ESS: Neutron Source of the Next Generation

F. Mezei

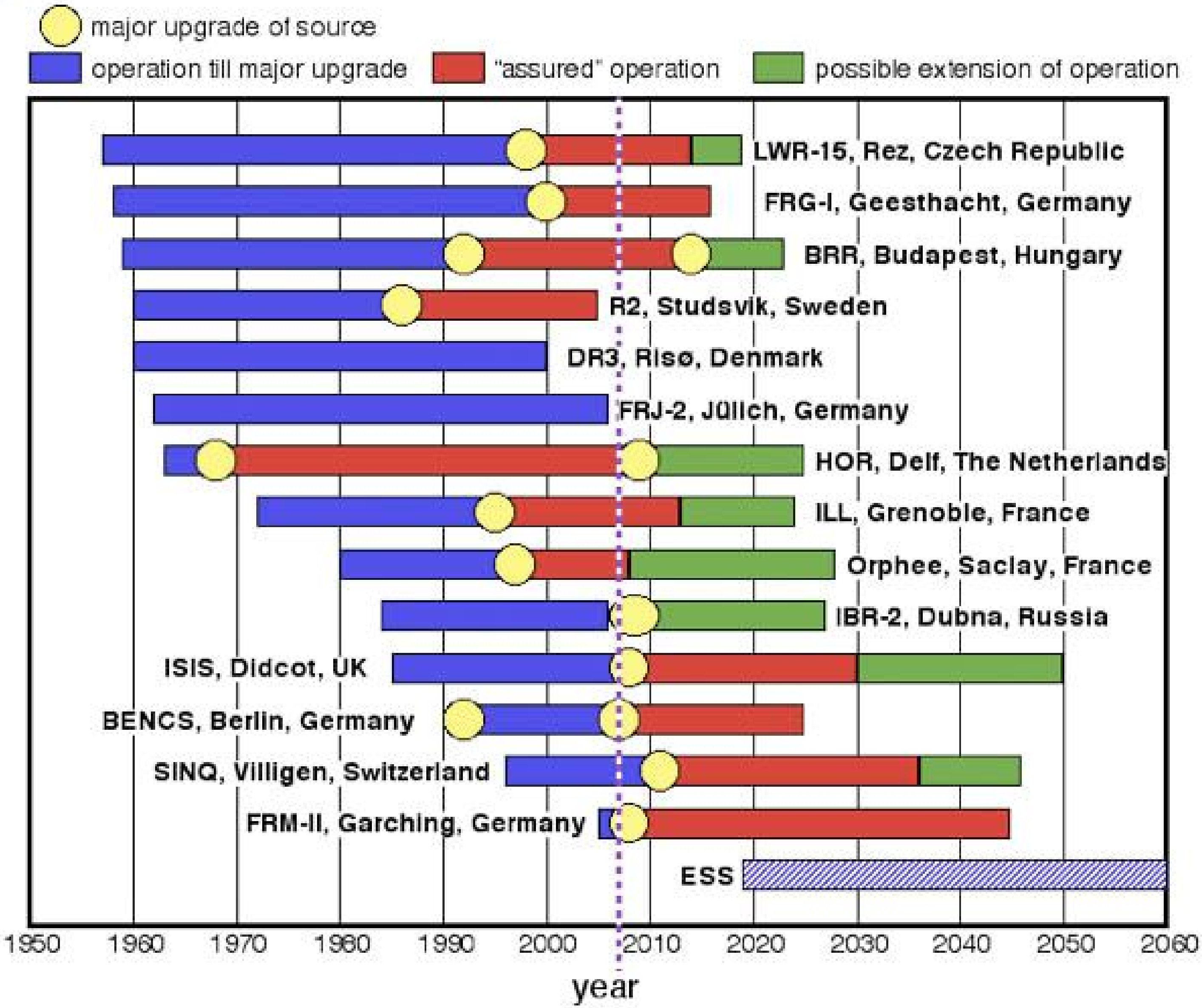
Hungary for ess european spallation source

Development of neutron sources

- Parasitic use of energy research reactors (1949…)
- Dedicated beam reactors (1958,….)
- ILL (1972): limit of power at reasonable costs
- Pulsed sources (1960's, Dubna):
  more efficient use of fewer neutrons produced
- Spallation sources (1970's,…)
  less heat / energy per neutron produced

Neutron research in Europe:

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



- ESFRI 2006 road map:

need for “top tier” neutron source for Europe

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.

info
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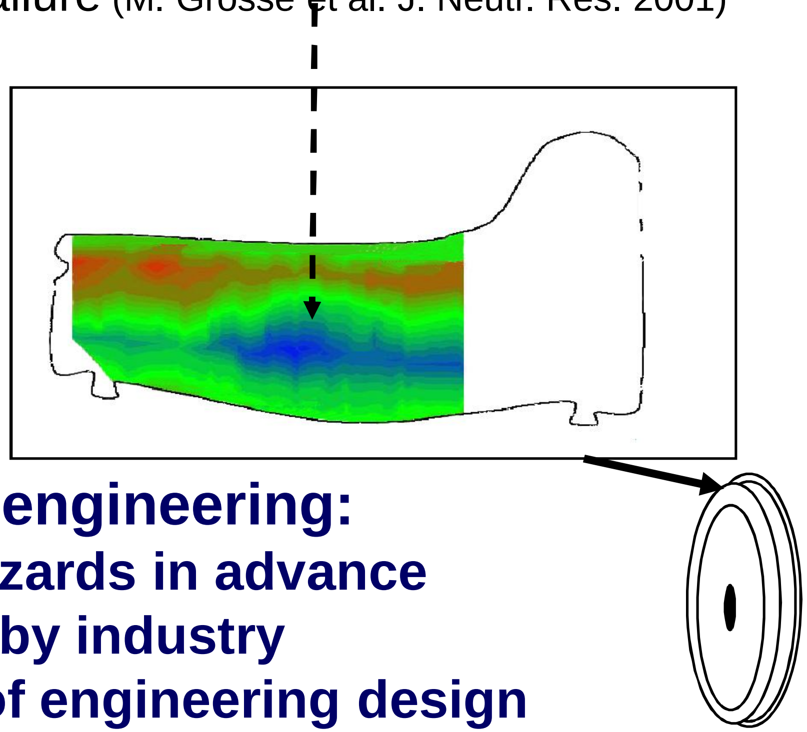
New opportunities in applied research

ICE wheel failure accident

Detect hazardous stress inside bulky parts

E.g. **(tensile) stress** that caused wheel failure (M. Grosse et al. J. Neutr. Res. 2001)



Much faster data collection rates in engineering:

- **more systematic surveys to find hazards in advance**
- **meet rapid response times needed by industry**
- **more experimental benchmarking of engineering design tools *(standard theory and practice on plastic deformation stresses was inadequate end of XXth !)***

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Energy efficiency is key for high intensity neutron beam production: fast neutrons produced / joule energy or heat

Fission reactors:	~ 10^{9}	(in ~ 50 liter volume)
Spallation:	~ 10^{10}	(in ~ 2 liter volume)
Fusion:	~1.5×10^{10}	(in ~ 2 liter volume)

(but neutron slowing down efficiency reduced by ~20 times)

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 the foreseeable future

Pulsed sources provide for more efficient used of the neutrons produced:

by the use of time-of-flight (TOF) methods

Total gain potential in efficiency:

x 6 energy of neutron production

x 10 – 100 by TOF on pulsed sources

⇨ Quantum leap in performance:

5 MW ESS: start with as many neutrons as e.g. ILL: the FIRST CHALLENGE of the NEXT GENERATION

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- MW class pulsed spallation sources (SNS, J-PARC)
  Leap in source performance to surpass ILL:
  fewer neutrons more efficiently produced and used
- SNS & J-PARC: reach limits of traditional pulsed spallation source technology: shock waves in target, space charge in accelerator ring,….

“Short” proton pulses using accelerating (or storage) rings:

- ~ 1 μs pulse length (due to speed of light), huge instantaneous heat deposition (~ 15 GW for 23 kj/pulse of SNS)

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- Proton pulse length poorly matches the 10 – 300 μs neutron moderator response time

- Pulse lengths < 4 ms meets resolution requirements in some key applications (e.g. SANS, NSE)

SNS (Oak Ridge, USA):

successfully achieved 0.5 MW power !! (goal 1.4 MW)

“Long” proton pulses using linear accelerators:

- **Linear accelerators can produce the same beam energy per pulse in ~ 100 μs pulses at much reduced costs**

~ 60 % of accelerator parts and complexity removed

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“Long” proton pulses using linear accelerators:

• Longer - hence more intense - pulses (ms) are advantageous for cold and thermal neutron applications: > 10^{14} n/cm^2/pulse (compared to < 10^{13} for SNS) at instantaneous power of ~ 90 MW

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“Long” proton pulses using linear accelerators:

- **Longer - hence more intense - pulses (ms) are advantageous for cold and thermal neutron applications: > 10^{14} n/cm^2/pulse (compared to < 10^{13} for SNS) at instantaneous power of ~ 90 MW**

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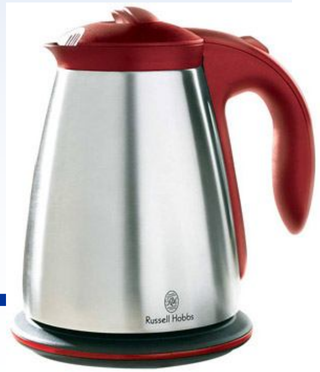
- **Total energy per pulse of a few hundred kJ is household experience (ESS: 300 kJ/pulse)**



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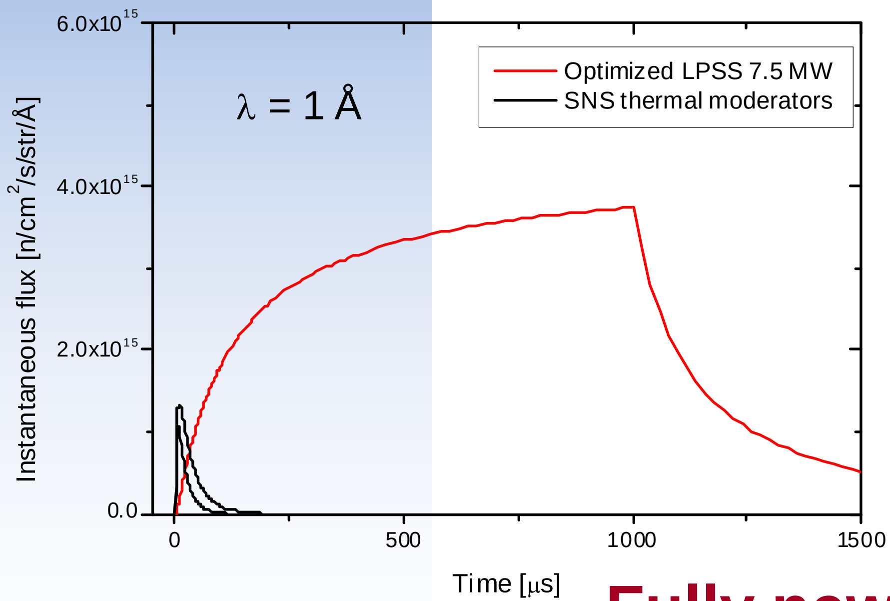
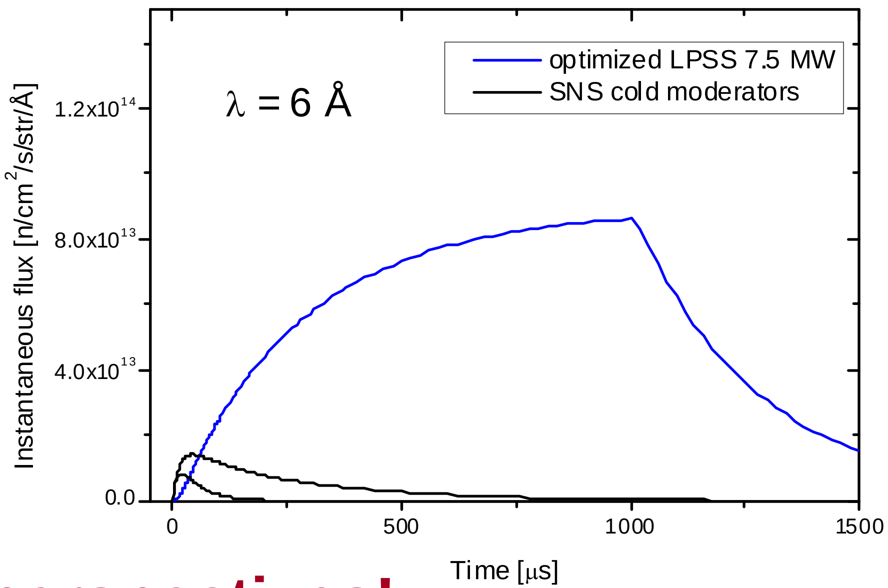
LP target operation: to 98 % in thermohydraulic equilibrium *(vs. 100 % non-equilibrium for short pulses)*

“Long” proton pulses using linear accelerators:

- **Longer - hence more intense - 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)



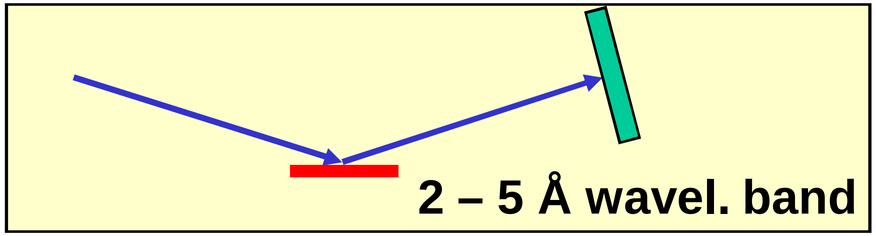


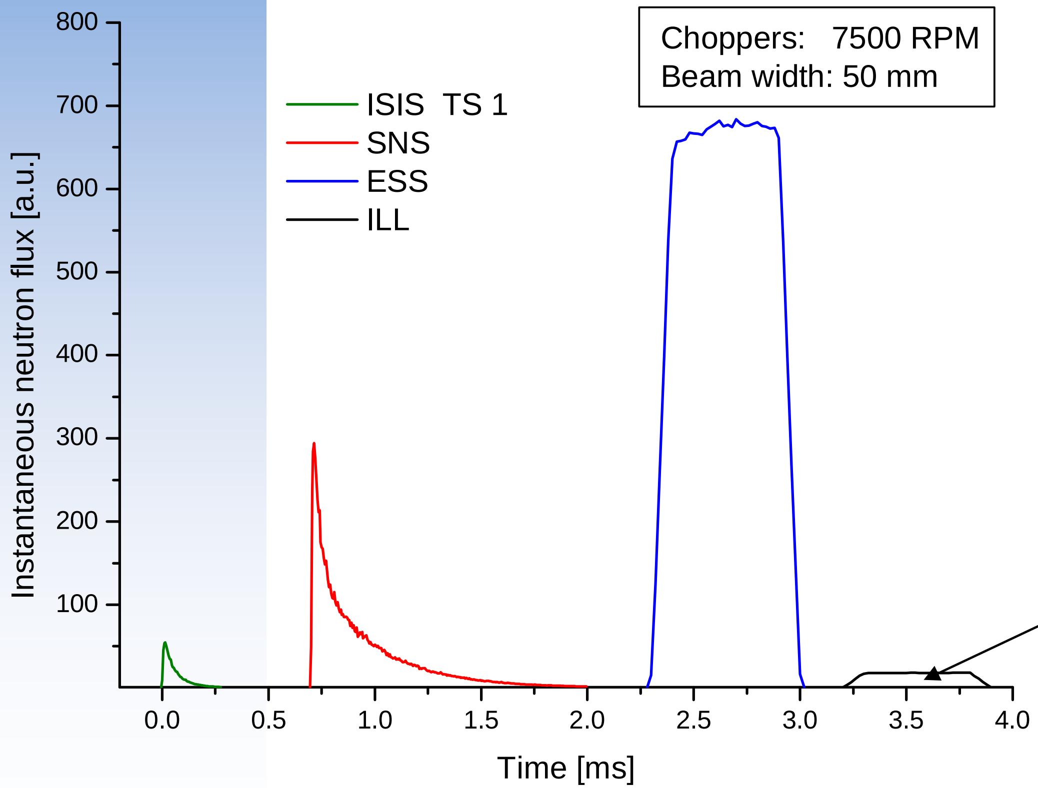
Fully new perspectives!

Huge gain in useful neutron intensity

Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ ~ 5 % at 4 Å



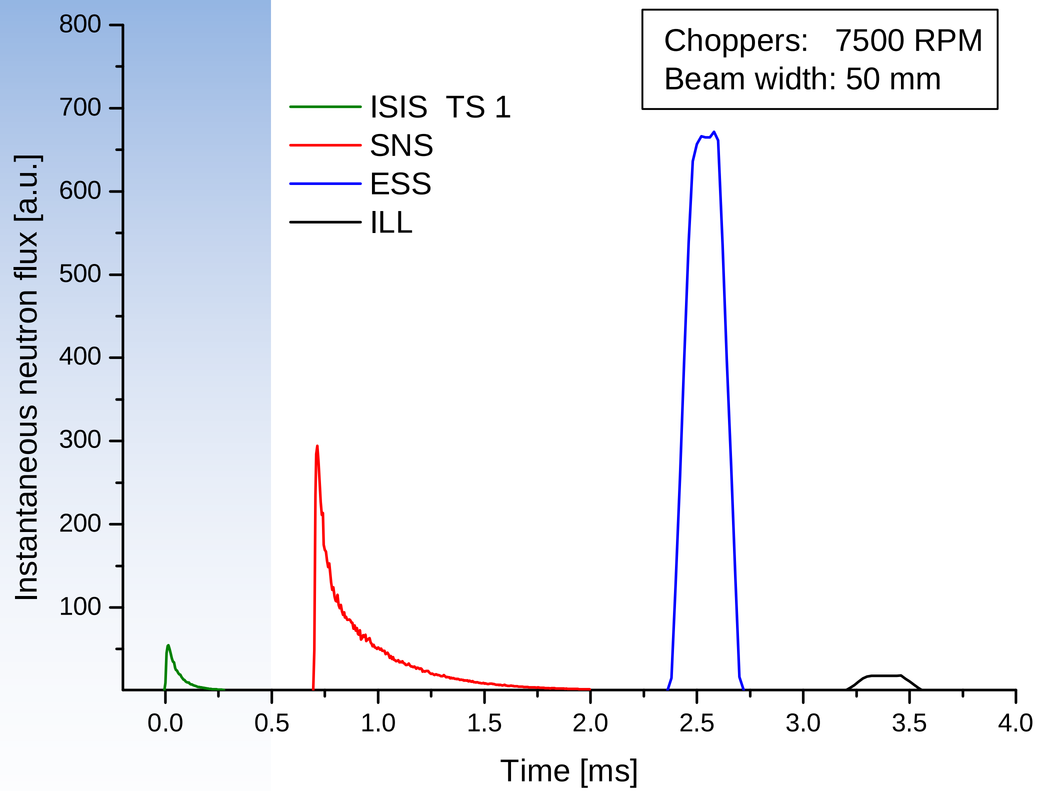


Useful beam intensity: peak / excessive resolution

Steady state sources: approximate equivalen-ce of TOF and mono-chromator methods amply demonstrated

Huge gain in useful neutron intensity
Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ ~ 2 % at 4 Å

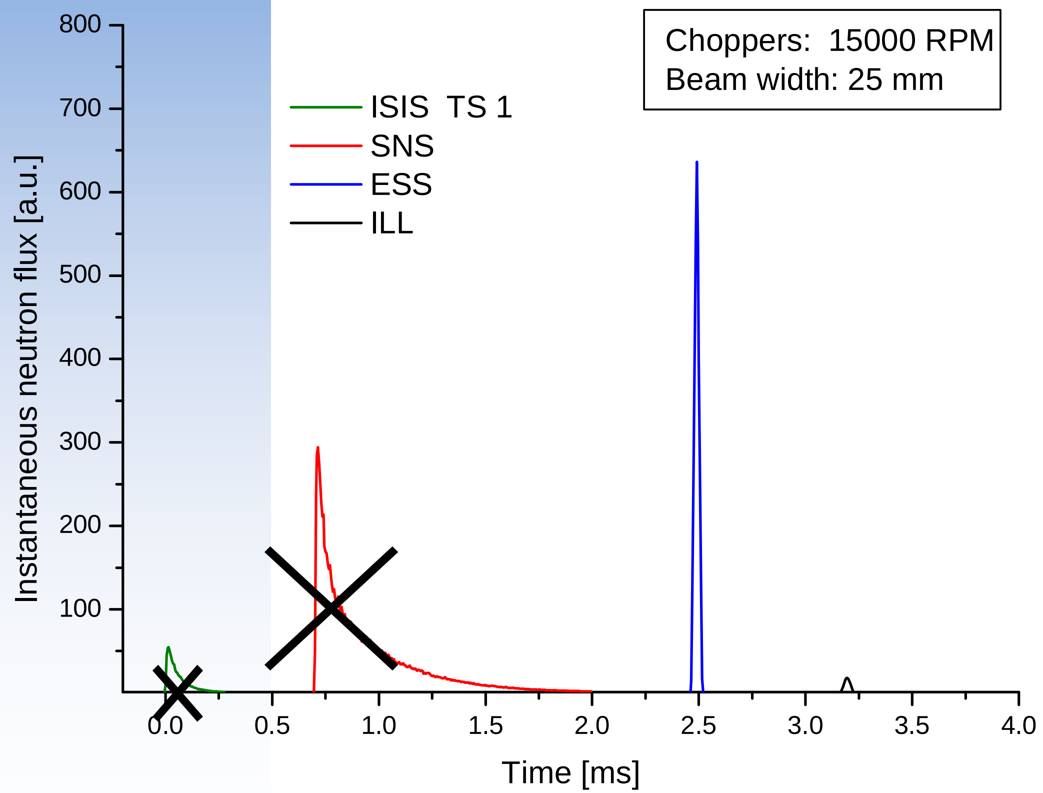


Useful beam intensity: peak / excessive resolution / line shape factor

Huge gain in useful neutron intensity

Example: reflectometer (~15 m)

$\delta\lambda/\lambda$ ~ 0.25 % at 4 Å



New capability: very high resolution

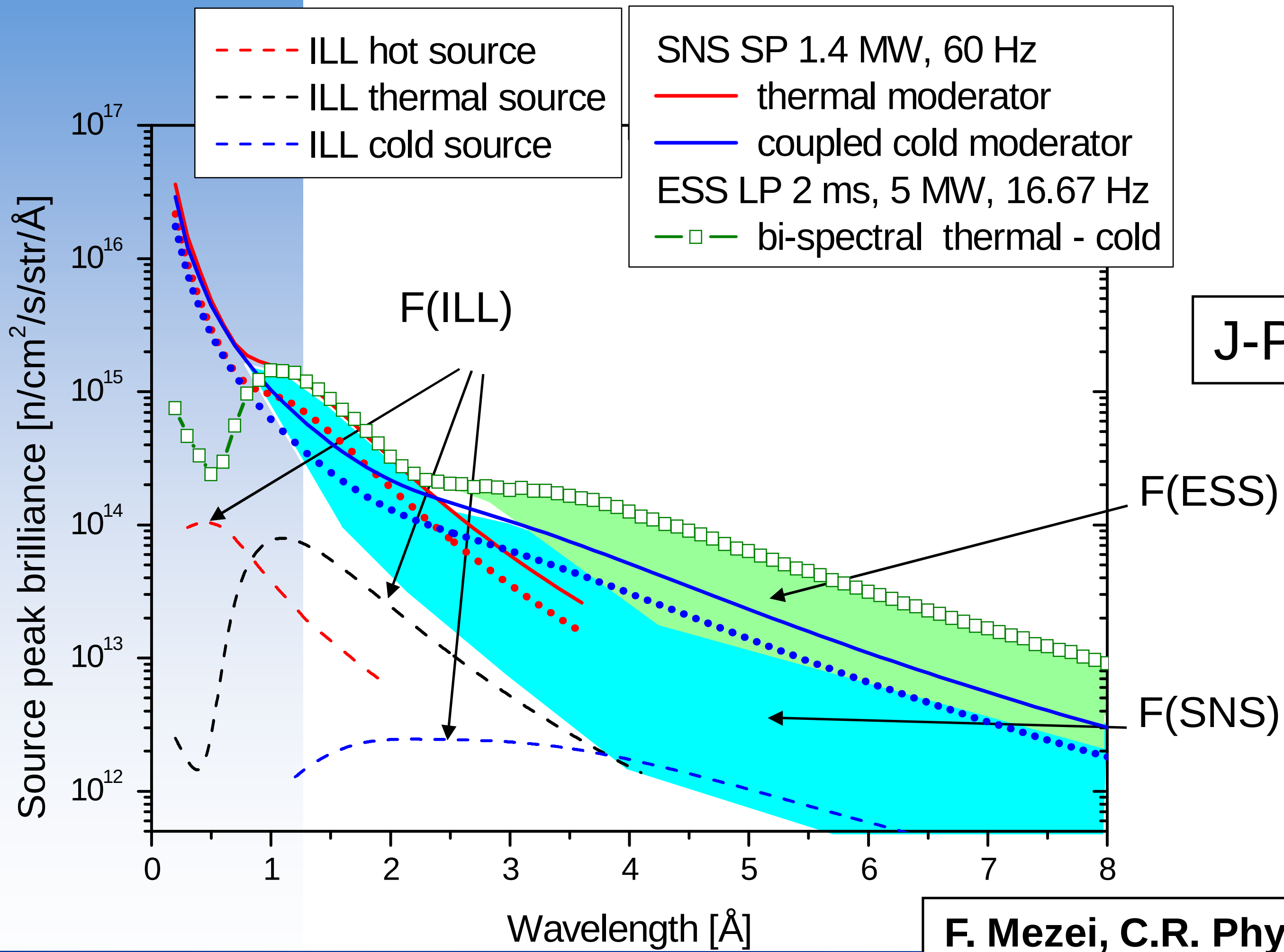
<u>More efficient option with identical result:</u>

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

→ ESS: 16.67 Hz

Source figure-of-merit (F):

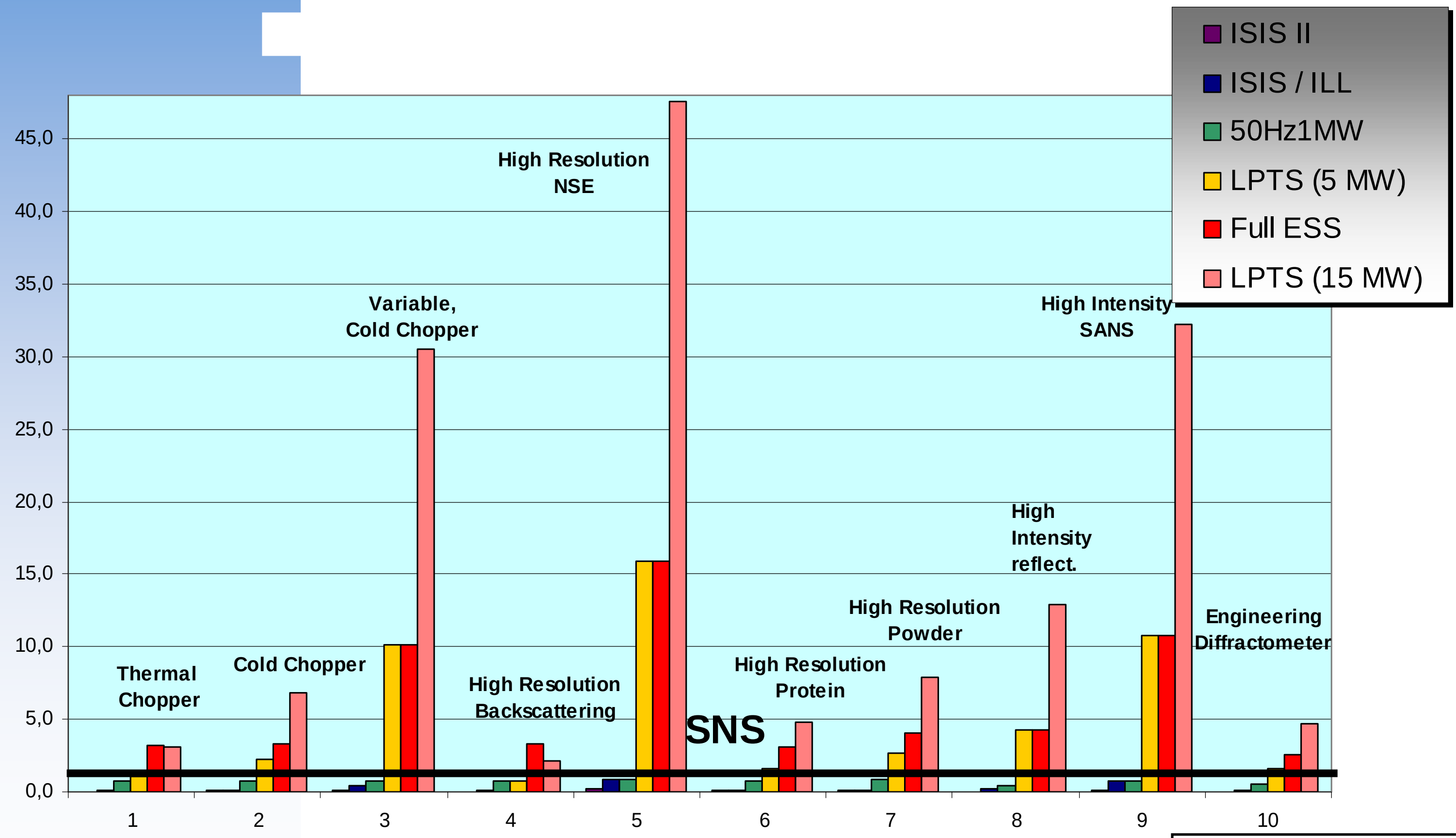
peak brilliance, if the well shaped pulses are long enough to avoid excessive resolution



J-PARC ~ SNS

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

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



ESS SAC workshop, 0ct 2002 for ESFRI report

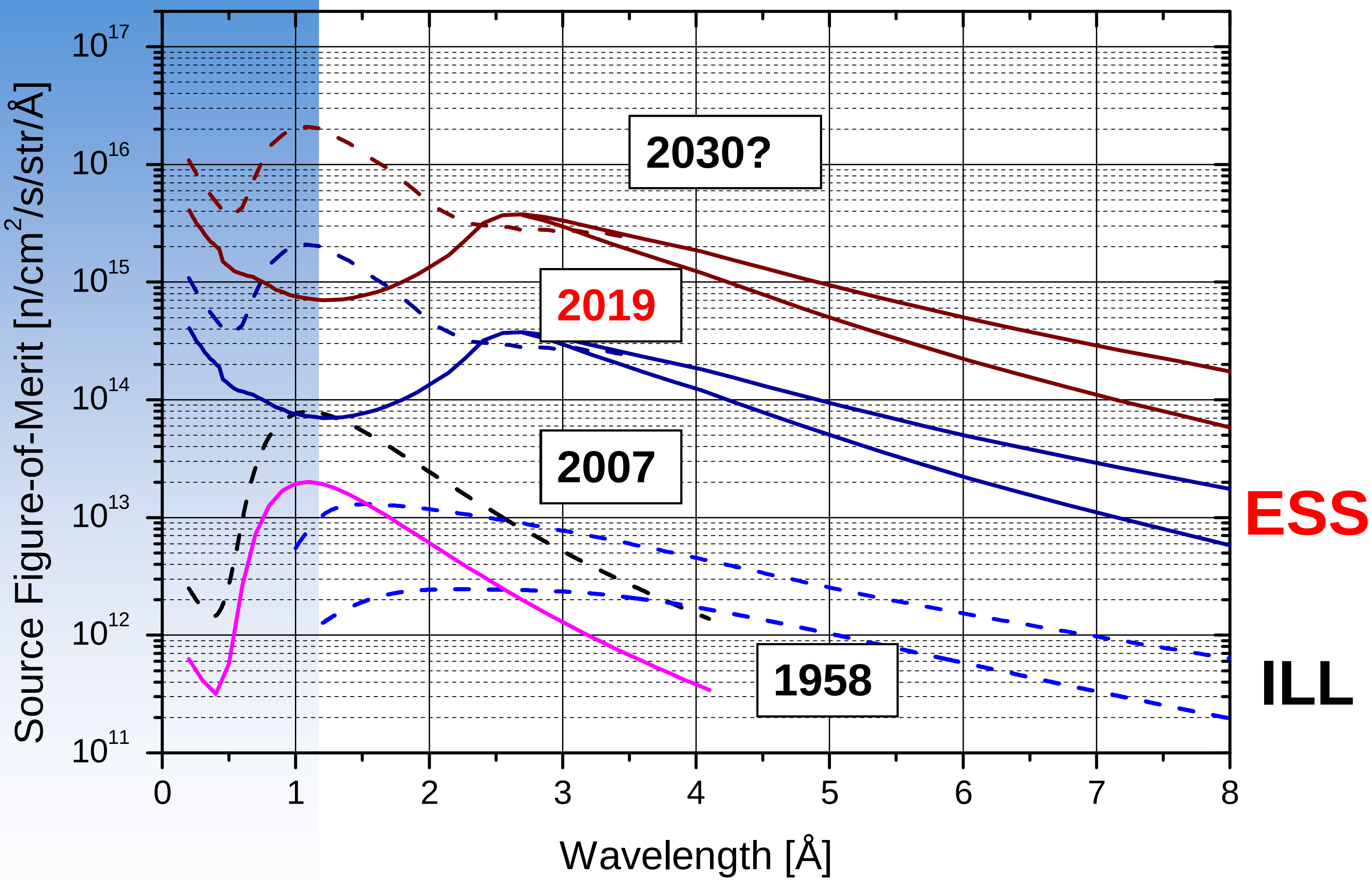
Innovative use of conservative, established technologies, reduced complexity

⇨ leap in performance at very favorable costs

ESS (5 MW LP):

- **Construction costs comparable to SNS and J-PARC**
- **Operational costs comparable to ILL (36 MW vs. 70 MW!)**
- **Many beam lines possible with long guides (similar to continuous sources)**
- **High power consumption efficiency of linear accelerators**
- **No alternative technology in sight to be available within decades**
- **A new approach with large long term development potentials and perspectives: 30 MW? 100 MW?**

New perspectives in neutron science



ESS:

will also be a magnet for new science in its region (e.g. nanoscience centres at Oak Ridge, Grenoble, etc...)

The Hungarian story:

In 2003 after the last ESS Council meeting: Why not to propose to locate ESS in one of the new accession countries? Then, F. Mezei and L. Rosta – proposed for the government to investigate the feasibility of ESS in Hungary

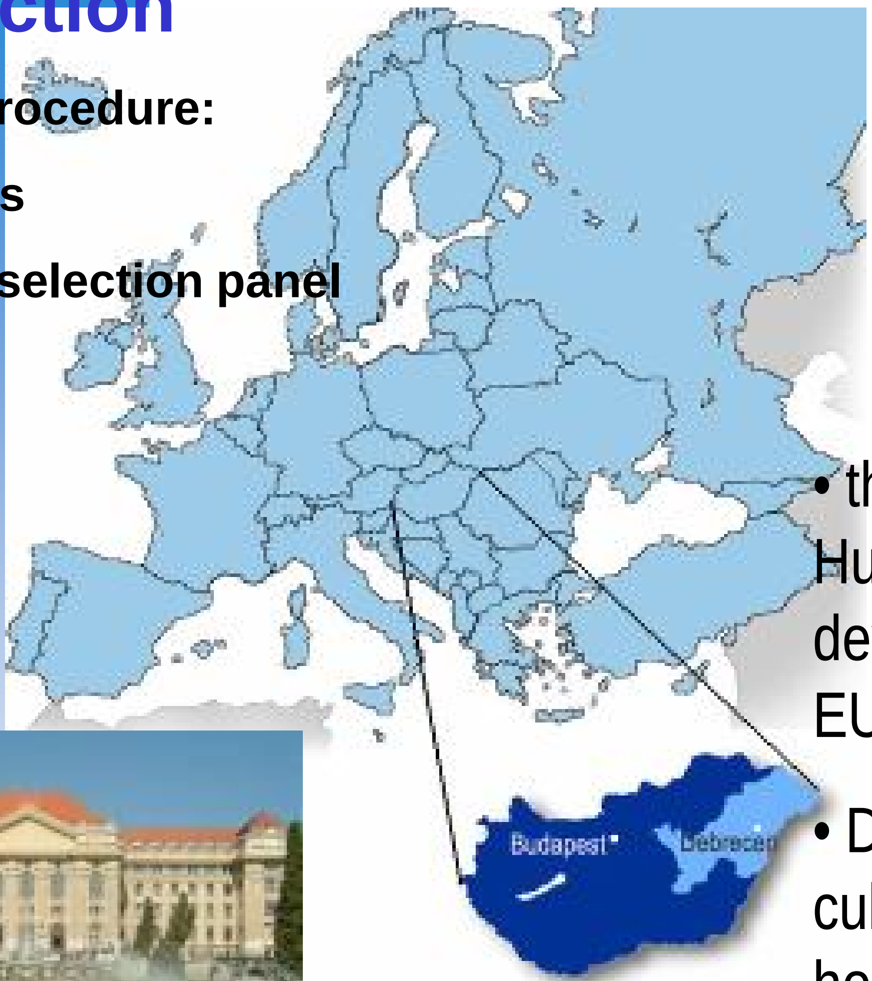
- **2004-06 Detailed socio-economic studies**
- **2006-07 Building up the project, fund raising, site selection**
- **April 2007: Government decision on R&D strategy (hosting ESS)**
- **December 2007: Final approval of the government for the ESS-Hungary project, decision on the site**
- **January 2008: The „Hungary for ESS" project was presented in Bussels (joint meeting together with the collaboration partner Spain, 21 countries represented)**
- **June 2008: Workshop to build up the regional ESS collaboration with delegates from Czech Republic, Romania, Austria, Poland…**
- **Bilateral contacts with several potential partners (CH, DE, FR, IT, NL, RU) and research centres (ILL, SNS, J-PARK, CEA Saclay)**

Site selection

Two phase procedure:

6/2 candidates

International selection panel

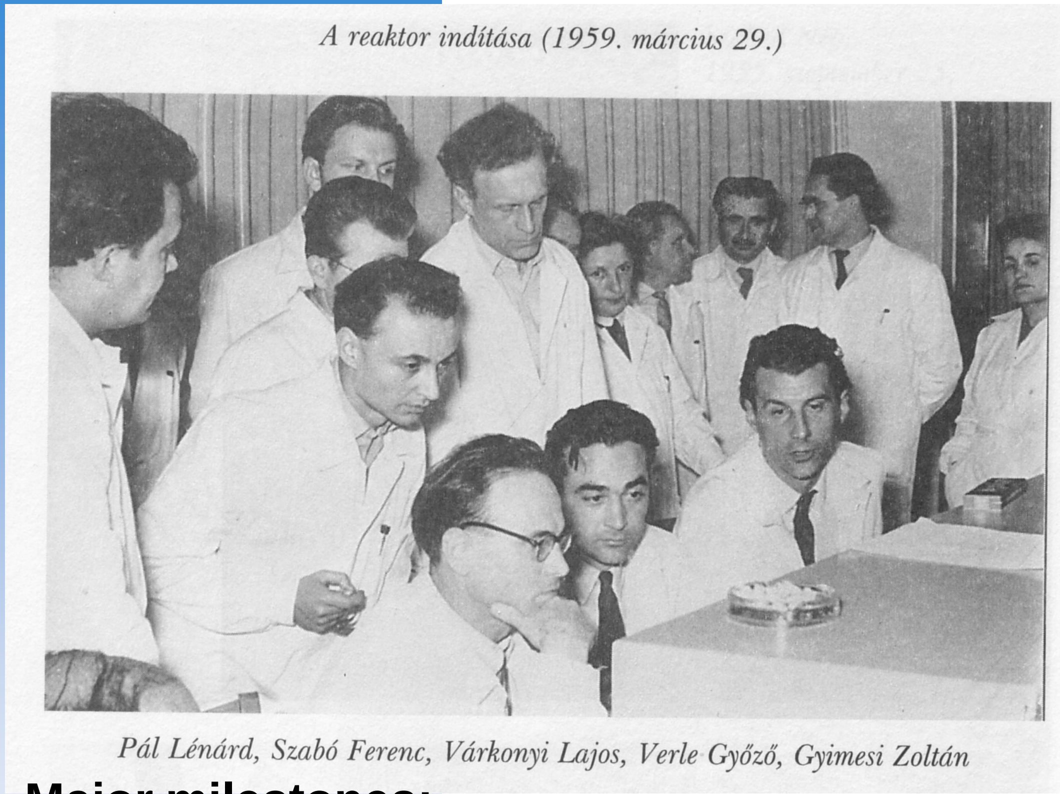


CITY OF **DEBRECEN**

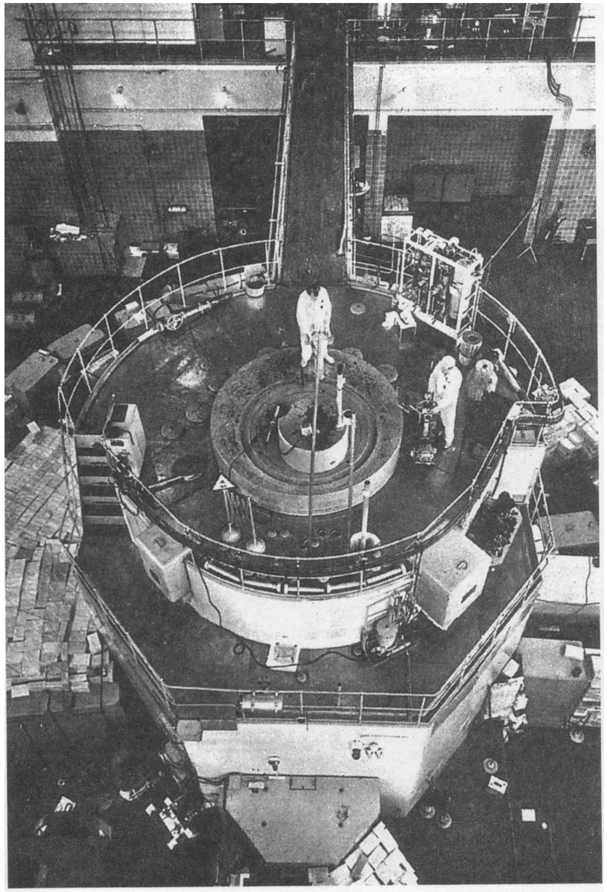
- the second largest city in Hungary in a region dynamically developing, main beneficiary of EU stuctural funds.

- Debrecen: Scientific centre,rich cultural life and a wealth of hospitality

Neutron Research Background in Hungary



Neutron research was established in Hungary with starting the reactor in 1959

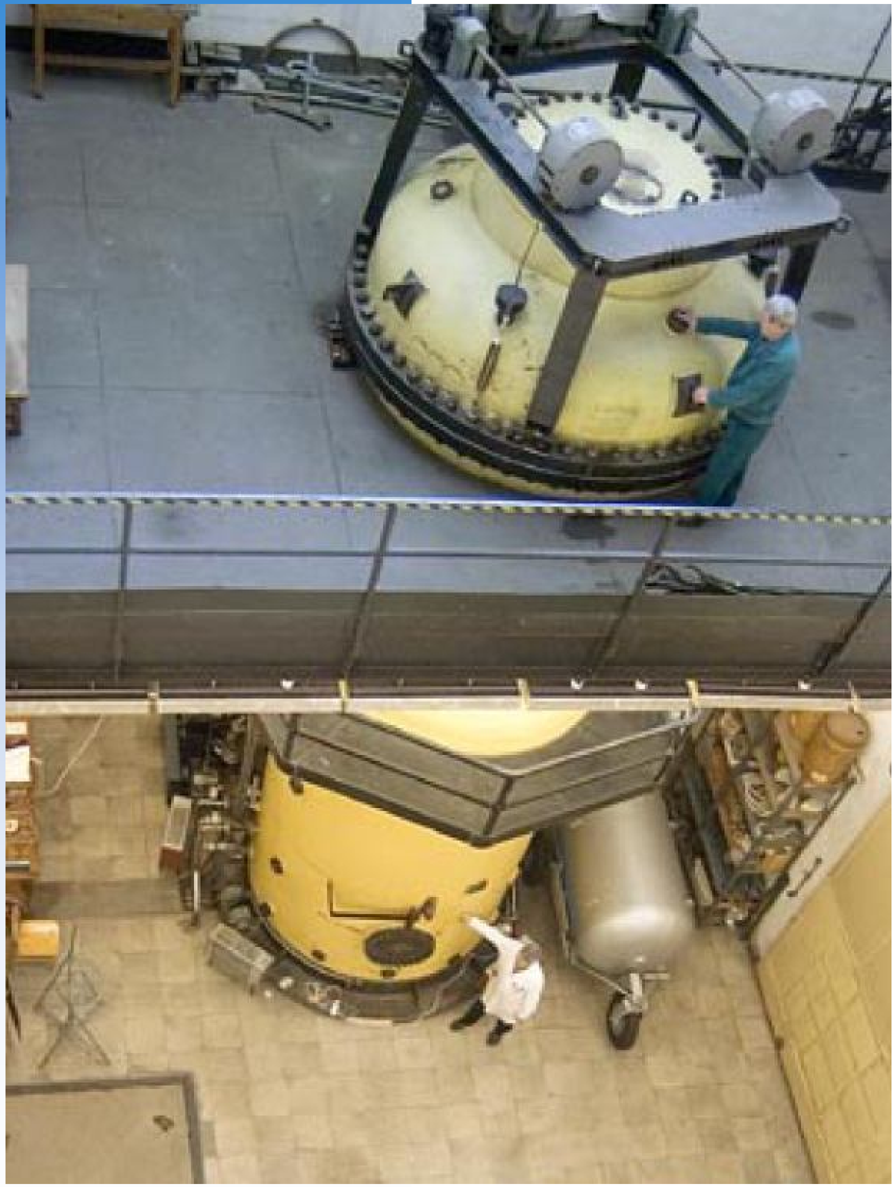


Major milestones:

Start: 1959, 2.5 MW
Upgrad: 1967, 5 MW
Full scale refurbishment: 1986-90
Recommissioning: 1992, 10 MW
Cold neutron source: 2000-01
Second operating cycle: 2004-14

Transition to 20% fuel, modernisation 2008-11

Panoramic view of the reactor hall 2007



Hungary for ess european spallation source

Nuclear research in Debrecen

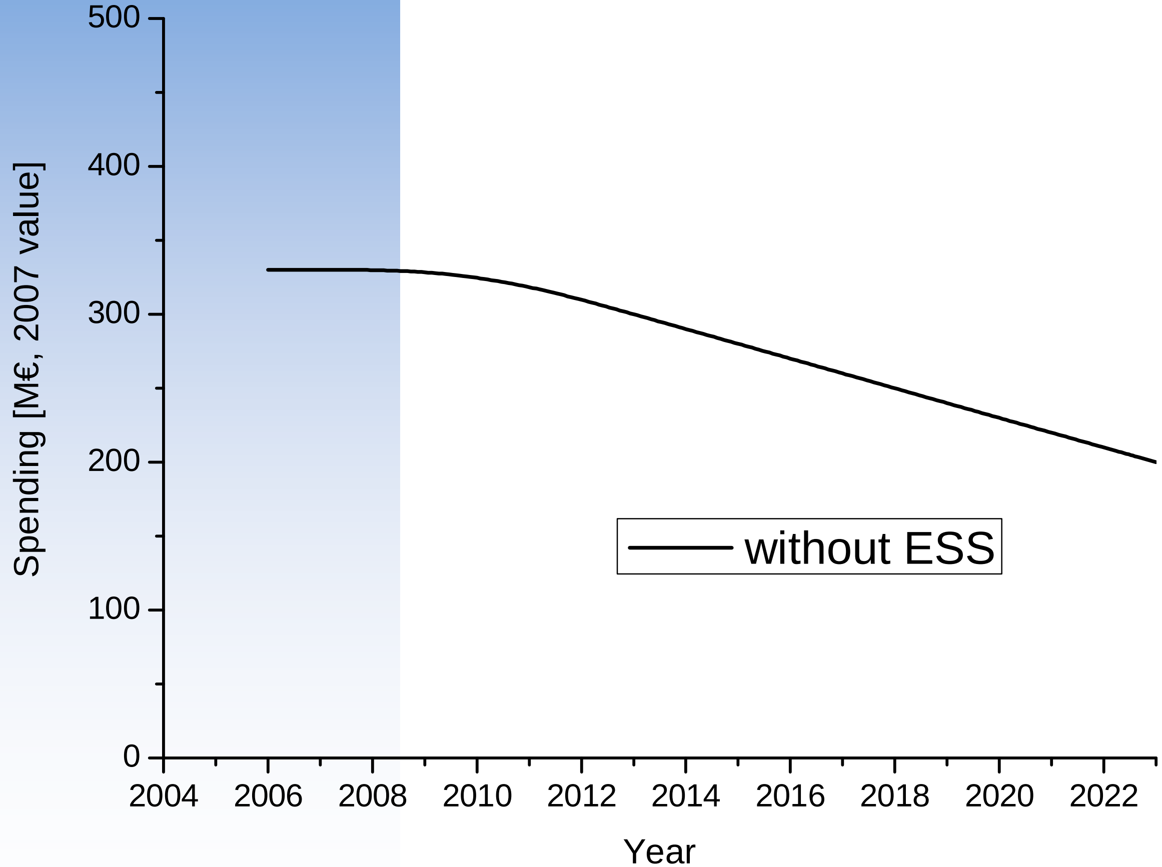
Science and techology of accelerators at ATOMKI (HAS):

- Two Van de Graaff accelerators.

- The cyclotron shown in the picture below is a major accelerator facility in Hungary

Business case for ESS Hungary

Expected European yearly spending profile:
2007: 14 facilities (2 under decommissioning)
2023: probably 8 facilities (3 under decommissioning)



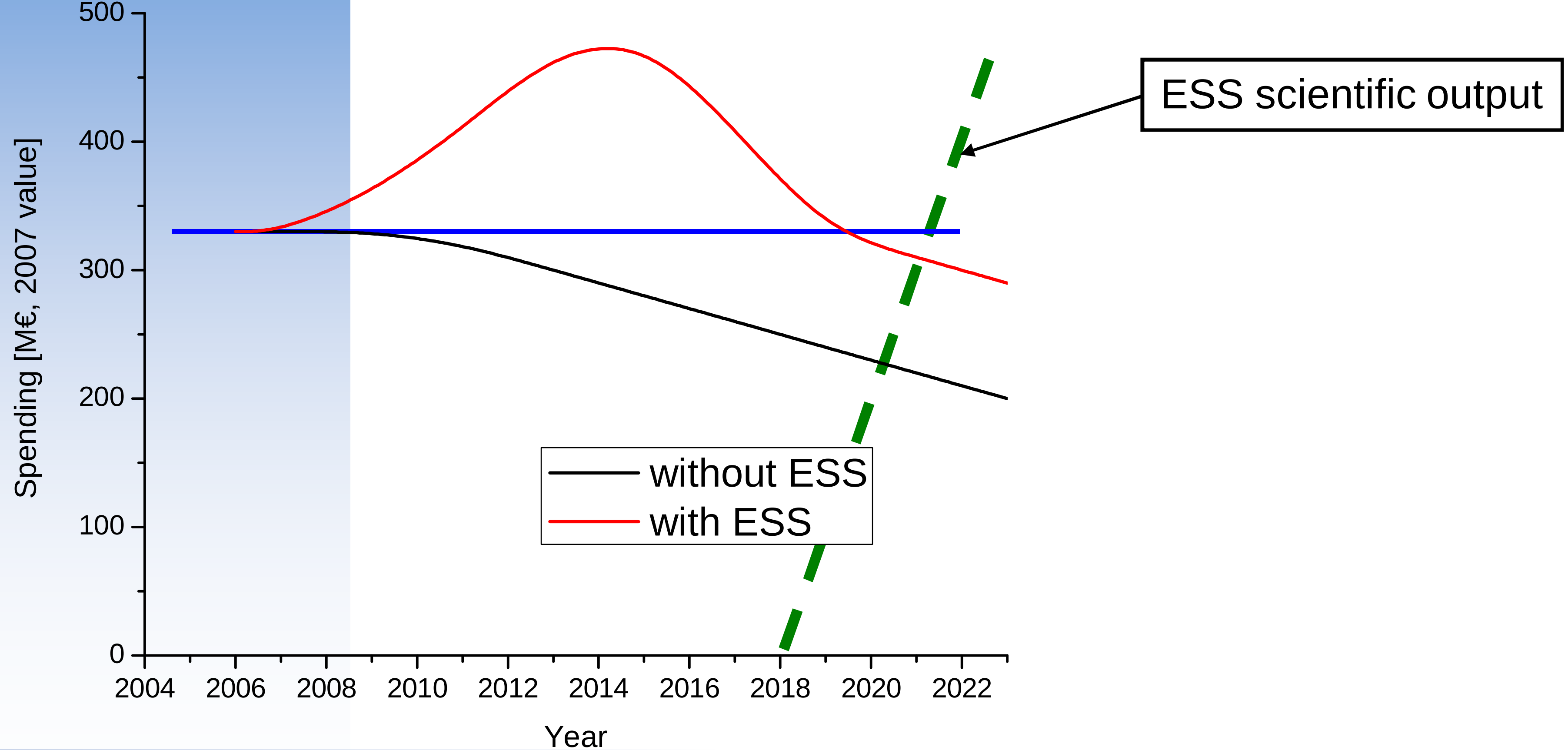
Business case for ESS Hungary

Expected European yearly spending profile:

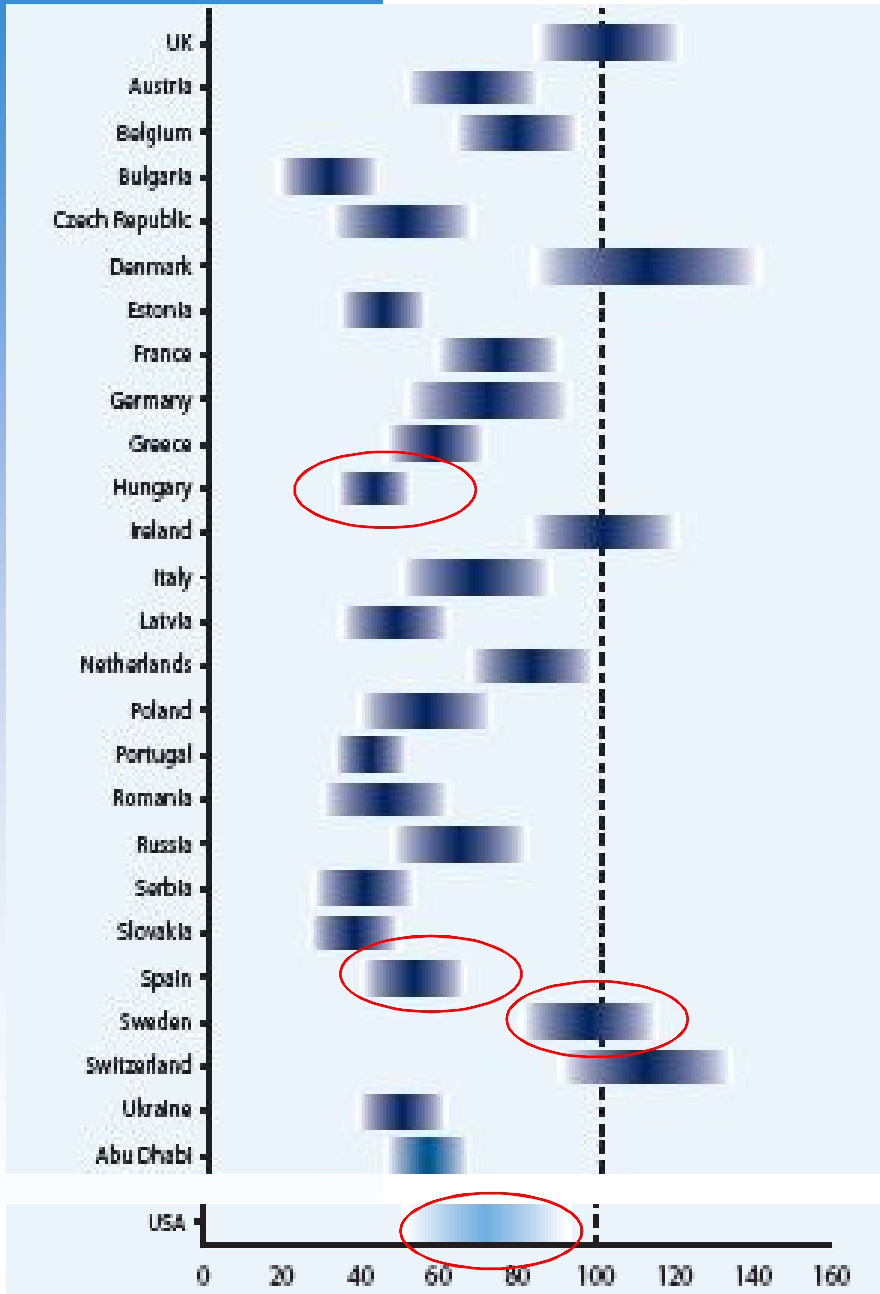
2007: 14 facilities (2 under decommissioning)

2023: probably 8 facilities (3 under decommissioning)

+ ESS-H (investment ~1.1 B€, operations 95 M€/year)



Global building costs (2007)



Hungary for ess european spallation source

Favourable living costs:

Housing (sales): 1000 €/m²

Hungarian wages vs. EU-15:

(2006 Gross Average Monthly Wages, UNECE)

HU: $ 814

EU-15 average: ~ $ 3200

Per capita purchasing power (PPP):

HU ~ 55 % of EU-15

Hungary for ess

All items for ESS in value of 1.1.2008	ESS Bilbao (M€)	ESS Lund (M€)	ESS Debrecen (M€)	SNS as built* (M€, 1 € =1.12 $)
Quoted in answers to ESFRI	1284	1377	1073	
Extra instruments included	-	135	-	-
Missing op. funds before 2018	70	67	-	-
Missing op. funds 2018-2020	-	133	-	-
Total construction phase Extrapolated from SNS actual	**1354** 1157	**1309** 1320	**1073** 995	**1207**
Site premium	-193	0	-213	0
100 % share: as quoted in answers Full operation / year (> 2025)	**1091** 113	**1377** 103	**860** 100	 116
Total spending for 10 % share from 2009-2025 (corrected for under-estimated pre-oper. & oper. costs)	**193** **(200)**	**193** **(213)**	**165**	-

SNS contracts in Tennessee (357 M€) scaled by global building costs

ESS-Hungary: **conservative cost estimate**

large savings for the partner countries

Hungary for ess
EUROPEAN SPALLATION SOURCE PROJECT

ESS in Hungary:

the best choice for Europe

28. July 2008