Neutron Detector Systems
Strategy for realising NSS project

Detectors for Early Instruments and Key Challenges

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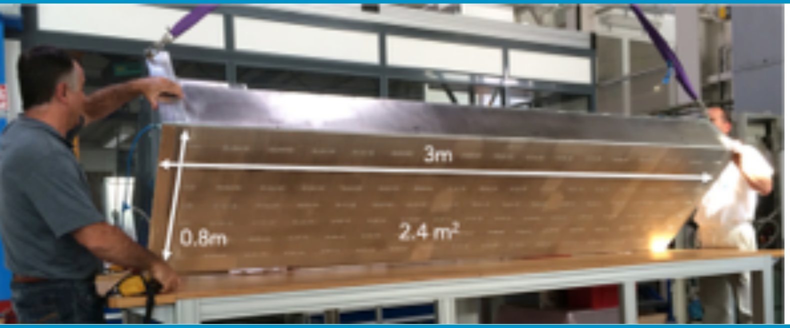
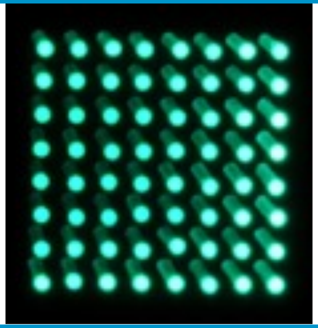
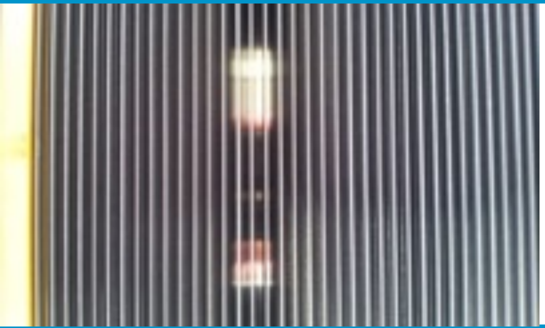
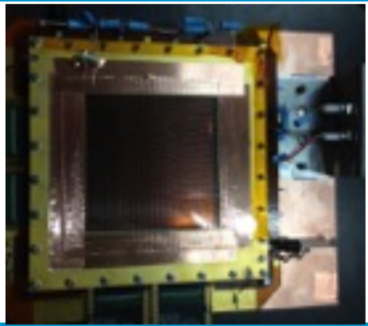
www.europeanspallationsource.se

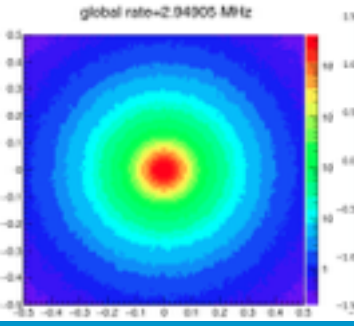
ESS Instruments Collaboration Board June 22nd, 2016

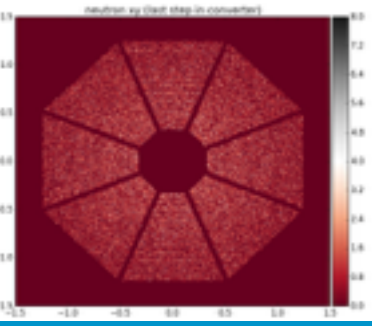


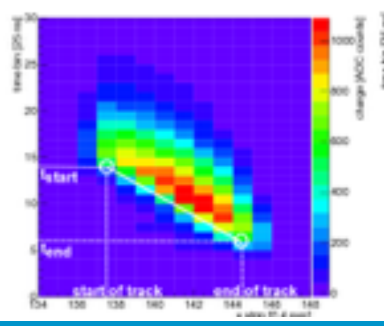


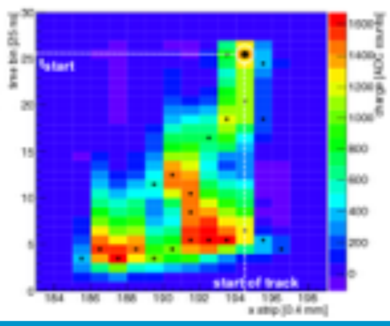


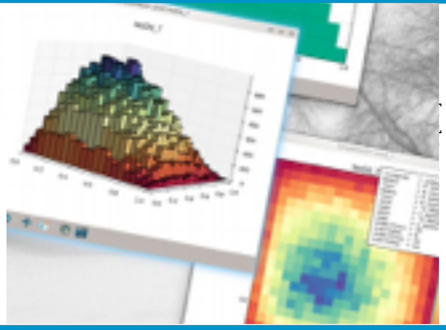


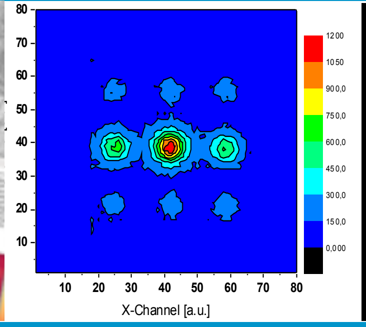


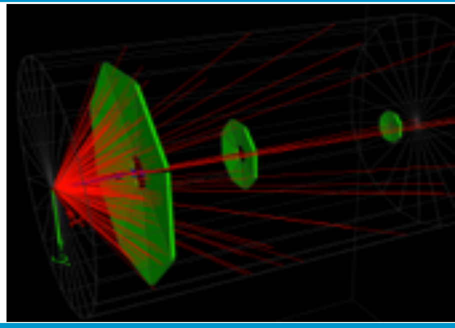












Overview

- SCOPE
- CHALLENGE
- STRATEGY
- RESOURCES, SCHEDULE AND RISKS
- (ACHIEVEMENTS)
- (Backup Material)

Scope

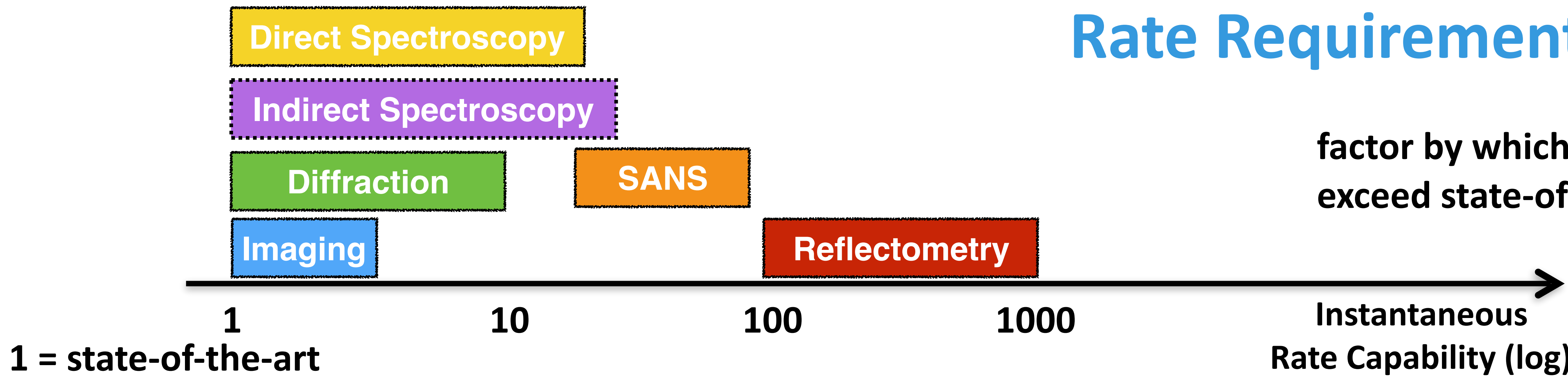
- Support and facilitate partners to be able to deliver performant detectors for world class instruments
- Act as a host institute to assist and enable in-kind partners to deliver where requested
- Facilitate installation and Commission detectors
- Operate and maintain detectors throughout their lifetime

- 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

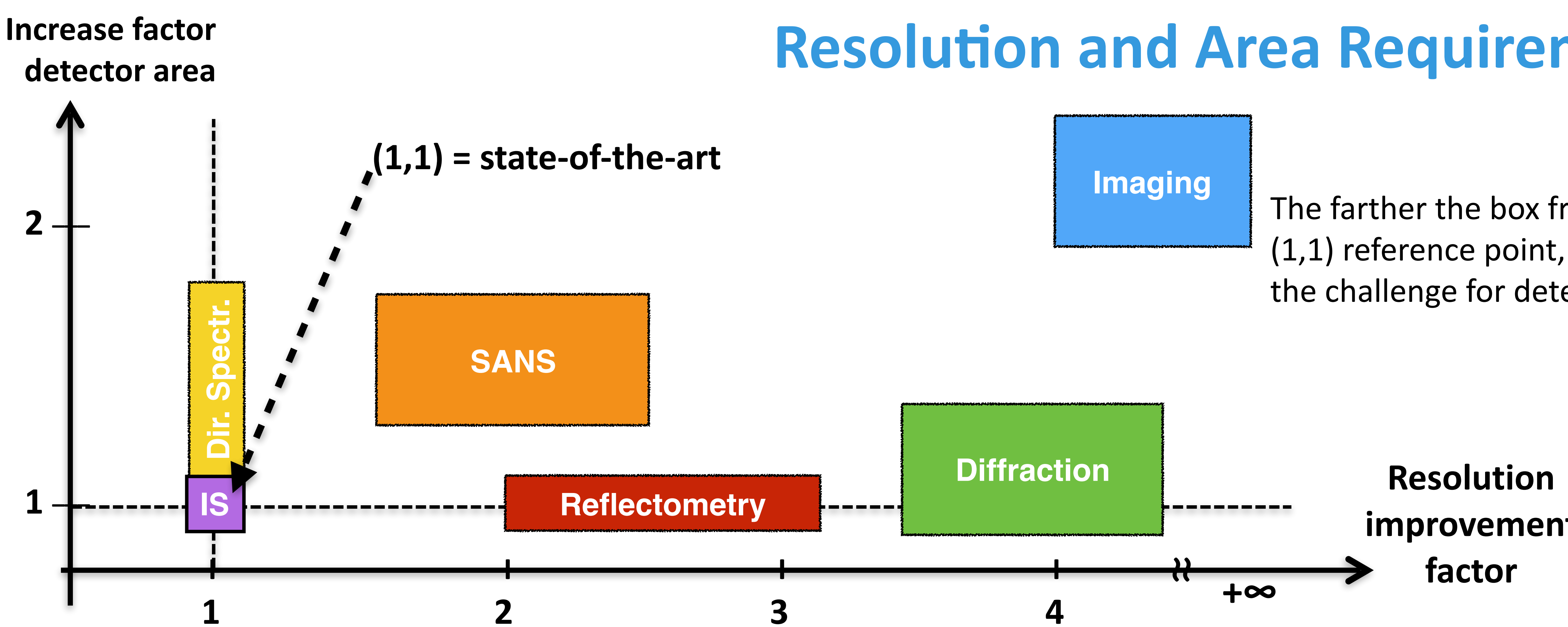
Requirements Challenge for Detectors for ESS:
beyond detector present state-of-the art

Rate Requirements

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



Resolution and Area Requirements



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

STRATEGY

- Involve in-kind partners and solve problems together
- Modularisation to tackle interfaces and integration
- Instrument baselines, detector design, design teams and build teams identified
- Close working collaborative relationships to mitigate risks
- Mitigation plan identified

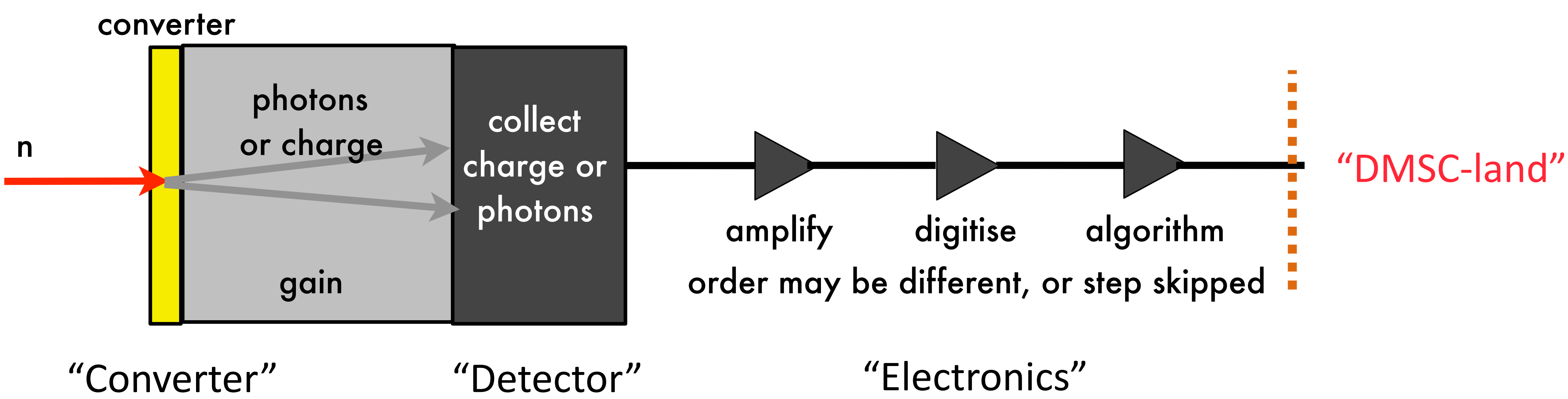
ESS Partners on Detectors
Solve problems together

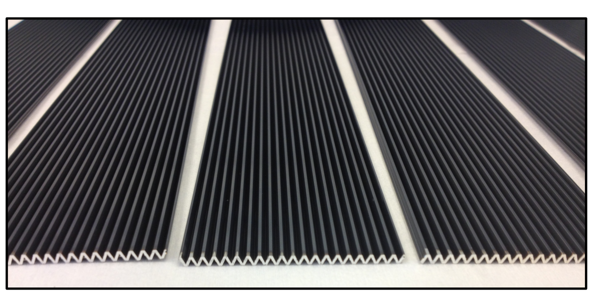
EUROPEAN SPALLATION SOURCE

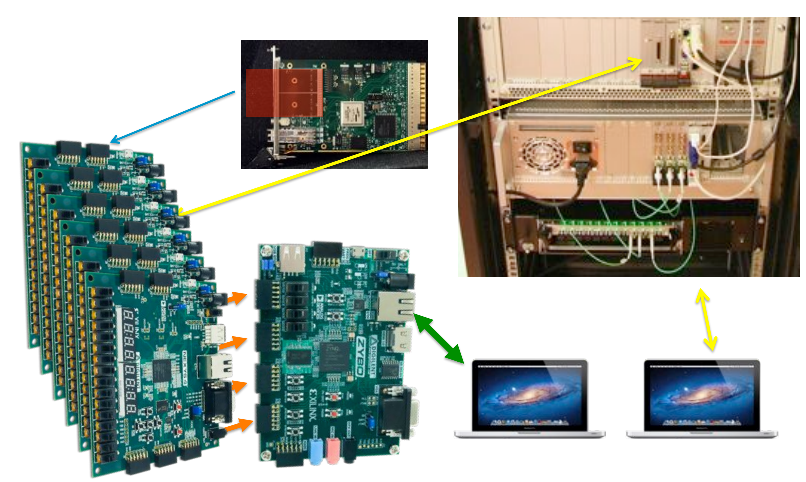
icnd.org { INTERNATIONAL COLLABORATION FOR THE DEVELOPMENT OF NEUTRON DETECTORS }

Neutron Detectors

Modularisation to tackle interfaces







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	Scintillators	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		Scintillators/10B-based	
	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	
		MIRACLES			
		VESPA	Count-rate	3He-based	
SPIN-ECHO	Spin-echo	tbd	tbd	3He-based/10B-based	

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

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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	High: Inst. Rate Req.?	Low
HEIMDAL	WLS Scintillator ? Jalousie? (SANS: BANDGEM imaging: Timepix options)	Workshop 14-15 March	DK/PSI/NO SANS:CNR	High (medium?)	unknown
MAGIC	Jalousie	POWTEX: FZJ/CDT (2012/3-…)	FZJ/CDT/LLB	Low	Medium
MIRACLES	Helium-3 PSD tubes	N/A	NBI. ESS-B?	Low	Low
VESPA	Helium-3 PSD tubes	N/A	CNR? ISIS?	Low/Medium Availability?	Low
SPIN-ECHO	3He-based/10B-based	N/A		Low	Low

Close working collaborative relationships to mitigate risks

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	17Q1/2: 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**

RESOURCES, SCHEDULE AND RISKS

Staffing

https://europeanspallationsource.se/page/detector-systems

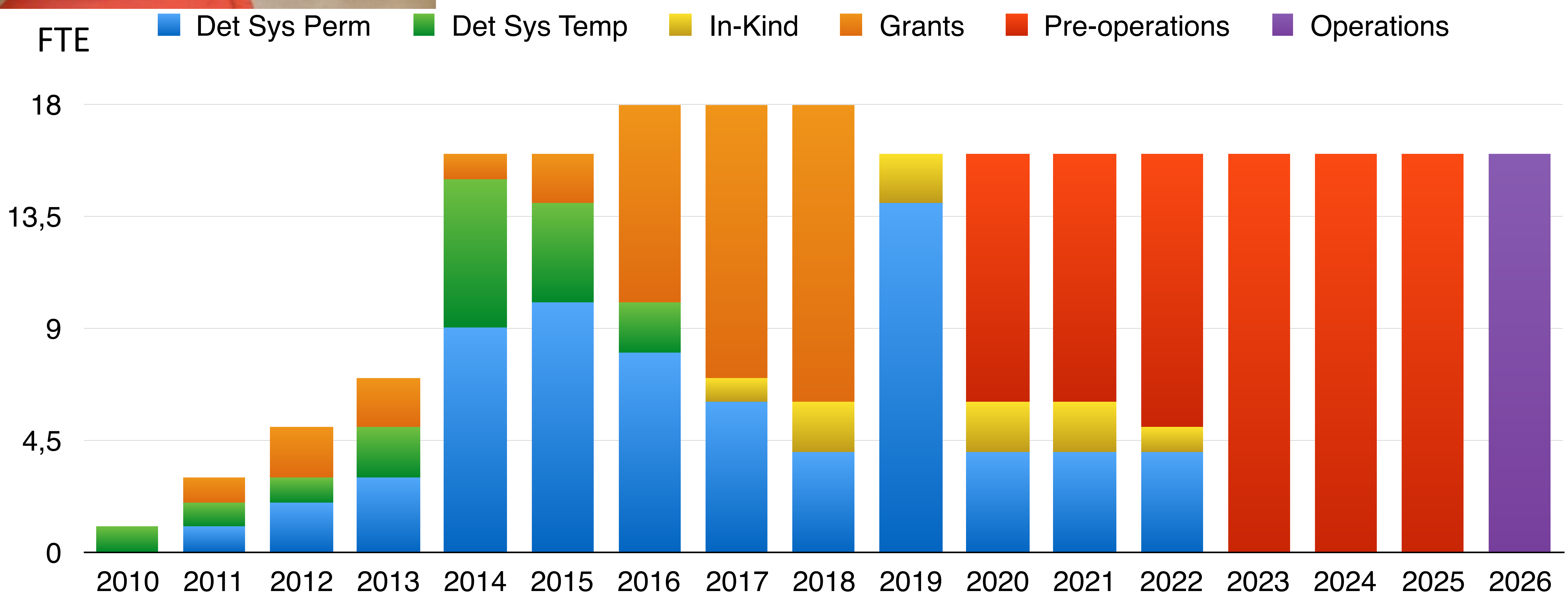
EUROPEAN SPALLATION SOURCE

Detector Group and friends

Detector Systems team in numbers

11 staff paid by NSS Detector Systems
2 contracts end in 2016
9 staff paid by BrightnESS (including 2 ongoing hires)

3 major awards for detector group members in 2015
1-2 people expected to be sponsored by in-kind during 2016



Resources and Realising In-Kind For Detector Systems during Construction

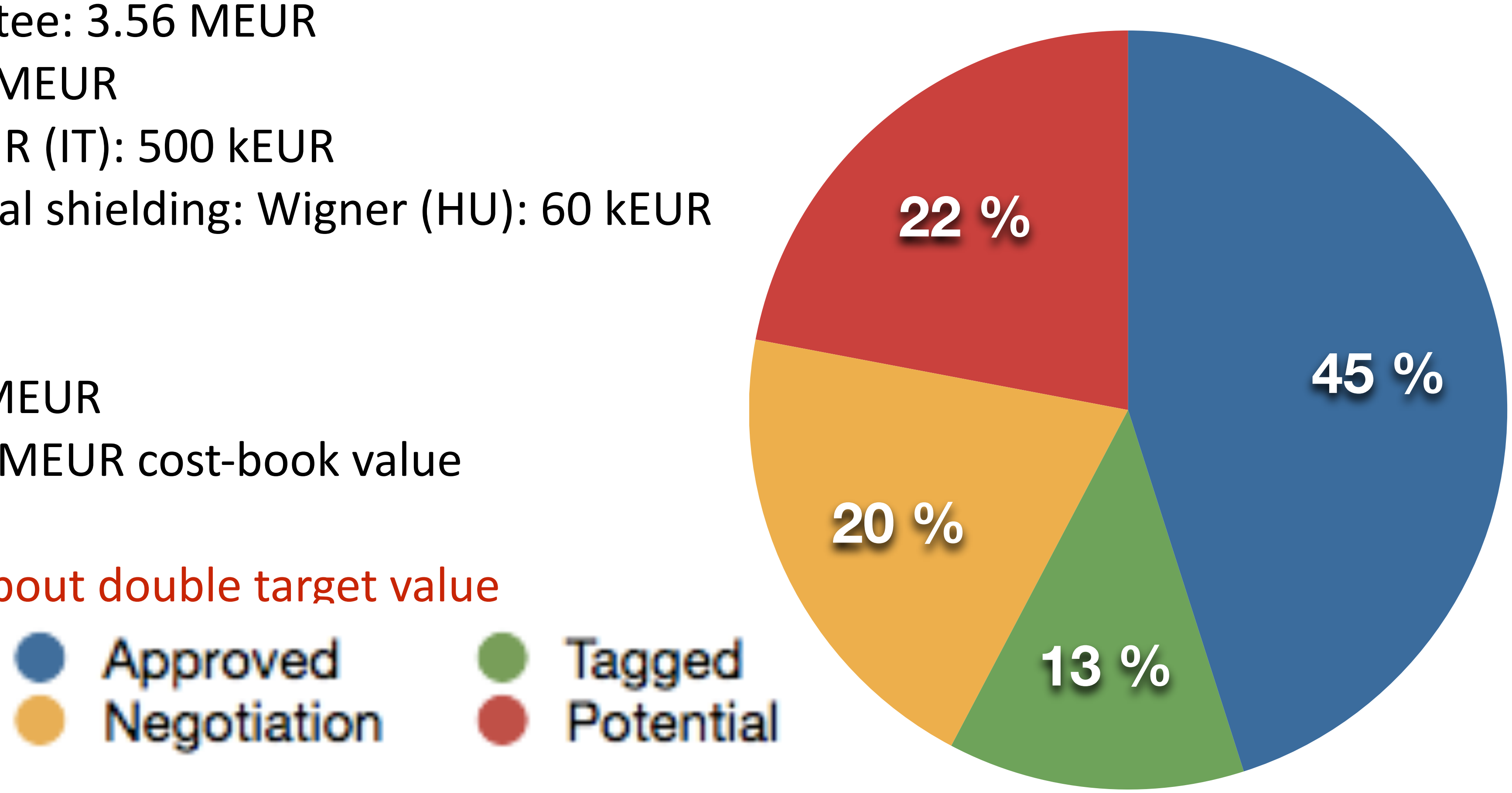
Sep'15 alignment exercise:
Cash reduction of 11.6 MEUR:
4 MEUR as scope contingency
5.3 MEUR covered by grants
2.3 MEUR transferred into in-kind

March Detector Strategy Review:
Identified 1.05 MEUR streamlining
0.55 MEUR Scintillator Development
0.5 MEUR Rates capability for inelastic instruments

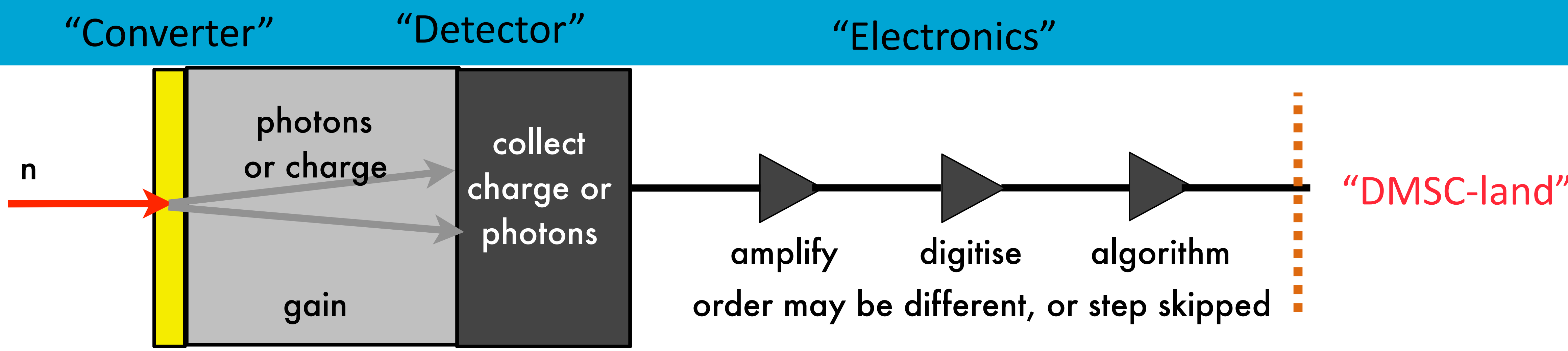
2015: "Expect to achieve In-Kind fraction of about double target value"
Prima Vera Cost Book Value increased from 3.6 to 6.8 MEUR
In-Kind Fraction: 30% of detector systems work package

- Approved by In-Kind Review Committee: 3.56 MEUR
  - Detector Electronics: STFC (UK): 3 MEUR
  - BandGem Detector (LOKI et al): CNR (IT): 500 kEUR
  - Enhanced S:B for detectors, inc local shielding: Wigner (HU): 60 kEUR
- Tagged:
  - Test Beamline: IFE (NO): 0.5 MEUR
  - Secondment of ESS personal: 0.5 MEUR
- Under negotiation: (DE, CZ, NO): 1.6 MEUR cost-book value

Expect to achieve In-Kind fraction of about double target value
Approved in-kind work on-schedule



Schedule of Key Activities



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

Key Activities for Coming Year

- Support phase 1 work for all instruments
- Detailed design work for LOKI and NMX
- Brightness, SINE2020 and SoNDE design work for ESS Instruments

- Baseline for detector electronics
- Definition of DG-DMSC and DG-ICS interfaces

- Finalise detector systems in-kind and successful launch of all in-kind work
- Strengthen collaborations for delivering detectors for ESS instruments

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

- Detector work now very much design, and not R&D
- Schedule and budget: make the detectors affordable and on time
- Enable partners

ACHIEVEMENTS

- Facilities
- Grants to mitigate risk on project scope
- Detector Electronics and interfaces to DMSC and ICS
- Detectors for Reflectometry
- Detectors for Direct Spectroscopy
- (more details in backup)

Facilities

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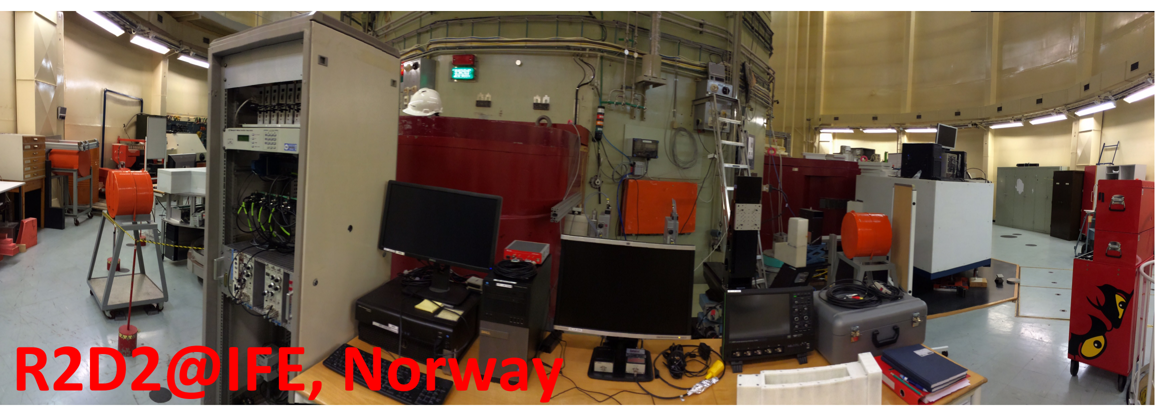
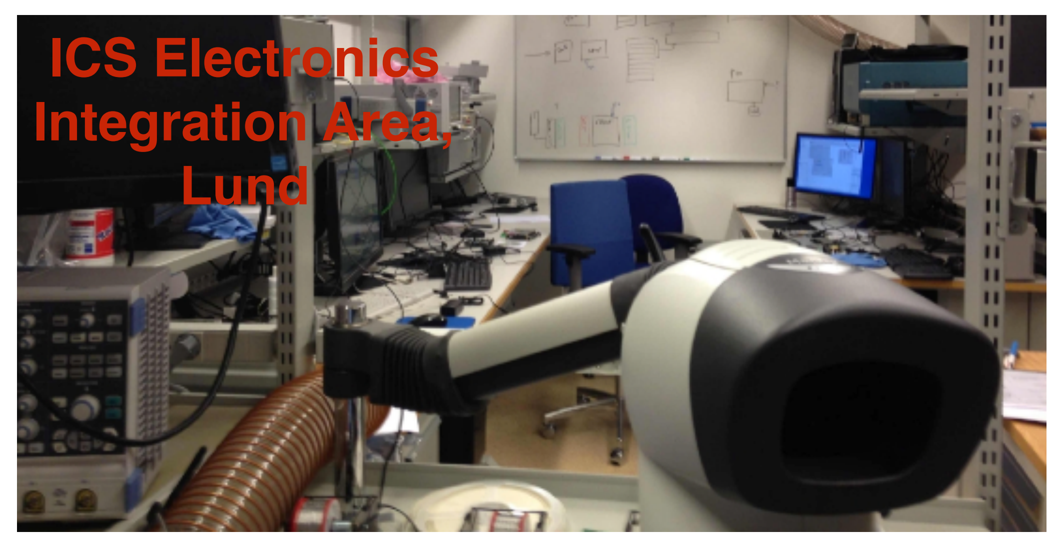


Facilities needed for project available

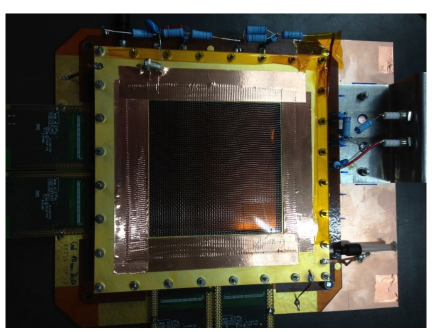


Grants turning developments into design

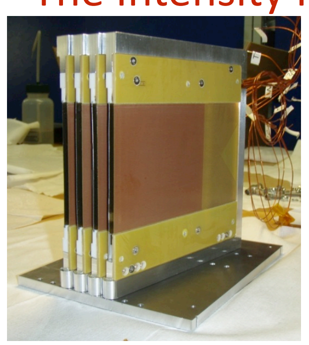
- Helps partners to be involved
- Mitigating risk for ESS project on critical items …
- Use grants to enhance scope of NSS
- Move beyond R+D: work moved into detector design phase

BrightnESS

Task 4.1
"The Resolution Challenge"

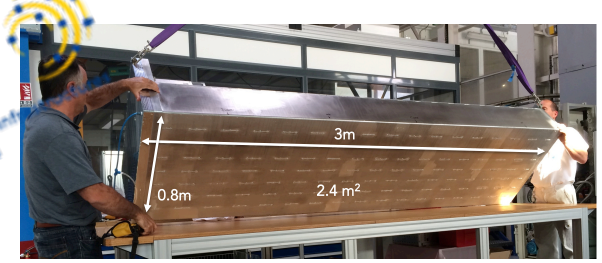


Task 4.2
"The Intensity Frontier"

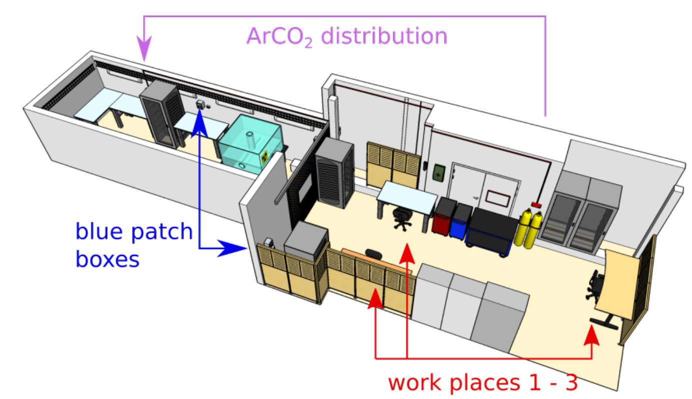


Task 4.3
"Realising Large Area Detectors"

CRISP The Cluster of Research Infrastructures for Synergies in Physics



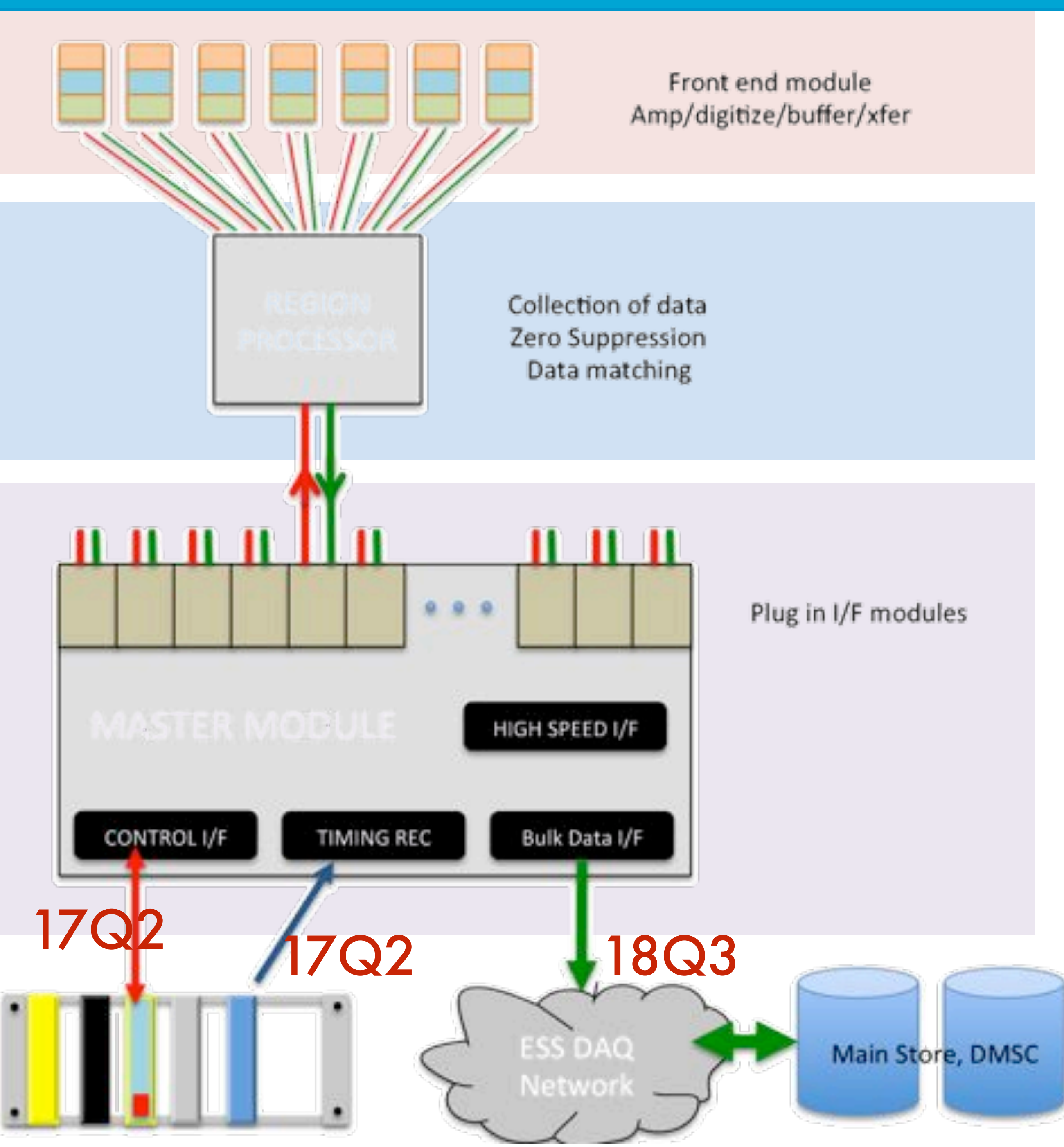
Task 4.4
"Detector Realisation"



SoNDe Solid-State Neutron Detector

SINE2020

Detector Electronics and Interfaces to DMSC and ICS



16Q3

17Q1

17Q1

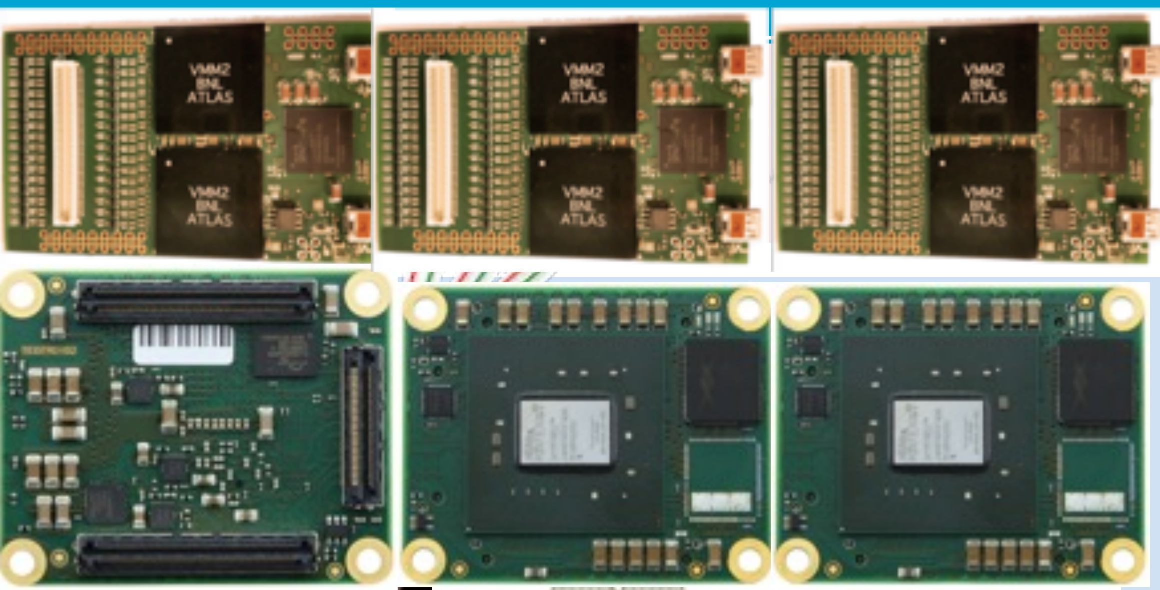
17Q4

- 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 started

Detector Electronics and Interfaces to DMSC and ICS



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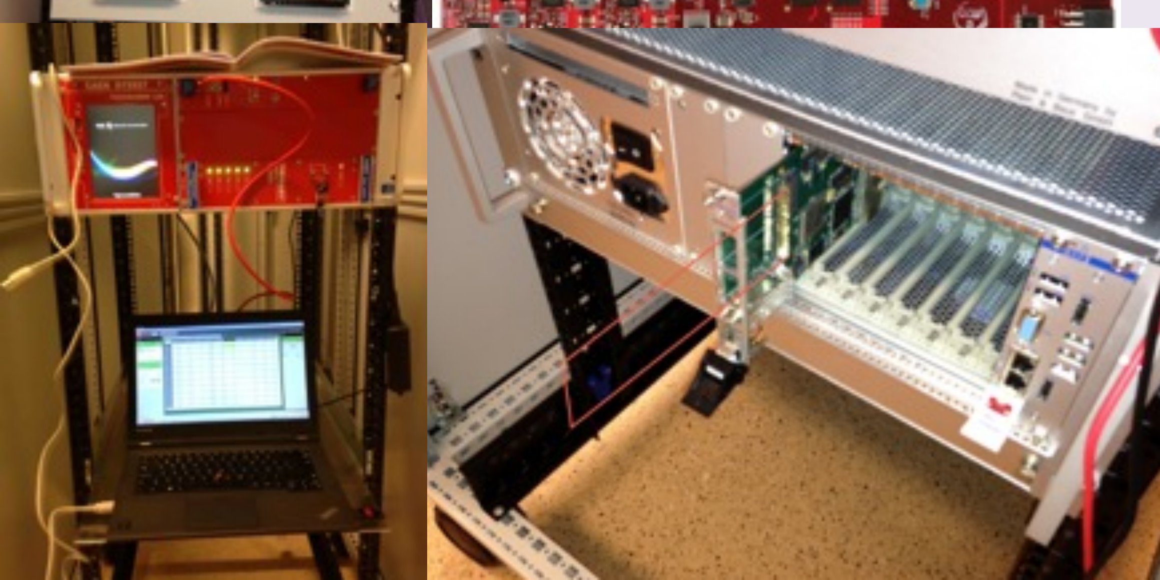
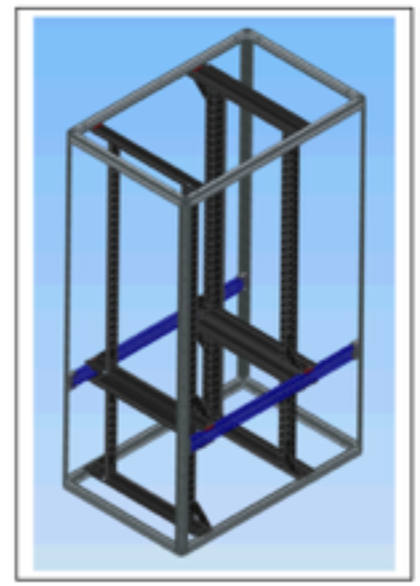
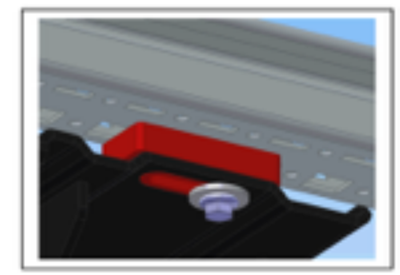
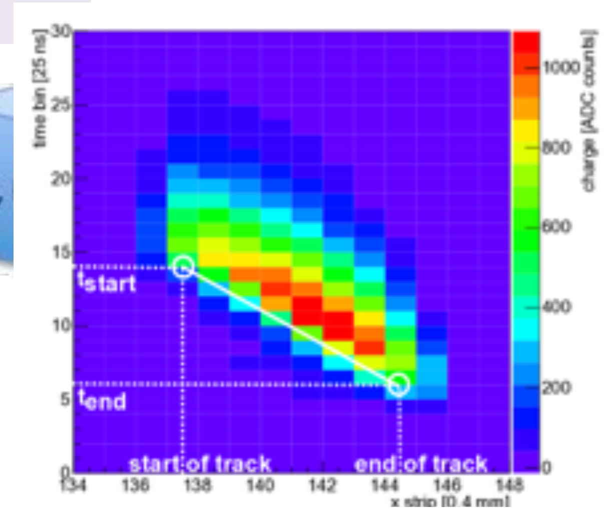




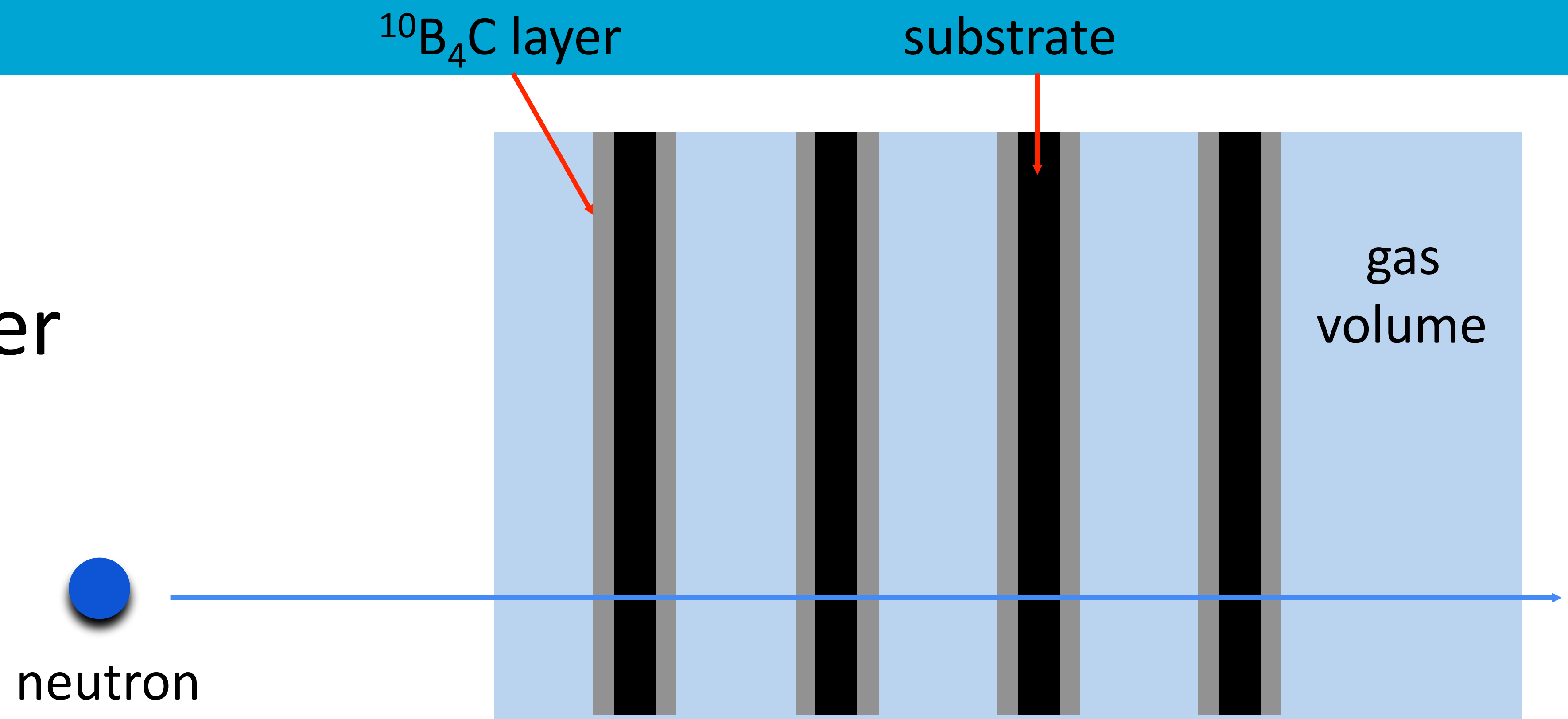




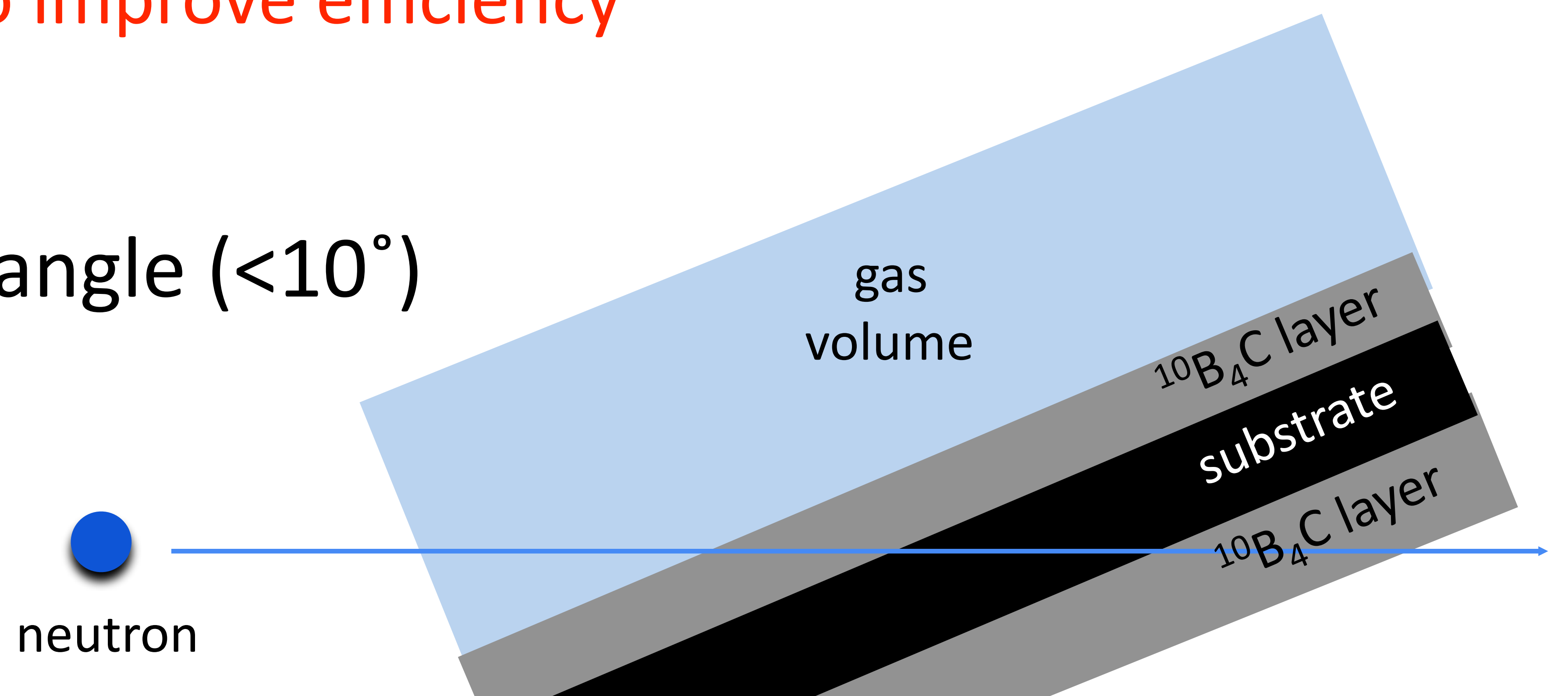
Enhancing the efficiency of ^{10}B-based Neutron Detectors

Generic approaches to improve efficiency

1 Multi layer



2 Grazing angle (<10˚)



Reflectometry Challenge

The state of the art

Instrument	Facility	techn.	area ($mm \times mm$)	spatial res. ($mm \times mm$)	efficiency	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
FIGARO [9]	ILL	^{3}He	512×256	$\sim 2 \times 7.5$	$\sim 63\%$ @ 2.5Å $\sim 90\%$ @ 10Å $\sim 80\%$ @ 30Å	$3 \cdot 10^7$	230
SuperADAM [11]	ILL	^{3}He	300×300	2.8×2.8	76% @ 4.4Å	$2 \cdot 10^5$	-
REFSANS [12]	FRM2	^{3}He	500×500	$\sim 2 \times 2$	58% @ 10Å $\geq 50\% \in [5, 18]$Å	$2.2 \cdot 10^5$	300
INTER [13]	ISIS	^{3}He, ^{6}Li	200×200	$\sim 1 \times 1$	-	-	-
POLREF [14, 15]	ISIS	^{3}He	200×200	$\leq 1 \times 1$	-	-	-
BIOREF [16]	HZB	^{3}He	300×300	2×3	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
LR	SNS	^{3}He	200×200	1.3×1.3	-	-	-
MR	SNS	^{3}He	210×180	1.5×1.5	-	-	-
Platypus [17]	OPAL	^{3}He	500×250	1.2×1.2	$\sim 60\%$ @ 10Å	$2 \cdot 10^5$	300
SOFIA [18, 19]	J-PARC	^{3}He ^{6}Li	128×128 256×256	2×2 4×4	- -	- -	300 300

factor few

factor 300

The ESS requirements

	FREIA	Estia	
Max local rate	10^5 n/s/Å/mm^2	• Conventional refl. • High intensity mode	10^5 n/s/Å/mm^2 10^4 n/s/Å/mm^2
Spatial resolution	4mm x 1mm	4mm x 0.5mm	

Multi-Blade Design

BrightnESS

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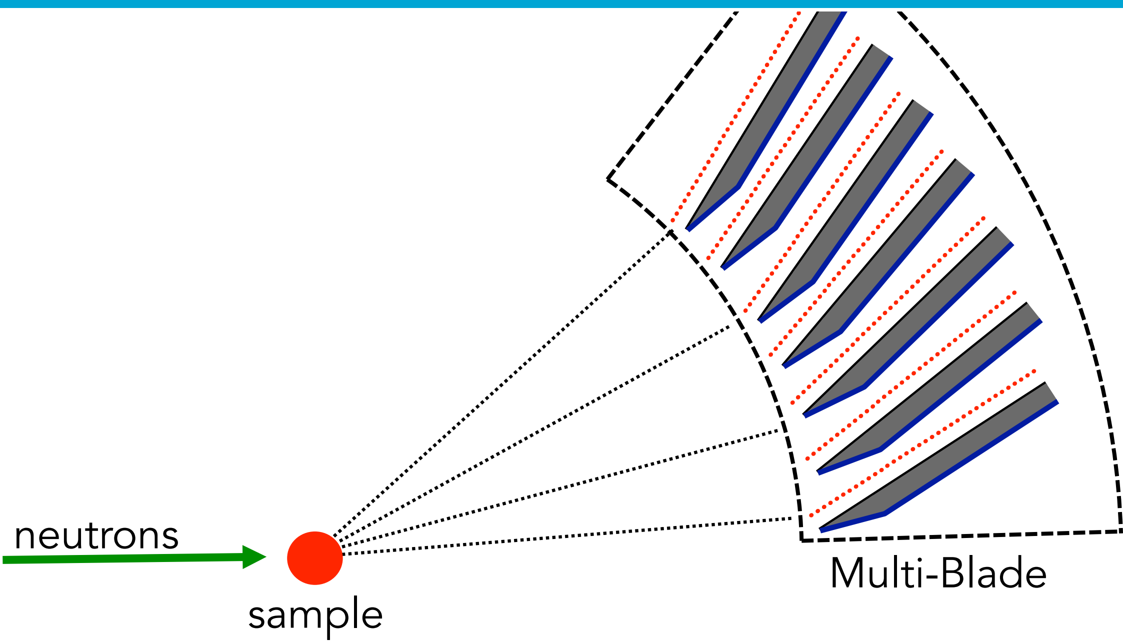
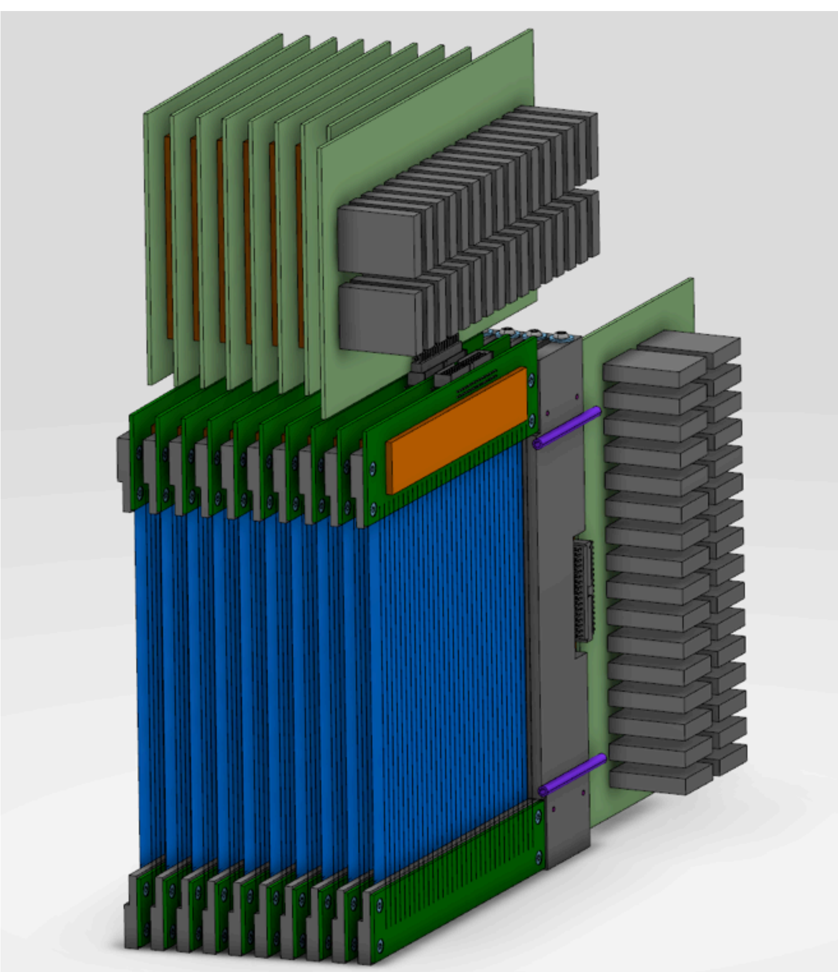
LUND UNIVERSITY

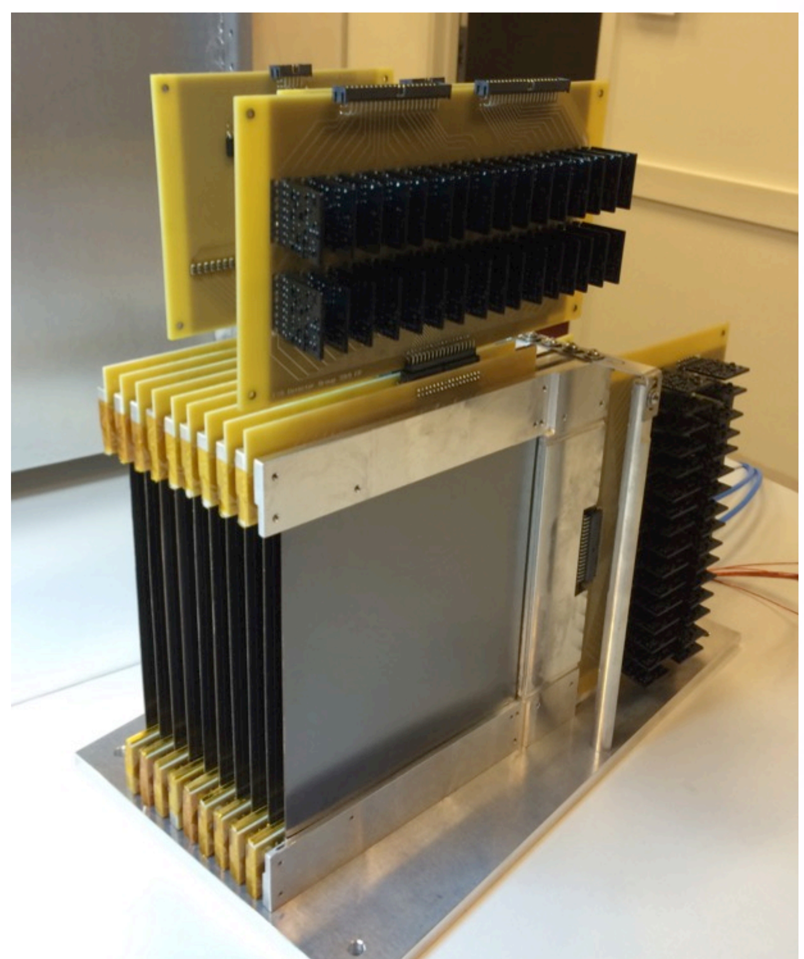
Wigner Research Institute

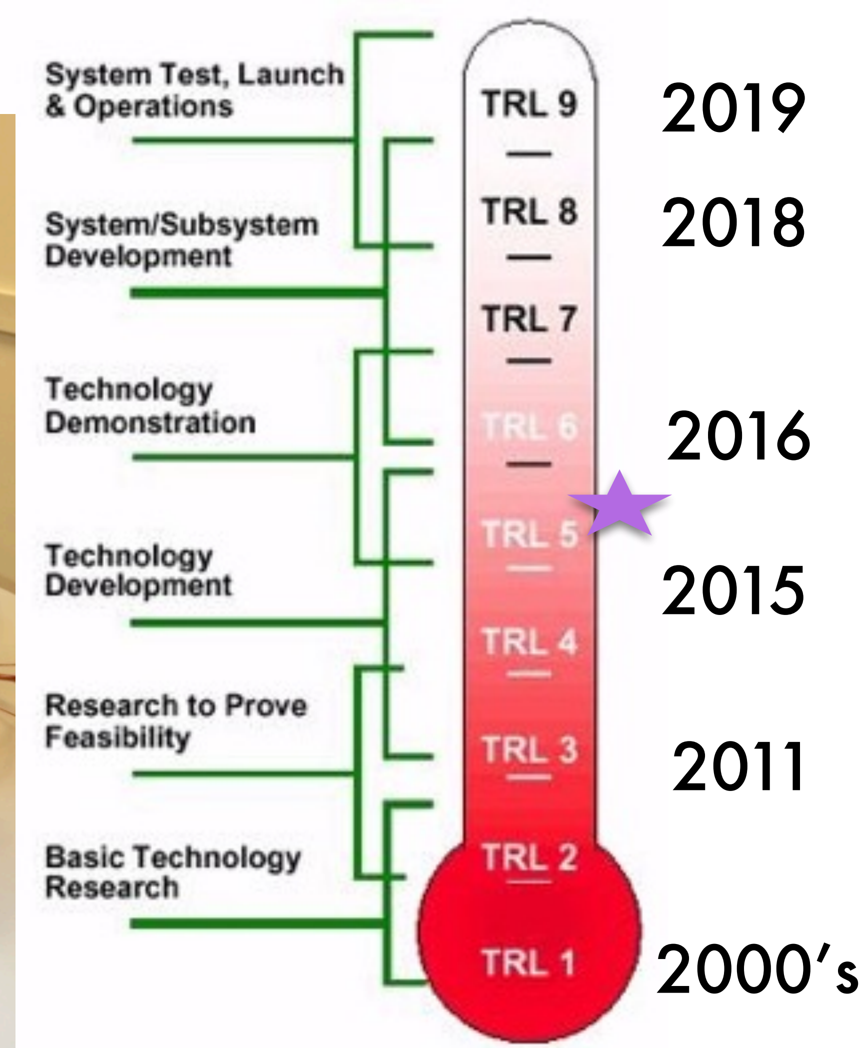
Budapest Neutron Centre



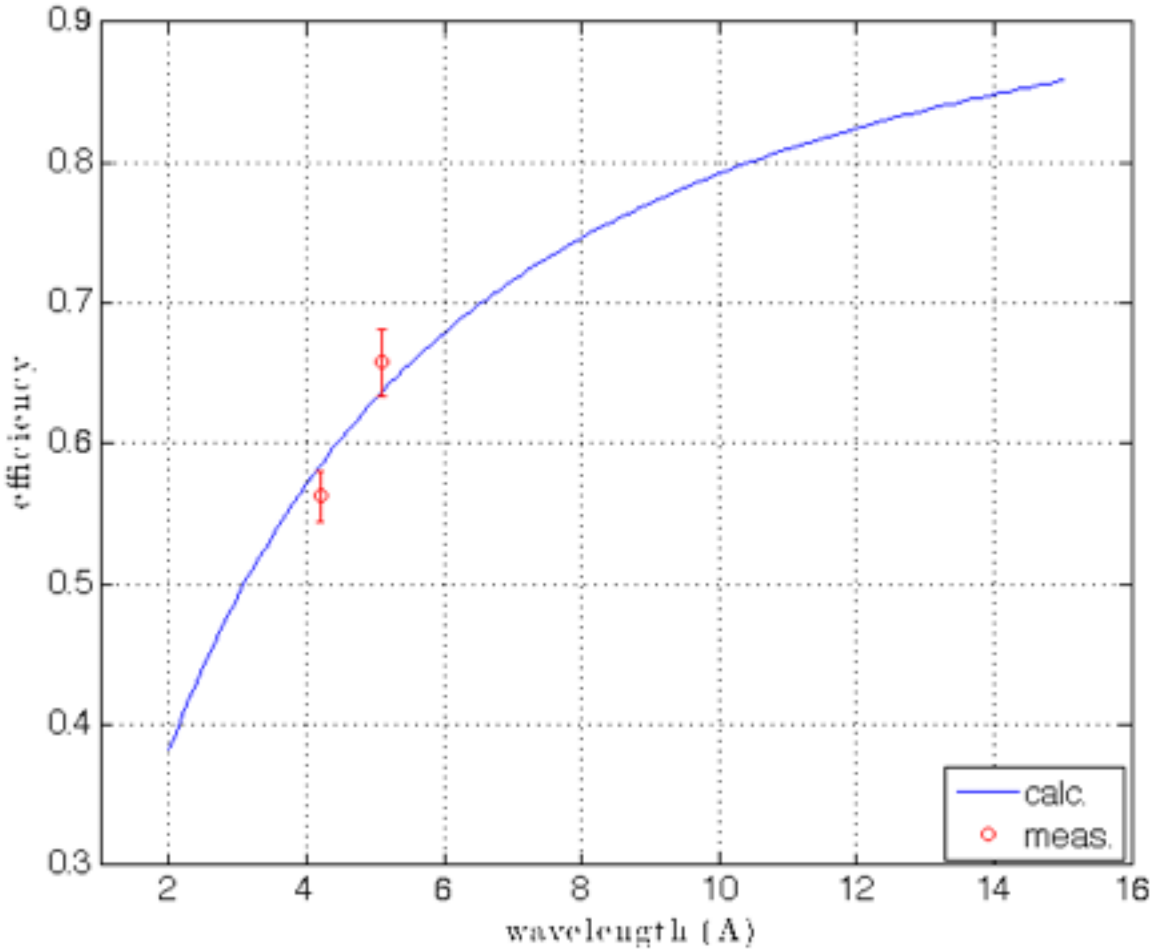
- Design simple: *"KISS"*
- Modular
- Cheap
- Make design available
- *"Open Source Hardware"*

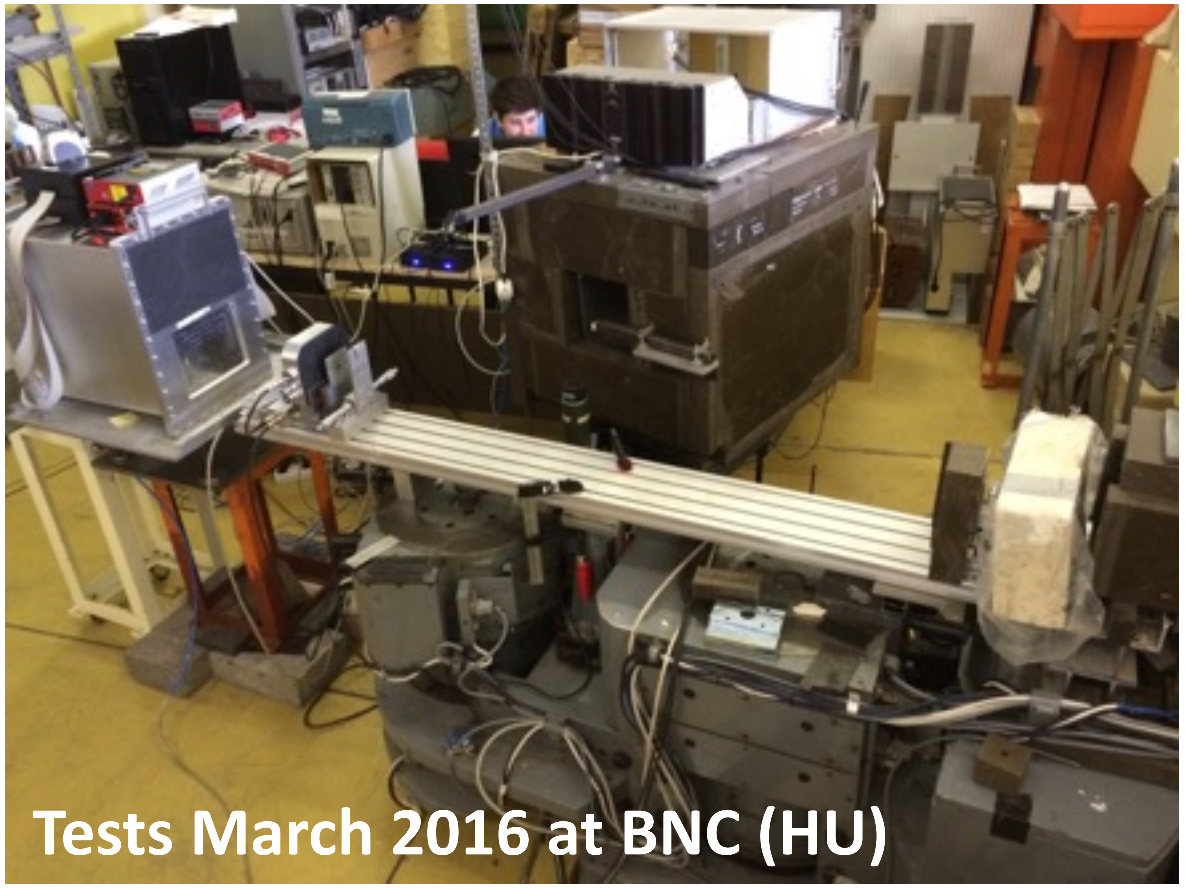


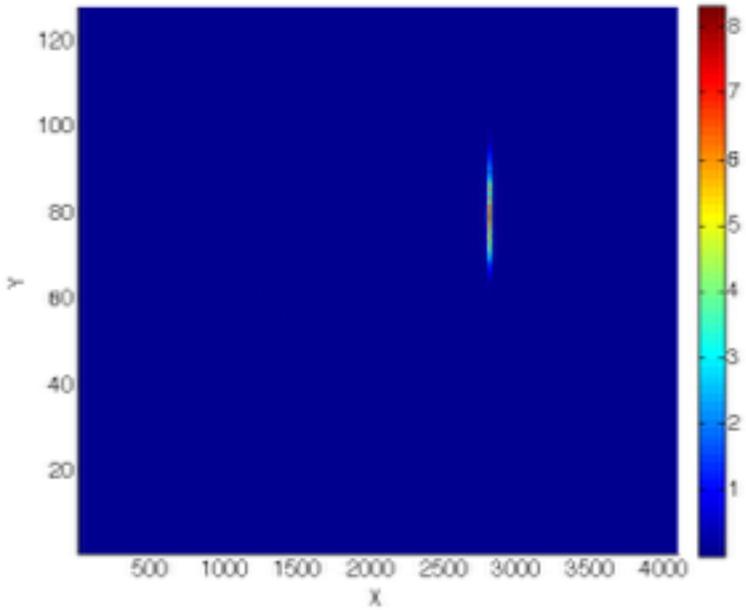




Multi-Blade Design

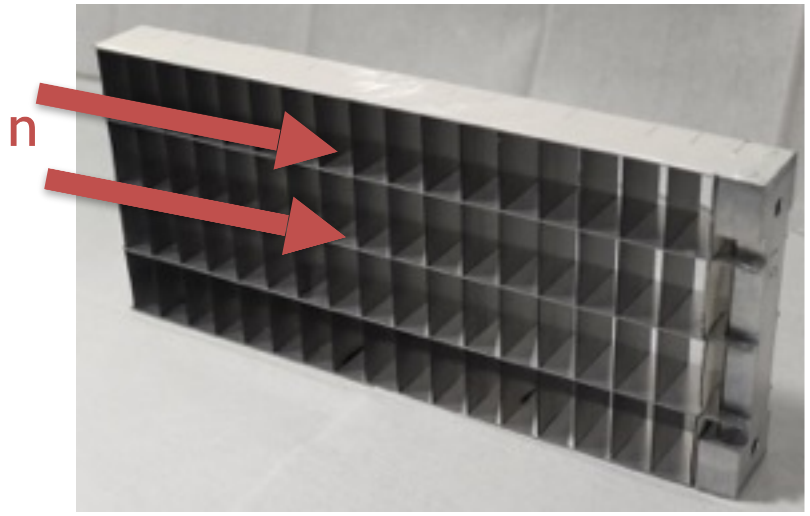


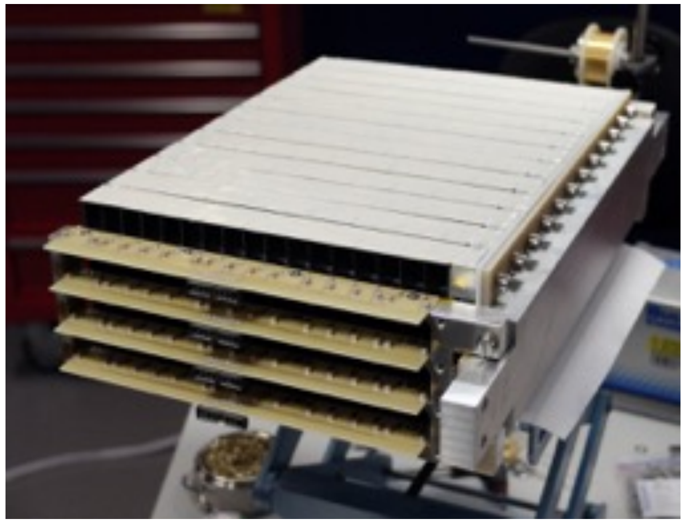


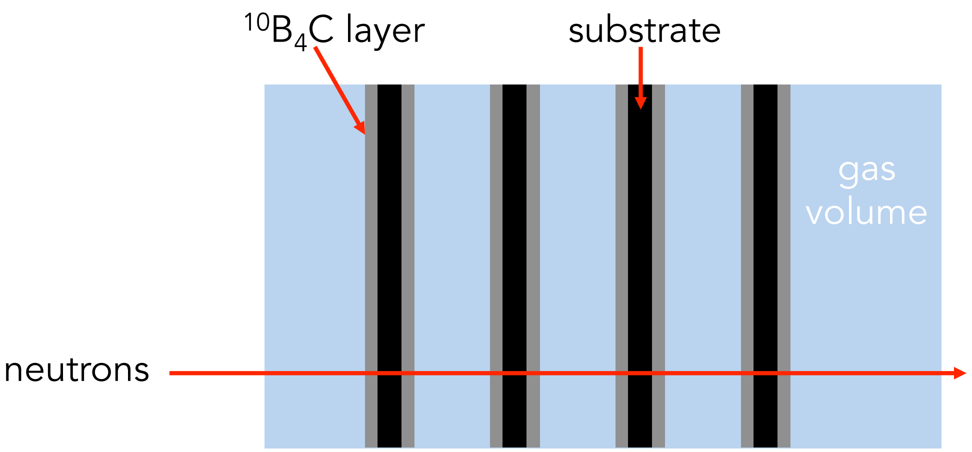


- Counting rate capability: no saturation observed up to 22kHz/mm^2
- ca. 0.4mm x resolution
- Further tests later in year, including scientific demonstration on reflectometry instruments

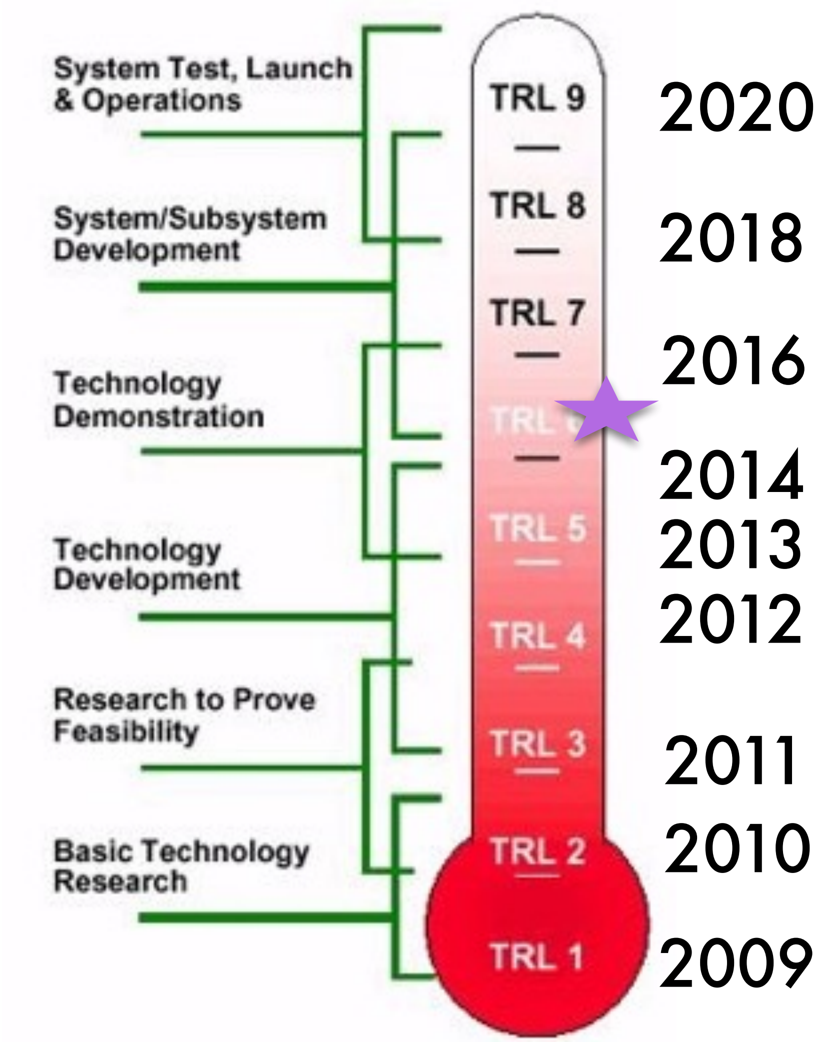
Large Area Detectors:
Multi-Grid Design

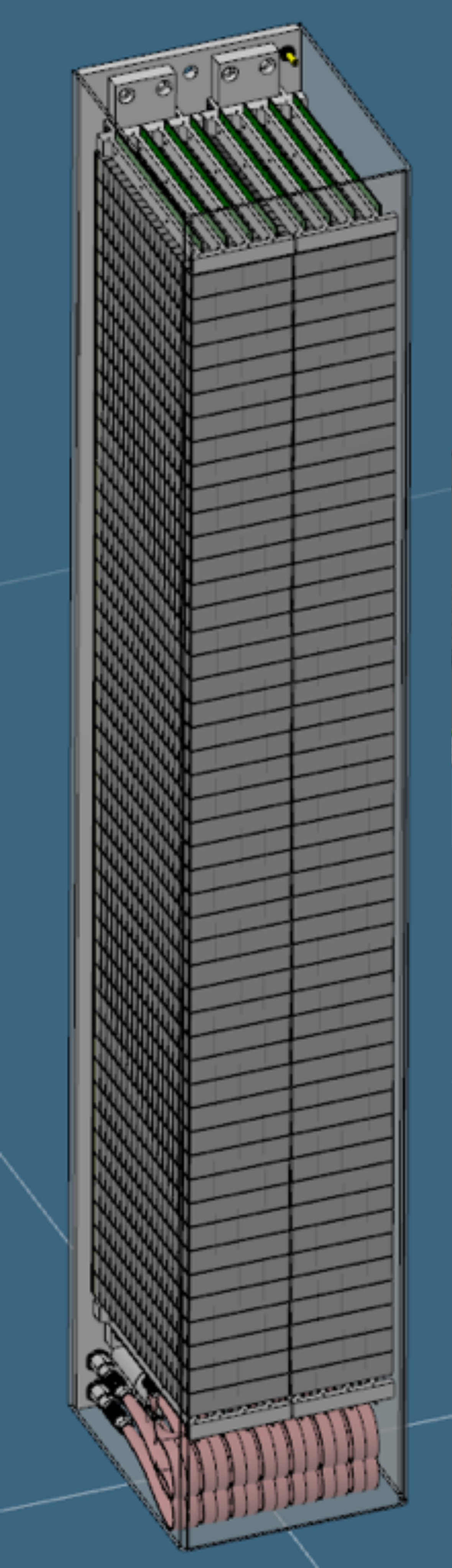






Technology Demonstrators of Scientific Performance planned for:
CNCS@SNS and TOFTOF@FRMII

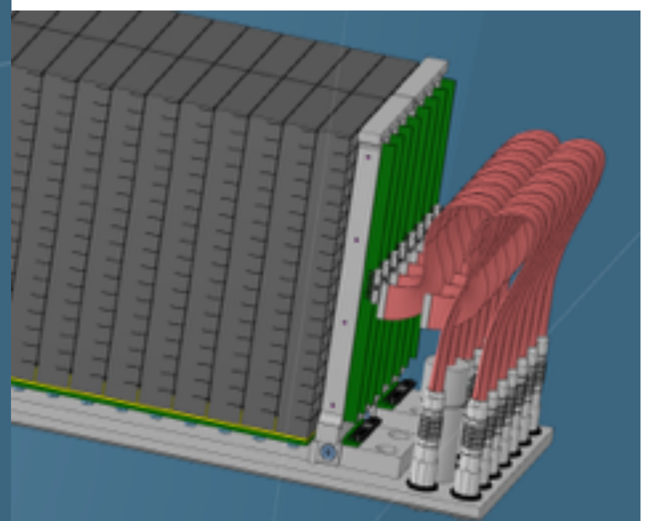


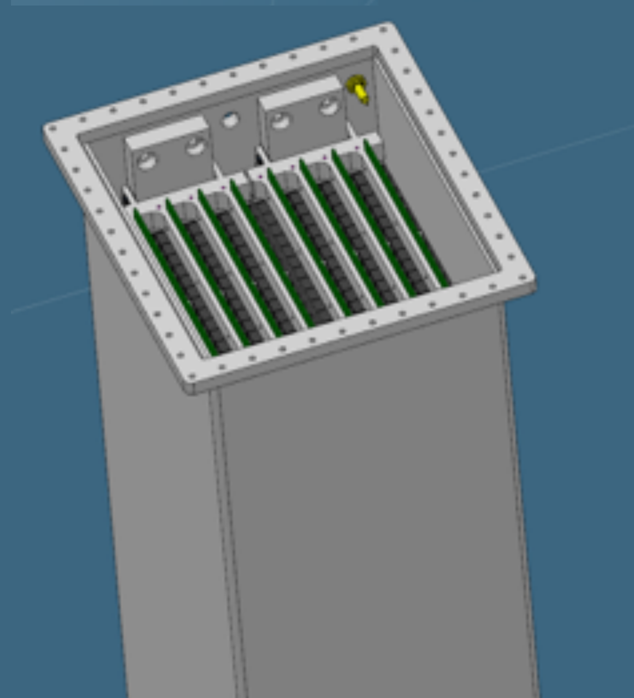


Multi-Grid Demonstrator for CNCS

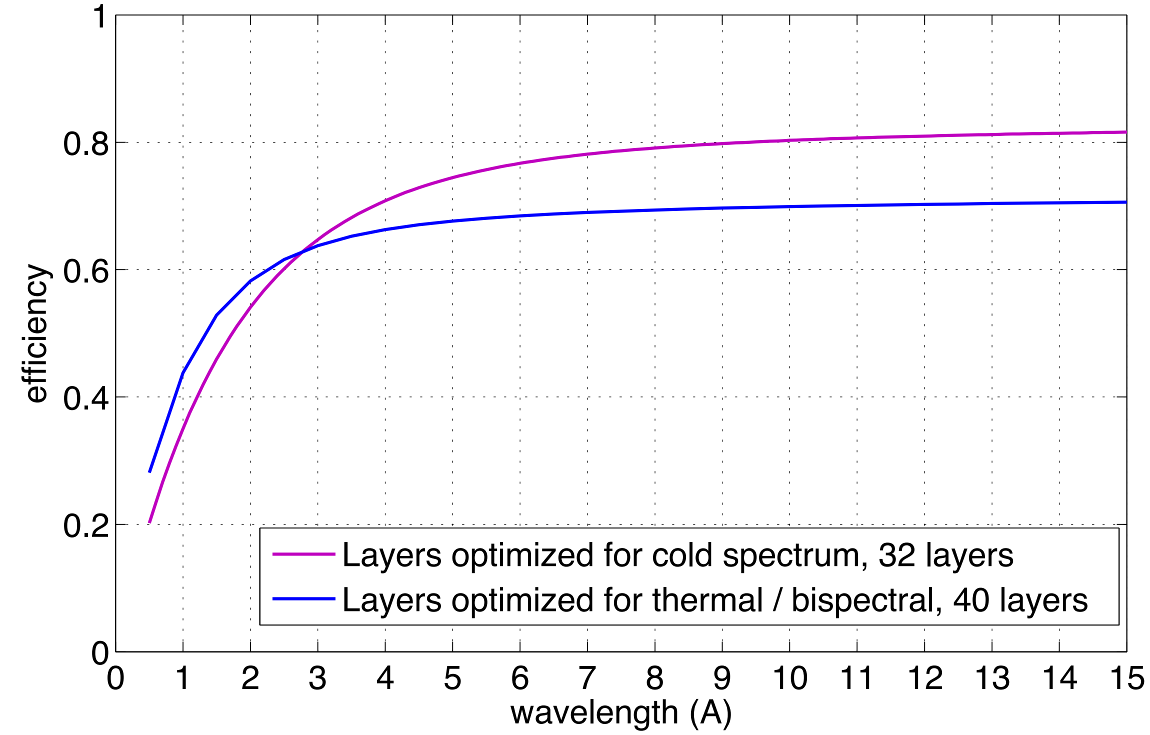
"8-Pack" replacement: 2 modules of 48 grids each
128 wire and 96 grid channels individual readout
1.15m x 19cm active area
Installation: June 2016
Operation: June-Dec

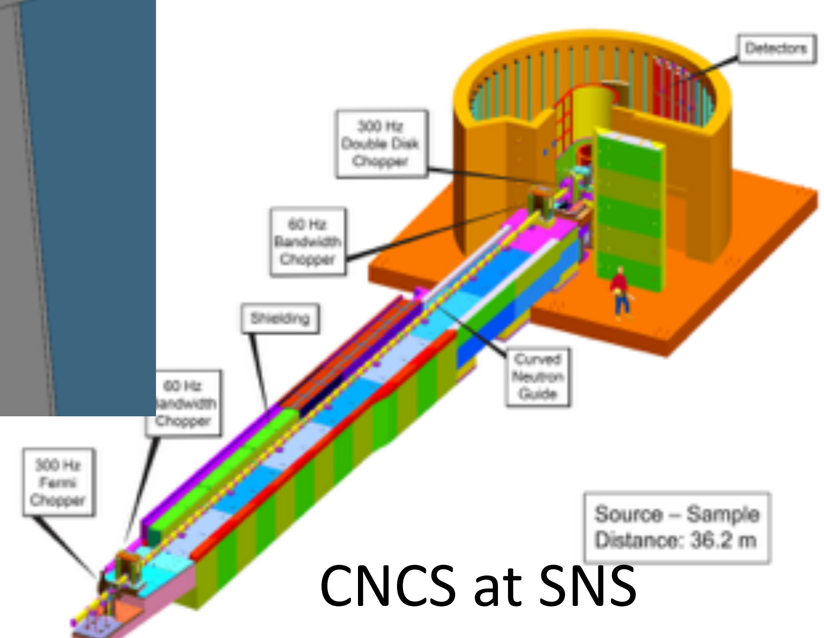
Aim:
- Scientific performance
- ToF performance at Spallation Source
- Long term operation



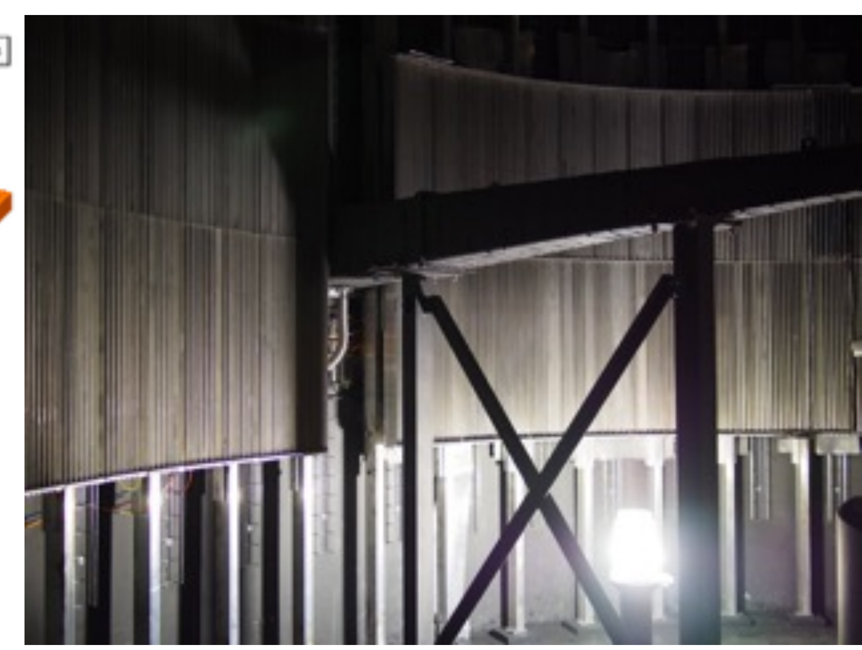


Efficiency optimisation
Cold: C-Spec, CNCS
Thermal/Bispectral: T-REX





CNCS at SNS



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

- Detector work now very much design, and not R&D
- Schedule and budget: make the detectors affordable and on time
- Enable partners

Backup Material

Recommendations from Annual Review 2015

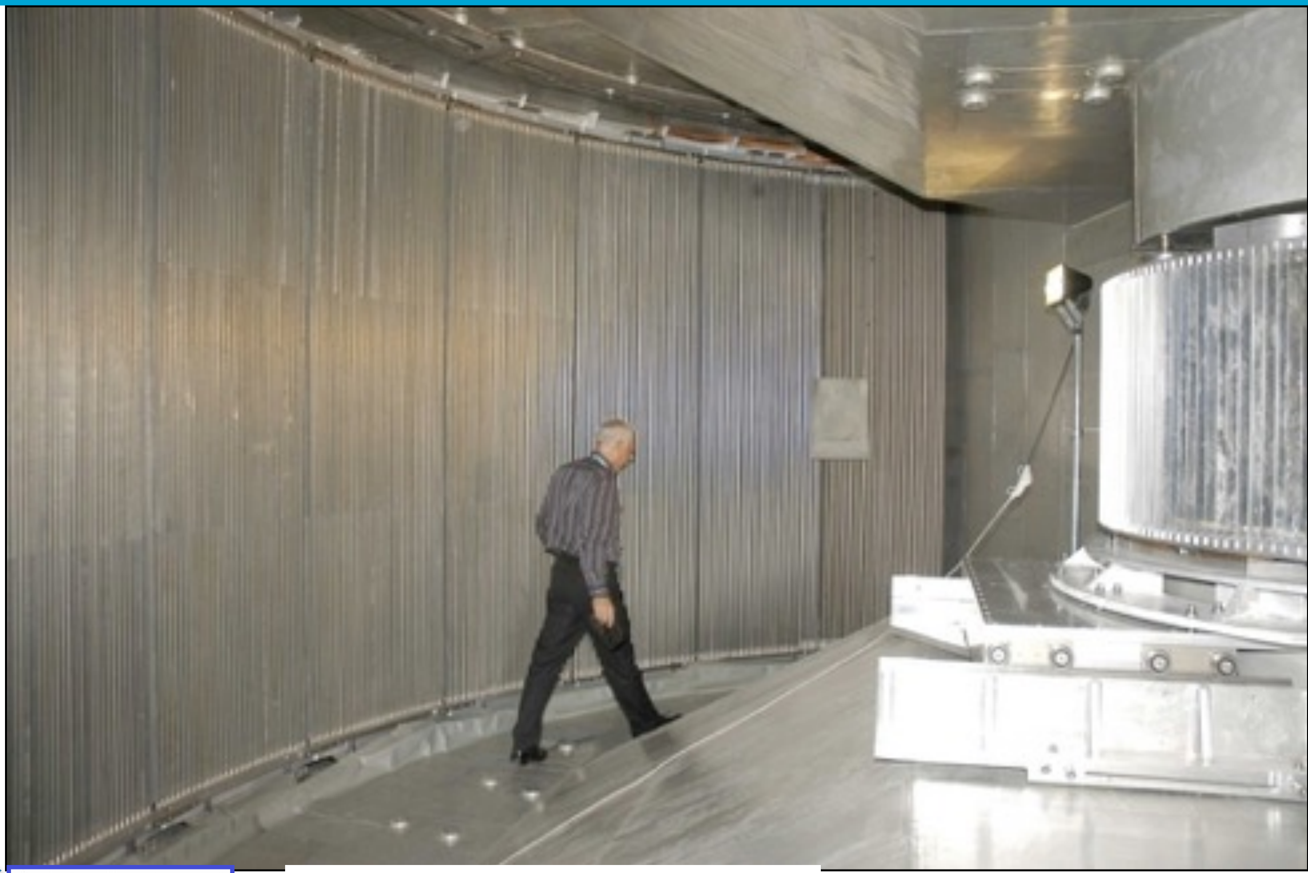
- NSS 4.3: Horizontal Contributions
- NSS 4.7: Staffing gaps in key areas (inc. detectors)
- NSS Verbal top 10: Test detectors on TOF:

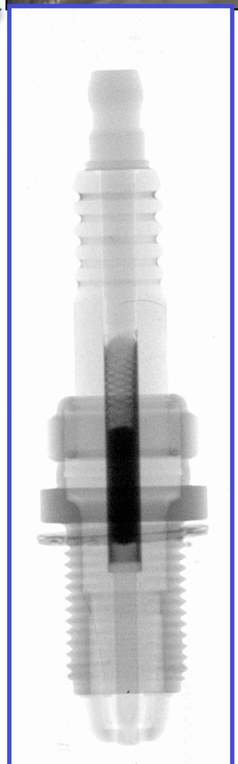
Recommendations from Annual Review 2015

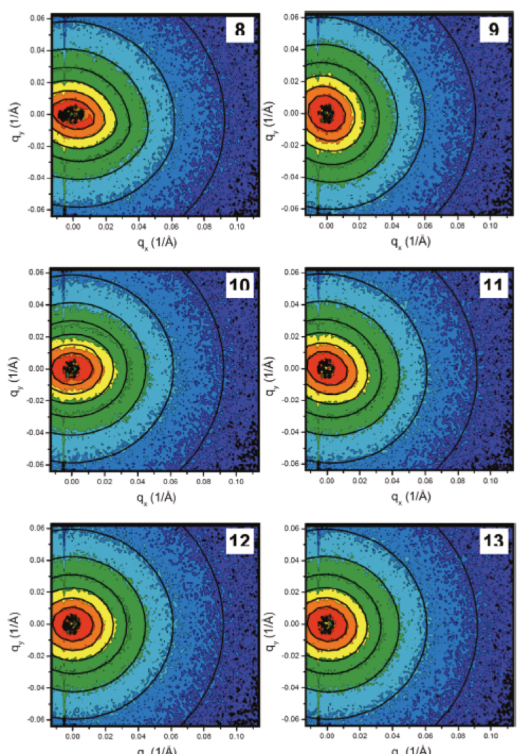
- NSS 4.3: Horizontal Contributions
    - Detector Electronics in-kind approved + started. Other developments stopped/done by grants
- NSS 4.6: Operational model, in particular consideration of future needs for staff skills
    - Hiring took account of future commissioning and staff skills for detector systems
    - Operational profile already represented
- NSS 4.7: Staffing gaps in key areas (inc. detectors)
    - ca. 50% of staff covered by grants activities
    - grant money allowed several hires this year
    - detector delivery model relies on in-kind partners: set of design and delivery partners for detectors identified
    - care and attention paid to attract competent in-kind
    - Staff retention still a significant risk
- NSS 4.8: Risk and Project Management Culture
    - Detector design and build partners identified.
    - Baseline, backup technologies, and secondary backup technologies identified for all instruments: in-depth risk model and critical decision points
    - Risks monitored and mitigation addressed
- NSS Verbal top 10: Test detectors on TOF:
    - Demonstrator planned for CNCS/SNS (Multigrid) Jun 2016, done on INES/ISIS for BANDGEM (LOKI). Others planned in 2016/17

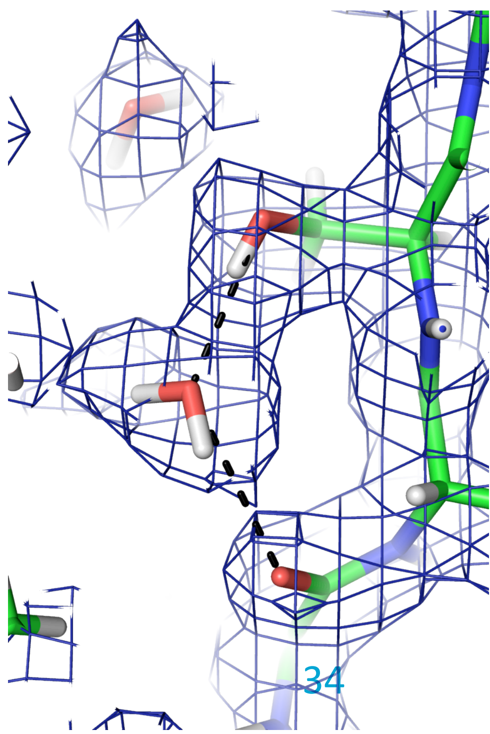
SCOPE

Detector Strategy:
how we get from here to there









CHALLENGE

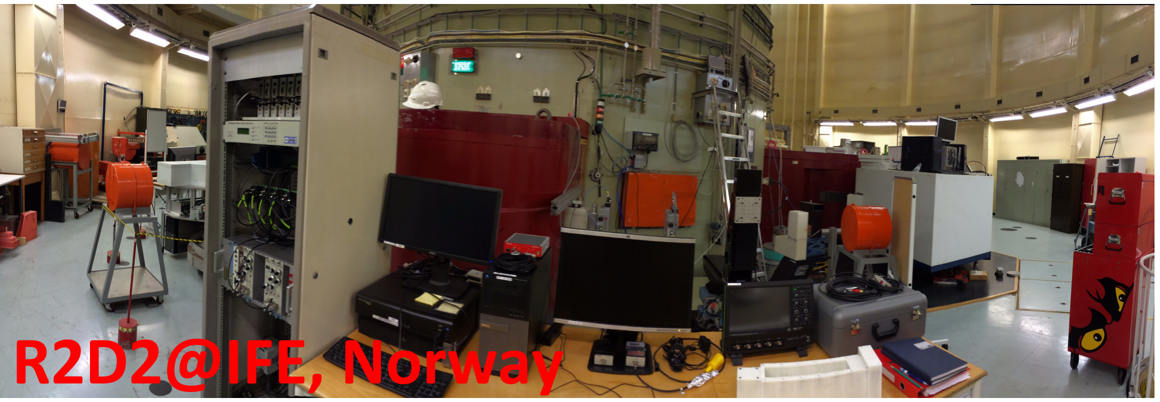
What can be done with ESS brightness?

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

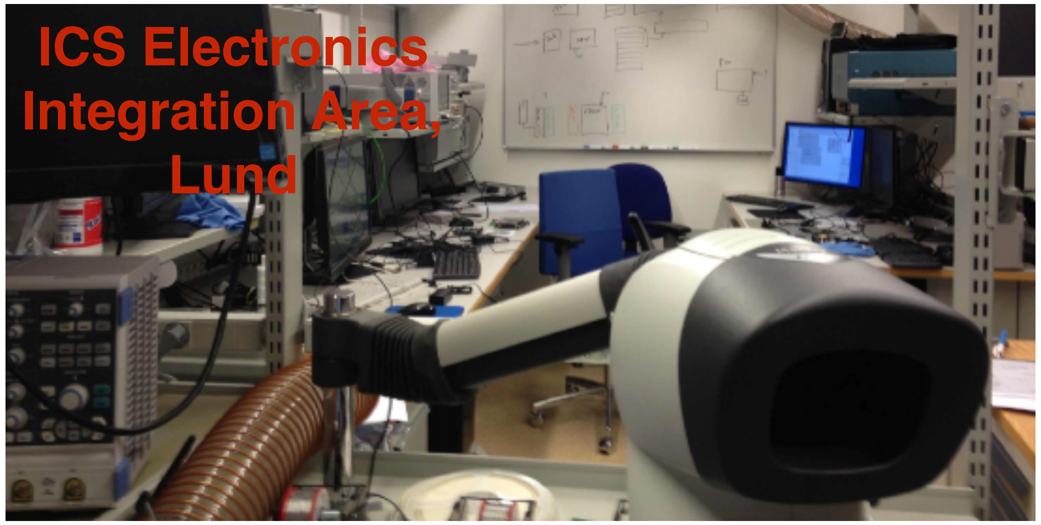
Also: scarcity of Helium-3 …

Developments required for detectors for new Instruments

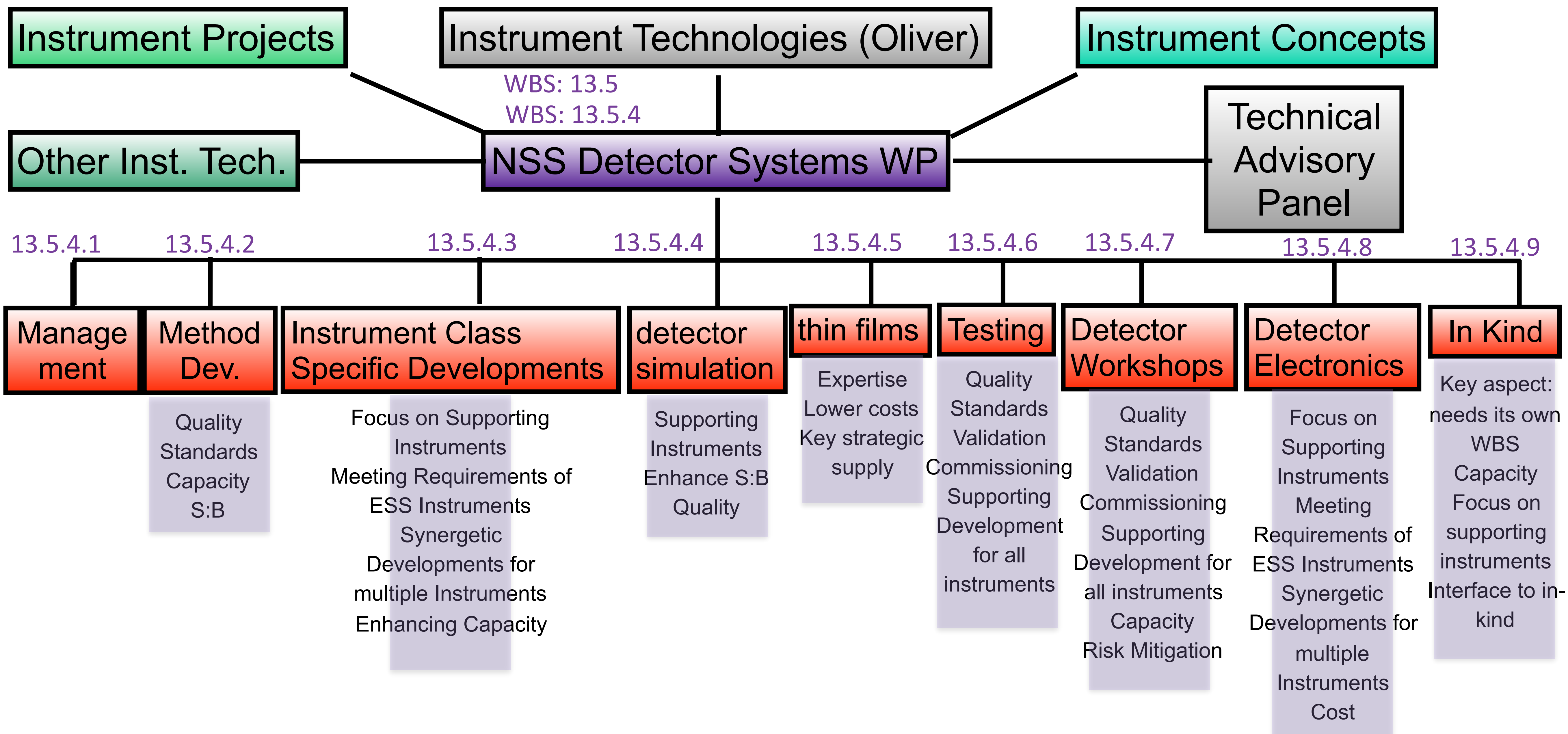
Facilities



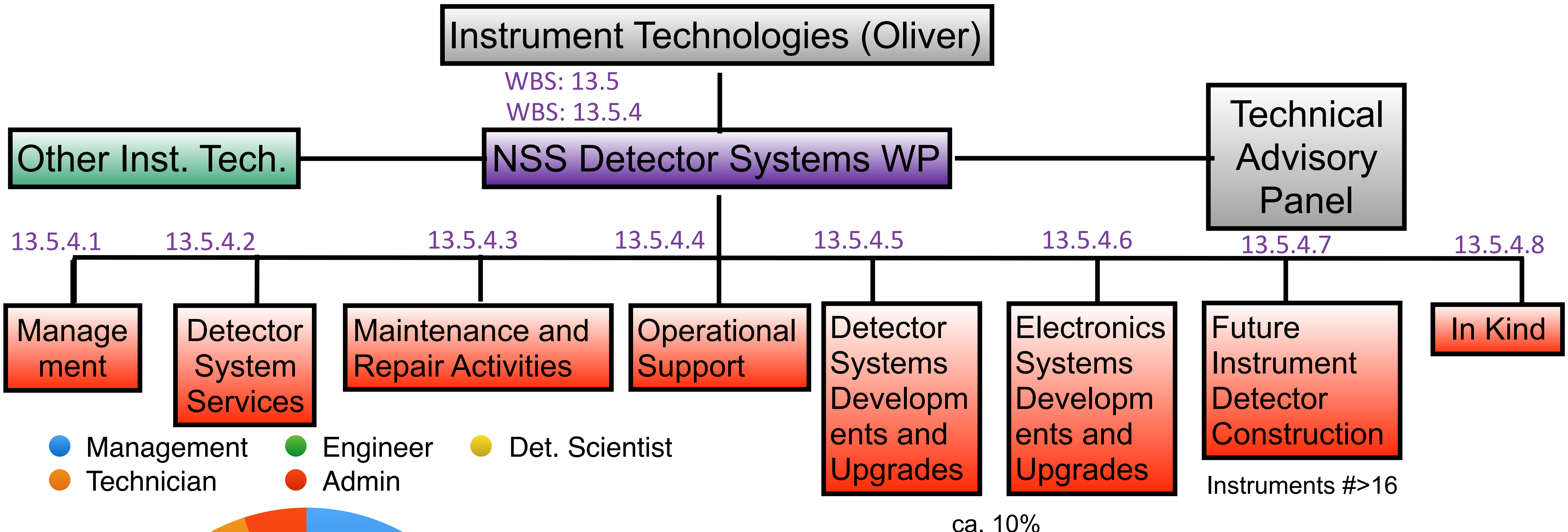
Facilities needed for project available

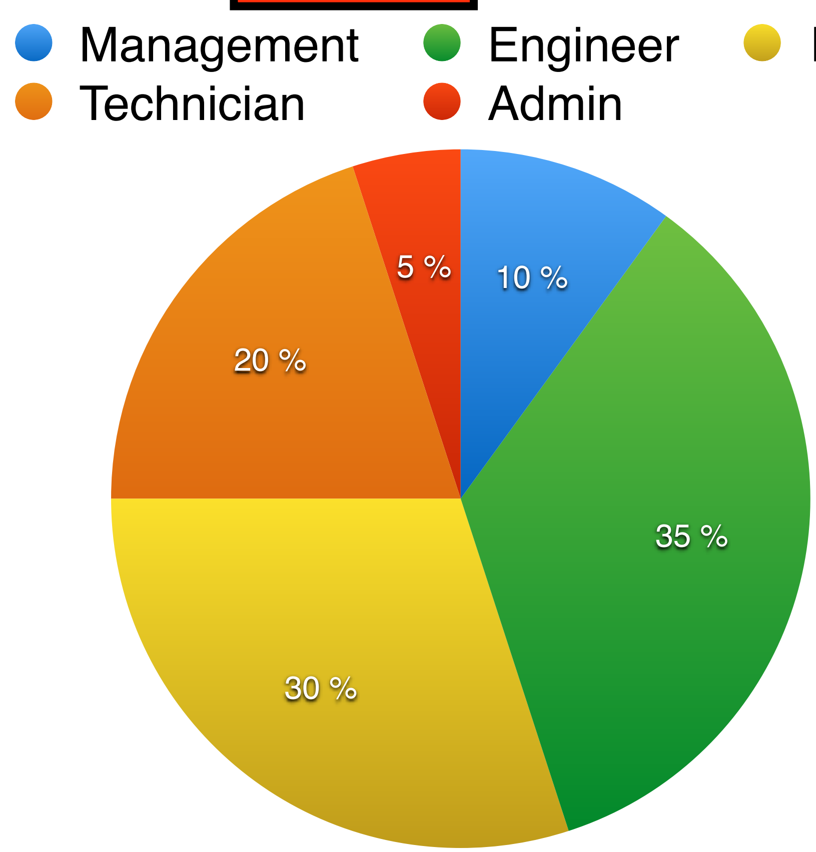


Organisation and Work Breakdown Structure: Addressing the challenges



Organisation and Work Breakdown Structure: Operations (and Pre-Operations)





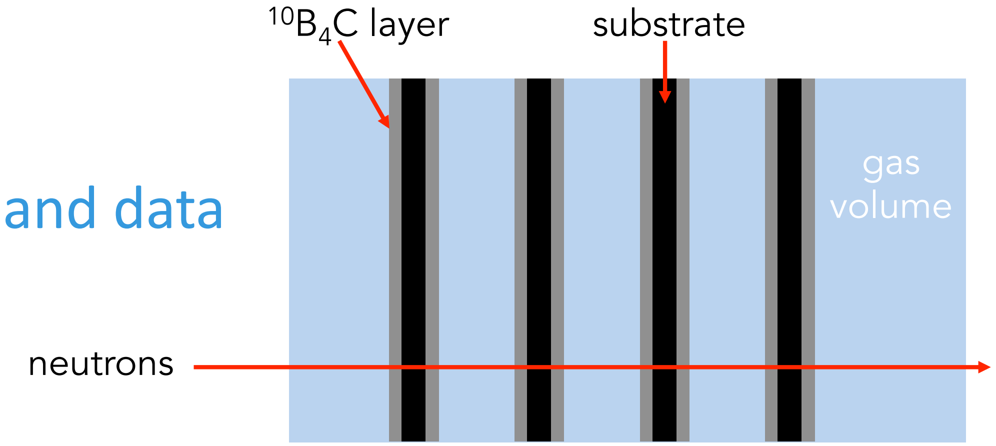
Group Skills Profile already under consideration for commissioning and operations

Group scope roughly compares to sum of Detector and Detector Acquisition Electronics groups at other facilities

Operational Size of Group (16) compares ISIS, ILL and SNS (2013 numbers) for similar scope

Efficiency of ^{10}B Detectors: Perpendicular Geometry

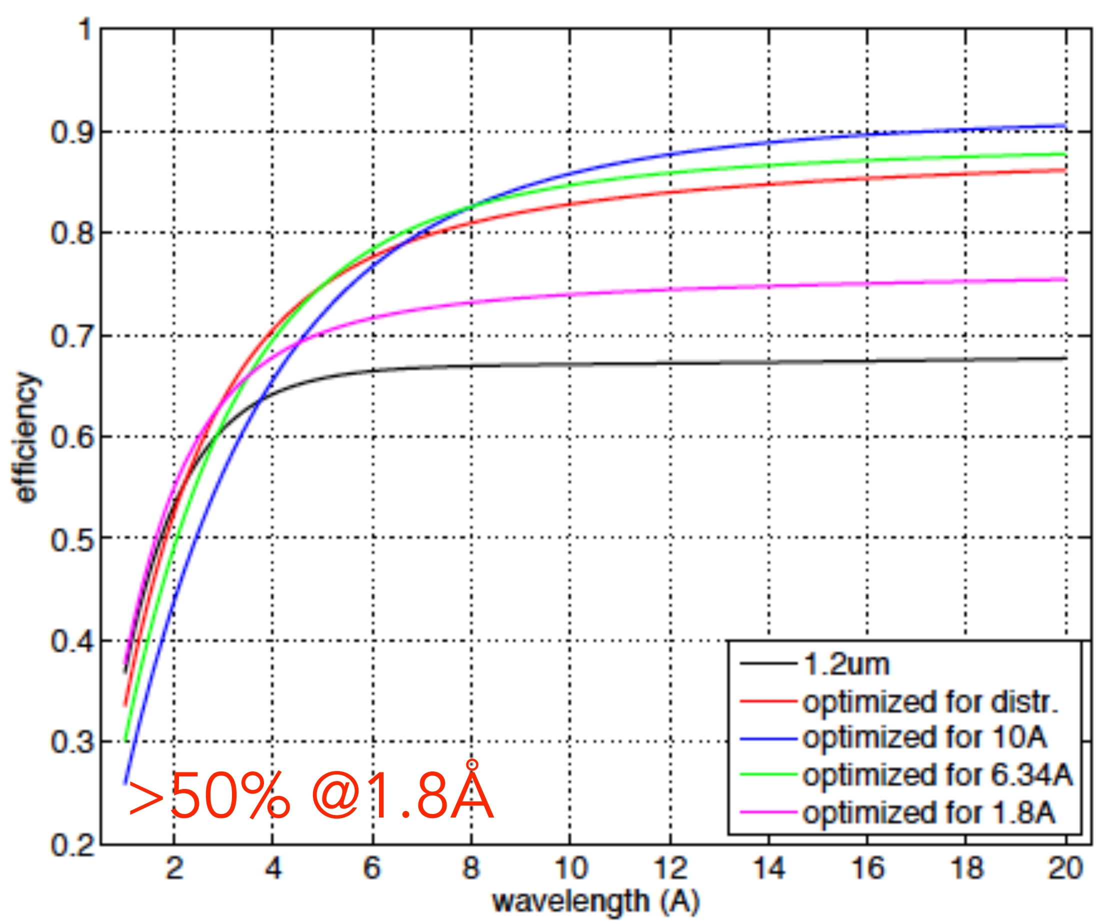
- Single layer is only ca.5%
- Calculations done by many groups
- Analytical calculations extensively verified with prototypes and data
- Details matter: just like for ^{3}He



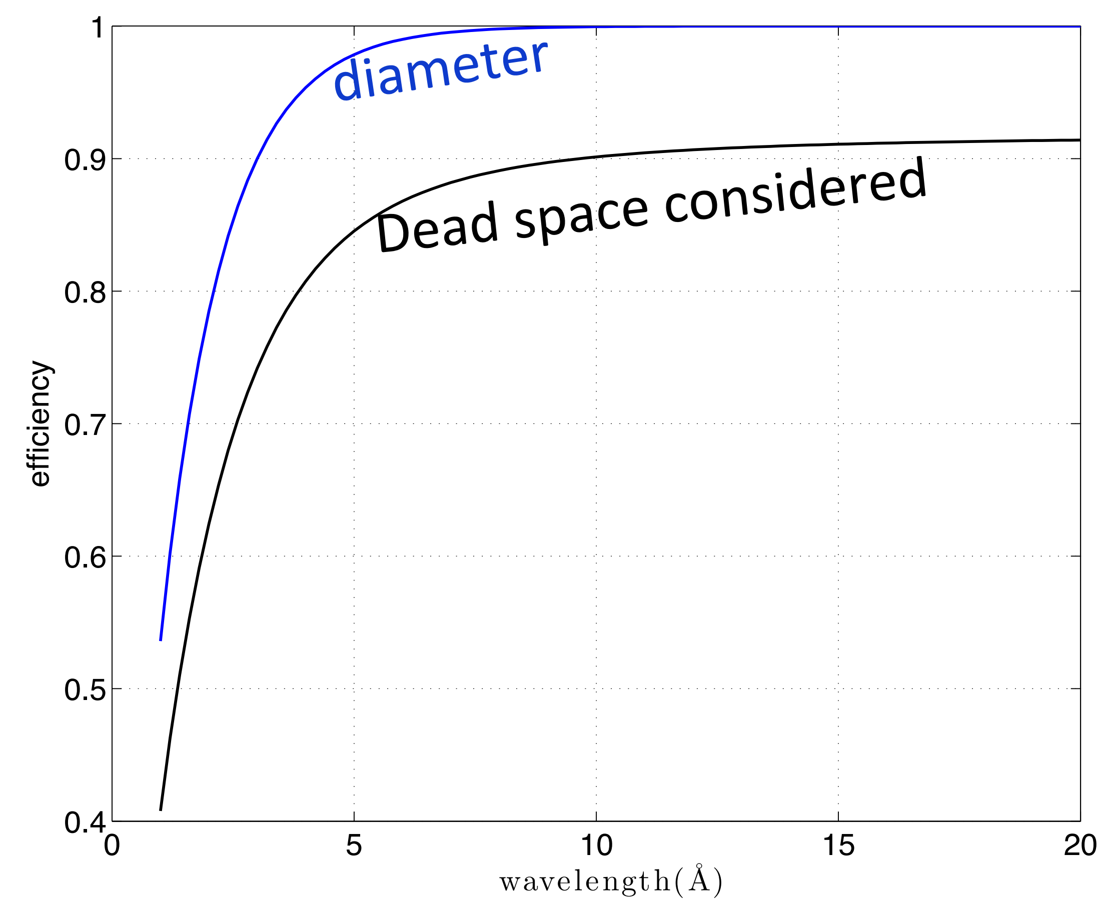
- Multilayer configuration (example):

JINST 8 (2013) P04020

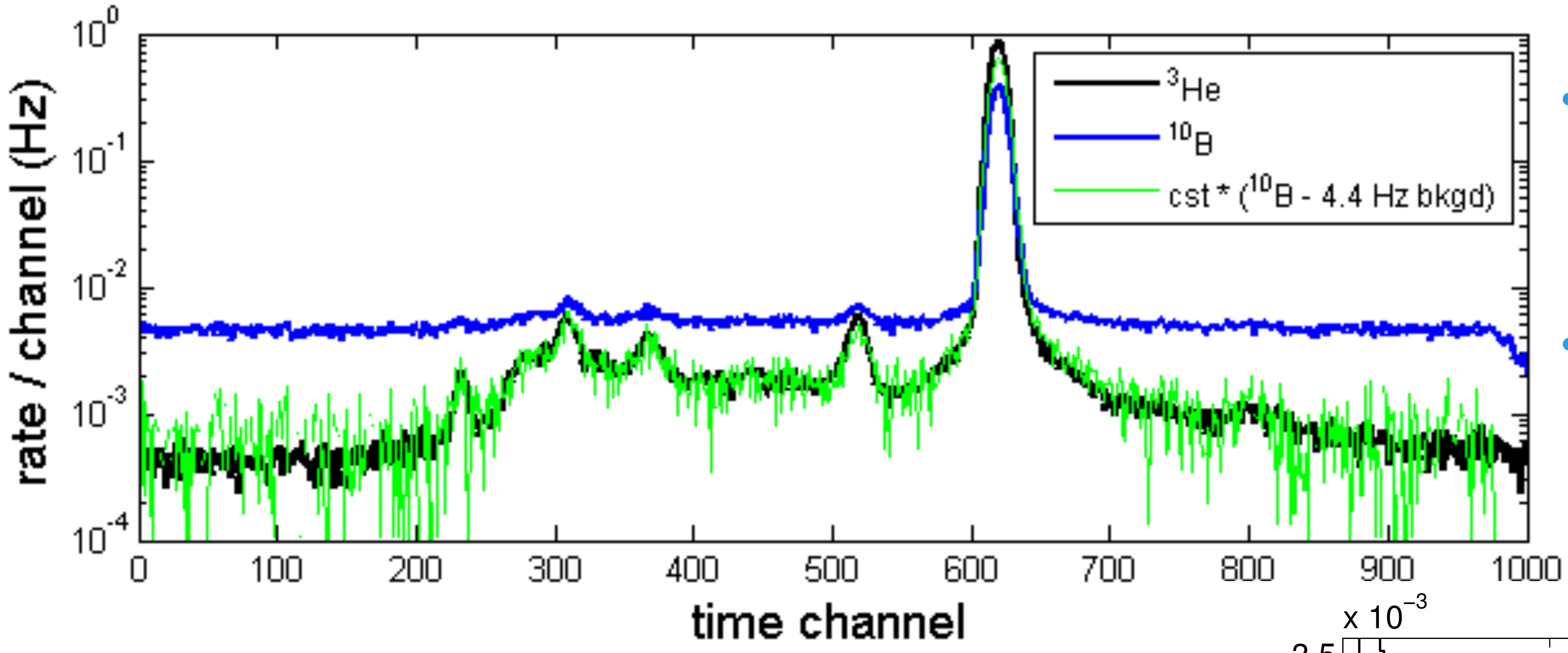
Multi-Grid



^{3}He tubes – 1 inch – 4.75 bar

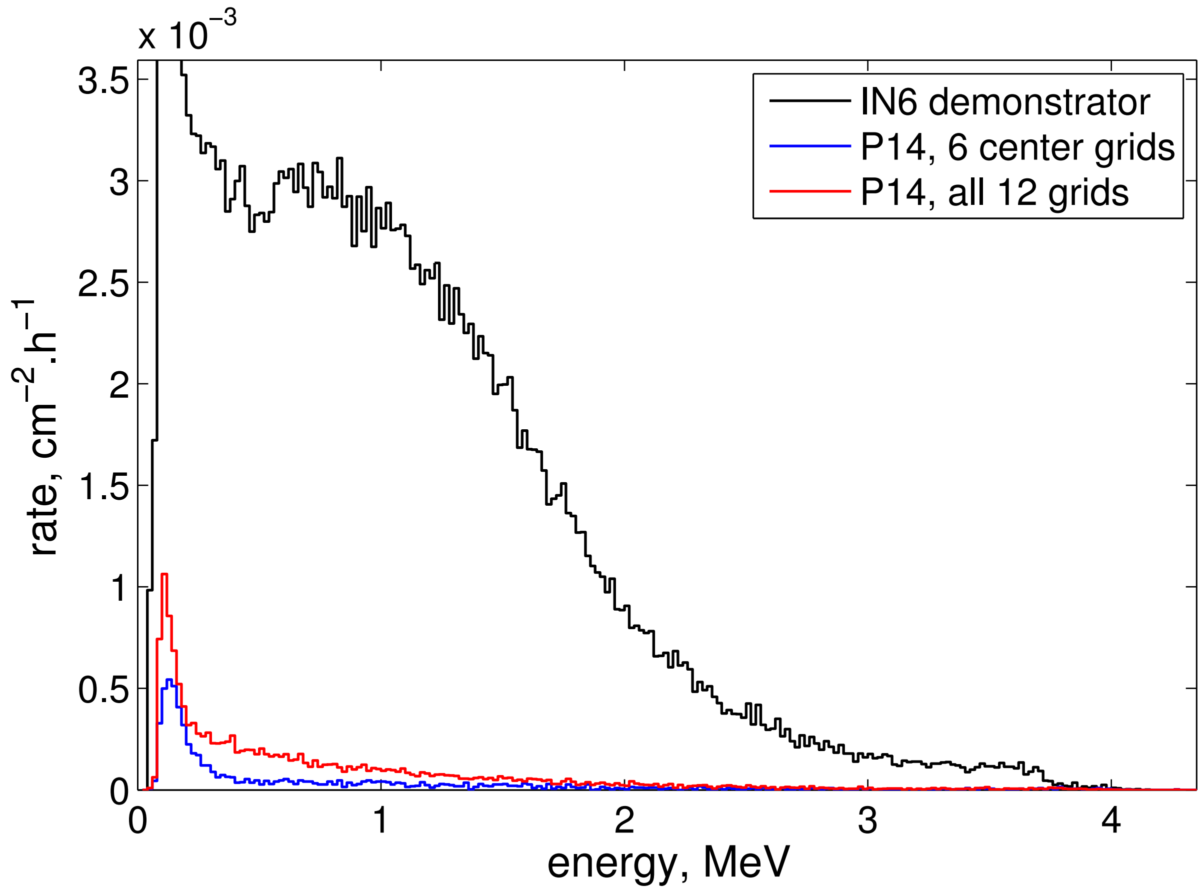


Background from natural radioactivity in Aluminium

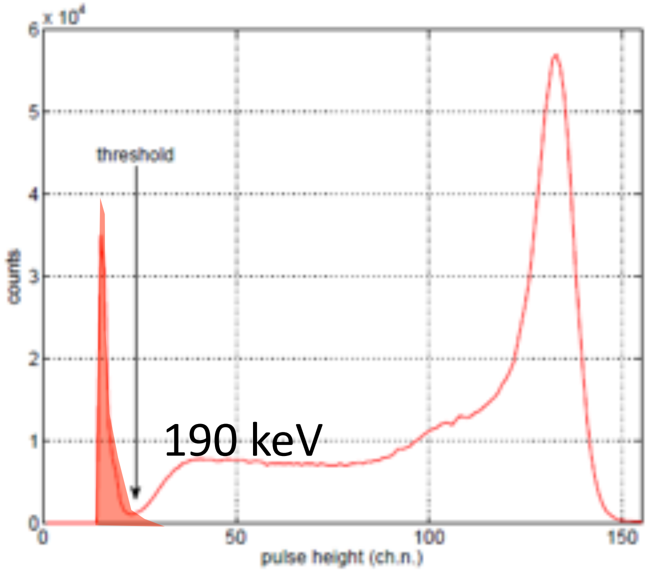


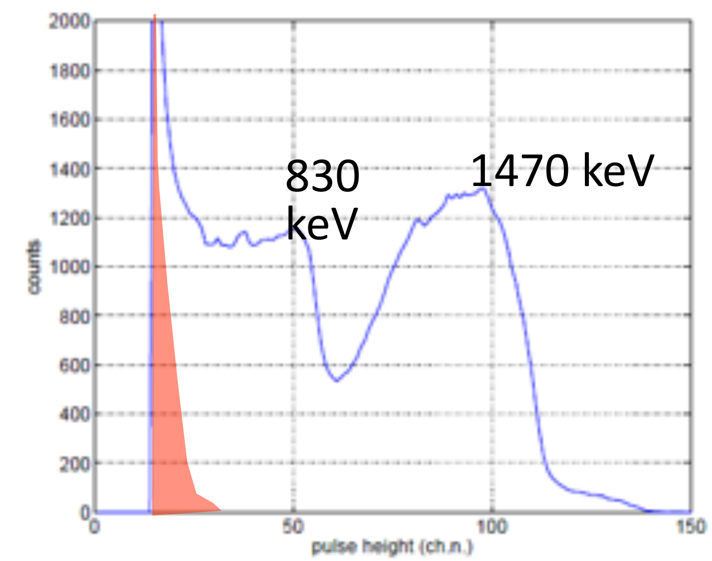
- Side-by-side test of prototype on IN6 instrument at ILL
- Performance matched He-3 except constant background level

- Source: natural alpha radioactivity in Aluminium
- By using ultrapure- or Nickel-plated- Aluminium removed this background



Background - Gamma Sensitivity





$<10^{-6}$

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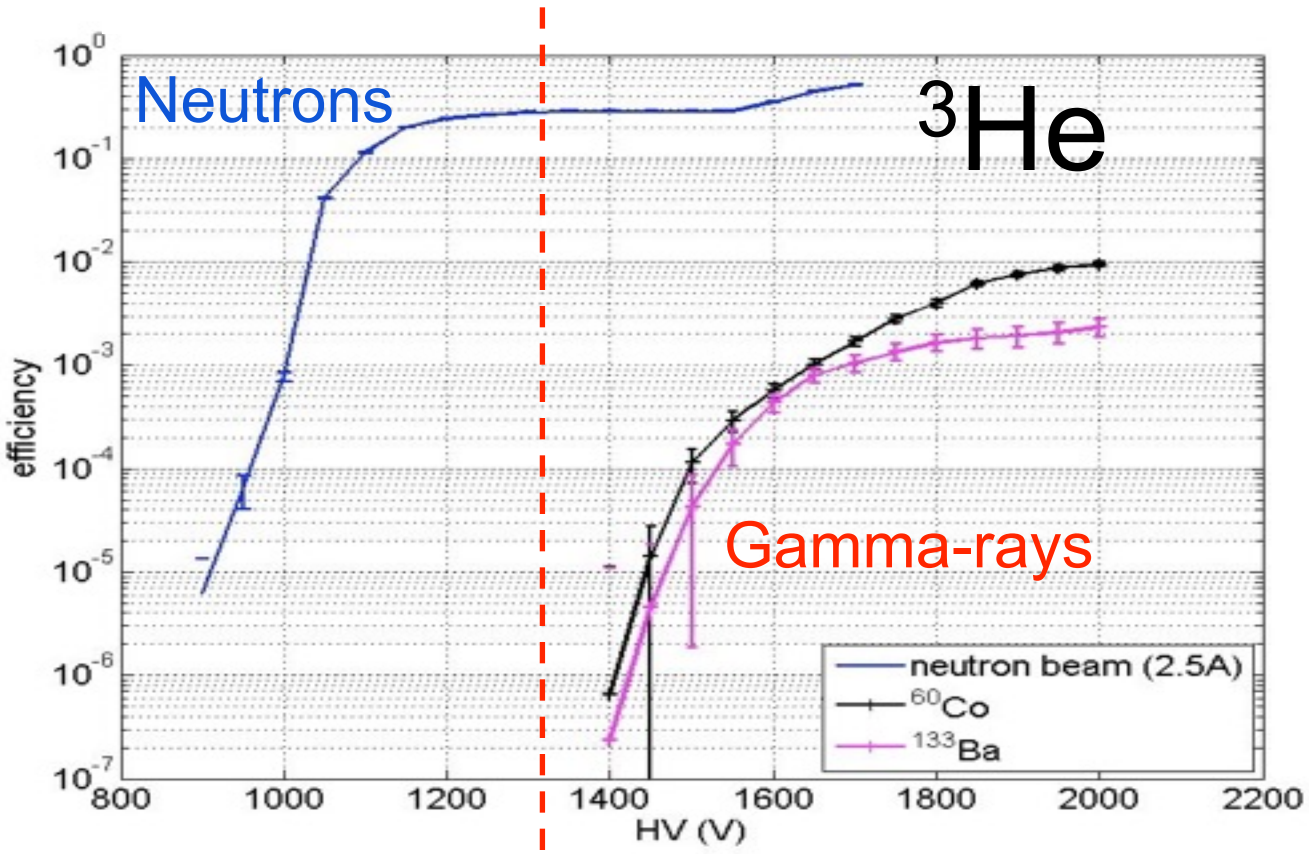
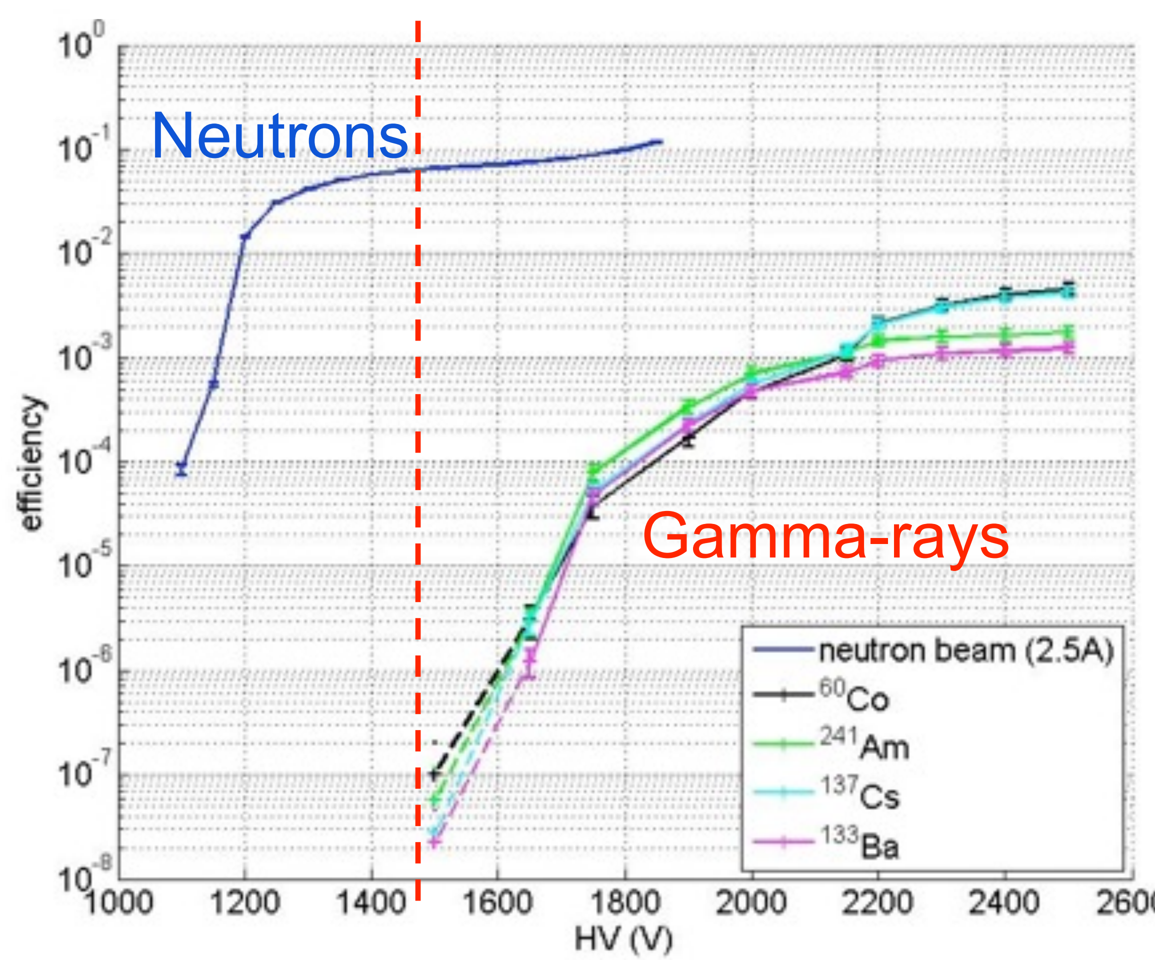




JINST 8 (2013) 10025

Economics of Boron-10 Large Area Detectors

IN5 Demonstrator verifies price target

Cost of "IN5-like design:" (30m^2/3.5bar He-3)

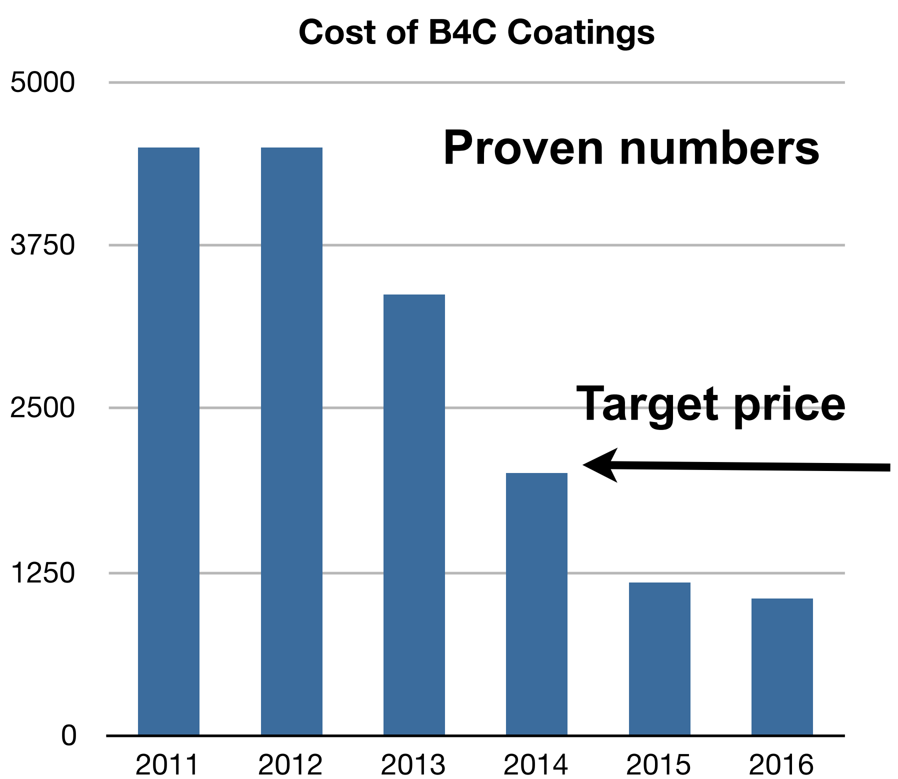
He-3 (RS): ca. 12 MEUR

B10 MG: 3-3.5 MEUR

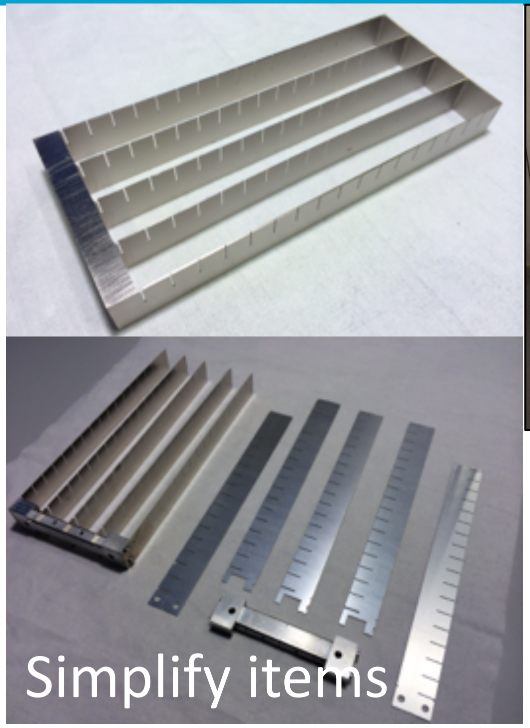
ca. Pre-2009 price

Divide this into envelopes for:

- coatings 25% : Proven
- mechanics 37% : Tight (proven)
- electronics 37% : Proven



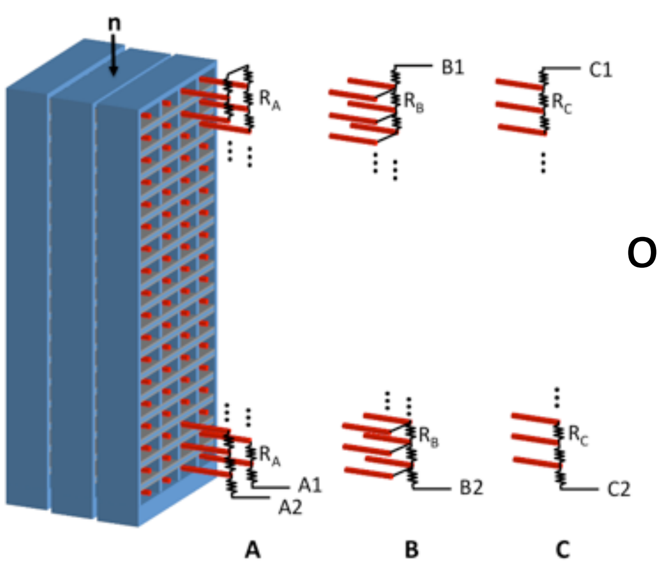
Coatings



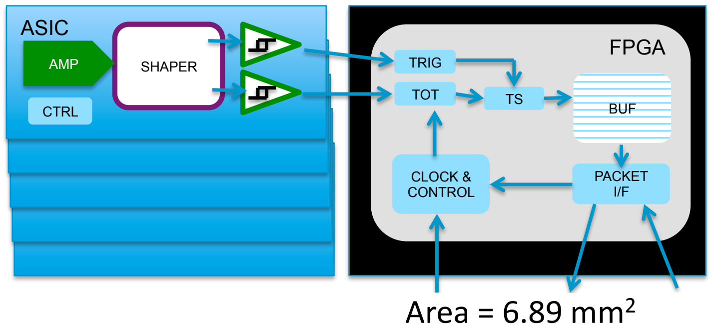
Non-artisan work

Production line-like

Mechanics



or



Area = 6.89 mm^2

ASIC+FPGA

Proven and feasible

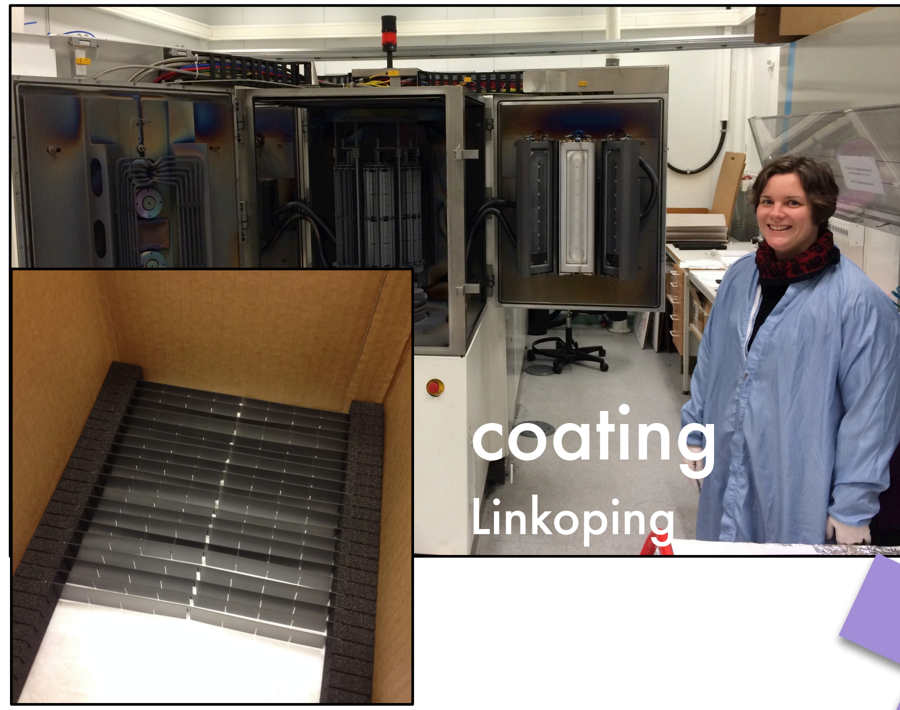
Electronics

EUROPEAN SPALLATION SOURCE

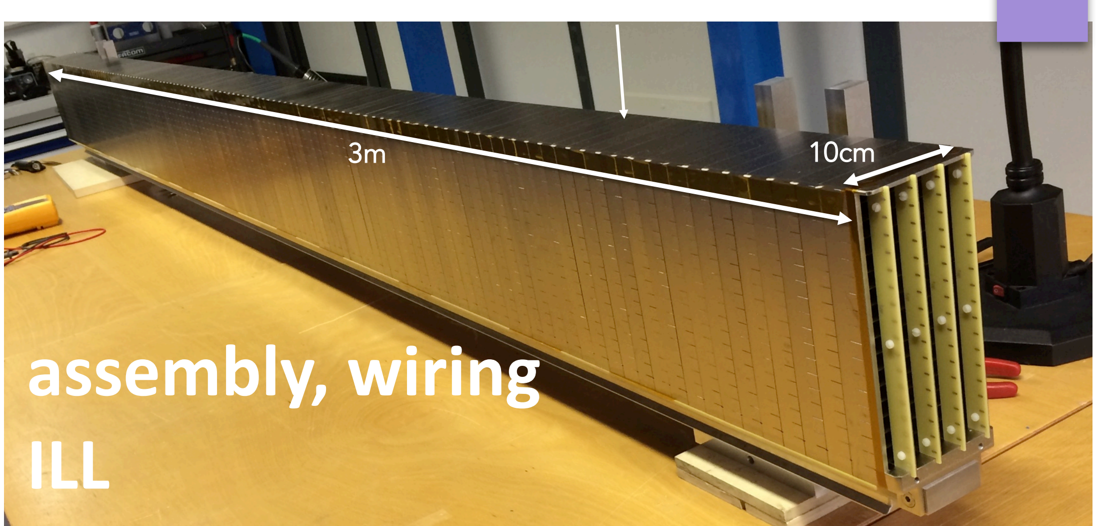
Linköping University

NEUTRONS FOR SCIENCE

Multi-Grid based detector built in a modular fashion

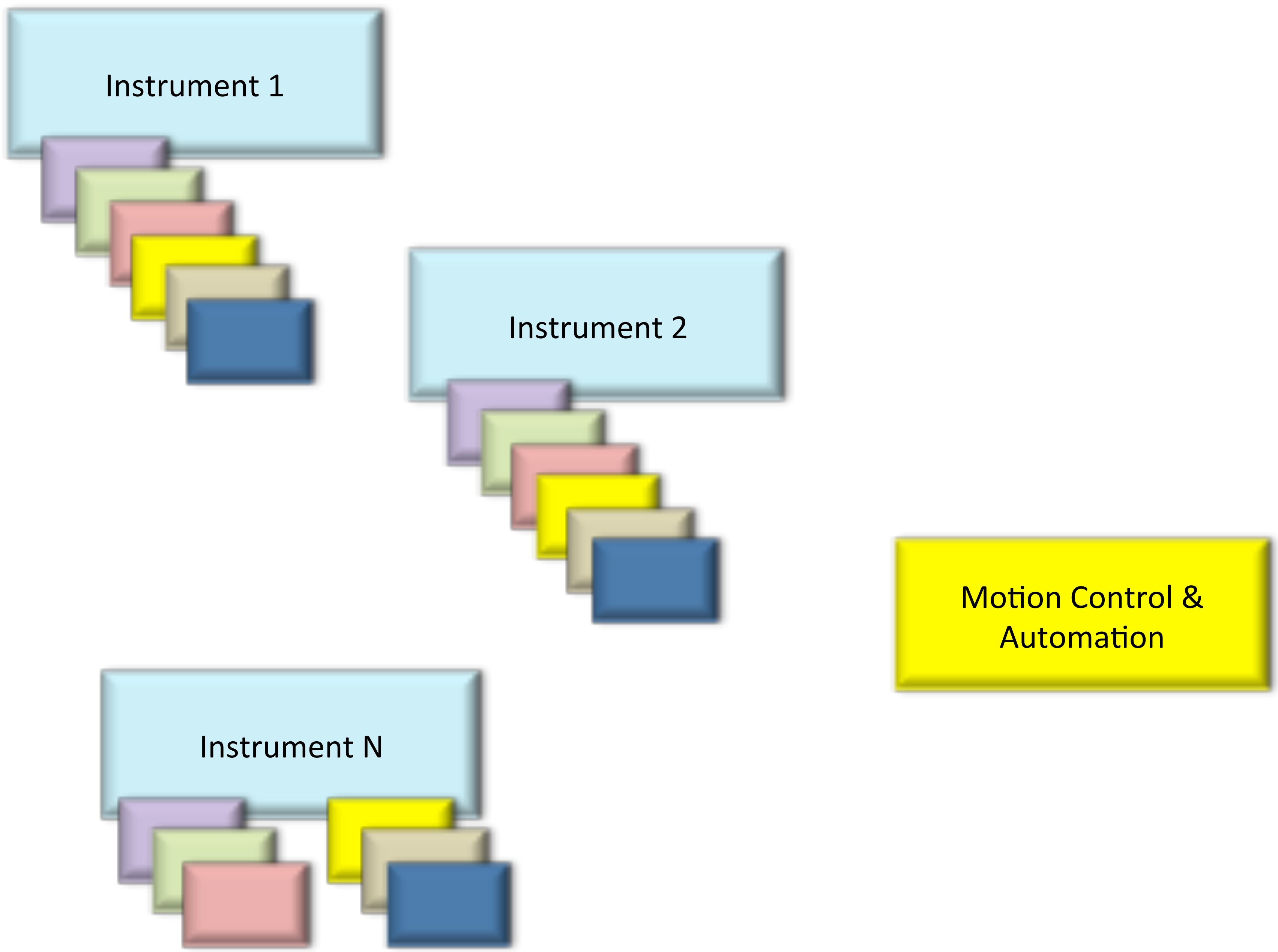


Multi-site fits in-kind



NSS – Functional decomposition

from Oliver



Functional decomposition facilitates to identify common / similar requirements

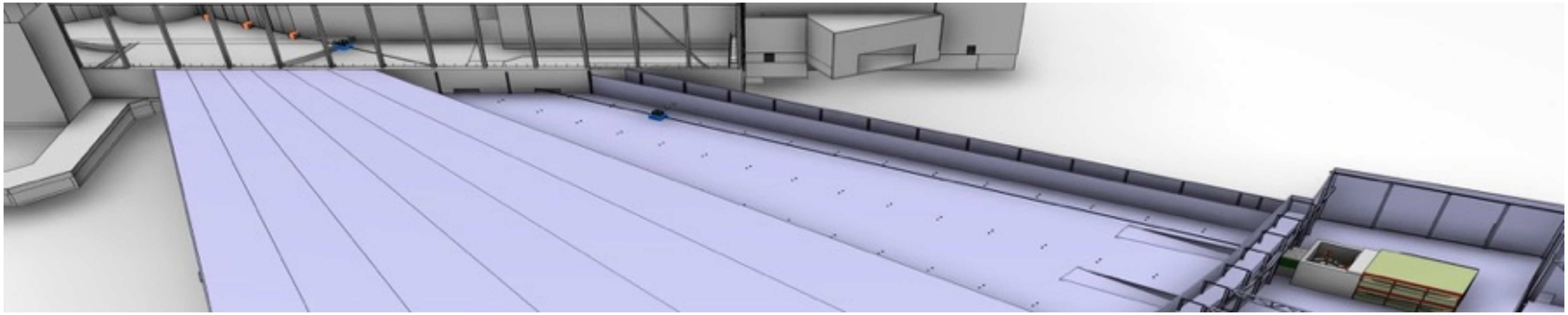
Create centralised workpackage to avoid recurring engineering cost in individual instrument projects; minimise risk

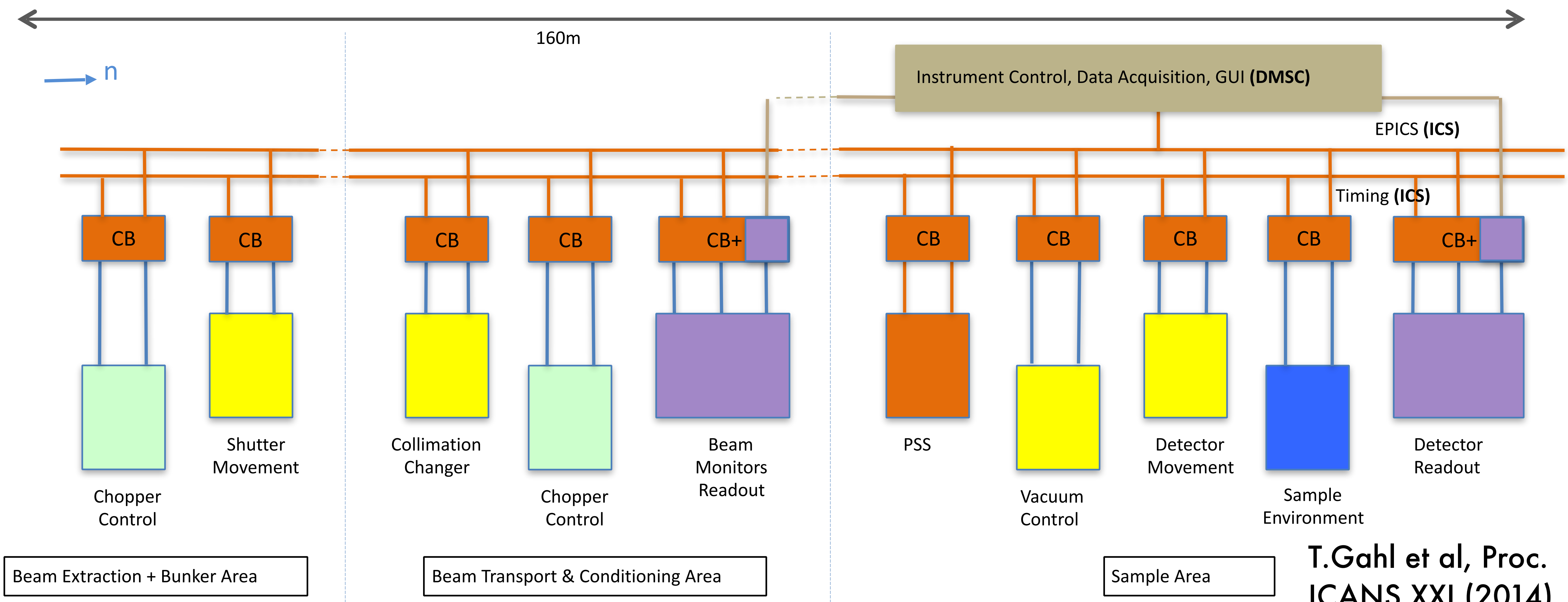
Ensure proper integration

Provide solution to instrument projects

Schedule is the driver

Modular Instrument Control Concept



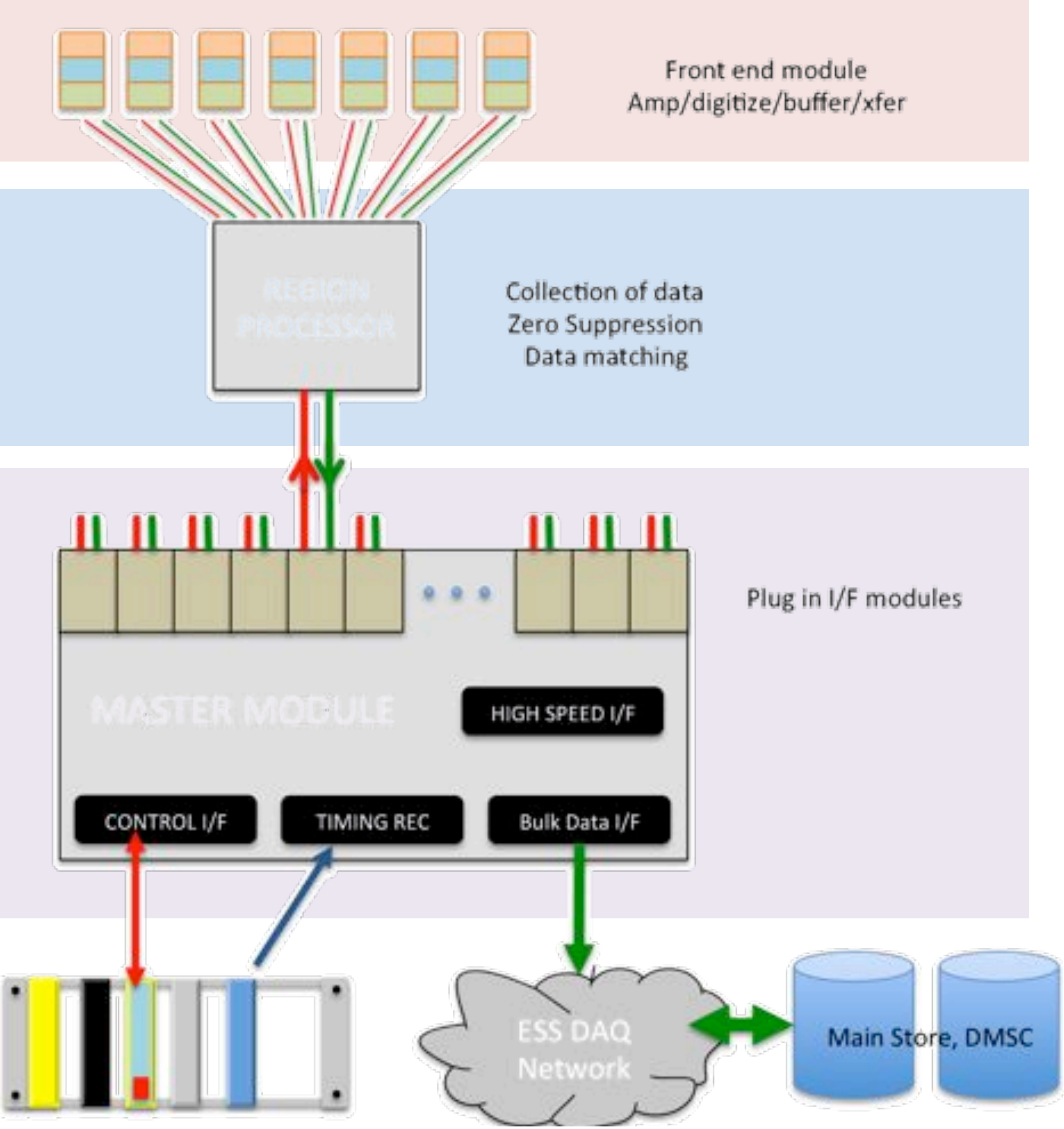


T.Gahl et al, Proc. ICANS XXI (2014)
arXiv: 1507.01838

- Modularisation to manage key interface

Modularisation for Detector Electronics

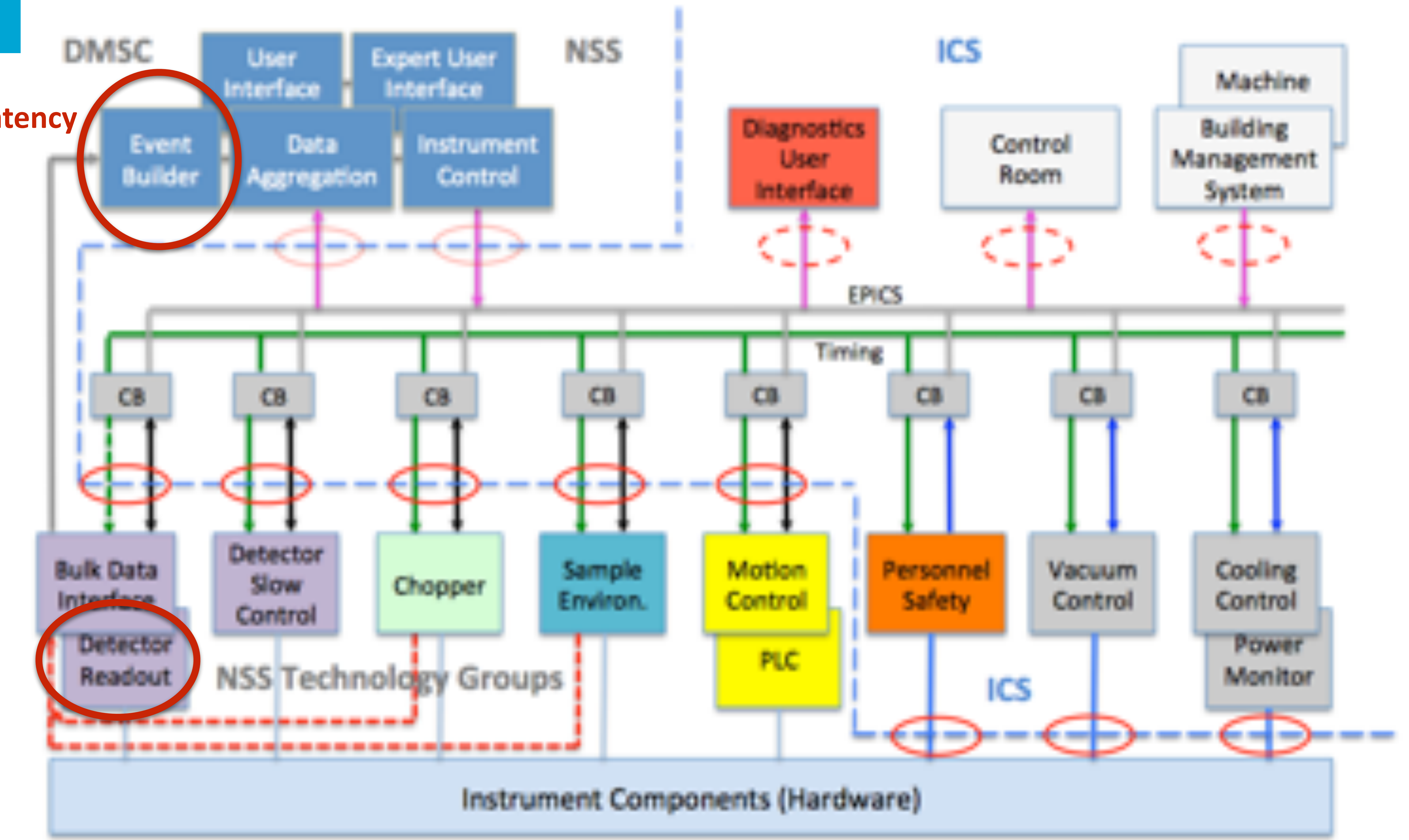
EUROPEAN SPALLATION SOURCE



- 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

Detector - DMSC Interface

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



Risks

Risks associated with detector delivery tracked with comprehensive backup plan with critical decision dates

Top risks are external to detector systems

Risk	Affects	Description	Mitigation
Delays in starting in-kind	Electronics; DMSC + ICS interface ; instruments design	Delays due to unclear process	Attention to most critical items (starting to resolve)
Departure of key persons	Schedule	Departure caused by uncertainty, conditions, or lack of action	Risk raised to project management
"Administrative headwind"	All in-house activities	Overhead on all activities: optimisation needed	Risk raised to project; high reliance on in-kind
Project Process: lack of organisational certainty:	Schedule and cost	Schedule delays and inefficiency introduced from changes	Risk raised to project

Main mitigation is open frank collaborative environment to solve problems together

Good reviewed plan, in-kind resources, committed partners, excellent people exist: just need to execute it!

Detectors: Risk and Mitigation

EUROPEAN SPALLATION SOURCE

Technical Risks: under control

- Early start (2011) for development and design effort for detectors through horizontal aspects
- Detailed and reviewed project planning and systems engineering approach
- Leading experts and groups both at partners and at ESS
- Enhanced the capacity of community by bringing in expertise from other disciplines
- In-depth core, backup and opportunity technologies identified well developed, and followed

Integrational Risks: under control

- Modular approach to simplify integration
- Interfaces identified, manned and managed early by the technical groups: strong engagement
- Strong dedicated in-kind partners involved
- Generous allocation of time and resources to testing, burn-in, integration, commissioning activities
- Detailed and reviewed project planning and systems engineering approach

Structural and Organisational Risks: main risks here: external to Detector Systems

- Project Process: lack of organisational certainty: e.g. TG2 review positive, but wait 12 months for "go"
- Delays in starting with the in-kind activities due to unclear process: (starting to resolve)
- Risk of departure of key persons caused by uncertainty, conditions, or lack of action
- "Administrative headwind": optimisation needed

Main mitigation is open frank collaborative environment to solve problems together

Good reviewed plan, in-kind resources, committed partners, excellent people exist: just need to do it!