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Polarised Neutron Capabilities at ANSTO

Wai Tung Hal Lee
Australian Centre of Neutron Scattering

ANSTO – OPAL Reactor

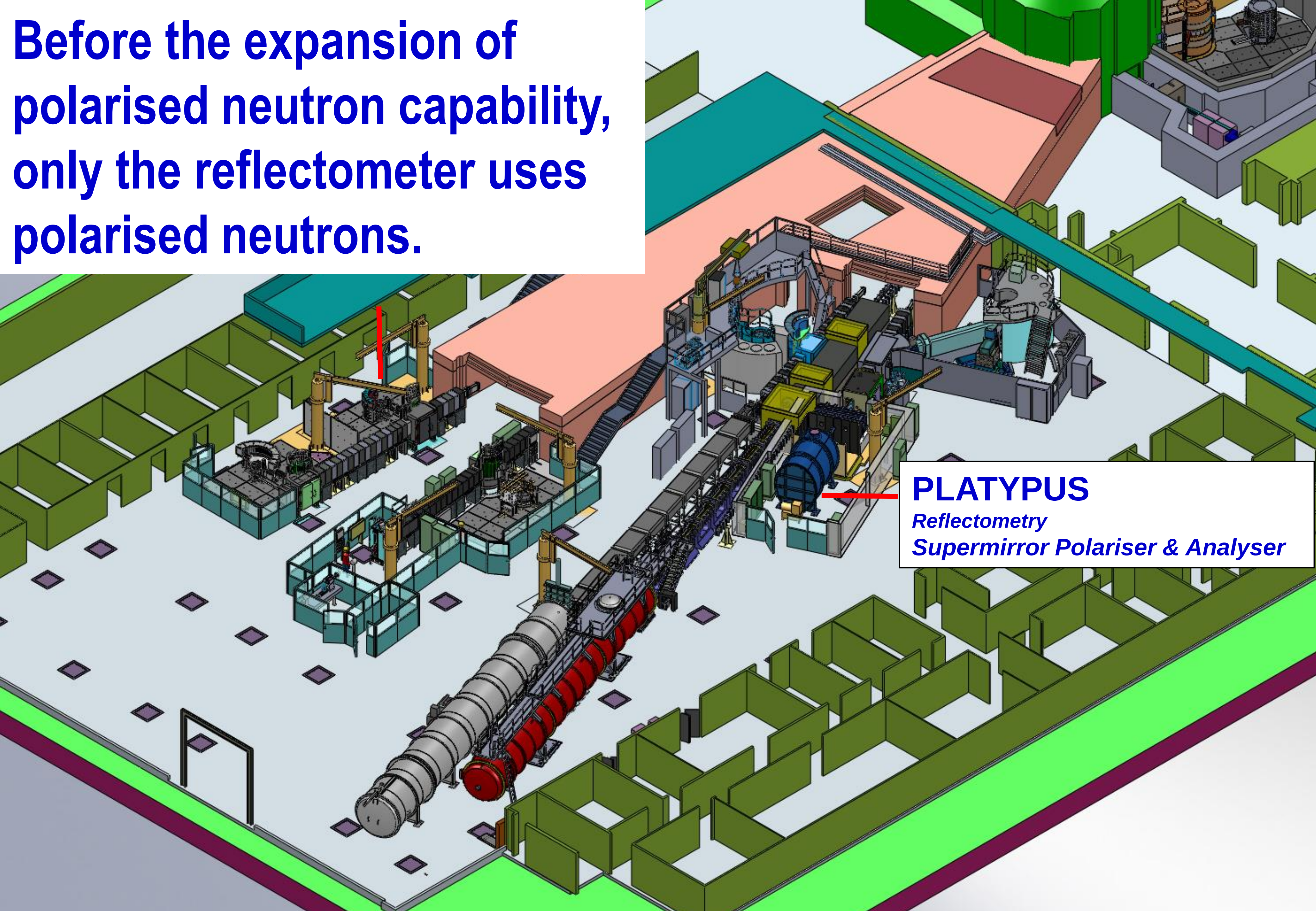
Present

- 20 MW research reactor
- 14 operating instruments
    - 5 Diffractometers
    - 3 Inelastic scattering instruments
    - 1 Backscattering spectrometer
    - 2 SANS
    - 1 Reflectometer
    - 1 USANS
    - 1 Imagining

Happening

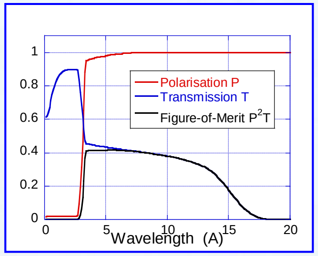
- Polarised neutrons on 7 instruments
    - 2 Diffractometers
    - 3 Inelastic scattering instruments
    - SANS & reflectometer
- 1 new reflectometer + Larmor

Before the expansion of polarised neutron capability, only the reflectometer uses polarised neutrons.

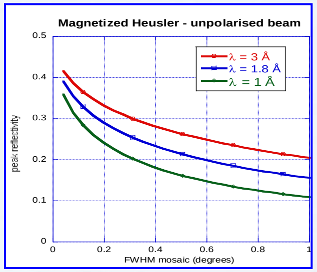


Comparison of neutron polarisation techniques (2008)

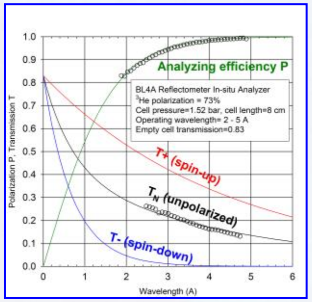
	^{3}He	Heusler	Supermirror (transmission)
Wavelength / Energy range and bandwidth	Epithermal to very cold. Works with monochromation or TOF. Wide bandwidth. Lower transmission for cold neutrons. Can tune to appropriate wavelength/energy.	5 meV (4 Å) - 105 meV (0.9 Å). Monochromation technique. Narrow bandwidth. Energy range & resolution ~ PG 002.	2.3 Å (15 meV) to cold. Work with monochromation or TOF. Wide bandwidth. Lower transmission for cold neutrons.
Spin-selection	Integrated ^{3}He spin-flipper	Separate neutron spin-flipper	Separate neutron spin-flipper
Flipping ratio	High flipping-ratio (comparable Figure of Merit with Heusler), varies over slightly a broad energy band	High flipping ratio (comparable Figure of Merit with ^{3}He), constant over a broad energy band	High flipping ratio for cold neutrons. Constant over a broad band Low flipping ratio for thermal neutrons.
Transmission / Reflectivity of unpolarised beam	Up to 0. 3, wavelength dependent	Up to 0.3, wavelength dependent	Up to 0.4, mild dependence on wavelength over working range.
Divergence, Angular span, Focusing beam	Accepts high divergence. Covers wide angular span. Works with focusing beam.	Accepts high divergence. Divergence limited by crystal mosaic Focusing	Limited divergence.
Beam direction	Does not change beam direction	Change beam direction	Does not change beam direction
Cross-section	Polarisation uniform across large beam	Polarisation and transmission may vary	Polarisation and transmission may vary
Sensitivity to interference	To magnetic field gradients. Magnetic shielding needed.	No sensitive	Not sensitive
Preparation and Operation	In-situ SEOP: >10 h setup and polarising. MEOP, off-situ SEOP: 1-3 h or >10 h to set up and polarise. 15 min every 12-24 h to exchange gas and check polarisations. >100 hour relaxation of polarisation	Can changed to polarised in automated way. Setup once, calibrate occasionally	Can changed to polarised in automated way. Setup once, realign occasionally
Maintenance	Filling station maintenance	Zero maintenance.	Zero maintenance.



Supermirror



Heusler alloy



Polarised ^{3}He

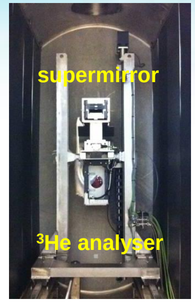
Polarised ^3He Neutron Spin Filters has been introduced to expand the use of polarised neutrons.

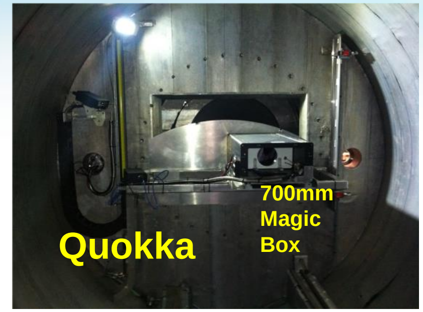
Prior to the polarised 3He project, ANSTO has polarising supermirrors for specular reflectivity measurements on PLATYPUS and installed polarising supermirror on QUOKKA SANS as polariser. To expand the use of polarised neutrons in scattering works, ANSTO has acquired from the Institute Laue-Langevin:

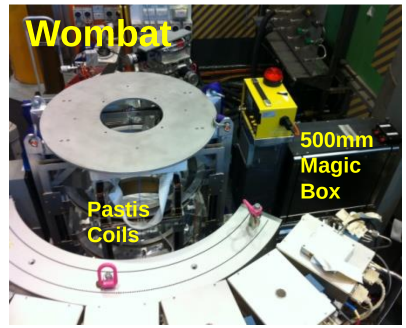
- **MEOP ^3He polarising station**
- **Silicon-windowed spin filter cell + "magic box"**
  Wide-angle analyser cell + "Pastis" coils
  "Local filling" setup + Transporter

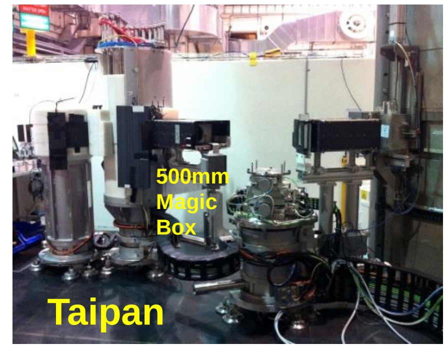
With the acquisition, ANSTO has built the infrastructure

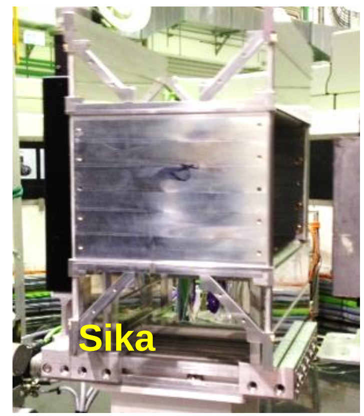
- **Integration to 6 instruments (now 7)**
  - **TAIPAN thermal triple-axis spectrometer**
  - **PELICAN chopper spectrometer**
  - **SIKA cold triple-axis spectrometer**
  - **WOMBAT high-intensity diffractometer**
  - **ECHIDNA high-resolution diffractometer**
  - **QUOKKA SANS instrument**
  - **PLATYPUS reflectometer**
- **^3He lab for polarising station operation**











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- **MEOP ^{3}He polarising station**
- **500mm 3-section Magic Box, 300mm "Super Box"**
  Modified "Tetra-coil" for vertical field
  Magnetube 2.0 (to be tested)

With the acquisition, ANSTO has built the infrastructure

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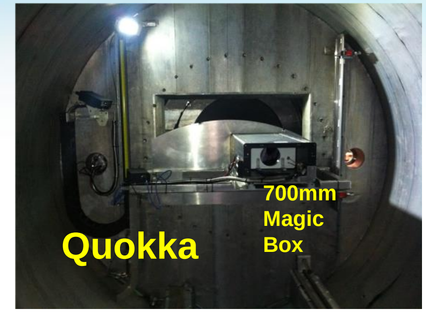

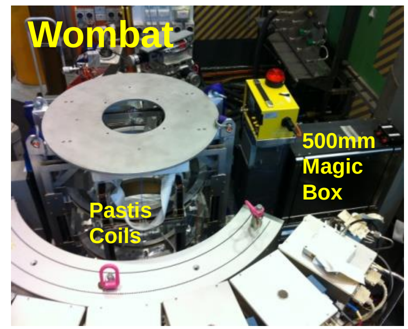

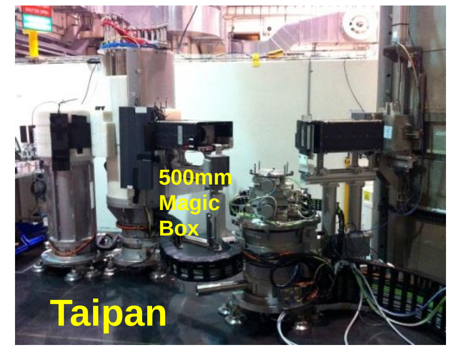

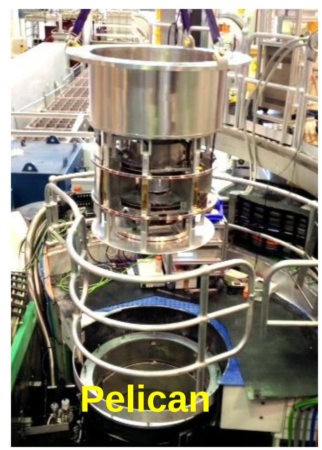

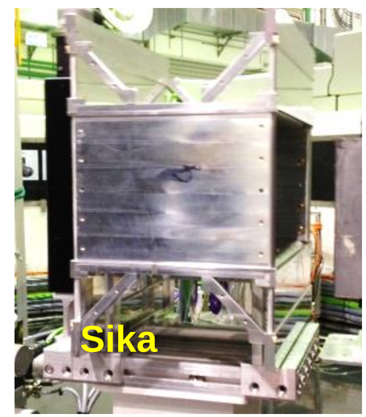

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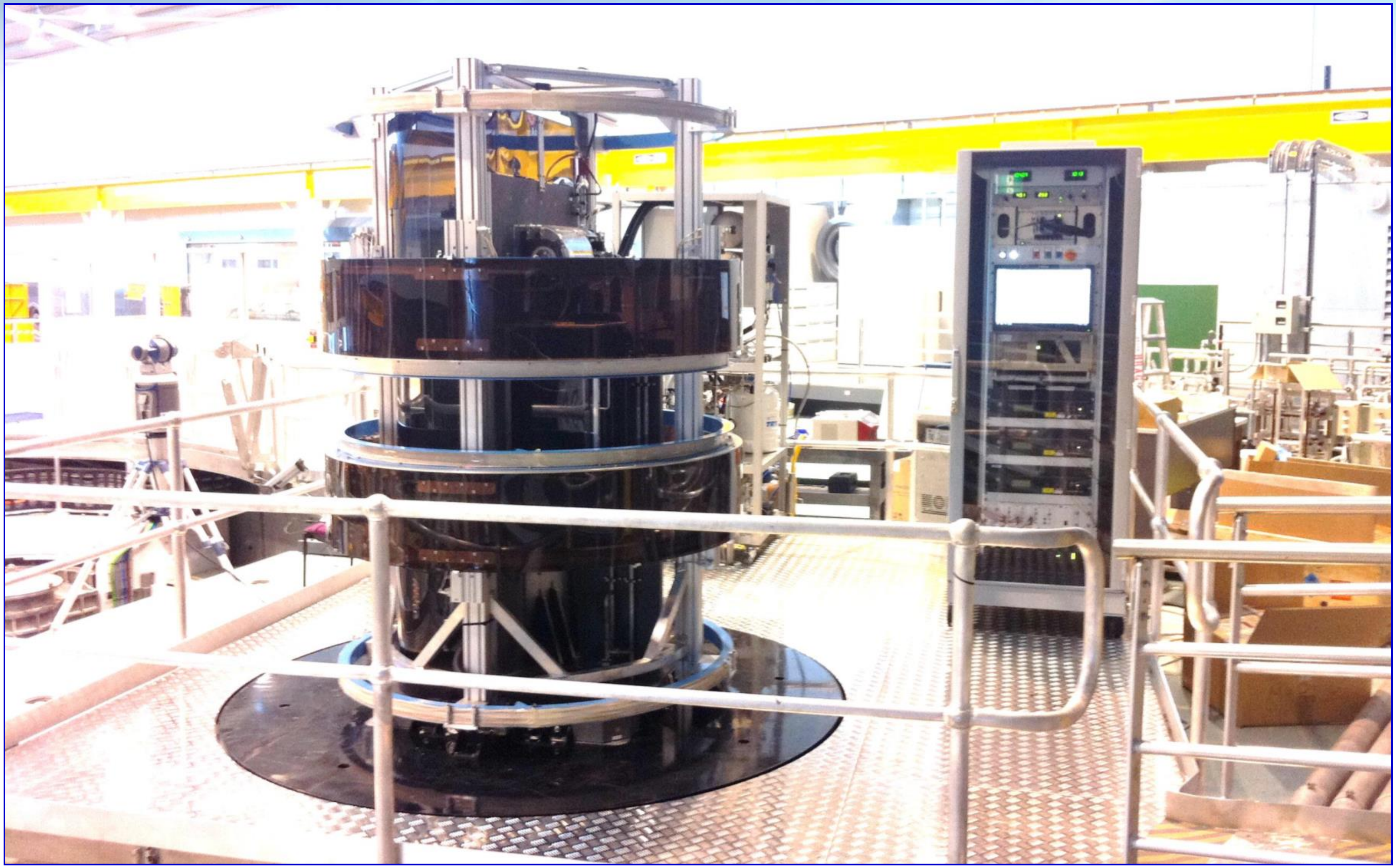
The ^{3}He polariser is completely operational and all its circuits are functioning perfectly.



> 70% ^{3}He Polarisation in neutron spin-filter cell at instrument

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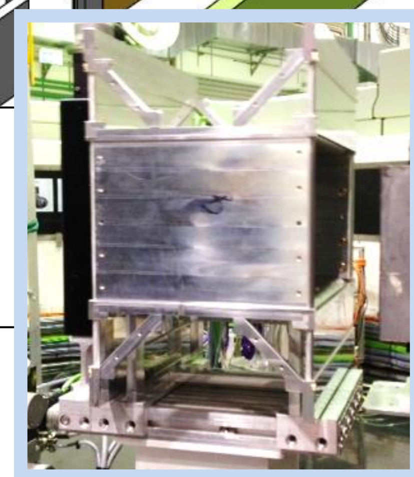
3 in user program now
4 more in 2016/2017
Wide-Angle Analyser
Polariser
WOMBAT
Diffraction, high-intensity
3He Polariser & Analyser
PELICAN
Inelastic scattering
Time-of-flight
Supermirror
Polariser & 3He Analyser
3He polarising station
Polarised 3He isotope gas for instruments
ECHIDNA
Diffraction, high-resolution
3He Polariser & Analyser
PLATYPUS
Reflectometry
Supermirror Polariser & Analyser
Large-Coverage 3He Analyser
QUOKKA
Small Angle Neutron Scattering
Supermirror Polariser + 3He Analyser
Inside detector tank
analyser
supermirror
3He analyser

3 in user program now
4 more in 2016/2017

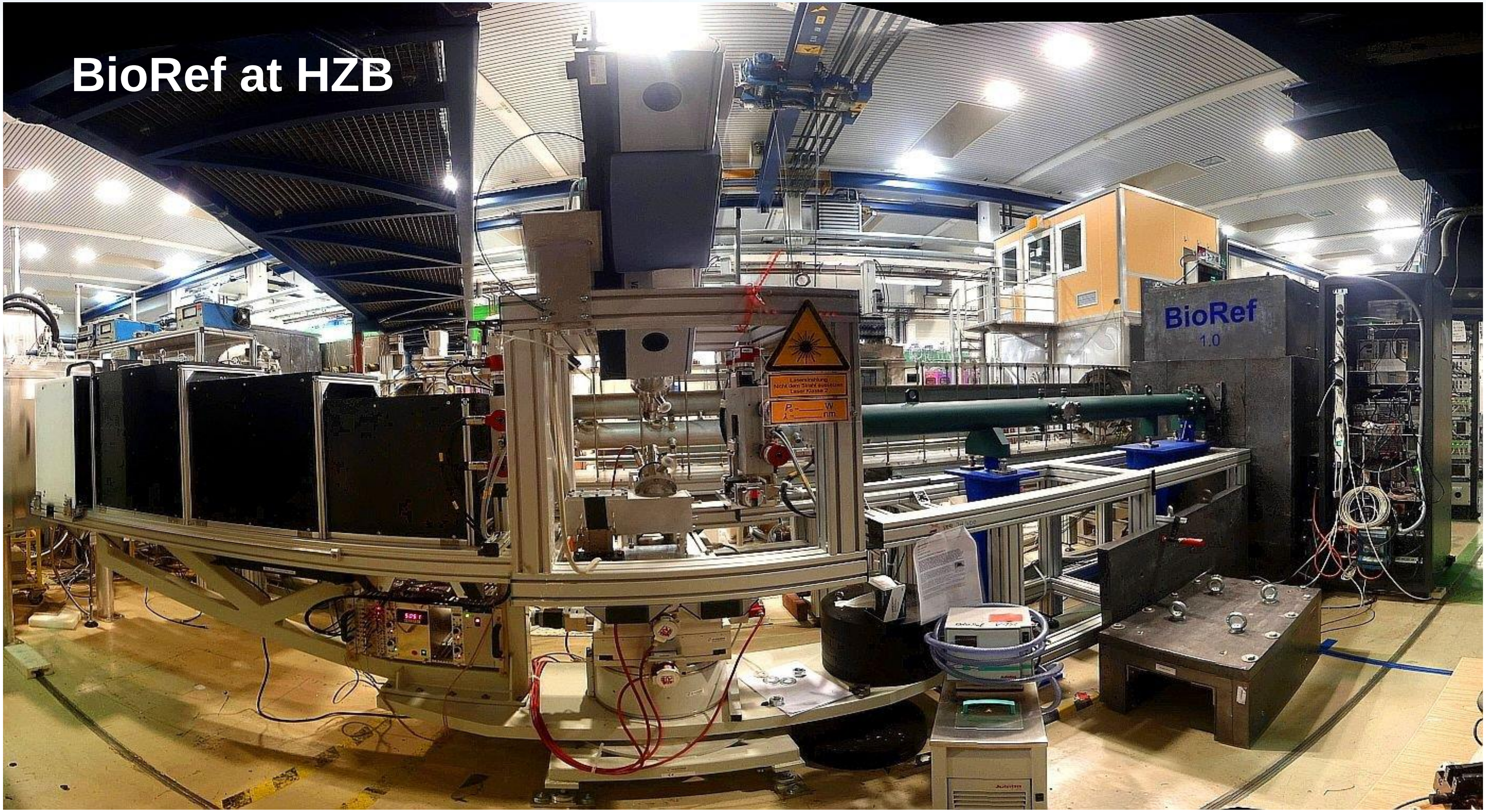
DINGO
Imaging
^{3}He Polariser & Analyser
Need monochromatic/TOF beam

TAIPAN
Inelastic scattering
Thermal neutron
^{3}He Polariser & Analyser

SIKA
Inelastic scattering
Cold neutron
^{3}He Polariser & Analyser



New instrument – collaboration with HZB



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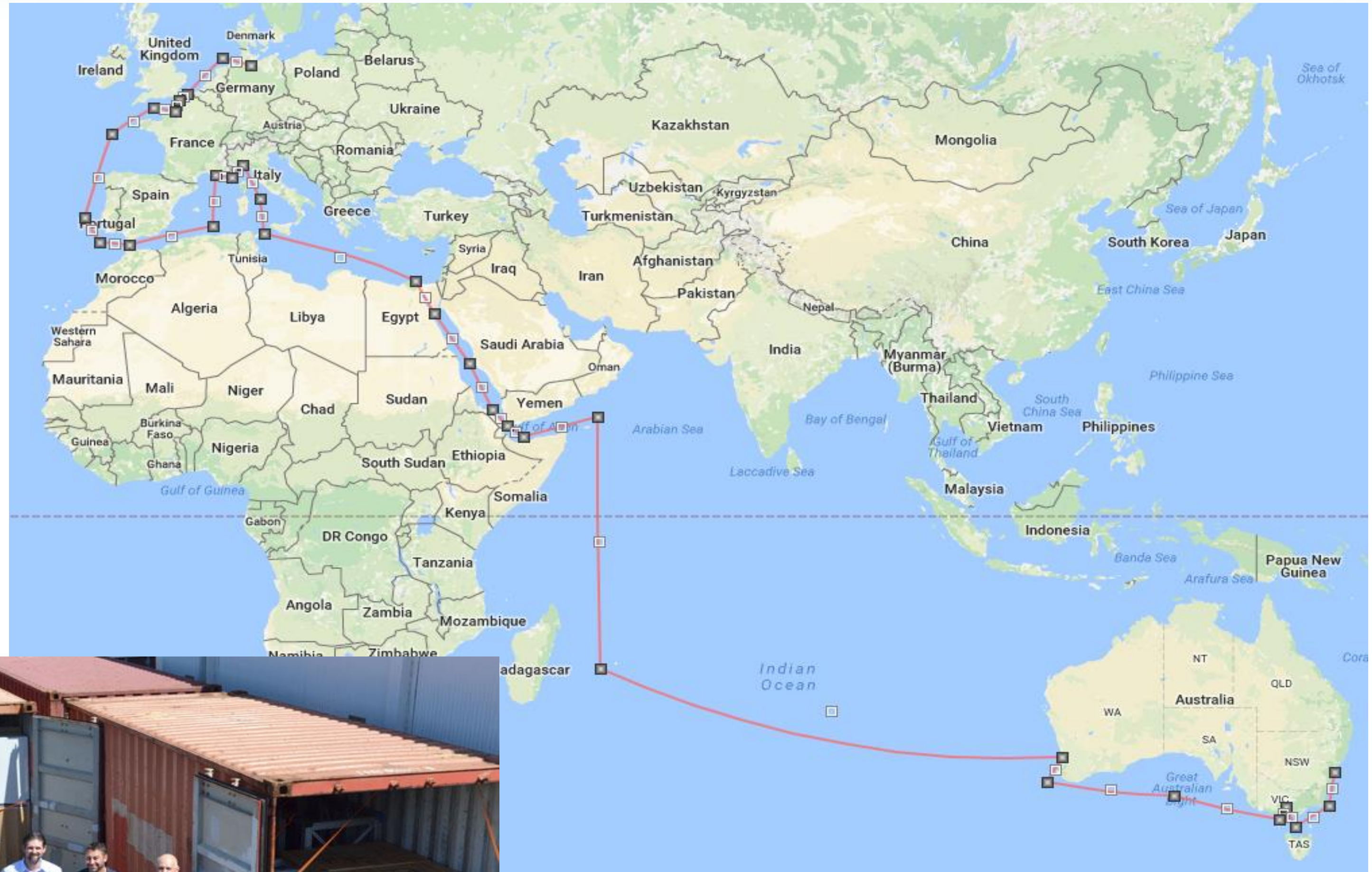
Milestones Achieved: Transfer from HZB

Started in Hamburg with stops in:

- Rotterdam,
- Le Harve,
- Fos-Sur-Mer,
- Genova,
- Reunion Island,
- Fremantle,
- Melbourne…

…and finally Port Botany.

45 days at sea covering approximately a distance of 26,254 km.



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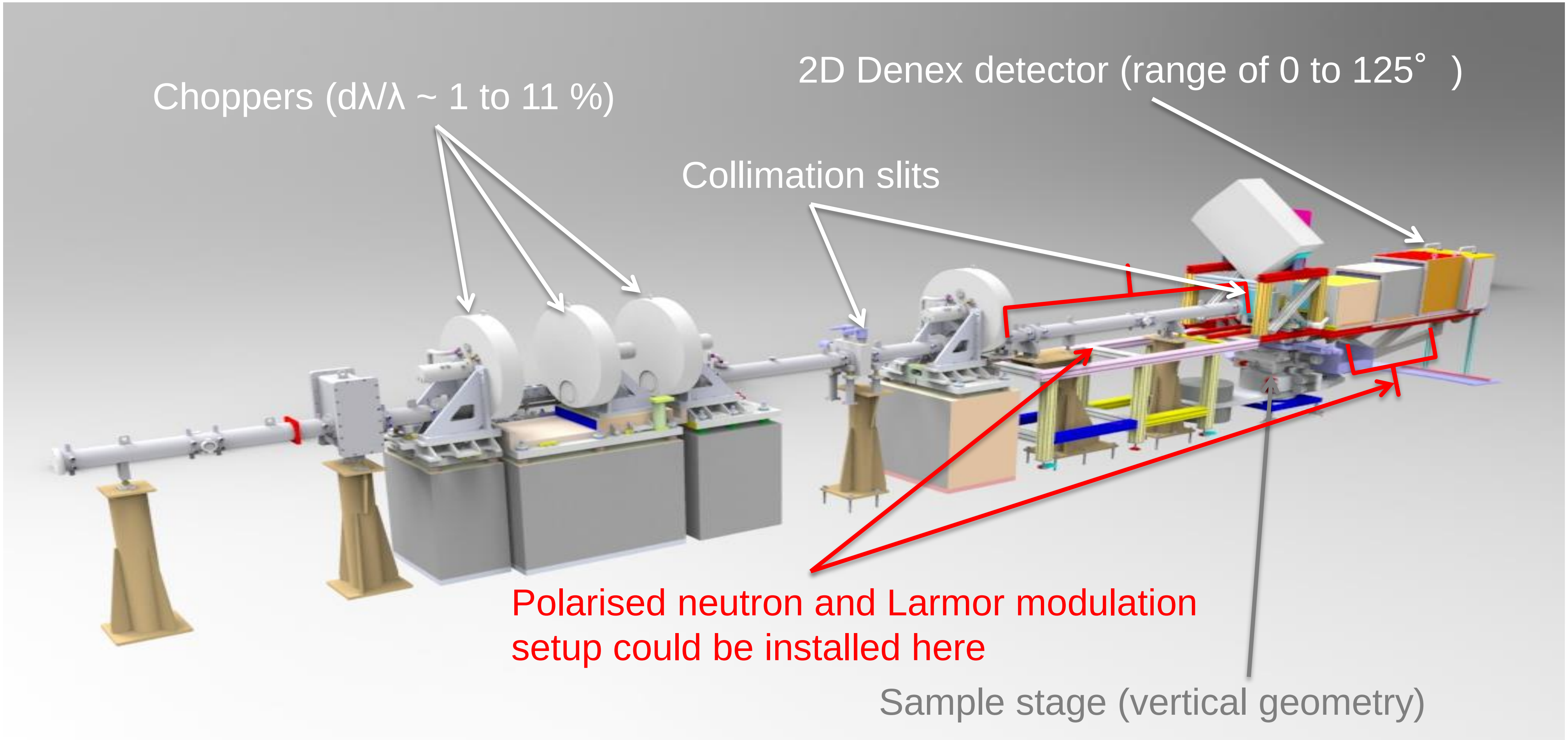
Spatz instrument Layout

This will likely be the first to use Larmor technique at ANSTO



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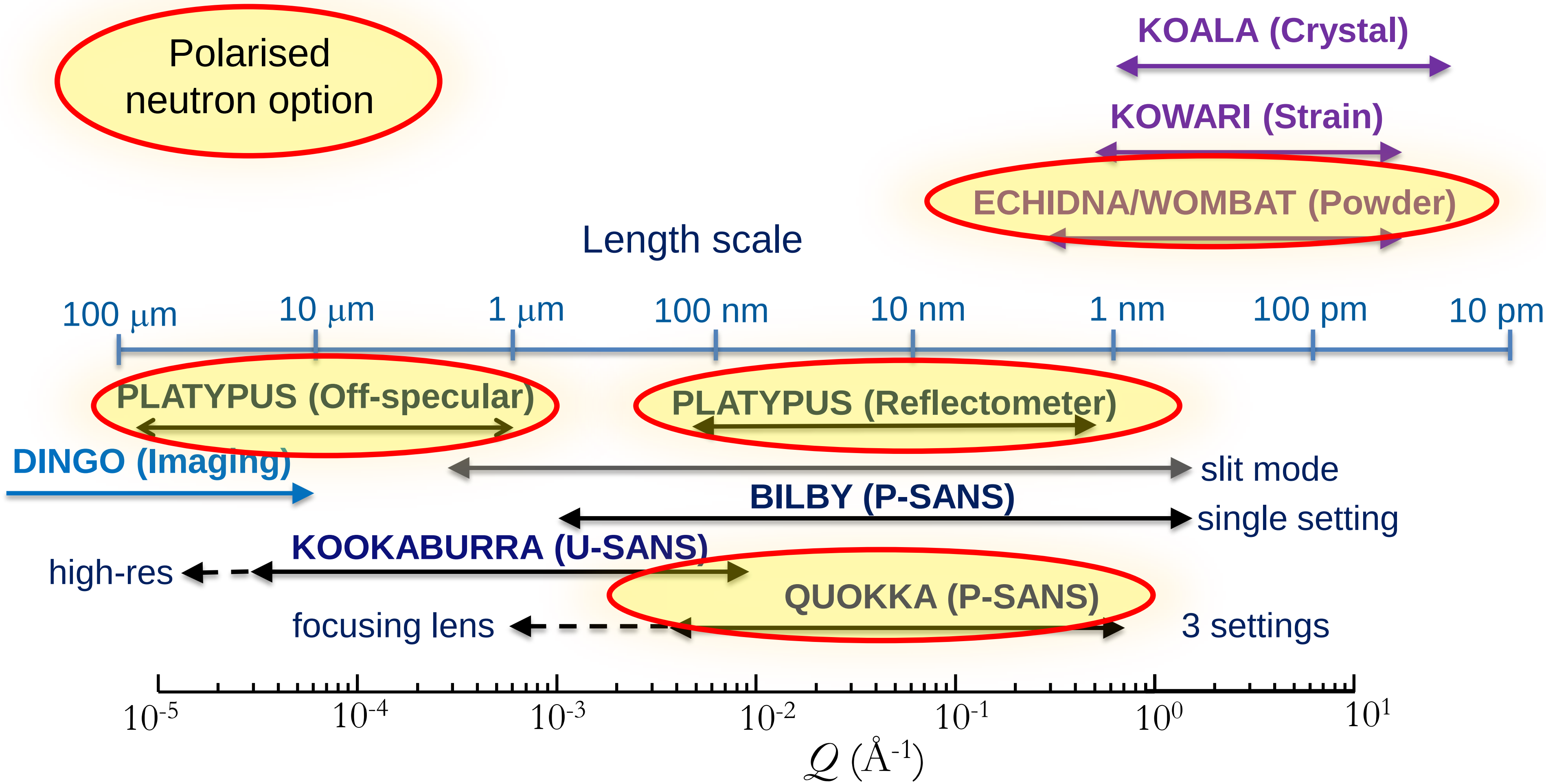
Capabilities for structural characterization at OPAL



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Capabilities for Dynamics and Excitations at OPAL

Current status:

SIKA (c-TAS)

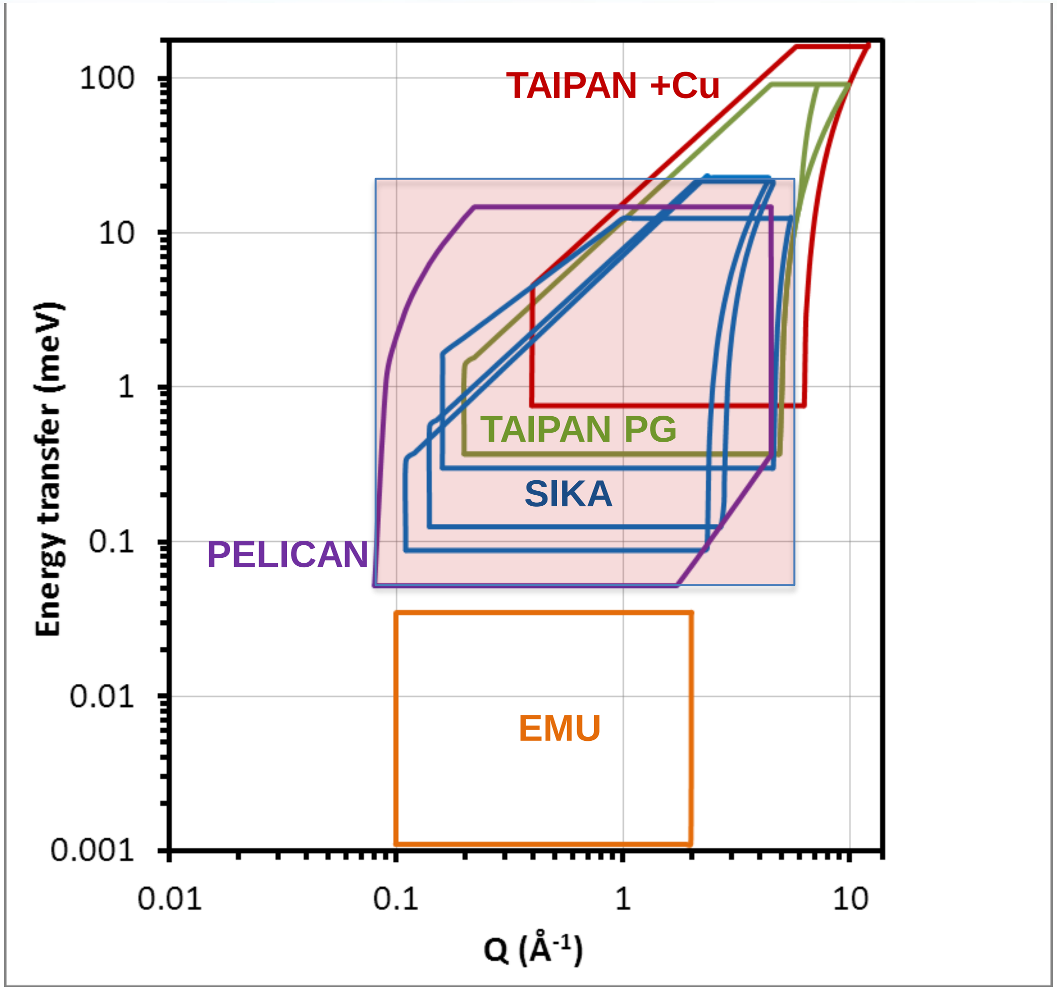
TAIPAN (t-TAS) PG

PELICAN (c-TOF)

EMU (Backscatter)

TAIPAN (t-TAS) Cu –under development

Polarised neutron option



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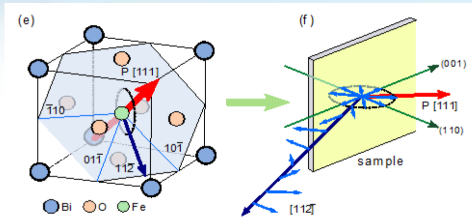
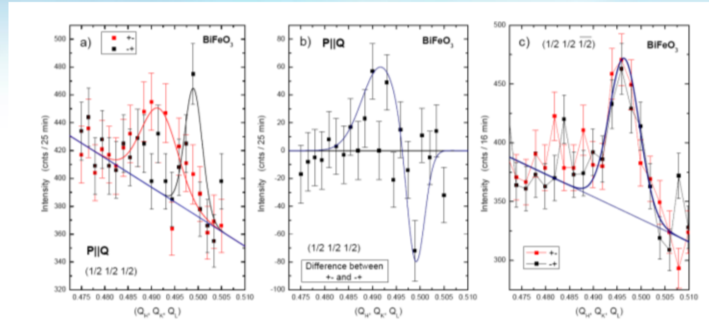
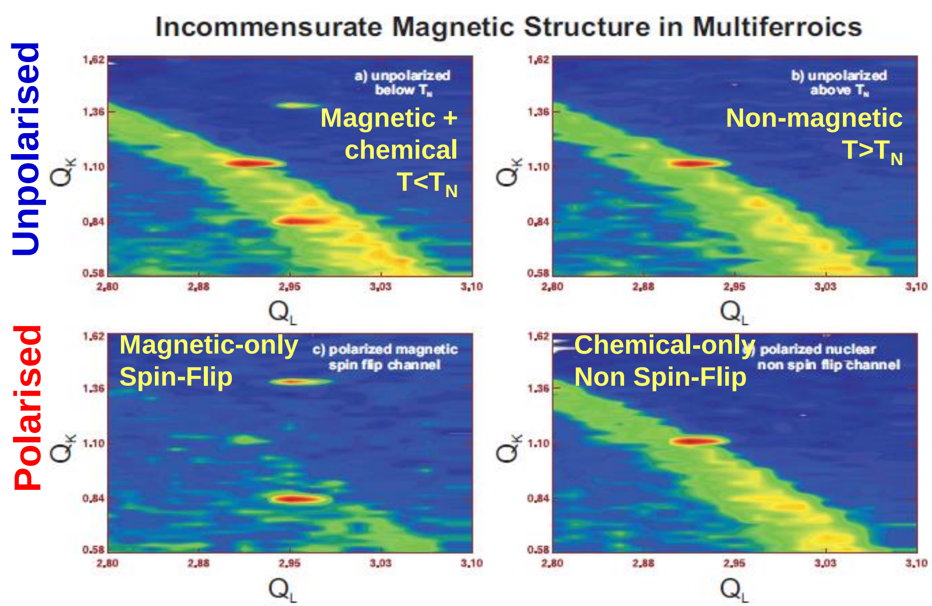
Highlights of polarised neutron scattering experiments at ANSTO

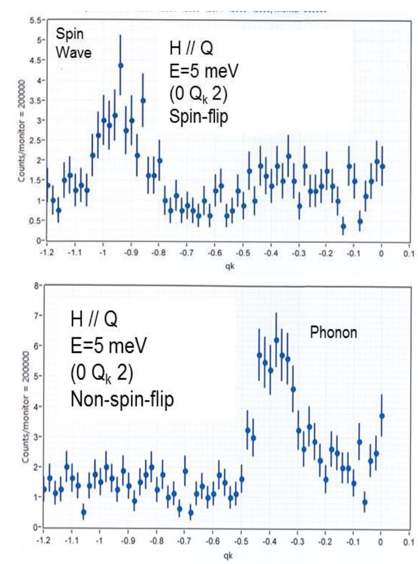




TAIPAN measurements definitively identified the chiral magnetic structure.
J. Bertinshaw, et. Al., Nature Communications 7, 12664 (2016)



WOMBAT measurements showing the separation of nuclear and magnetic scattering.



Spin wave

Phonon

TAIPAN measurements showing the separation of phonon and spin wave.

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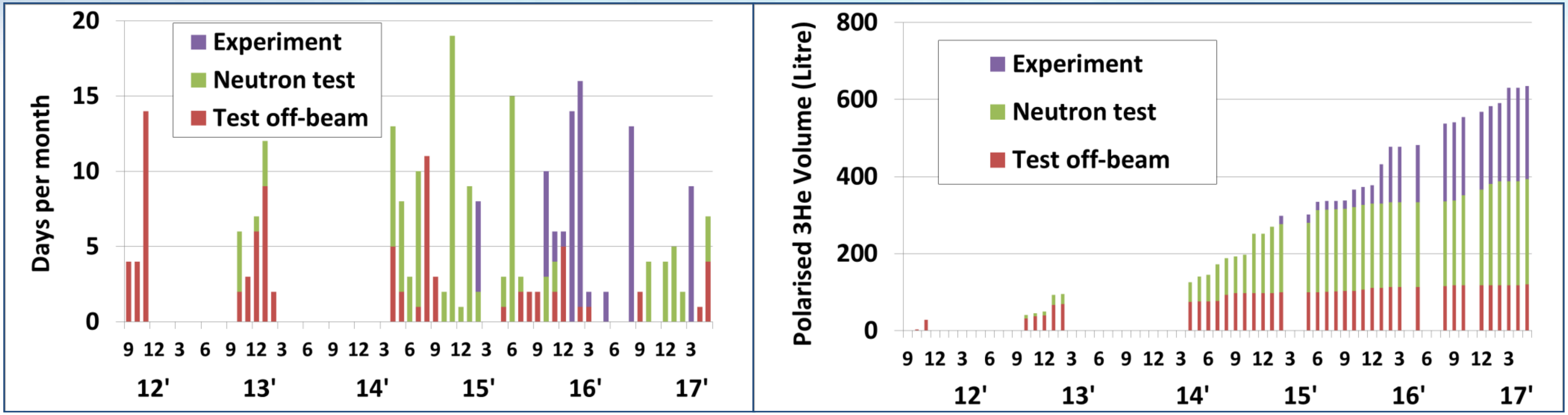
Current usage of polarised ^3He for neutron polarisation analysis



- Neutron tests began in 2014.
- First user experiment in 2015, available on
    - PLATYPUS (reflectometer)
    - TAIPAN (triple-axis)
    - WOMBAT (diffractometer)
- First scientific publication in 2016.
- User demand increasing. Conducted 14 user experiments in the past 18 months.
- **On-going collaboration with J-Parc on exploring new techniques and on scientific experiments.**

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Important lessons from upgrading existing instruments

- Good: Instruments reserve space and avoided using magnetic materials where they may interfere with the polarised neutron setup
  Do it even if it would mean more expensive for the instrument. Any complacency can eliminate the upgrade possibility all together.

- Bad: Modelling and planning of new components are usually insufficient.
  Space needed for new components can either be in the wrong place or used for something else, resulting in costly and time-consuming remaking of existing instrument components.
  Upgrades should be modelled at the same time of new instrument design as if they are being built.

- Often overlooked (we didn't…):
  - Interconnection of different components.
    Magnetic field from one component both connect but also interfere with the functionality of another component.
  - Real component is often different from first-principle calculation.
    Infinitely thin wire with harmonic expansion correction is nice for a first-cut calculation. But don't build the real thing on that result.

  MUST DO:
  Finite element calculation using the most realistic geometry
  Evaluate spin-transport / field interference from the FE calculation to identify troubles
  Monte Carlo ray-tracing simulation using field profiles generated from FE calculation

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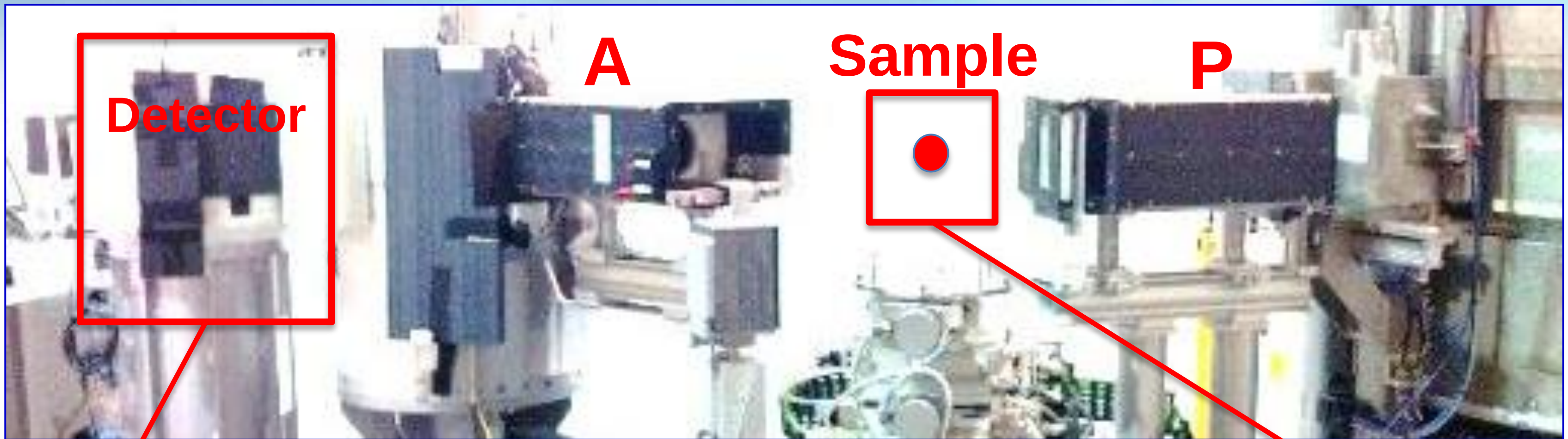
Measurement methodology and polarisation correction of data



$$\begin{pmatrix} I++ \\ I+- \\ I-+ \\ I-- \end{pmatrix} = \begin{pmatrix} S++ \\ S+- \\ S-+ \\ S-- \end{pmatrix}$$

In the ideal world

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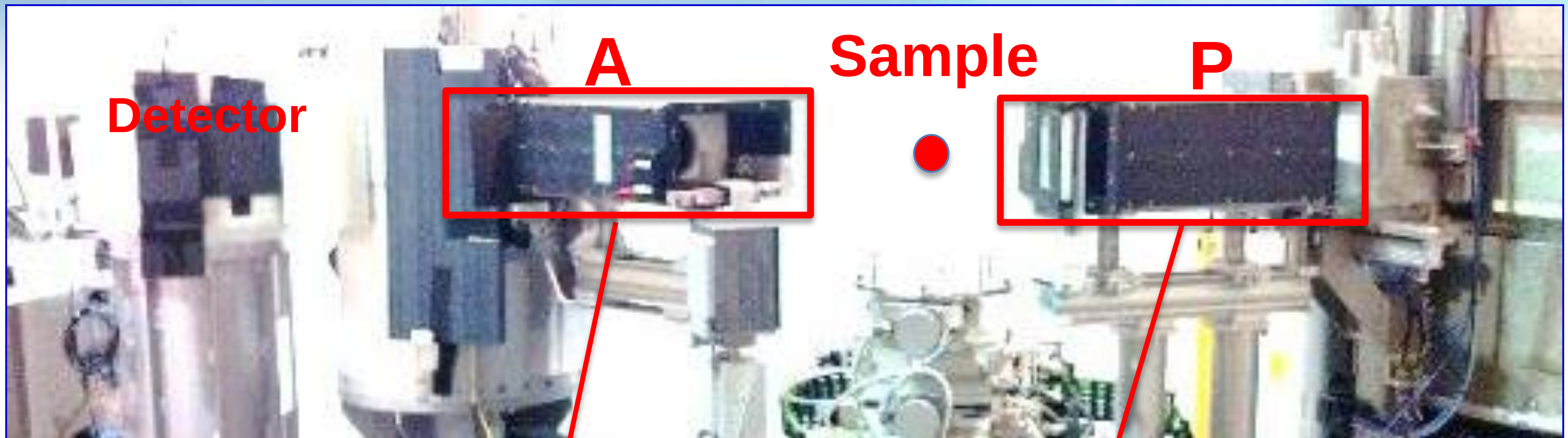
Measurement methodology and polarisation correction of data



$$\begin{pmatrix} I++ \\ I+- \\ I-+ \\ I-- \end{pmatrix} = \begin{pmatrix} \frac{1+A_+}{2} & \frac{1-A_+}{2} & 0 & 0 \\ \frac{1-A_-}{2} & \frac{1+A_-}{2} & 0 & 0 \\ 0 & 0 & \frac{1+A_+}{2} & \frac{1-A_+}{2} \\ 0 & 0 & \frac{1-A_-}{2} & \frac{1+A_-}{2} \end{pmatrix} \begin{pmatrix} \frac{1+P_+}{2} & 0 & \frac{1-P_+}{2} & 0 \\ 0 & \frac{1+P_+}{2} & 0 & \frac{1-P_+}{2} \\ \frac{1-P_-}{2} & 0 & \frac{1+P_-}{2} & 0 \\ 0 & \frac{1-P_-}{2} & 0 & \frac{1+P_-}{2} \end{pmatrix} \begin{pmatrix} S++ \\ S+- \\ S-+ \\ S-- \end{pmatrix}$$

A+ = Analyser spin+ analysis efficiency
A- = Analyser spin- analysis efficiency
1=perfect, 0=unpolarised

P+ = incident spin+ neutron degree of polarisation
P- = incident spin- neutron degree of polarisation
1=perfect, 0=unpolarised

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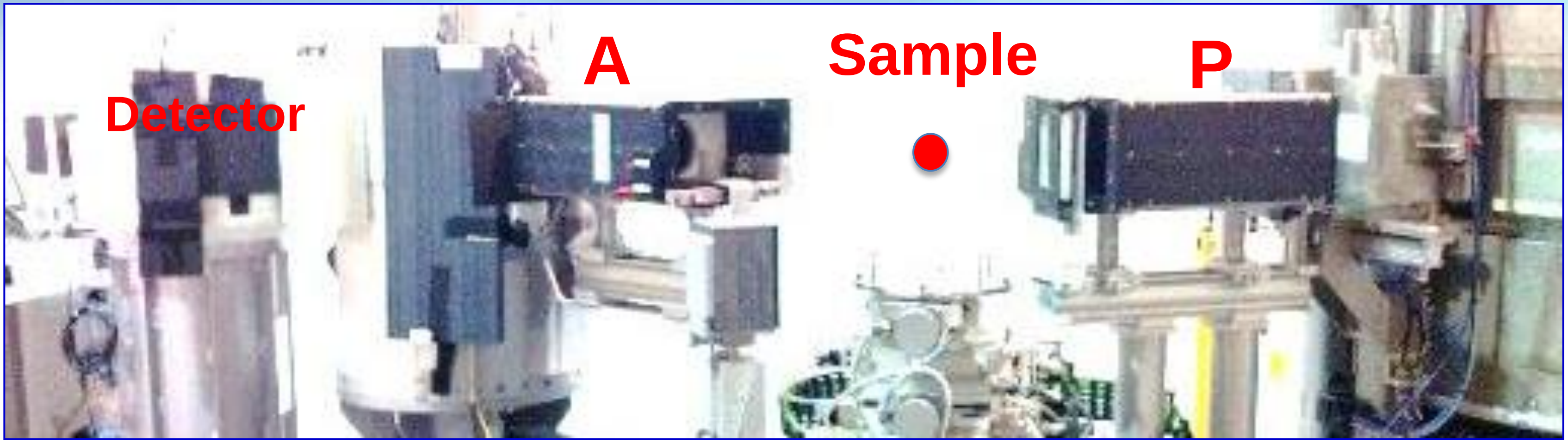
Measurement methodology and polarisation correction of data



To get P and A:

1. Periodically measure either direct beam transmission or chemical peak with only the polariser / only the analyser in the beam, e.g. Analyser only spin+ count-rate=T_N
2. Just before changing a cell, depolarise the cell and measure the same transmission or chemical peak, e.g. Depolarised, analyser only count-rate=T_0

$$\text{Analyser efficiency A+} = \sqrt{1 - \frac{T_0^{\ 2}}{T_N^2}} = \tanh\left(O\, P_{He}(t_0) \exp\left(-\frac{t - t_0}{T_1} \right) \right)$$

Polarisation correction is still possible if you cannot measure P & A independently but it rely on assumption that P and A are highly polarised and also depends on the sample scattering characteristics, such as S+- = S-+.

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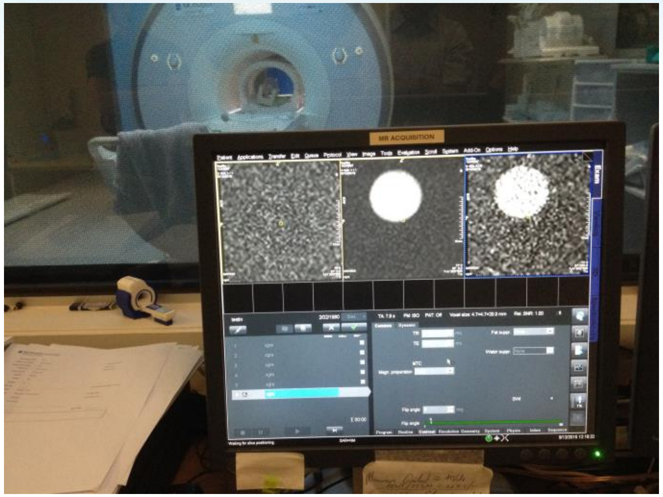
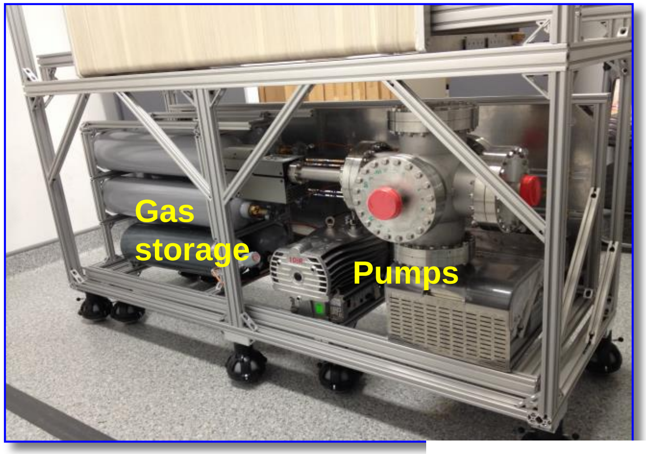
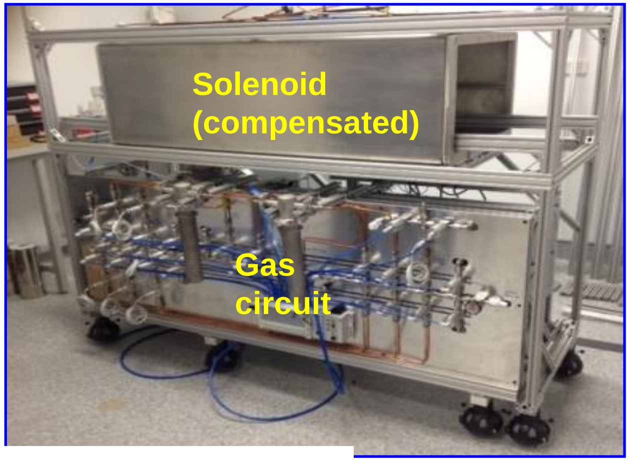
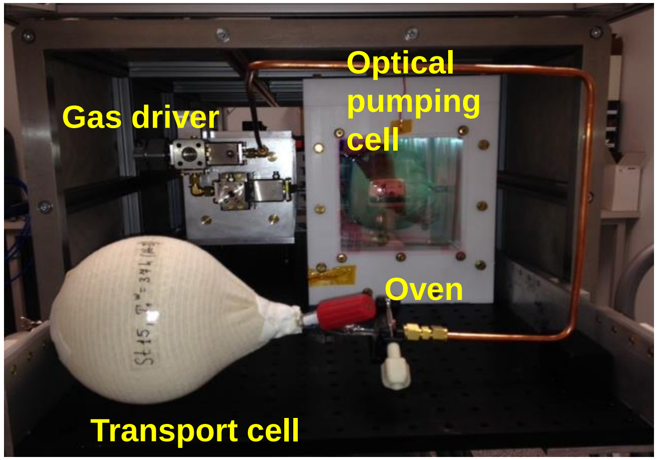
SEOP Polarised ^{3}He Filling Station for MRI

- We have constructed a Spin-Exchange Optical Pumping based Helium-3 and Xenon-129 polarising station for medical imaging uses at the Monash Medical Imaging Centre. Commissioning tests are underway.
- GE180 cell, Titanium gas transfer piston, compensated solenoid, Volume-Bragg-grating laser bandwidth narrowing, 240W laser each from both sides of optical pumping cell, ^{3}He gas recycling.
- Key components can be adopted for neutron scattering works.
- We are putting together EPR frequency shift device to measure the gas polarisation.









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Summary: Polarised neutrons at ANSTO

Available for users

TAIPAN
Triple-axis spectrometer

Full polarisation analysis with
1. 3-dimensional guide field and cryostat (RT to 4K)
2. mirror furnace (RT to 500° C)

WOMBAT
High-intensity diffractometer

1. Full polarisation analysis with 3-dimensional field & RT to 4K.
2. Incident polarised beam with up to 2.5 T vertical field & RT to 3K.

PLATYPUS
Polarised specular and off-specular scattering

Full polarisation analysis with up to 2 T vertical field & RT to 3K.

Available in 2017

Polarised inelastic scattering on 2 instruments: PELICAN (friendly user), SIKA (installation)

Polarised neutron diffraction: ECHIDNA (testing)

Polarised SANS for magnetic nanoparticles & organic materials: QUOKKA (friendly user soon)

Future – 2018 and beyond

BioRef -> SPATZ: Polarised option later in 2018, Larmor setup in 2018/2019

Second guide hall: Larmor setup using resonance coils? Collaboration to build conventional NSE?

We will continue to innovate!

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