 3.18 keV at IKRUM 15 and 3.79keV at IKRUM 60 using monochromatic radiation
- The dead time for 40 keV photons with IKRUM 60 and a 5.5 keV threshold is 0.6 us
- Dosepix can process ~3.6 Mcps/mm^2 for 40 keV photons and 5.5 keV threshold. This corresponds to ~80M photons/mm^2/s using a 300um sensor.
- Pulse pileup is a major issue for single photon processing hybrid pixel detectors working in high flux environments

Future work

- Improving the pileup simulations by feeding in pulses from geant4medipix
- Investigating the effect of pileup on image contrast and measured dose
- Investigate new pixel architectures and sensor configuration for increased high flux performance

ACKNOWLEDGEMENTS:
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Advanced Radiation Dosimetry European Network Training

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