IEEE NPSS Short Course

Radiation Detection and Measurement

October 19, 2008

2008 Nuclear Science Symposium and Medical Imaging Conference
Dresden, Germany

Front-End Electronics Systems for Particle Detection and Imaging

These course notes and additional tutorials at
http://www-physics.lbl.gov/~spieler

More detailed discussions in
H. Spieler: Semiconductor Detector Systems, Oxford University Press, 2005

Course Contents

1. Introduction
2. Signal Acquisition
    - Detector pulses
    - Voltage vs. Current Mode Amplifiers
    - Charge-Sensitive Amplifier
    - Frequency and Time Response
3. Resolution and Electronic Noise
    - Thermal Noise
    - Shot Noise
    - Low Frequency ("$1/f$") Noise
    - Signal-to-Noise Ratio vs. Detector Capacitance
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    - Pulse Shaping and Signal-to-Noise Ratio
5. Some Other Aspects of Pulse Shaping
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7. Digital Signal Processing
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    - Digital vs. Analog
8. Systems and Circuits
    - Applications in HEP, Nuclear Physics, Materials Science, and Biology
9. Why Things Don't Work

Many different types of detectors are used for radiation detection.

Nearly all rely on electronics.

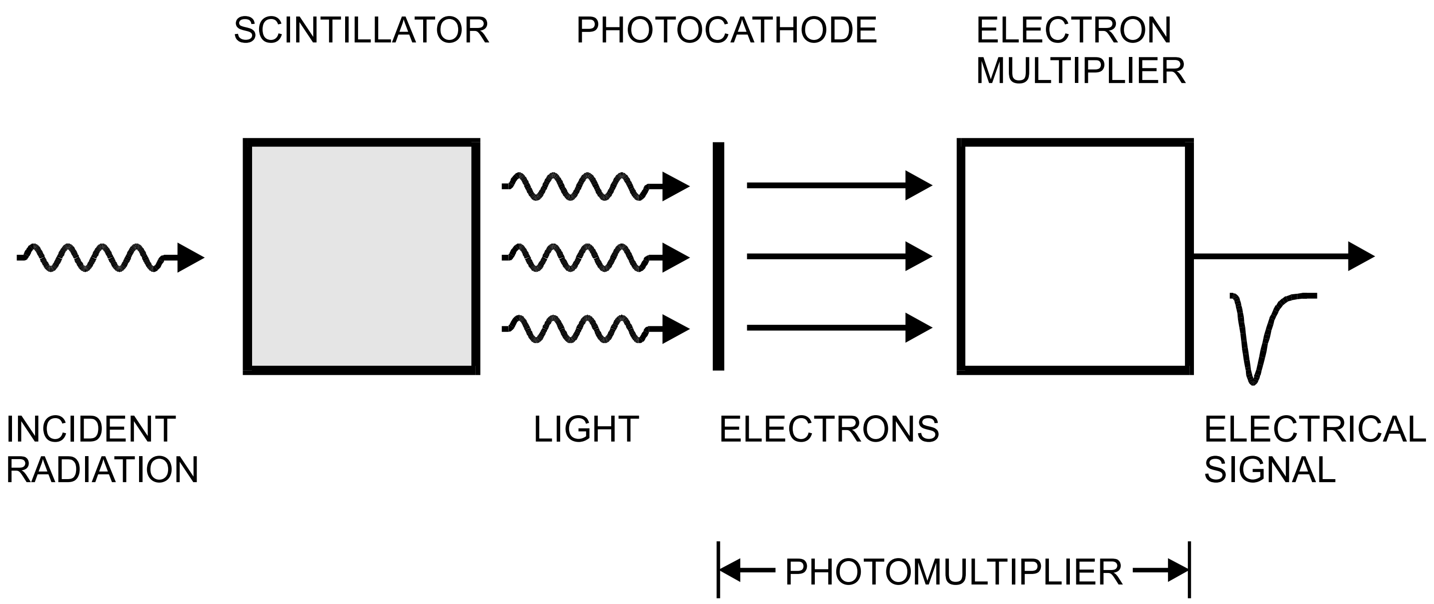
Although detectors appear to be very different, basic principles of the readout apply to all.

- The sensor signal is a current.
- The integrated current $Q_S = \int i_S(t)dt$ yields the signal charge.
- The total charge is proportional to the absorbed energy.

Readout systems include the following functions:

- Signal acquisition
- Pulse shaping
- Digitization
- Data Readout

Example: Scintillation Detector

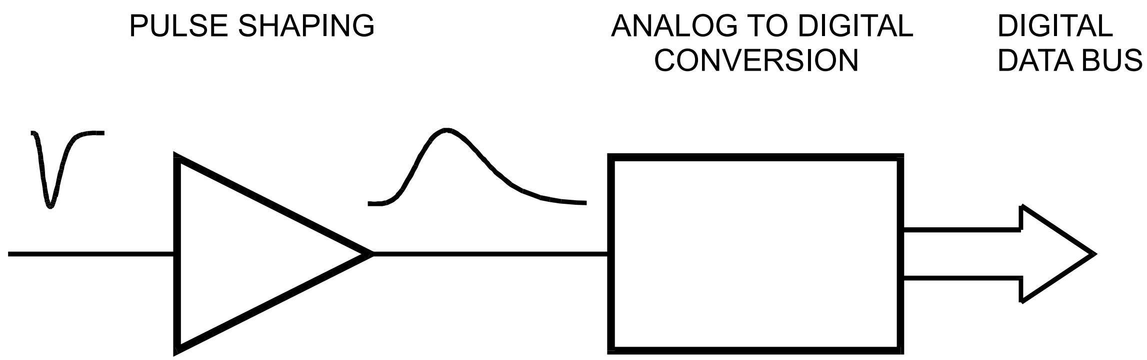


number of photons $\propto$ absorbed energy

number of photoelectrons $\propto$ absorbed energy

charge in pulse $\propto$ abs. energy

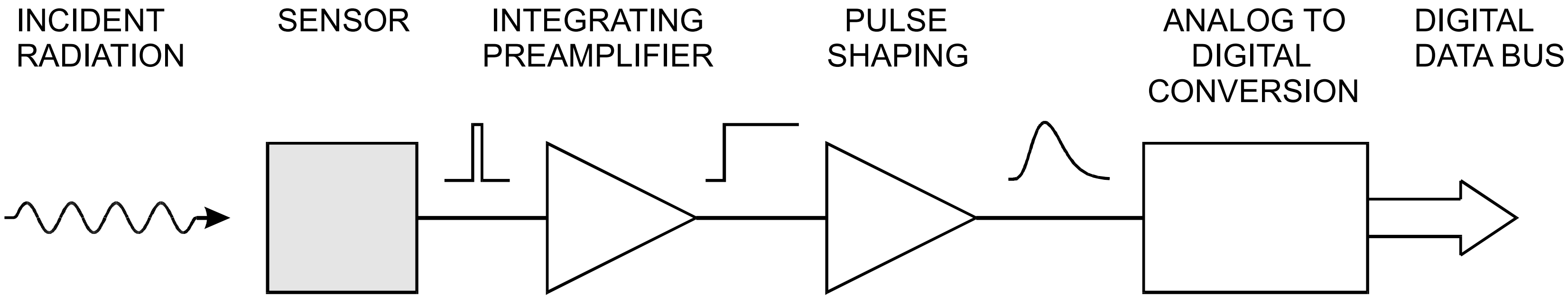
Readout



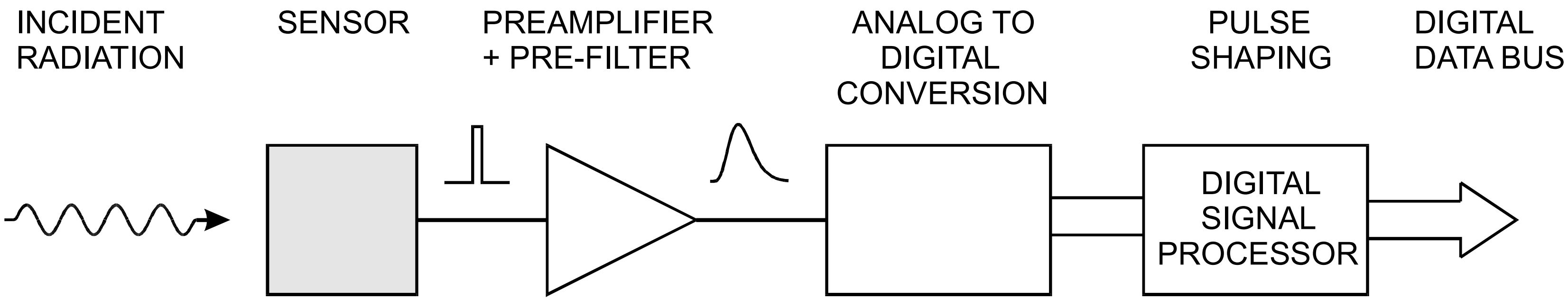
charge in pulse
$\propto$ absorbed energy

pulse height
$\propto$ absorbed energy

1. Basic Functions of Front-End Electronics

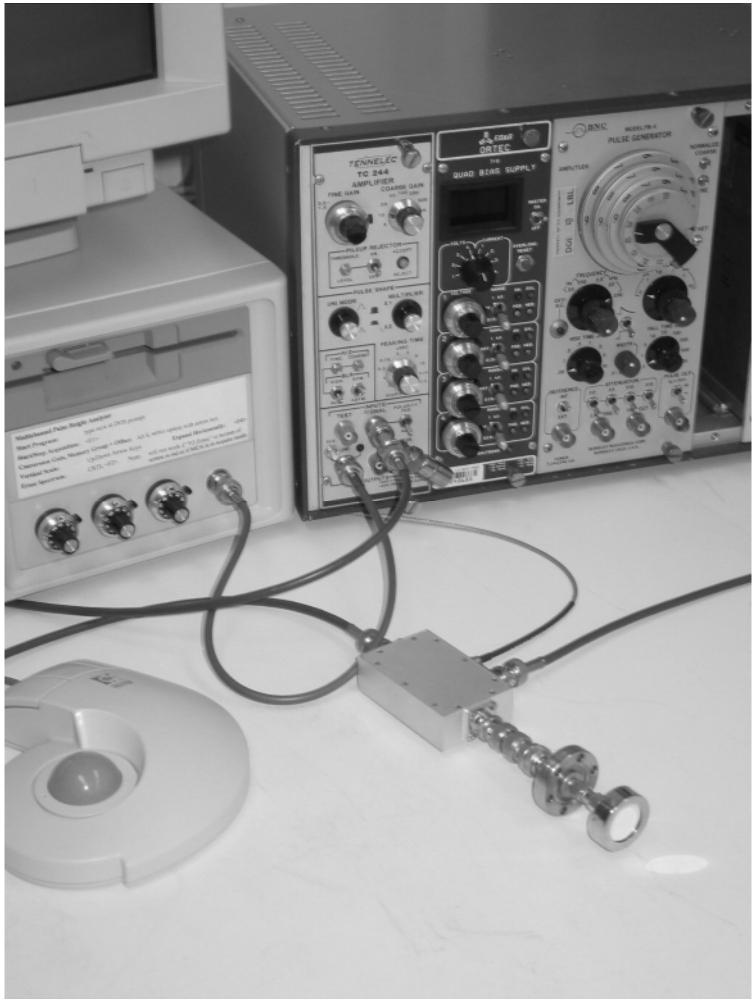


Pulse shaping can also be performed with digital circuitry:



Many Different Implementations

“Traditional” Si detector system
for charged particle measurements



Tracking Detector Module (CDF SVX)
512 electronics channels on 50 μm pitch

Spectroscopy systems highly optimized!

By the late 1970s improvements were measured in %.

Separate system components:

1. detector
2. preamplifier
3. amplifier
    - adjustable gain
    - adjustable shaping
        - (unipolar + bipolar)
    - adjustable pole-zero cancellation
    - baseline restorer

Beam times typ. few days with changing configurations, so equipment must be modular and adaptable.

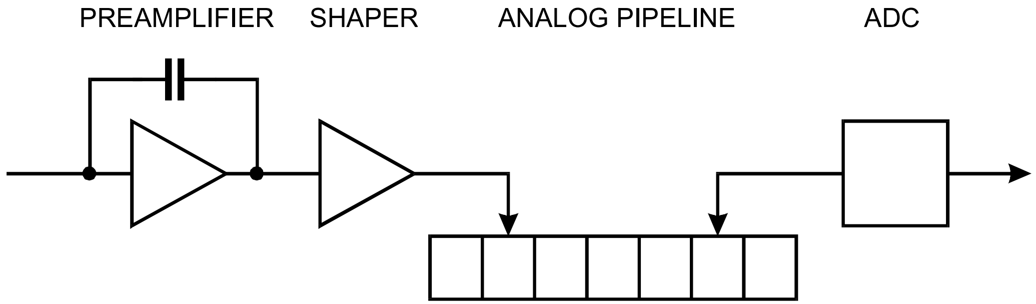
Today, systems with many channels are required in many fields.

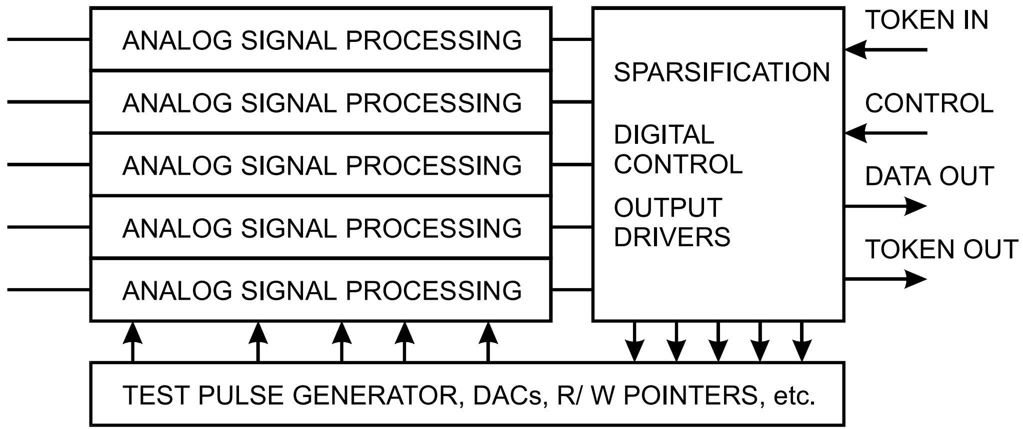
In large systems power dissipation and size are critical, so systems are not necessarily designed for optimum noise, but *adequate* noise, and circuitry is tailored to specific detector requirements.

Large-Scale Readout Systems

Example: Si strip detector

On-chip Circuits

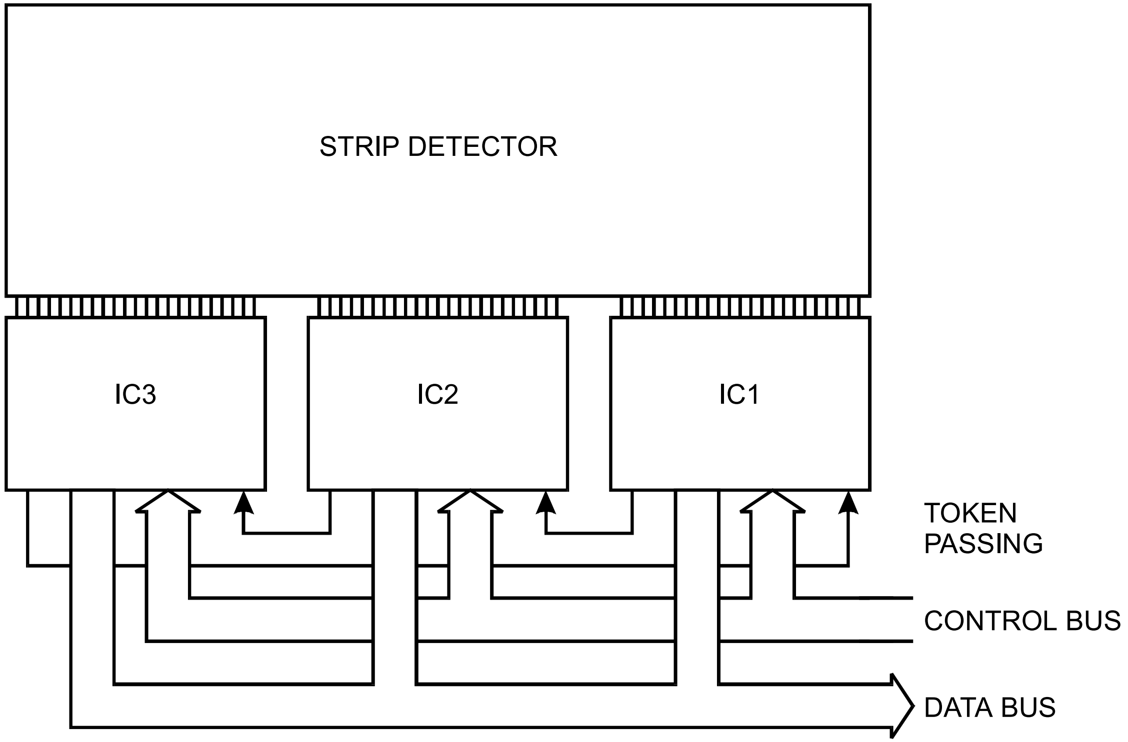




Inside a typical readout IC:

- 128 parallel channels of analog front-end electronics
- Logic circuitry to decode control signals, load DACs, etc.
- Digital circuitry for zero-suppression, readout

Readout of Multiple ICs



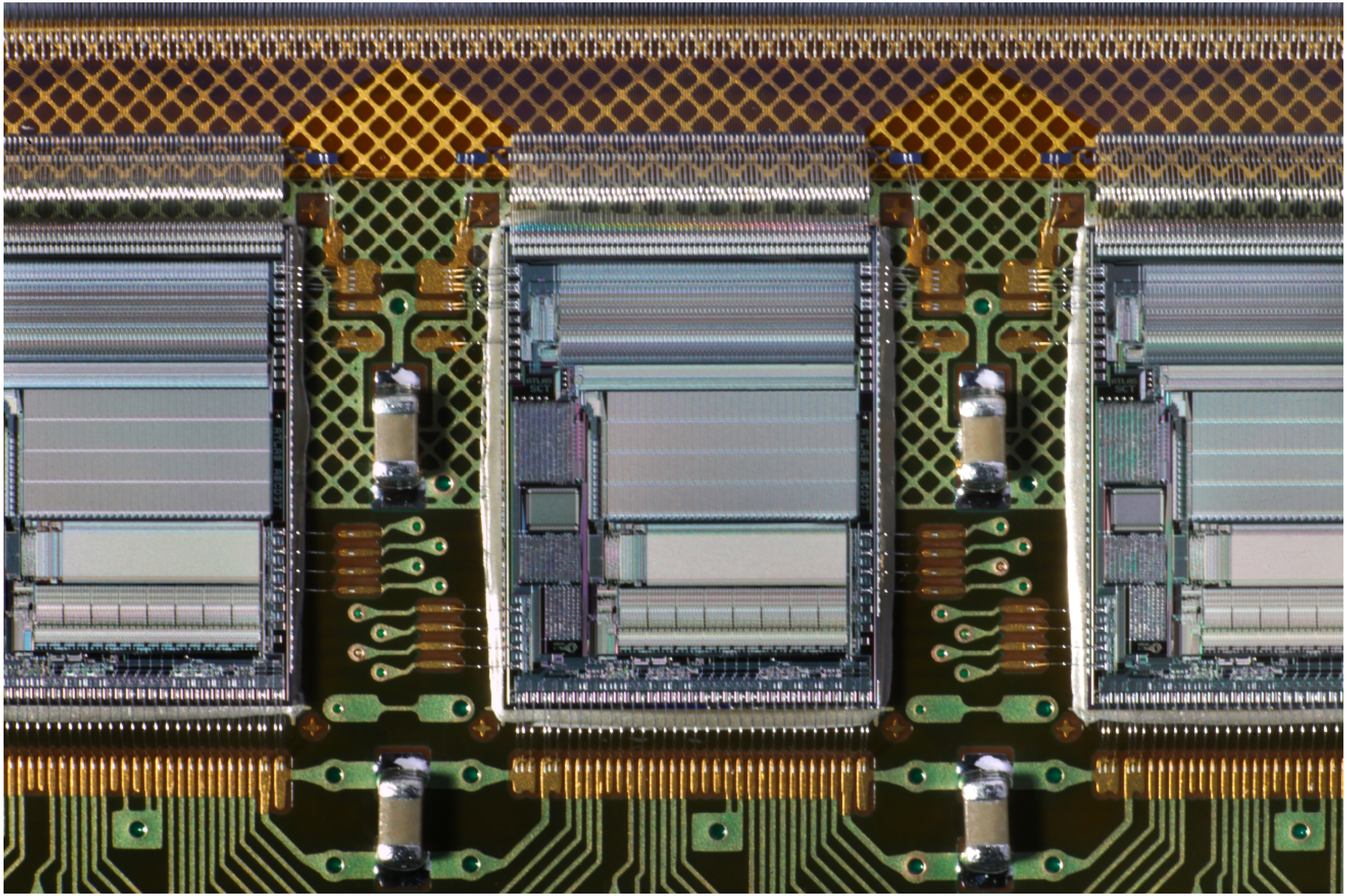
IC1 is designated as master.

Readout is initiated by a trigger signal selecting appropriate time stamp to IC1.

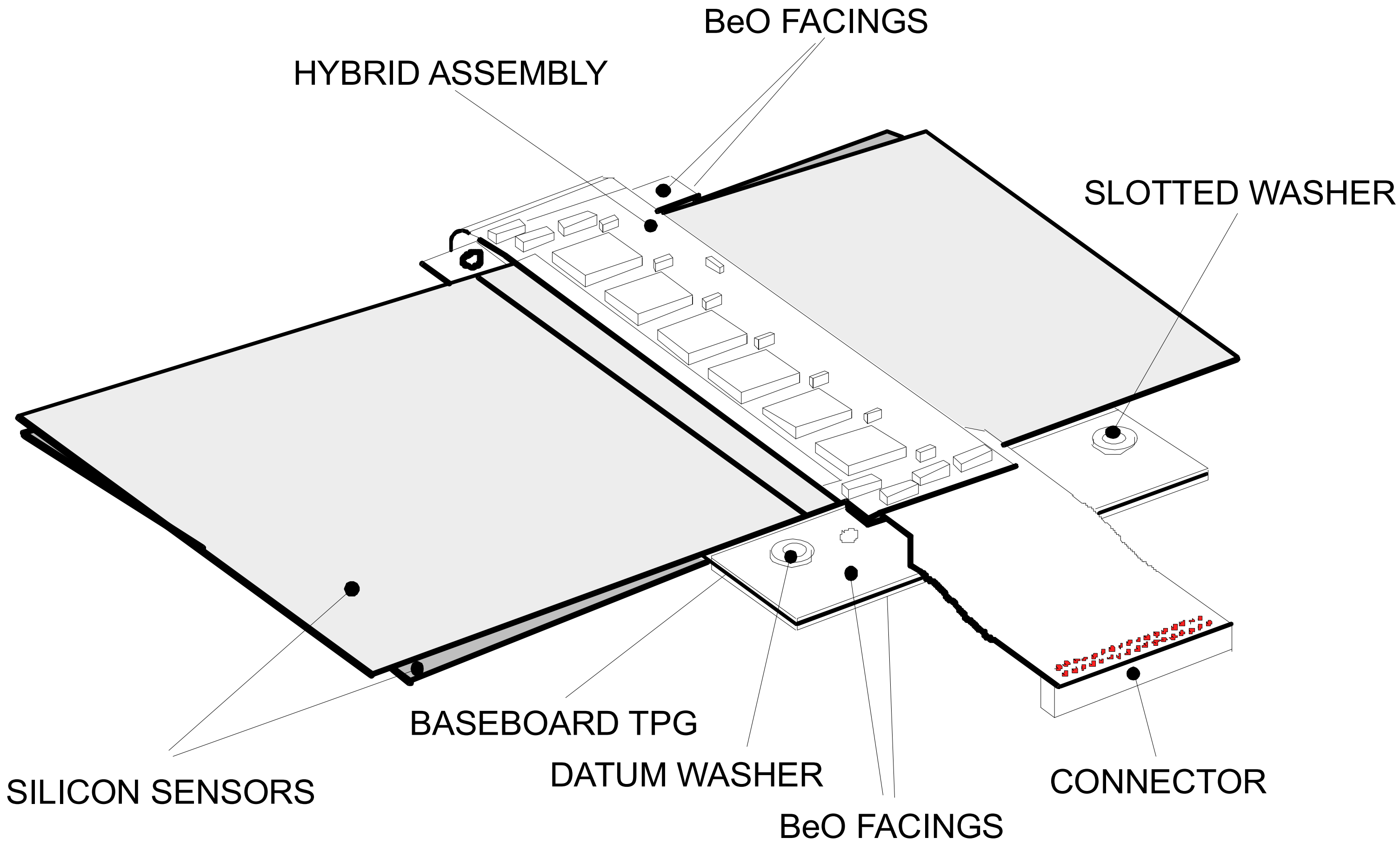
When all data from IC1 have been transferred, a token is passed to IC2.

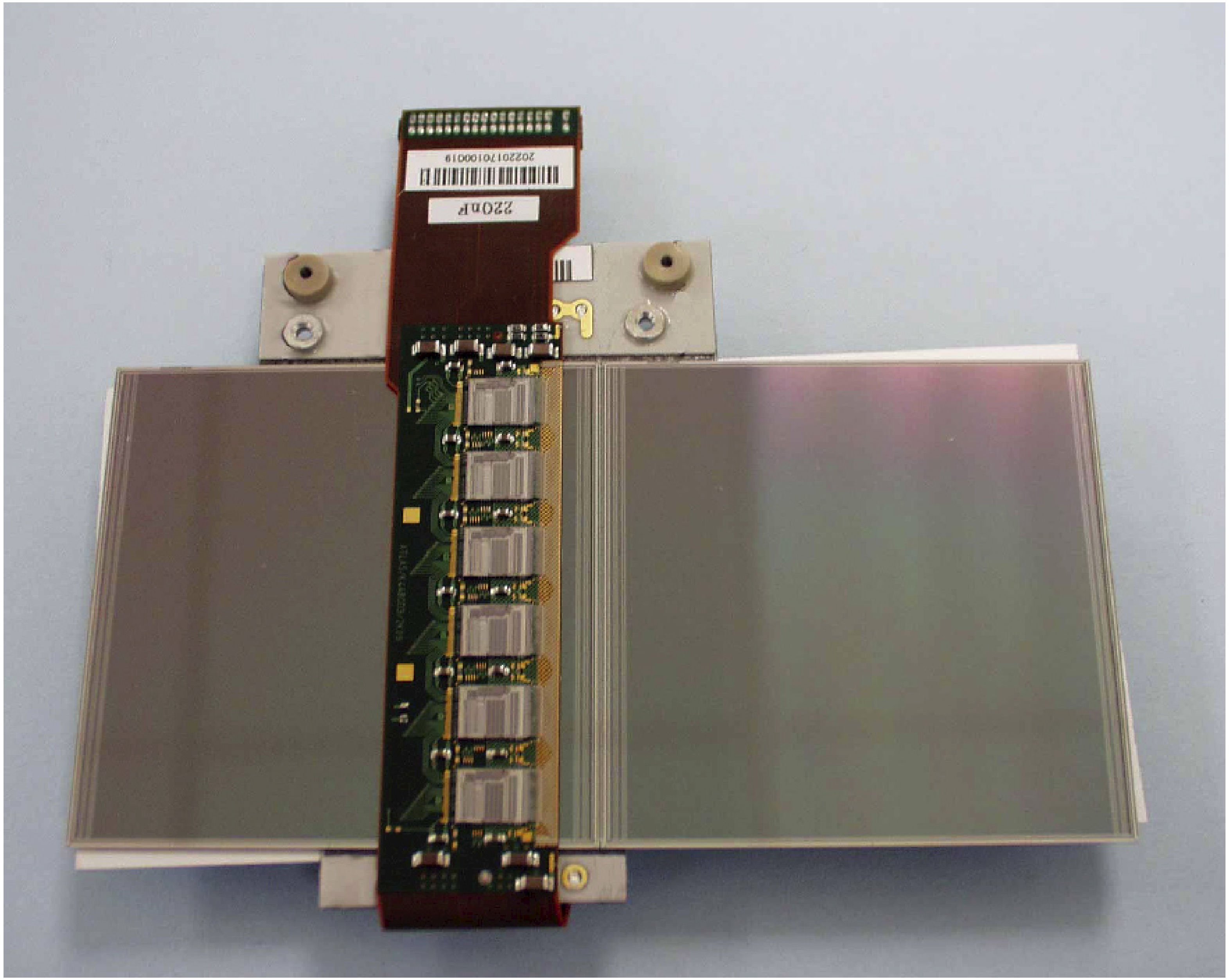
When IC3 has finished, the token is passed back to IC1, which can begin a new cycle.

ATLAS Silicon Strip system (SCT): ABCD chips mounted on hybrid

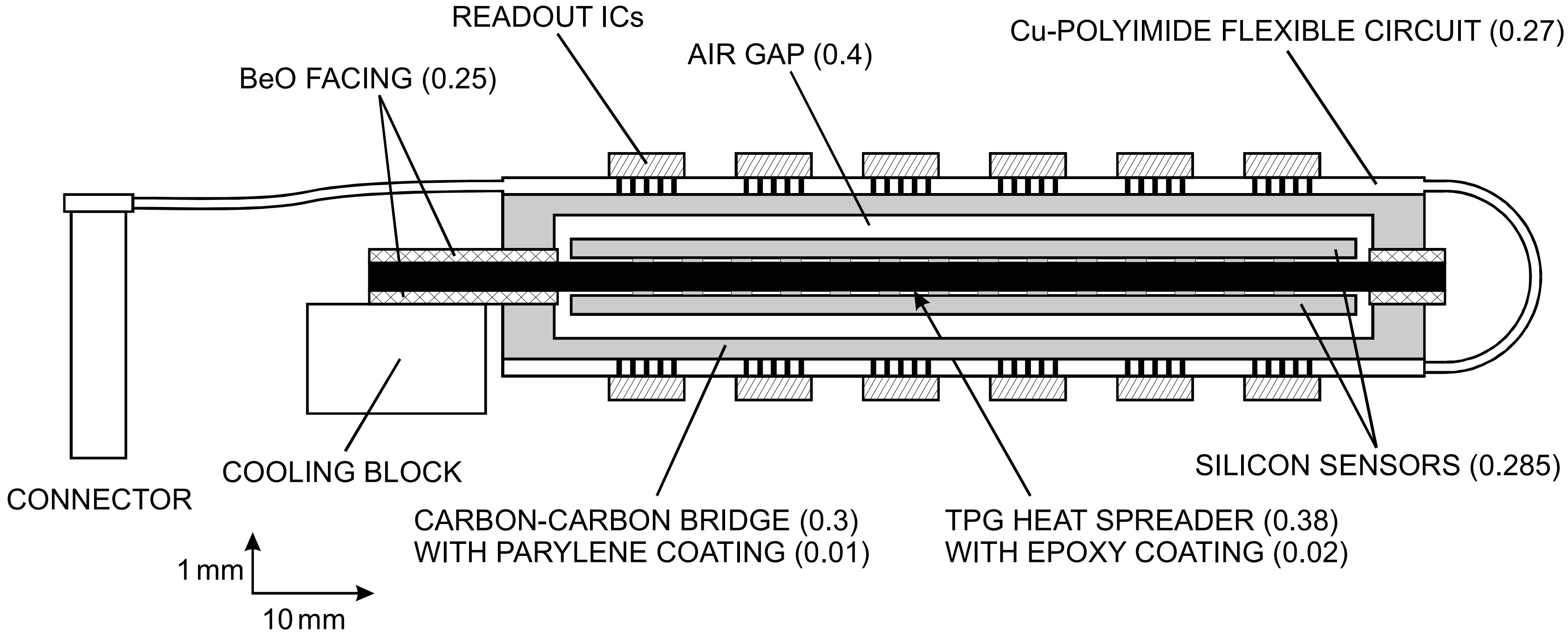


ATLAS SCT Detector Module





Cross Section of Module



Design criteria depend on application

1. Energy resolution
2. Rate capability
3. Timing information
4. Position sensing

Large-scale systems impose compromises

1. Power consumption
2. Scalability
3. Straightforward setup + monitoring
4. Cost

Technology choices

1. Discrete components – low design cost
   fix "on the fly"
2. Full-custom ICs – high density, low power, but
   better get it right!

Successful systems rely on many details that go well beyond "headline specs"!