# Correction of Differential Nonlinearities in Analog-to-Digital Converters used for Digital γ-ray Spectroscopy

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*** XIA LLC, Hayward CA 94544**


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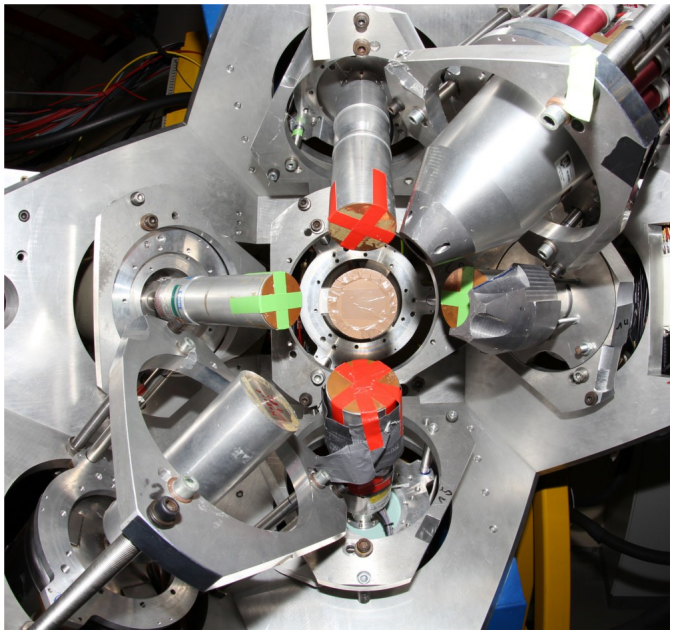
# Outline

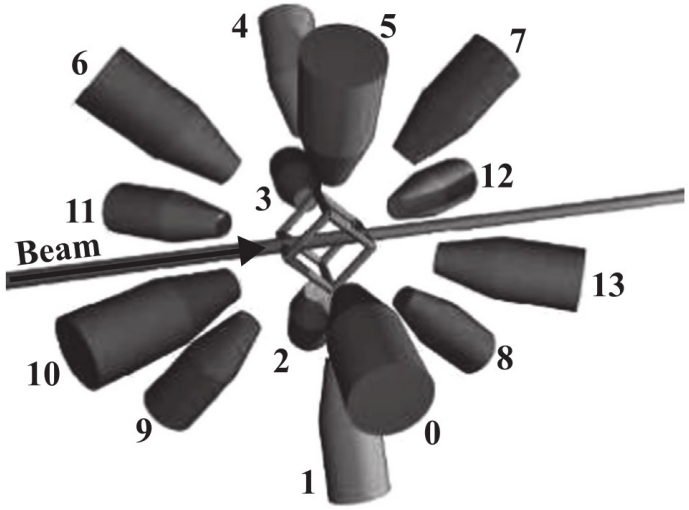
- Setup at HORUS in Cologne
- Observations: Dependence on energy range and count rate
- Differential nonlinearity (DNL)
- Calibration of DNL and correction algorithm
- Results

# HORUS Spectrometer

- 14 detector positions, HPGe and BGO shields

  → γ-γ and particle-γ coincidence with up to 36 channels @ 15-20 kcps



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# HORUS Spectrometer

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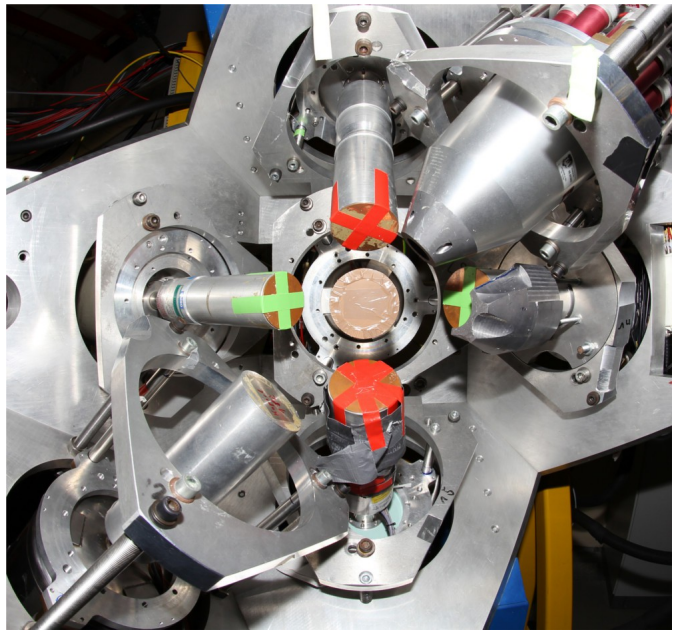
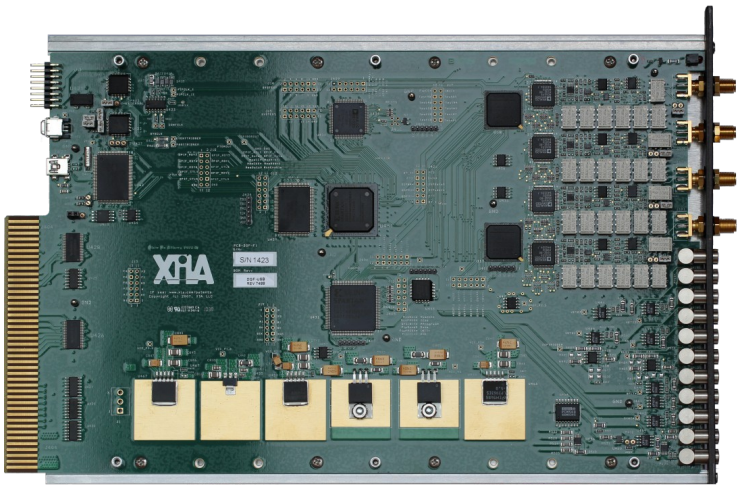




4 Channels

14 bit @ 80 Msps

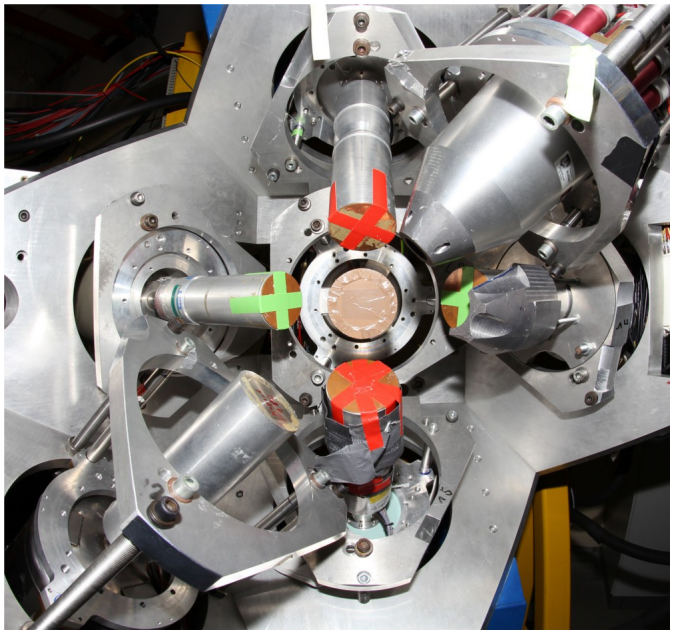
CAMAC

# HORUS Spectrometer

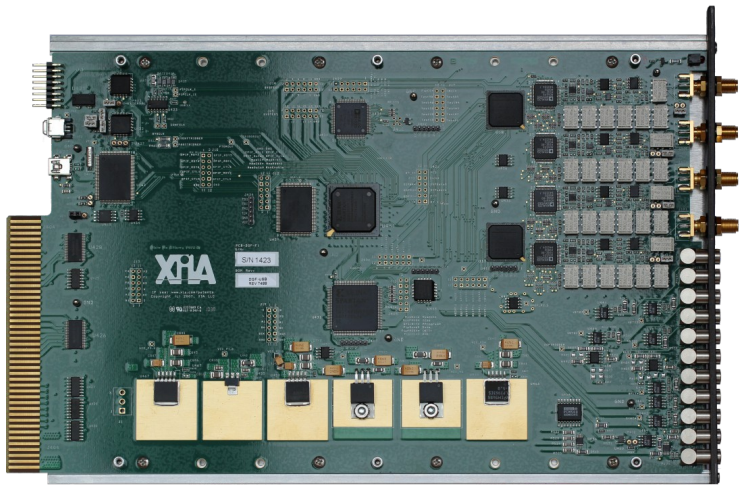
- 14 detector positions, HPGe and BGO shields

  → γ-γ and particle-γ coincidence with up to 36 channels @ 15-20 kcps

- Fully digitized DAQ with XIA DGF-4C
- Nucl. astrophysics and PDR experiments demand for high energy range (10–15 MeV)
- Beam time limited: high count rate desired



$^{226}$Ra, 23 kcps, 12.8 MeV range



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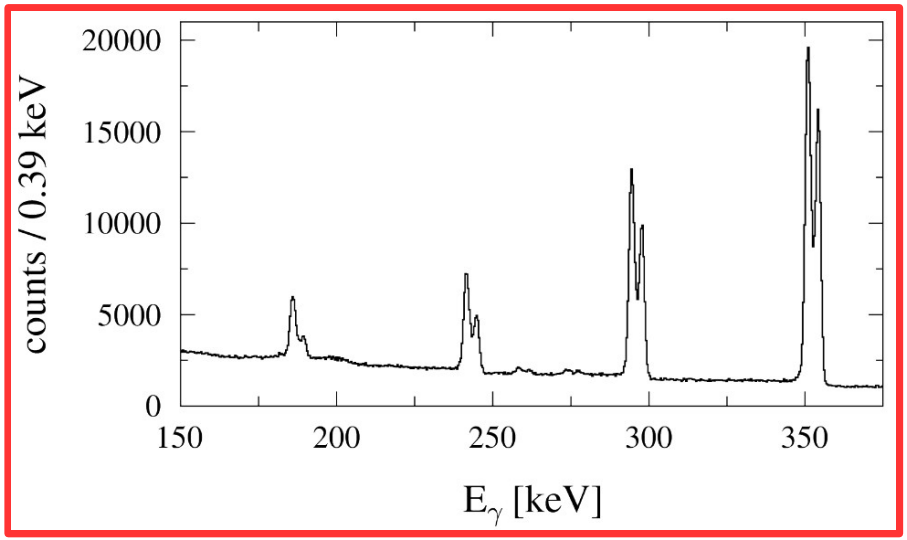


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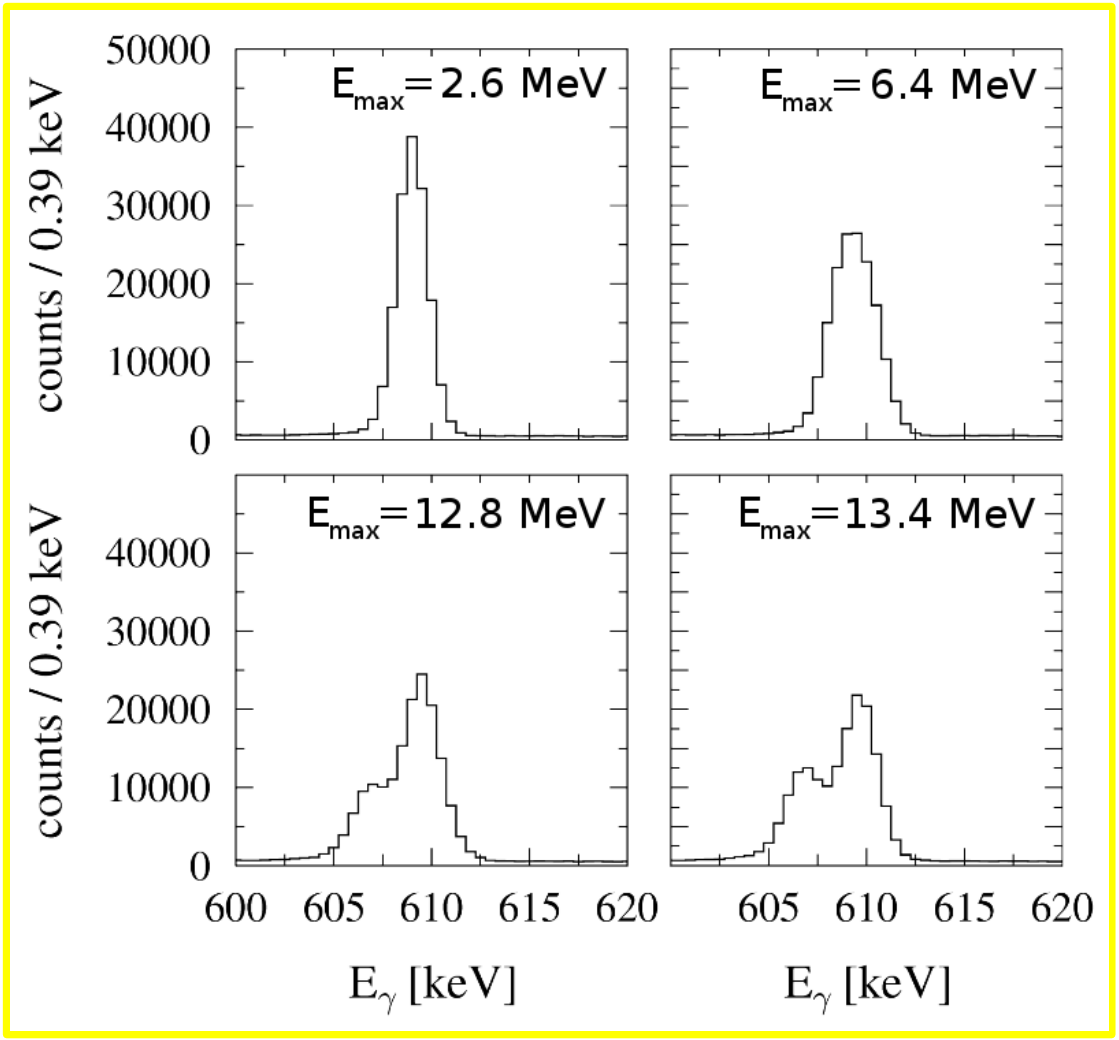
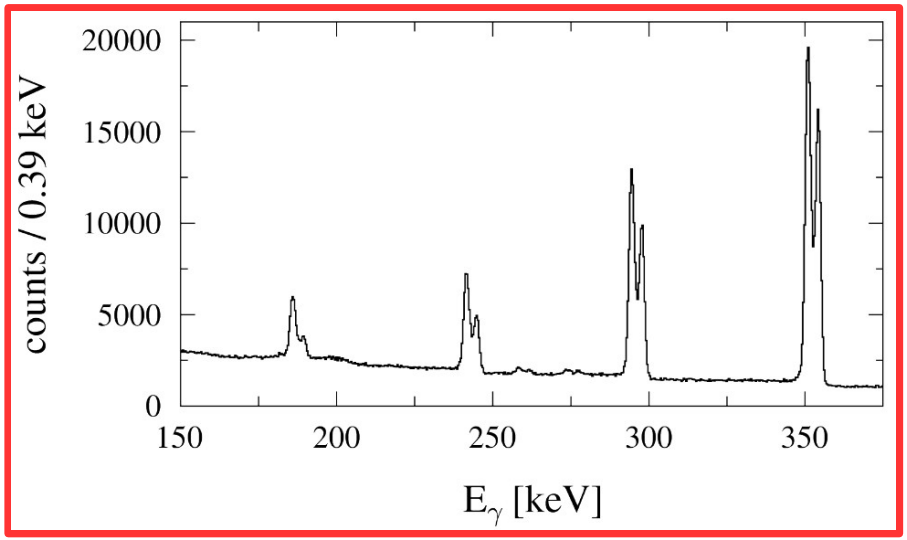
# Observations




Peak shape worsens as **energy range** is extended!

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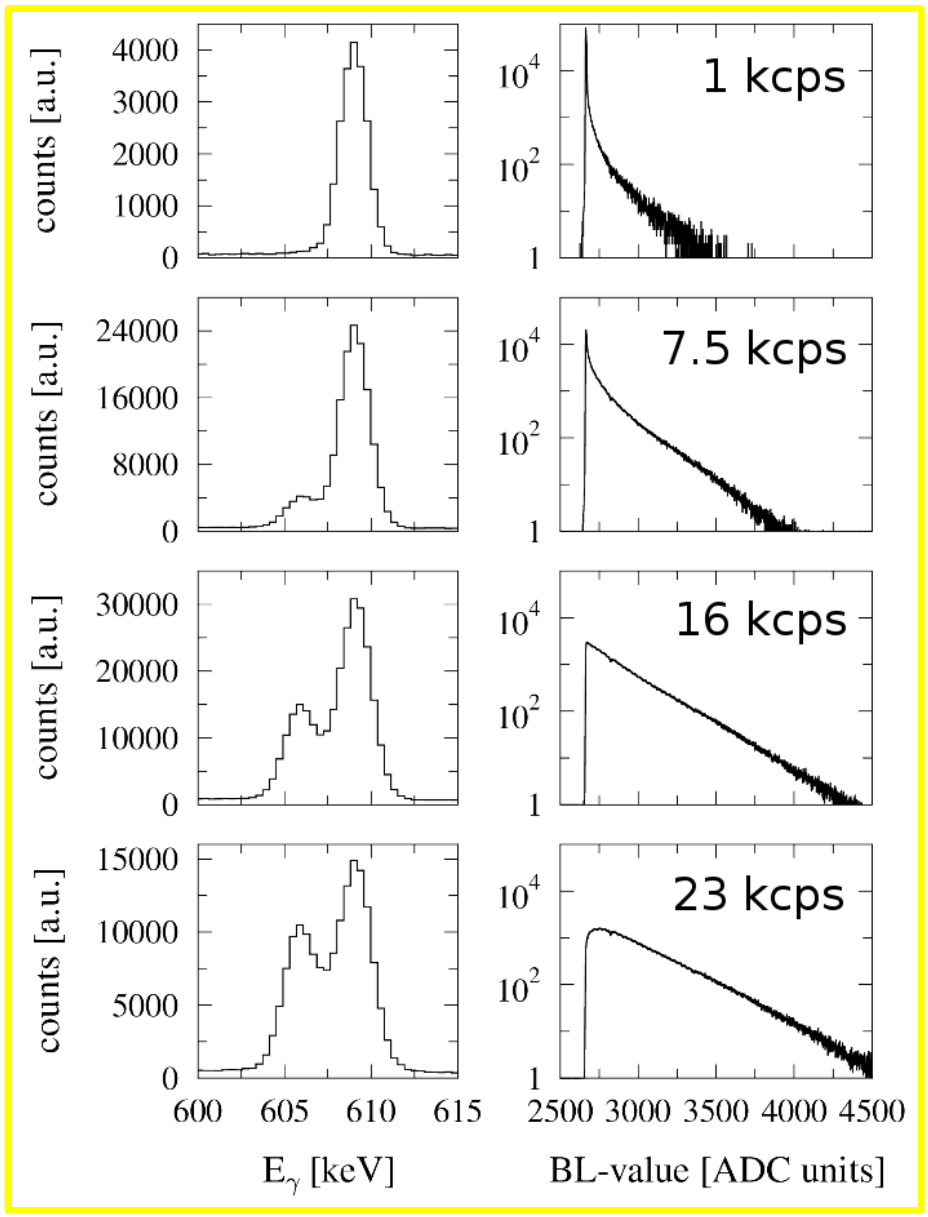
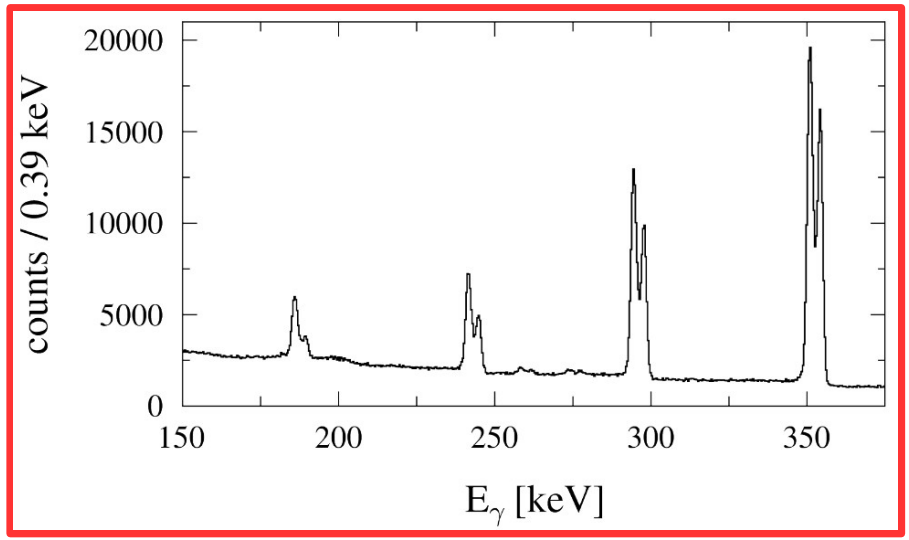



Peak shape worsens as **energy range** is extended!

Peak shape worsens as **count rate** is increased!

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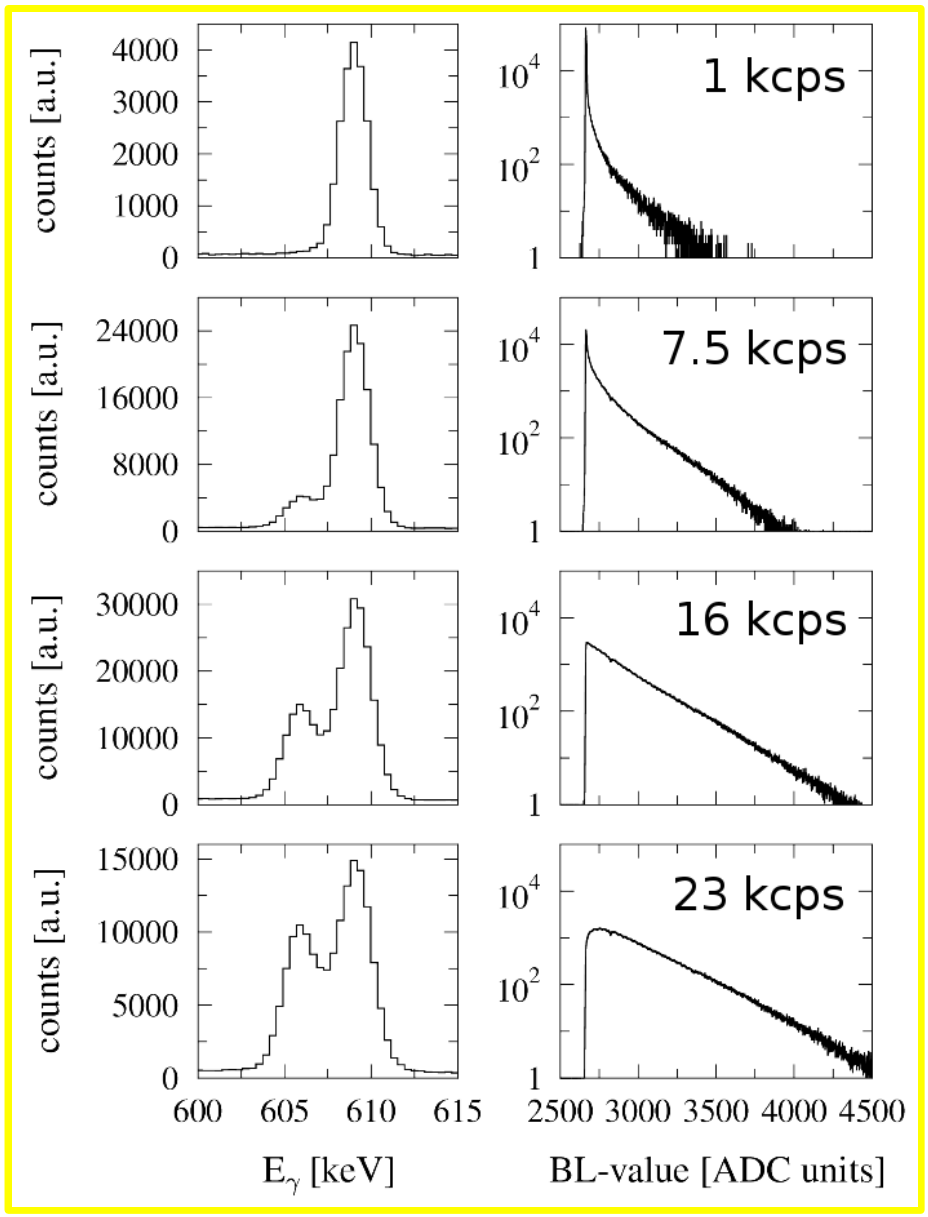
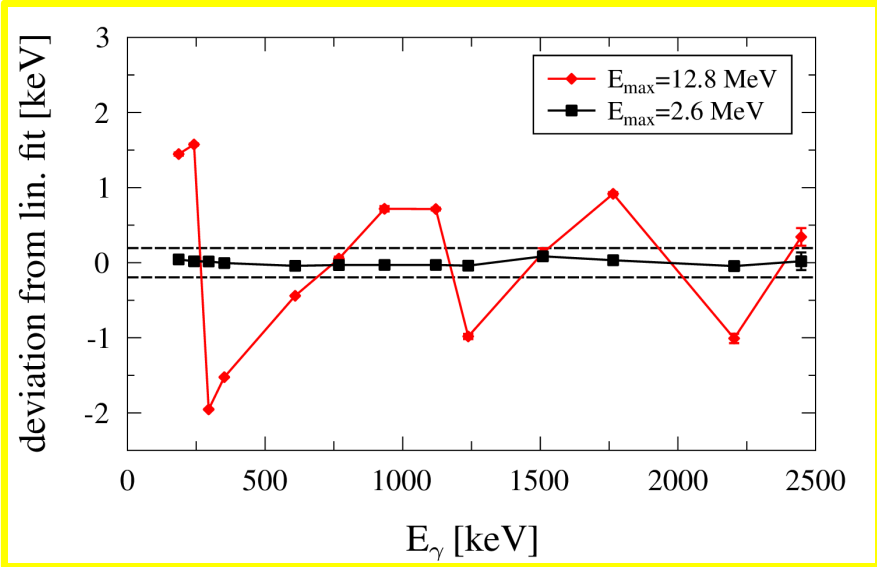



→ Peak shape worsens as **energy range** is extended!

→ Peak shape worsens as **count rate** is increased!

→ **Linearity suffers** from large energy range even at small rates

**Baseline dependence?**

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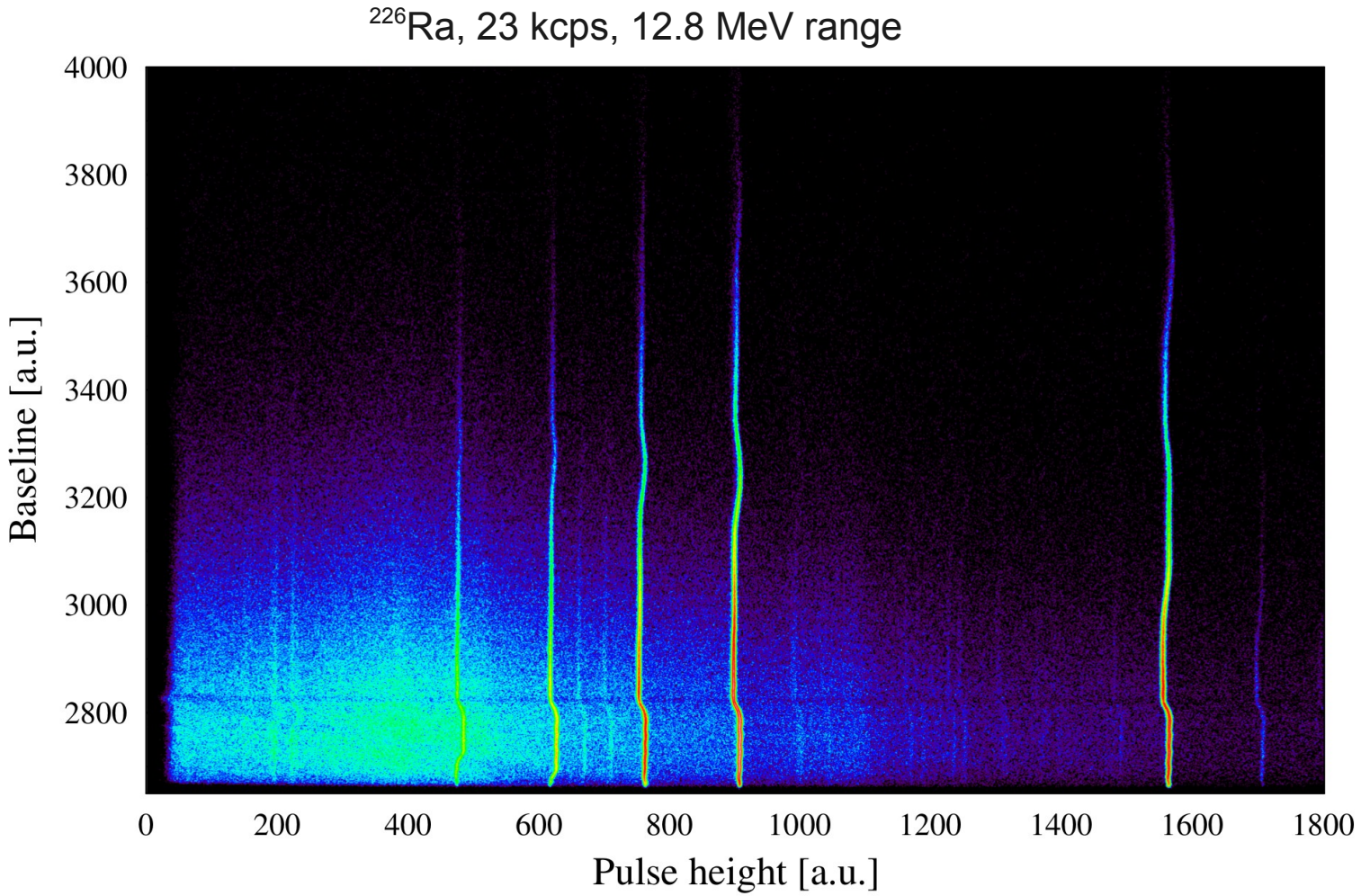
# Energy-Baseline Dependence



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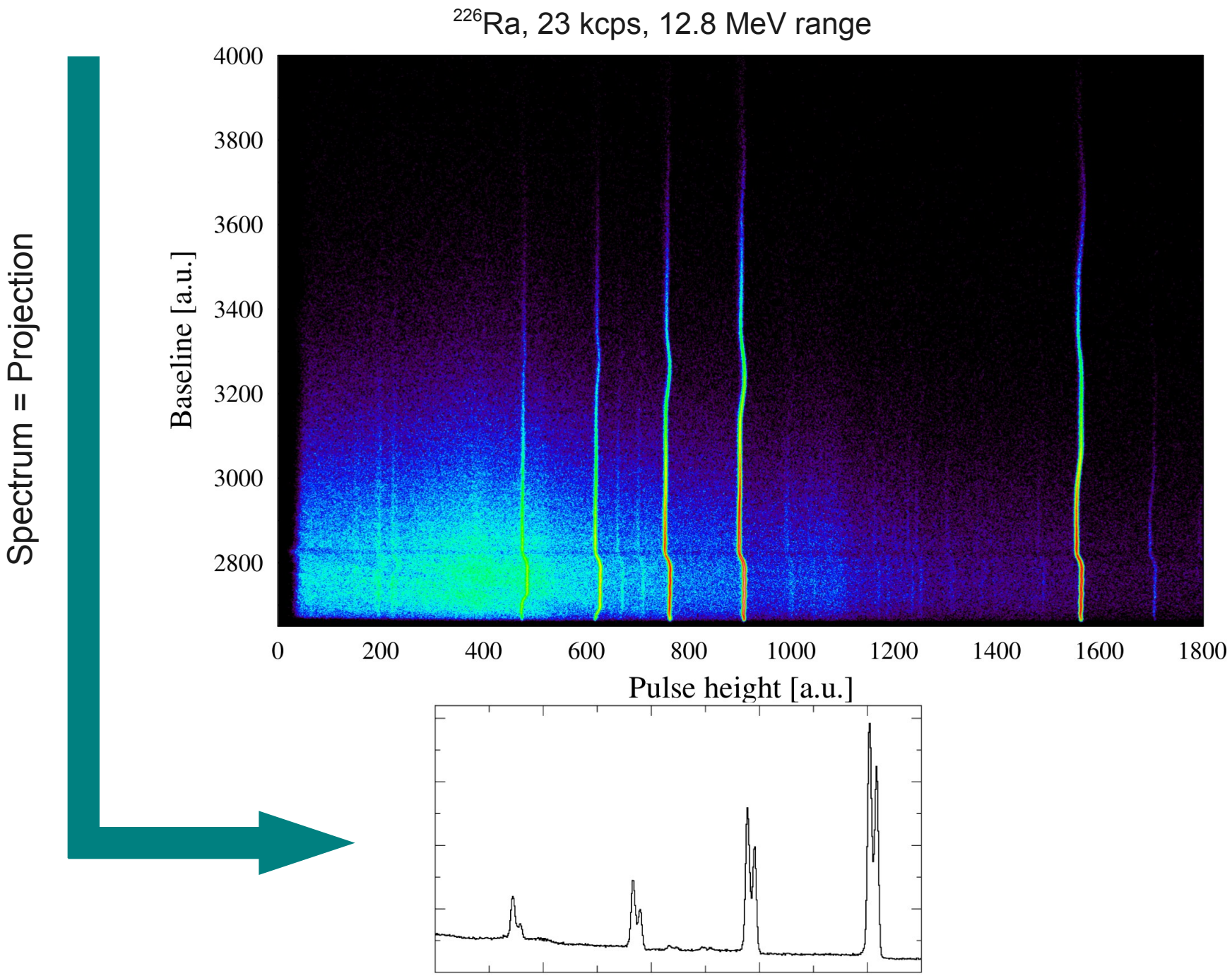

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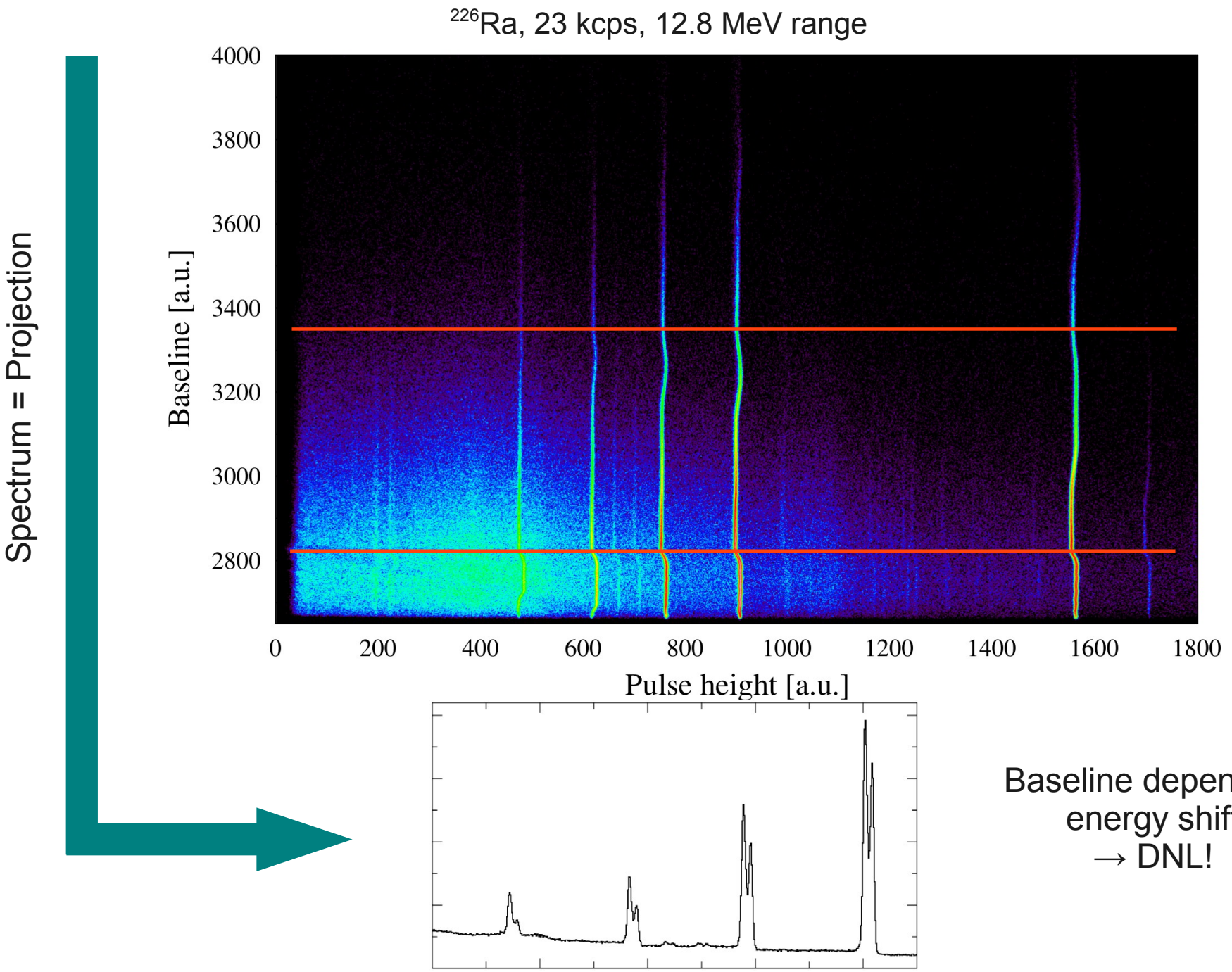
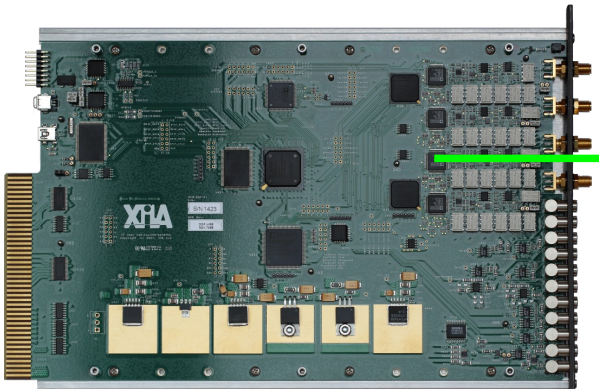
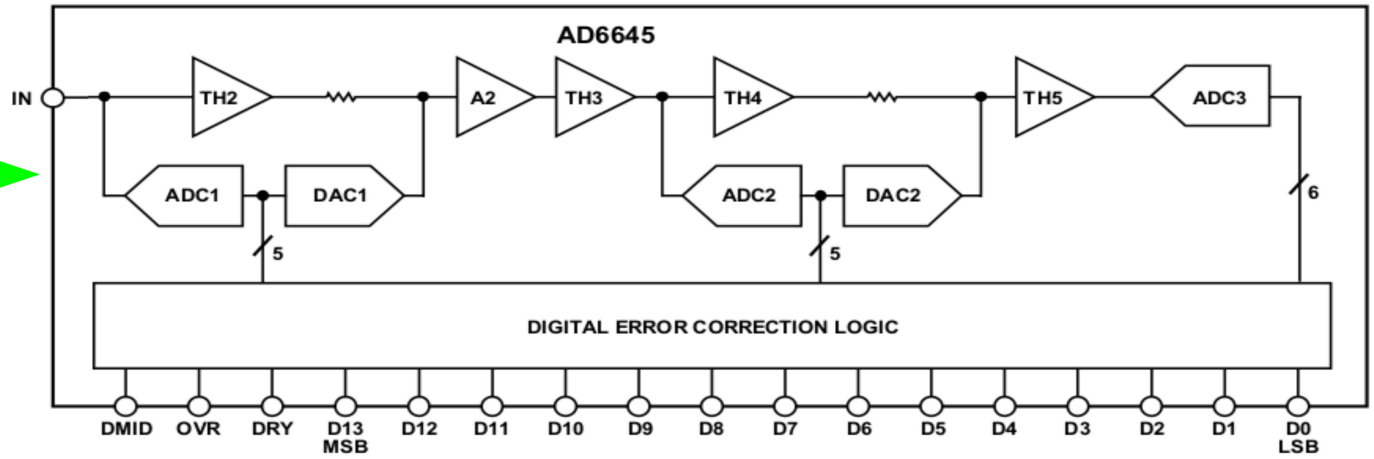



Baseline dependent energy shift → DNL!

# Signal digitization and DNL






W. Kester, Analog Dialogue **40** (2006) 2

- Sampling by 14 bit 80 Msps **pipelined succ. approx. ADC**

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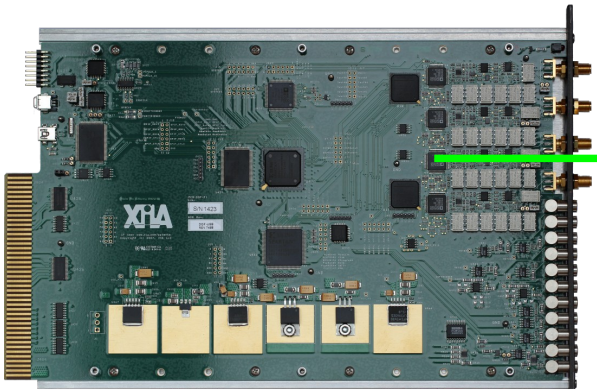

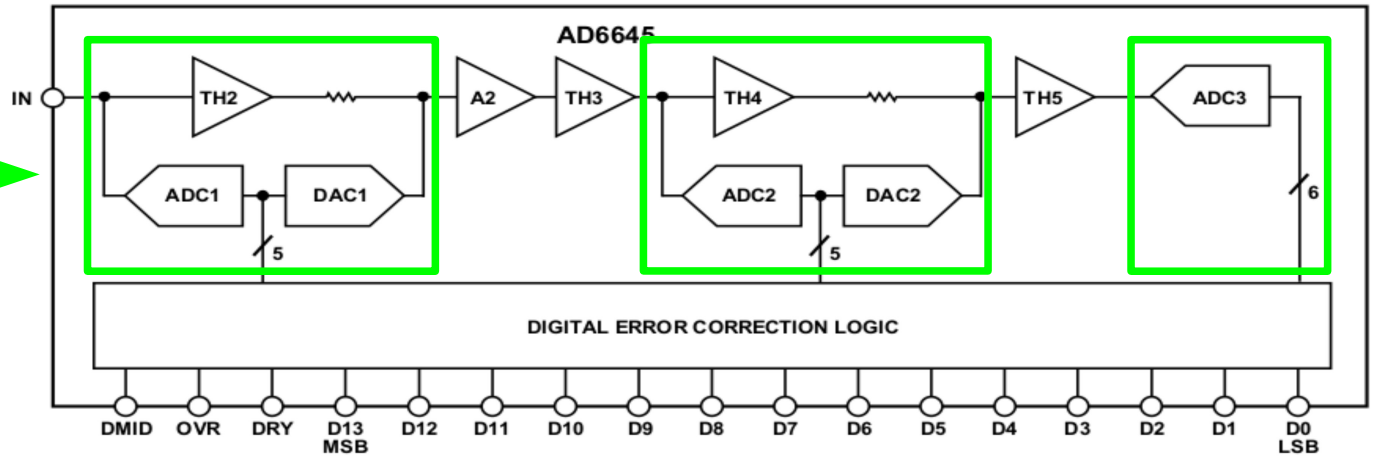


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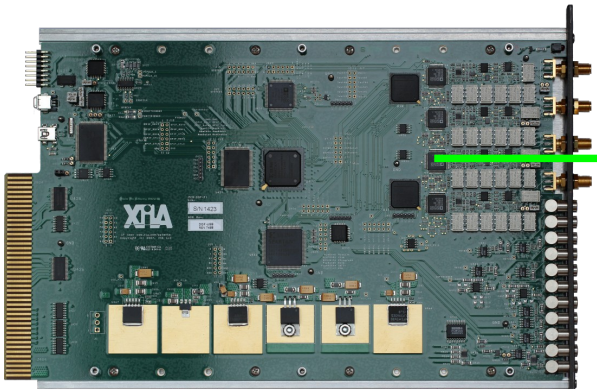

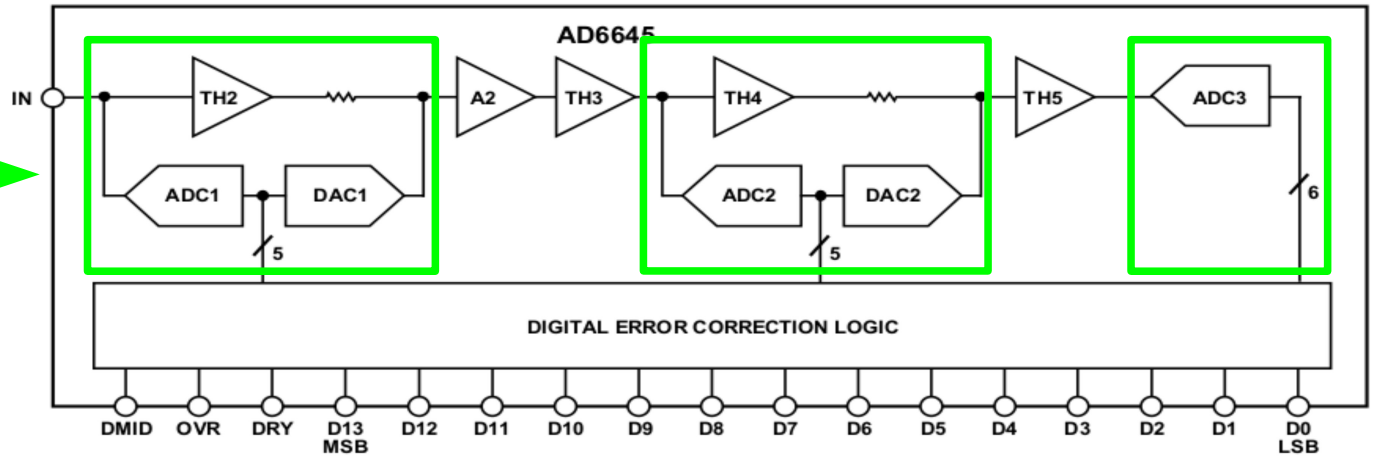


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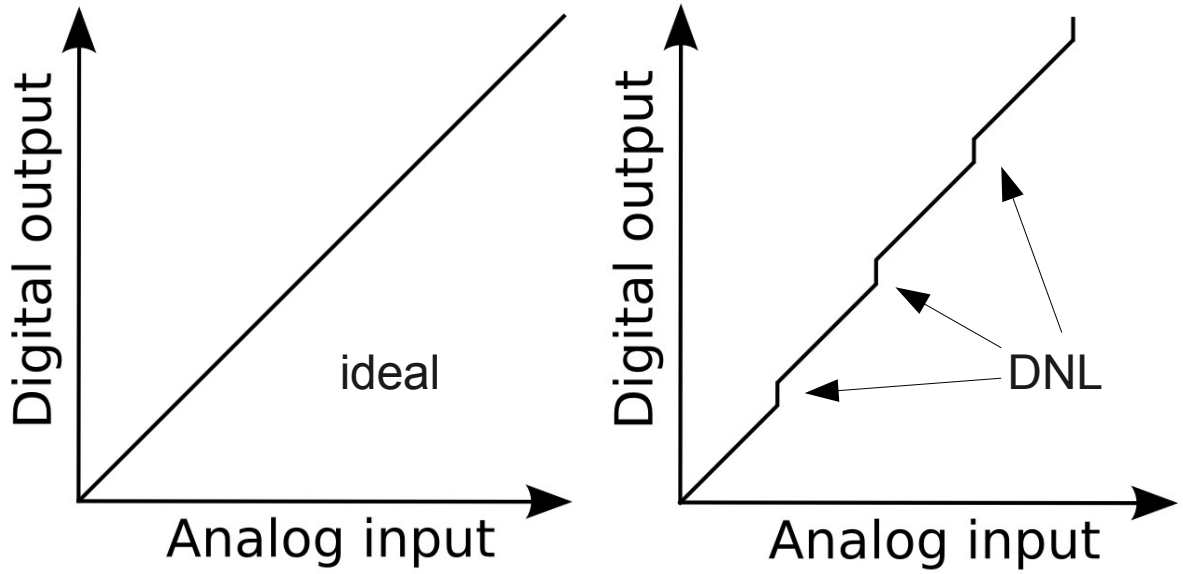

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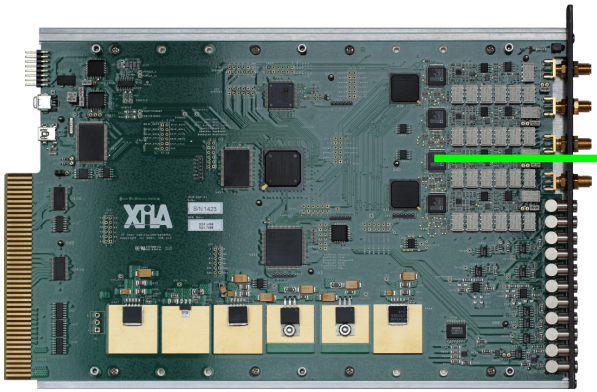

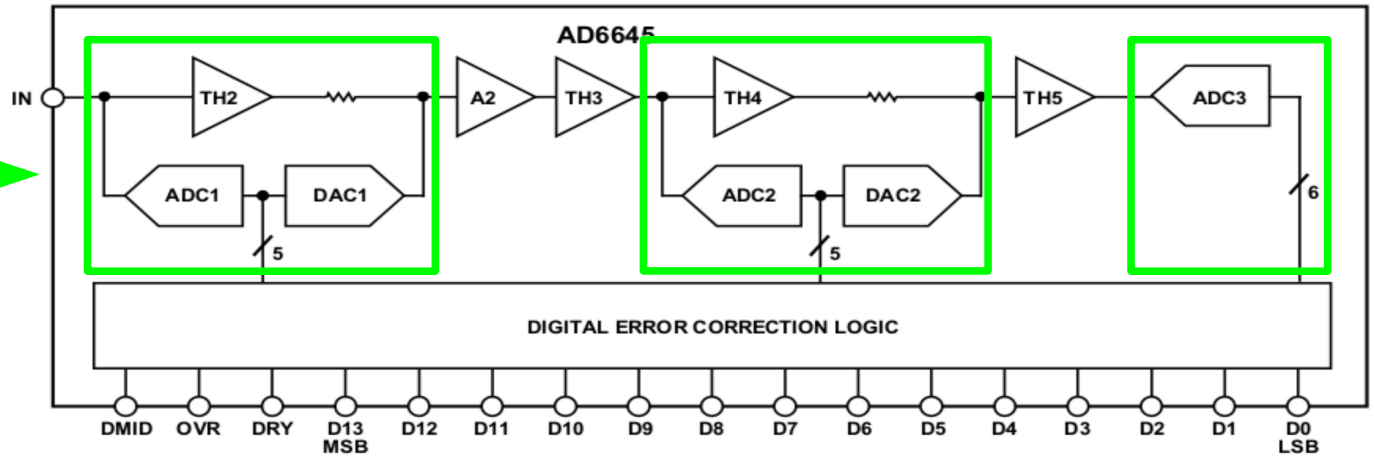


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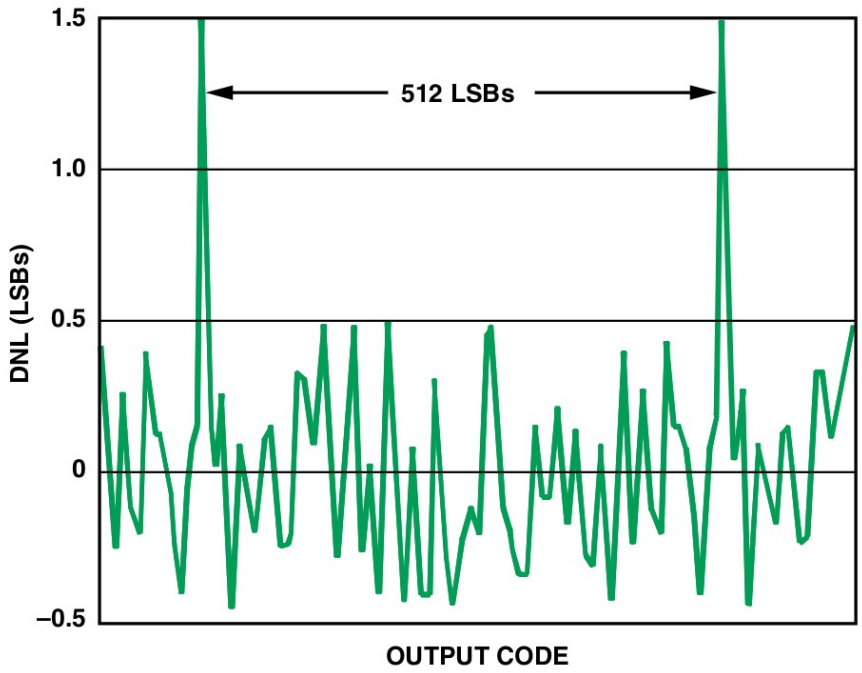
- DNL already measured



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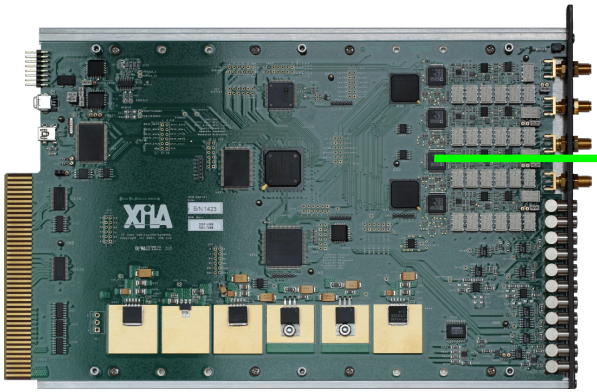


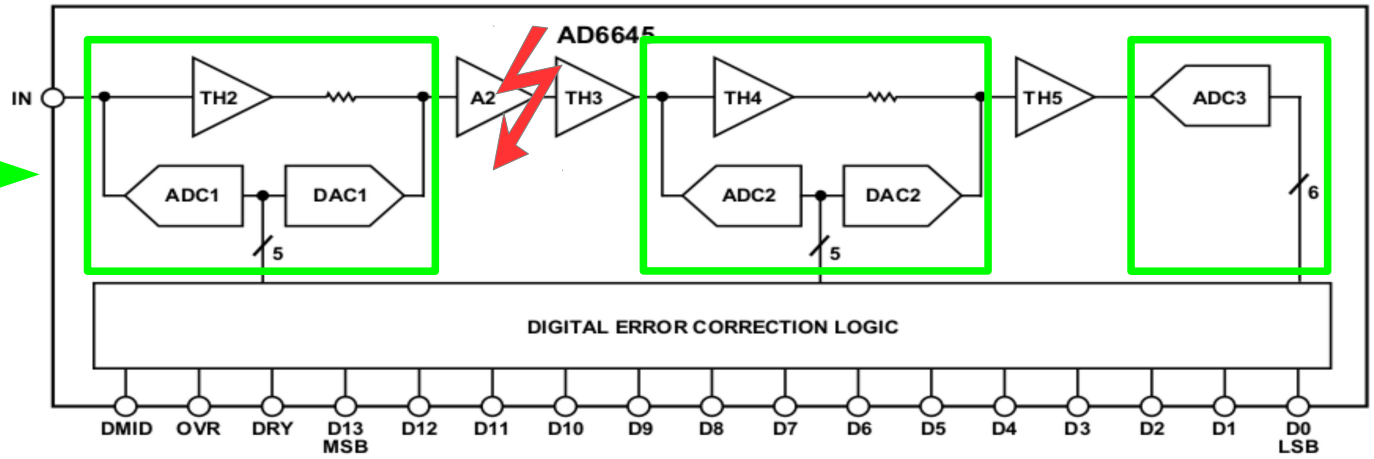


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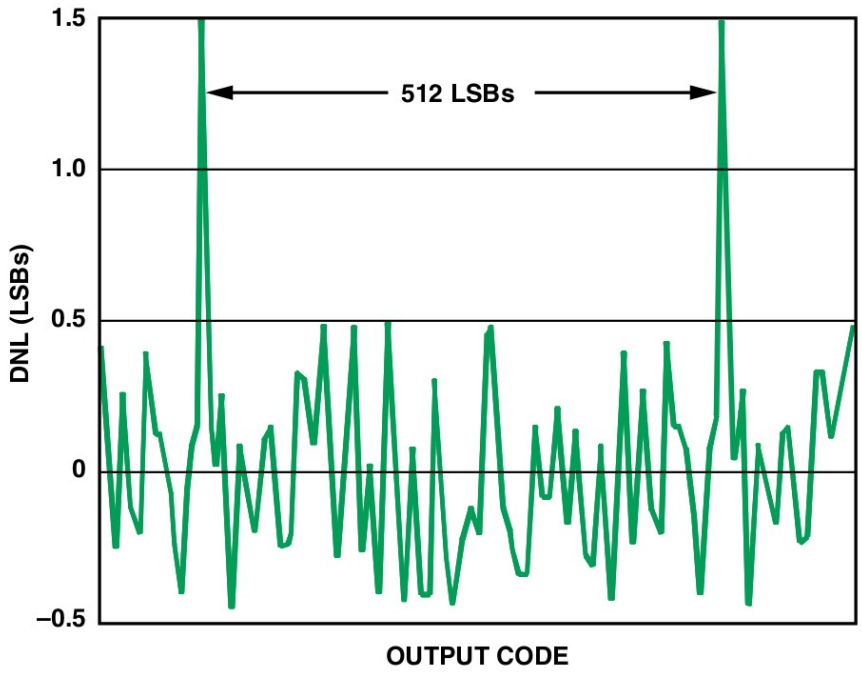

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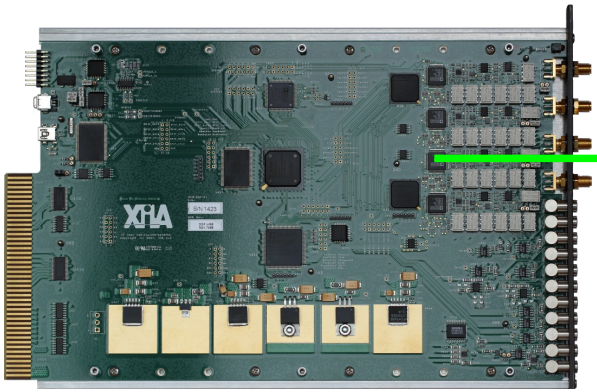
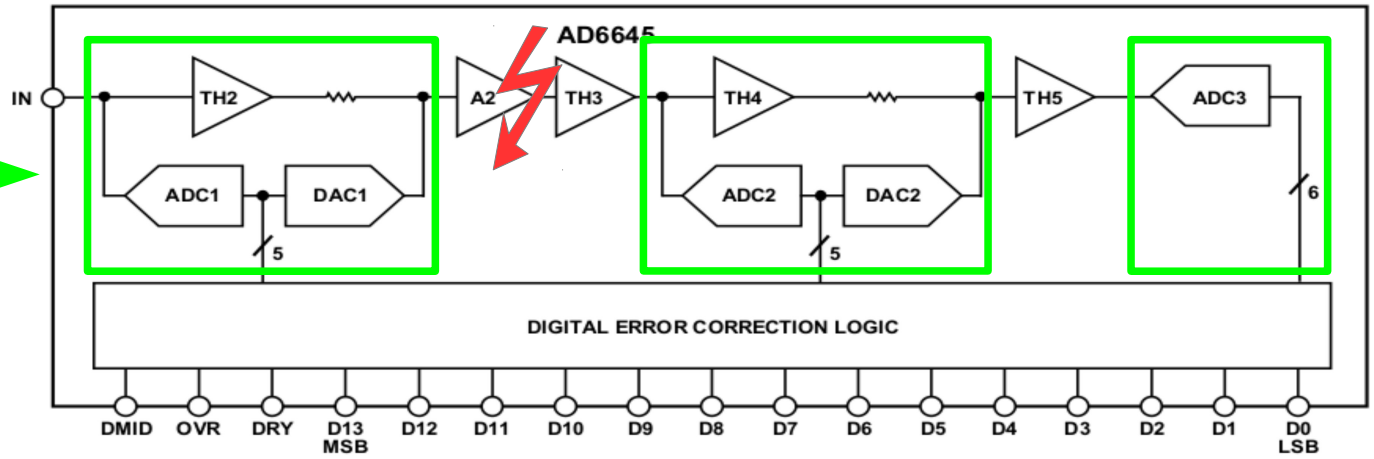
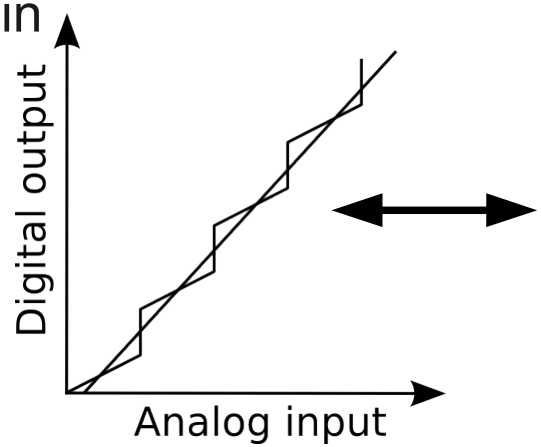
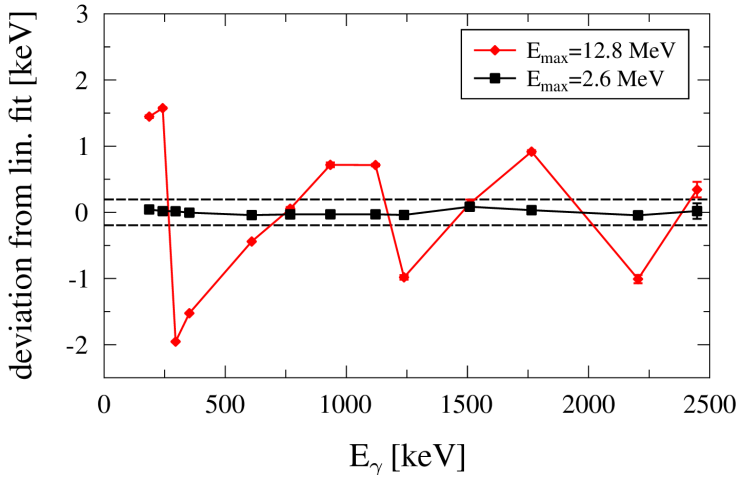





W. Kester, Analog Dialogue **40** (2006) 2

- Sampling by 14 bit 80 Msps **pipelined succ. approx. ADC**
- **Differential nonlinearity:** Deviation from ideal ADC-bin width of 1 LSB
- DNL already measured
- Known cause for peak broadening
- Explains linearity



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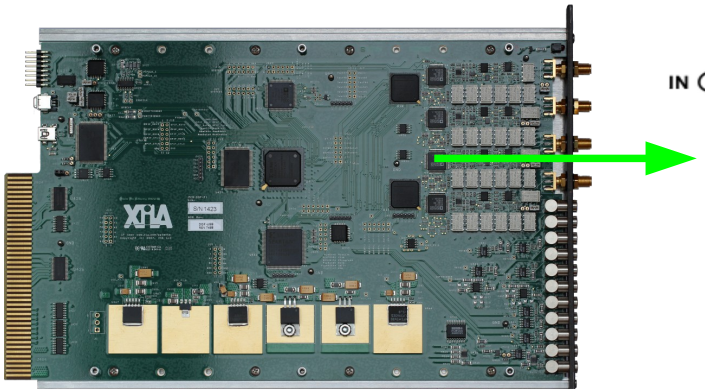

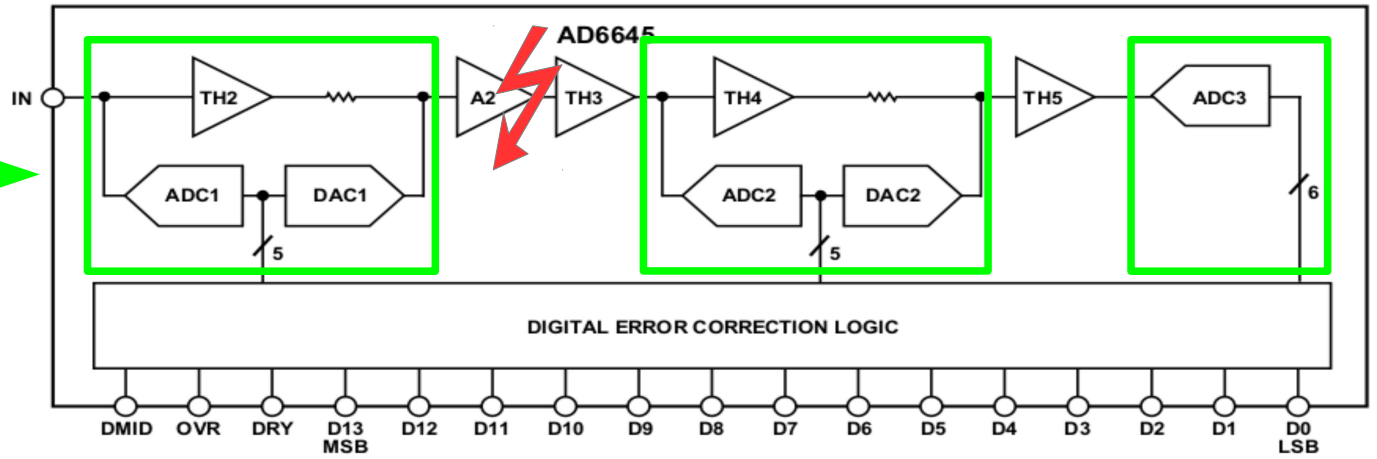


How to solve this?

- *Better ADC:* not possible
- *Dithering:* not possible

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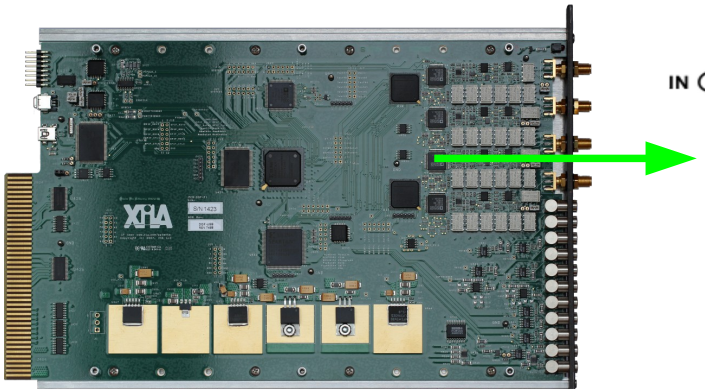

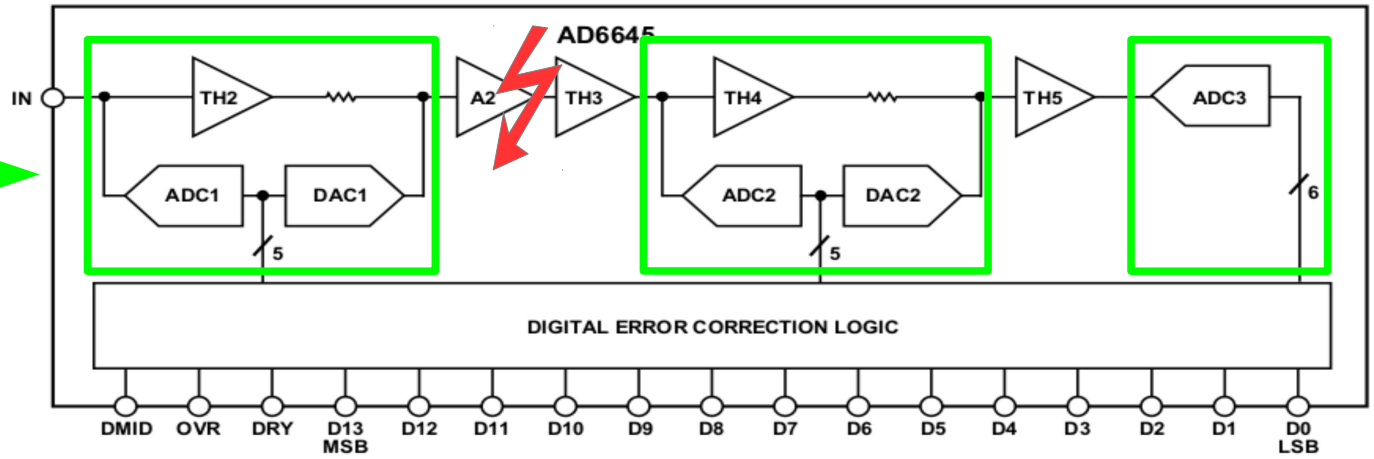


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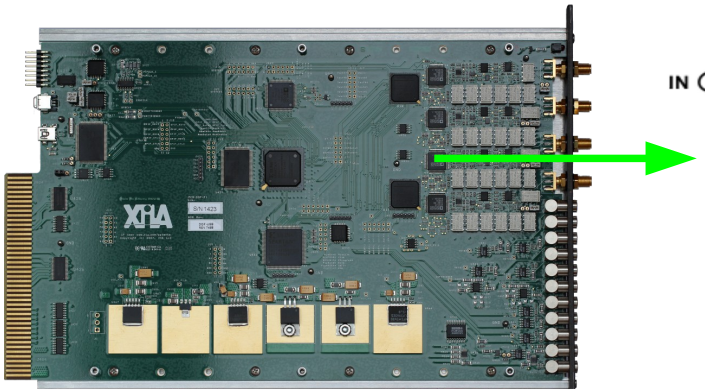

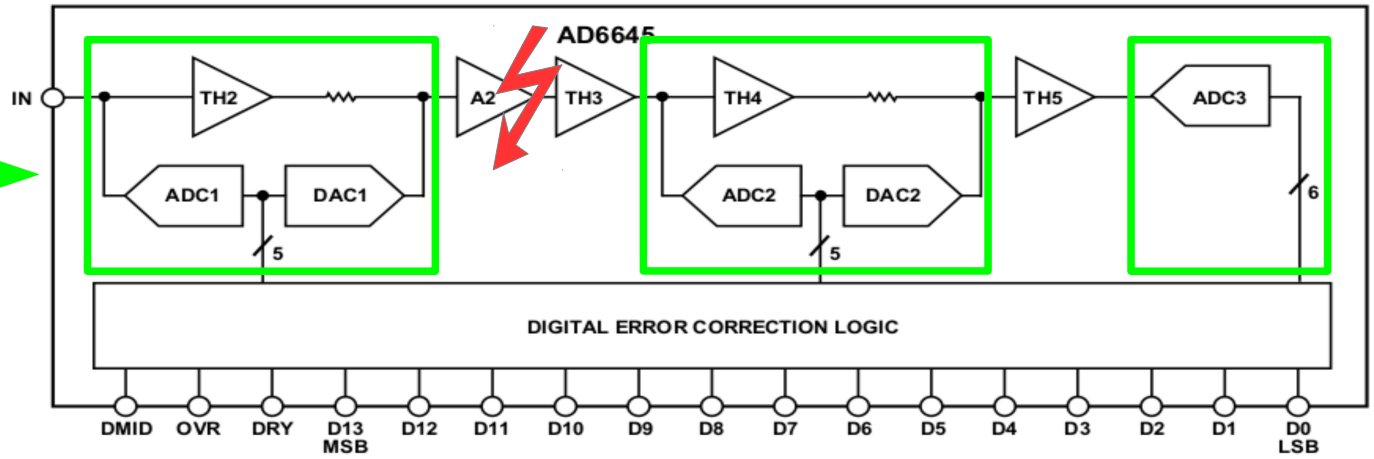


How to solve this?

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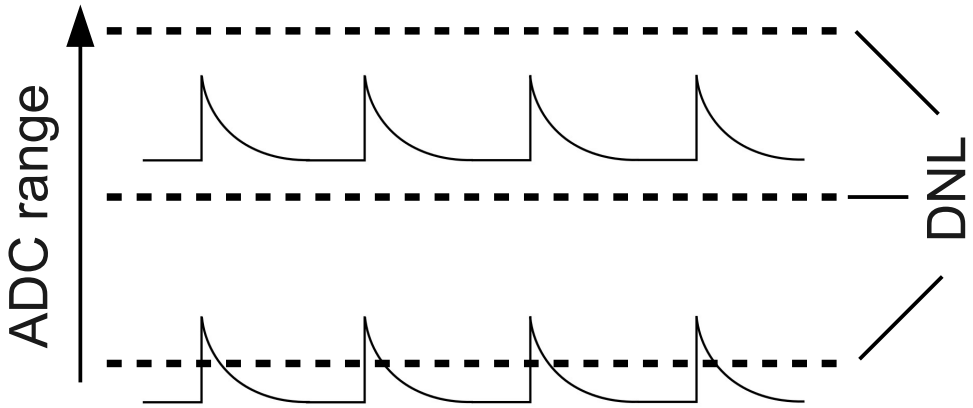
  → Offline correction algorithm
- Difficulty: convolution of preamp. signal shape, DNL and filter response

  → Calibration of DNL

# Calibration via pulse generator

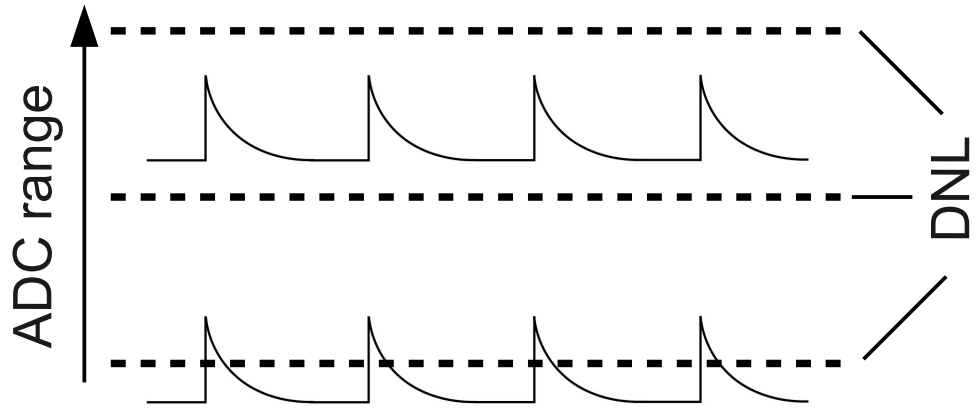
- Record pulse height spectra of constant artificial pulses
- Vary input offset

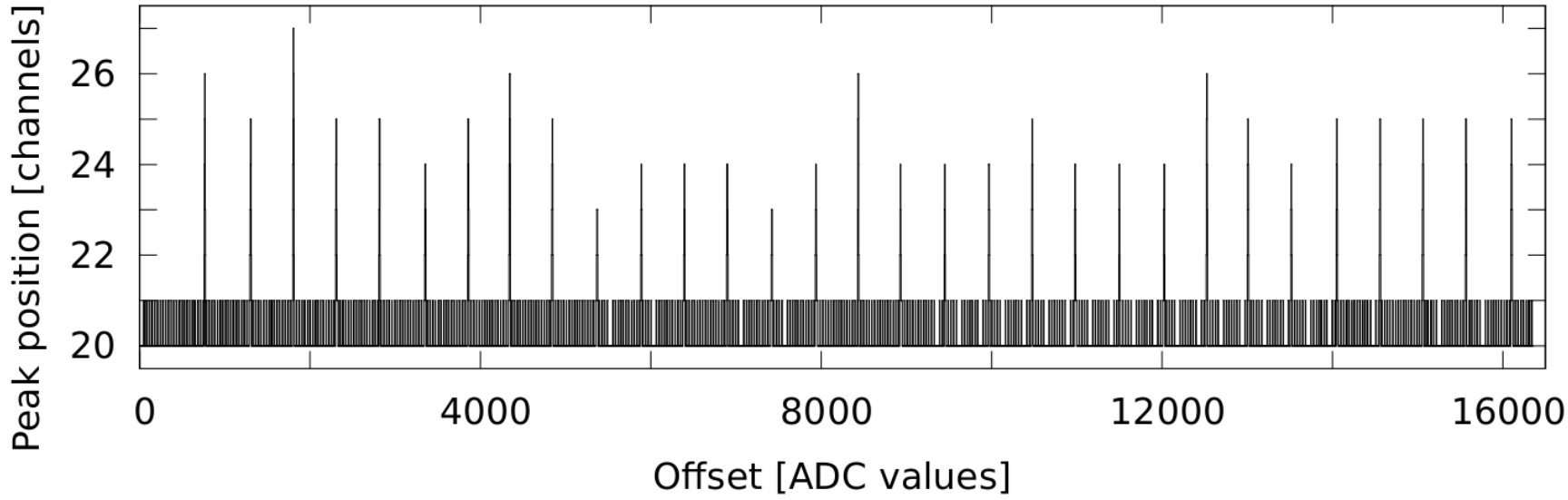


# Calibration via pulse generator

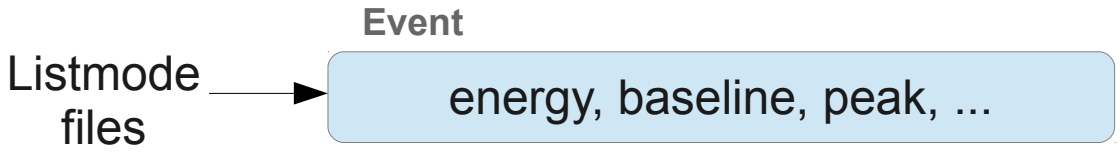
- Record pulse height spectra of constant artificial pulses
- Vary input offset
- Determine peak position for each offset

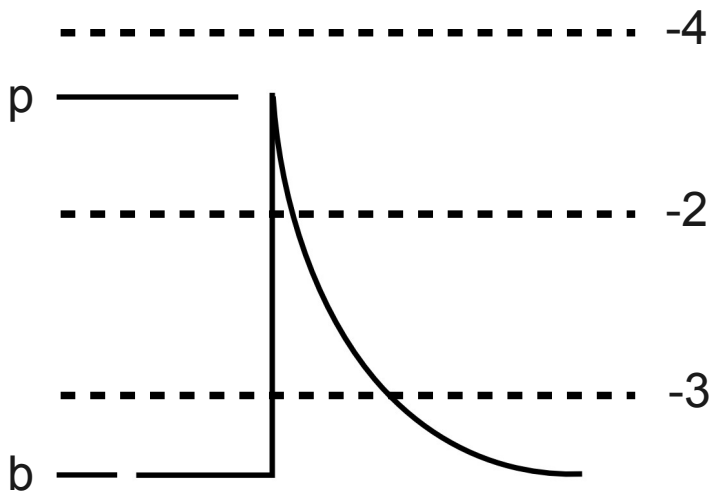
  → LUT with positions and shifts



# Correction algorithm



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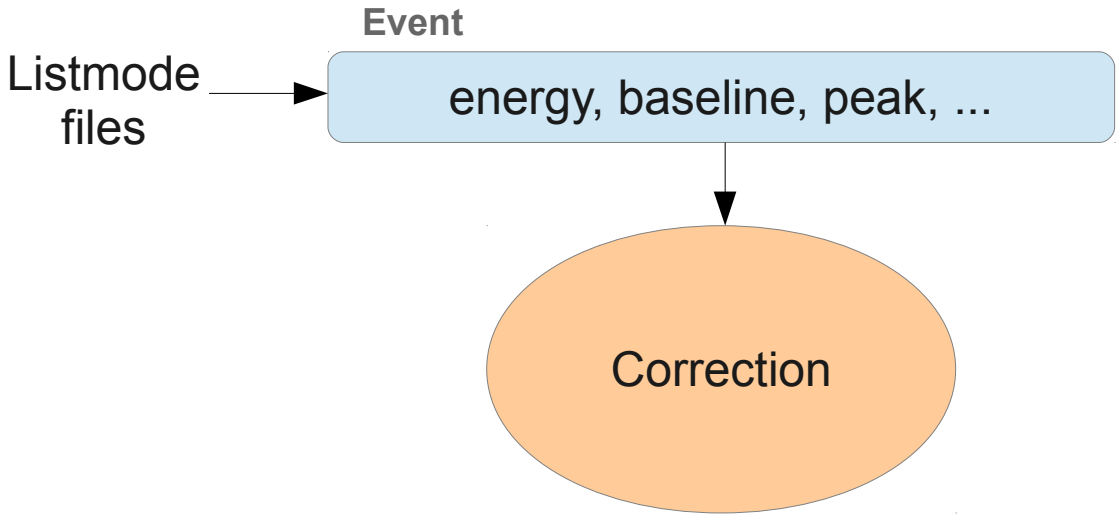


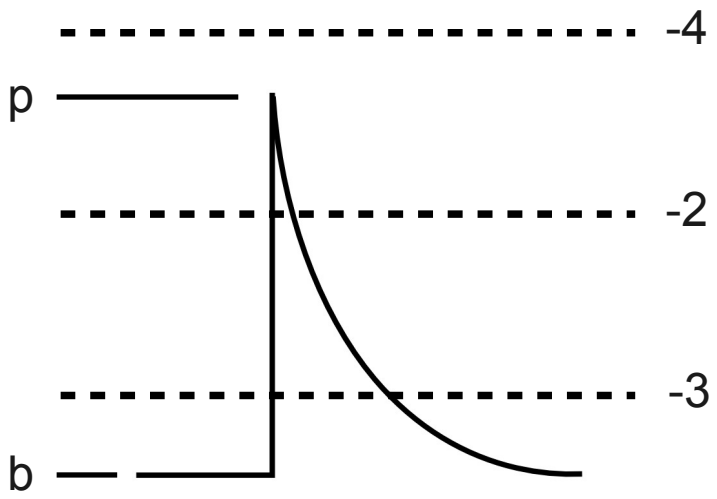

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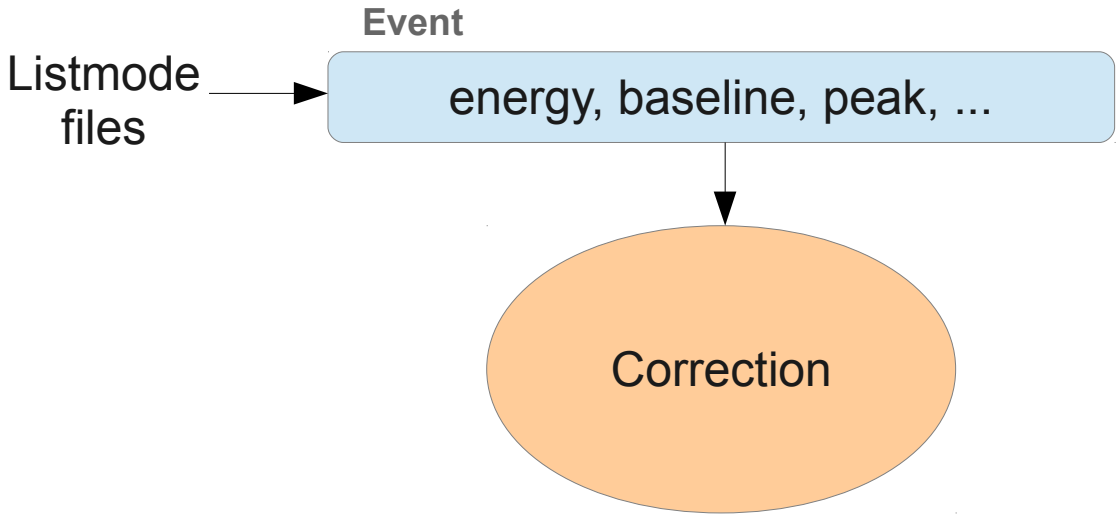
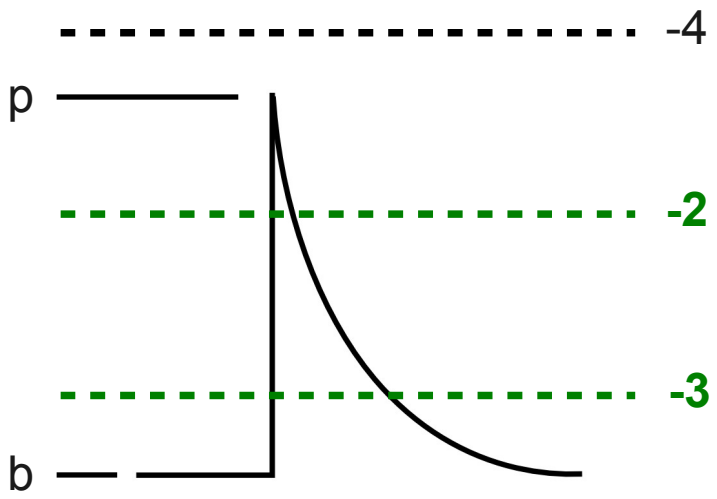
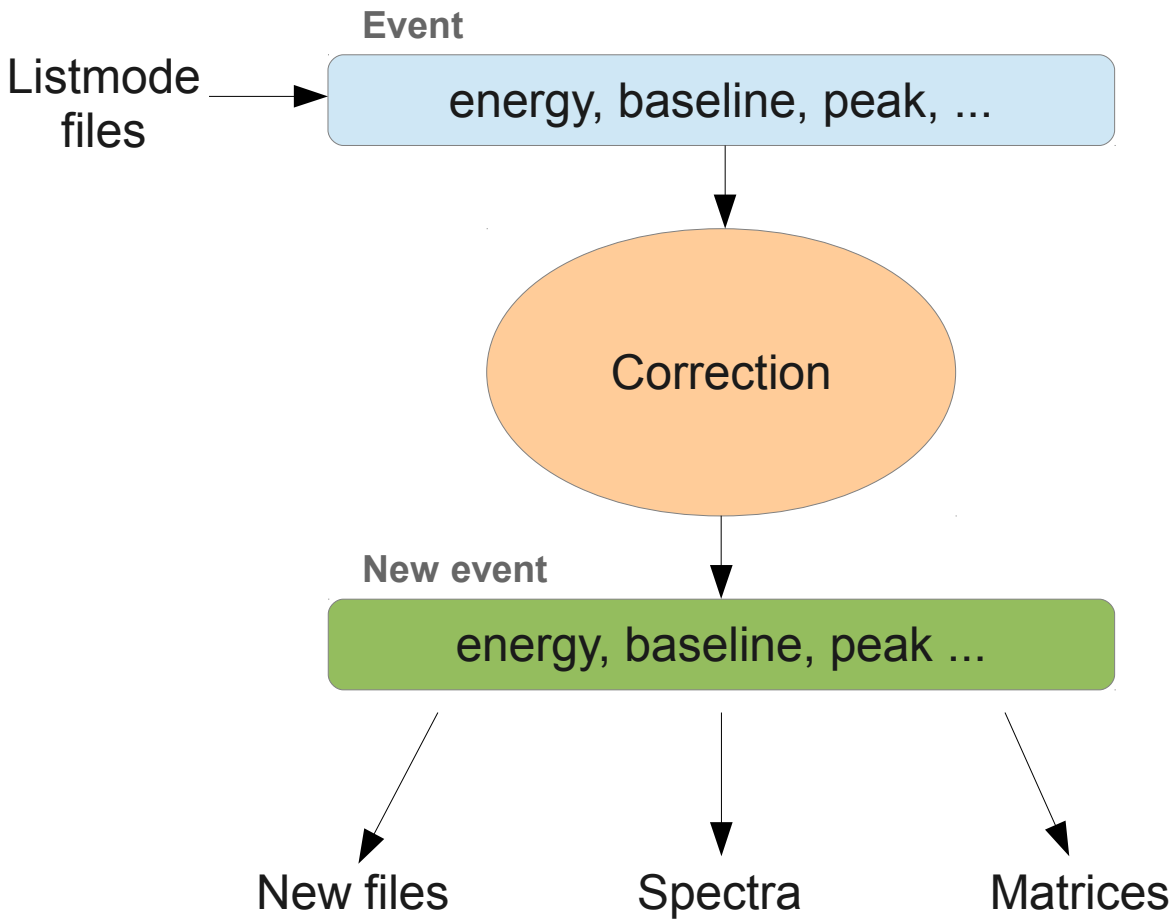
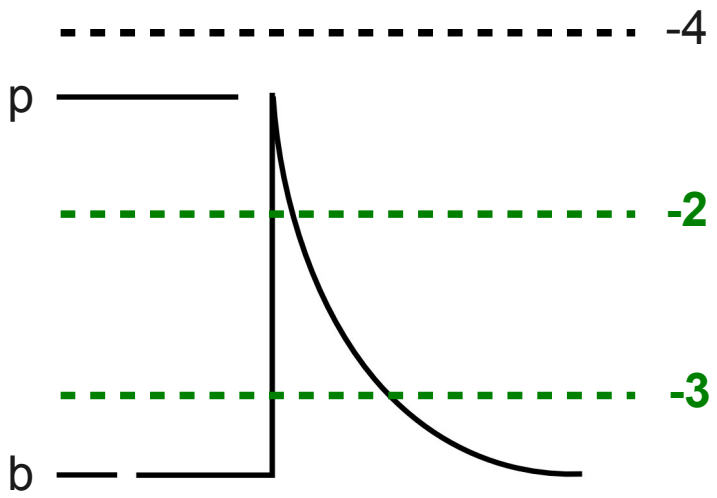



$E' = E - (2+3)$

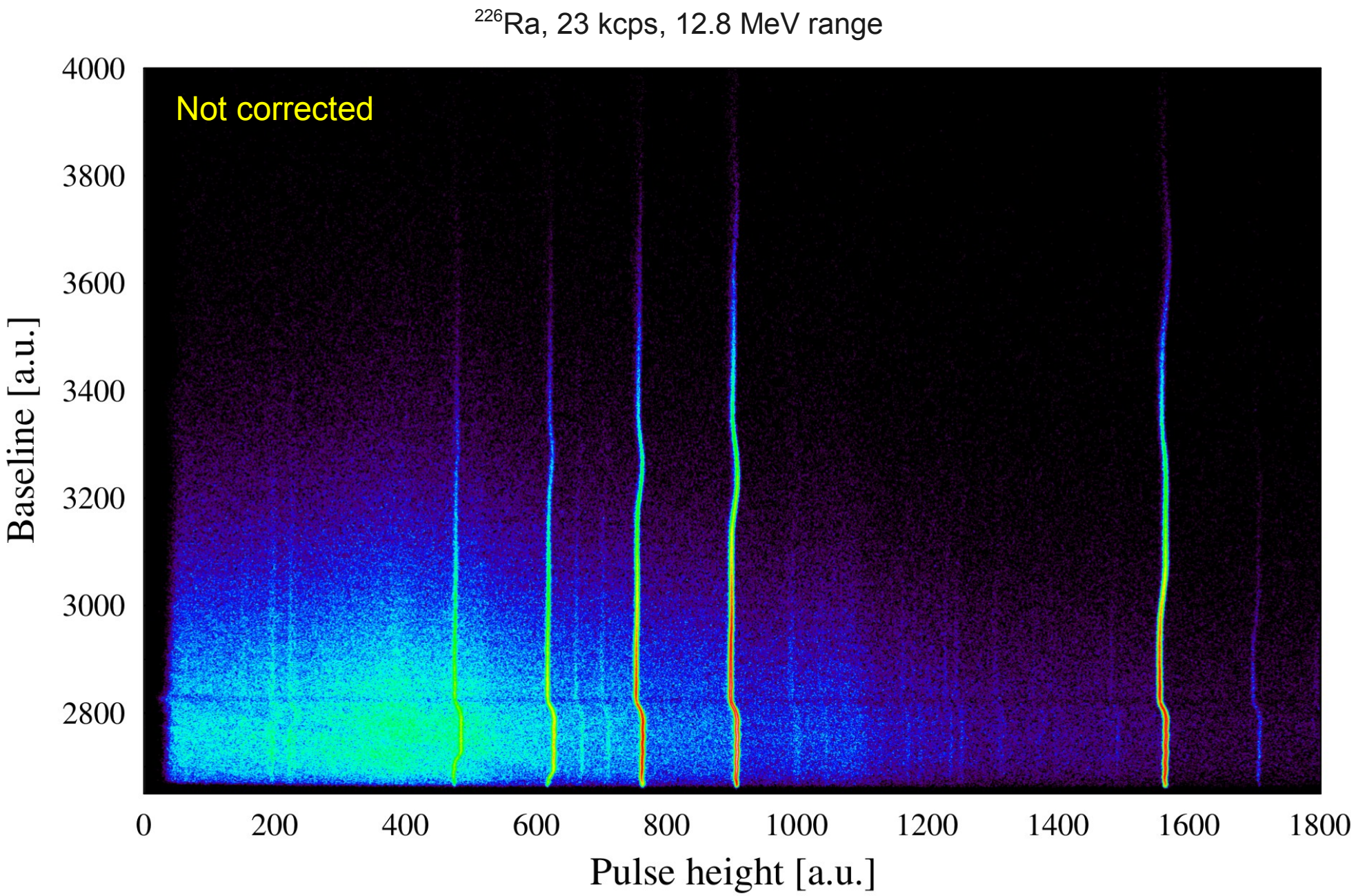
# Correction algorithm



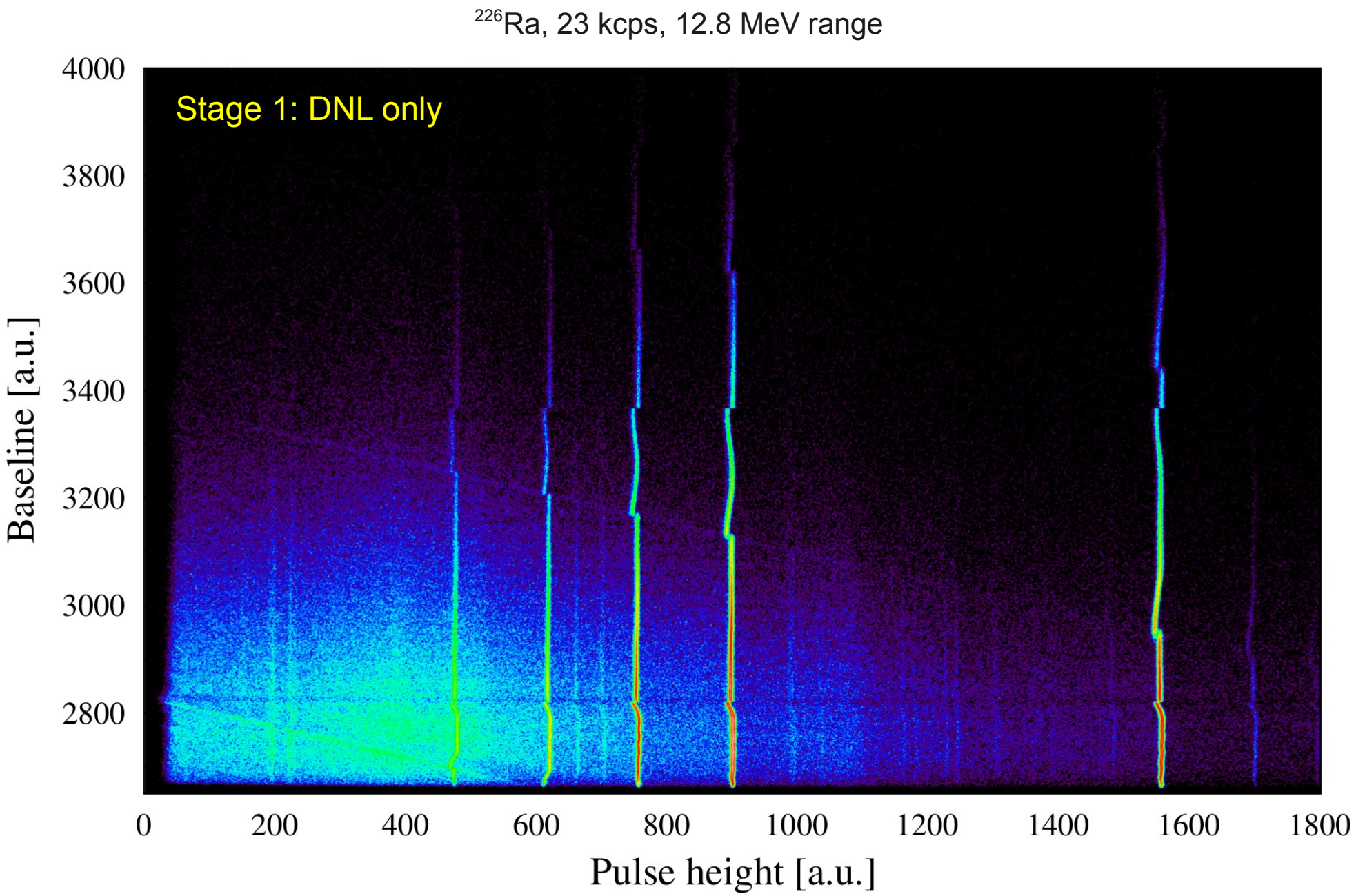




$E' = E - (2+3)$

# Results

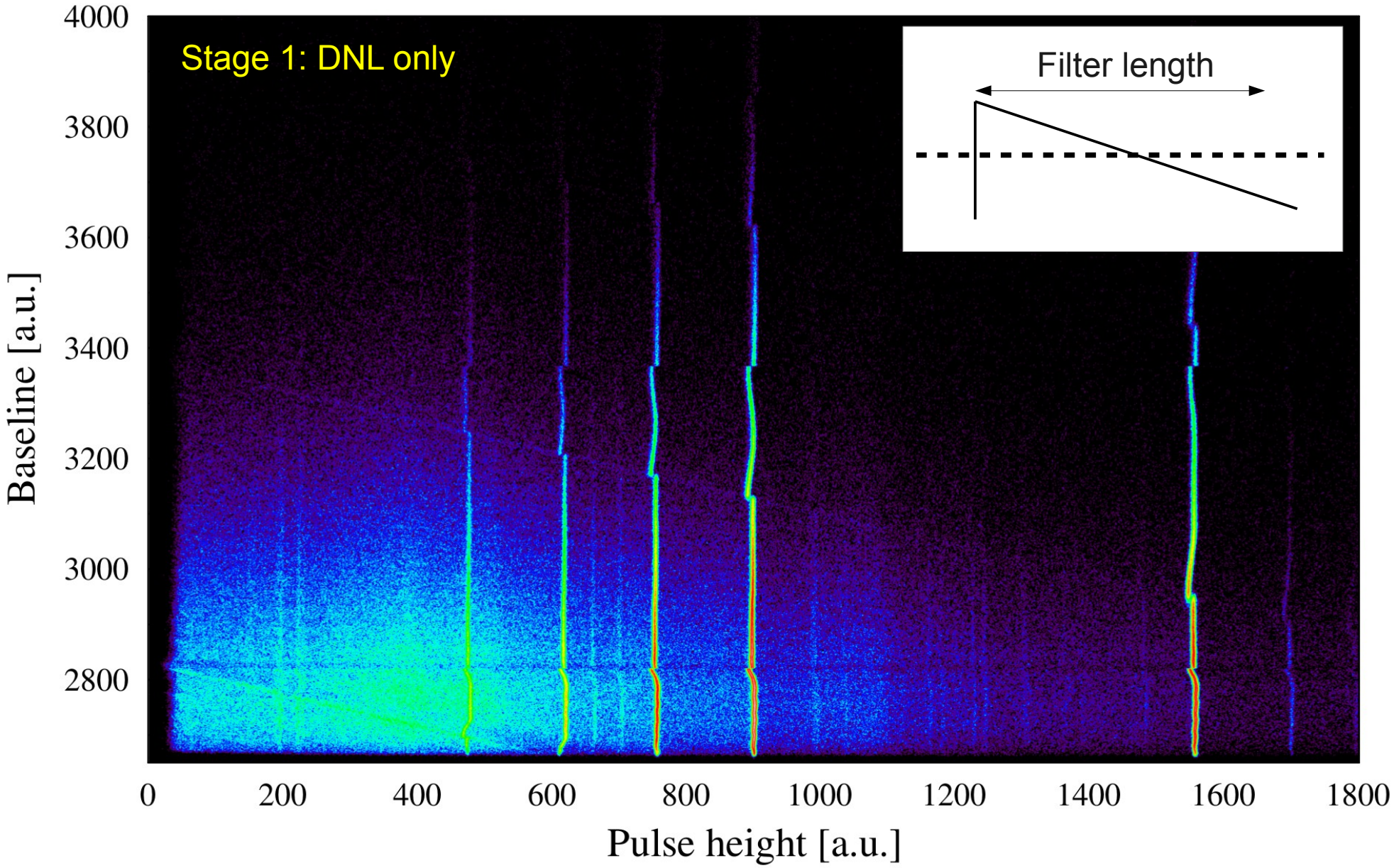

$^{226}$Ra, 23 kcps, 12.8 MeV range
Not corrected
Baseline [a.u.]
4000
3800
3600
3400
3200
3000
2800
0
200
400
600
800
1000
1200
1400
1600
1800
Pulse height [a.u.]

# Results


$^{226}$Ra, 23 kcps, 12.8 MeV range
Stage 1: DNL only
Baseline [a.u.]
4000
3800
3600
3400
3200
3000
2800
0
200
400
600
800
1000
1200
1400
1600
1800
Pulse height [a.u.]

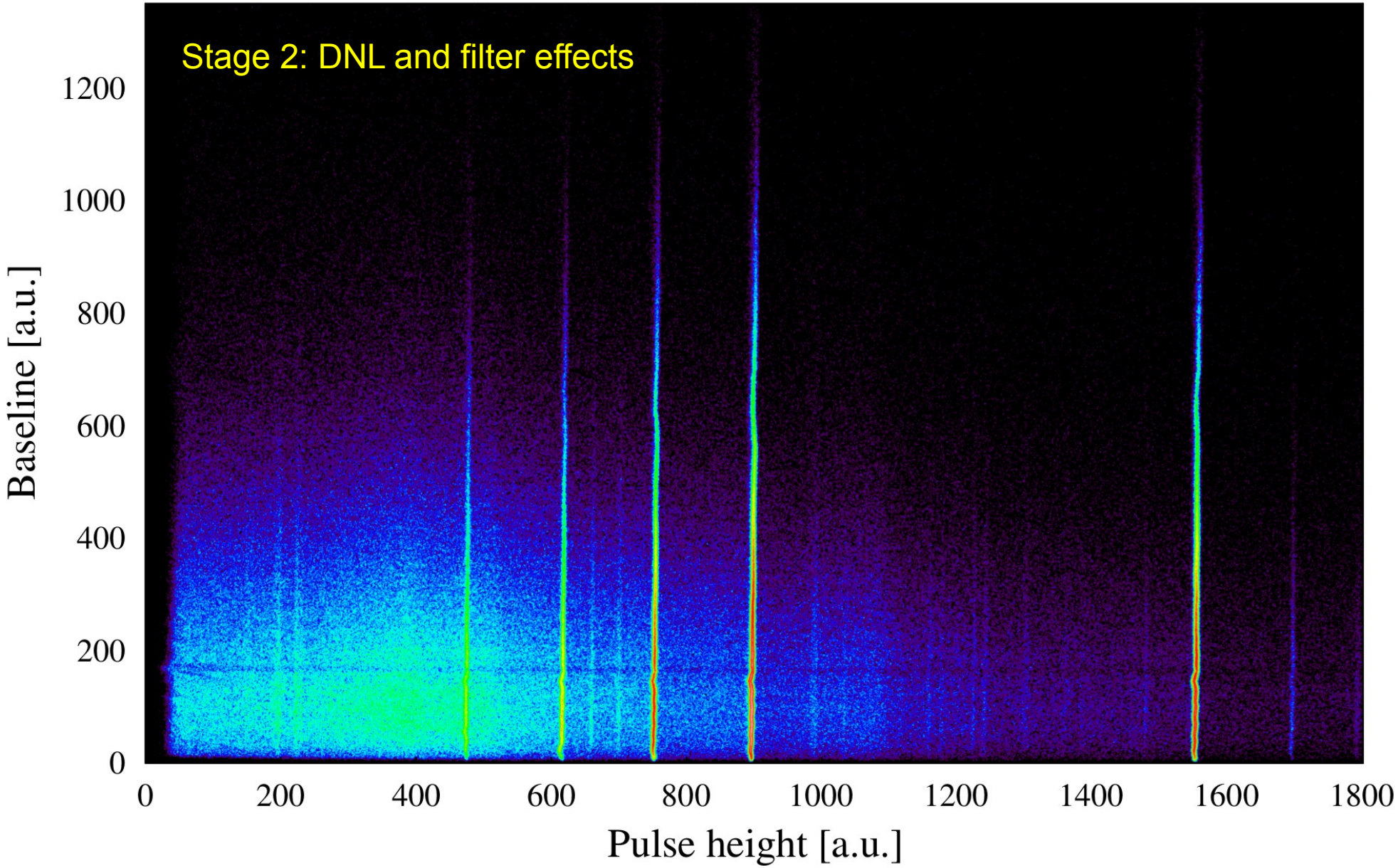
# Results

$^{226}$Ra, 23 kcps, 12.8 MeV range

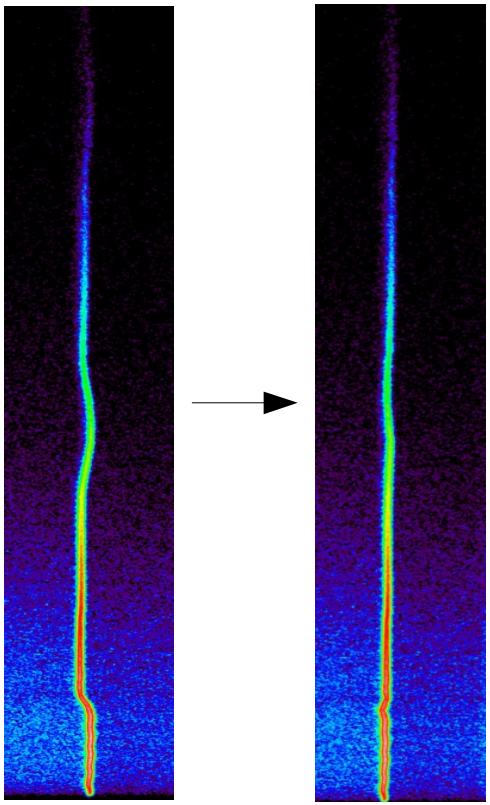


# Results

$^{226}$Ra, 23 kcps, 12.8 MeV range

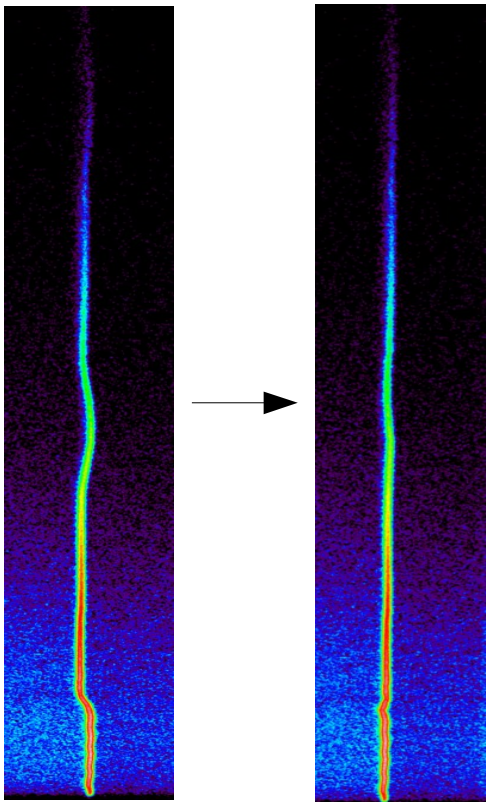


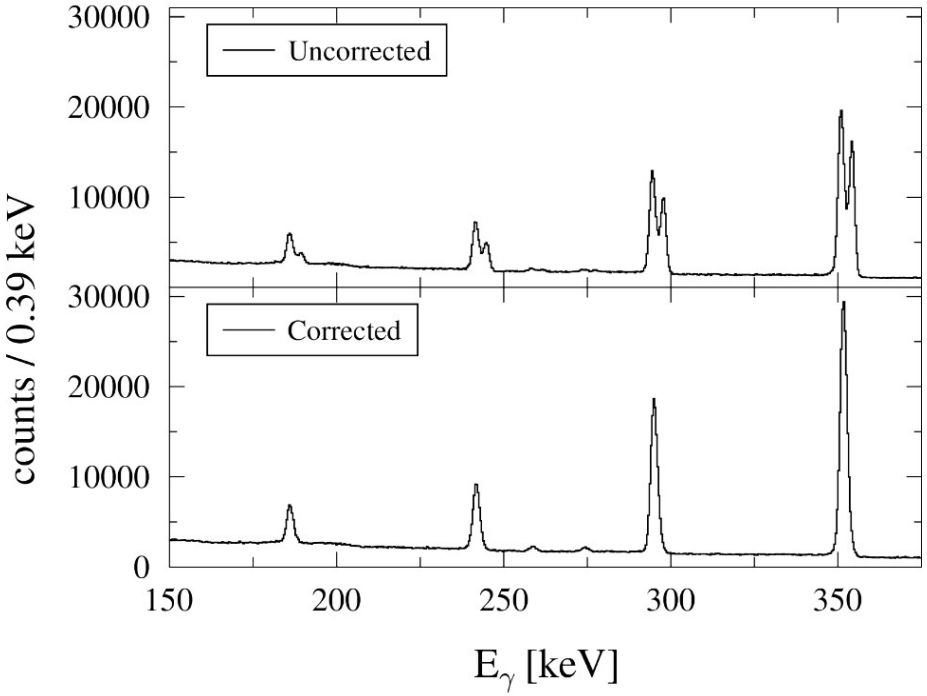
# Results



“Kinks” are removed

# Results






Peak shape is restored!

"Kinks" are removed

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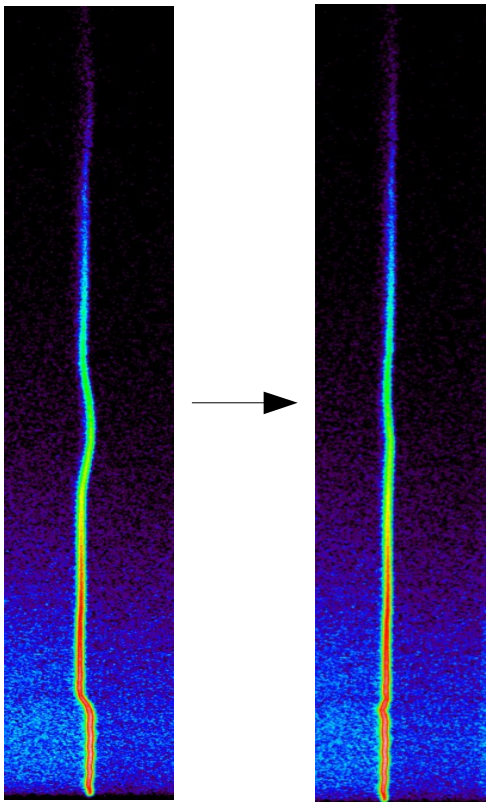
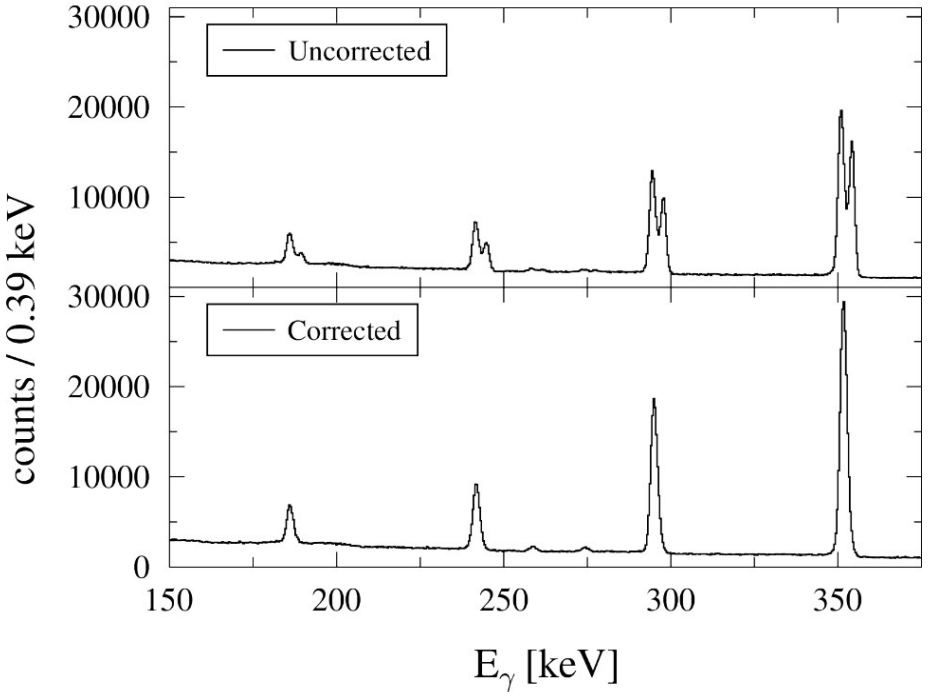
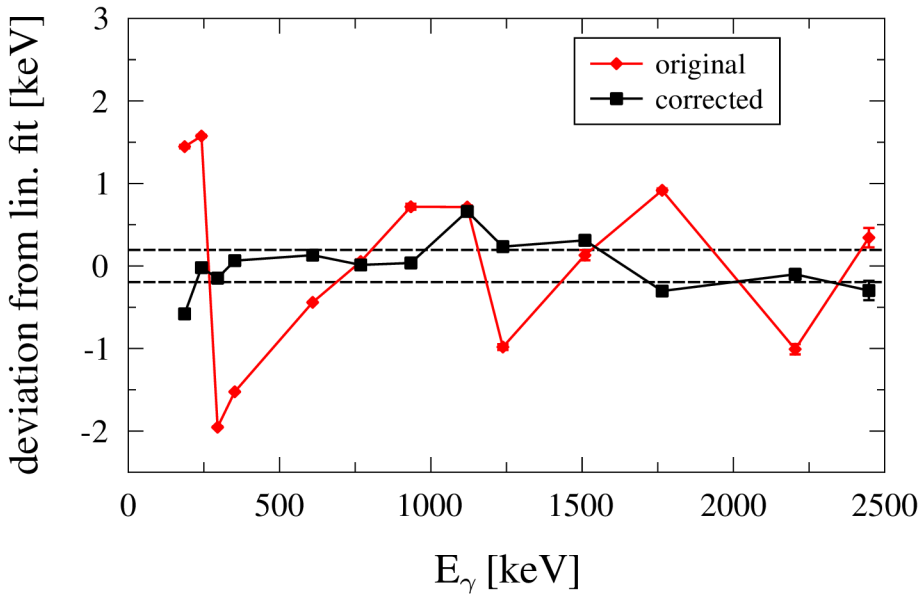
# Results



"Kinks" are removed




Peak shape is restored!




Linearity is improved!

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# Summary

- Setup in Cologne
  - Fully digitized DAQ
  - Readout of up to 36 channels @ 15-20 kcps
- Observations:
  - Peak shape distorted at high count rates
  - Linearity suffers from high dynamic energy ranges
  - Deviations stem from differential nonlinearity
- Digitization and differential nonlinearity
  - Periodic deviations from linear behavior
- Calibration method and correction algorithm
  - Calibrate ADC
  - Correct energy event-by-event
  - Double peaks vanish, linearity is improved