



A Vision For Detectors for the European Spallation Source ESS AB

Richard Hall-Wilton^{1,2}, Scott Kolya¹,

**Maddi Echegary¹, Kevin Fissum^{1,3}, Carina Höglund^{1,4}, Mewlude Imam^{1,4}, Kalliopi Kanaki¹,
Anton Khaplanov¹, Thomas Kittelmann¹, Björn Nilsson^{1,5}, Luis Ortega¹, Dorothea Pfeiffer^{1,6},
Francesco Piscitelli^{1,7}, Julius Scherzinger^{1,3}, Irina Stefanescu^{1,8}**

and through collaborations and in-kind partnerships most of the participants at the workshop

¹European Spallation Source (Lund, Sweden) ²Mid-Sweden University (Sundsvall, Sweden)

³Lund University (Lund, Sweden) ⁴Linköping University (Linköping, Sweden)

⁵MAX-IV Laboratory (Lund, Sweden) ⁶CERN (Geneva, Switzerland)

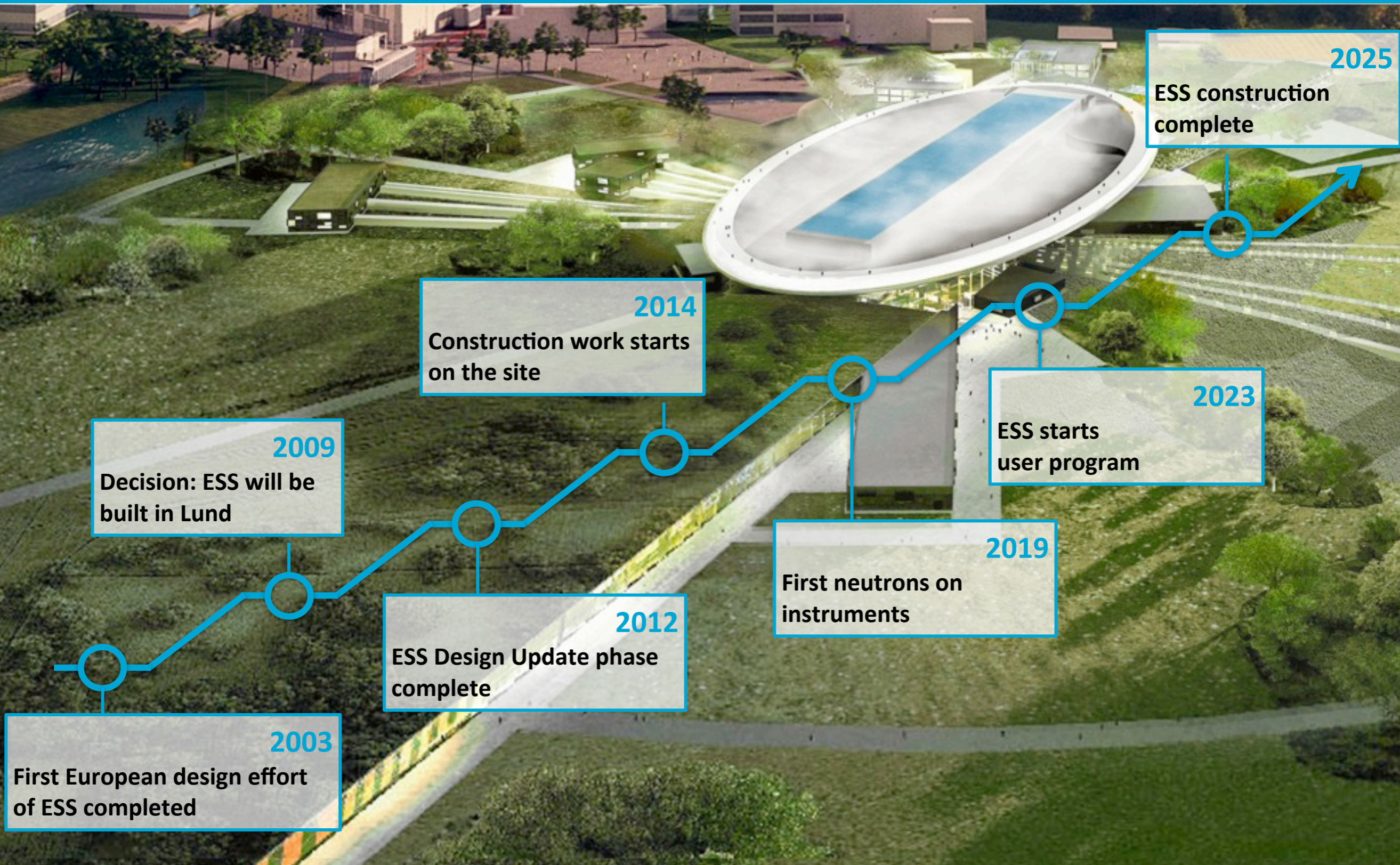
⁷ILL (Grenoble, France) ⁸FRM-II Laboratory (Münich, Germany)

Since the abstract was submitted, we have been joined by:

Yashika Bansal (April), Robert Andersson (May), Michail Anastasopoulos (Sep), Linda Robinson (Sep)

and Luis Ortega has moved on to bigger challenges within ESS

The road to realizing the world's leading facility for research using neutrons



Current status

- 3 instrument concepts have entered Construction Phase 1 – preliminary engineering design.
- 16 new instrument concepts have been proposed and reviewed by our independent advisory bodies, the STAPs and the SAC. The SAC will soon be making a recommendation on which ones to build and in what order.
- The construction licensing process is in its end stages.
- National funding negotiations are nearly finished; countries are committed.
- The archaeological survey of the land has been completed, and test piling etc. is on-going.
- We plan to break ground this summer!





EUROPEAN
SPALLATION
SOURCE

Detectors: where are we?

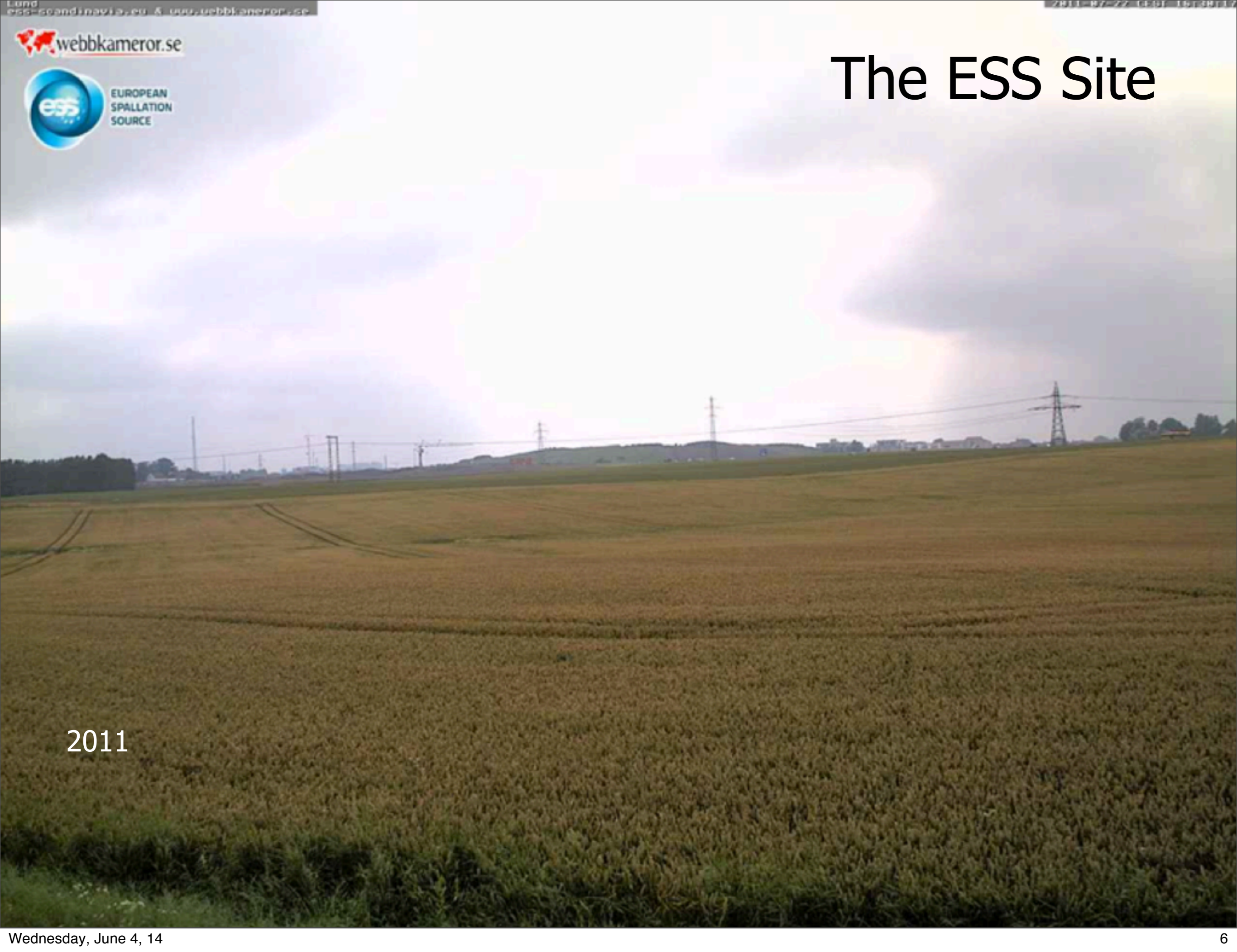
- The challenge
- Status of the group
- Standards
- In-kind for pre-construction
- Collaboration for construction
- How does it look like?

- A snapshot of where we are today



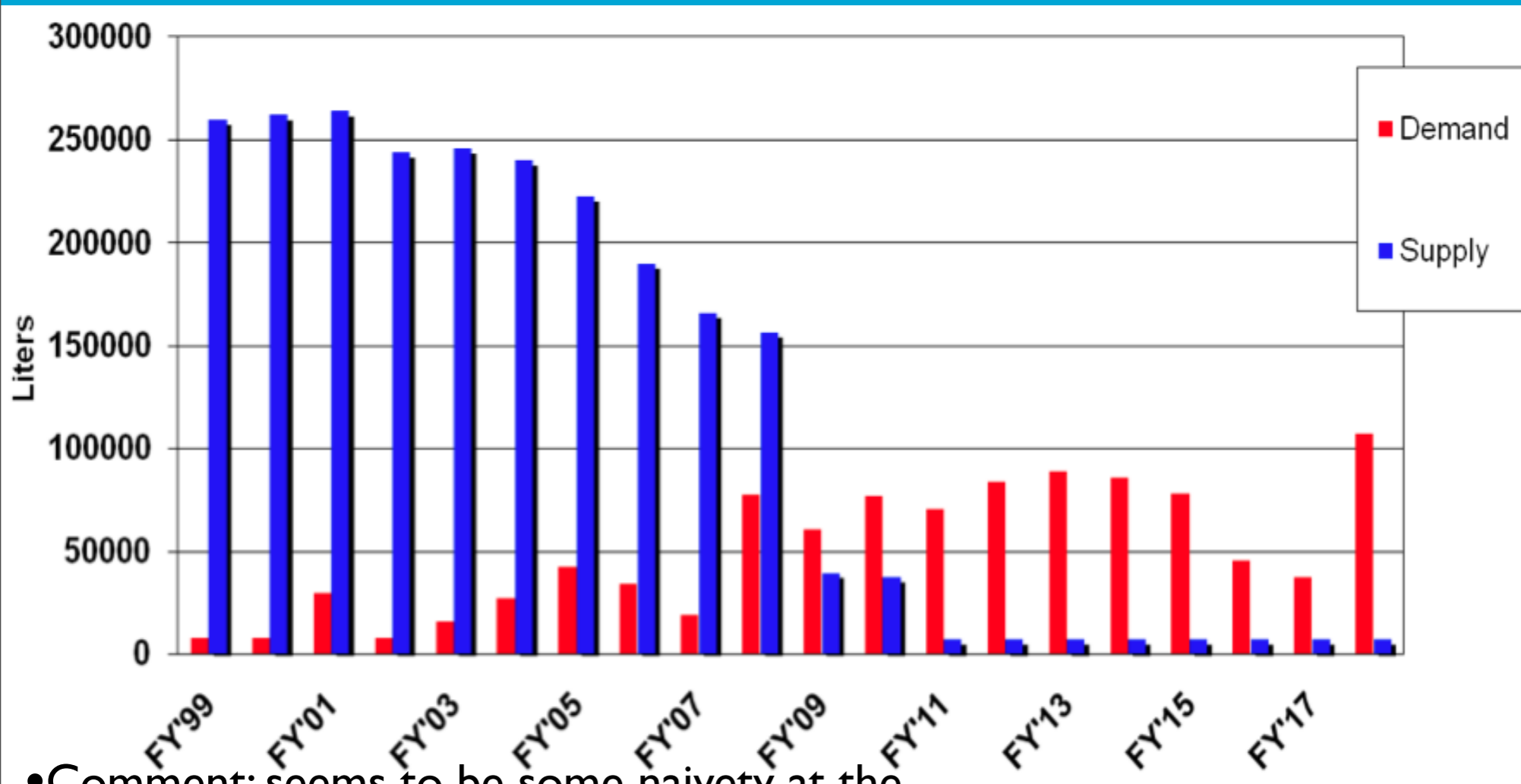
- Lets start by looking back to pre-history ...
- ... where were we in 2011 ... start of the design update ...

The ESS Site



2011

Helium-3 Crisis



- Comment: seems to be some naivety at the moment as stocks are being emptied rapidly
Aside ... maybe He-3 detectors are anyway not what is needed for ESS? eg rate, resolution reaching the limit ...

Crisis or opportunity ... ?

For almost all instrument classes, detectors are a limitation on performance

Context

Learn the lessons from other facilities

Collaboration

Participating Facilities

- ESS European Spallation Source, Sweden
- FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz, Germany
- HZB Helmholtz Zentrum Berlin, Germany
- ILL Institut Max von Laue – Paul Langevin, France
- ISIS Science and Technology Facilities Council, UK
- JCNS Jülich Centre for Neutron Science, Germany
- J-PARC Japan Proton Accelerator Research Complex, Japan
- NIST Centre for Neutron Research, USA
- ORNL Neutron Science Directorate, Oak Ridge National Laboratory, USA

Coordination

K. Zeitelhack, FRM II, GER; E-Mail: [✉ karl.zeitelhack@frm2.tum.de](mailto:karl.zeitelhack@frm2.tum.de)

Working Group Coordination

Scintillation detectors: N.J. Rhodes, STFC, UK; E-Mail: [✉ nigel.rhodes@stfc.ac.uk](mailto:nigel.rhodes@stfc.ac.uk)

B10 – detectors: B. Guerard, ILL, France; E-Mail: [✉ guerard@ill.fr](mailto:guerard@ill.fr)

BF3 – detectors: T. Wilpert, HZB, GER; E-Mail: [✉ wilpert@helmholtz-berlin.de](mailto:wilpert@helmholtz-berlin.de)

(... but no BF3 detectors for ESS ... safety !!)

new: plus PSI

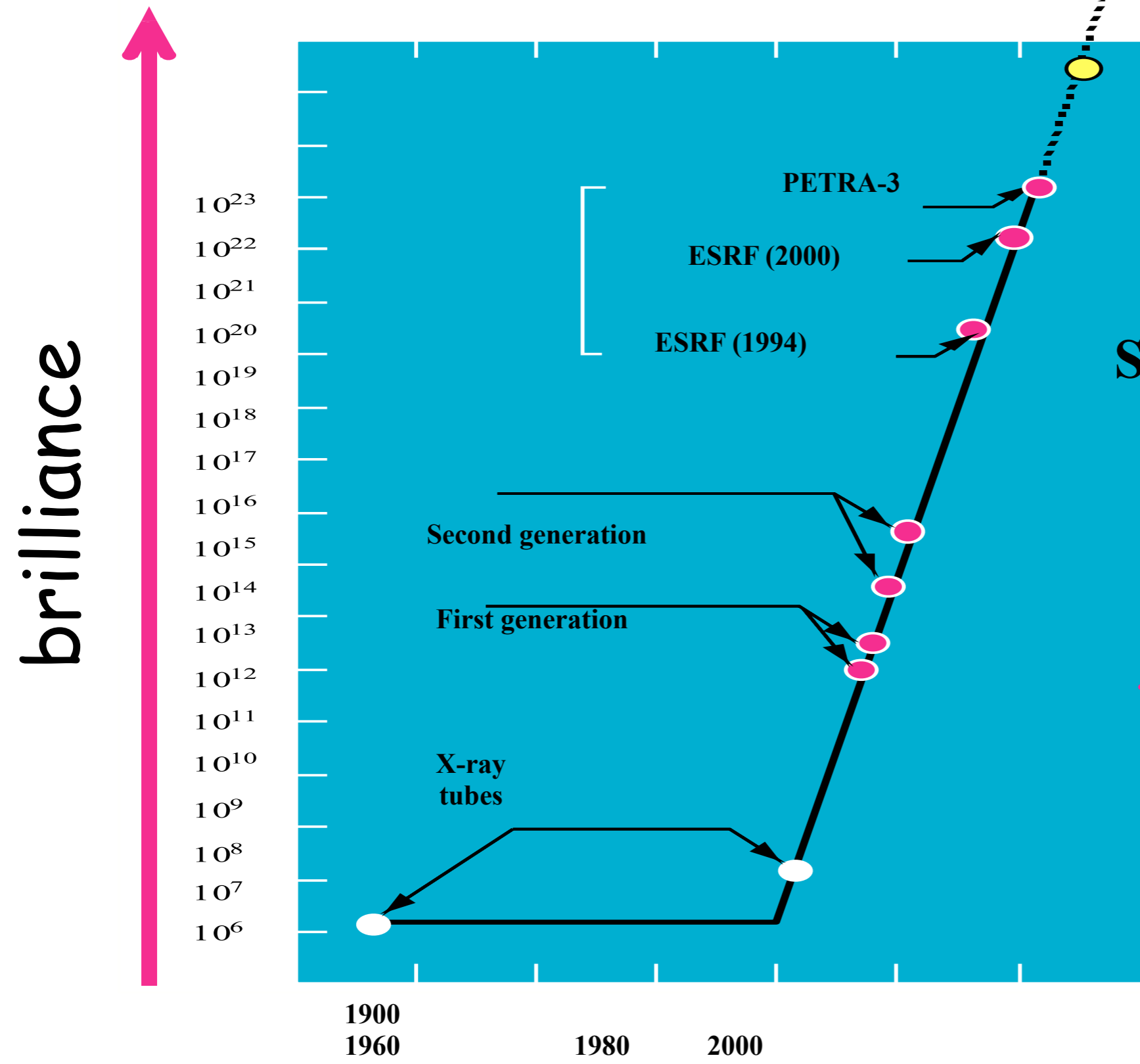
ESS cannot cover all technologies

ESS in-house will concentrate on B-10 detectors

Rely on others for Helium-3, Scintillator detectors

ESS will need all 3 detector technologies for the suite as a whole

The Detector Challenge: Synchrotrons



**NEUTRONS@ESS:
RATE IS AS BIG A
PROBLEM AS
HELIUM-3
AVAILABILITY**

Synchrotron Sources

- Last 5 years, they have got their act together and started:
 - a) Collaborating with other disciplines
 - b) Collaborate with each other
 - c) Started to put big money into detectors

There is a rate challenge for neutrons at ESS



Helium-3 Update



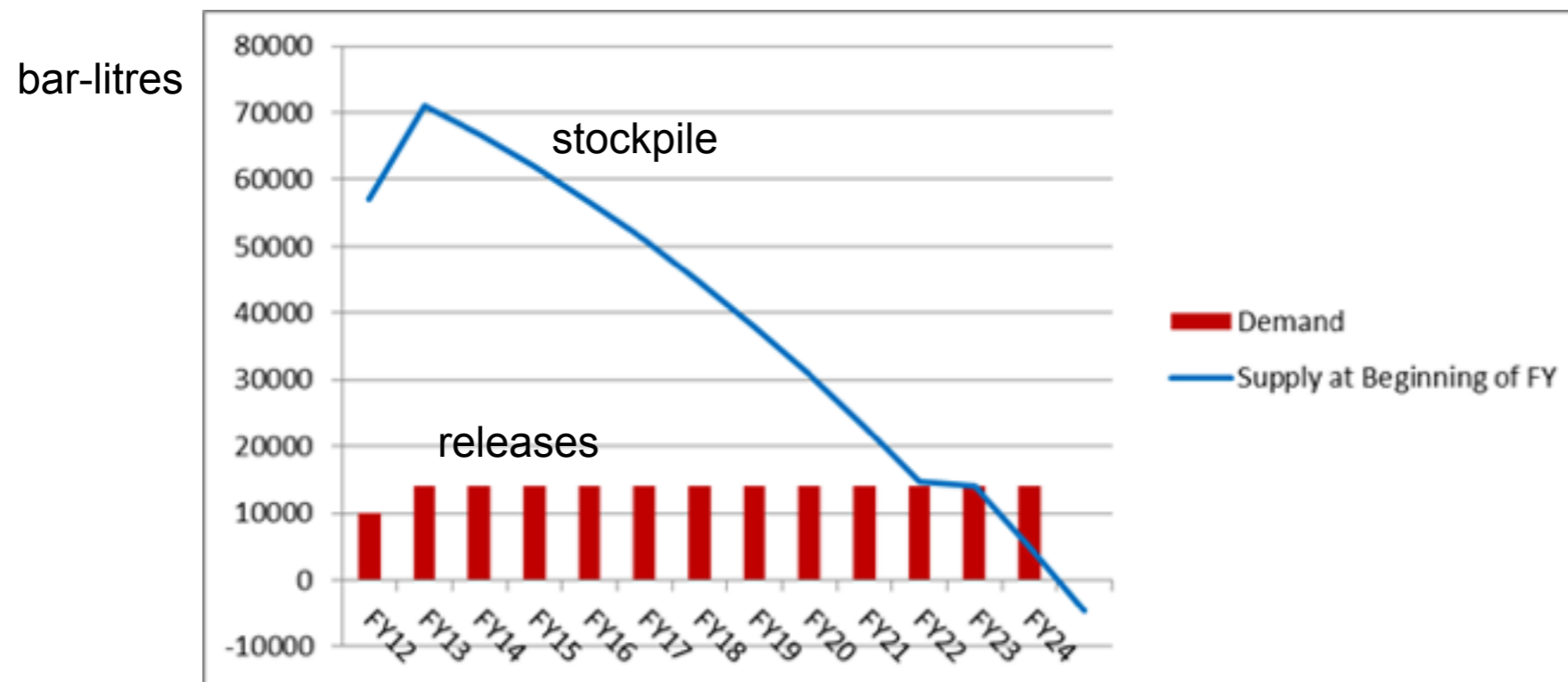
^3He Supply Forecast

Update from R. Kouzes, "End of He-3 As We Known It", IEEE NSS 2013

➤ Current intent for U.S. ^3He supply

- About 10k liter/year allocation for government use
- About 4k liter/year for auction *** this is what we can bid for ***
- About 10k liters added annually (diminishing)
- Supply is gone in ~2024

➤ DOE is relying on industry to develop new supply



Plot From Jehanne Gillo, DOE Office of Nuclear Physics, Dec 2012

Detector Requirements and Strategy



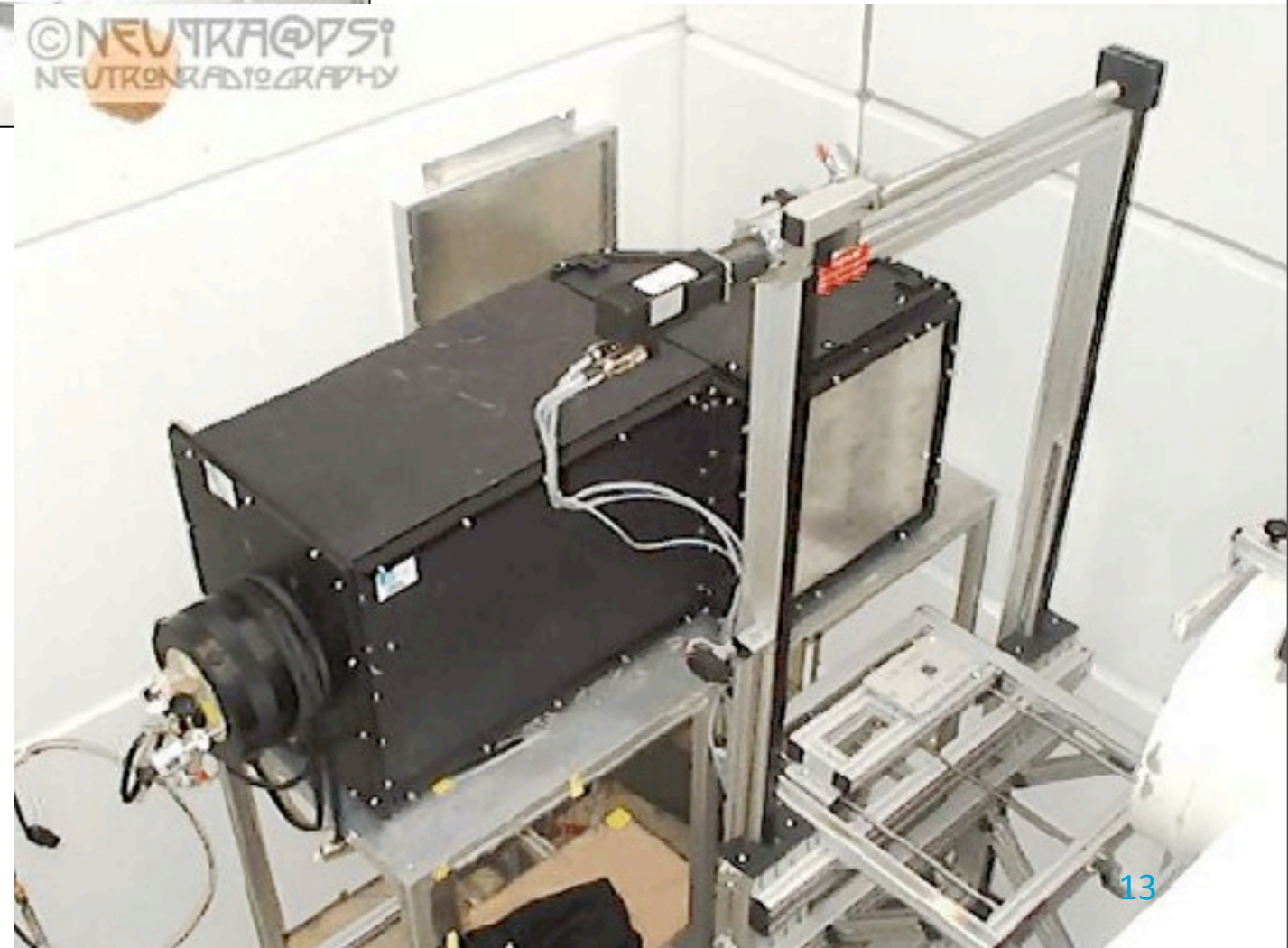


Simply put:

“get it done” (x22++)
“get it done well”
Keep’em working



build a technology and service
group and facilities capable of
doing this



Scope: Detector Requirements for Instruments



Instrument	Detector Area [m ²]	Wavelength Range [Å]	Time Resolution [μs]	Resolution [mm]
Multi-Purpose Imaging	0.5	1-20	1	0.001 - 0.5
General Purpose Polarised SANS	5	4-20	100	10
Broad-Band Small Sample SANS	14	2-20	100	1
Surface Scattering	5	4-20	100	10
Horizontal Reflectometer	0.5	5-30	100	1
Vertical Reflectometer	0.5	5-30	100	1
Thermal Powder Diffractometer	20	0.6-6	<10	2x2
Bi-Spectral Powder Diffractometer	20	0.8-10	<10	2.5x2.5
Pulsed Monochromatic Powder Diffractometer	4	0.6-5	<100	2 x 5
Material Science & Engineering Diffractometer	10	0.5-5	10	2
Extreme Conditions Instrument	10	1-10	<10	3x5
Single Crystal Magnetism Diffractometer	6	0.8-10	100	2.5x2.5
Macromolecular Diffractometer	1	1.5-3.3	1000	0.2
Cold Chopper Spectrometer	80	1 -20	10	10
Bi-Spectral Chopper Spectrometer	50	0.8-20	10	10
Thermal Chopper Spectrometer	50	0.6-4	10	10
Cold Crystal-Analyser Spectrometer	1	2-8	<10	5-10
Vibrational Spectroscopy	1	0.4-5	<10	10
Backscattering Spectrometer	0.3	2-8	<10	10
High-Resolution Spin Echo	0.3	4-25	100	10
Wide-Angle Spin Echo	3	2-15	100	10
Fundamental & Particle Physics	0.5	5-30	1	0.1
Total	282.6			

• Specifications very varied

• Typically superior to what is presently state-of-the-art at existing sources

• In many cases, instrument performance dominated by S:B rather than raw specifications here

COST!

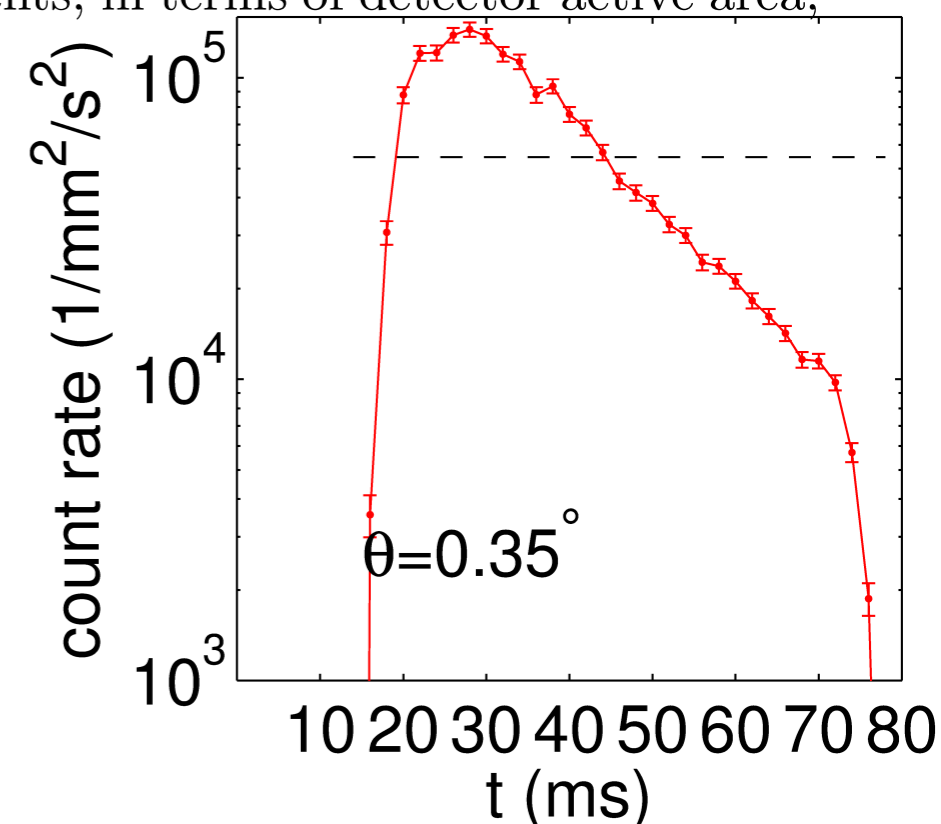
RATE!

• Updated soon with proposed instrument concepts submitted in this proposal round

Example of Challenges: Rates for Reflectometry

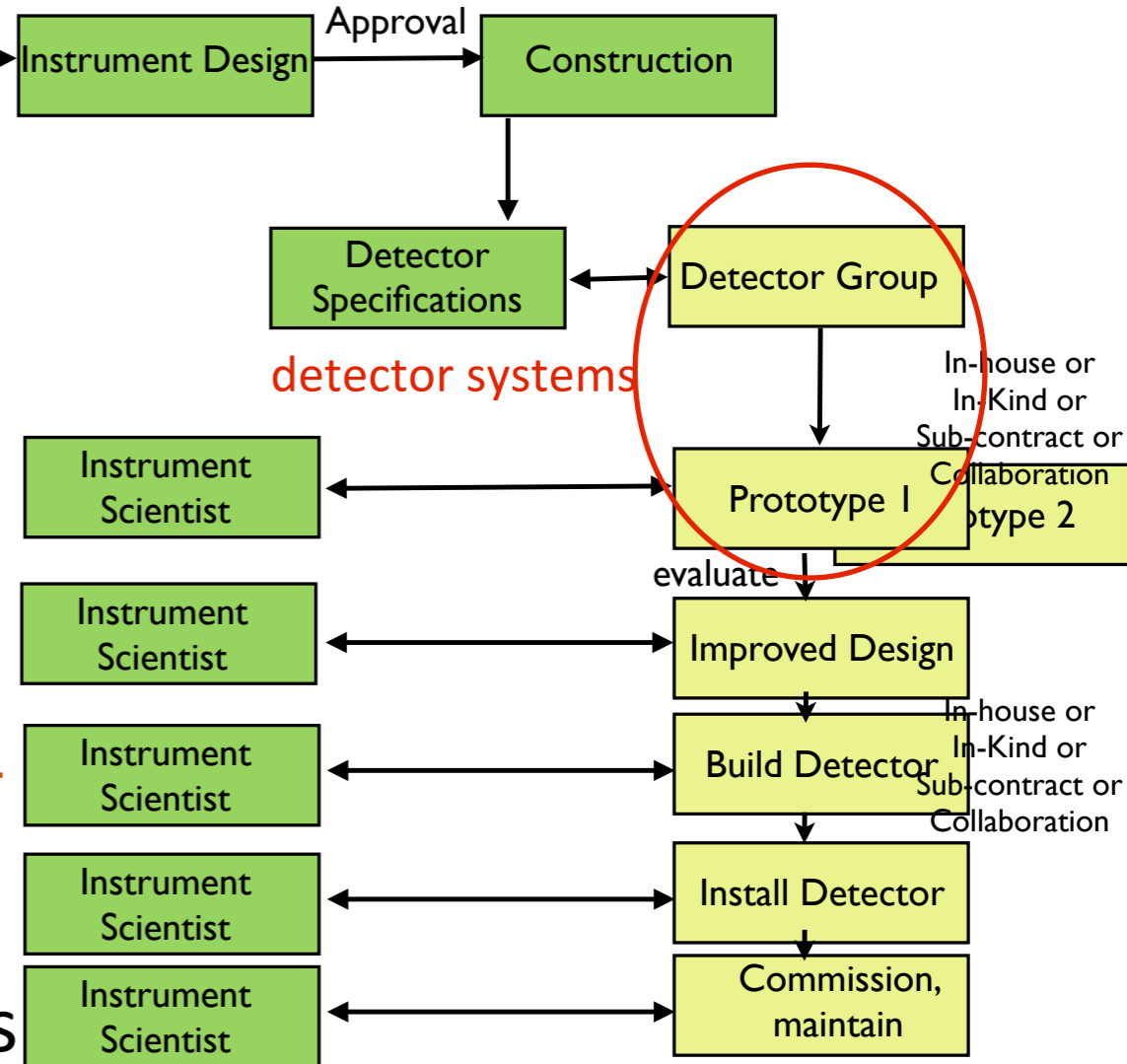
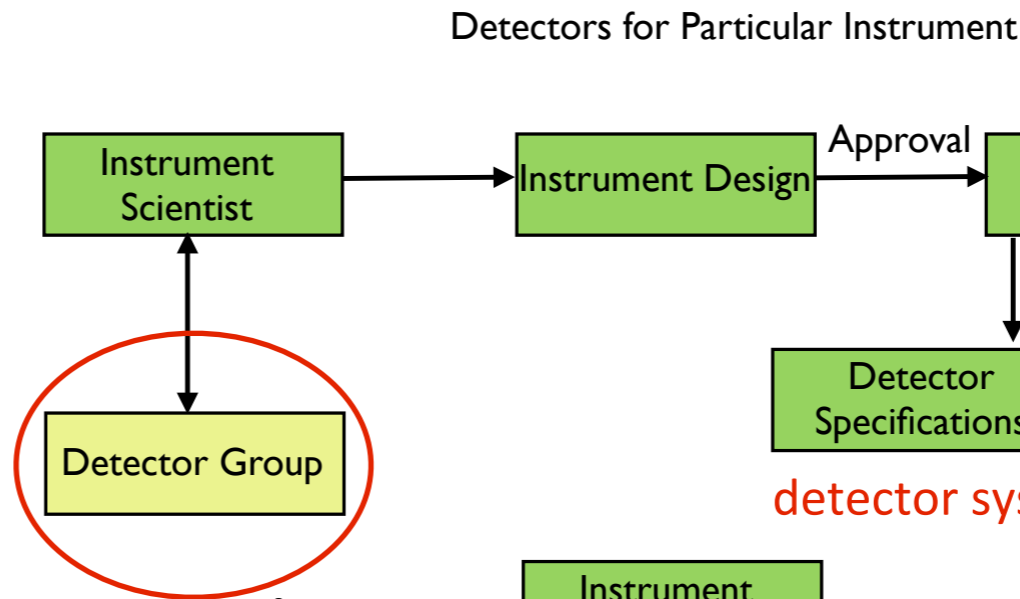
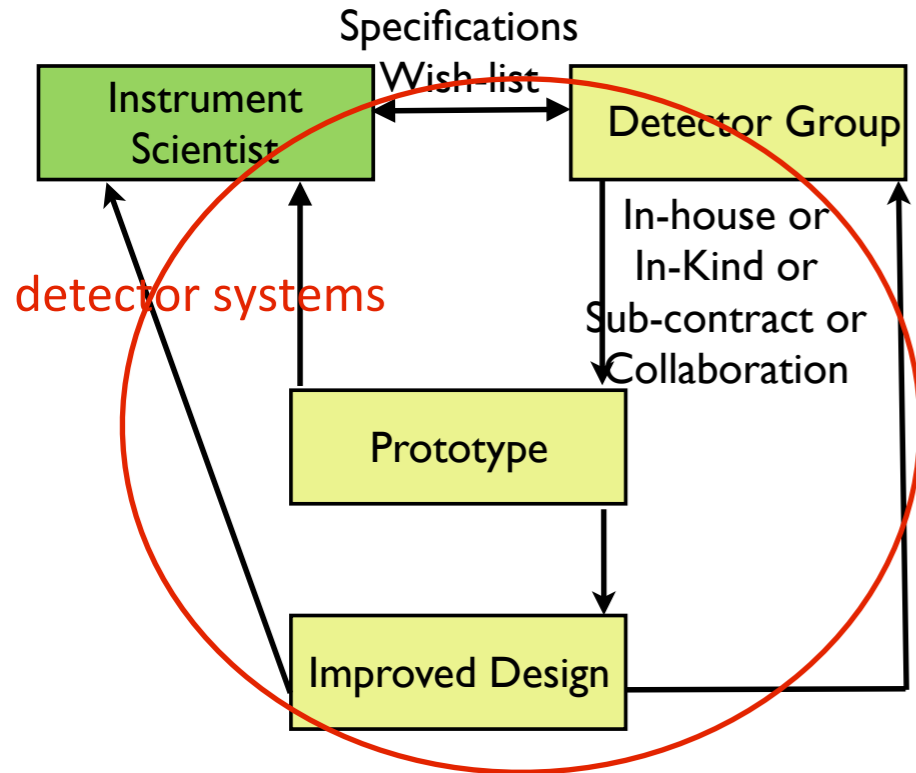
Instrument		area ($mm \times mm$)	Δx (mm)	Δy (mm)	global rate (s^{-1})	local rate ($s^{-1}mm^{-2}$)
ESTIA [2]	min	500×170	≤ 2	≥ 2	-	-
	ideal	500×500	≤ 0.5	≥ 0.5	$\sim 10^7$	$3 \cdot 10^4$
FREIA [3]	min	500×500	8	1	-	-
	ideal	500×500	≤ 8	≤ 1	$\sim 5 \cdot 10^5$	$\sim 3.5 \cdot 10^3$
THOR [4]	min	500×500	2	-	-	-
	ideal	500×500	≤ 2	-	-	-
VERITAS [5]	min	500×500	2	2	-	-
	ideal	500×500	≤ 2	≤ 2	$5 \cdot 10^5$	$5 \cdot 10^2$

Table 1: Detector requirements, for both ideal-world and minimal requirements, in terms of detector active area, spatial resolution, global and local rates for reflectometer proposals at ESS.



Specialise Principle: no prototypes installed in ESS

All activities collaborative



The division between instrument projects and detector systems is cope with development time > construction

All synergetic developments done within detector systems for instrument classes: lower the entry barrier for later instruments

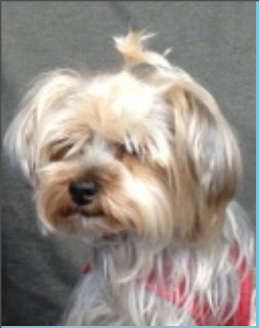
Added value to the instrument projects through support and expertise

Aim: lowest global cost for ESS from detectors, highest performant detectors for instruments

- Developments to enhance costs, ensure maturity and quality
 - **“No prototypes installed in ESS”**
 - Standards developed to evaluate detectors
 - Sufficient expertise to be able to engage with in-kind
 - Speculative R+D through grants
- In terms of detector technology choices - specialise:
 - B-10 detector effort led from ESS in-house efforts with in-kind partners. ESS as a centre of excellence for the community to support developments where needed
 - All scintillator detectors, He-3 detectors, supplied by collaborating with in-kind partners
 - No BF3 detectors due to safety and performance issues
- Detector construction will be a primarily distributed effort, with many partners
- Development of support workshop facilities in Lund to ensure that detector development is a efficient and cheap as possible, to support in-kind, and to ensure that detector group builds capacity to be ready for installation, and transmission to commissioning and operations

The ESS Detector Group





Organisation - Detector Group June 14



ILL



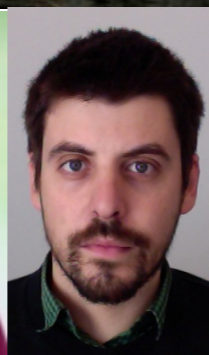
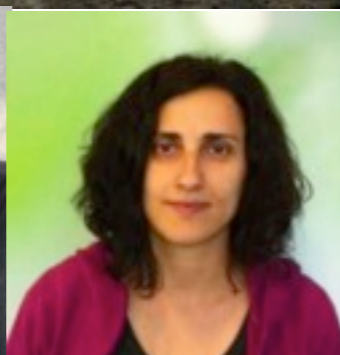
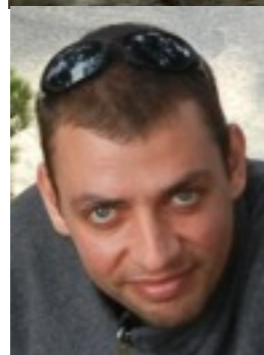
ESS



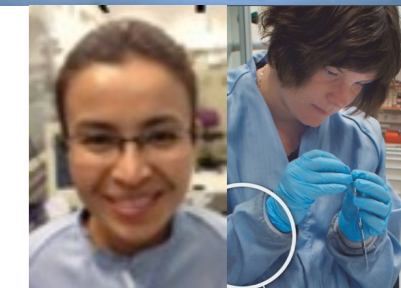
Linköping



Francesco Piscitelli

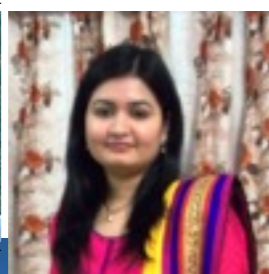


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Luis Ortega (deputy work package manager)
Irina Stefanescu



Carina Höglund
Linda Robinson (sep)
Mewlude Imam*

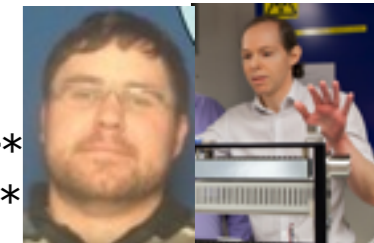
Isabel Llamas
Xiao Xiao Cai
Thomas Haraldsen



RED colour: ESS persons
BLACK colour: local collaborators
3 PhD Students (*)
(+5 bachelors/Masters Projects+2 interns)



Kevin Fissum
Björn Nilsson
Julius Scherzinger*
Vladimir Pastukov*



IFE

Yashika Bansal (Bergen)

Dorothea Pfeiffer
Filippo Resnati



CERN

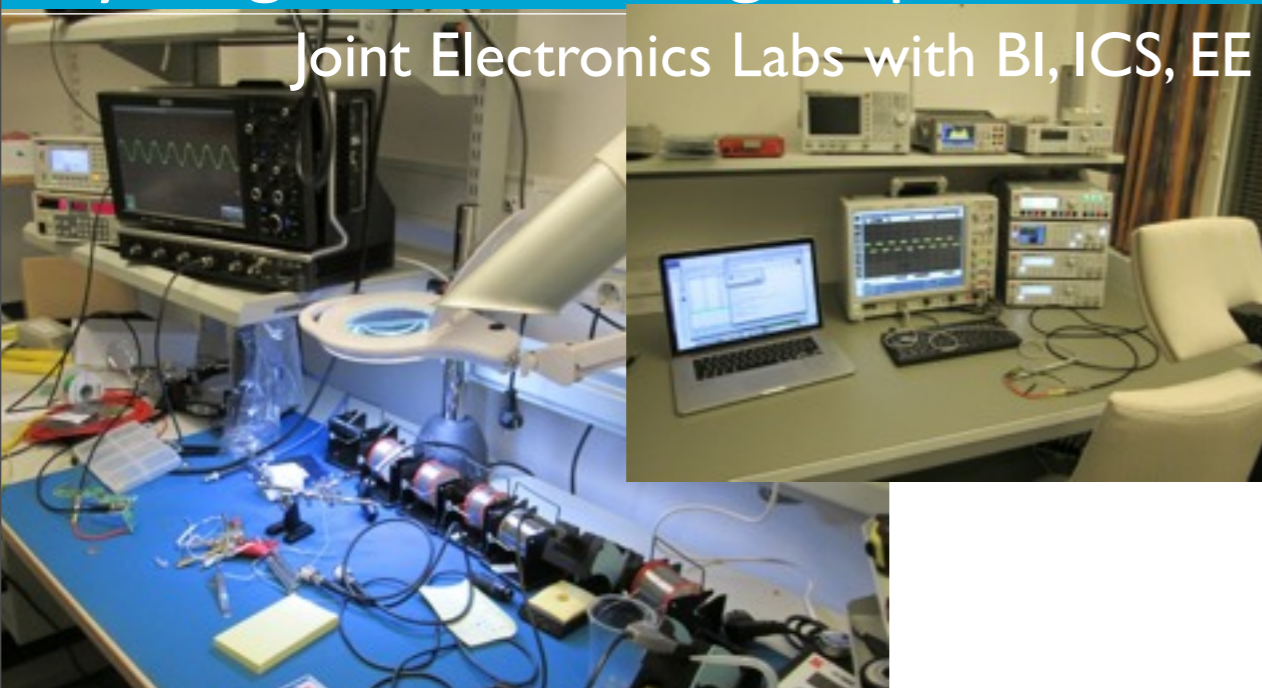


Lund U, LTH, MAXlab

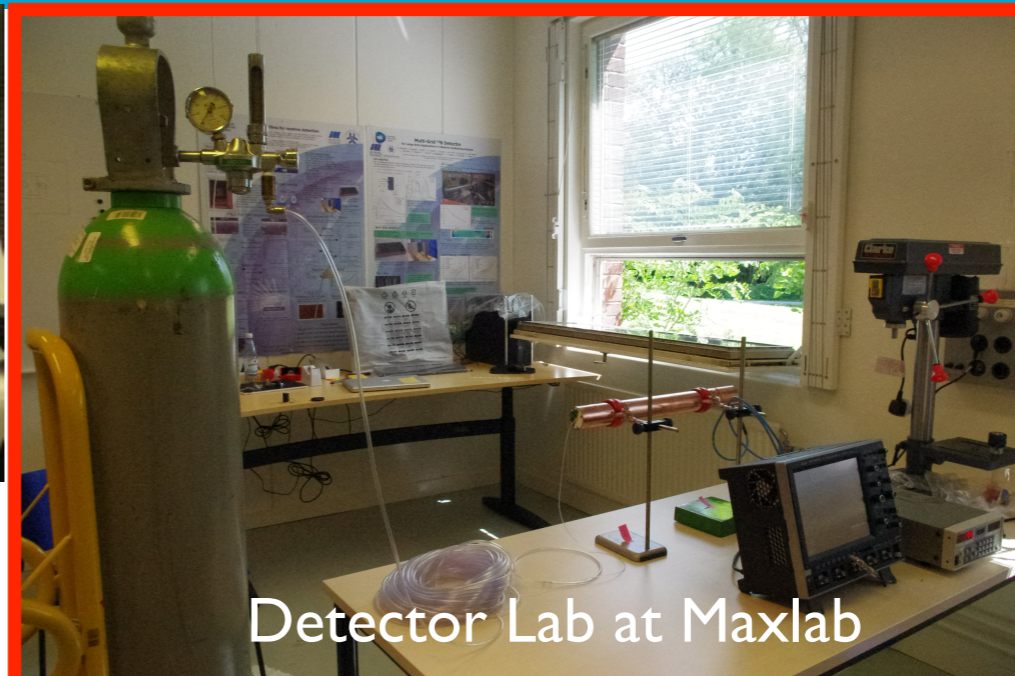
2014 - Labs - "Real things"

High quality facilities a priority (reminder: green field)

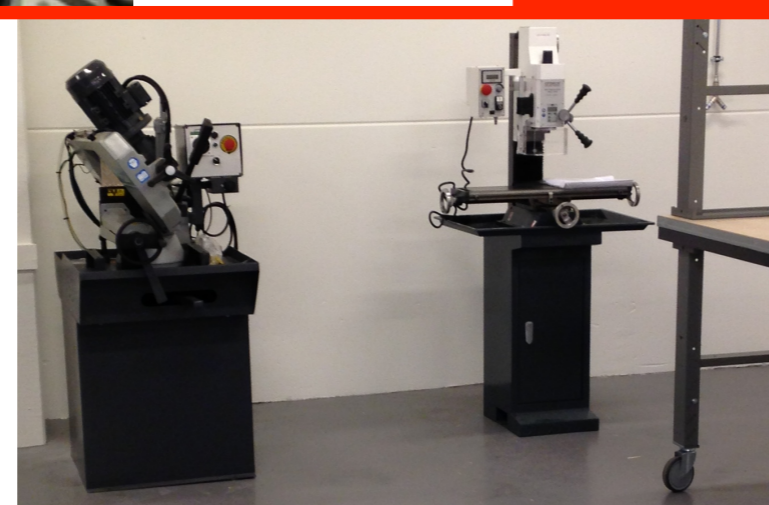
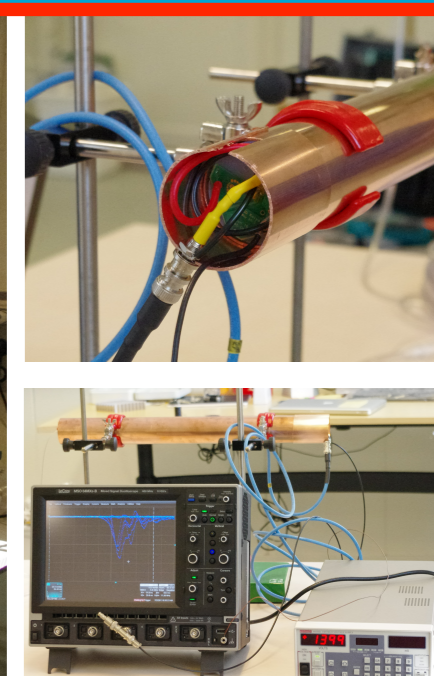
Synergies between groups



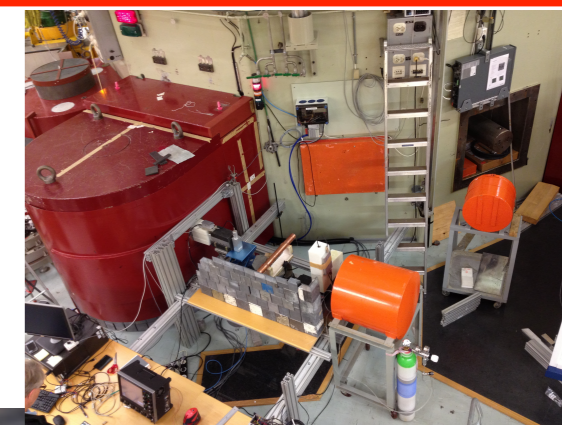
Joint Electronics Labs with BI, ICS, EE



Detector Lab at Maxlab



• Beamline at IFE

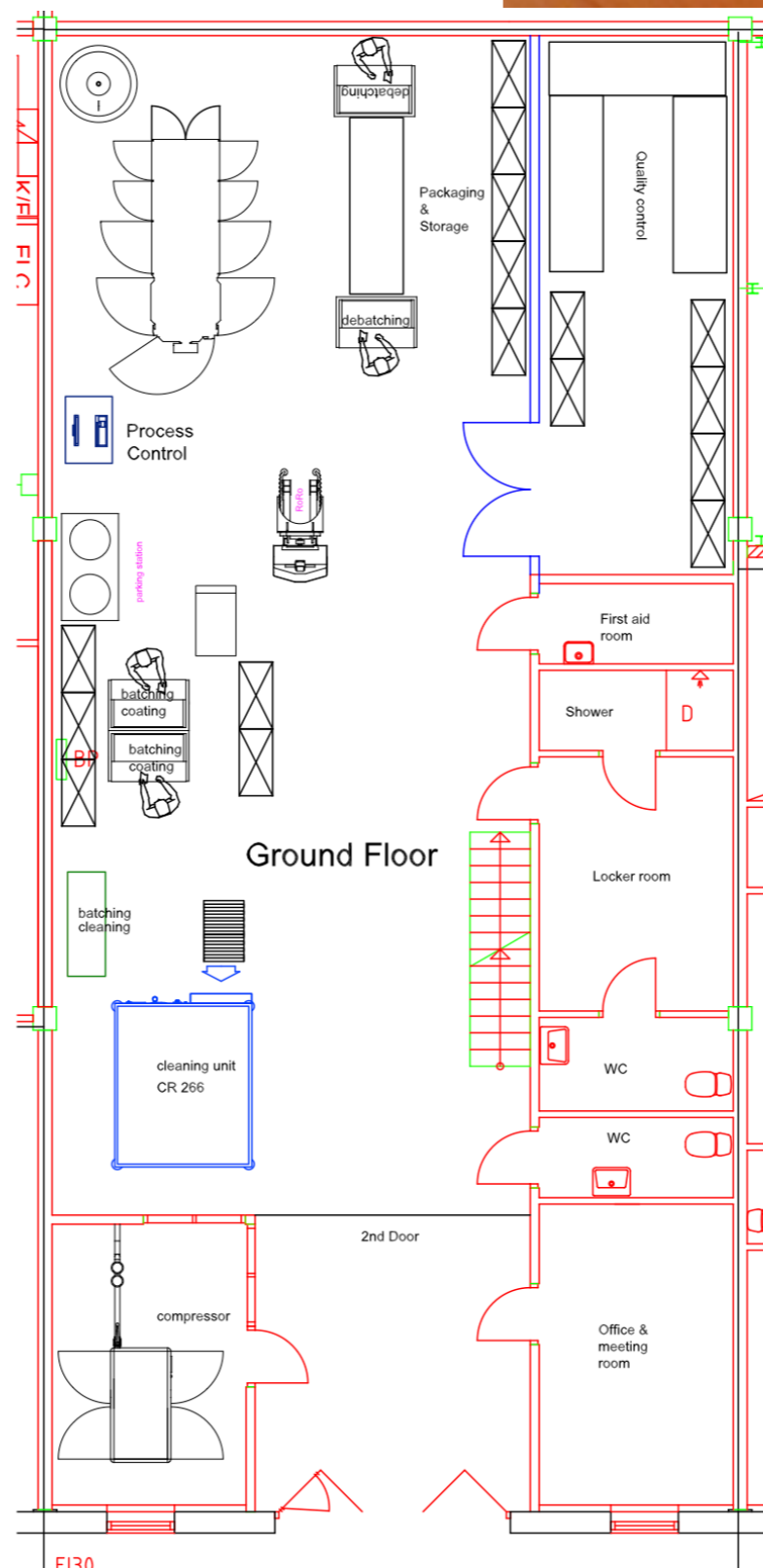
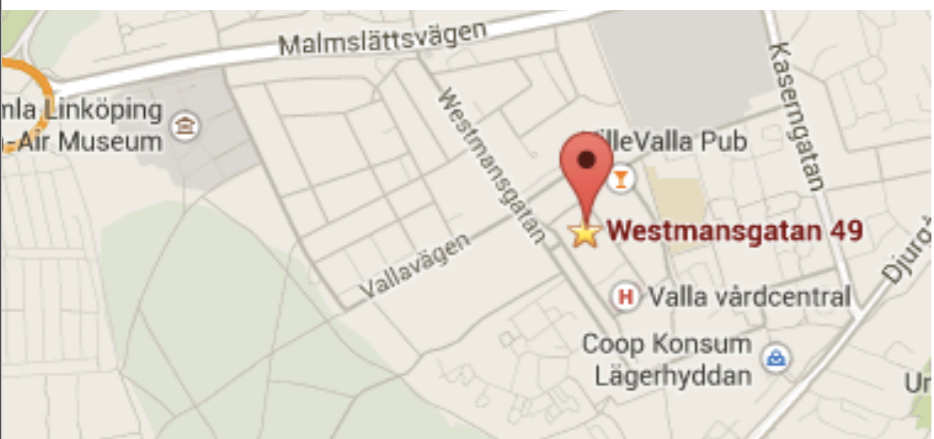
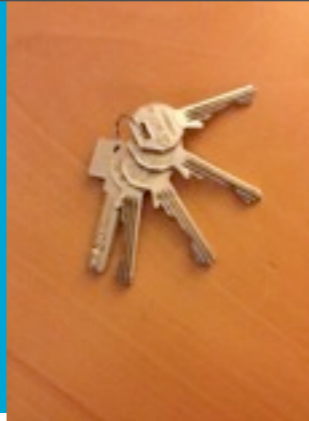


Joint Neutron Technology Mechanical Lab

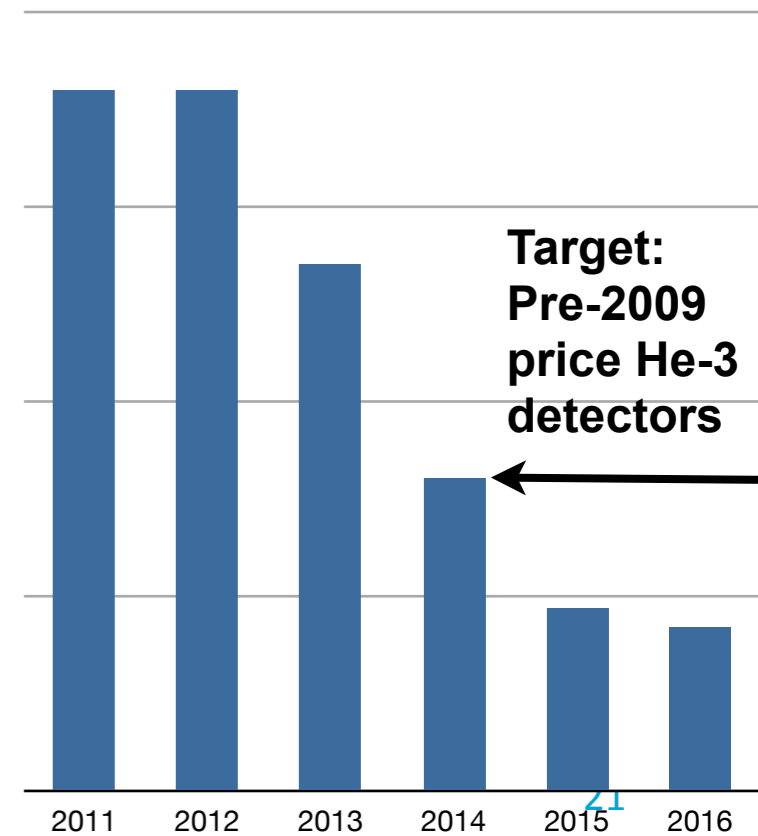


• Sources at Maxlab/
Lund U

Coating Facility in Linköping Turnkey Handover: July



Cost of B4C Coatings



Developments and Standards



“No Prototypes installed in ESS”: ensuring quality



Formally monitor development and availability as part of the strategy
This is addition with quality/requirement matching and cost

Develop Measurement Standards

Numbers quoted can be “economical with the truth”

Between neutron sources defines requirements are not defined in the same way

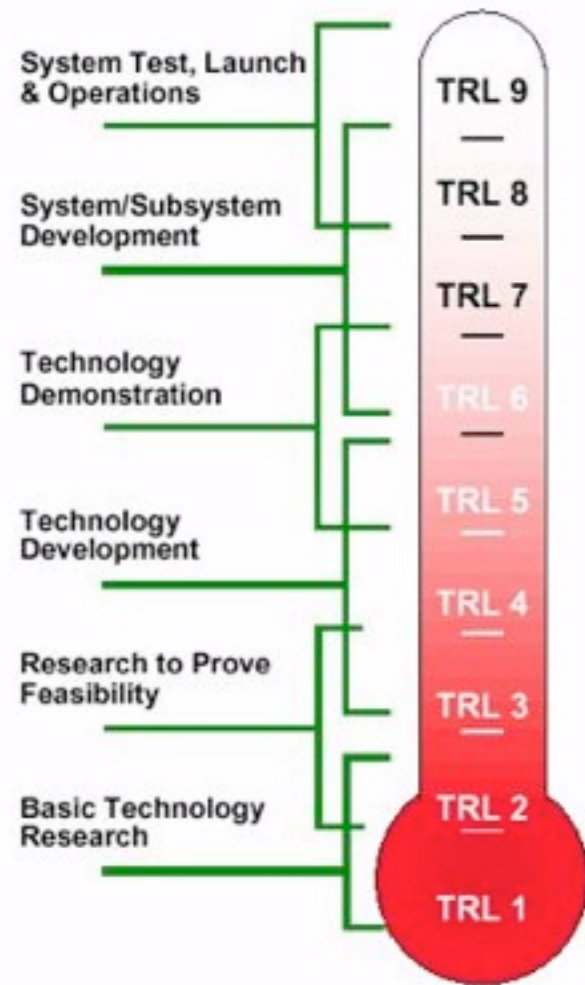
We will write down draft standards, open for critique by Autumn 2014

Prototype development also too long for instrument schedule
(10 years from start to on beam)

Divide the technological developments out to support classes of instruments

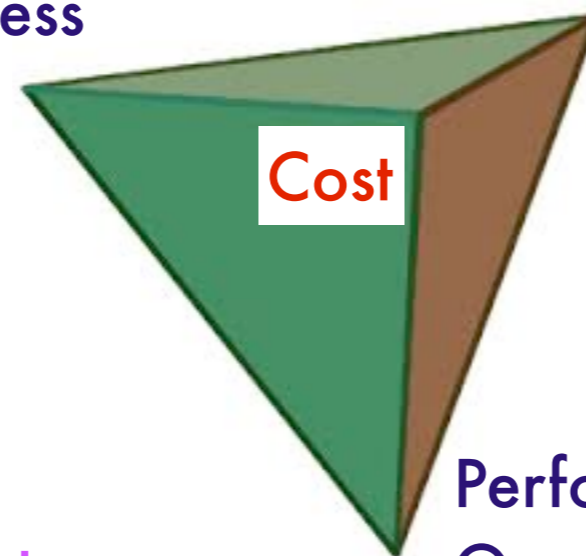
Everything fully prototyped and demonstrated BEFORE constructed and installed for ESS

“No Prototypes installed in ESS”: ensuring quality



Technology
Readiness

Availability



Detector
Technology
Evaluation

Performance/
Quality/
Reliability

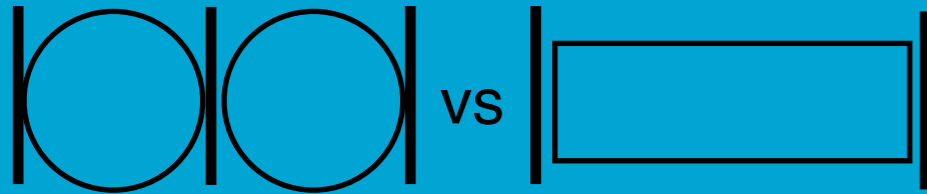
- Availability in supply or capacity a key issue
- Helium-3 is an obvious issue
- Collaborators/Suppliers have limited capacity ...
- Designs developed may be “lost”

- Standards
- Close Collaboration
- inc. background, lifetime, maintenance costs, etc

Formalise the approach

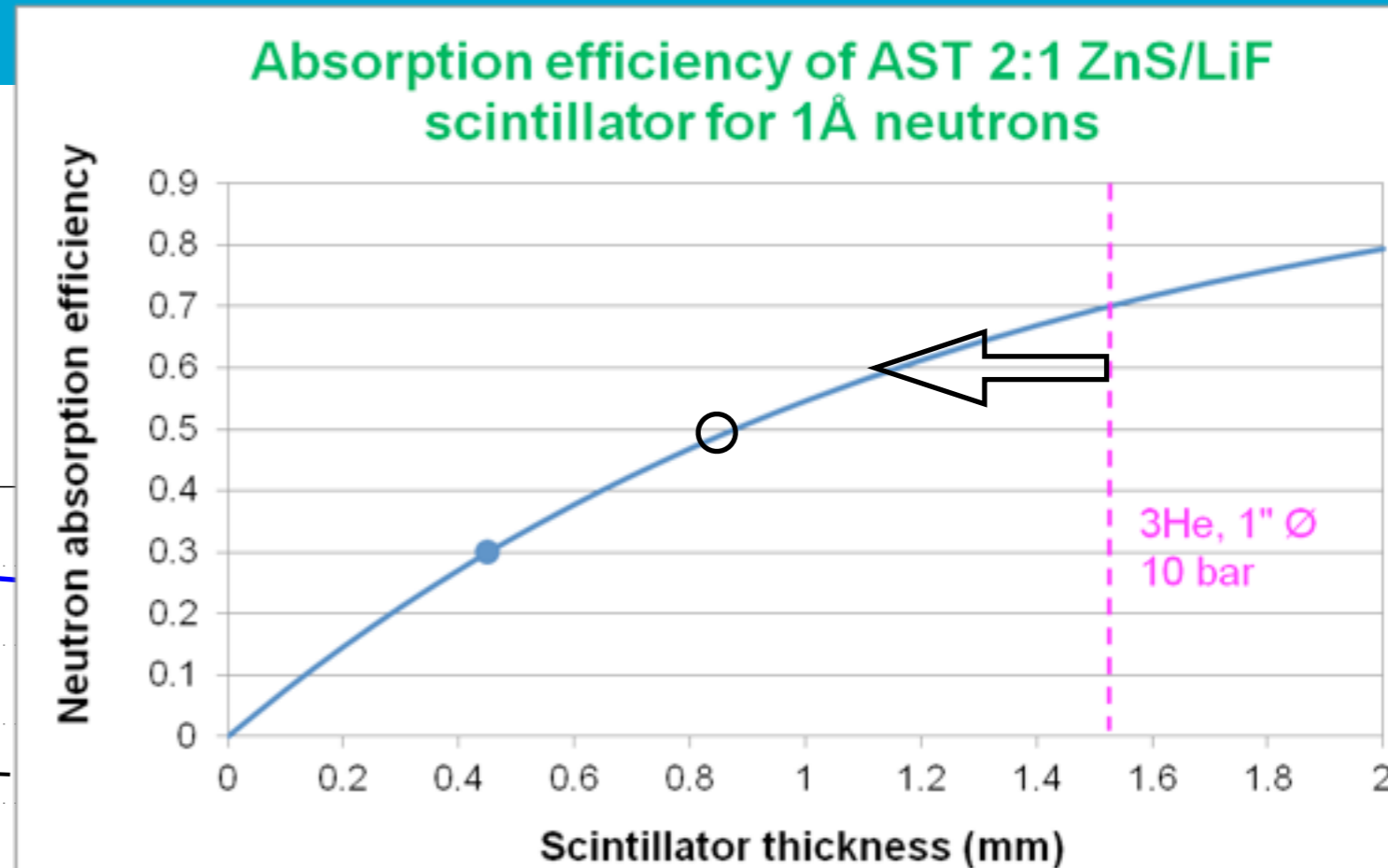
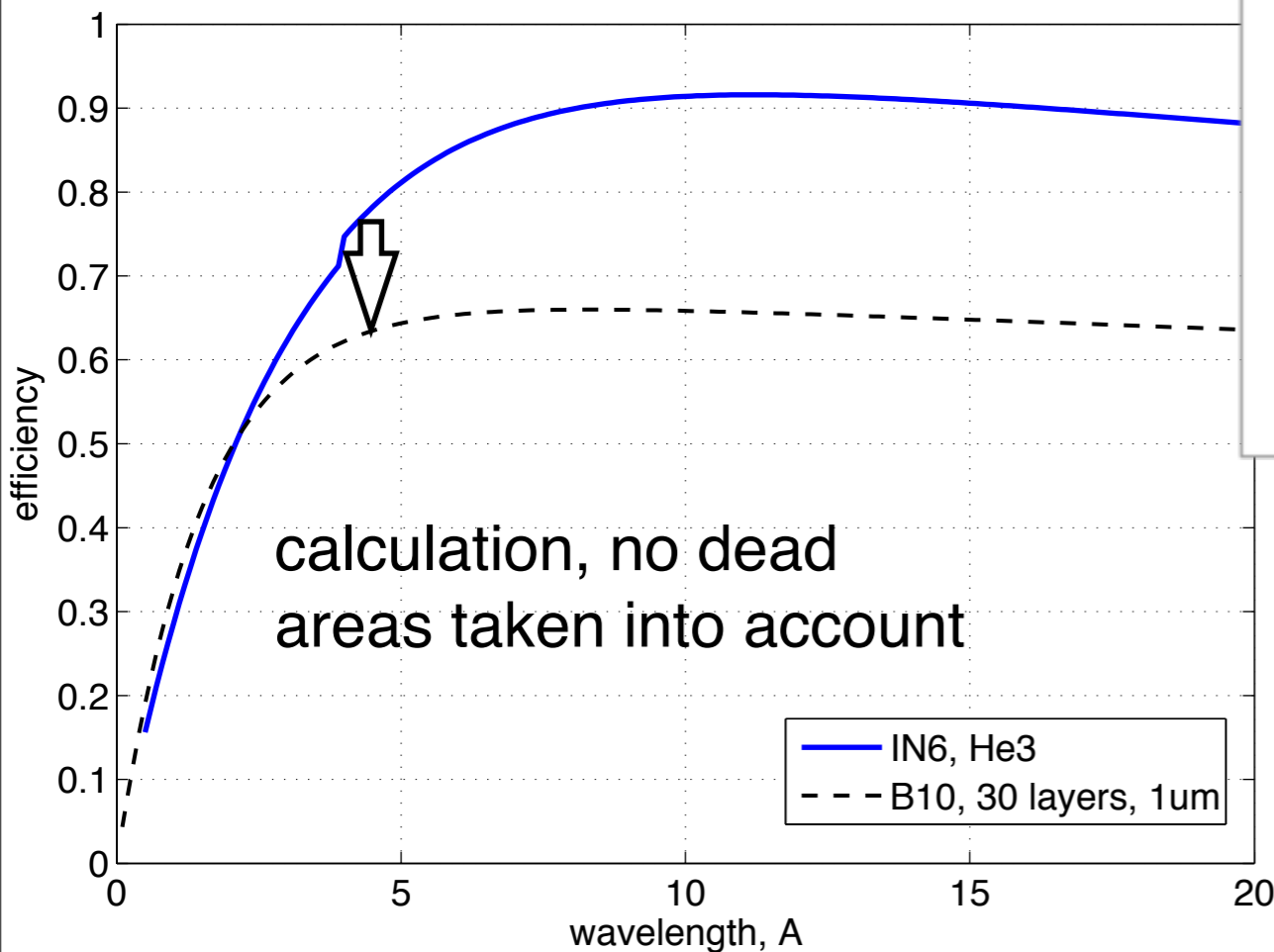
Quality and Standards: Detection Efficiency

cartoon:



“boundary conditions matter”

- Helium-3 is the gold standard, in particular in terms of detection efficiency
- However, efficiency numbers have rarely compared like-with-like



- Arrow indicate effect of dead regions into account with He-3 tubes
- Alternate technologies starting to approach raw efficiency numbers
- There is a need to compare like-with-like for the detailed instrument operating conditions
- Gamma rejection is a similar issue

Standards definition key part of ensuring best cost/quality detectors

compare like-with-like

Especially necessary with commercial suppliers, to define what we want measured

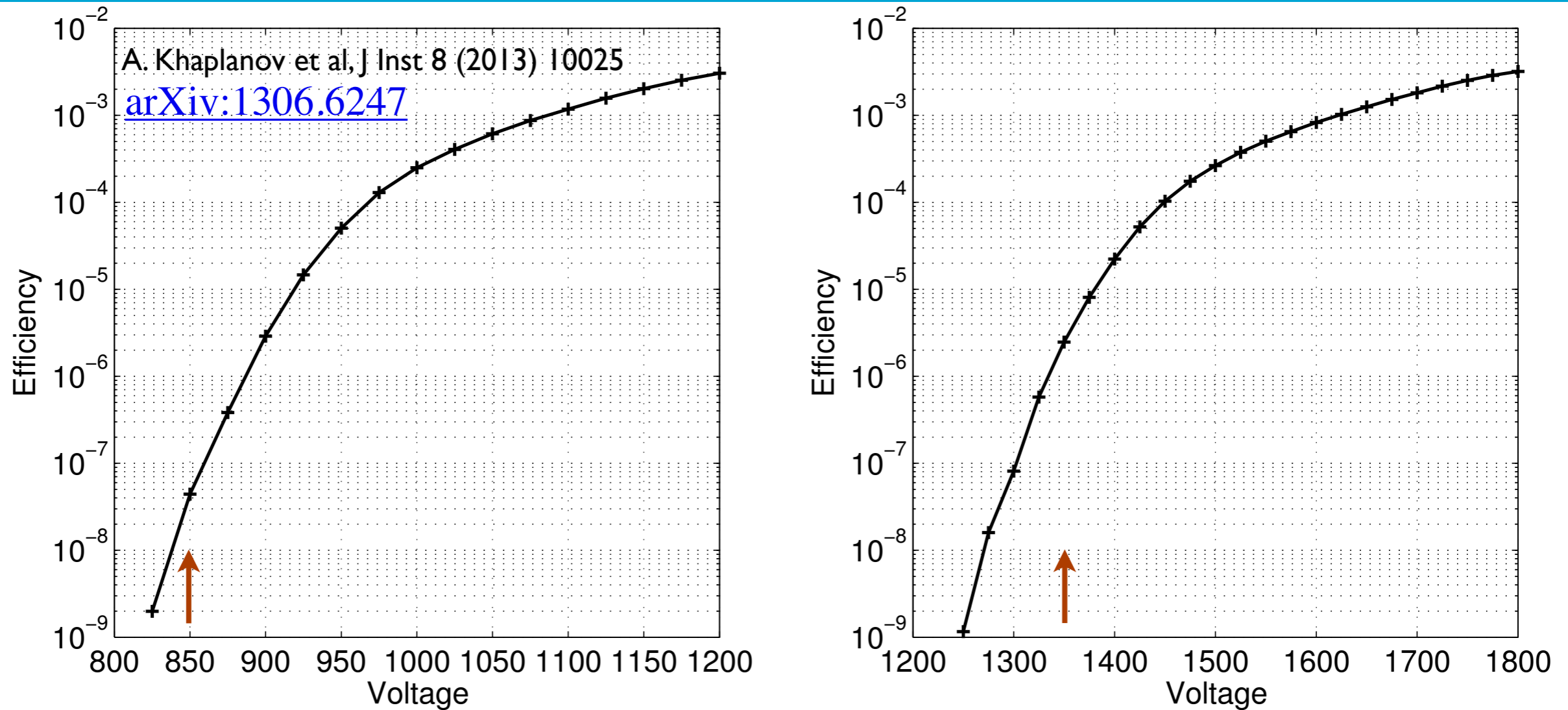


Figure 8: Plateau measurement with the Multi-Grid ^{10}B detector (left) and a Multi-Tube ^3He detector (right) with a strong ^{137}Cs source.

Quote gamma sensitivity at same working point as detection efficiency

Working on standards definition for other backgrounds and beam monitors

Collaborations

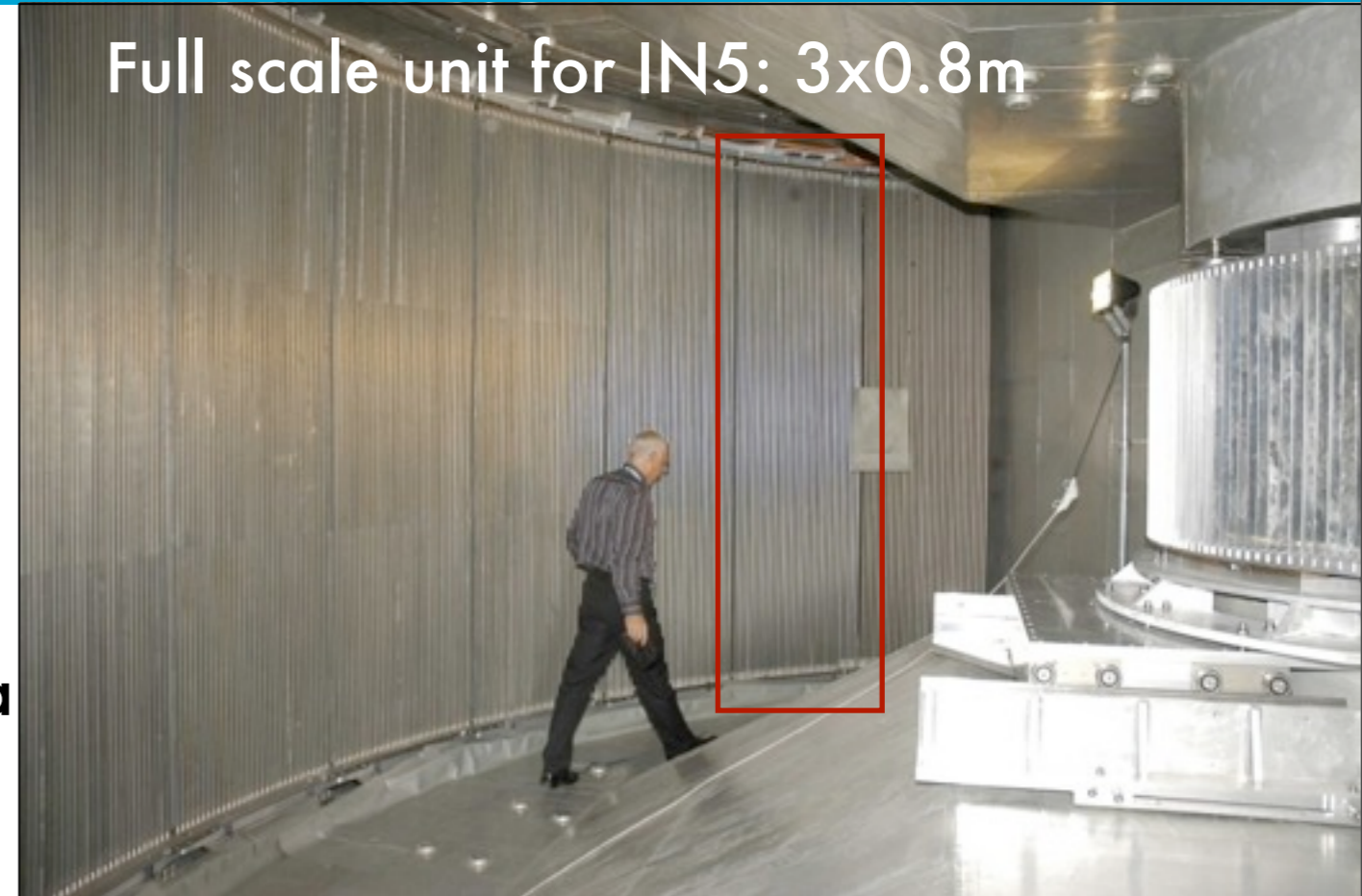
CMS



Multigrid Design: ILL/ESS/LiU Collaboration

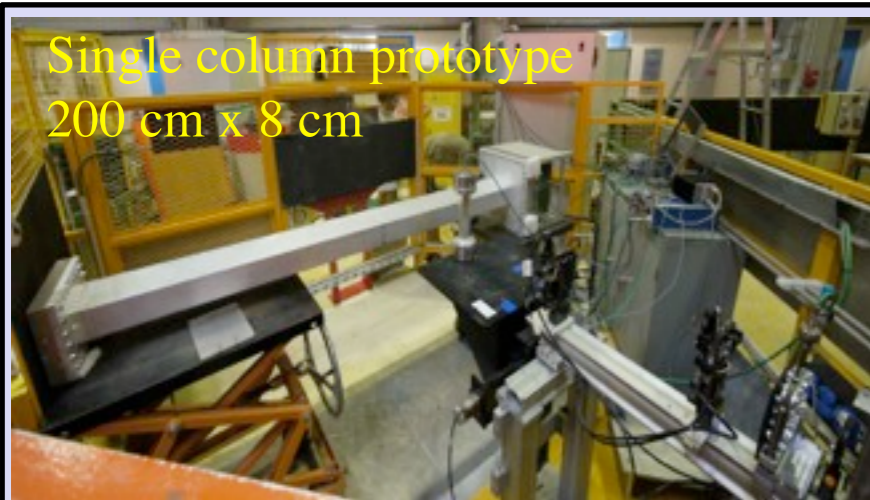
- This year: produce an IN5 equivalent module with the ILL Multigrid design
- Collaboration: ILL/LiU/ESS
- Detailed overview from Mathieu's talk
- $>70\text{m}^2$ B-10 coating
- IN6 demonstrator results showed that performance roughly equivalent to Helium-3
- NB started ca. 2009: if this is used on a tranche 1 ESS instrument, it is a 10 year development to beam cycle

Full scale unit for IN5: $3 \times 0.8\text{m}$



$^{10}\text{B}_4\text{C}$ thin film Multi-Grid detectors

The goal of the CRISP / WP15 work package is to show that the Multi-Grid concept + B_4C thin film converters is an alternative to ^3He for large area detectors



Single column prototype
200 cm x 8 cm

96 Grids and 60 wires readout individually

- 50% efficiency measured @2.5 Å
- B_4C coating process validated
- Film characterization
- Simulation of the detector
- Centre Of Gravity localization in Y
- Gamma sensitivity measured
- Ar- CO_2 & CF_4 tested at [0.2 - 1] Bar

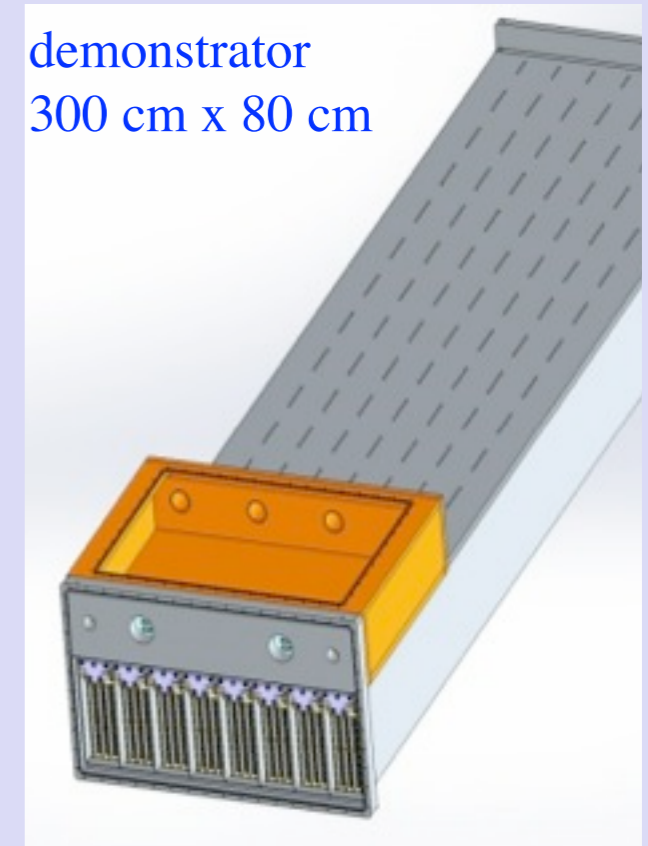
Where we were last year



IN6 prototype
32 cm x 50 cm

- 96 grids and 360 wires
- Grids of same Y connected by 3 → 32 channels
- Wires X_n & X_{n+1} connected with resistors → 24 channels
- Measurements on IN6
- Background observed, solved
- back scattering measured
- Electronics validated
- Demonstrator in fabrication

What has been achieved since then



demonstrator
300 cm x 80 cm

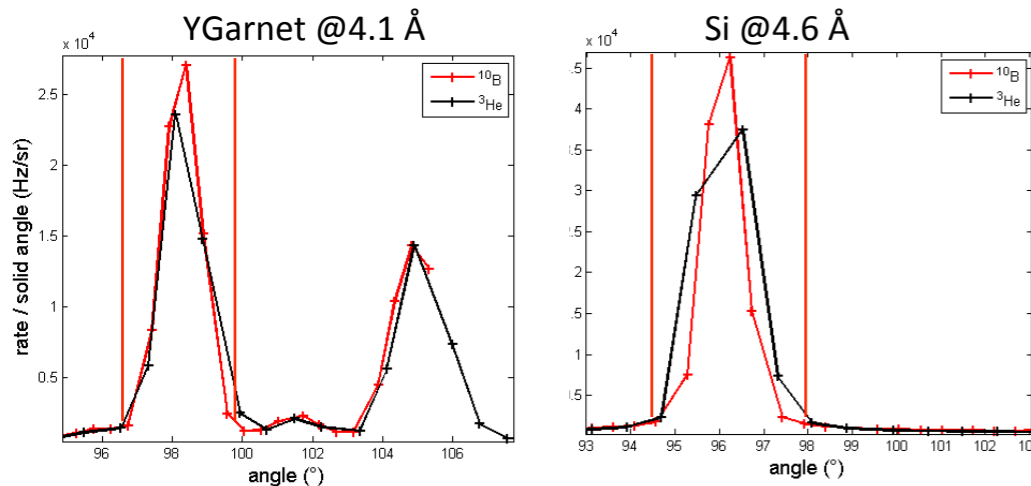
- 1024 grids/ 512 wires
- 256 x (4Grids) cath channels
- Wires X_n & X_{n+1} connected with resistors → 32 channels
- Pressure vessel tested
- Mass production of B_4C (70 m^2 !) and detector components
- real detector operational

Where we want to be next year

Multigrid Design: IN6 Demonstrator



IN6 Demonstrator



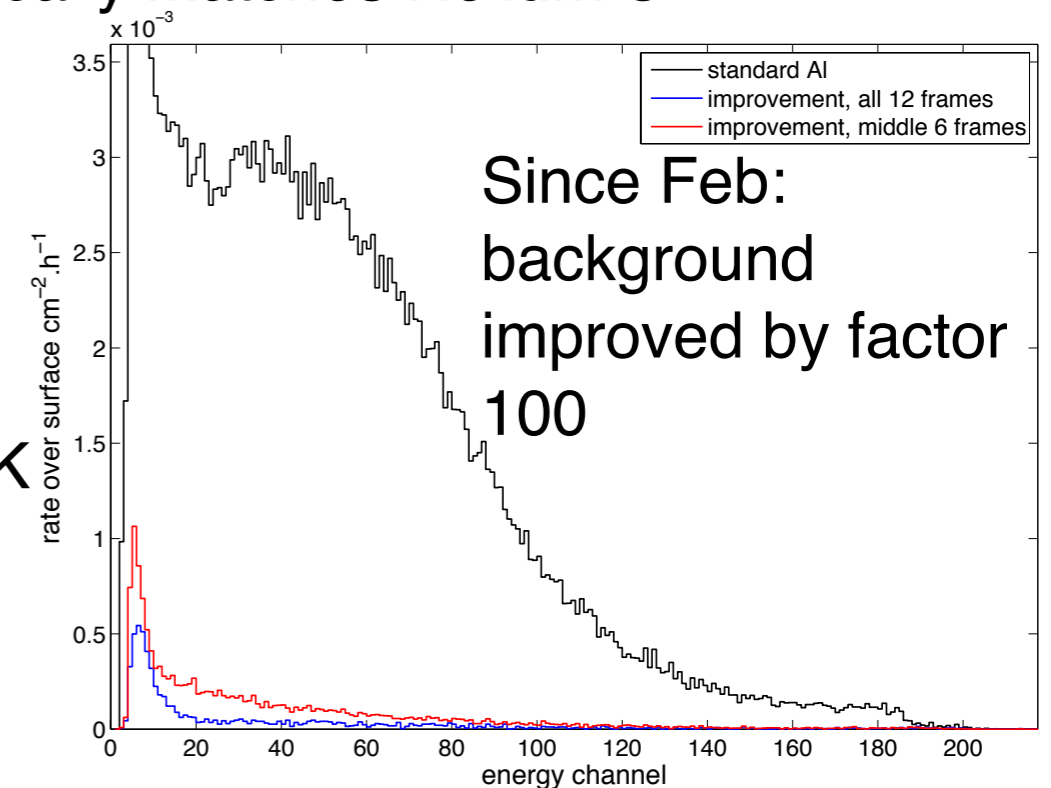
Ratio of integrated rates in Bragg peaks :

- 4.1 Å : $\text{rate}^{(10\text{B})} / \text{rate}^{(3\text{He})} = 1.08$
- 4.6 Å : $\text{rate}^{(10\text{B})} / \text{rate}^{(3\text{He})} = 0.97$

- background from alpha's in Al seen
- Plating or ultrapure Al solves it: now ok

• Performance basically matches Helium-3

- Efficiency - OK
- Data - OK
- Scattering - OK
- Gamma rej - OK
- t resolution - OK
- x,y resolution - OK

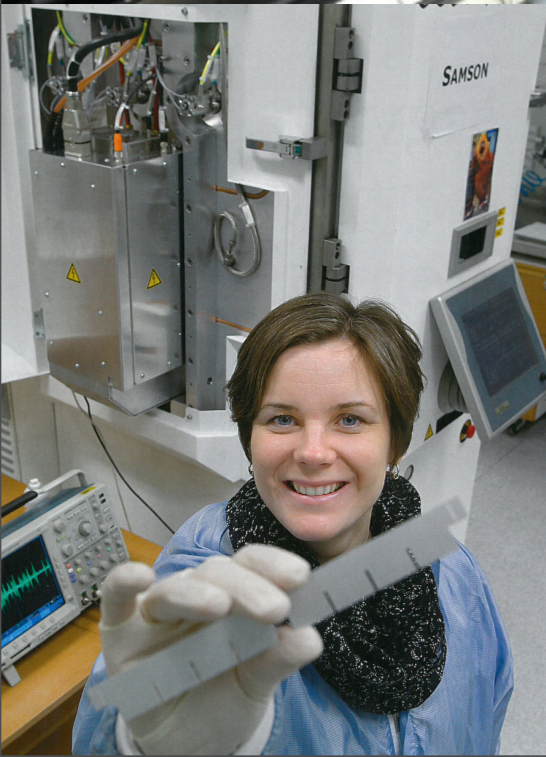
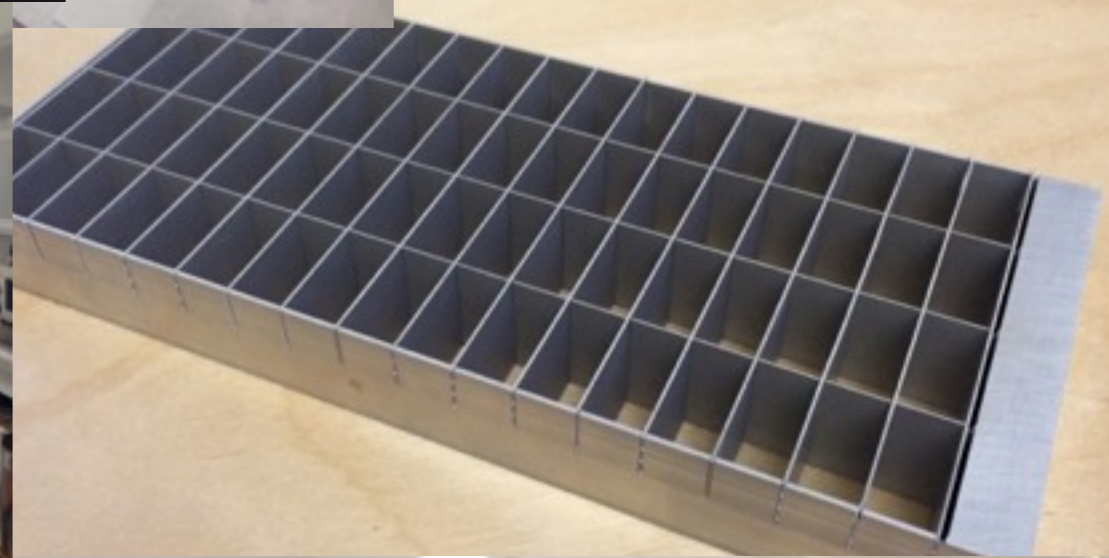
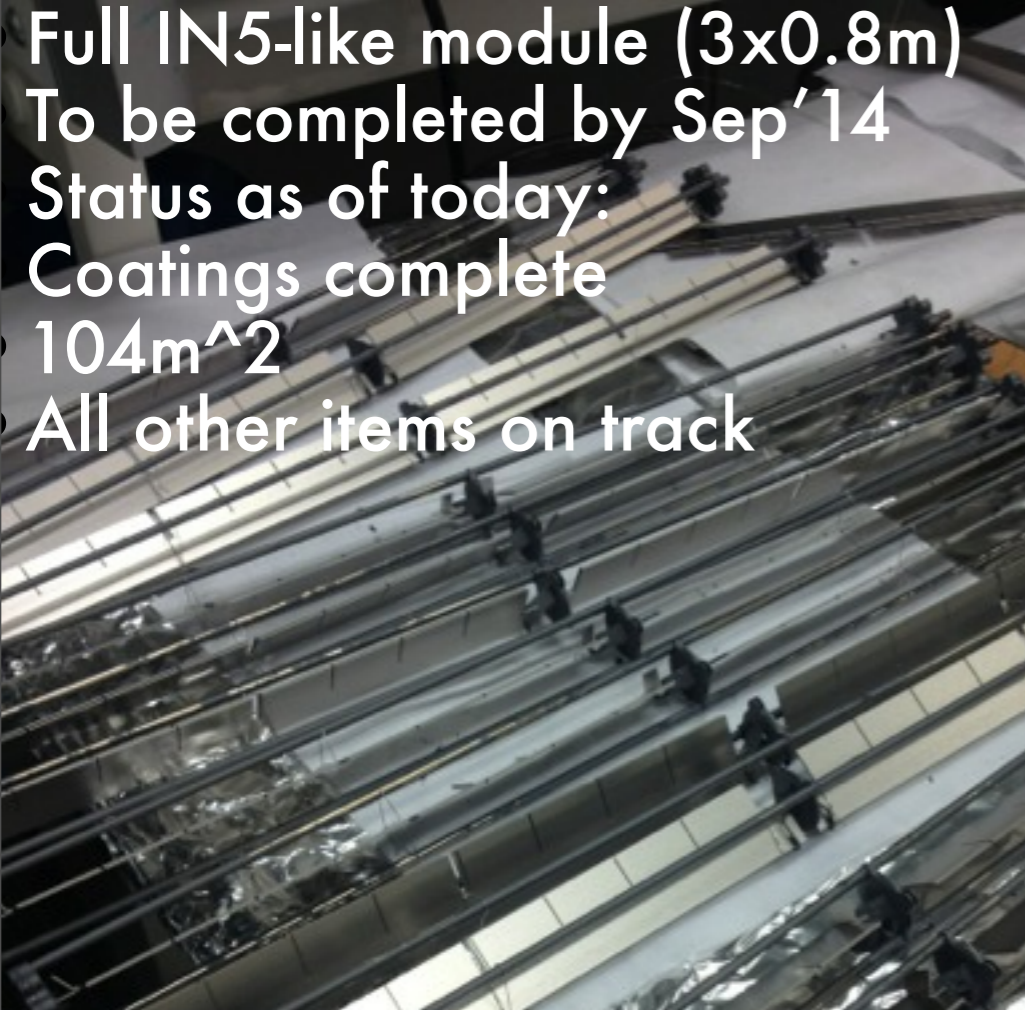
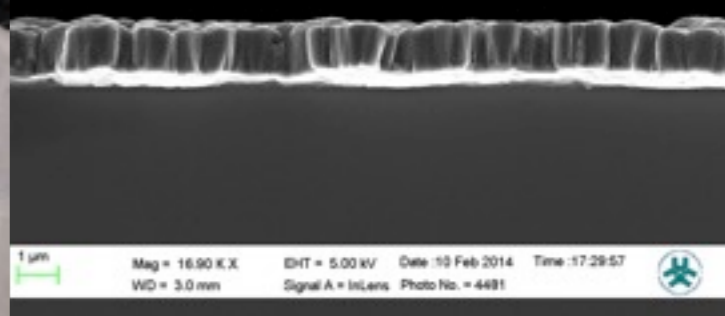
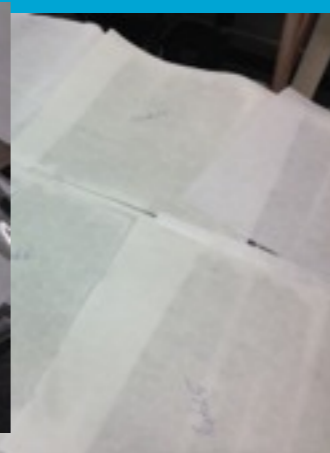


Since Feb:
background
improved by factor
100

Multigrid Design: IN5 Demonstrator

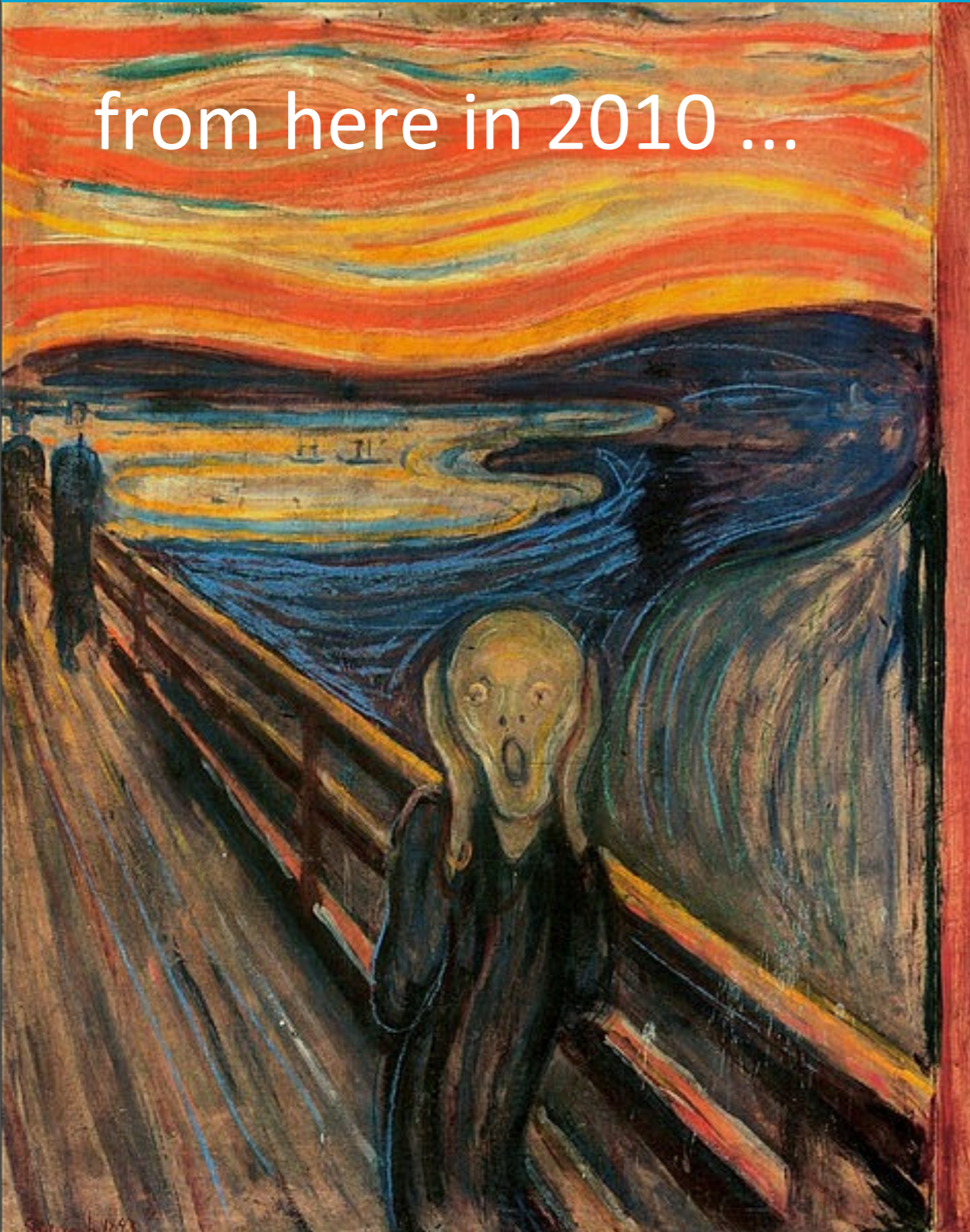
Mass production possible?

Full IN5-like module (3x0.8m)
To be completed by Sep'14
Status as of today:
Coatings complete
104m²
All other items on track



Mood Message for the R+D so far ...

from here in 2010 ...



to here in 2014...



Collaborations for Construction Phase

Instrument construction started for first 3 instruments

Challenge: select collaborative partners to build performant detectors



Collaborations for the Construction Phase



In-kind will be competitive: oversubscribed by factor 2++

Focus no longer on R+D but rather on advanced stage development and building detectors for instruments

In-Kind, Design Update



In-Kind, Construction Phase (so far ...)

Remember: front weighted



Collaborative Partners



Need partners to build detectors

Commercial Partners

Working with many commercial partners

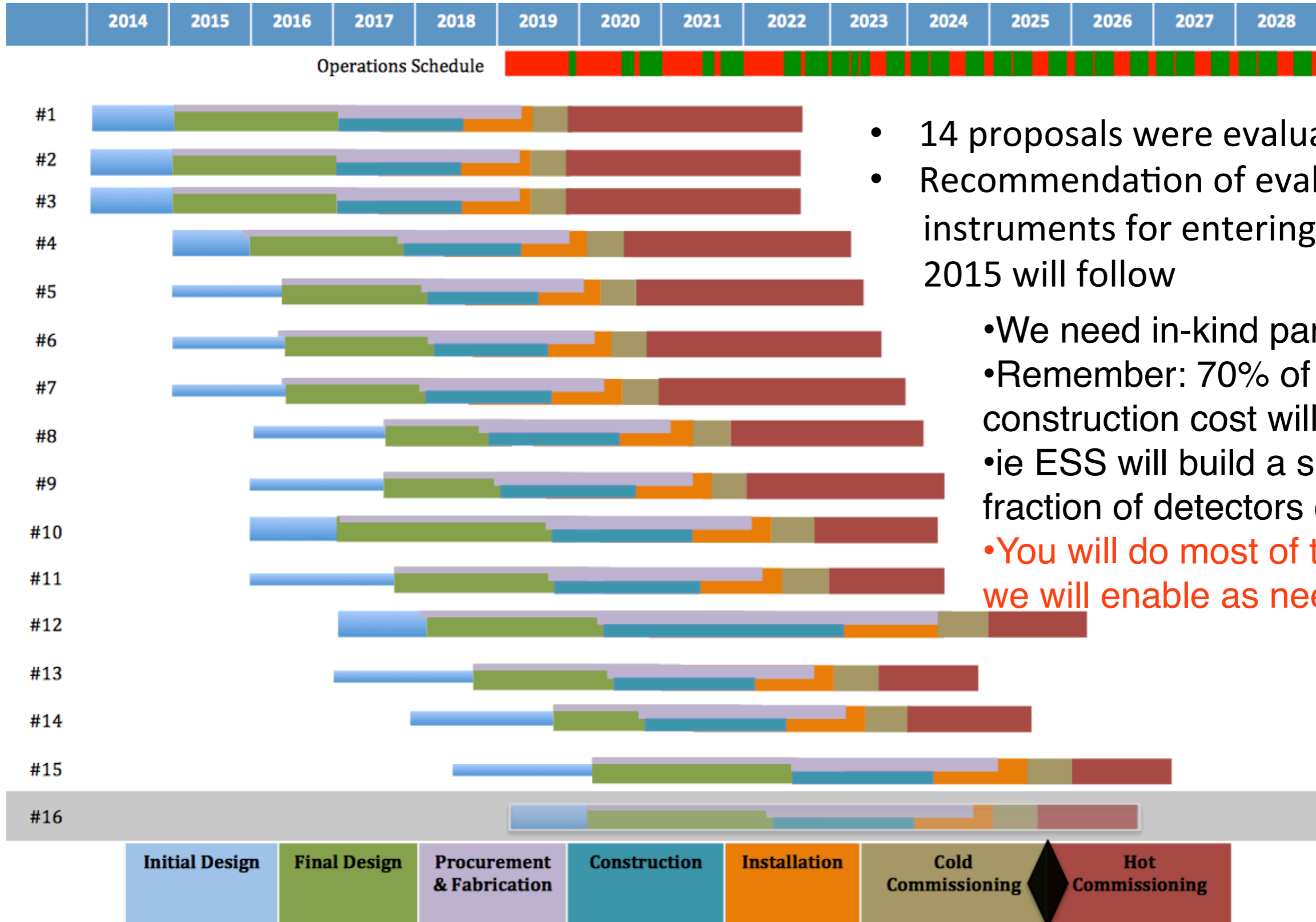
What is in-kind?

- In-Kind is a non-cash contribution to the ESS project
- Needs to be identified by ESS as useful for the ESS construction project
- Value will be identified by the ESS cost book and reviewed by the independent in-kind review panel
- This is not about sucking present resources from your present budgets, but rather opening up new resources (manpower, costs) for yourselves to do the scope of the work

- In-kind can be detector systems, detector parts (mechanics, electronics, etc), personal secondments or a particular study / tool
- In-kind can be from research institutes, universities, or industry (country dependent)
- From a partner country

- How does it work?
 - We start a dialogue with a partner.
 - If we can identify useful contribution(s) that fit both ESS needs and your capability, we start to draft it
 - This gets reviewed by ESS and by your country contacts
 - In-kind review committee reviews it
 - The ESS detector group works in partnership to help you deliver this contribution
 - You are funded through your national funding partner.
 - In-kind credit is given on agreed deliverables and milestones

From Construction to Operations



- 14 proposals were evaluated in May
- Recommendation of evaluated instruments for entering phase 1 in 2015 will follow
 - We need in-kind partners
 - Remember: 70% of detector construction cost will be in-kind
 - ie ESS will build a small fraction of detectors ourselves
 - You will do most of the build, we will enable as needed

• We need specialists not generalists

Timeline for detectors

• You saw a timeline for SANS (Loki) from Kelly yesterday

• Here is the equivalent for a thermal chopper spectrometer: “aggressive”

• We will be very focused on the first tranche of instruments that get accepted: “early success”

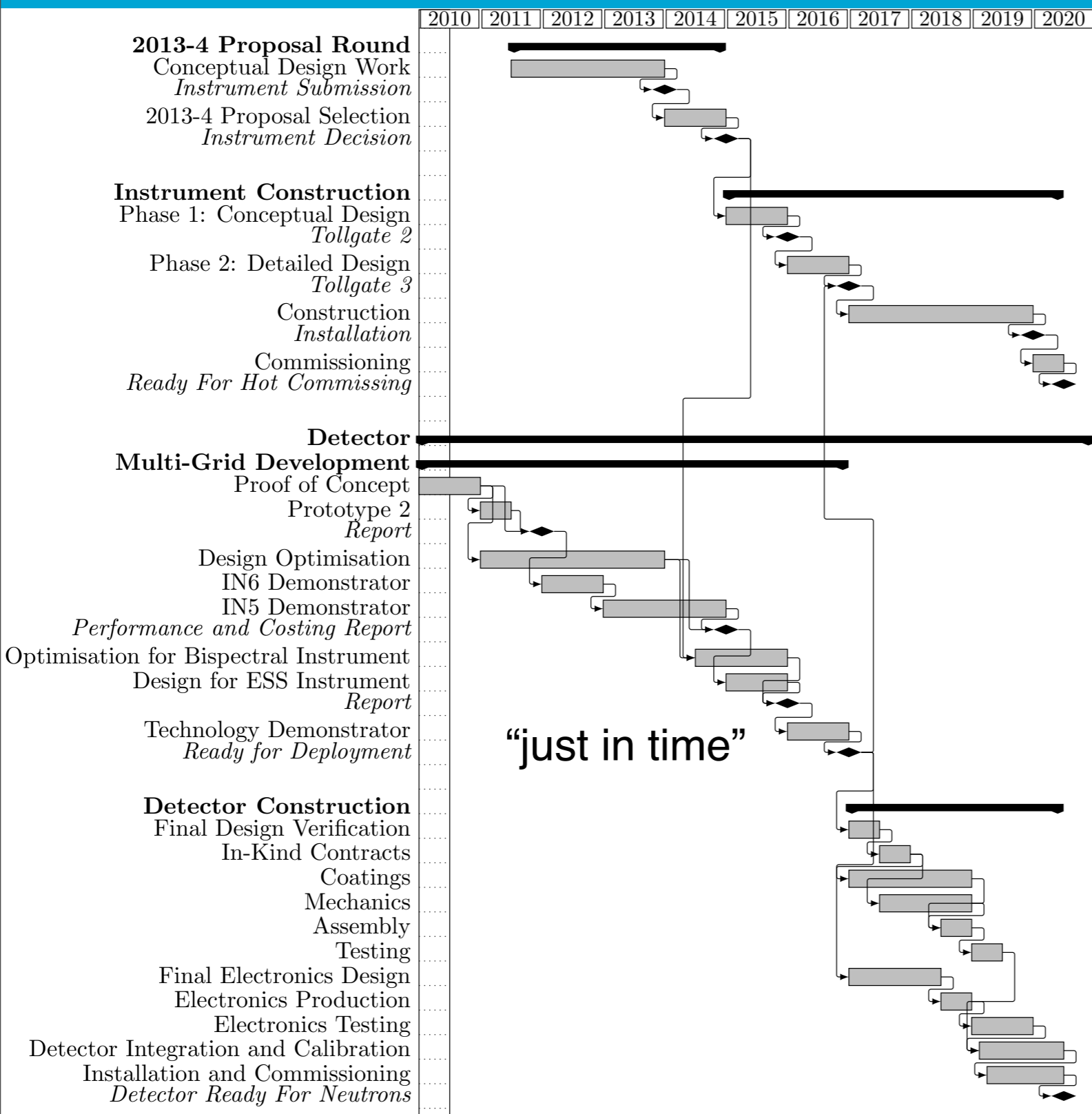
• Developments will be central: technologies which are ready and proven will be chosen

• Narrowing down the list of choices for the tranche 1 instruments

• 2019 is tomorrow: it means that any detectors built for then are well progressed with developments now

• We benefit and rely from the depth of expertise across our European partners: vast majority of work will be collaborative

• ESS will NOT be doing a large number of developments alone



HOW DID IT START?

Research on radiation detectors is truly multidisciplinary and does not fit into any call of the framework programmes of the European Union

There are several common challenges in detector development but the different communities tend to work on their own.

Each community is too small to influence the policies of the European Commission and the national funding agencies

There is strong tension between different organisations and different organisation networks.

slides from Christer Frojdh

THE IDEA

Create a bottom-up network with leading scientists in the field of radiation detection and imaging to exchange information between different application areas and to promote research in relevant fields at the European Commission and national funding agencies.

- individual based, not institute
- academia and industry
- will not run projects, nor administrative funding

slides from Christer Frojdh

ERDIT MISSION STATEMENT

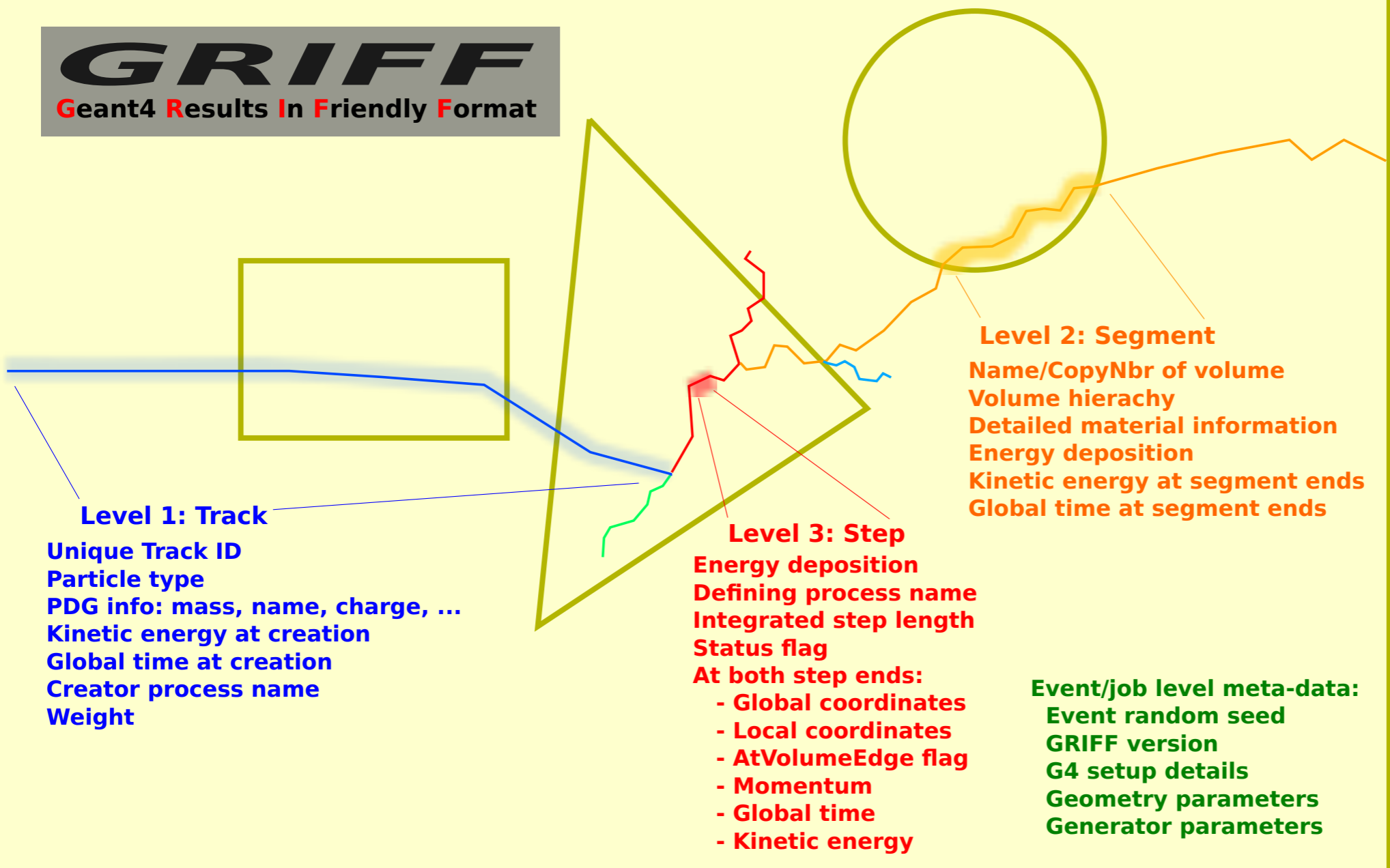
The mission of the European Radiation Detection and Imaging Technology Platform is to promote the research on radiation detectors and imaging at European level. The aim of this platform is to synergistically implement a common strategy across research infrastructures involving research laboratories, academy and industry, which would benefit fundamental science, promote innovation in industry and would feed into the crucial European societal challenges. This would be implemented through a process of guidance, prioritization and promotion of research, innovation and education with respects to fundamental science principles and contemporary benefit to society and growth of global competitiveness of European industries

<http://erdit.eu>

slides from Christer Frojdh

Summary

- Huge progress from the community as a whole for solving the Helium-3 crisis
- Very significant challenges still ahead for detectors ...
- Instrument construction started ...
- We are just about ready for it for detectors ...
- Core of detector group and facilities exists ...
- Looking forward to facing the challenge together ...
- We need to utilise the considerable expertise that exists across Europe
- Challenge is only achievable using in-kind
- Level of parallism needed for detector construction is suited to in-kind model
 - In-kind partnerships needed to complete bring the range of developments needed to the point that they can be installed on instruments
 - In-kind is about opening up extra resources for yourselves for synergetic benefit
 - Need to build up centres of excellence in Europe rather than a large numbers of all-rounders
- Single take-away message: the ESS project needs extensive collaboration and partnership on detectors for success

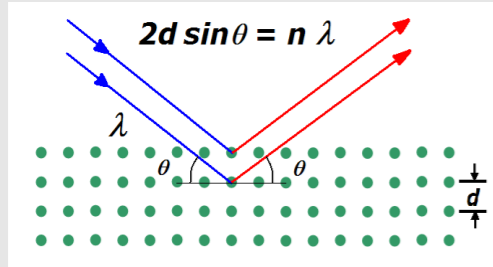


• As Kelly said yesterday: Triangle of Analytical Calculations, Simulation, Measurements complimentary

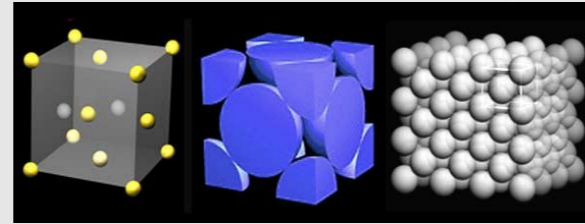
- GEANT4 is essential for detailed design of all these detectors
- Have a common framework for ourselves, centred around DMSC
- Primarily aimed at Boron-10 detectors initially

Neutron diffraction in polycrystals (Al, Cu, ...)

■ Neutrons with $\lambda \approx 1\text{\AA}$ scatters coherently on crystal planes at angles given by Bragg condition:

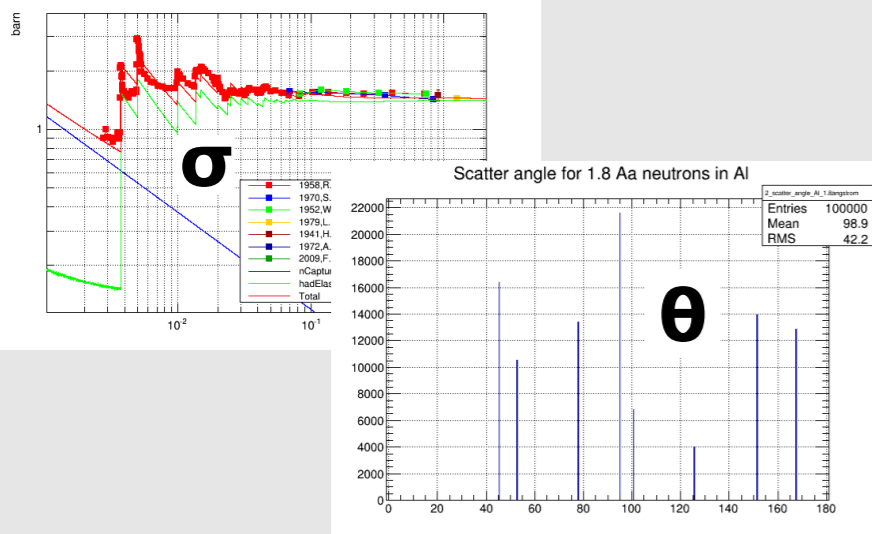


■ NXSLib provides first principle calculation of relevant quantities, based on crystal unit cell definition:



```
(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
```

■ Affects X-section and angular distribution:



■ Unit cell must be associated to G4Material during geometry construction.

■ Details of Geant4/NXSLib integration to be described in joint paper with NXSLib author M. Boin, Helmholtz-Zentrum Berlin

• implemented diffraction (via NXSLIB) in GEANT4

• See Proc. CHEP'13

• Paper submitted

