BIFROST – High level requirements and scientific background

Core team:
Instrument scientist: Rasmus Toft-Petersen (DTU/ESS)
Instrument engineer: Liam Whitelegg (ESS)
Instrument data scientist: Greg Tucker (ESS)

Kristine Krighaar (KU)
Jonas Okkels Birk (KU)
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Daniel Mazzone (PSI)
Henrik Rønnow (EPFL
Kim Lefmann (KU)
Niels Bech Christiensen (DTU)

Partners:

Danmarks Tekniske Universitet

Laboratoire Léon Brillouin

Paul Scherrer Institut

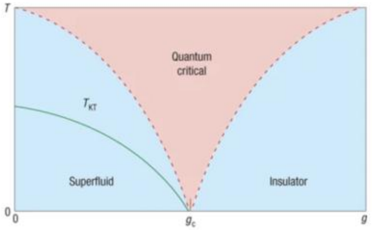
Institute for Energy Technology

Neutron spectroscopy

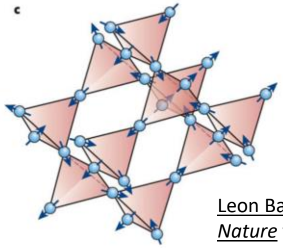
Rare earth

High-Tc superconductivity

Quantum magnetism

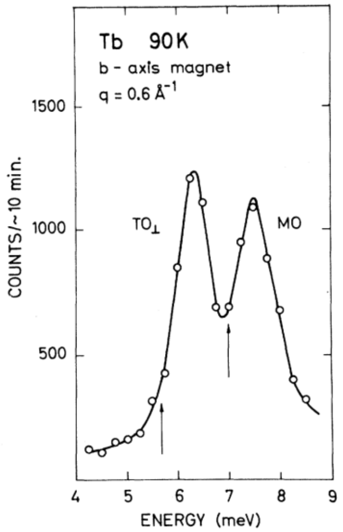


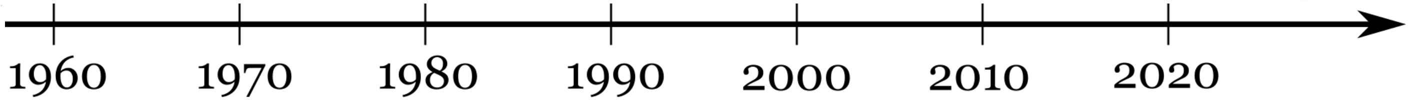
Frustrated magnetism,

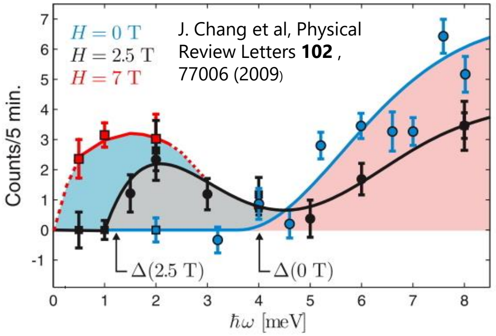


Leon Balents
Nature volume 464, pages,199–208 (2010)

J. Jensen and J. G. Houmann
Phys. Rev. B **12**, 320 (1975)

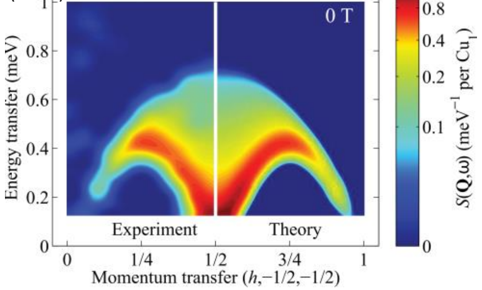


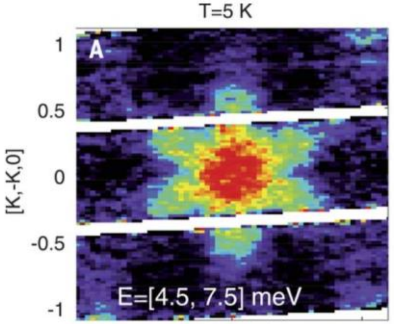




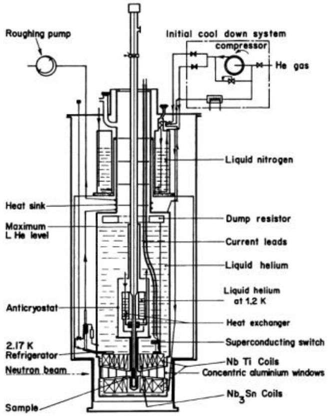
J. Chang et al, Physical Review Letters **102** , 77006 (2009)

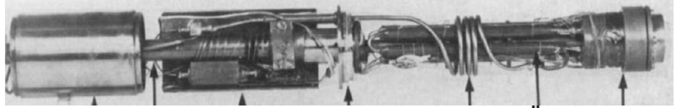
M. Mourigal et al., Nature Physics 9, pages 435–441 (2013)

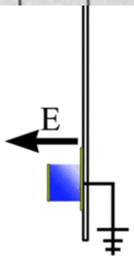




A. BANERJEE, ET AL, SCIENCE • 9 Jun 2017 Vol 356, 6342

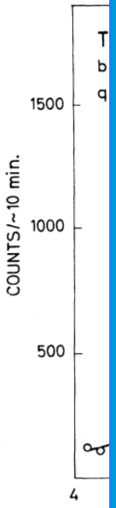






Neutron spectroscopy

J. Jensen and
Phys. Rev. B

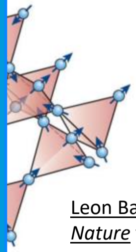


Evolution towards:

More complex phenomena
Smaller magnetic moments
Smaller samples
More complex sample environment

The easy experiments has been done

nagnetism,



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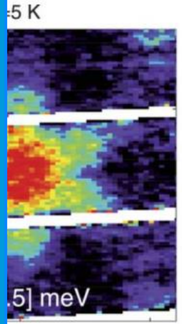

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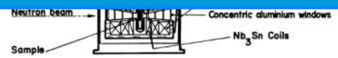
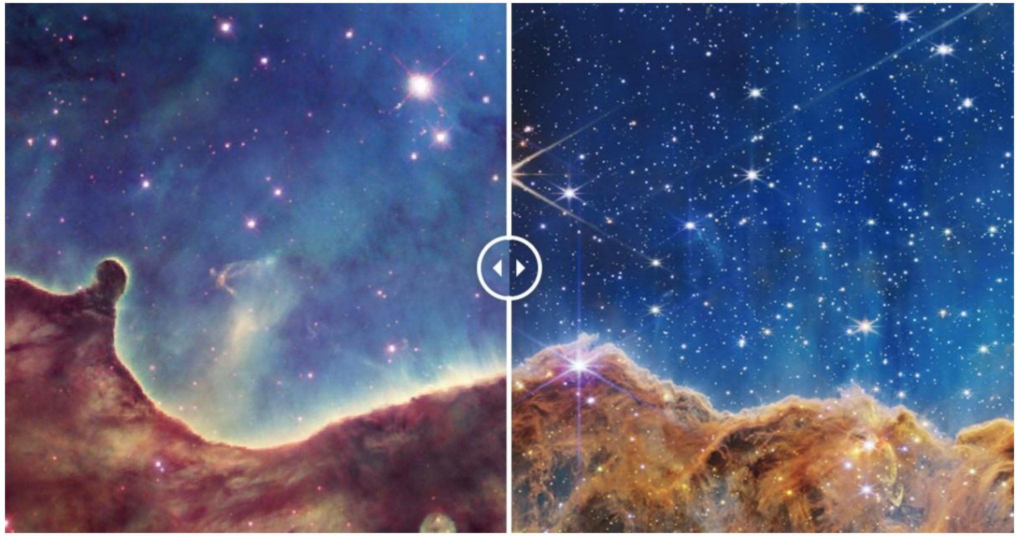
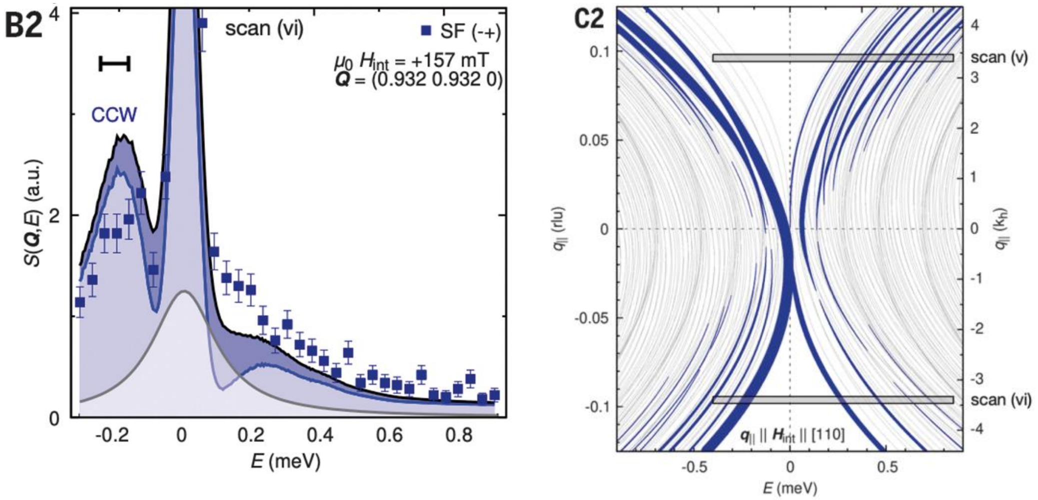


BIFROST goal: One example



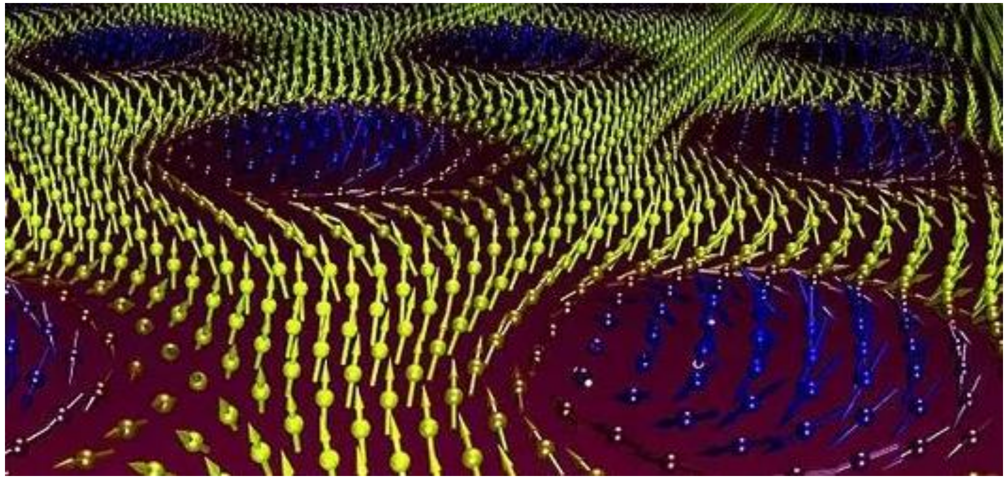


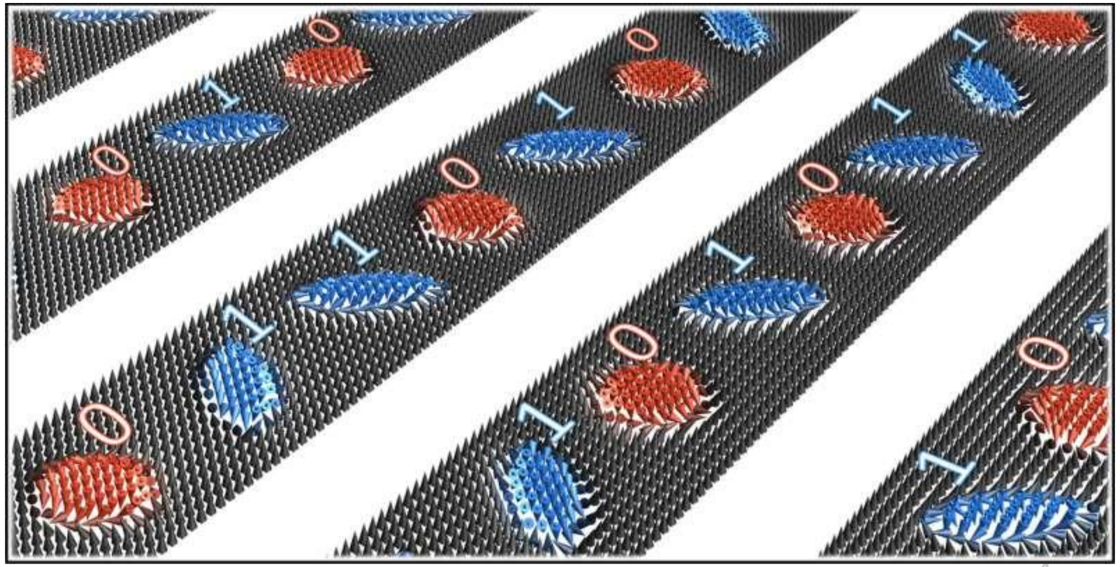
T. Weber, et. al, Science, 375, 2022

Topological magnon band structure of emergent Landau levels in a skyrmion lattice

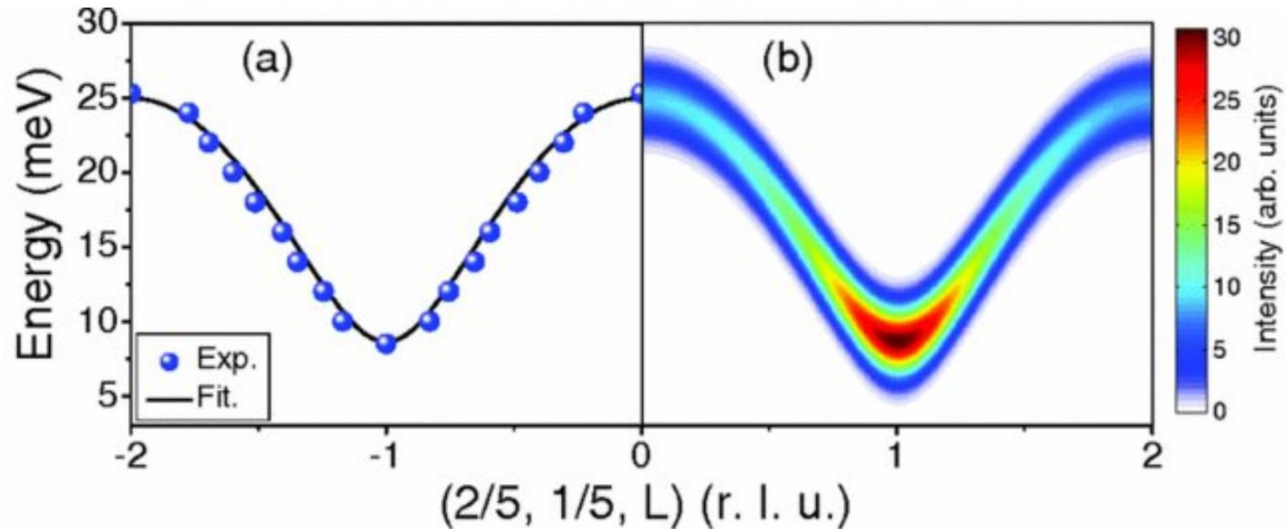
Resolution

- Resolution is often sacrificed for flux – we need the details!

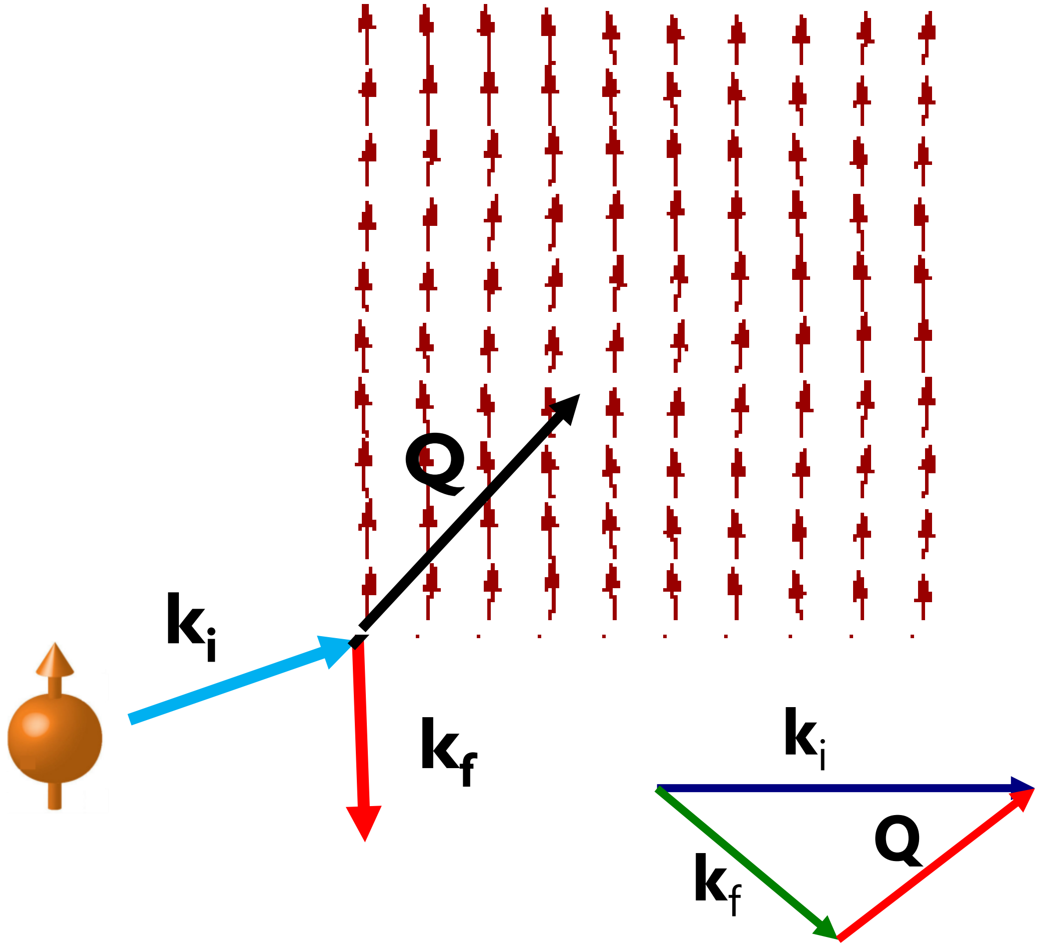




BIFROST goal: Measure propagating excitation of magnetic structures



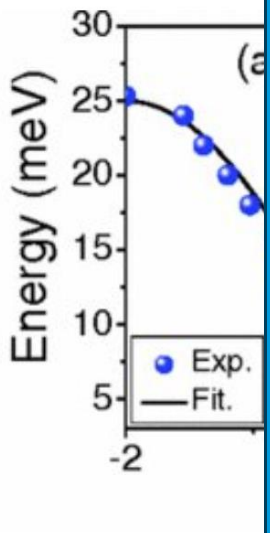
Pertubation of magnetic order behaves like a quasiparticle, that can be created and annihilated by neutrons



We can directly measure the excitation spectrum, and understand the interactions responsibe for the magnetic ground state

Incident neutron -> primary spectrometer
Scatter

BIFROST goal: Measure propagating excitation of magnetic structures



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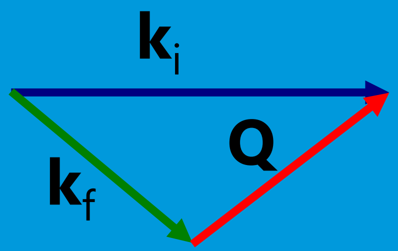
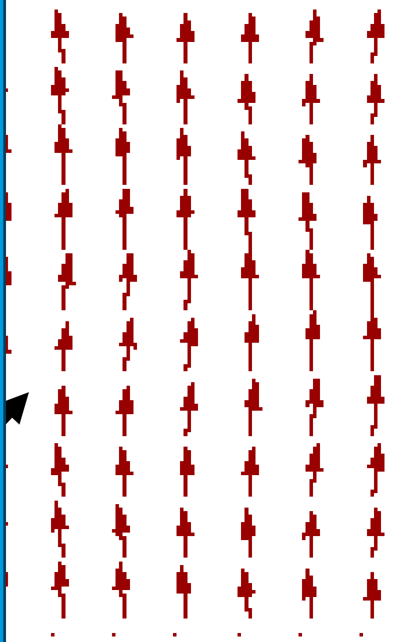


For every detected neutron, **we need to know the energies of the incident and scattered neutrons, as well as the scattering angle**

With spectroscopy, you cannot directly measure both the incident and scattered energies, you need to fix one and measure the other. On BIFROST we 'fix' the scattered neutron energy, and measure the incident neutron energy *indirectly*.

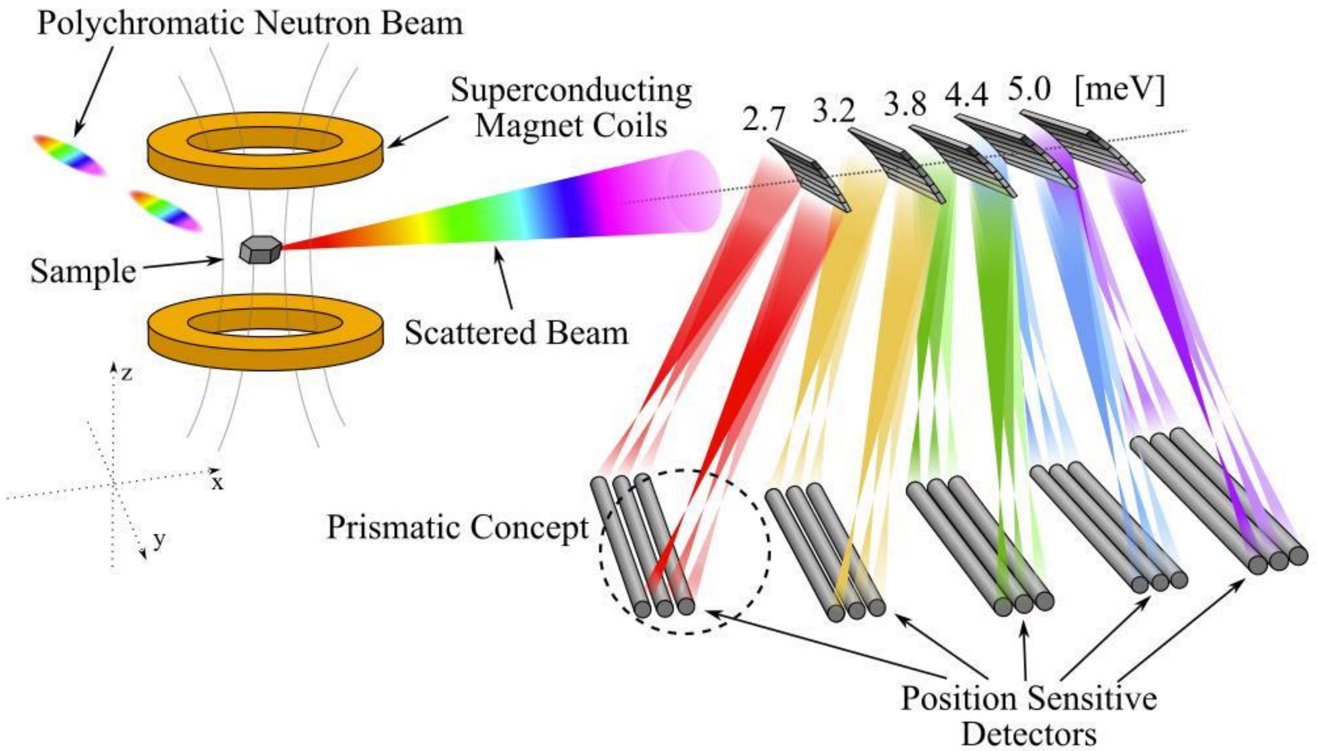


BIFROST: Methodology in time and space

Physical premise 1: The analysers reflect a known neutron energy to the detector

Physical premise 2: We know all flight paths before and after the sample

This is ensured by the design



Methodology:

- You record a neutron detection event at detector Y, position X at time t
- Coordinates X and Y gives you the scattering angle (if you know the tank position!)
- Since you know the scattered energy (velocity) and the flight path, *we calculate the scattering time.*
- Knowing the scattering time, *we can calculate the incident velocity of neutron and hence its energy*
- ***The uncertainty of the flight time determines how well we can determine this velocity***

BIFROST: Primary spectrometer

ID	Requirement	Couples to:	
13.6.14.r1	Using the full ESS pulse in the coarsest resolution mode, the primary spectrometer of Bifrost shall have an energy resolution $dE/E_i < 0.05$ at $E_i = 5$ meV	*Instrument length* *PSC chopper speed*	
13.6.14.r2	Bifrost shall have a tuneable energy resolution down to 0.03 meV in the finest resolution mode at $E_f = 2.7$ meV, as measured by FWHM of the elastic line	*Instrument length* *PSC chopper speed*	
13.6.14.r3	Bifrost should be able to employ an incoming bandwidth of 1.7 Å taking up the full-time interval between pulses at the sample position, having constant energy resolution within the frame and no frame overlap	*Instrument length* *PSC position* *FOC choppers* *BW chopper*	
13.6.14.r4	For an incoming wavelength band 2.5-4 Å, Bifrost shall have a neutron flux larger than 10^{10} n/s/cm^2 in coarse resolution mode, and 10^8 n/s/cm^2 in the finest resolution mode – at 5 MW	*Guide system*	
13.6.14.r5	Bifrost shall allow cold spectroscopy studies on samples smaller than 1 mm^3 and up to 20x20x20 mm^3.	*Guide system*	
13.6.14.r6	At an incoming wavelength 1.2 Å, Bifrost shall have a neutron flux larger than 5 % of the flux at an incoming wavelength of 3 Å	*Guide system*	

BIFROST: Secondary

ID	Requirement	Couples to:	
13.6.14.r7	Bifrost shall be able to measure at least 5 scattered energies from the sample in a single setting	*Analyser system*	
13.6.14.r8	Bifrost should fully cover a 90-degree scattering angle interval for all analyzer energies in two settings, and be able to reach scattering angles between 15-135 degrees	*Analyser and tank motion*	
13.6.14.r9	Bifrost shall have an angular resolution in the horizontal plane down to 0.7 degrees (FWHM)	*HOPG crystals (graphite)*	
13.6.14.r10	Bifrost shall be able to accommodate a vertical (horizontal) magnetic field of 15 T (10T) at the sample position and be easily upgradable to 35 T vertical field and 20 T horizontal field – allowing for a 0.9m diameter cryomagnet at the sample position.	*Non-magnetic surroundings*	
13.6.14.r11	Bifrost shall have an inelastic background of less than 30 cts/min on a single detector array belonging to a single analyser, as measured using the full ESS pulse and the 2.1-3.8 Å wavelength band on an empty ILL orange cryostat, using both radial collimation and Be-filtering.	*Detector system* *All background shielding* *Concrete cave* *Firmware* *event formation unit*	
13.6.14.r12	The detector ensemble belonging to any analyser shall not be able to detect scattering from any of the adjacent analysers (assuming 4 pi scattering off the analysers)	*Cross talk shielding*	

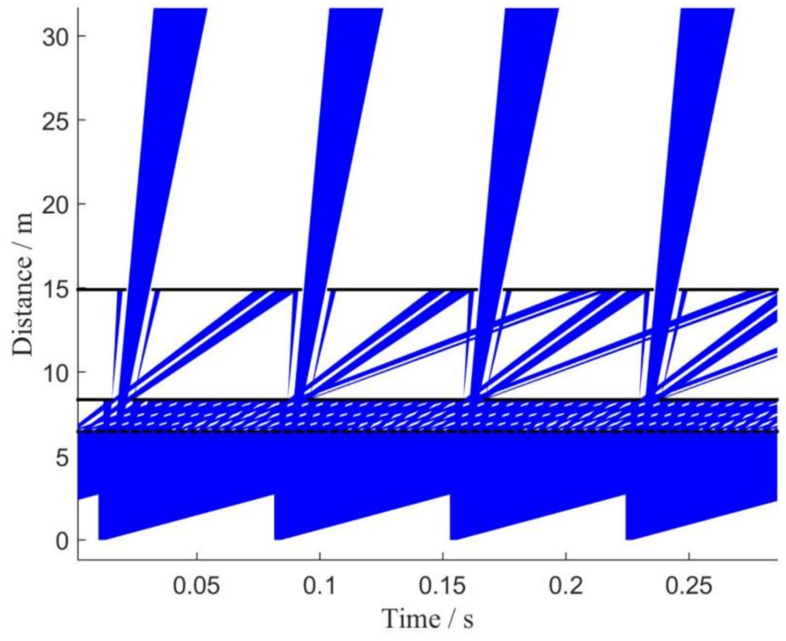
BIFROST: Upgrades and operations

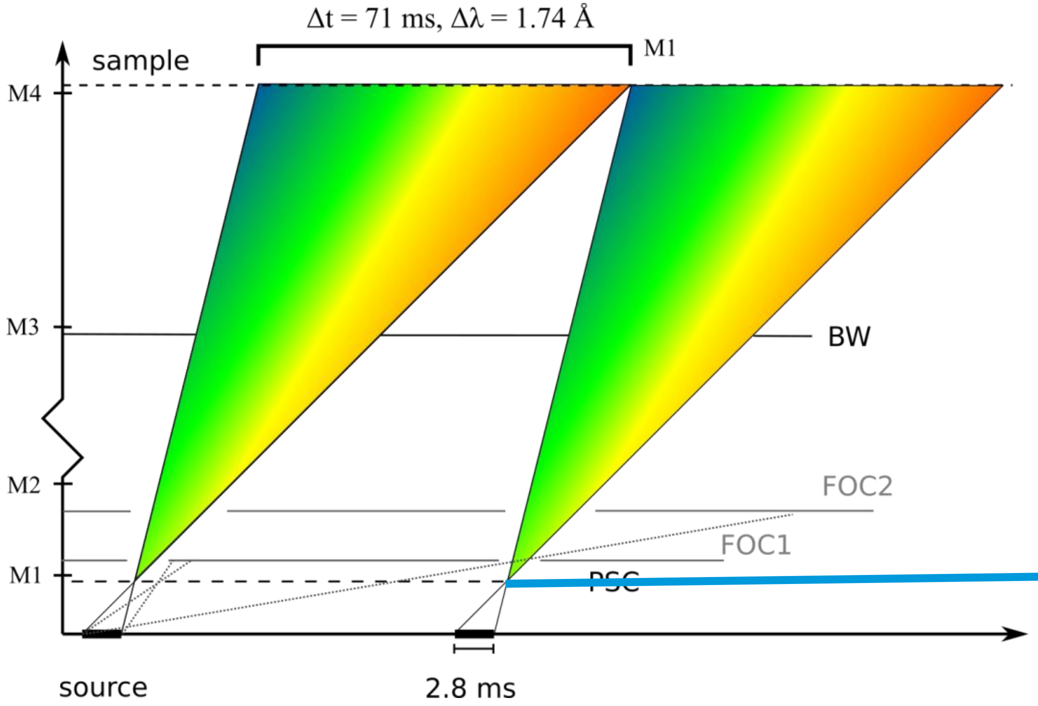
ID	Requirement	Couples to:	
13.6.14.r13	Bifrost shall be upgradable to allow polarization and flipping of the incident white beam	*Nonmagnetic environment* *Guide system*	
13.6.14.r14	Bifrost shall allow a two-stage upgrade path for polarization analysis, using a He-3 filter in stage 1 and either Heusler analysers or wide-angle supermirrors in stage 2.	*Analyser design* *guide design* *filter design*	
13.6.14.r15	Bifrost shall generally be designed to accommodate all types of sample environment equipment needed to meet the science case	*Sample exposure system* *non magnetic environment*	
13.6.14.r16	Bifrost shall be upgradable to allow using the HOPG(004) reflections for energy transfer analysis	*Non-magnetic surroundings*	
13.6.14.r17	Bifrost should serve the user and science and instrumental development program without interruptions during source operation.	*Hot commissiniong* *Facility operation* *Mature tech*	
13.6.14.r18	Bifrost shall allow a safe operation for both users and bystanders	*Radaition shielding* *motion safety* *IHA*	

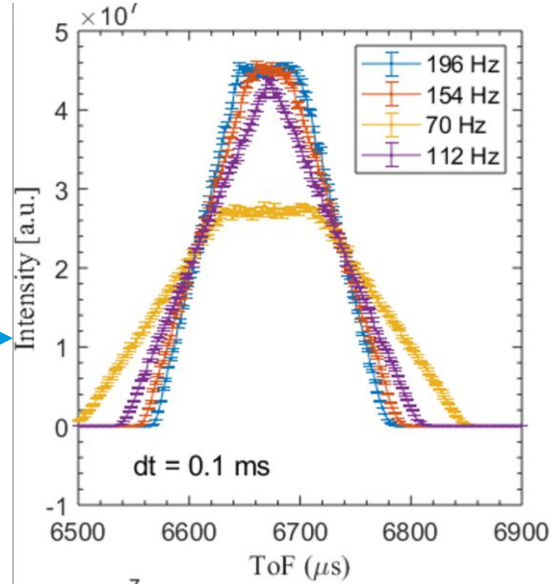
BIFROST: ToF front end – why we need the PSC

<u>Polychromatic beam:</u>

- High incident flux
- Energy resolution of primary spectrometer highly tunable via fast Pulse Shaping Chopper (PSC)







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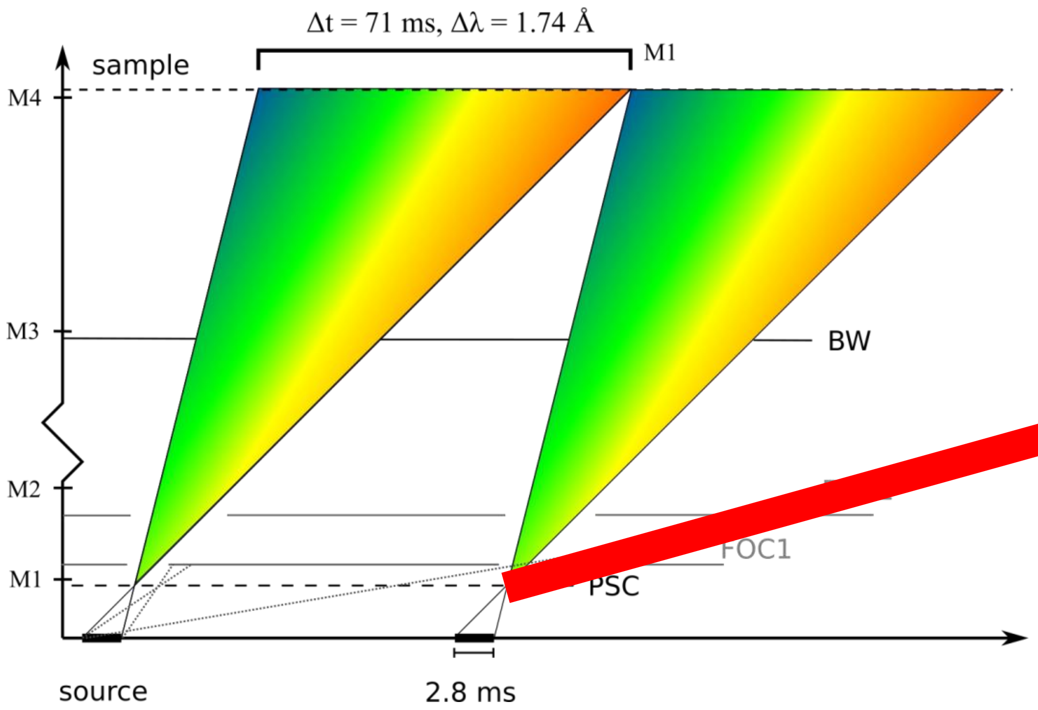

BIFROST: ToF front end – why we need the PSC

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- High incident flux
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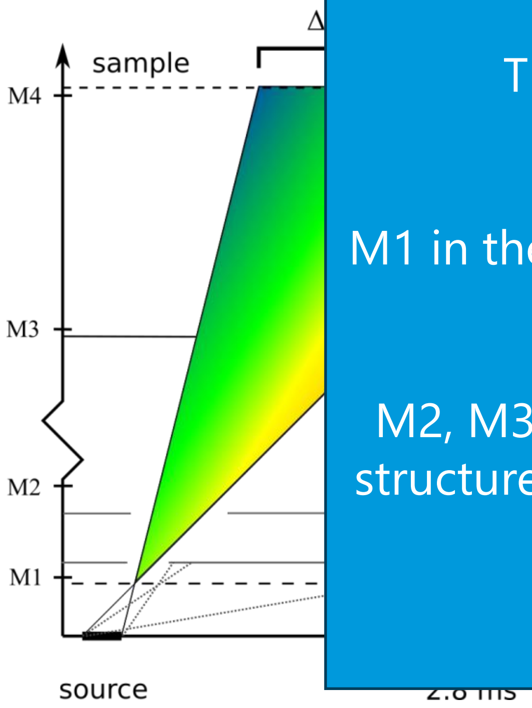
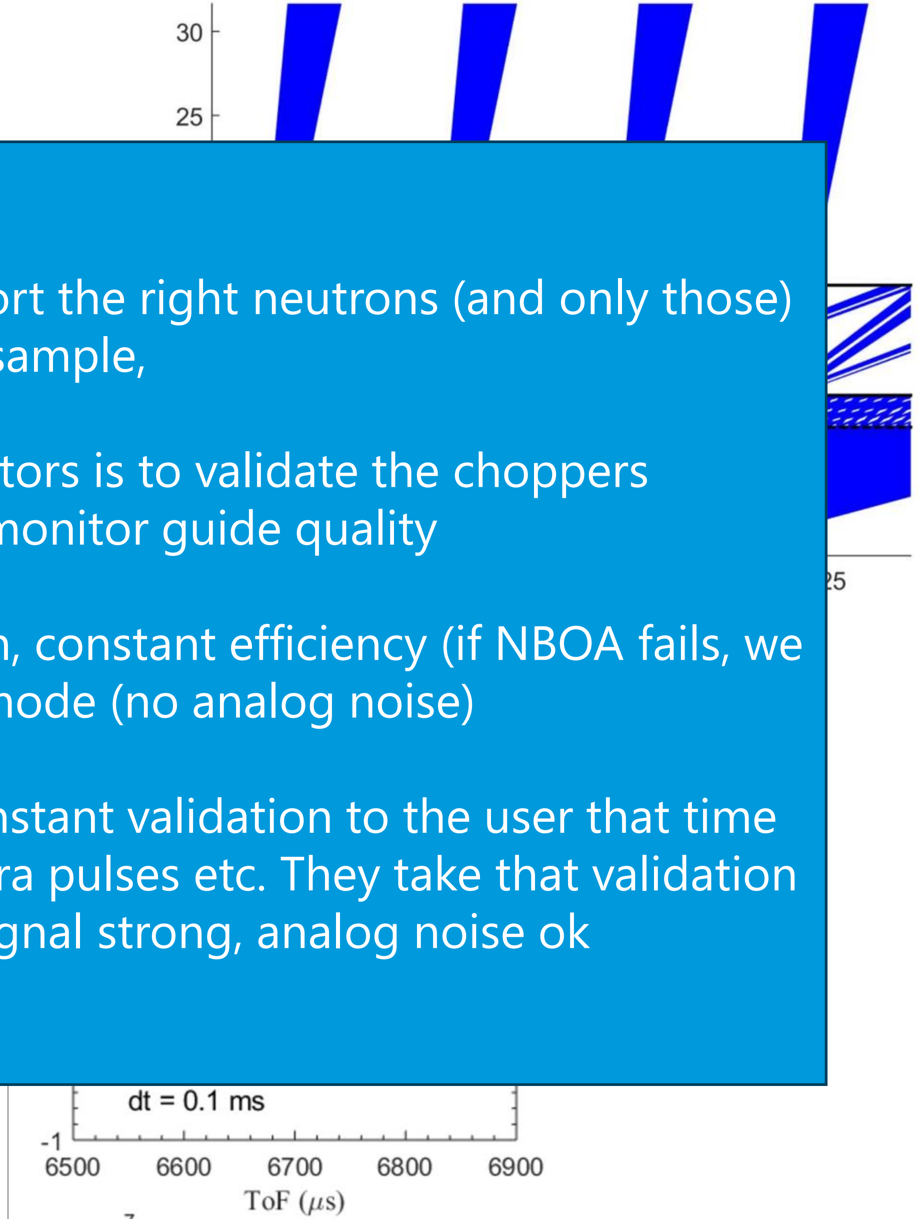


The purpose of the guide is to transport the right neutrons (and only those) to the sample,

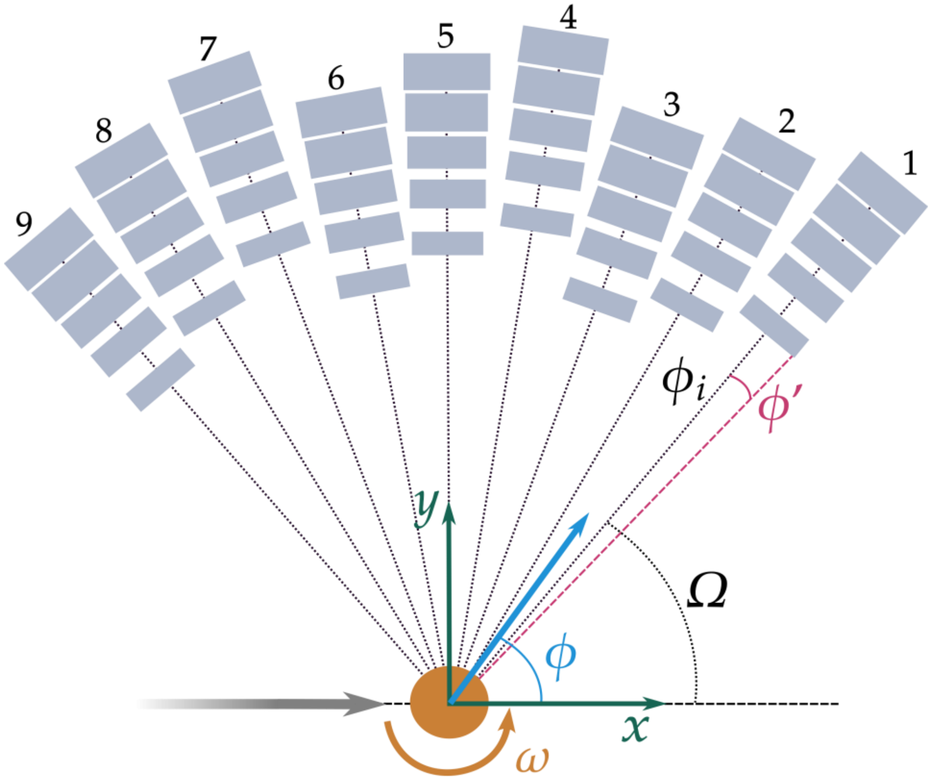
The purpose of the first 3 monitors is to validate the choppers experimentally, and monitor guide quality

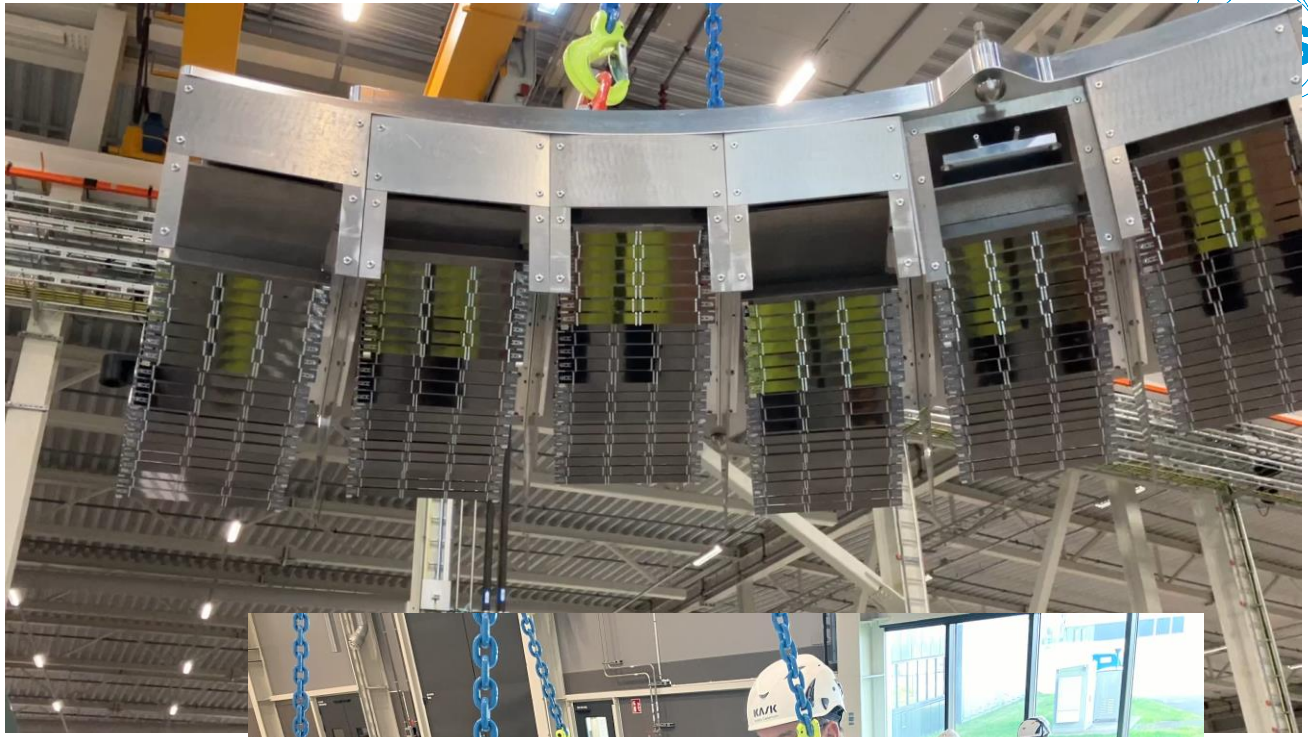
M1 in the bunker: Handle the radiation, constant efficiency (if NBOA fails, we need to know). Event mode (no analog noise)

M2, M3: Not attenuate the beam, constant validation to the user that time structure is kosher, they dont have extra pulses etc. They take that validation with them in the data file. Signal strong, analog noise ok



BIFROST: Analysers and angles





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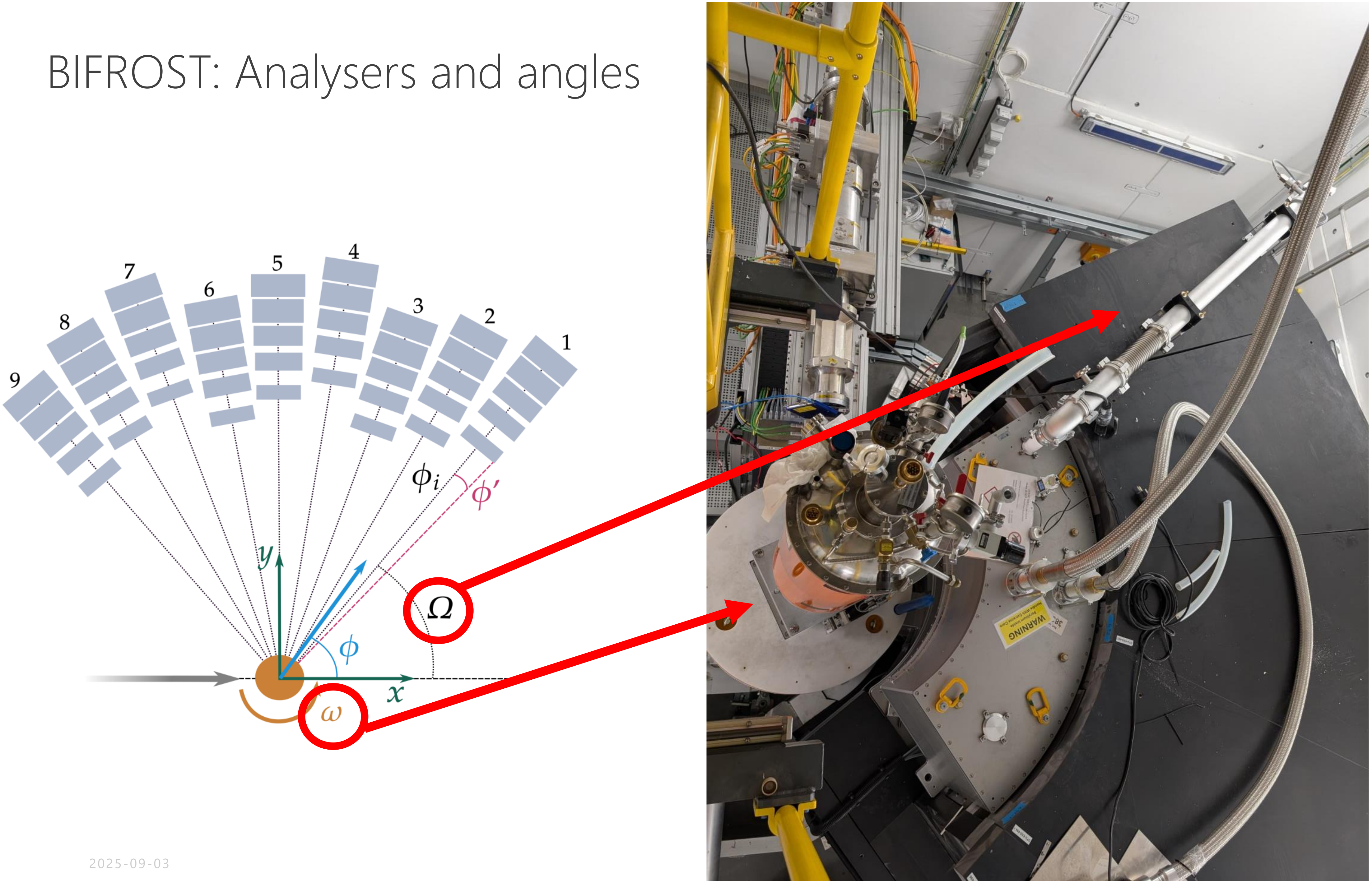
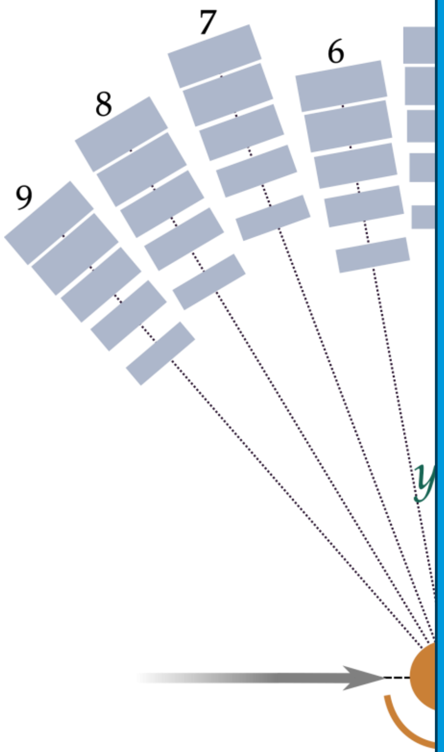
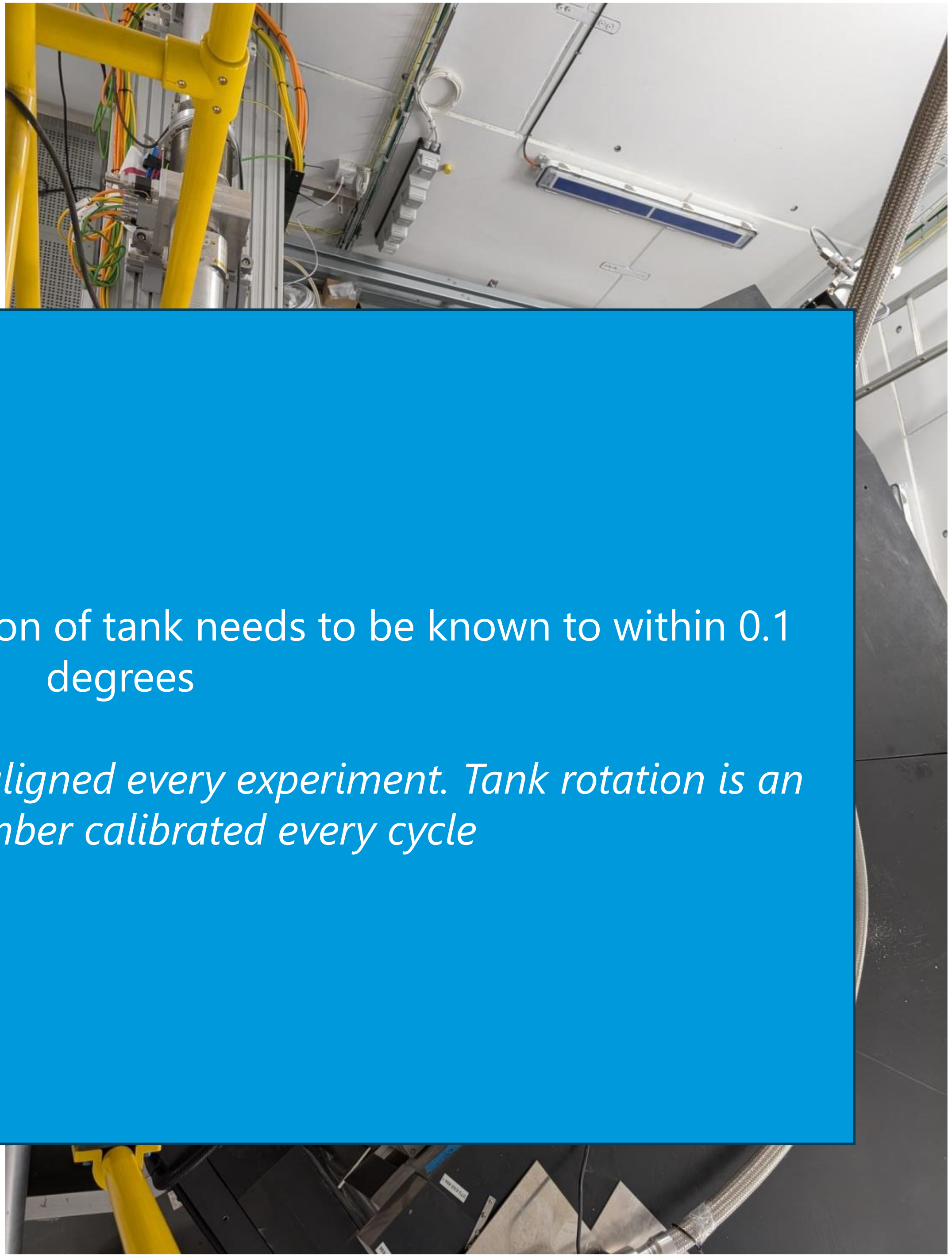


BIFROST: End of the guide

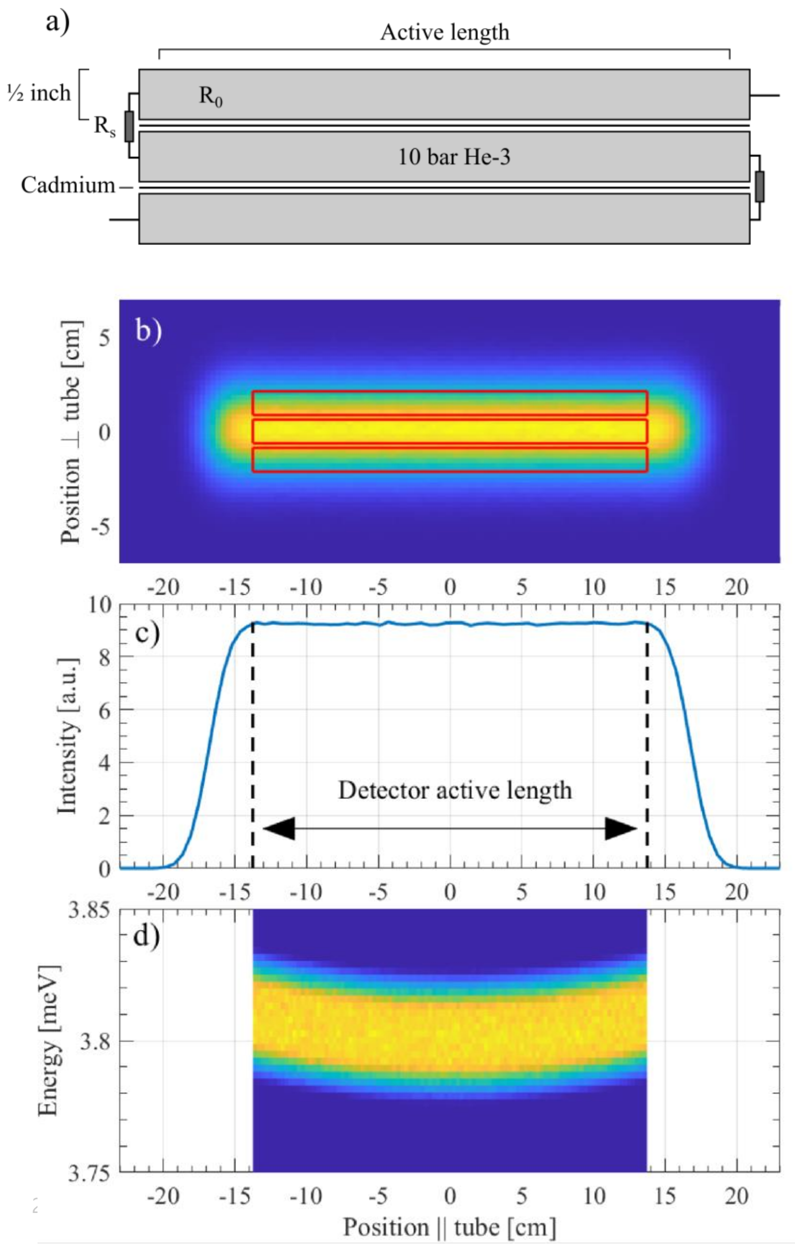


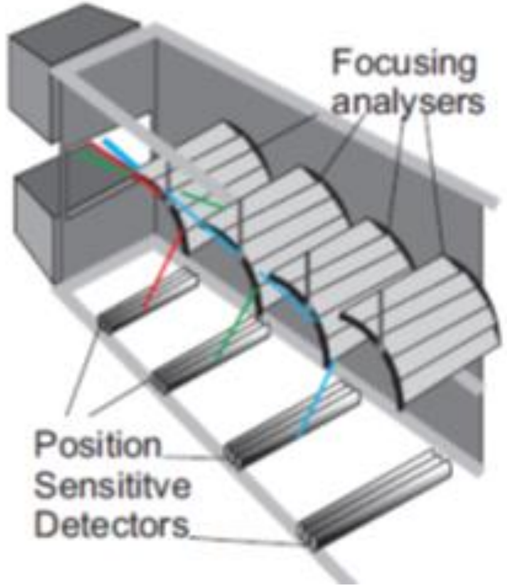


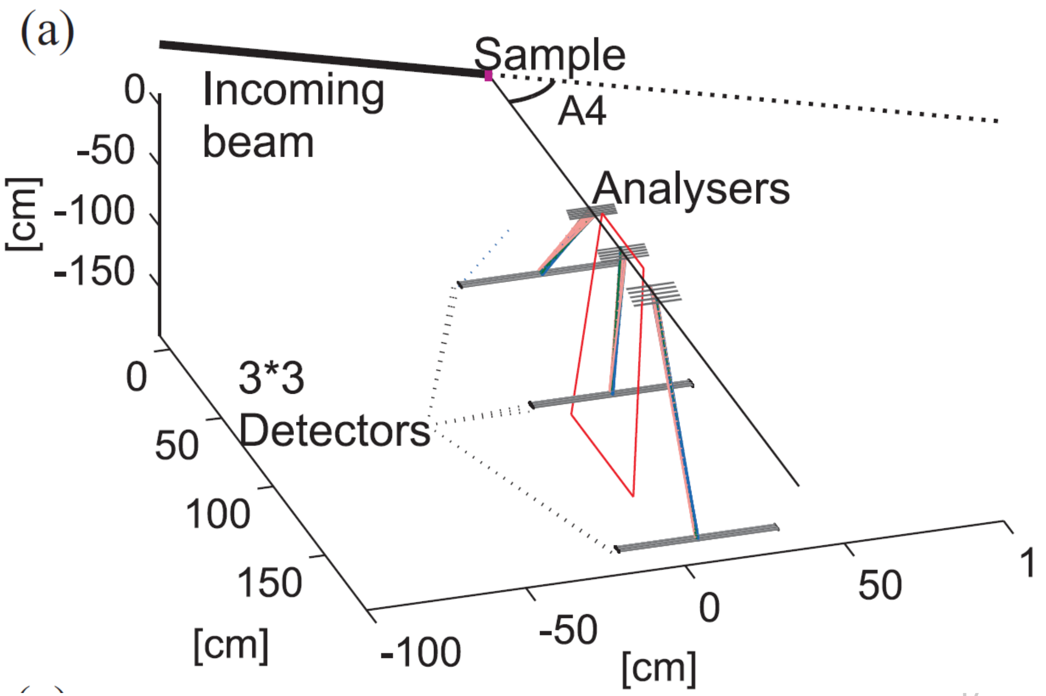
Rotation of sample and rotation of tank needs to be known to within 0.1 degrees

Sample rotation is calibrated/aligned every experiment. Tank rotation is an absolute number calibrated every cycle

Backend principle of BIFROST – reality







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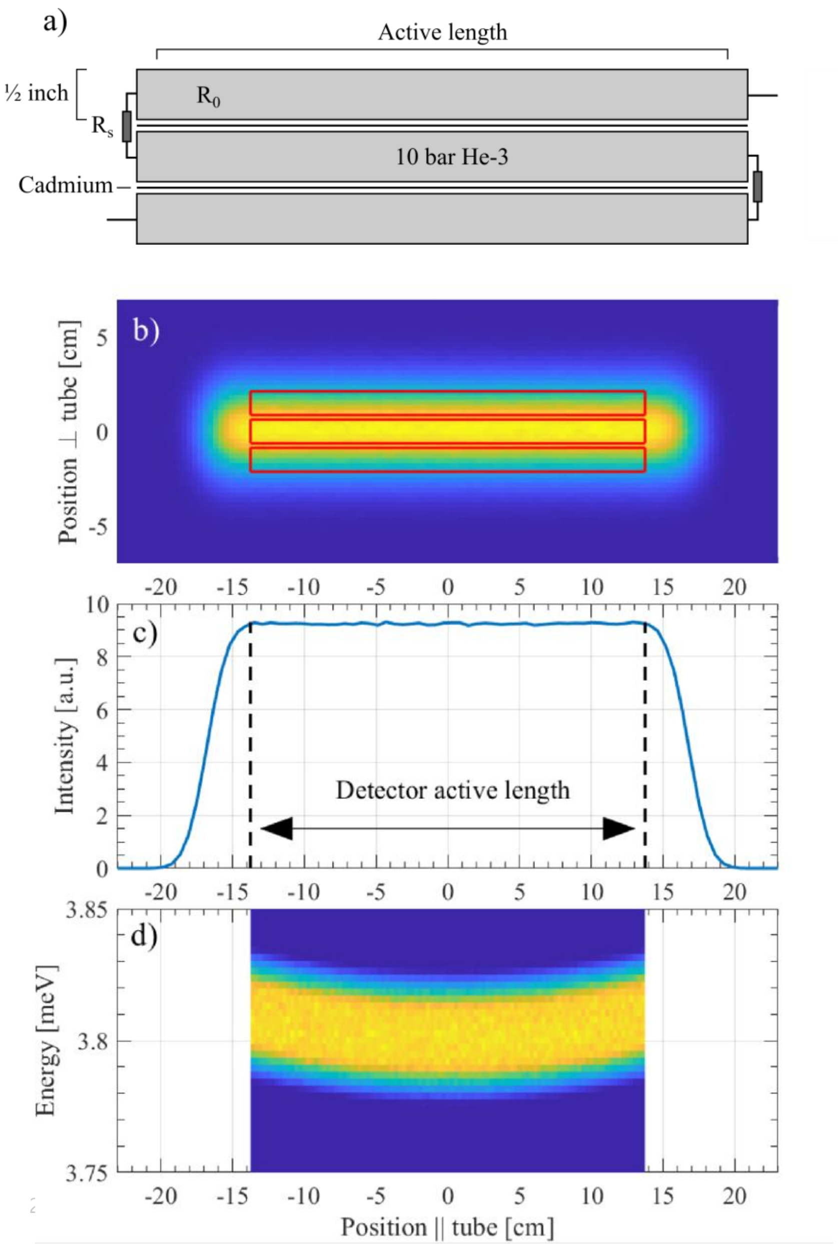

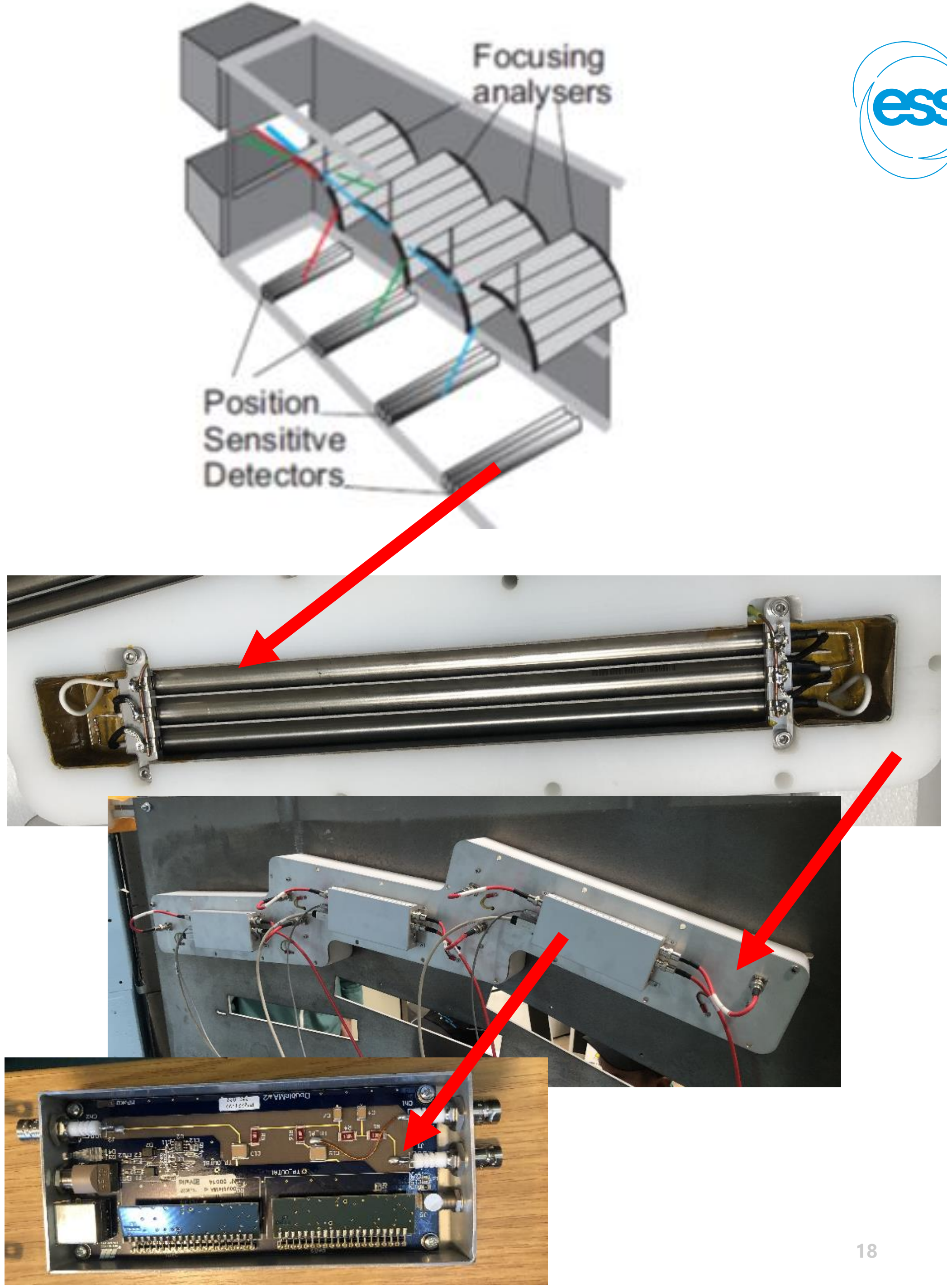

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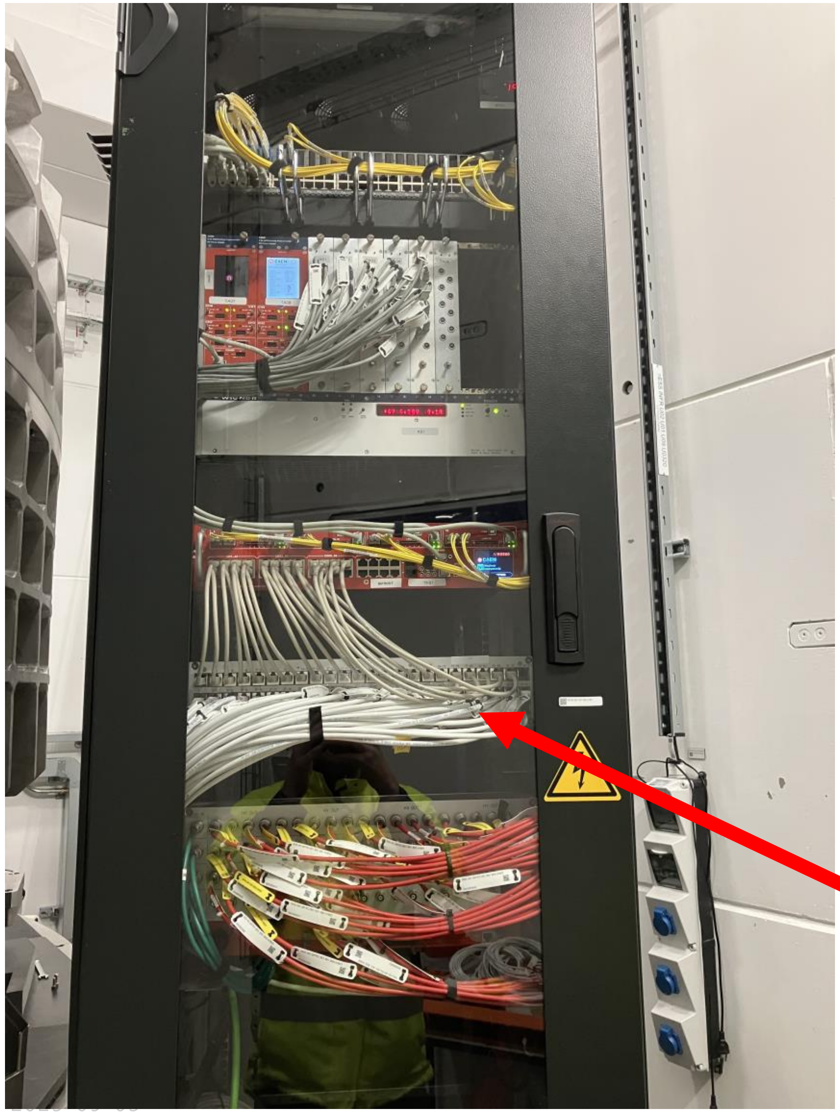

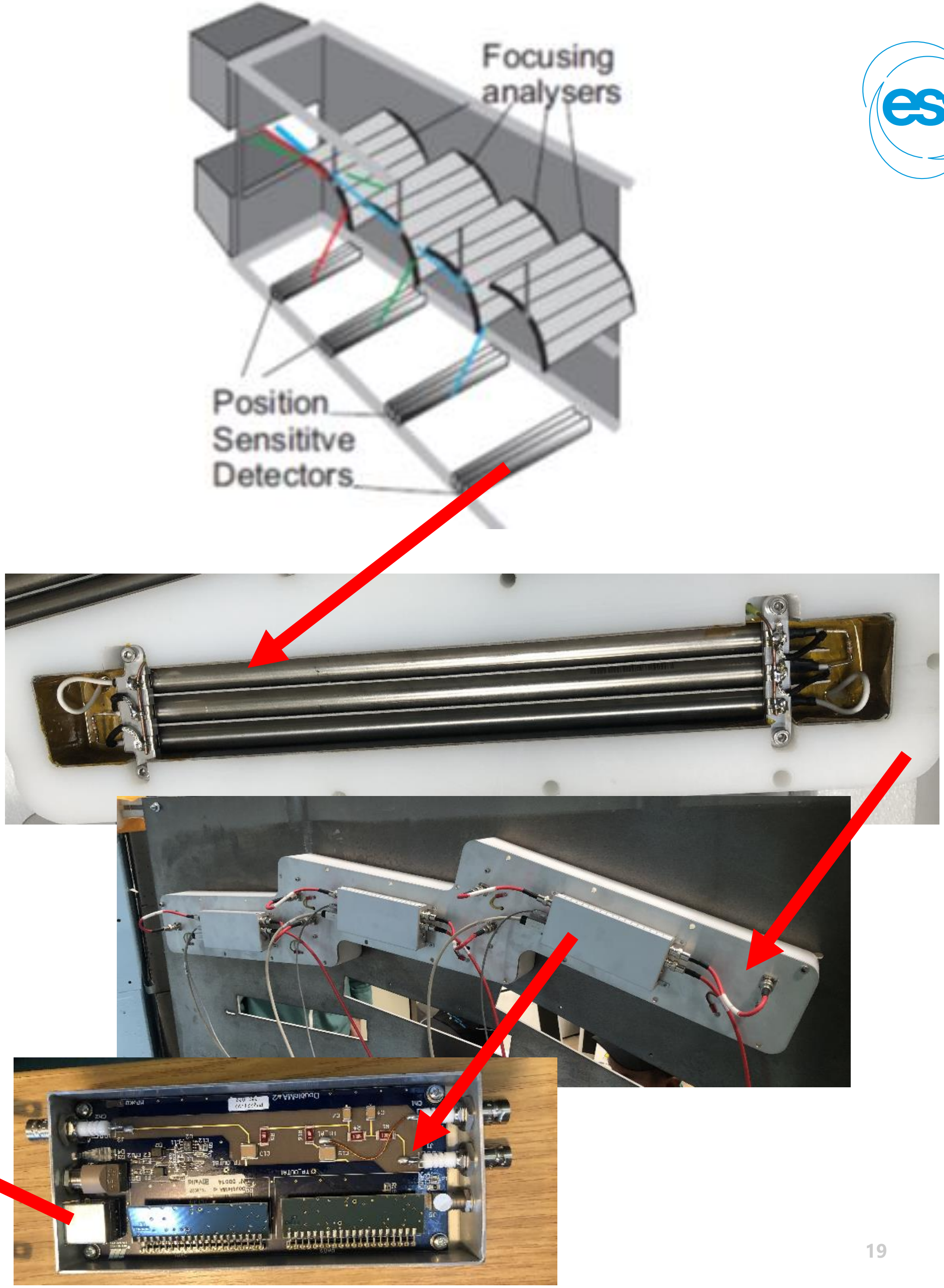

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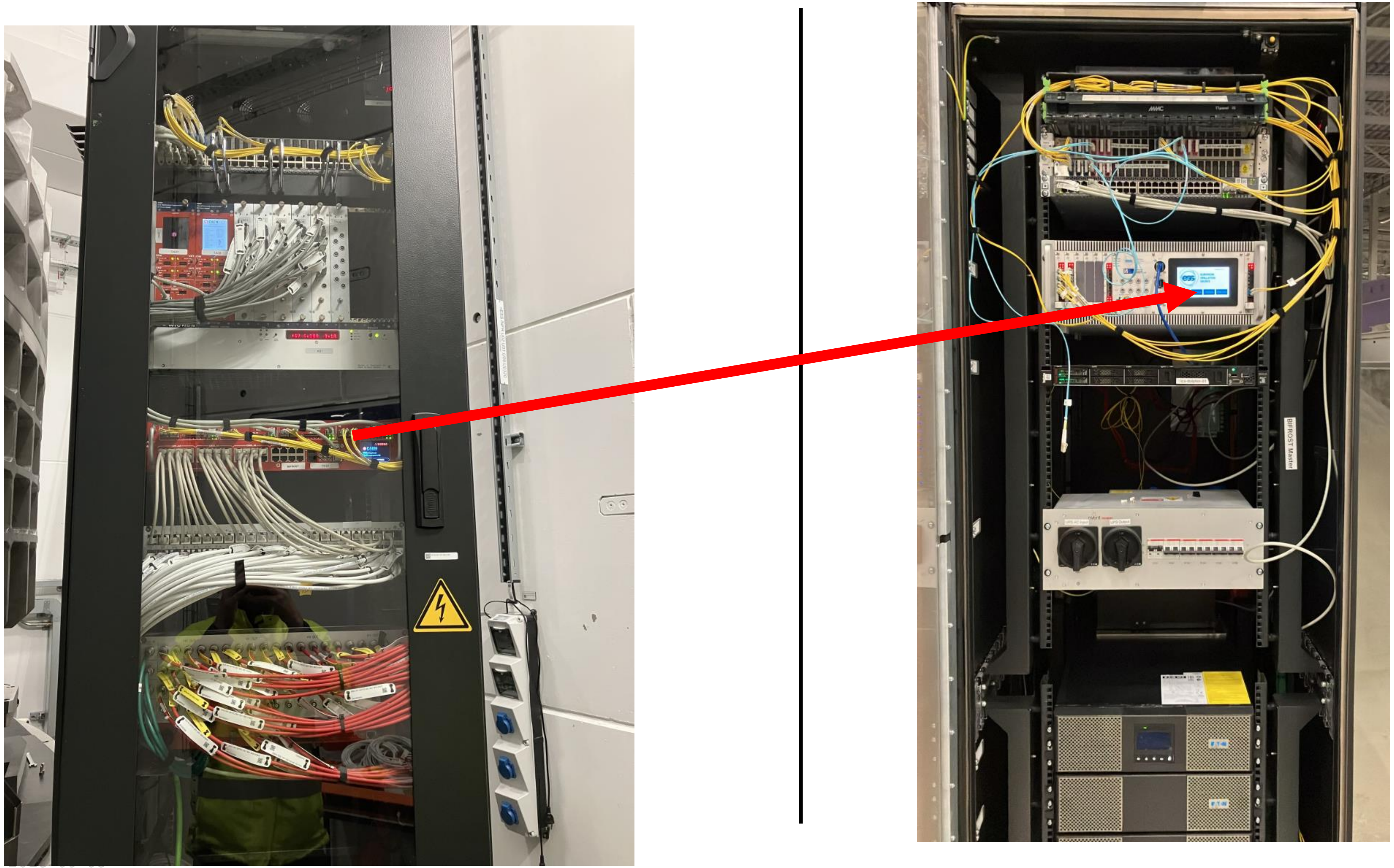

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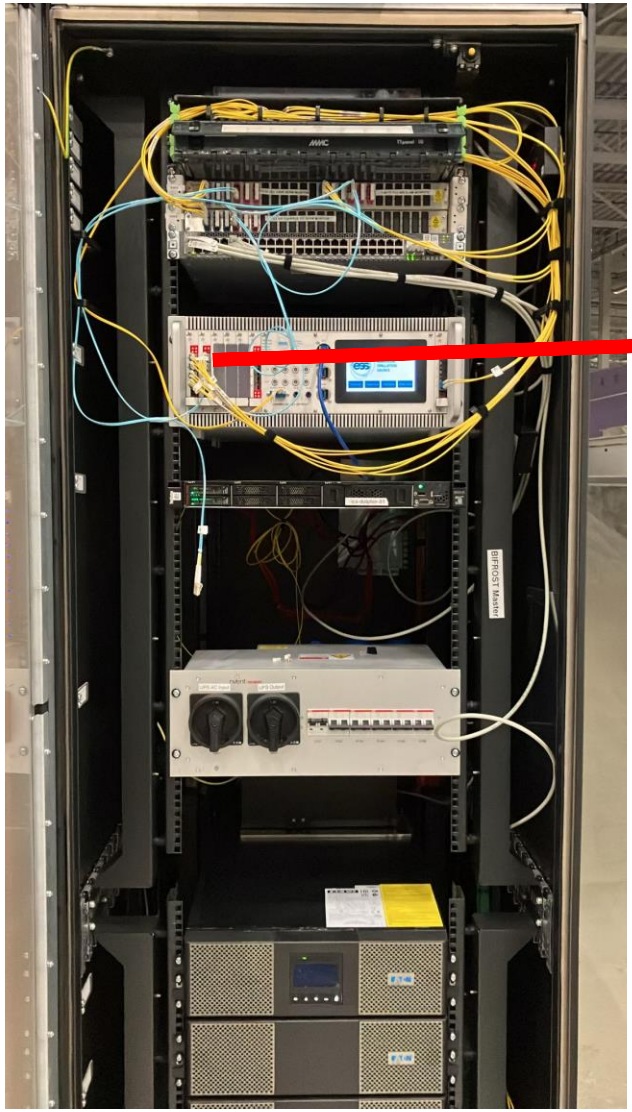

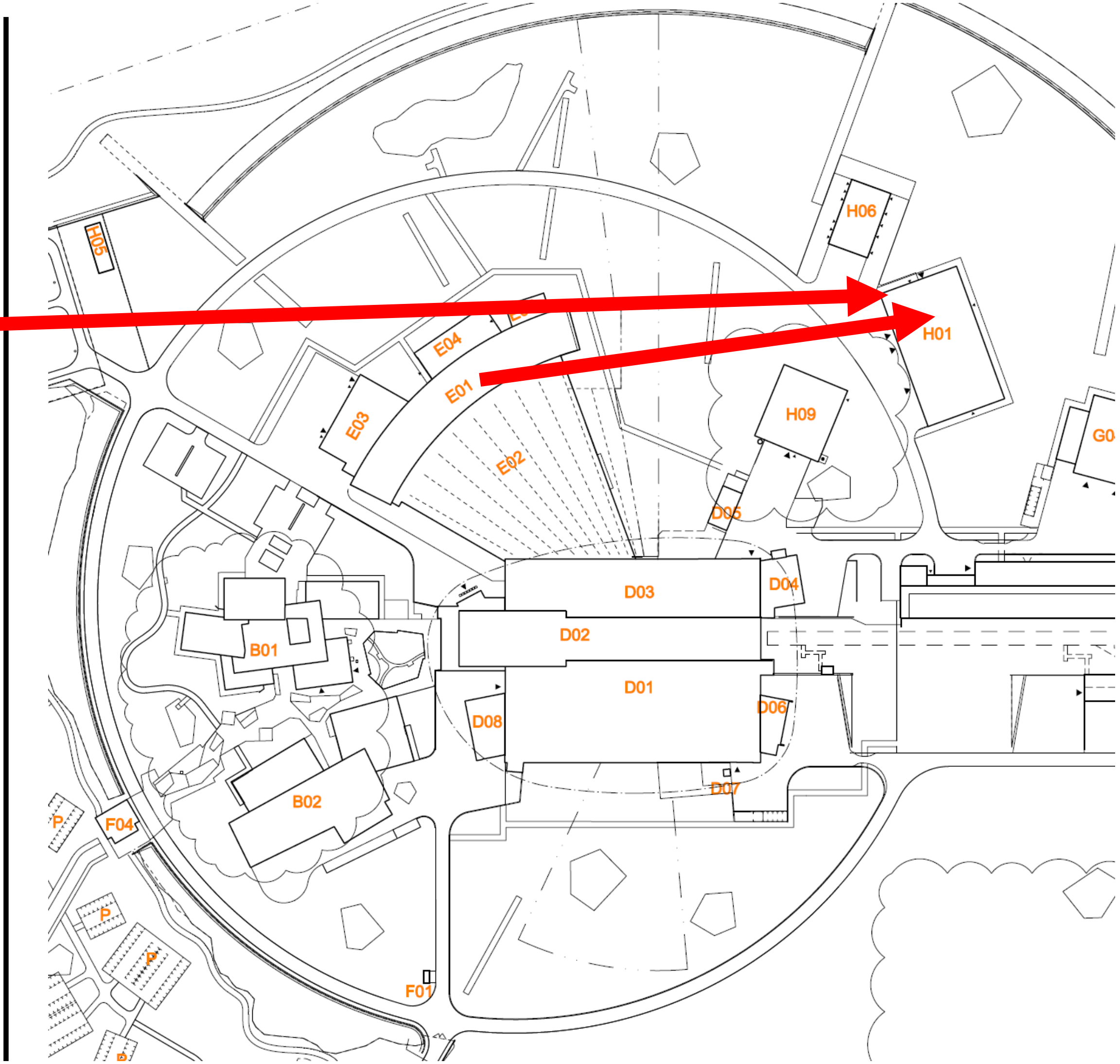

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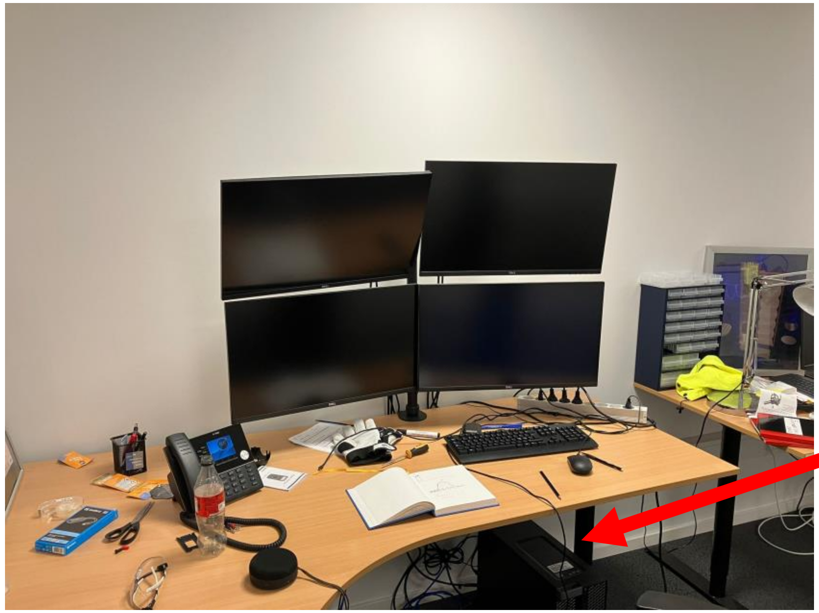


Expansion of detector requirements

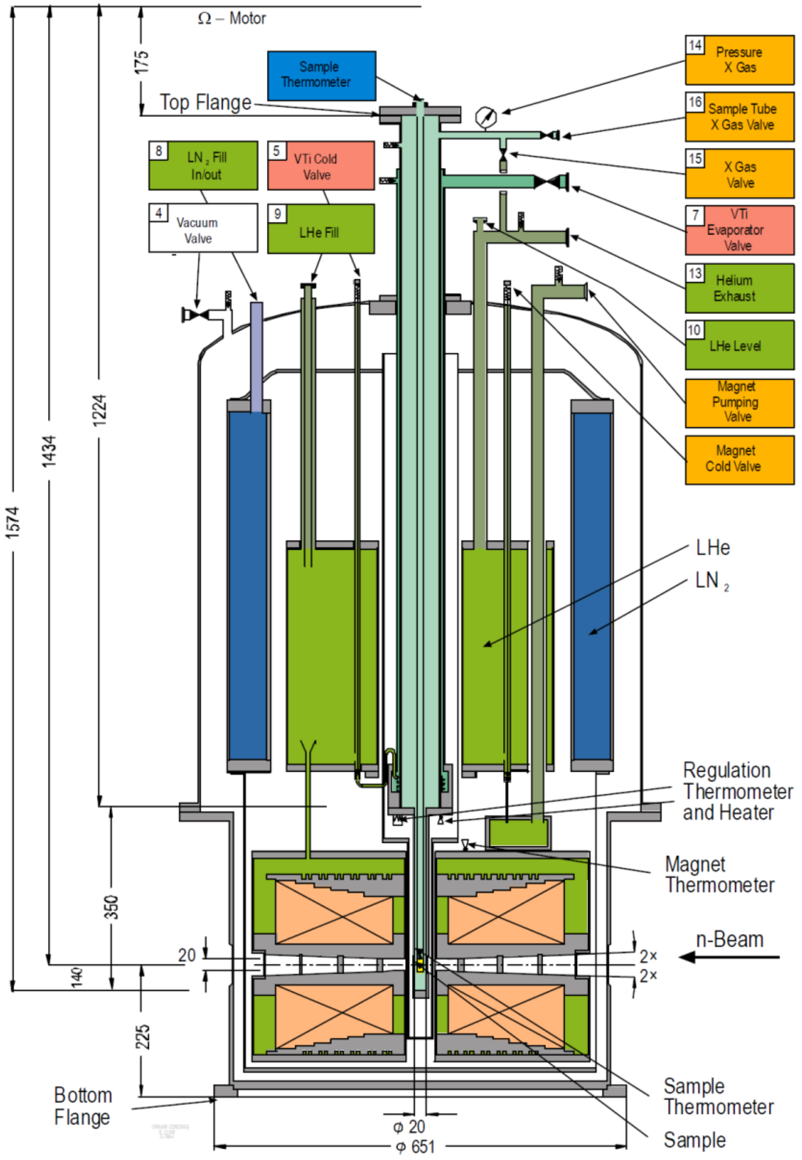
<u>Detector notes:</u>

- The nuclear process involved in neutron detection releases tiny amounts of charge, in the range of pico-Coulomb
- Noise and grounding are persistent challenges for any system
- Our standard signals are a few neutron counts pr second. The challenging ones, a few pr minute. **The system needs to be quiet**
- We built the ESS to increase the signal strength (flux/brilliance are just means to do this)
- Noise is almost just as important.

Sample environment

Sample environment

- Superconducting coils. Helium cools sample & magnet coils
- Magnetize surroundings why BIFROST is built of non-magnetic materials
- User and instrument scientist needs to constantly monitor temperature, cryogen levels needle valve



Thanks for your attention

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PAUL SCHERRER INSTITUT PSI

IFE Institute for Energy Technology

Sample environment