APOCAT IC – Array of Photon Counters above Threshold

16-Channel Readout for PMT and SiPM

For the IDEAS Team:
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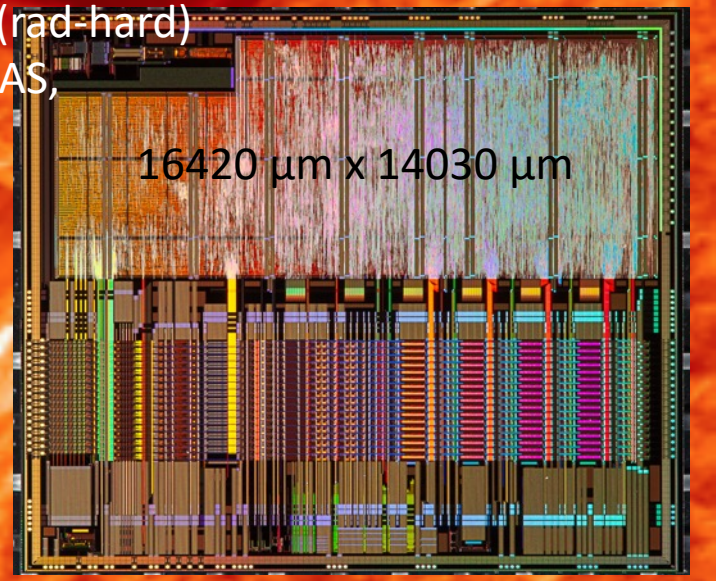
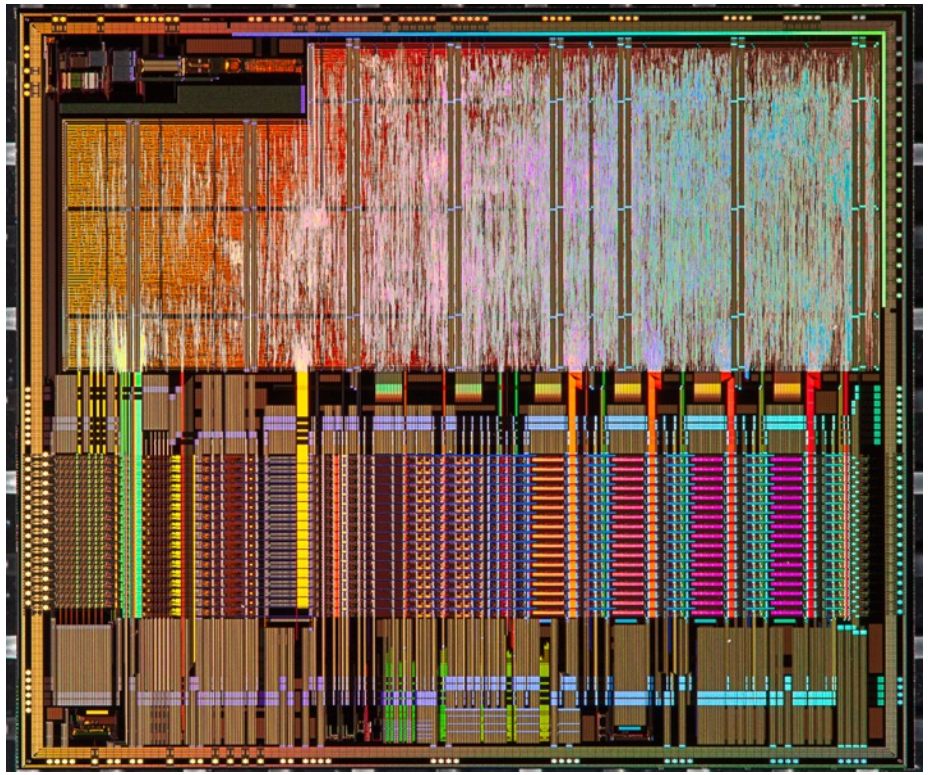
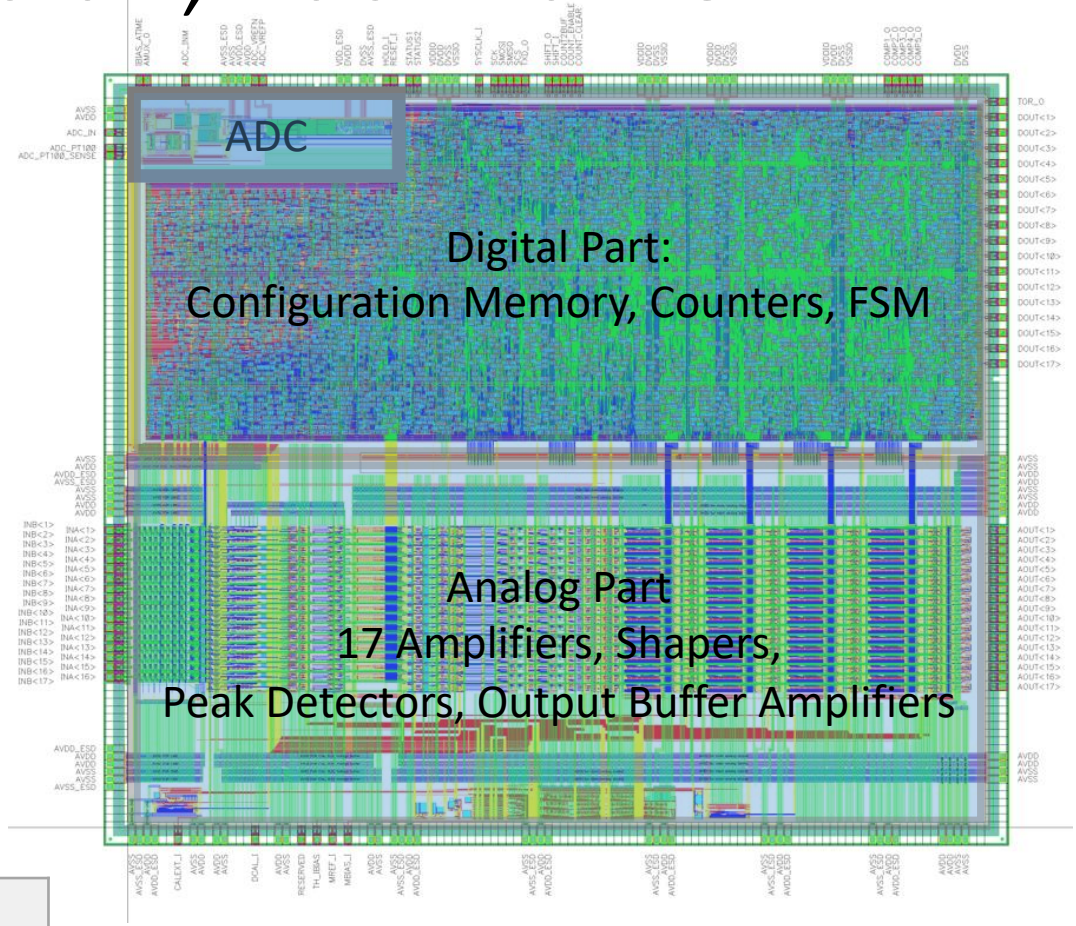
ideas
Integrated Detector Electronics AS

- PMT/SiPM Readout IC for high-rate, high-resolution x-ray and gamma-ray spectroscopy
- Operating in space and for solar missions
- High performance requirements (rad-hard)
- Flight Model IC for ASO-S PMO/CAS, launch 2022



APOCAT Bare Die, Floorplan, Pad Frame





Supply and Manufacture	IDEAS and AMS
Technology, Process	350nm CMOS, C35B4M6
Chip active area	16420 µm x 14030 µm
Number of pins	192

Planned Packaging Options:
Bare-die, chip-on-board, no plans yet,
QC-208398-WZ is feasible.

Introduction Background and Roadmap

IDEAS has tested SiPMs since 2003, and has developed readout ASICs for PMTs, MA-PMTs, APDs, and SiPMs

- VA64MaPMT, VA64TAP3 used in **POLAR**
- VA32HDR14.2 and VA32HDR14.3 used in **CALET**
- VATA64HDR16.2 used in **RICH/SPIDER**
- The IDE3380 and IDE3381 are for x-ray and γ-ray spectroscopy with scintillators and PMT/SiPMs, and can easily be connected and operated with micro-controllers or FPGA.

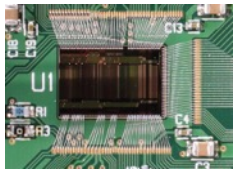
VA64MaPMT

VA64TAP3

- POLAR by CAS and Geneva/ Switzerland

VA32HDR14.2 and .3

- CALET by JAXA

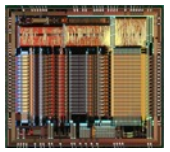


VATA64HDR16

- RICH (SPIDER) by INFN Siena

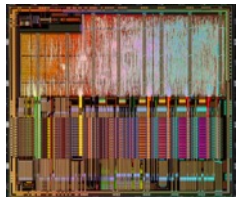
IDE3380 SIPHRA

- ESA TRL4/5
- AMEGO by NASA
- Cube-sat
- Other terrestrial



IDE-3381 APOCAT

- ASO-S by CAS



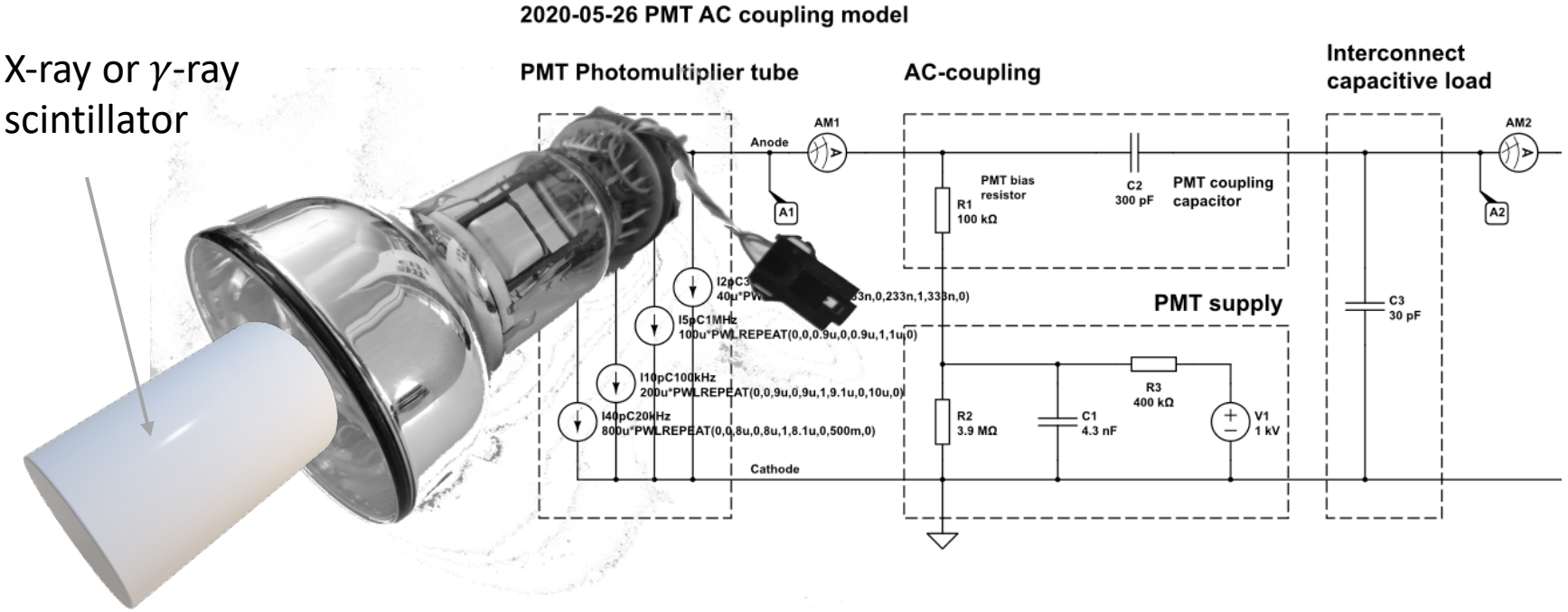
Miniaturization
(low mass, low volume)

Lower
- Power
- Cost

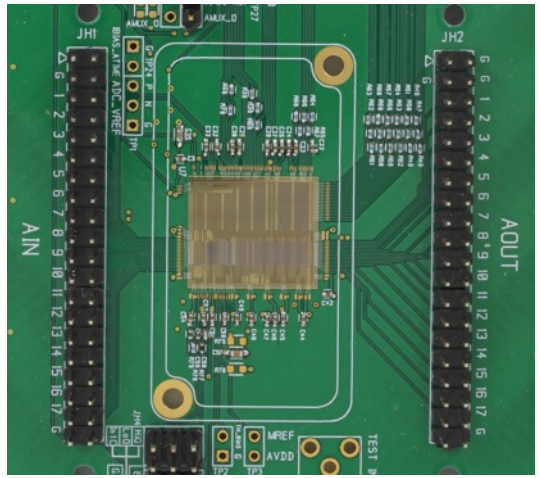
More/higher
- Functions
- Performance
- Reliability

PMT AC-Coupled to one Input of APOCAT

X-ray or γ-ray scintillator



APOCAT

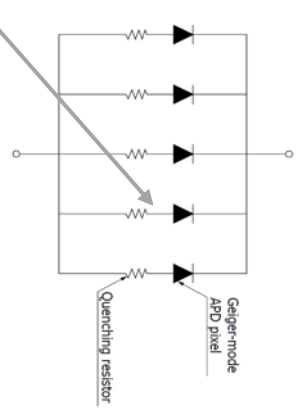


Output

- Pulse heights
  - Analog (Peak)
  - Digital from ADC
- Counts
- Timed pulses (triggers)

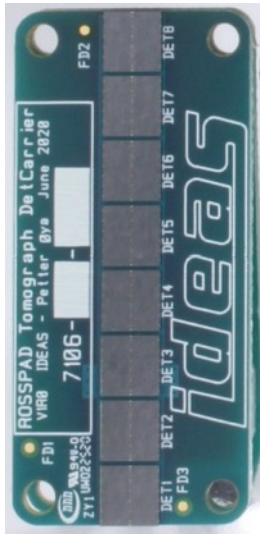
SiPM Array DC-Coupled to Inputs of APOCAT

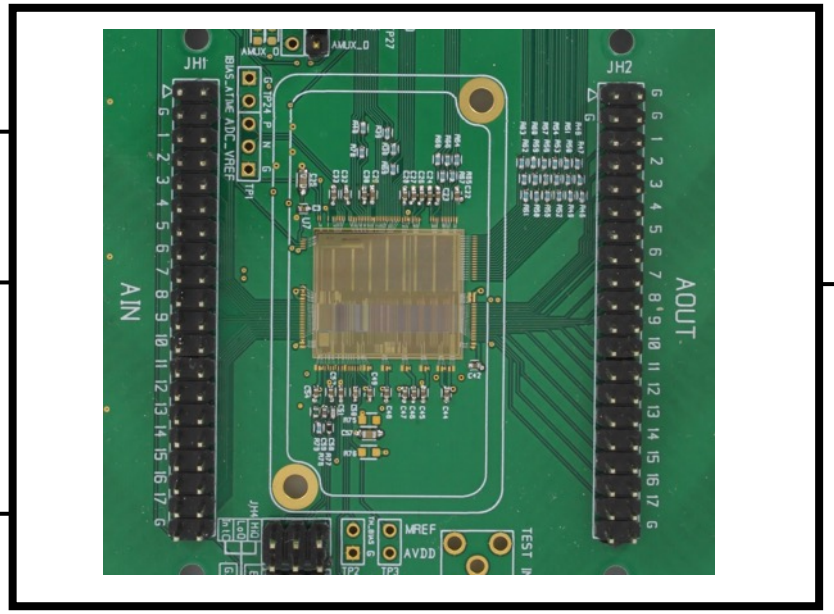
Light photon on SiPM
Discharges 1 or more SPADs



SiPM Array,
1D or 2D

APOCAT

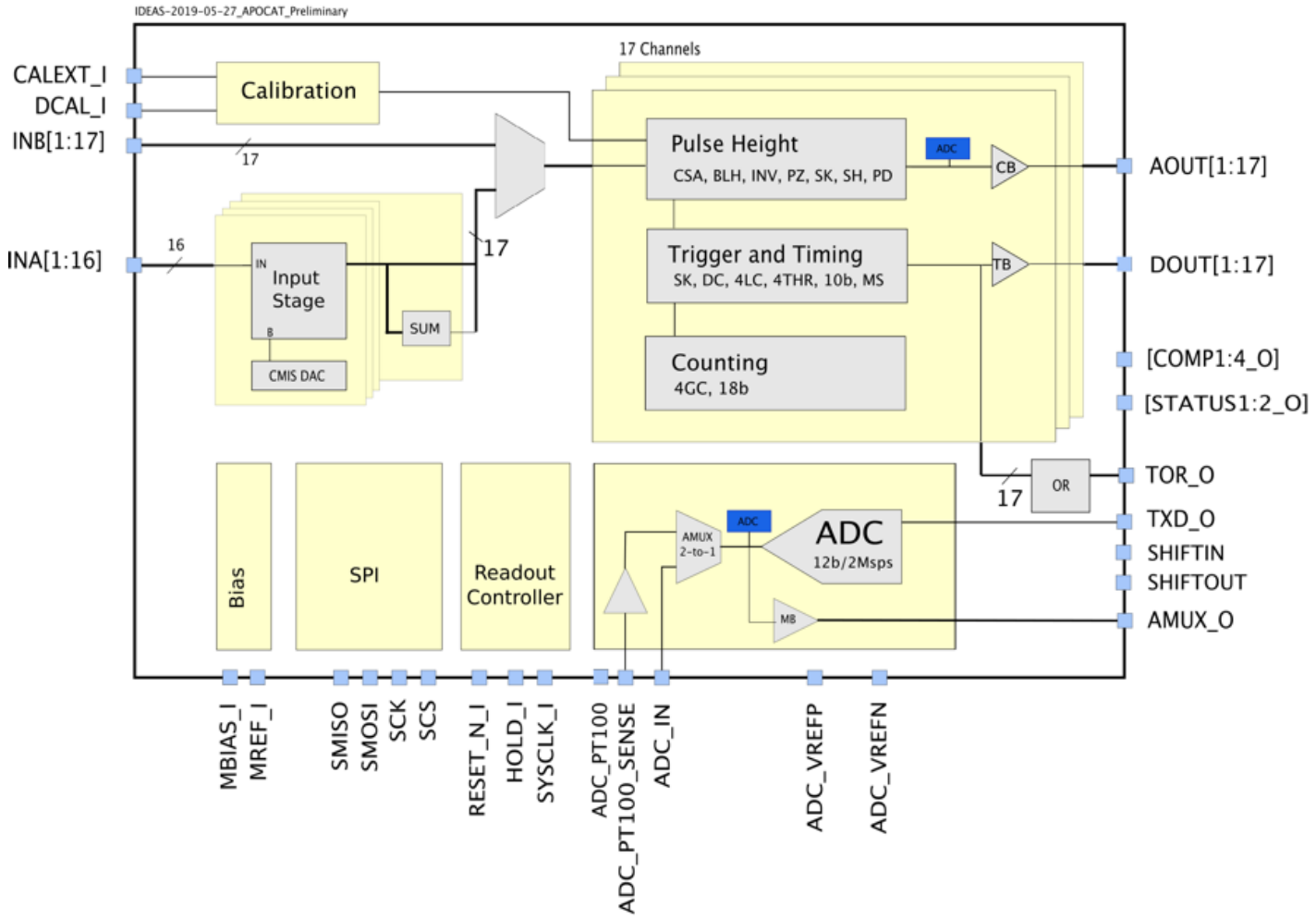




Output data

- Pulse heights
  - Analog (Peak)
  - Digital from ADC
- Counts
- Timed pulses (triggers)

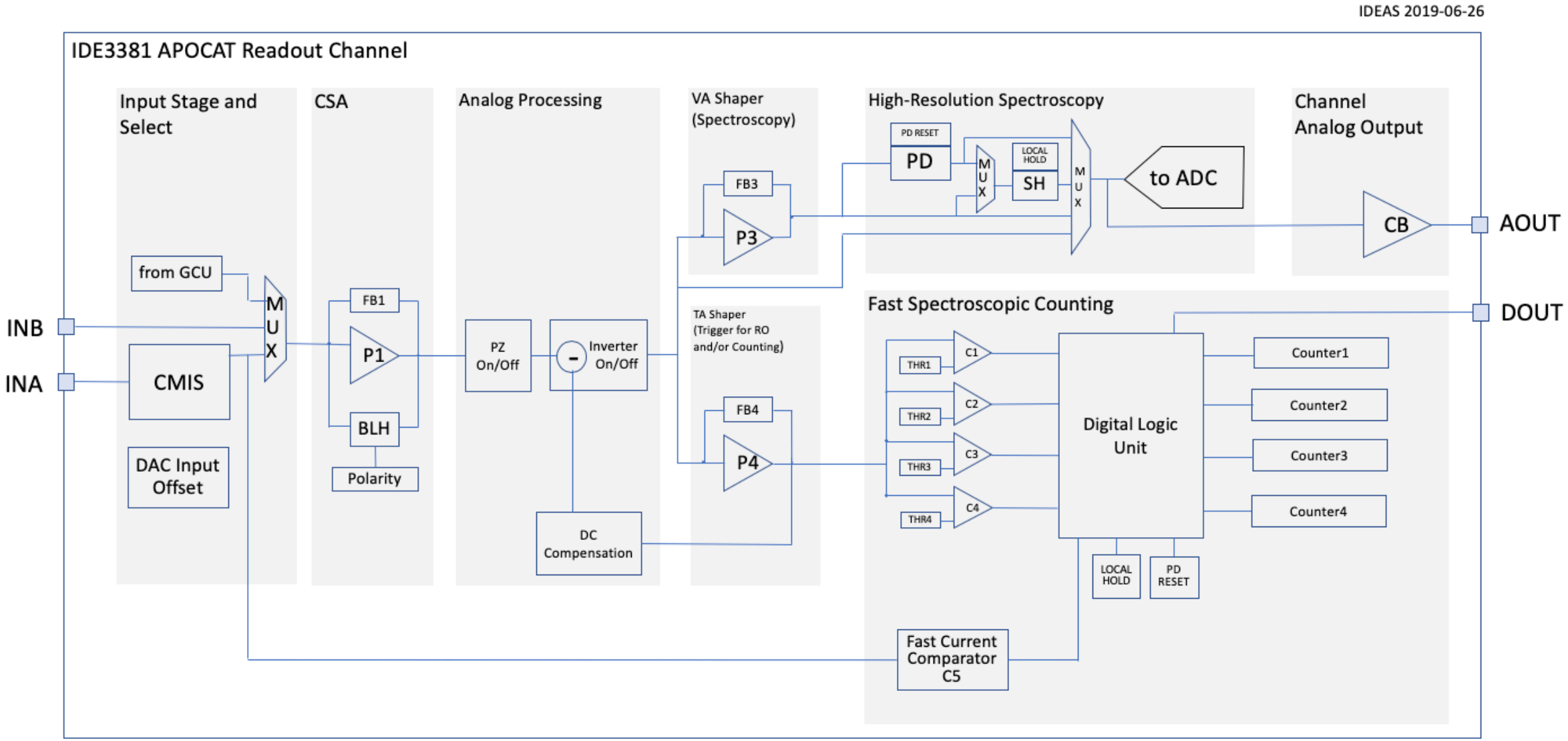
APOCAT Features and Block Diagram



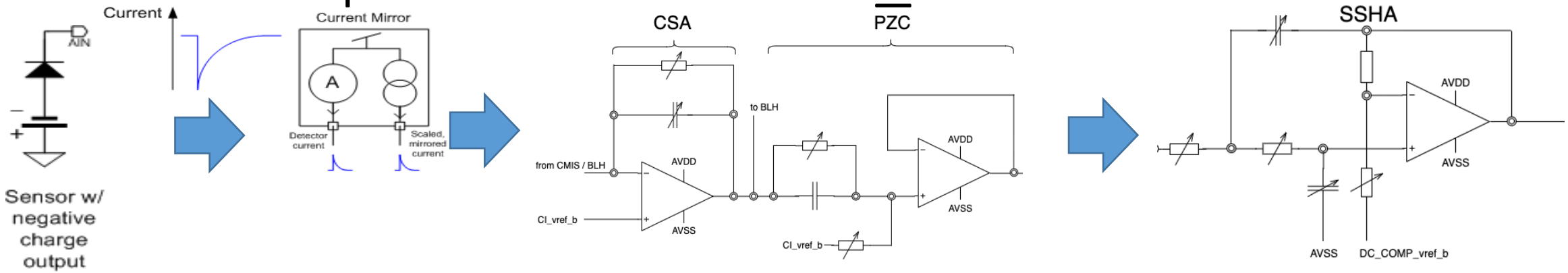
APOCAT Features

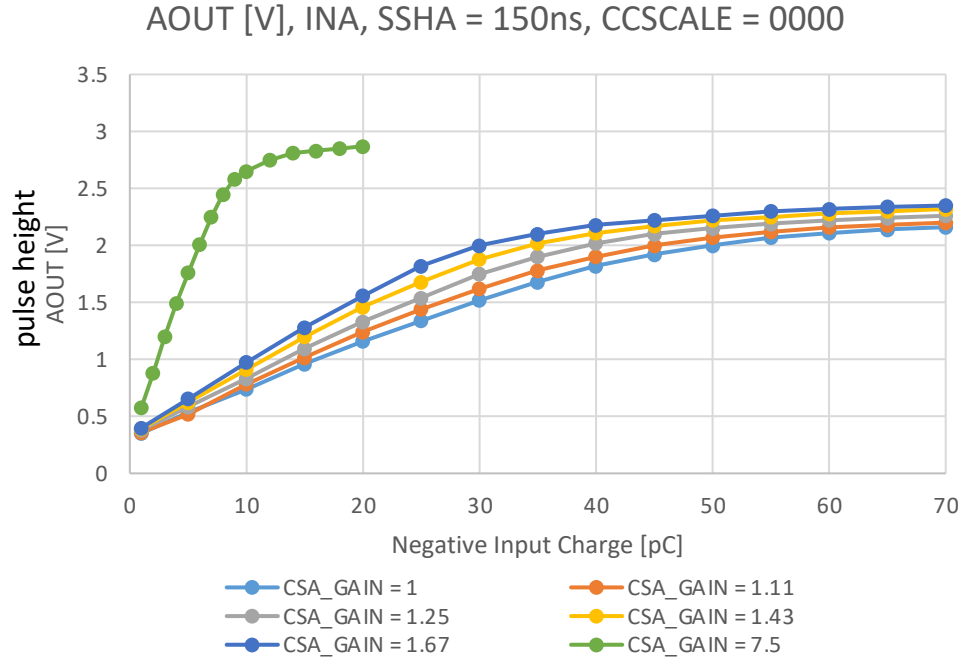
16 inputs for readout of PMTs or SiPMs	Each with programmable input bias voltage 1Mcps/channel asynchronous or synchronous 16 analog outputs for amplitude spectroscopy 1 summing channel
30 programmable gain settings	5 max. charge at INA [pC]: -40, -100, -200, -400, -800 6 fine gain tunings [mV/pC]: 46, 48, 51, 53, 55, 265 Negative and positive charge at INB up to ±40pC
Globally programmable peaking time	50ns, 150ns, 300ns, 2000ns ENC 7fC@50ns, 15fC@150ns, 31fC@300ns
Pulse height spectroscopy	16+1 channels, shaped pulse and peak detector Digital readout with on-chip ADC (12b/2Msps) Possibility for external ADC per channel
Sample&Hold timing generation	Programmable sampling time, hold duration, and reset time External sampling control (optional)
Counting with on-chip counters	4 x 18bit counters per channel
SPI interface	
Radiation environment	TID: up to 340 krad(Si) without relevant change SEL: up to 137 MeV cm² / mg without latch-up SEU/SET LET threshold 22 MeV cm² / mg or larger
Power	360 mW with CMIS and on-chip ADC 20mW per channel with analog output buffer on Flexible and programmable power-down options Single supply voltage of 3.3V

APOCAT Channel Block Diagram



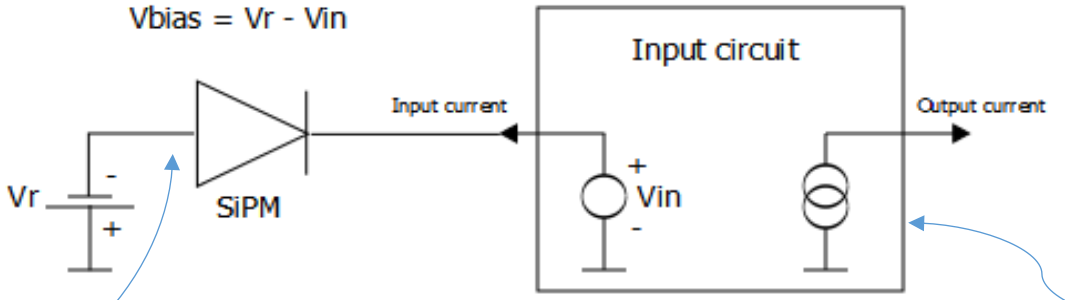
Example: -10pC, Trigger at DOUT_1 and 150-ns Shaped Pulse at AOUT_1

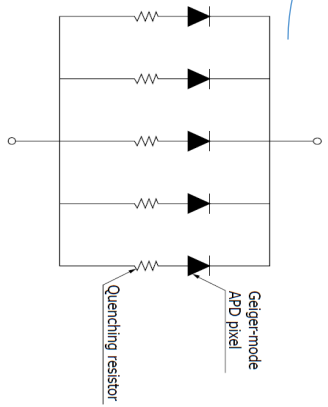


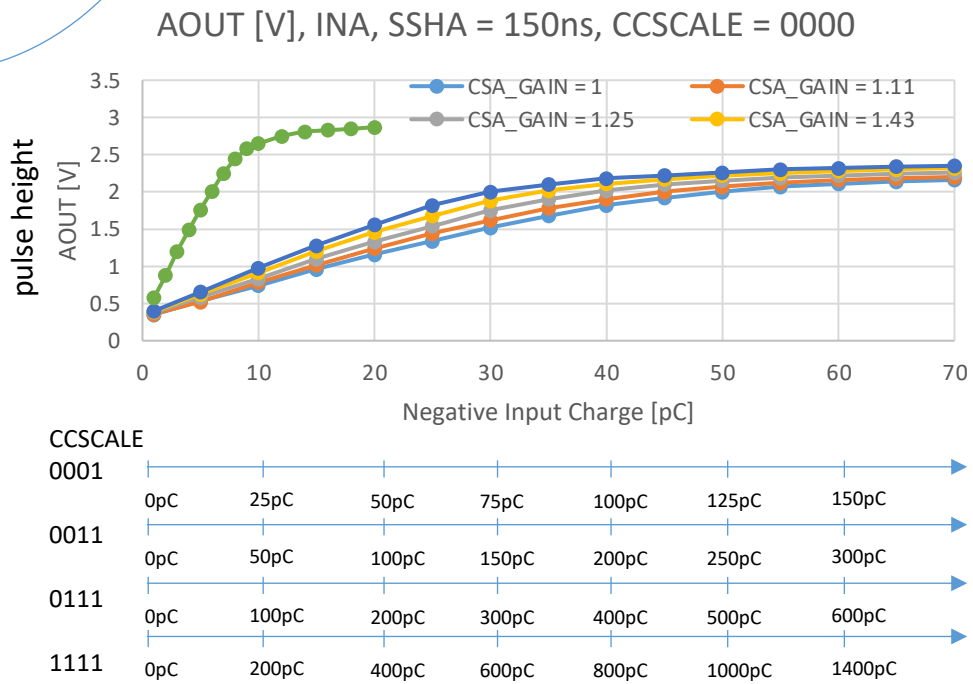


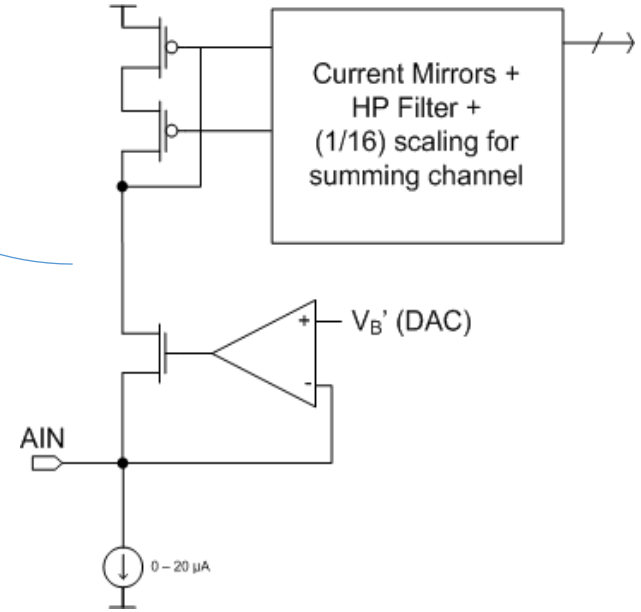
SiPM DC-Coupled to APOCAT Input INA

APOCAT has 16 inputs (INA), each with a Current Mode Input Stage (CMIS)



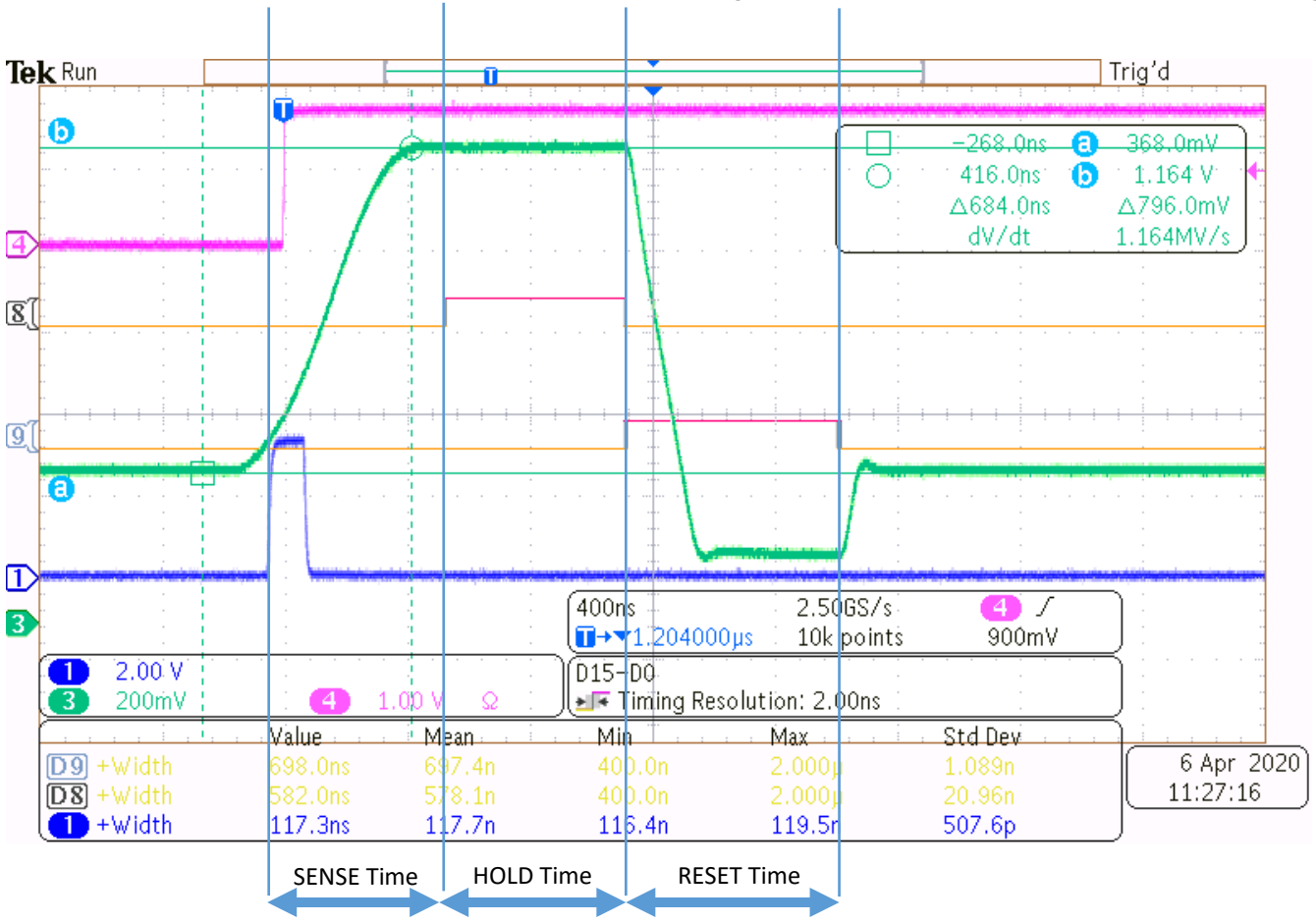






Programmable
- Global CCSCALE
- Individual CSA_GAIN

Peak Detector Output and Configuration Settings



G_1SHOT	0x44	1	Trigger duration	
G_DOUT	0x44	0	Mono C1	Scope ch 1(Blue)
G_STAT2_RESET	0x45	1		Scope ch D9
G_STAT1_HOLD	0x45	1		Scope ch D8
G_RESET_TIME	0x46	12		
G_HOLD_TIME	0x46	10		
G_SENSE_TIME	0x46	10		
COMP1_ENABLE ch1	0x47	1		
AOUT_TIRG_ENABLE ch1	0x4d	1		
IOFFSET ch 1	0x52	1		
QC1_THR ch1	0x63-64	15		
G_FSHA_TP	0x63	4	"150ns"	
G_SSHA_TP	0x62-63	4	"150ns"	
HYST	0x6c	0		
CB_SEL ch1	0x86	3		

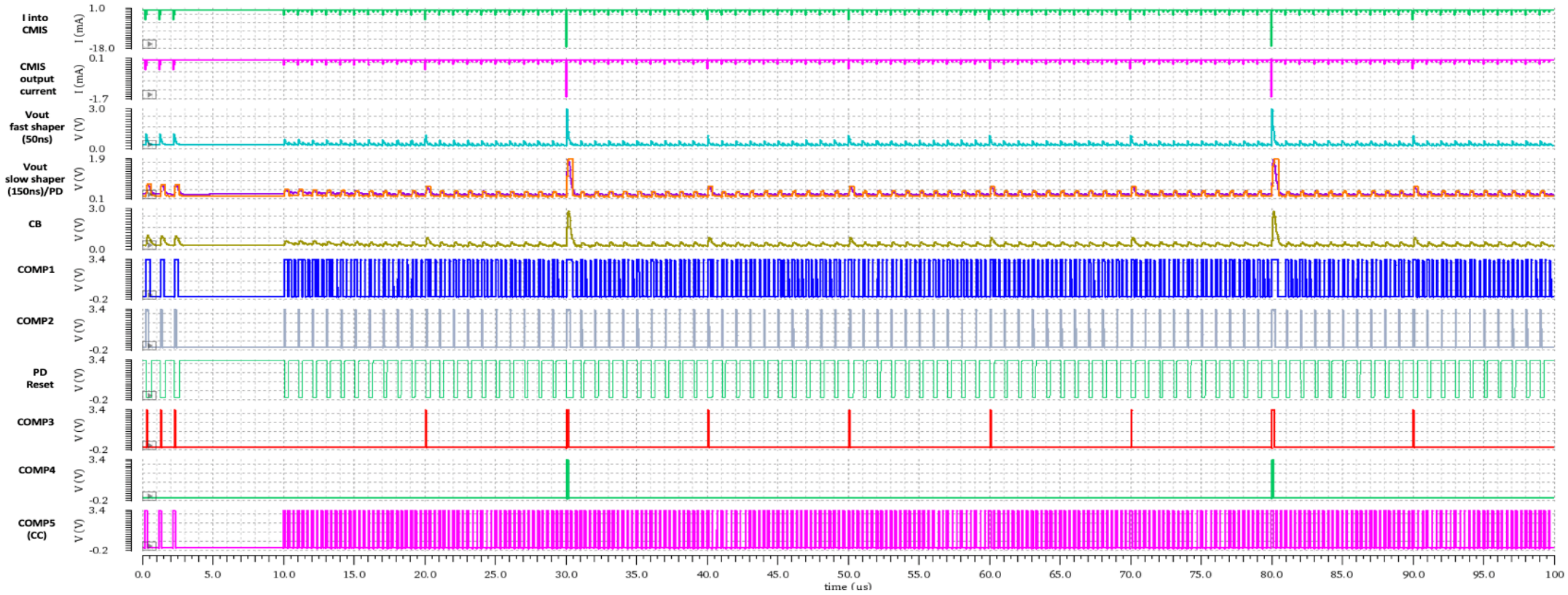
All other settings are zero.

Purple: Sync pulse from **saw-tooth function generator**, negative step generates only negative charge at INA via 100pF.
Green: Peak detector signal measured at channel buffer output AOUT channel 1.
Blue: COMP1 trigger pulse measured at DOUT channel 1.

The pulse at AOUT returns to the same baseline as before the pulse.

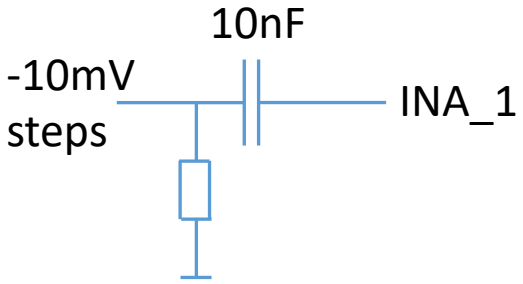
APOCAT Rate (HSPICE Simulation)

LaBr3 on PMT, 100kOHm bias resistor, AC-Coupling,
-20pC at 3MHz, -50pC at 1MHz, -100pC at 100kHz, and -400pC at 20KHz



Good rate performance: stable peaks at Channel Buffer (CB) out for charges from -20pC to -400pC (CMIS was set to att. 10).

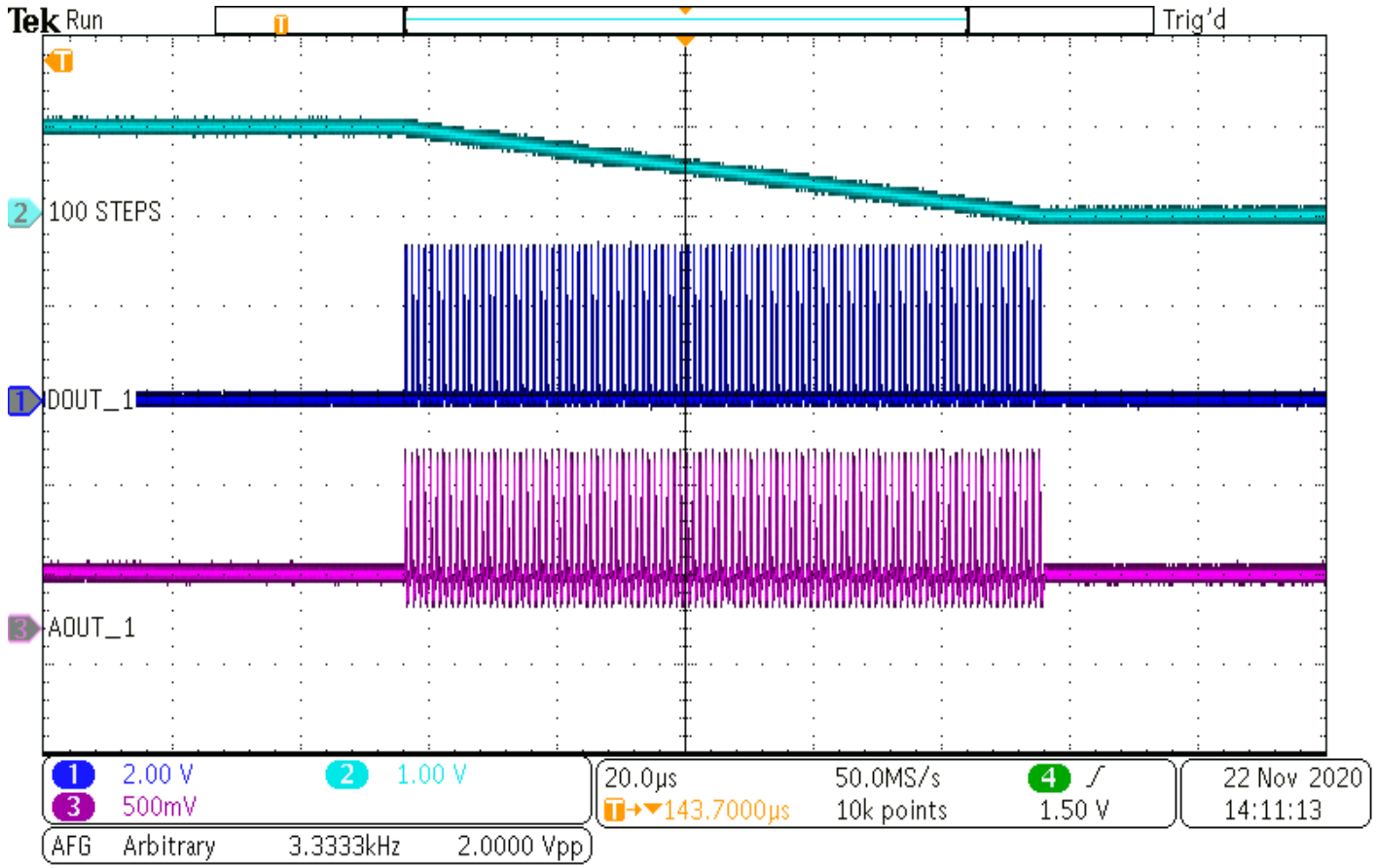
APOCAT Rate (Measurement)



Green: 100 pulses of -10pC at 1MHz injected at INA_1

Blue: 100 trigger pulses at DOUT_1

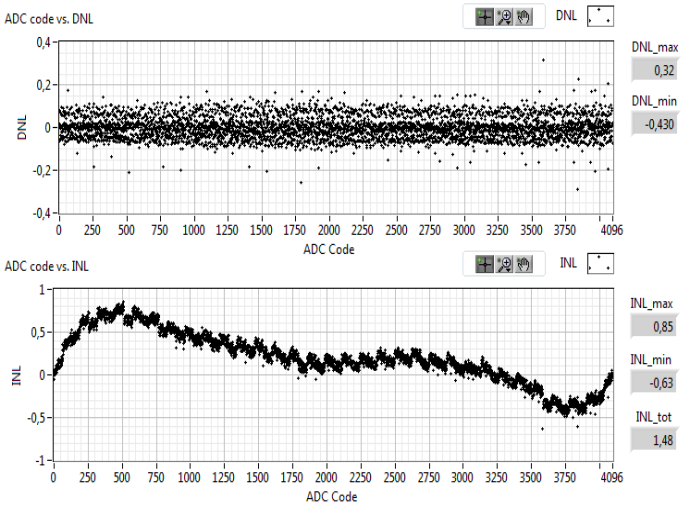
Purple: 100 shaped pulses at analog output AOUT_1.

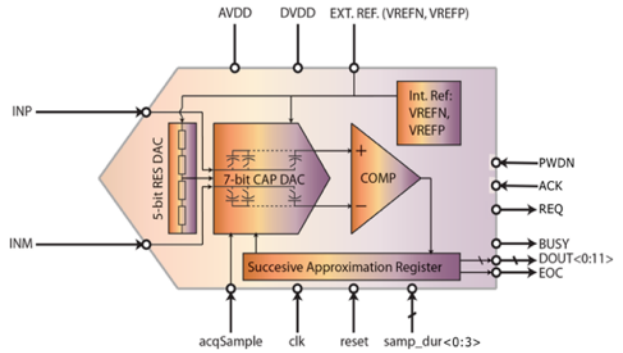


Good rate performance: stable peaks out at AOUT_1, for -10pC at INA_1 (CMIS was set to attenuation 1).

ADC 12b/2 Msps

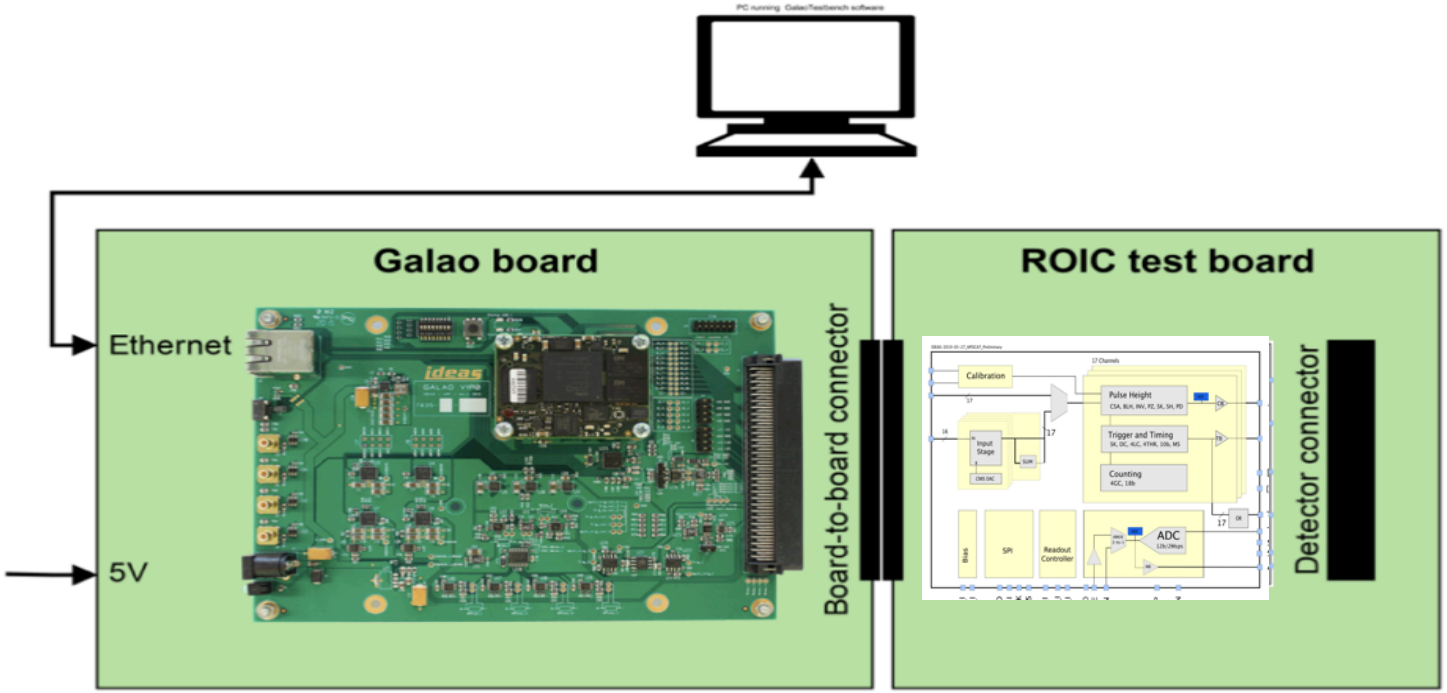
- **SAR – Successive Approx. Register**
- Internal or external references
- Offset cancellation
- Configurable sample duration
- Handshake interface
- Power-down





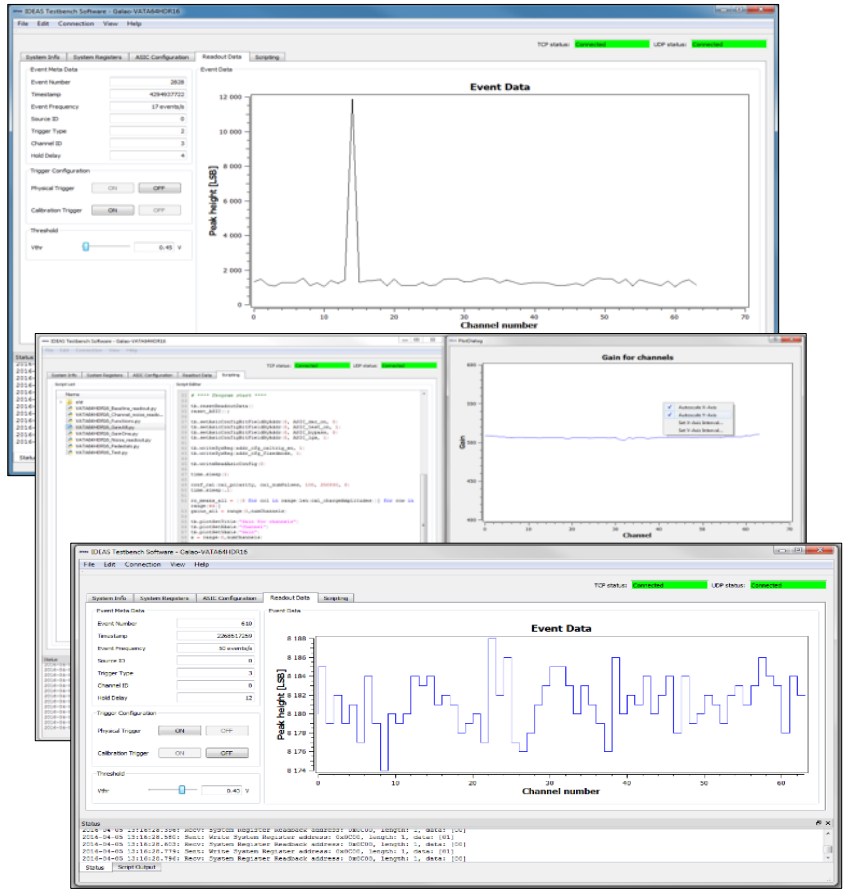
ID	NIR_ADC_SA12B2M
Process	**AMS 350nm**
Resolution	**12-bit**
Sampling rate (max)	**2.22 Msps**
DNL	< ± 0.43 LSB
INL	< ± 0.85 LSB
ENOB	11.5 @ fin=50kHz, 10.6 @ fin=800 kHz
Power	**50 mW at 2.2Msps**, RHBD
Temperature	- 196 °C to +50°C
Size	3000 µm by 280 µm, RHBD

IDE3381 Development System



Block diagram of the ASIC design validation and test system.

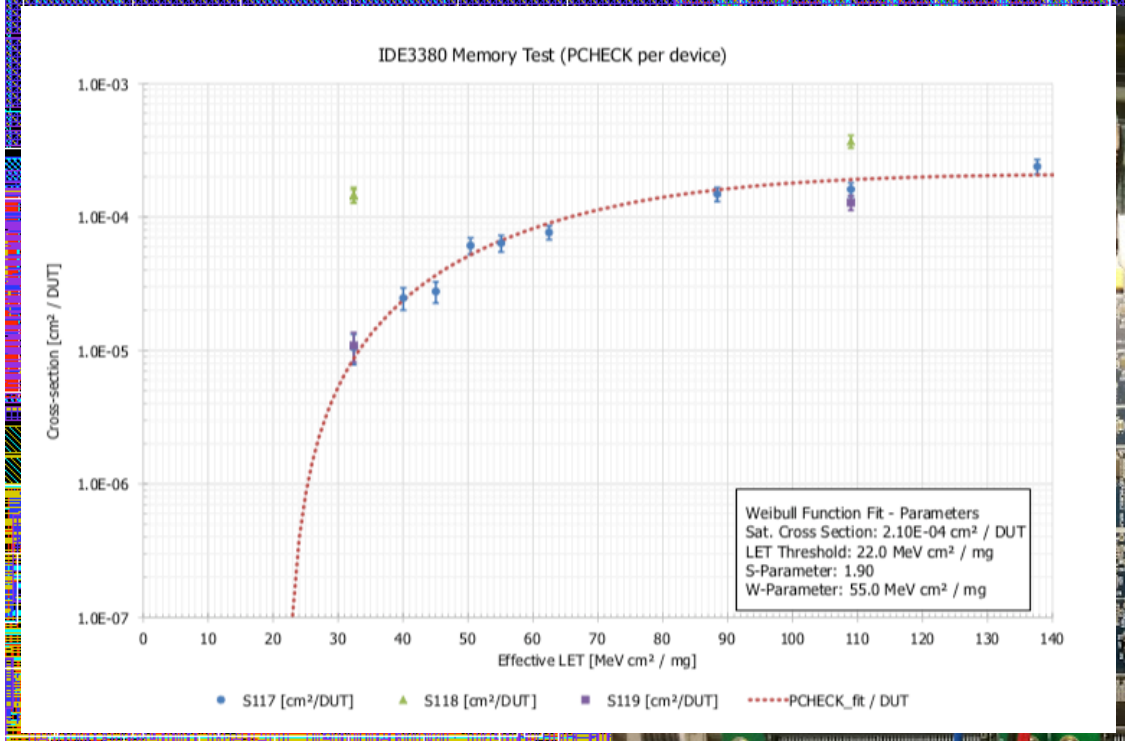
IDEAS Galao development kit to interface to ROIC test PCB. The Galao development kit is based on the Xilinx Zynq-7000 with custom firmware for the APOCAT ASIC readout and control. The system is controlled via Ethernet from a computer. The ROIC is located on the test board, which allows one to connect to the detector array.

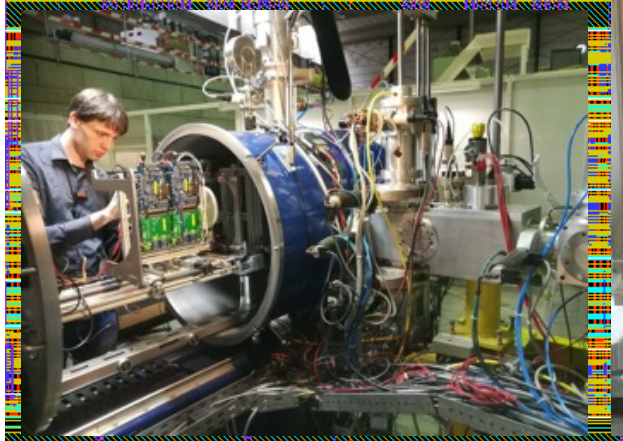


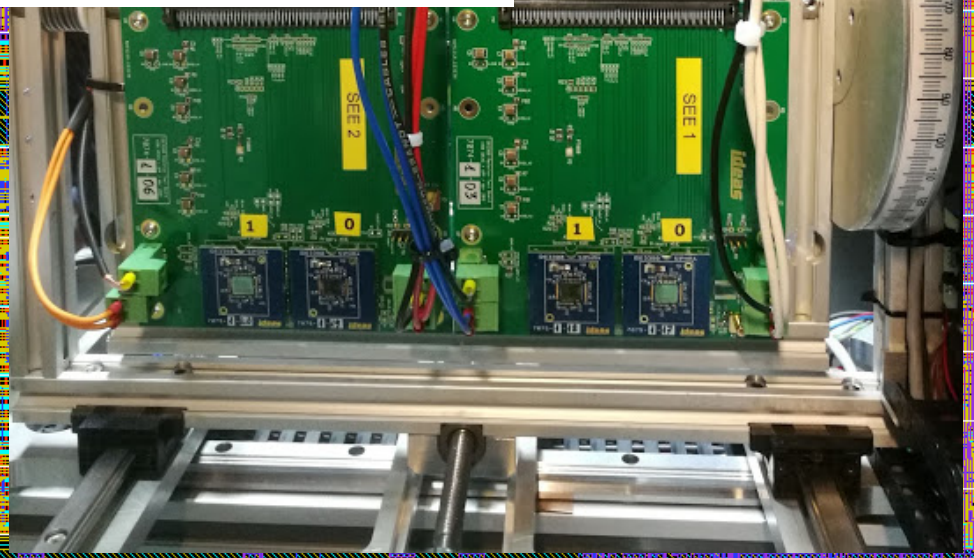
Software
(Python Scripting, LabView API)

IDEAS Radiation Tolerant Standard Cell Library

- 0.35µm AMS CMOS
- Small Library (<50 cells)
- Synthesis and Implementation with Cadence tools
- TID 340 krad(Si)
- SEE tests at UCL HIF
  - SEU LET^{th} 22 $MeVcm^2/mg$
  - SEL $LET^{th} \geq 137$ $MeVcm^2/mg$



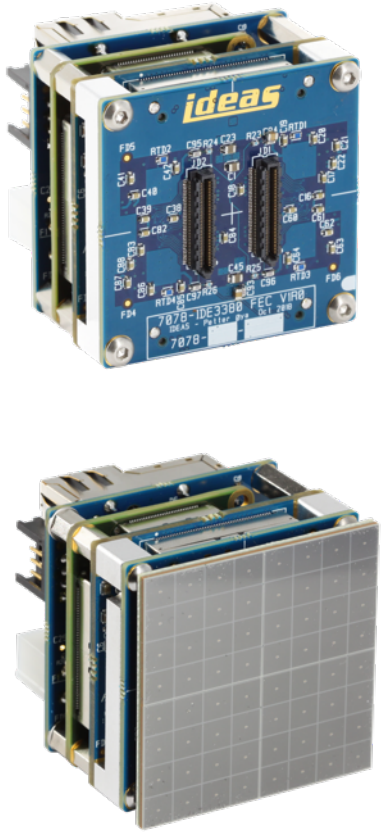




Next Steps

- Radiation (SEE, TID) qualification
- Testing by interested scientists and engineers
- Raise the TRL beyond 4
- Create instruments and applications

Example: ROSSPAD



Next - APOCAT for Prototyping Applications

N	Feature in APOCAT	Technology/Application	Comment
1	High-Rate event counting of charge pulses $\mathcal{O}$(pC) above programmable thresholds	Use in space with SiPM and PMT for x-ray and γ-ray spectroscopy	
2	Only power-up the channels needed; others are power-down. On-chip ADC digitizes only peak of pulses.	Portable γ-ray spectrometer with scintillator	Low-power. One single or summing channel might be sufficient. Histogramming off-chip.
3	Timed digital trigger output from all channels		Time stamp requires external time-to-digital converter (TDC), for example, in FPGA.
4	Time-over-threshold (TOT) from all channels		
5	Analogue waveform output from every channels, either after integrator or shaper	Continuous waveform sampling, high-dynamic range spectroscopy	Requires external fast sampling ADC for every channel.
6	Digital trigger from all channels individually, programmable threshold	X-ray counting, energy resolved	

If (Curious) Then { Contact Me }

Contact

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References

1. Advanced Space-based Solar Observatory, Chinese Academy of Sciences
2. D. Meier et al., “SIPHRA 16-Channel Silicon Photomultiplier Readout ASIC”, Proc. AMICSA&DSP 2016, 12-16 June 2016, Gothenburg, Sweden. Available from http://dx.doi.org/10.13140/RG.2.1.1460.8882
3. T. A. Stein et al., “Radiation Testing of the IDE3380 SiPM Readout ASIC”, Proc. RADECS 2019.