Neutron induced reactions studies in the 20-200 MeV energy range

The aim of the workshop is to discuss the current status of the iThemba LABS neutron beam facility, plans for the upgrade and the expectation of the fast neutron science communities.

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OUTLINE

- Why the 20-200 MeV energy range ?
- Which kind of measurements ?
- How technical needs fit with iThemba characteristics ?

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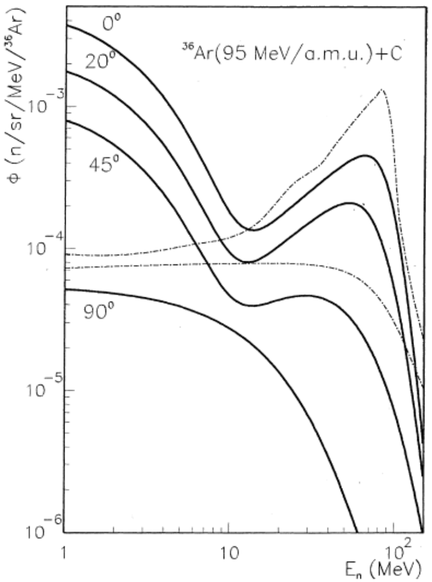
Exploitation of high energy accelerators

- High energy accelerators :
  - heavy ion beams interaction produce neutrons of high energy
  - Intense beam up to several mA
- Potential impact :
  - Radioprotection : dose equivalent calculation
  - Waste and operation management
  - Electronic resistance
- Needs of simulation tools :
  - Particle transport (MCNP, GEANT, PHITS …)
  - Activation (FISPACT, CINDER…)
- Neutron dosimeters : What is their reliability for neutrons E > 20 MeV ?

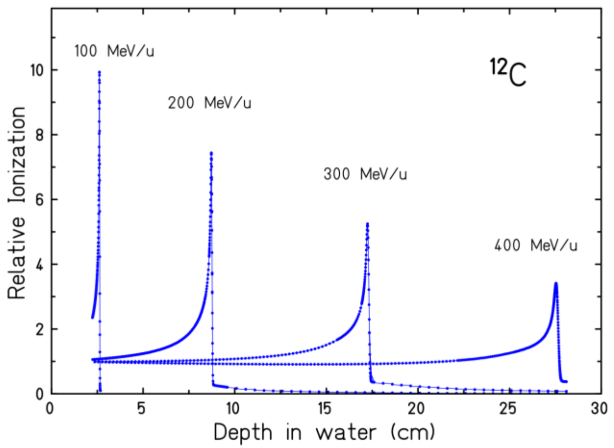


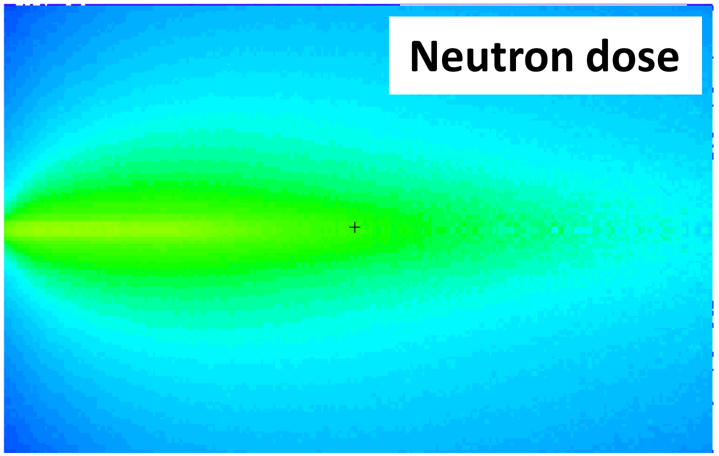
- Example of facilities :
  - Research facilities : GANIL,
  - Hadrontherapy
  - Spallation facilities: SNS, ESS
  - Fusion facilities : IFMIF

Needs of reliable evaluated data above 20 MeV

Hadron-therapy

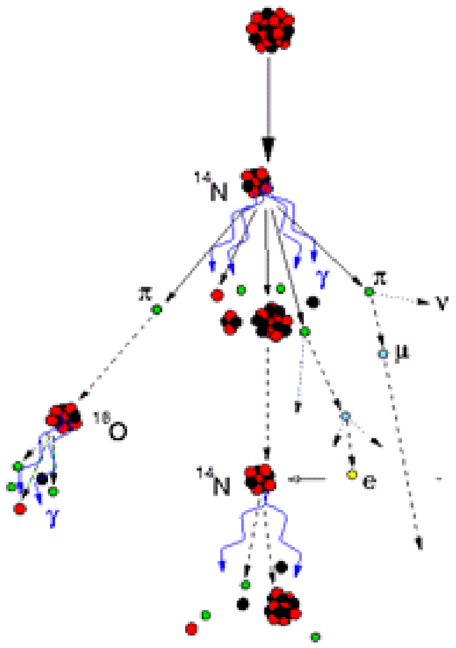
- Irradiation of tumor by heavy ion of high energy, typically Carbon ion at 400 MeV/A
- Ballistic interest for a better localization of the energy deposition
- But :
  - Production of secondary particles by fragmentation : neutron, light charged particles
  - Consequences : displacement of the dose deposition
  - Need of neutron induced cross-sections up to 400 MeV



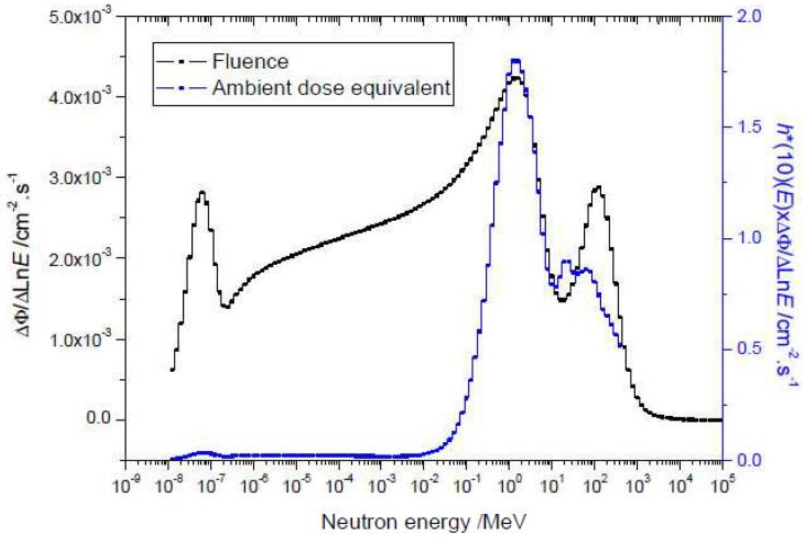


Needs: double differential cross-section of (n,lcp)

Atmospheric neutrons



- Neutrons produced as secondary particles in hadronic cascades in the Earth's atmosphere
- Neutron spectrum depends on the altitude
- Impact of neutron interaction
  - Dose for flight crew
  - Source of soft upsets
- Energy range of interest:
  - Around 1 MeV (evaporation spectrum)
  - Around 100 MeV (INC peak)

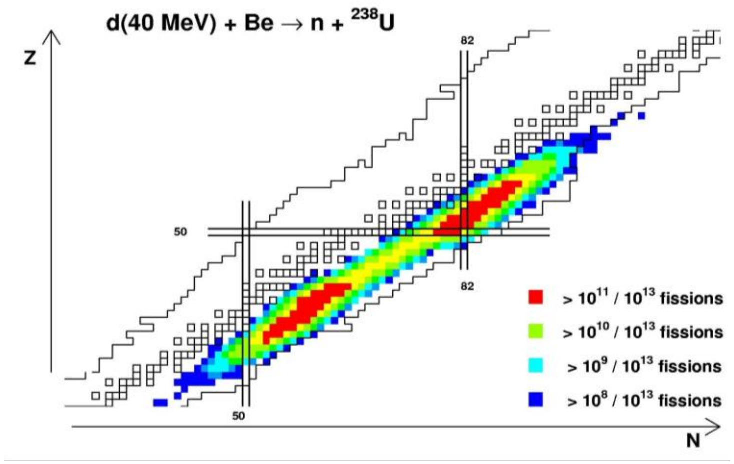


Needs:

- (n,lcp) reaction cross-section measurement
- Radiation hardness test capabilities

Neutron rich nuclei production

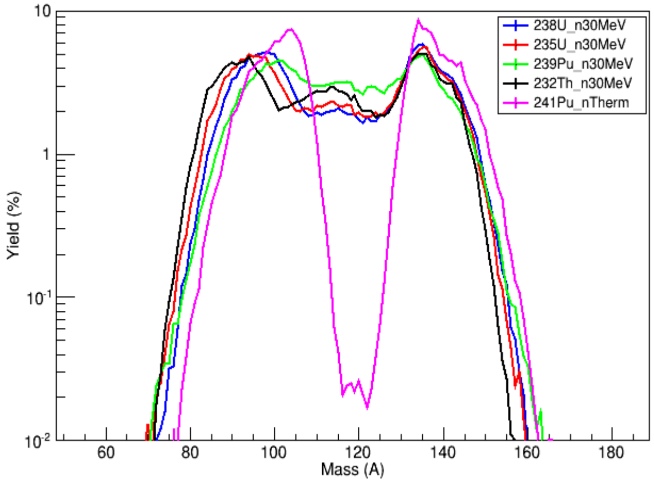
- Fission is an very efficient way to produce neutron rich nuclei
  - ILL
  - SPIRAL-2 project
- With thermal neutrons
  - Low excitation energy
  - Asymmetric fission
- With high energy neutrons
  - High excitation energy
  - Symmetric fission
  - High yield of 110<A<130



Applications :

Gamma spectroscopy of rich nuclei

Production of intense RIB



Needs : fission yields measurements

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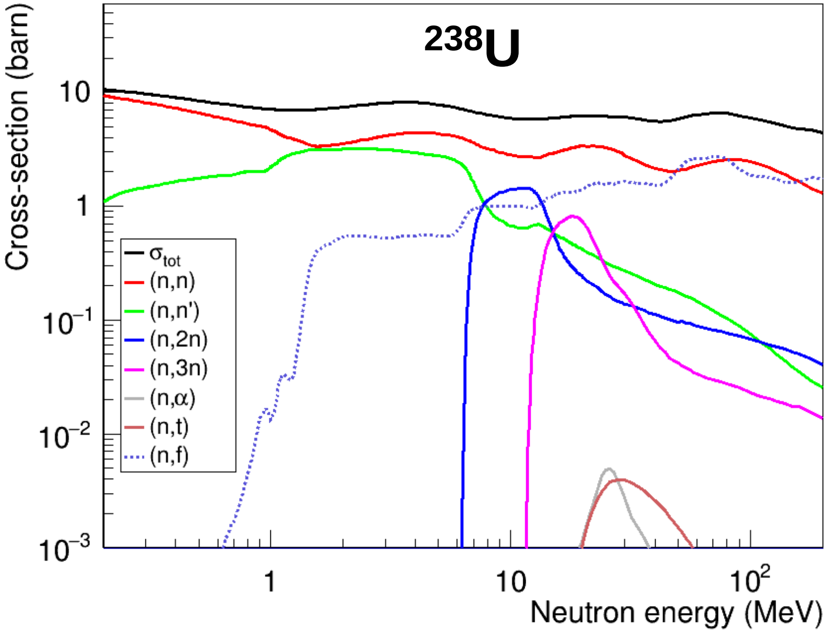
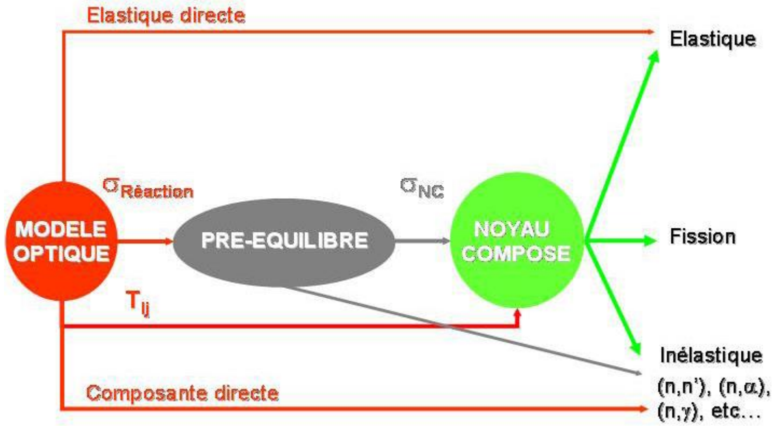
Evaluated data bases

- Many reaction channels are open in this energy domain
- Elastic, inelastic, fission, light charged particle production, (n,xn)
- For a coherent data evaluation all the reactions channels must be known
  - Accurate measurements
  - Reliable reaction models





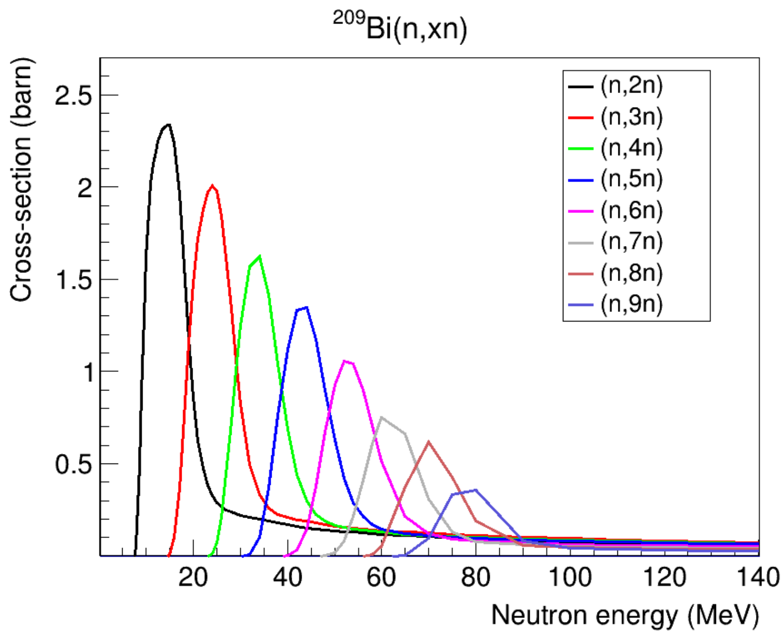
(n,xn)

(n,lcp)

(n,fission)

n,xn reactions

- Large part of cross-section above few MeV
- Few data for E>20 MeV or x>3
- Test of the reaction models
  - Mainly pre-equilibrium process
  - Measurement of several observables in coincidence
- Important role for some applications:
  - Damages of vessel or fuel
  - Waste production



Techniques:
- Direct measurement of neutrons
- Gamma spectroscopy
- Activation measurement

n,xn reaction direct neutron measurement

- Detection of the x emitted neutrons

❑ Advantages :

  - Direct measurement
  - Applicable to all nuclei

❑ Drawbacks:

  - Need a mono-isotopic target
  - Neutron detector of high efficiency
  - Non discrimination from of reaction channels

❑ Detector type :

  - Neutron balls
  - Neutron spectrometer

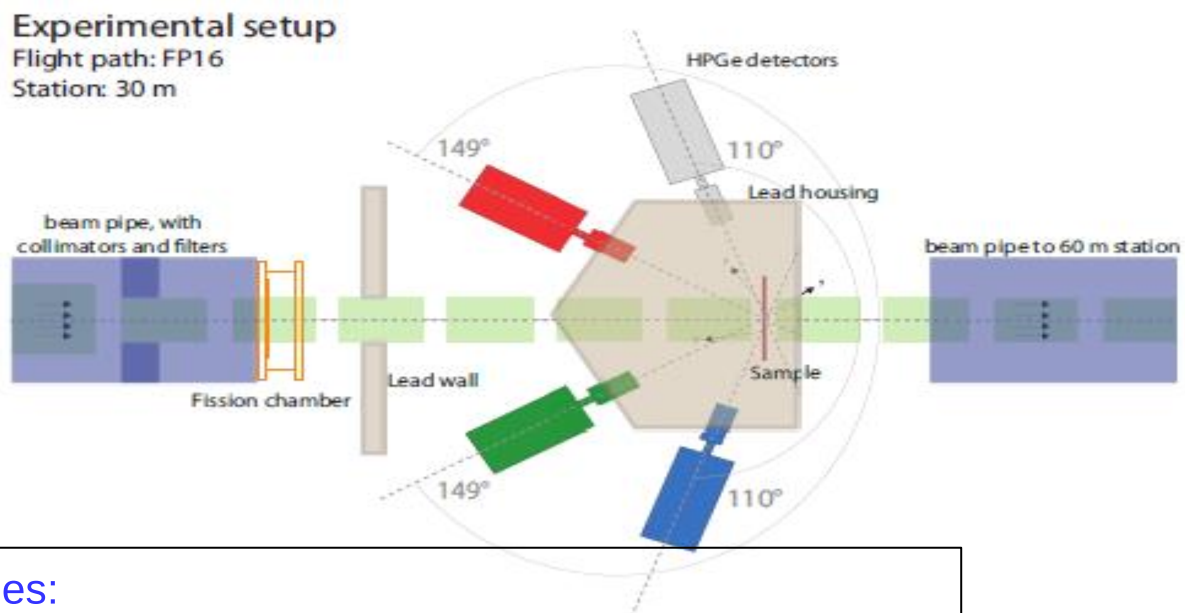
Needs : very well collimated neutron beam
Low gamma background

A added value would consist in measuring another observable in coincidence : the neutron spectrum for instance

n,xn : Prompt γ-ray spectroscopy

Detection of the γ-**rays stemming from the decay of excited states of nucleus created by the (n,xn) reaction.**

Measure on line of prompt gamma spectroscopy of the $^{A-x+1}_{Z}X$

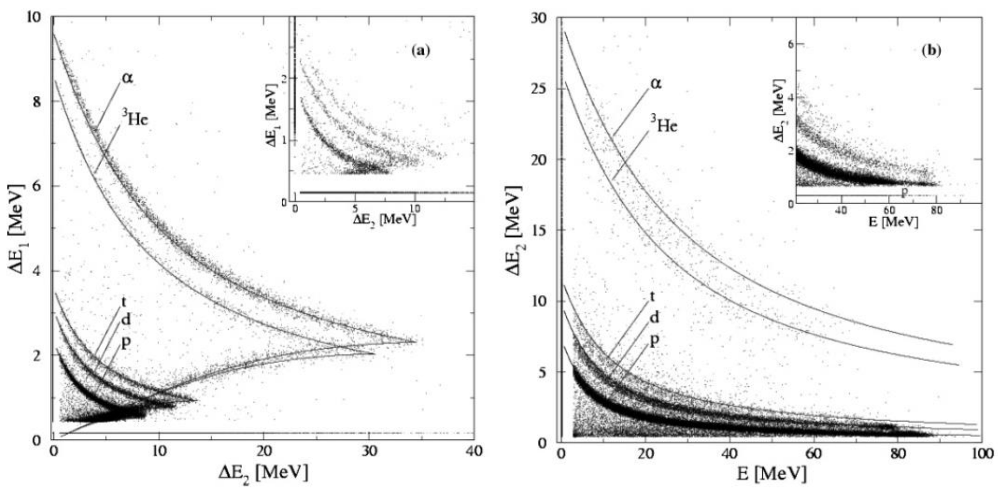


- **Advantages:**
  - The incident energy can be measured if the beam is pulsed
  - On-line measurement of several energies during the same run
  - Several isotopes can be measured simultaneously
- **Drawbacks :**
  - (n,xnγ) cross-section is measured
  - Calculations are required to determine the (n,xn) cross-section

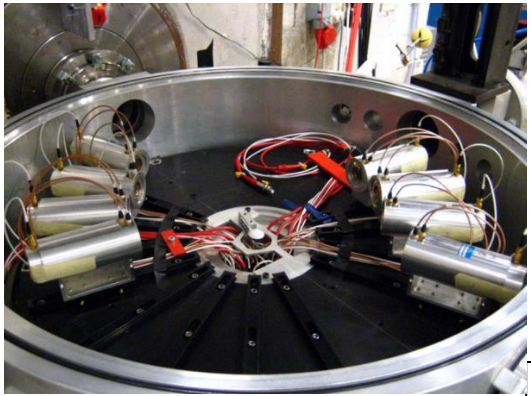
Needs :
- Well collimated neutron beam
- Low gamma background

Light Charged particle emission

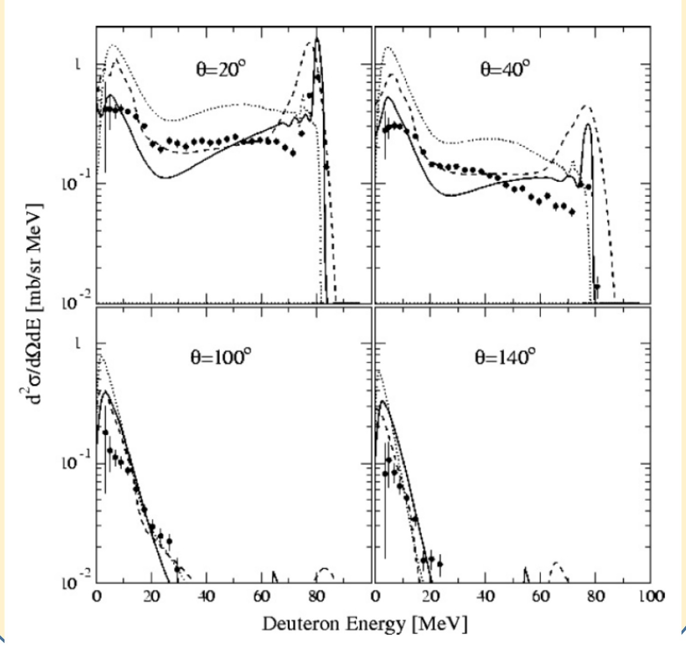
- Example : MEDLEY detector Uppsala University
- Neutron beam at 96 MeV produced by ^{7}Li(p,n) reaction
- MEDLEY detector : 8 telescopes for light ions measurement



Needs : quasi-mono-energetic or continuous spectrum



96 MeV C(n,xd)

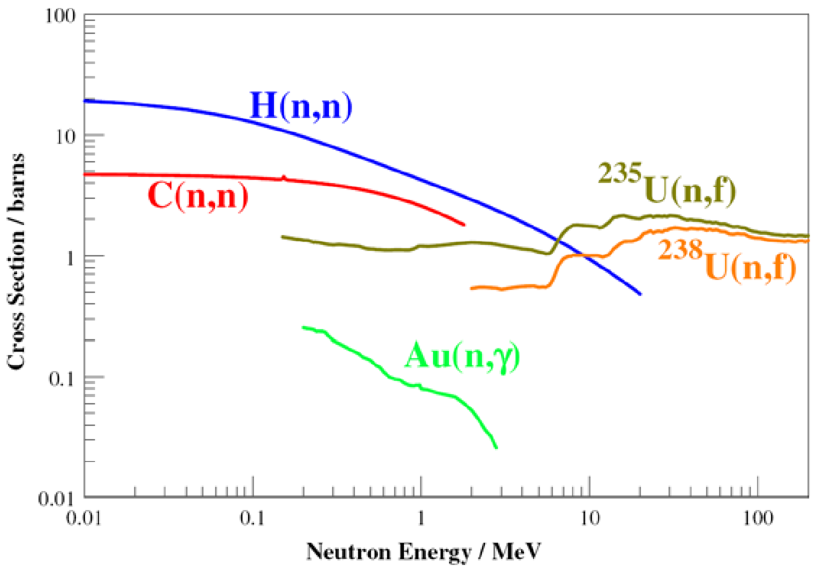


*Tippawan et al., Phys. Rev. C **79**, 064611 (2009).*

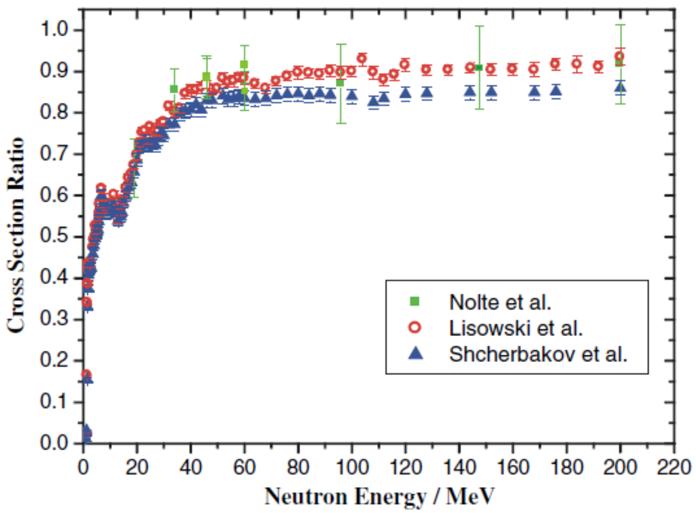
Fission : cross-section measurement

- Accurate data are needed for reliable evaluation
- ^{235}U(n,f) and ^{238}U(n,f) reactions are **neutron standards**

The measurement vs primary H(n,n) standard could minimize syst. uncertainties



A.D. Carlson, Metrologia **48** (2011) S328-

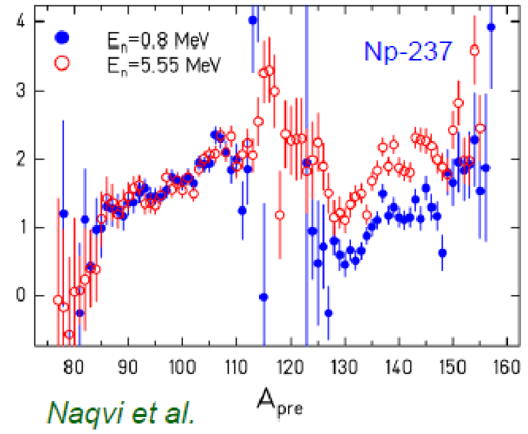


Technical needs :

- Neutron energy measurement
- Authorization for actinide sample
- Well characterized sample : mass purity
- High fluence rate because of low mass sample

Fission fragments yields measurements

- Distributions measurement for application and fission process study
- Fission fragment mass distribution measurement in fast neutron induced reaction
- Difficulties :
  - Detection of both fragments in coincidence → low efficiency
  - Low mass sample → low fission rate
  - Low energy fragment → cannot use a magnetic spectrometer
- Many techniques :
  - E-V
  - 2E-2V
- Many detectors running or under development:
  - VERDI, FALSTAFF, SPIDER, STEFF
- Measurement in coincidence of neutron and gamma rays

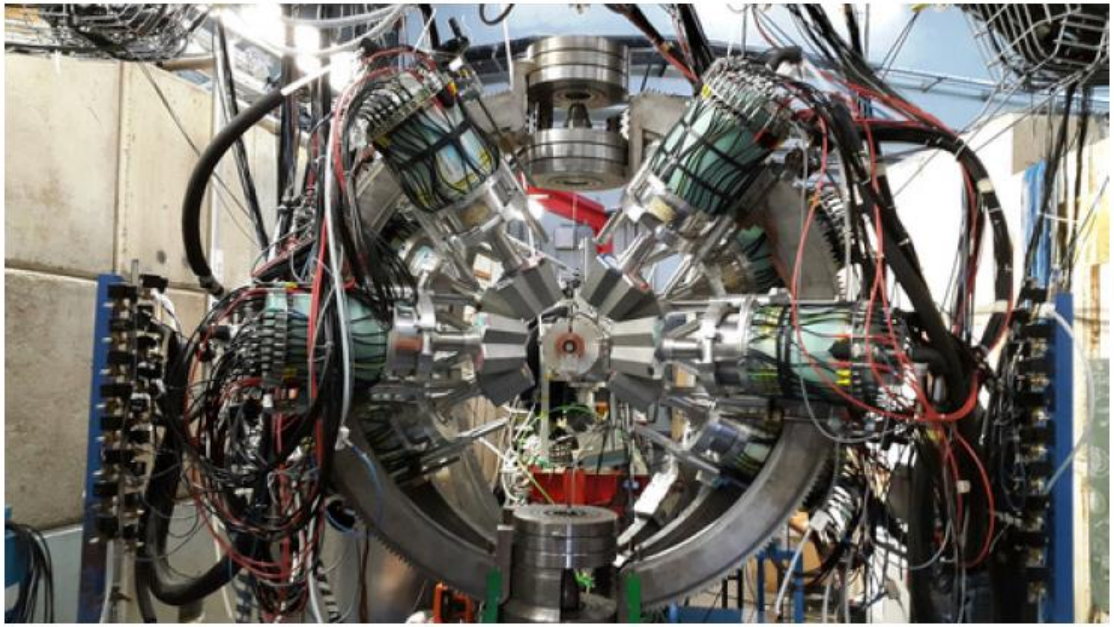


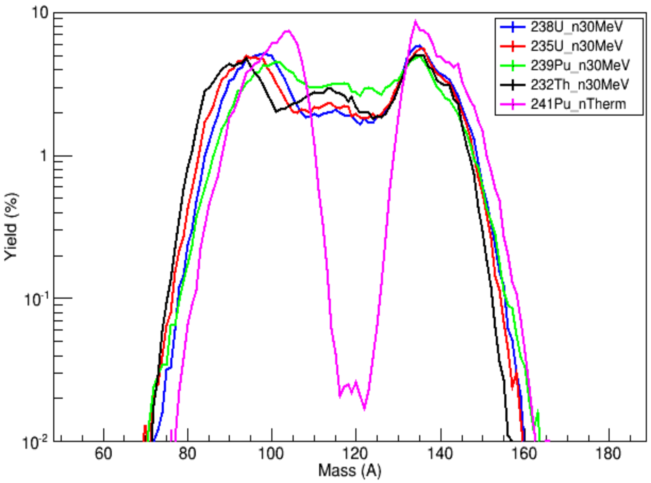
Technical needs :

- High flux
- Energy measurement
- Authorization for actinide sample

Gamma spectroscopy of fission fragments

- Gamma multiplicities and spectra measurements
- In-beam spectroscopy: Large detector array





Technical needs :

- Low gamma background
- Well collimated neutron beam

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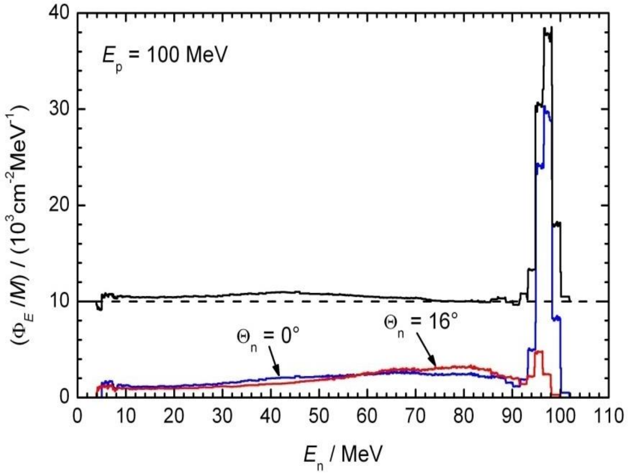
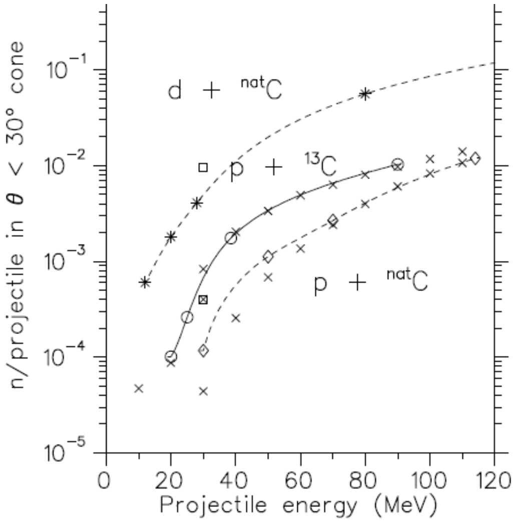
The iThemba LABS Neutron Beam Facility

- Targets:
  - Li, Be: quasi-monoenergetic
  - C: quasi-white ('grey')
- Beam currents
  - 3-5 μA (Ep < 100 MeV)
  - 300 nA (Ep = 200 MeV)
- Pulse selection: 1/1 – 1/7
- Time resolution: ≈ 1 ns
- Flight paths:
  - 10 m (0°)
  - 8 m (16°)



E_0 (MeV)	current (μA)	$d\Phi/dt$ (cm^{-2} s^{-1})
66	3.0	4.7×10^4
100	3.0	3.4×10^4
150	2.0	2.8×10^4
200	0.3	4.6×10^3

Z. Radivojevic et al., NIMB 183 (2001) 212-220



- Using a deuteron beam instead of proton one could provide a much higher flux
- Deuteron beam impinging a thick Be target
  - I=3μA →$d\Phi/dt \approx 2.3 \times 10^6$ $cm^{-2}.s^{-1}$
  - Continuous spectrum then f=1/7 →$d\Phi/dt \approx 2. \times 10^5$ $cm^{-2}.s^{-1}$

Time structure

Accelerator characteristics :

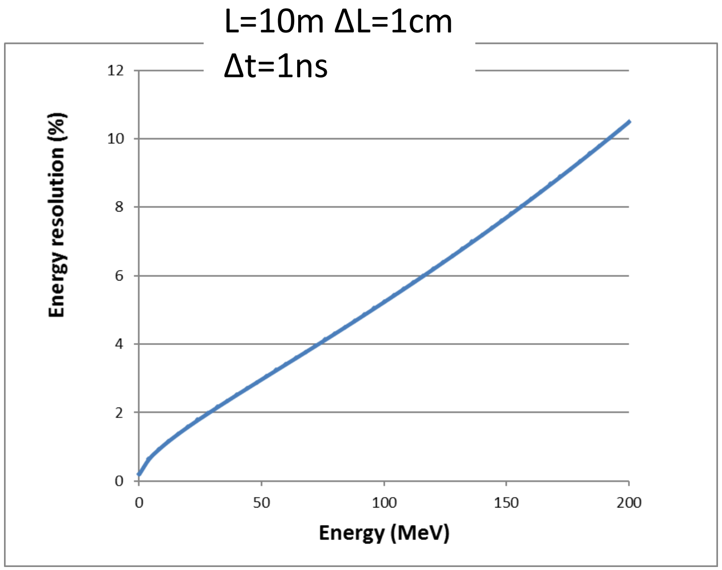
Time Resolution 1ns

Frequency 26 MHz → 2.5 MHz

Flight path 10 m

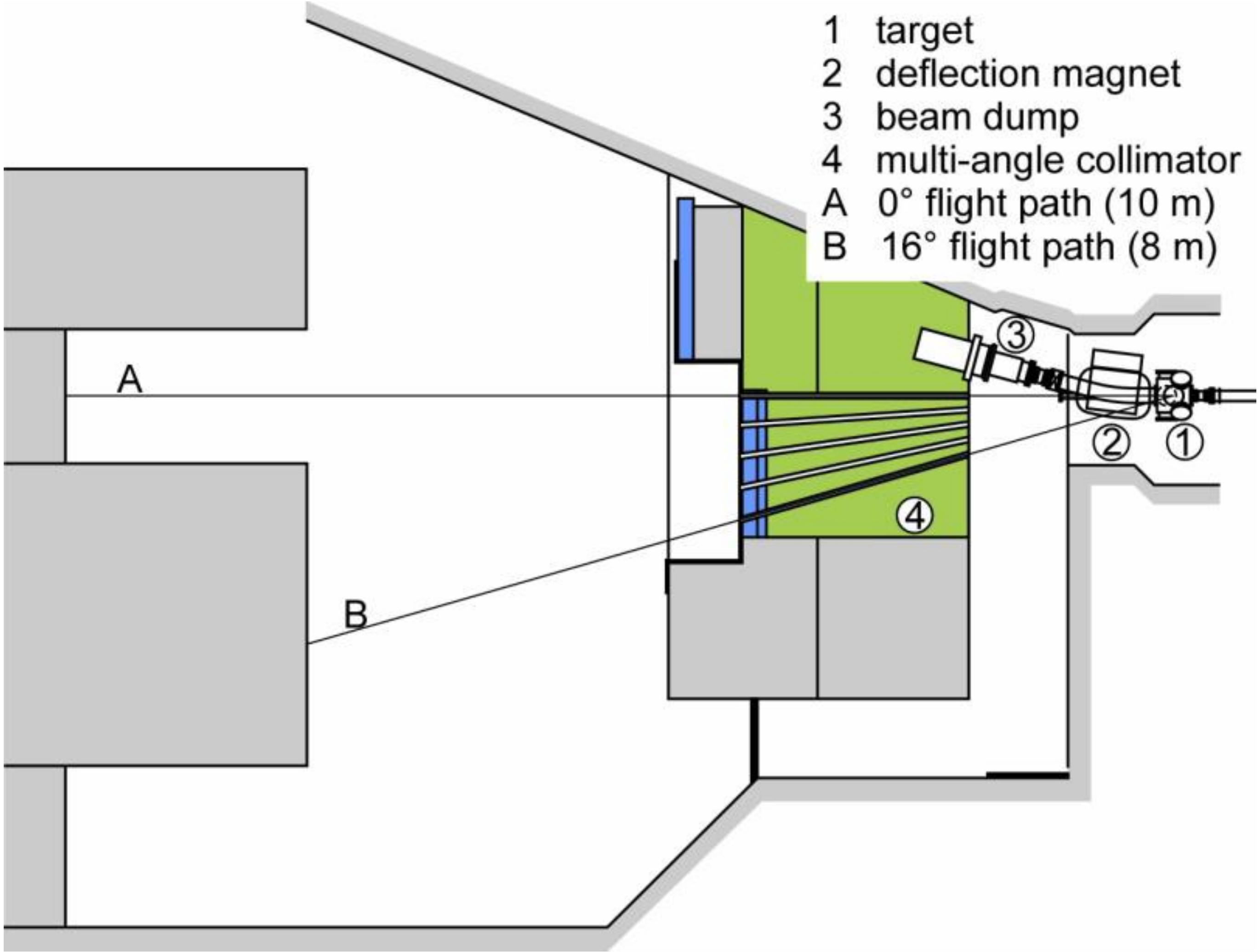
- Energy resolution

$$\frac{\Delta E}{E} = \gamma(\gamma+1)\sqrt{\left(\frac{\Delta t}{t}\right)^2 + \left(\frac{\Delta L}{L}\right)^2}$$

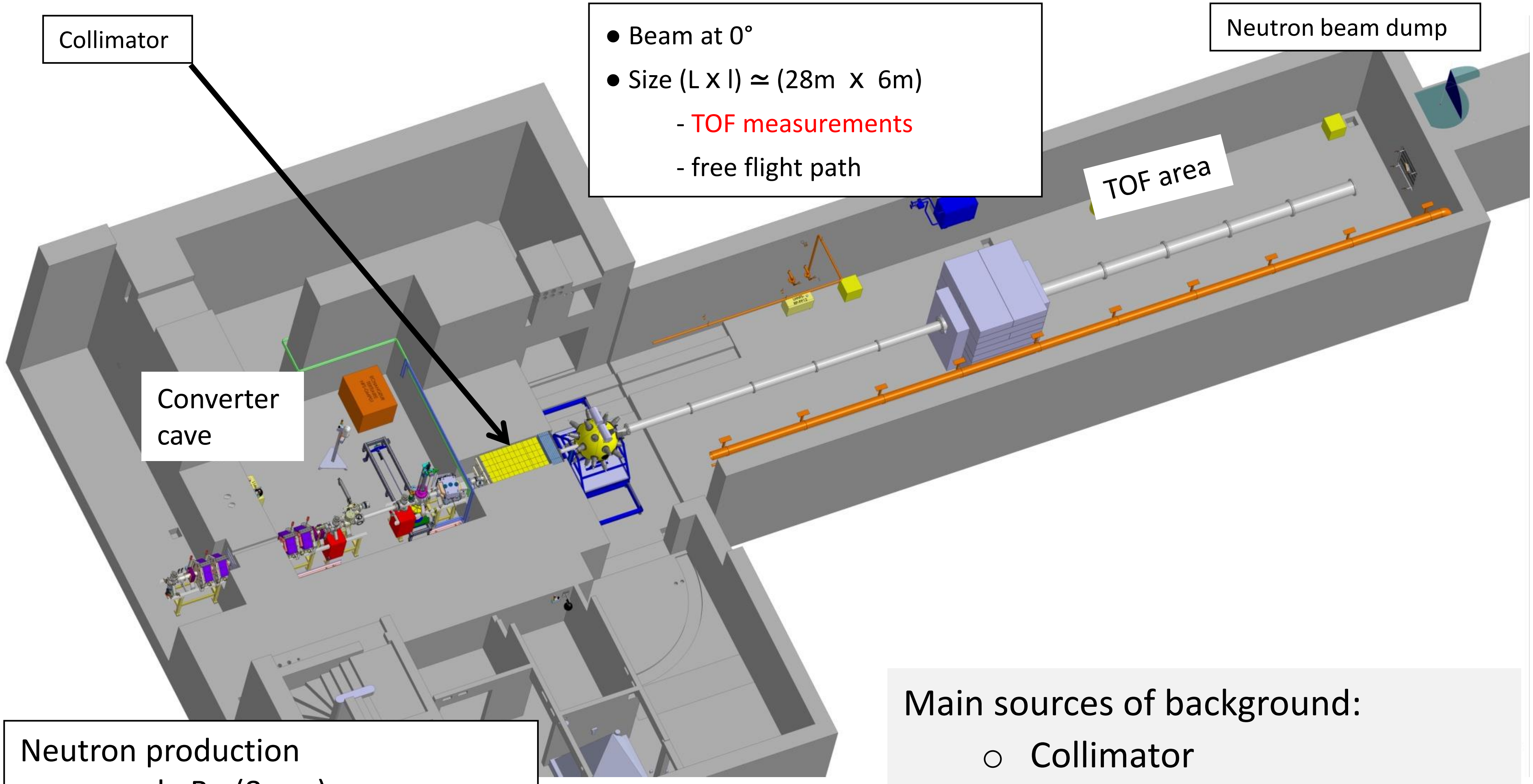


- Beam overlap : f=2,5MHz → Ethres ≈ 3 MeV
  f=26MHz → Ethres ≈ 120 MeV

Neutron and photon background ?



The Neutrons For Science Facility



- Beam at 0°
- Size (L x l) ≃ (28m x 6m)
  - TOF measurements
  - free flight path

Neutron production
- d+ Be (8mm)
  - I=50 µA
  - E=40 MeV
- p + ^{7}Li

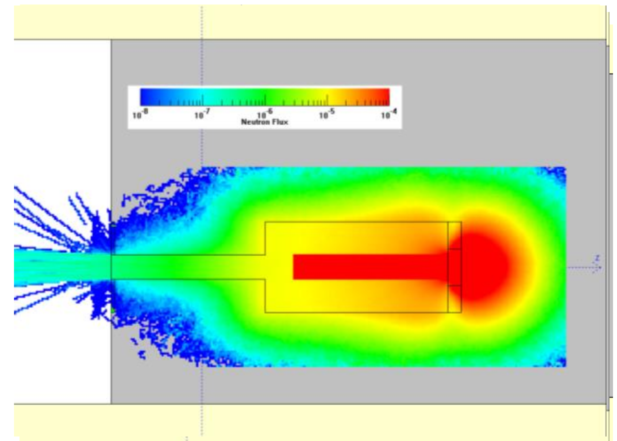
Main sources of background:
- Collimator
- Neutron beam dump
- Doors
- The neutron scattering on air

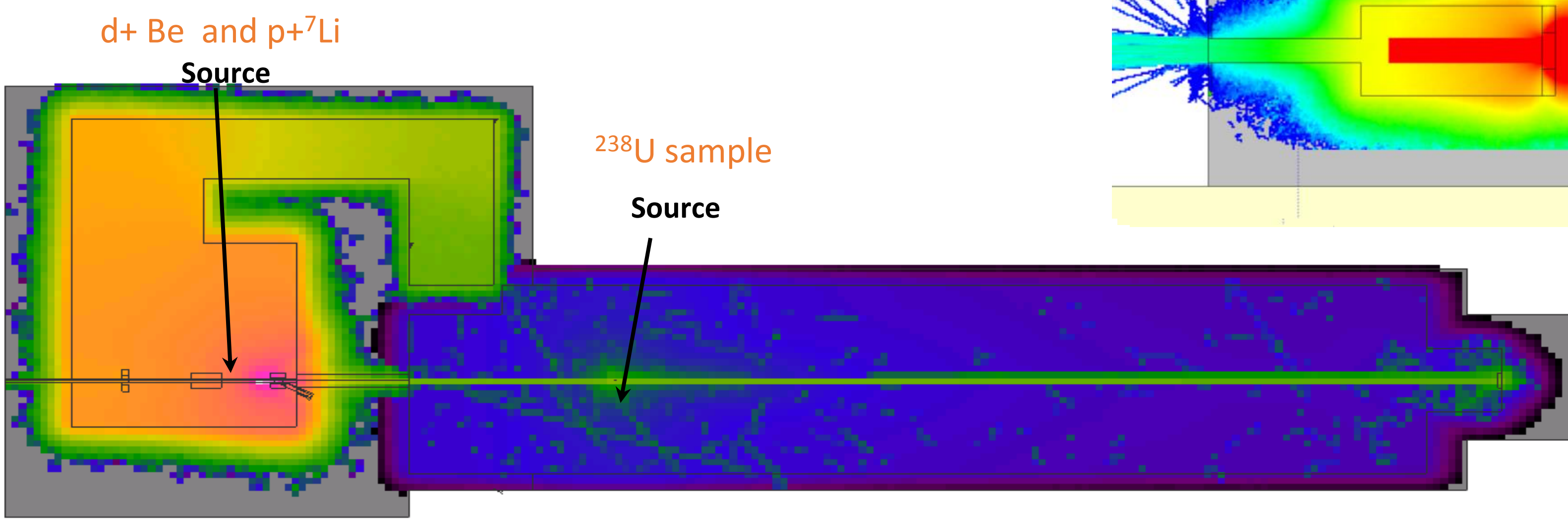
Neutron beam dump

Goal : minimization of neutron and gamma back-scattering to the TOF area

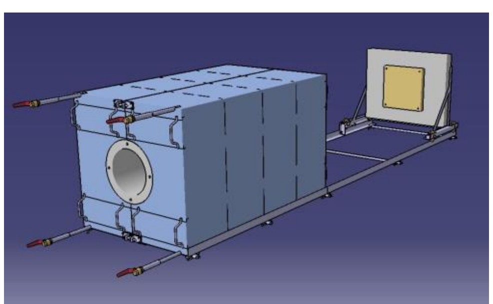
Basic design : hole of 4m long and 1x1m^2 section

Optimization : MCNPX calculations



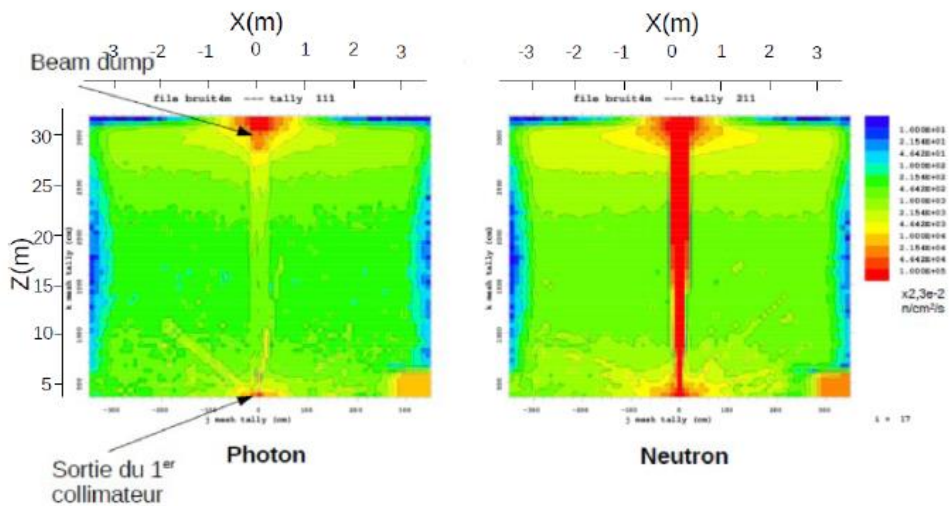


Interaction of the neutrons in the beam dump



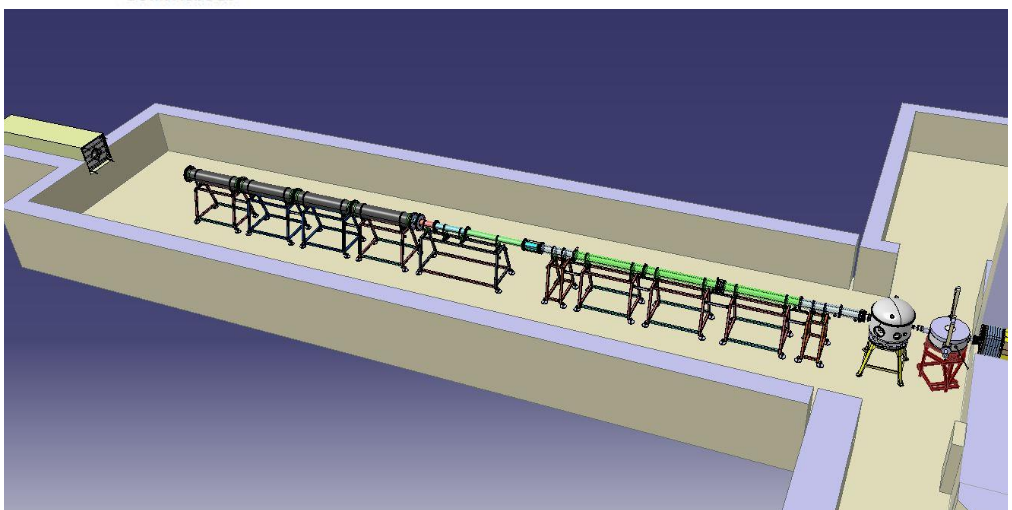
Beam line pipe

Beam pipe under vacuum allows reducing neutron and photon background



Beam on air

Beam on under vacuum



Summary

- Neutron induced reactions in the 20-200 MeV range play a key role in many domains
- Needs of reliable measurements for:
  - Nuclear data bases
  - Improvement of reaction models
- Reactions to study : (n,xn) (n,lcp) (n,fiss)
- Experiments at iThemba
  - Energy range and time structure seem well adapted for these studies
  - Background conditions should probably be improved