EUROPEAN SPALLATION SOURCE

Detectors for Spallation Sources

- Neutron Scattering Science
- How to design
- Detectors for the ESS
- Summary

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Detector Group Leader

NDRA2014

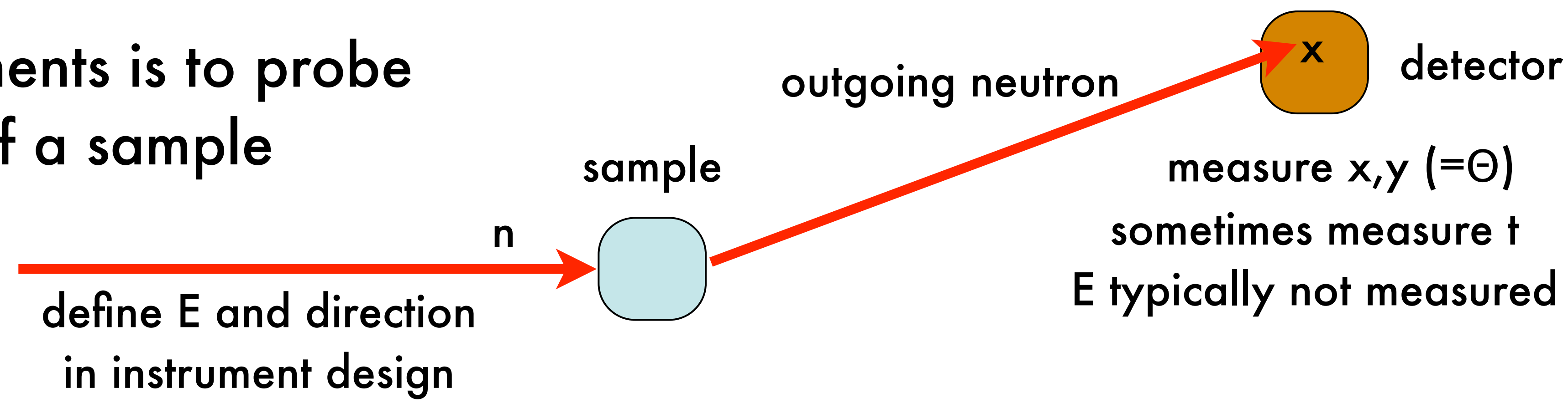
What I am going to talk about

- What is needed?
  - Always design to science goals (but not too closely)
- How to select based on the requirements
  - What can happen to a neutron?
  - Triangle of data/simulation/analytical calculation
  - Rate, dynamic range and noise
  - Resolution
  - Efficiency
  - Background
- Requirements for the European Spallation Source
- Specific examples
- Summary and a few observations

Try and work through as an example of how detector geometries are selected

Why?

- The purpose of the instruments is to probe with neutrons some aspect of a sample



- Very generically, this can be divided into elastic and inelastic categories
  - elastic: gives information on where atoms are
  - inelastic: gives information on what atoms do (ie move)
- This is measuring the cross sections:

elastic

$$\frac{d\sigma}{d\Omega}(\lambda, 2\theta, \psi)$$

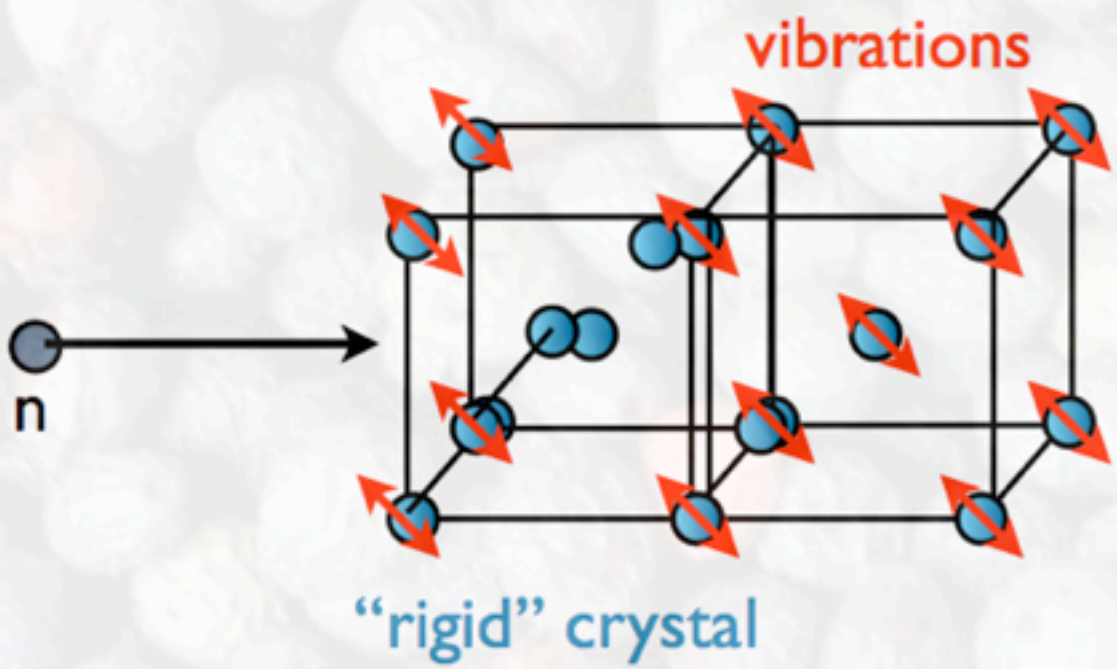
- cross section / scattering probability into a solid angle, as a function of wavelength, scattering angle and aximuthal angle

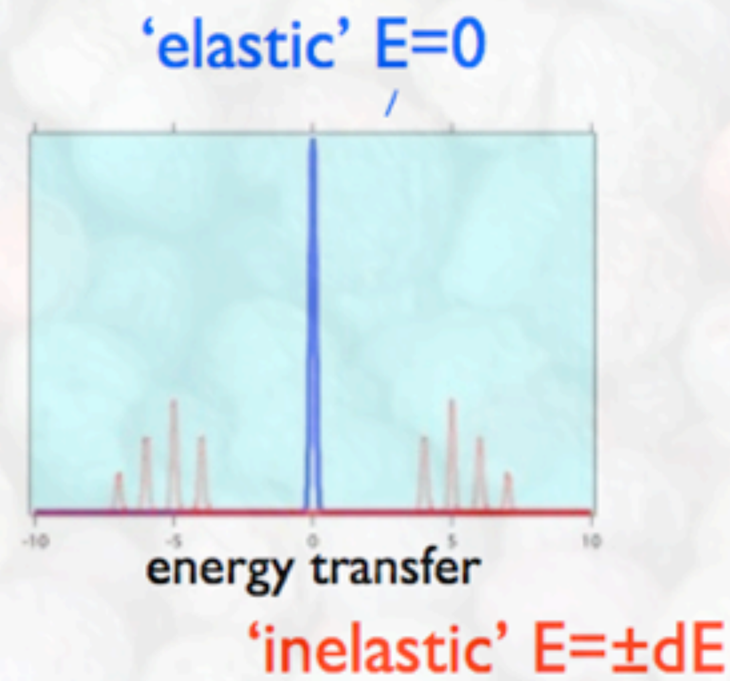
inelastic

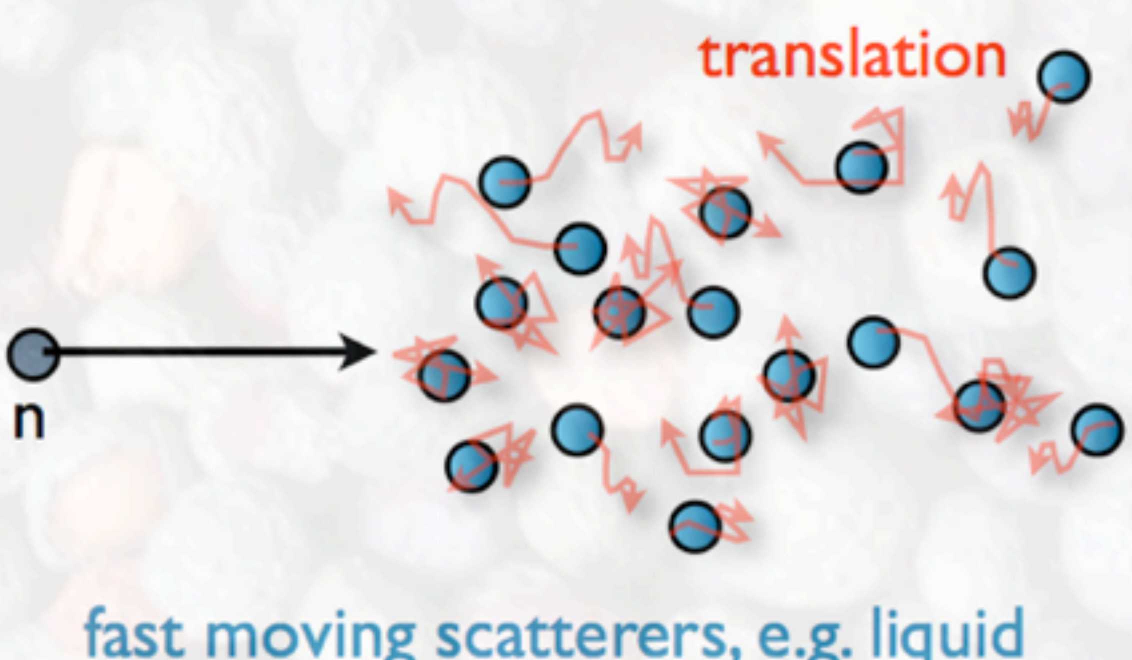
$$\frac{d^2\sigma}{d\Omega dE}(\lambda_{in}, \lambda_{sc}, 2\theta, \psi)$$

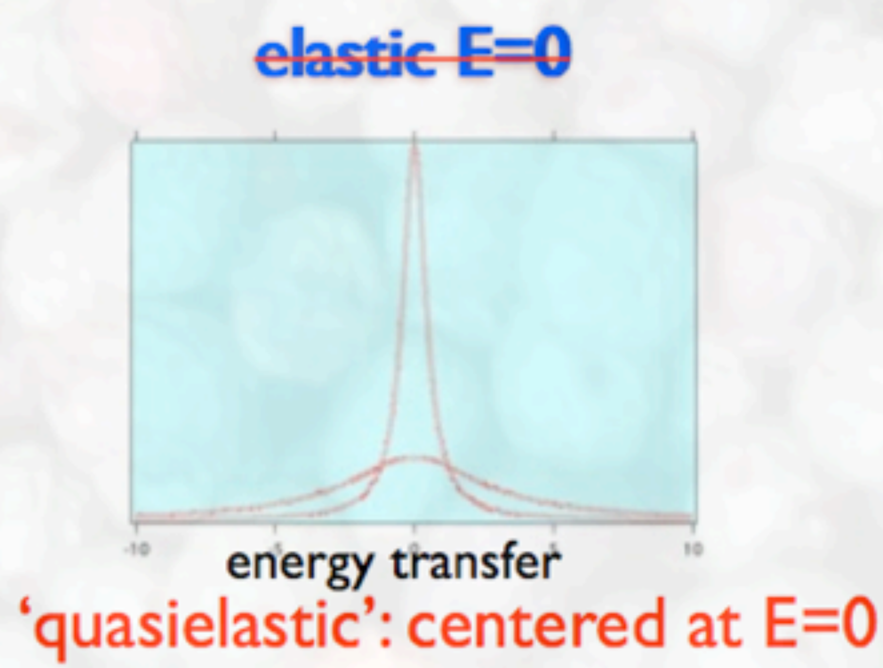
- double differential cross section / scattering probability into a solid angle, as a function of wavelength, scattered wavelength scattering angle and aximuthal angle

Elastic vs Inelastic



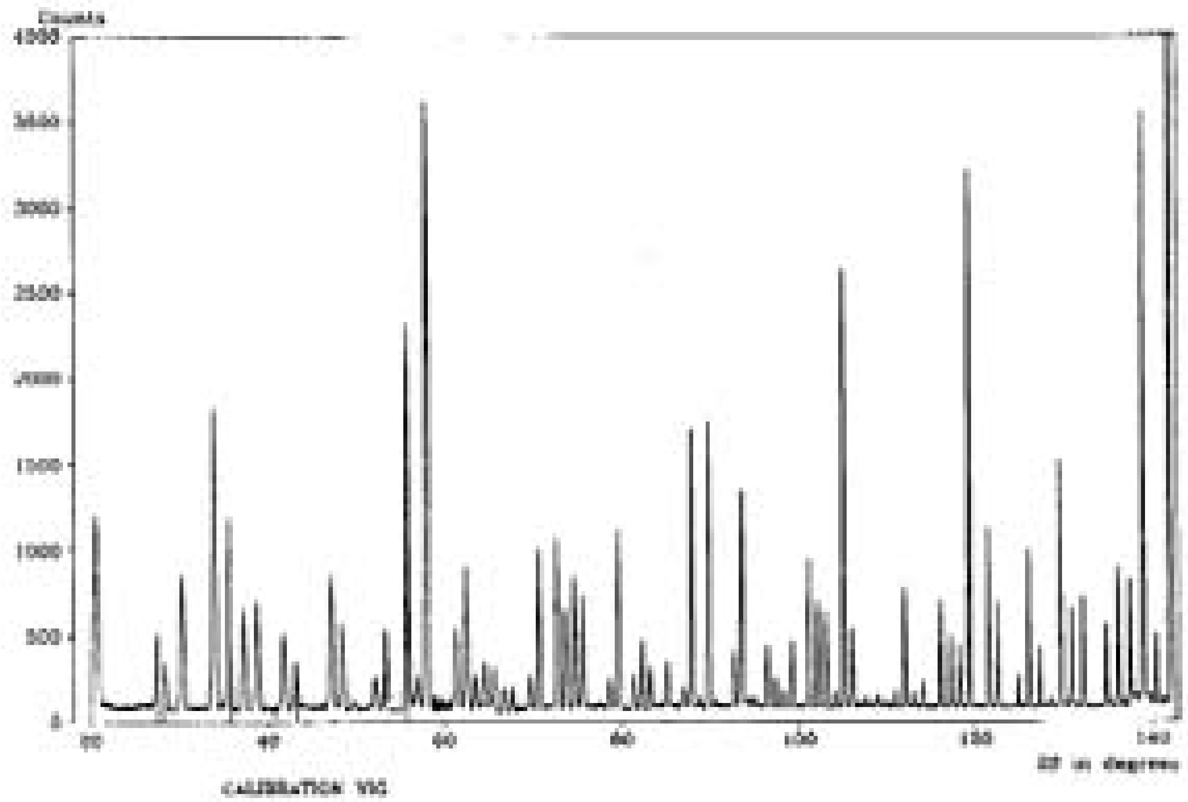






Detectors are tools

Basically, in some form,
you want to measure
Bragg's equation



$$\mathbf{n}\lambda = 2d\sin\theta$$

Define the neutron wavelength with your instrument design

Detectors allow you to measure theta

It means that you can calculate "d"

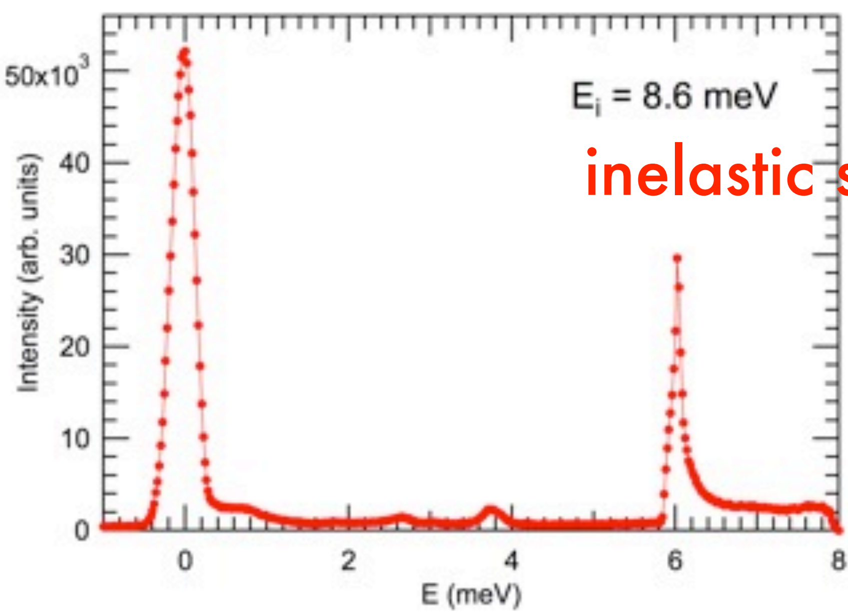
Therefore the detector should be designed to give you the most appropriate measurement of scattering angle for a instrument class

"horses for courses "

What do the detectors need to measure?

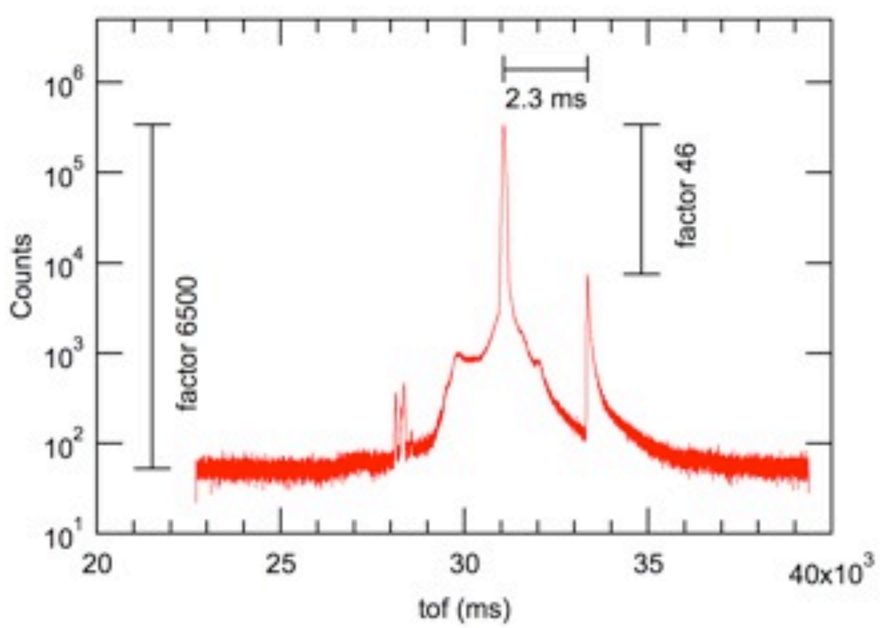
- Neutron Scattering for materials science comprise a great variety of instruments as tools for studying materials
- High efficiency is expected
- Each has its own "figure of merit"

"horses for courses "



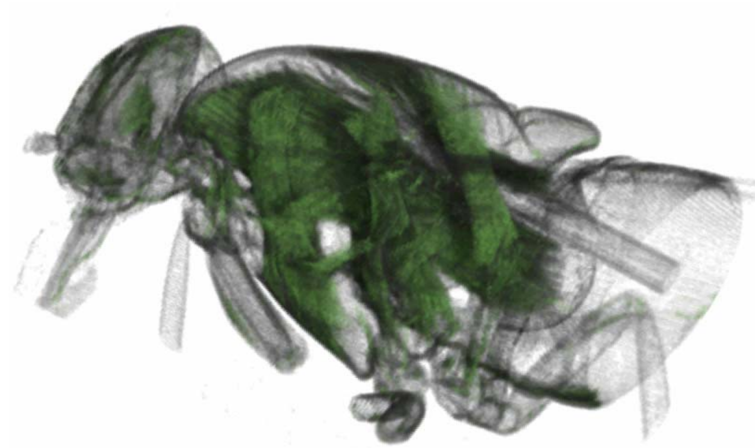
inelastic scattering

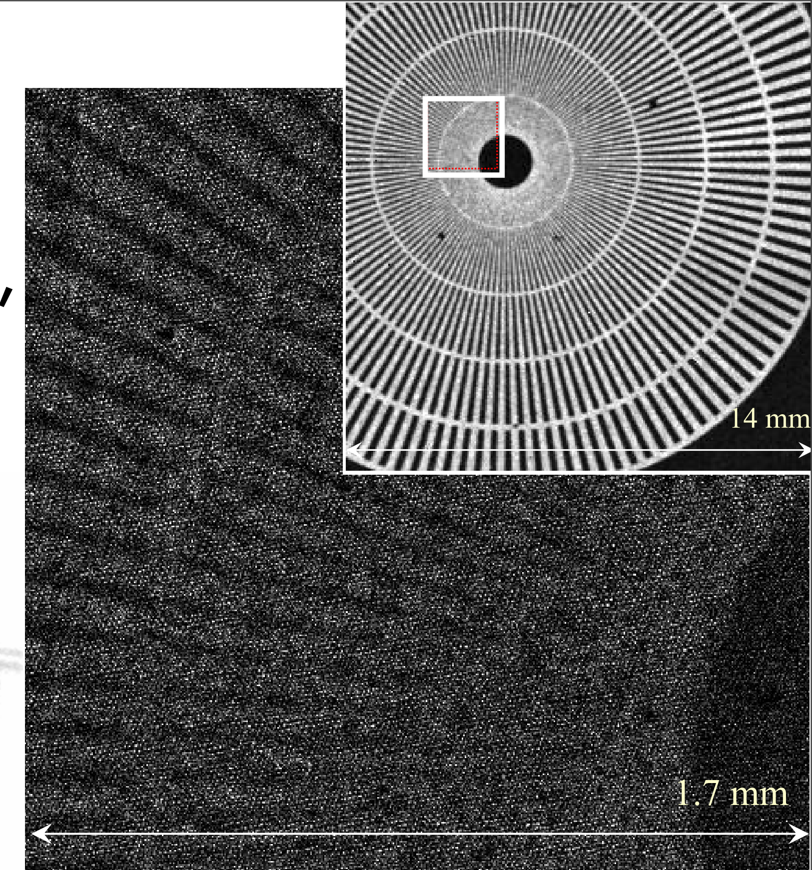
area, cost, background



imaging

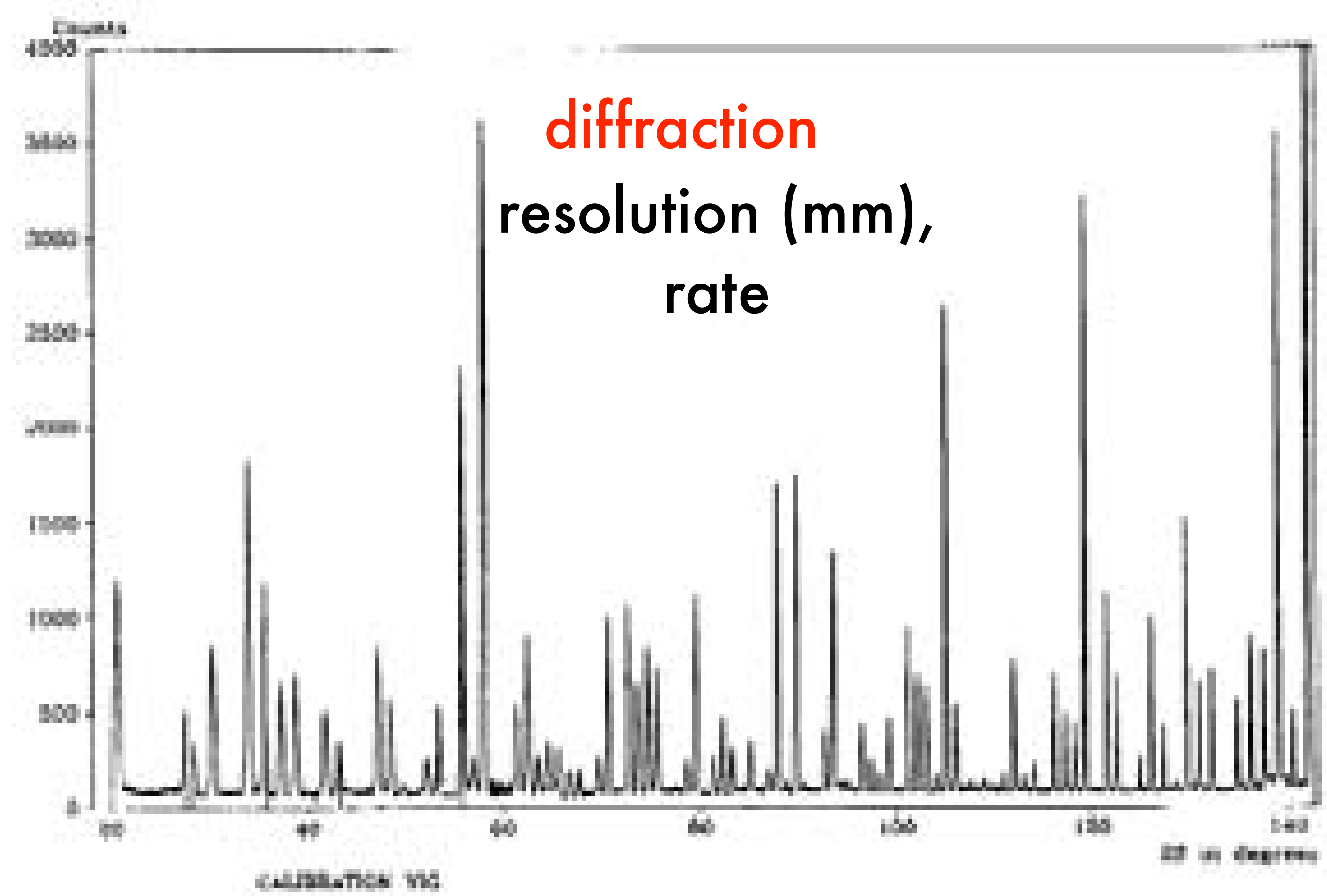
resolution (<100um), rate





diffraction

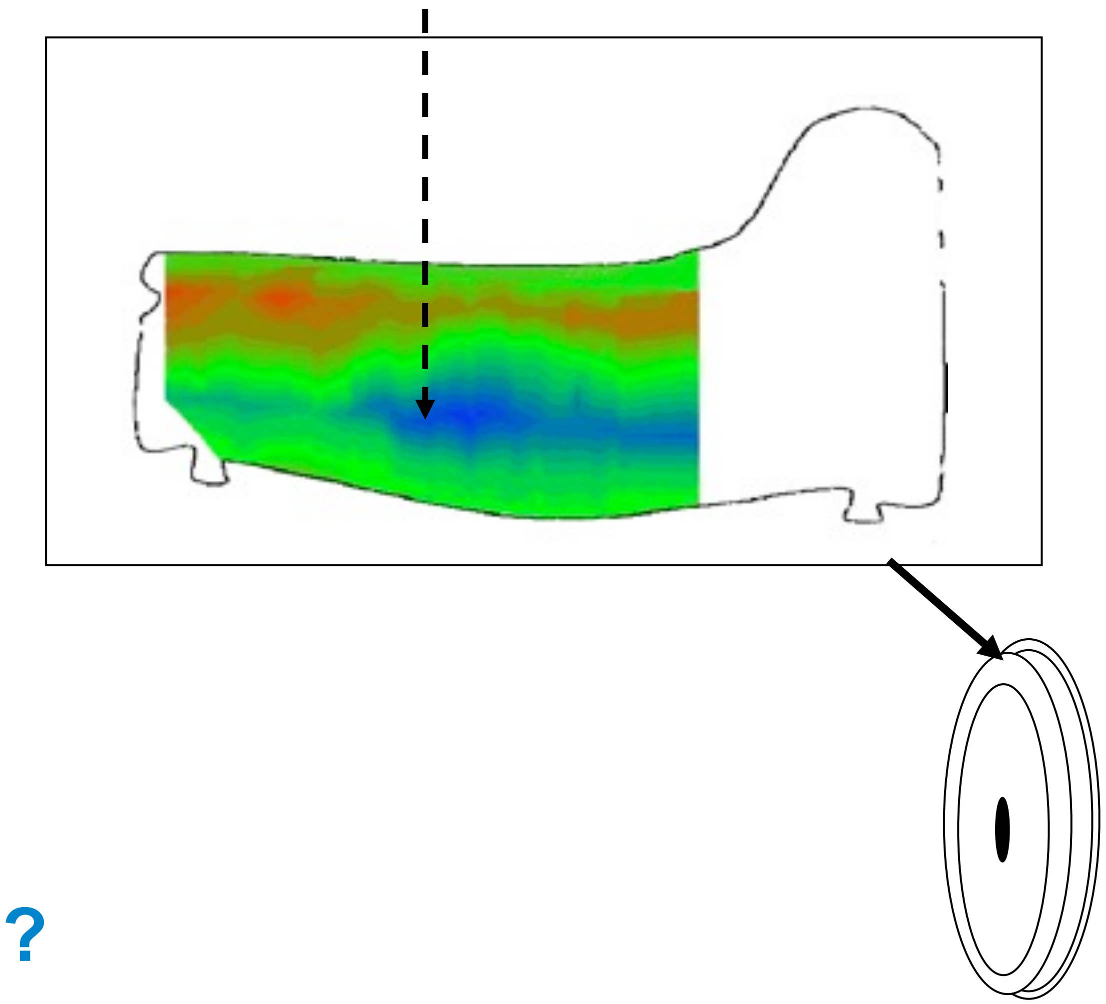
resolution (mm), rate



Neutron can see deep inside matter…

ICE accident, Eschede

Neutrons see **(tensile) stress** inside bulky metal parts that caused wheel failure: **standard engineering theory of plastic deformation stresses in error in the 1990s!!**

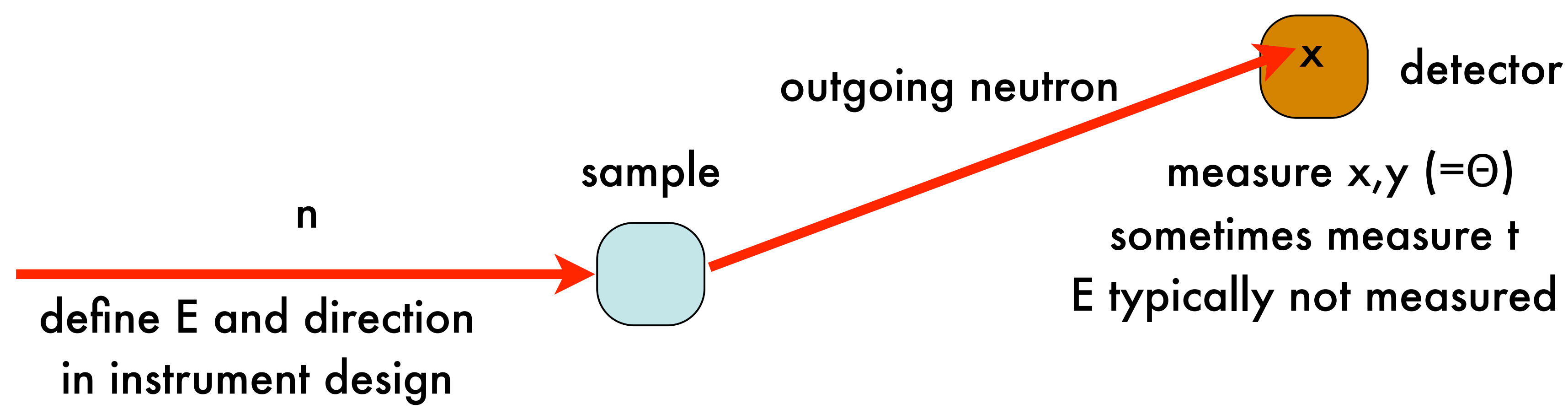


Knowledge based society??
Safety philosophy?
Industrial / proprietary use

Detector Requirements

- How to define the requirements
  - What can happen to a neutron?
  - Triangle: data/simulation/analytical.
  - Rate
  - Resolution
  - Efficiency
  - Background

Neutron Detectors - what information do you get?



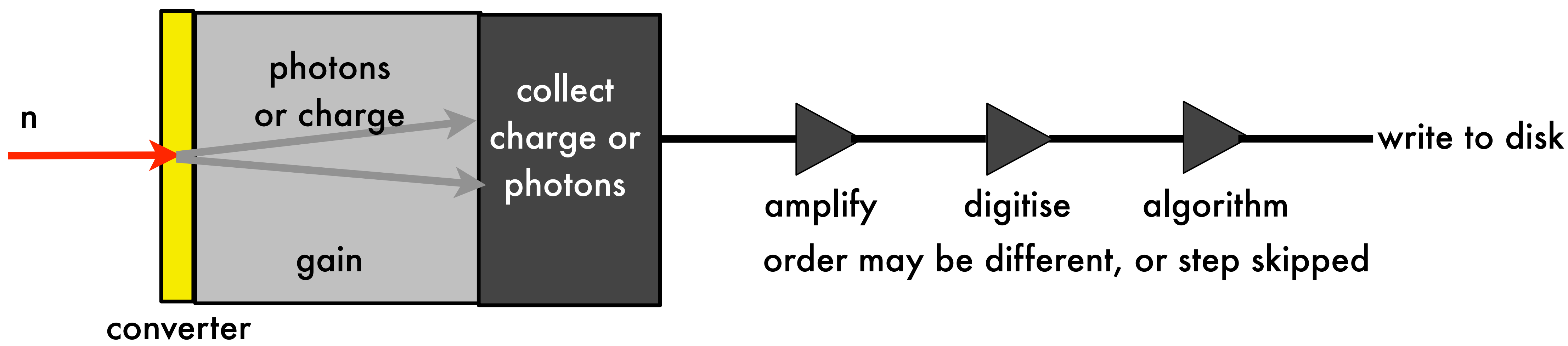
- Scattering angle measured through x,y position of the neutron detected
- Time of detection often used
  - It is vital to have good time resolution for instruments at spallation sources
- Energy typically not measured
  - In some ways, the holy grail to have a good energy measurement of the neutron?
- Detector needs to be adapted to the expectations for that instrument
  - Not one design fits all

Cost is always a limiting factor in the design of detectors
Schedule will determine what you can do about it

Detectors - what do we mean? An analogy ...

Basic Principles of Neutron Detectors

- Need to produce a measurable electric signal
- Not possible to directly detect slow neutrons - energy is too low
- Need to use nuclear reactions to convert neutrons into charged particles
- Then indirectly detect the charged particles in a charged particle detector
- Amplify, digitise, process as needed.
- Store data on disk



Cross-sections of Materials used (ILL Blue Book)

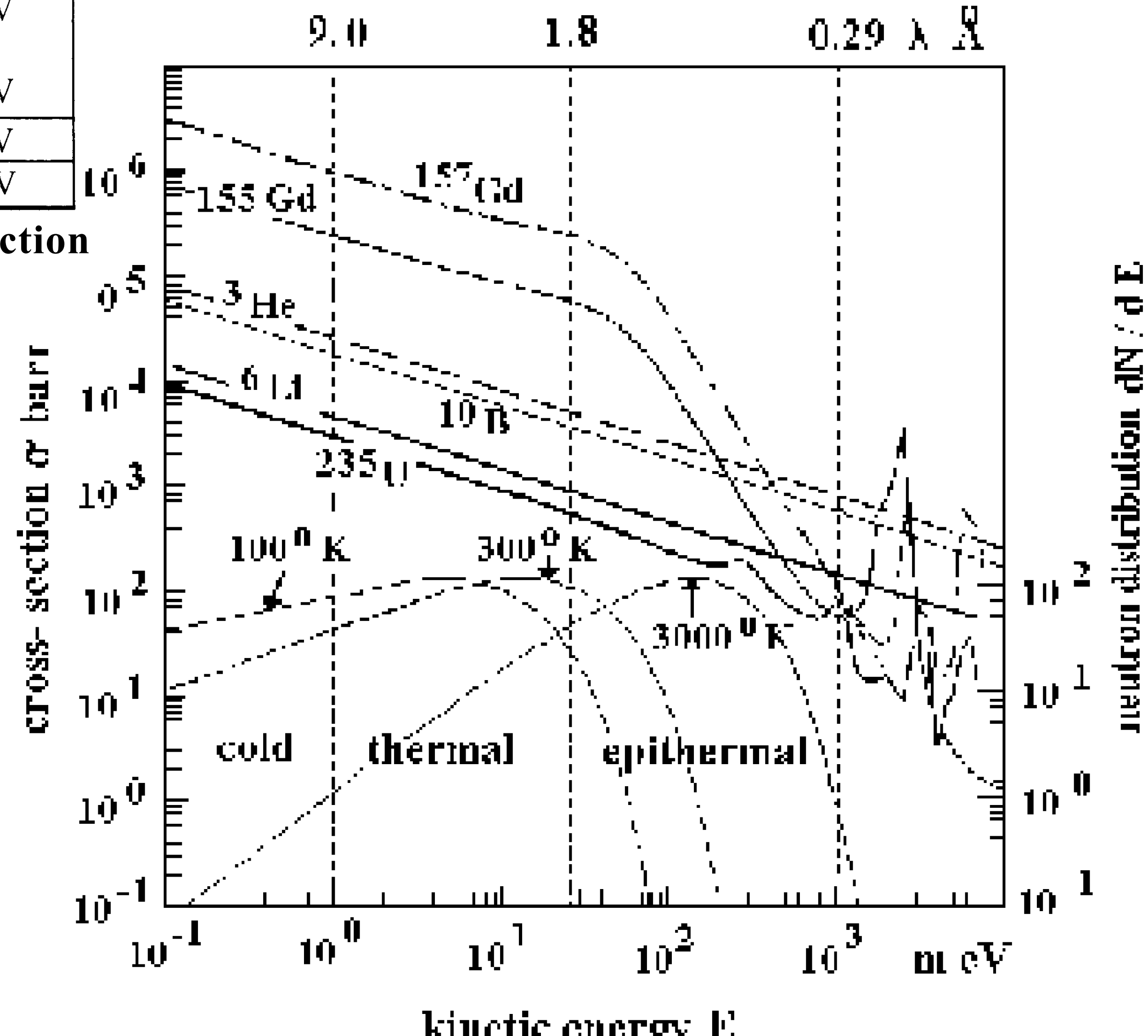
reaction	energy	particle	energy	particle	energy
n (^{3}He, p) ^{3}H	+0.77 MeV	p	0.57 MeV	^{3}H	0.19 MeV
n (^{6}Li, α) ^{3}H	+4.79 MeV	α	2.05 MeV	^{3}H	2.74 MeV
93 % n (^{10}B, α)^{7}Li +2.3 MeV + γ (0.48MeV)		α	1.47 MeV	^{7}Li	0.83 MeV
7 % n (^{10}B, α) ^{7}Li	+2.79 MeV	α	1.77 MeV	^{7}Li	1.01 MeV
n (^{235}U,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

Target-material		density g / cm^3	cross-section σ barn	abs. length μ cm	mass abs. dens. γ g / cm
^{3}He	gas 1bar	$1.27\ 10^{-4}$	$5.33\ 10^{3}$	7.36	$9.34\ 10^{-4}$
^{6}Li	metal	$4.70\ 10^{-1}$	$9.45\ 10^{2}$	$2.24\ 10^{-2}$	$1.05\ 10^{-2}$
Li nat	metal	$5.43\ 10^{-1}$	$6.62\ 10^{1}$	$3.20\ 10^{-1}$	$1.74\ 10^{-1}$
^{6}Li F	crystal	2.55	$1.21\ 10^{3}$	$1.56\ 10^{-2}$	$3.98\ 10^{-2}$
^{10}BF$_3$	gas 1bar	$2.82\ 10^{-3}$	$4.01\ 10^{3}$	9.80	$2.77\ 10^{-2}$
^{10}B	crystal	2.16	$4.01\ 10^{3}$	$1.92\ 10^{-3}$	$4.14\ 10$-^{3}
B nat	crystal	2.34	$7.50\ 10^{2}$	$1.2\ 10^{-2}$	$2.81\ 10^{-2}$
Mg	metal	1.74	$6.23\ 10^{-2}$	$3.67\ 10^{2}$	$6.39\ 10^{2}$
Al	metal	2.70	$2.38\ 10^{-1}$	$6.96\ 10^{1}$	$1.88\ 10^{2}$
Fe	metal	7.86	2.59	4.55	$3.57\ 10^{1}$
Cd	metal	8.64	$2.51\ 10^{3}$	$8.56\ 10^{-3}$	$7.40\ 10^{-2}$
Gd nat	metal	7.89	$4.61\ 10^{4}$	$7.16\ 10^{-4}$	$5.65\ 10^{-3}$
^{157}Gd	metal	7.89	$2.51\ 10^{5}$	$1.31\ 10^{-4}$	$1.03\ 10^{-3}$
Hg	metal	$1.35\ 10^{1}$	$3.70\ 10^{2}$	$6.68\ 10^{-2}$	$9.02\ 10^{-1}$
^{235}U	metal	$1.89\ 10^{1}$	$5.77\ 10^{2}$	$3.58\ 10^{-2}$	$6.77\ 10^{-1}$
U nat	metal	$1.91\ 10^{1}$	7.60	2.72	$5.20\ 10^{1}$

Table 2: Cross-section, absorption length and mass-absorption–density for thermal neutrons. (v = 2224 m/s; λ = 1.78 Å ; E$_{kin}$ = 26 m eV ; T = 300 °K). Isotopes with high cross-section and therefore used in neutron detection are marked in bold type.

Cross section: the chance of interaction between the neutron and target nucleus



Be aware of this: detectors are typically tuned for a certain wavelength range

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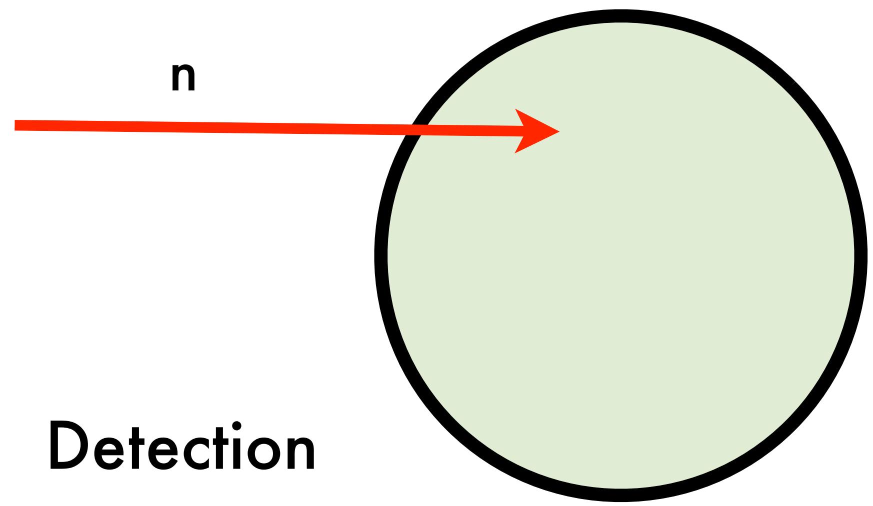
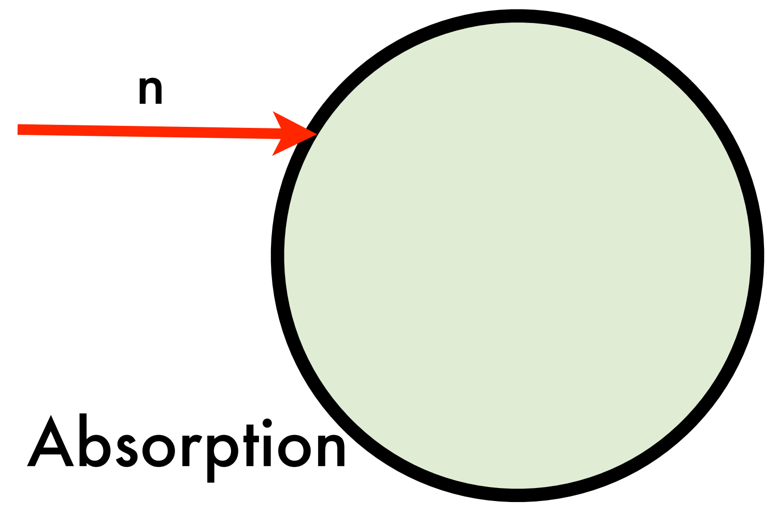
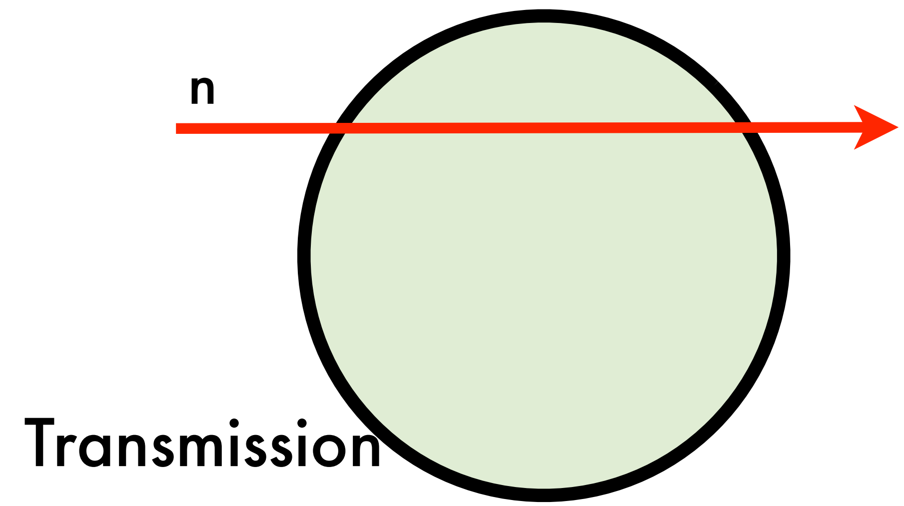
What can happen to a neutron?

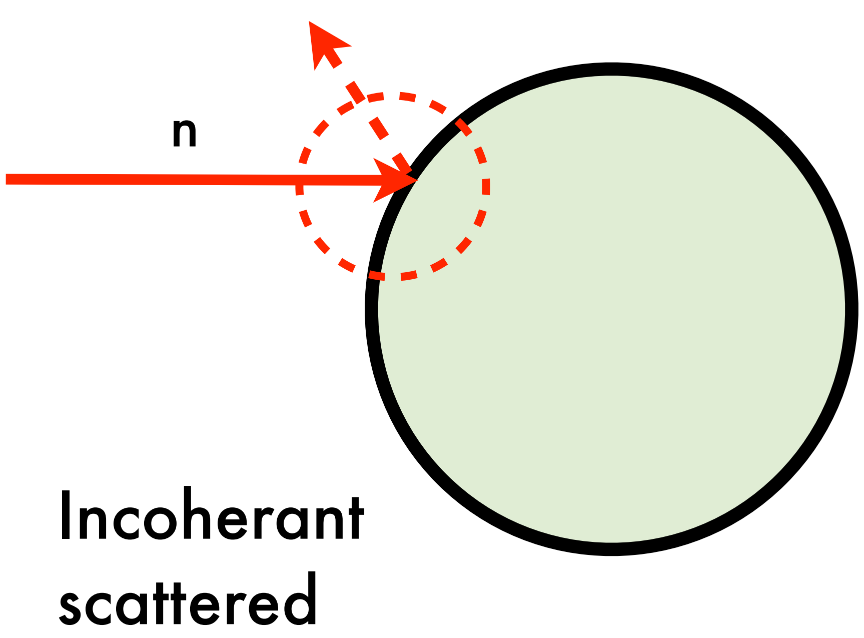
- Detection.
- Absorption.
- Transmission.
- Incoherant scattering
- Diffractive Scattering

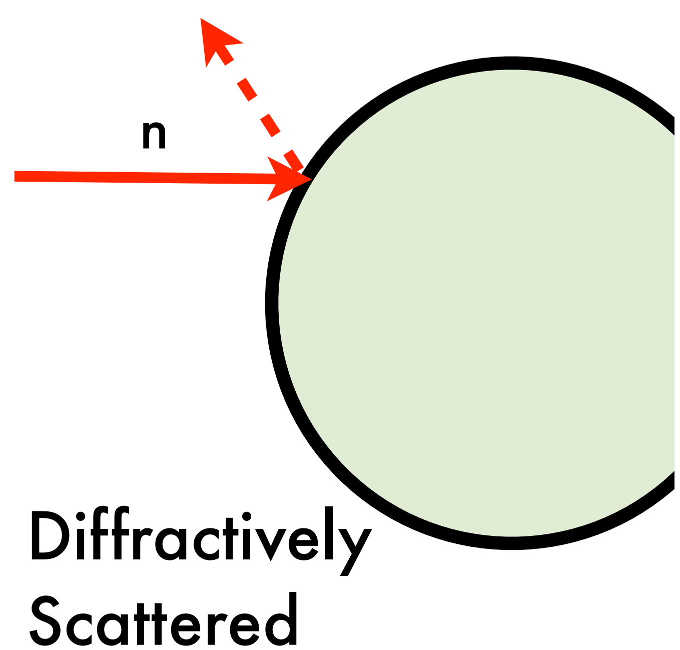
eg on a generic He-3 tube

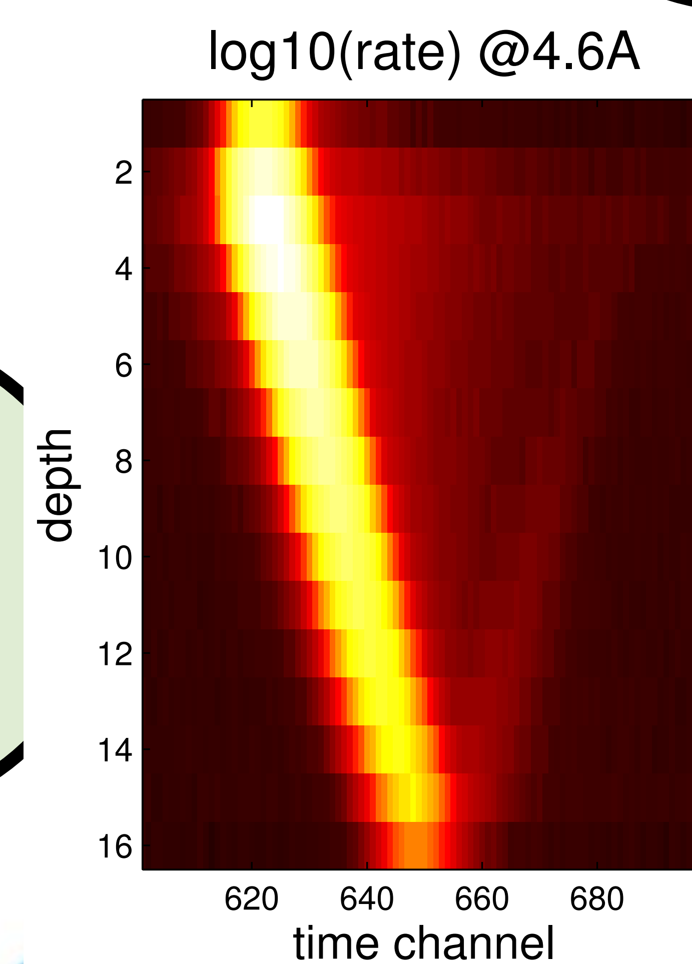












ILL-ESS-LiU Collaboration

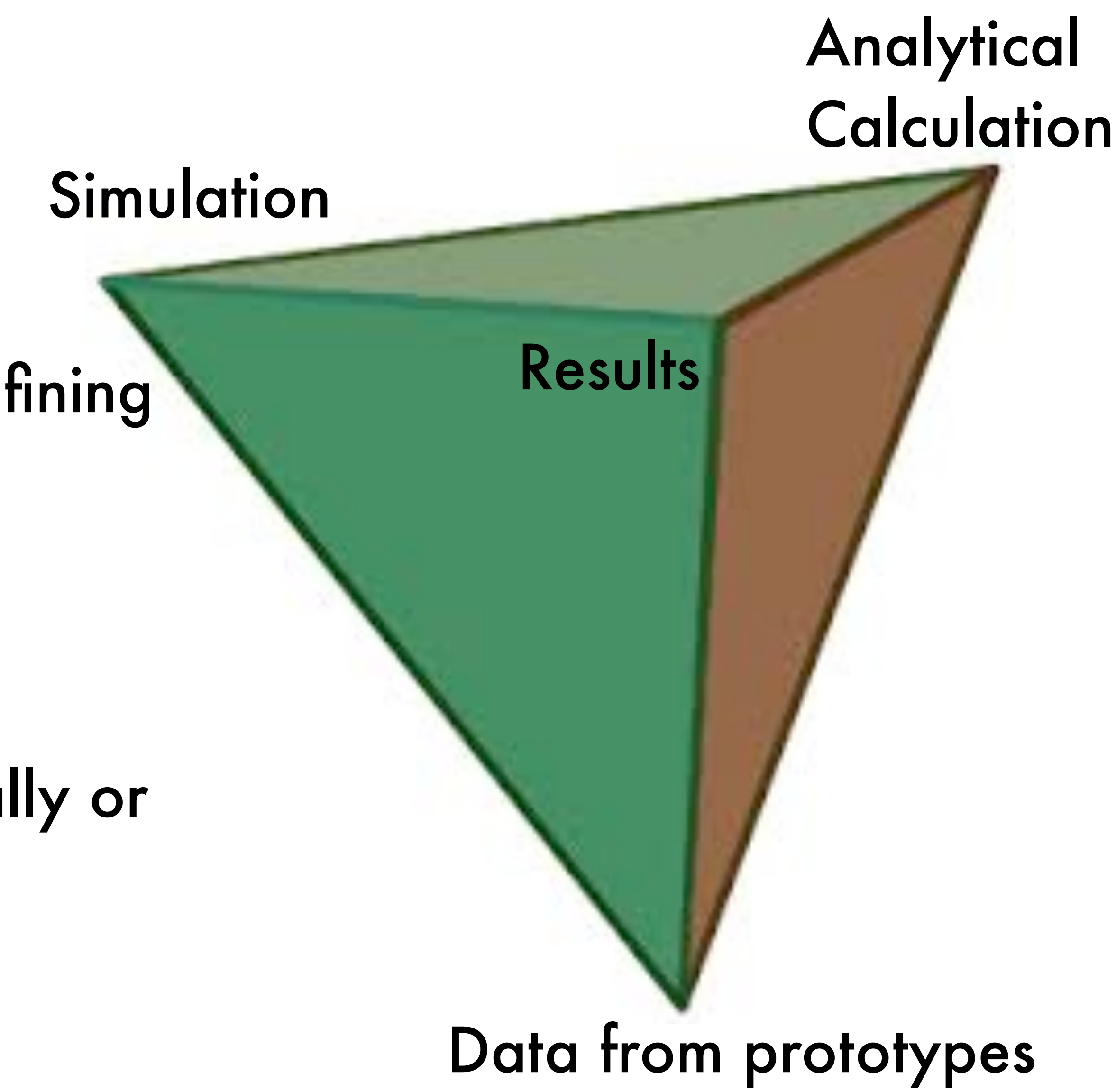
Calculation, Simulation, Data and All That

- As you have heard, simulation is a very powerful tool
- ... but the computer will always lie to you ...

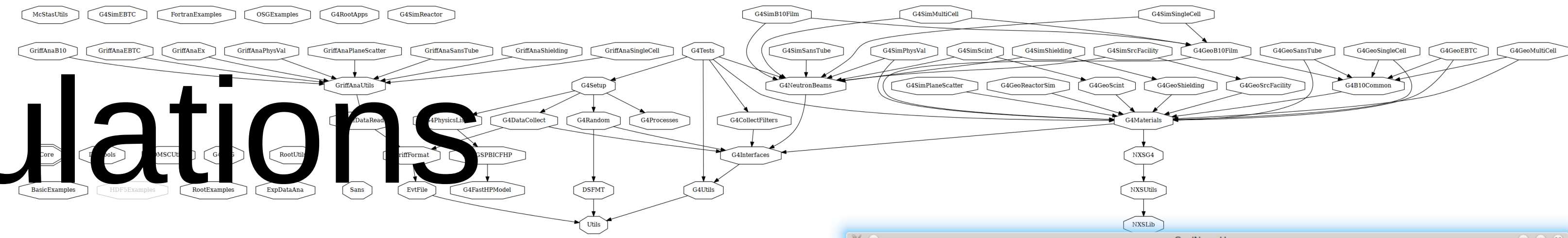
- Data from prototype tests is golden
- Lack of ability to trigger independently on the neutron means some degree of arbitrariness in defining the measurement
- Checking that your measured data is correct is complicated

- 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
- Expect "features" and non-agreement and investigate them
- Iterative

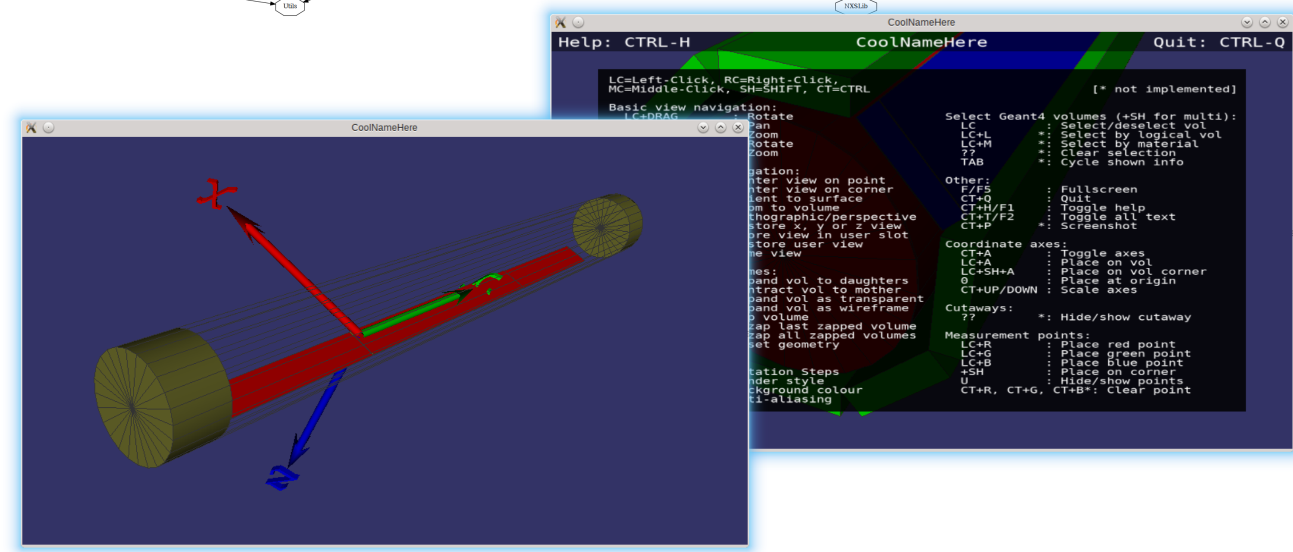


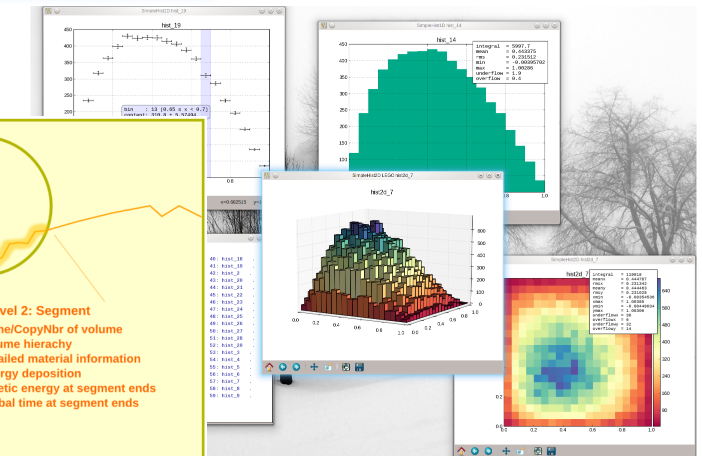
Coding & Simulations

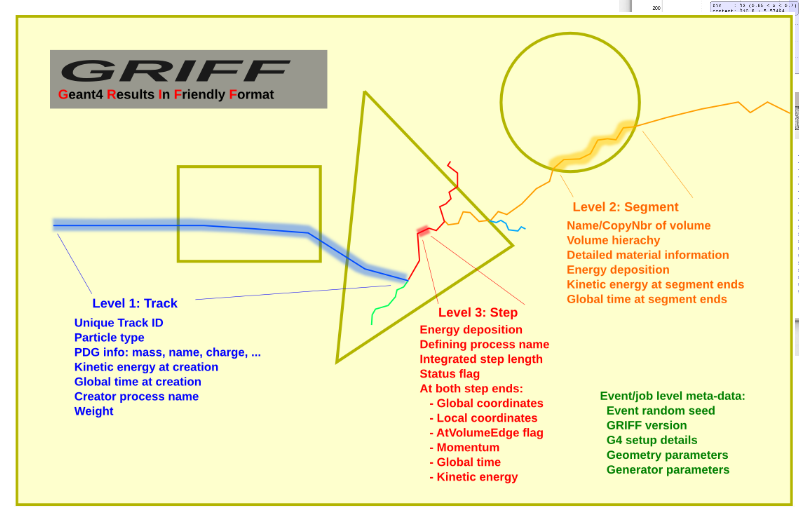


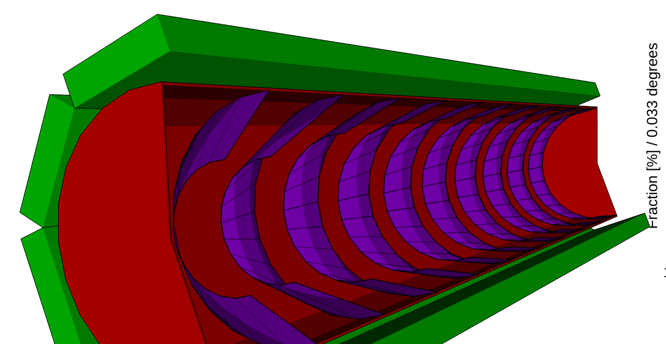
T. Kittelmann

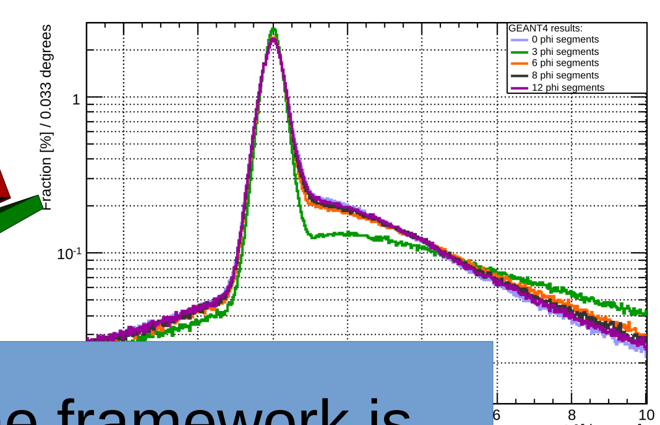
- Collaborative coding framework:
  - Structured repo with easy but powerful build and test system
- Primary deliverable is Geant4 based simulations, with features facilitating neutron detector R&D:
  - Flexible/modular with easy python/cmdline configuration
  - Relevant materials (enriched B4C etc.)
  - Custom geometry viewer for quick geometry development
  - Custom OO file format (Griff) and analysis framework.
  - Multiprocessing for high statistics.
  - Histograms for analysis in e.g. Pylab.
  - Proper diffraction (see next slide)
- Also a natural framework for sharing non-Geant4 specific work (analytical formulae, data analysis plots, etc.)











Naturally, the framework is available to the community!!

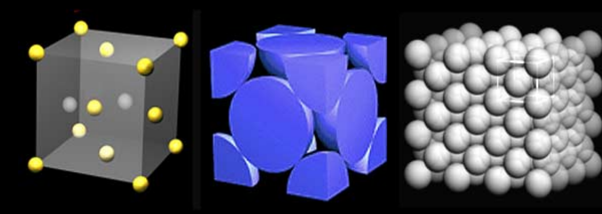
Diffractive add-on for Geant4

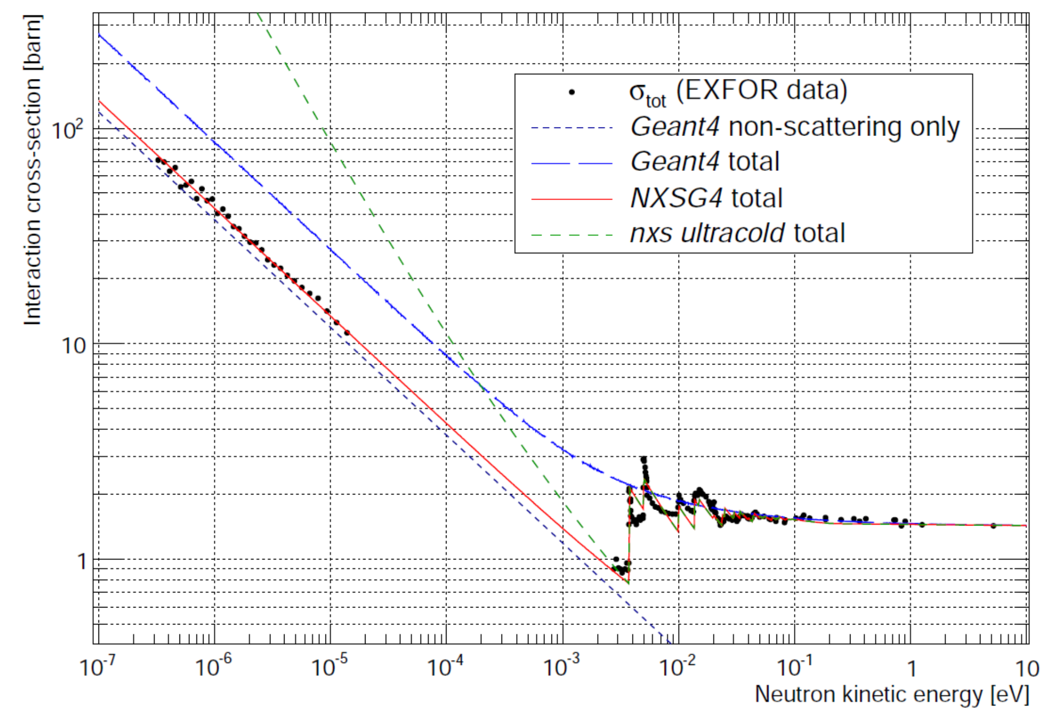
T. Kittelmann, M. Boin

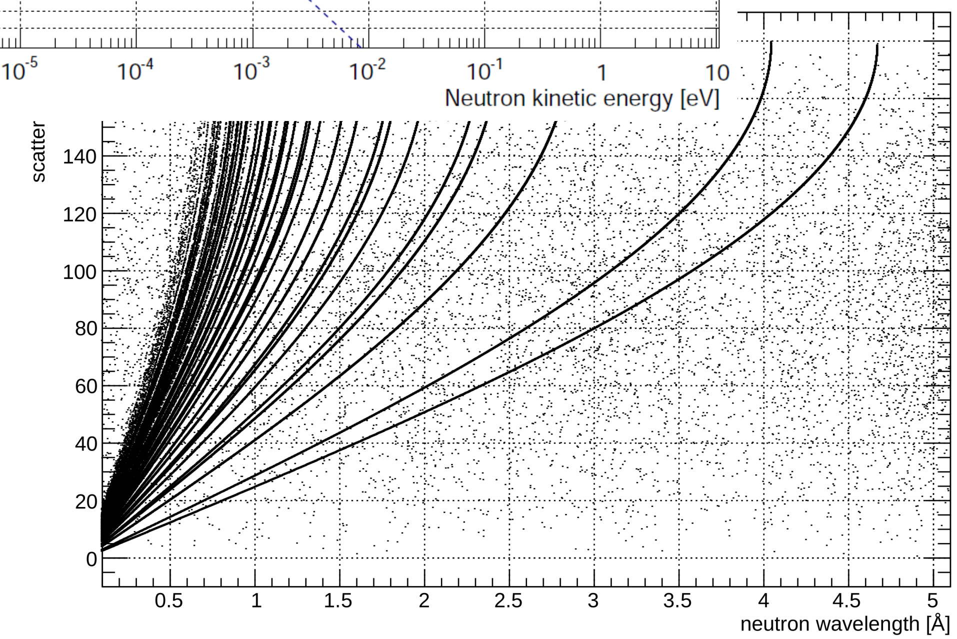
- Out of the box, Geant4 includes no capability for crystal diffraction.
- A new plugin, NXSG4, is provided which enables proper neutron diffraction in arbitrary polycrystalline materials:
- Based on the nxs library (used already in McStas, Vitess)
- Based on basic unit-cell parameters, just low-energy neutron scattering is overridden. All other Geant4 capability is retained, resulting in a rather complete tool for investigations of a multitude of phenomena at neutron facilities.
- Plugin freely available for non-commercial purposes at http://cern.ch/nxsg4) and documented in paper (submitted).

J. Comp Phys Comm

```
(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
```







Definitions and Standards

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"No Prototypes installed in ESS": ensuring quality

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Several competing technologies: Need to compare like-with-like

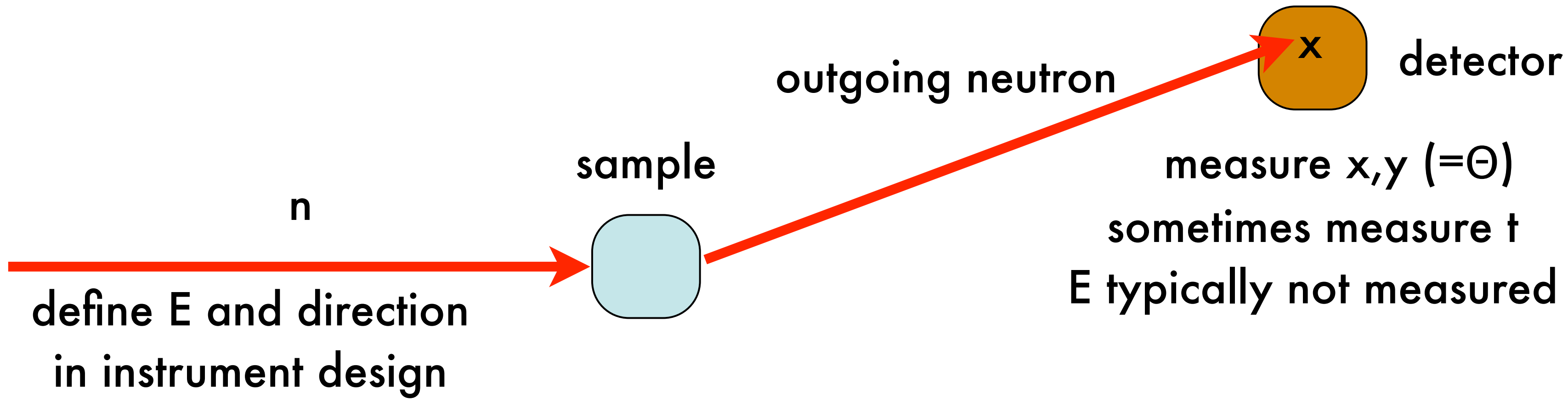
Develop Measurement Standards

- Between neutron sources 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

Definitions of Performance



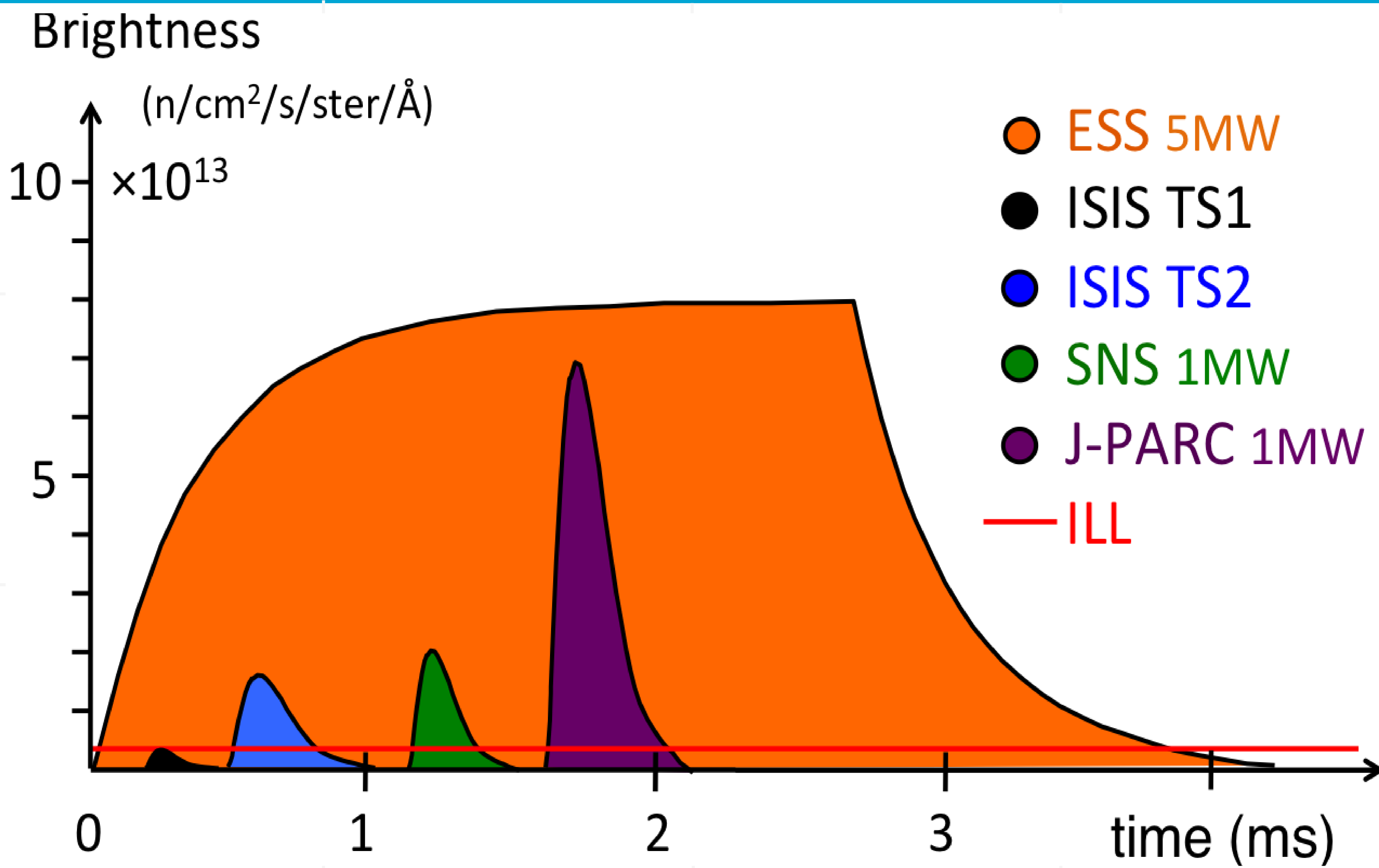
- Position/angular resolution: how well the position of detection is measured
- Time resolution: how well the time-of-arrival of the neutron is measured
- Efficiency: probability that a given neutron will be detected
- Noise: rate of fake hits
- Dynamic range: the "headroom" between noise and maximum rate
- Rate capability: the maximum rate of neutrons that can be detected either locally or globally
- (In-)Scattering: fraction of neutrons scattered from somewhere they shouldn't have (sample or instrument)
- Gamma rejection: fraction of gamma's that are falsely identified as a neutron
- A detector will often be described solely in terms of efficiency and resolution, whereas the scientific performance may be be determined by S/N, background, scattering, gamma sensitivity

Rate

- Rate is the number of neutrons incident per unit time
- For ESS, rate is a key issues for many instruments designs
- Three numbers of interest for assessing a detector choice:
  - Global rate: rate (Hz) over a larger area: detector unit or m^2
  - Local rate: rate over a smaller (channel/pixel): Hz/ca. mm^2
  - Local instantaneous rate: hits during a small interval of time over a smaller (channel/pixel): hits/100us-ms/ca. mm^2
  - The relevant size of the unit depends upon the details of the detection process

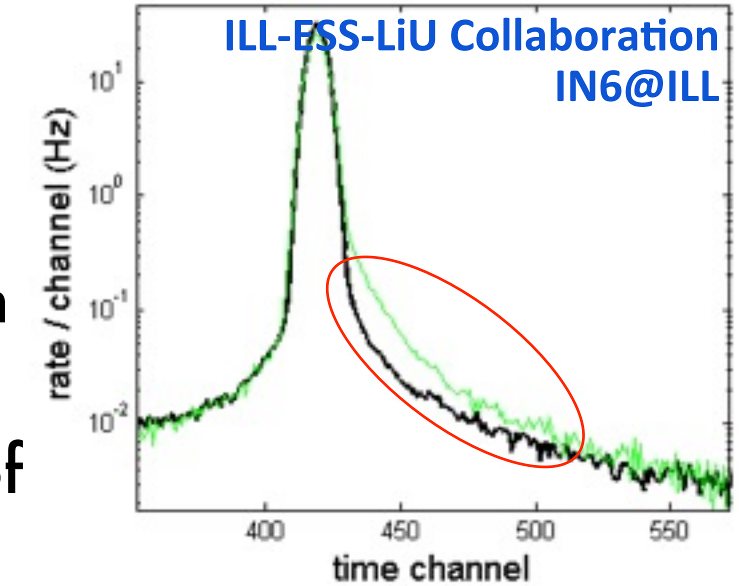
- Details of the detector system as a whole are important
- Even if the detection process can handle the rate, it might be that bottlenecks occur further on
- Important to keep in mind for the electronics and readout design of the detector

ESS is a Long-Pulse Source

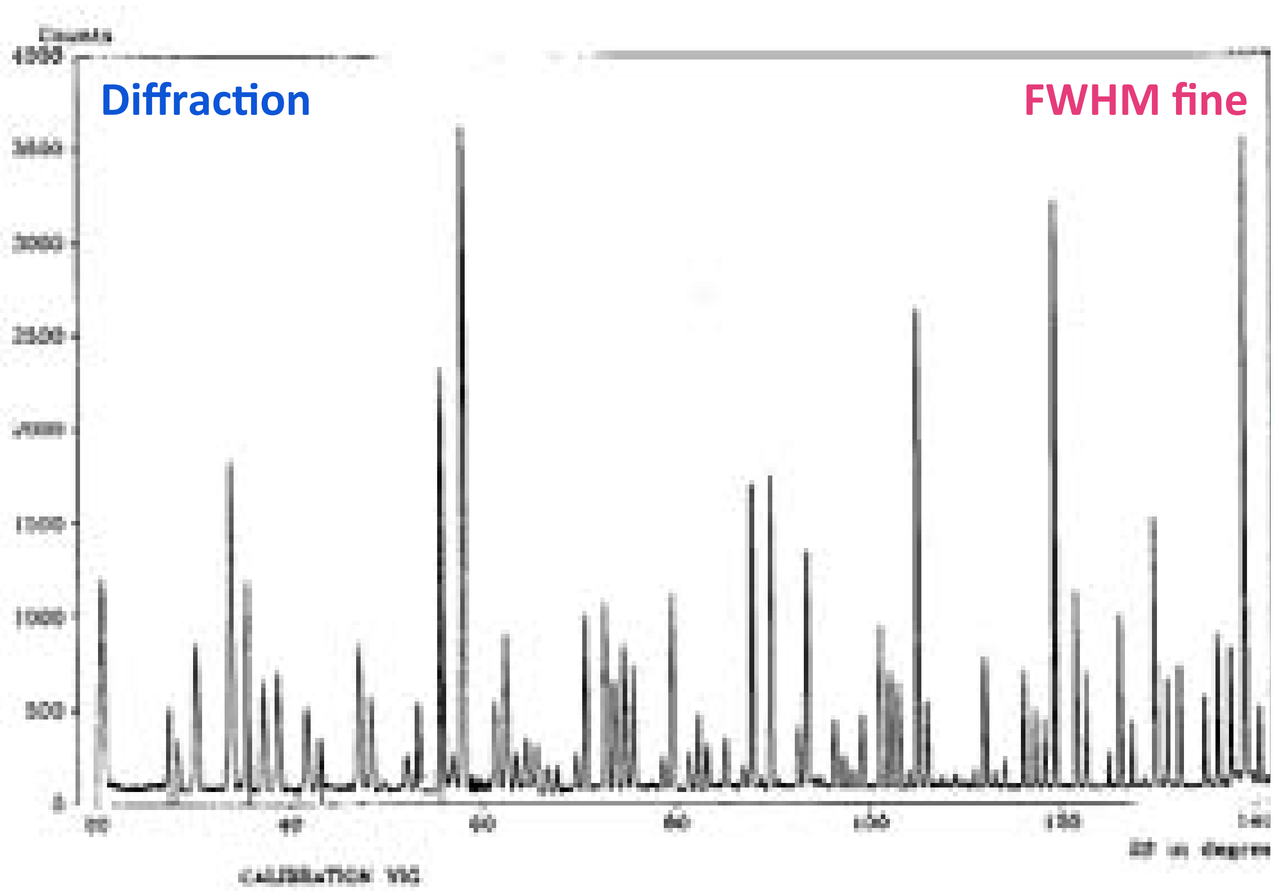


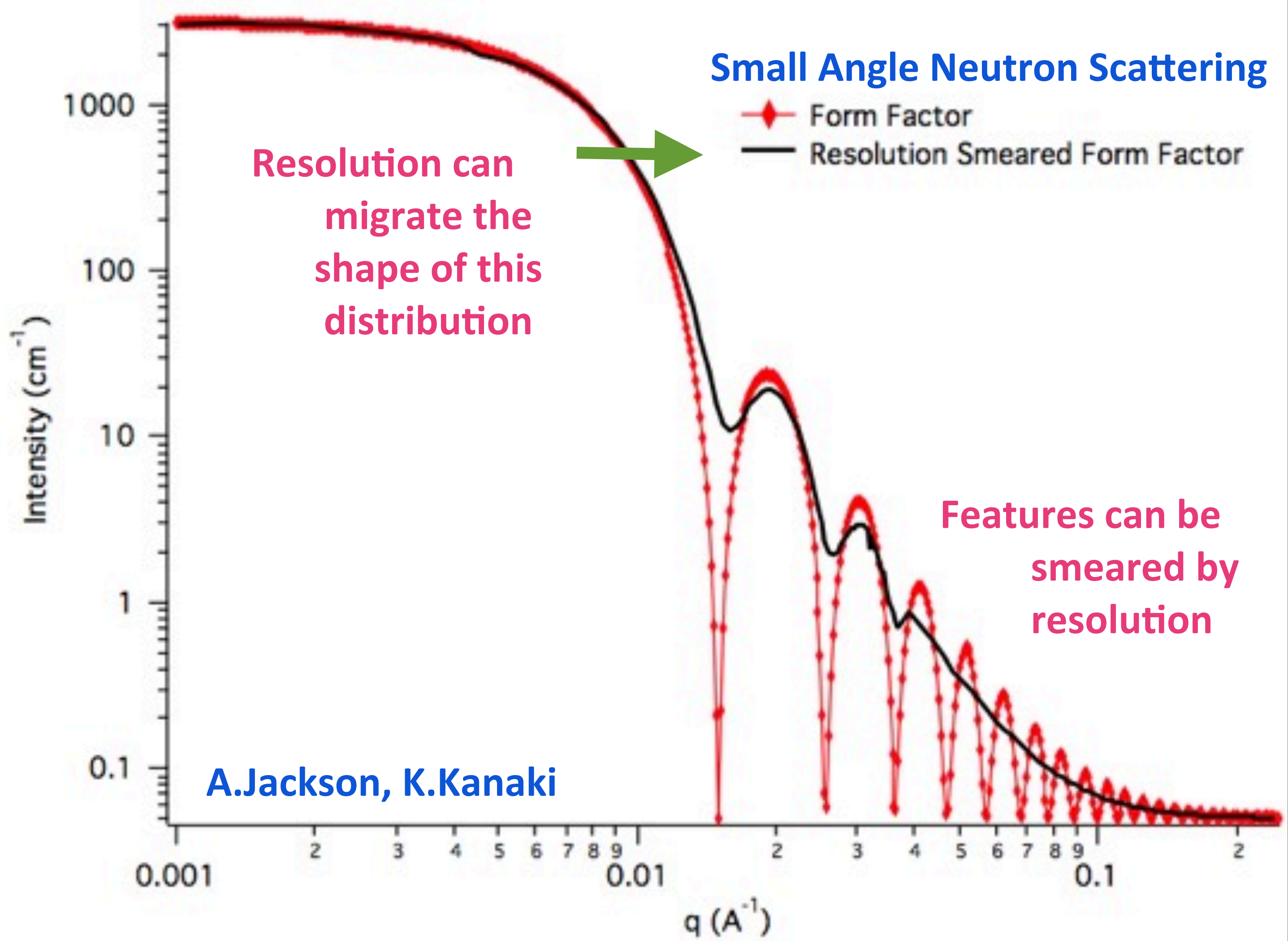
Position Resolution

- The position resolution is the distribution of the measured position of the neutron compared to the true position of the neutron
- Typically simply quoted as a Full-Width-Half-Maximum or width of a Gaussian fit
- However, the details of this distribution are important depending upon the application
- In particular be careful of quickly falling distributions: resolution can smear out features, and change the measurements from the plot



example of smearing from Al scattering



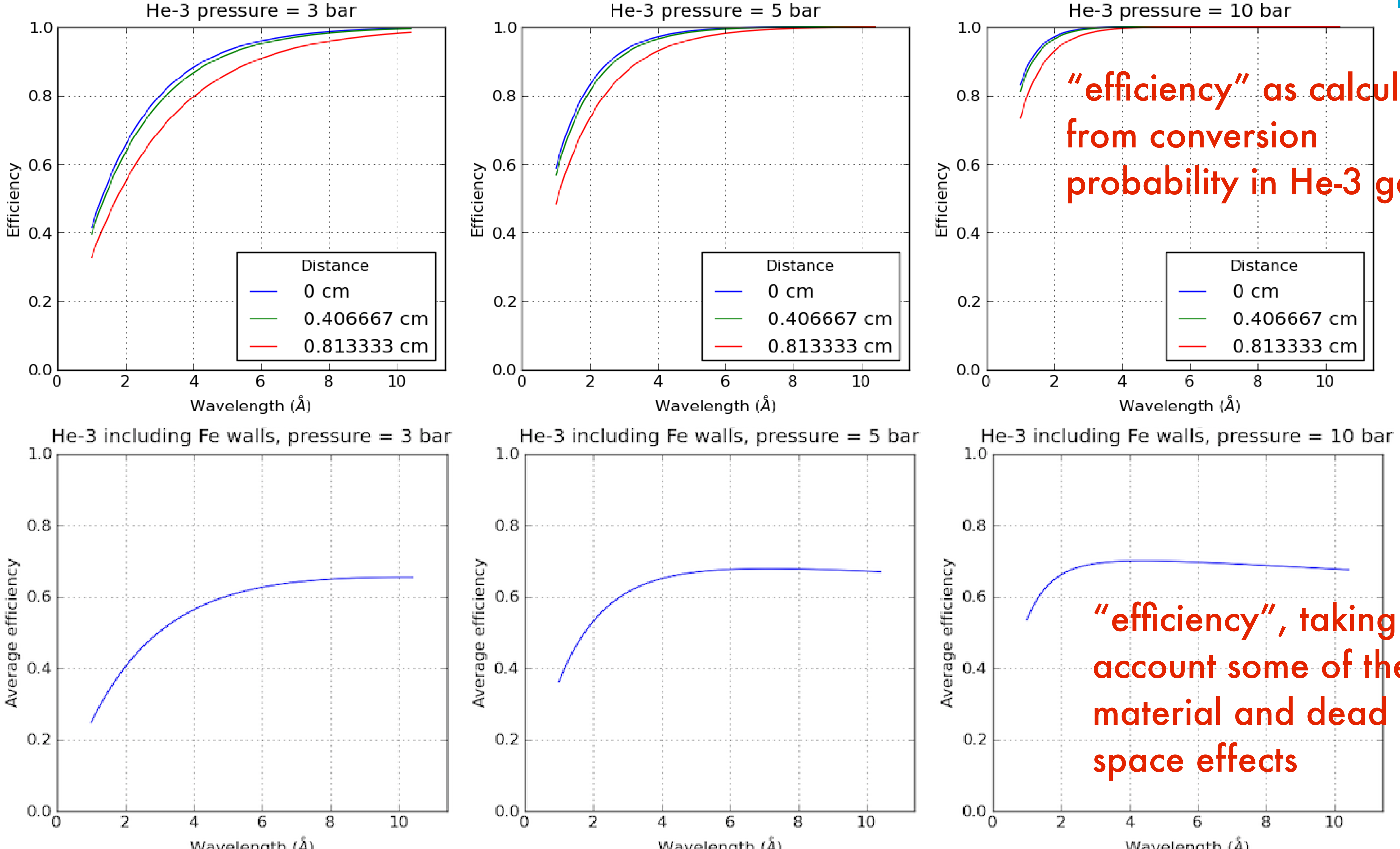


Efficiency

- Efficiency is the fraction of neutrons detected compared to the true number of neutrons
- Typically this is quoted as a point-like efficiency, at the most efficient point in the detector, also in the most efficient configuration of the detector
- Important to quote efficiency at the working point, and explain why the working point is there
- Additionally, whilst the point peak efficiency is a useful number, probably more useful:
  - global efficiency = detected neutrons into solid angle of interest / true number of neutrons into solid angle of interest
  - The solid angle of interest is that subtended by the detector system from the scattering sample
  - This then takes into account dead material (absorption and scattering), non–active areas, etc etc
- As the wavelength dependence of the efficiency is high, need a well-defined wavelength of the neutrons to make the measurement - not moderated radioactive sources
- Lastly, neutron efficiency typically is measured with respect to a “reference detector”
  - Clearly the understanding of this detector needs to be excellent
  - Need to understand possible systematic effects
  - eg background on both detectors needs to known and corrected for
  - Using an additional detector / method highly desirable to reduce errors
  - Uncertainty evaluation

He-3 Efficiency

Example of typical large area application:



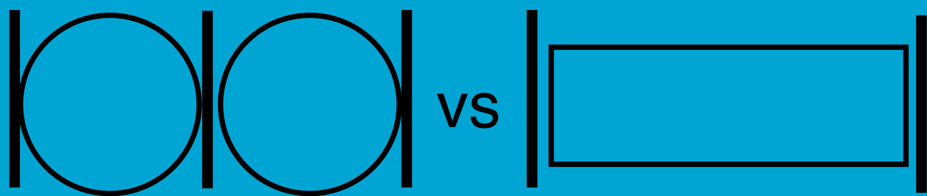
"efficiency" as calculated from conversion probability in He-3 gas

"efficiency", taking into account some of the material and dead space effects

Important to compare like-with-like, in particular when looking at different technologies

Quality and Standards:Detection Efficiency

cartoon:



"boundary conditions matter"

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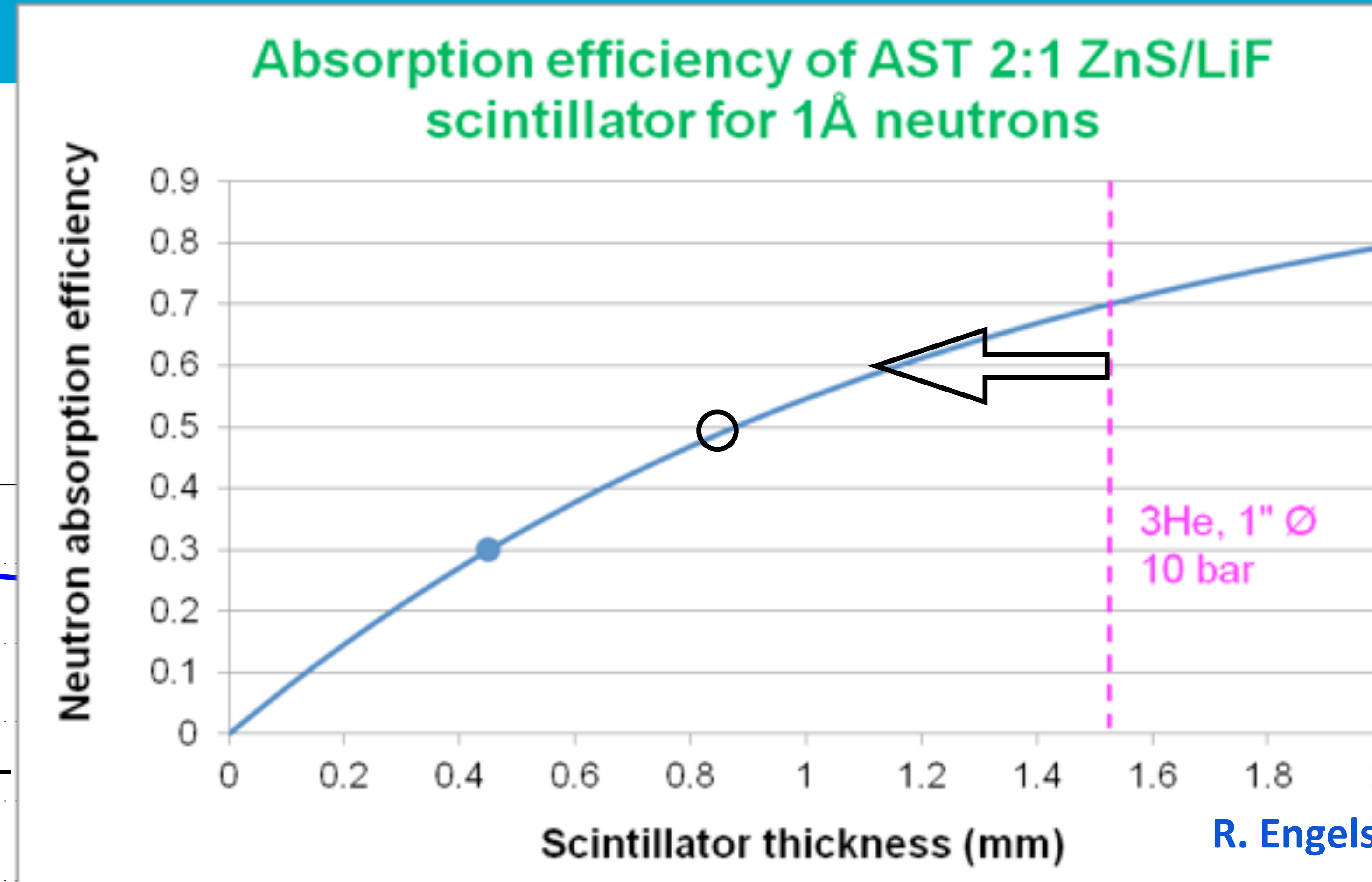
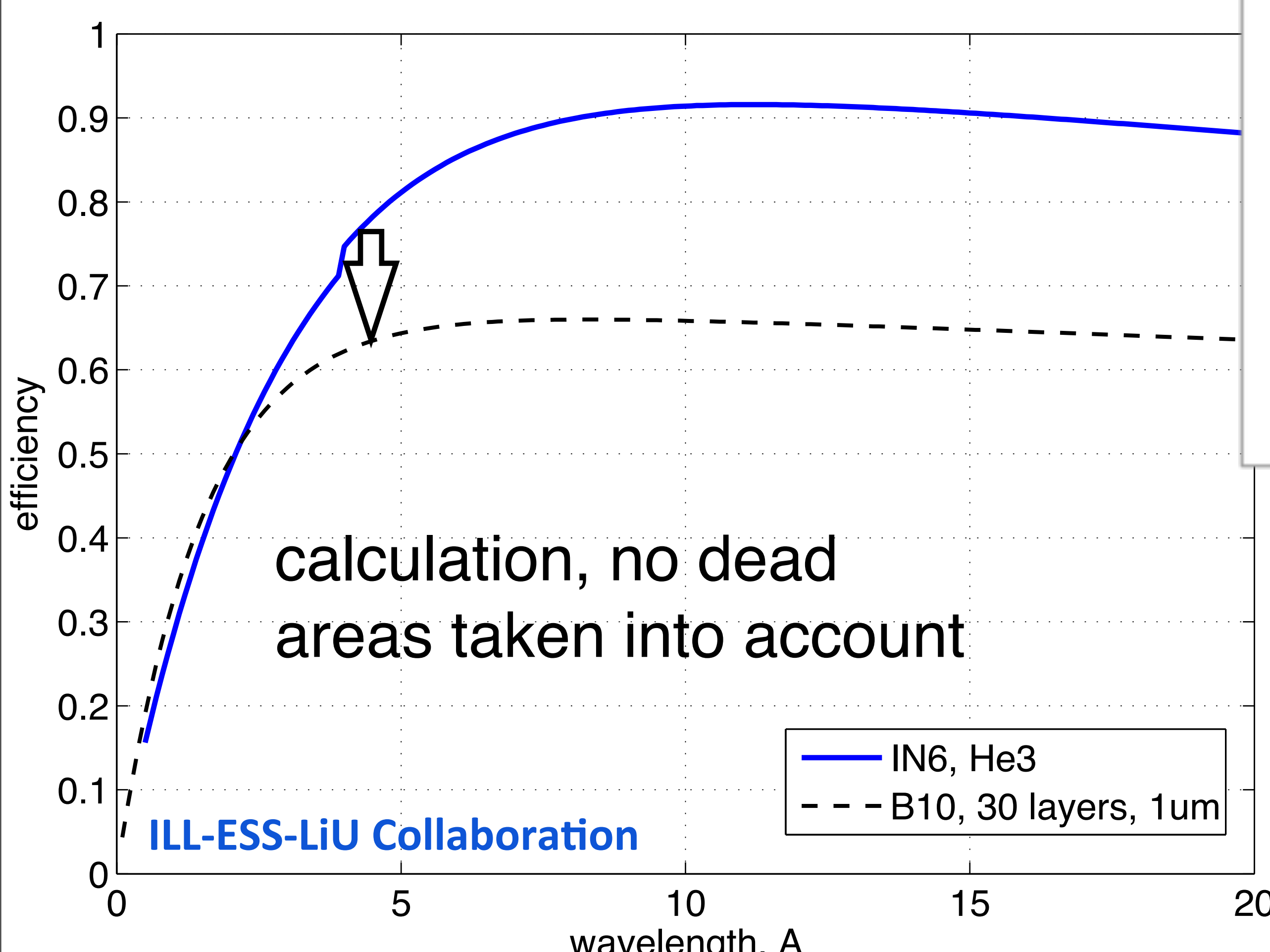
- Helium-3 is the gold standard, in particular in terms of detection efficiency
- However, efficiency numbers have rarely compared like-with-like





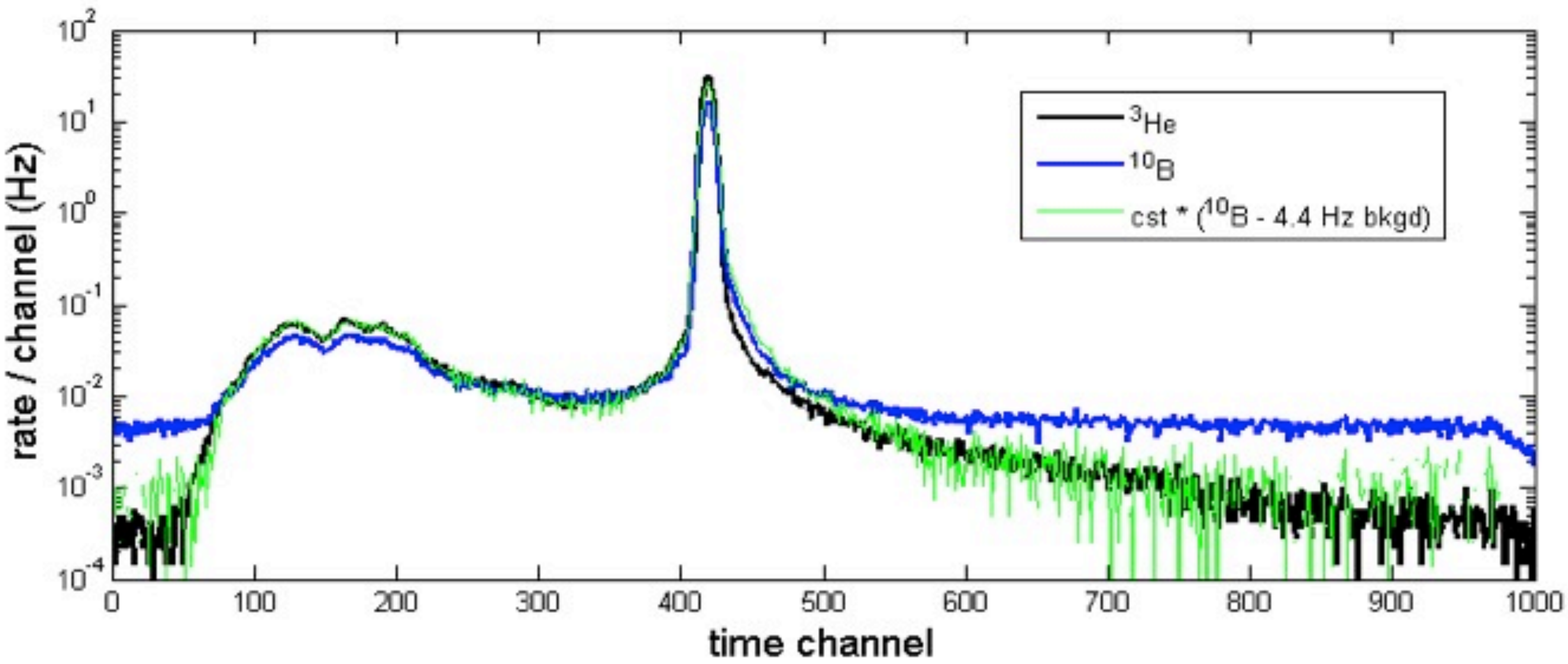
- Arrow indicate effect of dead regions into account with He-3 tubes
- Alternate technologies starting to approach raw efficiency numbers
- There is a need to compare like-with-like for the detailed instrument operating conditions
- Gamma rejection is a similar issue

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

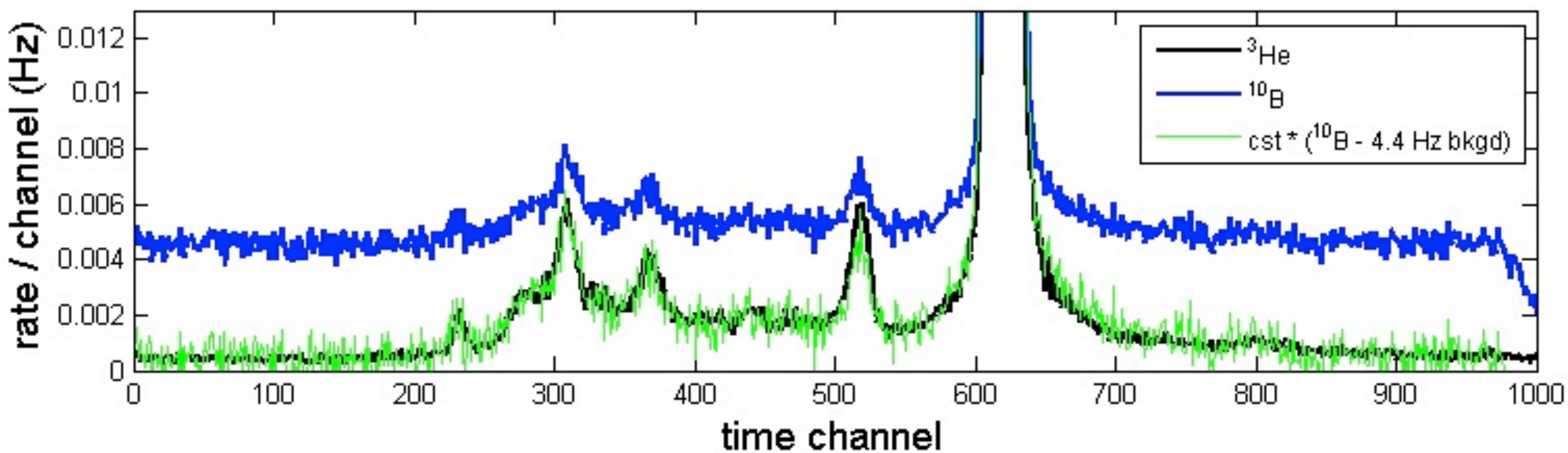
Level of Background: Observations from IN6 Inelastic Demonstrator



... background levels required incredibly low ...

- **4.4 Hz flat background** was observed (**no time structure**)
  -> independent of the IN6 instrument

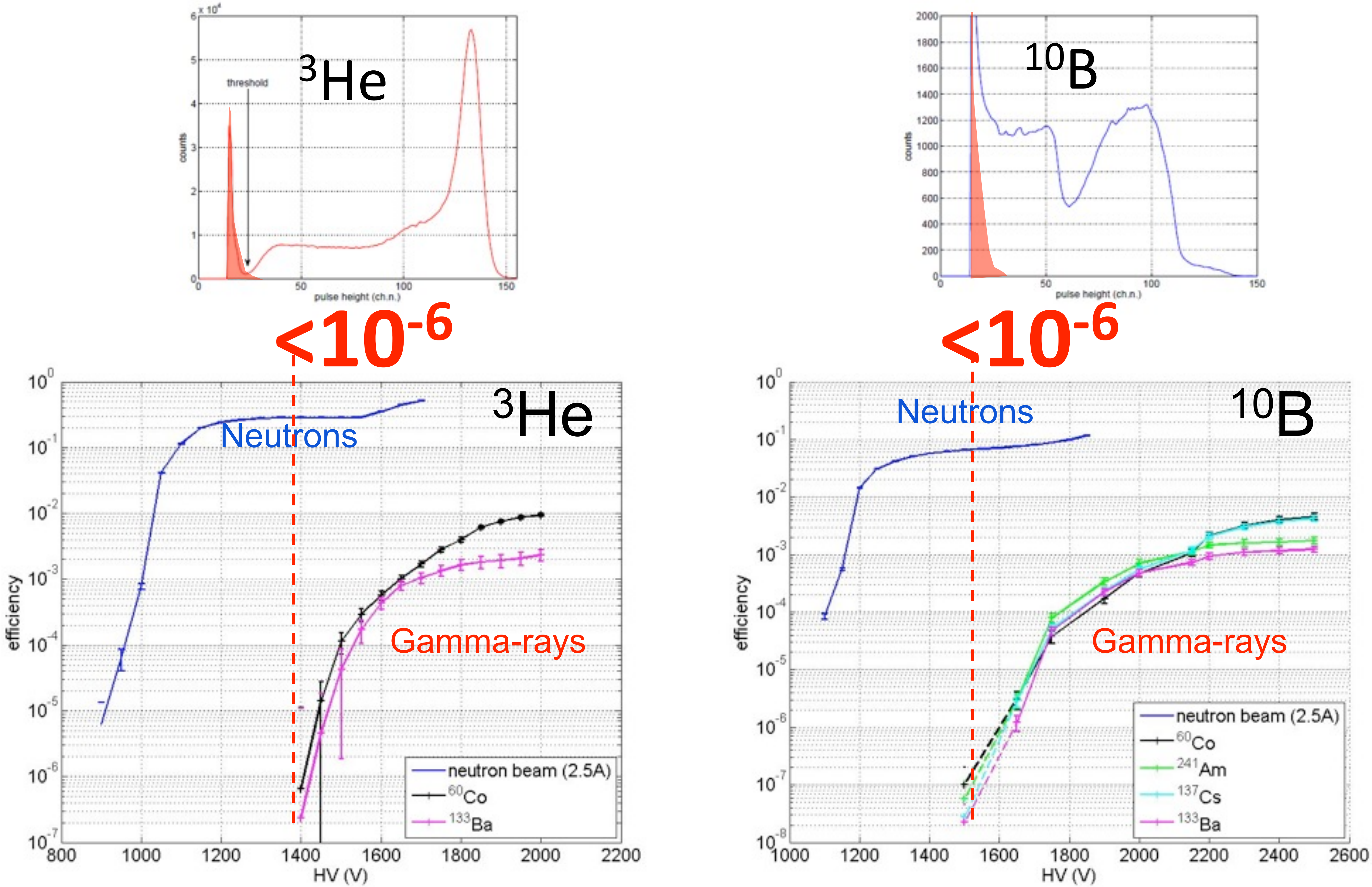
U,Th ppm in Al



ILL-ESS-LiU Collaboration

^{10}B-based Neutron Detectors: Gamma Sensitivity

A. Khaplanov , F. Piscitelli et al., JINST, v. 8, p. 10025, 2013



Quality and Standards: Gamma Sensitivity

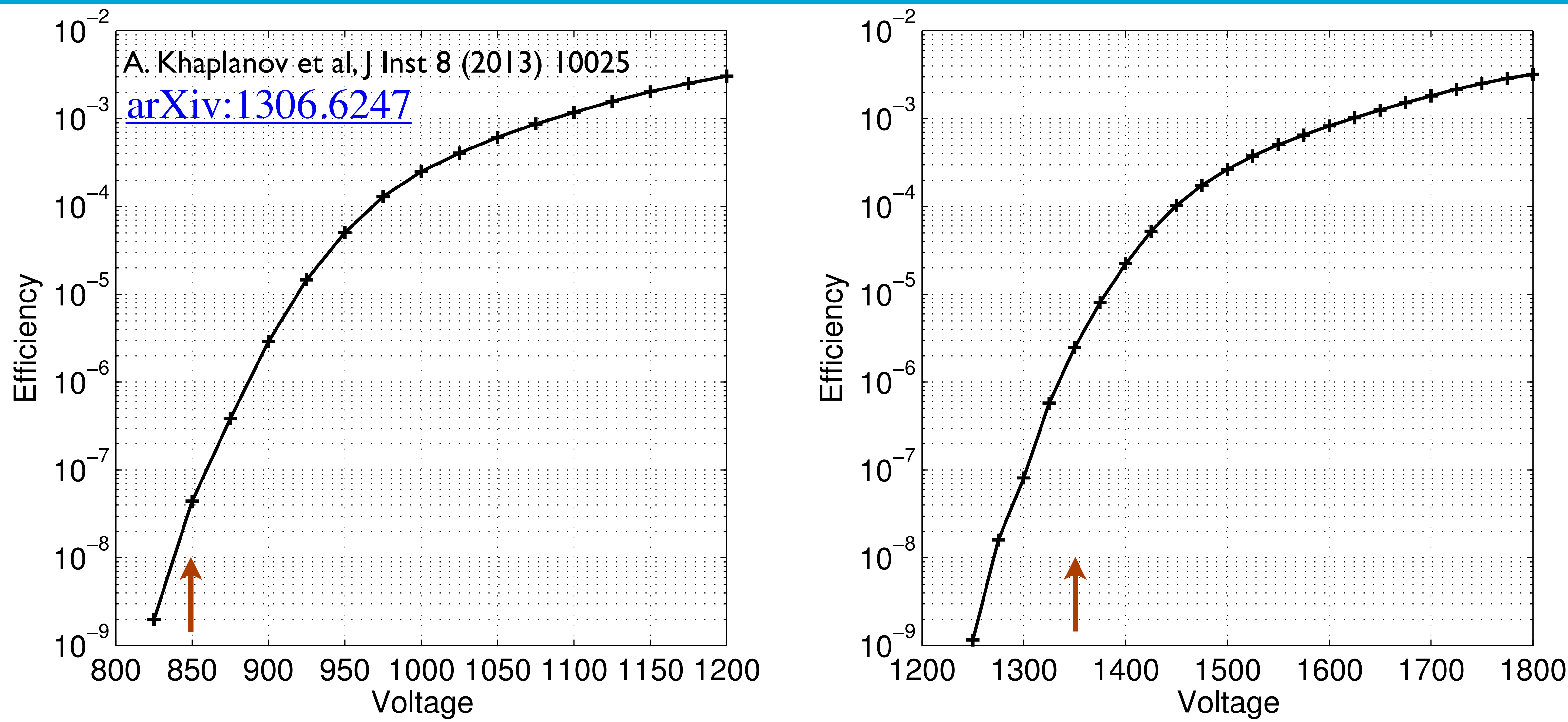
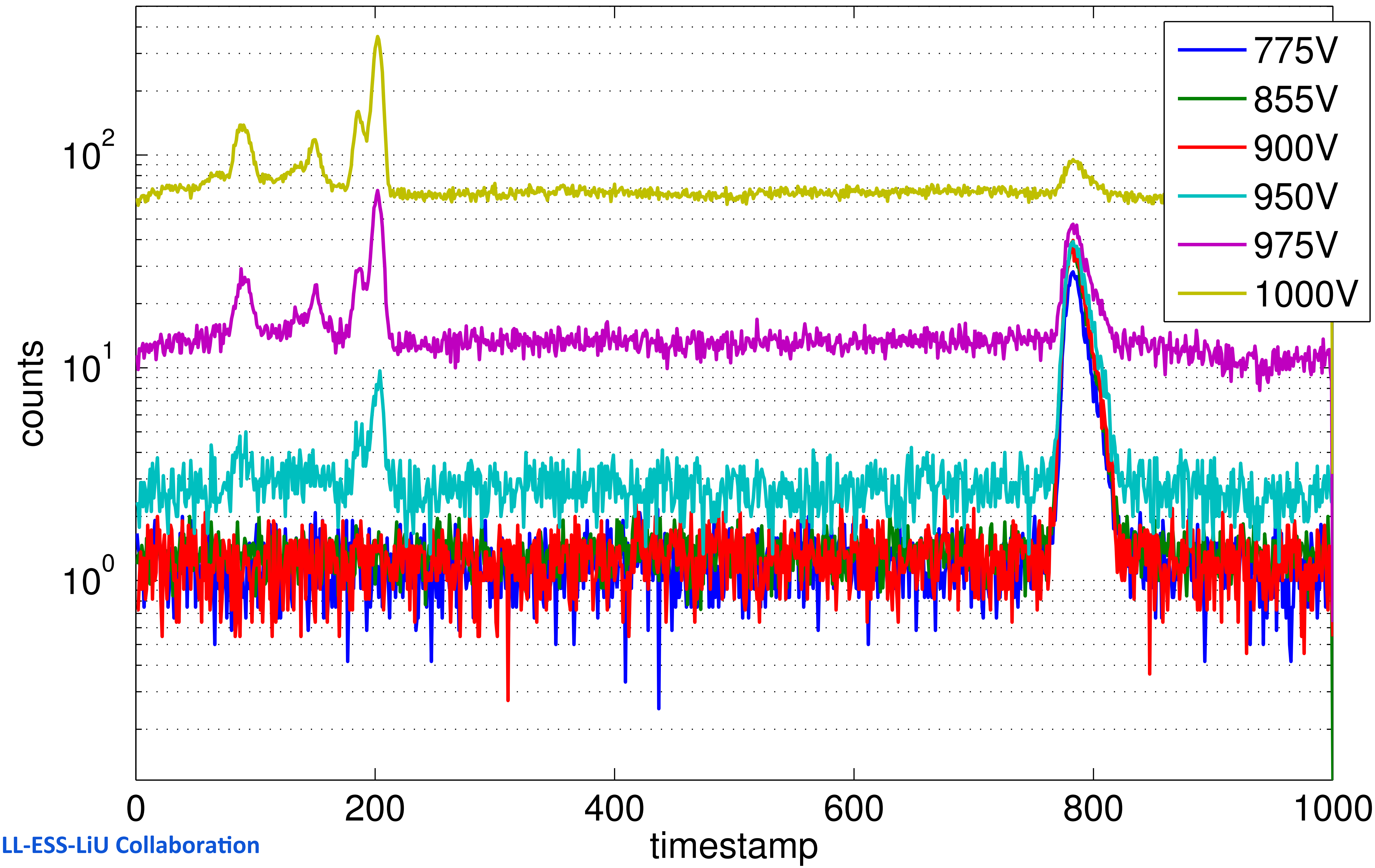


Figure 8: Plateau measurement with the Multi-Grid ^{10}B detector (left) and a Multi-Tube ^{3}He detector (right) with a strong ^{137}Cs source.

Quote gamma sensitivity at same working point as detection efficiency

Working on standards definition for other backgrounds and beam monitors

Turning a neutron detector into a gamma detector



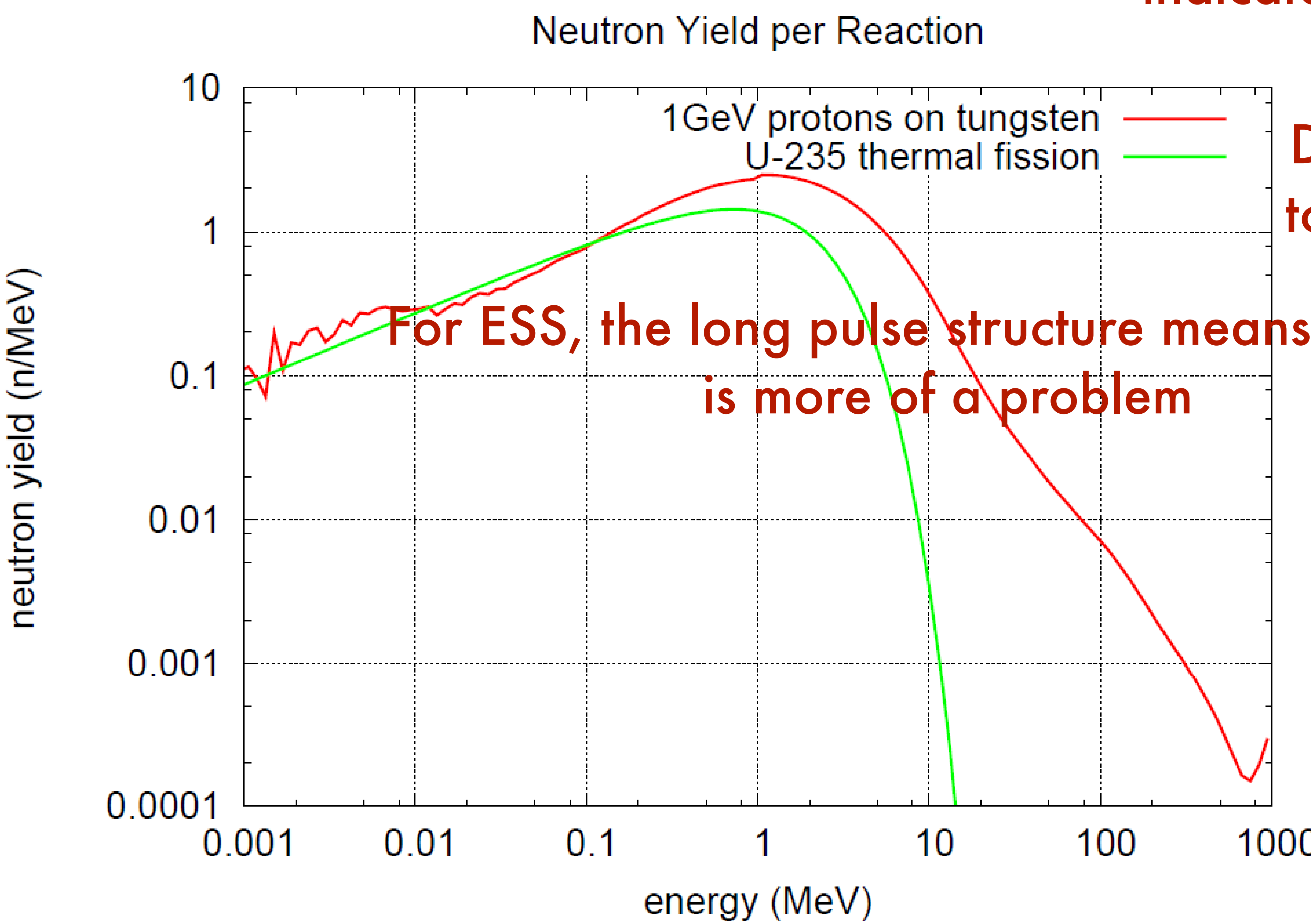
ILL-ESS-LiU Collaboration

fast neutrons are a menace for spallation sources

Why are we here today?

Fission and Spallation Neutron Spectra

For ESS, good control of backgrounds is going to be an indicator of success



Detector insensitive to backgrounds are a good start

For ESS, the long pulse structure means that this is more of a problem

(thanks to Ken Herwig)

Courtesy – Franz Gallmeier

Collaborative background studies with PSI

measurements at the SINQ target

paper in preparation
N. Cherkashyna et al.

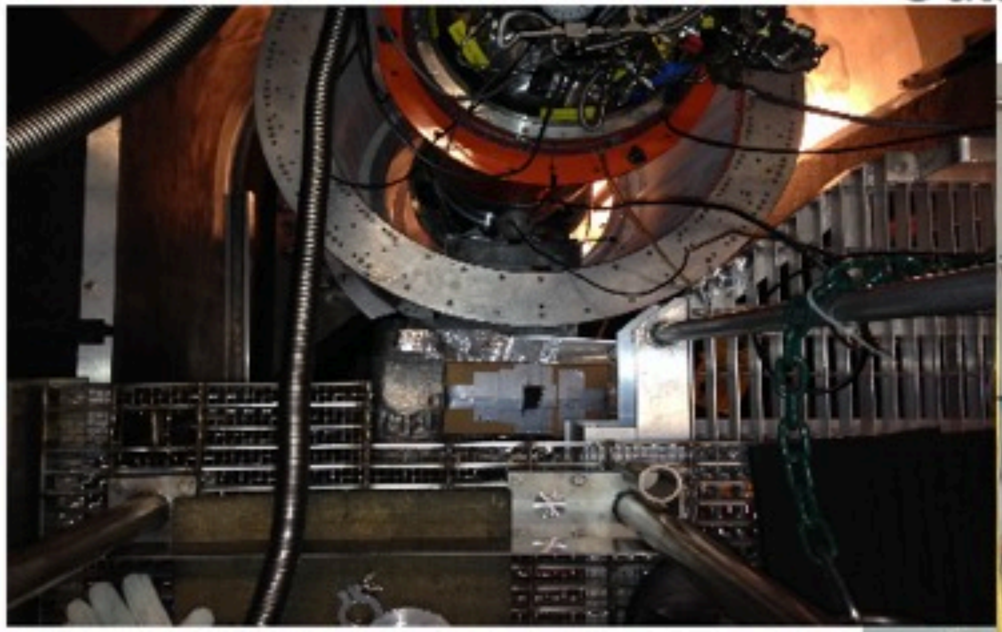
Collaborative background studies with SNS

ESS Detector & Neutron Optics and Shielding groups

Along basis-curved beamline

Outside: ring2target

Between BL13 & BL14



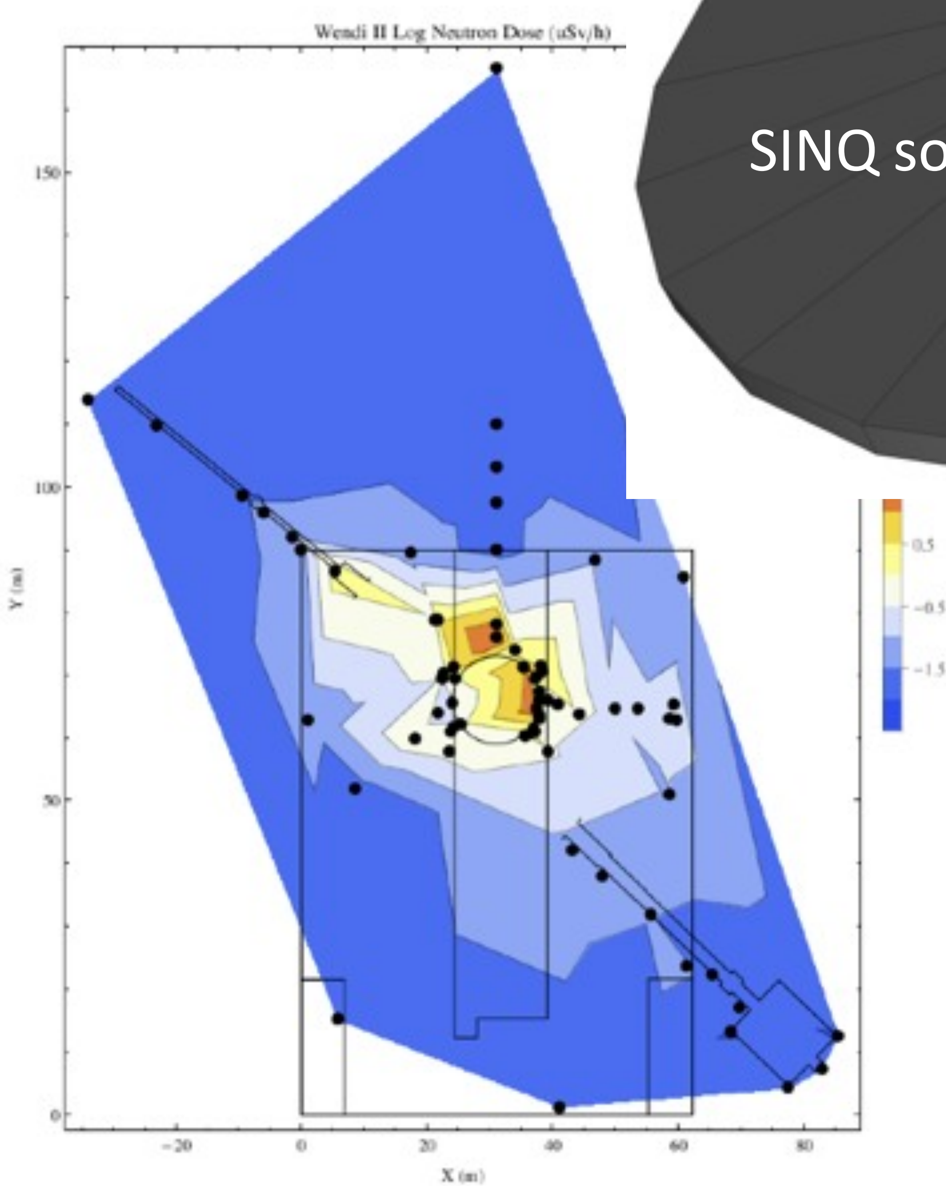
Inside CNCS

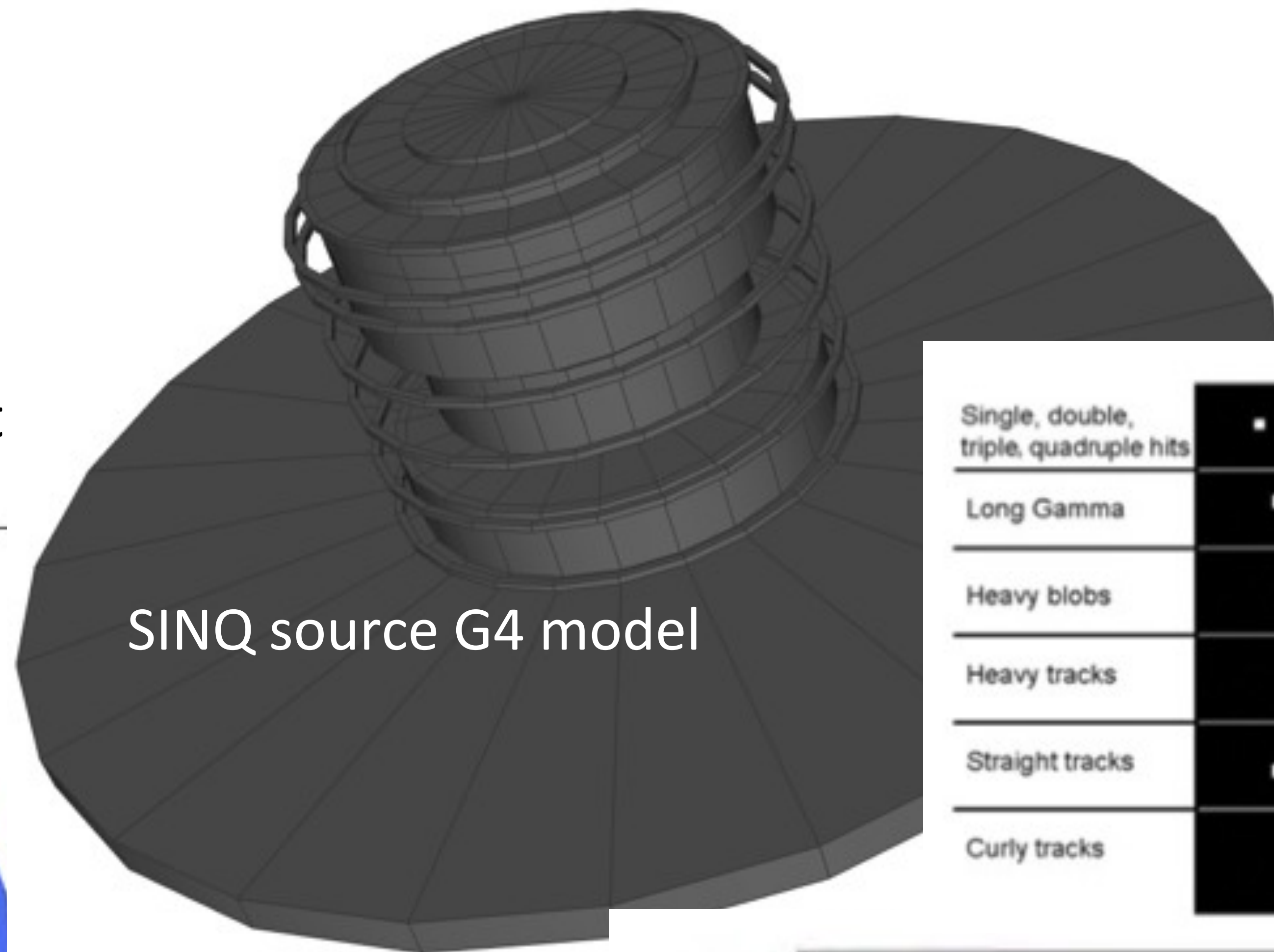
On top of BL14

paper in preparation
D. DiJulio et al.

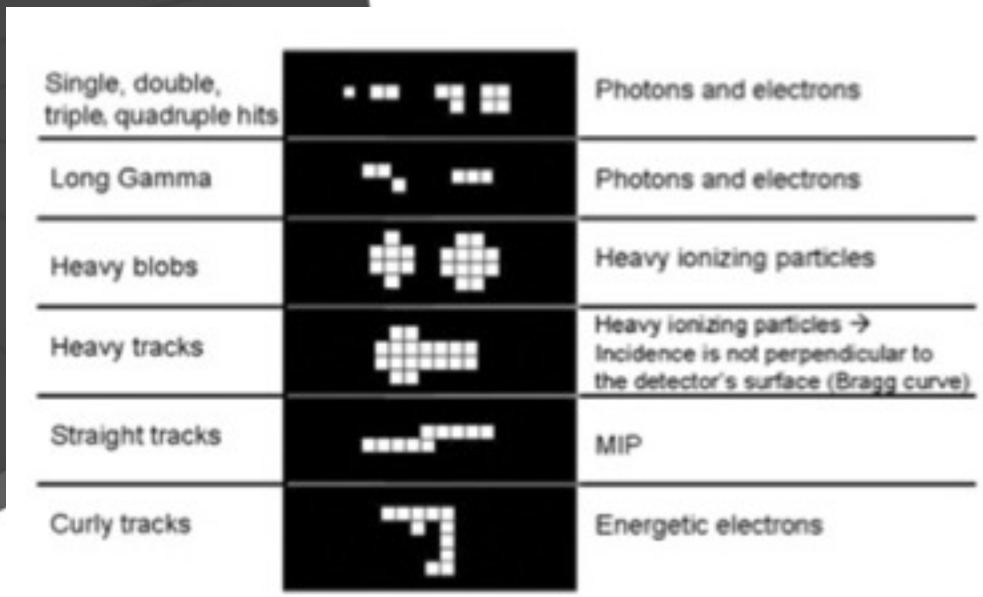
Measurements & Simulations

neutron dose map
around the SNS target
and POWGEN instrument

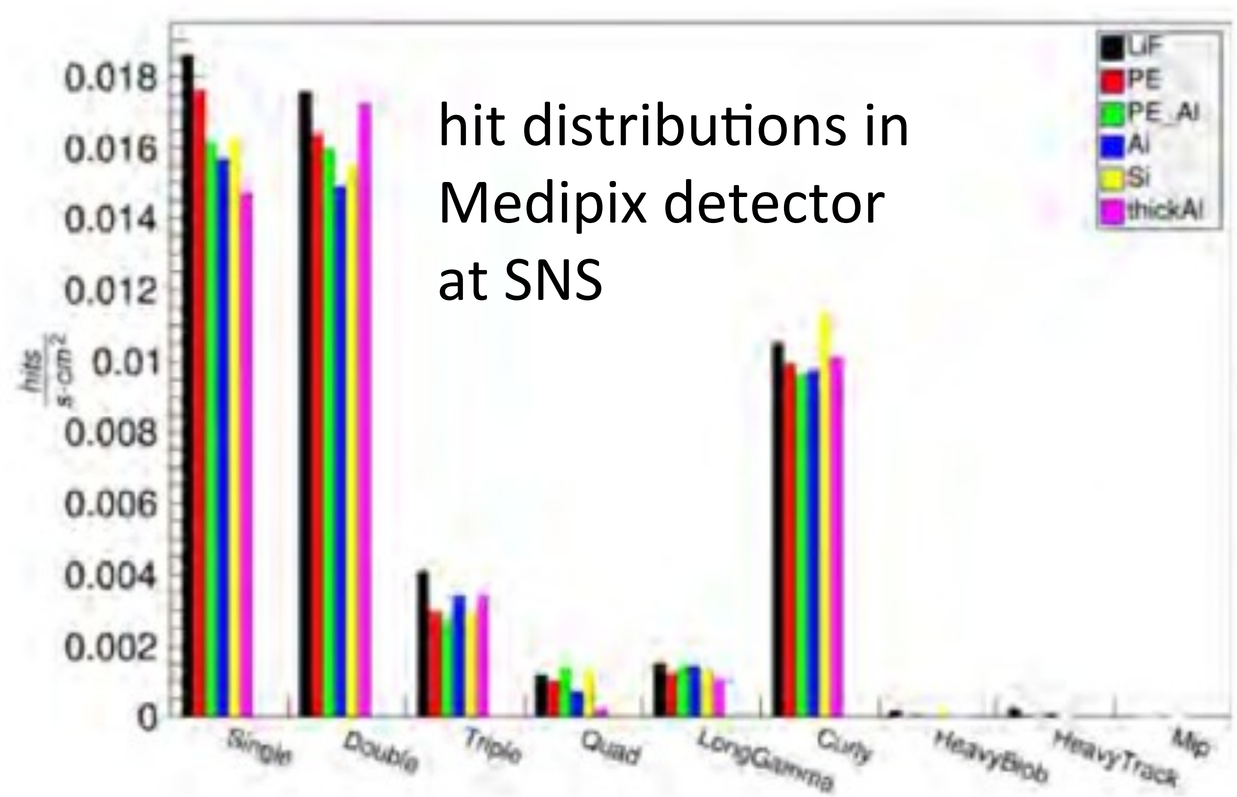




SINQ source G4 model



Single, double, triple, quadruple hits		Photons and electrons
Long Gamma		Photons and electrons
Heavy blobs		Heavy ionizing particles
Heavy tracks		Heavy ionizing particles → Incidence is not perpendicular to the detector's surface (Bragg curve)
Straight tracks		MIP
Curly tracks		Energetic electrons



hit distributions in
Medipix detector
at SNS

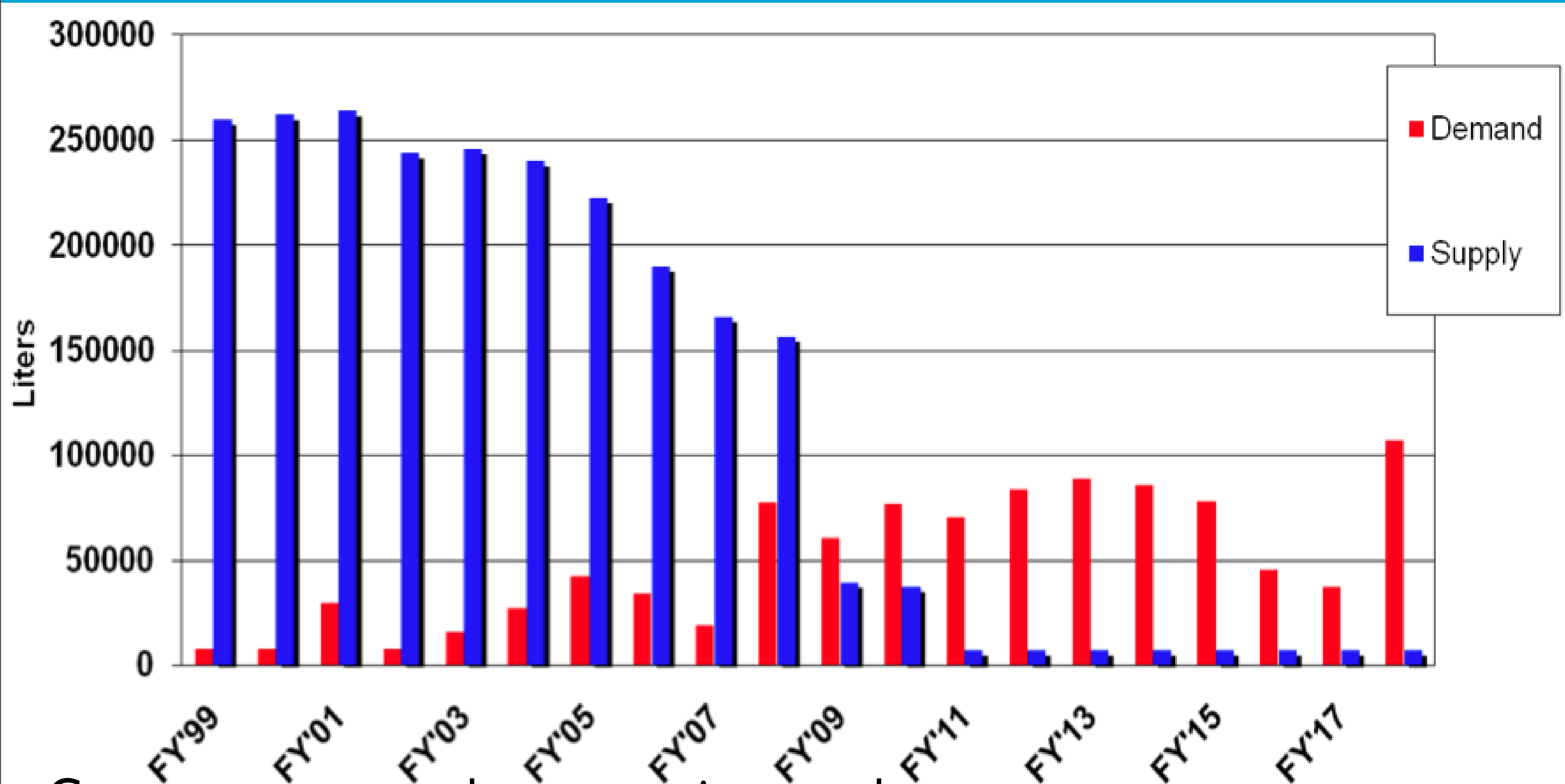
Detectors for the European Spallation Source

- Context
- Instruments at the European Spallation Source
- Requirements for the Instruments
- Detector design and developments to fulfill those requirements ESS requirements

The ESS Site

Helium-3 Crisis

EUROPEAN SPALLATION SOURCE

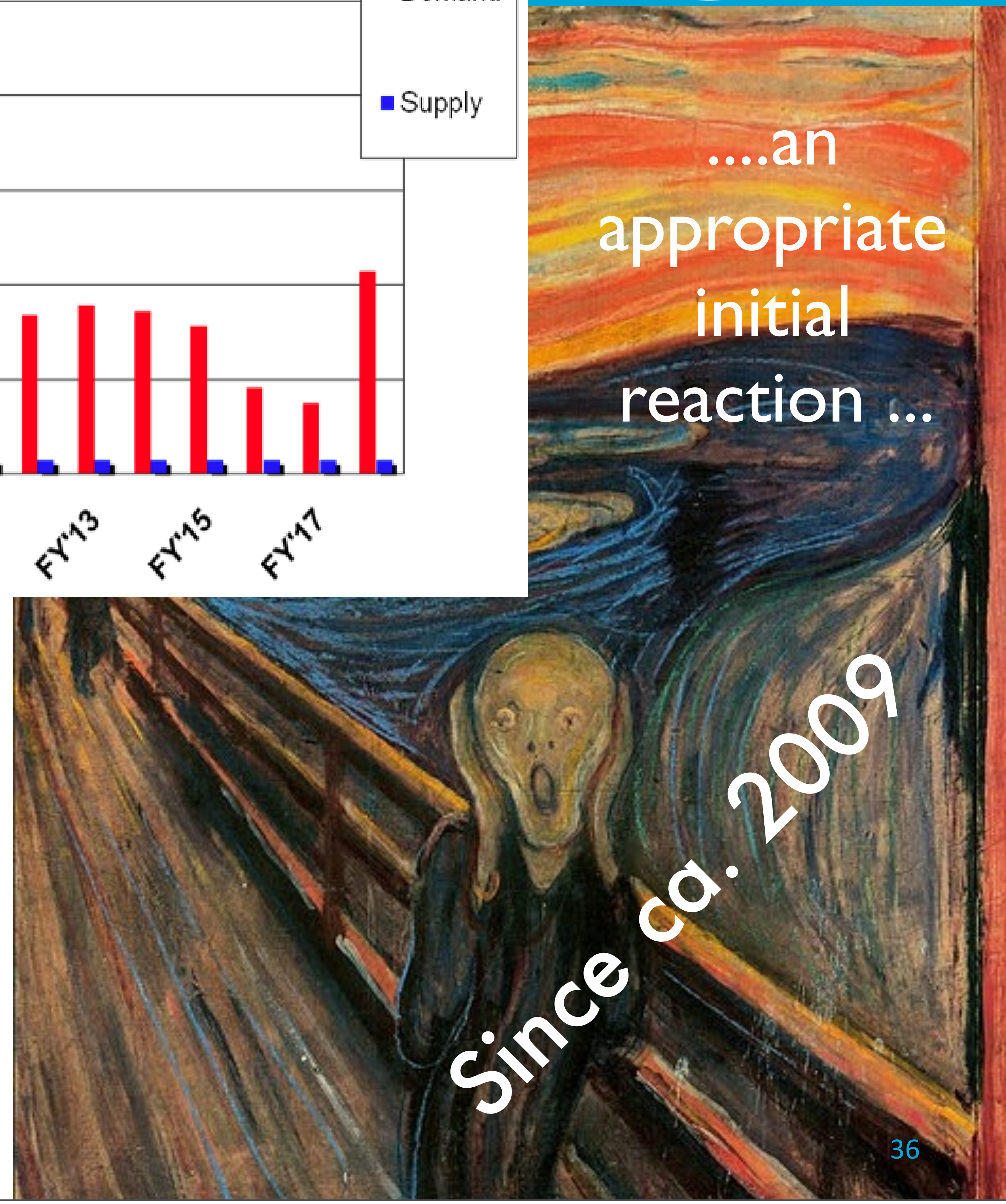


•Comment: seems to be some naivety at the moment as stocks are being emptied rapidly

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



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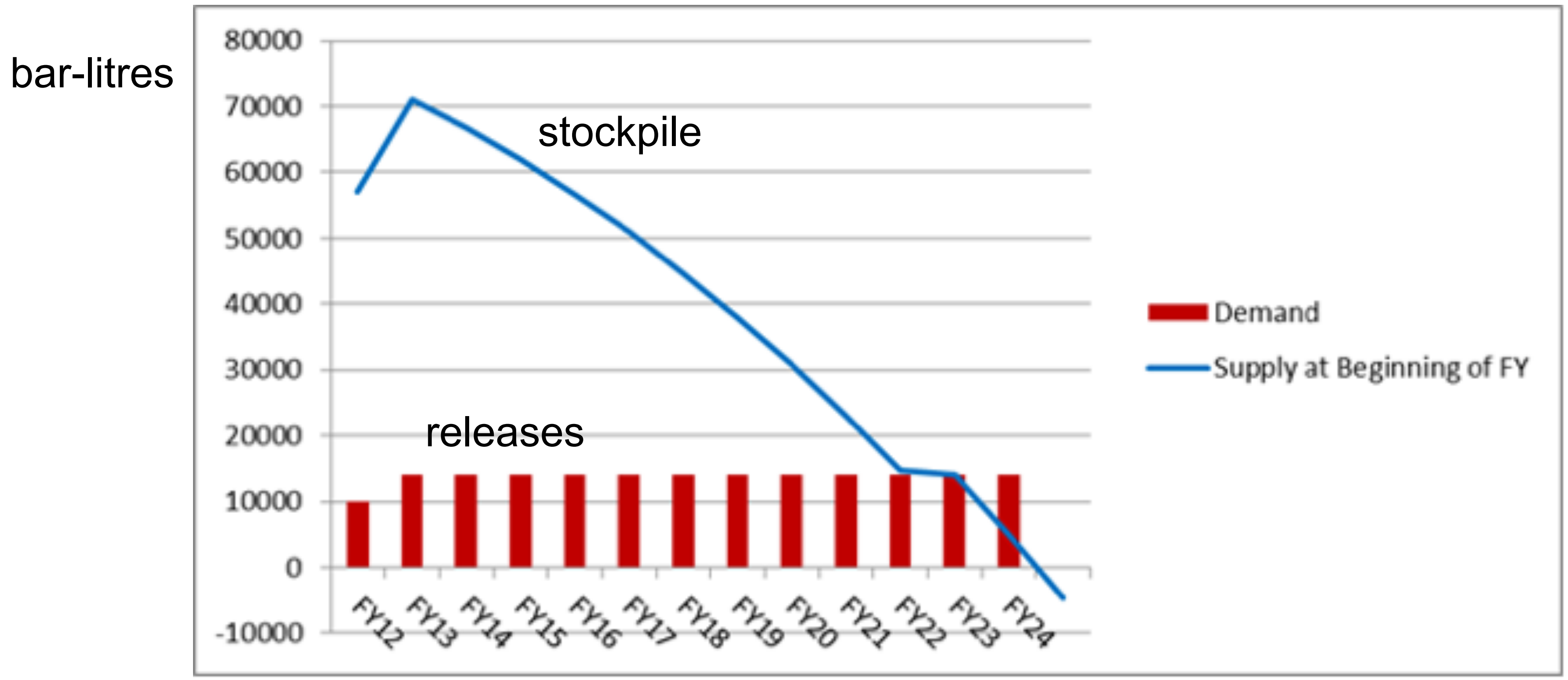
^{3}He Supply Forecast

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

- Current intent for U.S. ^{3}He 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

Pacific Northwest NATIONAL LABORATORY 37

Schedule ...

- 5 years until first neutrons ...

Instruments and their Requirements

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Science Drivers for the Reference Instrument Suite from the Technical Design Report

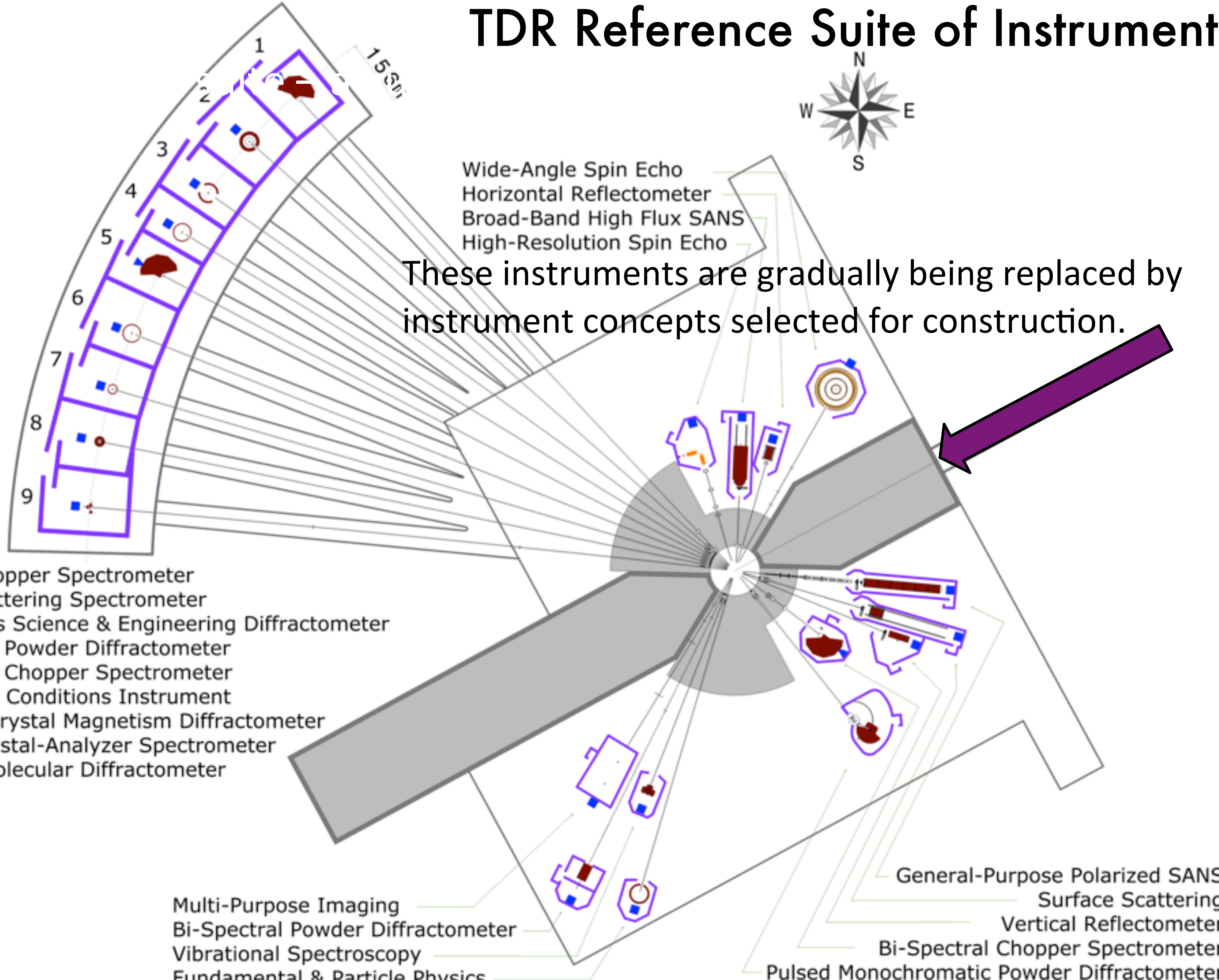
EUROPEAN SPALLATION SOURCE

Multi-Purpose Imaging	life sciences, soft condensed matter, magnetism & superconductivity, engineering & geo-sciences, archeology & heritage conservation
General-Purpose SANS	magnetism & superconductivity, soft condensed matter, chemistry of materials, energy research
Broadband SANS	soft condensed matter, life sciences
Surface Scattering	soft condensed matter, life sciences, chemistry of materials, magnetism & superconductivity
Horizontal Reflectometer	soft condensed matter, life sciences, chemistry of materials
Vertical Reflectometer	magnetism & superconductivity, chemistry of materials, energy research, soft condensed matter
Thermal Powder Diffractometer	chemistry of materials, energy research, engineering & geo-sciences, magnetism & superconductivity
Bispectral Power Diffractometer	magnetism & superconductivity, chemistry of materials, energy research, engineering & geo-sciences
Pulsed Monochromatic Powder Diffractometer	chemistry of materials, energy research, magnetism & superconductivity
Materials Science Diffractometer	engineering & geo-sciences, chemistry of materials
Extreme Conditions Instrument	energy research, magnetism & superconductivity, chemistry of materials
Single-Crystal Magnetism Diffractometer	magnetism & superconductivity, chemistry of materials
Macromolecular Diffractometer	life sciences, magnetism & superconductivity
Cold Chopper Spectrometer	life sciences, chemistry of materials, magnetism & superconductivity
Bispectral Chopper Spectrometer	life sciences, soft condensed matter, chemistry of materials, magnetism & superconductivity
Thermal Chopper Spectrometer	chemistry of materials, energy research, magnetism & superconductivity
Cold Crystal-Analyser Spectrometer	chemistry of materials, energy research, magnetism & superconductivity, engineering & geo-sciences
Vibrational Spectroscopy	chemistry of materials, energy research, magnetism & superconductivity
Backscattering Spectrometer	life sciences, soft condensed matter, chemistry of materials
High-Resolution Spin-Echo	life sciences, soft condensed matter, chemistry of materials, energy research
Wide-Angle Spin-Echo	energy research, magnetism & superconductivity, life sciences, soft condensed matter
Fundamental & Particle Physics	fundamental & particle physics

- life sciences
- magnetism & superconductivity
- soft condensed matter
- engineering & geo-sciences
- chemistry of materials
- archeology & heritage conservation
- energy research
- fundamental & particle physics

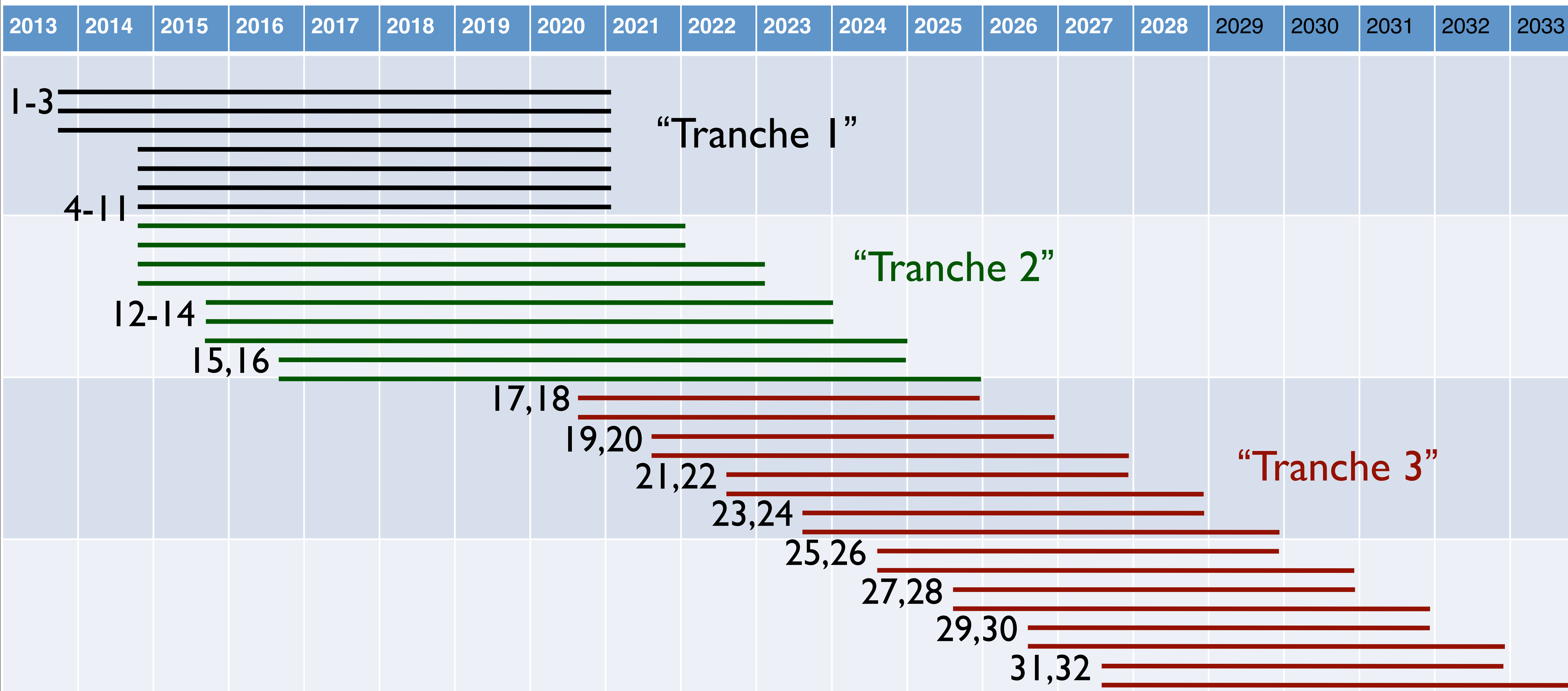
TDR Reference Suite of Instruments

These instruments are gradually being replaced by instrument concepts selected for construction.



1. Cold Chopper Spectrometer
2. Backscattering Spectrometer
3. Materials Science & Engineering Diffractometer
4. Thermal Powder Diffractometer
5. Thermal Chopper Spectrometer
6. Extreme Conditions Instrument
7. Single-Crystal Magnetism Diffractometer
8. Cold Crystal-Analyzer Spectrometer
9. Macromolecular Diffractometer

Instruments Will Move into Construction a Few at a Time



Scope: Detector Requirements for Instruments

EUROPEAN SPALLATION SOURCE

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**			

Estimates from TDR

- 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 accepted instrument concepts submitted in this proposal round

Detector Technologies for Baseline Suite

Instrument	Detector Technology						
	^{10}B Thin Films		Scintillators		^{3}He	Micropattern	
	⊥	‖	WLS	Anger		Rate	Resolution
Multi-Purpose Imaging	-	-	-	-	-	o	+
General Purpose Polarised SANS	o	+	-	+	o	+	-
Broad-Band Small-Sample SANS	o	+	-	+	-	+	-
Surface Scattering	o	+	-	+	o	+	-
Horizontal Reflectometer	-	o	-	+	+	o	-
Vertical Reflectometer	-	o	-	+	+	o	-
Thermal Powder Diffractometer	o	+	+	-	-	o	-
Bi-Spectral Powder Diffractometer	o	+	+	-	-	o	-
P-M Powder Diffractometer	o	+	+	-	-	o	-
MS Engineering Diffractometer	o	+	+	-	-	o	-
Extreme Conditions Diffractometer	o	+	+	-	-	o	-
Single Crystal Diffractometer	o	+	+	-	-	o	-
Macromolecular Diffractometer	-	o	o	o	-	+	+
Cold Chopper Spectrometer	+	o	o	-	-	-	-
Bi-Spectral Chopper Spectrometer	+	+	o	-	-	-	-
Thermal Chopper Spectrometer	+	+	+	-	-	-	-
Cold Crystal Analyser Spectrometer	-	o	-	+	+	-	-
Vibrational Spectrometer	-	o	-	o	+	-	-
Backscattering Spectrometer	-	o	-	+	+	-	-
High-Resolution Spin Echo	-	o	-	o	+	+	-
Wide-Angle Spin Echo	-	o	-	o	+	+	-
Fundamental & Particle Physics	-	-	-	-	+	+	+

Preliminary

+ = favoured option
o = option
- = disfavoured option

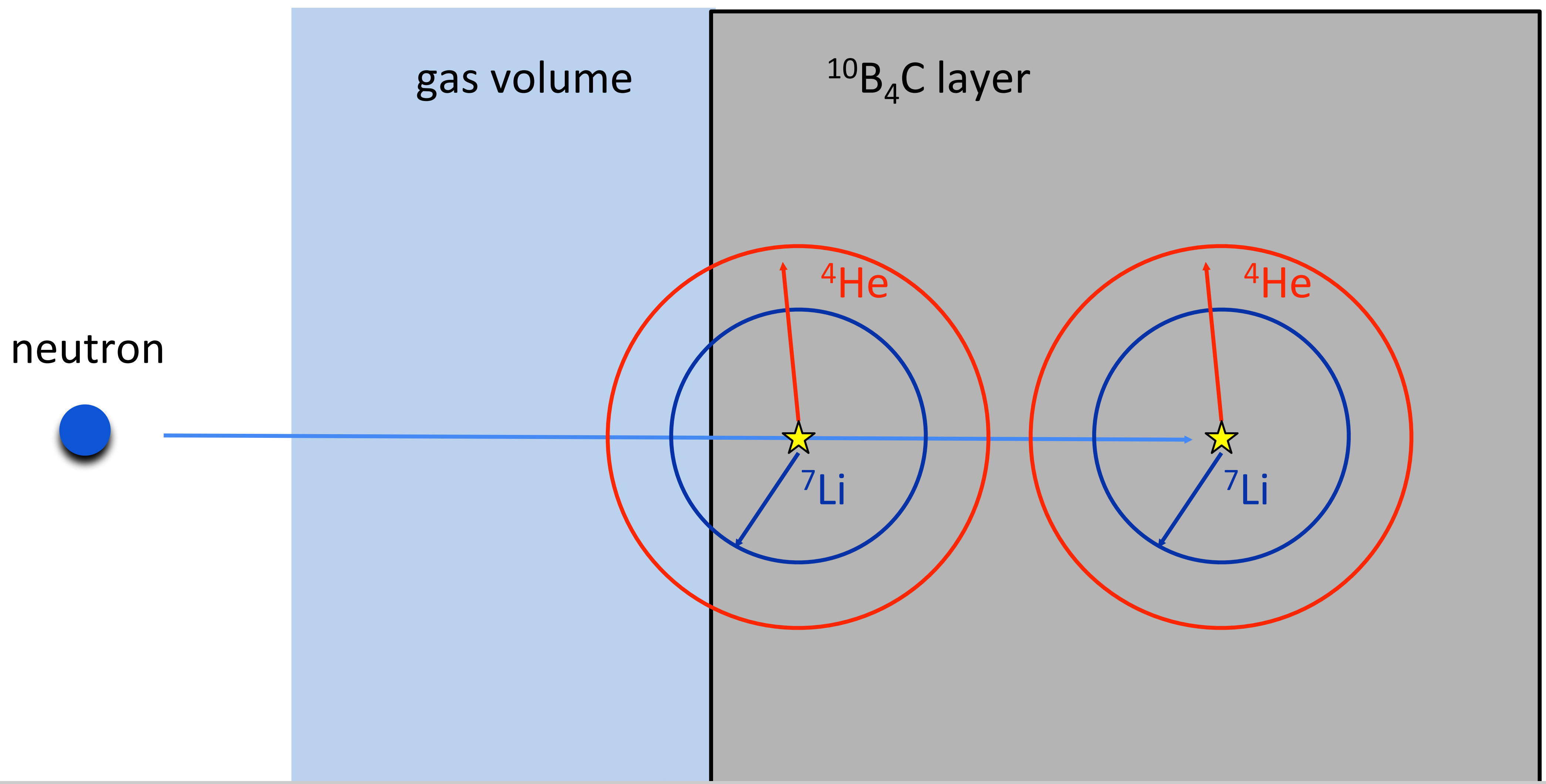
- Most instruments have "He-3-free" options
- Requirement for He-3 significantly reduced
- An array of technologies will be used
- dependent upon a wide range of sources for detectors

Collaborative and In-Kind needed to fulfill these needs

^{10}B-based Neutron Detectors

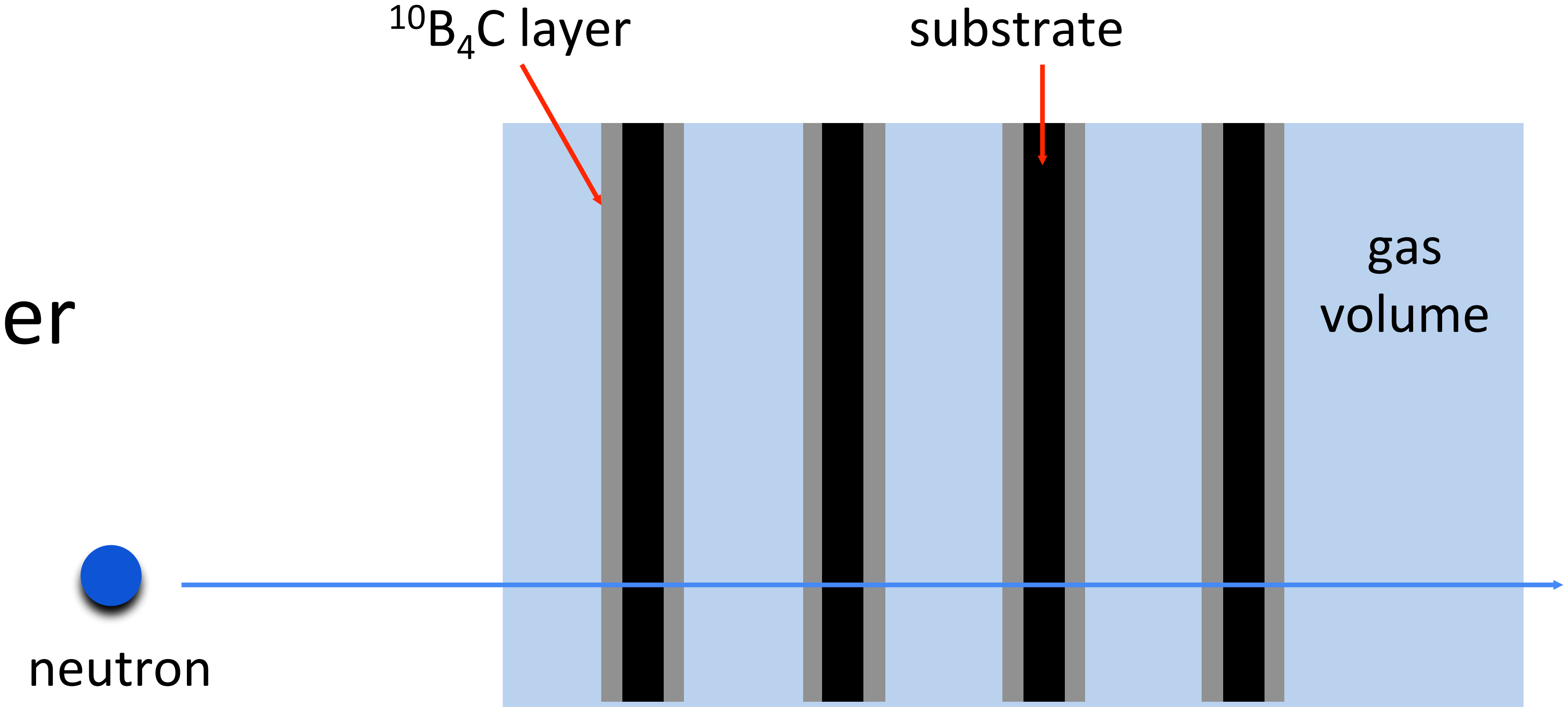
$$
\begin{aligned}
{}^{10}B + n \rightarrow {}^{7}Li^{*} + {}^{4}He \rightarrow {}^{7}Li + {}^{4}He + 0.48 MeV\, \gamma\text{-ray} + 2.3\ \ MeV \quad (94\%) \\
\rightarrow {}^{7}Li + {}^{4}He \qquad\qquad + 2.79 MeV \quad (6\%)
\end{aligned}
$$

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



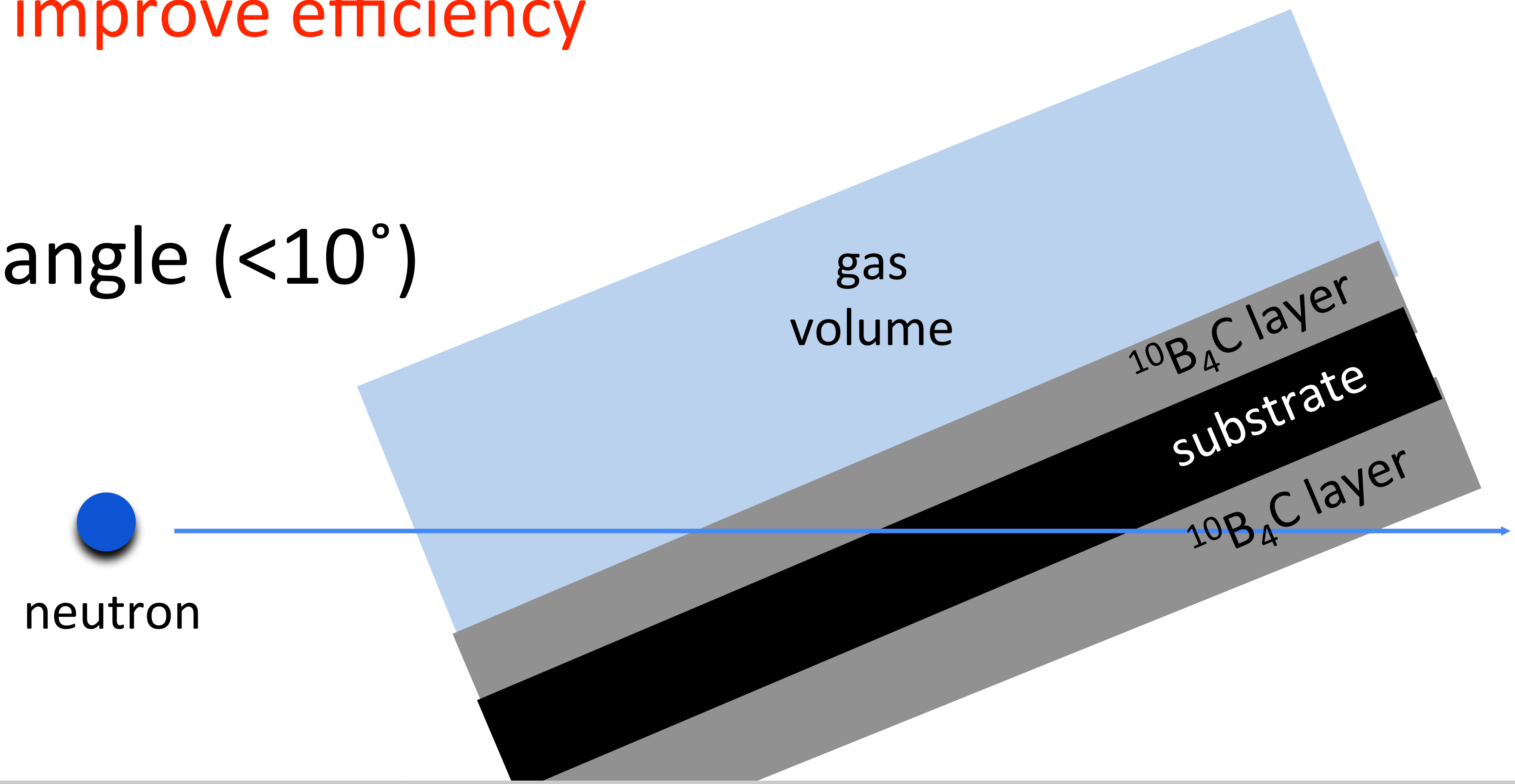
^{10}B-based Neutron Detectors

1 Multi layer



Generic approaches to improve efficiency

2 Grazing angle (<10˚)



Technologies for the Instruments

EUROPEAN SPALLATION SOURCE

Instrument	Detector Area [m^2]	Wavelength Range [Å]	Time Resolution [μs]	Resolution [mm]
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Thermal Powder Diffractometer	20	0.6-6	<10	2x2
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Material Science & Engineering D...e	10	0.5-5	10	2
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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**			

B-10

Scintillator

He-3

Exotica

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Specific examples

- Inelastic direct geometry spectroscopy
- Reflectometry
- Neutron Macromolecular Crystallography

Collaborations

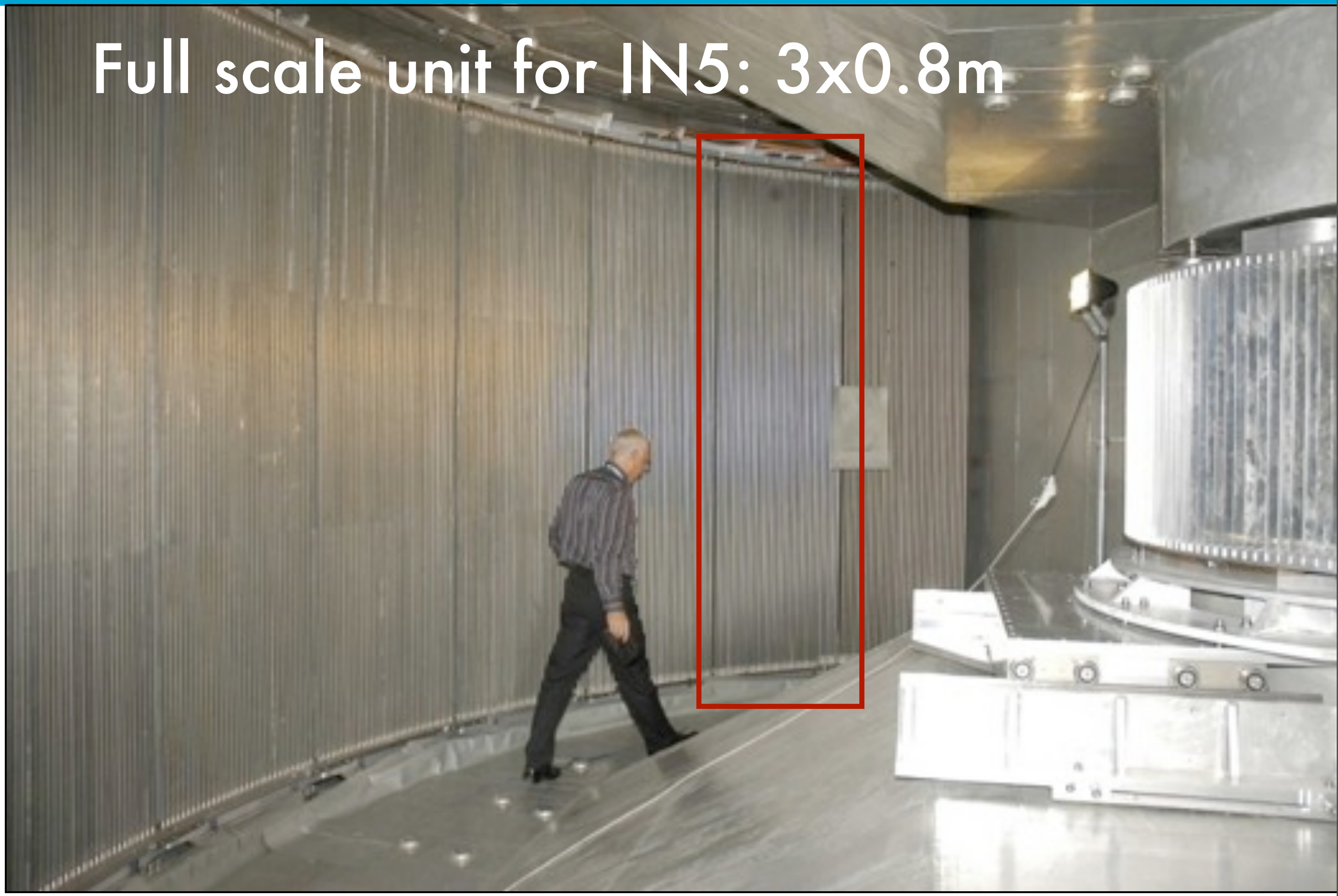
- Everyone should play to their strengths

Inelastic Direct Geometry Spectrometer

Multigrid Design: ILL/ESS/LiU Collaboration

- This year: produce an IN5 equivalent module with the ILL Multigrid design
- Collaboration: ILL/LiU/ESS
- >70m^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



(slide from B. Guerard)

CLUSTER OF RESEARCH INFRASTRUCTURES FOR SYNERGIES IN PHYSICS

$^{10}B_4C$ thin film Multi-Grid detectors

CRISP

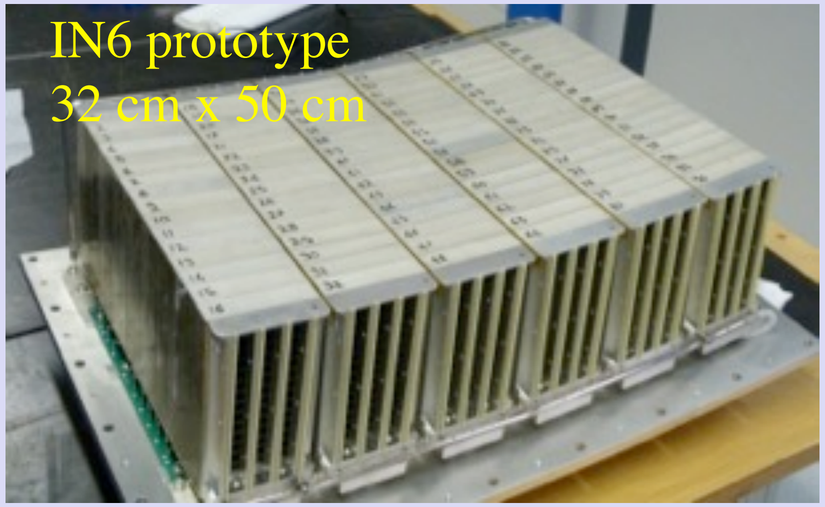
Participants: ESS, ILL, LiU

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

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
- $Ar\text{-}CO_2$ & CF_4 tested at [0.2 - 1] Bar

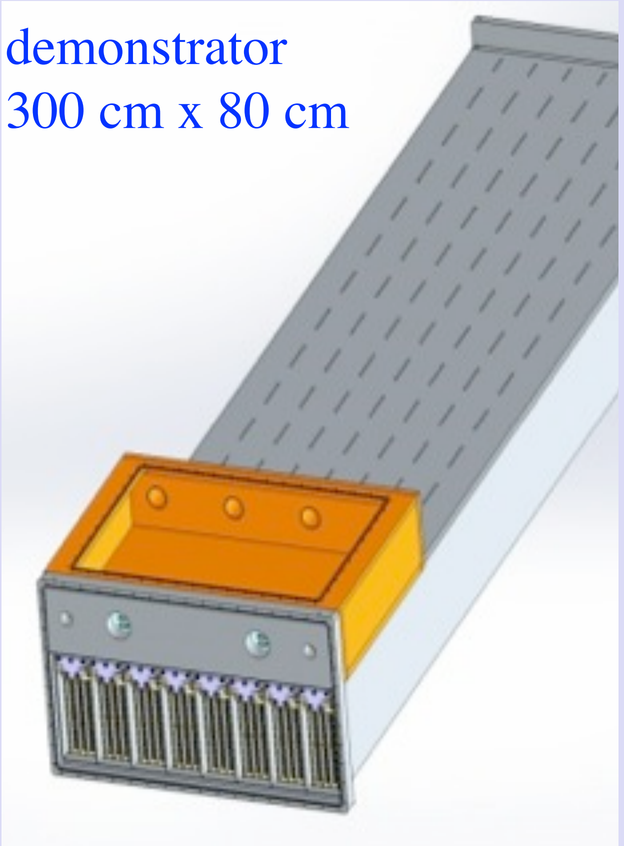
Where we were last year



- 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



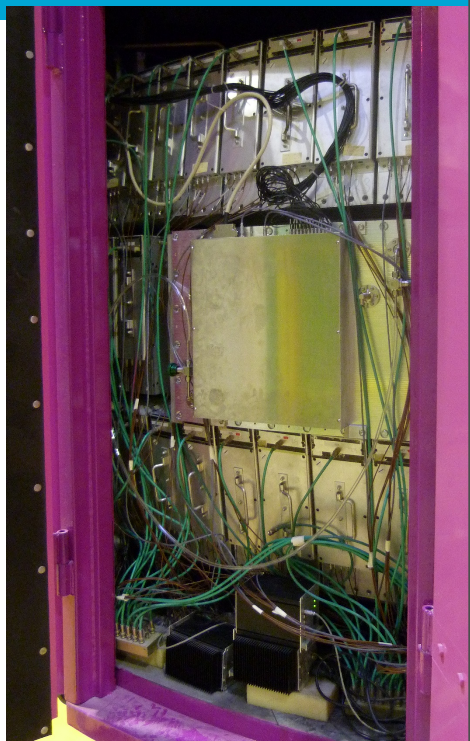
1024 grids/ 512 wires
- **256** x (4Grids) cath channels
- Wires X_n & X_{n+1} connected with resistors → **32** channels

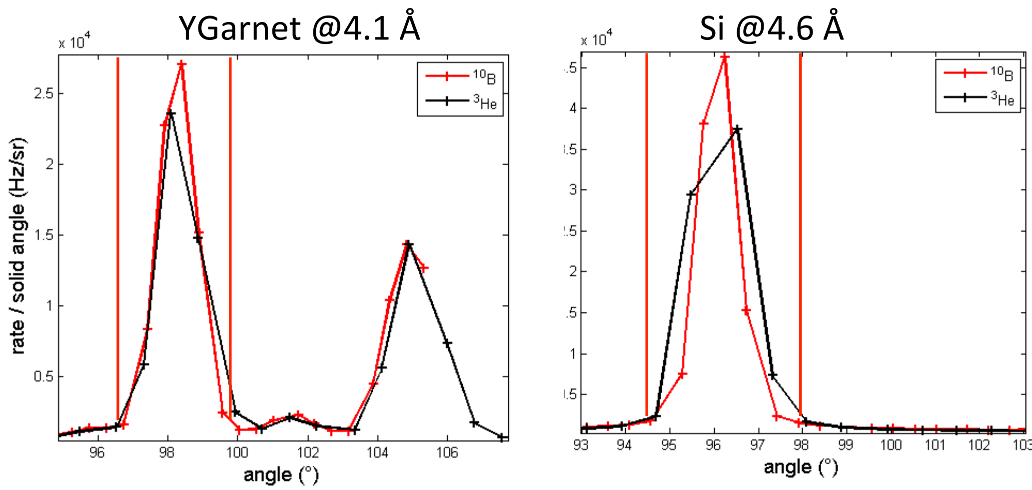
- Pressure vessel tested
- Mass production of B_4C (70 m^2 !) and detector components
- real detector operational

Where we want to be next year

Multigrid Design: IN6 Demonstrator

IN6 Demonstrator

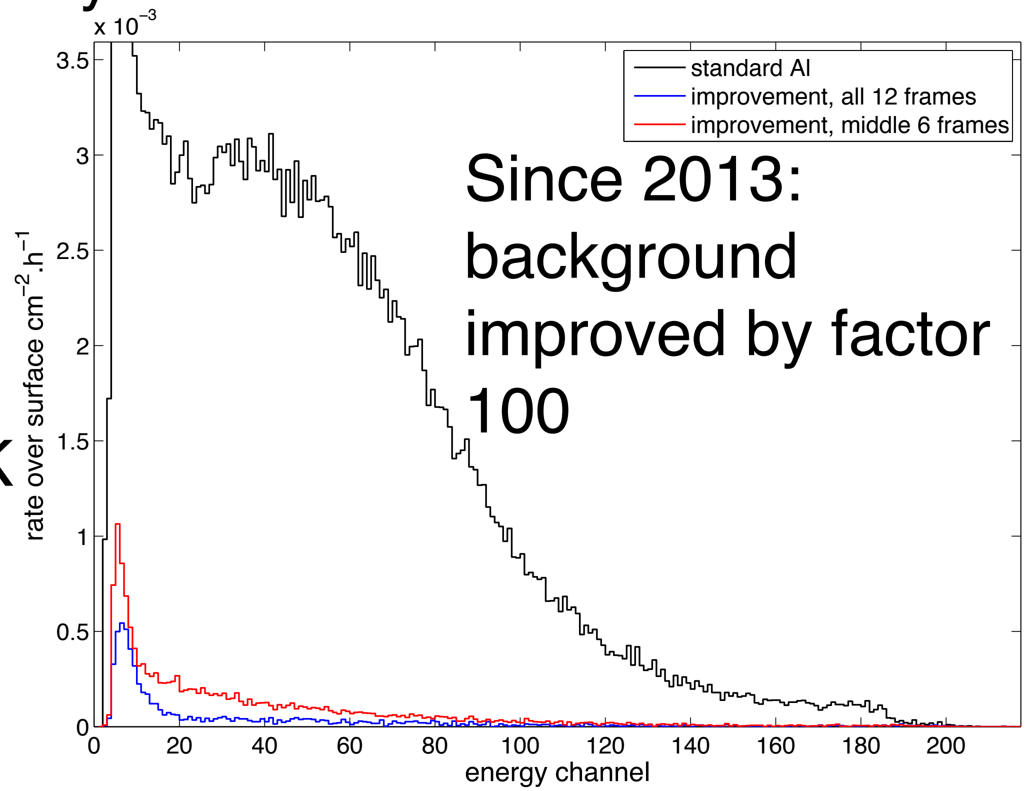




Ratio of integrated rates in Bragg peaks :

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

- •Performance basically matches Helium-3
- •Efficiency - OK
- •Data - OK
- •Scattering - OK
- •Gamma rej - OK
- •t resolution - OK
- •x,y resolution - OK

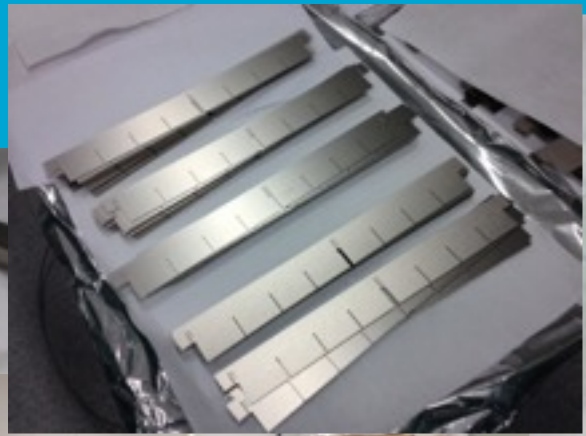


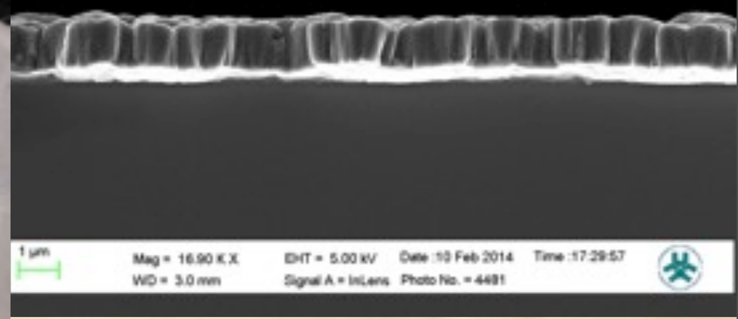
- •background from alpha's in Al seen
- •Plating or ultrapure Al solves it: now ok

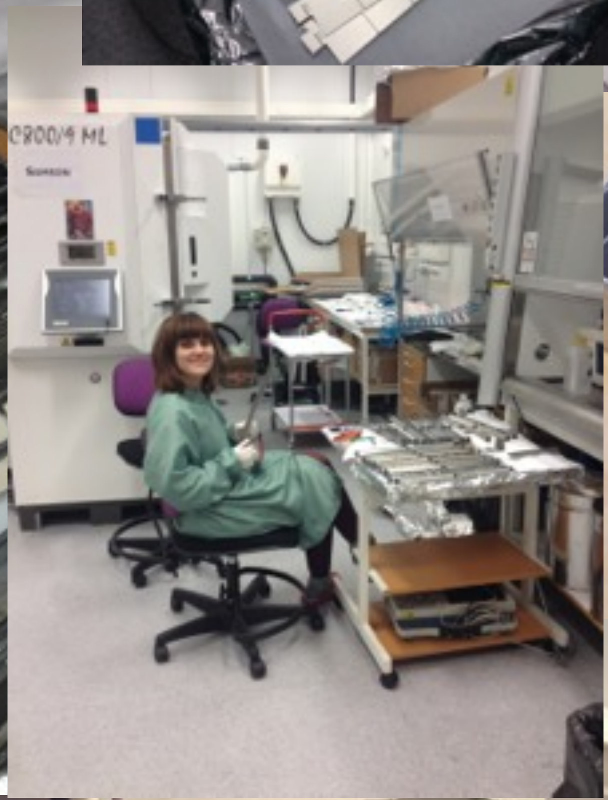
Multigrid Design: IN5 Demonstrator

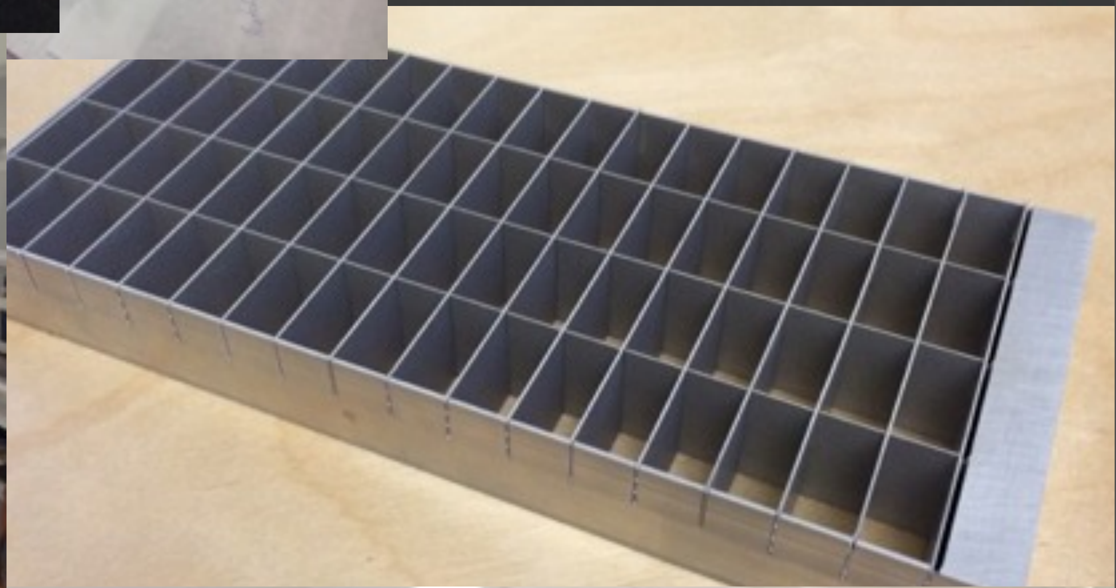
Mass production possible?

Full IN5-like module (3x0.8m)
To be completed by Sep'14
Coatings complete
104m^2









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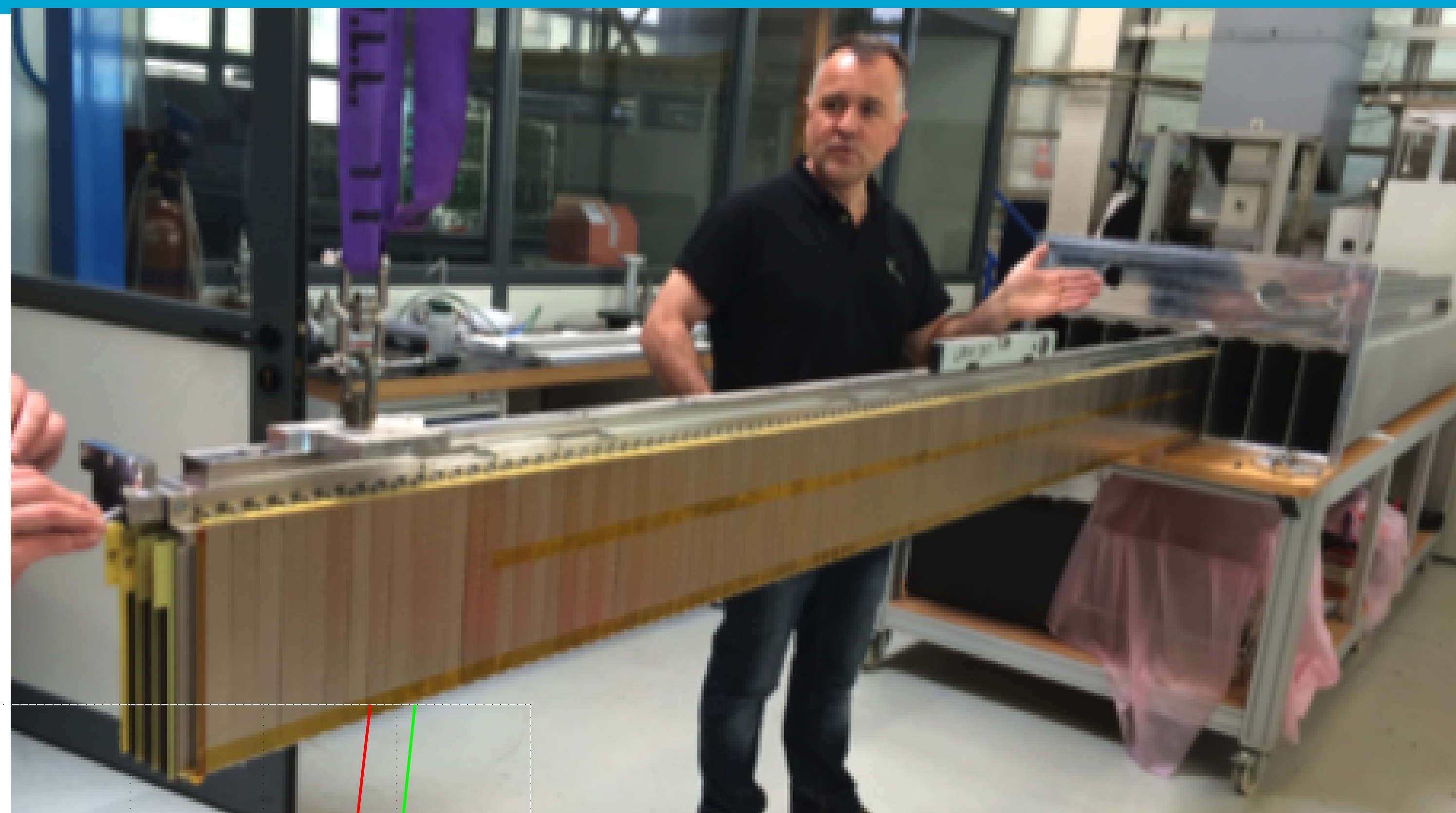
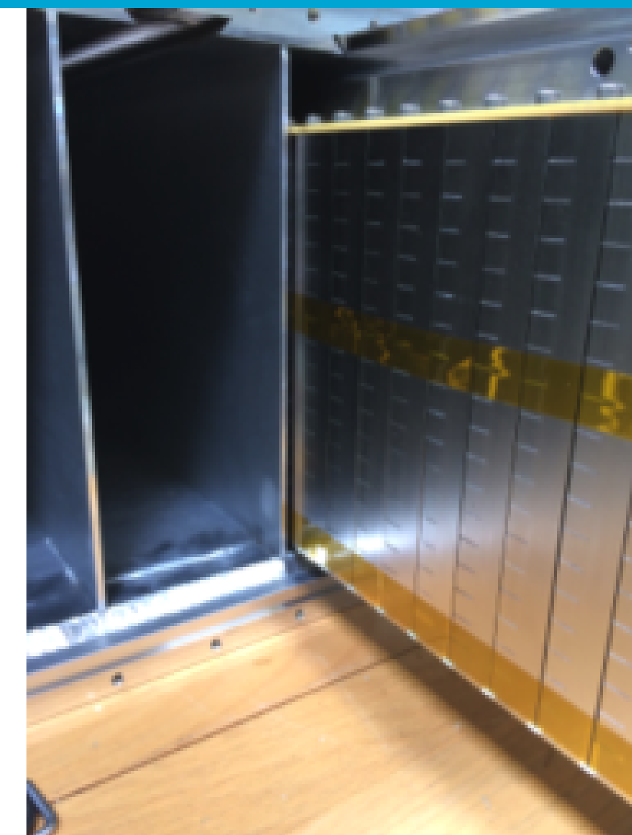
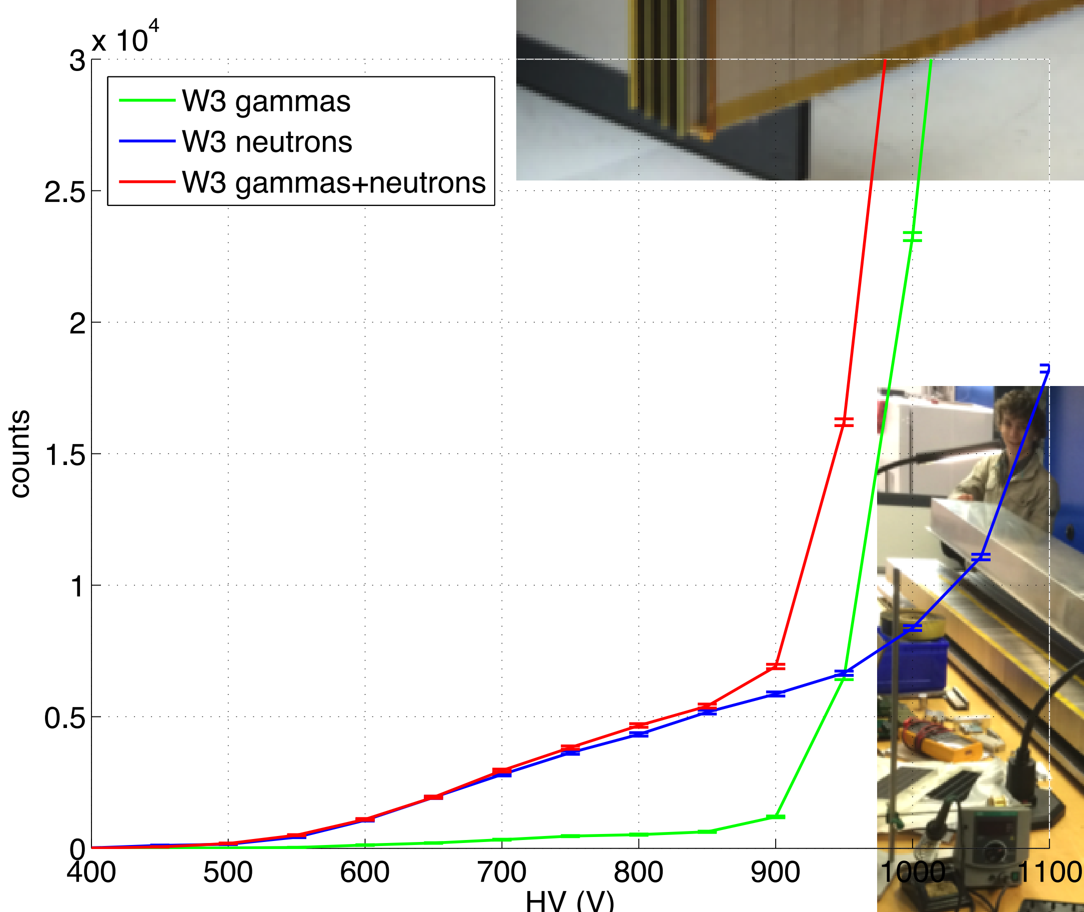
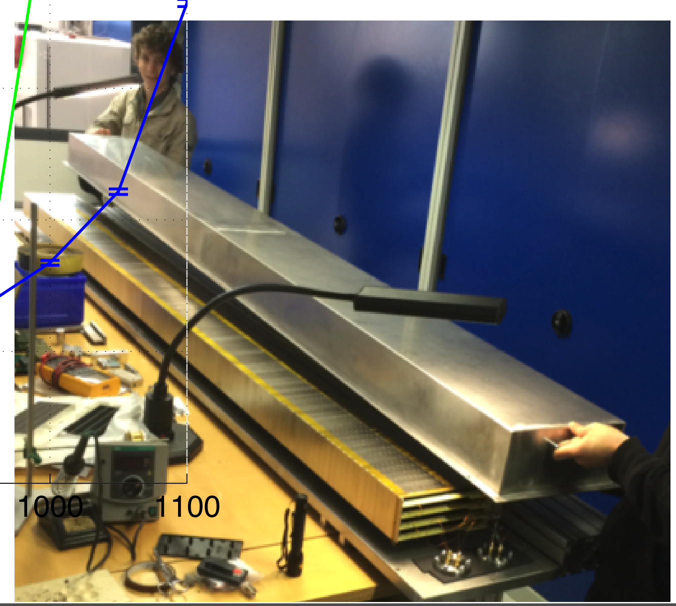
Multigrid Design: IN5 Demonstrator
Large area neutron detectors possible again
ILL/ESS/LiU Collaboration

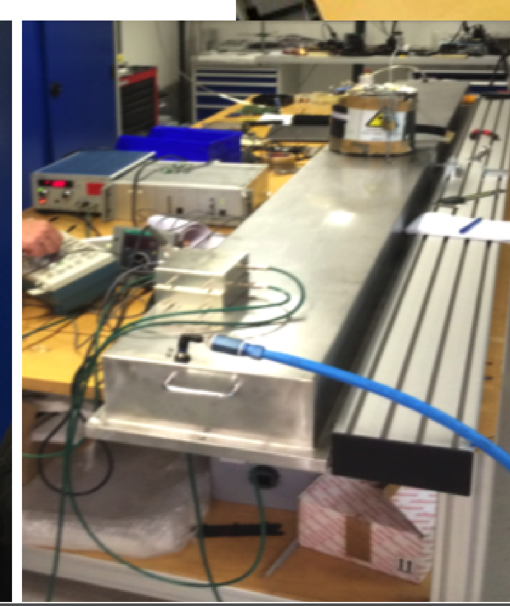
EUROPEAN SPALLATION SOURCE









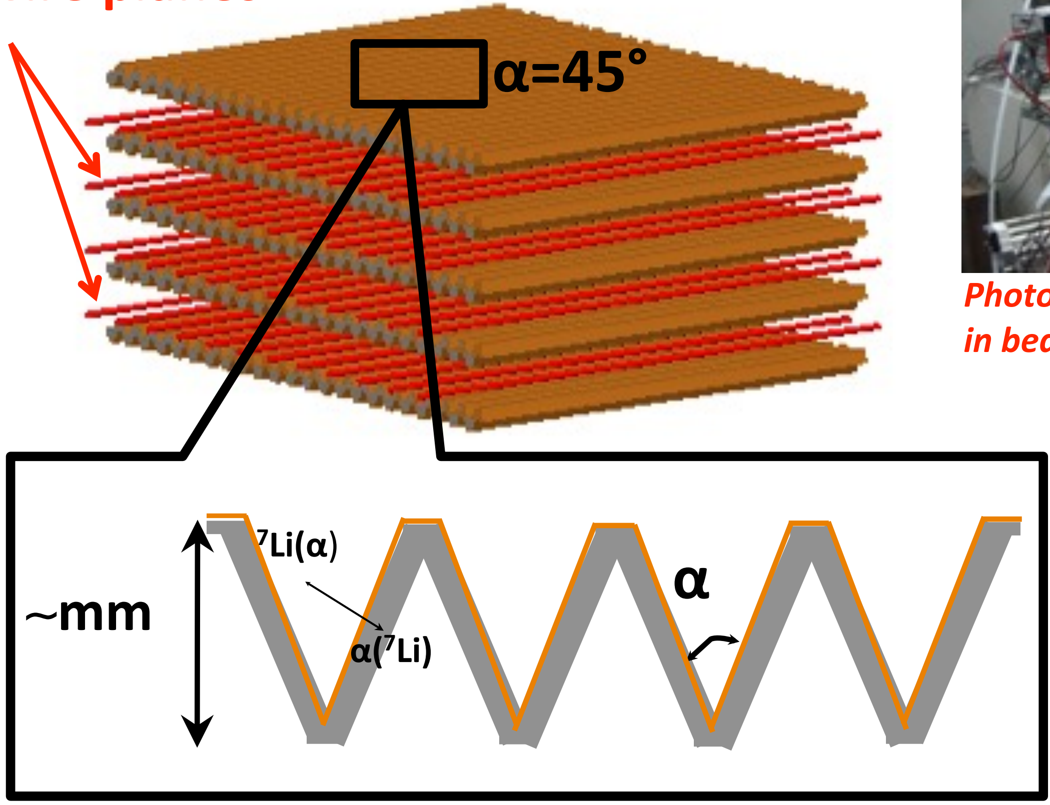


Macrostructured MWPC (FRM-II, ESS)

(alternate option)

Stack of MWPCs with Boron-lined "macrostructured" cathodes

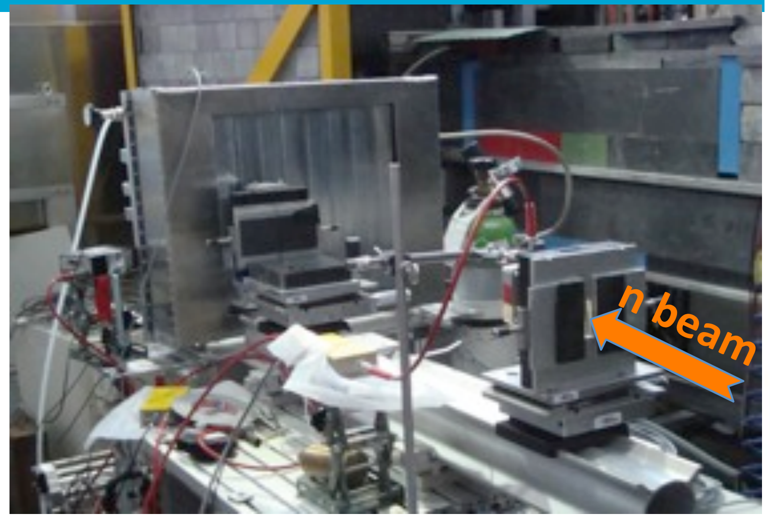
Sense wire planes



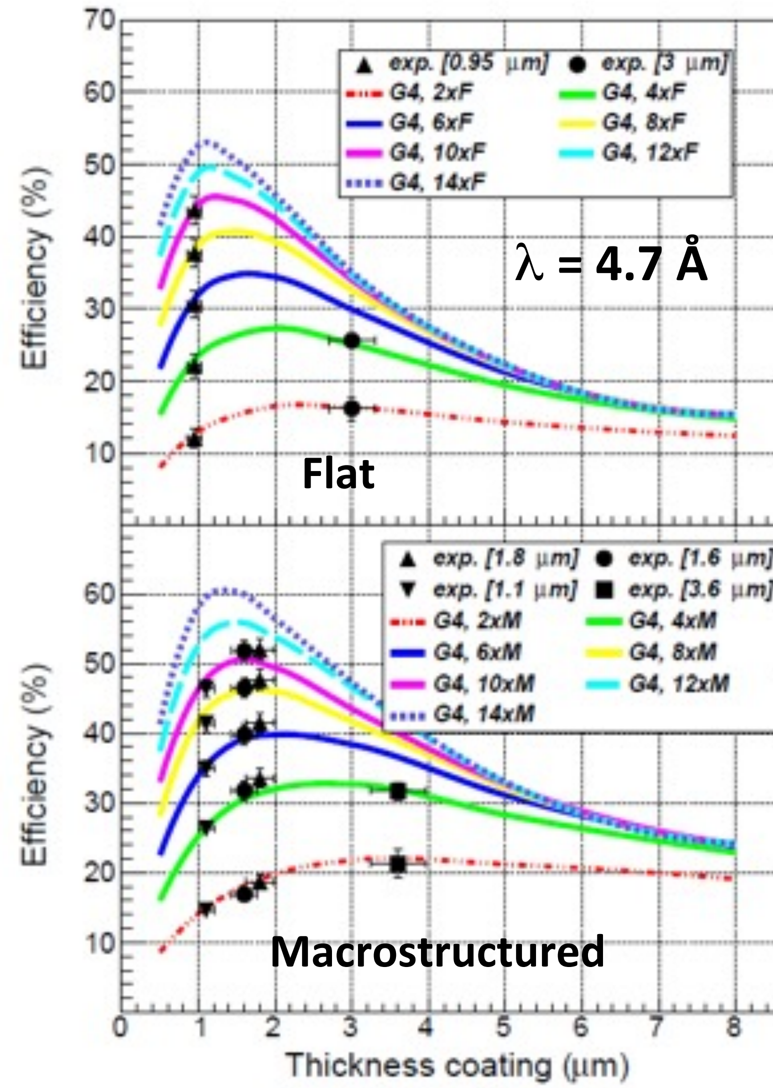
3D regular pattern consisting of grooves that can be created in the substrate material by milling, extrusion, forming, etc.

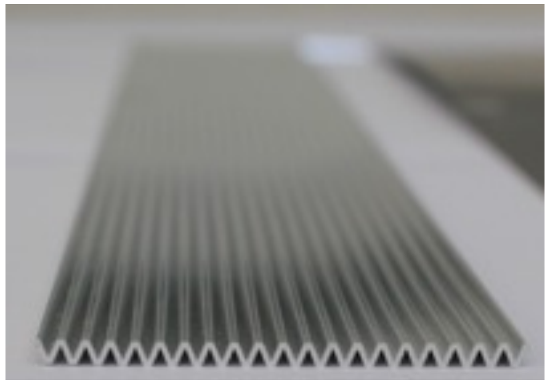
Similar concept ("microstructuring") used to increase the efficiency of the semiconductor neutron detectors.

J. Uher et al., NIMA 576(2007)32.

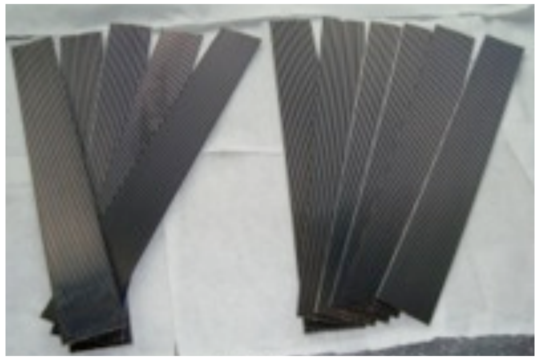


Photograph of the ^{10}B-demonstrator during the in beam tests at TREFF@FRM2 (λ=4.7 Å).

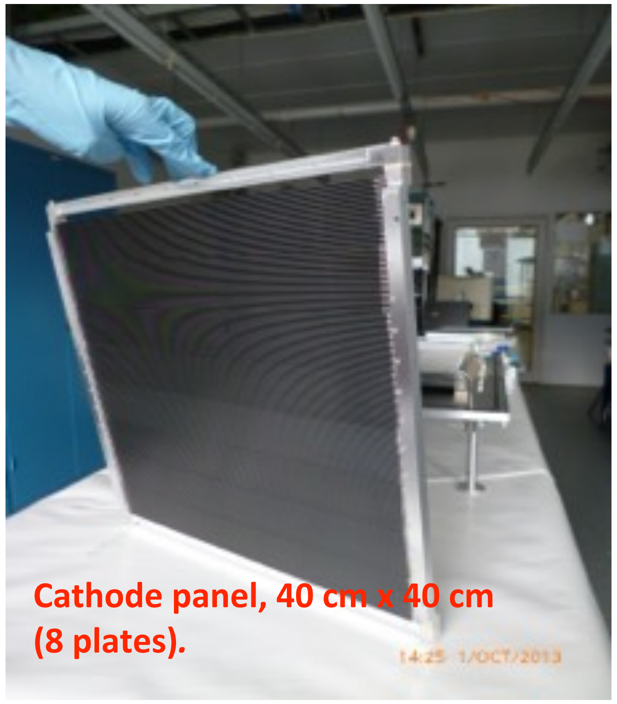




5 cm x 40 cm macrostructured plate fabricated by extrusion (MIFA, Holland).



$^{10}B_4C$-coated plates for the demonstrator (Univ. Linköping,



Cathode panel, 40 cm x 40 cm (8 plates).

I. Stefanescu

Reflectometer

- Bruno said quite a bit about the challenges of this yesterday ...
- Rate + Resolution
- Pushing the boundaries

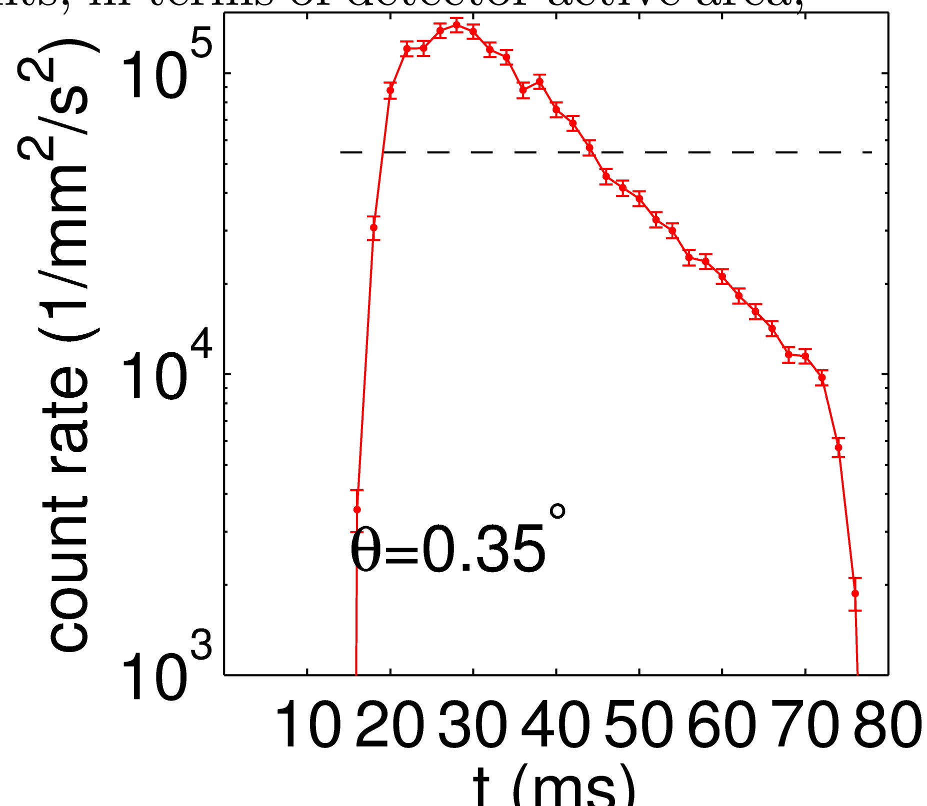
- Subject of a specific set of R+D
- 3 options under serious consideration:
  - He-3 MSGC (Bruno presented yesterday)
  - High rate capable scintillator detectors (WLS fibres and direct coupled)
  - Multi-Blade B-10 detector (Bruno presented yesterday)

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.

(preliminary)



Factor >100-1000 higher than state-of-art detectors today

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

(and high spatial resolution required)

Neutron Macromolecular Crystallography

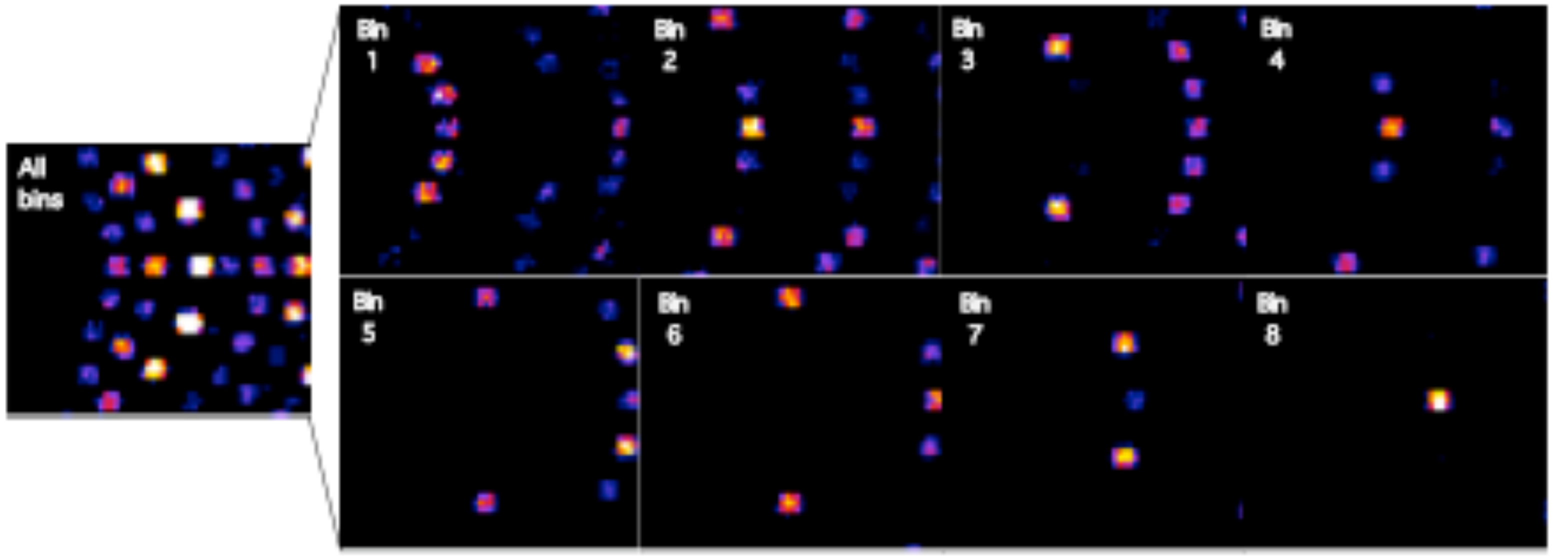


Figure 5 A crowded part of a simulated diffraction pattern from a 5 mm crystal of perdeuterated rubredoxin at detector distance of 20 cm and 2θ-angle of 45° split into nine time bins. Bin 9 contains no reflections and is hence not shown.

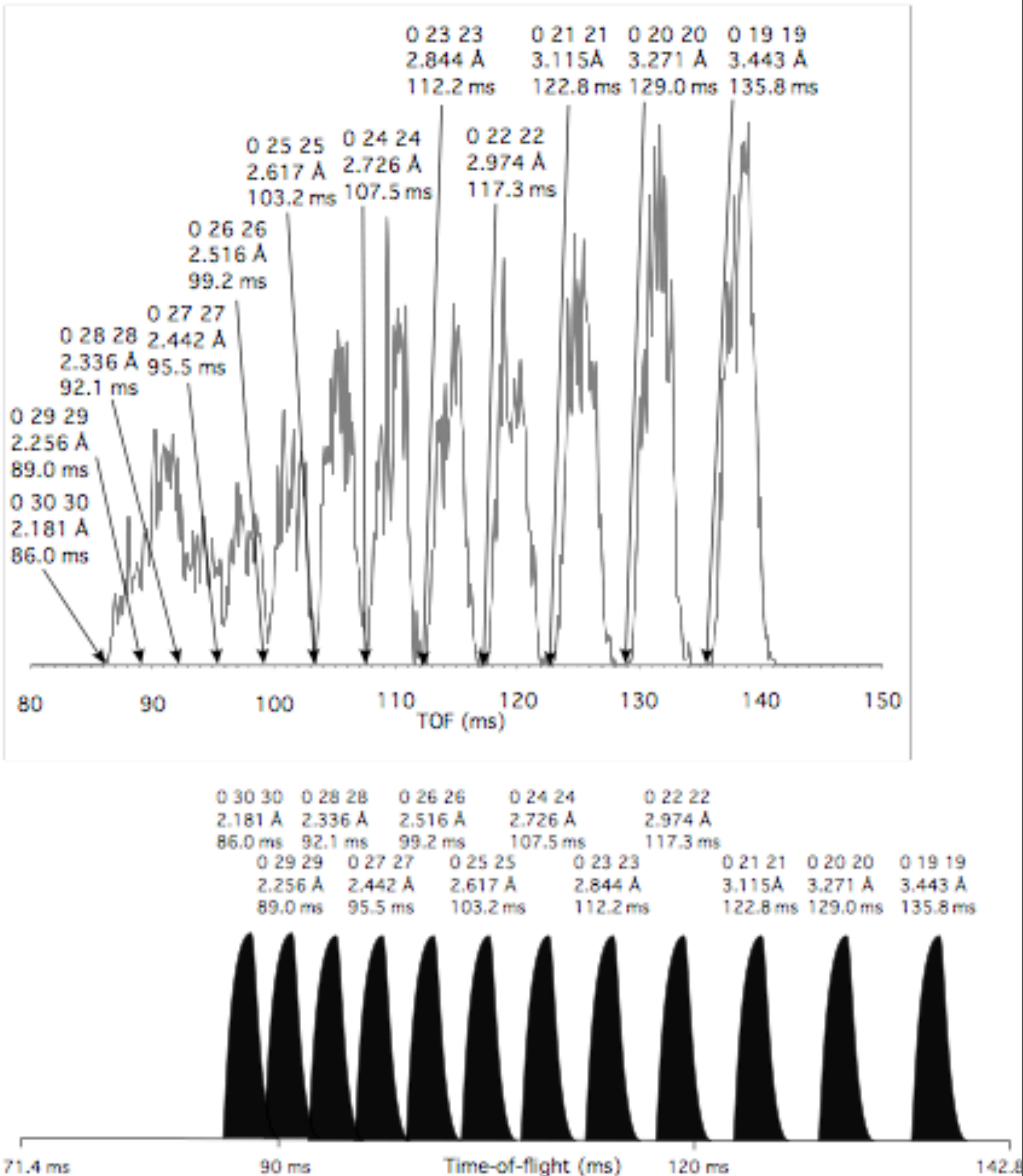


Figure 5 The simulated (top) and scale drawing (bottom) representing TOF separation of the harmonically overlapped reflections 0 19-30 19-30 using arbitrary reflection intensities. The time width in the scale drawi is 4 ms.

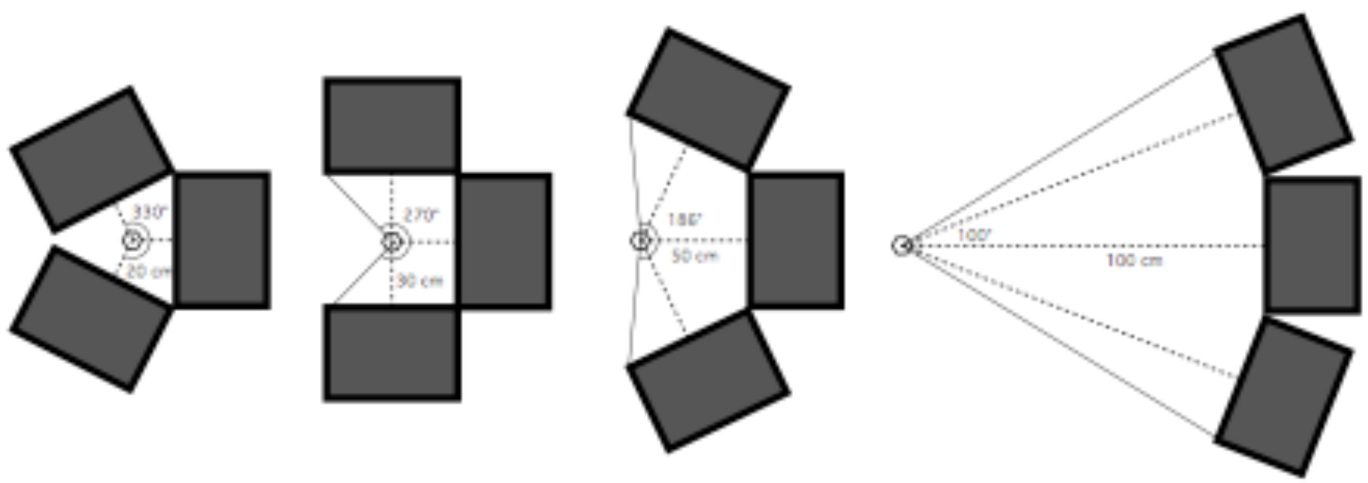


Figure 4 The detector geometry illustrated as a function of crystal-detector distance and the total scattering angle covered in the horizontal plane.

0.2mm Resolution
60x60cm modules?
Good time resolution

Gamma rejection not particularly important

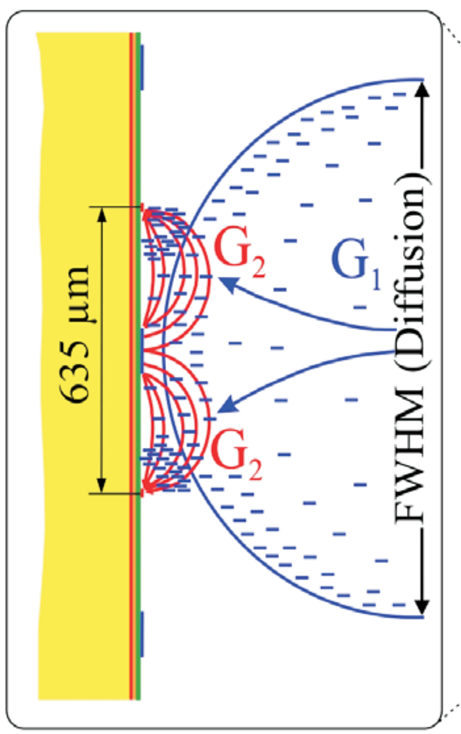
E. Oksanen

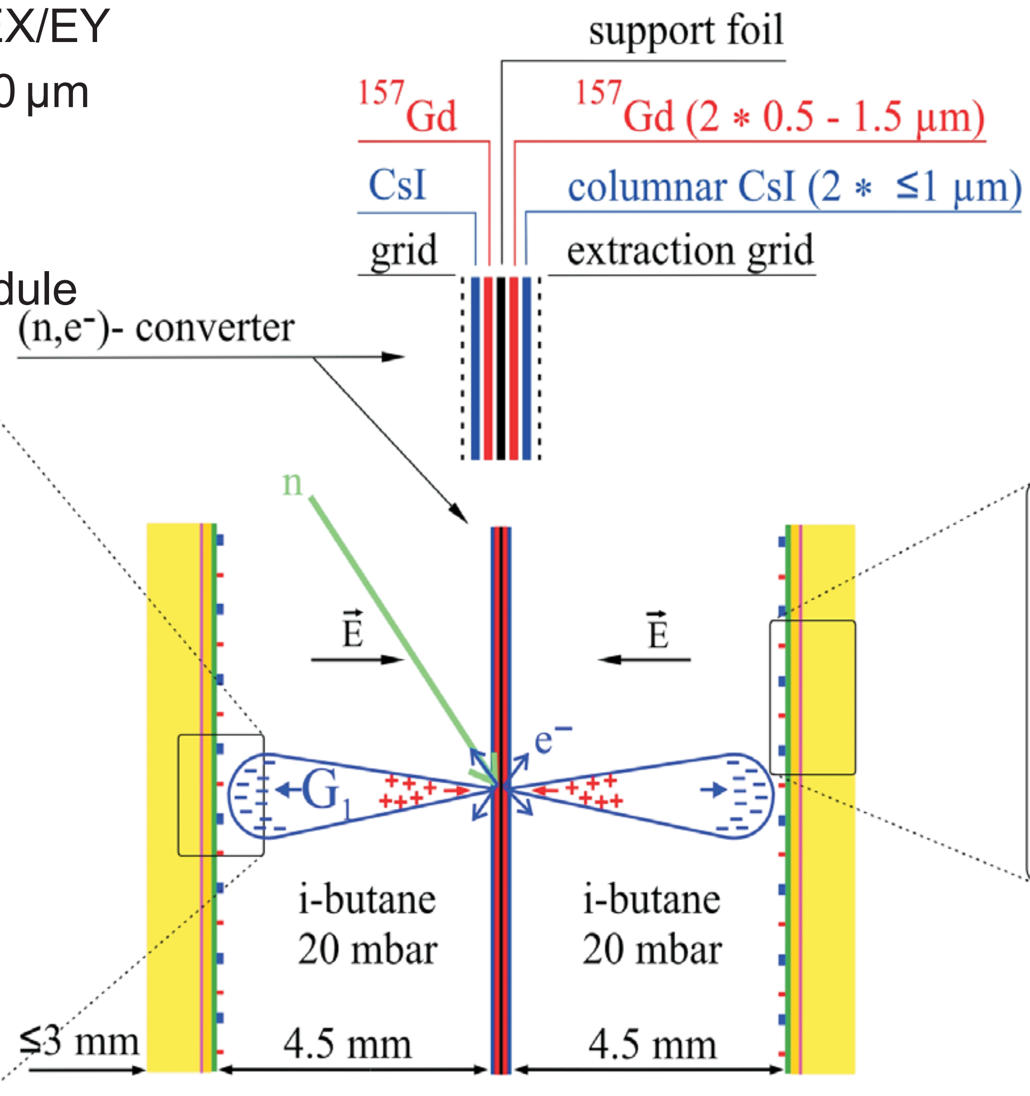
HZB in-kind contribution to ESS

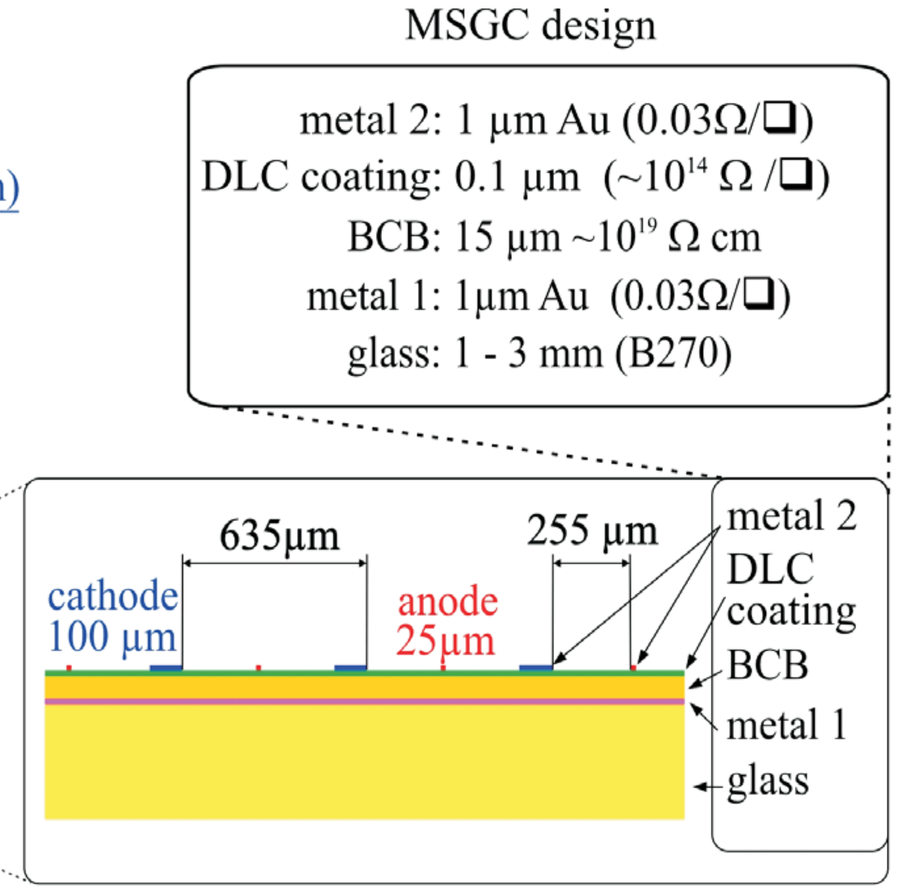
Gd-Based MSGC/GEM Detector

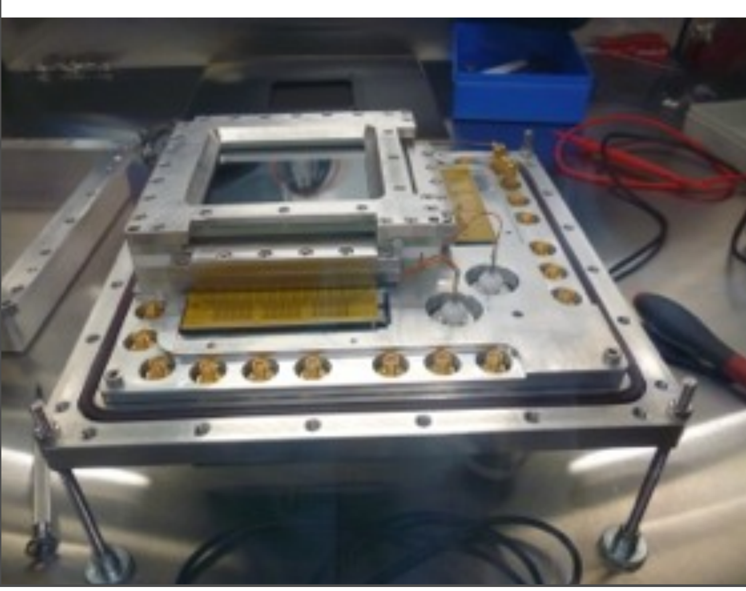
Detector specifications

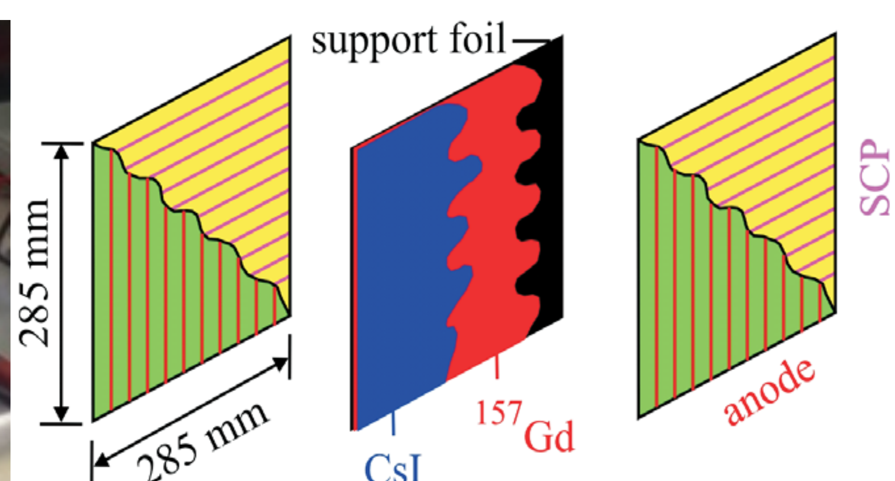
- Measured parameters: X/Y,T, EX/EY
- Position resolution: 100 µm - 300 µm
- Time-of-flight resolution: << 1µs
- Time resolution: 2 ns
- Counting rates: $5*10^7$ n/s per module

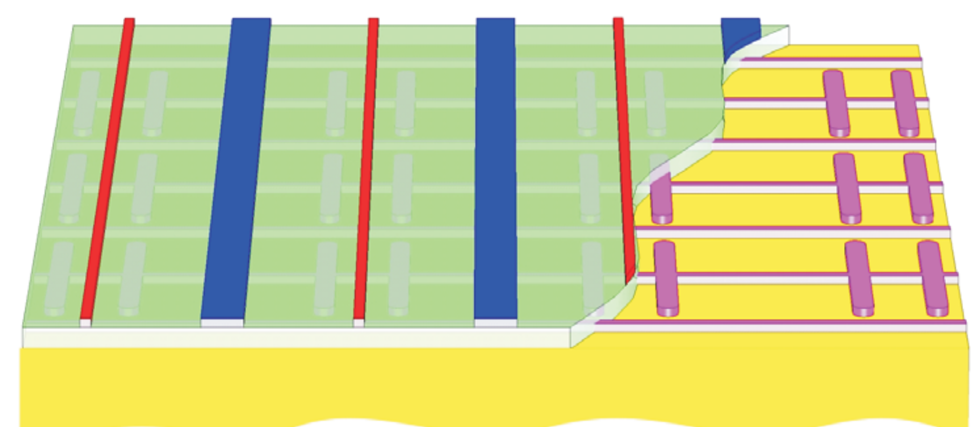












Substitute MSGC with GEMs: now a collaboration CERN-HZB-ESS

originally developed within context of DETNI /NMI3

Summary

Collaborations for Construction Phase

Instrument construction started for first 3 instruments

Challenge: select collaborative partners to build performant detectors

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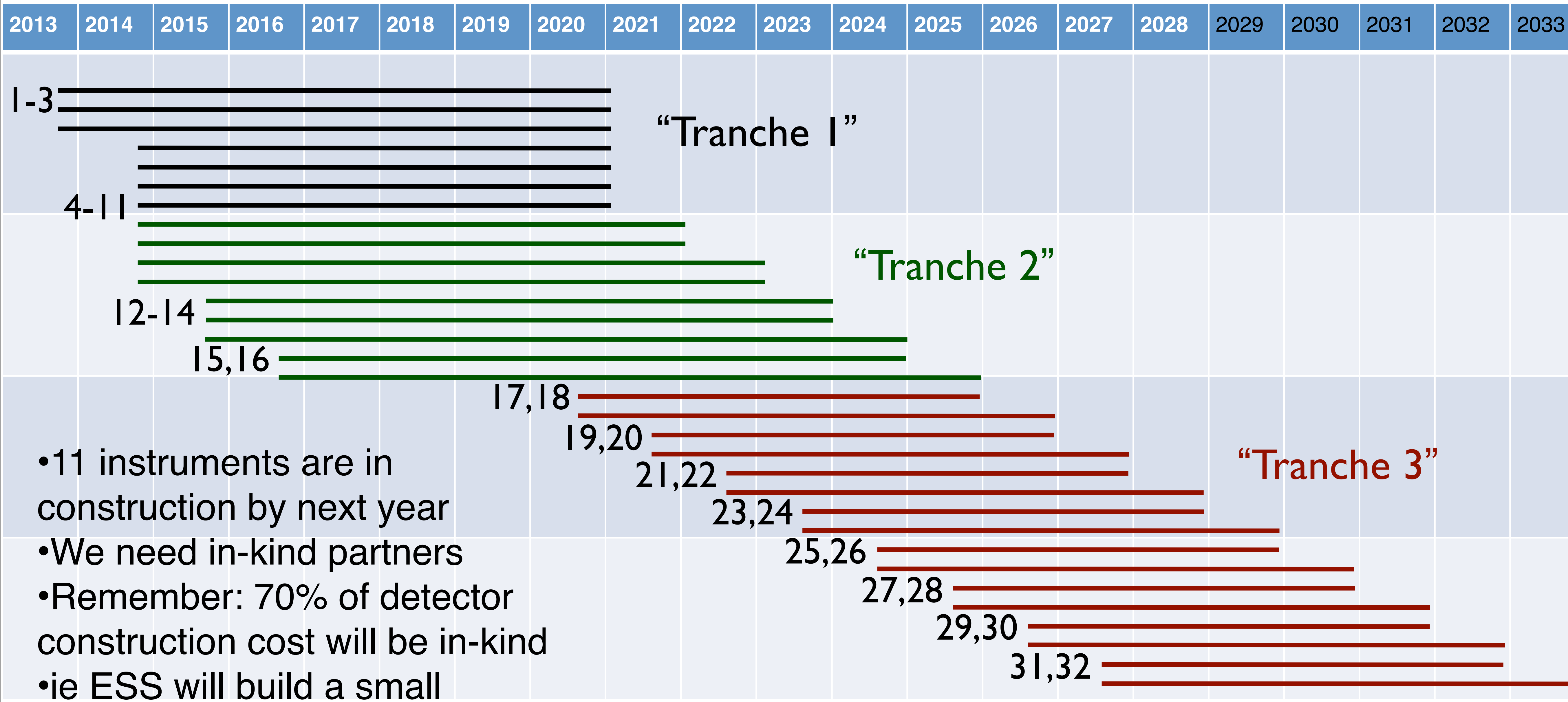
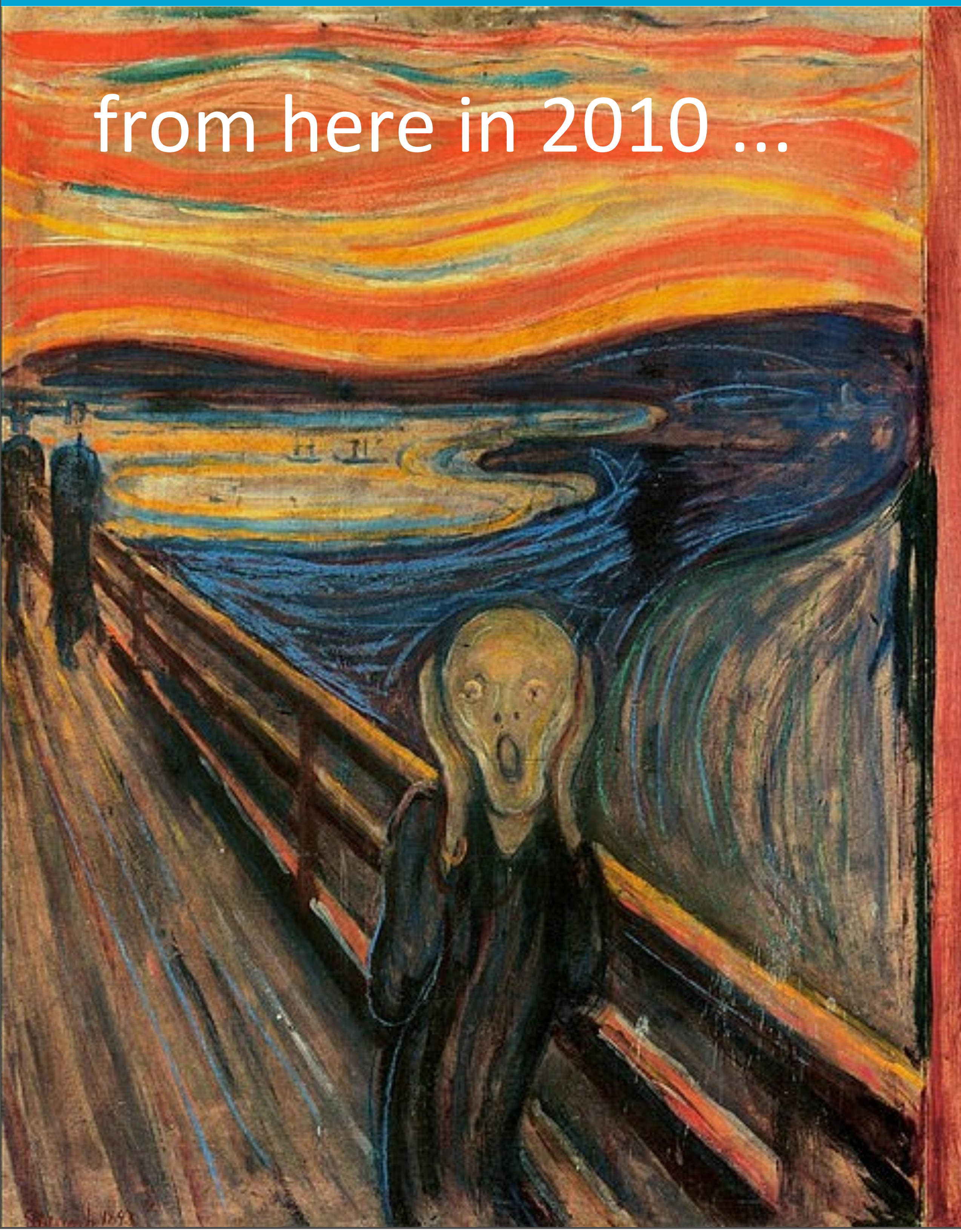
Instruments Will Move into Construction a Few at a Time

EUROPEAN SPALLATION SOURCE



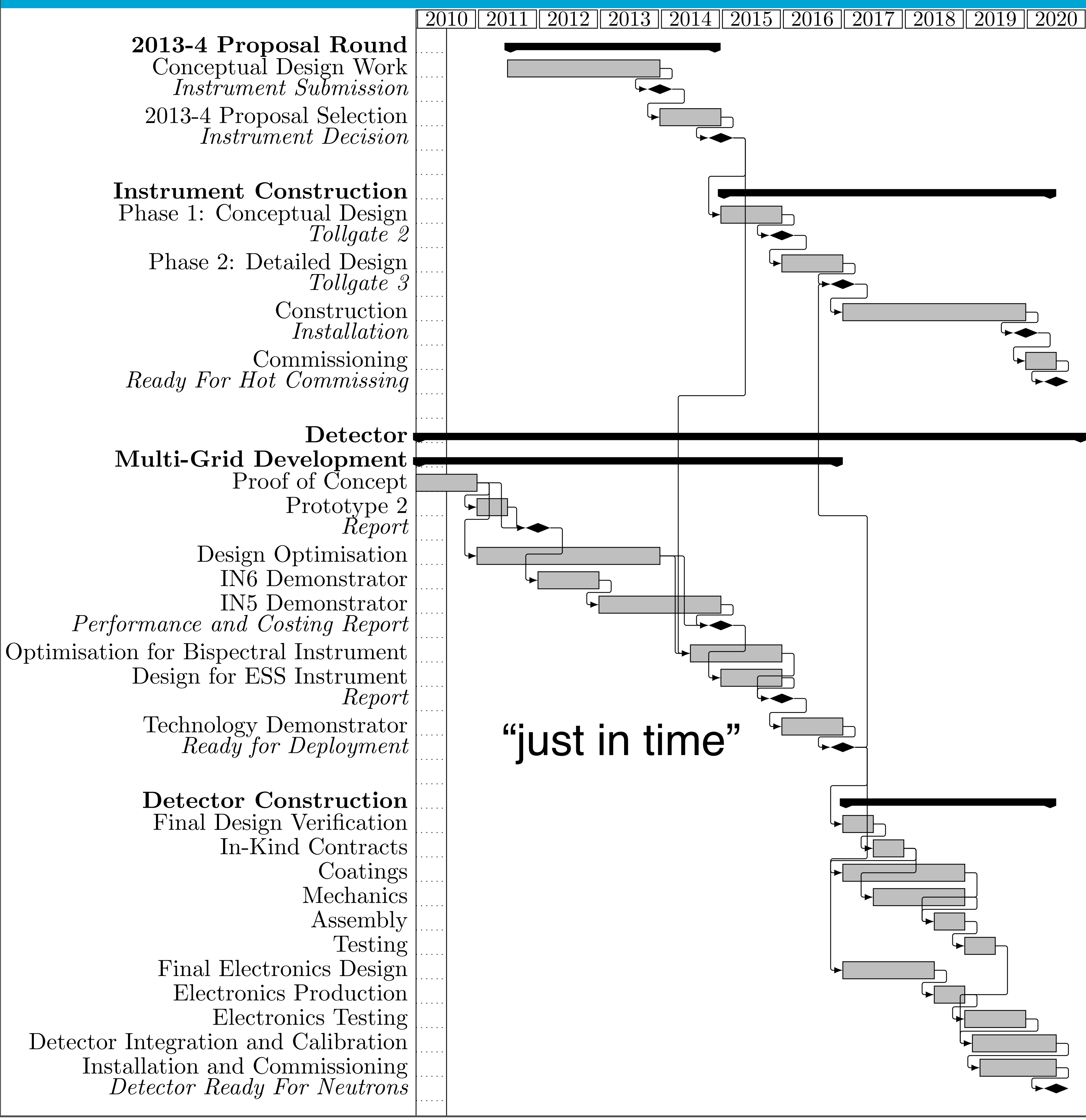
- 11 instruments are in construction by next year
- We need in-kind partners
- Remember: 70% of detector construction cost will be in-kind
- ie ESS will build a small fraction of detectors ourselves
- we will enable as needed

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



- Development time is long: typically 10 years from conception to utilisation
- Solve challenges one at a time, and remain calm

Timeline for detectors



- Here is the timeline for a thermal chopper spectrometer with one concept for detector technology
- note: 10 years from concept to (potential) utilisation
- note: neither the proof of concept nor construction phases dominate the timeline, but rather the numerous prototyping and demonstration phases in between
- 2019 is tomorrow: it means that any detectors built for then are well progressed with developments now

Teamwork …

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Collaborations for the Construction Phase

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

Detectors are fundamentally collaborative and interdisciplinary

EUROPEAN SPALLATION SOURCE

In-Kind, Design Update

HZB Helmholtz Zentrum Berlin

Helmholtz-Zentrum Geesthacht Zentrum für Material- und Küstenforschung

JÜLICH FORSCHUNGSZENTRUM

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

IFE Institute for Energy Technology

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

INFN

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

Remember: front weighted

JÜLICH FORSCHUNGSZENTRUM

TUM TECHNISCHE UNIVERSITÄT MÜNCHEN

SINTEF

IFE Institute for Energy Technology

UNIVERSITAS BERGENSIS

UNIVERSITAS OSLOENSIS MDCCCXI

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

INFN

TARTU ÜLIKOOL UNIVERSITAS TARTUENSIS 1632

Science & Technology Facilities Council ISIS

Collaborative Partners

NEUTRONS FOR SCIENCE

Linköping University

LUND UNIVERSITY

IEAP

Mittuniversitetet MID SWEDEN UNIVERSITY

CERN

MAX IV

Need partners to build detectors

Commercial Partners

Working with many commercial partners

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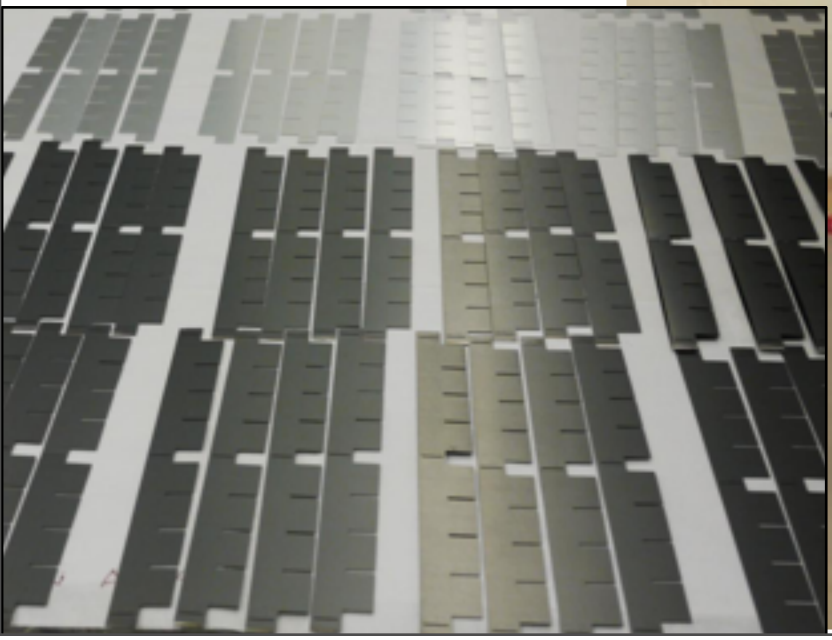
Specialise: example: Coating Facility in Linkoping for ESS

High quality enriched boron carbide coatings

- Need specialist centres of expertise, rather than a large number of generalists
- Do what you know, exceptionally.
- Share and collaborate and benefit from others expertise



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 ...
- Remember: typically 10 years concept to beamline
- We need to utilise the considerable expertise that exists across Europe
- Challenge is only achievable using in-kind
- Need to build up centres of excellence in Europe rather than a large numbers of all-rounders

- Used ESS as an example for how detector technologies are chosen

- Make sure that you define what you measure clearly and unambigiously
- Publish what you do: too many of the best results remain forgotten and are redone 3-10 years later