Development of neutron detectors
with solid converters and Timepix3 readout

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Highly granular gaseous detectors

Novel detectors with improved capabilities to improve the potential of future instruments

Expertise on Timepix3 readout with Scalable Readout Systems

Part of Research and Technology Center Detector Physics (FTD)
Research and Technology Center for Detector Physics

- Forschungs- und Technologie-Zentrum Detektorphysik (FTD)
- Studies on the latest detector technologies for the detection of radiation and particles
- Lab Space: 2010m²
- Nano-micro fabrications, bonding machines, inspection devices, SEM etc.
Team

Prof. Dr. Klaus Desch

Dr. Jochen Kaminski

Dr. Michael Lupberger

Dr. Markus Köhli

Dr. Saime Gürbüz

Divya Pal

Thomas Block

Markus Gruber

+ Former BSc. and MSc. students who graduated...
Novel neutron detectors
(@University of Bonn)

<table>
<thead>
<tr>
<th>Element</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$He</td>
<td>$^3$He + n $\rightarrow$ $^3$H + p + 764 keV</td>
</tr>
<tr>
<td>$^6$Li</td>
<td>$^6$Li + n $\rightarrow$ $^3$H + $\alpha$ + 4.78 MeV</td>
</tr>
<tr>
<td>$^{10}$B</td>
<td>$^{10}$B + n $\rightarrow$ $^7$Li + $\alpha$ + 2.79 MeV (6%)</td>
</tr>
<tr>
<td>$^{10}$B</td>
<td>$^{10}$B + n $\rightarrow$ $^7$Li* + $\alpha$ + 2.31 MeV (94%)</td>
</tr>
<tr>
<td>$^{113}$Cd</td>
<td>$^{113}$Cd + n $\rightarrow$ $^{114}$Cd + $\gamma$ + 9.04 MeV</td>
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<tr>
<td>$^{155}$Gd</td>
<td>$^{155}$Gd + n $\rightarrow$ $^{156}$Gd + $\gamma$ + e$^-$ (30–180) keV</td>
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<tr>
<td>$^{235}$U</td>
<td>$^{235}$U + n $\rightarrow$ fission fragments + 160 MeV</td>
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Solid converters

Scalable Readout System
Scalable Readout System (SRS)

- FPGA Board developed by the RD51 Collaboration
- Scalable from a single front end board to a mid-size experiment.
  - Larger user community
  - Several front-end chips implemented
  - Comparably low cost per channel


M. Lupberger et al. “Particle Physics Readout Electronics and Novel Detector Technologies for Neutron Science” NIMA 1046 (2023) 167753
Novel neutron detectors

Neutron Micro Channel Plate (nMCP)

Neutron Time Projection Chamber (nTPC)

Gaseous Electron Multiplier (GEM) based neutron detector (nGEM)
Novel neutron detectors

- Neutron Micro Channel Plate (nMCP)
- Neutron Time Projection Chamber (nTPC)
- GEM based neutron detector
Neutron Micro Channel Plate (nMCP)

**Experimental setup:**

- **B and Gd enriched Micro Channel Plates (MCP):** Converts neutrons to electrons and produces the signal.

- **Quad-Timepix3 ASIC:** Electrons are captured and data readout.

**Aim:** Combining features of the Timepix3 with the efficiency and spatial resolution of neutron sensitive MCP.

Quartz entrance window

$^{10}\text{B and Gd loaded MCP}$

Readout with 4 Timepix3
Neutron Micro Channel Plate (nMCP)

Experimental setup:

- n beam
- object
- detector
- 10B and Gd loaded MCP
- Quarz entrance window
- Readout with 4 Timepix3

Neutron Sensitive MCP with optical readout by S. Pinto

Neutron Sensitive MCP with timepix readout by A. Tremsin

References:

10.1016/j.nima.2009.01.137
Neutron Micro Channel Plate (nMCP)

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8 μm pore diameter
10 μm pore spacing

Design

Experimental setup:

- Object
- Detector
- Neutron beam \(n_{\text{beam}}\)
- Quarz entrance window
- \(^{10}\text{B}\) and \(\text{Gd}\) loaded MCP
- Readout with 4 Timepix3

Flanges and insulators machined in our mechanical workshop
Timepix3 ASIC

• Charge sensitive pixel in 130 nm CMOS technology
• Quad Timepix3 with an active area of 7.9 cm²
• Each ASIC: 256 × 256 pixels (55 µm pixel pitch)
• Advantages:
  • Simultaneous charge and time measurement
  • Time resolution: 1.56 ns
  • Zero suppression on chip
  • Self-triggered, continuous data-driven readout
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Better resolution in time & continuous readout
-> Time dependent imaging i.e. neutron radiography
nMCP current status and plans

- All the mechanical components are ready and tested.
- Vacuum level of $10^{-7}$ mbar is achieved.
- High voltage tests are finished.
- Readout electronic designs are ongoing.
- Readout software mostly ready with multi-chip support developments ongoing.
Novel neutron detectors

- Neutron Micro Channel Plate (nMCP)
- Neutron Time Projection Chamber (nTPC)
- GEM based neutron detector
Preliminary study

- 8 GridPixes based on Timepix
- GridPixes at a distance of 3.8 cm
- Spatial resolution < 100 µm

Figure 5: The event display showing exemplarily a collection of neutron conversions on the full Octoboard with Ar:CO₂ 80:20 at 350 V grid voltage. Two of the chips are disabled.
nTPC detector concept

Side wall:
- ~1 μm $^{10}$B layer
- 20 μm scintillator
- Quarz light guide
- Wavelength shifting fibers
- SiPMs for reading out WFSLs
- Reflector

$^{10}$B + n → $^7$Li + α + 2.79 MeV (6%)
$^{10}$B + n → $^7$Li* + α + 2.31 MeV (94%)
nTPC detector concept

### Mechanical Construction
- Detector is designed and built
- Field cage is ready
- Active area 10cm x 10cm
nTPC detector concept

Trigger

- SiPM feeding the Trigger Board
- GridPix readout
GridPix

- Invented and developed by Nikhef and University of Twente
- Used in CAST (up to seven Timepix), proposed for ILD TPC (ILC), EIC TPC and IAXO with Timepix3.
nTPC current status and plans

- Spatial resolution $< 100 \mu m$ is aimed for.
- Cosmic muon tests proves very low track distortion close to the field cage.
- Currently: Implementing boron layers.
- Plan to increase the number of the layers for better neutron detection efficiency.
Novel neutron detectors

Neutron Micro Channel Plate (nMCP)

Neutron Time Projection Chamber (nTPC)

GEM based neutron detector
GEM based neutron detector concept

• Similar to the CASCADE detector used at RESEDA/MIRA instrument (MIEZE) at the FRM II

• Our detector:
  • Independent layers, each with own cathode, coating and readout
  • Thin BC$_4$ coating $\implies$ Many layers needed
  • Increase the number of independent layers
nGEM current status and plans

- A first test layer is being assembled and can be equipped with readout electronics.
- Active area: $10 \times 10 \text{ cm}^2$ and plan to upgrade to $30 \times 30 \text{ cm}^2$ in future.
- Main challenge: significantly large number of electronic channels.
- VMM3a-based version of the Scalable Readout System (SRS) of the RD51 collaboration.
- PhD position available.

<table>
<thead>
<tr>
<th>Detectors</th>
<th>Readout Electronics</th>
<th>Active Area</th>
<th>Expected resolution</th>
<th>Benefits</th>
<th>Challenges</th>
<th>Possible Fields of Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timepix3 + SRS</td>
<td>2.8cm x 2.8cm</td>
<td>O(10 μm)</td>
<td>High position and time resolution</td>
<td>Vacuum requirements</td>
<td>Neutron imaging and radiography</td>
<td></td>
</tr>
<tr>
<td>GridPix + SRS</td>
<td>10cm x 10cm</td>
<td>O(10-100 μm)</td>
<td>Good position and time resolution</td>
<td>Trigger setup</td>
<td>Neutron scattering experiments</td>
<td></td>
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<tr>
<td>VMM3a + SRS</td>
<td>10cm x 10cm (30cm x 30cm)</td>
<td>O(100 μm)</td>
<td>High Rate (Large Area)</td>
<td>Large number of electronic channels</td>
<td>Neutron scattering experiments</td>
<td></td>
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Looking forward for future collaborations!