Jülich Centre for Neutron Science

“From neutron source to neutron instruments: neutronics for the DNS-IV”

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Workshop on a new Dubna Neutron Source *Dubna* *December 6-7, 2018*

What is a neutron source for scientists?

Point of view of a scientist: the neutron source is not a source of neutrons, but the source of useful neutron beams.

<u>Neutron beams are useful when they have:</u>

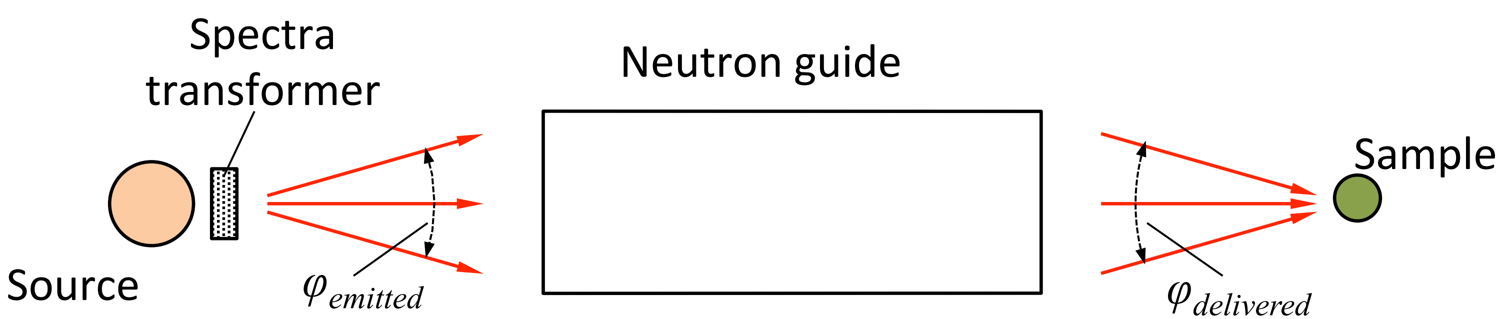
- desirable spectra (hot, thermal or cold)
- desirable divergences
- desirable time structure

} and, with all this, a high intensity!

$$Brightness = \frac{\text{intensity}}{\text{divergence} \cdot \text{cm}^2 \cdot \text{s}}$$

parameter well describing the required quality of neutron beams.

Thus, neutron source should be built in combination with proper spectrum transformers and neutron delivery systems to instruments.

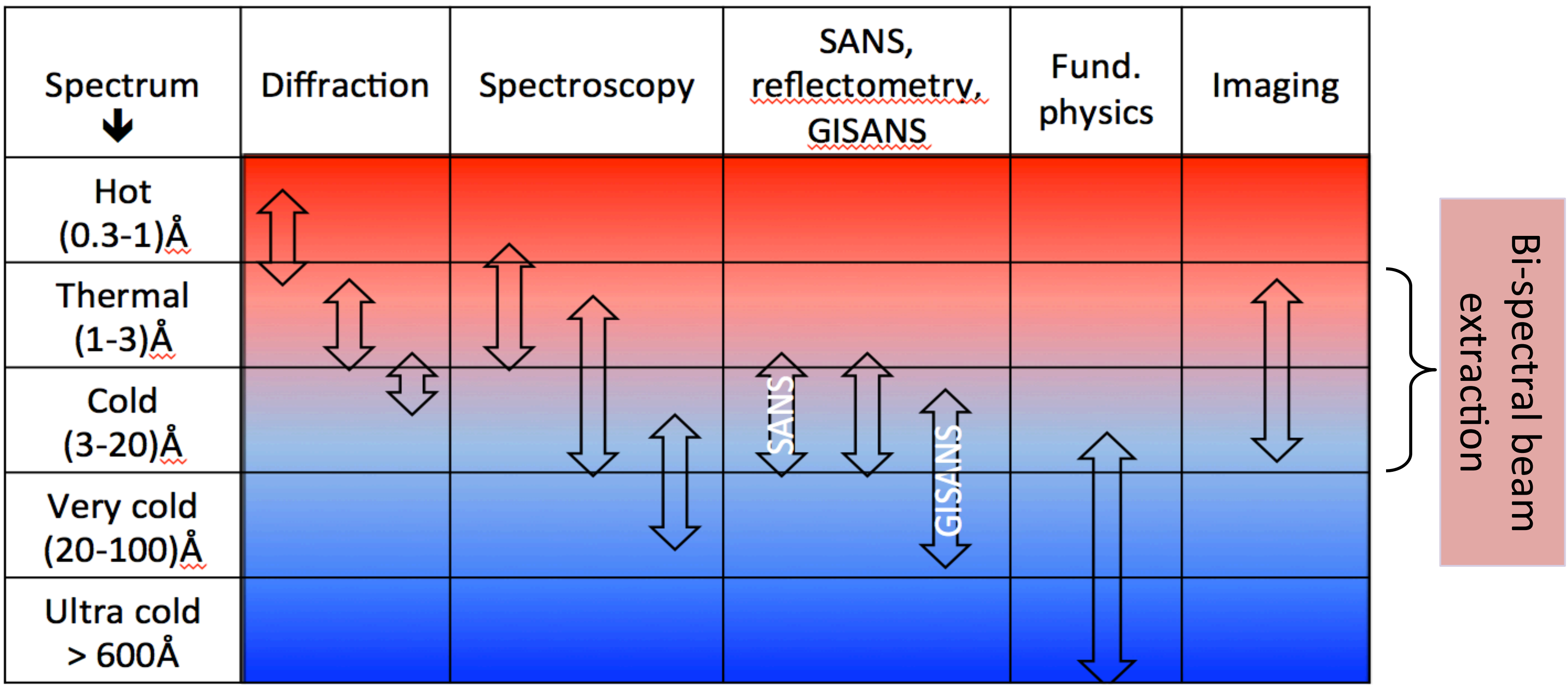


What is a dream neutron source for scientists?

Neutron beams are useful when they have:

- **desirable spectra (hot, thermal or cold)**
- desirable divergences
- desirable time structure

However, different requirements for different neutron instruments:



What is a dream neutron source for scientists?

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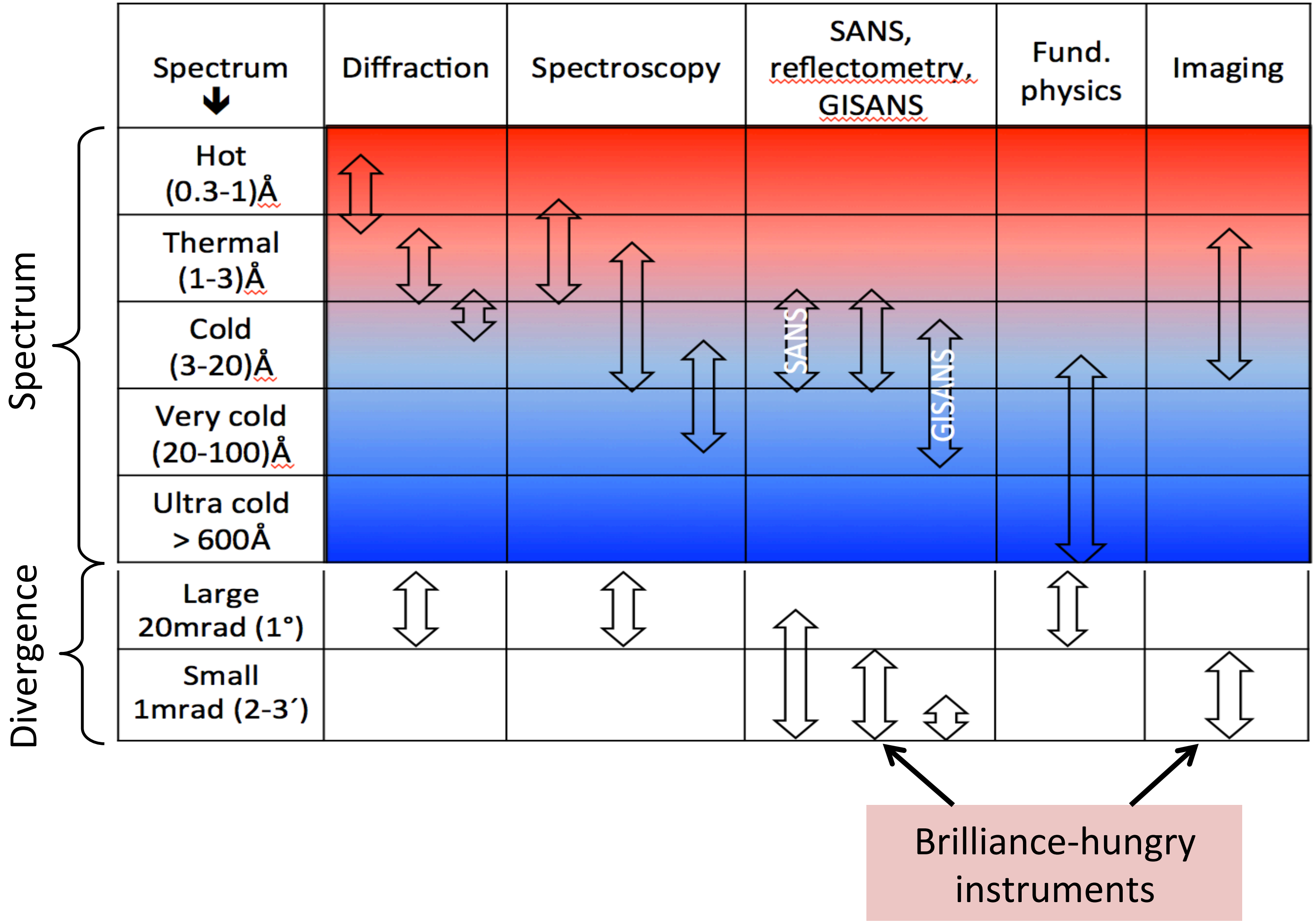
Beam divergences ↓	Diffraction	Spectroscopy	SANS	Reflect.	GISANS	Fund. physics	Imaging
Large 20mrad (1°)	⇕	⇕	⇕			⇕	
Small 1mrad (2-3´)			⇕	⇕	⇕		⇕

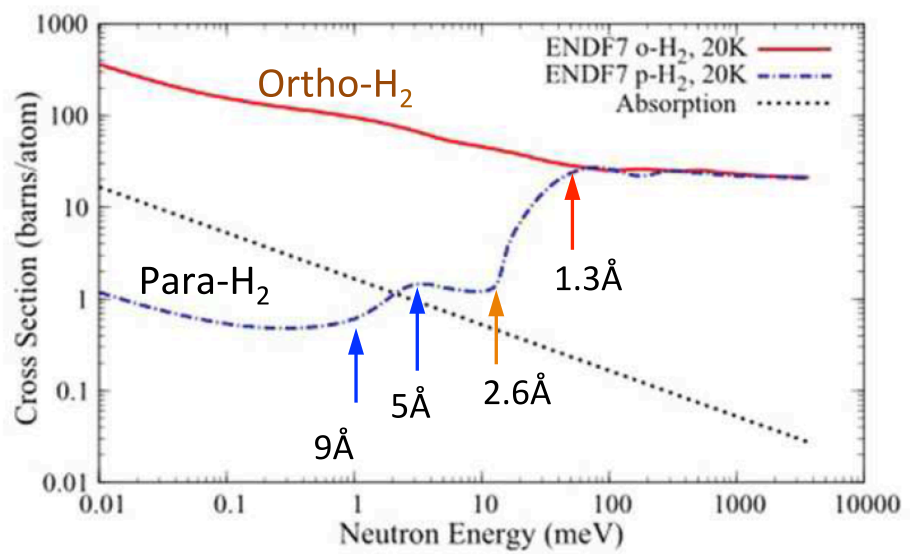
Each of instrument imposes specific requirements on spectrum and divergence of delivered neutron beams

Requirements to neutron beams



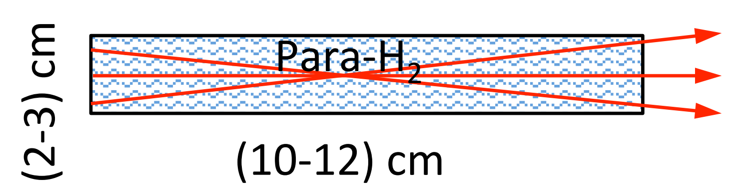
What moderators are answering these requirements best ?

Low-dimensional (flat) moderators



Scattering mean free path in pure para-H_2: ≈10 cm at 15 meV

- moderator is transparent to cold neutrons;
- the whole volume of moderator is the source of long wavelength neutrons;
- ortho-H_2 moderators: neutrons are mostly emitted at the exit surface;
- long wavelength neutrons have only one direction to escape the moderator.



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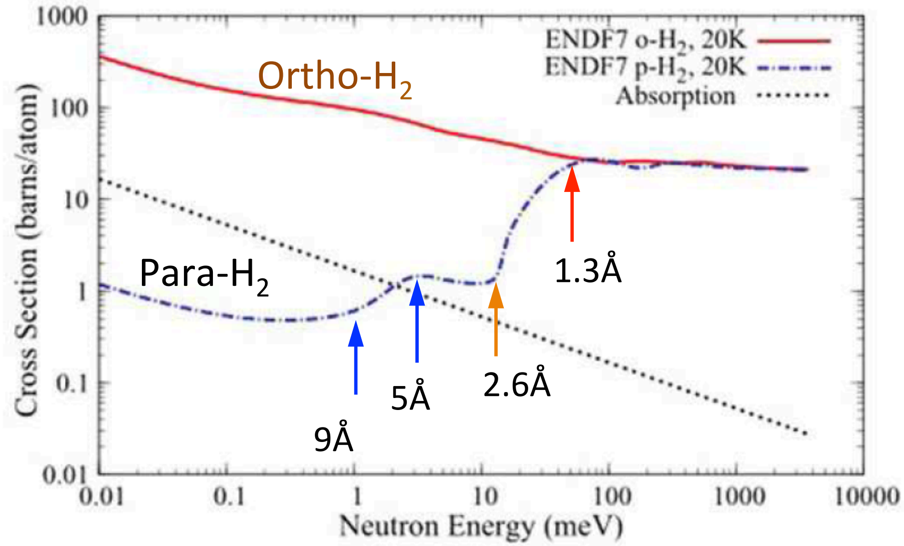
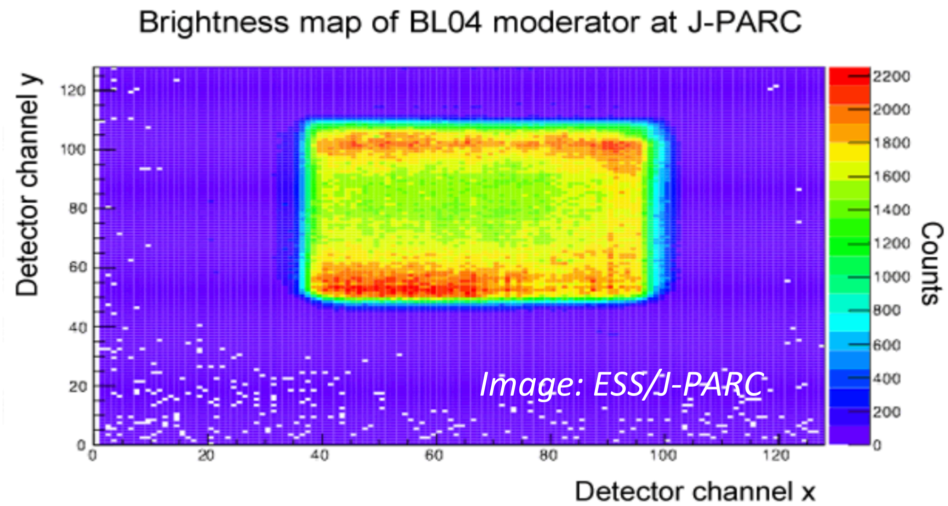




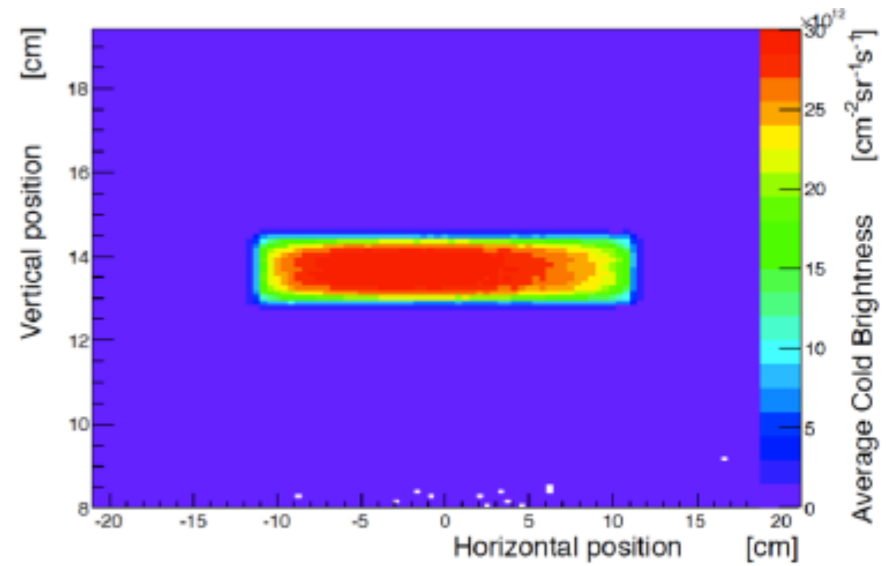
Scattering mean free path in pure para-H$_2$:
≈1 cm at 50 meV, ≈2 cm at 25 meV

⇩

A moderator with a small height, (1-2)cm, have enough hydrogen to thermalize neutrons to cold energies.

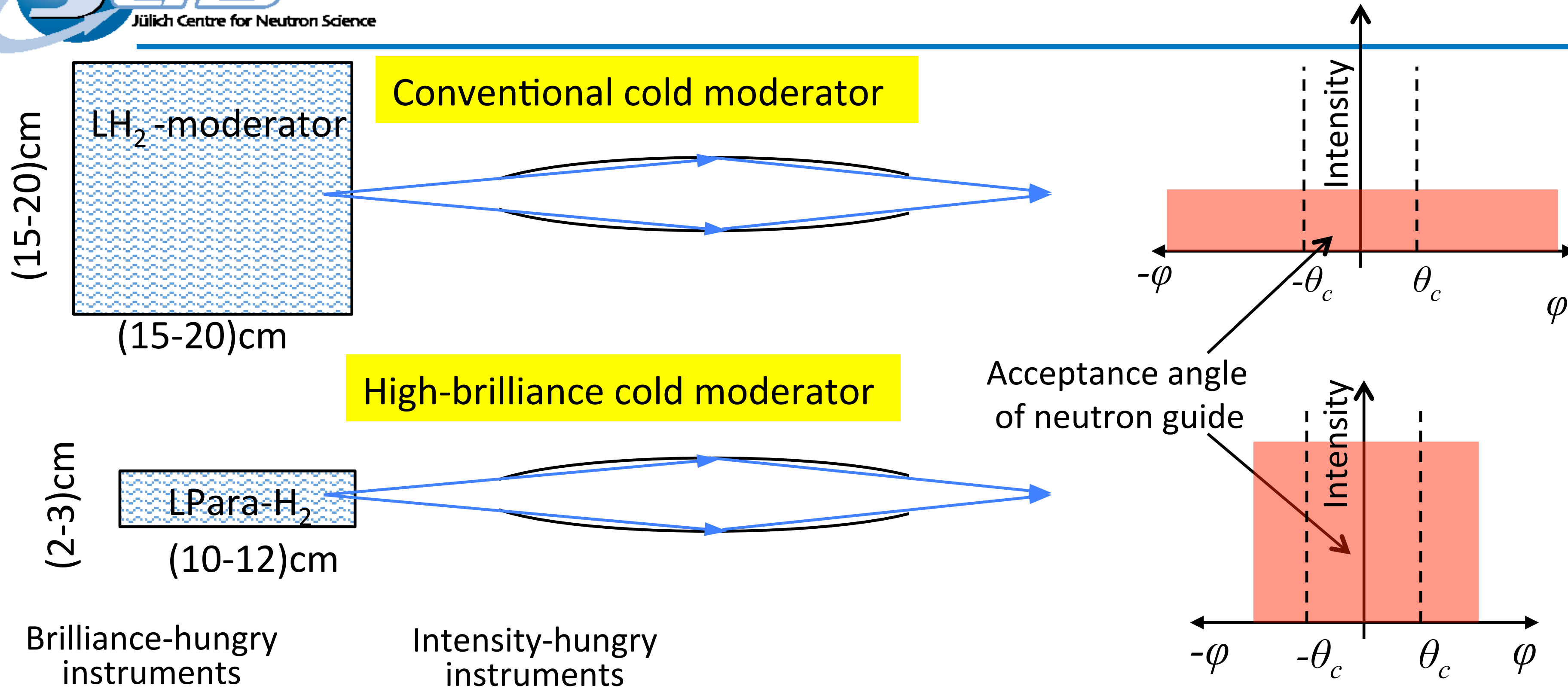
⇩

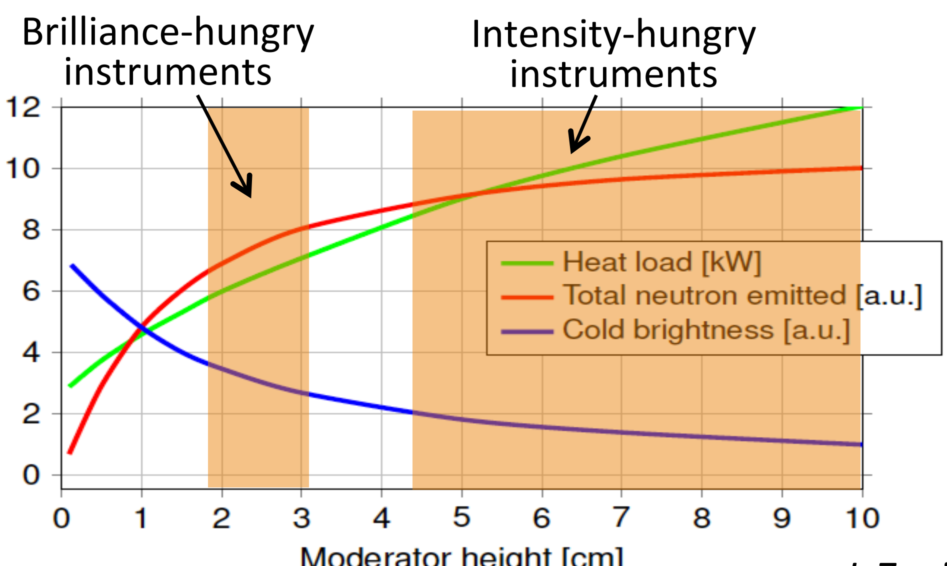
Smaller than conventional moderator.



F.Mezei et al., Journal of Neutron Research 17 (2014) 101

Cold moderators





<u>High-brilliance cold moderators:</u>
=> gain in intensity on the sample
for a certain class of instruments

At 3 cm 80% of total neutrons emitted compared to maximum

L.Zanini et al., Proceedings ICANS XXI, Japan, 2015.

What is a dream neutron source for scientists?

Neutron beams are useful when they have:

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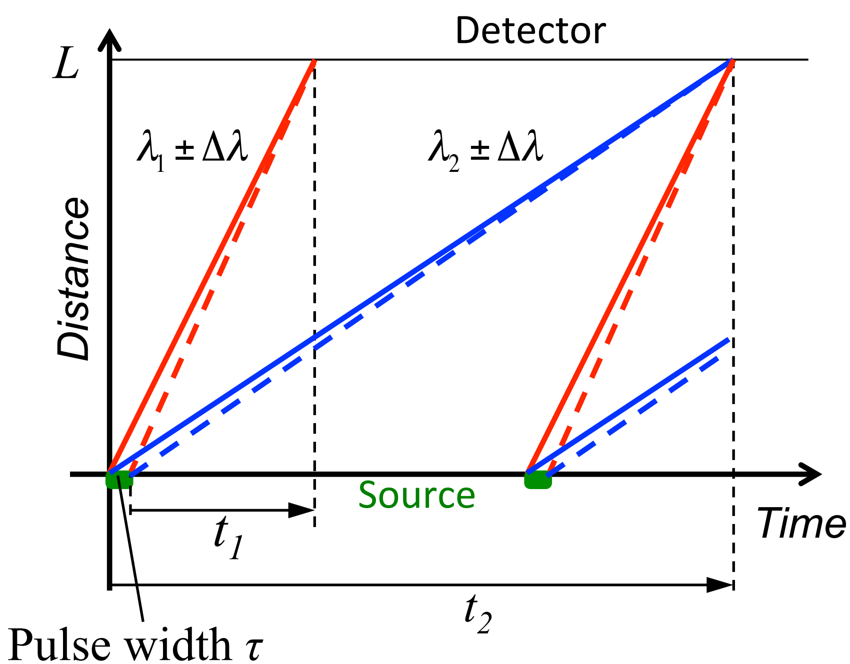
- **desirable time structure**

However, different requirements for different neutron instruments:

Q-resolution and Q-range vs. pulse width τ and source-detector distance L (instr. length)



$$\frac{\Delta\lambda}{\lambda} = \frac{\tau}{T_{TOF}} = \frac{m}{h}\cdot\frac{\tau}{L}$$

$$\Delta\lambda = \lambda_2 - \lambda_1 = \frac{m}{h}\cdot\frac{1}{f\cdot L}$$

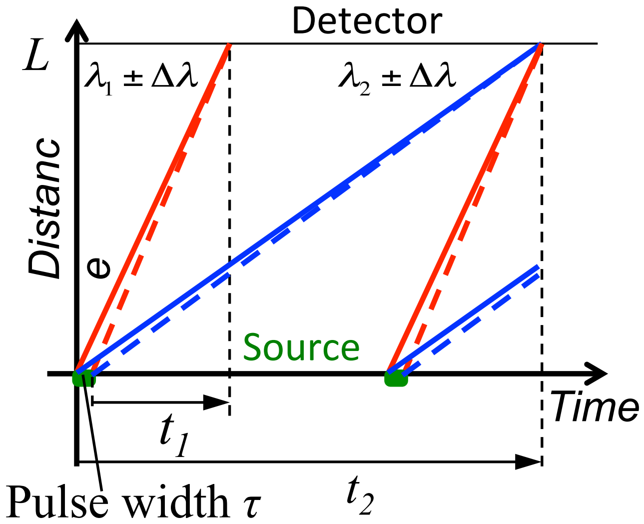
Good resolution:
⇒ short pulse
OR
long instrument
⇒ long pulse
AND
long instrument

Wide Q-range:
⇒ short instrument
(frame overlap)

Controversial requirements!

Way out:
Repetition rate multiplication *(F.Mezei, 1997)*

Resolution and band vs. instrument length



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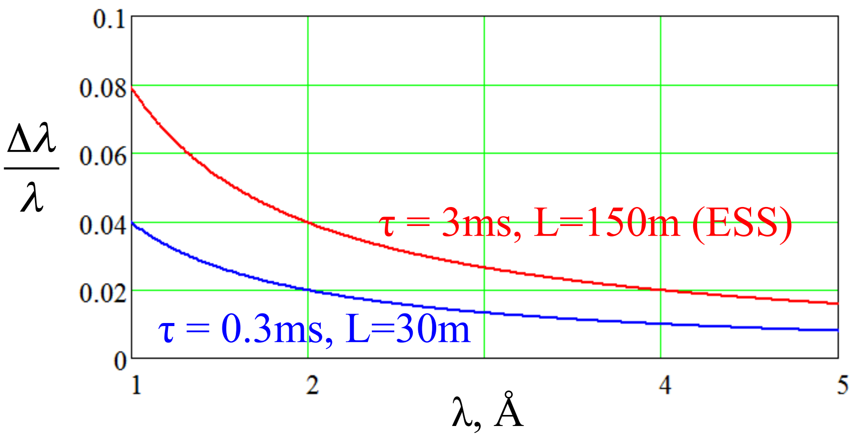
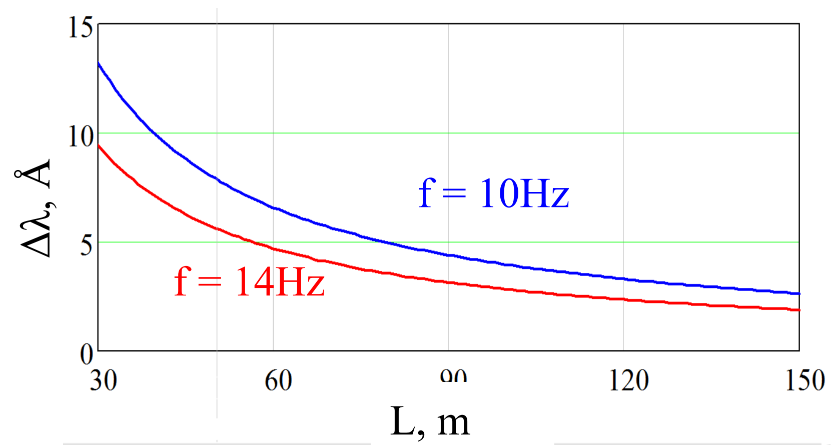




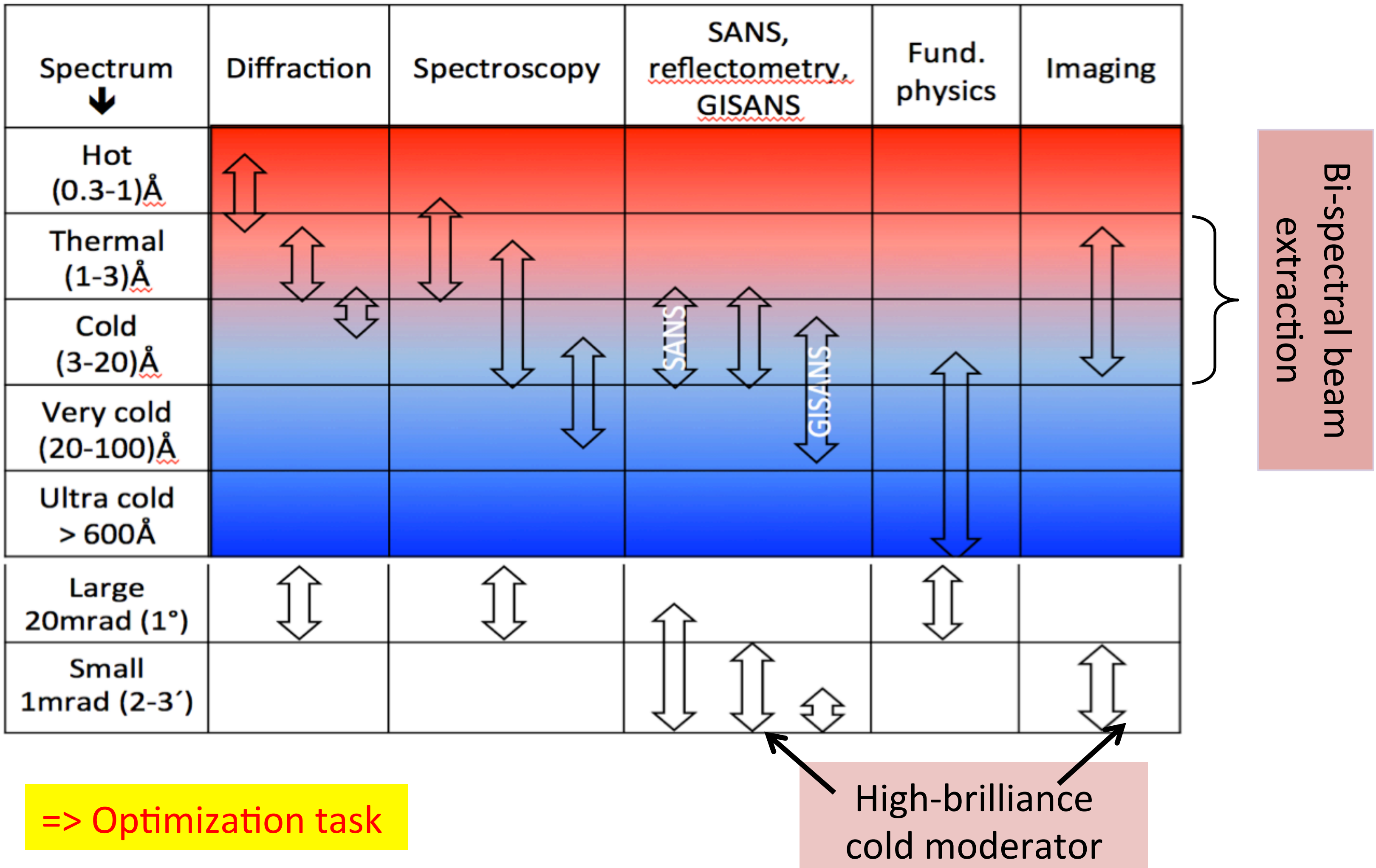
DNS-4 (τ = 0.3ms):

- high resolution for short instruments
- a large wavelength band in a single setting
- E.g. L=30m, res.=1% for 2A, band=8A

=> Short instruments

- Thermal moderators (grooved)
- Cold moderators (grooved?)
- High-brilliance cold moderators

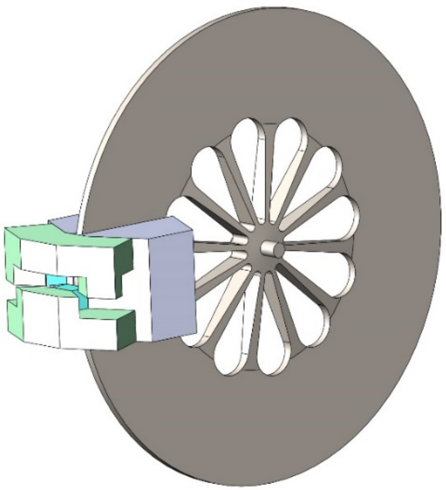
Instruments can be grouped to take a full advantage of optimized moderators

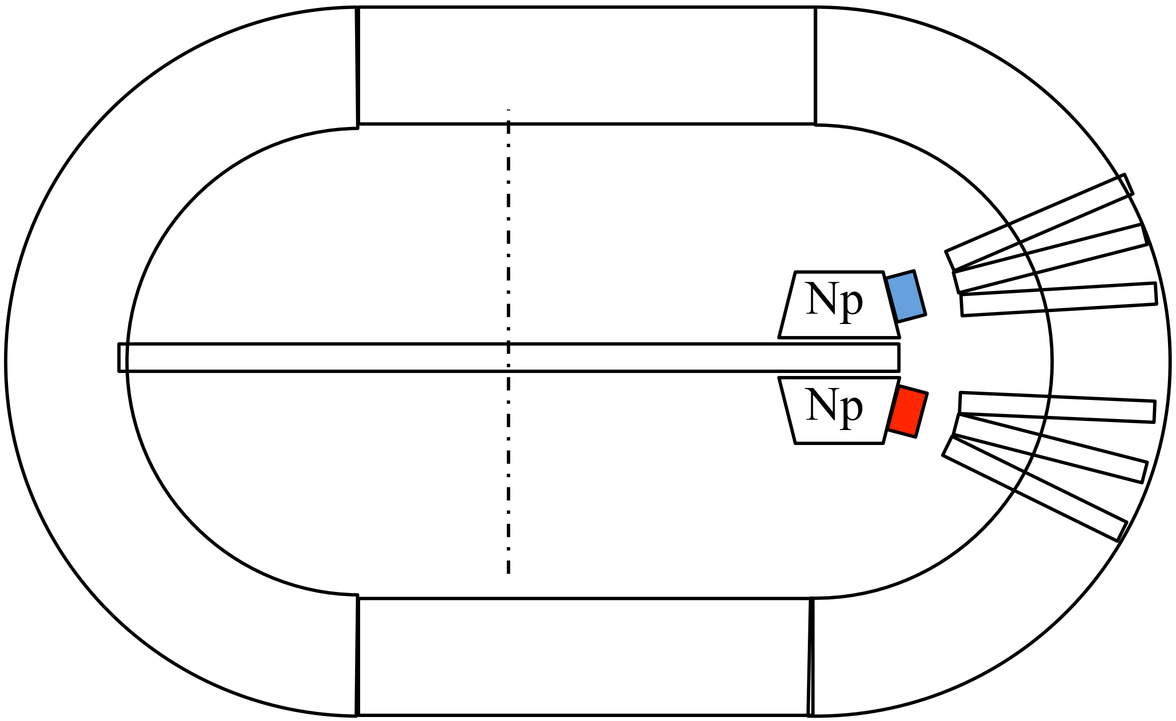


=> Optimization task

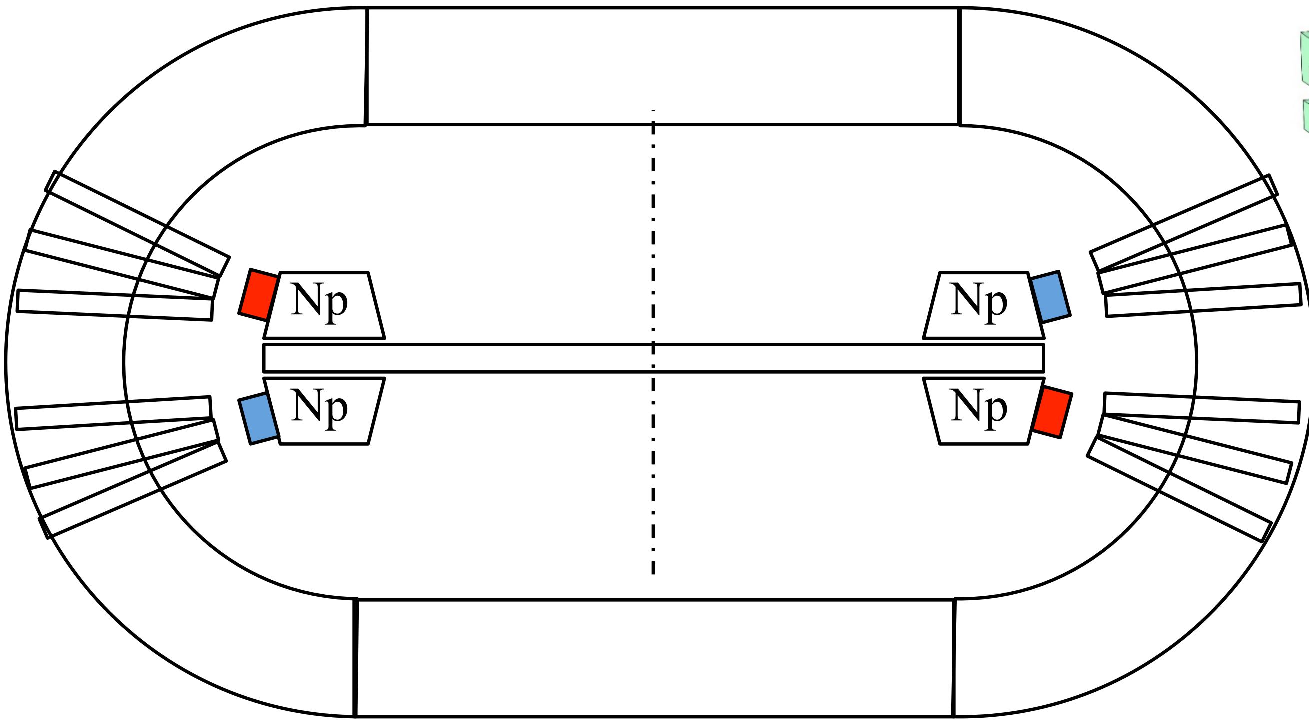
DNS-4: generic design:

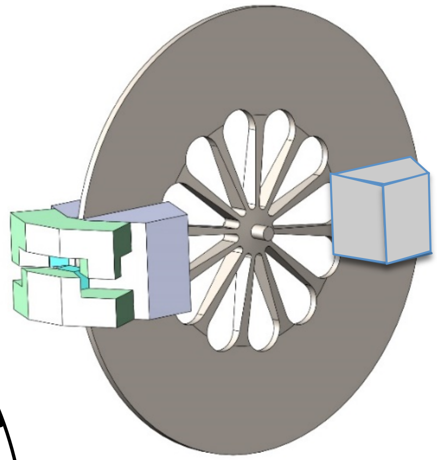
V.L.Aksenov, E.P.Shabalin et al., 2017





Why not the 2nd core?

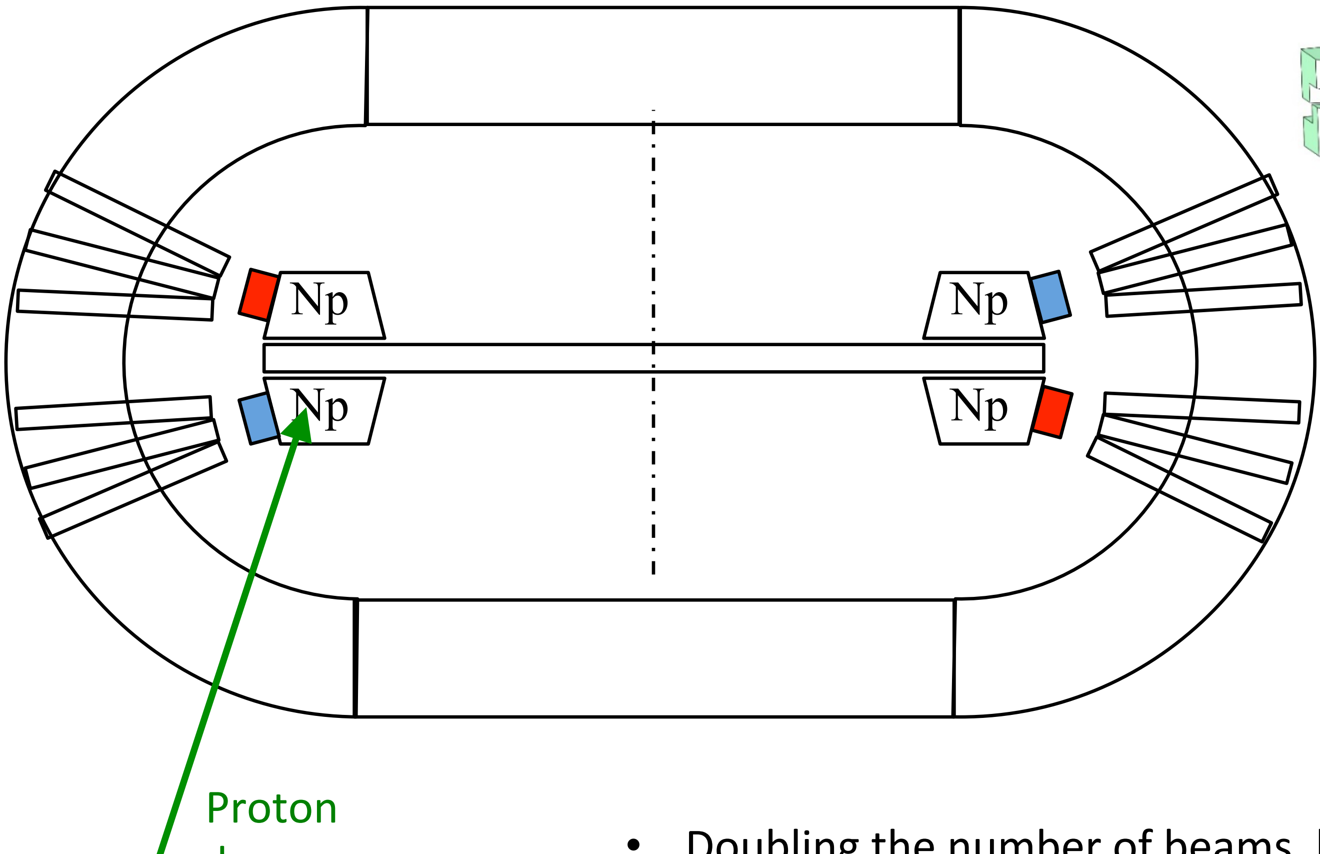


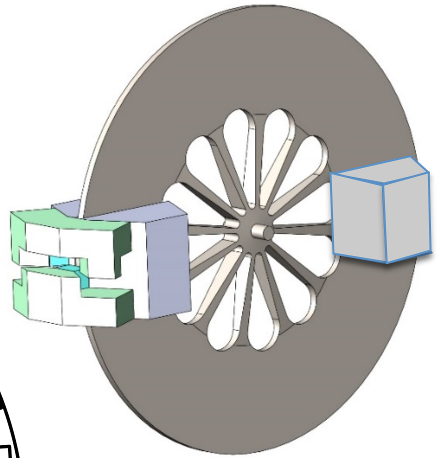


- Doubling the number of beams, but not budget!
- Better combination of moderators
- More freedom in combining instruments

2nd core + superbooster

Possibility for upgrade:
accelerator for short, about 30µs, pulses (superbooster)





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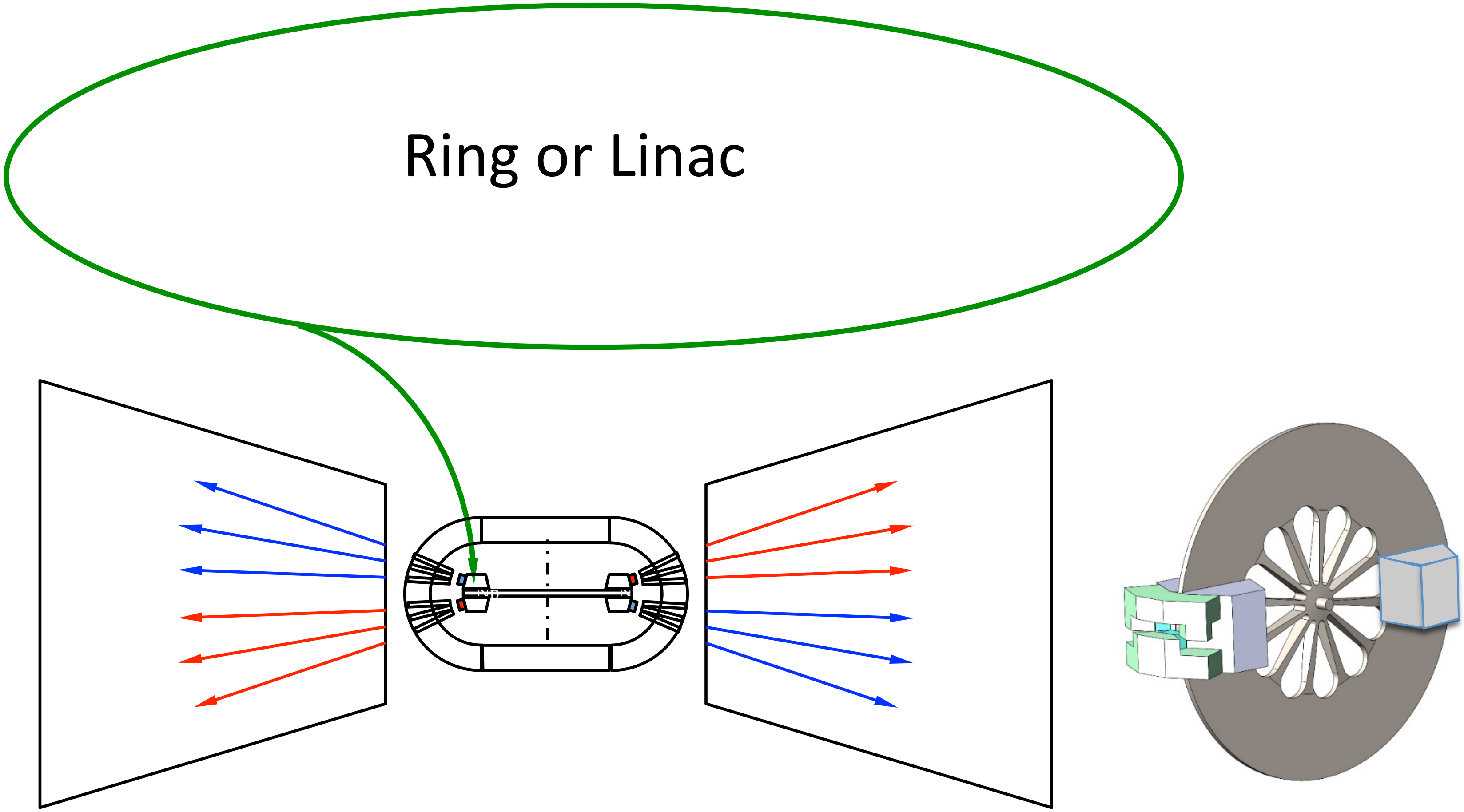

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Delayed neutrons: small amount, but a big problem…

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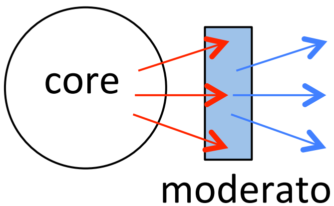
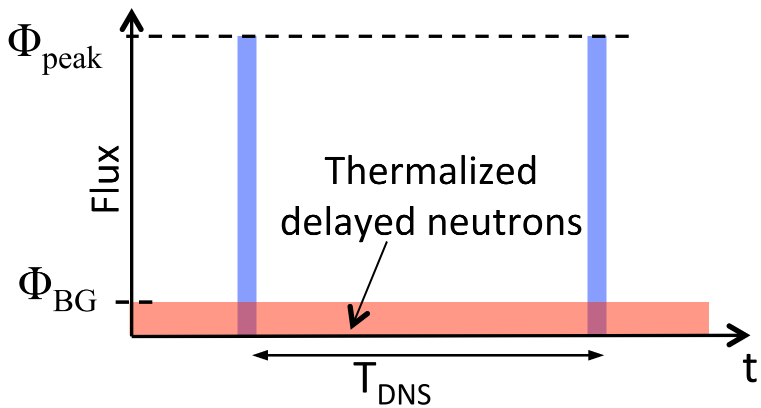
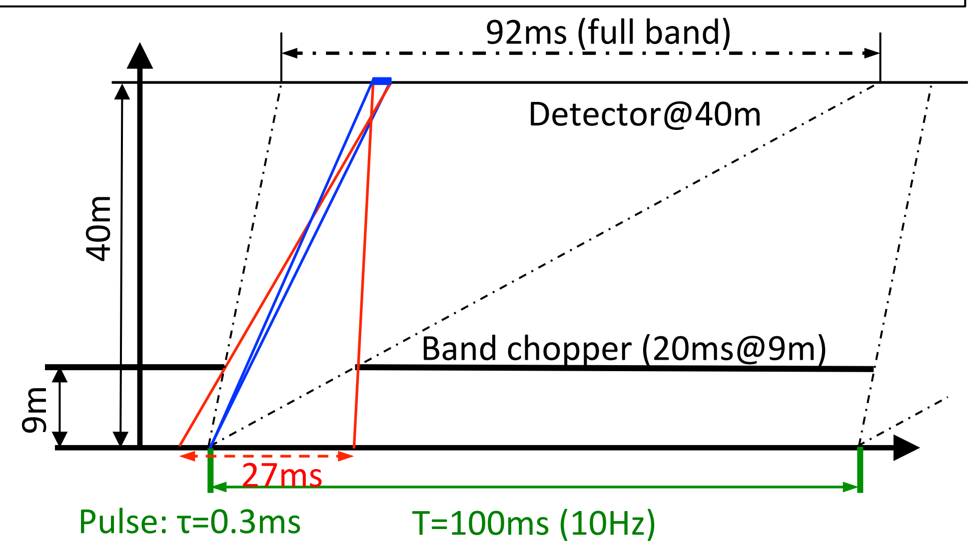
- Emitted (2-3)s after the fission; play the decisive role in the control of nuclear reaction
- Small amount: about 3% from averaged neutron flux, but is it really small?

Delayed neutrons



Maxwellian spectrum → Uncertainty in emission time << T_{DNS} → Continuous neutron emission as from steady power reactor





$\Phi_{peak} = 6 \cdot 10^{16}$ n/cm²/s ; $\Phi_{mean} = 3 \cdot 10^{14}$ n/cm²/s

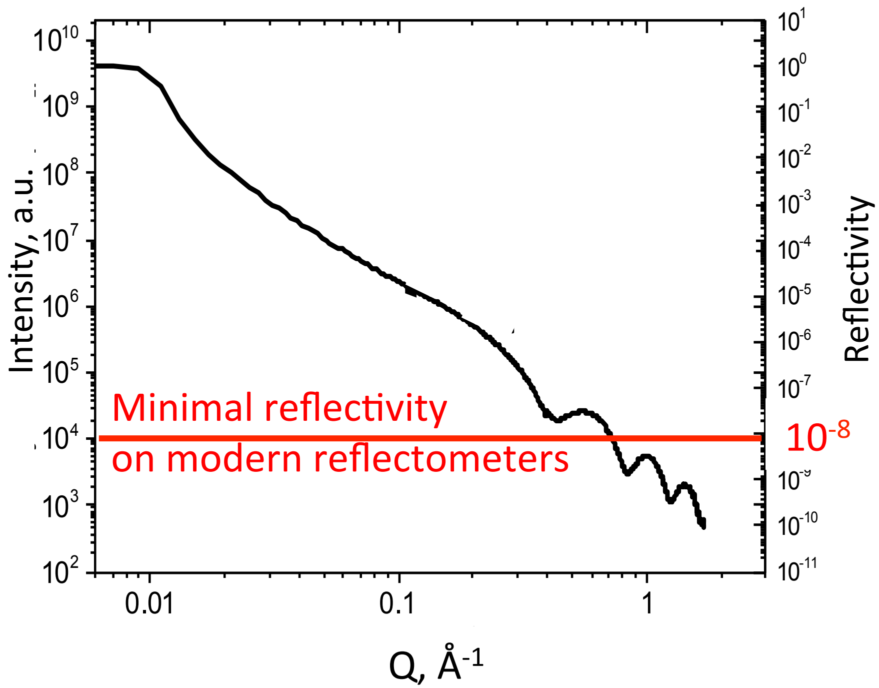
=> $\Phi_{BG} = 3.2\% \cdot \Phi_{mean} \approx 10^{13}$ n/cm²/s

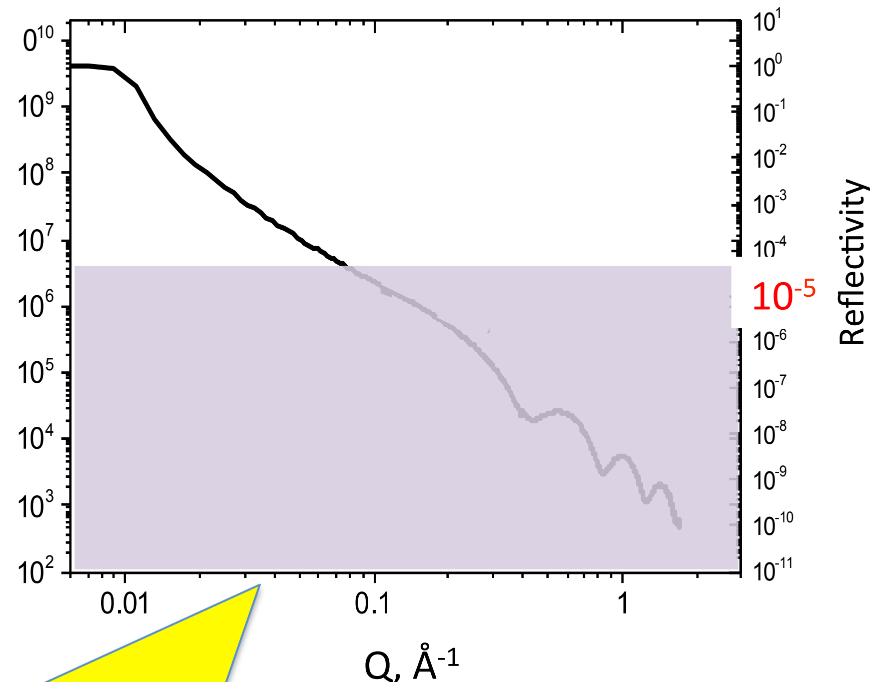
→ $\Phi_{BG}/\Phi_{peak} \cdot 27/100 \approx 5 \cdot 10^{-5}$ High background!

=> Serious problem for SANS and reflectometry studies at pulsed reactors

Why minimal reflectivity 10^{-5} is not sufficient?

Sample: 15Å thick SiO_2 layer on Si substrate (without roughness)



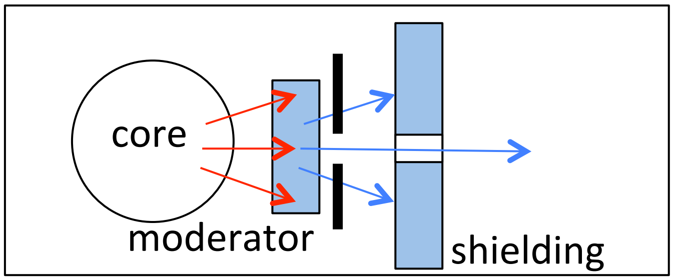


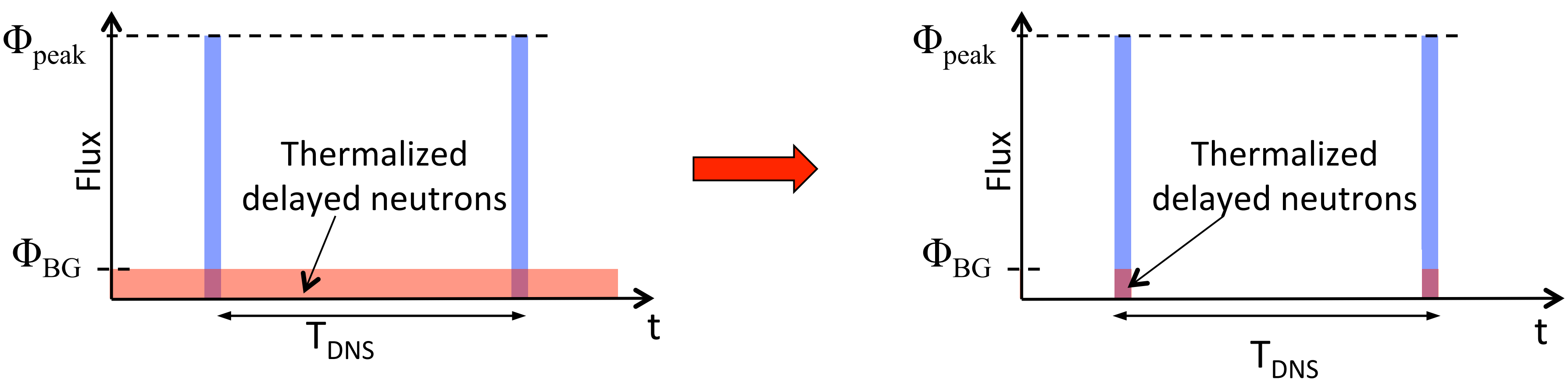
Relevant signature of a thin layer will not be observed!

No possibility to study thin interfaces,
minimal thickness only about 80A.

Delayed neutrons: small amount, but a big problem…

Evident solution: reduce the opening time of moderator to τ_{pulse} by a chopper
=> no delayed neutrons outside the neutron pulse are emitted



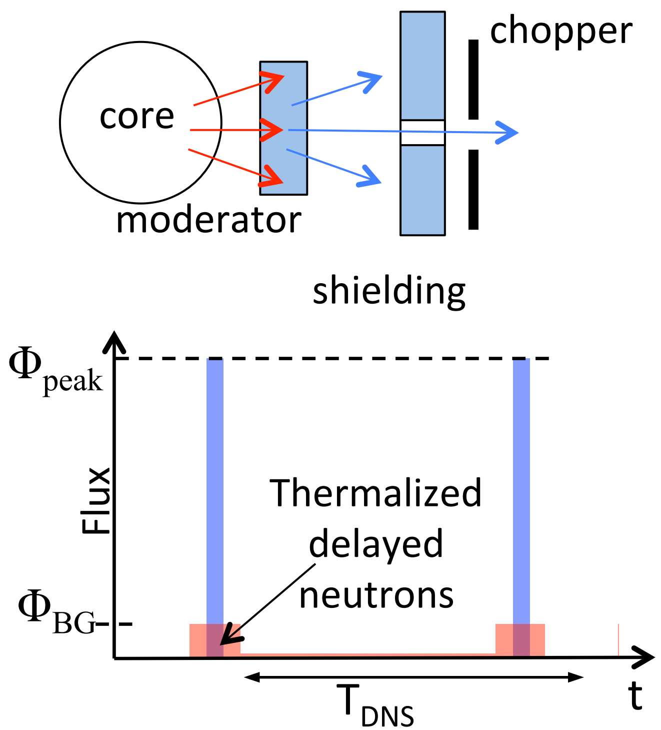


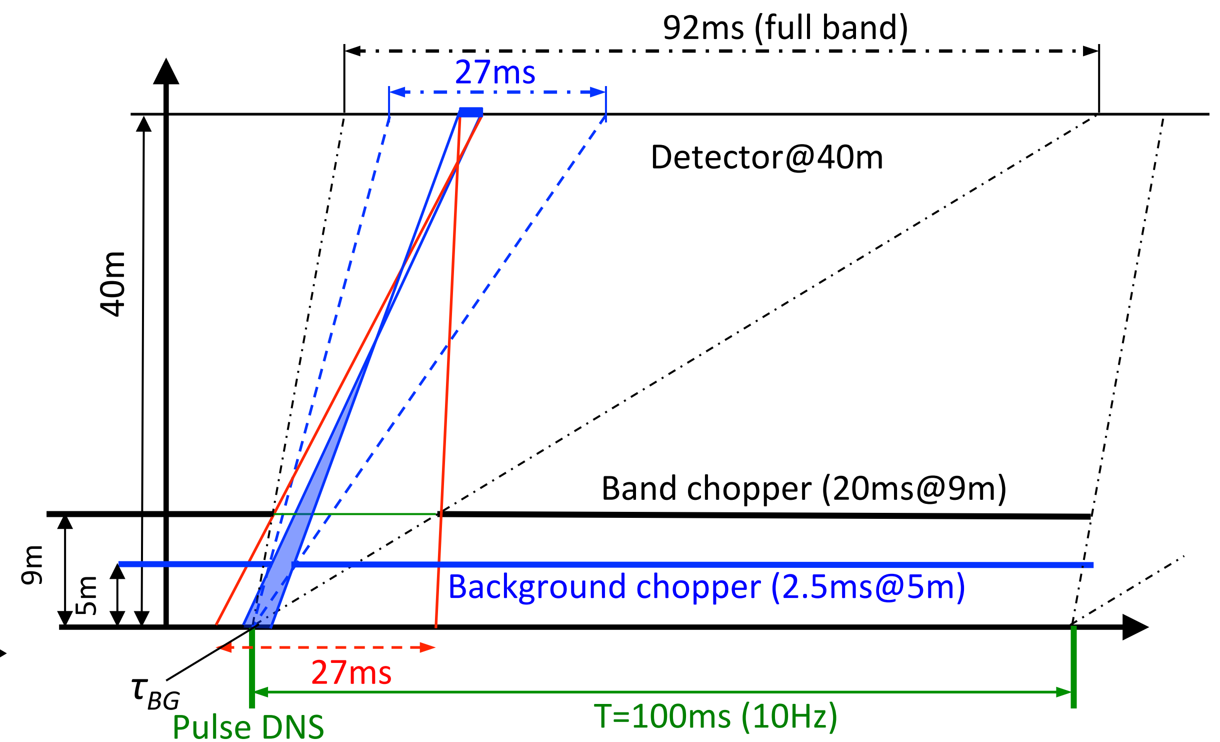
Chopper just next to moderator:

- high irradiation: life time?
- quick moving parts next to rotating reflector
- => complicate. Possible?

Delayed neutrons: a possible solution

Chopper after the shielding: the time when detector is exposed to the moderated delayed neutrons is reduced to ≈ $1.15\tau_{BG}$ (broadening because of 5m to the source).

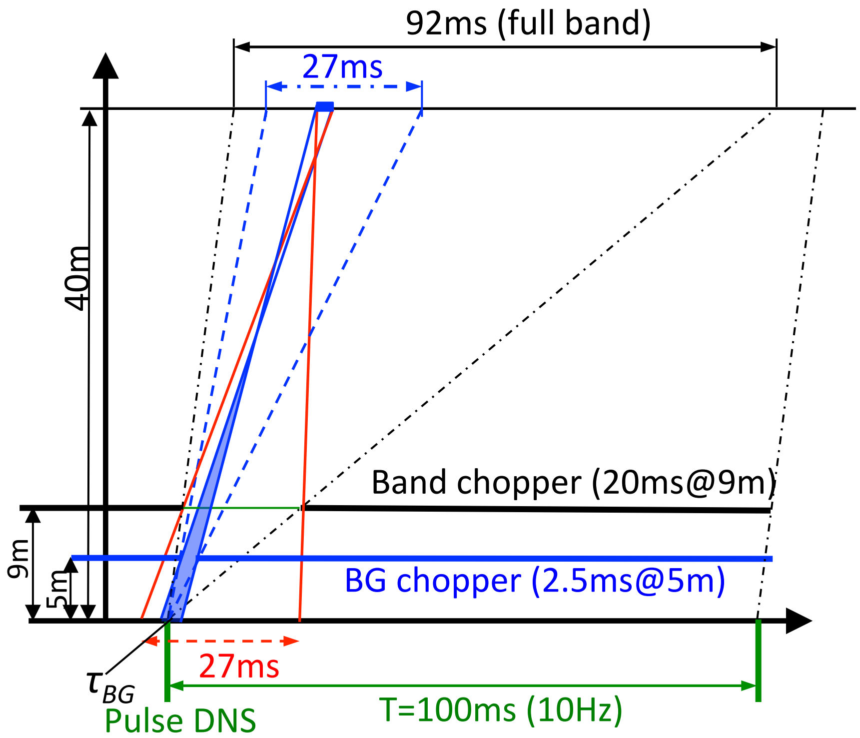


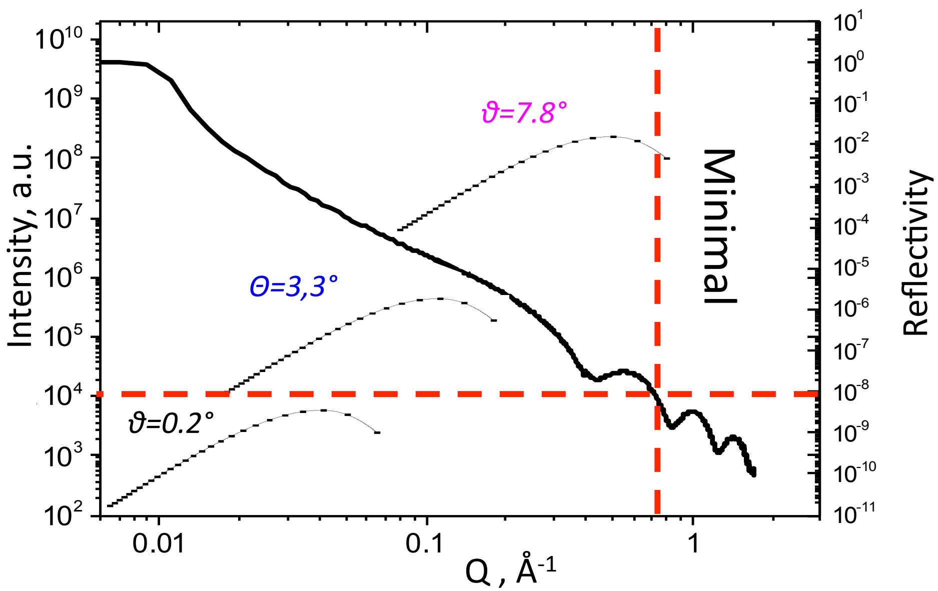


- Now only neutrons with a small λ-shift relative λ0 are seen in the detector time channel.
- The spectrum inside τ_{BG} is practically the same Maxwellian as in the neutron pulse
- **These neutrons are not the BG anymore - they are a part of the signal.**

Delayed neutrons: a possible solution

- BG chopper limits the λ-band accessible in a single reflectometry measurement.
- Not critical: a few measurements at different angles are anyway required to cover a large Q-range

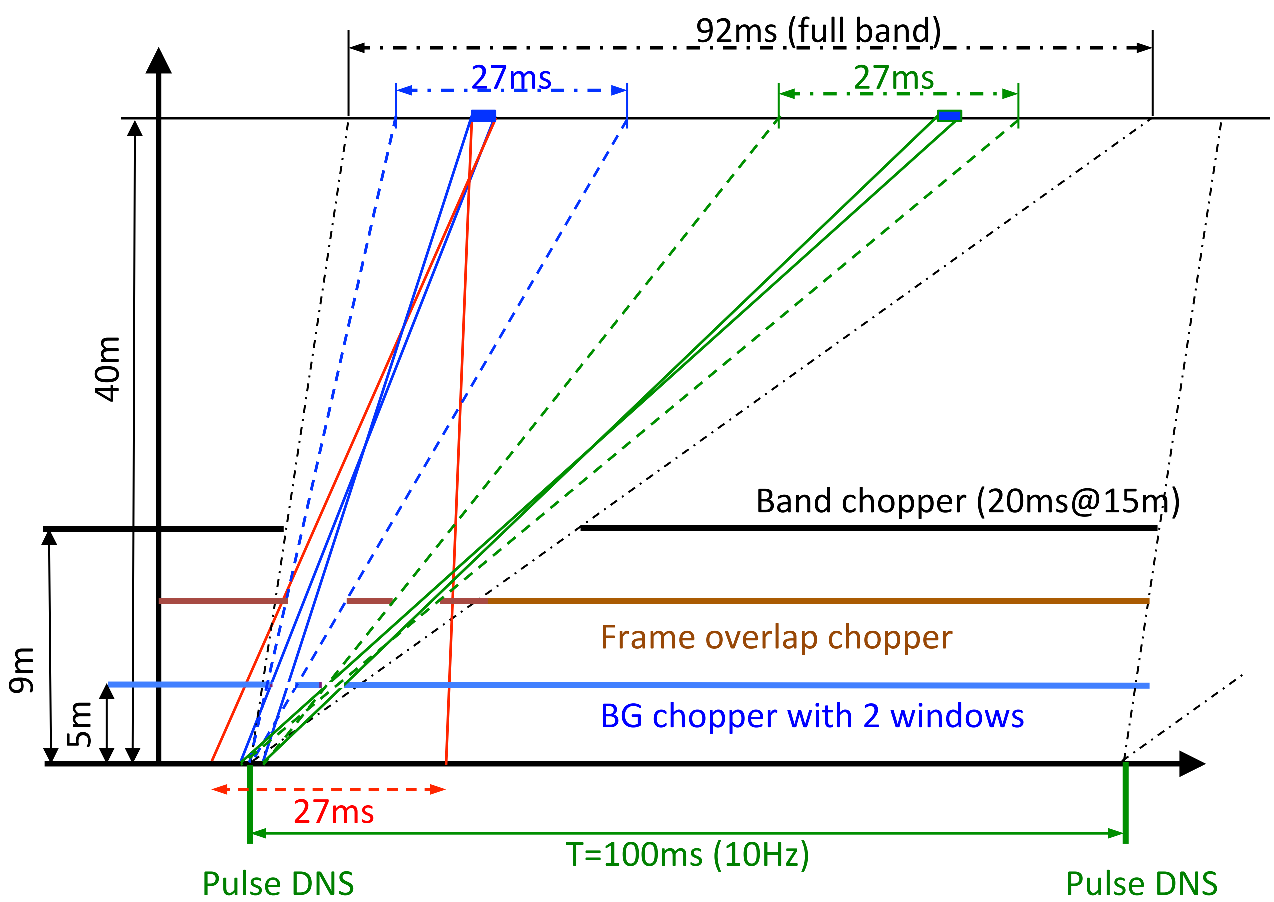




Reflectivity measurements down to 10^{-8} are possible.

Multiple bands: better Q-coverage

- BG chopper with 2 windows provides two λ-bands.
- Their full separation is achieved by frame overlap chopper.



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Thank you for attention!