XX INTERNATIONAL BALDIN SEMINAR ON HIGH ENERGY PHYSICS PROBLEMS

Measurement of Neutrons in the Pb/U Assembly Irradiated by Relativistic Protons and Deuterons by means of Activation Samples

(XX Baldin seminar)

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for collaboration "Energy plus transmutation"

(Russia, Belarus, Germany, Greece, Poland, Ukraine, Czech Republic …)

Neutron production measurements

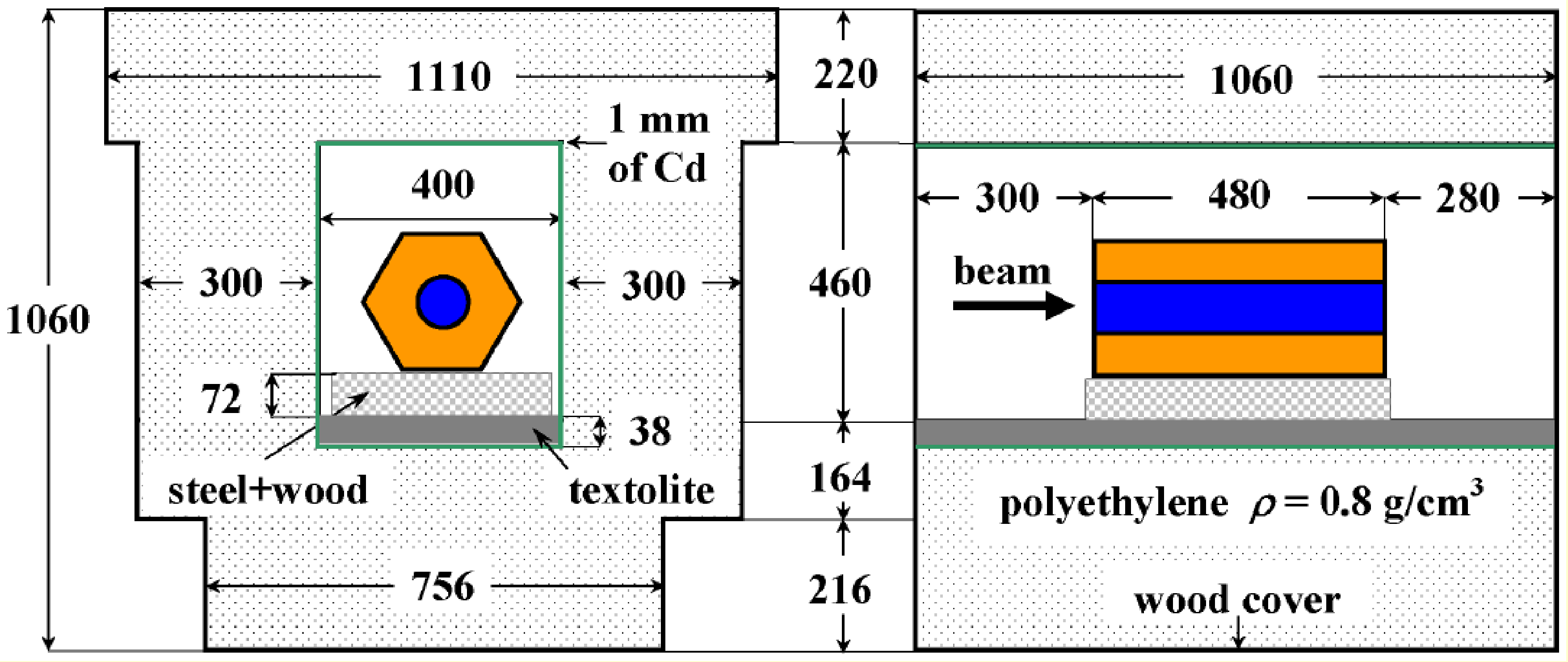
Neutron reaction cross-sections measurement

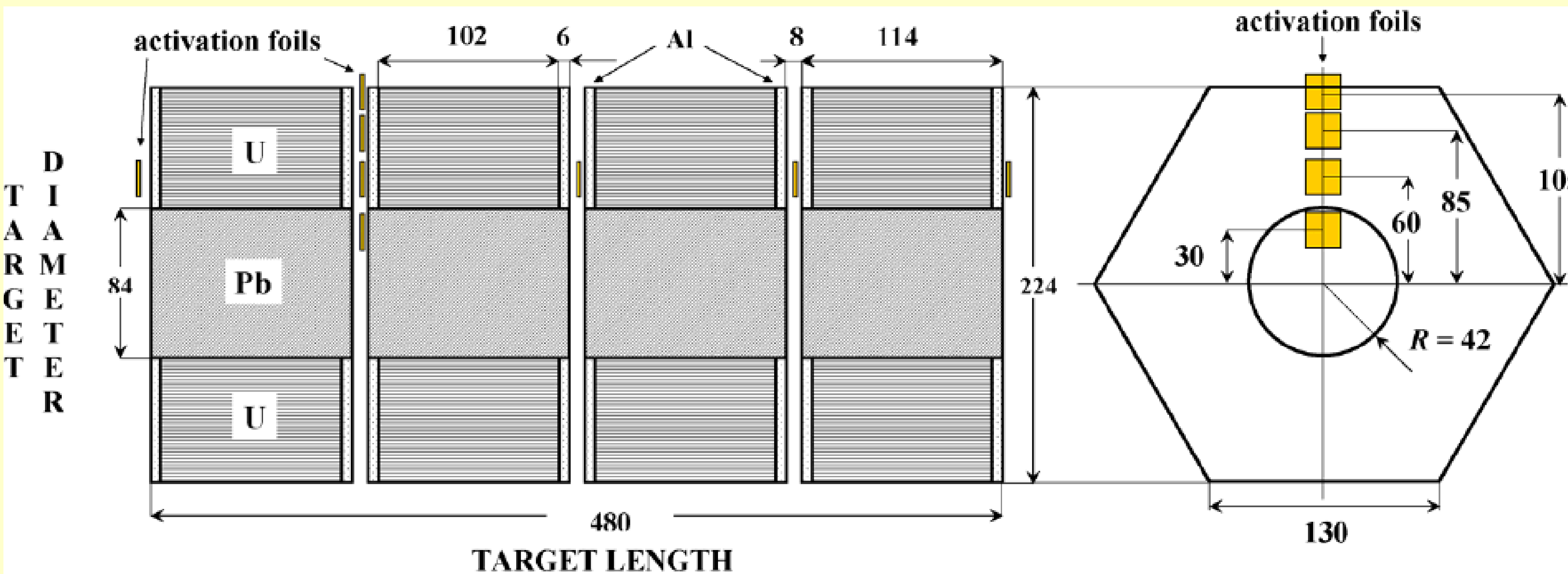
Energy + transmutation set-up

Set-up: **Lead target:** diameter 8.4 cm, length 48 cm
Natural uranium blanket: rods with Al cladding total weight 206.4 kg
Shielding box: polyethylene with 1 mm Cd on the inside side

Experiments: Proton beam (E = 0.7; 1.0; 1.5 and 2.0 GeV), deuteron beam (E = 1.6; 2.52 and 4.0 GeV)

Our main objectives: Neutron distribution studies – radiation samples

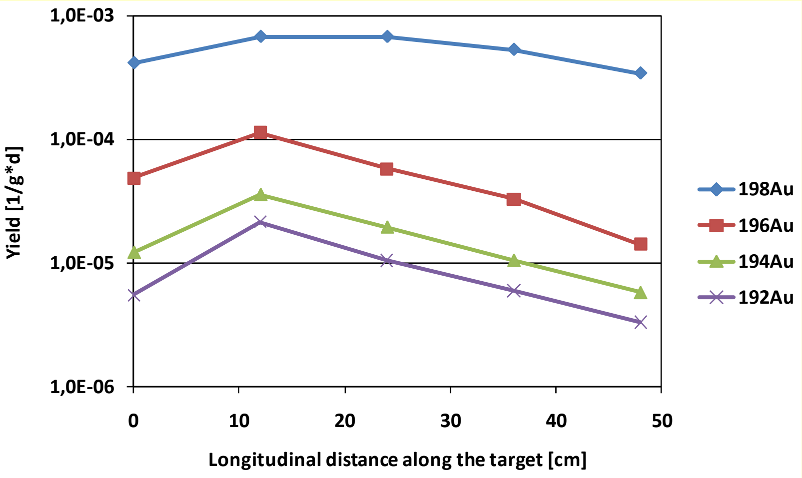


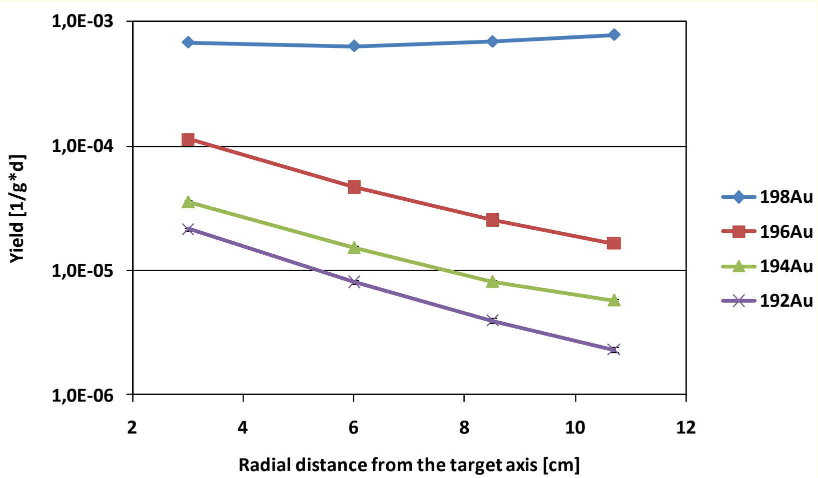


activation foils
102
6
Al
8
114
U
Pb
U
84
224
TARGET
DIAMETER
480
TARGET LENGTH
activation foils
105
85
60
30
R = 42
130

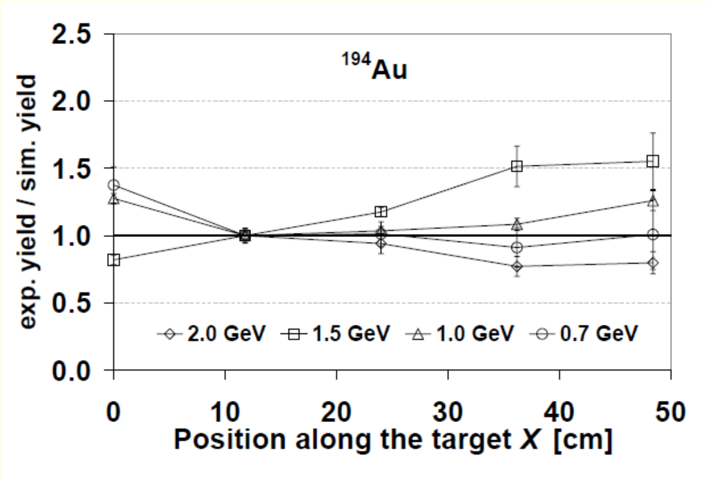
Main task – measurement of spatial distribution of high energy neutrons (E > MeV) by means of threshold reactions

Deuteron beam with 4 GeV ! preliminary ! analysis





Systematical comparison with MCNPX simulations:



Review of our proton beam data and their comparison with MCNPX simulations is at:

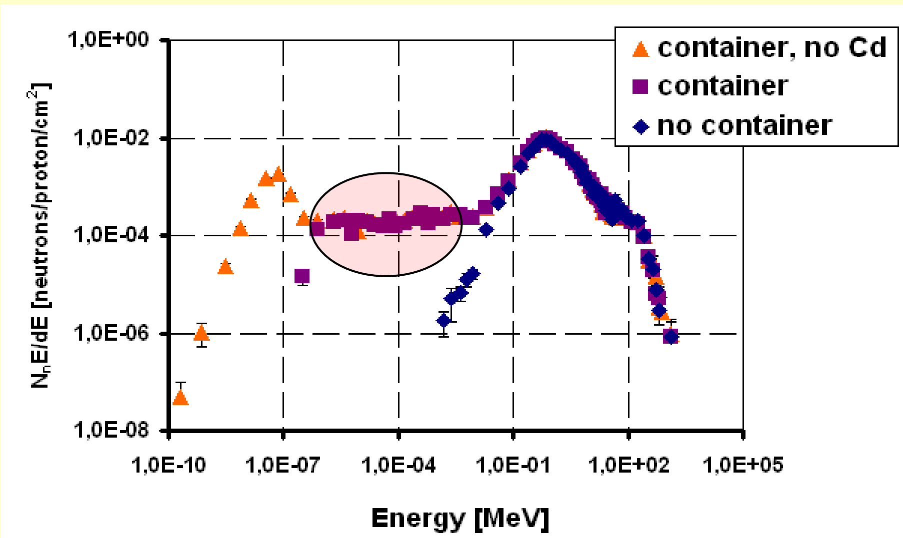
A. Krása et al: NIM A615 (2010) 70

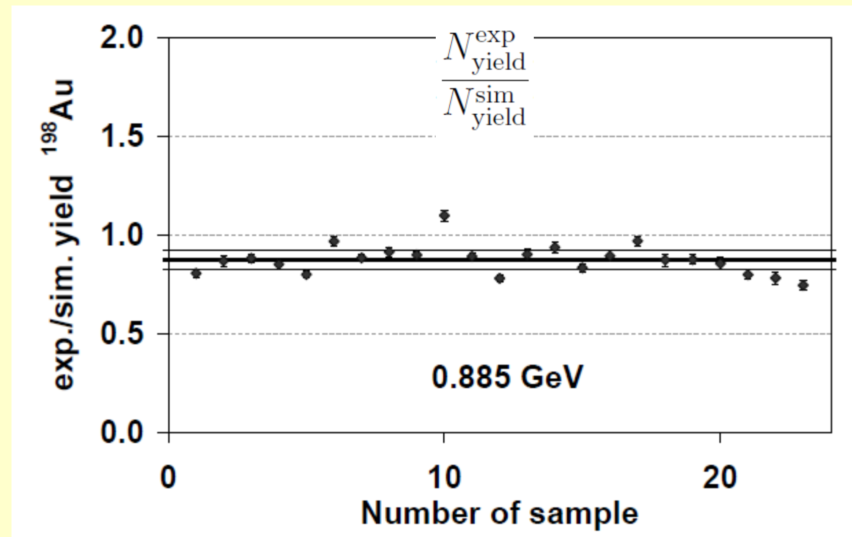
Determination of integral neutron number

Modified water bath / activation foils method

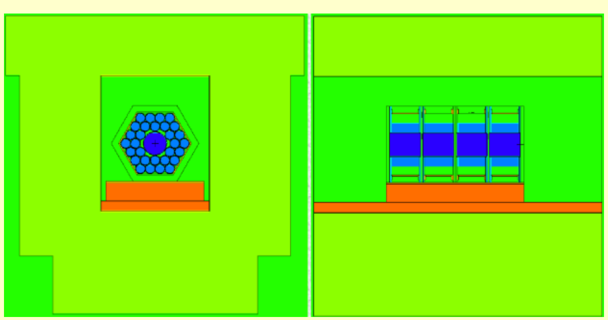
(K. Van der Meer et al: NIM B 217 (2004) 202)

The homogenous field of neutrons with energy 1 eV – 0.1 MeV is produced inside polyethylene container with 1 mm Cd on the inside side





Simulation - MCNPX

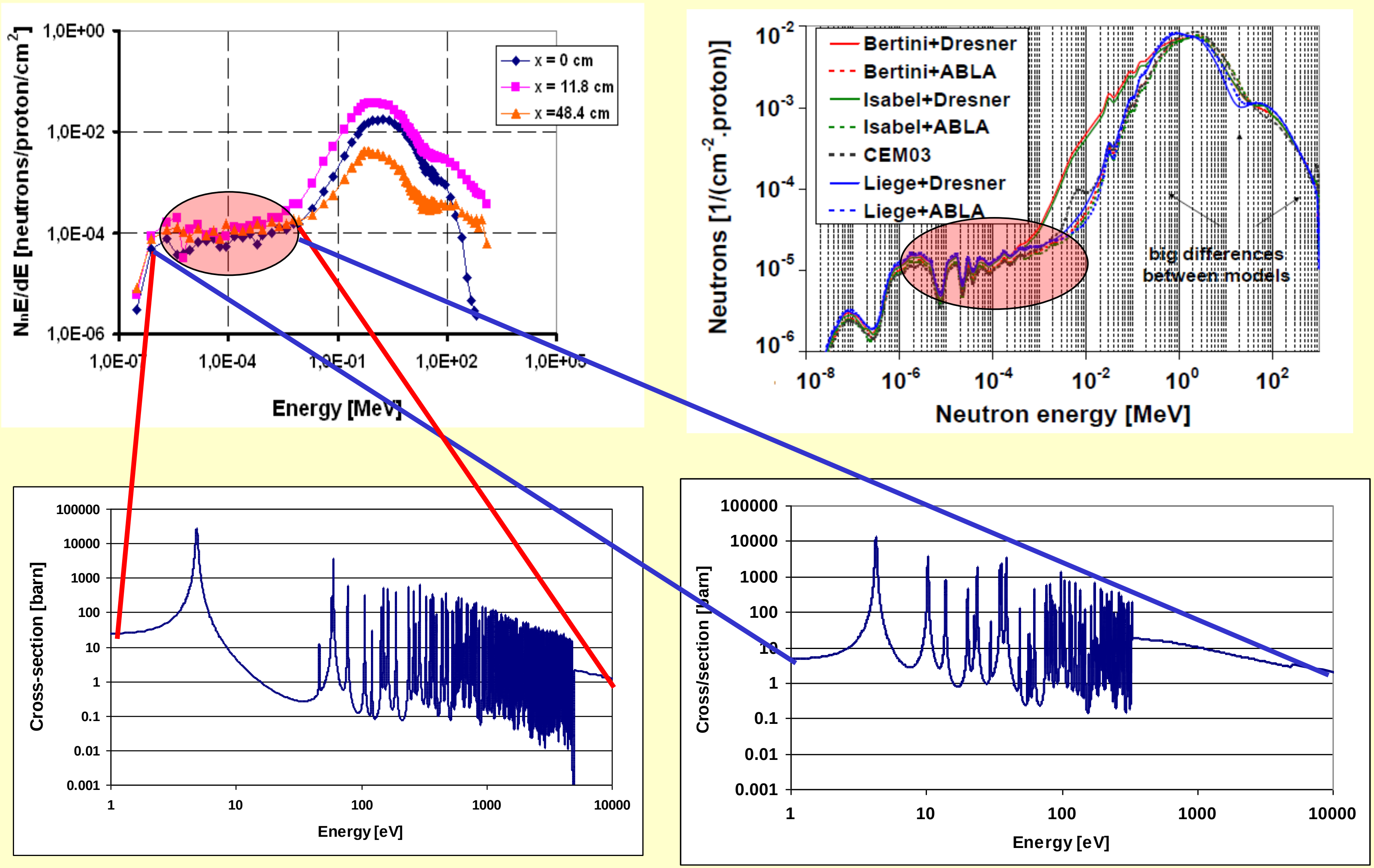


Many foils – (n,γ) reactions produced by epithermal (resonance) neutrons

$$M_n^{exp} = M_n^{sim} \langle \frac{N^{exp}_{yield}}{N^{sim}_{yield}} \rangle$$

where M_n – integral number of produced neutrons

N_{yield} – number of produced radioactive nuclei at foil

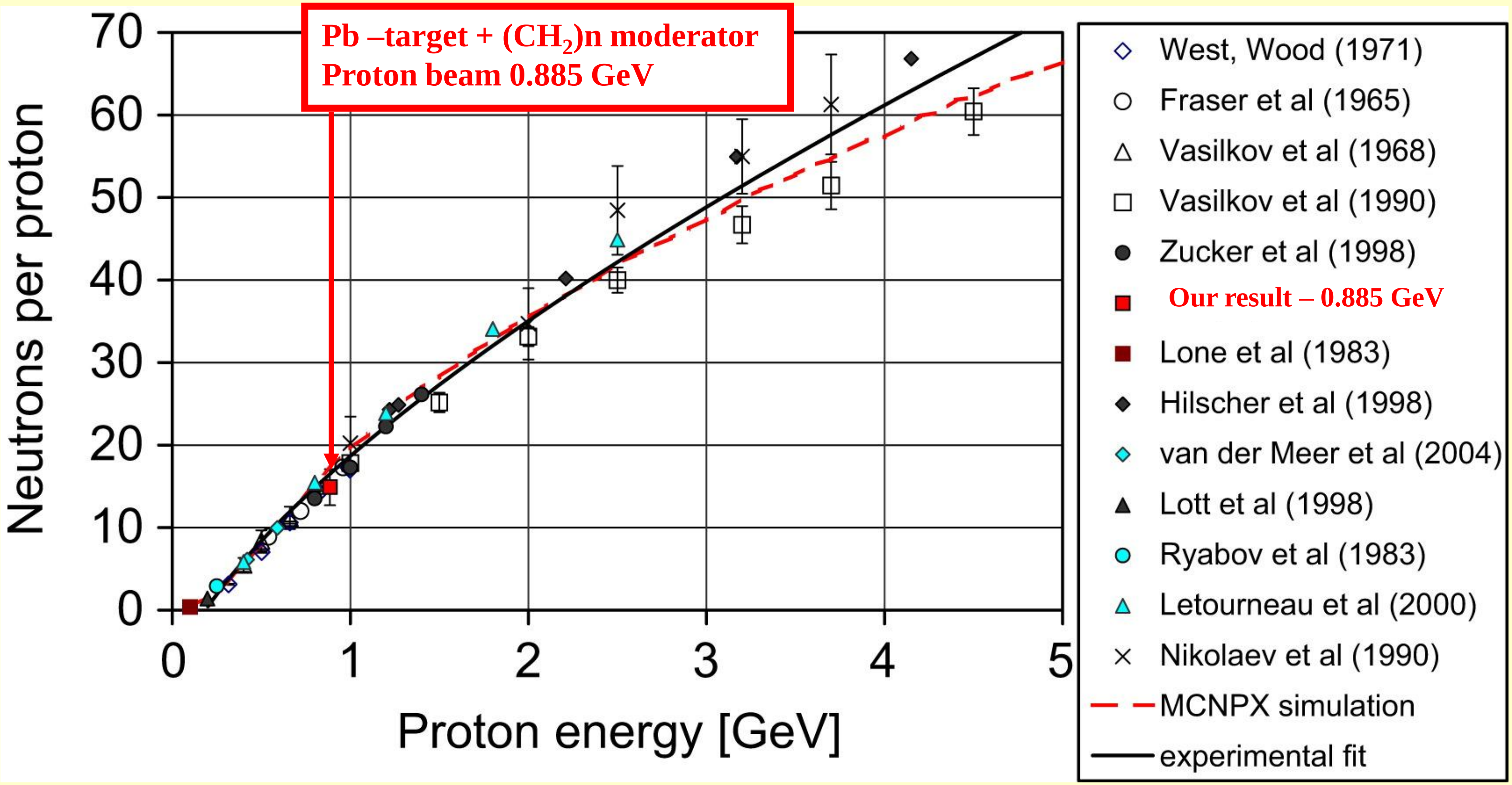


$^{197}Au(n,\gamma)^{198}Au$

$^{181}Ta(n,\gamma)^{182}Ta$

Test by means of simple lead target inside E+T container

Comparison of our obtained number of neutrons per proton with all other neutron numbers from different experiments



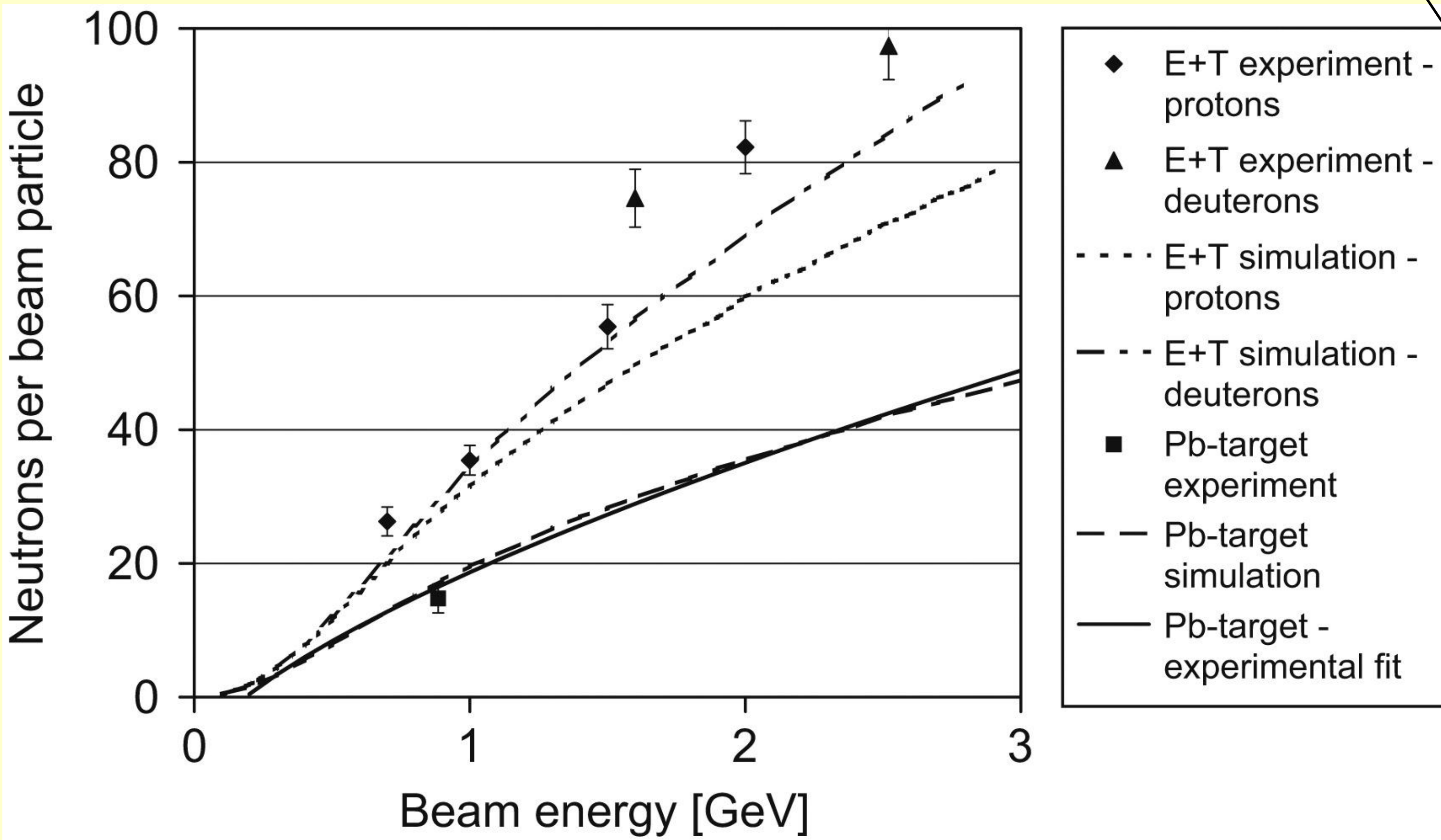
Systematic of E+T experiments with different proton and deuteron beams (energy from 0.7 GeV up to 2.52 GeV)

A. Krása et al: NIM A615 (2010) 70

Experiment	E_{beam} [GeV]	$\left\langle \frac{N^{exp}_{yield}}{N^{sim}_{yield}} \right\rangle$	M^{exp}_n	M^{sim}_n	M^{exp}_n
p+Pb	0.885	0.87(5)	14.8(2.2)	17.0	–
p+Pb/U	0.7	1.32(4)	26.3(2.2)	20.0	27(2)
	1.0	1.12(4)	35.4(3.3)	31.6	39(3)
	1.5	1.18(5)	55.4(3.3)	46.8	62(5)
	2.0	1.37(3)	82.3(3.9)	59.9	82(6)
d+Pb/U	1.6	1.32(6)	75(9)	56.6	64(5)
	2.52	1.16(3)	97(10)	84.3	101(9)

S. Stoulos et al: NIM A599(2009)106

M. Zamani-Valasiadou et al: Annals of Nucl.Ener 37(2010)241



Integral neutron number studied by tantalum

E(deuteron) = 2.52 GeV

Experiment/Simulation:

Tantalum : 1.131(23)
Gold: 1.16(3)

E(deuteron] = 4 GeV

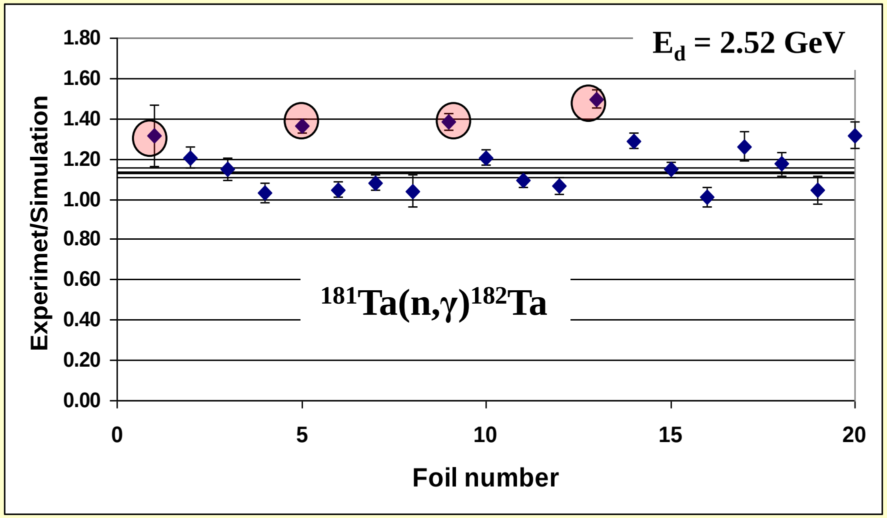
Experiment/Simulation Au ~ 1.7

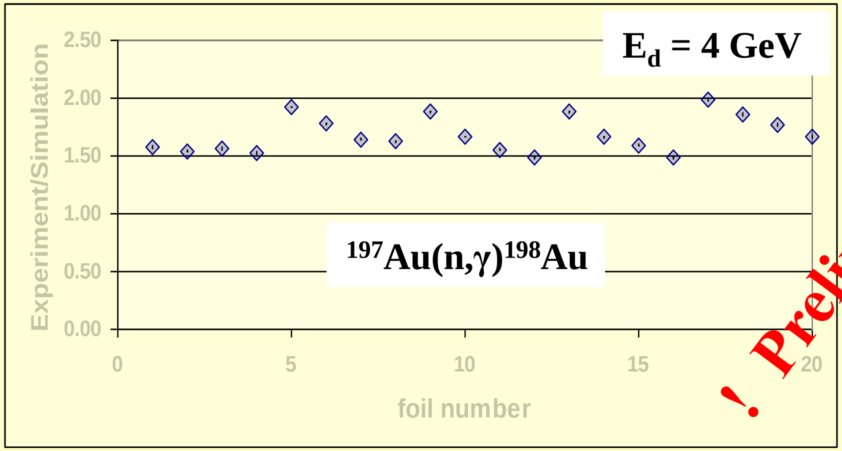
$M_n^{sim} = 112.5 \rightarrow M_n^{exp} \sim 189$

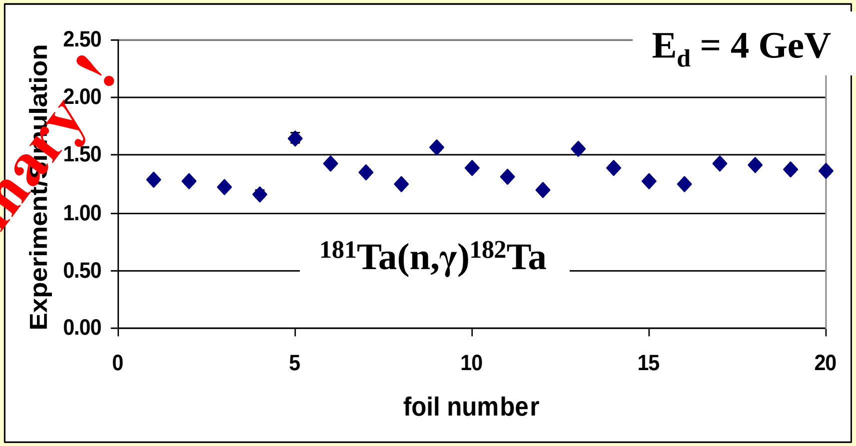
Ta ~ 1.4

Results using tantalum looks similar as for gold

Main source of uncertainties is determination of beam protons number



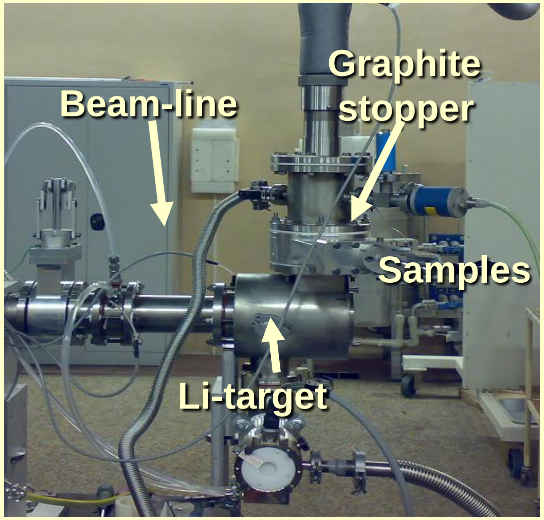




! Preliminary !

Measurement of neutron reaction cross/sections

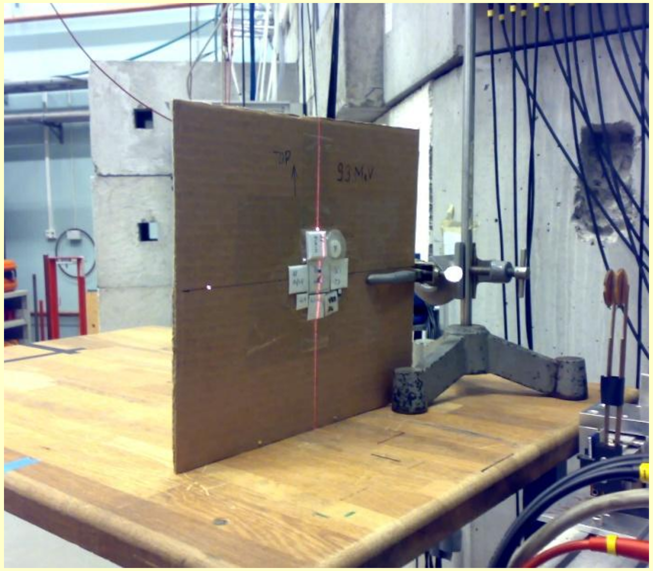
Quasi-monoenergetic neutron source:
protons from cyclotron + lithium target

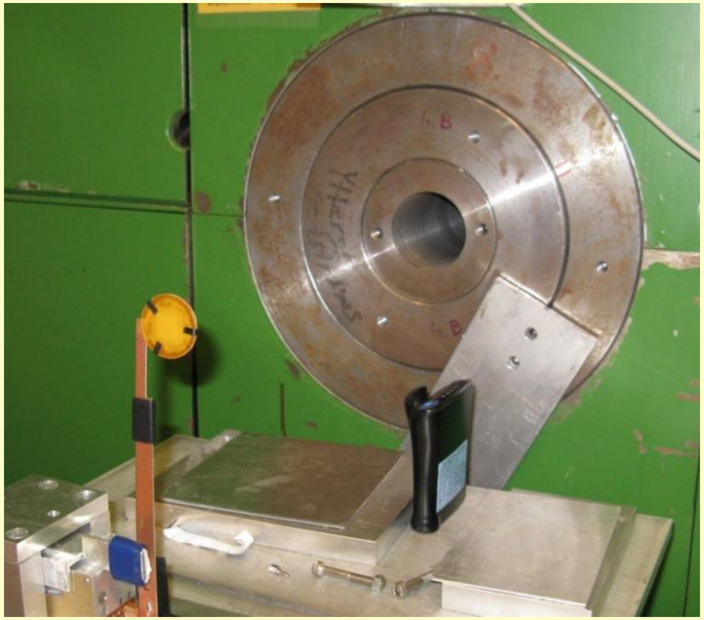


NPI ASCR Řež: Energy range 18 -37 MeV,
neutron intensity ~ 10^8 neutron cm^{-2} s^{-1}

TSL Uppsala: Energy range 25 – 200 MeV
neutron intensity ~ 10^5 neutron cm^{-2} s^{-1}

Advantage of two neutron sources: very wide energy range, partial overlap – better estimation of systematical uncertainties





Some details about measurements and analysis

Measured materials:
All irradiations: Al, Au, Bi, Ta, In and I
Some irradiations: Y, Co, Zn, Fe, Cu, Ni and Mg

NPI ASCR Řež:

4 measurements: neutron energies 17.5; 21.9; 30.4 and 35.9 MeV

TSL Uppsala:

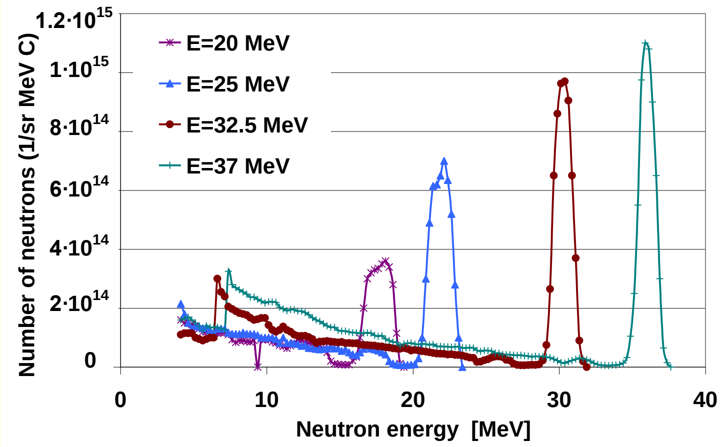
First set (2008): neutron energies 22; 47 and 94 MeV

Problem of background subtraction → important to have data for many neutron (proton) energies

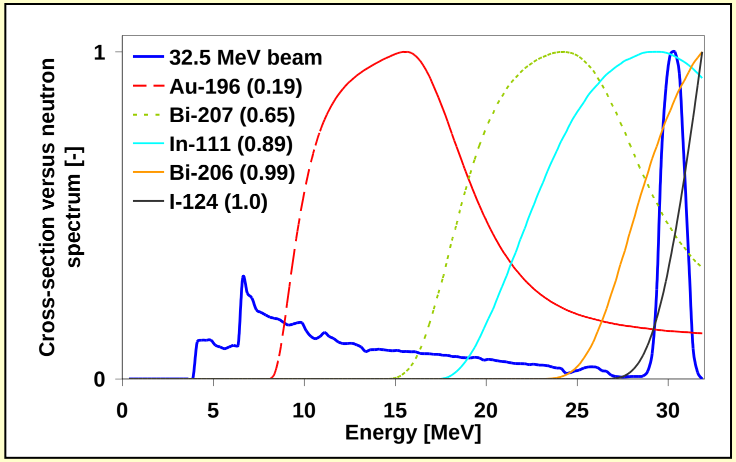
Second set (2010): proton energies 62; 70; 80 and 93 MeV

Main uncertainties: 1) Gauss shape fit > 1 %
2) Efficiency ~ 3 %
3) Spectroscopic corrections ~1 %
4) Neutron beam integral ~ 5 % (NPI), 10 % (TSL)
5) Neutron spectrum definition – background substraction

Supported by: EFNUDAT – European Facilities for Nuclear Data Measurements

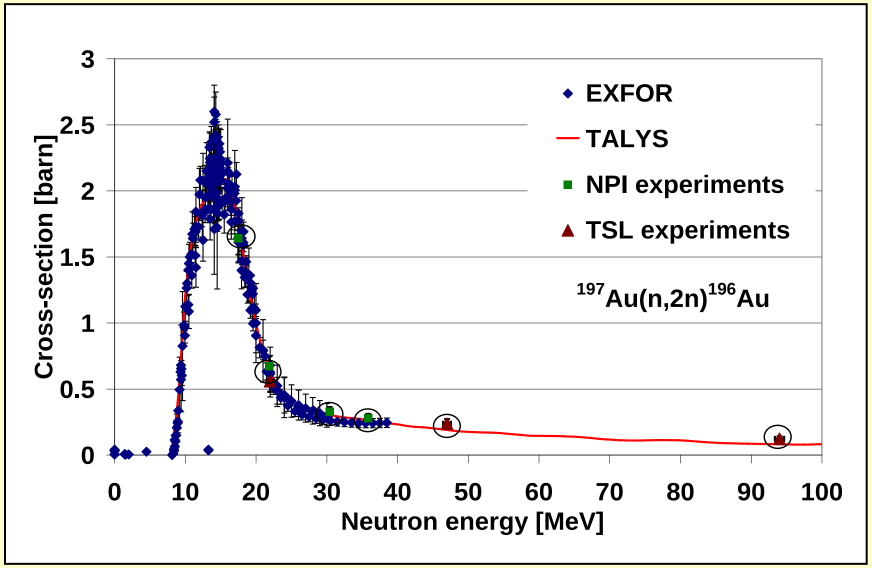


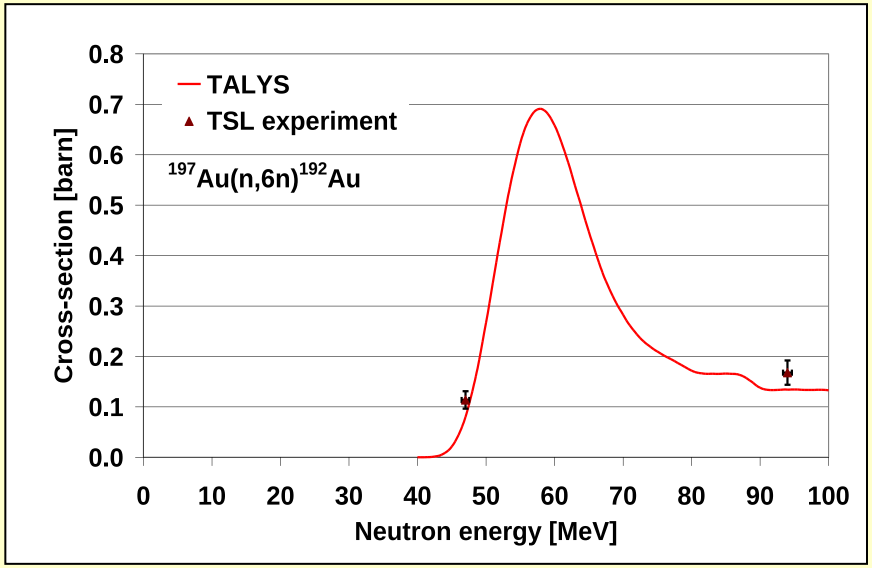
Neutron spectra for different proton energies (NPI ASCR Řež)

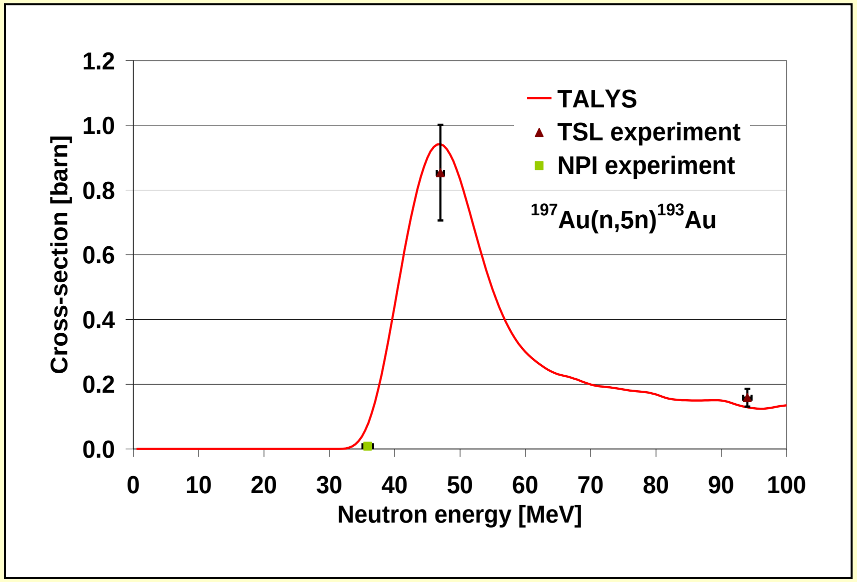


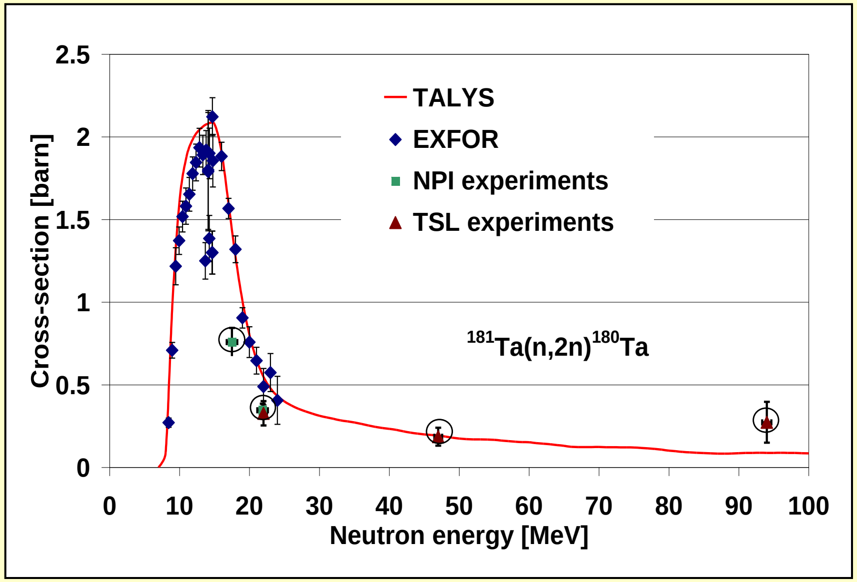
Example of different influence of background

Examples of results

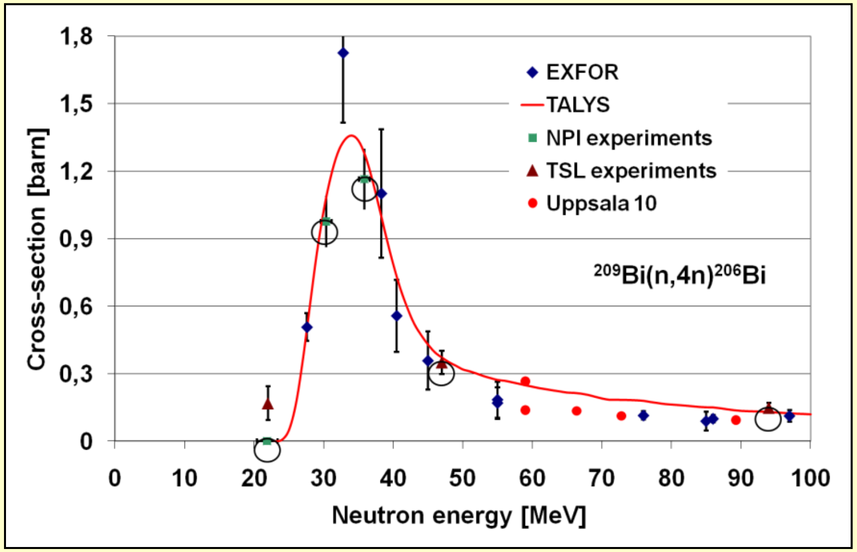


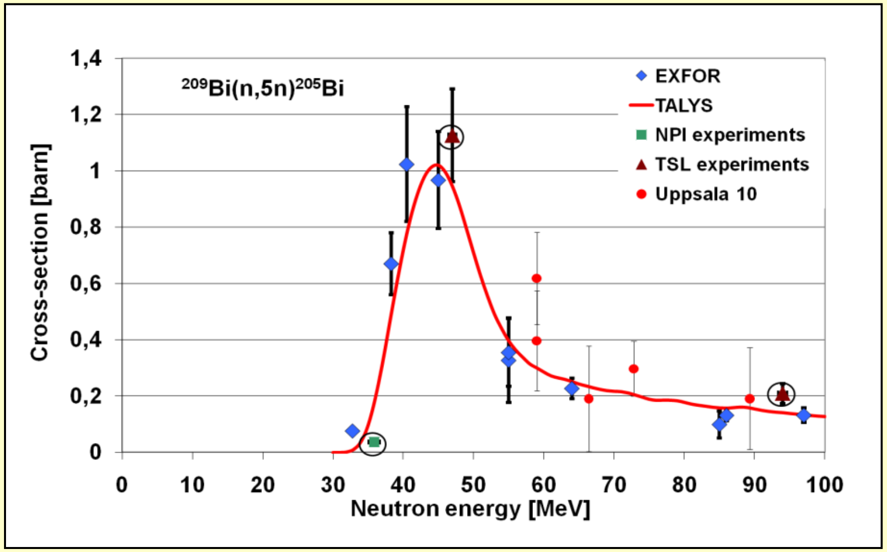


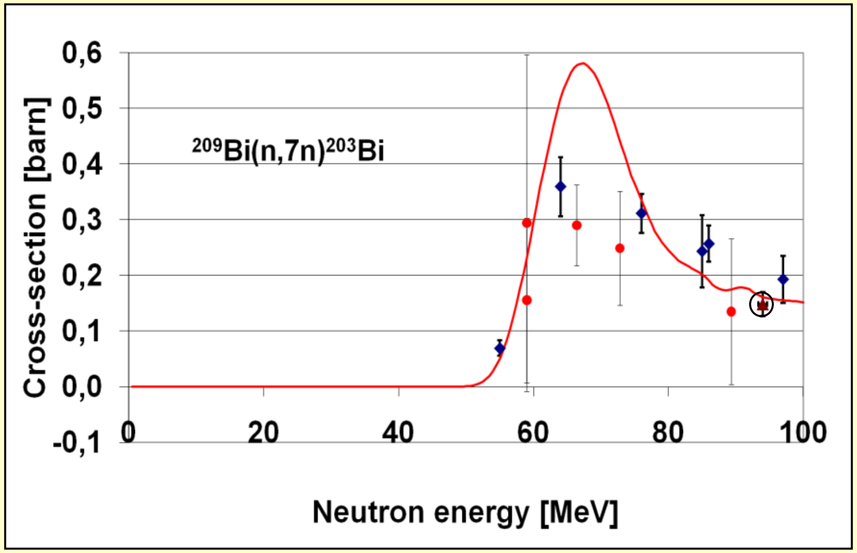


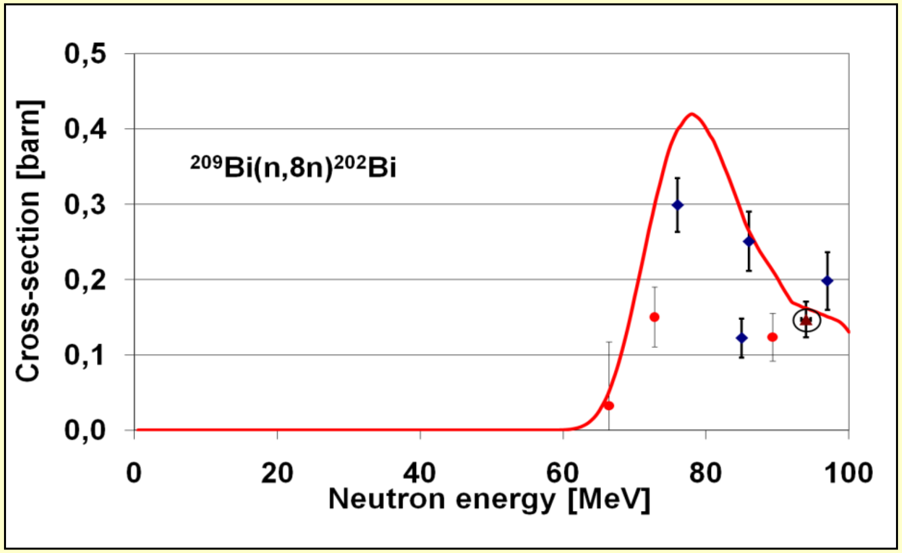


Uppsala February 2010 ! PRELIMINARY ! results









Conclusions

- **Using „Energy plus Transmutation“ set-up on JINR Dubna accelerator (different proton and deuteron energies) nice set of data for ADTT benchmark were obtained.**
- **Epithermal and resonance neutrons (^{198}Au production, newly we test also ^{182}Ta production) inform us about changes of integral neutron production with beam energy (experiments with shielding container).**
- **The biggest source of experimental uncertainties is inaccuracy of beam parameters determination**
- **The neutron production per beam particle end energy unit is approximately same for protons with energy from 0.7 GeV up to 2 GeV and deuterons with energy from 1.6 GeV up to 4 GeV.**
- **The quasimonoenergetic neutron sources are good tool for neutron cross-sections measurements, perfect knowledge of these cross-sections is important for measurements of neutron field by means of activation detectors.**
- **By means of Řež and Uppsala neutron sources we obtained nice set of neutron reaction cross-sections**
- **Such cross-section data are very important step to more effective usage of activation neutron detectors**

BIG THANKS

to students

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