The European Spallation Source:
The Next-Generation Neutron Science Facility

FASEM course

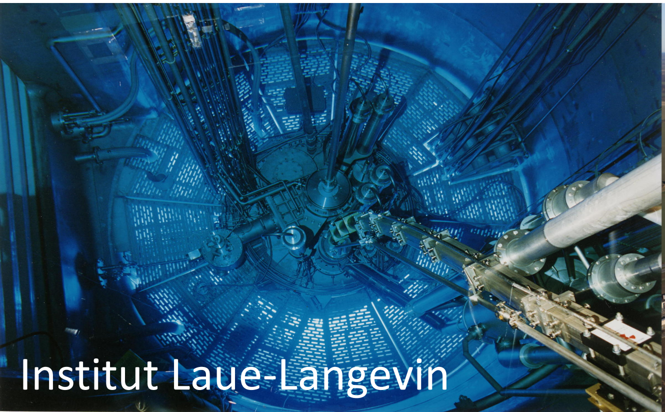
LINXS

16th May 2019

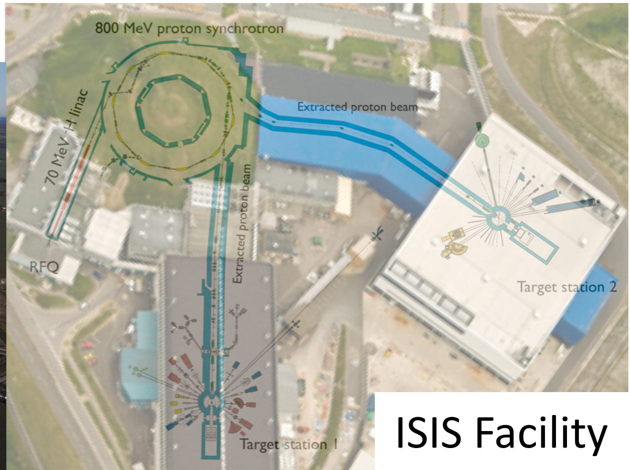
Ken Andersen, Neutron Instruments Division, European Spallation Source ERIC

Ken Holst Andersen – Curriculum Vitae

1988-1992	PhD in Physics in elementary excitations in superfluid ^{4}He from Keele University (UK) with ILL studentship
1992-1994	Post-doc at KENS (Japan) on percolating antiferromagnets
1995-1999	ILL (France) Instrument Scientist for D7 diffuse-scattering diffractometer with polarisation analysis
1999-2002	ISIS (UK) Instrument Scientist for OSIRIS backscattering spectrometer with powder diffraction
2002-2010	ILL (France) Head of Neutron Optics Laboratory
2010-	ESS (Sweden) Neutron Instruments Division Head
2012-	University of Copenhagen Adjunct Professor


Institut Laue-Langevin

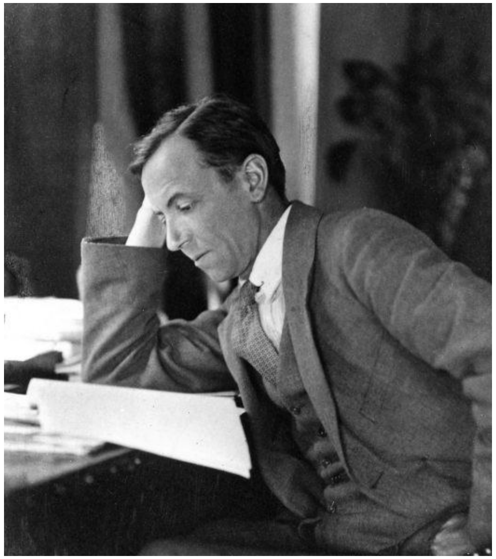

European Spallation Source



ISIS Facility

The first neutron source

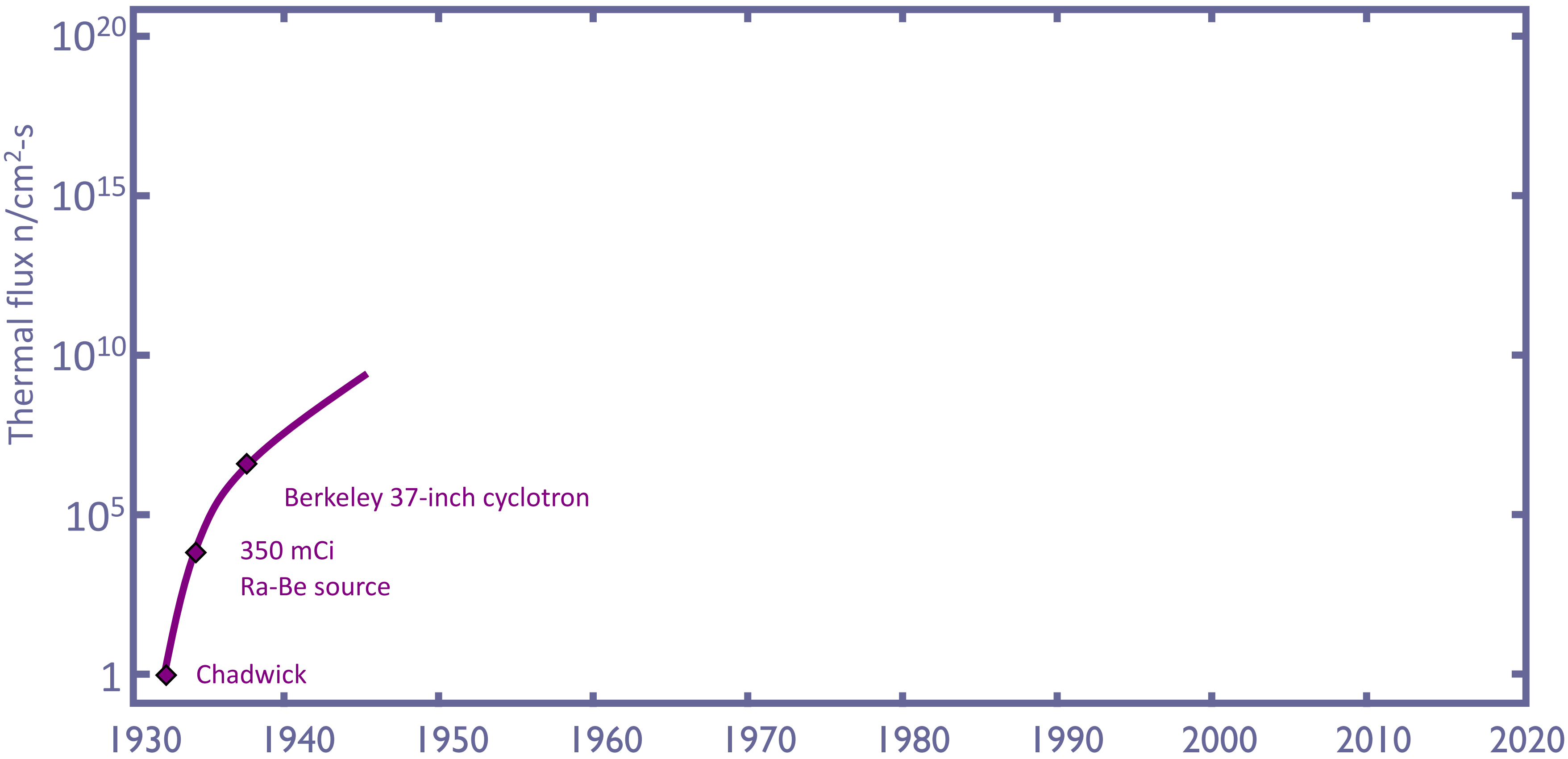
EUROPEAN SPALLATION SOURCE



James Chadwick:
used Polonium as alpha emitter on Beryllium

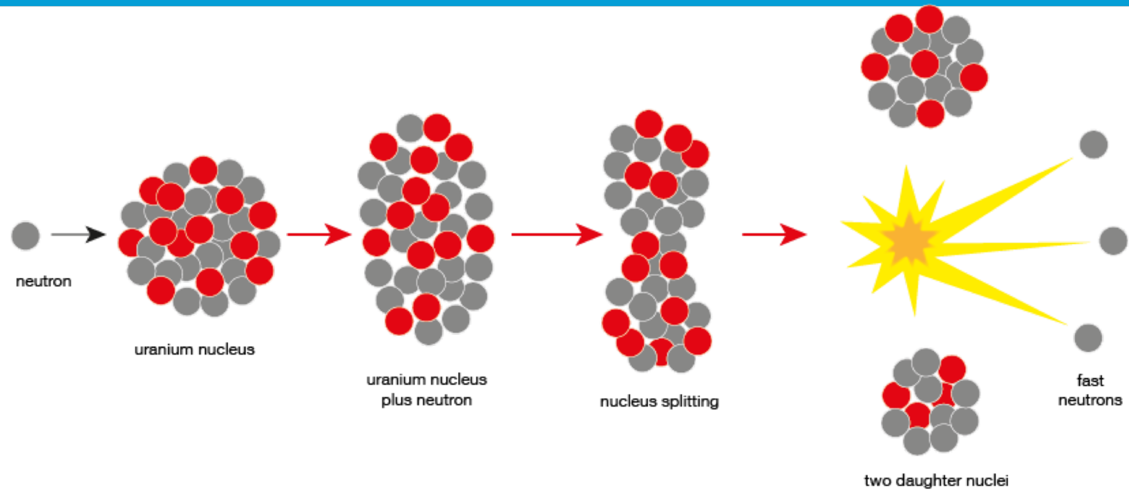
$$^{4}He + {}^{9}Be \rightarrow {}^{12}C + \text{neutron}$$

Evolution of neutron sources



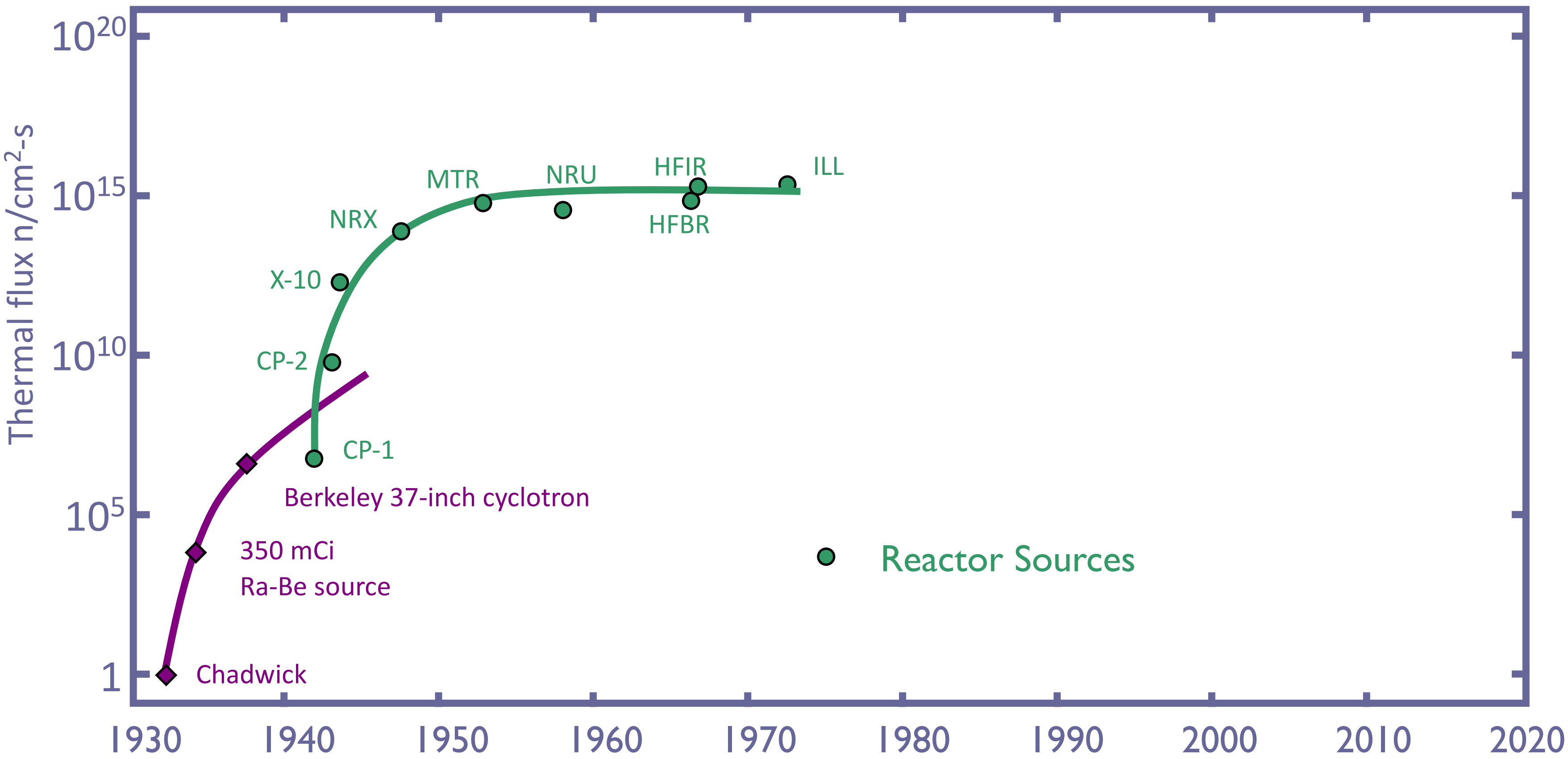
(Updated from *Neutron Scattering*, K. Sköld and D. L. Price, eds., Academic Press, 1986)

Nuclear Fission



Evolution of neutron sources

EUROPEAN SPALLATION SOURCE



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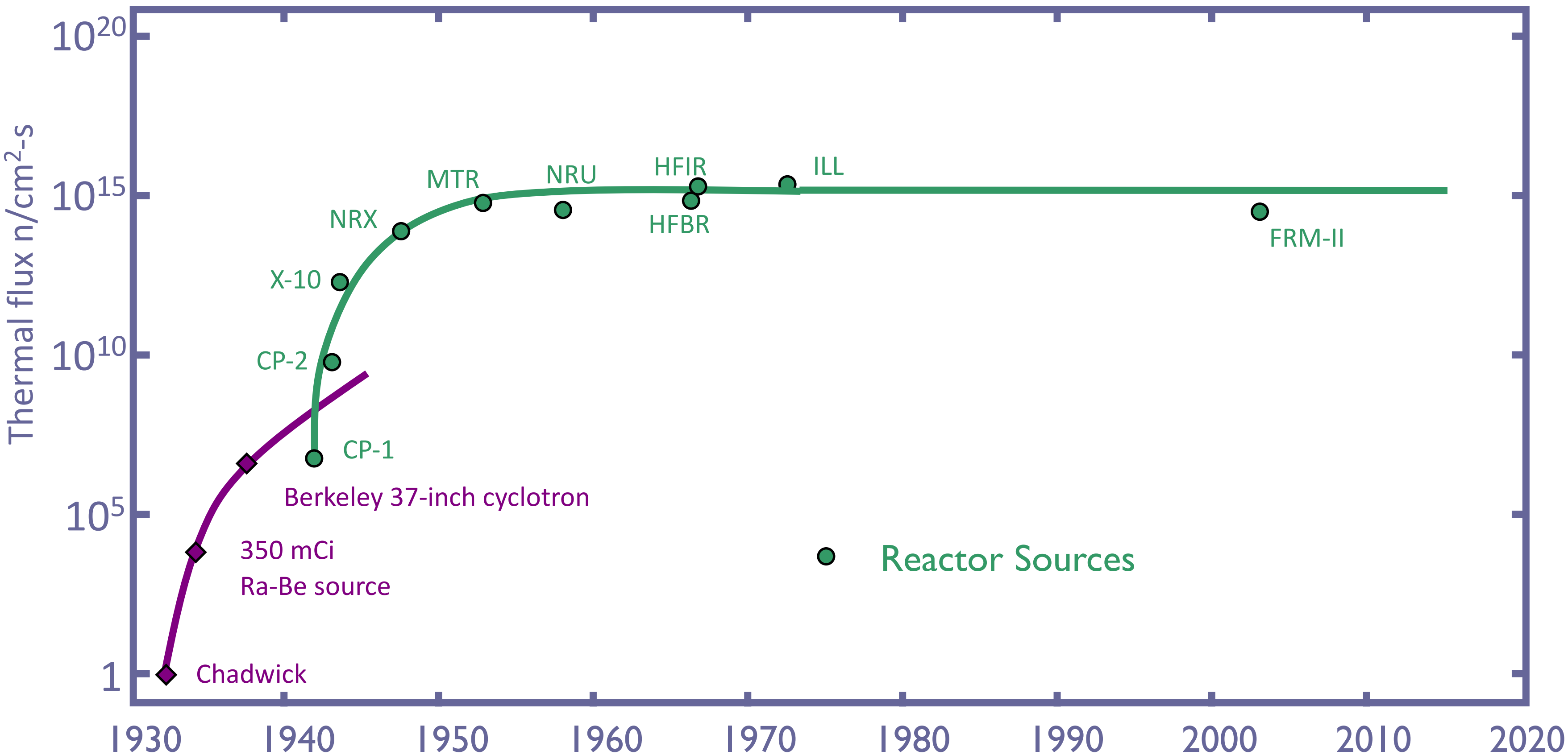
Evolution of neutron sources

EUROPEAN SPALLATION SOURCE



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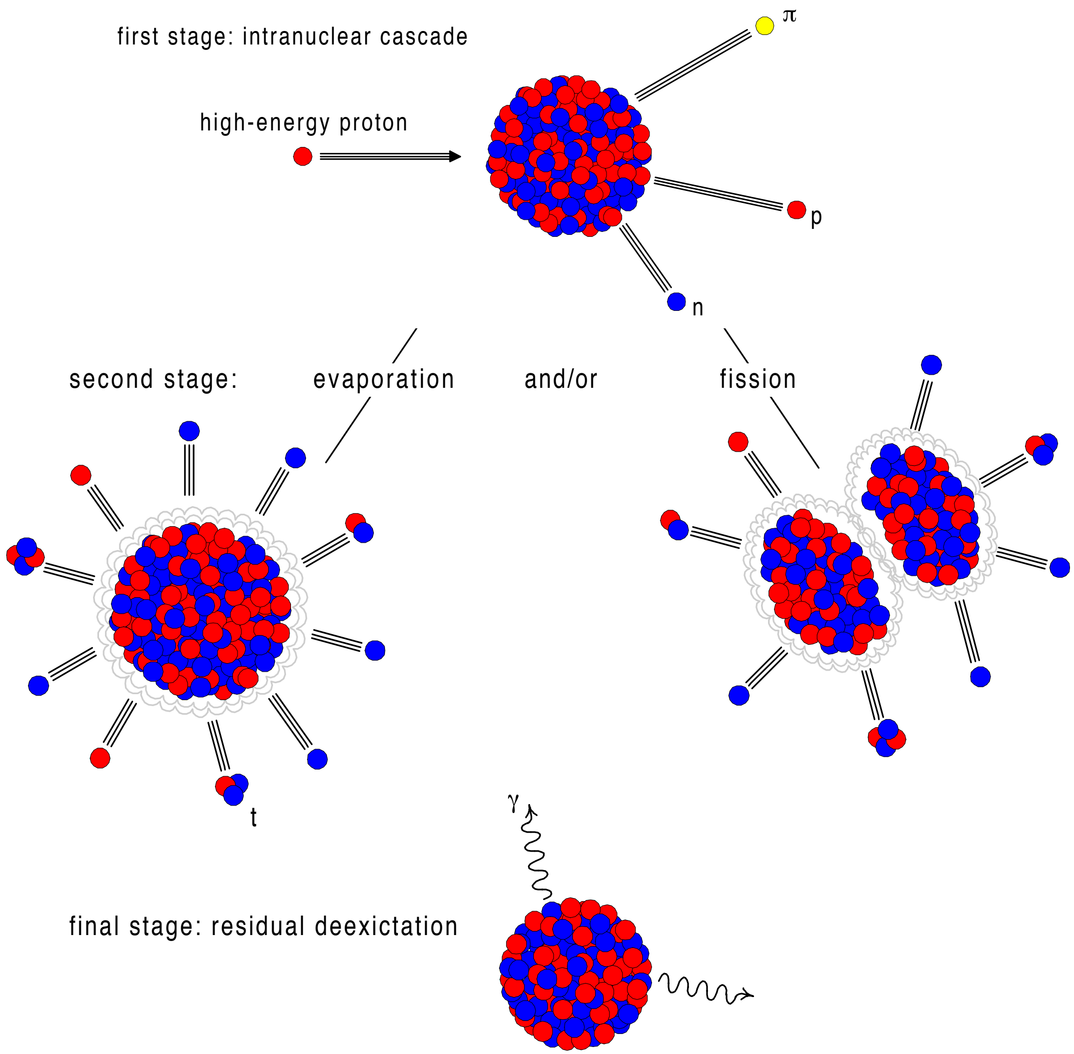
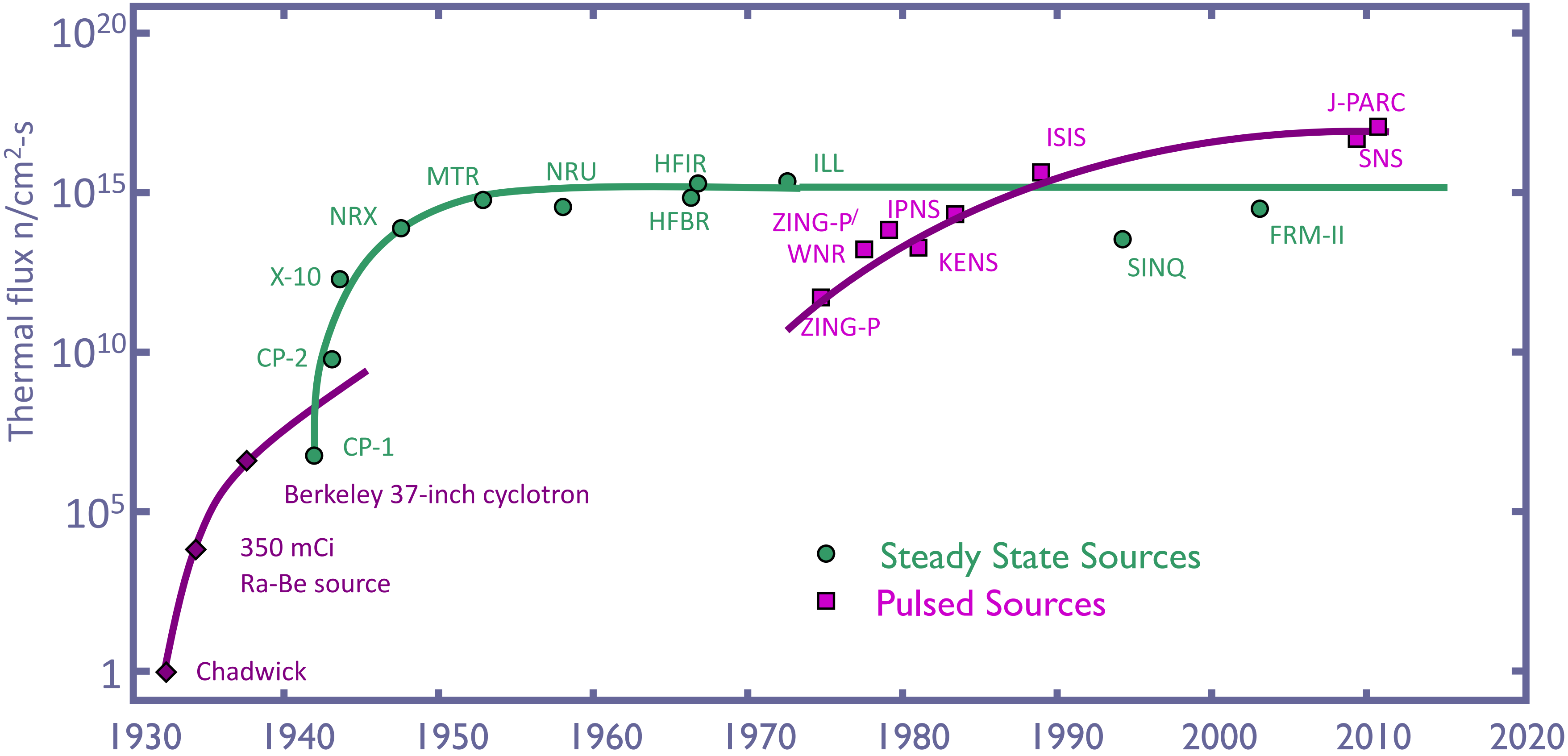
Nuclear Spallation



Evolution of neutron sources



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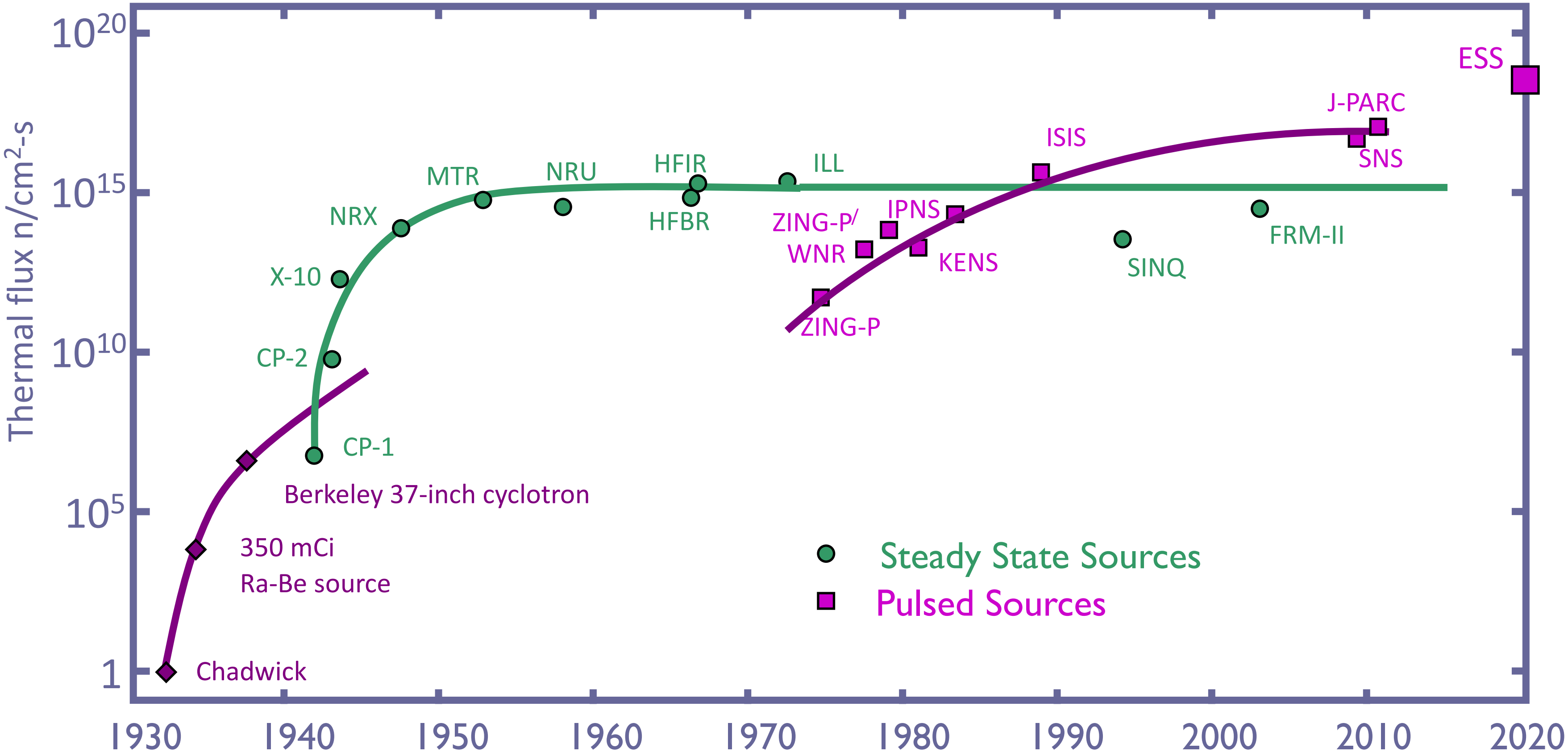

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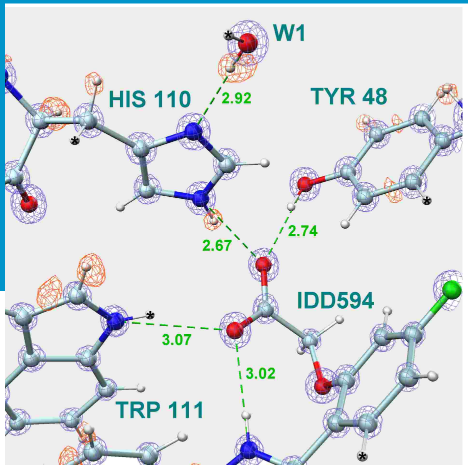
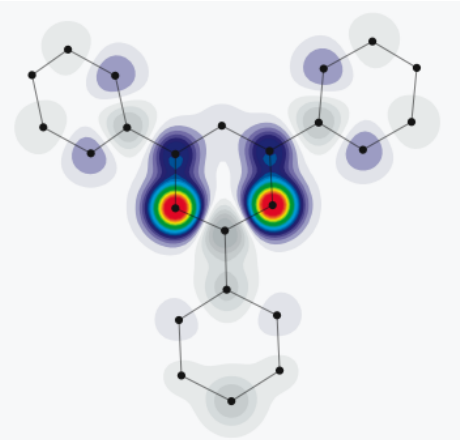
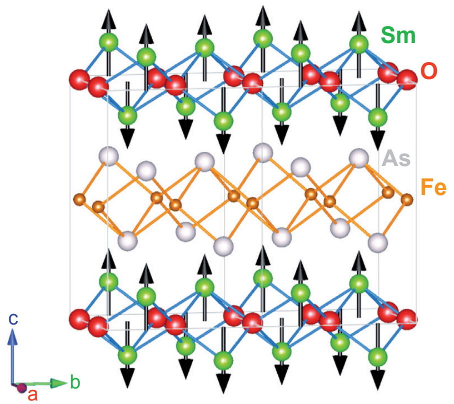
Neutrons are special

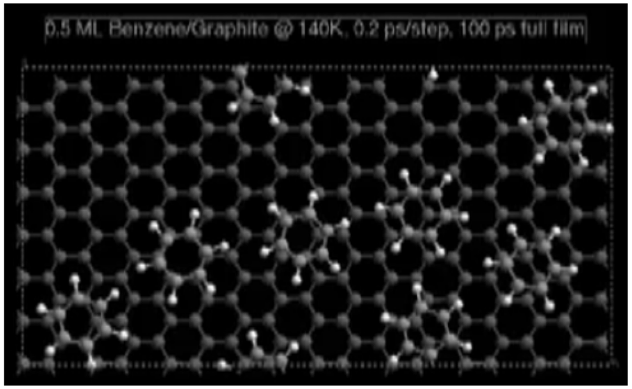


- charge neutral: deeply penetrating ... except for some isotopes
- nuclear interaction: cross section depending on isotope (not Z), sensitive to light elements.
- spin S = 1/2: probing magnetism
- unstable $n \rightarrow p + e + \underline{\nu}_e$ with life time $\tau \sim 900s$, $I = I_0 \; e^{-t/\tau}$
- mass: n ~p; thermal energies result in non-relativistic velocities.
  E = 293 K = 25 meV,
  v = 2196 m/s , λ = 1.8 Å

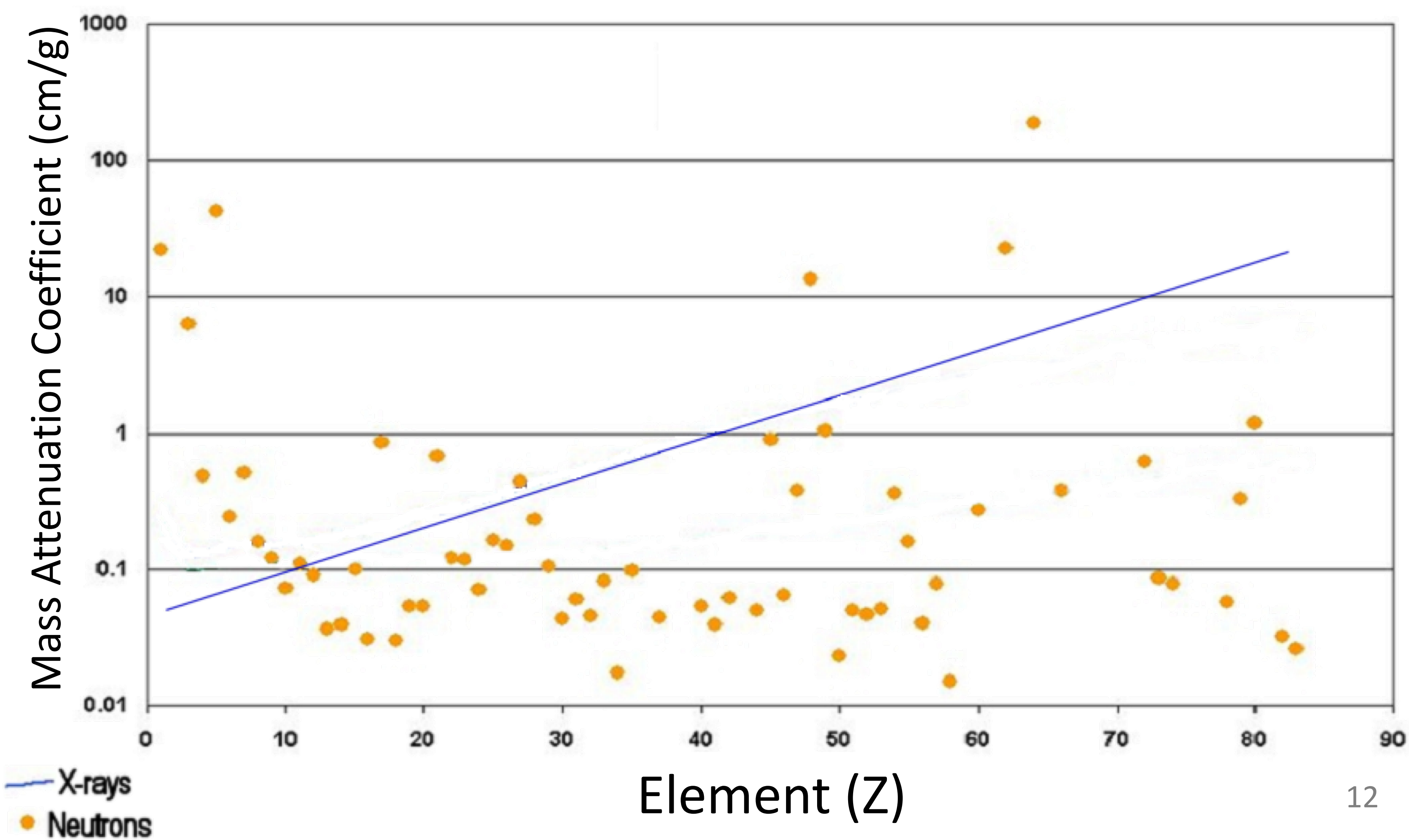




WHERE ARE THE ATOMS AND WHAT DO THEY DO?

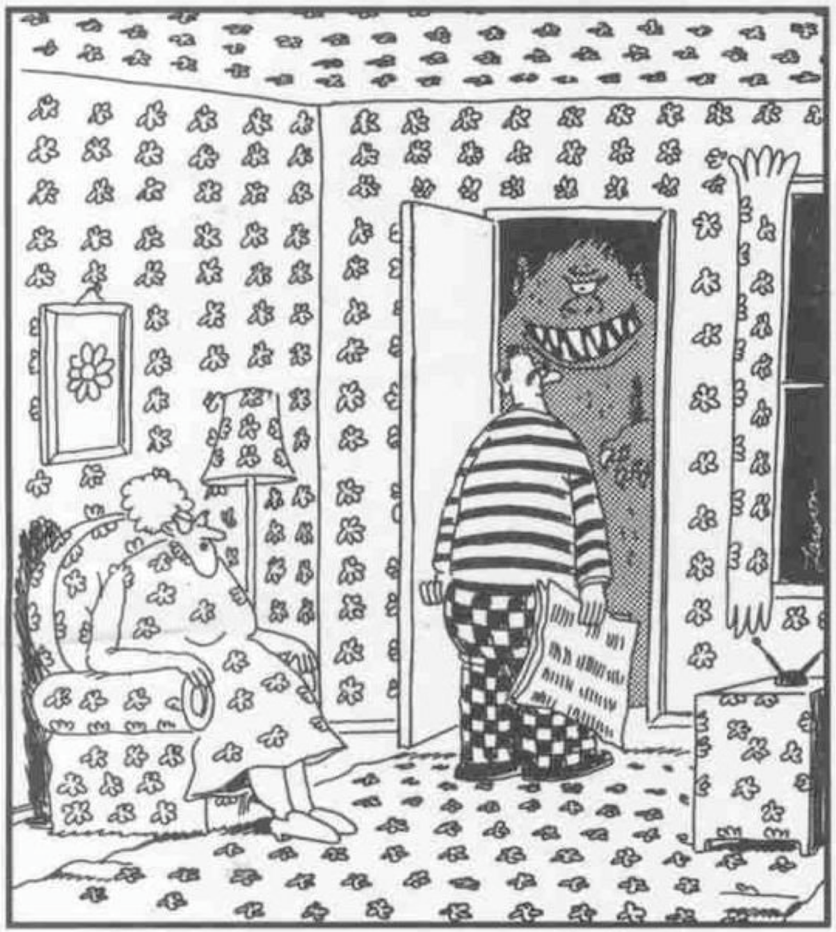


Why neutrons?



Contrast variation

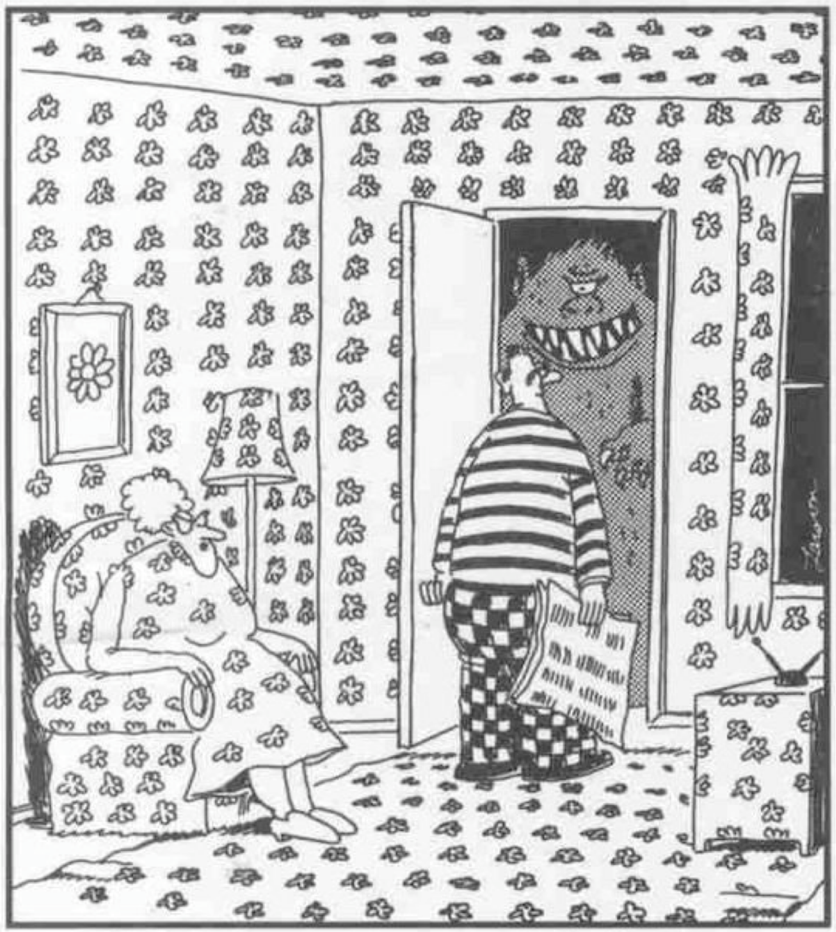
EUROPEAN SPALLATION SOURCE



When the monster came, Lola, like the peppered moth and the arctic hare, remained motionless and undetected. Harold, of course, was immediately devoured.

Contrast variation

EUROPEAN SPALLATION SOURCE



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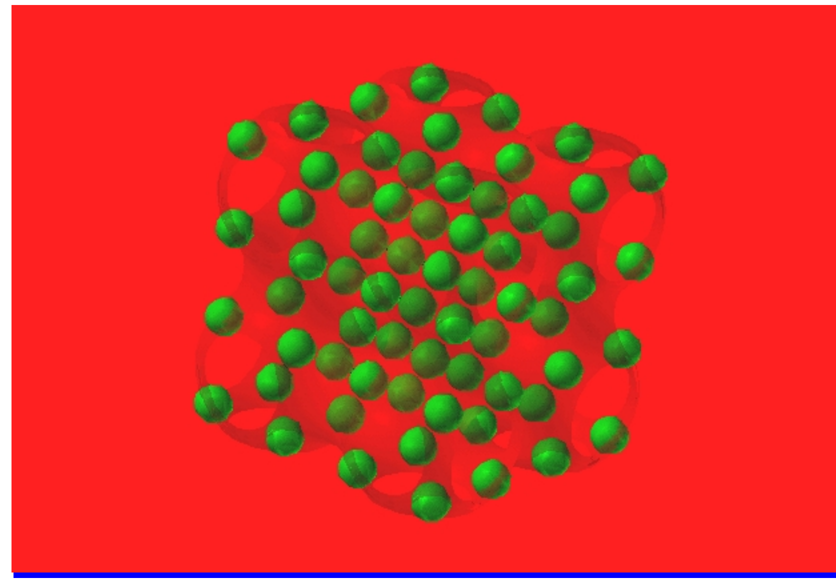
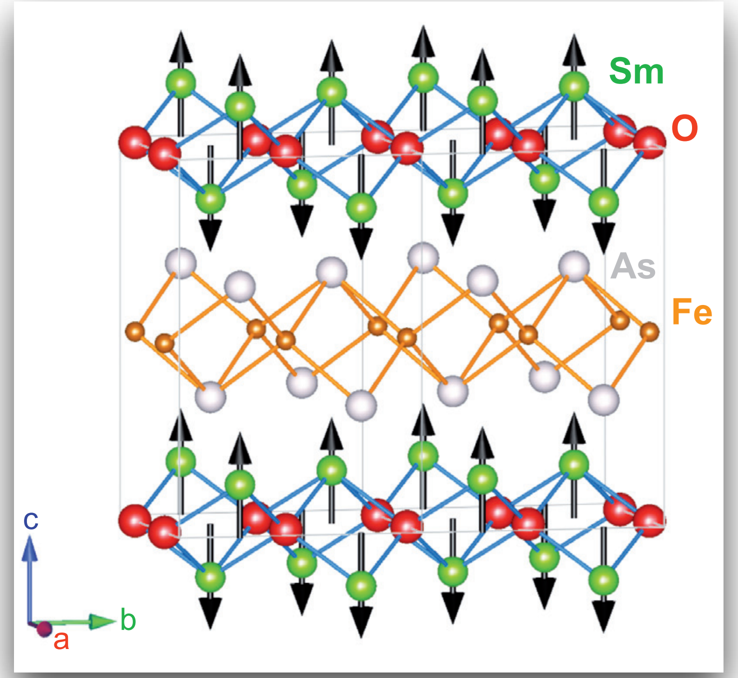


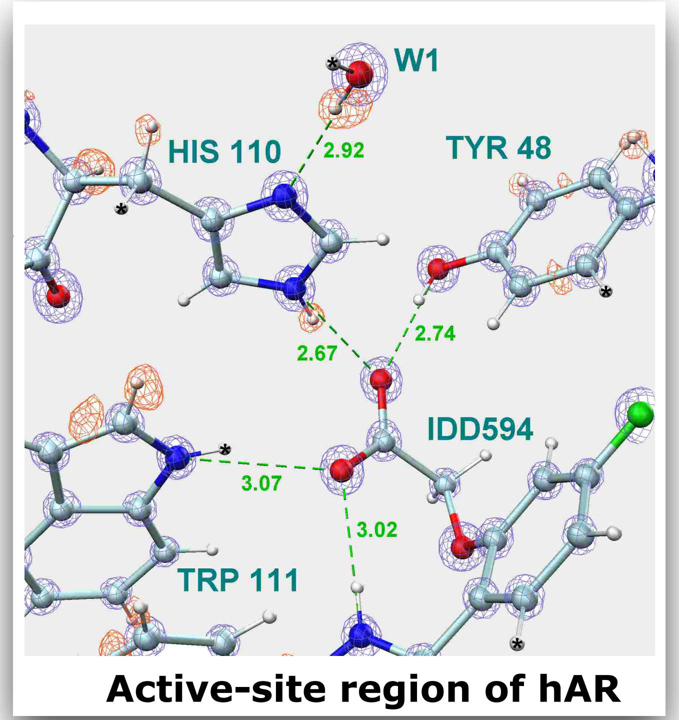
e.g. proteins in a deuterated lipid matrix: by changing solvent from H_2O to D_2O can mask out lipid contribution.

Contrast variation with stable Deuterium isotopes can selectively highlight features in organic & biological materials

Examples for Neutron Diffraction



magnetic structures



hydrogen in organic materials

Neutron Spectroscopy discovers when superconductivity and magnetism (maybe) fall in love

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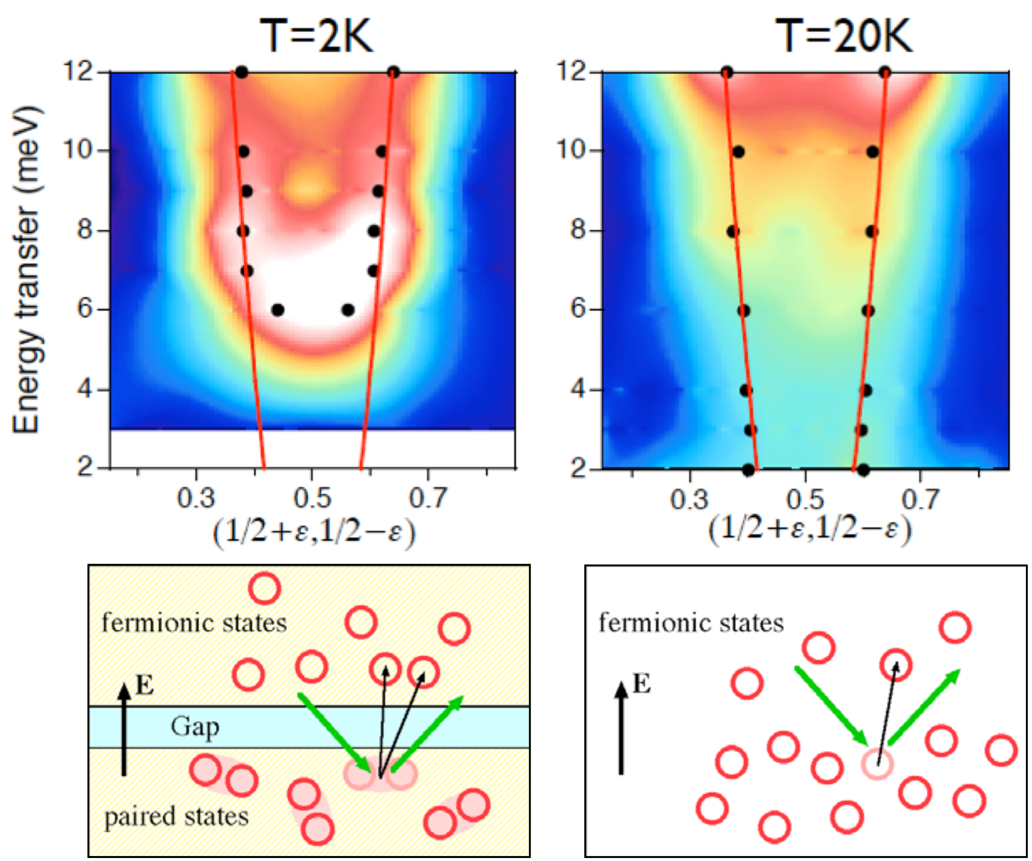
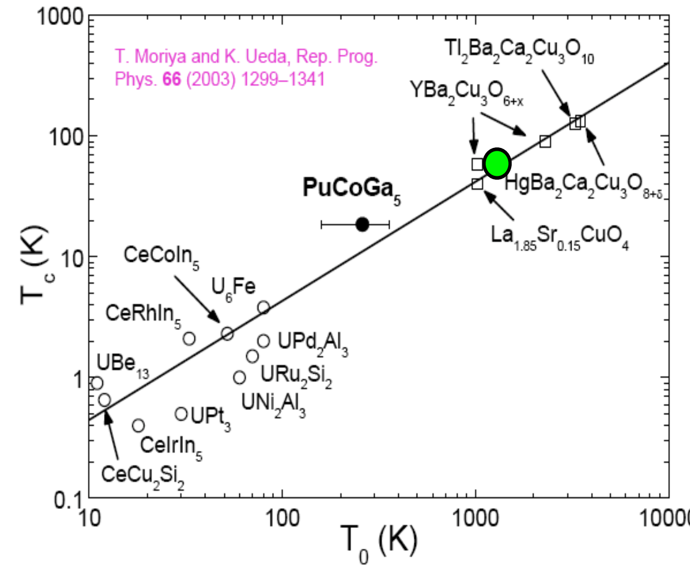
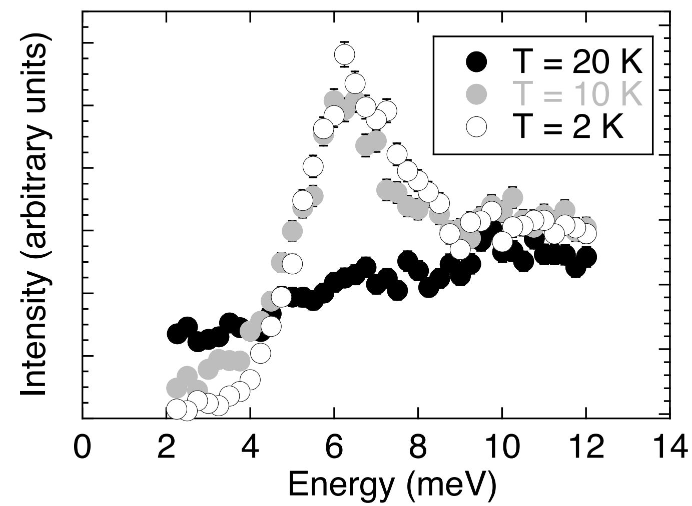
Magnetic and superconducting energy scales are related.
Neutrons see magnetism but no superconductivity (directly)
Though they discover the symmetries and the coupling.



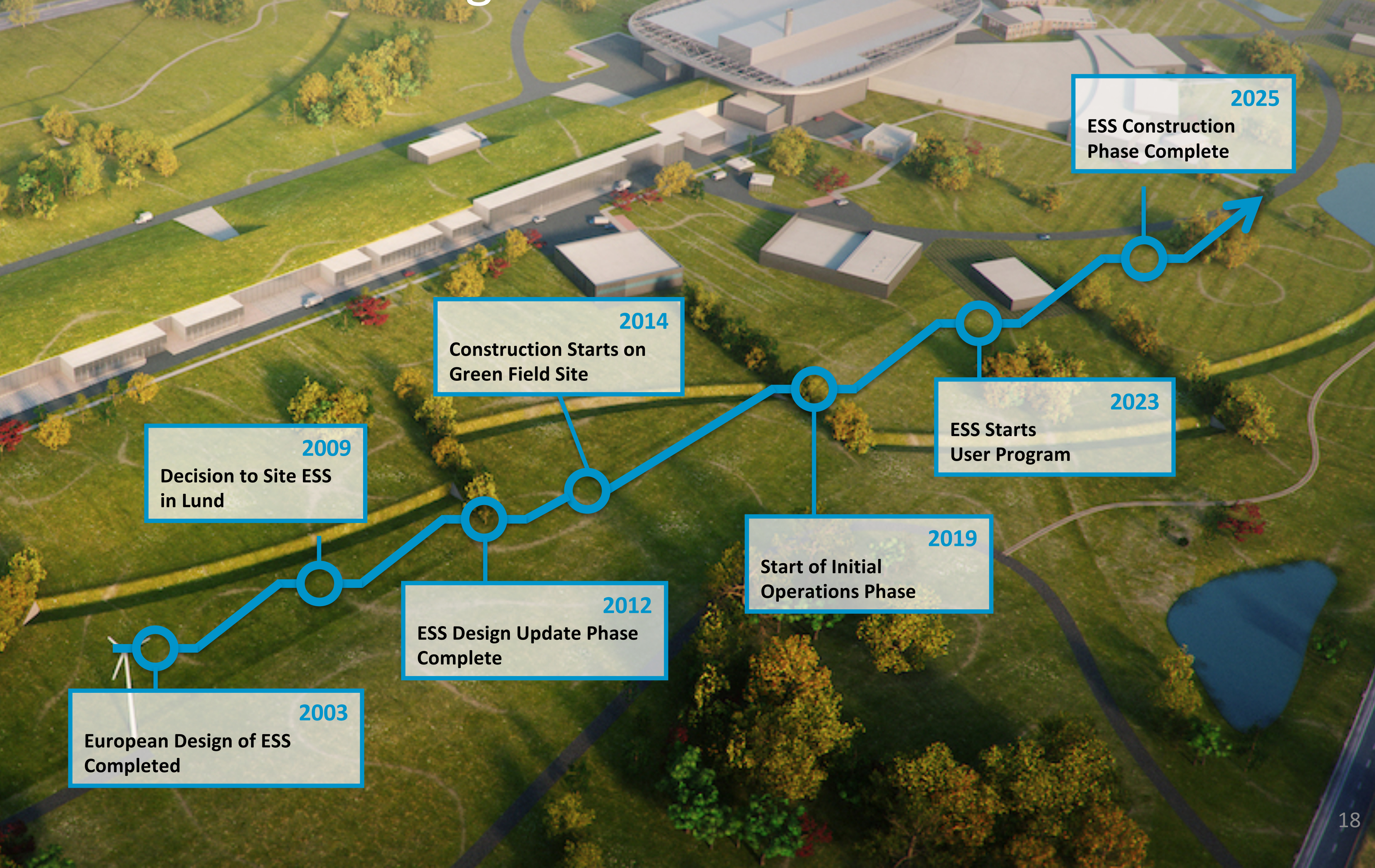




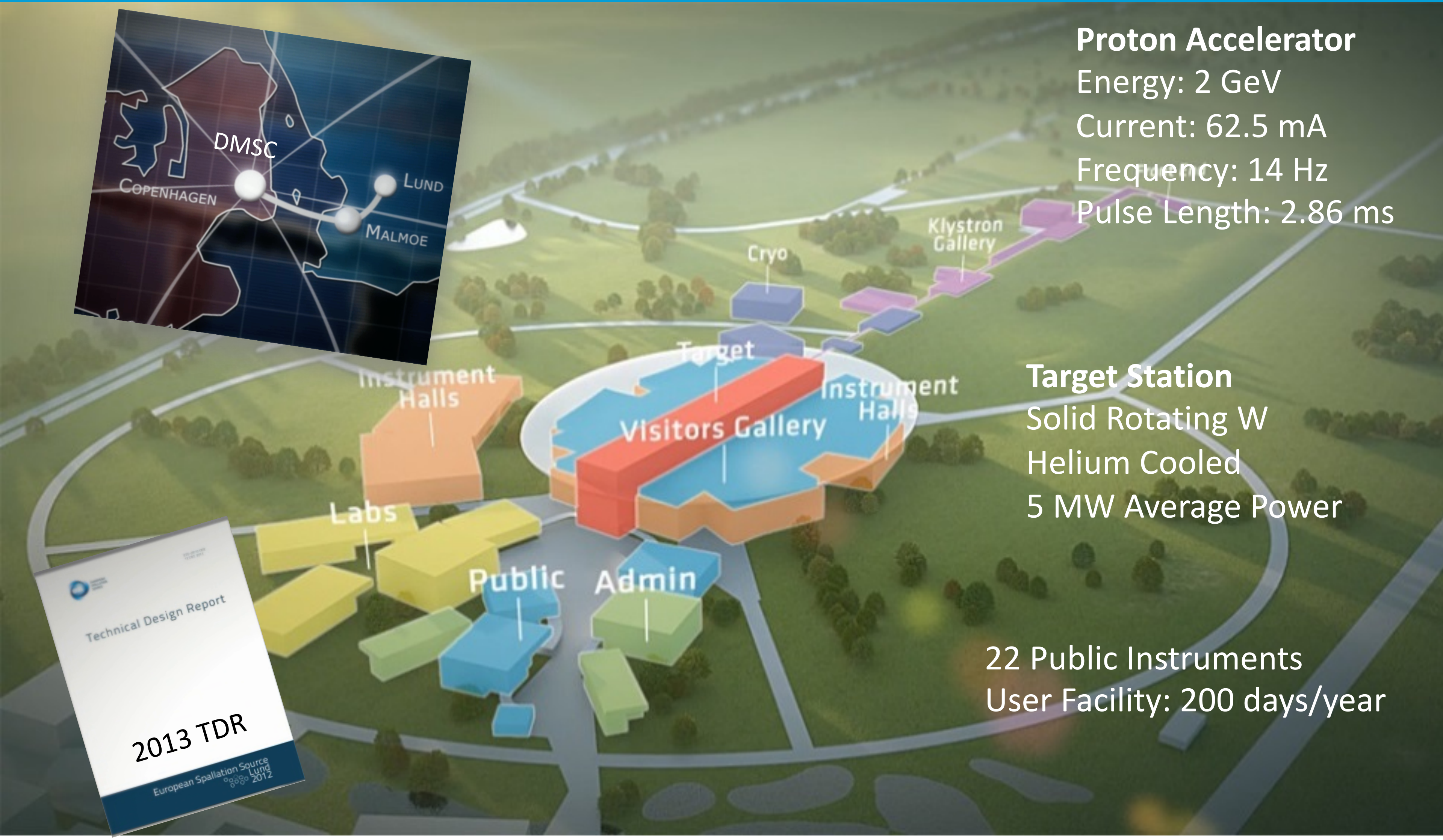

Lighting
New materials
Solar energy
Food
Medicine
Tailor made materials
Mobile phones
Cosmetics
Pacemakers
Implants
Transportation
Geo science
Bio fuels

Journey to deliver the world's leading facility for research using neutrons

EUROPEAN SPALLATION SOURCE



The ESS Project



Proton Accelerator
Energy: 2 GeV
Current: 62.5 mA
Frequency: 14 Hz
Pulse Length: 2.86 ms

Target Station
Solid Rotating W
Helium Cooled
5 MW Average Power

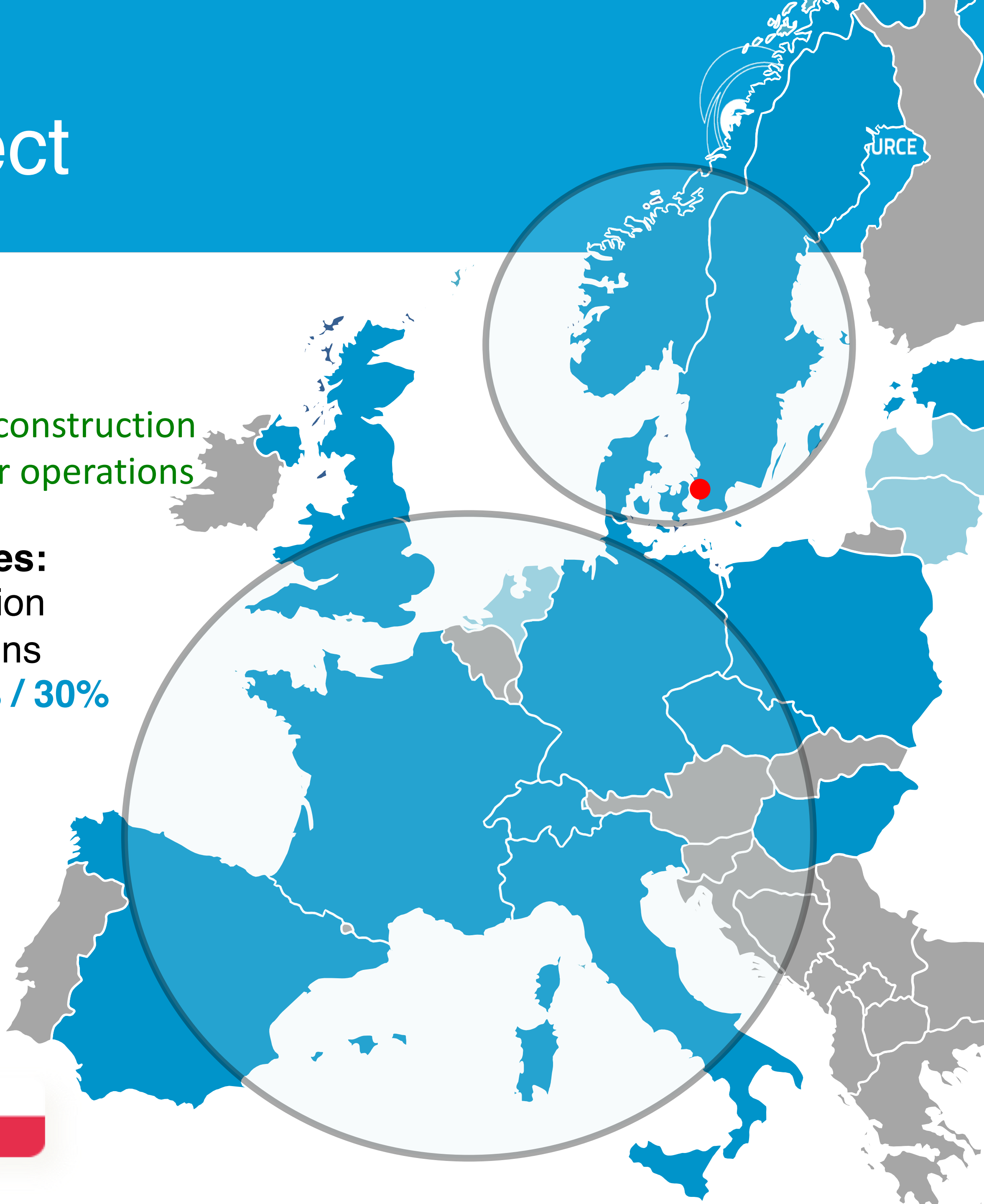
22 Public Instruments
User Facility: 200 days/year

The ESS Project

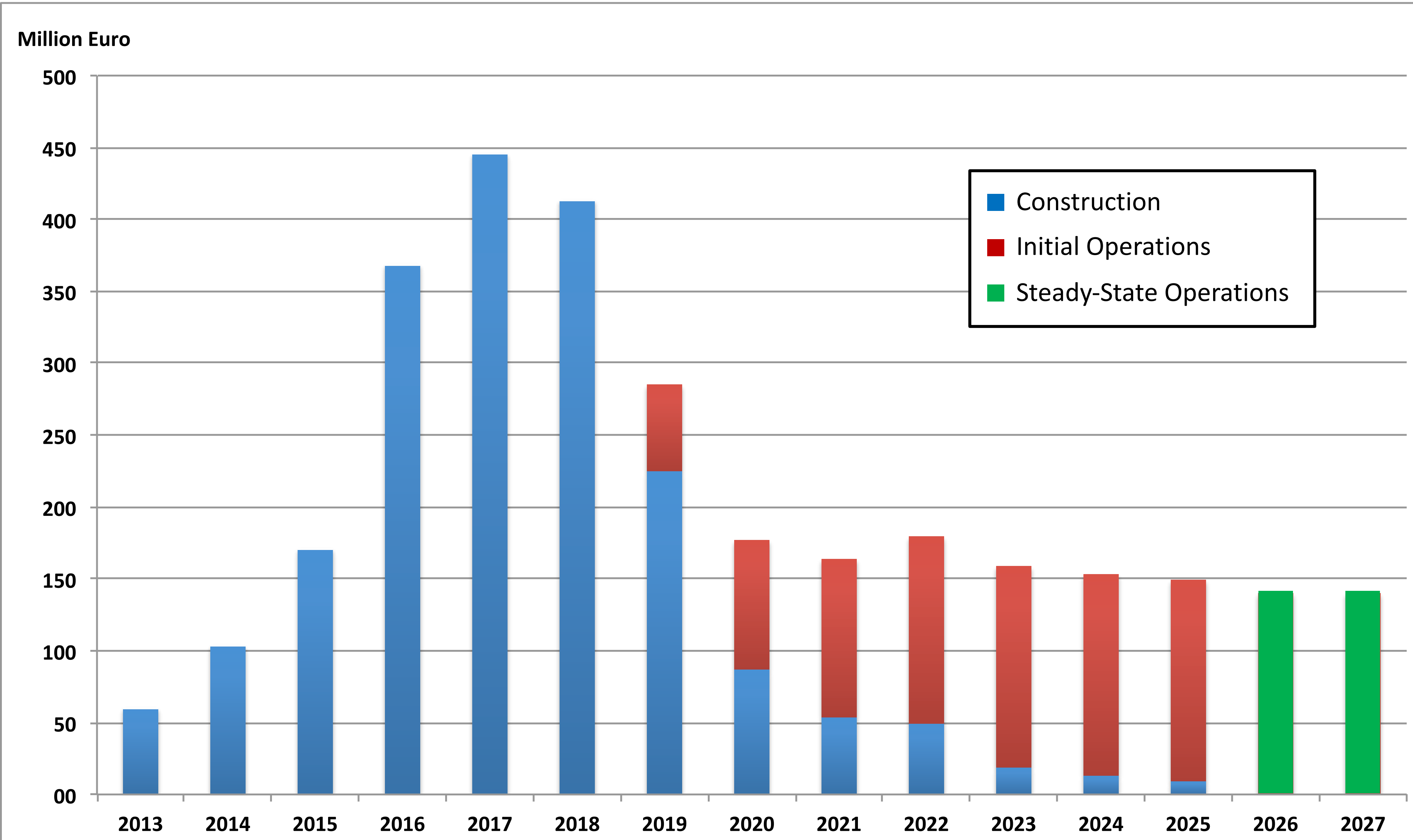
Sweden and Denmark:
47,5% Construction
15-20% Operations
Cash ~100%

1843 M€ construction
140 M€/yr operations

Partner Countries:
52,5% Construction
80-85% Operations
IKC/Cash ~ 70% / 30%



Construction and Operations Budgets



Organisation and People

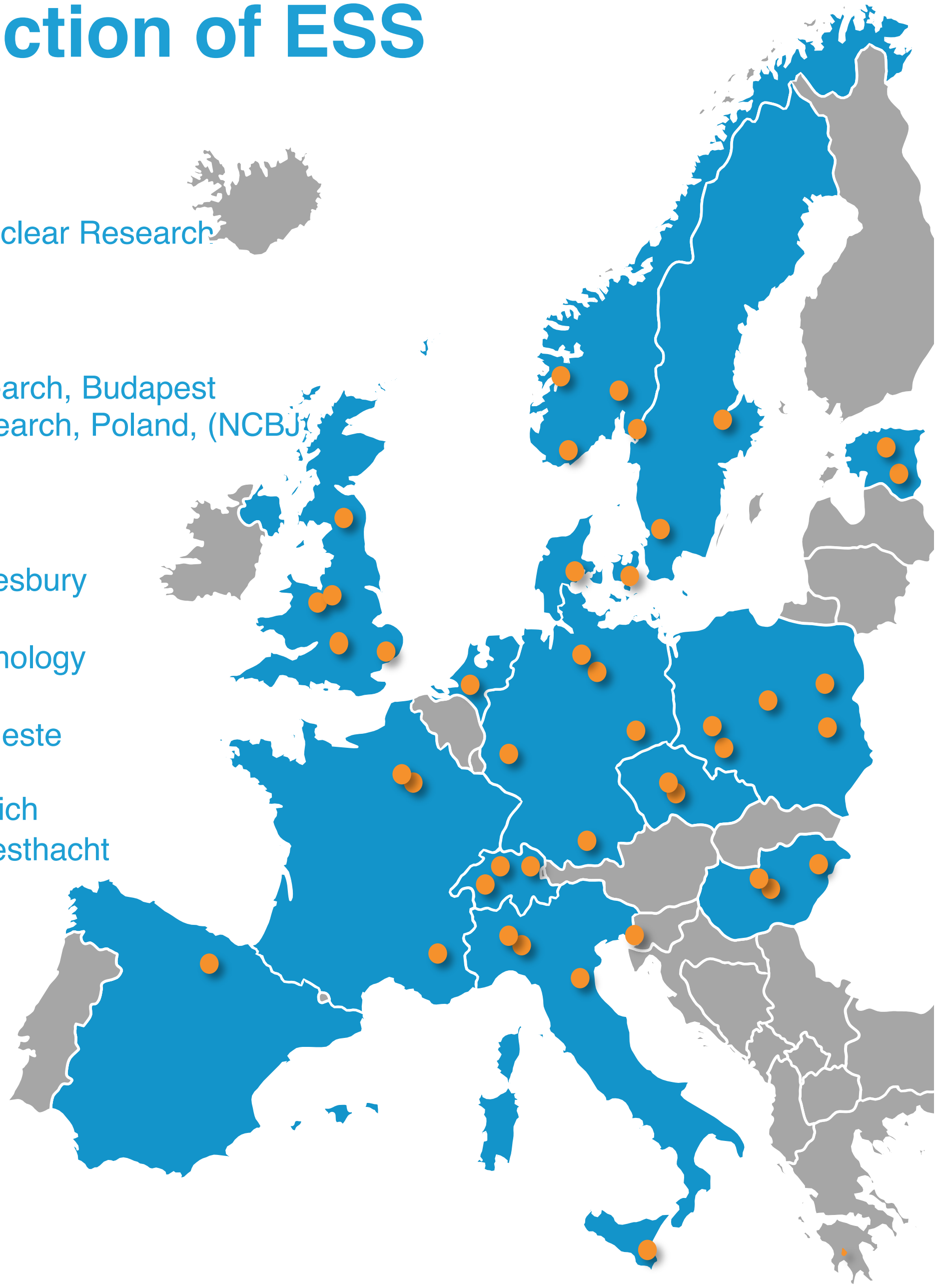
600
Employees

50
Nationalities

100
Collaborating Institutions

Partner institutions delivering the design & construction of ESS

Aarhus University
Atomki - Institute for Nuclear Research
Agder University
Bergen University
CEA Saclay, Paris
Centre for Energy Research, Budapest
Centre for Nuclear Research, Poland, (NCBJ)
CERN, Geneva
CNR, Rome
CNRS Orsay, Paris
Cockcroft Institute, Daresbury
DESY, Hamburg
Delft University of Technology
Edinburgh University
Elettra – Sincrotrone Trieste
ESS Bilbao
Forschungszentrum Jülich
Helmholtz-Zentrum Geesthacht
Huddersfield University
IFJ PAN, Krakow
INFN, Catania
INFN, Legnaro
INFN, Milan



Institute for Energy Research (IFE)
Institut Laue-Langevin (ILL)
Rutherford-Appleton Laboratory, Oxford(ISIS)
Copenhagen University
Laboratoire Léon Brilouin (LLB)
Lodz University of Technology
Lund University
Nuclear Physics Institute of the ASCR
Oslo University
Paul Scherrer Institute
Roskilde University
Tallinn Technical Univesrsity
Technical University of Chemnitz
Technical University of Denmark
Technical University Munich
Science and Technology Facilities Council
University of Tartu
Uppsala University
WIGNER Research Centre for Physics
Wroclaw Univesrity of technology
Warsaw University of Technology
Zurich University of Applied Sciences (ZHAW)

Site Photos

EUROPEAN SPALLATION SOURCE

Site Photos

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May 2019
April 2019

https://europeanspallationsource.se/site-weekly-updates

ESS looking towards MAX IV and Lund University

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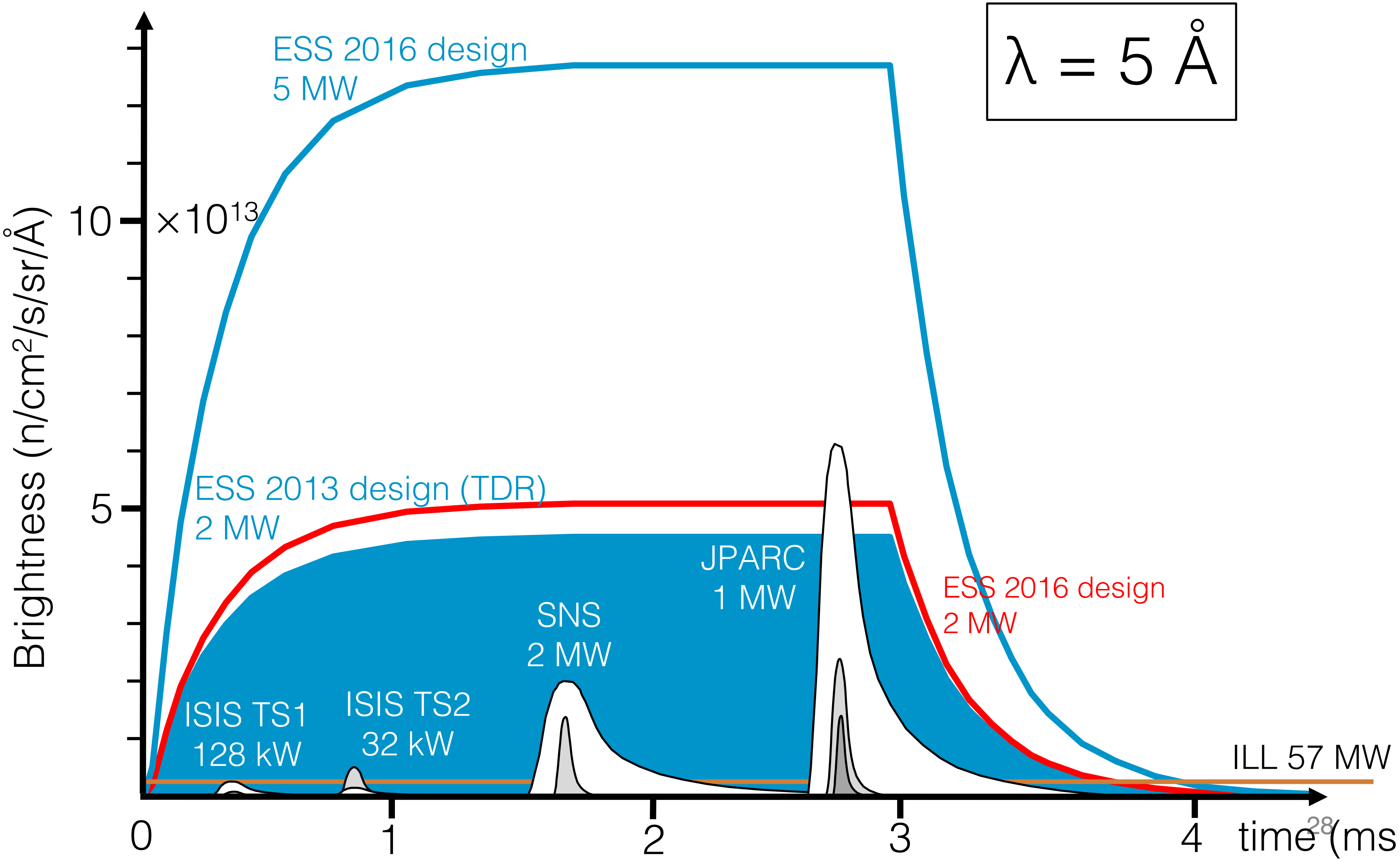
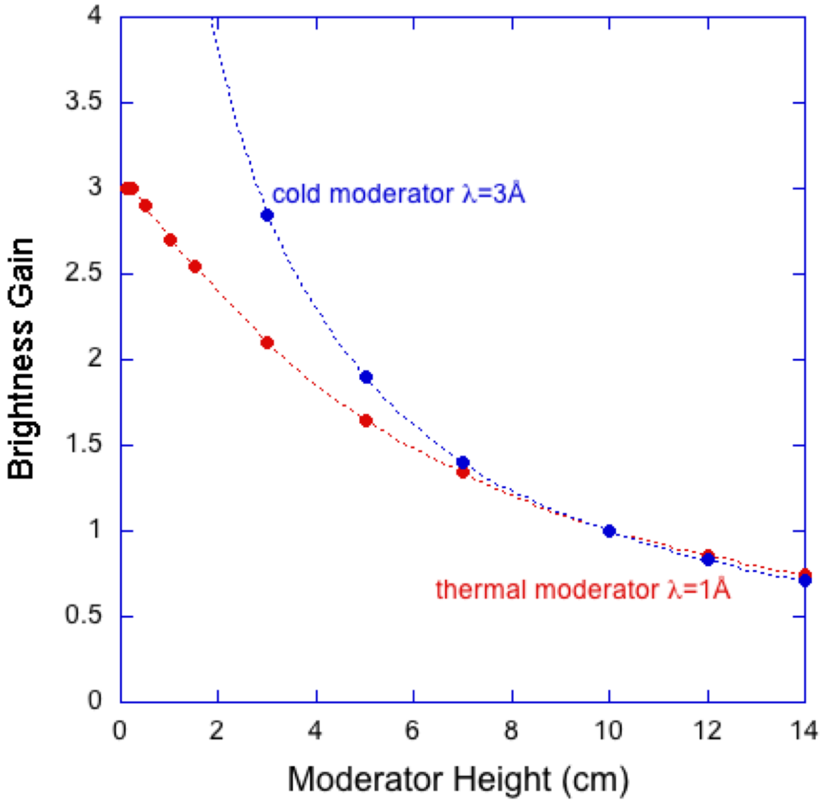
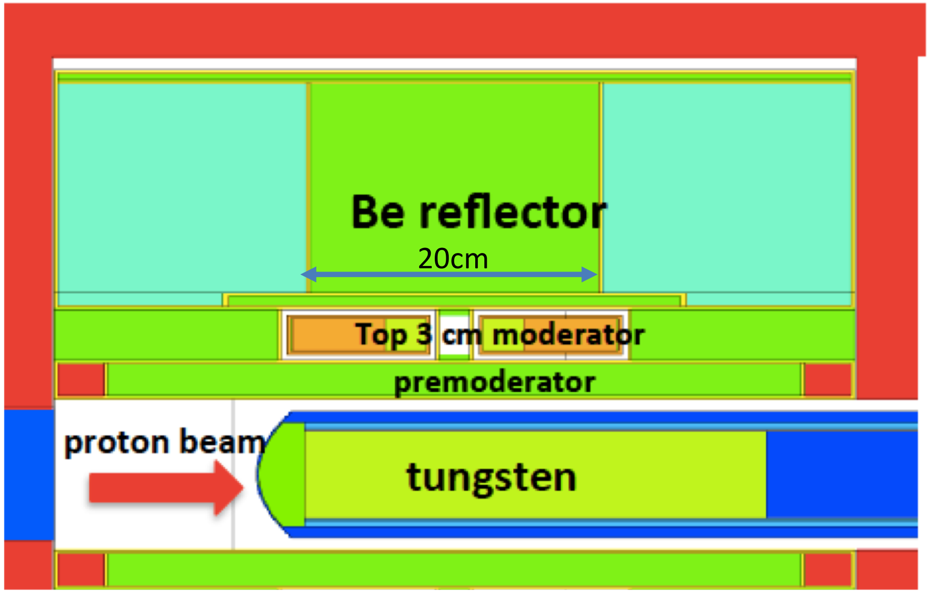
Long-pulse performance



ESS Moderator Design: Butterfly

<u>Above target</u>:
3cm tall butterfly moderator assembly





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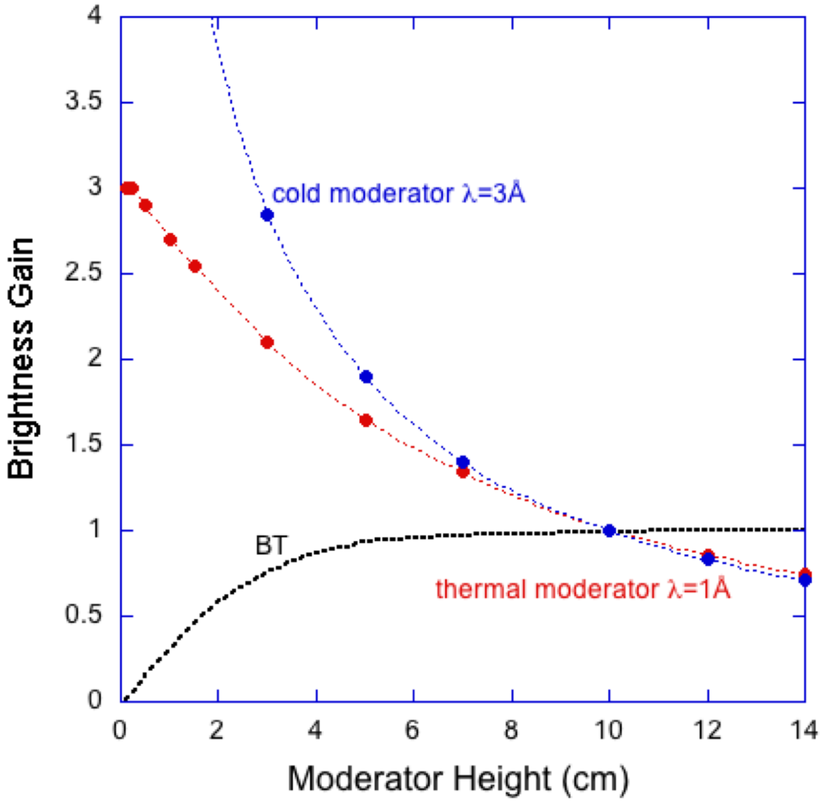

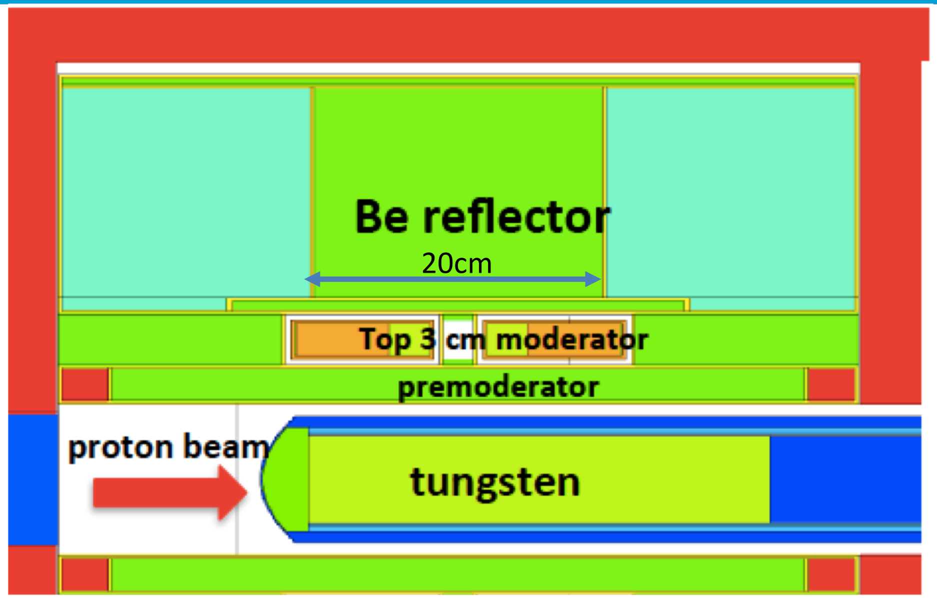

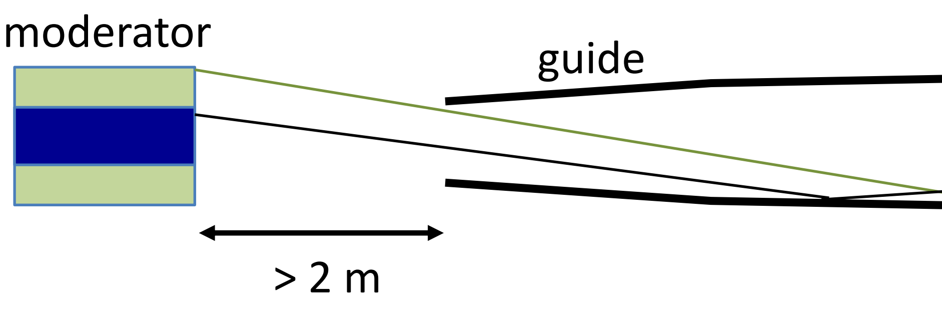

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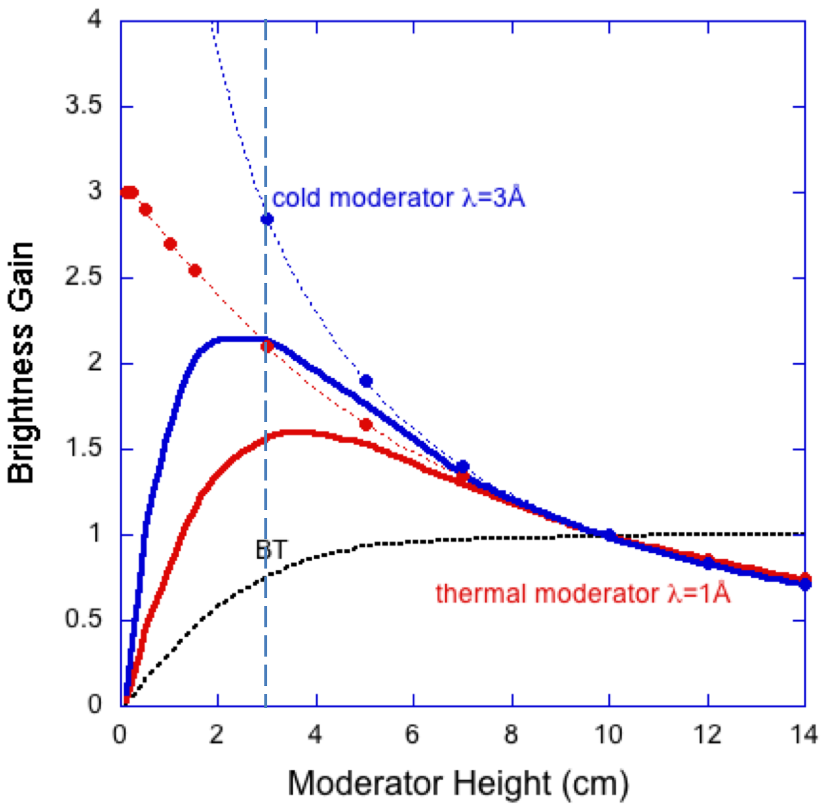

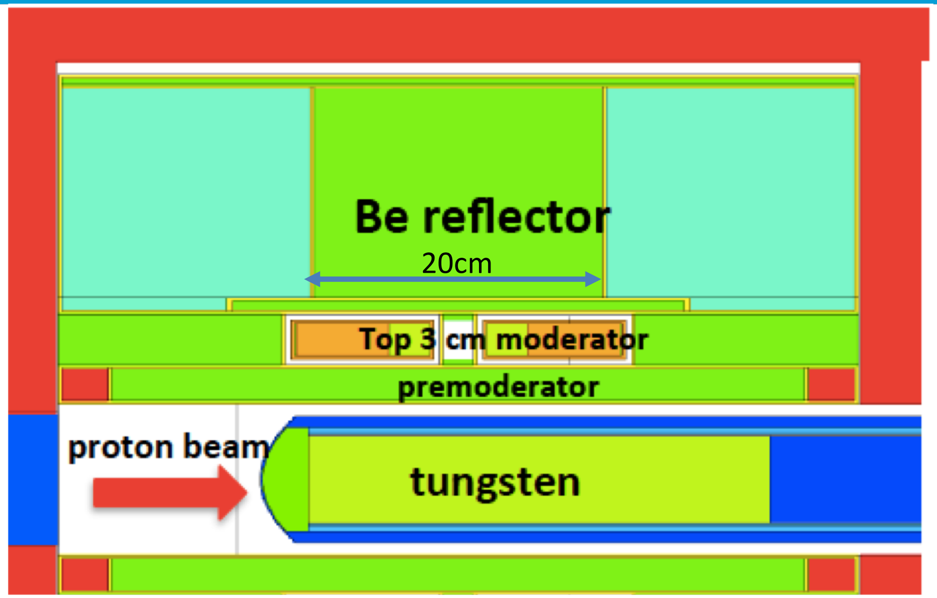

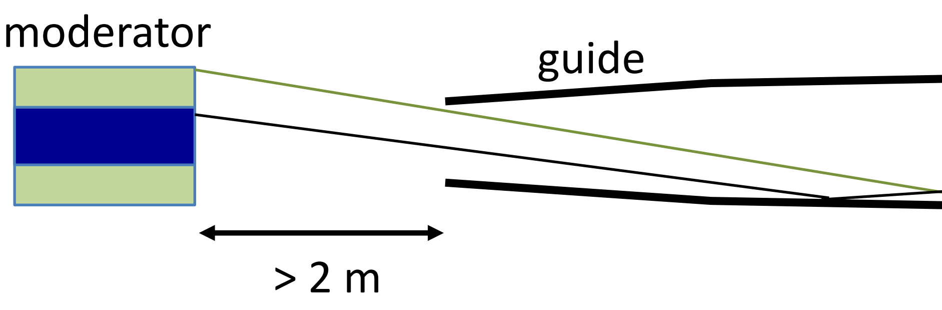

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<u>Above target</u>:
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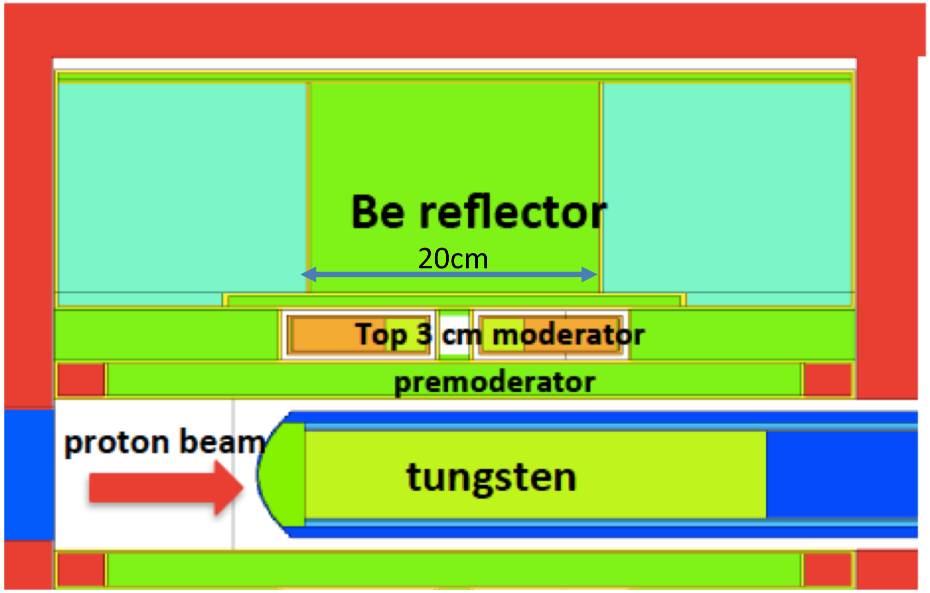
<u>Below target</u>:
space for future upgrade



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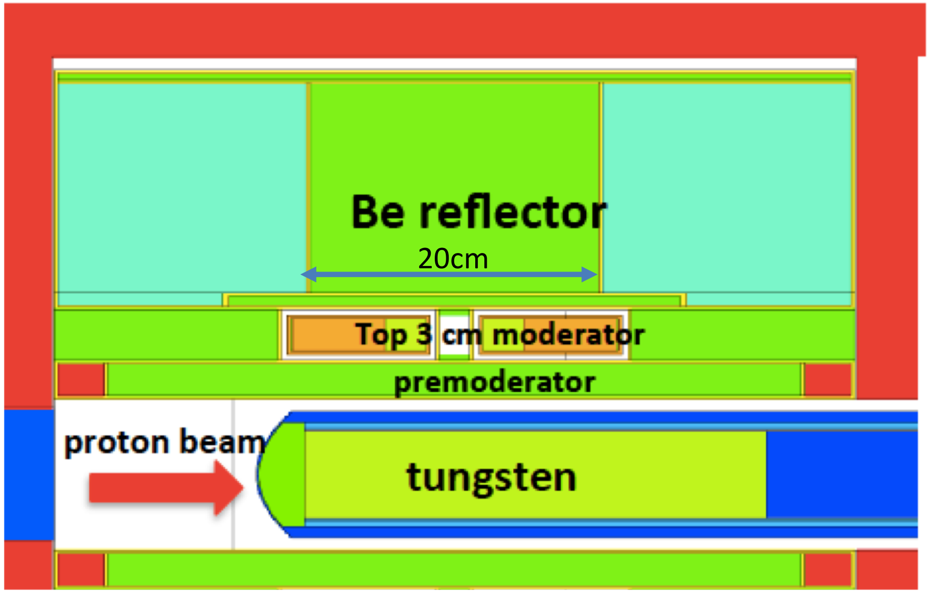
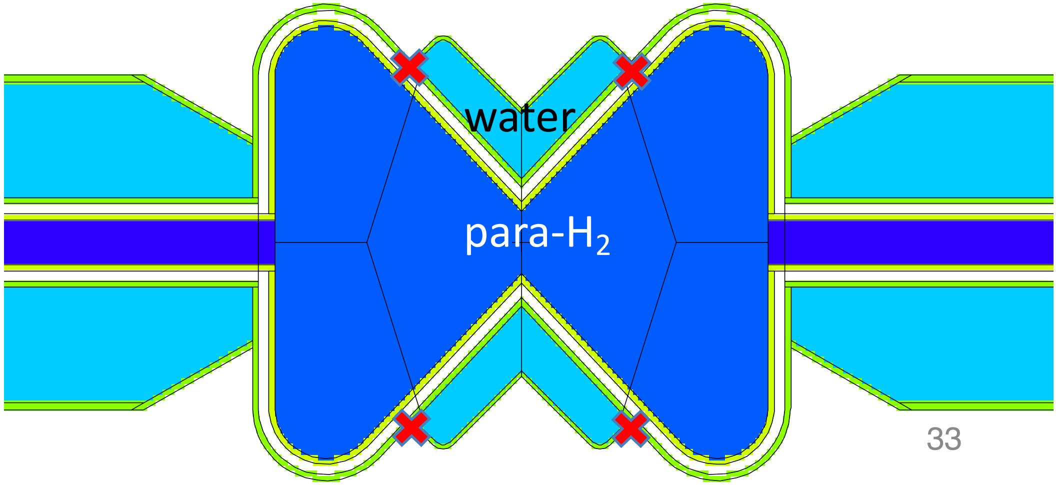


- Hydrogen for cold spectrum
- Water for thermal spectrum
- All beamports can view both



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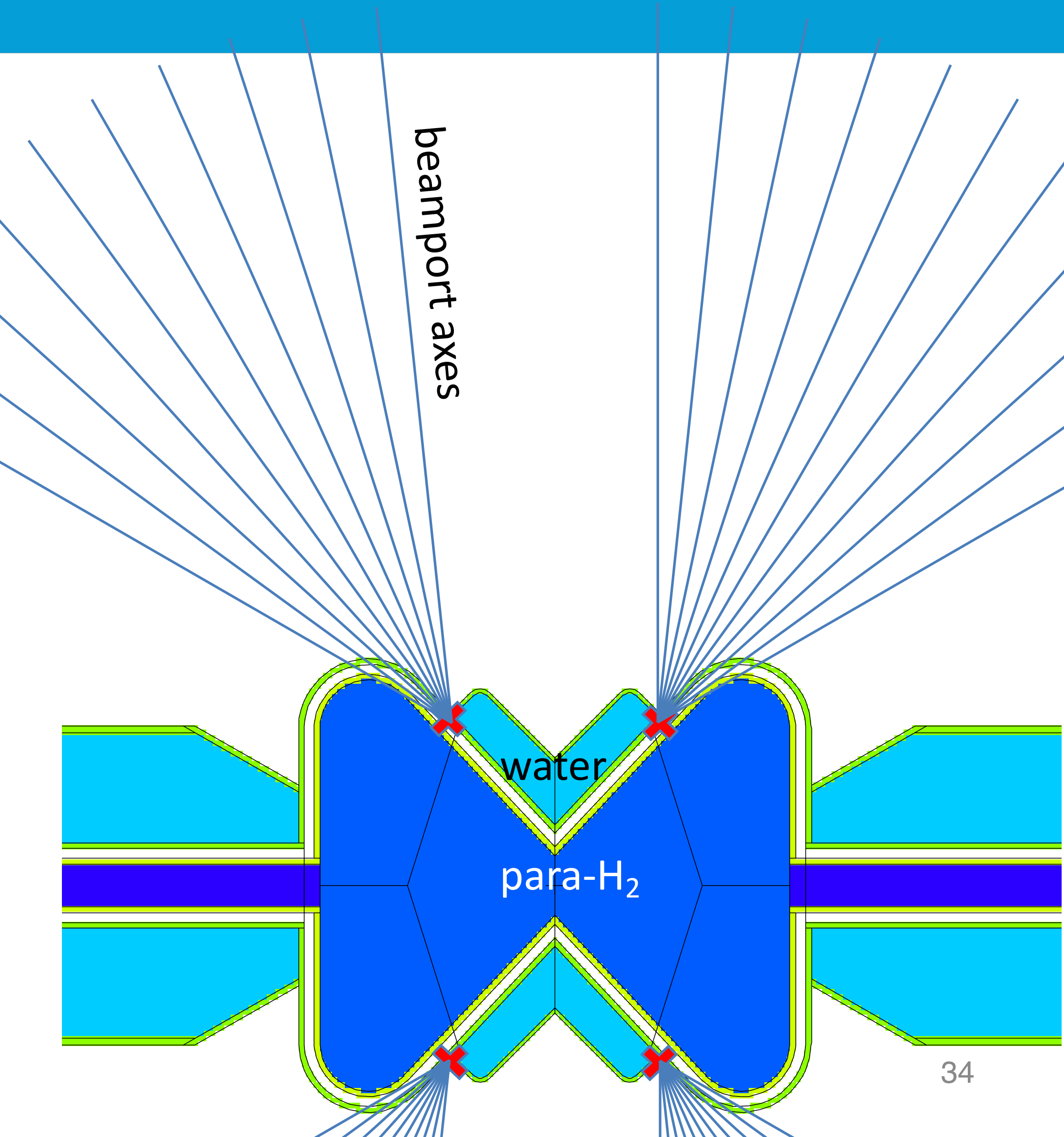

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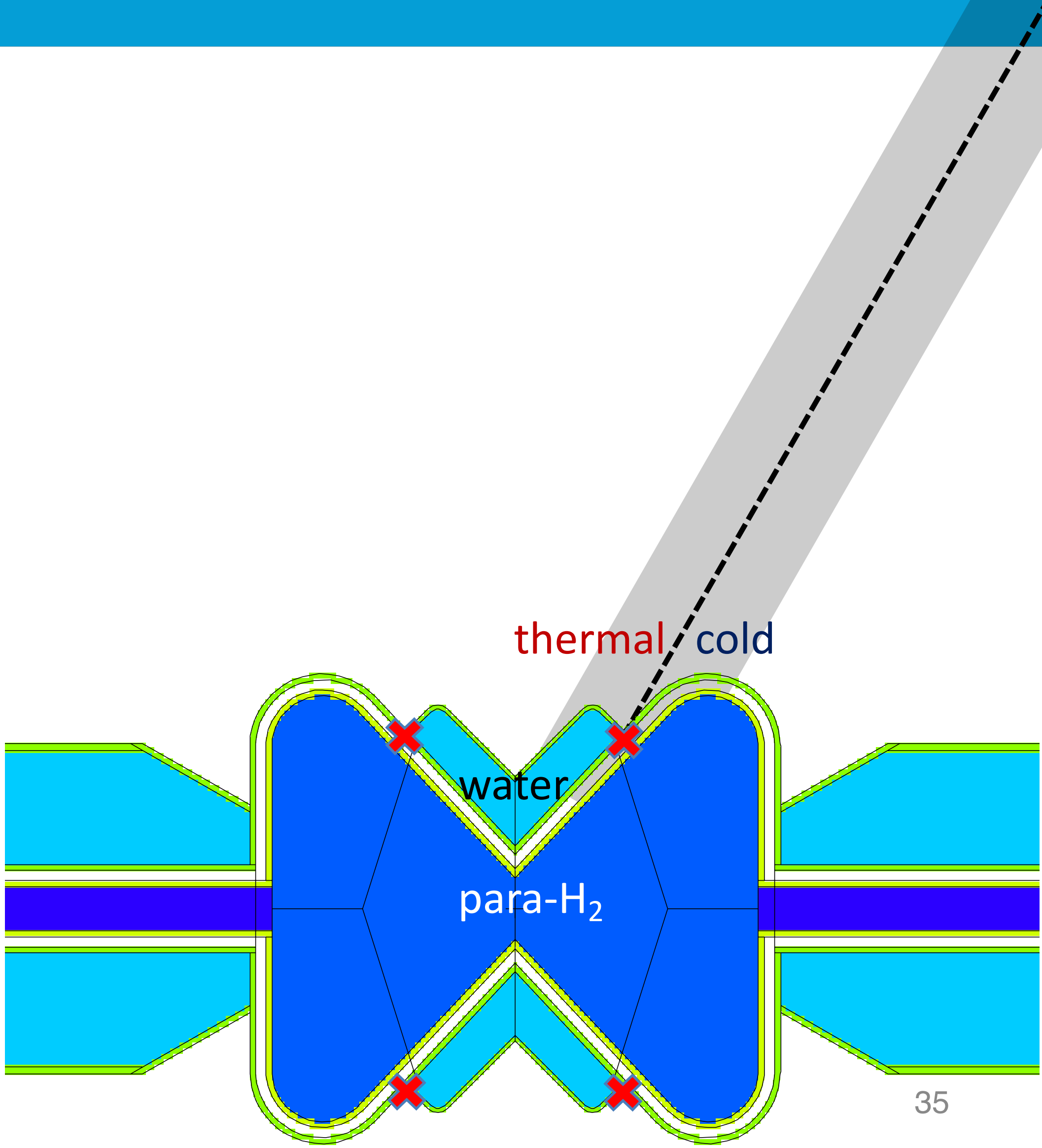

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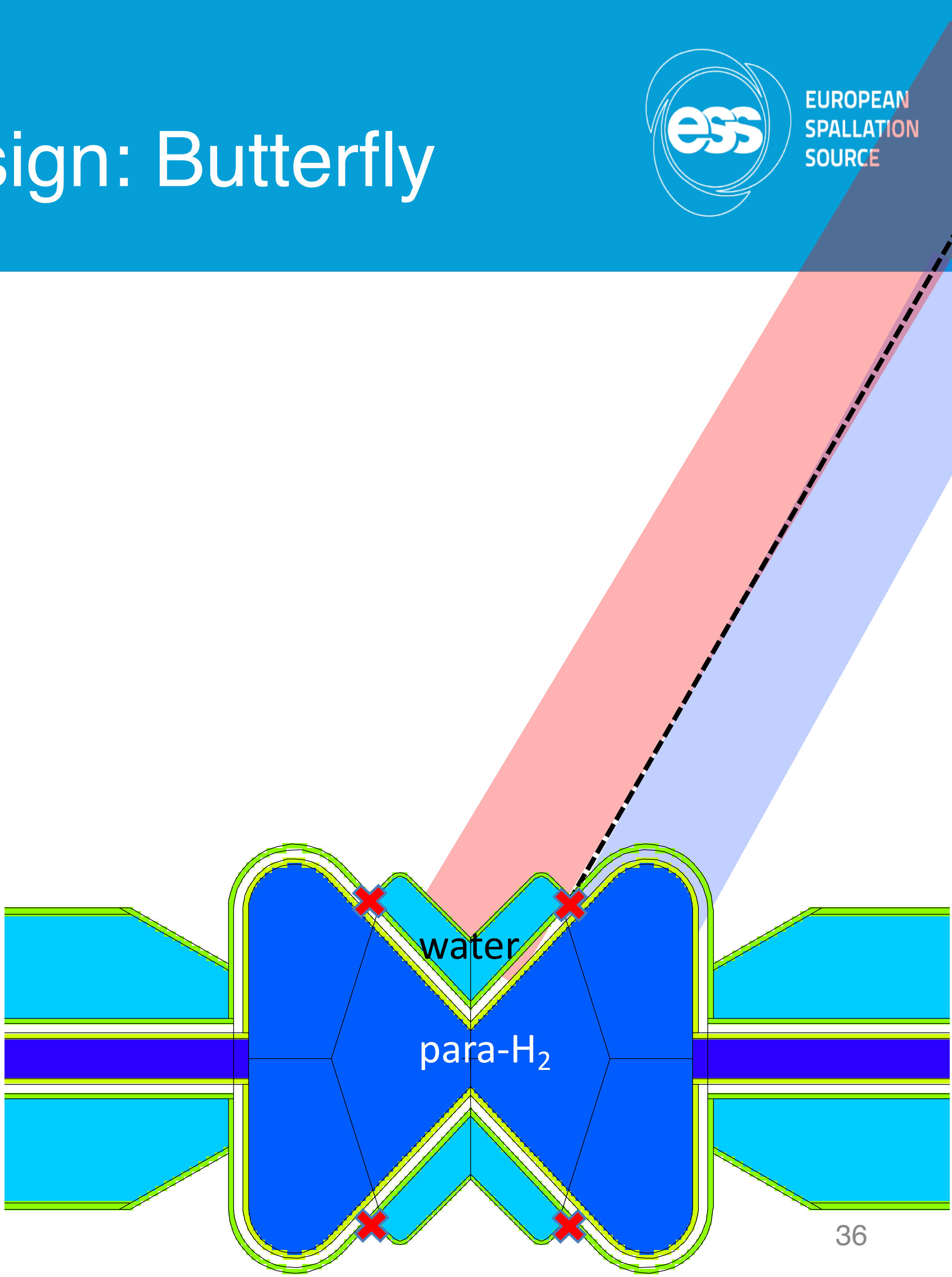

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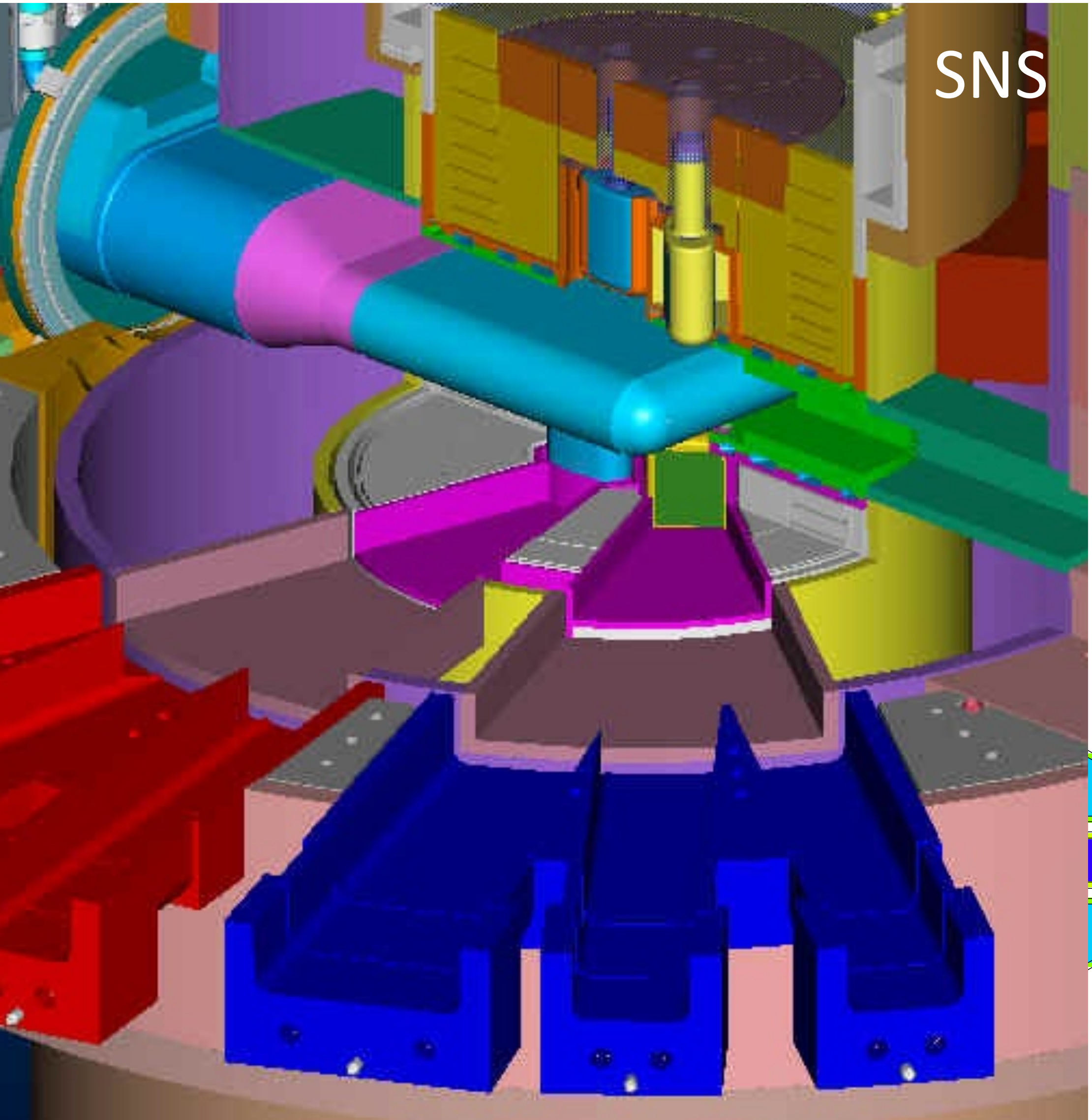
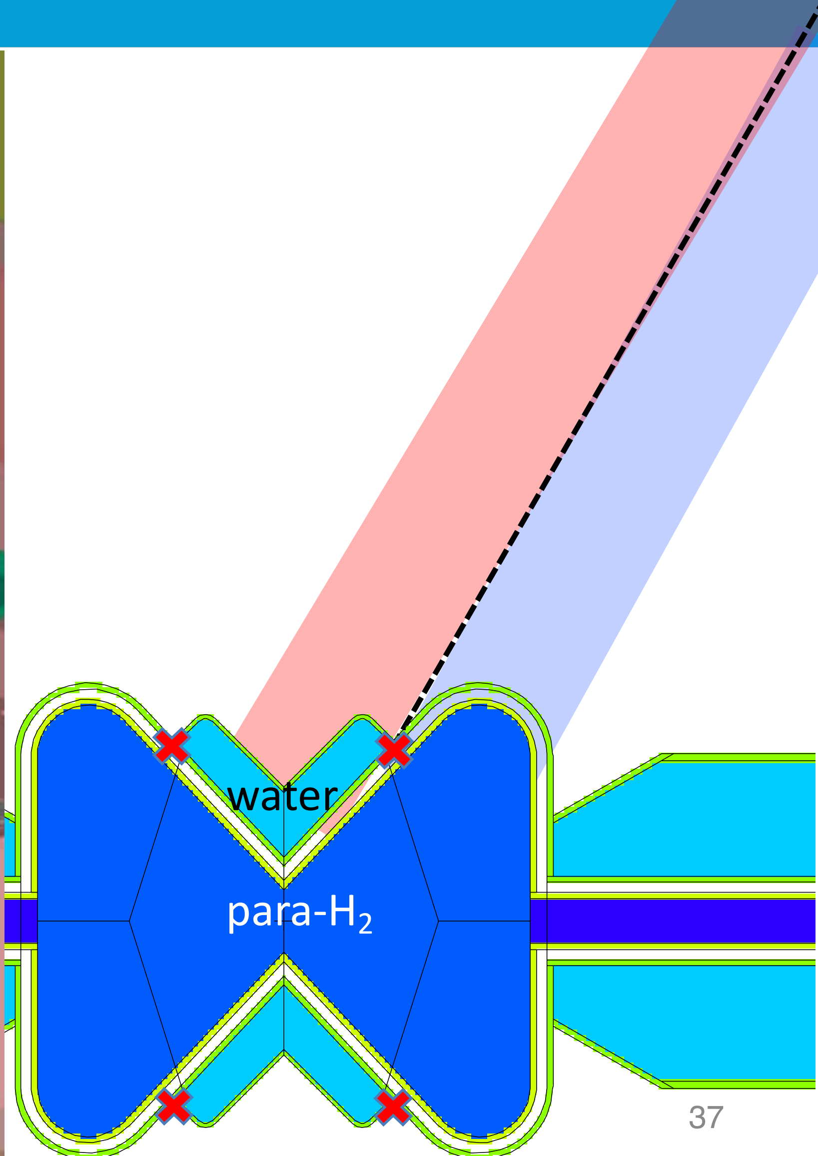
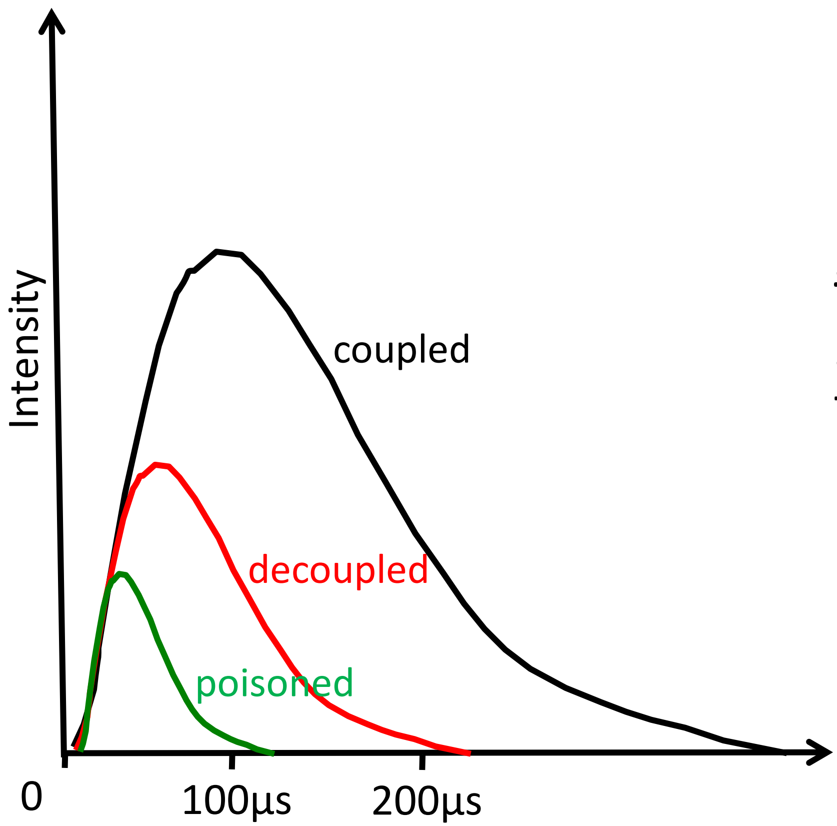




Adapting the pulse width

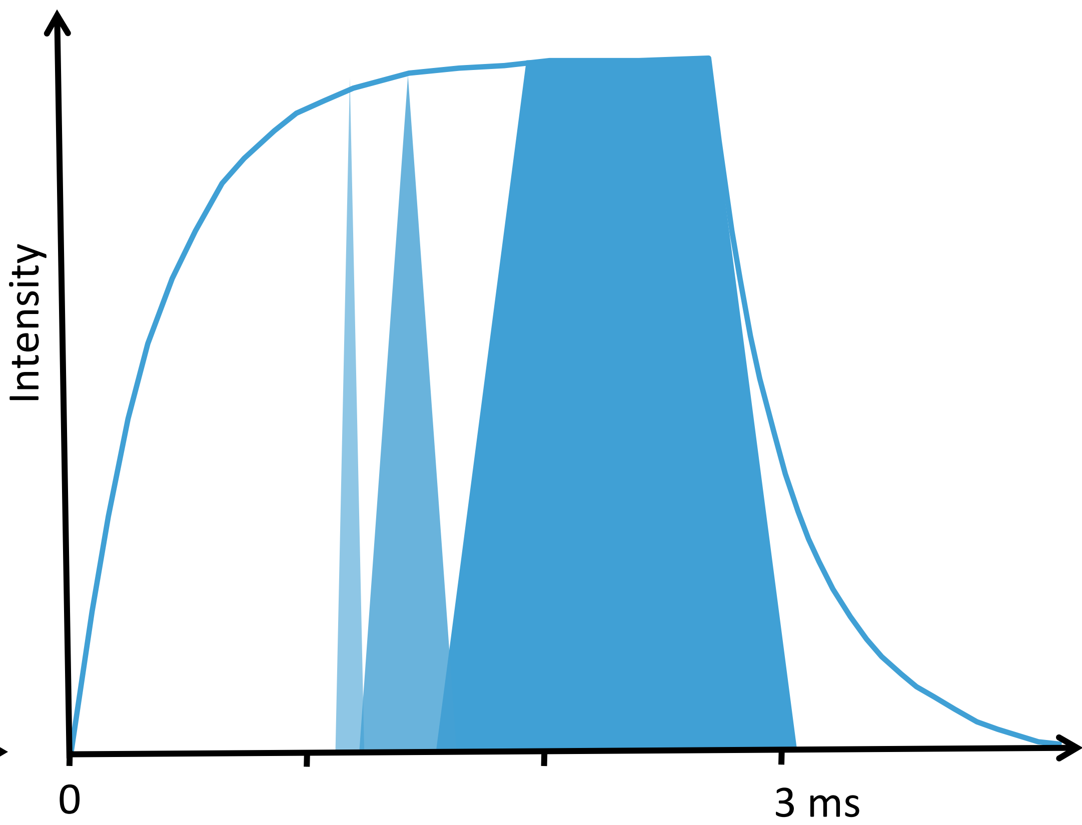
Short-Pulse Source

- set pulse width by choosing moderator



ESS

- set pulse width using pulse-shaping chopper



Upgradeability

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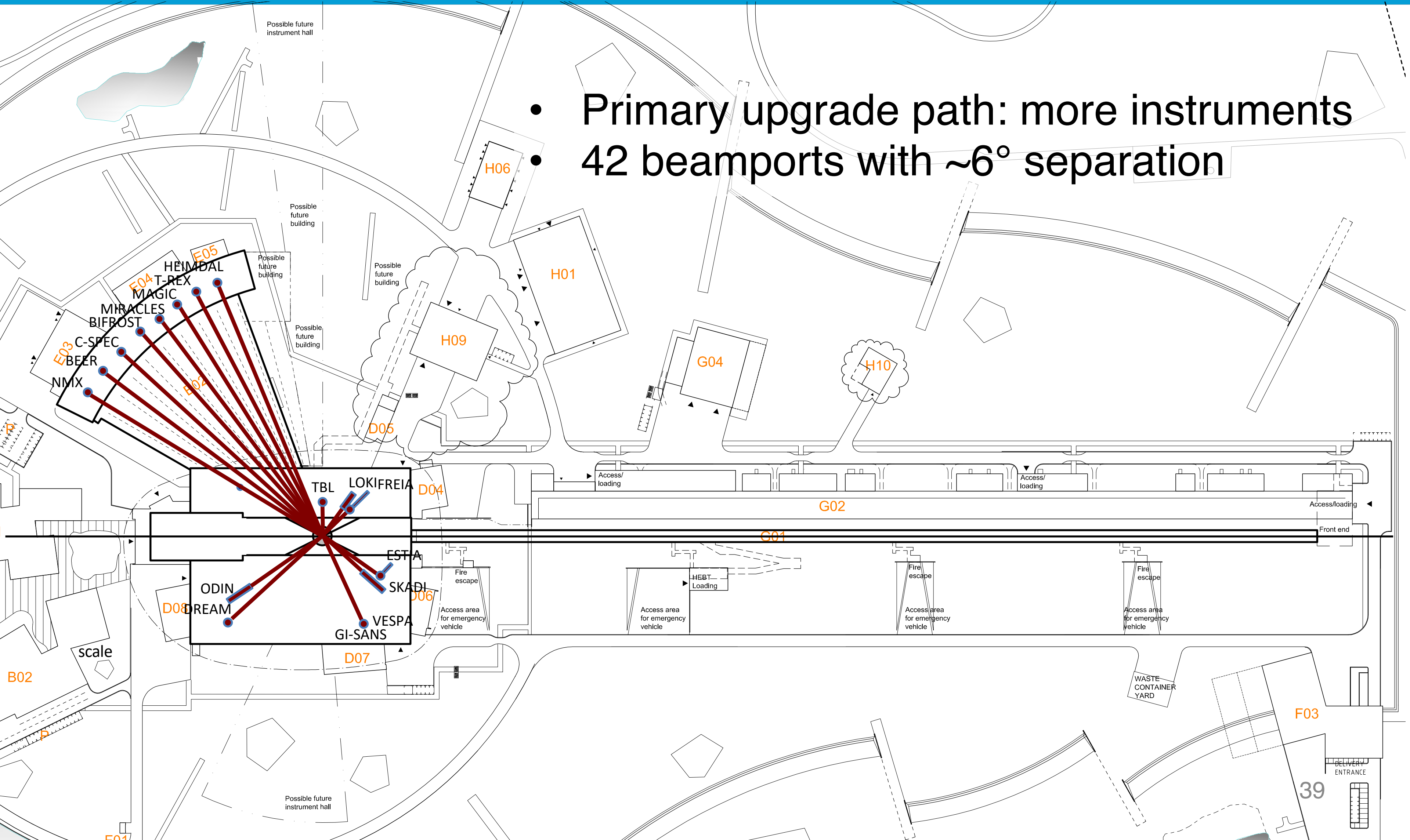
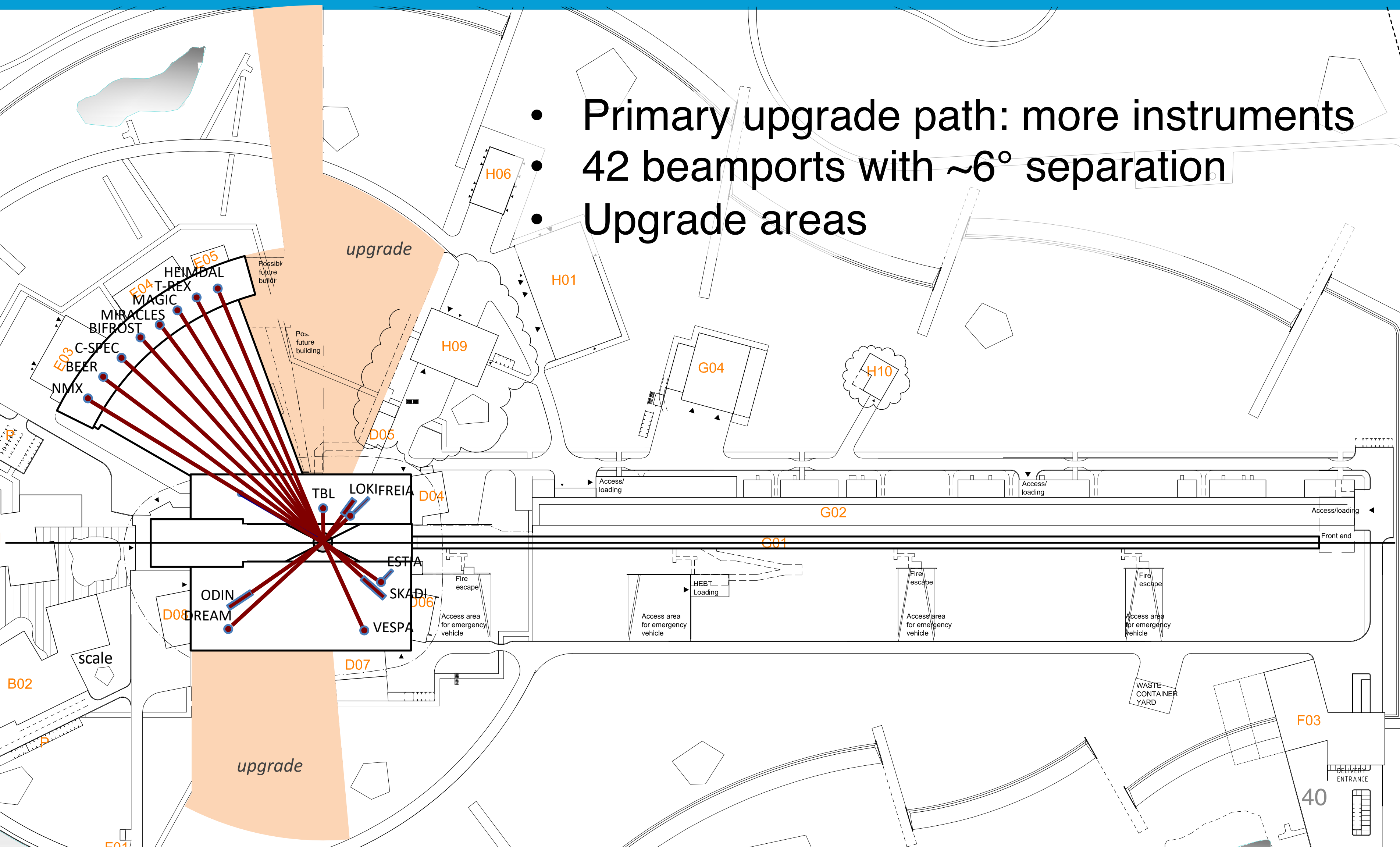
- Primary upgrade path: more instruments
- 42 beamports with ~6° separation

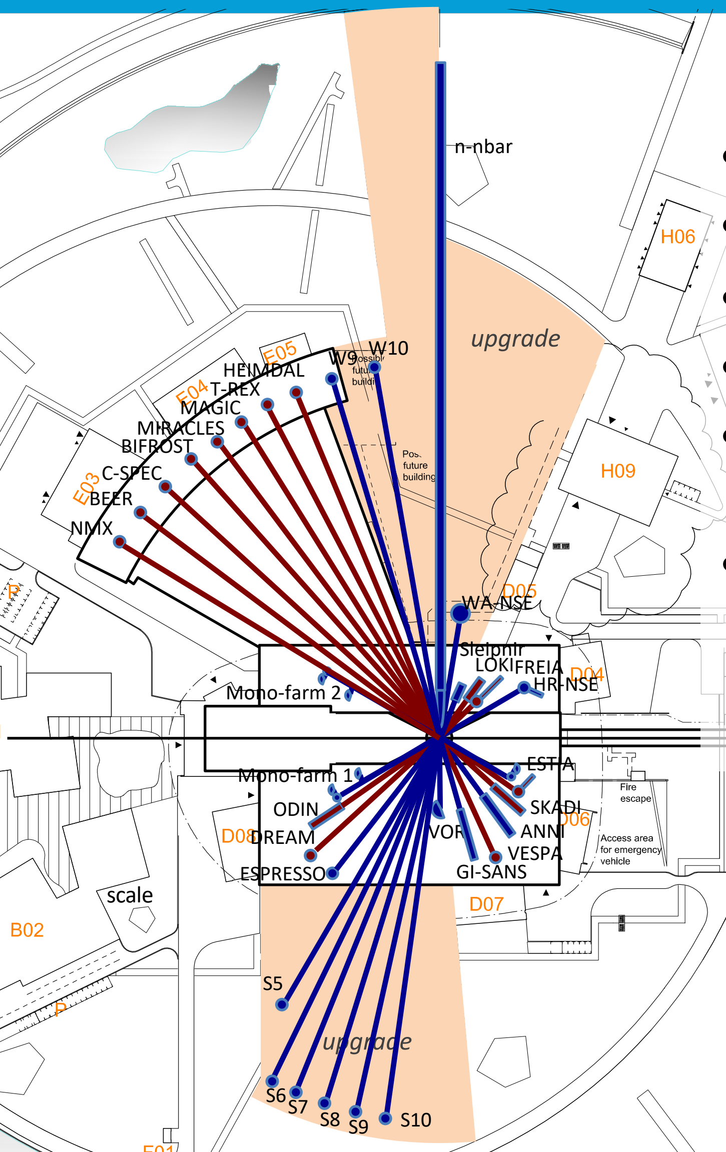


Upgradeability

- Primary upgrade path: more instruments
- 42 beamports with ~6° separation
- Upgrade areas

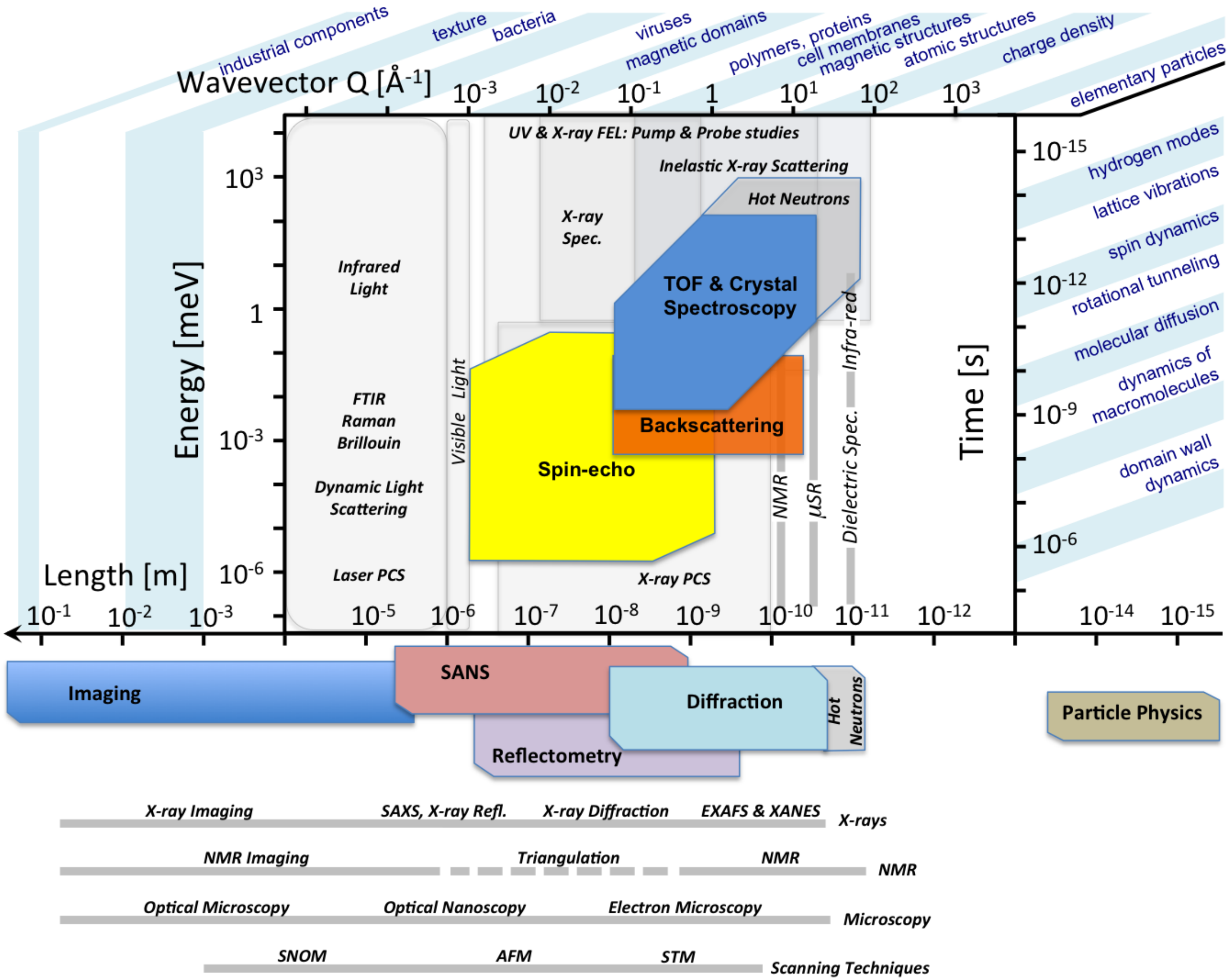


Upgradeability



- Primary upgrade path: more instruments
- 42 beamports with ~6° separation
- Upgrade areas
- Lower moderator not yet defined
- All beamports allow cold and/or thermal spectrum
- Freely tuneable resolution
  - adapt resolution to experimental needs

Length and Energy Scales



15 Instruments selected so far
8 to be in user operation by 2024

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Large-Scale Structures

- ODIN Imaging Instrument
- SKADI General Purpose SANS
- LOKI Broadband SANS
- Surface Scattering
- FREIA Horizontal Reflectom.
- ESTIA Vertical Reflectom.

Diffraction

- HEIMDAL Powder Diffract.
- DREAM Powder Diffract.
- Monochromatic Powder Diffract.
- BEER Engineering Diffract.
- Extreme Conditions Diffract.
- MAGIC Magnetism Diffract.
- NMX Macromolecular Diffract.

Spectroscopy

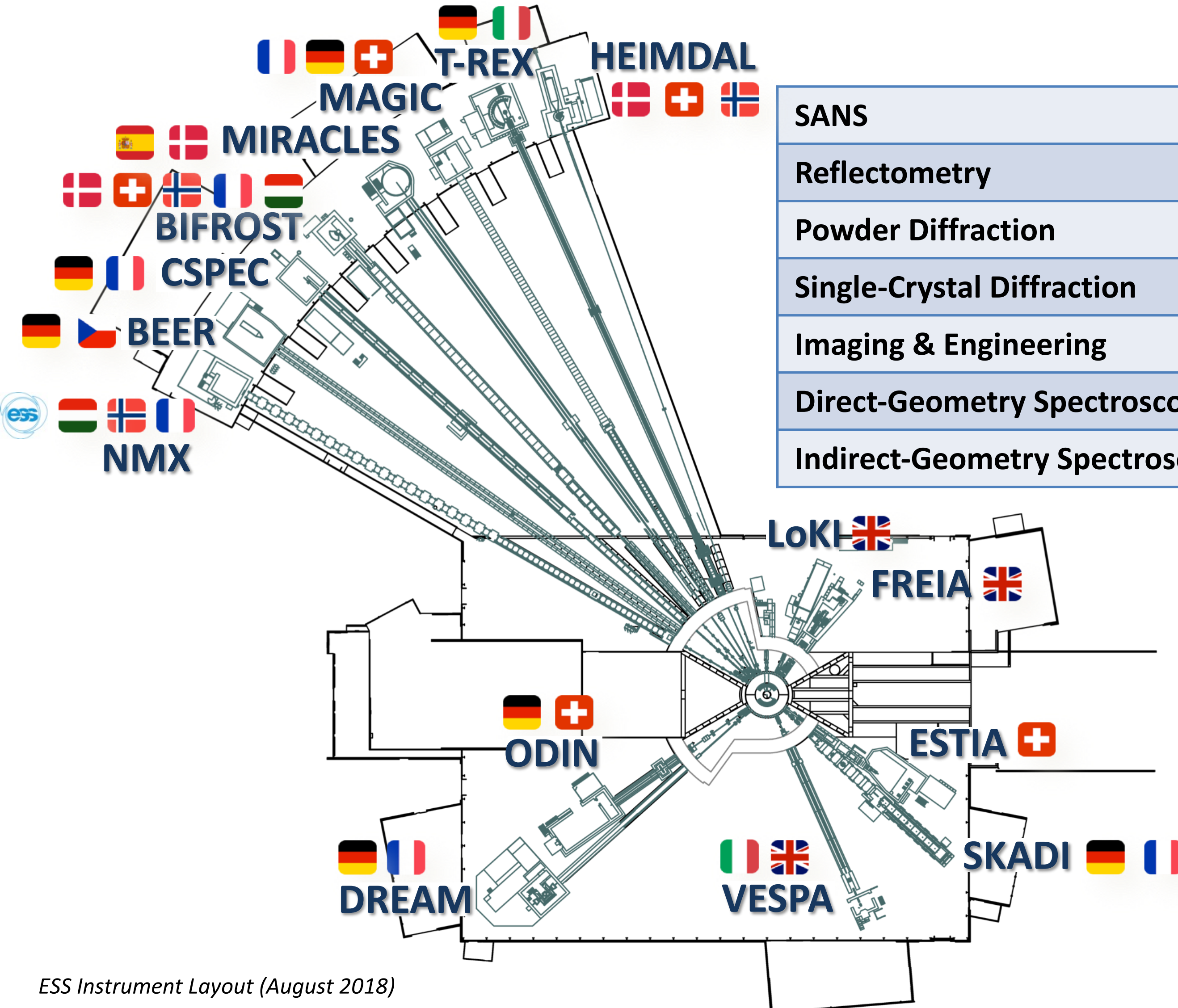
- CSPEC Cold Chopper Spec.
- Broadband Spectrometer
- T-REX Thermal Chopper Spec.
- BIFROST Xtal Analyser Spec.
- VESPA Vibrational Spec.
- MIRACLES Backscatt. Spec.
- High-Resolution Spin-Echo
- Wide-Angle Spin-Echo

- Particle Physics Beamline

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

Instrument Suite

SANS	**LOKI**, *SKADI*
Reflectometry	**ESTIA**, FREIA
Powder Diffraction	**DREAM**, HEIMDAL
Single-Crystal Diffraction	**MAGIC**, *NMX*
Imaging & Engineering	**ODIN**, **BEER**
Direct-Geometry Spectroscopy	**CSPEC**, *T-REX*
Indirect-Geometry Spectroscopy	**BIFROST**, MIRACLES, VESPA



ESS Instrument Layout (August 2018)

Summary

- ESS will provide break-through performance in a wide variety of scientific fields
  - Superior source brightness
  - Superior flexibility
  - World-leading instrument designs
- Addresses a large and vibrant European user community
  - Discussions on-going with prospective partner countries: Canada, South Africa, Israel, …
- Built by the European neutron labs in collaboration
- All of the 22 instruments will be available by peer-reviewed access
  - Ample scope for increasing that number
- First science expected in 2023
  - Followed by gradual ramp-up to full science capability
  - Supported by world-leading software, sample environment, …

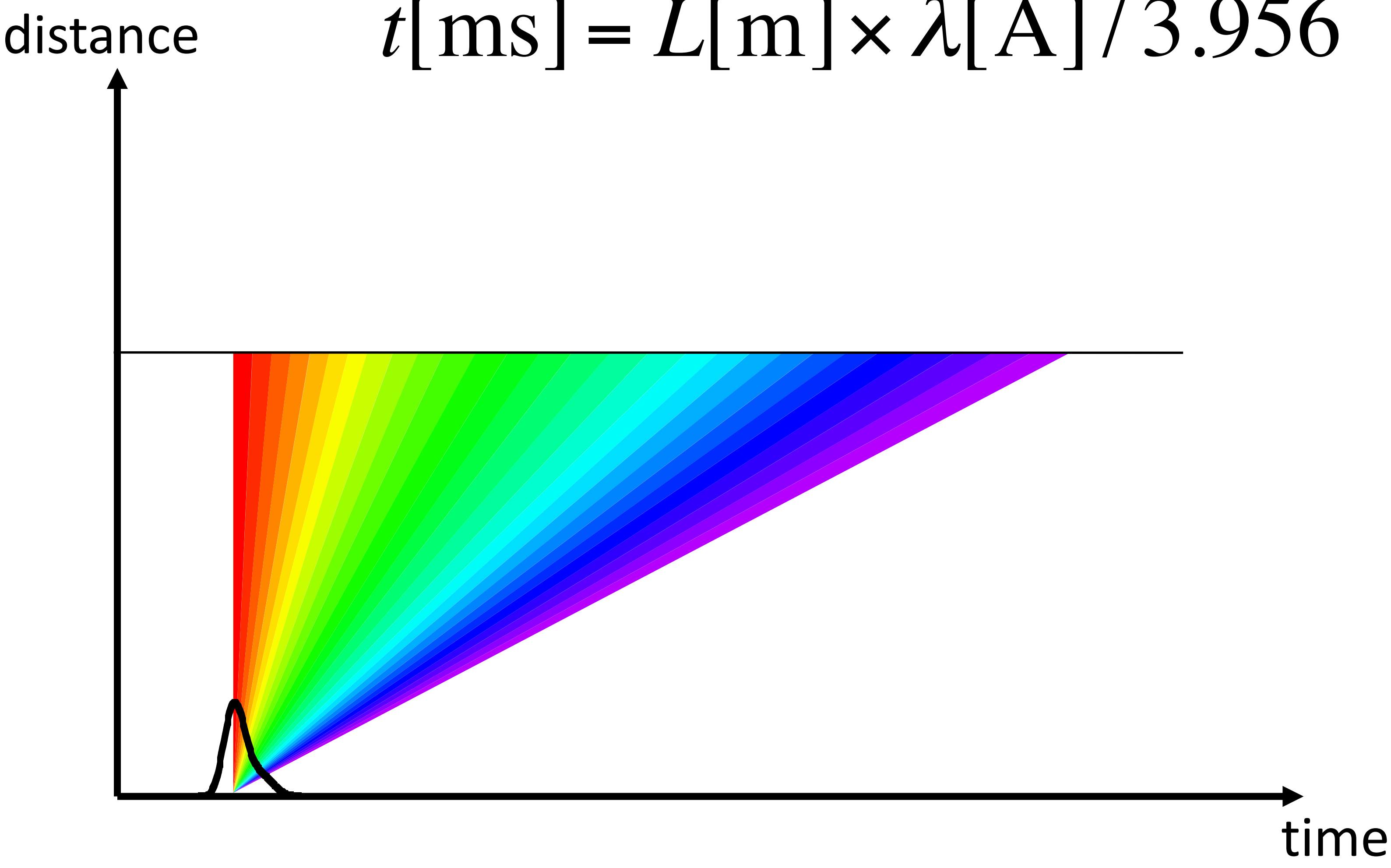
Thank you!

EUROPEAN SPALLATION SOURCE

ESS site 2016

The Time-of-Flight (TOF) Method

$$t[\mathrm{ms}] = L[\mathrm{m}] \times \lambda[\text{Å}] / 3.956$$

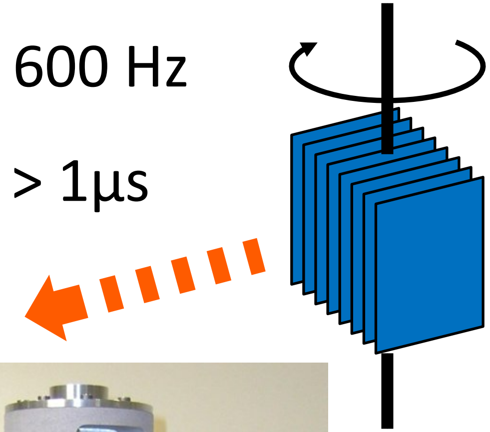


Neutron Choppers

Fermi choppers

$f < 600$ Hz

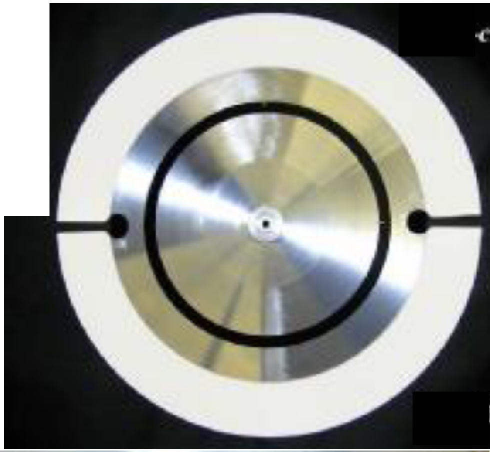
$\Delta t > 1\mu s$



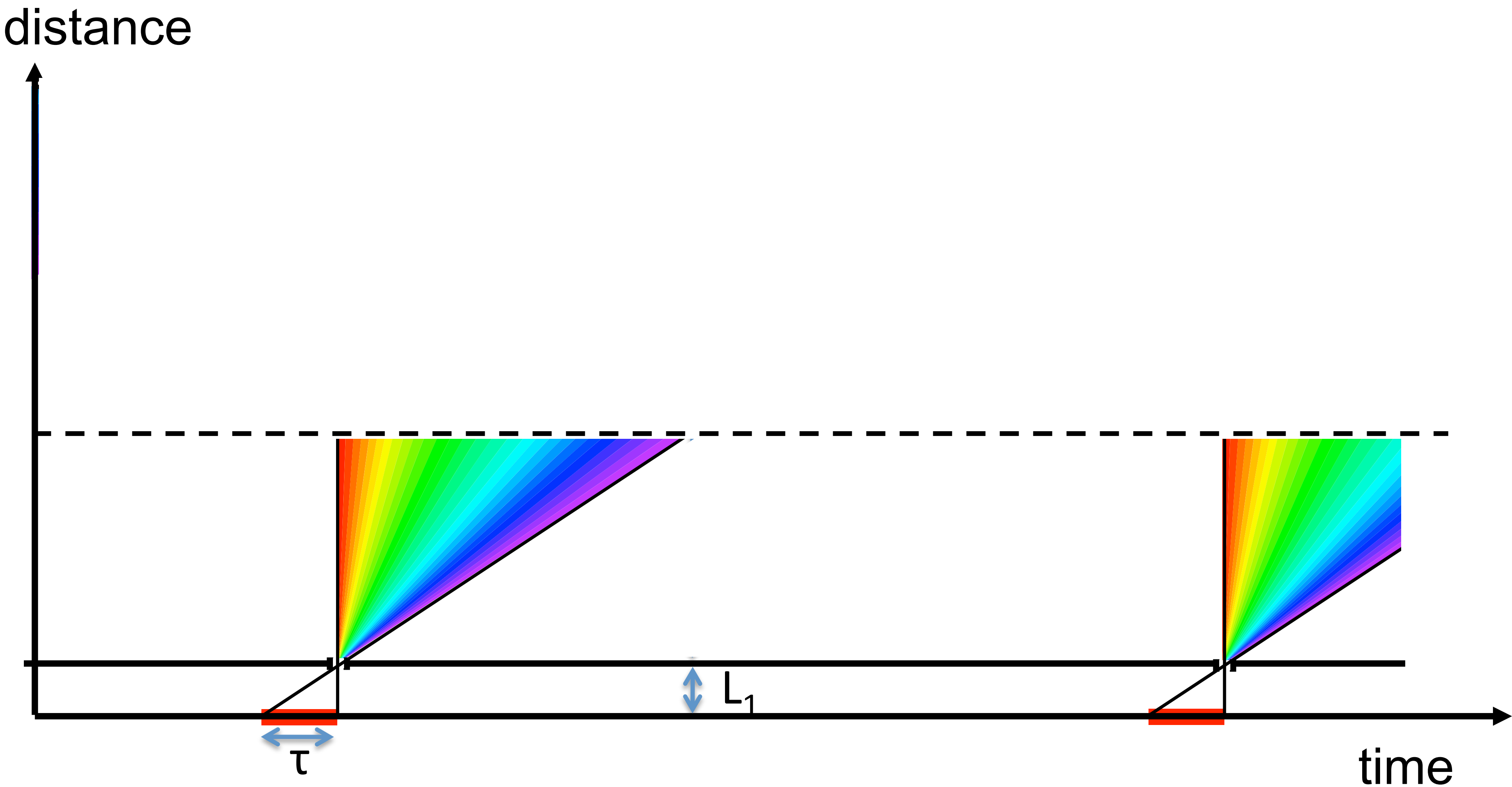
Disk choppers

$f < 300$ Hz

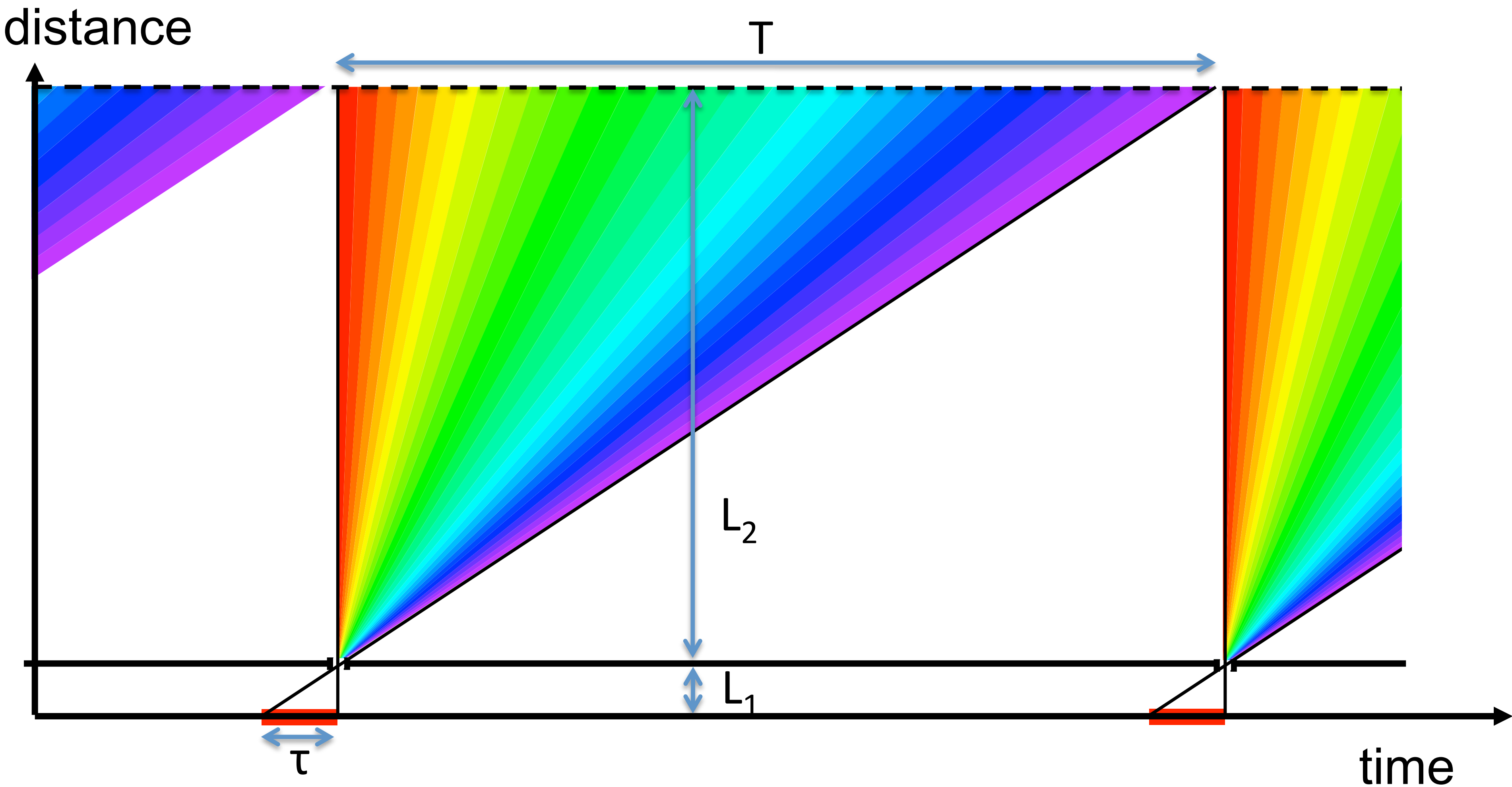
$\Delta t > 10\mu s$



Impact on bandwidth of pulse-shaping chopper

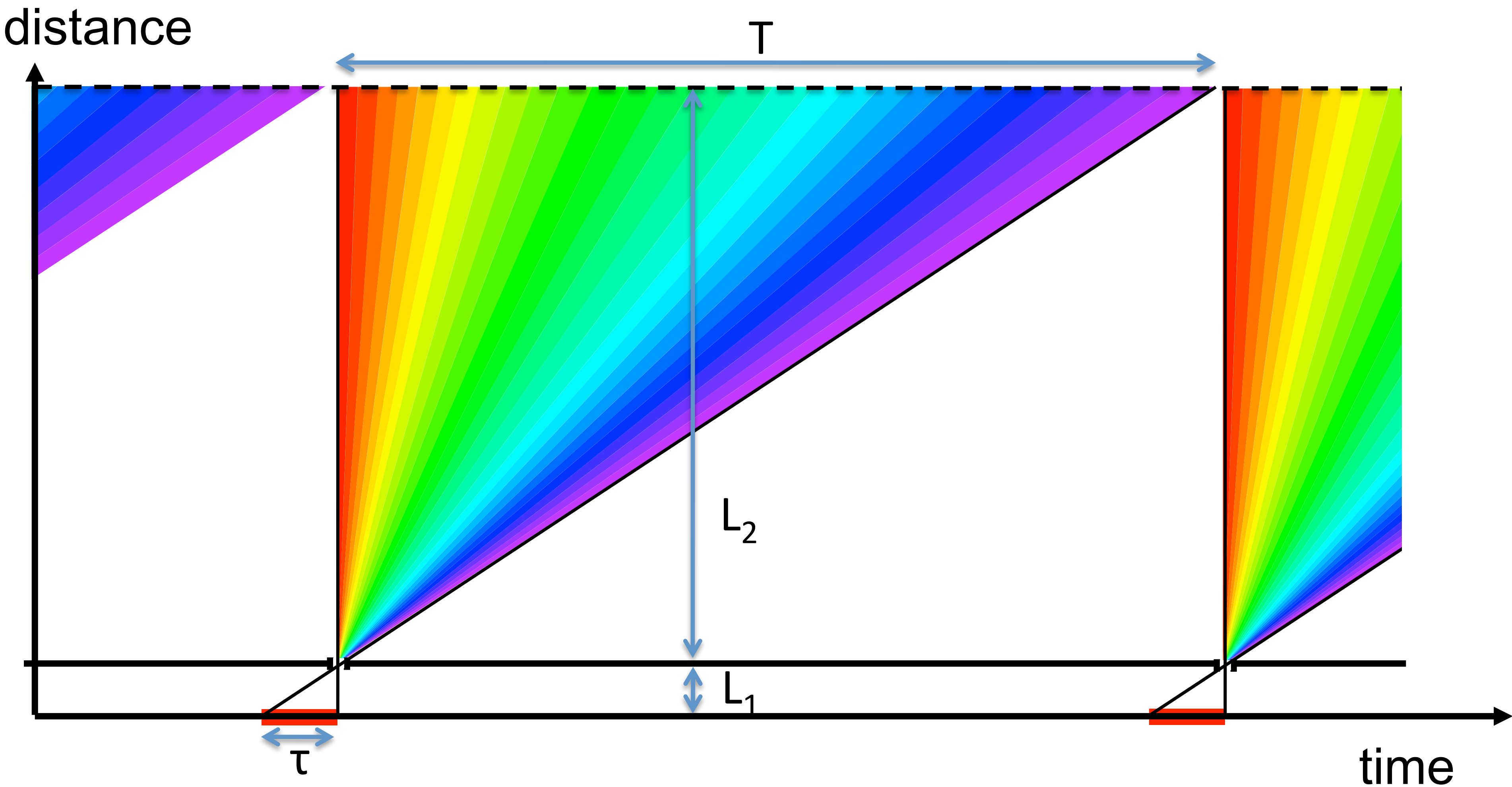


Impact on bandwidth of pulse-shaping chopper



Impact on bandwidth of pulse-shaping chopper

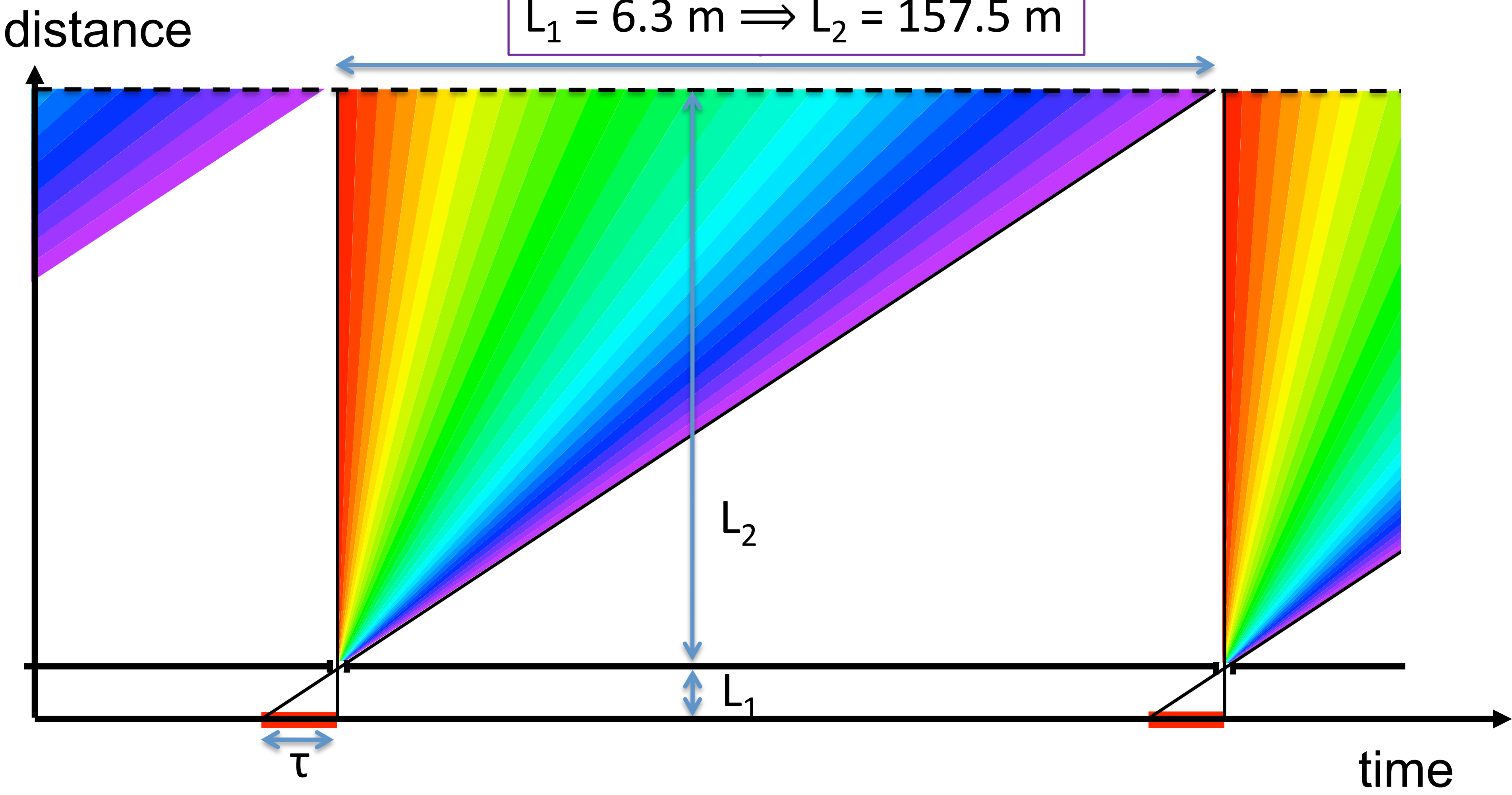
$$T/\tau = 25 \Longrightarrow L_2/L_1 = 25$$



Impact on bandwidth of pulse-shaping chopper

$T/\tau = 25 \Longrightarrow L_2/L_1 = 25$

$L_1 = 6.3$ m $\Longrightarrow L_2 = 157.5$ m

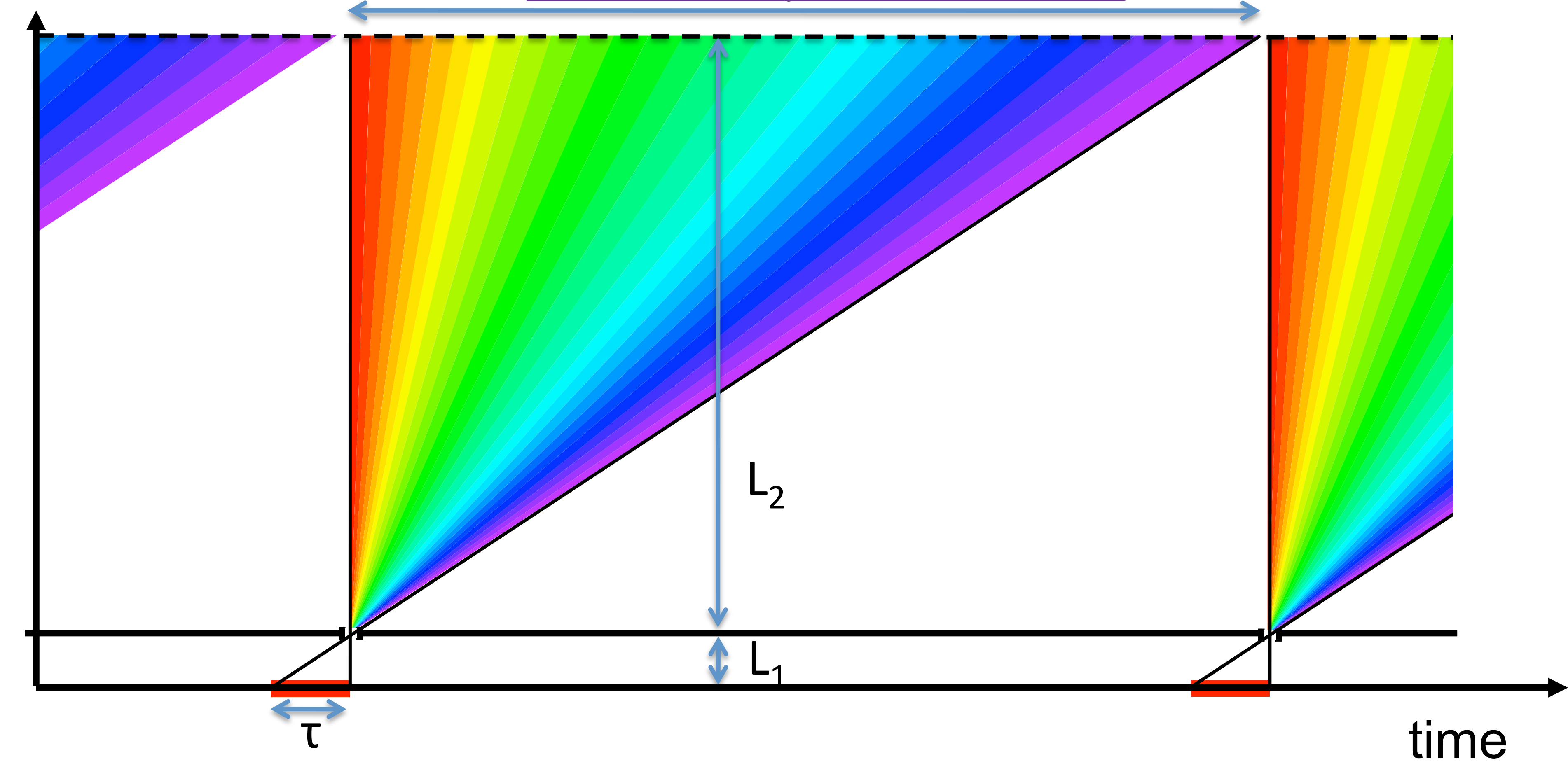


Impact on bandwidth of pulse-shaping chopper

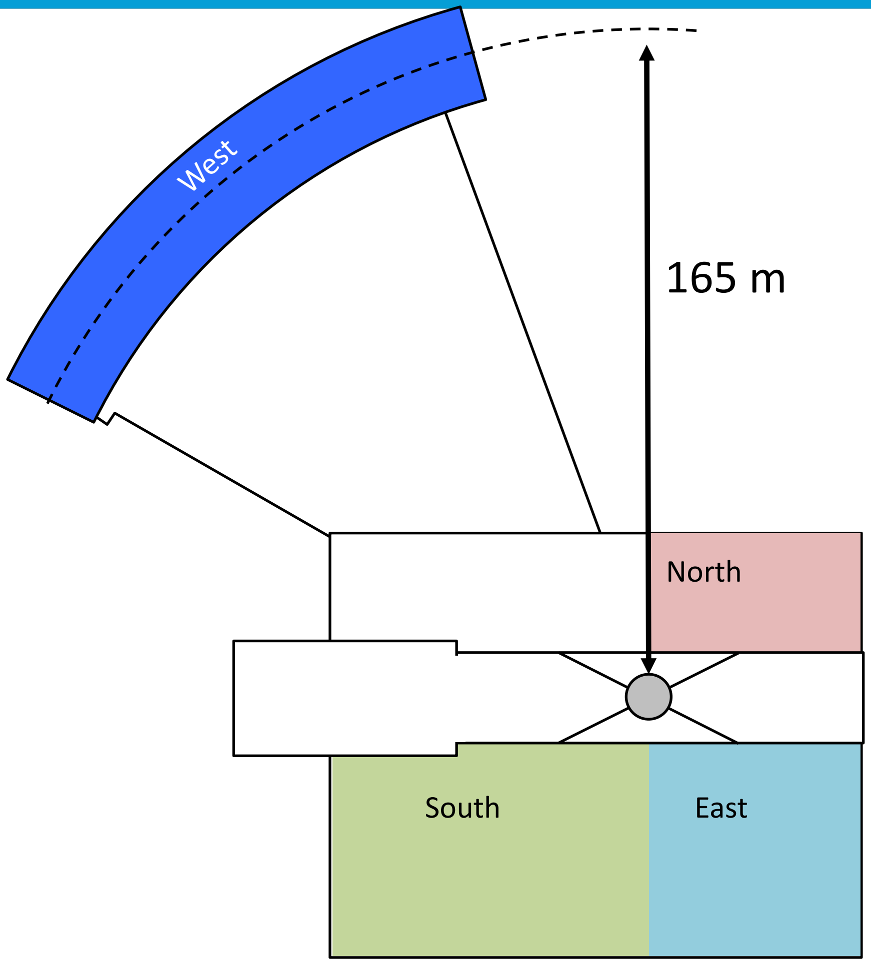
$T/\tau = 25 \Longrightarrow L_2/L_1 = 25$

$L_1 = 6.3$ m $\Longrightarrow L_2 = 157.5$ m

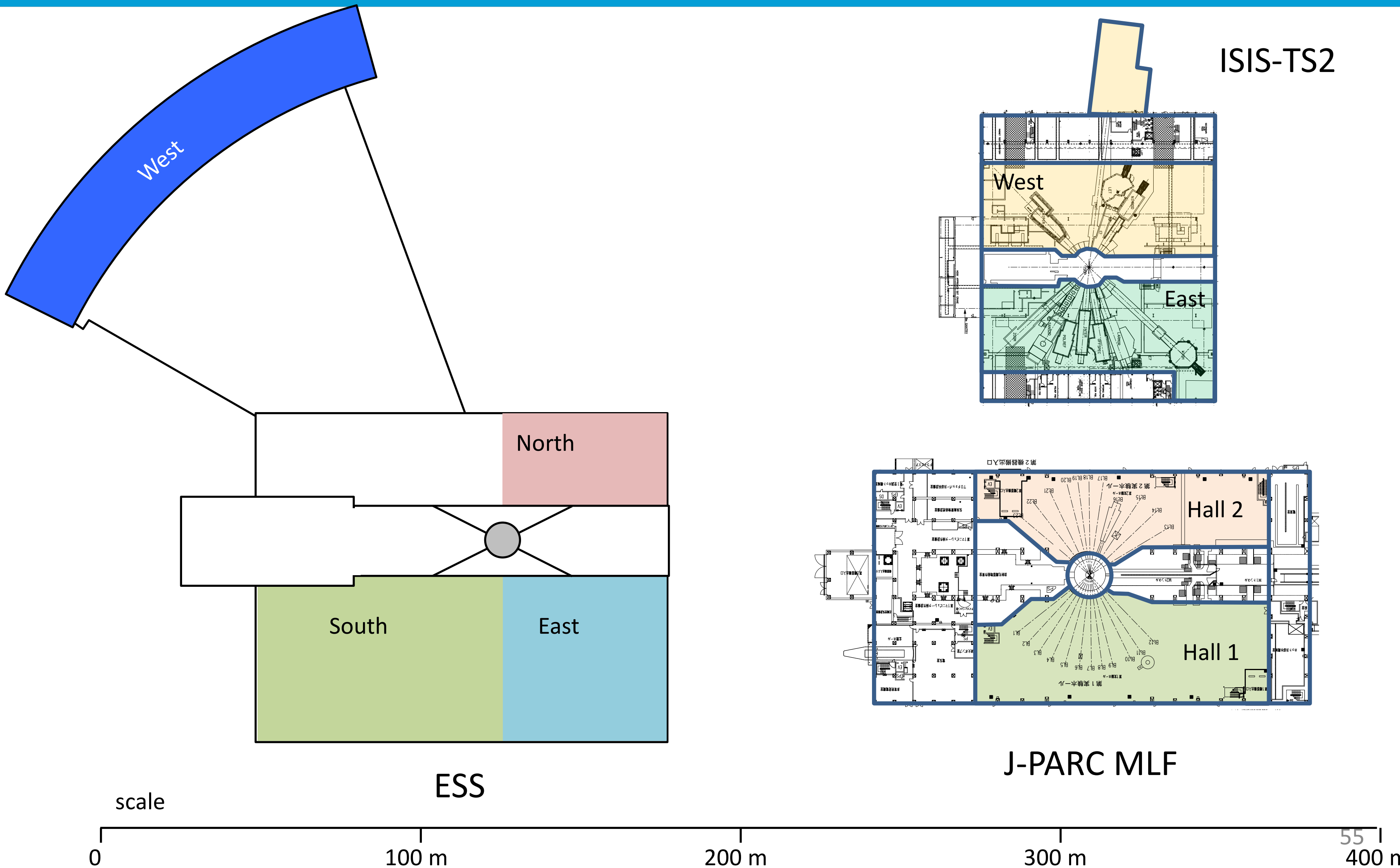
$\Longrightarrow \Delta\lambda = 1.8$ Å



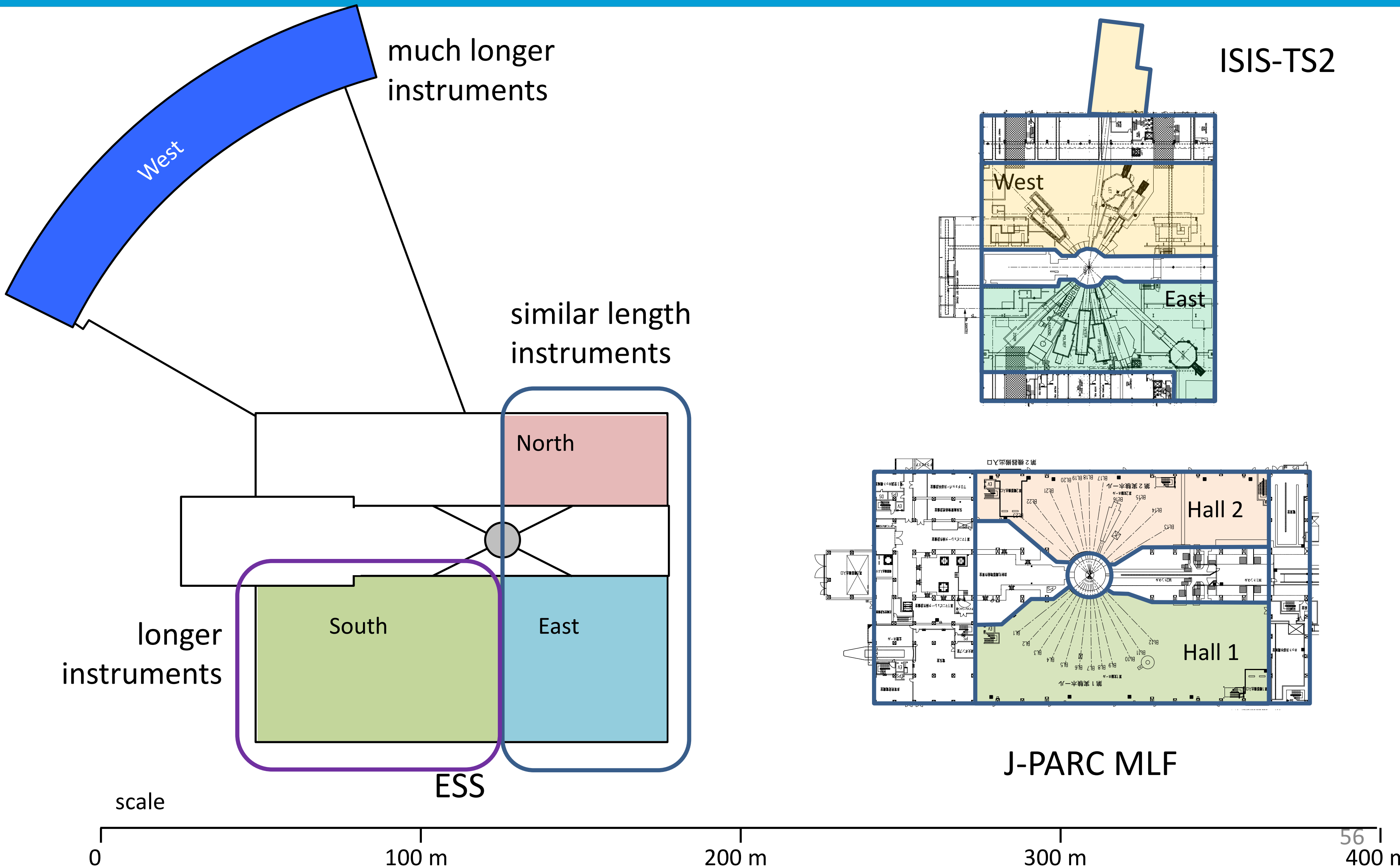
Hall Layout



Hall Layout


West
North
South
East
ESS
ISIS-TS2
West
East
Hall 2
Hall 1
J-PARC MLF
scale
0
100 m
200 m
300 m
400 m

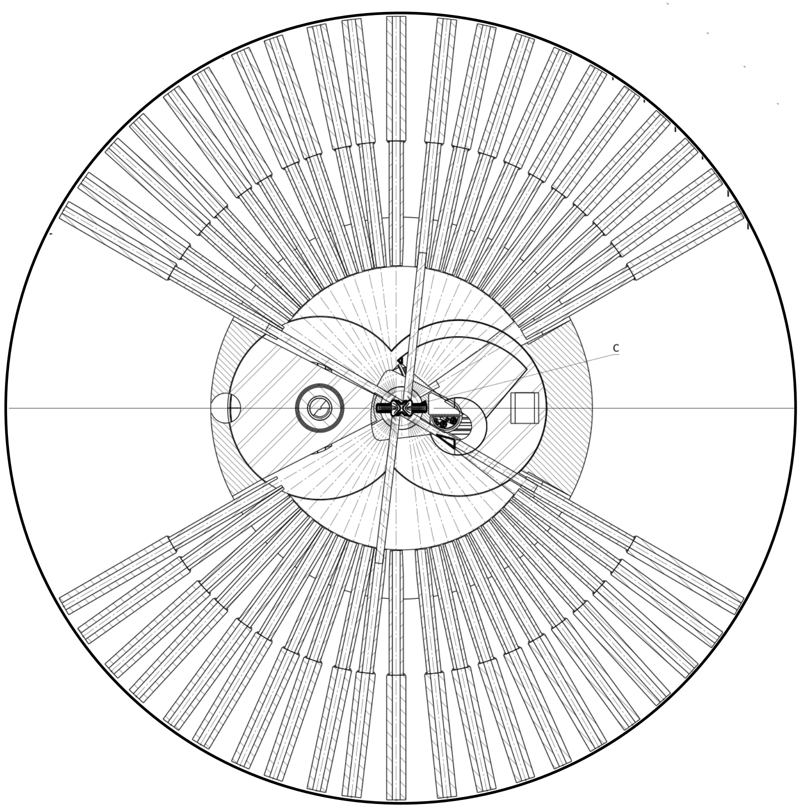
Hall Layout


much longer
instruments
West
similar length
instruments
North
South
East
longer
instruments
ESS
ISIS-TS2
West
East
Hall 2
Hall 1
J-PARC MLF
scale
0
100 m
200 m
300 m
400 m

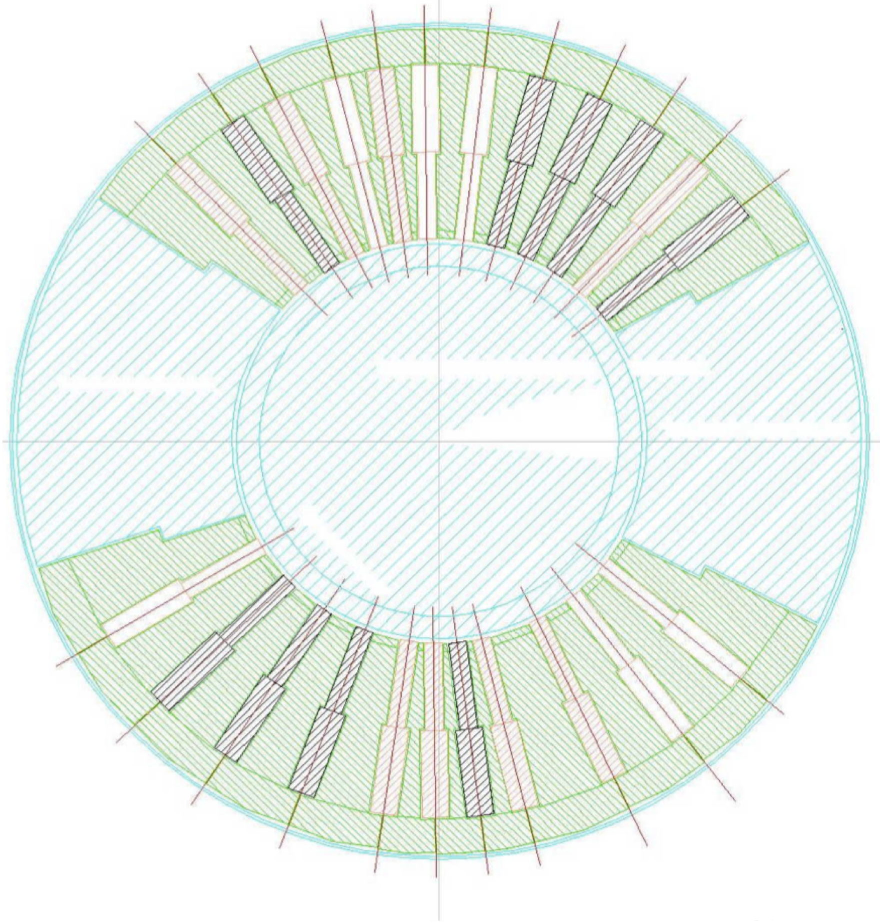
Beamport separation

EUROPEAN SPALLATION SOURCE

ESS: 42 beamports

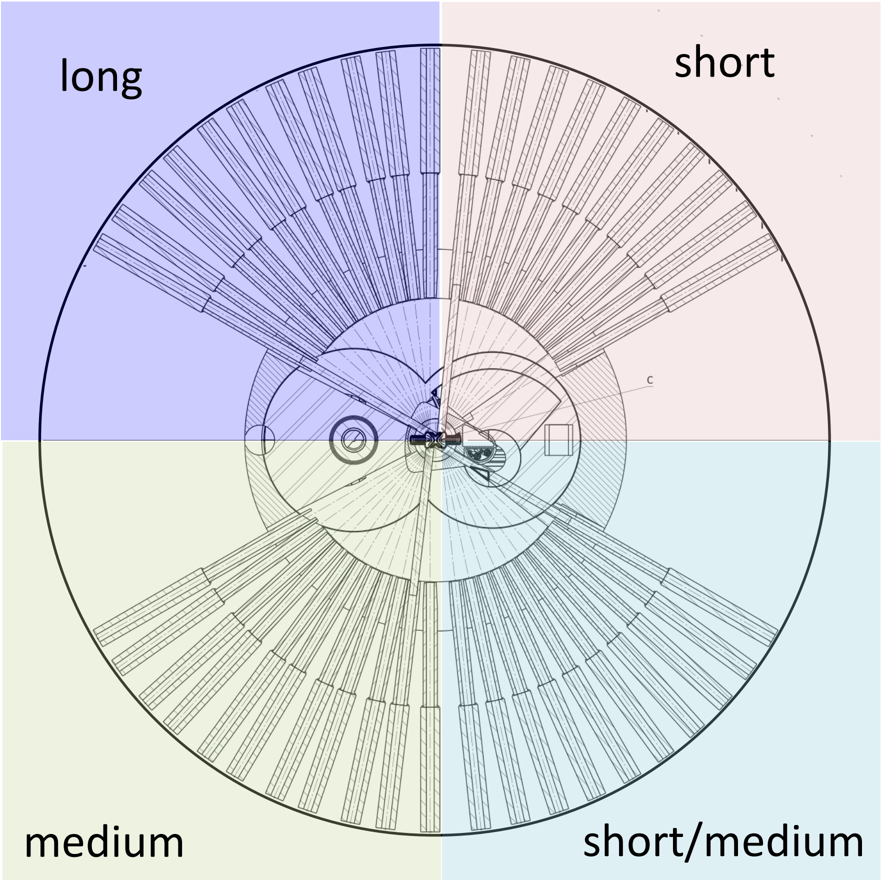


J-PARC: 23 beamports

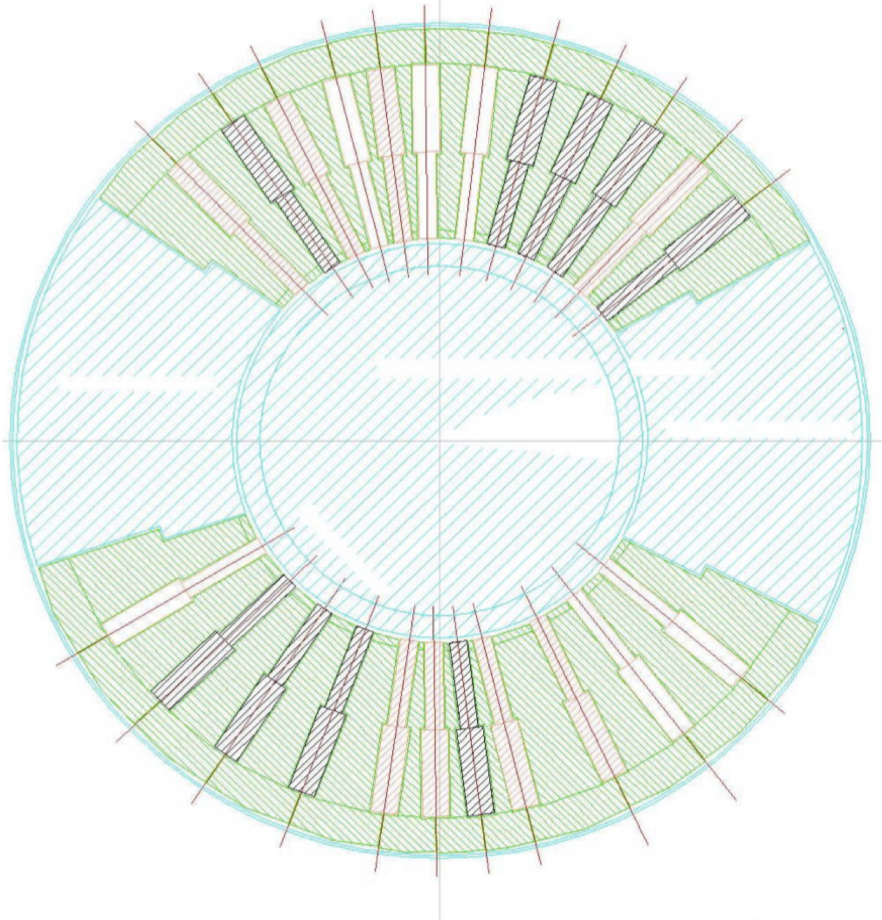


Beamport separation

ESS: 42 beamports

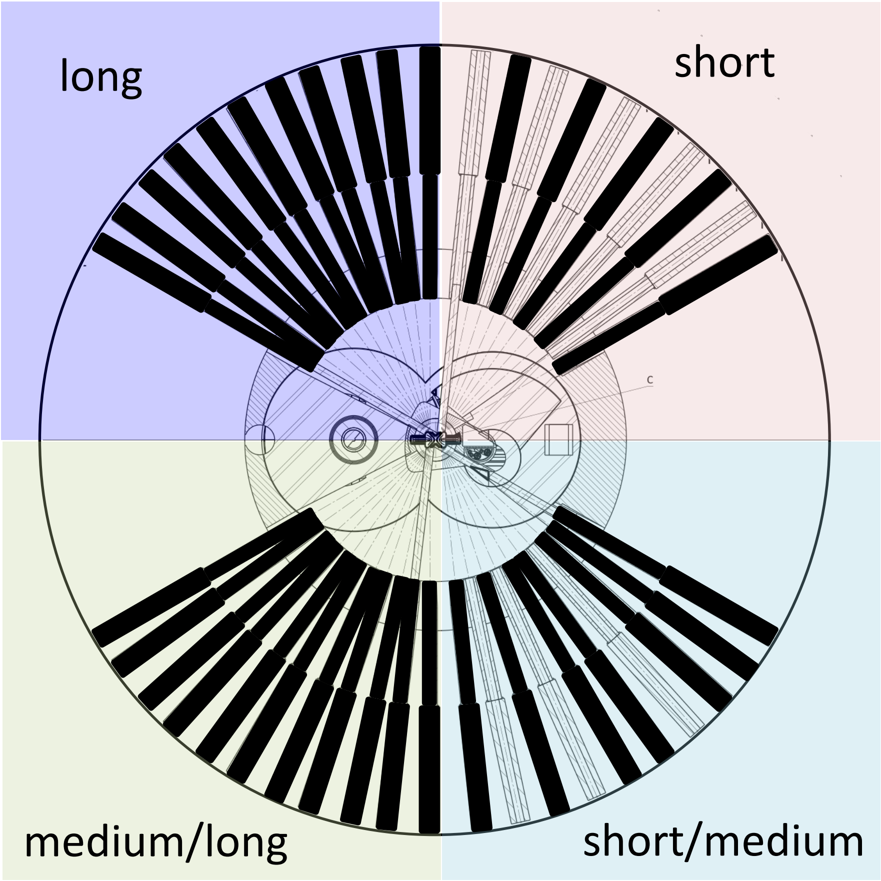


J-PARC: 23 beamports

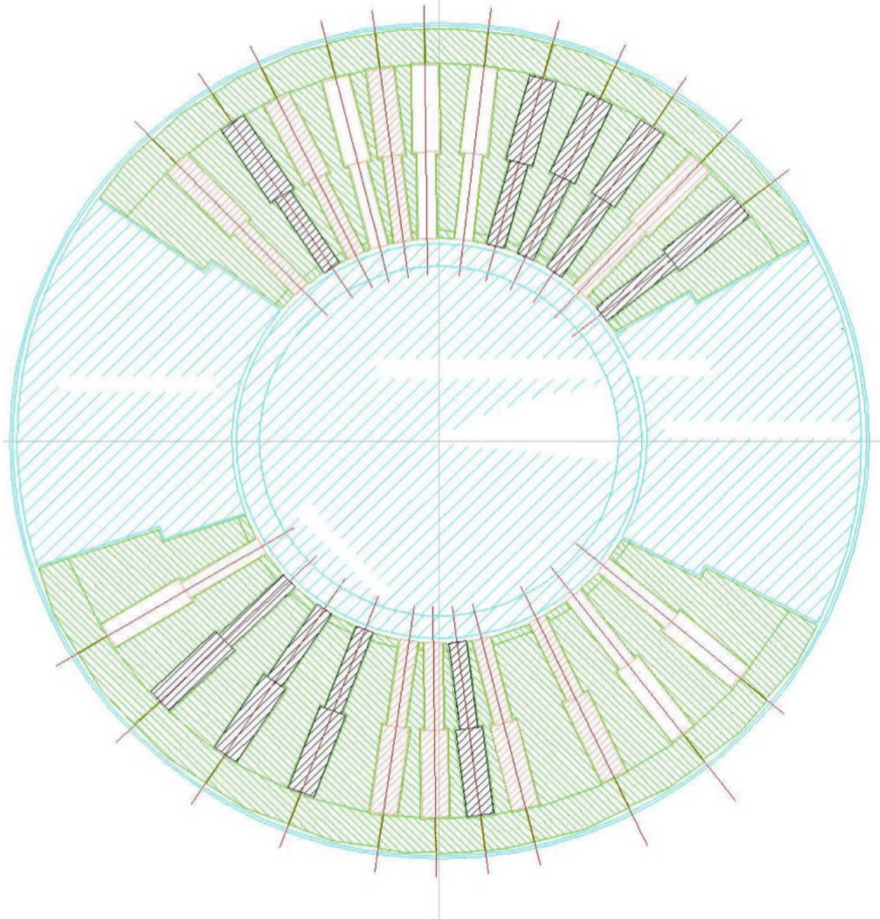


Beamport separation

ESS: 42 beamports

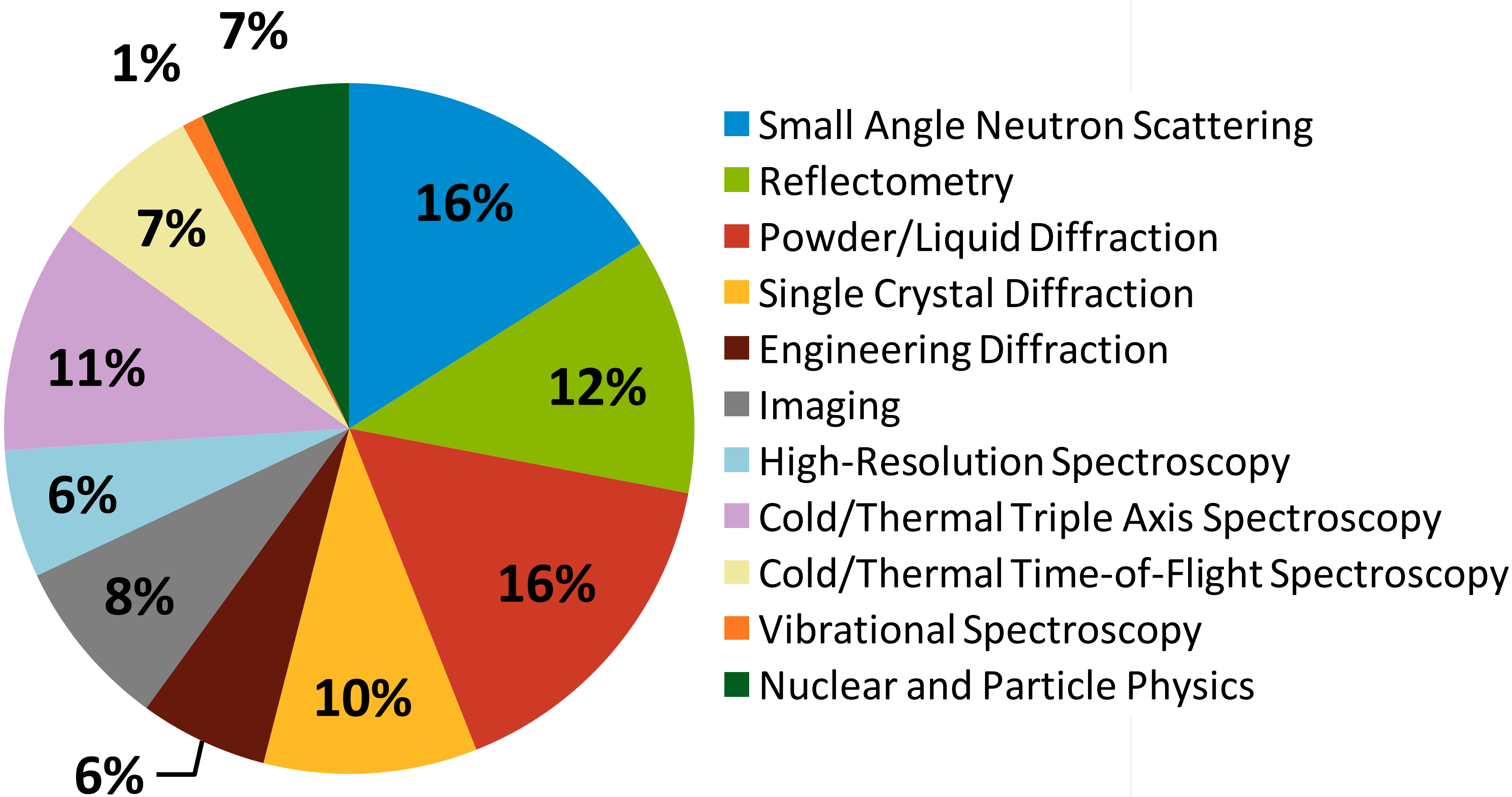


J-PARC: 23 beamports

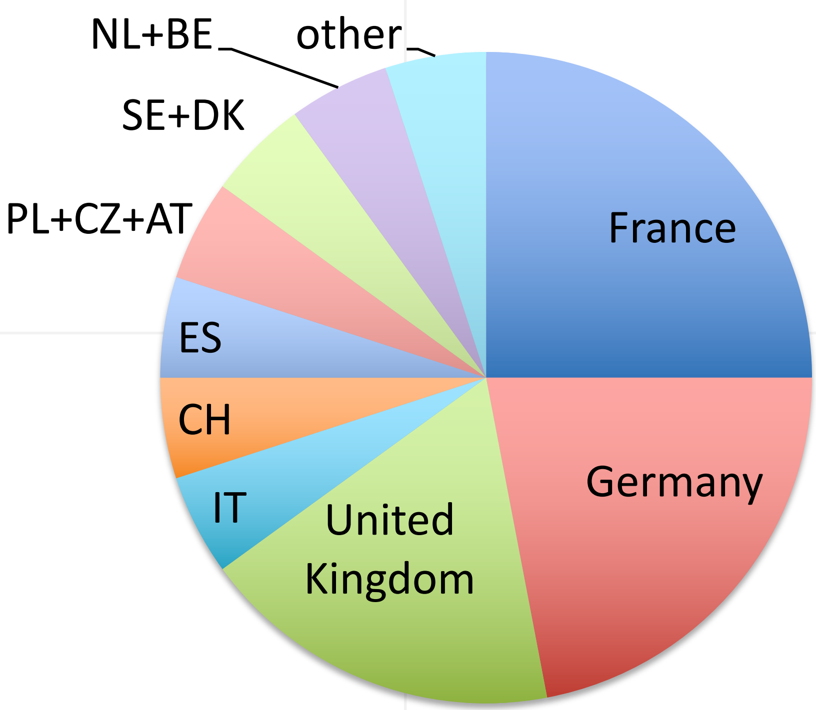


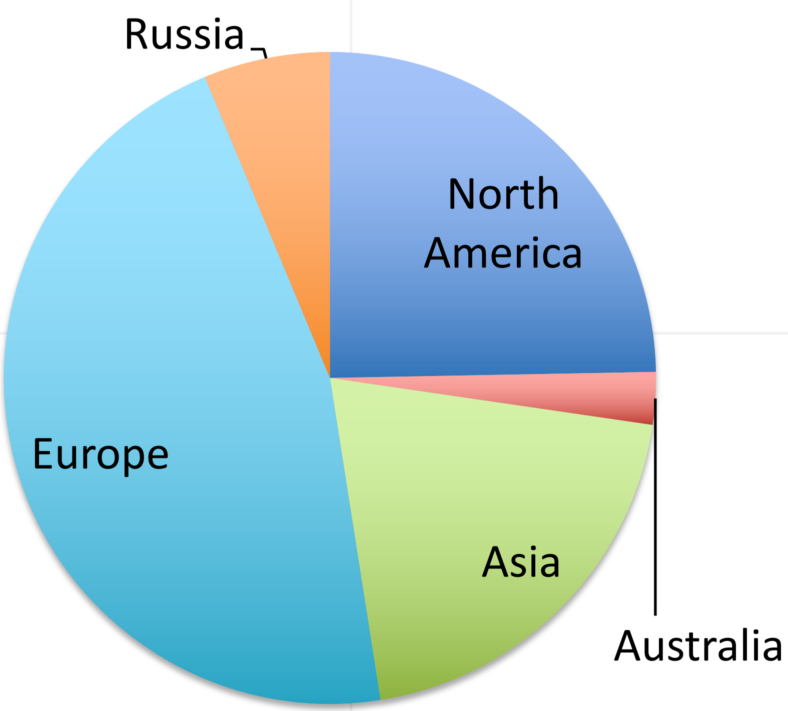
ESS looking towards MAX IV and Lund University

Facility-based Survey on Neutron Users



User Community based on publications





European Community
5000 - 6000 researchers
2000 publications per year

data: ESFRI, KFN

Facility-based Survey on Neutron Users