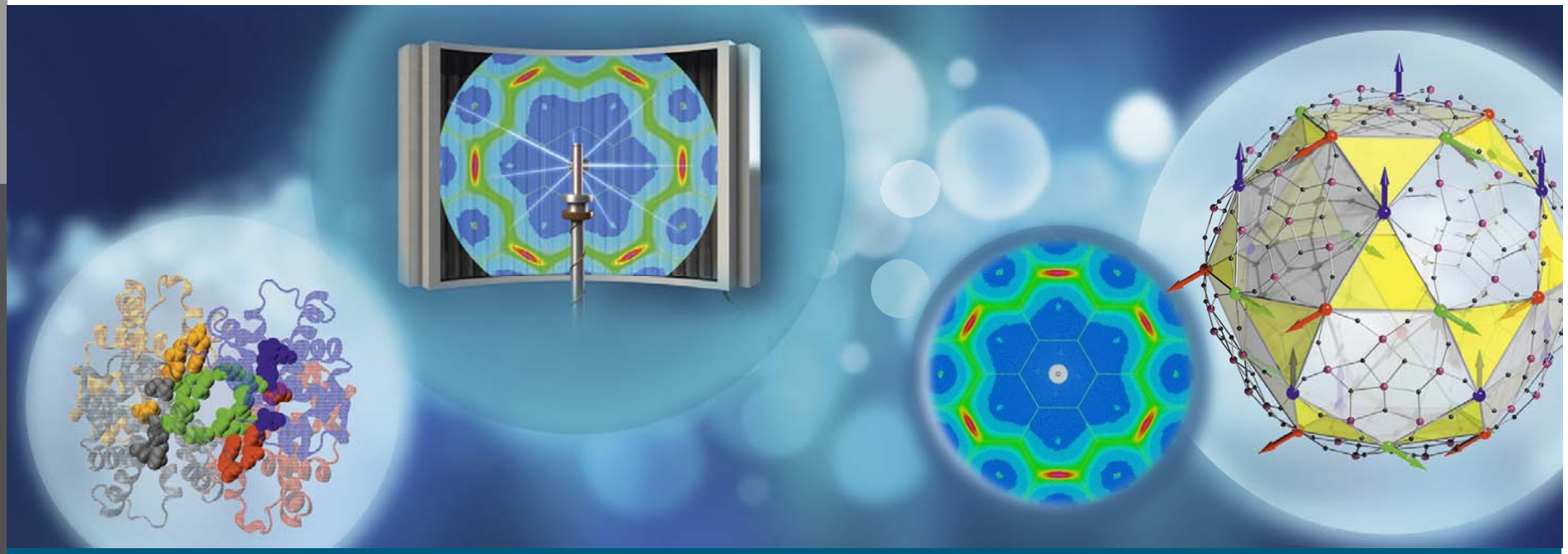

Research with Neutrons: Towards a High Brilliance Neutron Source

Thomas Brückel

Jülich Centre for Neutron Science JCNS, Forschungszentrum Jülich
& Heinz Maier-Leibnitz Zentrum MLZ, Garching

16. Februar 2017 | Forum Beschleunigerphysik, , TU Darmstadt

Mitglied der Helmholtz-Gemeinschaft

Jülich Centre for Neutron Science

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Research with Neutrons

Mitglied der Helmholtz-Gemeinschaft

Neutrons:
A special gift for science

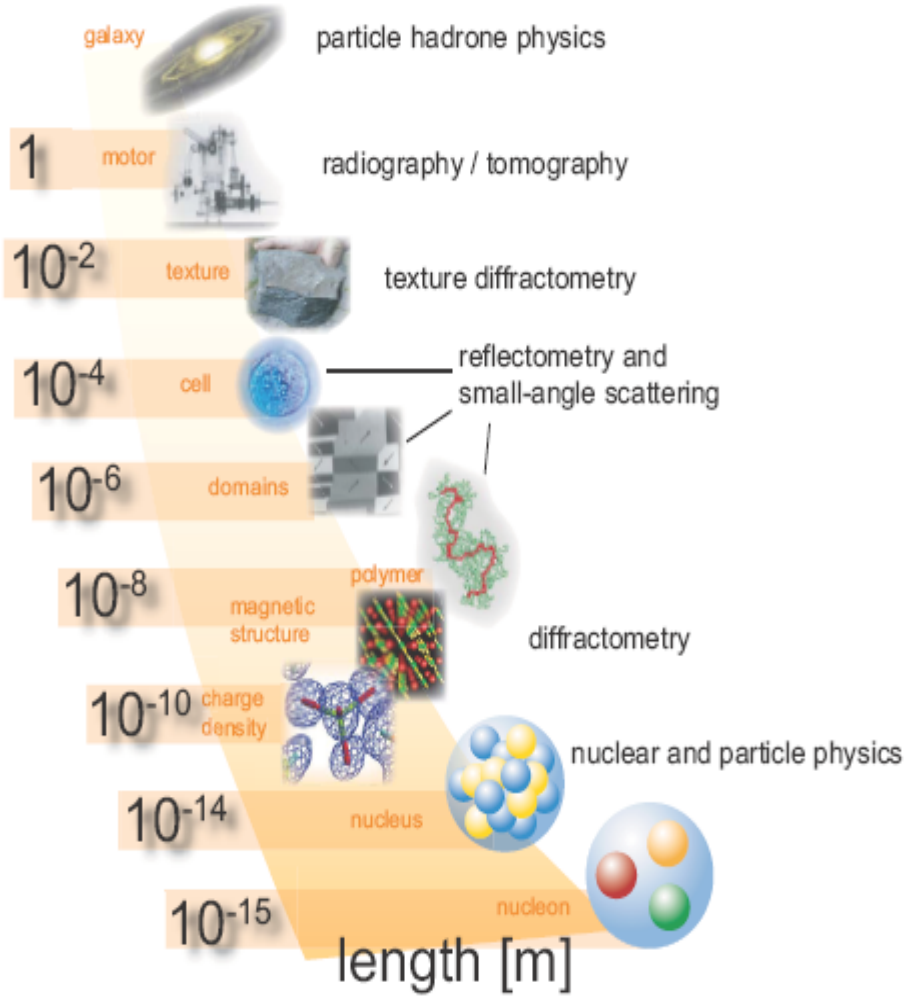
„Neutrons tell us
where the atoms are
and how they move.“

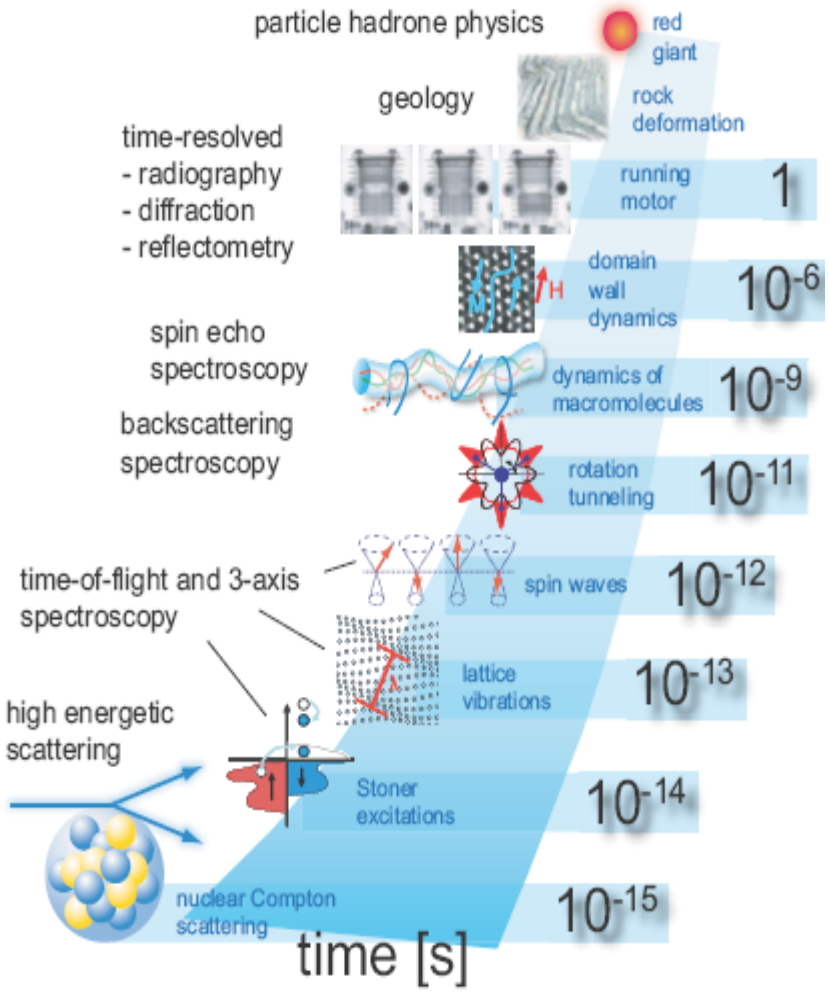
→ macroscopic functionalities of materials

Clifford Shull
Nobel Prize Physics

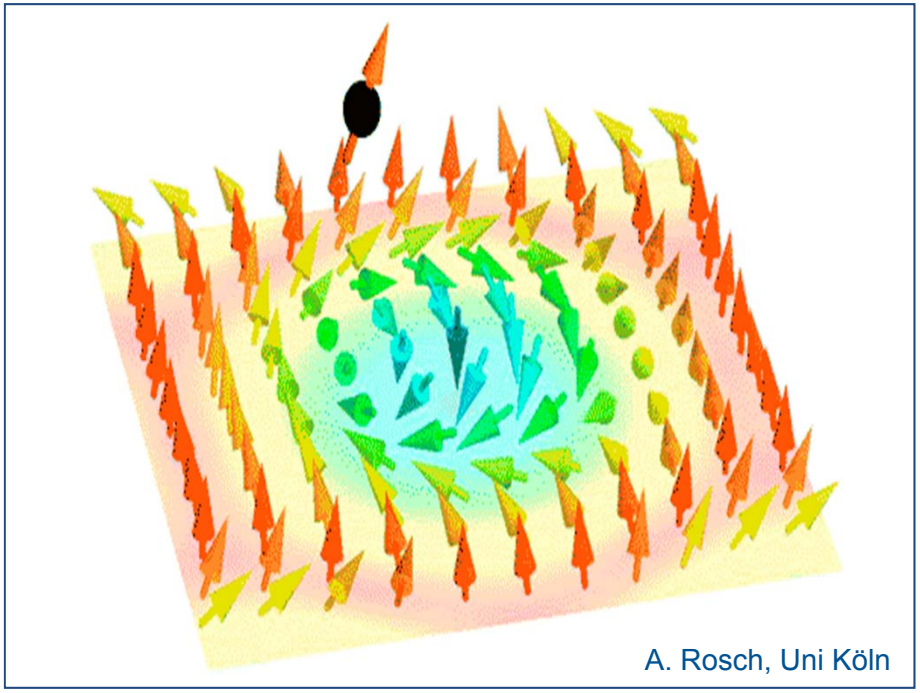
Neutrons are rarely the first,
but often the last probe
for new materials or new phenomena.

Length- and time scales
covered by research with neutrons





Key Technologies



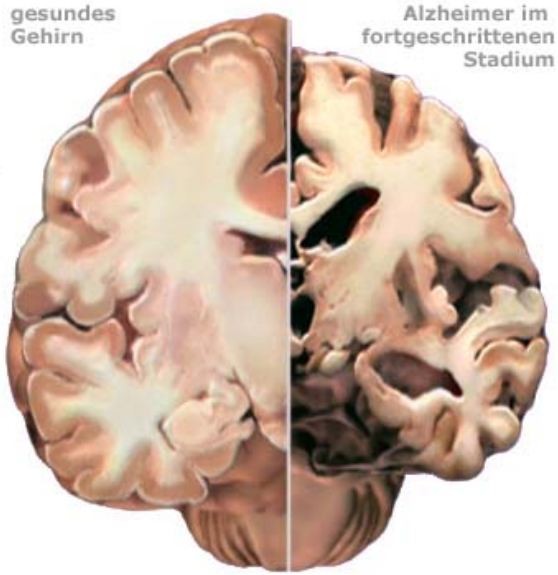
Skyrmions
- topologically stabilized spin vortices
- elements of future spin-based IT

Topology; compare:
Physics-Nobel prize 2016
David J. Thouless,
F. Duncan M. Haldane
and J. Michael Kosterlitz
& Europhysics Prize 2016

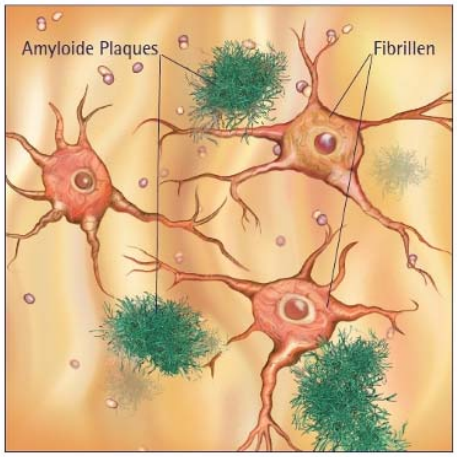
Neutron scattering:
- discovered at MLZ
- fundamental interactions

Magnon spectrum of the helimagnetic insulator Cu_2OSeO_3
P. Y. Portnichenko, et al.;
Nature Communications 7, 10725 (2016); DOI: 10.1038/ncomms10725

Health

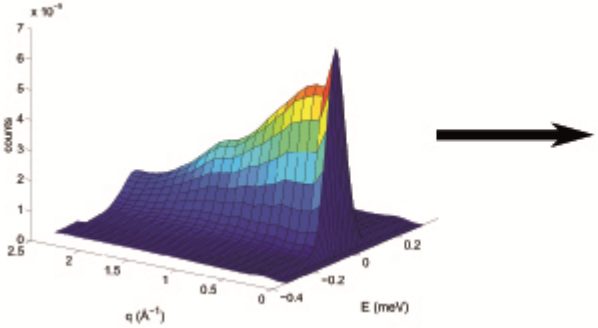


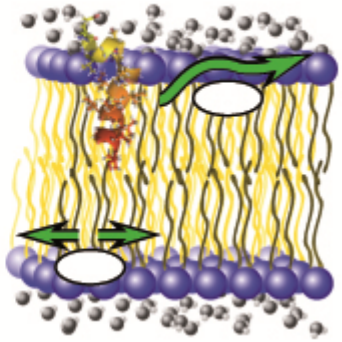
Alzheimer's Association



alzheimer-forschung.de

Alzheimer Disease:
- Peptide Amyloid-β Plaques

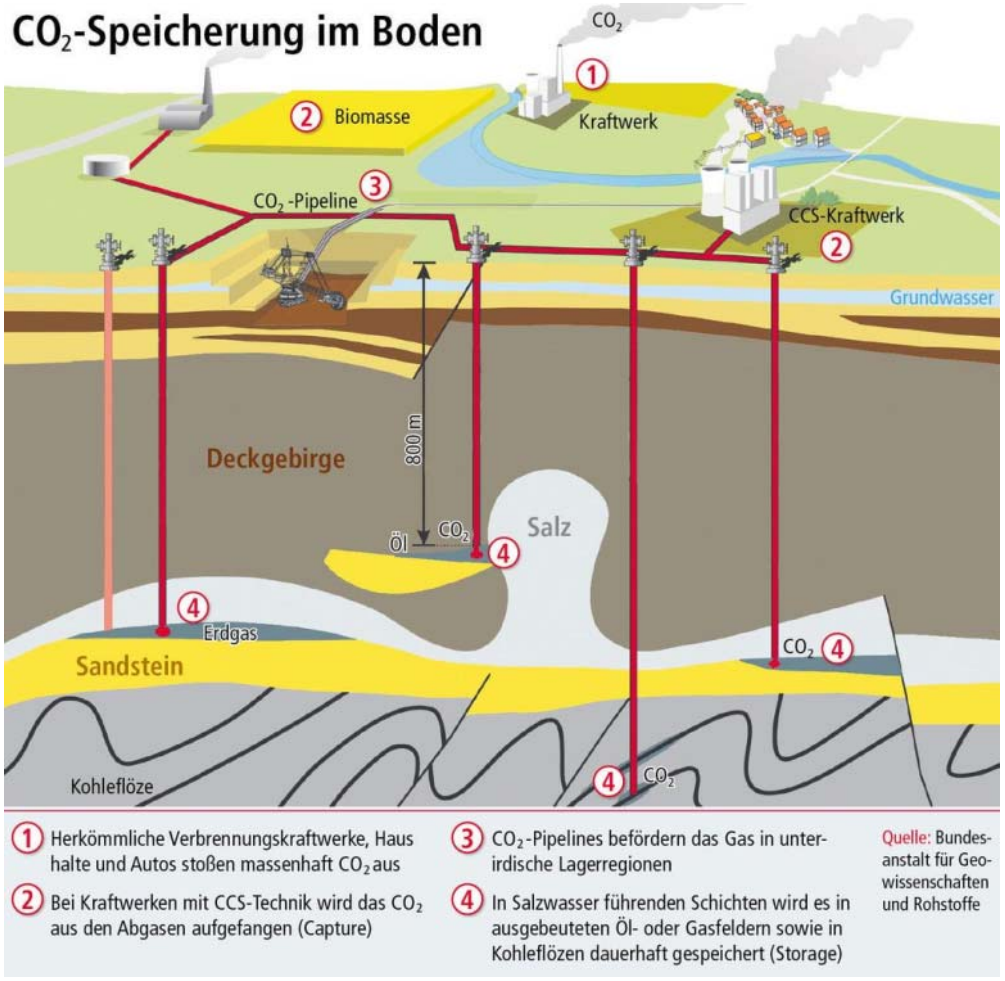




Neutron spectroscopy:
- alter movement of lipids
- eventual cell death

Alzheimer's peptide amyloid-β, fragment 22-40, perturbs lipid dynamics
MA.Barrett, M.Trapp, W. Lohstroh, T. Seydel, J. Ollivier, M. Ballauff, NA. Dencher, T. Hauß
Soft Matter 12 (2016), 1444-51; DOI: 10.1039/c5sm02026c

Earth and Environment

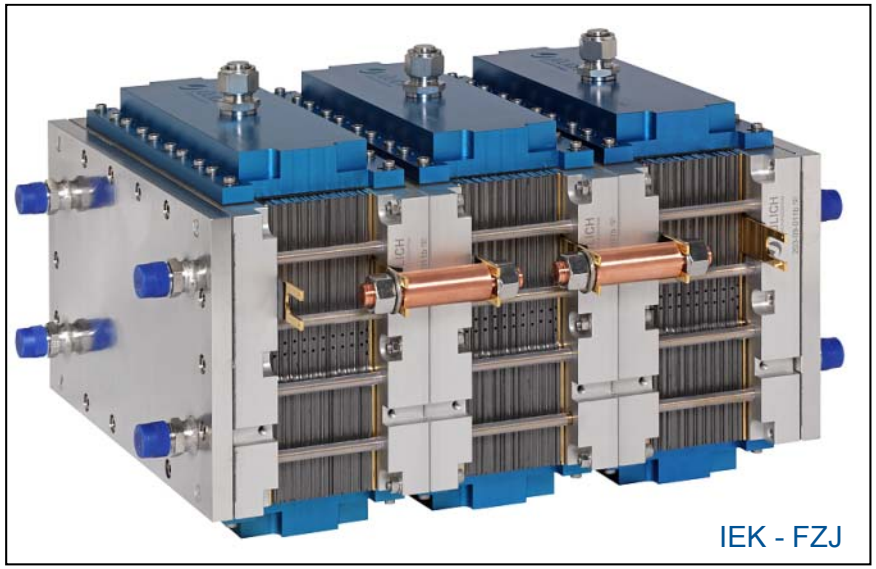


Can anthropogenic CO_2 be stored over million of years in cap rock formations?

Neutron Small Angle Scattering: determination of porosity and inner surfaces for reactive processes

Observational evidence confirms modelling of the long-term integrity of CO_2-reservoir caprocks;
N. Kampman et al.;
Nature Communications 7, (2016), 12268; DOI: 10.1038/ncomms12268

Energy



High Temperature-Polymer-Elektrolyt-Fuel Cells:

- conductivity depends on catalyst concentration

Neutron spectroscopy:

- determination of proton diffusion

Structure and Proton Dynamics in Catalytic Layer of HT-PEFC
M. Khaneft, O. Holderer, O. Ivanova, W.Lüke, E.Kentzinger, M.S.Appavou, R. Zorn, W.Lehnert
Fuel Cells 16 (2016), 406; DOI: 10.1002/fuce.201500167

Jülich Centre for Neutron Science

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Facilities for Research with Neutrons

Mitglied der Helmholtz-Gemeinschaft

Jülich Centre for Neutron Science

Jülich Centre for Neutron Science

JÜLICH FORSCHUNGSZENTRUM

MLZ Heinz Maier-Leibnitz Zentrum

13 instr.

1 (+4) instr.

1 (+2) instr.

JCNS strategy:
the best instruments at the best sources

Jülich Centre for Neutron Science

MLZ
Heinz Maier-Leibnitz Zentrum

JÜLICH
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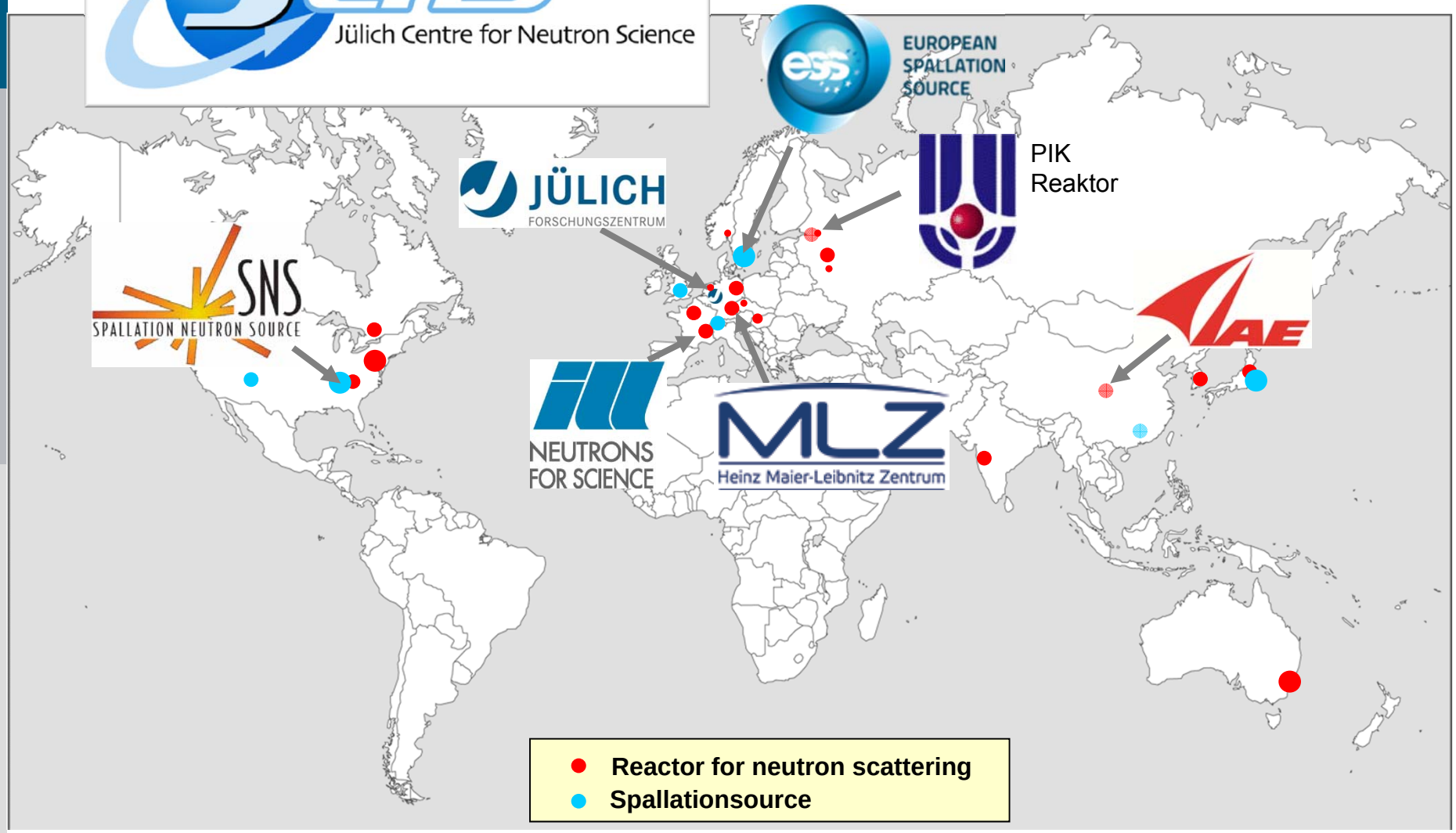
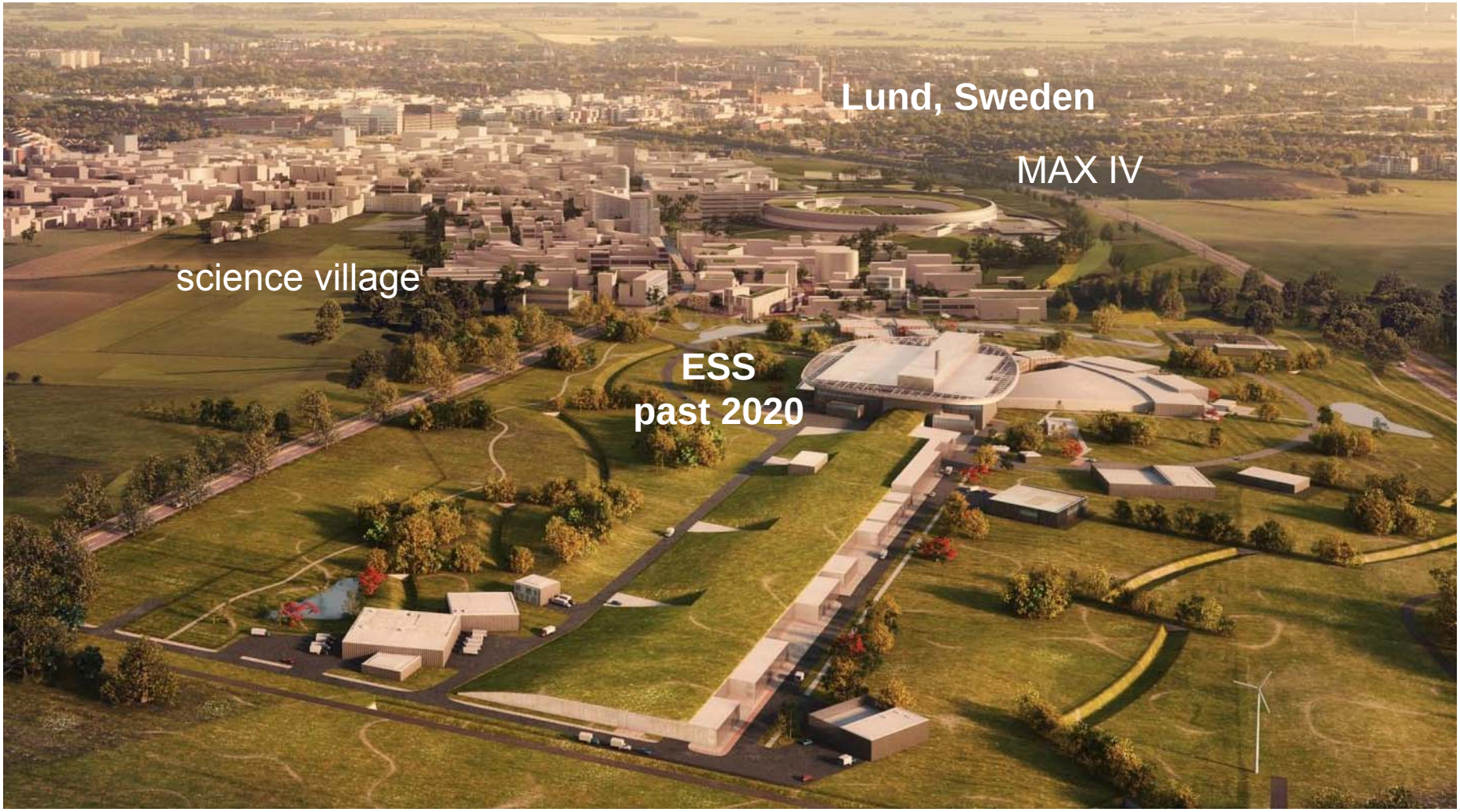
- national facility, where big science and university merge: TUM, FZJ-JCNS, HZG-GEMS
- 26 instruments in user operation, 8 instrument projects
- about 1000 users / year

New Opportunities

ESS & PIK: future neutron sources



European Spallation Source ESS



7 out of 15 day one instruments build by MLZ partners!

ESS

ERIC:
12 members
3 observers

typically more than two orders of magnitude more performant instruments:
not more of the same, but entirely new experiments!

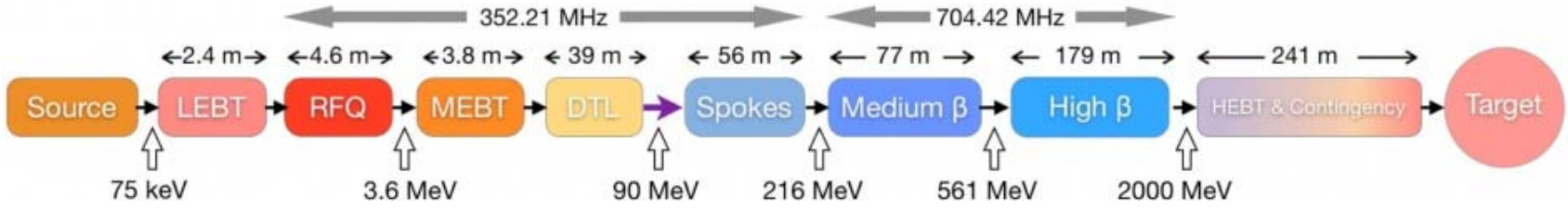
ESS Parameters

The ESS will be the world's most powerful neutron source

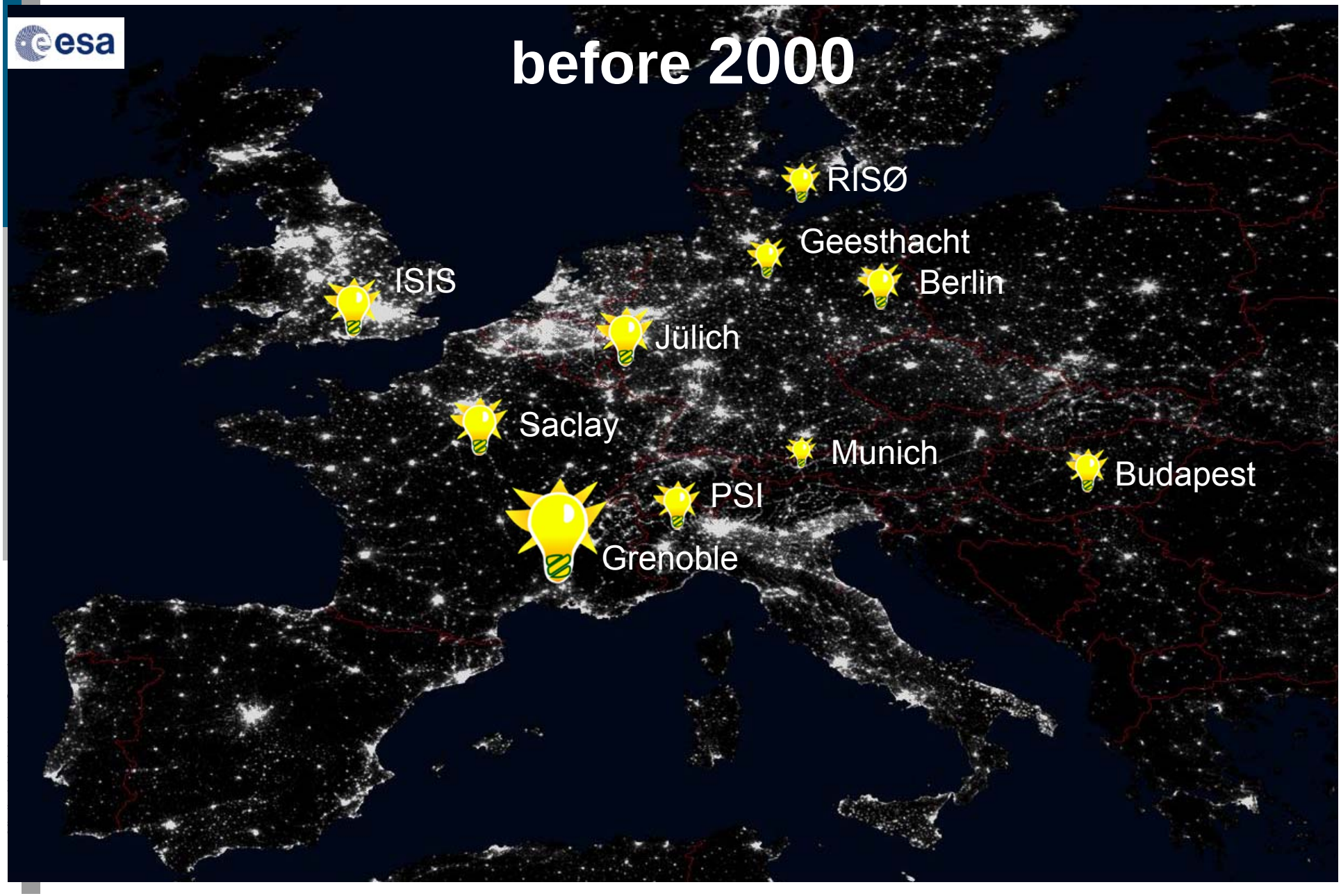
Proton Energy:	2.5 GeV
Pulse Frequency:	14 Hz
Pulse Length:	2.86 ms
Power:	5 MW
Target:	Rotating tungsten wheel cooled by helium or water
Instruments:	8 on day one (2019) 22 in 2025; start user operation in 2023
Costs:	1.843 Billion €

EUROPEAN SPALLATION SOURCE

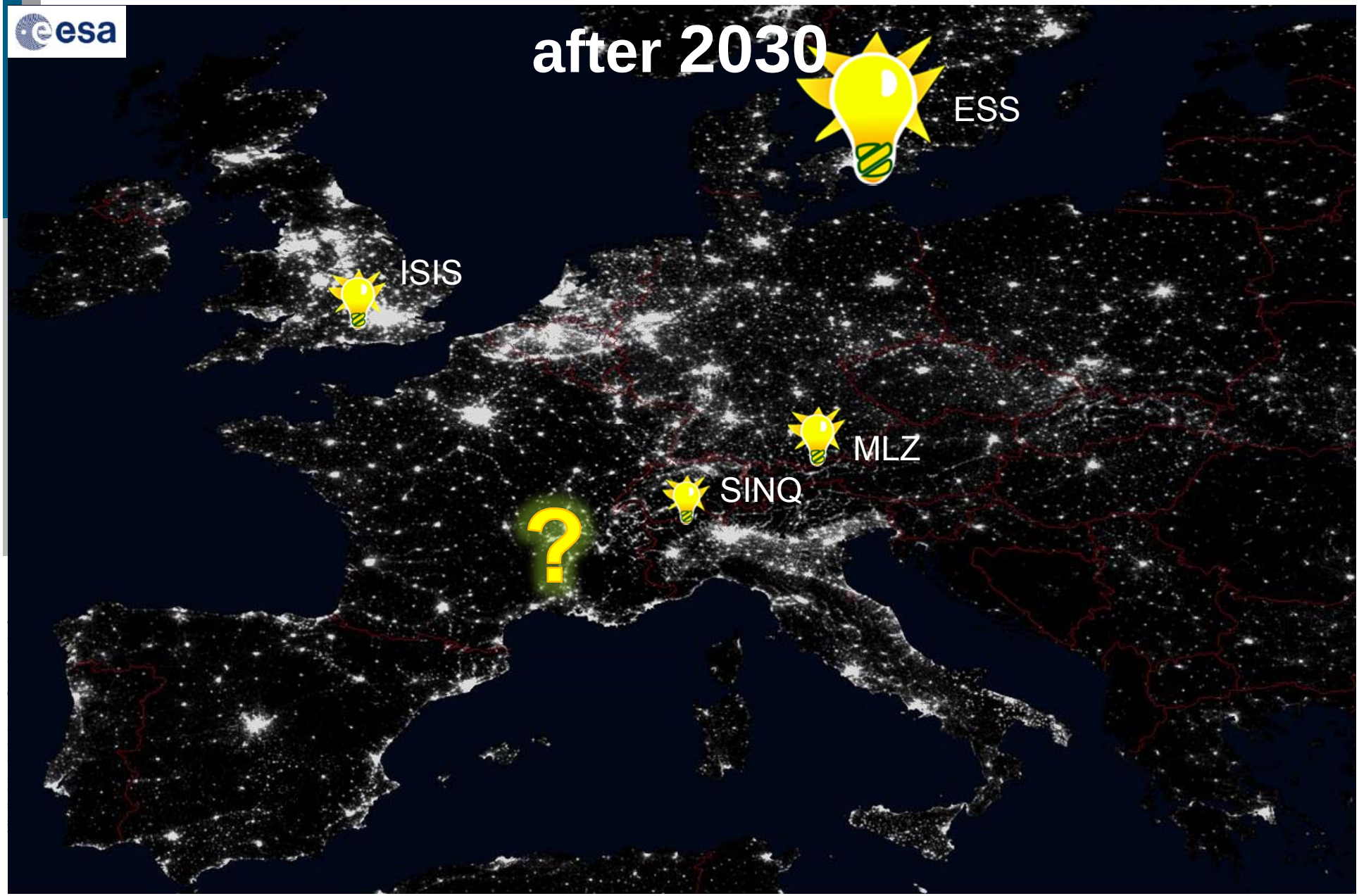
ESS accelerator: 2.5 GeV, 5MW



Larger Neutron Centres



Possible Neutron Scenario



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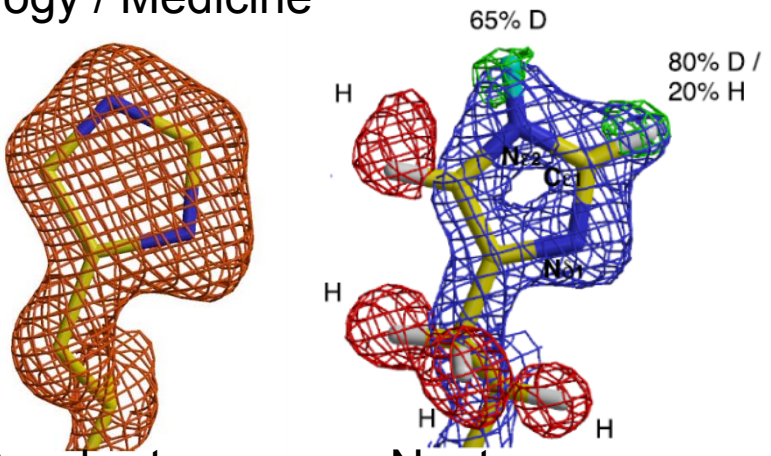
A New Type of Neutron Facility: A **H**igh **B**rilliance Neutron **S**ource - The Need -

Mitglied der Helmholtz-Gemeinschaft

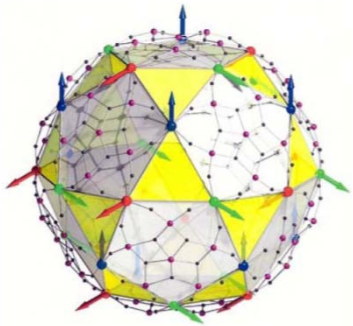
Compact Neutron Sources

Biology / Medicine



Synchrotron Neutrons

Nano-magnetism:



Novel sources:

- high brilliance for small samples
- easy access for universities and industry
- education, user recruitment

⇒ project of a scalable,
high brilliant neutron source HBS
with realistic budget

From Table-Top to Flagship Devices: Microscopy

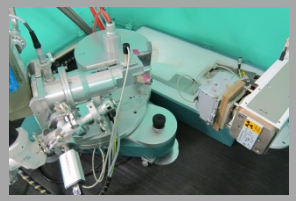
Confocal Microscope

FIB Microscope

Electron Microscope

PICO

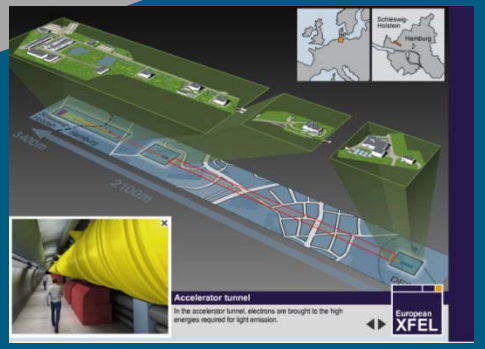
From Table-Top to Flagship Devices: X-Rays



Laboratory

Galaxi

Petra III (DESY)



XFEL (DESY)

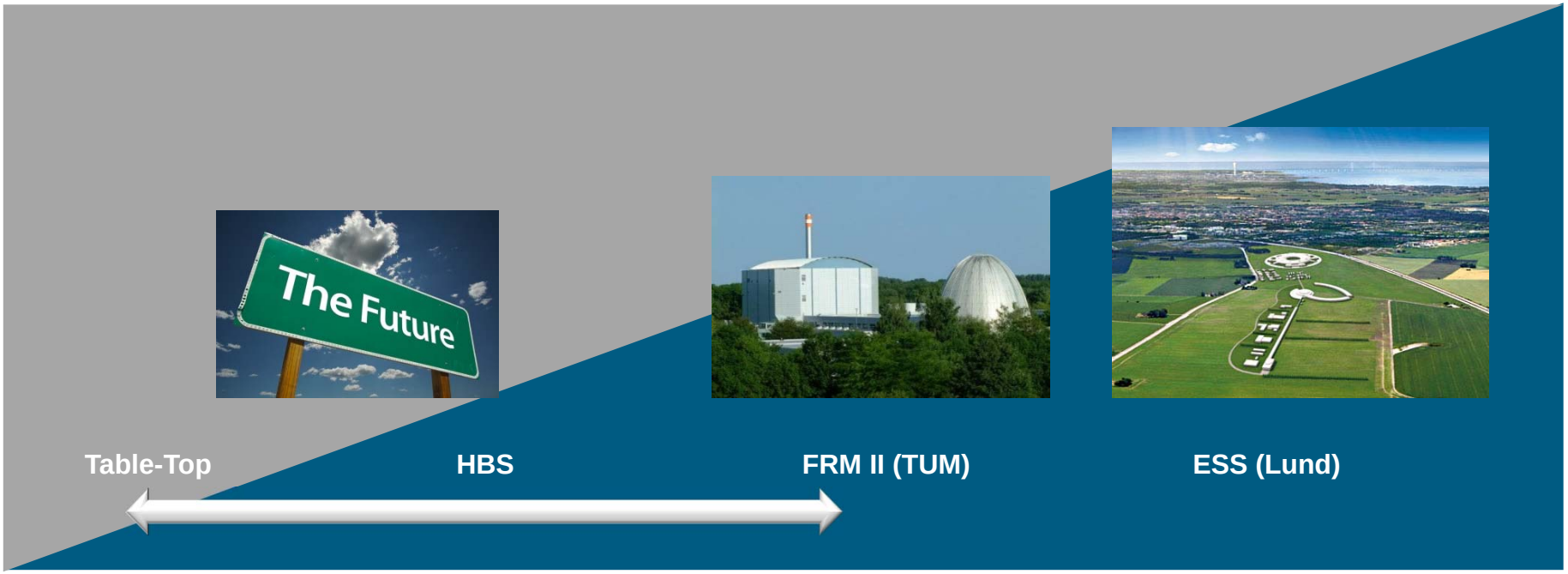
And Neutrons?

? ?

FRM II (TUM)

ESS (Lund)

Fill the Gap for Neutrons !



German Neutron Strategy

agreed strategy paper for research with neutrons by the

Helmholtz Association of National Research Centres approved by the KFN

Version adopted by the steering committee of the Research Field Matter of the Helmholtz Association on Dec. 4, 2014.

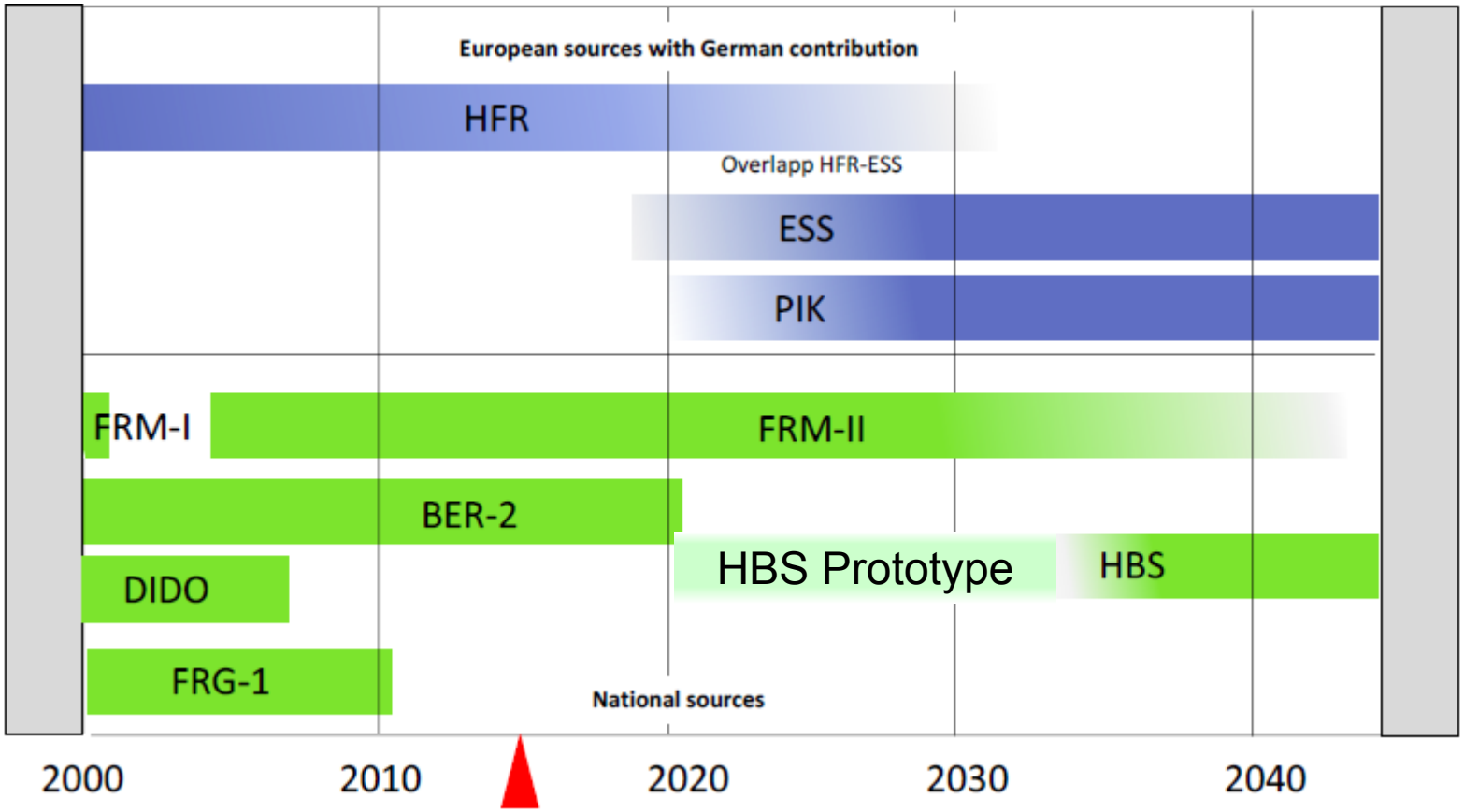
Strategy Paper
on

Neutron Research in Germany:
2015–2045

analysis of *science, users, facilities*

http://www.fz-juelich.de/SharedDocs/Downloads/JCNS/EN/HBS/Strategic%20paper.pdf

German Neutron Strategy until 2045



HBS on Helmholtz Roadmap

HOCHBRILLANTE NEUTRONENQUELLE HBS (HIGH BRILLIANCE NEUTRON SOURCE)

Die hochbrillante beschleunigerbasierte Neutronenquelle HBS stellt eine einzigartige Infrastruktur zur Neutronenanalytik (bildgebende Verfahren und Streuung) für eine Vielzahl von Wissenschaftsdisziplinen wie Physik, Chemie, Biologie, Geologie, Material- und Ingenieurswissenschaften dar. Unter Nutzung der neuesten Entwicklungen im Bereich Target, Moderator, Strahlextraktion, Strahlführung und Neutronenoptik lässt sich eine extrem kompakte Neutronenquelle mit Beschleunigern relativ niedriger Endenergie realisieren. Durch für spezifische Anwendungen dedizierte Targetstationen und die Optimierung auf die Untersuchung von kleinen Proben ergänzt sie die großen internationalen Anlagen wie die zukünftige Europäische Spallationsquelle ESS in idealer Weise.

Wissenschaftlicher Hintergrund
Mit ihren einzigartigen Eigenschaften sind Neutronen die idealen Sonden in kondensierter Materie. Sie sagen uns, wo die Atome sind, welchen Spin sie tragen, und wie sie sich bewegen. Die Anwendung der Neutronenanalytik ist im Wesentlichen zählratenlimitiert. Eine brillanzoptimierte Quelle, die intensive kleine Strahlen für angepasste Instrumentierung bereitstellt, wird die Neutronenanalytik für viele der modernen Fragestellungen an nanostrukturierten oder biologischen Materialien erschließen und eine räumliche Auflösung bieten, die den Systemen der Energietechnik oder Strukturmaterialien angepasst ist.

Nutzenperspektive
Die Entwicklung neuer Materialien und Materialsysteme, die die rasanten Fortschritte moderner Technologien ermöglichen und damit unseren Wohlstand begründen, ist eng an die Verfügbarkeit von leistungsfähigen mikroskopischen Analysemethoden geknüpft. Neutronen sind für Wissenschaftler vieler Disziplinen unverzichtbar. Die Vielfalt und Komplexität der Fragestellungen erfordert ein Netzwerk unterschiedlicher Quellen für Ausbildung, Methodenentwicklung und Spezialisierung. In diesem Netzwerk spielt die HBS eine zentrale Rolle. Gemäß dem „Strategiepapier zur Neutronenforschung in Deutschland 2015 bis 2045" des Forschungsbereichs „Materie" stellt die HBS langfristig die nationale Neutronenquelle dar.

Daten und Zahlen

Zeitplan:
- Bau: 2028 bis 2033
- Betrieb: 35 Jahre

Geschätzte Kosten:
- Vorbereitungs-/Planungskosten: 10 Mio. Euro
- Investitionskosten: 200 Mio. Euro insgesamt, getragen von Helmholtz (Stand 2014)
- Betriebskosten: 20 Mio. Euro pro Jahr

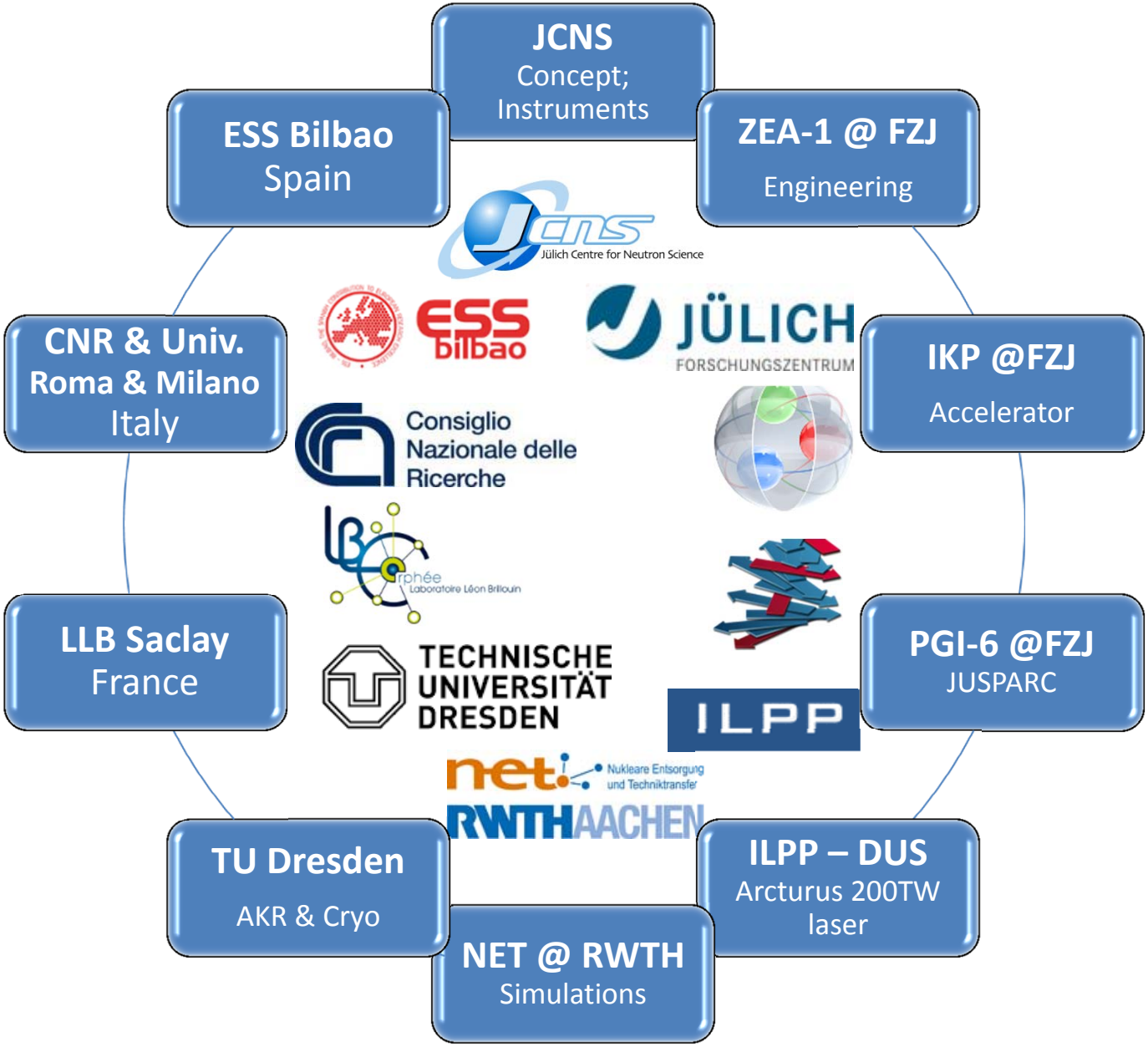
Internationale Dimension:
Die HBS wird eine wichtige Rolle im internationalen Netzwerk von Neutronenquellen spielen. Die Entwicklung kompakter Quellen gewinnt im Rahmen der „International Collaboration on Advanced Neutron Sources" ICANS an Bedeutung.

Rolle des Zentrums/der Zentren:
Das Forschungszentrum Jülich ist alleiniger Antragsteller. Der Standort für die HBS wird das Forschungszentrum Jülich sein.

Weitere Informationen:
Strategiepapier zur Neutronenforschung in Deutschland: 2015 bis 2045:
http://www.helmholtz.de/forschung/struktur_der_materie/forschung_mit_photonen_neutronen_und_ionen_pni/neutronen/

Materie

Present Design Network



Mitglied der Helmholtz-Gemeinschaft

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High **B**rilliance Neutron **S**ource
- The Concept -

Mitglied der Helmholtz-Gemeinschaft

Nuclear Reactions Producing Neutrons

Nuclear Process	Example	Neutron Yield	Heat Release [MeV/n]
D-T in solid target	400 keV D on T in Ti	4×10^{-5} n/d	10 000
Deuteron stripping	40 MeV D on liquid Li	7×10^{-2} n/d	3500
Nuclear photo effect from e-bremsstrahlung	100 MeV e^- on ^{238}U	5×10^{-2} n/e^-	2000
$^{9}Be(d,n)^{10}Be$	15 MeV D on Be	~~1 n/d~~ 1.5E-2 n/d	1000
$^{9}Be(p,n;p,pn)$	11 MeV p on Be	5×10^{-3} n/p	2000
Nuclear fission	Fission of ^{235}U by thermal neutrons	1n/fission	180
Spallation	800 MeV p on ^{238}U or Pb	27 n/p or 17 n/p	55 or 30

neutron gener.

HUNS (Hokkaido)

LENS The Low Energy Neutron Source

MLZ Heinz Maier-Leibnitz Zentrum

ESS EUROPEAN SPALLATION SOURCE

from: G. Mank, G. Bauer, F. Mulhauser,
Accelerators for Neutron Generation and Their Applications, Rev. Accl. Sci. Tech 04, 219 (2011)

Mitglied der Helmholtz-Gemeinschaft

Producing Neutrons

Comparison of production efficiency of fast neutrons

U+e: preliminary results, target geometry not optimized concerning photon absorption

ion	E [MeV]	n/nps_ion	n/s/mA	n/s/kW
Be+p	5	0.015%	9.49E+11	1.899E+11
Be+p	10	0.110%	6.86E+12	6.856E+11
Be+p	25	0.638%	3.98E+13	1.593E+12
Be+d	5	0.063%	3.94E+12	7.887E+11
Be+d	10	0.265%	1.65E+13	1.653E+12
Be+d	25	1.608%	1.00E+14	4.015E+12
Be+d	50	5.724%	3.57E+14	7.145E+12
Be+d	100	20.522%	1.28E+15	1.281E+13
Li+p	2	0.002%	1.02E+11	5.107E+10
Li+p	5	0.050%	3.15E+12	6.299E+11
Li+p	10	0.164%	1.02E+13	1.025E+12
Li+p	25	0.471%	2.94E+13	1.176E+12
U+e	20	0.396%	2.47E+13	1.236E+12
U+e	50	2.520%	1.57E+14	3.146E+12
U+e	100	5.695%	3.55E+14	3.555E+12
U+e	150	8.710%	5.44E+14	3.624E+12
U+e	200	11.861%	7.40E+14	3.702E+12

$^{9}Be(d,n)$

good efficiency, engineering o.k.

$^{7}Li(p,n)^{7}Be$

Efficiency too low, engineering difficult

$M\left(e^{-},\gamma\right)$ - Bremsstrahlung

$M\left(\gamma,n\right)$ - nuclear photoeffect

Interesting candidate

Mitglied der Helmholtz-Gemeinschaft

HBS:
Alternatives to spallation?

HBS - novel concept:

optimize the accelerator driven source from ion source to detector for every single instrument:

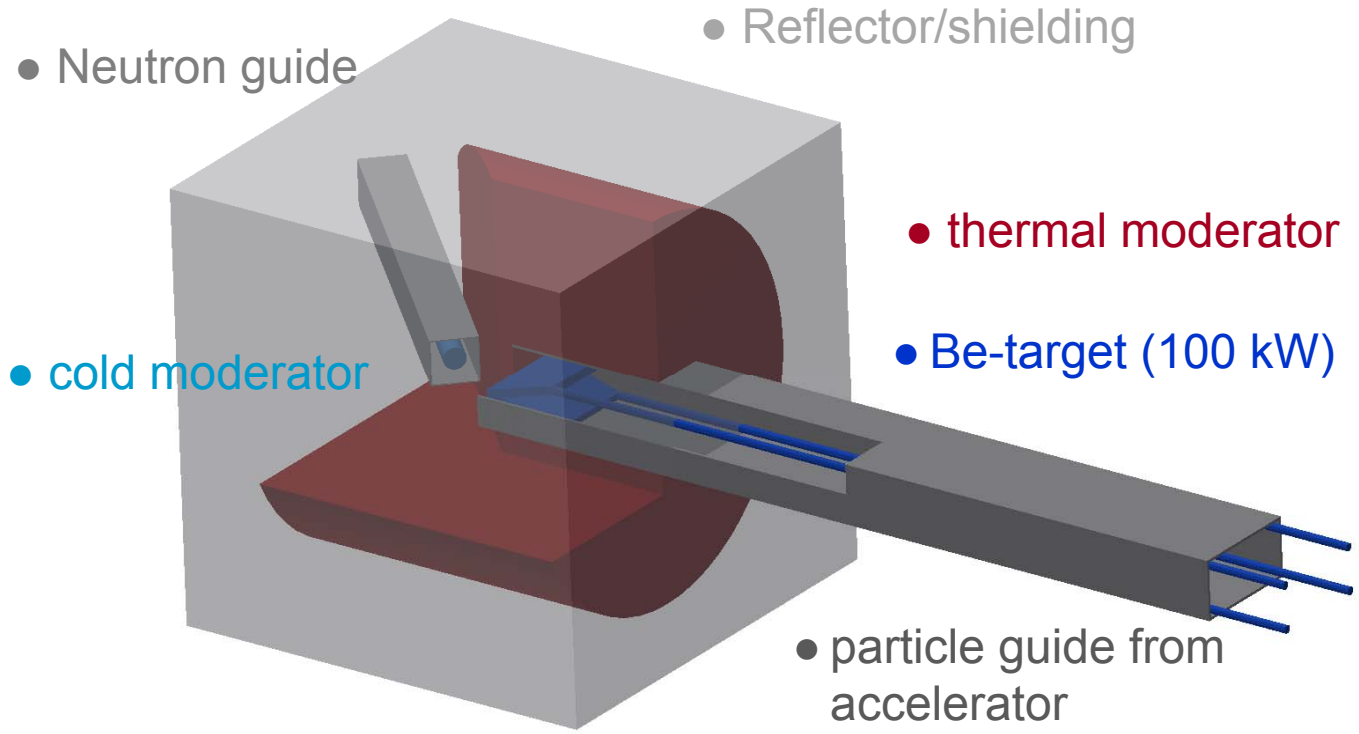
- ✓ adapted pulse time structure
- ✓ dedicated moderator
- ✓ dedicated optics

"every instrument has its own adapted neutron source!"

no "one fits all"
produce less (minimize cost!) - waste less (maximize brilliance!)

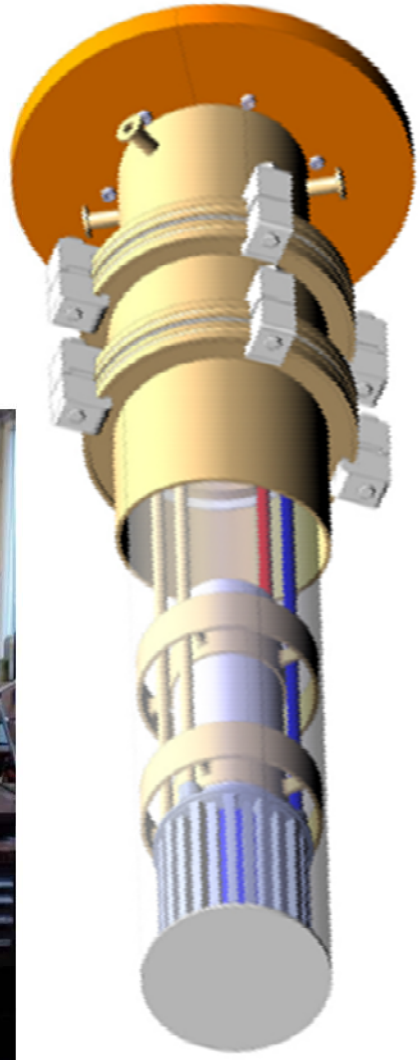
Mitglied der Helmholtz-Gemeinschaft

Efficient Coupling of Target to Moderator



no losses due to solid angle coverage!

Cold Source



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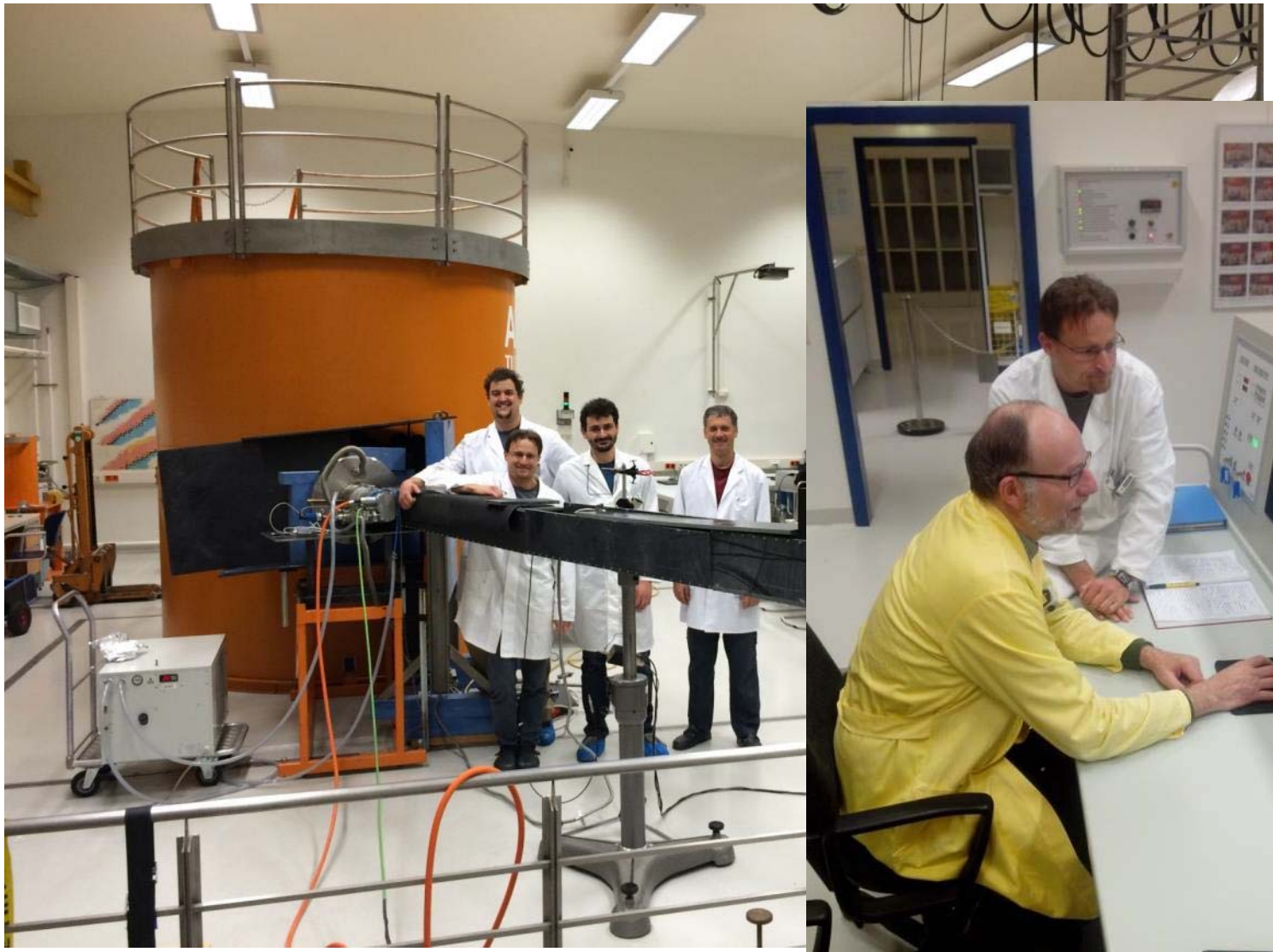
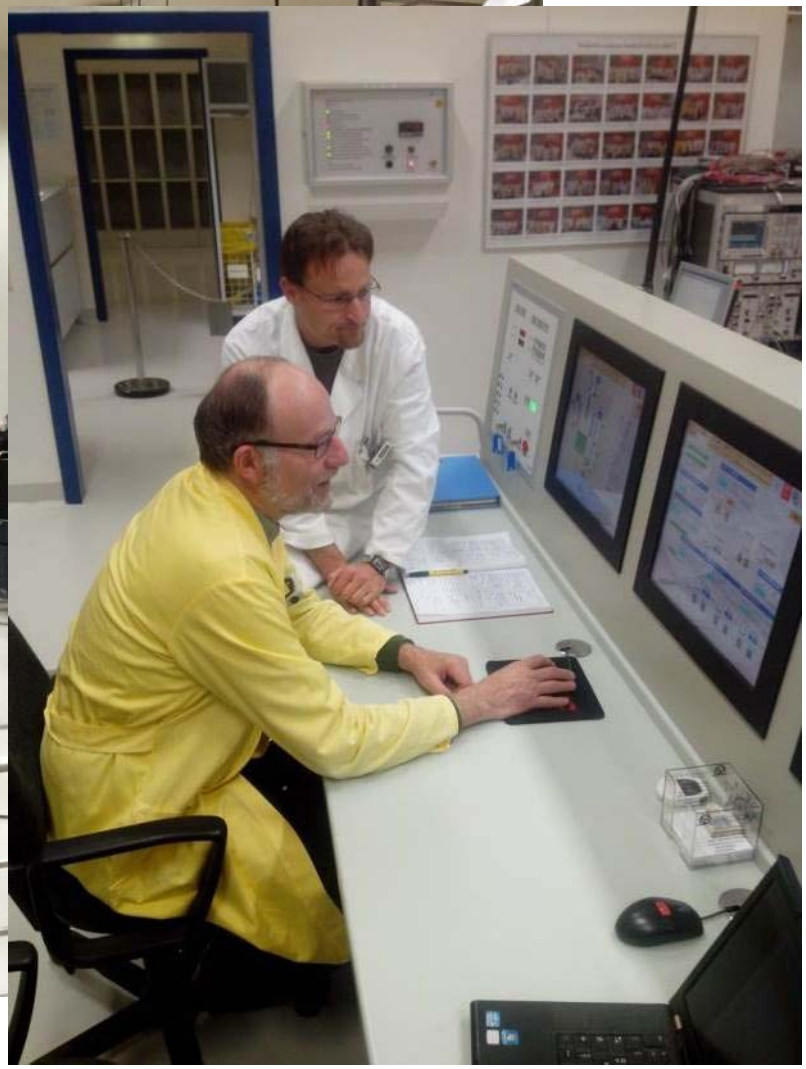
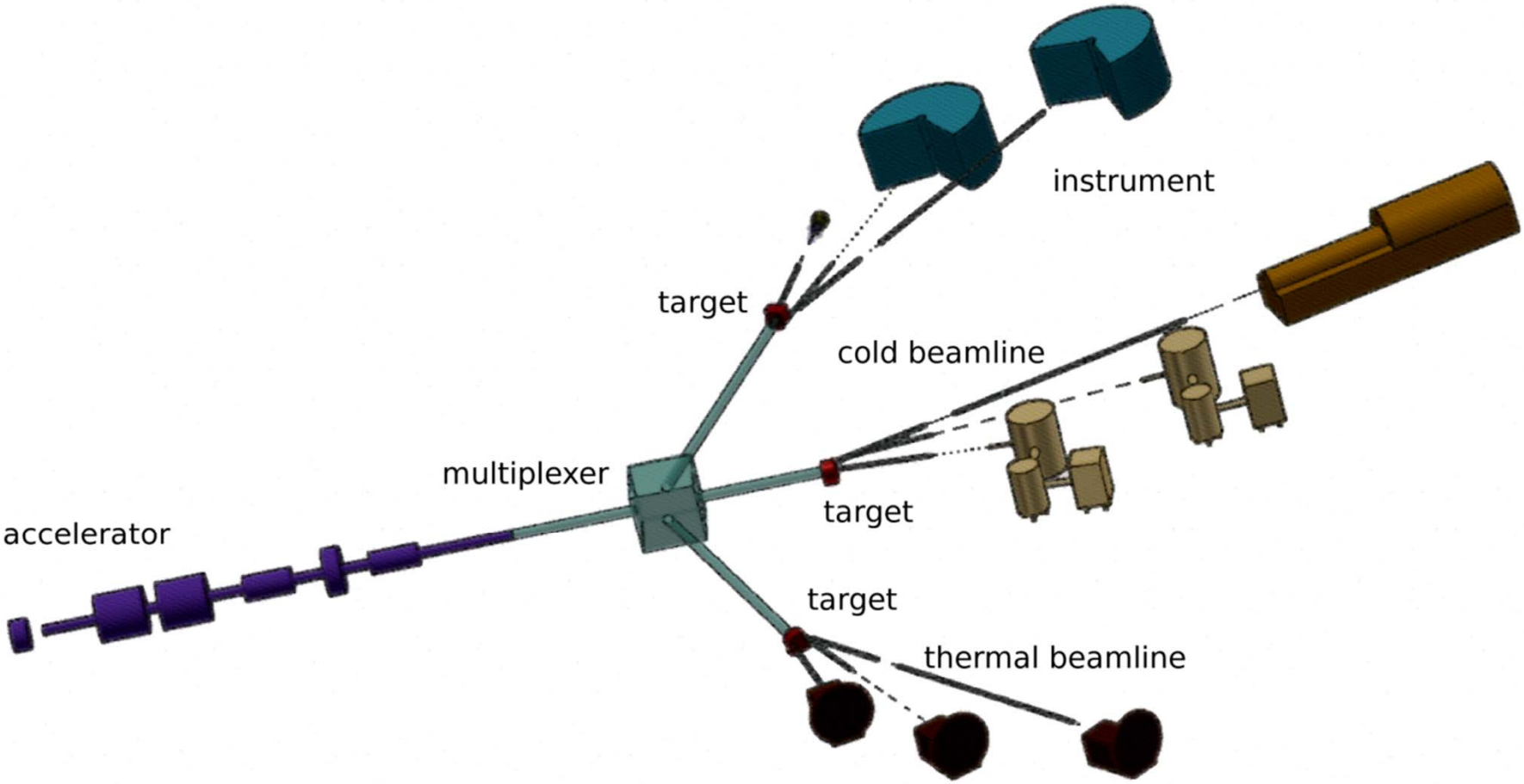
Test at AKR-2 – TU Dresden





Possible Facility Layout



The Jülich high-brilliance neutron source project

U. Rücker, T. Cronert, J. Voigt, J. P. Dabruck, P. -E. Doege, J. Ulrich, R. Nabbi, Y. Beßler, M. Butzek, M. Büscher, C. Lange, M. Klaus, T. Gutberlet and T. Brückel

Eur. Phys. J. Plus, 131 1 (2016) 19 | DOI: http://dx.doi.org/10.1140/epjp/i2016-16019-5

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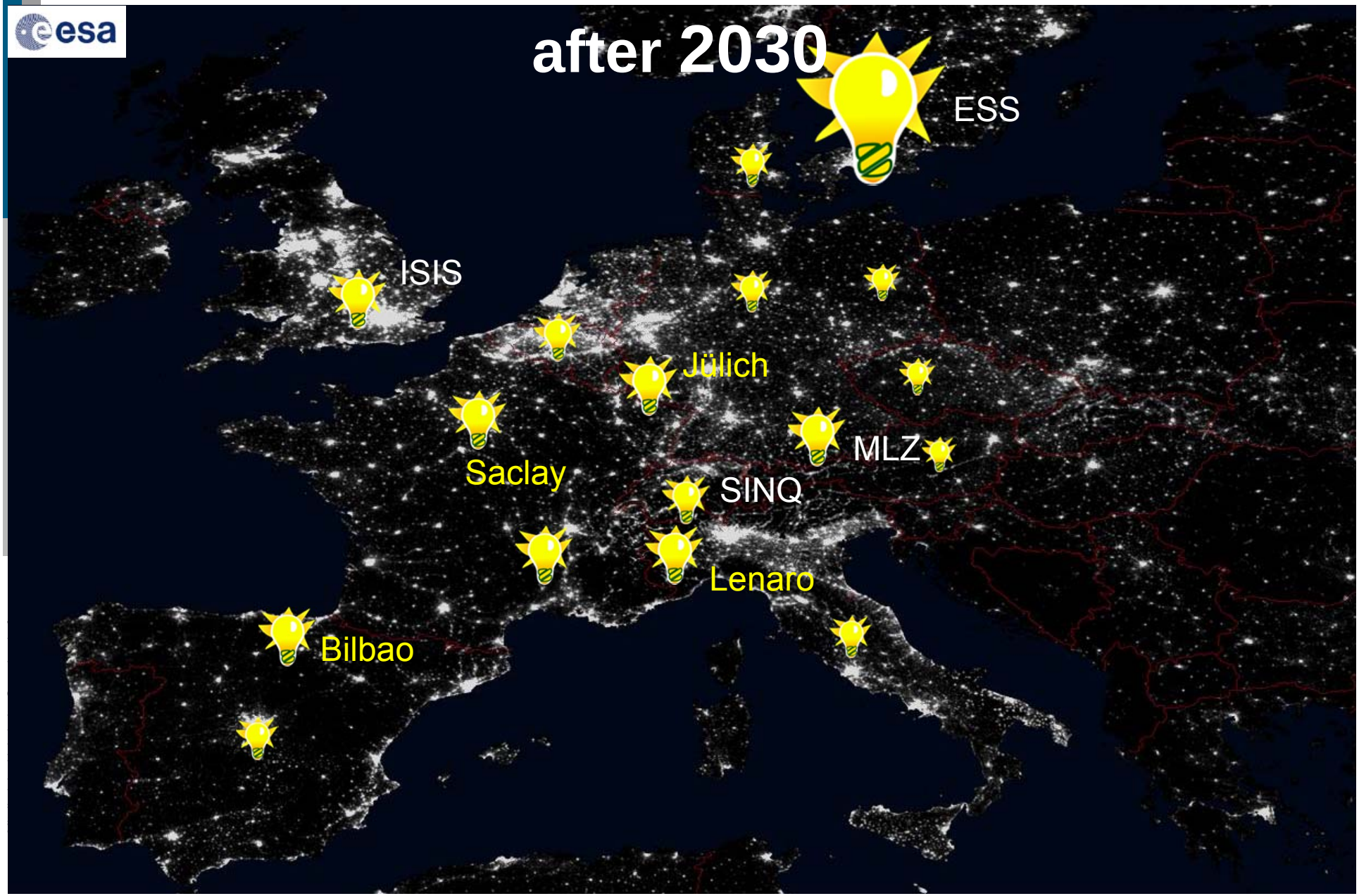
Desired Neutron Scenario



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Summary:
Present Facility Design Parameters

Mitglied der Helmholtz-Gemeinschaft

Present Design Parameters

Accelerator	
particles	deuterons
particle energies	5 – 50 MeV
peak current	100 mA
pulse length	50 μs – 2.5 ms
frequency	24, 96, 384 Hz / (quasi continuous ? variable 20-400)
Target	
Be slap	1.4 cm thickness
cooling	water (gallium)
max. power	100 kW per target station
number of target stations	3
number of beamlines	3 - 5 per target station
Moderator & Reflector	
thermal moderator	polyethylene slap
cold moderator	para-/ortho hydrogen & solid methane
reflector	beryllium / graphite

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Present Design Parameters

Beam extraction & transp.	
beam extraction	cold or thermal “finger”
neutron optics	solid state lenses / focusing neutron guide
Instruments	
large scale structures	SANS & reflectometers
diffractometers	single x-tal, powder, texture
inelastic	cold / thermal chopper, backscattering, NSE
others	imaging
Instrument performance	
e.g. cold chopper	$6.8 \cdot 10^4\ n/cm^2 \cdot s$ @ 5 meV †
Price tag	
small	10 M€ - 30 M€
full facility	200 M€ - 300 M€

† 2° divergence, *3m* distance sample-detector, *2%* resolution in E_i
(compare LET @ ISIS TS2: $5.6 \cdot 10^4\ n/cm^2 \cdot s$ @ 5 meV)

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Present Design Parameters (Accelerator)

Energy (MeV)	5	10	30	50
duty cycle	1-2% (1:100, 1:50)	1-5% (1:100, 1:20)	1-3.3% (1:100, 1:30)	1-2% (1:100, 1:50)
duty cycle of power supply		1.2-6 %		
average power (kW)	1	10	20	100
peak power (kW)	50	200	600	5000
peak current (mA)	10	20	20	100
frequenzy (Hz)	100 (20-400 variable)	100 (20-400 variable)	100 (20-400 variable)	24, 96, 384 (20-400 variable)
pulse length (μsec)	50-2500	50-2500	50-1000	50-1000
ion source	D^+	H^+, D^+	H^+, D^+	H^+, D^+

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