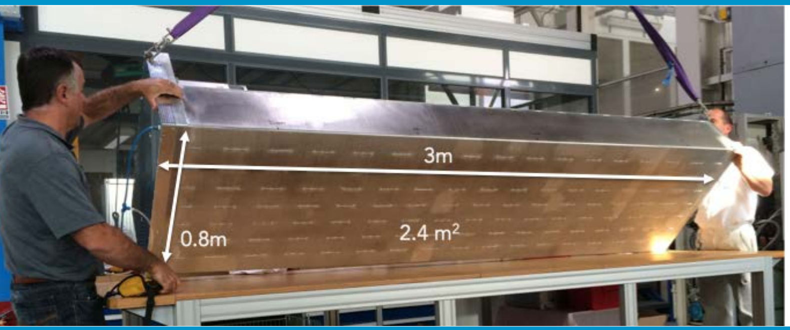
Boron-Based Thin Film Detectors at the European Spallation Source ERIC

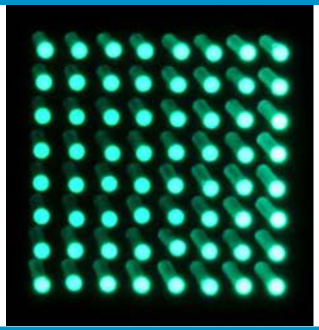
Richard Hall-Wilton

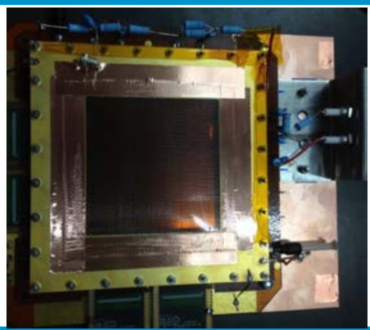
Leader of Detector Group

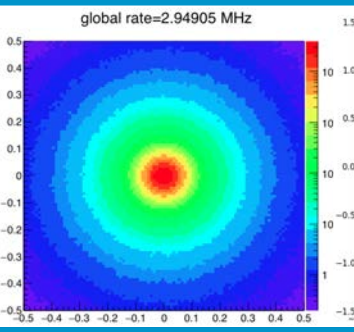
PNPI Workshop on PIK Instrumentation

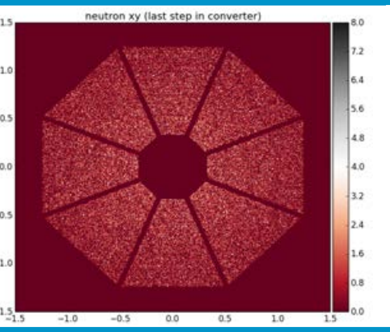
www.europeanspallationsource.se

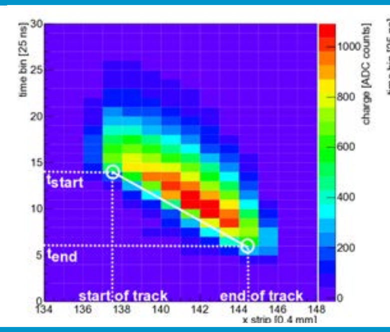


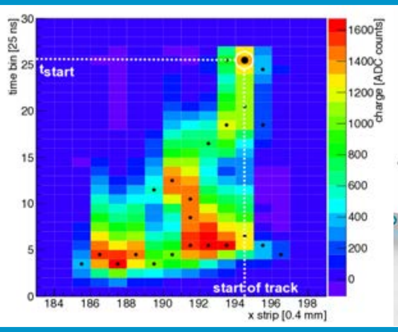


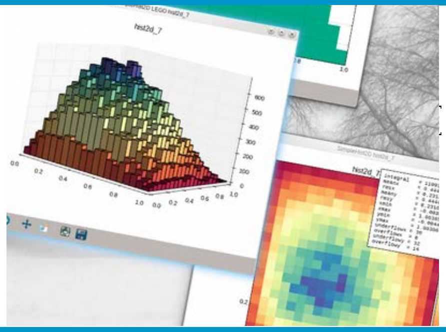


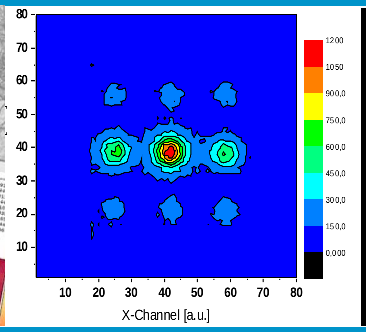


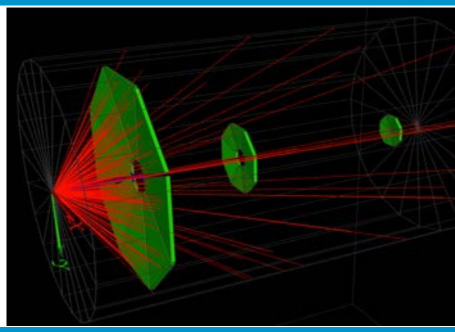












ESS Partners on Detectors

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EUROPEAN SPALLATION SOURCE

ILL

CERN

SNS
SPALLATION NEUTRON SOURCE

LINKÖPING UNIVERSITY

ESS bilbao

LUNDS UNIVERSITET

UNIVERSITAS BERGENSIS

Science & Technology Facilities Council

Science & Technology Facilities Council
ISIS

BNC
Budapest Neutron Centre

Wigner

Consiglio Nazionale Ricerche

IFP

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

INFN
Istituto Nazionale di Fisica Nucleare

JCNS
Jülich Centre for Neutron Science

DENEX
Detektoren für Neutronen GmbH
Stöteroggestraße 71 | 21339 Lüneburg
Tel.: +49 (0) 4131/248932

IEAP

CDT GmbH
CASCADE Detector Technologies

FZÚ

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

Risø DTU
National Laboratory for Sustainable Energy

ideas

COSYLAB

IFE
Institute for Energy Technology

JÜLICH
FORSCHUNGSZENTRUM

Mittuniversitetet
MID SWEDEN UNIVERSITY

icnd.org {

FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz

HZB Helmholtz Zentrum Berlin

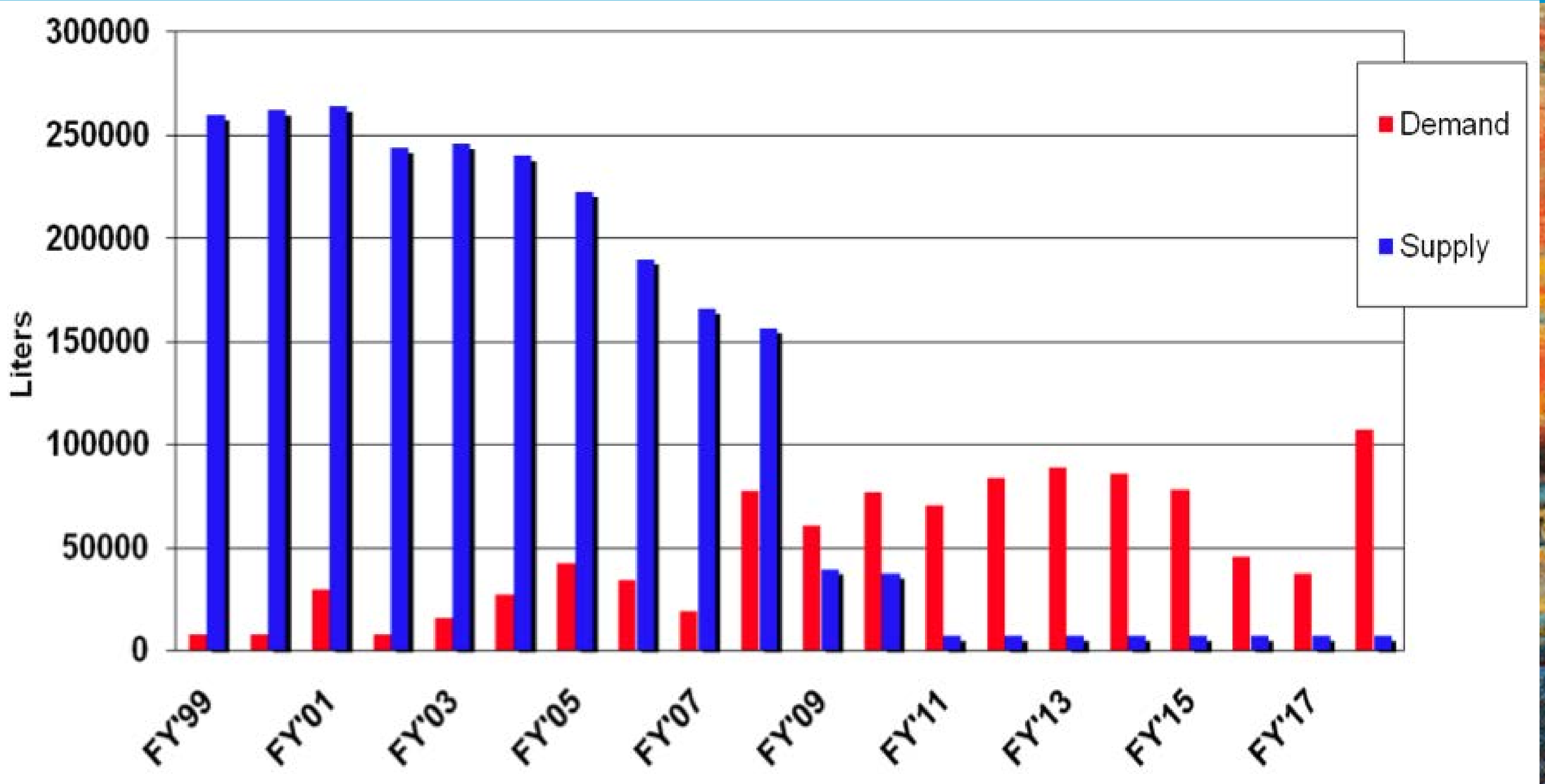
ISIS

J-PARC

NEUTRON SCIENCES

INTERNATIONAL COLLABORATION FOR THE DEVELOPMENT OF NEUTRON DETECTORS

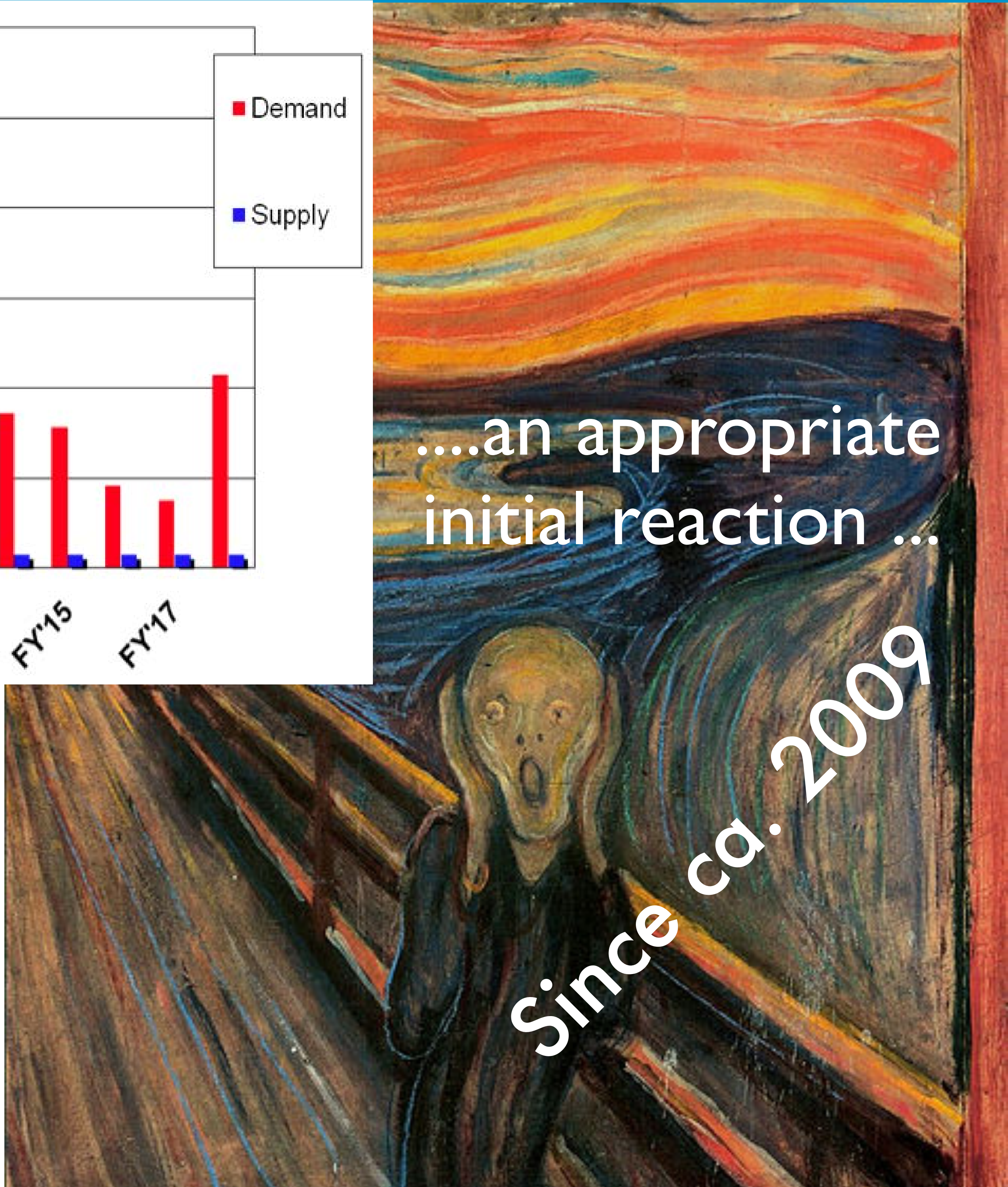
Helium-3 Crisis



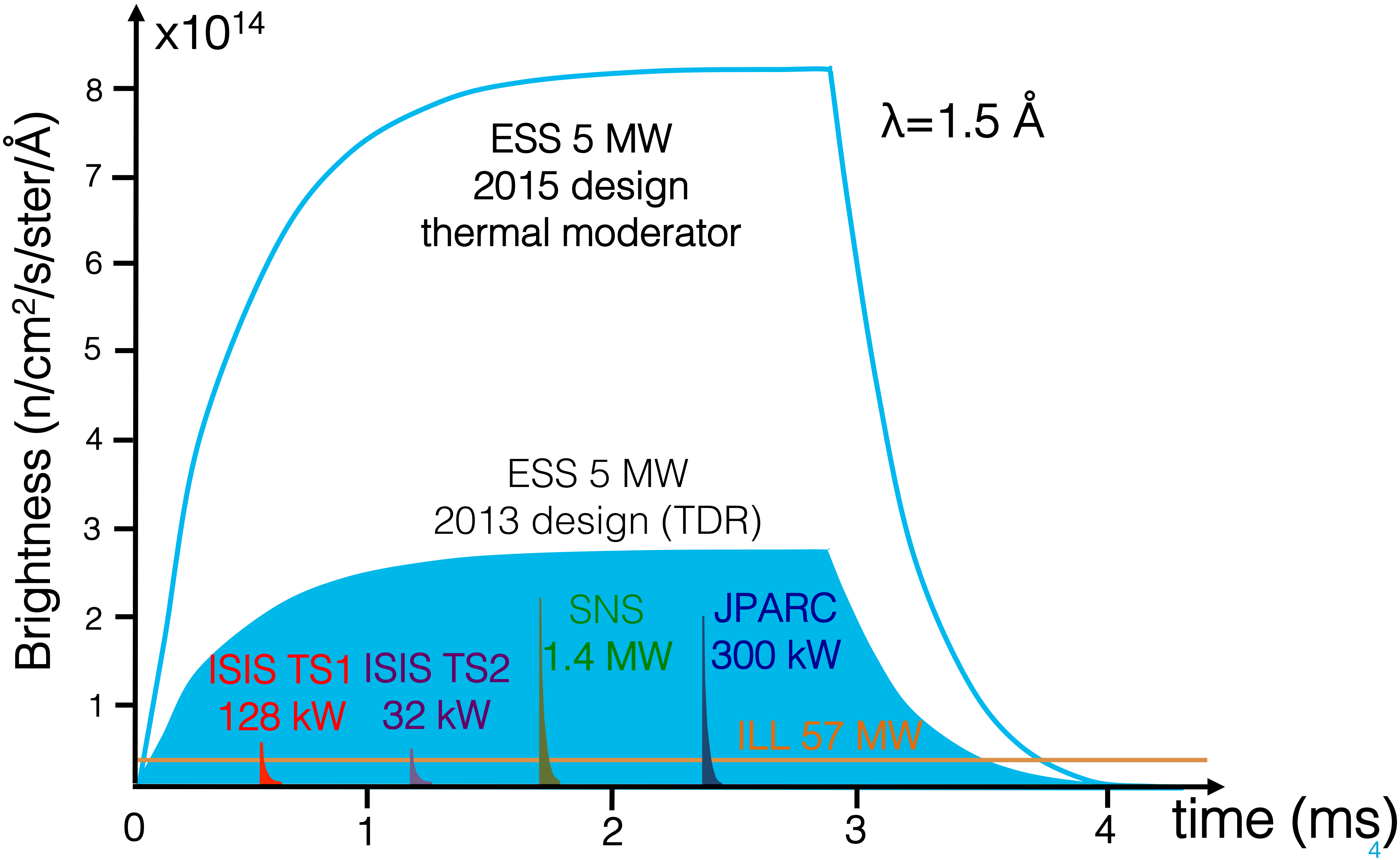
Comment: seems to be some naivety at the moment as stocks are being emptied rapidly

Aside ... maybe He-3 detectors are anyway not what is needed for ESS? eg rate, resolution reaching the limit ...

Crisis or opportunity ... ?



Challenge for Rate



The ESS site
2011


The ESS site
April 2018

ESS Neutron Instrument positions: December 2016

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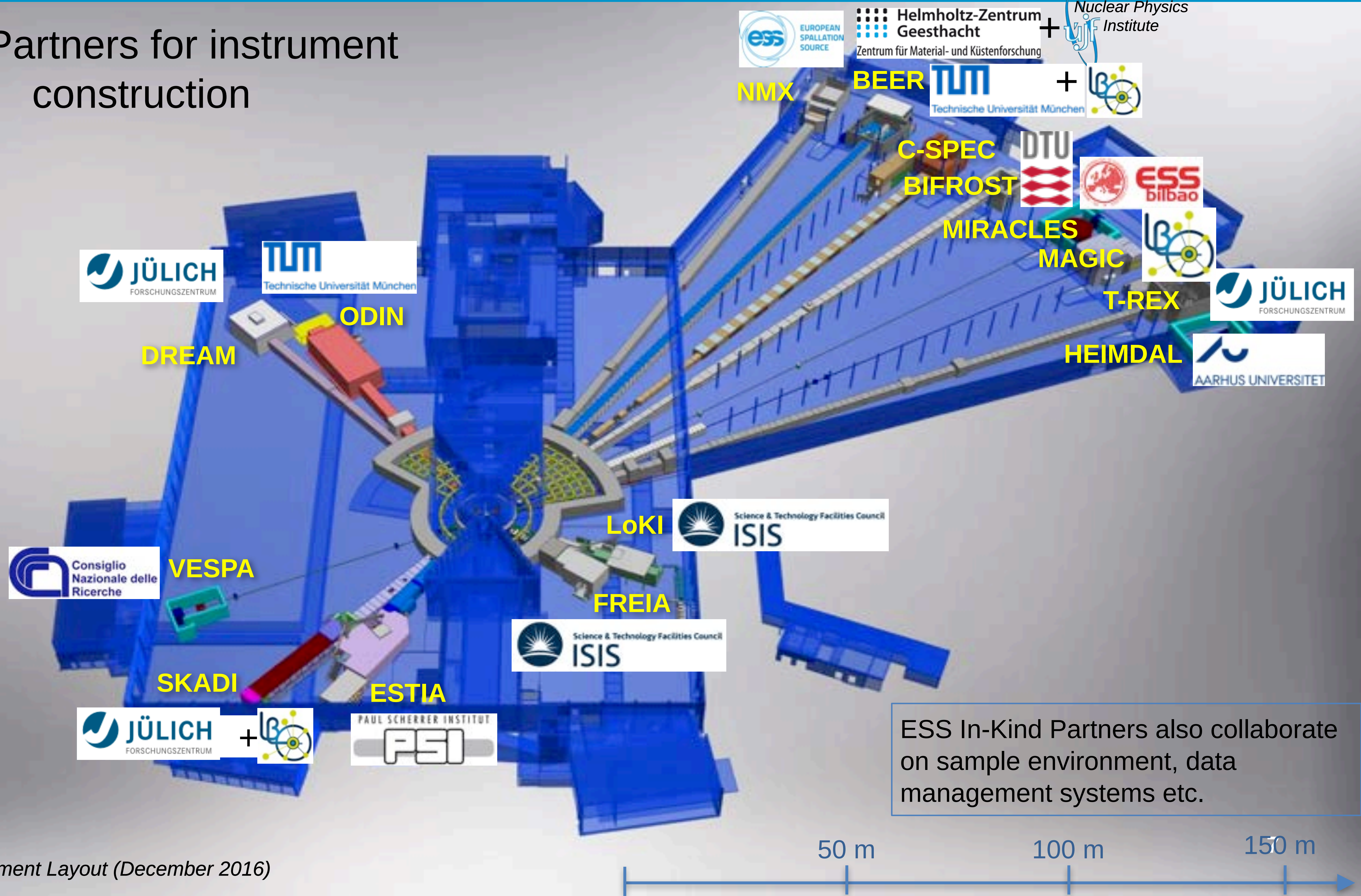
Lead Partners for instrument construction



ESS In-Kind Partners also collaborate on sample environment, data management systems etc.

ESS Instrument Layout (December 2016)

Detectors

What can be done with this brightness

Instrument Design	Implications for Detectors
Smaller samples	Better Resolution (position and time) Channel count
Higher flux, shorter experiments	Rate capability and data volume
More detailed studies	Lower background, lower S:B Larger dynamic range
Multiple methods on 1 instrument Larger solid angle coverage	Larger area coverage Lower cost of detectors

Also: scarcity of Helium-3 …

Developments required for detectors for new Instruments

Requirements Challenge for Detectors for ESS: *beyond detector present state-of-the art*

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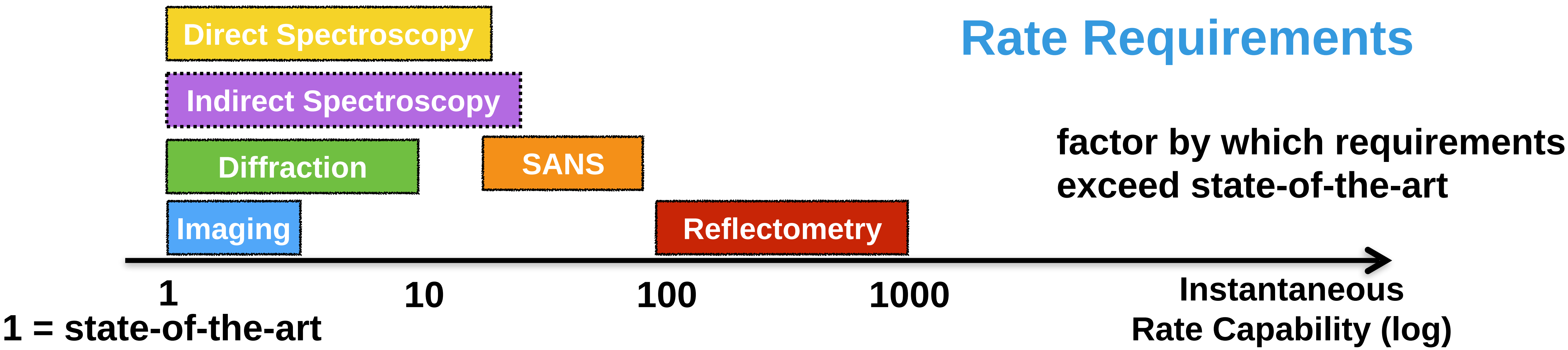

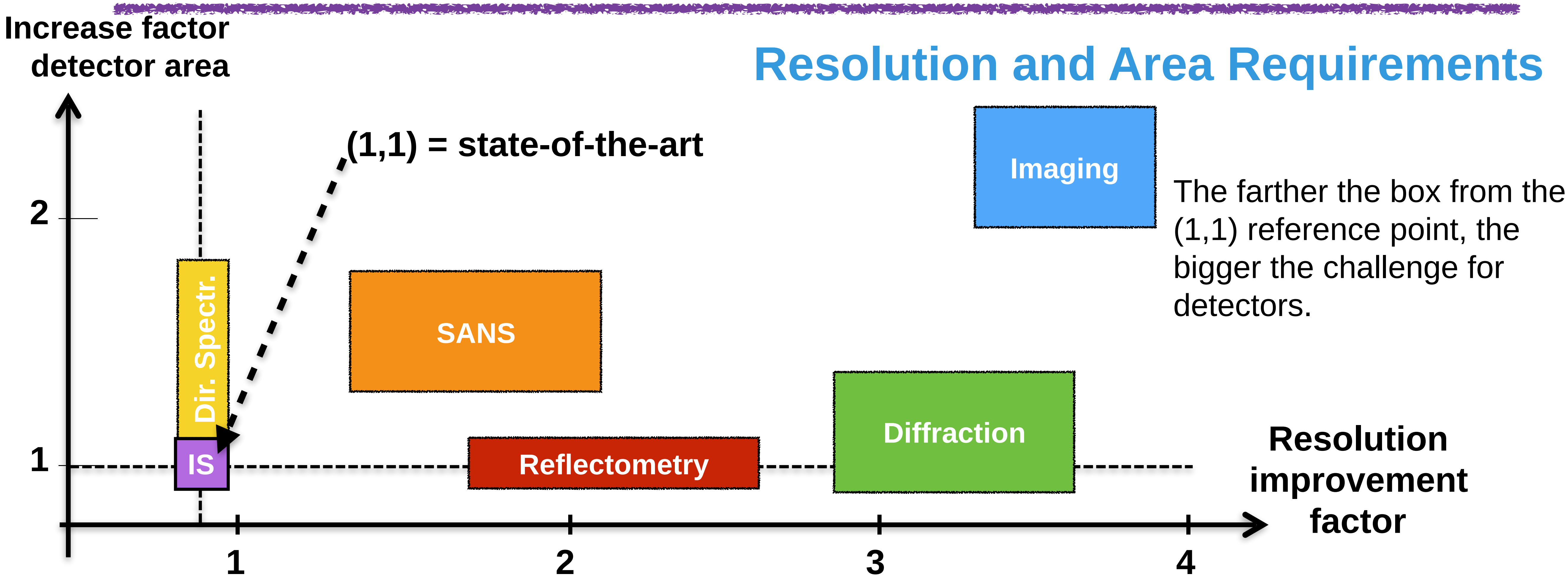

Detectors for ESS: design choices for 16 instruments

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Instrument class	Instrument sub-class	Instrument	Key requirements for detectors	Preferred detector technology	Ongoing developments
Large-scale structures	Small Angle Scattering	SKADI	Pixel size, count-rate, area	Pixellated Scintillator	SonDe (EU SonDe)
		LOKI		10B-based	BandGem
	Reflectometry	FREIA	Pixel size, count-rate	10B-based	MultiBlade (EU BrightnESS) * *
		ESTIA			
Diffraction	Powder diffraction	DREAM	Pixel size, count-rate	10B-based	Jalousie
		HEIMDAL		10B-based	Jalousie
	Single-crystal diffraction	MAGIC	Pixel size, count-rate	10B-based	Jalousie
		NMX	Pixel size, large area	Gd-based	GdGEM uTPC(EU
Engineering	Strain scanning	BEER	Pixel size, count-rate	10B-based	AmCLD, A1CLD
	Imaging and tomography	ODIN	Pixel size	Scintillators, MCP, wire chambers	Various
Spectroscopy	Direct geometry	C-SPEC	Large area (^{3}He-gas unaffordable)	10B-based	MultiGrid (EU BrightnESS) * * *
		T-REX			
		VOR			
	Indirect geometry	BIFROST	Count-rate	3He-based	He-3 PSD Tubes
		MIRACLES			He-3 PSD Tubes
arXiv:1411.6194		VESPA	Count-rate	3He-based	He-3 PSD Tubes
SPIN-ECHO	Spin-echo	tbd	tbd	3He-based/10B-based	

Good dialogue and close collaboration needed for successful delivery and integration

>10k readout channels:

Instruments moving from 100kPix to >10MPix

Baseline Detector Technologies for Initial Suite

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Detectors for ESS will comprise many different technologies

Imaging: 1 instrument
Various

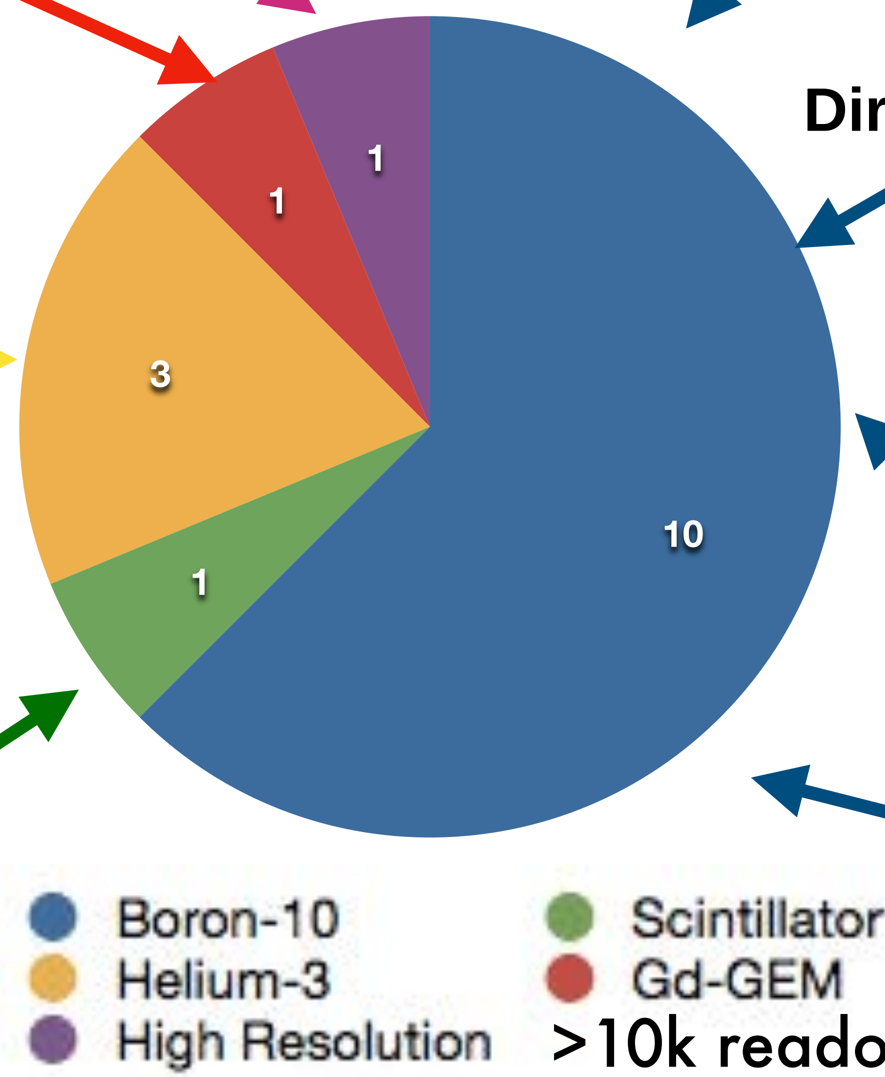
Diffraction: 4 instruments
Jalousie (3)
Am-CLD (1): B-10 MWPC

NMX: 1 instrument
Gd-GEM

Direct Spectroscopy: 3 instruments
Multi-Grid

Indirect Spectroscopy: 3 instruments
He-3 PSD Tubes

Reflectometry: 2 instruments
Multi-Blade



SANS: 1 instruments
SoNDe

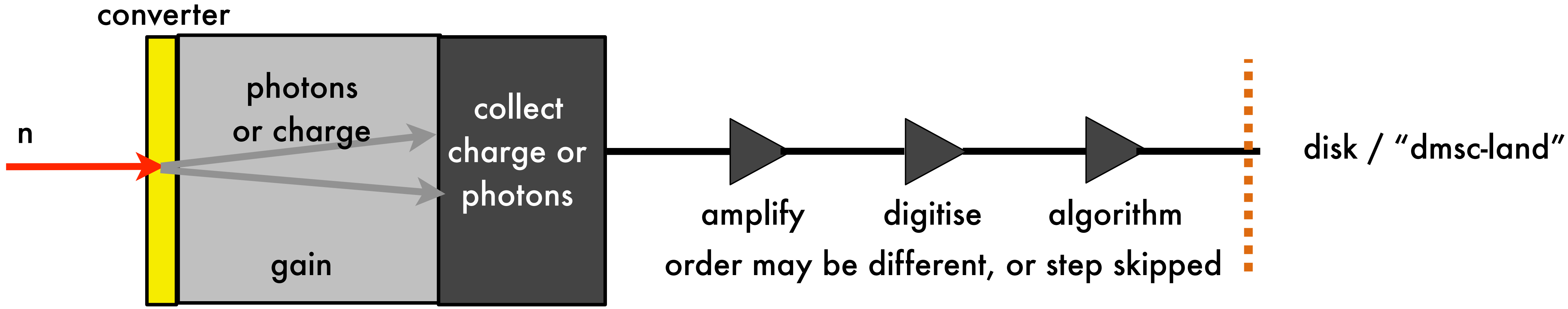
SANS: 1 instrument
BandGEM

>10k readout channels:

Instruments moving from 100kPix to >10MPix

Basic Principle of Neutron Detectors

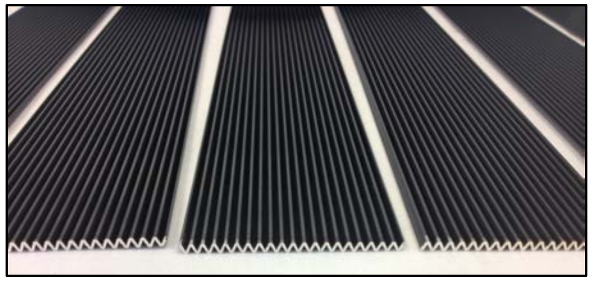
Efficient neutron converters a key component for neutron detectors



"Converter"

"Detector"

"Electronics"



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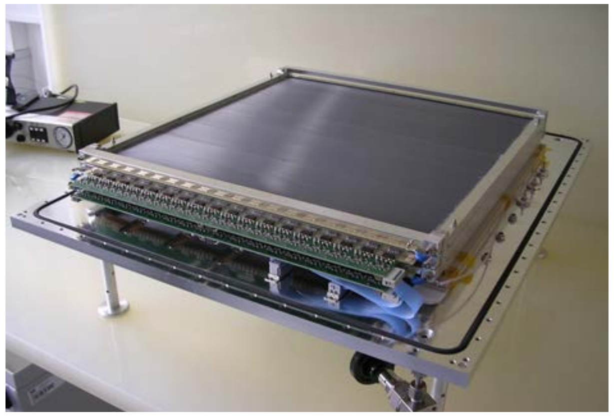

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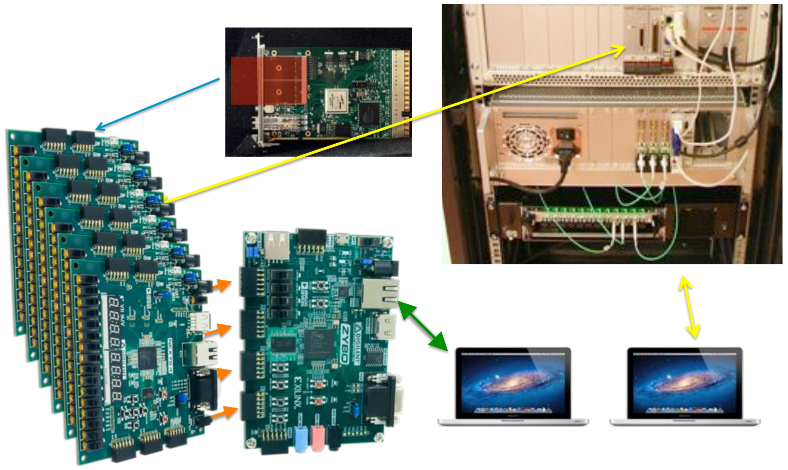

^{10}Boron-based Thin Film Gaseous Detectors

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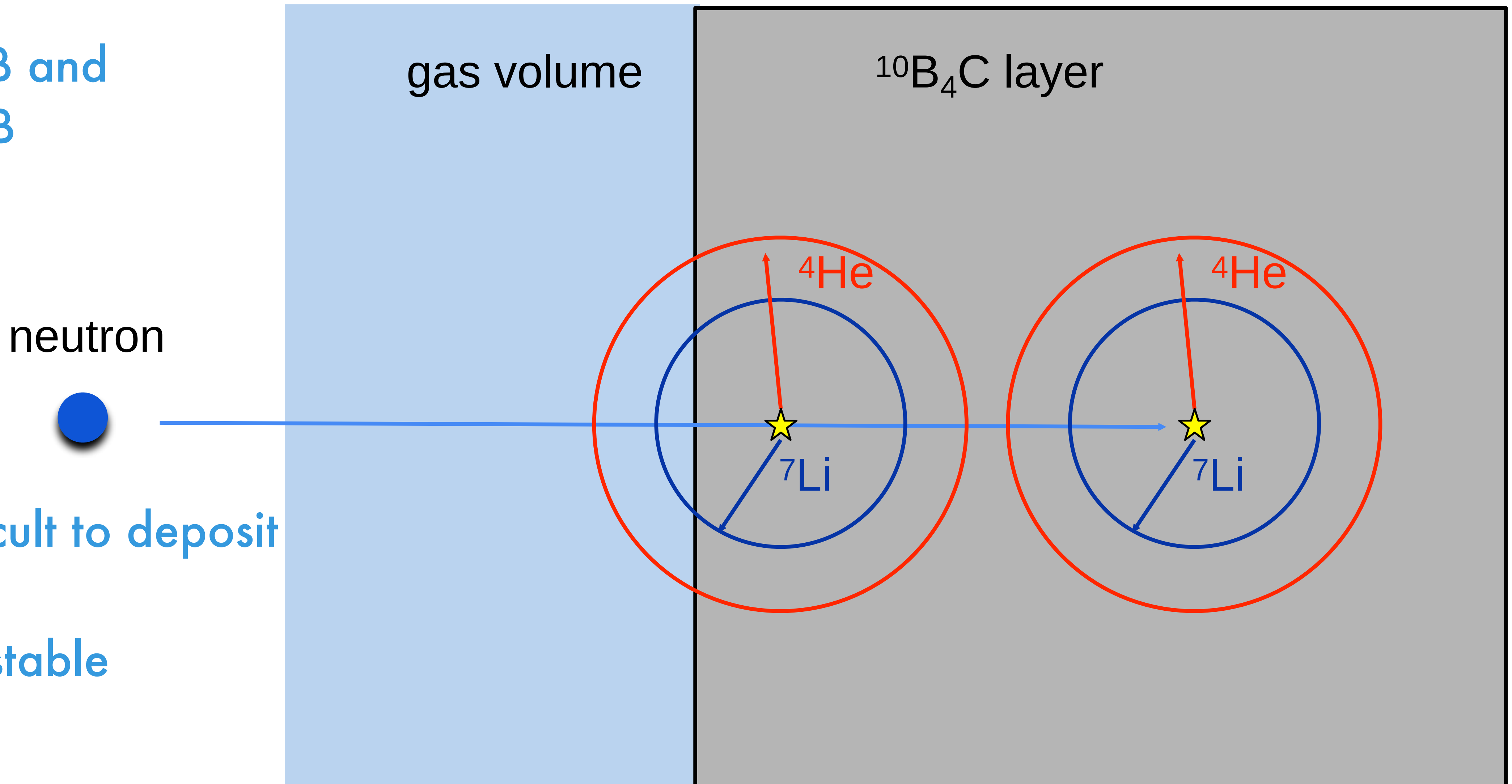
$$
\begin{aligned}
{}^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48MeV\,\gamma\text{-ray} + 2.3\ \ MeV \quad & (94\%) \\
\rightarrow {}^{7}Li + {}^{4}He \qquad\qquad\qquad\qquad + 2.79\,MeV \quad & (6\%)
\end{aligned}
$$

Efficiency limited at ~5% (2.5Å) for a single layer

- ^{nat}B contains
  80 at.% ^{11}B and
  20 at.% ^{10}B



- Boron is difficult to deposit
- Use $^{10}B_4C$
- Conductive, stable

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$^{10}B_4C$ Thin Film Coatings

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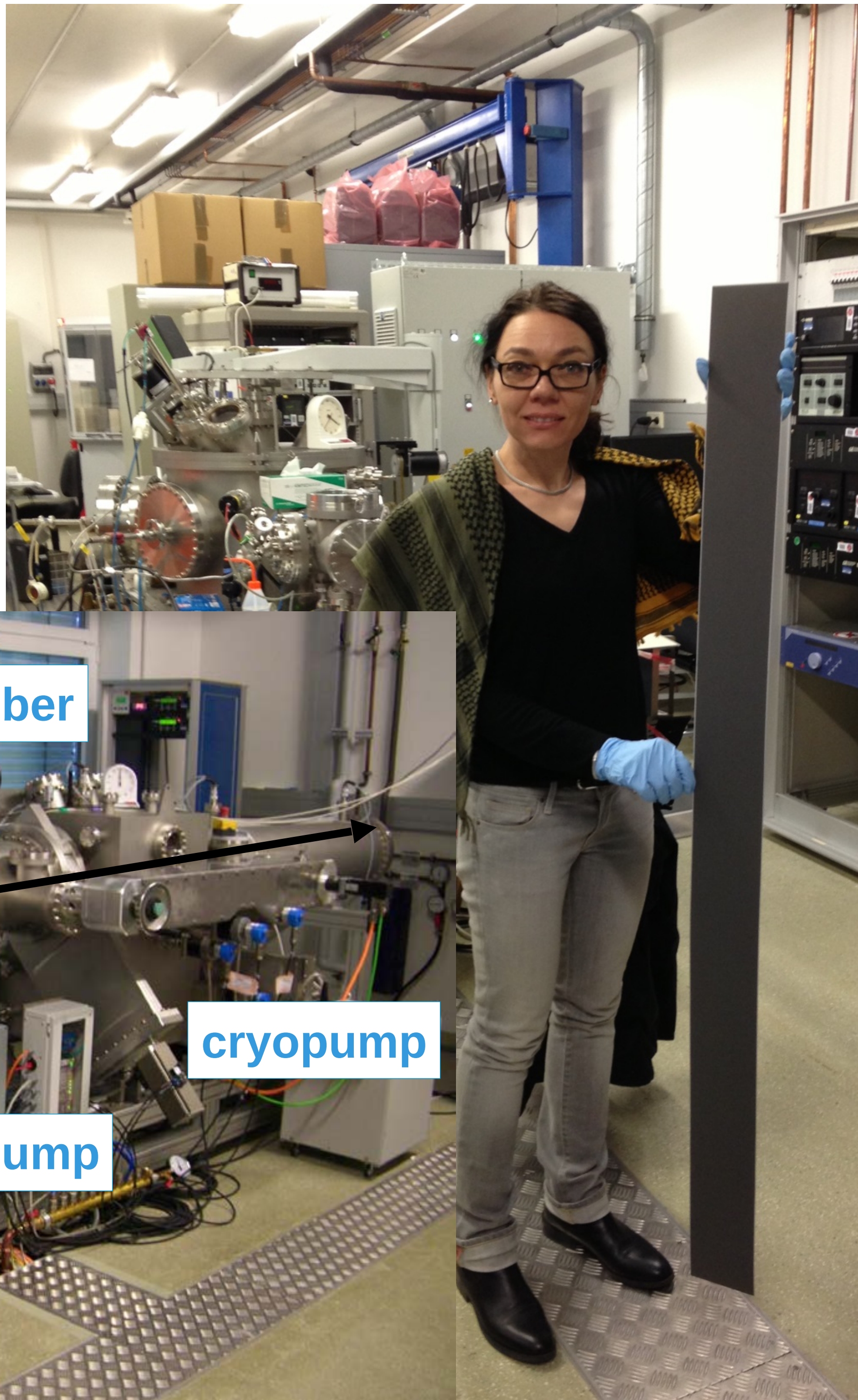
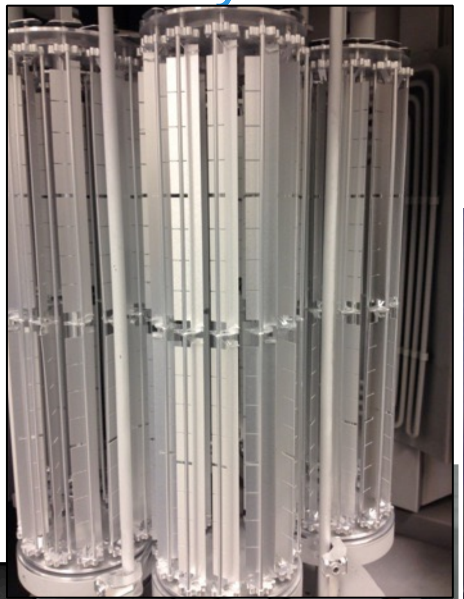
SOLVED

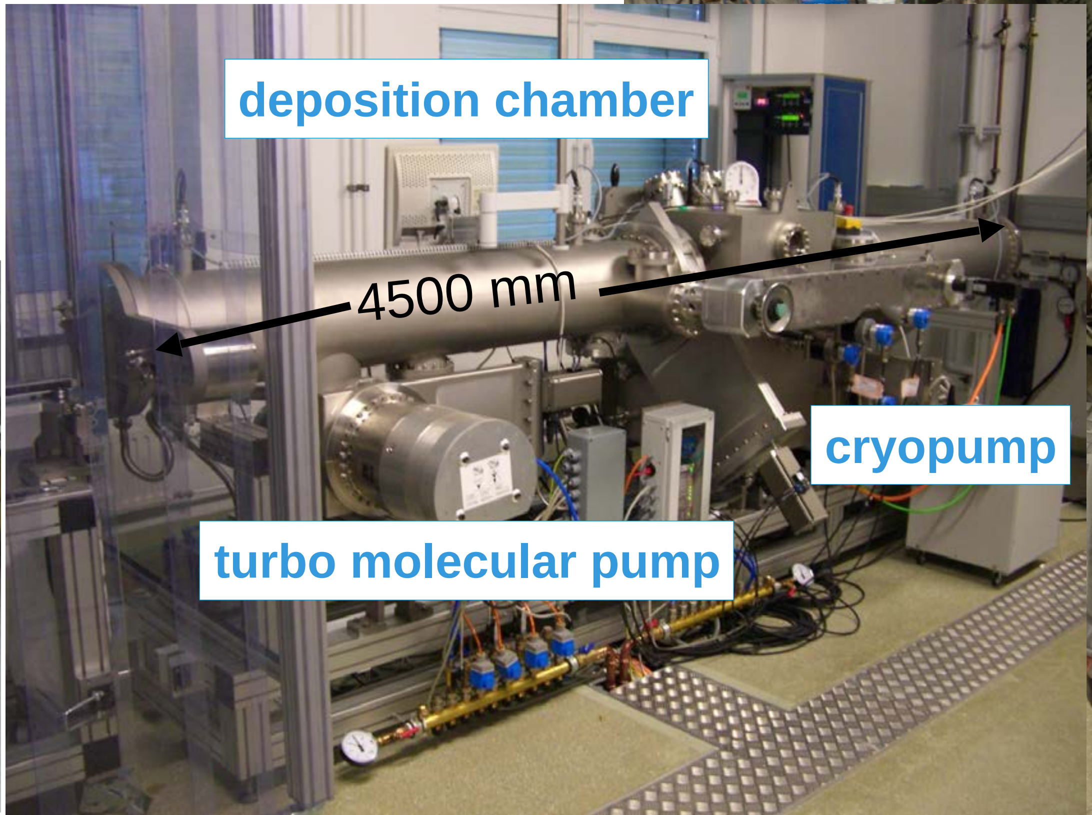
- A number of groups have shown it is possible to deposit large areas of high quality Boron Carbide cheaply
- PVD Magnetron Sputtering
- Deposition parameters highly adaptable
- A very interdisciplinary effort

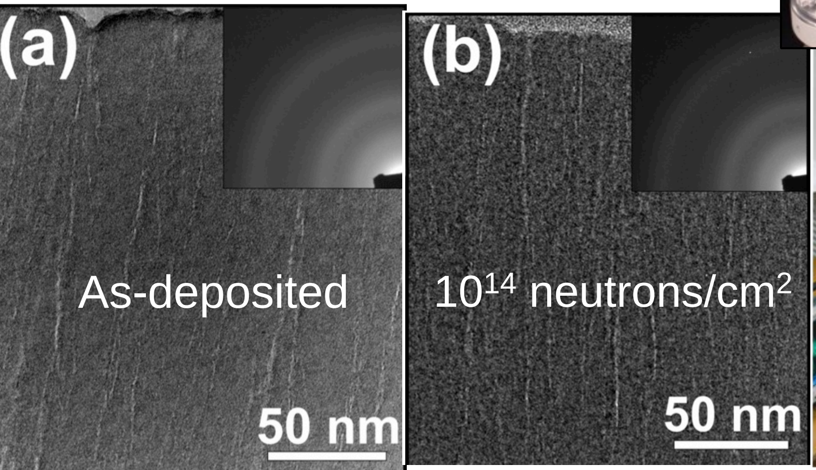
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research



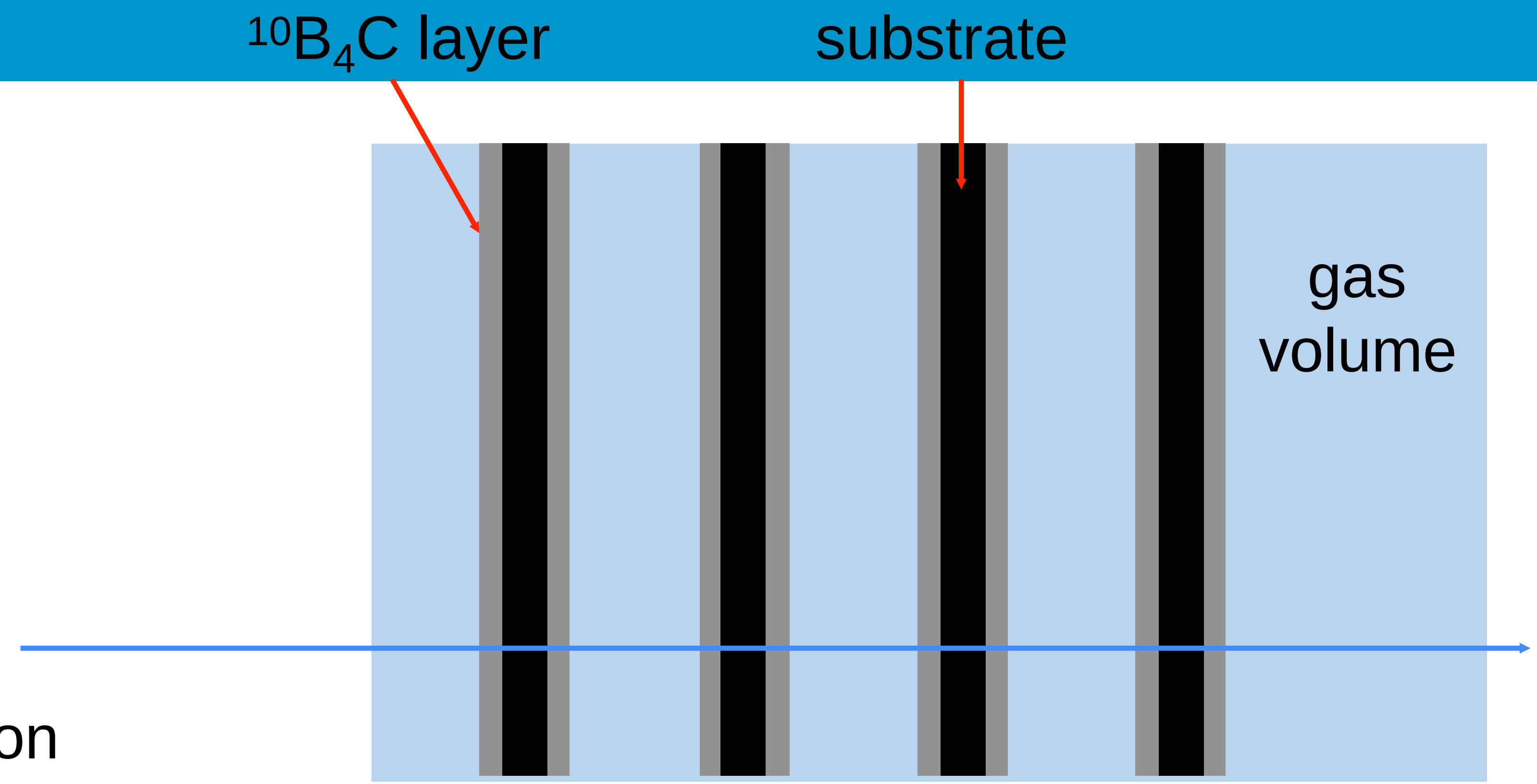
- ESS-Linkoping Deposition Facility
- Industrial Coating Machine
- Capacity: >1000m^2/year coated with $^{10}B_4C$
- **Cheap**







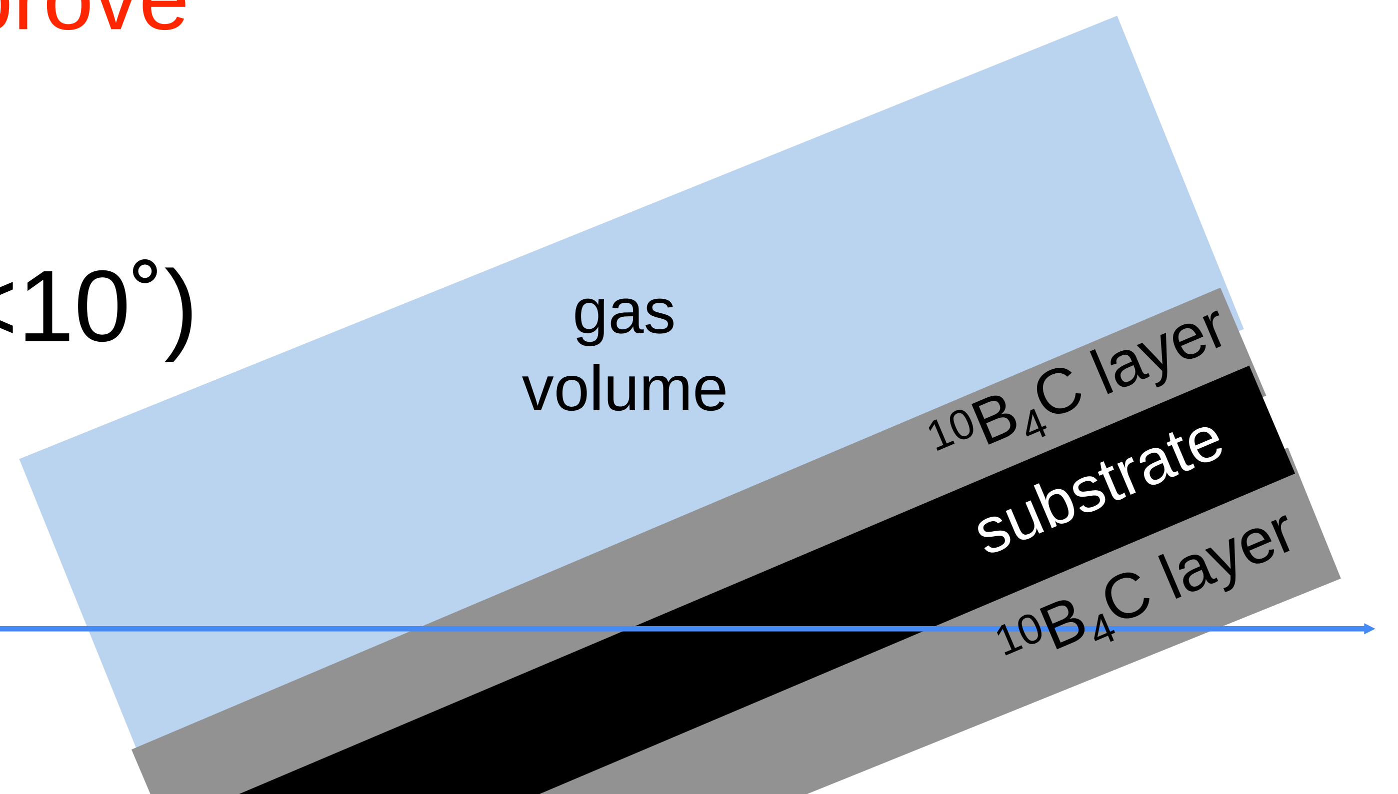
Enhancing the efficiency of ^{10}B-based Neutron Detectors



1 Multi layer

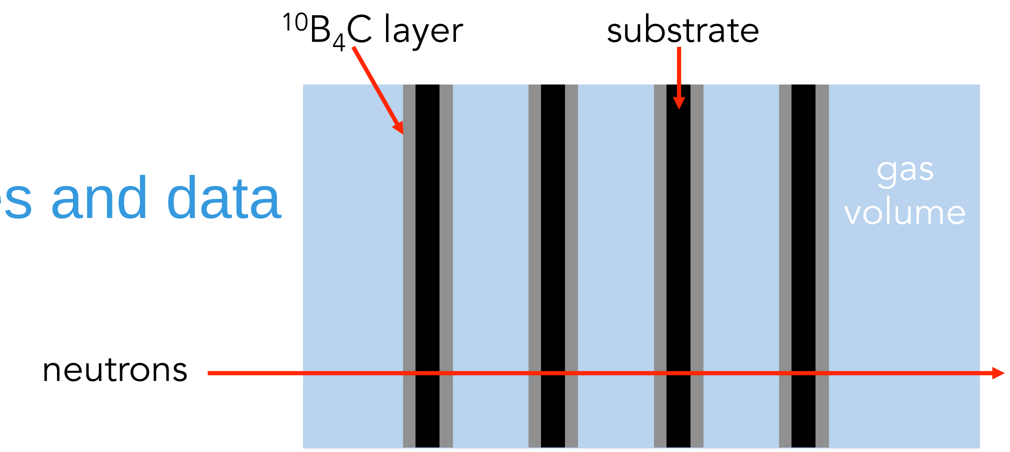
Generic approaches to improve efficiency

2 Grazing angle (<10˚)



Efficiency of ^{10}B Detectors: Perpendicular Geometry

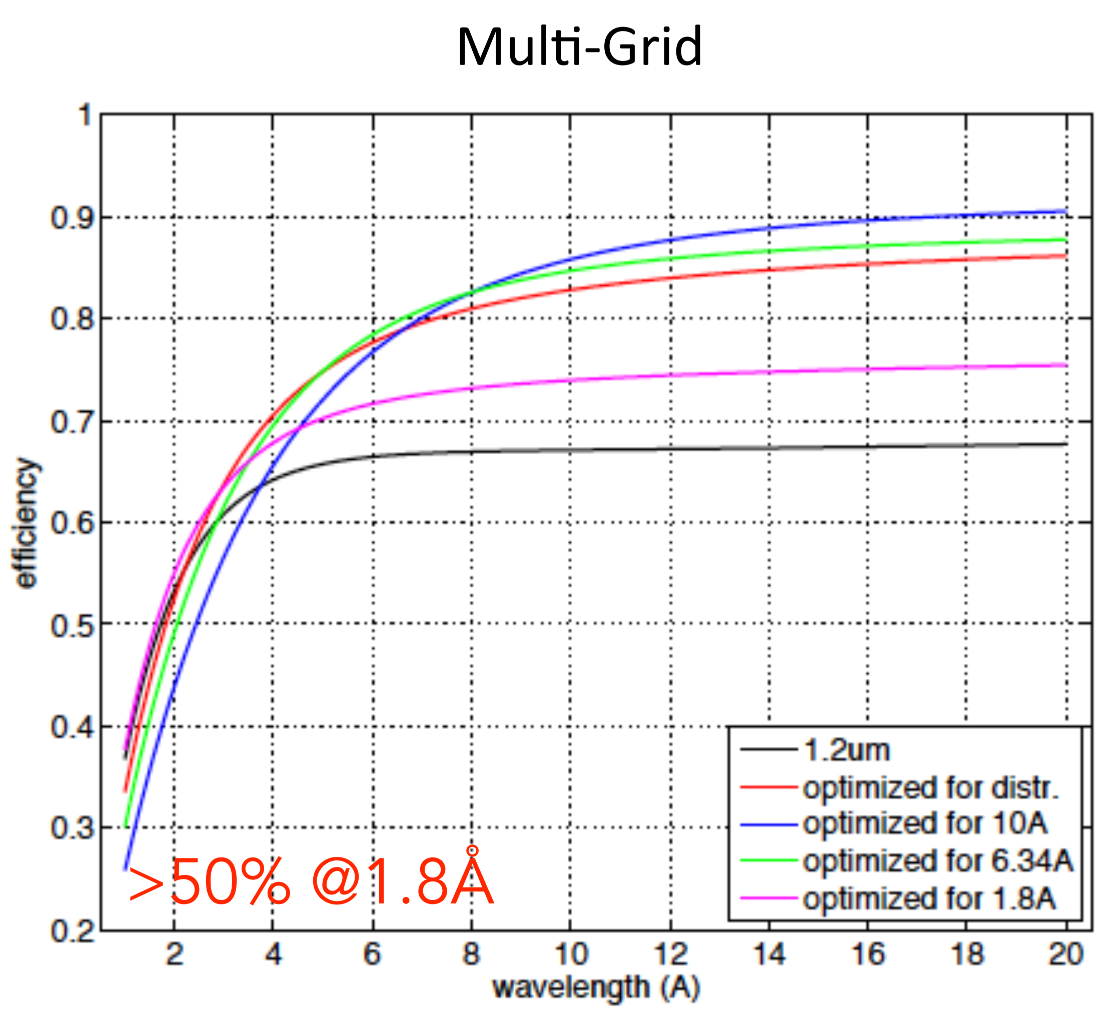
- Single layer is only ca.5%
- Calculations done by many groups
- Analytical calculations extensively verified with prototypes and data
- Details matter: just like for ^{3}He

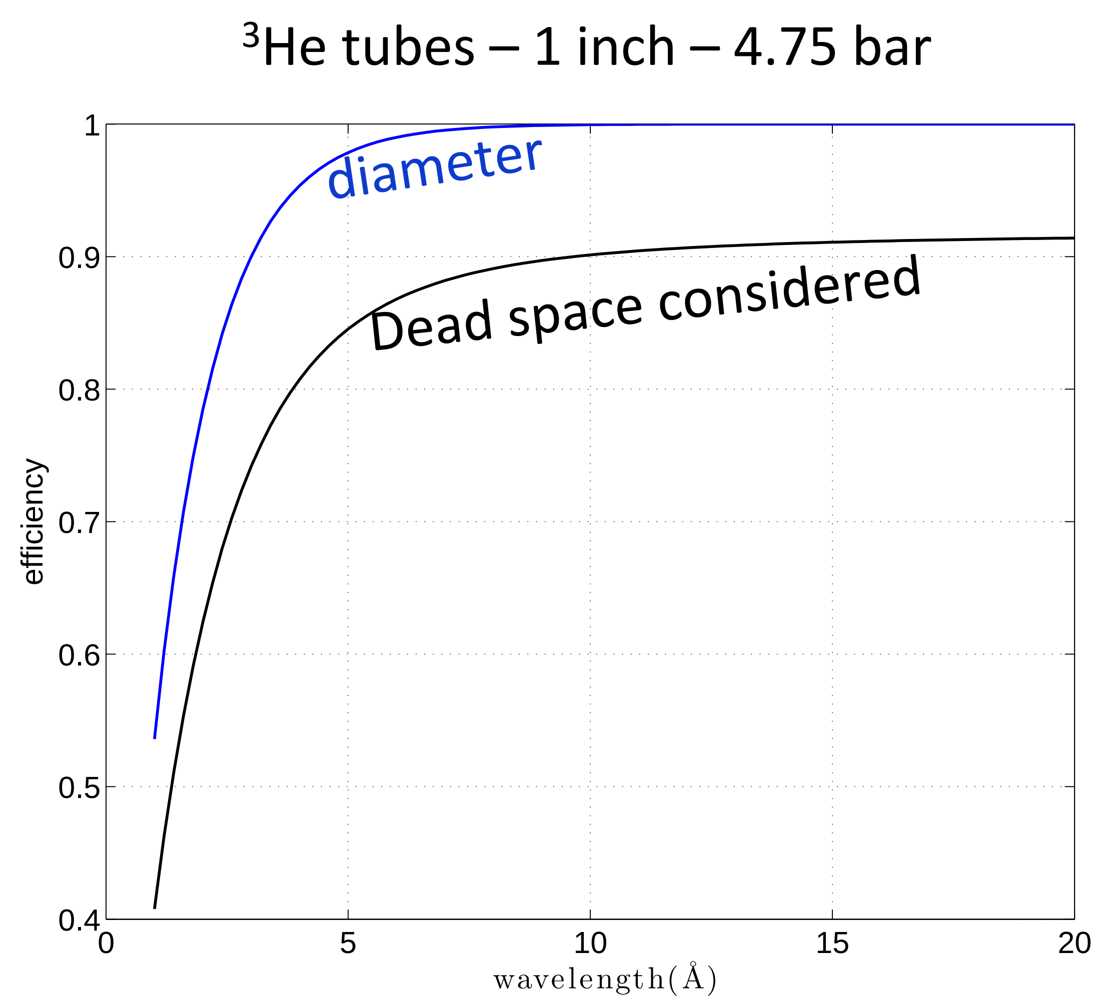


- Multilayer configuration (example):

A Carmona Basanez et al., Decal, a python tool for the efficiency calculation of thermal neutron detectors based on thin-film converters, subm. CPC (2018) arXiv:1801.07124

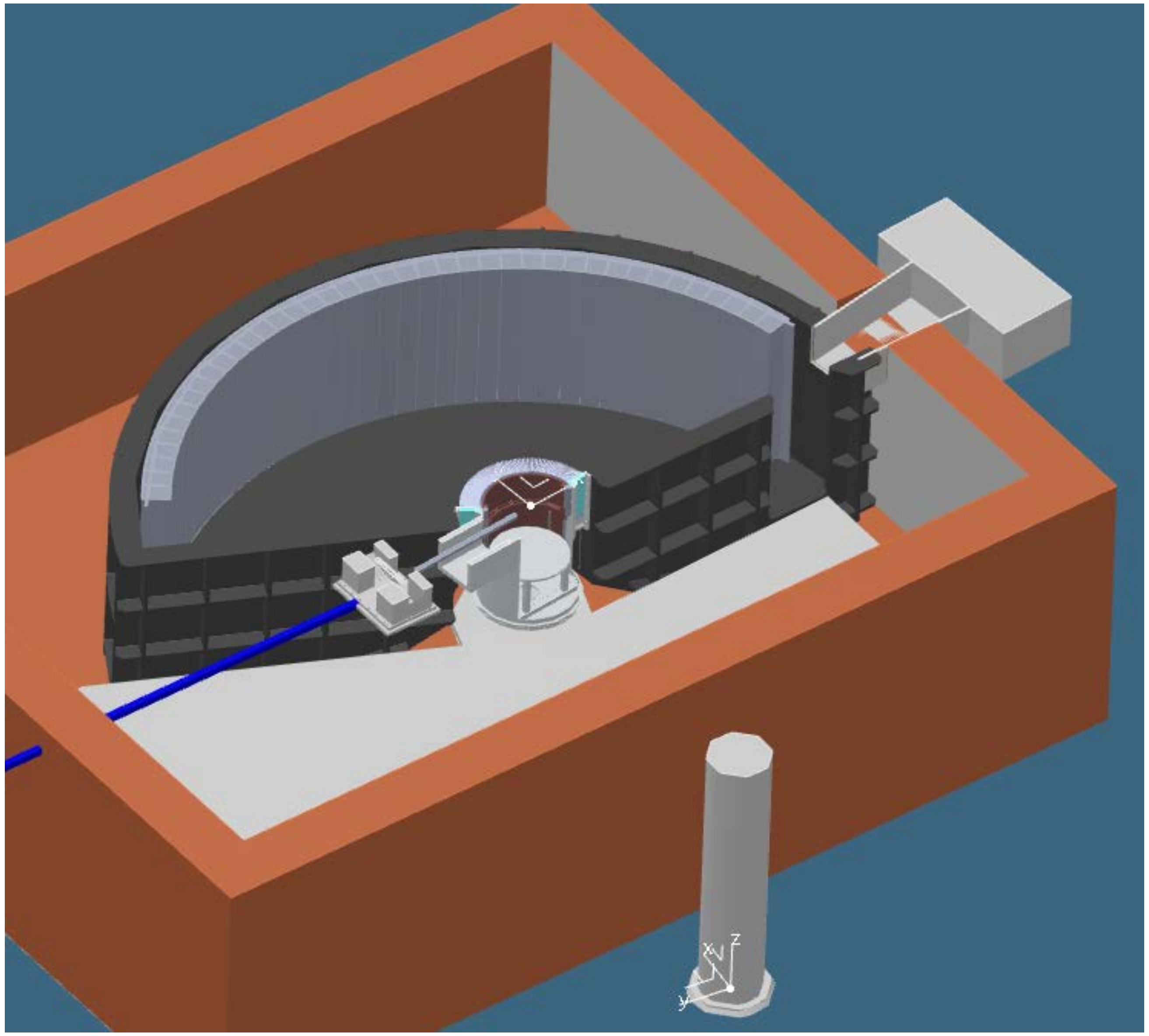
JINST 8 (2013) P04020

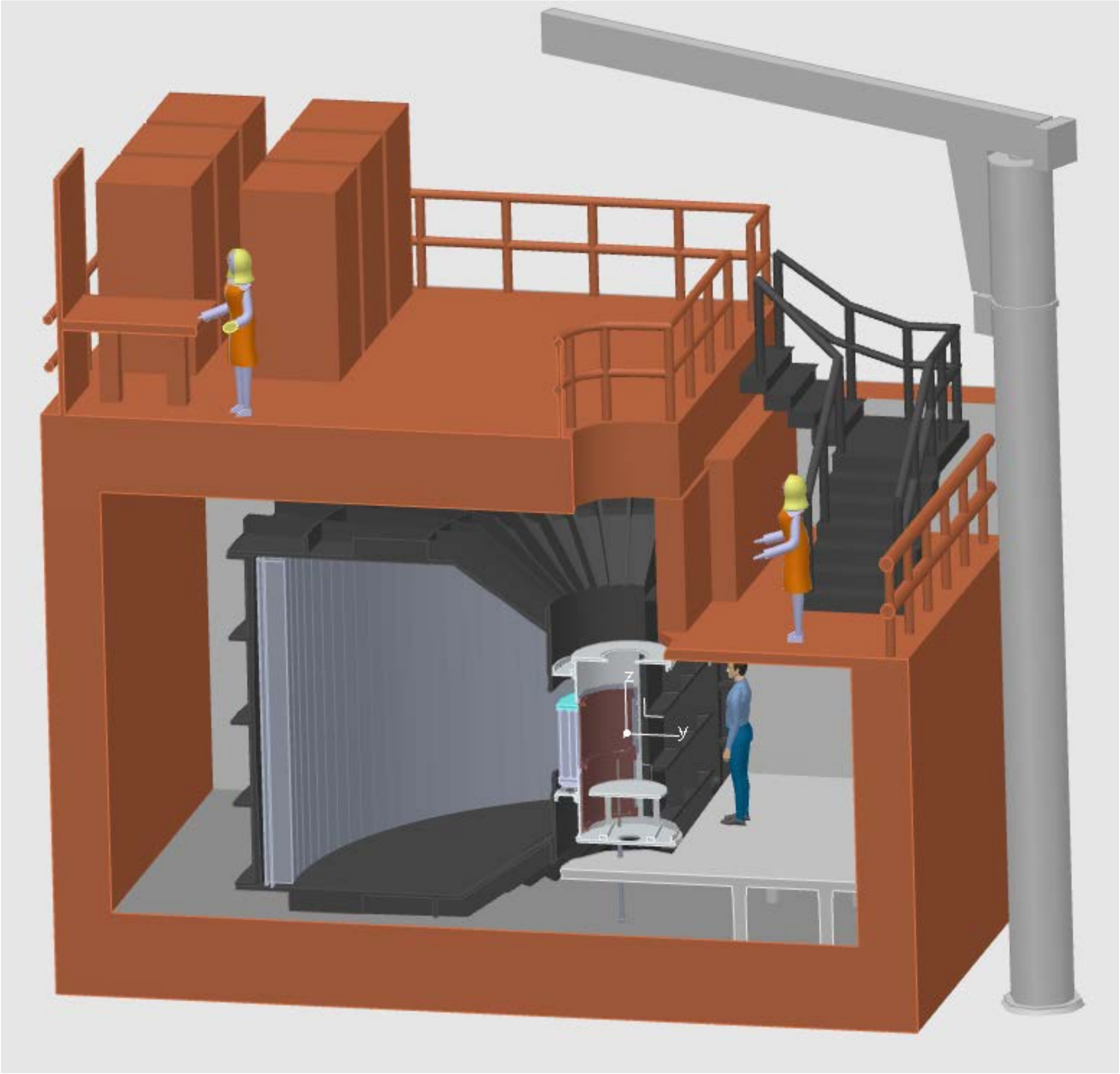




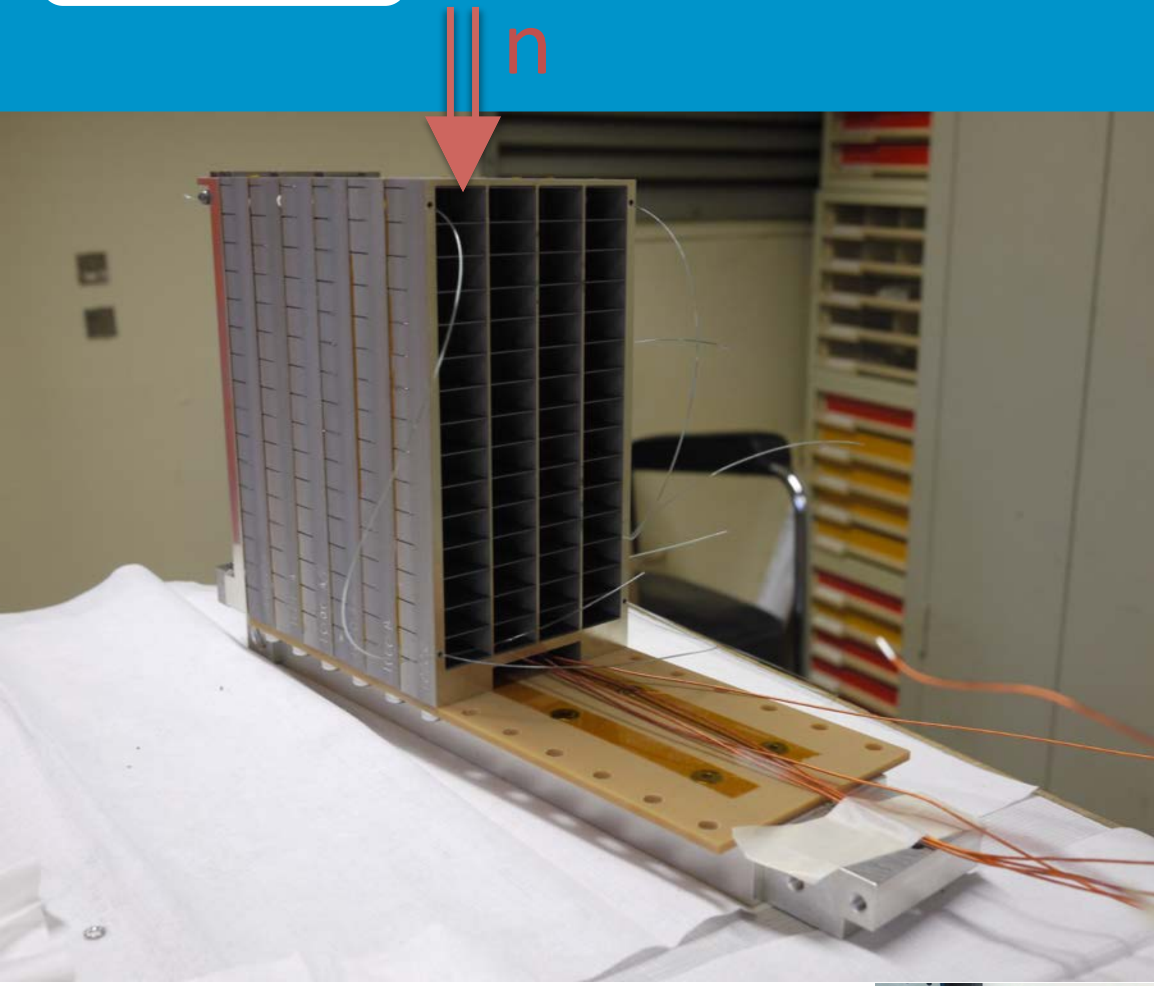
CSPEC at ESS

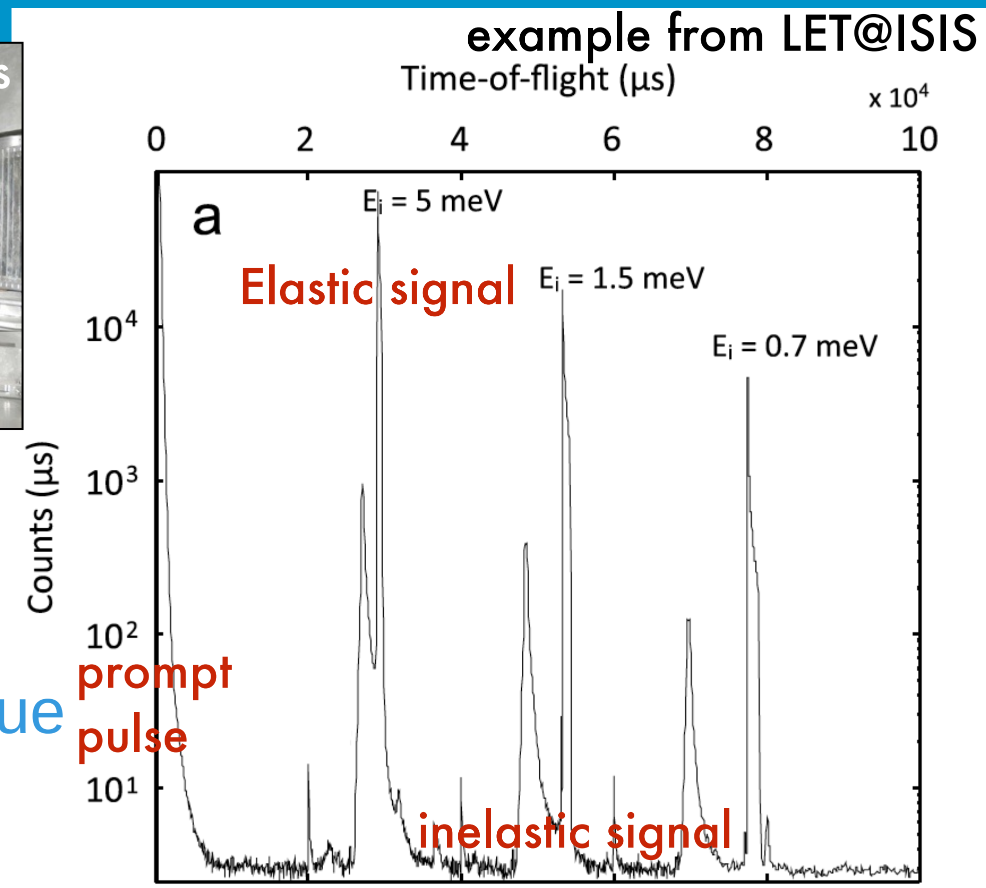
Cold direct geometry chopper spectrometer
0.2 meV < E_i < 20 meV
29m² detector
Horizontal coverage 5° to 135°
Vertical coverage -25° to 25°





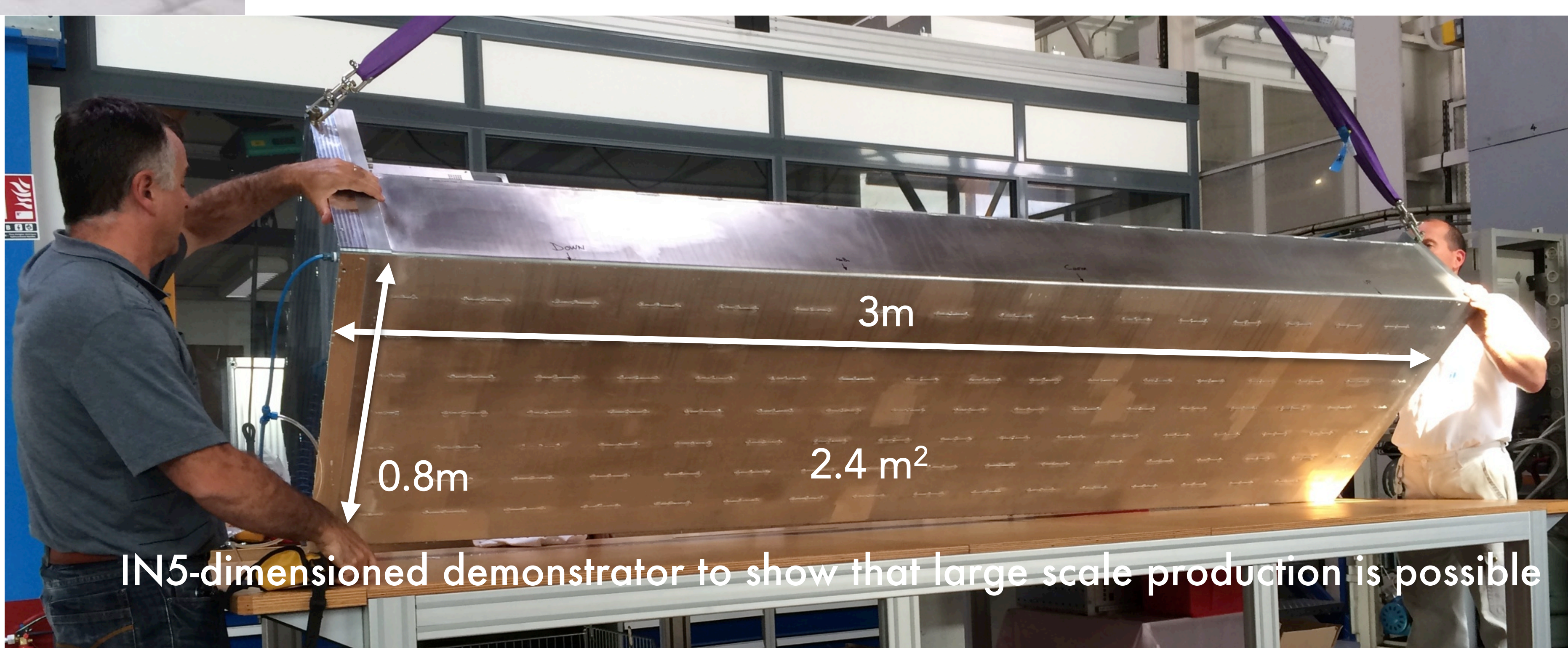
Multi-Grid Detector Design



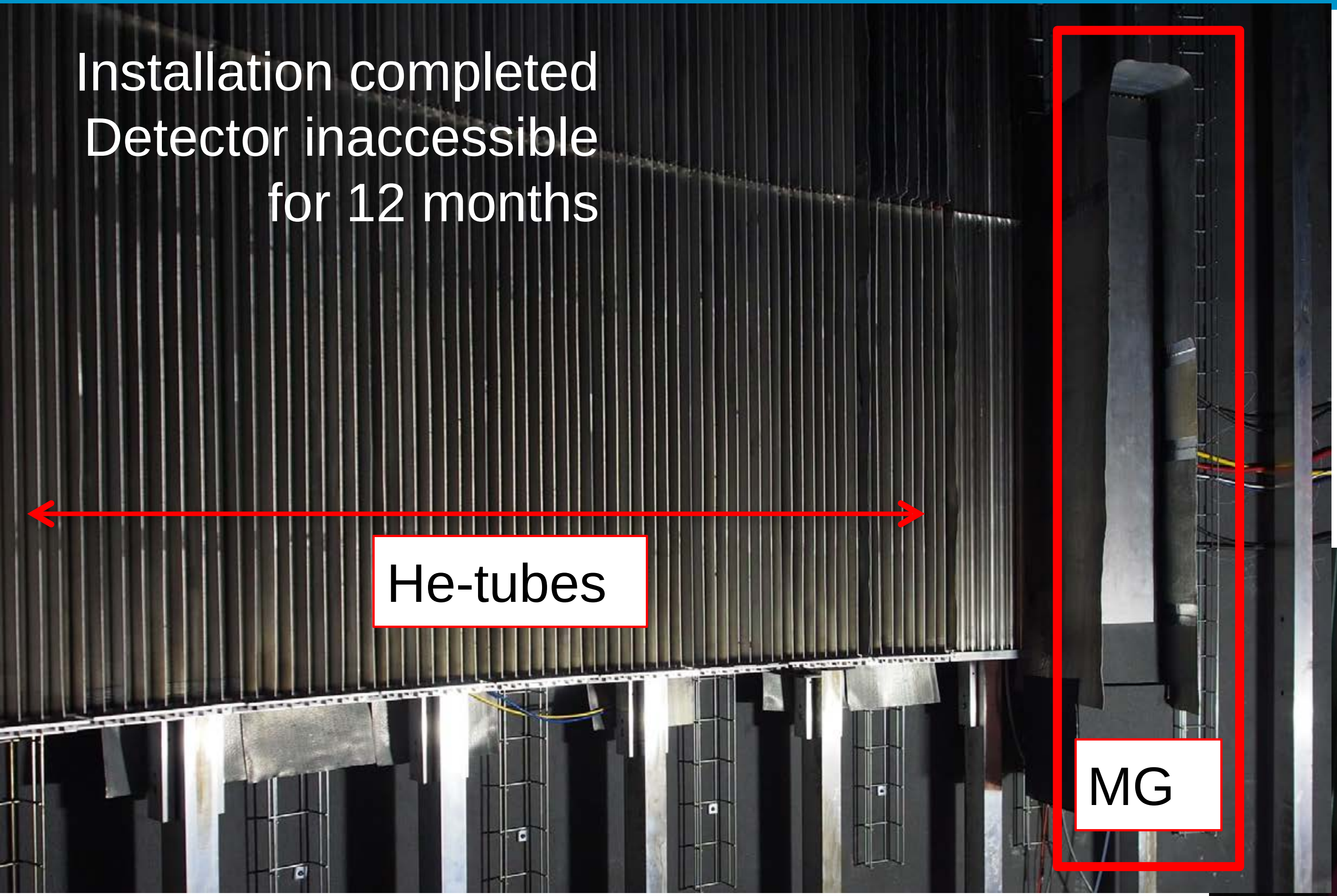


- Very background sensitive technique

- Designed as replacement for He-3 tubes for largest area detectors
- Cheap and modular design
- Possible to build large area detectors again
- 20-50m^2 envisaged for ESS



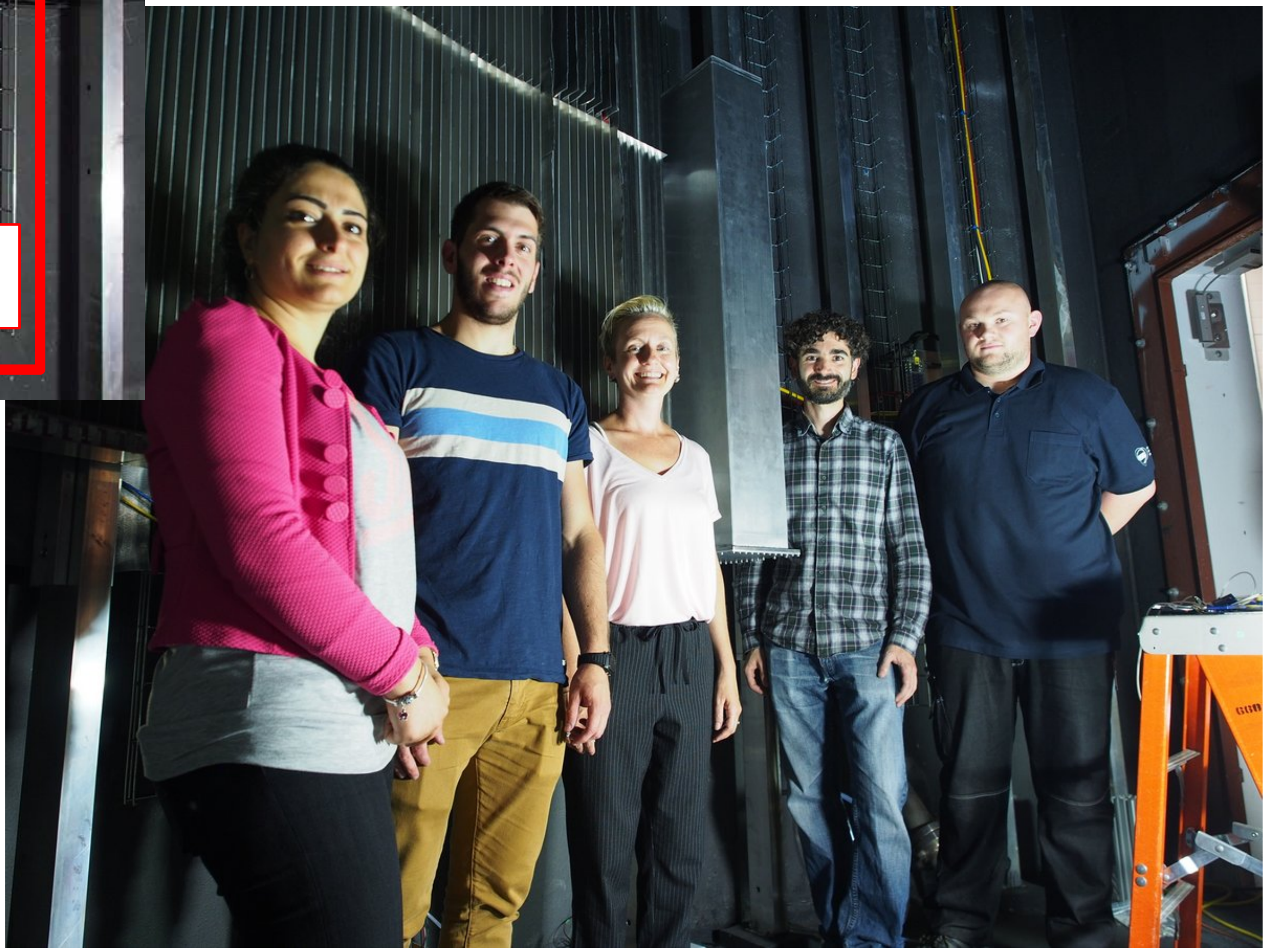
Multi-Grid test at CNCS



B10 Multi-Grid Detector Performance is equivalent to that of He-3 detectors

A.Khaplanov et al. ***"Multi-Grid Detector for Neutron Spectroscopy: Results Obtained on Time-of-Flight Spectrometer CNCS"*** **https://arxiv.org/abs/1703.03626 2017 JINST 12 P04030**

- Test side-by-side with existing technology in world leading instrument
- Realistic conditions
- "Science" or application performance
- 2 different technologies on the same instrument



Construction of MG.CNCS in Lund

LINKÖPING UNIVERSITY

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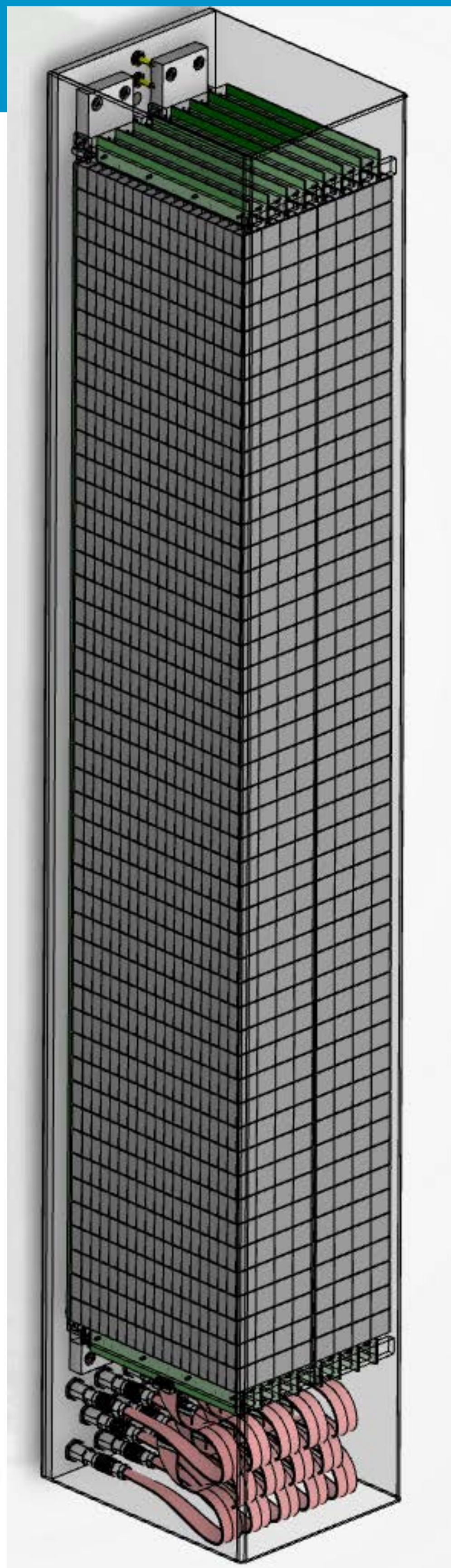
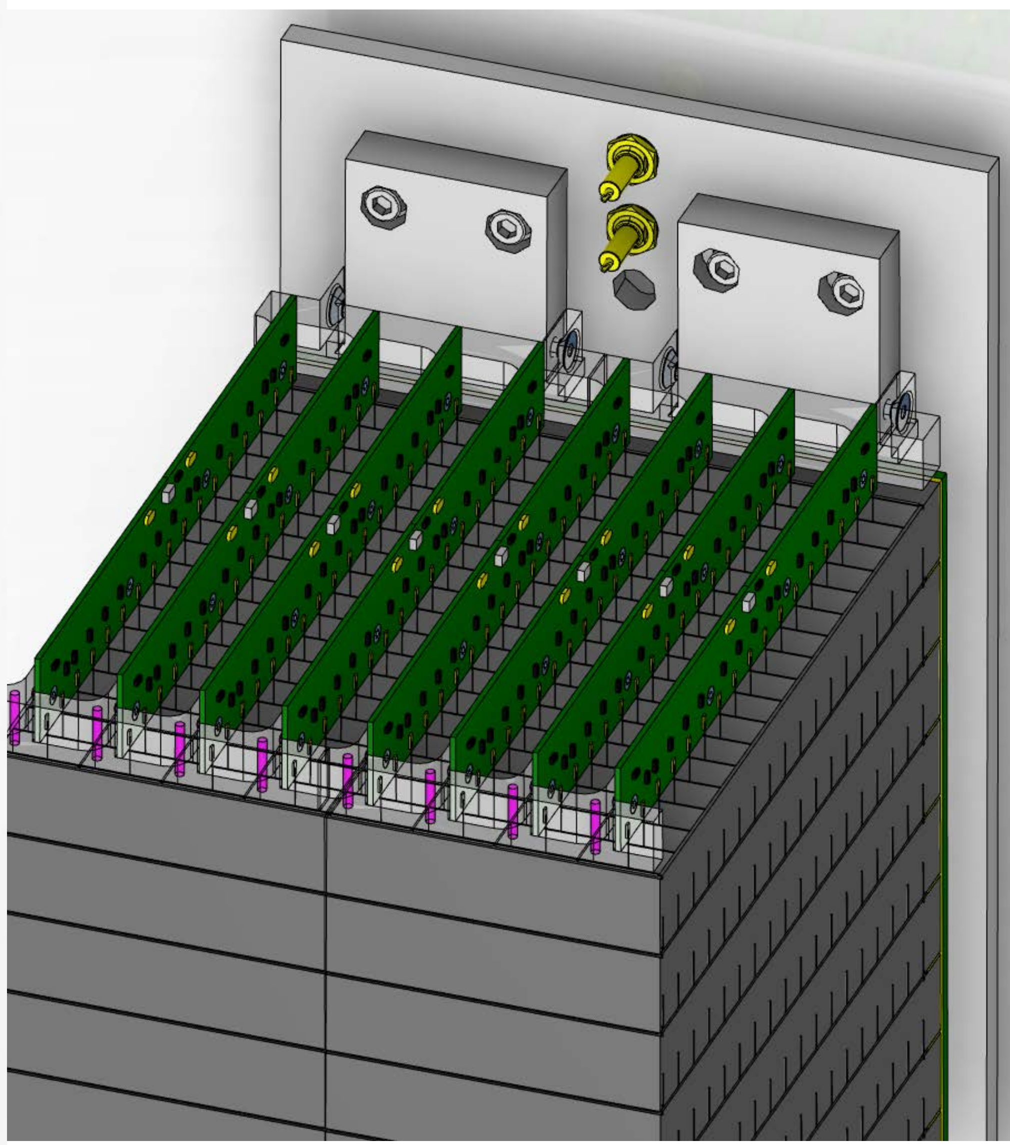
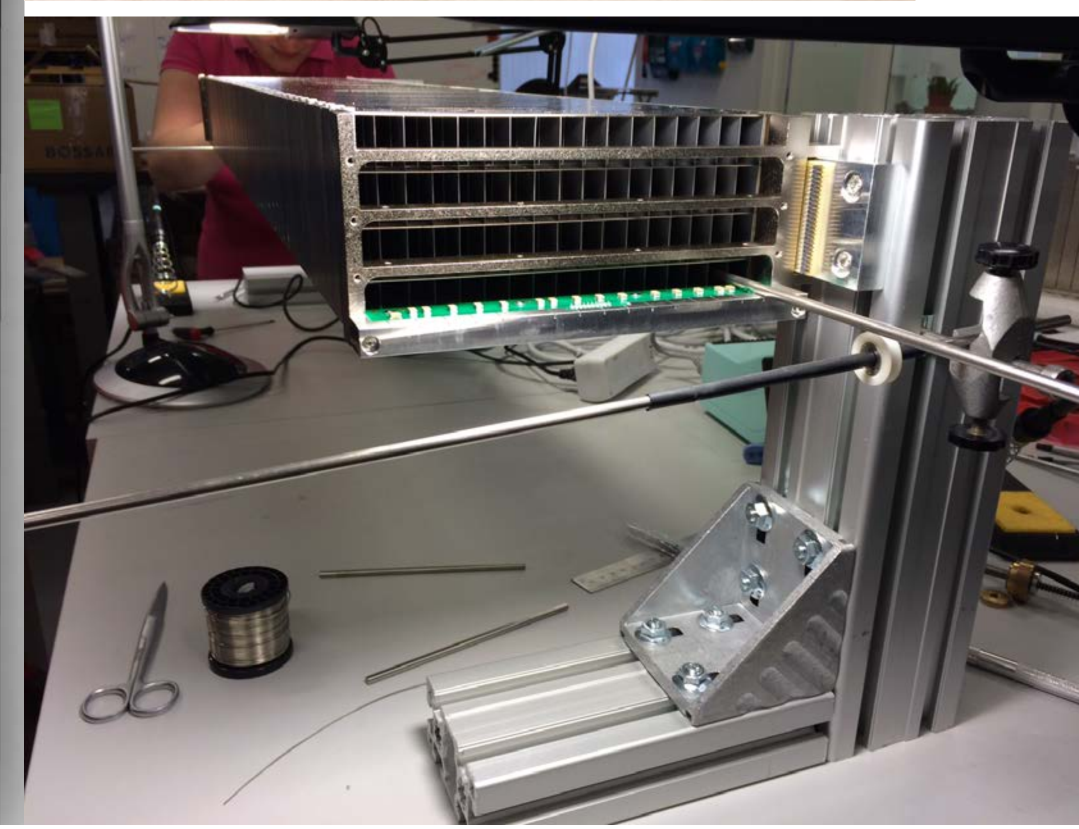
brightness

NEUTRONS FOR SCIENCE®

1.1m

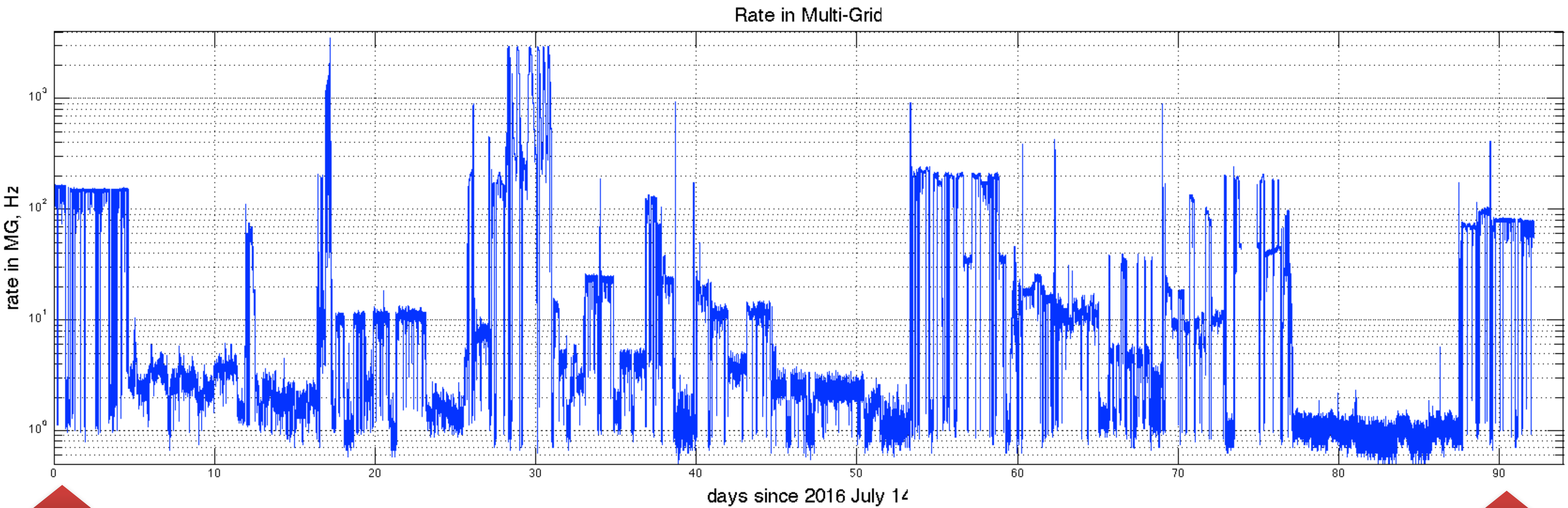






Operation since 2016-07-14

Operation between July 2016 - June 2017



First day

90 days

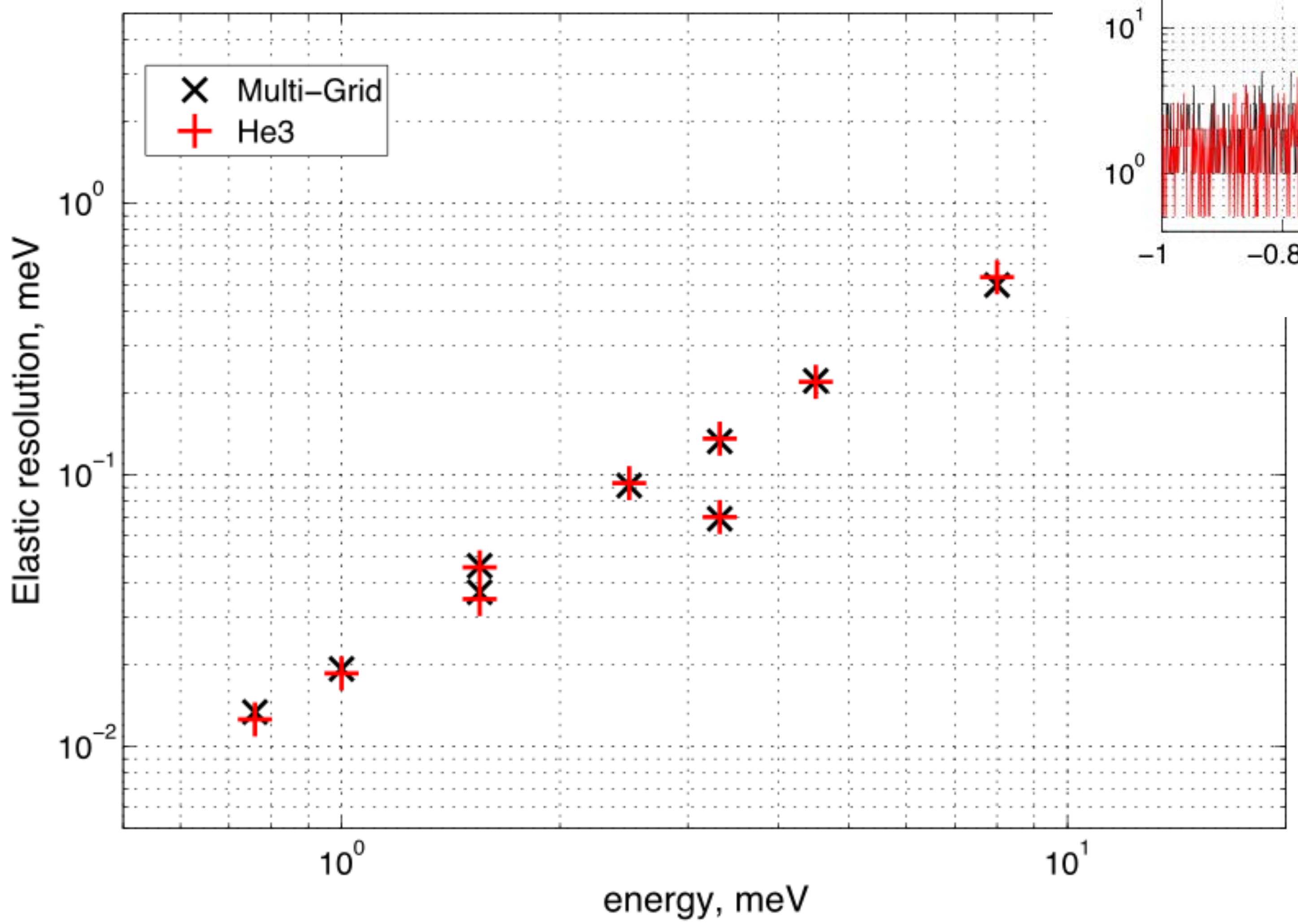
Operating without possibility of access since installation

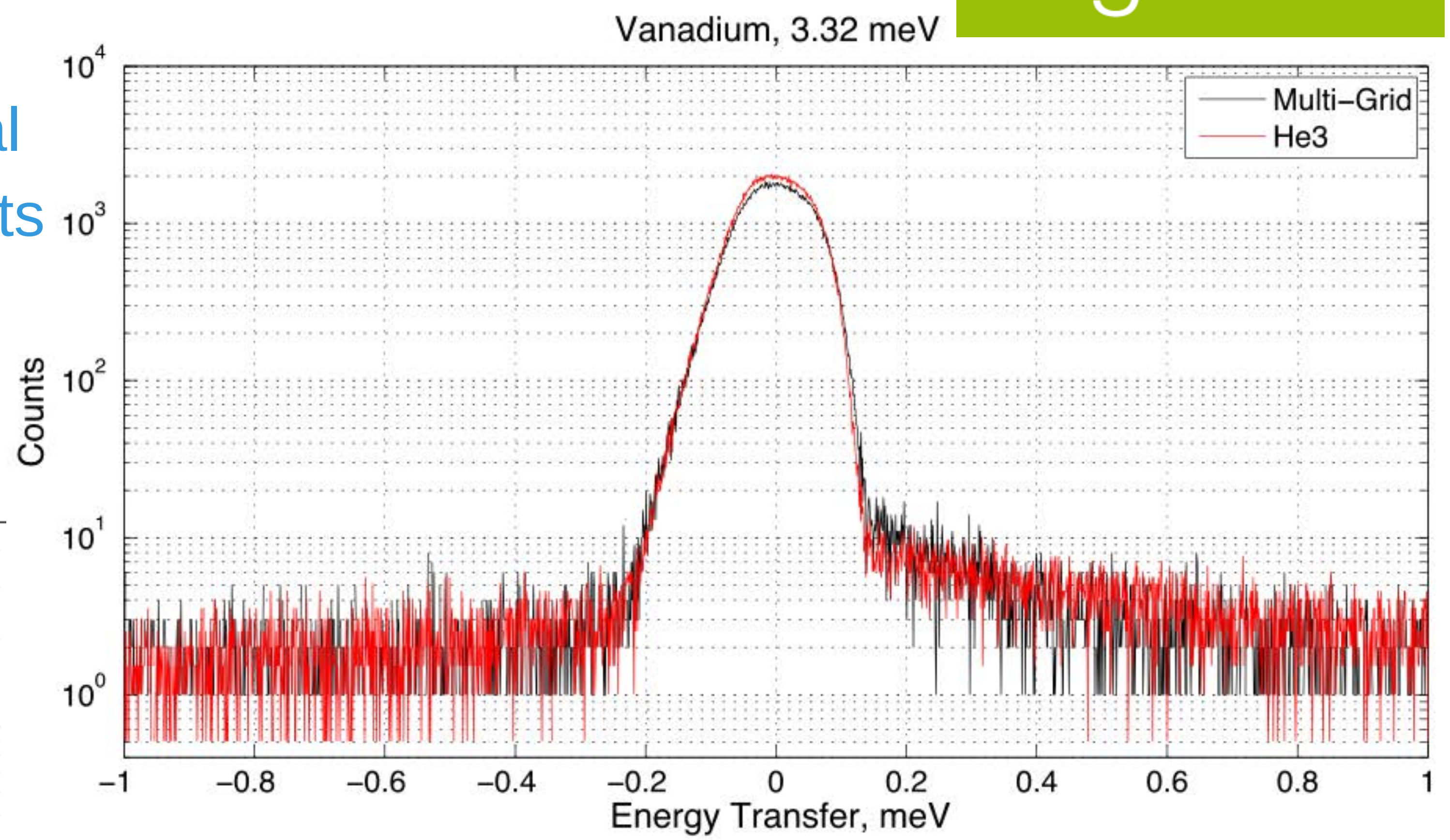
Count rate stable to within 1-2% for a constant setting

Multi-Grid test at CNCS

- Data and instrument resolution identical
- Technology suitable for ESS instruments

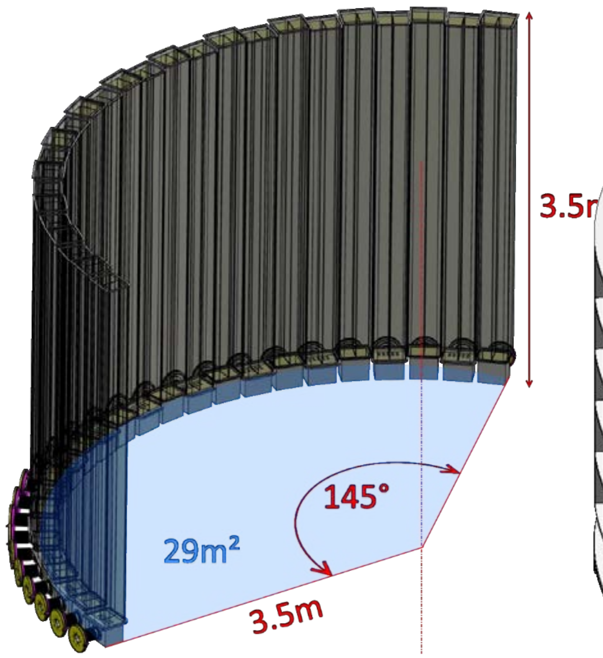
Technology demonstrated, ready for deployment

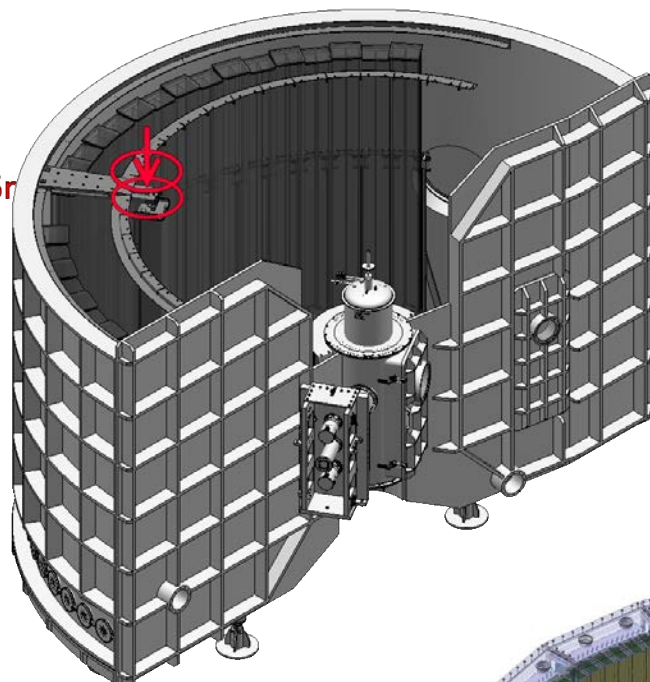


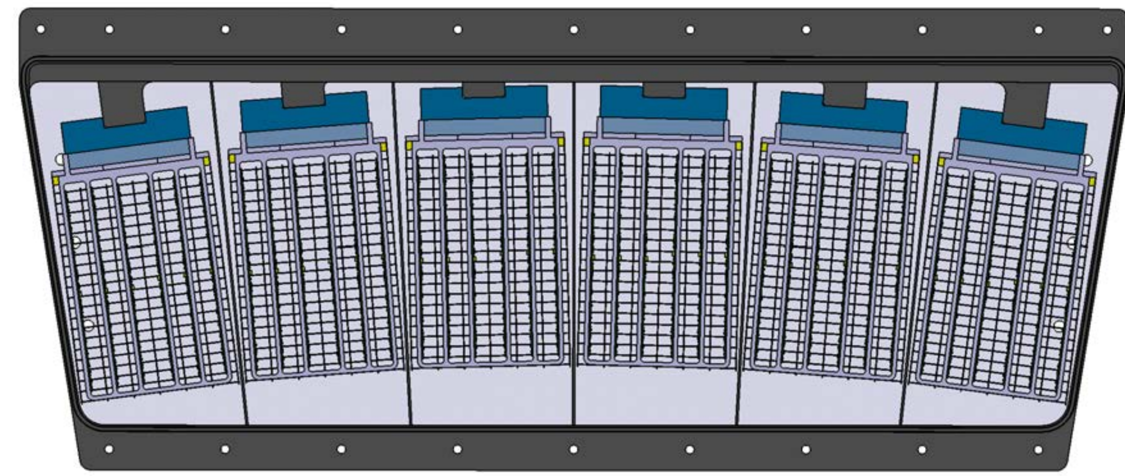


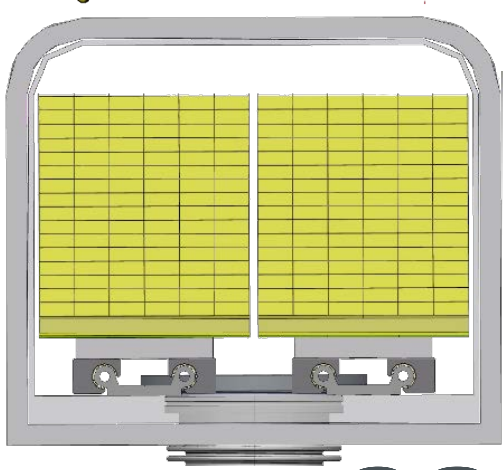
- Advantages over He3 tubes:
  - rate performance
  - fast neutron sensitivity

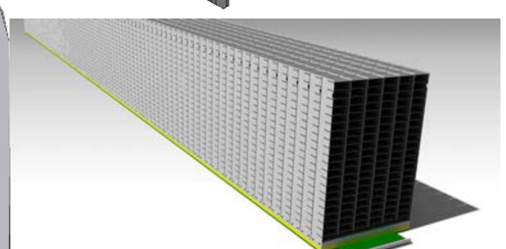
Realising Large Area Detectors

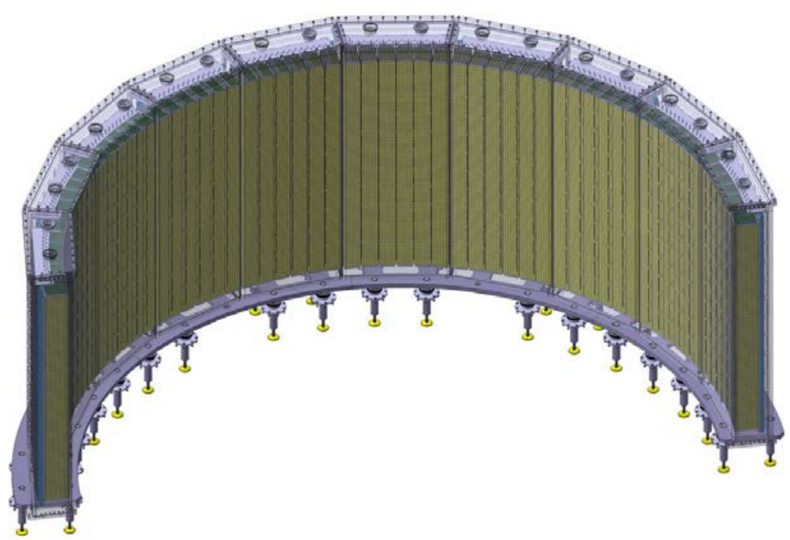


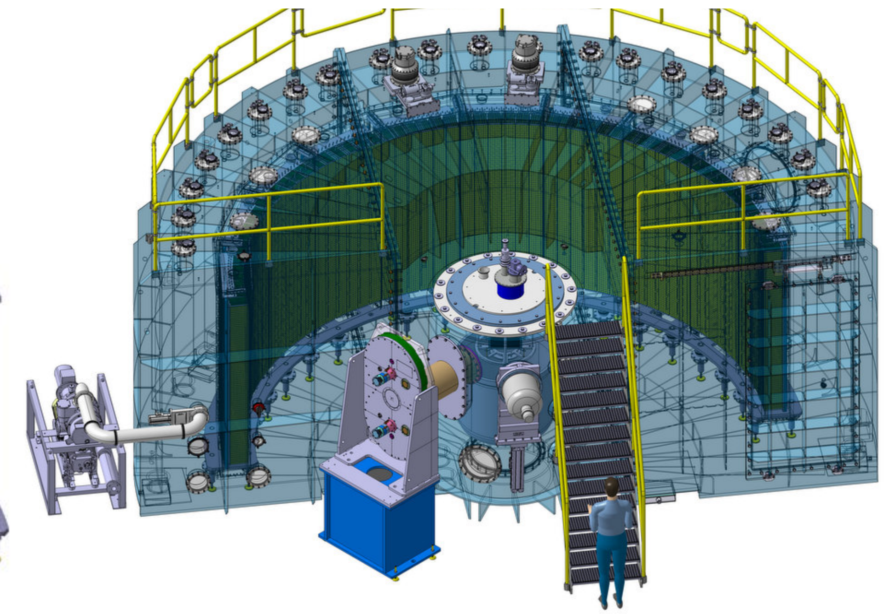












CSPEC

TREX

Detailed Engineering Design Started

BrightnESS is funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 676548

Wigner Research Institute

EUROPEAN SPALLATION SOURCE

LUND UNIVERSITY

Linköping University

The Multi-Blade project

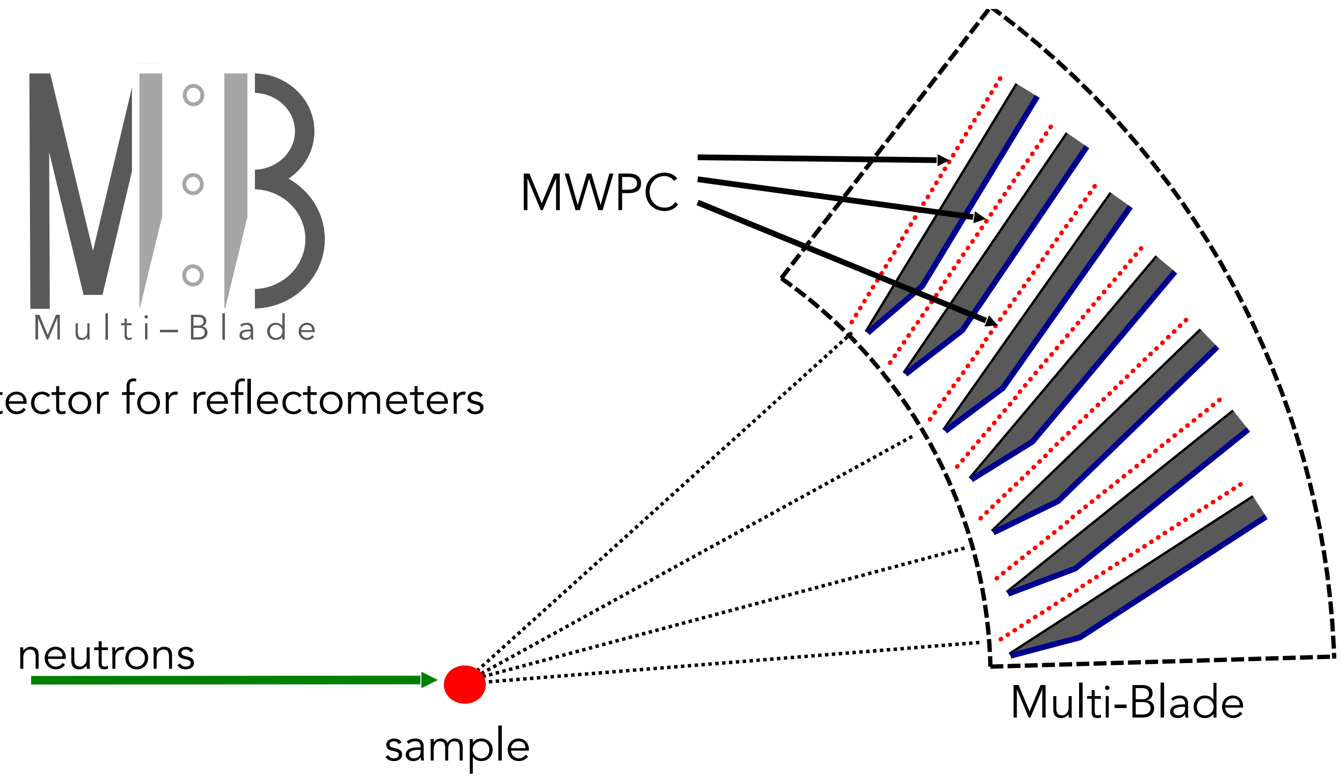
High counting rate capability

High spatial resolution

A single Boron layer inclined at 5 degrees

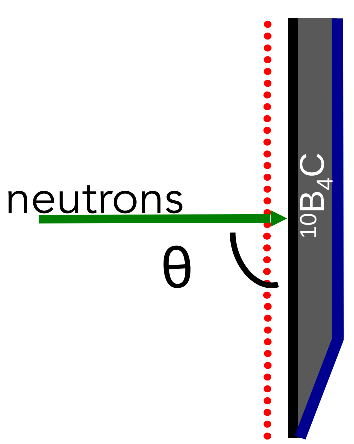
Multi-Blade

^{10}B-detector for reflectometers

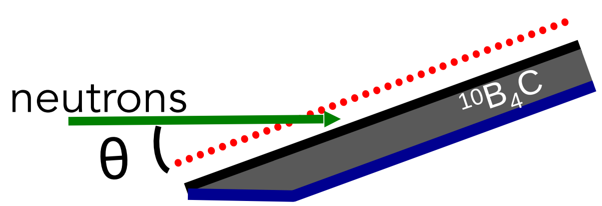


Efficiency <5% at 2.5Å

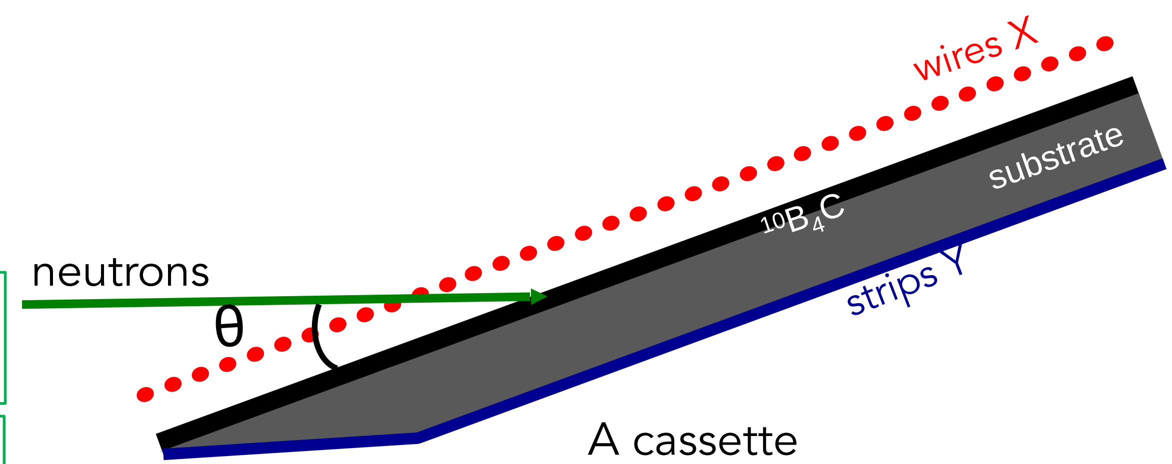
Efficiency 45% at 2.5Å



θ = 90 degrees



θ = 5 degrees



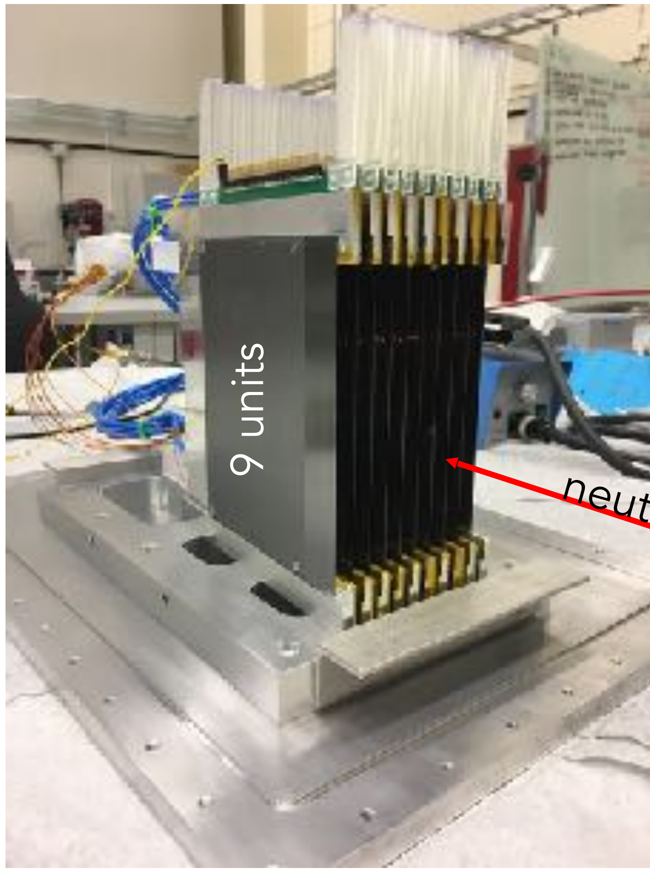
θ = 5 degrees

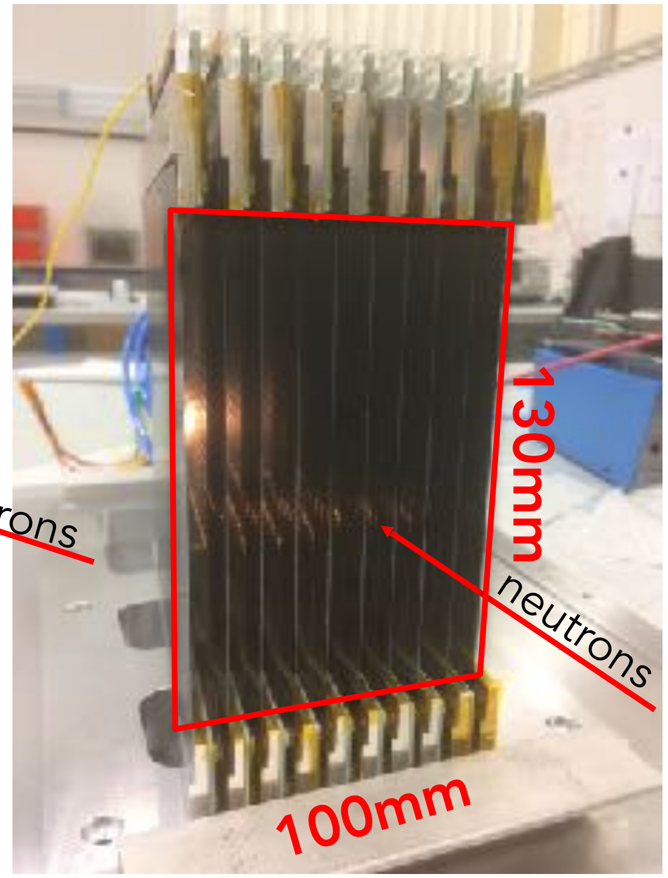
A cassette (unit)

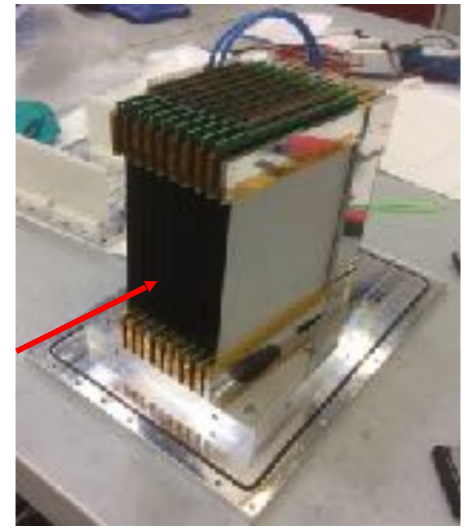
F. Piscitelli et al., The Multi-Blade Boron-10-based Neutron Detector for high intensity Neutron Reflectometry at ESS, JINST 12 (3) P03013 (2017).

F. Piscitelli and P. van Esch, Analytical modeling of thin film neutron converters and its application to thermal neutron gas detectors JINST 8, P04020 (2013) arXiv:1302.3153

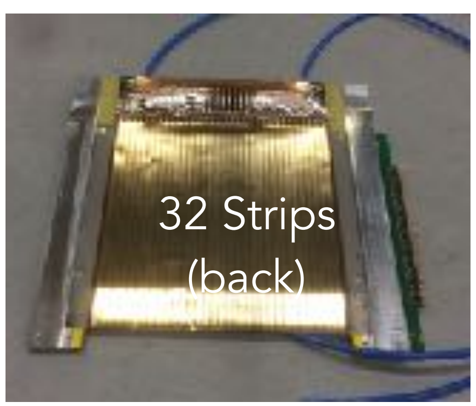
The Multi-Blade project

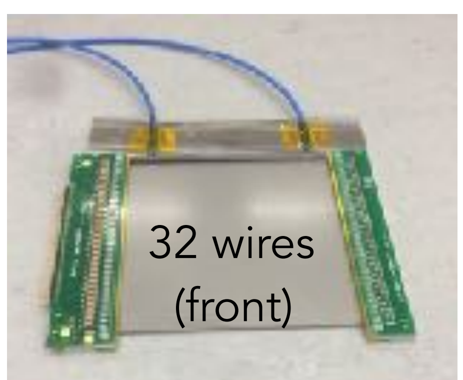


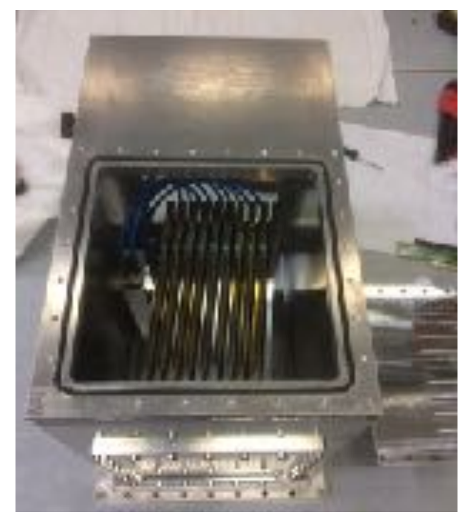




vessel

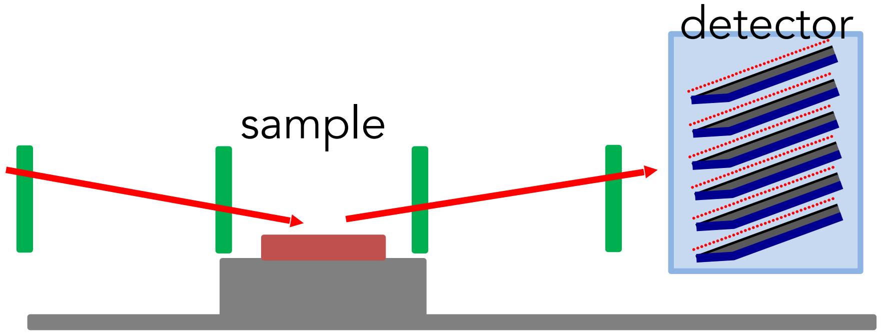


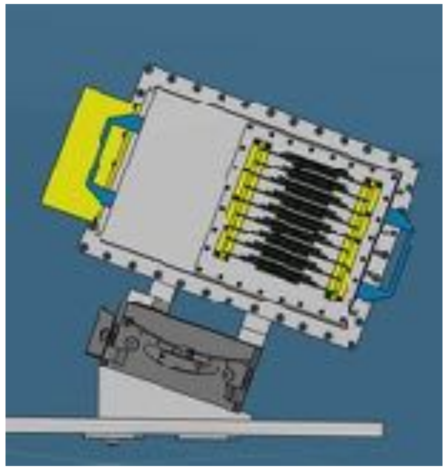


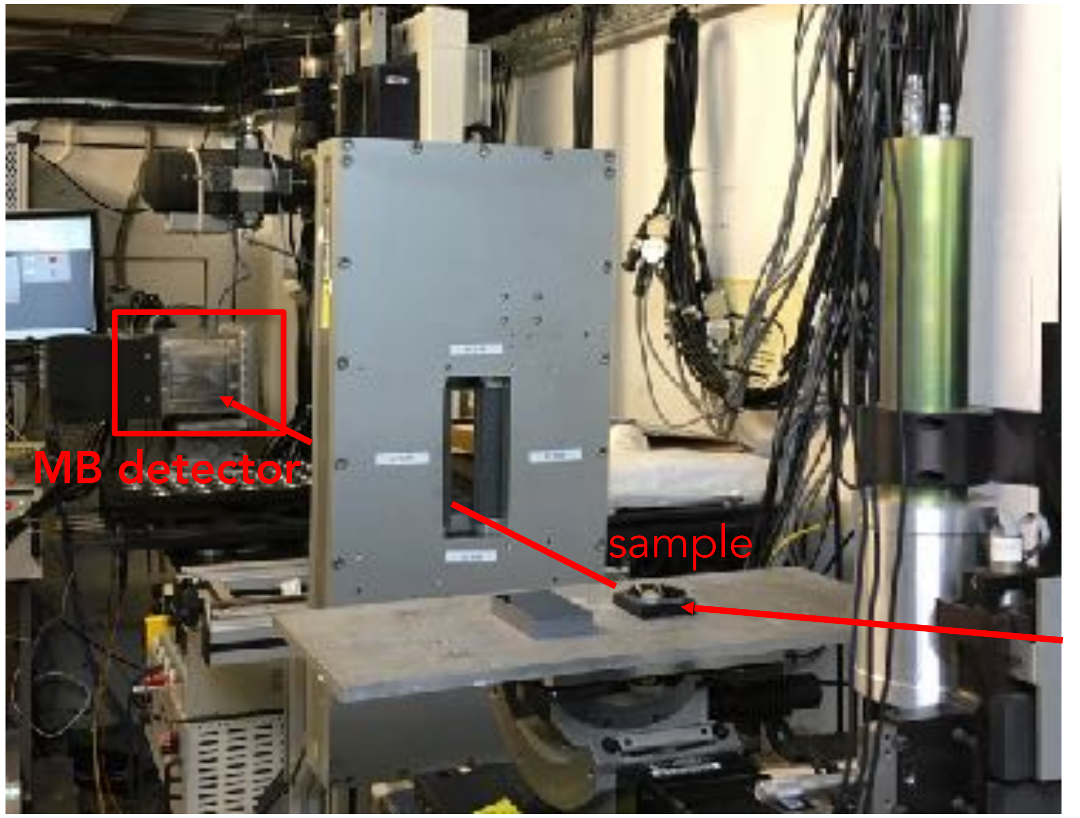


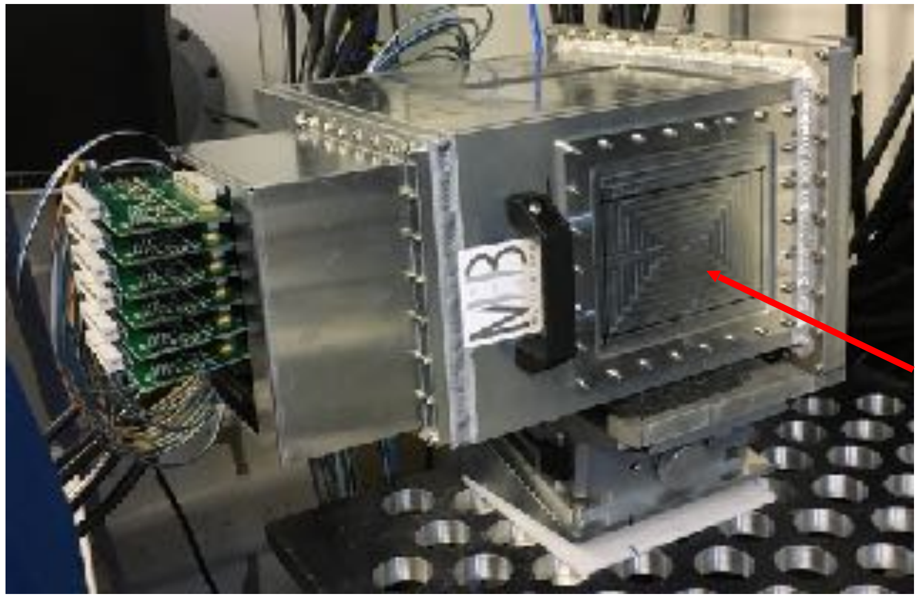
32 ch
front-end board

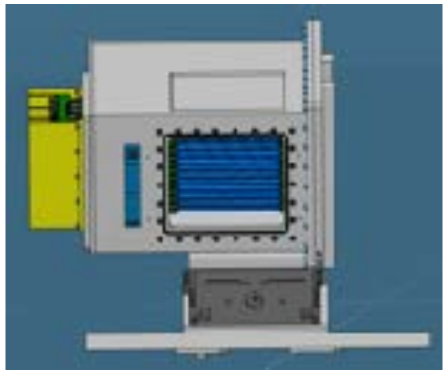
<u>CRISP reflectometer at ISIS</u>

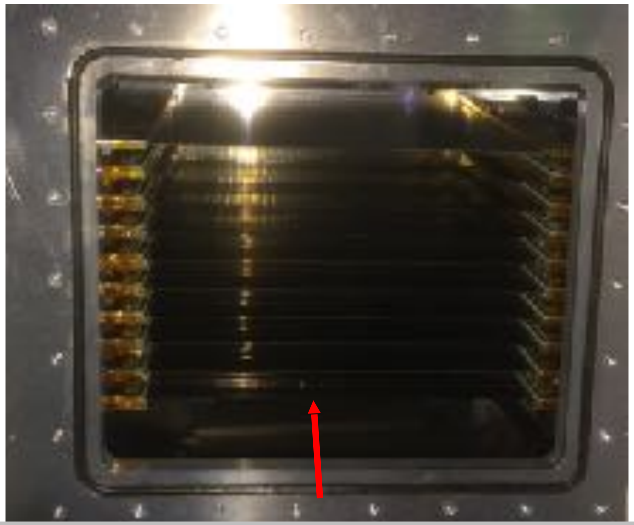


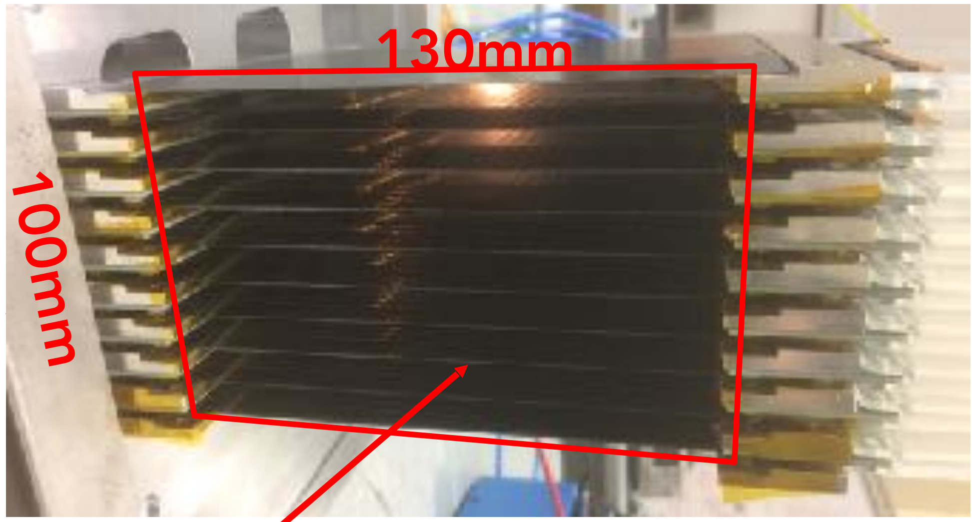




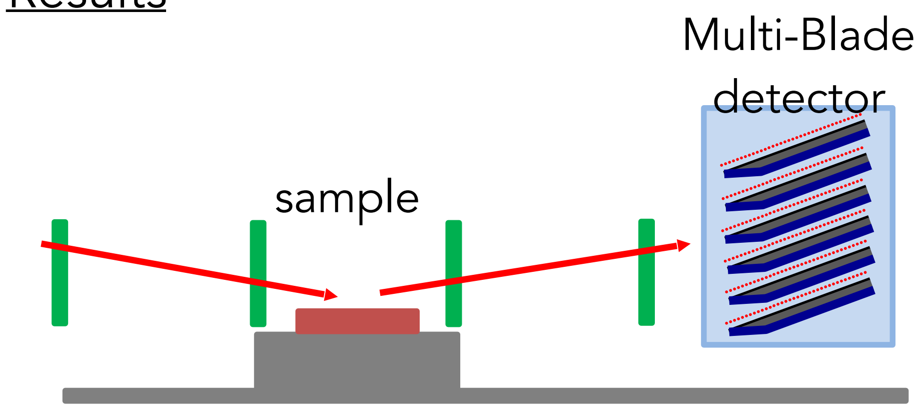


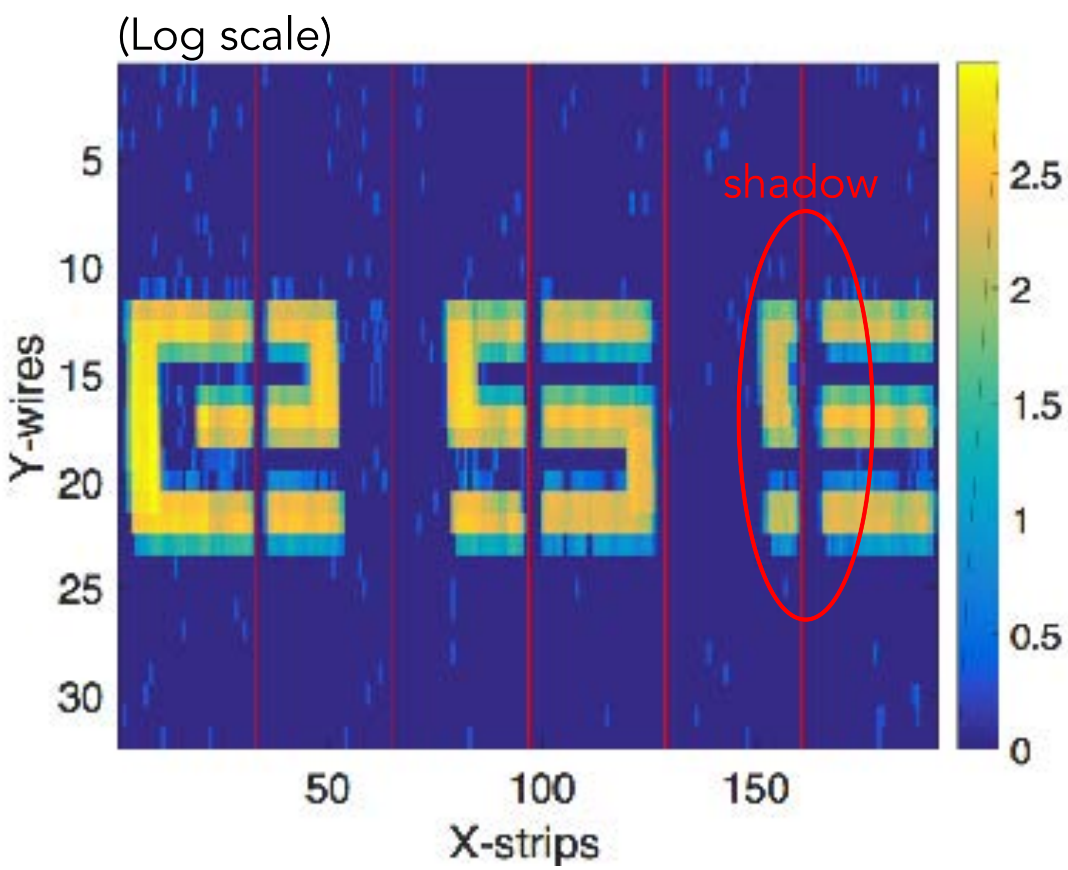


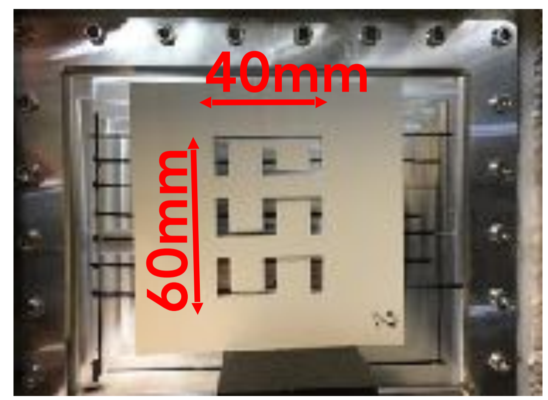


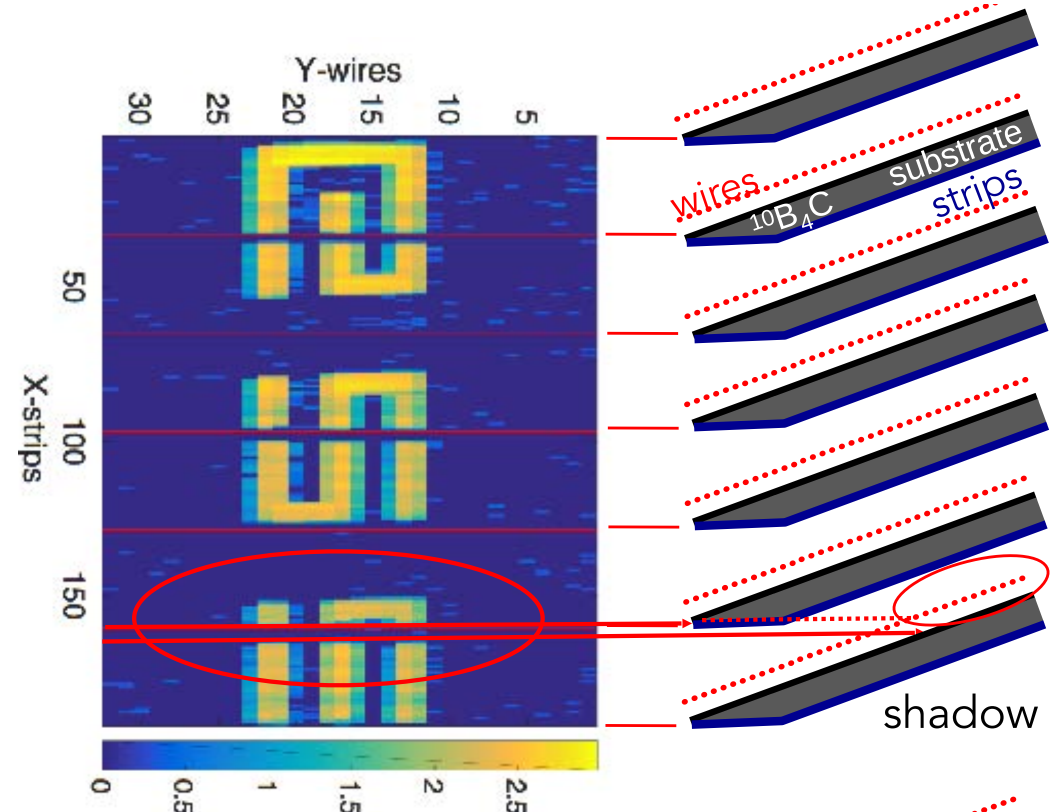


Results

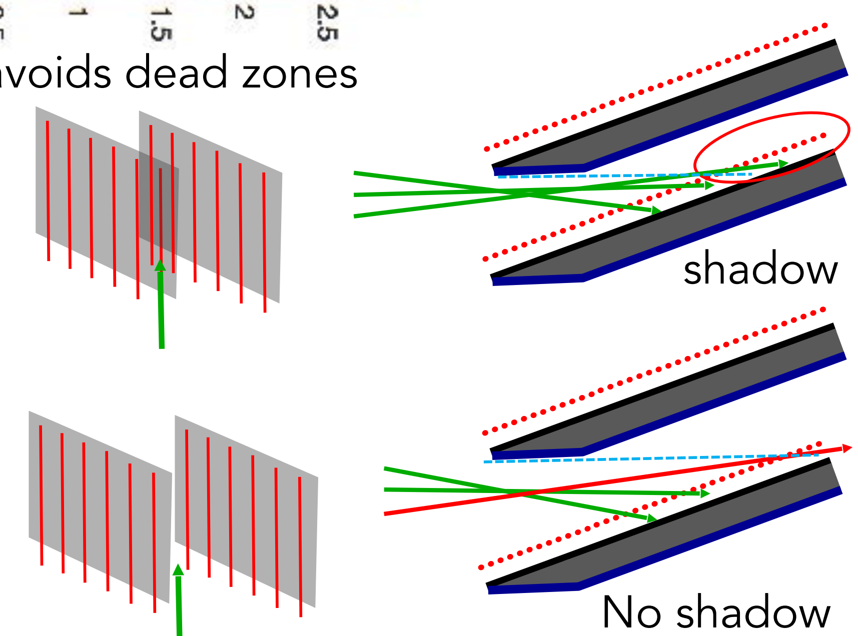








Not a dead area but the overlap avoids dead zones

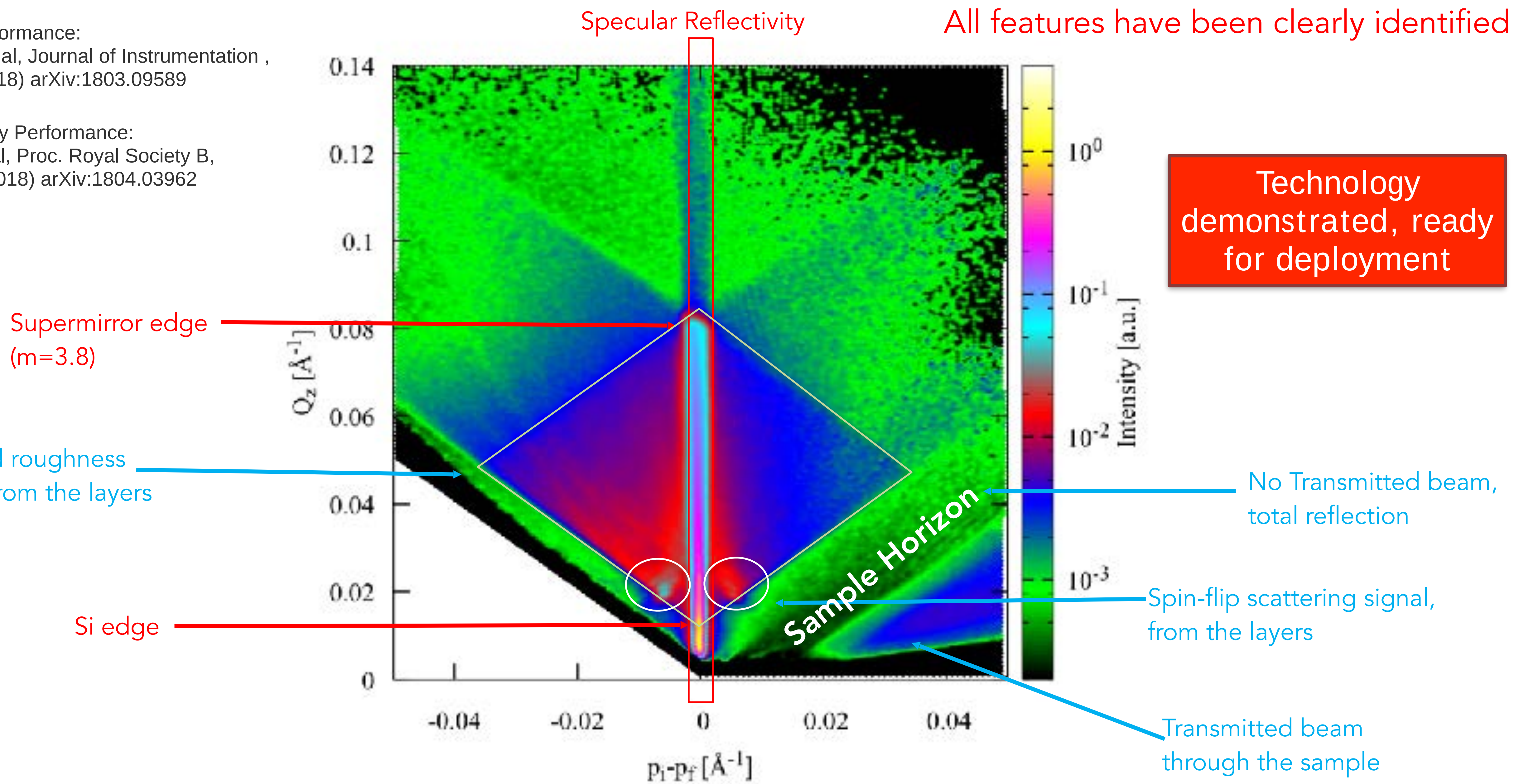


Results

Detector Performance:
F. Piscitelli et al, Journal of Instrumentation , accepted (2018) arXiv:1803.09589

Reflectometry Performance:
G. Mauri et al, Proc. Royal Society B, submitted (2018) arXiv:1804.03962

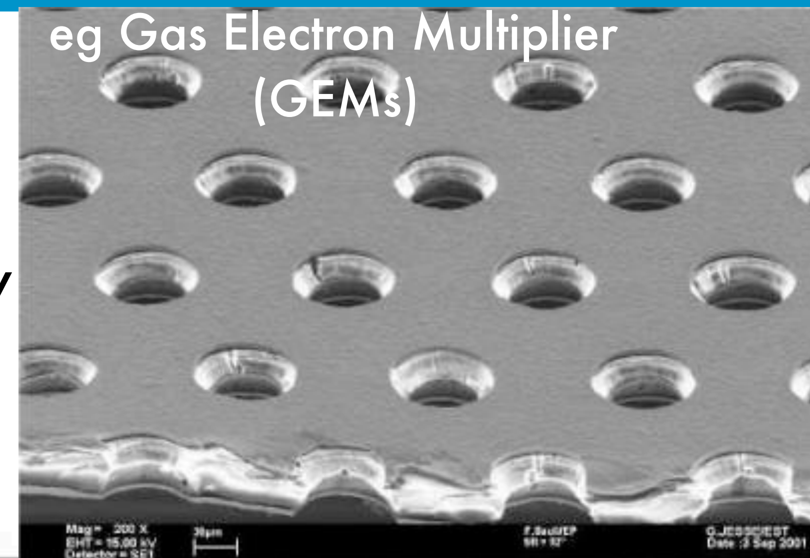
Off-specular scattering from Fe/Si supermirror

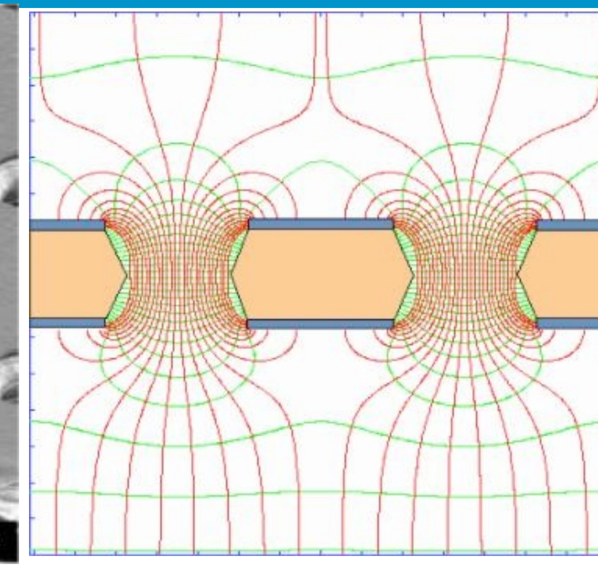


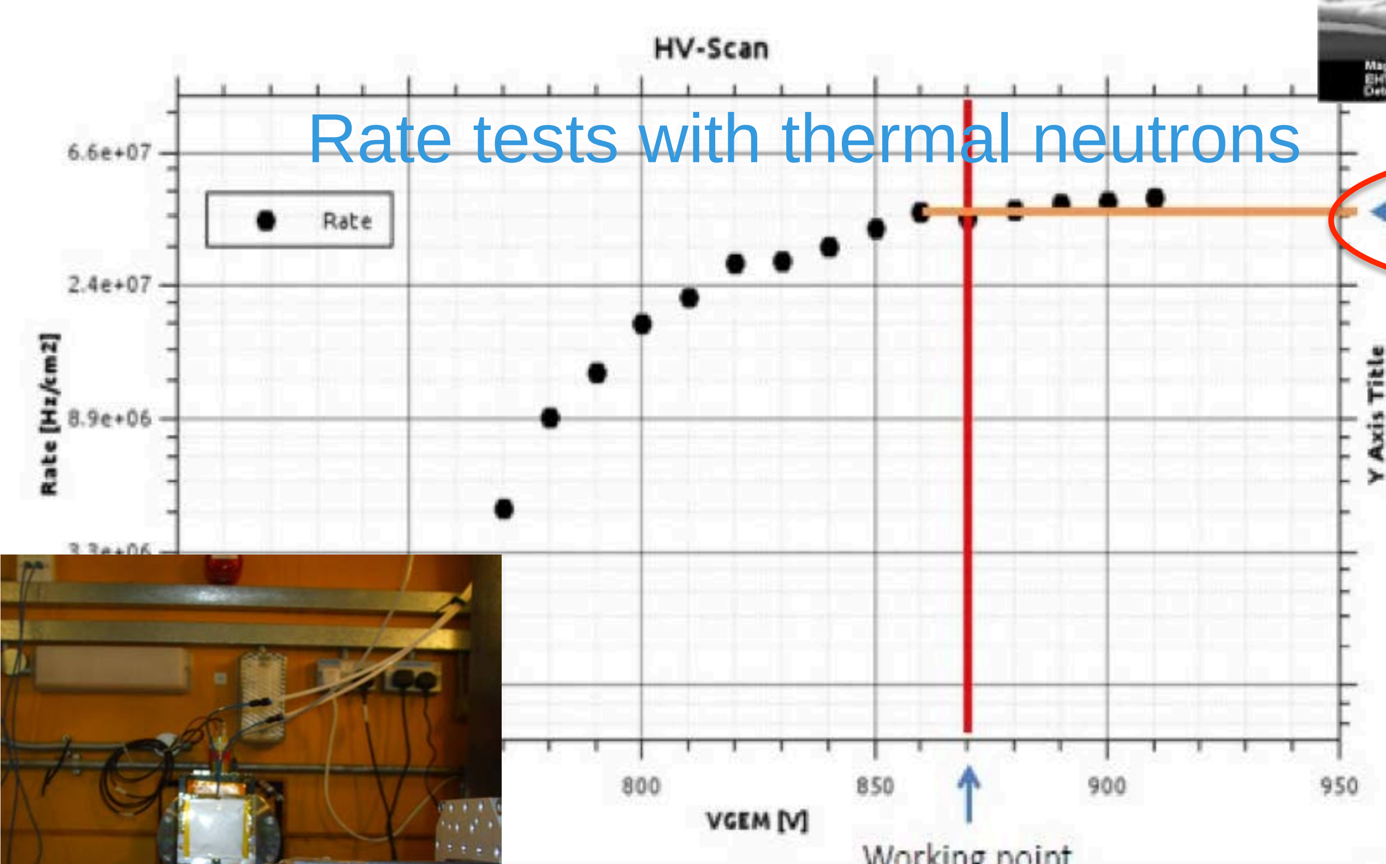
Trends

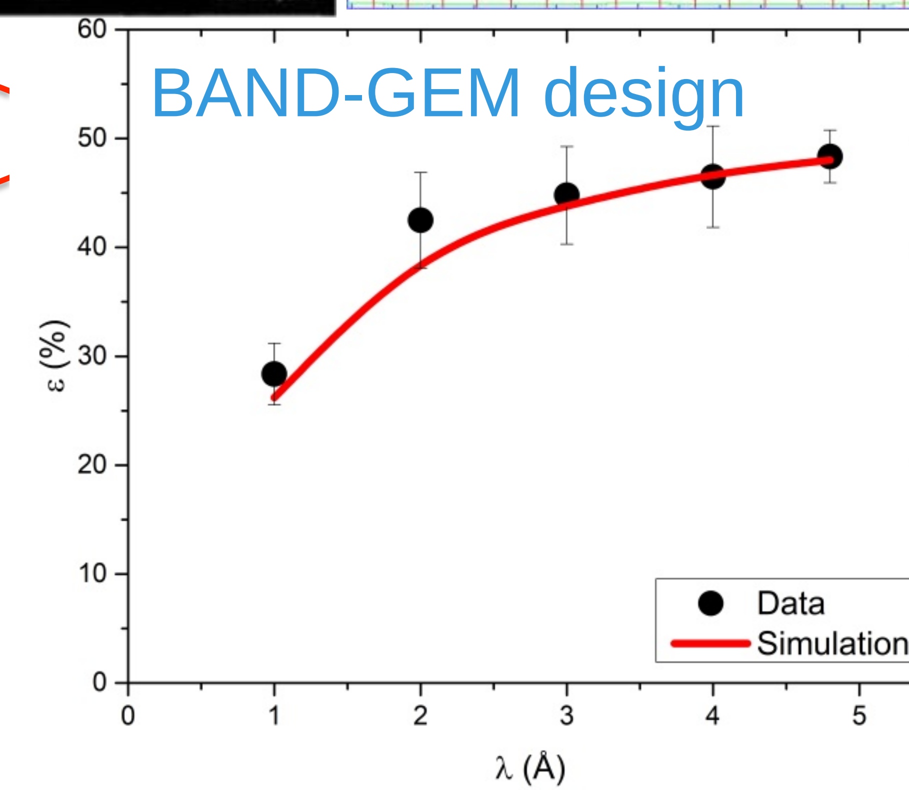
Micropattern Gaseous Detectors

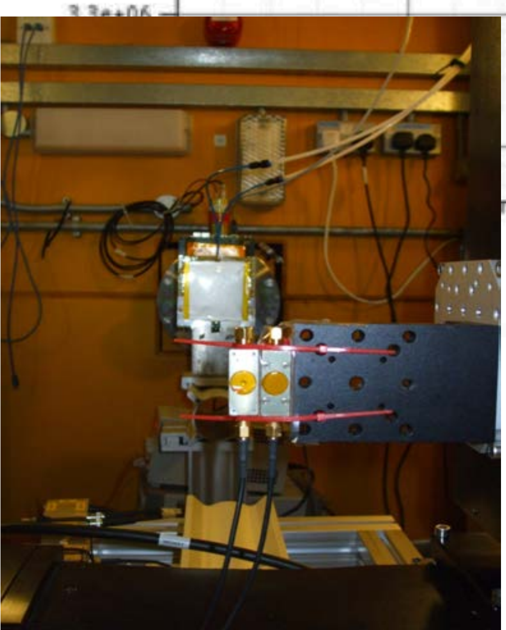
- Field started by A Oed at the ILL with the micro-strip gas chamber (MSGC) in 1988
- Now widespread: many variants
- Potentially excellent resolution and rate capability
- Growing interest for applications for neutron detection











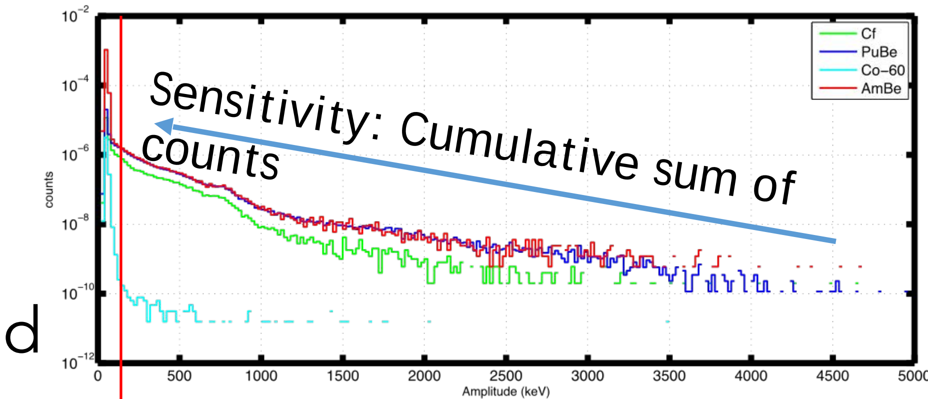
2 CERN RD51 Collaboration workshops on Neutron Detection using MPGDs

Summary of 1st workshop for MPGDs for neutron detection: arXiv:1410.0107

2nd Workshop: https://indico.cern.ch/event/365380/ arXiv:1601.01534

Some Thoughts on Background

<u>Fast neutron sensitivity</u>



G. Mauri et al., Fast neutron sensitivity of neutron detectors based on boron-10 converter layers. [arXiv:1712.05614](https://arxiv.org/abs/1712.05614) (submitted to JINST) (2018)

100 keV threshold

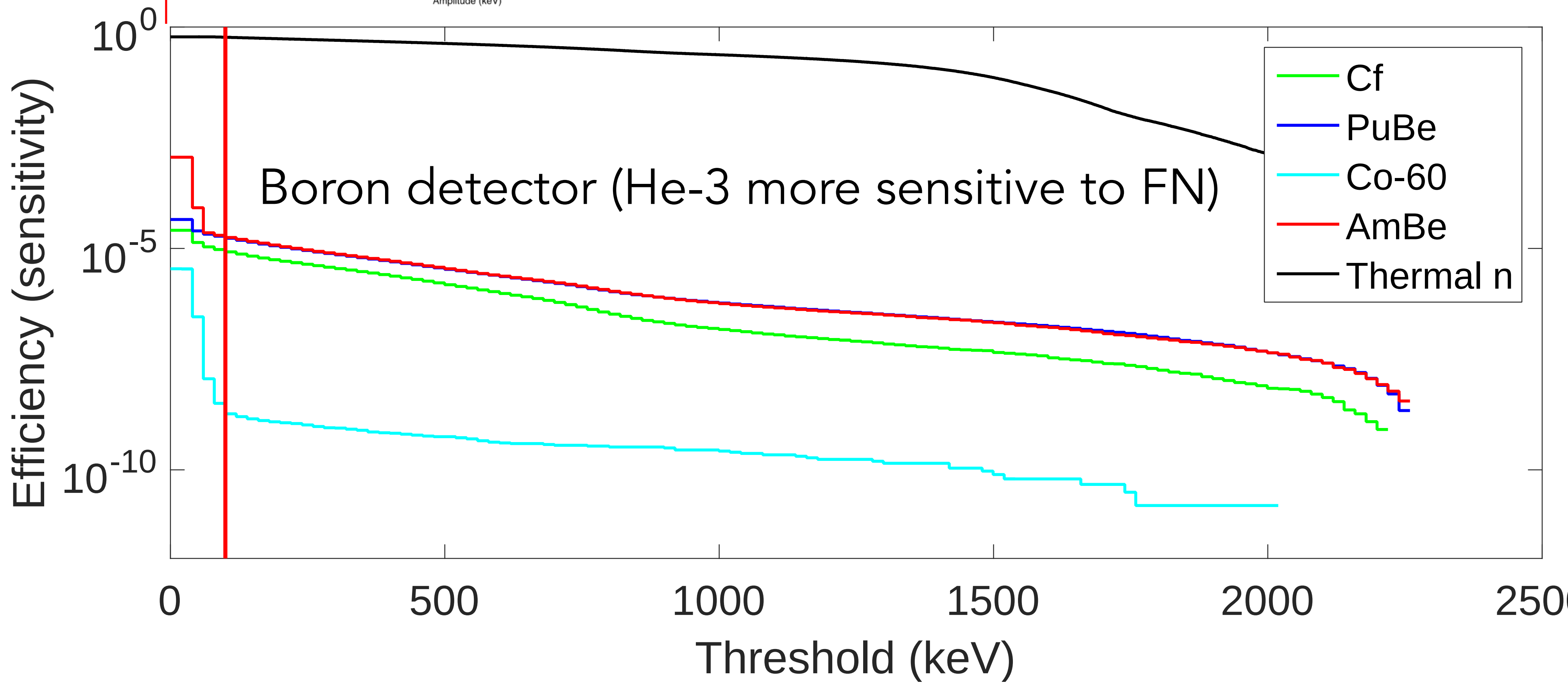
Thermal neutron ~0.6

Fast neutron ~ 10^{-5}

* first characterization for a thermal n detector

Gamma ~10^{-8}

✓ Agreement with previous work



At the detector, **it is 1000 times more important to remove** ***<u>fast neutrons</u>*** **than** ***<u>gamma</u>***
At the detector, **it is 10000 times more important to prevent** ***<u>scattering and local thermalisation</u>*** **than remove** ***<u>fast neutrons</u>***
Historically the emphasis has been opposite

Simulation tools

- New tools & utilities are recently developed for neutron studies
  - Physics
    - Coherent scattering
    - Inelastic scattering
    - Single- and poly-crystals…
  - And more
    - Communication
    - Visualisation
    - Ready-to use…

NXSG4
doi:10.1016/j.cpc.2014.11.009
http://nxsg4.web.cern.ch/nxsg4/

NCrystal
https://github.com/mctools/ncrystal/wi

MCPL -
Monte Carlo Particle List
https://mctools.github.io/mcpl/

ESS Coding Framework -
Geant4 simulation framework Developed by ESS Detector Group
doi:10.1016/S0168-9002(03)01368-8
doi:10.1088/1742-6596/513/2/022017

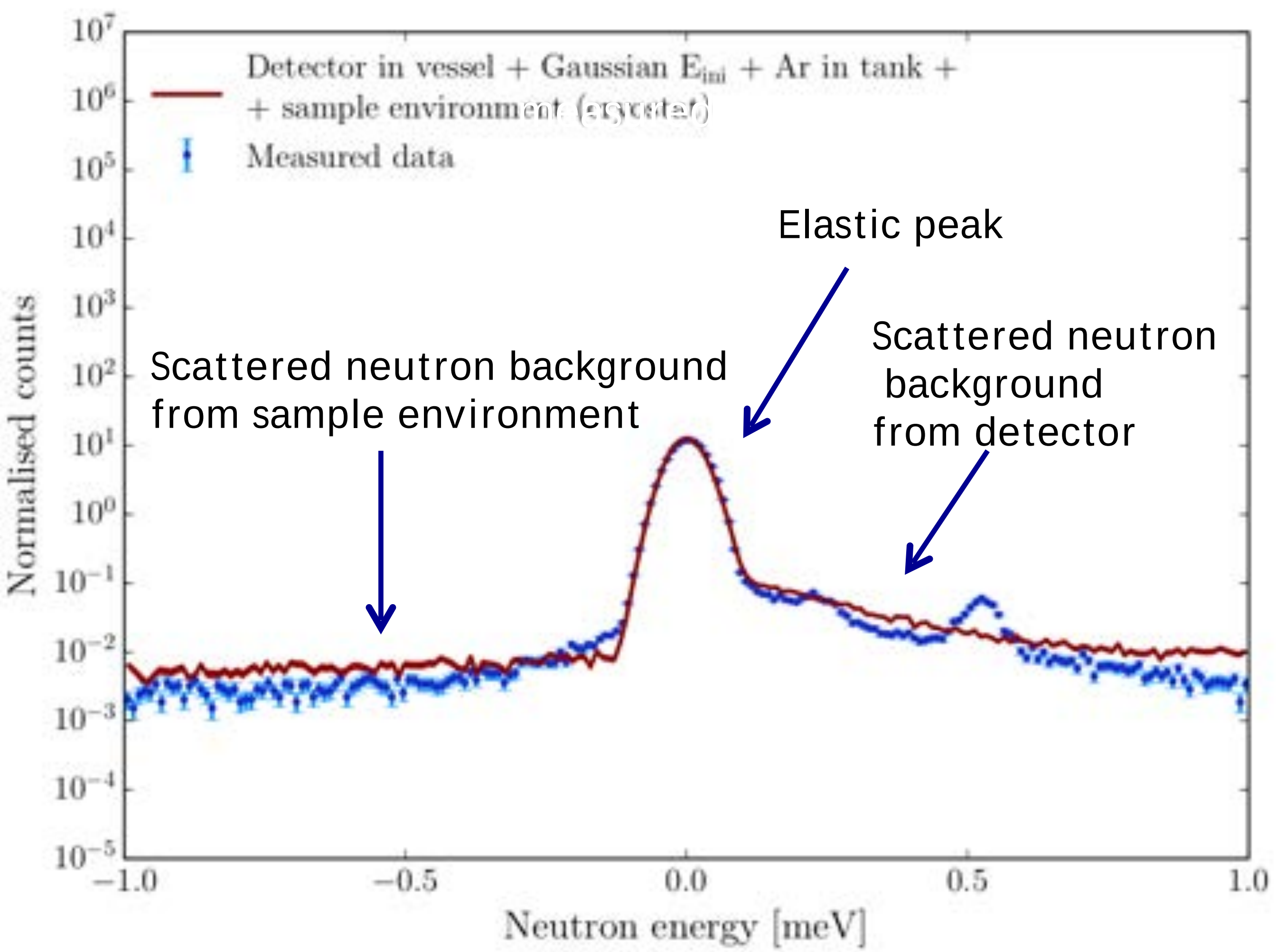
Example: simulation Multi-Grid Results

E. Dian et al. https://doi.org/10.1016/j.nima.2018.04.055

- Geant4 model was validated:
  - IN6 measurement: ToF comparison
  - CNCS measurement: ToF, energy transfer, etc

Validation

$E_{trf} = E_{initial} - E_{final}$

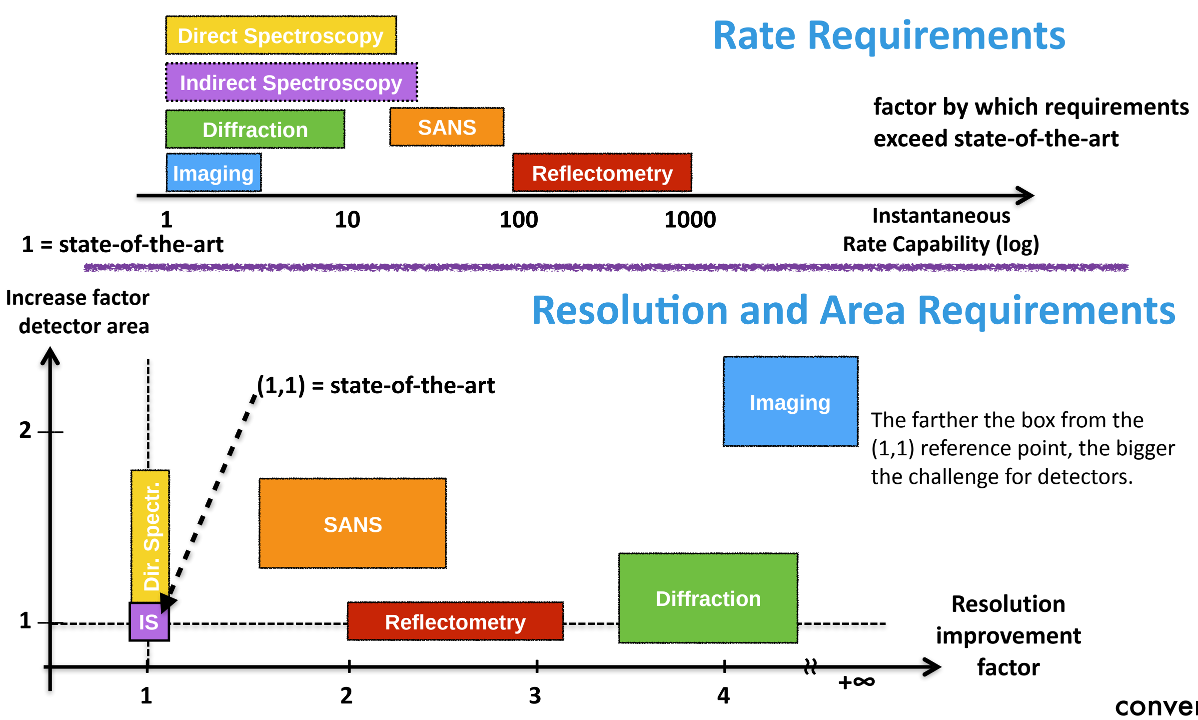


- Realistic Multi-Grid model built
  - reproduced measured results from IN6 and CNCS experiments
- Ready to use for optimisation
- Use the simulation to refine detector design

Thoughts …

- Detector development takes time
- Very difficult to go from concept to beam line in less than a decade
- e.g. Multi Grid started 2009/10. On ESS instrument ca. 2021/22
- Detector development time >> Instrument construction time

- This should be our aspiration level for a (every?) decade … :

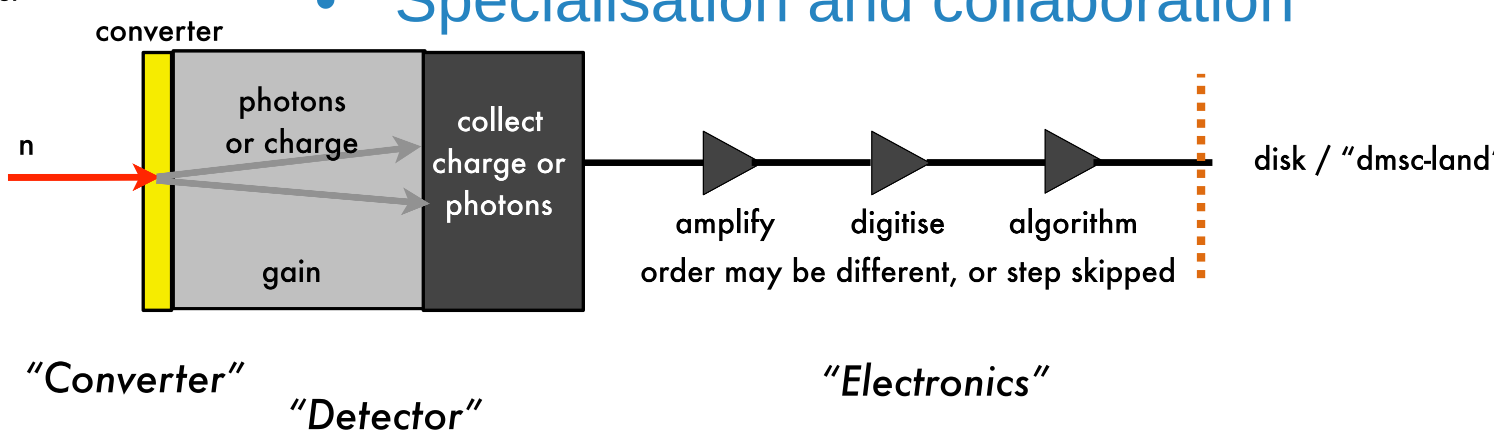


…and cost improvement of a factor of few …

- Computing and electronics have become ubiquitous and very cheap
- Future detectors will be much more designed around electronics
- Don't divide DAQ &detector efforts

- Simulation will play a much bigger role in design

- Specialisation and collaboration



Summary

- Brightness and science goals mean that the requirements for detectors cannot be met with todays state-of-the-art detectors
- Helium-3 crisis means that the "gold standard" for neutron detection is no longer default option

- Helium-3 replacement technologies and the large amount of new instrumentation is driving the detector development.
- Boron-10 Gaseous detectors becoming mature
- This is a very active topic

- First developments are coming to realisation: **yes there is post-helium-3 neutron science!**
- Neutron detectors for future instruments are going to look very different ...

brightness

SoNDe Solid-State Neutron Detector

Cremlin Connecting Russian and European Measures for Large-scale Research Infrastructures

What does this mean for detectors?

What does a factor 10 improvement imply for the detectors?

Implications for Detectors	Implications for Detectors
Better Resolution (position and time)	sqrt(10)
Channel count	pixelated: factor 10 x-y coincidence:sqrt(10)
Rate capability and data volume	factor 10
Lower background, lower S:B Larger dynamic range	Keep constant implies: factor 10 smaller B per neutron
Larger area coverage Lower cost of detectors	Factor of a few

Developments required for detectors for new Instruments

Isotopes Suitable as Cold and Thermal Neutron Convertors

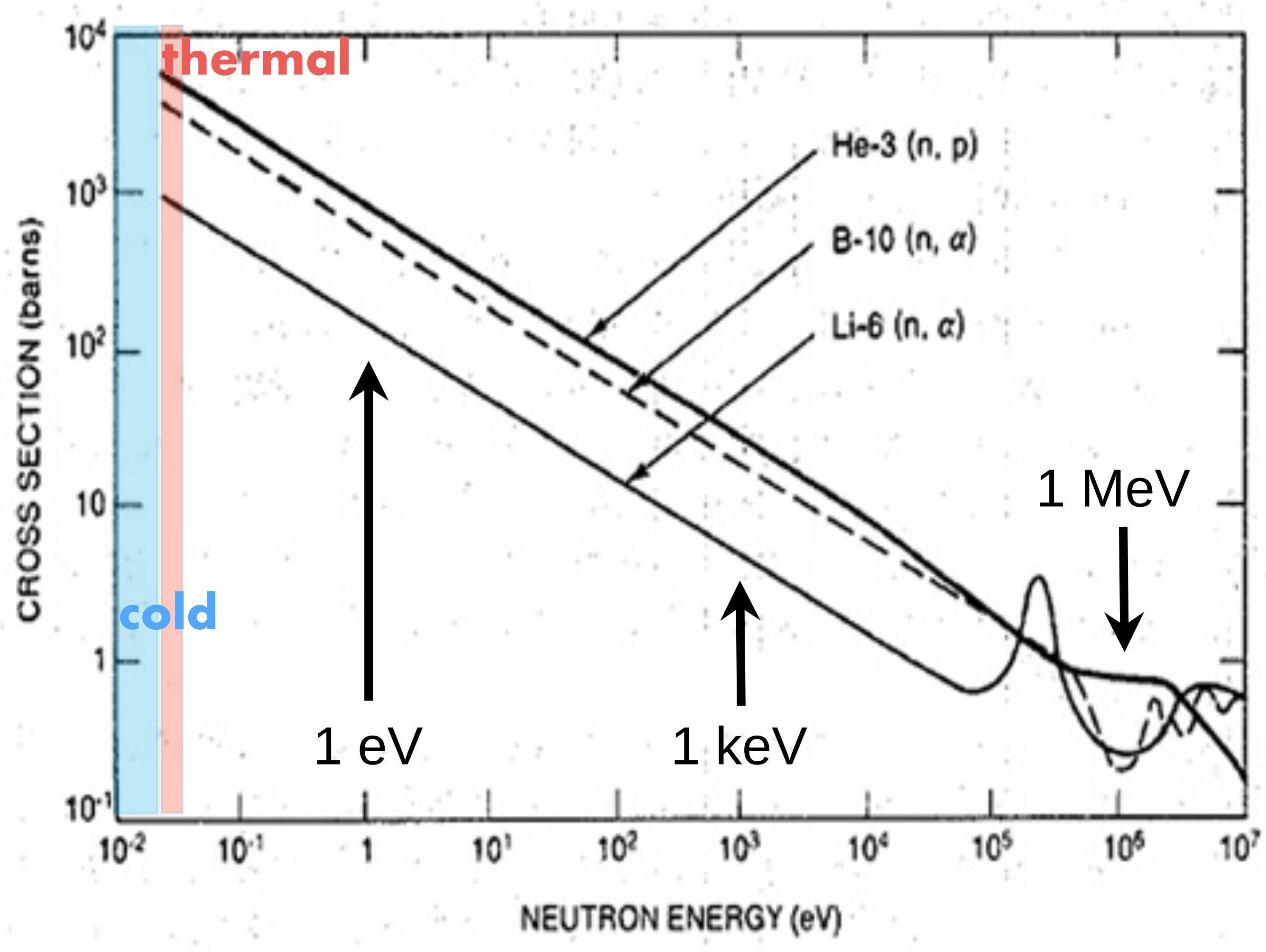
reaction	energy	particle	energy	particle	energy
n (^{3}He, p) ^{3}H	+0.77 MeV	p	0.57 MeV	^{3}H	0.19 MeV
n (^{6}Li, α) ^{3}H	+4.79 MeV	α	2.05 MeV	^{3}H	2.74 MeV
93 % n (^{10}B, α)^{7}Li +2.3 MeV + γ (0.48MeV)		α	1.47 MeV	^{7}Li	0.83 MeV
7 % n (^{10}B, α) ^{7}Li	+2.79 MeV	α	1.77 MeV	^{7}Li	1.01 MeV
n (^{235}U, Lfi) Hfi	+ ~ 100 MeV	Lfi	< = 80 MeV	Hfi	< = 60 MeV
n (^{157} Gd, Gd) e$^-$	+ < = 0.182 MeV	conversion electron		0.07 to 0.182 MeV	

Table 1: Commonly used isotopes for thermal neutron detection, reaction products and their kinetic energies.

- Only a few isotopes with sufficient interaction cross section
- To be useful in a detector application, reaction products need to be easily detectable

- In region of interest, cross sections scale roughly as 1/v
- G. Breit, E.Wiegner, Phys. Rev., Vol. 49, 519, (1936)

- Presently >80% of neutron detectors worldwide are Helium-3 based



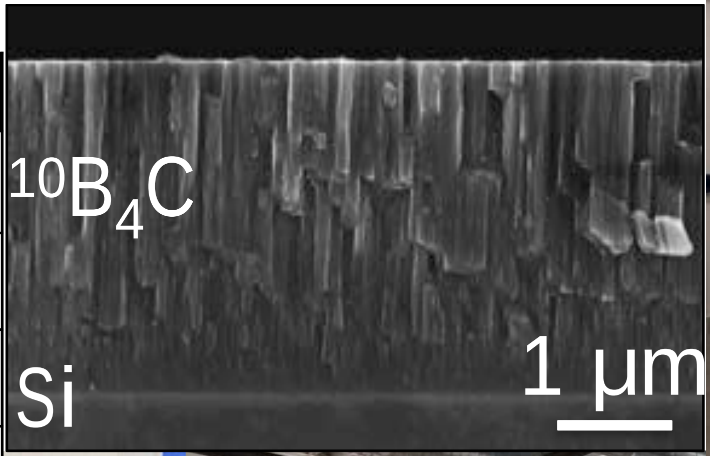
Mittuniversitetet
MID SWEDEN UNIVERSITY

ESS Thin Films Workshop

LINKÖPING UNIVERSITY
EUROPEAN SPALLATION SOURCE

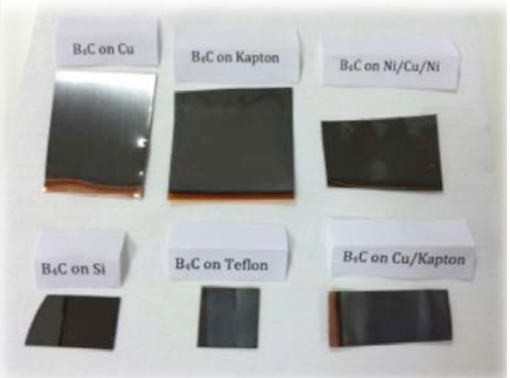
- Co-located w/ Linkoping University for synergies: expertise&facilities
- Industrial coatings machine and production line setup
- Capacity: several times ESS needs
- If interested in coatings: contact us

Required property	Result	OK?
Good adhesion	> 5 µm on Al, Si, Al_2O_3, etc	☺
Low residual stress	0.09 GPa at 1 µm $^{10}B_4C$	☺
Low impurities	H + N + O only ~1 at.%	☺
High ^{10}B content	79.3 at.% of ^{10}B	☺
n-radiation hard	Survive 10^{14} neutrons/cm^2	☺



- Many substrates possible:

Solved	Ongoing
Al	Glass - ok solution
Al-foil	Ni and Ni-coated - ok solution
Stainless steel	Cu coat. Kapton
Al_2O_3	MgO
Si	
G10	
Ti	
Cu	
Teflon	
Kapton foil	
Kapton tape	



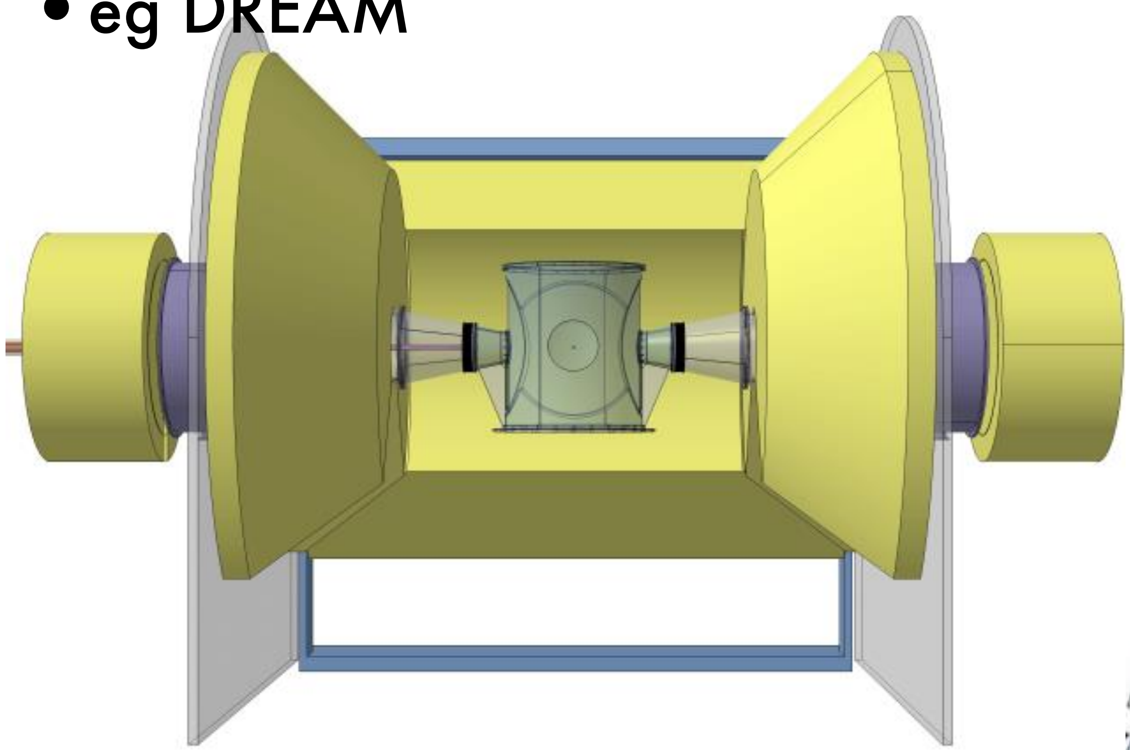
Publications:
*C. Höglund et al, J of Appl. Phys. 111, 104908 (2012)
*S. Schmidt et al, J. of Materials Science 51, Issue 23 (2016)
*C. Höglund, Rad. Phys. and Chem. 113 , 14-19 (2015);

Instruments: DREAM, MAGIC, HEIMDAL

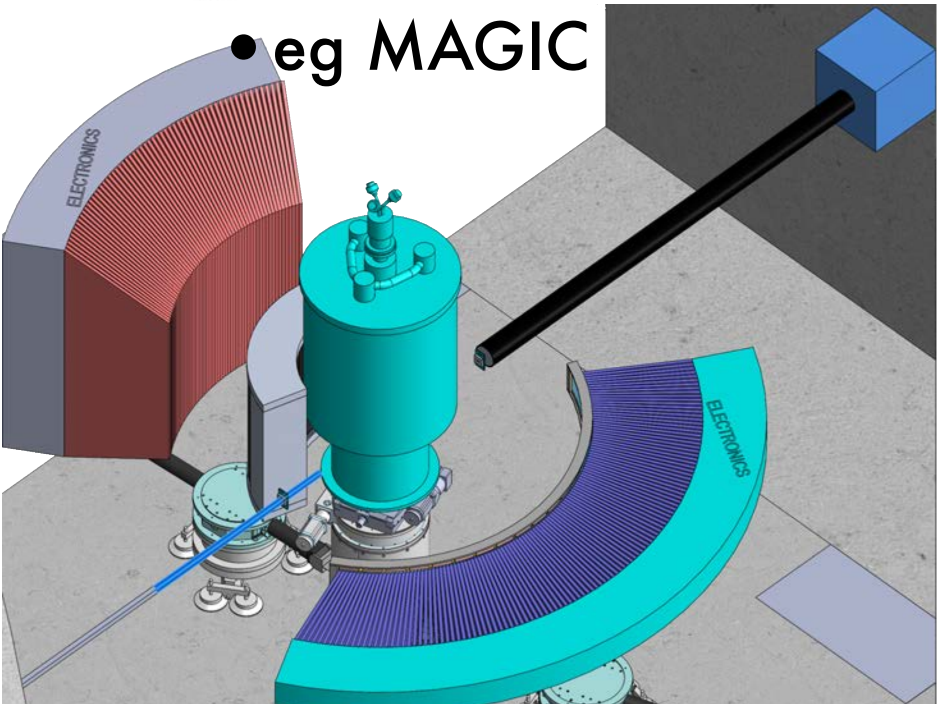
Diffractometers: Jalousie-like design

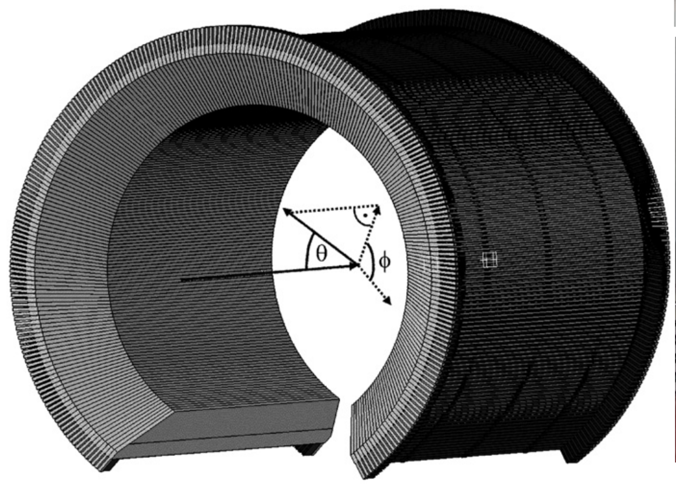
EUROPEAN SPALLATION SOURCE

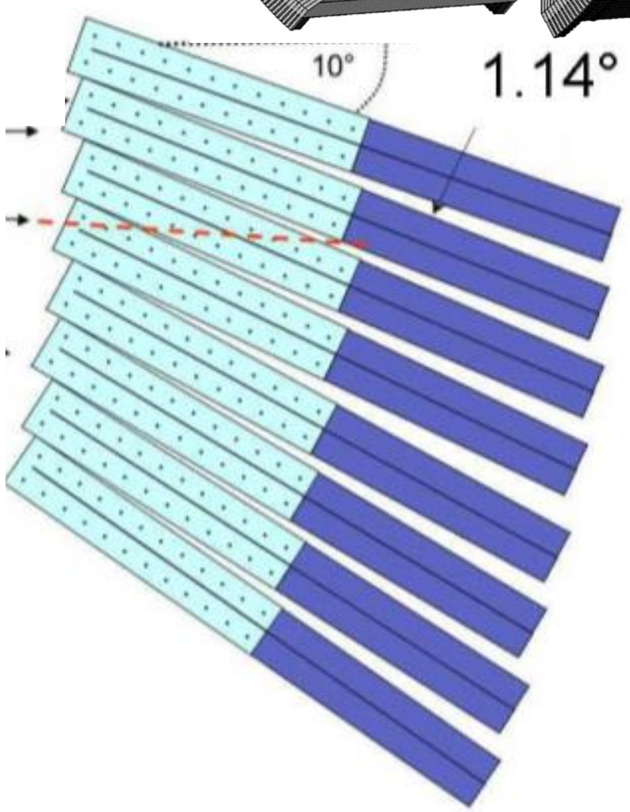
- Inclined angle B-10 detectors, angled at sample
- (CDT Heidelburg)
- eg DREAM



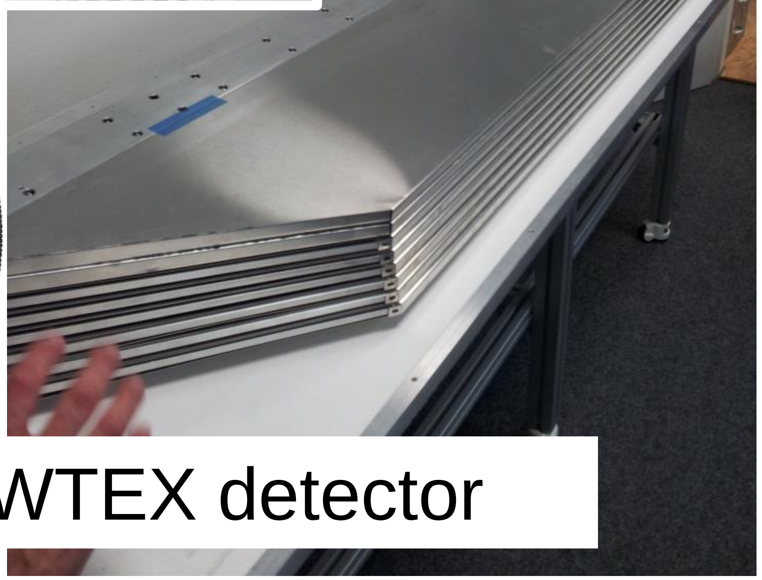
- eg MAGIC







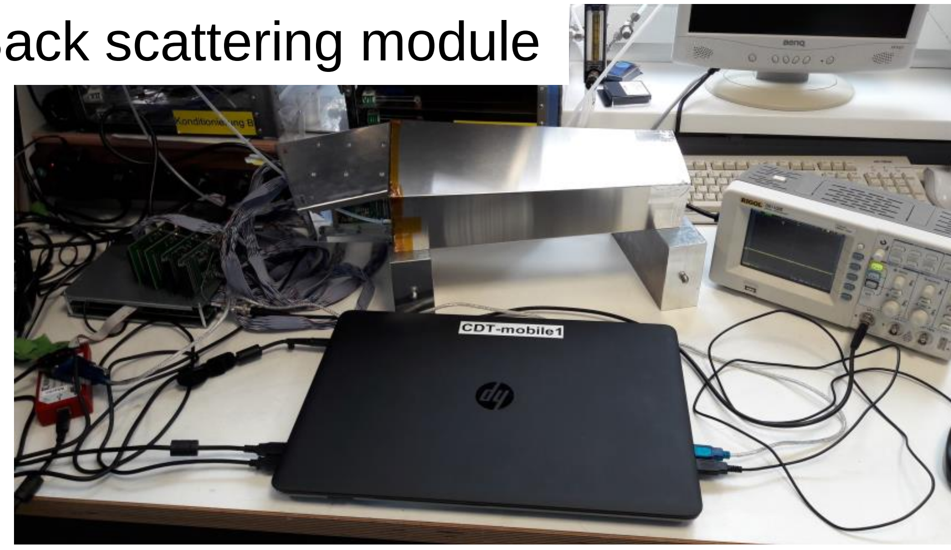
assembly



mantle

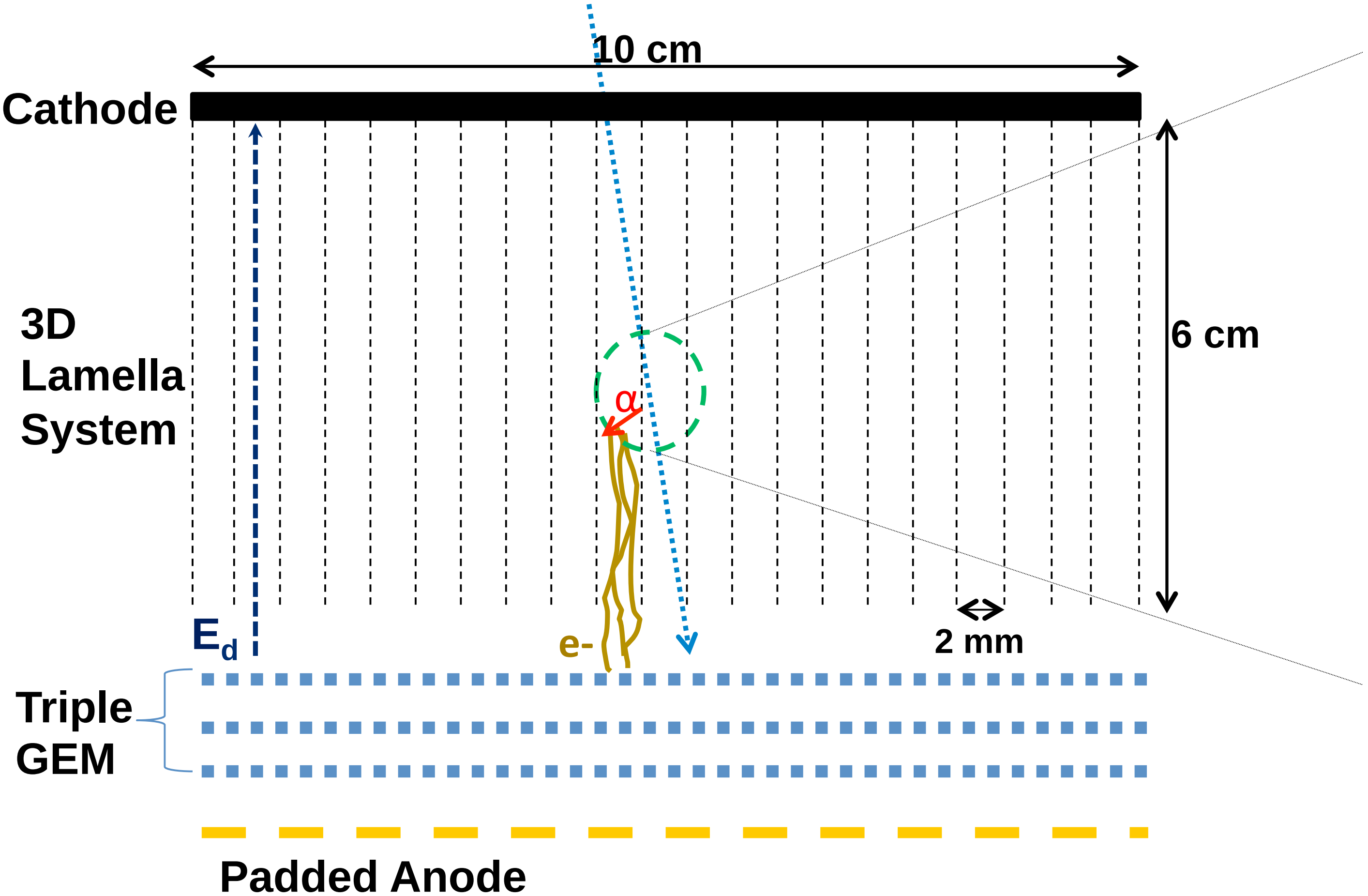
POWTEX detector

Back scattering module



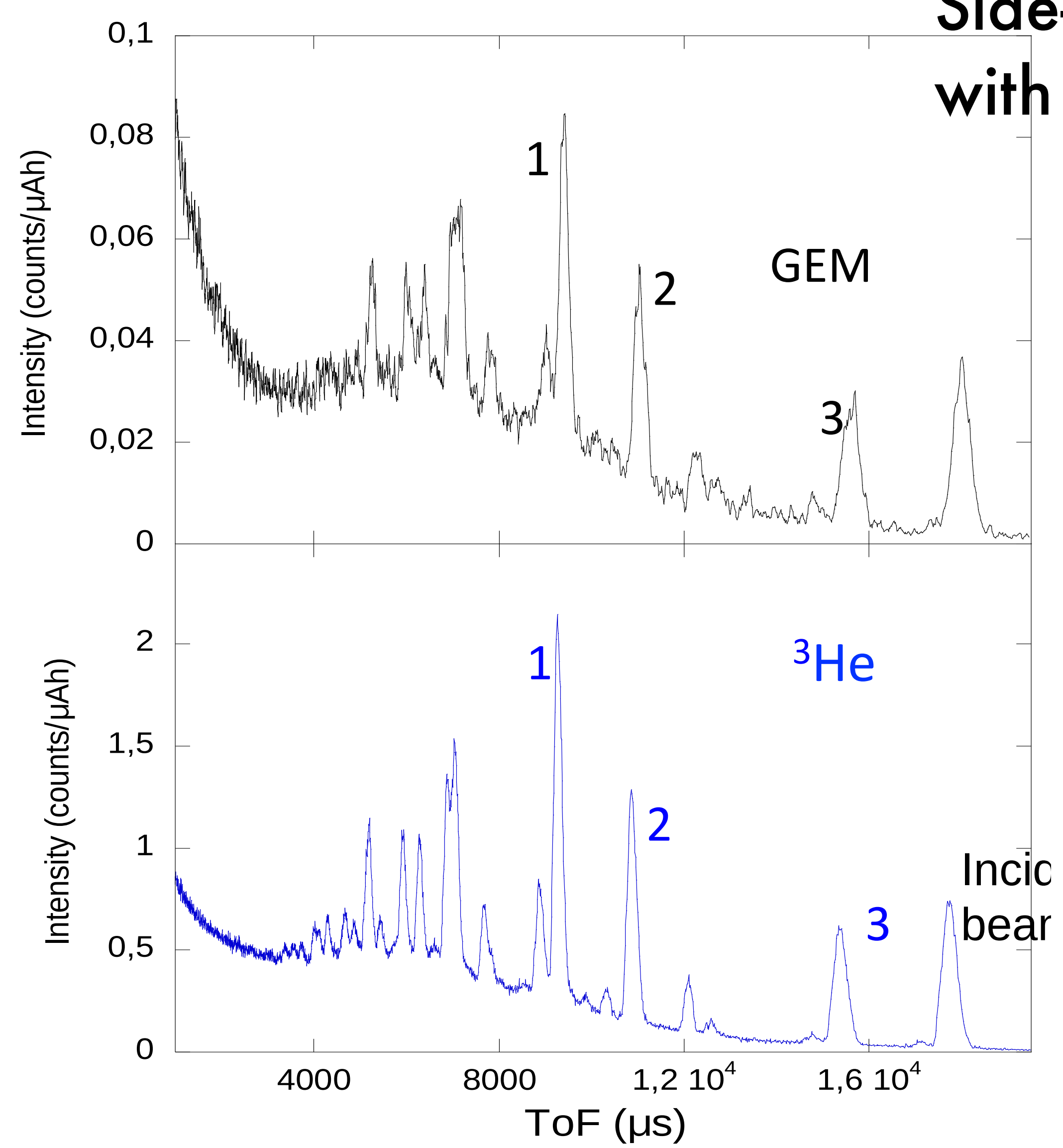
BANDGEM Detector

Analytical calculations are valid for this geometry

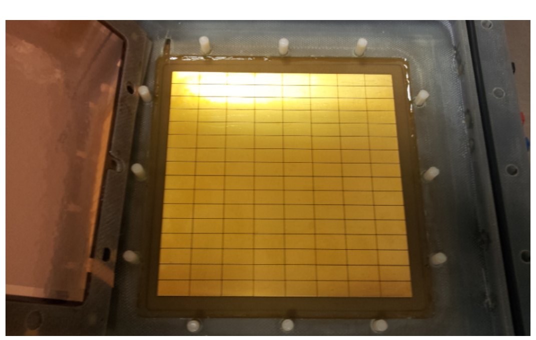


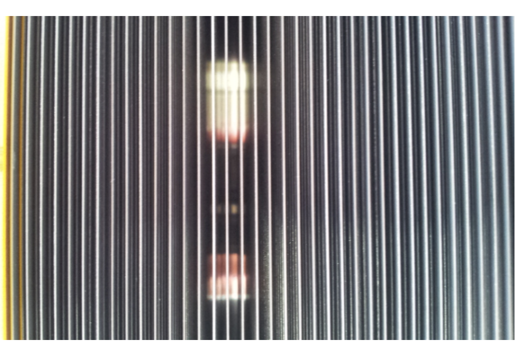
Alumina lamellae coated on both sides with $^{10}B_4C$

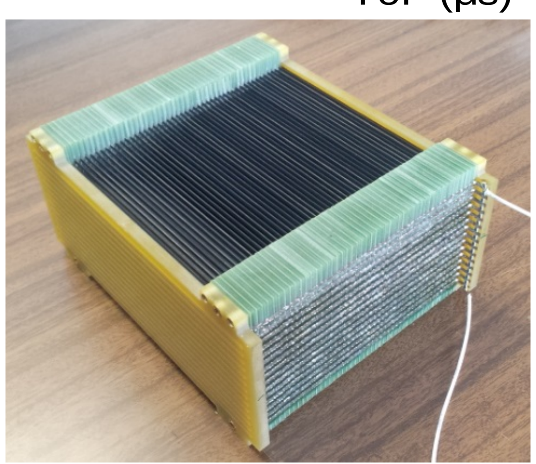
Side-by-side with He-3

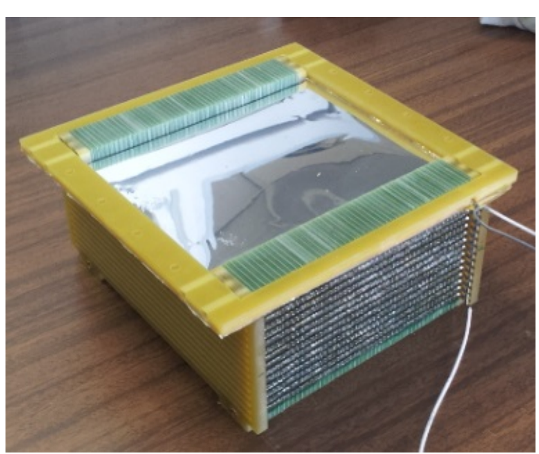


Using low θ values (few degs) the path of the neutron inside tl
B_4C is increased → Higher efficiency when detector is inclined









EUROPEAN SPALLATION SOURCE

Neutron Macromolecular Crystallography

Bovine heart

cytochrome c oxidase

$P2_12_12_1$

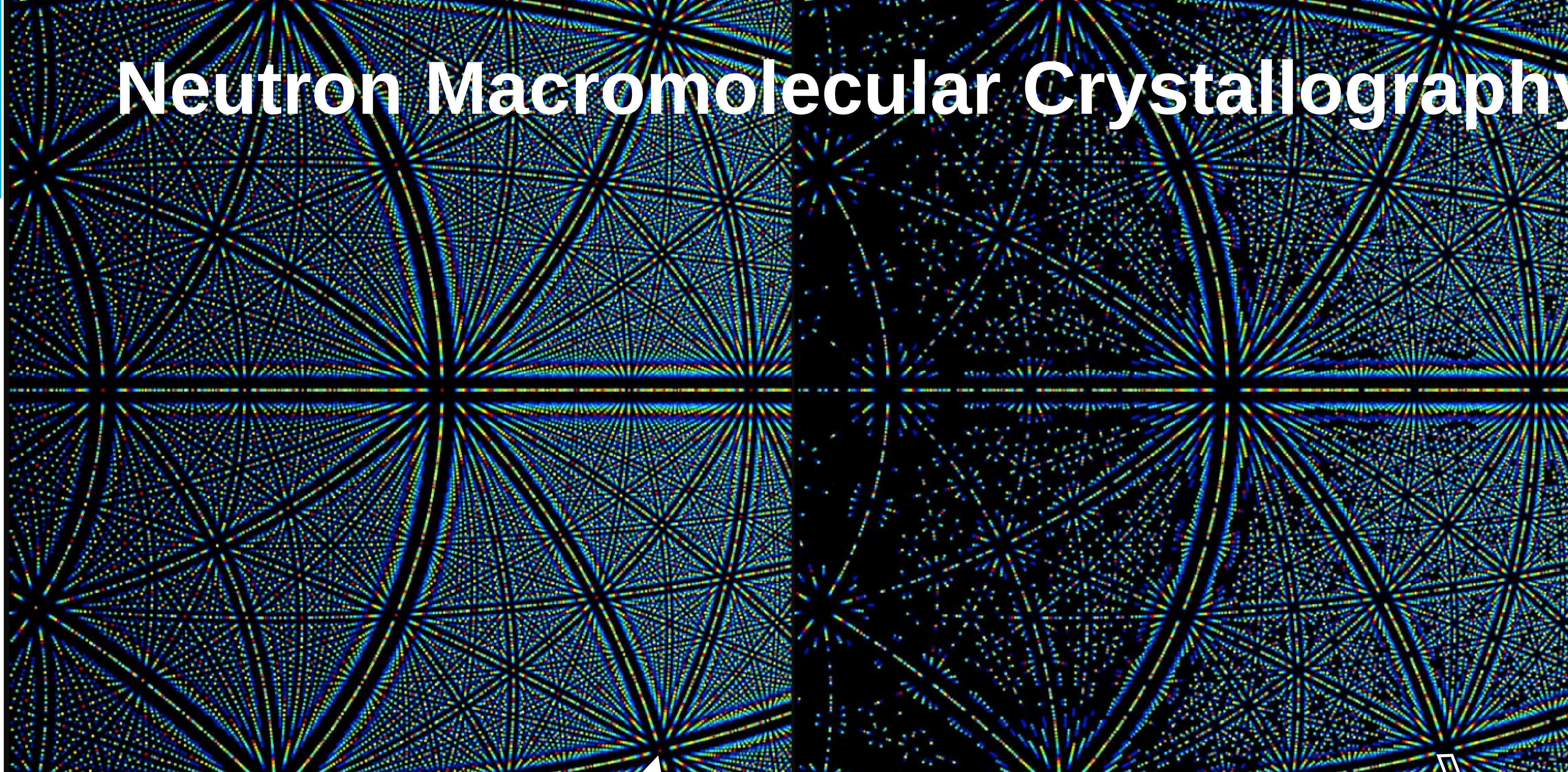
a = 182.59 Å

b = 205.40 Å

c = 178.25 A

Detector distance 1 m

<<1mm spatial resolution to be able to integrate intensities



All reflections

14 28 42 (3.409 Å, 134.4 ms) 21 35 49 (2.809 Å, 110.8 ms)
15 29 43 (3.309 Å, 130.5 ms) 22 36 50 (2.739 Å, 108.0 ms)
16 30 44 (3.215 Å, 126.8 ms) 23 37 51 (2.672 Å, 105.4 ms)
17 31 45 (3.124 Å, 123.2 ms) 24 38 52 (2.608 Å, 102.9 ms)
18 32 46 (3.040 Å, 119.9 ms) 25 39 53 (2.548 Å, 100.5 ms)
19 33 47 (2.959 Å, 116.7 ms) 26 40 54 (2.489 Å, 98.2 ms)
20 34 48 (2.882 Å, 113.6 ms)

Spatial overlaps only

27 53 79 (1.812 Å, 71.4 ms)
22 43 64 (2.236 Å, 88.2 ms)
18 35 52 (2.752 Å, 108.5 ms)
17 33 49 (2.920 Å, 115.1 ms)
19 37 55 (2.602 Å, 102.6 ms)
15 29 43 (3.327 Å, 131.2 ms)
27 52 77 (1.856 Å, 96.4 ms)
26 50 74 (1.933 Å, 76.2 ms)
24 46 68 (2.103 Å, 82.9 ms)
22 42 62 (2.306 Å, 90.9 ms)
21 40 59 (2.424 Å, 95.6 ms)
20 38 56 (2.553 Å, 100.7 ms)
28 53 78 (1.833 Å, 72.3 ms)

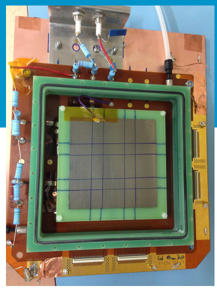
- 1.800 to 2.019 Angstroms
- 2.019 to 2.237 Angstroms
- 2.237 to 2.456 Angstroms
- 2.456 to 2.675 Angstroms
- 2.675 to 2.894 Angstroms
- 2.894 to 3.112 Angstroms
- 3.112 to 3.331 Angstroms
- 3.331 to 3.550 Angstroms

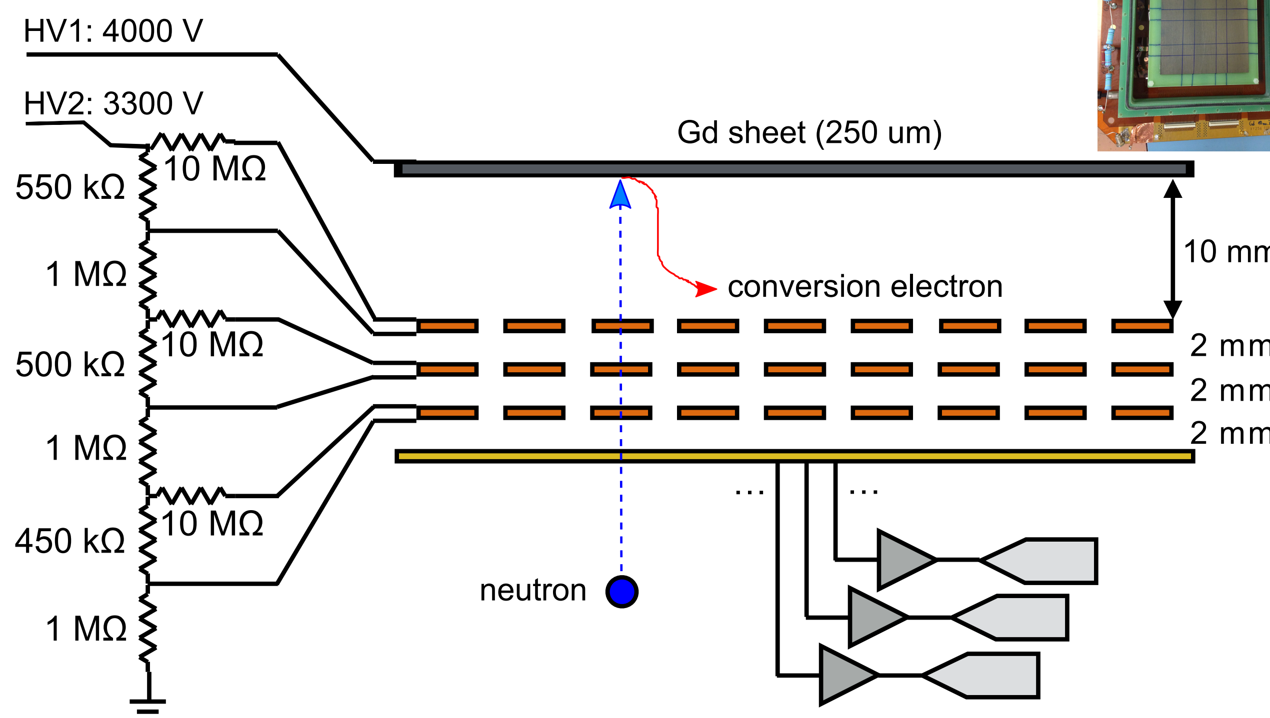
Generated using the Daresbury Laue Suite

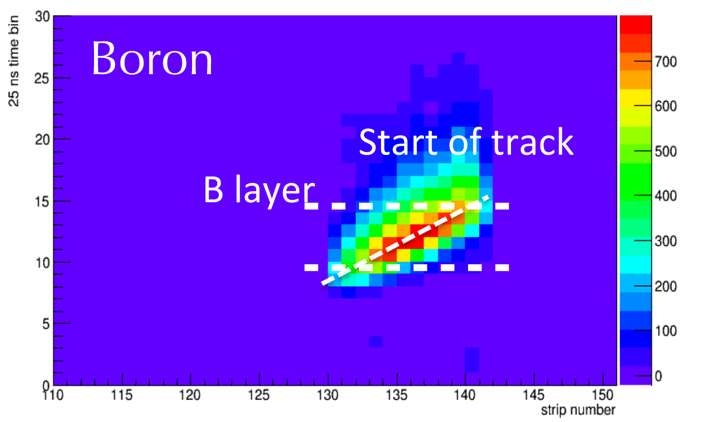
Campbell et al. J. Appl. Cryst. (1998). 31, 496-502
Artz et al. J. Appl. Cryst. (1999). 32, 554-562
Helliwell, J.R. et al. J. Appl. Cryst. (1989) 22, 483–497

Gd-GEM

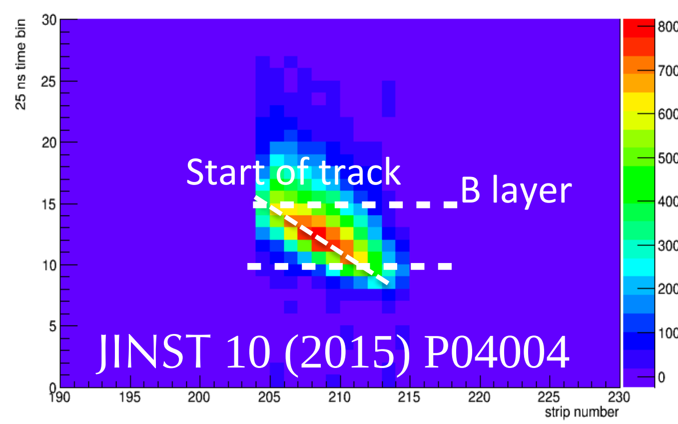
- NMX: <<1mm position resolution requirement, Time Resolved, ca. 1m^2 detector area
- Take Micro Time Projection Chamber concept from ATLAS experiment upgrade
- Resolution: use single layer Gd, look for



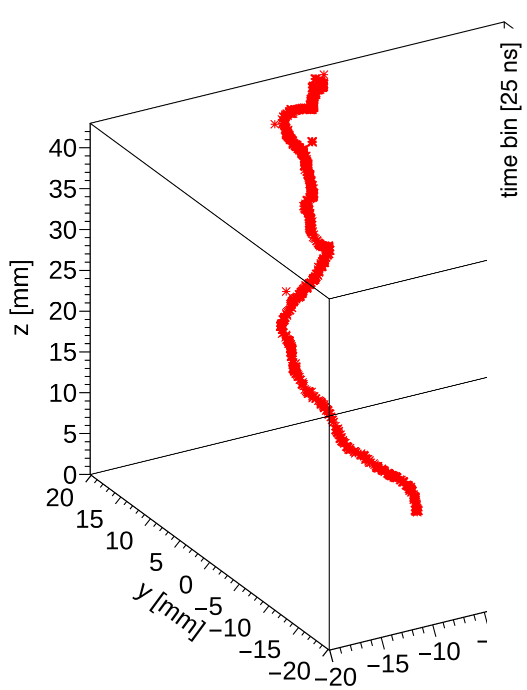


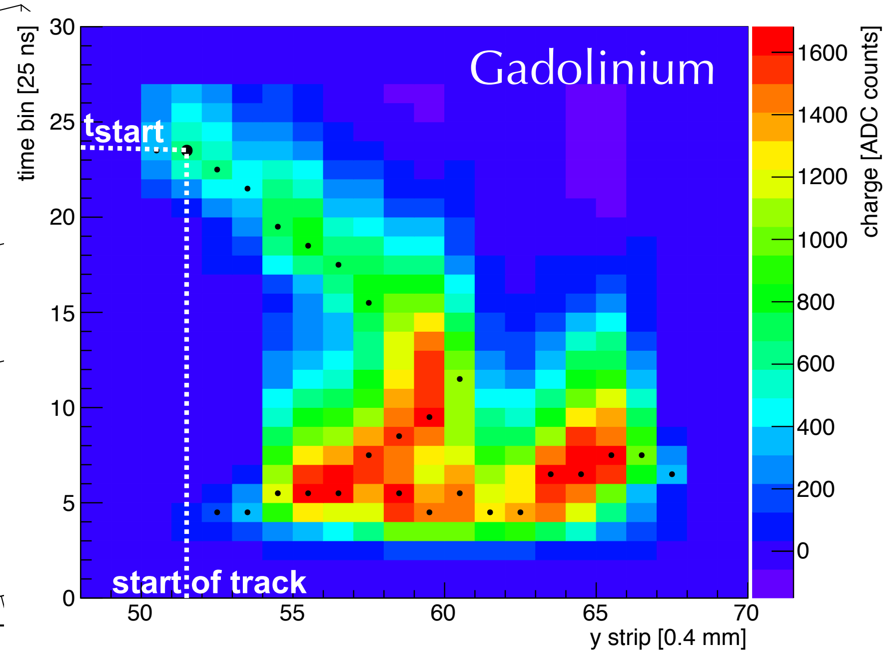


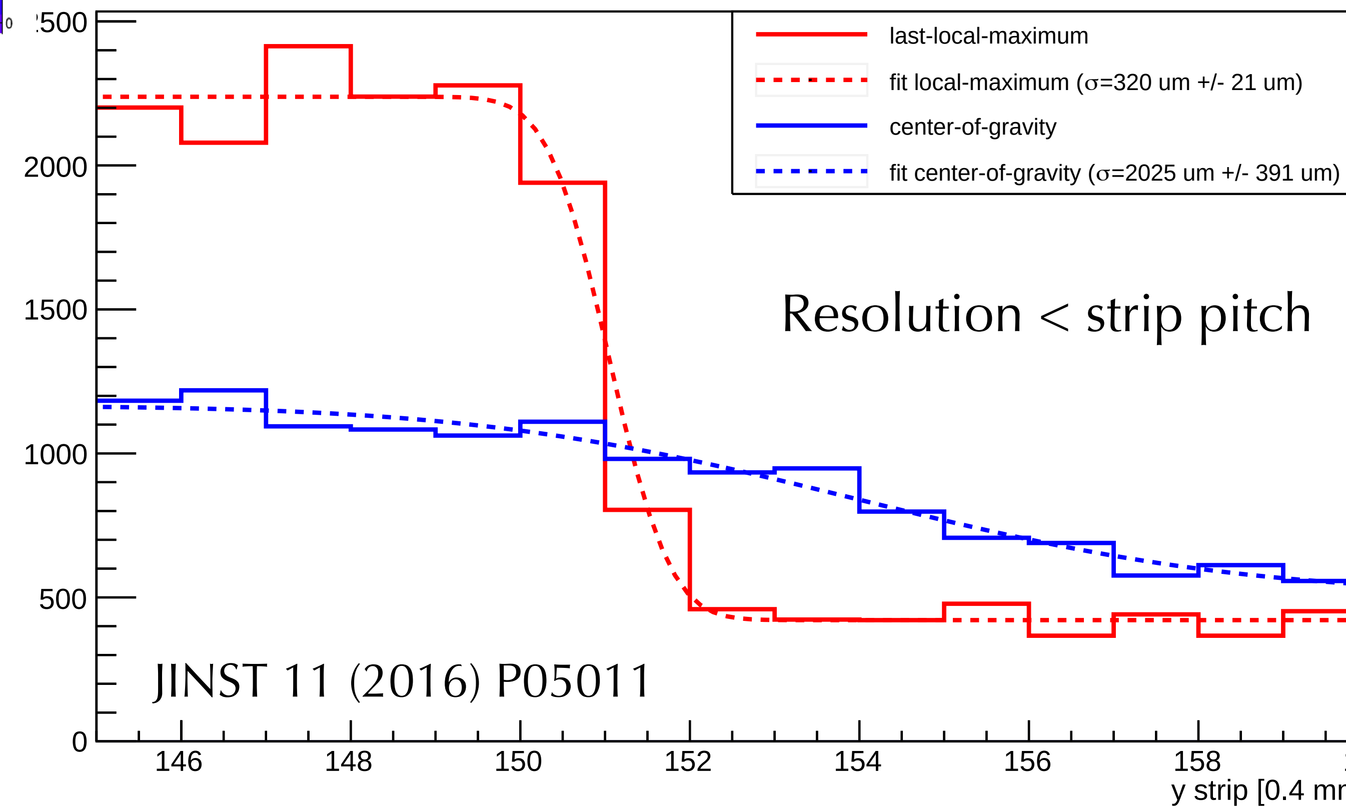
Track x



Track y



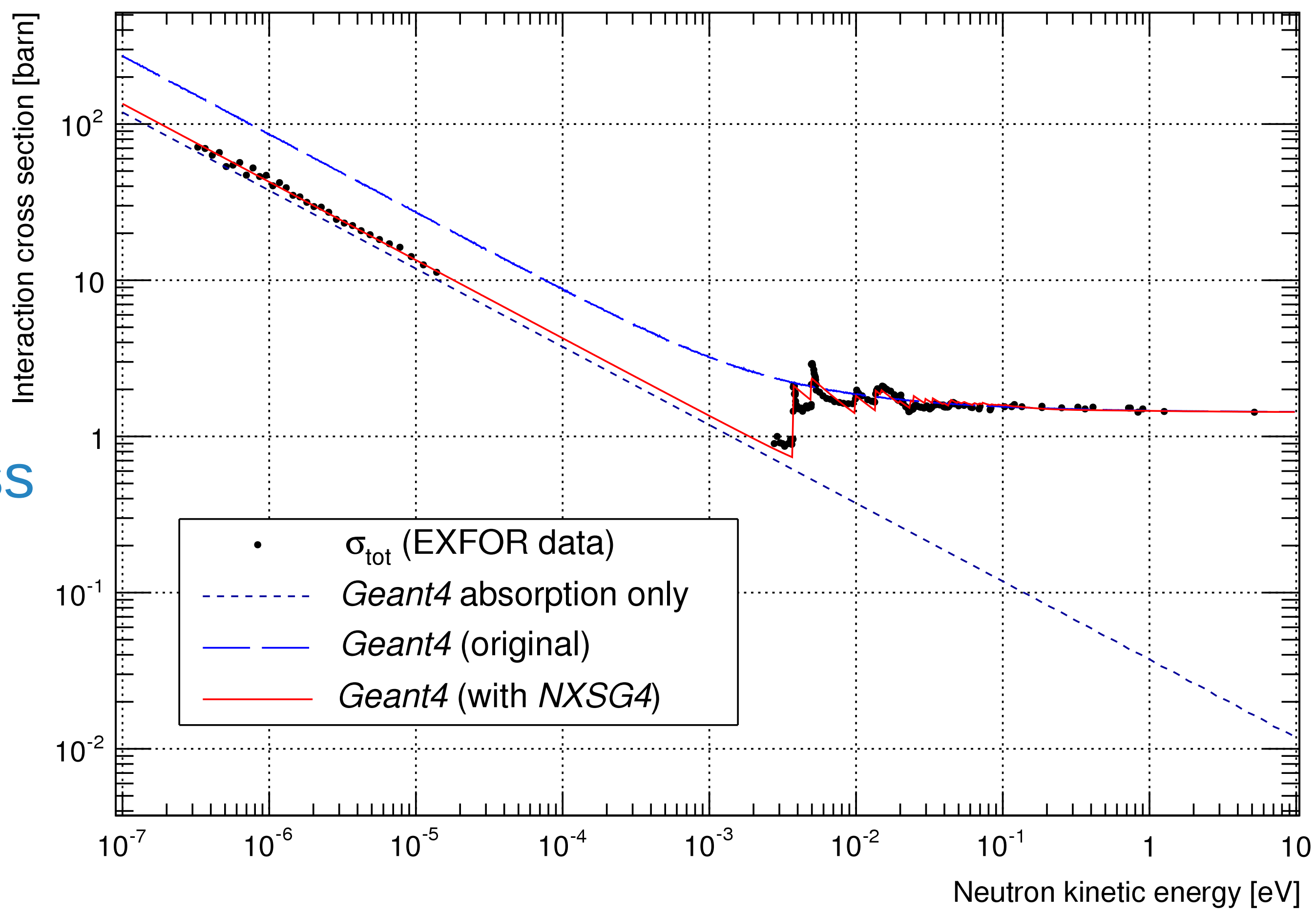




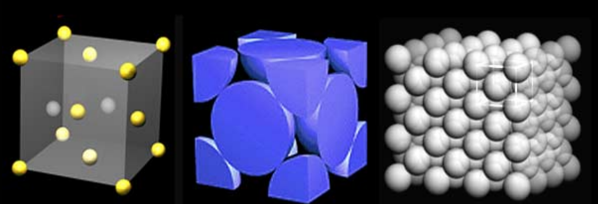
Neutron diffraction in polycrystalline materials: Add-on for GEANT4

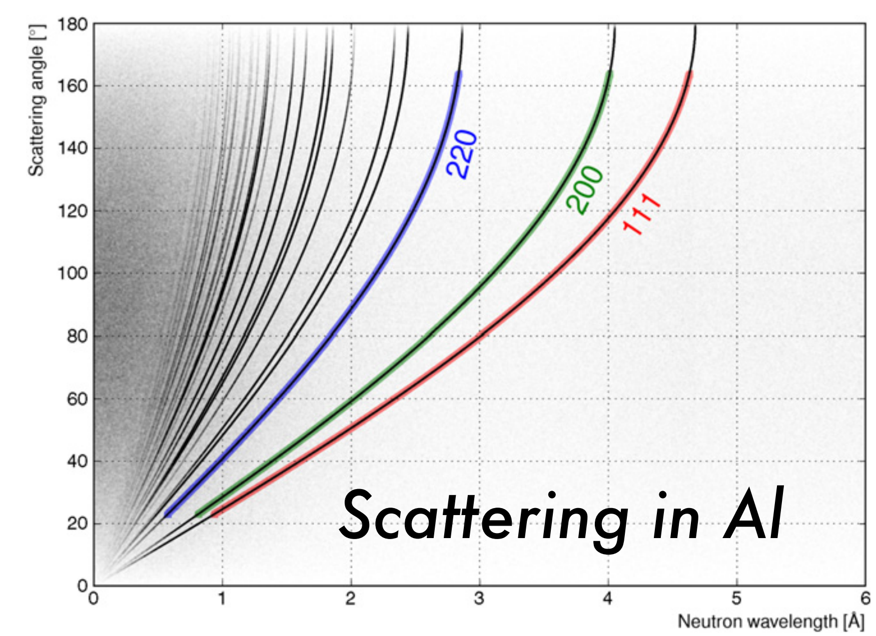
HZB Helmholtz Zentrum Berlin
Risø DTU National Laboratory for Sustainable Energy
EUROPEAN SPALLATION SOURCE

- GEANT4 is an invaluable simulation tool
- However, thermal/cold neutrons not well validated
- No support for crystal diffraction
- A new plugin NXSG4 allows neutron diffraction in polycrystalline materials
- Based on nxs library, used in McStas, Vitess
- Using simple unit cell parameters, only low energy neutron scattering is overriden. All other GEANT4 capability retained.




```
(tkittel@localhost data)> cat Al.nxs
space_group = 225
lattice_a = 4.049
lattice_b = 4.049
lattice_c = 4.049
lattice_alpha = 90
lattice_beta  = 90
lattice_gamma = 90
[atoms]
add_atom = Al 3.449 0.008 0.23 26.98 429.0 0.0 0.0 0.0
```





- Available at http://cern.ch/nxsg4
- J. Comp Phys Comm 189 (2015) 114

Monte Carlo Particle Lists: MCPL: Allows to pass particles between McStas, MCNP, GEANT4

https://mctools.github.io/mcpl/

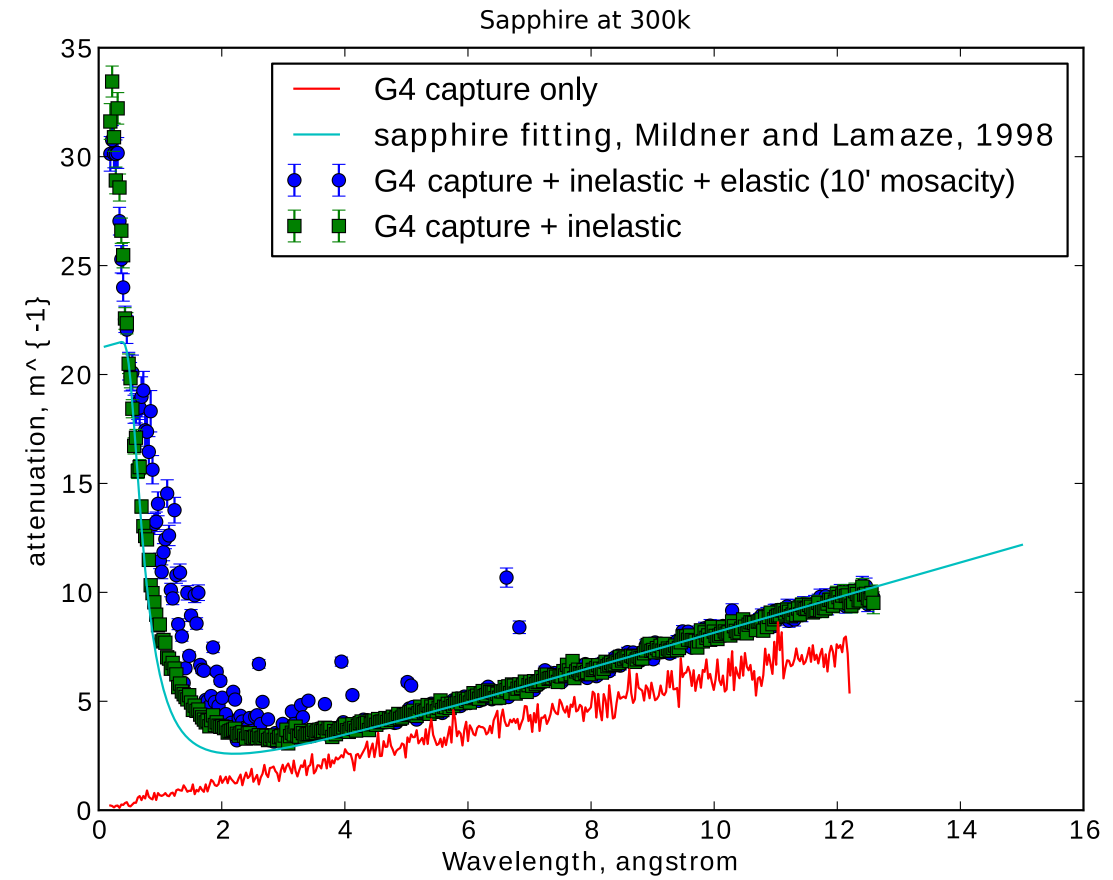
T. Kittelmann et al., subm. J. Phys Comm (2016) https://arxiv.org/abs/1609.02792

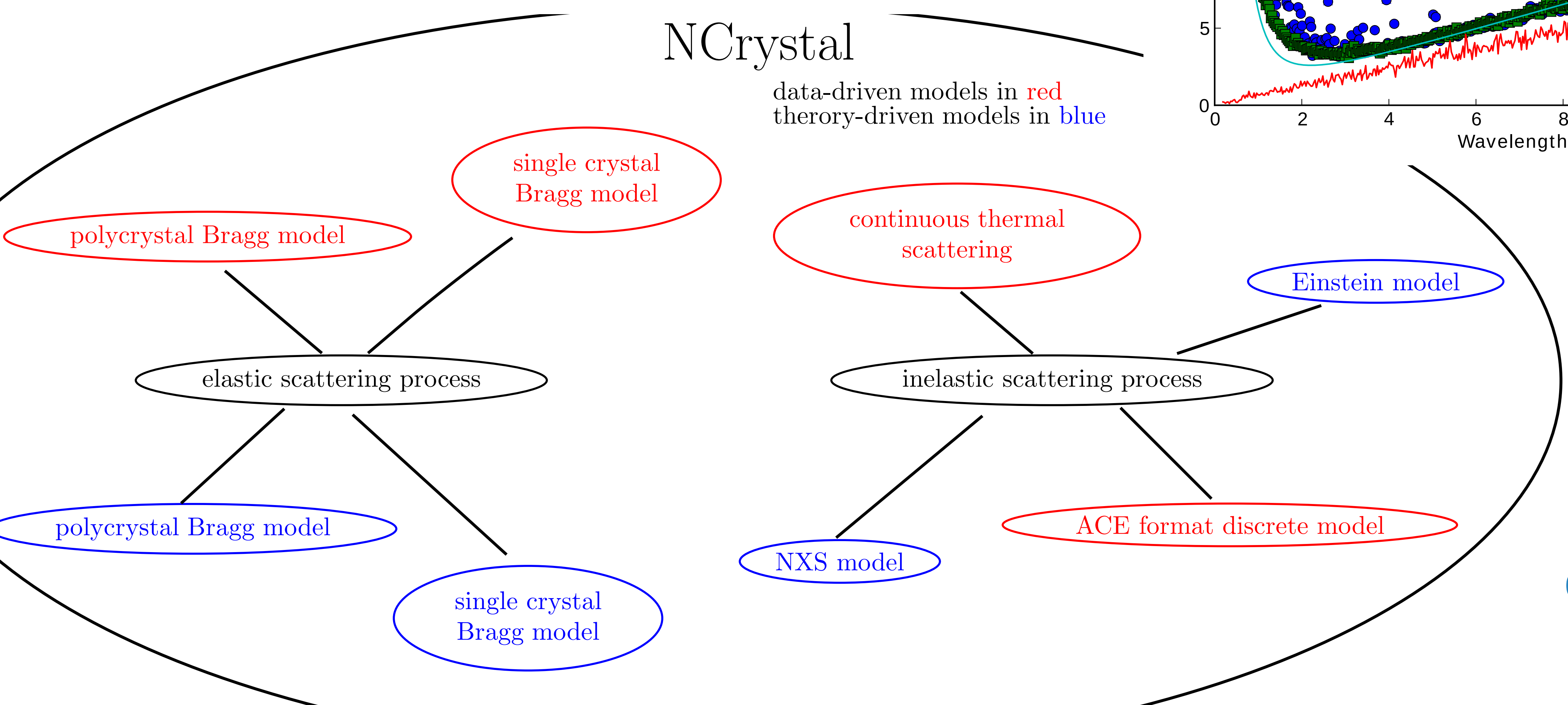
Simulation of Neutron Scattering in Crystalline Materials

- “NCrystal" models physics of thermal neutron transport in poly- and single-crystalline materials
- Interface to MC models: GEANT4, MCNP, McStas

The scattering physics in NCrystal is a combination of the inelastic and elastic scattering processes. The double differential cross section describes the likelihood of a neutron being scattered into a small solid angle $d\Omega$ with final energy between E' and $E' + dE'$. It can be expressed as

$$\frac{\partial^2\sigma}{\partial E'\partial\Omega} = \frac{\partial^2\sigma_{in}}{\partial E'\partial\Omega} + \frac{\partial^2\sigma_{el}}{\partial E'\partial\Omega}$$



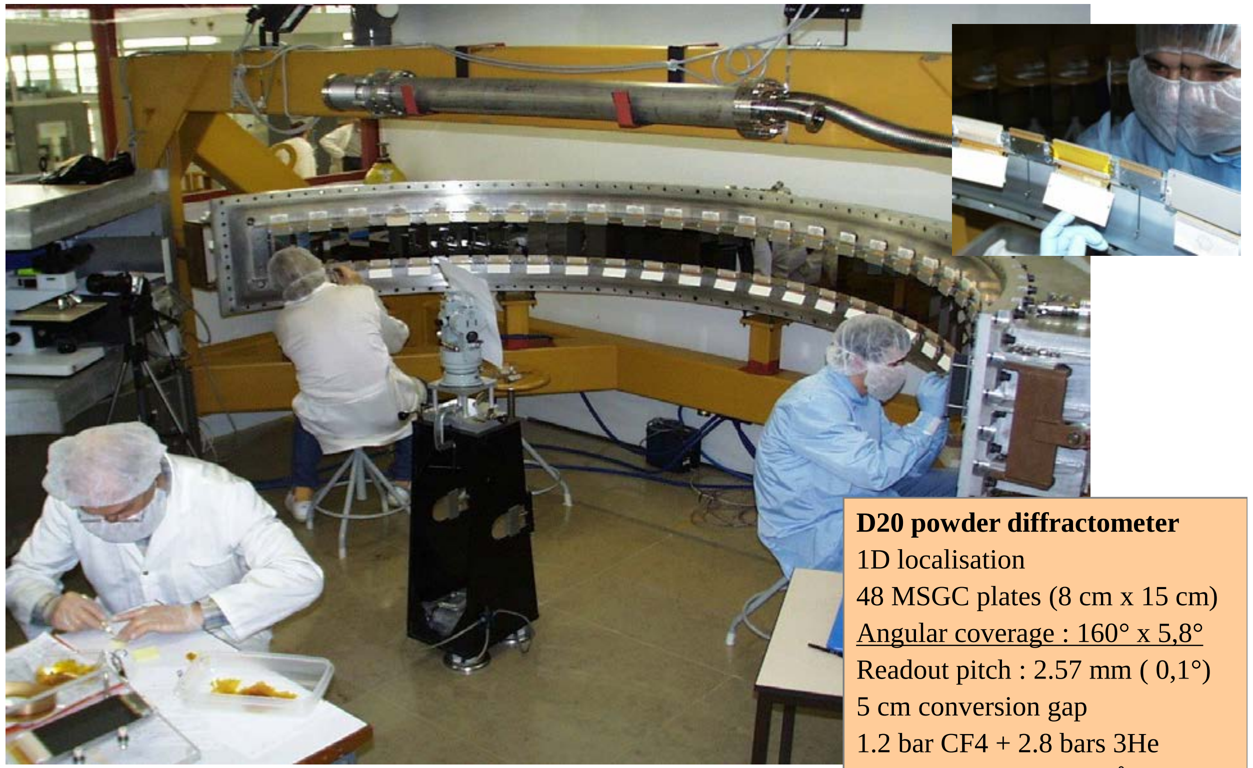


Extension under development

State of the Art of Neutron Detectors

- Helium-3 Tubes most common
- Typically 3-20 bar Helium-3
- 8mm-50mm diameter common
- Using a resistive wire, position resolution along the wire of ca. 1% possible

Curved 1D MSGC for the D20 Powder Diffractometer (2000)

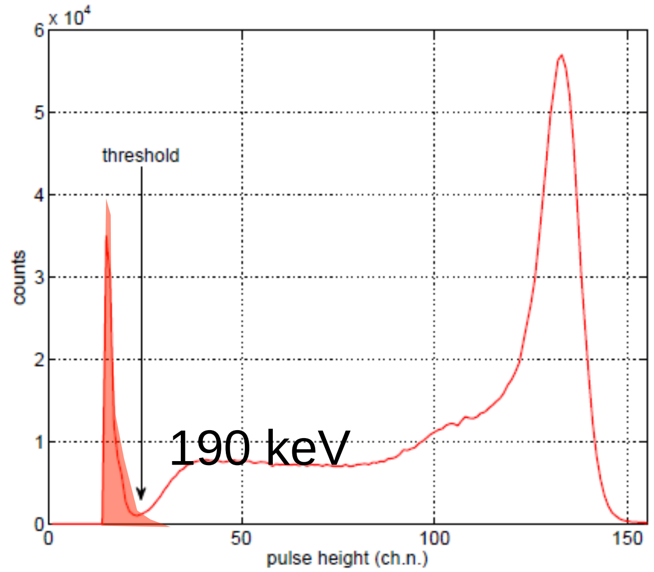


D20 powder diffractometer
1D localisation
48 MSGC plates (8 cm x 15 cm)
Angular coverage : 160° x 5,8°
Readout pitch : 2.57 mm (0,1°)
5 cm conversion gap
1.2 bar CF_4 + 2.8 bars ^3He
Efficiency 60% @ 0.8 Å

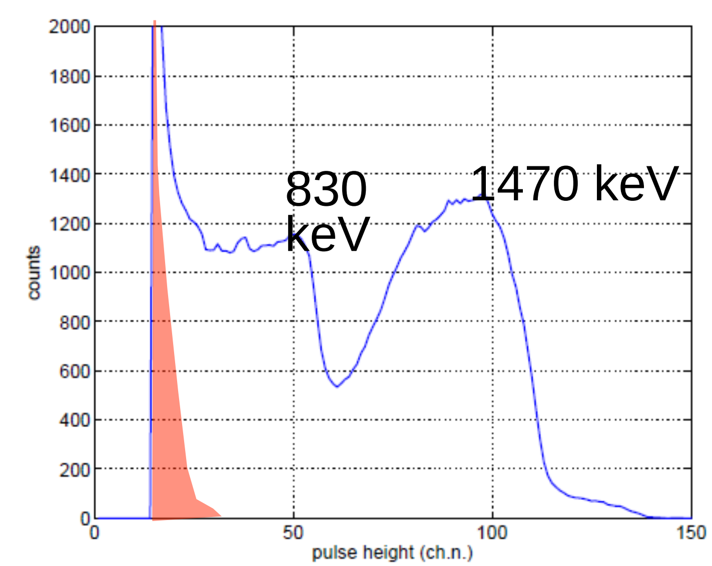
- First micro pattern gaseous detectors was MS invented by A Oed at the ILL in 1988
- Rate and resolution advantages
- Helium-3 MSGCs in operation


ESS construction
18 May 2017

Background - Gamma Sensitivity



<10^{-6}



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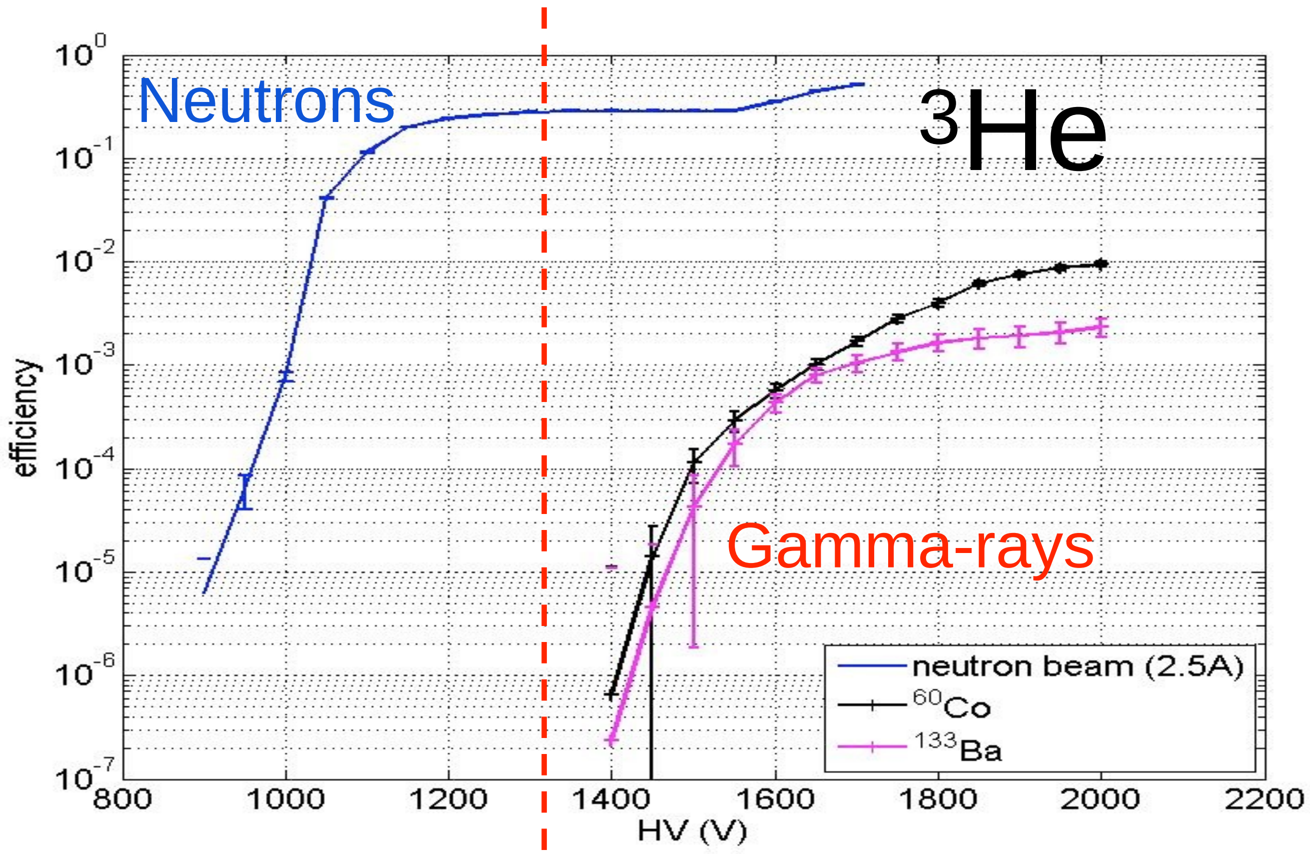
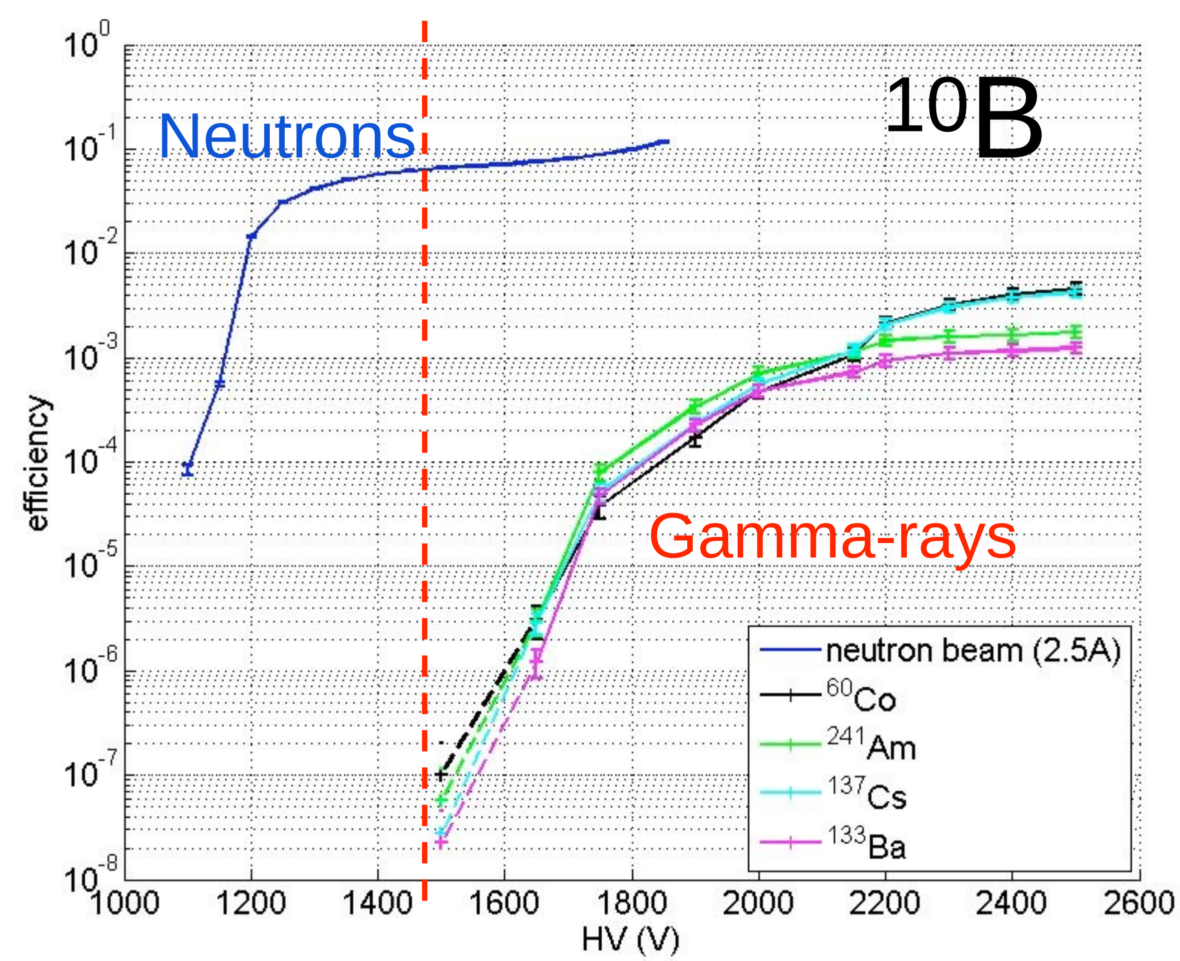
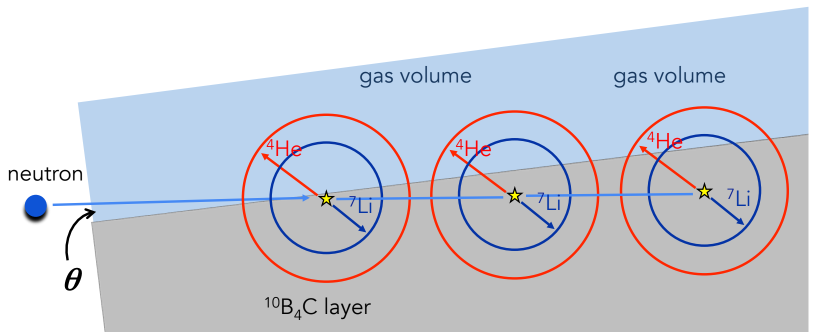
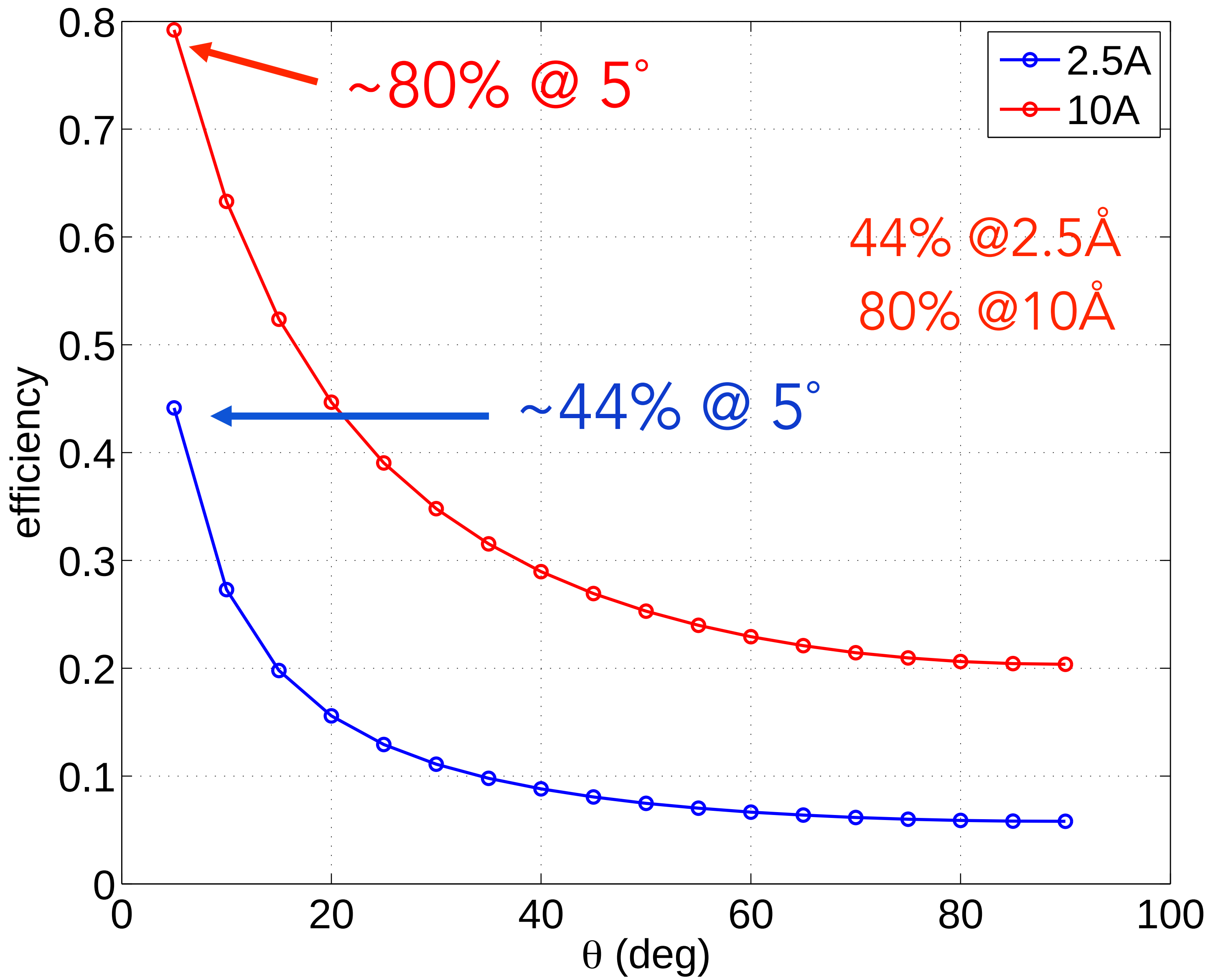




JINST 8 (2013) 10025

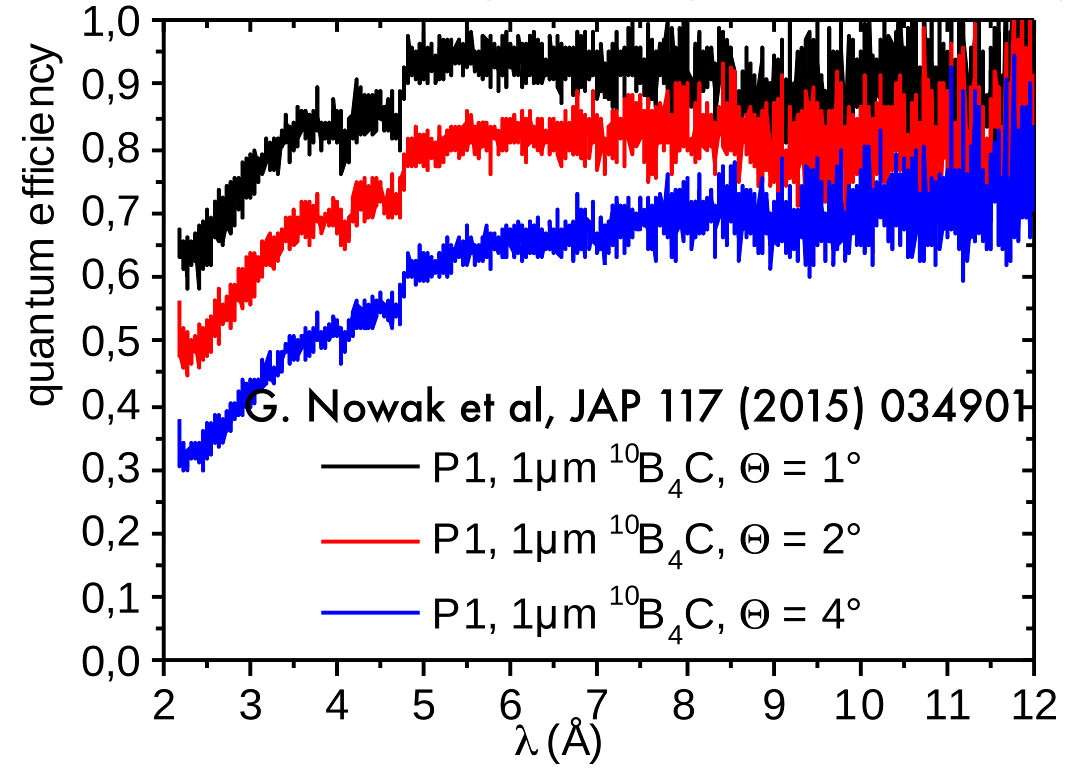
Efficiency of ^{10}Boron Detectors: Inclined Configuration

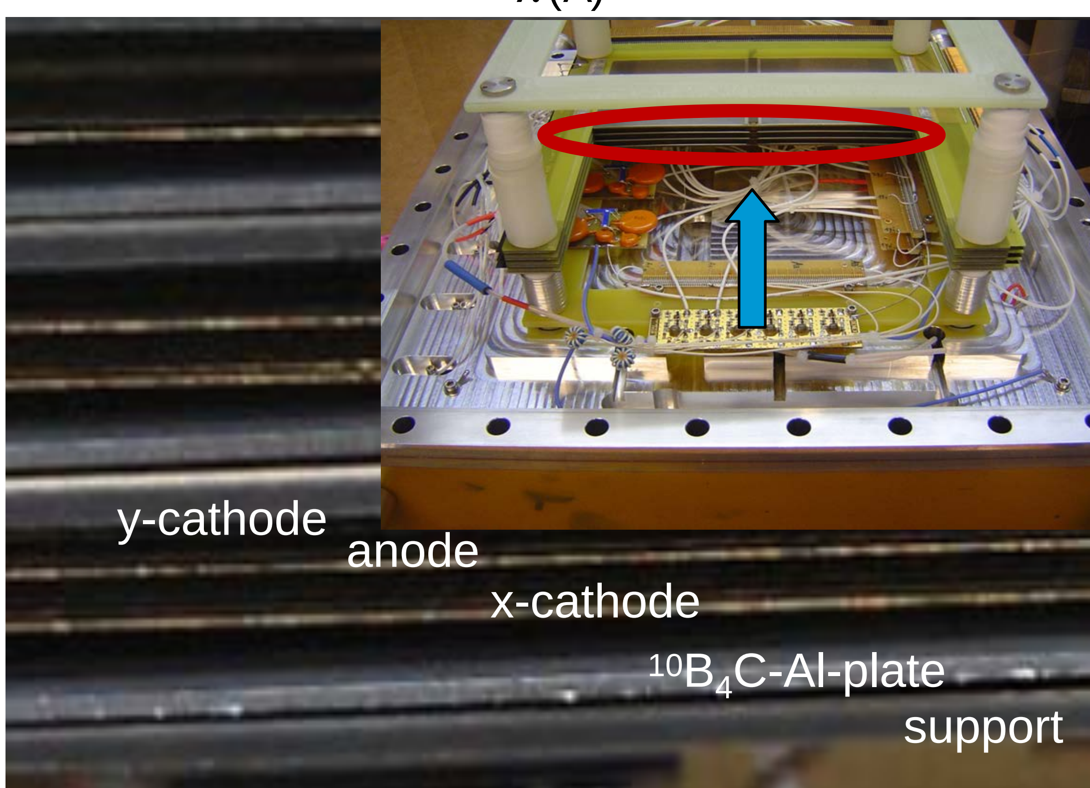




F. Piscitelli, PhD Thesis, U.Perugia (2014)

smaller inclined angles: higher efficiency





The Multi-Blade project

High counting rate capability

High spatial resolution

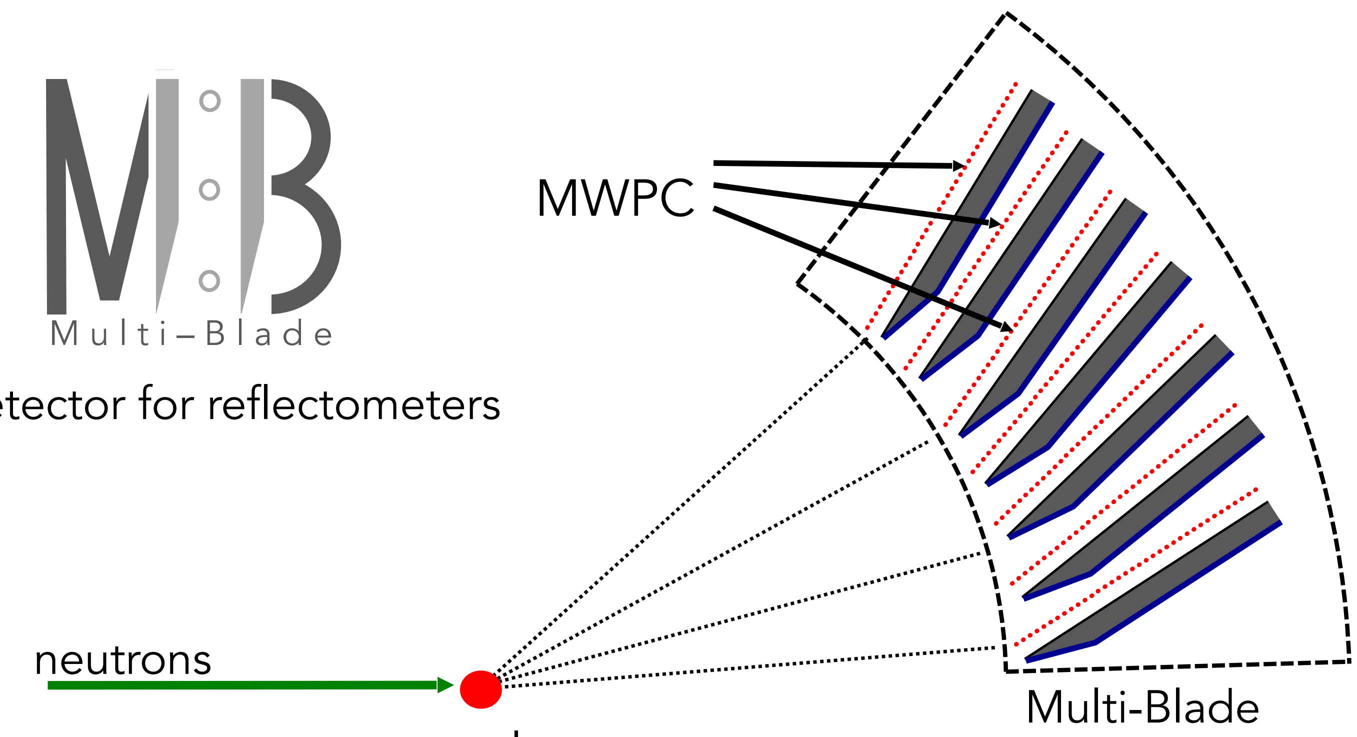
Why the counting rate capability is improved?

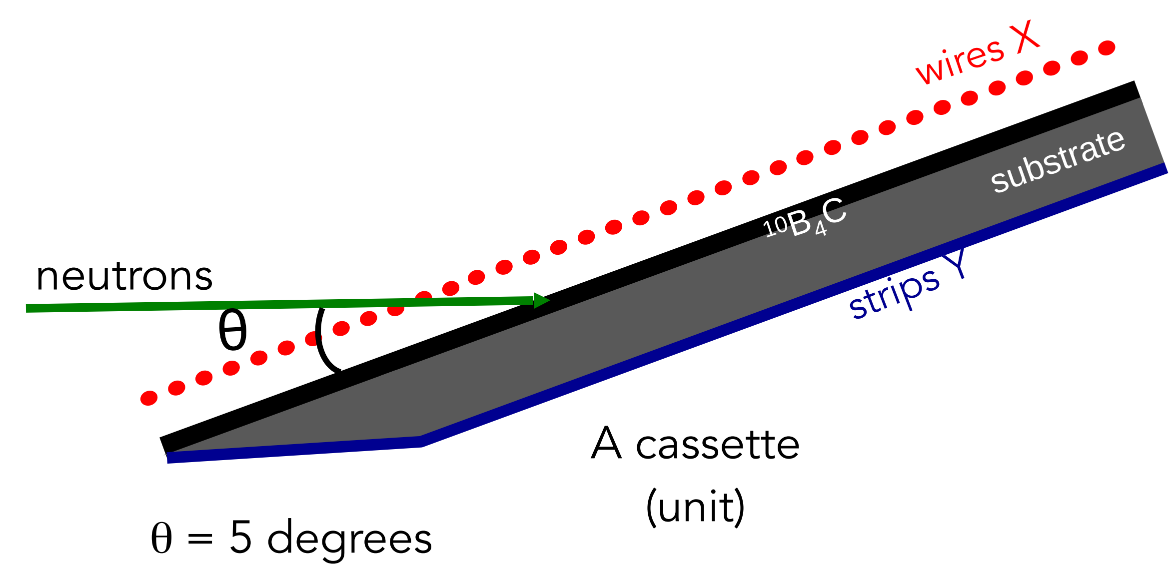
^{10}B-detector for reflectometers

1. The intensity is spread over a wider surface (5 degrees ~ factor x10)

2. Thin gap MWPC (4mm)

3. Low gas gain operation G~20 (max 0.2pC avalanches)





Simple, modular, cheap

Summary

Matching ESS requirements

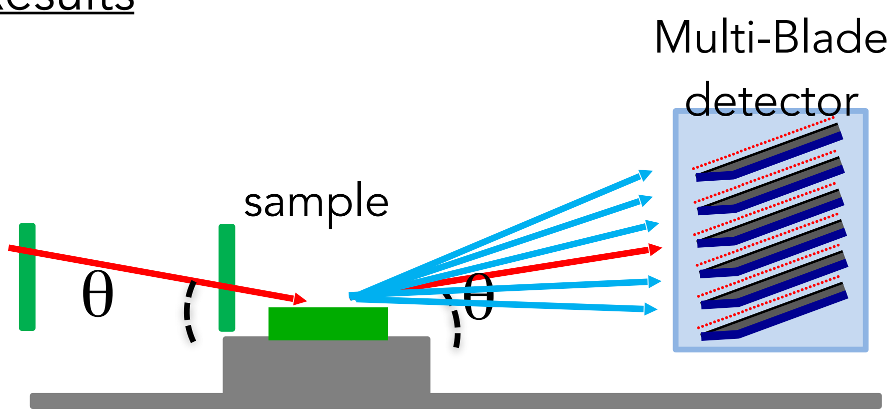
	Multi-Blade
gas gain	20
efficiency	45% @ 2.5Å 56% @ 4.2Å 65% @ 5.1Å
spatial resolution	$\boxed{0.5 \times 2.5\ \text{mm}^2}$
uniformity	10%
overlap	50% eff. drop in 0.5mm gap
stability	<1% in 12h
counting rate capability	>1.6 kHz/mm2 (lower limit) >17kHz / channel (lower limit)
gamma-ray sensitivity	< 10^{-7} (with 100keV threshold)

x3 better than state-of-the-art

x10 better than state-of-the-art

F. Piscitelli et al., The Multi-Blade Boron-10-based Neutron Detector for high intensity Neutron Reflectometry at ESS, JINST 12 (3) P03013 (2017).

Results



Ir sample
Si sample
Fe/Si sample