Neutron detector at the ESS

The European Spallation Source is the most advanced neutron facility in the world. It is a novel approach to the neutron production for condensed matter experiments with low energy neutrons

Proton linac, 5 MW, 14 Hz, 2.86 ms pulse length

30 times brighter than ILL reactor with similar average flux

22 beam new concept lines

Basic neutron science

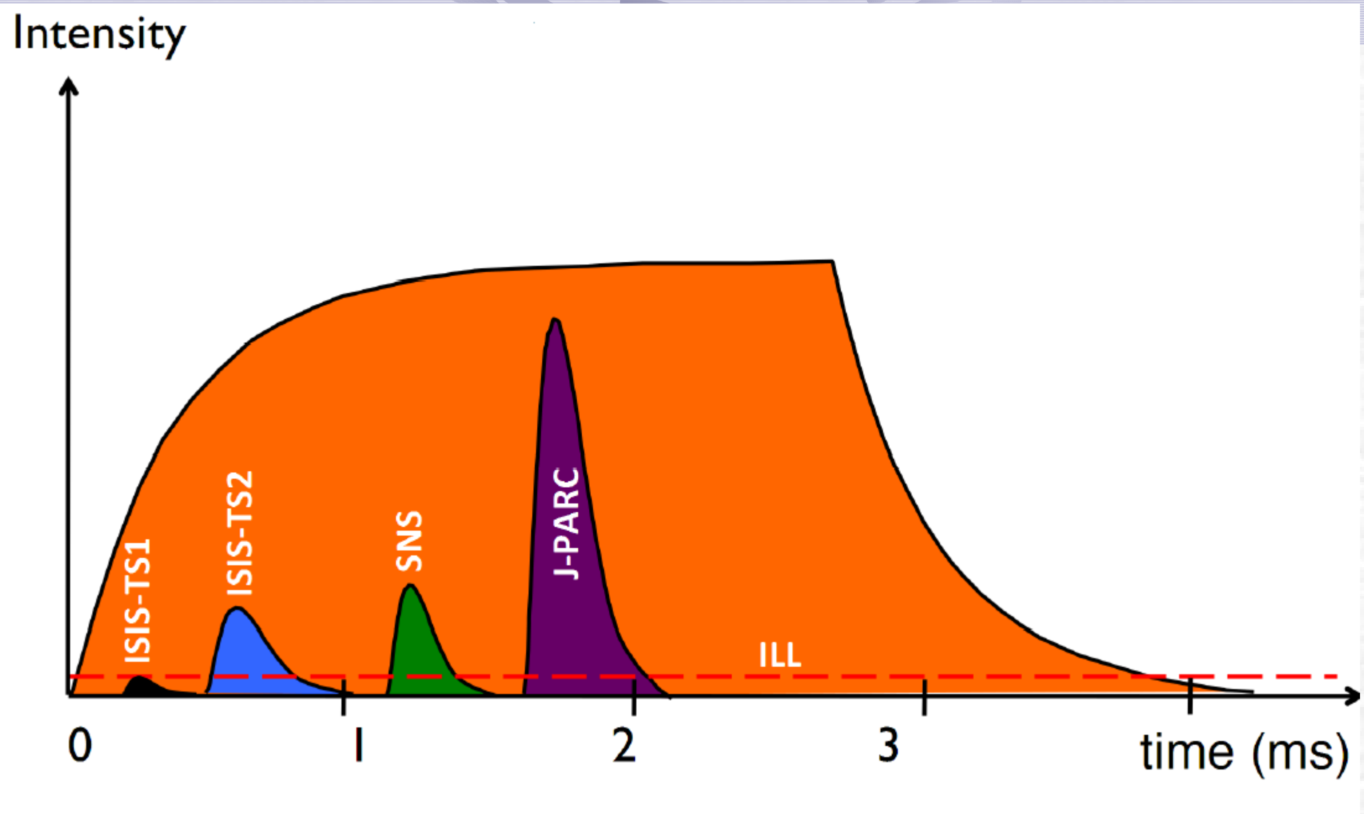
The cost of an increase of the neutron flux is extremely high:

ESS costs almost two billions euros

At Oak Ridge in the US it was evaluated (1994) the possibility of building a new high flux reactor (Advanced Neutron Source). It was concluded that a flux increase from 1.5 10^{15} n/cm^2/s up to 5 10^{15} n/cm^2/s would cost 2.5 billion USD. The FRM-II (2005, Munich, D) reactor has a flux of 0.7 10^{15} n/cm^2/s and the cost was about 0.5 billion euros. These facilities have to face the problem of using highly enriched uranium.

The reactor based sources have very tight safety constraints

The accelerator facilities have less tight safety constraints



Time structure of the major neutron facilities in the world

ILL: continuous, ISIS-TS1: 40 Hz, ISIS-TS2: 10 Hz, SNS: 60 Hz, J-PARK: 25 Hz

The average flux of ESS is equal to that of ILL

Each neutron is a good neutron.

The neutrons have a very high cost in terms of energy: 8 MeV on the average, that is 1 J per 10^{12} n in the best condition. In practice the energy per neutron is much higher: 100 MeV (fission), 40 MeV (spallation), 10 MeV (fusion) plus the effect of branching ratio if other reactions are possible.

Neutron is neutral and γ photons (MeV) are always present when neutrons are produced, therefore it is important a good n to γ discrimination

Neutron detector at the ESS:

Detection of neutrons in condensed matter experiments

At the ESS all sort of neutron experiments are performed:

- Time of Flight diffraction experiments

  High angle diffraction, small sample diffraction, low angle diffraction, reflectometry

- ToF based inelastic neutron scattering experiments

- High resolution imaging (ToF applications)

Performances of neutron detectors at the ESS

A) Diffraction, high angle

a) Efficiency E = 10 meV – 100 meV ~ 1 (>0.7)

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV < 10^{-4}

c) Pixels 0.5 x 0.5 mm^2 up to 10 x 10 mm^2

d) Local and global detection rate several MHz

e) Detector size up to 5 m^2

f) Possibility of use in magnetic field and vacuum. High life time and very good long term (days) stability (< 0.1%)

B) Diffraction, low angle

a) Efficiency E = 0.1 meV – 10 meV ~ 1 (>0.7)

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV < 10^{-4}

c) Pixels from 0.1 x 0.1 mm^2 up to 10 x 10 mm^2

d) Local and global detection rate several MHz

e) Detector size up to 2 m^2

f) Possibility of use in magnetic field and vacuum. High life time and good long term (several hours) stability (< 1%)

C) Diffraction, quasi Laue, large unit cell crystallography

a) Efficiency E = 1 meV – 20 meV ~ 1 (>0.7)

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV < 10^{-4}

c) Pixels from 0.1 x 0.1 mm^2 up to 2 x 2 mm^2

d) Local and global detection rate several MHz

e) Detector size up to 1 m^2

f) Flexible shape (cylinder, spherical), possibility of use in magnetic field and vacuum. High life time and good long term (several hours) stability (< 1%)

D) Inelastic ToF experiments, incoming energy, 2 meV to 100 meV, resolution 1% to 3%

a) Efficiency close to unity

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV $<<10^{-6}$

c) Pixels from 5 x 5 mm^2 up to 20 x 20 mm^2

d) Local and global detection rate about 1 MHz

e) Detector size up to 50 m^2

f) Any shape, possibility of use in magnetic field and vacuum. High life time and good long term (several days) stability (<1%)

D) Inelastic ToF experiments, very high energy resolution, < 5 μeV

a) Efficiency close to unity, individual detectors

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV $<<10^{-6}$

c) Pixels not very important, detector size ~ 1 cm

d) Local detection rate not important

e) Detector size not important

f) Any shape, possibility of use in magnetic field and vacuum. High life time and good long term (several days) stability (<1%)

E) Imaging

a) Efficiency not very important (>20%)

b) Efficiency for γ-rays E = 0.01 MeV – 10 MeV $<<10^{-4}$

c) Pixels typically 0.1 x 0.1 mm^2

d) Local detection rate very important, several MHz

e) Detector size several cm

f) Possibility of use in vacuum. ToF capability very important for wavelength selection (Bragg edge imaging)

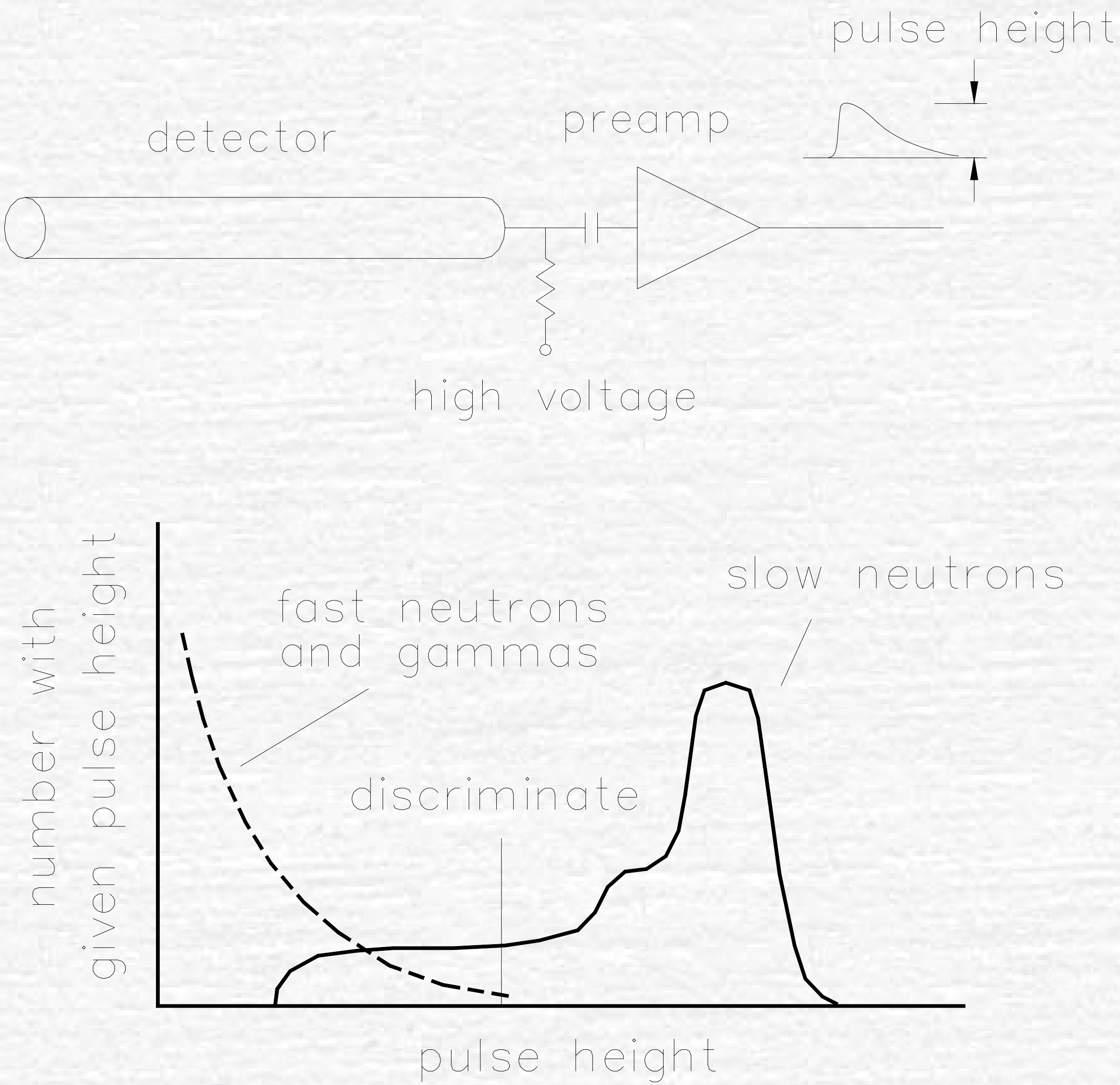
There are different designs for neutron detection:

Gas detectors where the charged particle released after the neutron capture ionize the gas and the electrons thus produced are collected by an electrode in ionization or proportional modes

Scintillators where the energy is stored and released through a luminescence process. The light so produced can be detected using high sensitivity detectors (e.g. photomultipliers)

Solid state where a converter (normally outside the sensor) produces charged particles which are then detected

Imaging systems exist which are not able to detect single neutrons but only the neutron intensity (e.g. image plates)


pulse height
detector
preamp
high voltage
slow neutrons
fast neutrons
and gammas
number with
given pulse height
discriminate
pulse height

Position Encoding

Discrete - One electrode per position

Discrete detectors

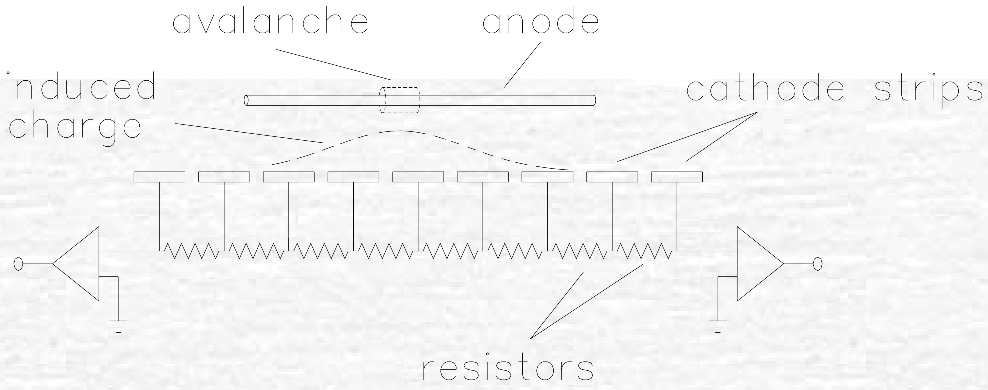
Multi-wire proportional counters (MWPC)

Weighted Network

Rise-time encoding

Charge-division encoding

Anger camera



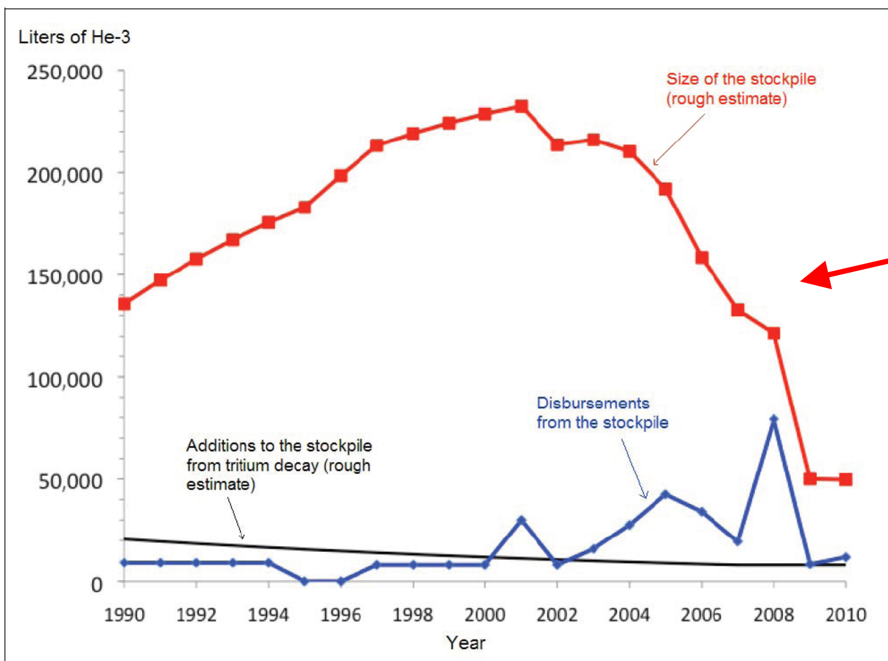
The present ^{3}He detectors are in normal use with different shape and size. Only some of them are possible at the ESS in 10 years time from now

Small ^{3}He tubes

Large area detectors: vacuum chamber of IN5 at ILL

Pressurized detectors up to 20 bar are used

Size of the Helium-3 Stockpile, 1990-2010



Source: Adapted from Steve Fetter, Office of Science and Technology Policy, "Overview of Helium-3 Supply and Demand," presentation at the American Association for the Advancement of Science Workshop on Helium-3, April 6, 2010.

^{3}He availability in recent times

NEW SOLUTIONS ARE NECESSARY