Lawrence Berkeley National Laboratory

# A High-speed Adaptively-biased Current-to-current Front-end for SSPM Arrays

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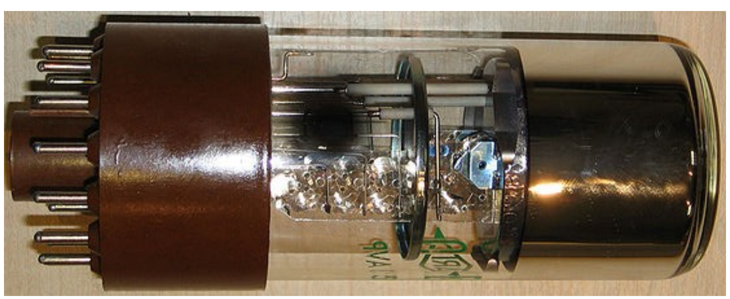
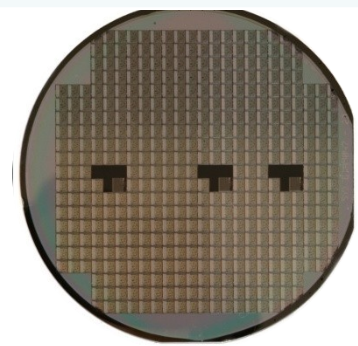
# Outline of Presentation

- Motivation for Solid State Photomultipliers (SSPM)
- SSPM Background
- ASIC Design Challenges and Avalanche Photodiode (APD) Background
- ASIC Design
- Results
- Future work

# Motivation for using SSPM’s

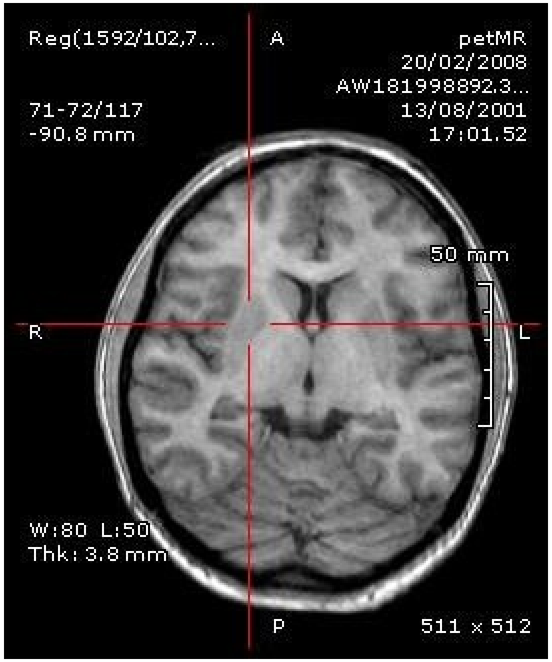
| PMT | SSPM |
|---|---|
| High gain | High gain |
| Sub-ns timing resolution | Sub-ns timing resolution |
| Vacuum tubes | Silicon |
| Discrete parts | Integrated |
| High power (bias voltage can exceed 1kV) | Low Power (bias voltages ~35V) |
| Large, expensive | Small, cheap |

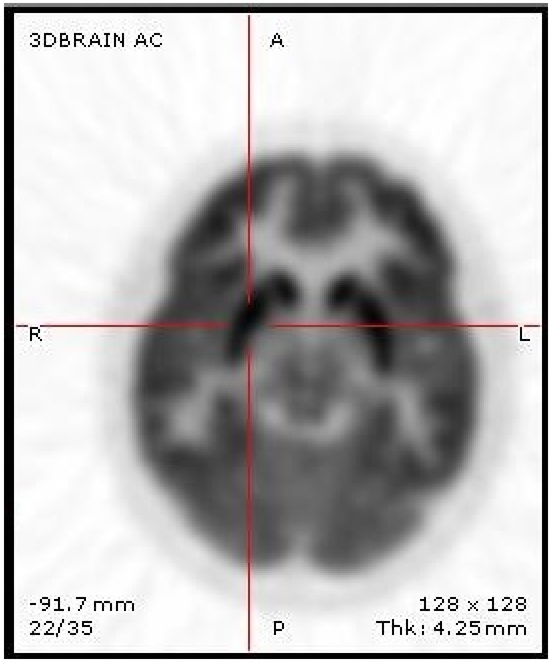


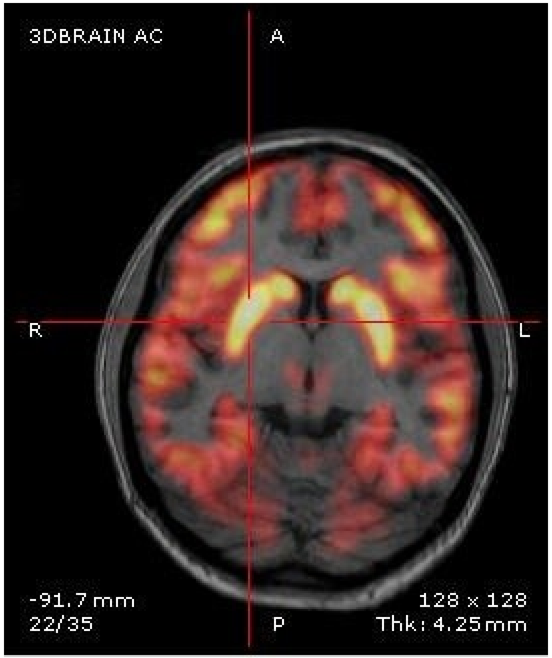


# Motivation (continued)

- Insensitive to magnetic fields, which allows for hybrid PET/MRI imaging
- Complementary imaging techniques reveals structure and function simultaneously

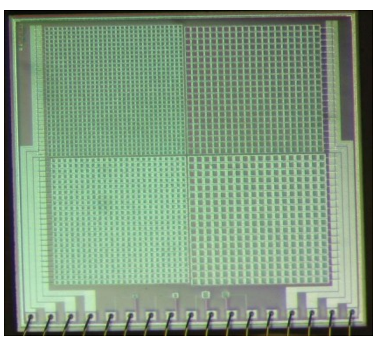


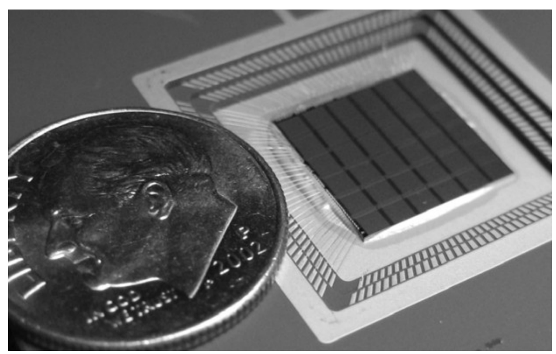



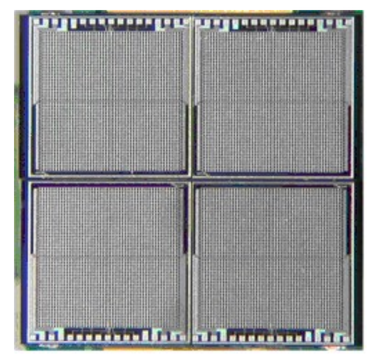



# Background: SSPM Arrays

- Large variety of SSPM detectors
  - Capacitance ranges from **20pF to 900pF**
  - Output currents ranges from **20μA to 20mA**
- For example: numerous arrays made by **RMD, Inc.** based in Watertown, MA.



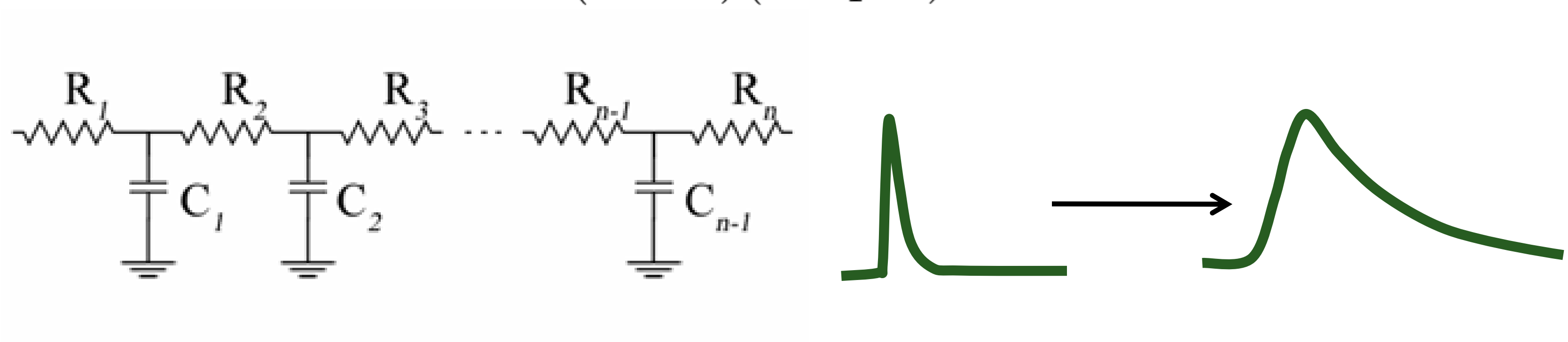




# Background: ASIC Design Challenges

- Large capacitance range and output current range
- To reduce number of outputs, our group uses resistive charge division network but directly connecting SSPM to network degrades timing resolution

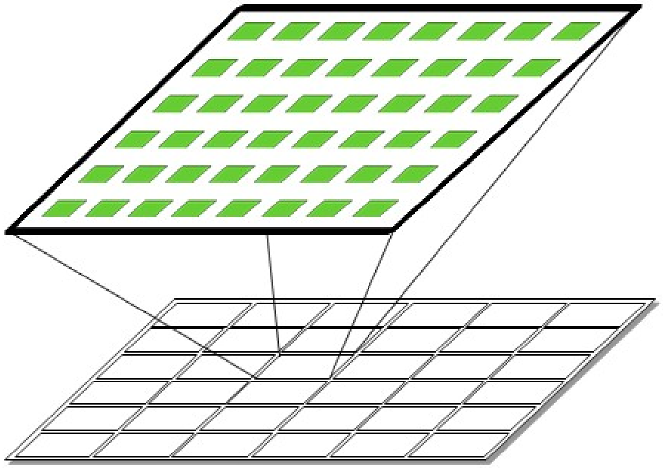
$$\tau = RC = (100\Omega)(900pF) = 90ns$$

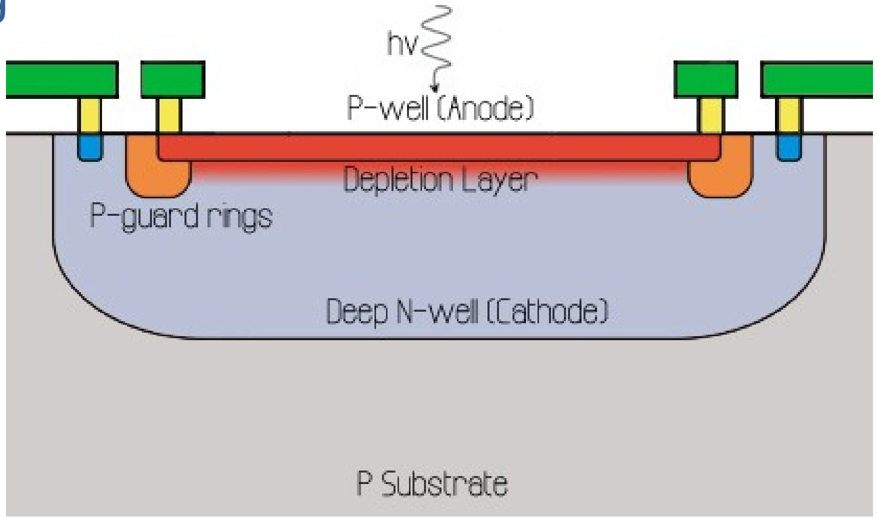



**•ASIC must handle large dynamic range without degrading performance of SSPM**

# Single Photon Avalanche Diode Background (SPAD)

- Produced by RMD, Inc. in AMS high-voltage 0.35μm technology
- Independent digital micropixel signals within macropixel sum together to produce analog signal
- Can be used for photon counting





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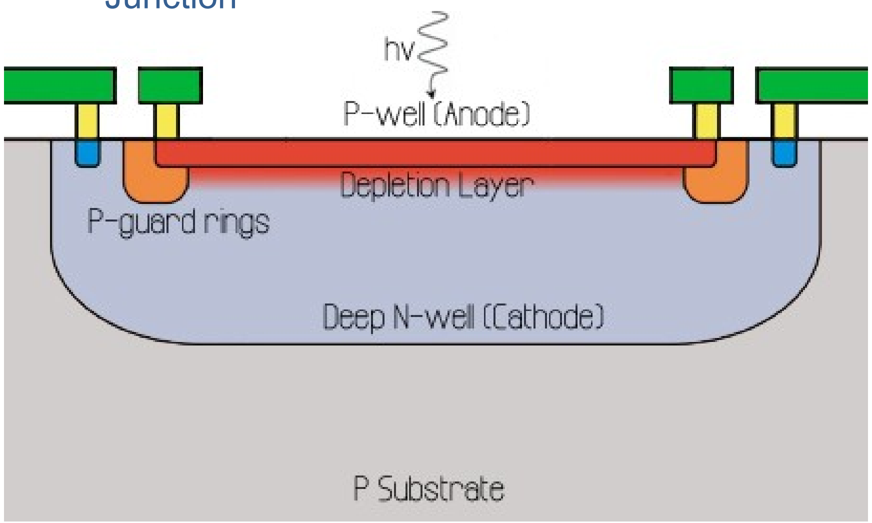
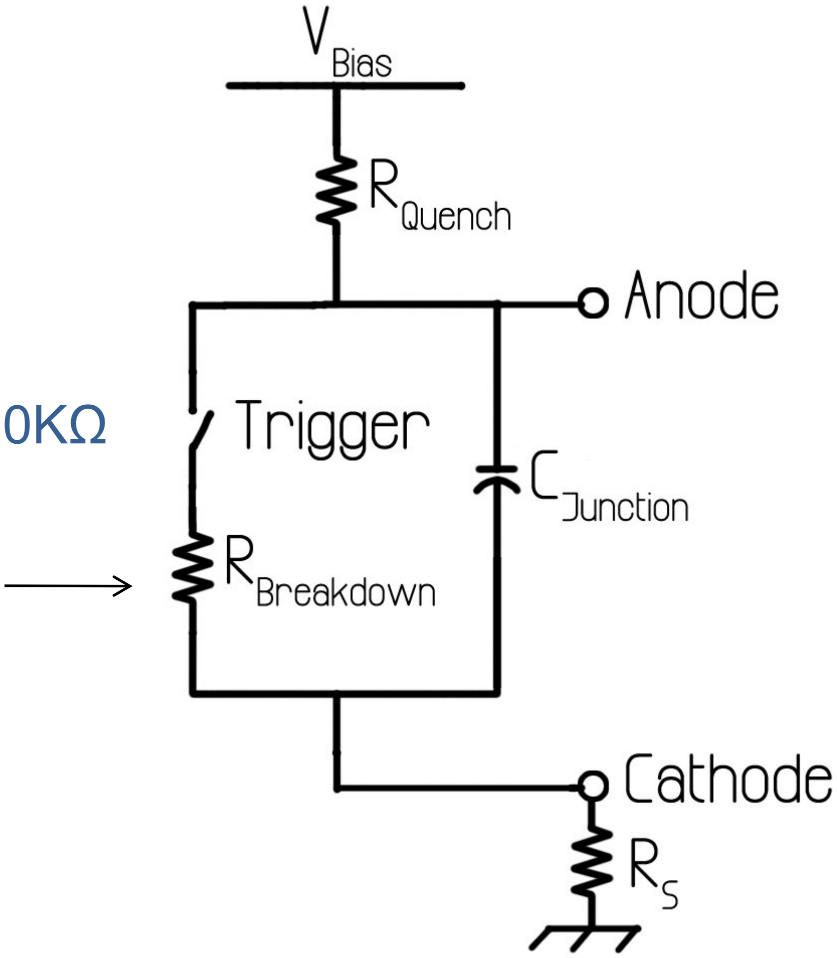
# SPAD Model

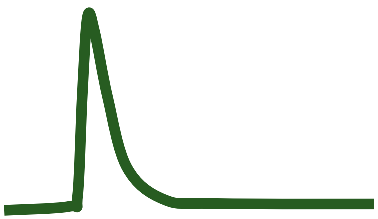
- $R_{Quench}$ stops avalanching process
  $R_{Breakdown}$ models resistance during avalanche
  $C_{Junction}$ models depletion cap
- E.g.: $R_{Quench}$ =100KΩ, $R_{Breakdown}$ = 20KΩ
  $C_{Junction}$ = 200fF



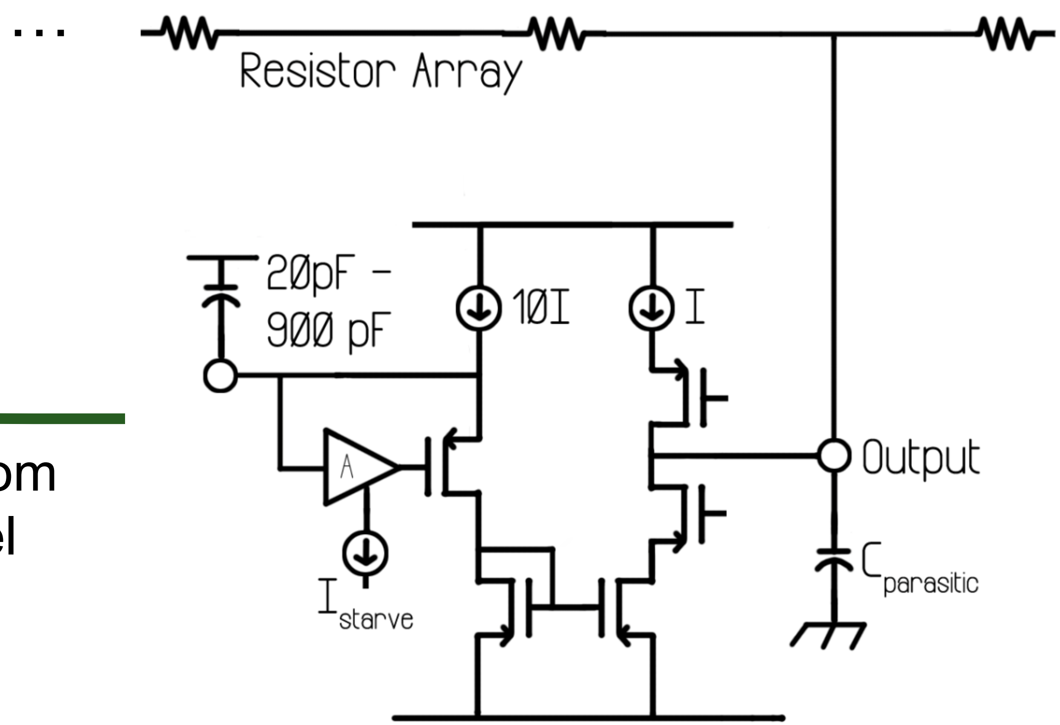



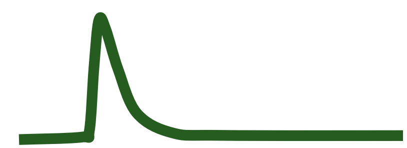
# Proposed Solution

- Isolate macropixel cathode by using a current conveyor
- $\tau_{new} = RC_{parasitic} << RC_{pixel}$. Minimal timing resolution loss



Current from macropixel

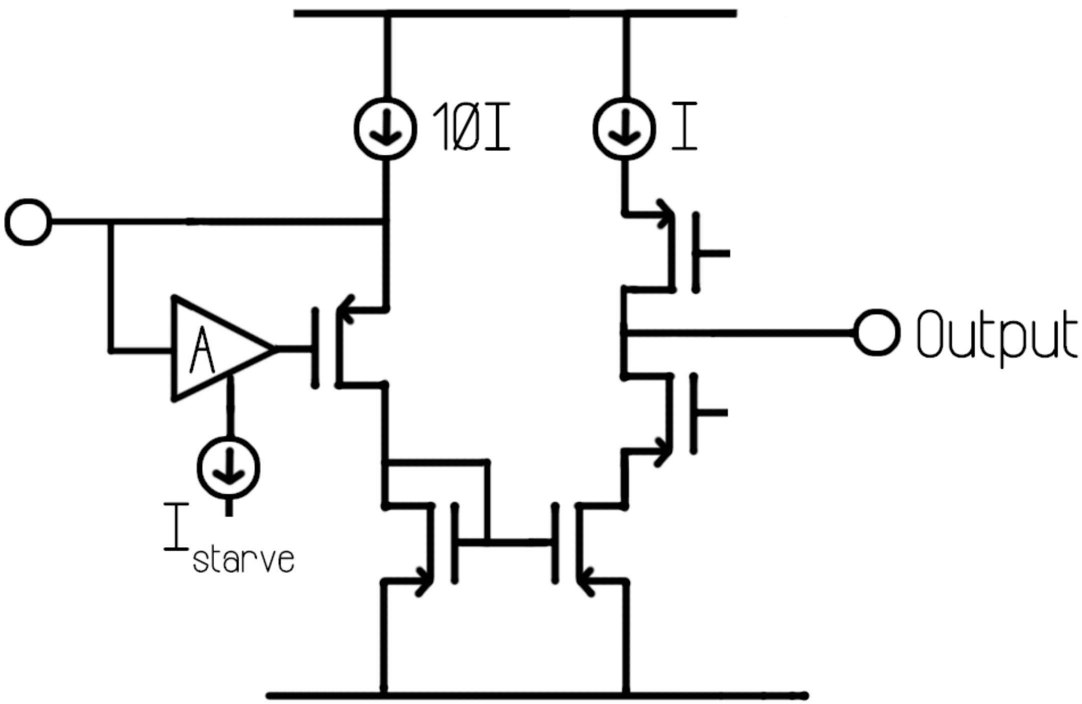


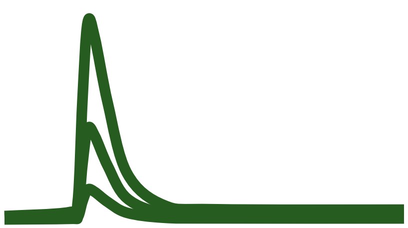



Scaled current out

# Front-End Circuit

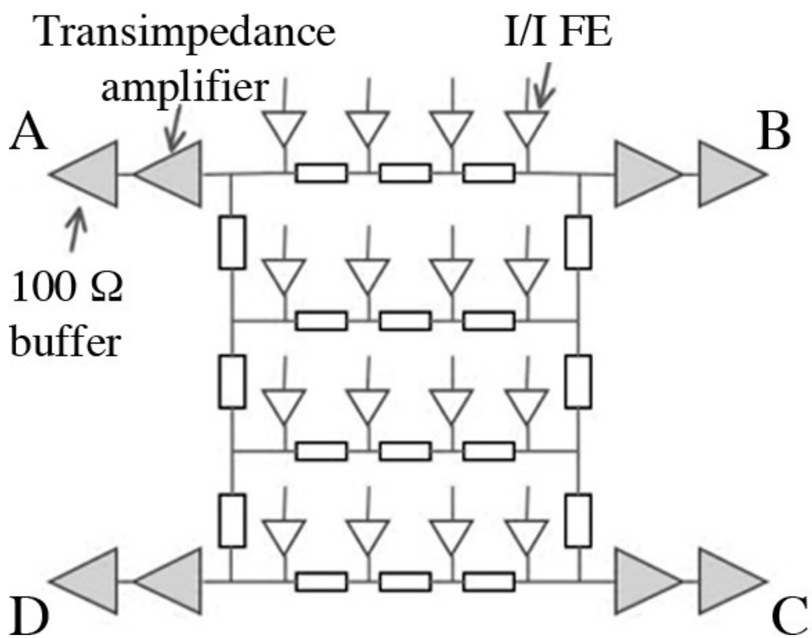
•Feedback amplifier gain controlled by starving current which ensures stability with pixel capacitances from 20pF up to 900pF and currents from 20uA up to 20mA



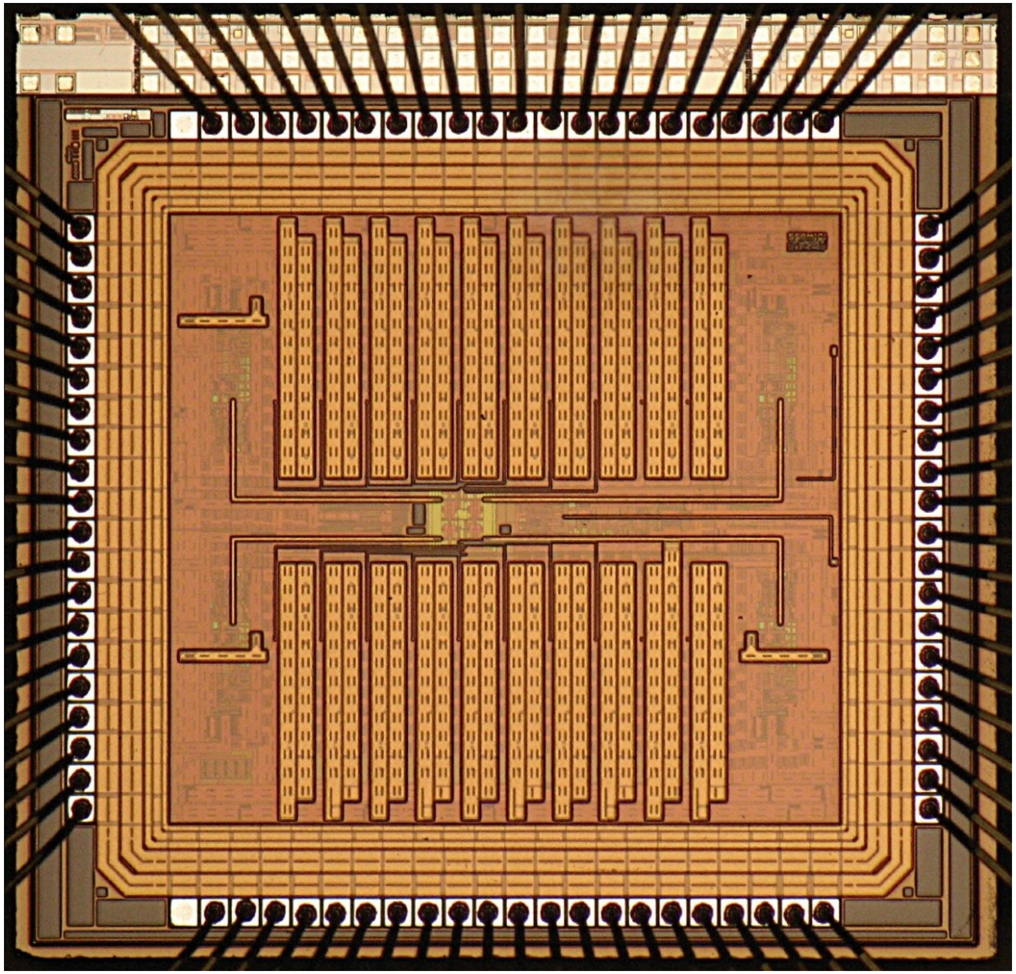



# Complete ASIC

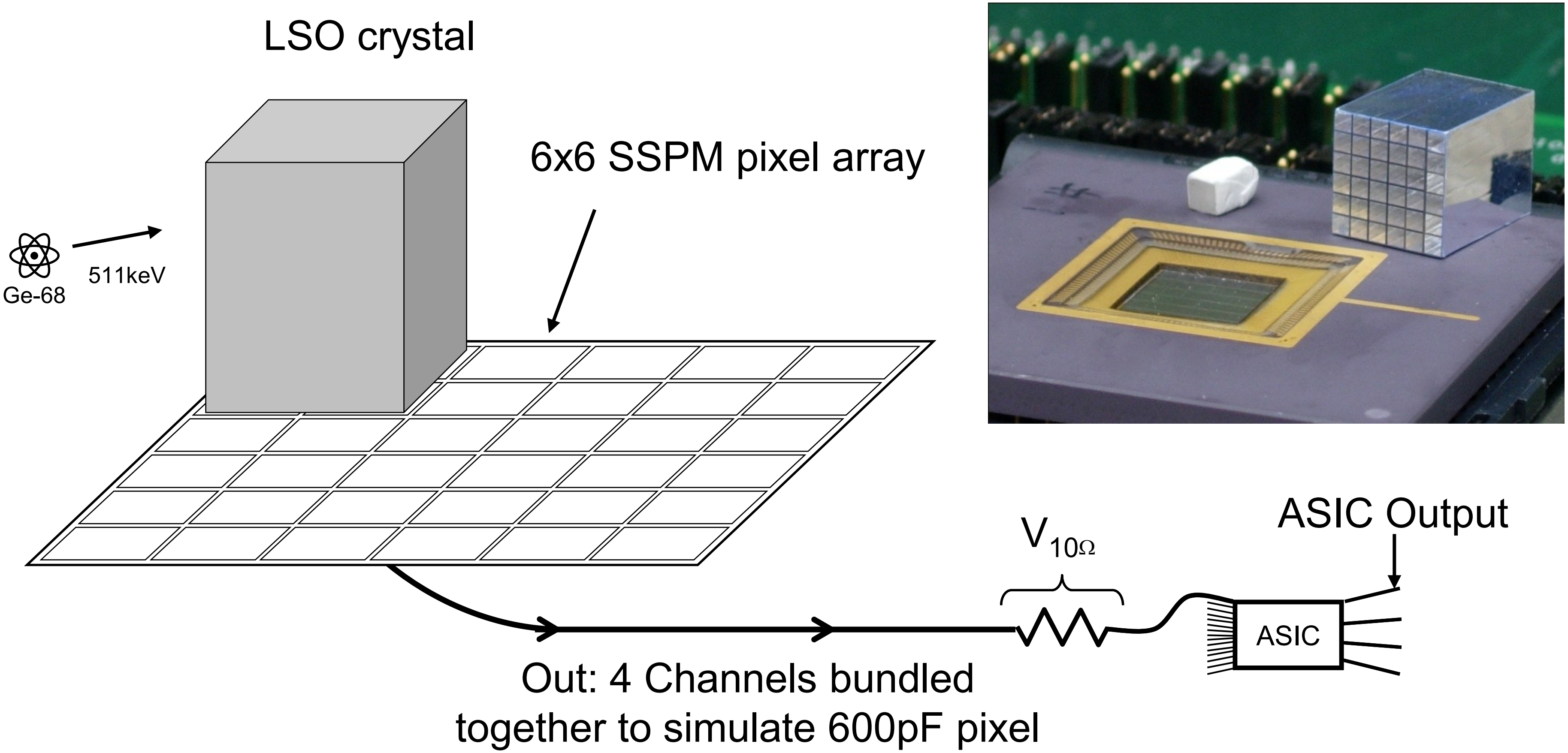
- Comprised of:
  - -16 Current-to-current front-ends
  - -Resistive charge division network
  - -4 Transimpedance amplifiers
  - -4 100Ω Output buffers



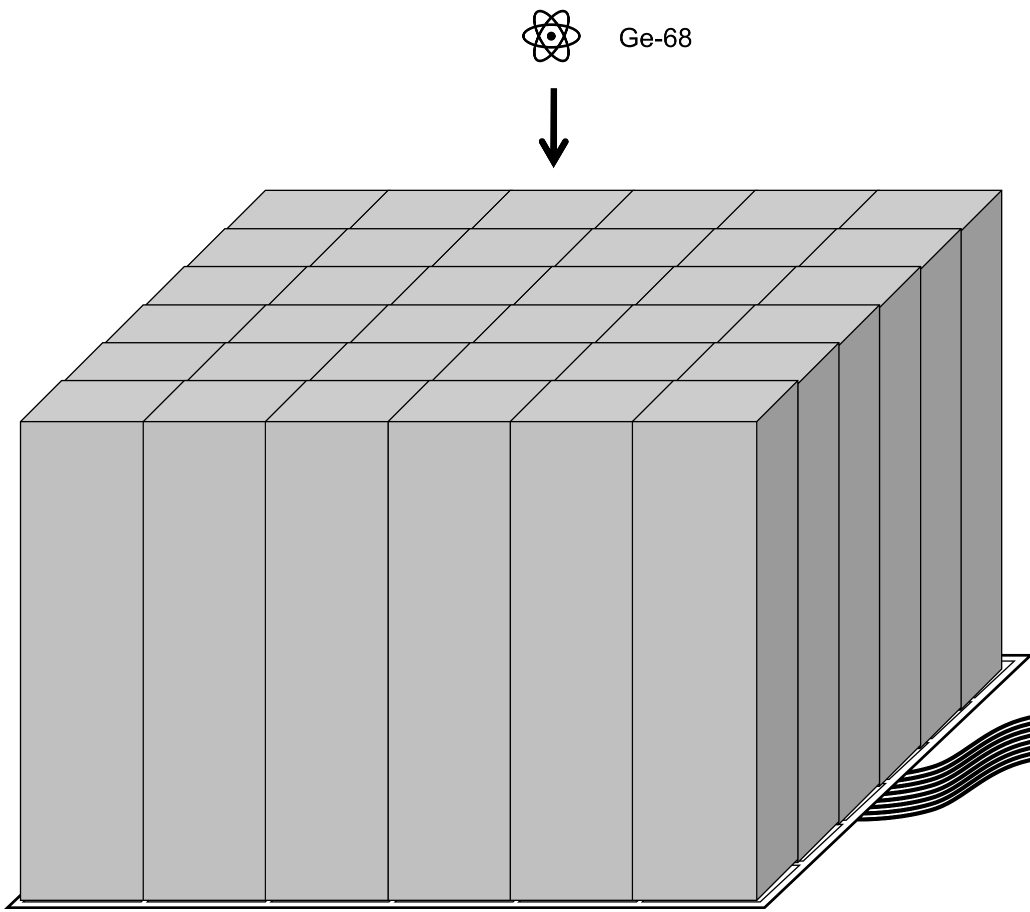
# Results – Micrograph

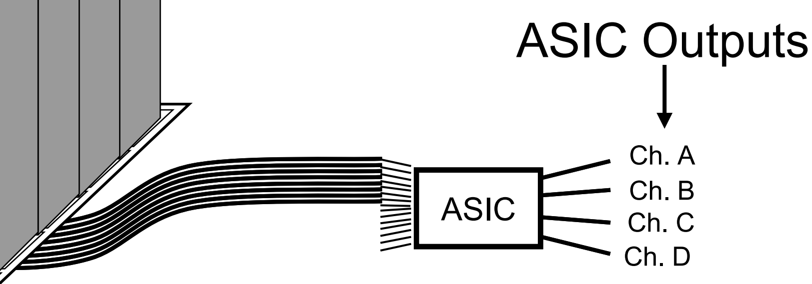


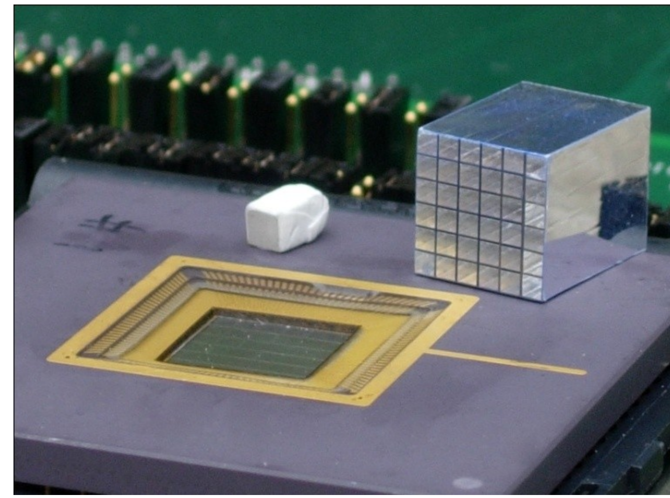
# Results – Measurement Setup



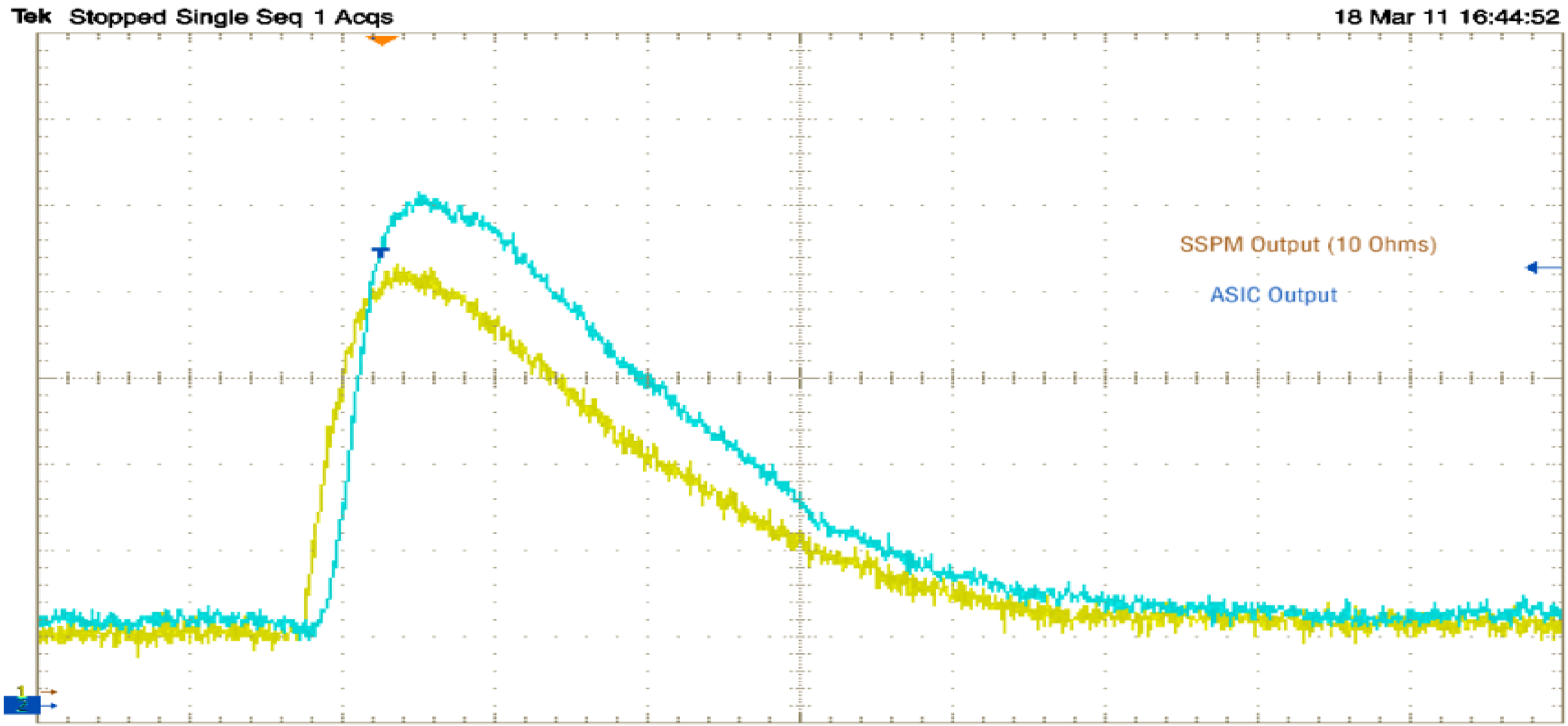
# Results – Measurement Setup



# Results – Transient Plots

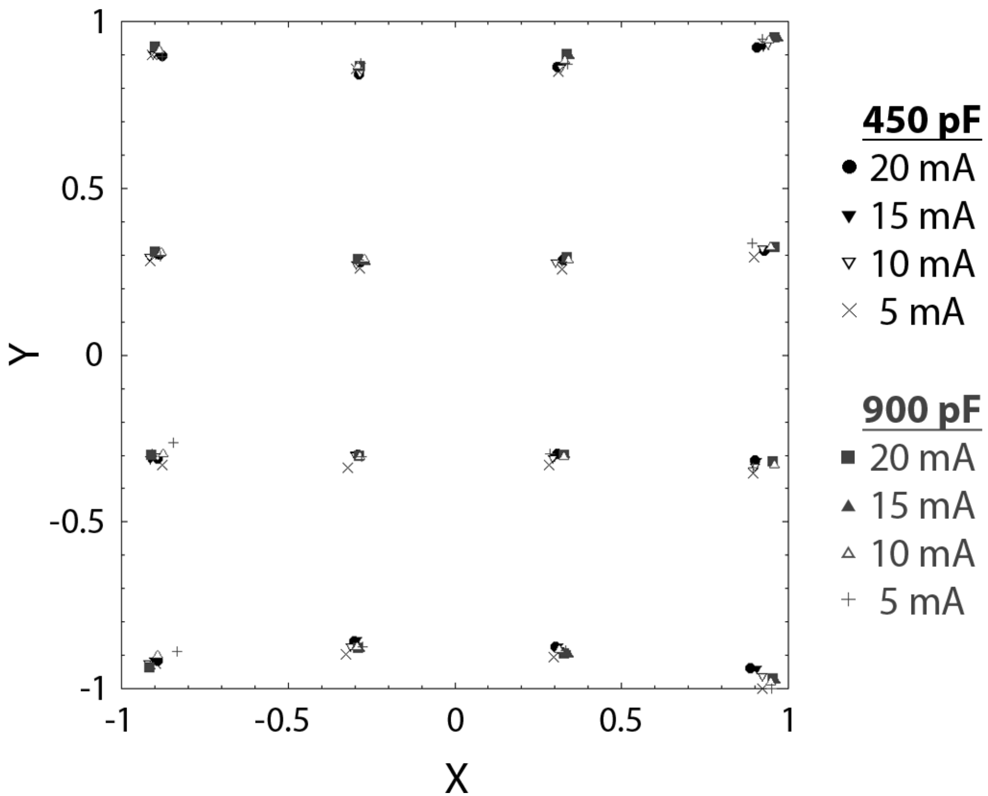



Risetime for this pulse: ~12ns

Degradation <2ns

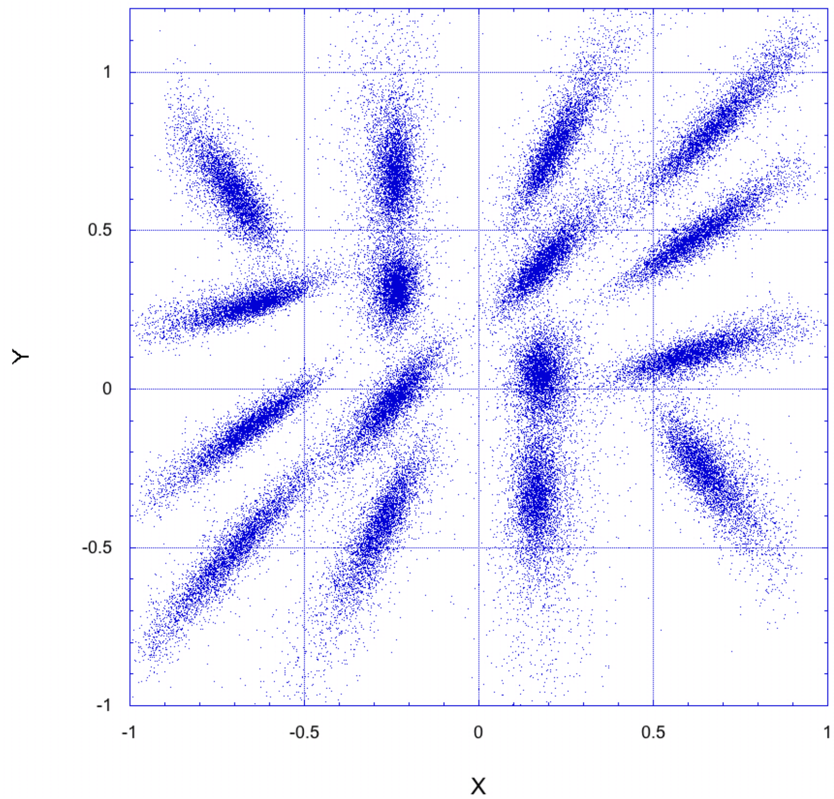
# Results – Position Plot

- Measured output of ASIC shows good separation. Input from emulator board.



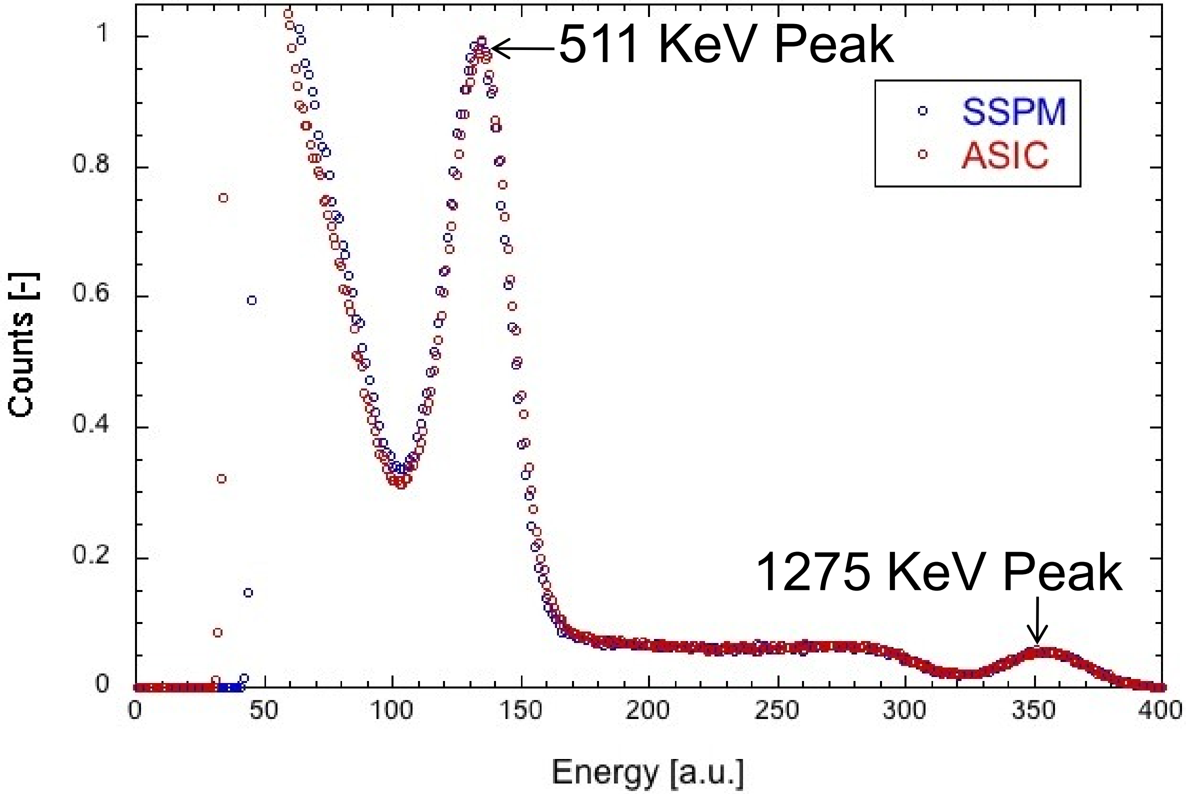
# Results – Crystal Decoding

•Distortion comes from test measurement setup. The multi-purpose PCB used, which is not optimized for our experimental setup.



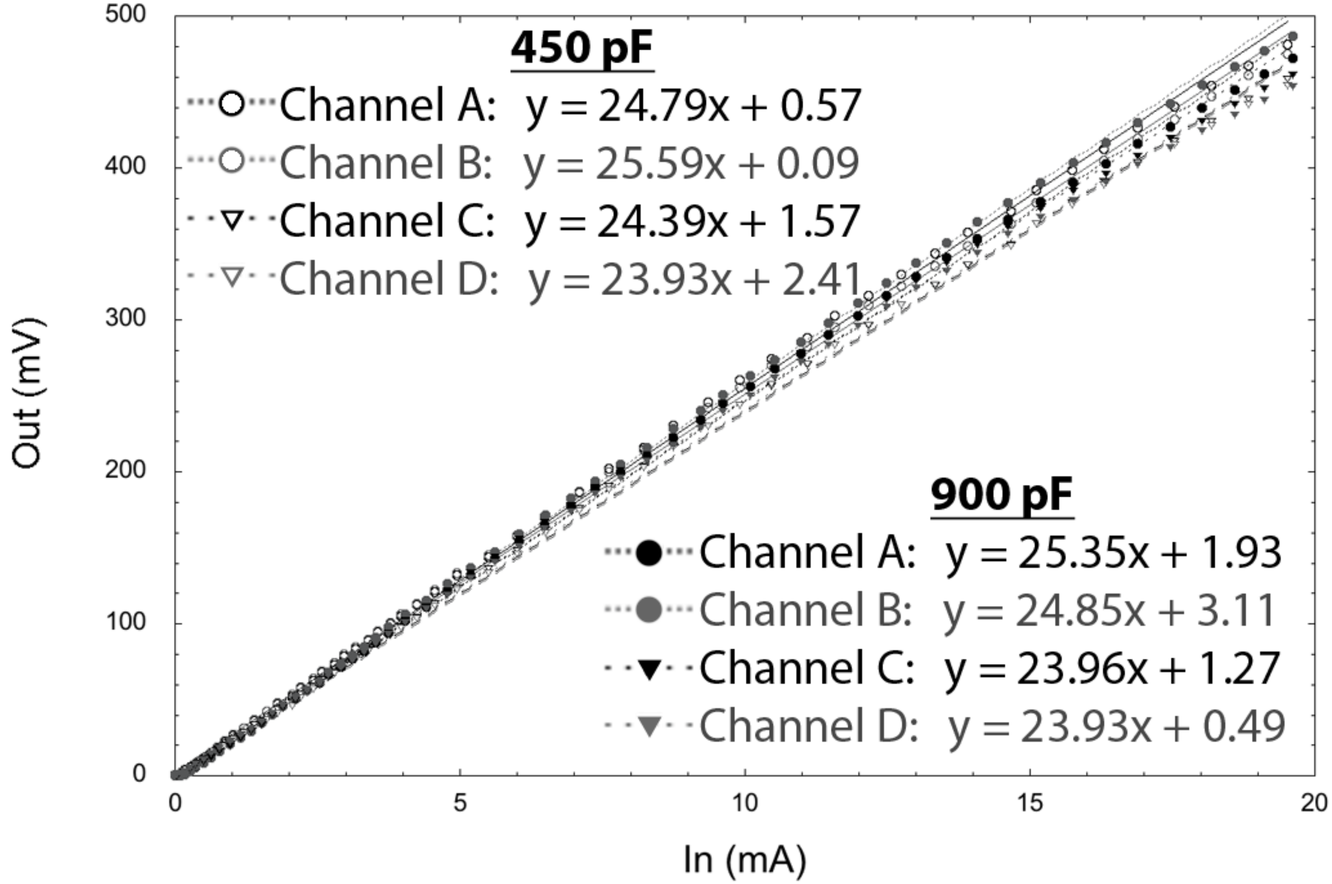
# Results – Energy Spectra

•For Na-22 source, energy resolution (FWHM) at 511keV peak is 20.4% for detector and 20.6% for detector and ASIC



# Results – Linearity

- Less than 4% deviation with large and small loads

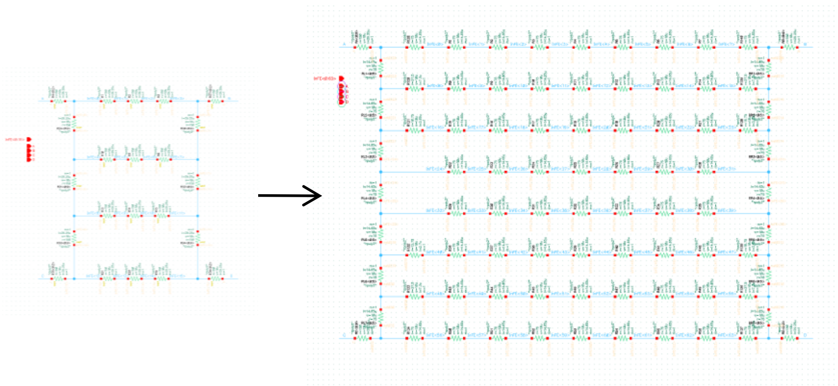


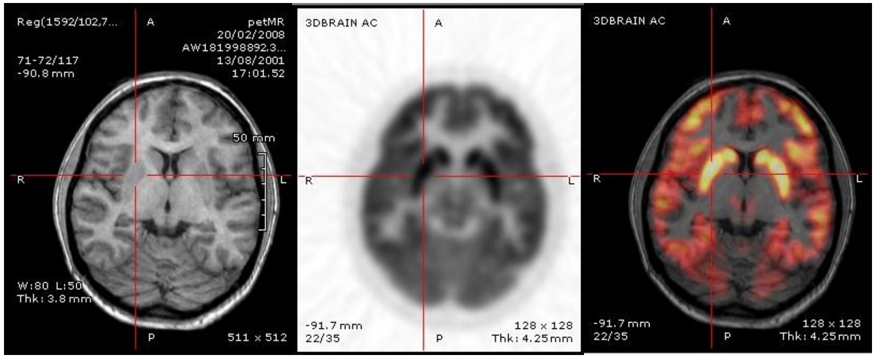
# Results - Summary

| | |
|---|---|
| Rise time degradation | <2ns |
| Input capacitance range | 20pF to 900pF |
| Total # of Inputs | 16 |
| Total # of Outputs | 4 |
| Power | ~12 mW/ channel, ~300mW full chip |
| Noise (rms) | < 1 $mV_{rms}$ |
| Noise (FWHM) | <1% added in quadrature to LSO crystal |
| Linearity | <4% deviation |

# Future Work

- Improve measurement setup
- Integrate SSPM and ASIC monolithically
- Increase the number of read-out channels from 16 to 64
- Add temperature stabilization and correction circuits for SSPM
- Use inside of MRI for hybrid PET/MRI imaging





# Acknowledgements

Financial support by

Detectors made by

# Thank you for your attention