Helium-3 Alternatives for Neutron Detection in Neutron Scattering Science

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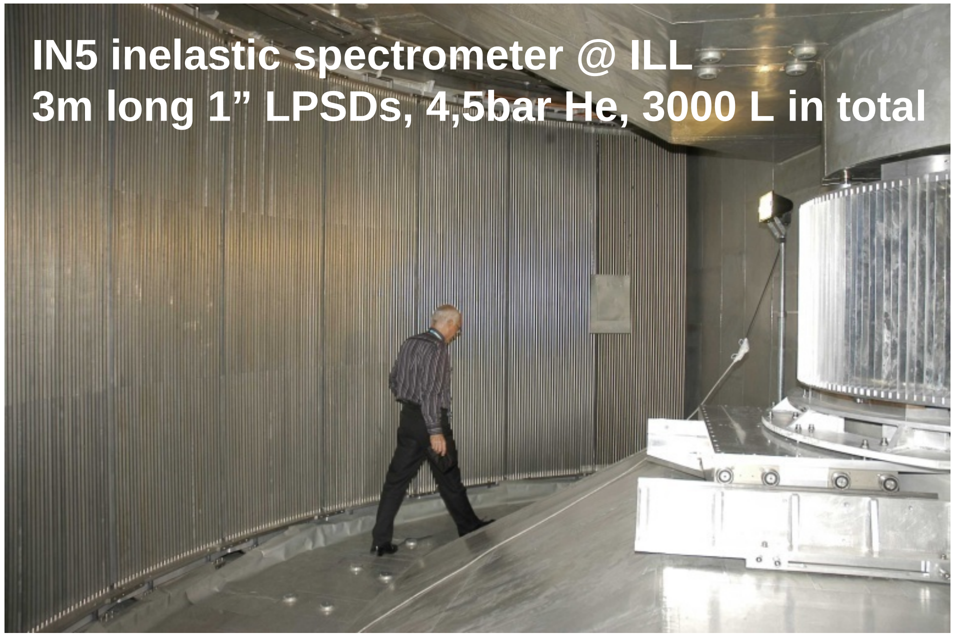
for the

International Detector Initiative

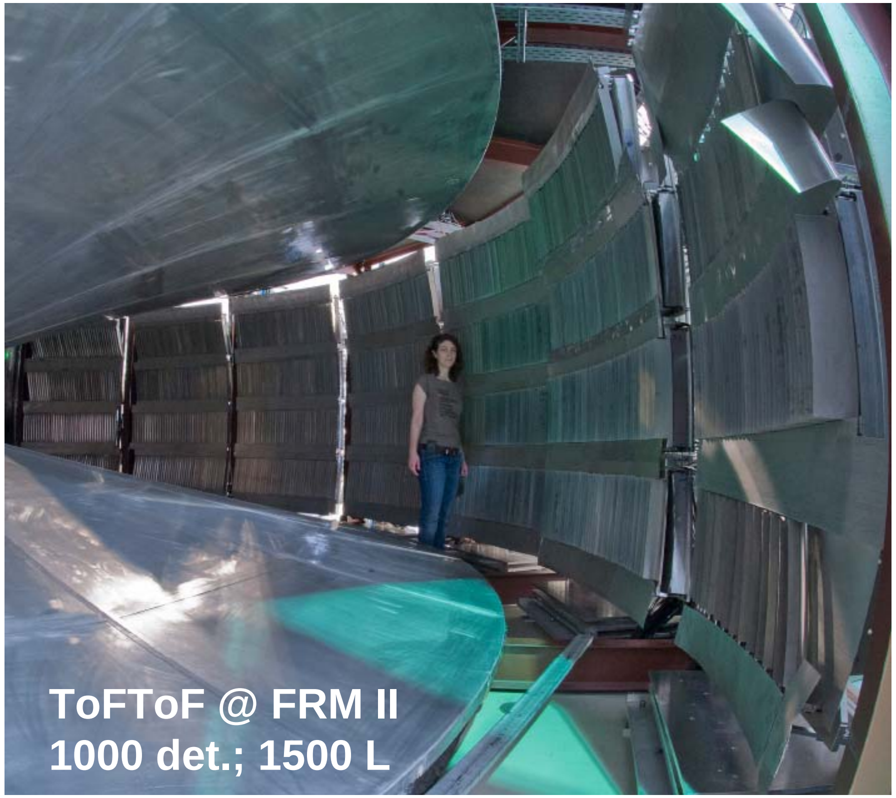
Introduction

About 75% of detectors for Neutron Scattering use He-3

- highly efficient
- good position resolution
- stable
- low background
- very good n / γ-separation
- adequate timing



IN5 inelastic spectrometer @ ILL
3m long 1” LPSDs, 4,5bar He, 3000 L in total



ToFToF @ FRM II
1000 det.; 1500 L

Typical Inelastic Instruments:

- Detector area is 15 – 50 m^2
- 1” LPSDs, 2 – 3m long
- He-3 content: 1000 - 4000 L

Detector characteristics to compete

Detector characteristics	10 bar 25 mm diameter ^3He
Neutron Efficiency	70% at 1 A
Gamma sensitivity	10^{-6}
Background	10 – 15 counts/ h / m
Width	25 mm
Length	1 - 3 m
Resolution	15 – 25 mm at FWHM
Local rate capability	50 kHz on a pixel
Global rate capability	50 kHz on a tube
Time resolution	1 μs
Area	15 – 40 m^2
Environment	Cryogenic vacuum

Development lines of Detector Initiative

Scintillation Working Group *(**ISIS**, JCNS, J-Parc, NIST, ORNL)*

Investigation and development of scintillation detector technologies for large area detectors

- Build on experience with detectors based on $ZnS{:}^{6}LiF(Ag)$ or $ZnS{:}^{10}B_2O_3(Ag)$ scintillators read out by coded arrays of clear or wavelength shifting fibres
- Investigate scintillators, optics, light readout devices, encoding schemes

^{10}B-Working Group *(**ILL**, ESS, FRM II, HZB, ORNL)*

Development of solid ^{10}Boron multilayer arrangements in gaseous large area neutron detectors

- Study ^{10}B-coating processes
- Investigate and optimize design and fabrication of a multilayer detector in view of performance and cost

BF_3-Working Group *(**HZB**, FRM II, ILL)*

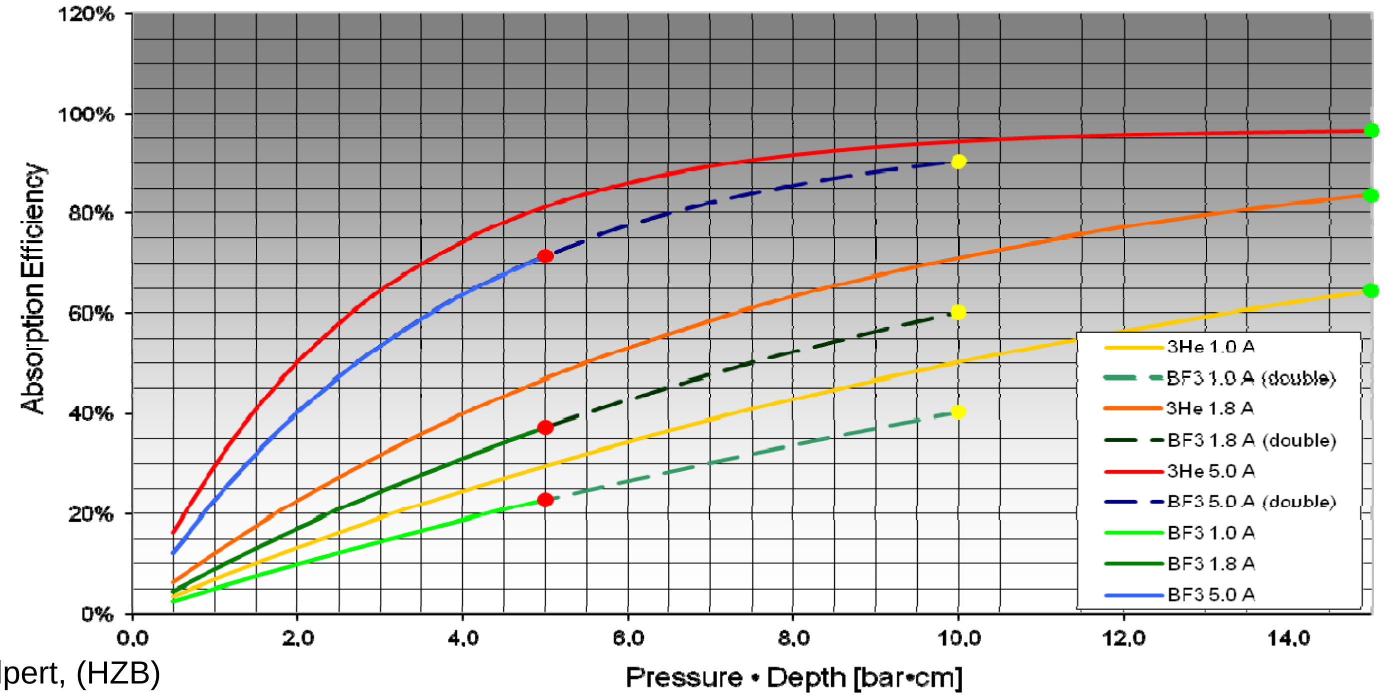
Investigate BF_3 as a potential fast and easy replacement of ^{3}He

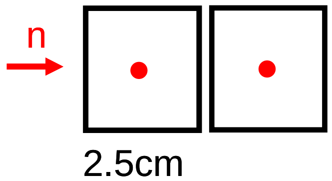
- Study gas properties, performance and limitations of BF_3
- Investigate safety issues for large scale use

$^{10}BF_3$ Proportional Counters

Simple Solution ! Just replace ^{3}He by $^{10}BF_3$ in present detector designs
Works as well in a proportional counter, LPSD, MWPC

- Energy deposit 2.3 MeV / neutron
- Cross section = 72% of Helium
- Corrosive and highly toxic
- low pressure operation (high operation HT, attachment)



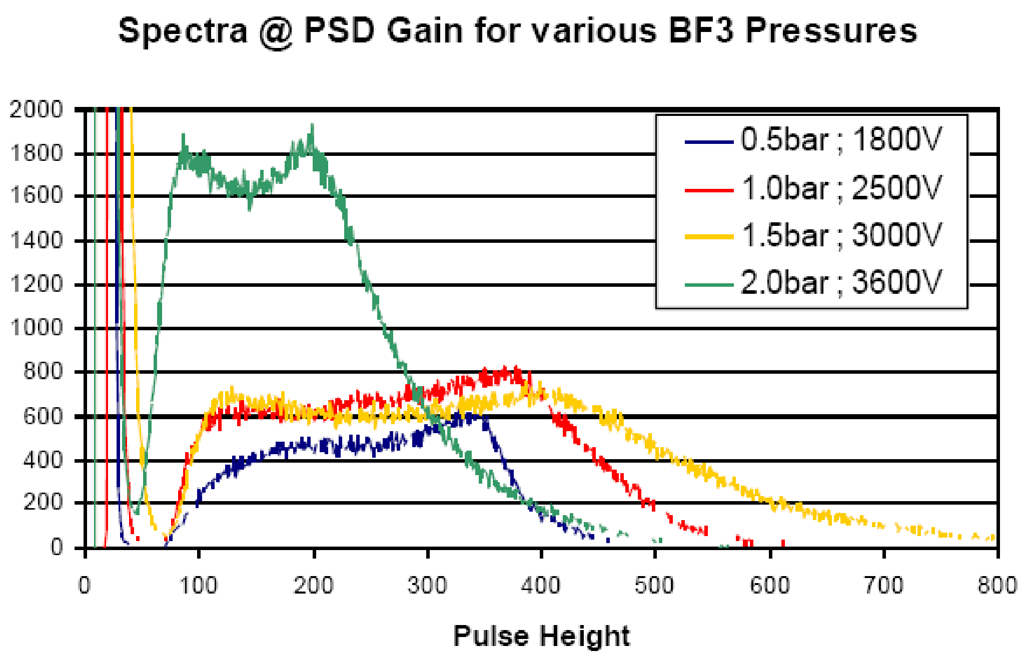


T. Wilpert, (HZB)

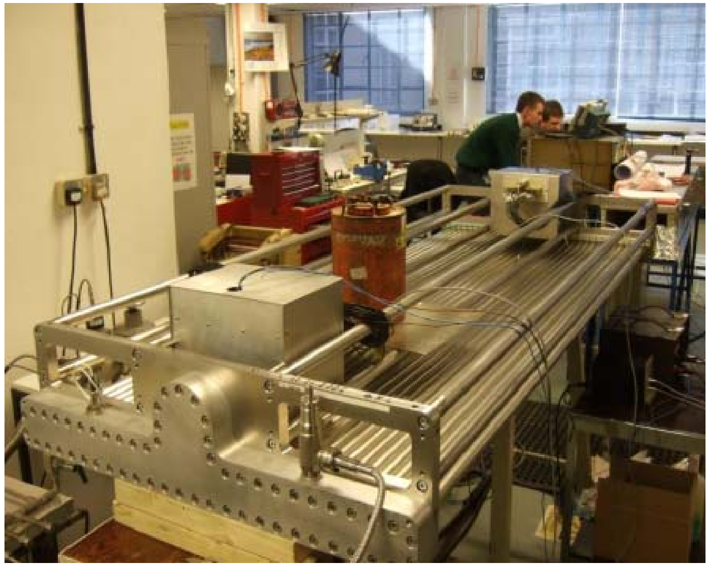
LPSD filled with $^{10}BF_3$ at high pressure

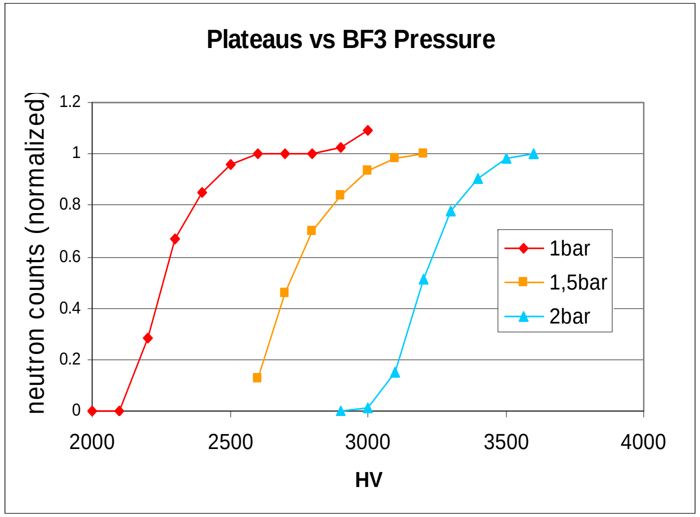
Test of ILL- IN5 prototype module filled with BF_3

- 32 tubes; 1” x 2m
- BF_3 pressure up to 2bar



B. Guerard, M. Platz, (ILL)

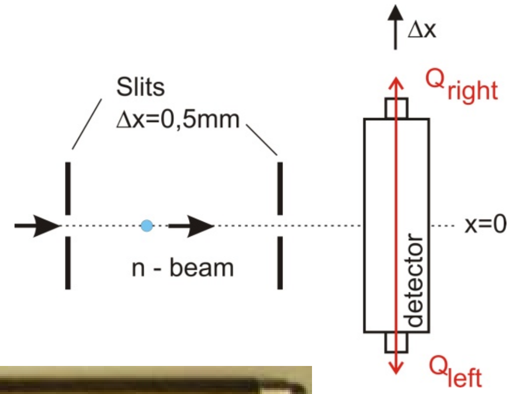


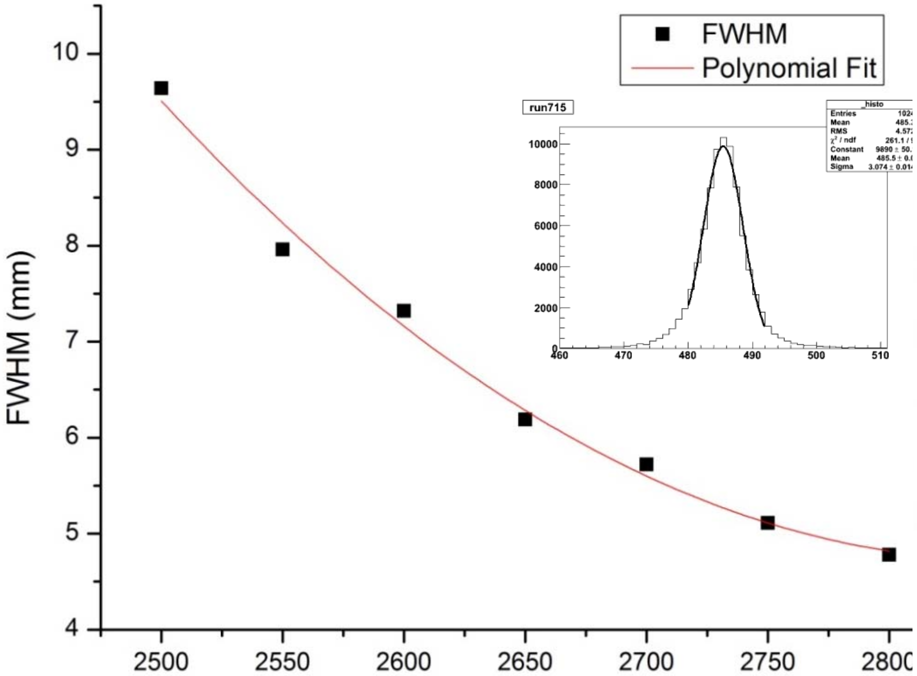


LPSD filled with $^{10}BF_3$ at high pressure

Evaluation of PSD at FRM II and HZB

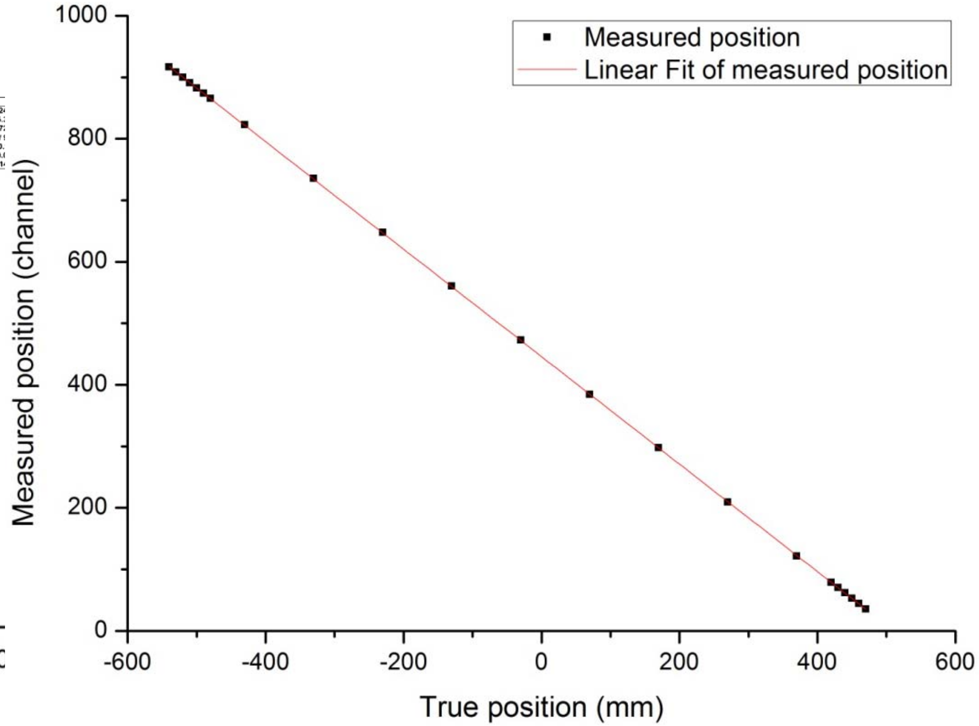
- 1" x 1m LPSD (made by Centronic, UK)
- 1.87 bar, 2800 V max. tested





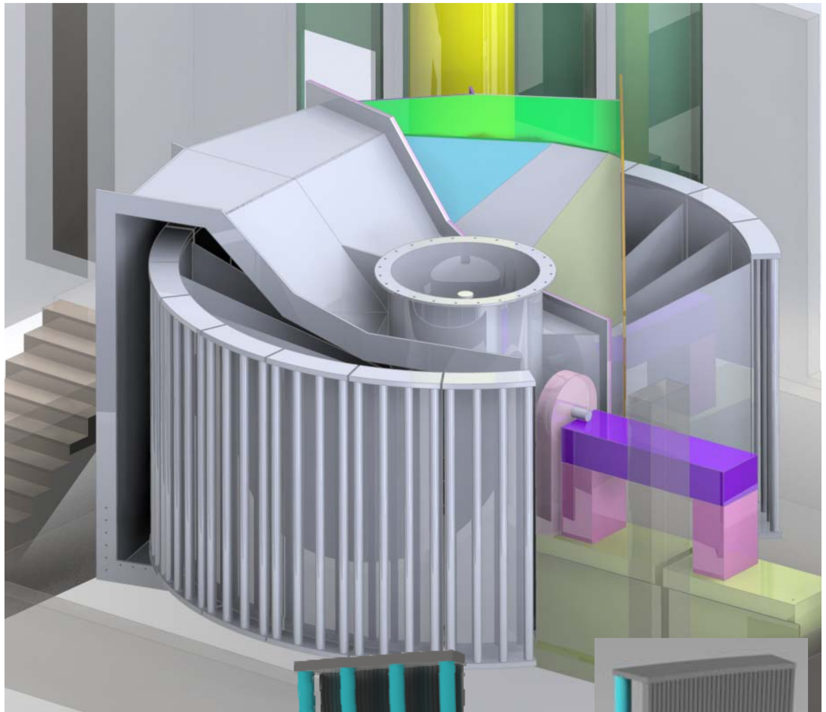
T. Wilpert, (HZB)

HV (V)



NEAT – ToF spectrometer at HZB

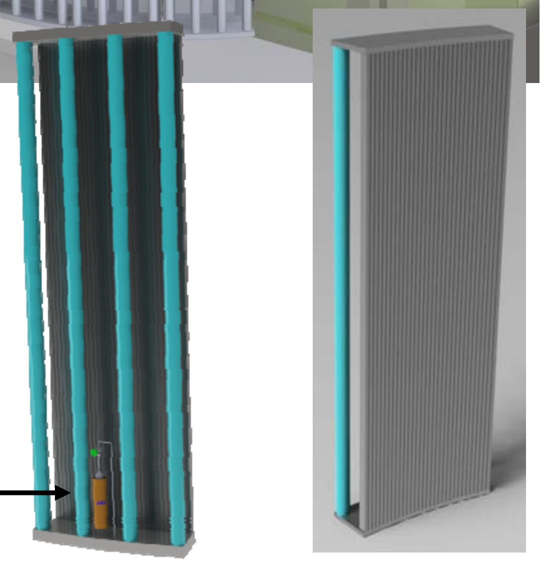
40 m² active detector area
544 LPSDs (17 Modules)
Pixel resolution 2.5 x 2.5 cm²
ToF resolution < 30 µs @ 5Å
1" width, 3 m long, 90%@ 5Å



BF3 Gas handling system

T. Wilpert, (HZB)

Detector module
with 32 double-tubes



LN_2-cold trap

^{10}B-converter in gaseous detectors

n + ^{10}B → ^{7}Li (0.84MeV) + α (1.47MeV) + γ (0.48MeV) (93%)

→ ^{7}Li (1.02MeV) + a (1.78MeV) (7%)

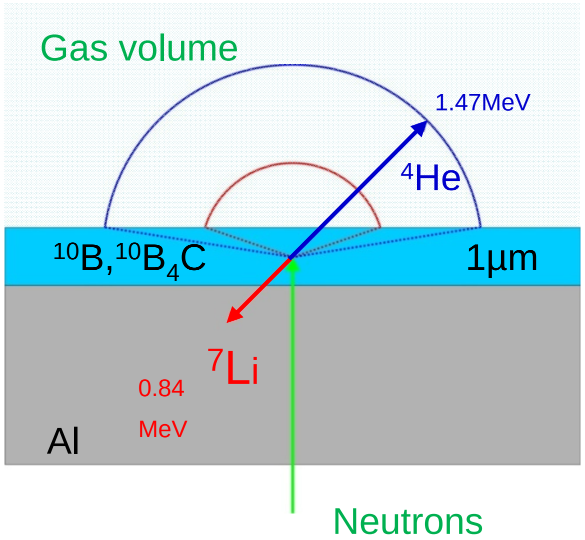
Why using Boron as solid converter ?

- B_4C stable, not hygroscopic (e.g. as Li)
- large charge signal in detector
- 96% enriched ^{10}B available

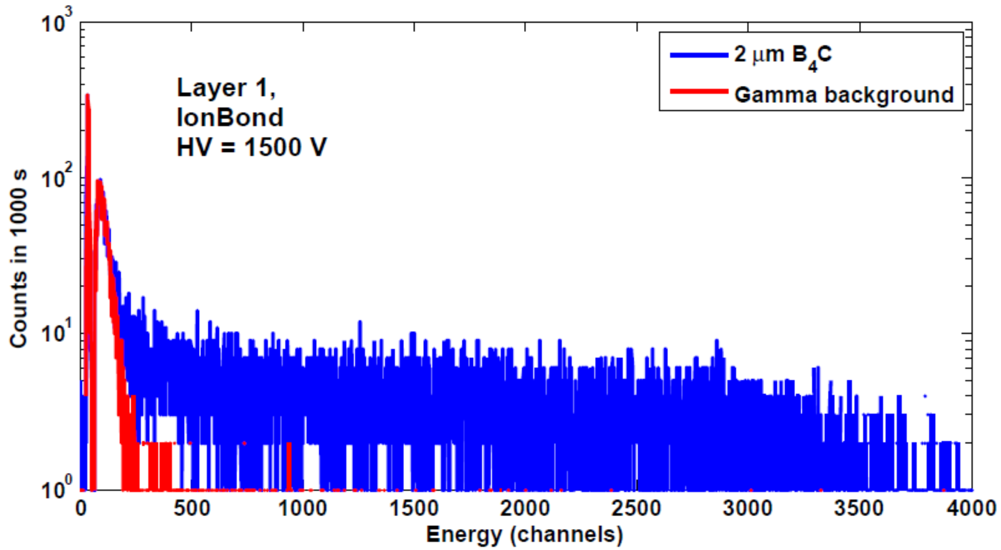
Boron:

λ_{abs} for therm. neutrons: 20 µm

Range: α = 3.14 µm; Li = 1,53 µm



Pulse height spectrum

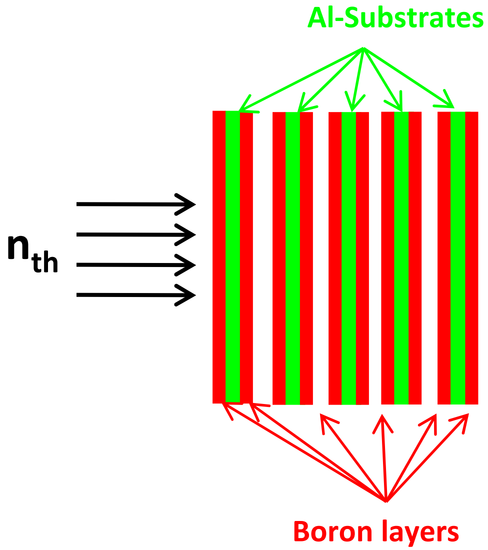


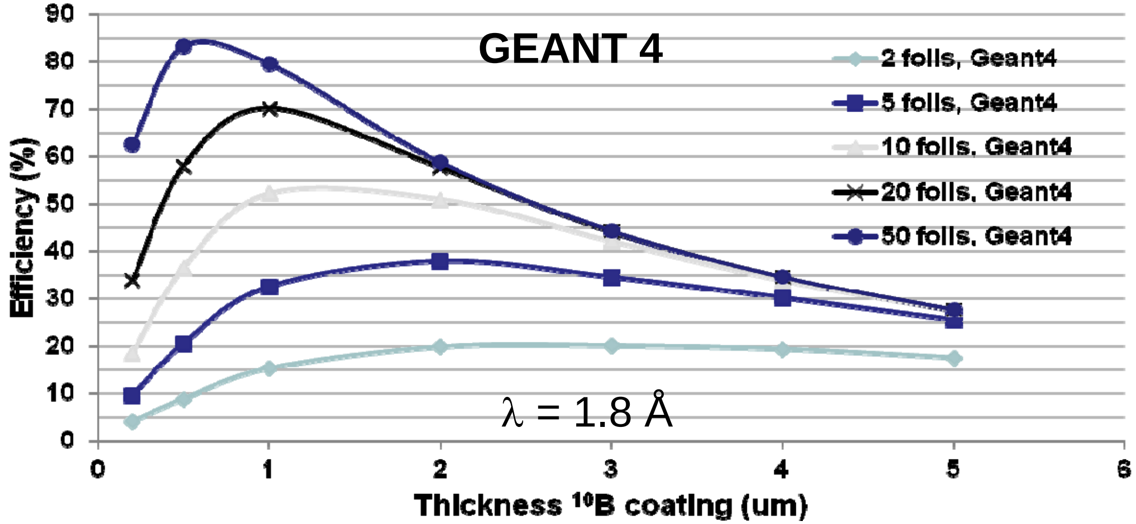
I. Stefanescu, (FRM II)

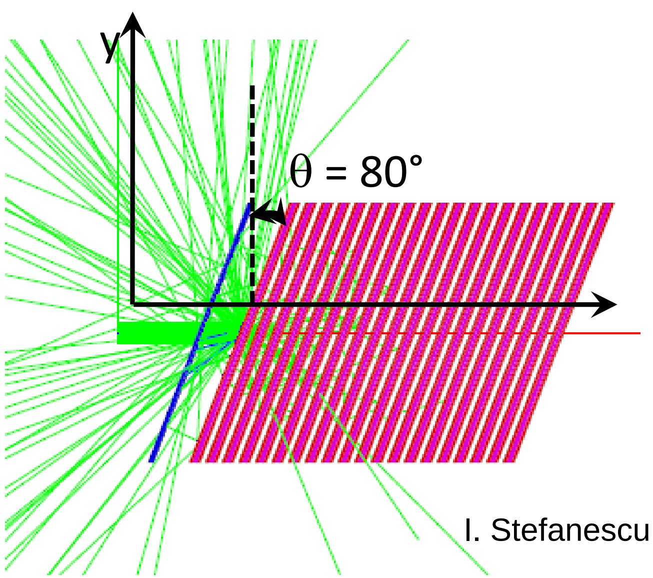
Charged Particle range limits single layer efficiency

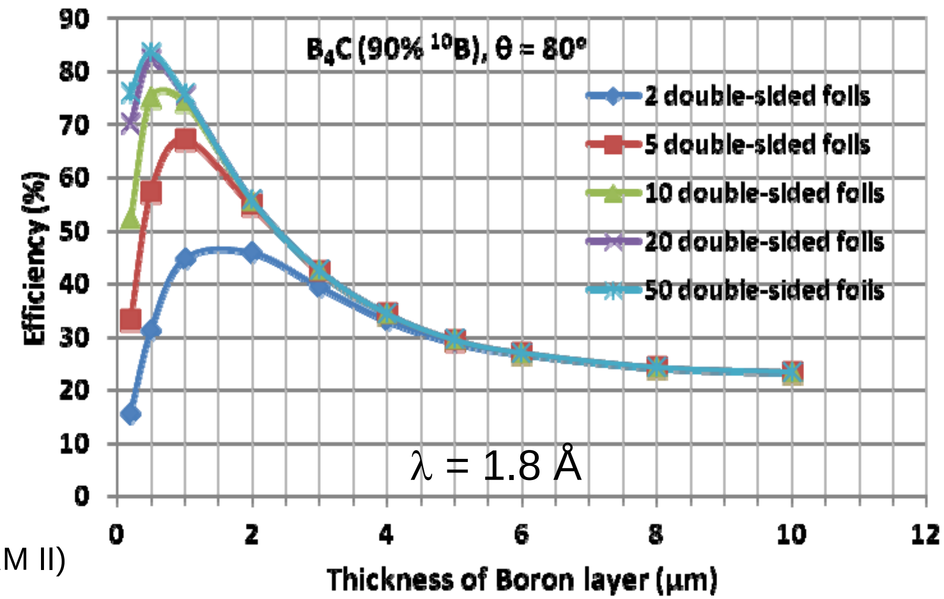
- Single layer: ε_{det} < 5% for therm. neutrons

Detection efficiency of ^{10}B converters









I. Stefanescu, (FRM II)

^{10}B / $^{10}B_4C$ layer production

To use this technology in large area detectors a cost effective production of the Boron layers is of crucial importance

- Deposition technologies

  RF / DC sputtering, e-beam evaporation, others

- Large scale production (~10^3 m^2)
- Layer composition: ^{10}B, $^{10}B_4C$, …

Open questions

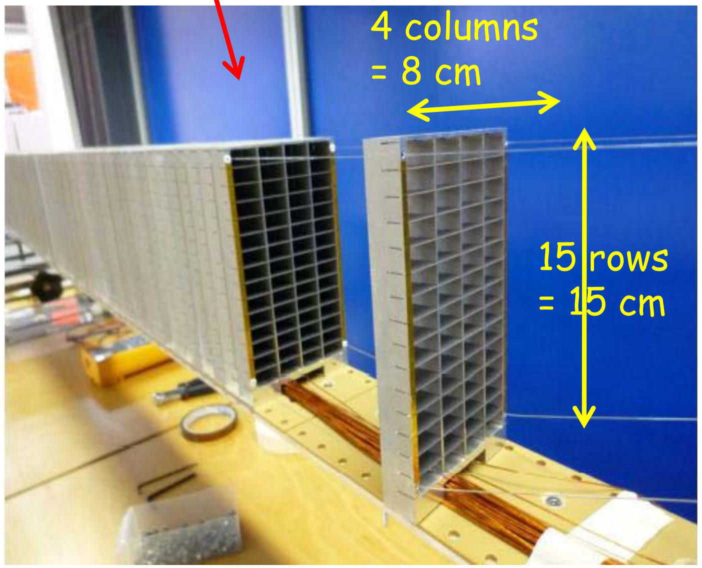
- Layer stability: adhesion, ageing
- Homogeneity, substrate, topology

At Linköping Univ. meanwhile about 1900 “Al-blades” (~6.3m^2) have been success-fully coated on both sides with $^{10}B_4C$ which were used in a 200cm x 8cm prototype built at ILL

R. Hall-Wilton, (*ESS)*

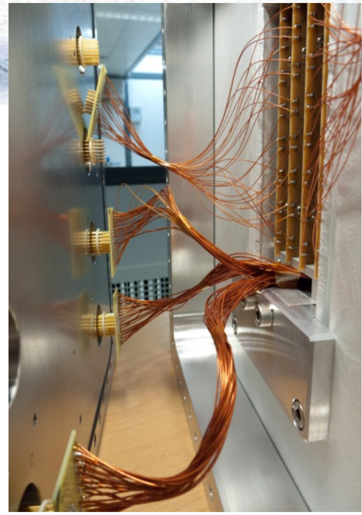
Multi-Grids detector
An ILL-ESS collaboration

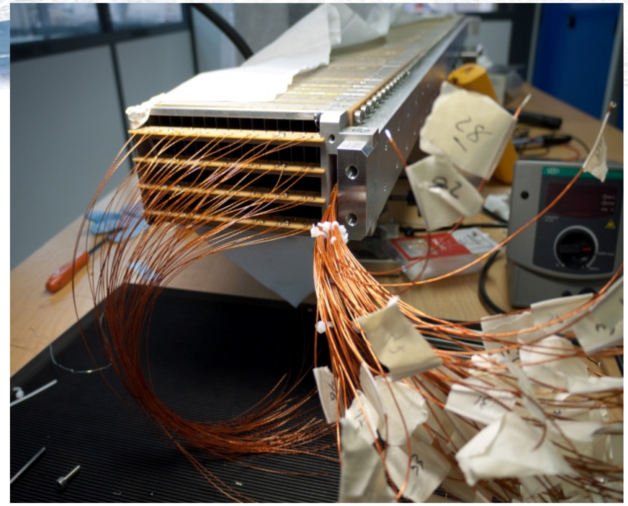
neutrons



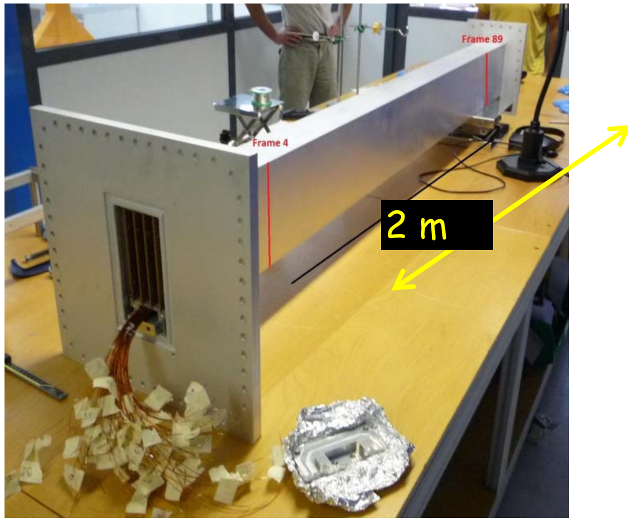
Stacking of 96 grids of 2 cm height electrically insulated from each other

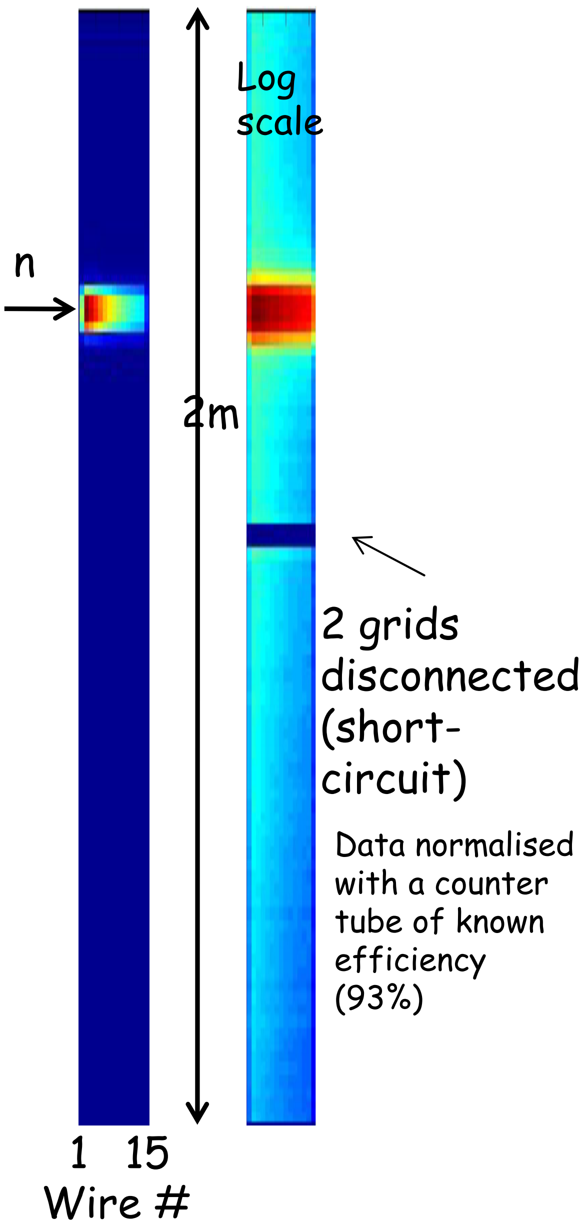
Individual readout electronics (anodes and grids)



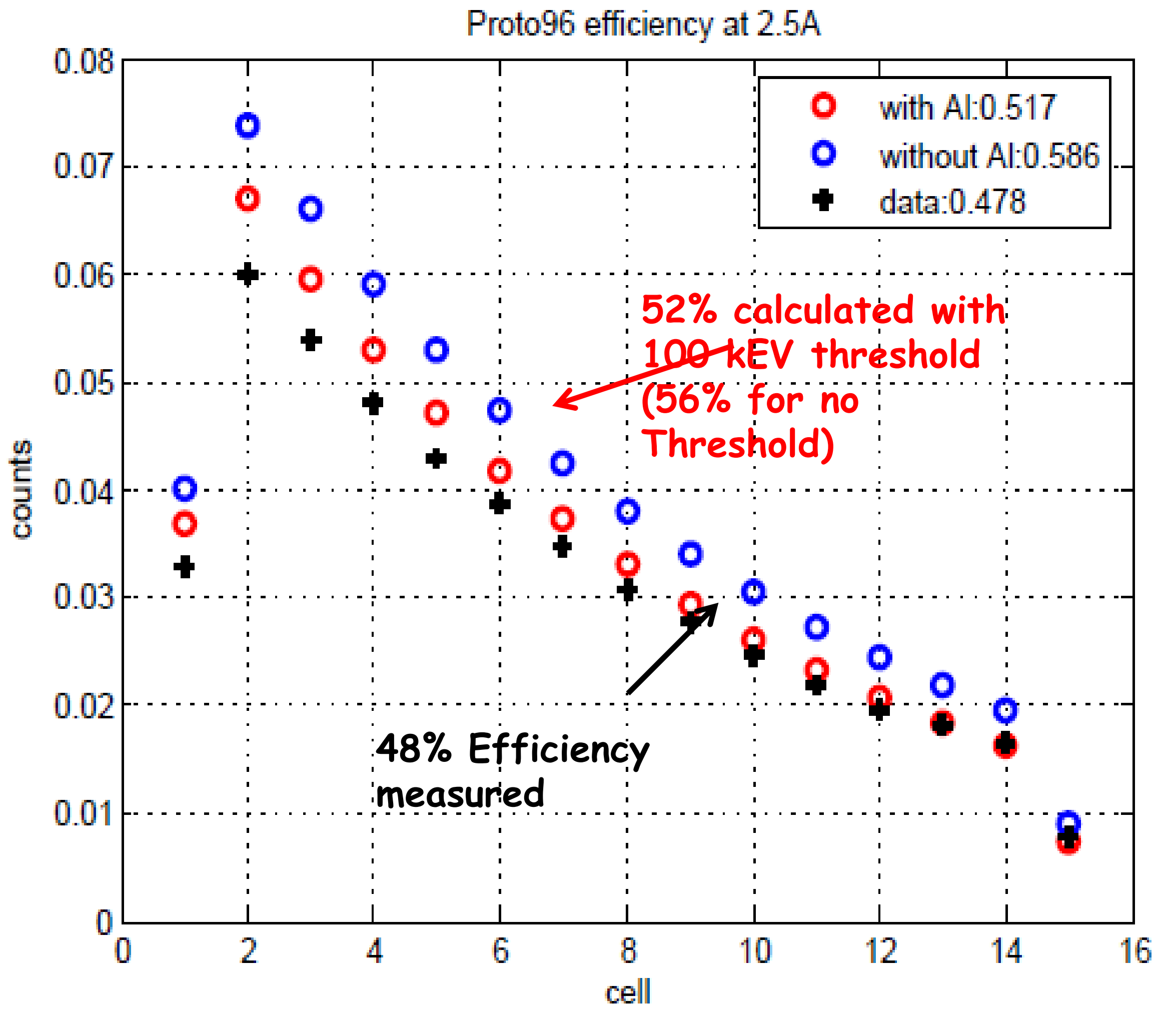


4 columns of 15 tubes of 192 cm length
→ 60 anode wires (gold plated W 20 μm)



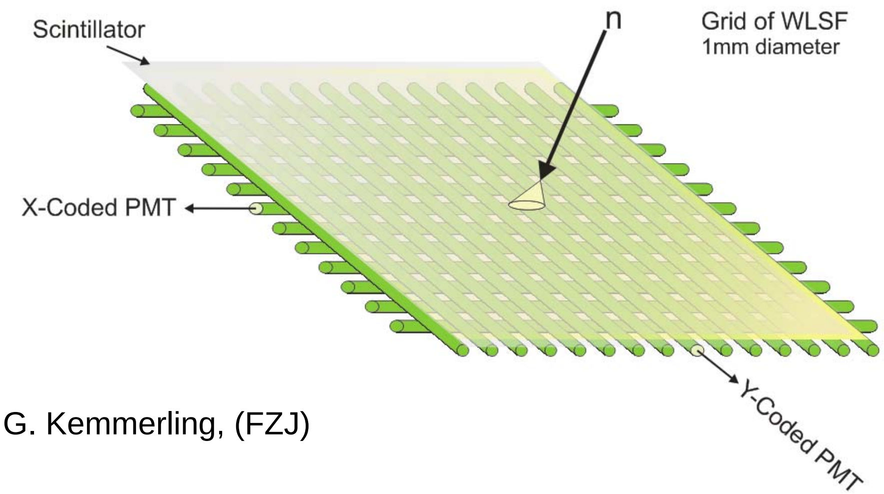


Data normalised with a counter tube of known efficiency (93%)



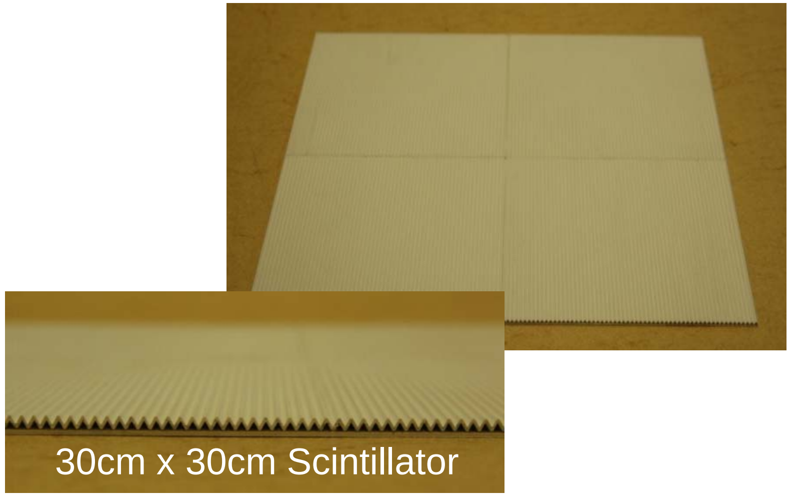
Wavelength Shifting Fibre Detector for Neutron Scattering

WLS-fibre readout of $^{6}LiF/ZnS$ & $^{10}B_2O_3$ /ZnS-scintillators

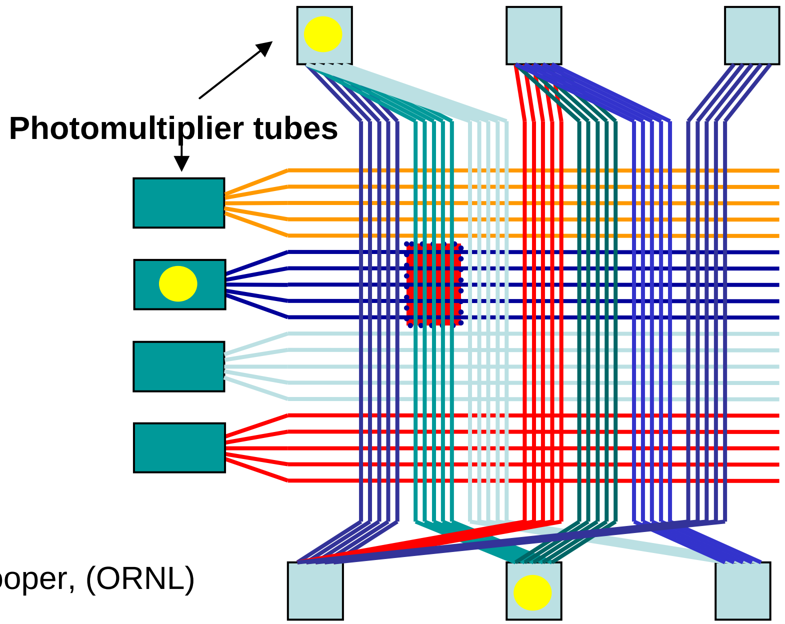


G. Kemmerling, (FZJ)

$^{6}LiF/ZnS$

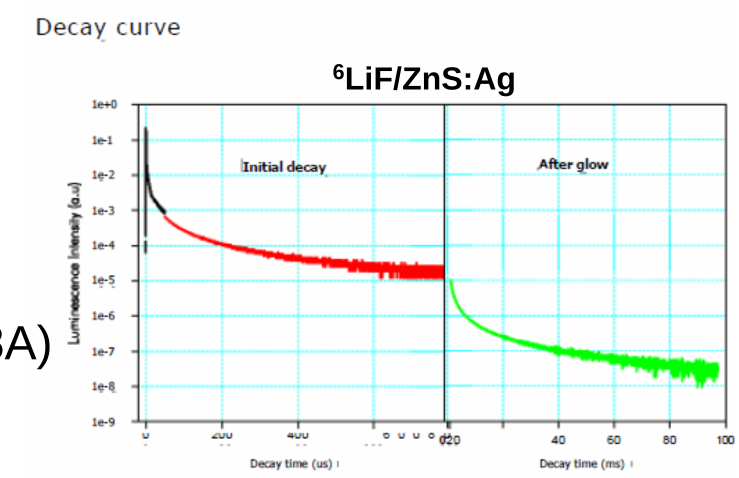


- **The incident neutron is captured in the $^{6}LiF/ZnS:Ag$ scintillator**
- **Some blue scintillation light from ZnS is shifted to green and trapped in the WLS-fibre**
- **This light is detected by PMTs in coincidence to determine the position**



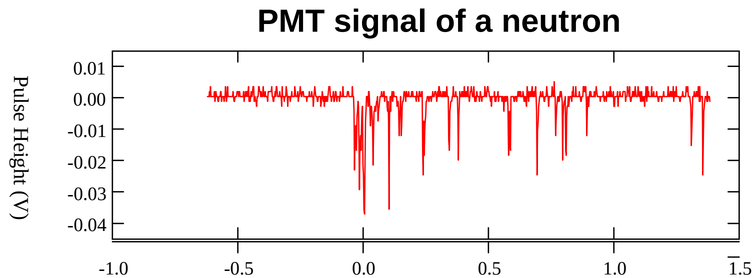
R. Cooper, (ORNL)

Challenges to a large area WLSF - detector



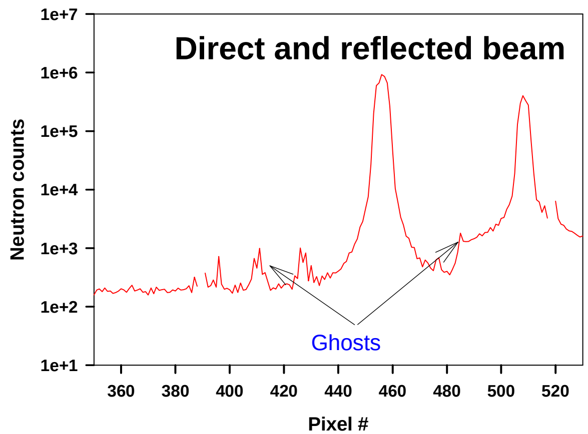
^{6}LiF/ZnS:Ag is a bright but slow scintillator

- decrease to 10% level is 80µs; "afterglow"
- limits local count rate capability to ~ 20kHz
- opaqueness limits neutron efficiency (50% @1.8A)



Low light output of WLS-fibres

- low light conversion and trapping efficiency
- losses due to damping and fibre bending



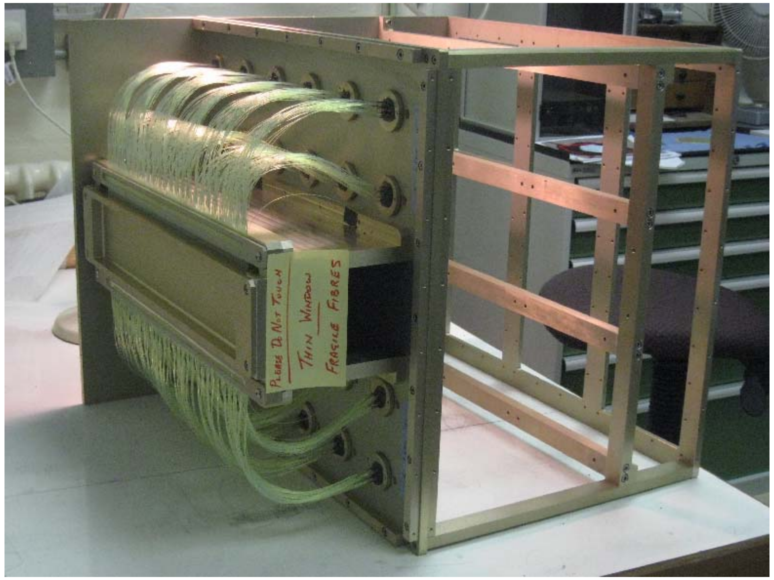
"Ghosting" (misplacement of neutrons)

- Occurs when afterglow from 2 neutron events cause signals in PMTs

Graphs taken from

G. Kemmerling, (FZJ); R. Cooper. (ORNL); E. Schooneveld, (*ISIS*)

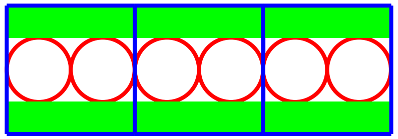
WLSF prototypes



- **Linear WLSF**
- **2 Flat ZnS sheets**
- **768 fibres, 0.51mm pitch, 0.5mm ∅**
- **16 Channel MA PMT**

Appropriate code and algorithm can reduce ghosting from 1% to 0.01%

Linear “sandwich” WLSF



16 elements, 2 x 200mm^2

coupled to single cathode PMT

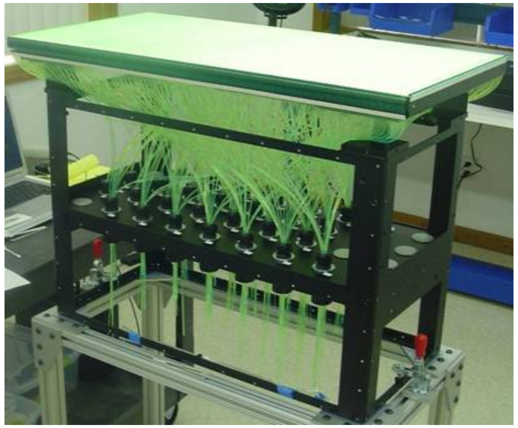
WLS fibres bending radius 2.5mm with only 10% light loss

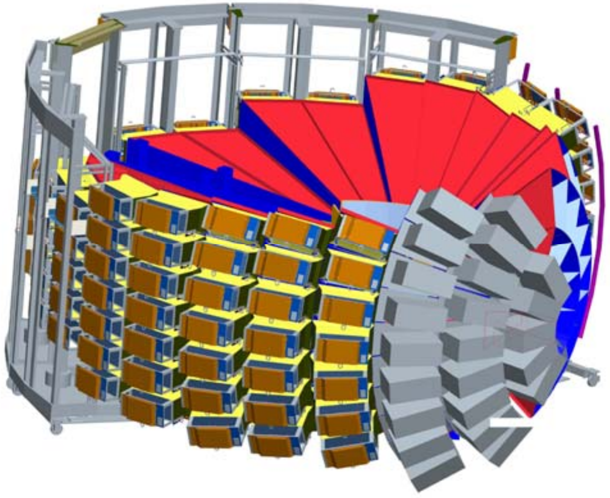
Detection efficiency at 1A: ~40 %

Gamma sensitivity at 1.2MeV: ~3x10^{-7}

Fiber-scintillator detectors

- Each module has 0.3 m^2 detection area.
- Totally 30 units (9 m^2) have been installed in 2 neutron diffractometers (POWGEN, VULCAN) at SNS.
- ZnS:Ag/6LiF microparticle scintillator is used.
- 154x7 pixels, each pixel has a size of 5x50 mm.





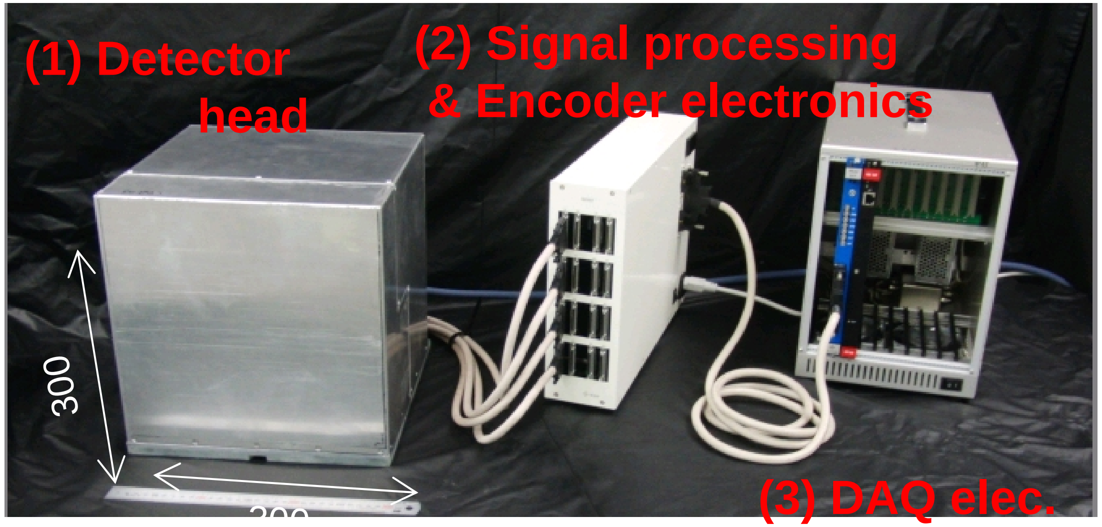
Spatial resolution along x-axis: 4.1±0.2 mm.

Ghosting/artifact in v.3 is greatly reduced.

The new type of 2-d WLS fibre scintillator detector

A wide area scintillator detector has been developed using the iBIX detector technology.

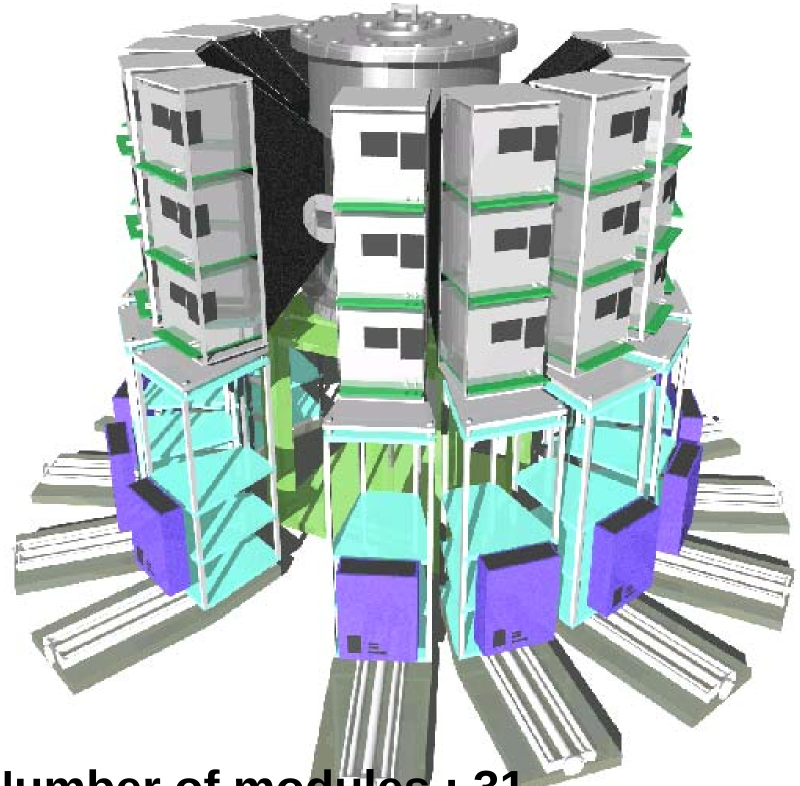
Detector module



Scintillator	: B_2O_3 / ZnS
Pixel size	: 4 × 4 mm
Sensitive area	: 256 x 256 mm
Detector efficiency	: 30-40% for 1.8Å
Pulse pair resolution	: < 5 μs
Gamma sensitivity	: ~10^{-6} (^{60}Co)
No. of pixels /detector	: 4096 (64 ×64)
No. of electronics channels	: 128 (64 x 2)
No. of PMTs	: 2

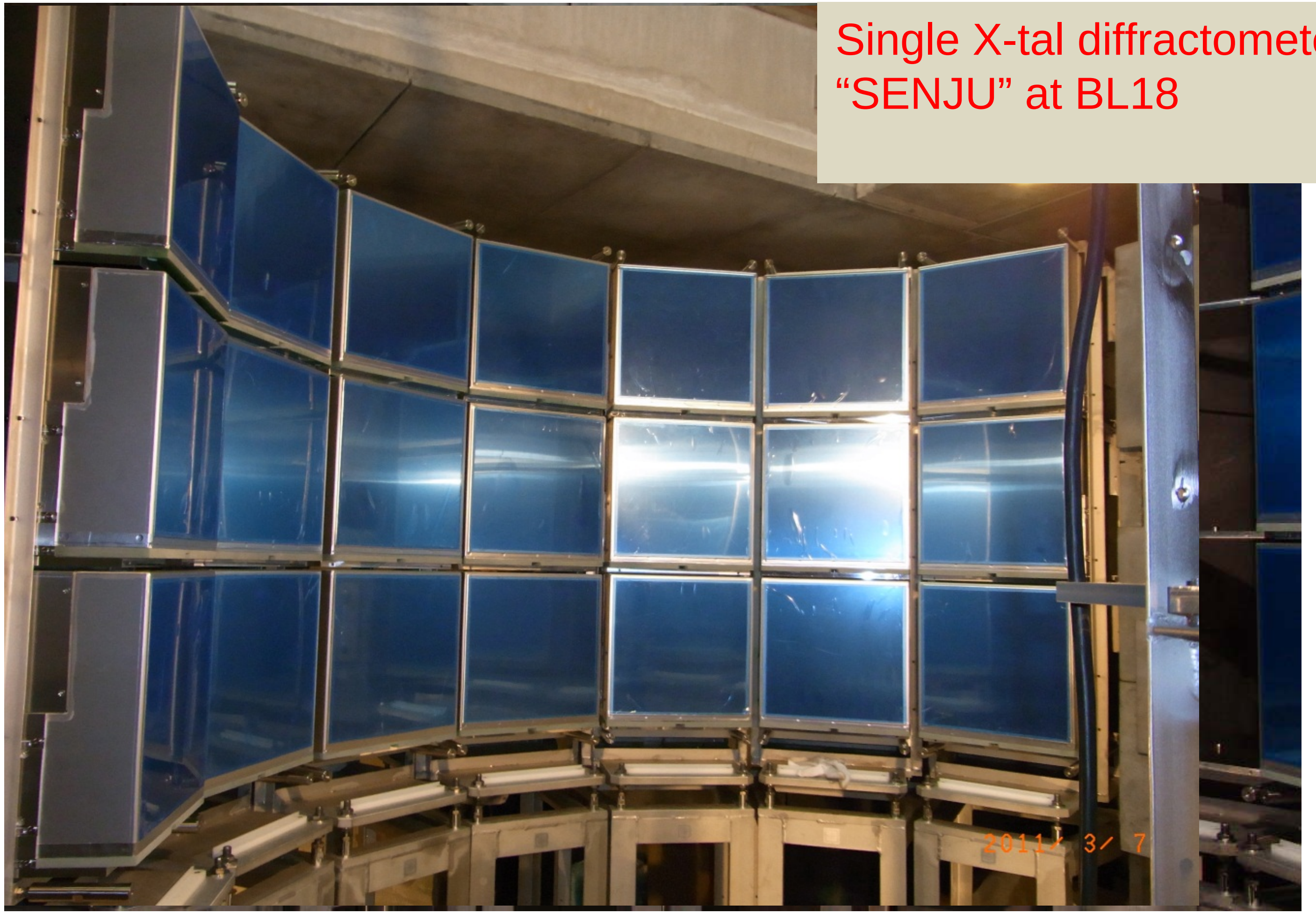
Single X-tal diffractometer "SENJU" at BL18

31 modules were fabricated, evaluated and installed.

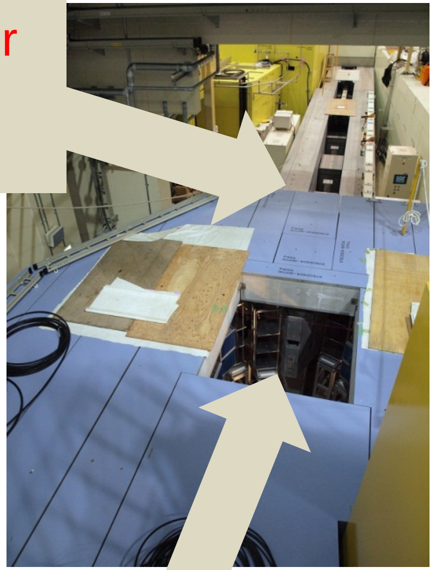


Number of modules : 31
Detection area : 2.8 m^2
Pixel size : 4 ×4 mm

Installation of “SENJU” Detectors at BL18



Single X-tal diffractometer
“SENJU” at BL18



Scintillator detectors
with WLSF read-out

31 detector modules
installed in the radiation shielding room of SENJU (BL18)

Conclusion and Outlook

We are on the track now !

Three working groups evaluate alternative n-detection techniques based on

- ^{6}LiF/ZnS and B_2O_3/ZnS scintillation detectors with WLS-fibre readout
- Solid ^{10}Boron converter in gaseous detectors
- BF_3-filled Linear Position Sensitive Proportional Detectors

First large scale prototype detectors were build and show promising results

There are still many open questions and problems to solve in order to achieve adequate performance

- Efficiency
- Count rate capability
- Long term stability
- Cost issues

Collaboration - ICND - Mozilla Firefox

icnd.org/collaboration.html

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INTERNATIONAL COLLABORATION FOR THE DEVELOPMENT OF NEUTRON DETECTORS

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Collaboration

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FRM II	Forschungs-Neutronenquelle Heinz Maier-Leibnitz, Germany
HZB	Helmholtz Zentrum Berlin, Germany
ILL	Institut Max von Laue – Paul Langevin, France
ISIS	Science and Technology Facilities Council, UK
JCNS	Jülich Centre for Neutron Science, Germany
J-PARC	Japan Proton Accelerator Research Complex, Japan
NIST	Centre for Neutron Research, USA
ORNL	Neutron Science Directorate, Oak Ridge National Laboratory, USA

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