Zimányi School 2009

Next Generation Neutron Sources

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Topics

- What means “next generation”?
- Can it readily be done?
- How?
- What are the advantages?
- And disadvantages?
- Perspectives

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Ways to produce neutrons

Energy balance decisive for condensed matter research:

fast neutrons produced / joule energy (heat produced / energy consumed)

Fission reactors:	~ 10^9	(in ~ 50 liter volume)
Spallation:	~ 10^{10}	(in ~ 1 liter volume)
Fusion:	~ 2×10^{10}	(in huge volume)
Photo neutrons:	~ 10^9	(in ~ 0.01 liter volume)
Nuclear reaction (p, Be):	~ 10^8	(in ~ 0.001 liter volume)
Laser induced fusion:	~ 10^4	(in ~ 10^{-9} liter volume)

Spallation: most favourable for foreseeable future!
Forget fusion!

One amazing example: table top neutron source

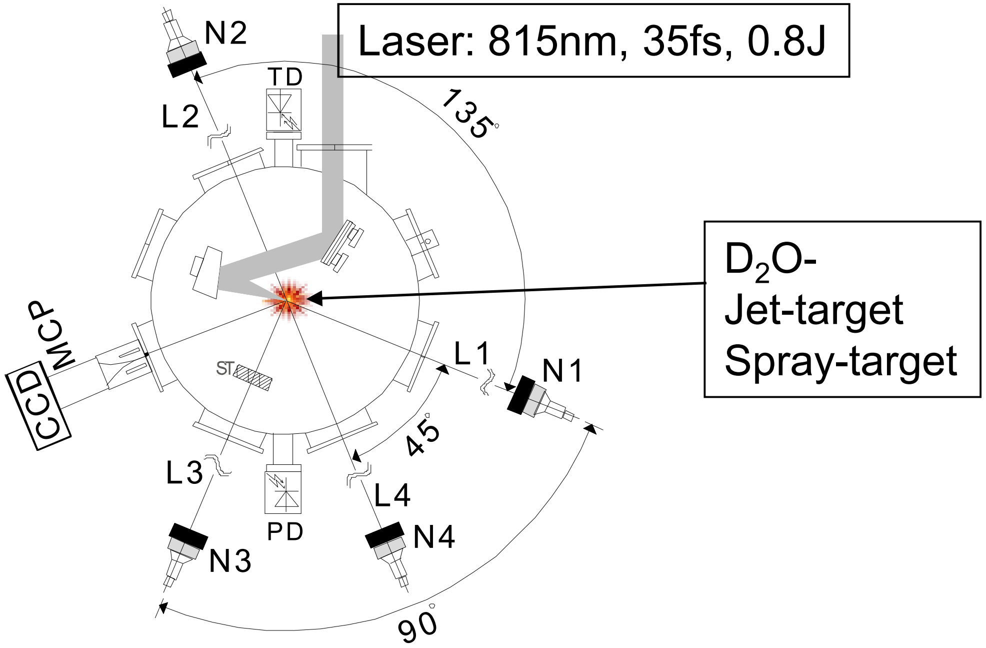
- **Nanoaccelerator by ultrashort, focussed laser pulse on 20 μ D_2O droplet: relativistic light intensities.** Field-strength: 1 MV/μm

  10^{19} W/cm^2 power → plasma → deuterons accelerated to MeV → **fusion !**

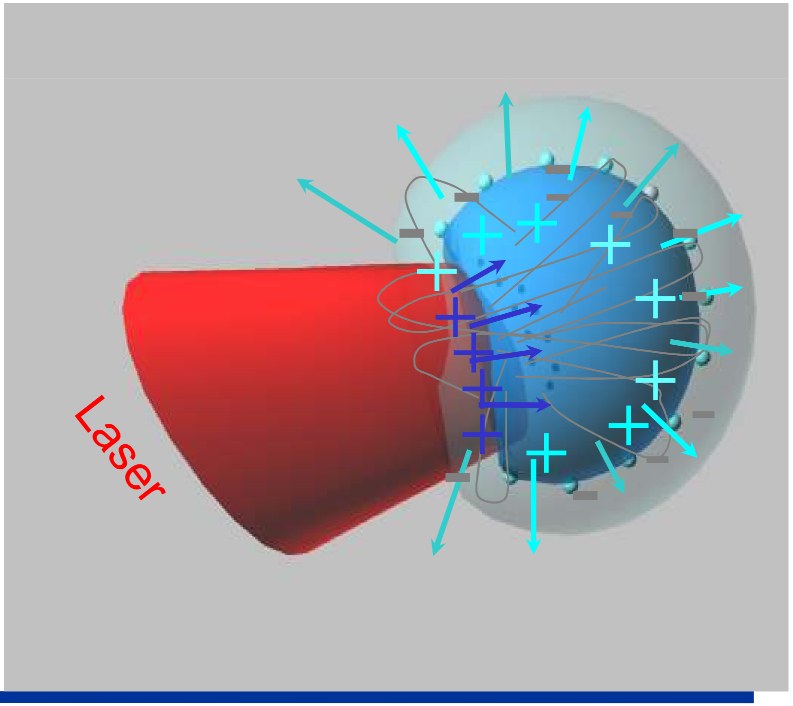
  Distribution of neutrons reveals plasma formation mechanism

  Laser driven μ-size source of (fast) neutrons (~10^4 neutron/ ~ 0.5 j pulse)

  d + D => 3He (0.82 MeV) + n (2.45 MeV): Neutron – spectroscopy


Laser: 815nm, 35fs, 0.8J

D_2O-
Jet-target
Spray-target



(Max Born Inst, HMI coop)

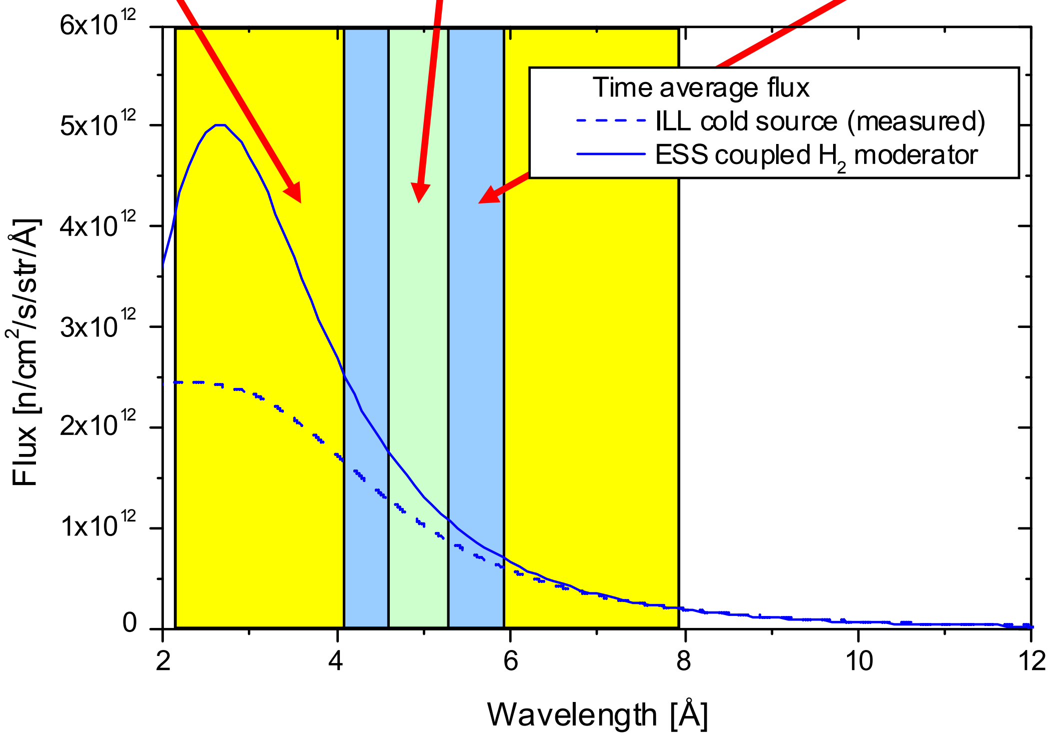
Efficiency gain by pulsed sources

Part of spectrum used by a D22 (ILL) class instrument

16.67 Hz pulsed source

continuous source

50 Hz pulsed source



Efficiency gain by pulsing:
≈ δλ/λ **~8-1000**

Next-generation?

State-of-the-art?

Linear accelerators alone can do the same in ~ 100 μs pulses:

~ 60 % of accelerator parts and complexity removed → simpler, cheaper

What is the longest acceptable pulse length?

- **Irradiation work: ∞**
- **Single (Q,ω) experiments (D3, TAS?): ∞**
- **SANS, NSE: 2 – 4 ms**
- **Reflectometry: 0.5 – 2 ms**
- **Single Xtal diffraction: 100 – 500 μs**
- **Powder diffraction: 5 – 500 μs**
- **Cold neutron spectroscopy: 50 – 2000 μs**
- **Thermal neutron spectroscopy: 20 – 600 μs**
- **Hot neutron spectroscopy: 10 – 300 μs**
- **Electronvolt spectroscopy: 1 – 10 μs**
- **Backscattering spectroscopy: 10 – 100 μs, …**

Rough estimate: $t_{min} / T \sim \delta\lambda/\lambda$

What is the longest acceptable pulse length?

Longer pulses ⇨ more neutrons but more power

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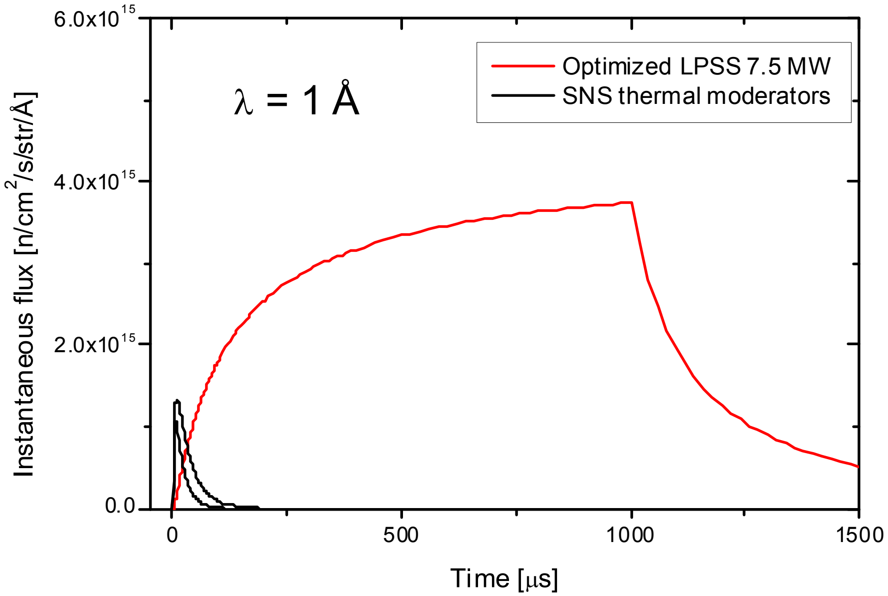
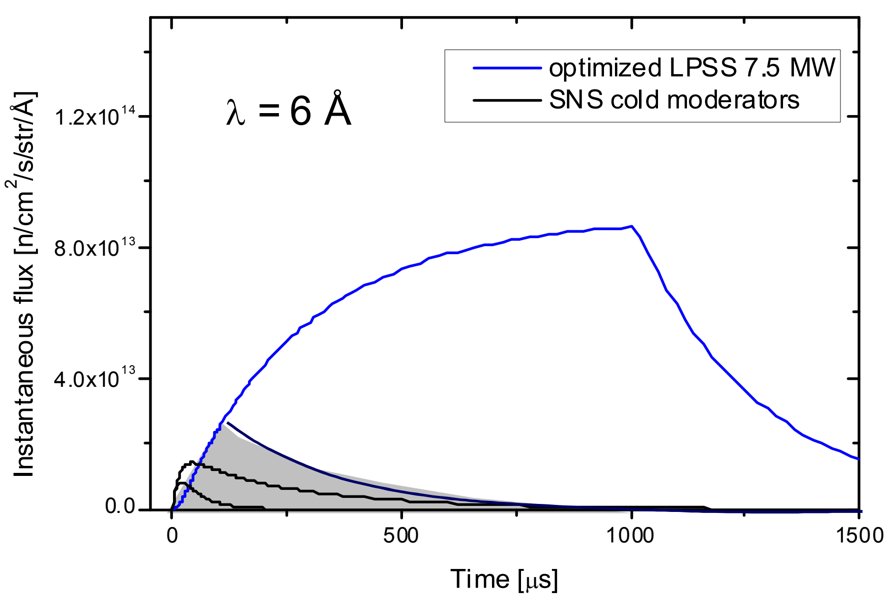
“Long” proton pulses using linear accelerators:

- **Longer pulses (ms) also provide** **higher peak flux at comparable costs and technical complexity**

Example:
450 kj/pulse long pulses **(350 MW inst.)** vs. 23 kj/pulse short pulse **(15 GW inst.**: SNS)





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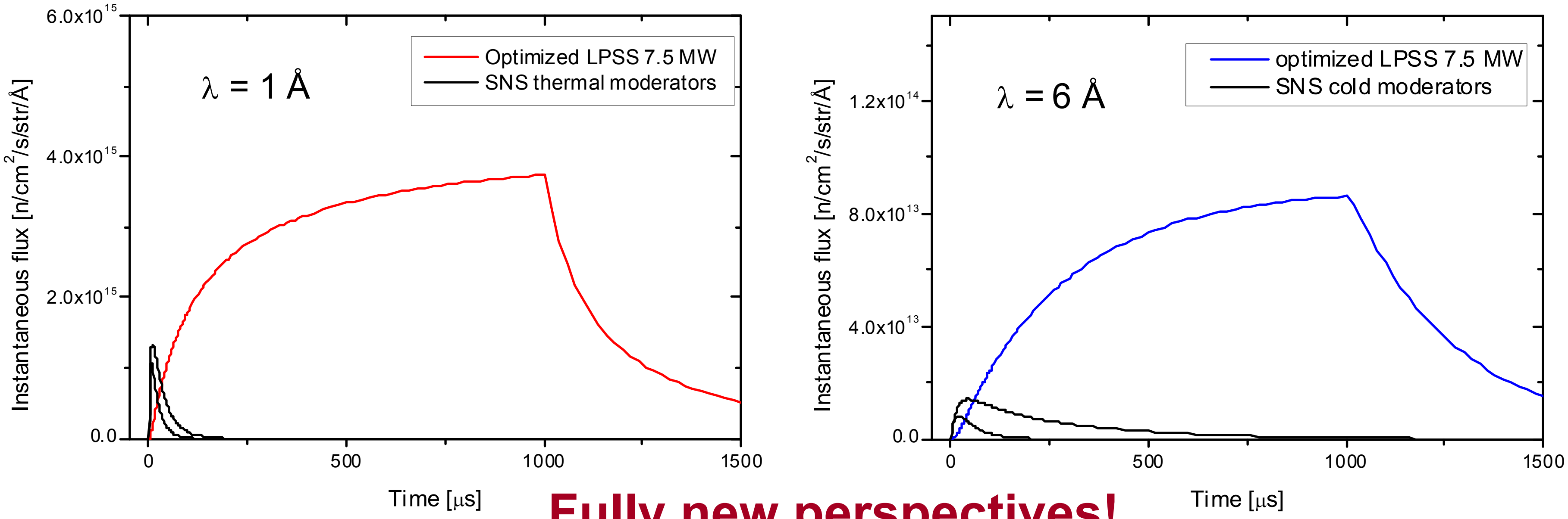

Fully new perspectives!

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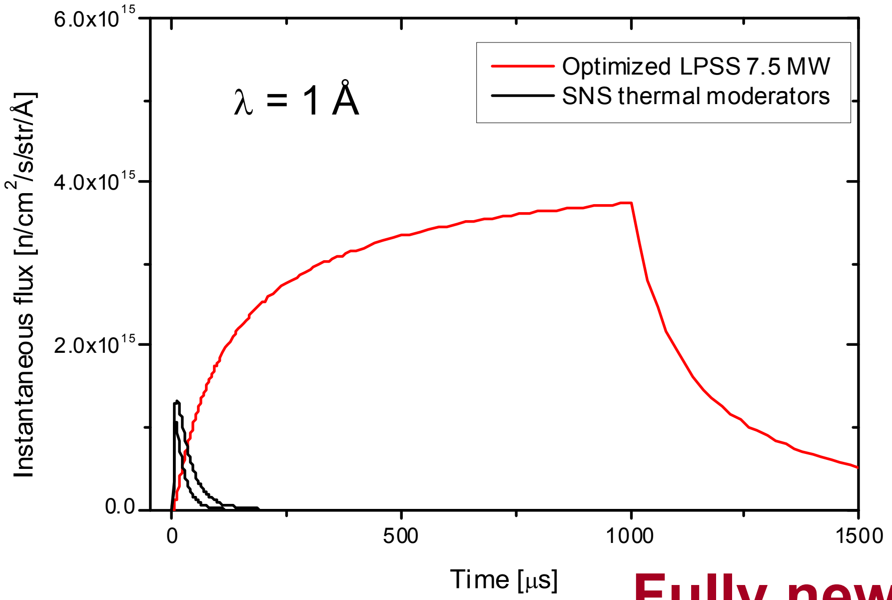
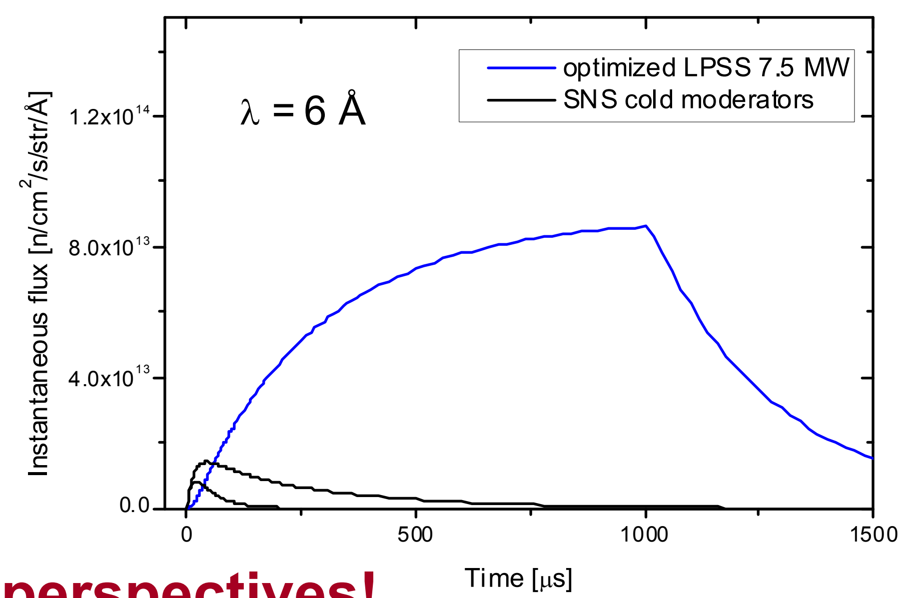




Fully new perspectives!

…if we can shape source neutron pulses

Compromise: 2 ms pulses for 5 MW power in ~20 Hz

ESFRI: need for “top tier” neutron source for Europe: ESS

European Strategy Forum
on Research Infrastructures

ESFRI

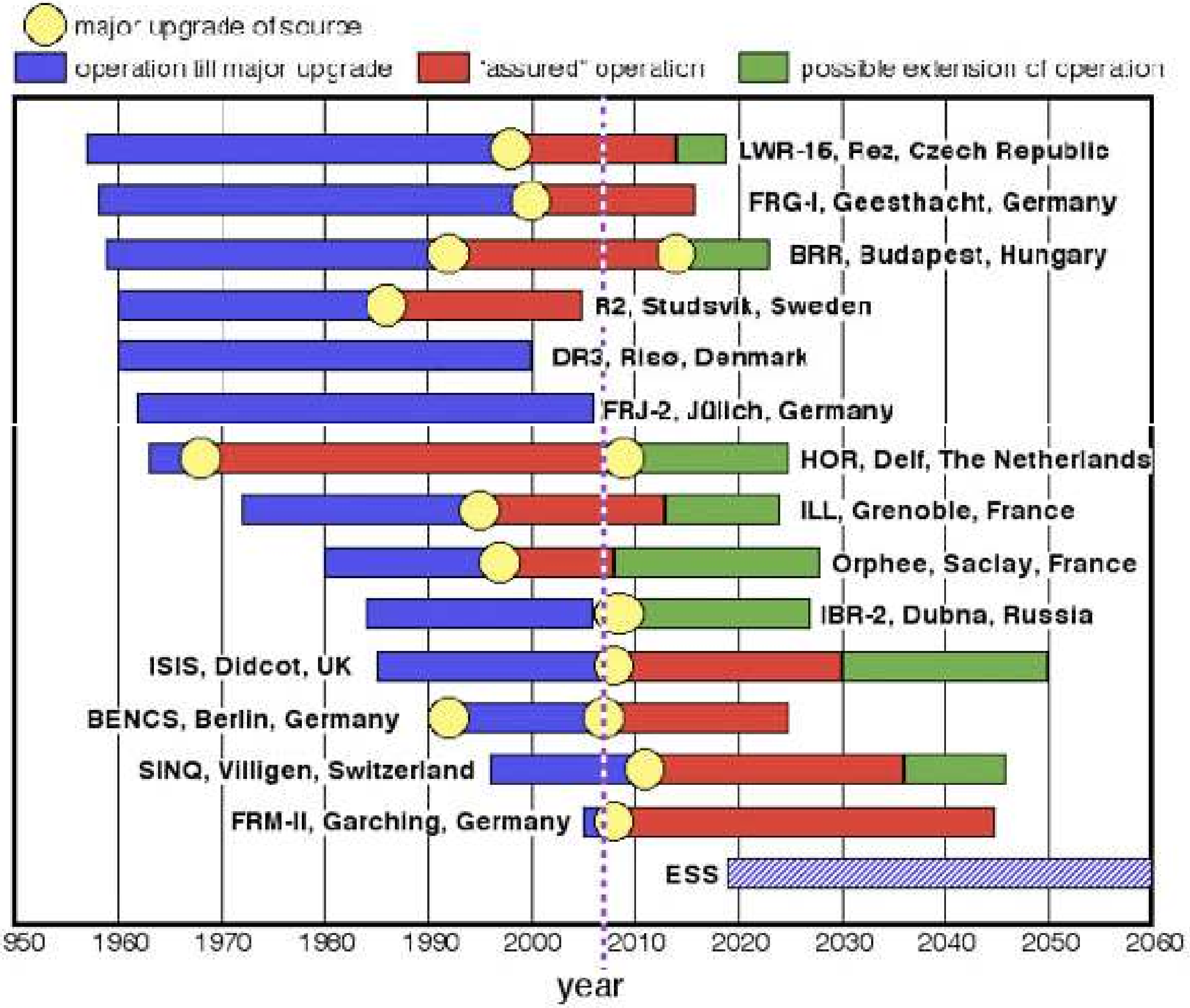
EUROPEAN ROADMAP
FOR RESEARCH
INFRASTRUCTURES

Report 2006

ESS will be the world’s most powerful source of neutrons. Its built-in upgradeability (more than the initial 20 instruments, more power, more target stations) makes it the most cost-effective top tier source for 40 years or more. A genuine pan-European facility, it will serve 4,000 users annually across many areas of science and technology.

Neutron research in Europe:

~4000 scientists, 11 facilities (and decreasing): ~ 330 M€/a



ESS:

- **Affordable costs**
  for 10 % share of use with 22 instruments:
  165 – 193 M€ investment + operations
  (1.1.2008 value) spread over 2009-2025

- **Established technologies used in innovative way:**
  low technological risks

- **More neutrons for less energy**
  ILL: ~ 70 MW,   ESS: ~ 30 M

- **Upgrade potentials: 2 – 3 x**

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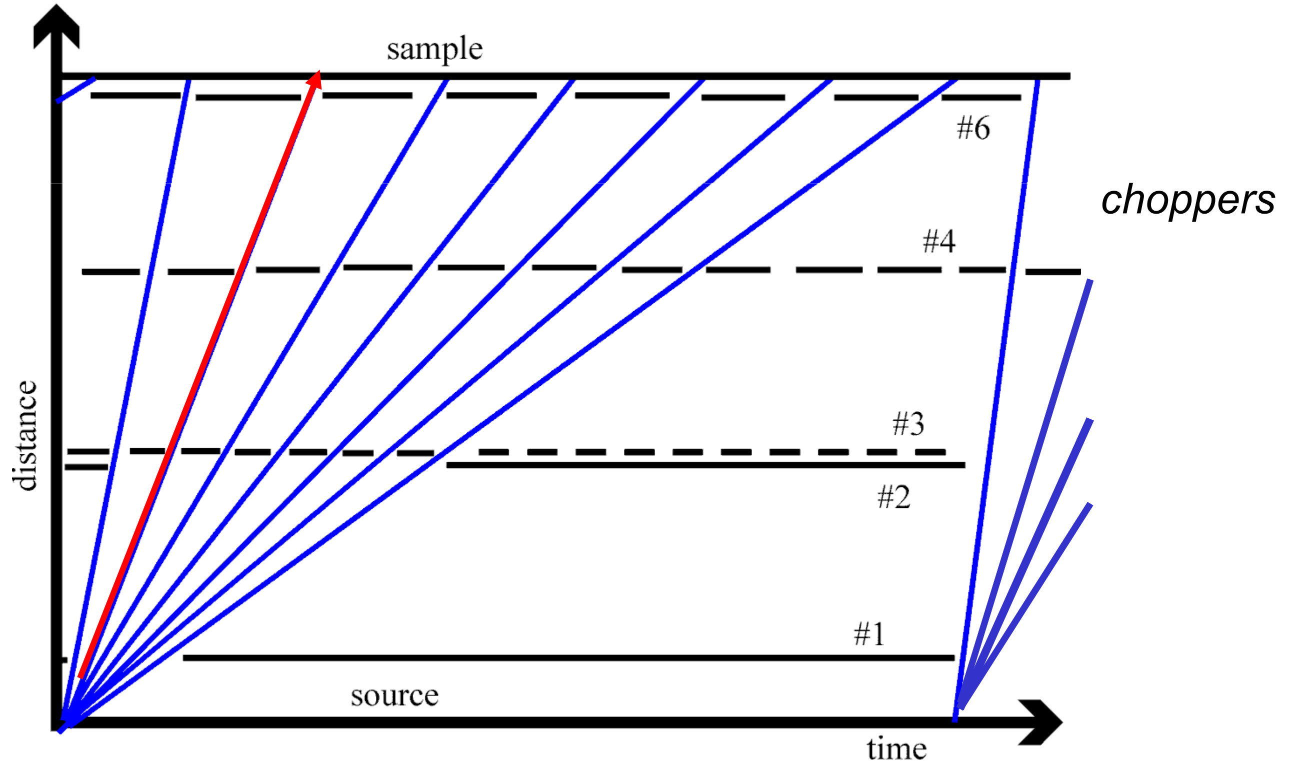
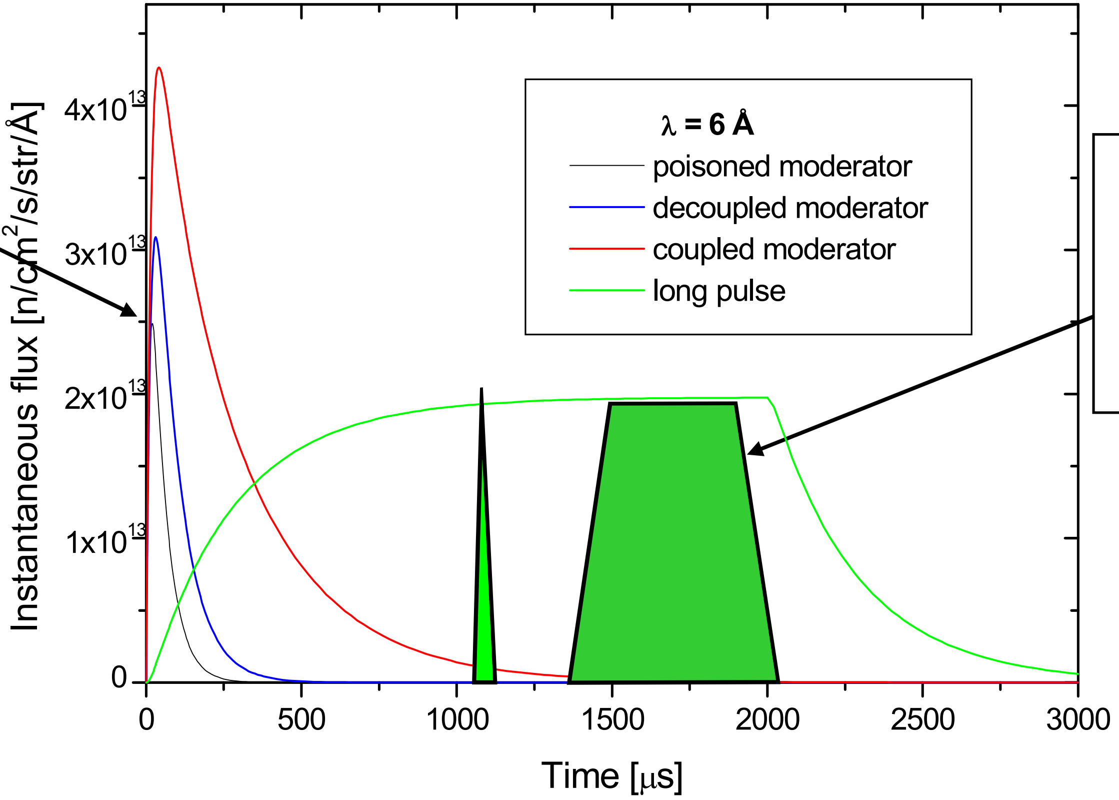
Technical preconditions, enabling technologies:

Advanced neutron guides (low loss at any L for λ>1 Å),
Repetition Rate Multiplication for TOF Spectroscopy: **to allow "reasonable" repetition rates both in diffraction (elastic scattering) and TOF spectroscopy (inelastic scattering) at the same time**



Technical preconditions, enabling technologies:

Advanced neutron guides (low loss at any L for λ>1 Å),
Repetition Rate Multiplication for TOF Spectroscopy
Pulse shaping: to allow to choose the best pulse length for each application

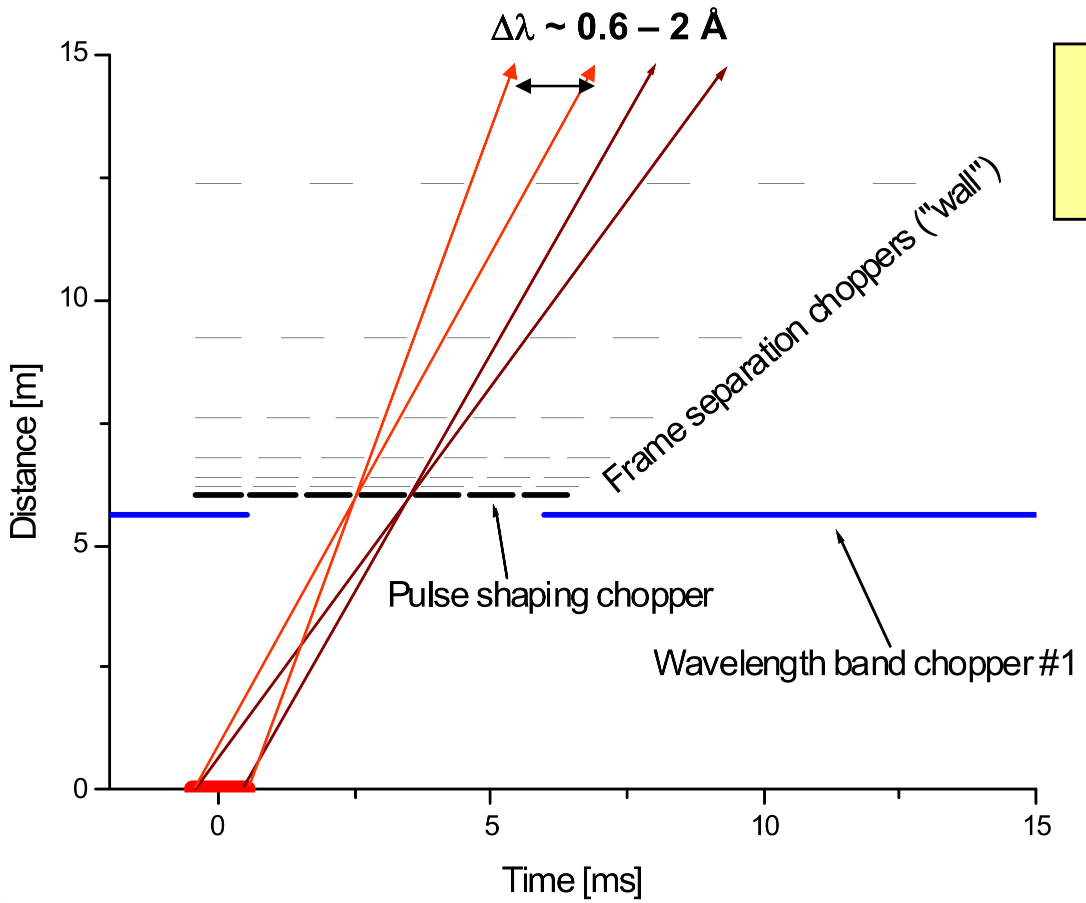


Choice of moderator coupling

Mechanical neutron beam choppers: **for ms pulses**

Pulse shaping technique for diffraction and inverted geometry spectroscopy at long pulse sources

Multiplexing chopper system (with phase slewing to source)



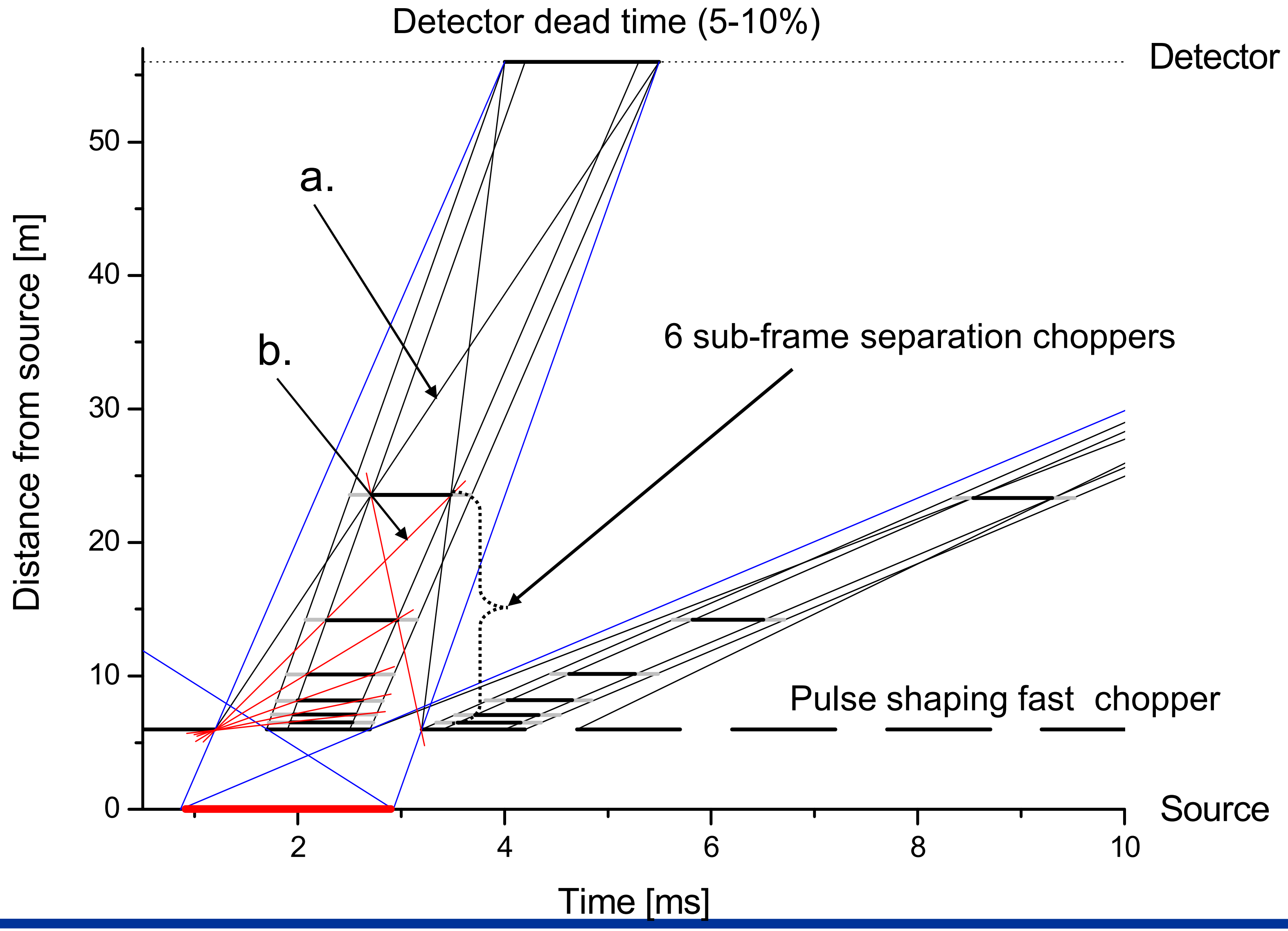
Wavelength Frame Multiplication

One to one relation between time at sample and chopper opening.

Shaped pulse repetition time: ~ source pulse length (0.8 – 2 ms → 500 – 1250 Hz)

F. Mezei, M. Russina (SPIE, 2002)

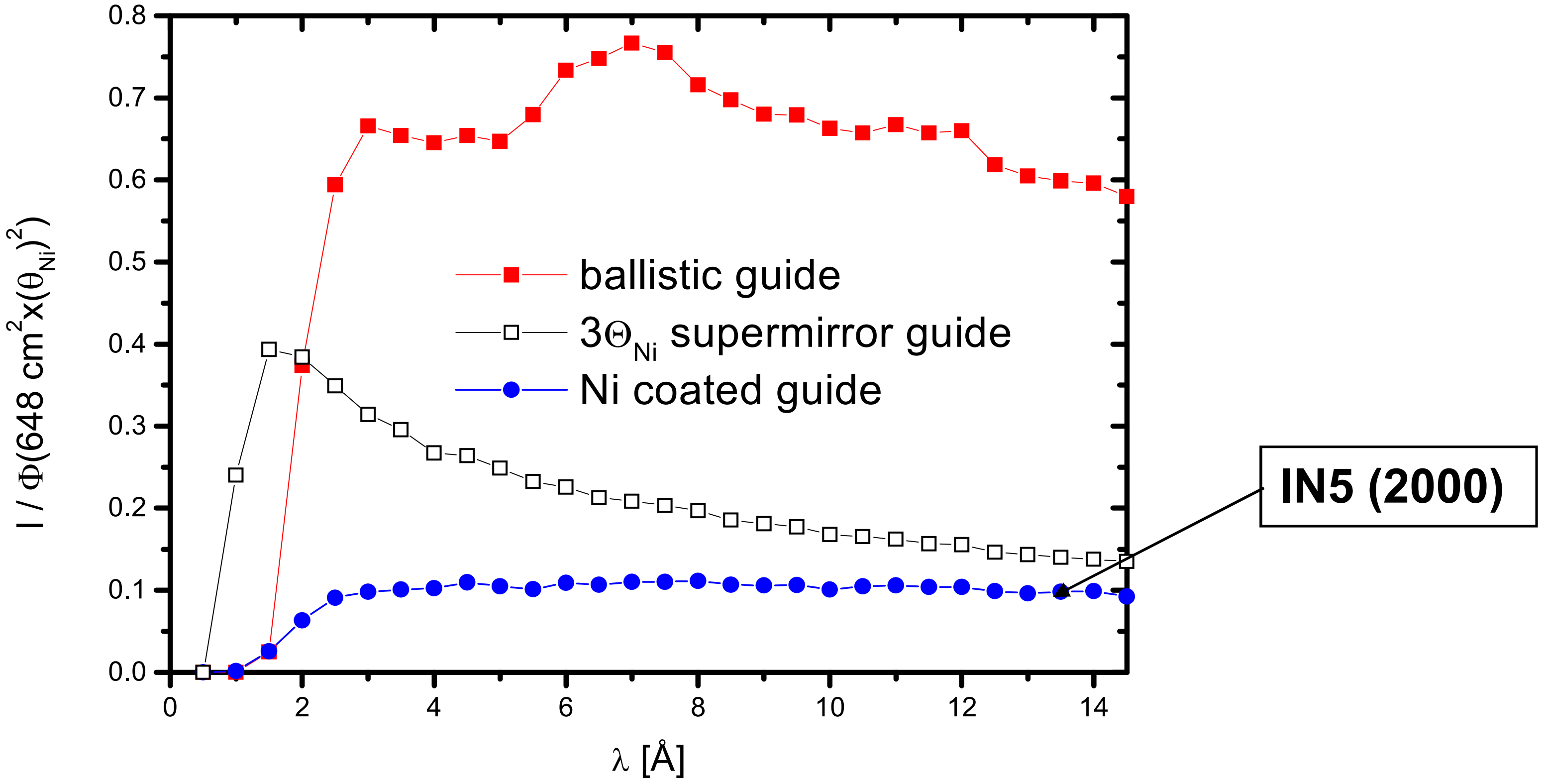
Pulse shaping technique for diffraction and inverted geometry spectroscopy at long pulse sources



First example: DNA – J-PARC (backscattering sptrm.)

Technical preconditions, enabling technologies:

Advanced, supermirror based neutron optical beam delivery, including large distances (~100 m)



Technical preconditions, enabling technologies:

Advanced, supermirror based neutron optical beam delivery

Multi-spectral beam extraction:

(Mezei, Russina, Patent, Berlin, **23.01.2002**)

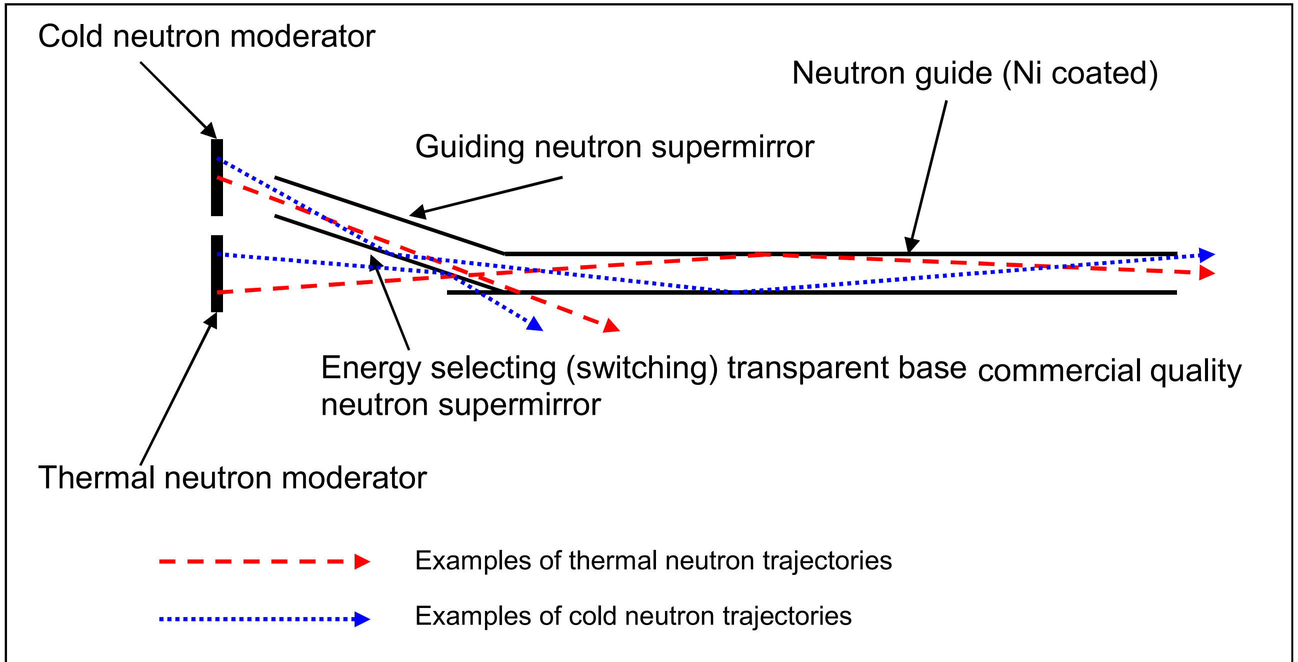


Fig.1. Example of realization of multi-spectral beam extraction

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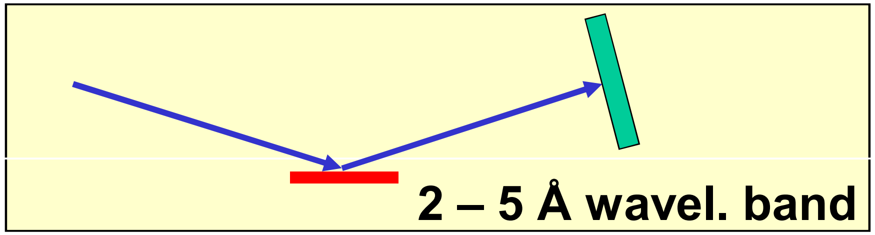
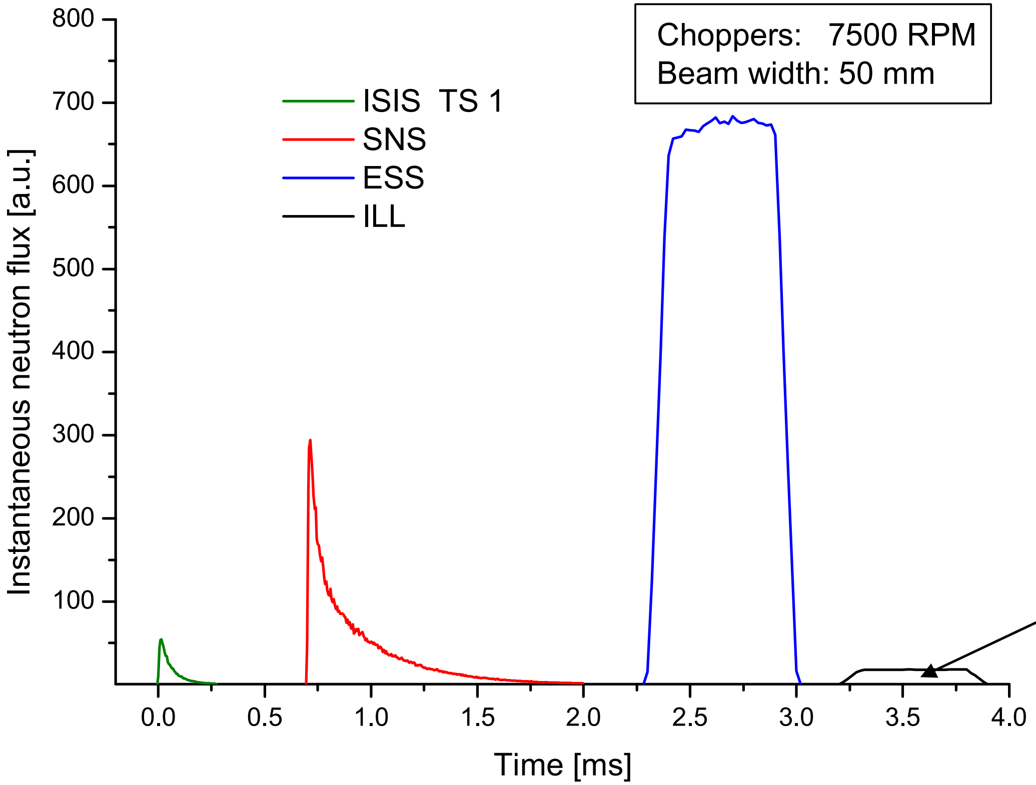
Huge gain in useful neutron intensity: polarization affordable

Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ ~ 5 % at 4 Å





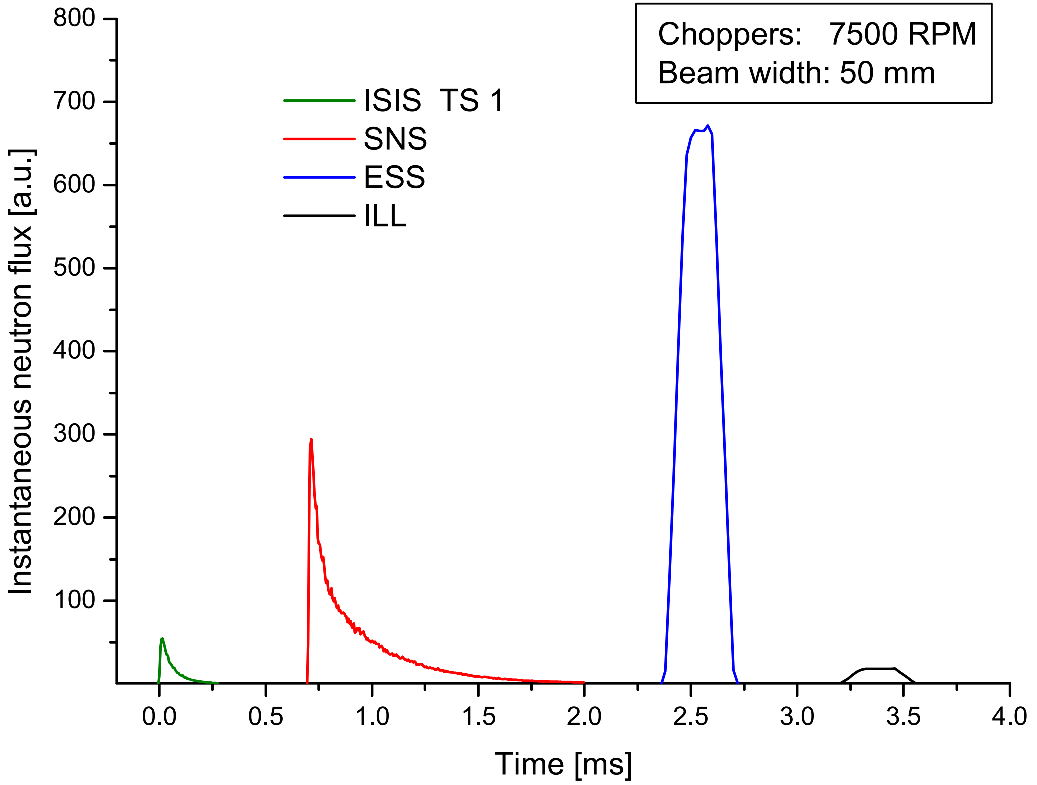
Useful beam intensity: peak / excessive resolution

Steady state sources: approximate equivalence of TOF and monochromator methods amply demonstrated

Huge gain in useful neutron intensity: polarization affordable

Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ **~ 5 % at 4 Å**

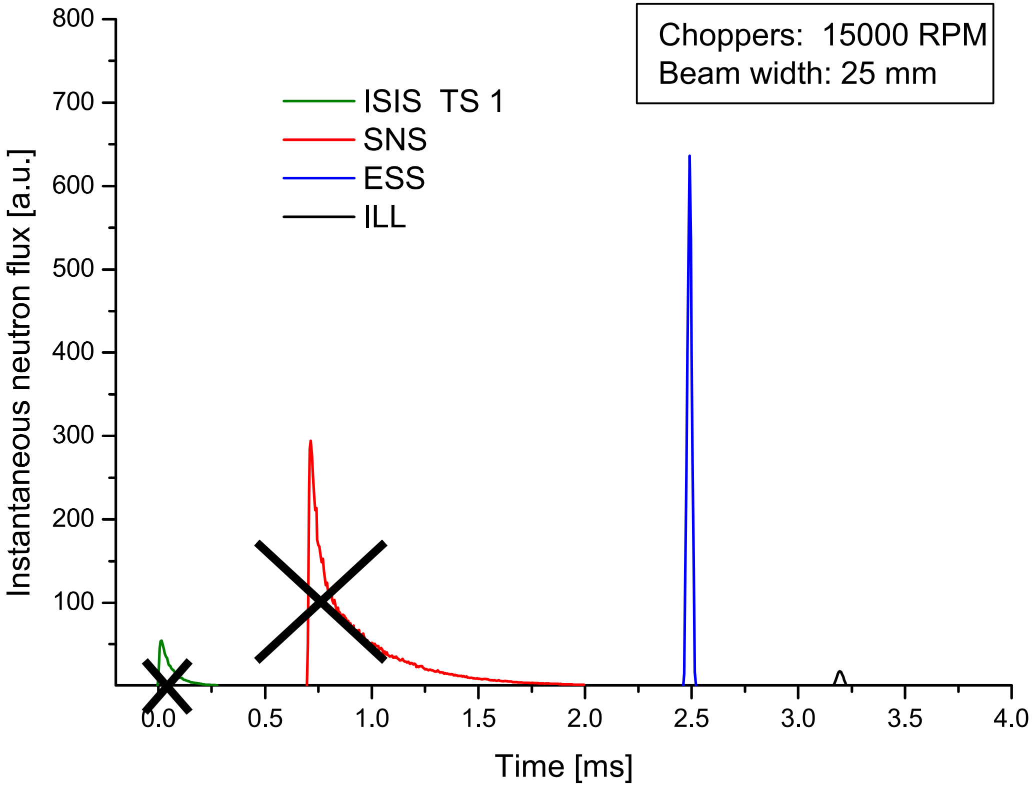


Useful beam intensity: peak / excessive resolution / line shape factor

Huge gain in useful neutron intensity: polarization affordable

Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ ~ 5 % at 4 Å



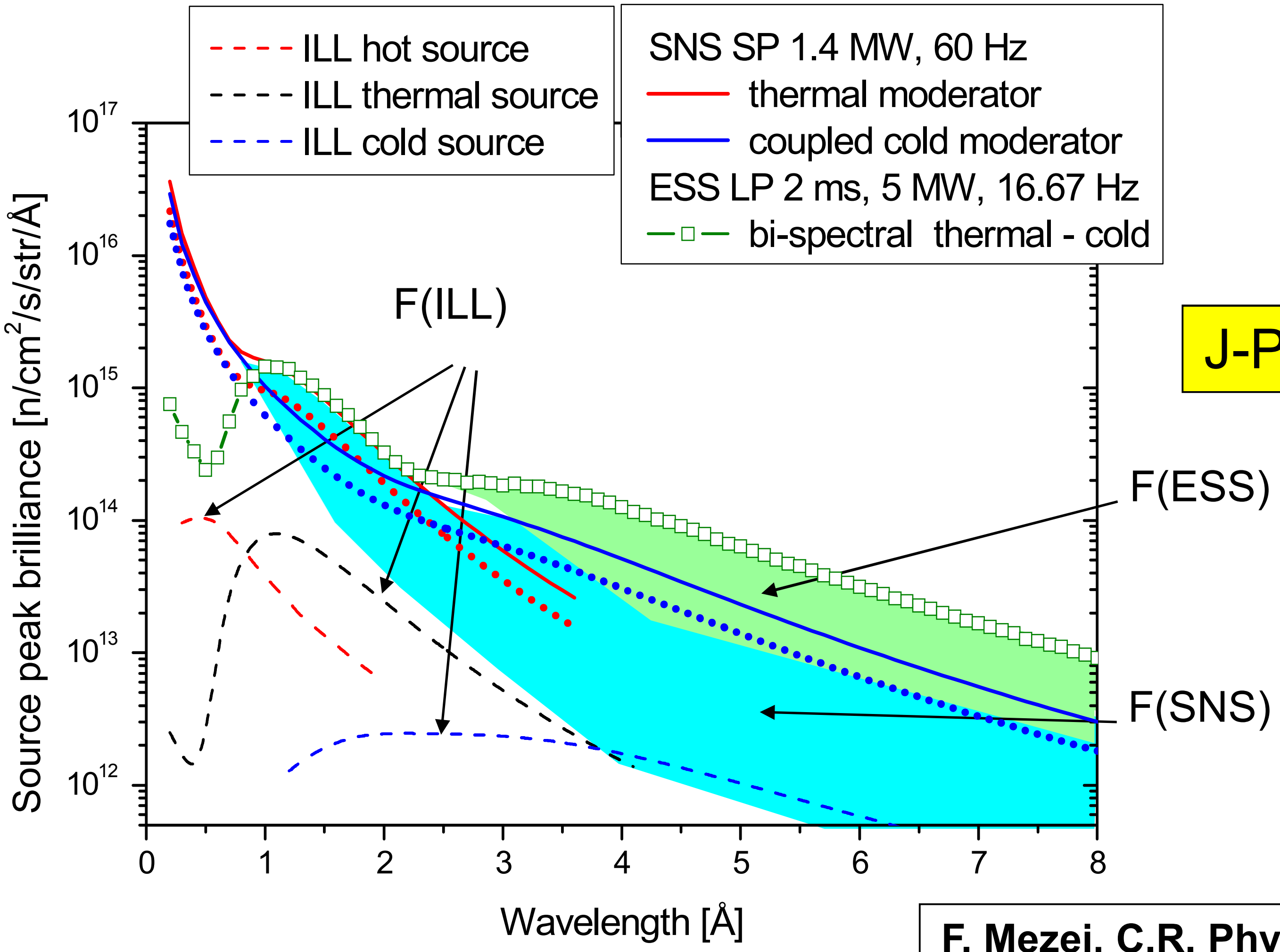
New capability: very high resolution

More efficient option with identical result:

- **-extend pulse length**
- **-extend instr. length**
- **-reduce pulse rate**

→ ESS: 16.67 Hz

Source figure-of-merit (F): peak brilliance, if the well shaped pulses are long enough to avoid excessive resolution

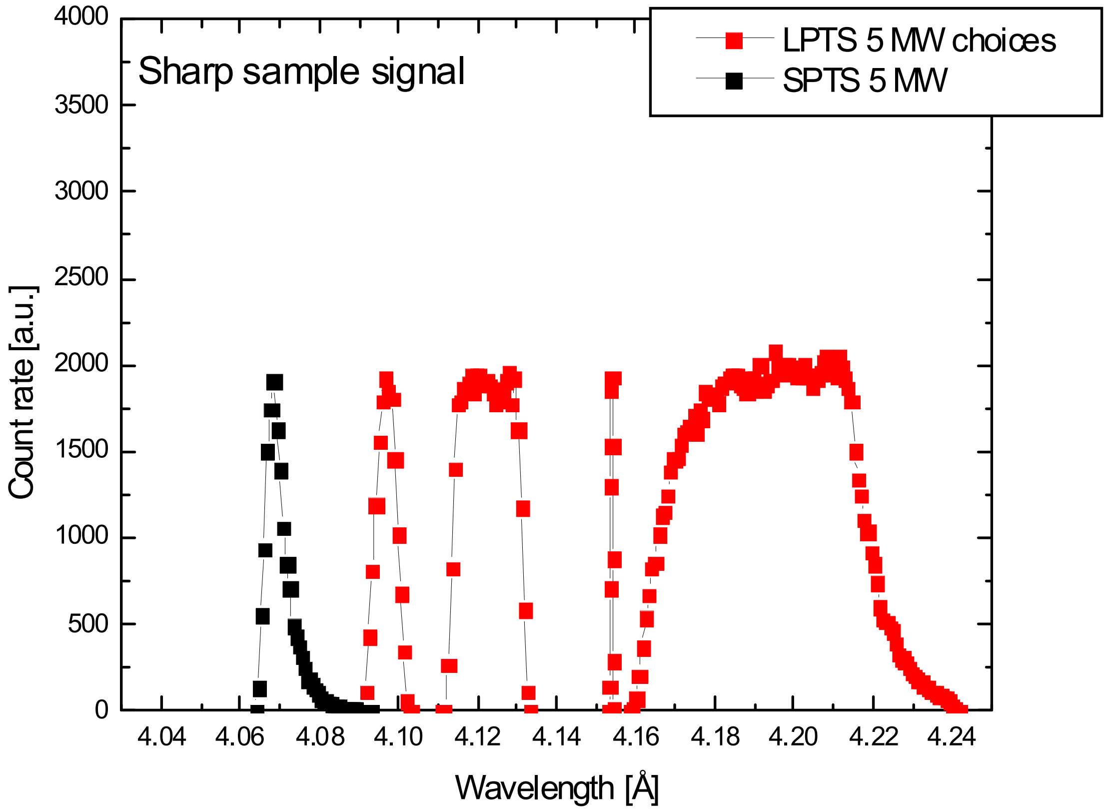


J-PARC ~ SNS

F. Mezei, C.R. Physique 8 (2007) 909
www.sciencedirect.com

New capability for pulse sources: extreme and variable resolution, much better efficiency

E.g. powder diffraction (simulated data)



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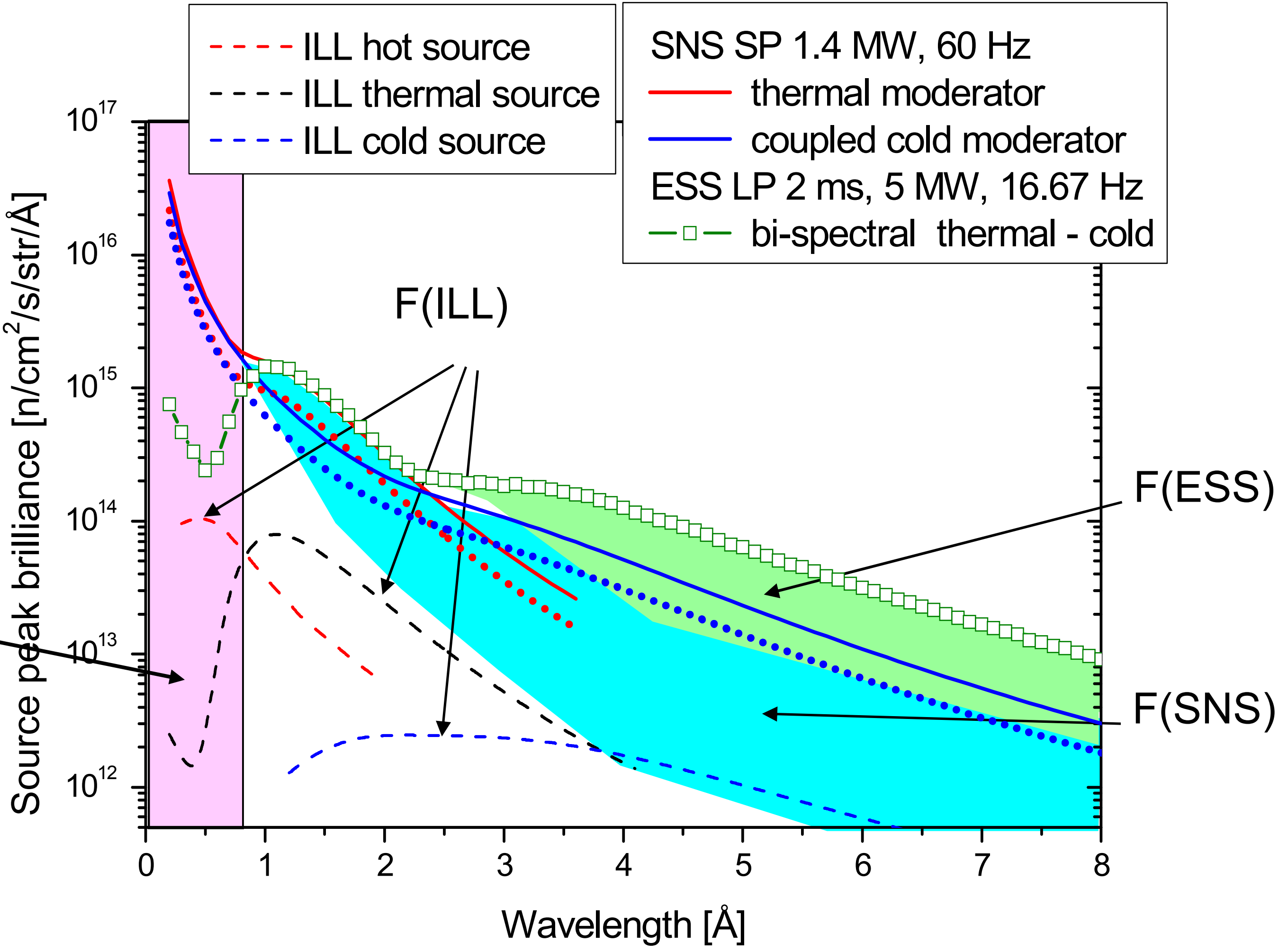
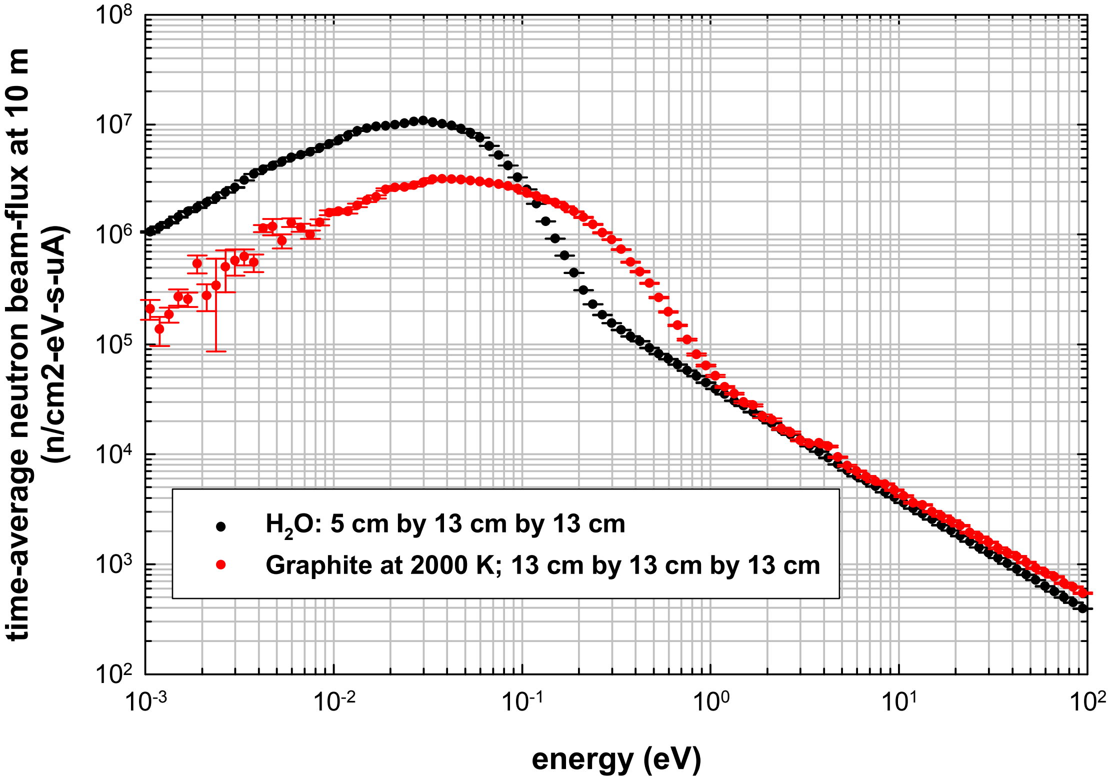
Source figure-of-merit (F): time average flux, if only one point in (Q, ω) space is of interest (e.g. polarization analysis in single crystals, CRYOPAD,…)

Hot neutrons (λ < 0.7 Å): relatively small chapter of neutron research, well served by existing reactors with hot source and SP sources



Hot neutron moderator at multi MW spallation source: time average flux approaches reactors + some fringe benefits from pulsed structure

comparison of fully-coupled flux-trap moderators
H_2O and graphite (2000 K)



Neutronics calculations by G. Russell (cf. poster)

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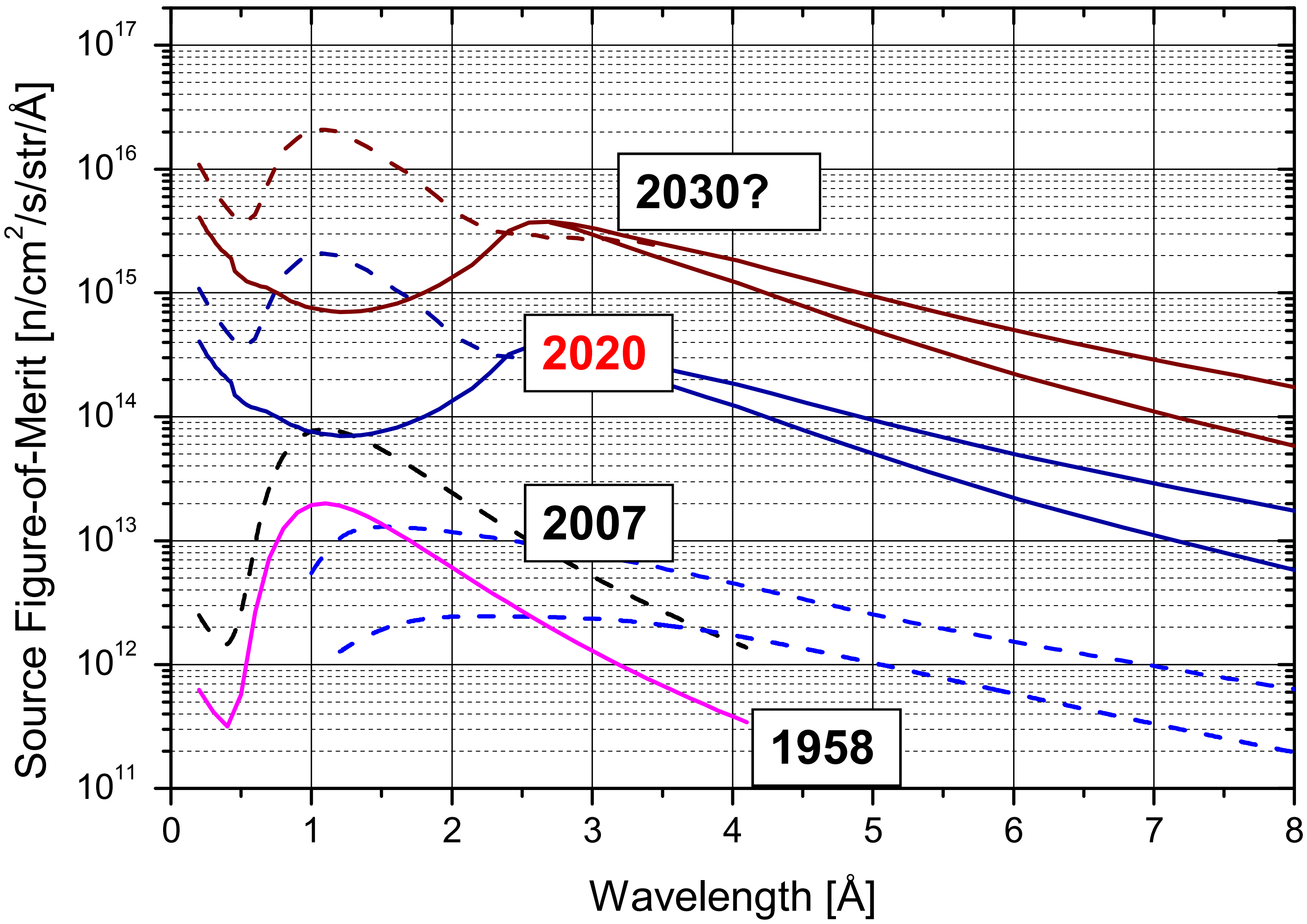
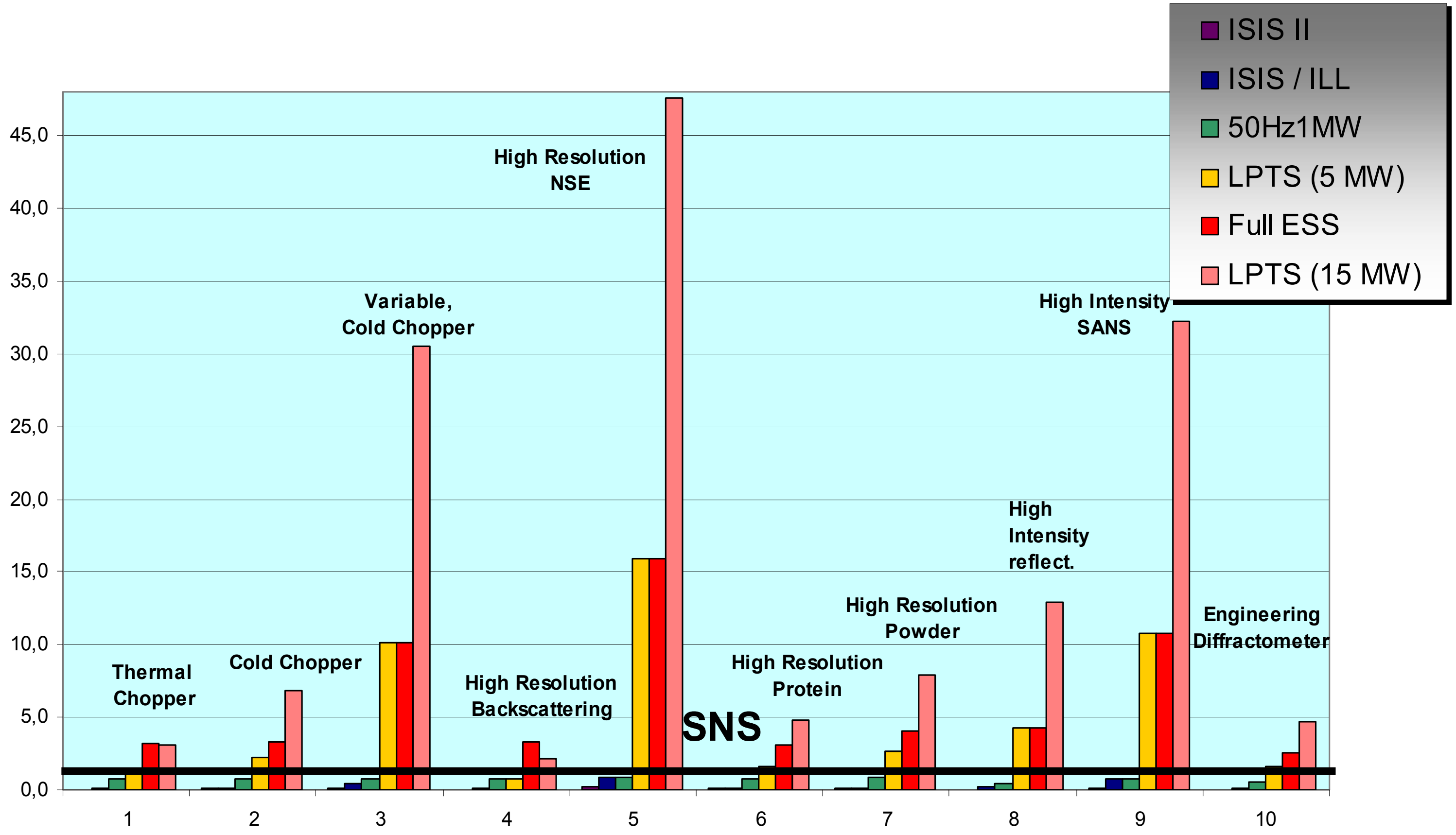
Up to another order of magnitude in the cards



Next generation, optimized spallation sources open up a cost effective way to vastly enhanced research opportunities at.



ESS SAC workshop, 0ct 2002 for ESFRI report