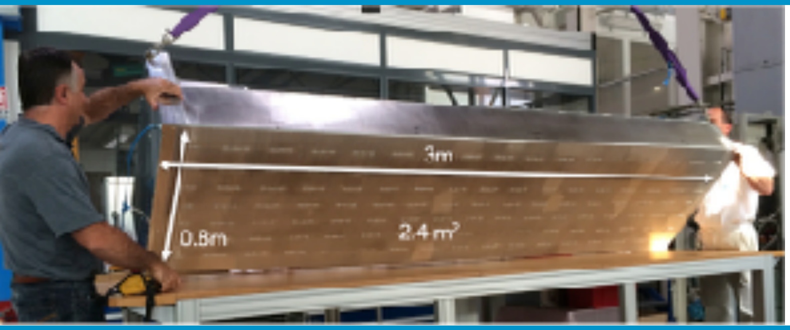
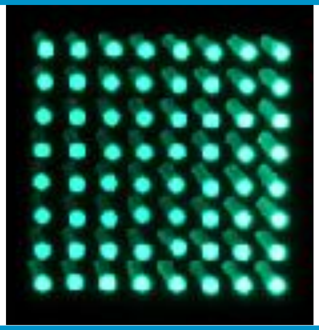
Neutron Detectors for the Initial Instrument Suite at the European Spallation Source

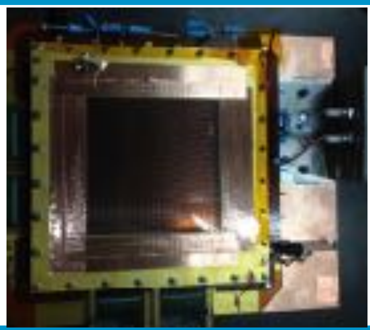
Richard Hall-Wilton

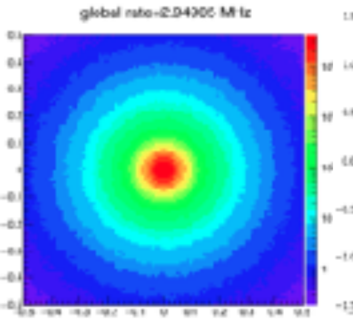
Leader of Detector Group
Deputy Division Head of Instrument Technologies

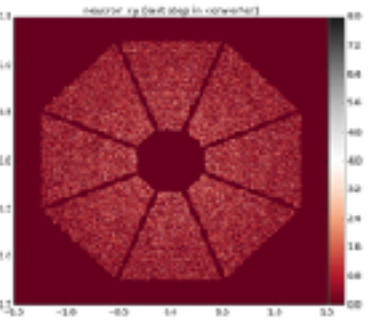
www.europeanspallationsource.se

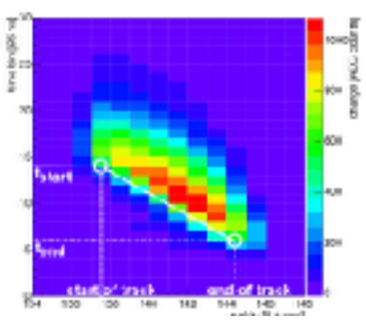


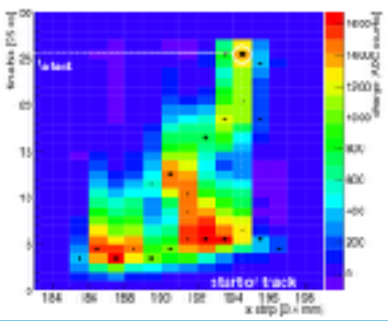


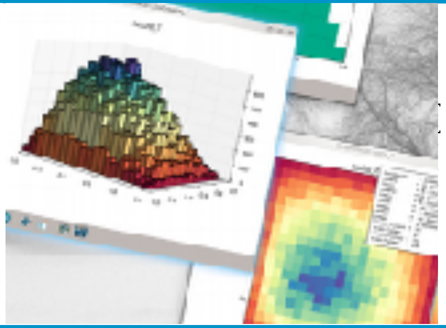


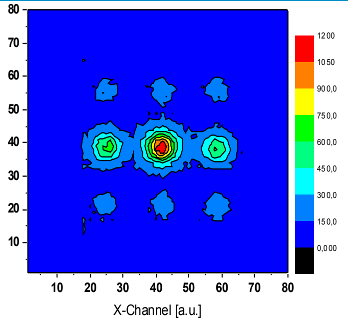


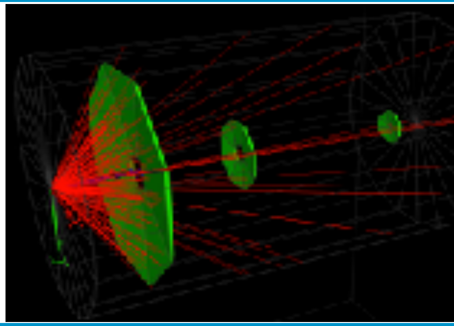




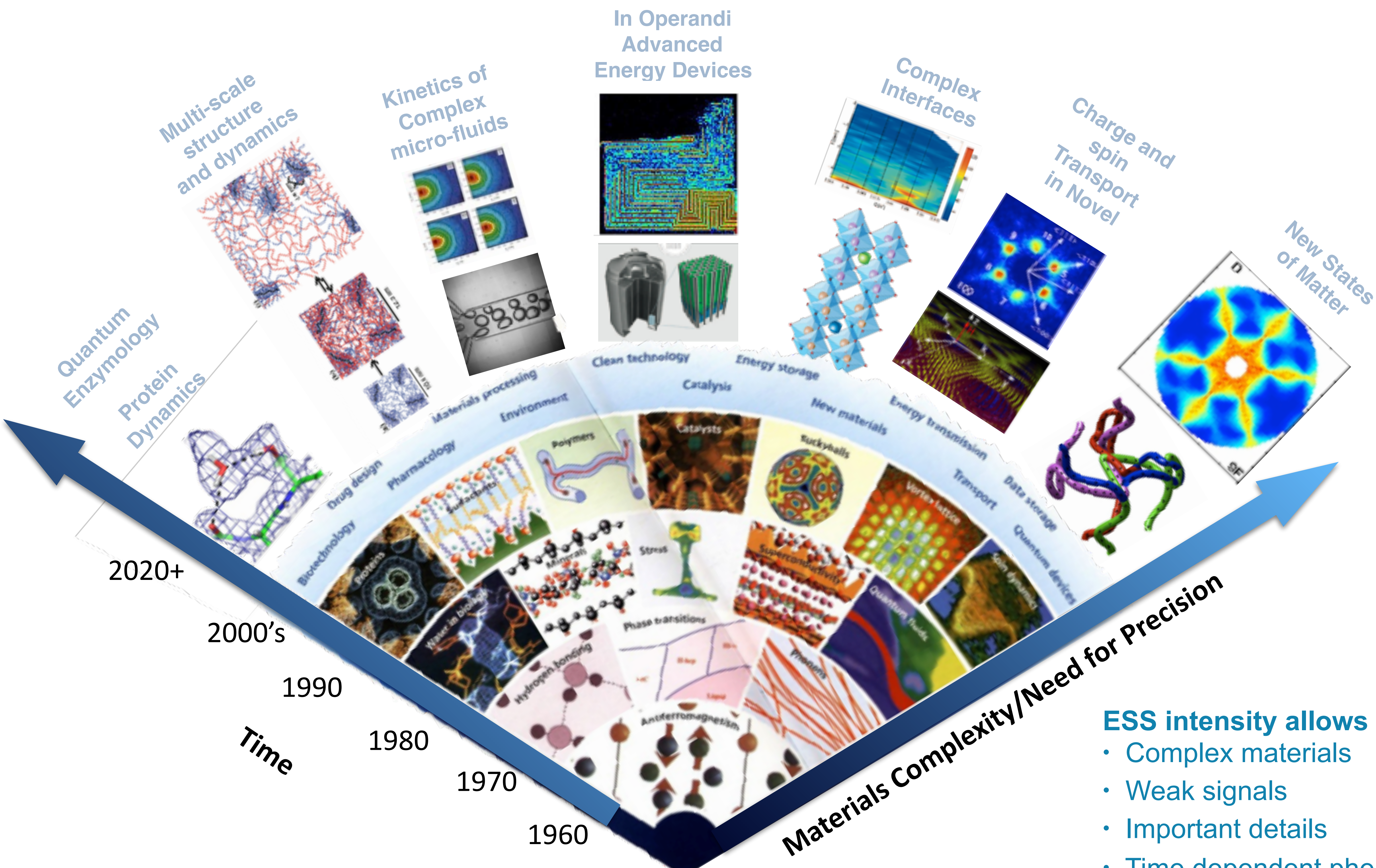








Neutron Science Pushes the Boundaries



ESS intensity allows studies of:

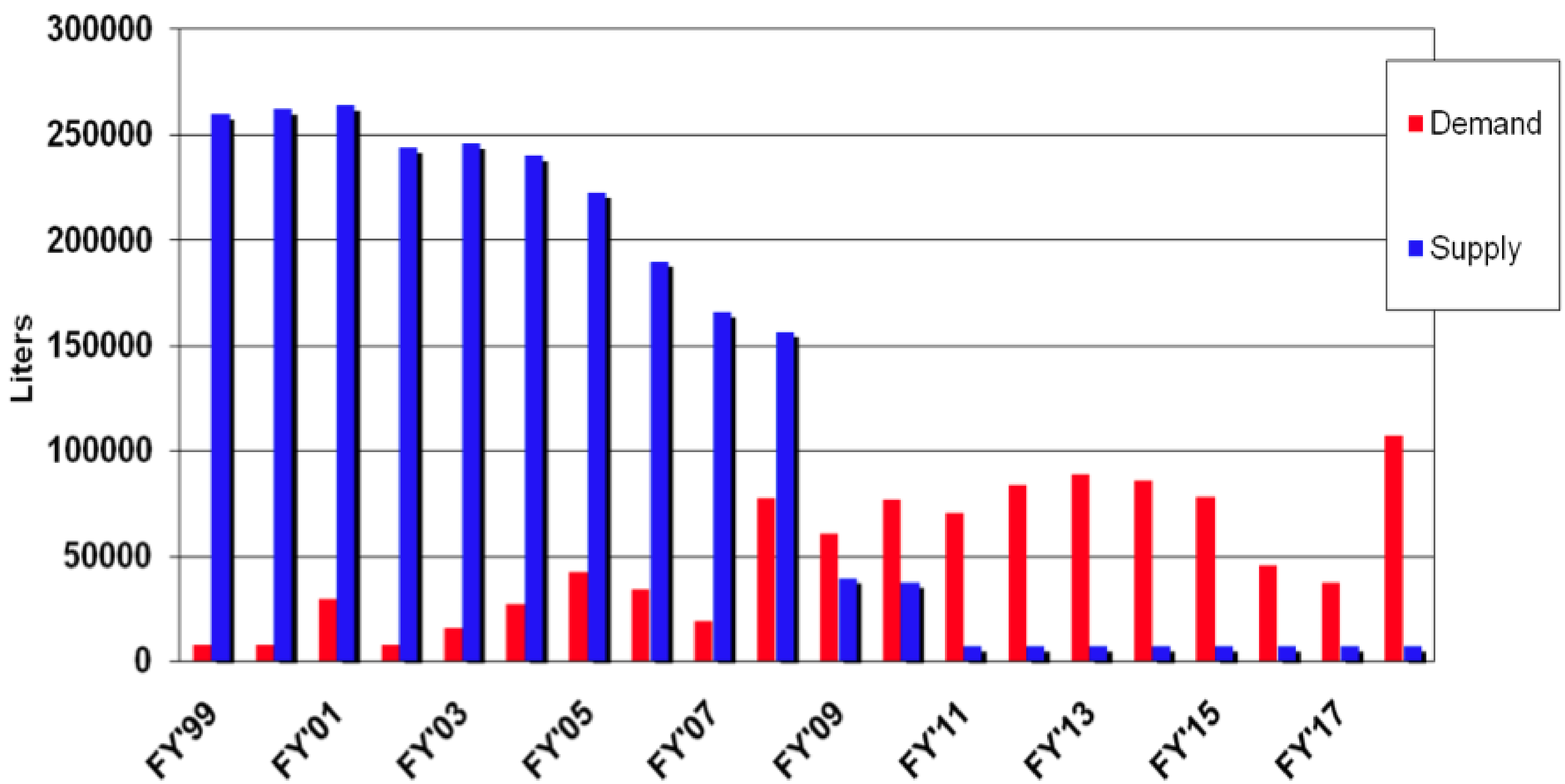
- Complex materials
- Weak signals
- Important details
- Time dependent phenomena

Upcoming Research Facilities

New facilities needed to:

- **replace capacity from closing research reactors**
- **enhance capability to enable new science**

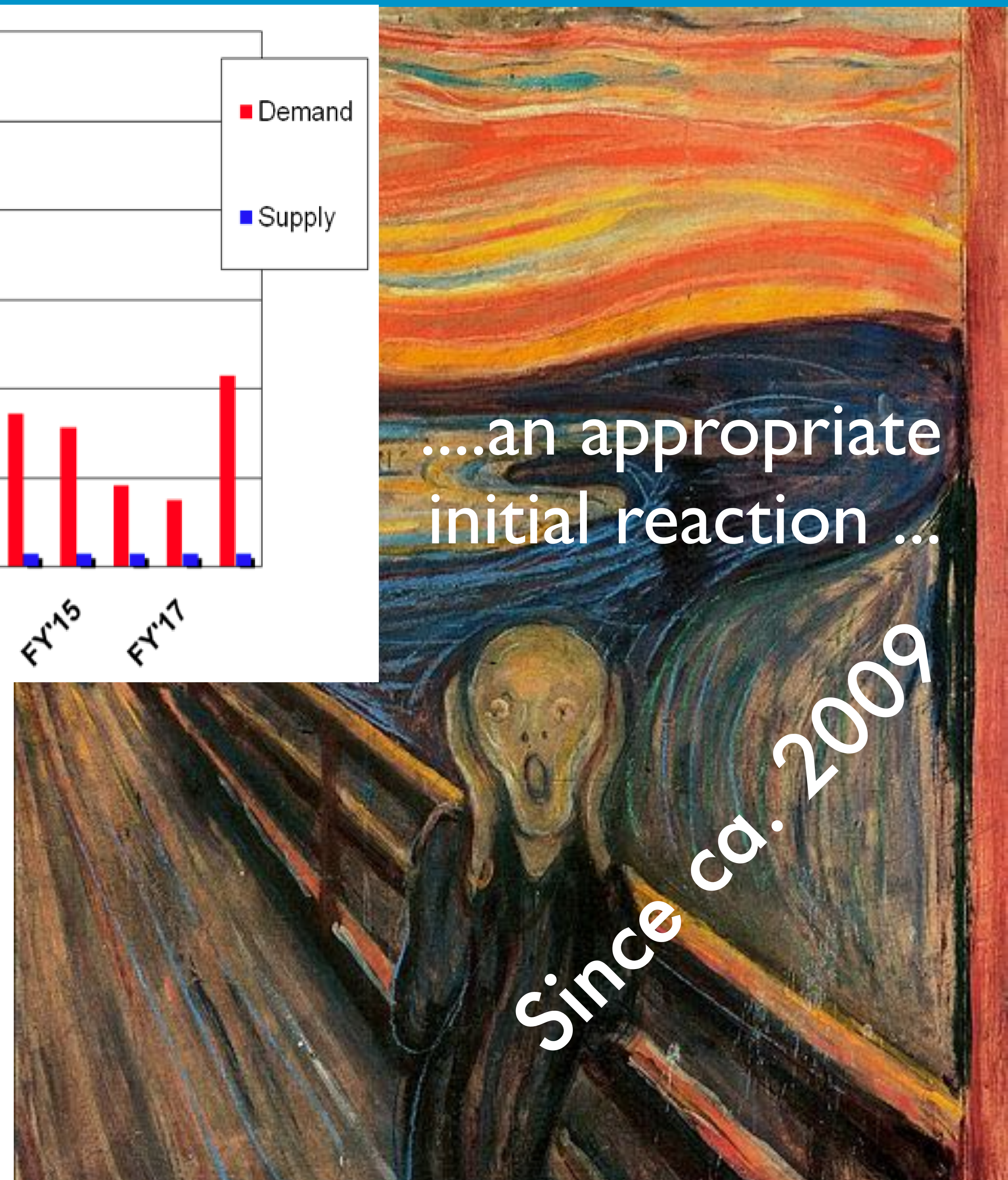
Helium-3 Crisis



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 … ?




webbkameror.se
EUROPEAN
SPALLATION
SOURCE
The ESS site
2011

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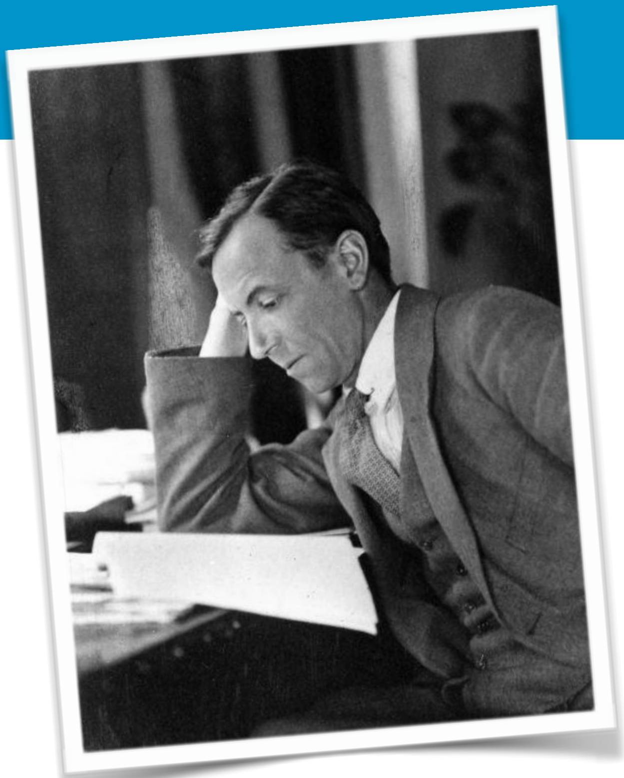
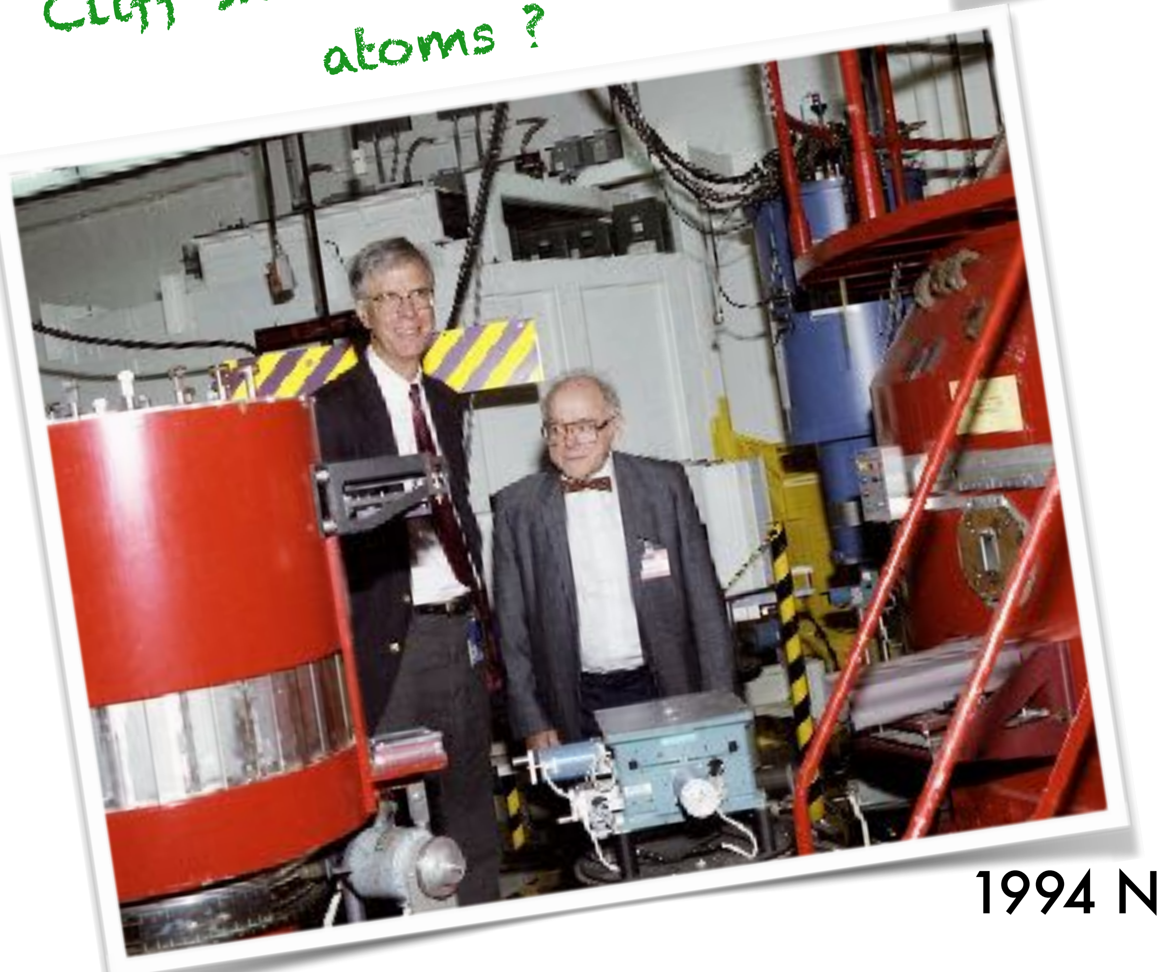
What is Neutron Scattering Science?

Neutrons



1932: Chadwick discovers "a radiation with the more peculiar properties", the neutron.

Cliff Shull: where are the atoms ?

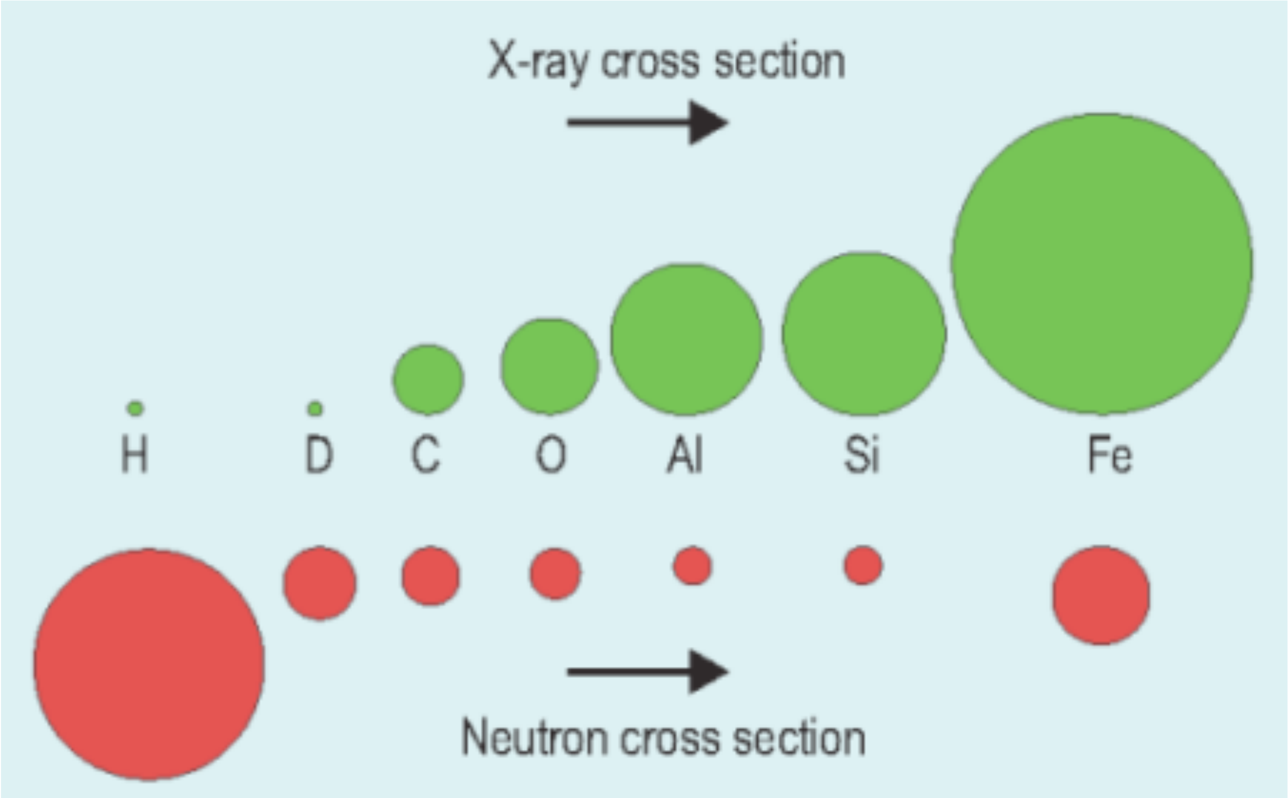


Bert Brockhouse: what do they do ?

1994 Nobel Prize in Physics

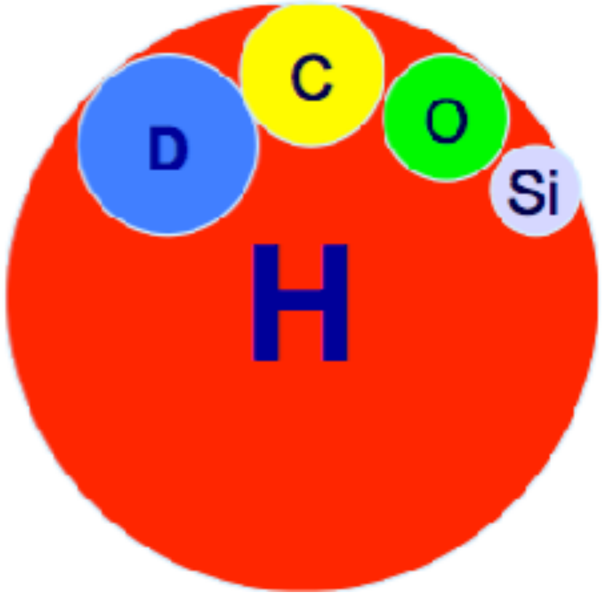
Why Neutrons?

Neutrons are:
- **low energy**
- **non-damaging**
- **penetrating**
- **broad wavelength range**



thermal and cold neutrons
meV
"with a small m"
wavelength ca. Å

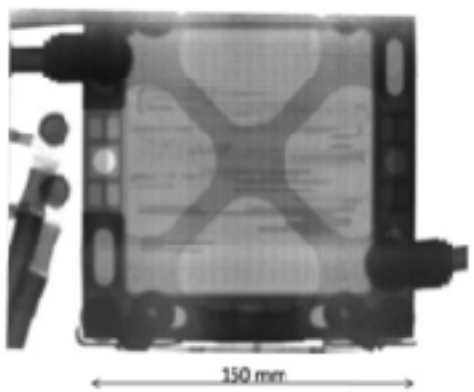
1) Ability to measure both energy and momentum transfer
   Geometry of motion
2) Neutrons scatter by a nuclear interaction => different isotopes scatter differently
   H and D scatter very differently
3) Simplicity of the interaction allows easy interpretation of intensities
   Easy to compare with theory and models
4) Neutrons have a magnetic moment



Applications of Neutron Science

Charge neutral

Deeply penetrating

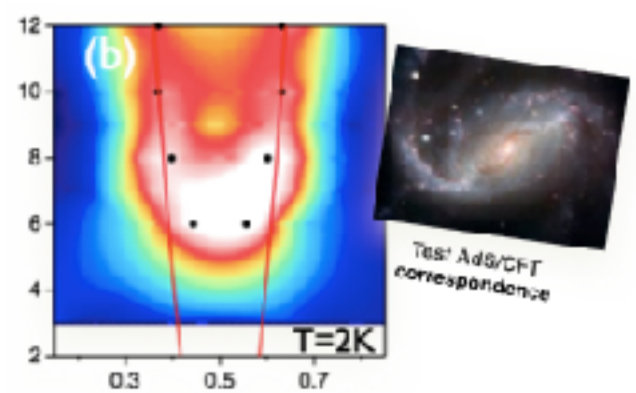


Li motion in fuel cells

Help build electric cars

S=1/2 spin

Directly probe magnetism

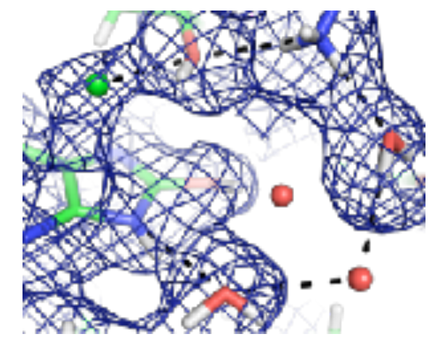


Solve the puzzle of High-Tc superconductivity

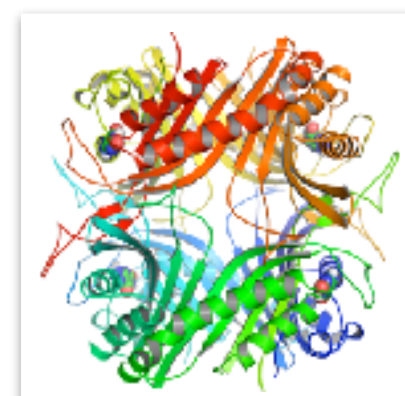
Efficient high speed trains

Nuclear scattering

Sensitive to light elements and isotopes

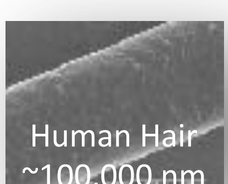


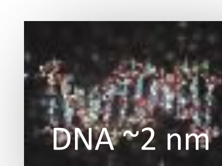
Active sites in proteins

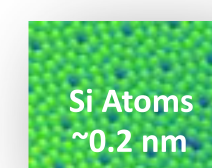


Better drugs

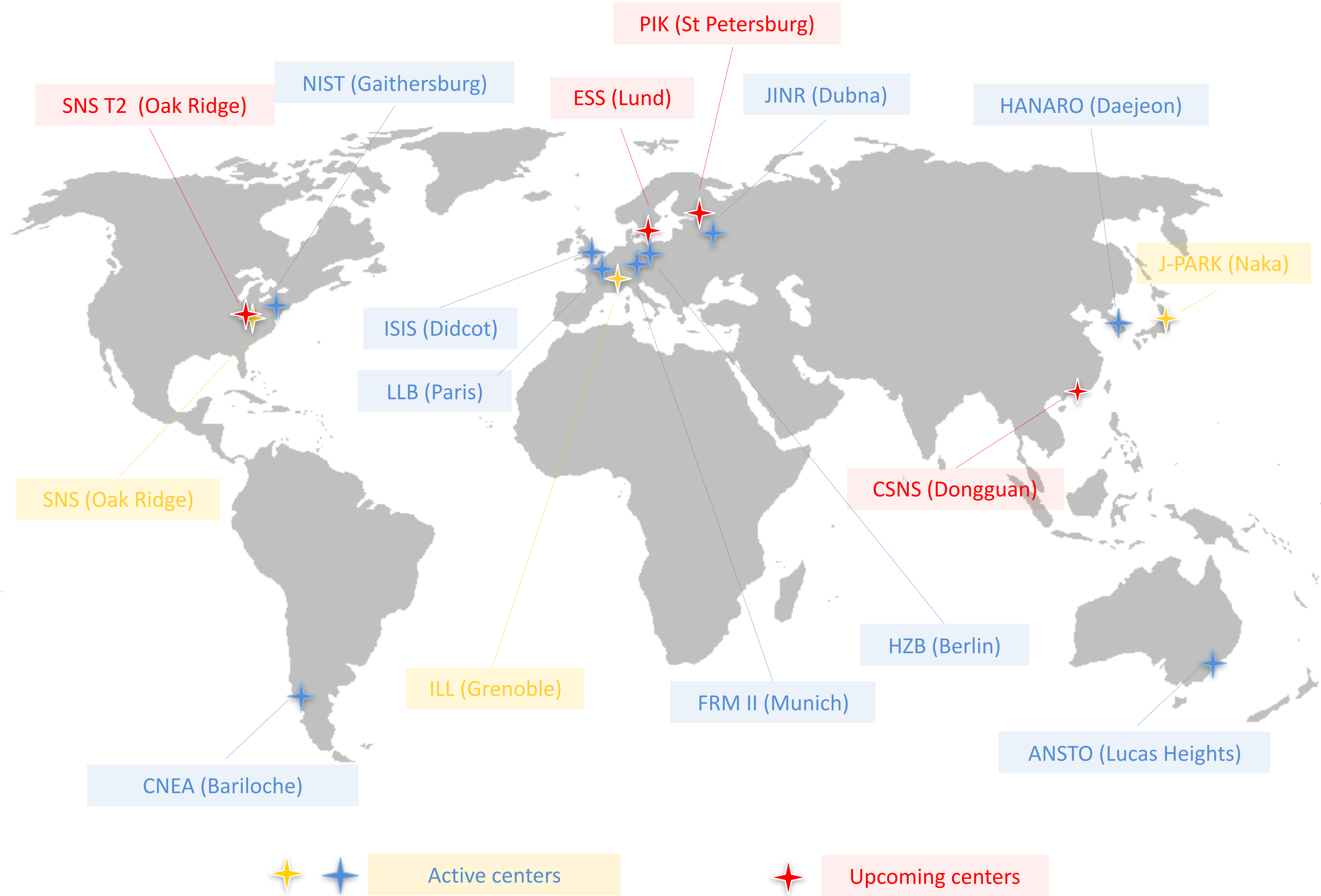
Probing length scales and dynamics







Present and Future of Neutron Research Facilities



... AND THESE ARE ONLY 14 OF THE ALMOST 50 NEUTRON RESEARCH FACILITIES WORLDWIDE

The European Spallation Source: view to the Southwest in 2025

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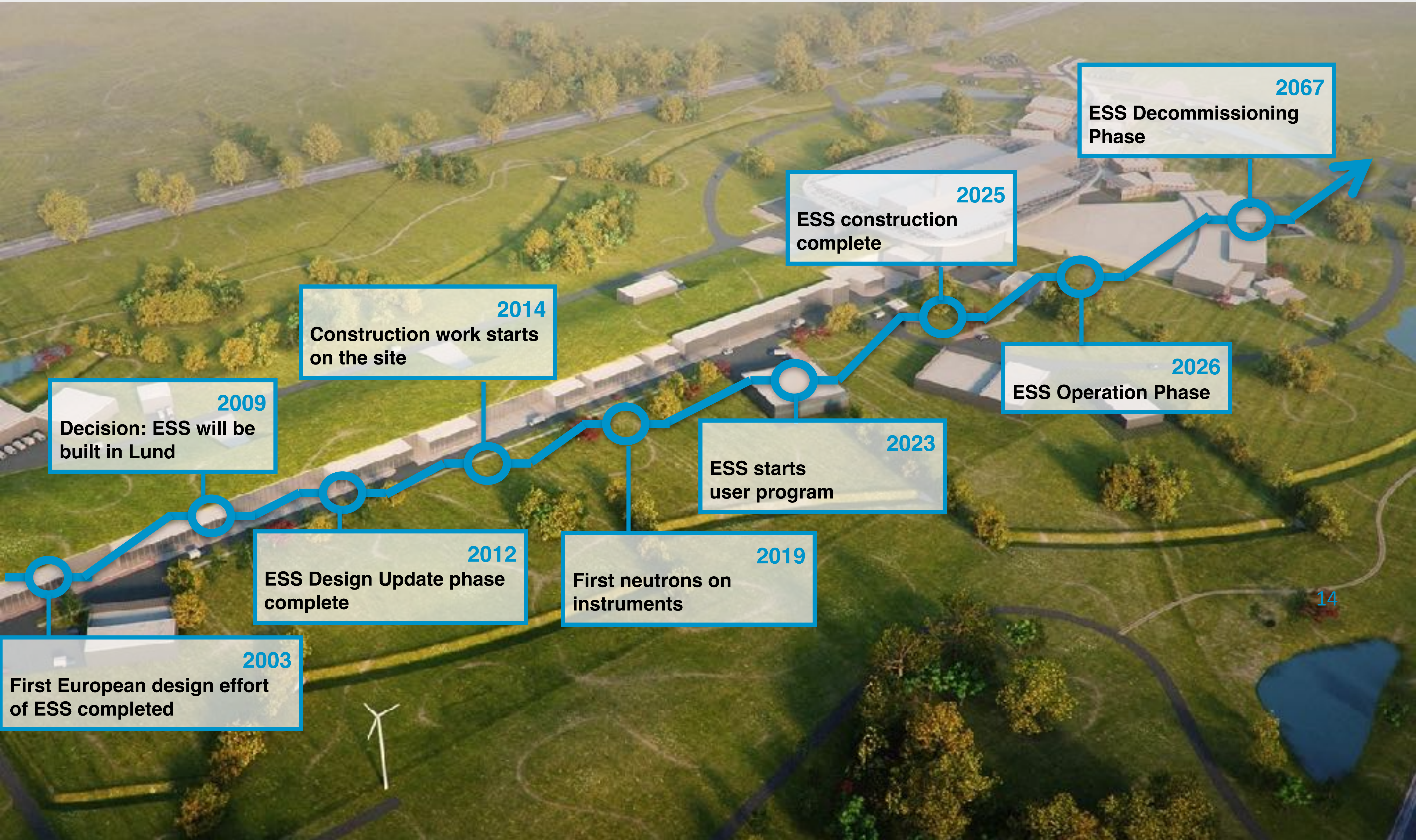
ESS: Project commitments

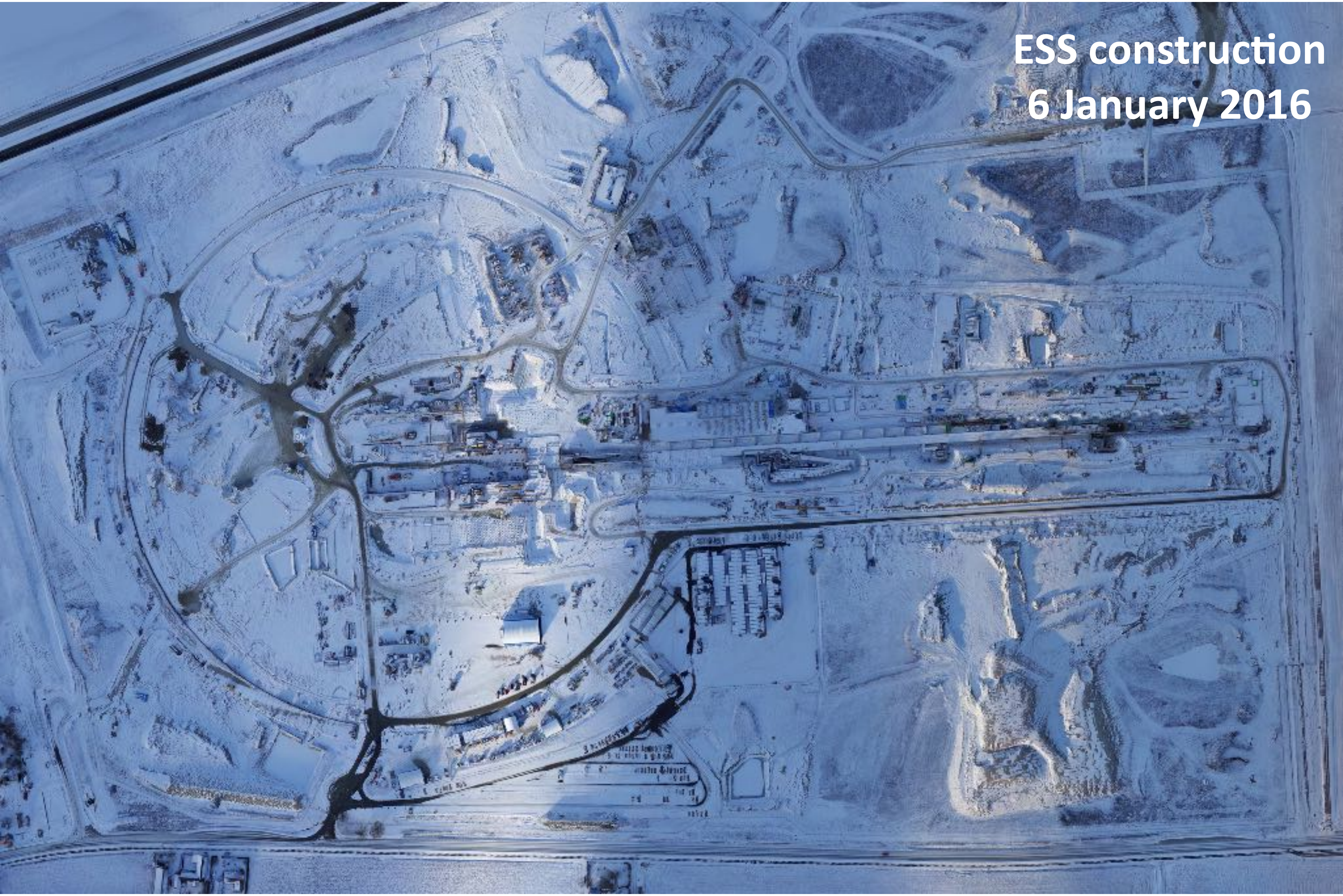
EUROPEAN SPALLATION SOURCE

- ☑ European Project: 17 countries building together
- ☑ 5 MW accelerator capability,
  30 times brighter than exisiting facilities
- ☑ 22 Public Instruments, state-of-the-art technologies
- ☑ Construction cost of 1,843 B€
- ☑ Steady-State Ops at 140 M€/year

Time plan


2003
First European design effort of ESS completed
2009
Decision: ESS will be built in Lund
2012
ESS Design Update phase complete
2014
Construction work starts on the site
2019
First neutrons on instruments
2023
ESS starts user program
2025
ESS construction complete
2026
ESS Operation Phase
2067
ESS Decommissioning Phase

The ESS site
2011


ESS construction
6 January 2016

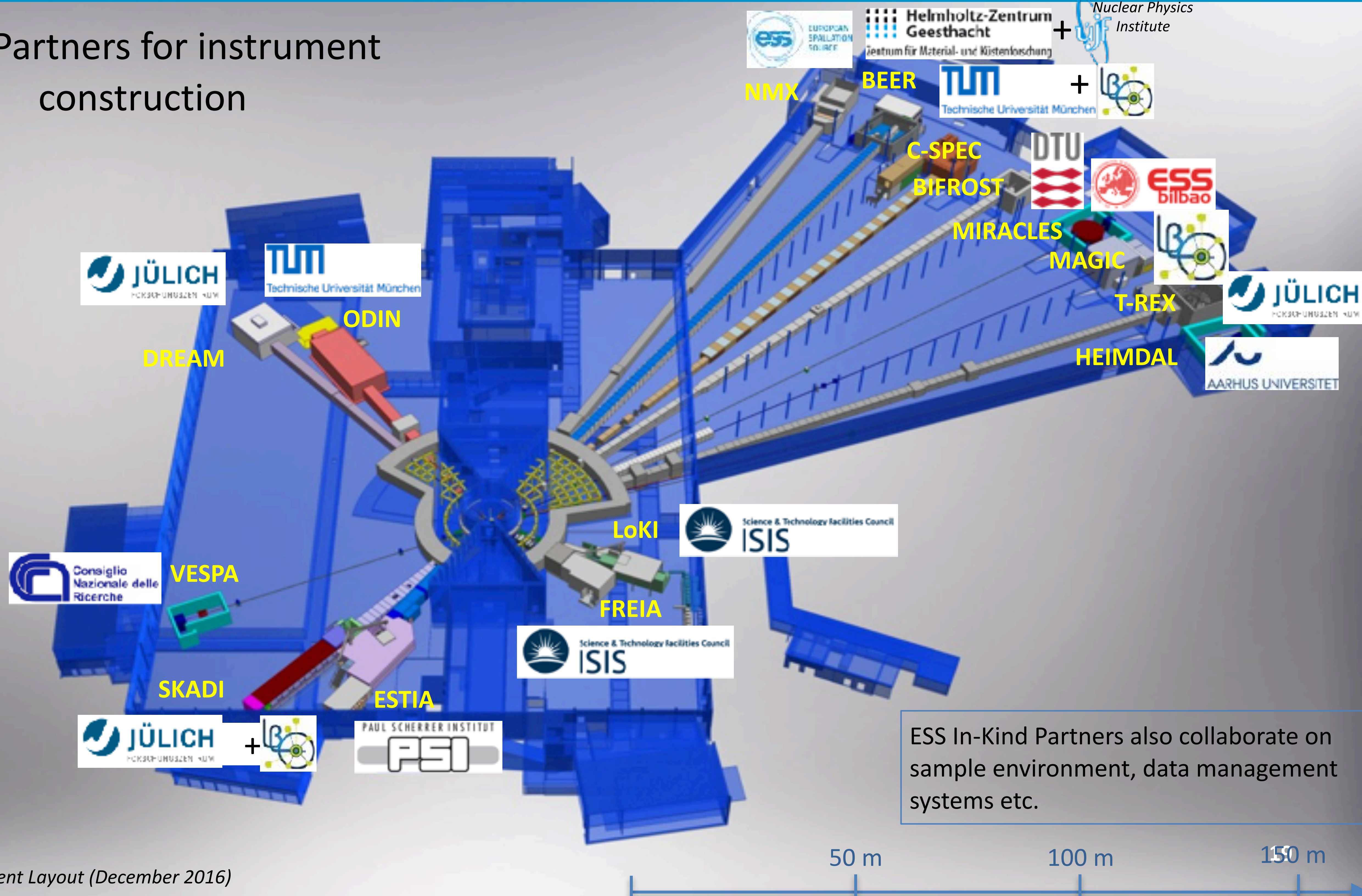

ESS construction
13 October 2016


ESS construction
18 May 2017

ESS Neutron Instrument positions: December 2016

EUROPEAN SPALLATION SOURCE

Lead Partners for instrument construction



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

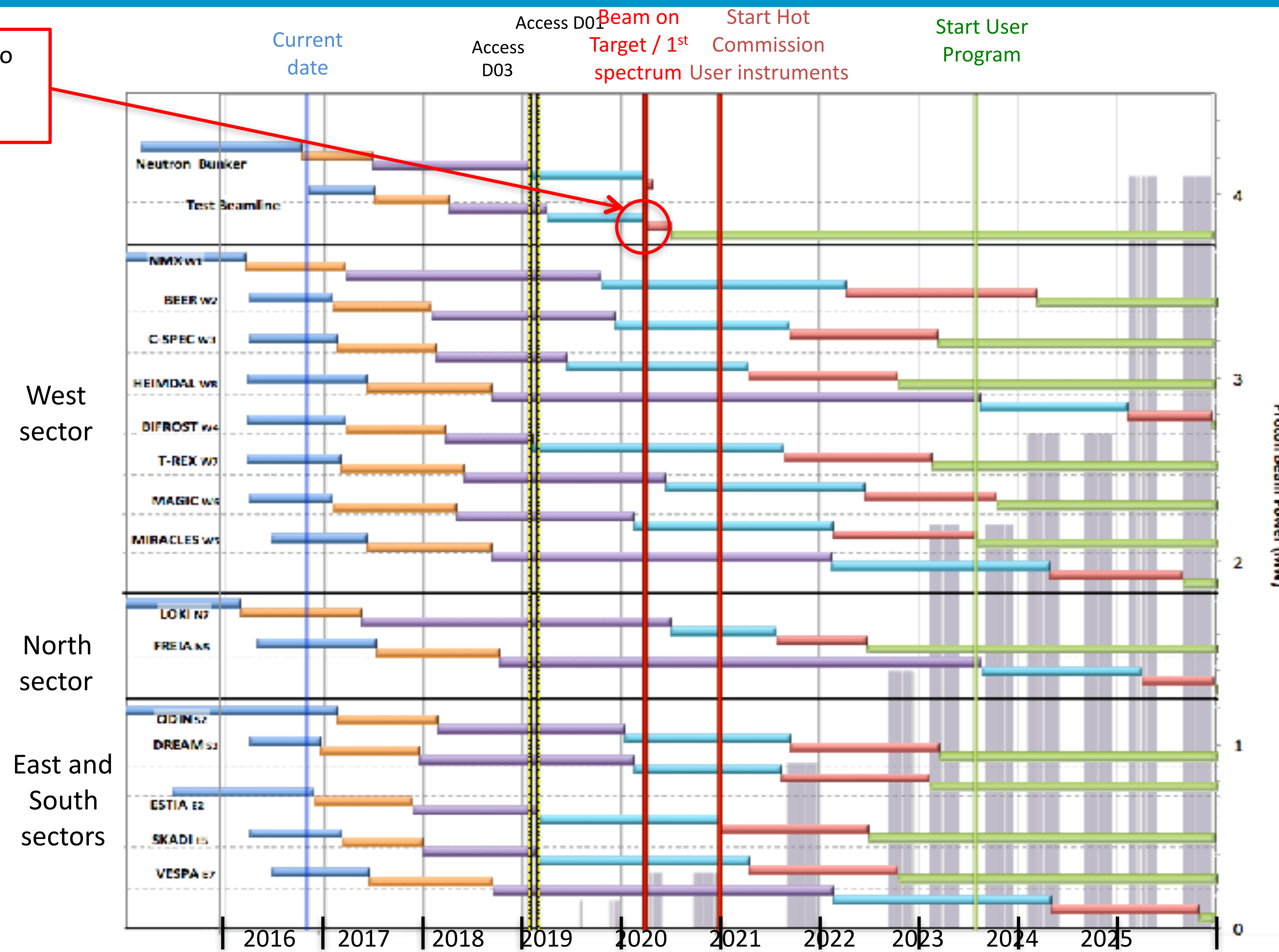
ESS Instrument Layout (December 2016)

Council.07.14.a

Neutron Beam Instrument Draft Schedule

V2.0, 2nd November 2016

Commissioning of test beam – to demonstrate performance and inform instrument projects

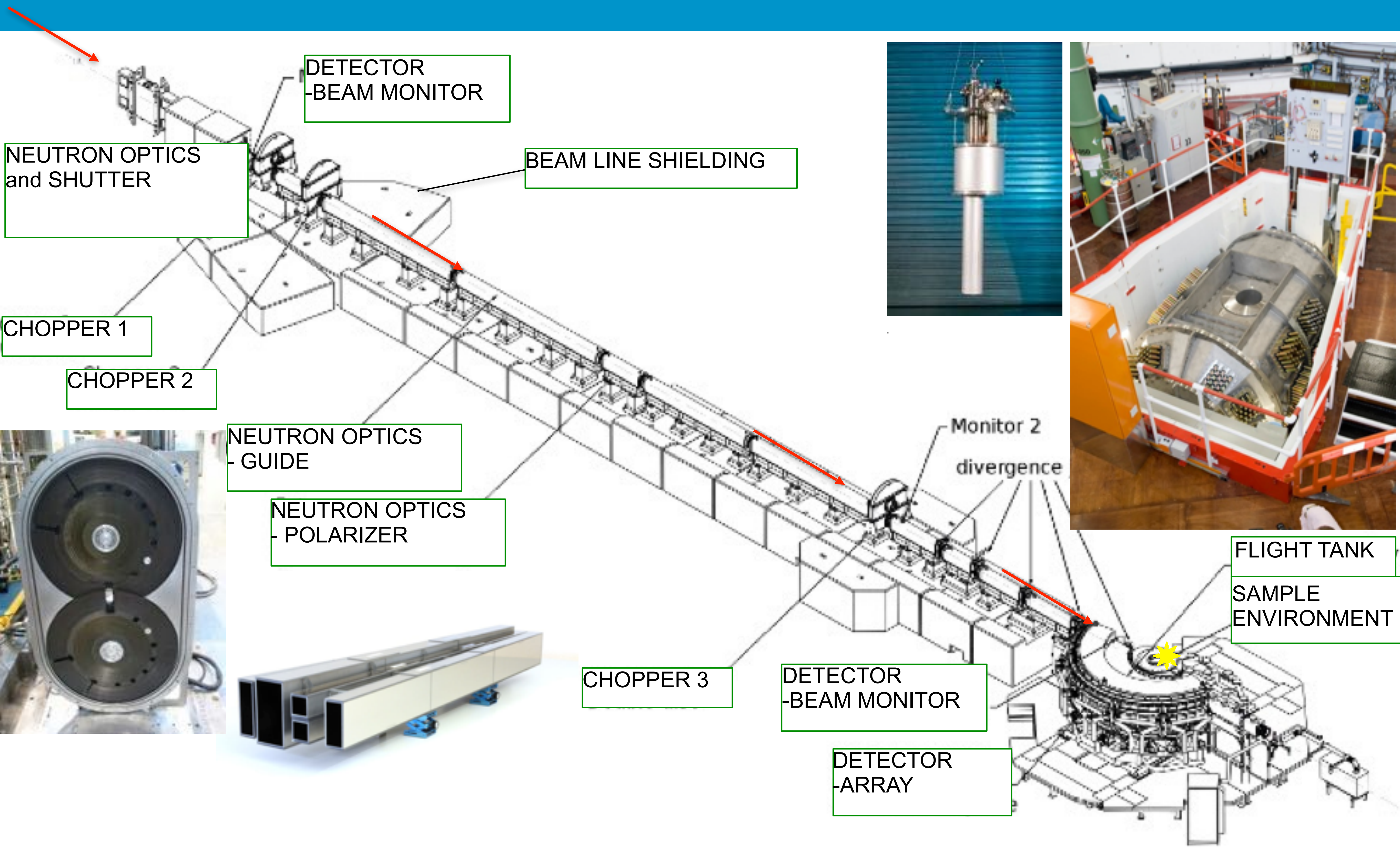


Notes;

- Access & B.O..T dates yet to be confirmed
- Instrument dates from scope setting
- HC start;
  - E ≥ 200 MeV
  - P ≥ 200 kW
  - January 2021

Preliminary Design
Detailed Design
Manufacturing & Procurement
Installation & Integration
Hot Commissioning and early science
Operation

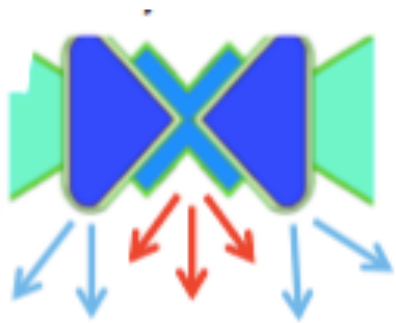
Layout of a Neutron Instrument

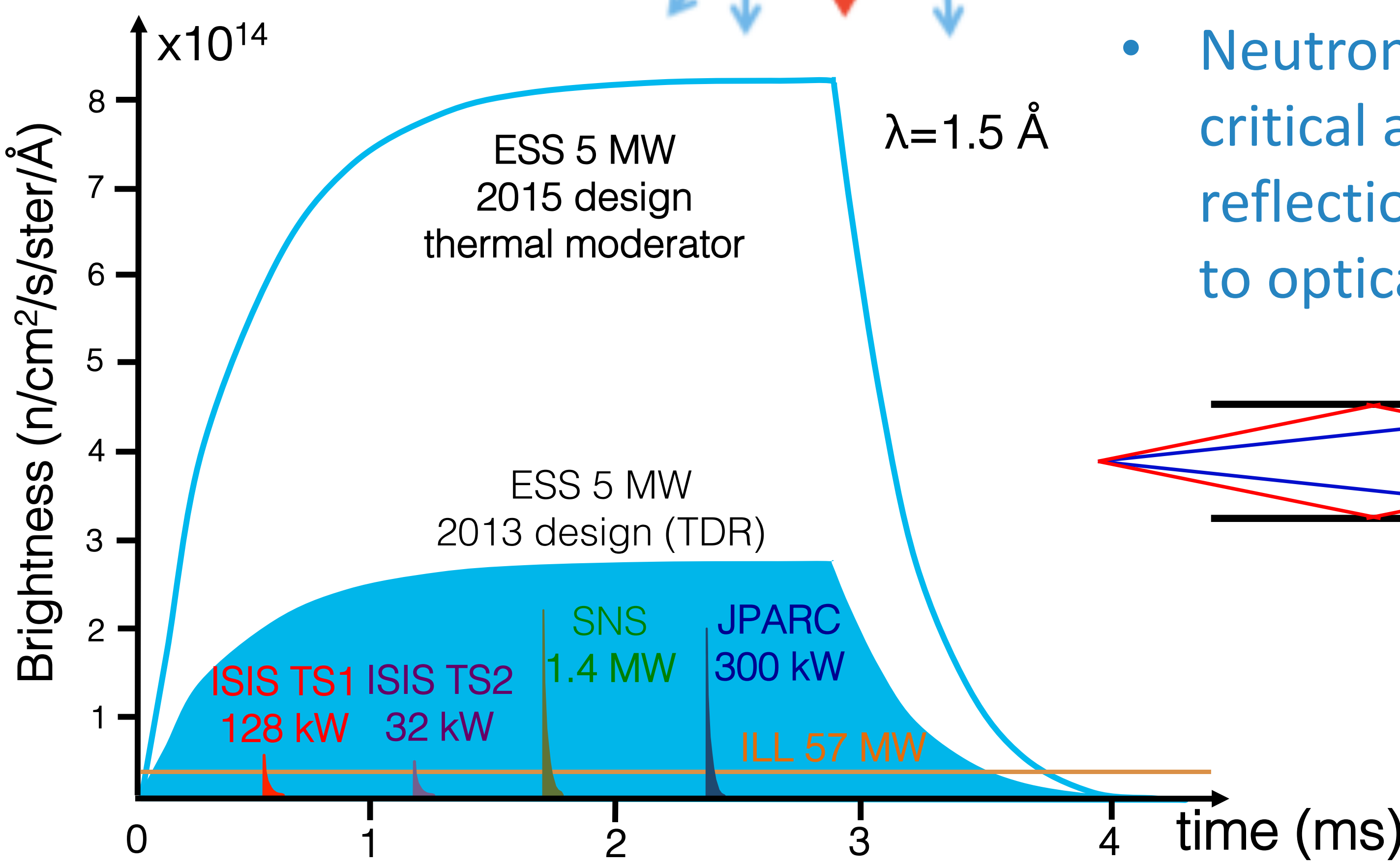


Neutron Instrumentation Technology

- ESS will be more powerful and several times brighter than existing facilities.
- However, over the past decades the major order of magnitude gains have been in the instrumentation design

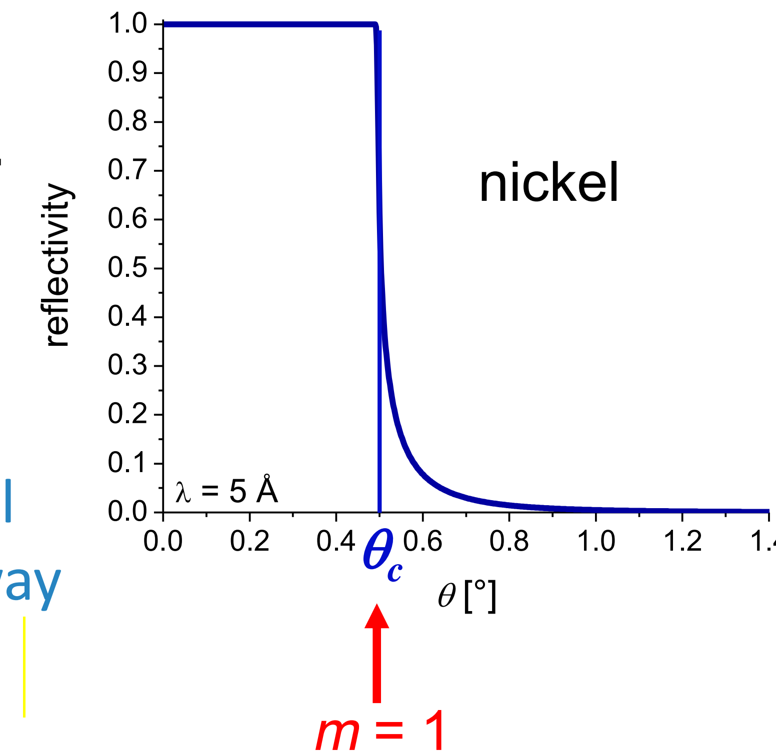
eg neutron moderators

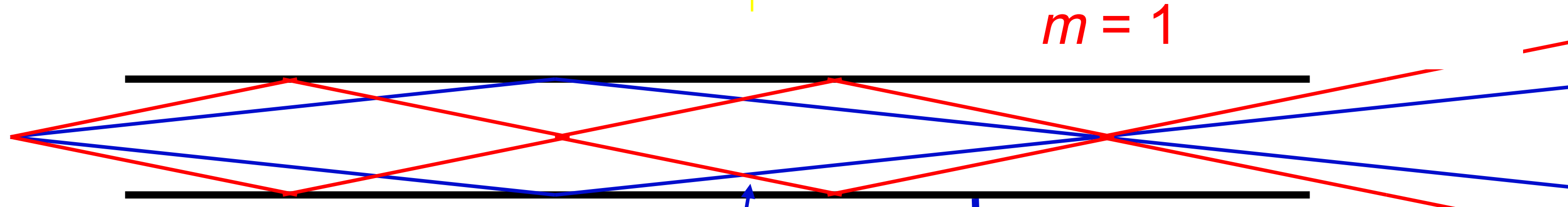




eg neutron transport "neutron optics"

- Neutron guides use this critical angle for internal reflection, in a similar way to optical fibres

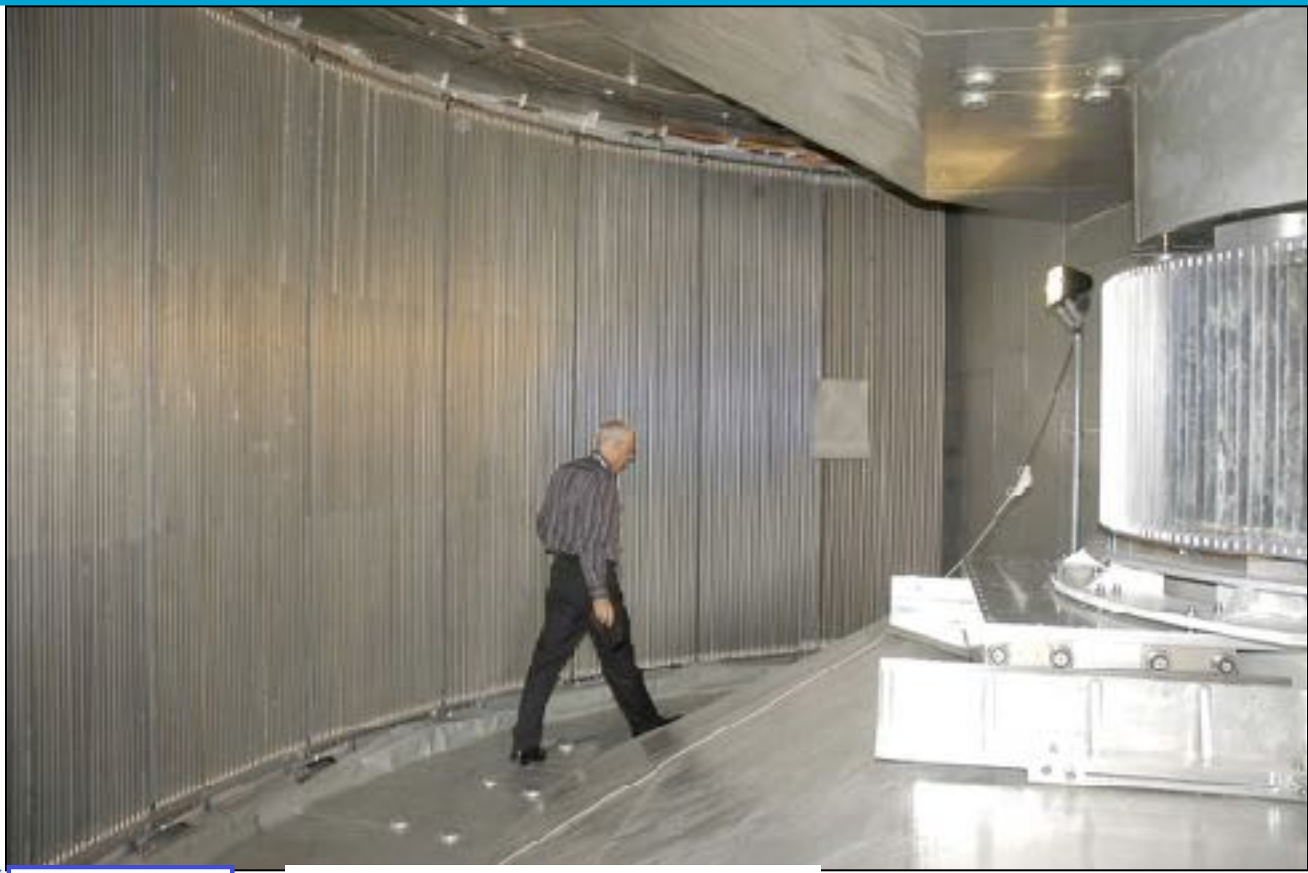


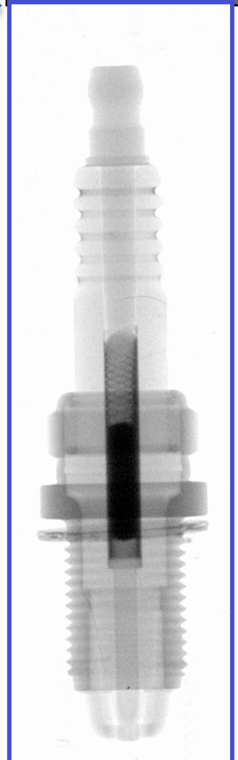


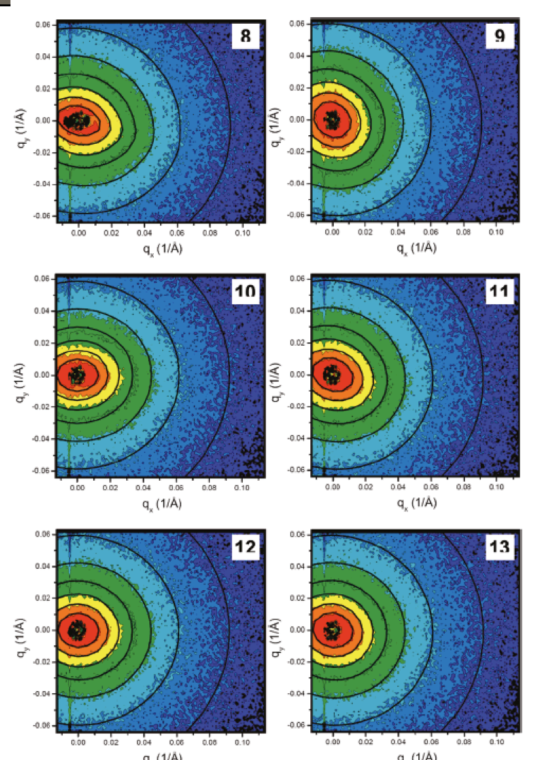
- The advances in neutron detection have been more modest, until recently …

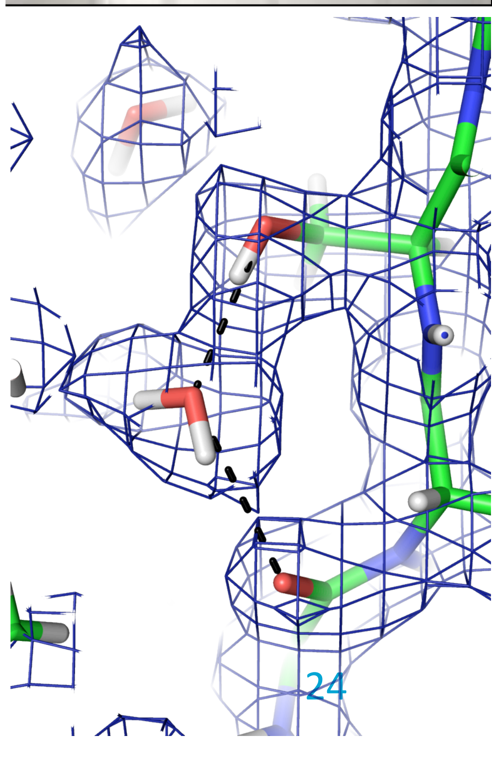
Detectors

Detector Strategy:
how we get from here to there



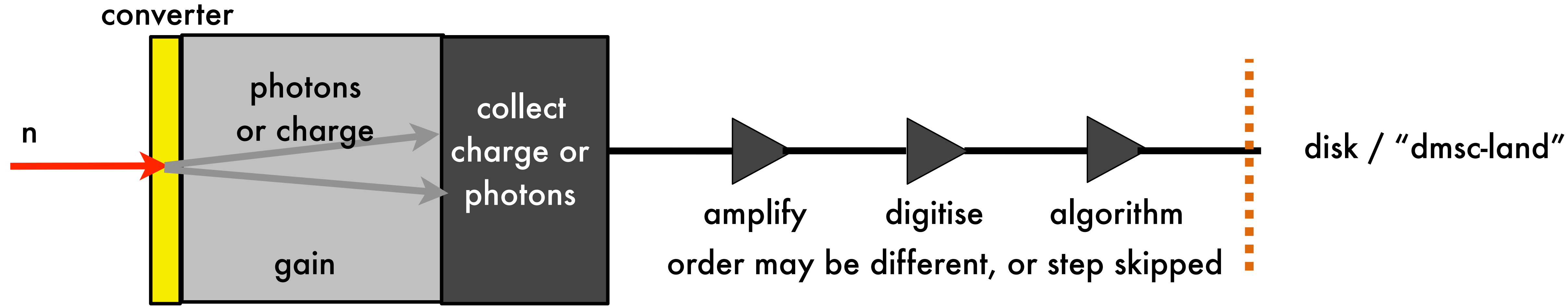






Basic Principle of Neutron Detectors

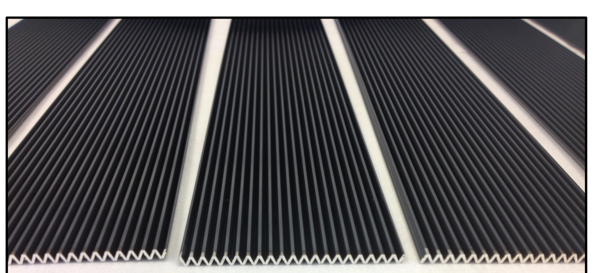
Efficient neutron converters a key component for neutron detectors



"Converter"

"Detector"

"Electronics"



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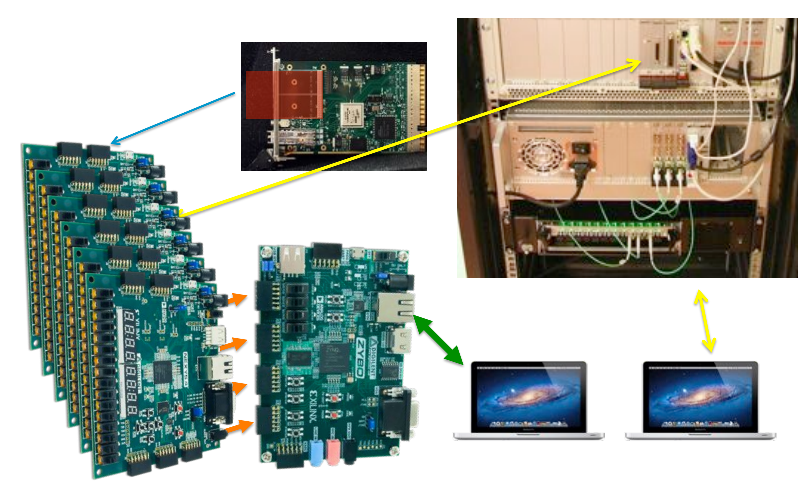

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Isotopes Suitable as Cold and Thermal Neutron Convertors

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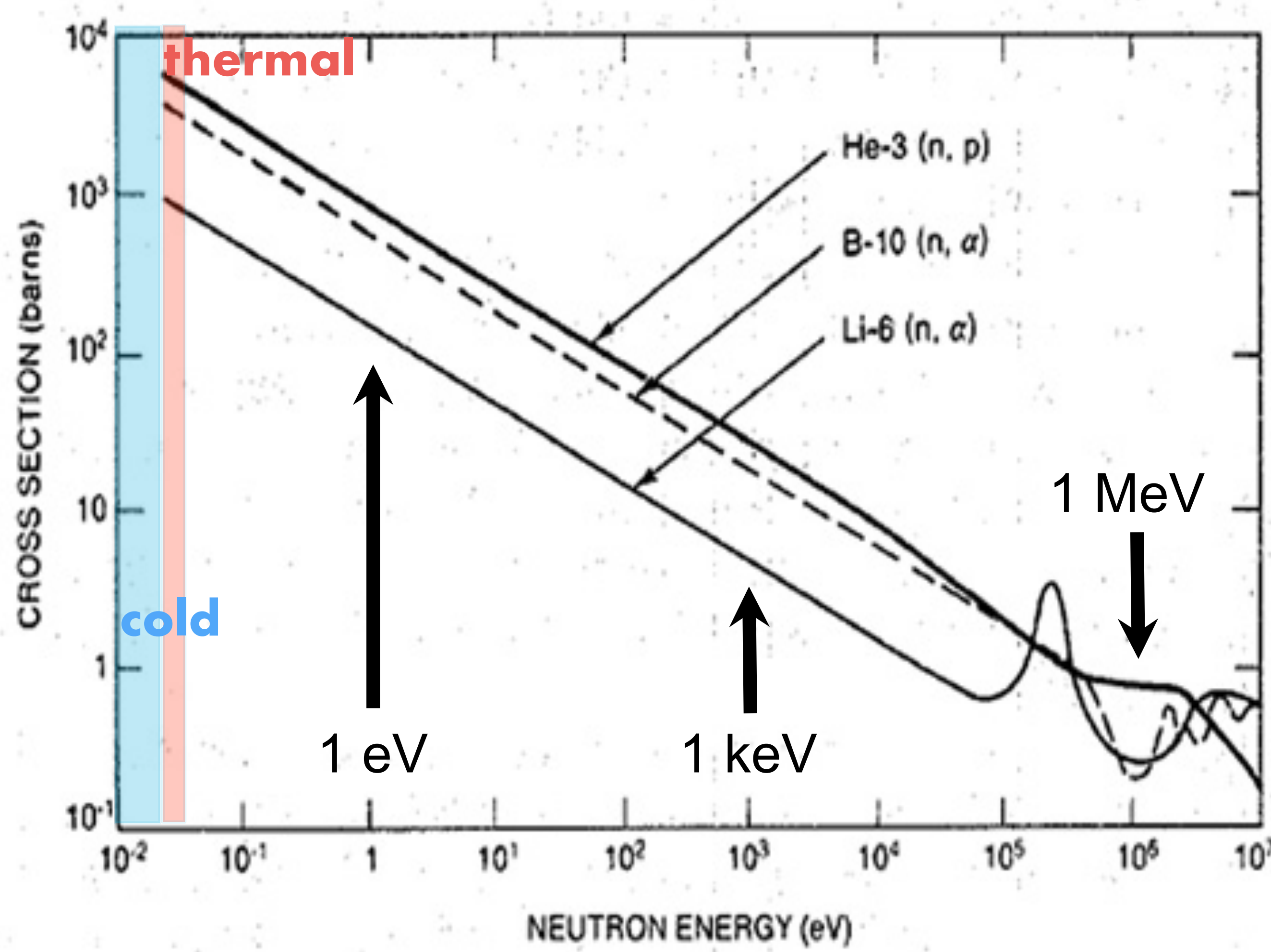
reaction	energy	particle	energy	particle	energy
n (^{3}He, p) ^{3}H	+0.77 MeV	p	0.57 MeV	^{3}H	0.19 MeV
n (^{6}Li, α) ^{3}H	+4.79 MeV	α	2.05 MeV	^{3}H	2.74 MeV
93 % n (^{10}B, α)^{7}Li +2.3 MeV + γ (0.48MeV)		α	1.47 MeV	^{7}Li	0.83 MeV
7 % n (^{10}B, α) ^{7}Li	+2.79 MeV	α	1.77 MeV	^{7}Li	1.01 MeV
n (^{235}U, 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)

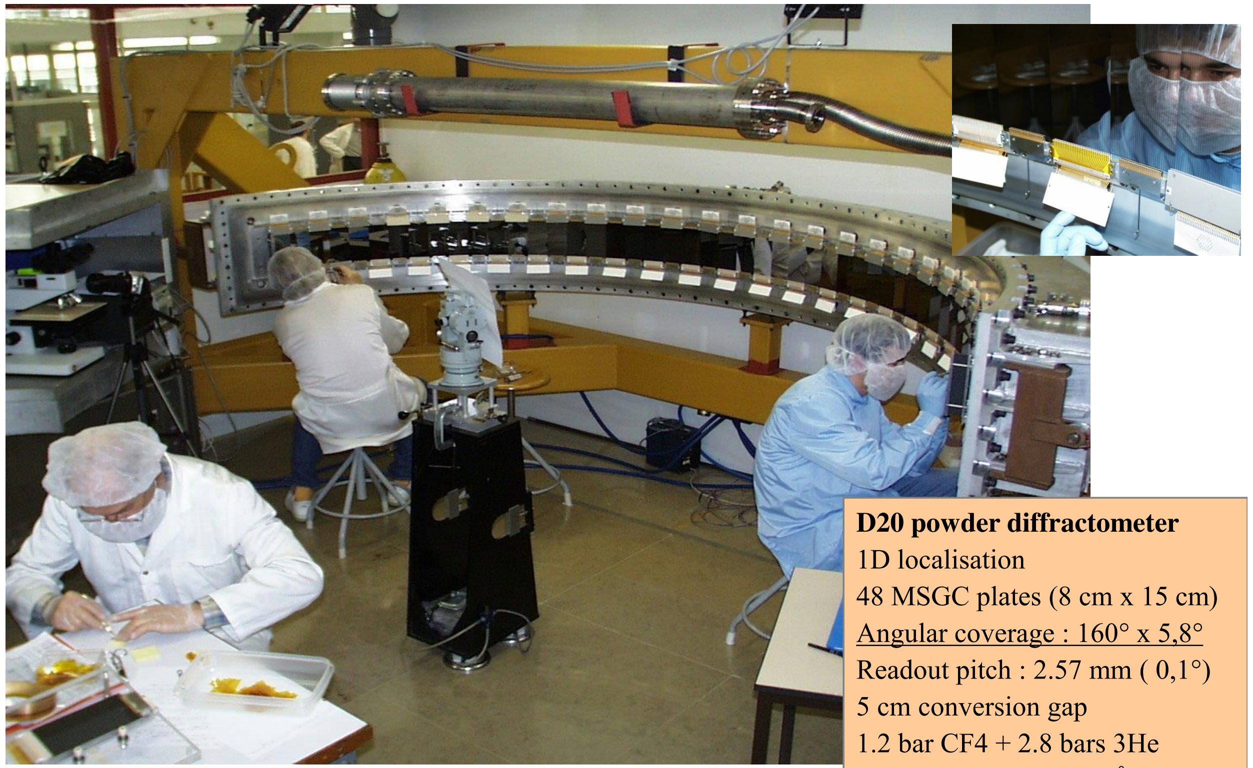
- Presently >80% of neutron detectors worldwide are Helium-3 based



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 CF4 + 2.8 bars 3He
Efficiency 60% @ 0.8 Å

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

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

What can be done with this brightness

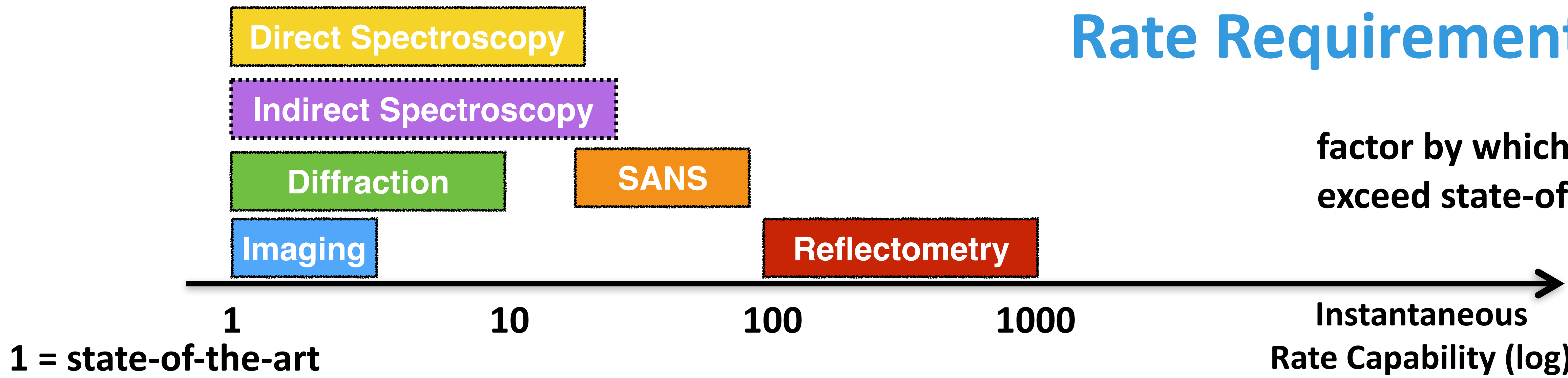
What does a factor 10 improvement imply for the detectors?

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

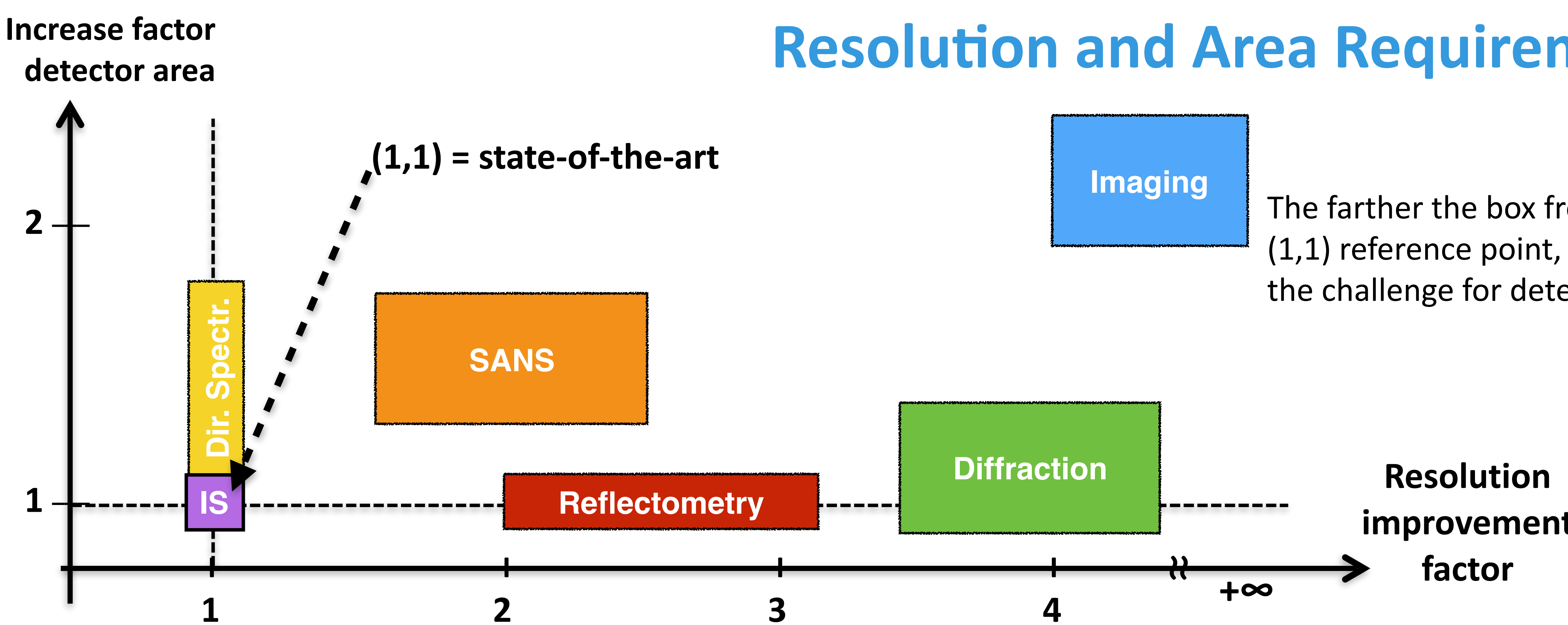
Requirements Challenge for Detectors for ESS:
beyond detector present state-of-the art

Rate Requirements



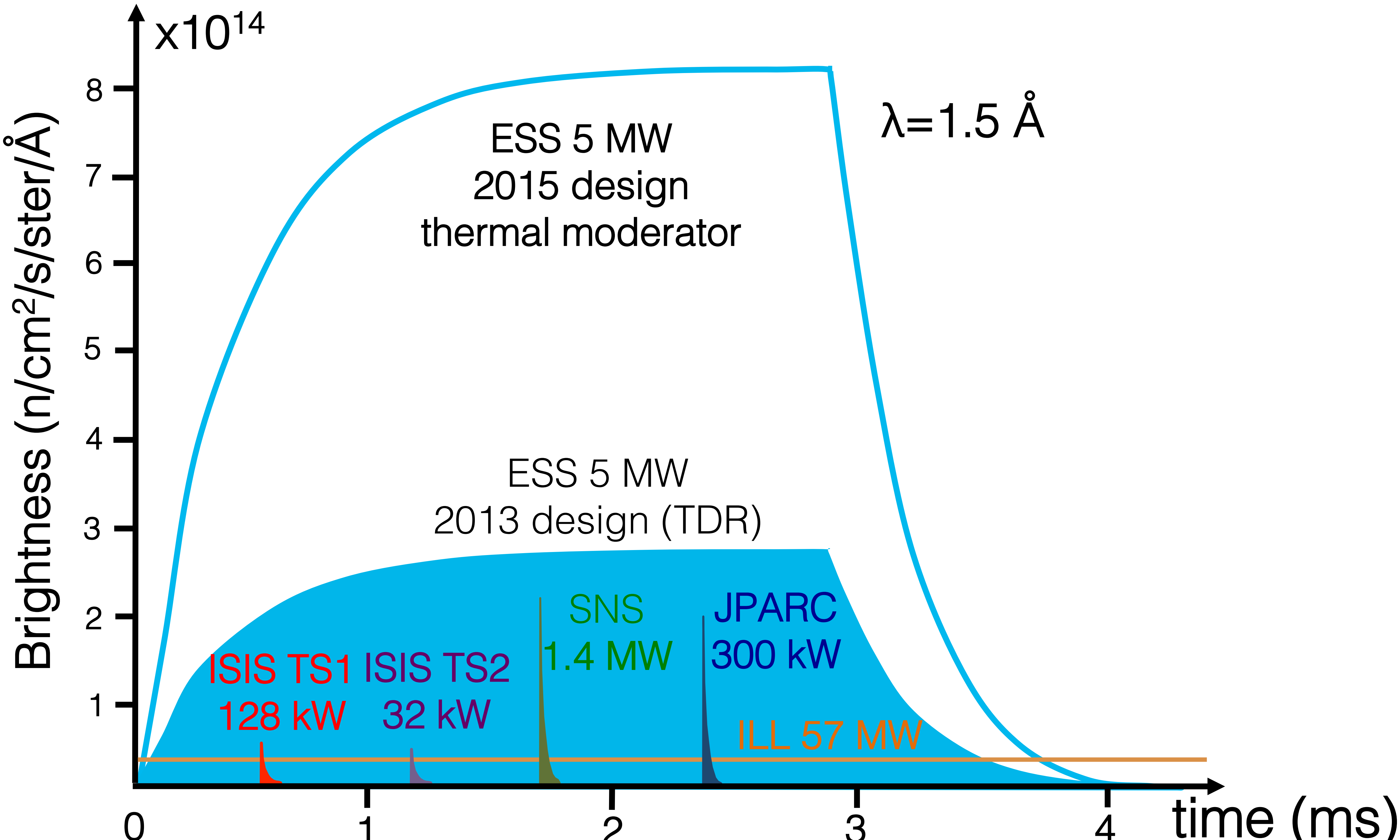
factor by which requirements exceed state-of-the-art

Resolution and Area Requirements



The farther the box from the (1,1) reference point, the bigger the challenge for detectors.

Challenge for Rate



ESS Partners on Detectors

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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) 4131/248032

I E A P

CDT GmbH
CASCADE Detector Technologies

FZÚ

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

University of Malta
L-Università ta' Malta

Risø DTU
National Laboratory for Sustainable Energy

ideas

COSYLAB

IFE
Institute for Energy Technology

JÜLICH
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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

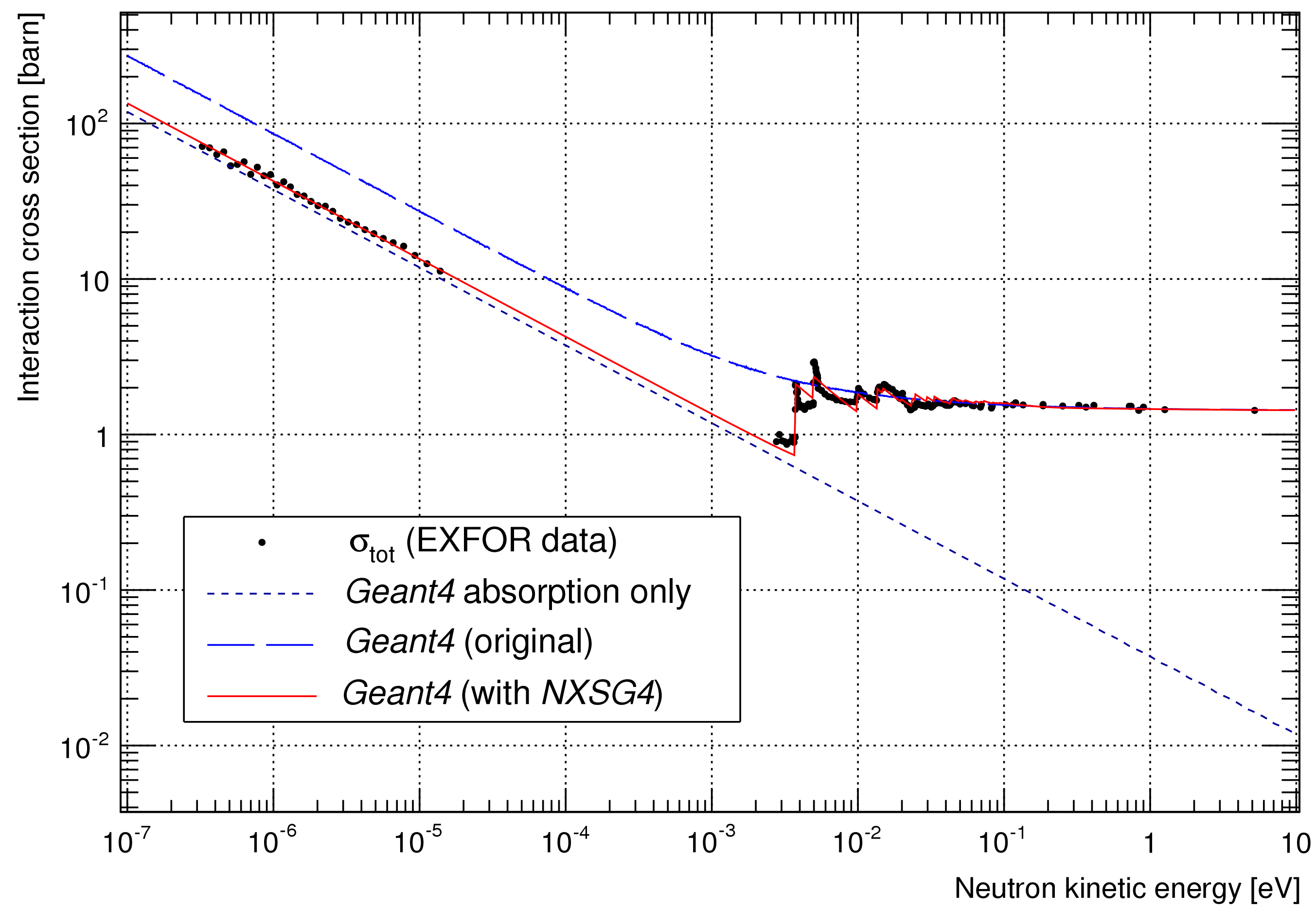
Neutron diffraction in polycrystalline materials: Add-on for GEANT4

HZB Helmholtz Zentrum Berlin

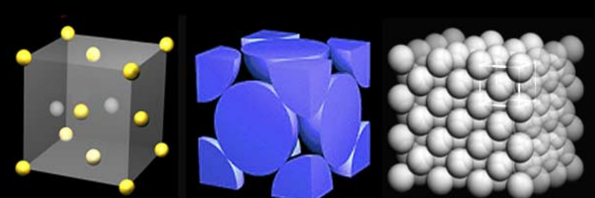
Risø DTU National Laboratory for Sustainable Energy

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.

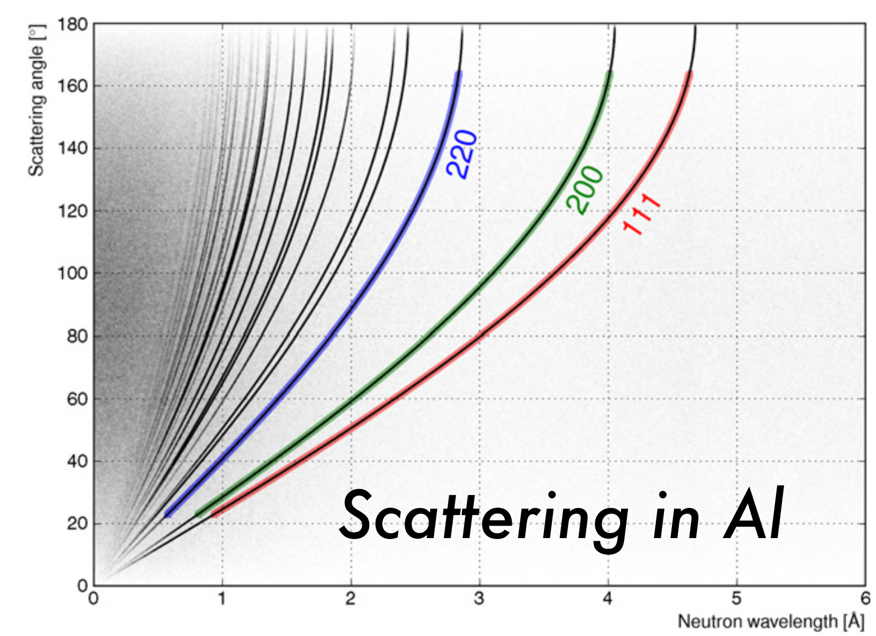



```
(tkittel@localhost data)> cat Al.nxs
space_group = 225
lattice_a = 4.049
lattice_b = 4.049
lattice_c = 4.049
lattice_alpha = 90
lattice_beta  = 90
lattice_gamma = 90
[atoms]
add_atom = Al 3.449 0.008 0.23 26.98 429.0 0.0 0.0 0.0
```



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

Abstract N28-18 this week



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

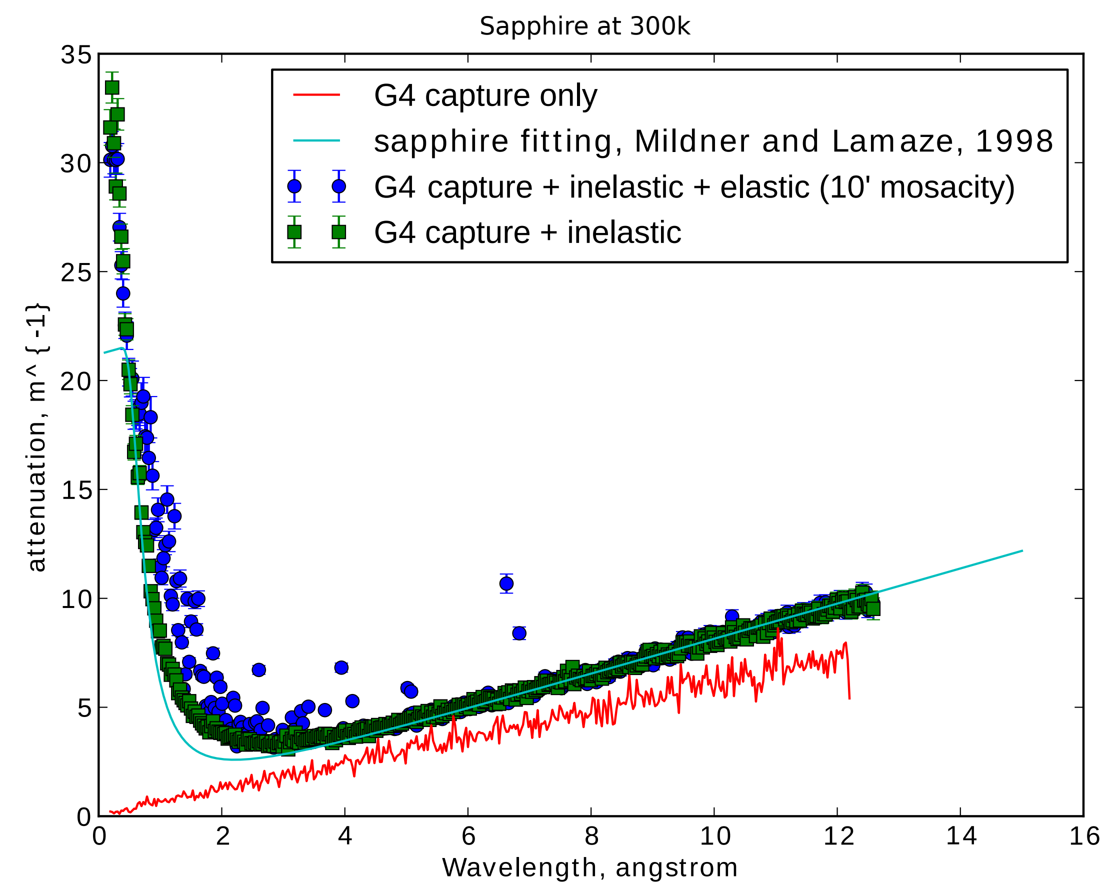
Simulation of Neutron Scattering in Crystalline Materials

Risø DTU
National Laboratory for Sustainable Energy

brightness

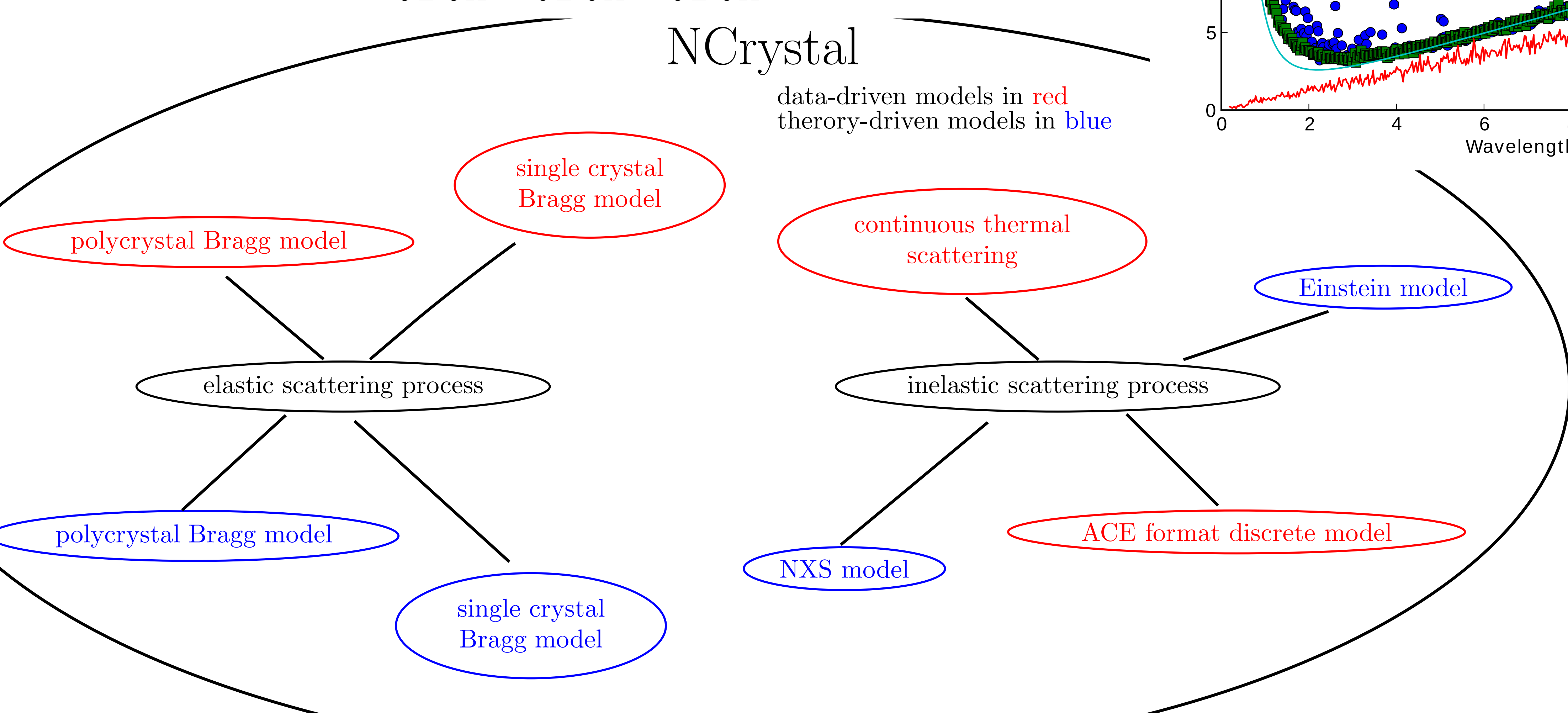
EUROPEAN SPALLATION SOURCE

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



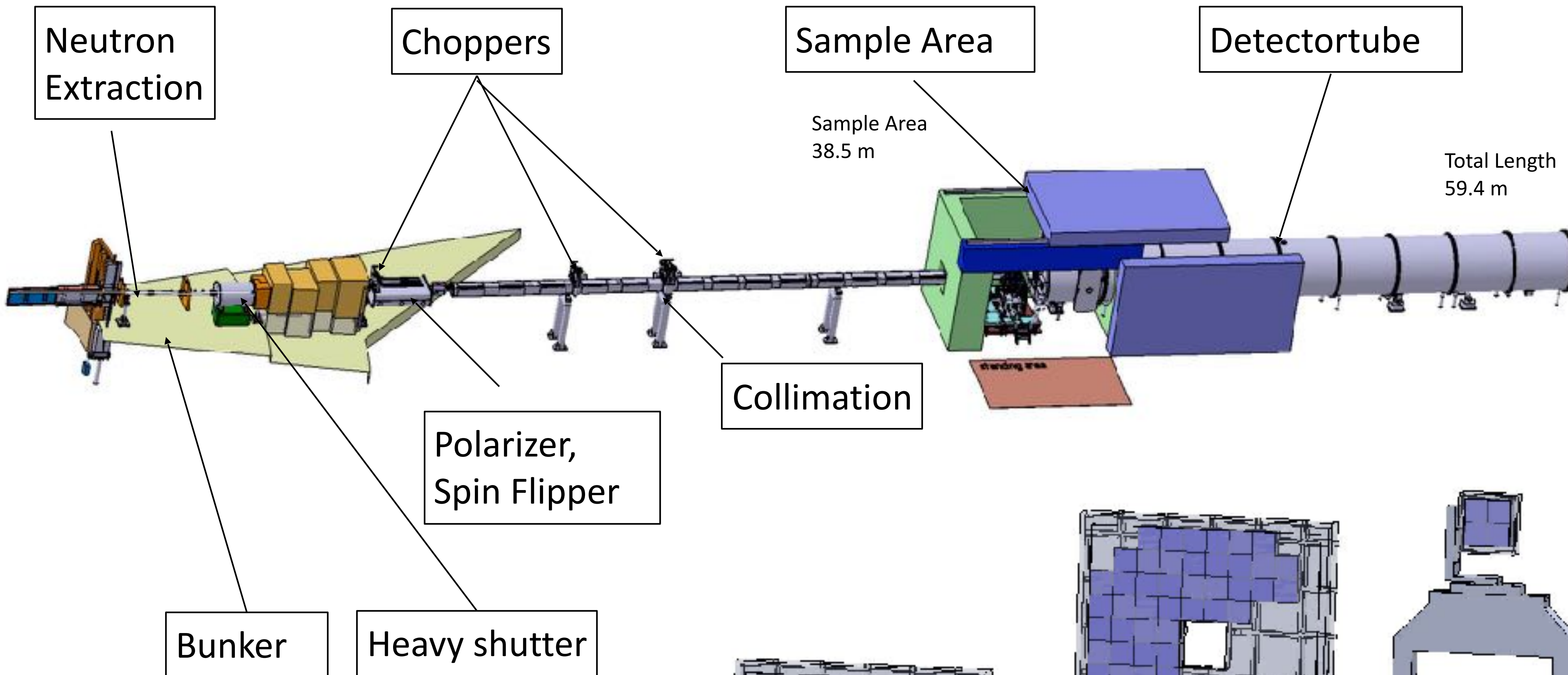
The scattering physics in NCrystal is a combination of the inelastic and elastic scattering processes. The double differential cross section describes the likelihood of a neutron being scattered into a small solid angle $d\Omega$ with final energy between E' and $E' + dE'$. It can be expressed as

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

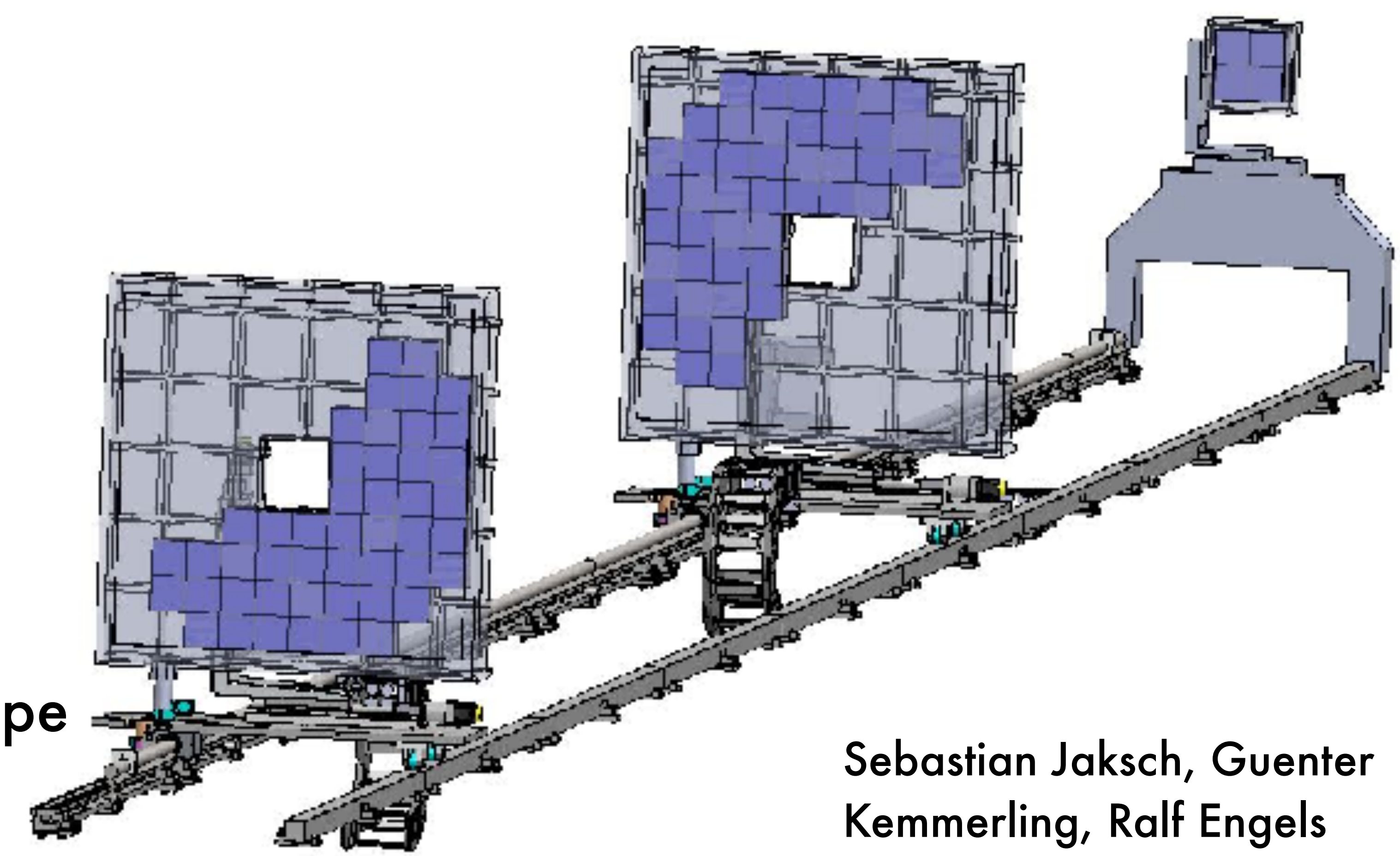


Extension under development

SKADI layout: SANS instrument



- 2 moving detectors
  - $1m^2$ – pixel 6 mm
  - 400 modules / detector
- 1 fixed detector @20 m
  - $20x20\ cm^2$ – pixel 3 mm



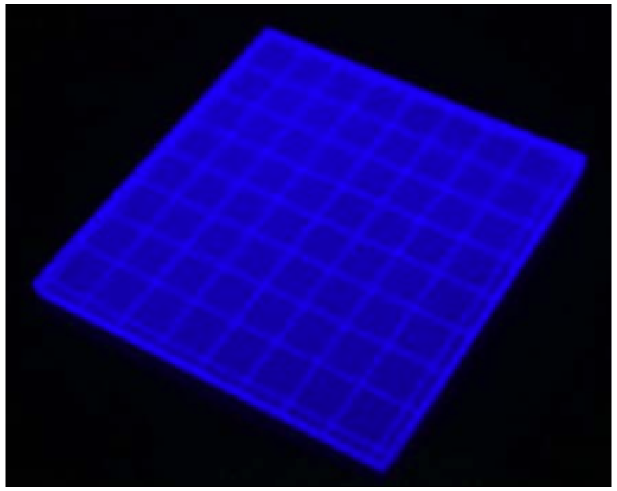
- about half detector area in initial scope
- half in later upgrade

Sebastian Jaksch, Guenter Kemmerling, Ralf Engels

SoNDe Detector

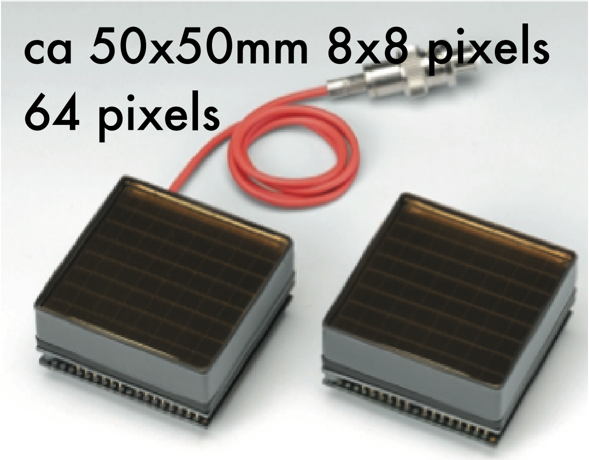
Develop a high-resolution neutron detector technique for enabling the construction of position-sensitive neutron detectors for high flux sources.

- high-flux capability for handling the peak-flux of up-to-date spallation sources (x 20 over current detectors)
- high-resolution of 6 or 3 mm by single-pixel technique
- high detection efficiency of up to 80 %



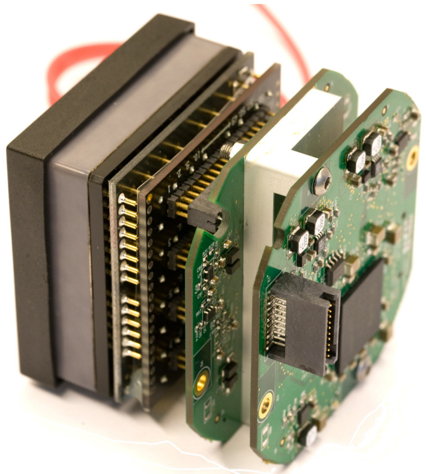
Grooved Li glass (GS20)

+

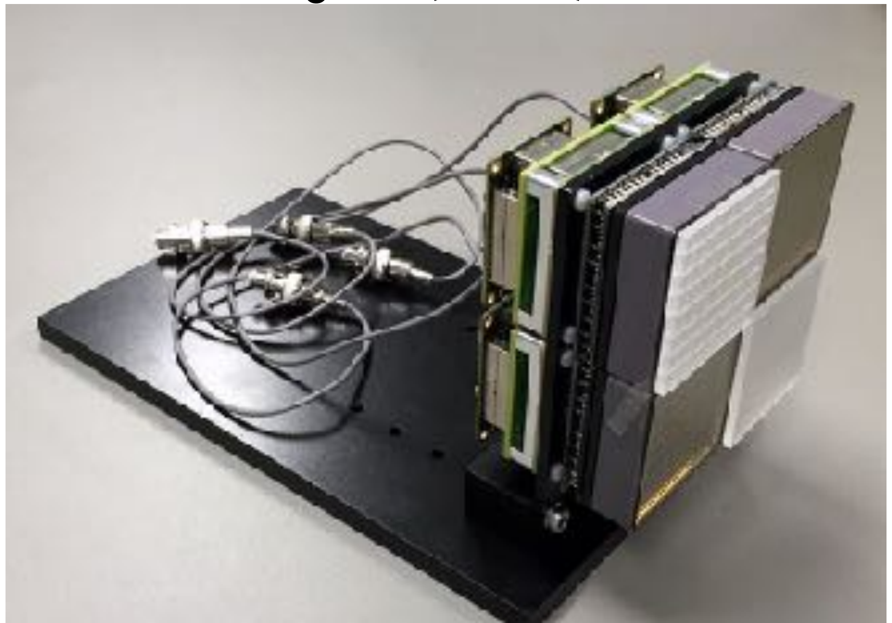


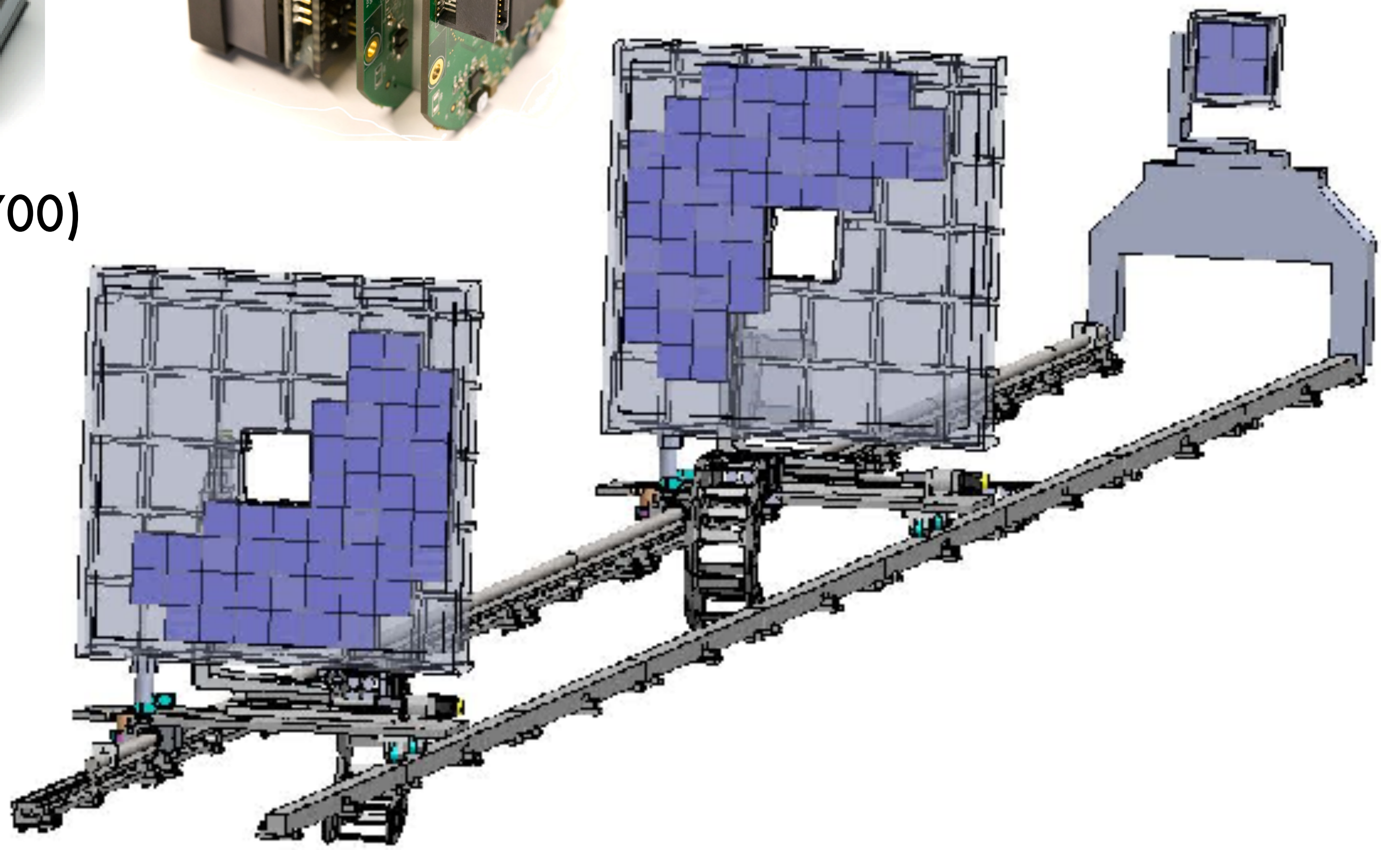
MA-PMT (H9500 or H12700)

+

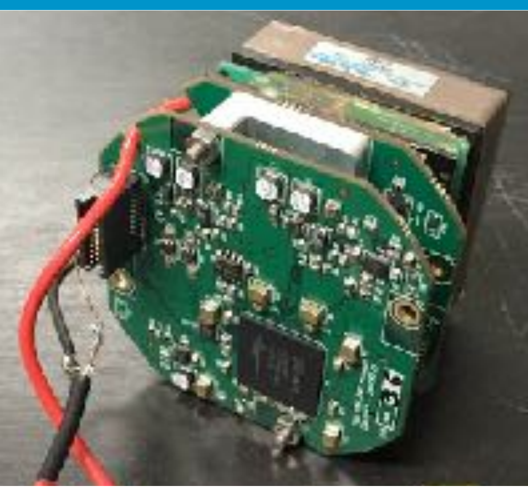


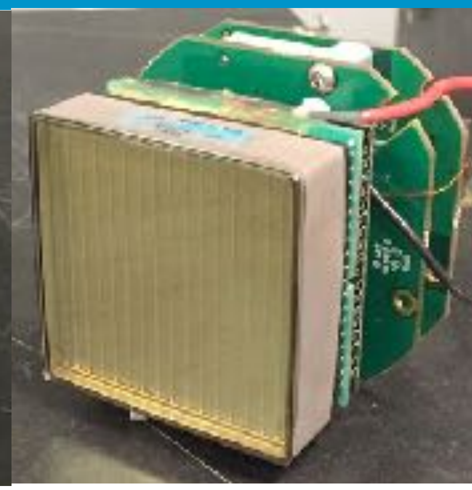
IDEAS IDE3465
+FPGA



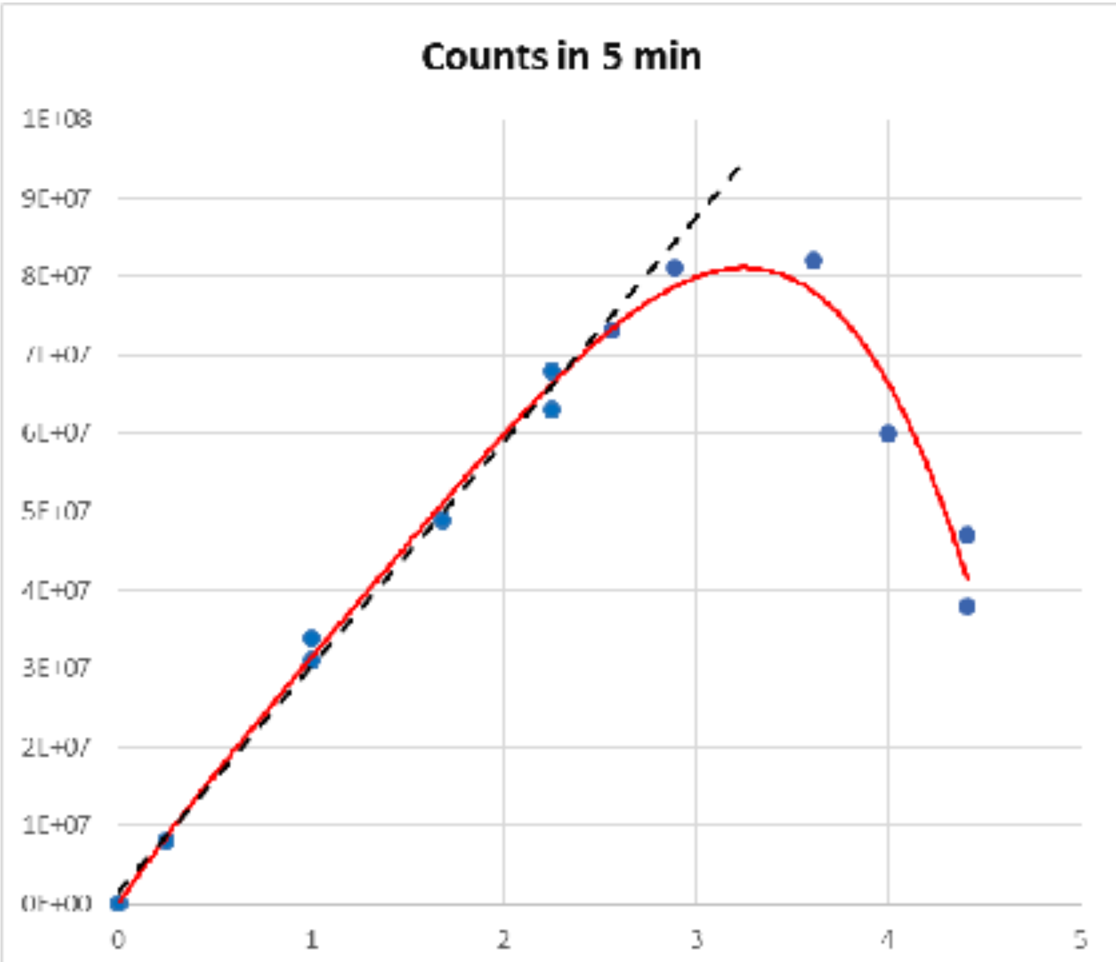


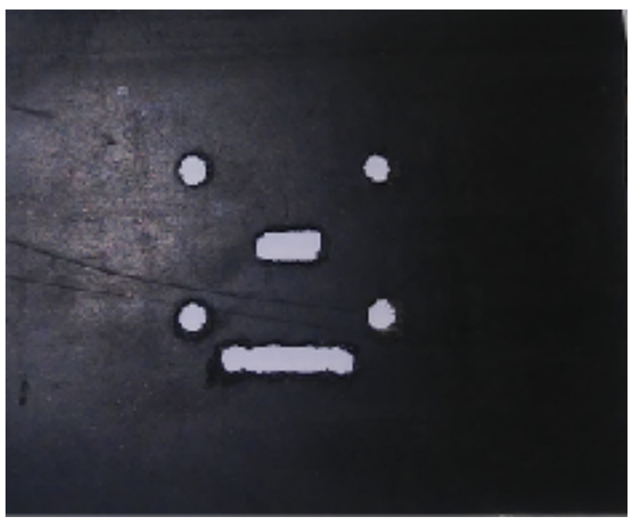
SoNDe Detector

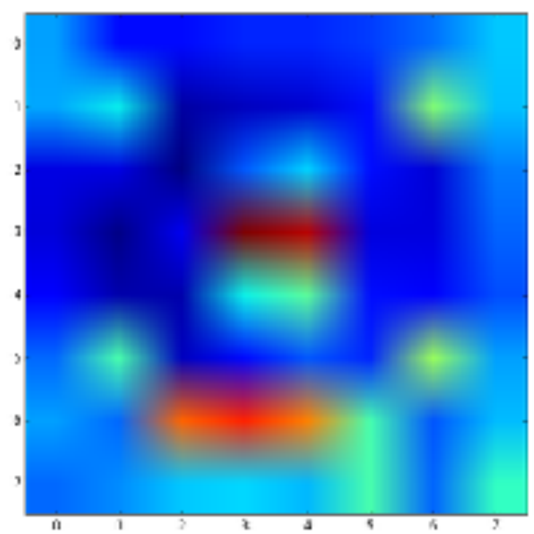




- Results from initial evaluation system







- Count rates on a module up to 250 kHz, linear to 200 kHz
- Corresponds to >20 MHz @10% deadtime for full 1m^2
- No degradation up to 5E14 neutrons integrated flux

^{10}Boron-based Thin Film Gaseous Detectors

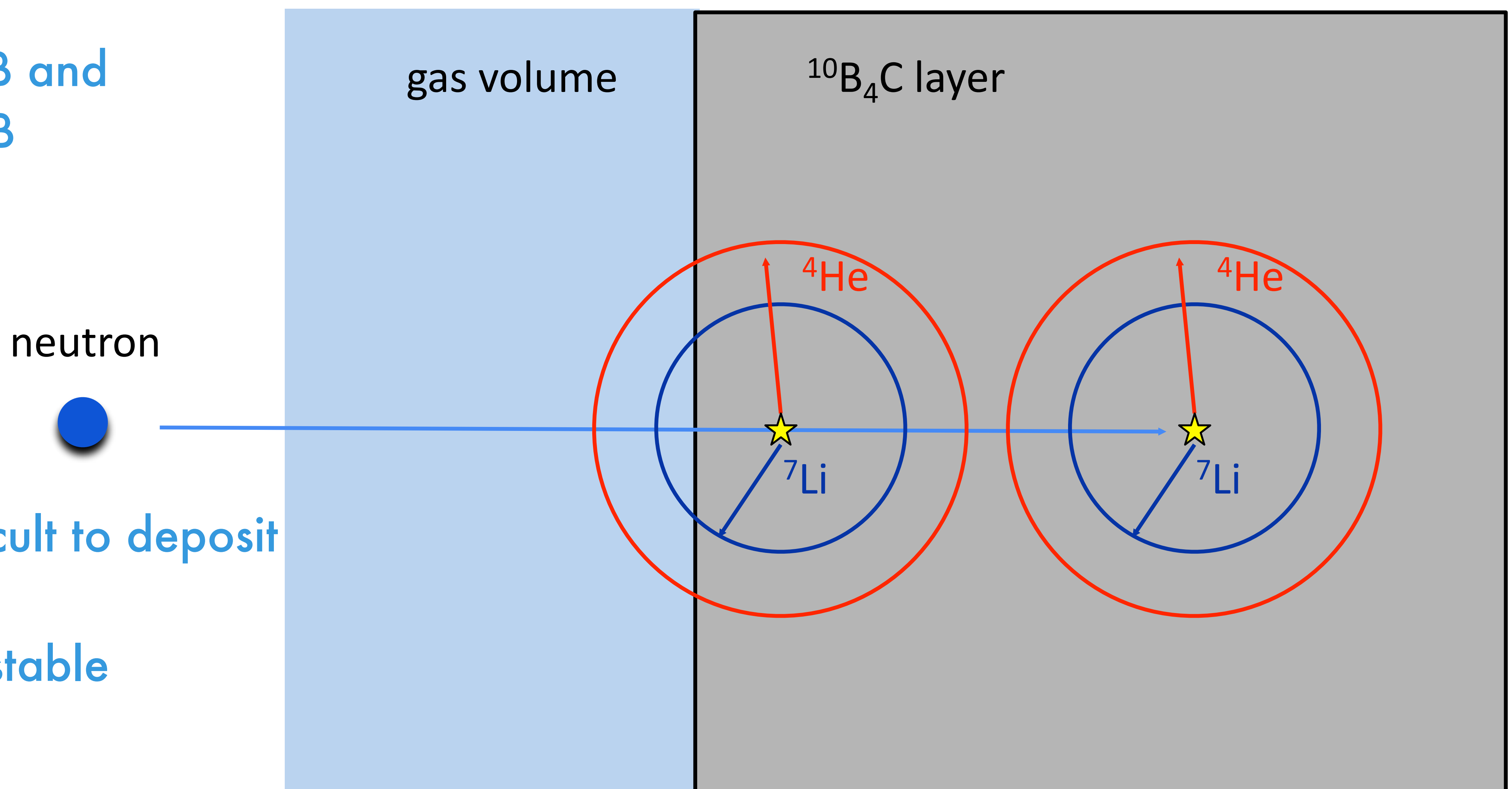
Mittuniversitetet MID SWEDEN UNIVERSITY

EUROPEAN SPALLATION SOURCE

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

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

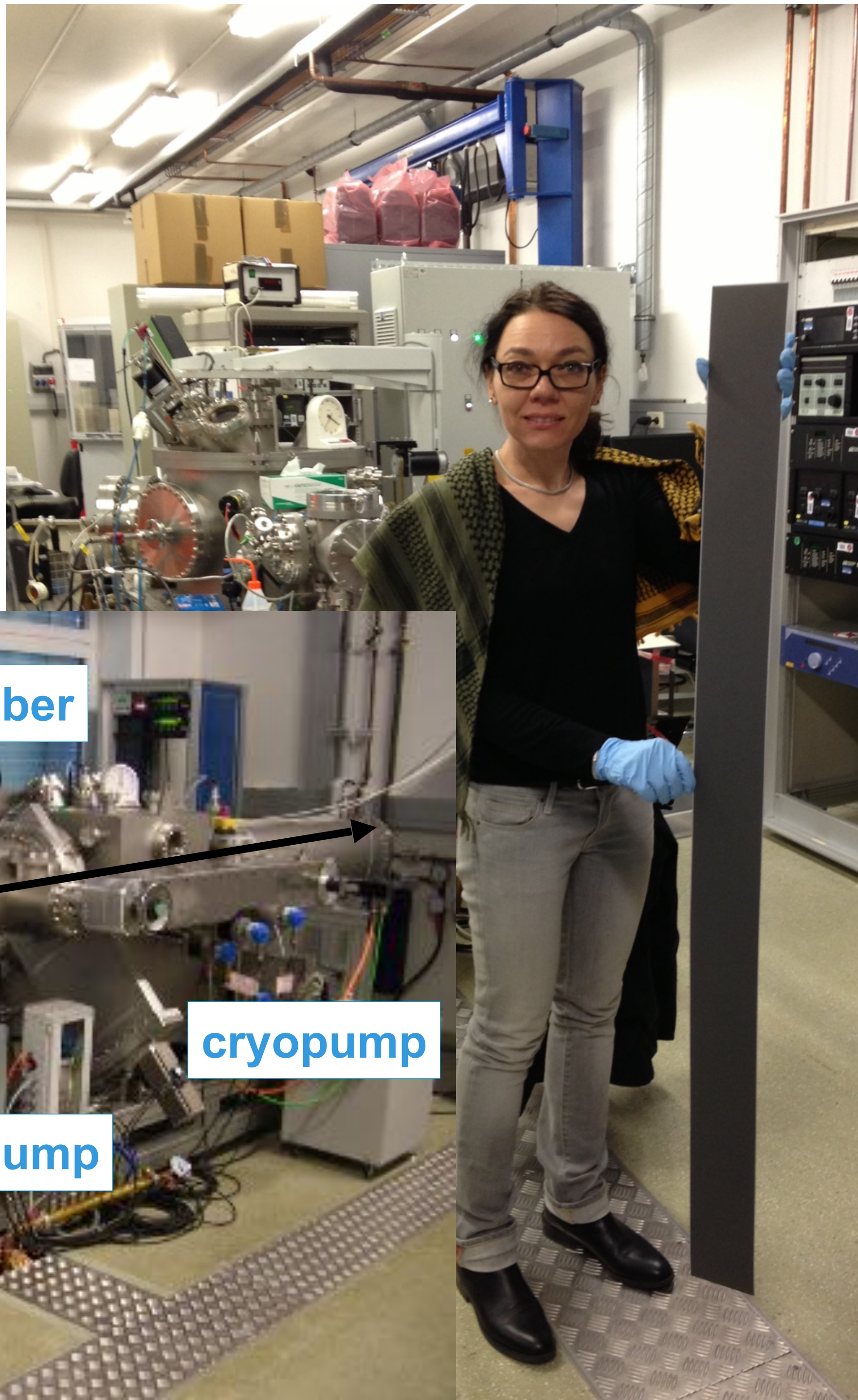
- ^{nat}B contains
  80 at.% ^{11}B and
  20 at.% ^{10}B



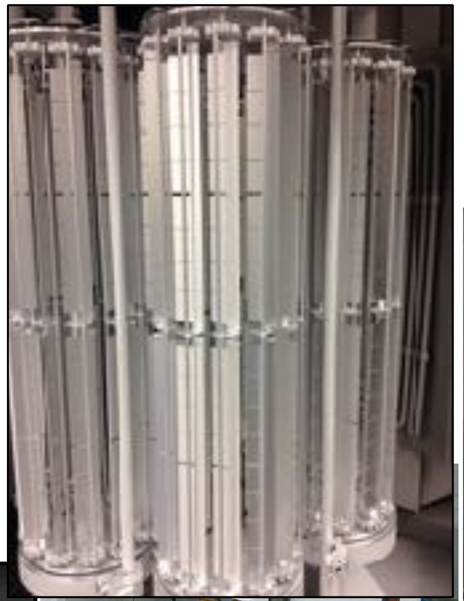
- Boron is difficult to deposit
- Use $^{10}B_4C$
- Conductive, stable

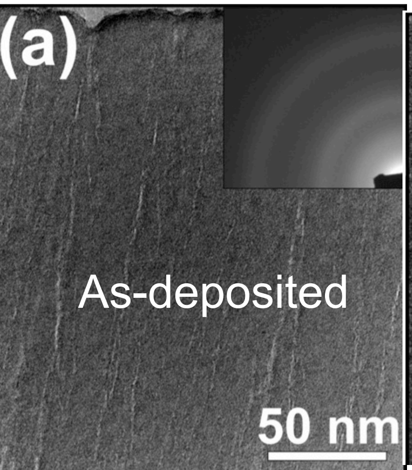
$^{10}B_4C$ Thin Film Coatings

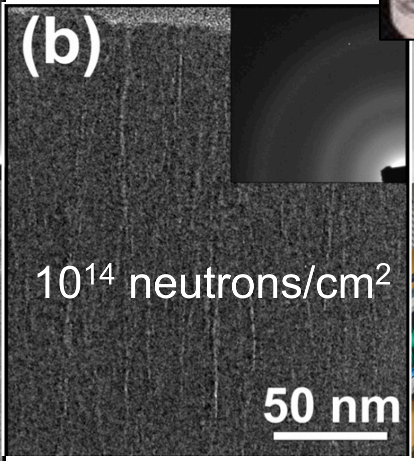
- A number of groups have shown it is possible to deposit large areas of high quality Boron Carbide cheaply
- PVD Magnetron Sputtering
- Deposition parameters highly adaptable
- A very interdisciplinary effort

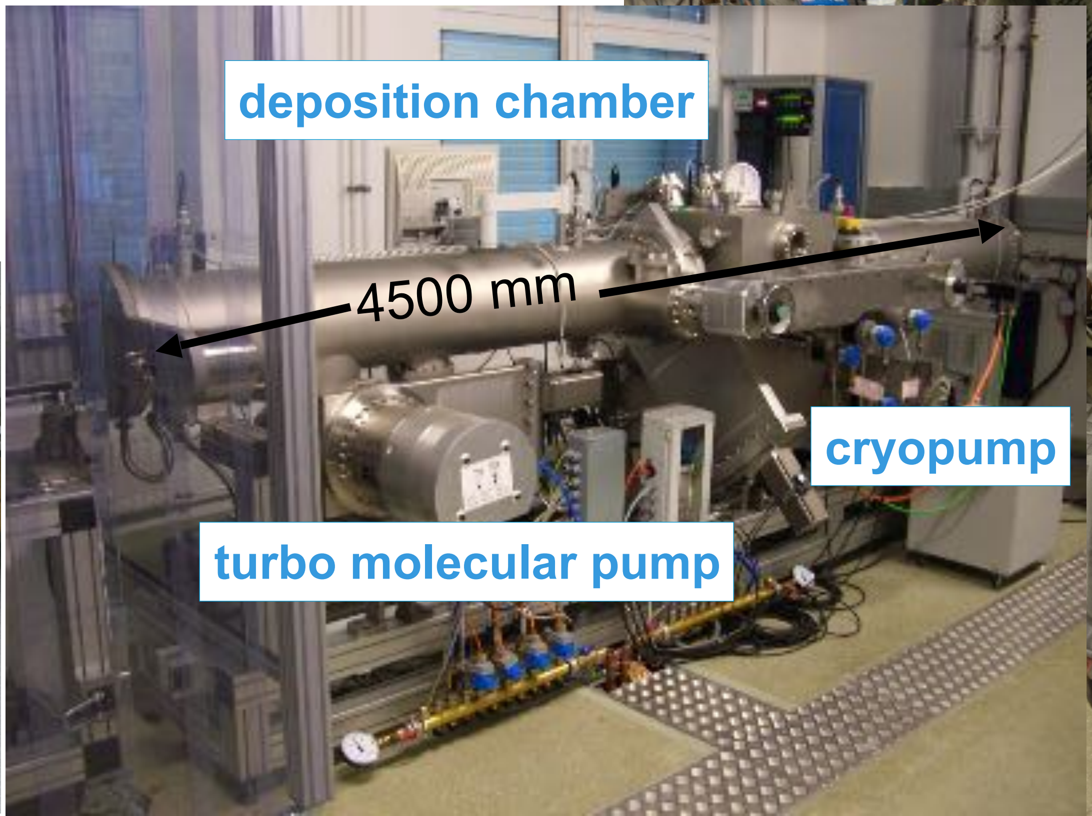


- ESS-Linkoping Deposition Facility
- Industrial Coating Machine
- Capacity: >1000m^2/year coated with $^{10}B_4C$









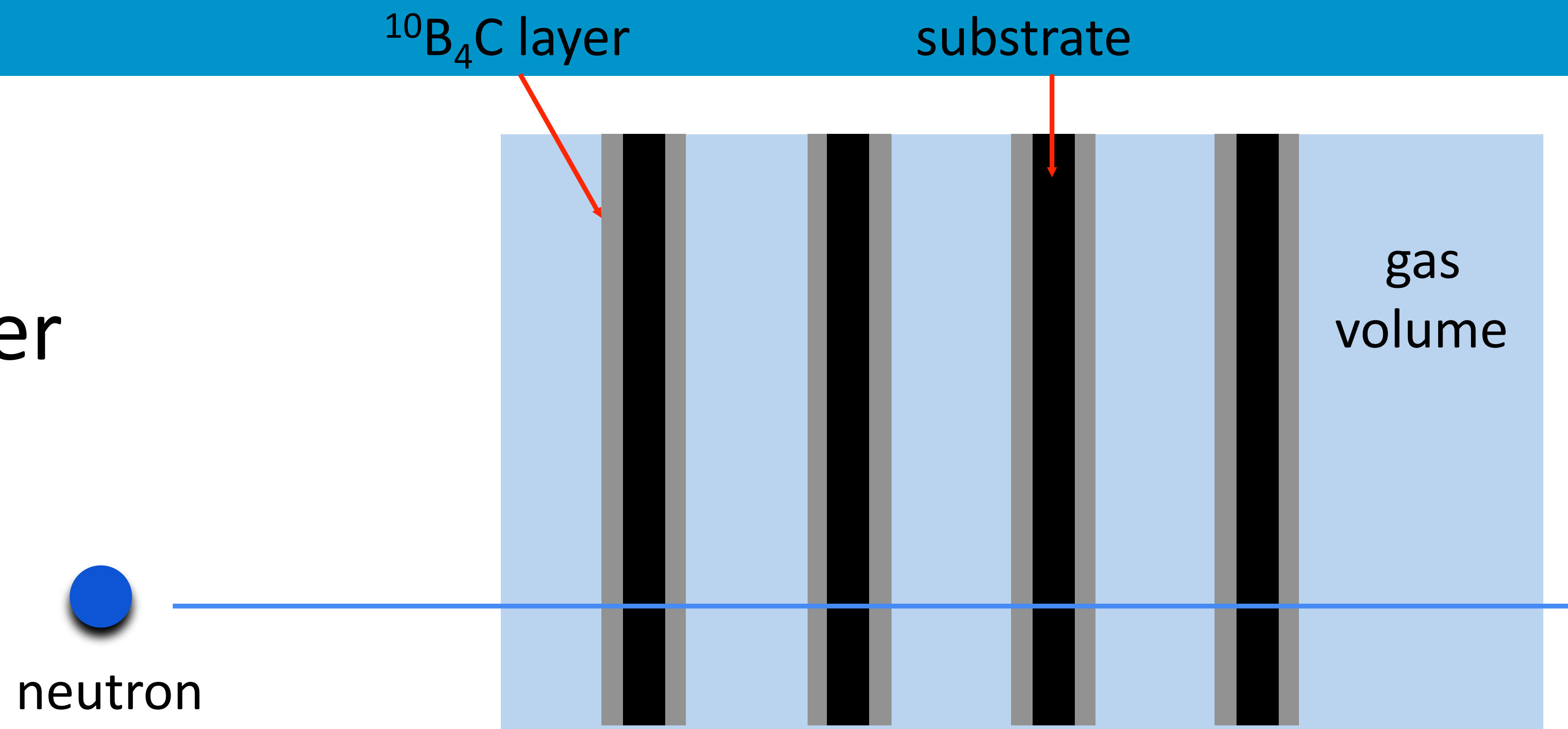
Thin Films Workshop

- Co-located with Linkoping University for synergies in expertise and facilities
- Just moved across the road to location available until 2025
- Industrial coatings machine and production line setup
- Capacity: several times ESS needs
- If interested in coatings: contact us

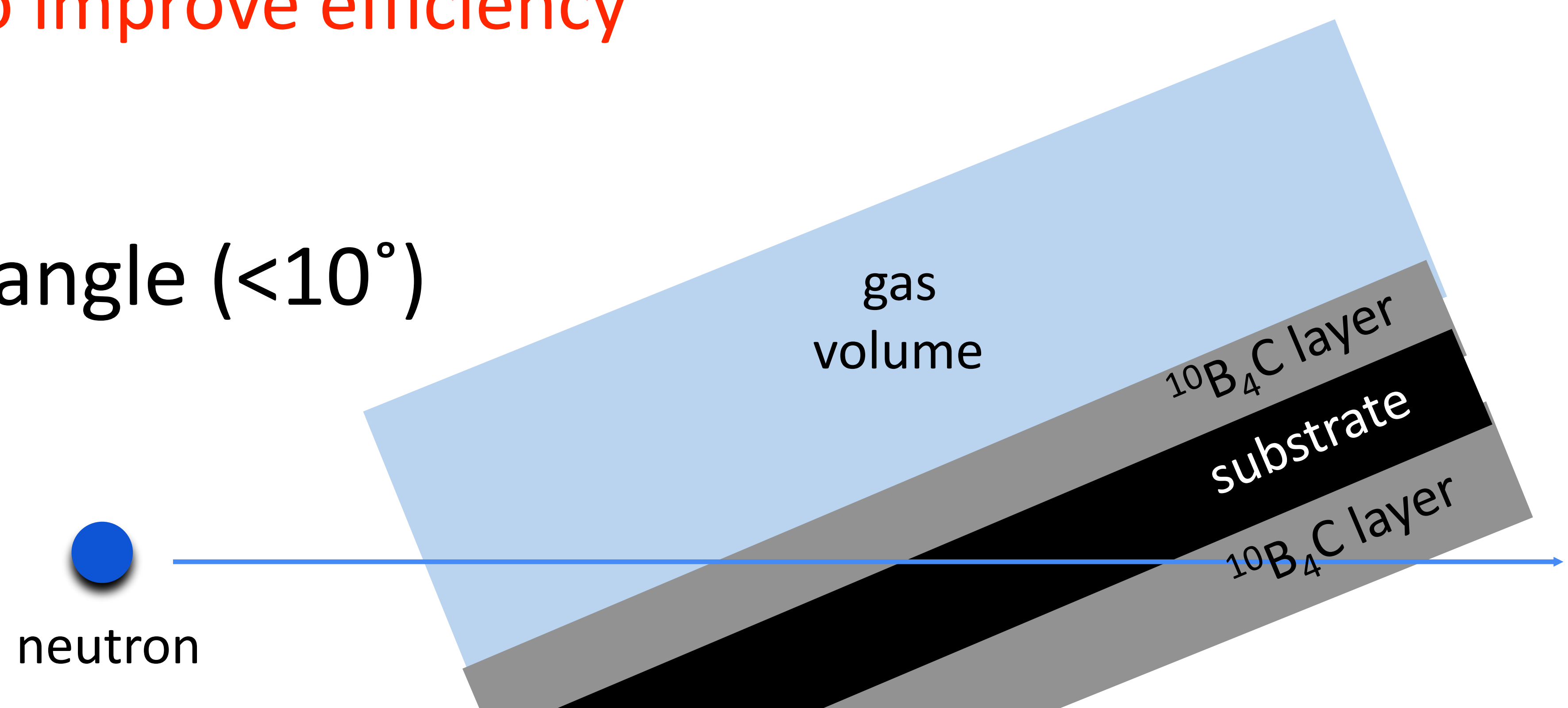
Enhancing the efficiency of ^{10}B-based Neutron Detectors

Generic approaches to improve efficiency

1 Multi layer

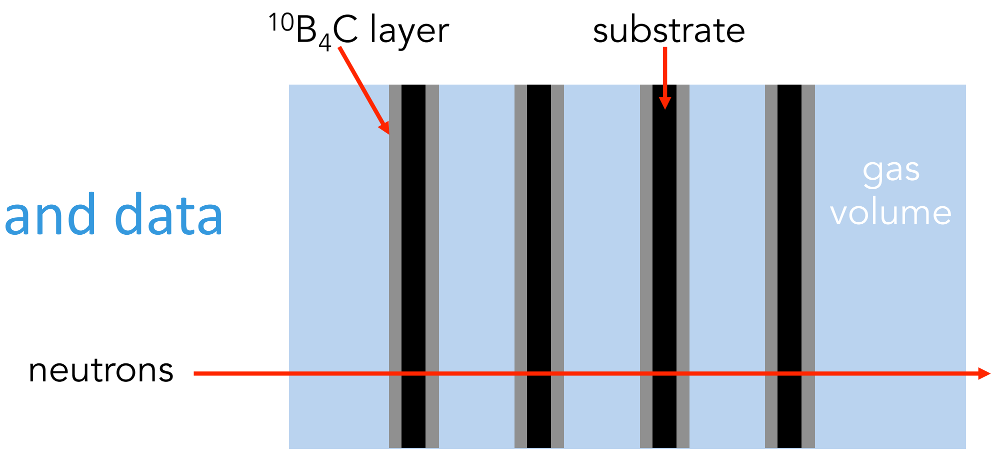


2 Grazing angle (<10˚)



Efficiency of ^{10}B Detectors: Perpendicular Geometry

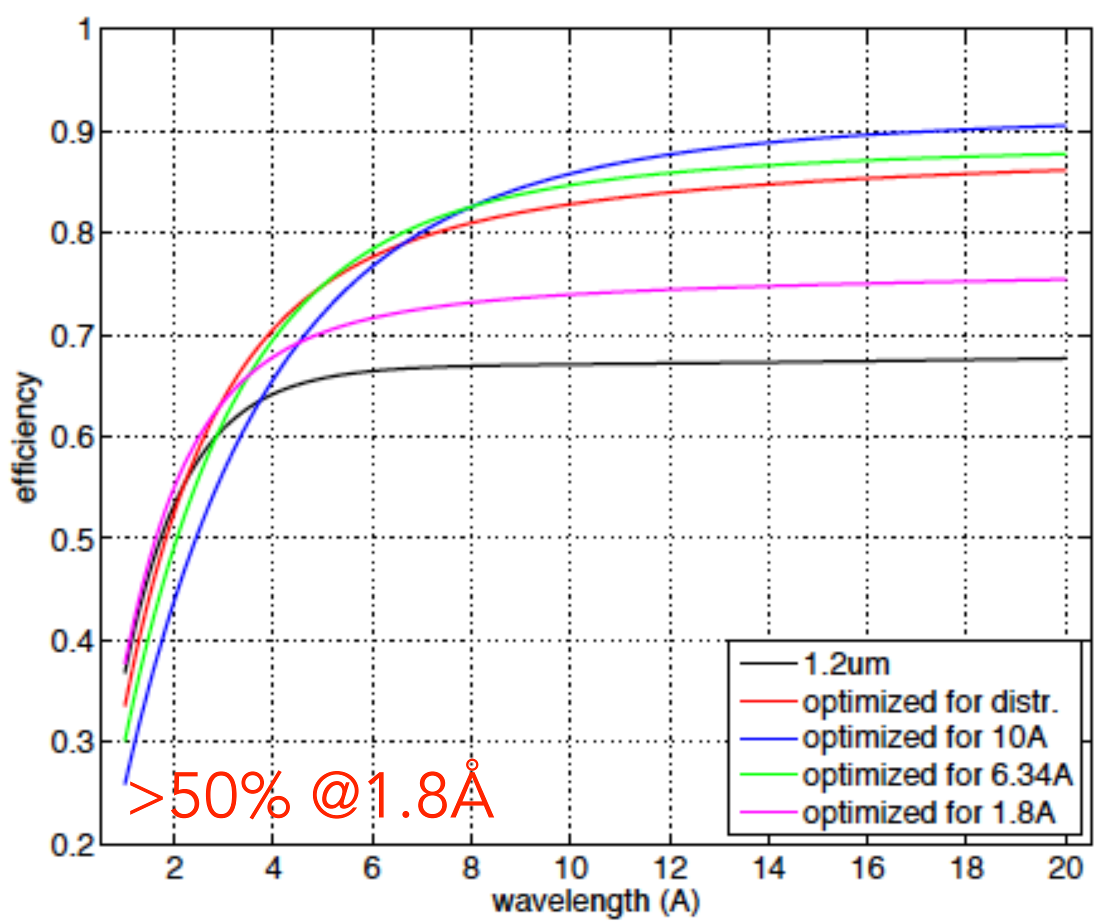
- Single layer is only ca.5%
- Calculations done by many groups
- Analytical calculations extensively verified with prototypes and data
- Details matter: just like for ^{3}He



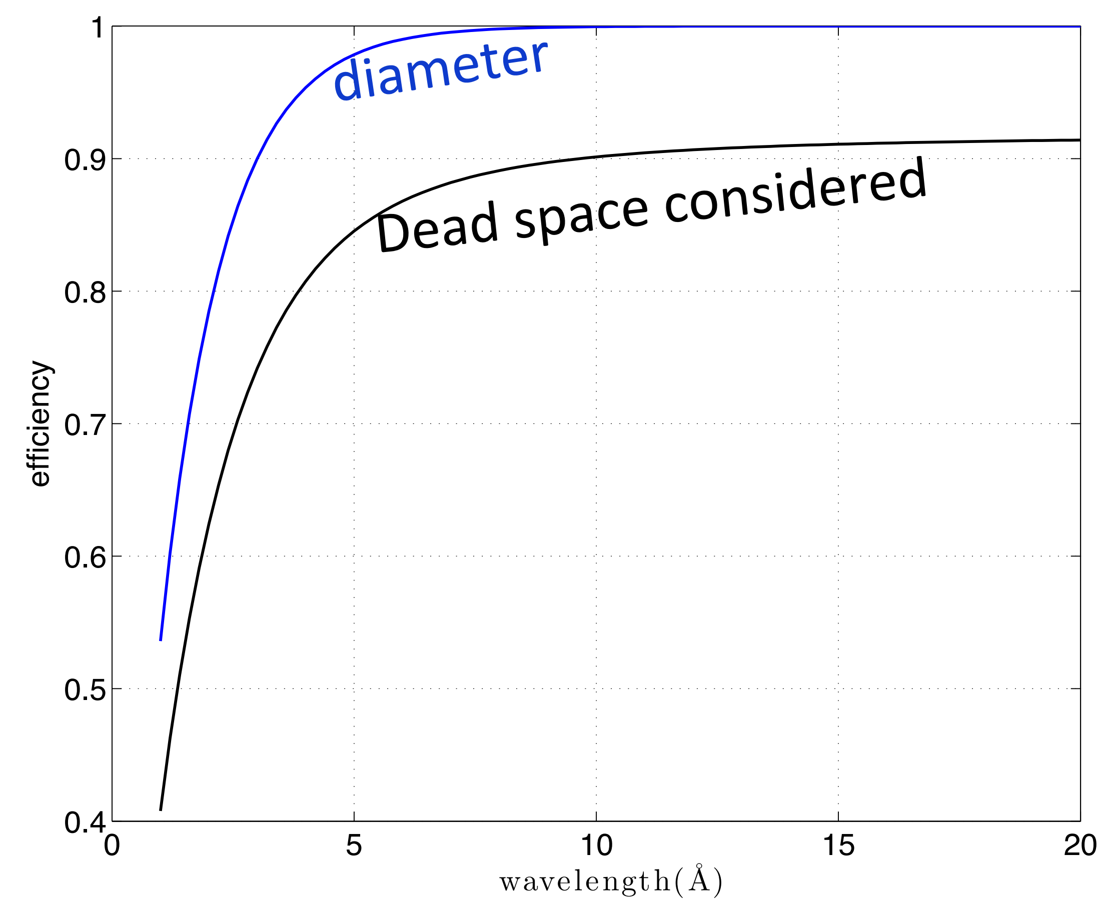
- Multilayer configuration (example):

JINST 8 (2013) P04020

Multi-Grid

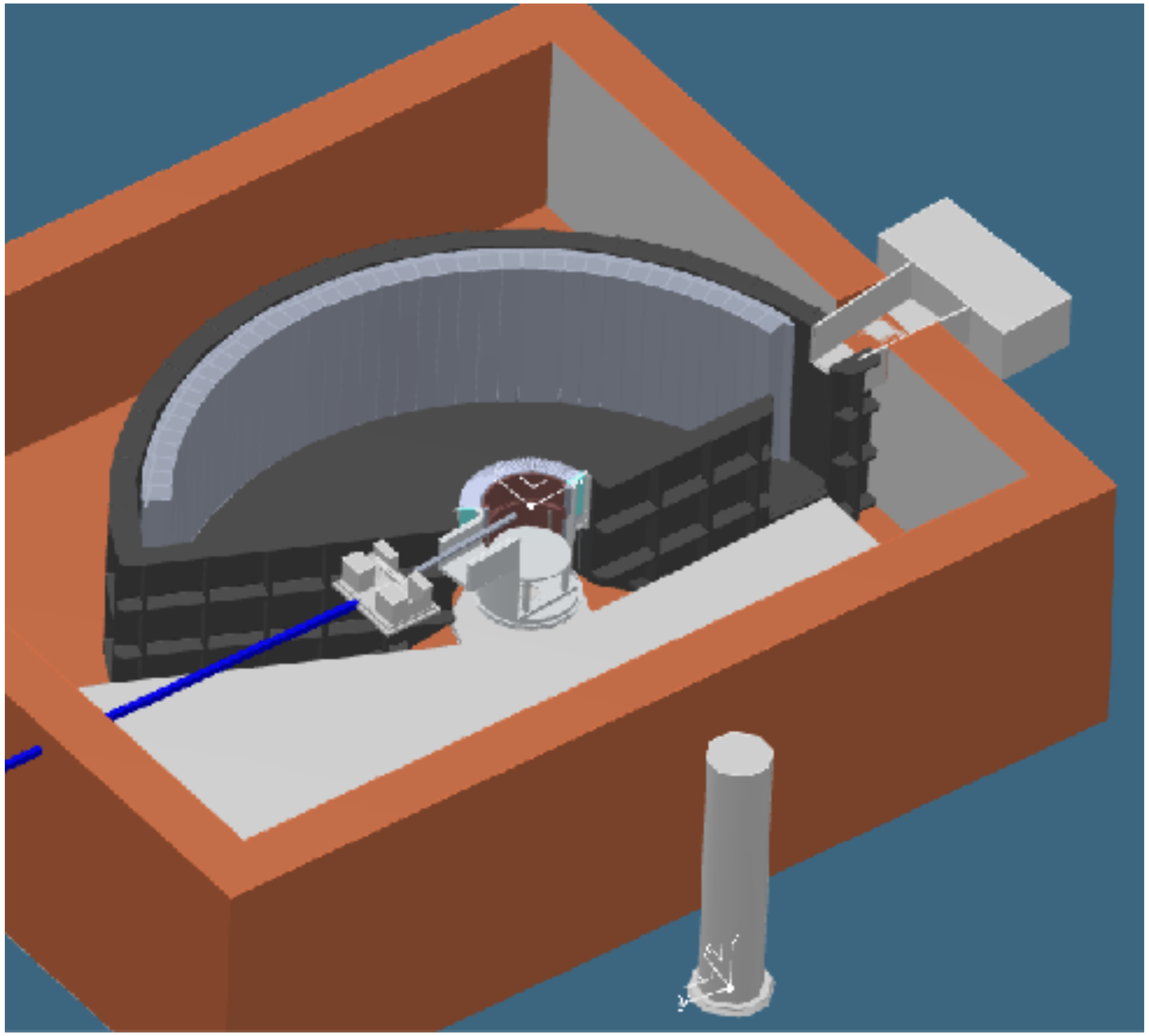


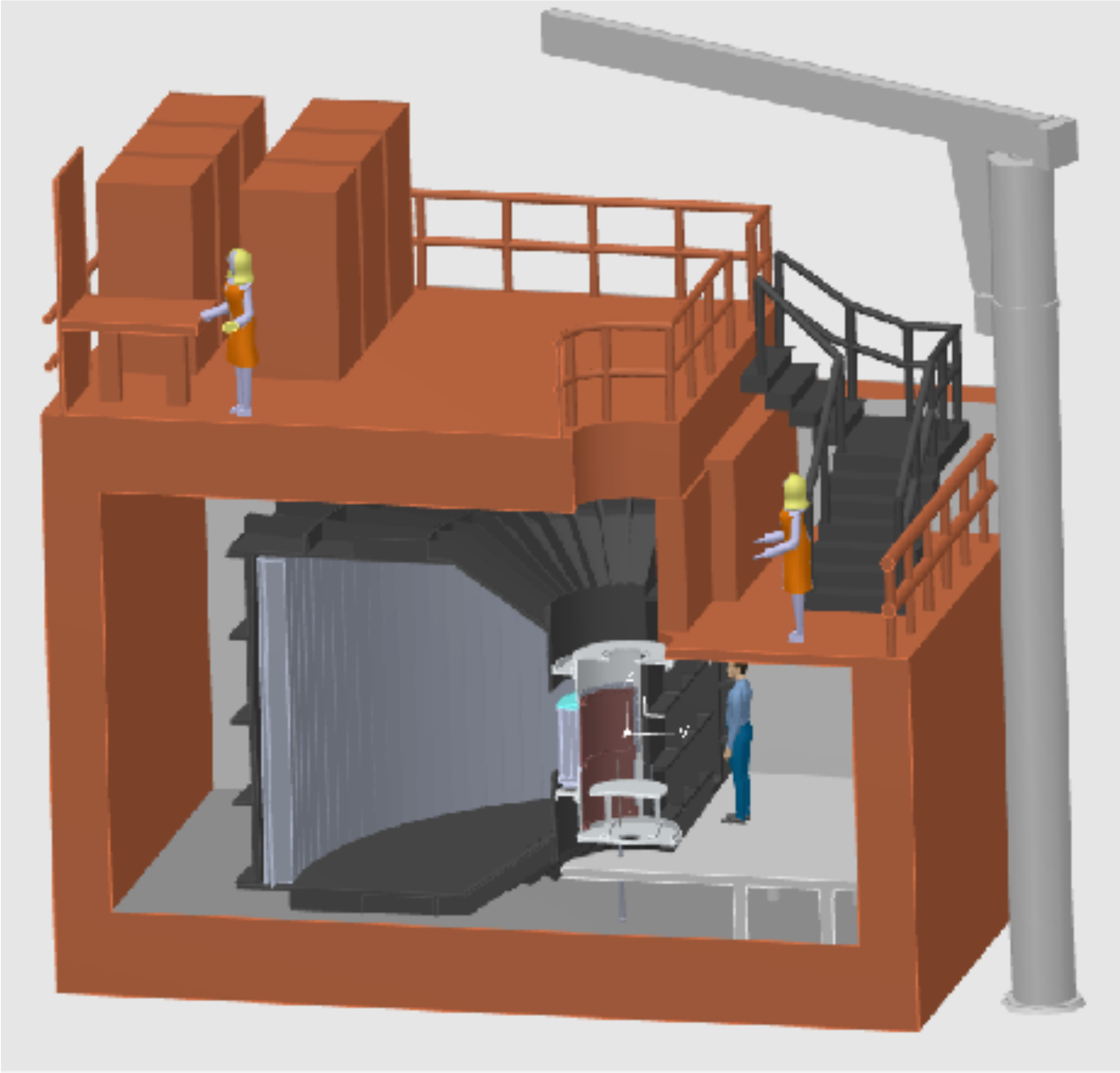
^{3}He tubes – 1 inch – 4.75 bar



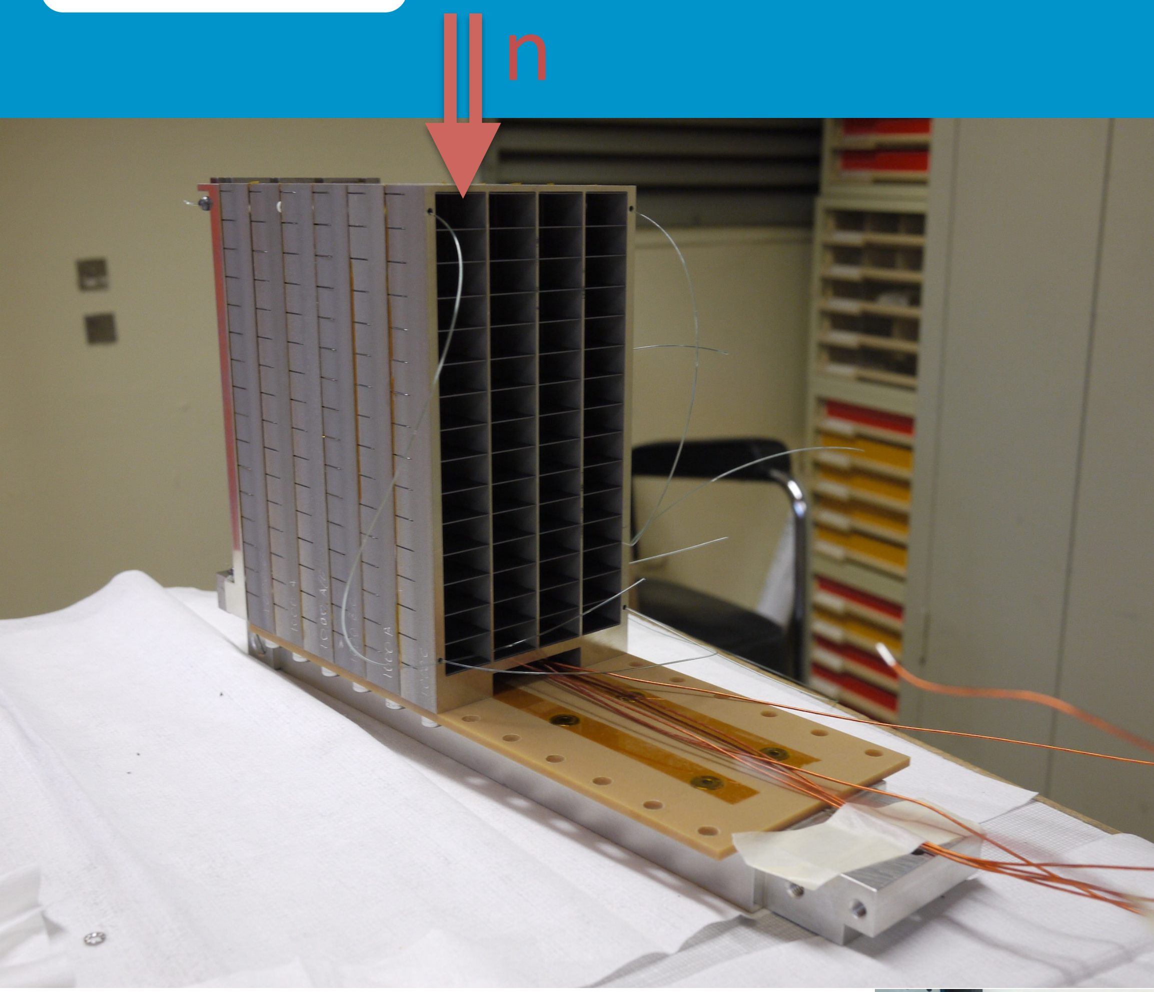
CSPEC at ESS

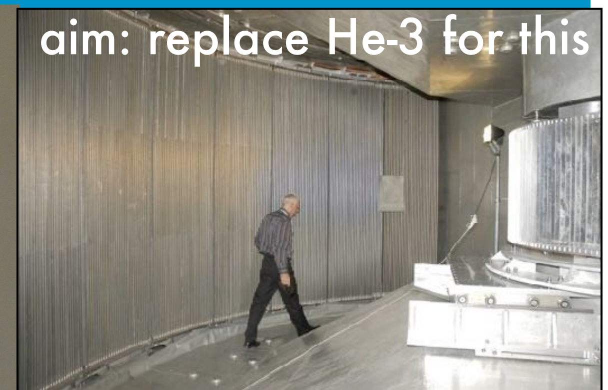
Cold spectrometer
0.2 meV < E_i < 20 meV
29m^2 detector
Horizontal coverage 5° to 135°
Vertical coverage -25° to 25°



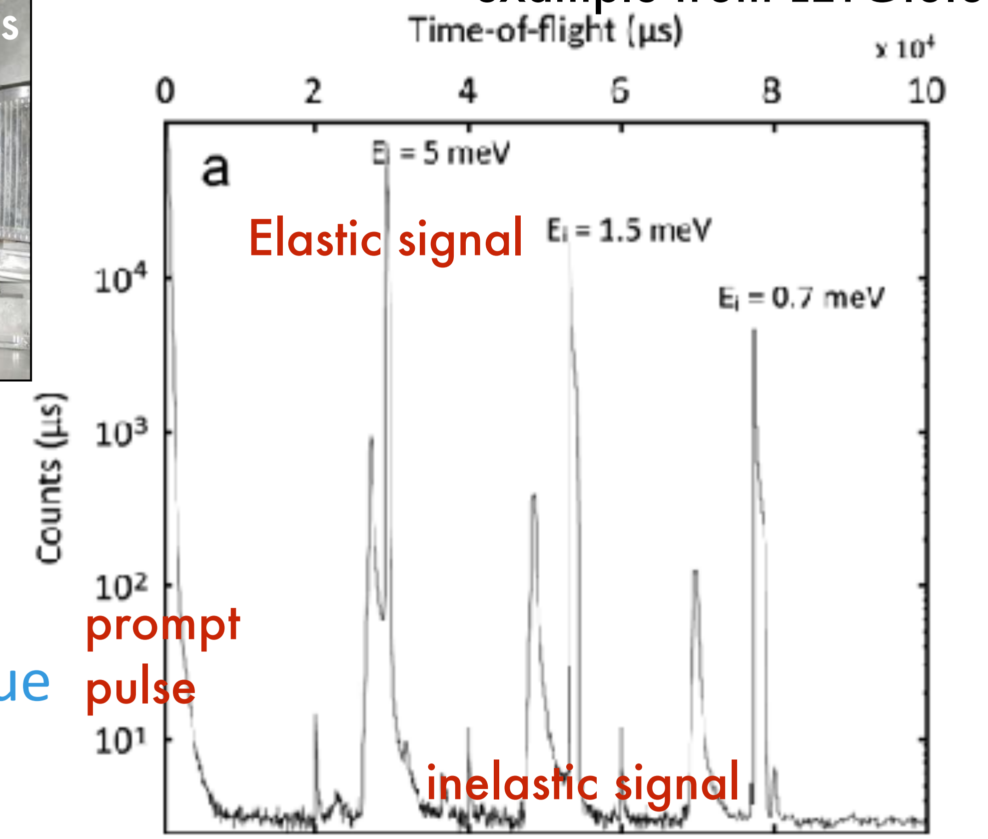


Multi-Grid Detector Design



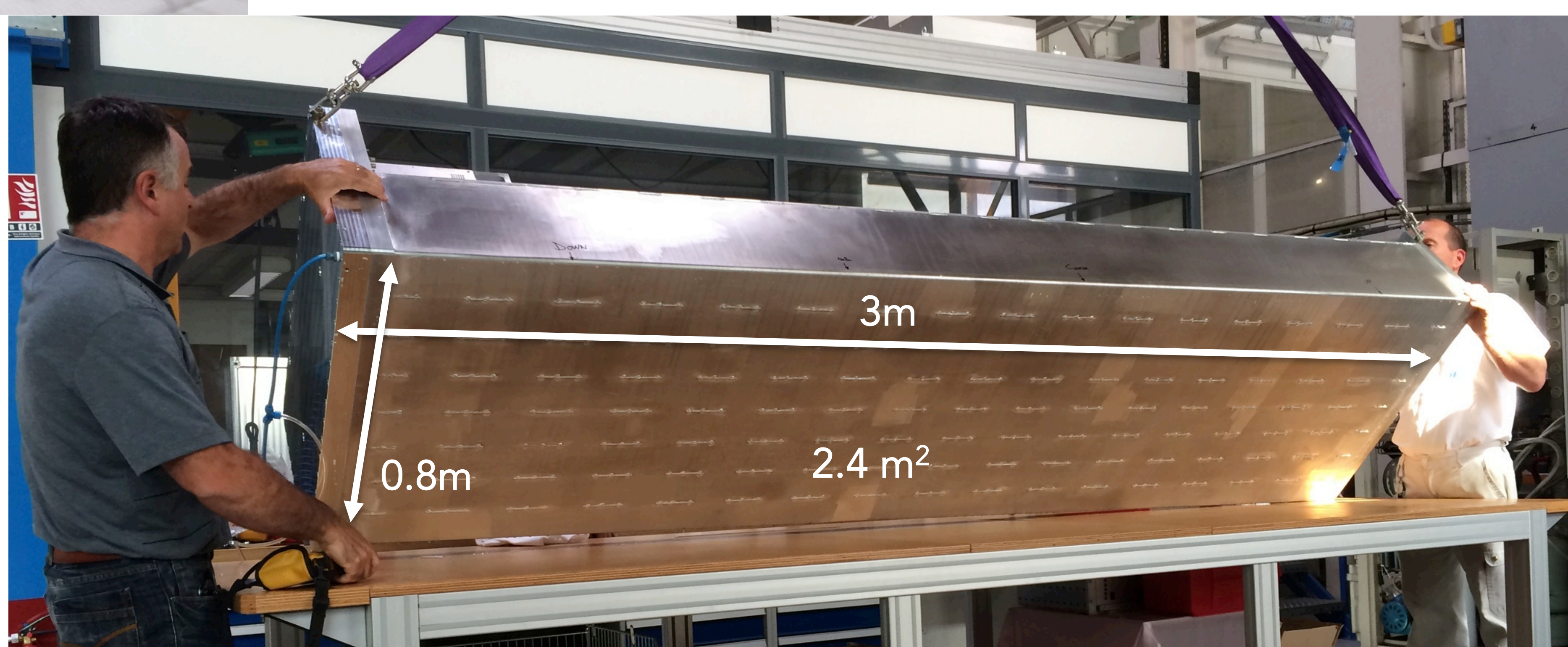


example from LET@ISIS

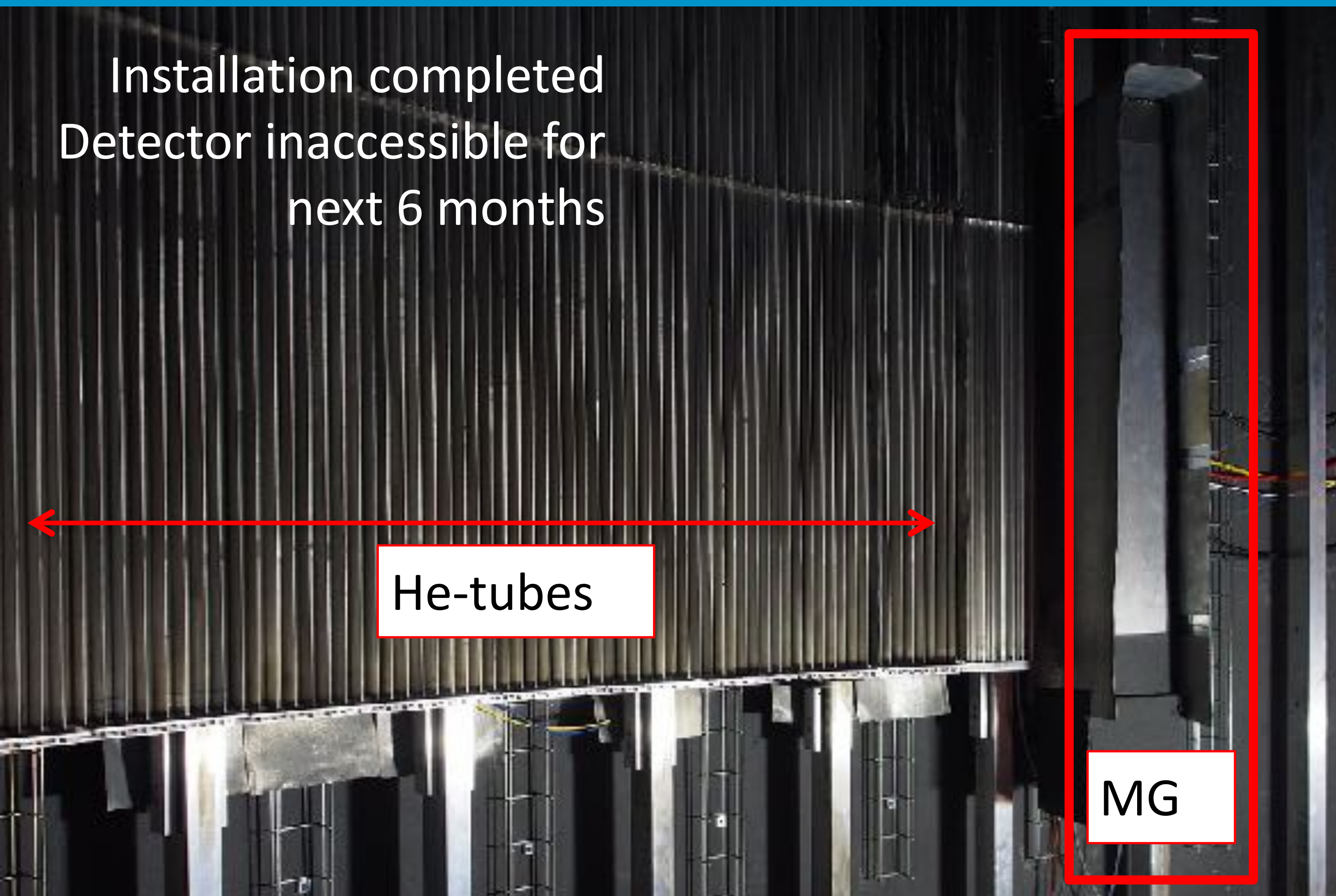


- Very background sensitive technique

- 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

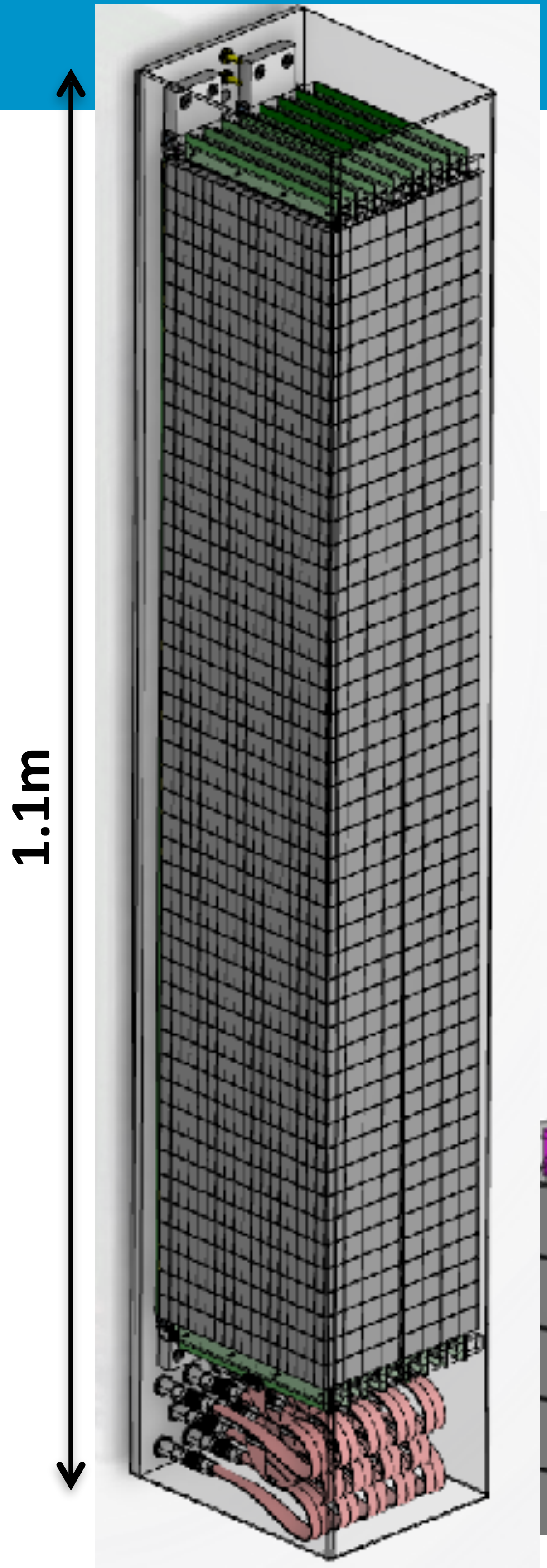


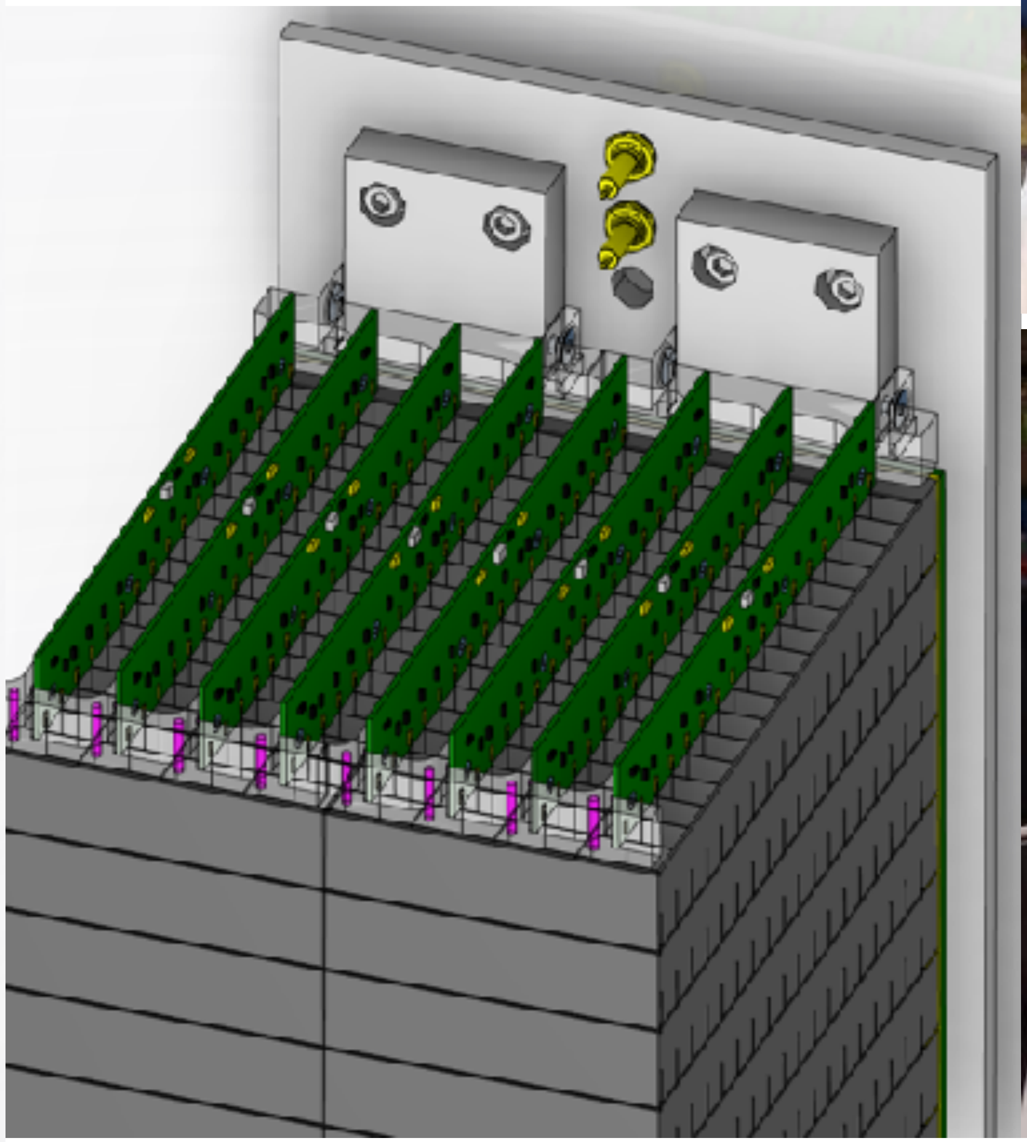
B10 Multi-Grid Detector Performance is equivalent to that of He-3 detectors

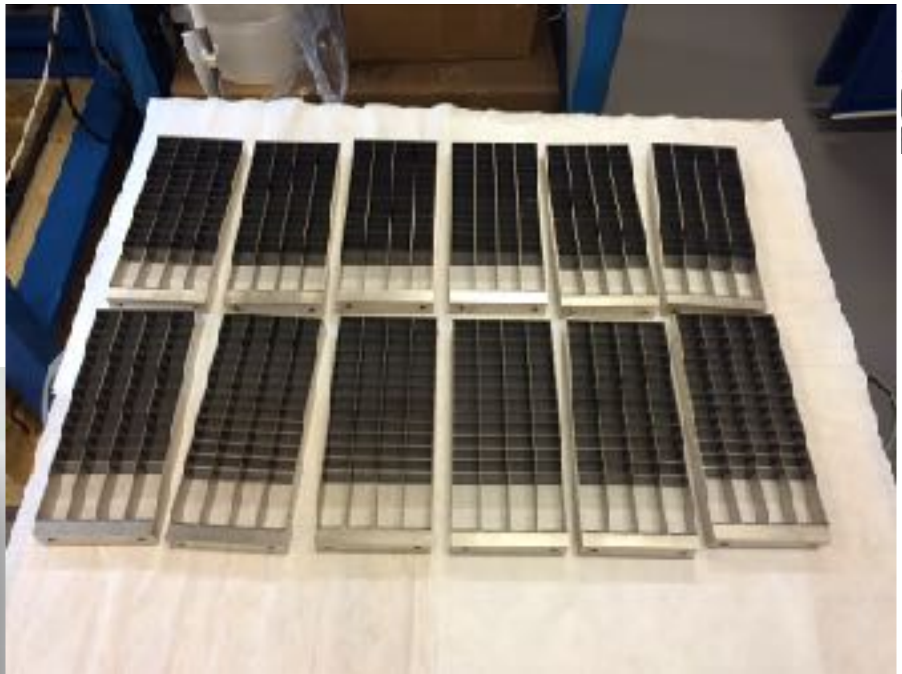
A.Khaplanov et al. *"Multi-Grid Detector for Neutron Spectroscopy: Results Obtained on Time-of-Flight Spectrometer CNCS"* https://arxiv.org/abs/1703.03626
2017 JINST 12 P04030

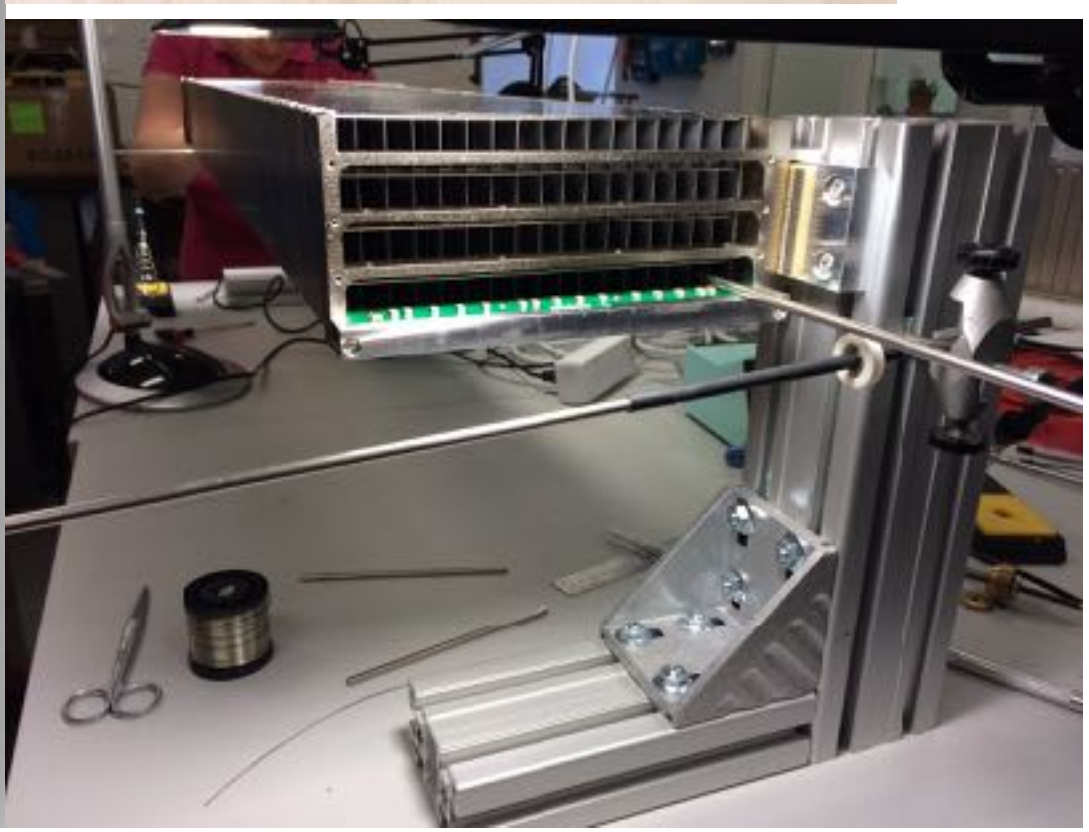
- Test side-by-side with existing technology in world leading instrument
- Realistic conditions
- "Science" or application performance
- 2 different technologies on the same instrument

Construction of MG.CNCS in Lund

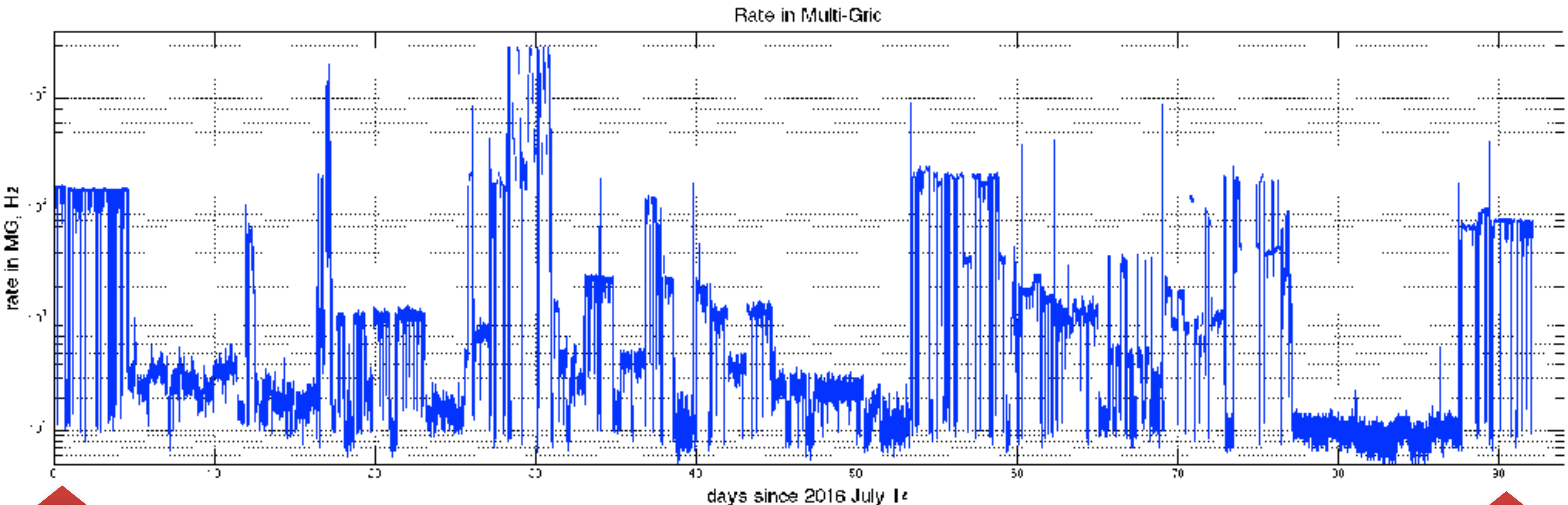








Operation since 2016-07-14



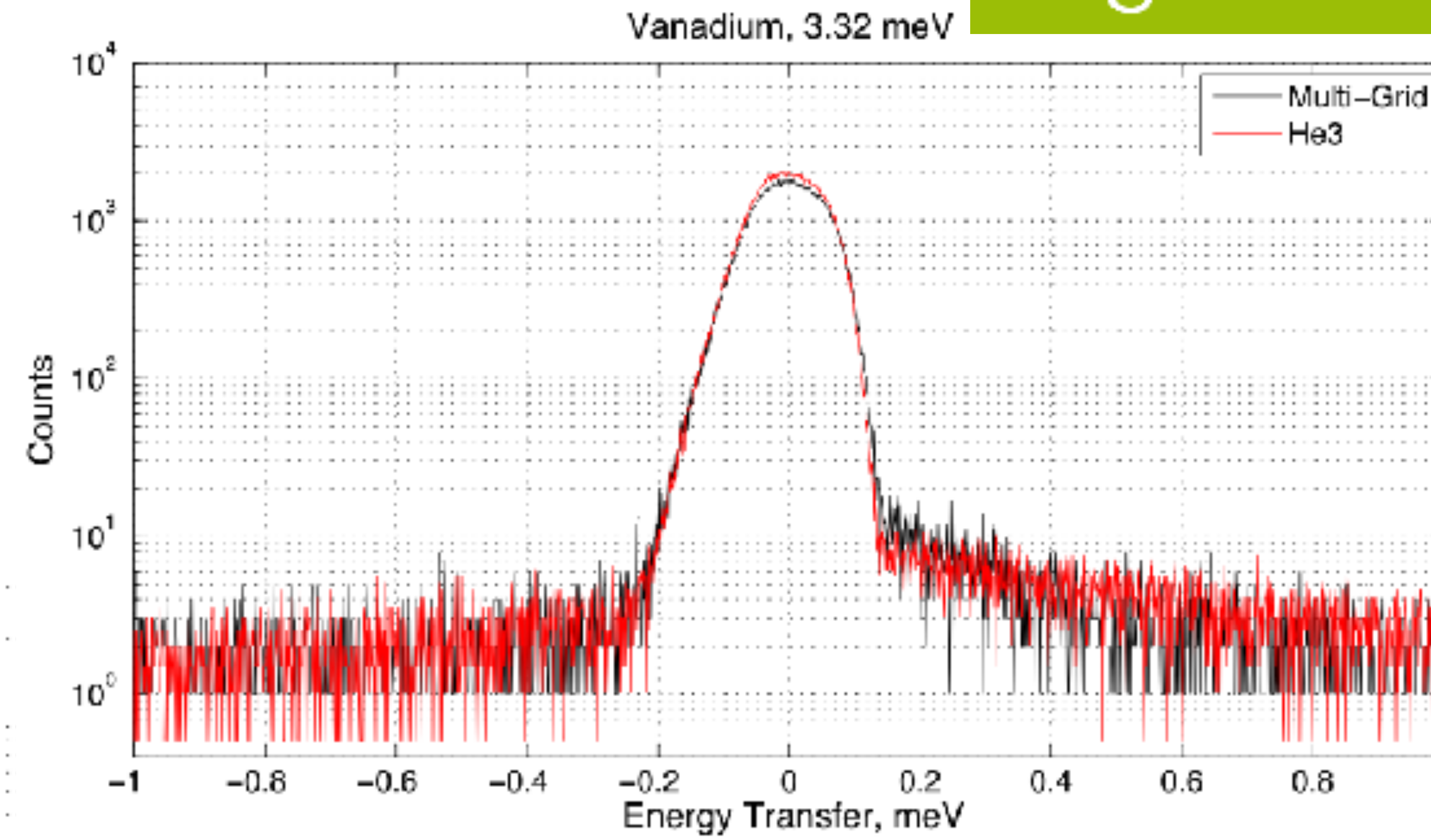
First day

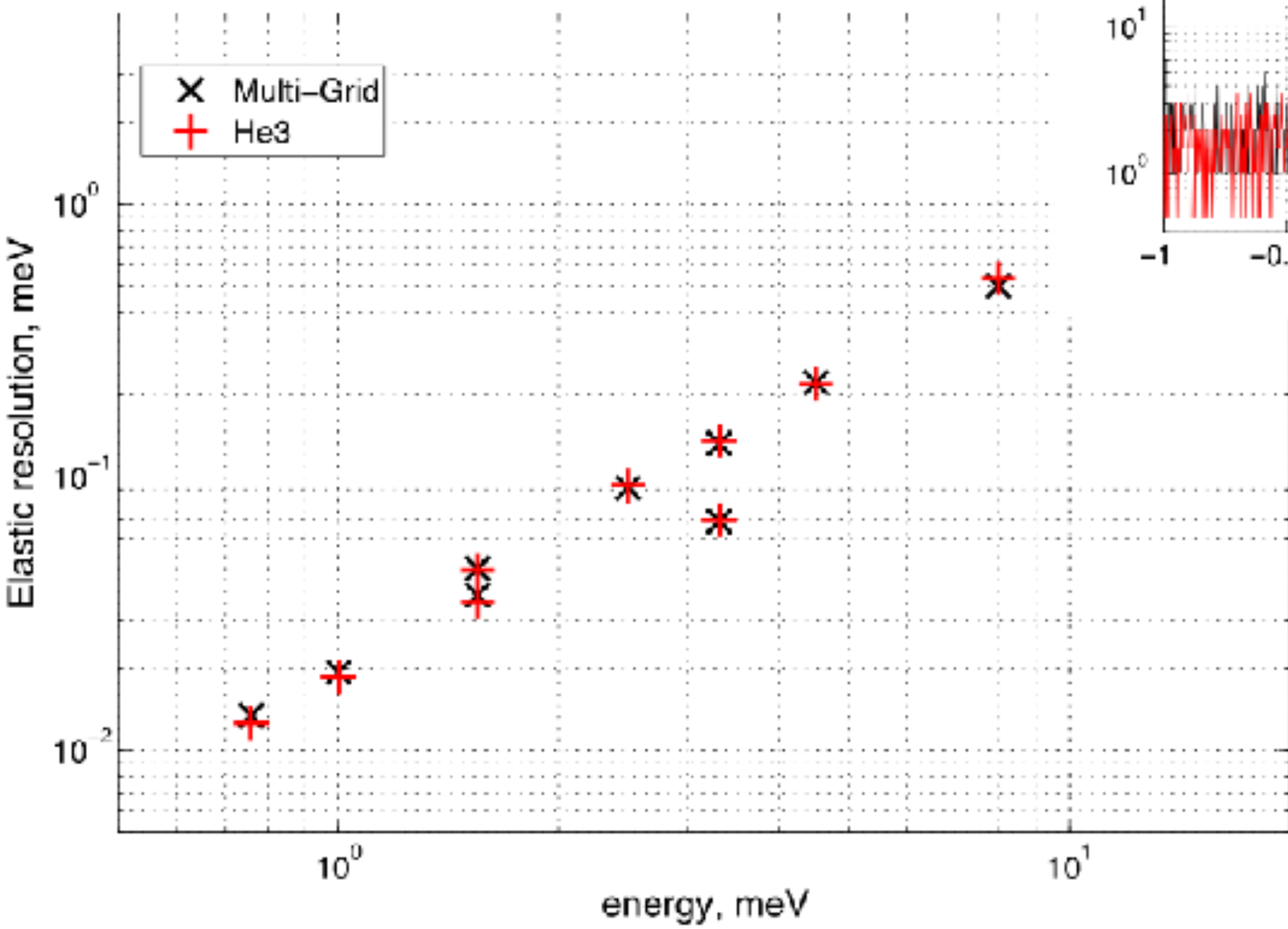
90 days

Operating without possibility of access since installation

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

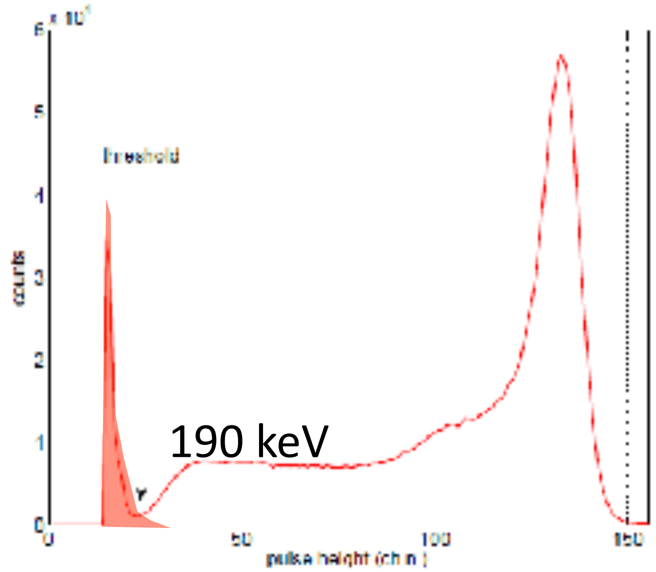
Multi-Grid test at CNCS



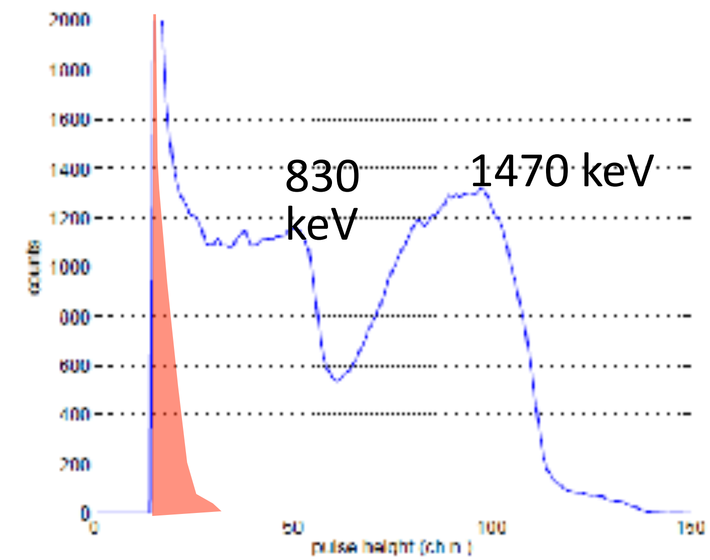


- Data and instrument resolution identical
- Technology suitable for ESS instruments

Background - Gamma Sensitivity



<10^{-6}



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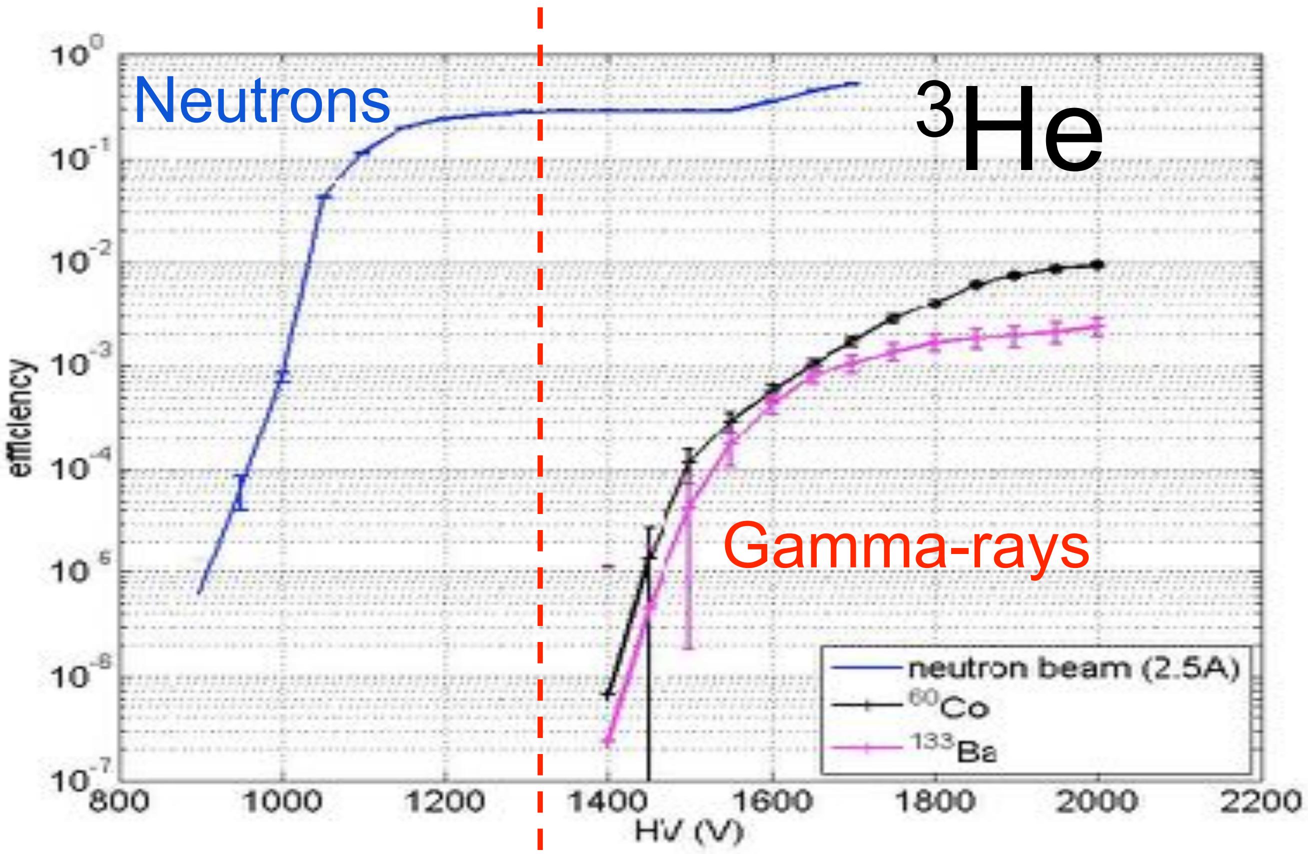
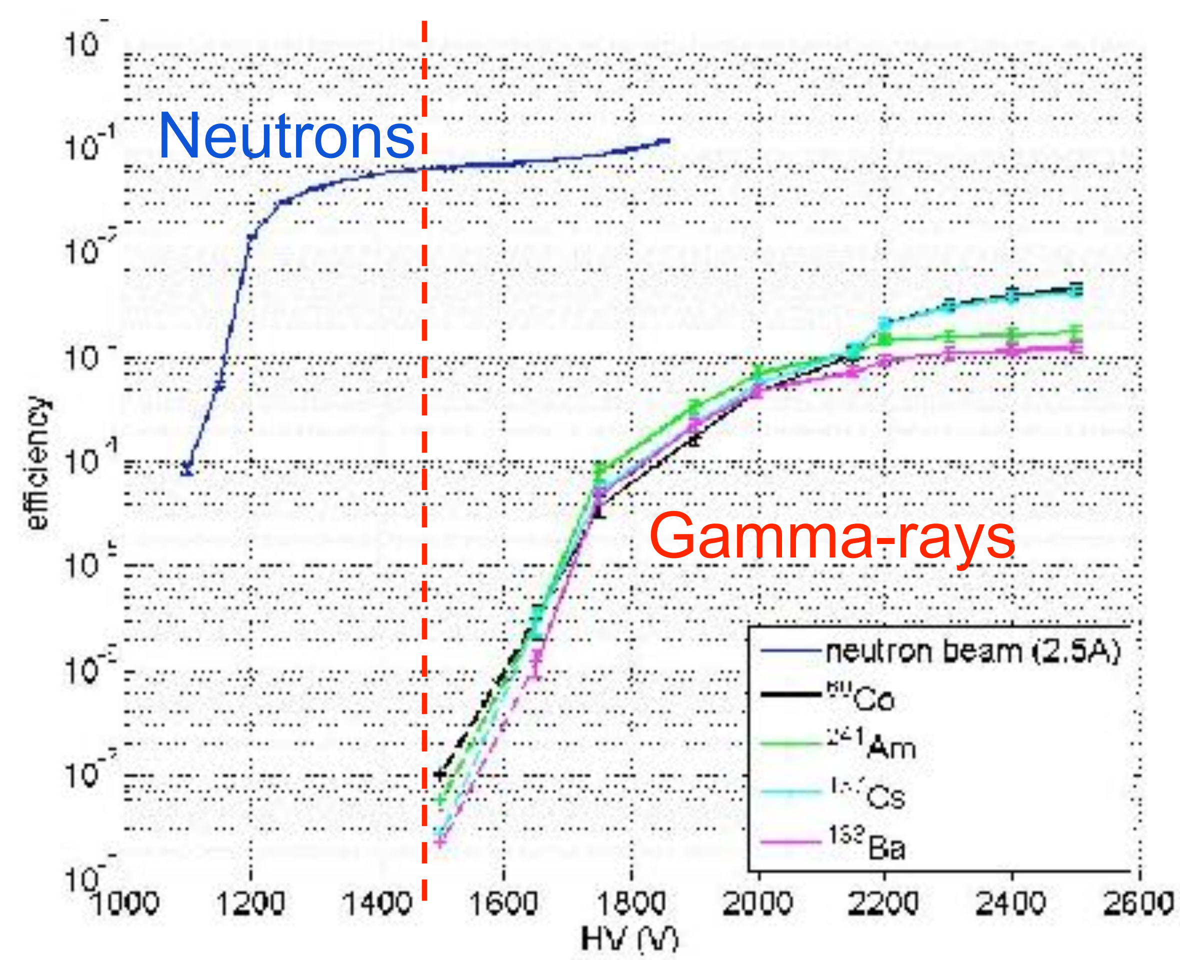
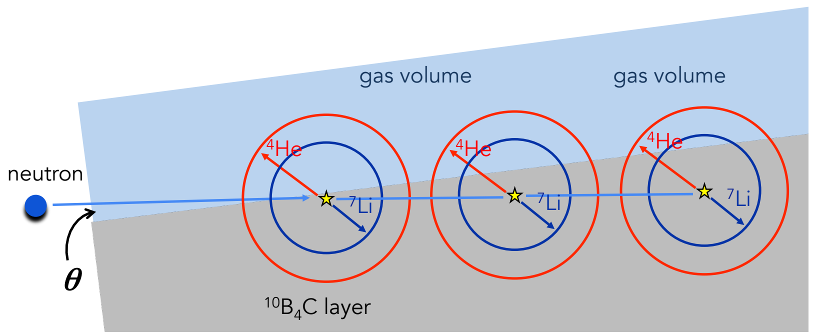
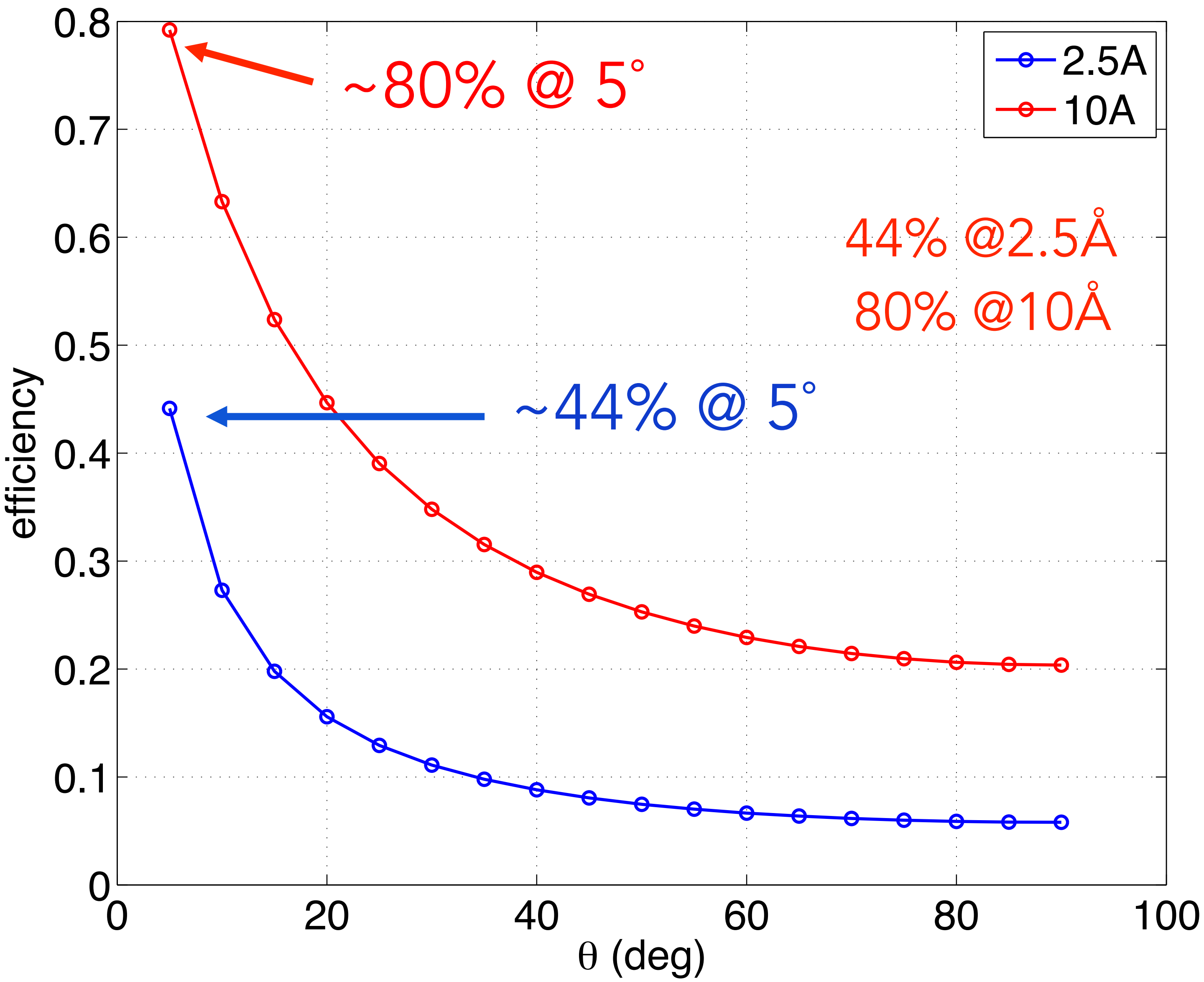


JINST 8 (2013) 10025



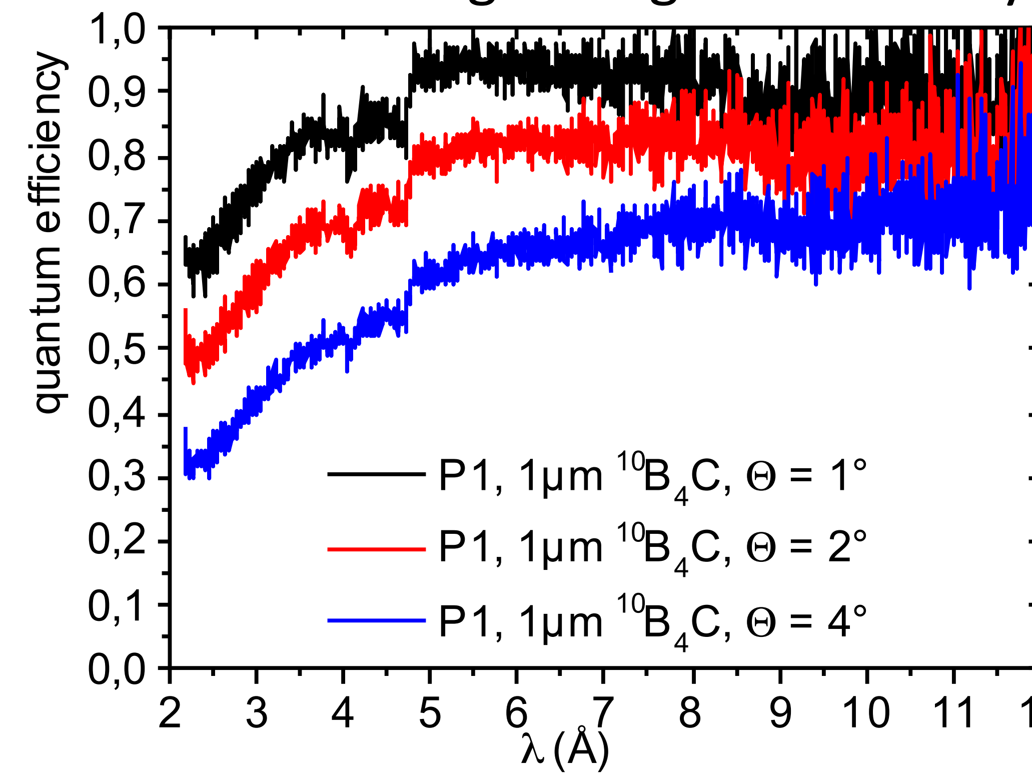
Efficiency of ^{10}Boron Detectors: Inclined Configuration

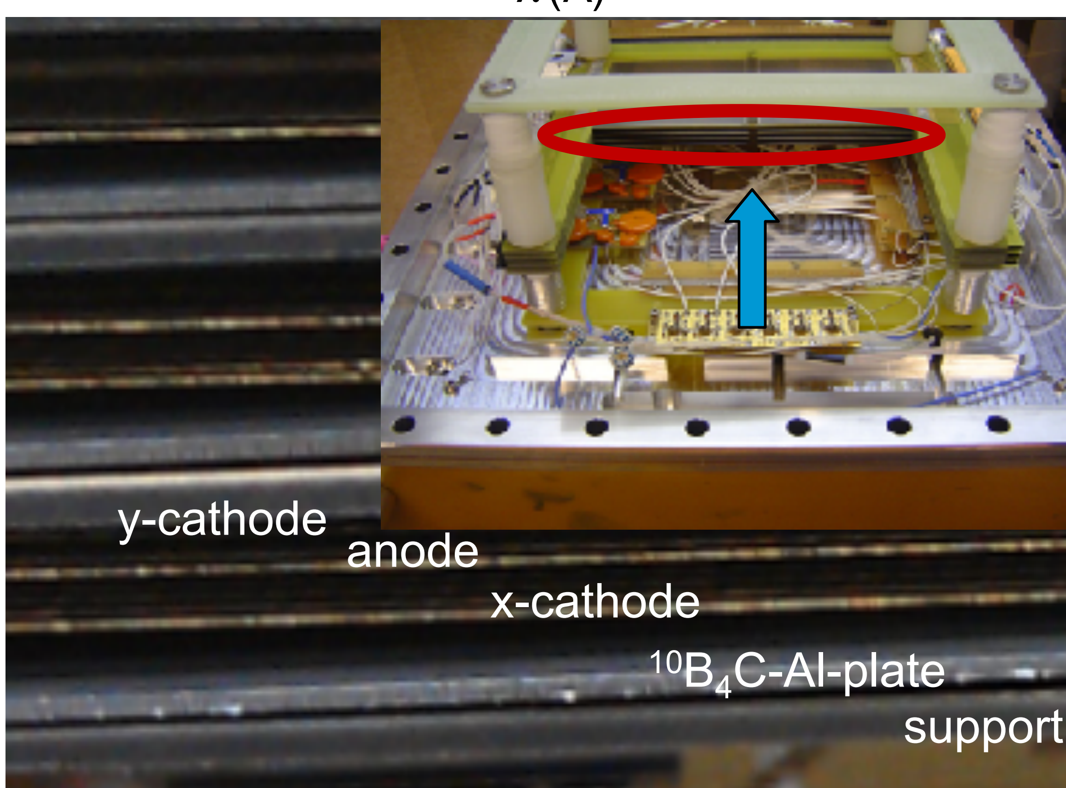




F. Piscitelli, PhD Thesis, U.Perugia (2014)

smaller inclined angles: higher efficiency





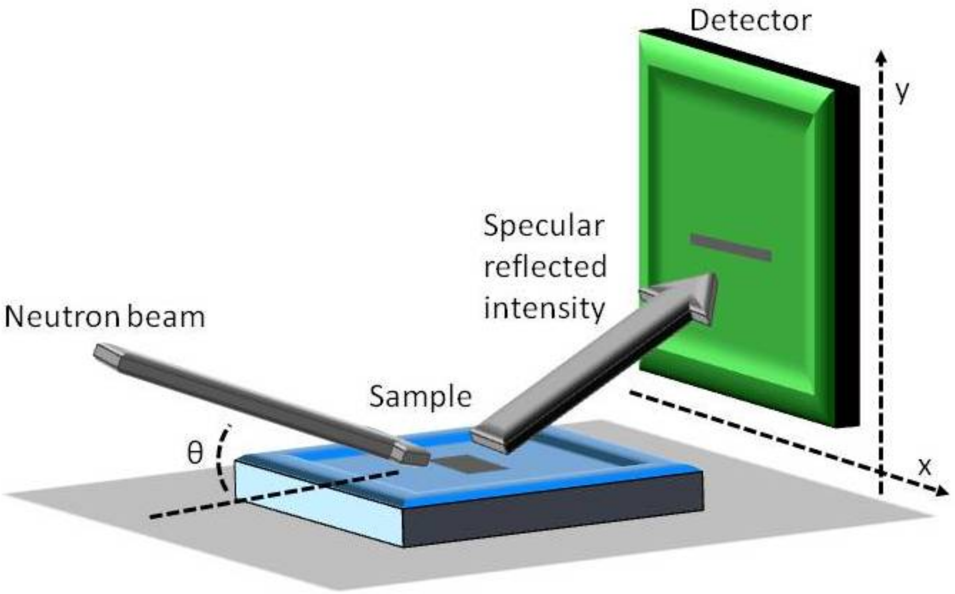
Neutron Reflectometry: A Rate Challenge

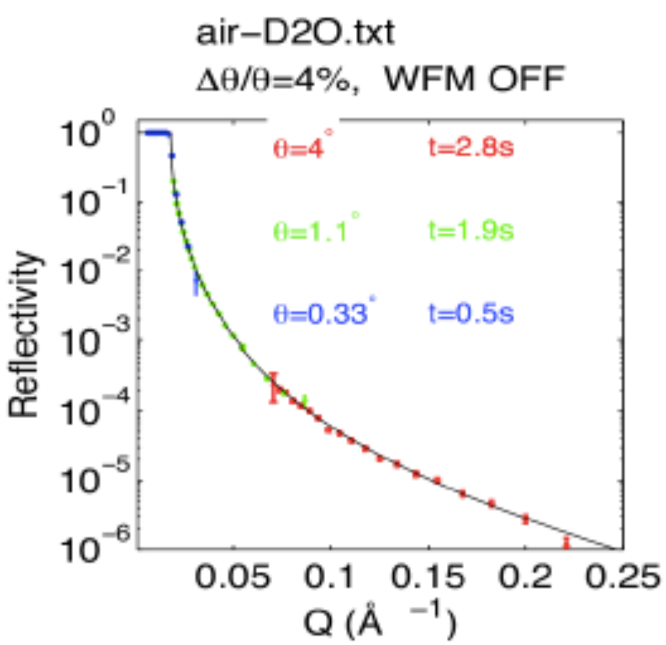
brightness

NEUTRONS FOR SCIENCE

ess EUROPEAN SPALLATION SOURCE

- Rate requirements is high:
  - Intensity of new sources
  - Time structure of pulse
  - Advanced design instruments





ESS requirements

area $(mm \times mm)$	spatial resolution $(mm \times mm)$	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
500×500	$[\leq 0.5, 2] \times 2$	$[5, 100] \cdot 10^5$	$[5, 300] \cdot 10^2$

x10 x100

The state of the art

area $(mm \times mm)$	spatial resolution $(mm \times mm)$	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
500×500	1×2	$100 \cdot 10^5$	300

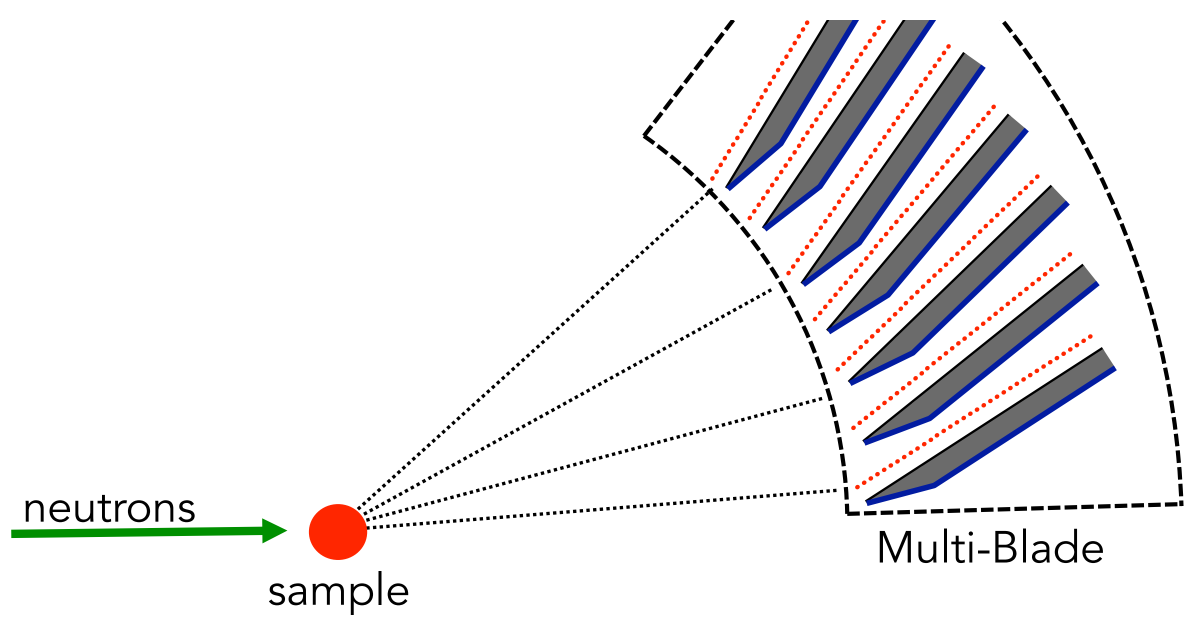
^{3}He technology

x1 x10

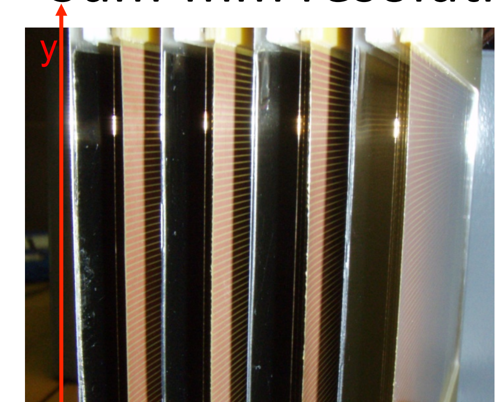
Multi-Blade

area $(mm \times mm)$	spatial resolution $(mm \times mm)$	global rate (s^{-1})	local rate $(s^{-1}mm^{-2})$
	0.3 x 4		>1000

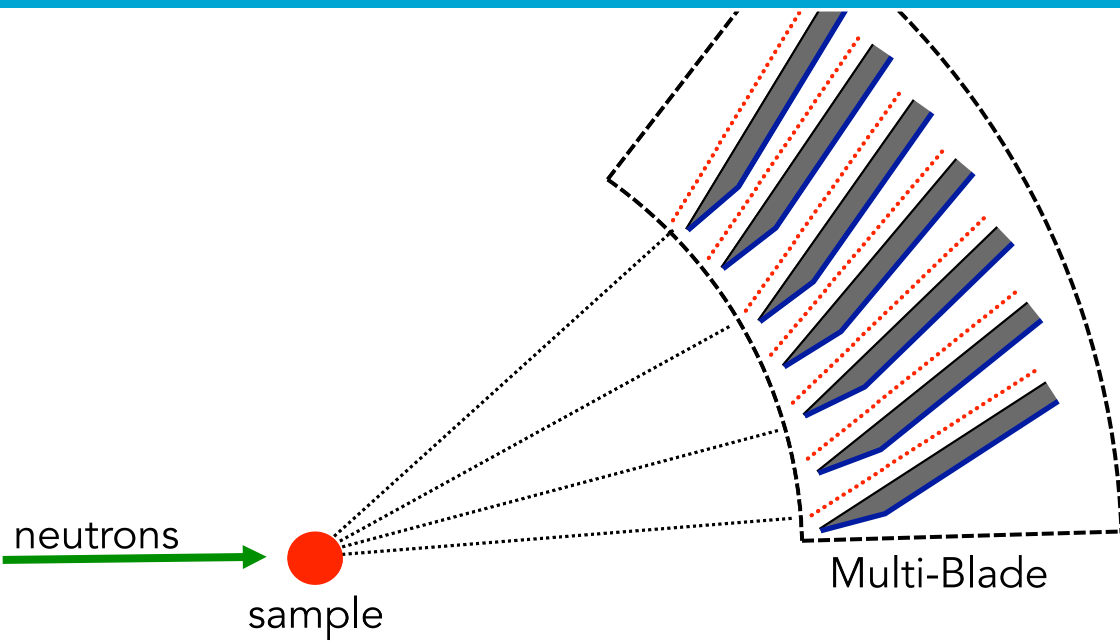
^{10}B technology



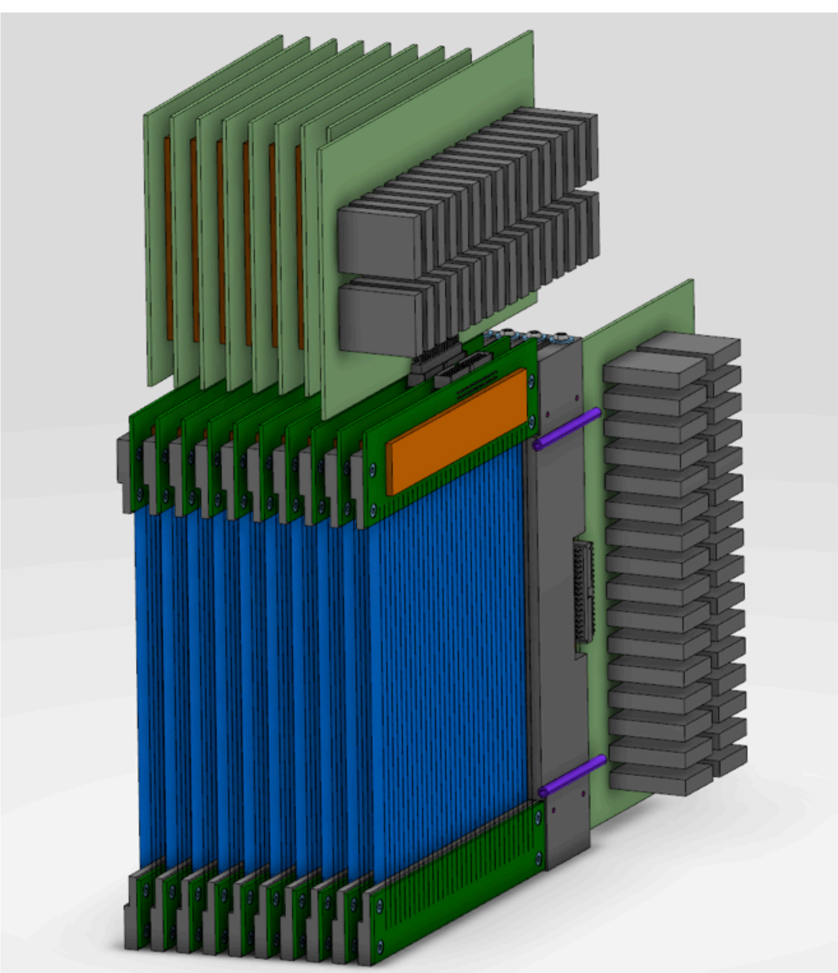
Multi-blade design:
- High rate capability
- Sum-mm resolution

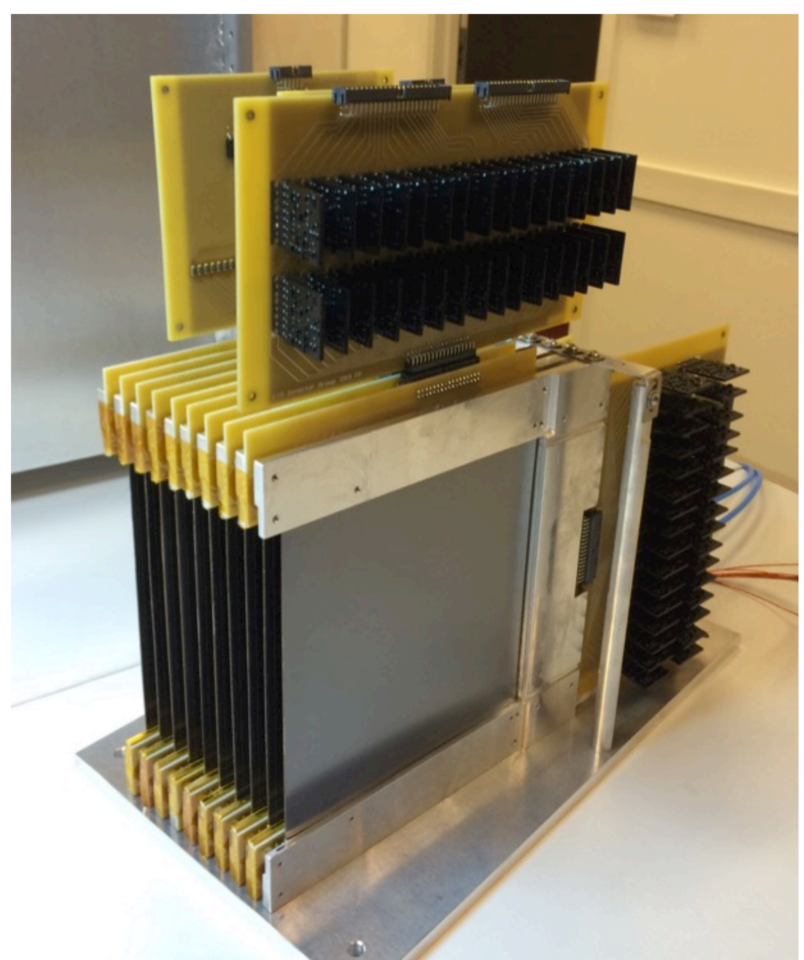


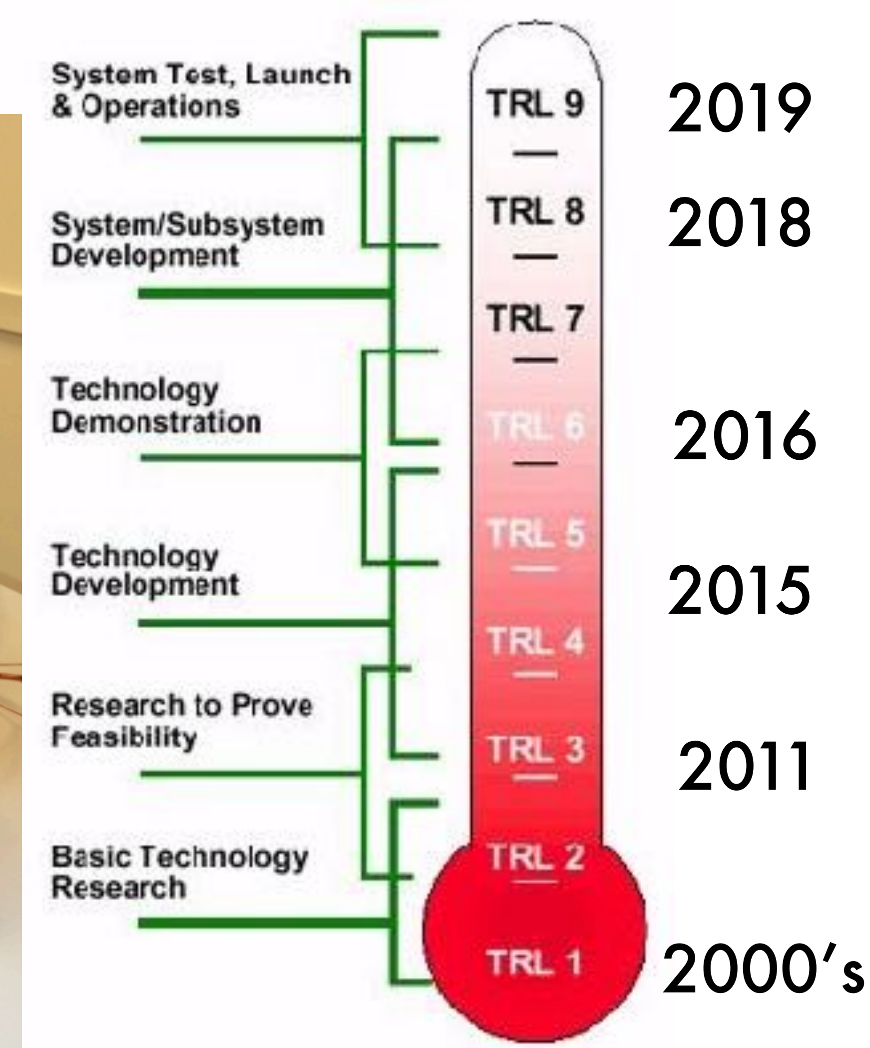
Multi-Blade Design



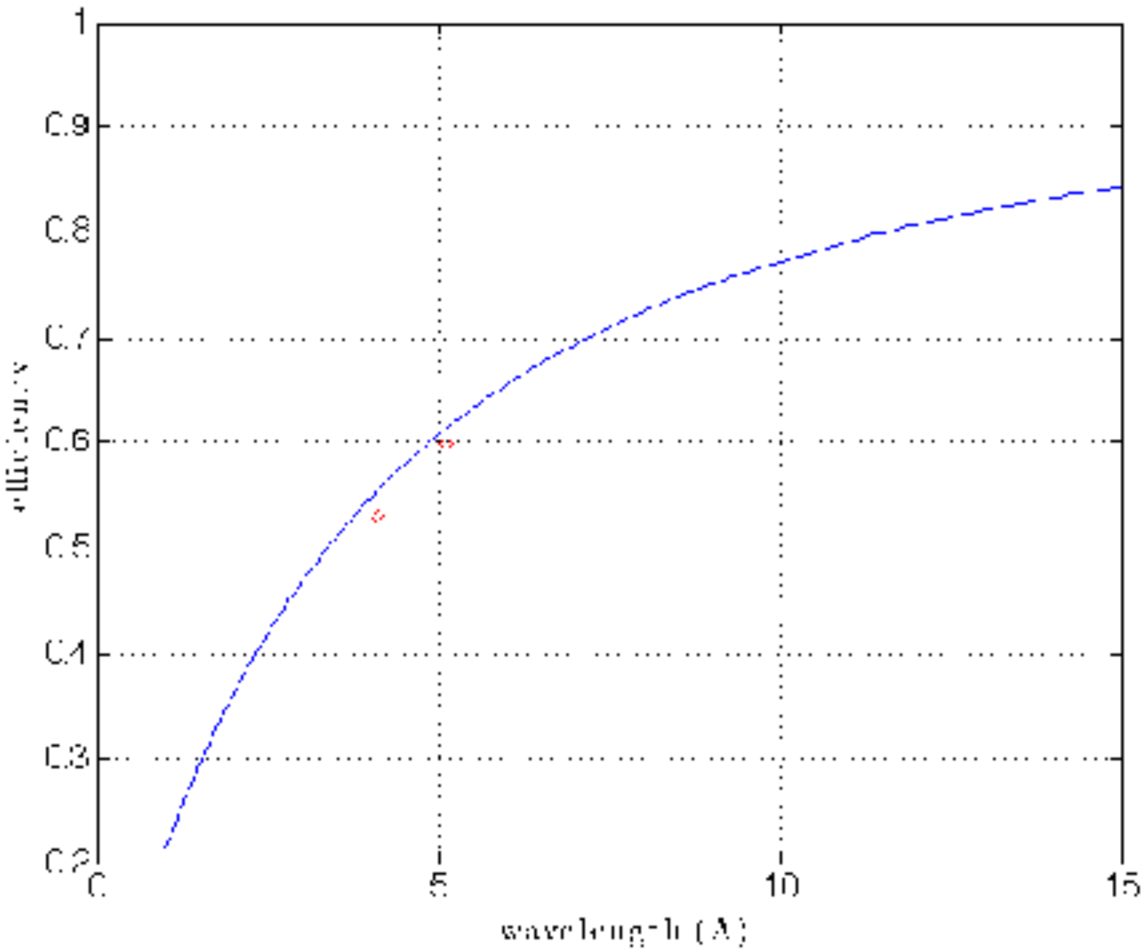
- Design simple: *"KISS"*
- Modular
- Cheap
- Make design available
-

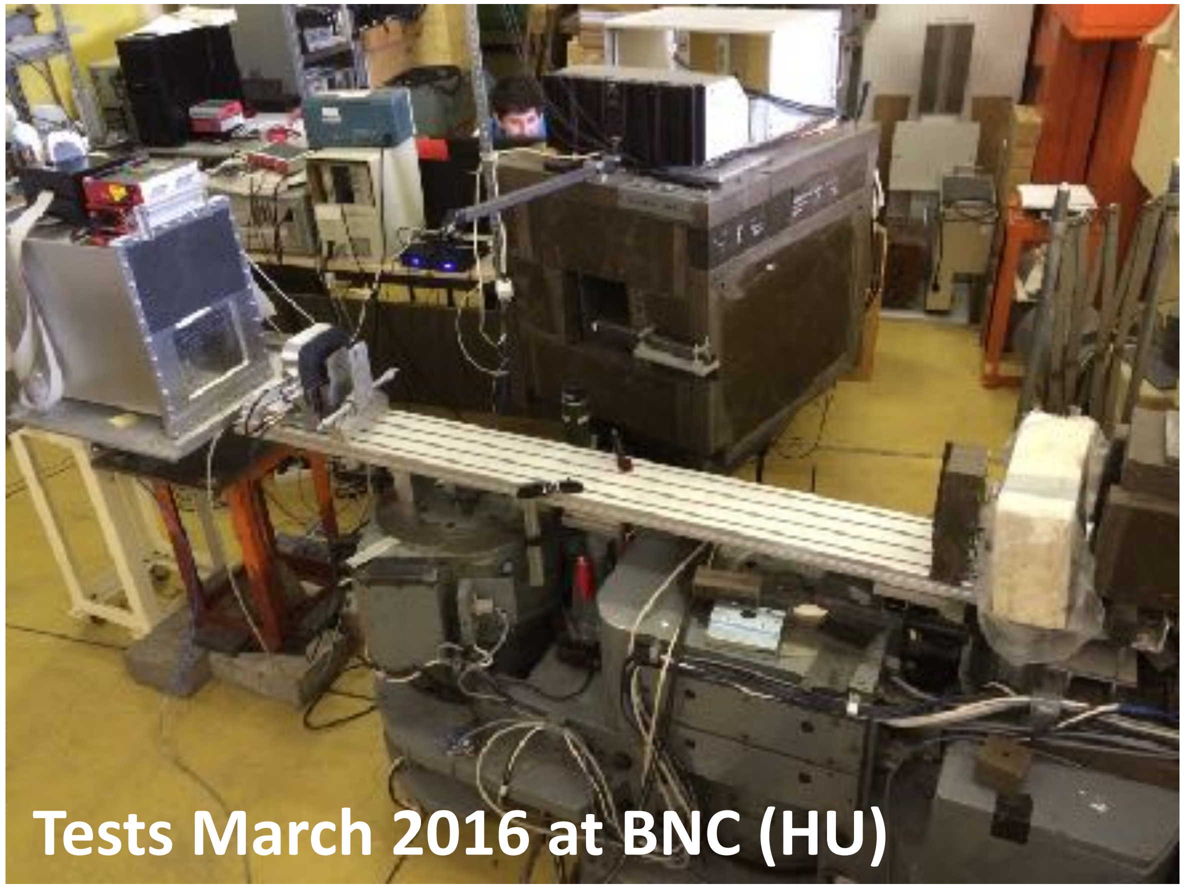




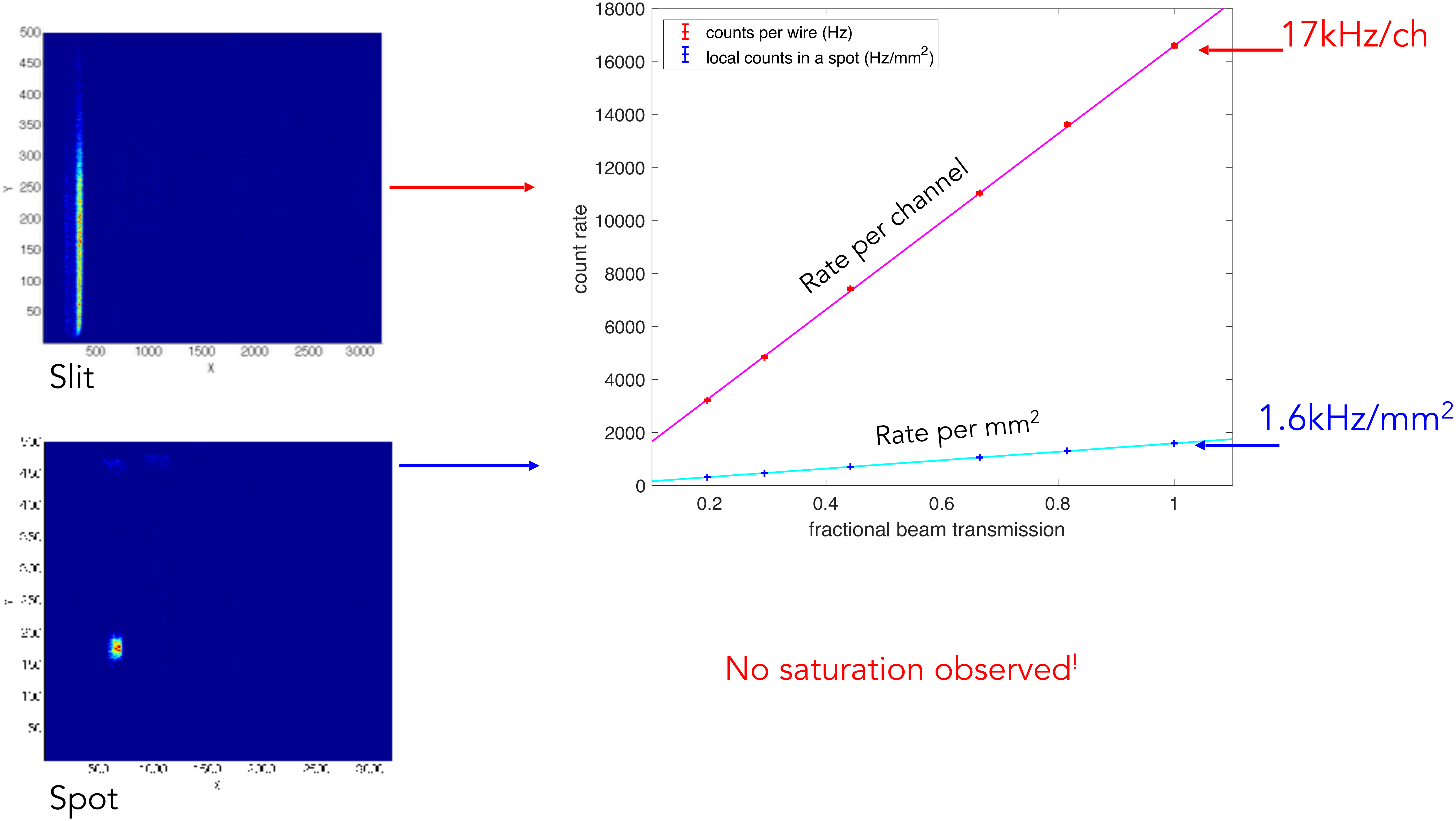


Multi-Blade Results





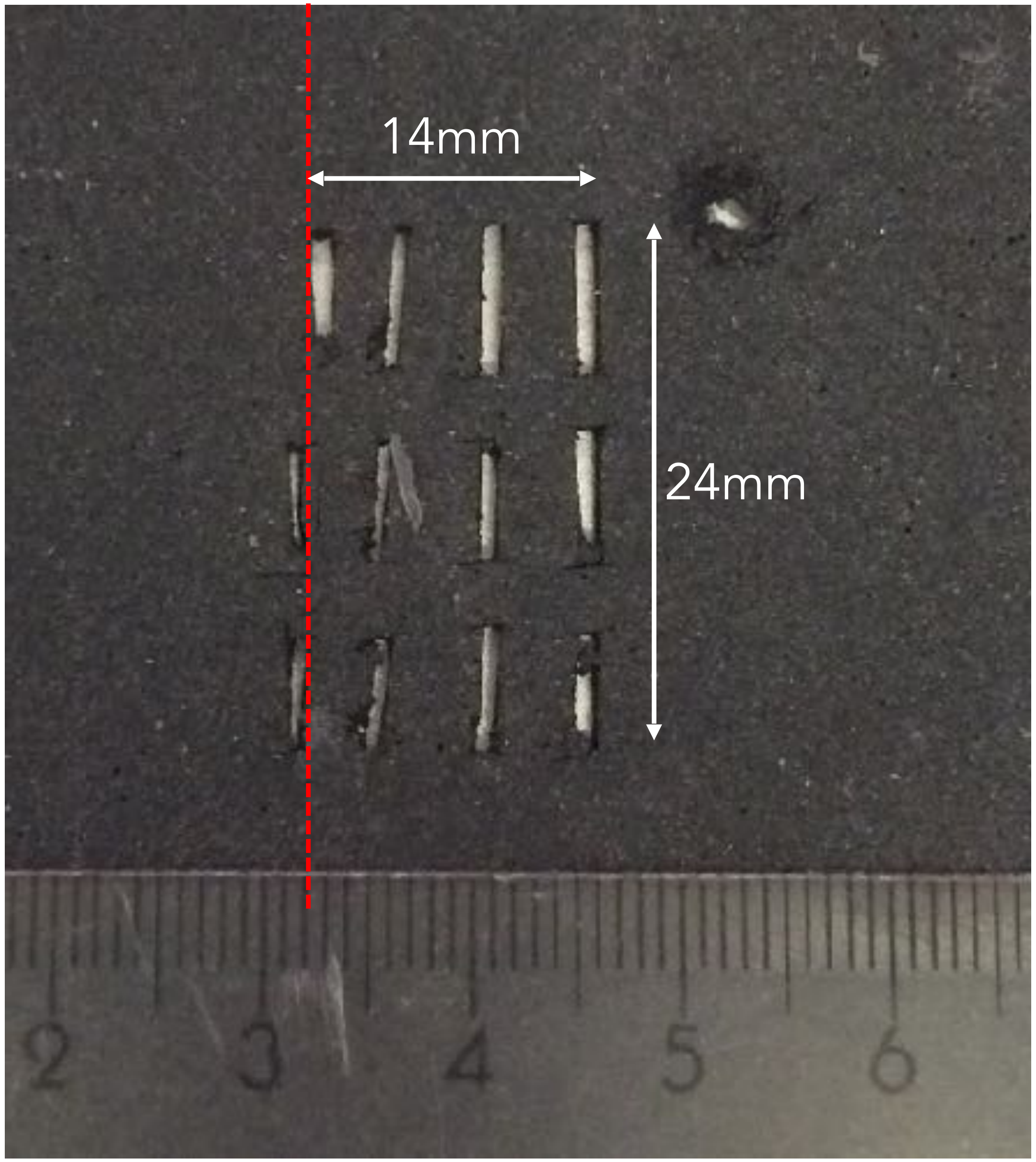
Counting rate capability



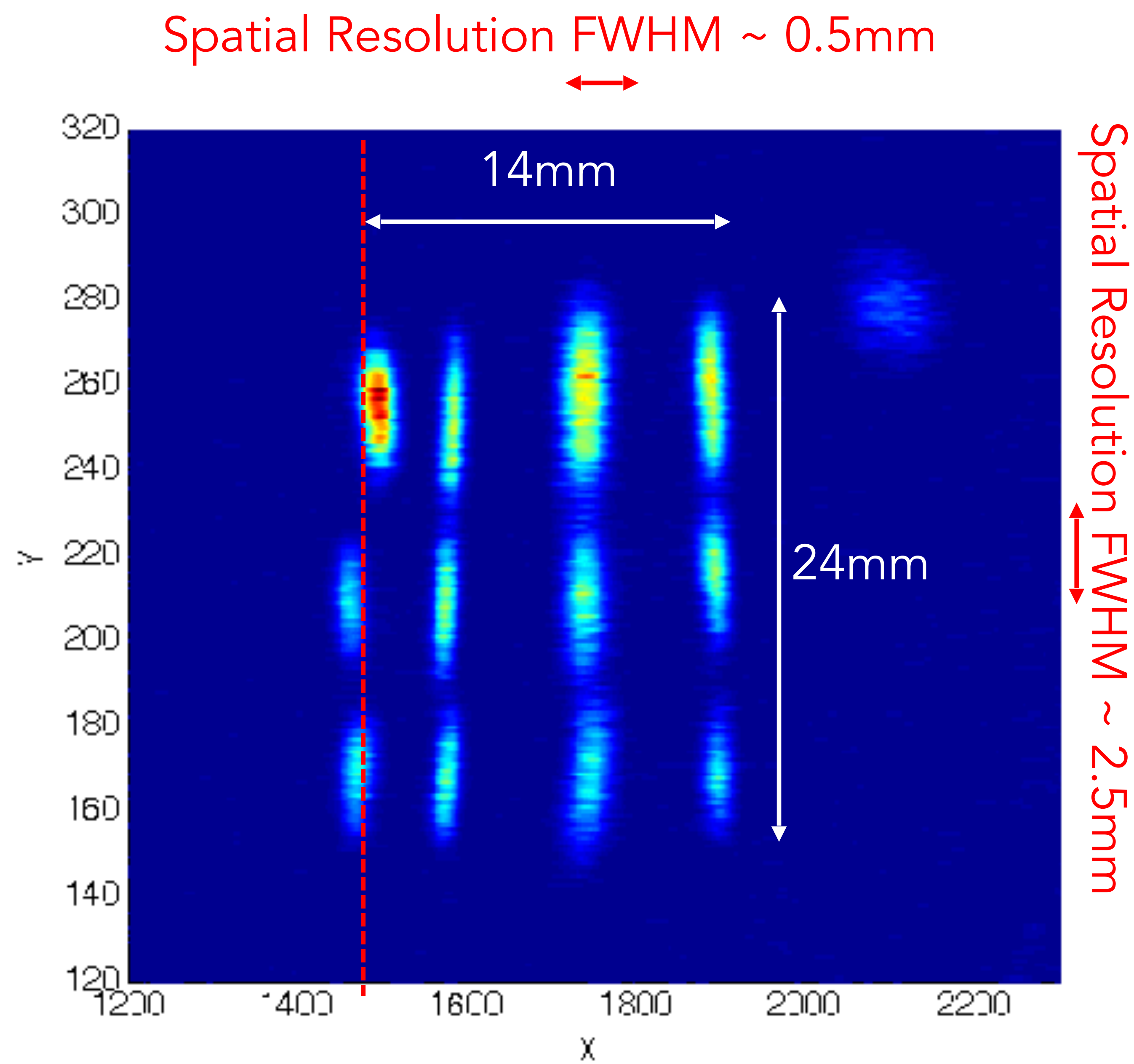
No saturation observed!

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

Images



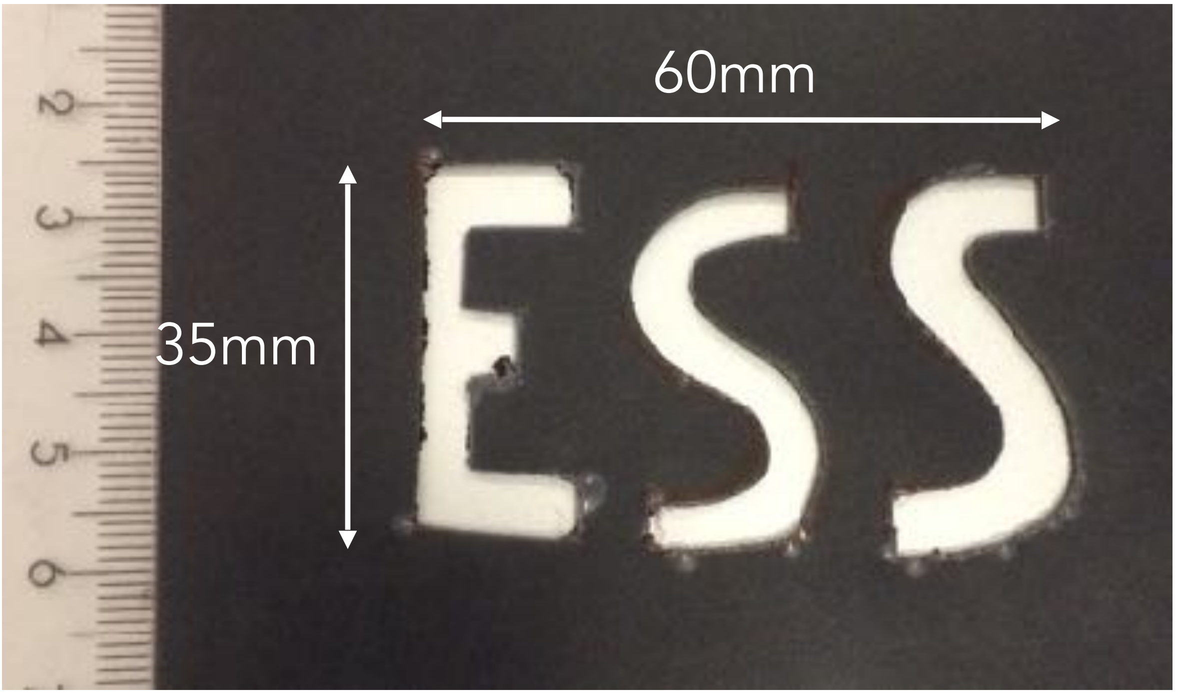
Mask

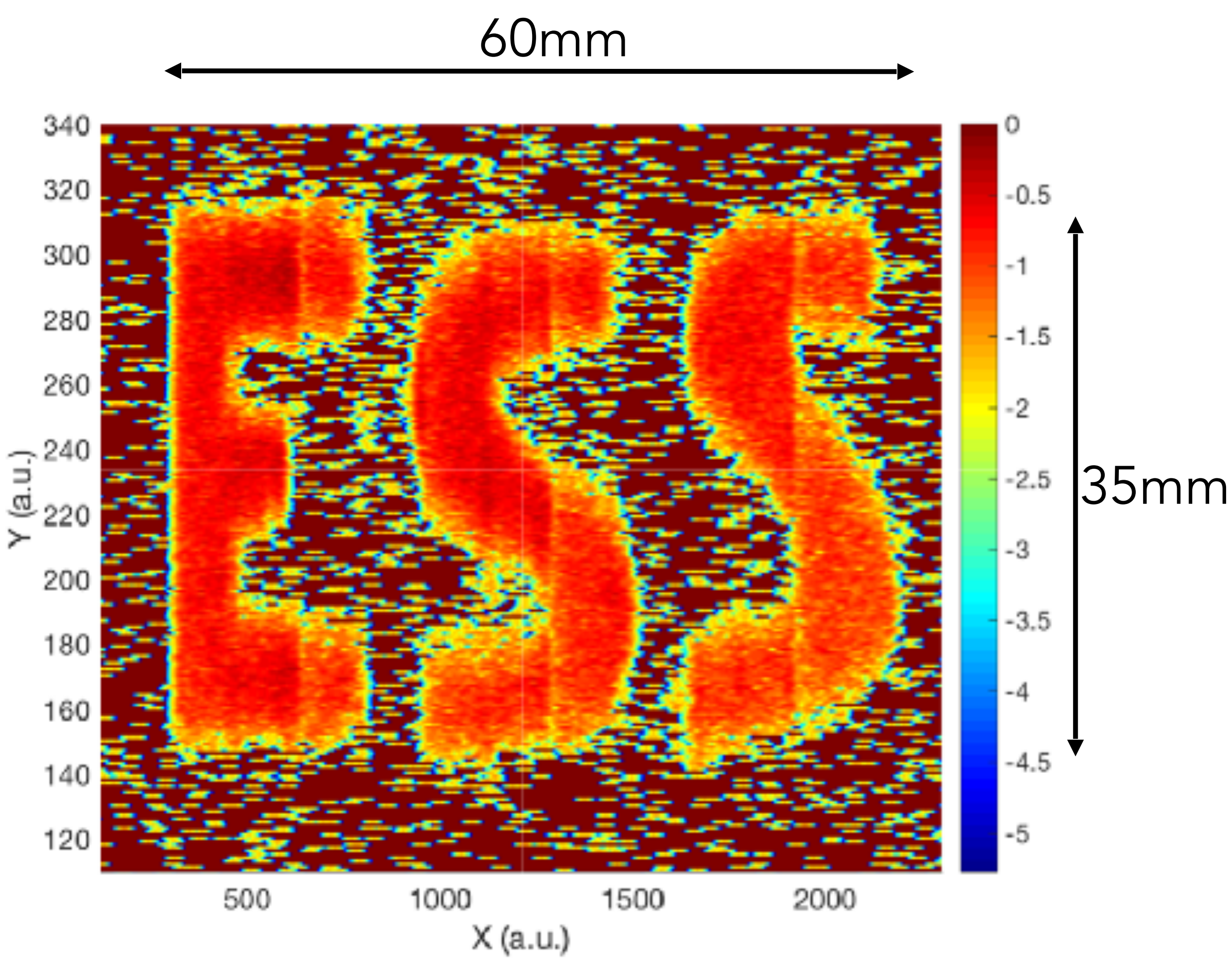


Raw image from the detector

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

Images





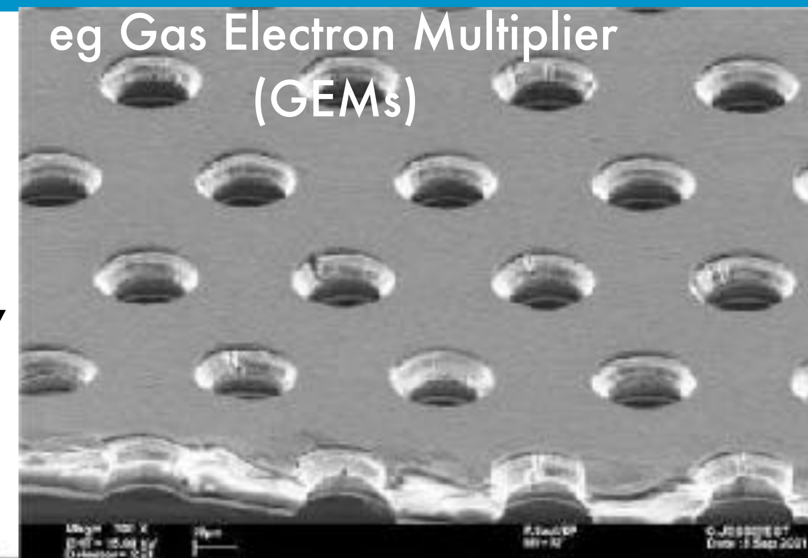
Mask

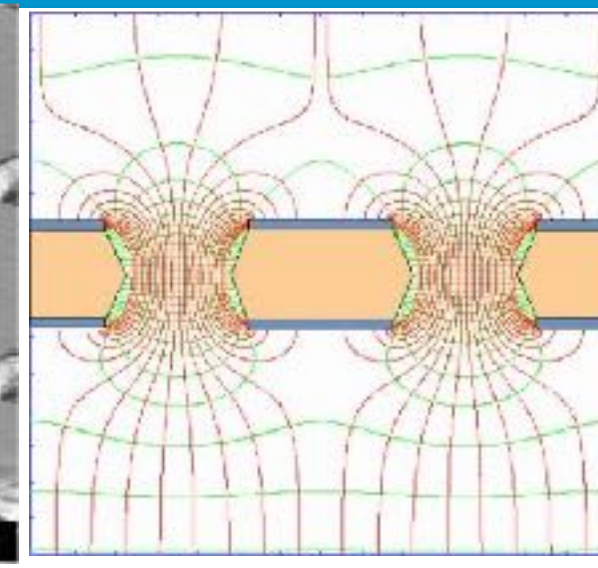
Raw image from the detector (log scale)

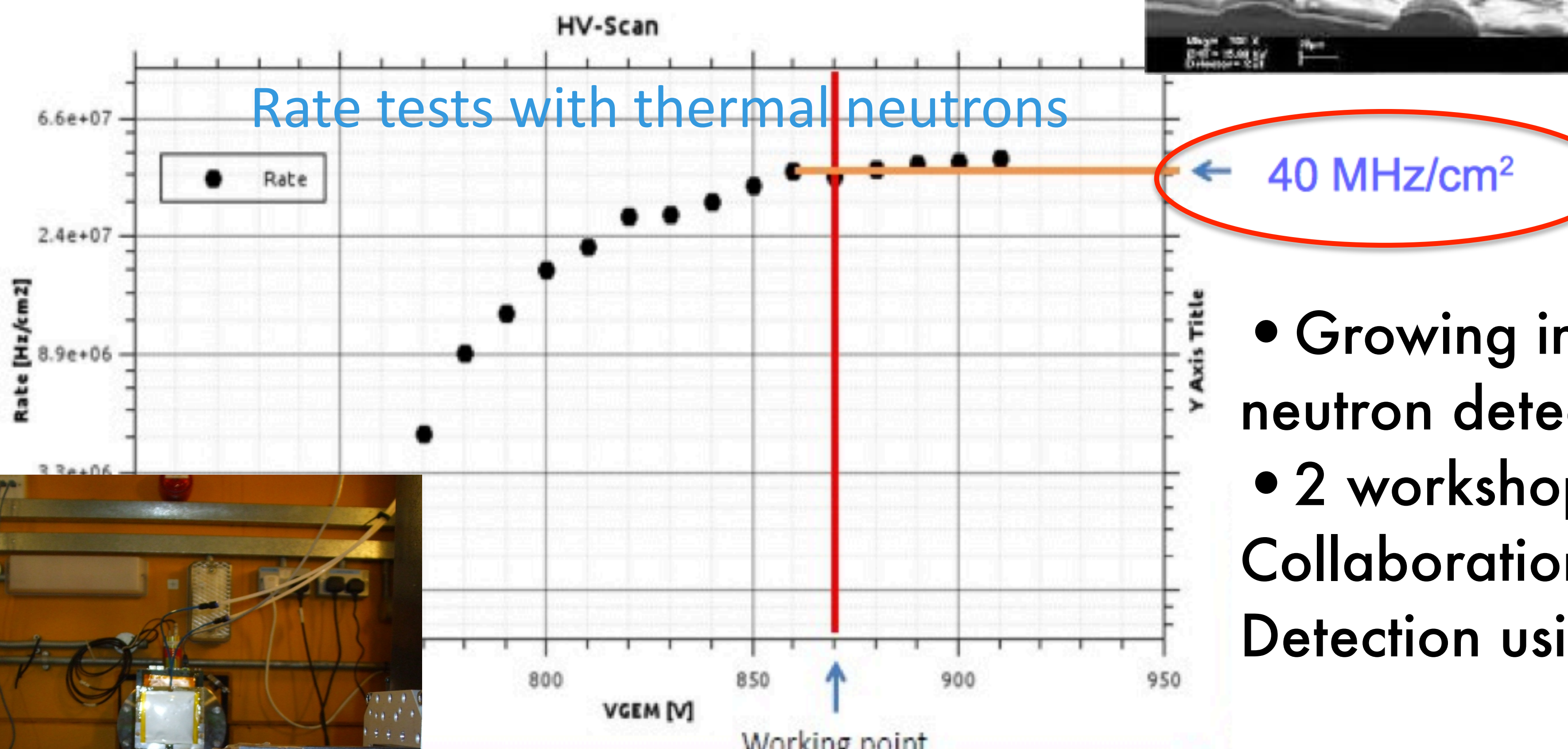
F. Piscitelli et al., The Multi-Blade Boron-10-based Neutron Detector for high intensity Neutron Reflectometry at ESS, JINST 12 (3) P03013 (2017).

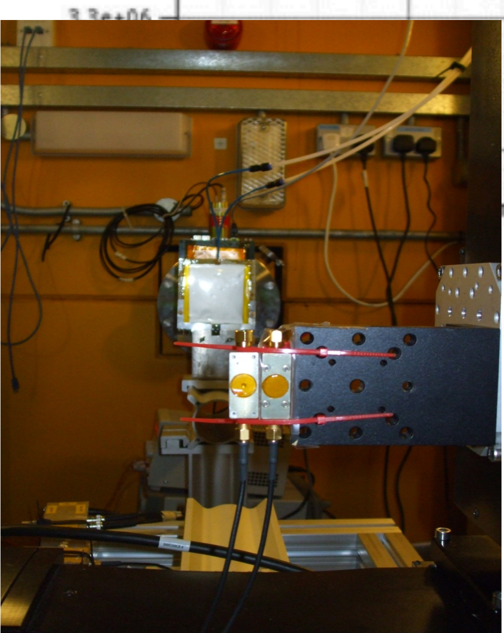
Micropattern Gaseous Detectors

- Field started by A Oed at the ILL with the micro-strip gas chamber (MSGC) in 1988
- Now widespread: many variants
- Potentially very good resolution and very high rate capability









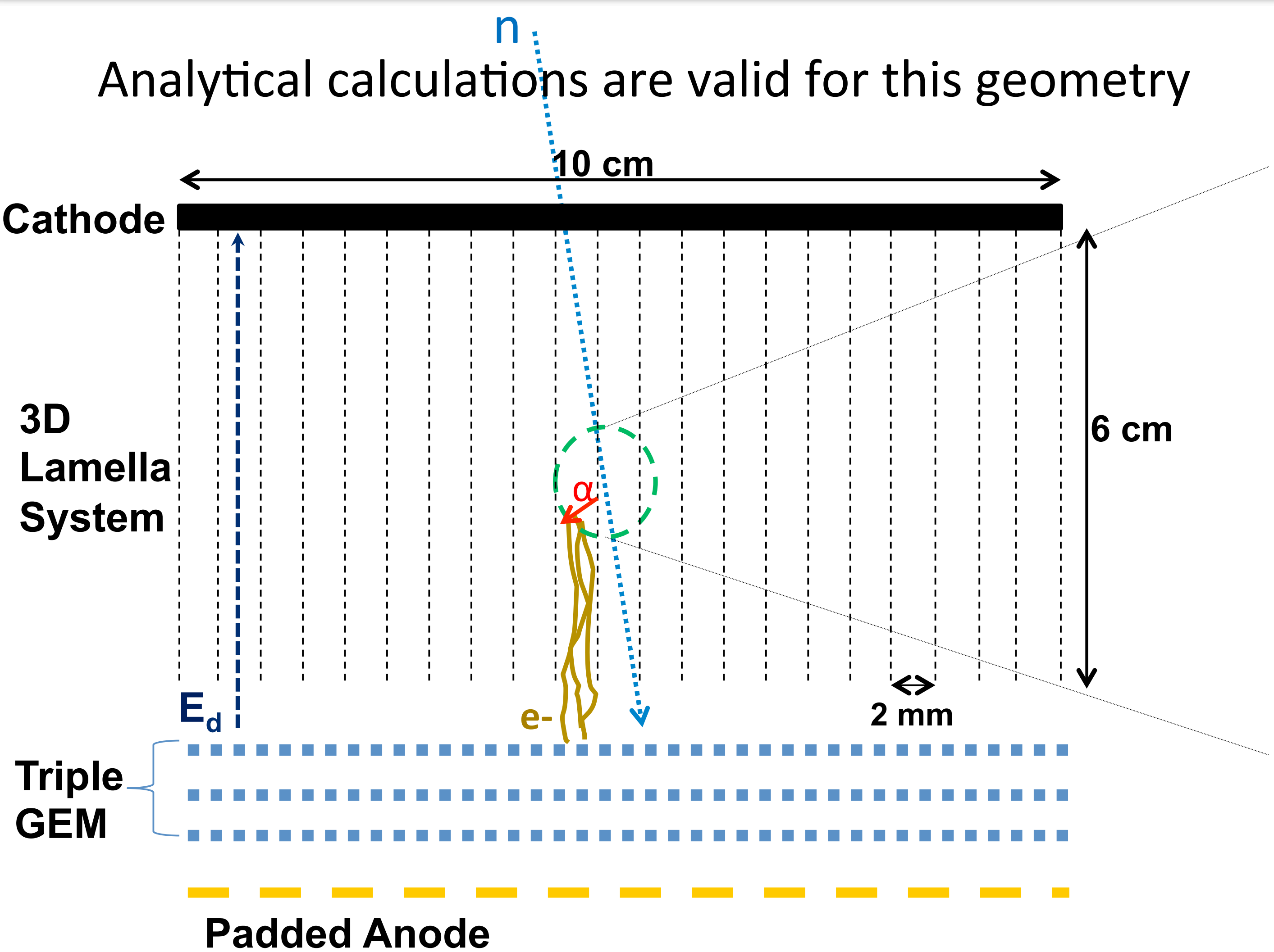
- Growing interest for applications for neutron detection
- 2 workshops organised by CERN RD51 Collaboration (with HEPTECH) on Neutron Detection using MPGDs

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

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

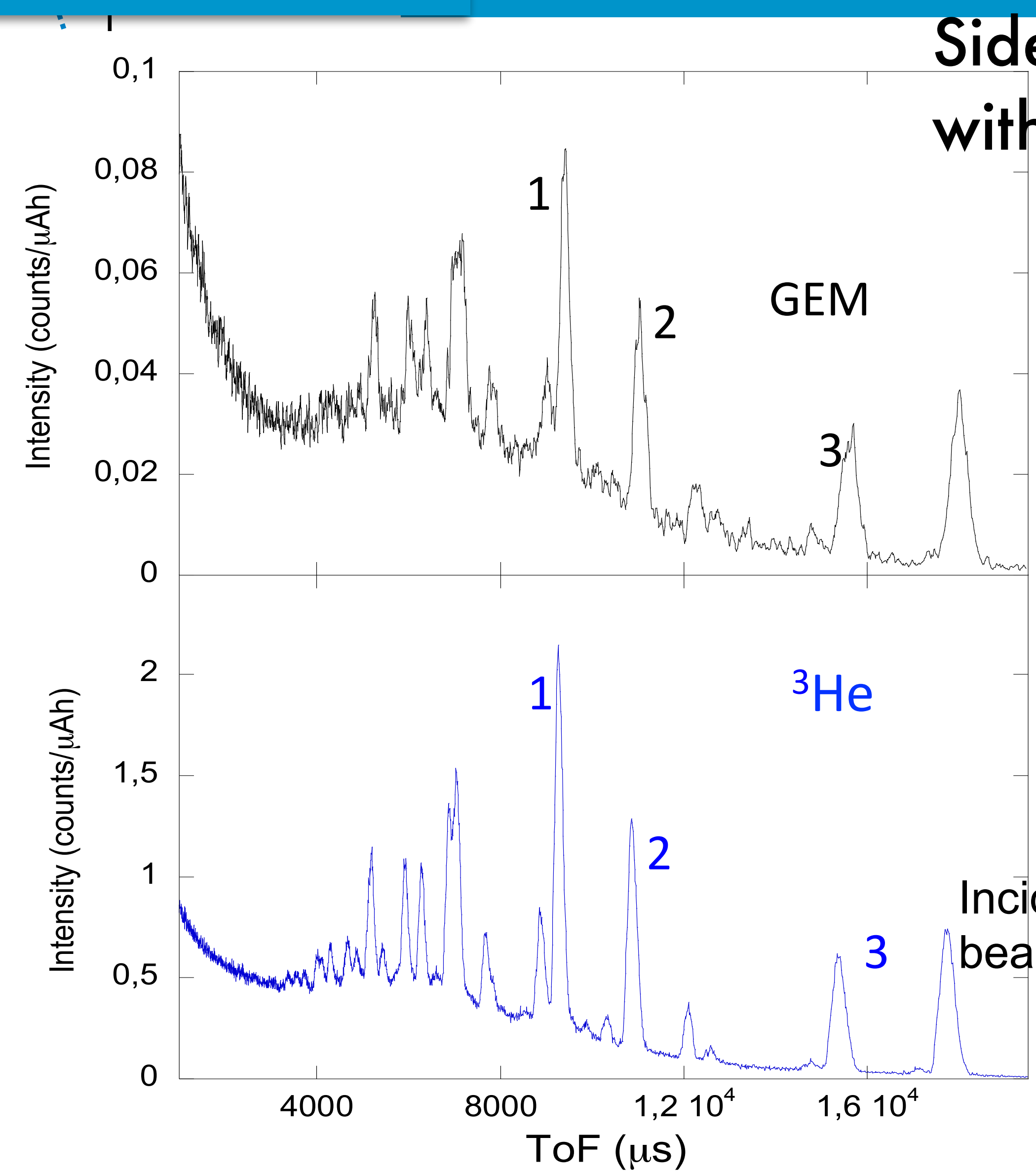
BANDGEM Detector

Analytical calculations are valid for this geometry

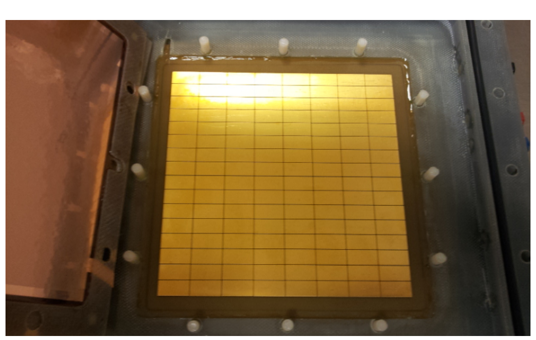


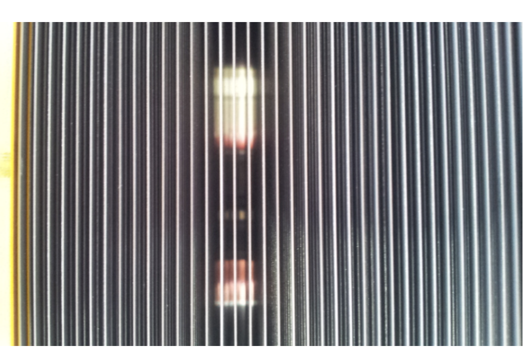
Alumina lamellae coated on both sides with $^{10}B_4C$

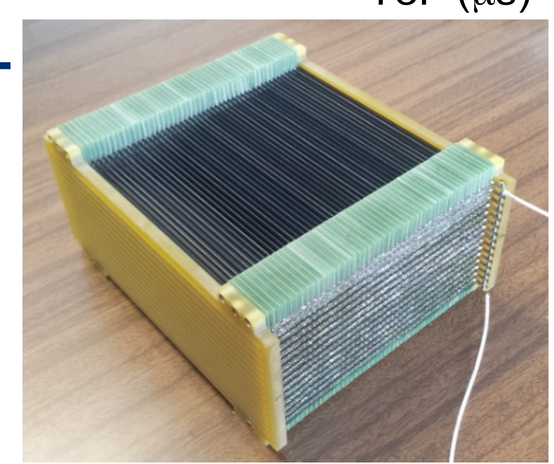
Side-by-side with He-3

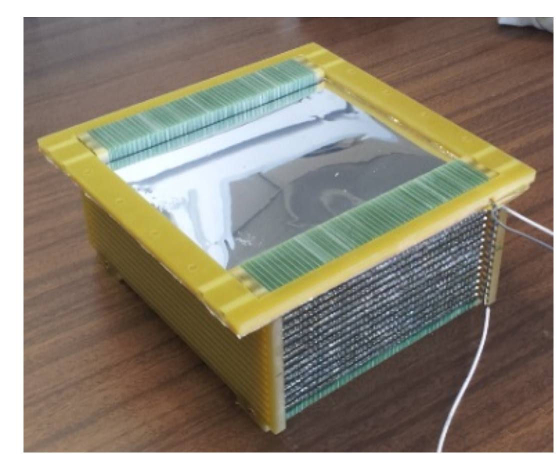


Using low θ values (few degs) the path of the neutron inside tl
B_4C is increased → Higher efficiency when detector is inclined









Neutron Macromolecular Crystallography

Bovine heart

cytochrome c oxidase

$P2_12_12_1$

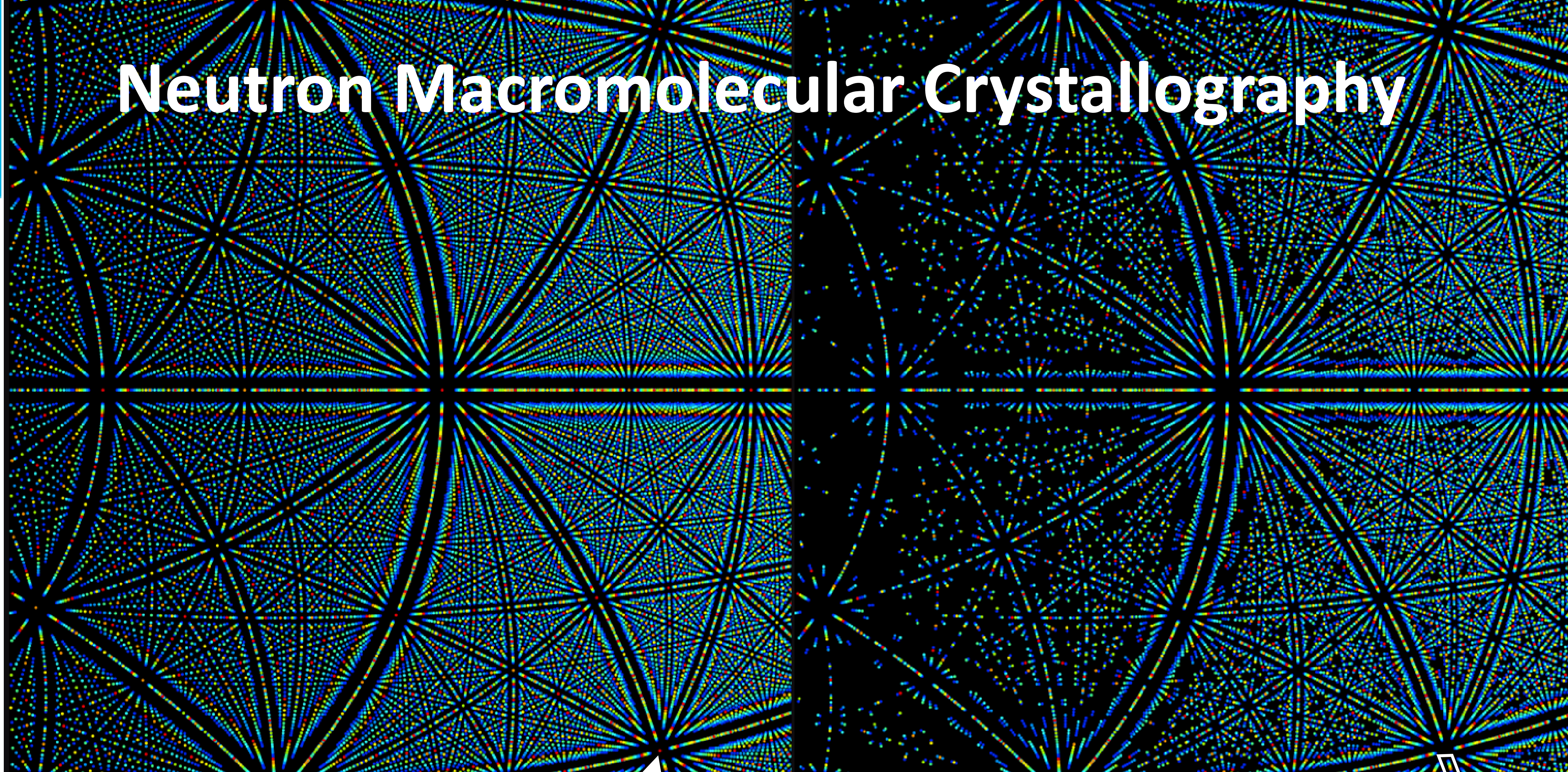
a = 182.59 Å

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)

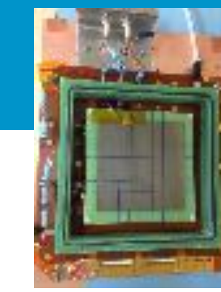
1.800 to 2.019 Angstroms
2.019 to 2.237 Angstroms
2.237 to 2.456 Angstroms
2.456 to 2.675 Angstroms
2.675 to 2.894 Angstroms
2.894 to 3.112 Angstroms
3.112 to 3.331 Angstroms
3.331 to 3.550 Angstroms

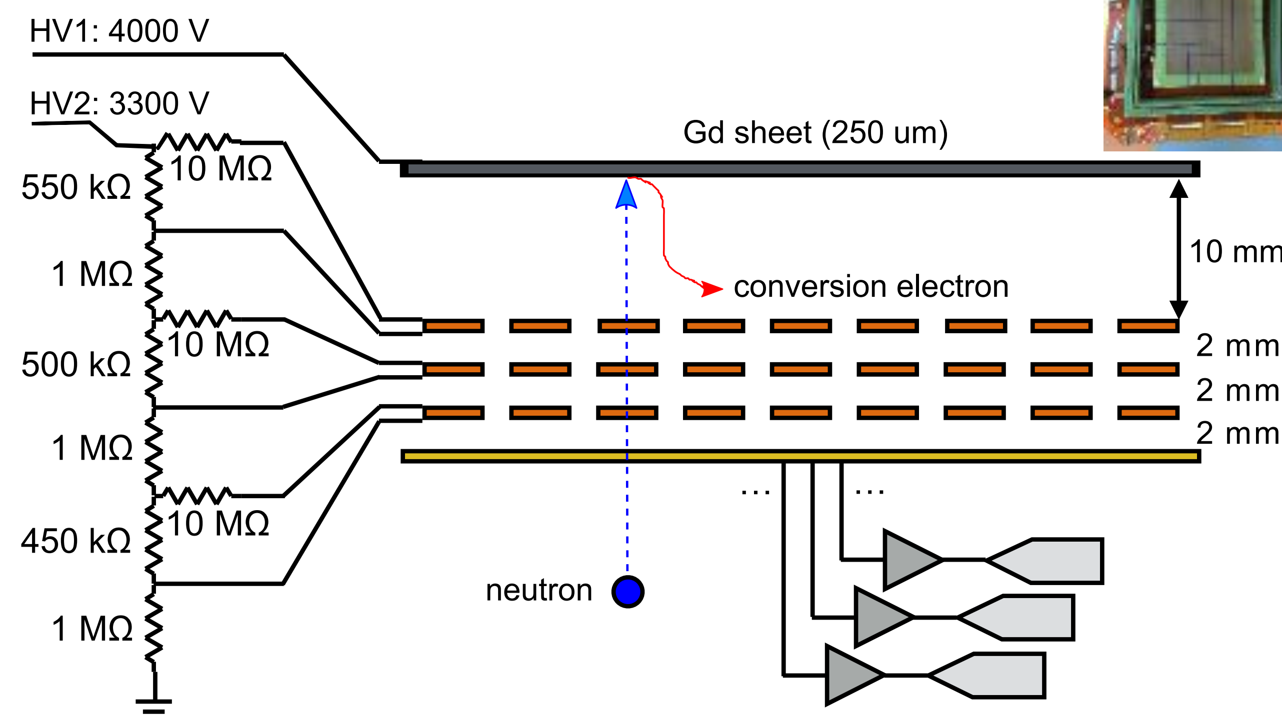
Generated using the Daresbury Laue Suite

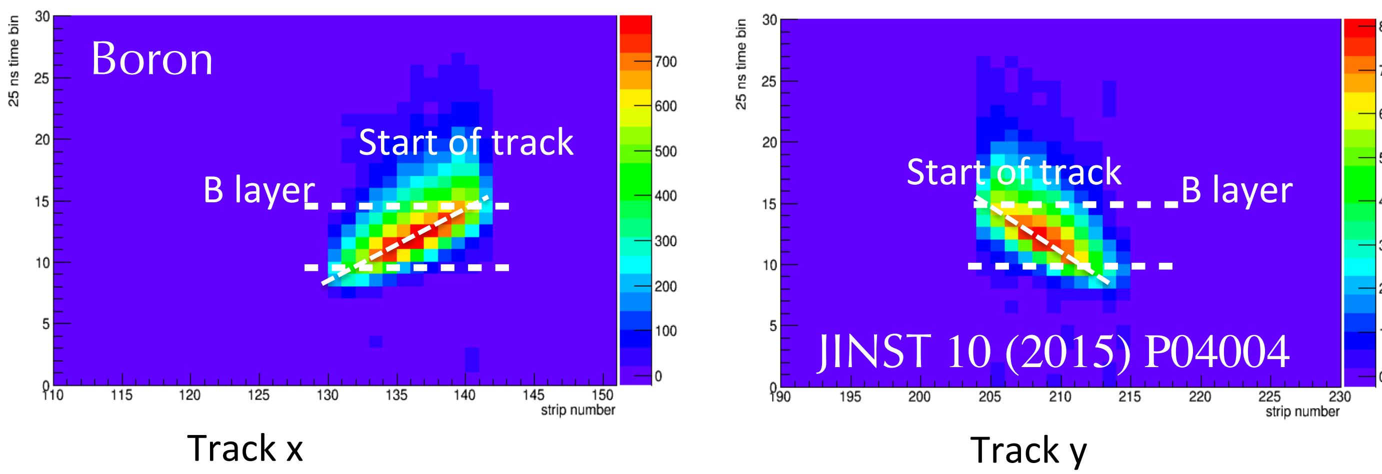
Campbell et al. J. Appl. Cryst. (1998). 31, 496-502
Artz et al. J. Appl. Cryst. (1999). 32, 554-562
Helliwell, J.R. et al. J. Appl. Cryst. (1989) 22, 483–497

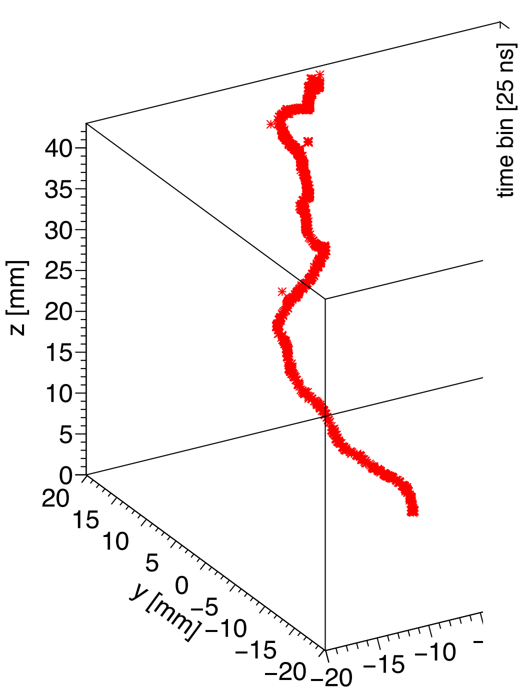
Gd-GEM

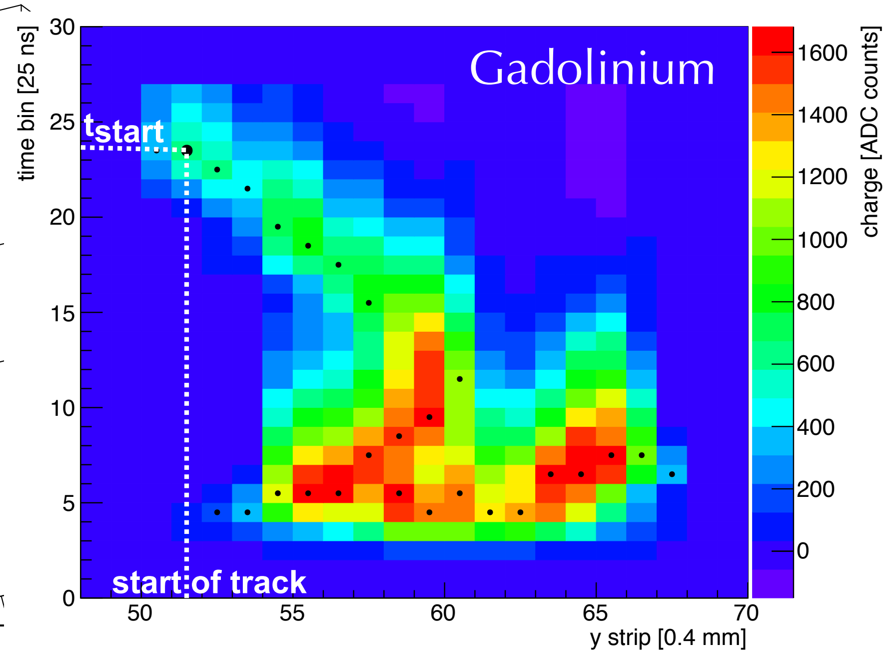
- NMX: <<1mm position resolution requirement, Time Resolved, ca. 1m^2 detector area
- Take Micro Time Projection Chamber concept from ATLAS experiment upgrade
- Resolution: use single layer Gd, look for electrons

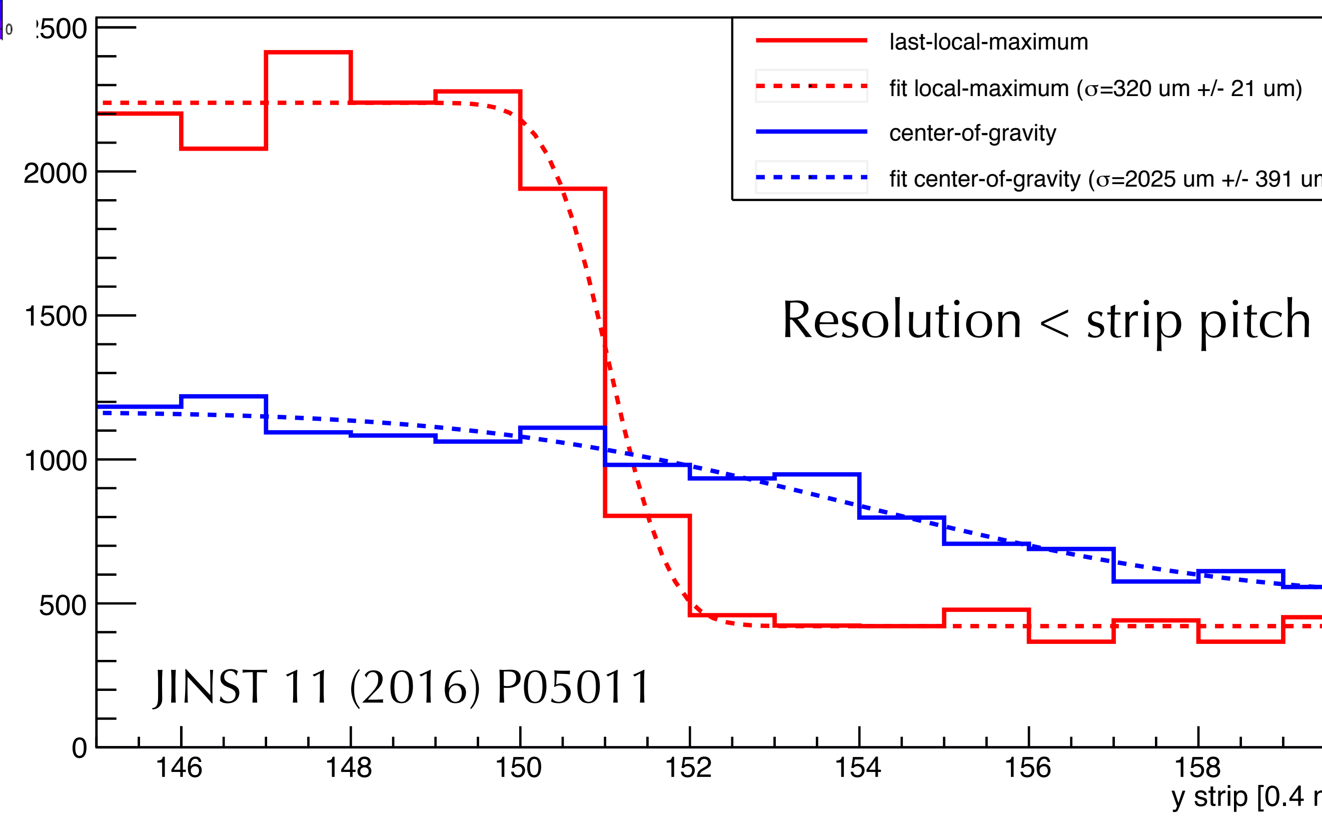








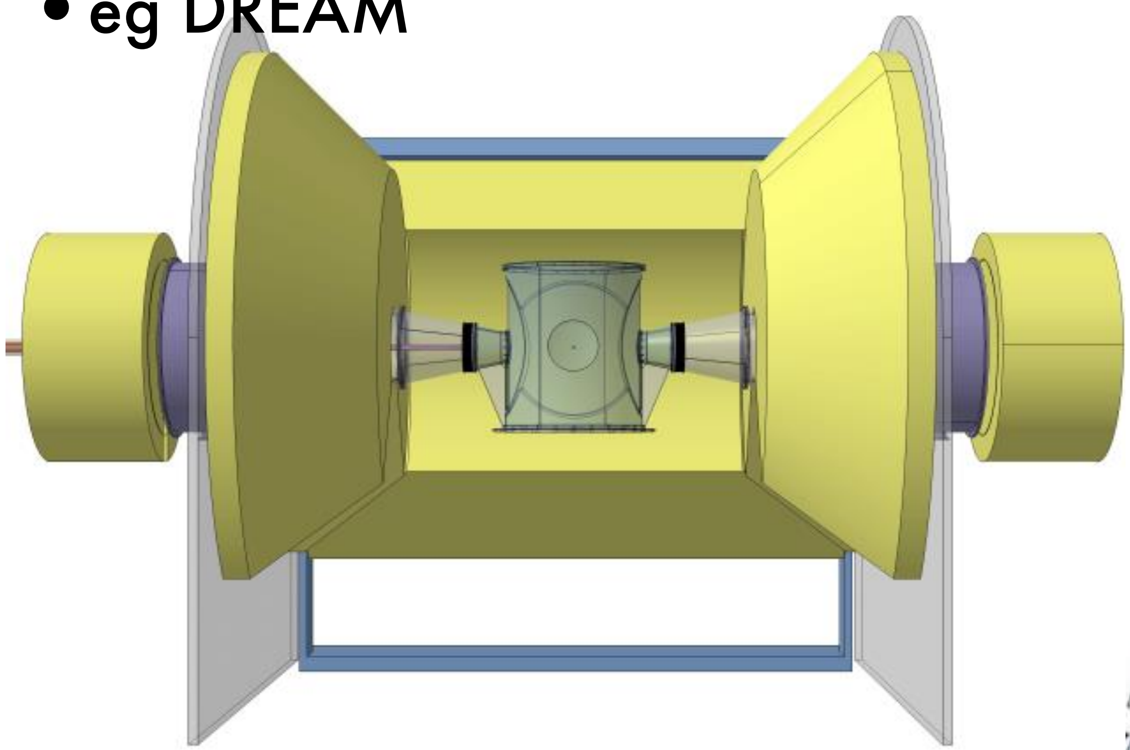




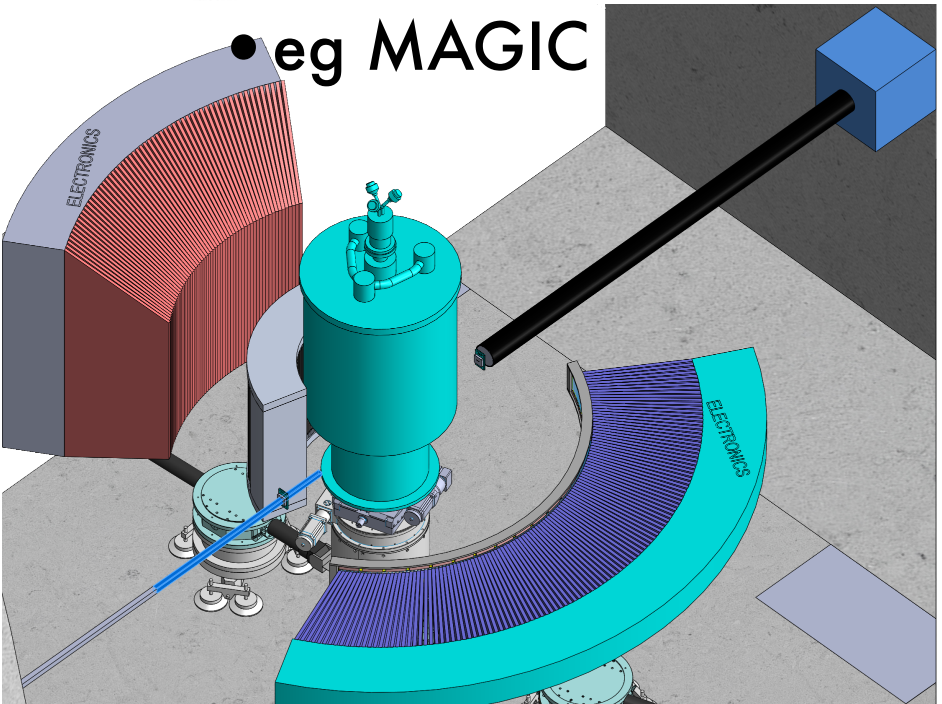
Instruments: DREAM, MAGIC, HEIMDAL

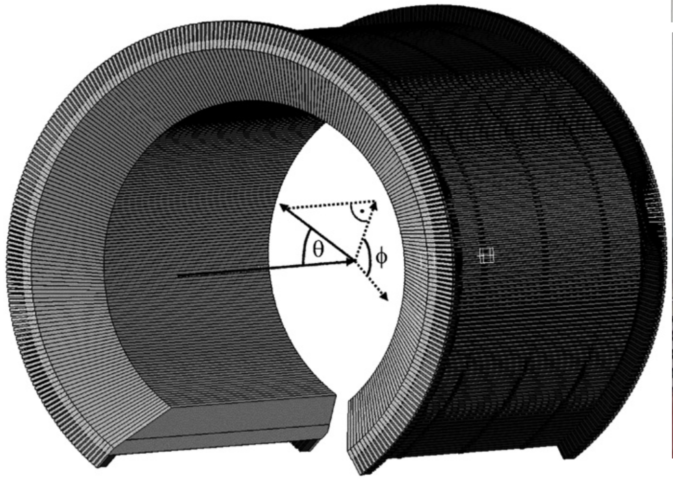
Diffractometers: Jalousie-like design

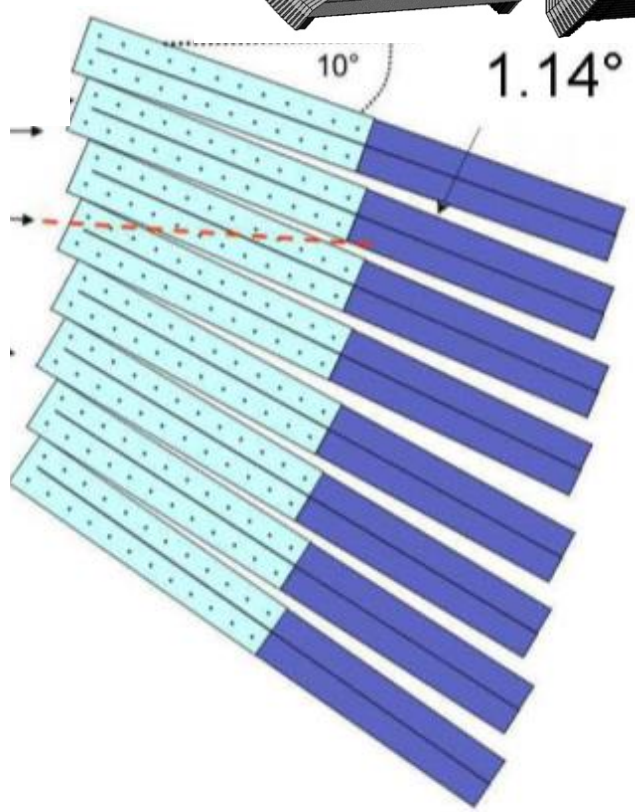
- Inclined angle B-10 detectors, angled at sample
- (CDT Heidelburg)
- eg DREAM

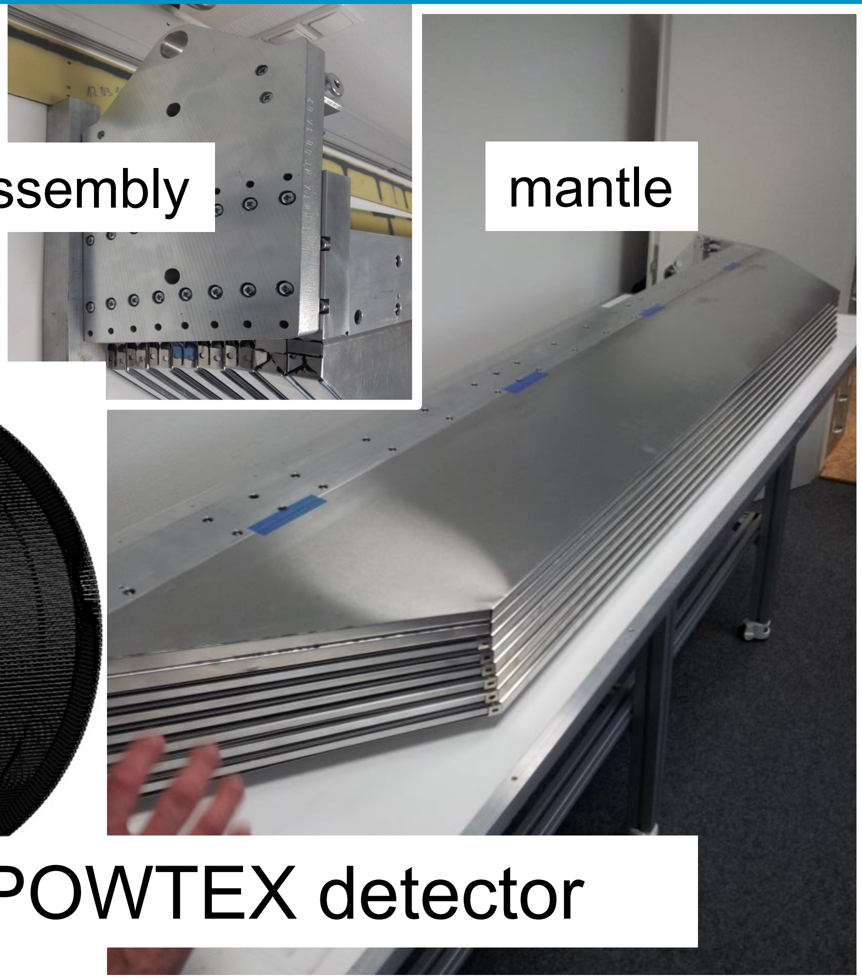


- eg MAGIC

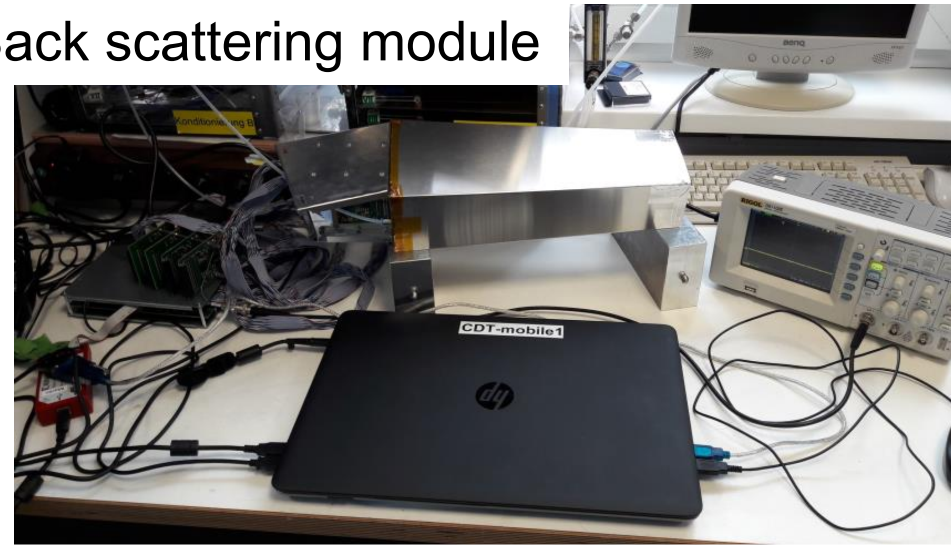








Back scattering module



Detectors for ESS: strategy update for 16 instruments

Instrument class	**Instrument sub-class**	**Instrument**	**Key requirements for detectors**	**Preferred detector technology**	**Ongoing developments (funding source)**
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 BrightnESS)
Engineering	Strain scanning	BEER	Pixel size, count-rate	10B-based	AmCLD, A1CLD
	Imaging and tomography	ODIN	Pixel size	Scintillators, MCP, wire chambers	
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
		VESPA	Count-rate	3He-based	He-3 PSD Tubes
SPIN-ECHO	Spin-echo	tbd	tbd	3He-based/10B-based	

arXiv:1411.6194

Good dialogue and close collaboration needed for successful delivery and integration

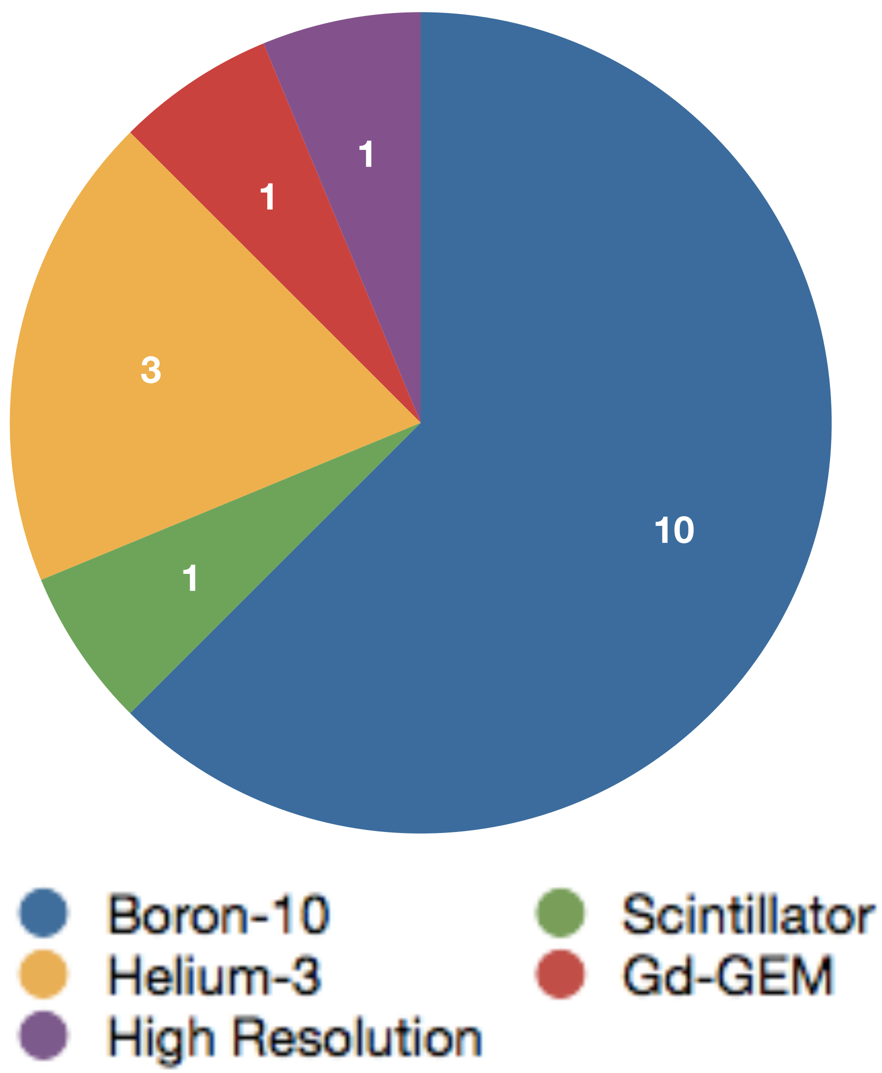
Detector Baseline for Early Instruments (2017)

Instrument	Installation Start (est.)	Lead Institute	Main Detector Technology	Main Detector Developer	Front End Readout	FE Readout Developer	Integration Model
LOKI	Q1 2019	ISIS	BandGEM	Milan	Gemma/Gemini	Milan/INFN	B/X
			B10 Straws	ISIS (PT Inc)	VMM	ISIS/STFC/ESS	A
NMX	Q1 2019	ESS	Gd-GEM	CERN/ESS (BrightnESS)	VMM	CERN/ESS (BrightnESS)	A/X
ODIN	Q3 2019	TUM/PSI	MCP, Silicon, etc	Lots	Lots	Lots	X/XX
BEER	Q4 2019	HZG/NPI	A1CLD, AmCLD	HZG/DENEX	Delay Line	HZG/DENEX	Probably C
SKADI	Q4 2019	FZJ/LLB	SoNDE Pix Scinit	SoNDE	IDEAS ASIC	SoNDE	Probably B
DREAM	Q4 2019	FZJ	Jalouise	Julich/CDT	CIPix	CDT	B/C
ESTIA	Q1 2020	PSI/ESS/LU/HU	Multi-Blade	Wigner/ESS (BrightnESS)	VMM	ESS Led (IK + BrightnESS)	A
C-SPEC	Q2 2020	ESS/TUM/LLB	Multi-Grid	ILL/CERN (BrightnESS)	VMM	ESS Led (IK + BrightnESS)	A
CAMEA/BIFROST	Q1 2021	DTU	He3 Tubes	Commercial	Commercial?	Commercial?	Probably X/XX
HEIMDAL	Q1 2021	PSI/DK/NO	Jalouise	Julich/CDT	CIPix	CDT	B/C
FREIA	Q3 2021	ISIS	Multi-Blade	Wigner/ESS (BrightnESS)	VMM (MB)	ESS Led (IK+ BrightnESS)	A
T-REX	Q4 2021	ESS/FZJ	Multi-Grid	ILL/CERN (BrightnESS)	VMM	ESS Led (IK+ BrightnESS)	A
MAGIC	Q4 2021	FZJ/CDT/LLB	Jalouise	Julich/CDT	CIPix	CDT	B/C
MIRACLES	Q1 2022	ESS-B	He3 Tubes	Commercial	Commercial?	Commercial?	Probably X/XX
VESPA	Q3 2022	CNR	He3 Tubes	Commercial	Commercial?	Commercial?	Probably X/XX
VOR??	???	ESS/WIGNER	Multi-Grid	ILL/CERN (BrightnESS)	VMM	ESS Led (IK+ BrightnESS)	A

Preferred Detector Technologies for Baseline Suite

Detectors for ESS will comprise many different technologies

Best-Guess at Detector Technologies for 16 Instruments:



Summary

- 4 major new neutron sources coming online in next decade

- 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.
- 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