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SoNDe Solid-State Neutron Detector

brightness

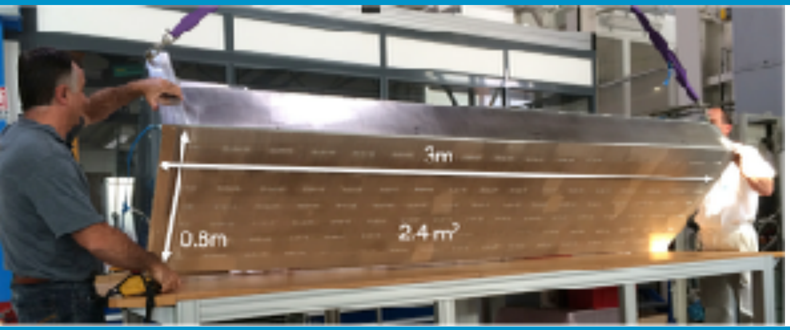
ess EUROPEAN SPALLATION SOURCE

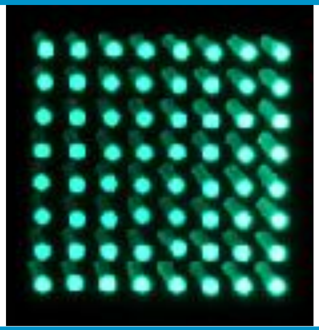
Where we are with NSS Detector Systems

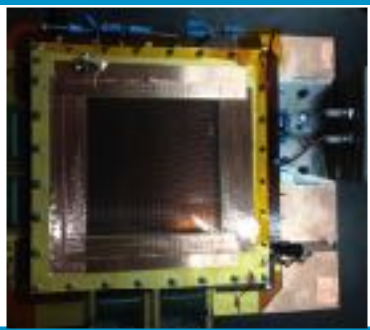
Richard Hall-Wilton

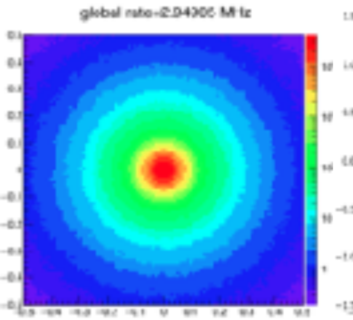
Leader of Detector Group
Deputy Division Head of Instrument Technologies

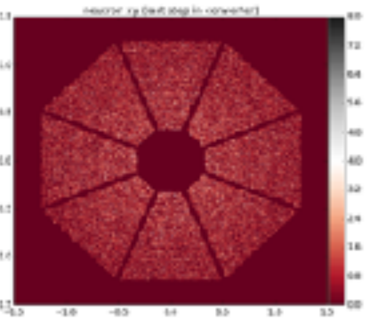
On Behalf of the ESS Detector Group and Partners

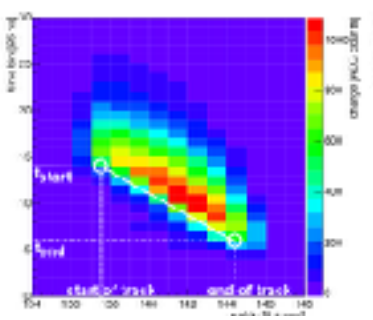


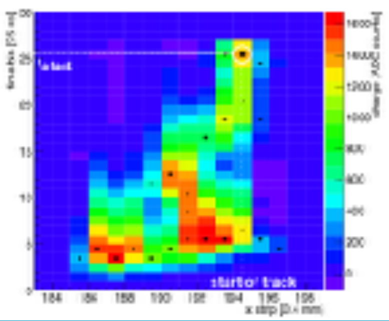


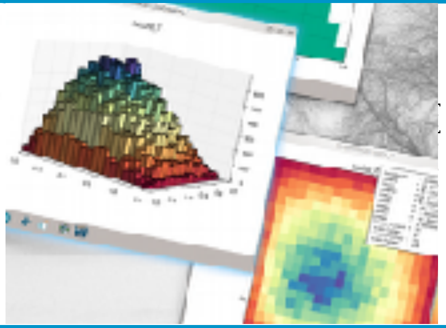


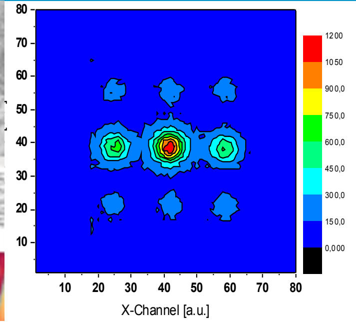


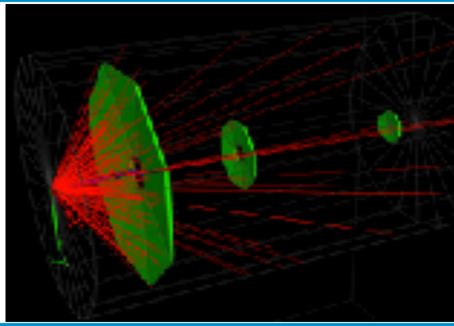












ESS Partners on Detectors

On Behalf of the ESS Detector Group and Partners

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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

Laboratoire Léon Brillouin

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) 4131/249032

IEAP

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
FORSCHUNGSZENTRUM

FLNP

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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

ESS Partners on Detectors

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the detector developments are **team efforts**: large number of people and institutes involved

… for example: MultiGrid …

everyone who made a material contribution

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

M. Anastasopoulos[a], R. Bebb[a], K. Berry[b], J. Birch[c], T. Brys[b], J.-C. Buffet[d], J.-F. Clergeau[d], P. P. Deen[a], G. Ehlers[b], P. van Esch[d], M. Everett[b], B. Guerard[d], R. Hall-Wilton[a,e], K. Herwig[b], L. Hultman[c], C. Höglund[a,c], I. Iruretagoiena[a], F. Issa[a], J. Jensen[c], A. Khaplanov[a*] O. Kirstein[a], I. Lopez Higuera[a], F. Piscitelli[a], L. Robinson[a], S. Schmidt[a], I. Stefanescu[a]

[a] *European Spallation Source, P.O Box 176, SE-22100 Lund, Sweden*
[b] *Spallation Neutron Source, 1 Bethel Valley Road, Oak Ridge, TN 37831, USA*
[c] *Linköping University, Thin Film Physics division, IFM, SE-581 83 Linköping, Sweden*
[d] *Institute Laue Langevin, 71 avenue des Martyrs, FR-38042 Grenoble, France*
[e] *Mid-Sweden University, SE-85170 Sundsvall, Sweden.*
E-mail: Anton.Khaplanov@esss.se

The Multi-Blade Boron-10-based Neutron Detector for high intensity Neutron Reflectometry at ESS

F. Piscitelli,[a,1] F. Messi,[b] M. Anastasopoulos,[a] T. Bryś,[a] F. Chicken,[a] E. Dian,[c] J. Fuzi,[d] C. Höglund,[a,e] G. Kiss,[d] J. Orban,[d] P. Pazmandi,[d] L. Robinson,[a,e] L. Rosta,[d] S. Schmidt,[a,e] D. Varga,[d] T. Zsiros,[d] R. Hall-Wilton[a,f]

[a] *European Spallation Source ERIC (ESS), P.O. Box 176, SE-22100 Lund, Sweden.*
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[d] *Wigner Research Centre for Physics, Konkoly Thege Miklós út 29-33, H-1121 Budapest, Hungary.*
[e] *Thin Film Physics Division, Linköping University, SE-58183 Linköping, Sweden.*
[f] *Mid-Sweden University, SE-85170 Sundsvall, Sweden.*

E-mail: francesco.piscitelli@esss.se

… for example: MultiBlade …

Contents of this talk:

ESS Neutron Instrument positions: December 2016

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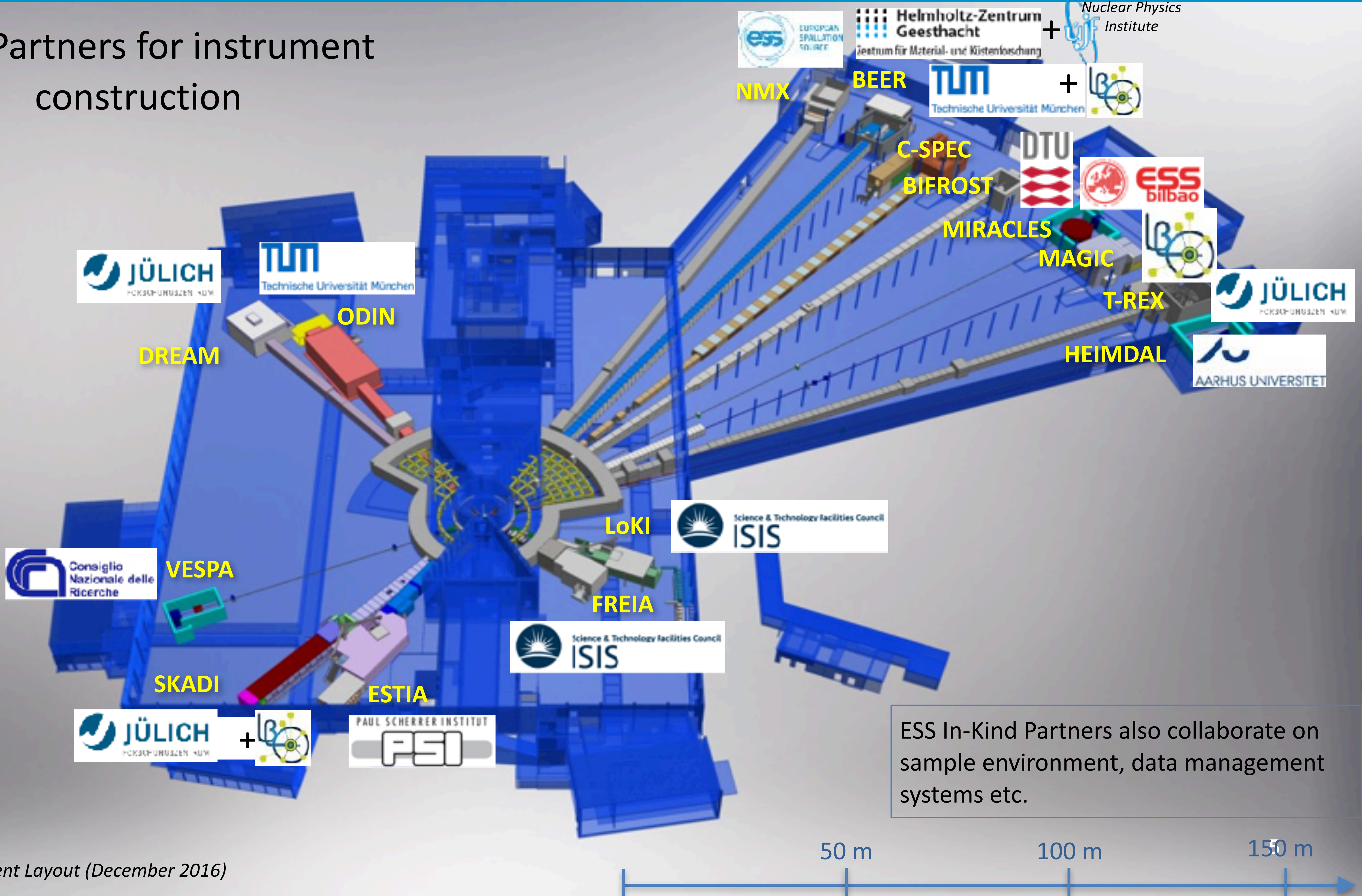
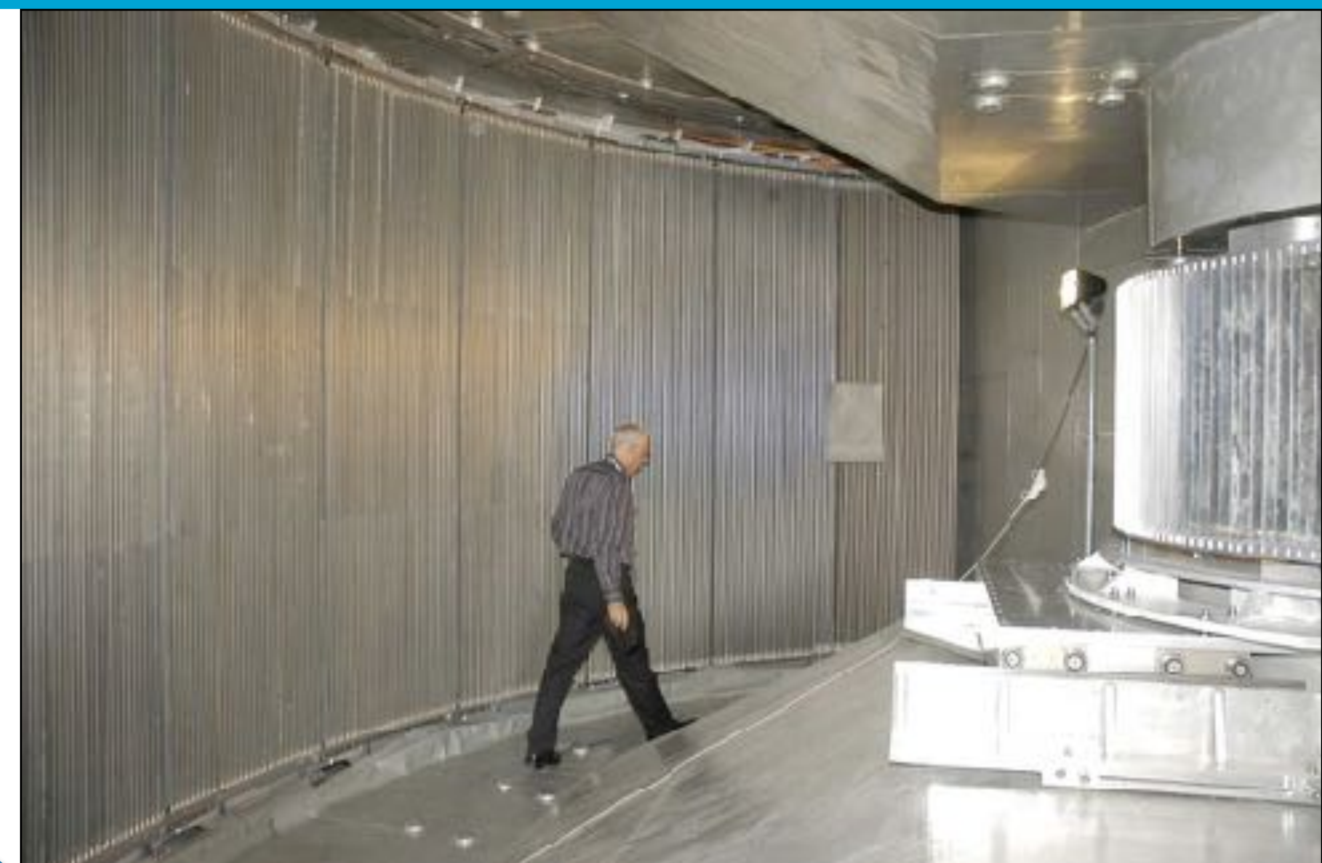
Lead Partners for instrument construction

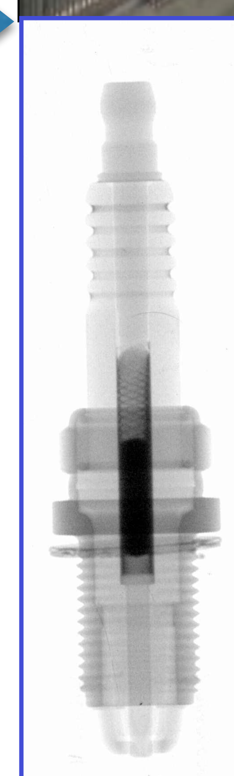


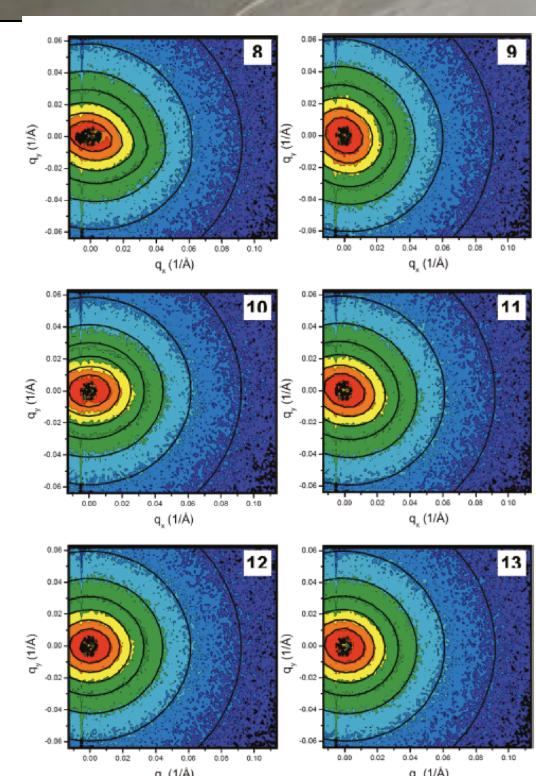
ESS In-Kind Partners also collaborate on sample environment, data management systems etc.

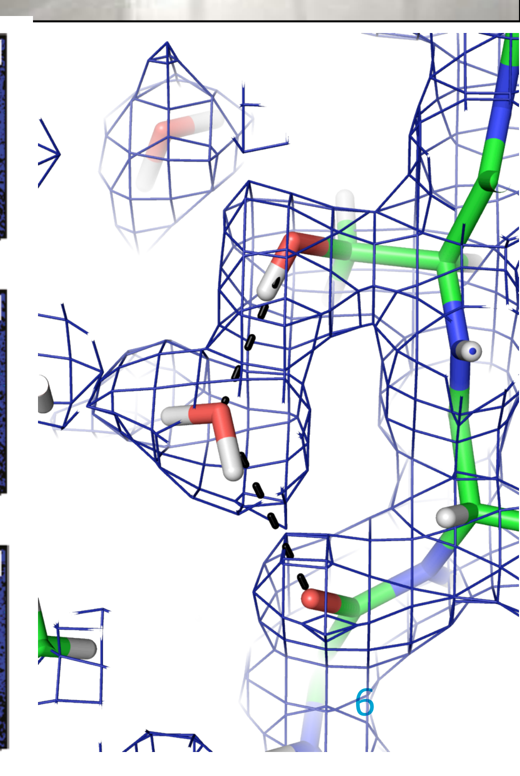
ESS Instrument Layout (December 2016)

Detector Strategy:
how we get from here to there







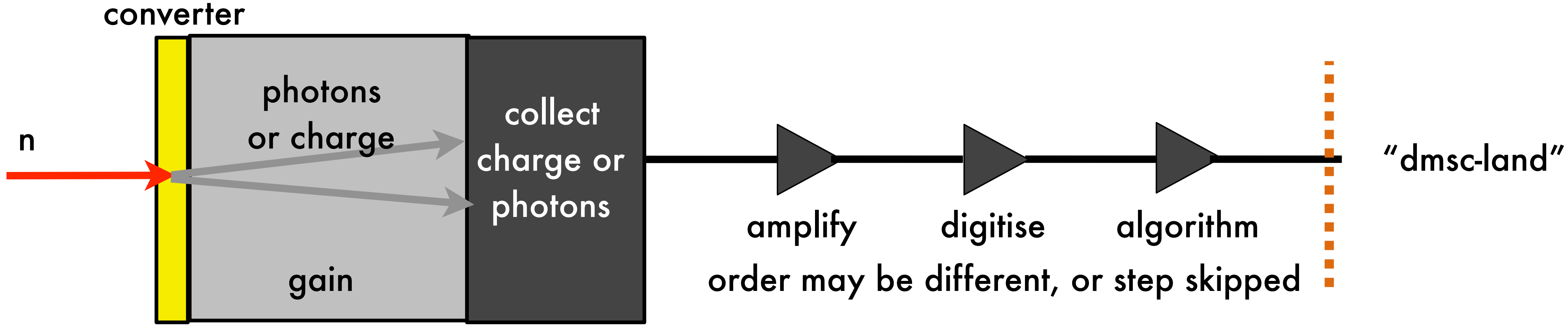


Challenges for Detectors for ESS Instruments

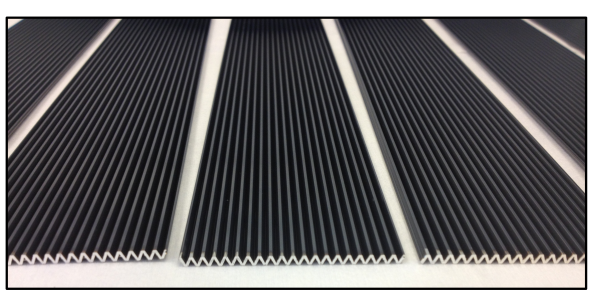
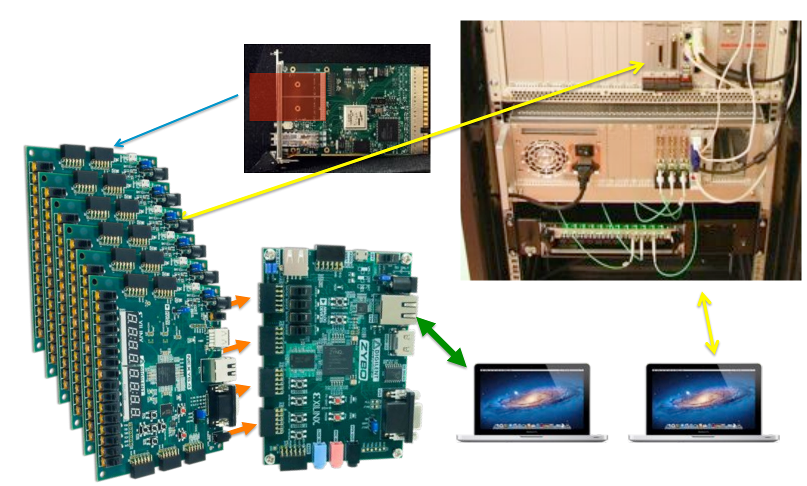
- Each Instrument class faces different challenges in terms of requirements

Basic Principle of Neutron Detectors

Efficient neutron converters a key component for neutron detectors



"Converter" *"Detector"* *"Electronics"*

 +  + 

Isotopes Suitable as Cold and Thermal Neutron Convertors

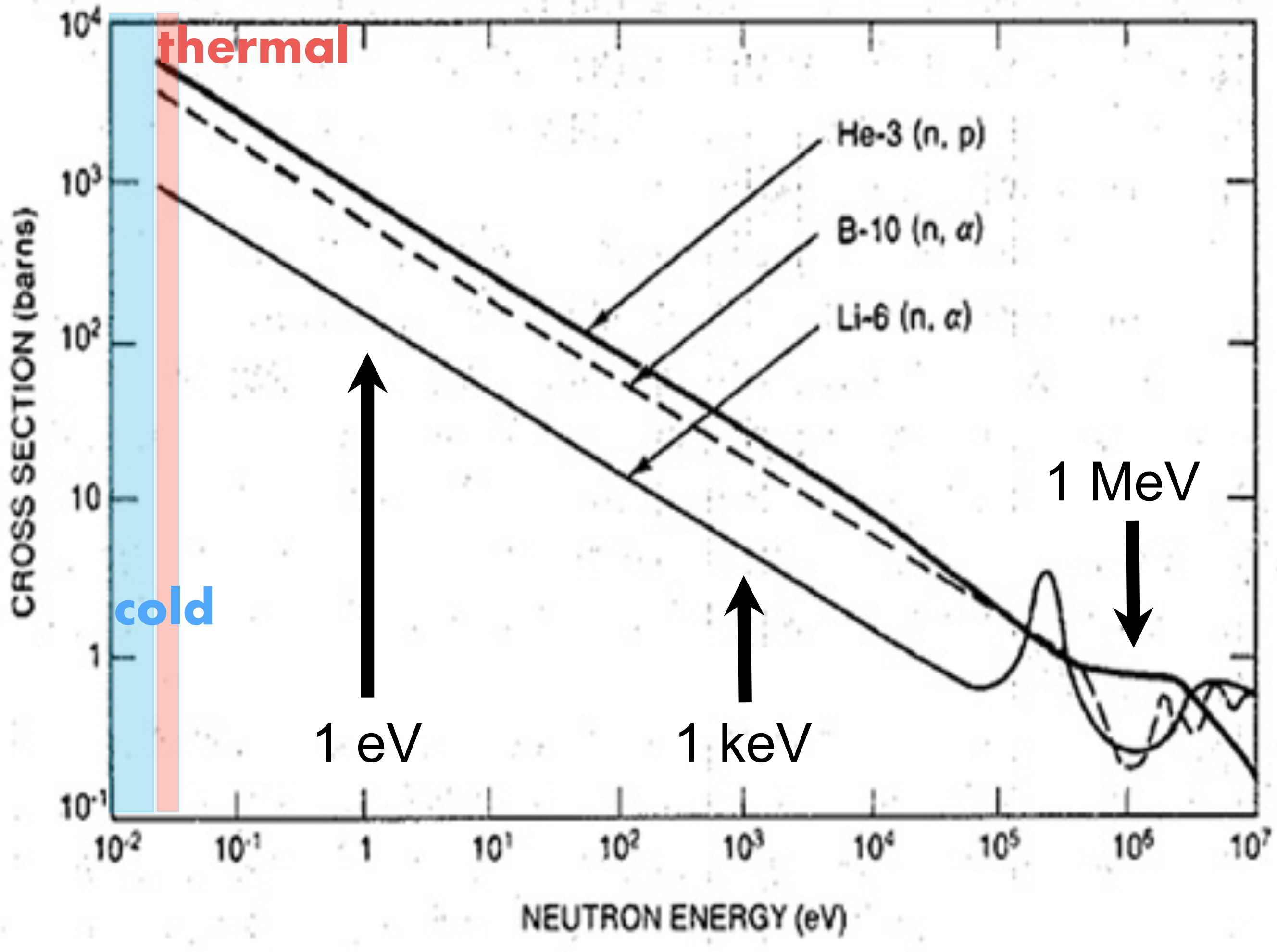
reaction	energy	particle	energy	particle	energy
n (^{3}He, p) ^{3}H	+0.77 MeV	p	0.57 MeV	^{3}H	0.19 MeV
n (^{6}Li, α) ^{3}H	+4.79 MeV	α	2.05 MeV	^{3}H	2.74 MeV
93 % n (^{10}B, α)^{7}Li +2.3 MeV + γ (0.48MeV)		α	1.47 MeV	^{7}Li	0.83 MeV
7 % n (^{10}B, α) ^{7}Li	+2.79 MeV	α	1.77 MeV	^{7}Li	1.01 MeV
n (^{235}U,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



(ILL Blue Book)

State of the Art of Neutron Detectors

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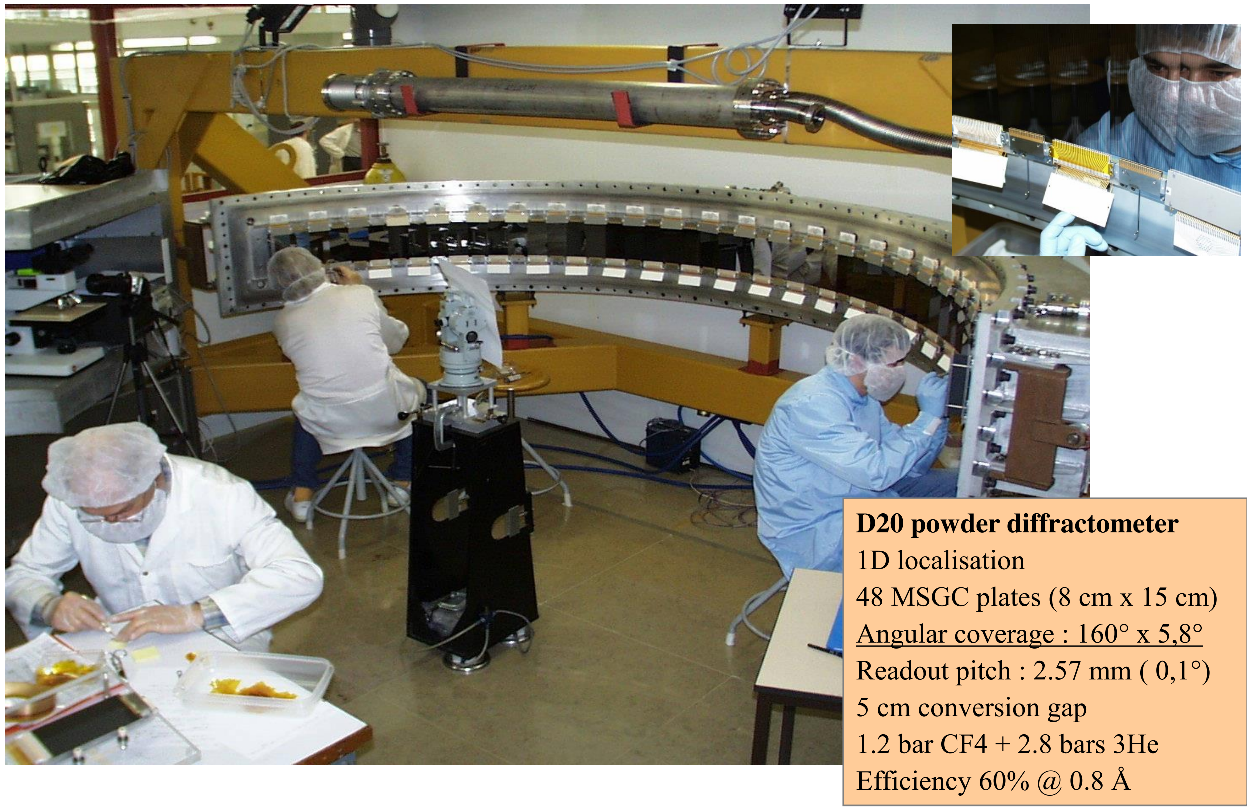
- Helium-3 Tubes most common
- Typically 3-20 bar Helium-3
- 8mm-50mm diameter common
- Using a resistive wire, position resolution along the wire of ca. 1% possible
- See abstract N13-2 this week

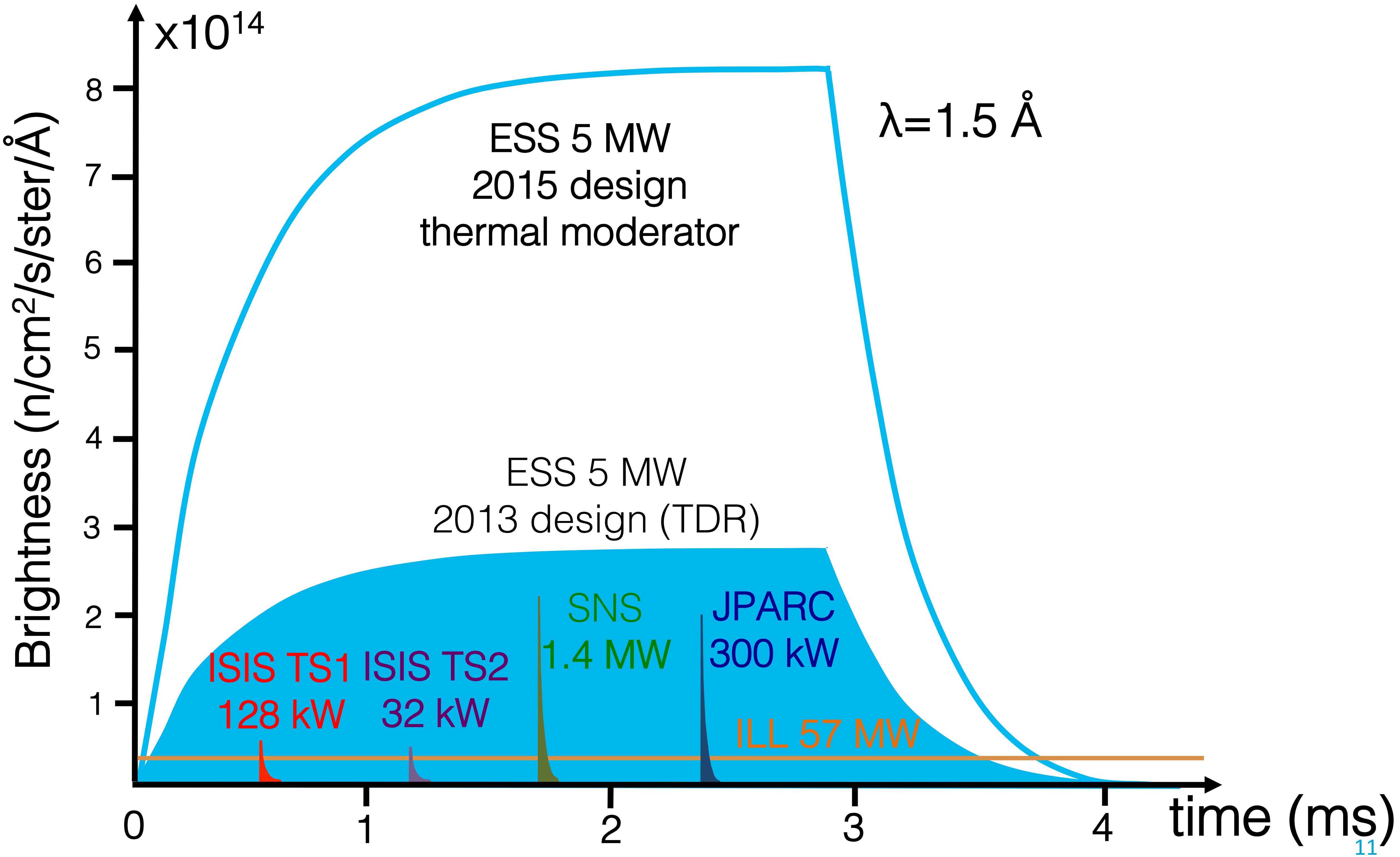
NEUTRONS FOR SCIENCE

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



- First micro pattern gaseous detectors was MSGC invented by A Oed at the ILL
- A. Oed, NIM A 471 (1988) 351
- Rate and resolution advantages
- Helium-3 MSGCs in operation

Challenge for Rate



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

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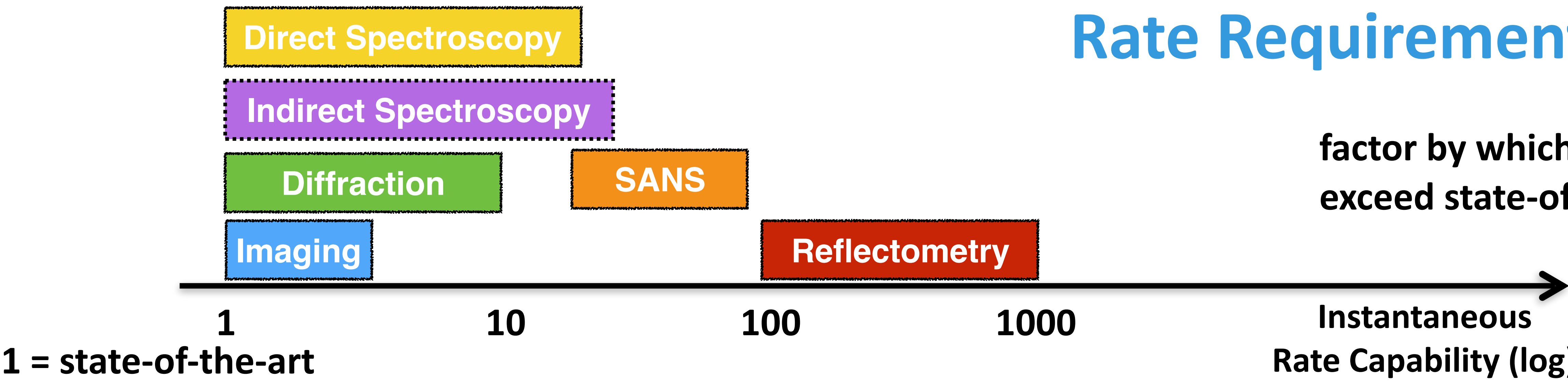
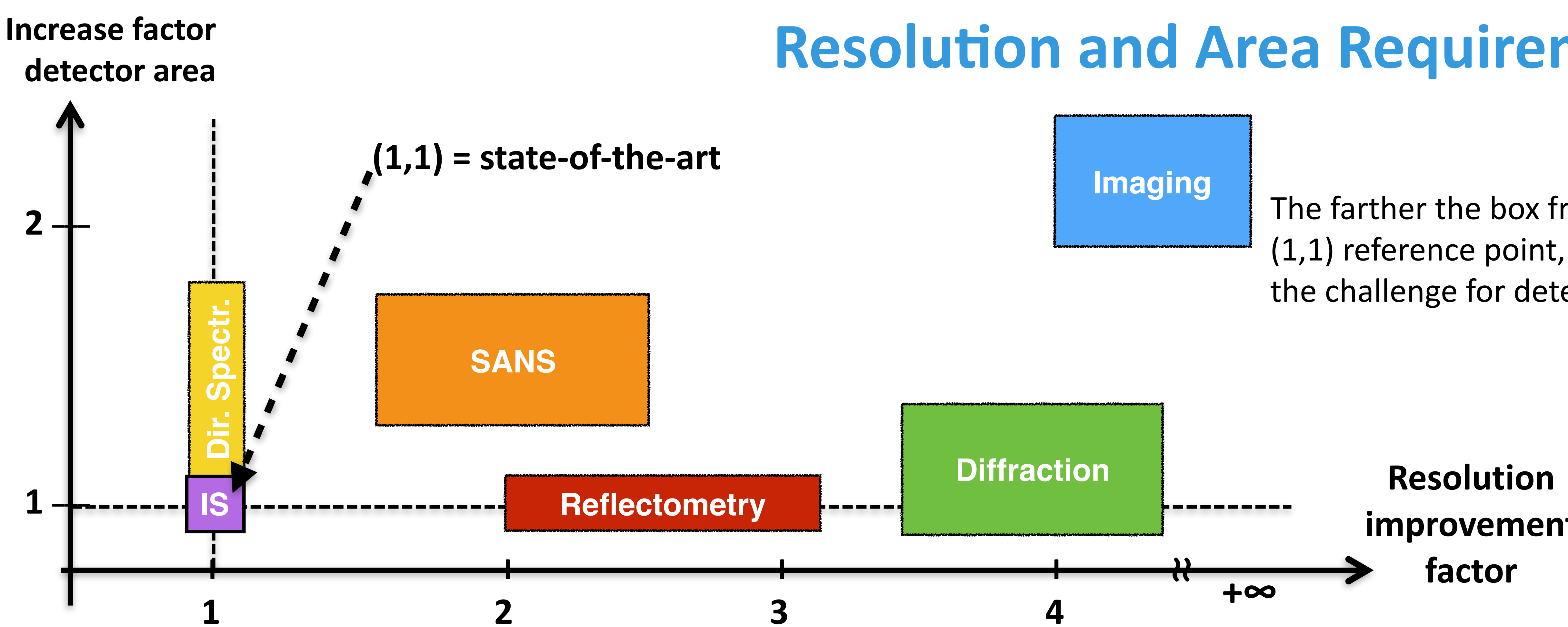
Rate Requirements

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 by Instrument Class

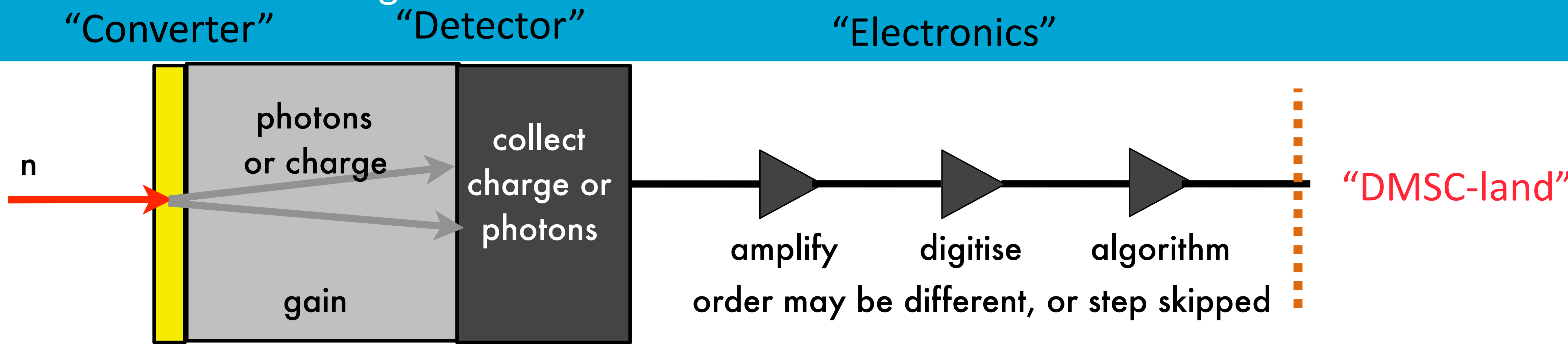
Instrument Class	Challenge which dominates detector design on instrument
Reflectometry	Rate, Resolution
SANS	Rate, Resolution, Area (cost)
Imaging	Resolution, Rate
Diffraction	Resolution
Direct Spectroscopy	Area (Cost), Rate
Indirect Spectroscopy	Rate

Varied Challenges

Strategy for the ESS Instrument Suite

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	Instrument Detector Design
					ICS/DMSC interface	Electronics
					Instrument conceptual design	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

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	

Good dialogue and close collaboration needed for successful delivery and integration

Detectors for ESS instruments: establish a baseline (1/2)

Instrument	Detector Design	Design Teams	Build Teams	Technical Risks	Schedule Risks
LOKI	BandGEM	Milan-Biccoca/CNR/INFN/ESS (2011-…)	Milan-Biccoca/CNR/INFN/ESS	Medium/ Low	Low
SKADI	Pixelated Scintillator (SoNDe)	SoNDe: FZJ/LLB/IDEAS/LU/ESS (2011-…)	SoNDe: FZJ/LLB/IDEAS/LU/ESS	Low	Low
NMX	Gd-GEM	BrightnESS:ESS/CERN (2014-…)	BrightnESS:ESS/CERN U. Bergen and/or Wigner / ESS	Medium *	Low
ODIN	Misc: MCP, Scintillator, Semiconductor	Various: PSI, Berkeley, ISIS … BrightnESS: IAEP, MiUN, ESS …	PSI	Low	Low
DREAM	Jalousie	POWTEX: FZJ/CDT	FZJ POWTEX	Low	Medium
BEER	A1CLD AmCLD	HZG/DENEX (2011-…)	HZG/DENEX	Low	Medium (ik start delay)
FREIA	Multi-Blade	BrigthnESS: ESS/LU/Wigner (2013-…)	ISIS/ESS/LU/Wigner	Medium	Low
ESTIA	Multi-Blade	BrigthnESS: ESS/LU/Wigner (2013-…)	PSI/ESS/LU/Wigner	Medium	Low

Baselines, detector design, design teams and build teams identified

Detectors for ESS instruments: establish a baseline (2/2)

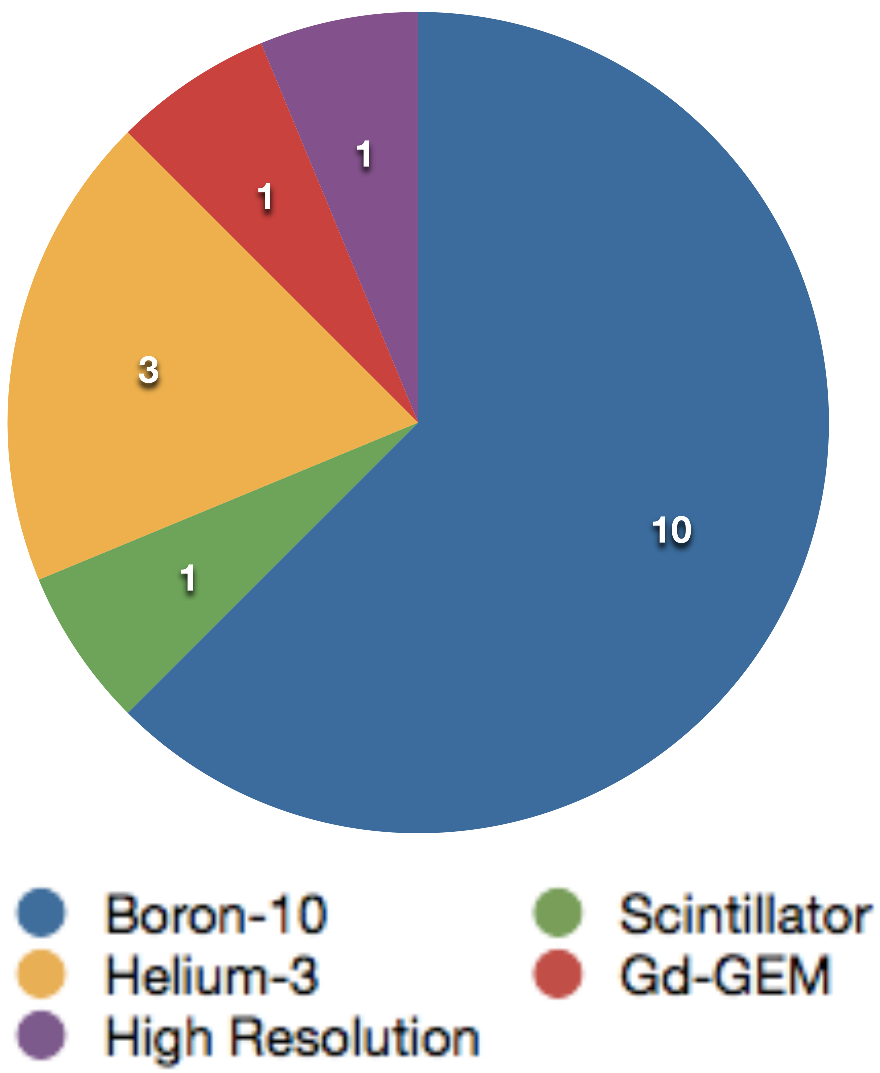
Instrument	Detector Design	Design Teams	Build Teams	Technology Risks	Schedule Risks
VOR	Multi-Grid	CRISP: ESS/ILL Linköping Univ. BrightnESS: ESS/ILL (2009-…)	ESS/Wigner? *	Low	Low
C-SPEC	Multi-Grid	CRISP: ESS/ILL Linköping Univ. BrightnESS: ESS/ILL (2009-…)	ESS/TUM/LLB? *	Low	Low
T-REX	Multi-Grid	CRISP: ESS/ILL Linköping Univ. BrightnESS: ESS/ILL (2009-…)	ESS/FZJ? *	Low	Low
BIFROST	Helium-3 (tubes)	PSI	PSI	Medium: Inst Rate?	Low
HEIMDAL	Jalousie		DK/PSI/NO	Low	medium
MAGIC	Jalousie	POWTEX: FZJ/CDT (2012/3-…)	FZJ/CDT/LLB	Low	Medium
MIRACLES	Helium-3 PSD tubes	N/A	ESS-B	Low	Low
VESPA	Helium-3 PSD tubes	N/A	CNR/ISIS	Low/Medium Availability?	Low
SPIN-ECHO	3He-based/10B-based			Low	Low

Close working collaborative relationships to mitigate risks

Preferred Detector Technologies for Baseline Suite

Detectors for ESS will comprise many different technologies

Best-Guess at Detector Technologies for 16 Instruments:



Mitigation Plan

Instrument	Primary Detector Technology	Critical decision dates	Backup Detector Technology	Cost Backup Detector Technology (EUR)	Critical decision dates for Day 1 Option	Secondary backup Detector Technology (Day 1 configuration)	Cost of secondary Day 1 option to contingency (EUR)
LOKI	BandGEM	17Q3: final technology decision	SONDE	7 M	2019 Q2	He-3 PSD MWPC	500 k
ODIN	Misc: MCP, Scintillator, Semiconductor, …	2018	Several Technologies already involved	N/A	2019 Q2	Scintillator+CCD	100 k
BEER	AmCLD/A1CLD	2018 Q1	Jalousie	3 M	2020 Q1	He-3 PSD MWPC	500 k
C-SPEC	Multi-Grid	Technology Decision 2017Q4	He-3 Tubes	>10 M	2020 Q1	MultiGrid Prototypes	200 k
ESTIA	Multi-Blade	Technology decision (17Q4?)	SINE2020	750 k	2020 Q1	He-3 8mm PSD Tubes	500 k
DREAM	Jalousie	TG3: 17Q4?	AmCLD/A1CLD	2.5 M	2020 Q1	He-3 PSD MWPC	500 k
MAGIC	Jalousie	TG3: 18Q2?	AmCLD/A1CLD	2.5 M	2020 Q1	He-3 PSD MWPC	500 k
BIFROST	He-3 Tubes	TG3: 19Q1?	Helium-3 Pixels	1,5 M	N/A	N/A	0

Risk exposure (delta): >15 MEUR **Risk exposure: 2.8 MEUR**

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^{10}Boron-based Thin Film Gaseous Detectors

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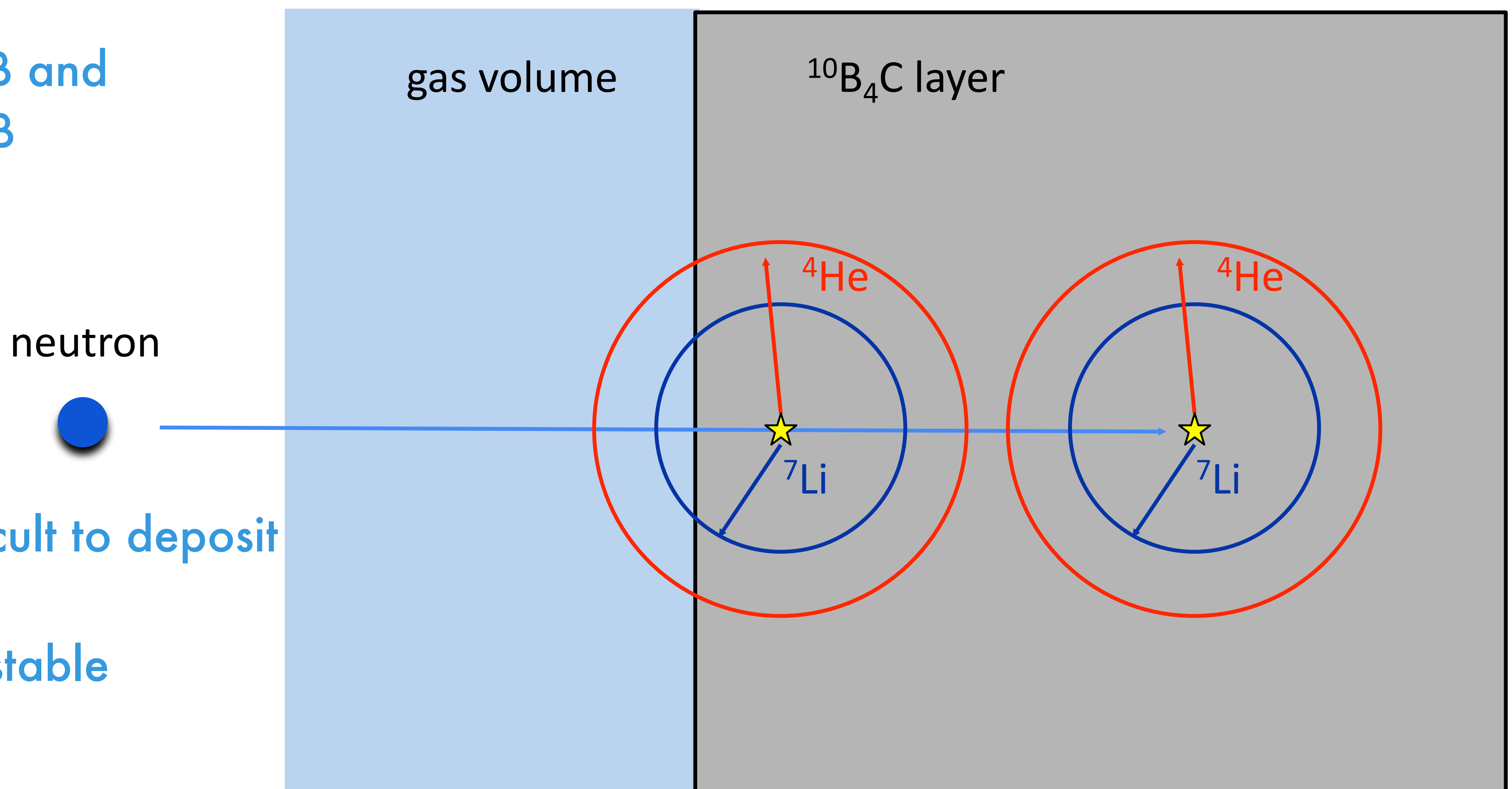
$$
\begin{aligned}
{}^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He &\rightarrow {}^{7}Li + {}^{4}He + 0.48MeV\,\gamma\text{-ray} + 2.3\ \ MeV \quad (94\%) \\
&\rightarrow {}^{7}Li + {}^{4}He \qquad\qquad\qquad\qquad\ + 2.79\,MeV \quad (6\%)
\end{aligned}
$$

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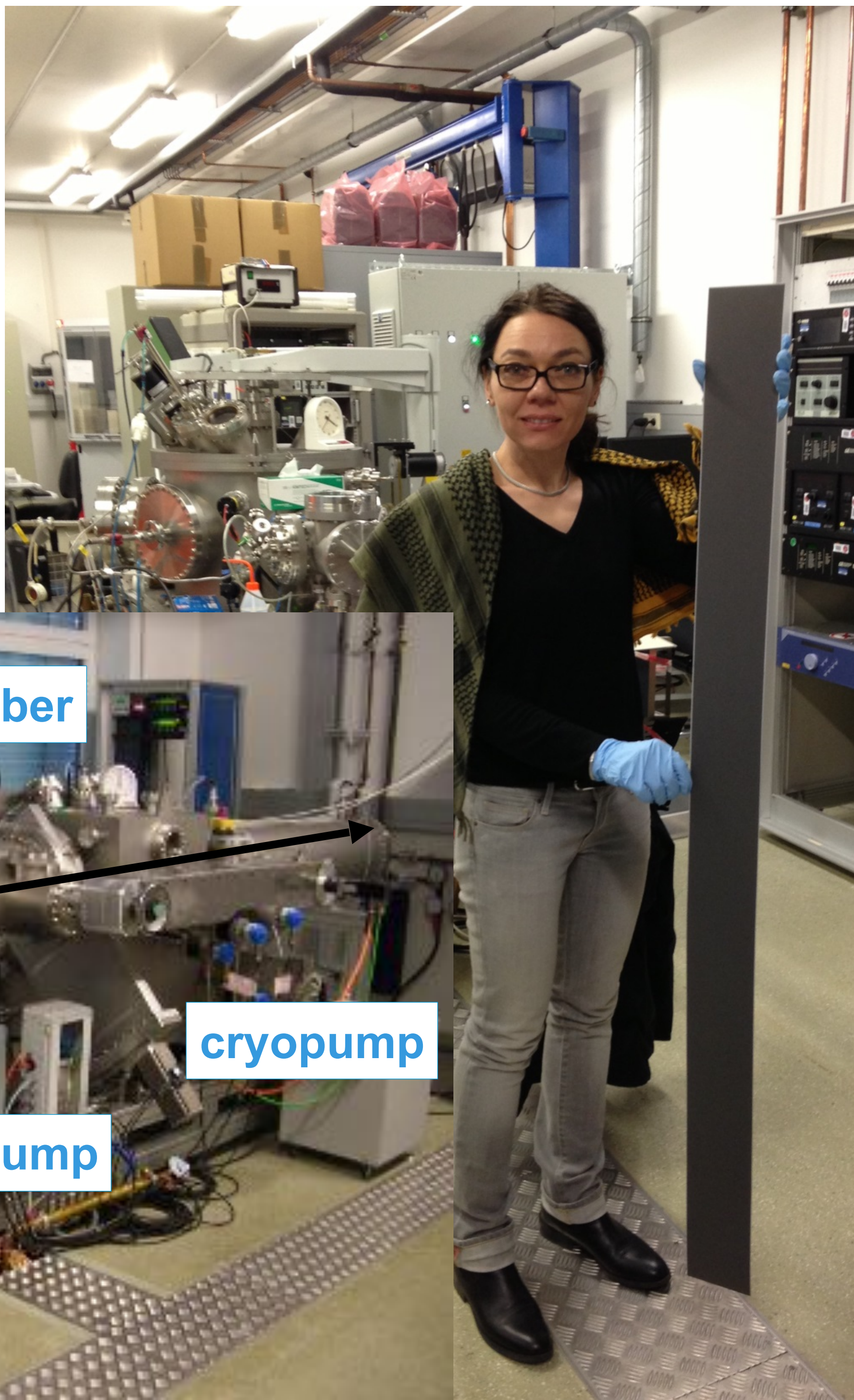
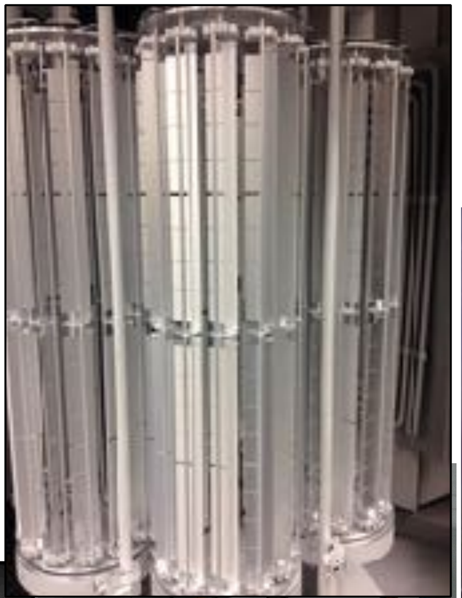
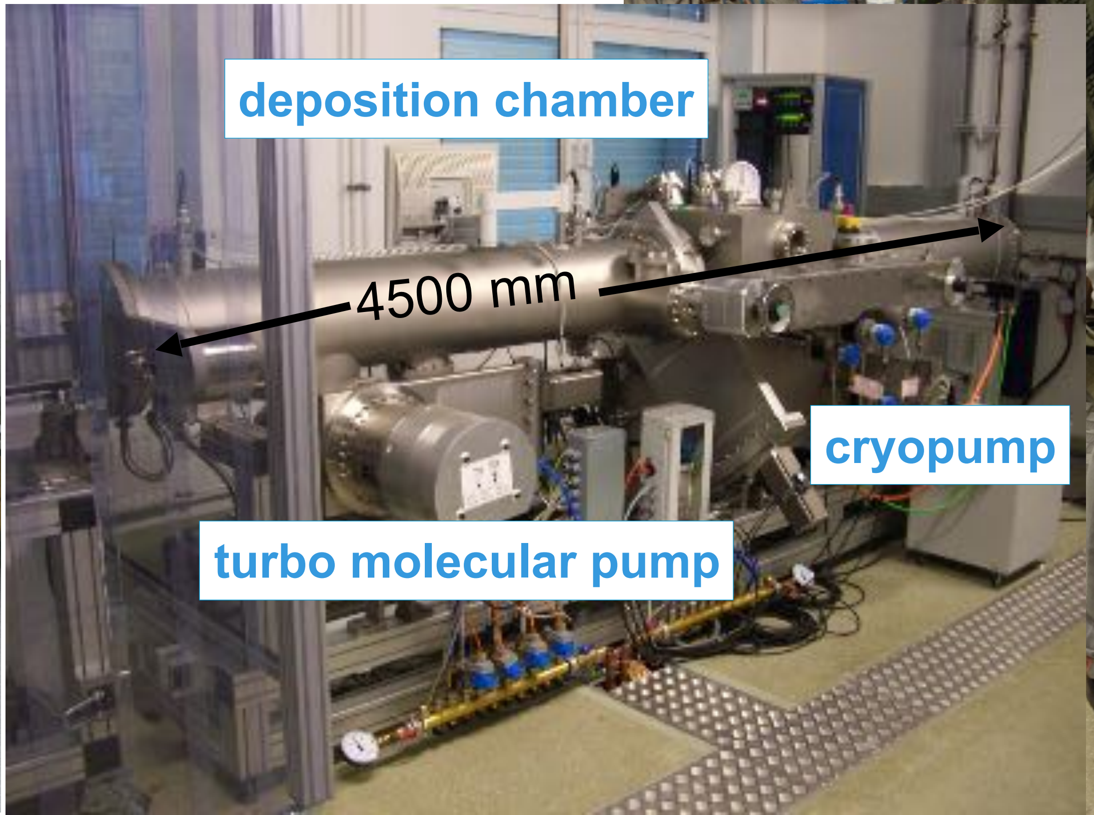
- A number of groups have shown it is possible to deposit large areas of high quality Boron Carbide cheaply
- PVD Magnetron Sputtering
- Deposition parameters highly adaptable
- A very interdisciplinary effort

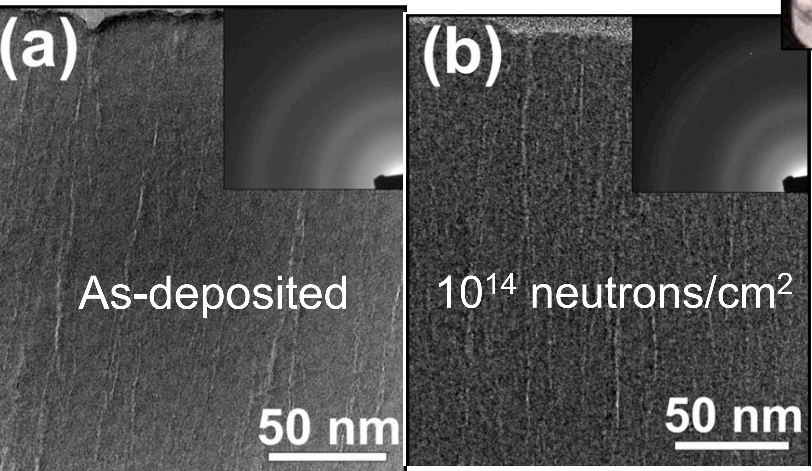
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research



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

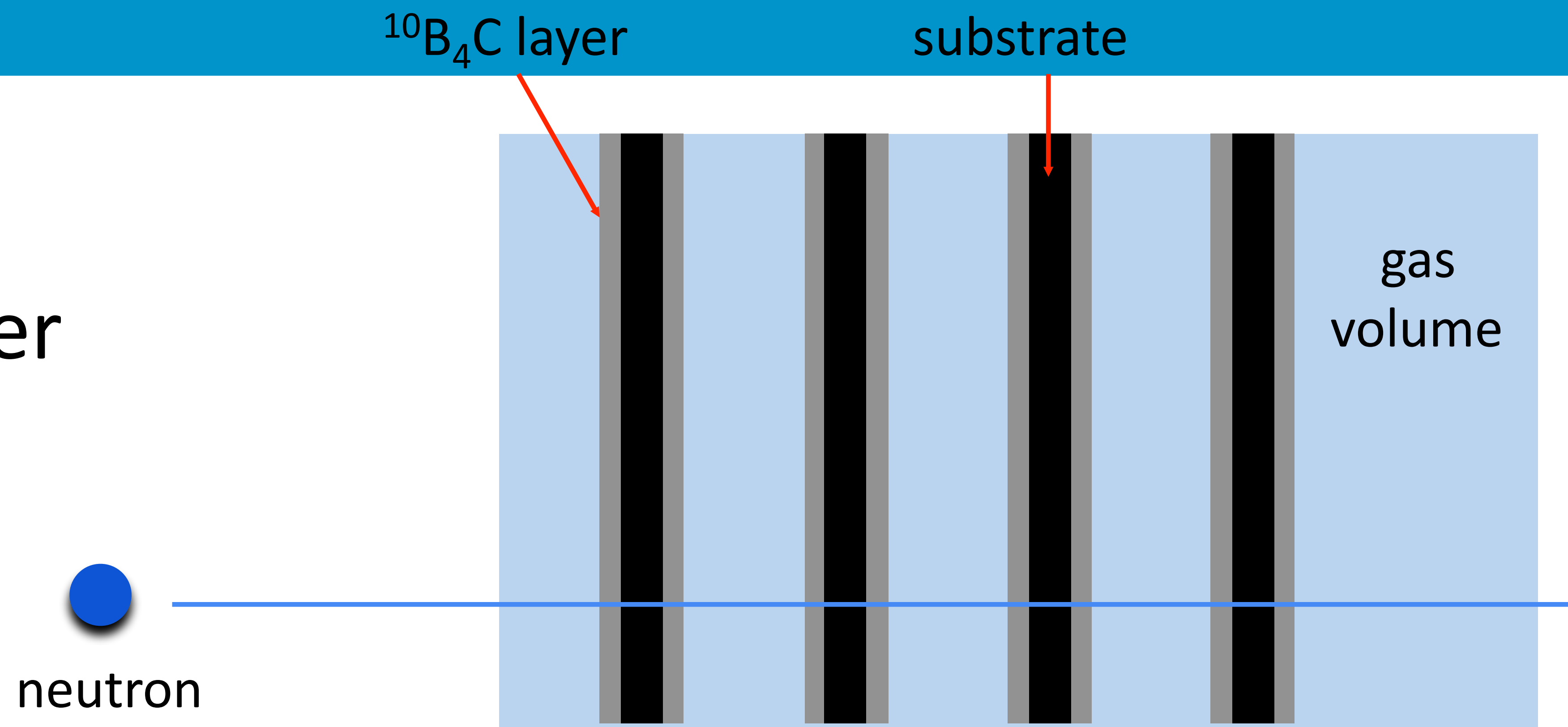






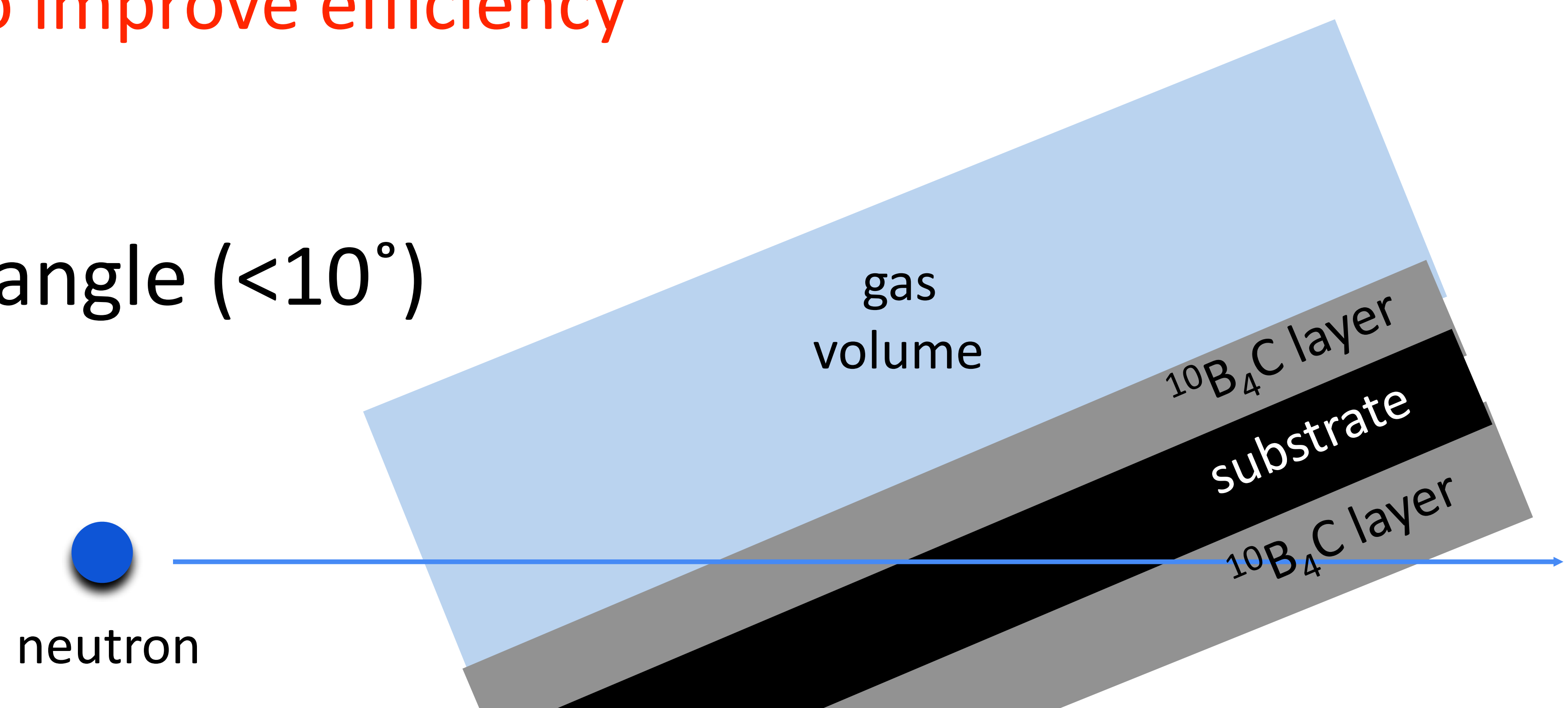
Enhancing the efficiency of ^{10}B-based Neutron Detectors

1 Multi layer

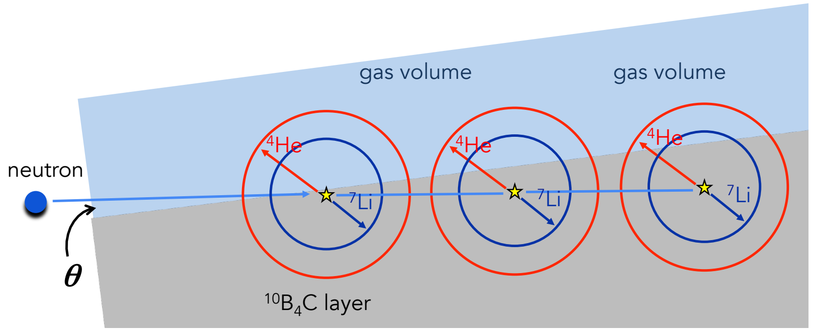


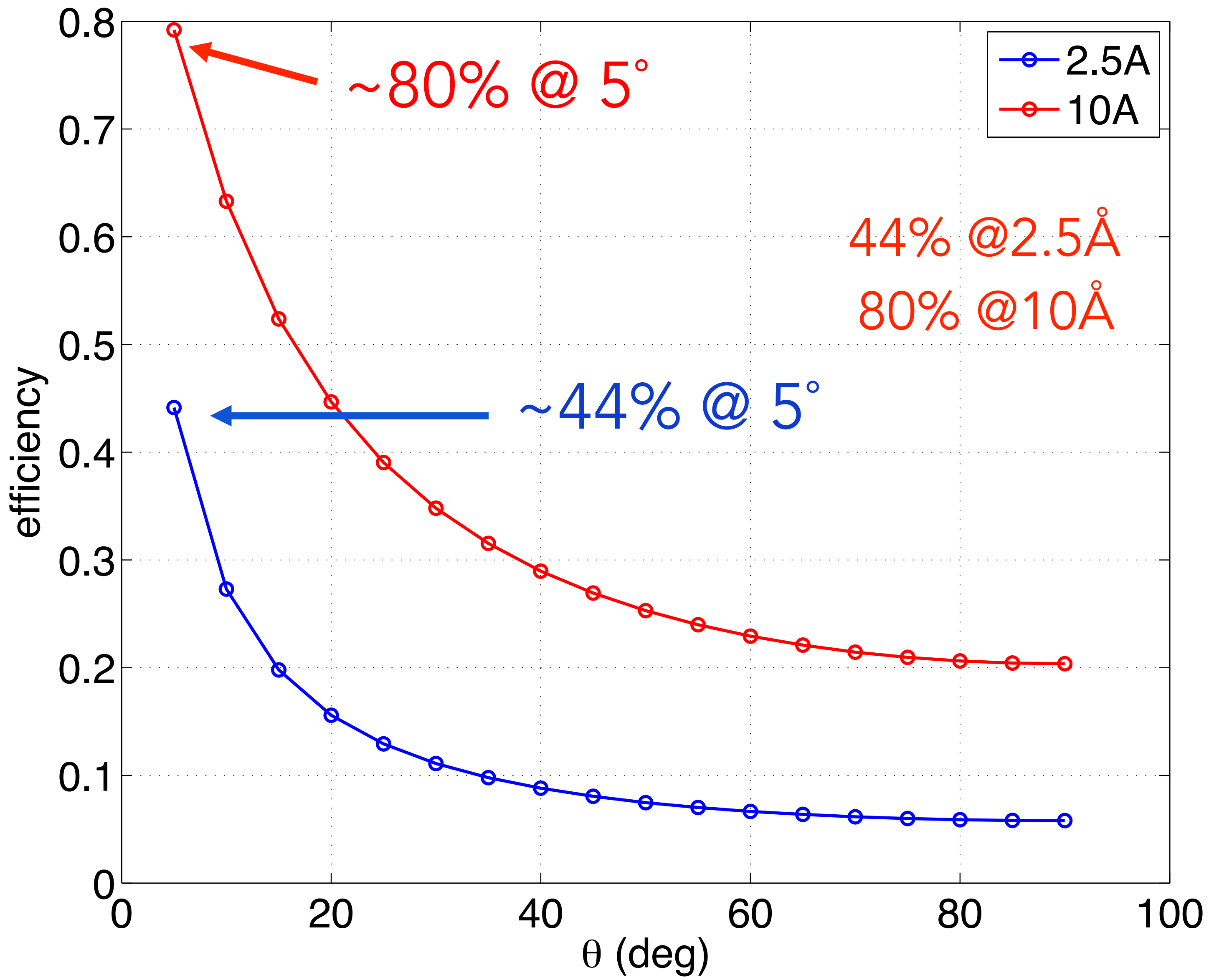
Generic approaches to improve efficiency

2 Grazing angle (<10˚)



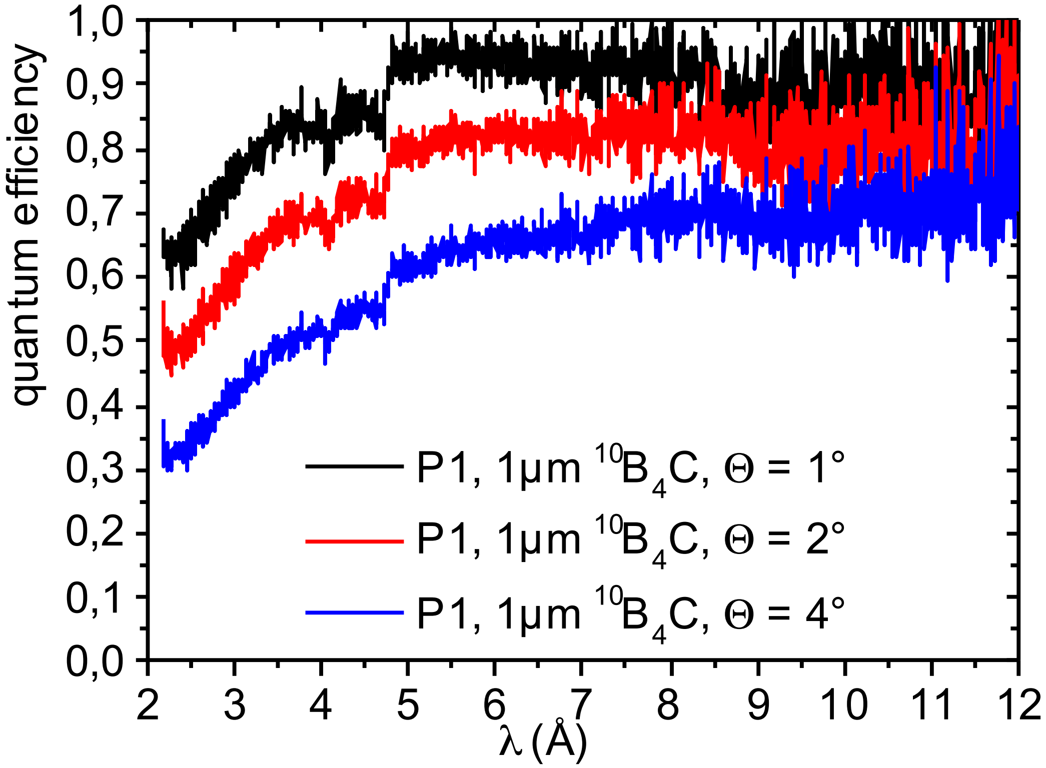
Efficiency of ^{10}Boron Detectors: Inclined Configuration

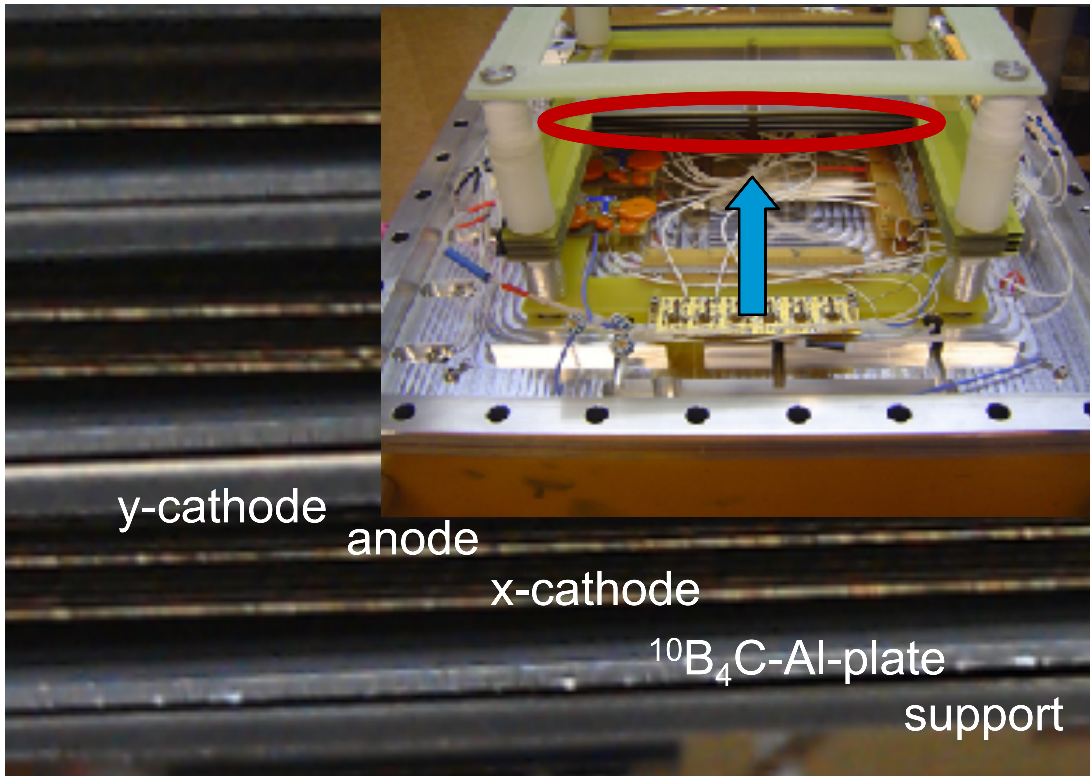




F. Piscitelli, PhD Thesis, U.Perugia (2014)

smaller inclined angles: higher efficiency

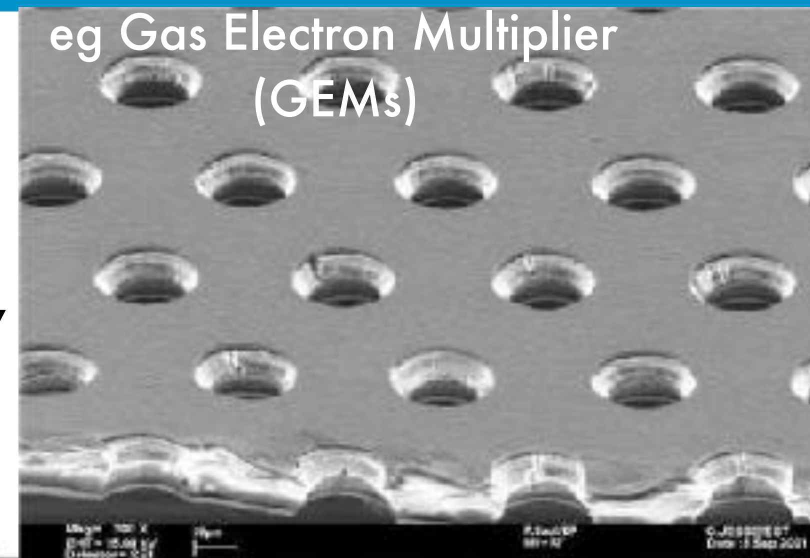


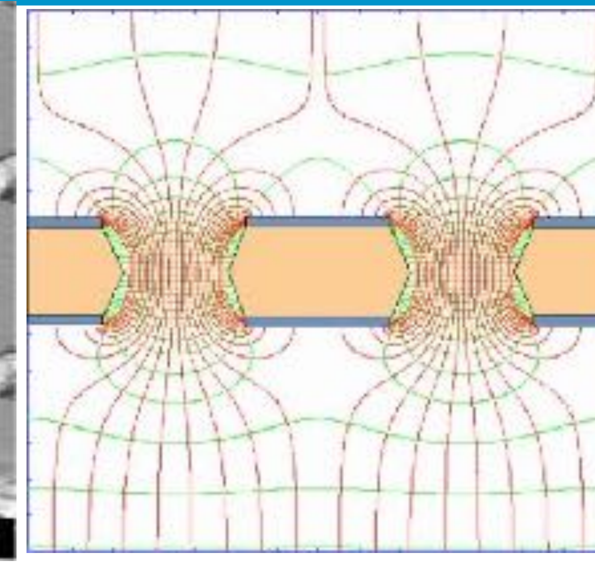


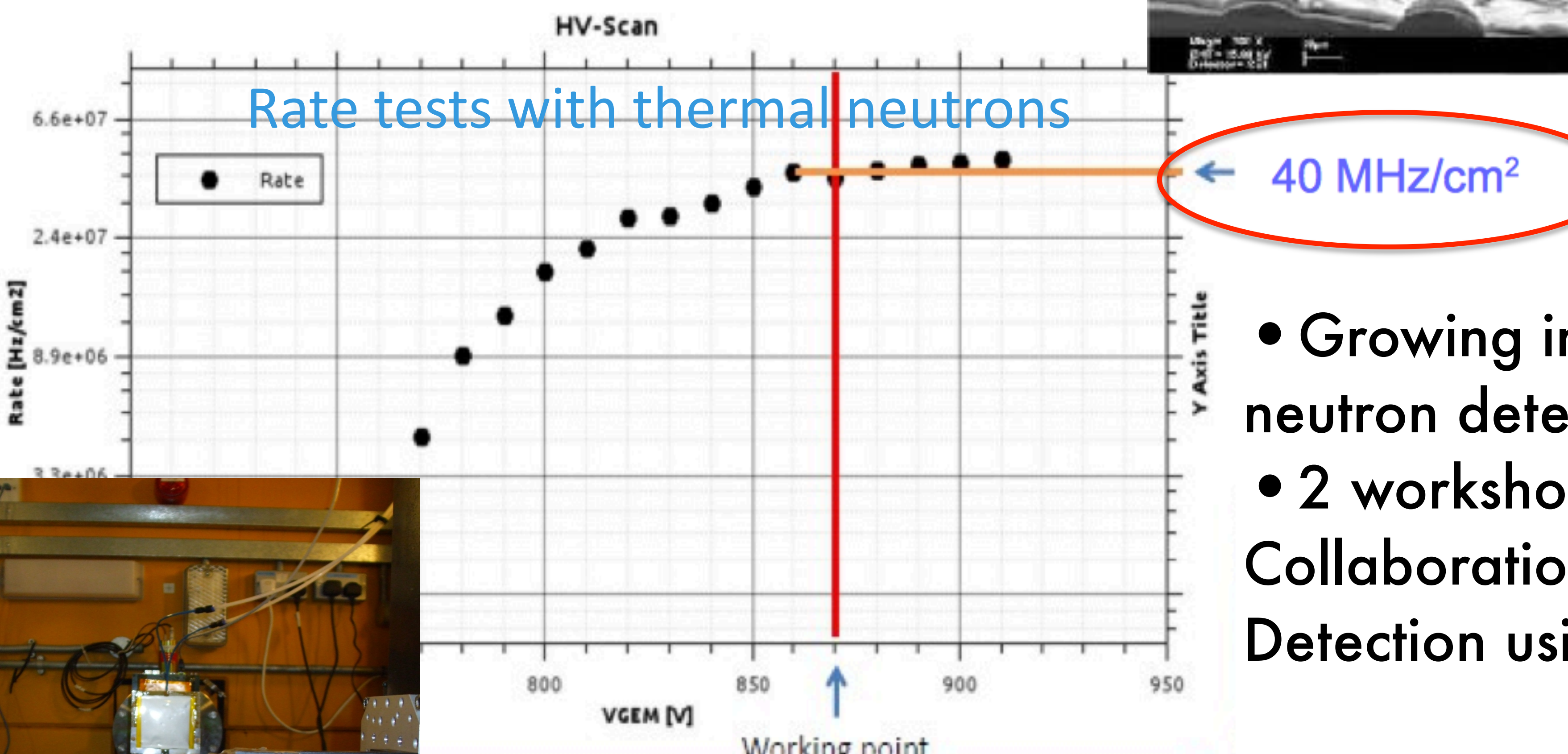
Micropattern Gaseous Detectors

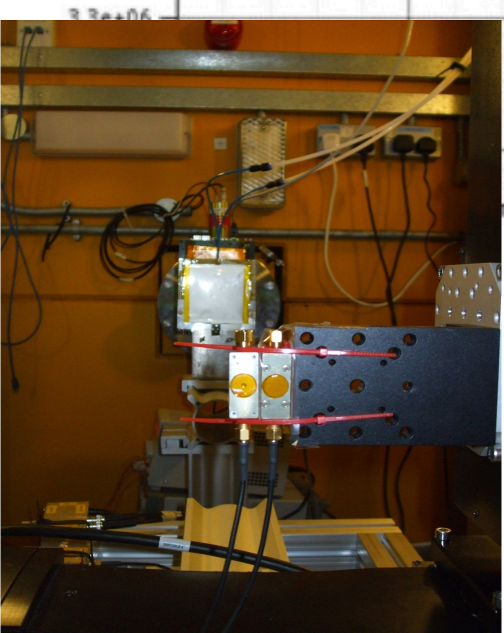
- Field started by A Oed at the ILL with the micro-strip gas chamber (MSGC) in 1988
- Now widespread: many variants
- Potentially very good resolution and very high rate capability

eg Gas Electron Multiplier (GEMs)









- 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

A run through the individual instrument classes

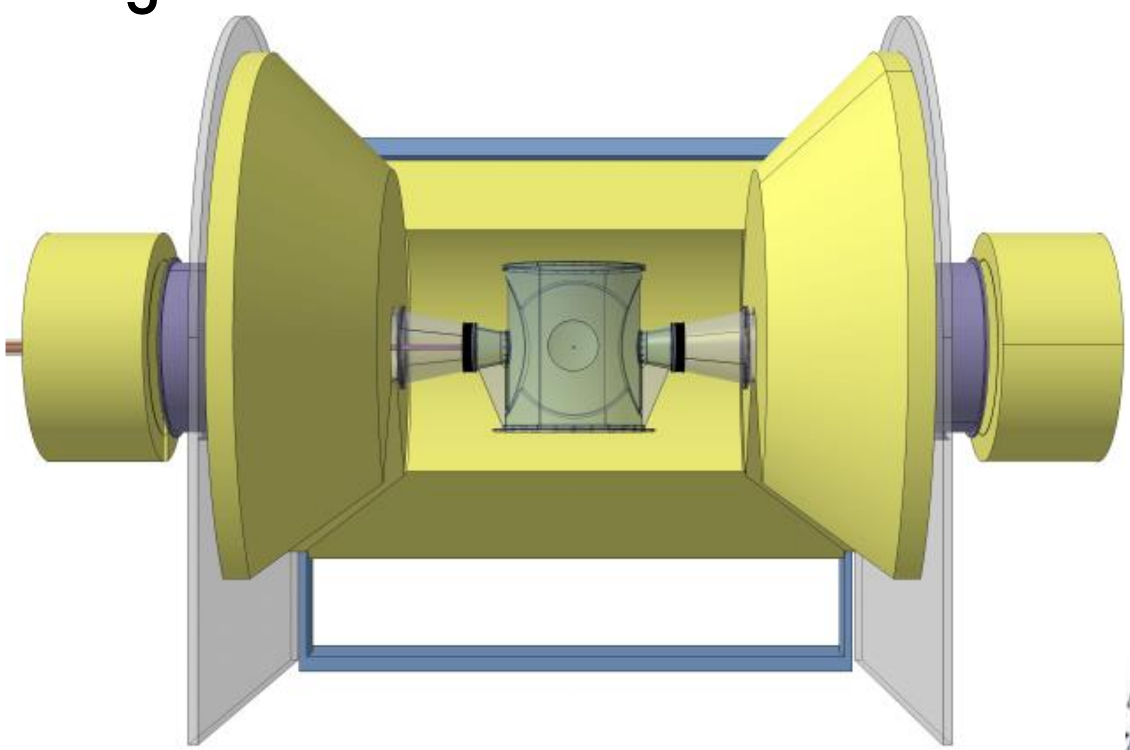
- Diffractometers
- Engineering Diffractometer
- NMX
- Reflectometry
- SANS
- Direct Spectrometry

- This is by no means a comprehensive overview

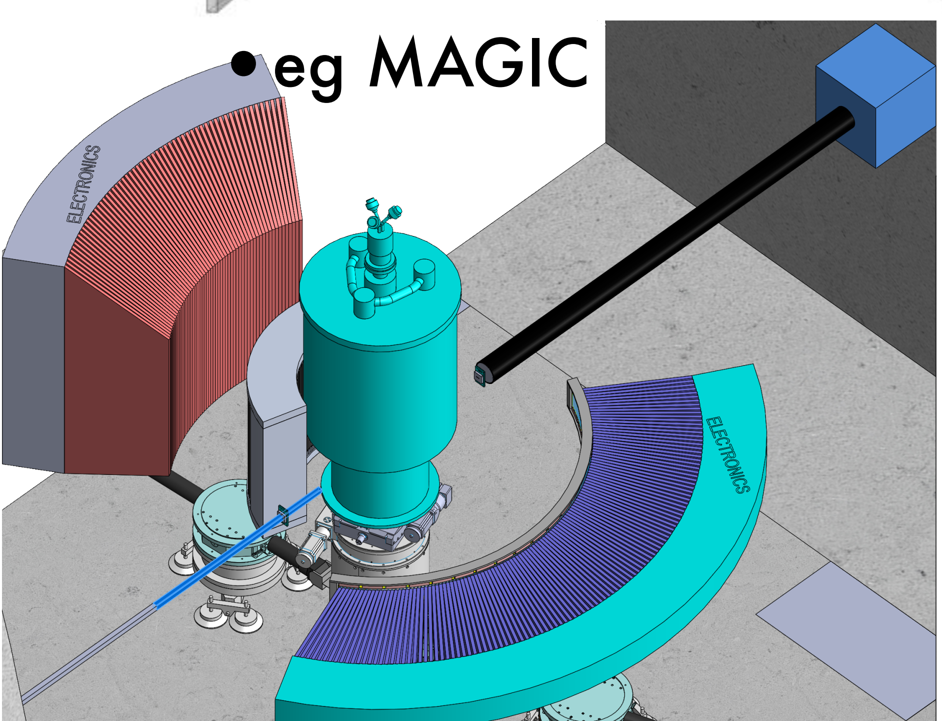
Instruments: DREAM, MAGIC, HEIMDAL

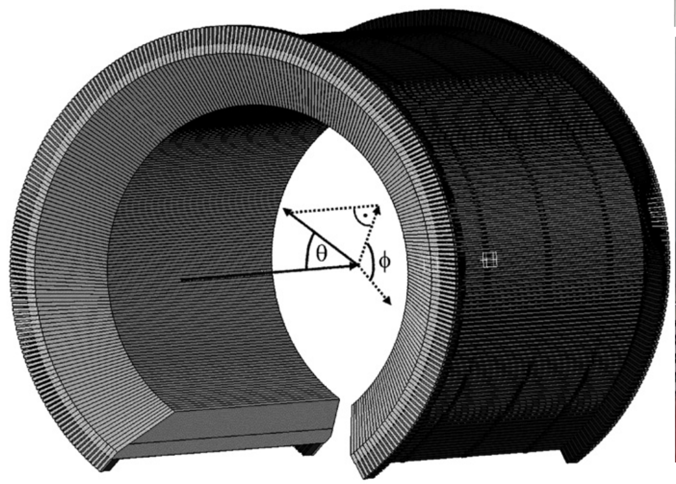
Jalousie-like design

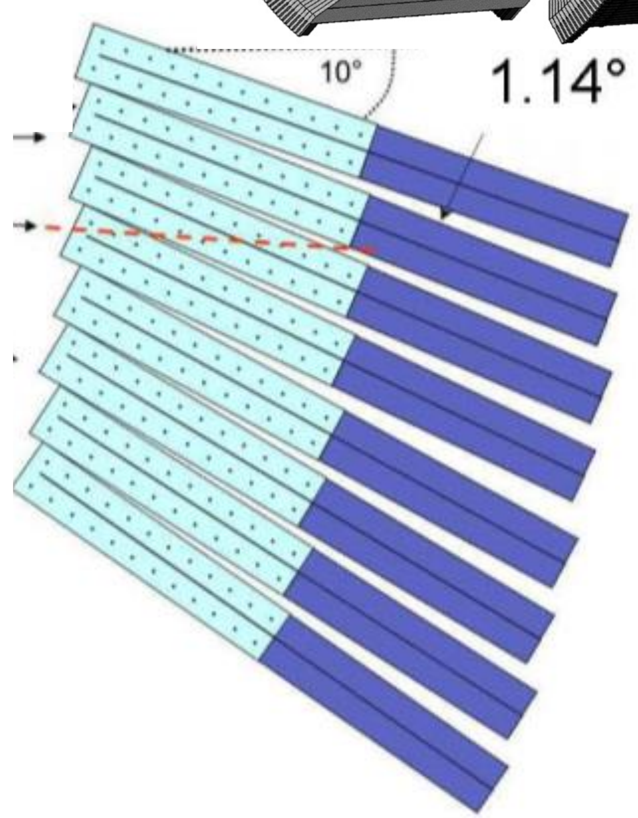
- Inclined angle B-10 detectors, angled at sample
- eg DREAM

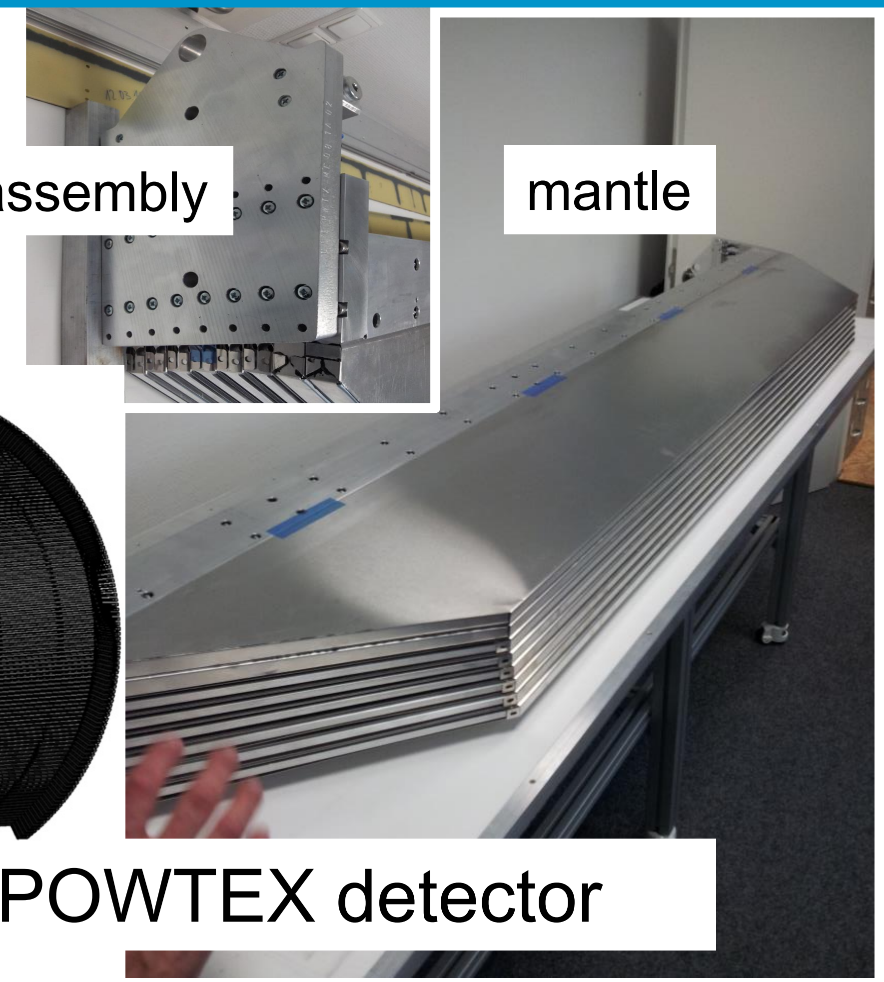


- eg MAGIC





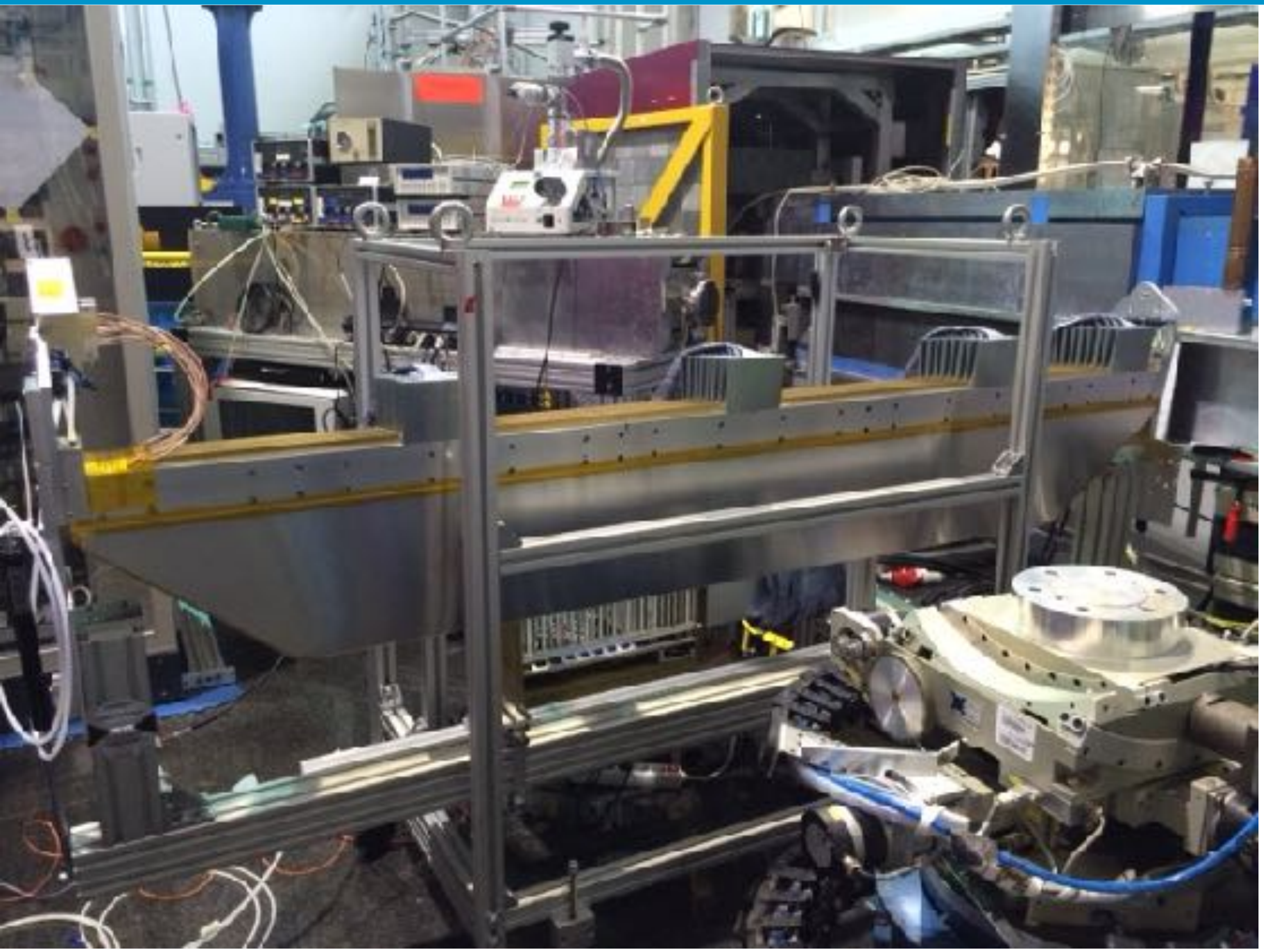




Back scattering module

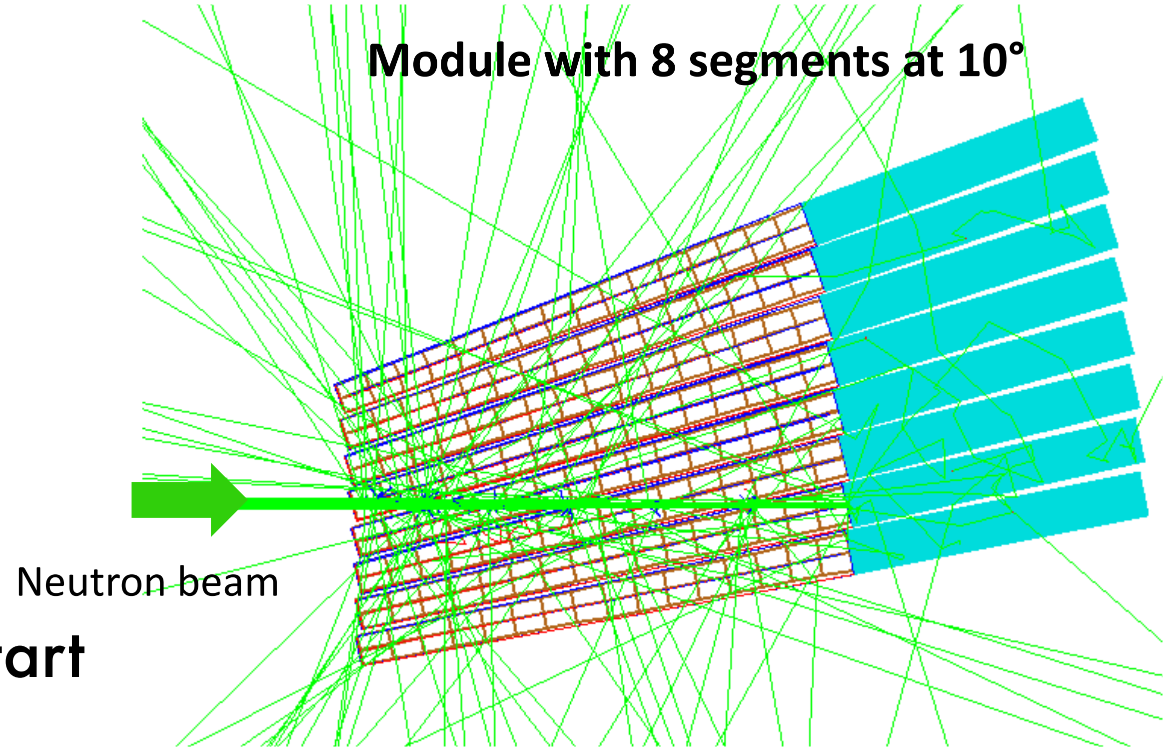
Instruments: DREAM, MAGIC, HEIMDAL

Jalousie



position resolution can be roughly reproduced by simulation

integration of electronics into ESS DAQ about to start



Instruments: DREAM, HEIMDAL, (MAGIC)

Rates …

- **Global time-averaged detector rate**, which is defined as the total number of neutrons per second recorded by the whole detector. This is relevant to designing the bandwidth in the data acquisition and storage chain.
- **Local time-averaged detector rate**, which is defined as the total number of neutrons per second recorded in a detector pixel, channel or unit. The local rates for the detectors deployed at diffractometers are usually given per tube (if ^{3}He-tubes are used) or PMT (if scintillator detectors are used). For simplicity, we normalise the local rates to cm^2.
- **Global instantaneous peak detector rate**, which is defined as the highest instantaneous neutron count rate on the whole detector.
- **Local instantaneous peak detector rate**, which is defined as the highest instantaneous neutron count rate on the brightest detector pixel, channel or unit. At pulsed sources, the instantaneous rate could be more than an order of magnitude higher than the average rate as the neutron emission is concentrated in short bursts. The knowledge of this rate is important in determining whether a detector technology is suitable to be utilised for a specific application and has impact on the design of the detector and electronics.

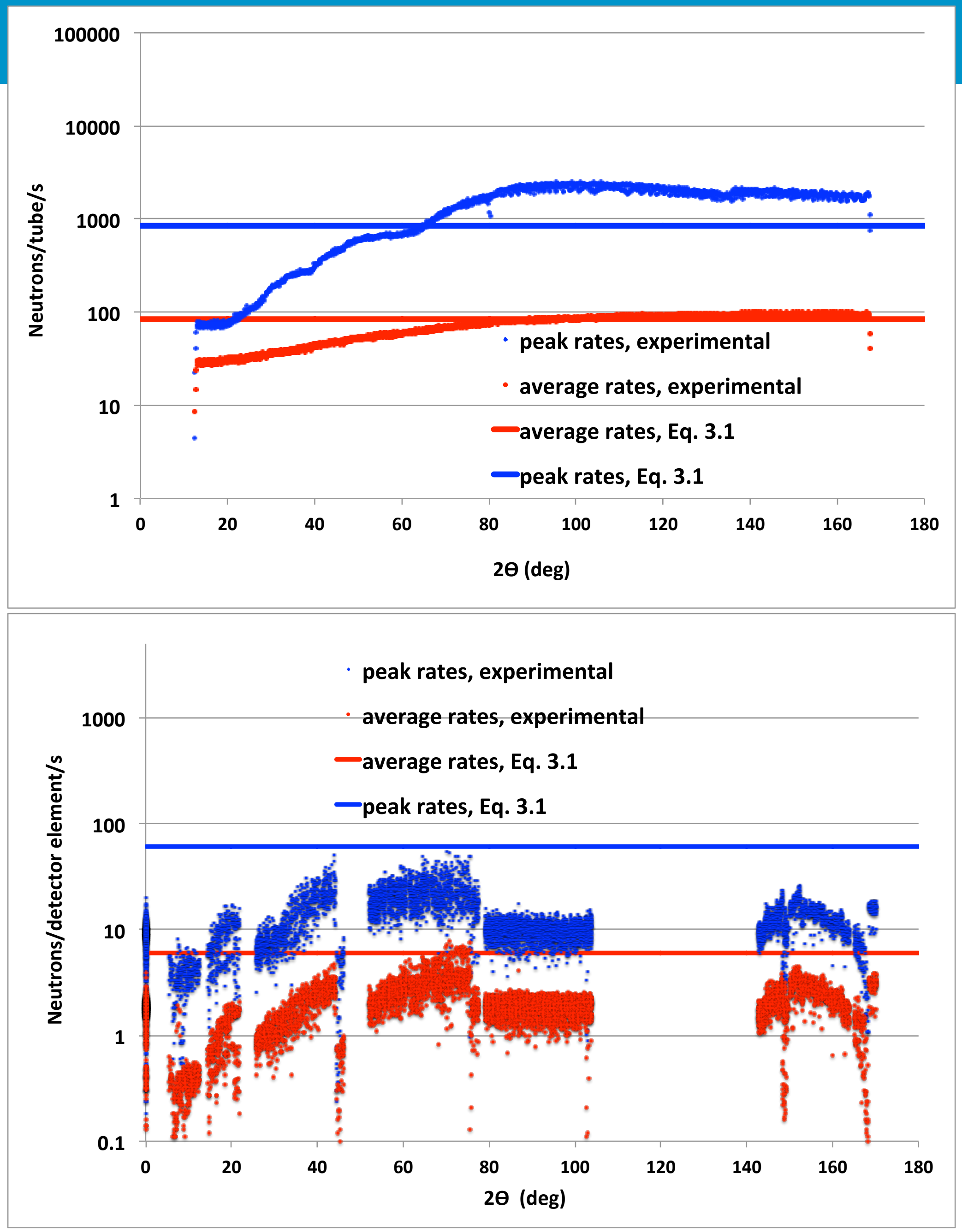
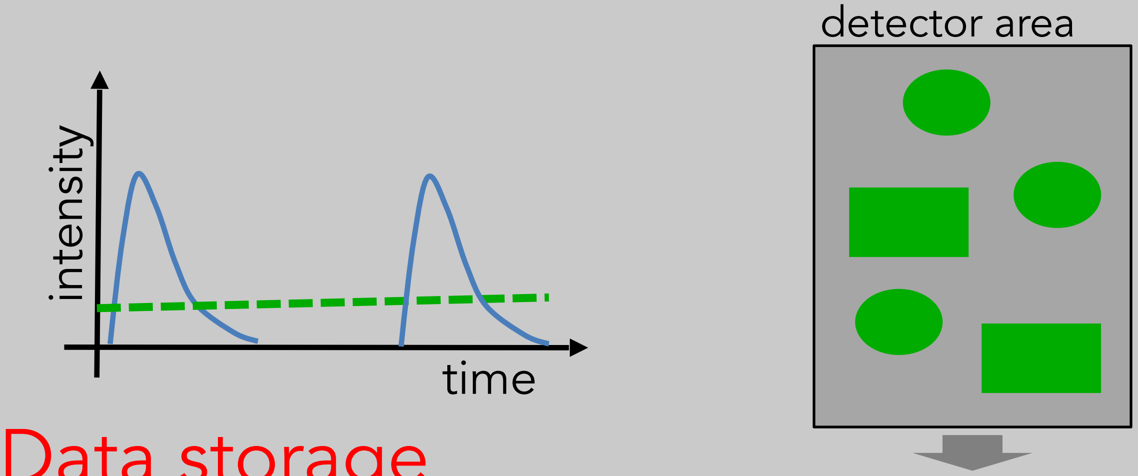
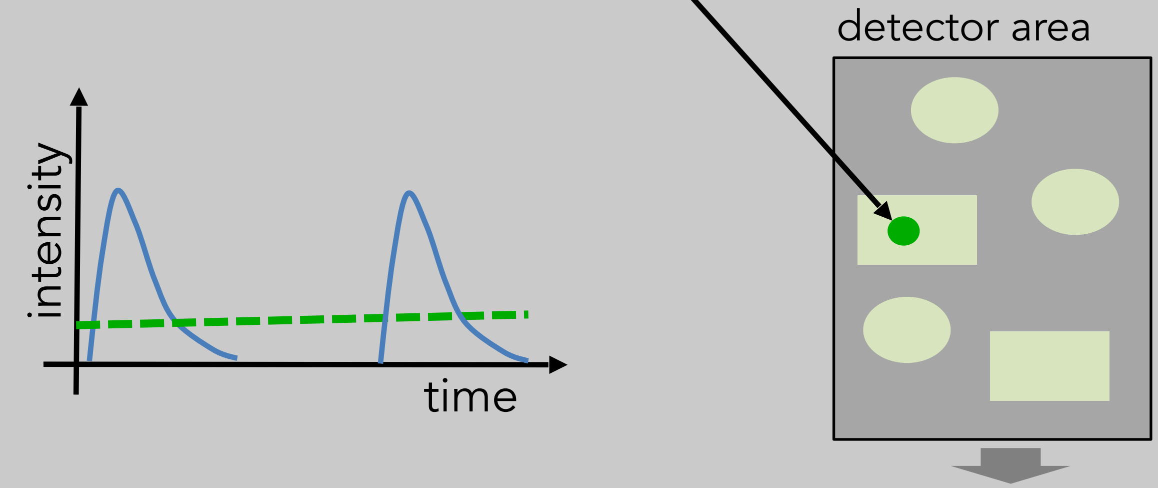
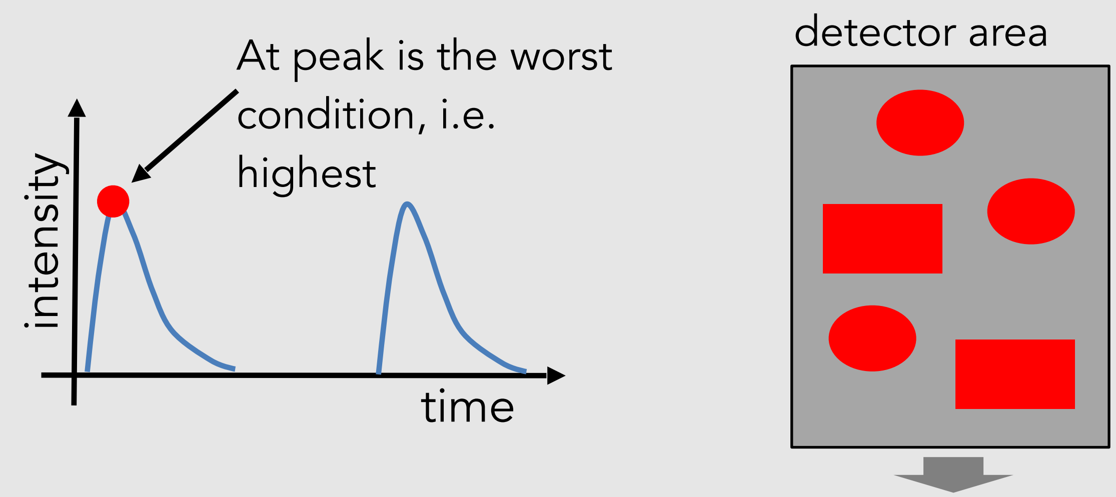
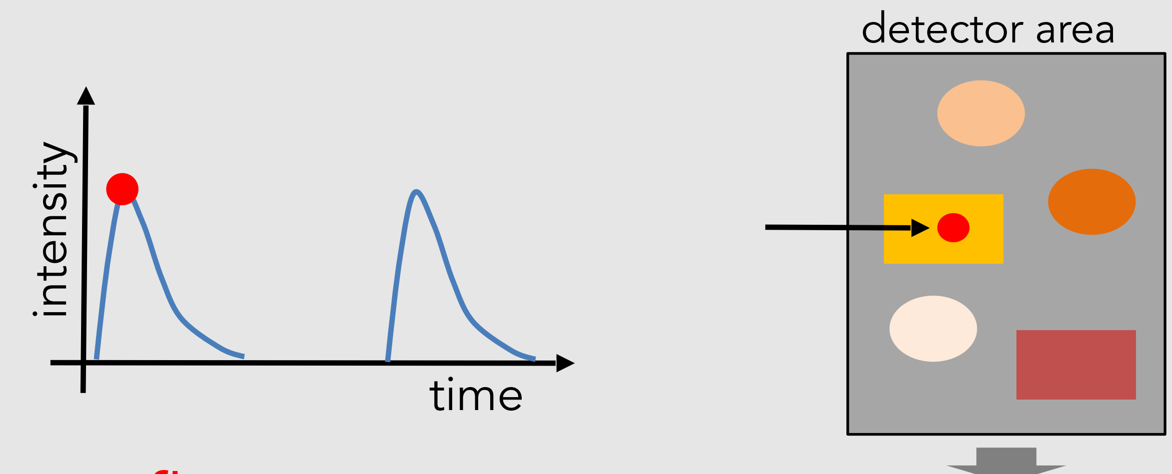


Figure 5. Distribution of the neutron events per second detected in the WISH position-sensitive detectors (top) and GEM scintillator elements (bottom) as a function of the scattering angle 2θ. The experimental data were collected with the same $Na_2Ca_3Al_2F_{14}$ reference sample. The experimental error bars are smaller than the size of the symbols. The red horizontal lines correspond to the rates estimated with Eq. 3.1, by using the time-averaged flux values quoted in literature for both instruments [8, 35] and a sample scattering factor of 5%, as extracted from the VITESS simulation with the $Na_2Ca_3Al_2F_{14}$ sample [95].

http://arxiv.org/abs/1607.02324

I. Stefanescu et al, JINST 12 (2017) P01019

Counting rate definitions

	Global over whole detector area	**Local** per cm^2, mm^2 or pixel
Time-averaged per s	 Data storage Relevant for bandwidth in DAQ and storage Total number of neutrons per second on whole detector area	 Readout Design Total number of neutrons per second on a pixel or unit area
Instantaneous per s	 SANS Relevant for detector technology choice Highest instantaneous number of neutrons per second on whole detector area	 Reflectometry Highest instantaneous number of neutrons per second in the brightest pixel or unit area

*I. Stefanescu et al. ,"Neutron detectors for the ESS diffractometers," Journal of Instrumentation , vol. 12, no. 01, p. P01019, 2017.

Engineering Diffractometer: BEER

Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

EUROPEAN SPALLATION SOURCE

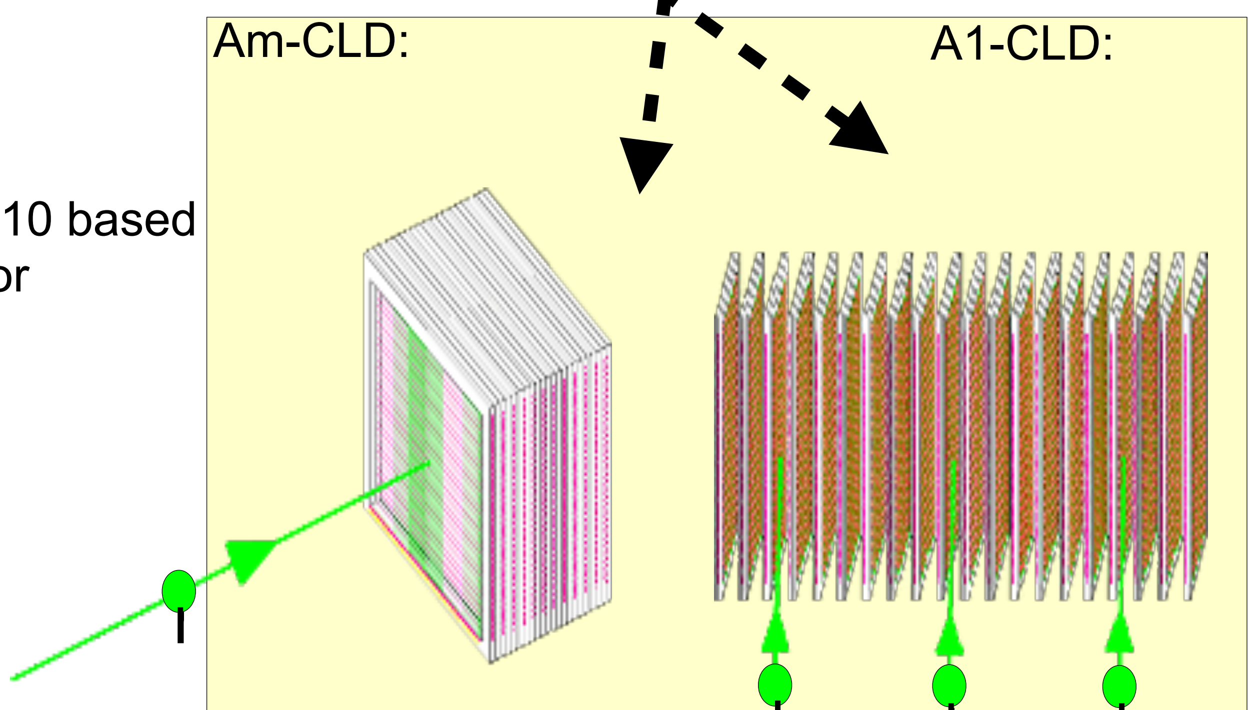
<u>D1-D4 Detectors at 2m to sample:</u>

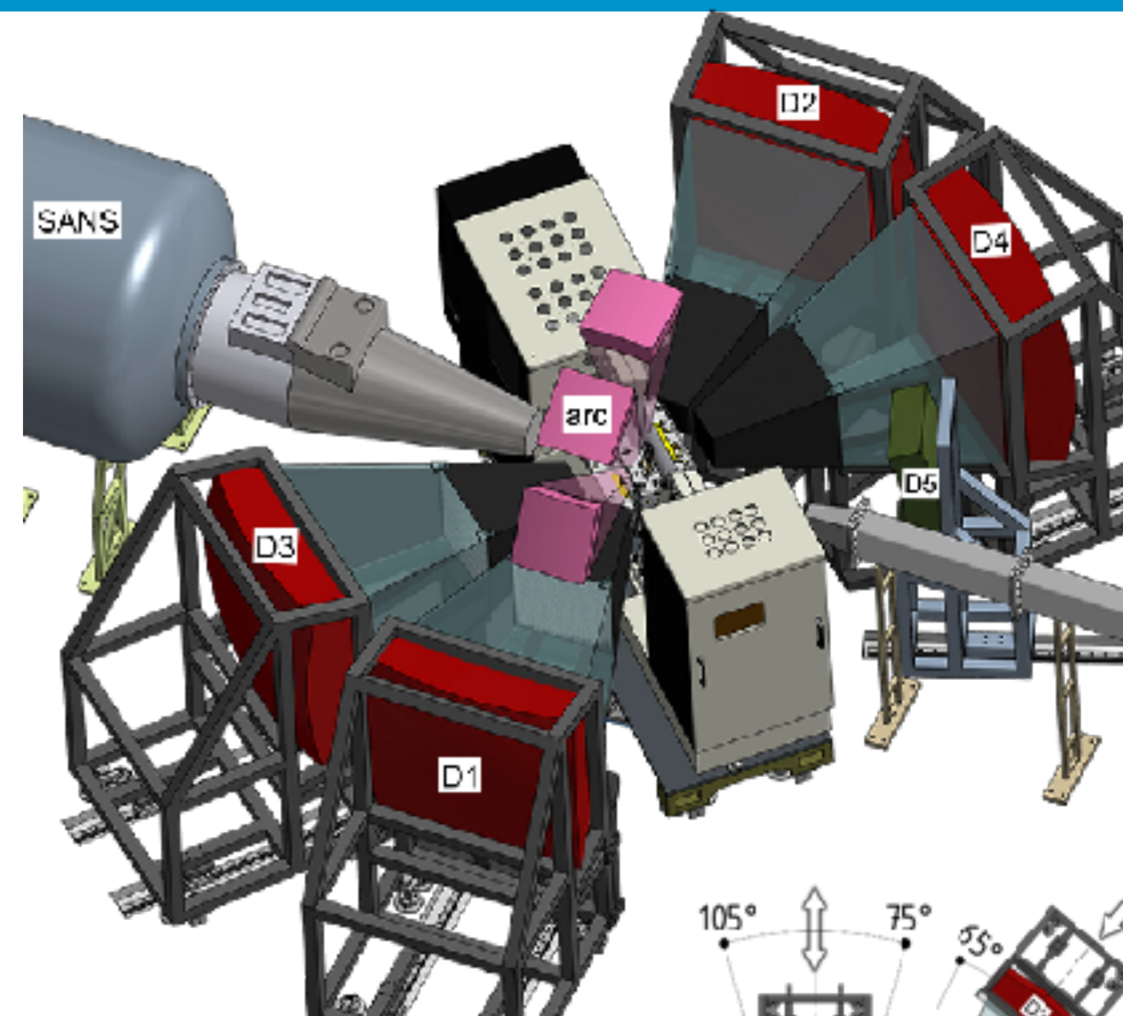
- 1 m x 1m i.e. 30° x 30°
- η > 60 % (2Å)
- Position Resolution: 2 mm x (5 mm)
- Max Rate:< 10^6 1/s (global)
- moveable

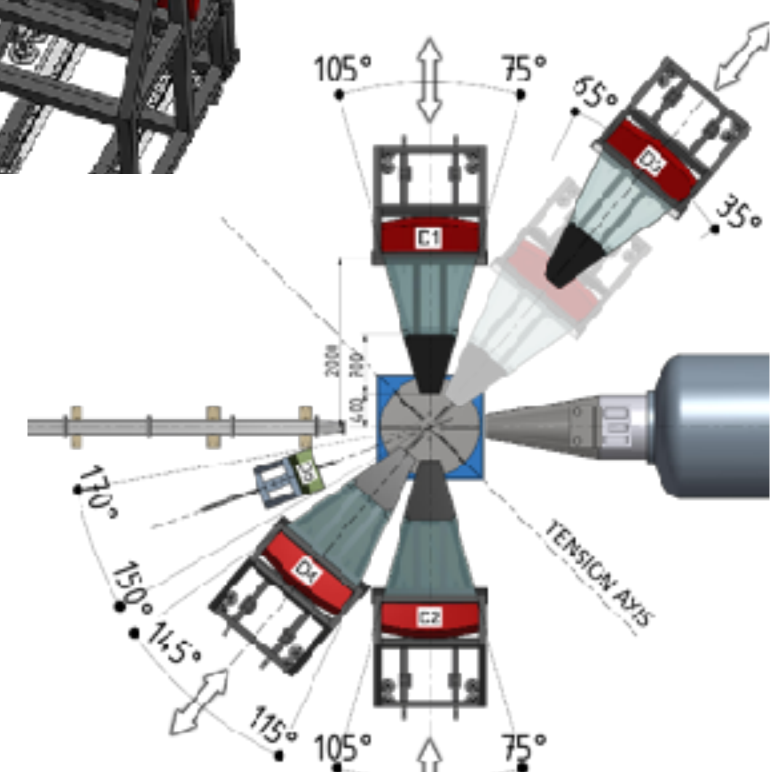
<u>Arc-Detectors at 1m to sample:</u>

- 1.5 m x 0.5 m i.e. 100° x 30°
- η > 60 % (2Å)
- Position Resolution: 2 mm x 5 mm
- Max Rate: 10^6 1/s (global)

- Boron-10 based detector



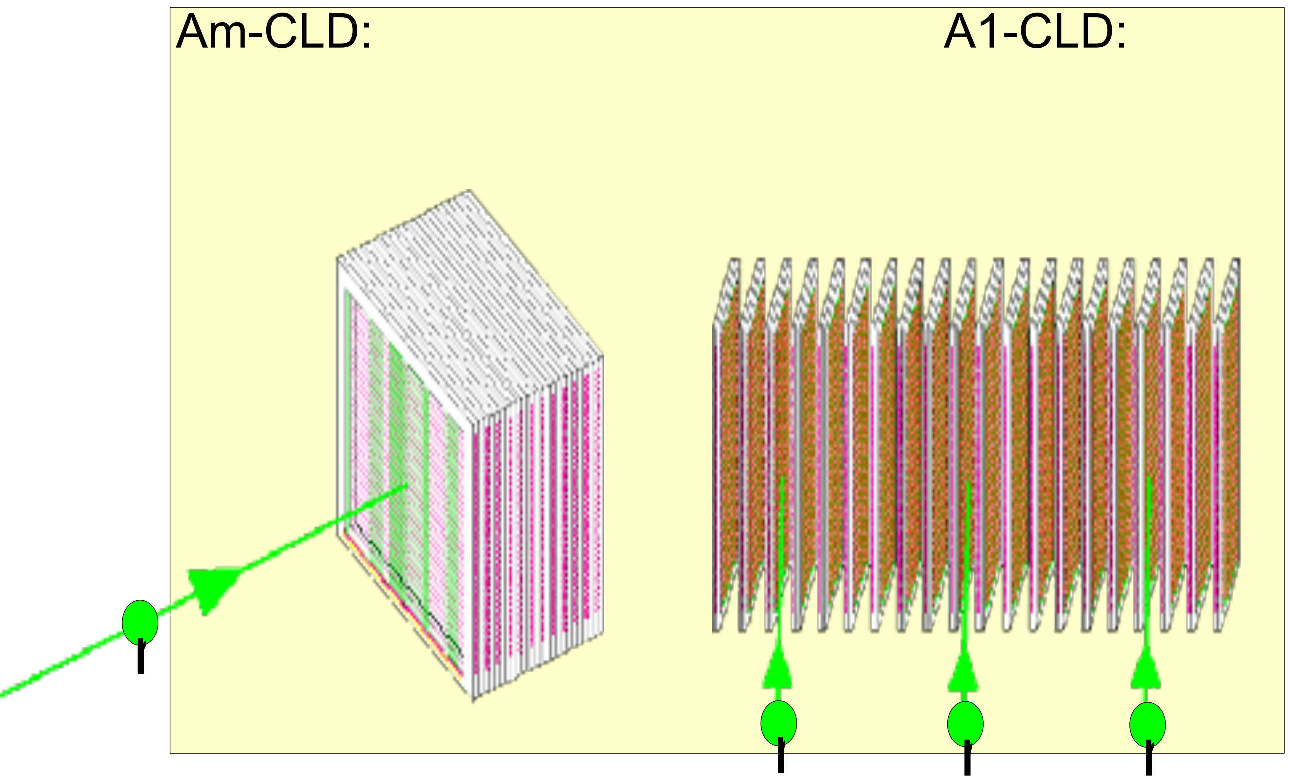


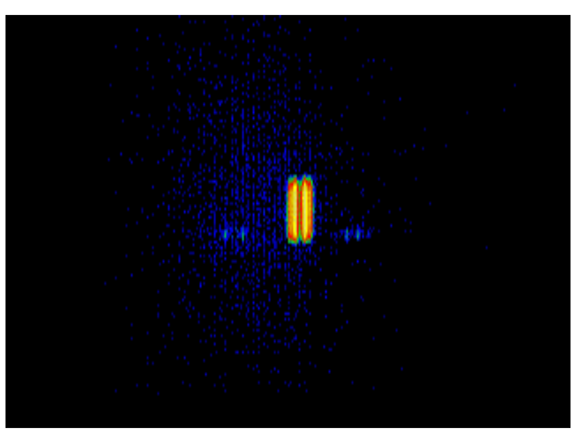


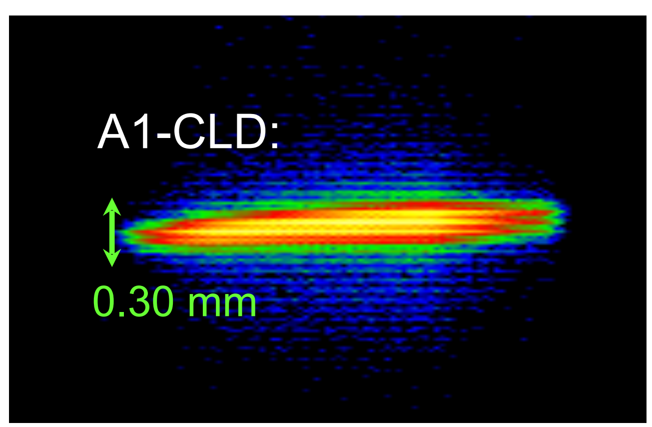
Helmholtz-Zentrum Geesthacht
Zentrum für Material- und Küstenforschung

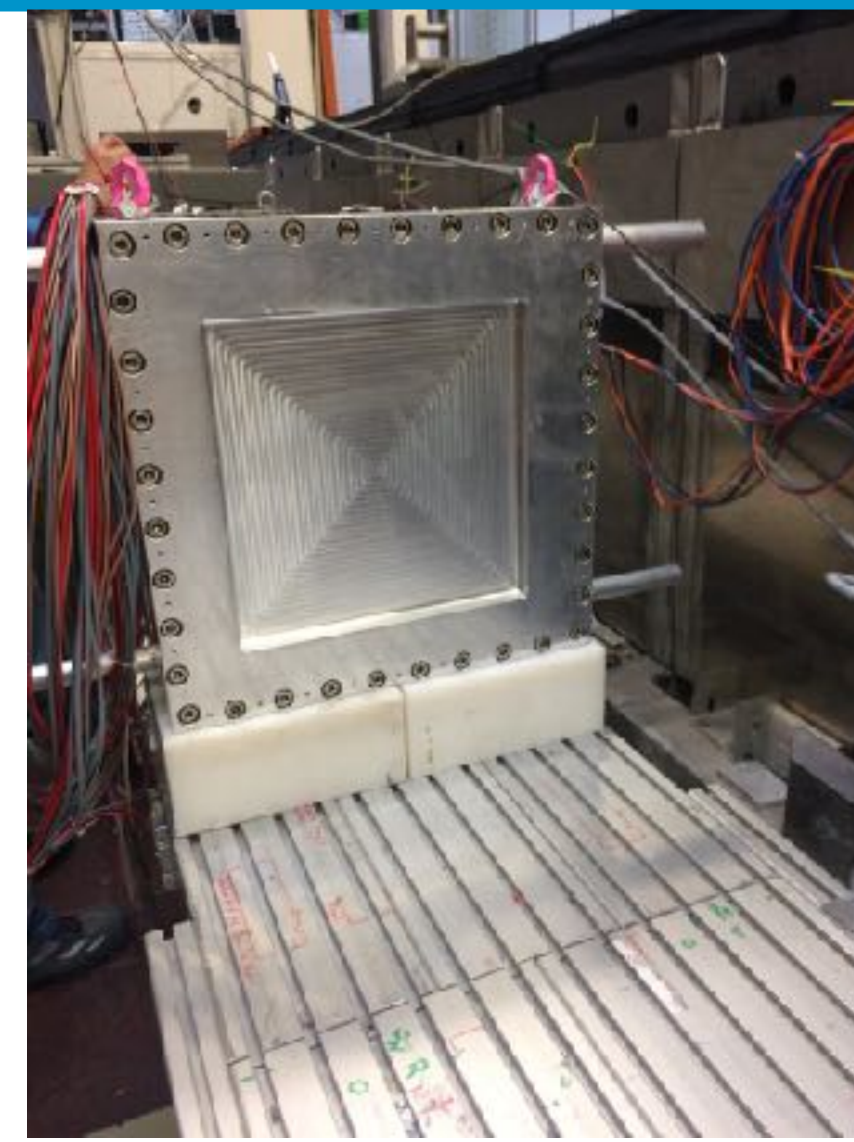
Engineering Diffractometer: BEER

EUROPEAN SPALLATION SOURCE









prototype Am-CLD on test at V20, HZB April'17

- mm position resolution
- variable efficiency

- sub-mm position resolution
- very high efficiency
- mechanically very complicated

EUROPEAN SPALLATION SOURCE

Bovine heart

cytochrome c oxidase

$P2_12_12_1$

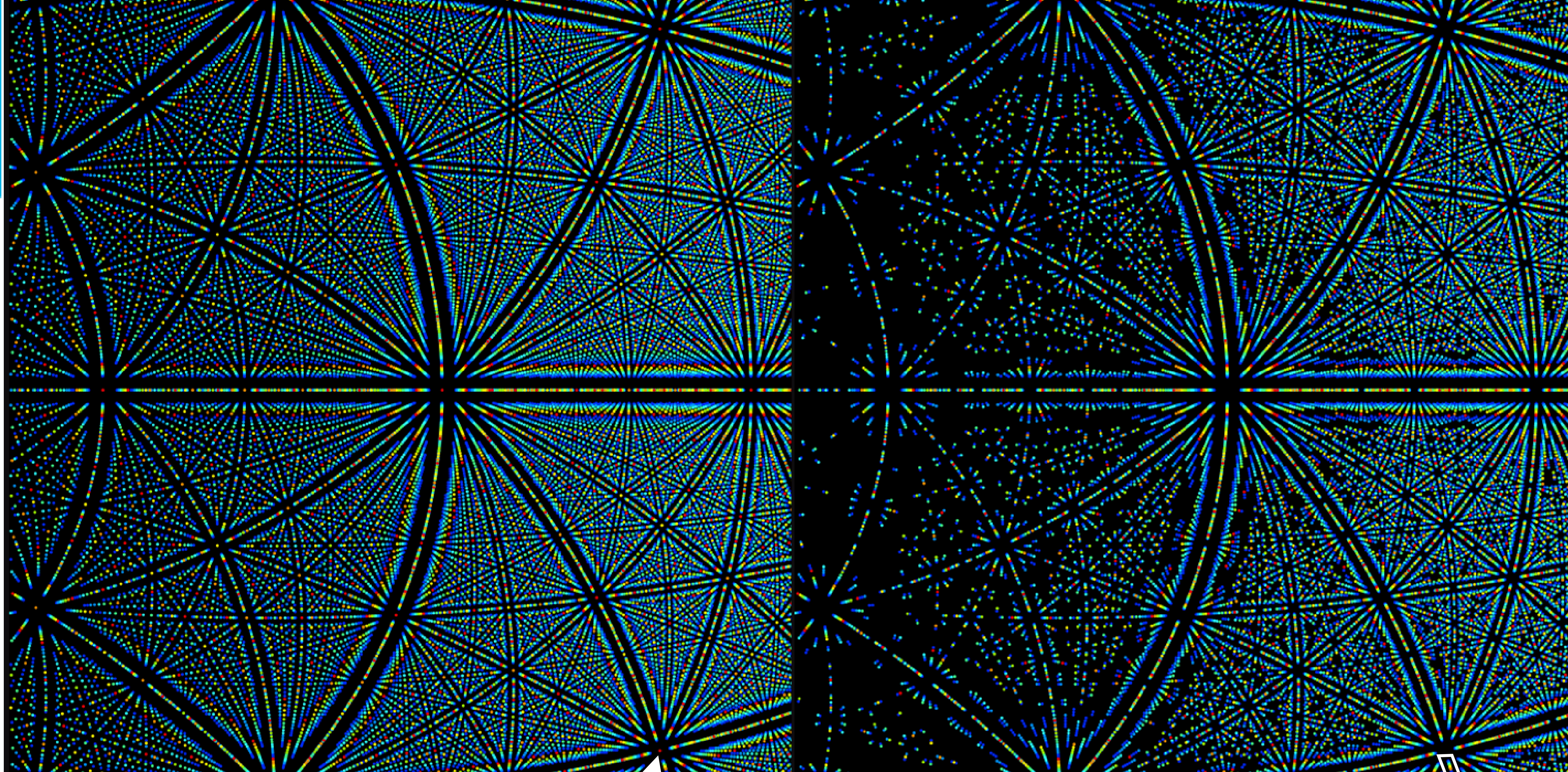
a = 182.59 Å

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)

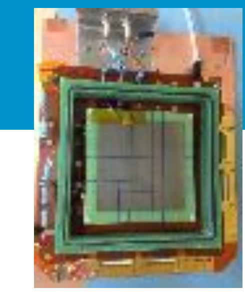
1.800 to 2.019 Angstroms
2.019 to 2.237 Angstroms
2.237 to 2.456 Angstroms
2.456 to 2.675 Angstroms
2.675 to 2.894 Angstroms
2.894 to 3.112 Angstroms
3.112 to 3.331 Angstroms
3.331 to 3.550 Angstroms

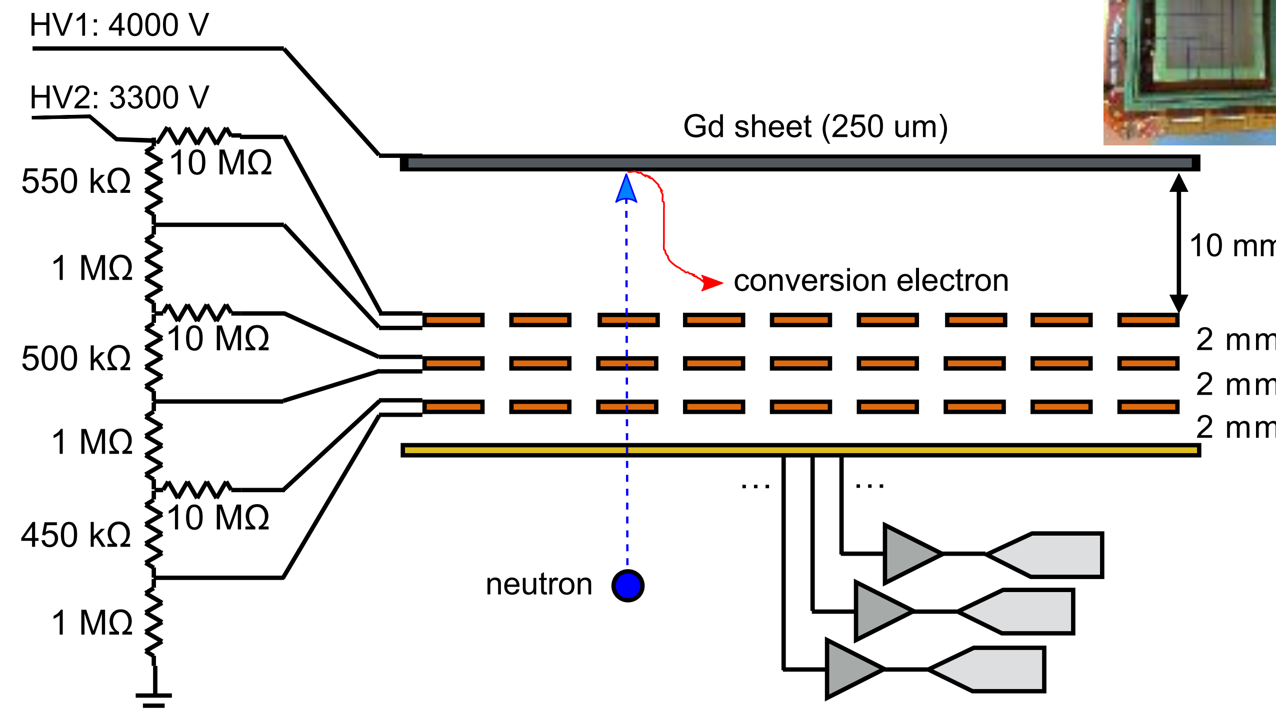
Generated using the Daresbury Laue Suite

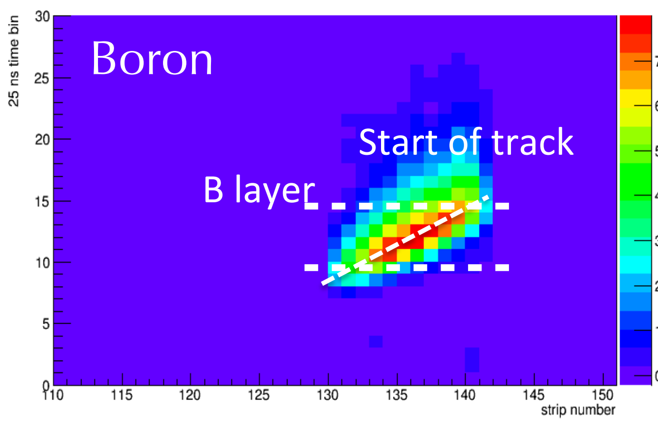
Campbell et al. J. Appl. Cryst. (1998). 31, 496-502
Artz et al. J. Appl. Cryst. (1999). 32, 554-562
Helliwell, J.R. et al. J. Appl. Cryst. (1989) 22, 483–497

Gd-GEM

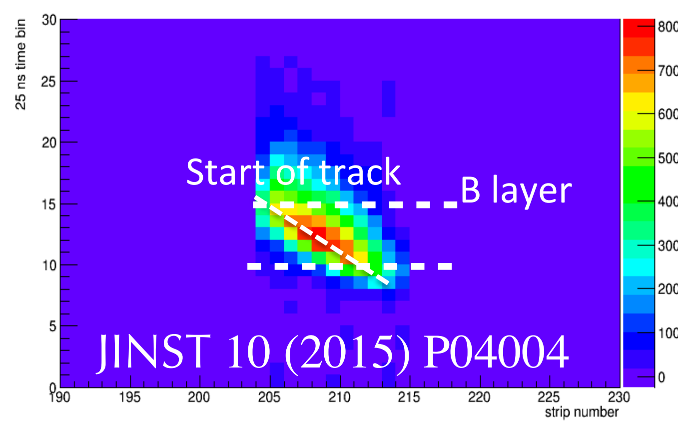
- NMX: <<1mm position resolution requirement, Time Resolved, ca. 1m^2 detector area
- Take Micro Time Projection Chamber concept from ATLAS experiment upgrade
- Resolution: use single layer Gd, look for electrons



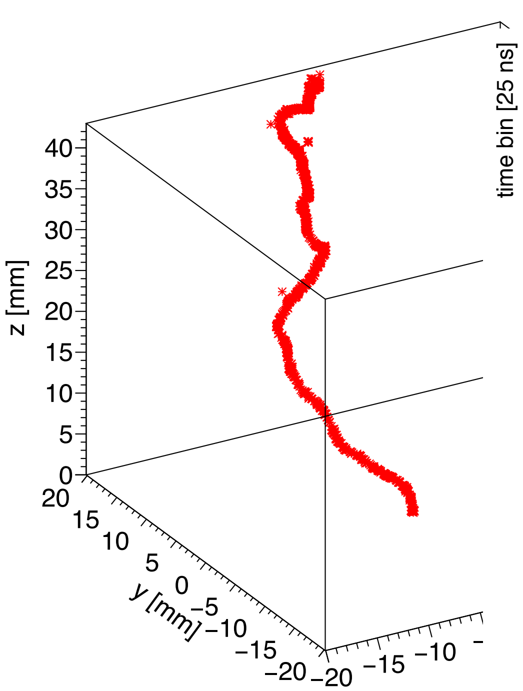


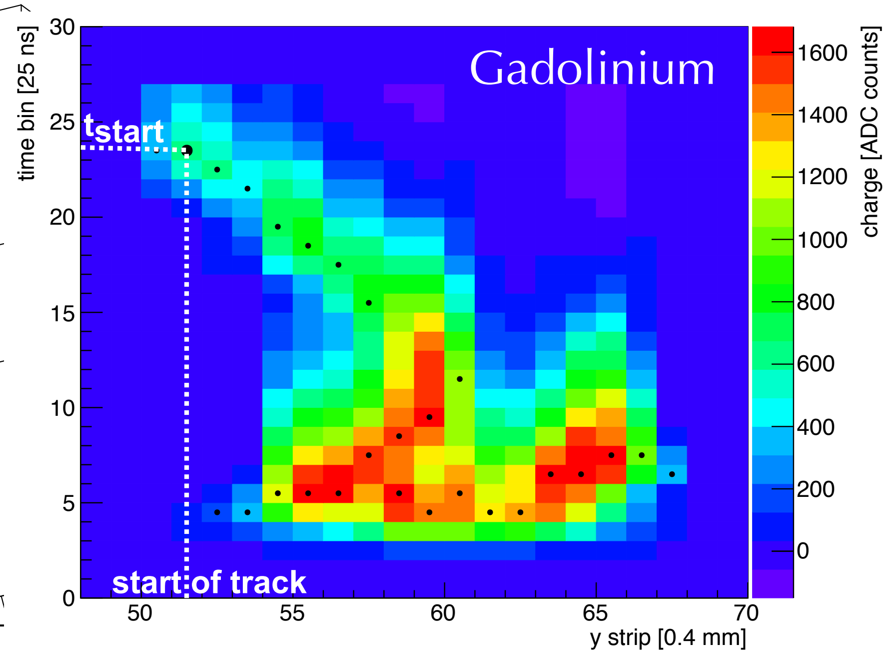


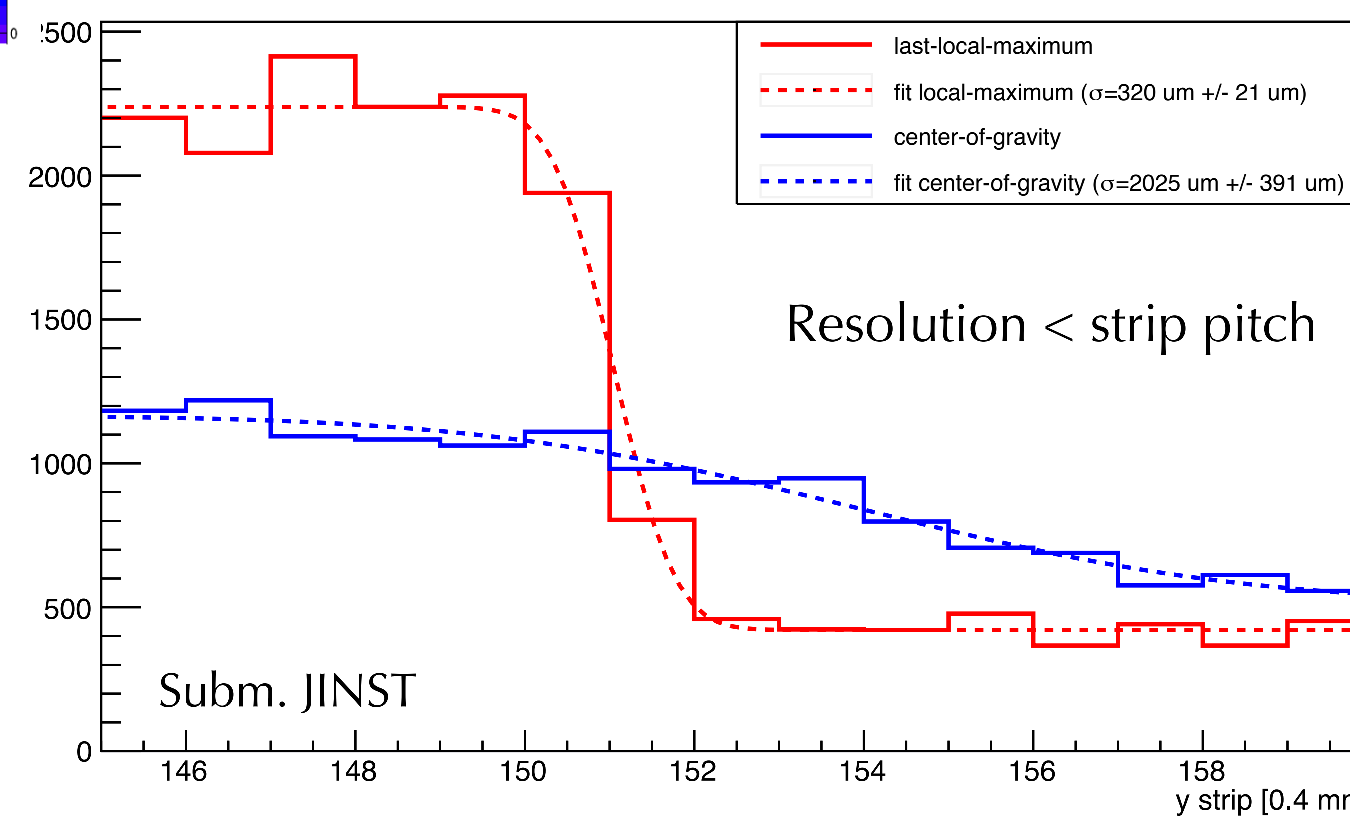
Track x



Track y







Neutron Reflectometry: A Rate Challenge

brightness

- 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

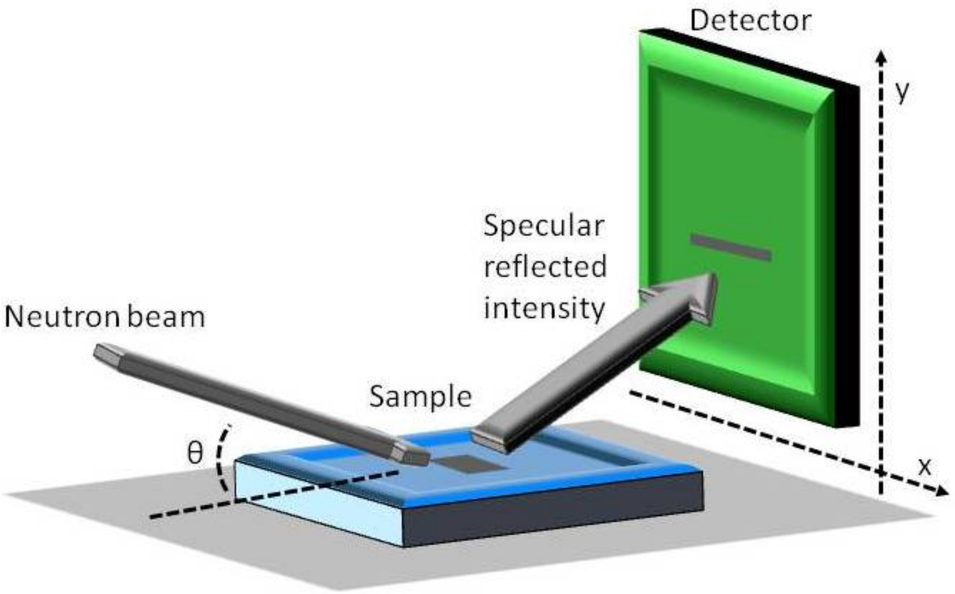
^{3}He technology

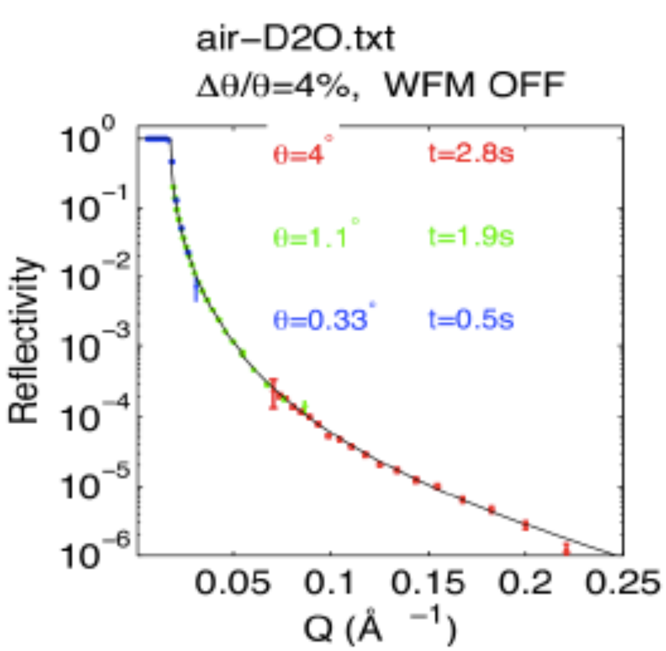
x1 x10

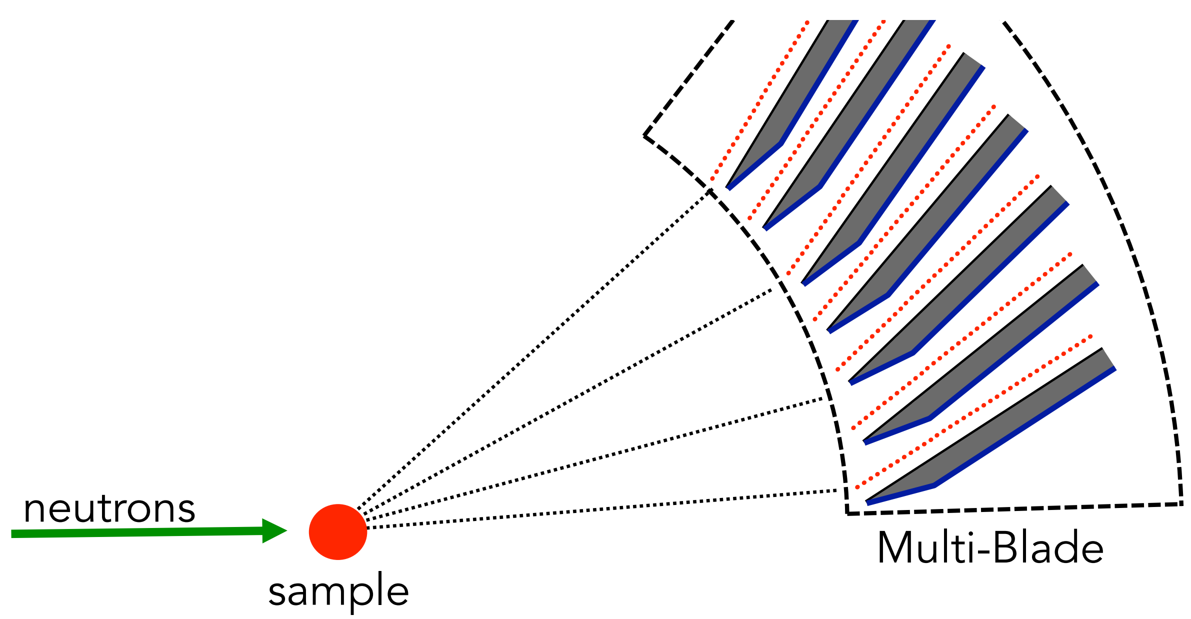
Multi-Blade

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

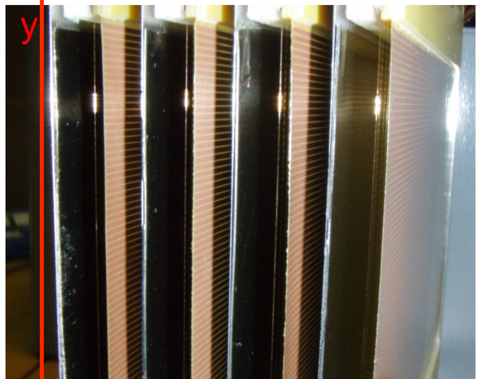
^{10}B technology







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



Multi-Blade Design

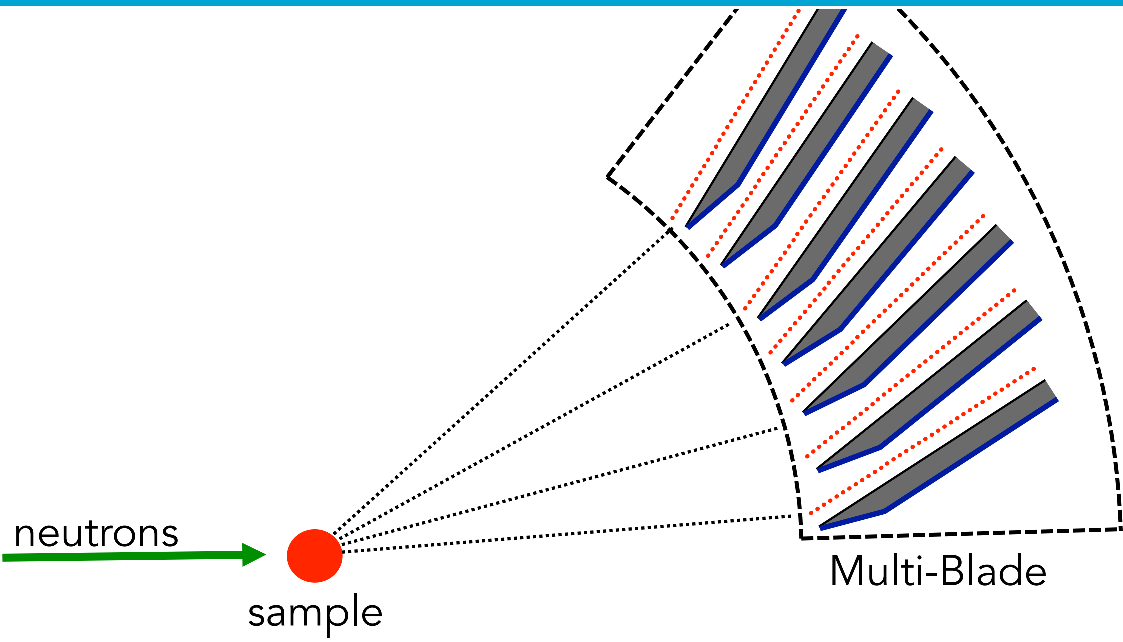
BrightnESS

EUROPEAN SPALLATION SOURCE

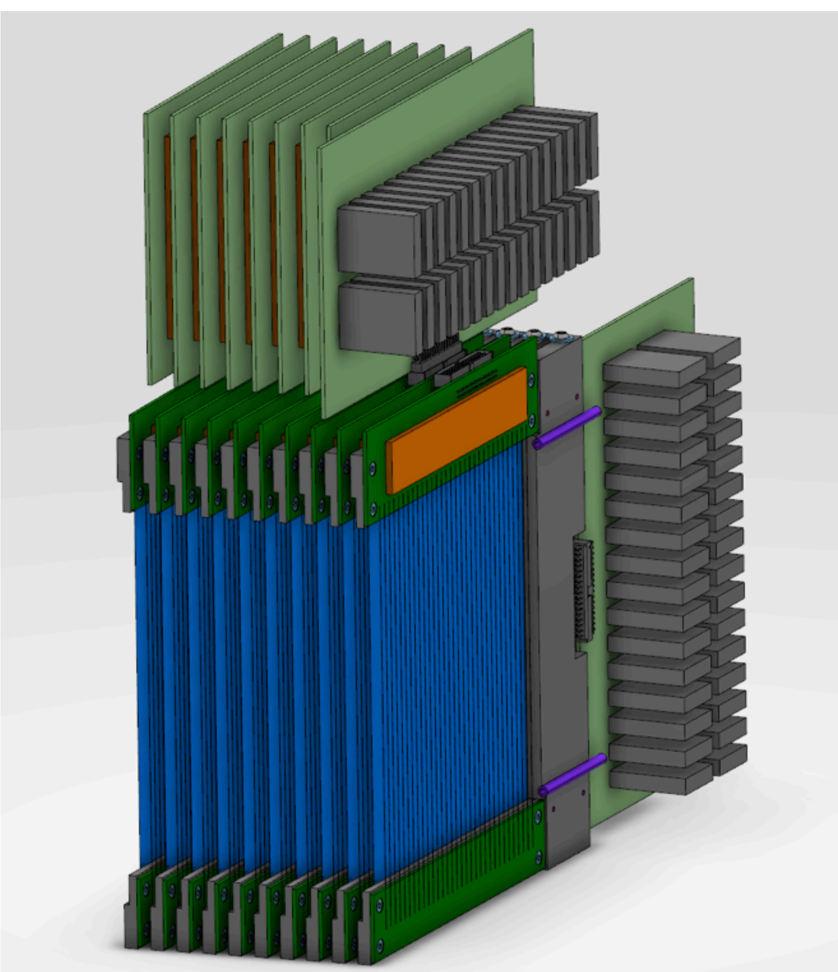
LUND UNIVERSITY

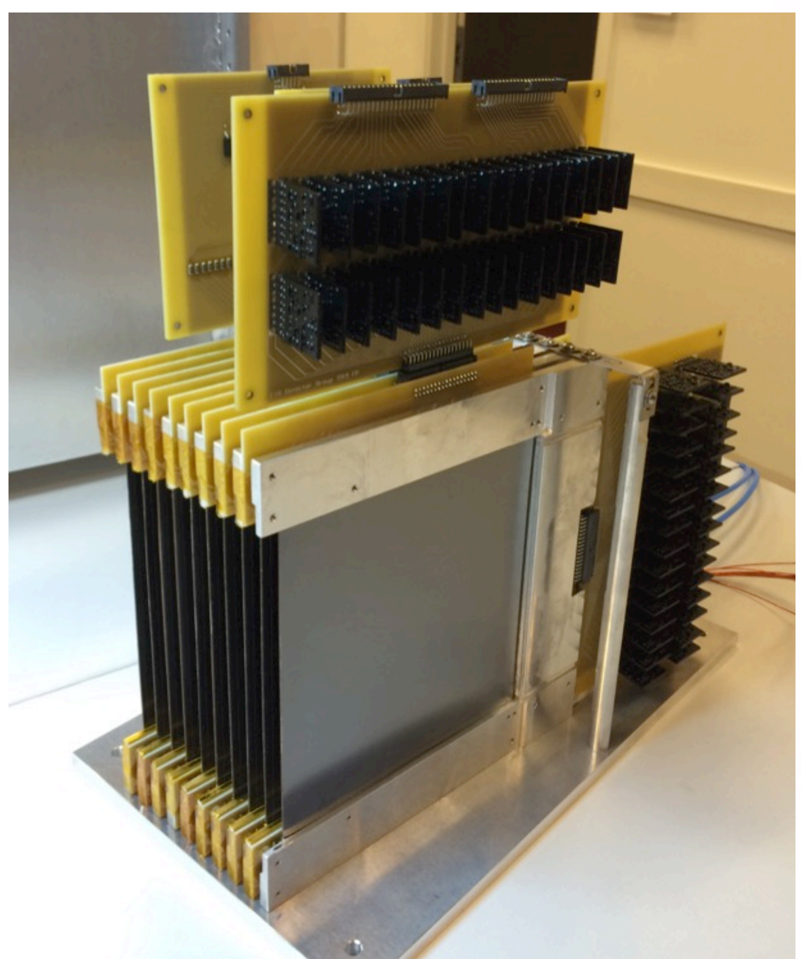
Wigner Research Institute

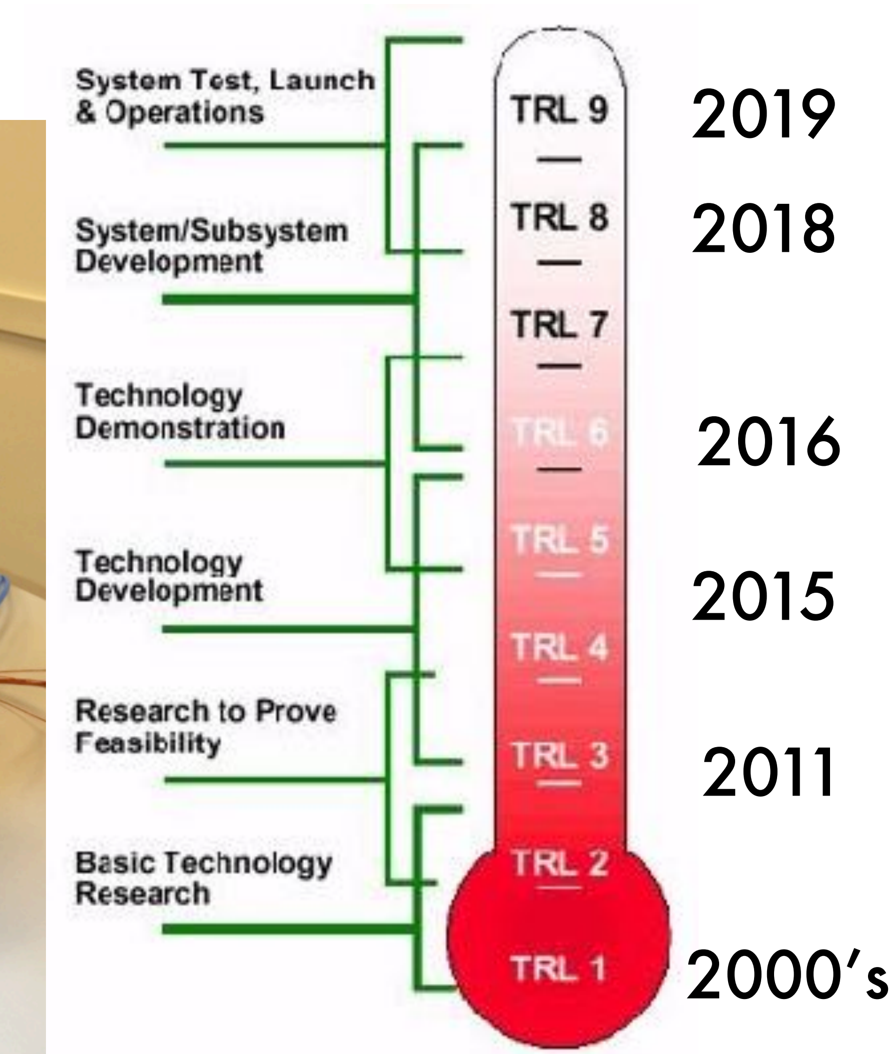
BNC Budapest Neutron Centre



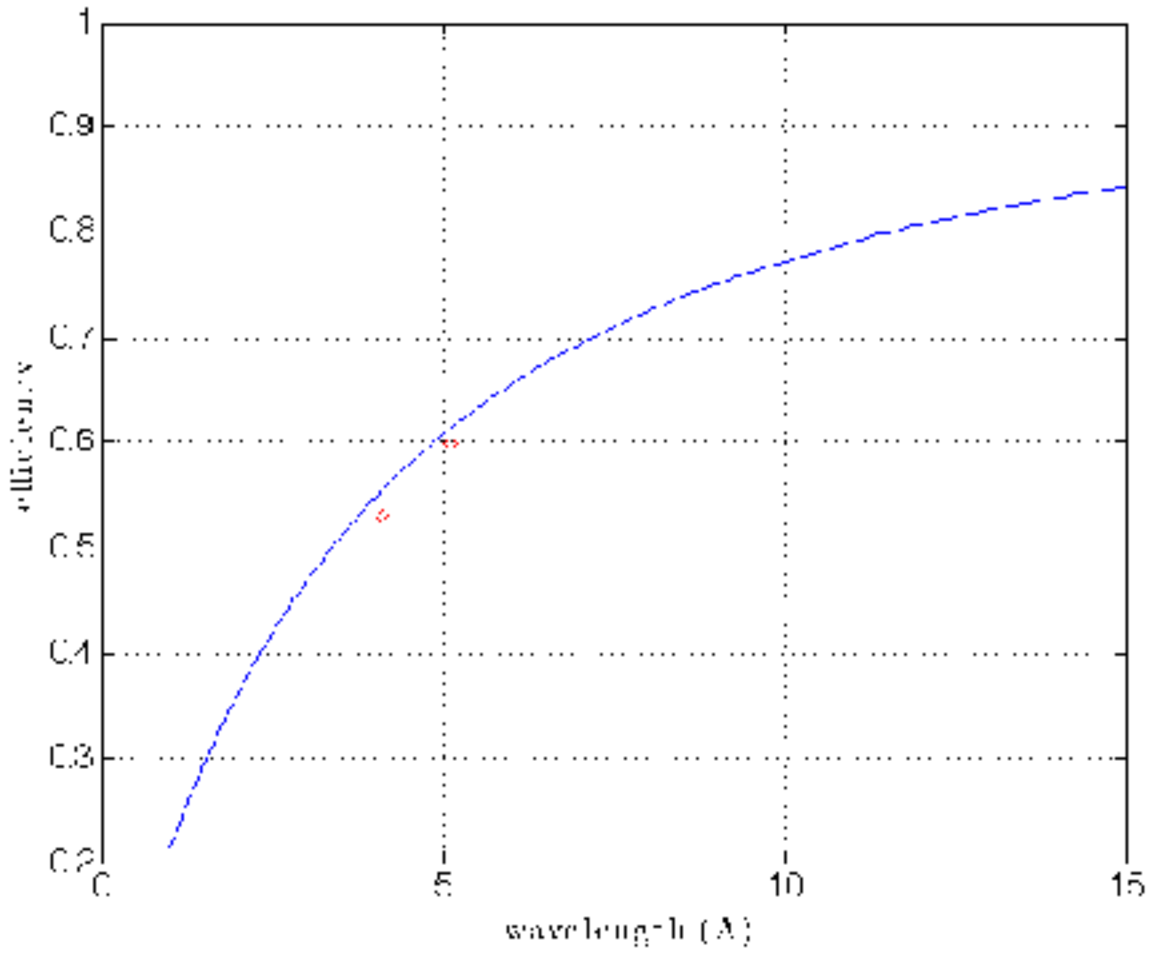
- Design simple: *"KISS"*
- Modular
- Cheap
- Make design available
- *"Open Source Hardware"*

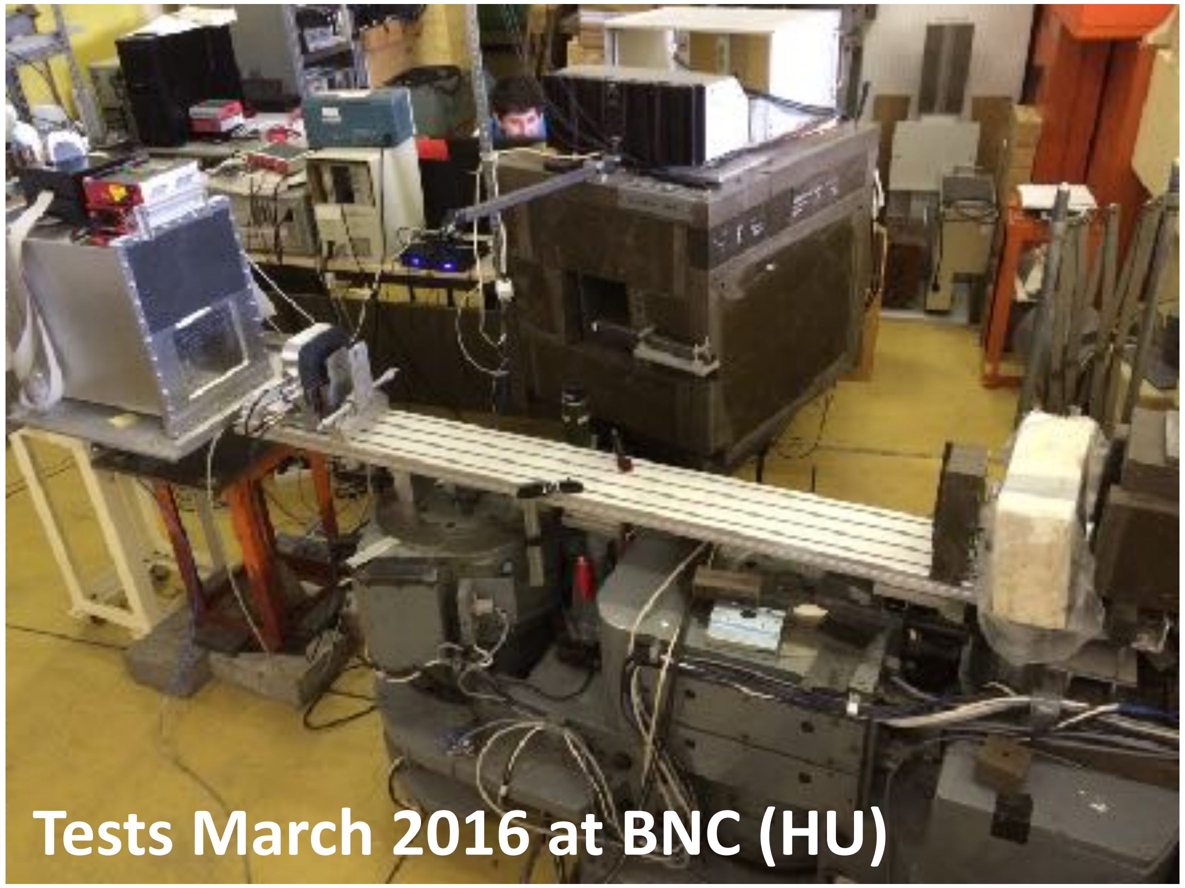




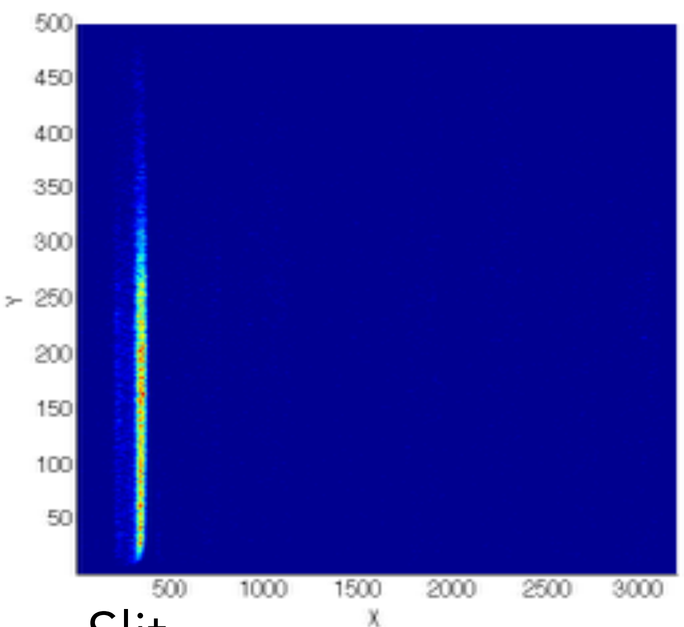


Multi-Blade Results

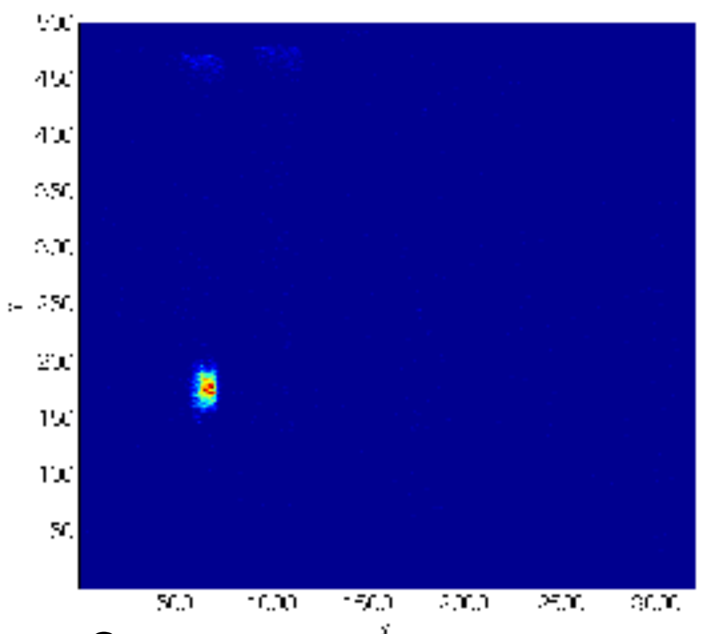




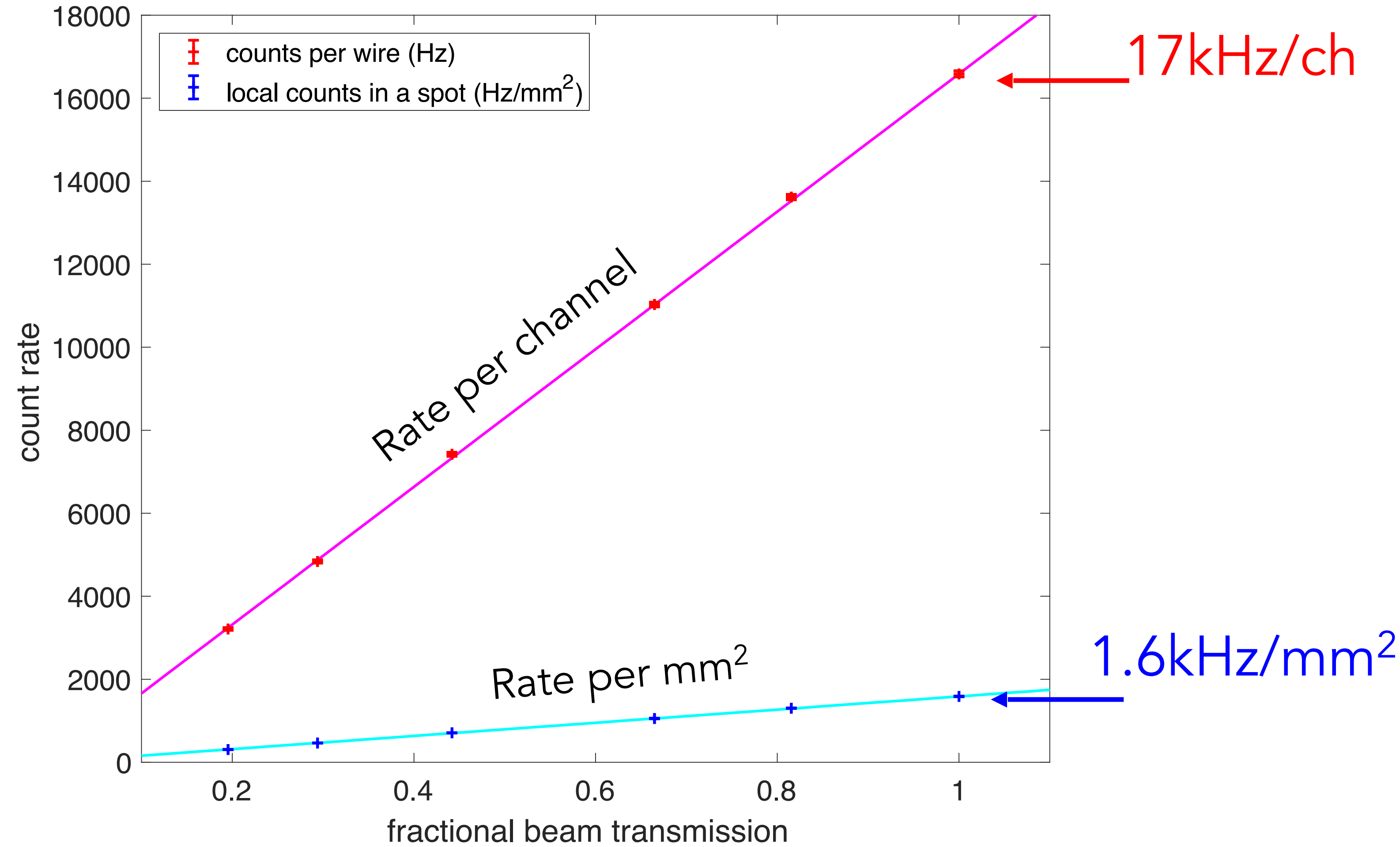
Counting rate capability



Slit



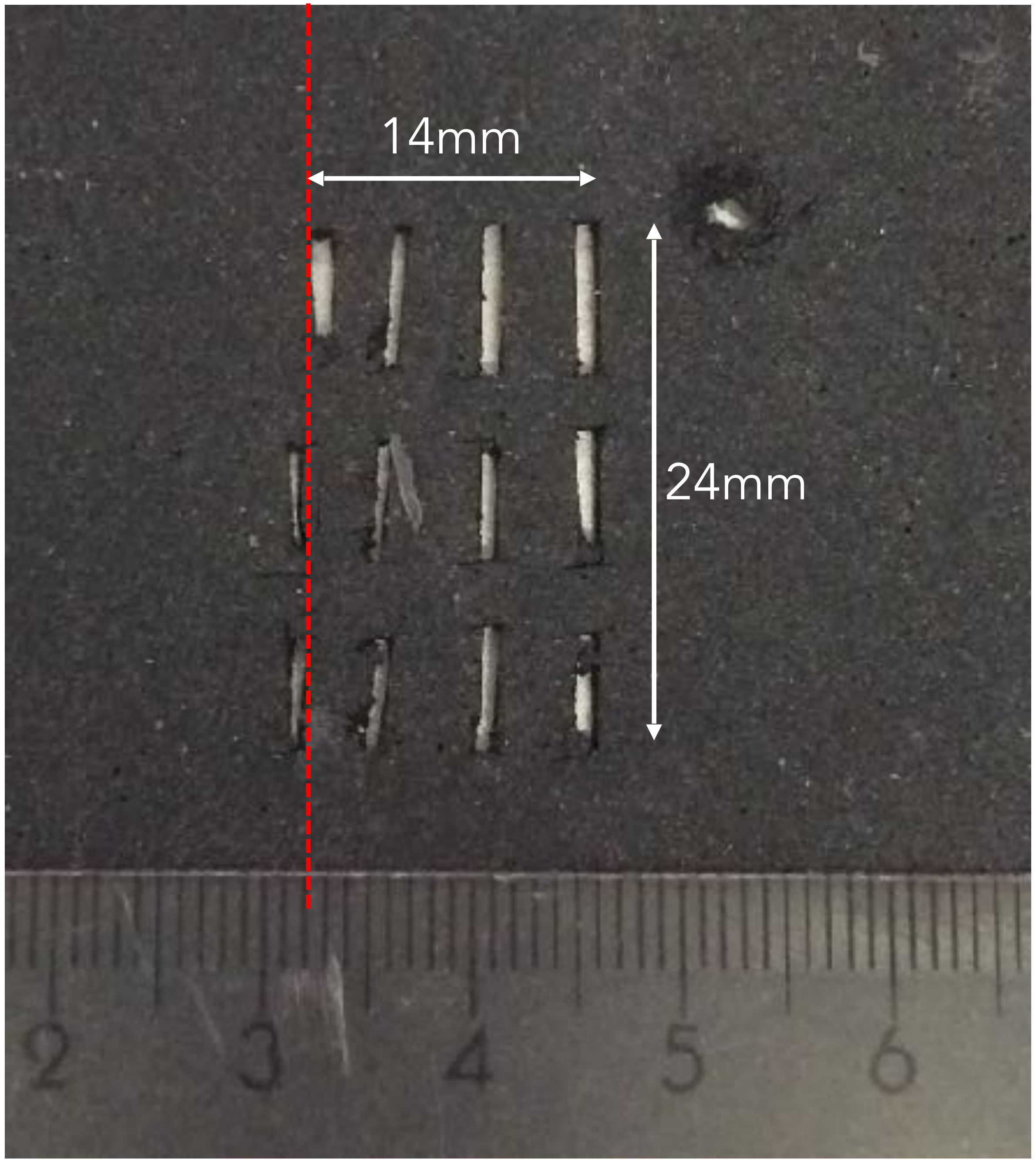
Spot



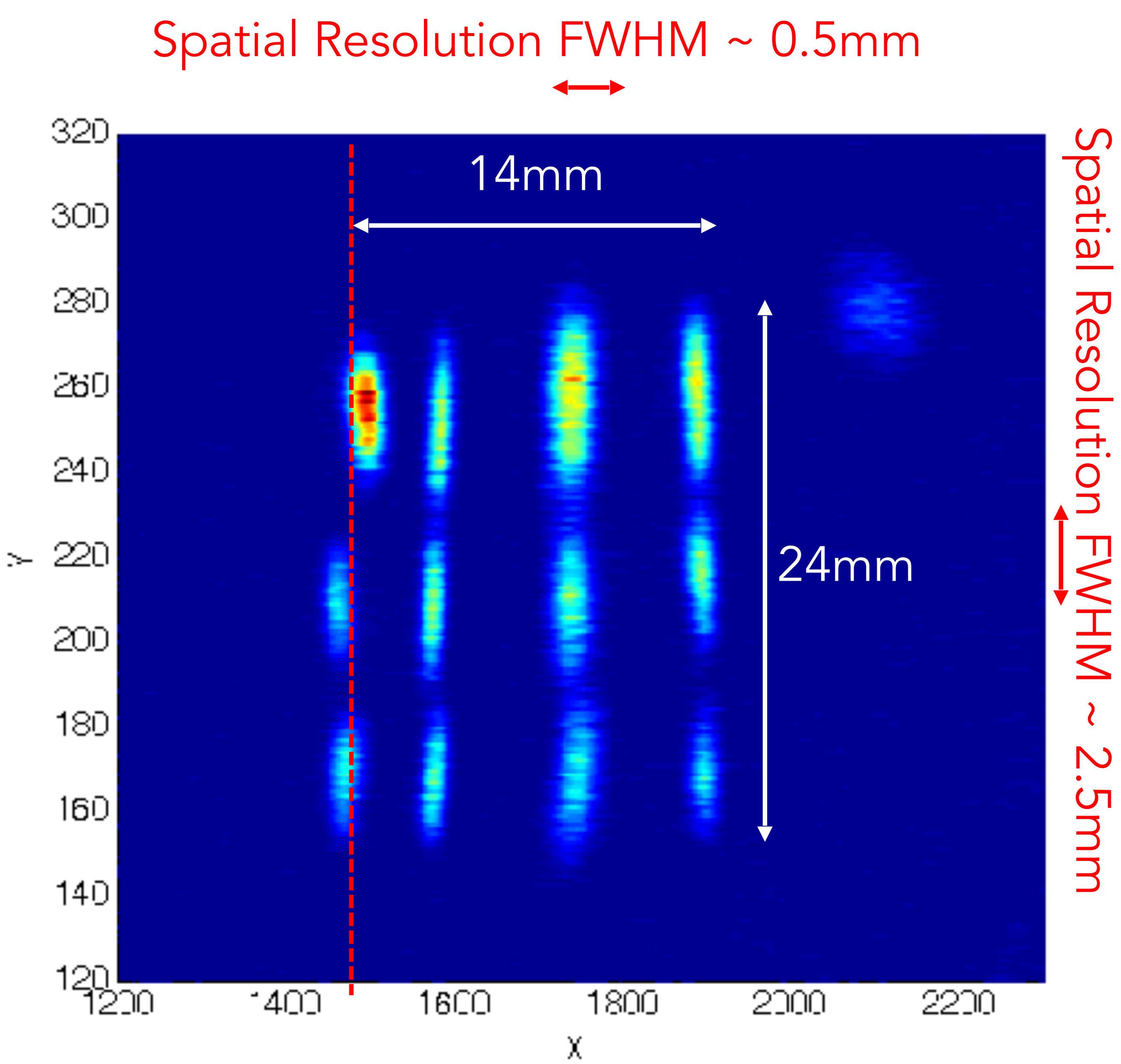
No saturation observed!

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



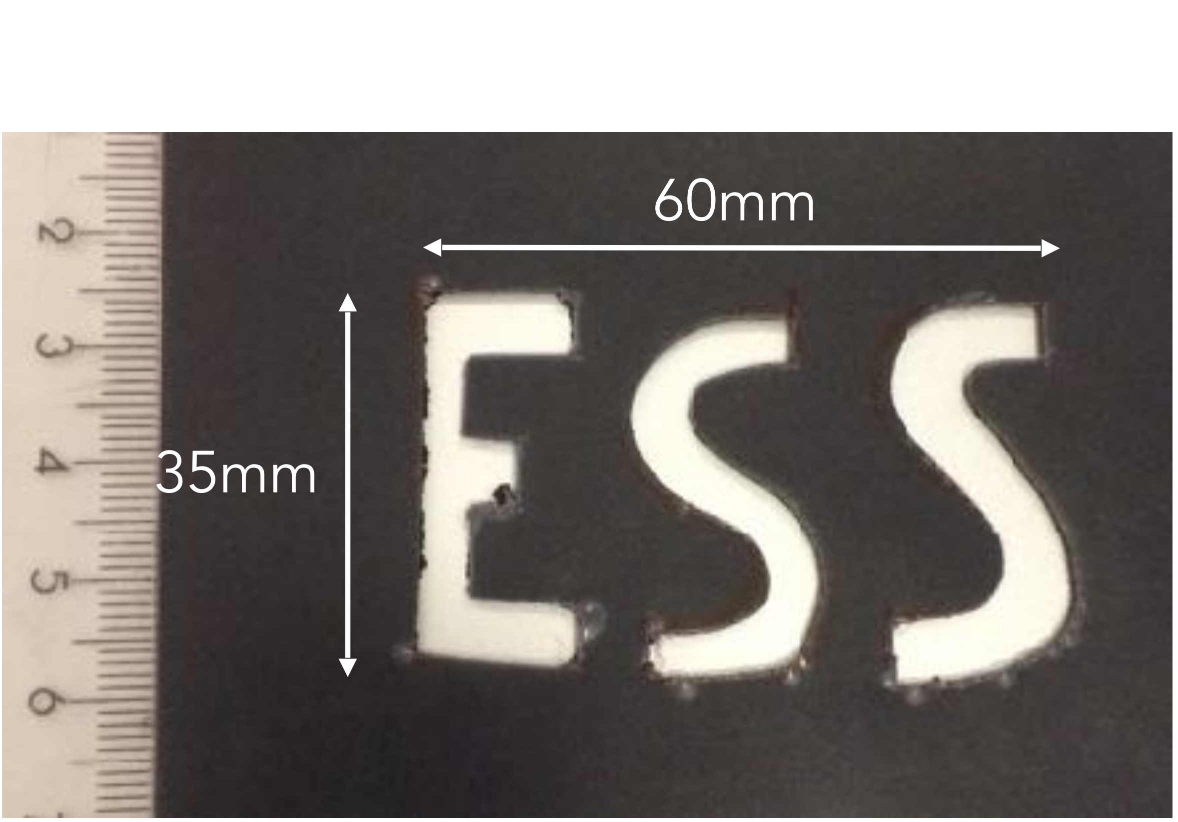
Mask

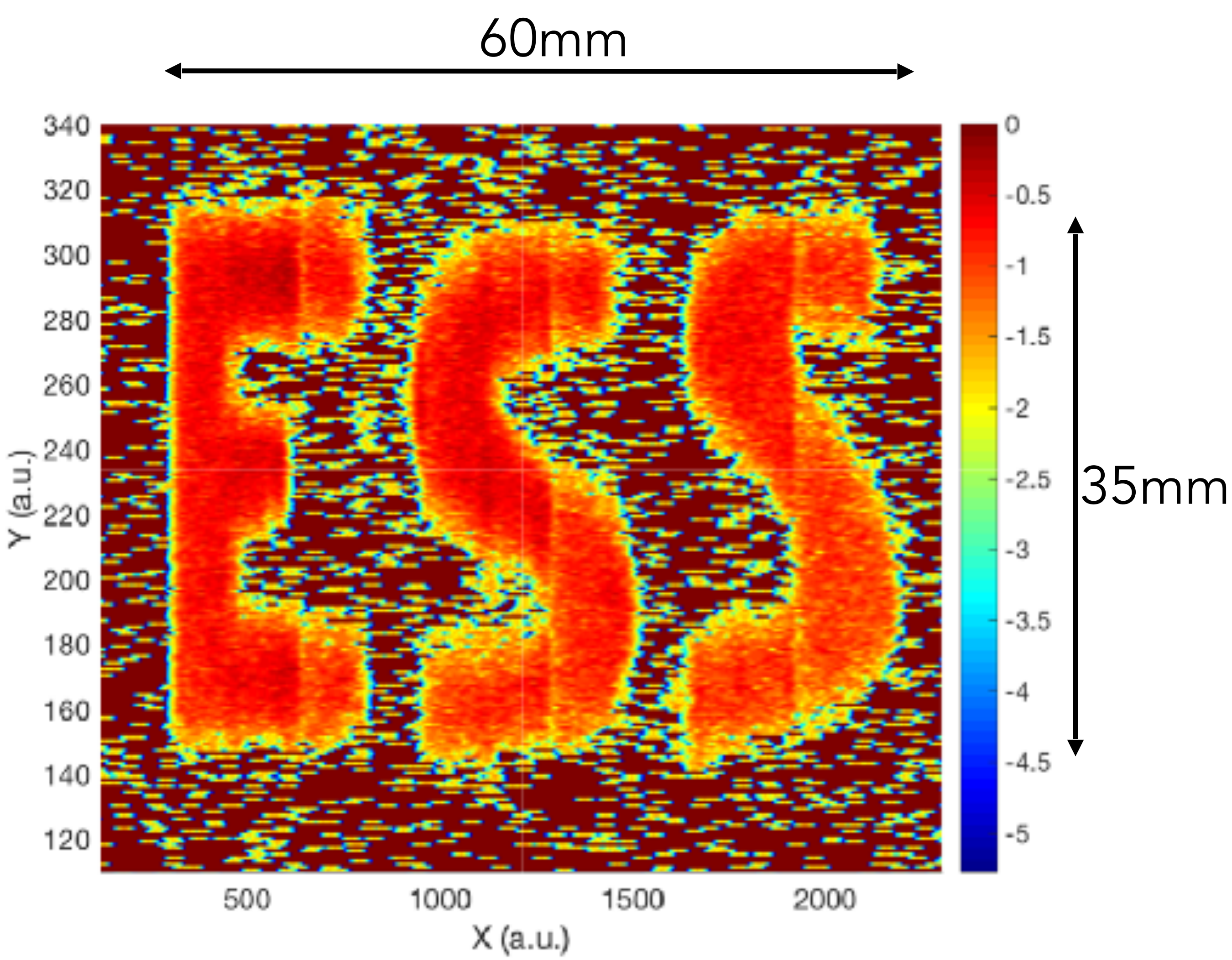


Raw image from the detector

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





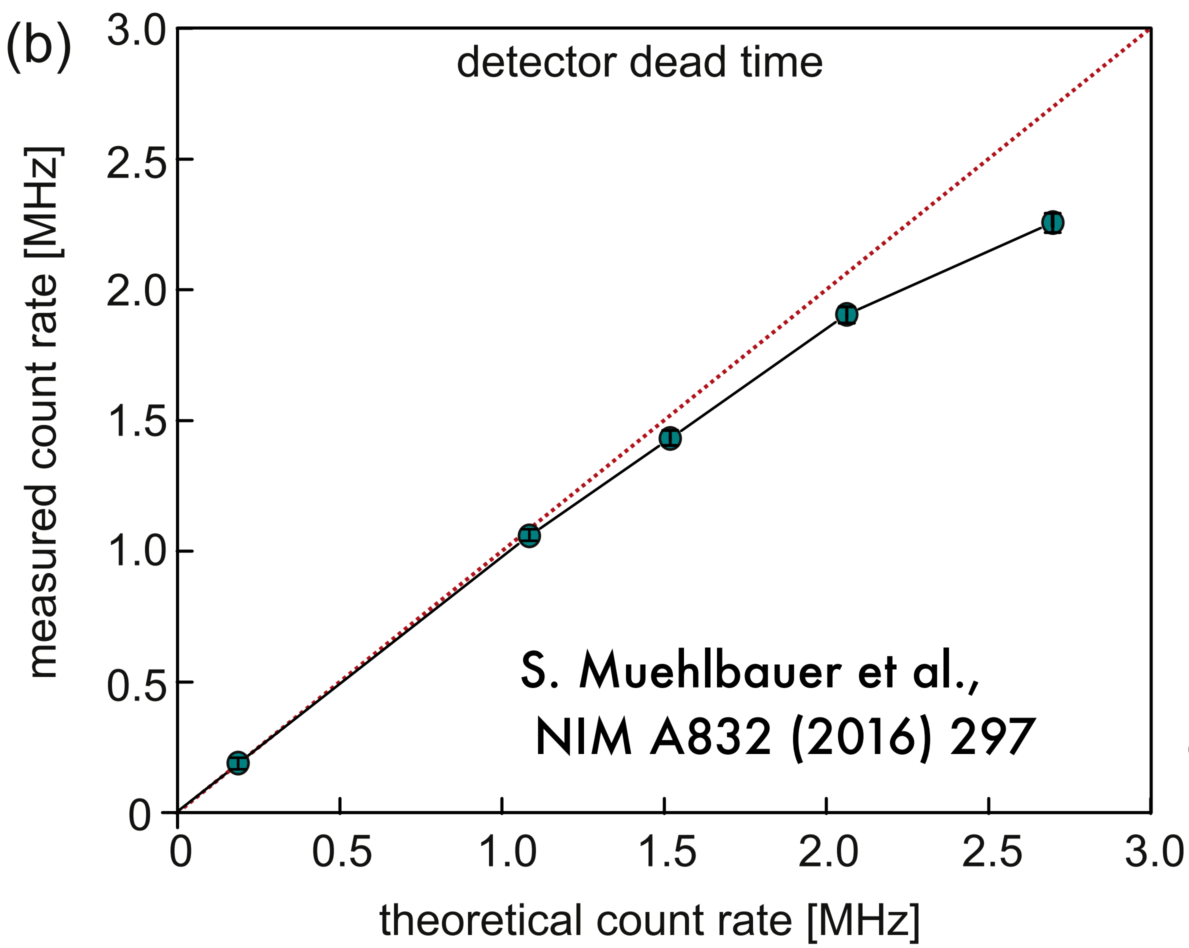
Mask

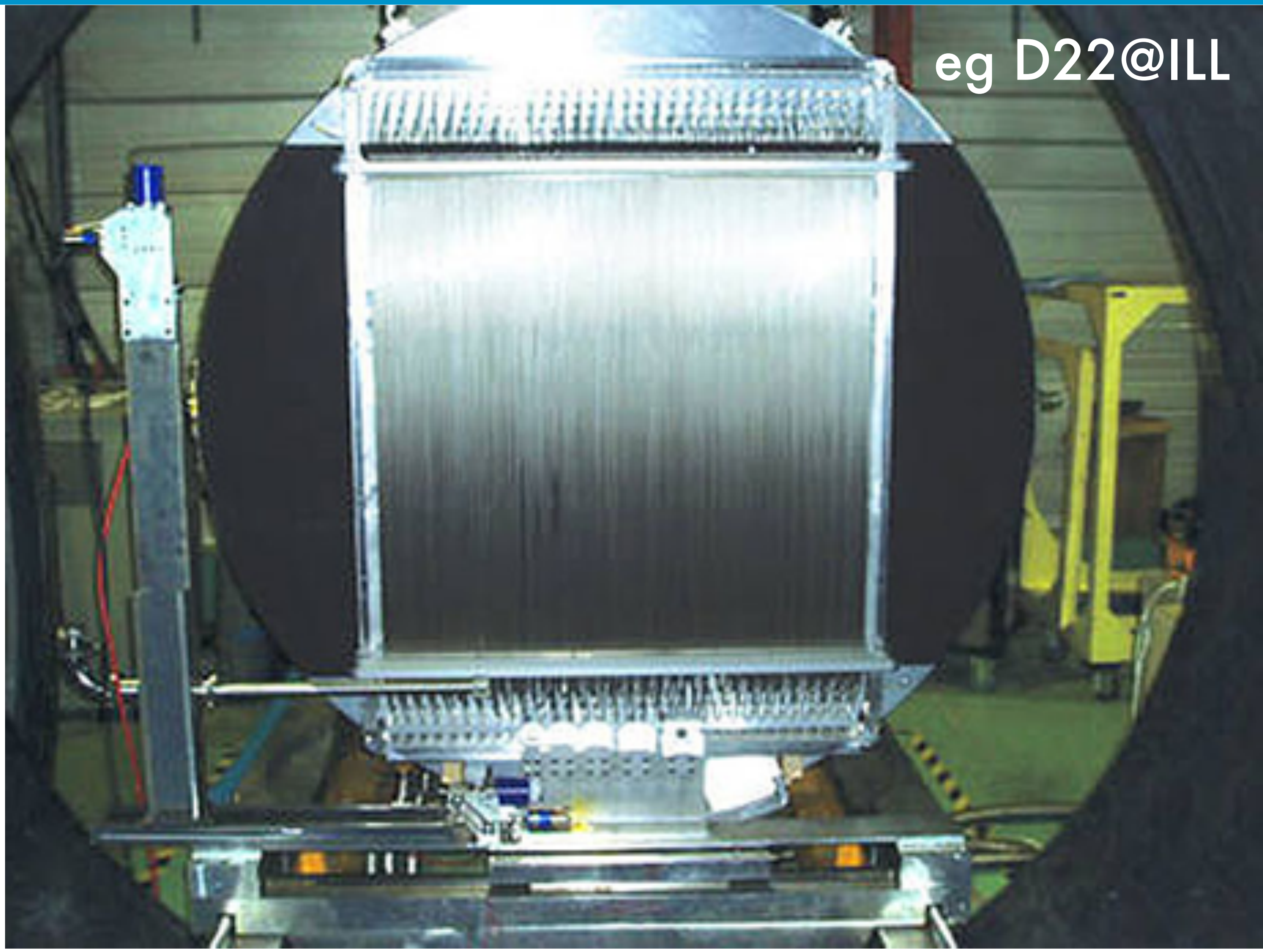
Raw image from the detector (log scale)

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

SANS: State-of-the-art

- Typically stacks of 1m long 8mm He-3 tubes
- Rate limitation few MHz for 10% dead time
- Resolution defined by tube dimensions

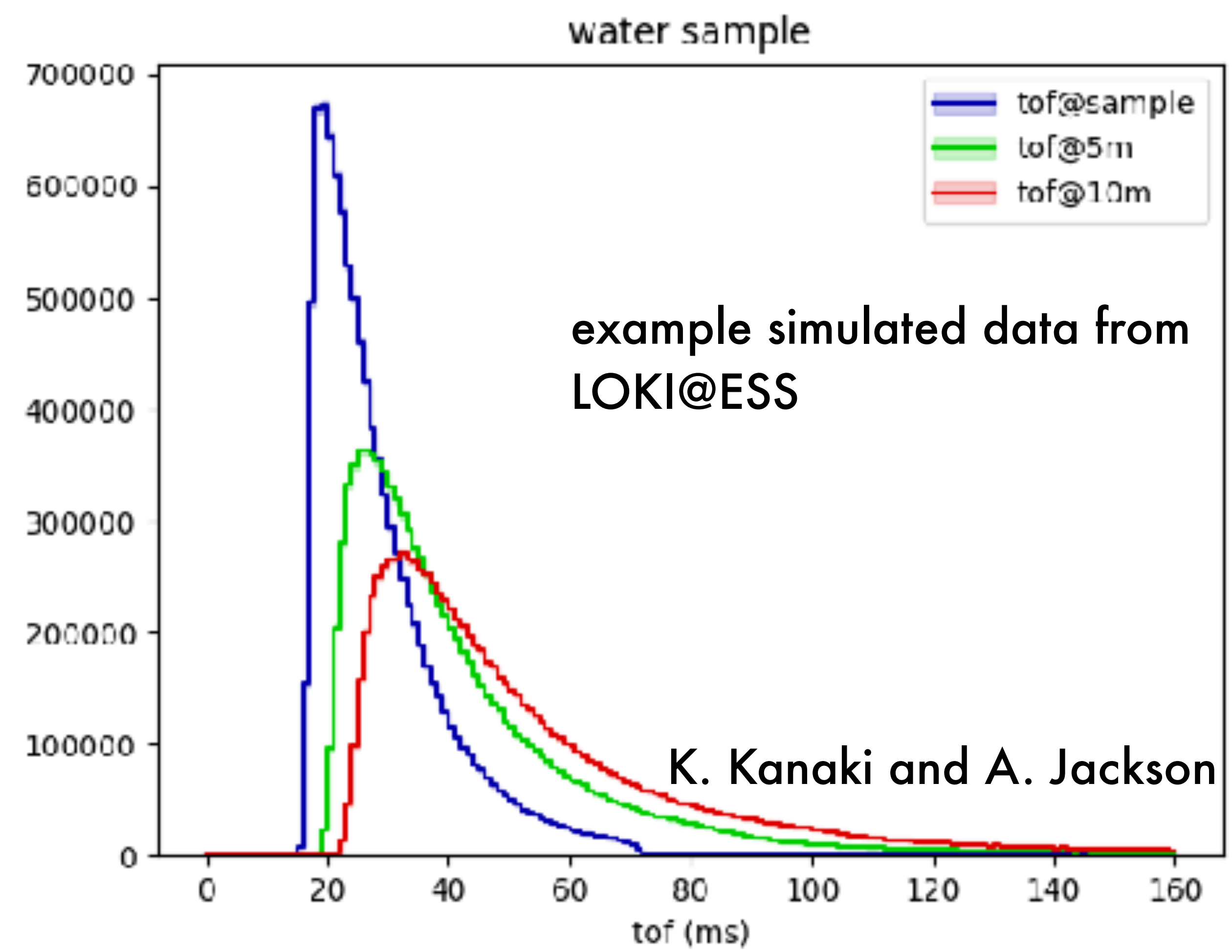


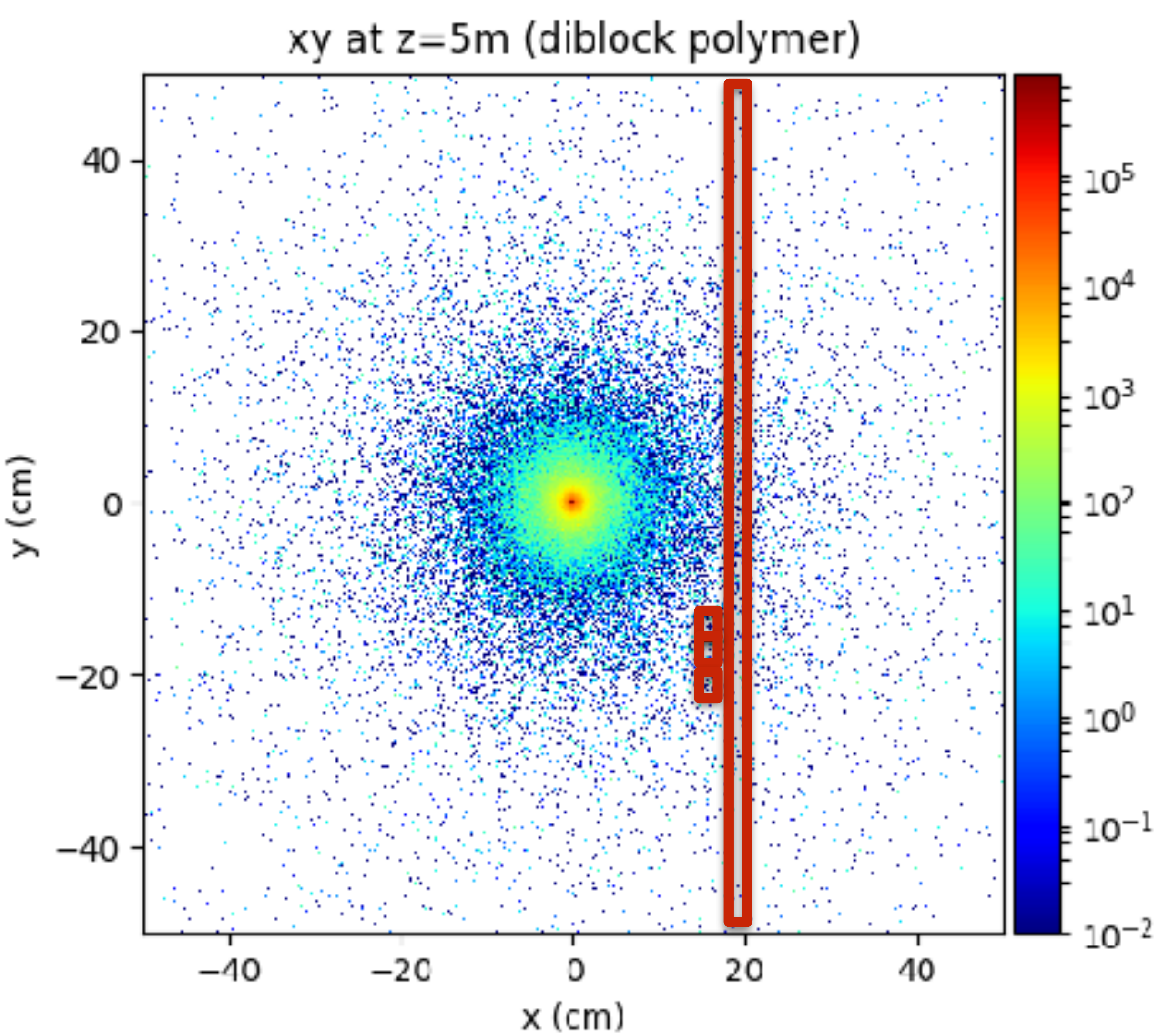


eg SANS-1 at FRM-II

Rates in SANS Data

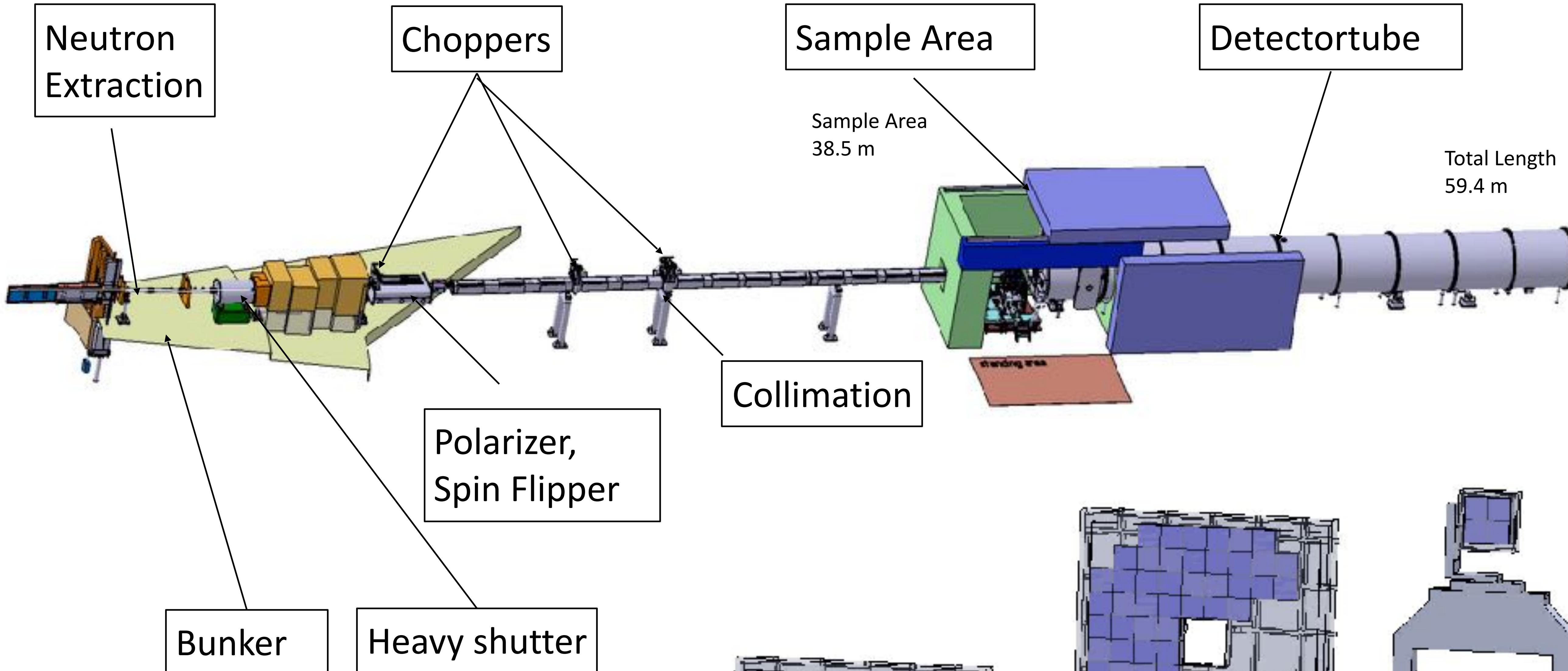
- At spallation sources, data is highly peaked in time
- Additional challenge for the detector rate requirements



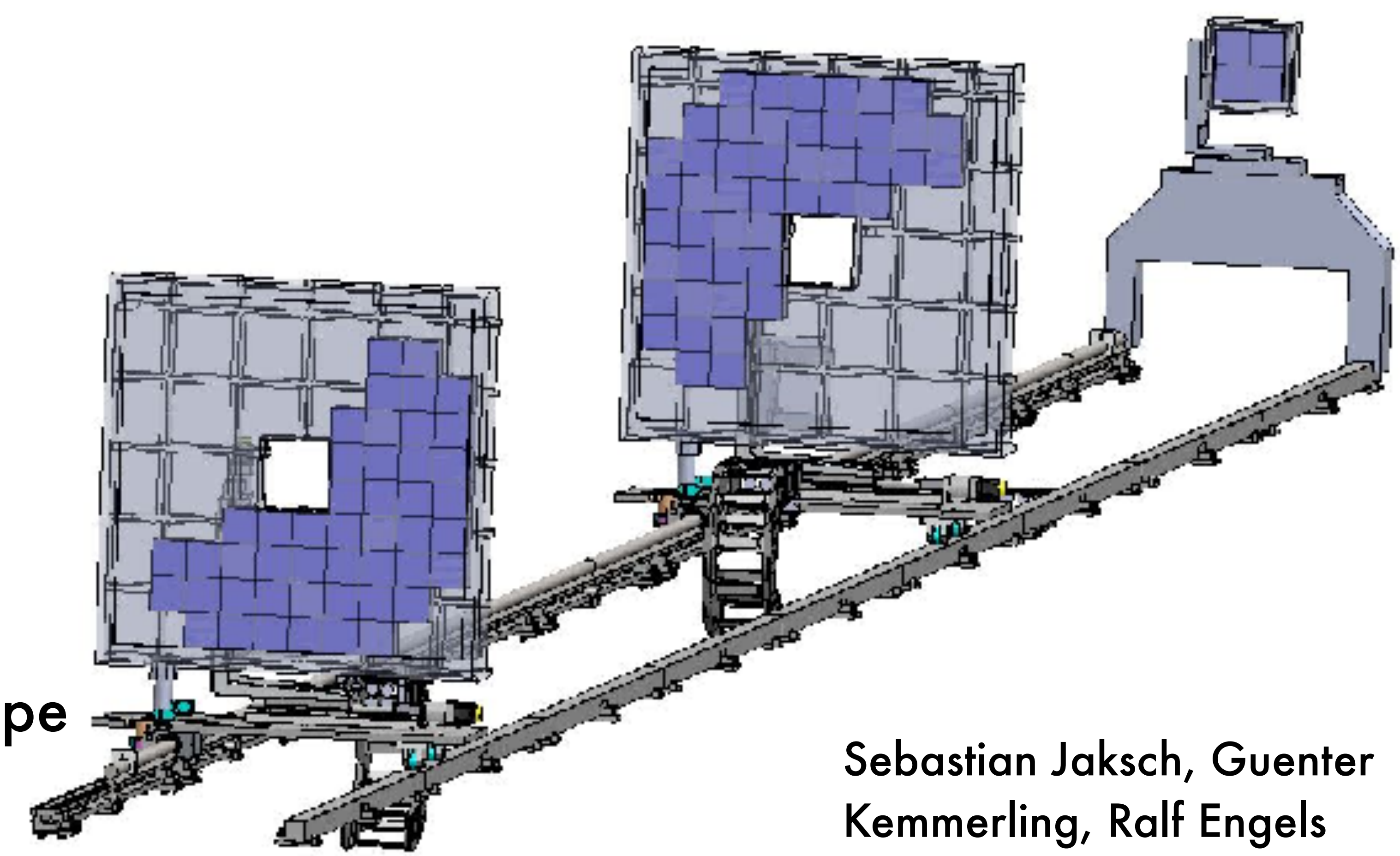


- A 1m 8mm psd He-3 tube detects across ca. 80cm2
- To improve rate capability need to reduce this area:
  - Pixelate
  - Multiple layers in depth

SKADI layout



- 2 moving detectors
  - 1m² – pixel 6 mm
  - 400 modules / detector
- 1 fixed detector @20 m
  - 20x20 cm² – pixel 3 mm



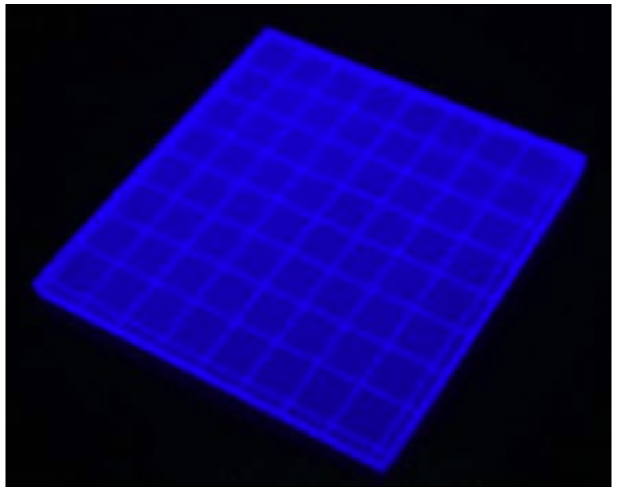
- **about half detector area in initial scope**
- **half in later upgrade**

Sebastian Jaksch, Guenter Kemmerling, Ralf Engels

SoNDe Detector

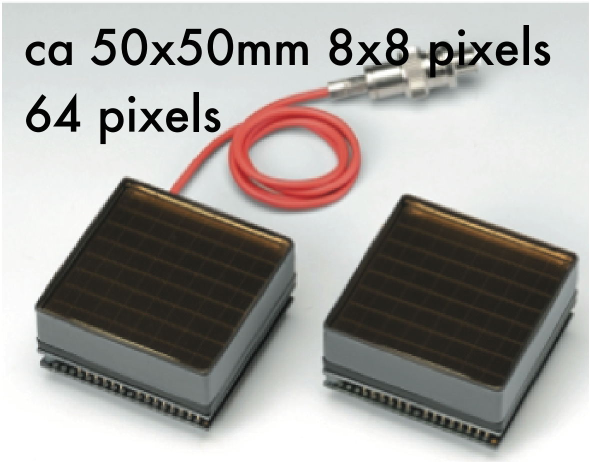
Develop a high-resolution neutron detector technique for enabling the construction of position-sensitive neutron detectors for high flux sources.

- 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 %



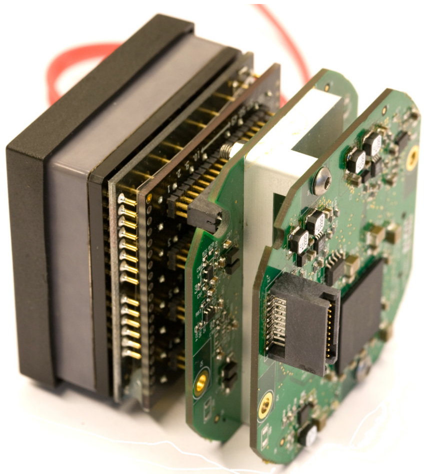
Grooved Li glass (GS20)

+

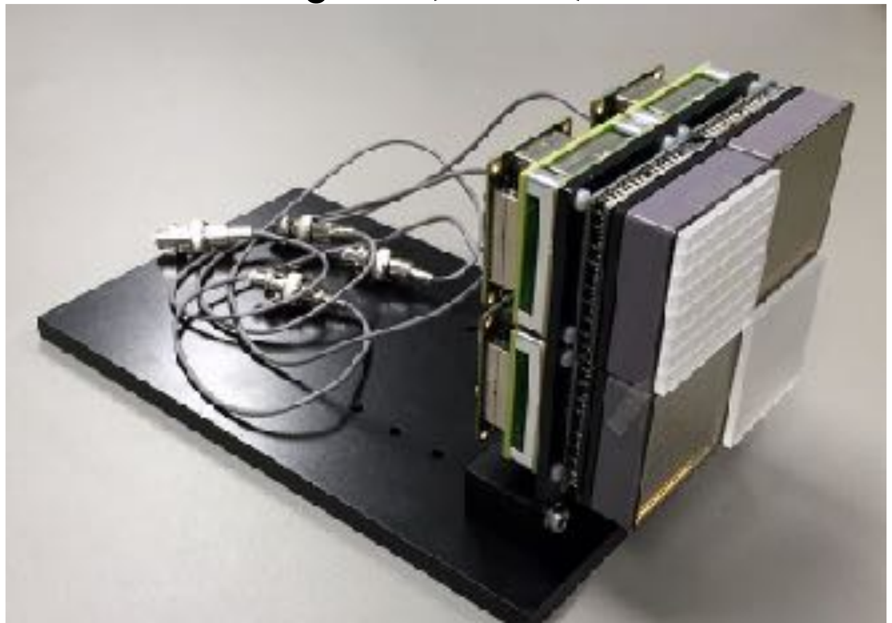


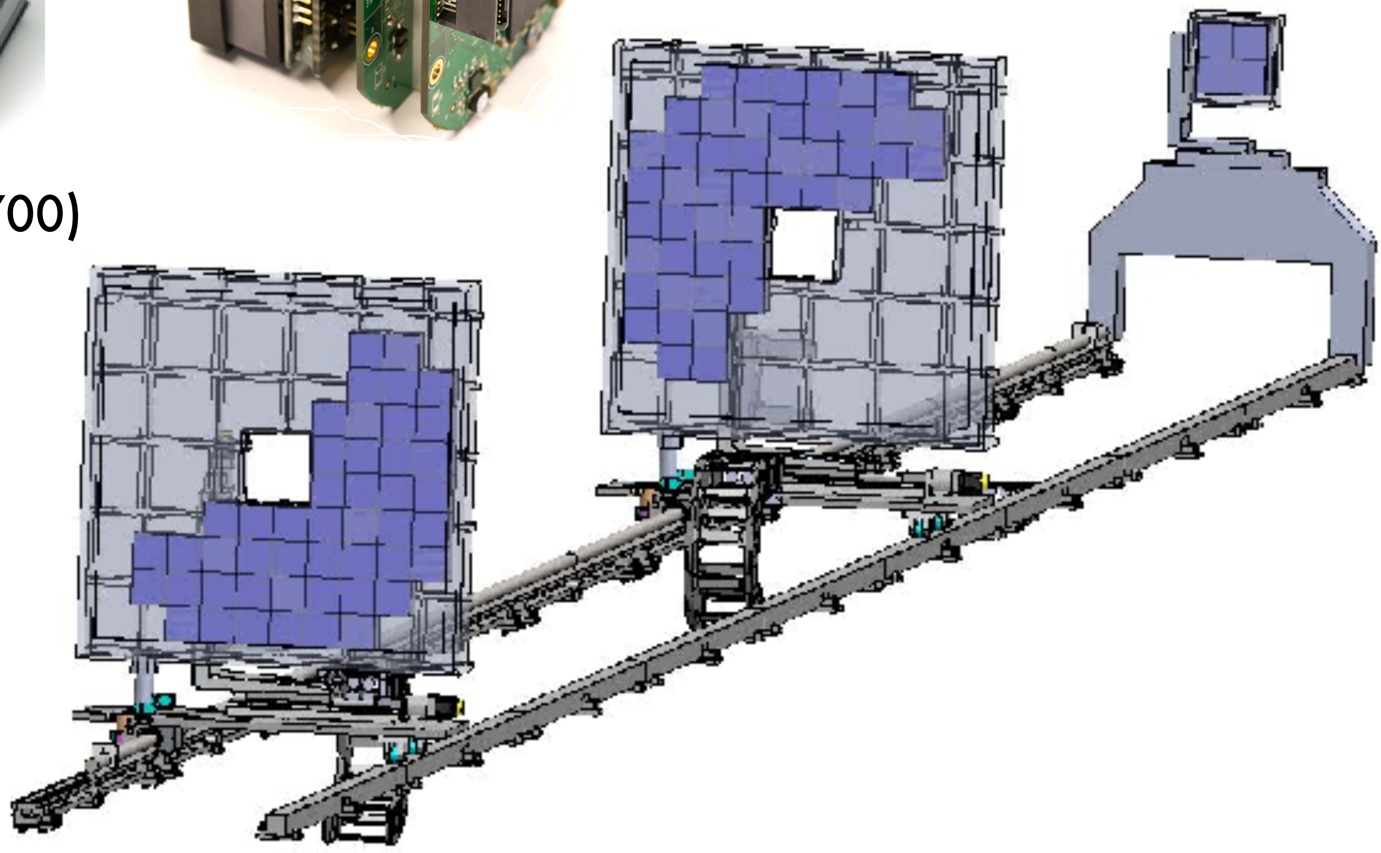
MA-PMT (H9500 or H12700)

+

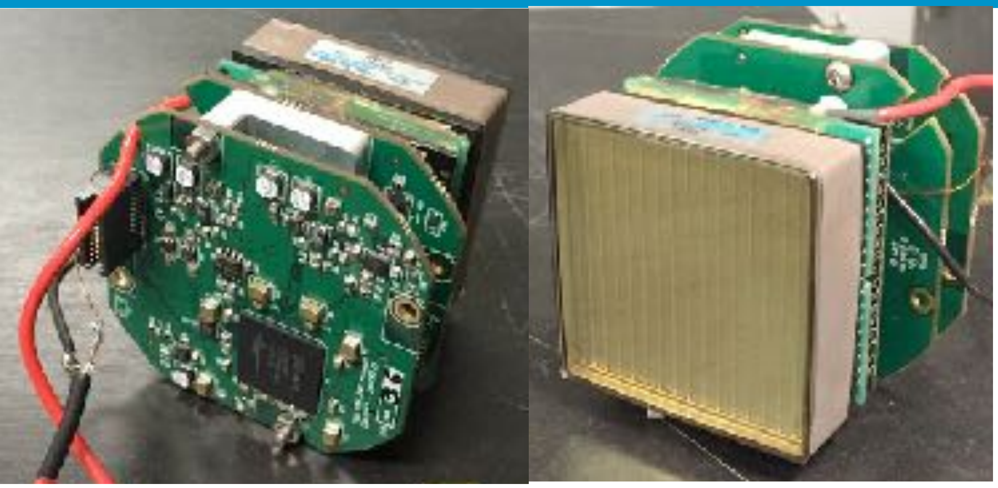


IDEAS IDE3465
+FPGA

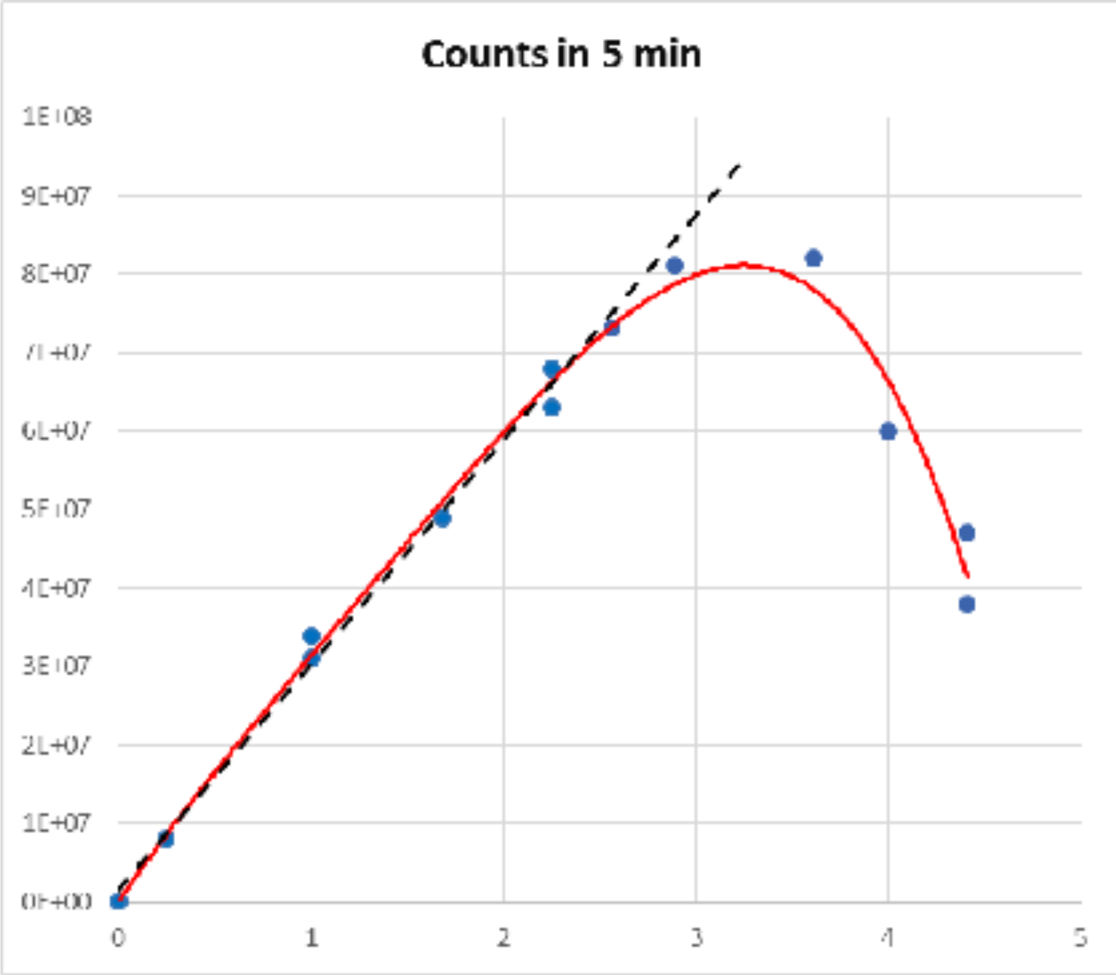


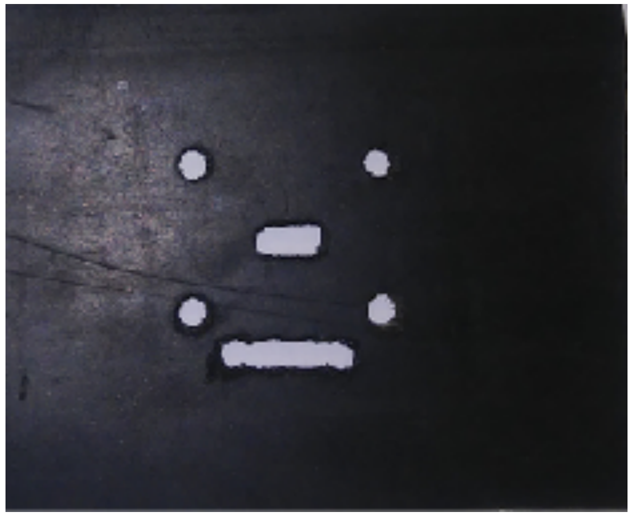


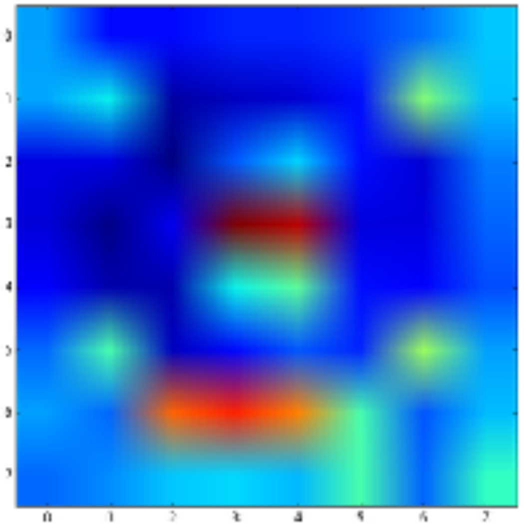
SoNDe Detector



- Results from initial evaluation system

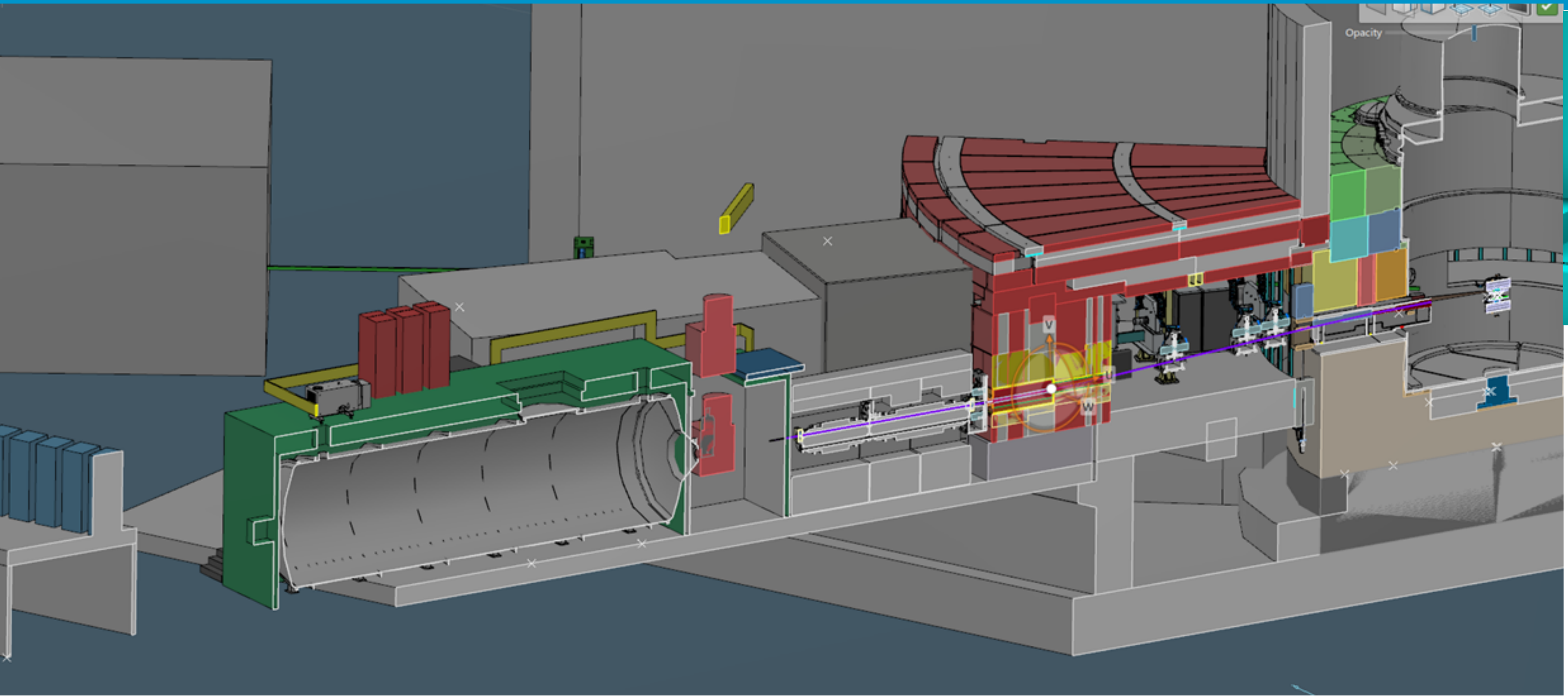


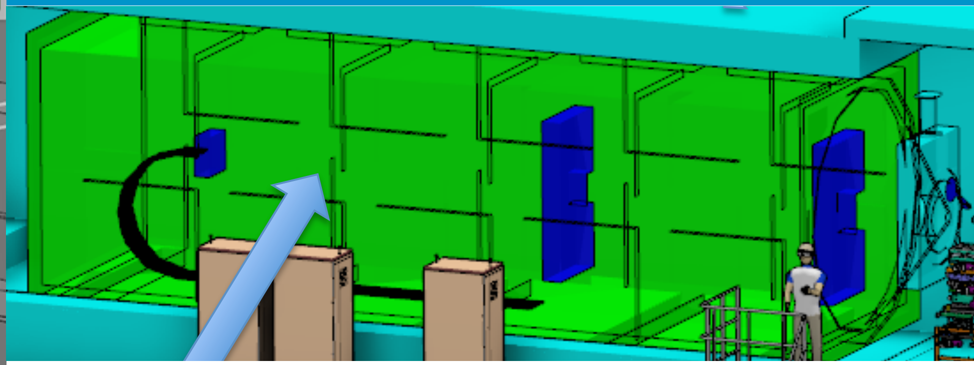




- Count rates on a module up to 250 kHz, linear to 200 kHz
- Corresponds to >20 MHz @10% deadtime for full 1m^2
- No degradation up to 5E14 neutrons integrated flux

LOKI Detector Requirements





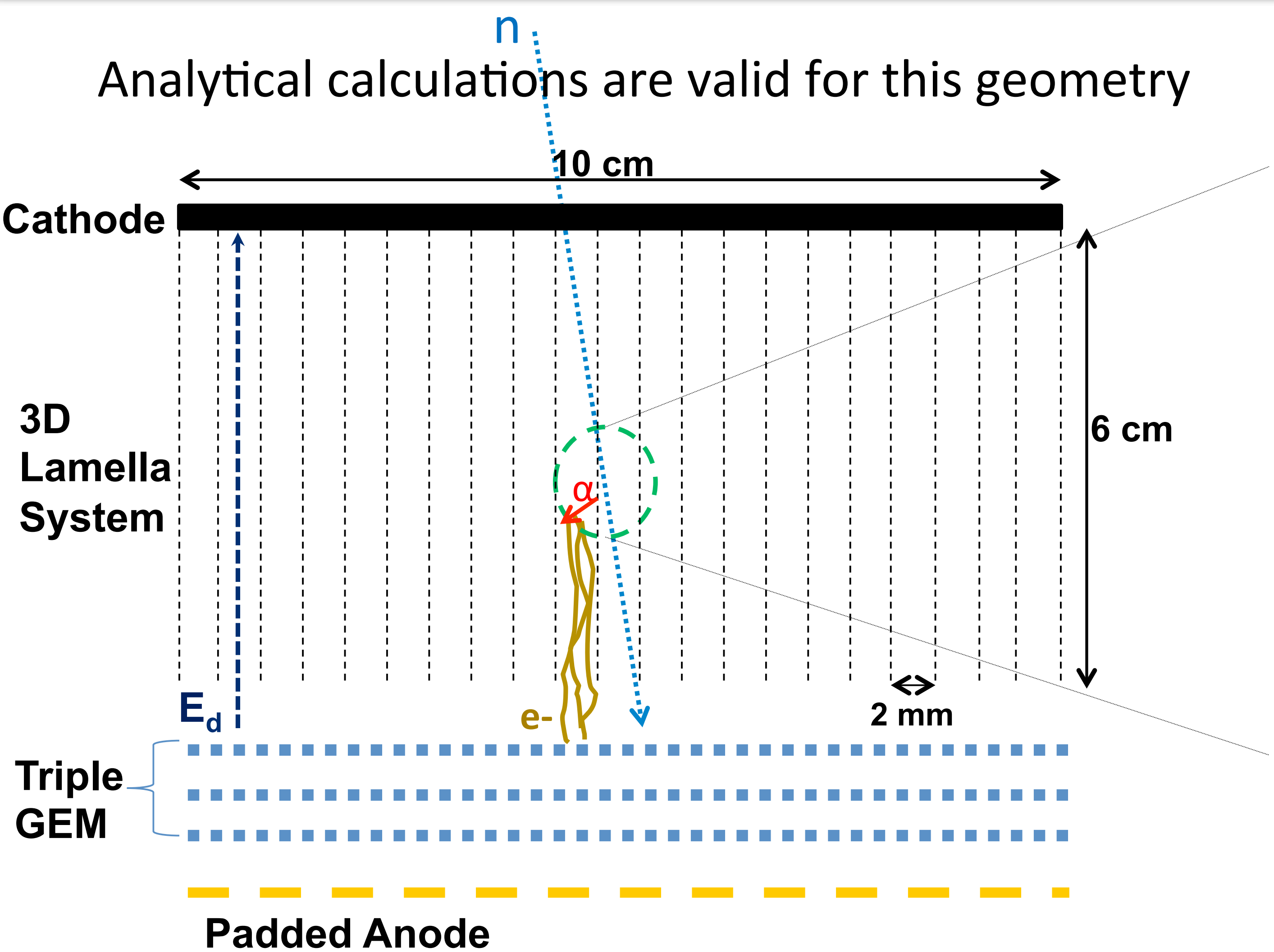
- Short instrument
- Wide angle detector coverage up to 45 deg
- Arranged in 3 banks
- total 9m^2

- Rearmost bank ca. 1x1m, movable
- 6mm resolution
- Other banks 2x2m fixed. Relaxed resolution requirements

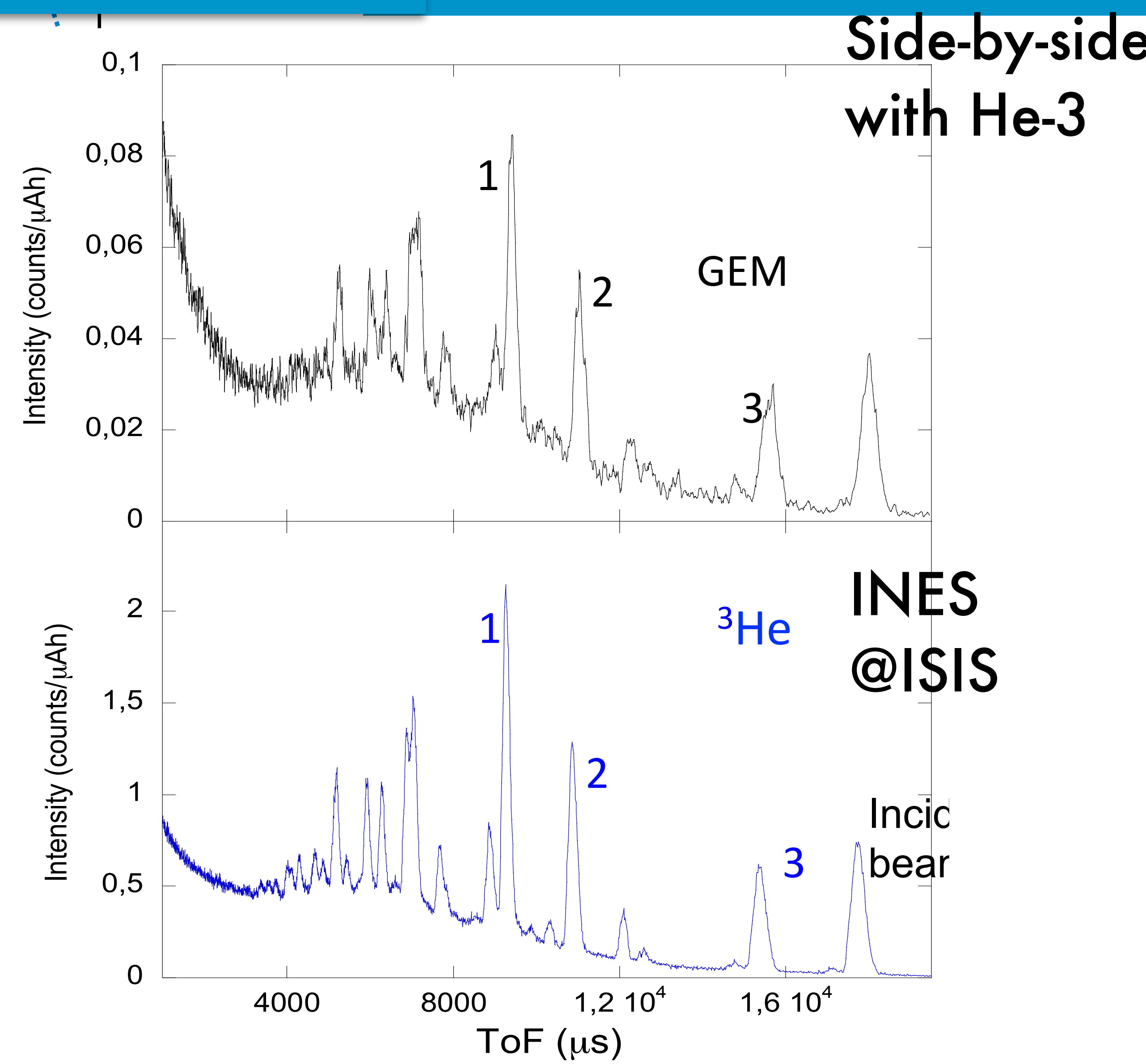
- about half detector area in initial scope
- half in later upgrade

BANDGEM Detector

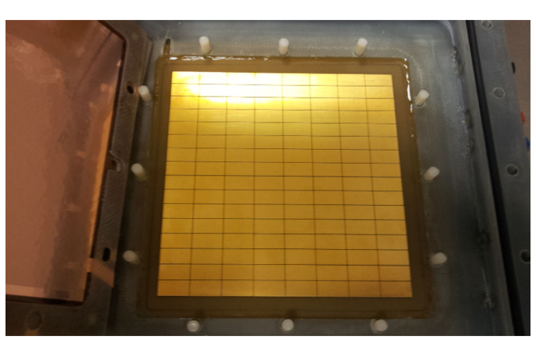
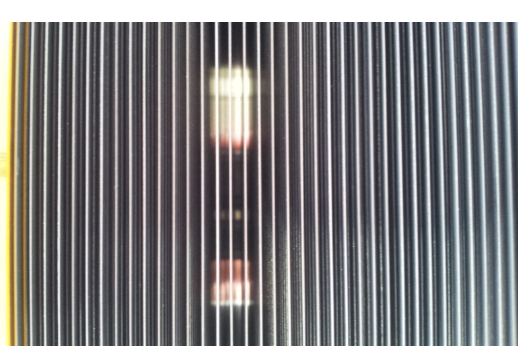
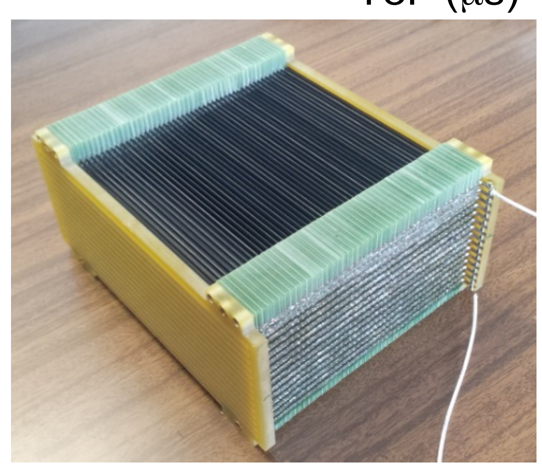
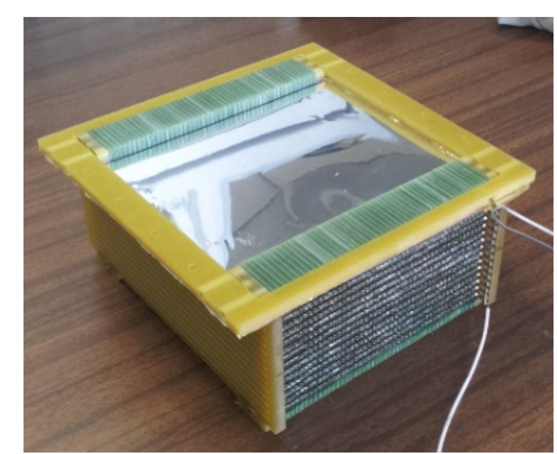
Analytical calculations are valid for this geometry



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

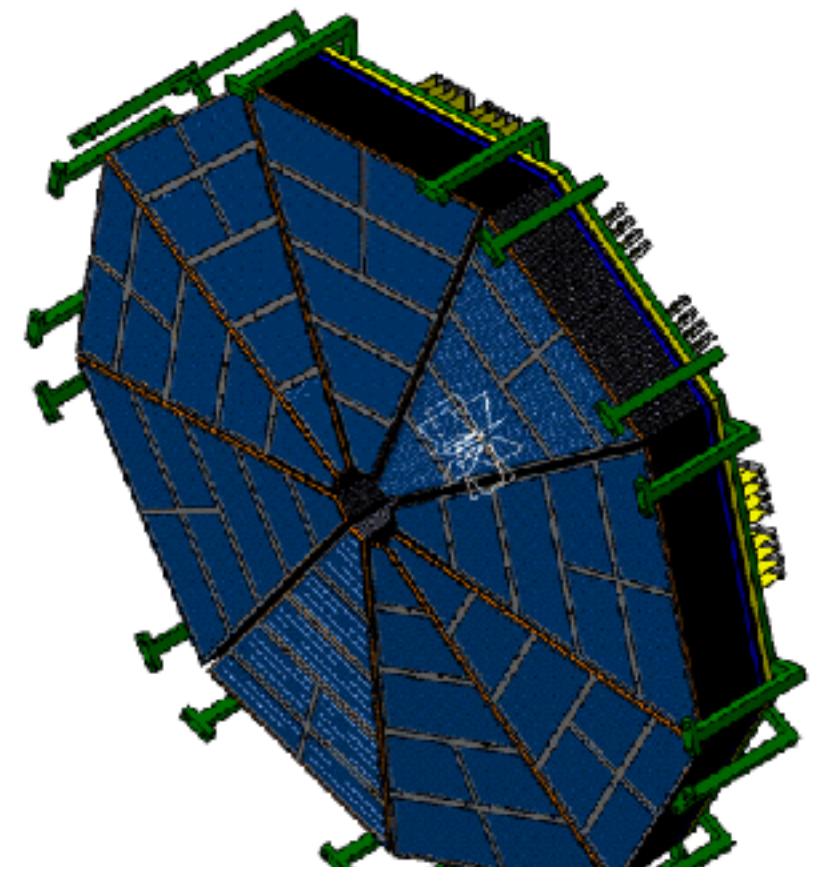


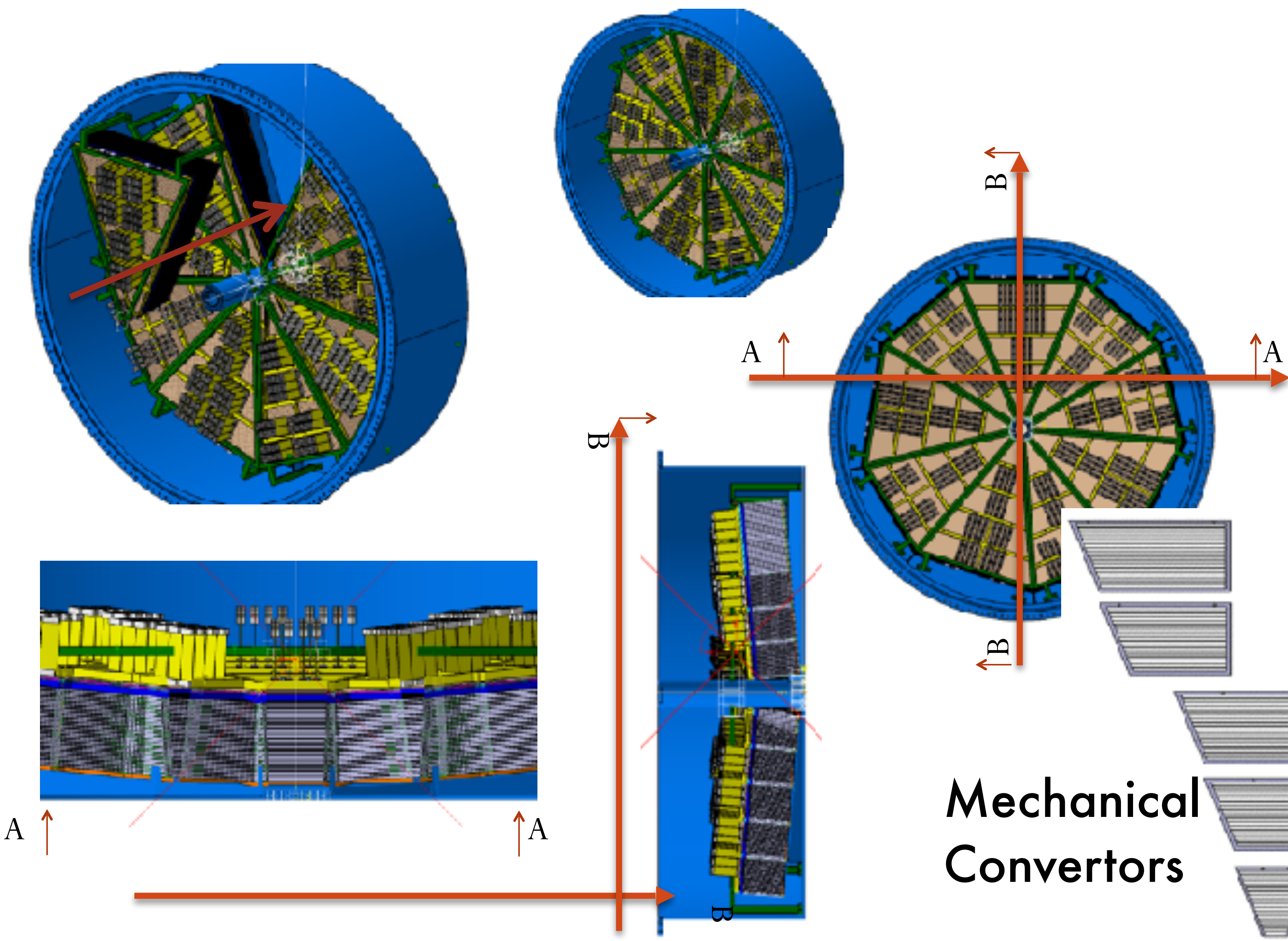
Using low θ values (few degs) the path of the neutron inside tł
B_4C is increased → Higher efficiency when detector is inclined

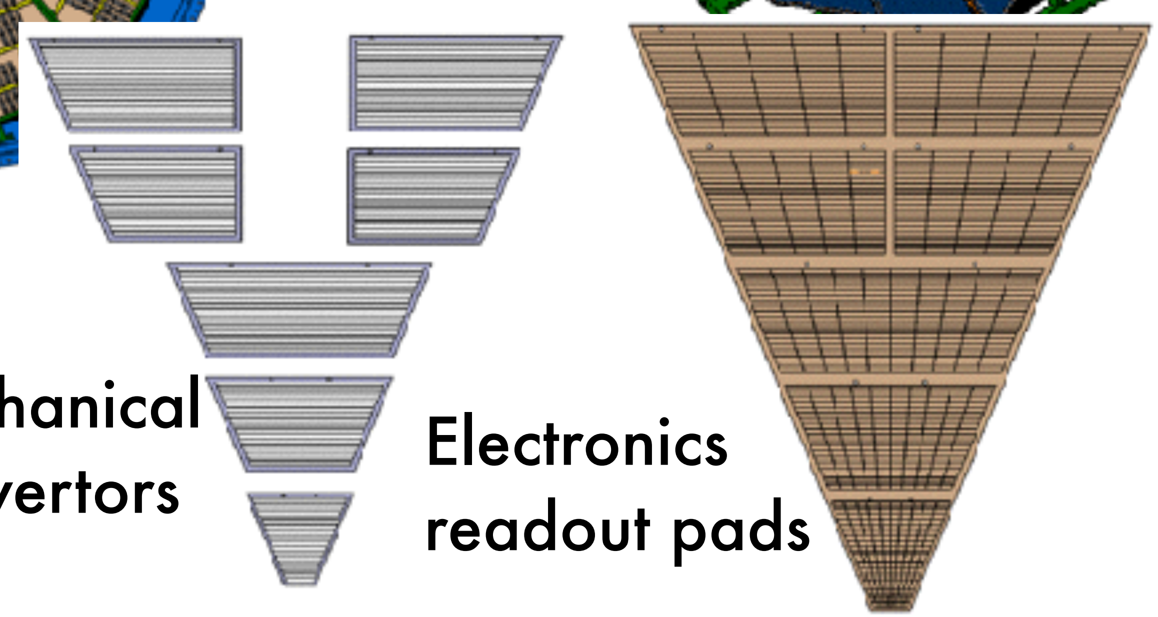






BANDGEM Detector for LOKI

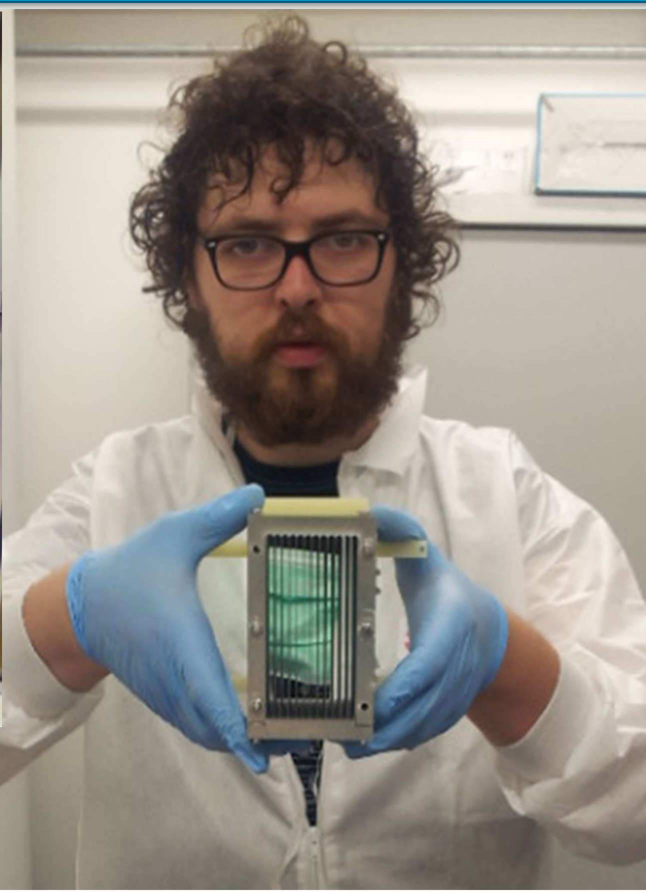
Rear Detector: Assembly

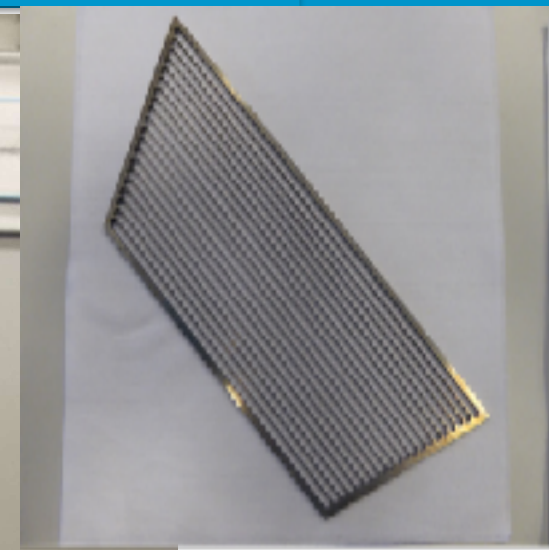


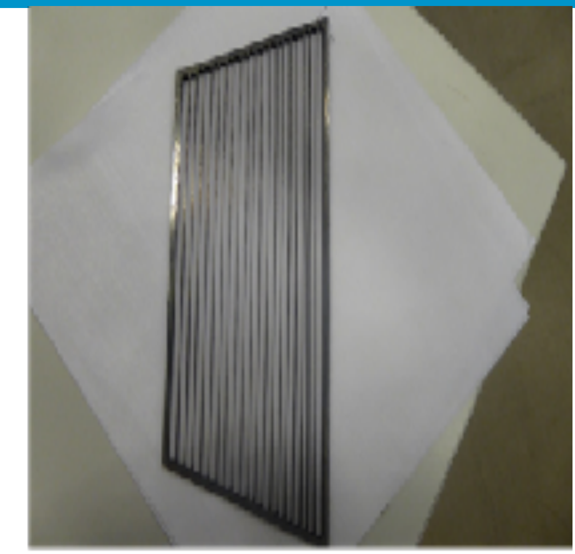


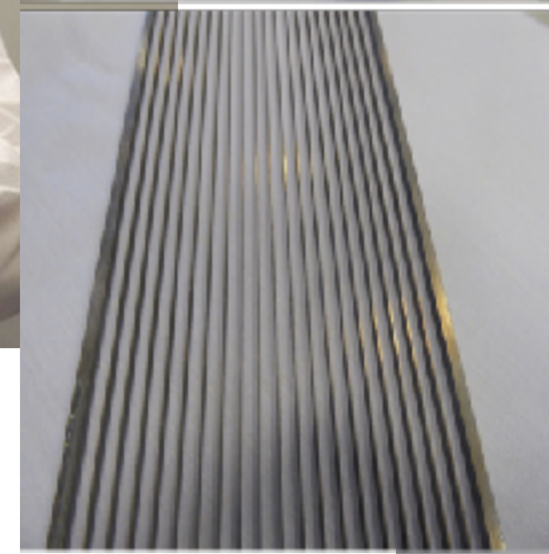


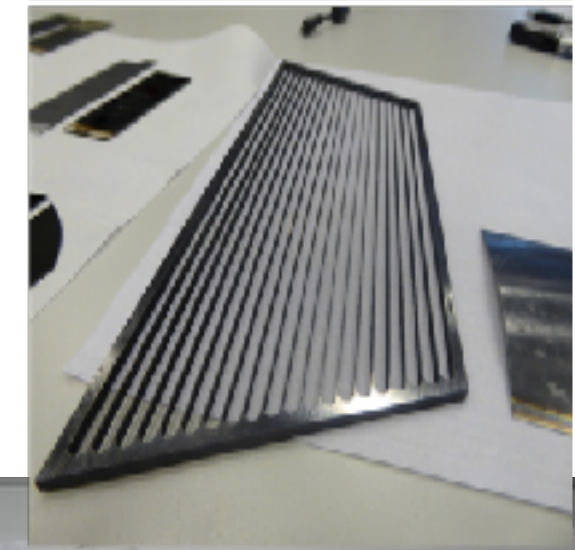
BANDGEM Detector for LOKI

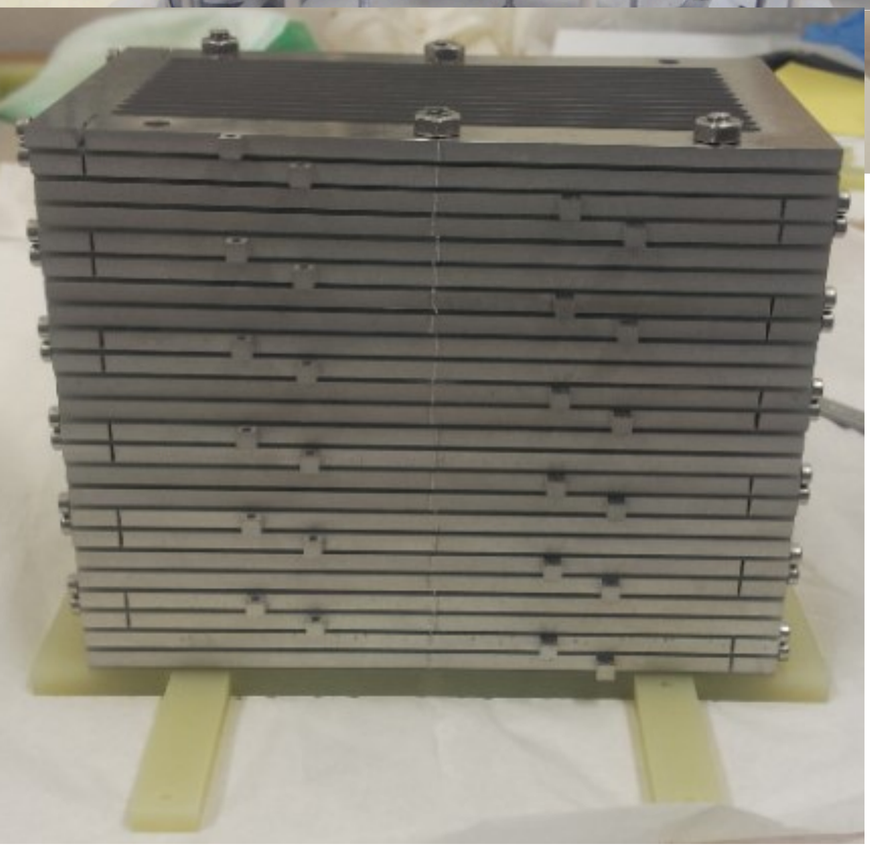






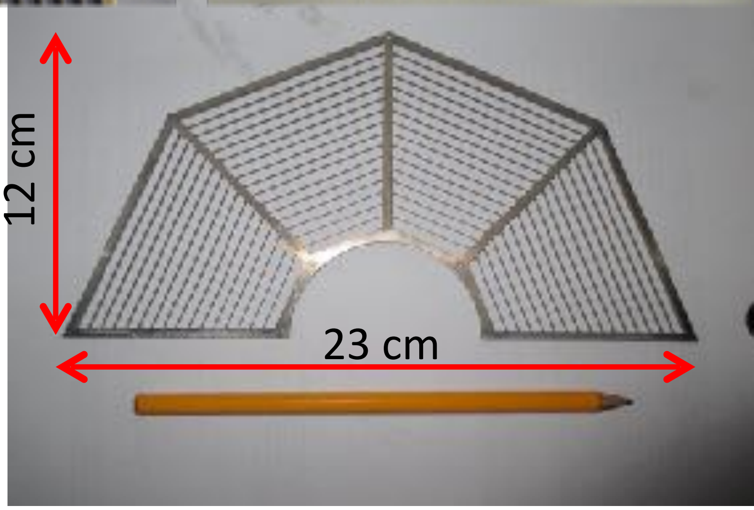






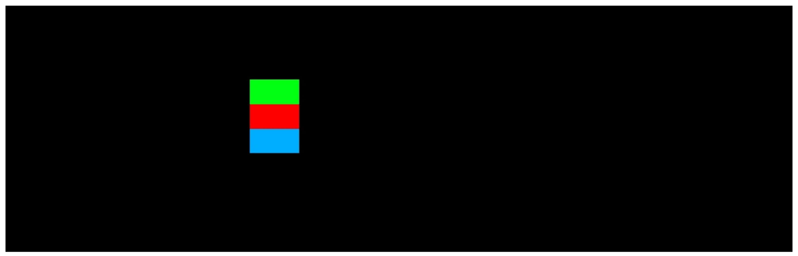
Stack of Conversion elements can be produced and coated

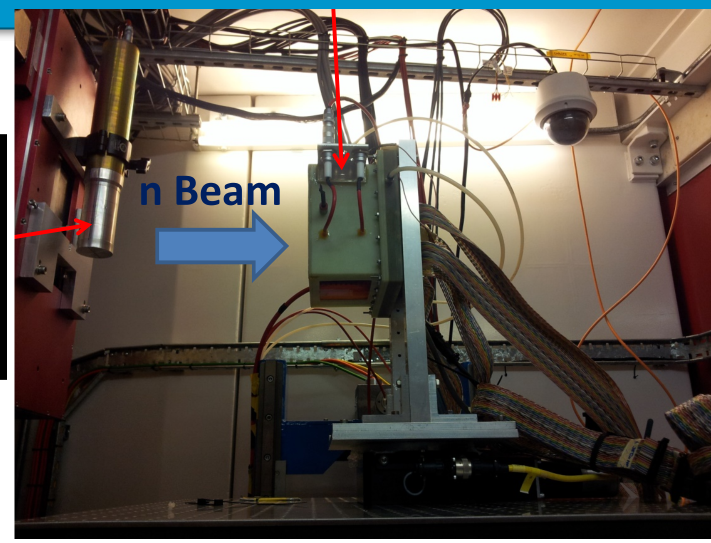
Precision waterjet cutting (Watajet, Milan)

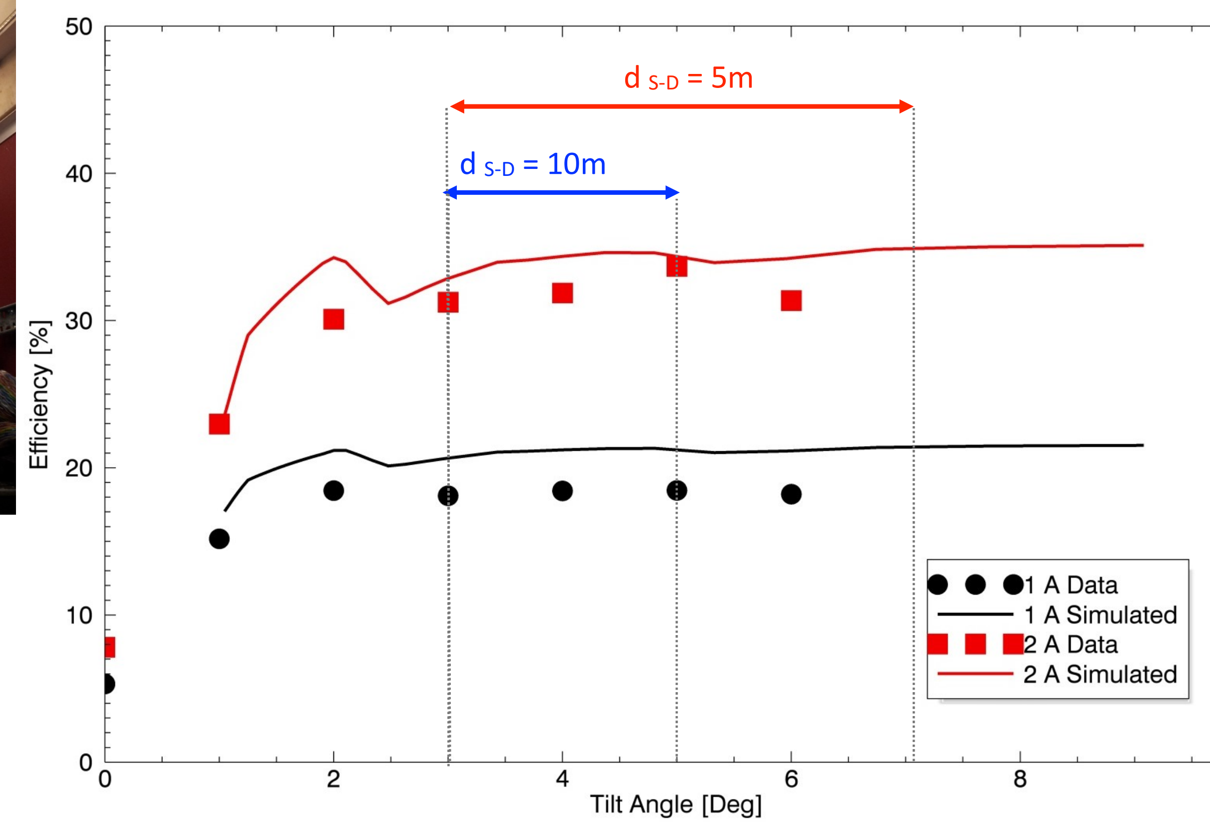


BANDGEM Detector Results

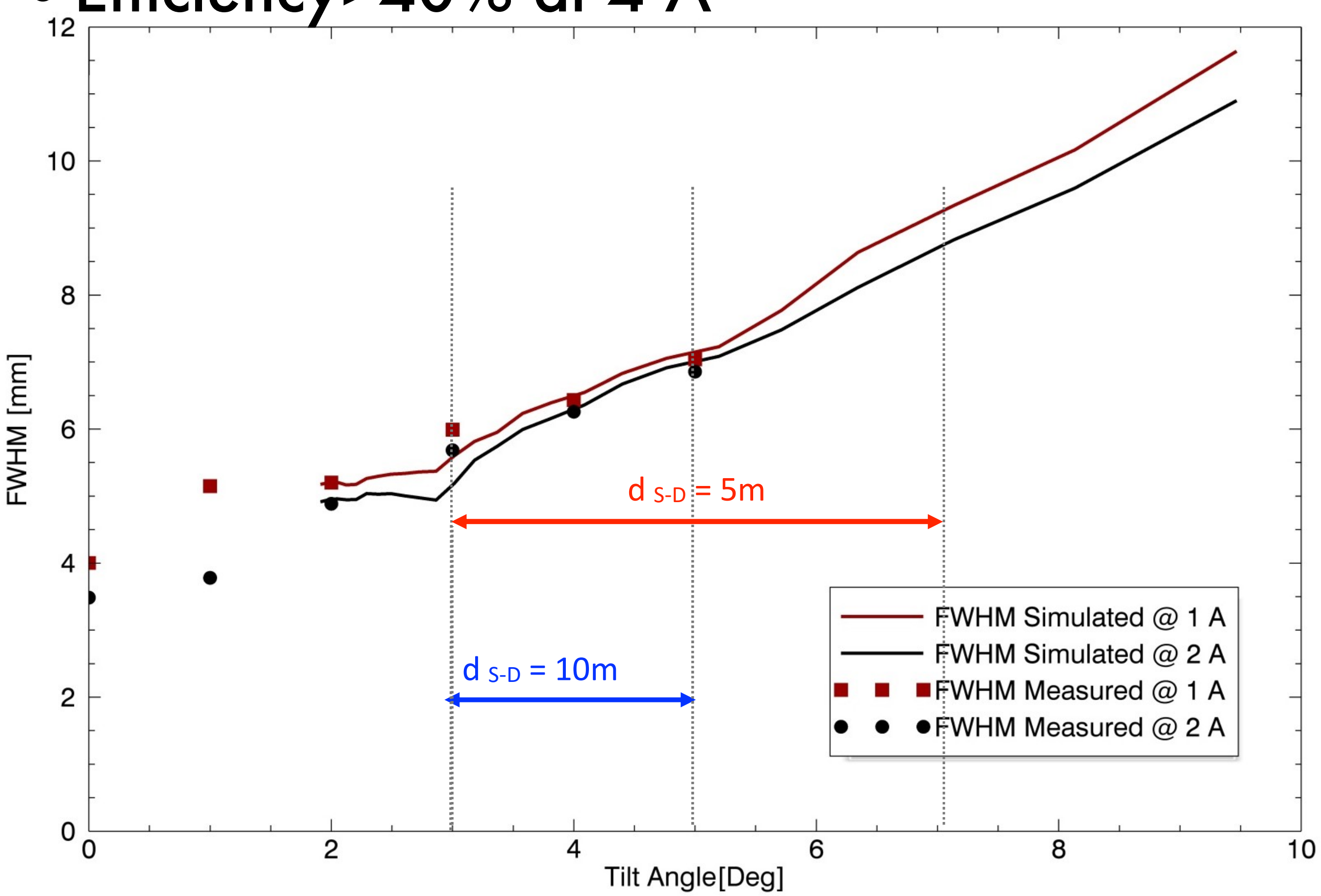
on EMMA@ISIS

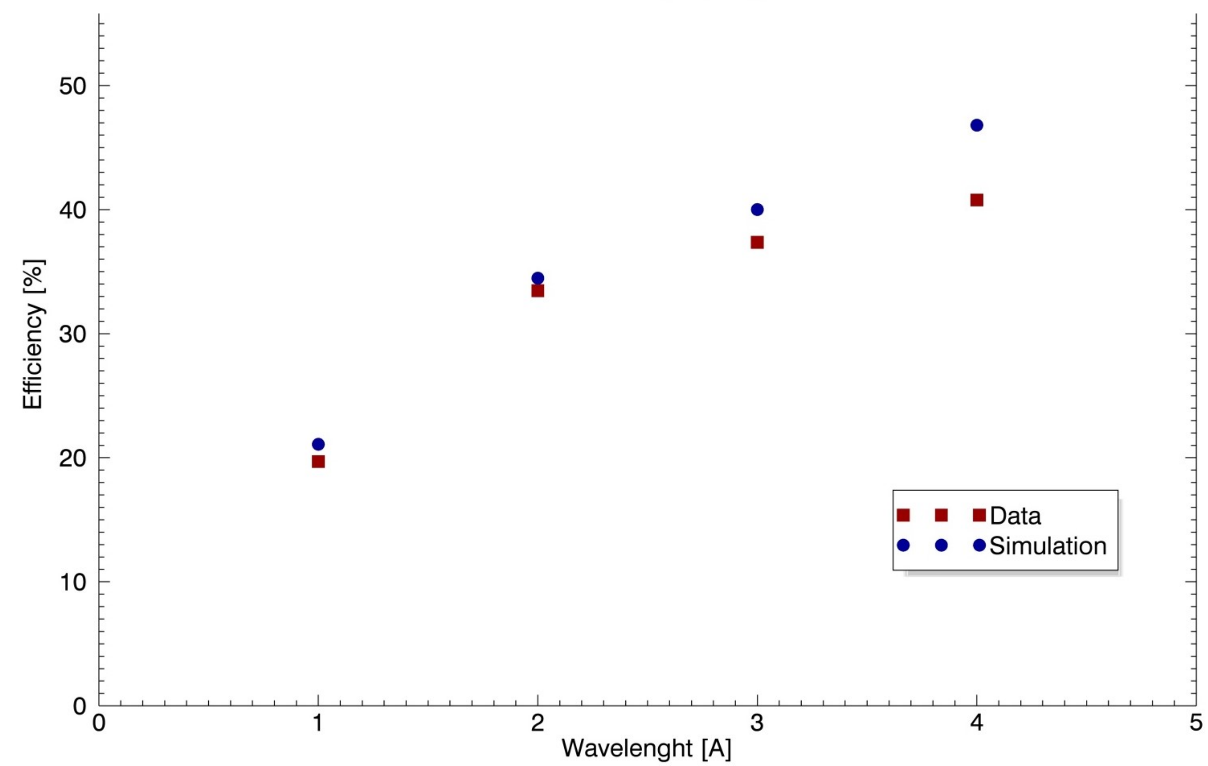




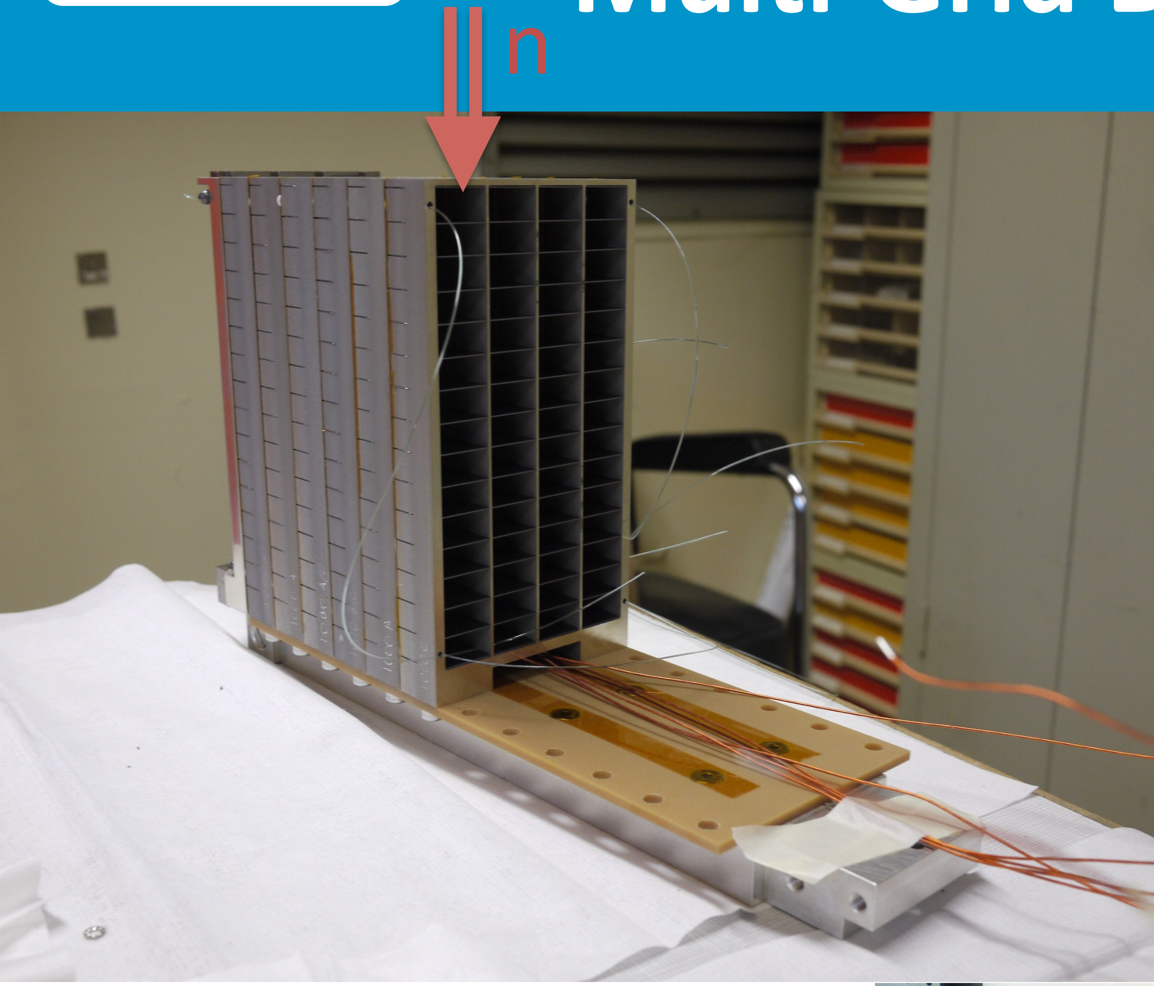


- Resolution as expected
- Efficiency with tilt angle as expected
- Efficiency>40% at 4 A

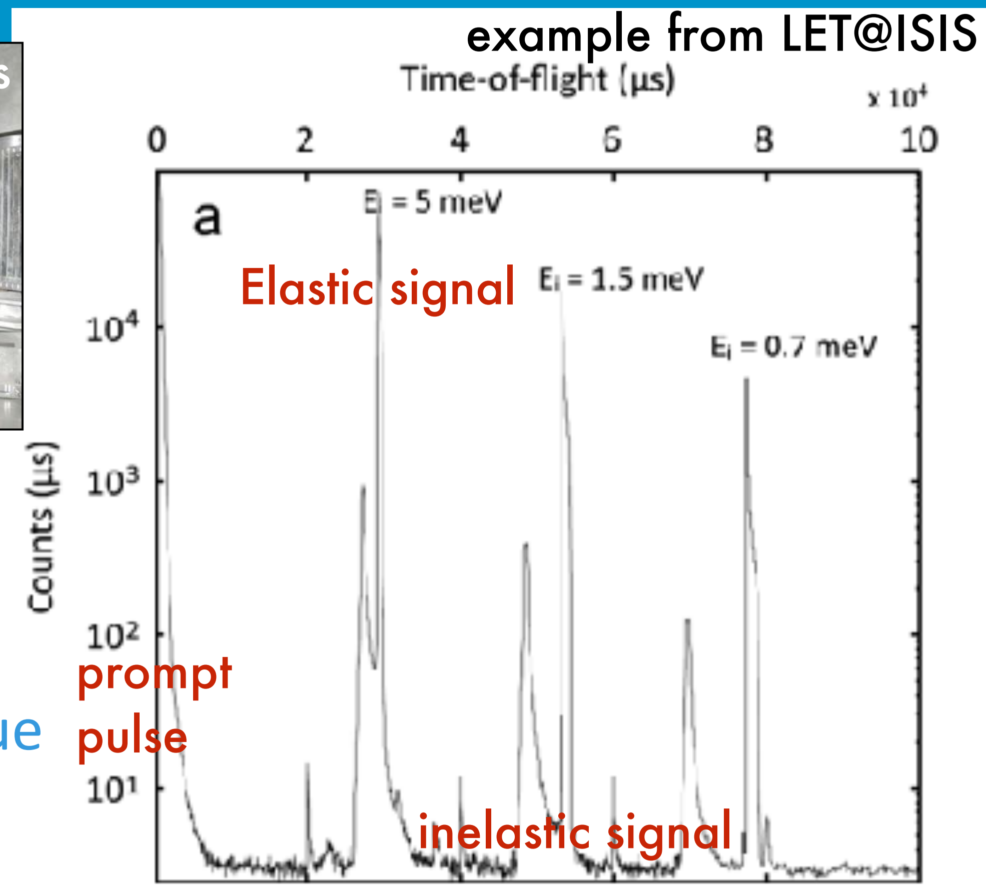




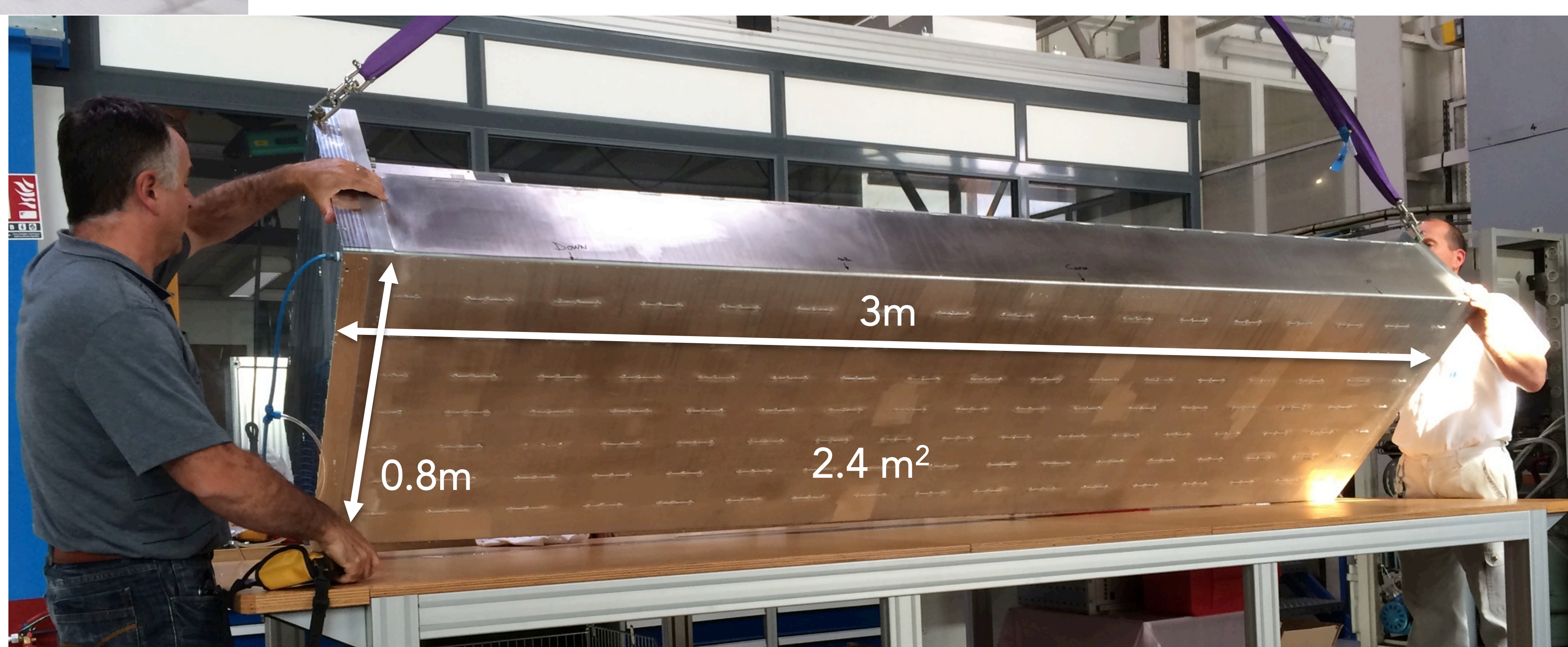
Direct Spectrometers: Multi-Grid Detector Design



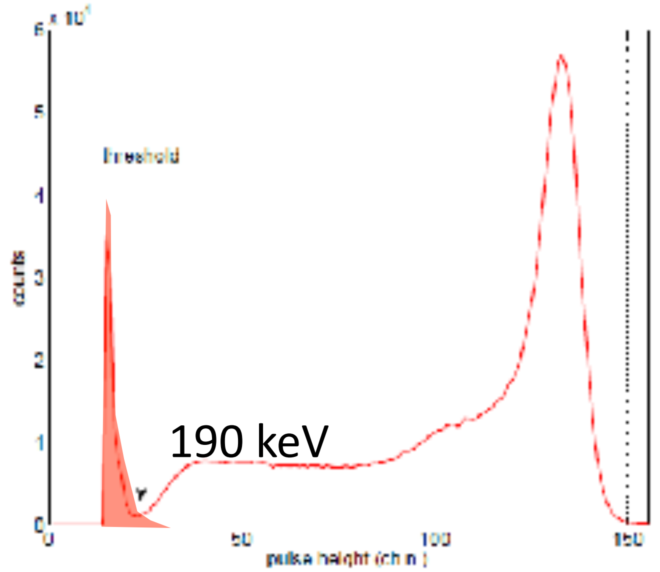
- Very background sensitive technique



- 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



Background - Gamma Sensitivity



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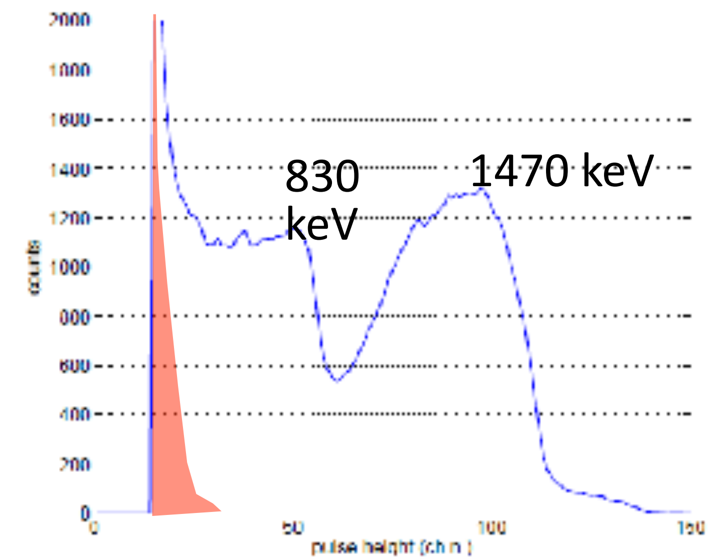

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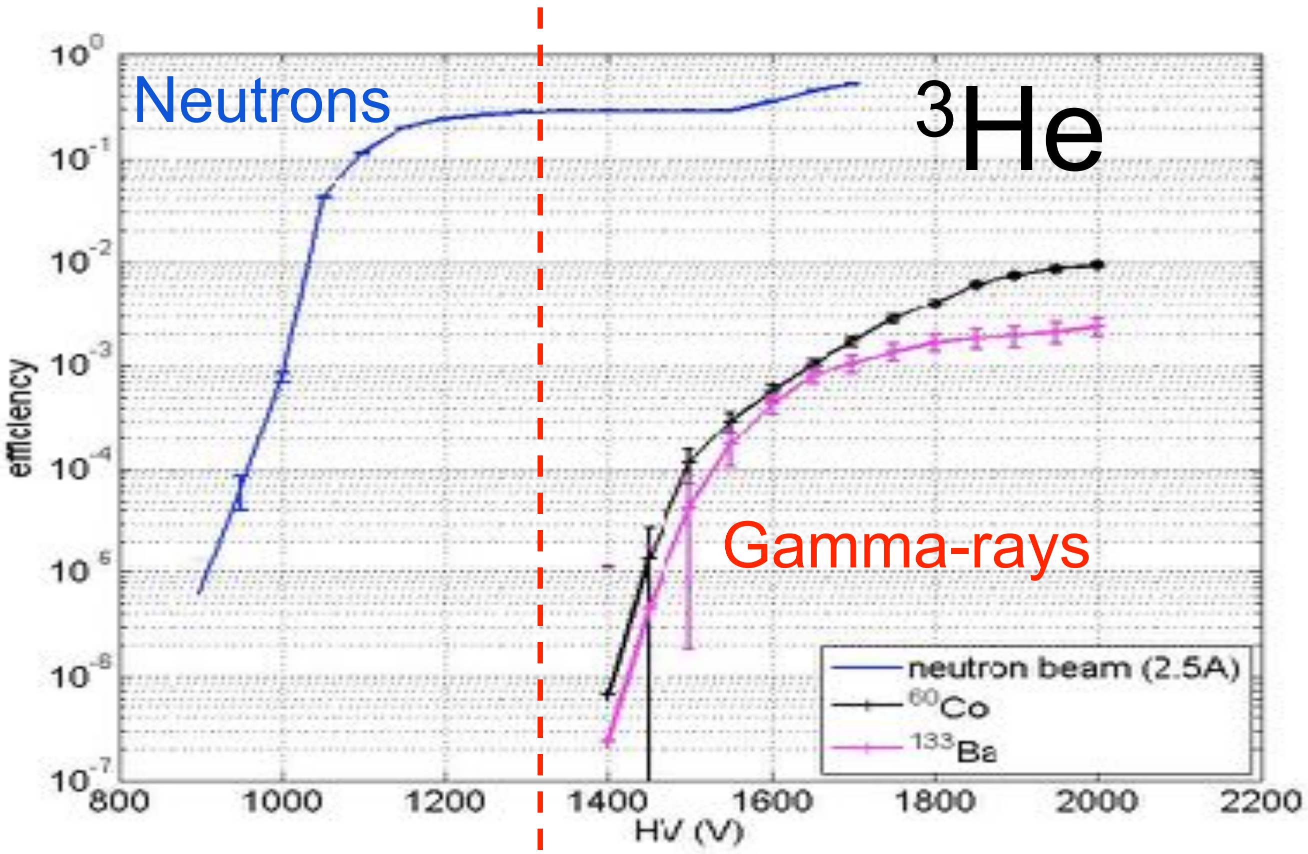
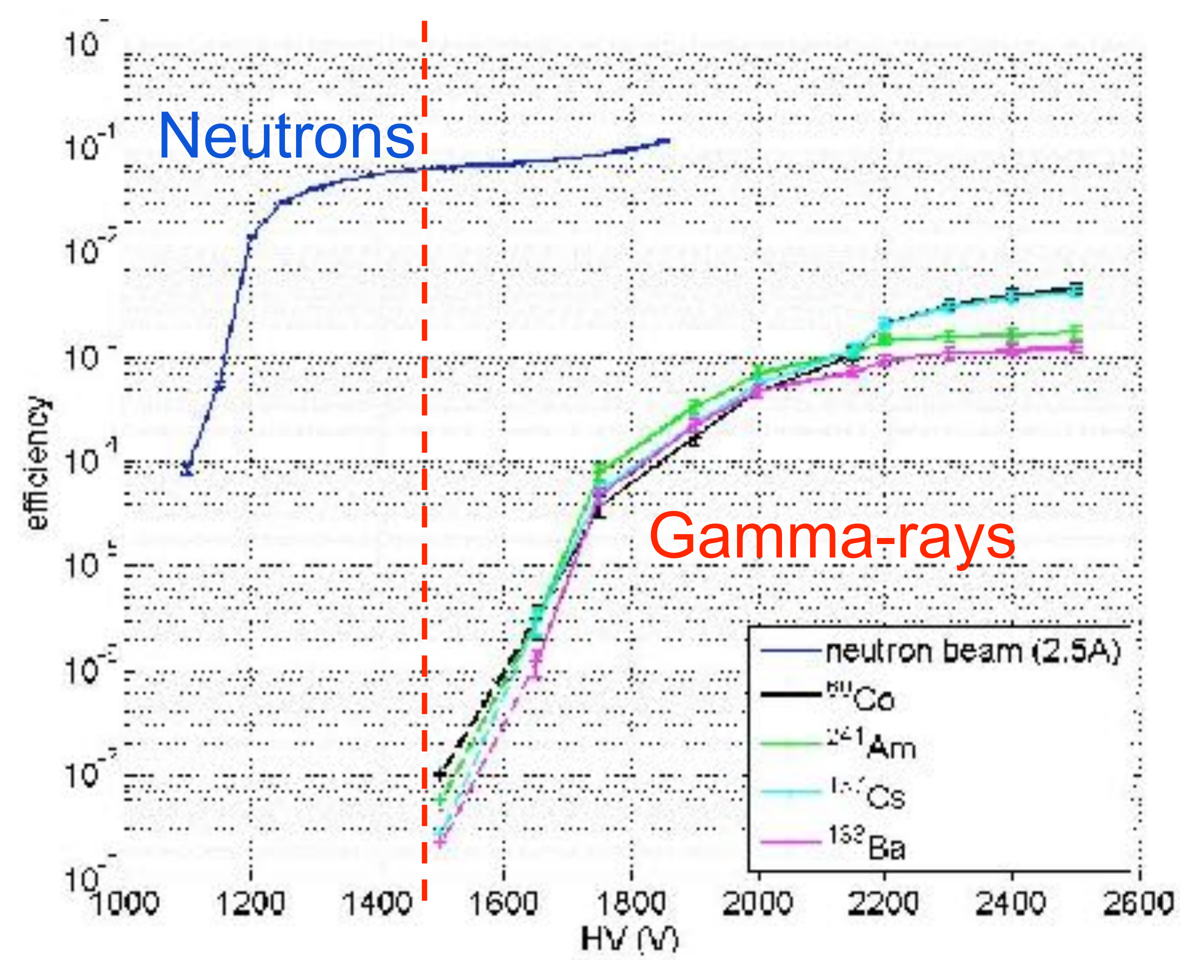
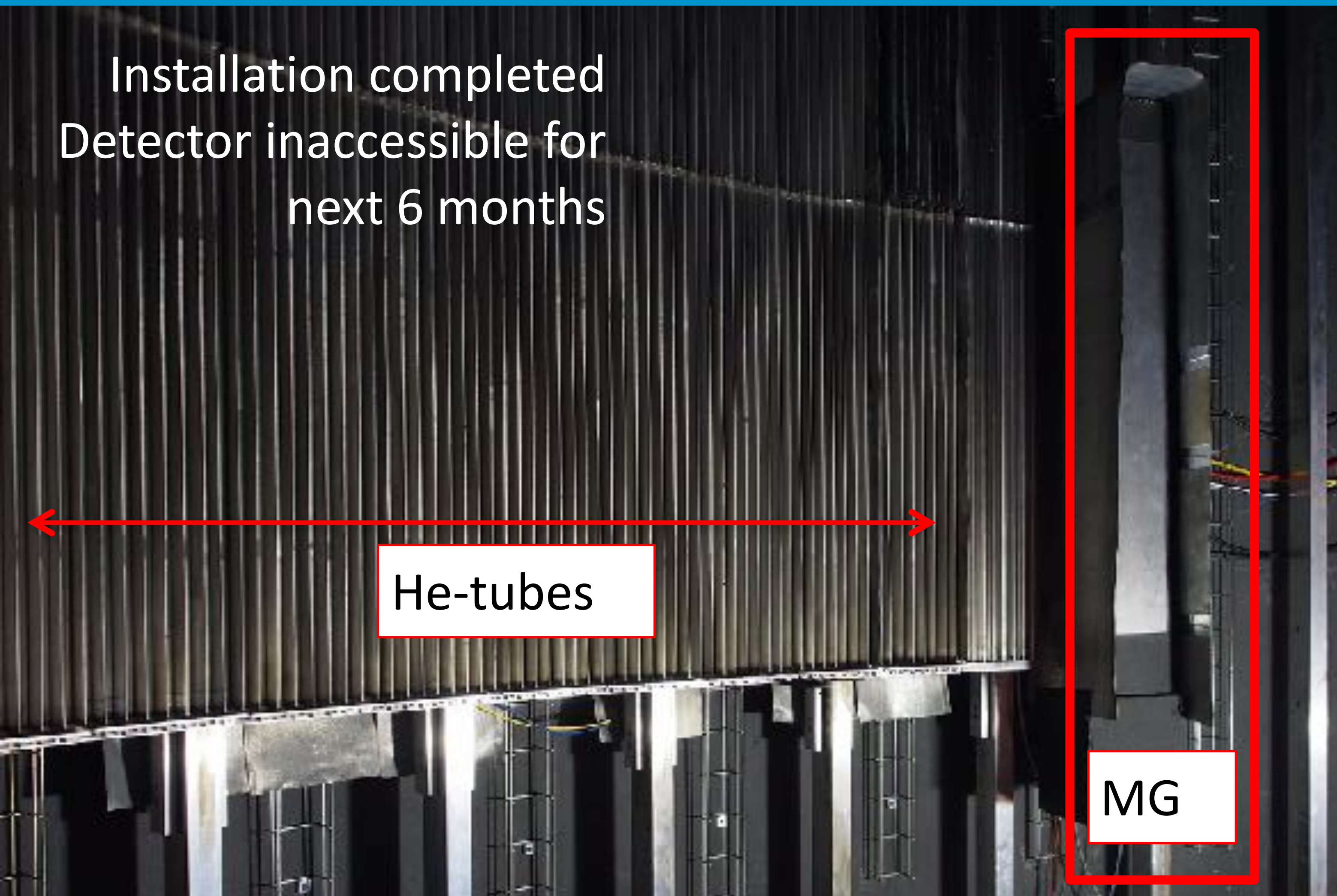


JINST 8 (2013) 10025

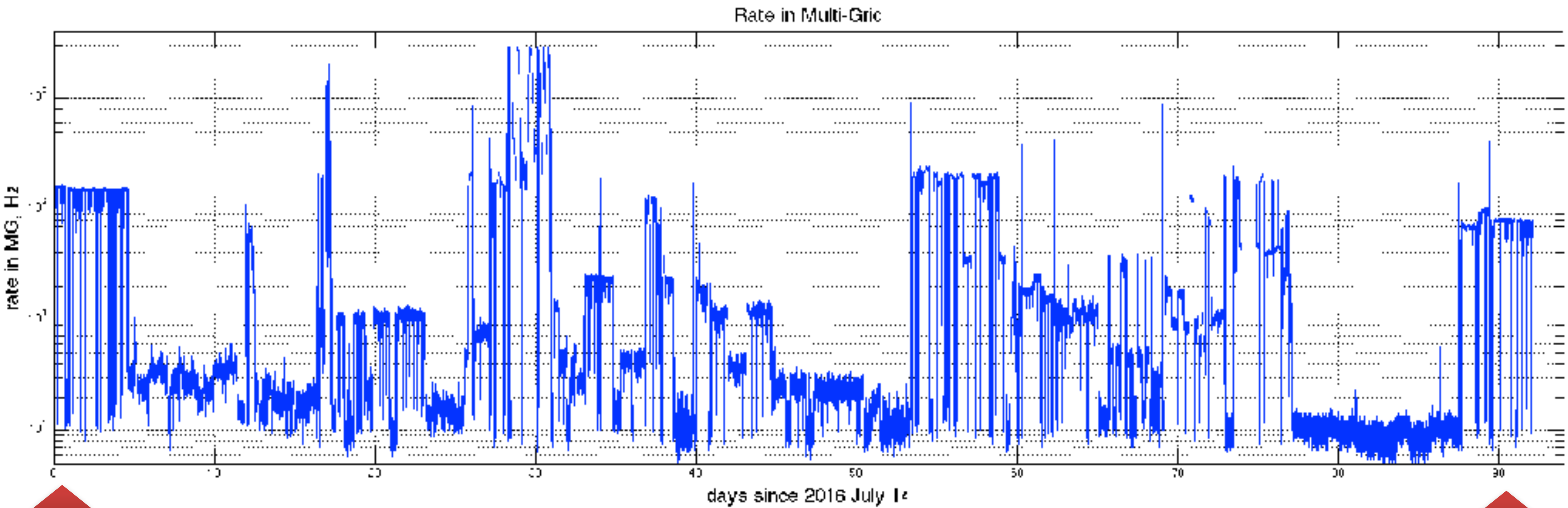


Multi-Grid test at CNCS



- Test side-by-side with existing technology in world leading instrument

Operation since 2016-07-14



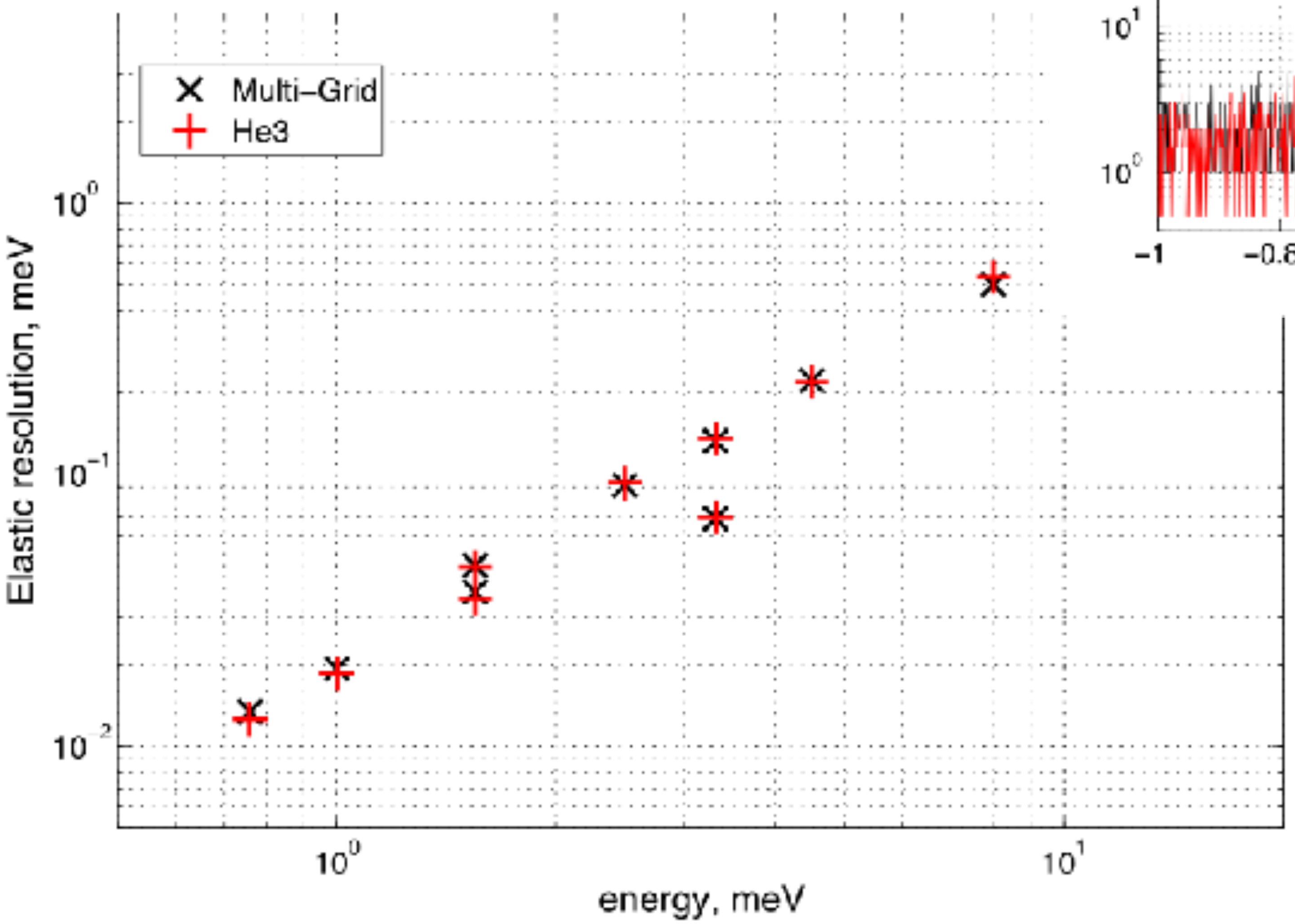
First day

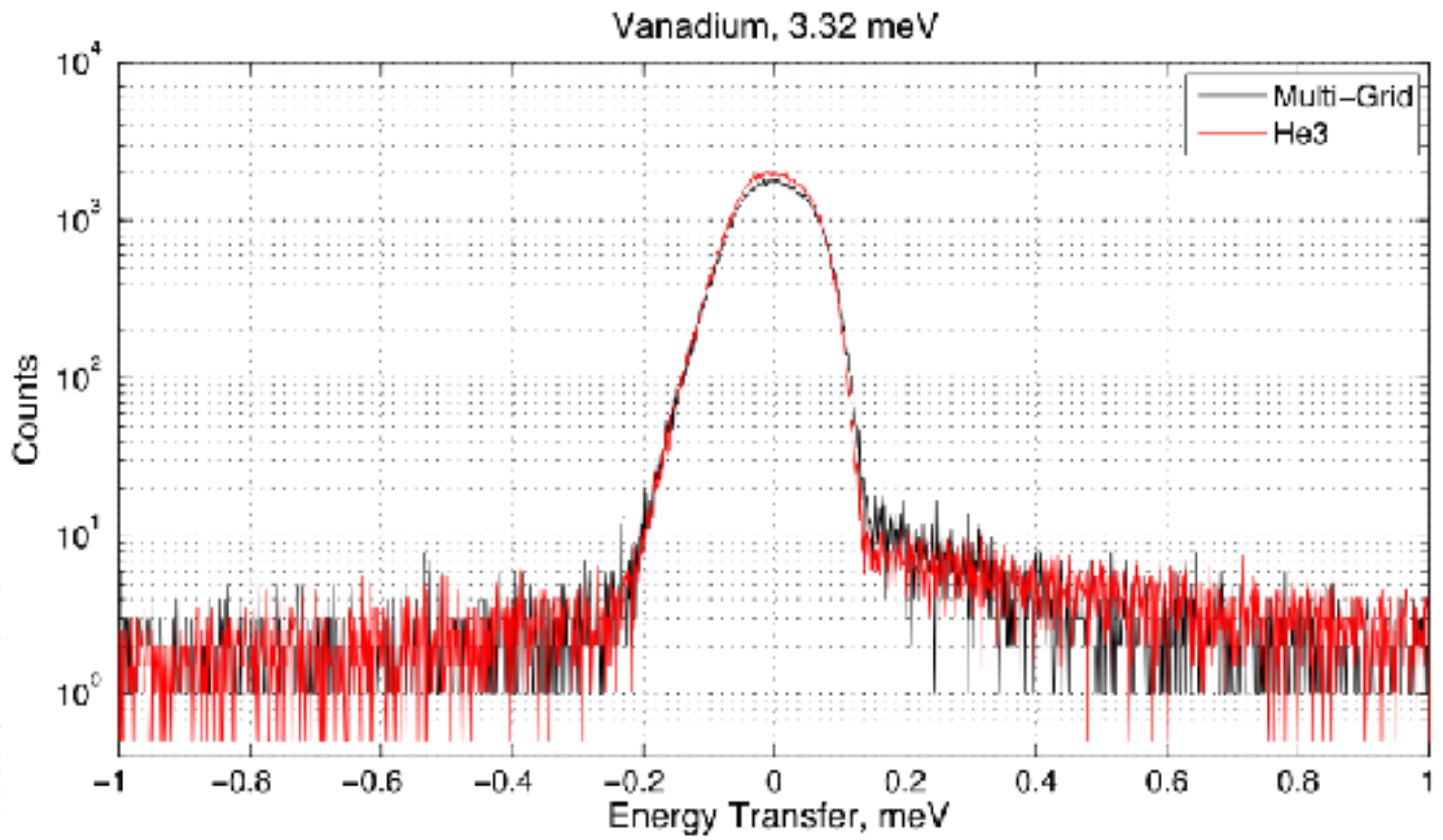
90 days

Operating without possibility of access since installation

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

Multi-Grid test at CNCS



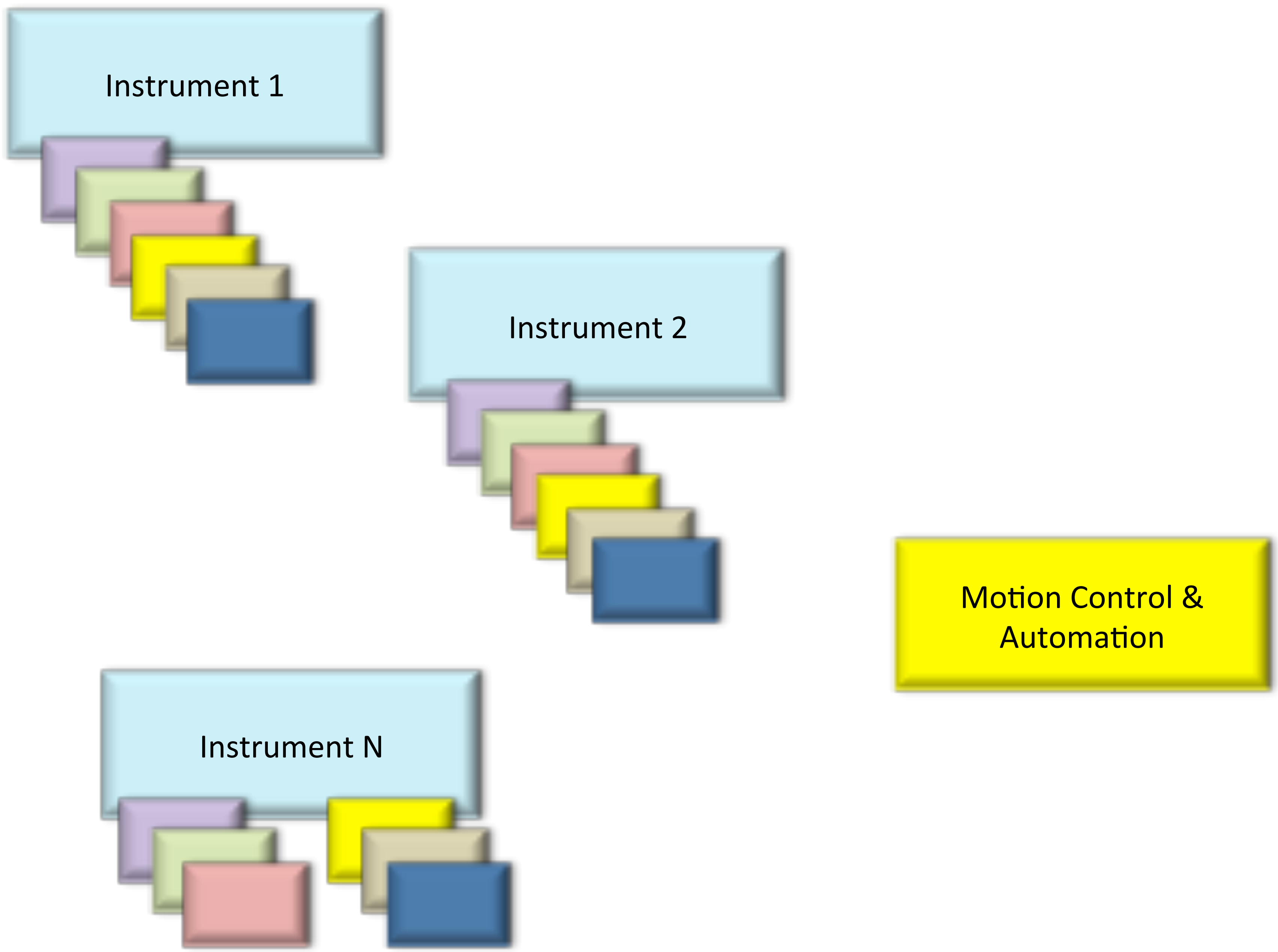


- Data and instrument resolution identical
- Technology suitable for ESS instruments

Electronics

NSS – Functional decomposition

from Oliver



- need to efficiently maintain and operate equipment

Functional decomposition facilitates to identify common / similar requirements

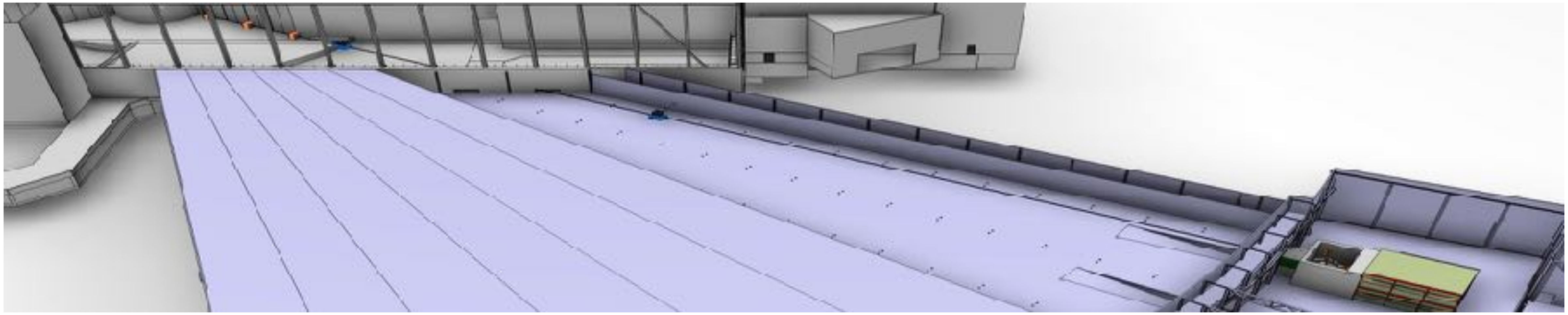
Create centralised workpackage to avoid recurring engineering cost in individual instrument projects; minimise risk

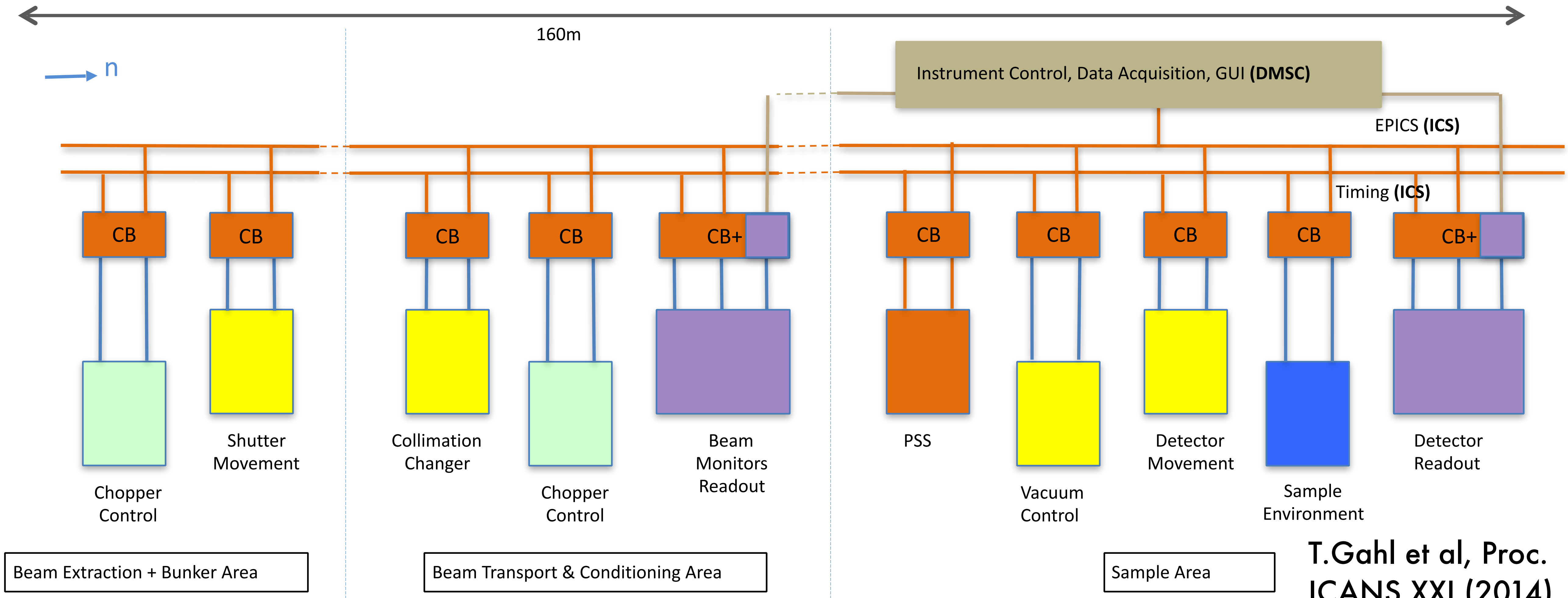
Ensure proper integration

Provide solution to instrument projects

Schedule is the driver

Modular Instrument Control Concept



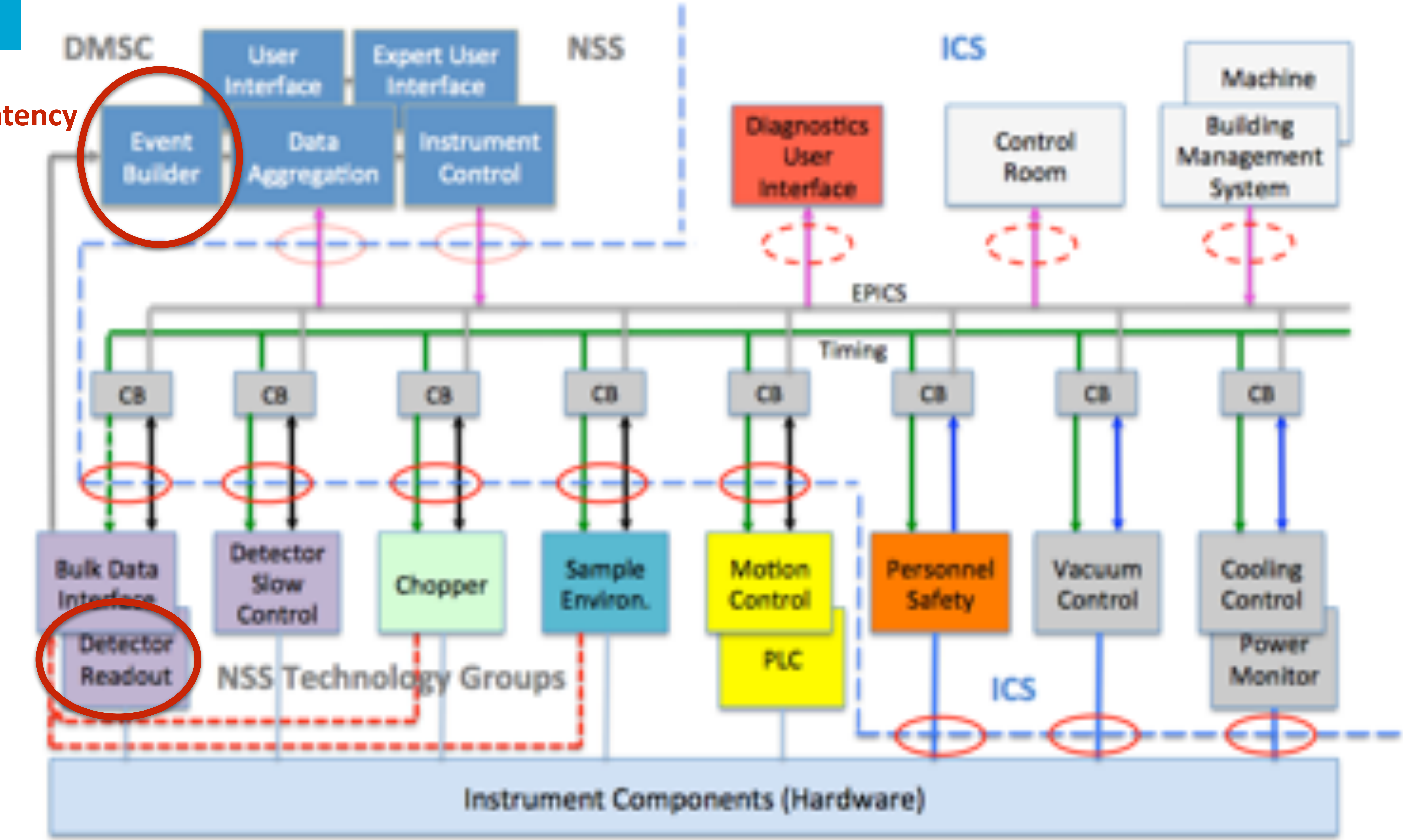


- Modularisation to manage key interface

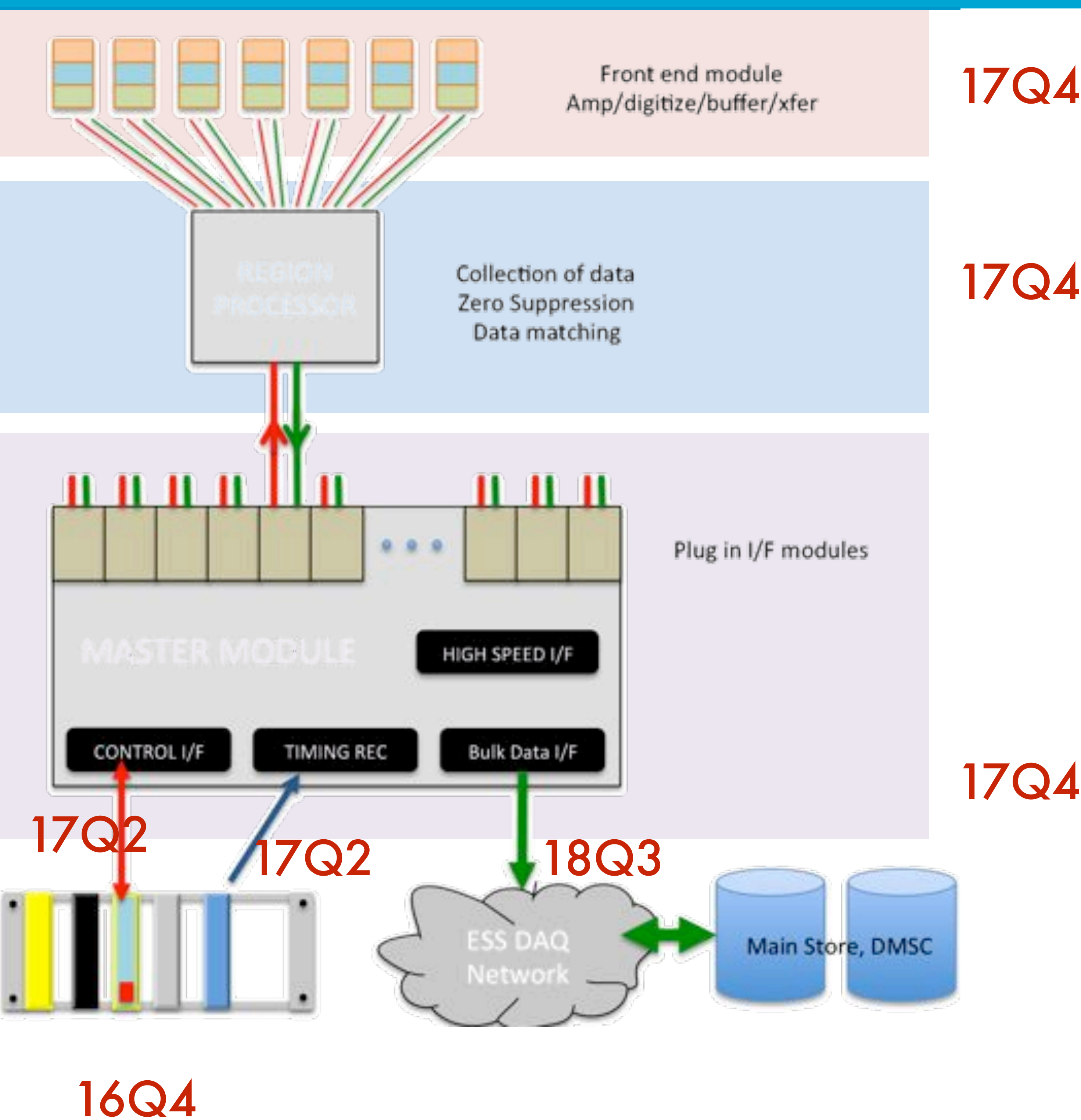
T.Gahl et al, Proc. ICANS XXI (2014)
arXiv: 1507.01838

Detector - DMSC Interface

- DG- DMSC interface ..
- Covered by Brightness (Tasks 5.1 and 4.4)



Detector Electronics and Interfaces to DMSC and ICS



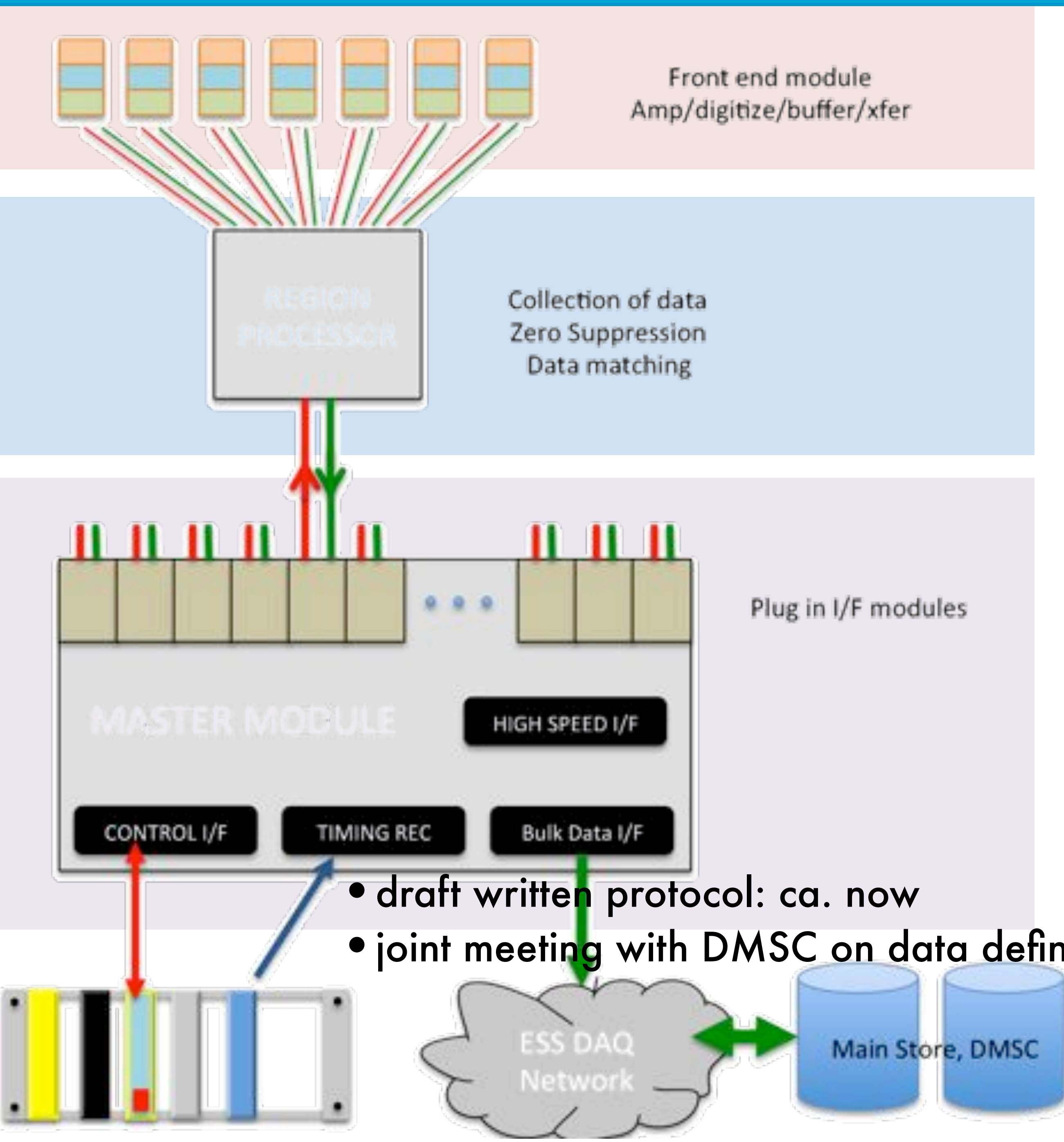
- Design underway for all aspects
- Modularisation to manage key interface
- Single in-kind partner (STFC, UK) for backend readout
- Example of synergy with existing European expertise to reduce developments needed by ESS
- Adapting rather than developing

- ICS interface design and prototyping underway
- Design model: arXiv: 1507.01838

- DG-DMSC interface covered by BrightnESS task 5.1 and 4.4
- Resources in place: work well underway

Detector Electronics and Interfaces to DMSC and ICS

Status of each layer



- Detailed discussions underway
- in-house: VMM chip available, and integration underway
- CPIX (CDT) IDEAS(SKADI) GEMINI(LOKI) well advanced

- Candidate hardware purchased
- implementation ongoing
- 1st prototype: this year

- Candidate hardware purchased
- implementation ongoing
- 1st prototype: this year. prob summer

- Rack+UPS:
- Candidate systems being tested.
- 1-2 chosen and qualified.

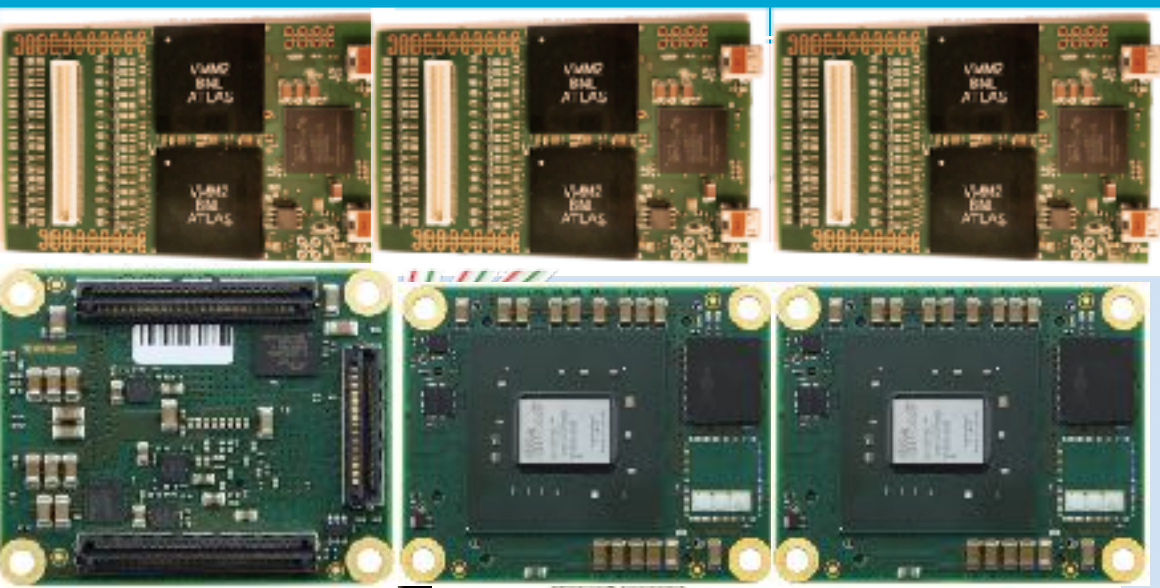
- draft written protocol: ca. now
- joint meeting with DMSC on data definition: 9 May

- HV/LV crates: 2 systems integrated to EPICS at IIIP
- Moving to using for detectors in workshop

- ICS IK at Daresbury in-place
- work restarted

- event formation: underway
- Tobias' group and Brightness task 5.1

Detector Electronics and Interfaces to DMSC and ICS



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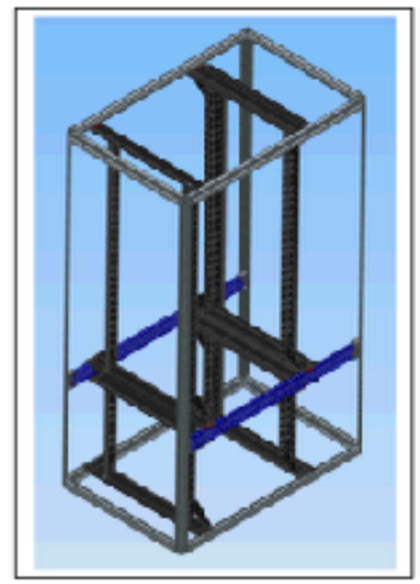
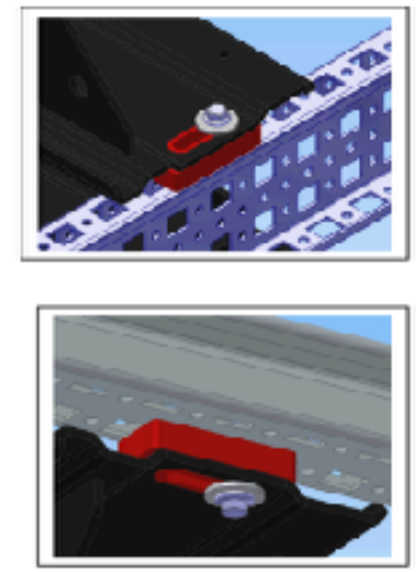
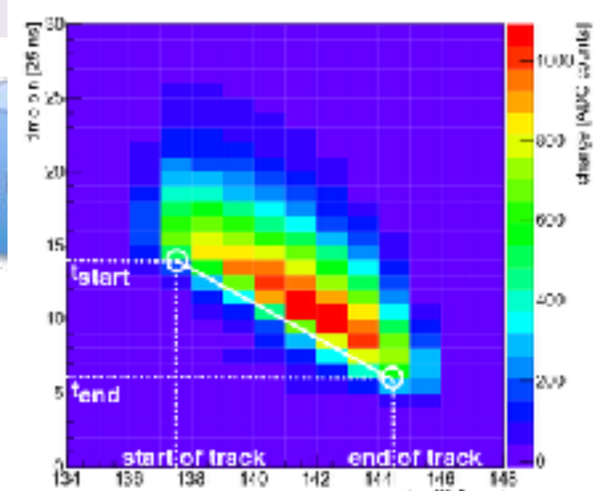
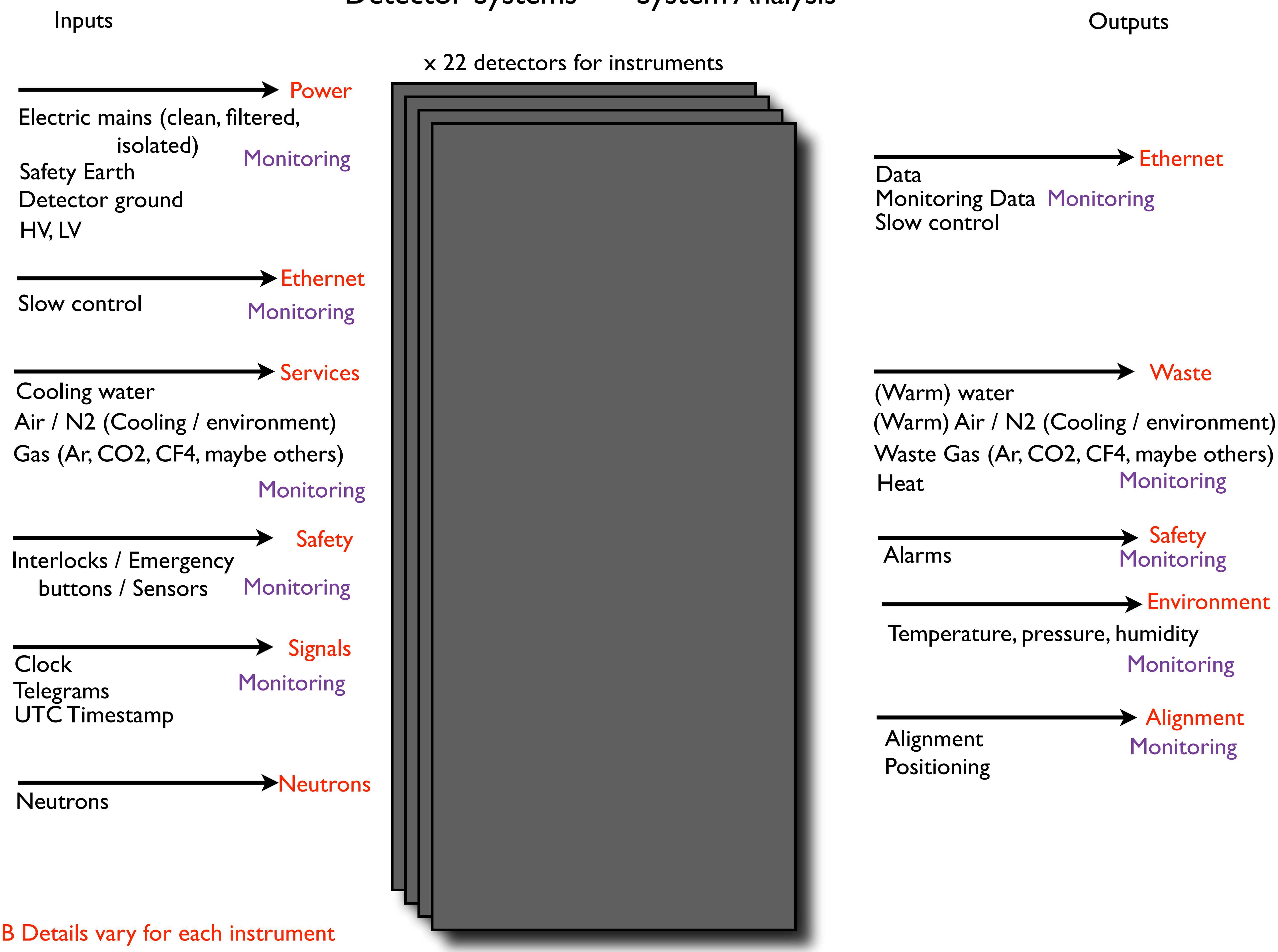






Detector Systems --- “System Analysis”

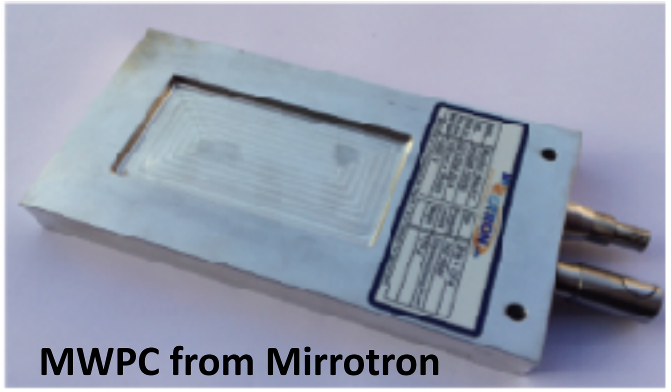


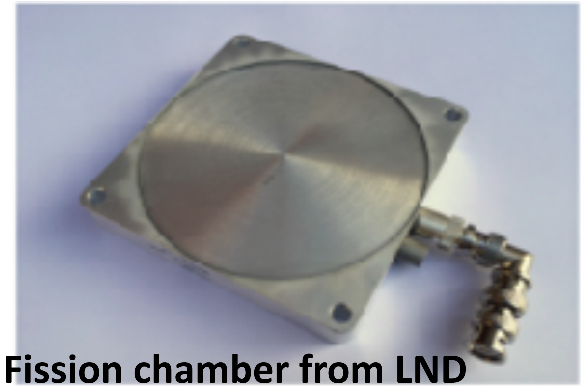
NB Details vary for each instrument

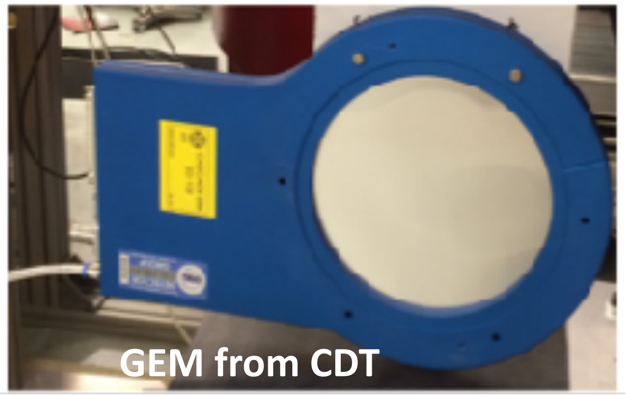
Beam Monitors

Beam Monitors


Scintillator from Detector Quantum

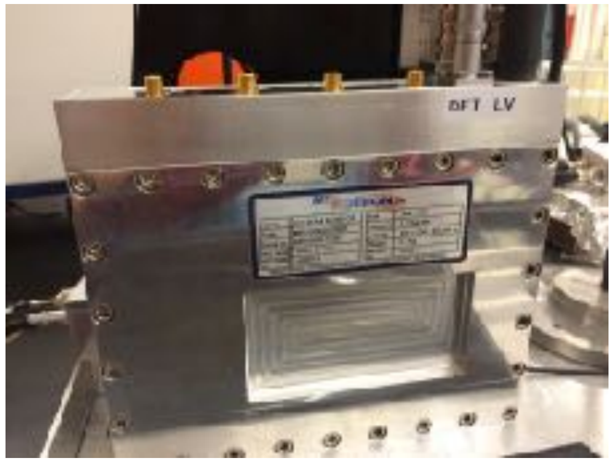

MWPC from Mirrotron

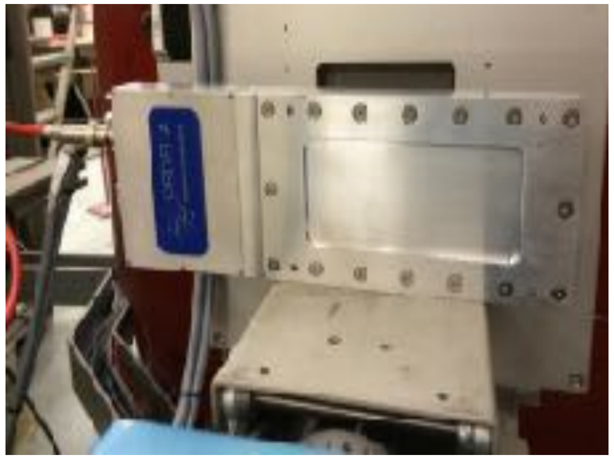

Fission chamber from LND

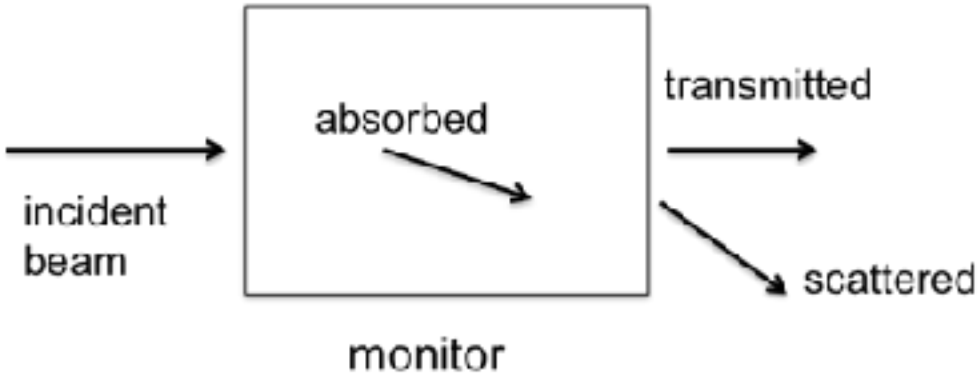

GEM from CDT

Type	Supplier	
MWPC (4)	Mirrotron-ORDELA	Filled with ^{3}He gas or ^{14}N
Fission chamber (1)	LND	^{235}U
GEM (1)	CDT	Coated with ^{10}B
Scintillator (1)	Detector Quantum	Li-glass beads

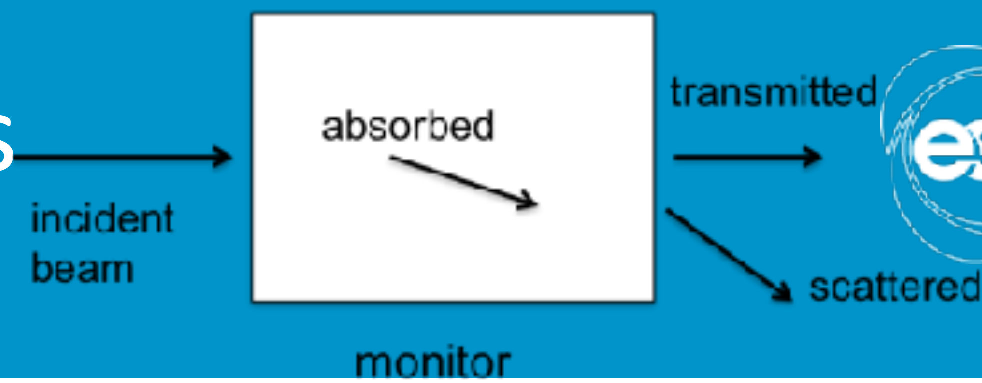
2D-GEM monitor for ESS realized by Milan-CNR
Mirrotron to be filled by Nitrogen


2D-MWPC from Mirrotron


Two MWPC from ORDELA ,filled with ^{3}He or ^{14}N



Beam monitors-main results



EUROPEAN SPALLATION SOURCE

	MWPC from ORDELA	MWPC from ORDELA	MWPC BM-100X50 from Mirrotron	2D-MWPC from Mirrotron	2D-GEM from CDT	Scintillator from Quantum Detectors, UK	Fission chamber from LND
Isotope used for neutron capture	^{3}He	^{14}N	^{3}He	^{3}He	^{10}B	^{6}Li	^{235}U
Gas pressure mbars	Partial pressure 6,0795	Partial pressure 81,06	Partial pressure 6,5	Partial pressure 0.4	Total pressure 100	------	Total pressure 1013,2
Filled gas	$^{3}He+^{4}He+CF_4$	$N+CF_4$	$^{3}He+CF_4$	$^{3}He+CF_4$	Ar/CO_2	--------	P10
Active Area (mm^2)	114 x 51	114 x 51	100 x 50	100 x 50	Diameter 100 mm	28 x 42	Diameter 108.0 mm
Applied voltage (V)	850	850	1300	Anode at -3500V Drift at 1500V	-1000	650	300
Attenuation %	4.5	4.4	2.5	7.3	11.1	0.49	3.87
Calculated attenuation %	4	4	2			0.1	2
Measured Efficiency at 2.4Å %	0.12	3.3×10^{-3}	0.11	0.01	2.7	0.052	0.01
Supplier efficiency % at 1.8Å	0.1	0.001	0.1	0.015			
Scattering %	3.9	3.8	4	9	10.3	0.74	3.8

What now?

- Updating requirements from instruments for monitors both for commissioning and operation
- Taking into account operational environments
- By autumn will have a draft set of recommendations

The ESS Detector Group

Scope

- Support and facilitate partners to be able to deliver performant detectors for world class instruments
- Act as a host institute to assist and enable in-kind partners to deliver where requested
- Facilitate installation and Commission detectors
- Operate and maintain detectors throughout their lifetime

- Interface management for in-kind partners with other parts of NSS and ESS and other in-kind partners
- Integrate detectors into a homogeneous ESS instruments suite
- Where necessary, assist in the design and development of detectors with partners for partners
- A technology service group capable of long term support

Detector Group and friends (Jan '16)

Detector Workshops and Facilities available in Lund

- Detector workshop
- Source Facility
- Thin Films workshop
- Simulations

The ESS Detector Group: Facilities

Detector Coating Workshop

In-house production facility in Linköping, which will carry out the manufacturing of $^{10}B_4C$ coatings needed for the construction of detectors, supplying high quality neutron converters. The production capacity exceeds the 1000 m^2 of $^{10}B_4C$ coating per year.

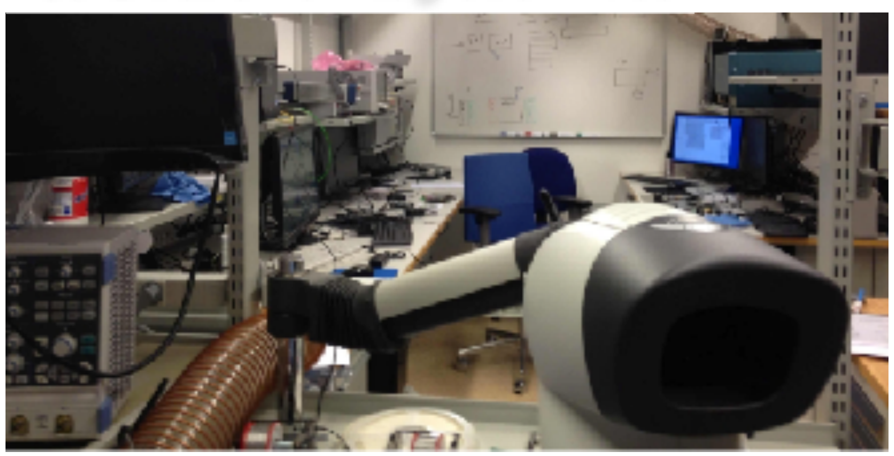
Embla Workshop

Facility shared with the Chopper Group composed of a fully equipped machine shop and an area to build and assembly detector mechanical components.

LU Source Facility

Laboratory to test detectors and prototypes. It is a collaboration between the ESS Detector Group and The Department of Nuclear Physics of Lund University.

ICS Electronic Integration Area

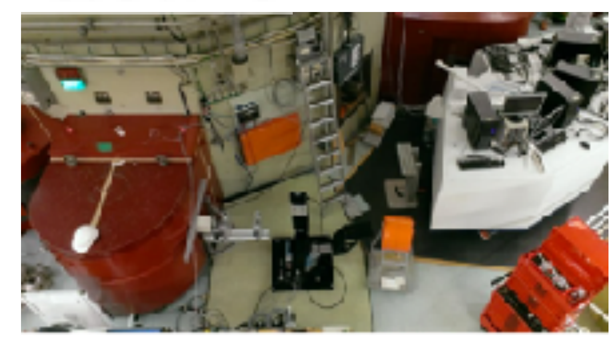


Detector Group has set up an electronics lab for long-term readout development work at the ESS headquarters in Lund.

Utgård Detector Workshop

This workshop is a share space between Accelerator Division, Scientific Activities Division and Detector Group.

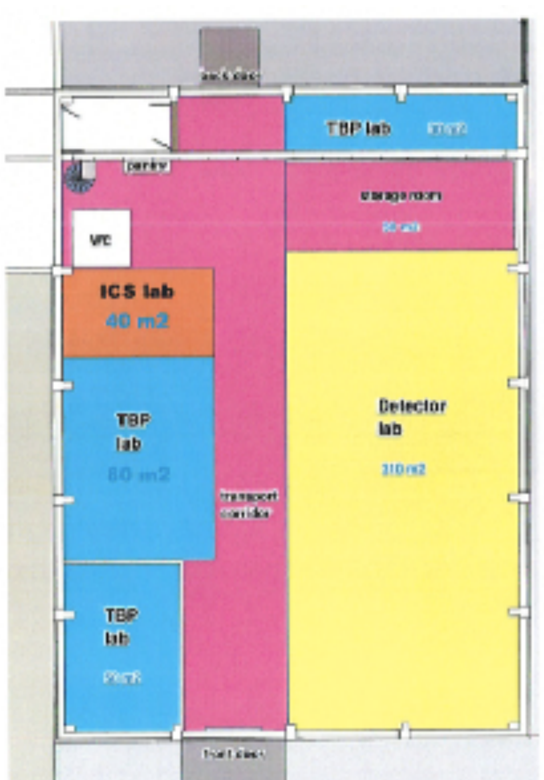
R2D2 at IFE



R2D2 is the test beam line that the Detector Group is setting up in collaboration with IFE at the JEEPII reactor. The main goal is to provide a dedicated beam channel for testing of detectors and the development of new neutron techniques relevant to ESS.

Detector Workshop

- ca. 700m^2 shared between **sample environment**, **integrated control systems** and **detector group**
- about 500m north of present offices
- Reconfigurable based upon need



scale matched to meet needs
during construction and installation

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

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Source Facility

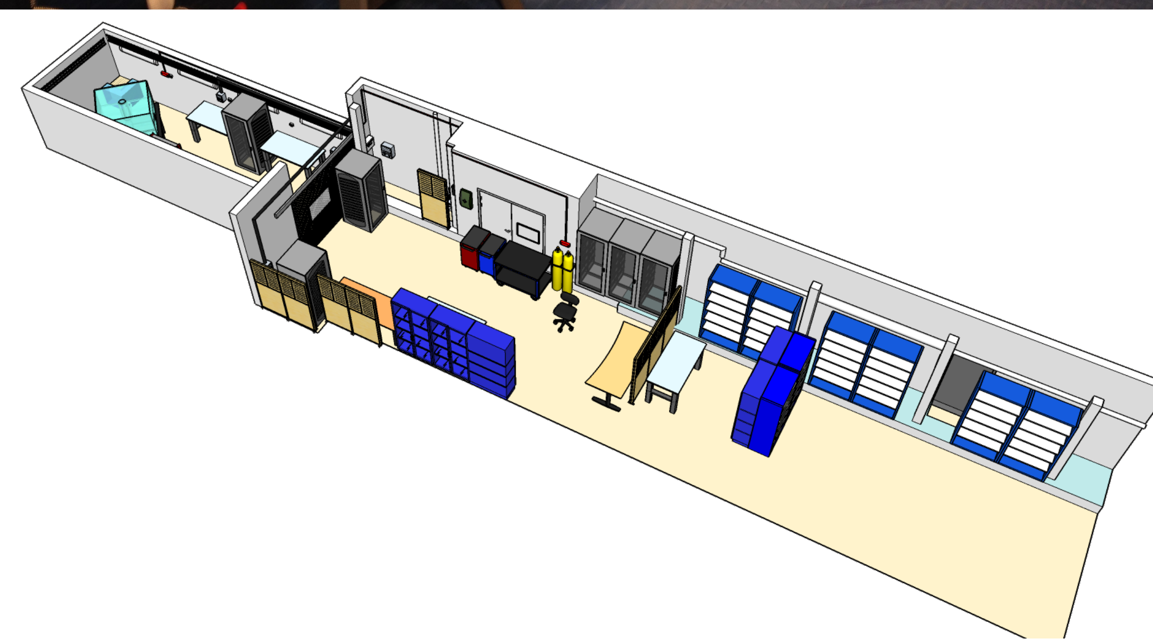
LUNDS UNIVERSITET

EUROPEAN SPALLATION SOURCE

- Located in basement of Lund U physics dept
- ca. 700m from present offices
- Uses radiation source permit from Lund U
- Possibility to use radioactive sources in Lund
- ie development, testing, quality assurance, …
- SAT possible for detectors in Lund
- Heavily used over last couple of years

- Many neutron and gamma sources available
  - neutron: Am/Be
  - Gamma: Fe-55, Co-57, Co-60, Ba-133, …
- Electronics, DAQ, gas, infrastructure, elog available for testing

- Tagging method available for fast neutrons
- eg as recently used for evaluating B-loaded concrete



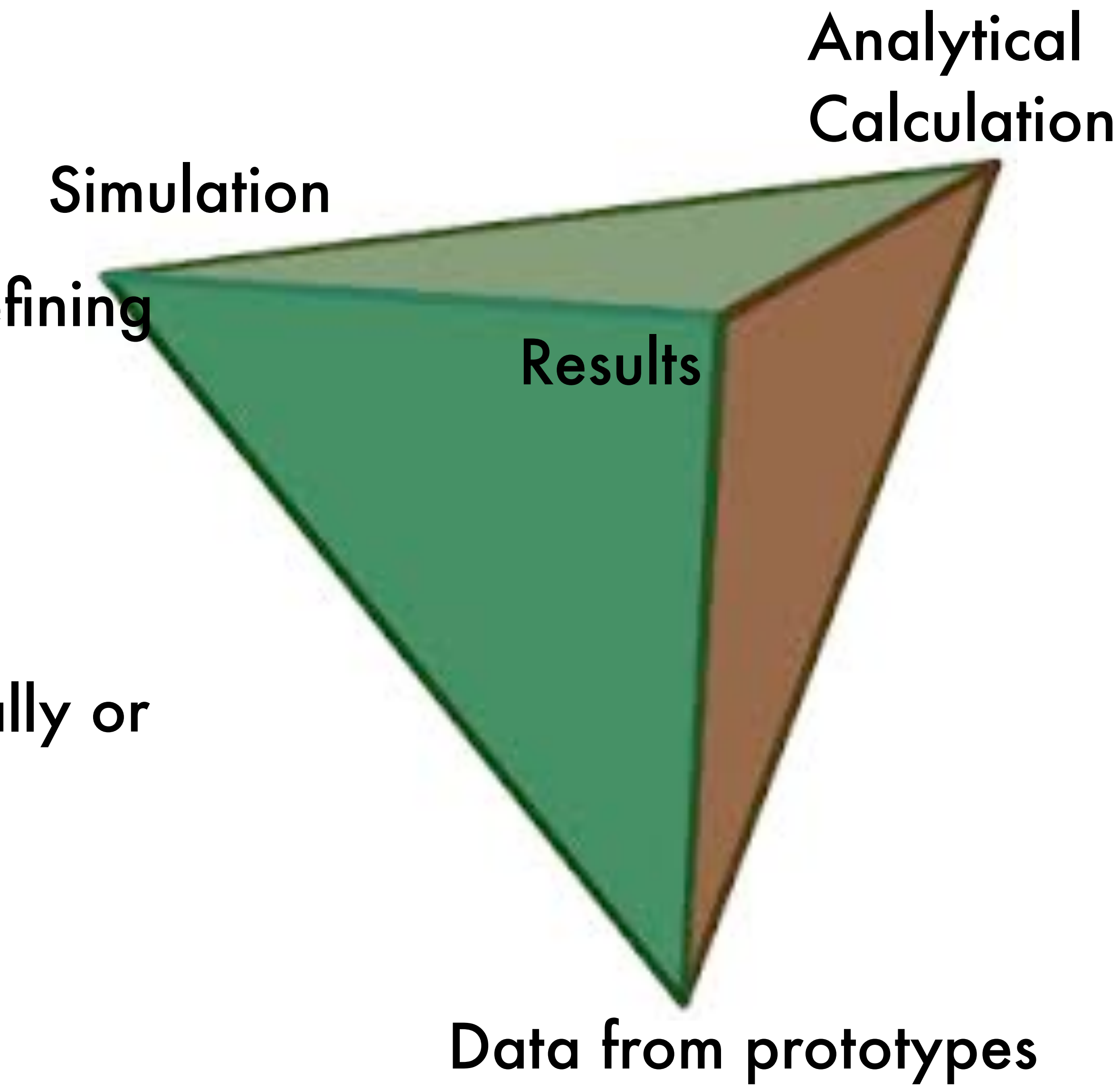
Calculation, Simulation, Data and All That

- Simulation is a very powerful tool
- ... but the computer will always lie to you ...

- Data from prototype tests is golden
- Lack of ability to trigger independently on the neutron means some degree of arbitrariness in defining the measurement
- Checking that your measured data is correct is complicated

- Additionally, always try and calculate analytically or "back of envelope" what your expectation is
- (Or at least upper and lower limits)

- Use all 3 of these **together** to understand the performance of your prototypes



It is much cheaper to simulate a detector than build it: faster development cycle

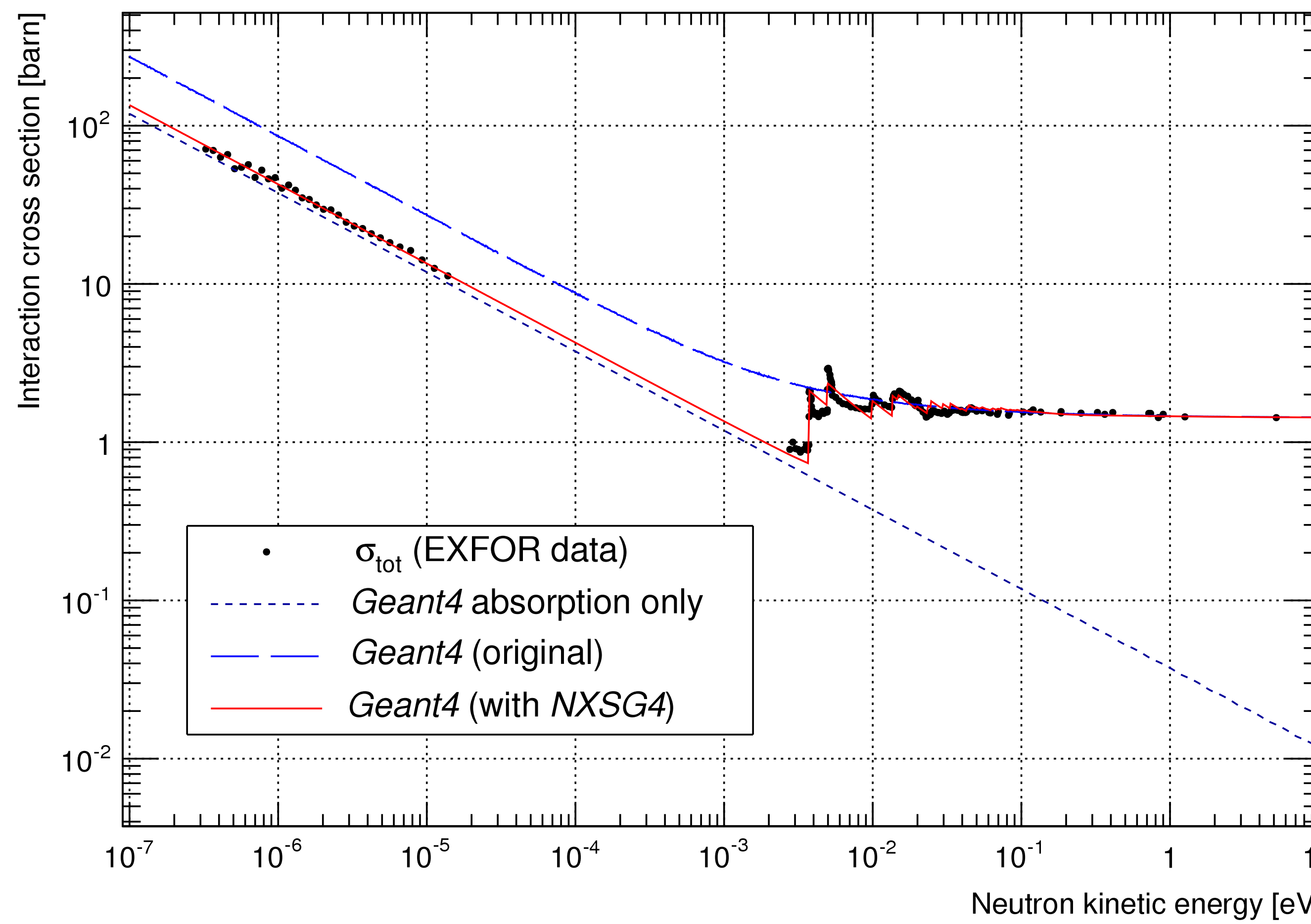
Neutron diffraction in polycrystalline materials: Add-on for GEANT4

HZB Helmholtz Zentrum Berlin

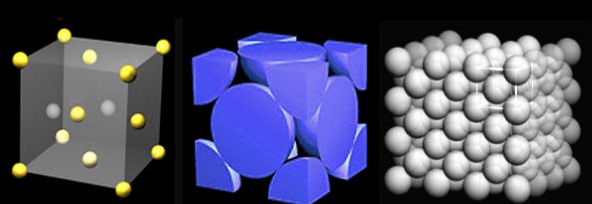
Risø DTU National Laboratory for Sustainable Energy

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.

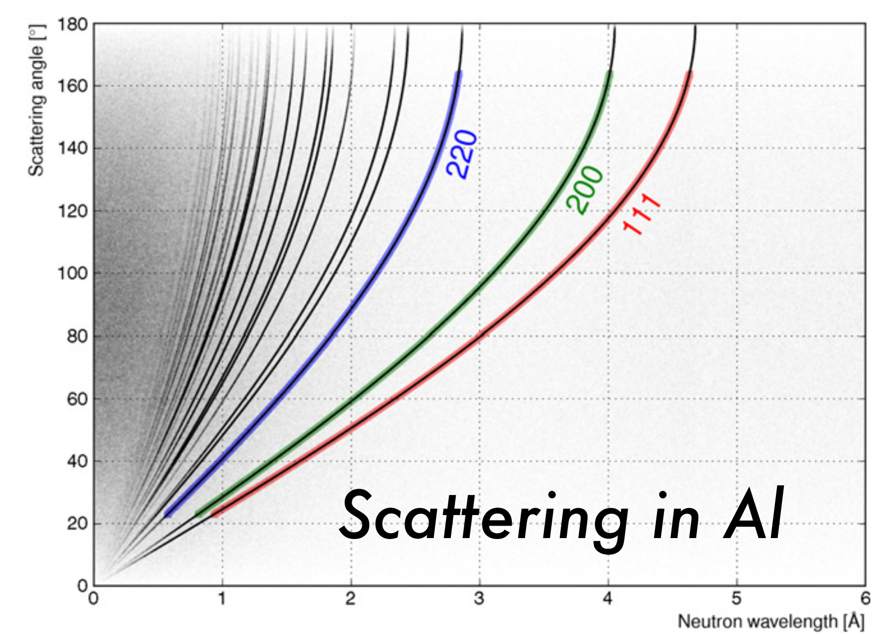



```
(tkittel@localhost data)> cat Al.nxs
space_group = 225
lattice_a = 4.049
lattice_b = 4.049
lattice_c = 4.049
lattice_alpha = 90
lattice_beta  = 90
lattice_gamma = 90
[atoms]
add_atom = Al 3.449 0.008 0.23 26.98 429.0 0.0 0.0 0.0
```



- 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

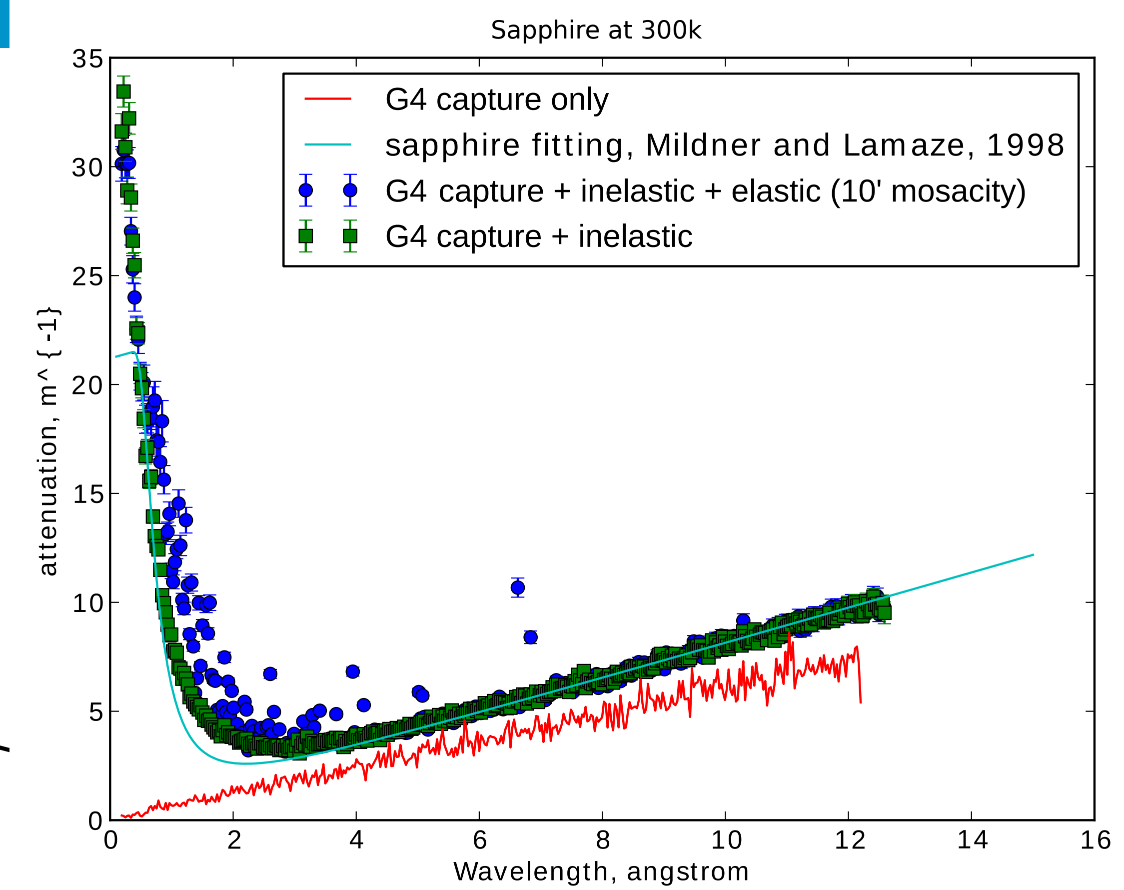
brightness

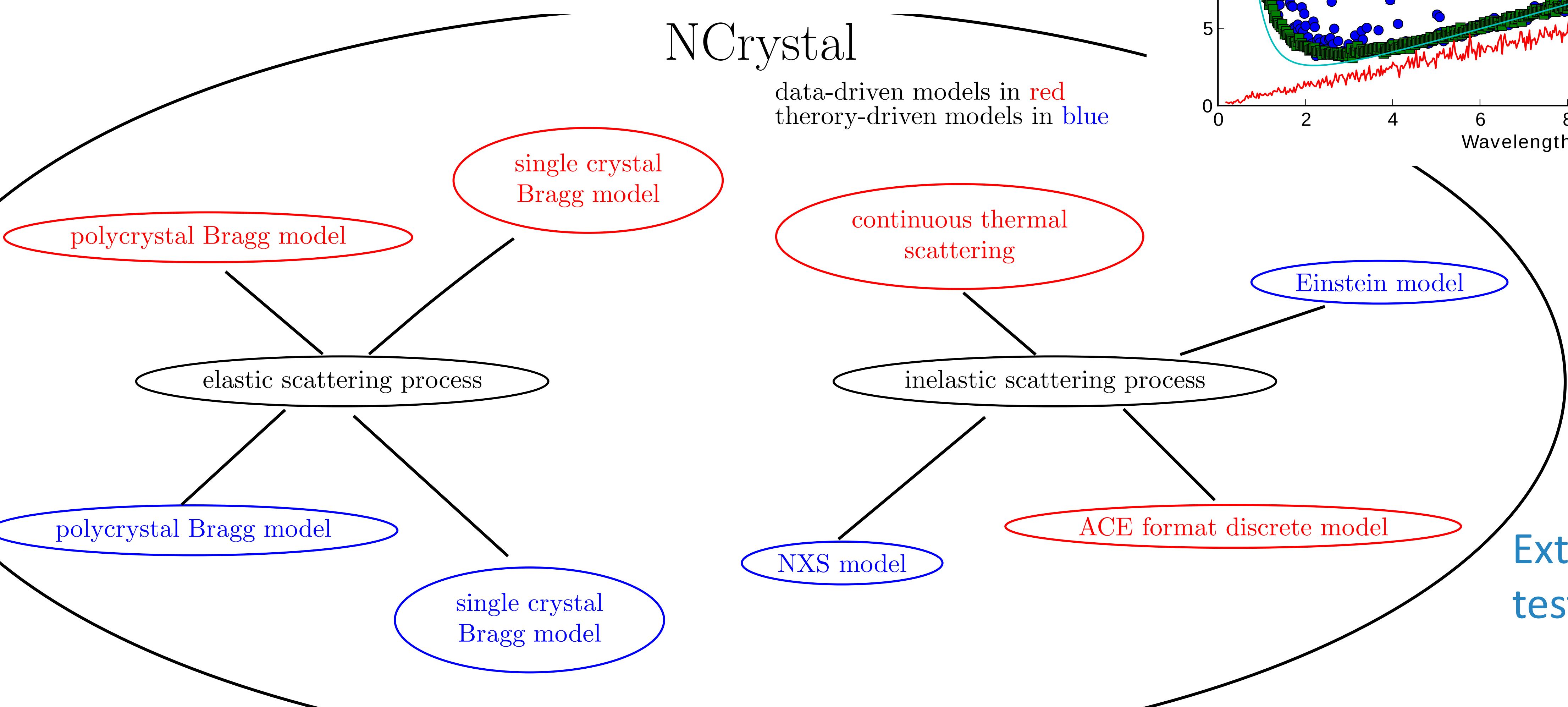
EUROPEAN SPALLATION SOURCE

- “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

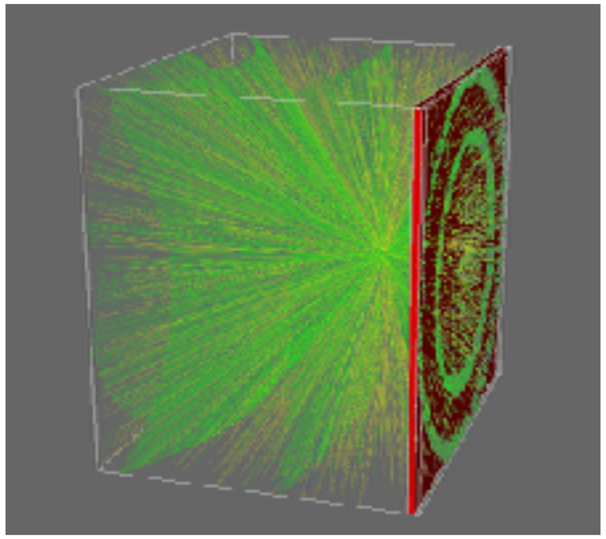
$$\frac{\partial^2 \sigma}{\partial E' \partial \Omega} = \frac{\partial^2 \sigma_{in}}{\partial E' \partial \Omega} + \frac{\partial^2 \sigma_{el}}{\partial E' \partial \Omega}$$

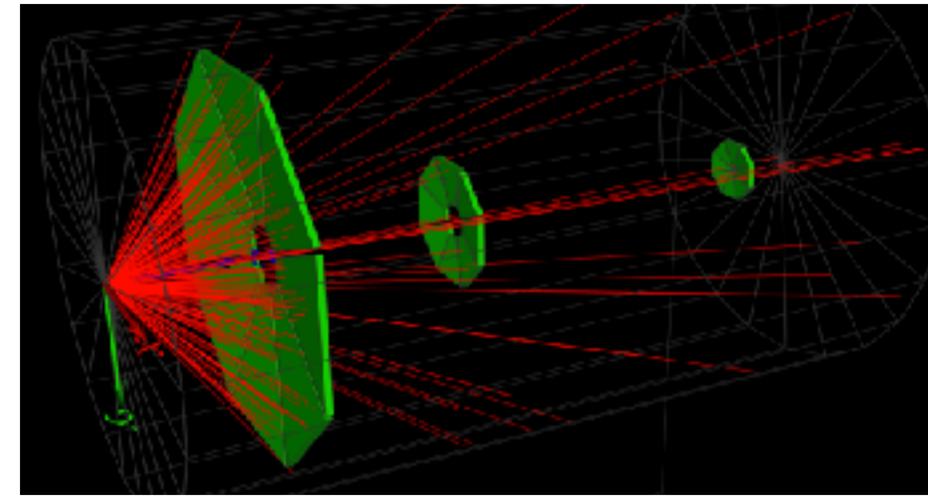


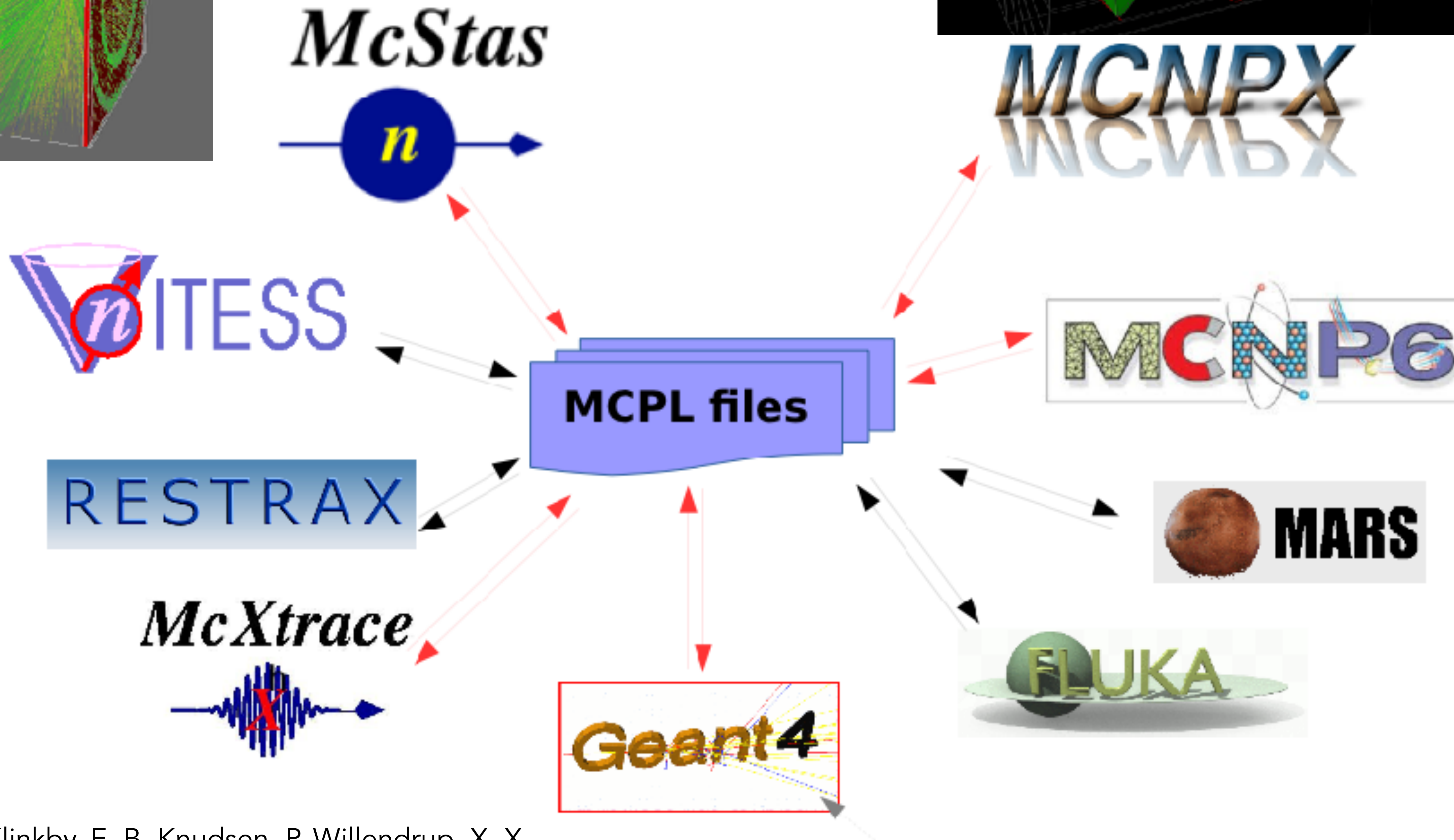


Extension under alpha testing

The ESS Detector Group: Simulation Framework



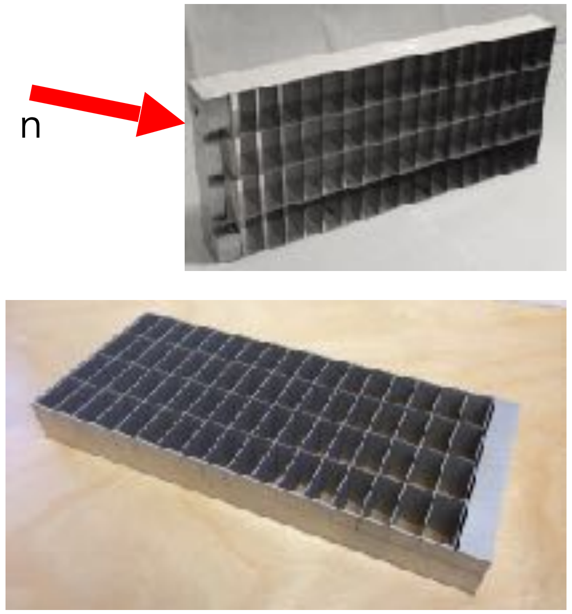


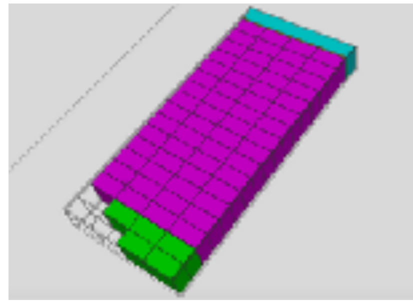


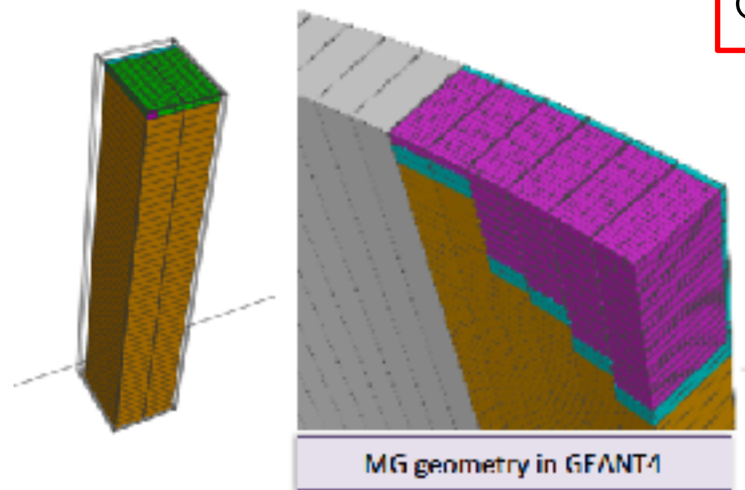
T. Kittelmann, E. Klinkby, E. B. Knudsen, P. Willendrup, X. X. Cai, K. Kanaki. "**Monte Carlo Particle Lists: MCPL**", Submitted to Computer Physics Communications (2016); [arxiv:1609.02792.](arxiv:1609.02792)

The ESS Detector Group: Simulation Framework–MultiGrid

Work of Eszter Dian
CER, Hungary in-kind contribution

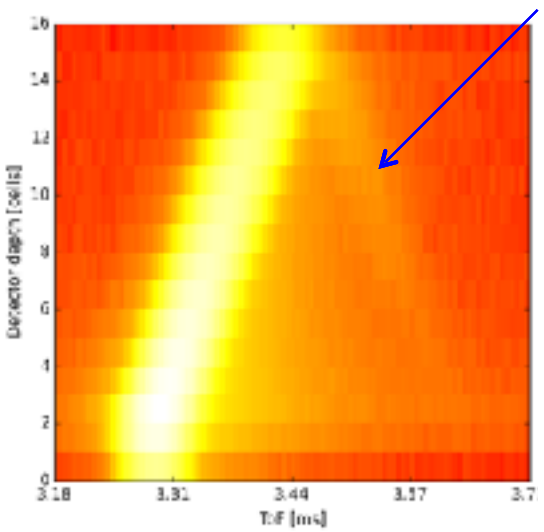


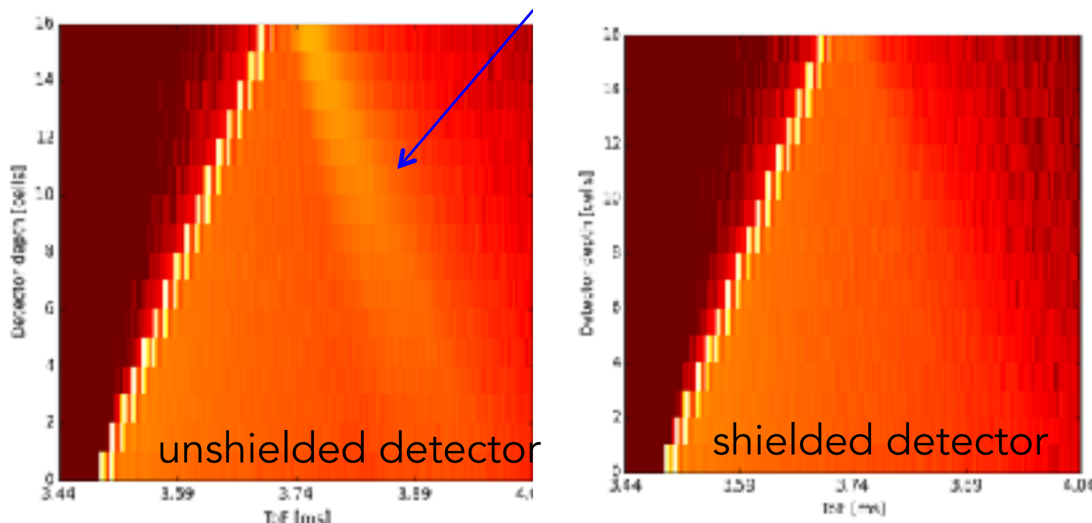


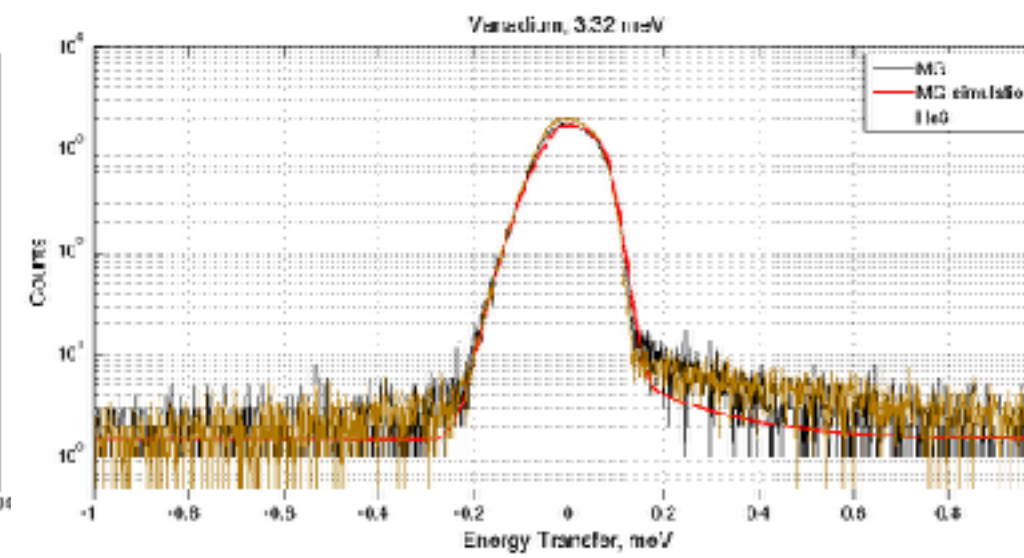


Bragg-scatter from end of detector

Vanadium energy transfer spectrum
Above and below Bragg edge







Measured time spectrum as a function of depth for 4.6 Å neutrons – IN6 demonstrator

n

Simulated time spectrum as a function of depth for 4.6 Å neutrons

Simulated and measured time spectrum

A. Khaplanov et al. "In-beam test of the Boron-10 Multi-Grid neutron detector at the IN6 time-of-flight spectrometer at the ILL", Journal of Physics: Conference Series 528 (2014); doi:10.1088/1742- 6596/528/1/012040.

A List of Reference Material

- A lot of material is publicly available: here is a partial list and where to find it

References

- Comprehensive references willl be added to archive version of the talk ...
- come back in a few days

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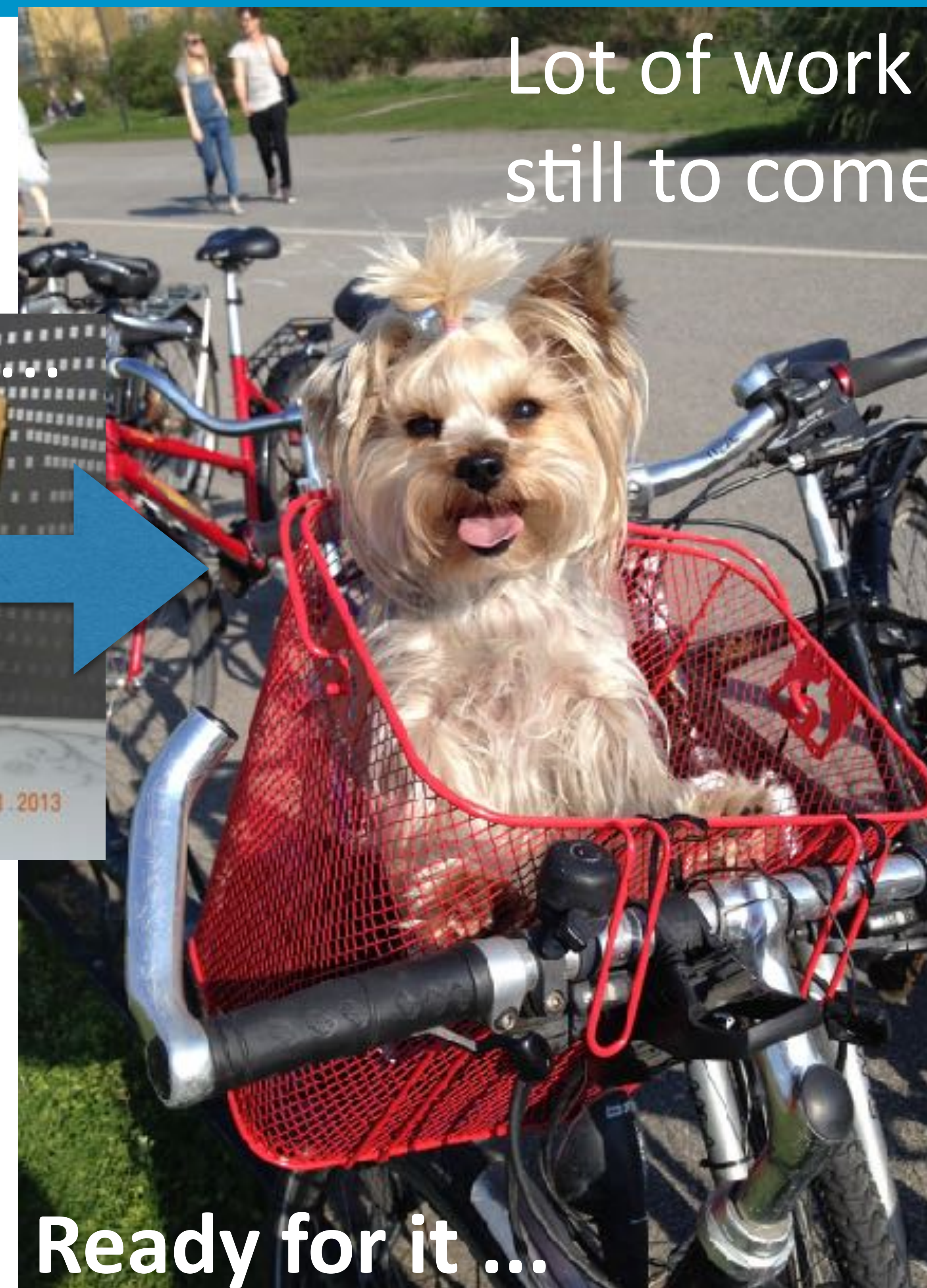
Mood Message so far …

EUROPEAN SPALLATION SOURCE

- Development time is long: typically 10 years from conception to utilisation



- Solve challenges one at a time, and remain calm

Summary

- ESS will provide increased neutron brightness
- Novel instrument designs push requirements for detectors well beyond current day state-of-the-art

- Detector systems project in good shape, and running at full speed
- Baseline detector designs exist
- Set of design and build partners identified and available
- Very much an open collaboration of groups across (mostly) Europe
- Having a capable build group and set of willing expertsise is as important as the details of the design

- Detector work now very much design, and not R&D
- Have the capability to support partners as needed
- Enable partners