ITALIAN NATIONAL AGENCY
FOR NEW TECHNOLOGIES, ENERGY AND
SUSTAINABLE ECONOMIC DEVELOPMENT

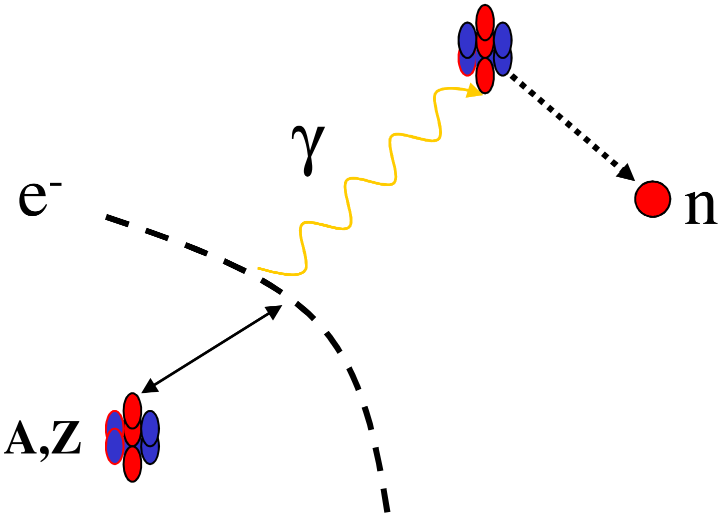
IRIDE photo-production workshop

A case for a neutron photo-production source at IRIDE

Proposed Beam configurations and comparisons with other facilities

Antonino Pietropaolo
Nuclear Technologies Laboratory
Associazione EURATOM ENEA sulla Fusione
ENEA C.R. Frascati, via E. Fermi, 45
00044 Frascati (Rome) Italy

(γ,n) Production



- **Electron slowing down into the target**
- **Bremsstrahlung radiation emission**
- **(γ,n) reactions + nuclei evaporation**

Neutron Yield (n per primary electron, Y) mainly depends on target material and geometry:

Y < **0.1 n/e** for E_e < 200 MeV (W,Ta)
Y ~ **0.2 n/e** for E_e = 500 MeV (W,Ta)
Y ~ **0.7** for E_e > 1 GeV (W,Ta)
Y ~ **0.7** for E_e=500 MeV (U)

For E_e>150 MeV hadonic processes due to pions productions: intra- and inter-nuclear cascades (photofission in te case of Uranium)

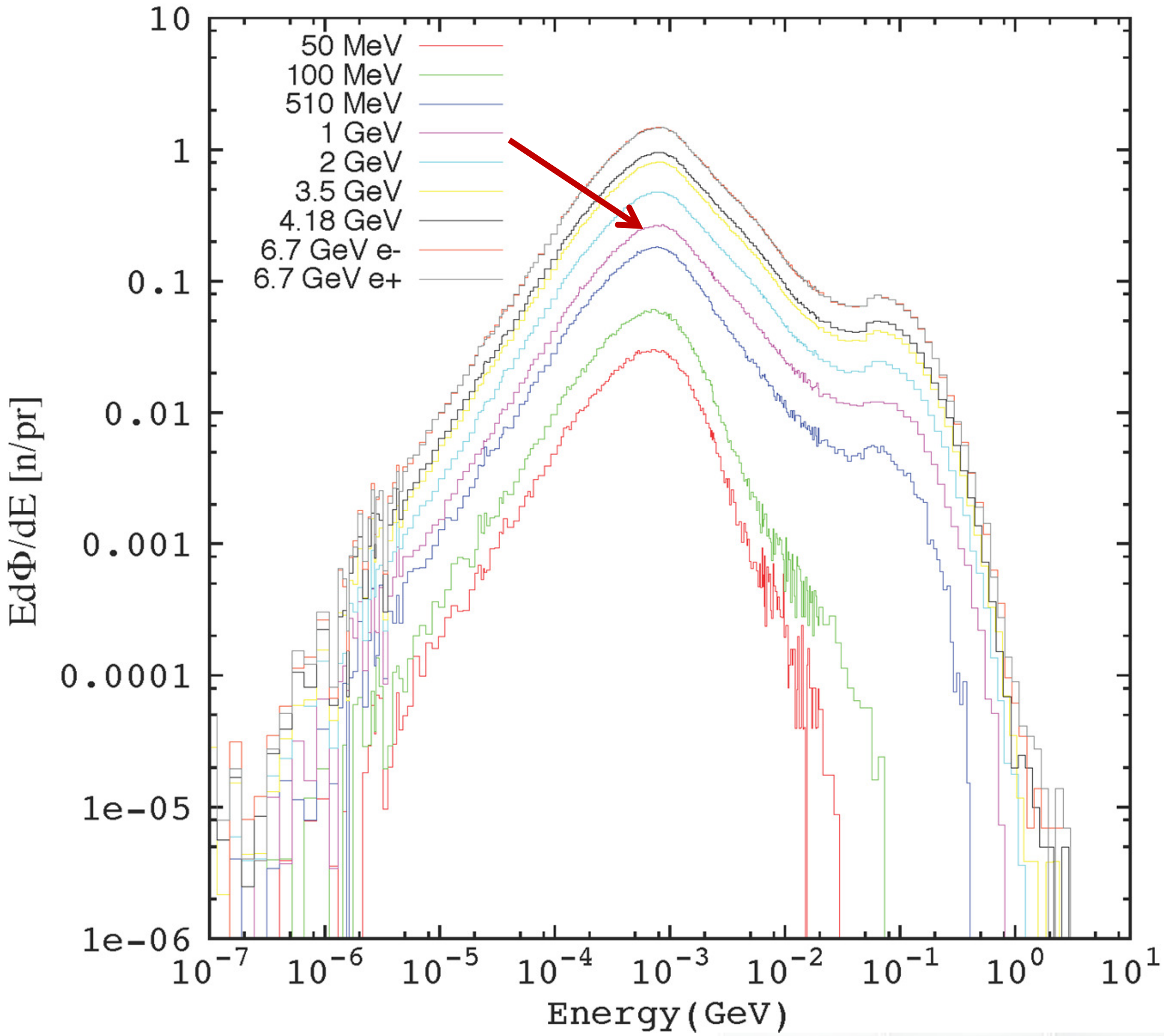
Calculations and simulations from feasibility studies for the n@BTF facility

Y depends also on the target thickness but ere is the problem of power dissipation → segmented or rotating target to improve cooling.

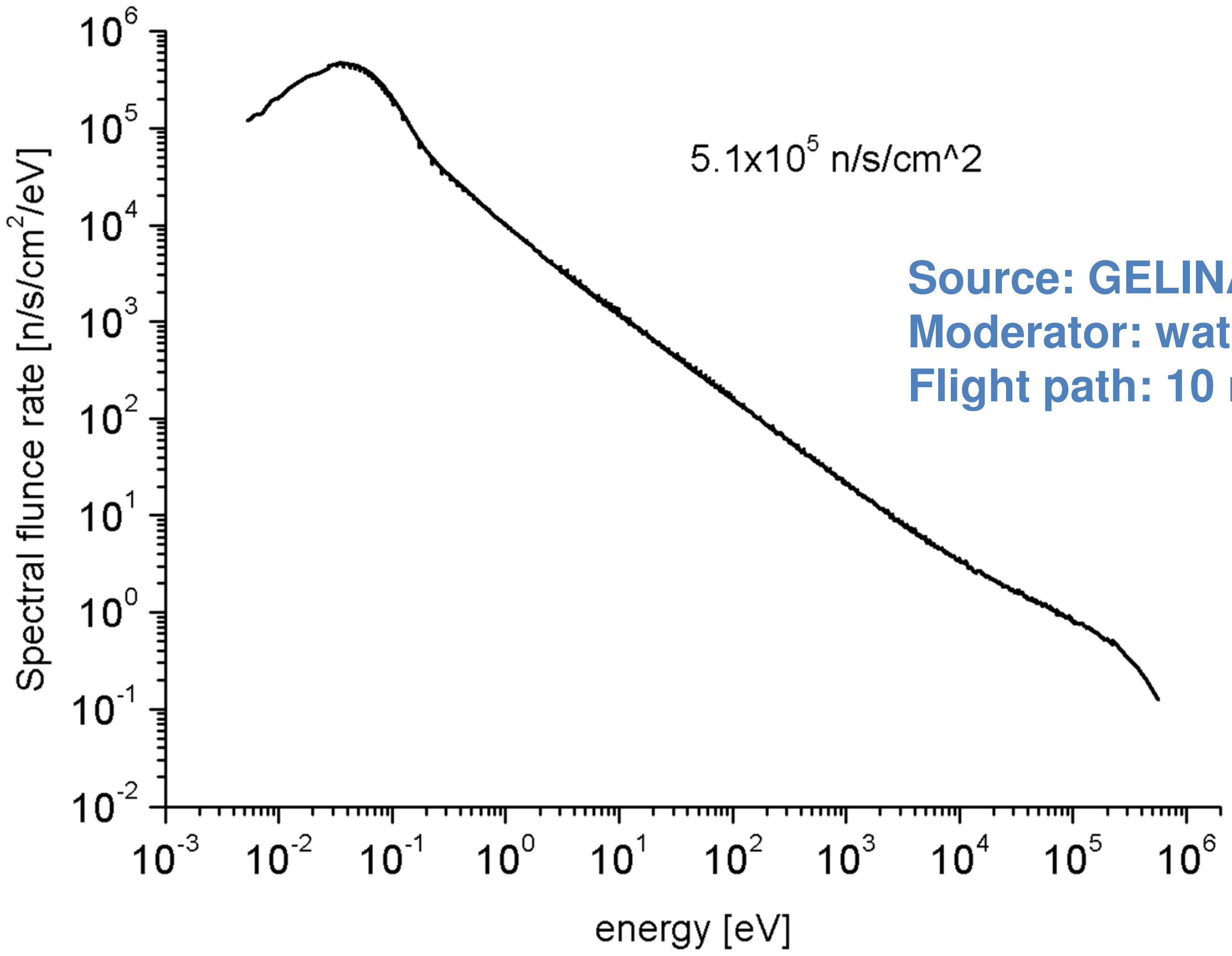
Neutron spectra@ target

Evaporation peak (related to the equilibrium nuclear temperature) depends on target material.

In the present case is W



A typical moderated spectrum



Source: GELINA
Moderator: water
Flight path: 10 m

An outlook on some accelerator-driven neutron facilities worldwide

Existing (Japan)

Name	Type	Primary Particles	Reaction	Intensity	Moderator	Application
HUNS (Hokkaido University Neutron Source)	Linac	Electrons energy: 35MeV, current 30 µA single-100 Hz (Usually up to 50Hz)	Photoproduction	1.6×10^{12} n/sec @ 35 MeV and 1kW	Water thermal moderator and coupled methane moderator	Imaging, SANS, device development, nuclear data
RIKEN Accelerator-driven Neutron Source (RANS)	proton Linac	Protons peak current:10mA average current: 100uA Pulse width:30-200µsec frequency 20–200 Hz duty 1%	Be(p,n)	10^{12}n/s (100uA, 7MeV by simulated)	thermal, polyethylene (1st phase) cold, mesitylene (2nd phase)	thermal: imaging, detector development cold: SANS, pulse imaging
Kyoto Univ. Accelerator-driven Neutron Source (KUANS)	proton Linac	Proton peak current: 10mA , average current: 101µA Pulse width: 30-200µsec repetition 20 - 200Hz duty 1%	Be(p,n)	10^{11}n/s (100uA, 3.5MeV by simulated)	thermal, polyethylene	imaging, detector development, education
J-PARC	Proton synchrotron	Protons Energy: 3 GeV 333 µA Repetition 25 Hz	spallation	3-5x10^{16} n/s	Liquid hydrogen	Diffraction, spectroscopy, spin-echo, imaging.

Y.K. Kyanagi

Y.K. Kyanagi

Existing（out of Japan)

Name	Type	Primary Particles	Reaction	Intensity	Moderator	Application
Compact Pulsed Hadron Source (CPHS) China	proton Linac	Protons energy: 3 MeV (stage 1) / 13MeV(stage 2), peak current: 50 mA, average current: 1.25mA pulse duration: 500μs, frequency: 50Hz,	Be(p, n)	~5×10^{13}n/s (1.25mA, 13MeV, by simulated)	Thermal, Polythene (stage 1); Cold, solid methane (stage 2)	SANS, neutron instrument development, imaging, detector development
PKUNIFTY (Peking University Neutron Imaging Facility) China	RFQ linac	Deuteron, Energy: 2 MeV, Peak current: 40 mA Average current: 400 μA Pulse width: 0.2-1 ms Frequency:100 Hz	Be(d, n)	3×10^{12} n/s @ average current of 4 mA (simulation) 3×10^{11} n/s @ average current of 0.4 mA (current experiments)	polyethylene and light water	imaging, education
GELINA (Belgium)	Van Der Graaf	protons, alpha and lithium. ΔV: 7 MV max cw current: 30 μA pulse width < 1 ns frequency: multiple of 330 ns	Li7(p,n)Be7	3´10e8 n/s @ 2 MeV and 30 μA	none. the neutron spectra is shaped by shaping the proton energy spectra	nuclear astrophysics, neutron activation, validation of nuclear data, next generation reactors data
LENS (Low Energy Neutron Source) USA	RFQ + 2 LINAC Sections	Protons, Energy: 13 MeV, Peak current: 25 mA (peak) (current) pulse width 0.015–0.6 ms frequency 20 Hz Planned parameters Energy: 18 MeV Peak current: 100 mA Pulse width: 0.015-2.0 ms Frequency: 20 Hz	Be(p, n)	Target station 1 – 3 x10^{11} n//s current. 5 x 10^{12} n/s (planned) Target station 2 – ~10^{13} n/s (current), ~5x10^{13} n/s (planned)	Target Station 1 User selectable – None, water, poly without light water reflector. Target Station 2 Solid methane at 4K with light water reflector	**Target Station 1** Radiation effects – commercial and military electronics testing Neutron imaging (radiography and tomography) – geology **Target Station 2** SANS – geology, materials science, biophysics Spin polarized reflectometer – biophysics, polymers Test Beam Line – detector and optics development, moderator research
ORELA US	Electron LINAC	Electrons Energy: 180 MeV 20 A (peak current) Repetition: 525 Hz Target: Ta	photoproduction	10^{14} n/s@50 kW	Liquid water	Neutron capture for nuclear physics and nuclear astrophysics

Main (accelerator driven) neutron sources in Europe

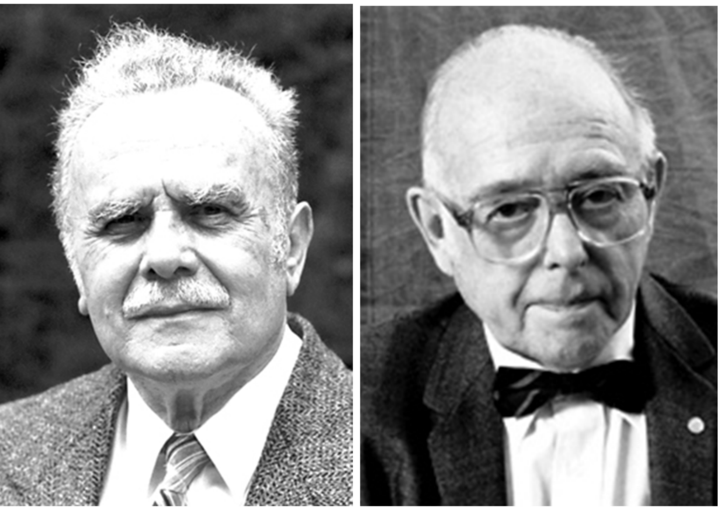
Name	Type	Primary Particles	Reaction	Intensity	Moderator	Application
ISIS Spallation Neutron Source UK http://www.isis.stfc.ac.uk/	proton Synchrotron	proton, energy: 800 MeV Average current: 200μA, pulse duration: two bunches 100 ns width and 200 ns apart frequency: 40Hz for TS-I and 10 hz for TS-II Target: W/Ta	spallation	~10^{16}n/s (estimated)	Water Methane (solid) Liquid hydrogen	Diffraction Quasi Elastic scatterjng spectroscopy Small Angle reflectometry
SINQ @ PSI Swizterland http://www.psi.ch/sinq/	cyclotron	proton energy: 590 MeV Current: 1 mA frequency;. Continuous Target: lead rods Envisaged rotating euthectic lead-bismuth (MEGAPIE project, successful test in 2006) to improve by 80% the neutron flux	spallation	3x10^{16} n/s	Heavy water Liquid deuterium	Diffraction Small Angle Scattering Spectroscopy Raadiography Imaging reflectometry
Frascati Neutron Generator ENEA-Frascati	Deuteron Linear Accelerator	Deuterons Deuteron energy: 260 keV Current: 1 mA Target: deuterium or tritium Frequency: continuous	$D(d,n)^3He$ or $T(d,n)\alpha$	D-D reaction 10^9 n/s @ 2.5 MeV D-T reaction 10^{11} n/s @ 14 MeV	The monochromatic beams at 2.5 and 14 MeV can be moderated by movable moderation systems to obtain thermal neutrons fpr specific measurements	Benchmark experiments Activation cross sections measurements, fast neutron activation analysis, detector development
GELINA Belgium	Electron LINAC	Electron energy: 100 MeV Average current: 100 μA Frequency: 800 Hz Pulse width: 1 ns Target: uranium	Photoproduction	3.4 x 10^{13} n/s	Both moderated and non moderated beams	NRCA Neutron data Nuclear structure
n-ELBE Germany	Electron SC LINAC	Electron Energy: 40 MeV Average Current: 1 mA Frequency: 1.5 MHz Pulse width: 0.4 ns Target: liquid Pb	Photoproduction	2.7·10^{13} s^{-1}	No-moderators	Neutron cross section data or fast fission reactors physics; Long-lived to short lived nuclei transmutation processes
N_TOF @ CERN Switzerland	Proton synchroron	Proton energy: 20 GeV Average current: 1 uA Frequency: 0.83 Hz Pulse width: 6 ns rms Target: Pb	Spallation	About 1e15 n/pulse	Water moderator	Basic nuclear physics Nuclear astrophysics Nuclear technology

The Spallation Neutron Source in US

Name	Type	Primary Particles	Reaction	Intensity	Moderator	Application
Spallation Neutron Source* USA http://www.bnl.gov/cad/sns/	proton Synchrotron	proton, energy: 1 GeV Average current: 2 mA, pulse duration: 695 ns frequency: 60Hz, Target: rotating liquid Hg	spallation	~10^{17}n/s (estimated)	Water Methane (solid) Liquid hydrogen	Diffraction spectroscopy Small Angle reflectometry

*** Parameters from SNS design: present performances possibly reduced due to target problems**

A brief overview of techniques



The Nobel Prize in Physics 1994 was awarded *"for pioneering contributions to the development of neutron scattering techniques for studies of condensed matter“* jointly with one half to

Bertram N. Brockhouse
"for the development of neutron spectroscopy"

Clifford G. Shull
"for the development of the neutron diffraction technique".

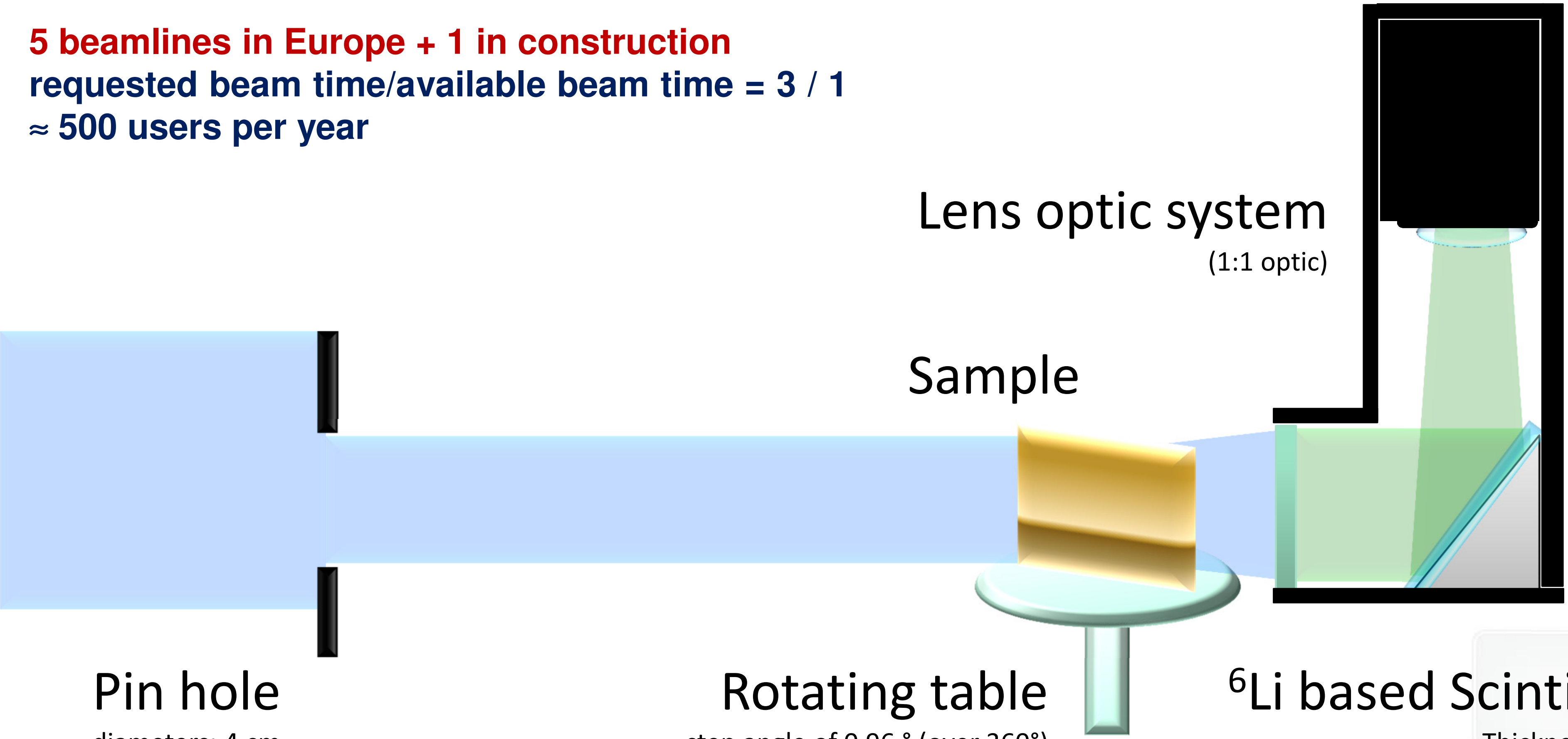
Neutron show where atoms are (structure) and what atoms do (dynamics)

Some talks today are focussed on possible neutron techniques
that may be envisaged for IRIDE facility

Neutron imaging

Neutron Imaging (radiography and tomography) is a technique able to perform spatial and volumetric maps of samples in order to study their morphology

5 beamlines in Europe + 1 in construction
requested beam time/available beam time = 3 / 1
≈ 500 users per year



Andor DV 436 16-bit CCD Detector

2048×2048 pixels
nominal pixel size of 13.5 µm (CCD chip size: 2.76 cm x 2.76 cm)

Lens optic system

(1:1 optic)

Sample

Pin hole

diameters: 4 cm
L/D achieved: 178

Rotating table

step angle of 0.96 ° (over 360°)
exposure time for projection: range from 5 s to 60 s

^{6}Li based Scintillator

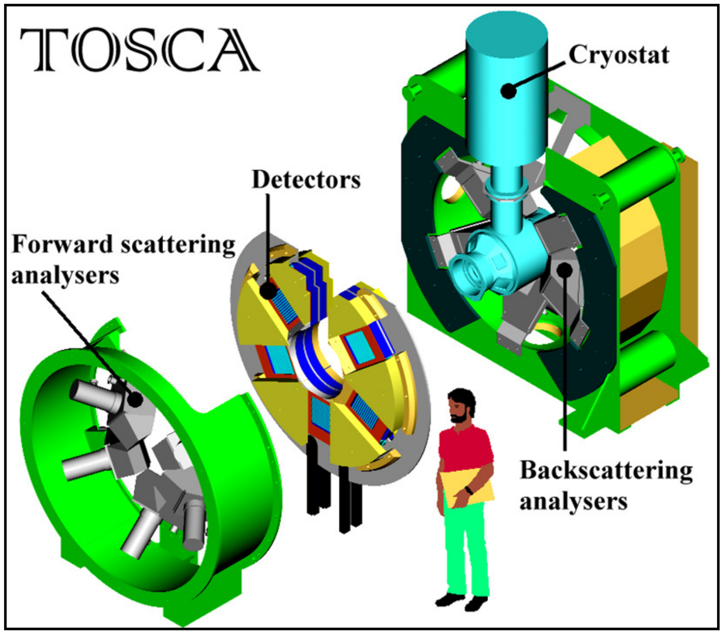
Thickness: 100 µm

Neutron Scattering

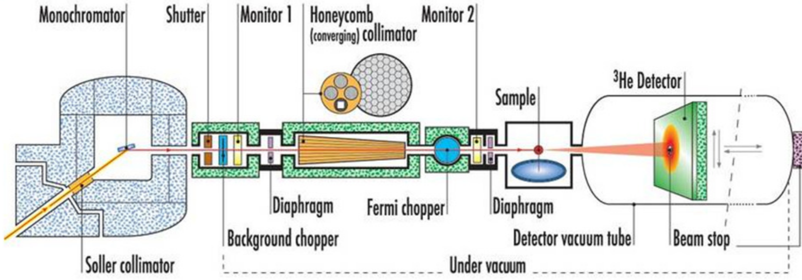
Elastic, quasi-elastic and inelastic scattering, a wide range of techniques to investigate:

- **lattice structure (diffraction),**
- **macrostructure (small angle scattering),**
- **interface morphology (reflectometry)**
- **diffusion processes (quasi elastic scattering),**
- **collective and vibrational states of matter (inelastic scattering)**
- **Single atom short time dynamics (deep inelastic scattering)**

More than 100 beamlines in Europe
requested beam time/available beam time = 2 / 1 ≈ 6000 users per year
≈ 200 Italian users



T.O.S.C.A. : *Thermal Original Spectrometer with Cylindrical Analyzers*



BRISP@ILL - TOF Spectrometer for Small Angle Inelastic Scattering

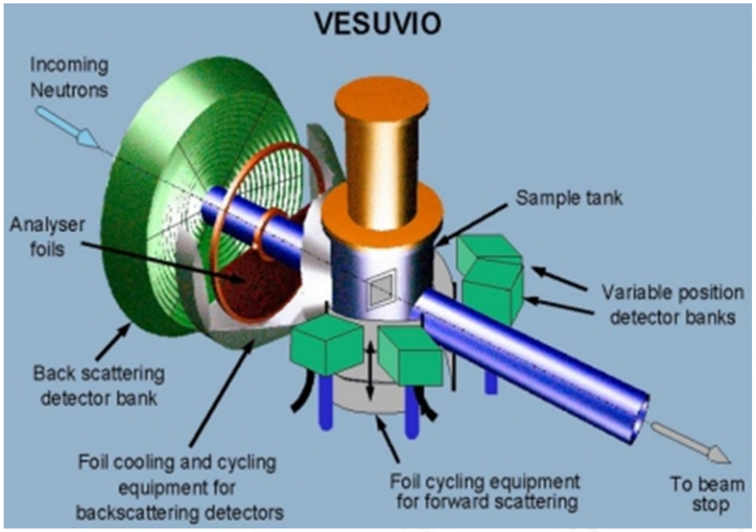
BRISP is a new concept thermal neutron Brillouin scattering spectrometer which exploits the time-of-flight technique and is optimized to operate at small scattering angles with good energy resolution.

Applications

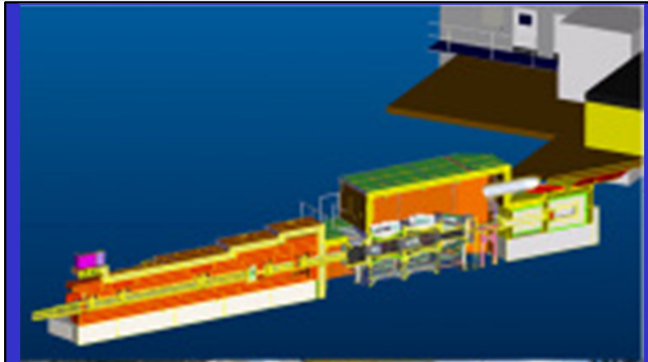
Biological systems: proteins, biological membranes, magnetic systems, Confined Liquids, macromolecular Systems, Liquids

Amorphous solids, Glasses, Polymers, Liquid metals and alloys

VESUVIO@ISIS is an inelasic eV neuon spectrometer deveoted to e measurement of the mean ineic eegy and m,onetum distibution of single atoms in H-contining systems and quantum systems (He3, He4 and mixtures)



Neutron Scattering



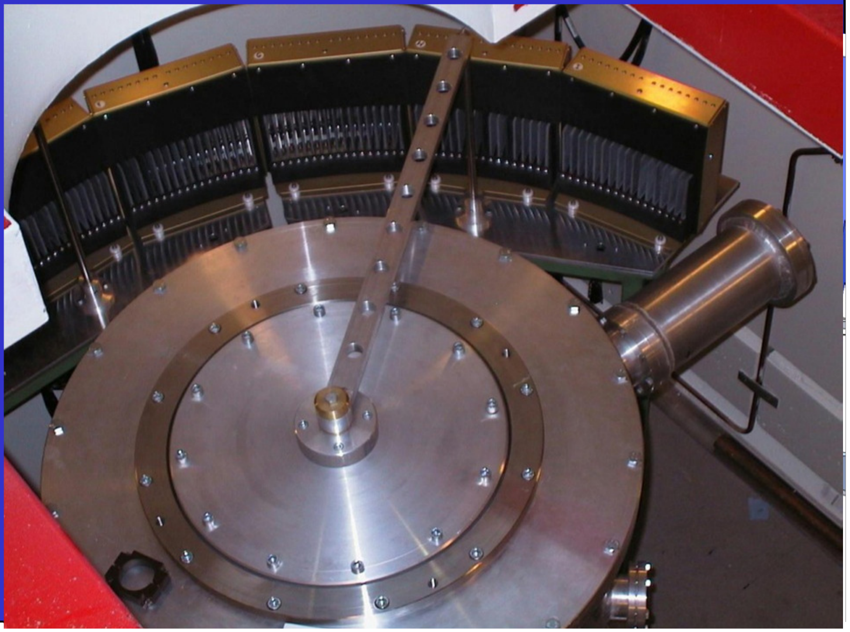
NIMROD@ISIS TS2

Near and InterMediate Range Order Diffractometer

Nimrod is a near and intermediate range order diffractometer designed to provide continuous access to length scales ranging from the interatomic (<1 Å) through to the mesoscopic (>300 Å).

Applications
Complex and confined liquids
Functional and composite materials
Phase behaviour and nucleation

Techniques
Neutron diffraction
Neutron diffraction with Isotopic substitution
Small angle scattering



INES @ ISIS TS1

is a powder diffractometer, built and managed by the Italian National Research Council (CNR) within the cooperation agreement with STFC.

INES is a general purpose diffractometer and is mainly devoted to materials characterization (structure refinement and phase analysis), cultural heritage studies and equipment tests.

Neutron irradiation

Single event effects (**SEE**) are defined as disturbance of an active electronic device caused by a single energetic particle:

- Upset (SEU): change in logic state, simplest example is a memory cell in RAM
- Latchup (SEL): sharp increase in current resulting from turning on parasitic *pnpn*
- Damage or burnout (SEB) of power transistor or other high voltage device
- Functional interrupt (SEFI): malfunctions in more complex parts sometimes as lockup, hard error, etc

These effects are needed to be investigated in many application fields

Aviation

Automotive

IT Infrastructure

Medical

Long lasting measurements in atmosphere !

Due to the low neutron flux in the atmosphere, the characterization of the behaviour of electronics in the atmospheric neutron field requires very long data taking to achieve statistically significant results.

That’s why neutron sources are useful to accelerate tests that can be carried out in a few minutes to simulated one year of data taking. This is very important as industries produce new devices in rapid times and need to speed up, using effective protocols, robustness tests.

World-wide irradiation facilities

A neutron source for IRIDE

- A neutron source in the IRIDE complex would be interesting for different communities of users if capable of providing:
  - An "intense" neutron flux in the interesting energy region
  - User-friendly beam-lines
    - Instruments, access, etc.
- Even though not competitive with spallation sources and reactors in terms of absolute flux, a photo-production facility with a significant neutron yield would help to:
  - **Increase the available beam-time and enlarge the community (for the specific applications we envisaged for IRIDE)**
  - **Develop new technologies and detectors**
  - **Provide training for beam-line scientists, accelerator experts, computing, electronics, detectors**
- **Essentially two scenarios**
  - **Continuous**
  - **Pulsed**

a. Continuous source

Charge in one bunch: **Q = 1 nC**
Bunch rate: **R = 1 MHz**
Average current: **<I> =** $Q*R = 10^{-9}*10^{6}$= **1 mA**

# of electrons/second: $\mathbf{N_e}=Q*R/e= 10^{-3}C\ s^{-1}/e=\mathbf{0.625\times10^{16}\ s^{-1}}$
T = Q*R*Y/e= $\mathbf{1.25\times10^{15}}$ **n/s** @target for Y/e=0.2
T = Q*R*Y/e= $\mathbf{5.0\times10^{15}}$ **n/s** @target for Y/e=0.8

Techniques:
- Very interesting for imaging (tomography and radiography)
- Using monochromators, it would be possible to perform measurements with diffraction, SANS, reflectrometry

Typically time-of-flight techniques are not used in continuous mode, although it can be possible to use ToF by chopping the beam.

P1

Diapositiva 19

P1 io leverei questa frase
Pillon; 03/06/2013

b. Pulsed source

Charge in one bunch: **Q = 1 nC**
Bunch rate: **R = 1.3 GHz**
Burst width: **W = 500 ns**
Repetition (burst) rate: **r = 50 Hz**
Beam loading: 20%
Average current: **<I>** = Q*R*W*r = **32.5 μA**

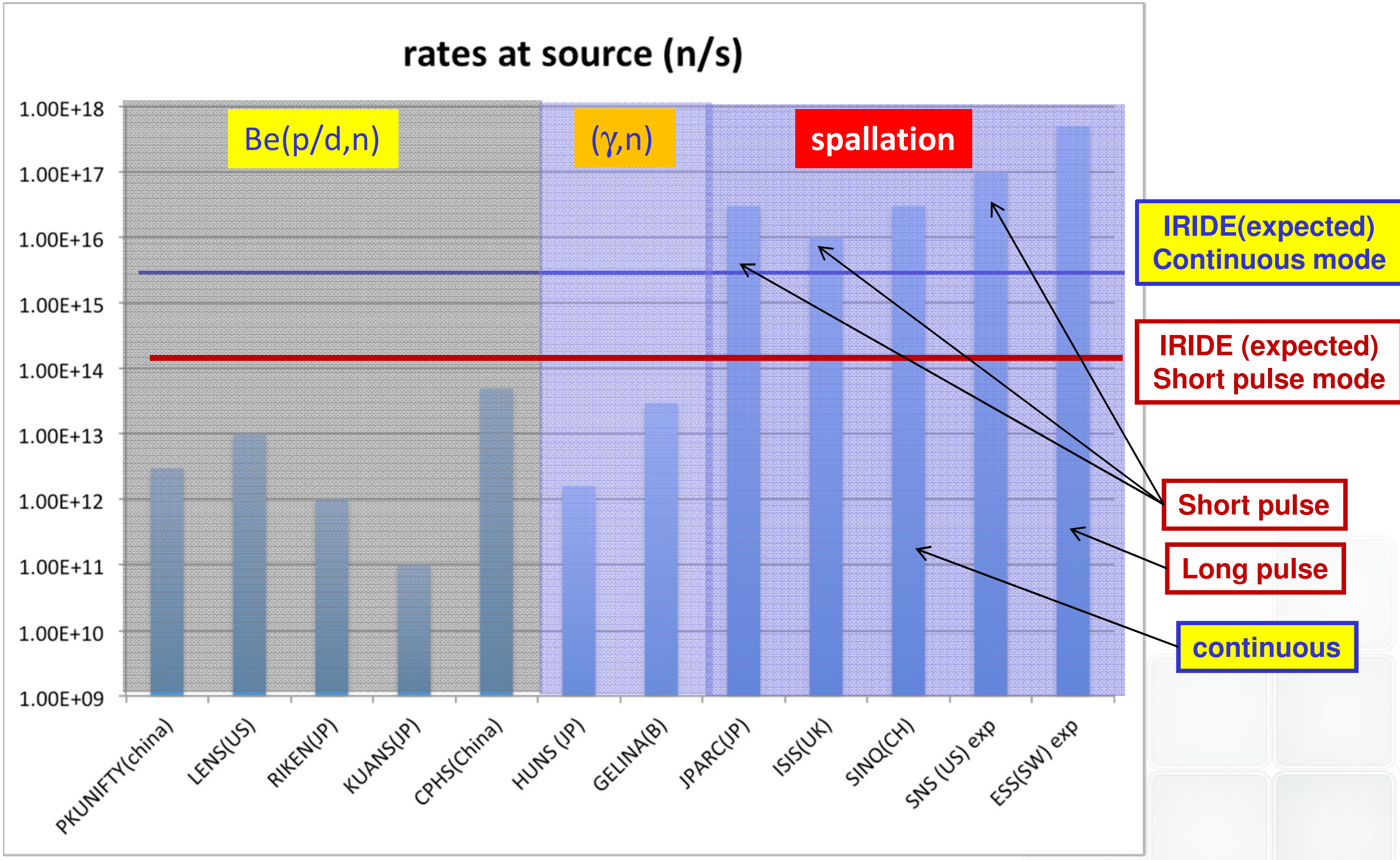
# of electrons/second: $\mathbf{N_e}$=Q*R*W*r/e= $\mathbf{2.03\times10^{14}\ s^{-1}}$
T = #e*Y/e = $\mathbf{1.625\times10^{14}}$ **n/s** @target for Y/e=0.8

Techniques:
- Diffraction with time of flight,
- SANS, reflectometry
- Energy resolved imaging

Cons and Pros:
- Time structure is important: probably difficult to run in “parasitic” mode with other experiments/facilities
- Lower yield with respect to continuous mode…

Time-of-flight can be easily used

Comparison with some accelerator driven sources



rates at source (n/s)

IRIDE(expected) Continuous mode

IRIDE (expected) Short pulse mode

Short pulse

Long pulse

continuous

Technical issues to be addressed

Rotating
Segmented

Target

Cooling system

Coolant
Thermal calculations
Effects on neutron flux

Material and geometry

Reflector system

Target shielding

Neutron and gammas
Radioprotection rules

Materials and configuration
H_2, CH_4, H_2O
Poisoned, coupled, decopuled ad their combinations

Moderators

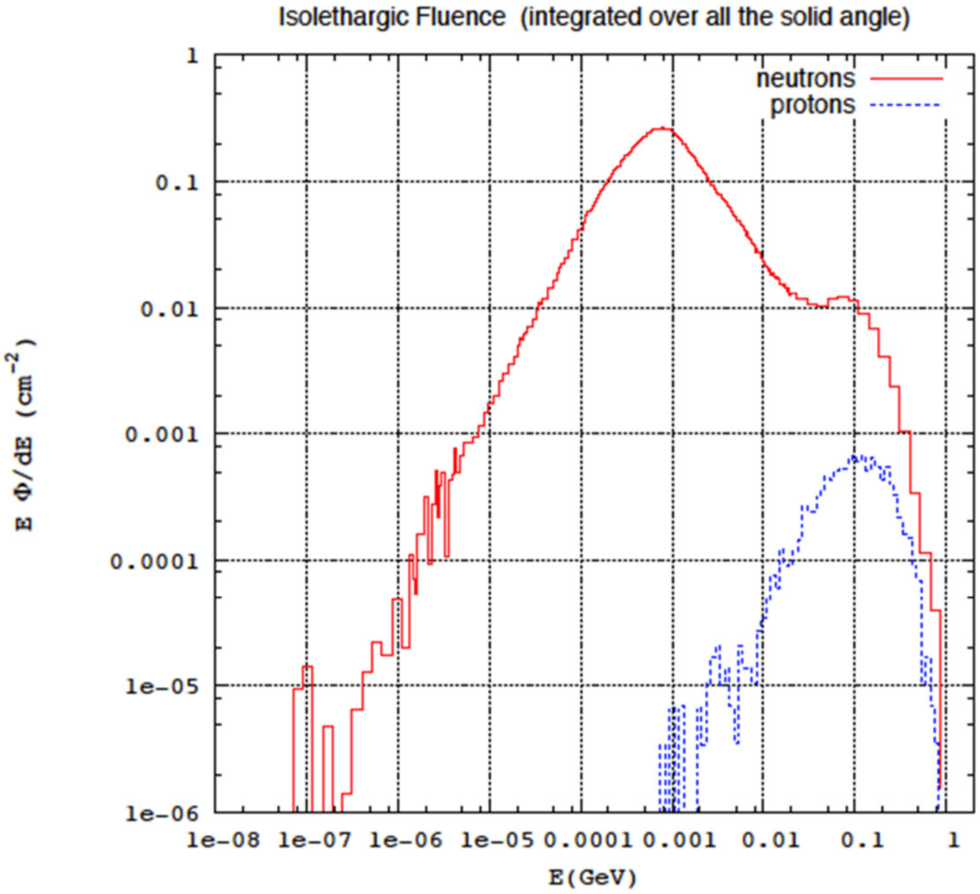
beamline

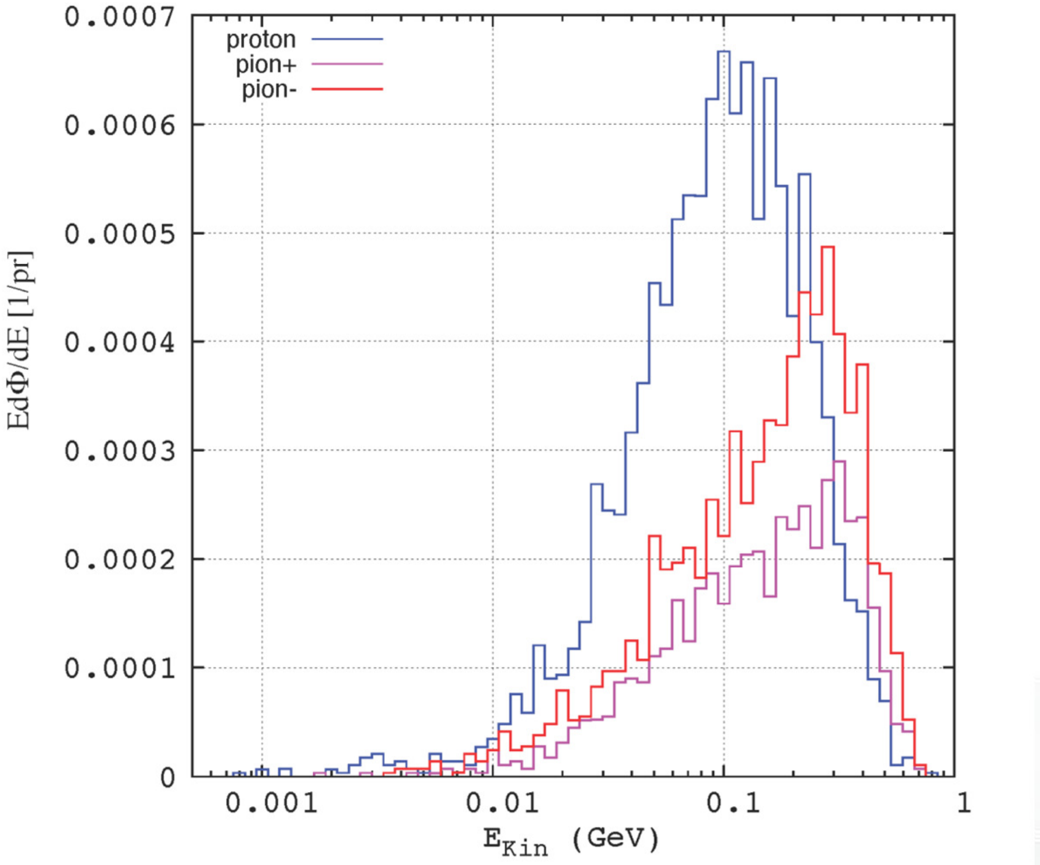
Flight path,
vacuum pipes,
Neutron guides.
Experimental hall (block house) shielding issues,
Beam dump,
Detectors,
Full characterization of neutron beams over the whole spectrum

Dependent on chosen applications

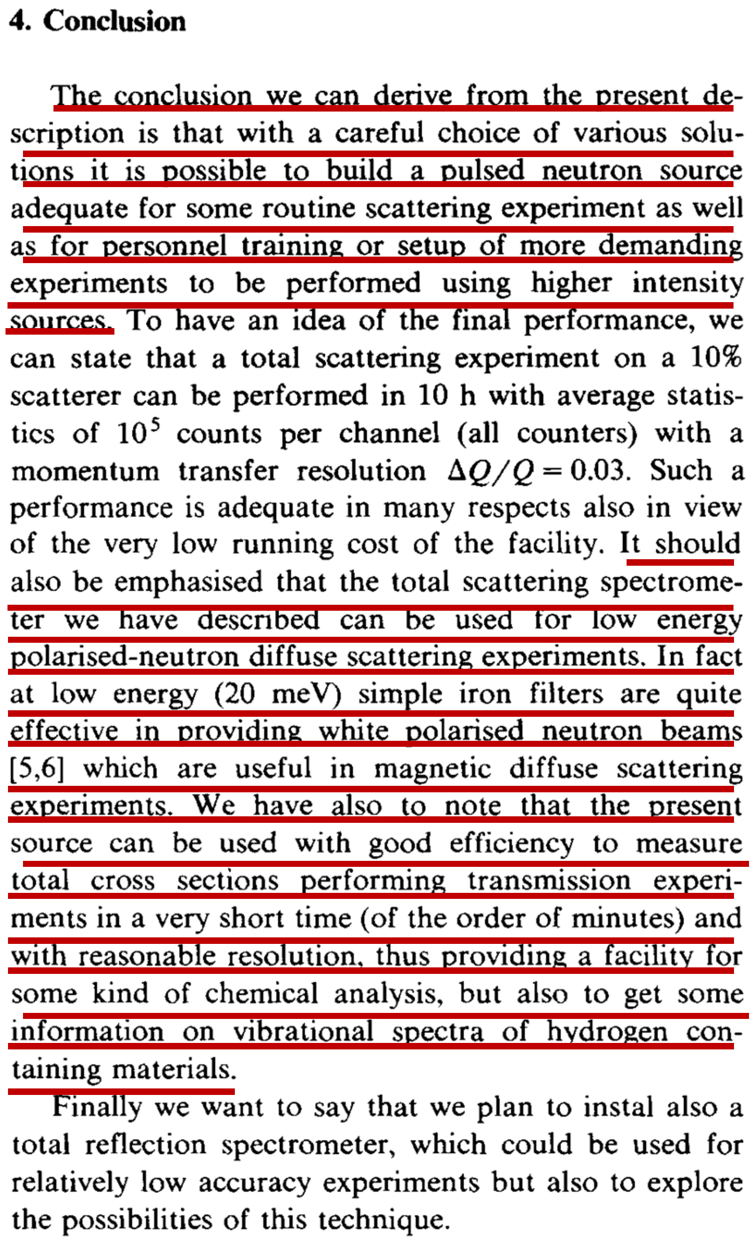
DAQ

More than neutrons


Isolethargic Fluence (integrated over all the solid angle)



Valuable inputs from past experinences



4. Conclusion

The conclusion we can derive from the present description is that with a careful choice of various solutions it is possible to build a pulsed neutron source adequate for some routine scattering experiment as well as for personnel training or setup of more demanding experiments to be performed using higher intensity sources. To have an idea of the final performance, we can state that a total scattering experiment on a 10% scatterer can be performed in 10 h with average statistics of 10^5 counts per channel (all counters) with a momentum transfer resolution $\Delta Q/Q = 0.03$. Such a performance is adequate in many respects also in view of the very low running cost of the facility. It should also be emphasised that the total scattering spectrometer we have described can be used for low energy polarised-neutron diffuse scattering experiments. In fact at low energy (20 meV) simple iron filters are quite effective in providing white polarised neutron beams [5,6] which are useful in magnetic diffuse scattering experiments. We have also to note that the present source can be used with good efficiency to measure total cross sections performing transmission experiments in a very short time (of the order of minutes) and with reasonable resolution, thus providing a facility for some kind of chemical analysis, but also to get some information on vibrational spectra of hydrogen containing materials.

Finally we want to say that we plan to instal also a total reflection spectrometer, which could be used for relatively low accuracy experiments but also to explore the possibilities of this technique.

Can we do more with IRIDE’s neutrons?

We hope to have some preliminary indications in this WORKSHOP!

Enjoy these two days!