



Detectors and electronics for neutron detection in the NMX instrument of European Spallation Source (BrightnESS T4.1)

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* Multi-disciplinary research facility currently constructed in Lund, Sweden (1800 M Euro project of the EU, start 2023)



Outline

- BrightnESS task 4.1
- The NMX instrument
- Detector demonstrator prototype
- Detector read-out chain and electronics
- Conclusions



Development of detectors as "in-kind" contribution** from CERN

- A) Neutron converter: Gadolinium
- B) Detector technology: Gaseous Electron Multiplier (GEM)
- C) Read-out technique: Micro Time Projection Chamber (µTPC)

*Horizon2020 project of the European Commission, budget ≈ 20 M Euro
 ** Two fellow positions in the GDD group

DT-DD Meeting - CERN- 01/12/2017

People in BrightnESS task 4.1









Filippo Resnati **CERN Fellow from March 2014** Coordination of WP 4.1 Since March 2017: CERN Staff on CERN neutrino platform

Dorothea Pfeiffer ESS Staff from Sept. 2013 Software development for μ -TPC, simulation, coordination with WP 5.1

Patrik Thuiner CERN Fellow from Feb. 2016 Detector construction: GEMs, optimisation for scattering

Michael lupberger CERN Fellow from May 2016 Detector Readout: VMM ASIC Gadolinium cathode, design & integration, readout electronics, SRS firmware development, DAQ

We are part of the CERN Gaseous detector group within the EP-DT-DD section lead by Leszek Ropelewski

BrightnESS task 4.1 A) Neutron converter: Gadolinium





BrightnESS task 4.1 B) Detector technology: Gaseous Electron Multiplier (GEM)

Metal-clad polyamide foil (usually 50 μ m Kapton[®] with 5 μ m Cu on both sides)

- Perforated with **double-conical holes** in a honeycomb pattern (e.g. 70 μ m diameter and 140 μ m pitch)
- Cathode on high negative potential with respect to GEM and anode
- **Potential difference** applied between **top and bottom electrode** (typically in the order of 300-400 V)
- Usually **more than one GEM used in series** to achieve stable operation at increased amplification



Already working read-out technique

BrightnESS task 4.1

demonstrated for 10B⁺ and Gd[‡] neutron converters



position resolution of **O(200μm)**

(strongly depending on read-out but generally improved by μTPC)

time resolution O(ns)



⁺ D. Pfeiffer et al., JINST 10 (2015) 04, P04004 & ⁺ D. Pfeiffer et al, 2016 JINST 11 P05011 BrightnESS D4.3 BrightnESS D4.3

C) Read-out technique: Micro Time Projection Chamber (µTPC)

The NMX instrument Neutron macromolecular diffractometer

Determinate structures of proteins, location of hydrogen atoms Optimised for small samples and large unit cells

Time-of-flight (TOF) quasi-Laue diffractometer Wavelength band from 1.8 Å to 3.55 Å (6.49 to 25.25 meV) $2 \cdot 10^9$ n/s on 5 × 5 mm² sample (~ 4 kHz n/cm² on detector)

Approx. 0.8 m² detector active area No fixed instrument geometry

Quasi-Laue Time-Of-Flight Diffractometry Example diffraction pattern





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The NMX instrument No fixed detector geometry



Fe Detector Positioning System for ESS NMX, Final Design Report





Detectör demonstrator prototype



The NMX demonstrator cross-section Detector prototype v0 "Zita"

an a

Read-out

High voltage PCB

Chamber

frame

Top cover

Cathode support

Field cage

GEM stack

Read-out board

Read-out foil



Read-out flex Read-out PCB Hirose connector

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neutrons



thermal neutron shield

neutron transparent

thermal neutron shield

(not yet designed as part of WP 4.1)

(not yet designed as part of WP 4.1)

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Cathode assembly due to maximum foil size

Ultrasonic welding for mechanical and electrical connection with

No dead area







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Conclusions Detector demonstrator prototype

- NMX instrument will be first instrument without fixed geometry Three **fully integrated and moveable detector units**
- Testing and assembly has started early October
- Close to requirement of 200 μm spatial resolution
- First gadolinium cathodes produced with ultrasonic welding Possibility to upgrade to **enriched Gd-157** studied and is **viable future upgrade path**

Detector read-out chain and electronics



NMX prototype: 5120 strips w/ 4 kHz hits per strip

 \rightarrow fast dense electronics needed to process charge signal: integrated circuit

 μ TPC requires time resolution O(ns) \rightarrow high time resolution required

Robotic arms restrict number of cables from detector to back-end

 \rightarrow digitise data on detector

Use VMM ASIC from ATLAS New Small Wheel project

Electronics The Scalable Readout System

Implementation of the VMM into Scalable Readout System (SRS) of RD51 Collaboration



Electronics Readout chain and components

New hybrid and adapter card, FPGA firmware, and PC software has been designed to implement VMM in SRS



 $\mathsf{VMM}\;\mathsf{Hybrid}\to\mathsf{HDMI}\;\mathsf{cable}\to\mathsf{Adapter}\;\mathsf{card}+\mathsf{FEC}\to\mathsf{Ethernet}\to\mathsf{Switch}\to\mathsf{Ethernet}\to\mathsf{PC}$

Scalability: up to 8 VMM hybrids/FEC, many FECs/PC \rightarrow system scalable from one to 64 hybrids and more





SRS FEC and adapter card for VMMs



Slow control

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Electronics Latest test beam at CERN North area with beam from SPS



Triple-GEM detector with copper cathode (no gadolinium for muons and pions)

Three VMM3 hybrids (2 on x-axis, 1 on y-axis)

- Continuous data in self-triggered mode at 5kHz readout frequency
- Goal of test: operate electronics and test different settings





Electronics Latest test beam at CERN North area with beam from SPS



Electronics Latest test beam at CERN North area with

Clustered data from pion beam

VMM3 is working and will also work with all diffraction patterns!



htemp s 2562682

Entries

clusterY

70000

M. Lupberger

Conclusion Electronics

SRS + VMM readout still in prototype status with development ongoing CERN test beam has shown that:

- Prototype system is operational and can read out signals from detector
- All hardware components work
- Software for slow control, online monitoring and data acquisition is available and allows for smooth operation of the system
- System can handle data rates up to about 50 Mbit/s/VMM for 6 VMMs (NMX prototype: 80 VMMs at equal data rates)
- Data analysis software available (Lara's Summer Student project)

Conclusions NMX @CERN

Everything running according to schedule

Delivery of detector components, electronics,...

Concept for **detector** has been proven to work and **close to requirements Electronics are working** like expected

Detailed engineering and implementation has started

Outlook: Test beam with neutrons at reactor in Norway next week with mockup of prototype detector and SRS + VMM electronics

Latest Deliverables and Milestones for BrightnESS

Task 4.1 @CE	RN ₋	Oct 2015		Dec 2016	De	Now c 2017	Sep 2018 ¬
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nttp://www.atlasexperiment.org

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Electronics The ATLAS New Small Wheel Upgrade

In the scope of the high luminosity upgrade of the LHC at CERN, the ATLAS experiment replaces parts of its muon detectors





Anode strips read-out similar to our GEM detector

Insulator

Readout Cu strip

M. Lupberger

Electronics The VMM ASIC – Features

- 130 nm CMOS technology
- 64 input channels, each w/ preamplifier, shaper, peak detector, several ADCs
- Pos. & neg. polarity sensitive
- Digital block w/ neighbouring logic, FIFO, multiplexer
- Adjustable gain 0.5 16 mV/fC
- Adjustable shaping time from 25 ns – 200 ns
- Input capacitance from few pF – 1 nF



Electronics The VMM ASIC – Features (continued)

- Internal test pulser with adjustable amplitude
- Global threshold & adjustment per channel
- Self-triggered, zero suppressed
- 38 bit per hit (if input charge goes over threshold)
 - 1. Event flag (1 bit)
 - 2. Over threshold flag (1 bit)
 - 3. Channel number (6 bit)
 - 4. Signal amplitude (10 bit)
 - 5. Arrival time (20 bit)



Electronics Slow control for the readout system

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