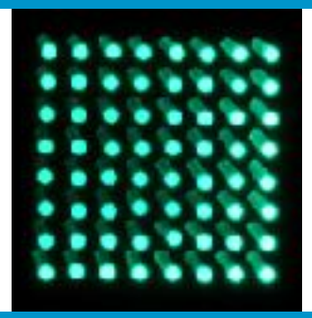
Neutron Detectors for the Initial Instrument Suite at the European Spallation Source

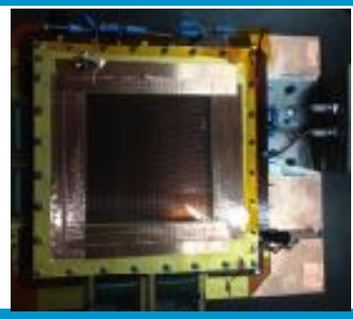
Richard Hall-Wilton

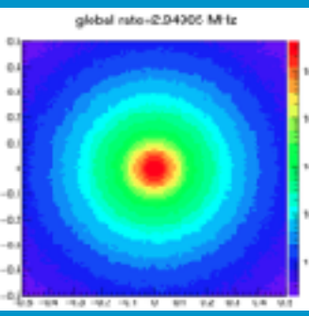
Leader of Detector Group
Deputy Division Head of Instrument Technologies

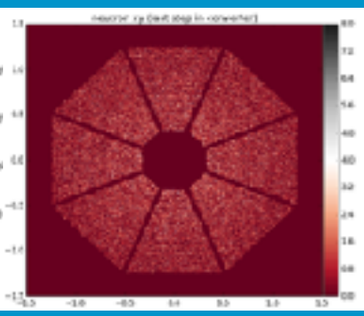
SINE2020: WP9 Instrumentation: Detectors RTD Meeting, PSI, CH 14 June 2017

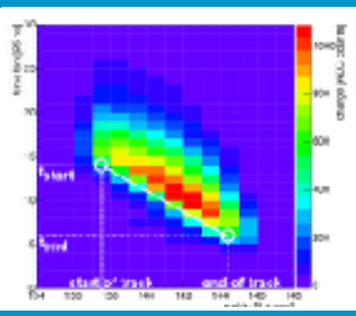
www.europeanspallationsource.se

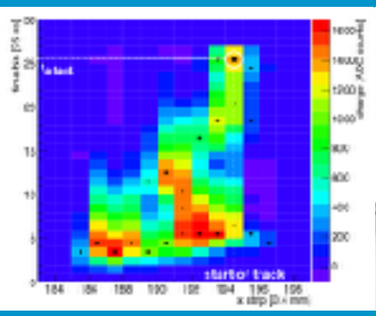


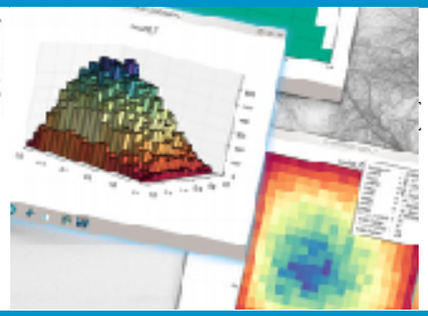


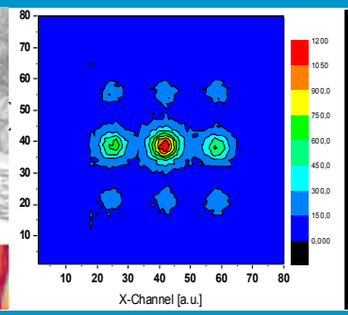


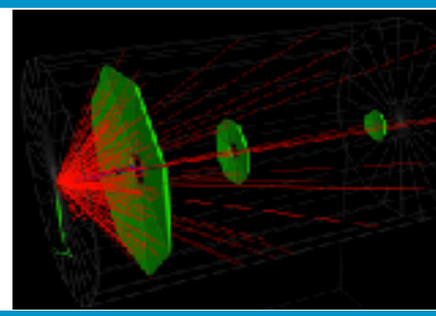












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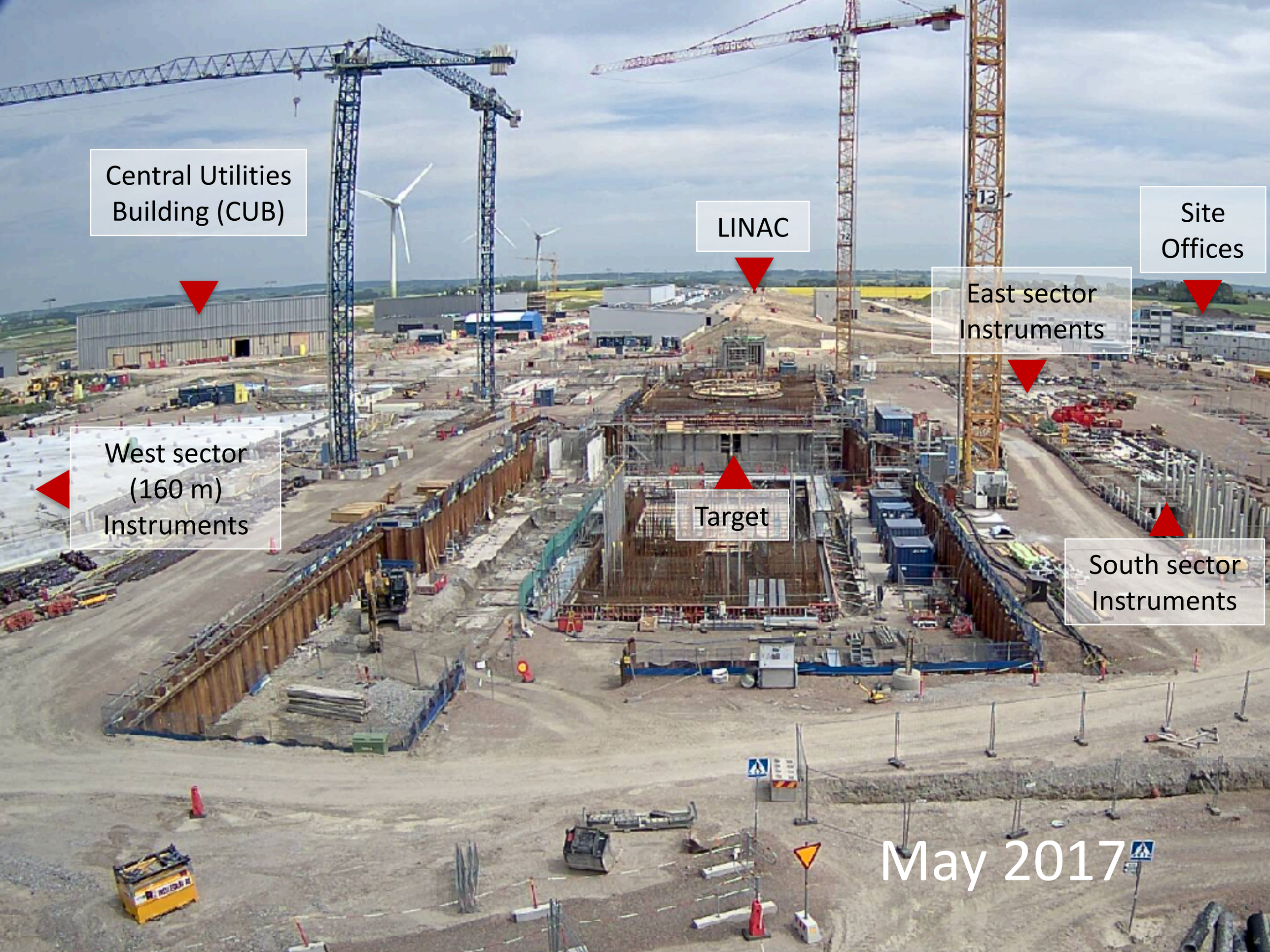
Update on Status of ESS

The ESS site
2011

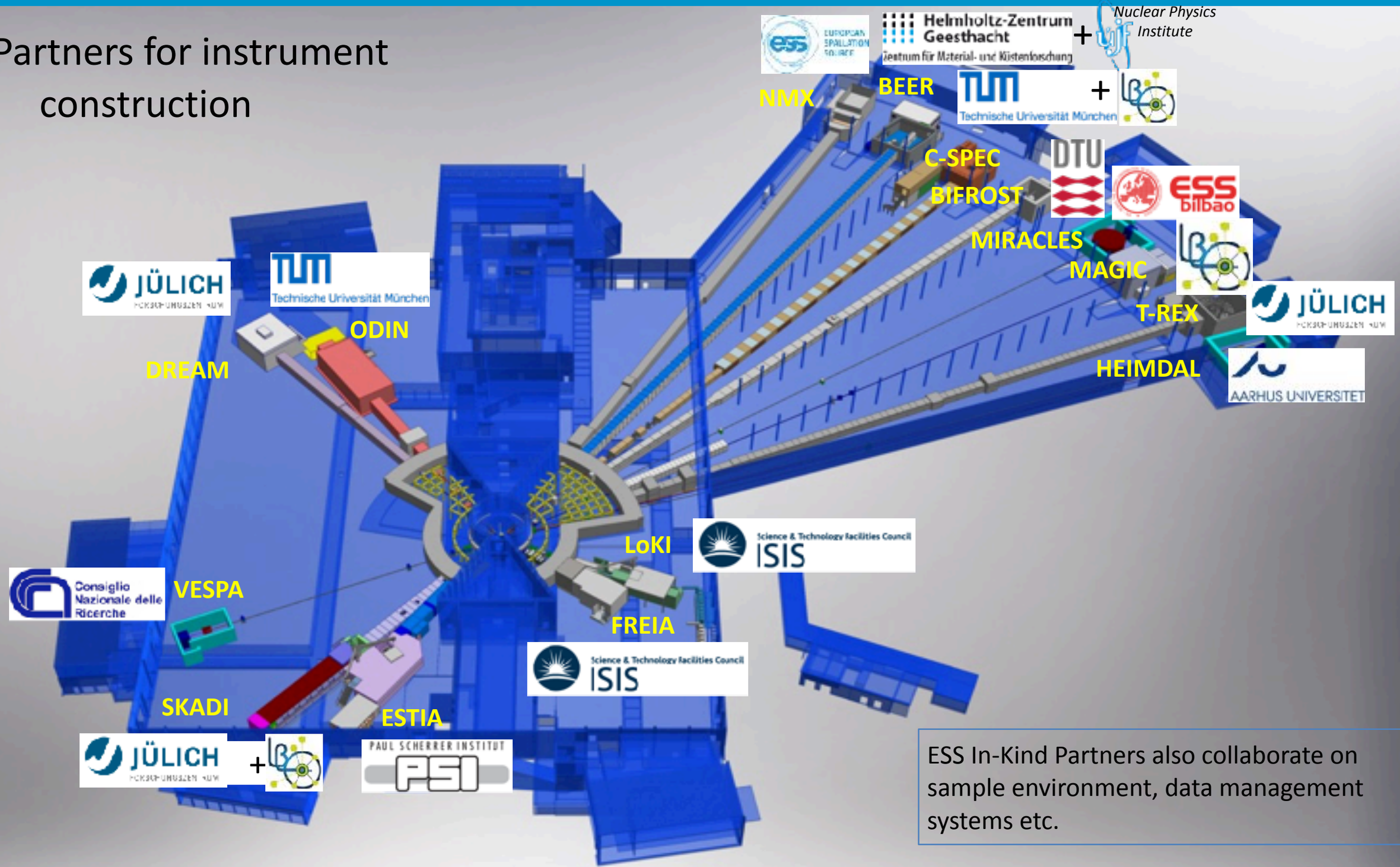

ESS construction
18 May 2017


Central Utilities Building (CUB)
LINAC
Site Offices
East sector Instruments
West sector (160 m) Instruments
Target
South sector Instruments
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)

Neutron Beam Instrument Draft Schedule

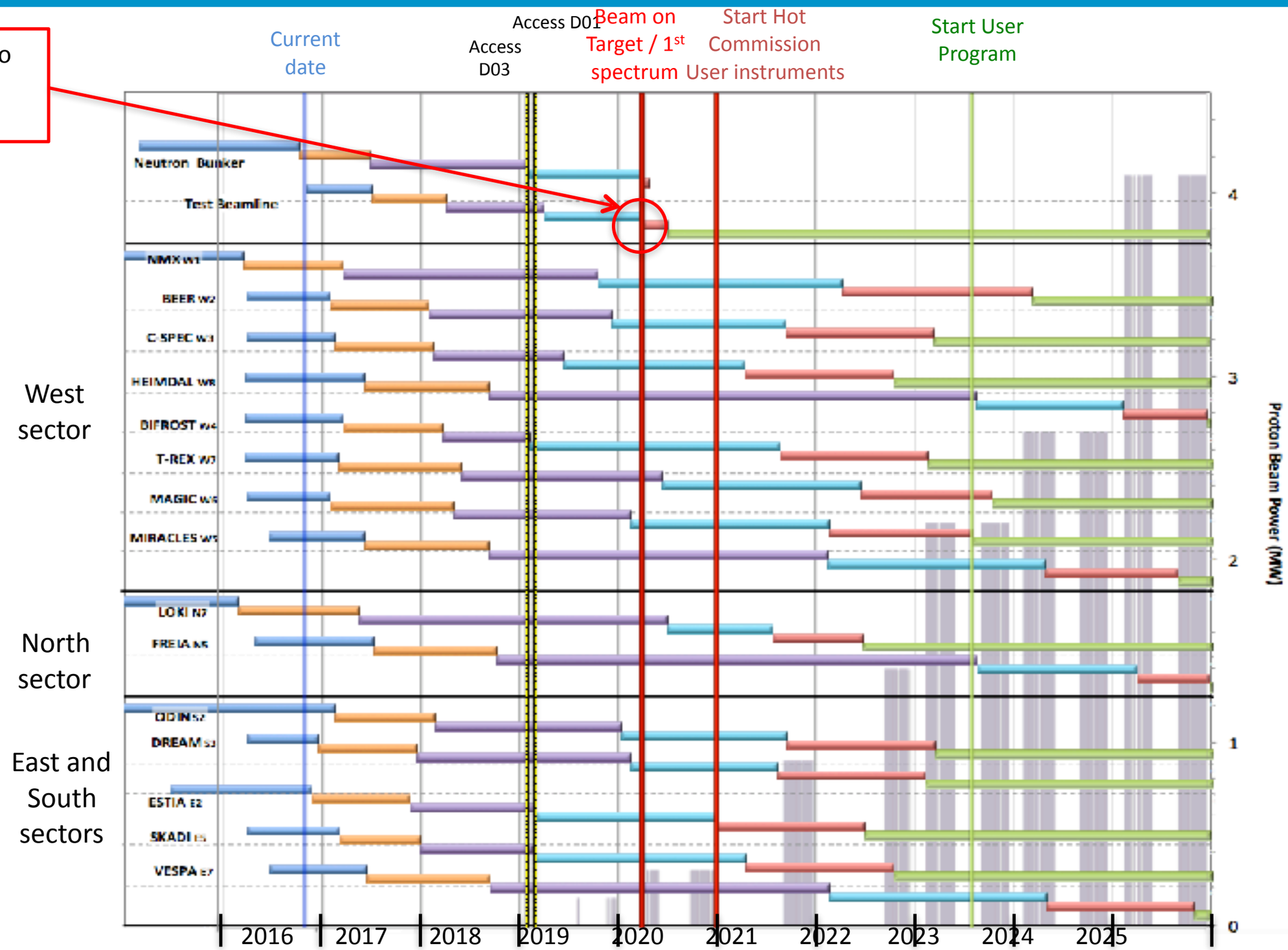
V2.0, 2nd November 2016

EUROPEAN SPALLATION SOURCE

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

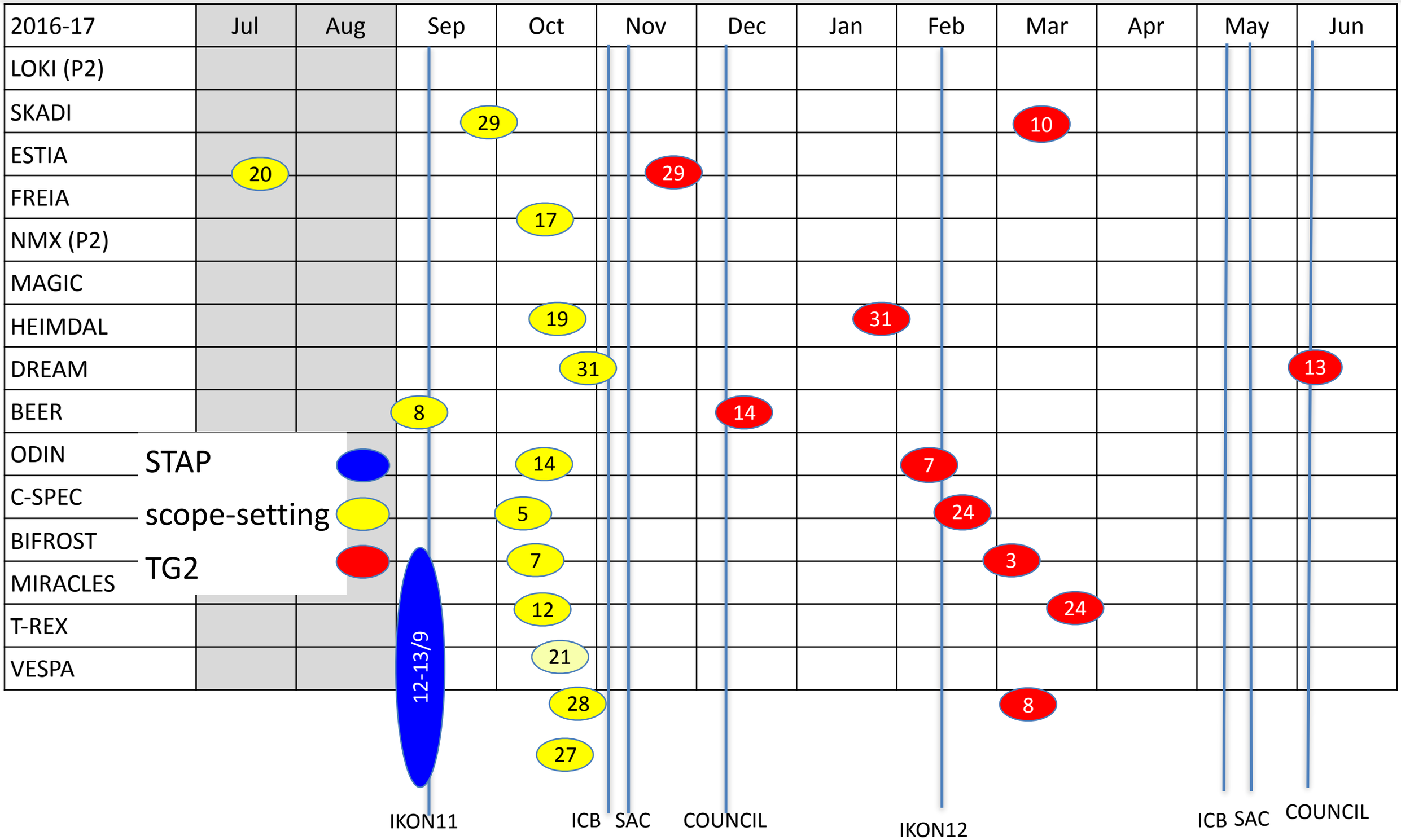
Notes;

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



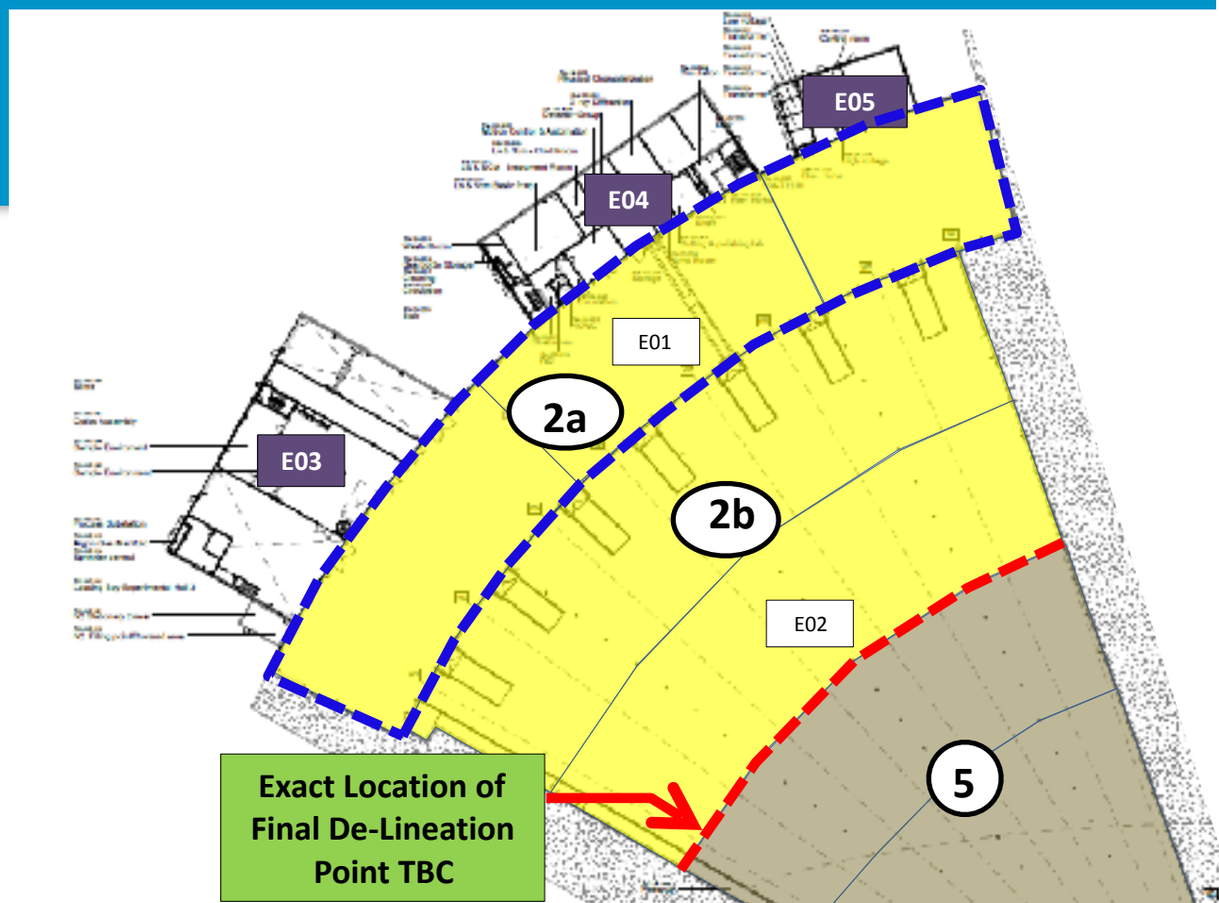
Preliminary Design
Detailed Design
Manufacturing & Procurement
Installation & Integration
Hot Commissioning and early science
Operation

Neutron Instruments: Phase 1 schedule



2019/2020: NSS Proposed Access Dates (Excludes Full Access Dates)

SKANSKA ESS CONSTRUCTION



1 D08 RML Lab – Early Access 10-Jan-19 (Level 1b MS)

2a E01 – Full Access 27-Apr-19 (Level 1 MS)

2b E02 Area 1 – Partial Access 27-Apr-19 (Level 1 MS)

3 D03 Bunker – * Early Access 03-Jun-19 (Level 1 MS)

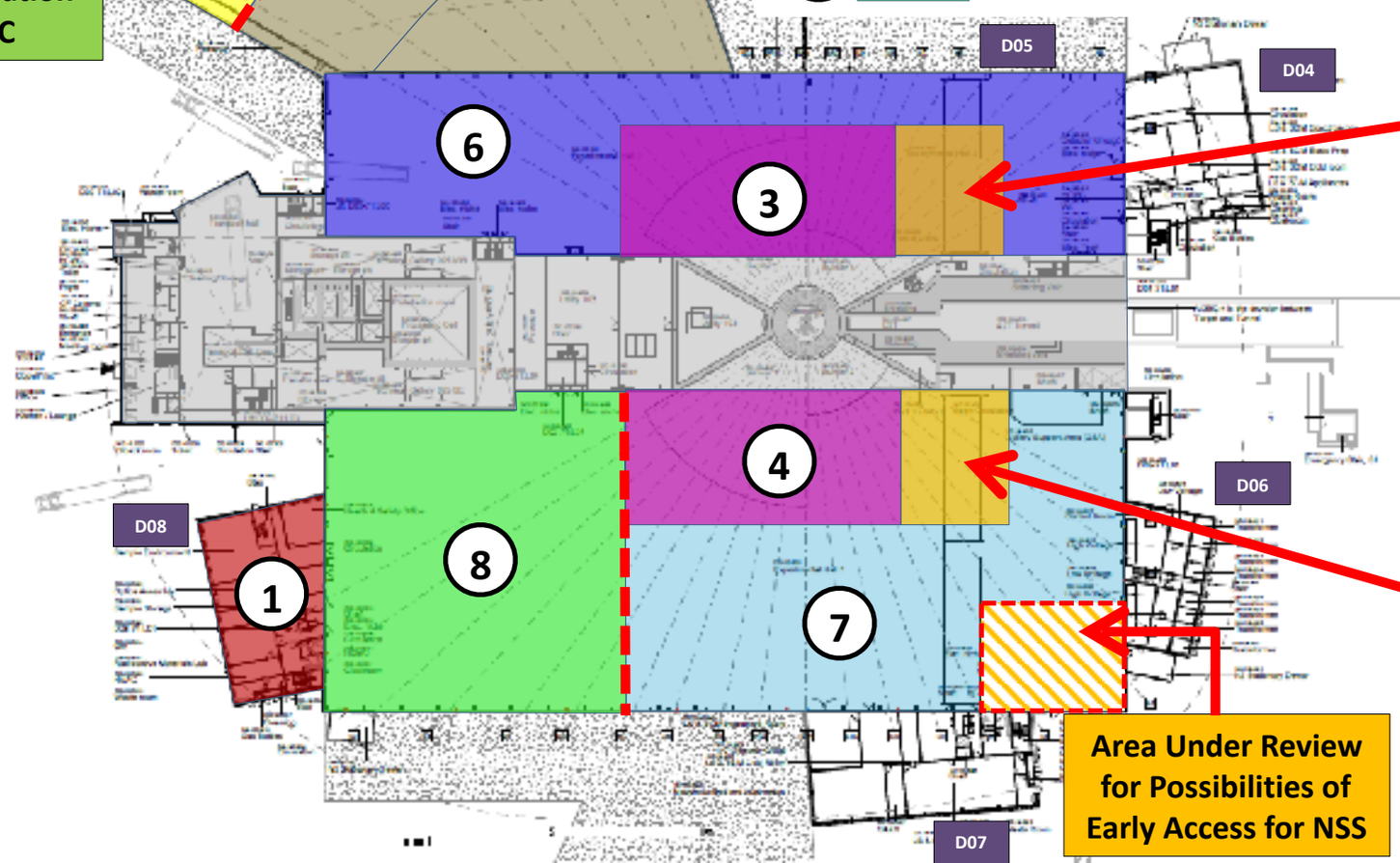
4 D01 Bunker – * Early Access 14-Aug-19 (Level 1 MS)

5 E02 Area 2 – Partial Access 15-Oct-19 (Level 1b MS)

6 D03 Main Hall – Partial Access 01-Nov-19 (Level 1b MS)

7 D01 Main Hall Ph 1 – Partial Access 06-Jan-20 (Level 1b MS)

8 D01 Main Hall Ph 2 – Partial Access 02-Mar-20 (Level 1b MS)



Additional Area Made Available for Storage of Blocks

D03 Cranes Operational: 13-Aug-19

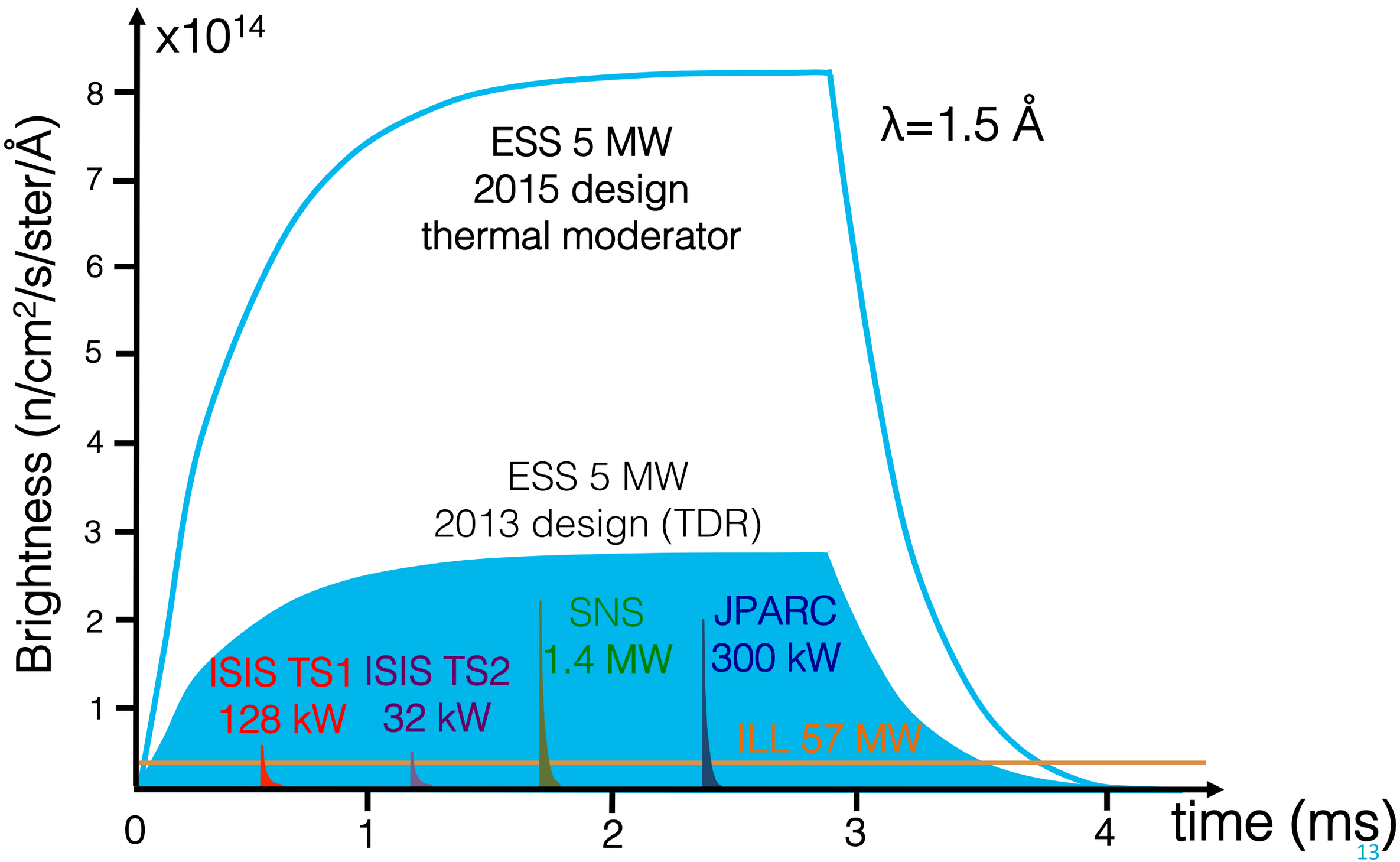
Additional Area Made Available for Storage of Blocks

D01 Cranes Operational: 28-Oct-19

Area Under Review for Possibilities of Early Access for NSS

Update on Status of ESS Detectors

Challenge for Rate



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

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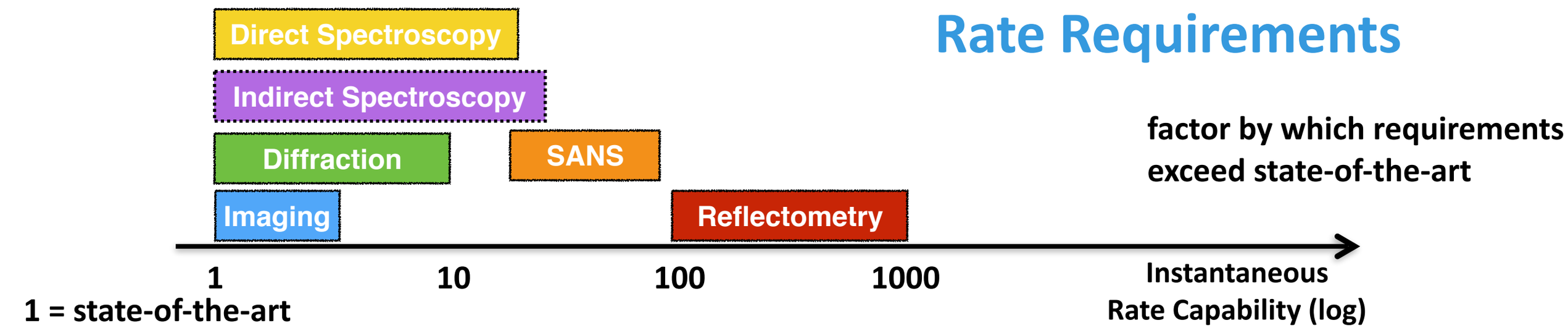
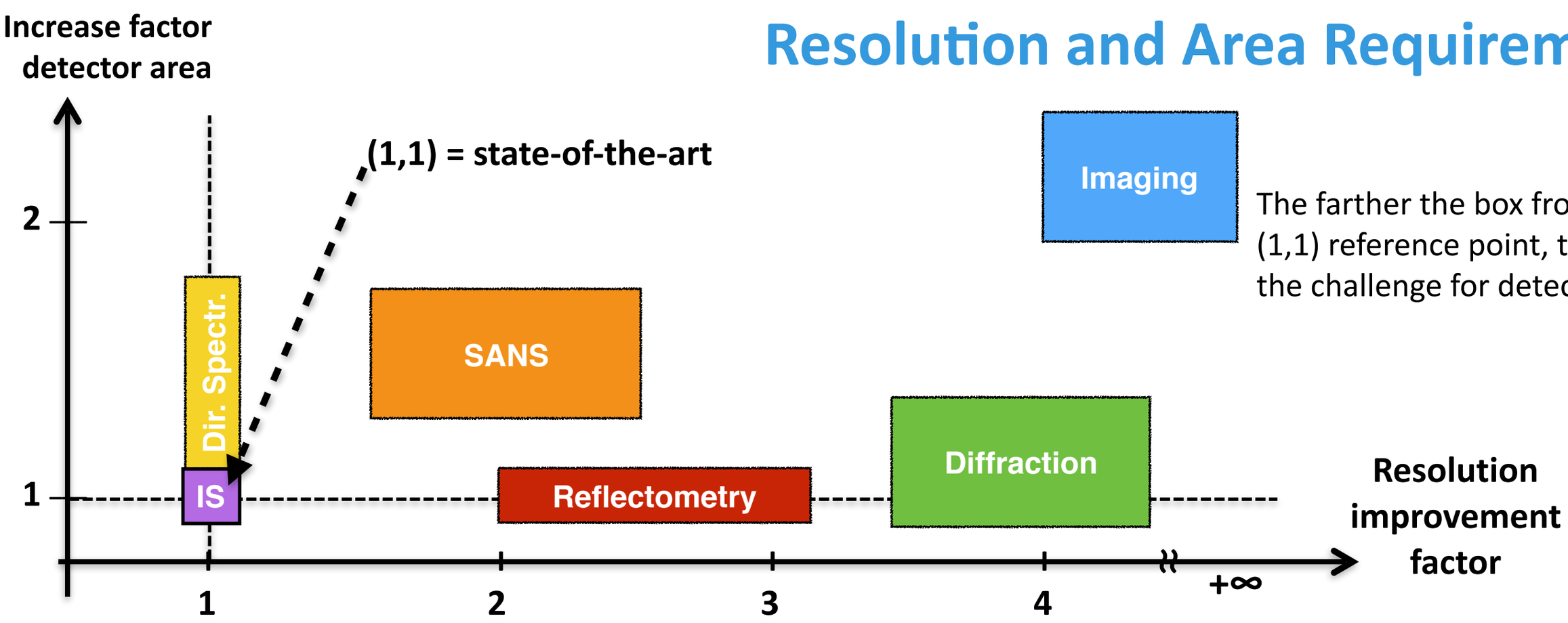
Rate Requirements



Resolution and Area Requirements



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

Facilities

Thin Films Workshop

- ESS Facility, 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
- Capacity: >1000m2/year coated with 10B4C
- If interested in coatings: **contact us**
- **Please give feedback!**

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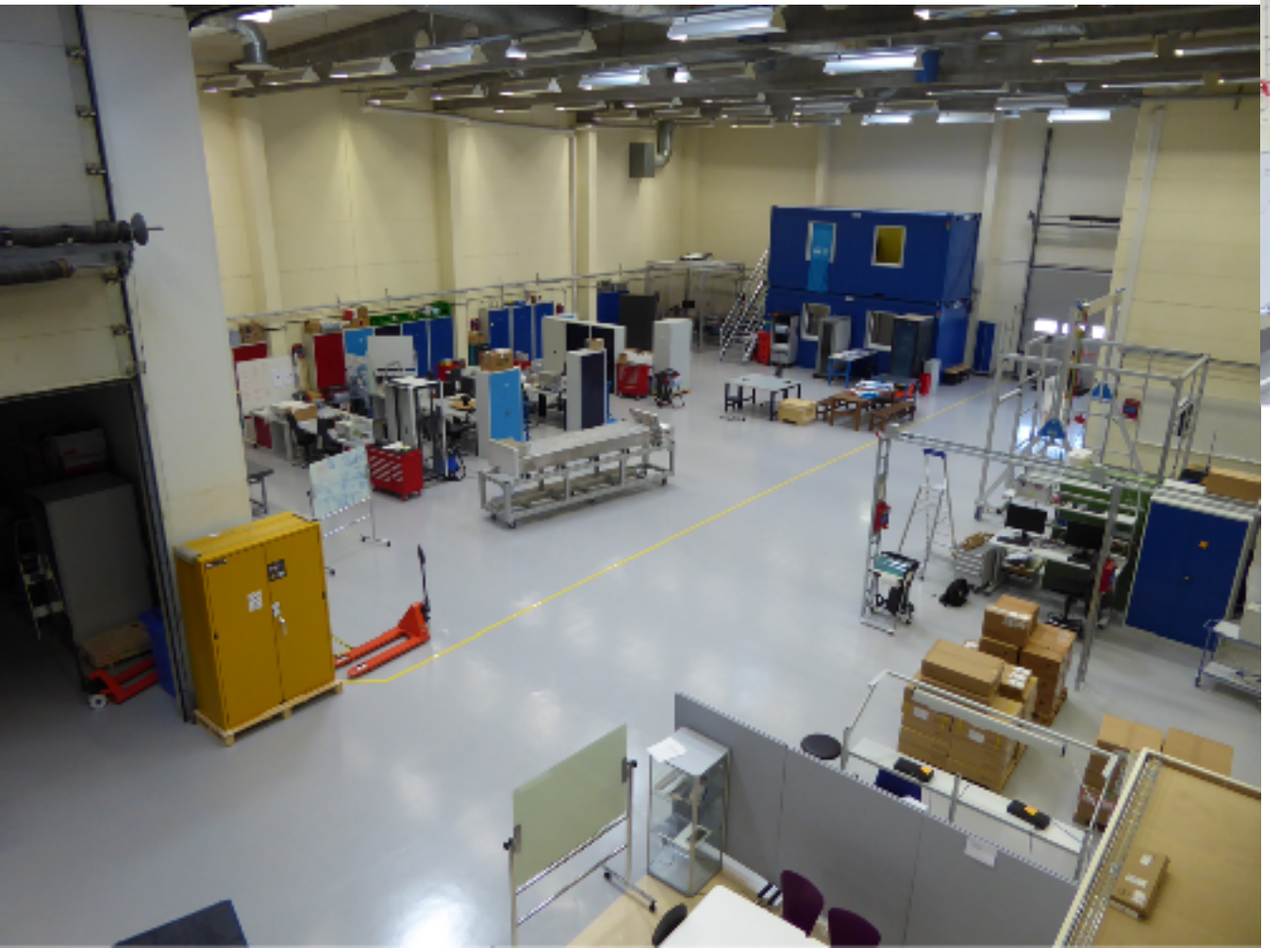
Detector Workshop

EUROPEAN SPALLATION SOURCE



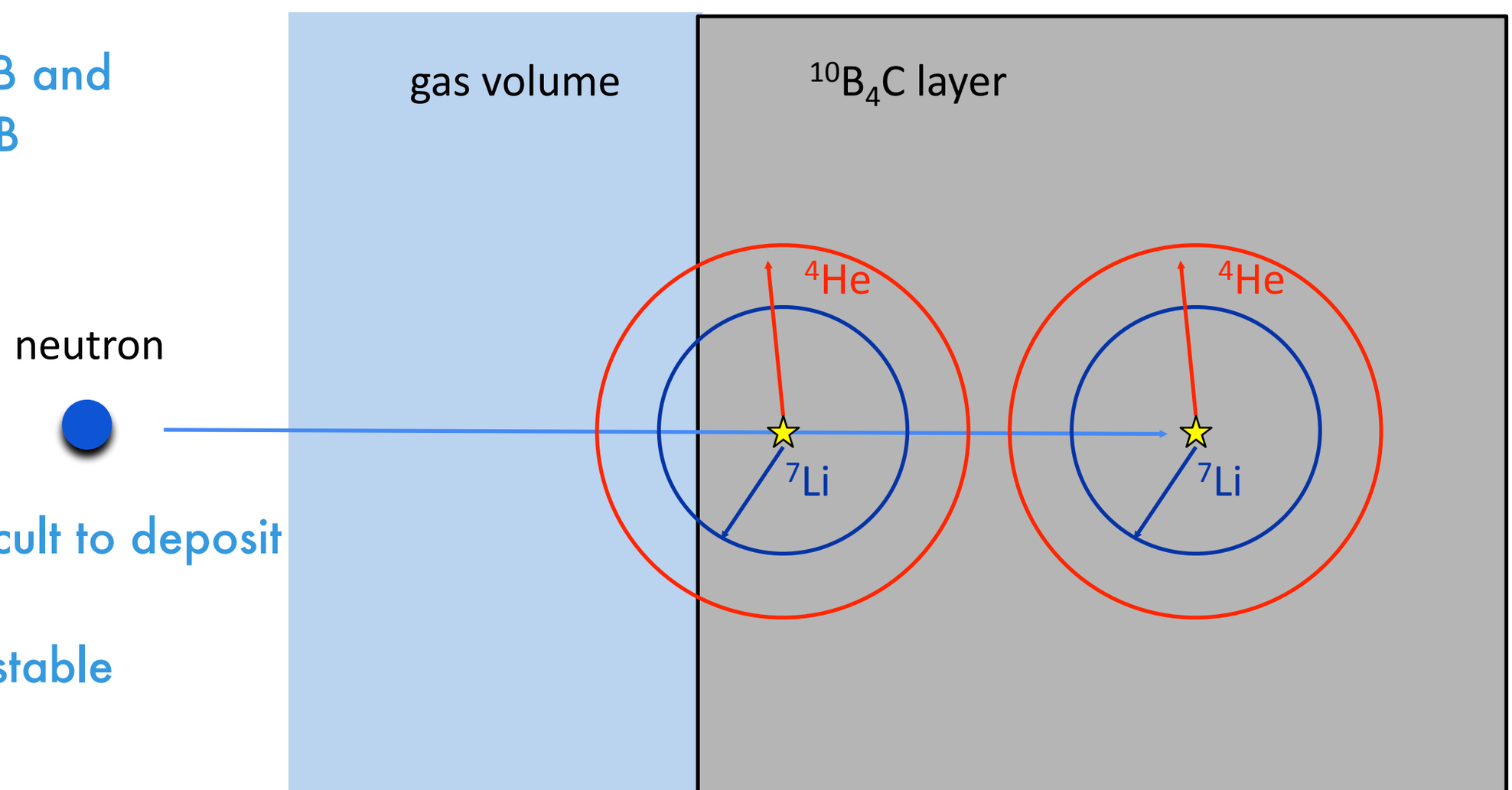
MultiGrid and Multiblade

^{10}Boron-based Thin Film Gaseous Detectors

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

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

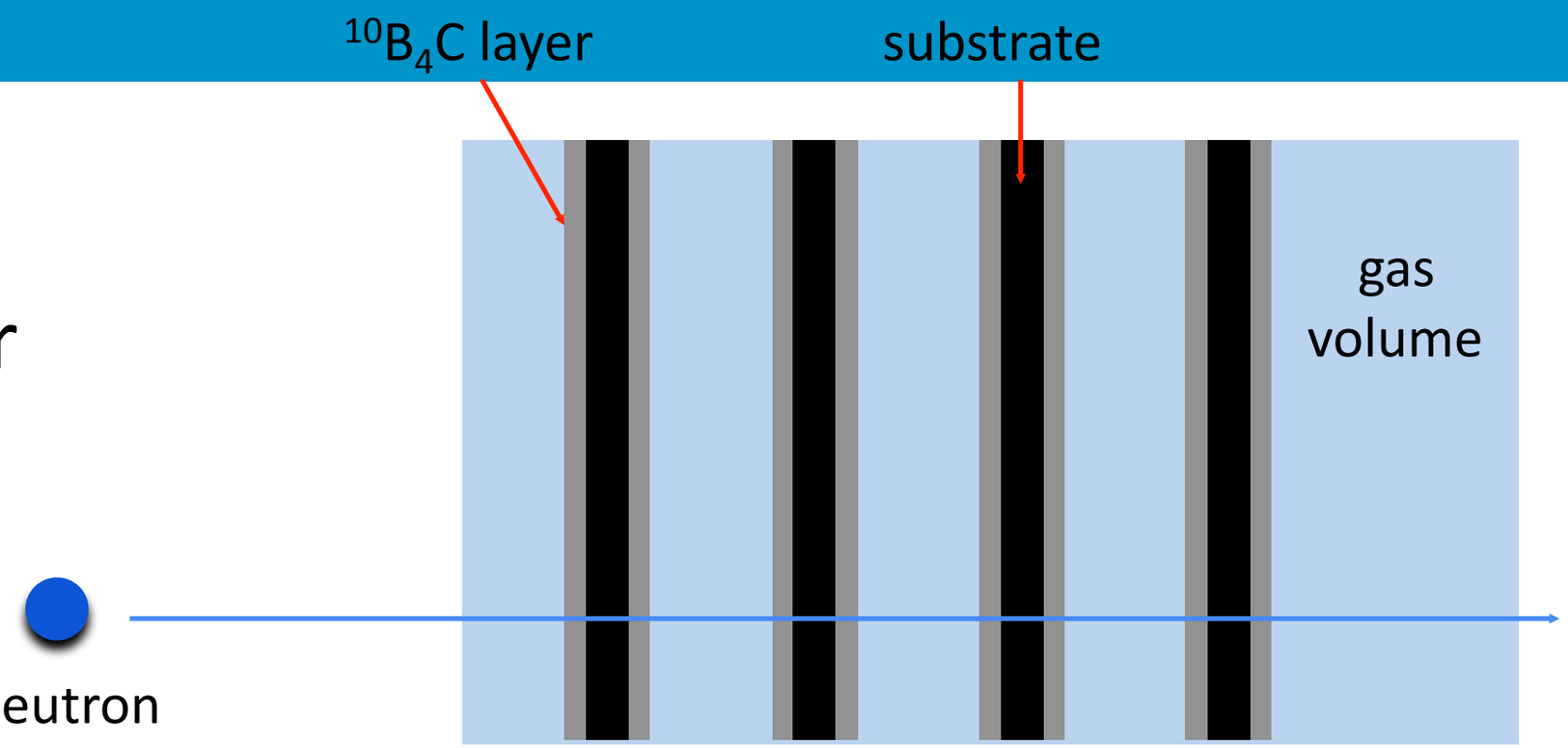
- ^{nat}B contains
  80 at.% ^{11}B and
  20 at.% ^{10}B



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

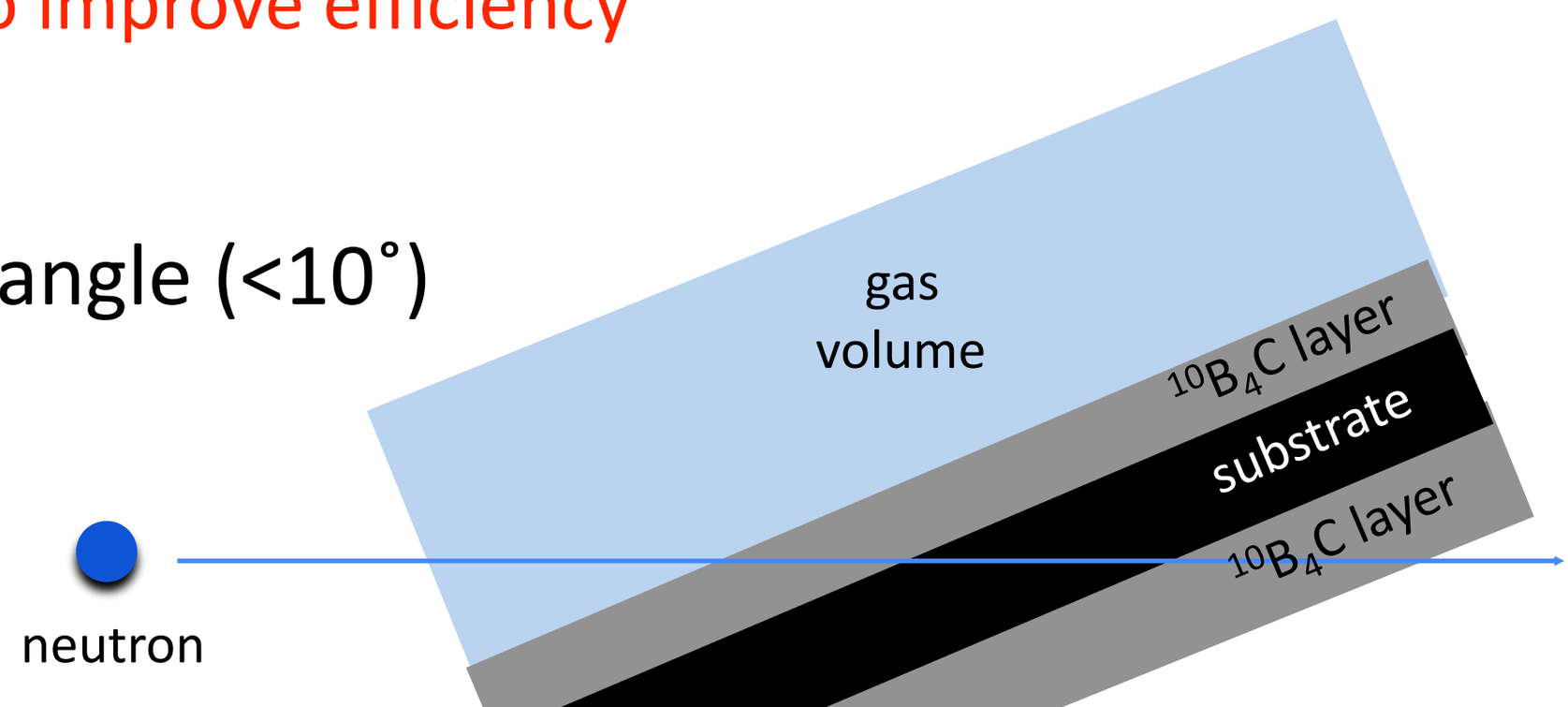
Enhancing the efficiency of ^{10}B-based Neutron Detectors

1 Multi layer



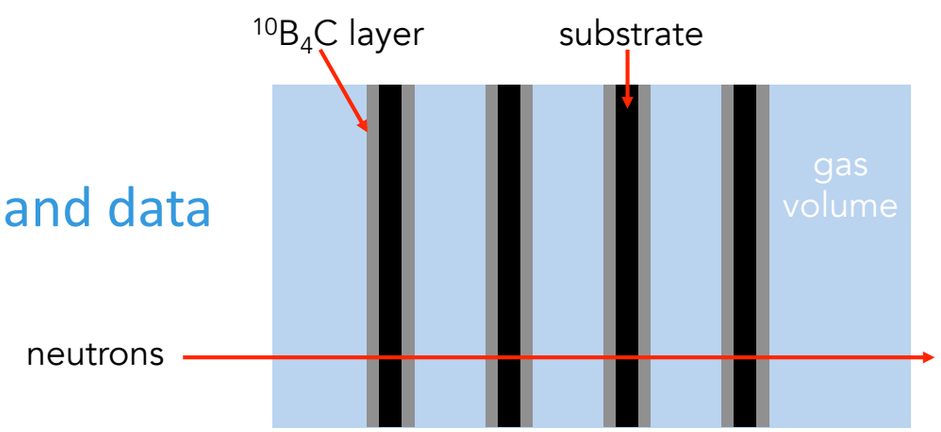
Generic approaches to improve efficiency

2 Grazing angle (<10˚)



Efficiency of ^{10}B Detectors: Perpendicular Geometry

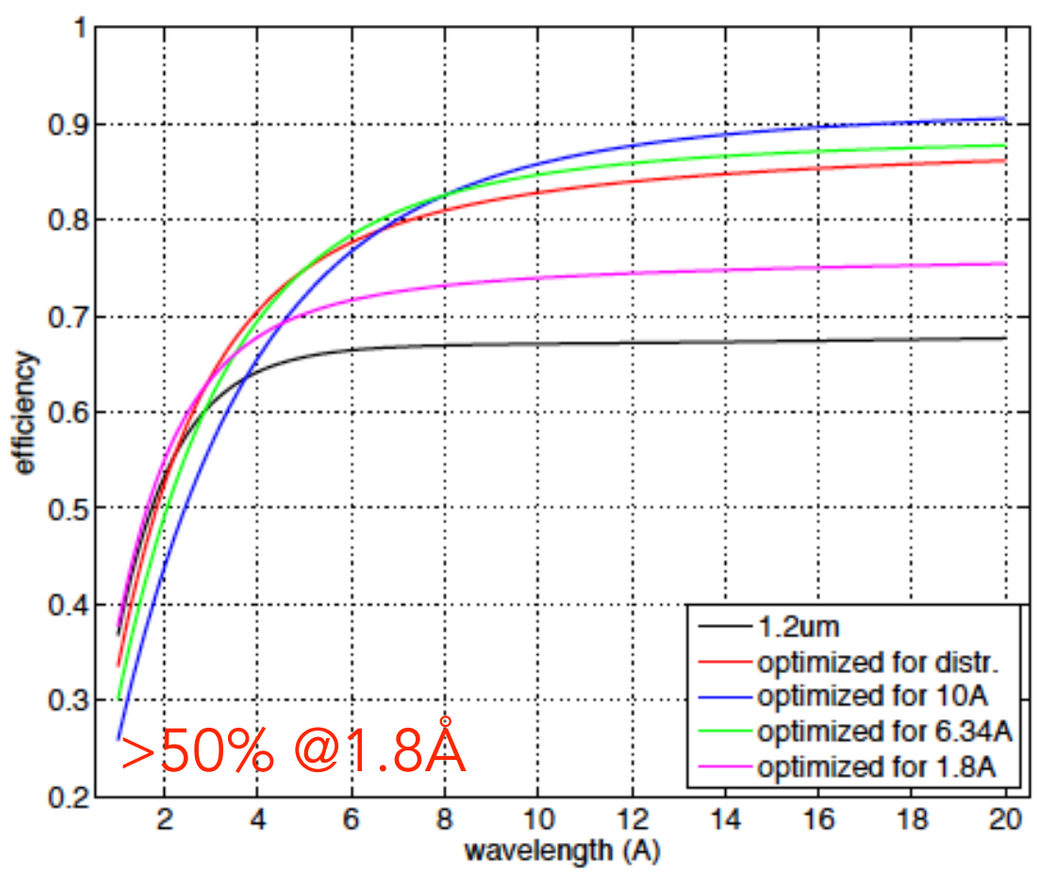
- Single layer is only ca.5%
- Calculations done by many groups
- Analytical calculations extensively verified with prototypes and data
- Details matter: just like for ^{3}He



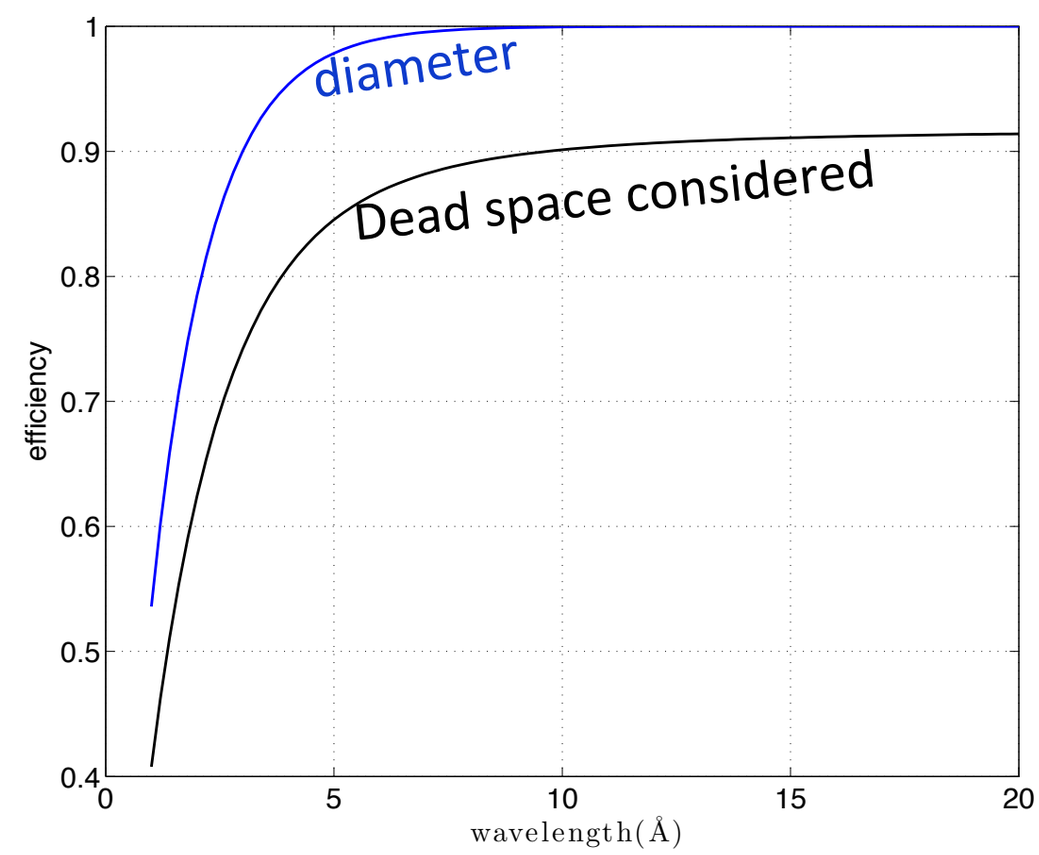
- Multilayer configuration (example):

JINST 8 (2013) P04020

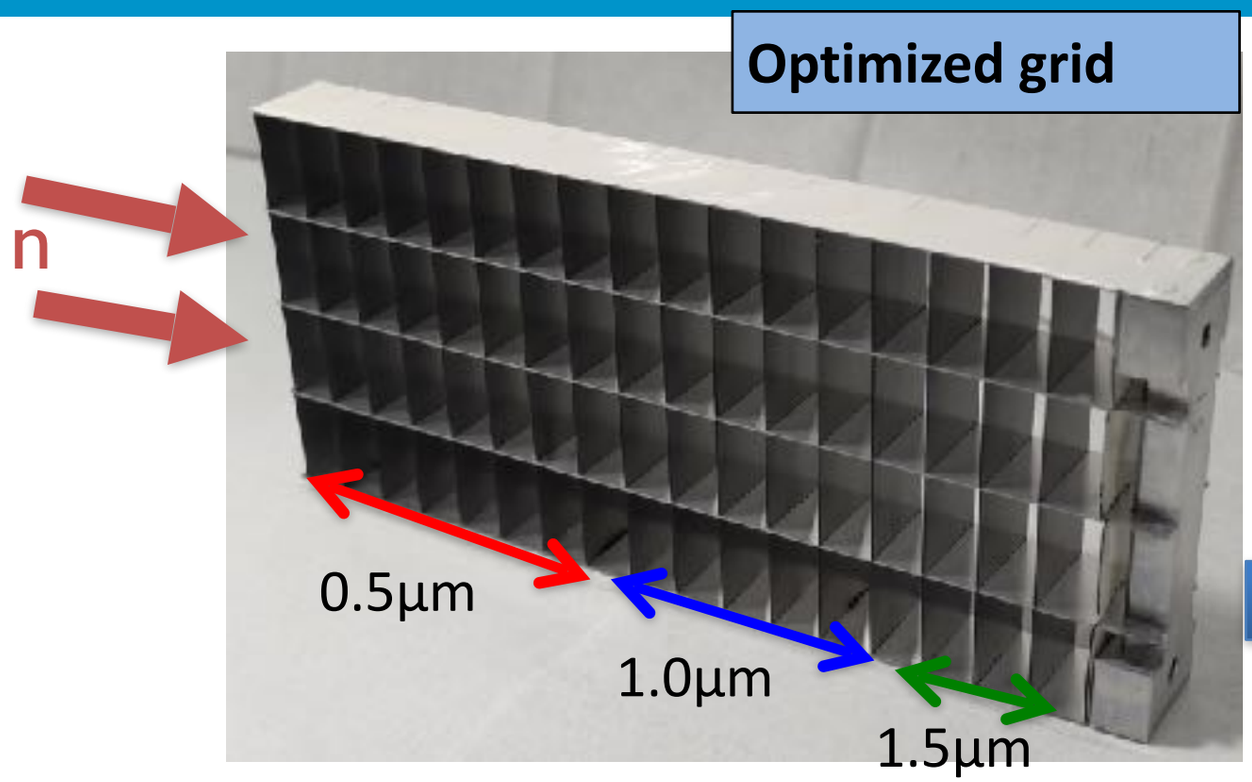
Multi-Grid



^{3}He tubes – 1 inch – 4.75 bar



Efficiency Optimizations



Layer thicknesses in MG.CNCS (16 blades):

7 blades 0.5µm,

7 blades 1.0µm,

3 blades 1.5µm

Would like to test:

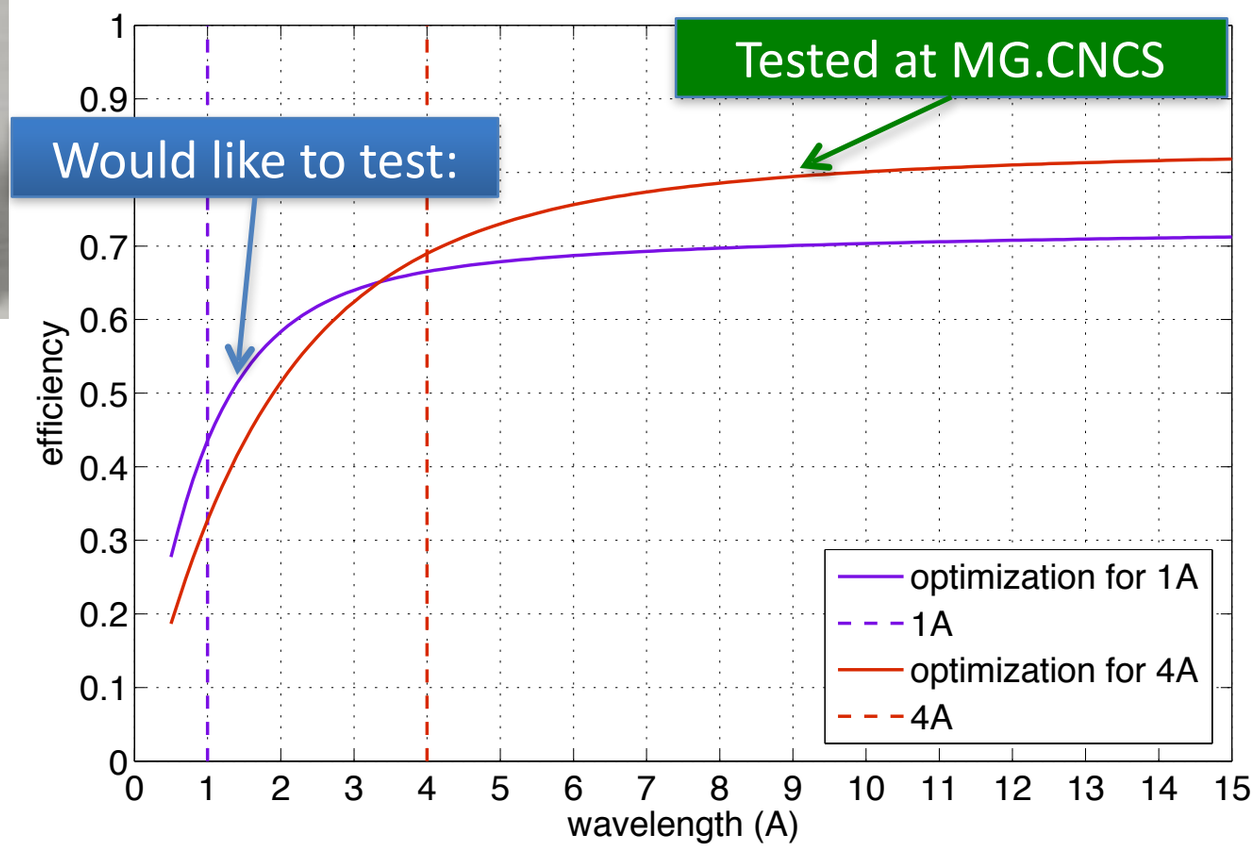
Proposed for a thermal detector (20 blades):

4 blades 1.0µm,

10 blades 1.25µm,

6 blades 2.0µm.

Efficiency as a function of wavelength for MG optimized for cold vs. thermal spectrum



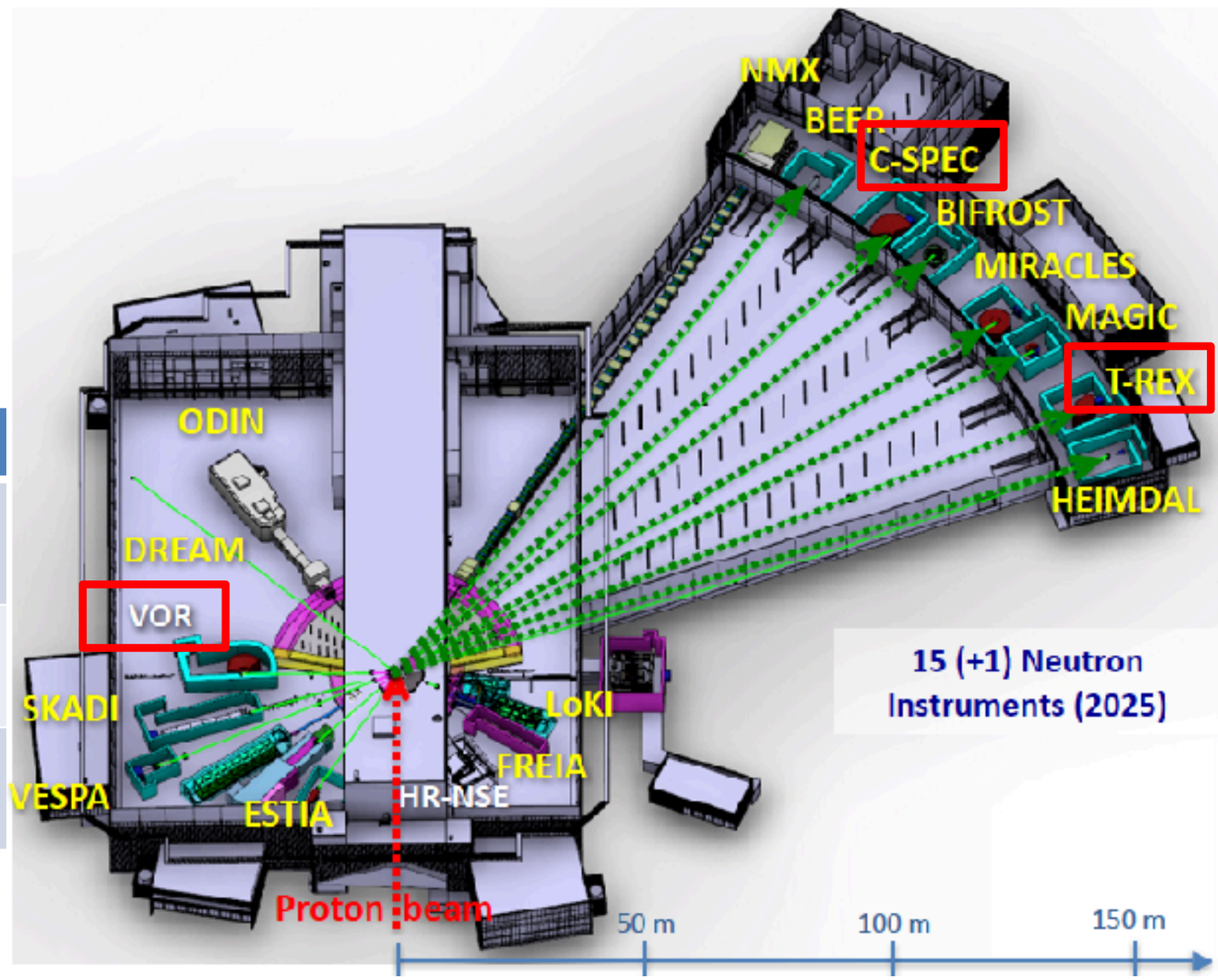
- Cold – optimization centered on 4Å
- Thermal – optimization centered on 1Å

Time-of-Flight Spectrometers at ESS

- First 16 instruments chosen
- 3 ToF spectrometers for ESS
- CSPEC and T-REX – design phase
- VOR – accepted proposal
- **Multi-Grid** as **baseline** detector technology

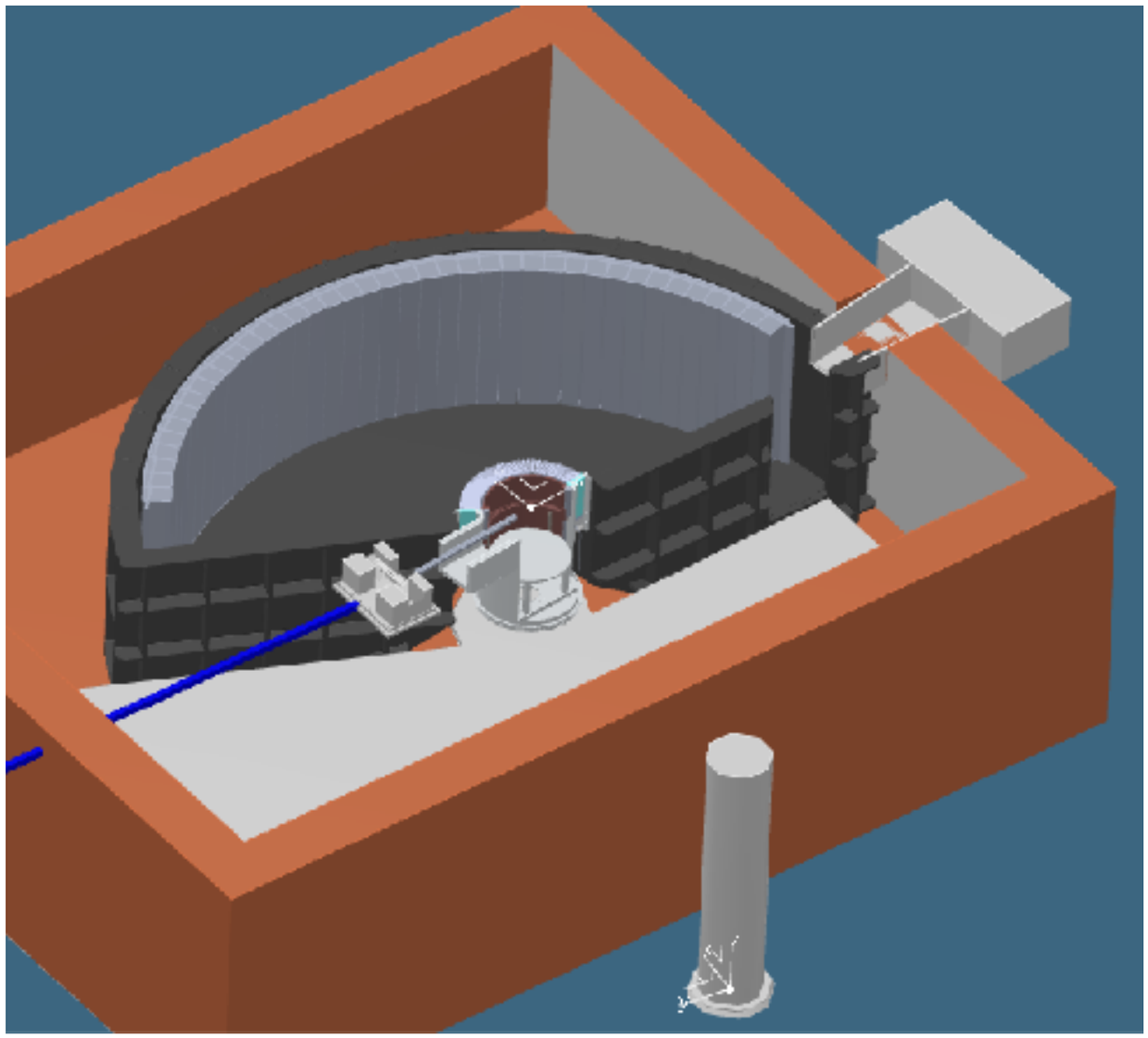
Instrument	C-SPEC	T-REX	VOR
Sample – detector	3.5 m	3 m	3 m *
Detector height	3.5 m	2.2 m	3 m *
Detector area	29 m^2	21 m^2	37 m^2 *

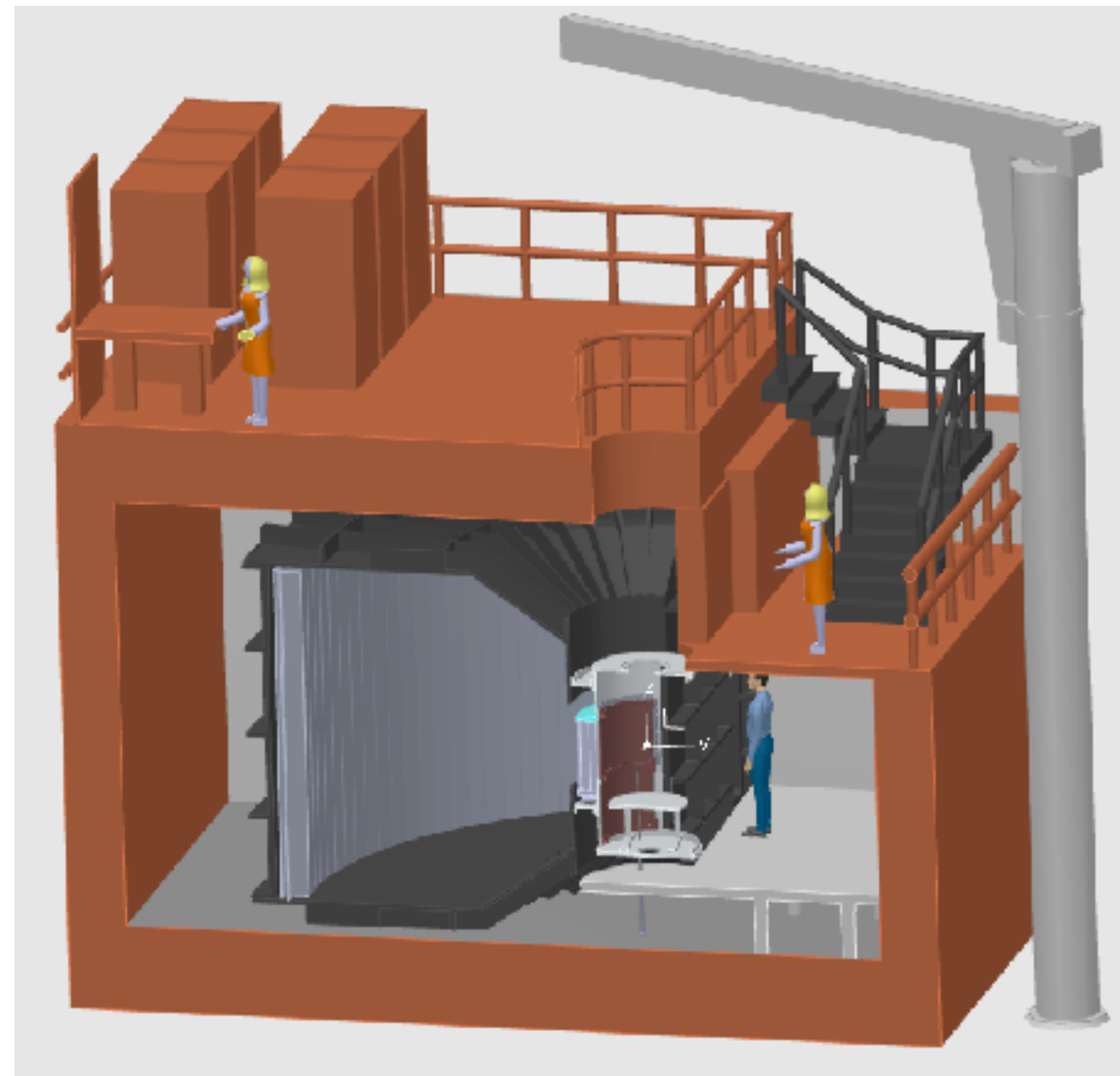
*preliminary



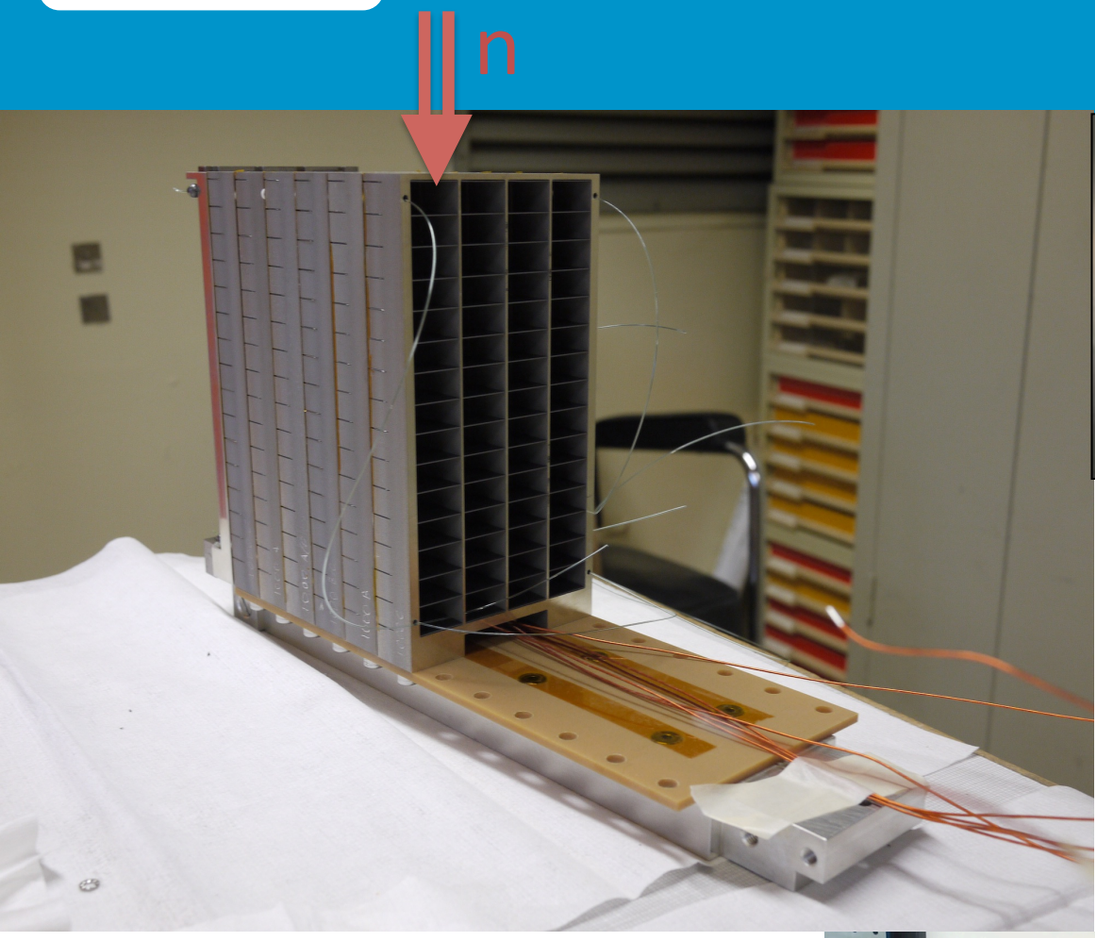
CSPEC at ESS

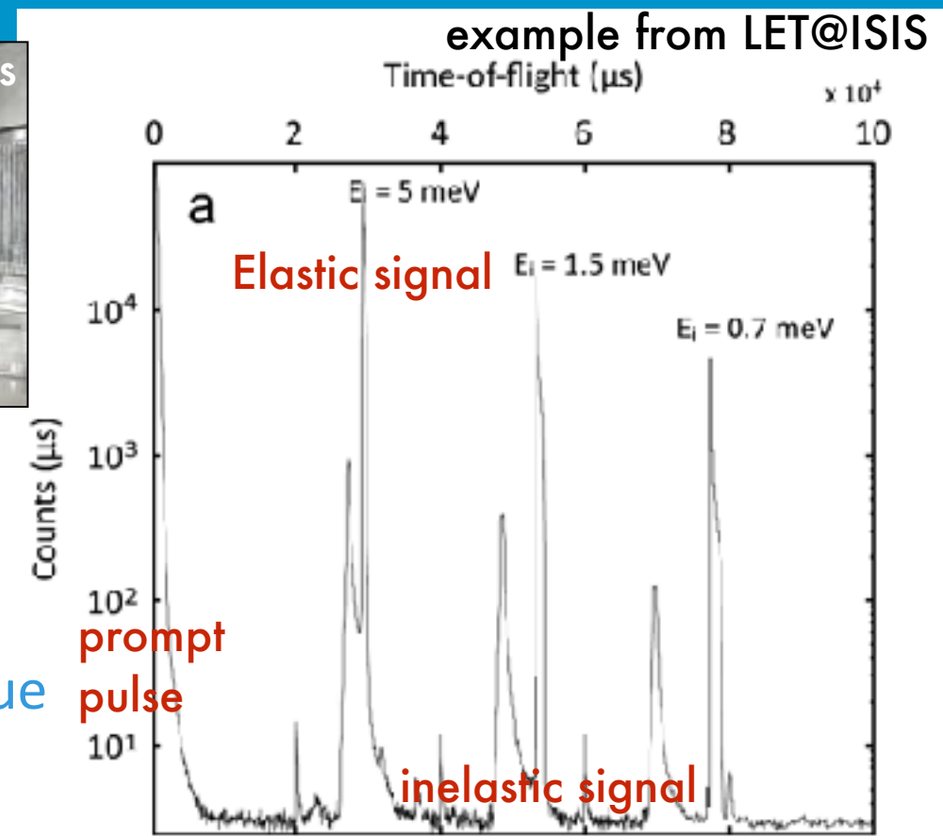
Cold spectrometer
0.2 meV < E_i < 20 meV
29m^2 detector
Horizontal coverage 5° to 135°
Vertical coverage -25° to 25°





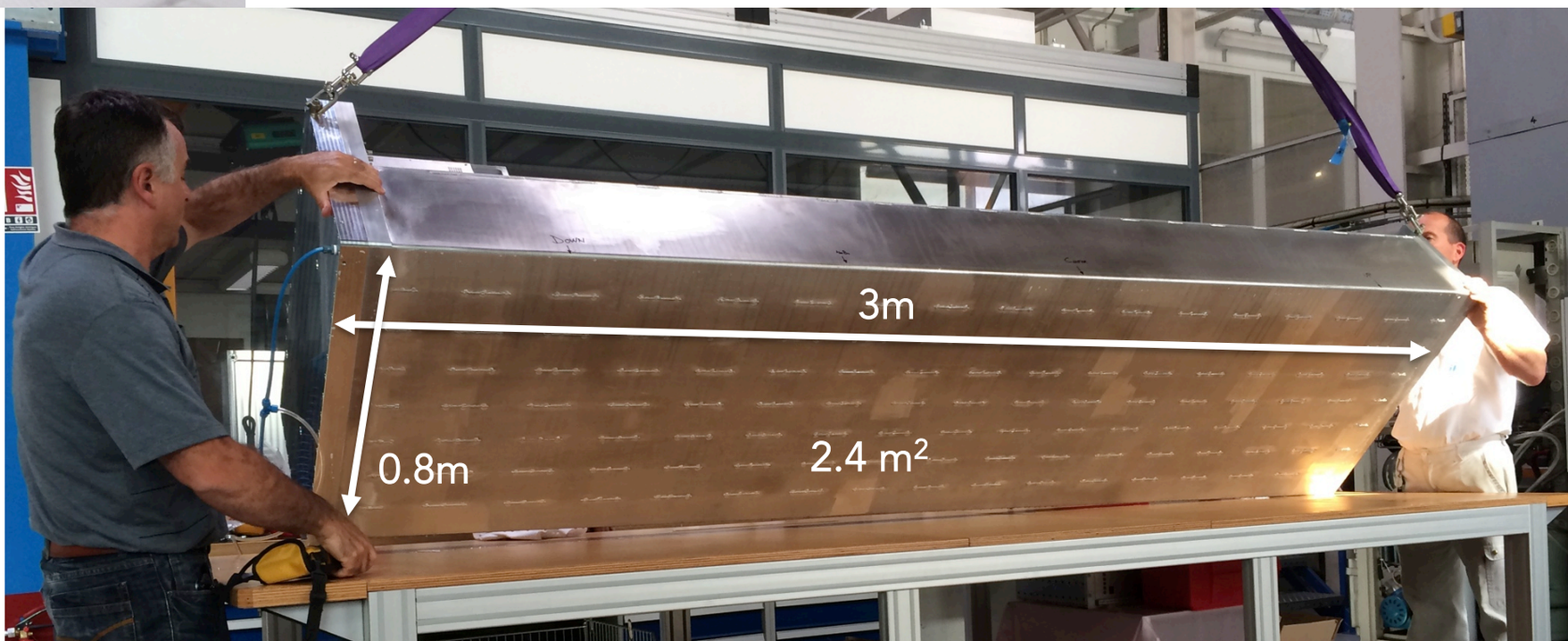
Multi-Grid Detector Design





- 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



Introduction

ILL:
Bruno Guerard, Jean-Claude Buffet,
Jean-Francois Clergeau, Anthony Leandri

ESS:
Anton Khaplanov, Fatima Issa, Richard Hall-Wilton, Oliver Kirstein, Tomasz Brys, Michail Anastasopoulos, Isaak Lopez Higuera, Richard Bebb, Sara Arranz, Carina Höglund*, Linda Robinson*, Susan Schmidt*

Centre for Energy Research (Hungary):
Eszter Dian

Linköping University:
Jens Birch, Lars Hultman, (also *)

SNS:
Ken Herwig, Georg Ehlers, Michelle Everett, Kevin Berry

Earlier – the participants of the CRISP project on Large-Area detectors.

Horizon 2020 grant agreement 676548

WP 4.3: Large-Area Detectors

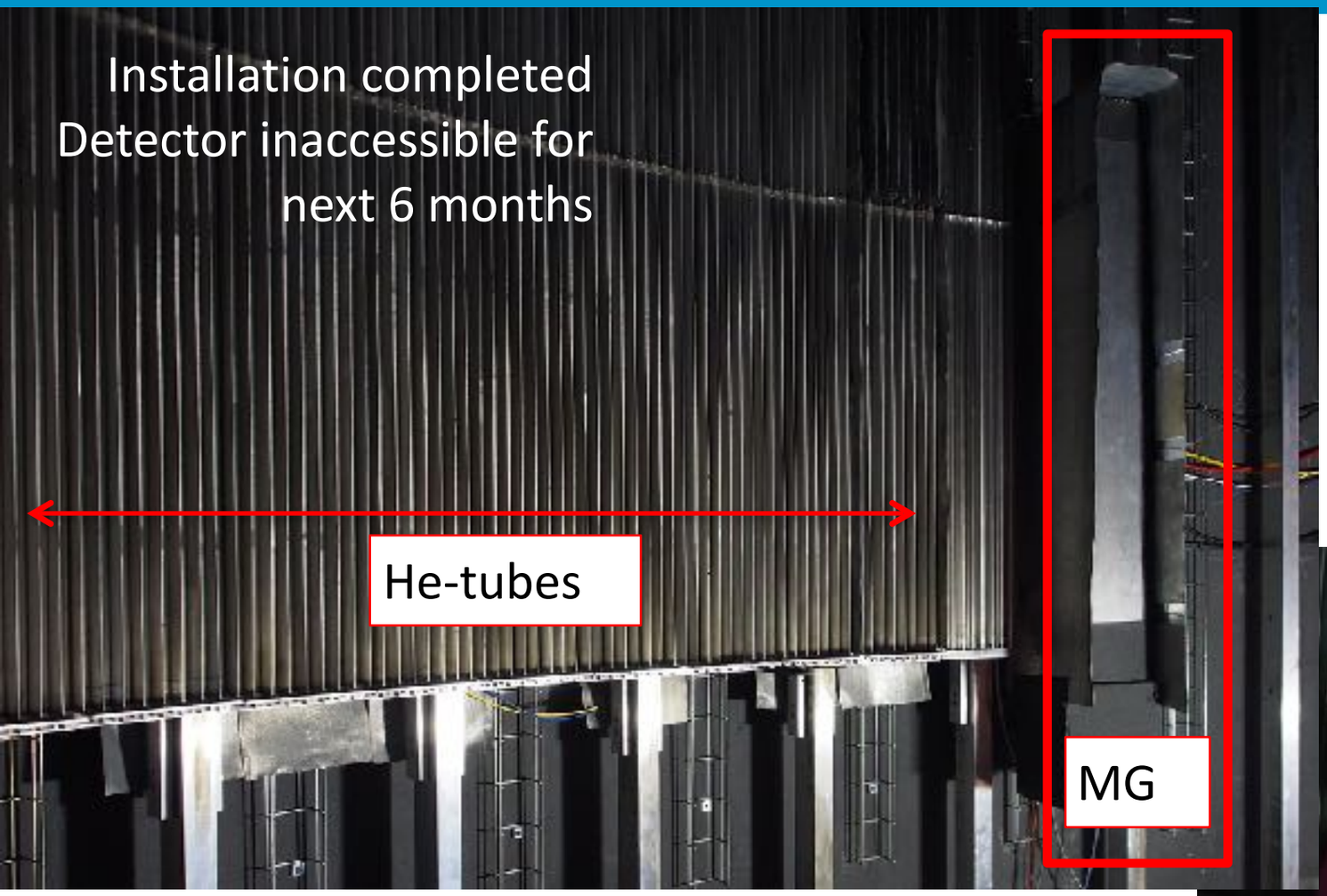
Previous publications:

B4C layers:
*C. Höglund et al, J of Appl. Phys. 111, 104908 (2012)
Characterization:
*A. Khaplanov et al., arXiv:1209.0566 (2012)
*B Guerard et al., NIMA, 720, 116-121 (2013), http://dx.doi.org/10.1016/j.nima.2012.12.021iJ
*J. Correa et al., Trans. Nucl. Sc. (2013), DOI: 10.1109/TNS.2012.2227798
*A. Khaplanov et al., (2014) *J. Phys.: Conf. Ser.* **528** 012040 doi: 10.1088/1742-6596/528/1/012040
Gamma sensitivity:
*A. Khaplanov et al., JINST 8, P10025 (2013), arXiv:1306.6247
Alpha background:
*A. Khaplanov et al., JINST 10, P10019 (2015); doi: 10.1088/1748-0221/10/10/P10019

Current work:

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

Multi-Grid test at CNCS

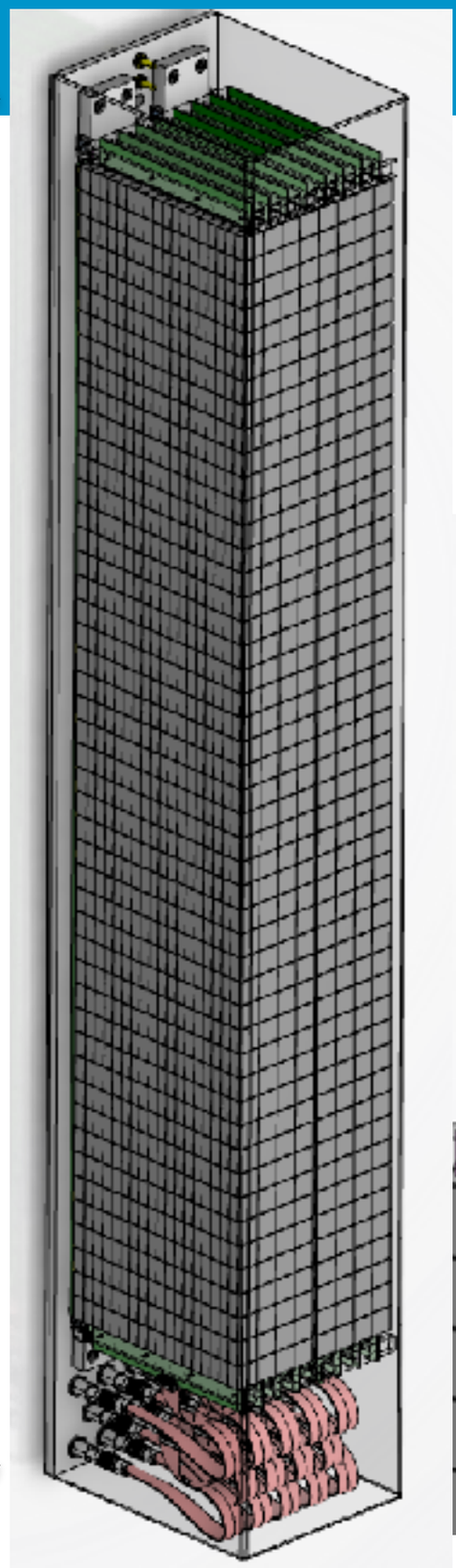


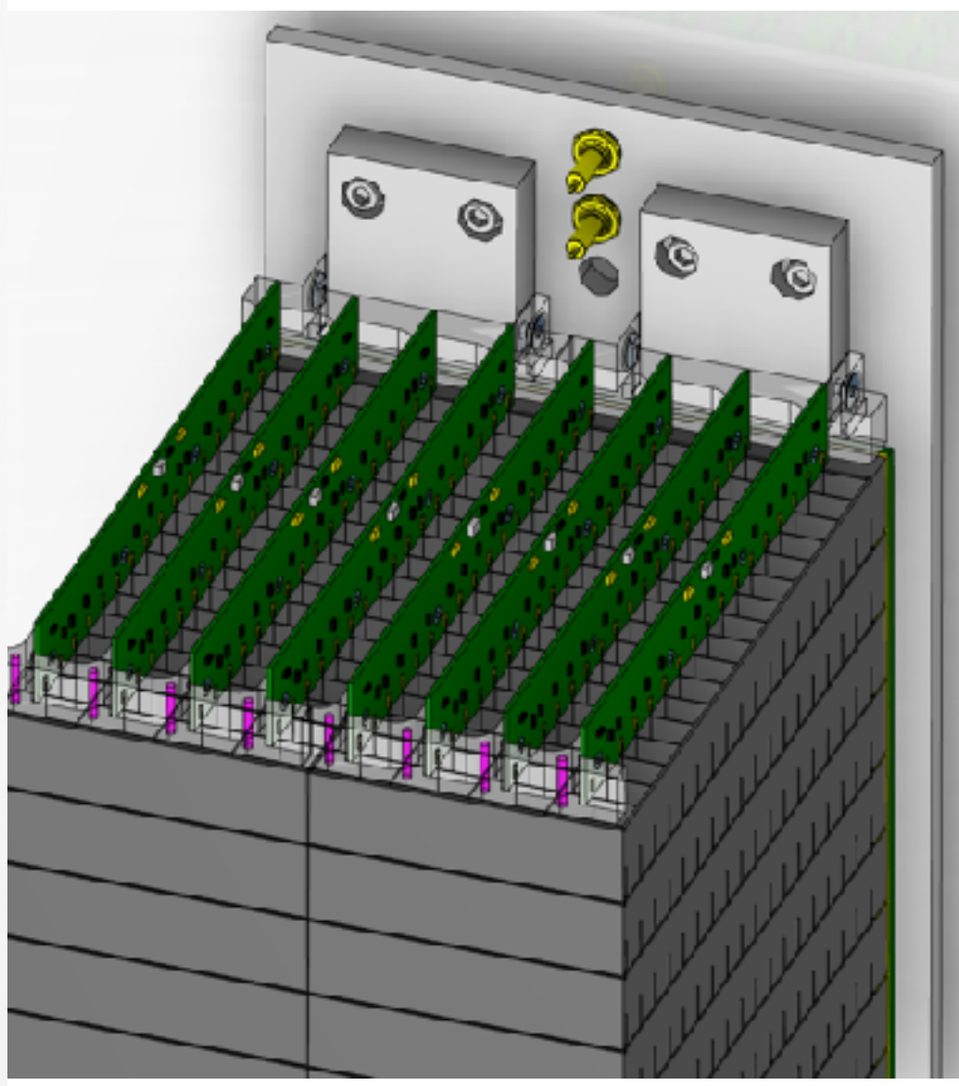
B10 Multi-Grid Detector Performance is equivalent to that of He-3 detectors

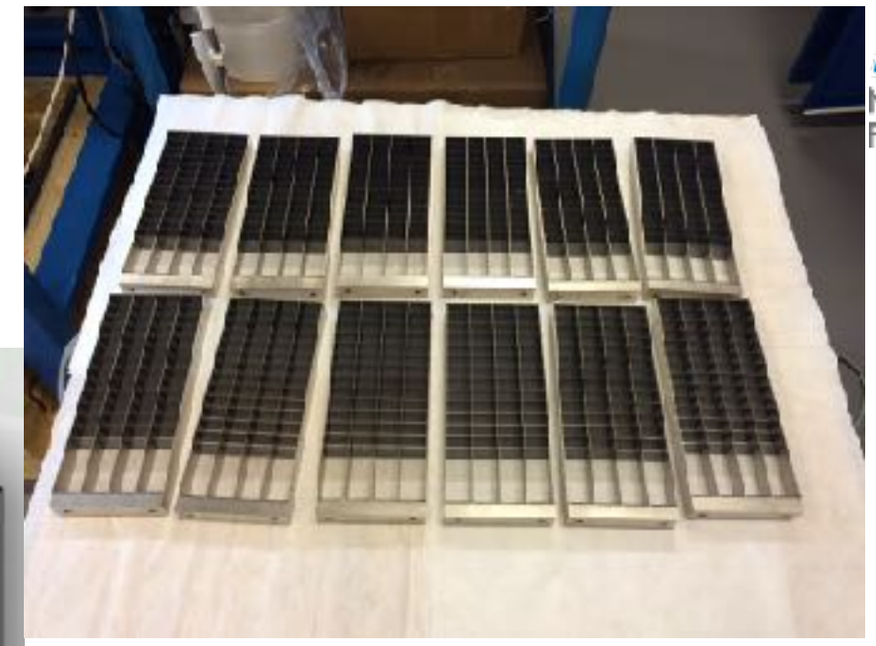
A.Khaplanov et al. *"Multi-Grid Detector for Neutron Spectroscopy: Results Obtained on Time-of-Flight Spectrometer CNCS"* https://arxiv.org/abs/1703.03626
2017 JINST 12 P04030

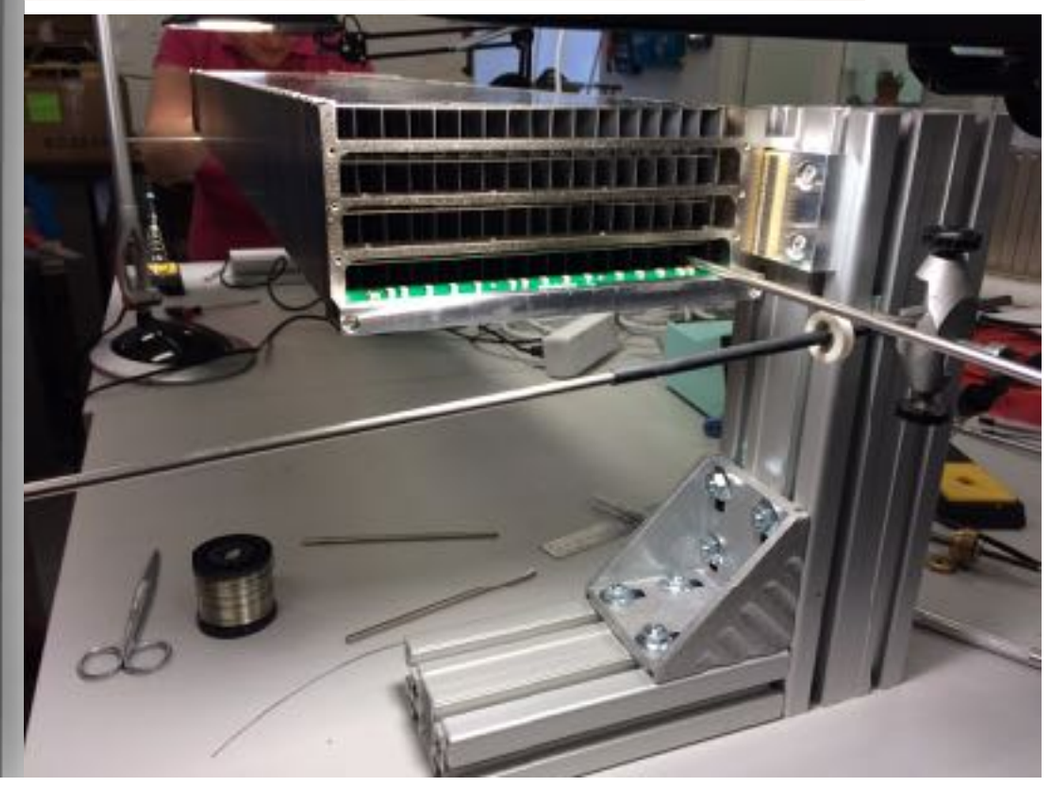
- Test side-by-side with existing technology in world leading instrument
- Realistic conditions
- "Science" or application performance
- 2 different technologies on the same instrument

Construction of MG.CNCS in Lund

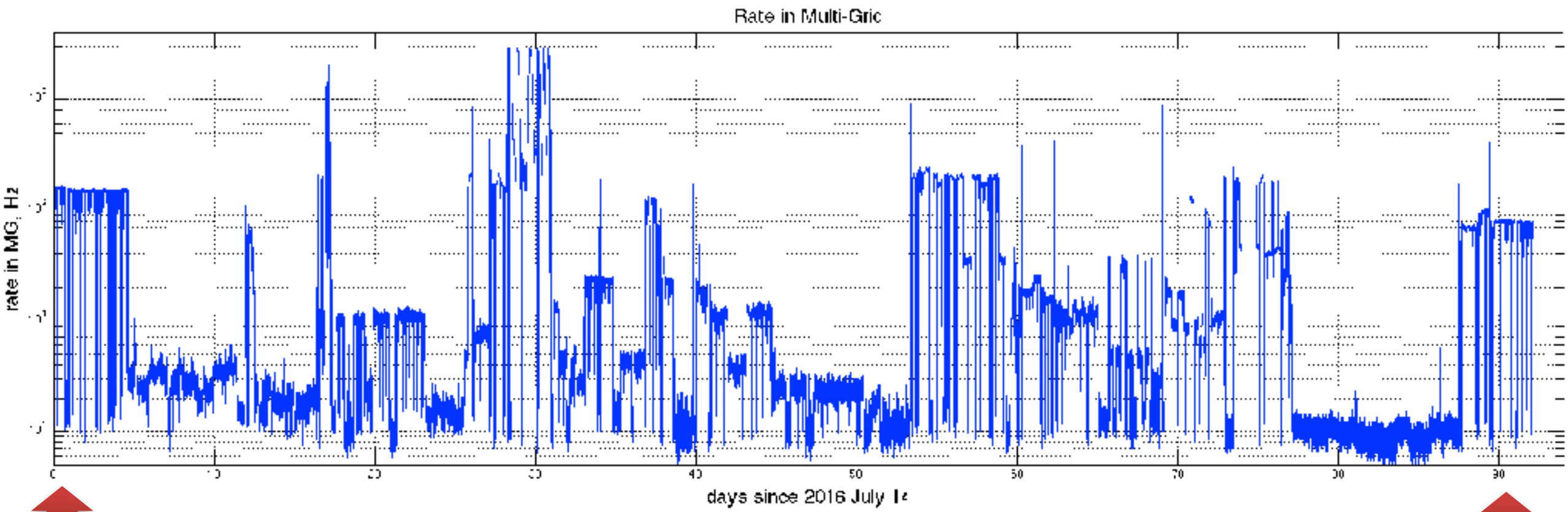








Operation since 2016-07-14



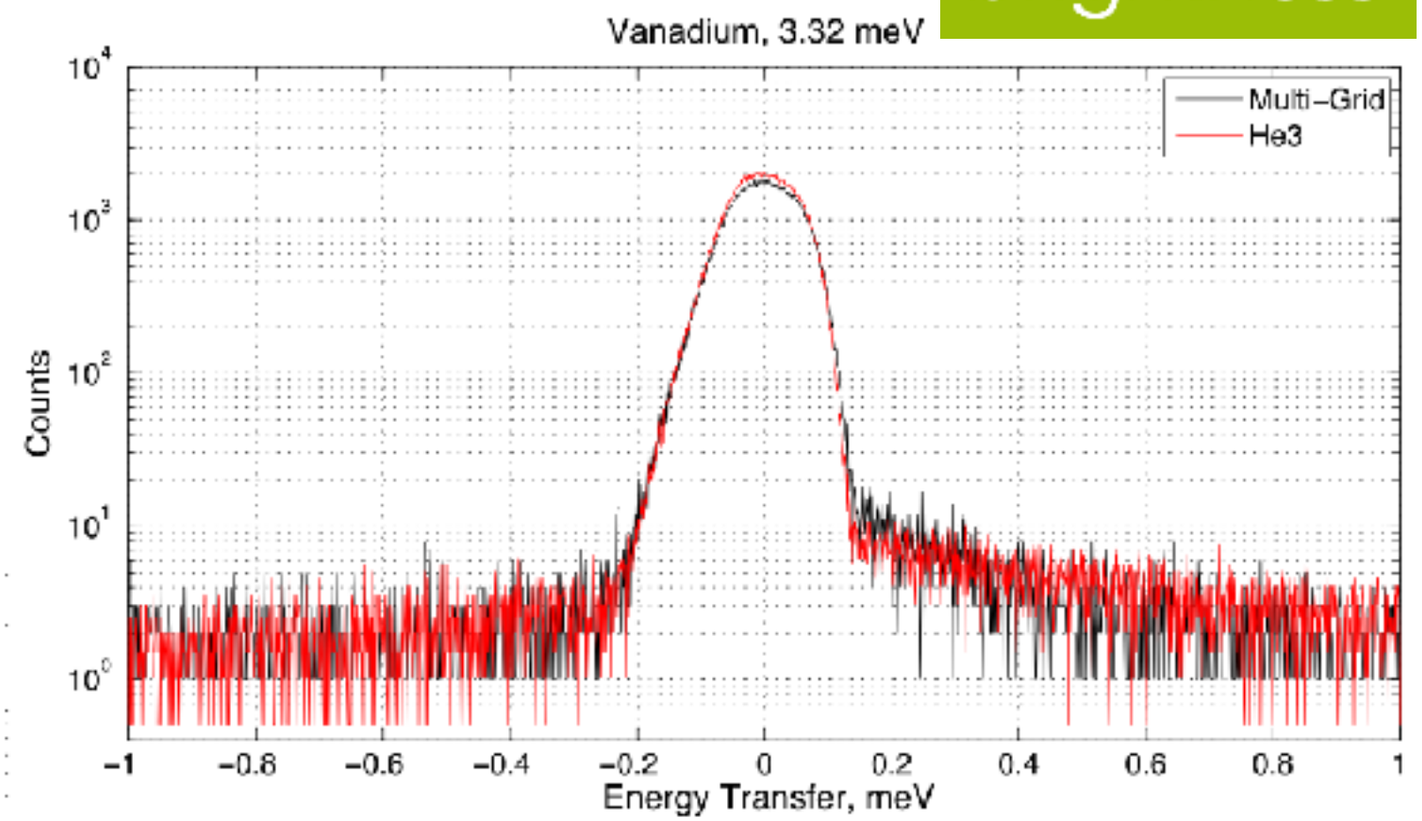
First day

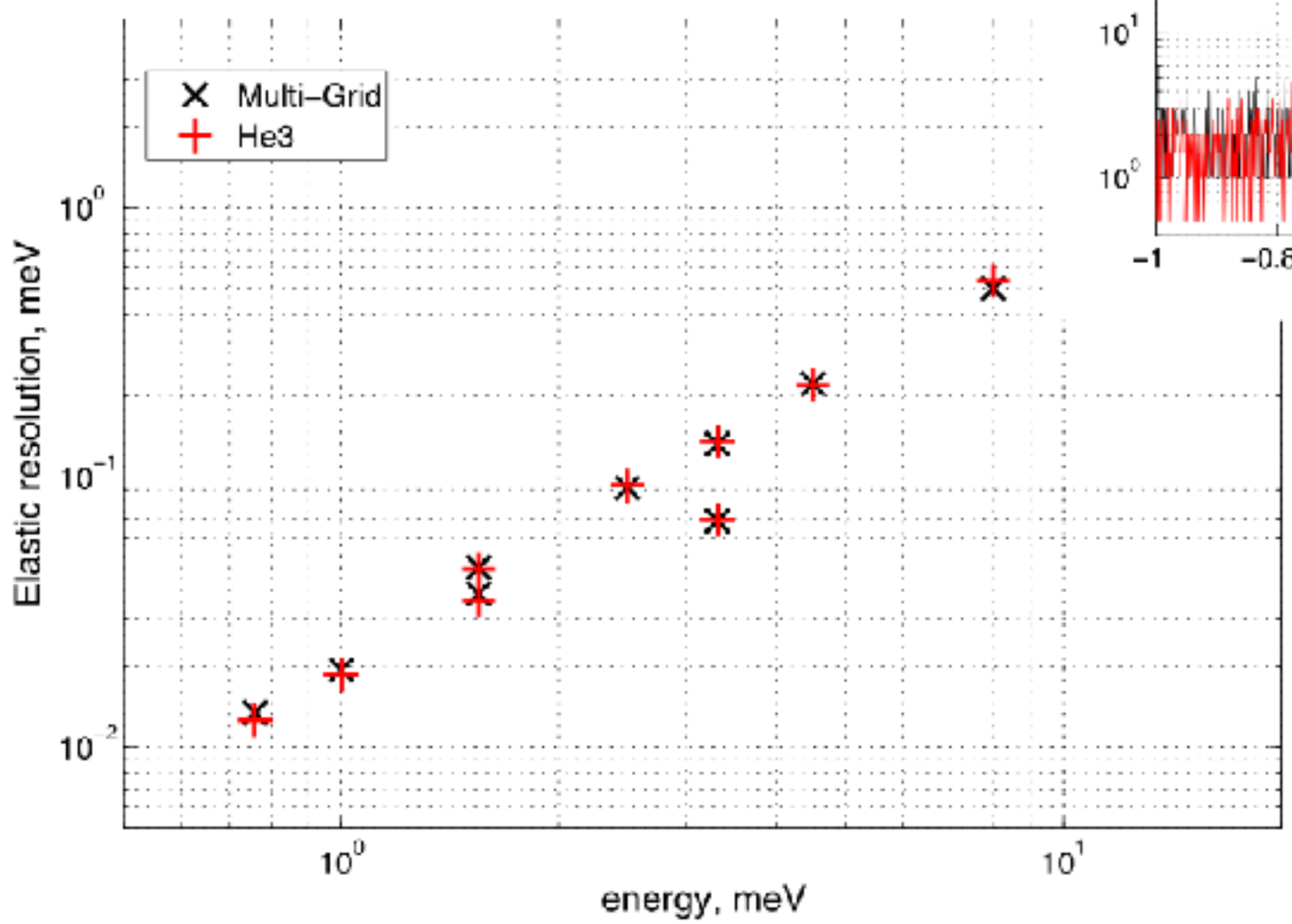
90 days

Operating without possibility of access since installation

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

Multi-Grid test at CNCS

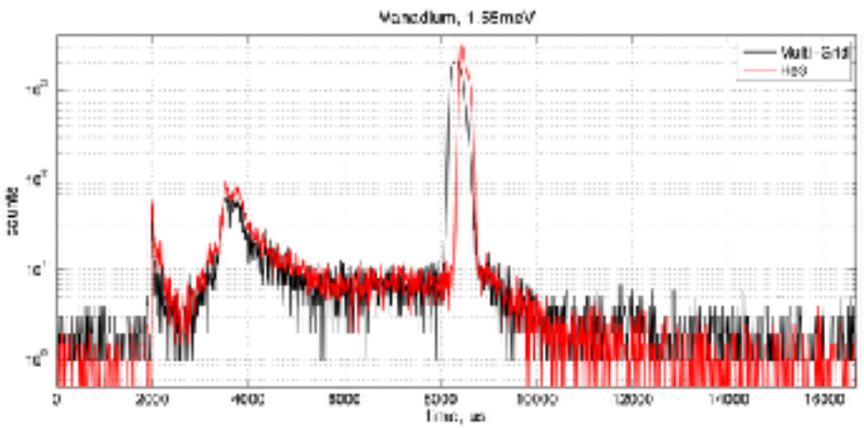




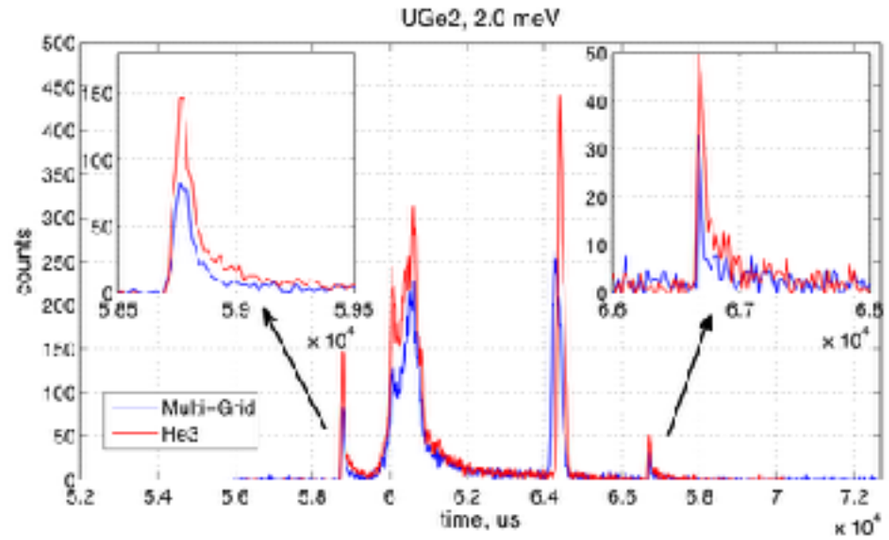
- Data and instrument resolution identical
- Technology suitable for ESS instruments

Methods Used for Tests

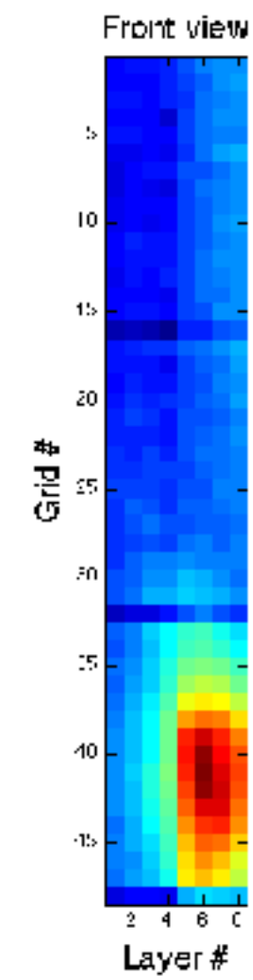
Vanadium



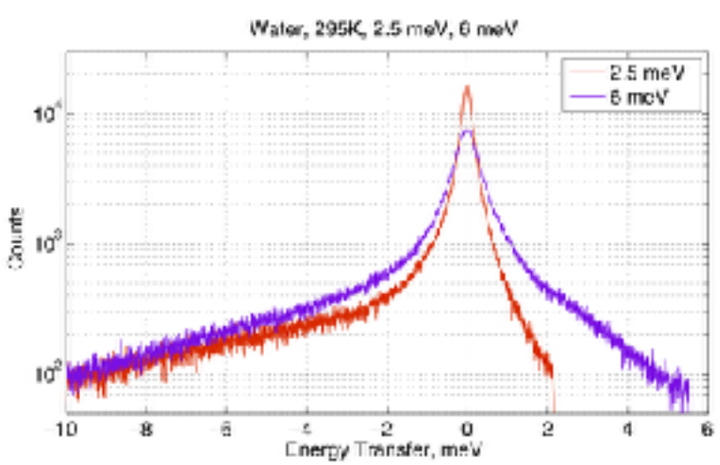
Fast neutrons (fission, prompt)



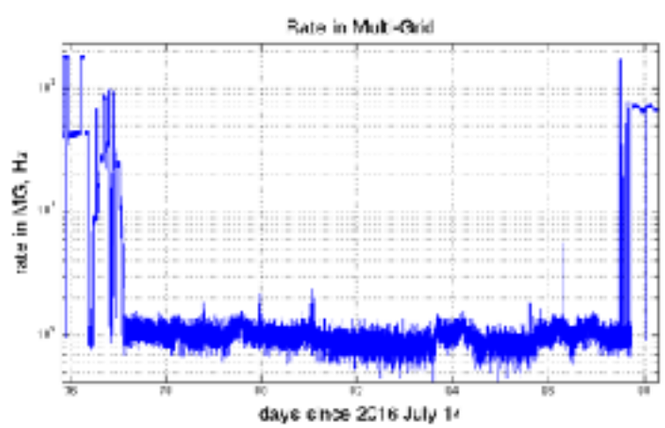
Single crystal



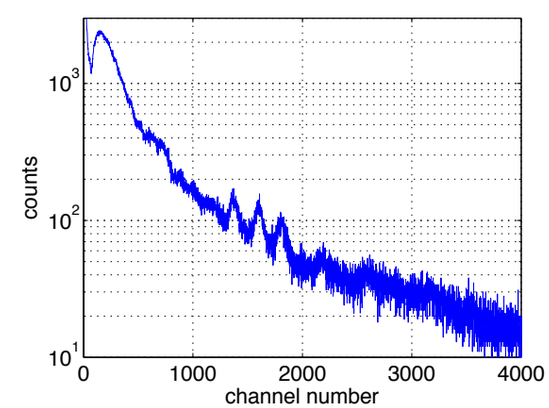
Water, Ice



Background



Gamma background (NaI detector)



Allowing to measure:

Energy resolution, efficiency, scattering, background sensitivity, saturation

Results of CNCS Test

- **Operation with no access for 11 months, until end May.**
- **Essential demonstration. MG is now the baseline detector for CSPEC and T-REX**
- **Energy resolution, efficiency, backgrounds**
  shown to be comparable between MG and He3.
- **Better performance in high rate in Multi-Grid**
- **JINST paper, 2017 JINST 12 P04030 https://arxiv.org/abs/1703.03626 for all results**

Thanks to the colleagues at SNS for this opportunity and cooperation!
These results would not be possible without you!

Prepared for submission to JINST

Multi-Grid Detector for Neutron Spectroscopy: Results Obtained on Time-of-Flight Spectrometer CNCS

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[b] *Instrument and Source Division, Spallation Neutron Source, 1 Bethel Valley Road, Oak Ridge, TN 37831 6476, USA*
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[d] *Institute Laue Langevin, 71 avenue des Martyrs, FR 38042 Grenoble, France*
[e] *Quantum Condensed Matter Division, Spallation Neutron Source, 1 Bethel Valley Road, Oak Ridge, TN 37831 6475, USA*
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[g] *Instrument and Source Division, Spallation Neutron Source, 1 Bethel Valley Road, Oak Ridge, TN 37831-6466, USA*
[h] *School of Mechanical Engineering, University of Newcastle, Callaghan, Australia*

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Abstract: The Multi-Grid detector technology has evolved from the proof-of-principle and characterisation stages. Here we report on the performance of the Multi-Grid detector, the MG.CNCS prototype, which has been installed and tested at the Cold Neutron Chopper Spectrometer, CNCS at SNS. This has allowed a side by side comparison to the performance of He 3 detectors on an operational instrument. The demonstrator has an active area of 0.2m^2. It is specifically tailored to the specifications of CNCS. The detector was installed in June 2016 and has operated since

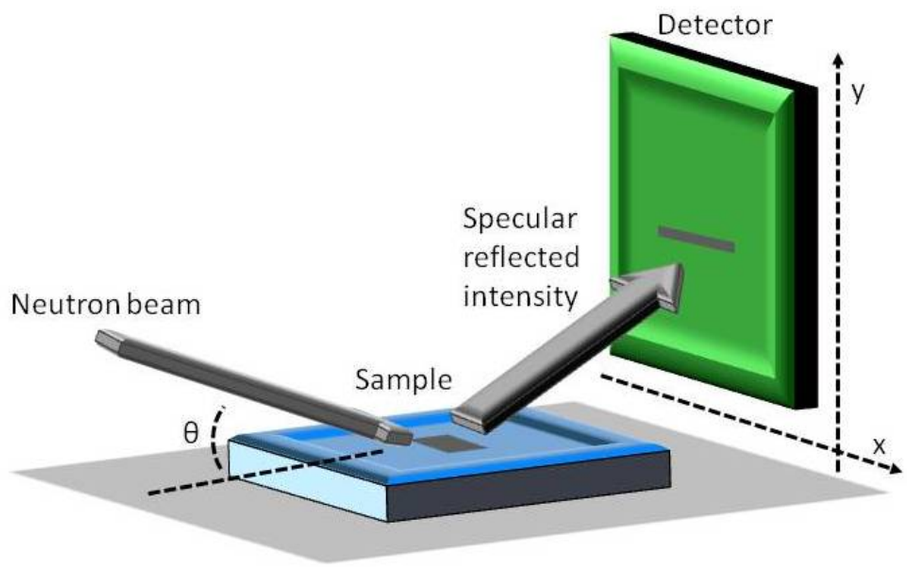
Multi-Grid test at CNCS

Next Steps:

- Data analysis still ongoing
- “Thermal” instrument demonstrator planned
- In past couple months, have visited 4SEASONS@JPARC, DIN-2PI@IBR2 and SEQUOIA@SNS to investigate feasibility and interest
- Services, vacuum, etc under design
- Integration into instrument design
- Design for CSPEC and TREX started

Neutron Reflectometry: A Rate Challenge

- 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

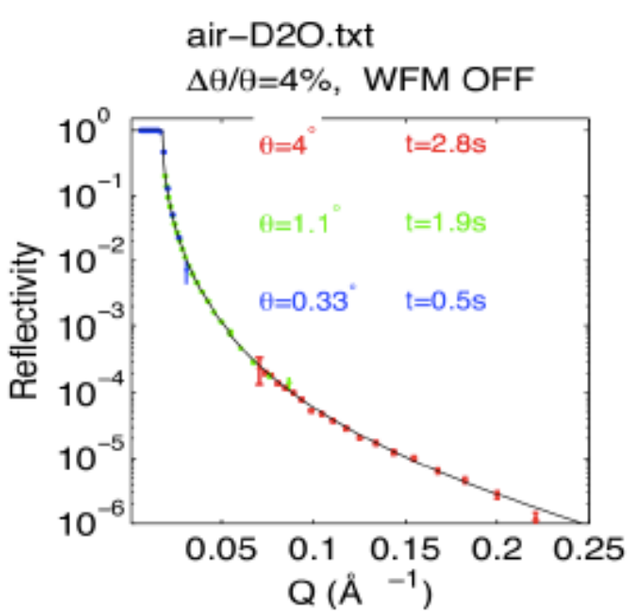
^{3}He technology

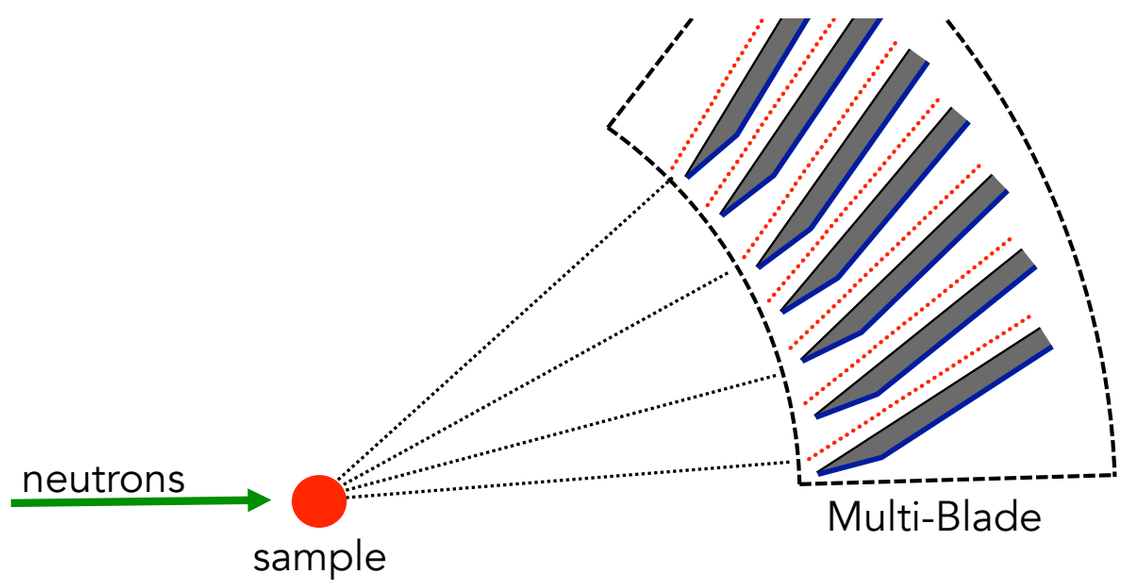
x1 x10

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

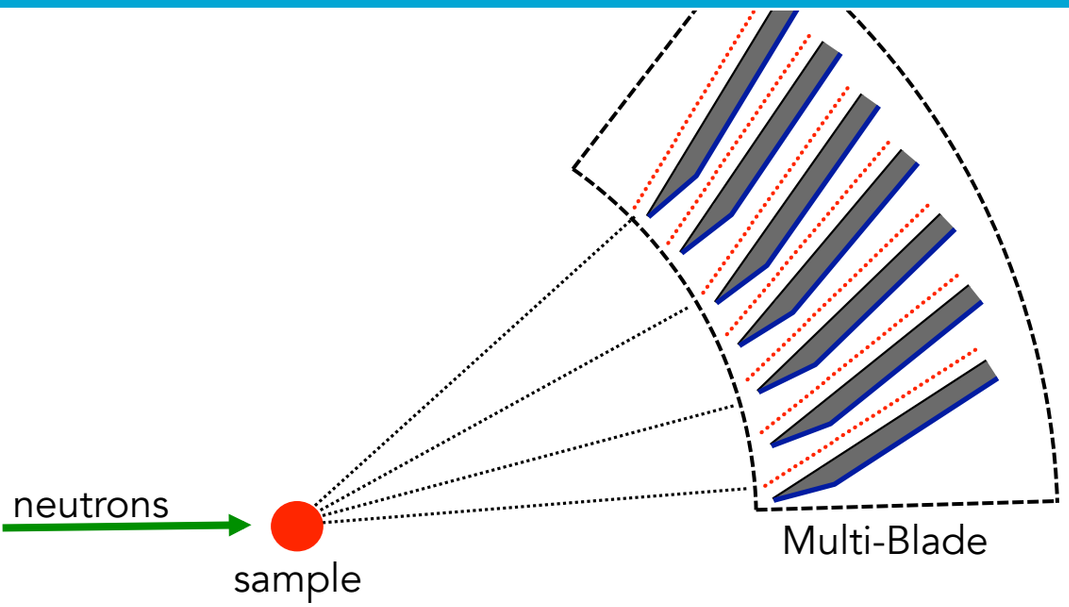
BrightnESS

EUROPEAN SPALLATION SOURCE

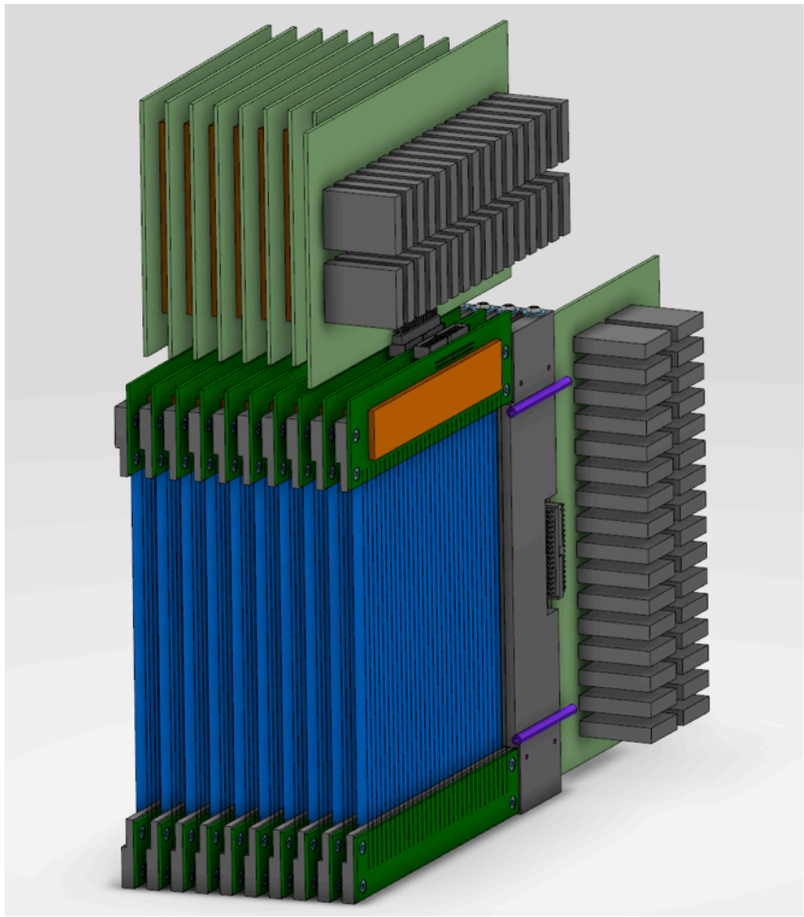
LUND UNIVERSITY

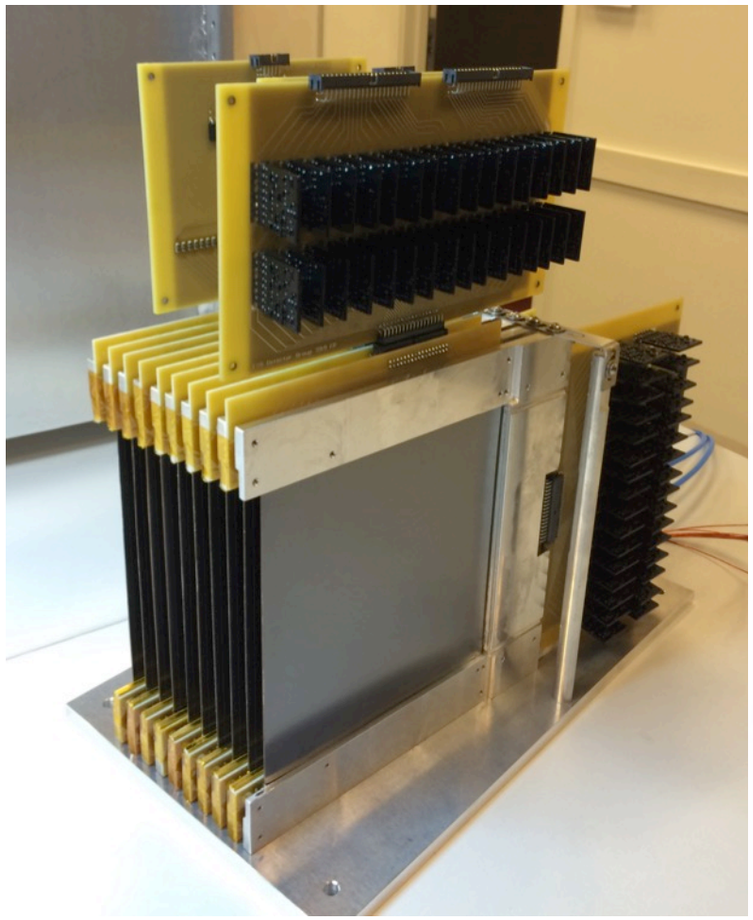
Wigner Research Institute

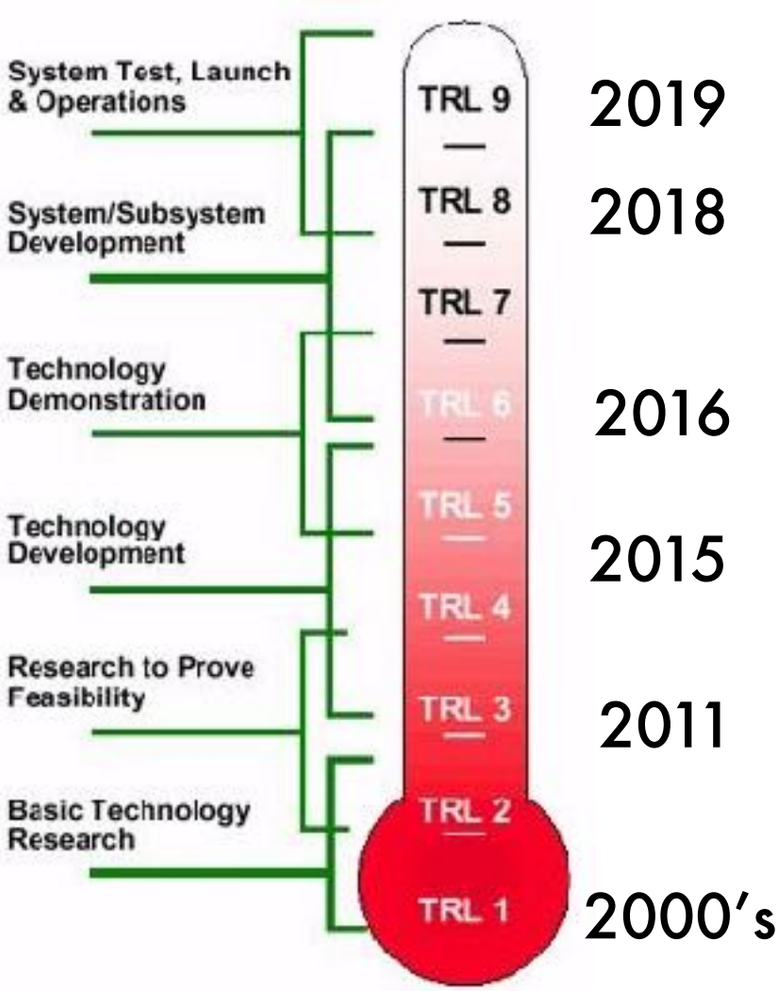
Budapest Neutron Centre



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

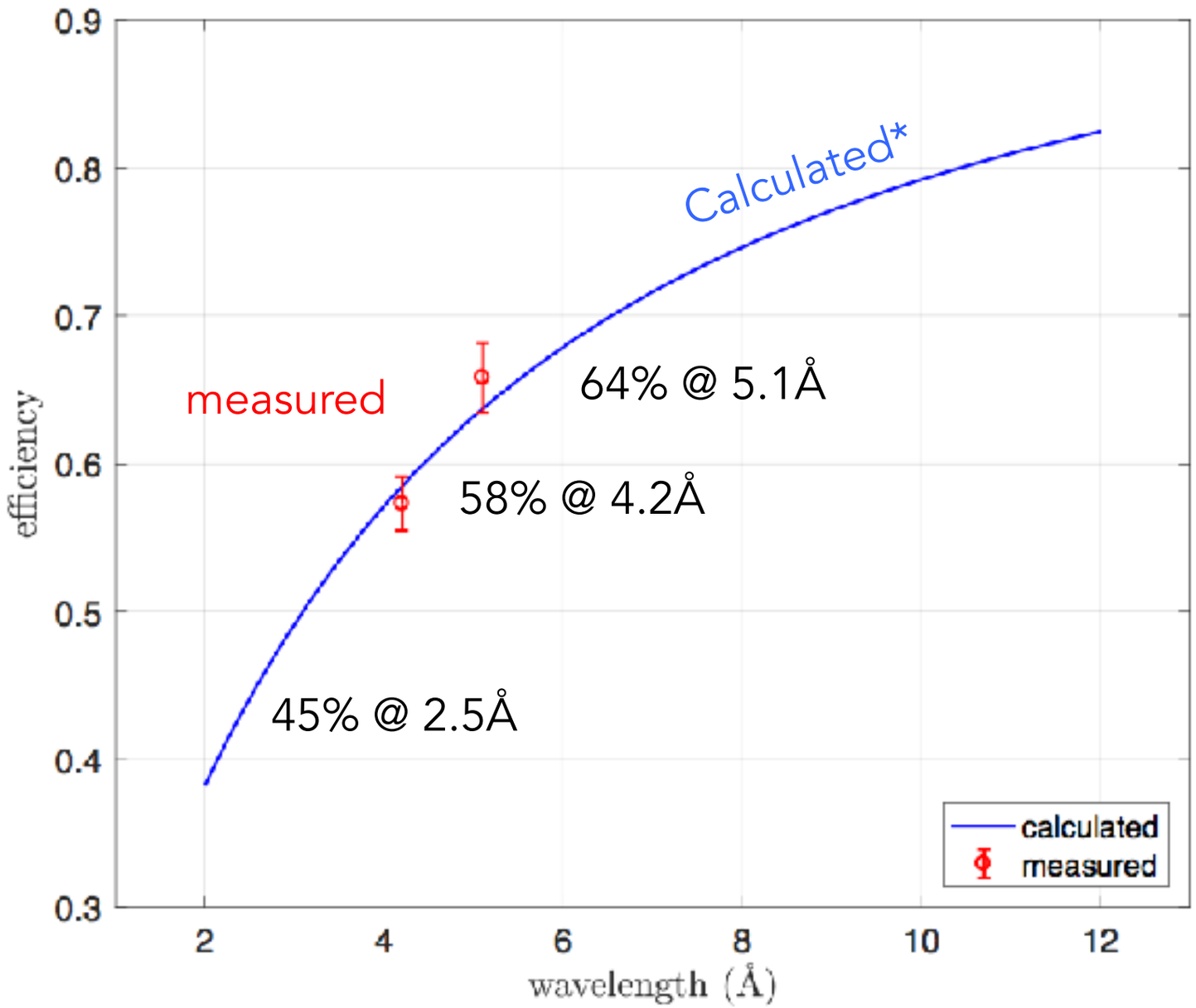


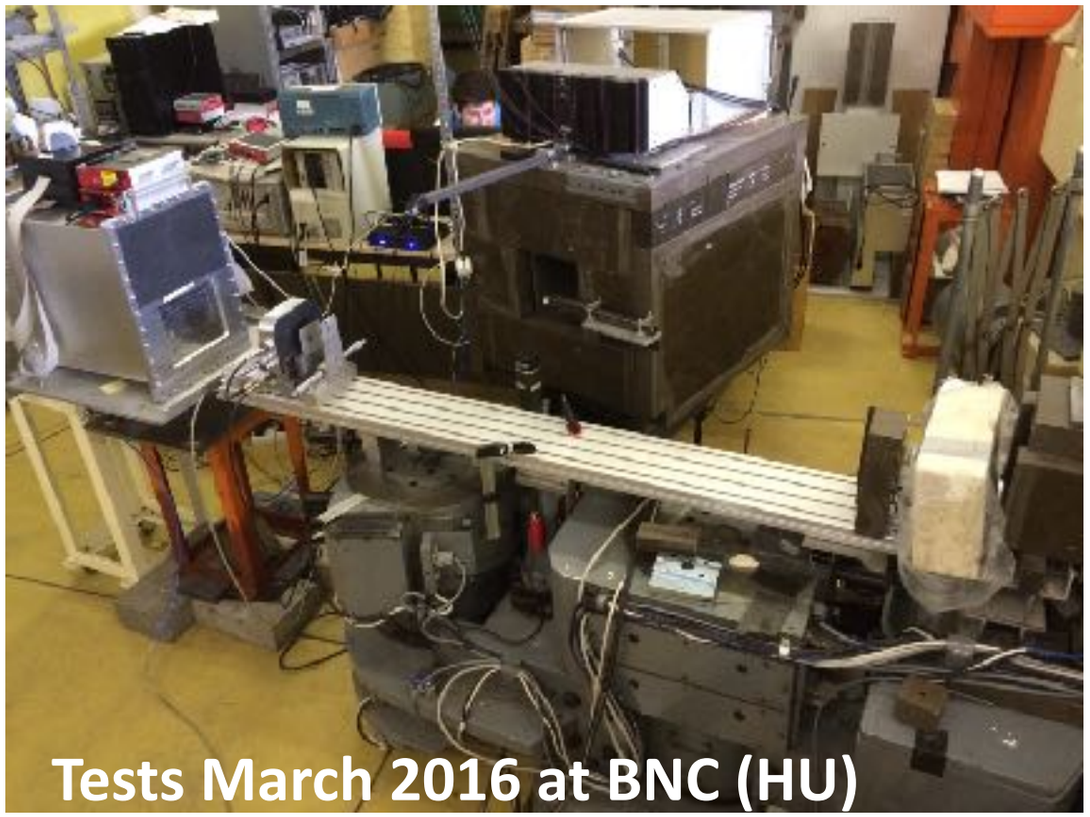




Efficiency

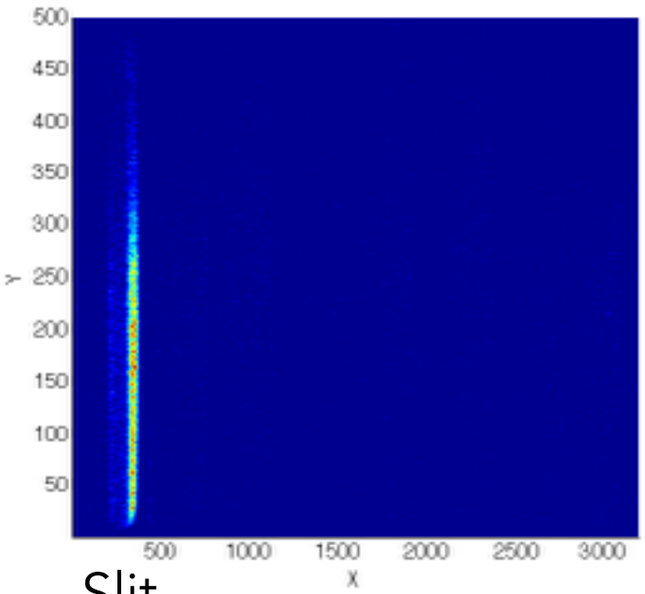
*F. Piscitelli and P. van Esch,
Analytical modeling of thin film neutron converters and its application to thermal neutron gas detectors
J. Instrum. 8, P04020 (2013)
arXiv:1302.3153



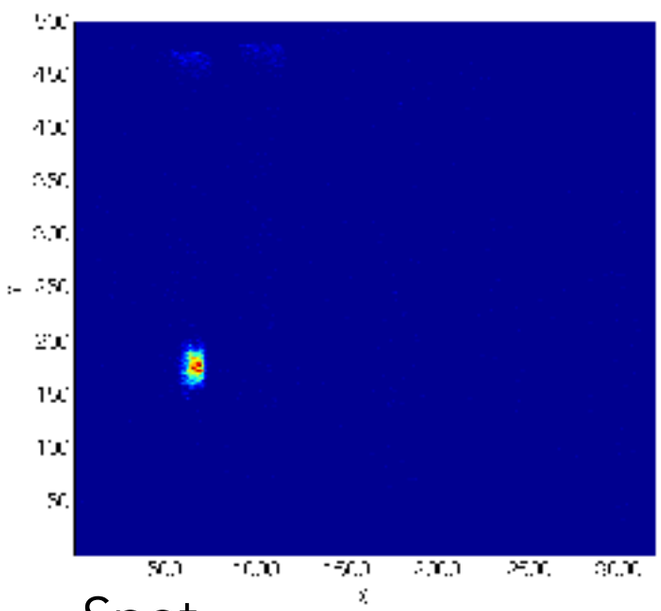


F. Piscitelli et al., The Multi-Blade Boron-10-based Neutron Detector for high intensity Neutron Reflectometry at ESS, JINST 12 (3) P03013 (2017).

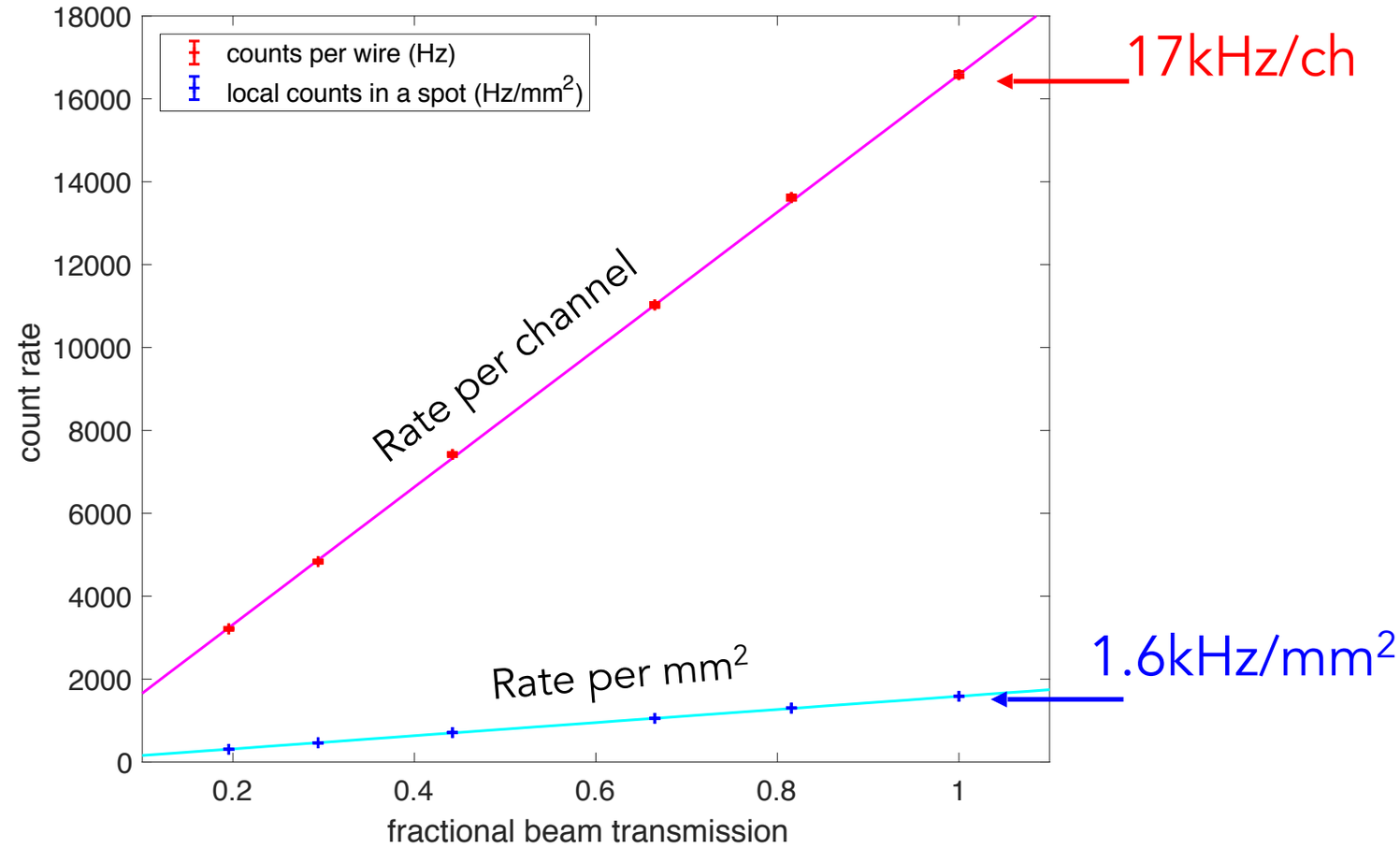
Counting rate capability



Slit



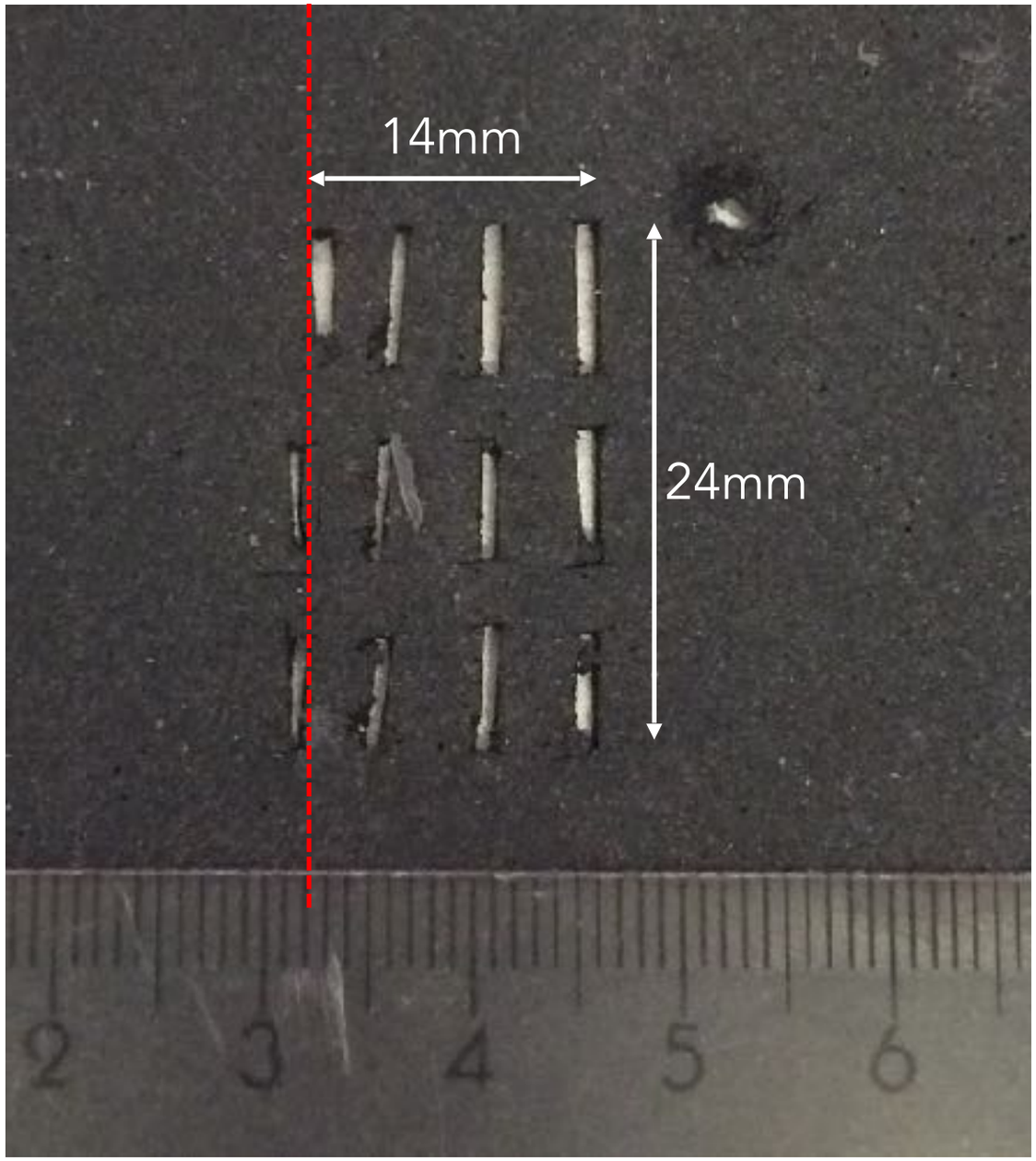
Spot



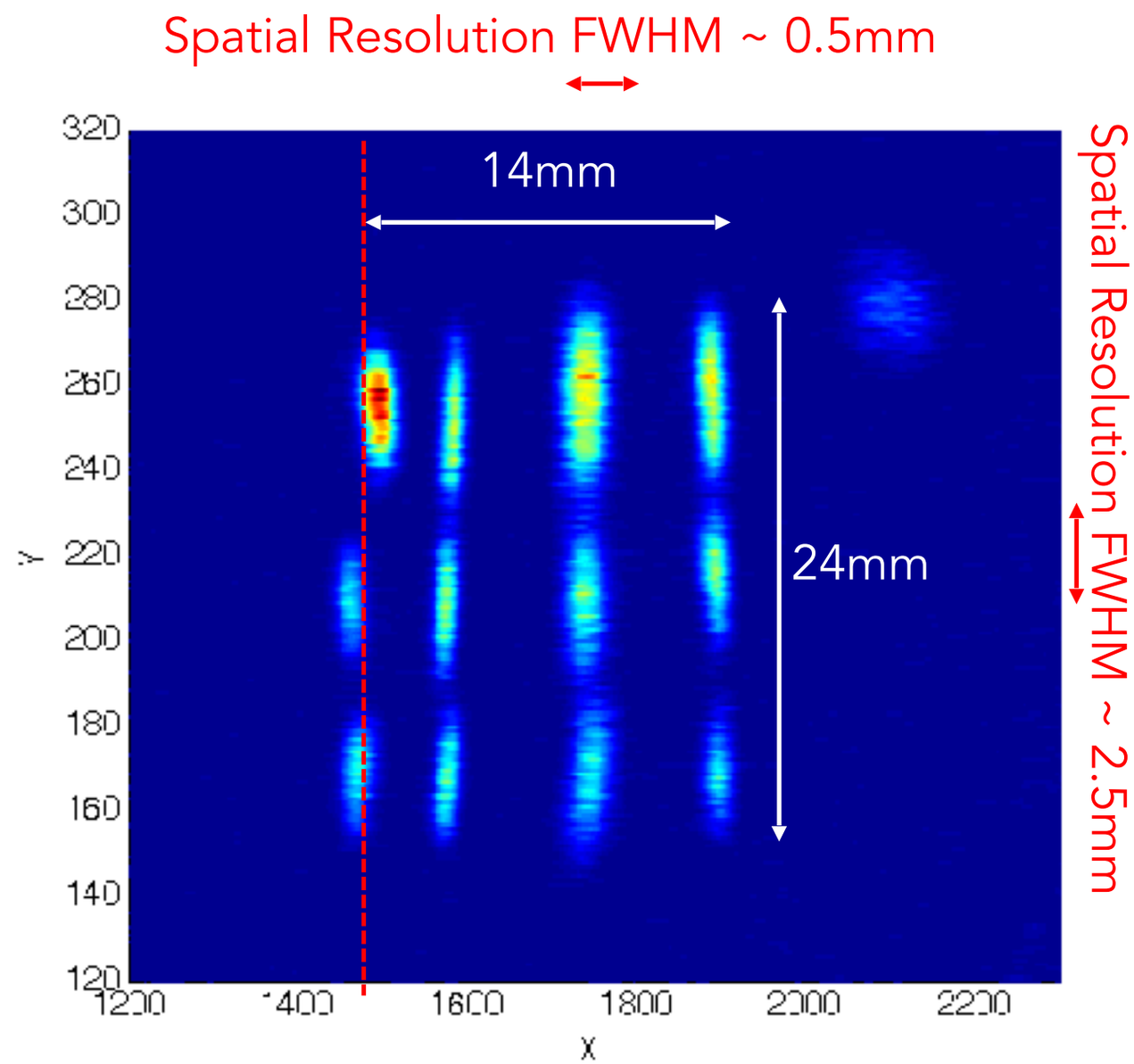
No saturation observed!

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



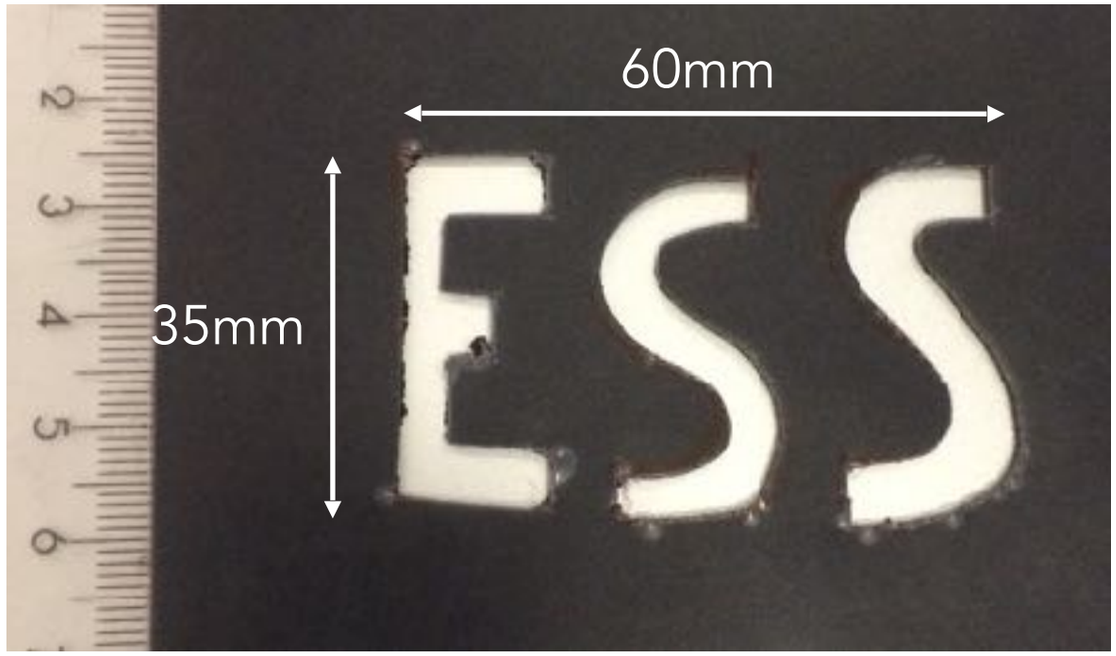
Mask



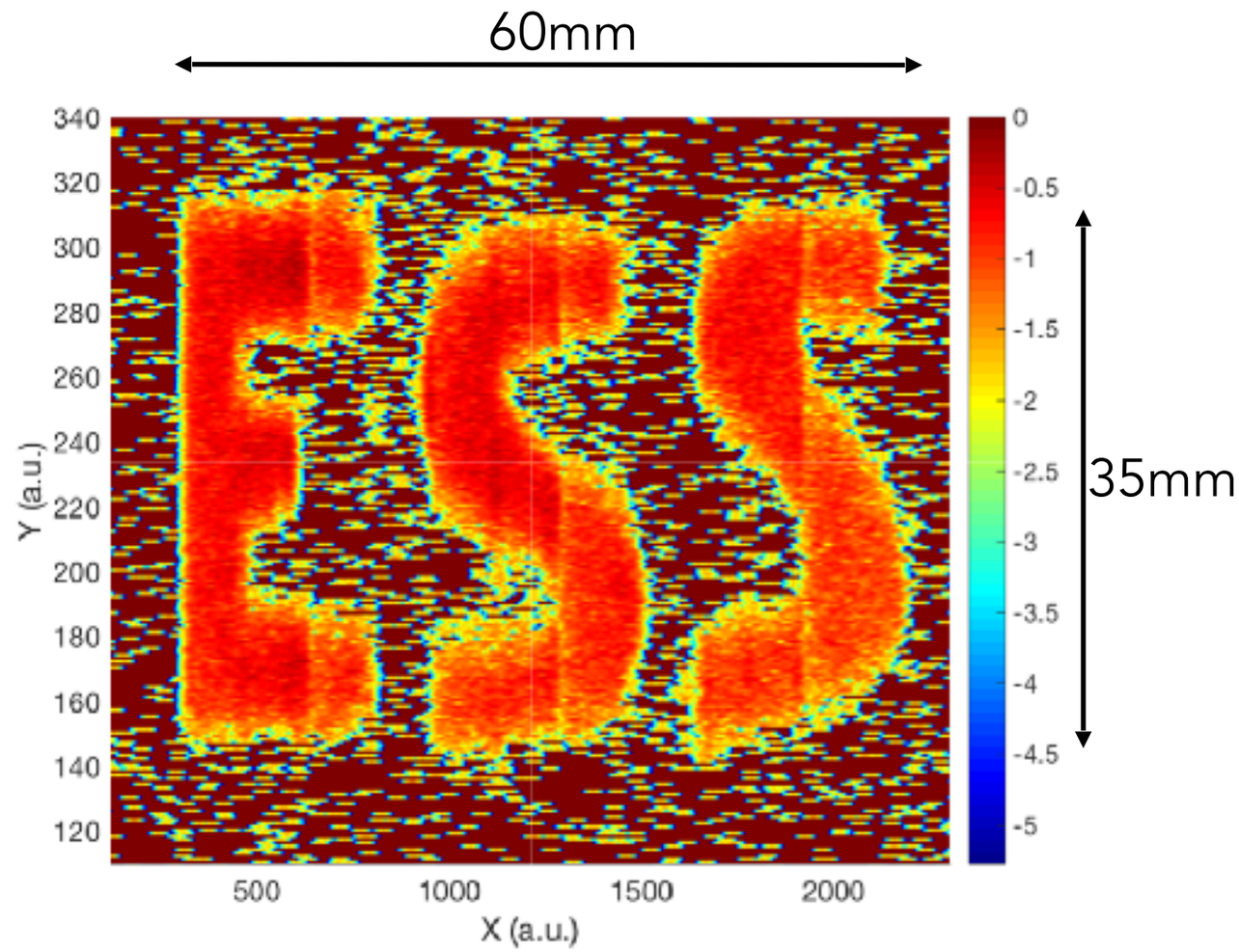
Raw image from the detector

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



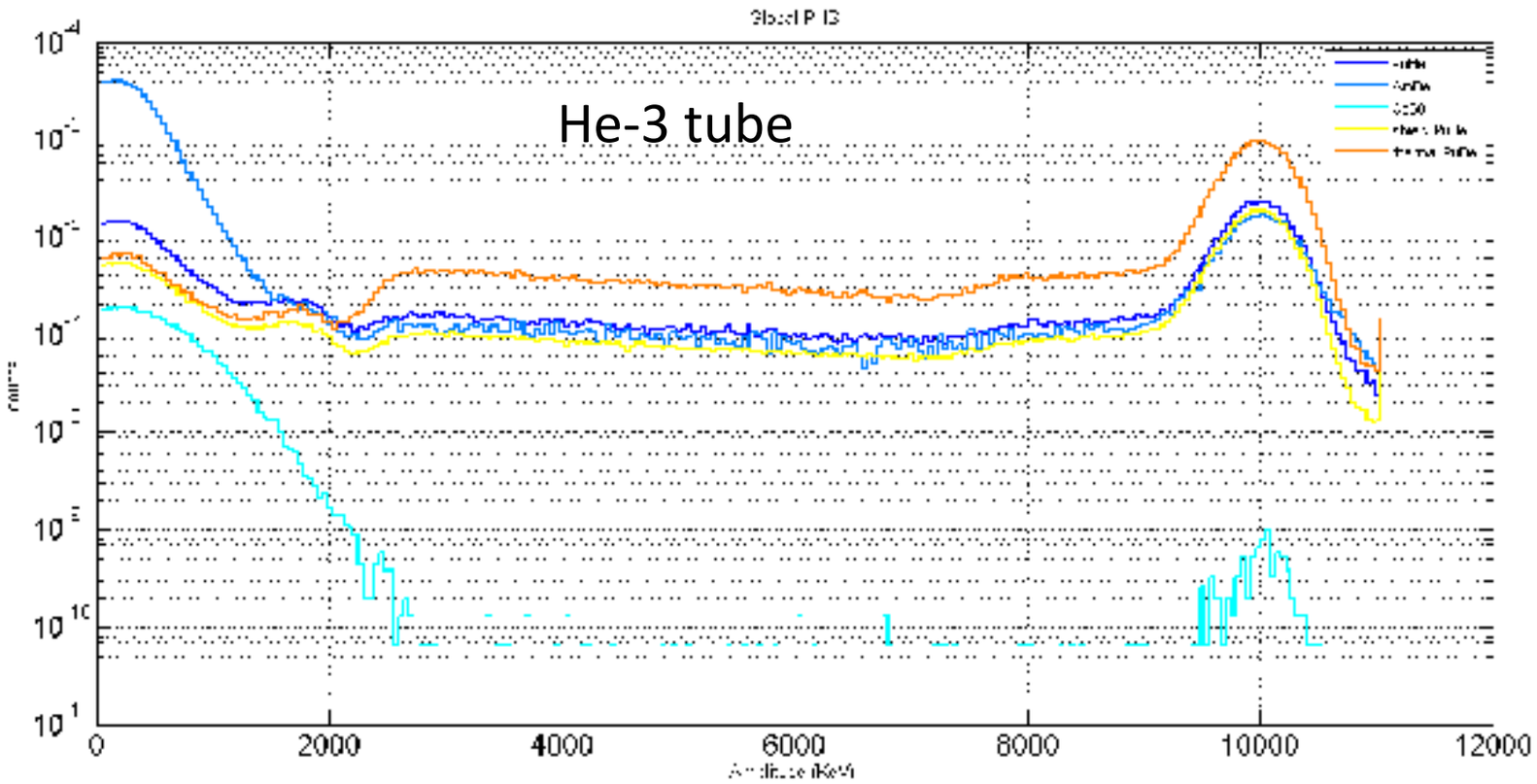
Mask



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).

A very first look at fast neutrons

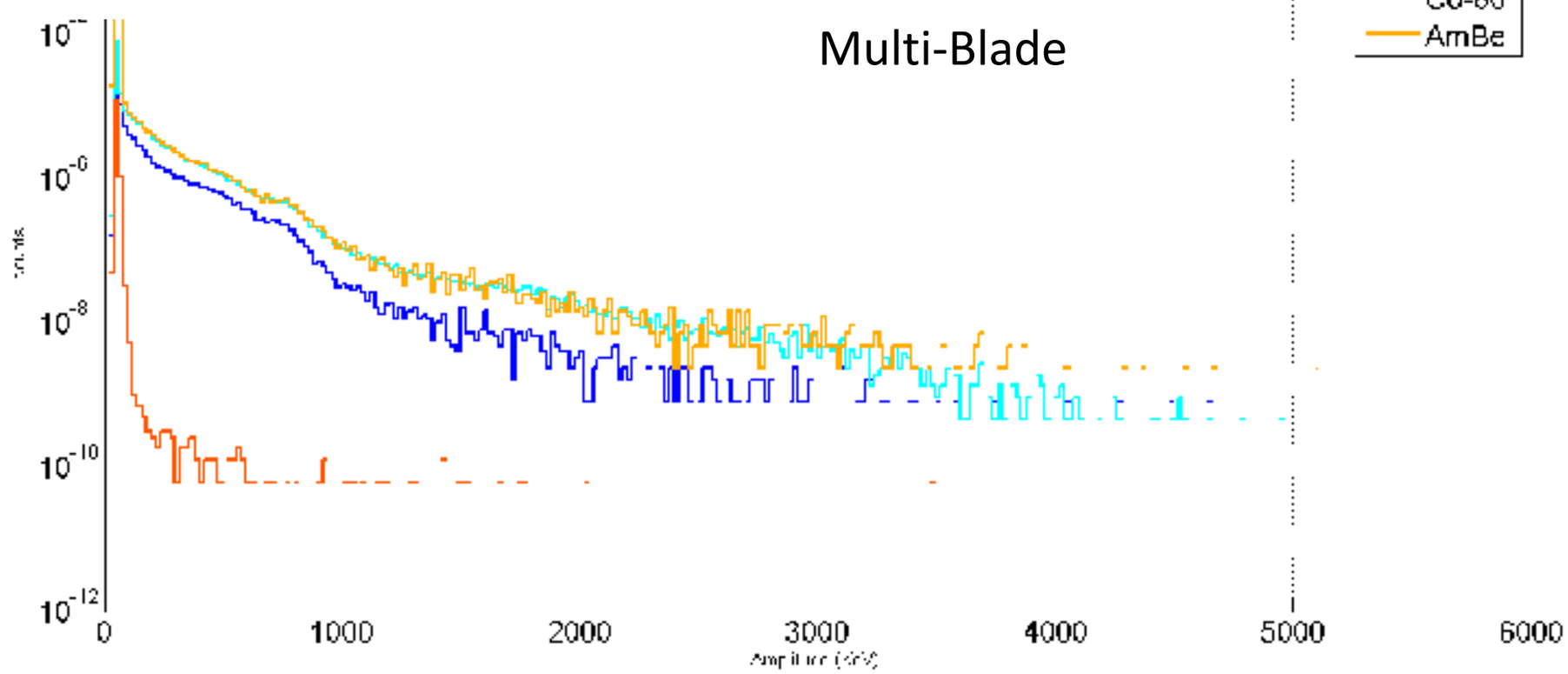


Unmoderated source

Very raw and preliminary data …

Very different response

"work in progress"



Qualitatively what has been seen for MG

Giacomo Mauri (U Perugia) &
Francesco Messi (Lund U) &
Francesco Piscitelli

Summary

Matching ESS requirements

	Multi-Blade 2013	Multi-Blade 2016
gas gain	58	$20 \perp 3$
efficiency	$(26 \pm 0.2)\,\%$ at $(10°, 2.5Å)$	44% at $(5°, 2.5Å)$ (calculated) $(56 \pm 2)\,\%$ at $(5°, 4.2Å)$ $(65 \pm 2)\,\%$ at $(5°, 5.1Å)$
spatial resolution	$\approx 0.3 \times 1\,mm^2$	$\approx 0.5 \times 2.5\,mm^2$
uniformity	$\leq 2\%$	$\leq 10\%$
overlap	$\approx 50\%$ eff. drop in $2\,mm$ gap	$\approx 50\%$ eff. drop in $0.5\,mm$ gap
stability	–	$< 1\%$ in 12h
counting rate capability	– –	$> 1.6\,KHz/mm^2$ $> 16.6\,KHz/channel$
gamma sensitivity	– –	$< 10^{-7}$ (for $100\,KeV$ threshold)

x3 better than state-of-the-art

x10 better than state-of-the-art

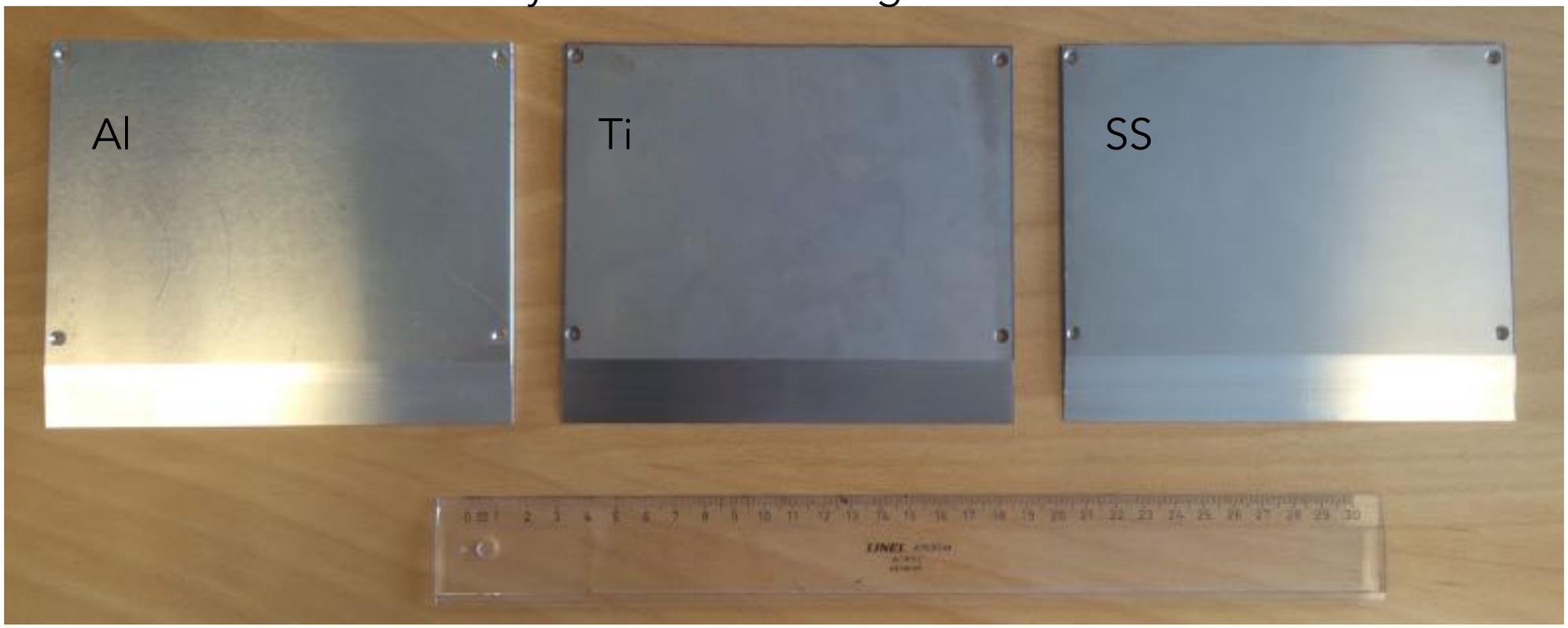
new detector built (2 copies):

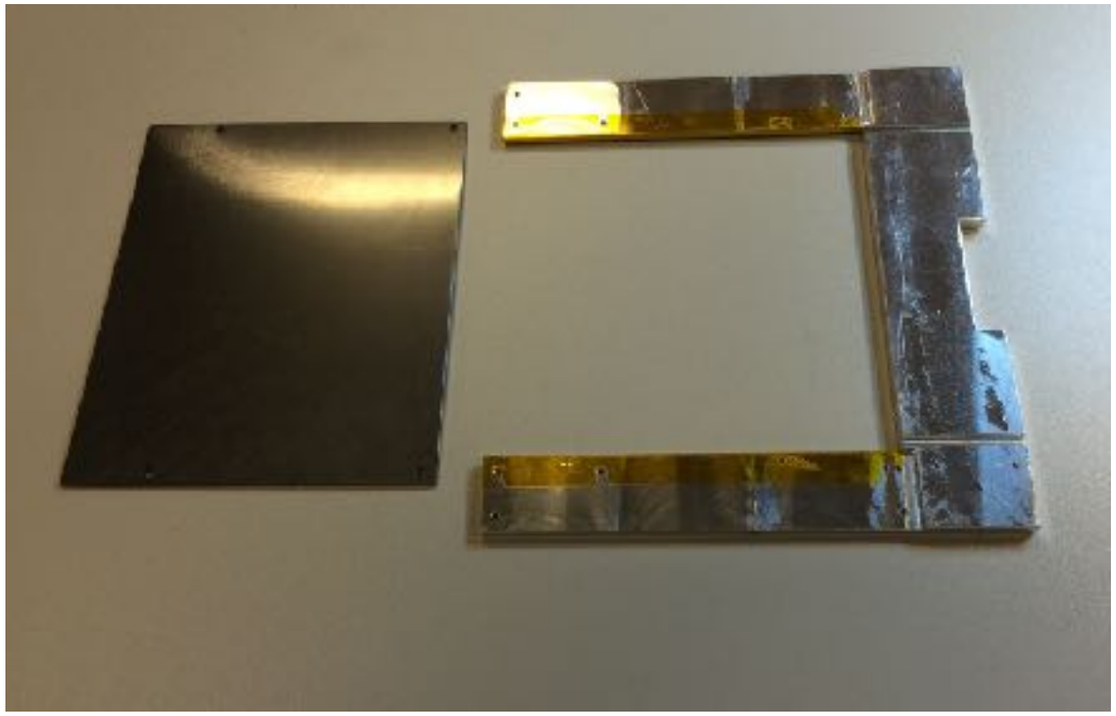
1 in Lund, 1 in Wigner (HU)

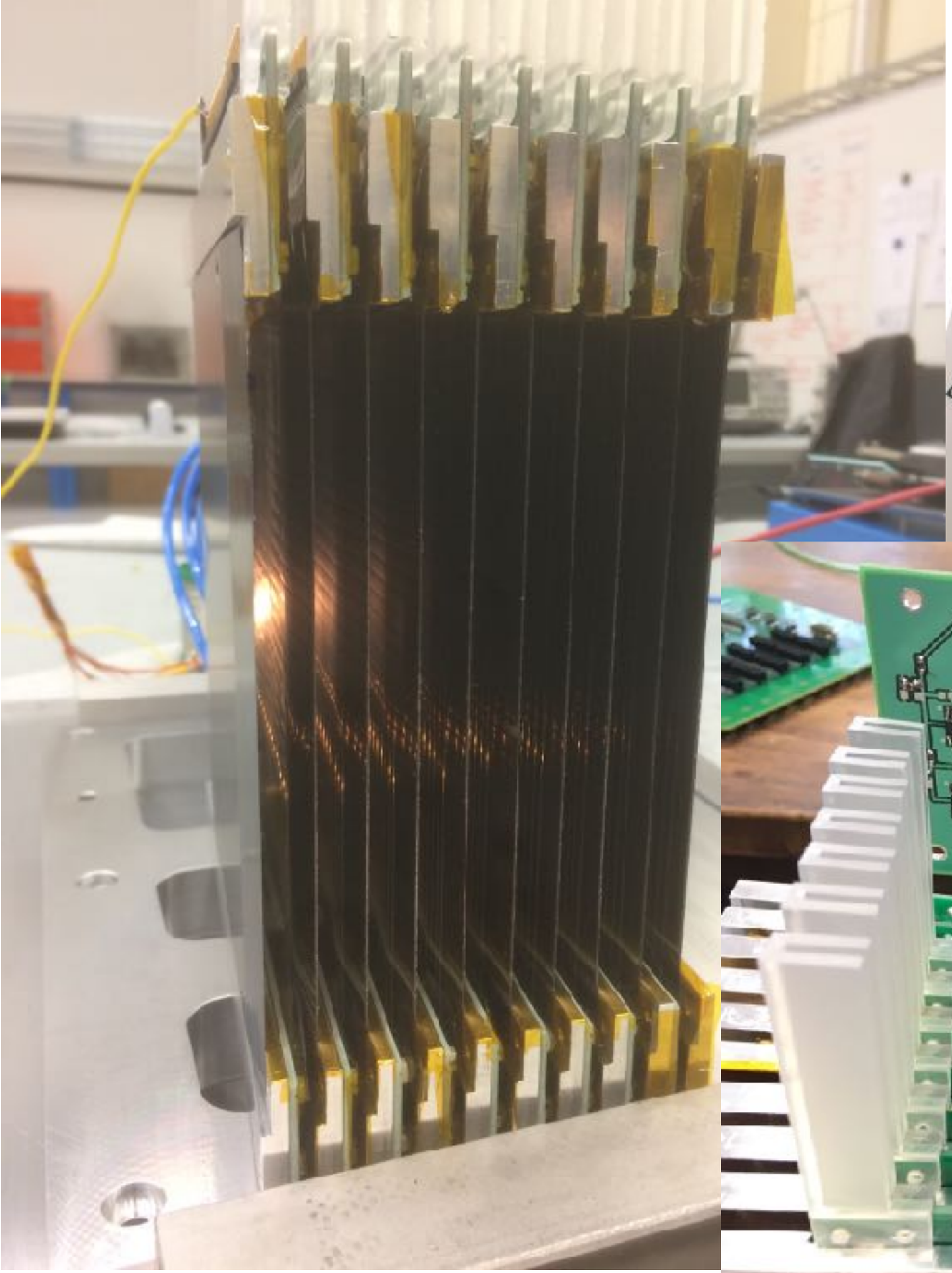
First test of electronics+detector will take place at BNC next week

The new detector is going to be tested this year on a Reflectometer (ISIS, maybe at ILL)

Planarity is an issue on large surfaces on Al







Detectors for ESS: strategy update for 16 instruments

EUROPEAN SPALLATION SOURCE

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)

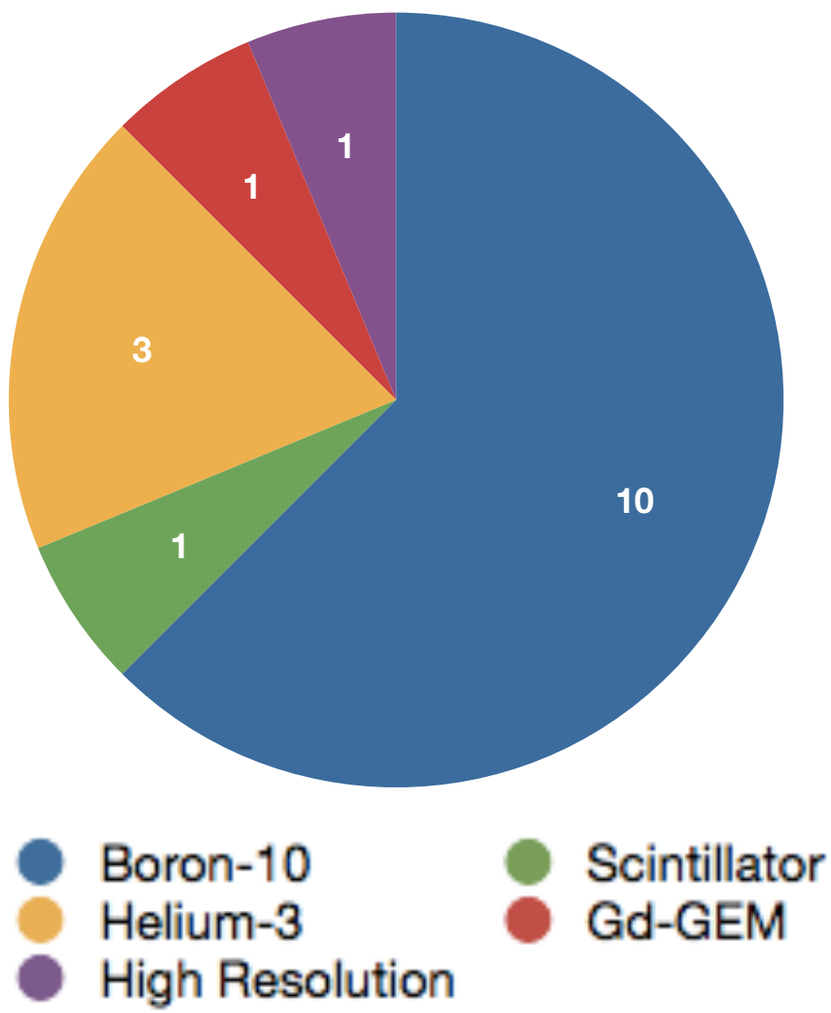
EUROPEAN SPALLATION SOURCE

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

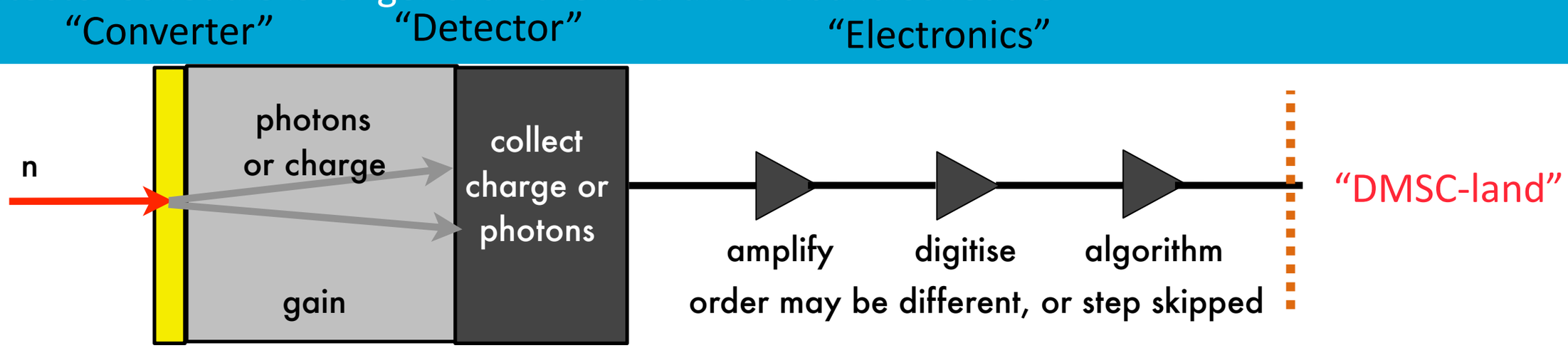
Detectors for ESS will comprise many different technologies

Best-Guess at Detector Technologies for 16 Instruments:



Schedule: Where are we for detectors?

Detector schedule is longer than the instrument build schedule



2011	2012	2013	2014	2015	2016	2017
Coatings	Detector Conceptual Designs	Detector Prototype Designs	Strategy for Instruments, Instrument Designs	People, workshops and facilities, Instrument Designs	Electronics ICS/DMSC interface Instrument conceptual design	Instrument Detector Design Electronics ICS/DMSC interface Construction

2018	2019	2020	2021	2022	2023	2024	2025
Electronics /ICS/DMSC	Design	Construction	Construction	Construction	Installation	Installation	Installation
Design	Construction	Installation	Installation	Installation	Commissioning	Commissioning	Commissioning
Construction	Installation	Commissioning	Commissioning	Commissioning	Operation	Operation	Operation

ESS Partners on Detectors

Mittuniversitetet
MID SWEDEN UNIVERSITY

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
UNIVERSITA' 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
IEAP
CDT GmbH CASCADE Detector Technologies
UJF
FZÚ
Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung
UNIVERSITY OF MALTA
Risø DTU National Laboratory for Sustainable Energy
ideas
COSYLAB
IFE Institute for Energy Technology
JÜLICH FORSCHUNGSZENTRUM
Mittuniversitetet MID SWEDEN UNIVERSITY

icnd.org {

NEUTRONS FOR SCIENCE · ess · FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz · HZB Helmholtz Zentrum Berlin · ISIS · J-PARC · JCNS · NMI3 · Oak Ridge National Laboratory Neutron Sciences

INTERNATIONAL COLLABORATION FOR THE DEVELOPMENT OF NEUTRON DETECTORS }

Summary

- Construction is proceeding rapidly
- 15 instruments are entering construction for ESS
- There is a baseline detector design for these instruments
- Developments are proceeding well

brightness SoNDe Solid-State Neutron Detector SINE 2020