Towards a 60 x 60 cm² demonstrator for the NMX instrument at the European Spallation Source ERIC

G. Aprigliano¹, F. Brunbauer², J. Busom Descarrega², A.T. Perez Fontenla², R. Hall-Wilton¹, I. Llamas-Jansa⁵, M. Lupberger², E. Oksanen¹, R. De Oliveira², E. Oliveri², D. Pfeiffer¹,², F. Resnati², L. Ropelewski², M. Shetty¹, C. Strel³, P. Thuiner², M. Van Stenis²

¹ European Spallation Source ESS AB, Sweden
² CERN, CH-1211 Geneva 23, Switzerland,
³ Vienna University of Technology, A-1040 Wien, Austria,
⁴ Mid-Sweden University, SE-85170 Sundsvall, Sweden,
⁵ Institute of Energy Technology IFE, NO-2007 Kjeller, Norway
Outline

The European Spallation Source ERIC
The NMX instrument
Quasi-Laue TOF diffractometry
Detector baseline
Current status of detector demonstrator prototype
Conclusions and outlook
The European Spallation Source Campus and surroundings

Malmö

Copenhagen

Lund

MAX IV
synchrotron-radiation facility

Science City
campus

ESS
The European Spallation Source Performance
The European Spallation Source
The instruments

- BEER
- ESTIA
- FREIA
- C-SPEC
- HEIMDAL
- DREAM
- NMX
- SKADI
- LOKI
- VOR
- CAMEA
- ODI
The NMX instrument
Neutron macromolecular crystallography

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 $5 \times 5$ mm$^2$ sample (~ 3 kHz n/cm$^2$ on detector)

Approx. 0.8 m$^2$ detector active area
No fixed instrument geometry
Quasi-Laue Time-Of-Flight Diffractometry
Principle and example diffraction pattern

bovine heart cytochrome c oxidase
a = 182.59 Å, b = 205.40 Å, c = 178.25 Å
detector distance = 1 m
Quasi-Laue Time-Of-Flight Diffractometry
Separation of harmonic reflections

- 1.800 to 2.019 Å
- 2.019 to 2.237 Å
- 2.237 to 2.456 Å
- 2.456 to 2.675 Å
- 2.675 to 2.894 Å
- 2.894 to 3.112 Å
- 3.112 to 3.331 Å
- 3.331 to 3.550 Å
Quasi-Laue Time-Of-Flight Diffractometry

Separation of spatial reflections

- 1.800 to 2.019 Å
- 2.019 to 2.237 Å
- 2.237 to 2.456 Å
- 2.456 to 2.675 Å
- 2.675 to 2.894 Å
- 2.894 to 3.112 Å
- 3.112 to 3.331 Å
- 3.331 to 3.550 Å
The NMX instrument
No fixed detector geometry
The NMX instrument

No fixed detector geometry
NMX detector baseline

Triple-GEM detector in Ar/CO$_2$ 70:30 gas mixture
Natural (enriched) gadolinium cathode
Neutron detection efficiency <14% (<31%)
Backward configuration: neutrons pass full detector volume before reaching cathode
Hit position reconstructed with μTPC method
NMX detector baseline

Drift length

Conversion electrons with energy 10 to 250 keV

Should be fully contained in drift volume

10 mm drift length is sufficient to contain electrons with energies up to 30 keV
NMX detector baseline
Forward vs. backward configuration

Converter

Triple-GEM

Read-out

neutron

electrons

Converter thickness (µm)

CE probability (%)

Simulation

sum

natural Gd

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm

backward: ≥ 10 µm

Simulation

electrons

Natural Gd

forward: 5 µm
NMX detector baseline

Scattering

[1] https://webapps.frm2.tum.de/intranet/neutroncalc/
NMX detector baseline
Position resolution

200 µm or better
µTPC method improves position resolution considerably

Not yet there but close
Study with mask this summer

[Image of NMX detector baseline and position resolution graphs]
The NMX detector demonstrator
Design of first prototype
The NMX detector demonstrator
Design of first prototype

1. GEMs
2. Readout
3. Cathode
The NMX detector demonstrator
Design of first prototype

**Detector**
Triple-GEM with active area of 51.22 x 51.22 cm²
10 mm drift gap with field cage, other gaps 2 mm
Chamber approx. 60 x 55 x 4 cm³ (without electronics)

**GEMs**
Single-mask, 70µm holes and 140 µm pitch
25 sectors (strips)
Glued triple-GEM stack with spacer grid
The NMX detector demonstrator
Design of first prototype

Readout

Four 25.6 x 25.6 cm$^2$ sectors

x/y Cartesian strips, 400 µm pitch
640 channels / coordinate / module

Strips read out by VMM3 and SRS
(see M. Lupberger’s talk)

Passive cooling of VMMs

No material behind readout
The NMX detector demonstrator
Design of first prototype

**Cathode**

Natural gadolinium, 25 µm thick

Design already foreseen for possible upgrade to enriched Gd-157 (ongoing study)

Assembled from 25 individual gadolinium foils on aluminium frames

Costs: 2k$ / foil (>12 k$ for Gd-157)
Ultrasonic welding of gadolinium cathodes

Principle
Ultrasonic acoustic vibrations + pressure
Molecules of one material diffuse into other material

Advantages
Joining of dissimilar materials
Precise and clean welds
Electrical and mechanical stability
Ultrasonic welding of gadolinium cathodes

25 µm gadolinium on 1 mm aluminium, 5 x 5 cm²
Ultrasonic welding of gadolinium cathodes

Measurement with segmented cathode (3x Gd, 1x Cu)

Welding pattern not visible with current settings but will be studied in greater detail.
Conclusions and outlook

NMX instrument will be first instrument without fixed geometry
Three fully integrated and moveable detector units
Close to requirement of 200 µm spatial resolution
Studies with slit mask ongoing
VMM readout will be capable of handling the high neutron flux (see M. Lupberger’s talk)
First gadolinium cathodes produced with ultrasonic welding
Possibility to upgrade to enriched Gd-157 currently studied
Detector design ready and currently reviewed
Production of components will start in July
First prototype will be ready by end of October