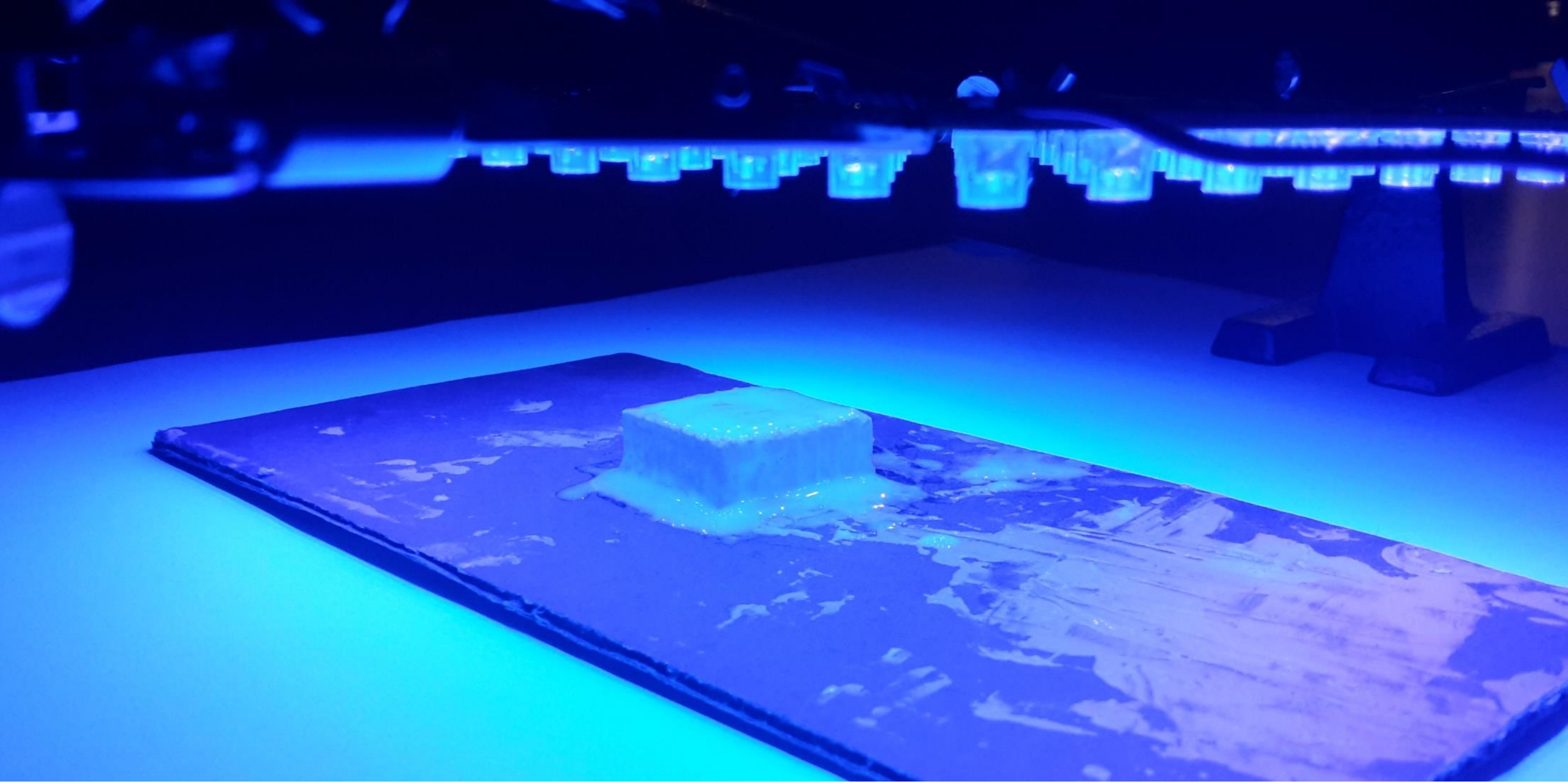

Modern Detector Concepts for Fast-Neutron Radiography

PERTINaX – **PER**iodic **T**esting by **I**maging with **N**eutrons in **a**ddition to **X**-rays

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Nuclear Engineering and Technology Transfer

RWTH AACHEN UNIVERSITY

Introduction – Motivation and Main Goals

Motivation

1. Improvement of PGNAA results via fast-neutron radiography
2. Estimation of the influence of sample geometry on γ- and neutron- selfshielding factors
3. Structural information about samples taken by neutron radiography (and radiography with γ- or X-rays)

Main Goals

1. Development of a compact fast-neutron radiography system for large volume samples (e.g. 200-l drums), combination with PGNAA
2. Main research: general concept and detector development

Example – Drum measurement system at FH Aachen University

FH AACHEN
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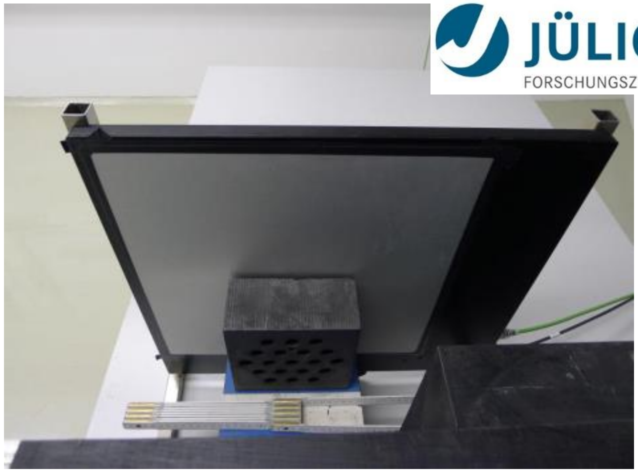
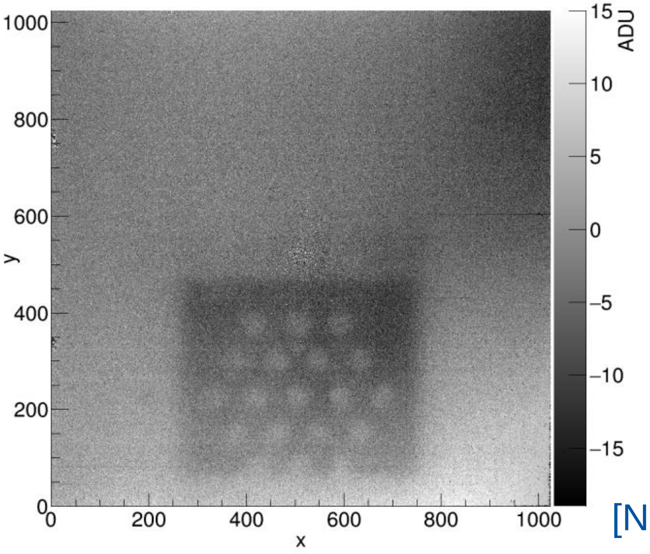
Fast neutron radiography?

- Mobile system required
- Thick objects or thermal neutron absorbers can be radiographed
- Example: mixture of materials inside of lead shielding
- Compact neutron sources usable
- Can be combined with PGNAA systems
- Low cross-sections compared to slow neutrons

Previous Research:

Neutron Imaging System for Radioactive-Waste Analysis (NISRA)





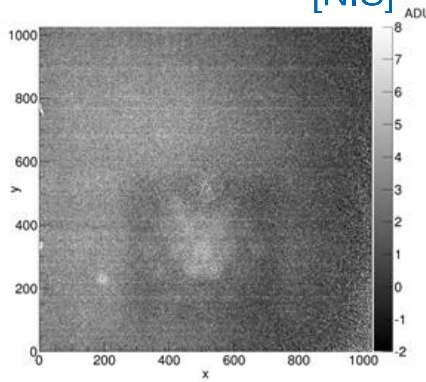
[NIS]

Previous research: aSi-Flatpanel Detector – Measurements / Results @ NISRA

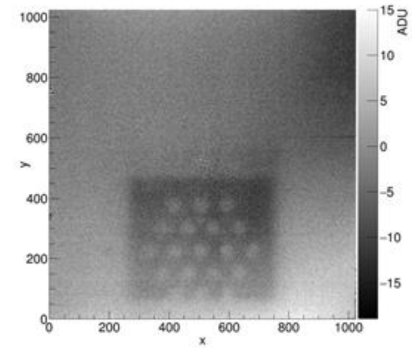
Scintillator plate EJ-260

Scintillating fibers array

[NIS]



[NIS]



JÜLICH FORSCHUNGSZENTRUM

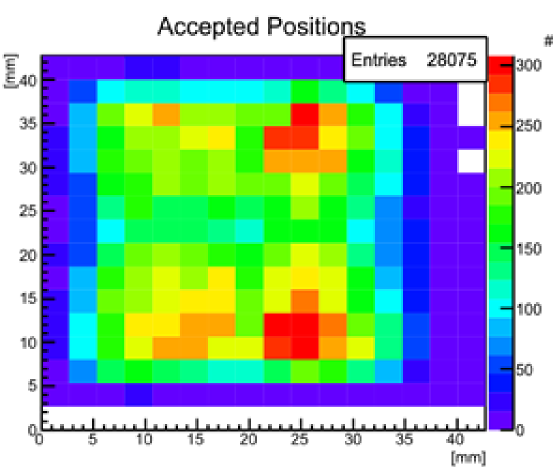
- 3 mm thick plastic scintillator plate (EJ-200/EJ-260)
- Low resolution
- Low signal
- High noise

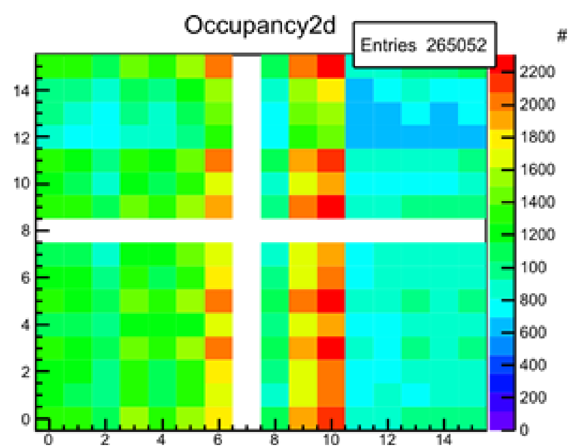
- 8 mm thick bundles made out of scintillating fibers (SCSF-3HF)
- Increased resolution
- Increased signal
- High noise

Previous research: WSF Scintillator Module @ NISRA

- Fast-Neutron scintillator EJ-410 based on ZnS(Ag) embedded in hydrogenous polymer matrix
- Threshold energy needed to cause scintillation
- Resolution of the detector system not high enough to evaluate the scintillator properly

[ELJ]



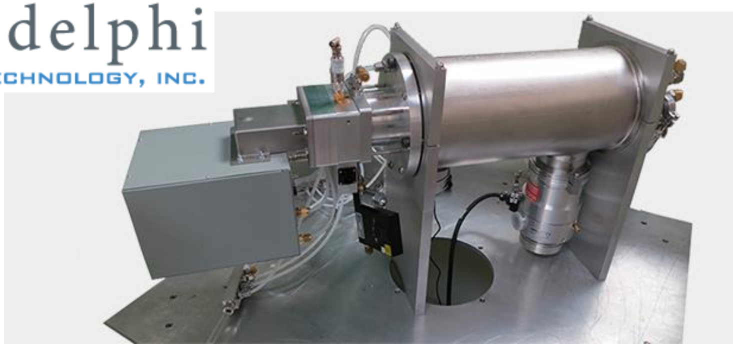


[NIS]

Fast Neutron Sources

Neutron Generators | Radioisotopes

adelphi
TECHNOLOGY, INC.



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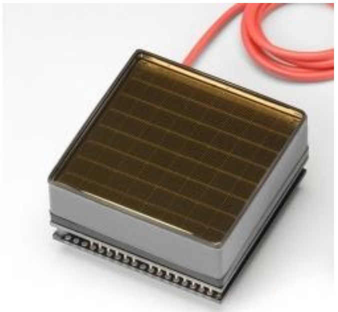
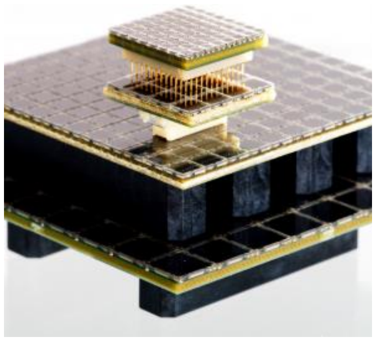
- Discrete neutron spectra
- Negligible γ-yield
- Neutron emission only when operated
- Neutron emission up to 10^{10} n/s
- Neutron energy 2.45 MeV (DD)

- Continuous neutron spectra
- High γ-yield
- Permanent emission of radiation
- Neutron emission up to 10^{7} n/s
- Neutron energies up to 10 MeV

Detectors for Readout

Flatpanel Detectors	MA-Photomultiplier Tubes	Silicon Photomultipliers
 [NIS]	 [HAM]	 [SEN]

Flatpanel Detectors

- Used in medicine / radiography
- High spatial resolution large area
- Easy to use
- Electronics on board, can‘t be changed
- No PSD possible

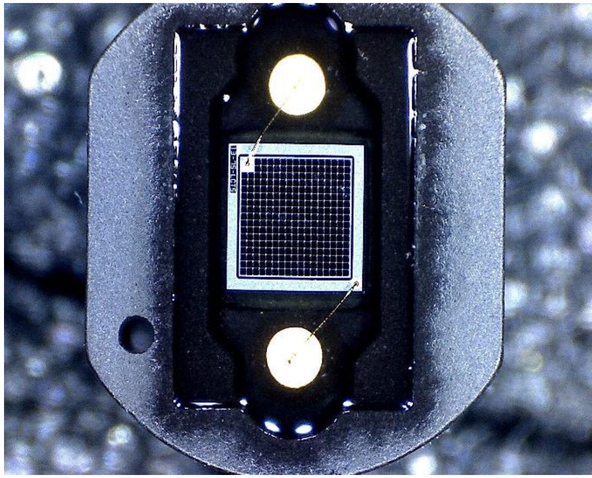
MA-Photomultiplier Tubes

- Used in medicine with scintillator arrays
- Large pixels
- Fragile
- Electronics can be selected
- Allow PSD

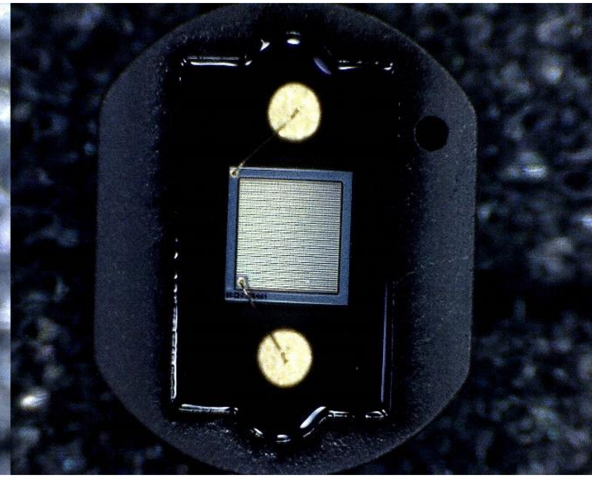
Silicon Photomultipliers

- Used in medicine / high energy particle physics
- Pixel size comparable to MA-PMTs
- Electronics can be selected
- Allow PSD

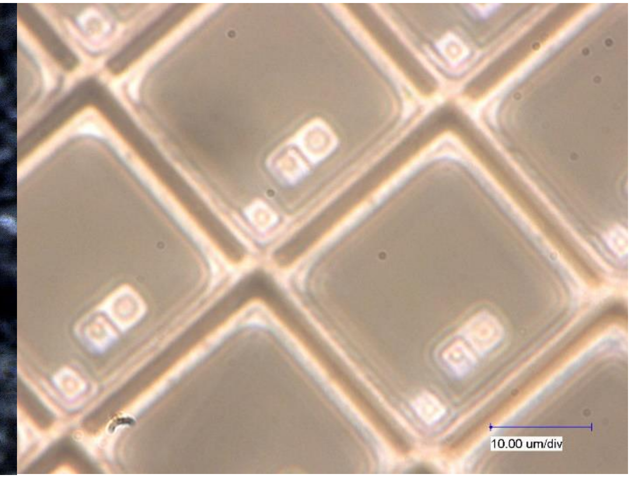
Silicon Photomultipliers (SiPM)

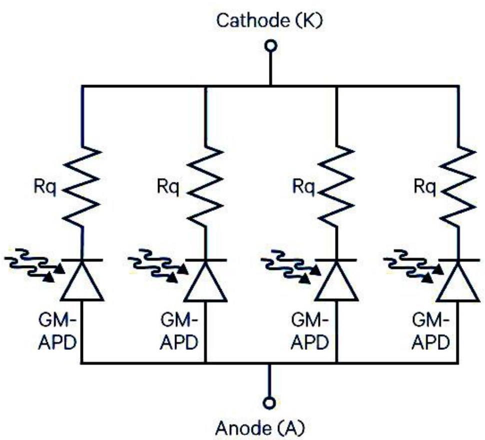


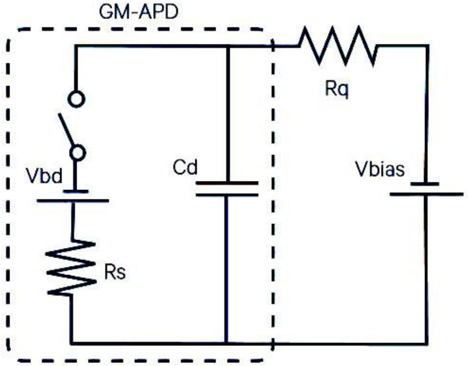
Hamamatsu
S-13360-1325CS



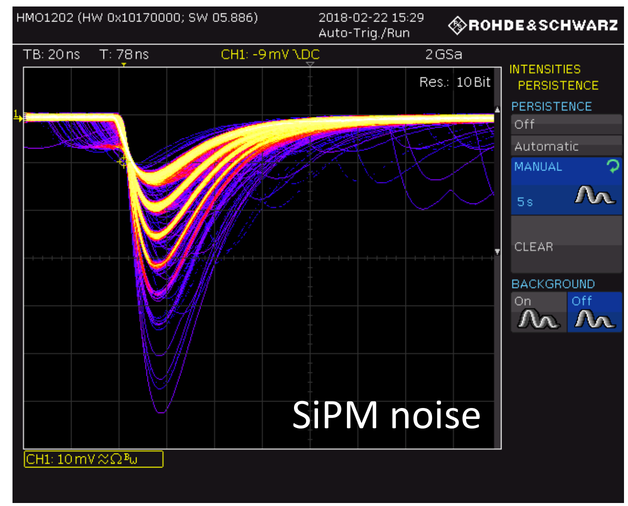
Hamamatsu
S-13360-1375CS





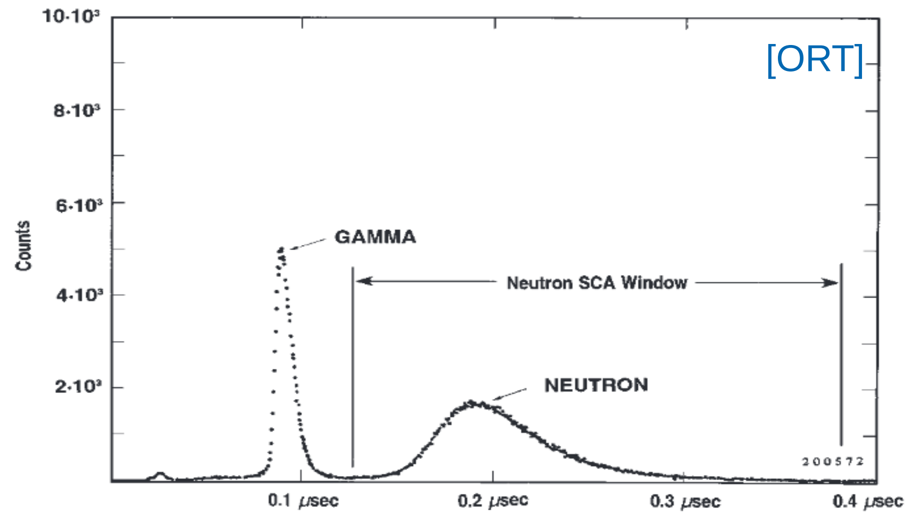


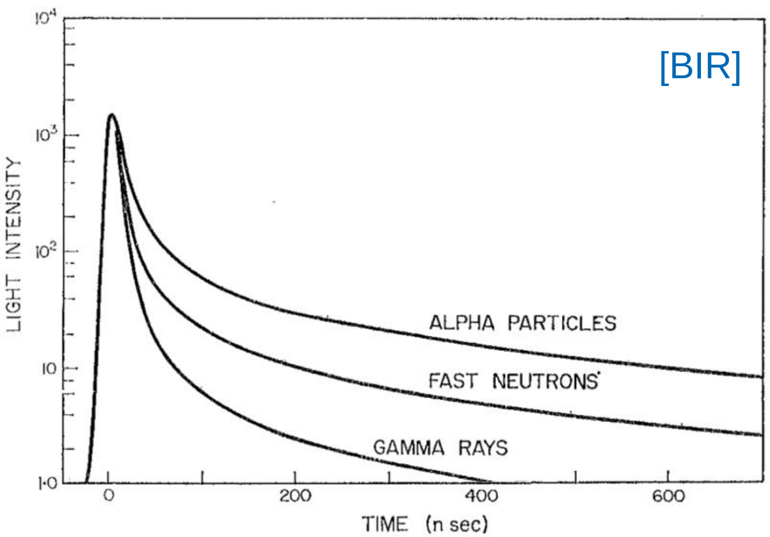
[FST]

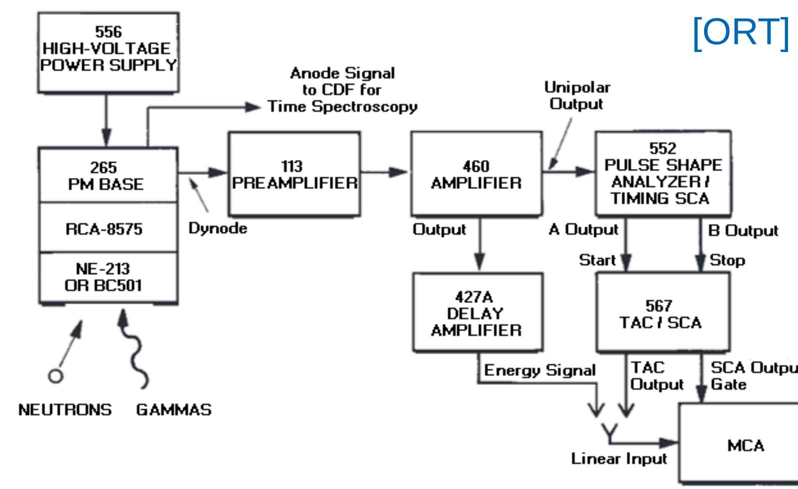


Pulse-Shape-Discrimination

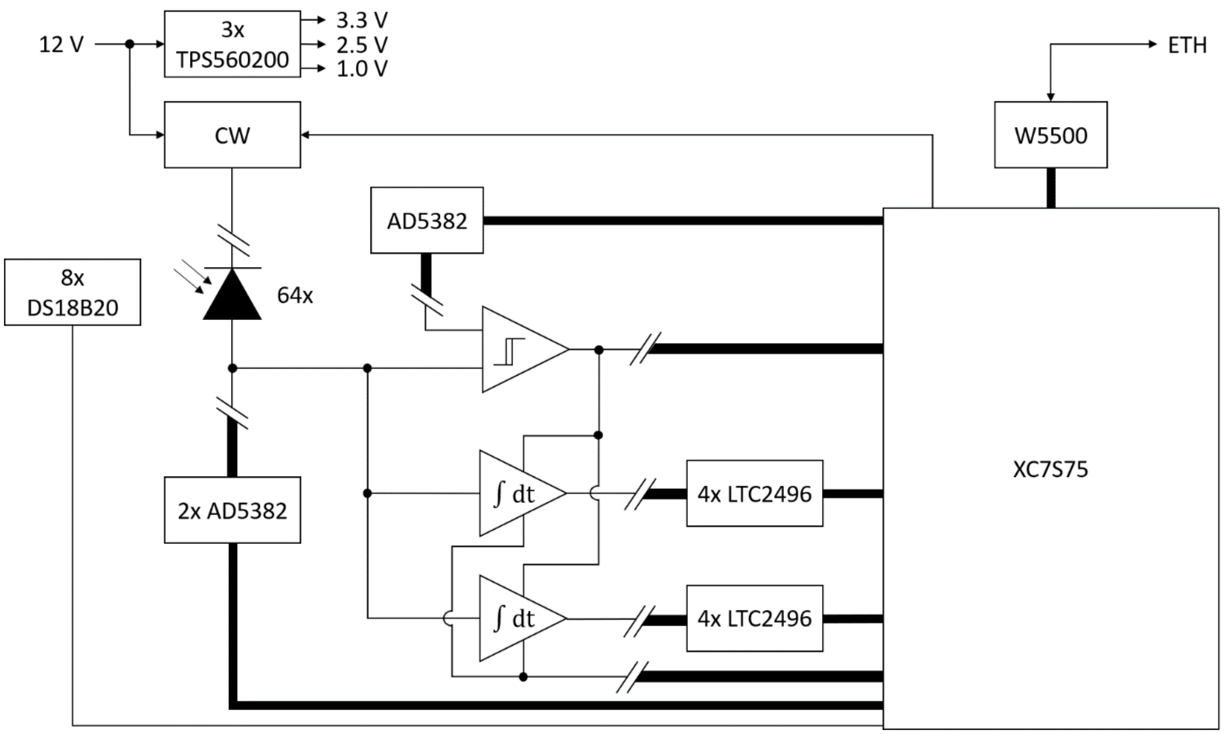
- Suitable combinations of scintillators and detectors for readout allow PSD
- PSD can be used to separate neutrons from γ-radiation
- Reduction of γ-fogging
- Solution via FPGA
- Cost saving solution ?







Idea for SiPM Front End Electronics, 8x8 readout



- Shared V_C
- Adaption for V_{BR} via V_A (DAC - AD5382, 14bit, 32ch)
- Temperature compensation (DS18B20, one-wire)
- Threshold via DAC through fast comparator
- Two time constants (integral)
- Digitization of the integrated signal via ADC (LTC2496?)

Readout and control via Xilinx XC7575

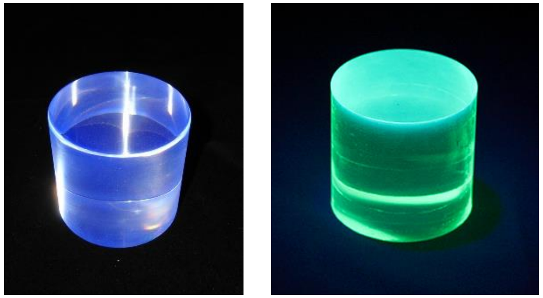
Communication via Ethernet (W5500)

Scintillators suitable for PSD

- Stilbene-(Compound)-Scintillators
  (PSD, high efficiency)
  → 390 nm

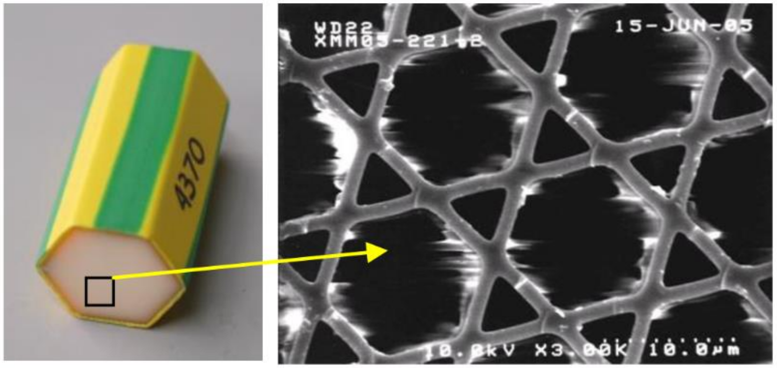
[MOR]

- Plastic Scintillators
  (EJ-299-33A/34, EJ-276/G)
  → 425 nm vs. 490 nm



[EJP]

- Liquid scintillators
  (PSD, light guided via matrix)
  → 425 nm for EJ-301



[LLN]

- Optimize thickness, mounting
  (better efficiency)

Outlook

- Finalize schematics (front end)
- Circuit simulation, manufacturing, revisions (front end)
- Programming and testing of the FPGA
- Manufacturing of the scintillators
- Coupling SiPM/scintillator
- Evaluation

Picture Credits

[NIS] NISRA-Abschlussbericht

[HAM] https://www.hamamatsu.com/eu/en/product/alpha/P/3002/H8711-20/index.html

[SEN] http://sensl.com/products/sipm-arrays/

[ELJ] http://www.eljentechnology.com/index.php/products/neutron-detectors/ej-410

[EJP] https://eljentechnology.com/products/plastic-scintillators/ej-276

[LLN] Lawrence Livermore National Laboratory – www.llnl.gov

[MOR] I. Mor et al. – Fast-neutron imaging spectrometer based on liquid scintillator loaded capillaries

[ORT] Ortec Modulare Pulse-Processing Electronic Catalog

[BIR] J.B. Birks, The Theory and Practice of Scintillation Counting

[FST] First Sensor: Introduction to Silicon Photomultipliers (2016)

Contact & Discussion

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