ESS Neutron Scattering Facility

Linear Accelerator
2 GeV
3 ms Pulse
62.5 mA
# ESS Instrumentation

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Detector area [m²]</th>
<th>Wavelength range [Å]</th>
<th>Time resolution [µs]</th>
<th>Spatial resolution [mm]</th>
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<tr>
<td>Multi-purpose imaging</td>
<td>0.5</td>
<td>1 - 20</td>
<td>1</td>
<td>0.001 - 0.5</td>
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<tr>
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<td>Broad-band small sample SANS</td>
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<td>2 - 20</td>
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<td>Surface scattering</td>
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<td>4 - 20</td>
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<td>Horizontal reflectometer</td>
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<td>5 - 30</td>
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<tr>
<td>Vertical reflectometer</td>
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<tr>
<td>Thermal powder diffractometer</td>
<td>20</td>
<td>0.6 - 6</td>
<td>&lt; 10</td>
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<tr>
<td>Bi-spectral powder diffractometer</td>
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<td>0.8 - 10</td>
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<td>Vibrational spectroscopy</td>
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<td>Wide-angle spin echo</td>
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<td>2 - 15</td>
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## ESS Instrumentation

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<th>(^{10}\text{B thin films})</th>
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ESS TDR 2013
Neutron Examples

Neutron Examples

Neutron Examples

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[1]
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[1] The Multi-Blade Detector, ILL Grenoble
[3] PSI, neutron radiography
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<td></td>
<td>Resolution</td>
<td>+</td>
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1. The Multi-Blade Detector, ILL Grenoble
2. (MCP) [www.neutrondetector.com](http://www.neutrondetector.com)
3. PSI, neutron radiography
The MediPix Family

Hybrid-Detector Concept:

MediPix 1
- active area 1,2 cm²
- matrix of 64 x 64 pixels
- 1,6 M transistors/chip
- 170 x 170 μm² per pixel
- 1 discriminator per pixel
- 15-bit counter
- threshold (whole chip): ≈ 1500 e⁻

MediPix 2
- 1,4 x 1,4 cm²
- matrix of 256 x 256 pixels
- 0.25 μm CMOS technology (33M transistors/chip)
- 55 x 55 μm² per pixel
- serial or parallel I/O (min. readout time of full matrix 266 μs)
- preamplifier/shaper (t-rise ≈ 150 ns)
- 2 discriminators (lower and upper threshold)
- 14-bit counter
- threshold (whole chip): ≈ 1000 e⁻

TimePix

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Journal/Conference</th>
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<td>2003</td>
<td>Single neutron pixel detector based on Medipix-1 device</td>
<td>(IEEE)</td>
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<td>2005</td>
<td>Spatial resolution of Medipix-2 device as neutron pixel detector</td>
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<td>2004</td>
<td>Properties of the single neutron pixel detector based on the Medipix-1</td>
<td>(NIMA)</td>
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<td>Properties of neutron pixel detector based on Medipix-2 device</td>
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<td>2006</td>
<td>Neutron imaging with Medipix-2 chip and a coated sensor</td>
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<td>2008</td>
<td>Detection of fast neutrons with the Medipix-2 pixel detector</td>
<td>(IEEE)</td>
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<td>2008</td>
<td>High-resolution UV, alpha and neutron imaging with the Timepix CMOS readout</td>
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<td>Neutron Detector Based on Timepix Pixel Device with Micrometer Spatial Resolution</td>
<td>(SPIE)</td>
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<td>2009</td>
<td>A coated pixel device TimePix with micron spatial resolution for UCN detection</td>
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<td>2009</td>
<td>High-resolution neutron radiography with microchannel plates: Proof-of-principle experiments at PSI</td>
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<td>Fast neutron detector based on TimePix pixel device with micrometer spatial resolution</td>
<td>(IEEE)</td>
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<td>2010</td>
<td>Monte-Carlo simulation of fast neutron detection using double-scatter events in plastic scintillator and Timepix</td>
<td>(IEEE)</td>
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<td>2011</td>
<td>Design, Implementation and First Measurements with the Medipix Neutron Camera in CMS</td>
<td>(arxiv)</td>
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<td>Detection of fast neutrons with particle tracking detector Timepix combined with plastic scintillator</td>
<td>(Rad. Meas.)</td>
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<td>High-resolution strain mapping through time-of-flight neutron transmission diffraction with a microchannel plate neutron counting detector</td>
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<td>2012</td>
<td>A highly miniaturized and sensitive thermal neutron detector for space applications</td>
<td>(AIP)</td>
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<td>2012</td>
<td>High resolution neutron counting detectors with microchannel plates and their applications in neutron radiography, diffraction and resonance absorption imaging</td>
<td>(Neutron News)</td>
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<td>2012</td>
<td>Neutron radiography with sub-15 μm resolution through event centroiding</td>
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<td>Position sensitive detection of neutrons in high radiation background field</td>
<td>(Rev. Sci. Instrum.)</td>
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<td>2014</td>
<td>Characterization of Timepix Detector Coated with 1084C Film for High Resolution Neutron Imaging</td>
<td>(Proc. ICATPP)</td>
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<td>Dosimetry measurements using Timepix in mixed radiation fields induced by heavy ions; comparison with standard dosimetry methods</td>
<td>(J. Radiat. Res.)</td>
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<td>Time-of-flight measurement of fast neutrons with Timepix detectors</td>
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<td>Time-resolved neutron imaging at ANTARES cold neutron beamline</td>
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<td>2016</td>
<td>Development and characterization of high-resolution neutron pixel detectors based on Timepix read-out chips</td>
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<td>Energy-Resolved Neutron Imaging for Reconstruction of Strain Introduced by Cold Working</td>
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<td>Towards high-resolution neutron imaging on IMAT</td>
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The Time Projection Chamber

The Neutron TPC Trigger

Neutron collision with a boron nucleus ($^{10}\text{B}$)
The Neutron TPC Trigger
The Neutron TPC Trigger
The Neutron TPC Trigger

Neutron → $^{10}\text{B}$ → $^{11}\text{B}^*$ → $^4\text{He}^{2+}$

- $0.48\text{ MeV} \gamma$
- $0.84\text{ MeV}$
- $1.47\text{ MeV}$

Track & Trigger
The Neutron TPC

Diagram showing the components of a neutron time projection chamber (TPC):
- **Trigger**
  - Lightguide
  - Reflector
- **Converter**
  - Boron
  - Scintillator
- **Track**
  - Gas
The Neutron TPC

- Trigger
- Converter
- Track

- Lightguide
- Boron
- Gas

- Reflector
- Scintillator

$n$
The Neutron TPC
The Neutron TPC

Diagram showing the components of a Neutron Time Projection Chamber (TPC): Trigger, Converter, and Track. Key elements include Lightguide, Reflector, Scintillator, Boron, and Gas. Elements labeled with $R_n$, $R_{\text{He}}$, $R_{\text{Li}}$, and $R_{\text{Gas}}$.
The Detector
The Neutron TPC

TimePix3
(Ingrid)

Photon Sensor
The Neutron TPC: BODELAIRE
Field Cage Design

- Boron Carbide
- Boron Nitride
- Boron

Diagram showing the layers of materials:
- Reflector
- Lightguide
- Scintillator
- Reflector
Field Cage Design

Simulation: Electric Field Homogeneity
The TimePix Chip
The TimePix Chip

- 256 × 256 pixels @ 55 × 55 μm²
- 1.4 × 1.4 cm²
- 40 MHz clock
- ENC ca. 90 e⁻
The TimePix Chip

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The TimePix Chip

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- ENC ca. 90 e⁻

Modes:
- Time Over Threshold (TOT)
- Time of Arrival (ToA)
- Geiger Counter
The TimePix Chip

- 256 × 256 pixels @ 55 × 55 μm²
- 1.4 × 1.4 cm²
- 40 MHz clock
- ENC ca. 90 e⁻

Modes:
- Time Over Threshold (TOT)
- Time of Arrival (ToA)
- Geiger Counter
TimePix Readout System

Octoboard:

[2] H. Muller, RD51 SRS Status December 2016, CERN
TimePix Readout System

Octoboard:

- Ethernet to PC
- FEC voltage supply
- Front end card incl. FPGA
- Chip voltage supply
- VHDCI cable
- Adapter card
- Timepix chip
- Intermediate board

[2] H. Muller, RD51 SRS Status December 2016, CERN
LCTPC Event Display

Detecting Neutrons
Test Detector

- Boron coated cathode
- Anode
- GridPix chips
Test Detector

- Boron coated cathode
- Anode
- GridPix chips
Neutron Conversion Tracks
Neutron Conversion Tracks

5-23 % Time Pixel (Random Pattern)
Event Example: Lithium
Event Example: Helium

![Spatial Projection and Time Projection](image)
Analysis and Results
Energy Loss in Gas

Energy loss of conversion ions in ArCO$_2$(70:30)

- Helium 1.50 MeV
- Lithium 1.00 MeV
Energy Loss in Gas

Energy loss of conversion ions in ArCO₂(70:30)

- Helium 1.50 MeV
- Lithium 1.00 MeV

Sim:Li

Sim:He
Energy Loss in Gas

Energy loss of conversion ions in ArCO₂(70:30)

- Helium 1.50 MeV
- Lithium 1.00 MeV

Spatial Projection

Sim:Li
Sim:He
Energy Spectrum

Simulation: 1 μm Layer of Boron

Folded with 25 % FWHM
Energy Spectrum

Simulation: 1 μm Layer of Boron

Folded with 25 % FWHM

TOT Spectrum (fiducialized)
Spatial Resolution

Boron Sheet
Spatial Resolution

1 cm
Spatial Resolution

Boron Sheet

1 cm
Spatial Resolution

Edge Projection

\[ \chi^2 / \text{ndf} \] 614.6 / 621
Amplitude 40.79 ± 0.29
Width 1.728 ± 0.062

1 cm
Spatial Resolution

Edge Projection

\[ \chi^2 / \text{ndf} = 614.6 / 621 \]
Amplitude: \[ 40.79 \pm 0.29 \] μm
Width: \[ 1.728 \pm 0.062 \] μm

Spatial Resolution \( \sigma \) (95 +/- 4) μm

@ 315 V – 385 V
High Resolution Neutron Detection
The Neutron Time Projection Chamber
Summary

High Resolution Neutron Detection
The Neutron Time Projection Chamber

- Trigger & Track Principle
Summary

Markus Köhli
Physikalisches Institut (LCTPC)
Rheinische Friedrich-Wilhelms-Universität Bonn

High Resolution Neutron Detection
The Neutron Time Projection Chamber

- Trigger & Track Principle
  - Using both conversion products
High Resolution Neutron Detection
The Neutron Time Projection Chamber

• Trigger & Track Principle
  • Using both conversion products
  • Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]
Summary

High Resolution Neutron Detection
The Neutron Time Projection Chamber

- Trigger & Track Principle
  - Using both conversion products
  - Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]
  - Spatial Resolution $\sigma$ [$(95 \pm 4) \mu m$]
High Resolution Neutron Detection
The Neutron Time Projection Chamber

- Trigger & Track Principle
  - Using both conversion products
  - Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]
  - Spatial Resolution $\sigma$
  - $(95 \pm 4) \mu m$
Summary

High Resolution Neutron Detection
The Neutron Time Projection Chamber

- **Trigger & Track Principle**
  - Using both conversion products
  - Combination of gaseous tracking detector [TimePix] and a photo sensitive detector [SiPMs]

\[
\text{Spatial Resolution } \sigma = (95 \pm 4) \, \mu m
\]
Backup
Detection Efficiency

Simulation of the 2D efficiency with different coating thicknesses

- 5.4 Å
- 3.5 Å
- 1.8 Å
- 1.0 Å

Efficiency % vs. Boron Layer Thickness [µm]

CASCADE 6 layer efficiency
- Simulation 1.0 Å
- Simulation 1.8 Å
- Simulation 3.5 Å
- Simulation 5.4 Å