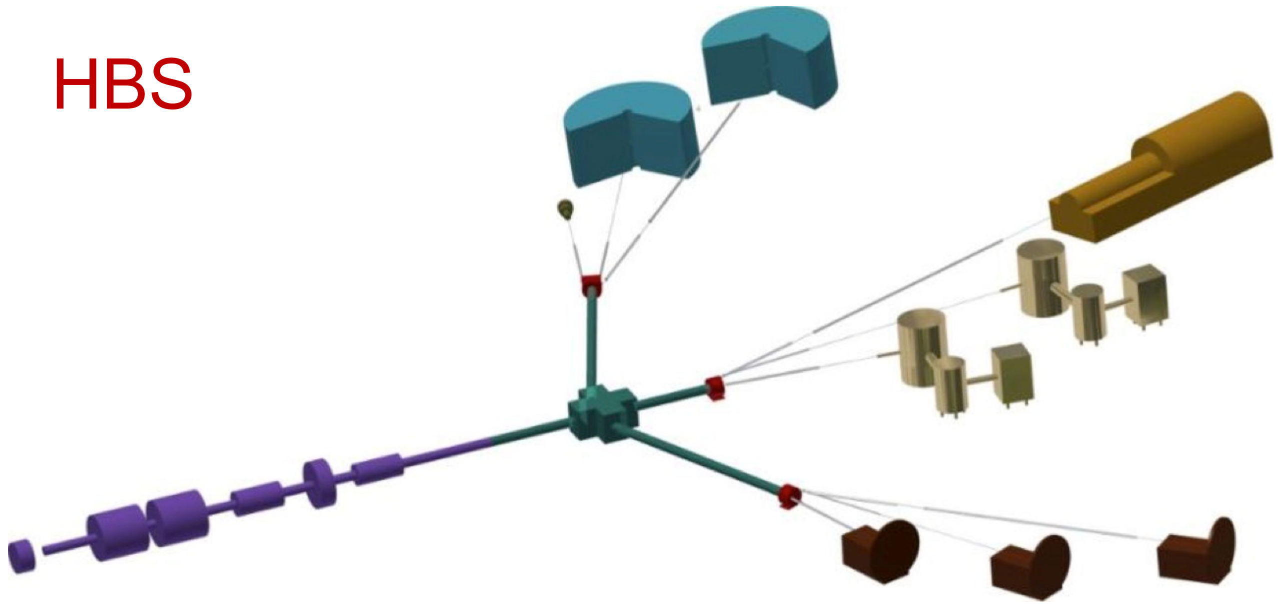


The HBS Project for a High Brilliance Neutron Source

Paul Zakalek, Jülich Centre for Neutron Science JCNS

European Neutron Landscape

Recipe for success: network of sources & peer review access

- **ILL & ESS** for flux hungry experiments

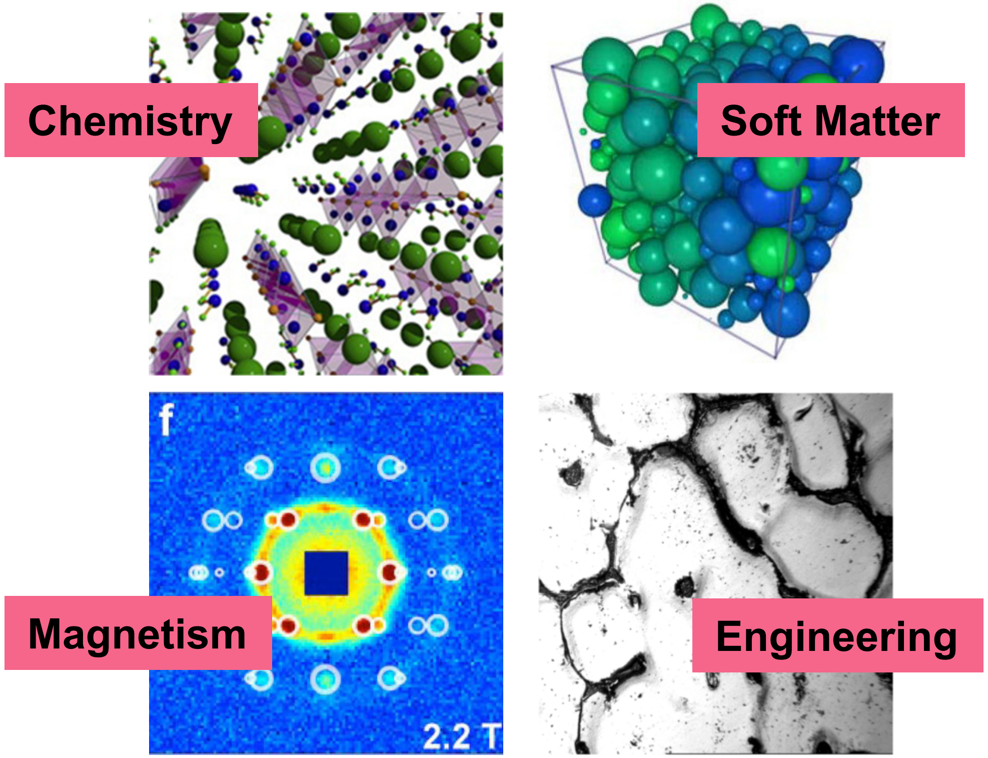
- **medium flux** sources for
  - method development
  - capacity & capability
  - user training

- **low flux** sources
  - at universities
    (e.g. Delft, Mainz, Wien)

- 8000 users
- 19 neutron sources in Europe
- 32.000 instrument beam days per year
- 1900 publications each year
- Collaboration and Flow
- New users welcome
- Supporting industry

European Neutron Landscape

Science with neutrons



The requirements:

- provide easy access
- allow proof of principle
- optimize for small samples

European Neutron Landscape

From table-top to flagship

HBS project:

Development of a scalable accelerator driven neutron source

High Brilliance Neutron Source Project

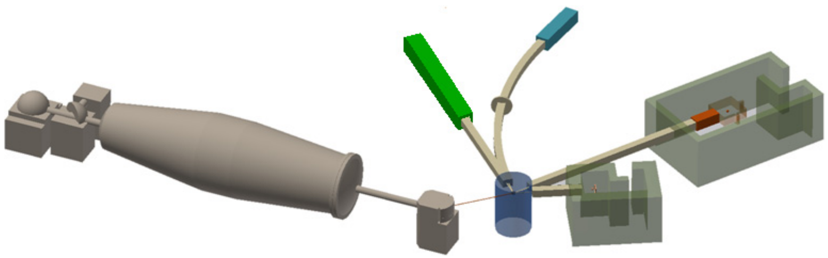
Realizations

Laboratory facility: NOVA ERA

Neutrons Obtained Via Accelerator for Education and Research Activities

- small accelerator (≈ 10 MeV)

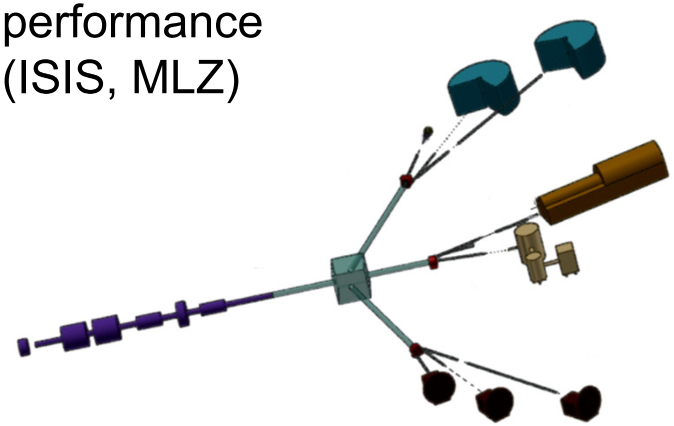
  commercial tandetron
- single target station
- basic instruments for research, education and training



Large-scale facility: HBS

High Brilliance neutron Source

- linear accelerator (≈ 30 - 80 MeV)
- several target stations
- full suite of instruments with competitive performance (ISIS, MLZ)



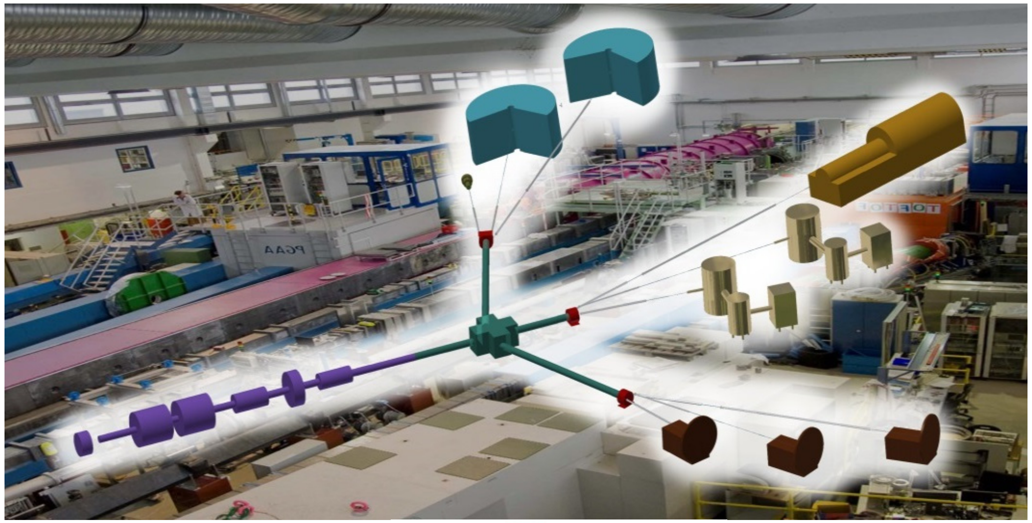
High Brilliance Neutron Source Project

Realizations

- Accelerator driven pulsed neutron source
- Optimized for neutron scattering on small samples
- Low- or medium flux neutron laboratories
- Reasonable costs (~10 to ~300 MEUR)

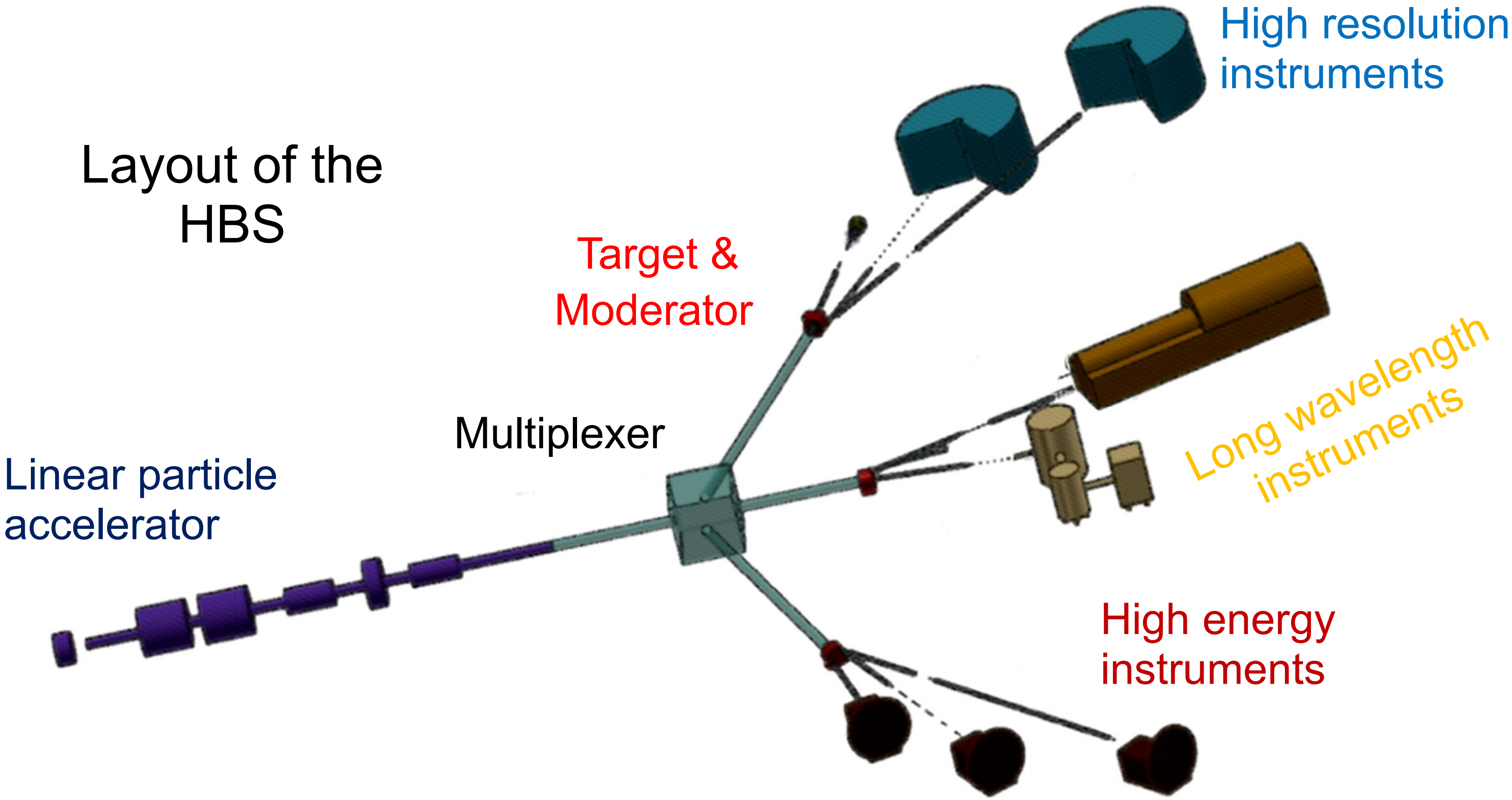
Holistic optimization of

- **Accelerator**
- **Target**
- **Moderator**
- **Instrumentation**



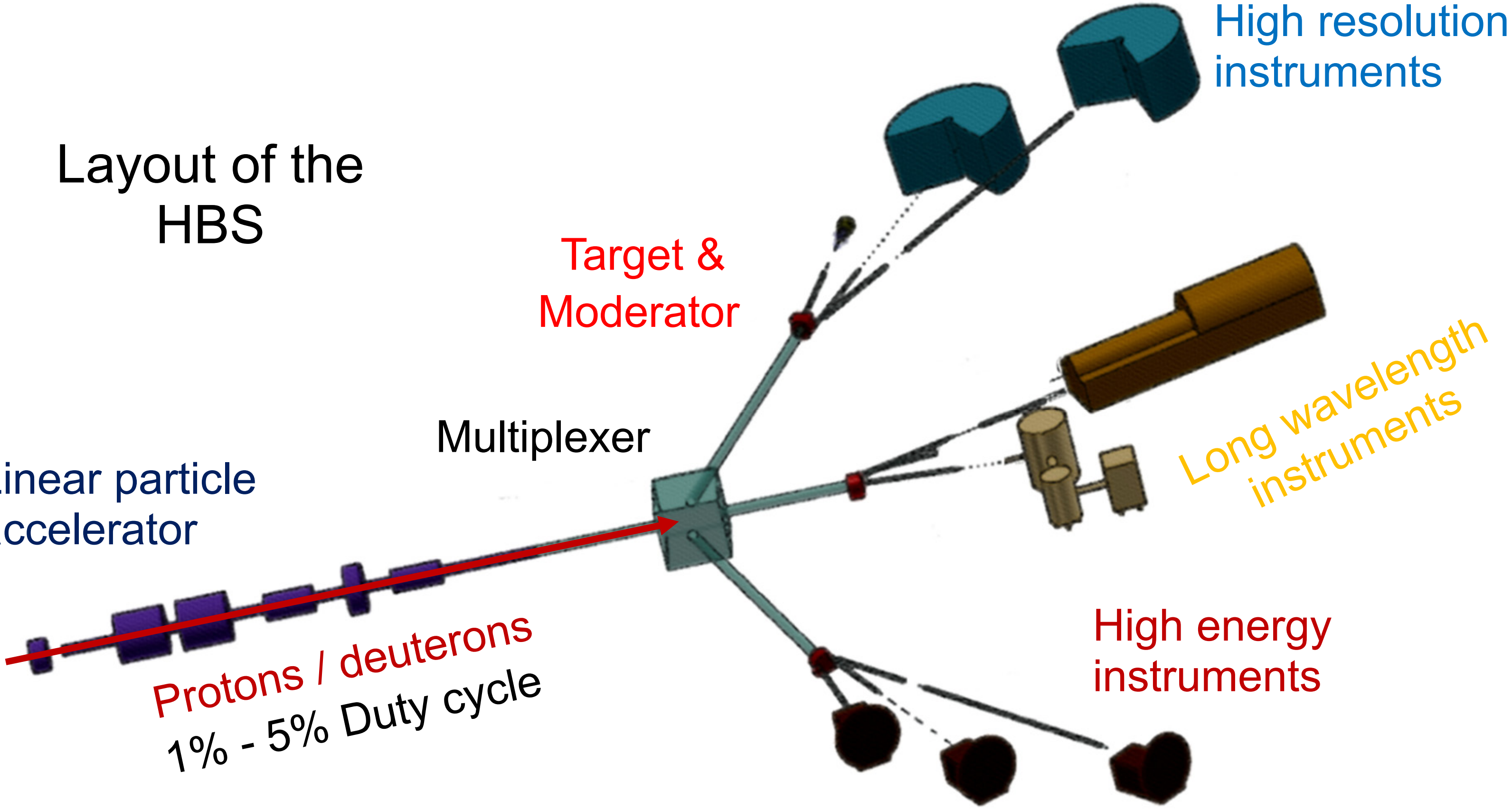
High Brilliance Neutron Source Project

Realizations



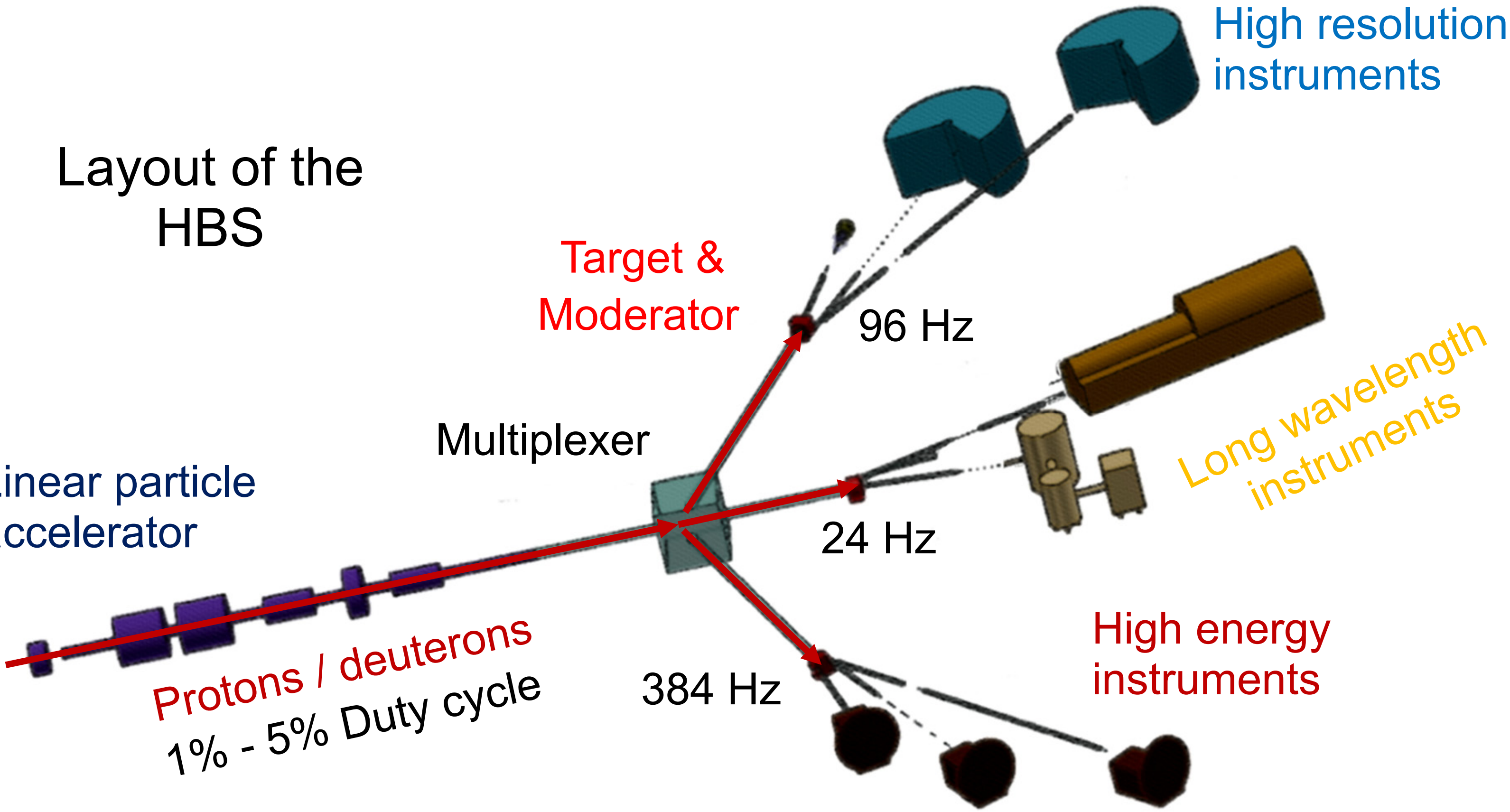
High Brilliance Neutron Source Project

Realizations



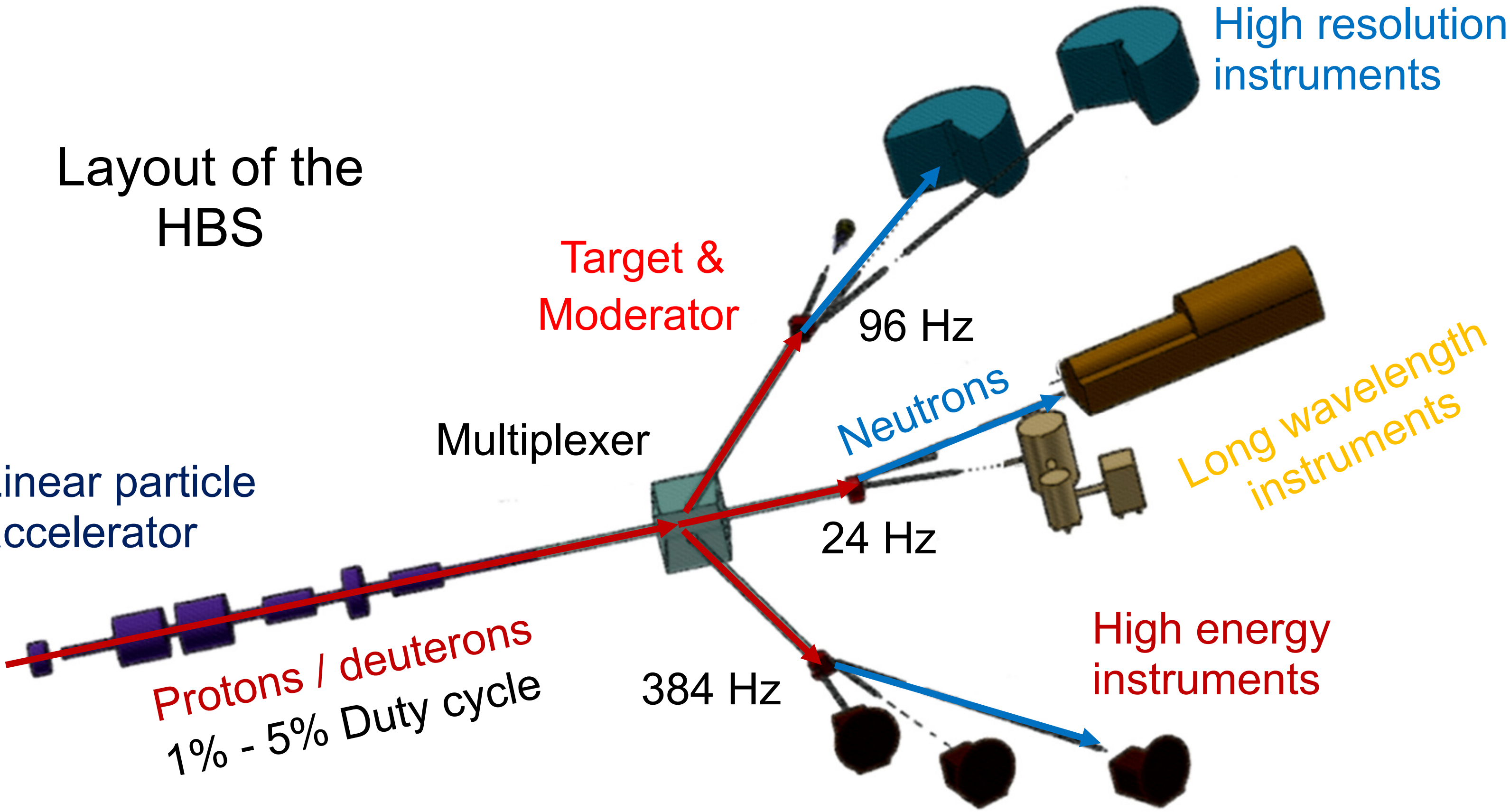
High Brilliance Neutron Source Project

Realizations



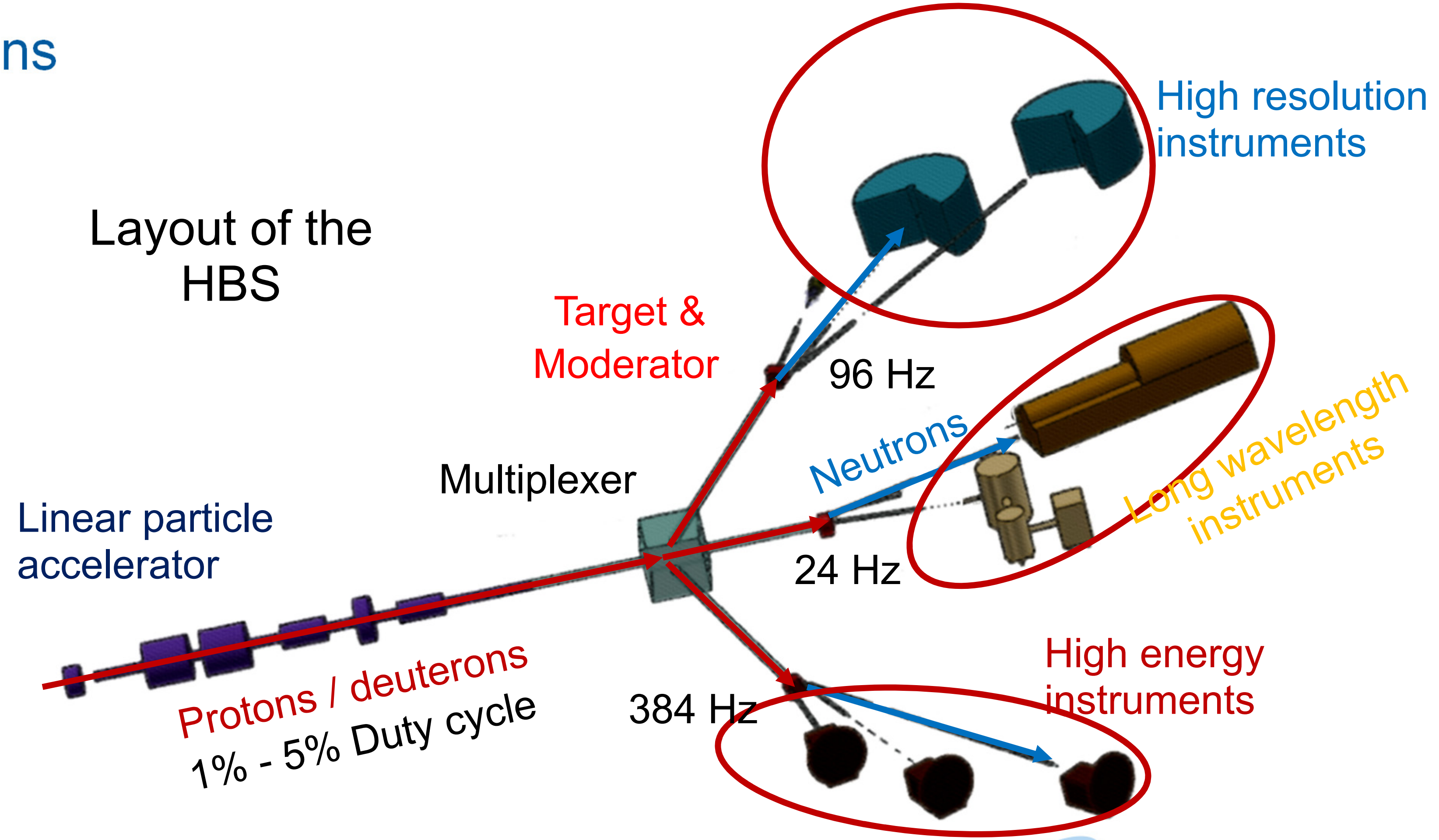
High Brilliance Neutron Source Project

Realizations



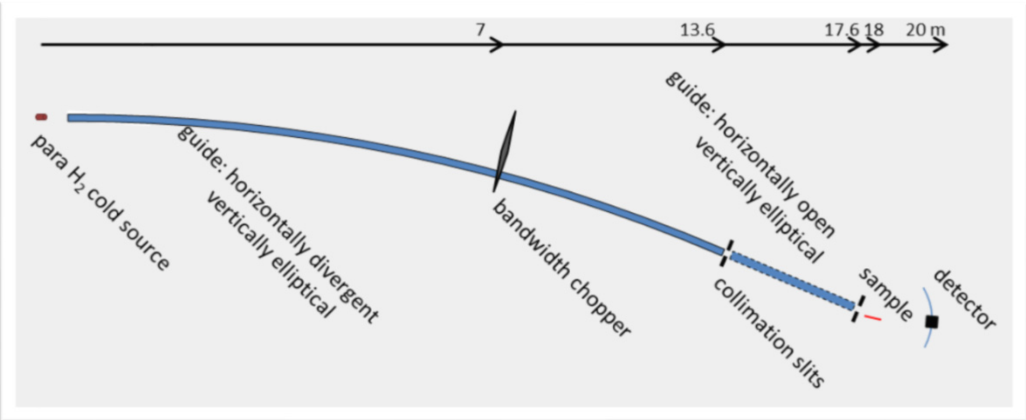
High Brilliance Neutron Source Project

Realizations



Instrument Performance

Large Scale Structure & Diffraction

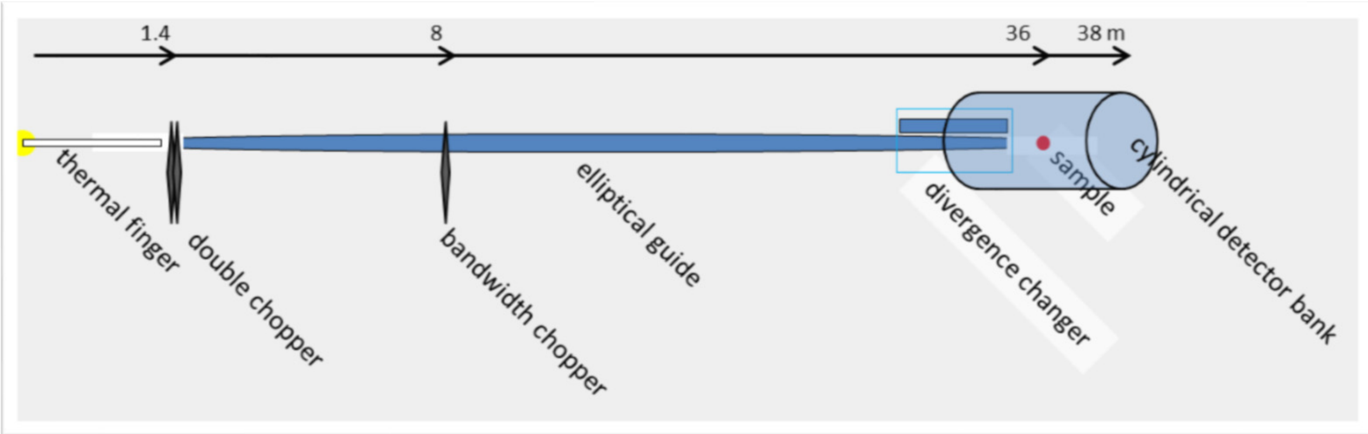


Reflectometer
Slow target station: 48 Hz rep.rate
Para H_2 cold moderator
Wavelength range λ = 1.2 … 5.7 Å
Resolution: 5% at λ = 4 Å
Flux: 1.3 * 10^8 n/cm²s at 3 mrad div.

compare MARIA @ MLZ

Powder diffractometer
Medium target station: 96 Hz rep.rate
40 µs chopper opening → 3 * 10^{-3} Δd/d
Wavelength range λ = 1.1 … 2.0 Å or
λ = 2.15 … 3.05 Å
Flux: 6 * 10^6 n/cm²s at 10 mrad div.

compare POWTEX @ MLZ



Instrument Performance

Spectrometer

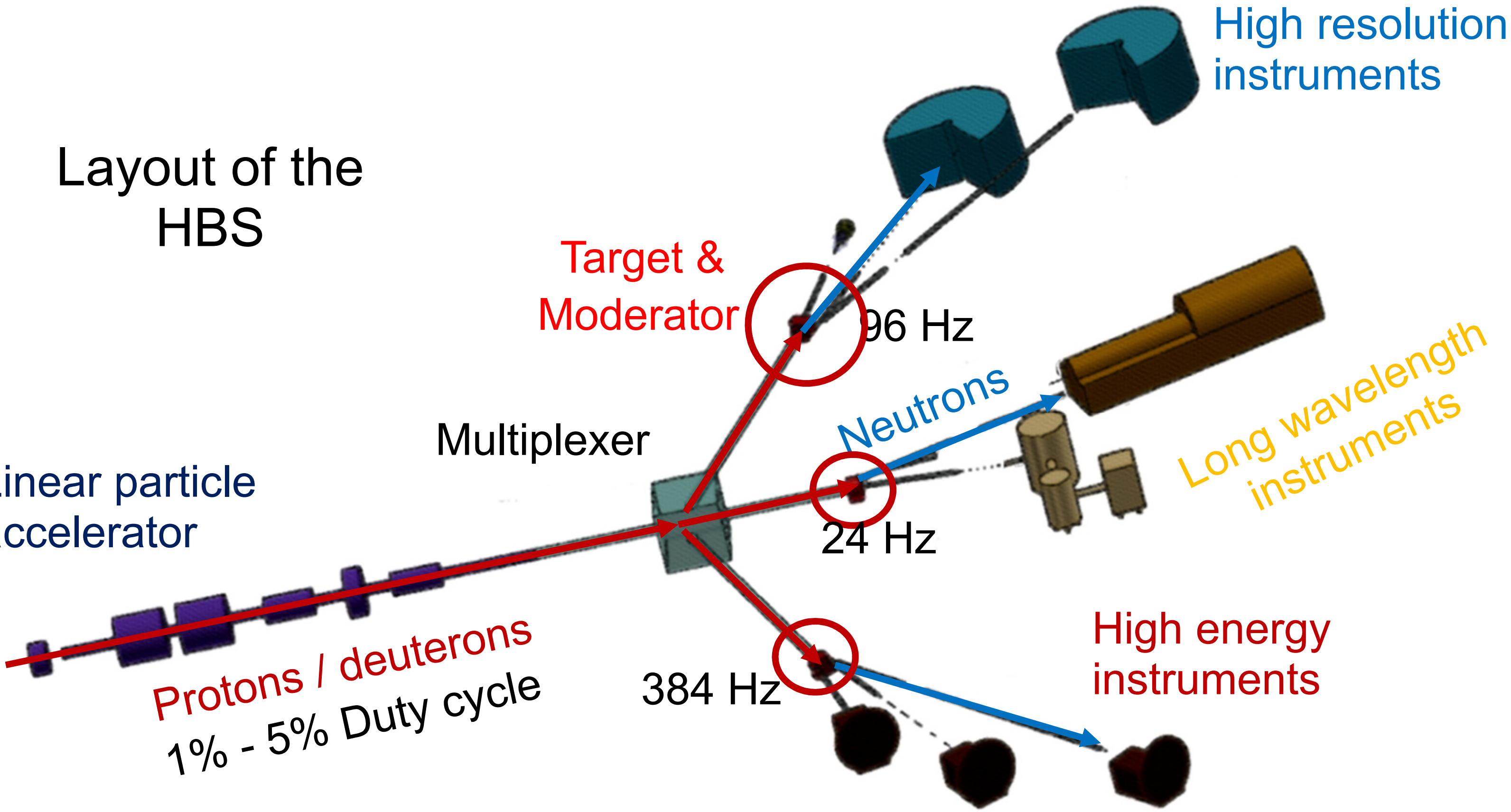
For a medium flux HBS with 100 kW beam power, 100 mA peak current and 50 MeV deuteron energy

	Backscattering	Cold ToF	Thermal ToF
$E_{i,f}$ (meV)	1.84	5	45
$\frac{\Delta E_i}{E_i}$ (%)	1	2	5
$\Delta\theta(^\circ)$	4	2	0.75
$\Delta t(\mu s)$	120	50	18
Rep. rate (Hz)	200	100	400
Flux ($cm^{-2}s^{-1}$)	2.5×10^7	1.3×10^5	1×10^5
Reference instrument	OSIRIS	LET	MERLIN
Flux reference ($cm^{-2}s^{-1}$)	2.7×10^7	5×10^4	6×10^4

Spectrometers for compact neutron sources
J. Voigt, S. Böhm, J.P. Dabruck, U. Rücker, Th. Gutberlet and Th. Brückel
Nuclear instruments & methods in physics research / A 884, 59- 63 (2018) [10.1016/j.nima.2017.11.085]

High Brilliance Neutron Source Project

Realizations



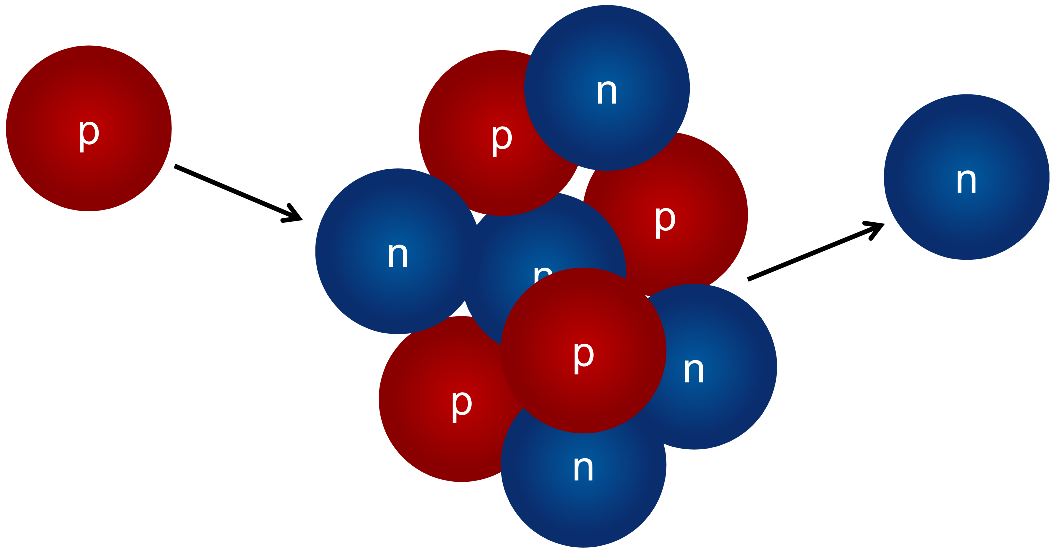
From Proton to Neutron

Basic principle

- **Nuclear reactions → neutrons**
- **Pulsed** proton or deuteron beam
- Energies about **10 MeV** (NOVA ERA) / up to **80 MeV** (HBS)
- Metal **target** material with high (p, n) cross section (e.g. beryllium for NOVA ERA)
- **Simulations and experimental validation**

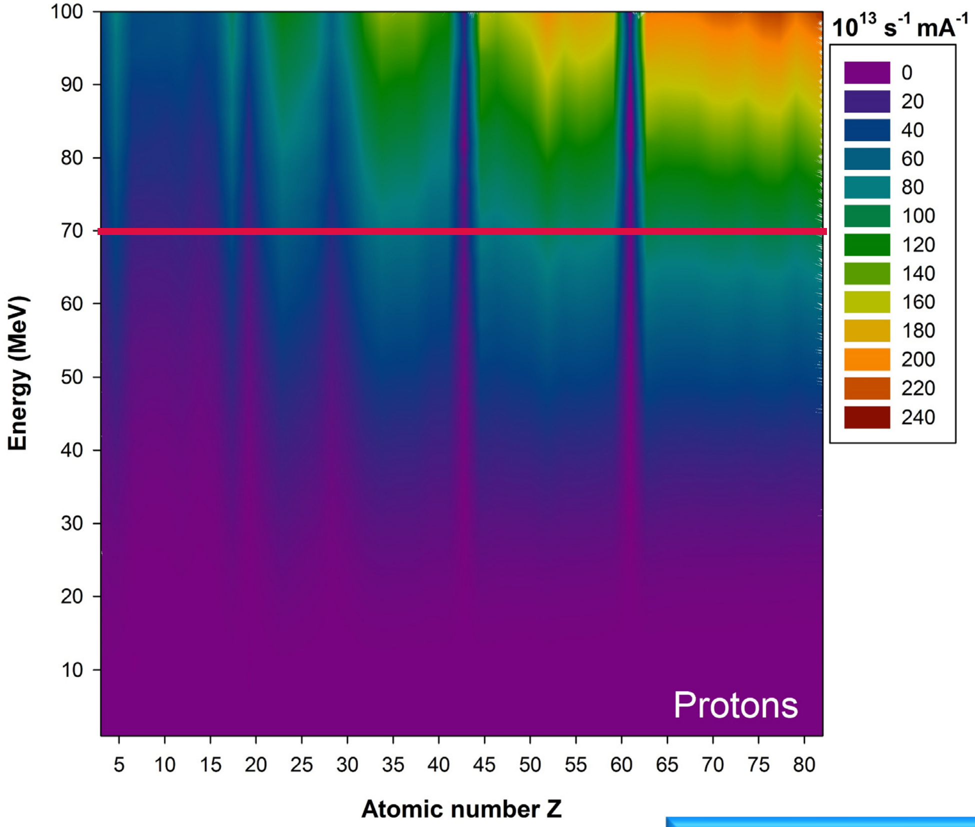
$${}^{9}_{4}Be(p, n; p, pn)$$

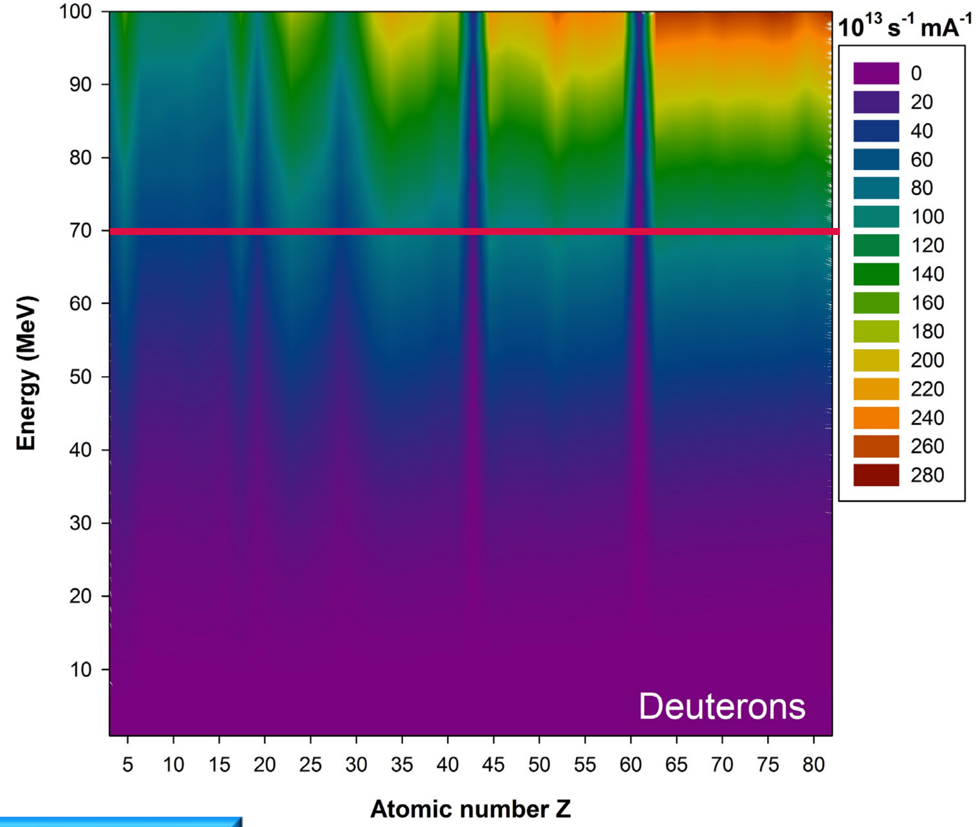
$$proton \quad + \quad {}^{9}_{4}Be \quad \rightarrow \quad neutron\ (+\ {}^{9}_{5}B)$$



From Proton to Neutron

Neutron Yield

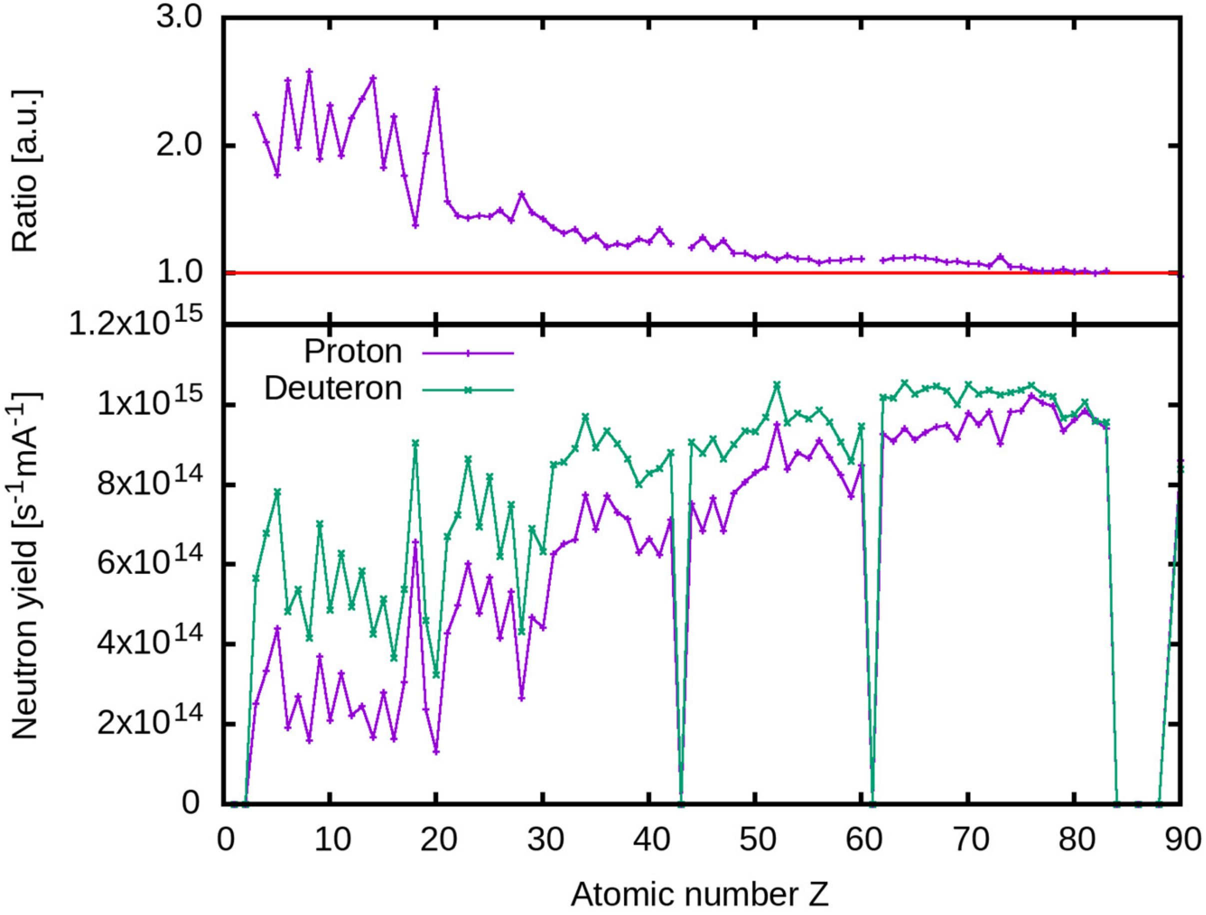




Use of intermediate energy

From Proton to Neutron

Neutron Yield

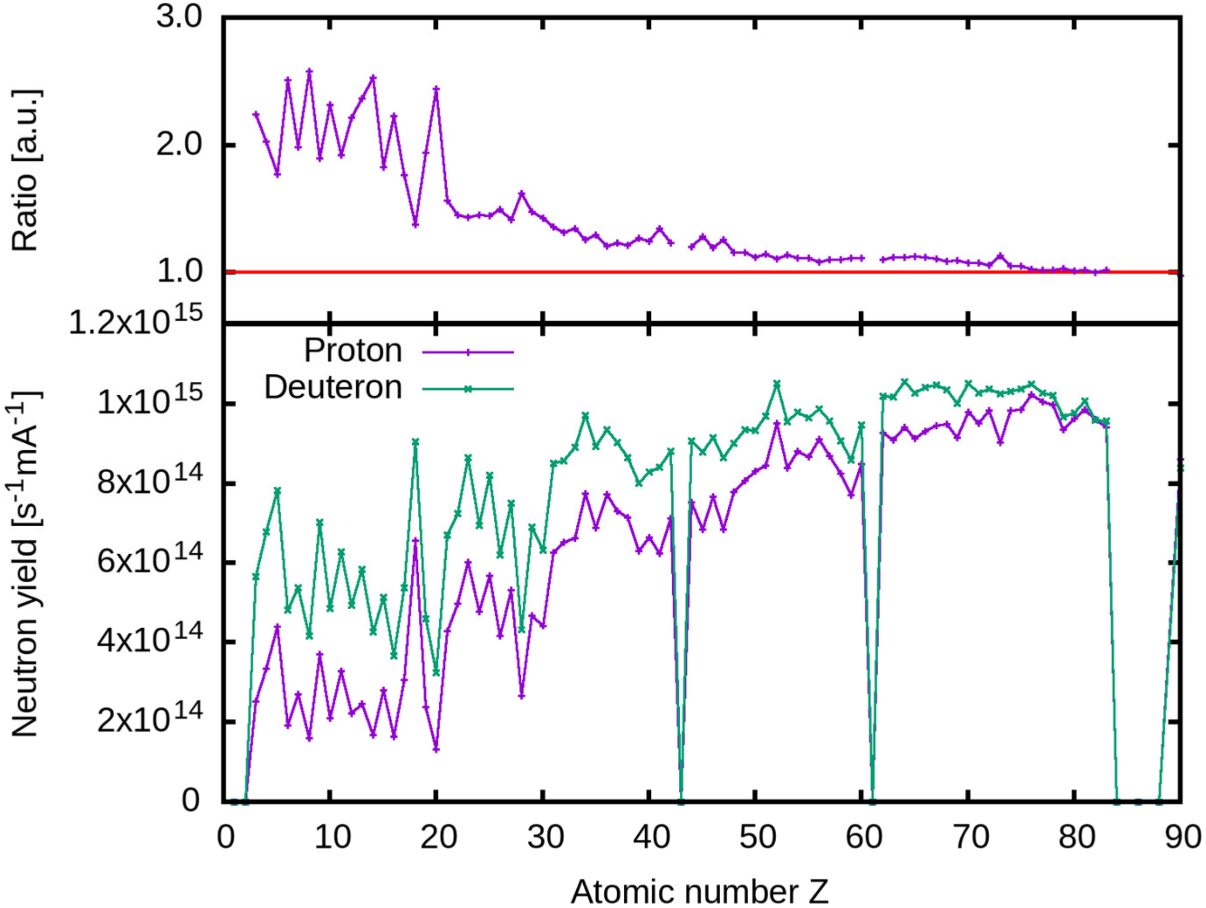


Target choice:
High Z material

Primary particle choice:
Proton

From Proton to Neutron

Neutron Yield



Target choice:
High Z material

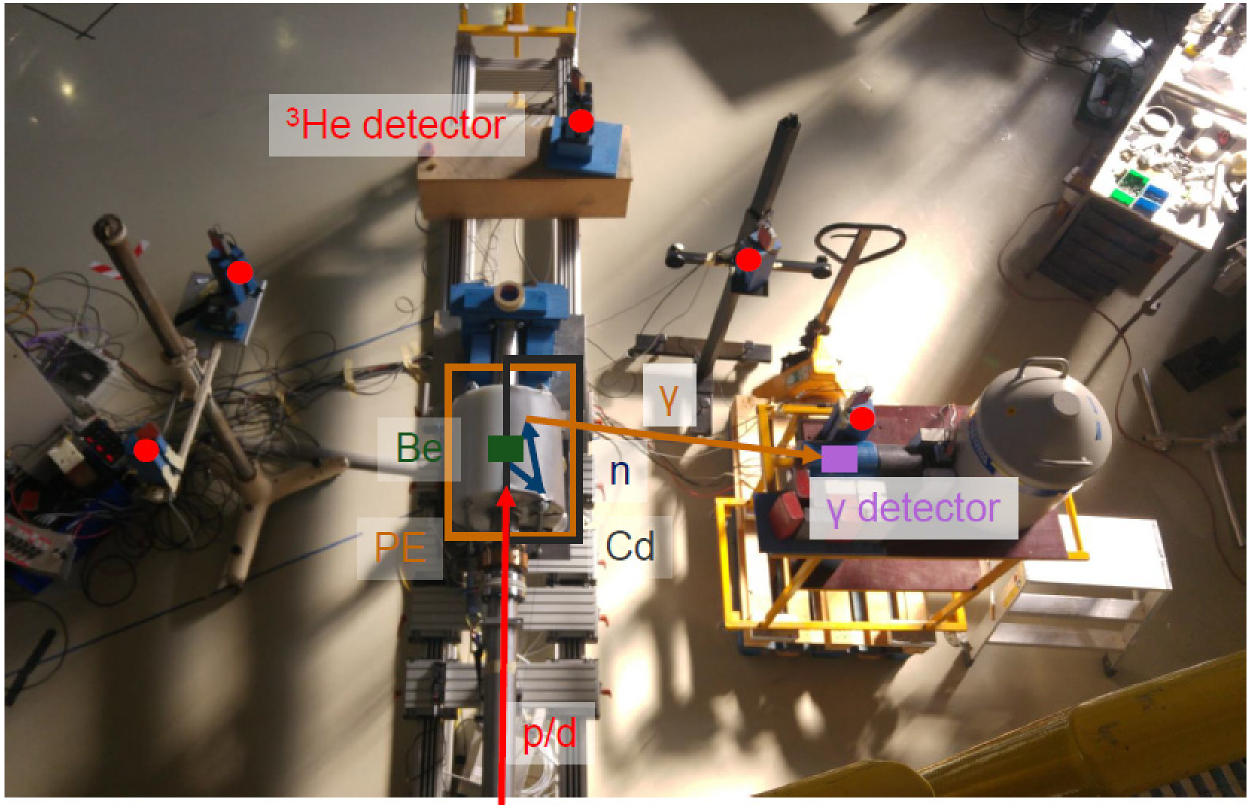
Primary particle choice:
Proton

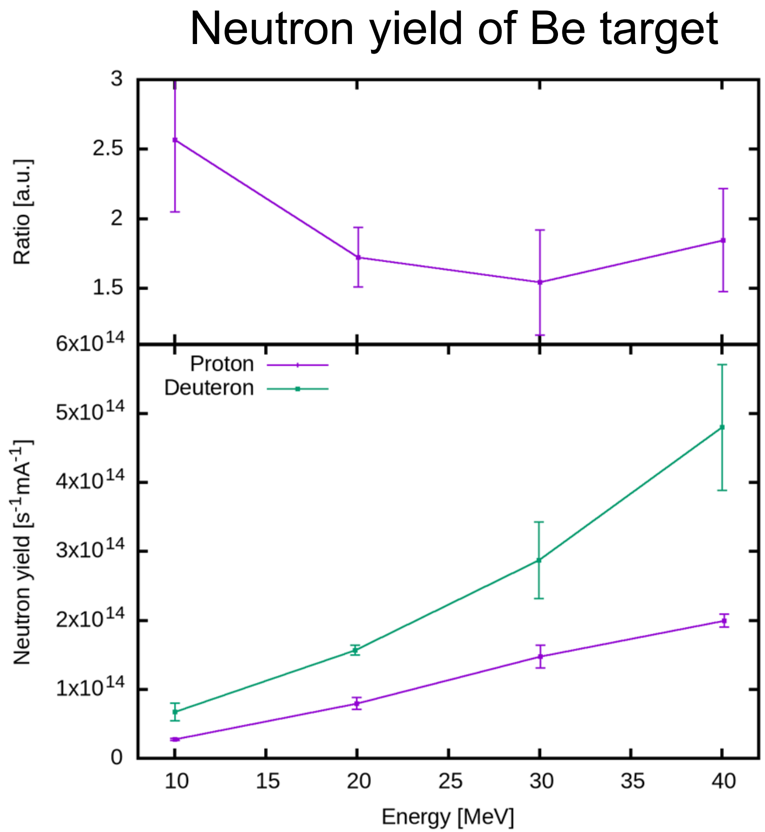
Tantalum

High neutron yield ~ 10^{15} $s^{-1}mA^{-1}$
Good machinability and thermo / mechanical properties
Hydrogen storage material

From Proton to Neutron

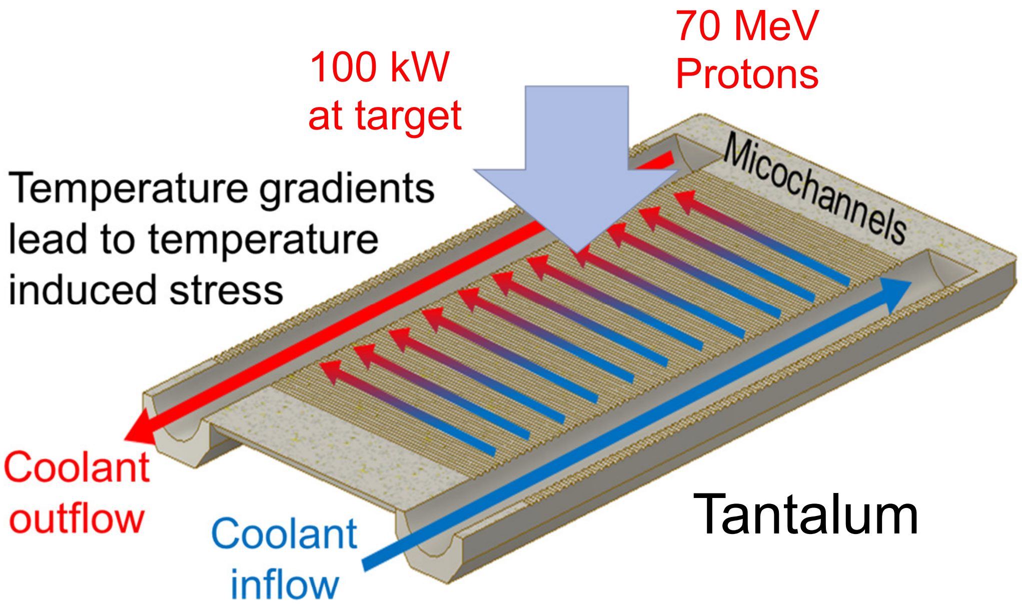
Experimental Validation @COSY

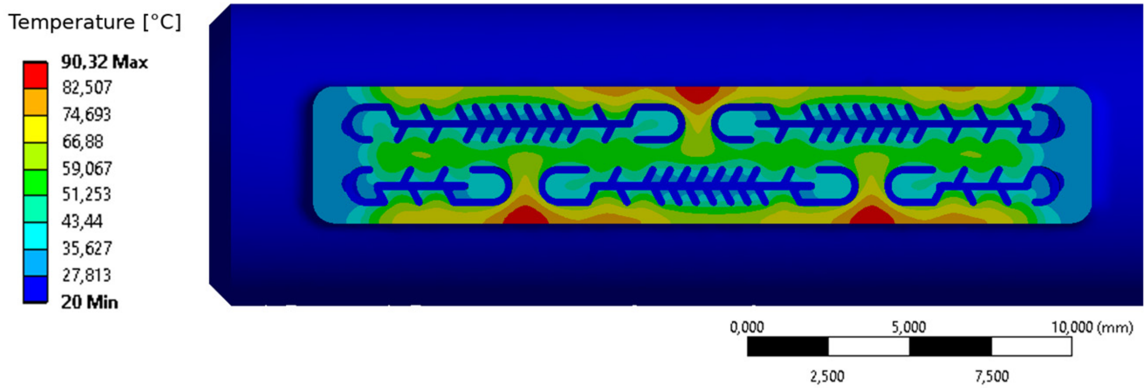


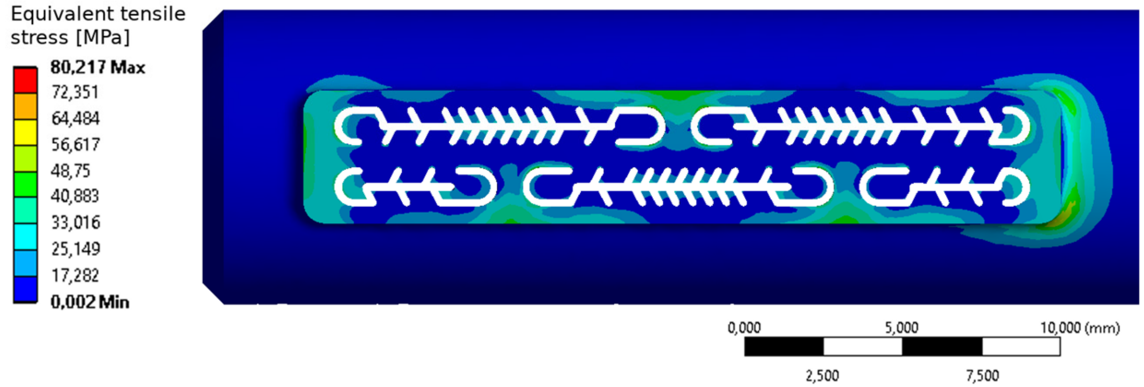


From Proton to Neutron

Neutron production







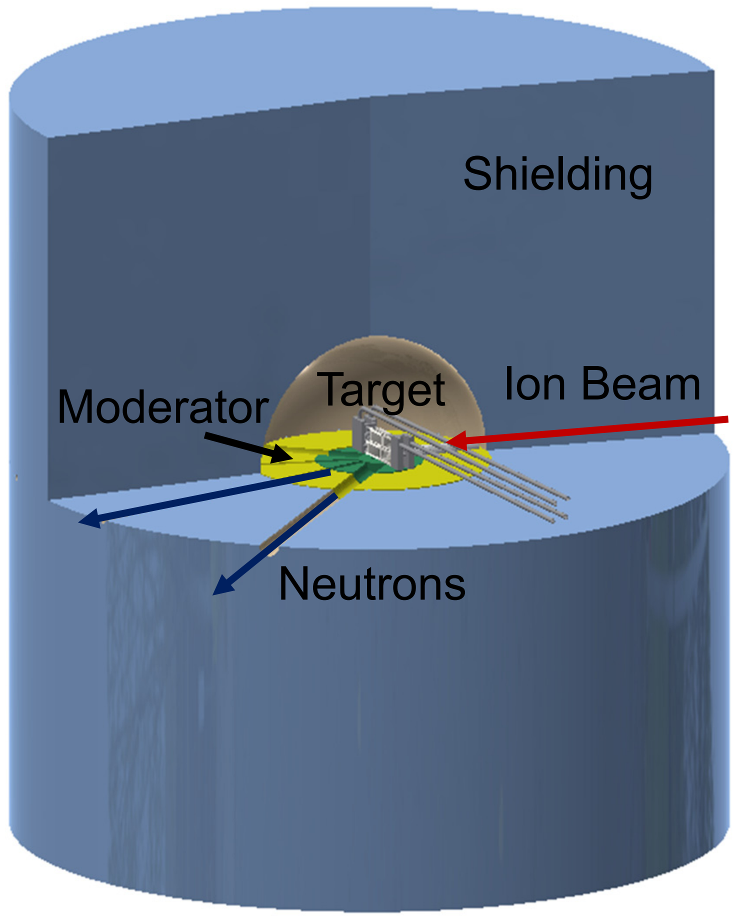
Engineering challenges manageable

Target / Moderator / Shielding assembly

Compact design

- Low energy enables design of **compact** target / moderator assembly
- Optical elements can be placed **close to target / moderator**

Large phase space volume can be transferred to the instruments
- ➢ produce less (cost!)
- ➢ waste less (max. brilliance!)

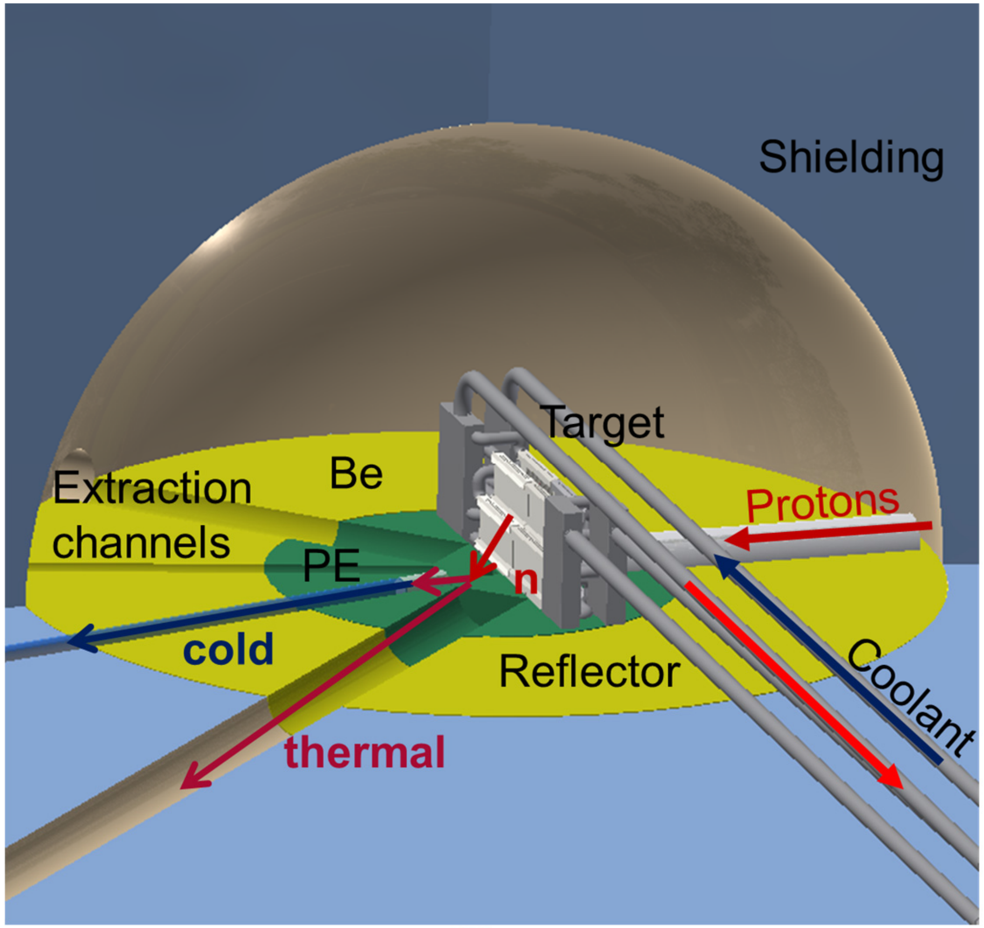


From fast/thermal Neutrons to cold Neutrons

Thermal and cold moderators

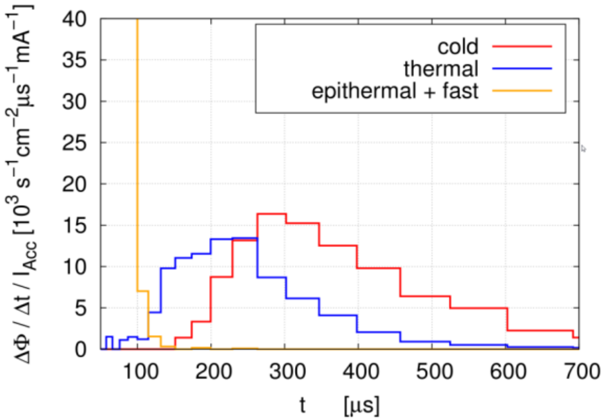
- **Moderation** of fast neutrons to thermal and cold energies
- “one”-dimensional **“finger-”moderators with high brilliance**!
- **e.g. para-hydrogen**

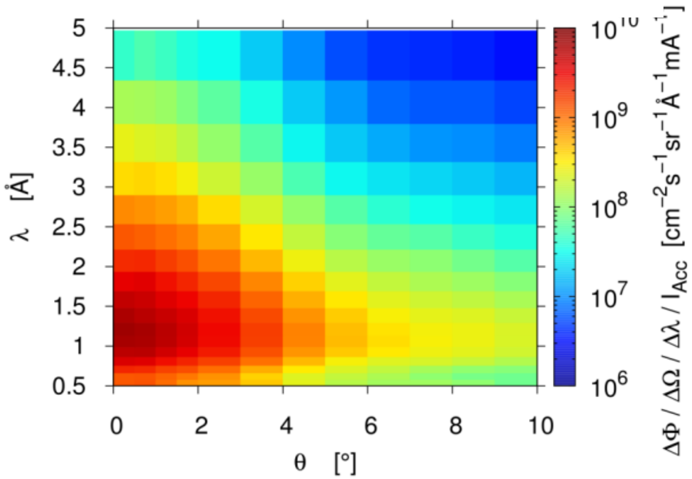
Change of paradigm:
every instrument has its own adapted neutron source:
no “one fits all”
➢ produce less (cost!)
➢ waste less (max. brilliance!)

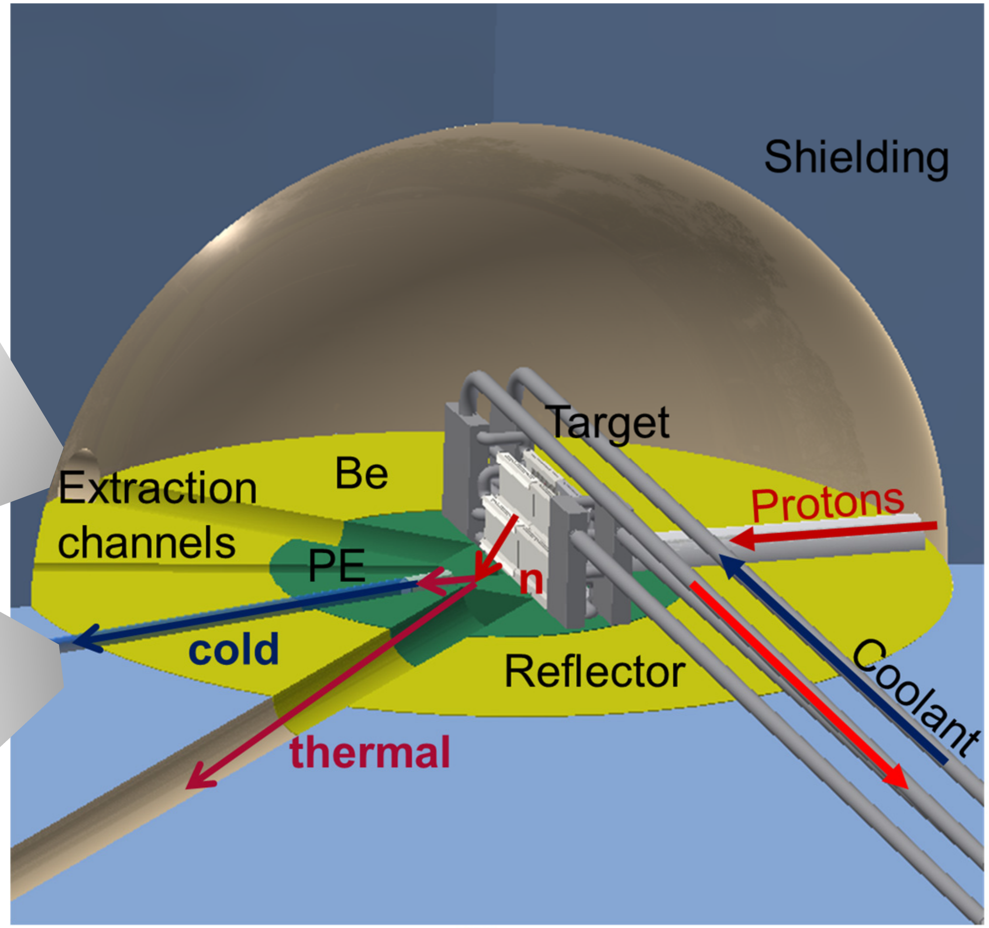


From fast/thermal Neutrons to cold Neutrons

Thermal and cold moderators

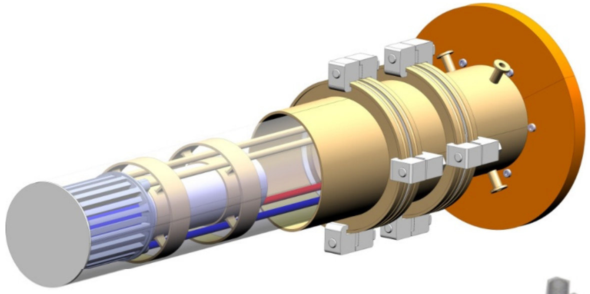


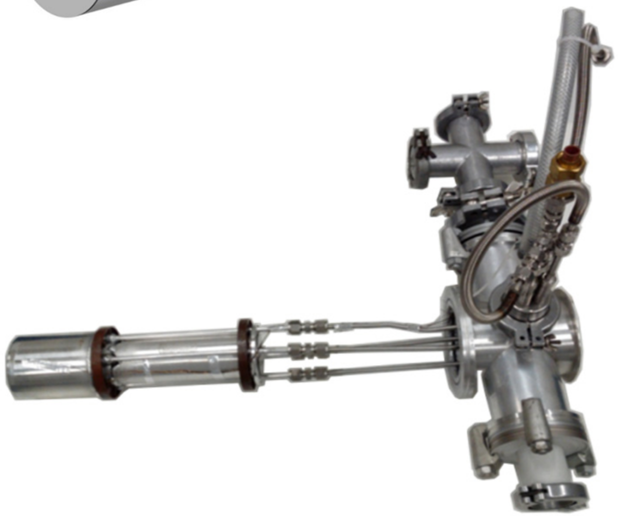


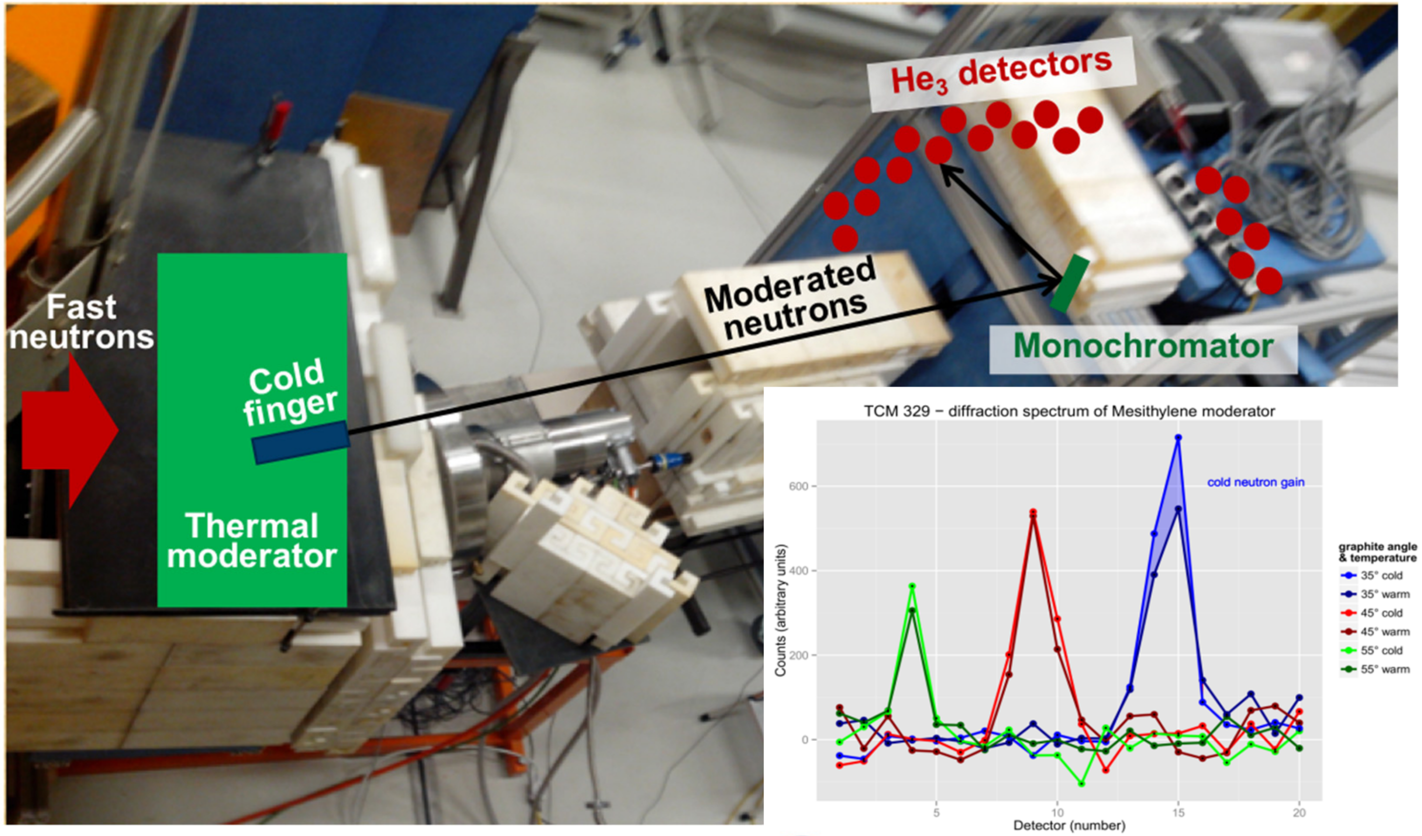


From fast/thermal Neutrons to cold Neutrons

Design, construction and experiment for a finger moderator @AKR-II

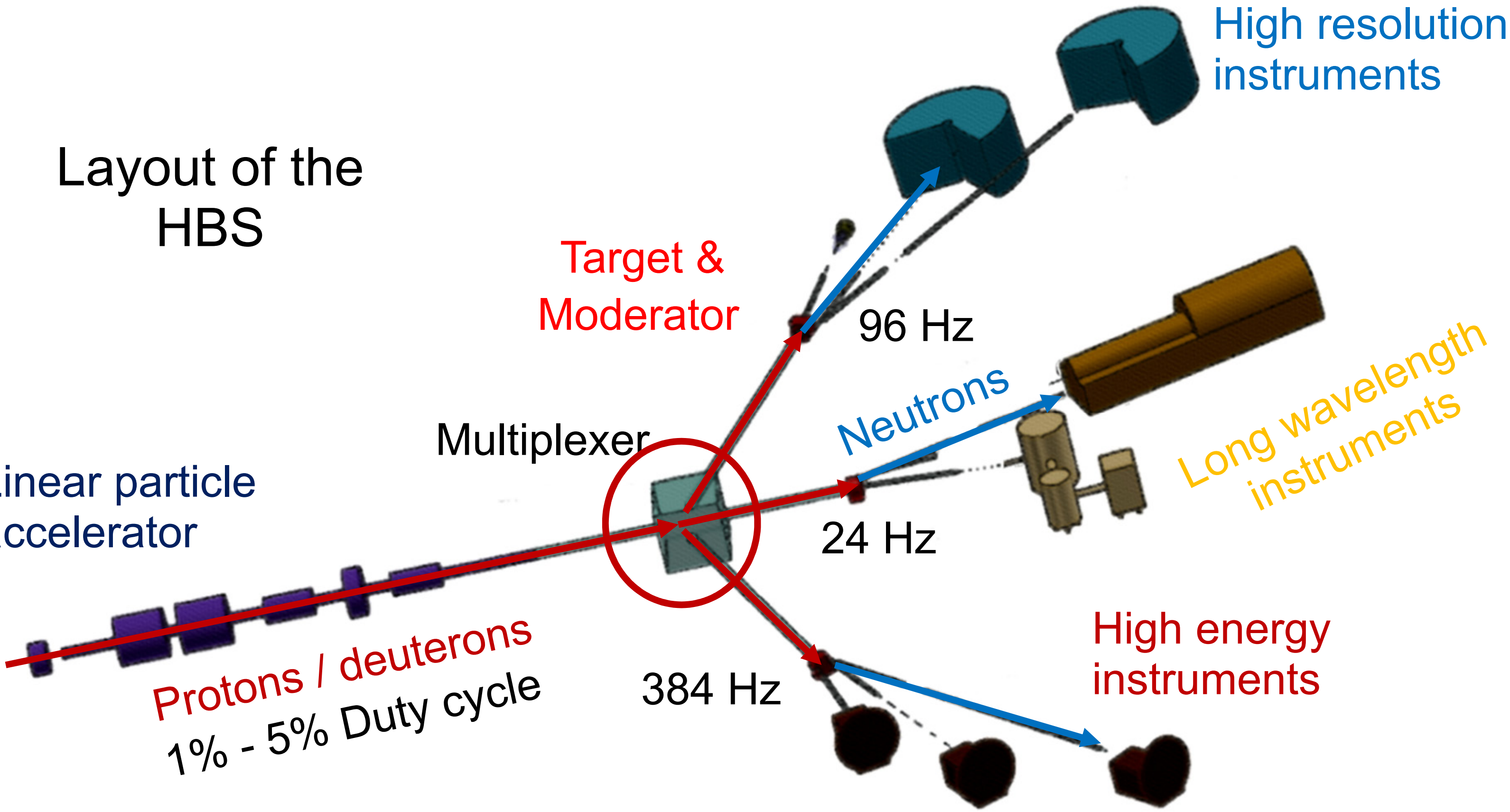






High Brilliance Neutron Source Project

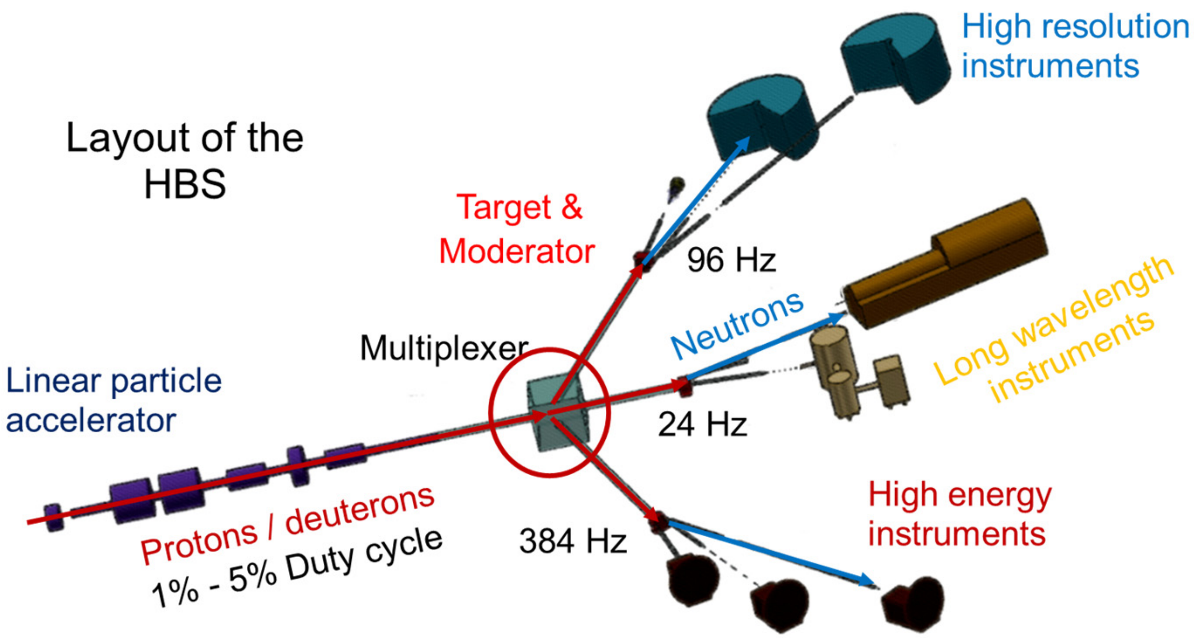
Realizations

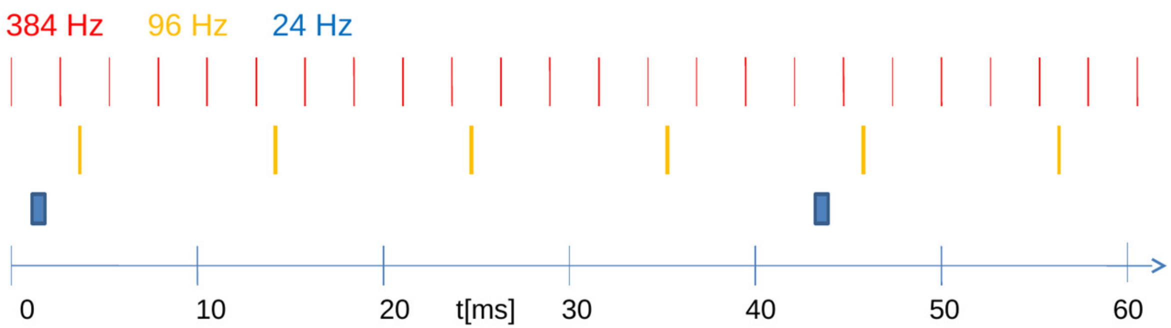


Distributing the protons

Multiplexer

- Separate proton beam to 3 different target stations
- Duty cycle of 2%
- T_{384} = 2.6 ms t_{384} = 52 µs
- T_{96} = 10.4 ms t_{96} = 208 µs
- T_{24} = 41.7 ms t_{24} = 833 µs





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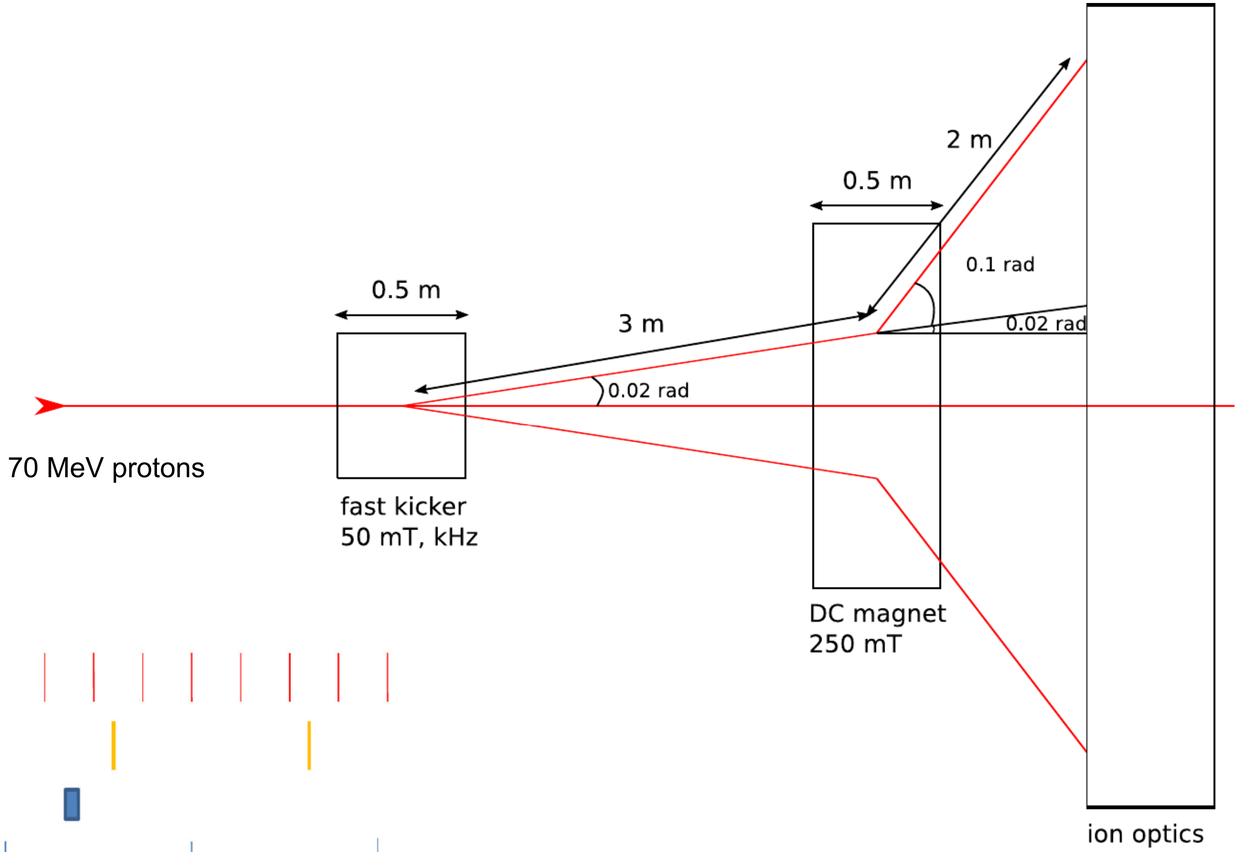

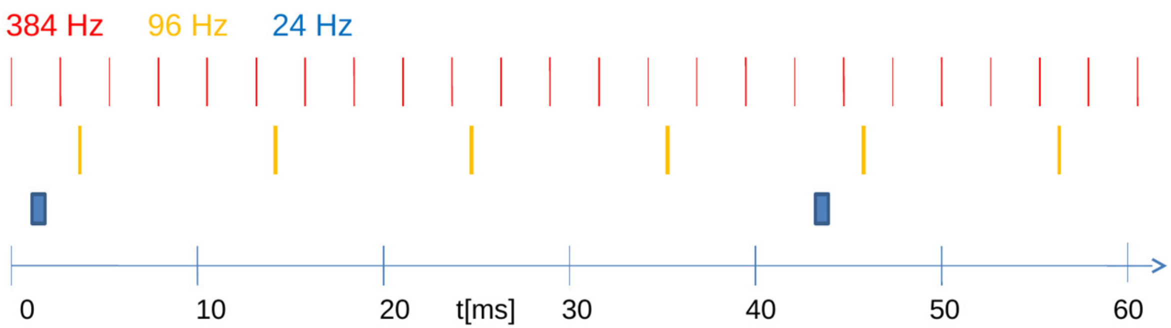

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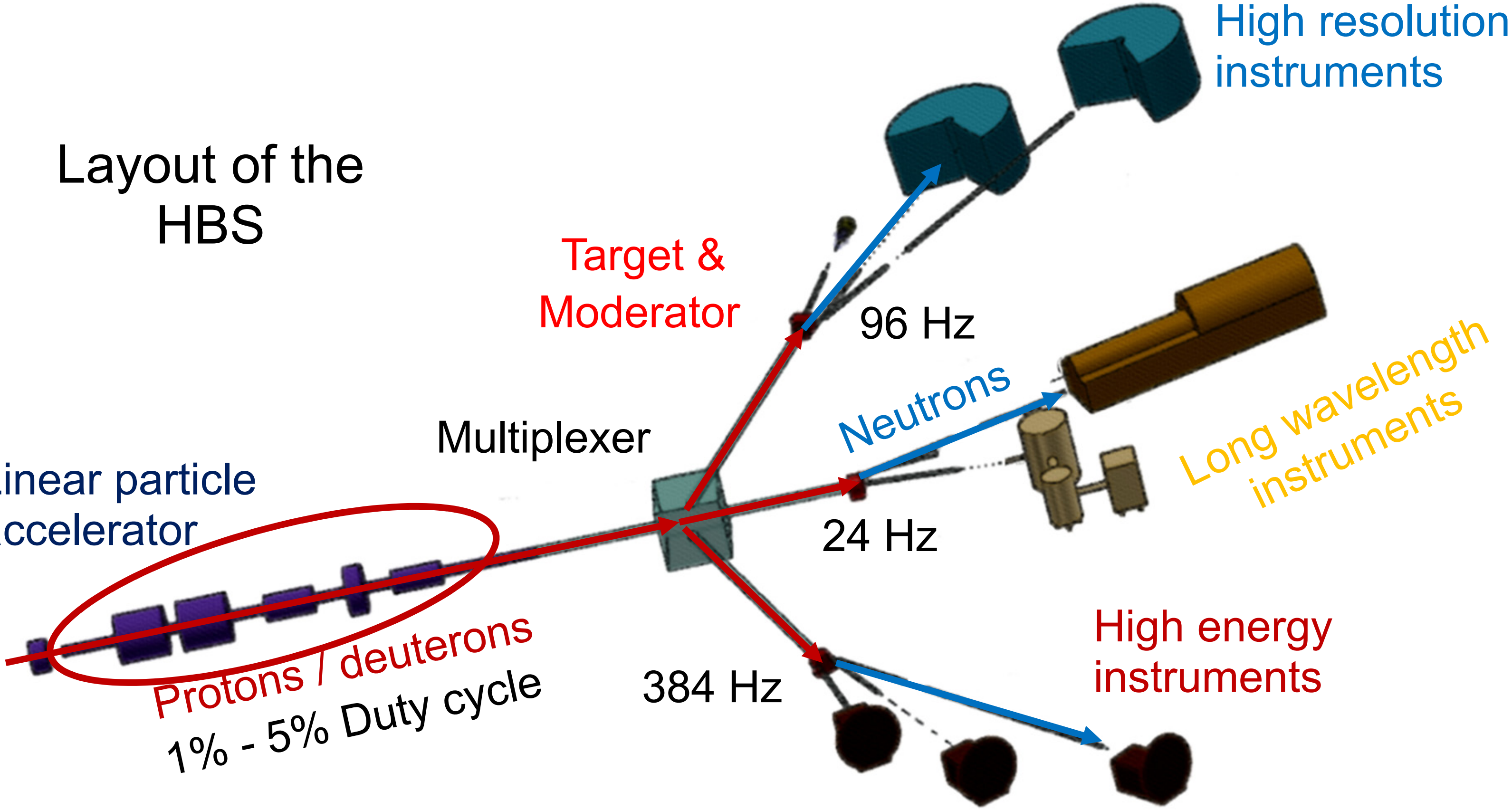
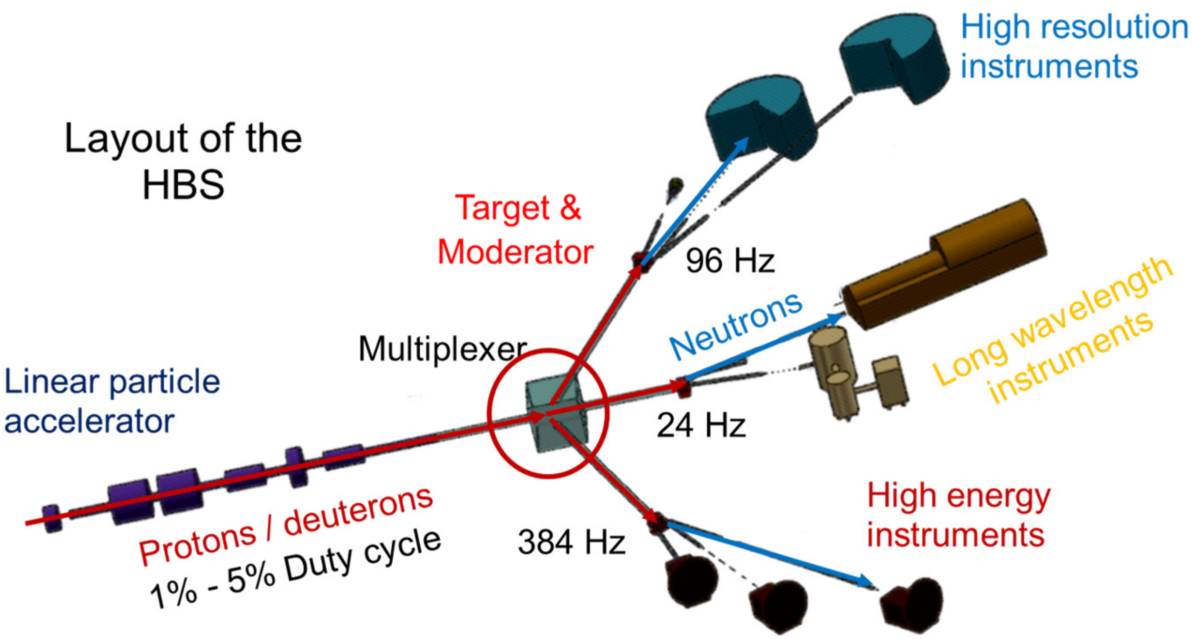


HBS: Pushing Accelerators to the Limit

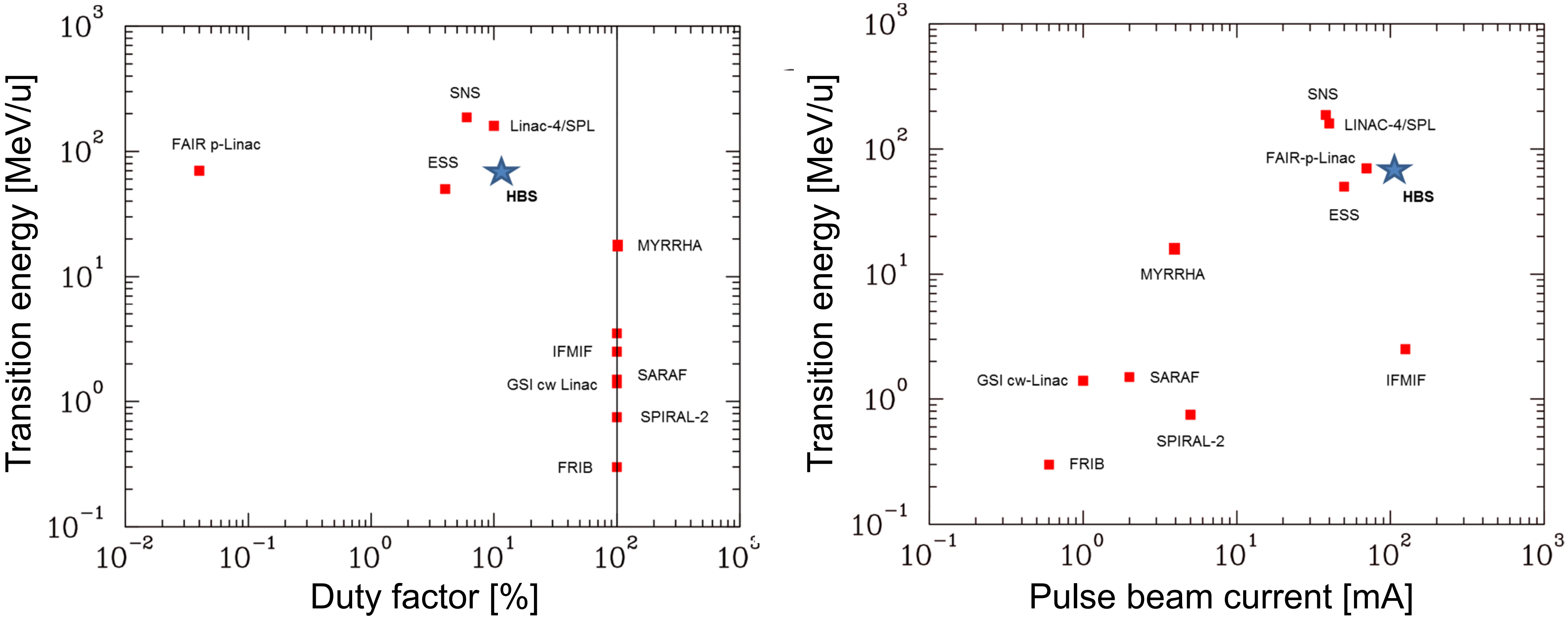
H. Podlech, O. Meusel, M. Schwarz (Univ. Frankfurt)



Parameter	Value	Unit
Particles	Protons	
Energy	70	MeV
Current	100	mA
Pulse length	52/208/833	µs
Rep rate	384/96/24	Hz
Duty cycle	6	%
Frequency	176.1	MHz
Beam power	420	kW

HBS: Pushing Accelerators to the Limit

Transition Energy RT-SC vs Duty factor and Peak Current



HBS: Pushing Accelerators to the Limit

Room Temperature Solution

- Much simpler technology
- Easy access to all components
- No cryo-plant: less cost
- No cryo-modules: less operation cost
- Beam losses less severe (quenches): more reliable...
- Easier beam dynamics
  (no additional drifts due to cold-warm-transitions)
- Already available technology

Peak beam power: 7 MW

Peak RF power: ≈12 MW

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  (no additional drifts due to cold-warm-transitions)
- Already available technology

Peak beam power: 7 MW

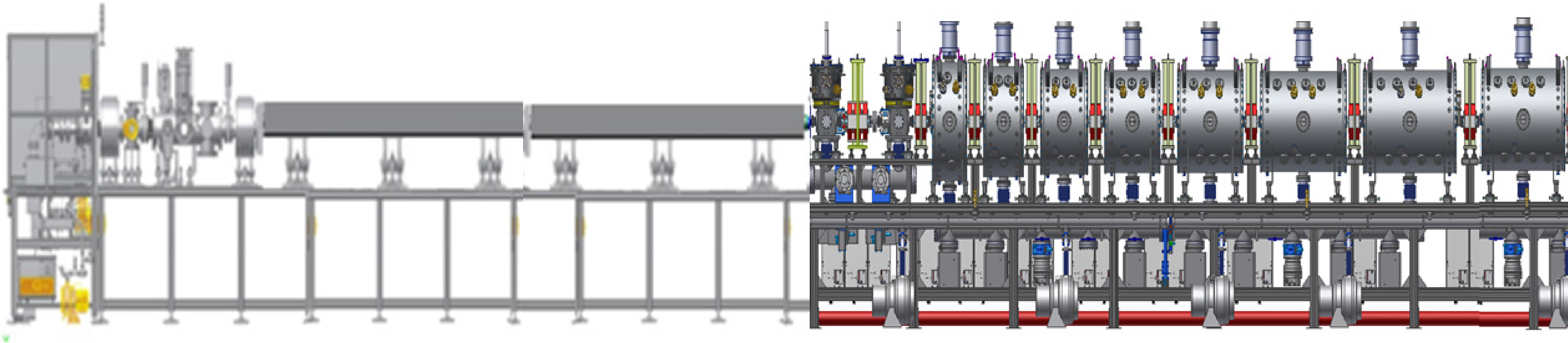
Peak RF power: ≈12 MW

A room temperature linac is the most reasonable and safe solution

HBS: Pushing Accelerators to the Limit

Concept of the HBS-Accelerator

- Modular
- Accessibility
- Identical parts (power coupler, tuner, quadrupoles)



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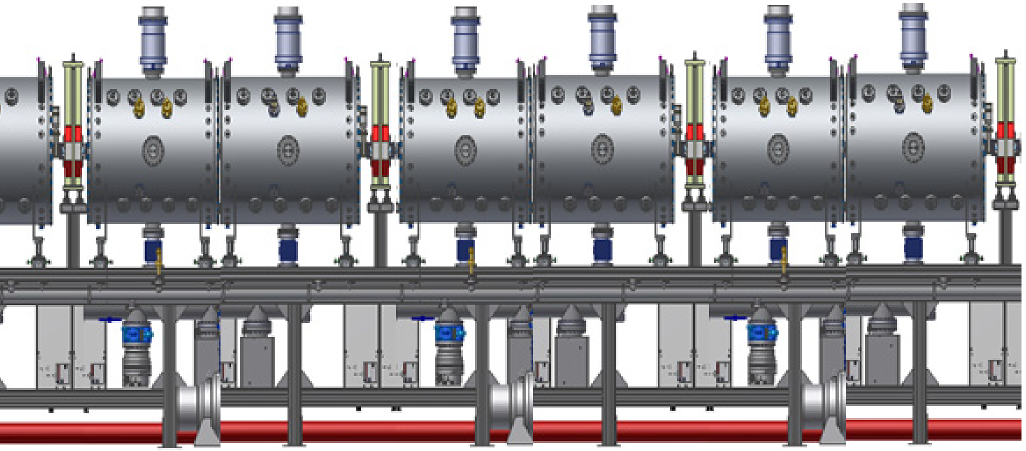
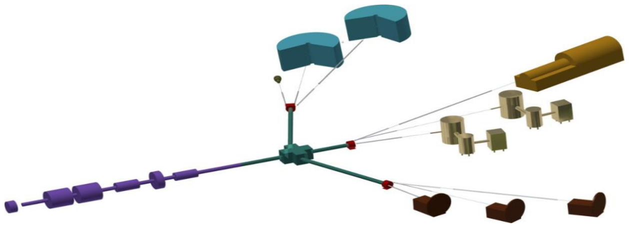


Timeline

2018	• Conceptual Design Report
2019	• Technical Design Report
2020	• Start construction of prototype facility
2023	• Start operation of prototype facility
2024	• Start friendly users @ prototype facility
2027	• Start construction of HBS facility
2030	• Start operation of HBS facility



HBS Team

J. Baggemann
T. Cronert
P.-E. Doege
J. Li
E. Mauerhofer
U. Rücker
J. Voigt
P. Zakalek
T. Gutberlet
Th. Brückel

Experimental verification Instrumentation

ZEA-1:
- Y. Bessler
- M. Butzek

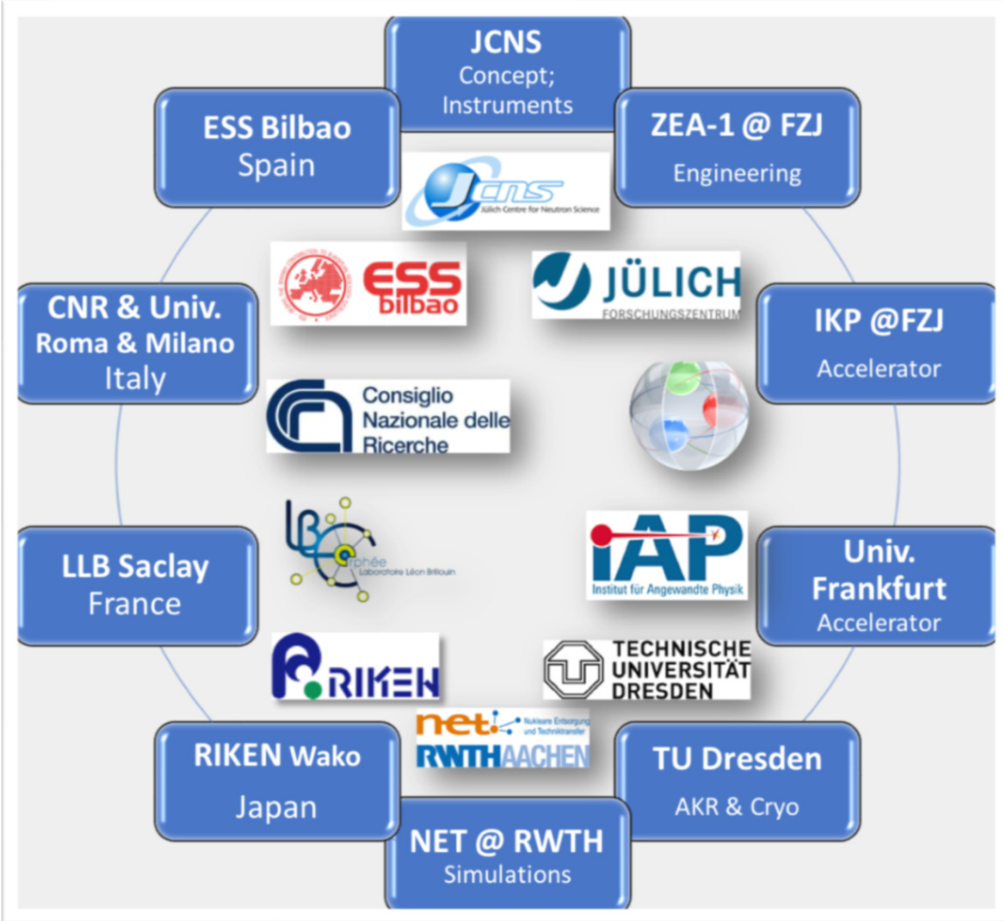
IKP-4:
- D. Prasuhn
- O. Felden
- R. Gebel
- C. Li
- M. Bai (→ GSI)
- M. Rimmler

Nuclear physics Engineering (cold source)

S. Böhm
J.P. Dabruck
A. Nalbandyan
R. Nabbi
- *Nuclear simul.*

C. Lange
T. Langnickel
M. Klaus
- *AKR-2, liquid H_2*

H. Podlech
O. Meusel
M. Schwarz
- *Accelerator*



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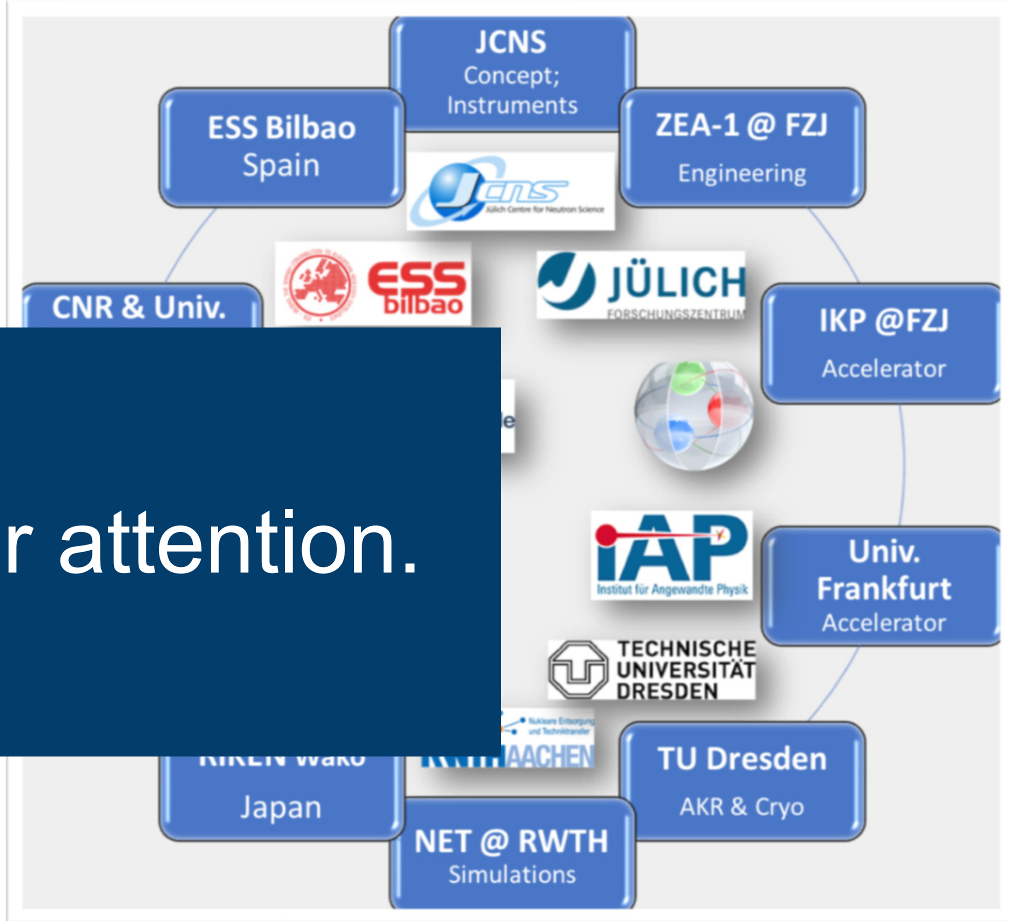
- Accelerator

Thank you for your attention.



HBS Present Design Parameters

Accelerator	
particles	protons
particle energy	70 MeV
peak current	100 mA
pulse length	50 µs - 2 ms
frequency	10 – 300 Hz / continuous
Target	
Ta slap	5 mm thickness
cooling	water (gallium)
average power	100 KW per target station
number of target stations	3 - 5
number of beamlines	3 - 5 per target station
Moderator & Reflector	
thermal moderator	polyethylene
cold moderator	para-/ortho hydrogen & solid methane
reflector	beryllium / graphite

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,…
inelastic	Cold / thermal chopper,…
Instrument performance	
e.g. cold chopper	$\sim 1 \cdot 10^5\ \mathrm{n/cm^2 \cdot s}$ @ 3 meV
Price tag	
full facility (HBS)	200 M€ - 300 M€ (e.g. 3-4 target stations, 2-4 instruments each)