IRSN
INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE
Enhancing nuclear safety

LPSC Grenoble
Laboratoire de Physique Subatomique et de Cosmologie

Production and measurement of neutron reference fields: the AMANDE facility and MIMAC prototype.

IRSN: C. Golabek, L. Lebreton, M. Petit, S. Valdenaire

LPSC: J. Billard, G. Bosson, O. Bourrion, O. Guillaudin, C. Grignon, F. Mayet, J-P. Richer, D. Santos

AGENCE NATIONALE DE LA RECHERCHE ANR

LNE Le progrès, une passion à partager

Aim of the μ-TPC project dedicated to neutron metrology in the IRSN context

IRSN: Institut de Radioprotection et de Sûreté Nucléaire

- **Nuclear safety:** reactors, fuel cycle, waste, medical applications and transports
- **Protection of workers, population and environment** against ionizing radiation risks
- **Emergency** preparedness and post-accident operational support
- **Protection and control** of nuclear sensitive materials
- **Protection of nuclear facilities** and transport of radioactive and fissile materials against malicious acts

→ Effective dose estimation is necessary to evaluate associated risk

Effective dose depending of : nature of body tissues, nature of radiation

For neutron radiation:
neutron nuisances on the body function of neutron energy
(as neutron-matter interactions)
equivalent dose is then function of :
- energy and fluence [m^{-2}]

→ Need to study and calibrate neutron dosimeters
-> need neutron calibration facilities

↓

Activities of the neutron metrology and dosimetry laboratory: LMDN

LMDN: laboratory associated with the national standard laboratory (LNE)

LNE
Le progrès, une passion à partager

For physics and dosimetry standards such as:

- Neutron fluence rate : Φ [$m^{-2}.s^{-1}$] → Energy distribution of the fluence gives dosimetric quantities

- Neutron kerma rate in tissues : $K_{tissues}$ [$Gy.s^{-1}$]
- Ambient dose equivalent rate : H(10) [$Sv.s^{-1}$]
- Personal dose equivalent rate $H_p(10,\alpha)$ [$Sv.s^{-1}$]

Major tasks as associated laboratory

✓Development, upgrade and maintain of

- tools to implement standard quantities in different values ranges →
- standard instruments for standard quantities measurement and associated uncertainty budget →

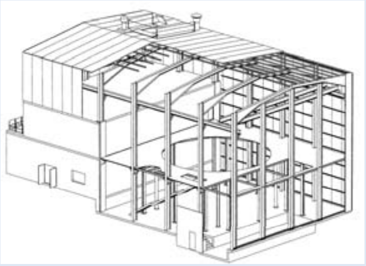
AMANDE facility

µ-TPC

✓Participating and being in charge of comparison exercises between different laboratories (national or international: NPL, PTB, …) → evaluation of uncertainties due to technical methods and data processing

The AMANDE facility :

Monoenergetic neutron fields
2 keV – 20 MeV
For tests and calibrations of neutron detectors



AMANDE team: V. Gressier, A. Martin, M. Pepino, M. Petit

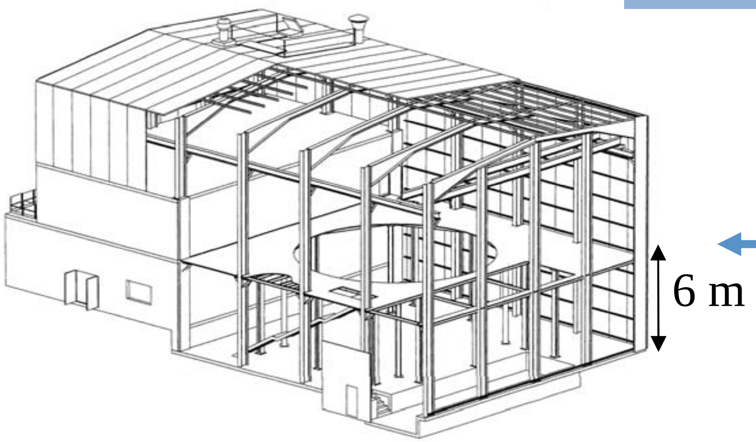
How to produce mono-energetic neutron fields?

Reactions between incident beam (d, p) and target: ^{2}H,^{3}H, ^{7}Li et ^{45}Sc

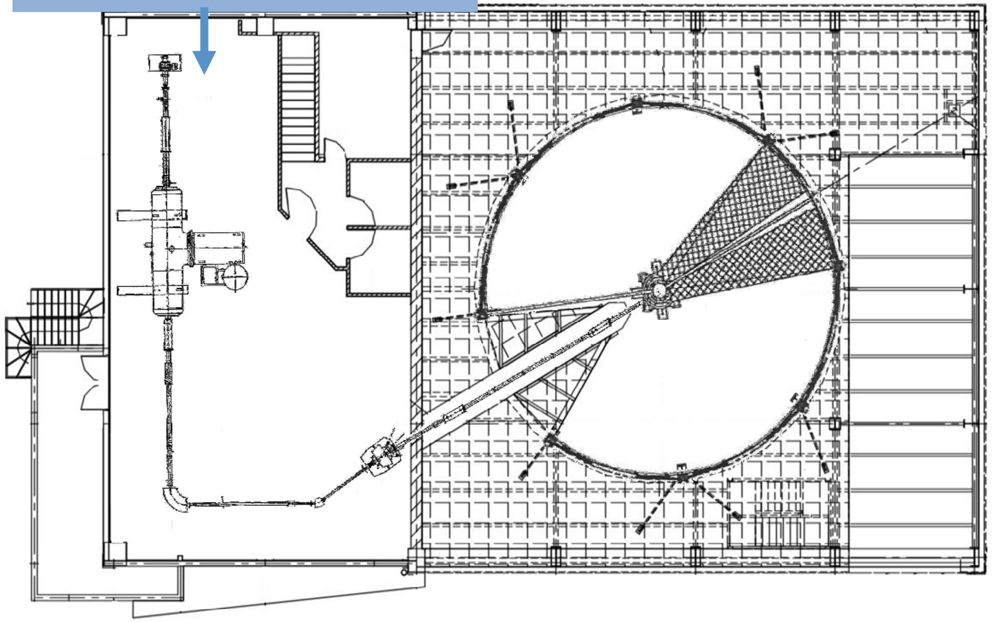
-Neutron emission within 4π
-At a precise direction angle with respect to the direction of the beam line: a unique peak neutron energy distribution
-Maximal emission rate (within 4π) from 10^5 s^{-1}(Sc 2keV) to 5.910^8 s^{-1} (TiT 2MeV) depending on reaction and target thickness
(for nominal running, the emission rate is divided by 2)

Incident particules (Beam)	TARGET	Reactions	Beam Energy Range	Neutrons Energies Range at (0°)
Protons	Scandium	$^{45}Sc(p, n)^{45}Ti$	2.91 to 2.95 MeV	5.6 to 52 keV
Protons	Lithium	$^{7}Li(p, n)^{7}Be$	1.92 to 2.38 MeV	120 à 650 keV
Protons	Tritium (TiT)	$^{3}H(p, n)^{3}He$	1.15 to 8.35 MeV (4.45)	290 keV to 7.6 MeV (3.7)
Deutons	Deutérium (TiD)	$^{2}H(d, n)^{3}He$	0 to 4.45 MeV	2.45 to 7.7 MeV
Deutons	Tritium (TiT)	$^{3}H(d, n)^{4}He$	0 to 3.7 MeV	14.0 to 20.5 MeV

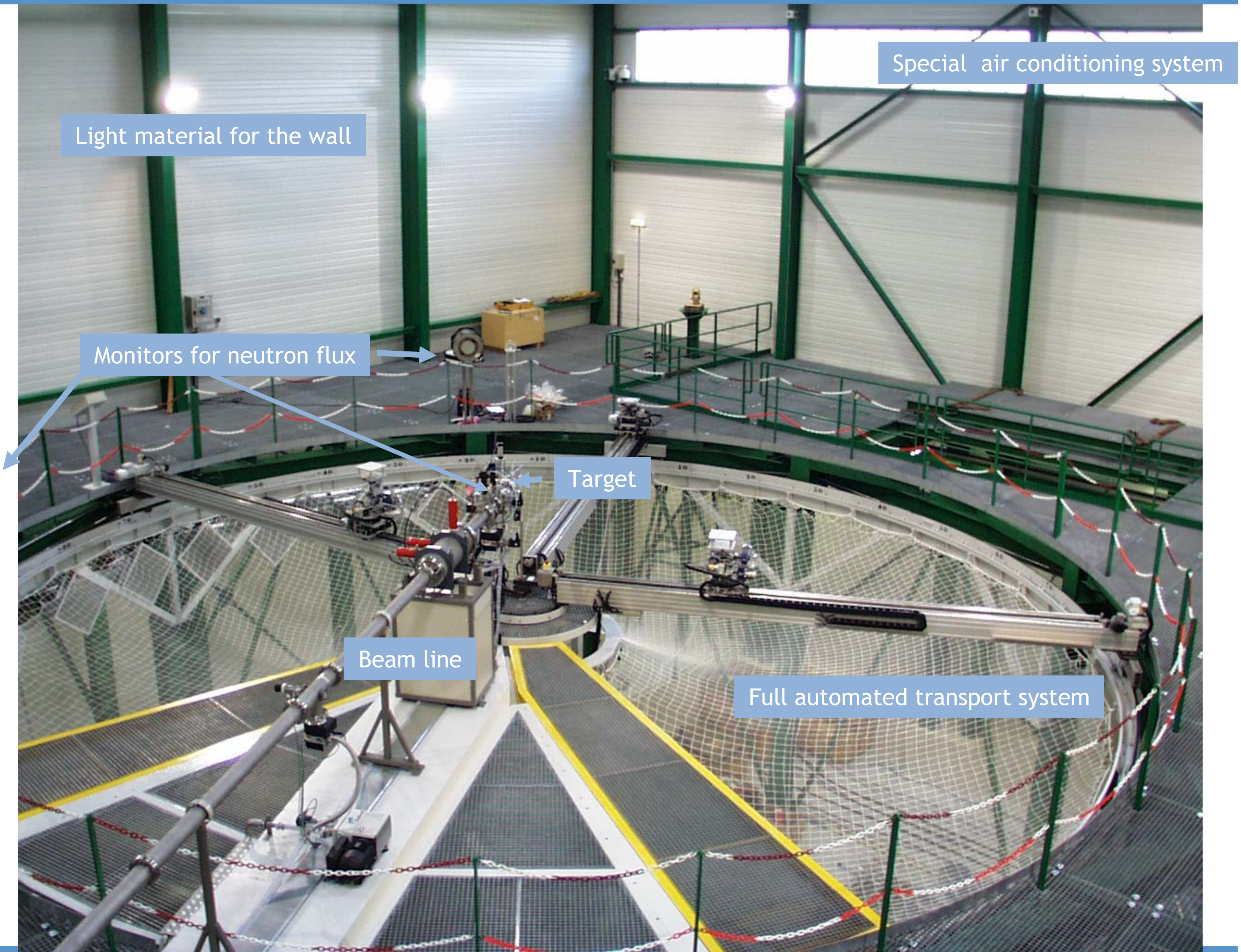
dedicated building to reduce neutron diffusion
(from 2%(TiD) to 18%(Sc) of diffused neutron depending of the reaction used)

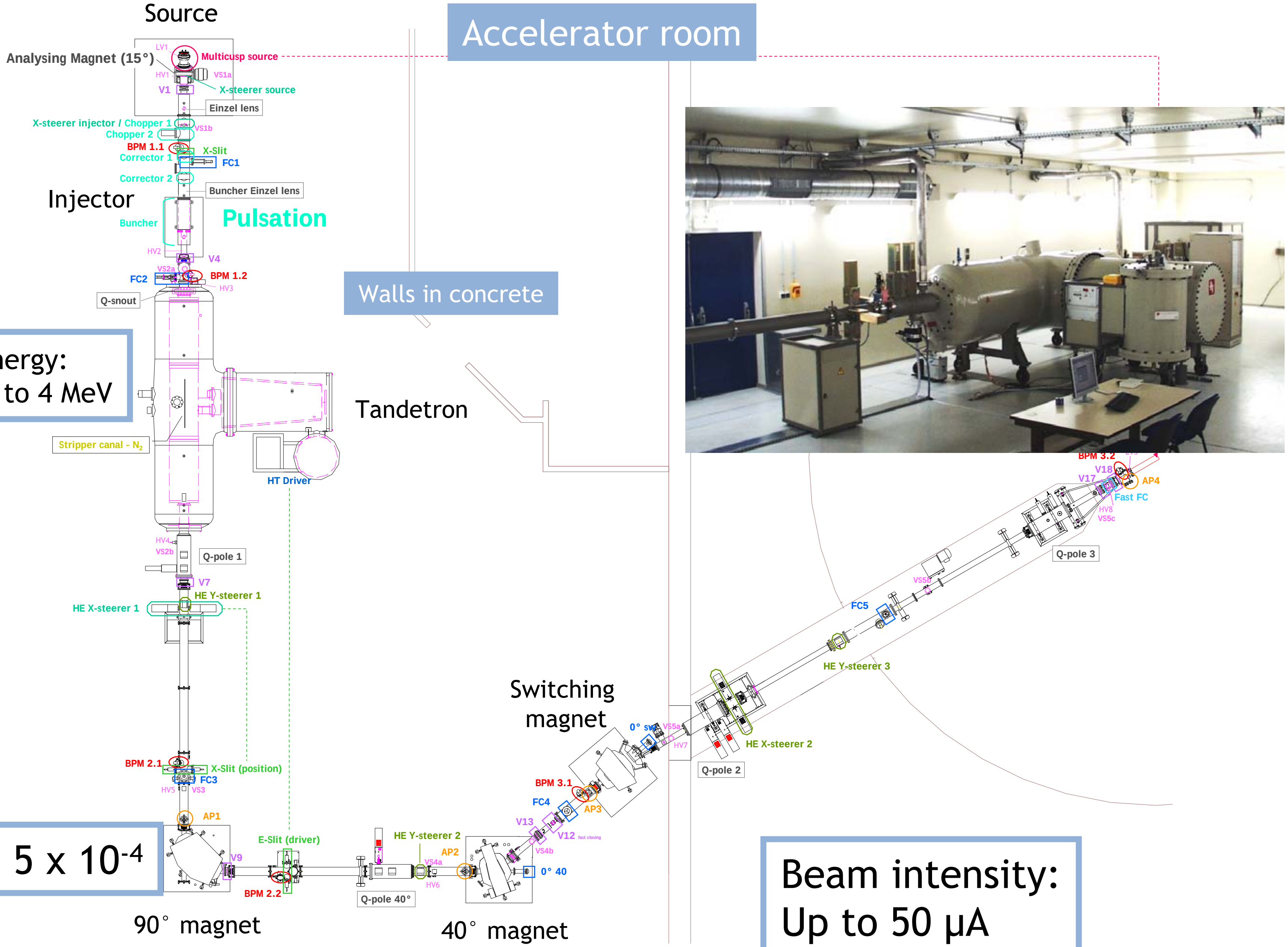


2MV accelerator tandem



Designed to spend relaxing and pleasant time
(if facility is switch off)


Special air conditioning system
Light material for the wall
Monitors for neutron flux
Target
Beam line
Full automated transport system

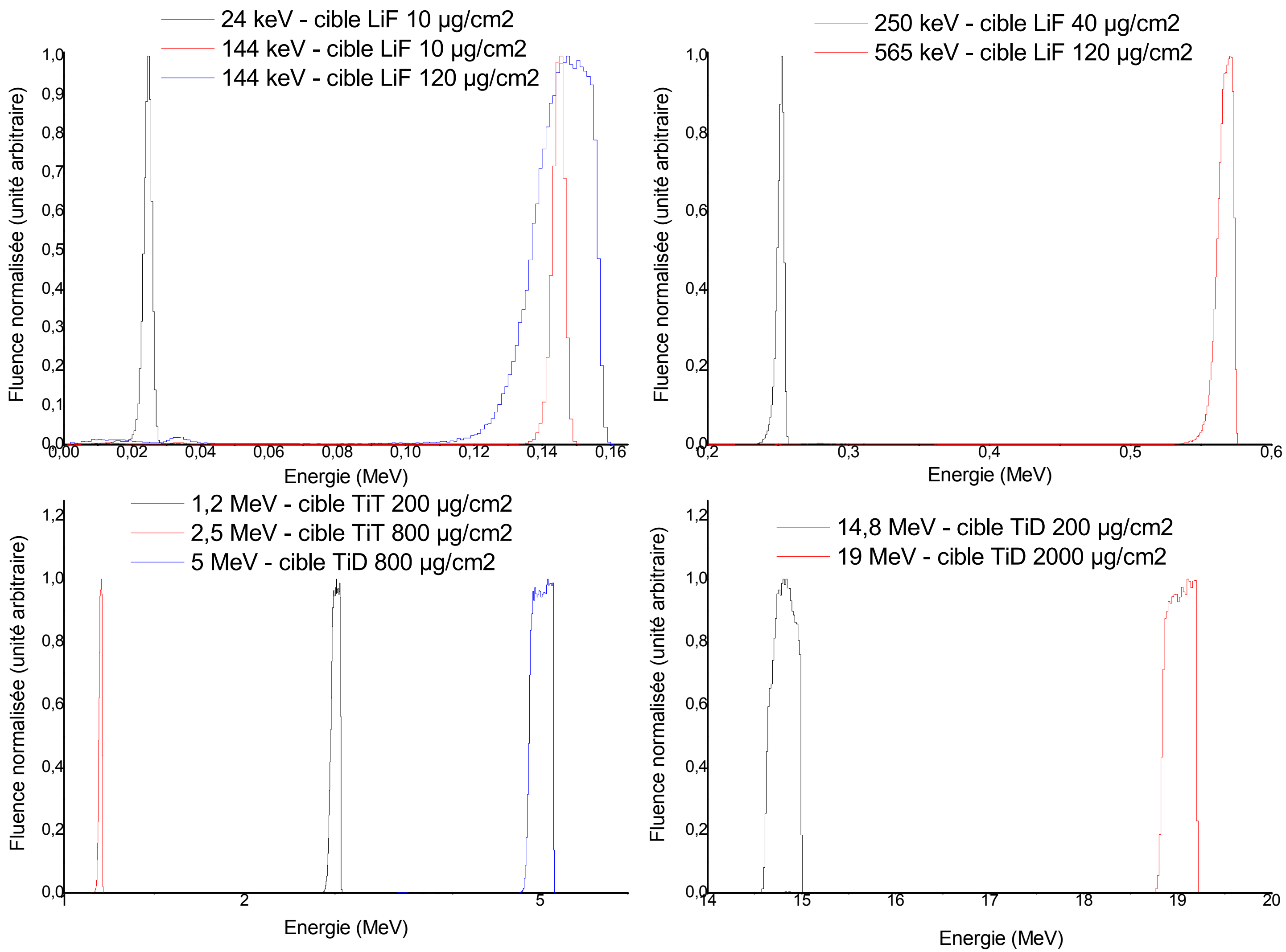


Beam Energy:
100 keV to 4 MeV

$\Delta E/E = 5 \times 10^{-4}$

Beam intensity:
Up to 50 µA

Resolution of the neutron energy distributions as function of the target thickness and the reaction used (simulations with TARGET code)

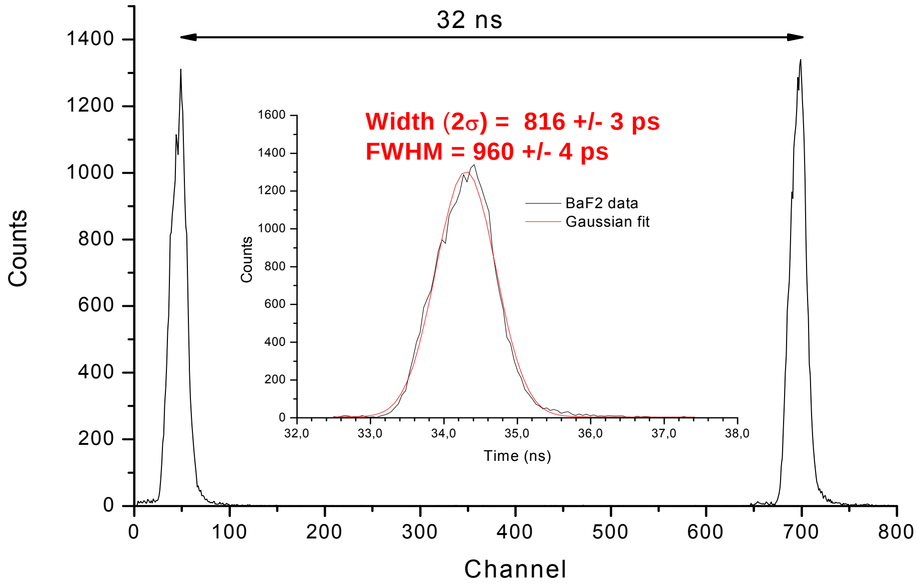


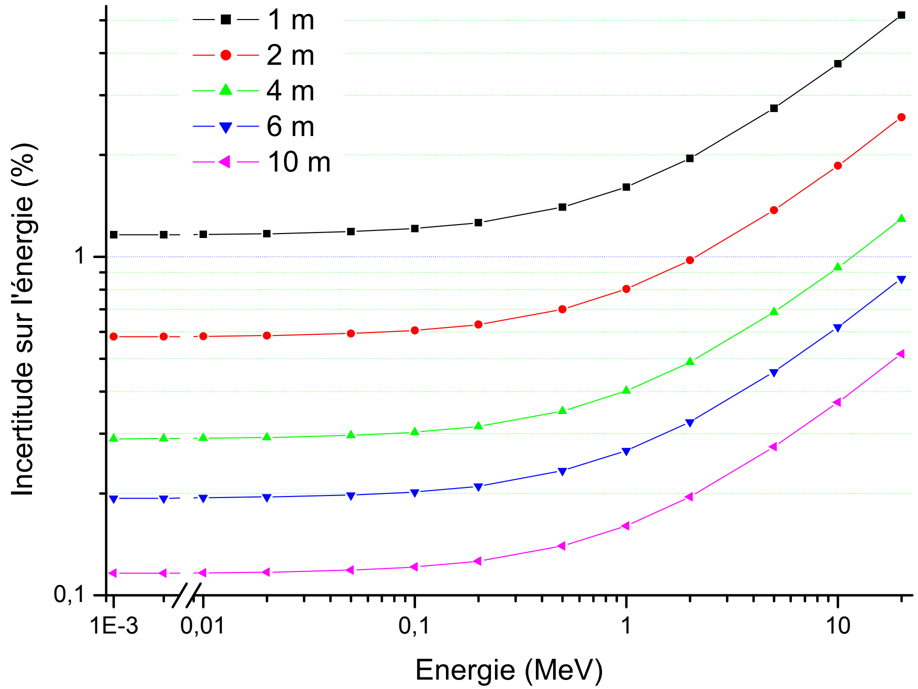
Two running modes : continuous and pulsed mode

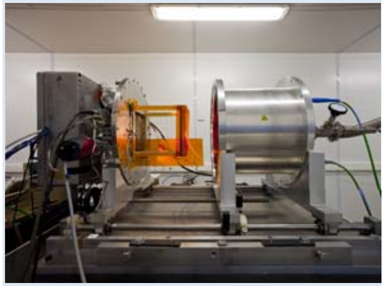
- **Neutron energy determined by Time Of Flight measurements**

- **Performances:**

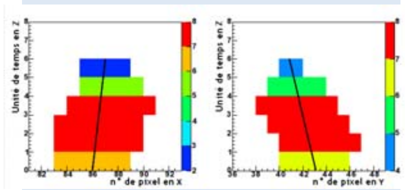
- flight path up to 10 m at 0° (6 m)
- pulsed mode frequency between 2 MHz and 62.5 kHz
- pulse width < 1 ns



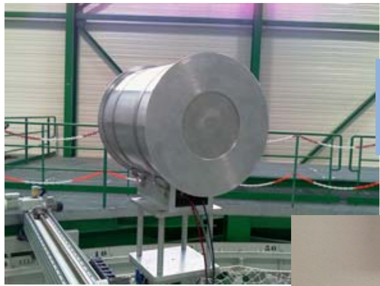




μ-TPC
Development of a reference detector to characterise neutron fields

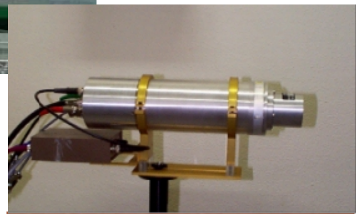


Present reference detectors at LMDN



Neutron integration from thermal to 20 MeV

- Long counter device for fluence determination (V. Lacoste)



BC501A
From 1 to 20 MeV

- TOF with BC501A for energy in pulsed mode (M.A. Cognet, V. Gressier)

SP2
From 100 keV to 2 MeV

- Proton recoil devices for energy fluence distributions (SP2, BC501A) (V. Gressier, L. Lebreton)

But:

✓No detection device at low energy (2 keV-100 keV)

✓SP2, BC501A are secondary standard detectors because of calibration using neutron fields at PTB

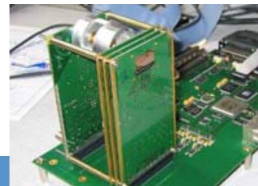
mono-energetic neutron fields produced by AMANDE are secondary references compared to PTB's ones

How to establish AMANDE neutron fields as national references (i.e. primary references) ?

(main goal for LNE associated laboratory)

Developing system for energy and fluence measurements without previous calibration using neutron field.

At high energy (from 5 to 20 MeV) a TPR-CMOS is under development
LMDN-IPHC Strasbourg (J. Taforeau, L. Lebreton, D. Husson, S. Higueret, T.D. Le)



IRSN

Developing a new device
- for detection at low energy (2 keV)
- using a primary reference measurement procedure

For energy:

Elastic collision of neutron in a converter material (target nuclei)

$$E_n = \frac{(1+A)^2}{4A} E_r / \cos^2\theta$$

Recoil nucleus (E_r)

Measurement of emission angle and energy of the recoil nucleus

→ **Direct measurement of neutron energy**

For fluence: → **Function of detected nucleus recoil number**

Good knowledge of :

- ✓Composition of the converter material
- ✓Elastic cross section
- ✓Geometrical efficiency
- ✓Correction factor (dead time correction, threshold, …)

For low energy detection: → gas as converter and detection technique

For good detection efficiency:

Use hydrogen as recoil nucleus (highest elastic cross section, no resonance)
Use localisation system to enhance solid angle but keep angular resolution

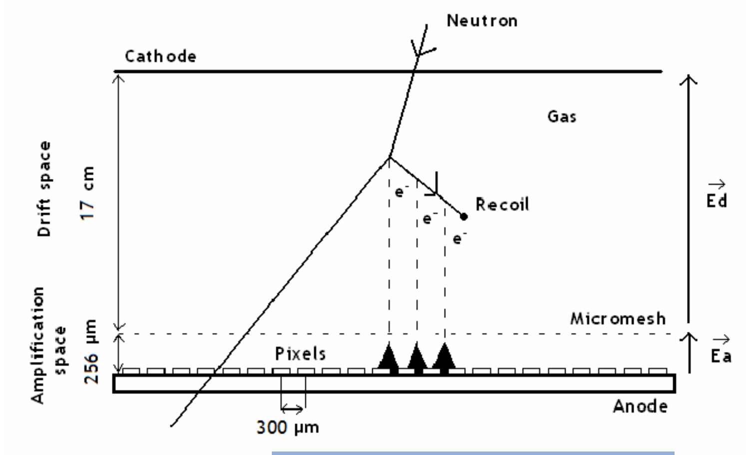
For hydrogen

$$E_n = \frac{E_p}{\cos^2(\theta)}$$

MIMAC prototype as reference neutron detector

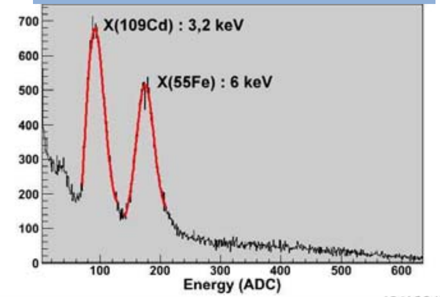
Gas mixture composed with hydrogen atoms
C_4H_{10}, ~~CH_4~~

$$E_n = \frac{E_p}{\cos^2(\theta)}$$



For proton recoil energy measurement

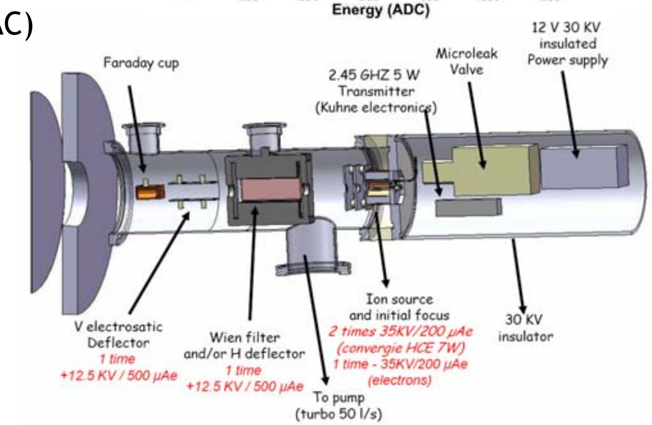
Energy threshold less than 2 keV neutron



✓Measure of ionisation charge collected on the grid

✓Calibration procedure with electron (^{55}Fe, ^{109}Cd, ^{133}Ba, RX generators, COMIMAC)

✓Knowledge of quenching factor (COMIMAC)



Coupling COMIMAC accelerator to µ-TPC neutron chamber
For quenching factor and calibration measurements
Exactly in the same experimental conditions than neutron measurements

MIMAC prototype as reference neutron detector

For recoil proton emission angle determination

Ref. talks: J. Billard, O. Guillaudin, O. Bourrion, E. Ferrer Ribas

Recoil proton track reconstruction

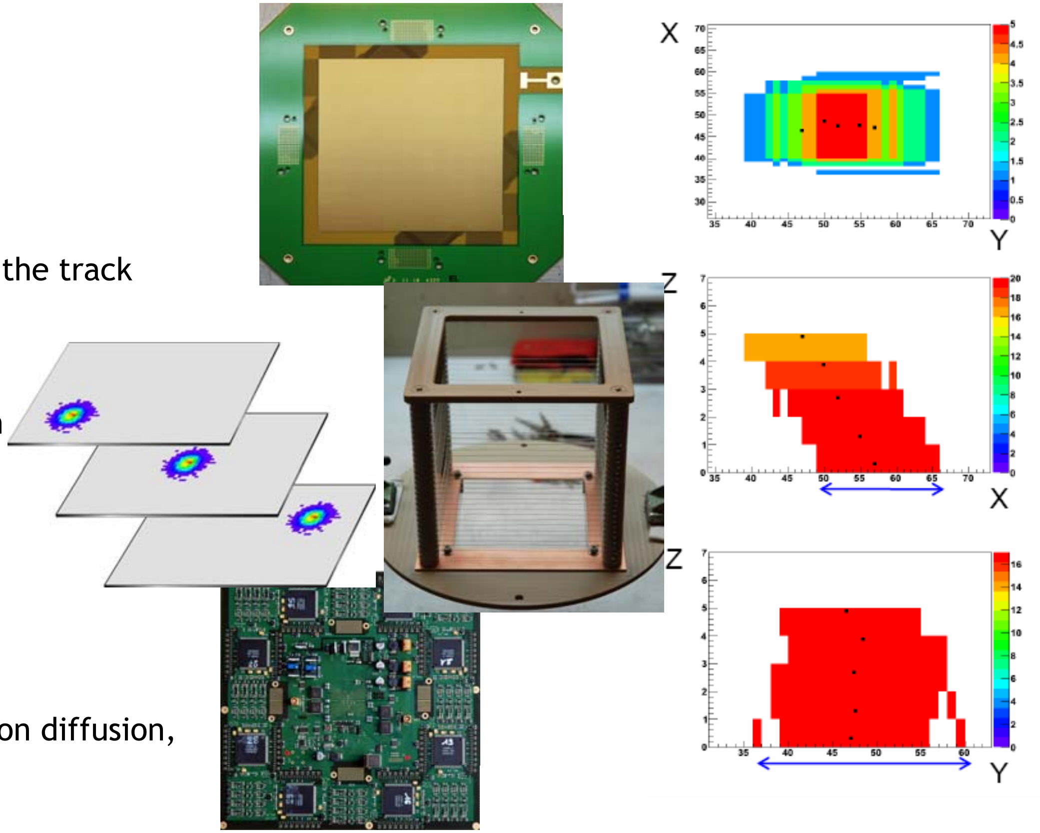
✓Gas mixture to obtain tracks as long as possible

✓MICROMEGAS pixellised anode for 2D projection of the track

✓Drift velocity measurement for the third dimension

✓Associated with fast electronics (50 MHz)

✓Non trivial method for track reconstruction (electron diffusion, likelihood function, …)



MIMAC prototype as reference neutron detector

For fluence rate measurement

$$\frac{d\Phi}{dt}(r/\Theta_d) = \frac{1}{r^2}\frac{1}{k_\varepsilon \varepsilon_{geom}}\frac{M_{mol}}{\rho N_A \sigma(E_n) n}\frac{dN_{int}}{dt}$$

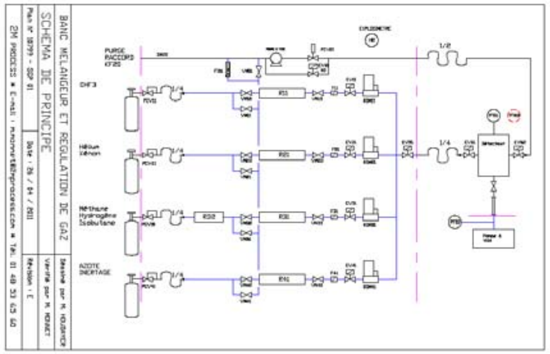
✓Geometrical efficiency $\varepsilon_{geom} = \int_V \sin\theta dr d\theta d\phi$

✓Correction factor for efficiency (events loss : threshold, dead time , incompletes tracks,…) : simulation

✓Cross section (n,p) : well known

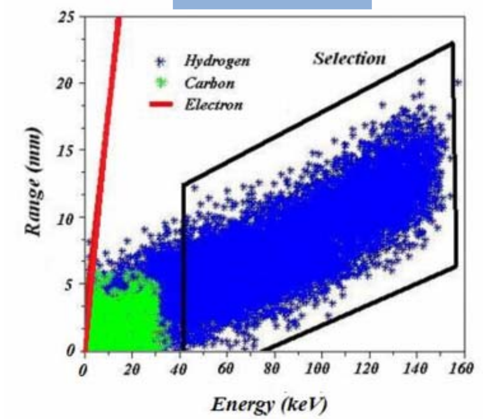
✓Gaseous converter material characteristics (pressure inside the chamber)

✓Number of recoil protons detected in the sensitive volume V

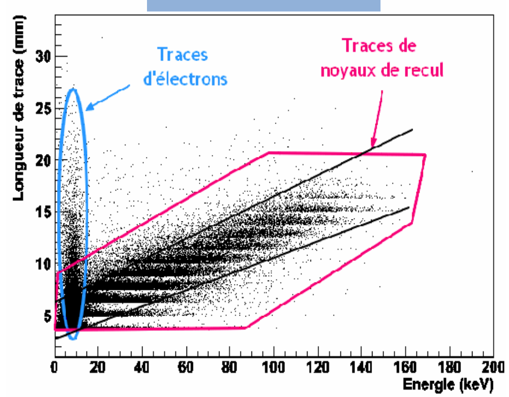


Good knowledge of the number of target nuclei in the sensitive volume

simulation



measurement



Recoil nuclei discrimination

C_4H_{10} 50 mbar

E_n = 144keV

IRSN

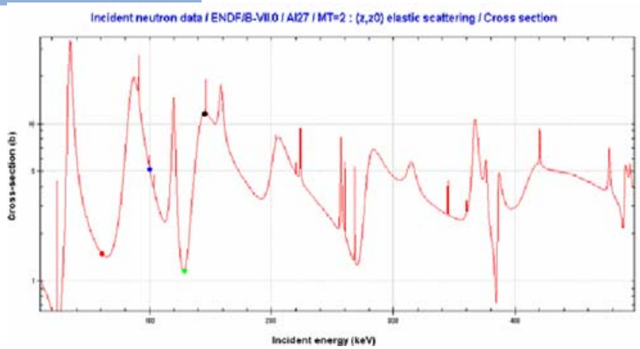
Conclusion and outlook

First results obtained with MIMAC prototype → validation of the concept: neutron detector

There is still a long way before establishing µ-TPC as a reference instrument for neutron energy and fluence measurements

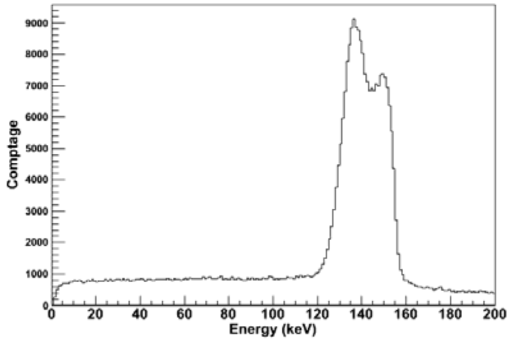
For proton recoil emission angle determination

Neutron diffused in Al chamber:



bad incident direction,
bad reconstructed energy,
events not taken into account for fluence

Cylindrical chamber with 2 cm Al entrance wall

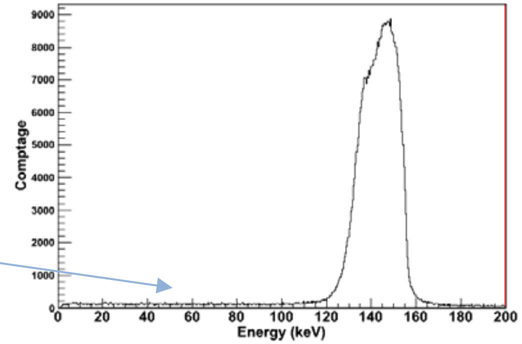


Built a new chamber

Reduction of the diffusion

MCNPX simulations (S. Valdenaire)

Cubic chamber with 3mm stainless steel



Track reconstruction is the sinews of war (emission angle at the beginning of the tracks, method is not trivial)
Which energy resolution we will obtain ?

IRSN

Conclusion and outlook

For proton energy

- Calibration process with nuclear sources and COMIMAC: traceability to charged particles quantity value

Proof of the energy calibration linearity up to ~ MeV ?

- Collection of the totality of the charge: depends of the gas mixture and applied potential
- Quenching factor: with COMIMAC (establish the best process)
- What is the high energy threshold ?

For fluence

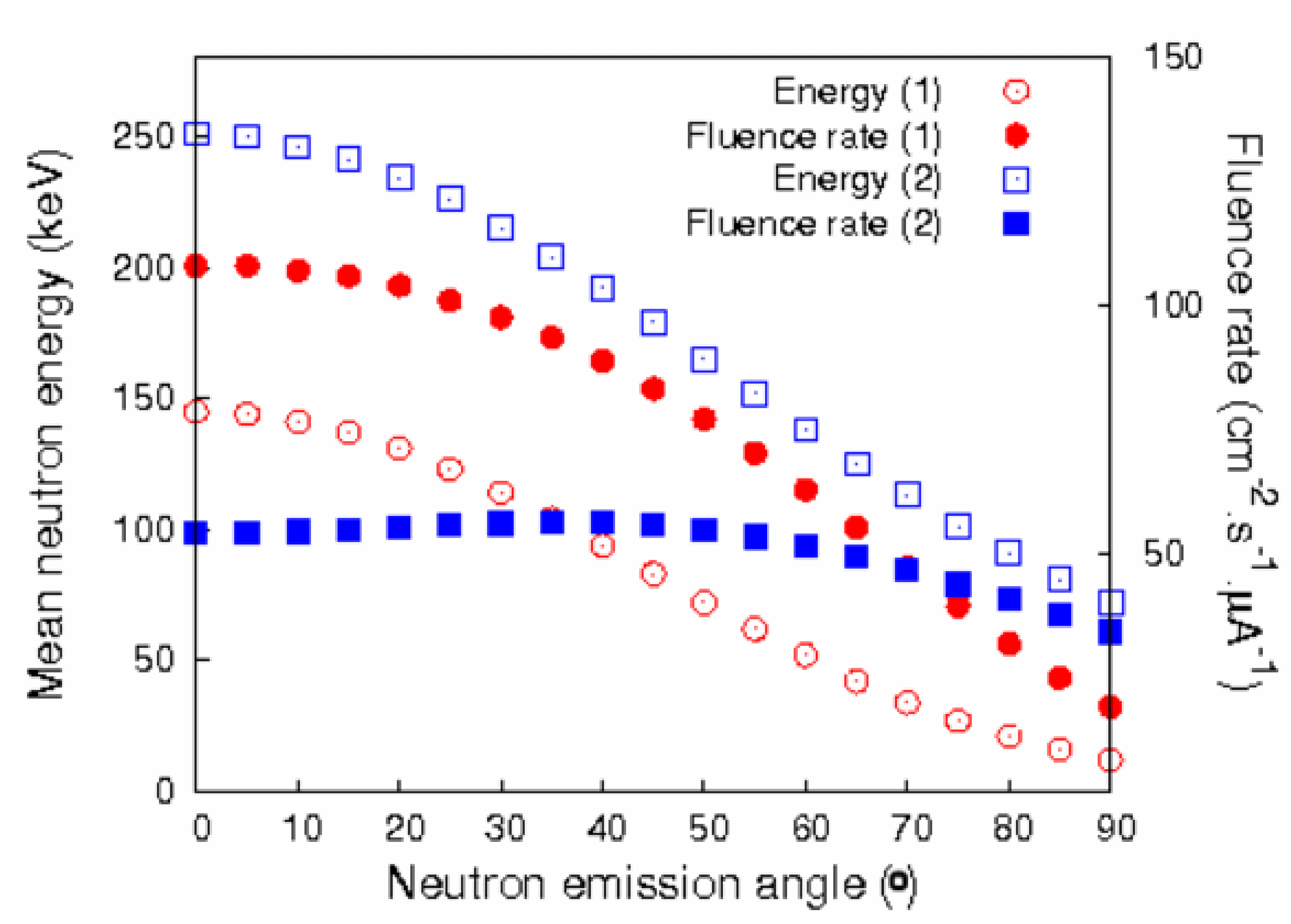
- Gas purity, pressure and temperature must be mastered
- Correction factor for events lost: good simulation is a hard work!

Security and environment rules

- Choice of the gas mixture: fluoride gas management?
- Use of mini-accelerator device: COMIMAC
- Use of α nuclear source

Precise uncertainties budget calculation must be done for energy and fluence measurement

For qualification: intercomparison exercise will be planned with other foreign national laboratories


Energy (1)
Fluence rate (1)
Energy (2)
Fluence rate (2)
Mean neutron energy (keV)
Fluence rate (cm-2.s-1.µA-1)
Neutron emission angle (°)
0
50
100
150
200
250
0
10
20
30
40
50
60
70
80
90
50
100
150