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Other techniques: a comparison with neutron scattering

Non-scattering Neutron techniques

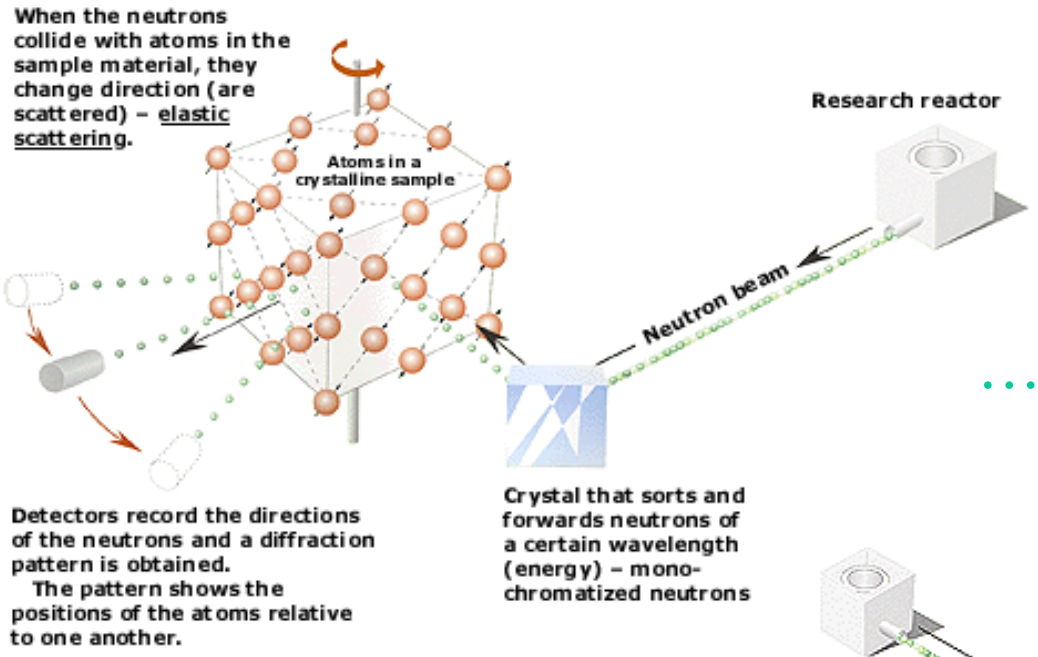
Constructability

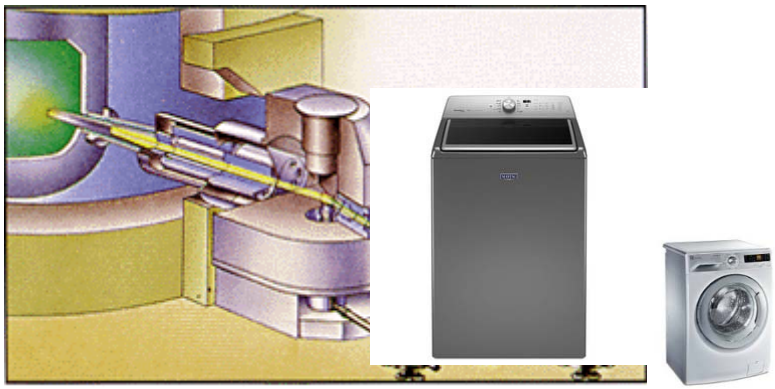
Robert McGreevy

ISIS, STFC Rutherford Appleton Laboratory, UK

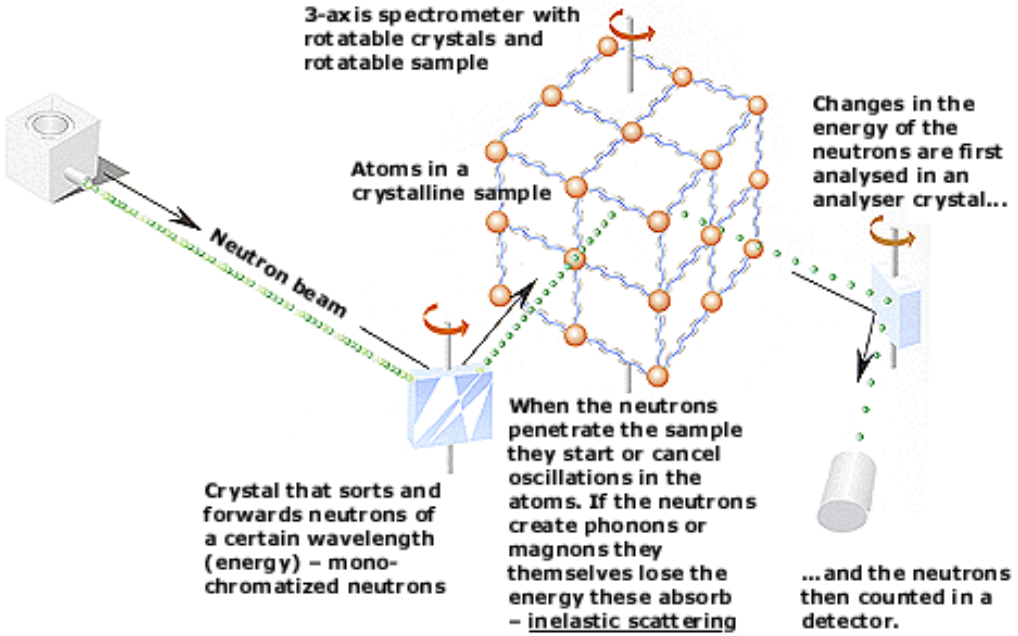
The 1994 Nobel Prize in Physics – Shull & Brockhouse

Neutrons show where the atoms are….





…and what the atoms do.



Why do we build neutron instruments?

To do science

Not to be better than other neutron instruments

…which is usually the first thing people do …

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Why are we learning about other techniques?

Eddie the Eagle

Because being a heroic failure is not a business strategy!
(at least in science)

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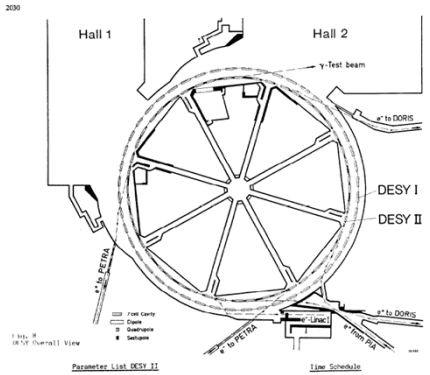
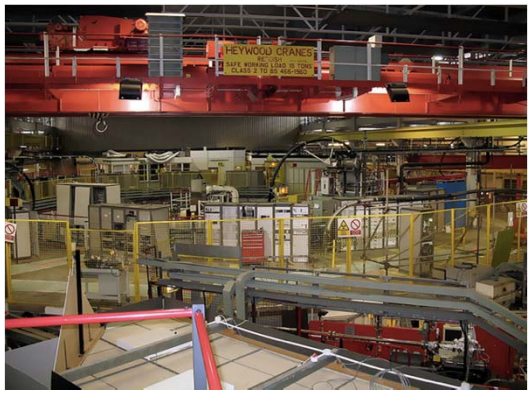
Why are we learning about other techniques?





Synchrotron x-rays have evolved from parasitic to custom built
Brightness increase is orders of magnitude more than cost increase

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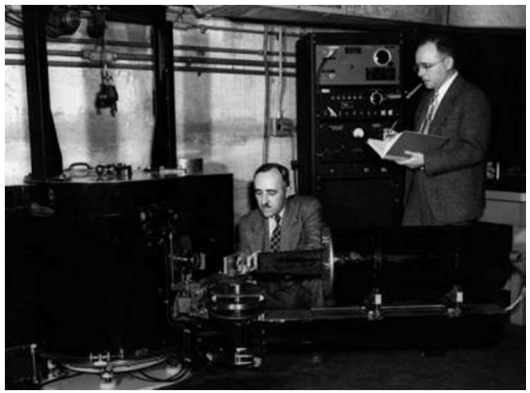
Why are we learning about other techniques?



Neutron scattering sources have also evolved from parasitic to custom built
Brightness increase matches cost increase

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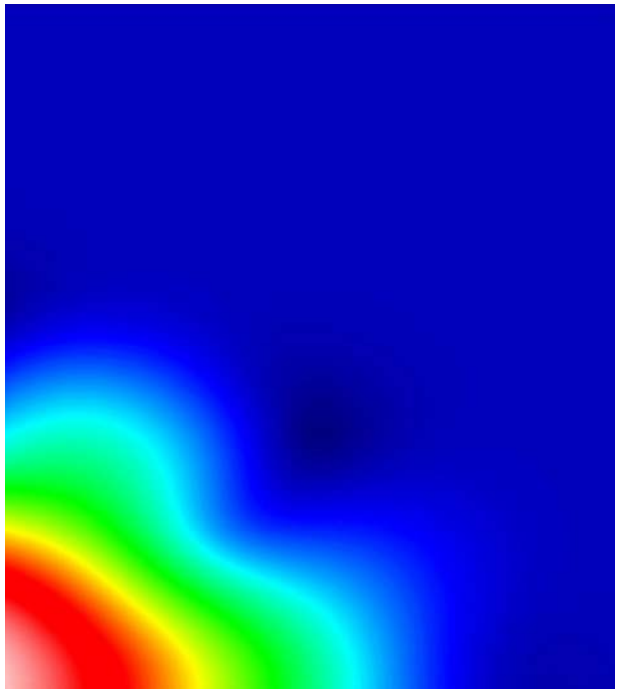
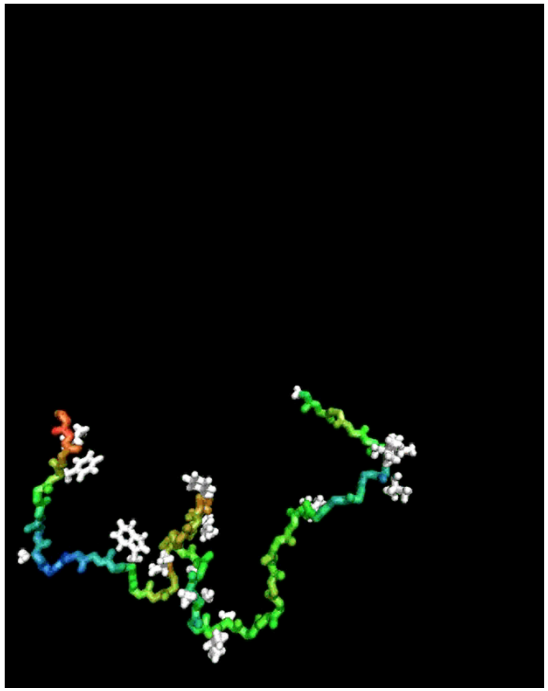
Why neutrons? – five good reasons





Length and time scales

10^{-11} – 10^{-1} m 10^{-14} – 10^{4} s

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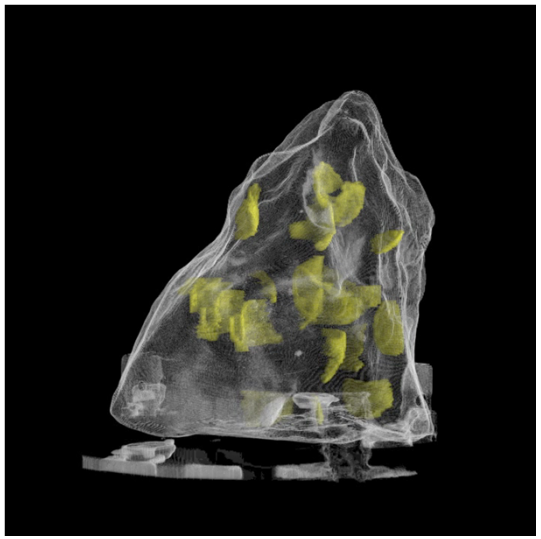
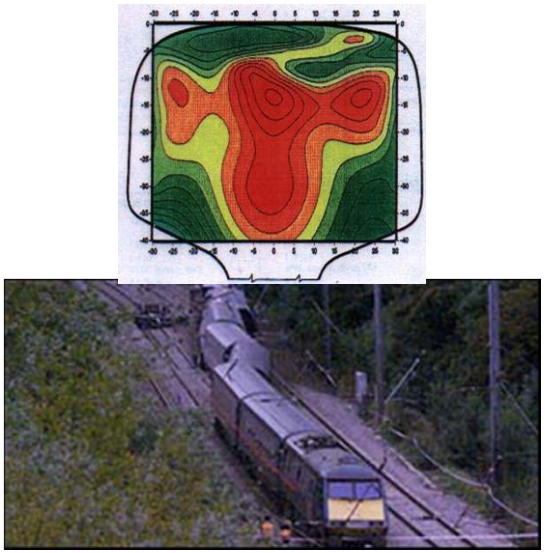
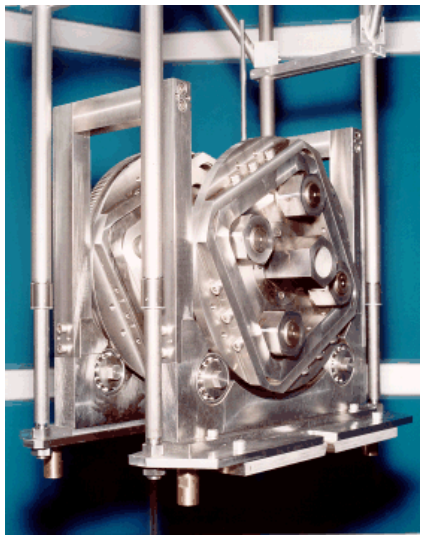
Why neutrons? – five good reasons







Penetration

Large samples, buried interfaces, extreme conditions, non-destructive

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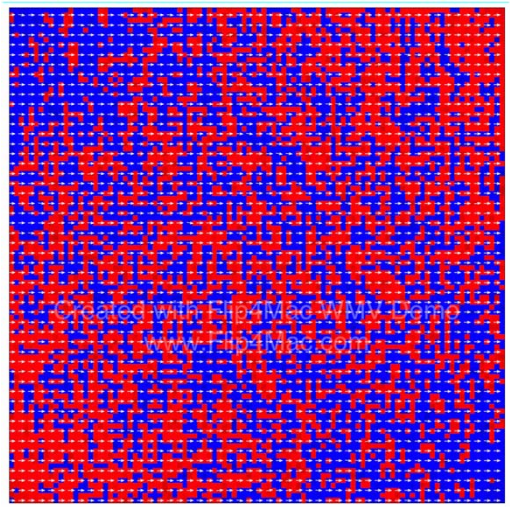
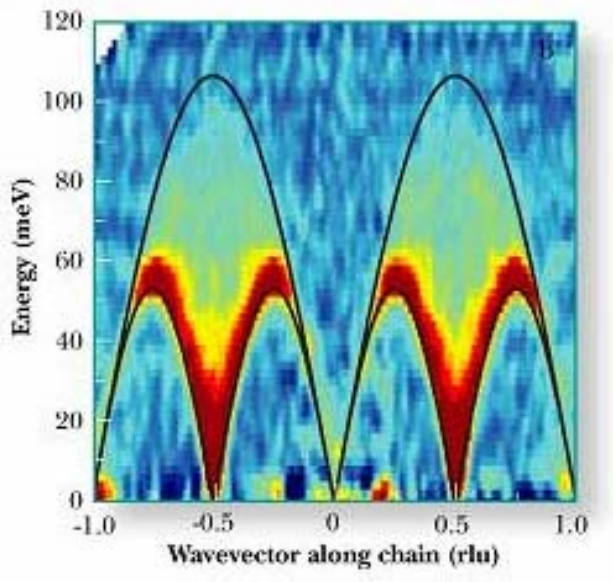
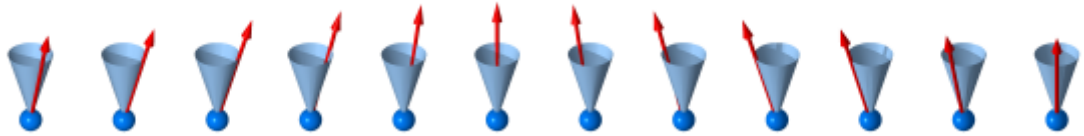
Why neutrons? – five good reasons







Magnetism

The neutron has a magnetic moment but no charge

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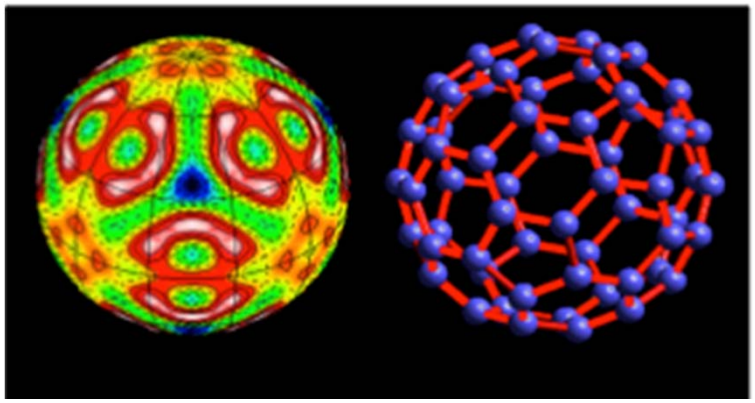
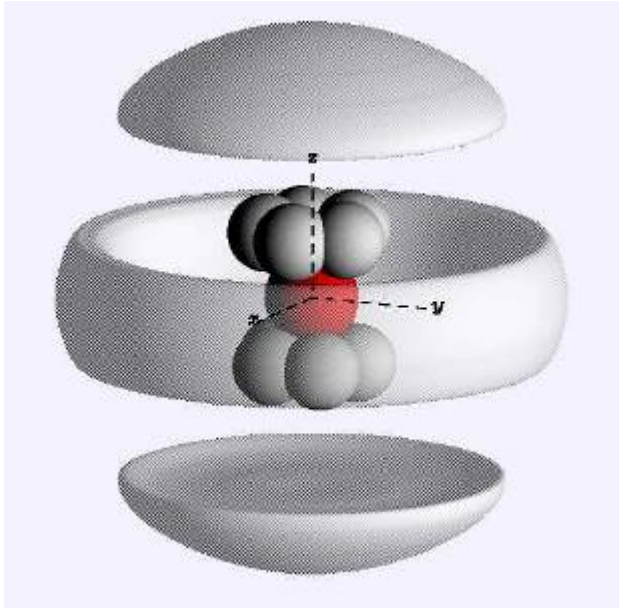
Why neutrons? – five good reasons





Precision

Weak interaction, simple interaction

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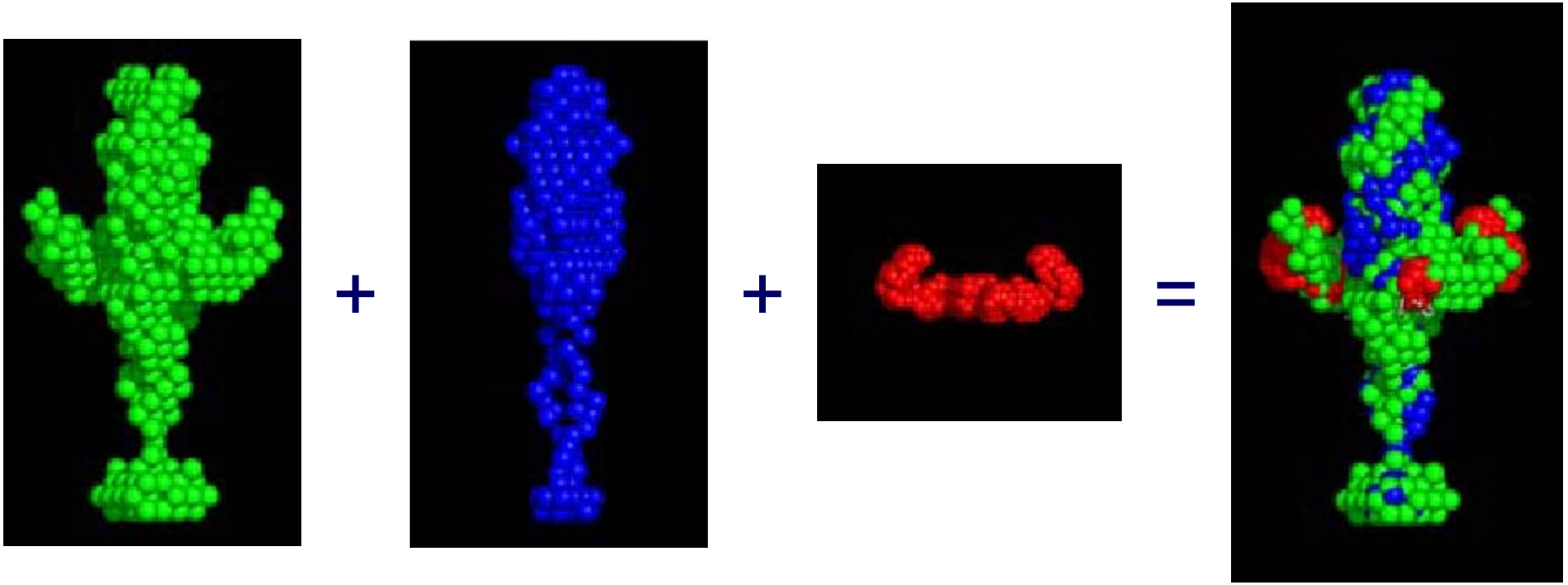
Why neutrons? – five good reasons



Sensitivity and selectivity

Isotopic substitution/contrast variation

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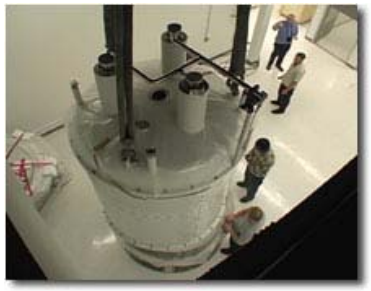
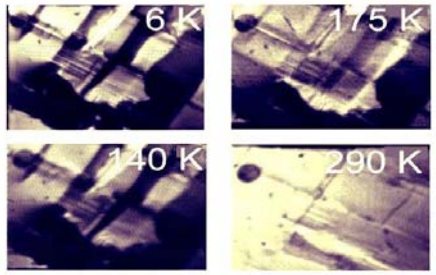
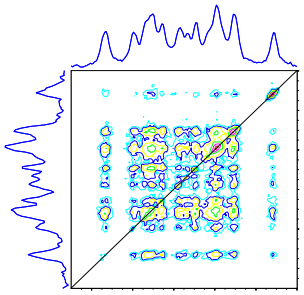
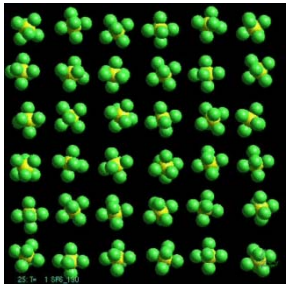
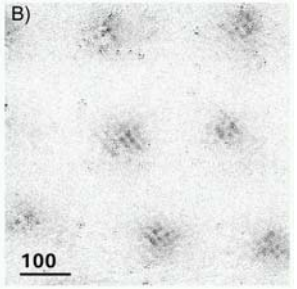
But …











Synchrotrons NMR Computing Microscopy

Most research that use neutron scattering also uses several complementary techniques

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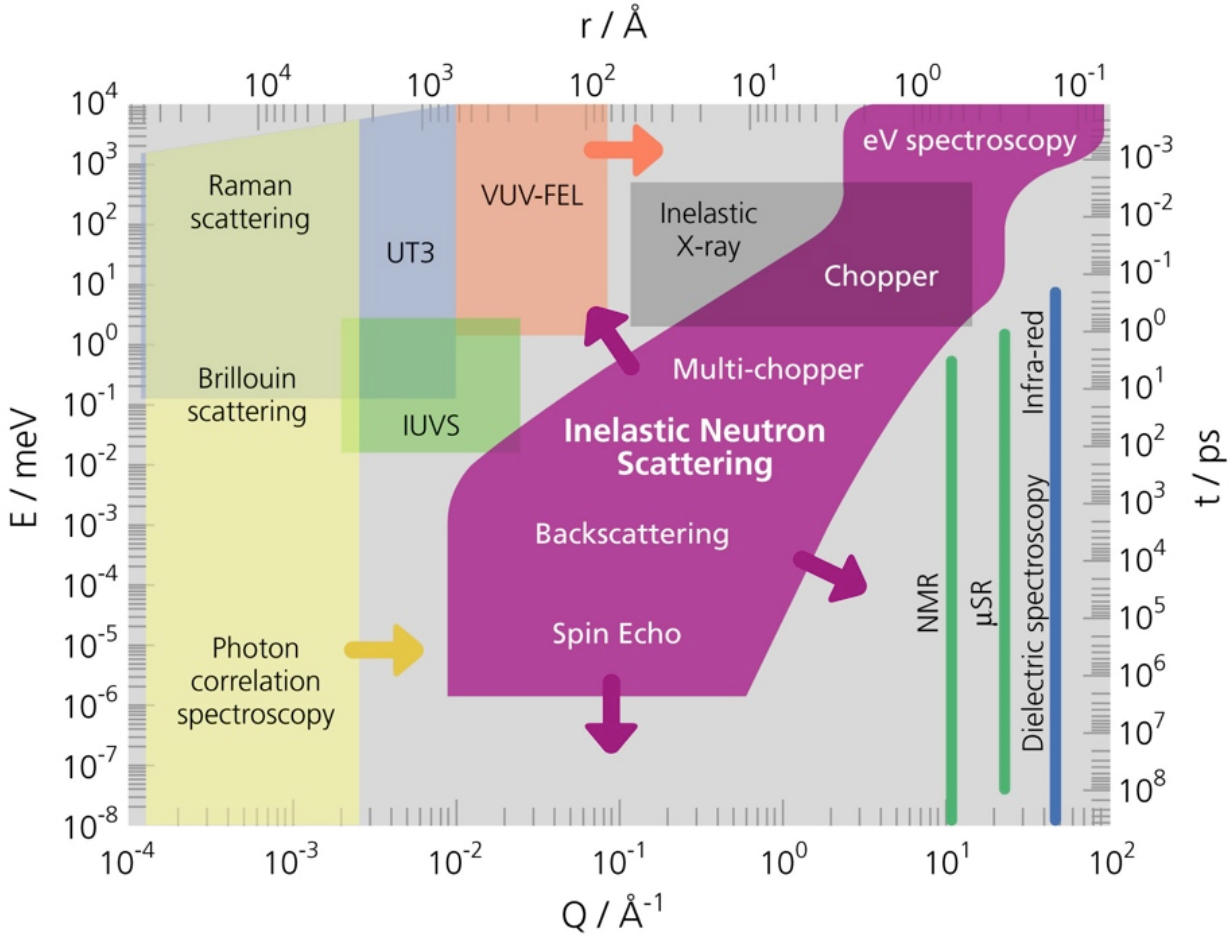
Why neutrons?



Neutron scattering 'simultaneously' covers a broad (Q,ω) range

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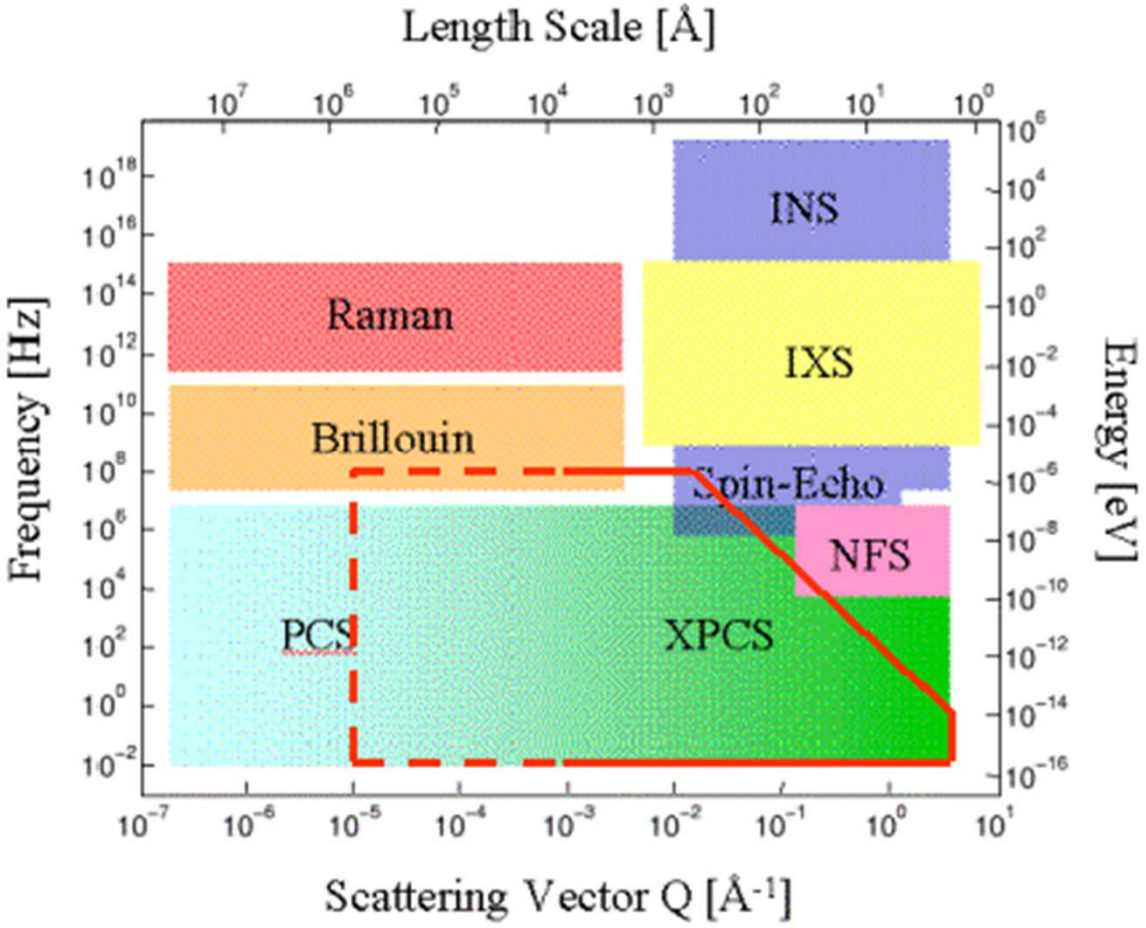
Why not neutrons?



It may not look so broad when viewed from a different perspective!

Macroscopic property measurements

- Density
- Specific heat
- Conductivity
- Susceptibility
- …

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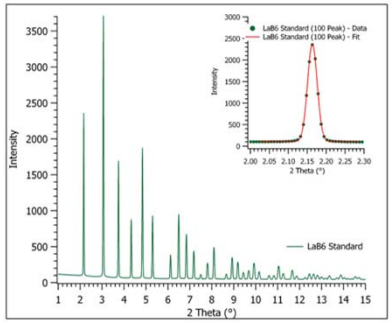
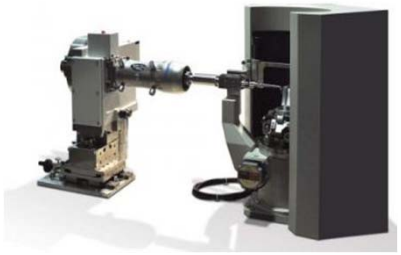
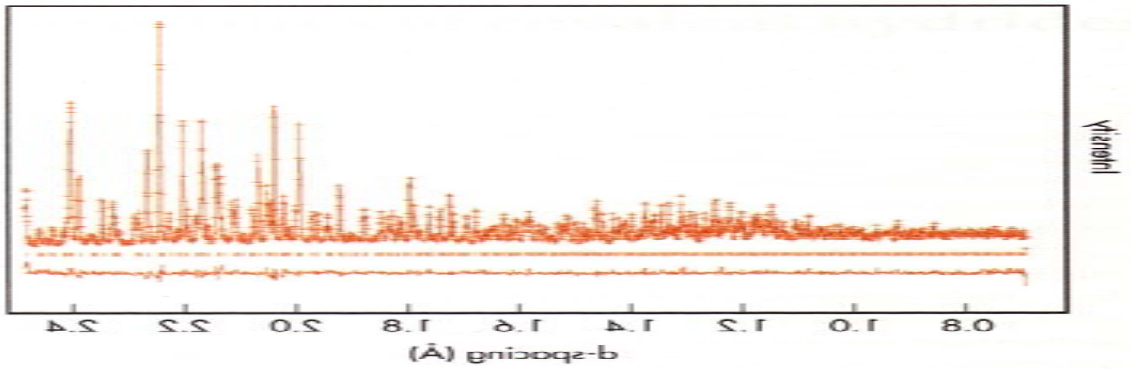
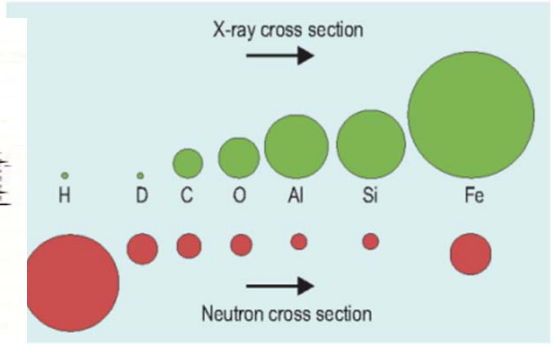
X-ray diffraction









X-ray diffraction is cheap, convenient and can do many, many things
Neutrons help for high Q, light atoms, similar Z atoms, magnetism

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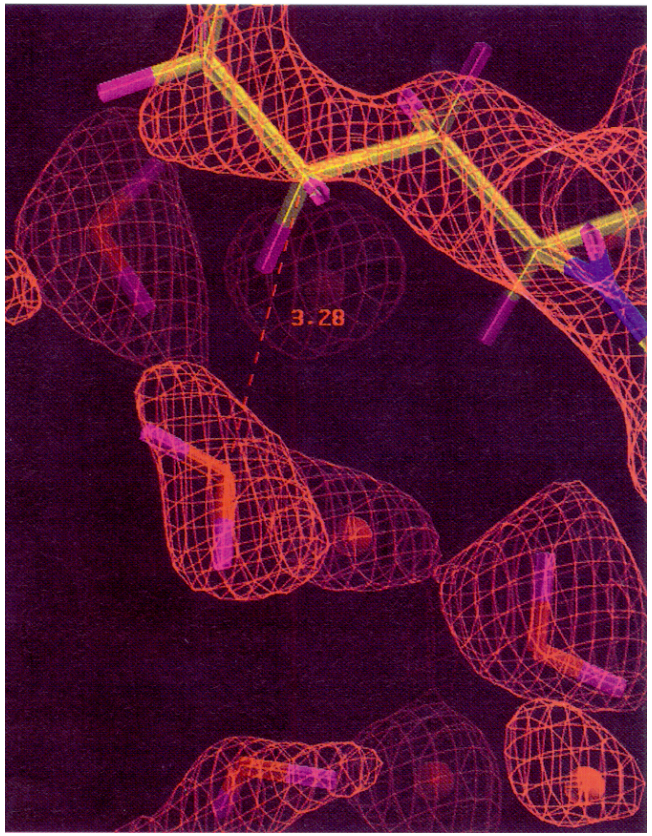
Lesson …



Don’t say ’X-rays can’t see hydrogen’
Say ’neutrons can help see hydrogen better, when used together with X-rays’

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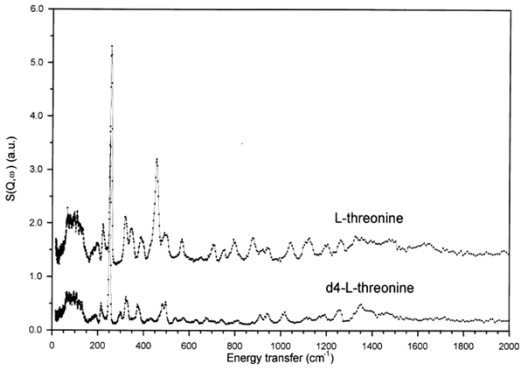
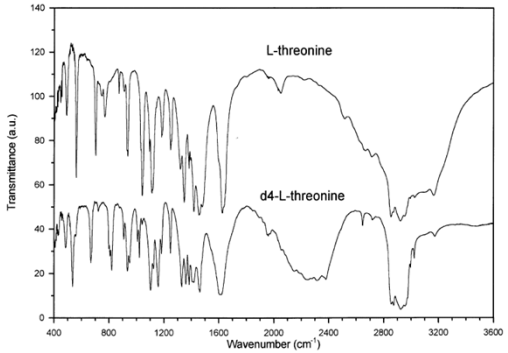
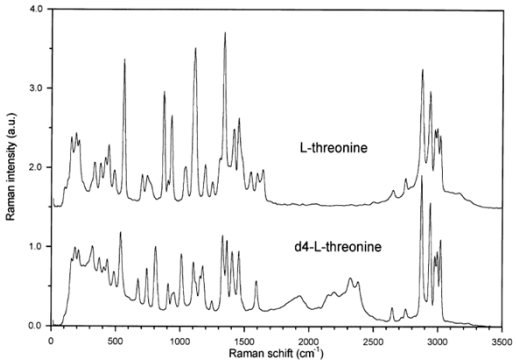
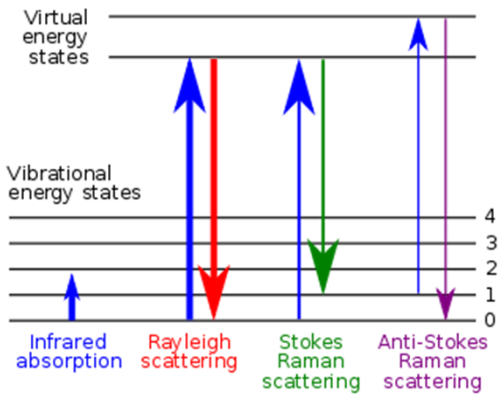
Raman scattering/Infrared spectroscopy









Photons are cheap, convenient and can do many, many things
Neutrons give absolute intensities with no selection rules

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Dynamic light scattering

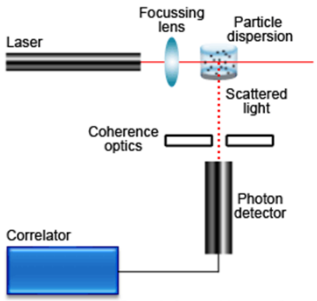
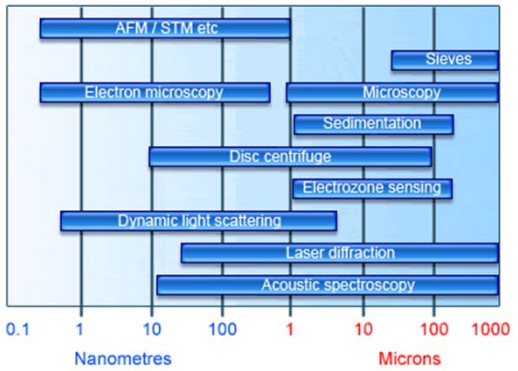
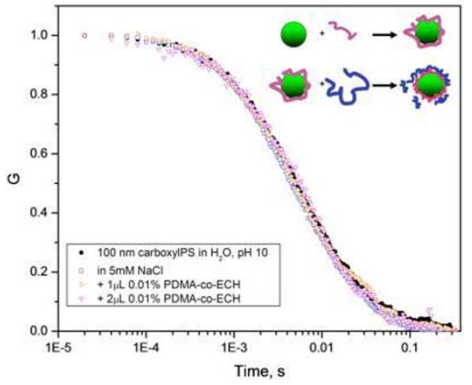


Figure 1: Schematic diagram of a conventional, 90° dynamic light scattering instrument.





DLS exploits coherence, covers many decades in time
1-D information only, needs transparent samples

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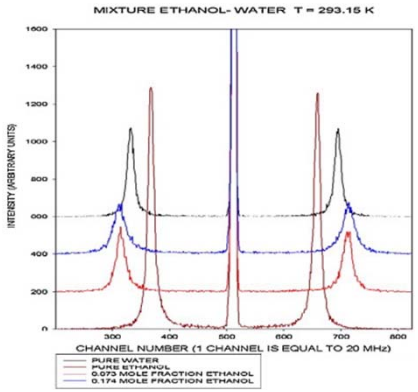
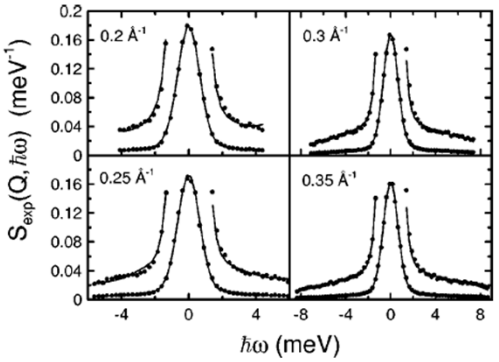
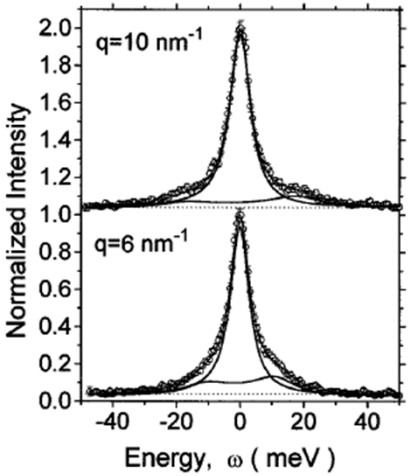
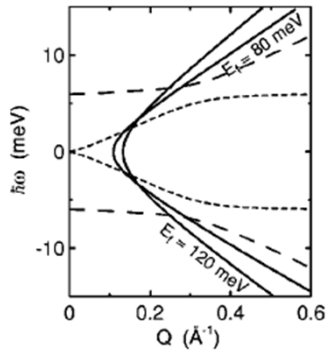
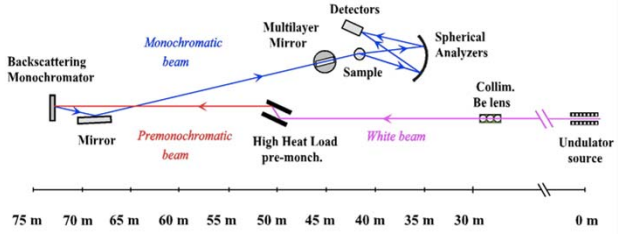
Brillouin scattering, Inelastic X-ray scattering











X-rays now 1-2 meV resolution; complementarity poorly exploited
Neutrons struggle at low Q because of kinematic restrictions

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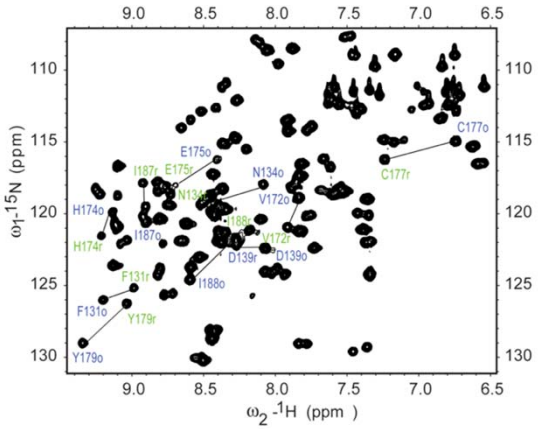
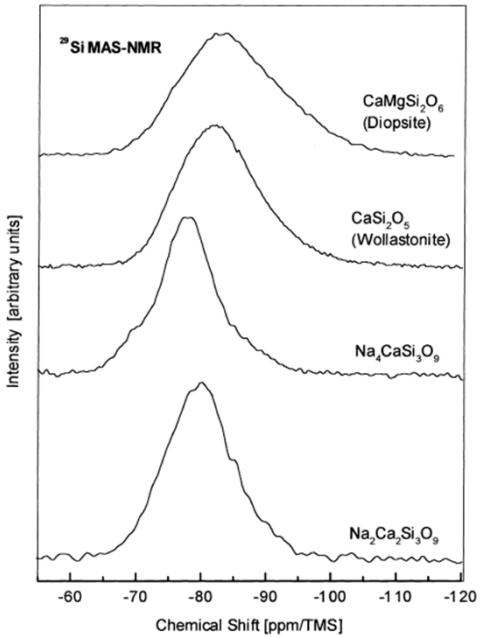
NMR (1D, 2D, FT, MAS …)





NMR naturally provides many-body correlations
In all normal circumstances neutrons provide only 2-body correlations

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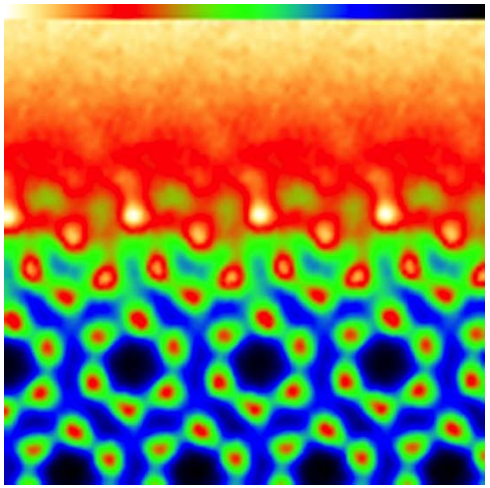
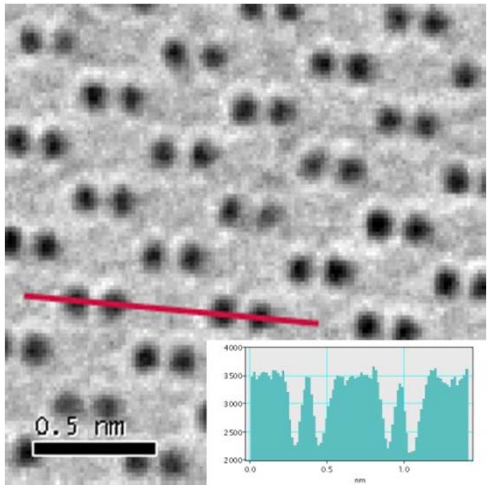
Electron diffraction/microscopy





Now close to 1 Å resolution; can do liquids and glasses
Small samples, 'local' structure

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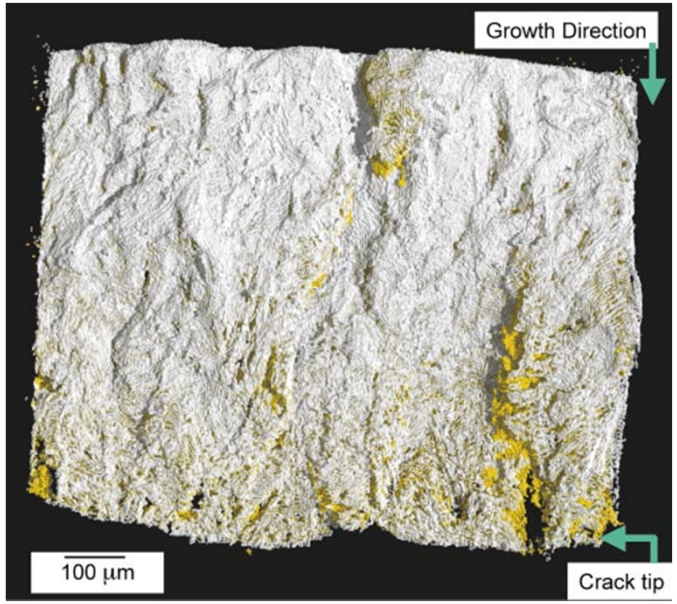
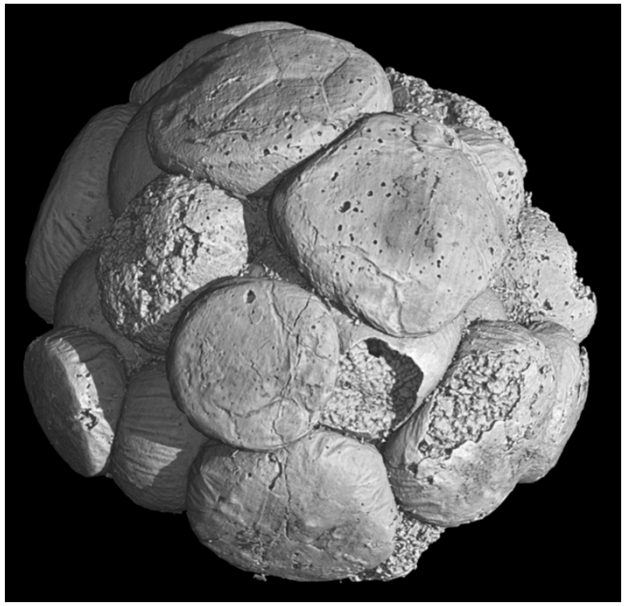
Imaging





http://paleo.esrf.eu/

Sub-µm resolution; keV x-rays give high penetration
Neutrons only 50µm, but better for light elements

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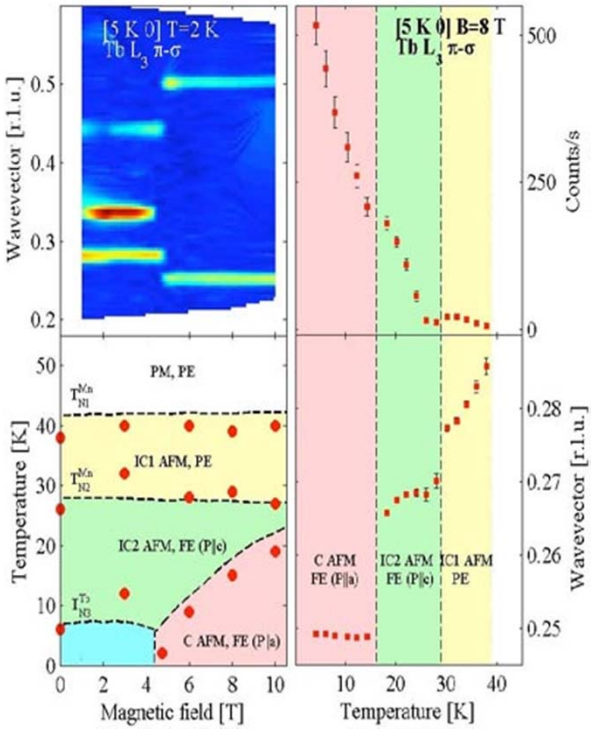
Resonant X-ray scattering



Element and electron shell selective (e.g. orbital ordering)
But probably can't interpret without neutron data as well …

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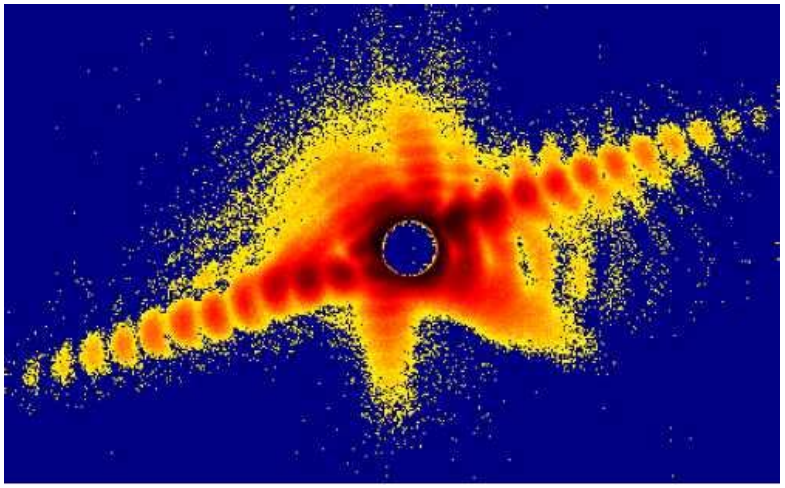
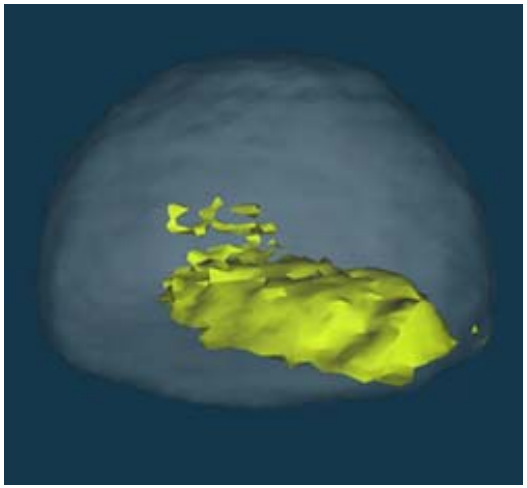
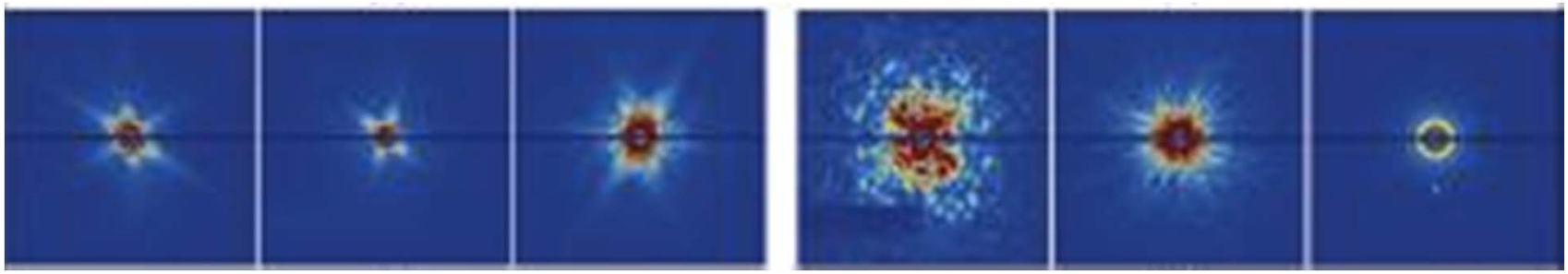
Coherent X-ray diffraction, FEL







Structure and stress distribution in single nano-particles; fs diffraction
But sometimes you need to look at more than one …

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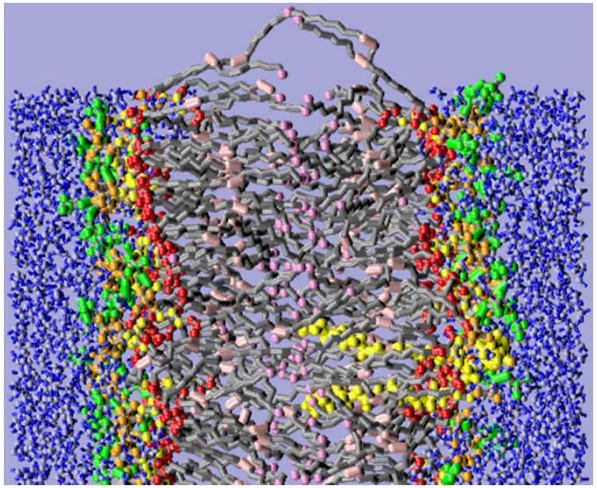
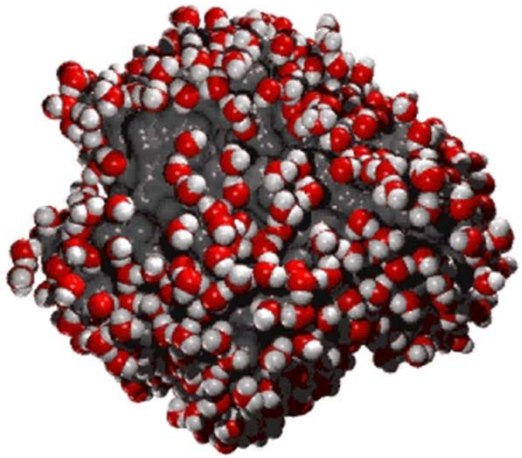
Computers





Simulation and modeling cover a very similar (r,t) range to neutrons
Neutron data can be calculated directly and easily from simulations

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Conclusions

- Neutron scattering is (always going to be) an expensive technique

  We must provide a quality product

- Neutron instruments must exploit neutron strengths, not amplify neutron weaknesses

  e.g. absolute accuracy, signal to noise

- Neutron instruments must exploit complementarity

  e.g. molecular spectroscopy, computer simulation

- Do not design or build a neutron instrument just because it's better than another neutron instrument …

  … which is usually the first thing people do …


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Non-scattering Neutron techniques

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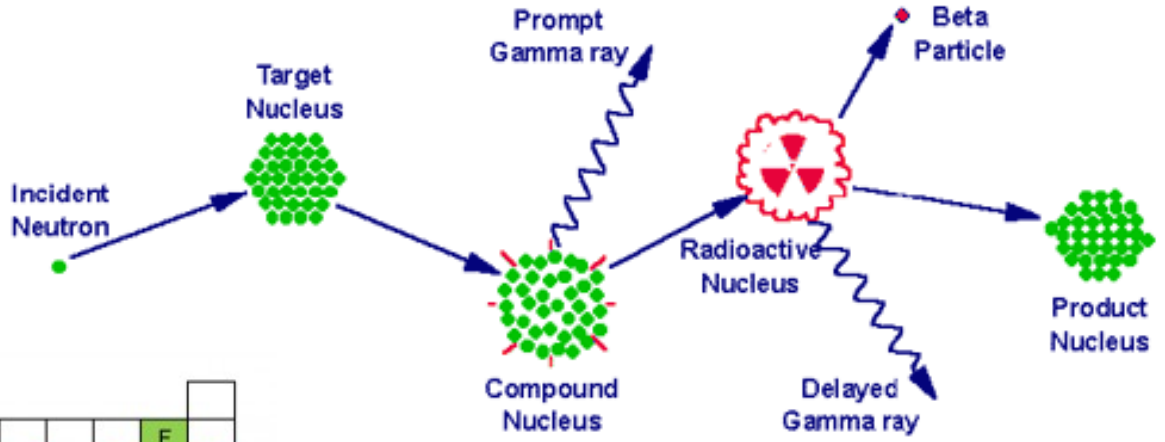
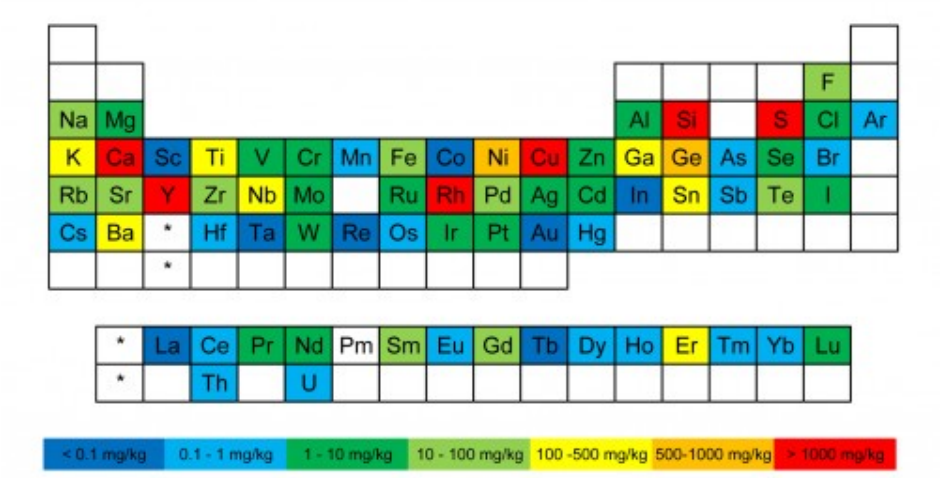
Activation analysis

Prompt gamma, delayed gamma





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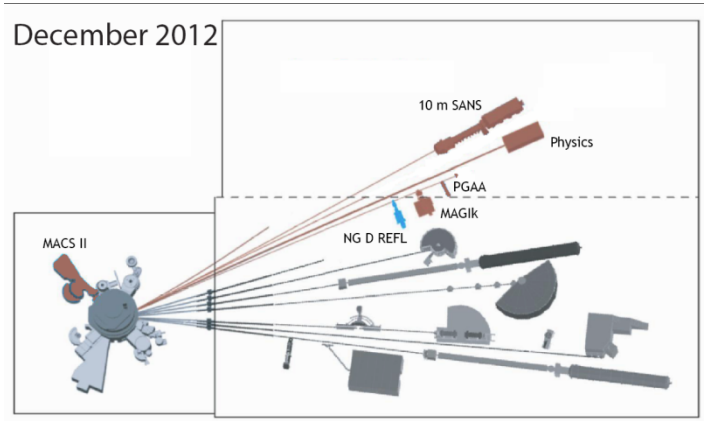
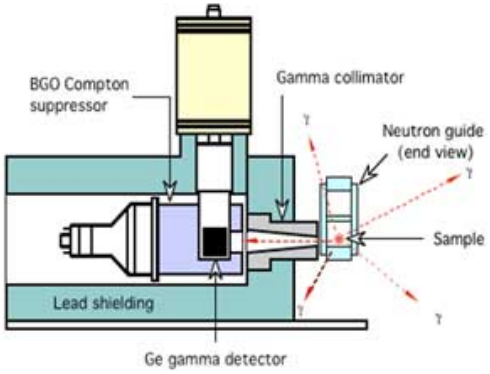
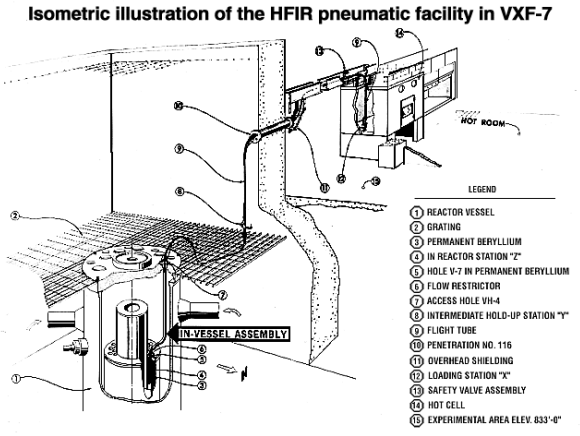
Activation analysis

Prompt gamma





Delayed gamma



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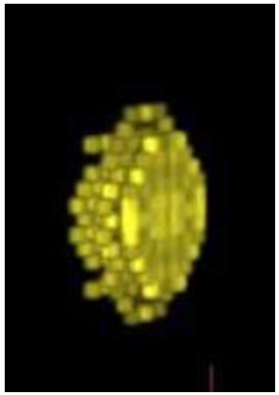
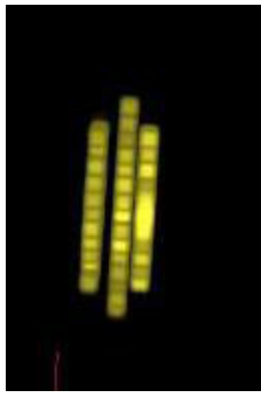
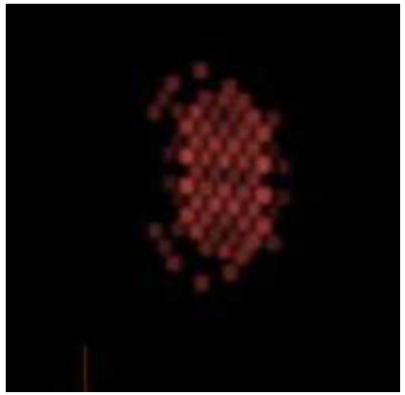
Prompt Gamma Activation Imaging

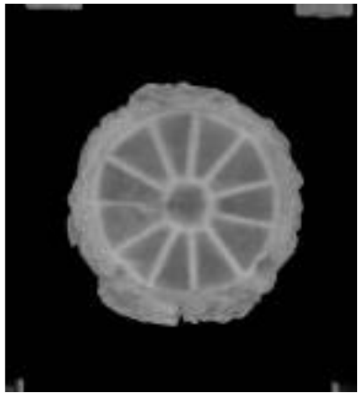




Gold



Copper



Neutron radiography

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Neutron autoradiography

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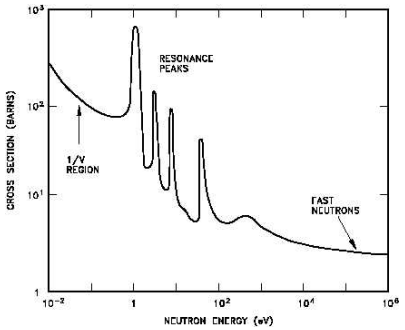
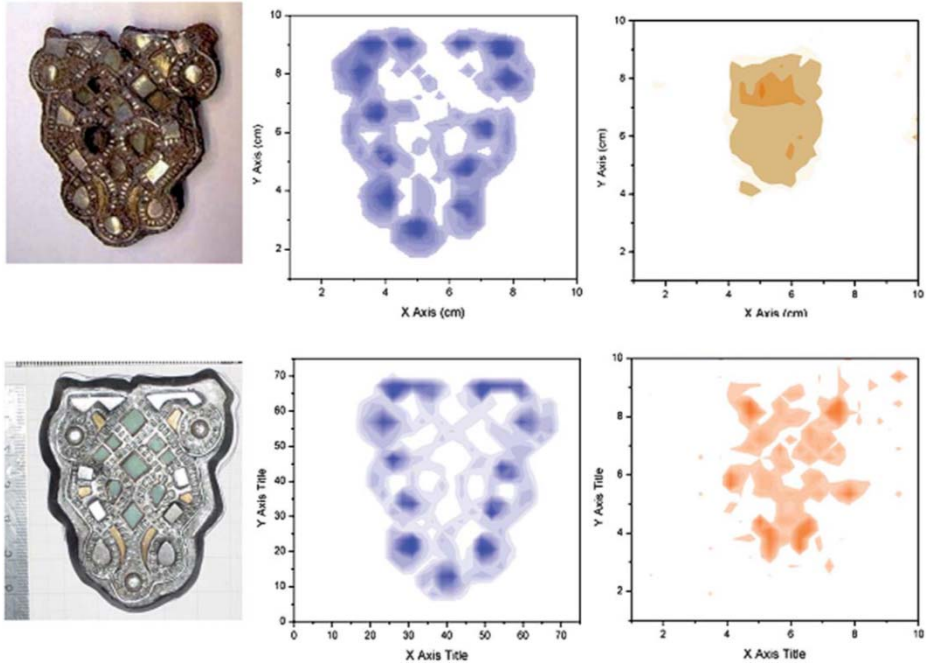
Neutron Resonant Capture Imaging





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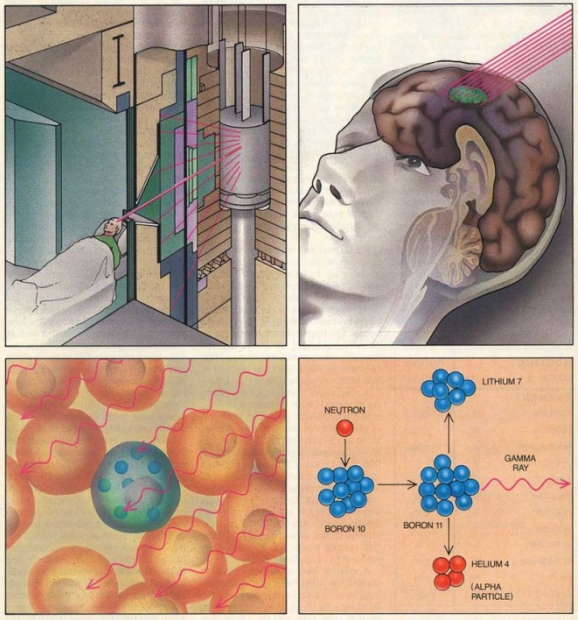
Boron Neutron Capture Therapy (BNCT)



BNCT treatment at the Studsvik R2-0 reactor

$$^{10}B + n_{th} \rightarrow [^{11}B]^* \rightarrow \alpha + {}^{7}Li + 2.31\ MeV$$

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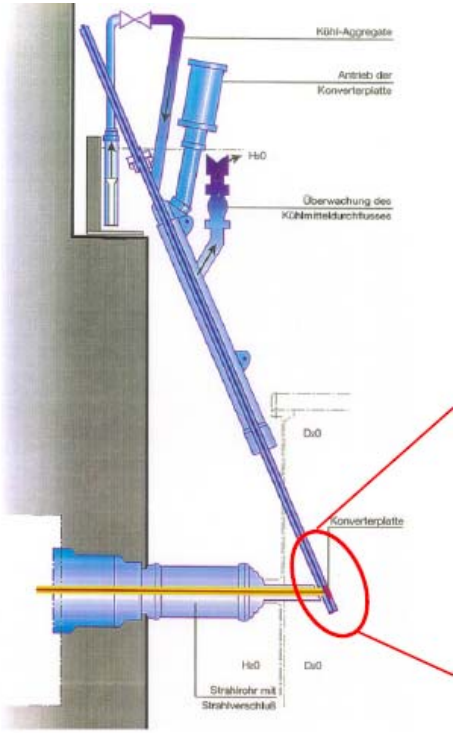
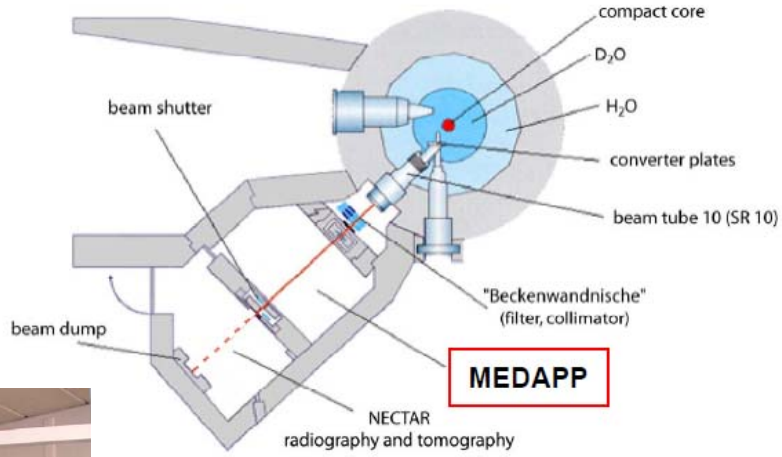
Fast Neutron Therapy





MEDAPP facility at the
FRM-II reactor

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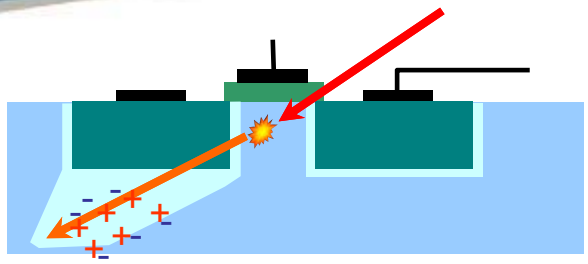
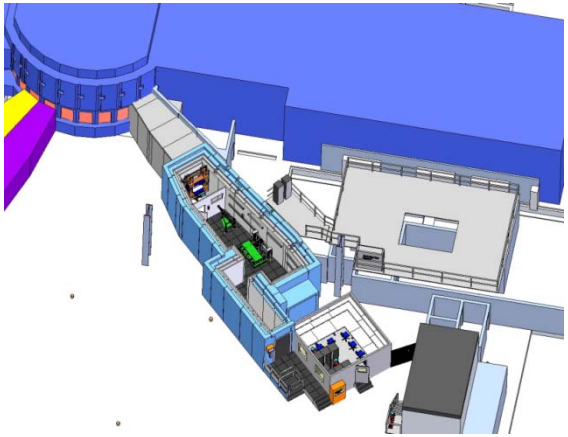
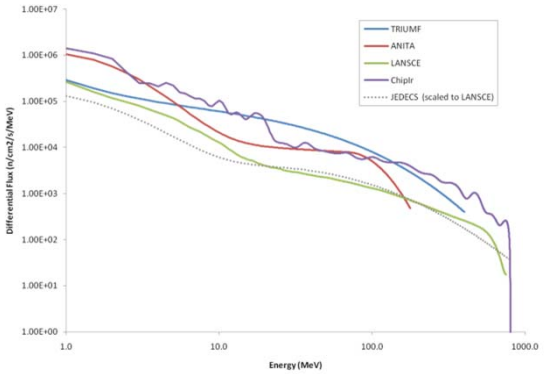
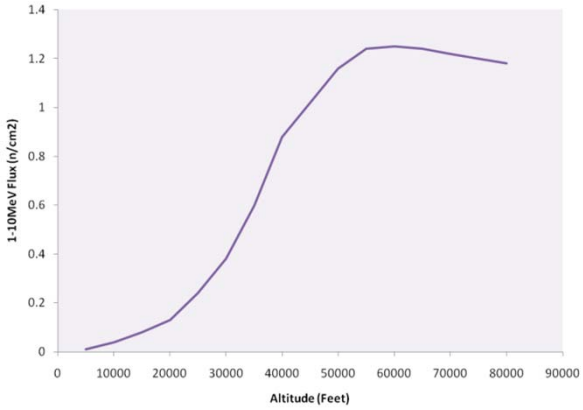


Chip Irradiation





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Constructability

Getting real …

Robert McGreevy

ISIS, STFC Rutherford Appleton Laboratory, UK

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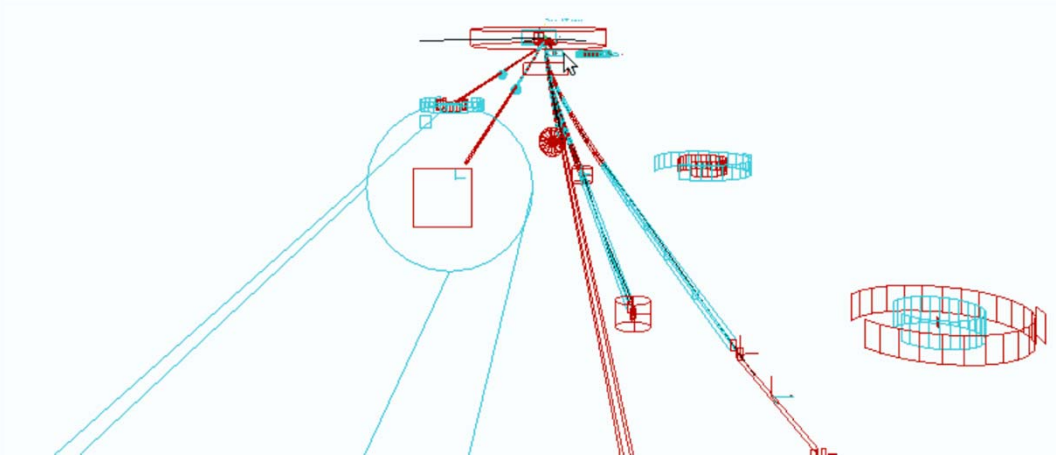
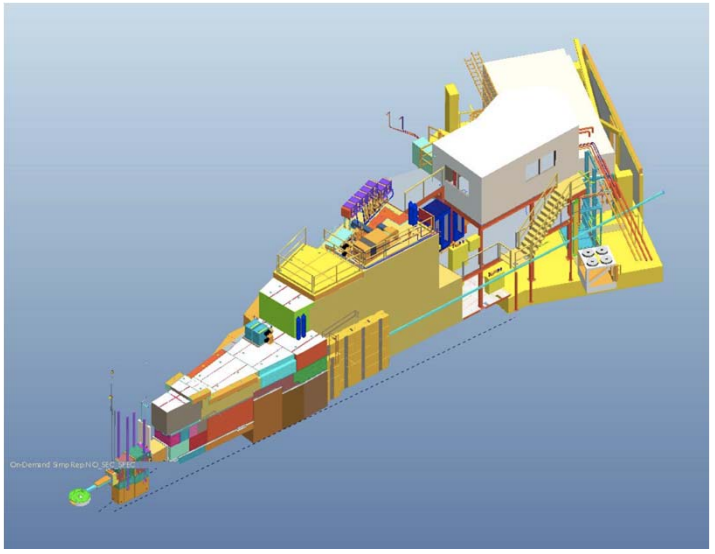
These are the easy bits …





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A real instrument will have a budget and it will never be big enough

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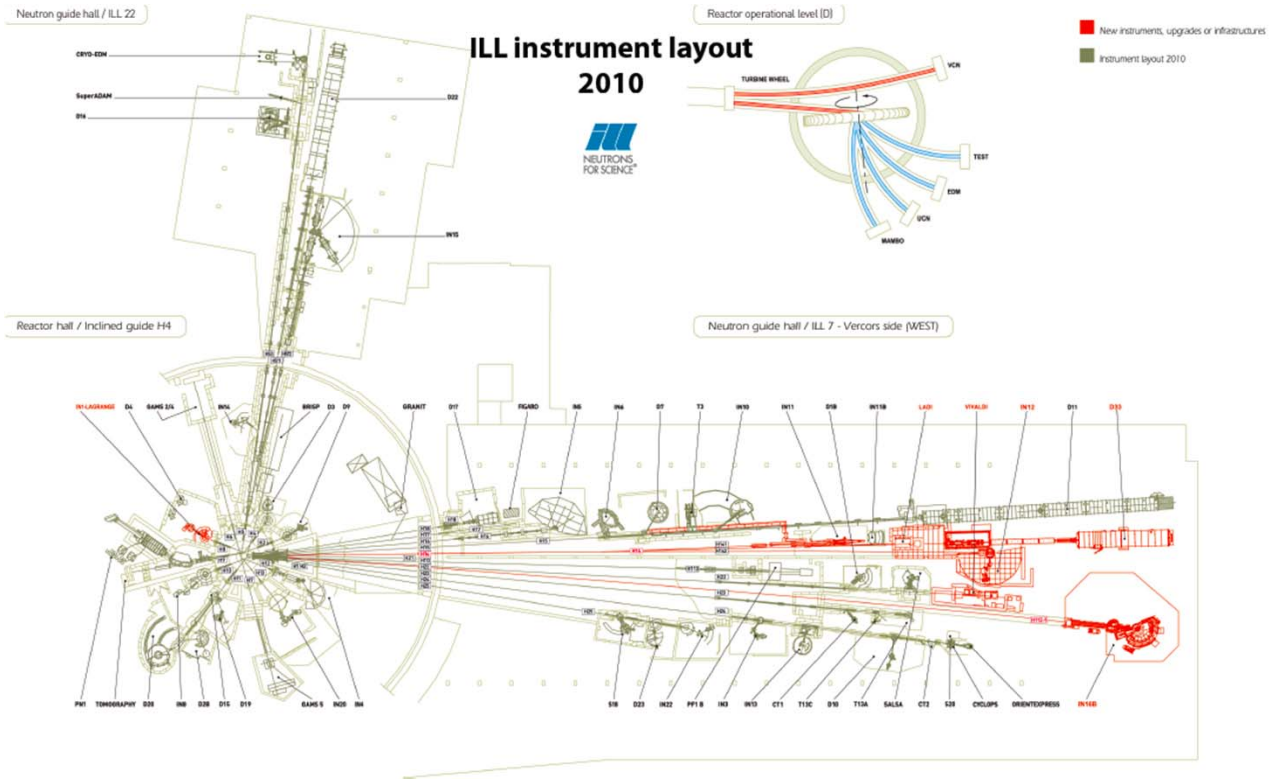
Guides transformed neutron scattering



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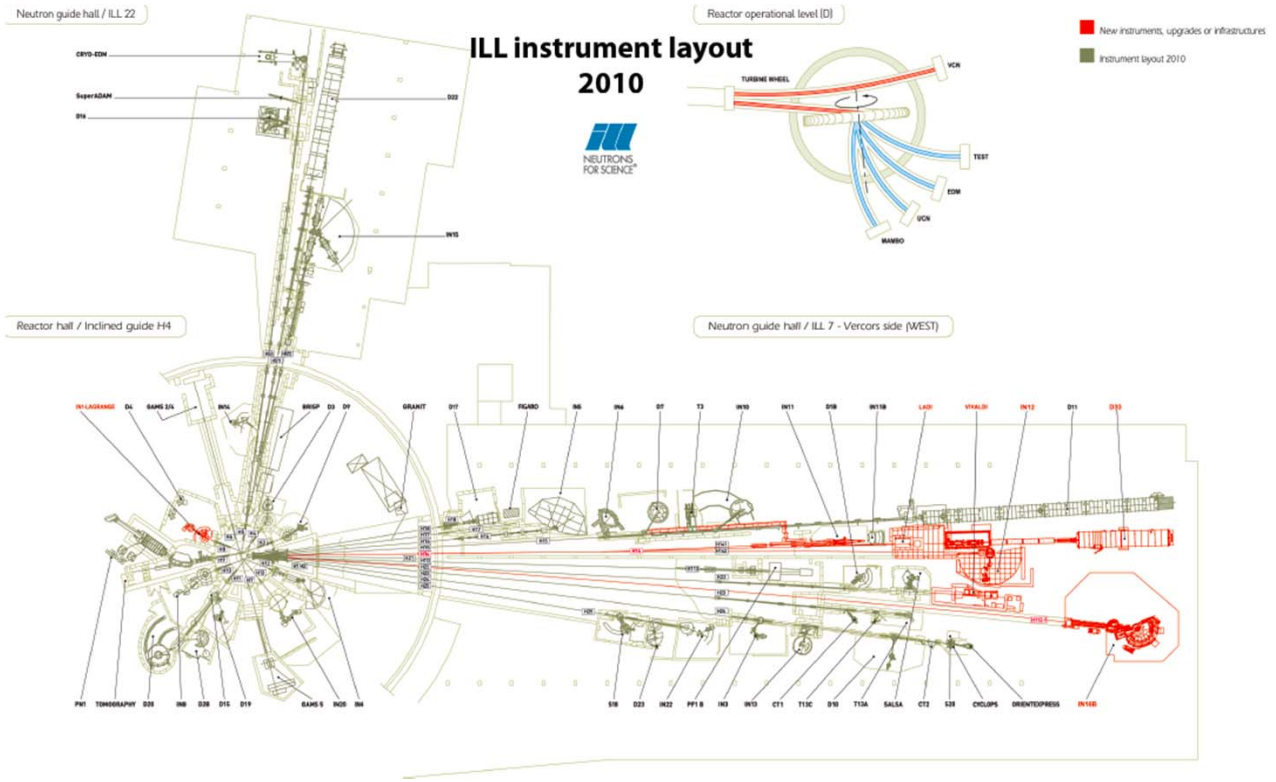
A real instrument will have to fit into a real space, and it will never be big enough …



For many continuous source instruments, the length is not a parameter; for all pulsed source instruments it is.

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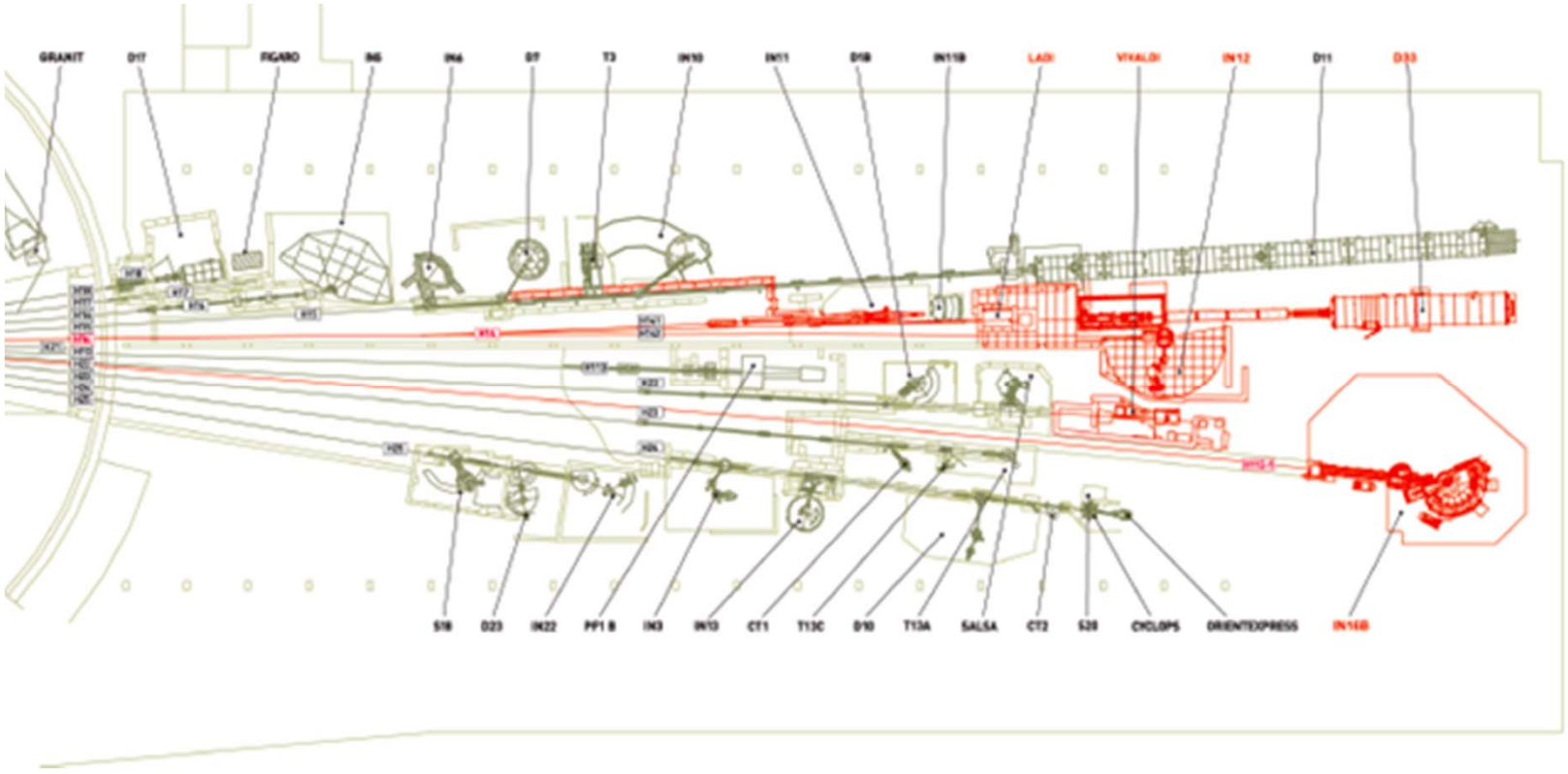
A real instrument will have to fit into a real space, and it will never be big enough …



Continuous sources can build multiple (narrow bandwidth) instruments on a single beamline, for pulsed sources you (generally) cannot

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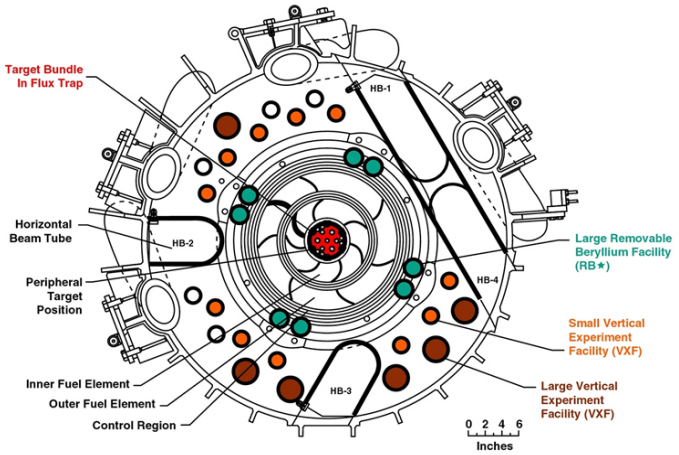
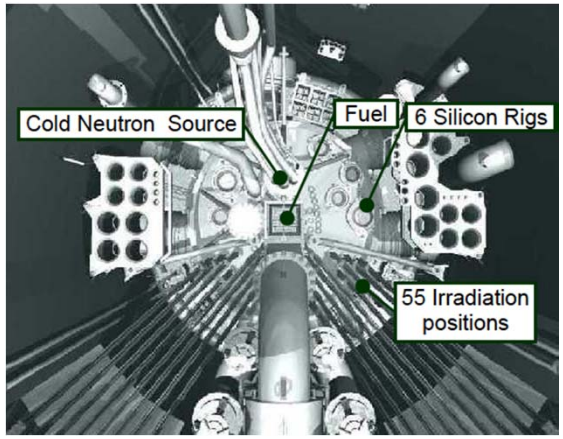
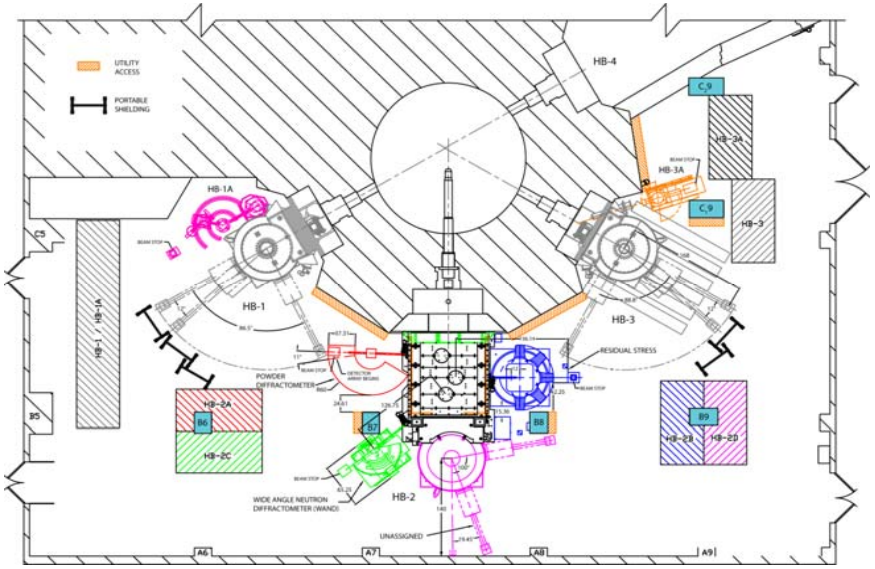
A real instrument will have to fit into a real space, and it will never be big enough …







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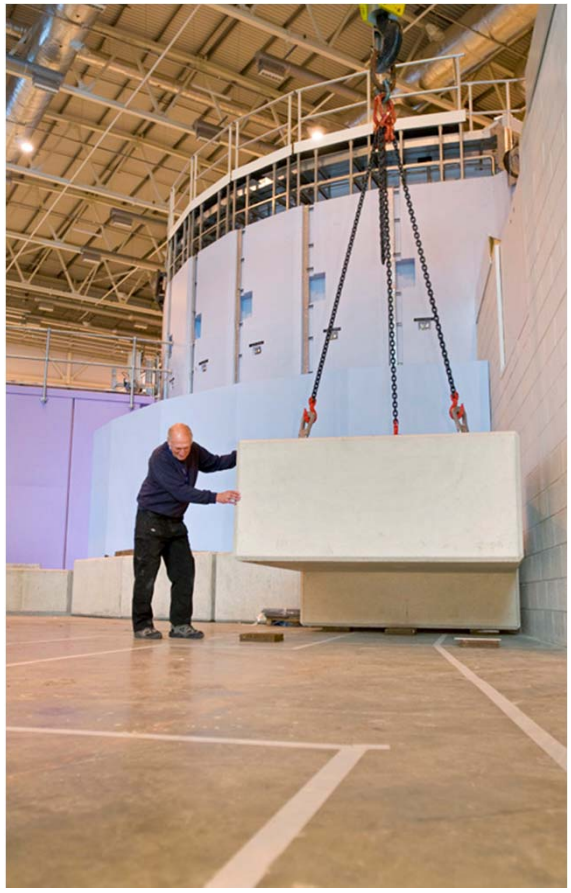
A real instrument will have to fit into a real space, and it will never be big enough …



Unless yours is the first instrument …

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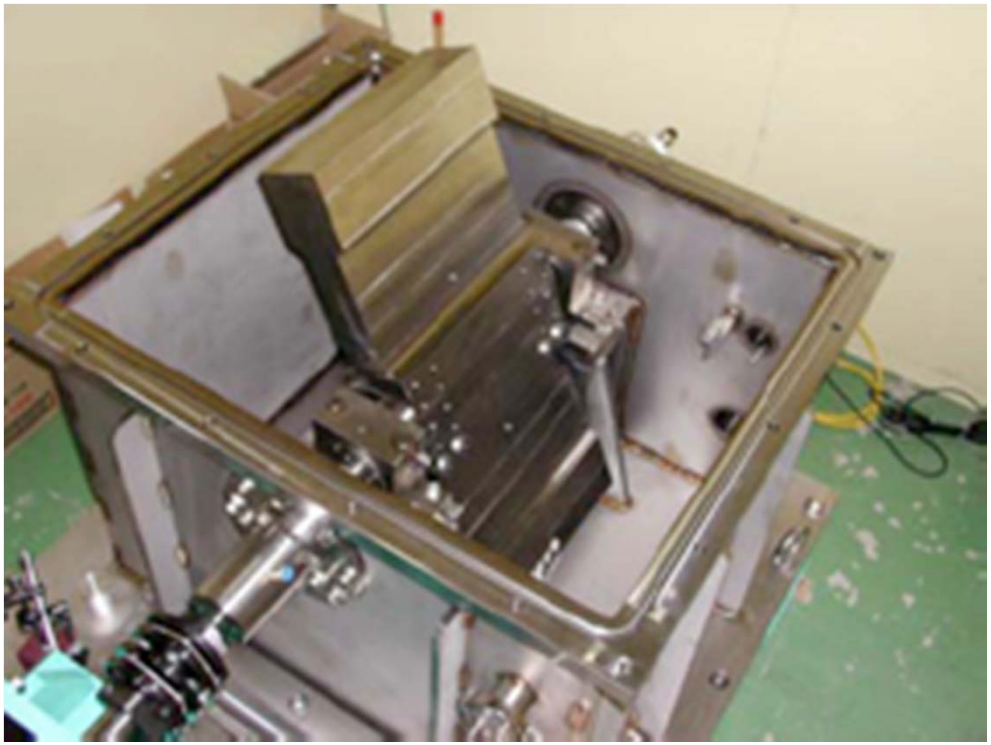
A real instrument will have to fit into a real space, and it will never be big enough …



T0 chopper 0.7m diameter + 2*0.6m shielding @ 11m = 18°

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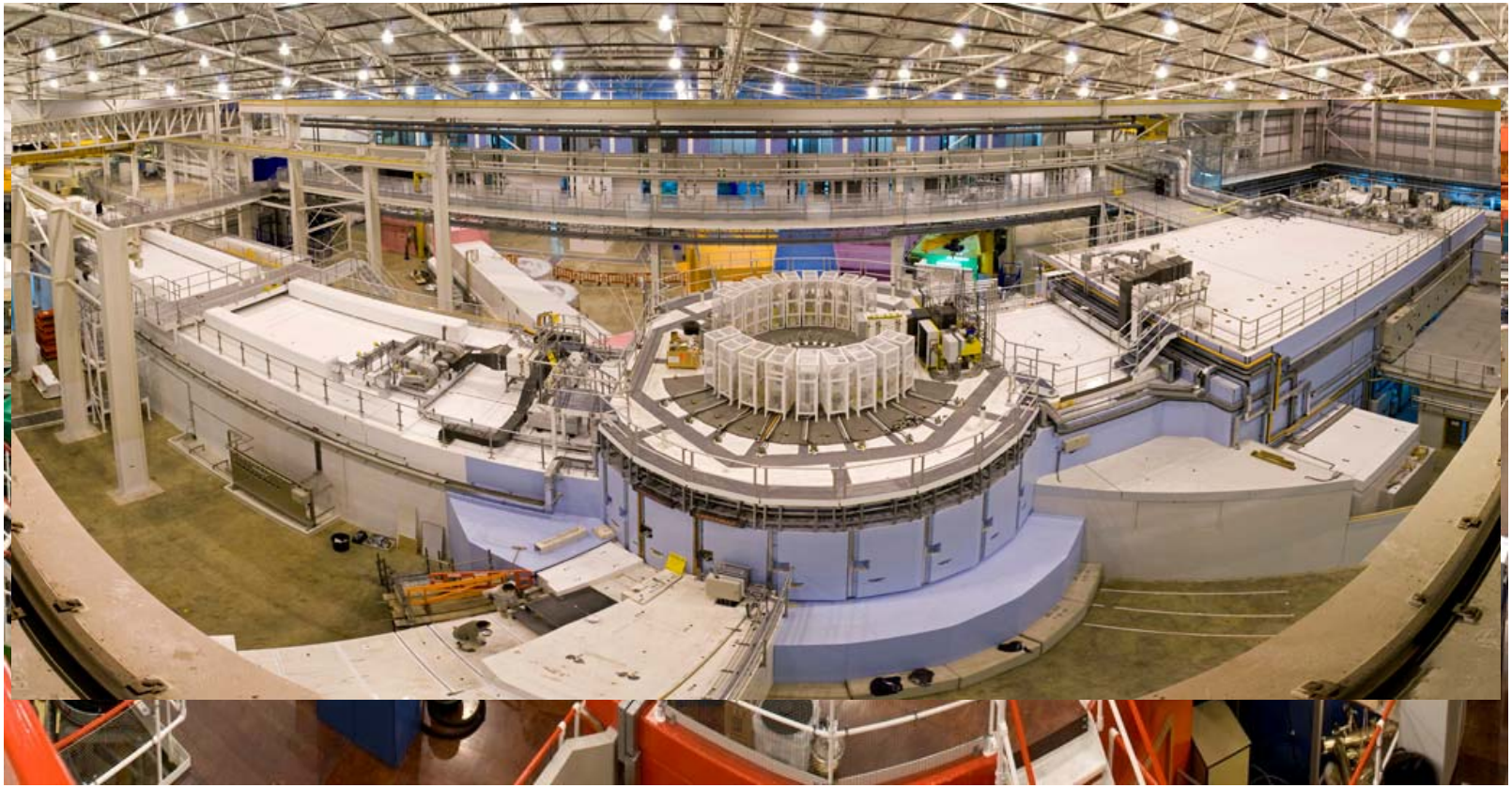
What is the most important piece of equipment in an instrument hall?



The crane!

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A real instrument will have to fit in a real space, and it will never be in the right place …

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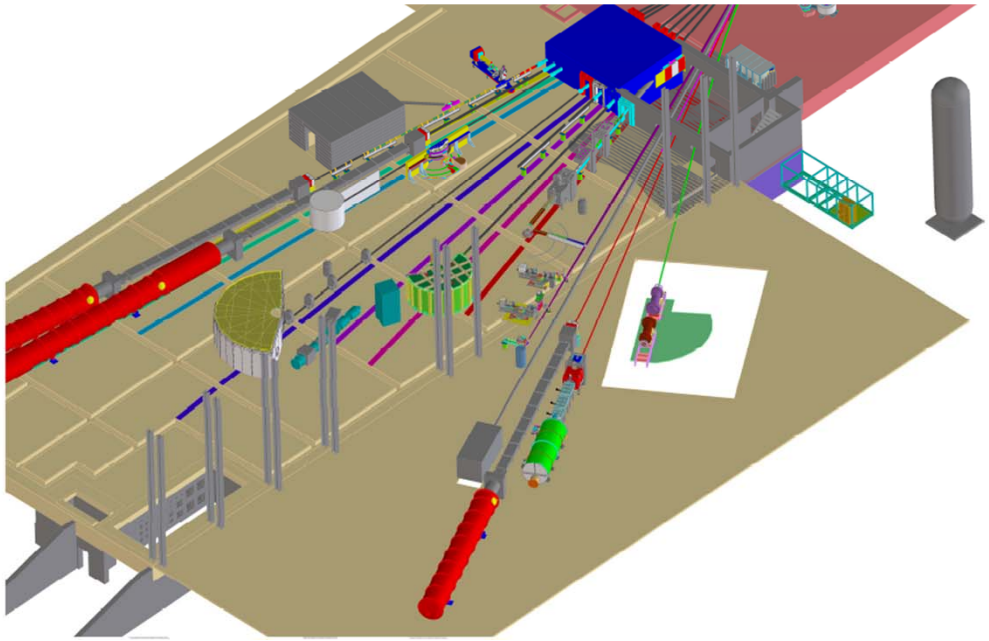
Integrating and optimising multiple instrument designs



NCNR new guide hall

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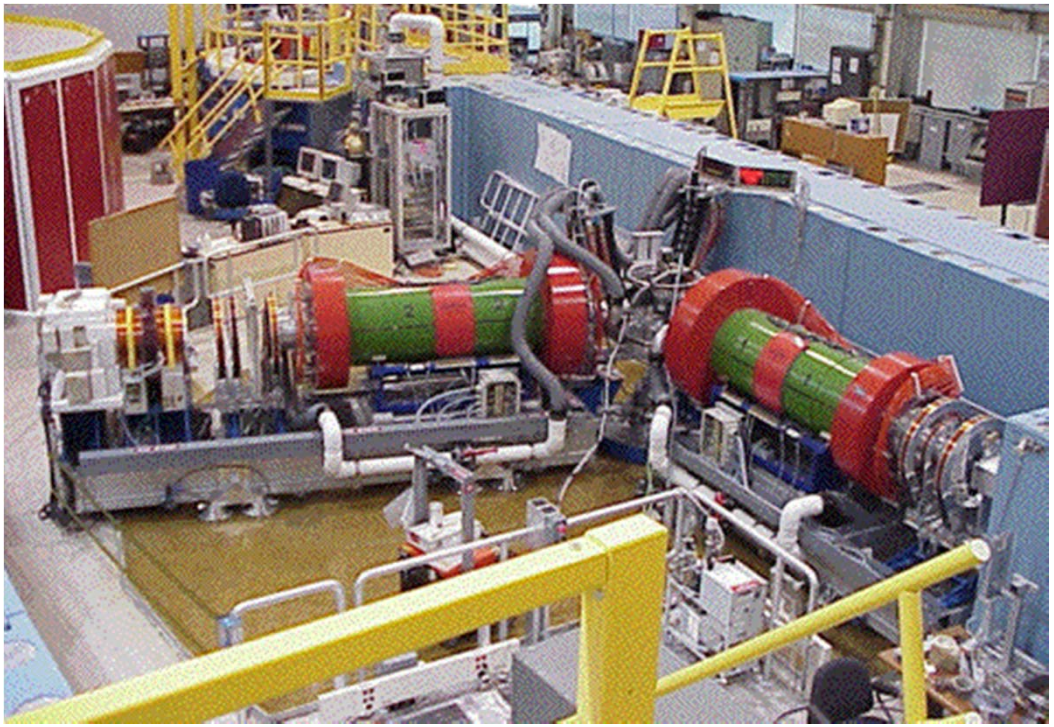
Many neutron instruments use (and are sensitive to) magnetic fields



Magnetic field policies are a nuisance for some, but life and death for others …

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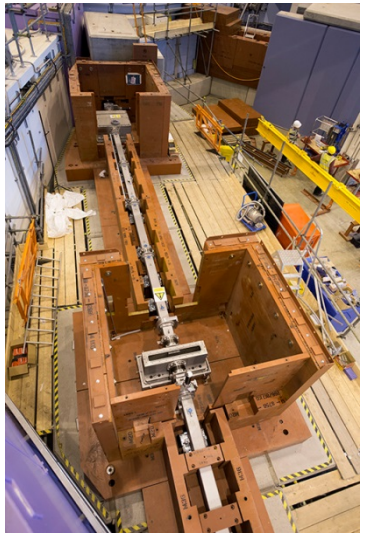
Shielding stops radiation from getting out, and from getting in …

Shield against fast neutrons, thermal neutrons, gammas

- Hydrogeneous (concrete, wax, polyethylene, water)
- Iron (steel), lead
- Boron (B_4C, BN, $AlMgB_{14}$, ^{10}B)
- ^{6}Li
- Cd
- Gd/GdO

Need to consider neutron thermalisation and gamma production



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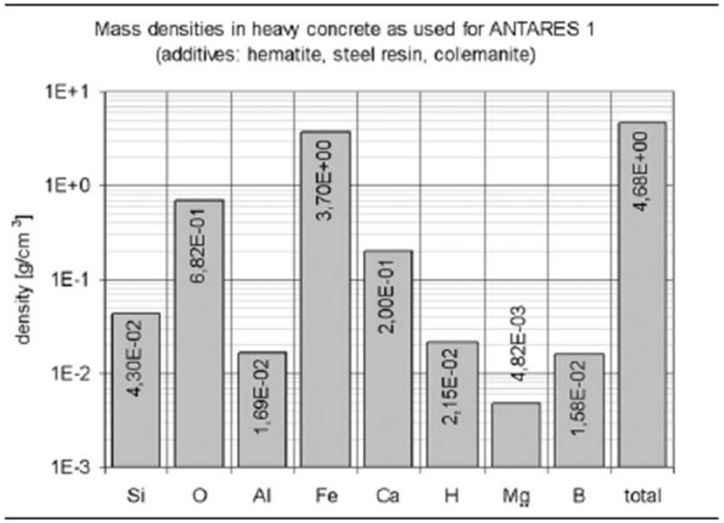
Shielding stops radiation from getting out, and from getting in …

Table 1
Mass densities in heavy concrete as used for the former ANTARES facility.



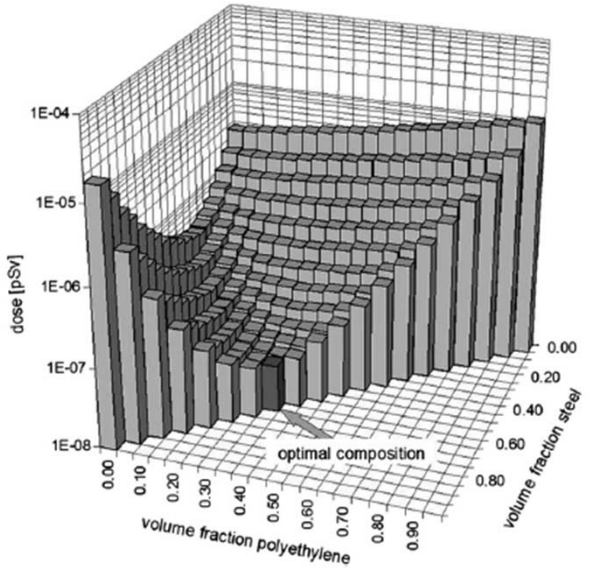


Fig. 4. Total dose on the outer surface of the sphere.

Shield against fast neutrons, thermal neutrons, gammas

Steel, ferroboron, paraffin composite
Calzada et al. (Munich) NIMA 2011

We need to develop better (and cheaper) shielding …

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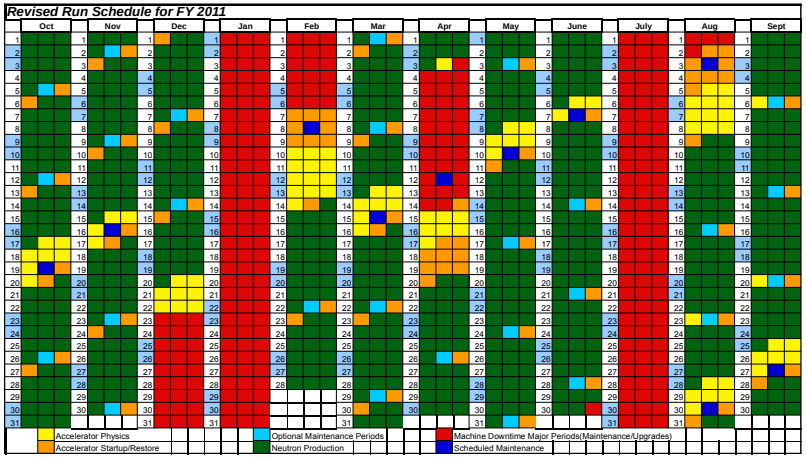
Building new instruments at a new facility is much easier (of course …)



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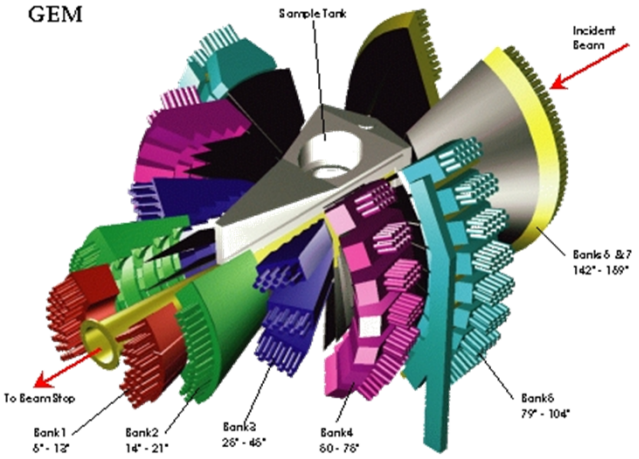
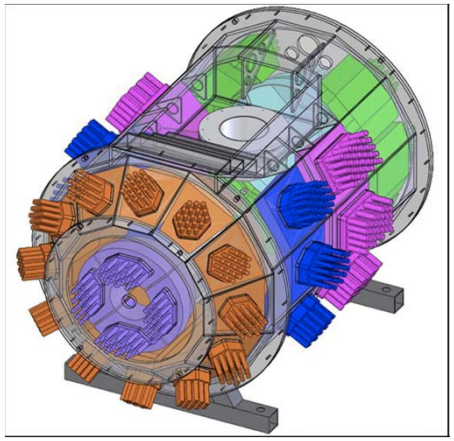
Instruments must be accessible for people …





GEM and POLARIS instruments (ISIS powder diffraction)

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Instruments must be inaccessible for people …

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Instruments must be accessible for samples and sample environment …

VULCAN instrument (SNS materials/engineering diffraction) with multi-axial load frame

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Back to money …

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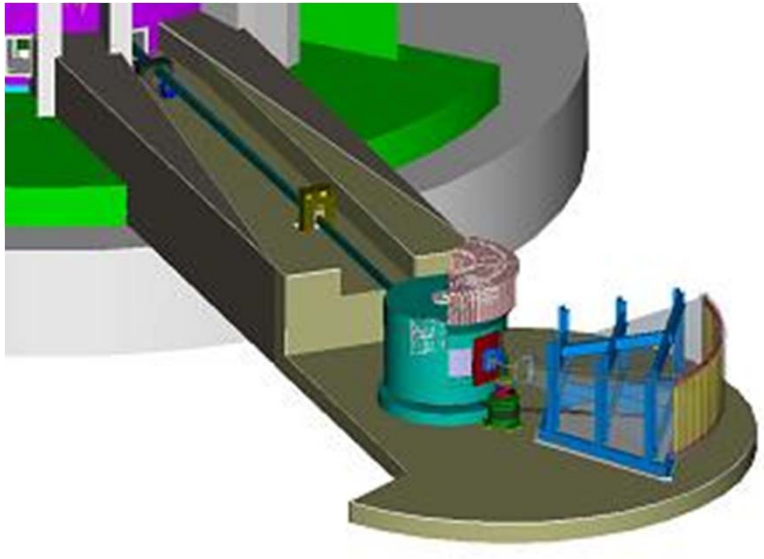
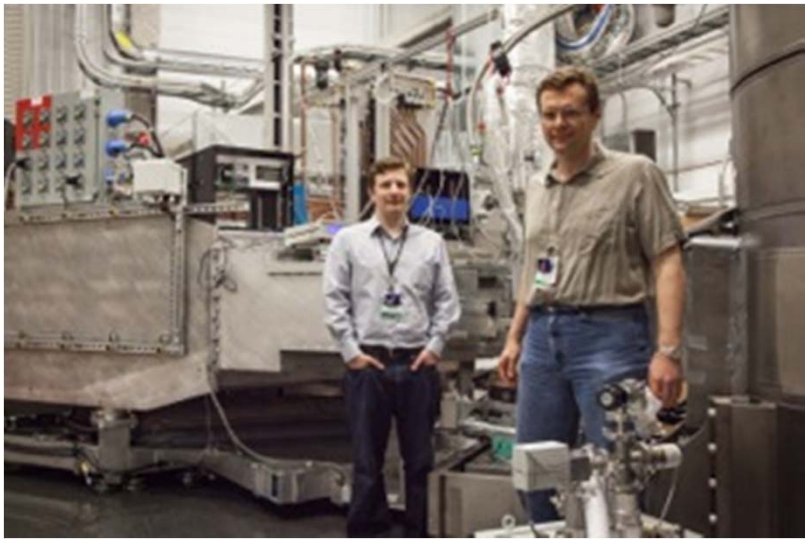
What does it cost to build an instrument?





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What does it cost to build an instrument?

- SNS SING-II: 4 instruments $60M
- ISIS TS2 Phase II: 4 instruments £30M

… and these are 'incomplete' instruments …

(usually detectors are descoped)

75% Materials 25% Labour

Front end: shielding (concrete, steel, wax) ≥ guide

and what was missing from the list?

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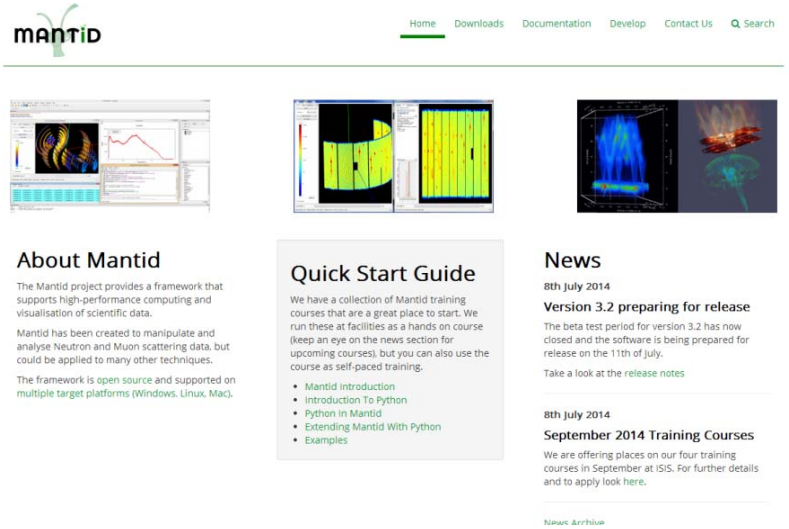
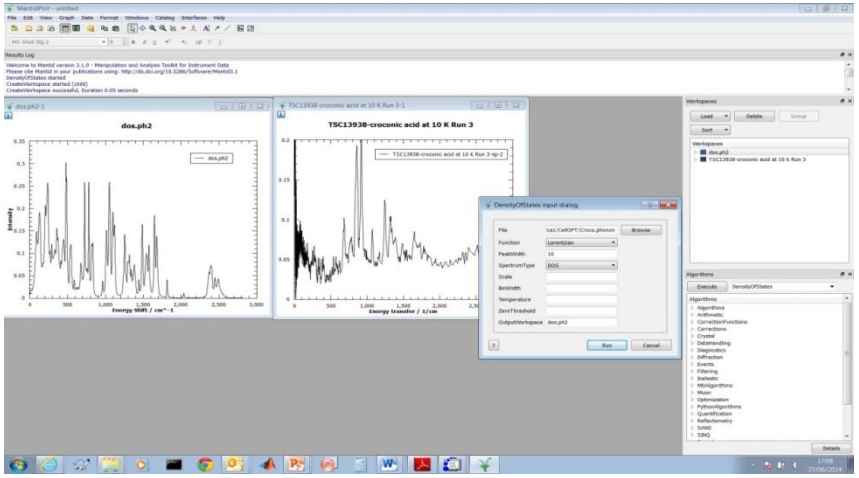
Sample environment, software





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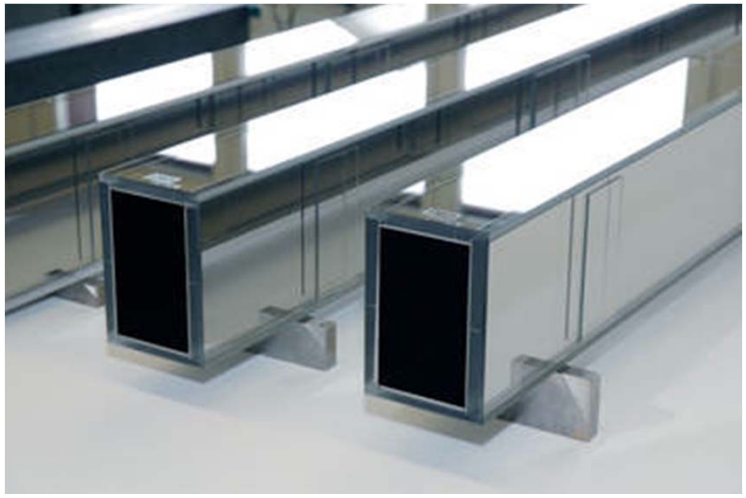
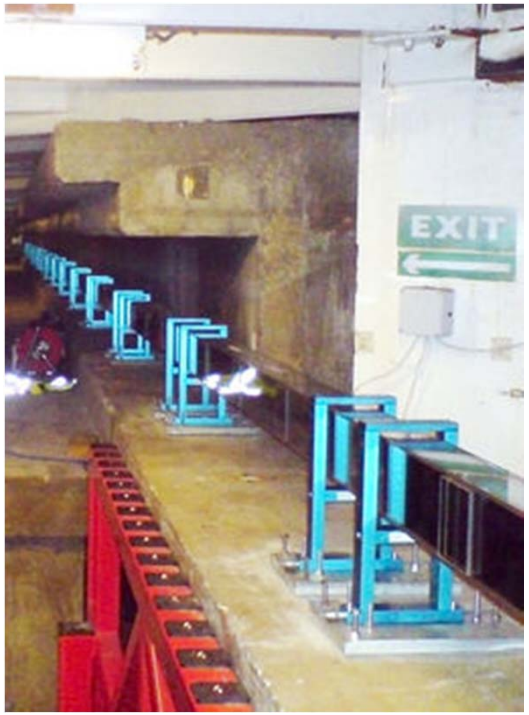
A ‘simple’ example – optimising the cost of a guide



The higher the m value, the higher the cost



HRPD, ISIS: double elliptical focusing guide

Conclusions

- Neutron scattering is (always going to be) an expensive technique

  so you must optimise the cost/benefit

  and define the ‘benefit’

- Think about the engineering and operational practicalities in the design

  or pay for it for the next 15 years

- The ‘clever’ bits of the instrument are equal in cost and equal in importance to the ‘dumb’ bits, but both are much cheaper than the source

  there is no point in putting effort into the source if you’re not also going to put effort into the shielding

- Try not to be developing the technology at the same time as you’re building the instrument …