Updates of frequency domain multiplexing for the X-ray Integral Field Unit (X-IFU) on board the Athena mission

H. Akamatsu (SRON)

L. Gottardi, J. van der Kuur, C.P. de Vries, M.P. Bruijn, J.A. Chervenak, M. Kiviranta, A.J. van den Linden, B.D. Jackson, A. Miniussi, K. Ravensberg, K. Sakai, S.J. Smith, N. Wakeham

X-IFU related contributions

[Talk]	N.Wakeham	: This morning
	M. Durkin	: Just before
	C. Macculi	: Thus
[Poster]	F. Pajot	: 241-162
	S. Smith	: 67-355
	A. Minniussi	: 69-128, 68-81
	C. Pobes	: 71-176
	M. Biasotti	: 101-401
	M. D'Andrea	: 66-172
	C. Kirsch	: 78-247
	W.B. Doriese	: 146-299
	P. Peille	: 162-249

X-IFU related SRON contributions

[Talk]	E. Tallari	: This morning
[Poster]	L. Gottardi	: 79-97, 64-99
	K. Nagayoshi	: 211-132
	M. Ridder	: 172-351
	J. van der Kuur	: 129-204

and all missing contributions and references are HA's fault

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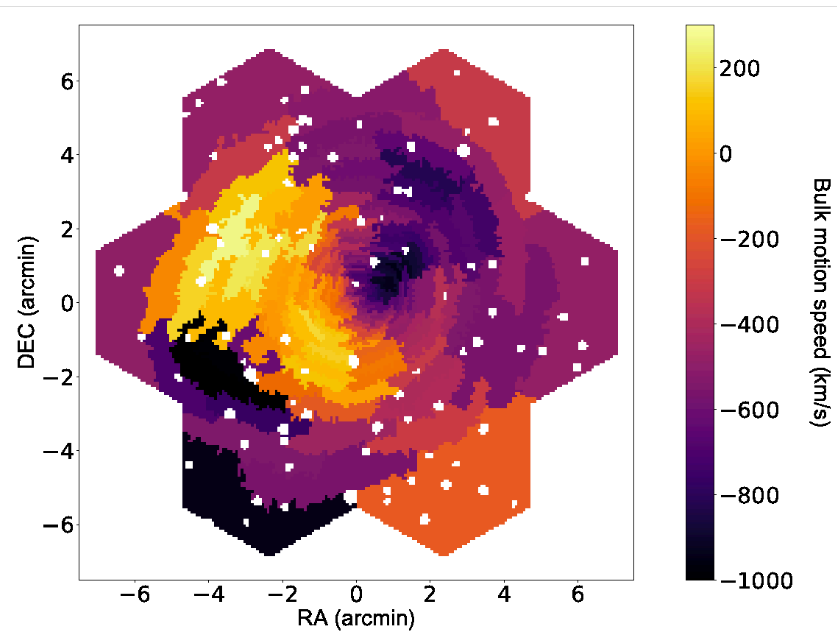
Athena X-ray Integral Field Unit (X-IFU)

Cucchetti et al. 2018, Barret et al. 2018



ESA's L2 mission (2031~): *Hot and Energetic Universe*

X-IFU (see also F. Pajot: 241-162)
- ~3168 of TES X-ray micro calorimeters
- *ΔE*=2.5 eV @ 6 keV (upto 7 keV)

SRON
- Focal Place Assembly
- Readout technology
- Back up TES array =>

[Talk] E. Tallari (This morning)
[Poster] L. Gottardi : 79-97, 64-99
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Frequency domain multiplexing (FDM)

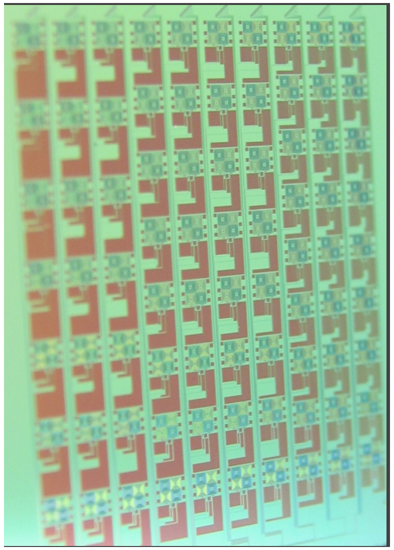
Multiplexing in frequency domain space

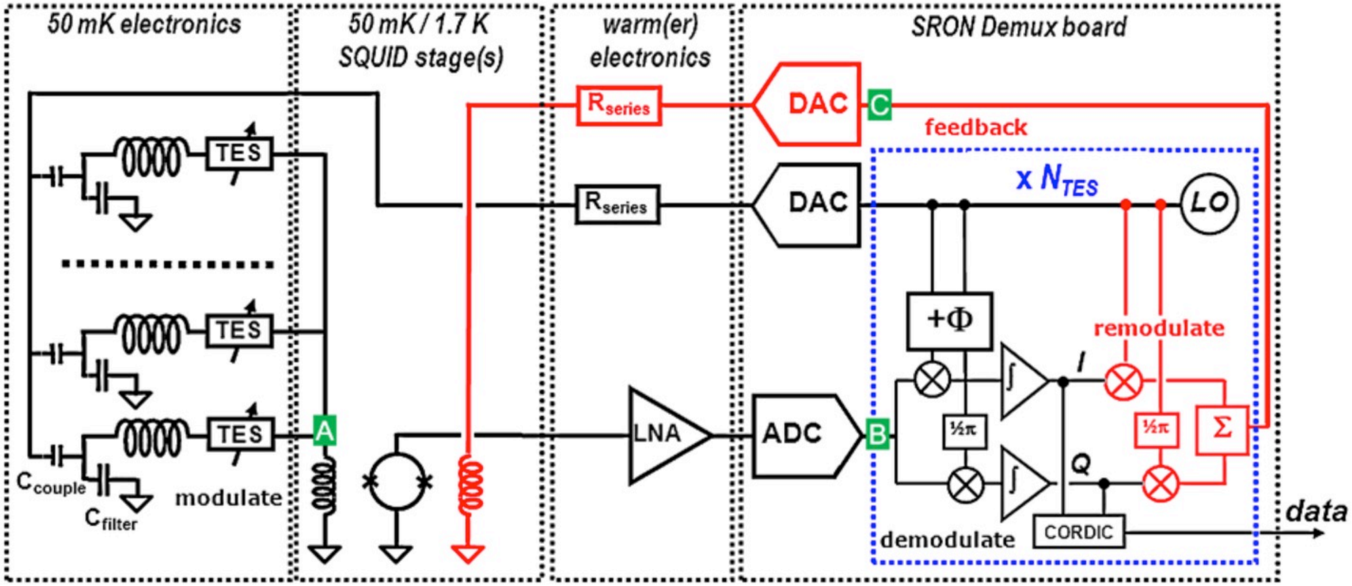
- **Each TES is connected to a LC filter (passive resonator)**
- **TESes are biased with MHz alternative current (AC Bias)**
- **Signals are summed up at SQUID amp**

X-IFU requirements (TBD)

- **~40 pixels/channel, 96 channels**
- **Bandwidth: 1-5 MHz, 100 kHz separation**

High-Q LC filter (SRON)





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Development of FDM for the X-IFU

H. Akamatsu et al. LTD18 @ Milan, Italy, 2019/07/22

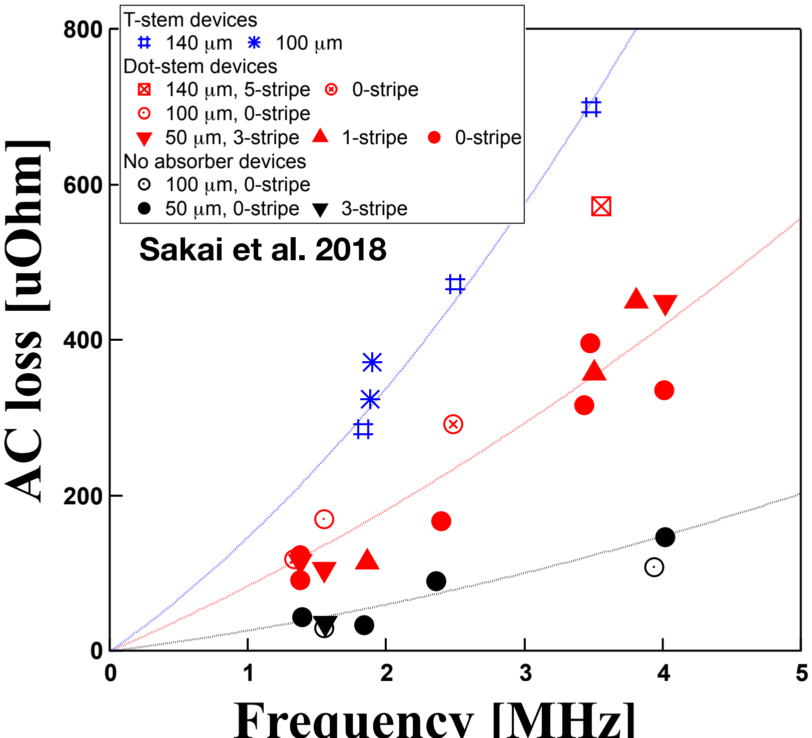
NASA/GSFC TES X-ray calorimeter & cooler

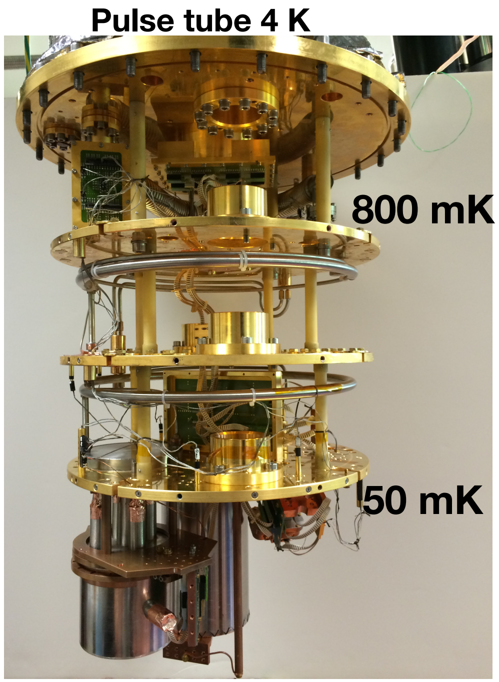
Moderate-Z TES array (GSFC-A6, A7)

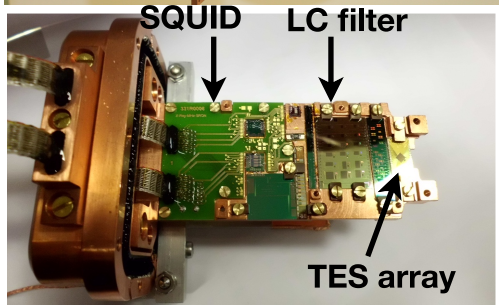
- TES size: 100 um^2 (A6), 120 um^2 (A7)
- Normal resistance Rn~25—35 mOhm
- Resistive AC loss
- Weak link (AC Josephson) effect

Cryogenic test-setup

- Cryogen free dilution cooler (400 uW@ 100 mK)
- Nice temperature stability (< 1 uK @ 50 mK)
- For 18 pixels FDM demo (will be update to 32 pix)
- Shared with other setups (7 setups in one cooler)







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Development of FDM for the X-IFU

H. Akamatsu et al. LTD18 @ Milan, Italy, 2019/07/22

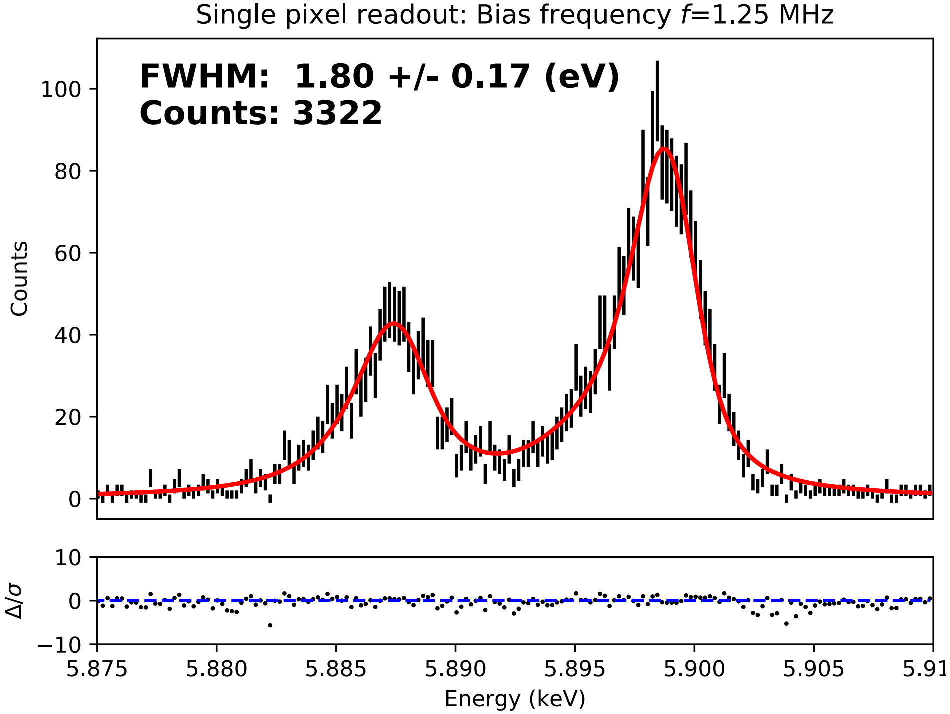
Single pixel performances under AC bias

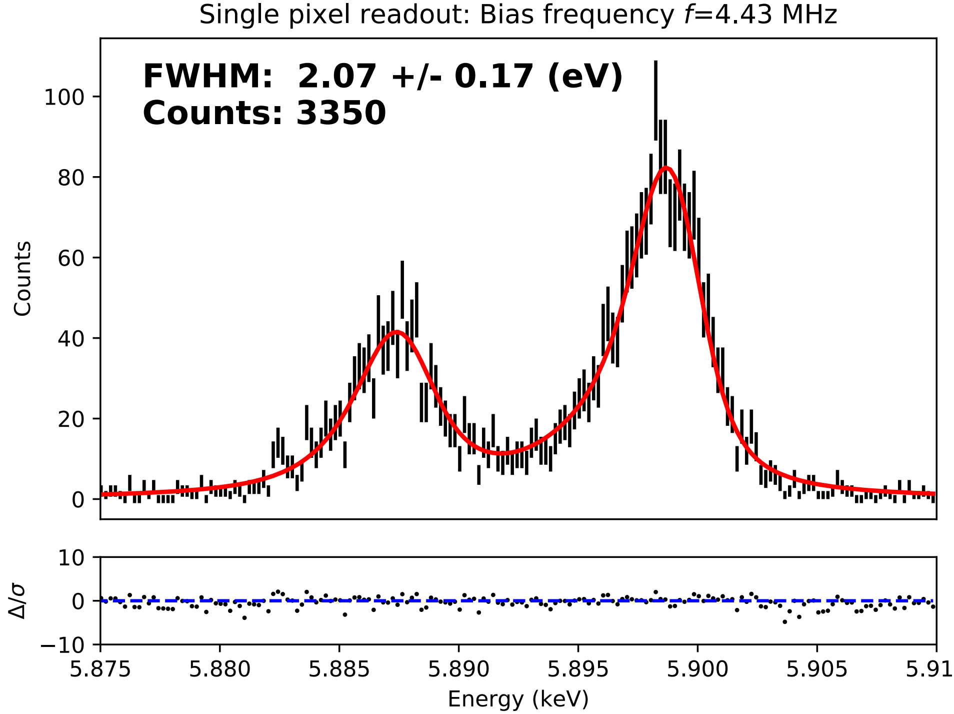
Early 2018, we introduced quasi-uniform moderate-Z TES array (GSFC-A6)
100 um², dotted coupled, no-T stem and no-stripes

ΔE=1.8 eV @ 1.3 MHz

ΔE=2.1 eV @ 4.4 MHz

Compatible AC bias performances with DC bias
(1.6-1.9 eV @ 6 keV: S. Smith et al. 2016, A. Miniussi et al. 2018)





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Development of FDM for the X-IFU
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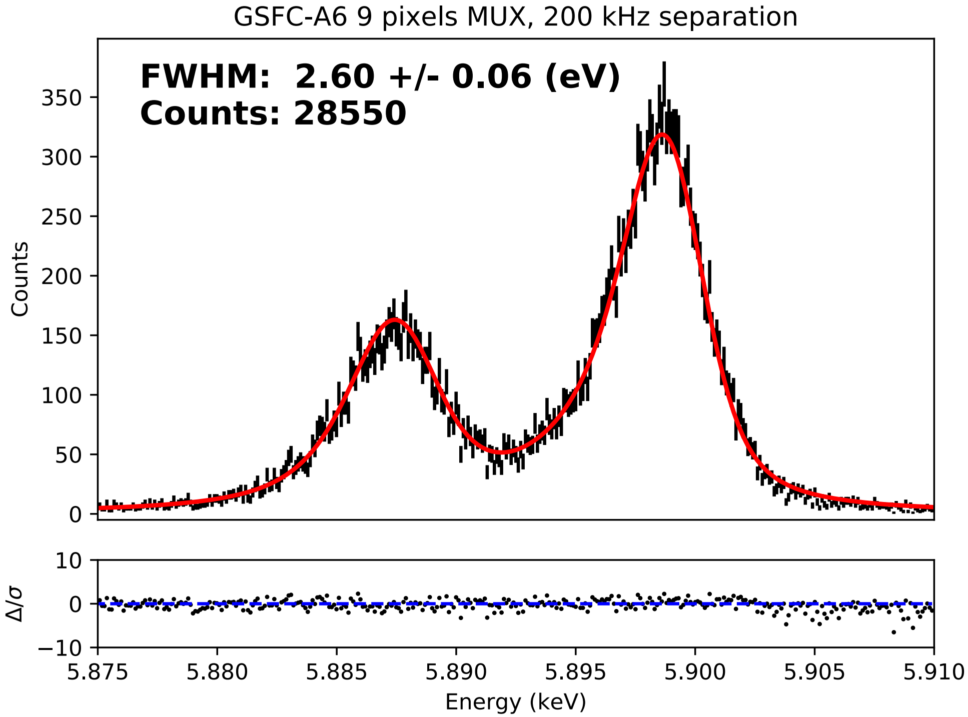
Multiplexing experiments

ΔE=2.6 eV with 9 pixels MUX with GSFC-A6 (100 um²)

some pics suffer damaged membrane, 200 kHz separation
Room for further tuning, surpassed the 3 eV DM req with a margin



Multiplexing experiments

ΔE=2.6 eV with 9 pixels MUX with GSFC-A6 (100 um²)

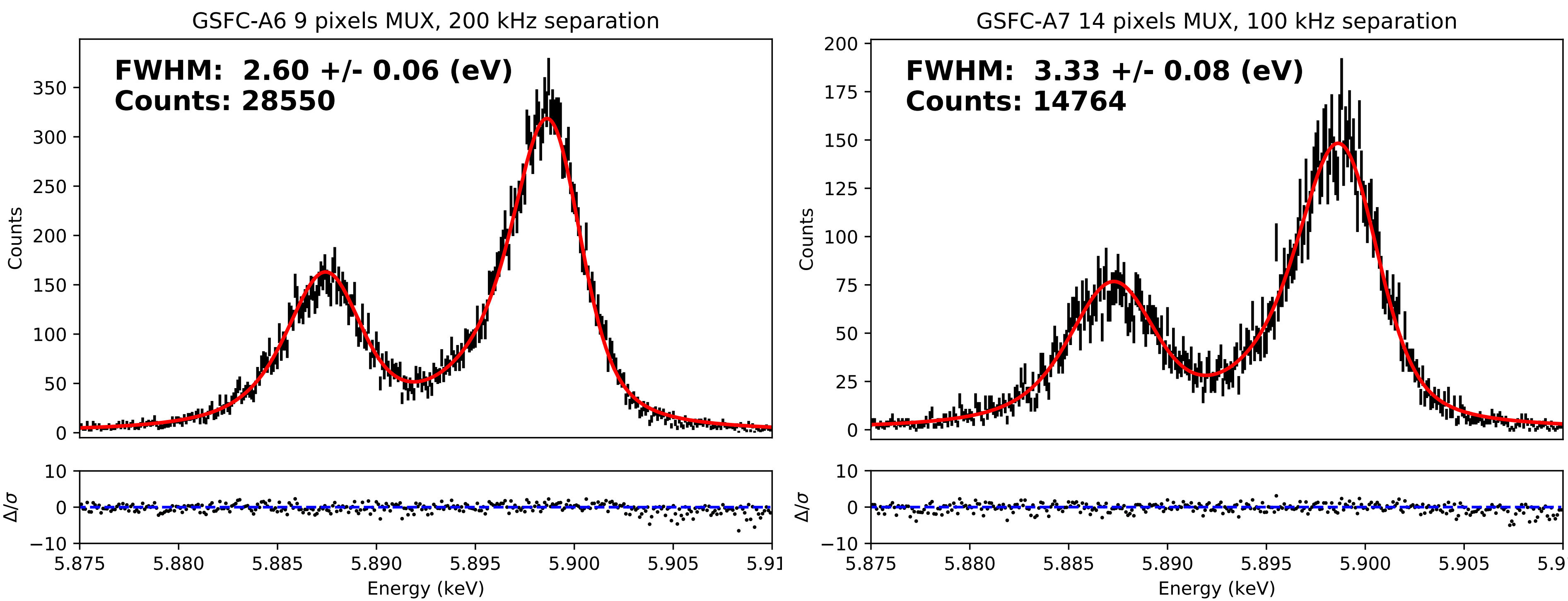
some pics suffer damaged membrane, 200 kHz separation

Room for further tuning, surpassed the 3 eV DM req with a margin

ΔE=3.3 eV with 14 pixels MUX with GSFC-A7 (120 um²)

100 kHz separation

Significant degradation from 200 kHz separation case



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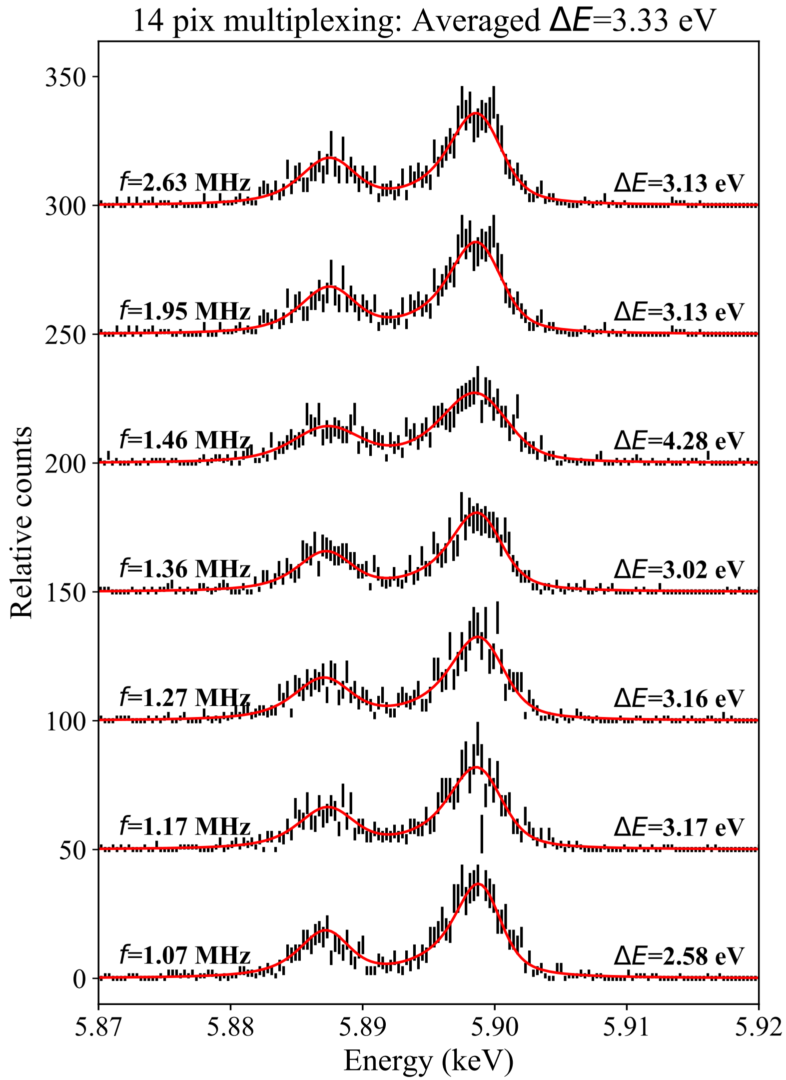
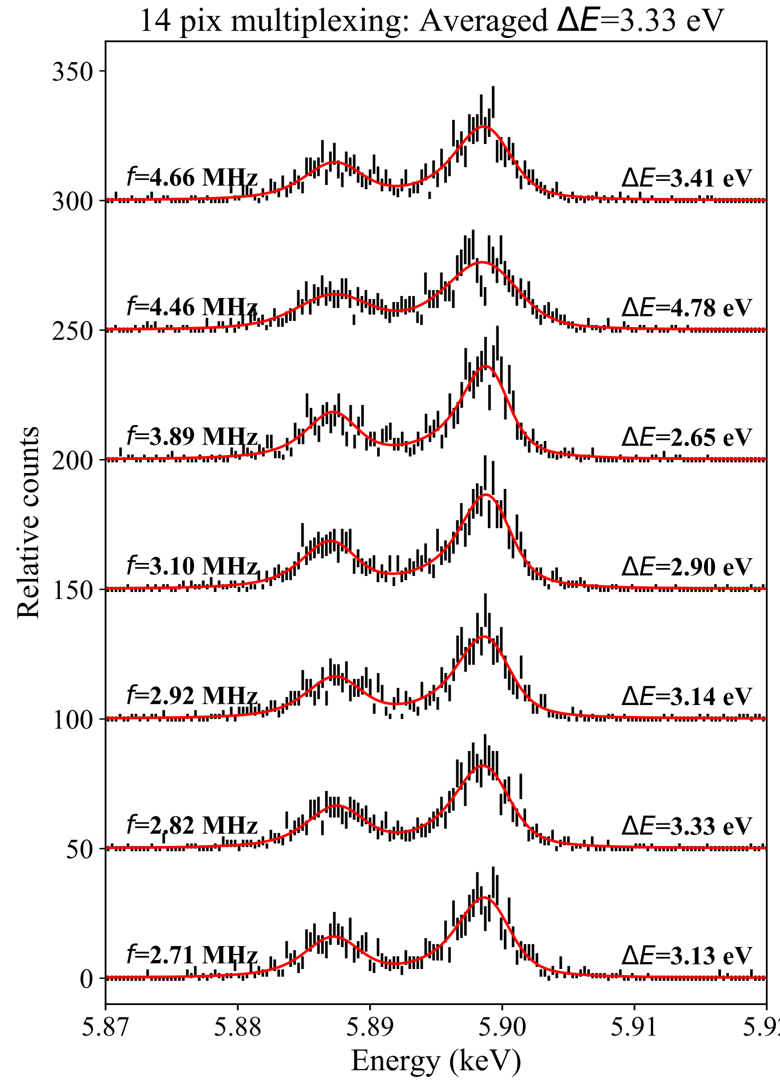
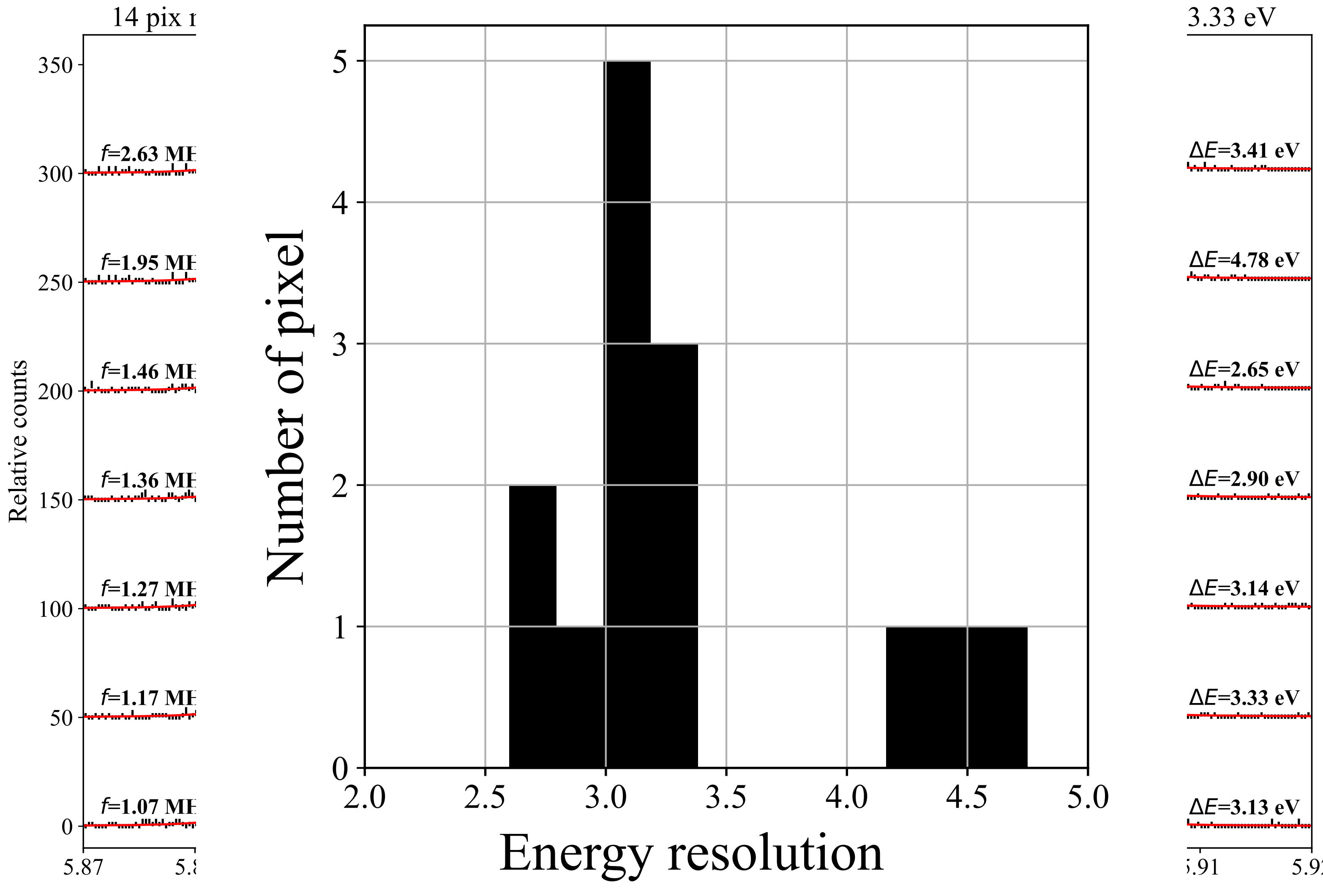
ATHENA X-ray Integral Field Unit

Multiplexing experiments



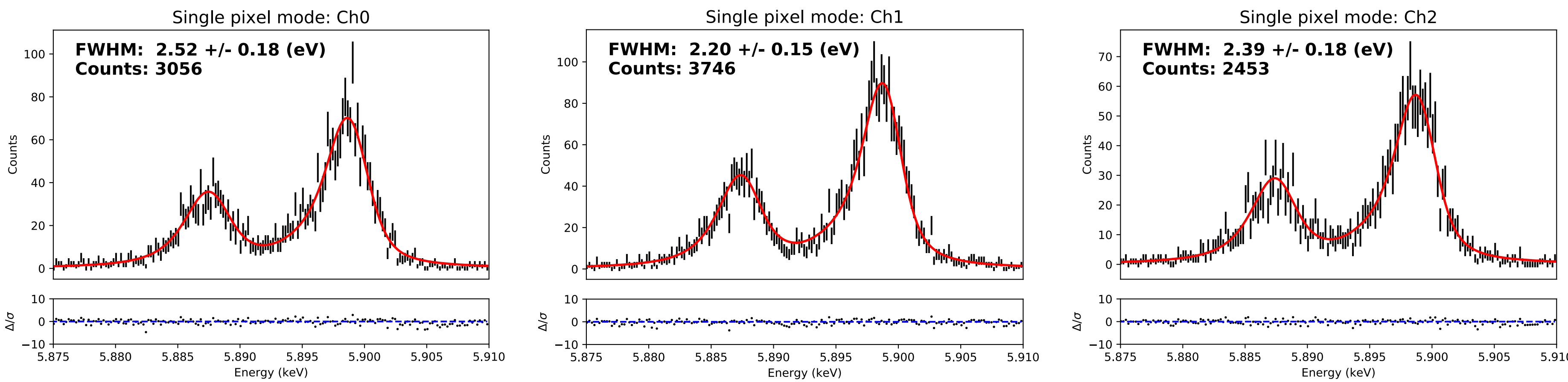


Multiplexing experiments



Further test: 3 pixel MUX experiment

Single pixel mode performances



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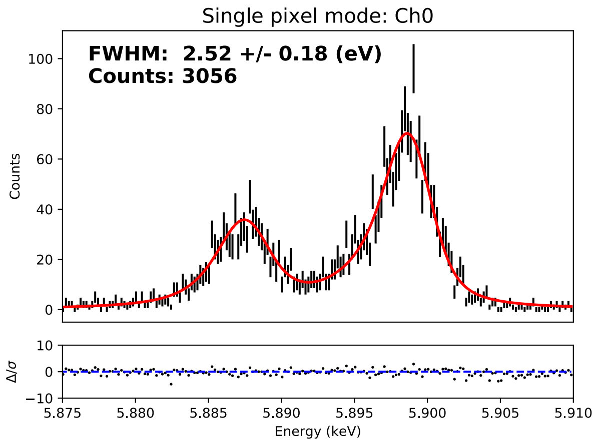
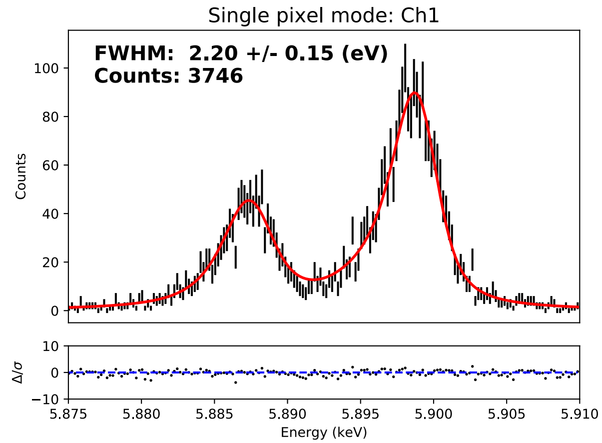
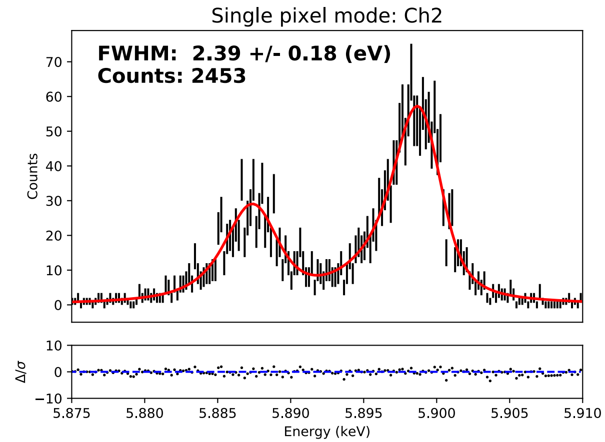
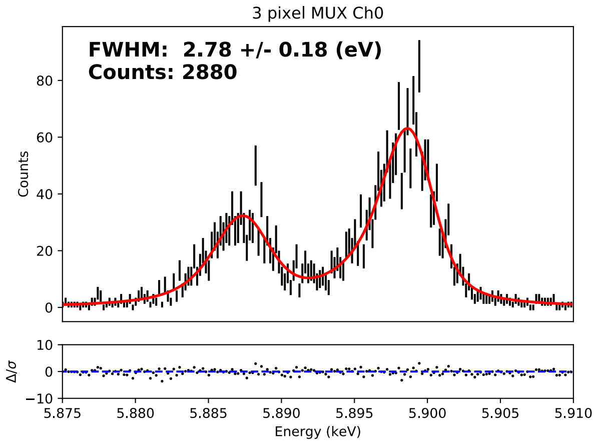
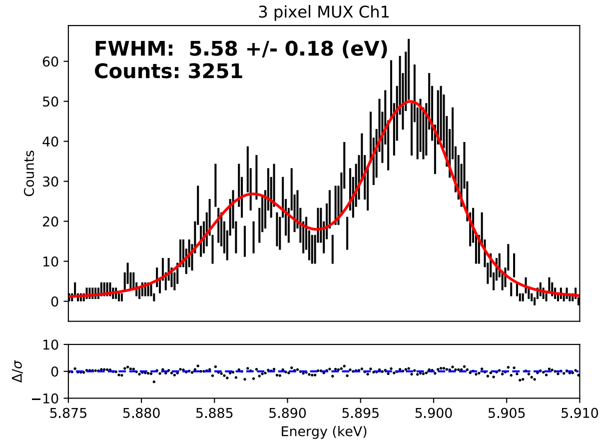


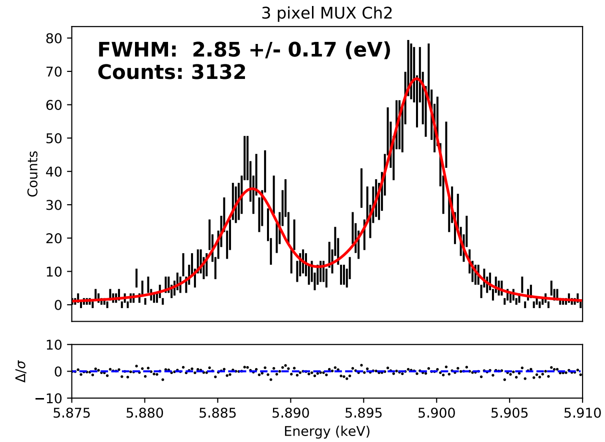




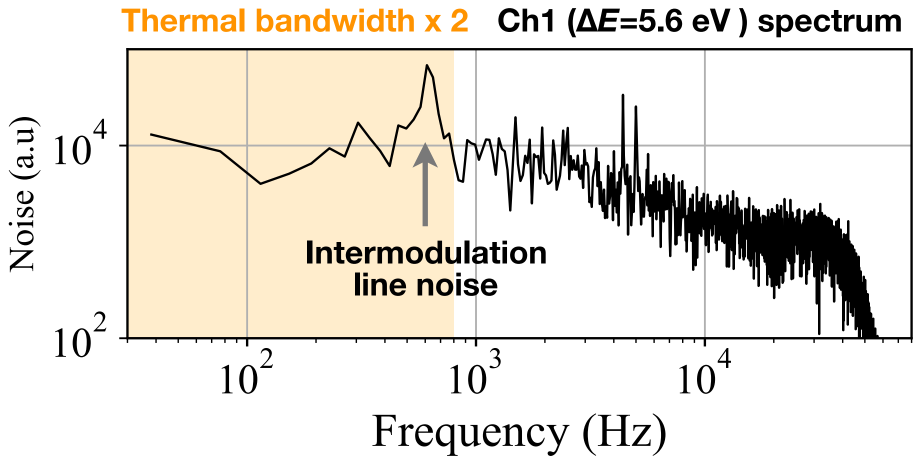
3 pixel MUX in 100 kHz separation







Issue: Intermodulation line noise



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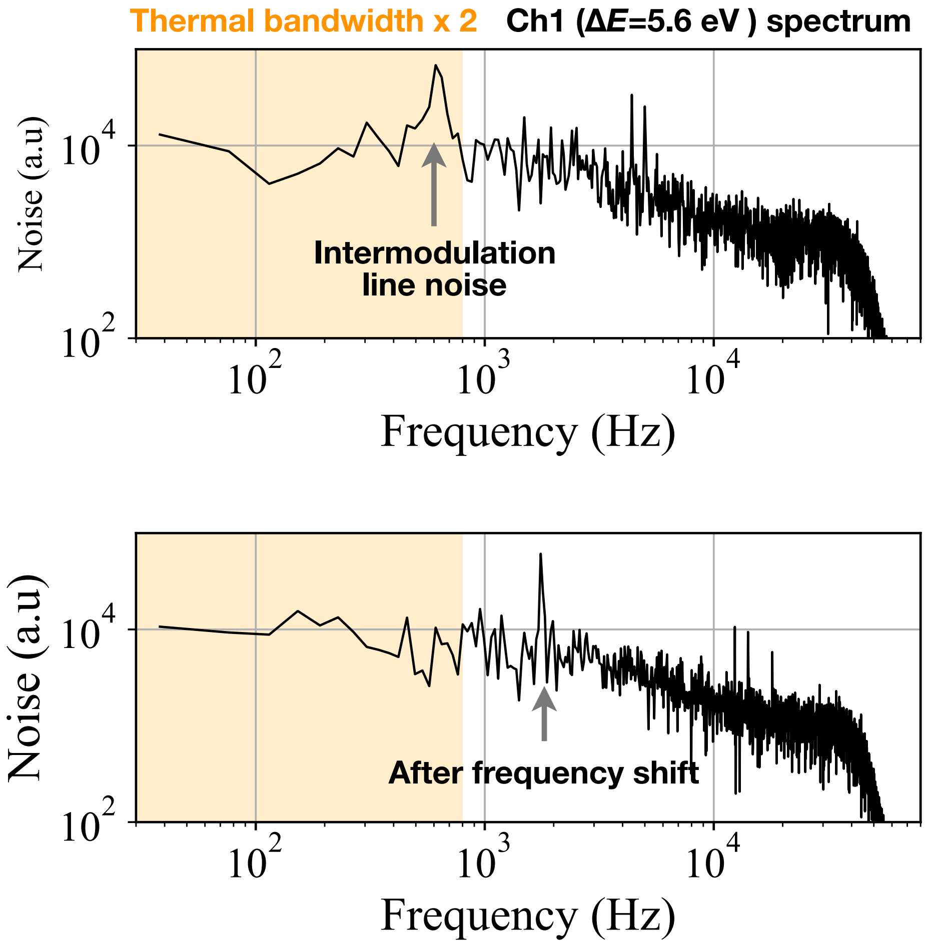

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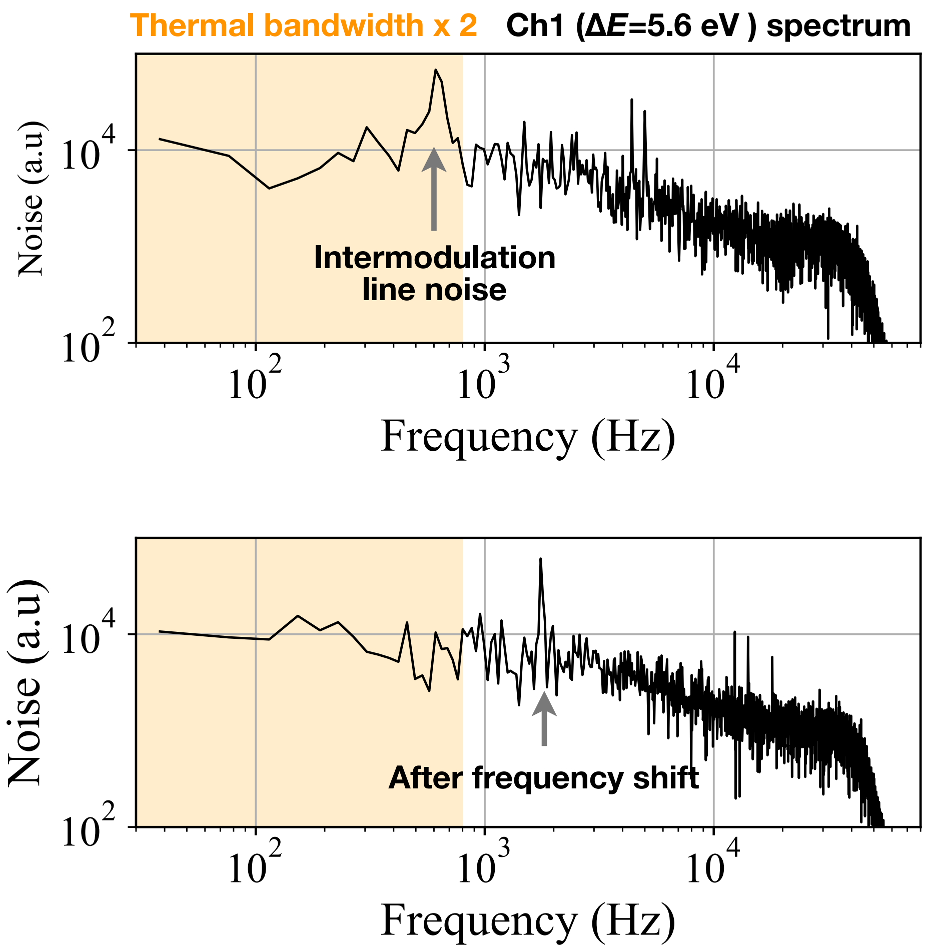
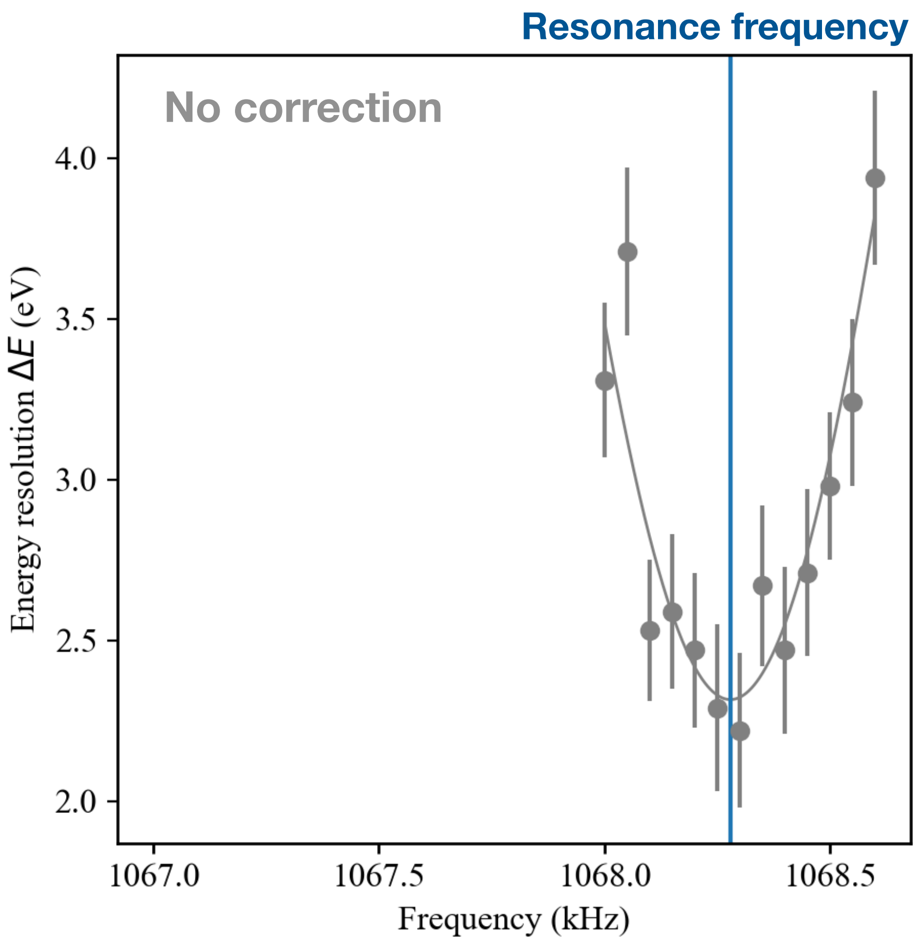
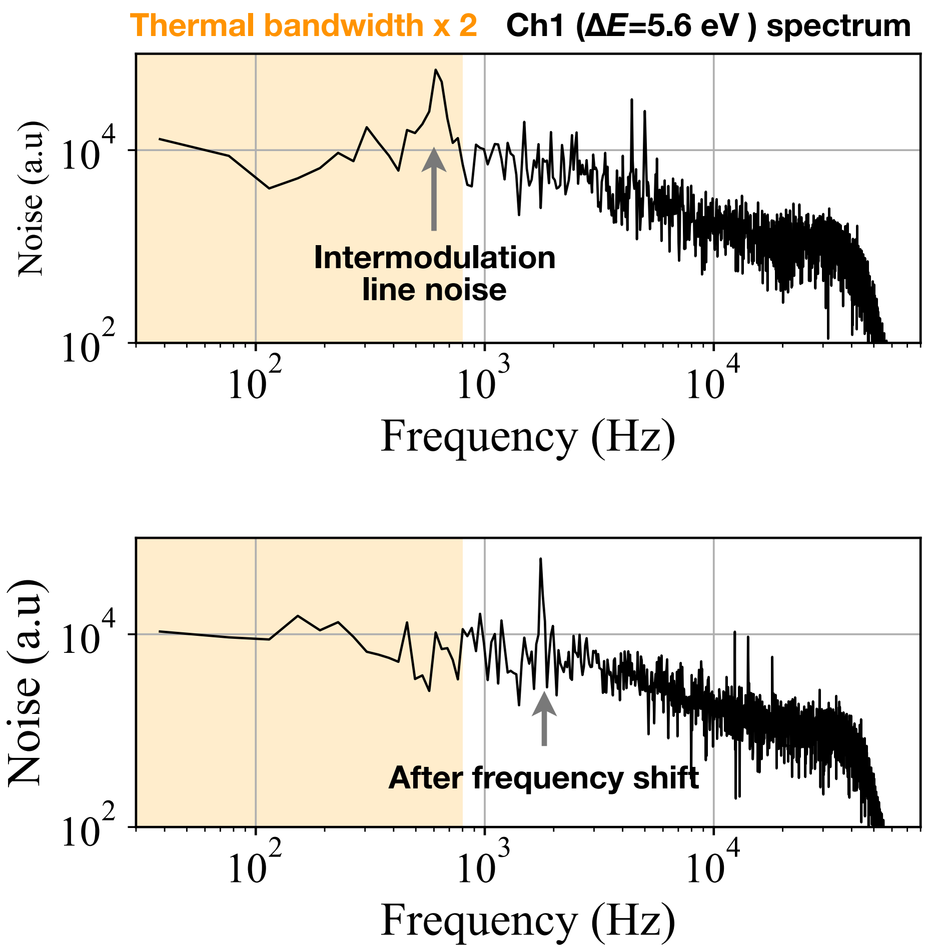


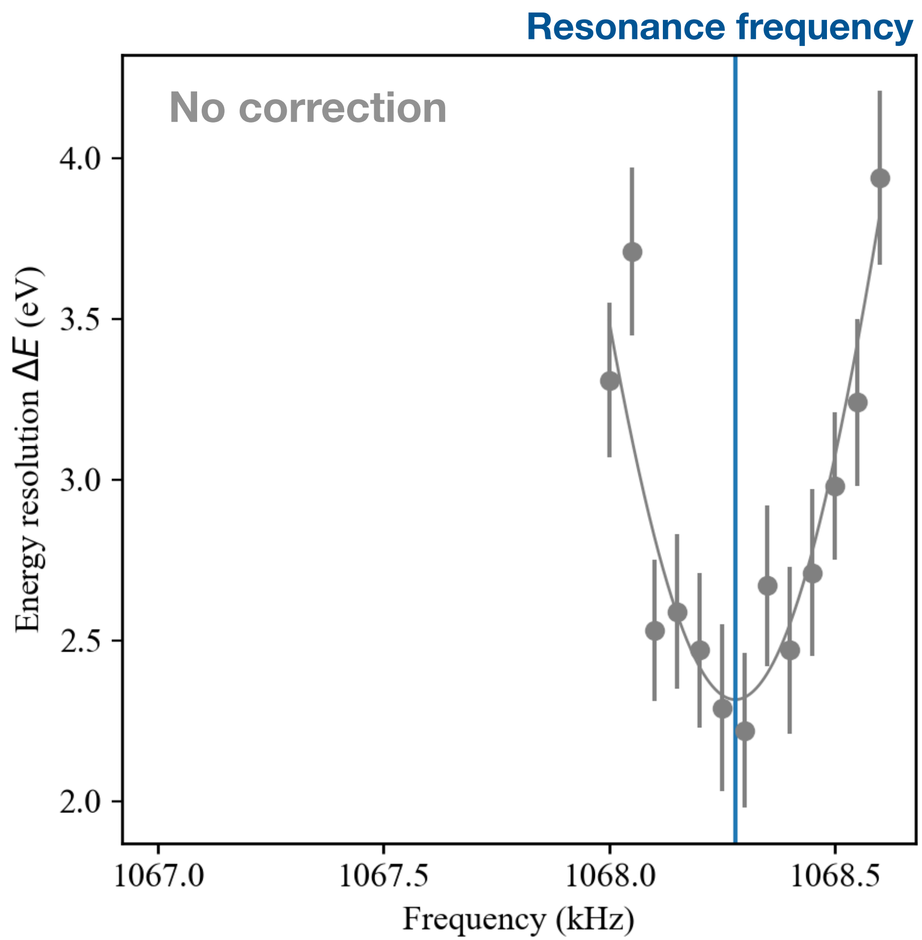


Issue: Intermodulation line noise

Frequency shift algorithm (FSA)

J. van der Kuur et al. 2018





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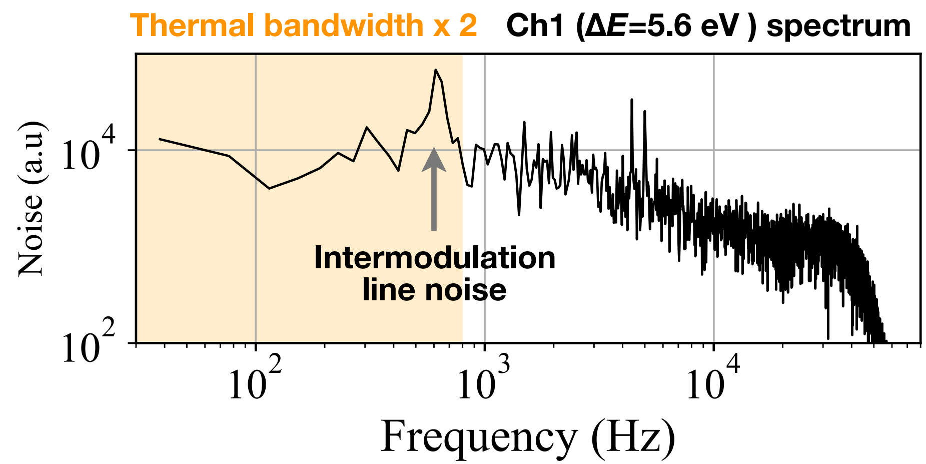

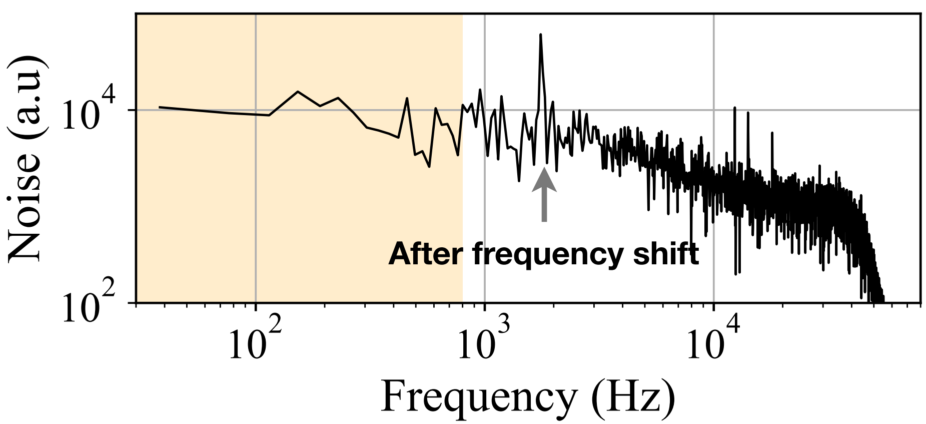

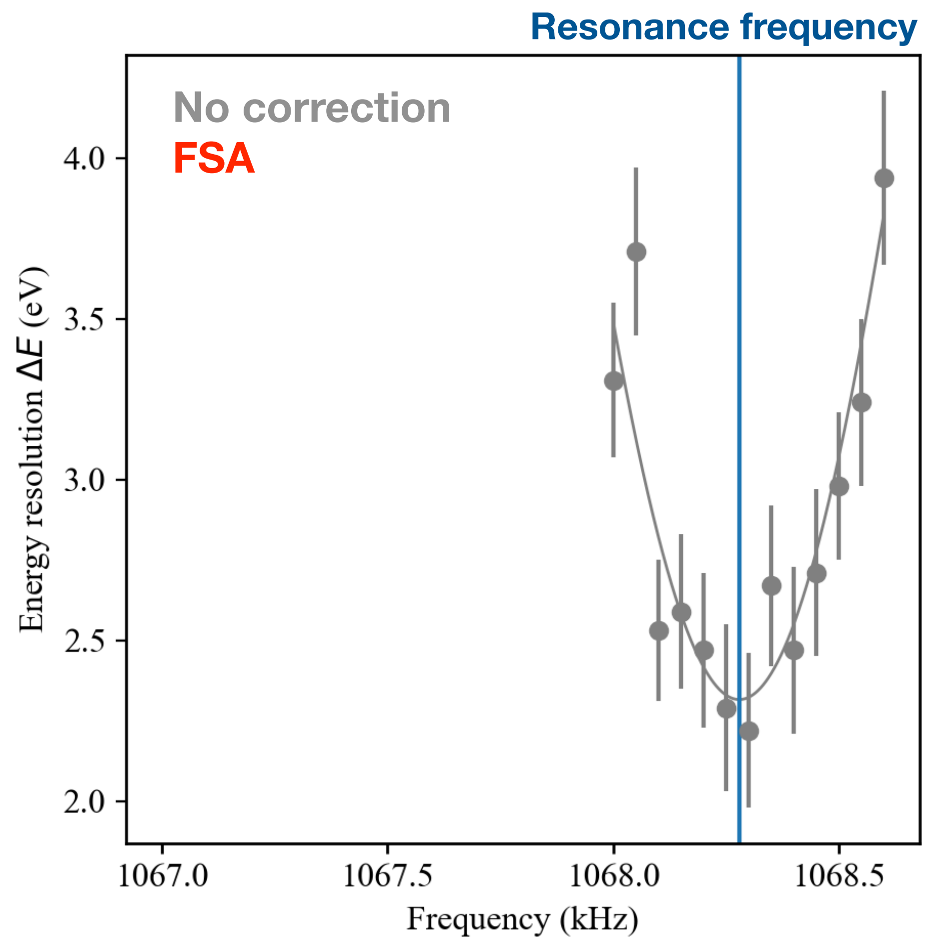

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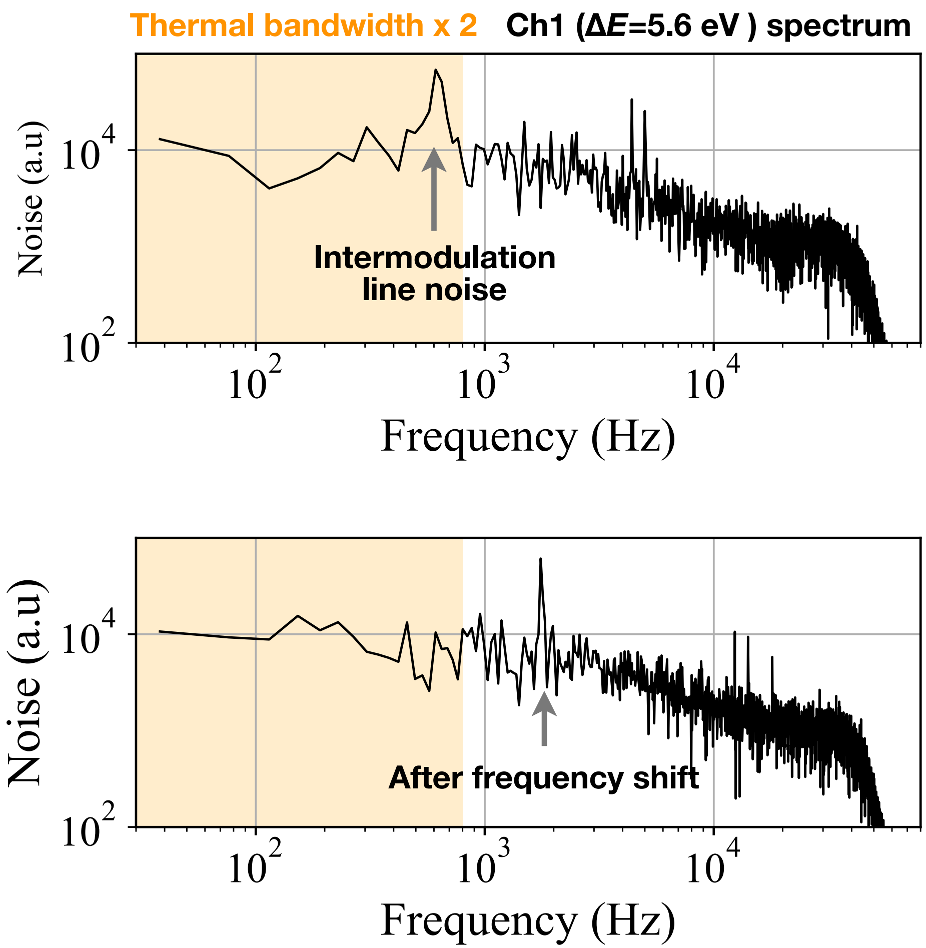
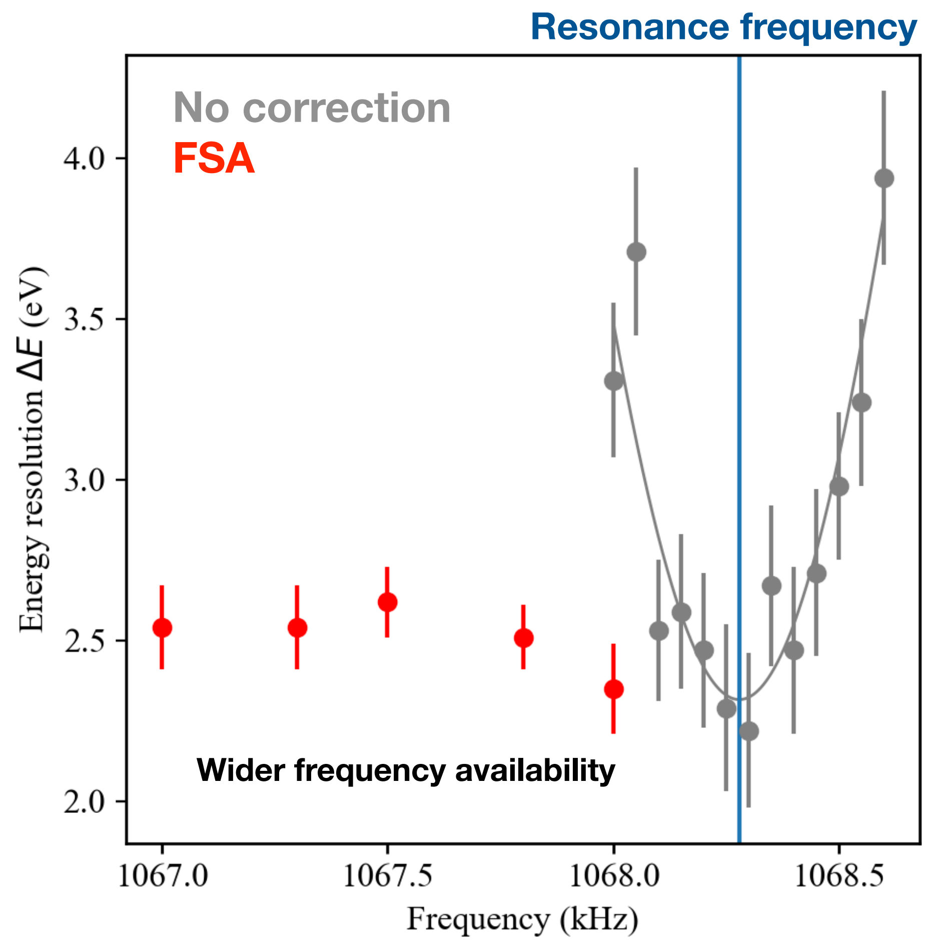
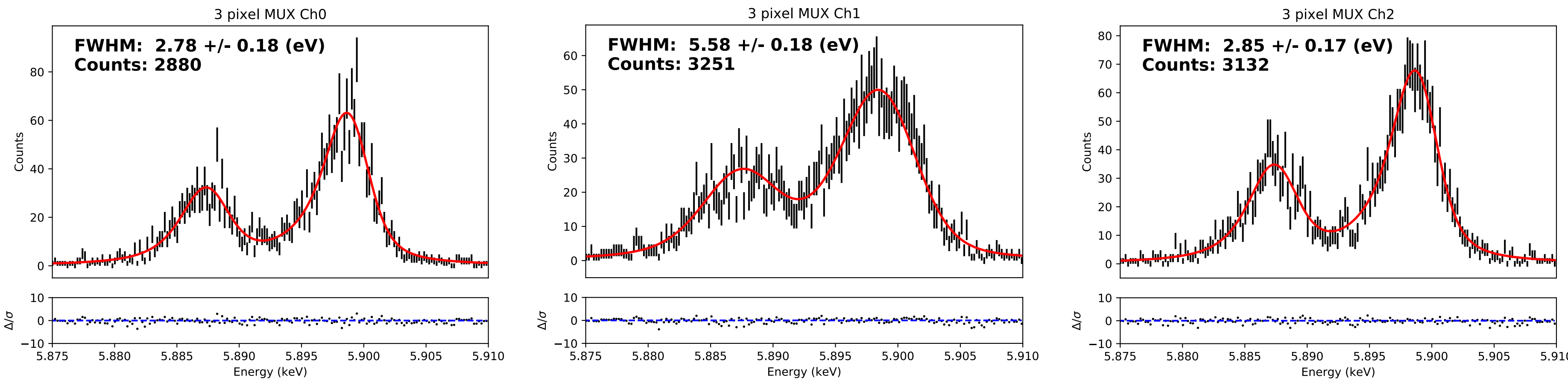




Close look of 3 pixel MUX experiment

3 pixel MUX in 100 kHz separation



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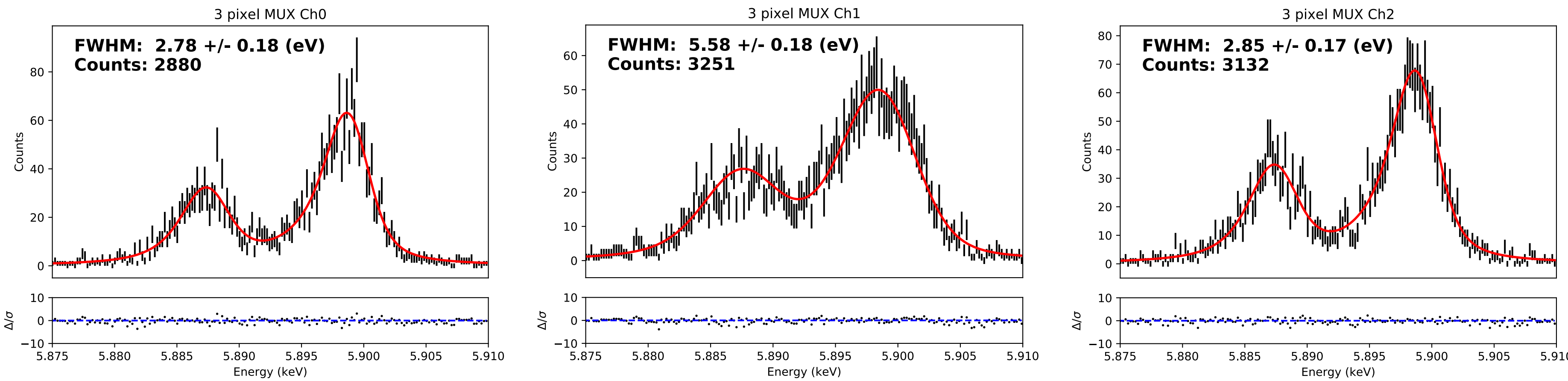
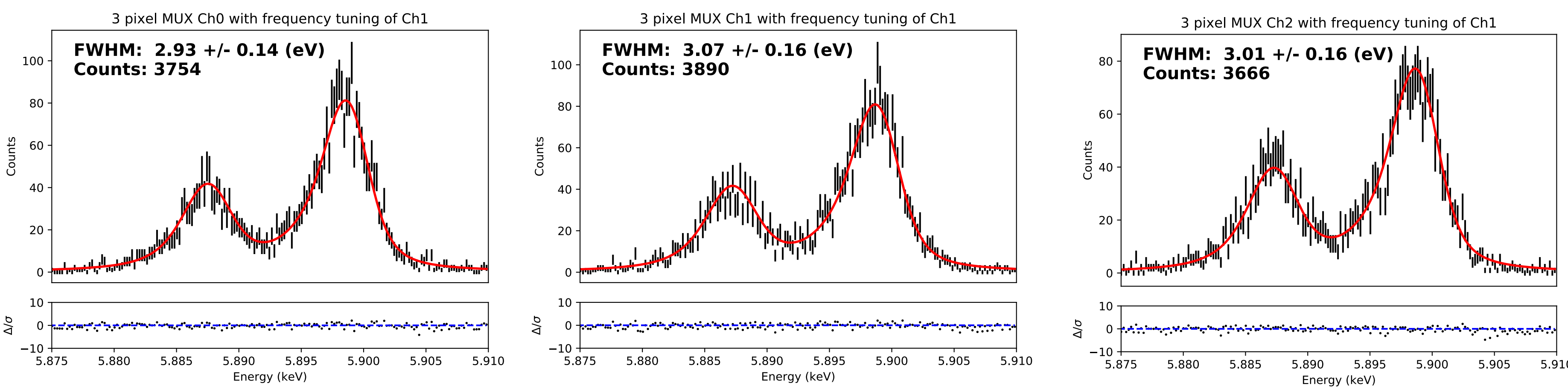
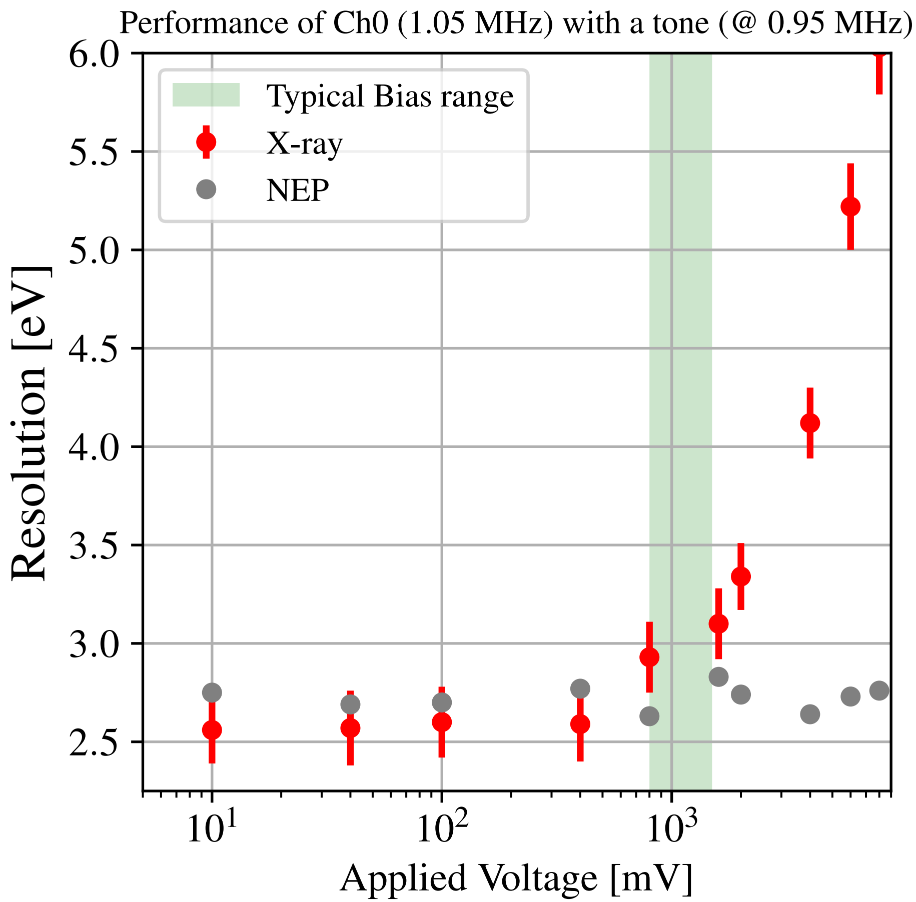


3 pixel MUX with frequency tuning for Ch1



Issue: Interference from neighbouring pixels

Even two pixels MUX, dE=2.5 -> ~3 eV
Voltage/frequency scans show similar results



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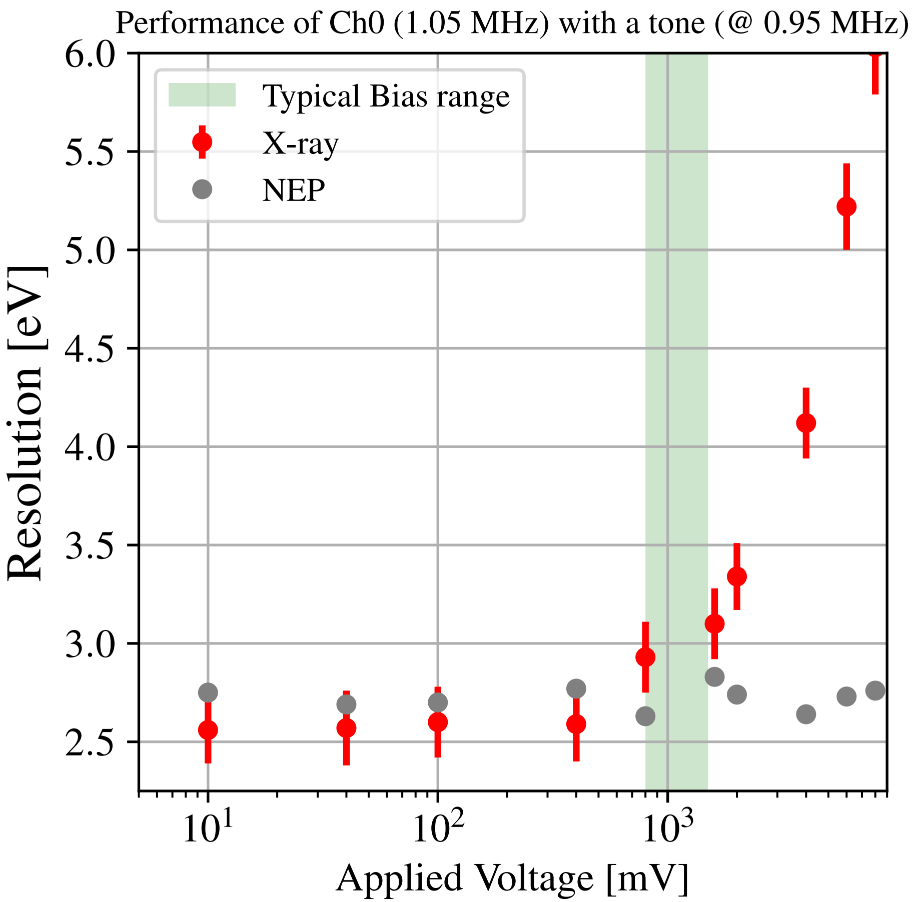

TES feels neighbouring bias voltage
Electrical band (~*R*/*L*) is still too large

(J. van der Kuur et al. 2001, 02)

=> Larger frequency separation
(from system requirement, no choice for this option)

or

=> <u>Slower device</u>
(allows to use larger *L* to make detector critically dump)
Note: Current devices are a factor 2-3 faster than X-IFU req

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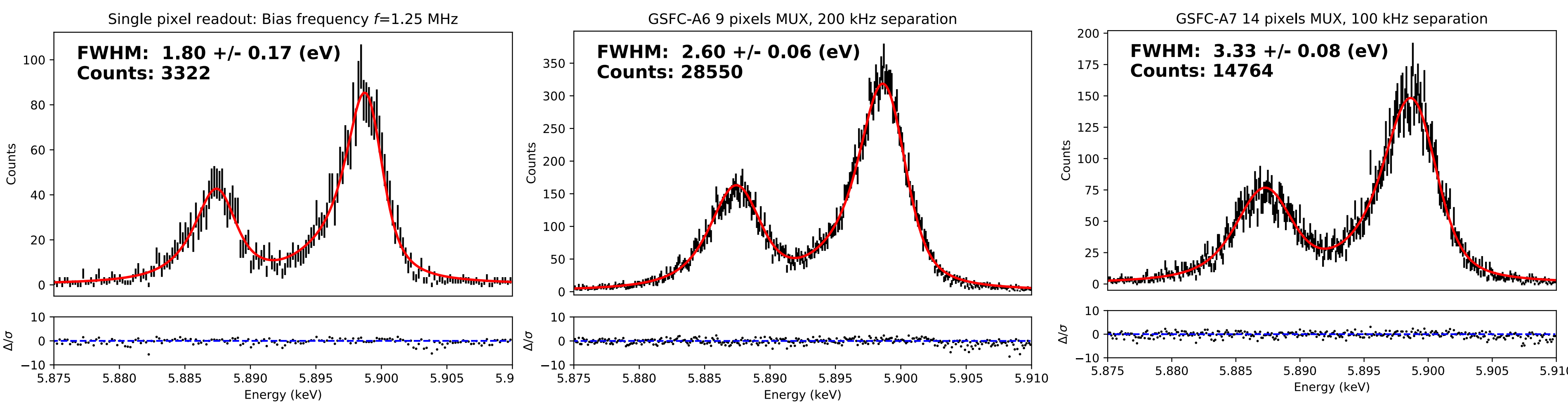
Summary

Together with uniform GSFC array, improved LC filter, SC transformer,
Successful demonstration of 9/14 pixels FDM readout
Performances as expected for the current available components:

ΔE @ 1.3 MHz	**~ 1.8 eV**	**<= Compatible with DC bias**
ΔE @ 9 pixs	**~ 2.6 eV**	**<= Good for DM across 1.4-4.7 MHz**
ΔE @ 14 pixs	**~ 3.3 eV**	**<= Origins of the degradation are identified**

These progress confirm that following items are well defined and realistic
1.) understanding of the detector and read-out performance
2.) path to further improve the multiplexing and energy resolution

The FDM systems are well under-control and related issues are identified



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