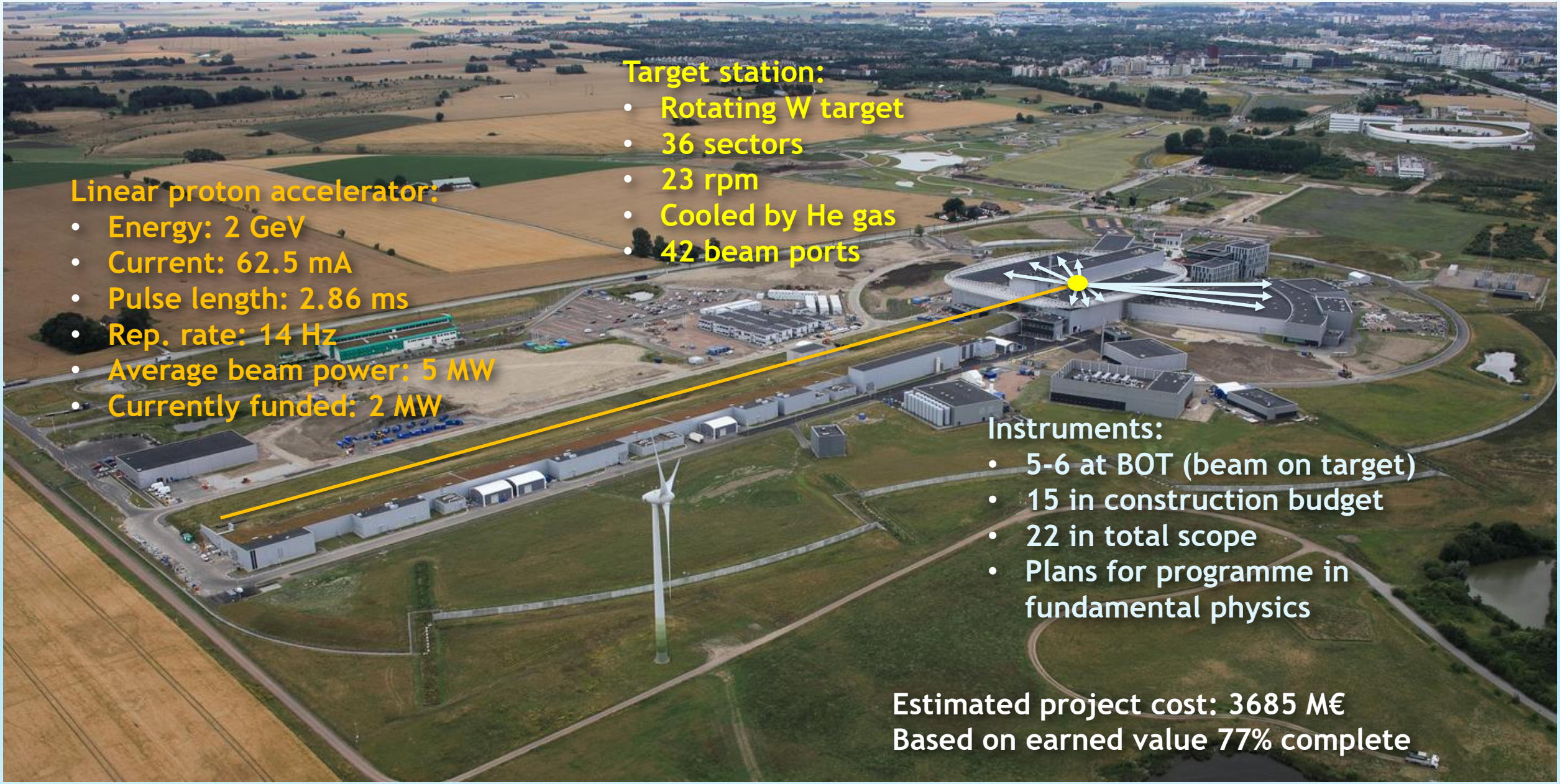
Neutron Scattering @ ESS

(selected topics)

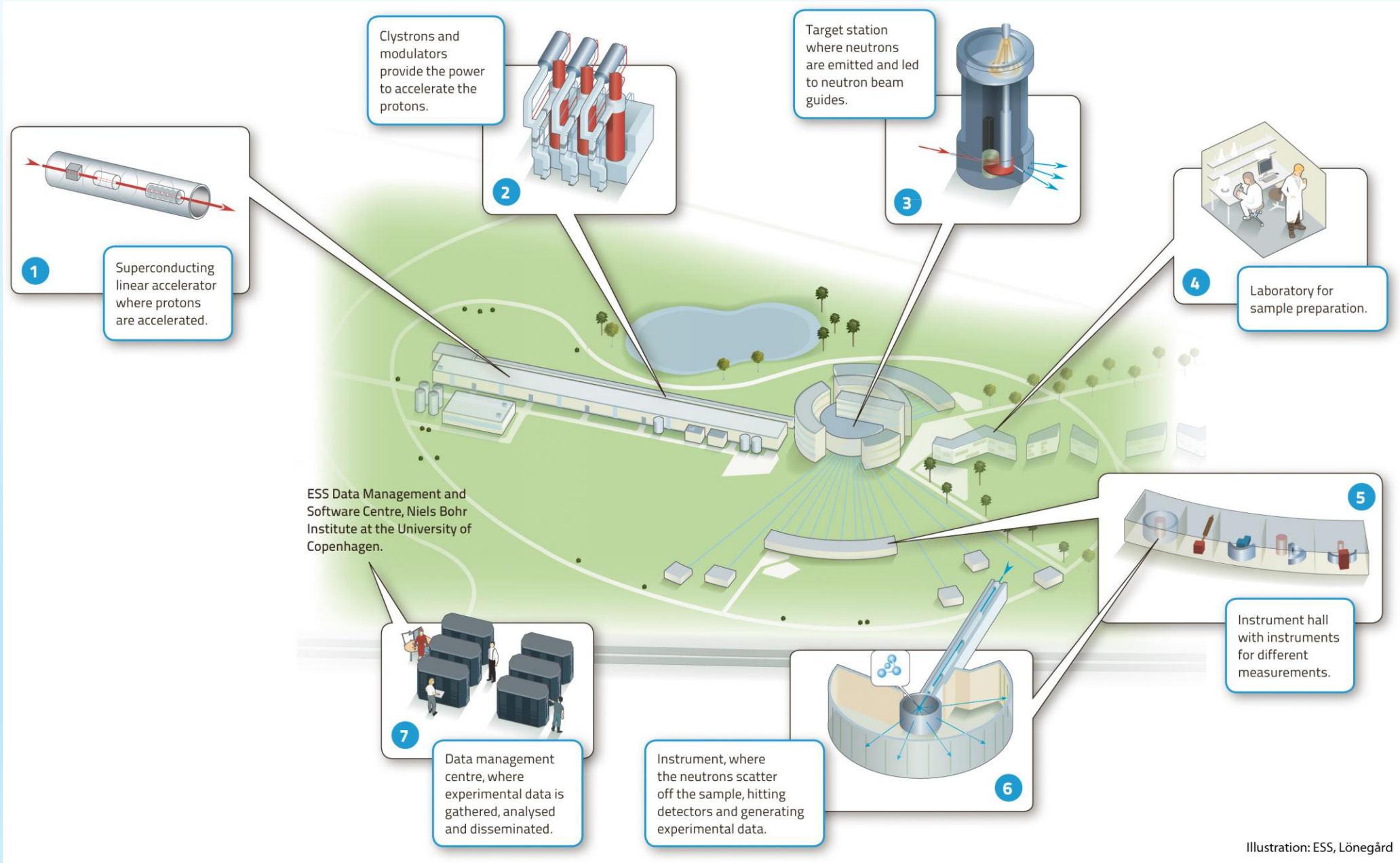
Wojciech Zając

ESS – sept. 2020

World's brightest pulsed neutron source, one of the biggest and most advanced research infrastructures.
ERIC since 2015

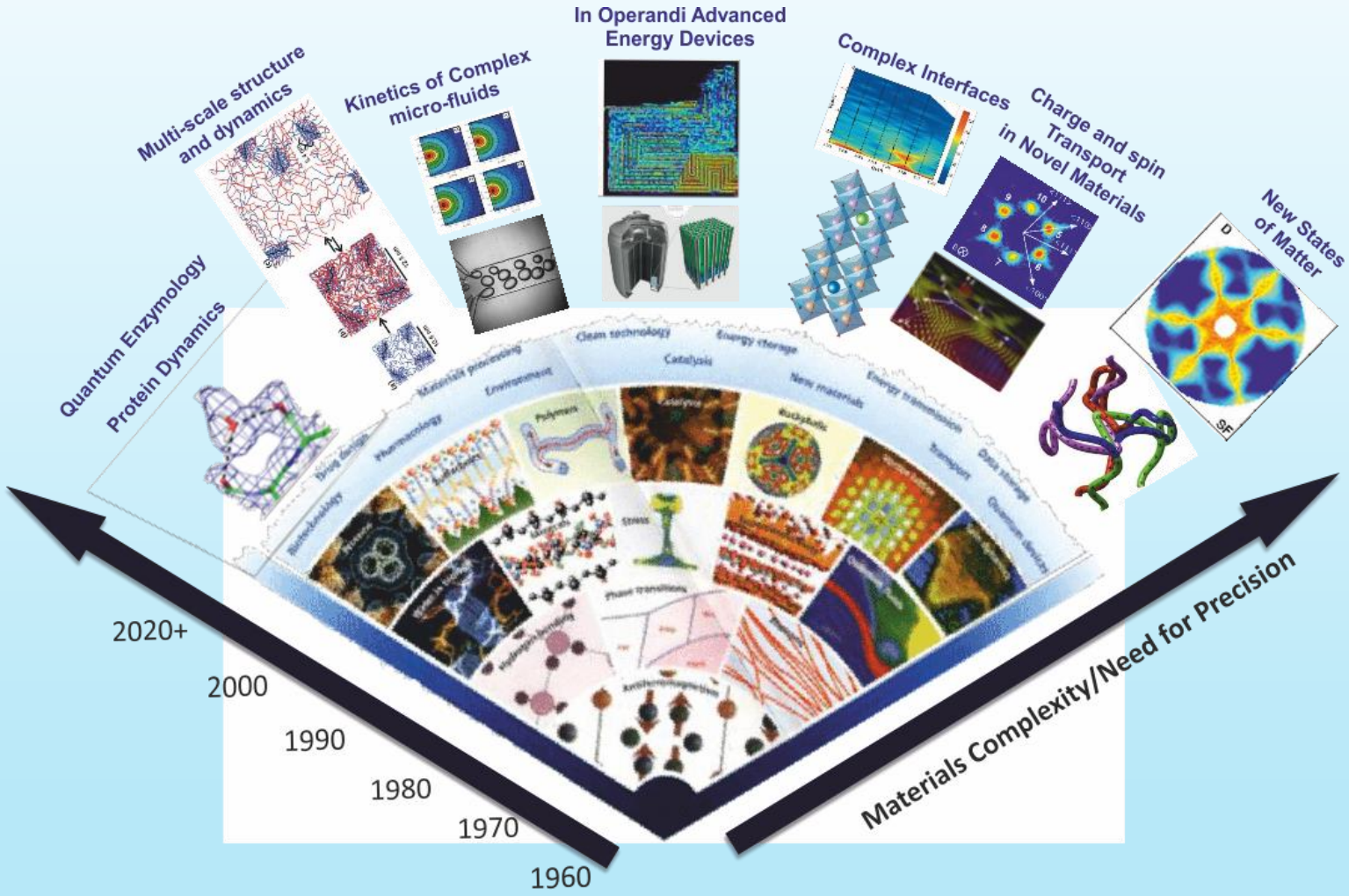


ESS – schematic site layout



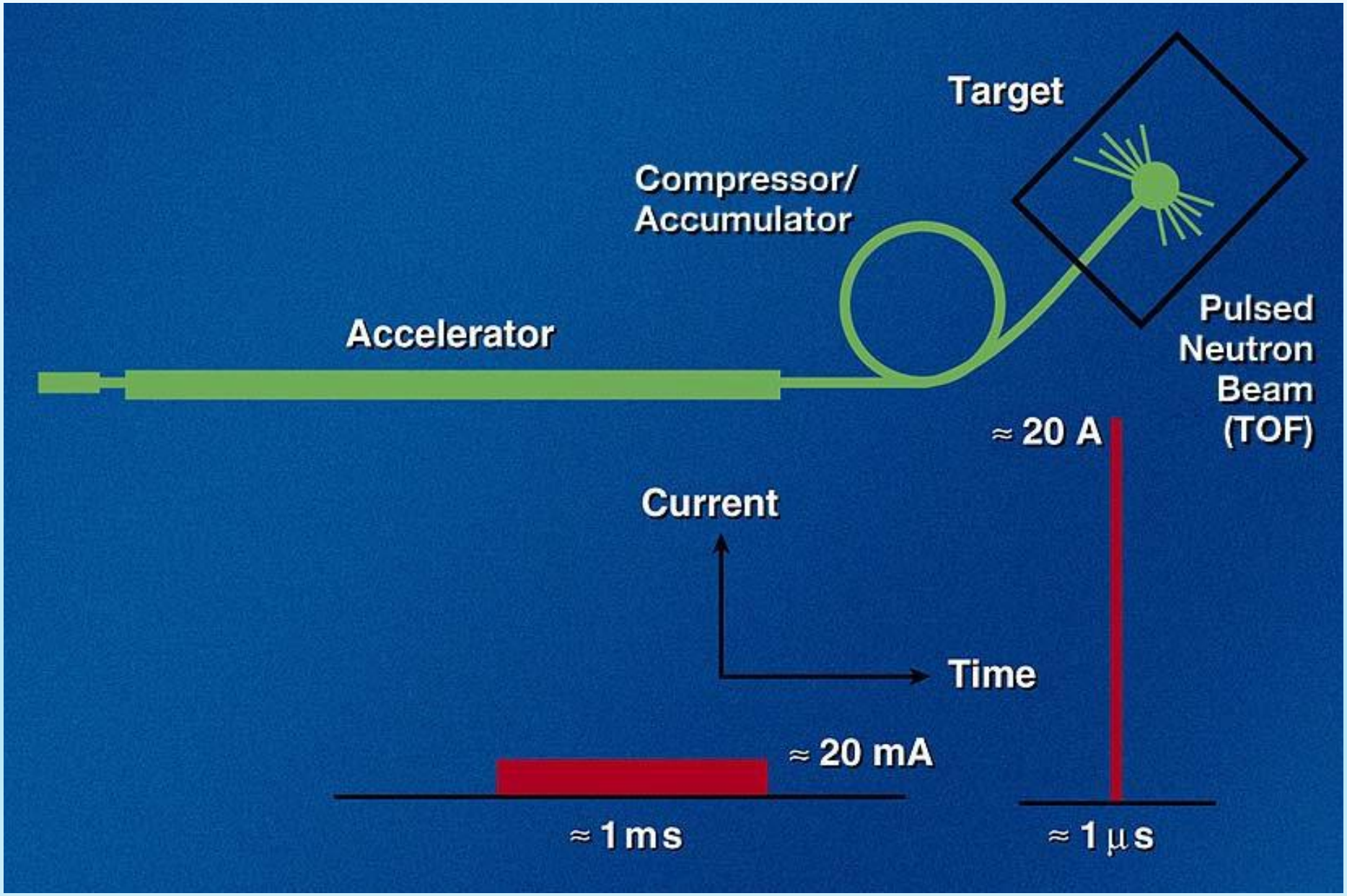
ESS designed to meet the present and future research needs in:

- Physics
- Chemistry
- Materials sciences
- Engineering of modern machinery
- Energy production and storage
- Environmental sciences
- Life and health sciences



Poland contributes 1.8% of the ESS building budge1.t

What would we need for a shot-pulse source?



ESS – how it works

1 Protons are generated in the ion source

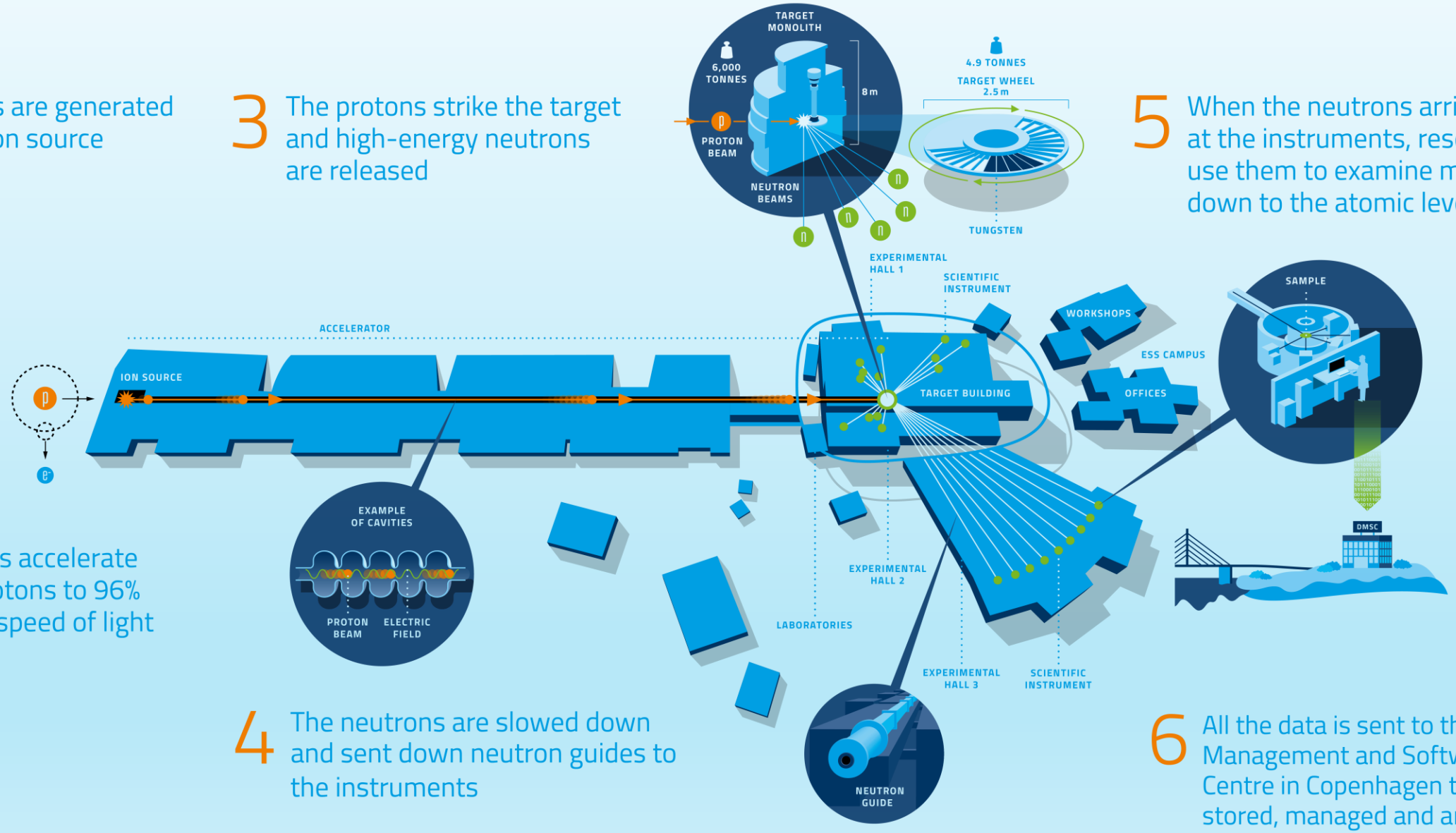
2 Cavities accelerate the protons to 96% of the speed of light

3 The protons strike the target and high-energy neutrons are released

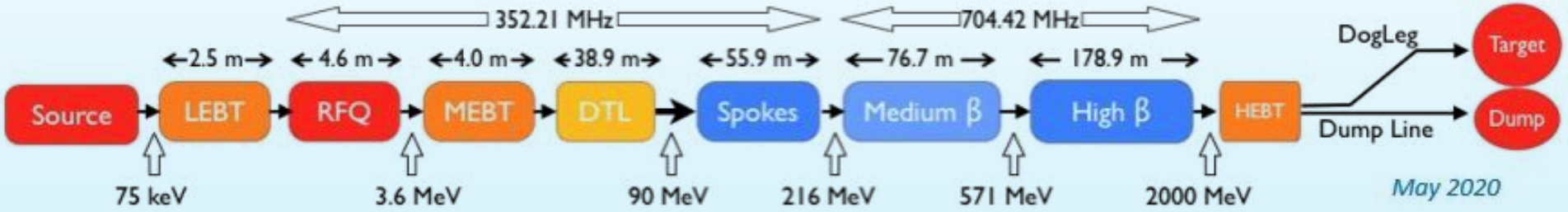
4 The neutrons are slowed down and sent down neutron guides to the instruments

5 When the neutrons arrive at the instruments, researchers use them to examine matter down to the atomic level

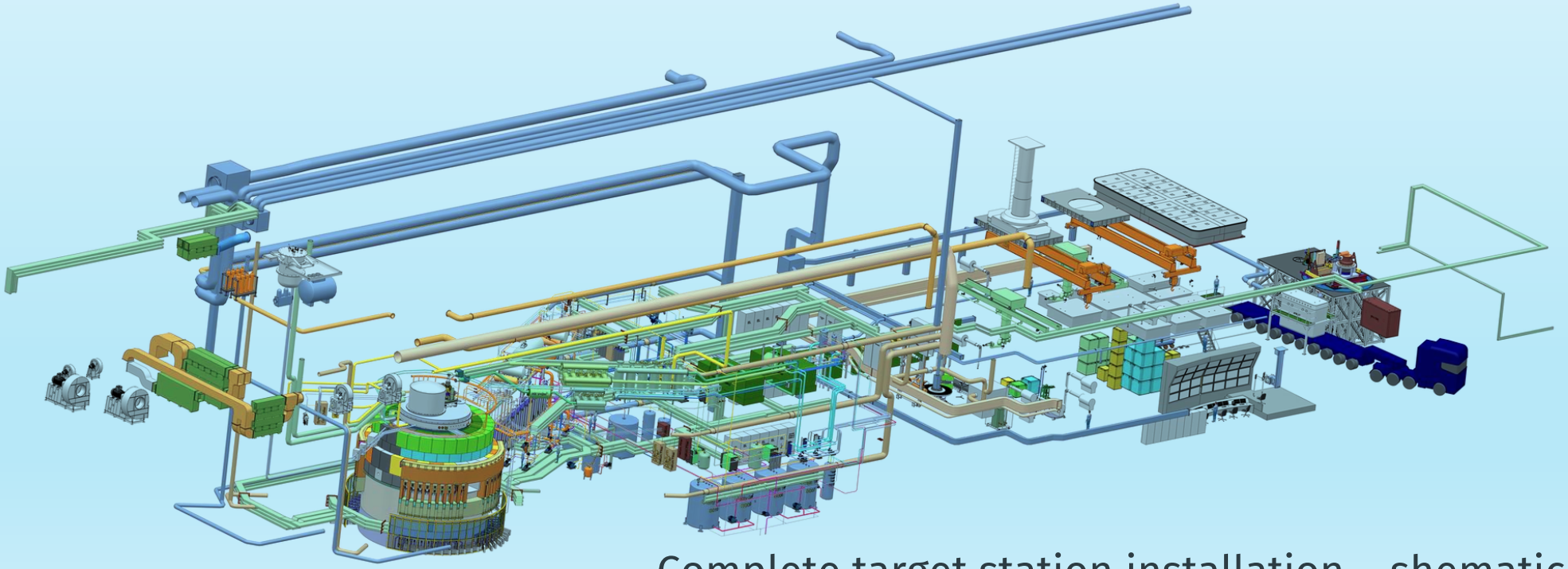
6 All the data is sent to the Data Management and Software Centre in Copenhagen to be stored, managed and analysed with the researchers



ESS – how it works

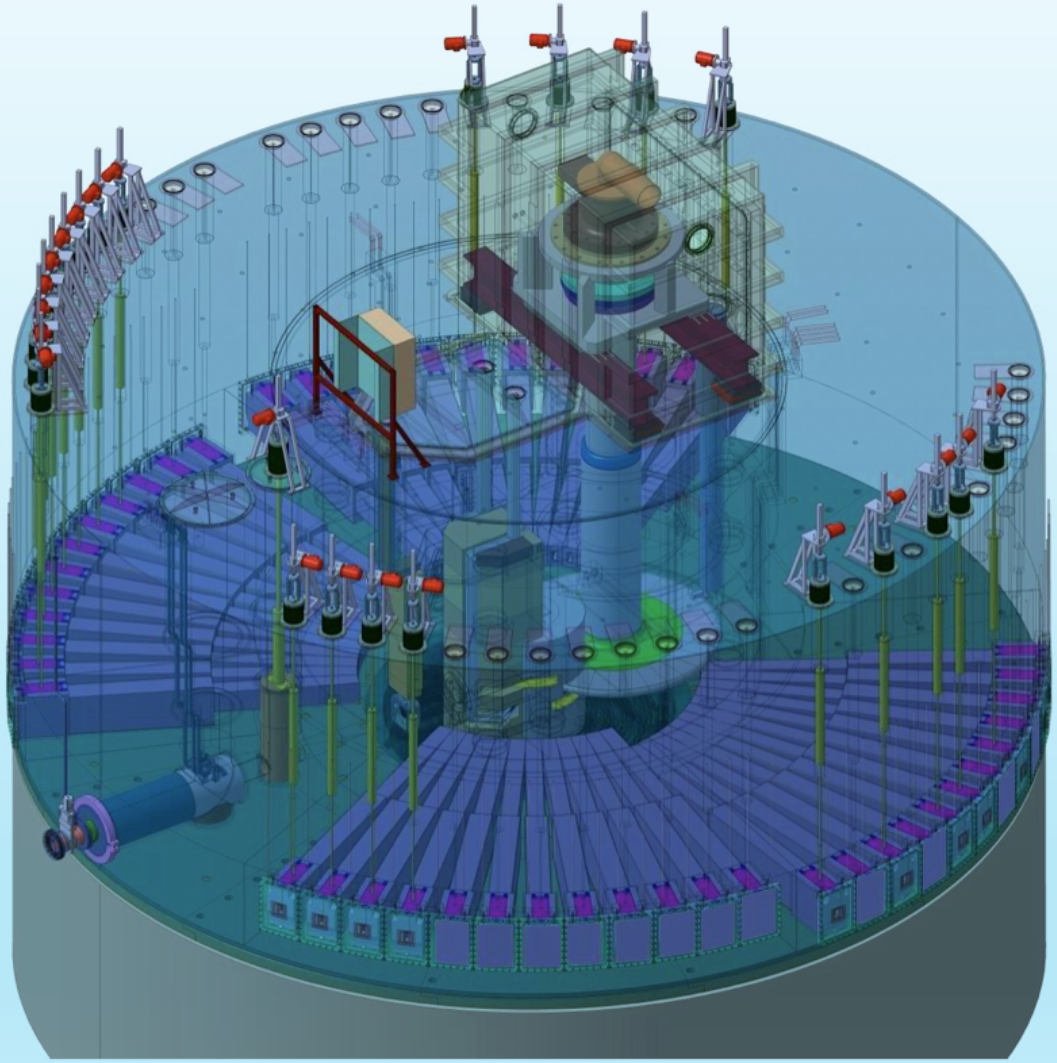


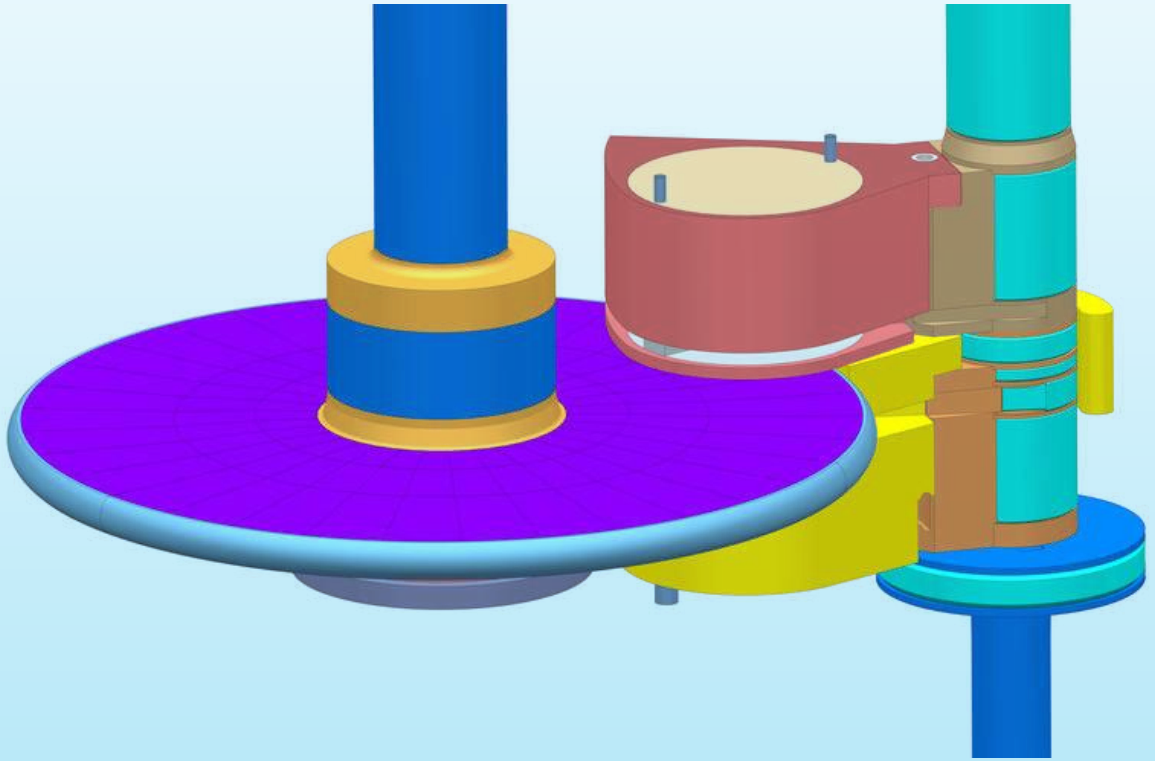
Linac delivers 2—2.5 GeV protons at the target



Complete target station installation – shematic drawing

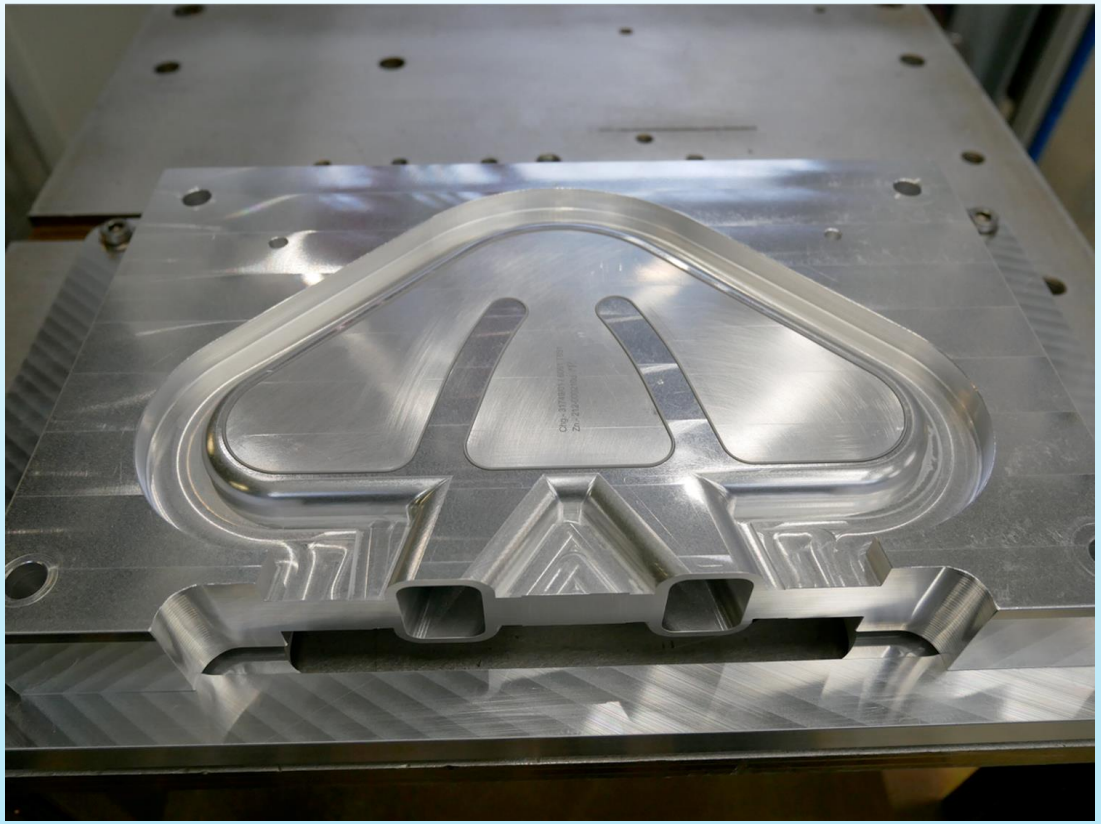
ESS – target station



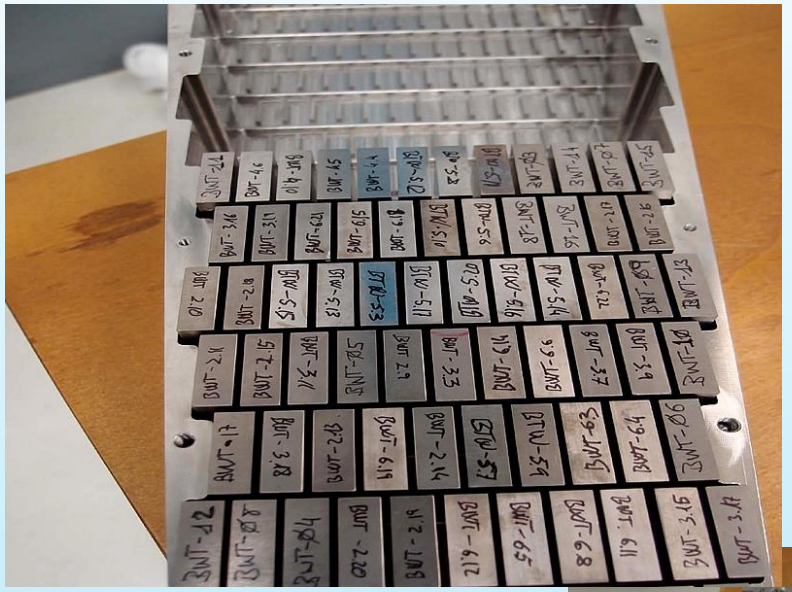


Target station – shematic drawing

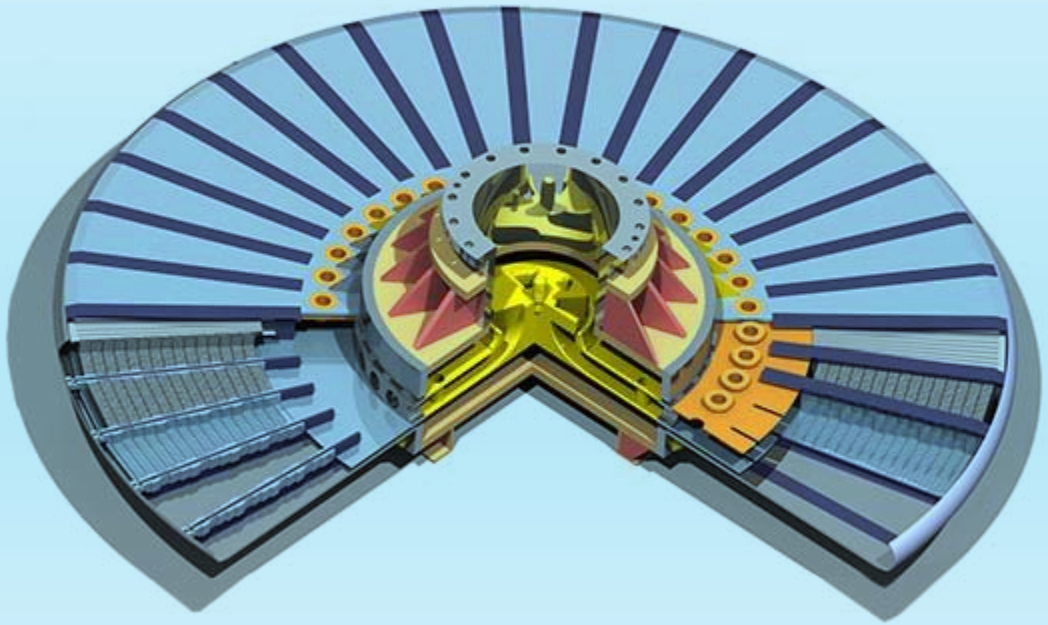
ESS – target wheel and the moderator housing

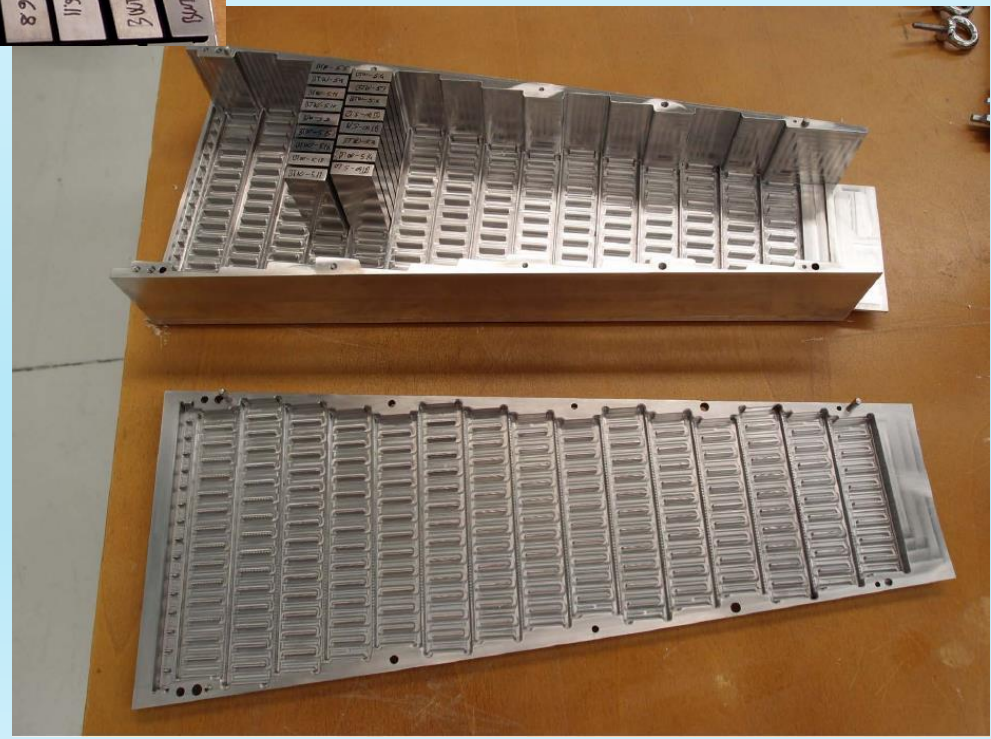


ESS – target monolith

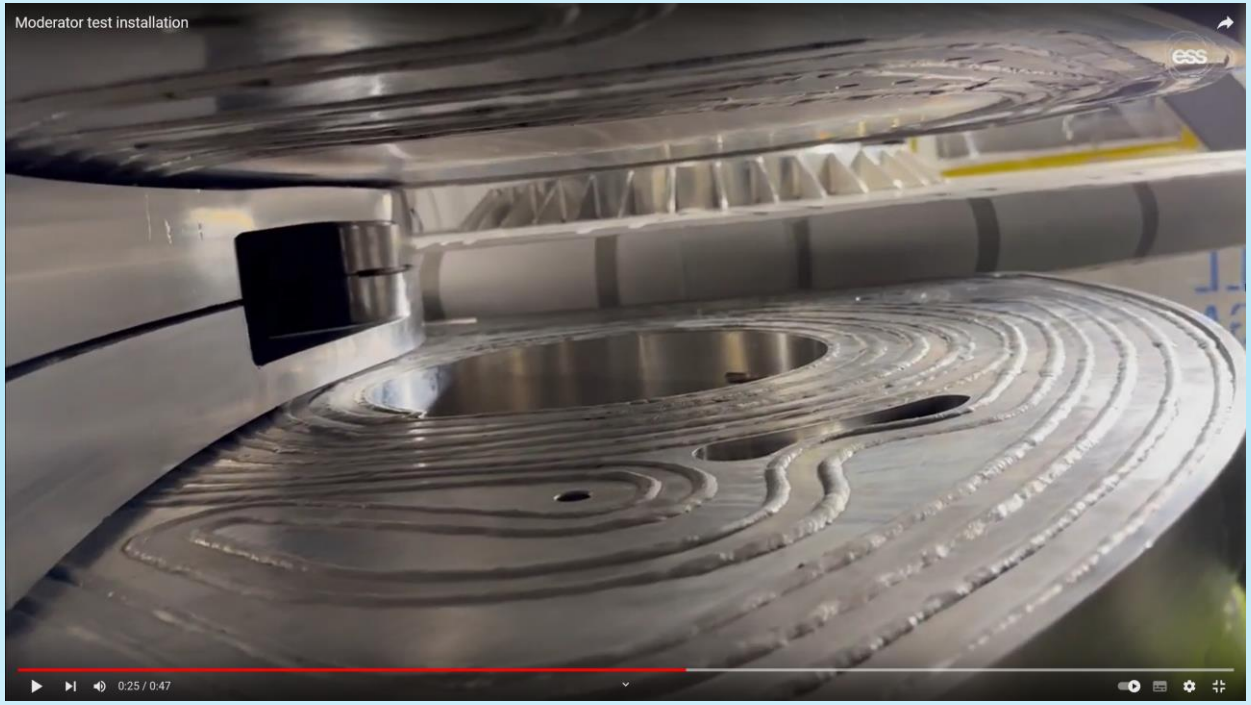


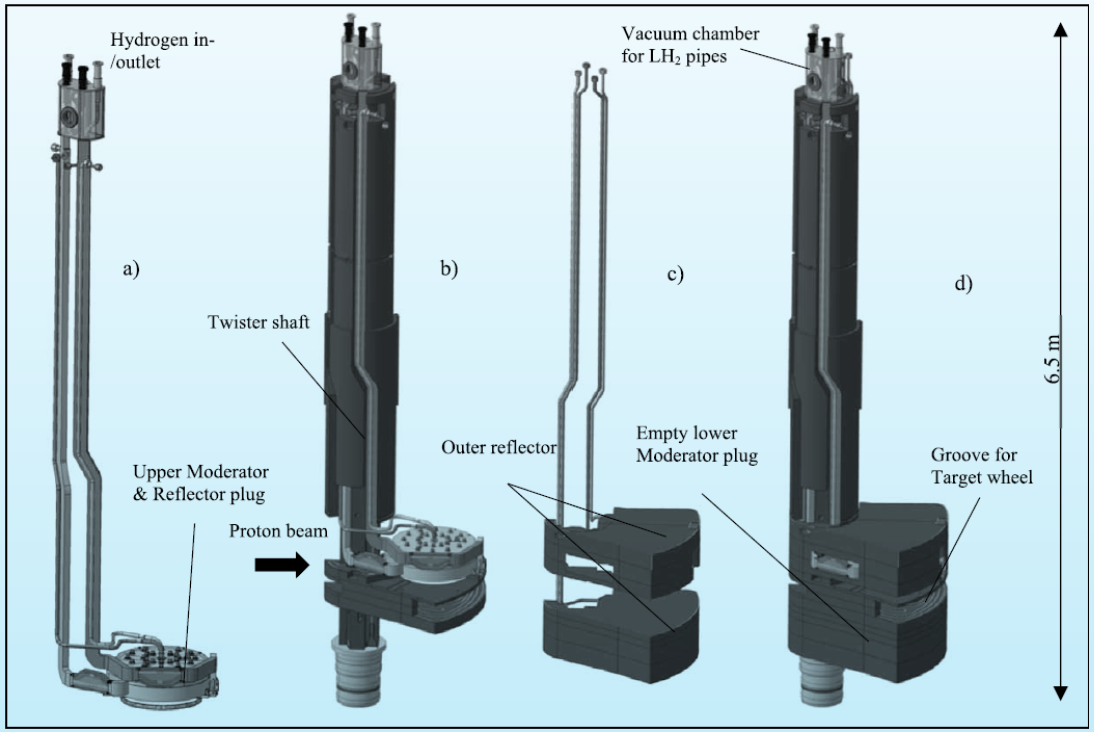
7000 tungsten bricks ready for mounting on the ESS target wheel prototype.



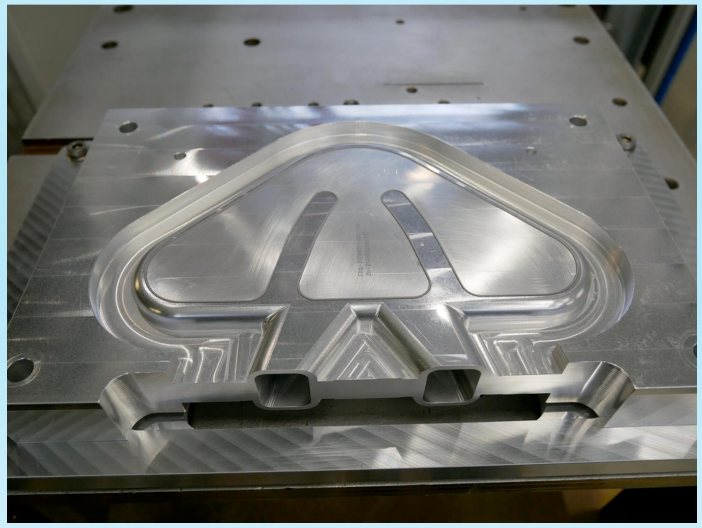


ESS moderators

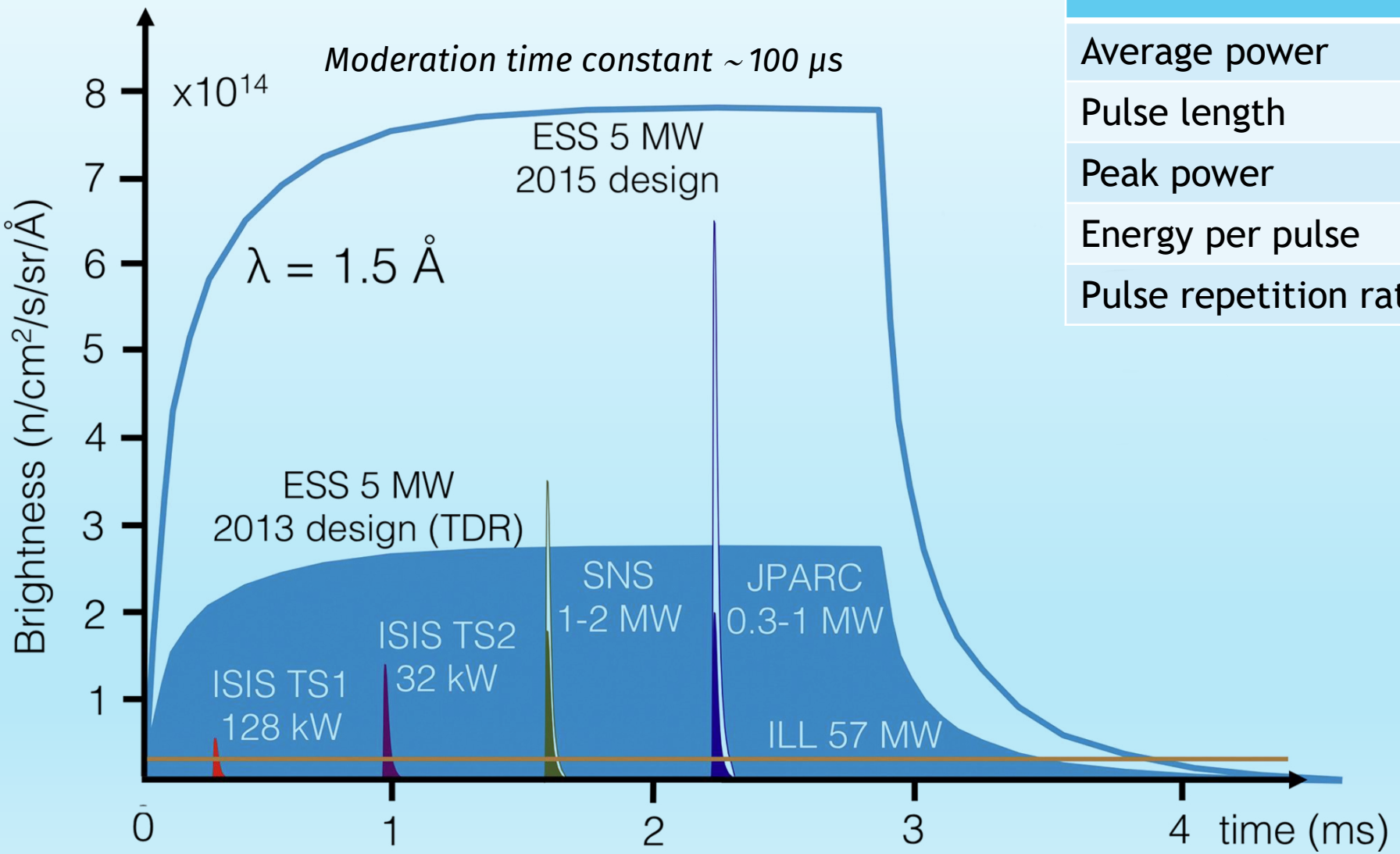




„Butterfly" moderator



ESS – the long pulse source

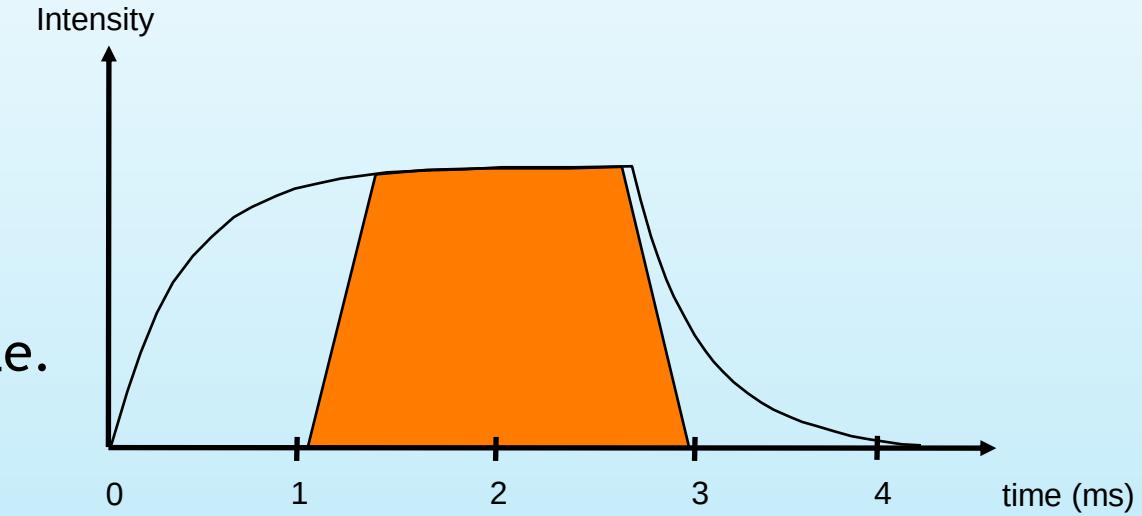


	SNS	ESS
Average power	1.4 MW	5 MW
Pulse length	695 ns	2.86 ms
Peak power	34 GW	125 MW
Energy per pulse	24 kJ	357 kJ
Pulse repetition rate	60 Hz	14 Hz

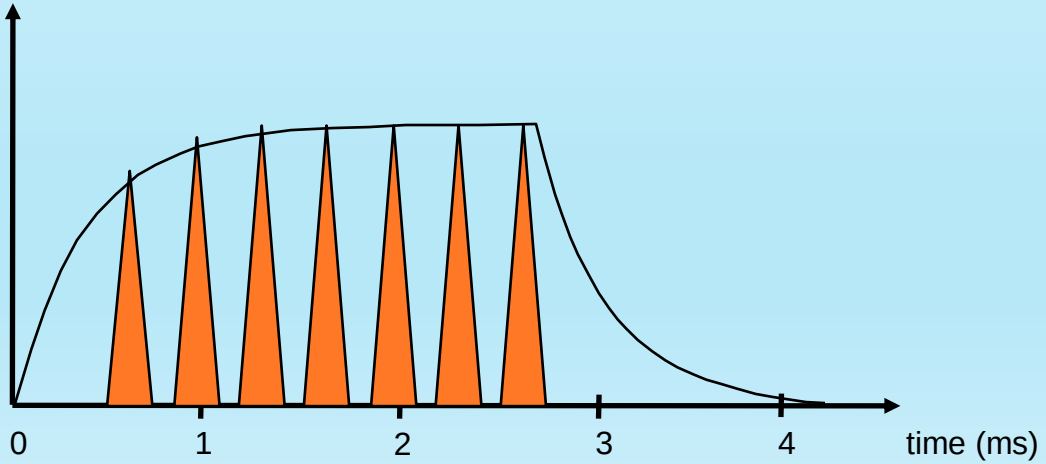
Time-averaged brightness:
ESS ~ ILL
Peak brightness:
ESS ~ 30 × ILL

ESS – the long pulse source

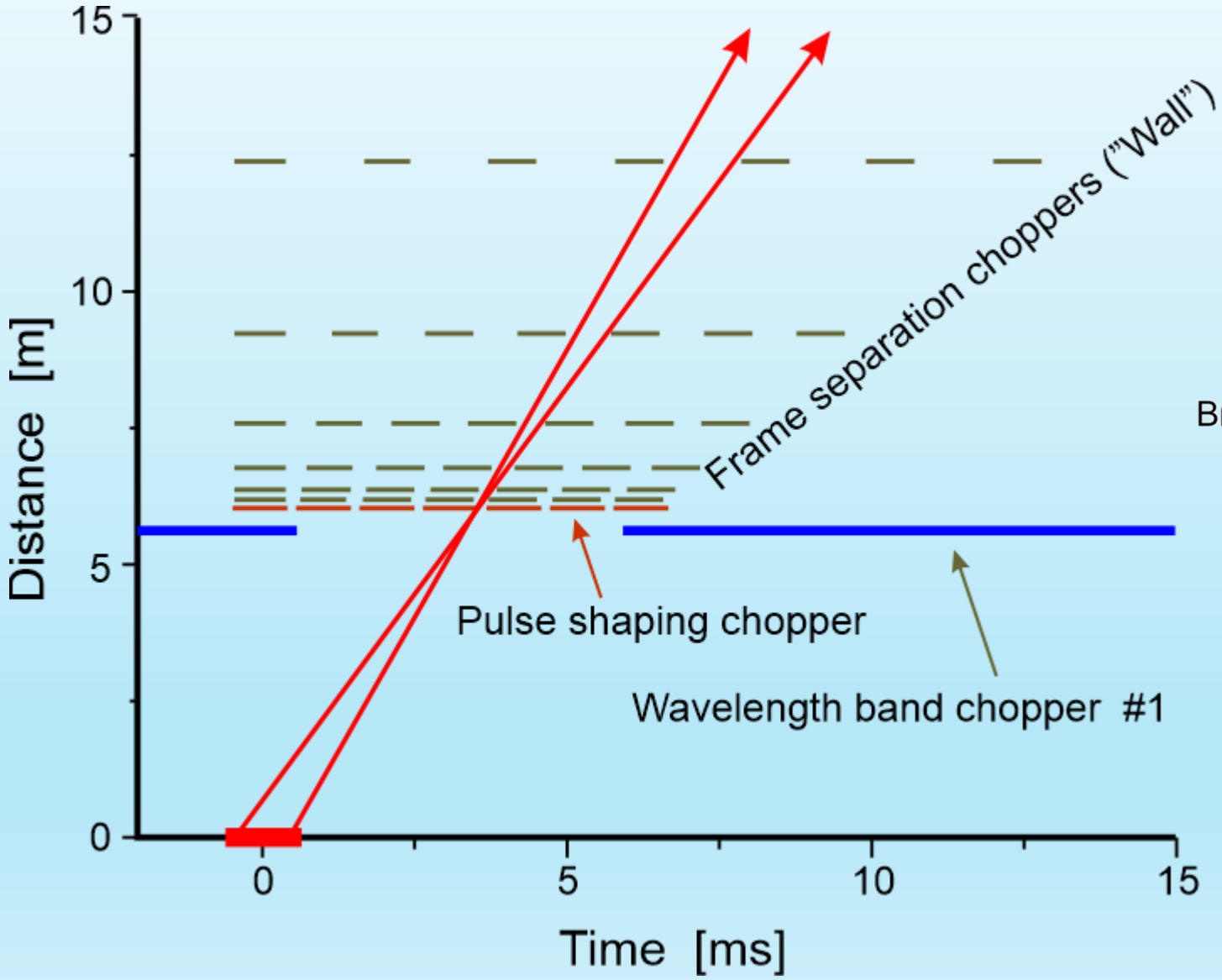
Use as much as possible of the whole pulse:
Good for low wavelength resolution instruments.
SANS, Reflectometry, single crystal diffraction.
Estimated gains **10—100 times** the currently available.

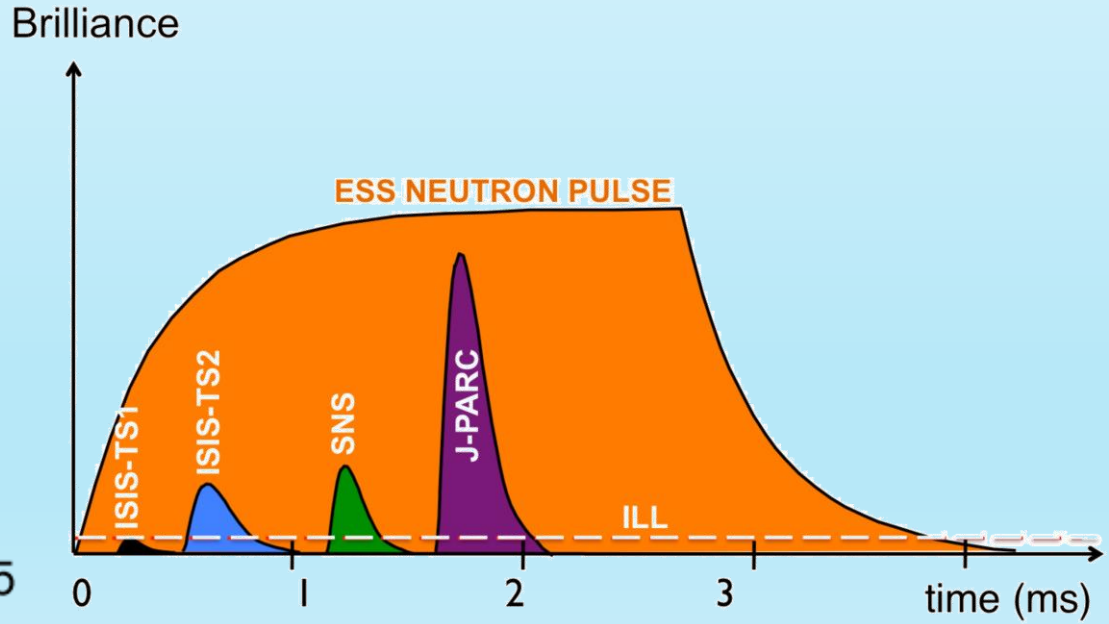


Cut the long pulse into smaller pulses:
Good for higher wavelength resolution instruments
Diffraction, cold/thermal spectrometers.
Long Instruments (80-100 m)
Estimated gains **10-30 times** than currently available.
Thermal gains lower.



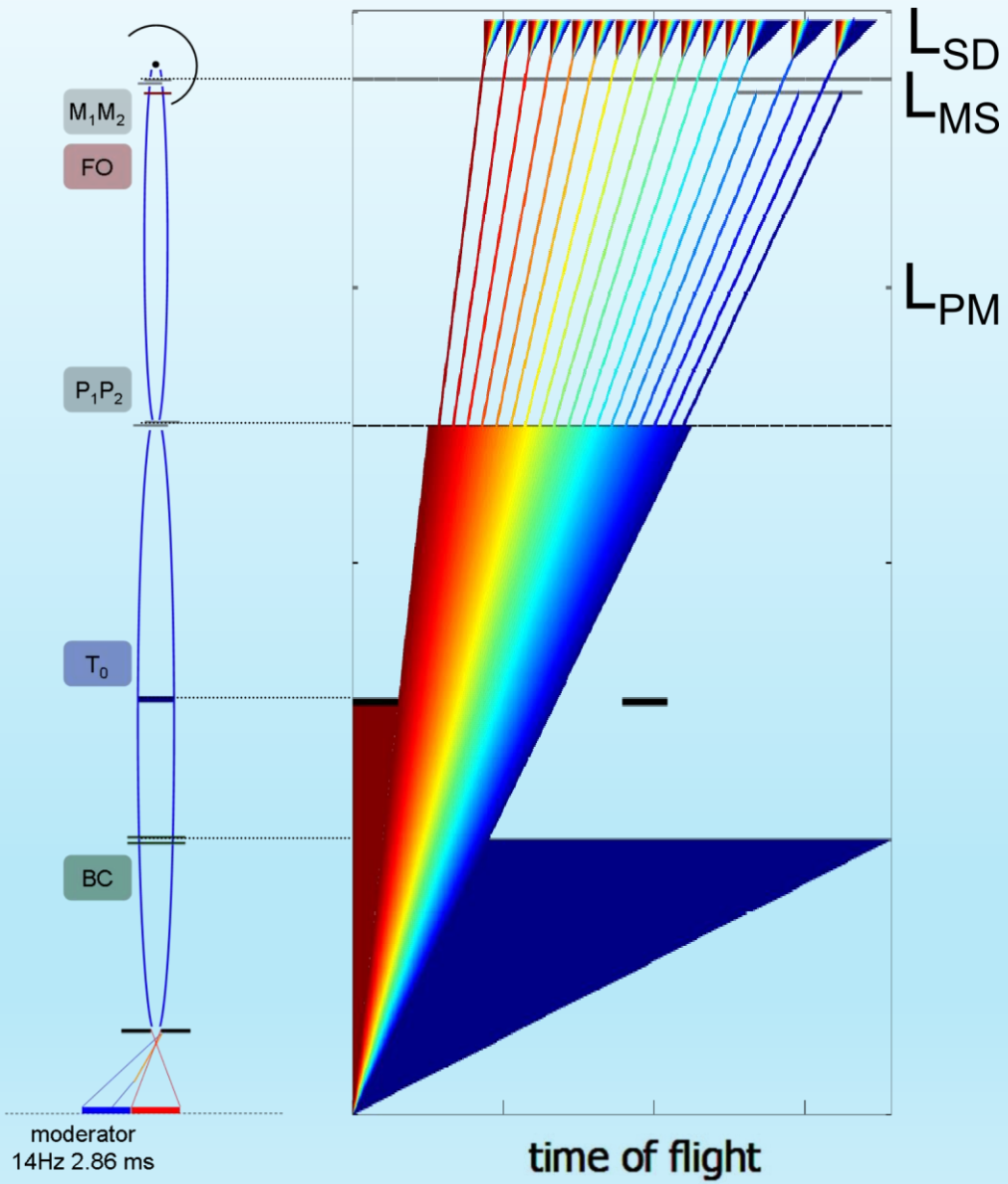
ESS – secondary pulse shaping (Mezei)





ESS – repetition rate multiplication

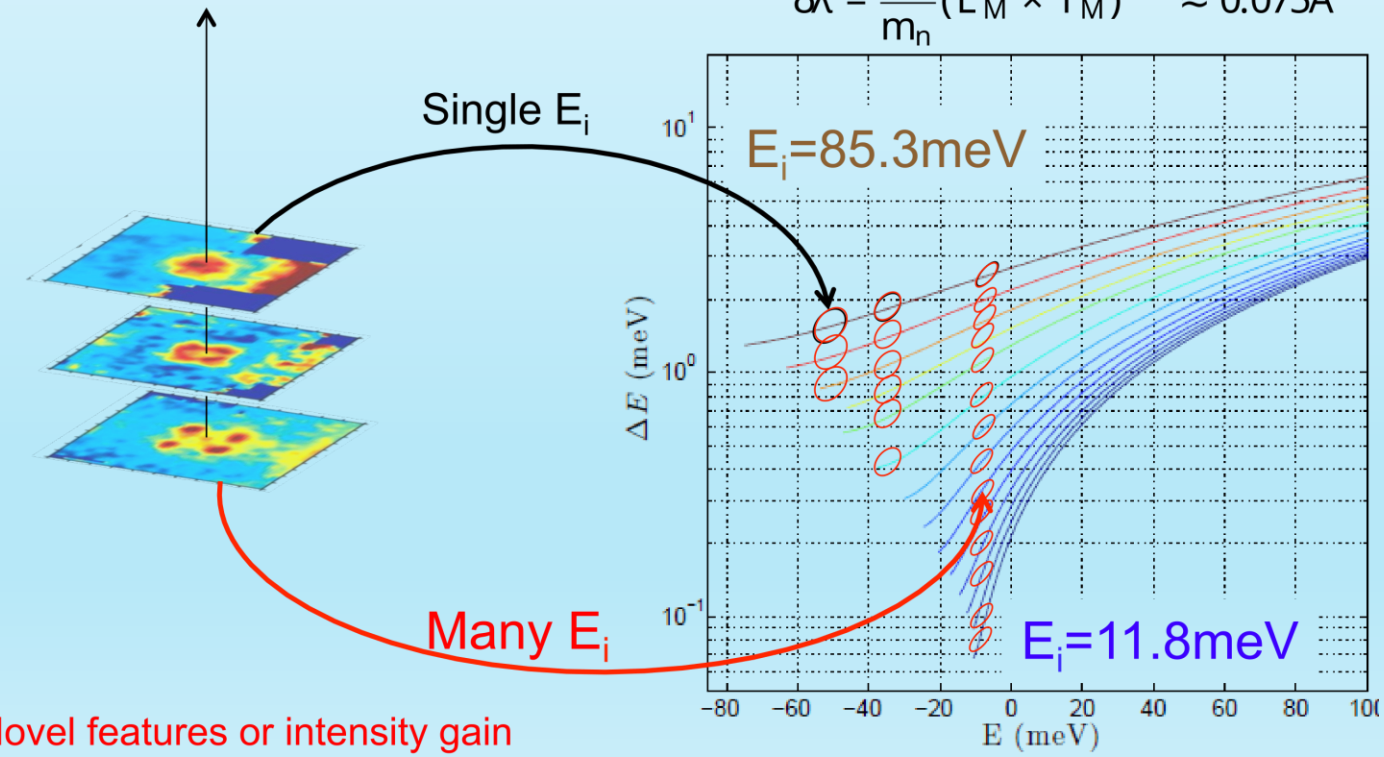
(from T-REX original proposal)



$$L = 155\text{m}, L_M = 150\text{m}$$

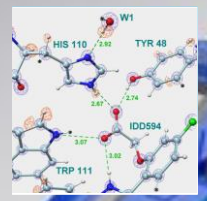
$$\Delta\lambda = \frac{h}{m_n}(L \times 14\text{Hz})^{-1} \approx 1.8\text{Å}$$

$$\delta\lambda = \frac{h}{m_n}(L_M \times f_M)^{-1} \approx 0.075\text{Å}$$



Novel features or intensity gain

Instrument classes
- Imaging (ODIN)
- SANS (LoKI)
- Reflectometers (Estia)
- Spectrometers (BIFROST)
- Diffractometers (NMX, DREAM)

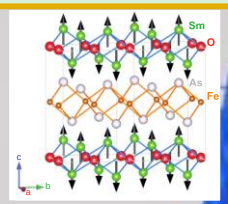


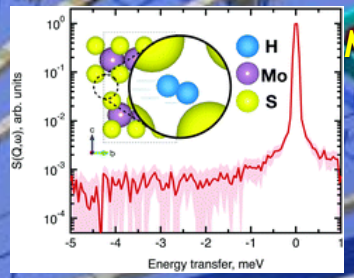
NMX

BEER

C-SPEC

BIFROST





MIRACLES

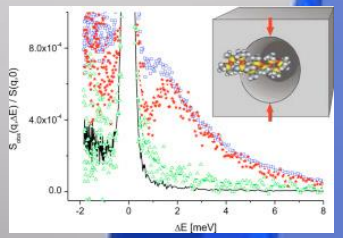
MAGIC

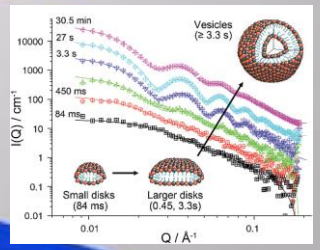
T-REX

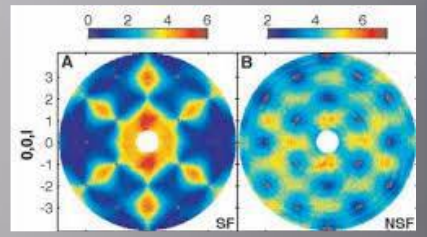
HEIMDAL

ODIN

DREAM



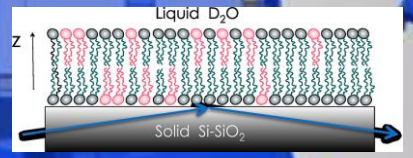




LoKI

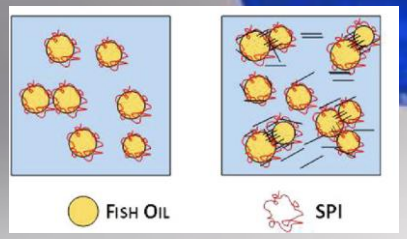
VESPA

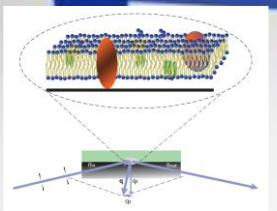
FREIA



SKADI

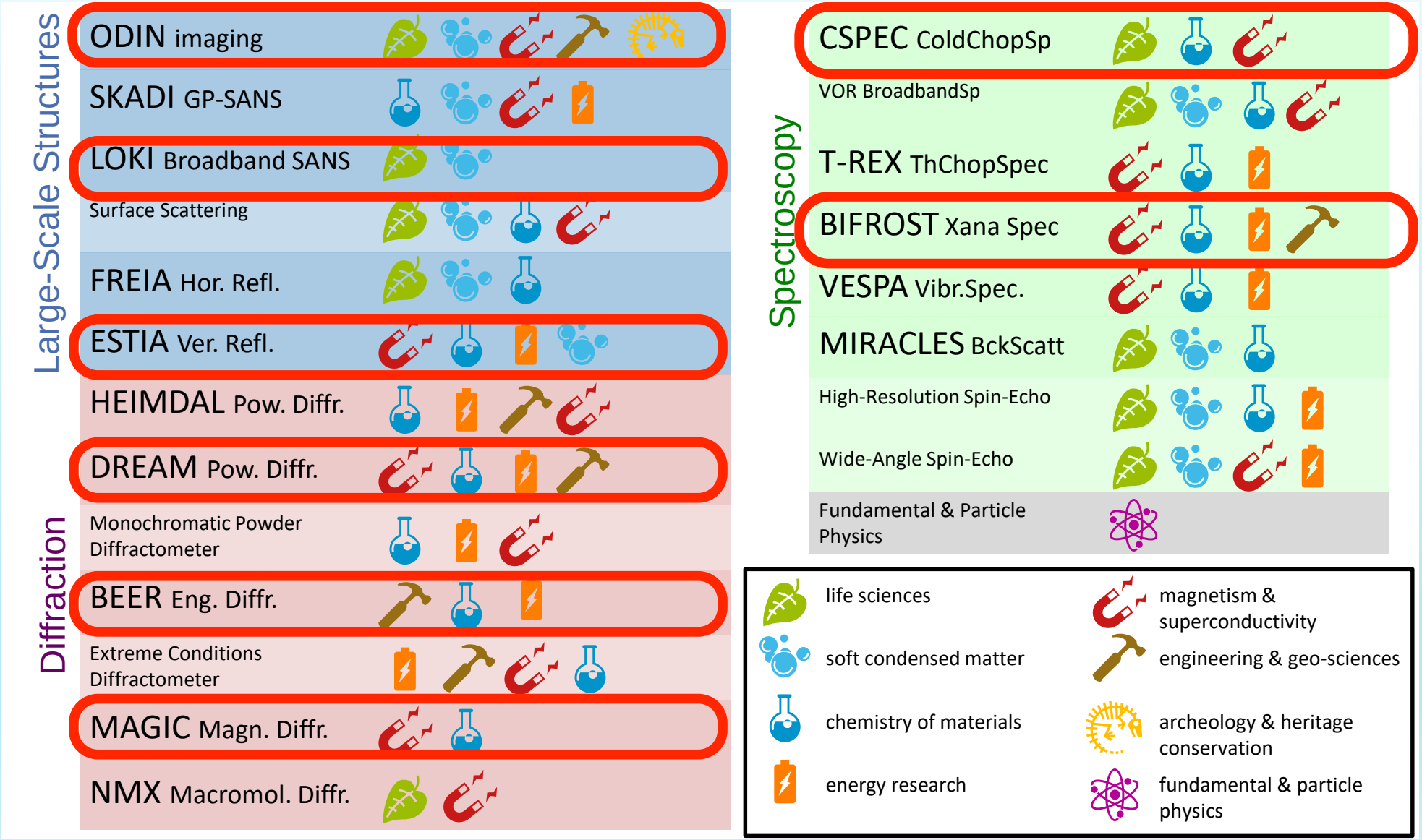
ESTIA





The first 15 instruments at the ESS

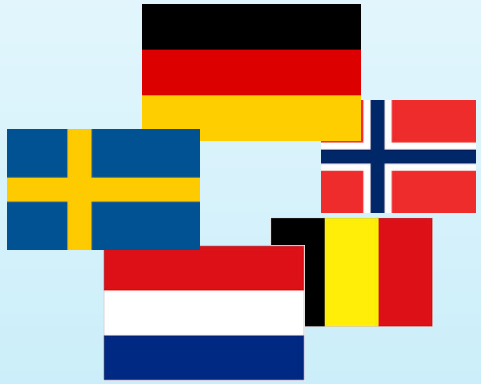
ESS instrument suite

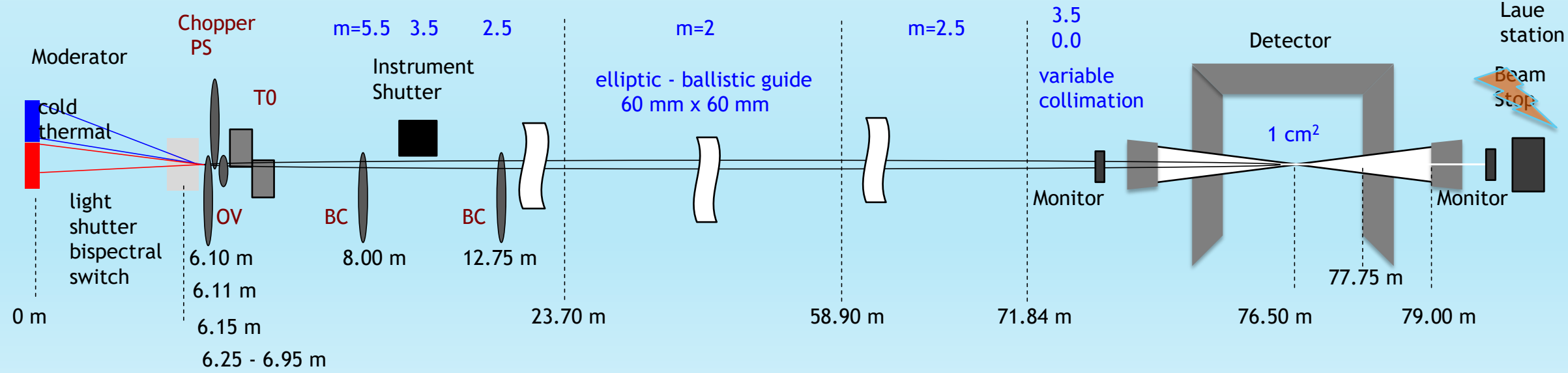


15 approved
8 at «Day 0»

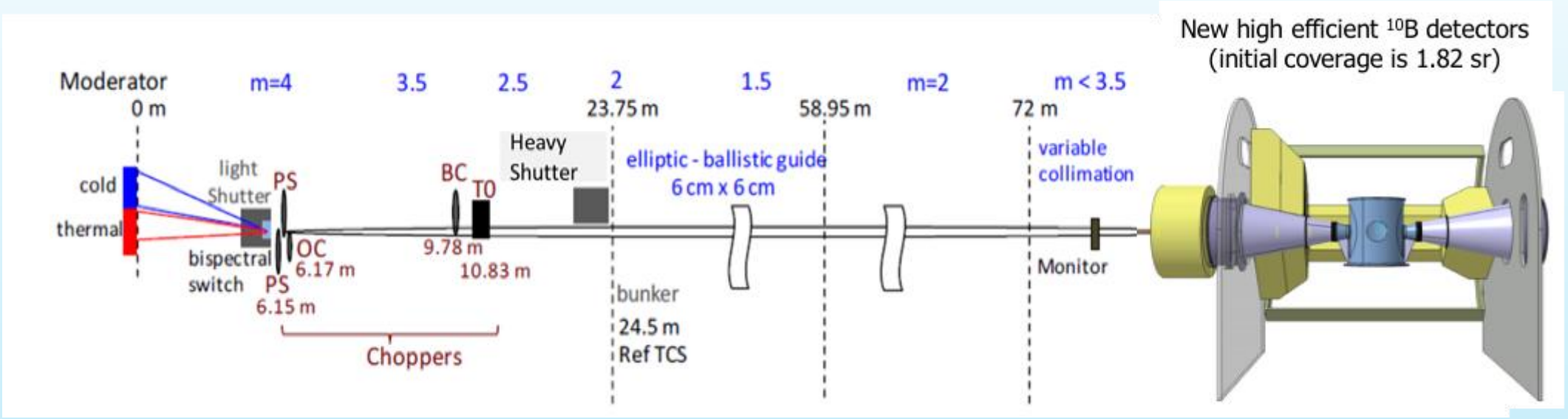
DREAM — Bispectral Powder Diffractometer

Diffraction Resolved by Energy and Angle Measurements

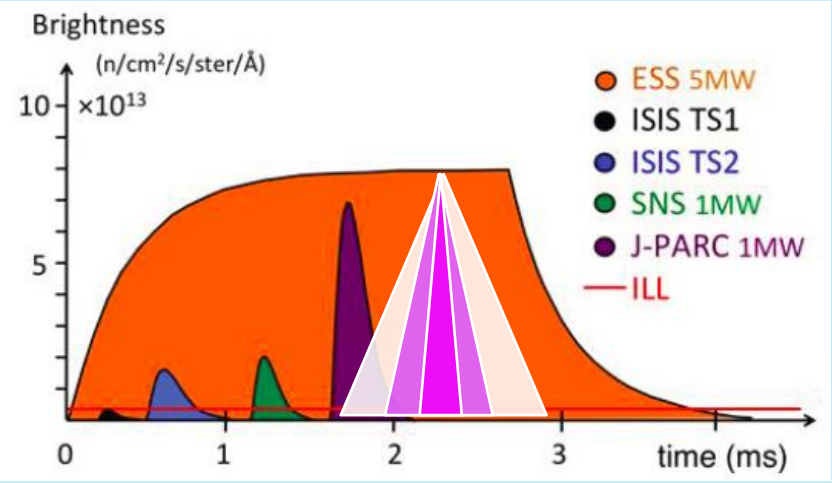




DREAM – Bispectral Powder Diffractometer



Brightness



pulse shaping

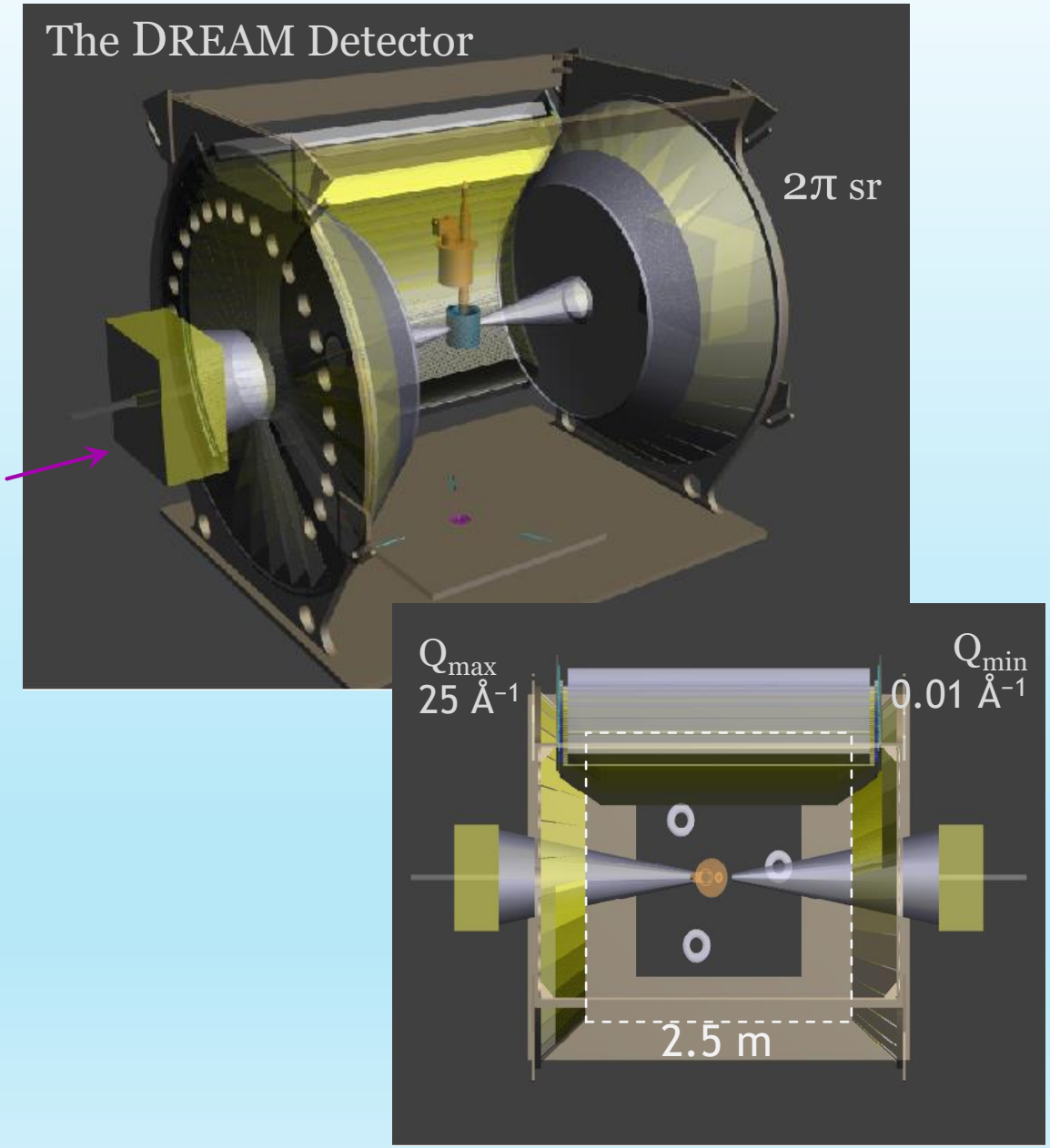
75 m length
bandwidth includes thermal and cold peak

thermal spectrum gives $Q_{max} < 25$ Å^{-1}

high flexibility in trading resolution *vs* intensity
ideal peak shape

using the intense cold spectrum with best ever resolution

DREAM – Bispectral Powder Diffractometer



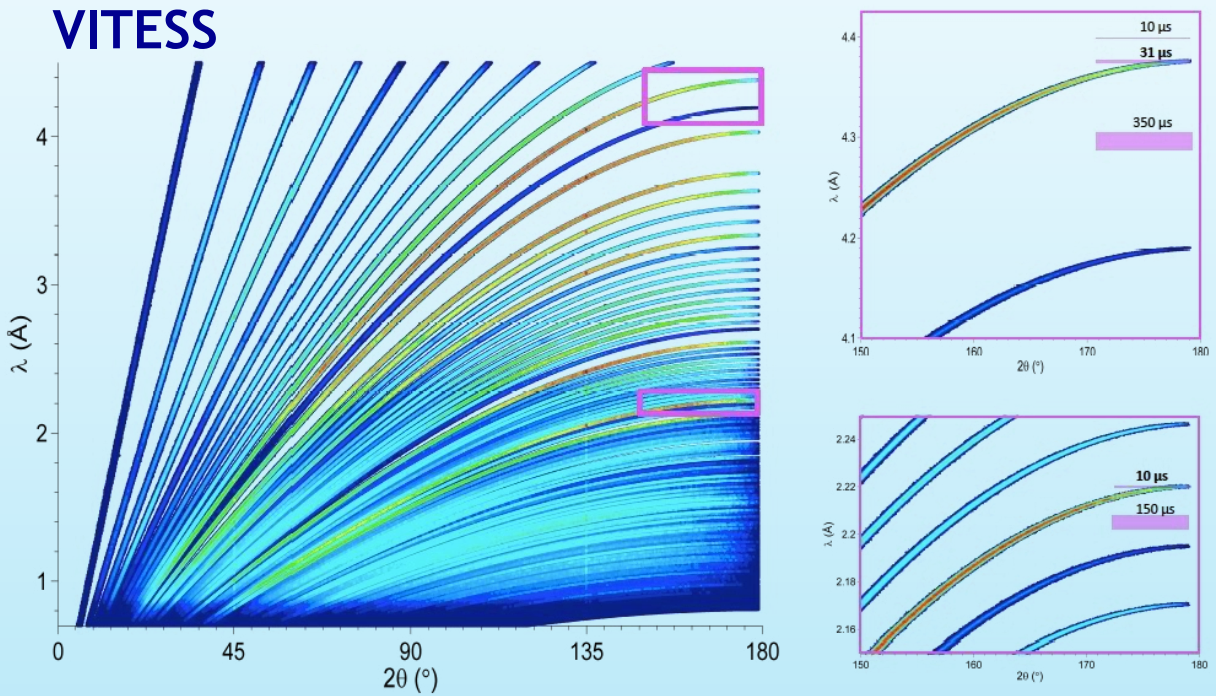
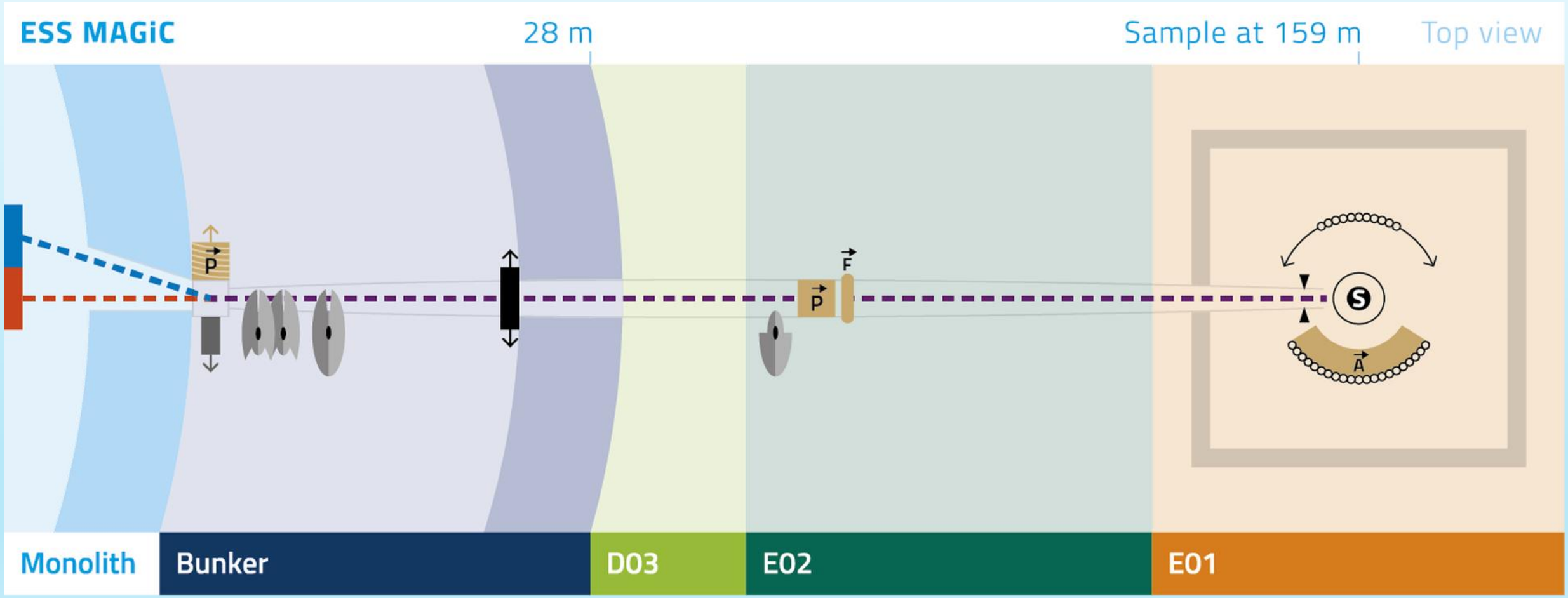


Fig. 5 Diffraction diagram of a reference sample (0.4 cm³ $Na_2Ca_3Al_2F_{14}$) in high resolution mode (left). In backscattering, the asymptotic limit is essentially determined by the time resolution, see enlarged regions (right)

MAGiC — Magnetism Single-Crystal Diffractometer

Polarized time-of-flight single-crystal diffractometer

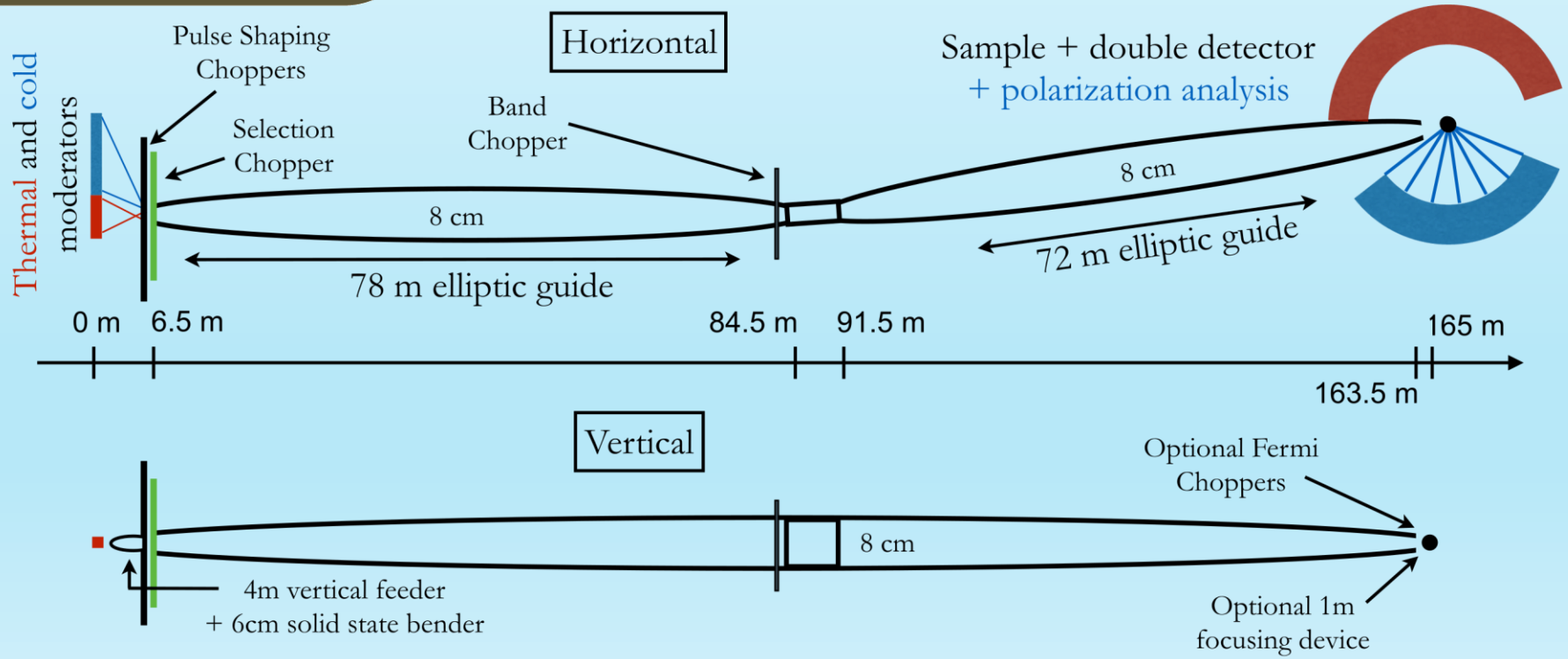


MAGiC — Magnetism Single-Crystal Diffractometer

The magnetic moment is a vector 

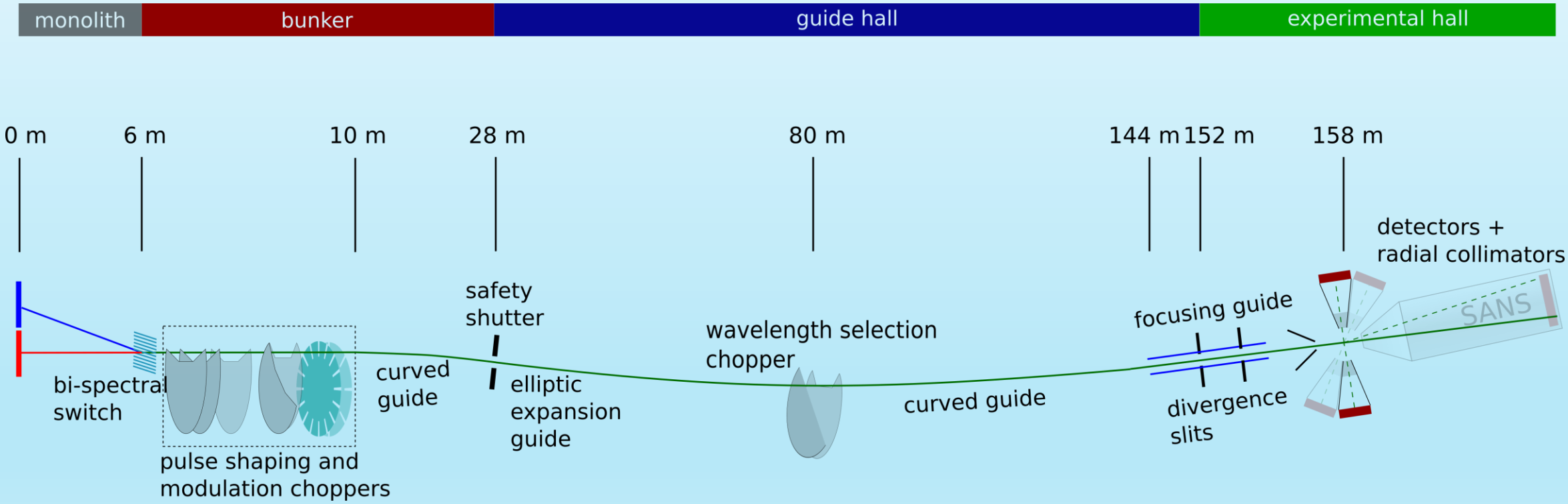
Usually intensities are only measures of scalar products.
The neutron dipolar interaction probes magnetic moments perpendicular to the scattering vector $\vec{S}_{\perp\vec{Q}} \cdot \vec{S}'_{\perp\vec{Q}}$

Polarized neutrons measure vector properties, vector products and vector directions $\vec{S}_{\perp\vec{Q}} \times \vec{S}'_{\perp\vec{Q}}$



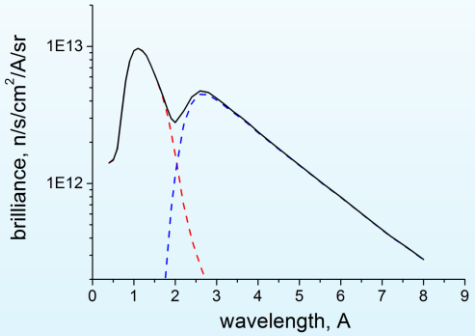
BEER – Engineering Diffractometer

Beamline for European Engineering Materials Research

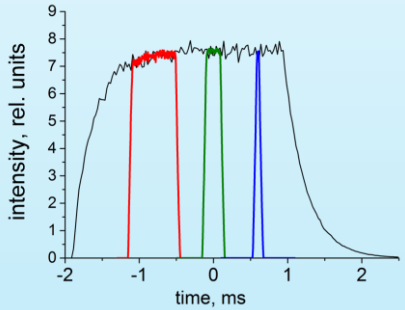


BEER — Engineering Diffractometer

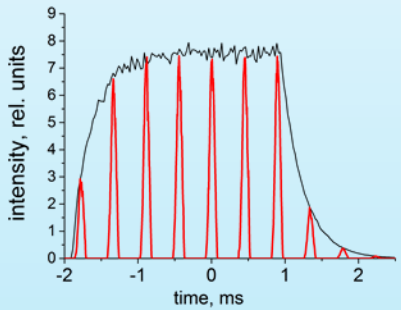
bi-spectral source



chopper system for wide range of resolutions



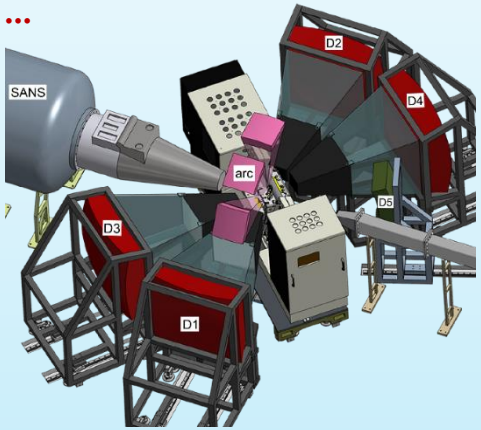
pulse shaping

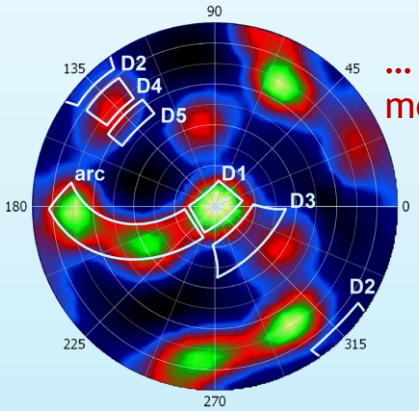


pulse modulation

retractable detector banks allowing for large sample environment

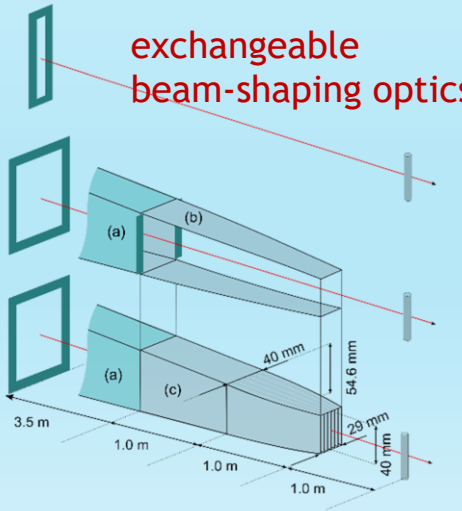
…

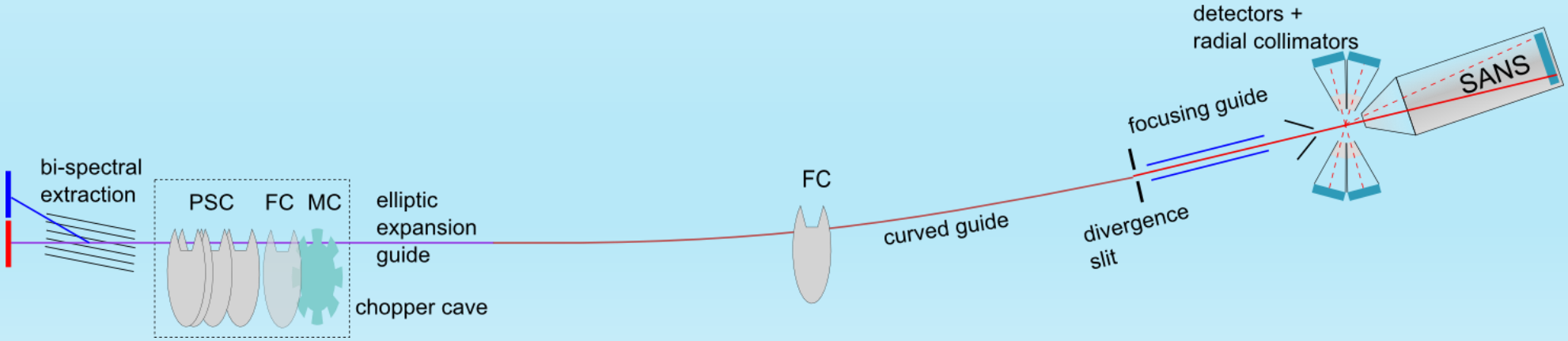




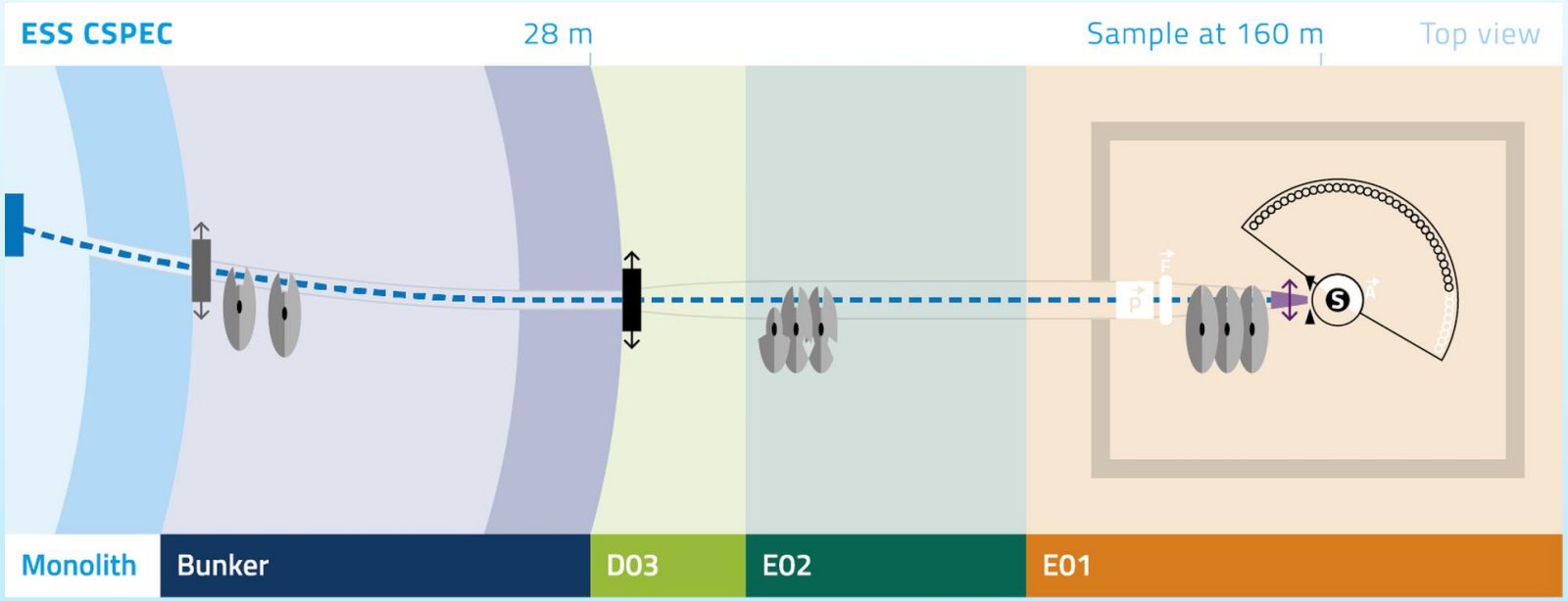
… and texture measurements

exchangeable beam-shaping optics



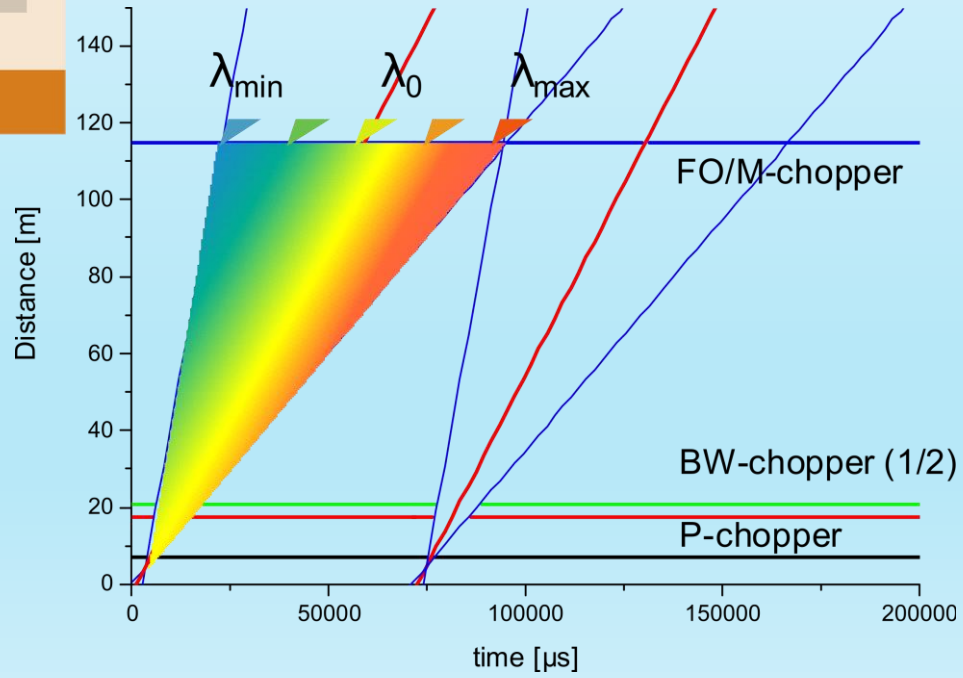


CSPEC — Cold Chopper Spectrometer



CSPEC will be used in a wide variety of scientific applications, spanning the life sciences, functional materials and chemistry. *Its key capability is to follow kinetic events in situ or in operando, enabled by very high flux.*

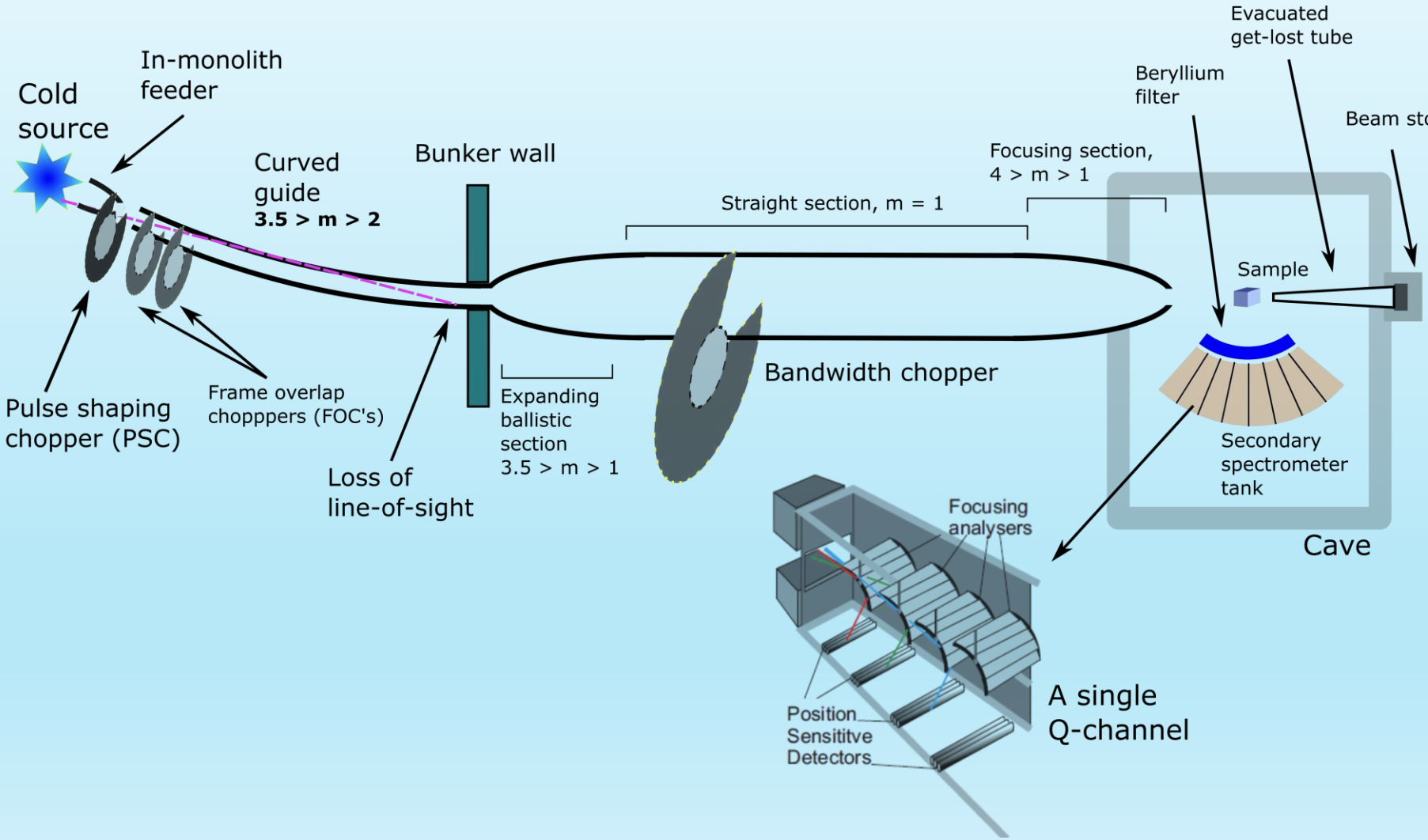
CSPEC is a direct geometry time of flight spectrometer developed as a German/French collaboration between FRM II and LLB.

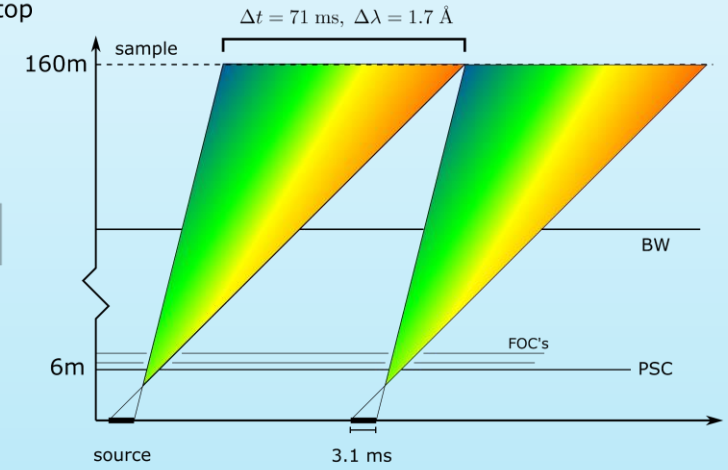


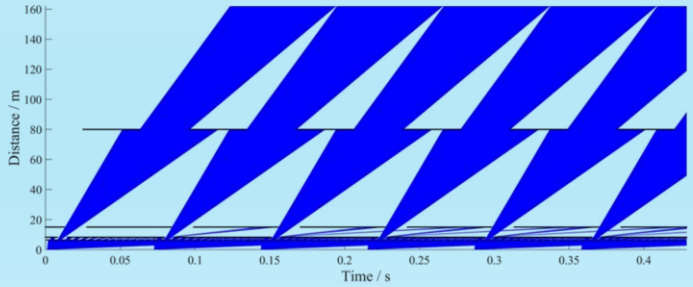
BIFROST — Extreme Environment Spectrometer

BIFROST — inverted geometry spectrometer

(evolved from **CAMEA**)

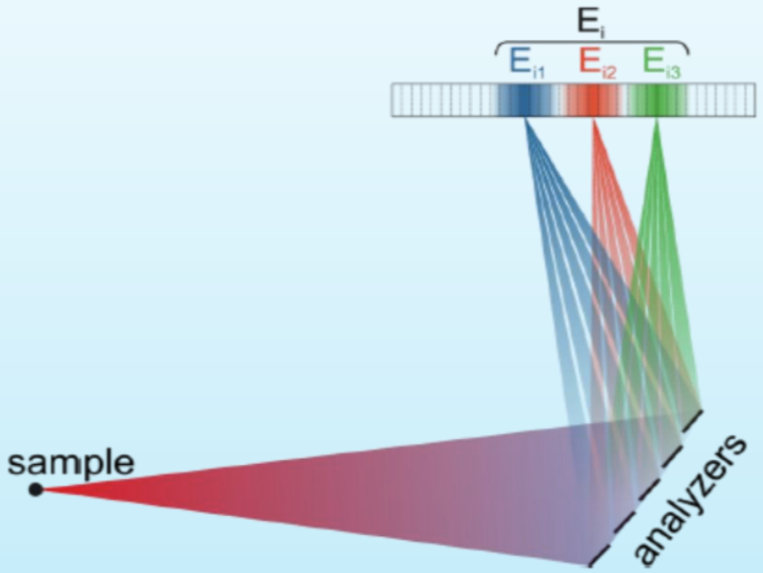


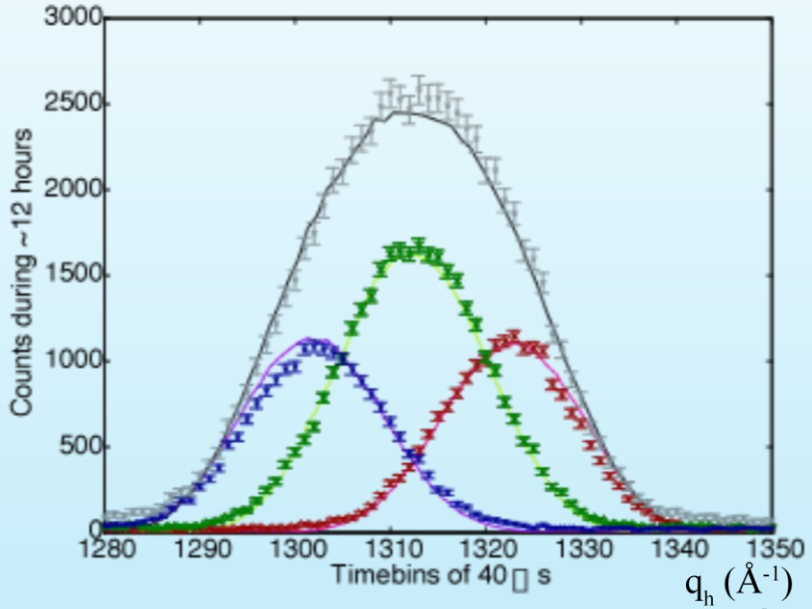


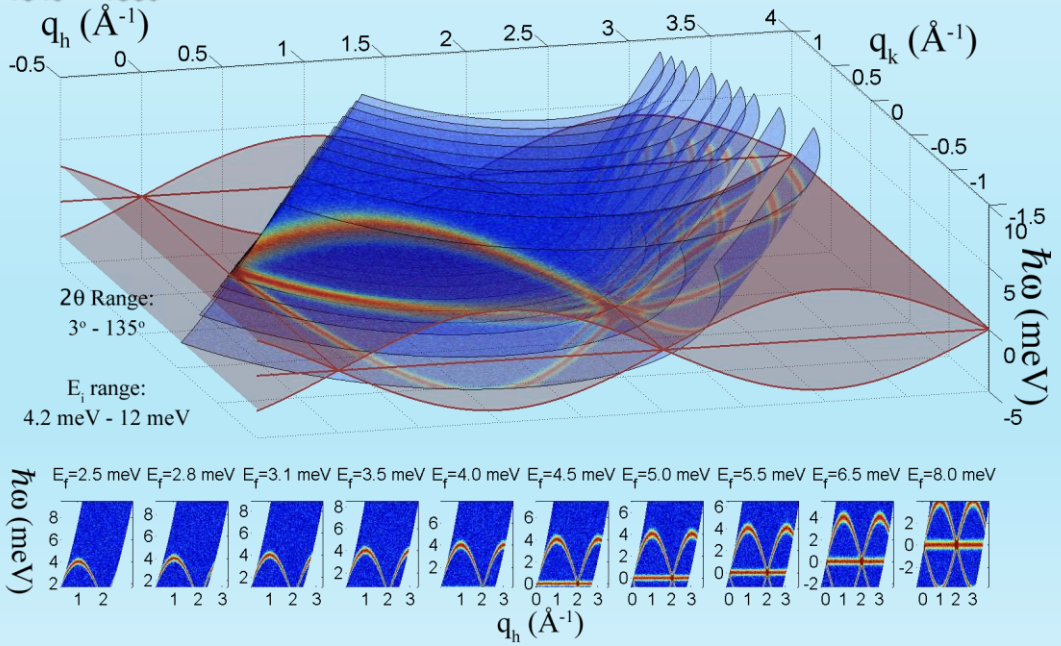


BIFROST primary spectrometer

BIFROST — Extreme Environment Spectrometer

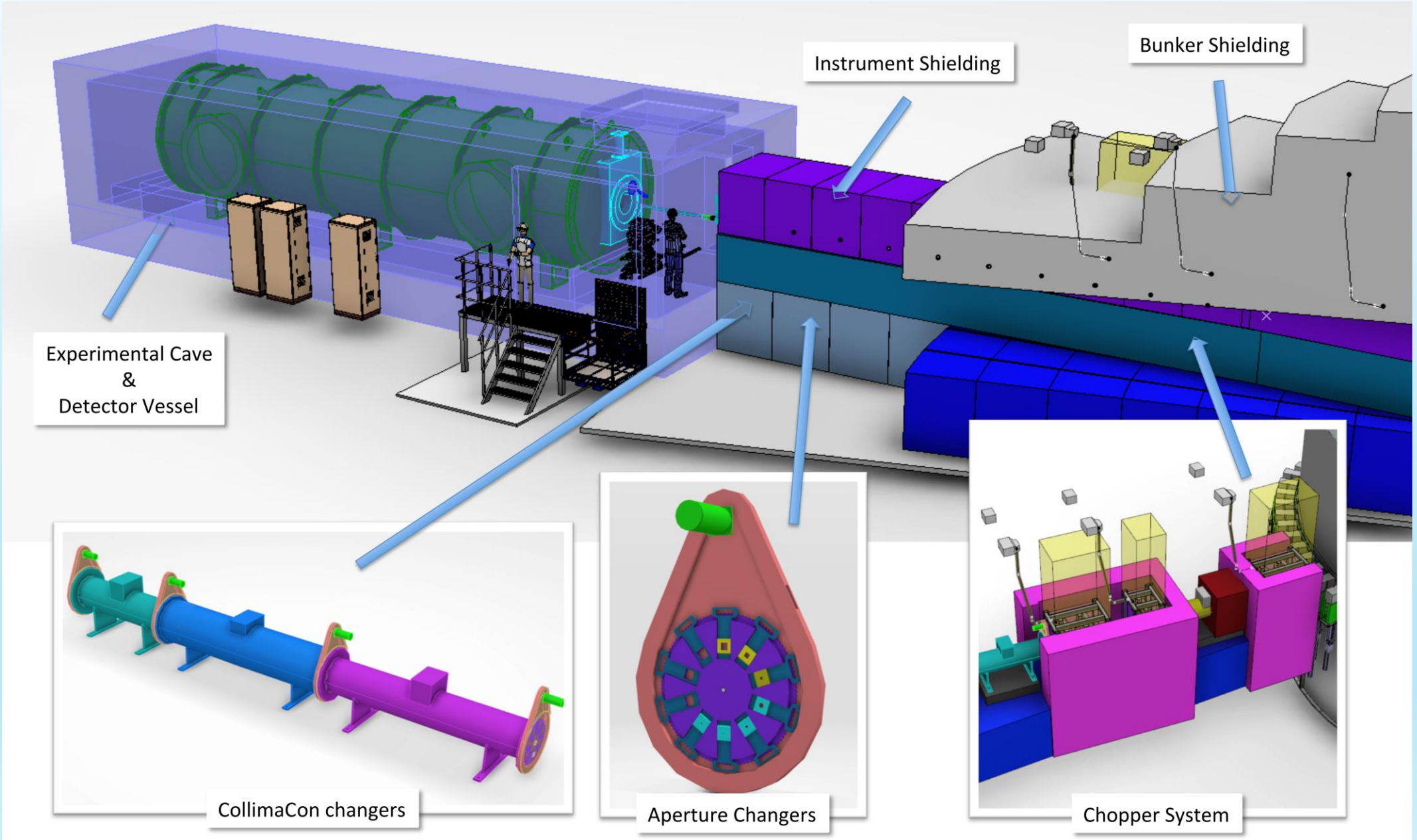






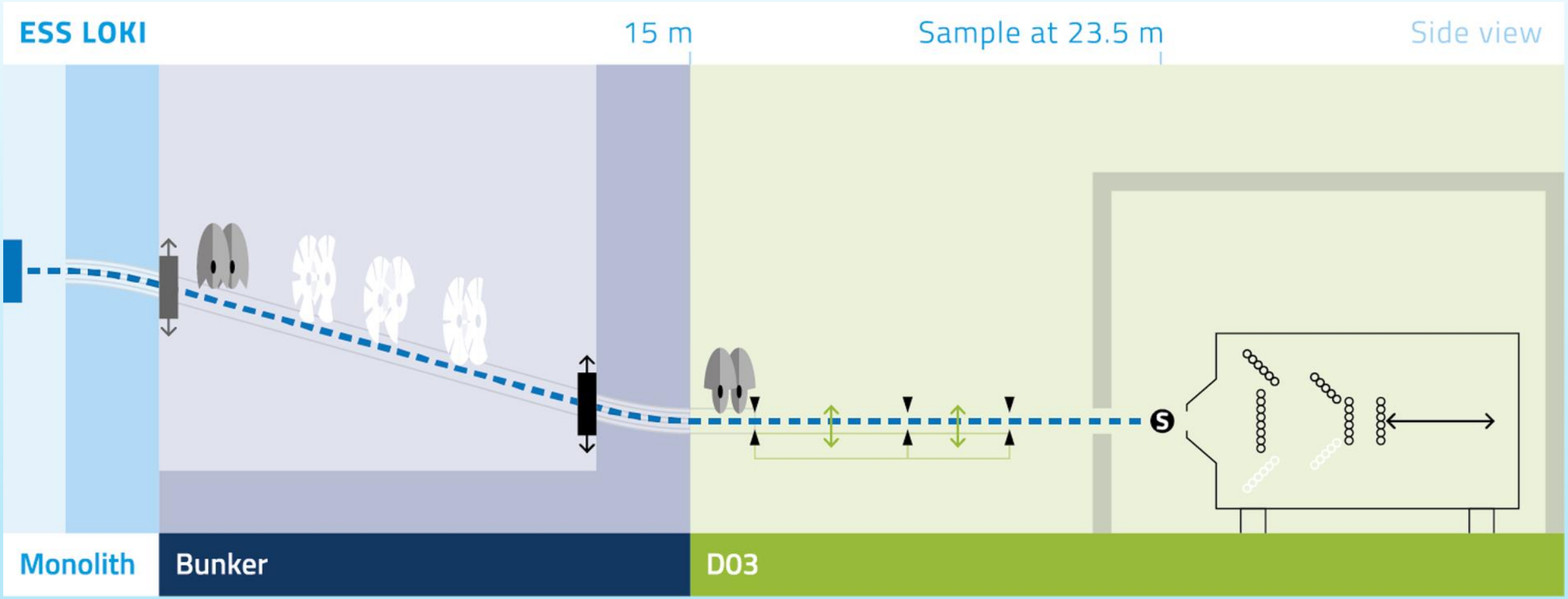
BIFROST — the concept of prismatic spectroscopy

LoKI – Broadband SANS



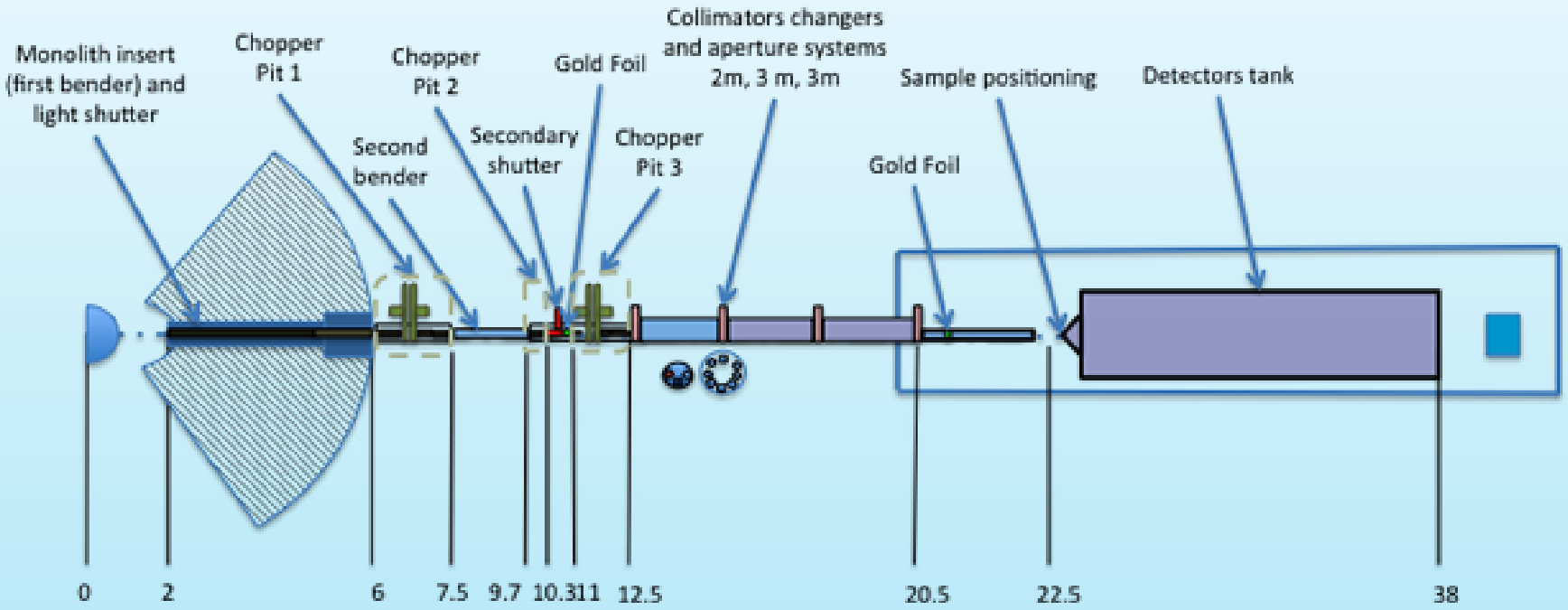
LoKI – Broadband SANS

A broad Q range, high flux SANS instrument for soft matter, bio-science and materials science



LoKI is the shorter of the two SANS instruments being built at ESS. The sample position is located at 23.5 m from the source and the maximum sample-to-detector distance is 10 m.

LoKI – Broadband SANS



Loki, the Norse god of mischief

(appears in Richard Wagner's opera cycle Ring of the Nibelung)

$L1_{max}$ = 10m
$L2_{max}$ = 10m
Repetition rate = 14Hz or 7Hz
$\delta\lambda_{max}$ = 10Å at 14Hz

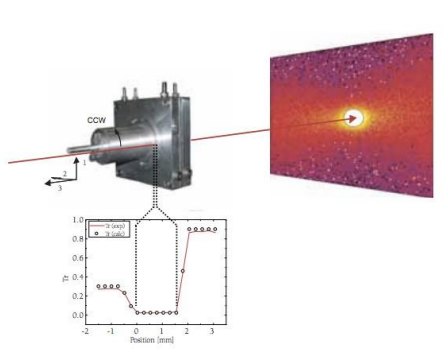
Max flux on sample ~$1x10^9$ n/cm^2/s

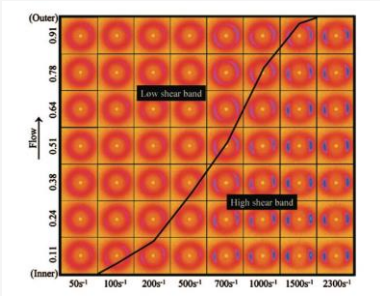
2x line-of-sight closure

LoKI – Broadband SANS

Shear Banding in CTAB wormlike micelles providing confirmaCon of rheological model. (Helgeson et al. (2009) J. Rheol 53, 727)

FLOW

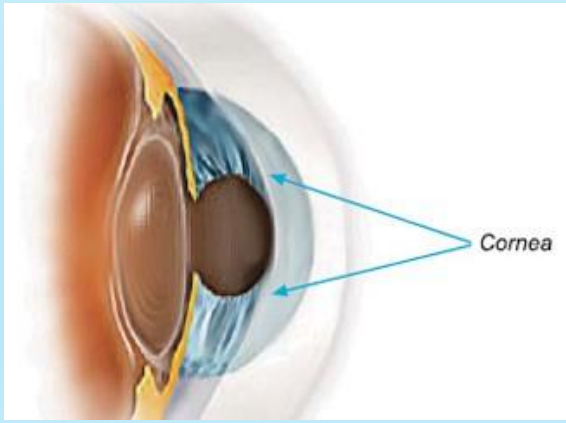


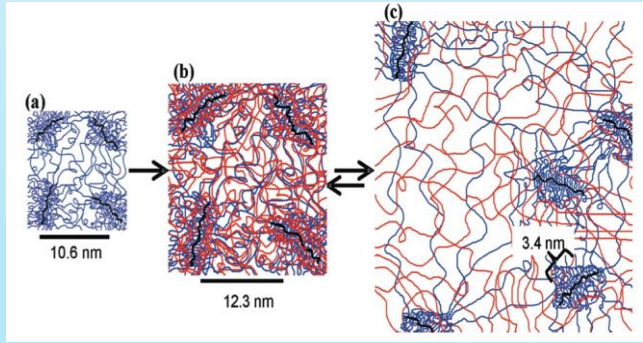


The flow of **complex fluids** through **complex geometries** is relevant to many industrical processes. There is a need to understand **structur effects of flow** both for pracCcal purposes and to compare with fluid flow models.

KINETICS

Gel structure forms over **mulDple length scales. KineDcs** of gelaCon can be rapid needing **sub–second** time resolution. Neutrons provide the structure of each component in the presence of the other.

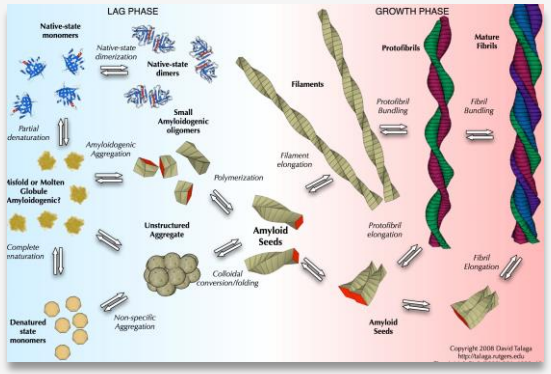




Swelling of a double network hydrogel designed for use as a cornea replacement. (Frank Group, Stanford)

LoKI – Broadband SANS

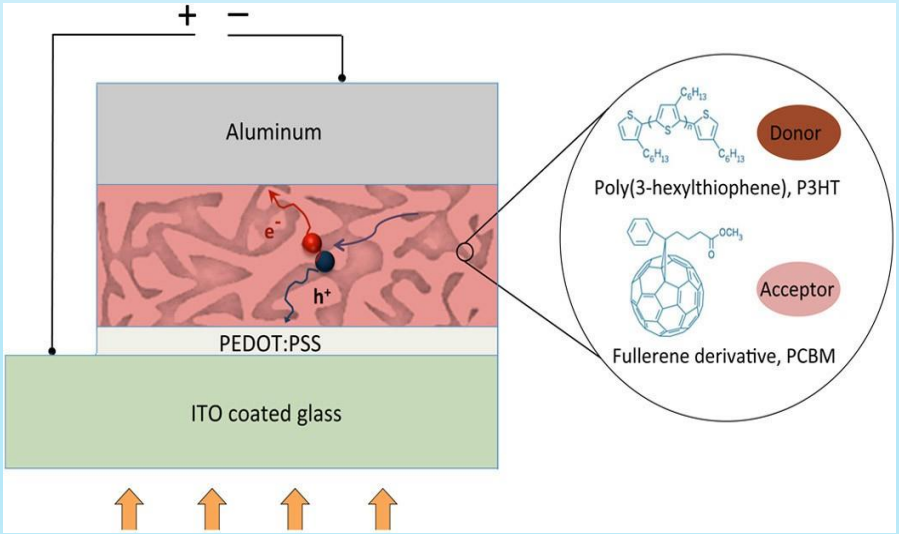
MULTI SCALE



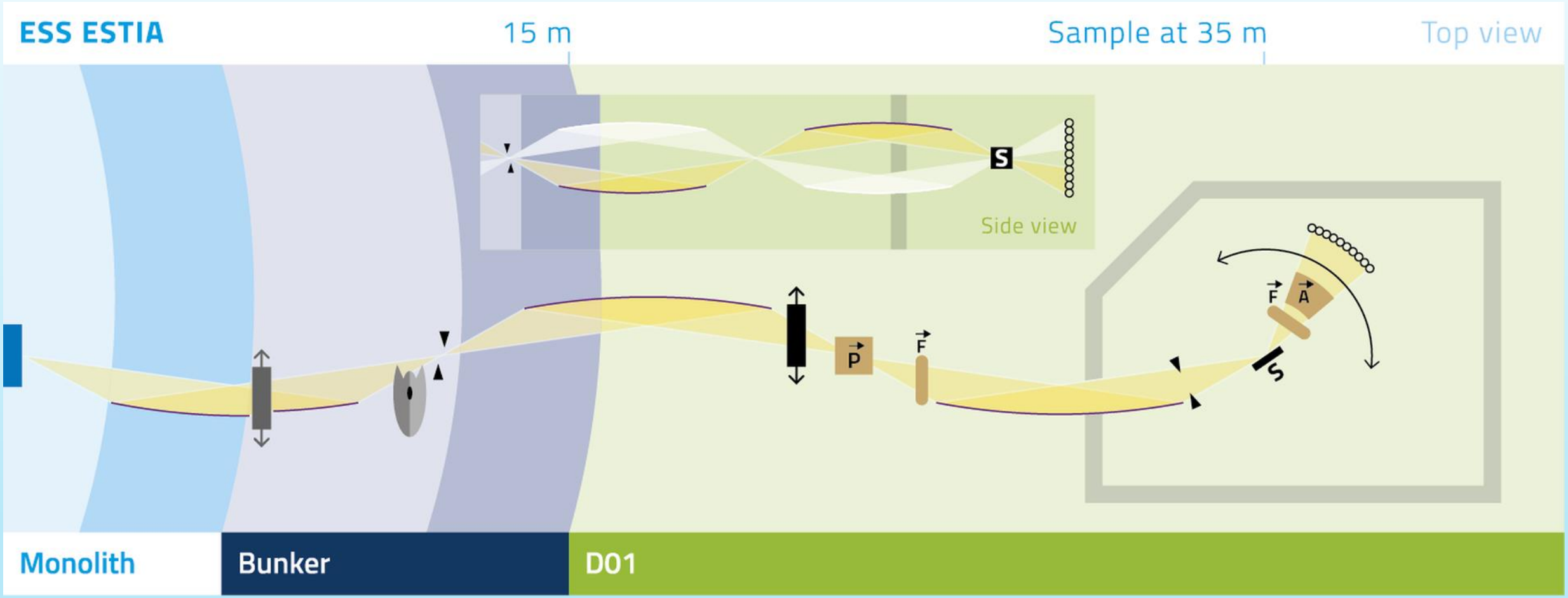
Amyloid fibril formation and growth is a **multi-length scale problem** and to understand methods of formation and inhibition the structural evolution must be observed.

DEVICES

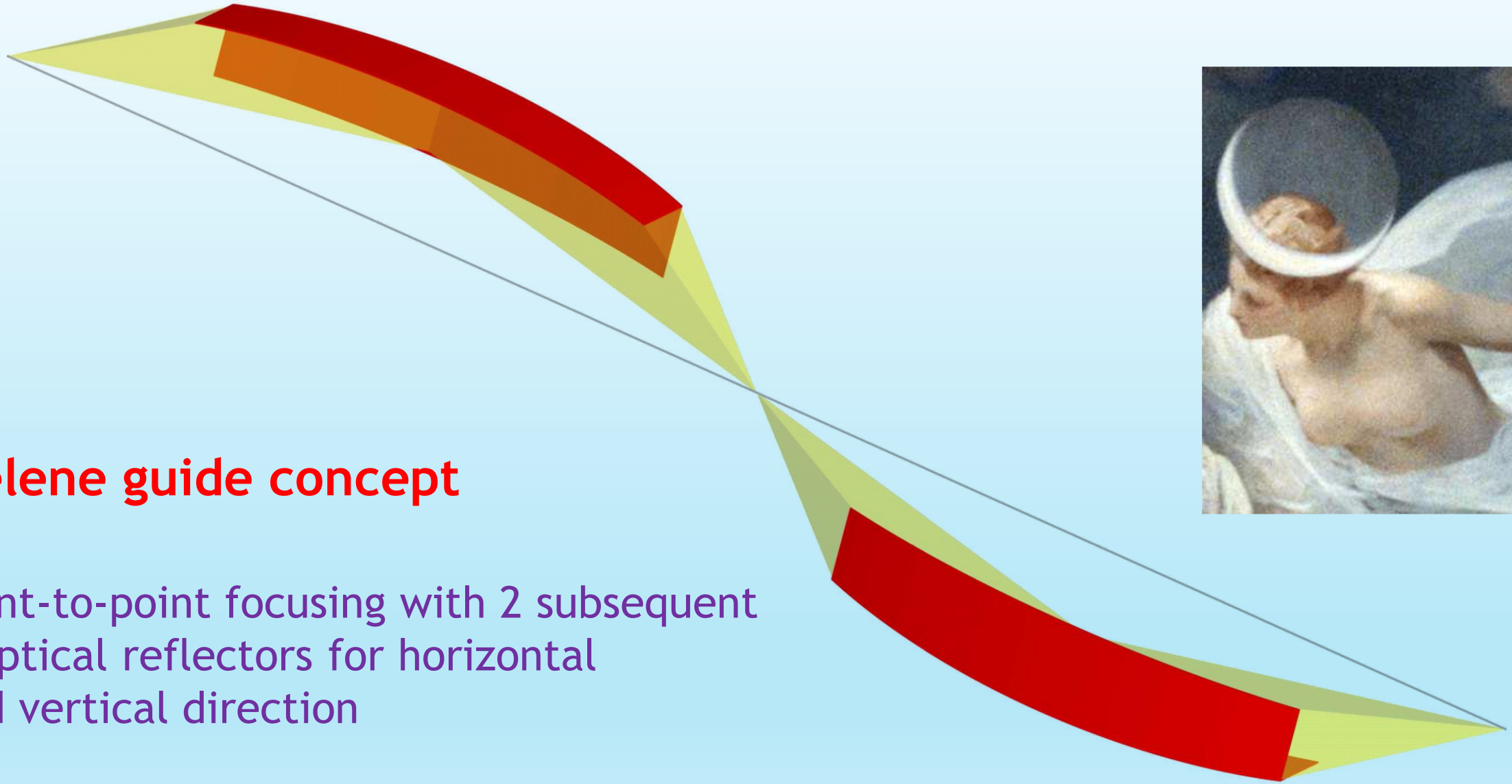
Organic Solar Cells promise to provide cheap and accessible solar energy. The **lifespan** and **efficiency** of the devices depends on the **nano–structure** polymer mixture. Understanding the **structural evolution** under operation guides development of new devices.



ESTIA – Focusing Reflectometer



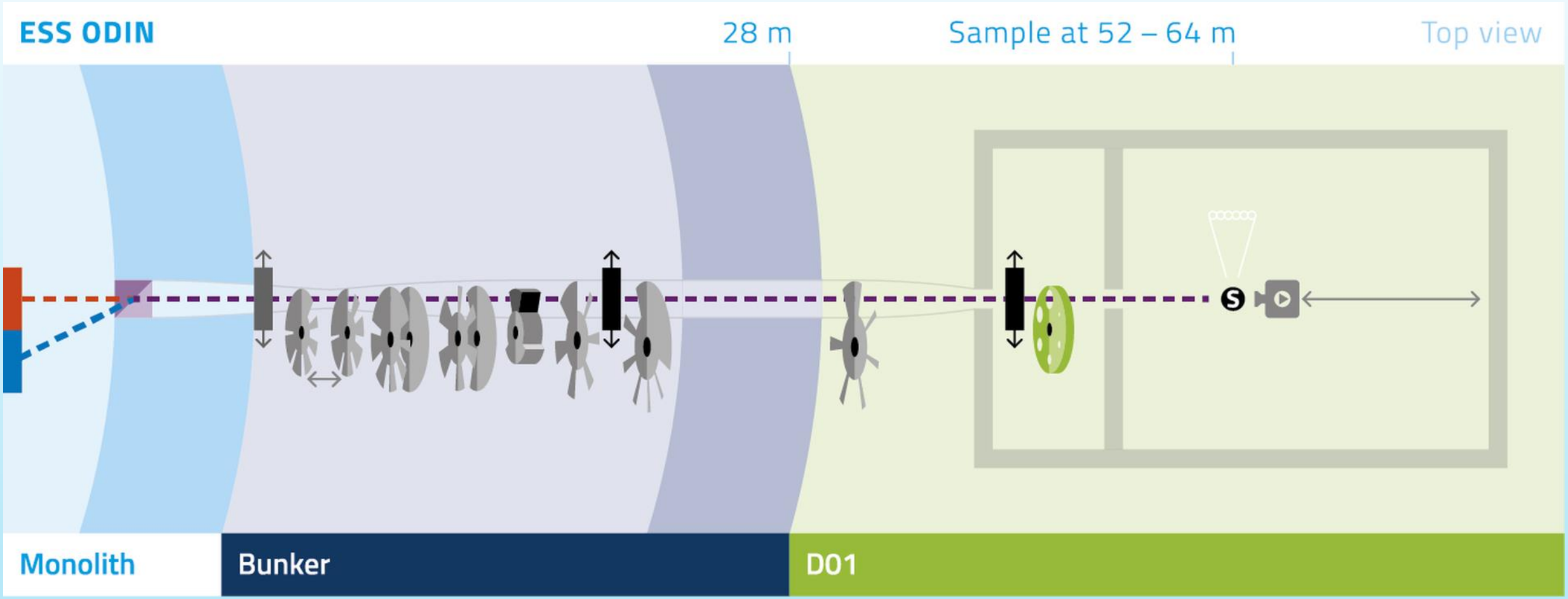
ESTIA – Selene guide concept



Selene guide concept

point-to-point focusing with 2 subsequent elliptical reflectors for horizontal and vertical direction

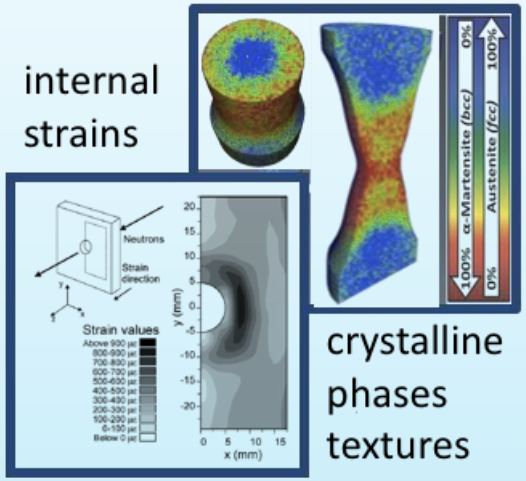
ODIN – Multipurpose Imaging



Neutron imaging is a real-space technique examining the inner structure of potentially highly complex components and samples by detecting the transmitted beam.

ODIN – Multipurpose Imaging

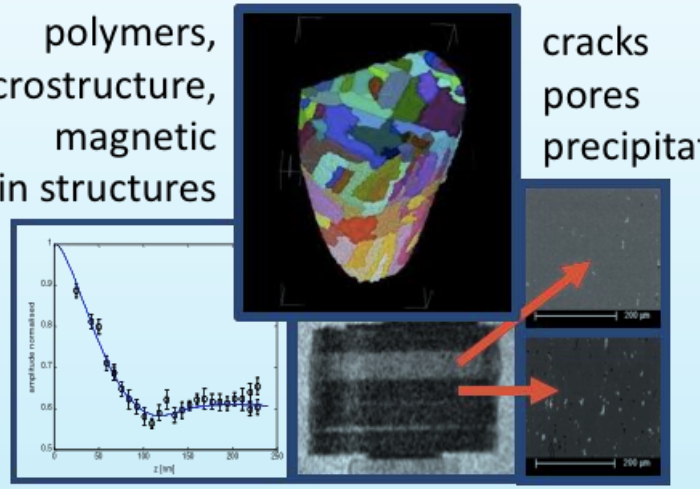
internal strains



crystalline phases textures

Diffraction regime

polymers, microstructure, magnetic domain structures



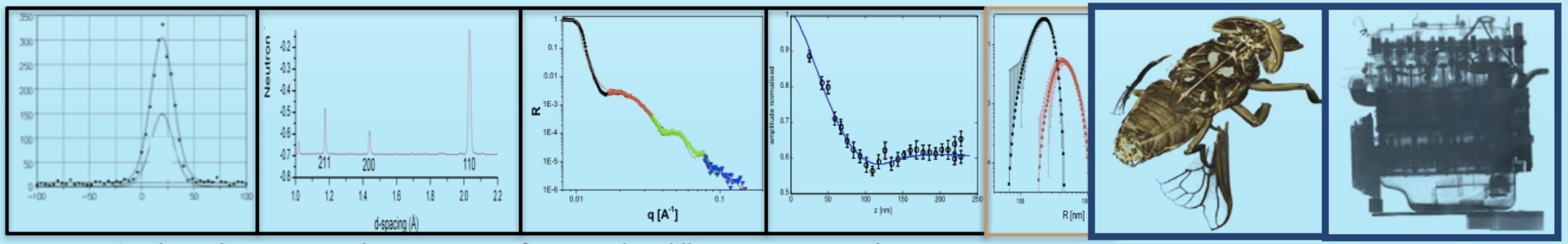
cracks pores precipitates

SANS and Dark-field imaging regime

Length scale in nm

0.01 0.1 0.3 1.0 3.0 10 100 1000 10000 100000

Conventional imaging regime



atomic and magnetic structures

organic molecules

surfaces and multilayers

inhomogeneities

viruses

cracks and voids

magnetic defects

micelles

critical phenomena

pharmaceuticals

proteins

internal strain

supermolecules

polymers

Systems and components

Konsorcjum «Neutrony dla polskiej nauki» koordynowane przez

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