

Overview

Recent advances in time-of-flight mass spectrometry (TOF-MS) have achieved ion fluxes exceeding 10^9 ions/second with sub-nanosecond peak widths.

Two years ago, we introduced the M-TOF PMT-based detector, demonstrating its ability to handle high fluxes and detect up to 10,000 ions/peak. However, the ~ 1 ns peak width can impact mass resolution, potentially limiting its application, especially in high-performance TOF-MS systems.

This work presents a new version of the MTOF detector comprising a fast hybrid photodetector (HPD) light sensor.

Evaluated in a multi-reflecting TOF analyzer (IMS-MRT by MSC) with high-bandwidth preamplifier, the detector showed single ion pulse width ~ 0.75 ns.

The wide dynamic range of the detector, combined with dual-channel amplifier (Teledyne), allows detection of ions up to 4 orders of magnitude per peak per shot.

Methods

MTOF-HPD detector

-The MTOF detector comprises an ion-to-electron converter, a fast scintillator and a custom fast HPD as light sensor.

-Ions hit the convertor and generate secondary electrons. Electrons move along a curved trajectory towards the scintillator by means of ExB fields. The fast scintillator converts and amplifies the signal into photons, which are detected by the HPD.

-Uniformity of E and B field, fast scintillator decay time and fast HPD response ensure sub-ns detector time.

-Absence of MCP or convertor coating, together with inorganic scintillator and sealed multiplication stage, enables detector long lifetime (>300 C output charge)

Methods

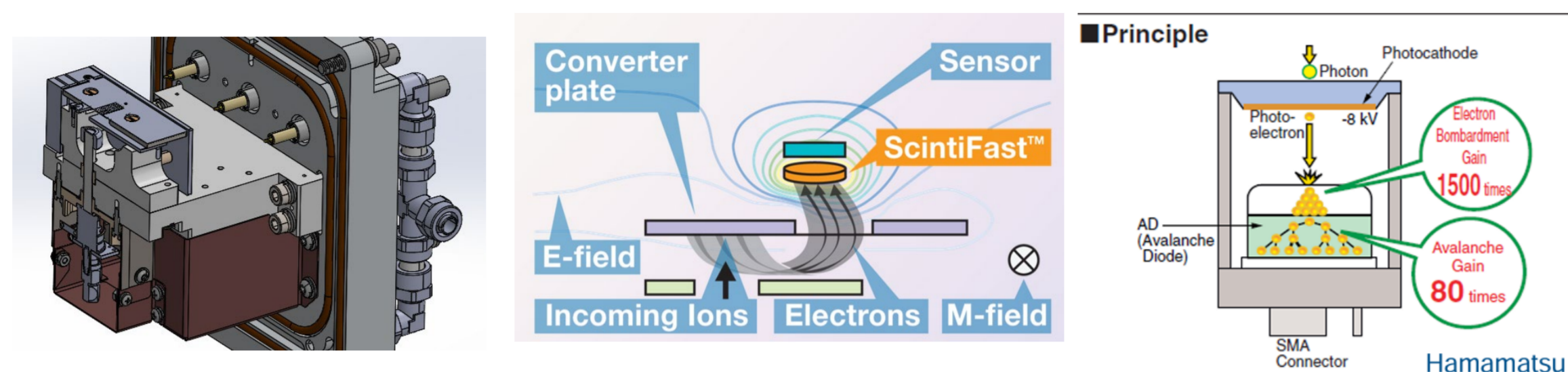


Fig 1. MTOF-HPD detector prototype (Left), MTOF principle of operation (Center), and HPD principle of operation (Right)

Dual Gain enhanced dynamic range

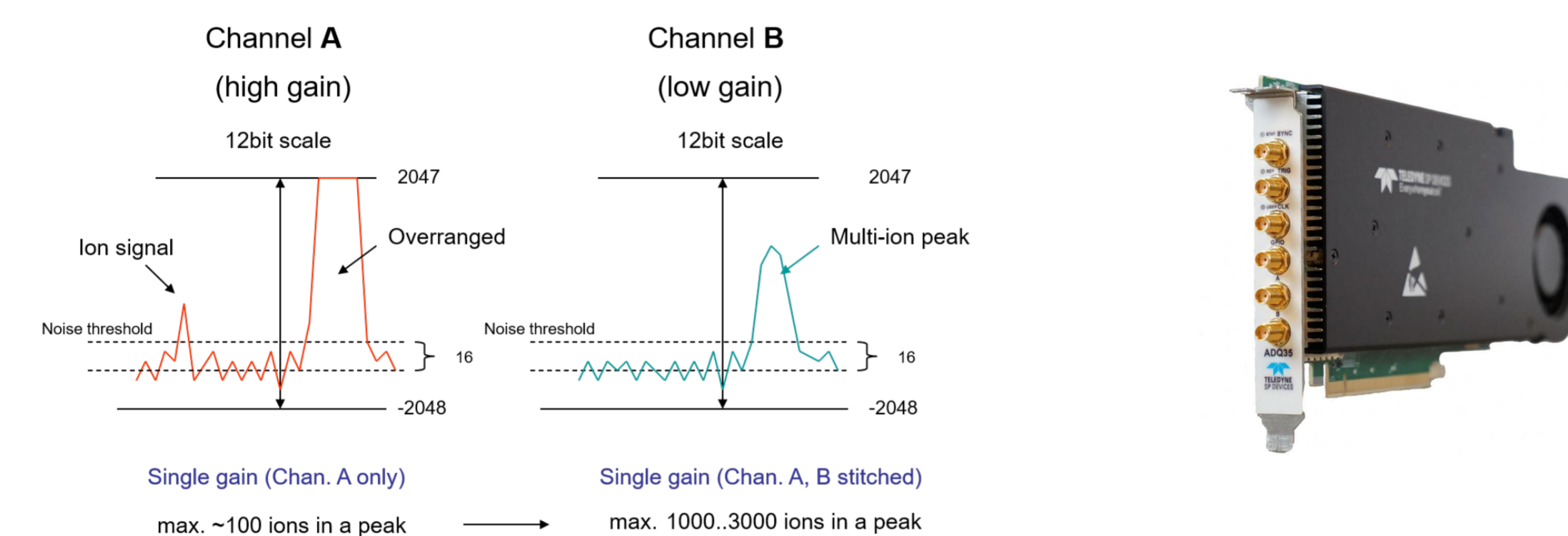


Fig 2. Principle of dual gain dynamic range extension with dual gain amplifier (Left) and ADC - Teledyne ADQ35 used for this study (Right)

Main specifications of dual channel Data Acquisition Card (DAC)

- Two analog channels at 5 GS/s per channel
- Bandwidth 2.5 GHz
- Voltage range 0.5V pp, 12 bits resolutions
- 14 Gbytes / s sustained data transfer rate to CPU / GPU
- General Purpose Input / Output (GPIO)
- Open FPGA for real time signal processing
- Firmware option for averaging records
- Firmware option for pulse analysis
- 10 bit data compression for continuous streaming to GPU

IMS-Multireflecting TOF MS

Main parameters are:

- resolution ADC ~ 50 k
- mass accuracy <1 ppm
- 2kHz sampling
- IMS resolution ~ 10

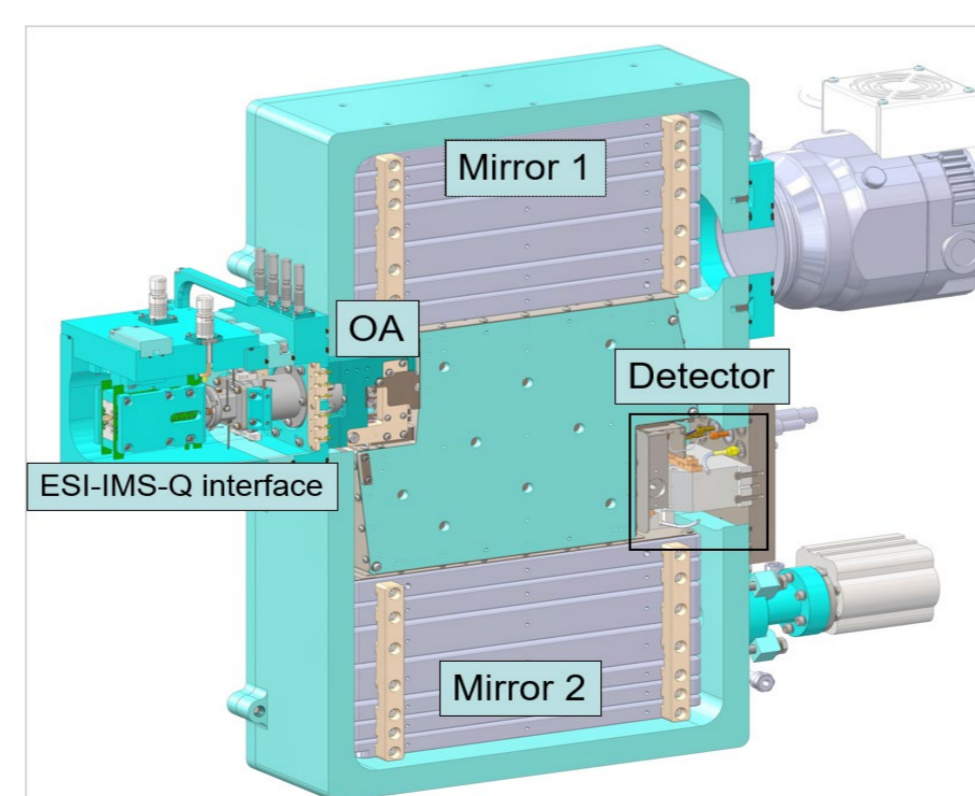


Fig 3. Mass analyzer of IMS-Q-MRT prototype

Results

Time resolution (Subassembly)

First measured in subassembly [scintillator + lightguide + HPD]. Detector response to single electron input on scintillator is characterized by a pulse FWHM ~ 0.7 ns, intrinsic ringing below 0.5% and overall max. gain $\sim 10^6$.

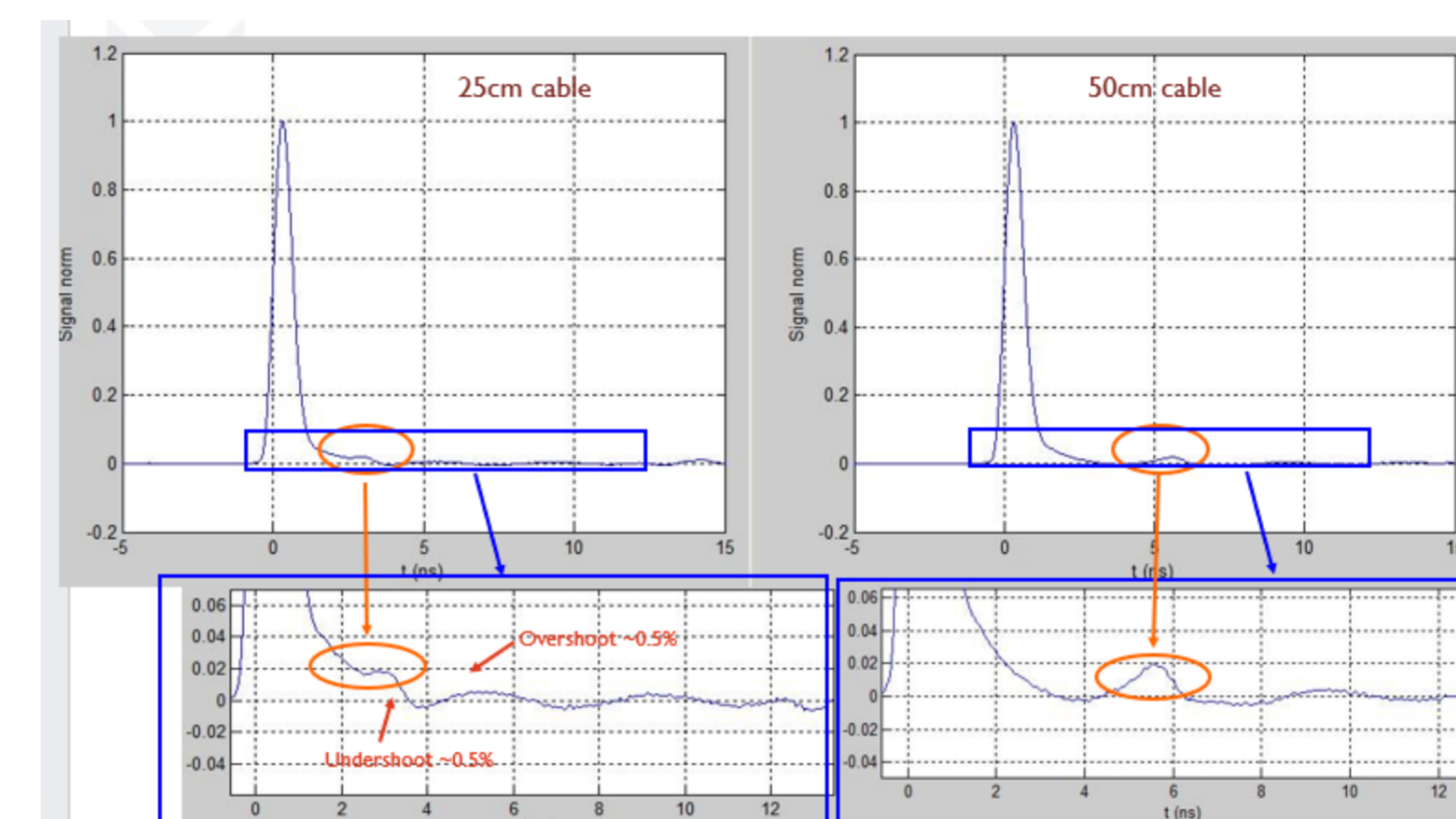


Fig 4. Sub-assembly single electron response. $\sim 2\%$ ringing can be attributed to slight impedance mismatch and cable reflection

Time resolution (full detector)

Time resolution measured in full detector (~ 0.75 ns FWHM) closely matches sub-assembly time response. Detector low noise floor allows for easy detection and measurement of single ion signal (about 50 times above noise floor rms in high gain channel).

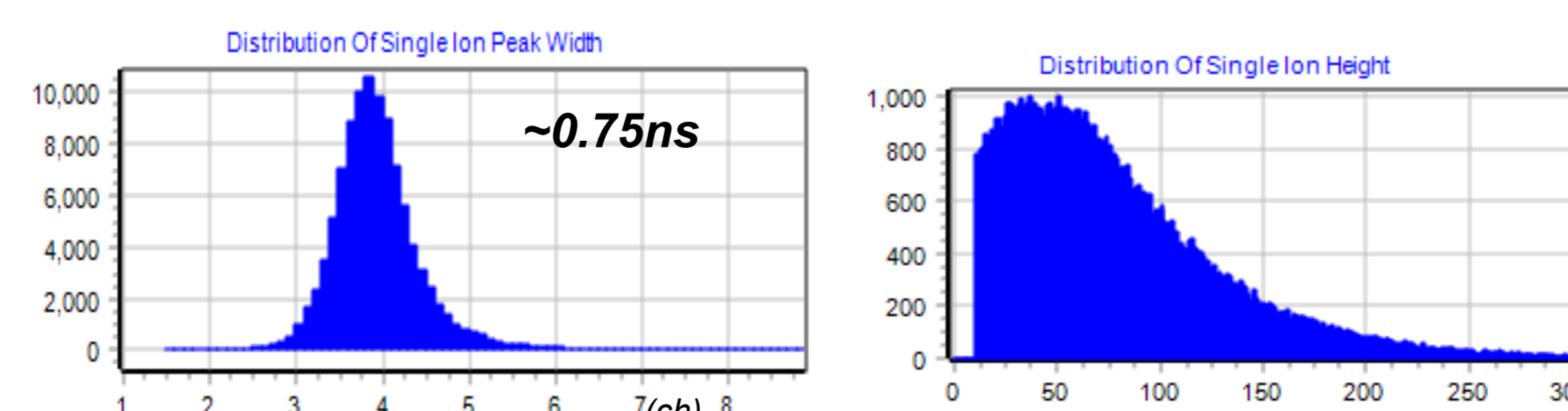


Fig 5. Single ion response measured in analyzer. Peak width distribution (Left). Pulse height distribution (Right).

Results

Linearity & Dynamic Range

HPD response (measured with pulsed ps laser) was found to be linear up to at least 4V. MRT signal grows slower with beam intensity (DRE factor), likely due to ion space charge effects.

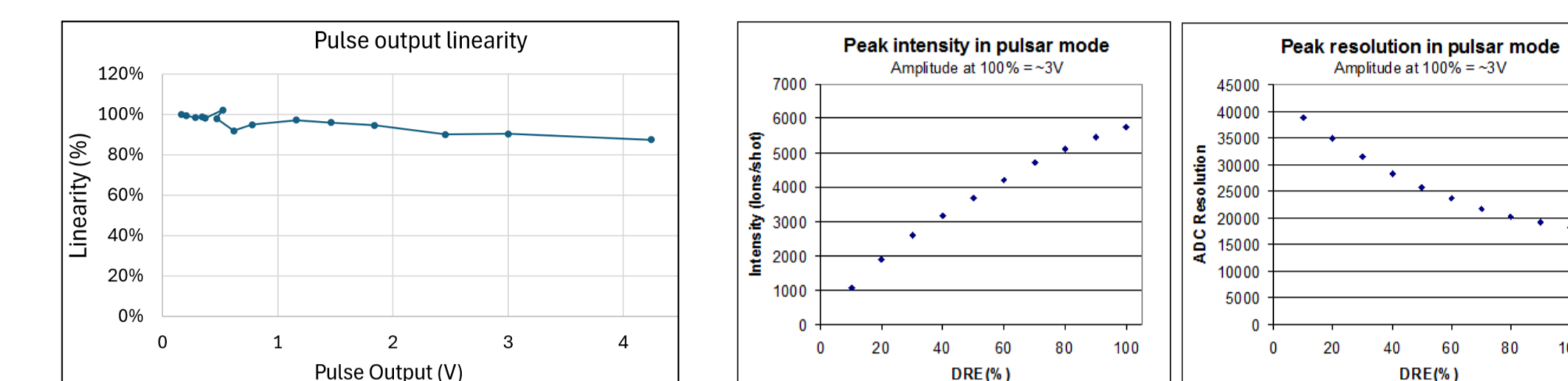


Fig 6. HPD linearity measured with pulsed ps laser (Left). Detector linearity measured in MRT analyzer (Center). MRT resolution vs. beam intensity -DRE (Right).

Dual Gain Response

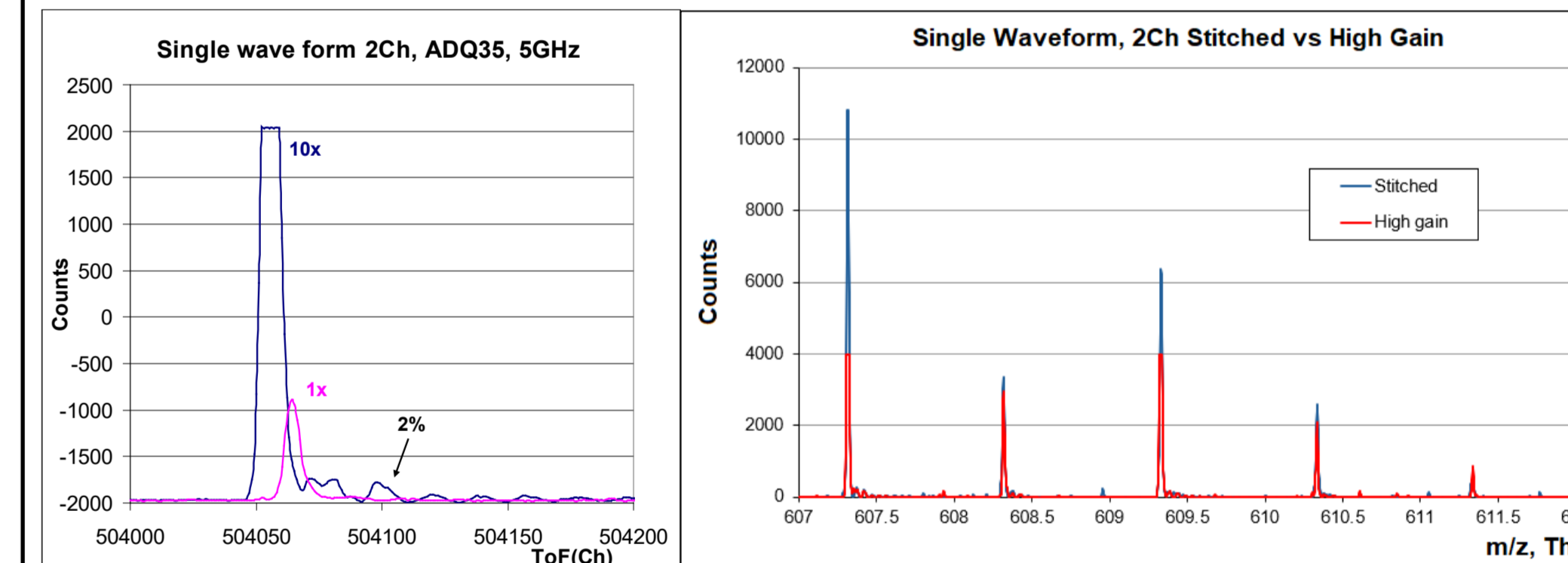


Fig 7. Synchronous response from high & low gain channel (Left). Spectrum acquired in both high and low gain channels. The two waveforms are stitched with a proprietary algorithm to compose a single stitched waveform (spectrum) of enhanced dynamic range. (Right)

Conclusion

Superior mass resolving power, combined with wide dynamic range and with overall performance of the MTOF platform on other aspects (high longevity, 100% convertor fill factor), makes MTOF-HPD the detector of choice for high-end TOF-MS systems.

Conflict of Interest

The authors declare no competing financial interest.