2015 CAP Congress

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Coincidence Measurements using the SensL MatrixSM-9 Silicon-photomultiplier Array

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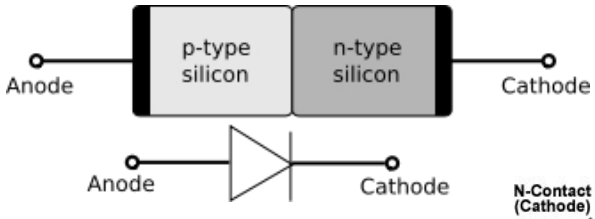
University of Regina

* Funded by Fedoruk grant

§ Funded by NSERC Engage grant

Outline

- **Silicon photomultipliers (SiPMs)** - aka **Multi-pixel photon counters (MPPCs)**
  - Photodetector that converts light into a current.
- **Plant Imaging**: (large-area devices)
  - PhytoPET detector
  - Magnetic-field resistant detectors
    - Custom configuration
- **Current work** at the U of Regina.



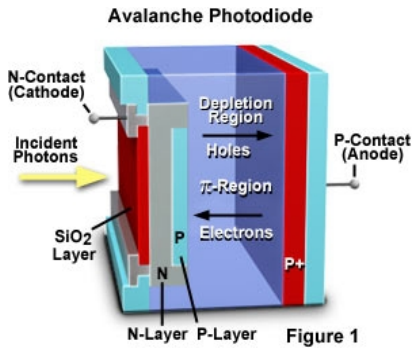
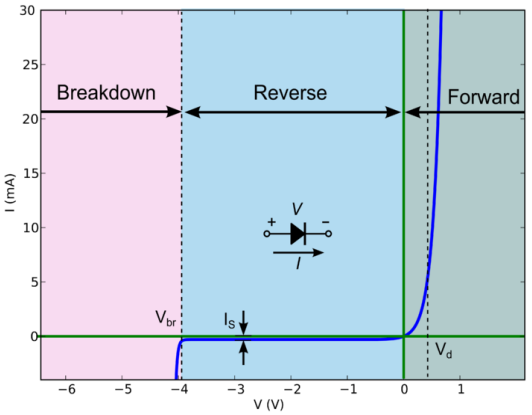
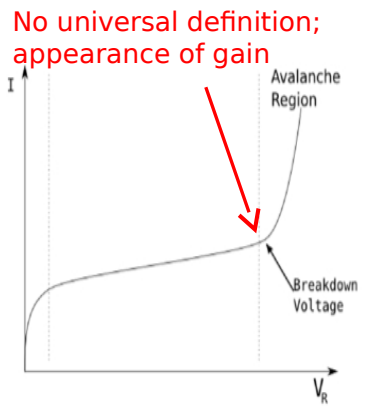


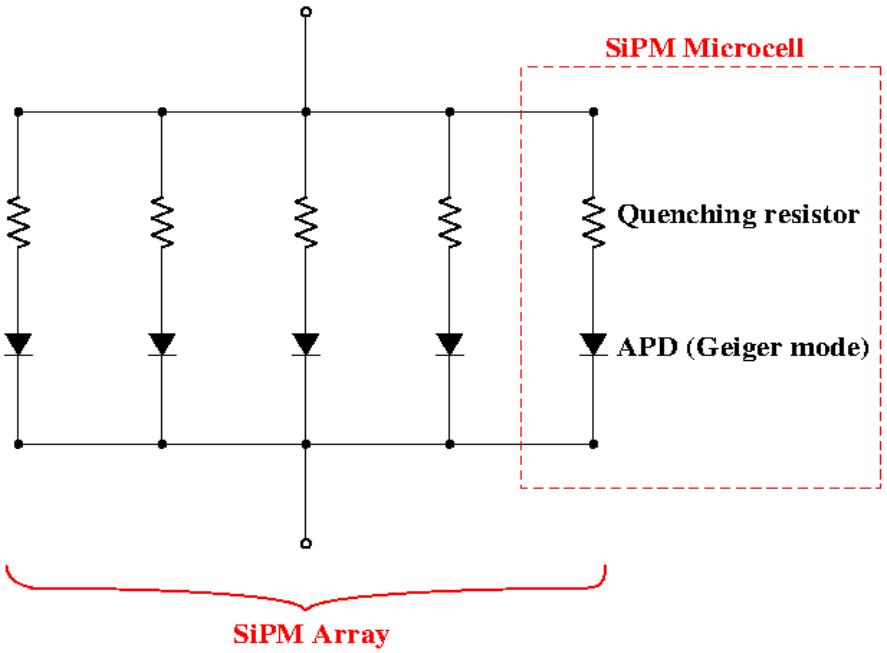
Figure 1

SiPMs



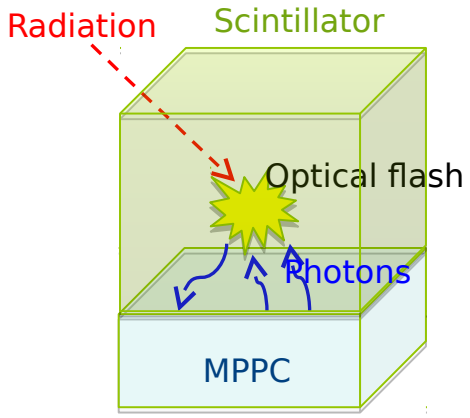


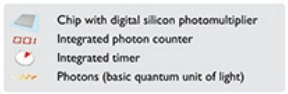
- **Photodiode**: p-n junction or PIN structure.
- Photon incident on depletion layer can cause **inner photoelectric effect**.
- **APD Geiger mode:** if $V \geq V_{br}$ **avalanche** occurs (electrons and holes), subsequently quenched.
- Charges swept from the junction by the built-in electric field of the depletion region: **current** generated - holes move to anode, electrons to cathode.



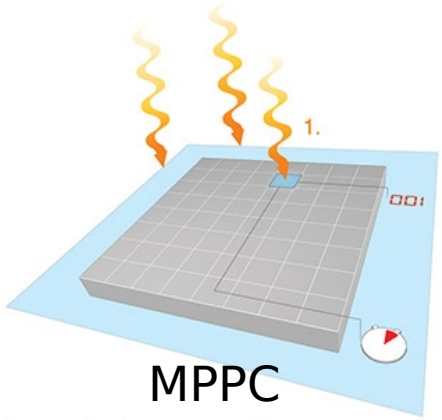
SiPMs/MPPCs at work

1 Particle produces light flash

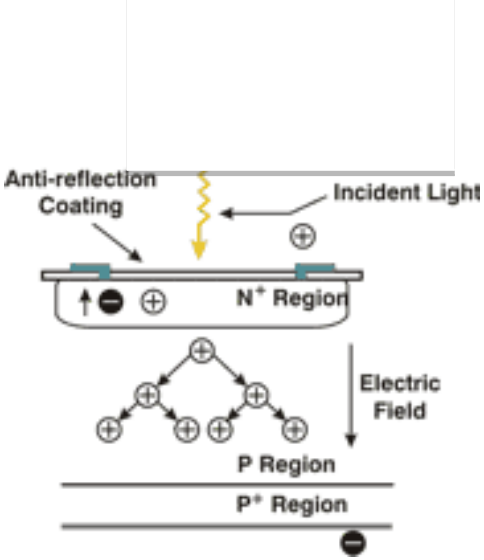




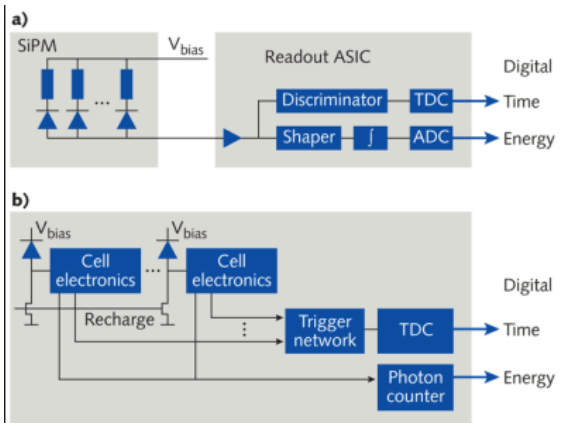
2 Light falls on photosensor



3 Avalanche turns Light into a current

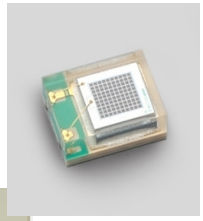


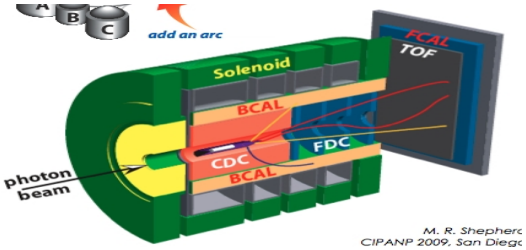
4 Signal is digitized

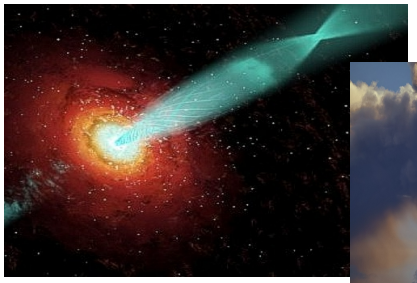


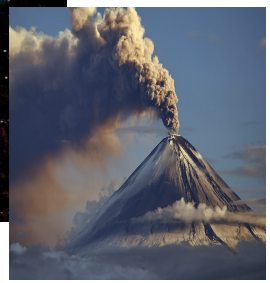
5 Algorithms: form image

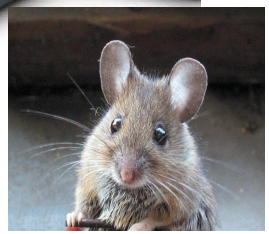
Applications of SiPMs











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GLUEXcitations Experiment
Jefferson Lab
NSERC CRSNG
University of Regina

Plant Imaging

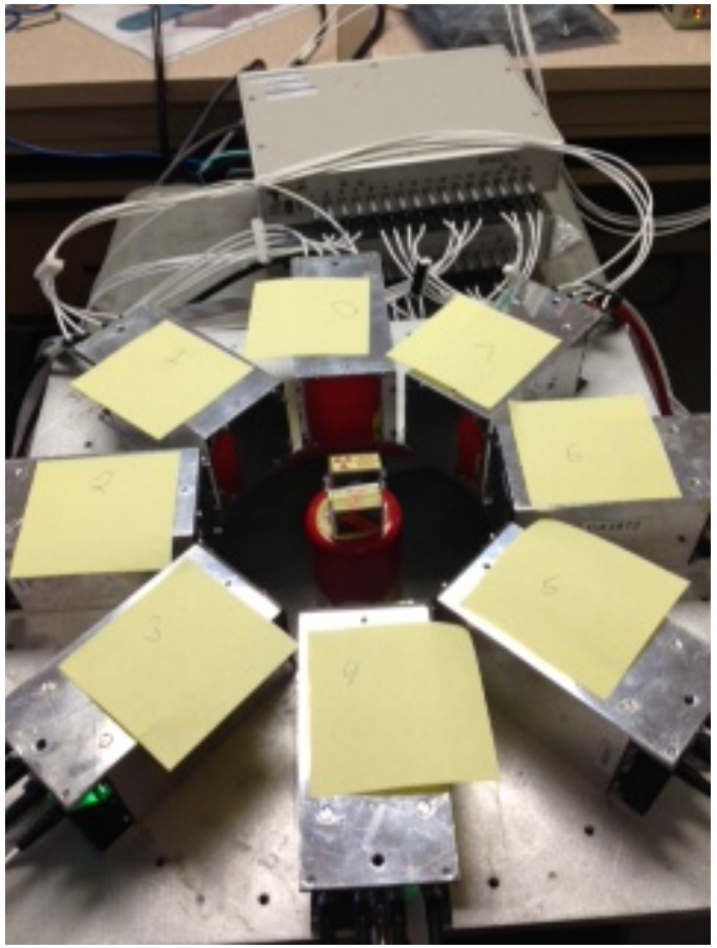
Tomato plant

Courtesy Jefferson Lab

- Pioneer new imaging tools in fundamental areas that include: adaptation to environmental stresses, disease, efficient nutrient and water use, and seed quality, enabling the development of improved fertilizers and microbial inoculants.
- Practicalities:
  - R&D at UofR, deployment at Fedoruk. Portable solution?
  - Define application parameters
  - Develop software algorithms: DOI, LOR, resolution, visualization.
  - Hybrid detector systems: PMT- and SiPM-based solutions
- Key requirements: clean signals and fast timing towards sub-mm image resolution.

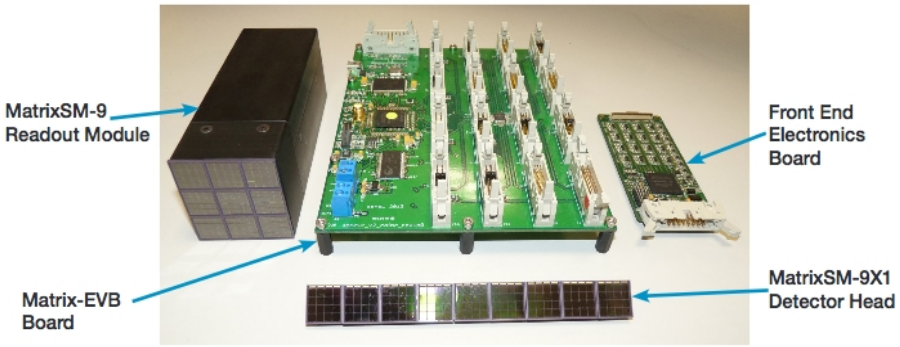
PhytoPET System (Hamamatsu)

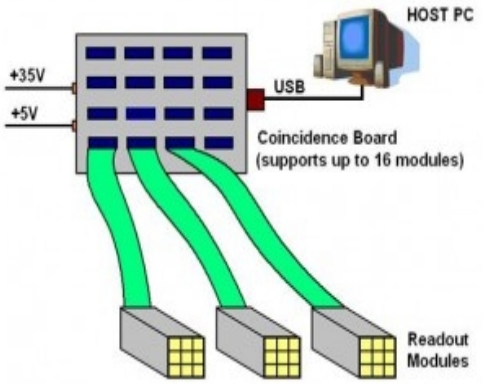
- Partnership: Jefferson Lab RD&I Group.
- Multi-anode PMT detector heads – no SiPMs
- Custom electronics
- Proven performance (at Duke U.)
- CRADA contract: import to Saskatchewan
- Future: magnetic-immunity by using SiPMs or dSiPMs.

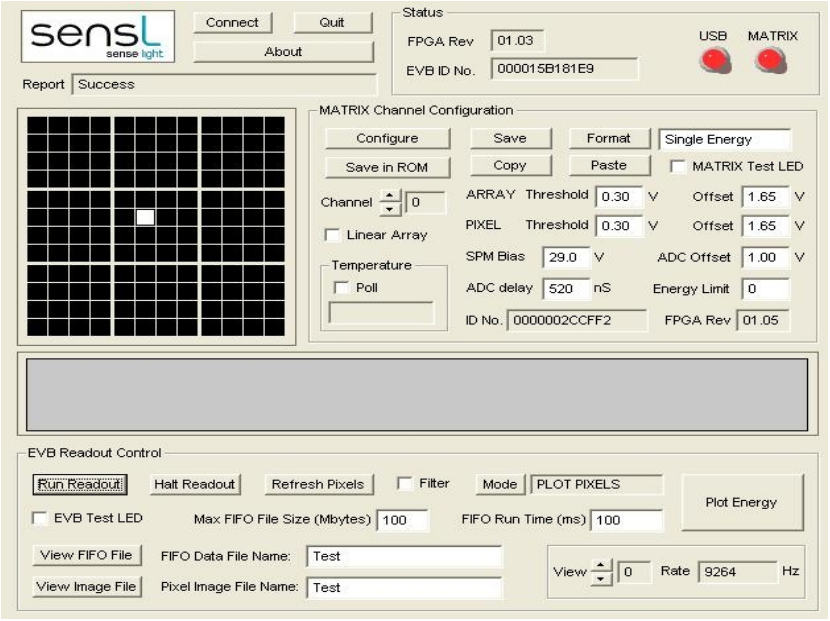


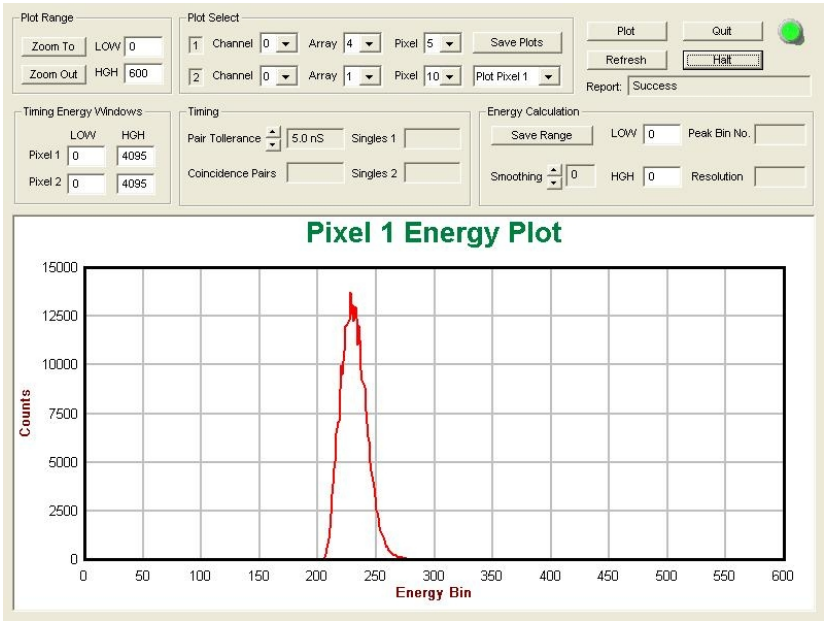
Turn-key System (SensL)

- Detector
- Frontend
- Evaluation
- Coincidence, DAQ, Software: using ^{90}Sr, ^{22}Na









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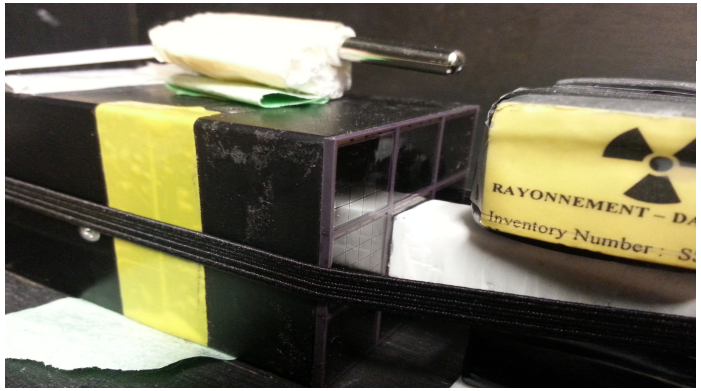
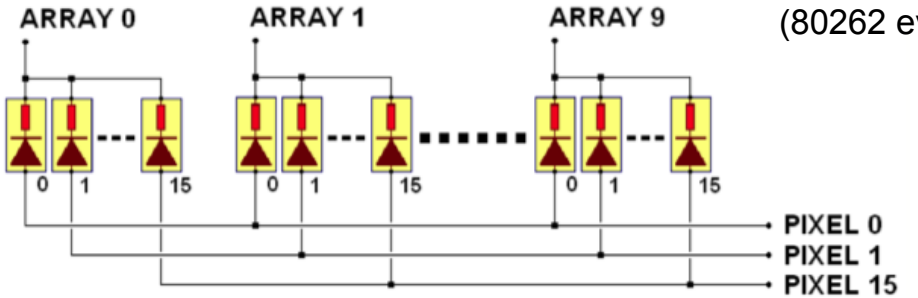
GlueX Collaboration Experiment — Jefferson Lab — NSERC CRSNG

University of Regina

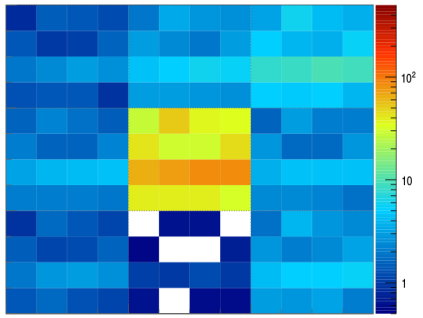
Singles

- Common plastic scintillator
- Teflon wrapped, greased
- Noise, ^{90}Sr measurements
- Characterise OLD/NEW mods

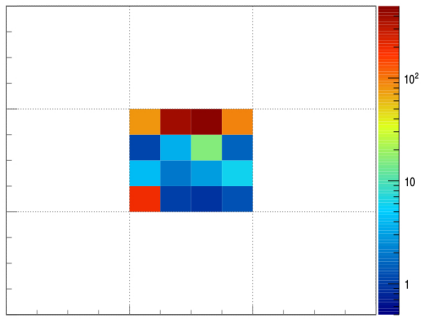




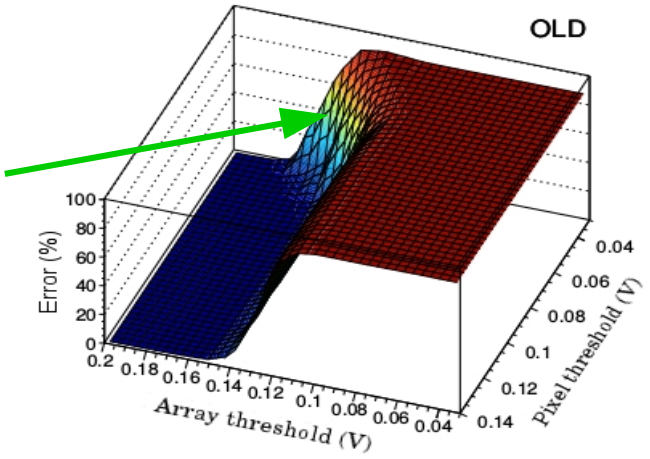
(66723 events, 60 s)

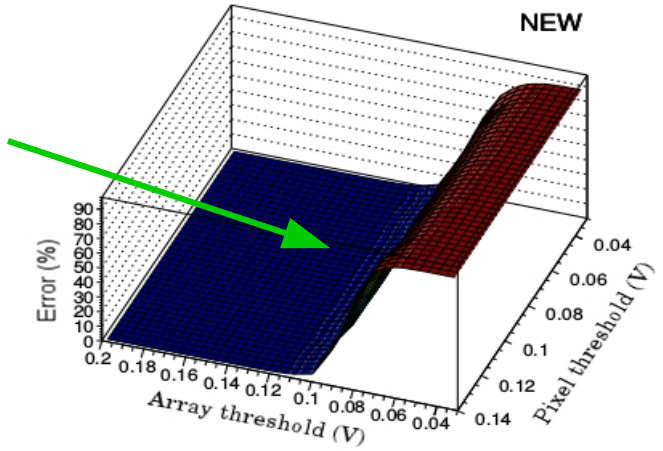


Array threshold: 0.13 V
Pixel threshold: 0.07 V



(80262 events, 60 s)





(Frequencies)

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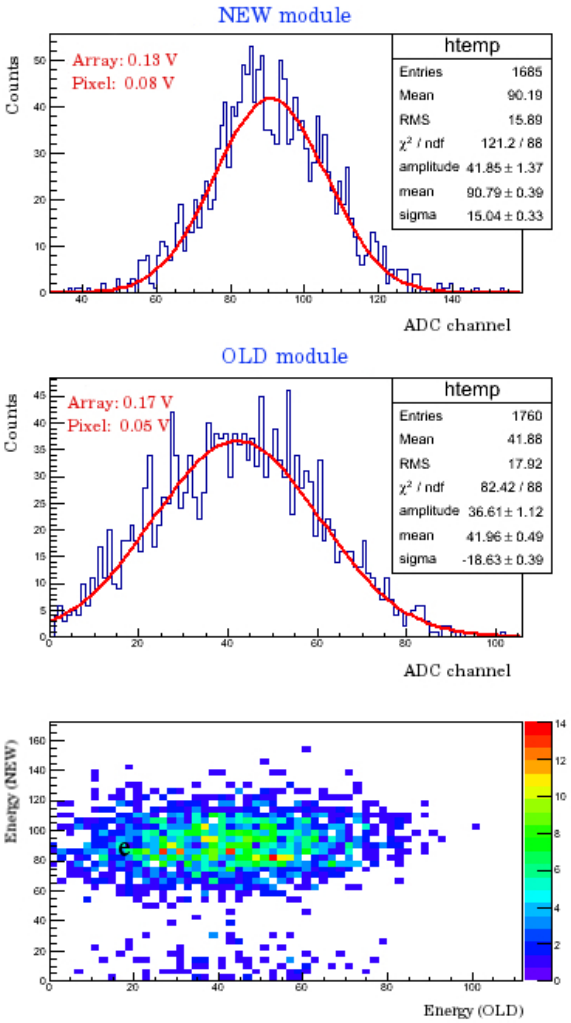
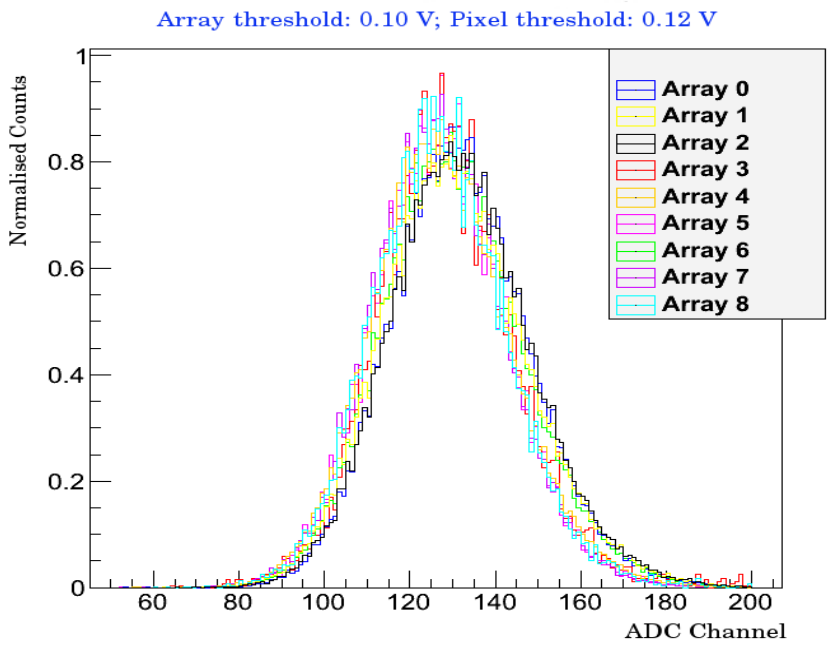
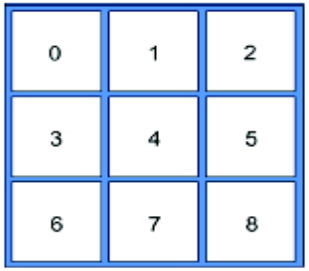
GlueX Collaboration Experiment — Jefferson Lab — NSERC CRSNG — University of Regina

Coincidence







Gain uniformity test

- Coincidence window 20 ns
- ^{90}Sr source, teflon-wrapped plastic scintillator, 600 s run time
- Multiple array/pixel thresholds
- Multiple configurations
- Array gain-uniformity tests
- Multiple sources: ^{22}Na, etc.

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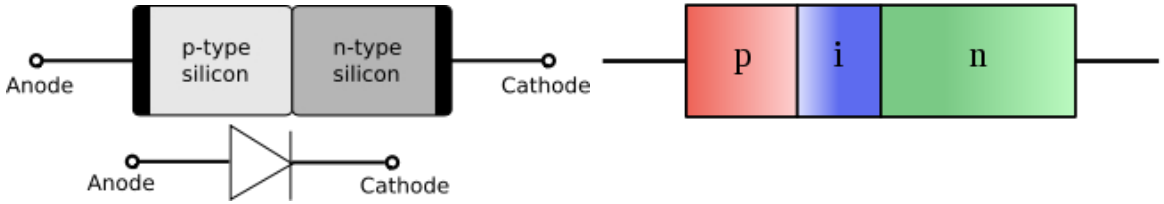
GlueX Collaboration Experiment — Jefferson Lab — NSERC CRSNG — University of Regina

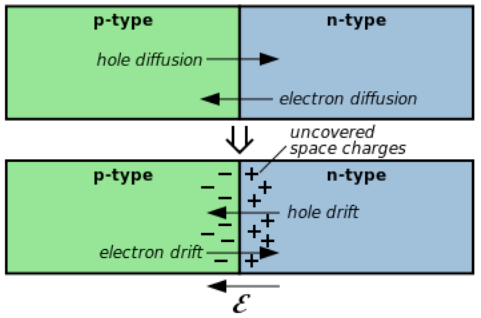
Acknowledgements

- Prof. Z. Papandreou, Dr. A. Yu. Semenov
- Sylvia Fedoruk Canadian Centre for Nuclear Innovation
- NSERC Engage
- NSERC Discovery, DOE infrastructure
- Jefferson Lab

Thank you

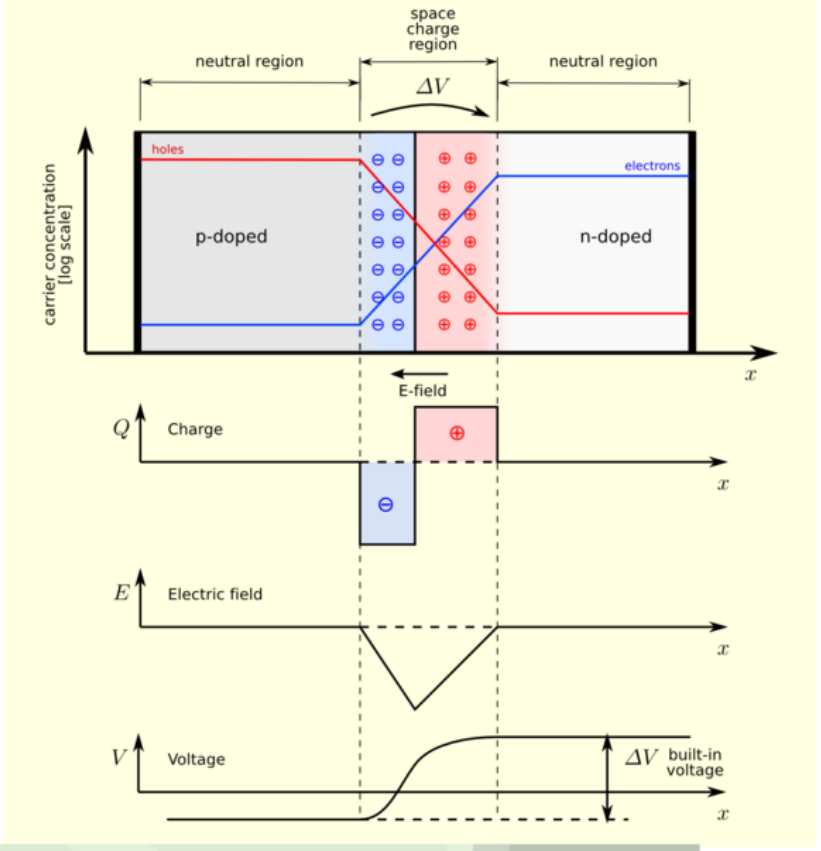
Backup Slides





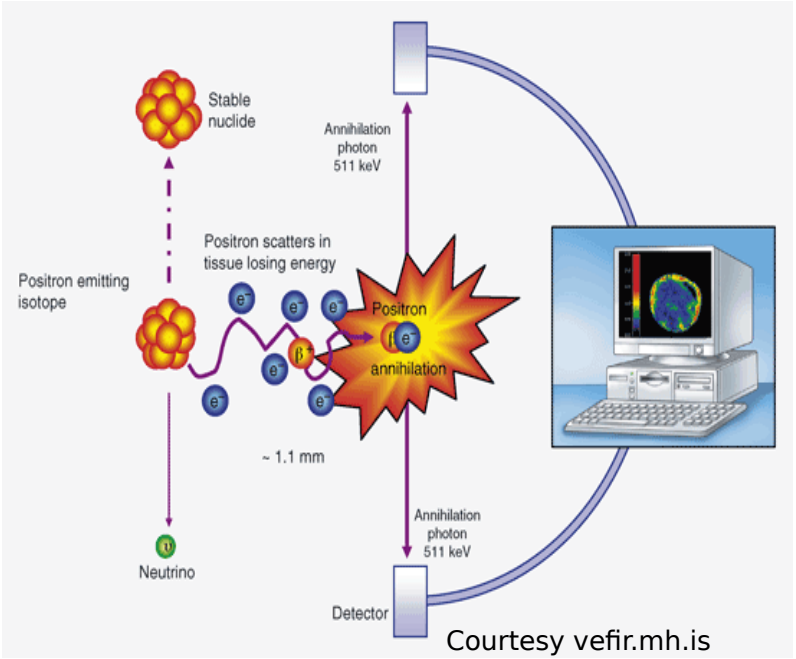
Photodiode

- **Photodiode**: p-n junction or PIN structure.
- **Depletion region**: an insulating region within a conductive, doped semiconductor material where the mobile charge carriers have diffused away.
- Incident photon can cause **inner photoelectric effect** in the depletion region.
- Charges swept from the junction by the built-in electric field of the depletion region: we have a **current**: holes move to anode, electrons to cathode.



PET in Plants

- a **nuclear imaging** technique:
  - Positron-annihilation gamma from a radio-isotope tracer introduced to plant via biologically active molecule
  - 3D image functional processes via computer algorithms
- modular gamma-ray imaging detectors to allow for different plant geometries.

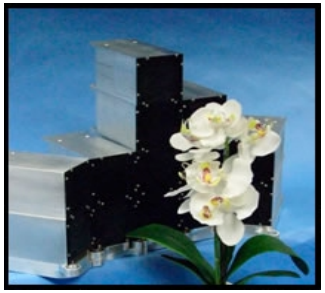


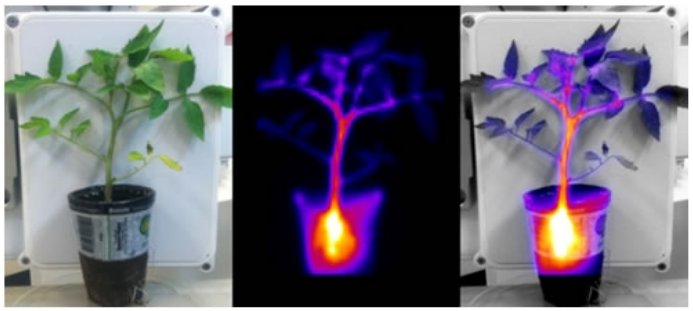
Courtesy vefir.mh.is

Tomato plant

Common tracers: ^{11}C, ^{52}Fe

MPPCs: around leaves





Courtesy Jefferson Lab

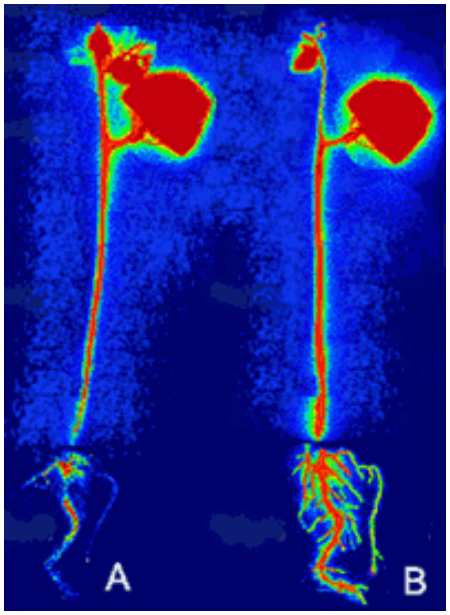
PET: Plant Imaging Opportunities

	Humans	Plants
Ethics Committee	✓	✗
GMP (Drug QA)	✓	✗
Clinical Trial	✓	✗
Radiochemical Synthesis	✓	✓
Resolution	~mm	~mm, or ~0.1mm ✓

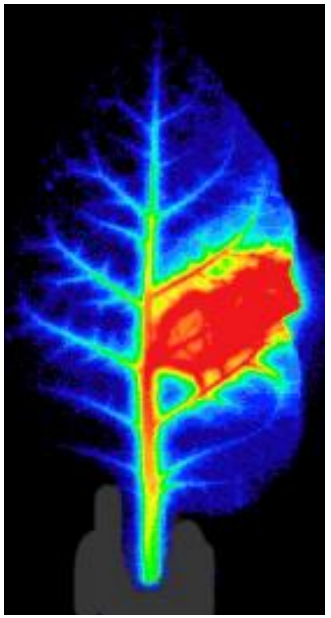
Field is where small animal imaging was ~15 years ago

Achievable Image Resolution

~ few mm



~ few tenths mm



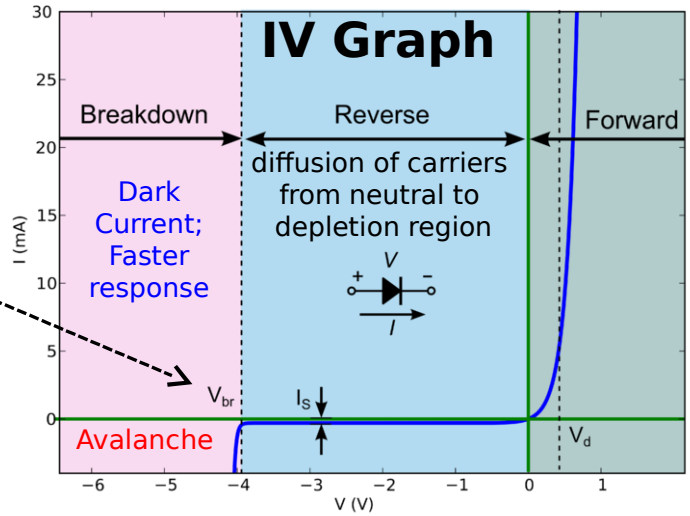
Plans and Partners

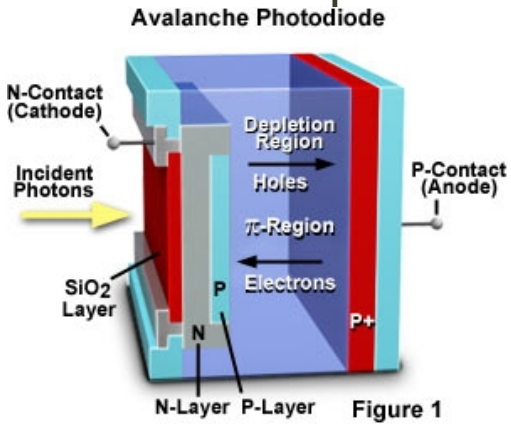
- It's stressful out there for plants:
  - Bugs chew on them
  - they get fungal infections
  - they can get too hot or cold
- JLab and Duke Phytotron Lab
  - Environmetal growth chambers
  - Study nutrients …to pollutants in the air
    - E.g. common barley plant response to higher levels of CO_2 in the atmosphere
    - E.g. stress to bugs munching on plant
  - PhytoPET and PhytoBeta systems
  - Modular, custom-fit sensors around plants, non-intrusive, reflective

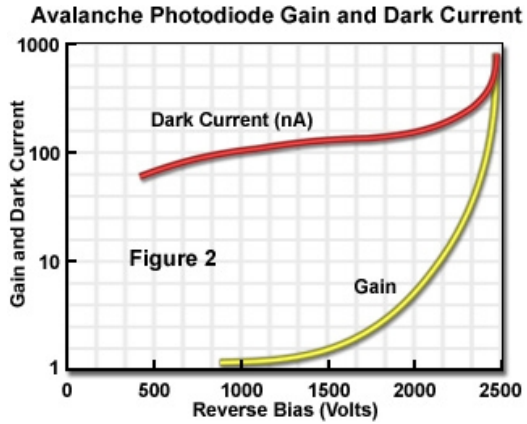
Mechanical design
Detector development
Image reconstruction
Lab implementation
Data analysis
Detector integration

MPPC Advantages & Issues

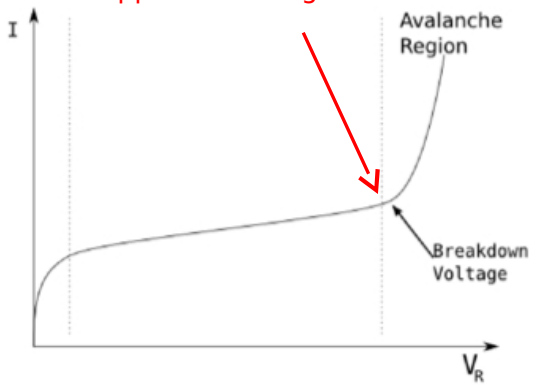
- Low bias, compact, high gain
- **Replace PMT and GM**
- Breakdown voltage
  - Needed to know gain
- Temperature dependence
  - Affects breakdown point
- Dark current (noise)
- Stable operation







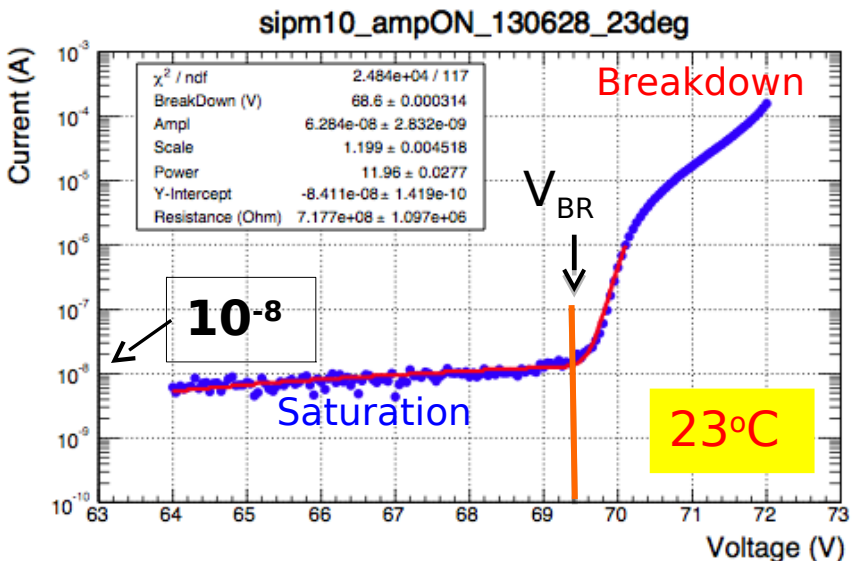
No universal definition; appearance of gain

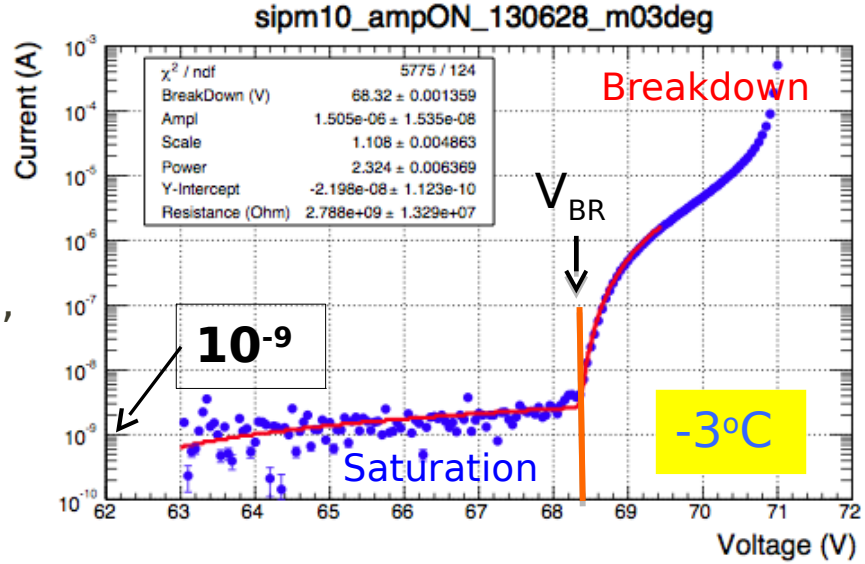


IV Curves

- Semiconductor diode's behavior in a circuit is given by its I-V graph
- Depletion zone acts like insulator
- Develop method to locate V_{BR} (large number of electrons and holes are created at, and move away from the p–n junction)

Hamamatsu





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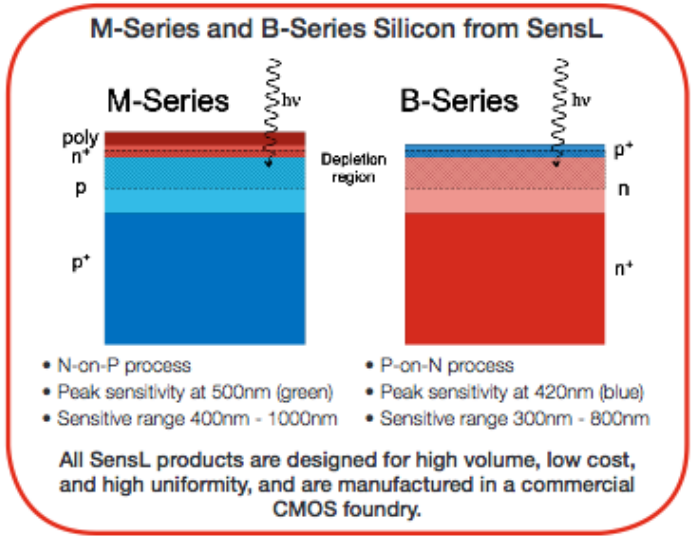
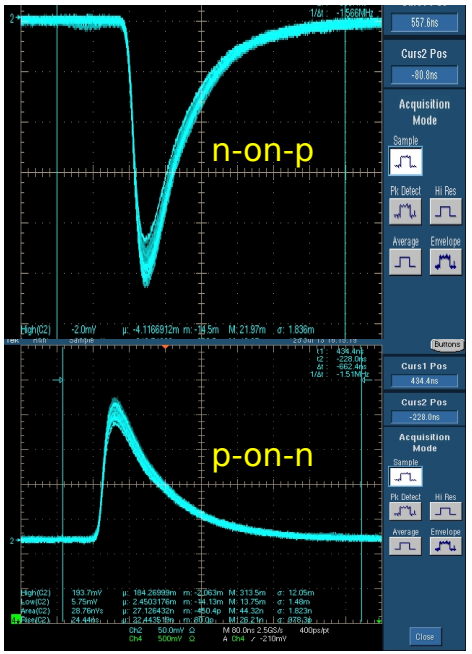
SensL

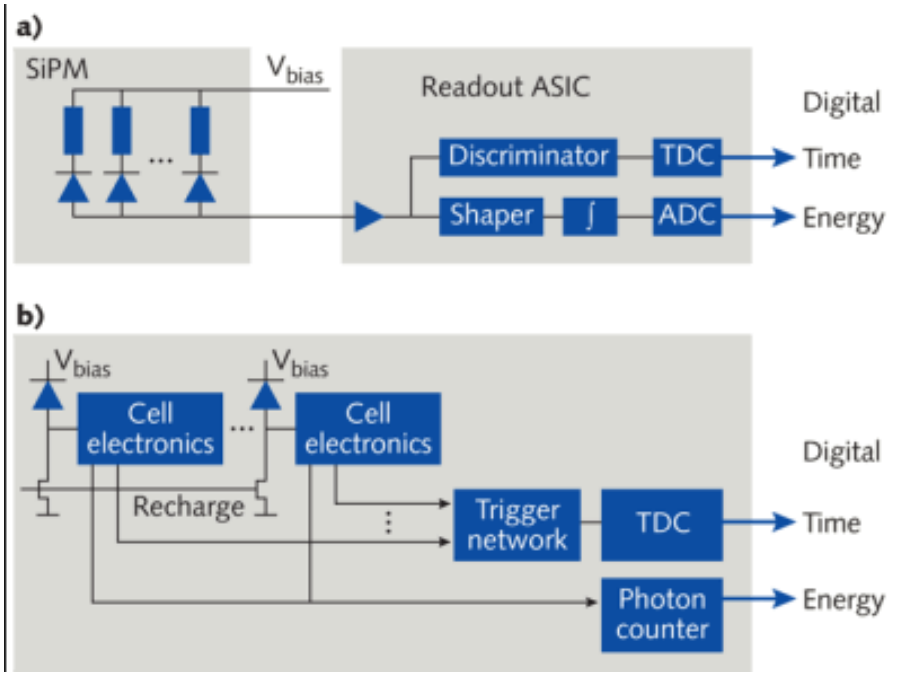
- 30-34 V operation
- 20 mV/deg factor
- Ceramic packaging
- TEC cooling
- Form factor 200µm deadspace
- 13% energy resolution at 511keV using L(Y)SO for nuclear medicine
- Gain & optical uniformity <10%
- 250ps CRT for L(Y)SO
- n-on-p and p-on-n substrates:
  - 40% PDE

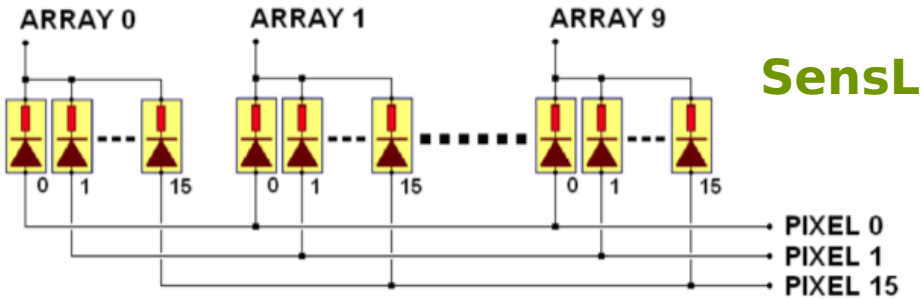




MPPC Circuits

- Amplification
- Shaping
- Discrimination
- Digitization





SensL

Scrambled Crosswire Architecture