XXII INTERNATIONAL BALDIN SEMINAR ON HIGH ENERGY PHYSICS PROBLEMS

Nuclear data for advanced nuclear systems

(XXII Baldin seminar)

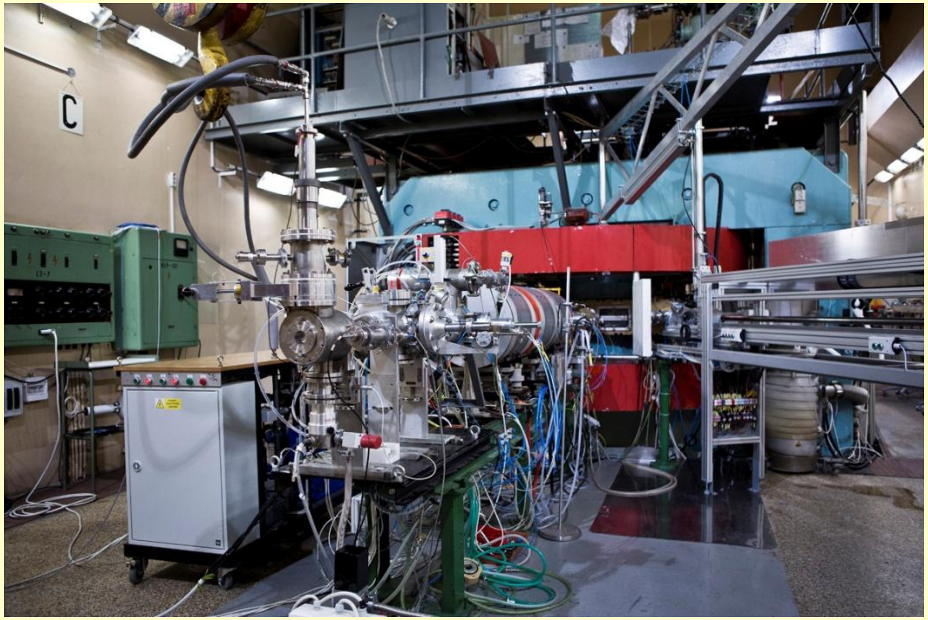
Vladimír Wagner

Nuclear physics institute of CAS, 250 68 Řež, Czech Republic, E_mail: wagner@ujf.cas.cz

for collaboration "Energy plus transmutation"

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

1) Introduction
2) Necessity of nuclear data
3) Relativistic ions reactions
4) Neutron sources usage
5) European projects ERINDA and CHANDA

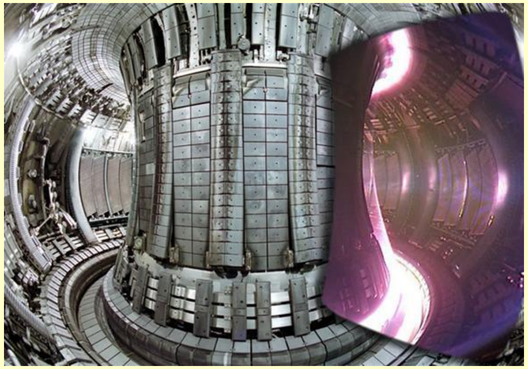


Neutron source of NPI AS CR Rez

Importance of nuclear data

Aplications: **fission and fusion, nuclear medicine, object and material analysis, radiation protection , nuclear safety and security**

Science: **astrophysical reactions, reactions and structure of nuclei, basic physics**



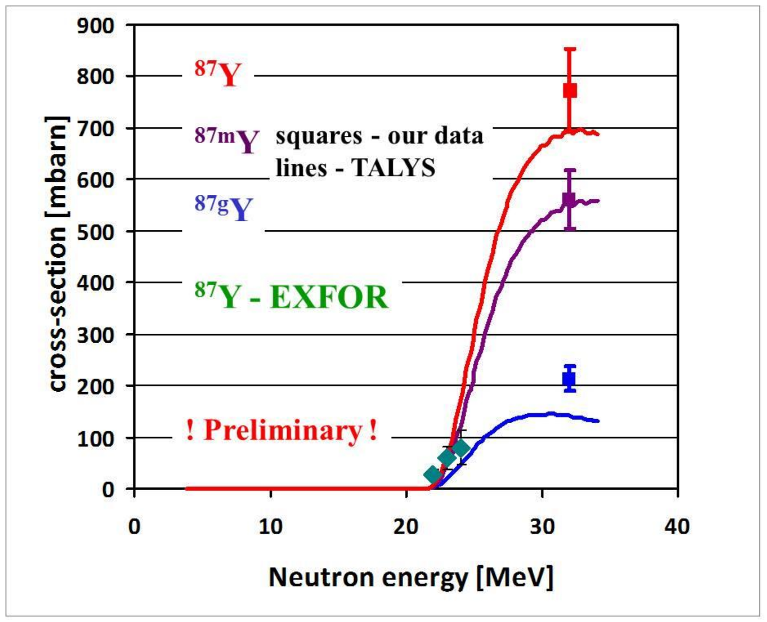
Role of nuclear data

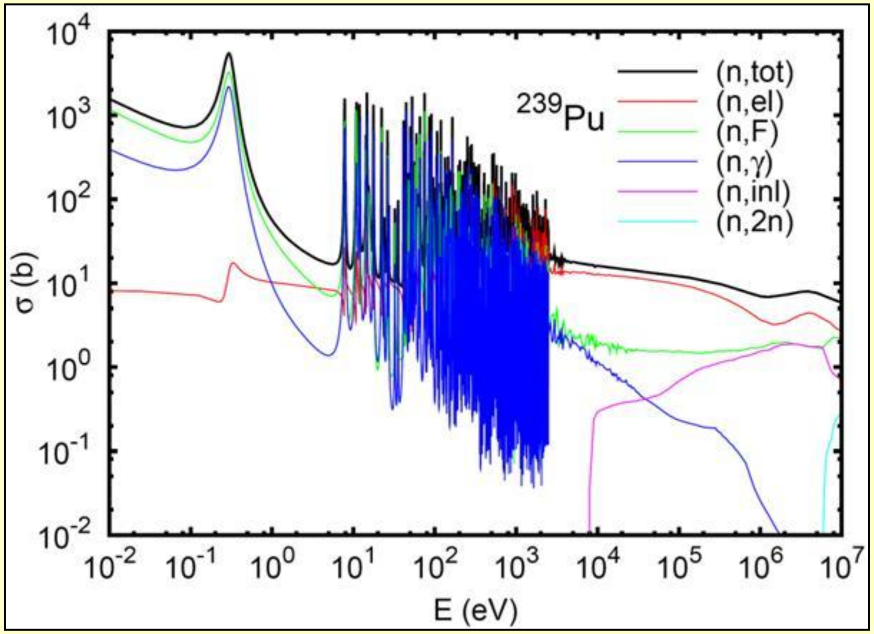
Important – how well we calculate neutron fields, reaction rates, radioactivity …?
what is the penalty for inaccuracy of our data libraries?

Nuclear modeling lacks accuracy for detailed prediction of cross-sections

Data are needed for developing models, determining model parameters, benchmark of model parameter databases and overall model performance

Practical information for experiments – cross-sections of materials used as activation detectors – increase of accuracy of measurements

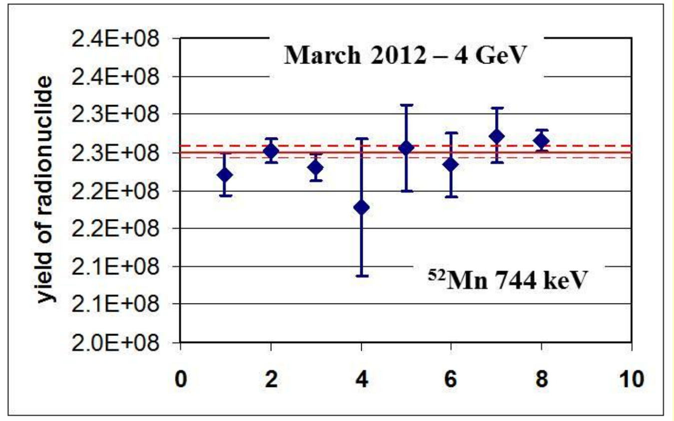




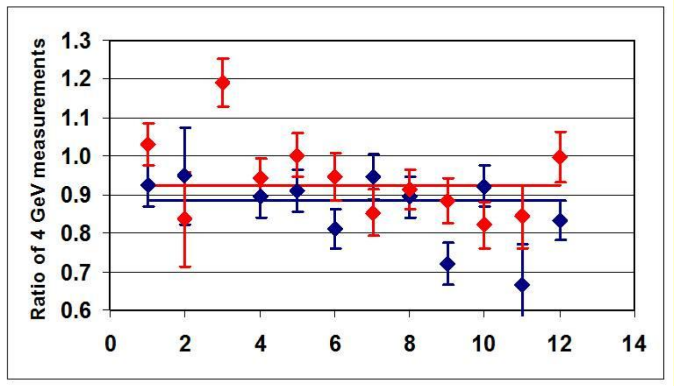
Studies of relativistic deuteron reactions on natural copper

(production of ^{57}Ni, ^{58}Co, ^{56}Co, ^{55}Co, ^{56}Mn, ^{52}Mn, ^{48}Cr, ^{48}V, ^{48}Sc, ^{47}Sc, ^{44m}Sc, ^{43}Sc, ^{43}K, ^{38}S, ^{28}Mg, ^{28}Al, ^{24}Na, ^{22}Na, ^{7}Be … not all are shown ☺)

Energy range of deuteron beam from 1 GeV up to 8 GeV (during QUINTA irradiations)



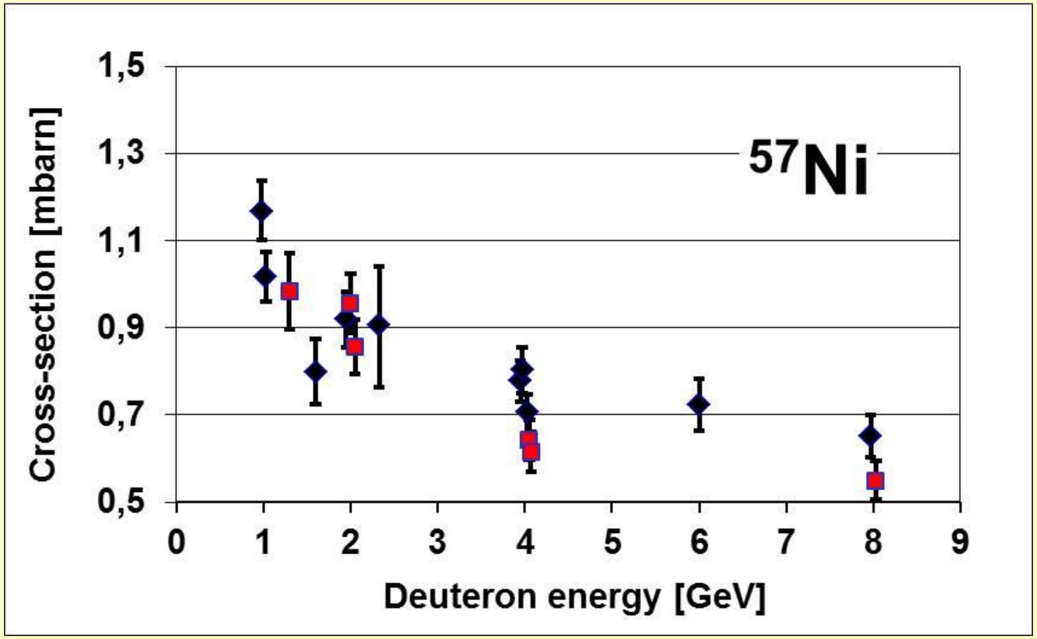
More measurements of activity



More irradioations with same deuteron energy

Five series of irradiations (last two - red signs)

Activation method was used

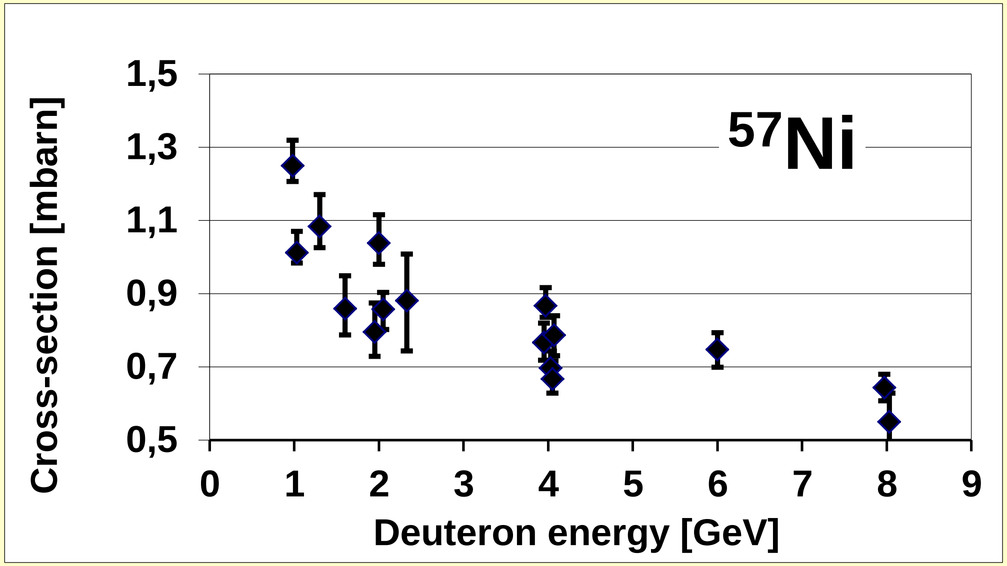


Example of simple decay results

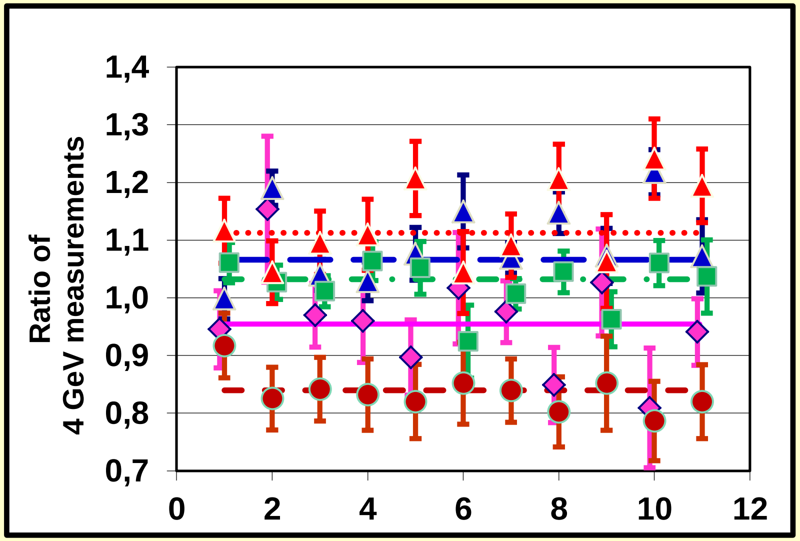
More measurements for one energy

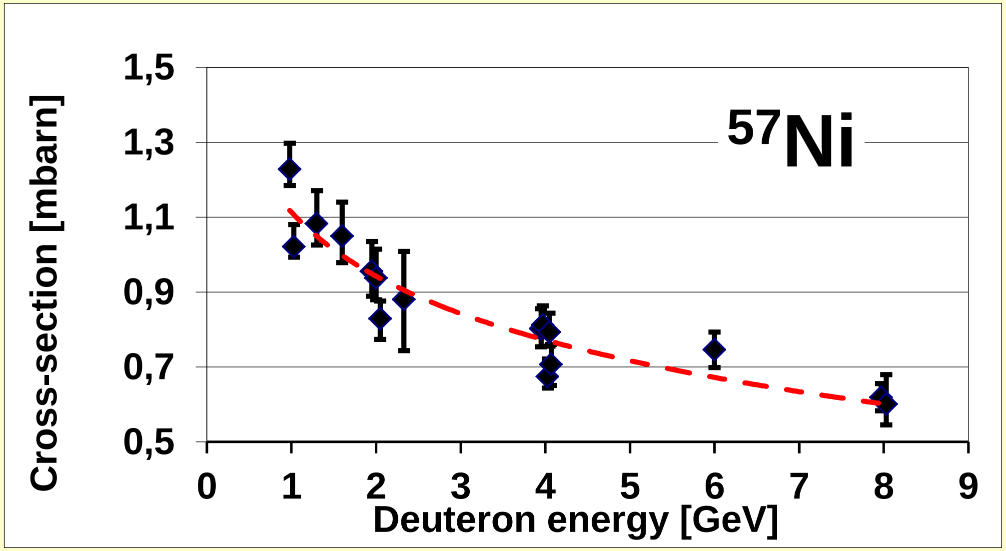
We see systematic uncertainties for beam integral determination about 15 %.

We used more measurements to correct partly influence of such uncertainties



without corrections





with corrections

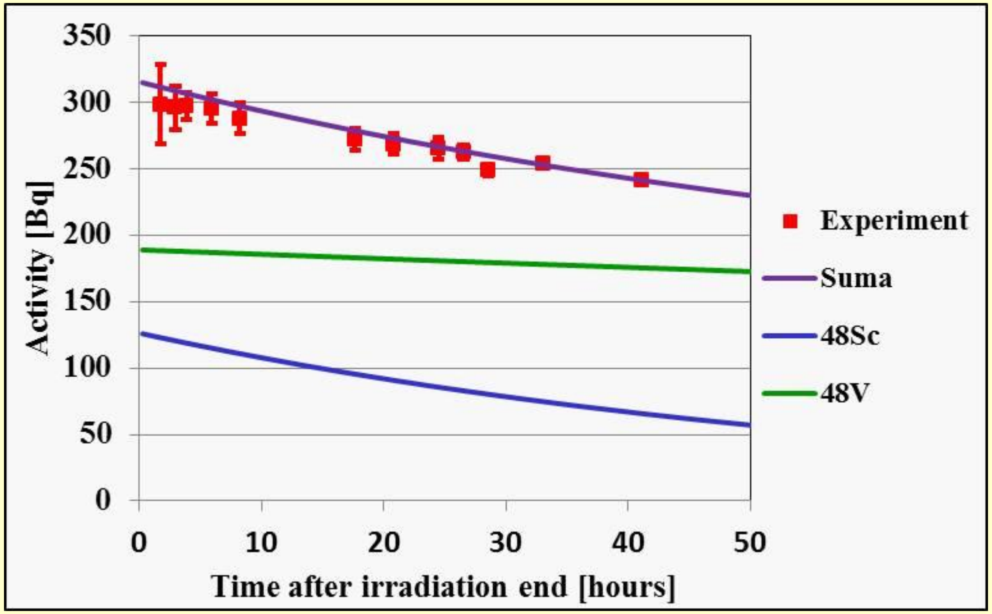
$^{48}Sc \rightarrow ^{48}Ti \leftarrow ^{48}V$

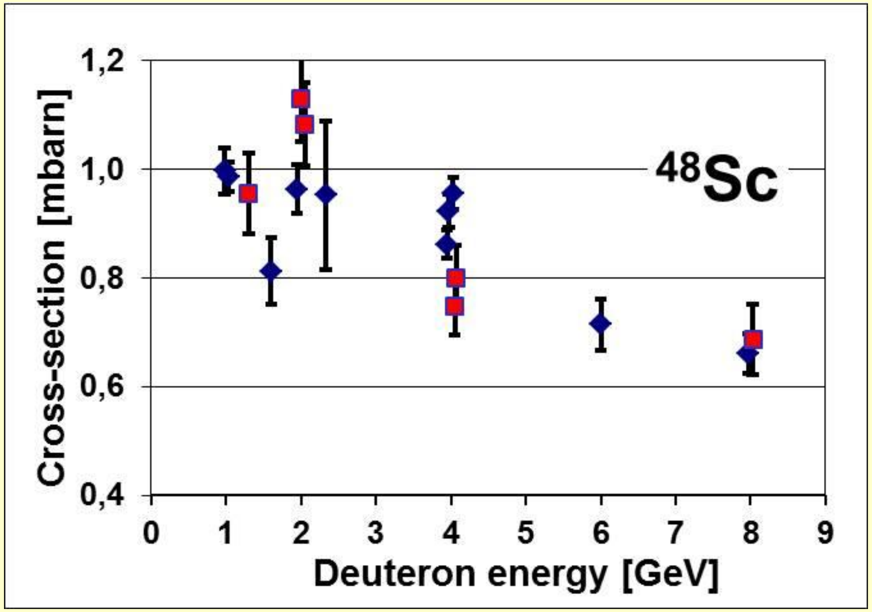
T1/2 **43.7 h** **383.3 h**

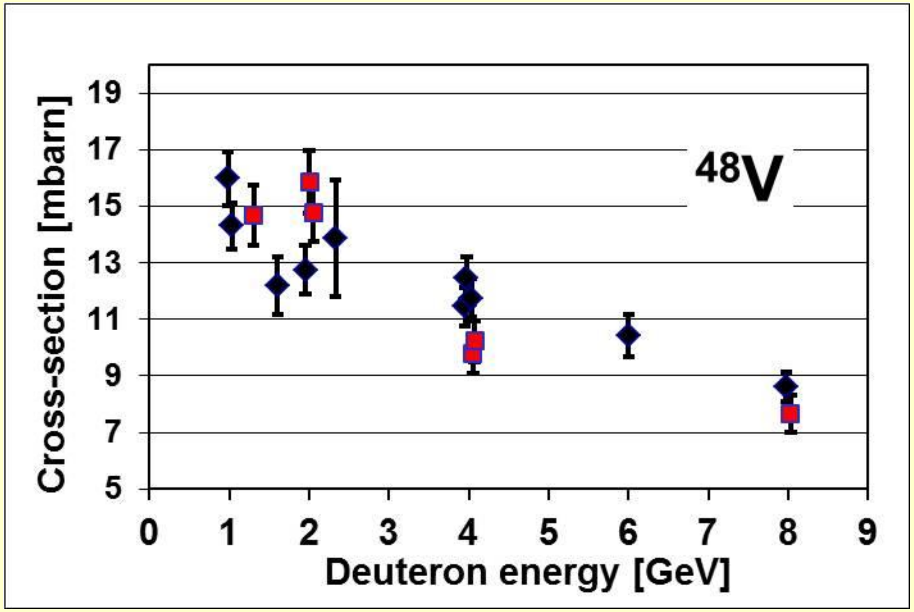
Gamma lines:

^{48}Sc only: 1037.6 keV (subtract ^{56}Co)

^{48}Sc + ^{48}V: 983.5 keV and 1312.1 keV







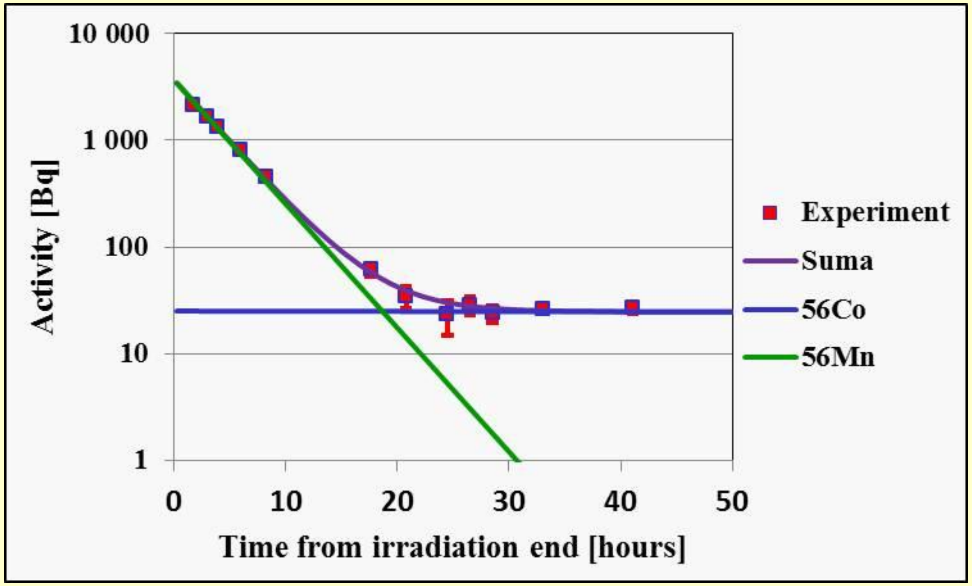
$^{56}Mn \rightarrow ^{56}Fe \leftarrow ^{56}Co$

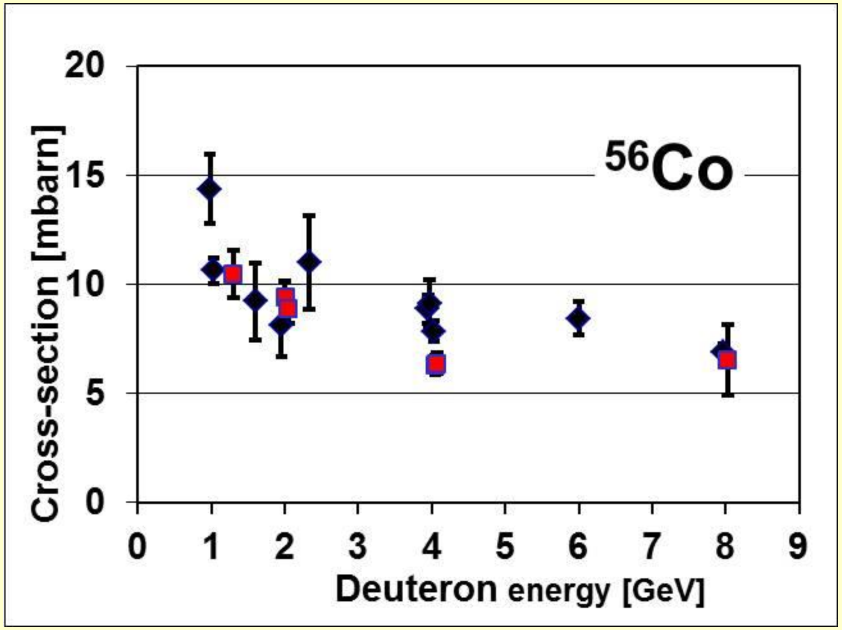
$T_{1/2}$ 2.6 h 1854.5 h

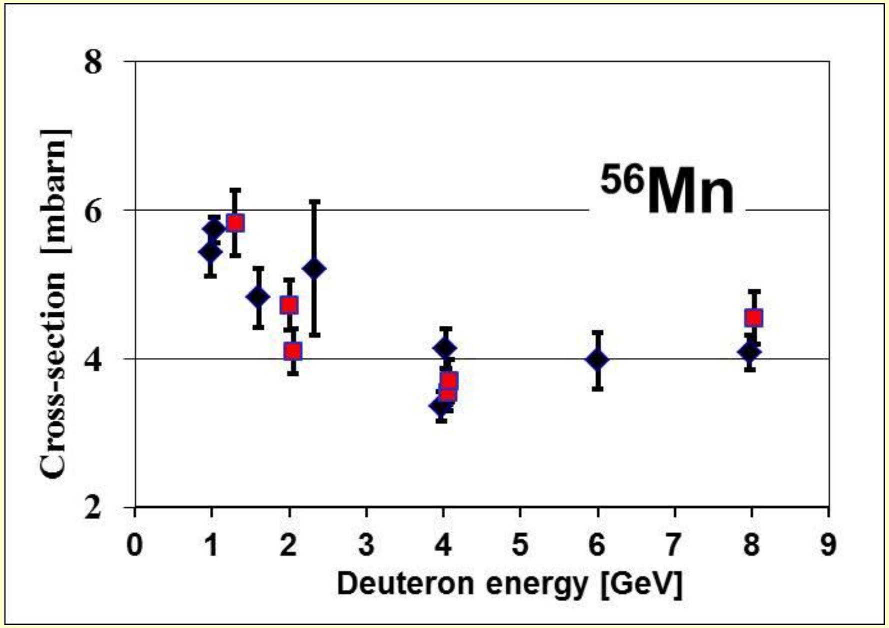
Gamma lines:

^{56}Co only: 1238.3 keV

$^{56}Co + ^{56}Mn$: 846.8 keV







Isomeric state

$^{44m}Sc \rightarrow {}^{44}Sc \rightarrow {}^{44}Ti$

$T_{1/2}$ 58.6 h 3.9 h

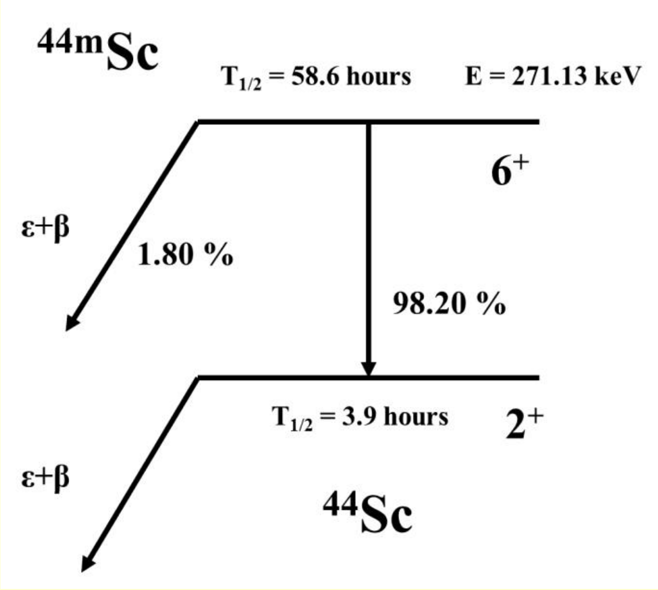
$T_{1/2}(^{44m}Sc) \gg T_{1/2}(^{44}Sc)$

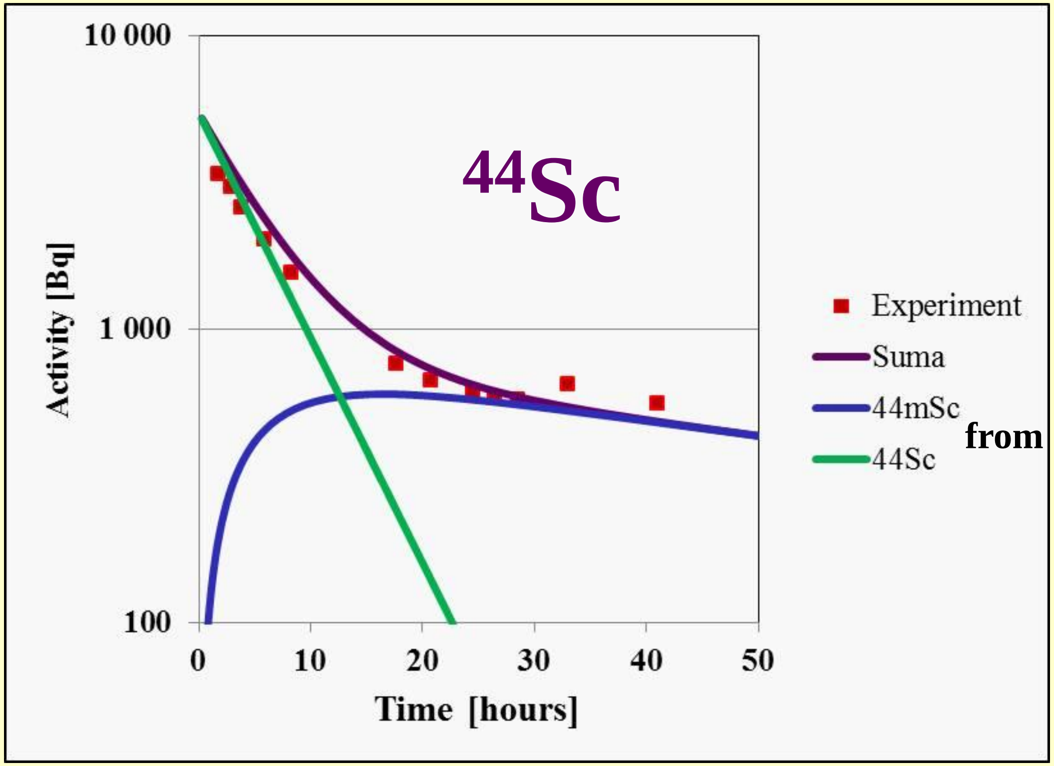
^{44m}Sc $N_1 = N_{01} e^{-\lambda_1 \cdot t}$

^{44}Sc $N_2 = N_{02} \cdot e^{-\lambda_2 \cdot t} + \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} \cdot \left(e^{-\lambda_2 \cdot t} - e^{-\lambda_1 \cdot t}\right)$

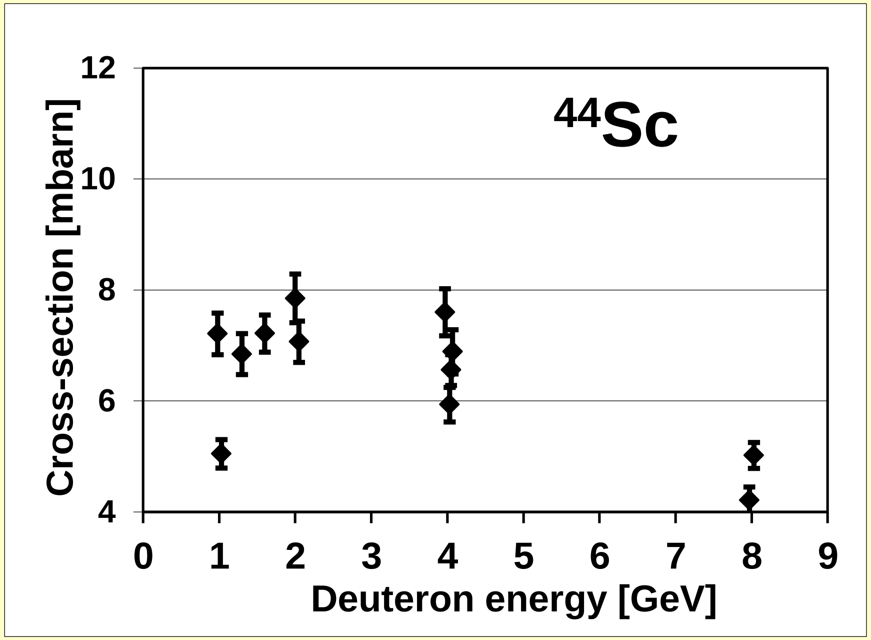
$t \rightarrow \infty$ $N_2 = -\frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} e^{-\lambda_1 \cdot t}$

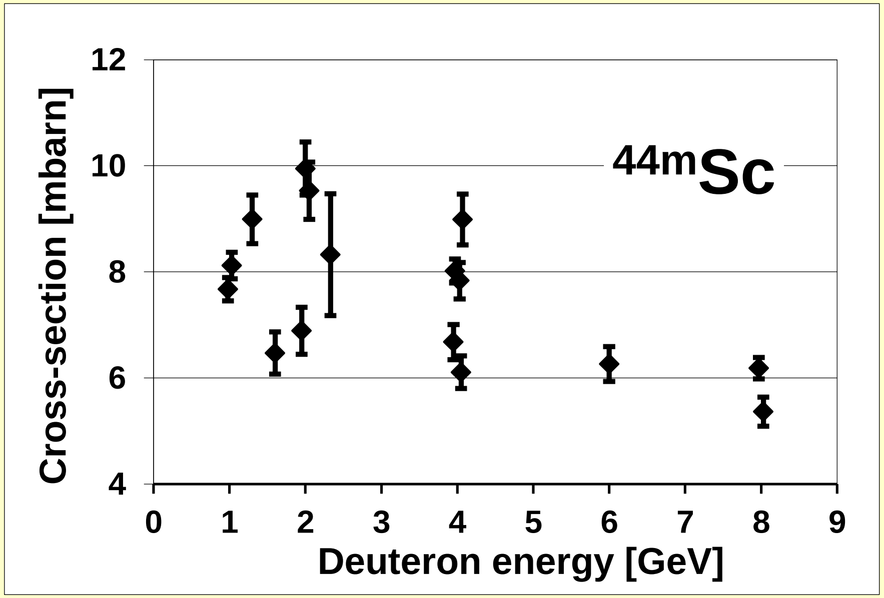
only N_{01} information

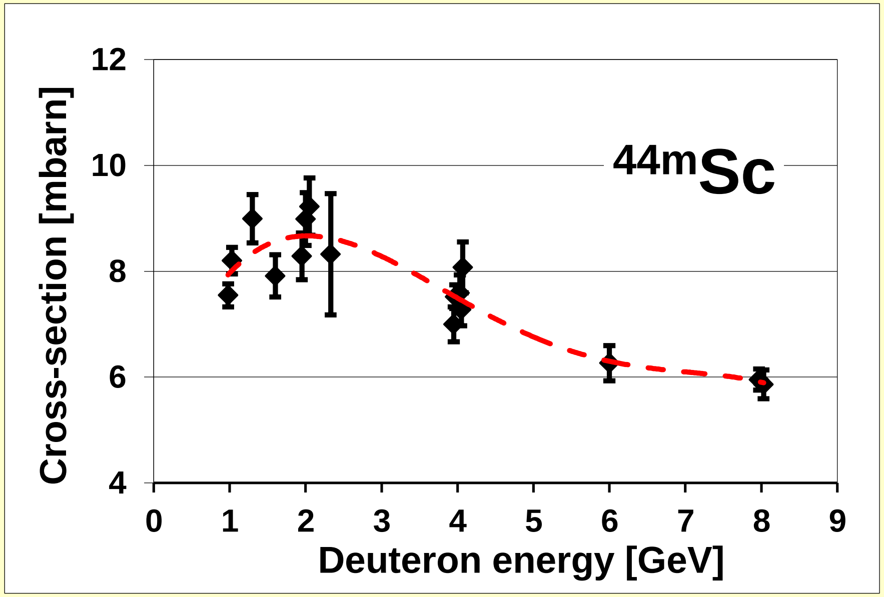




For some irradiations measurements started so late to obtain information about ^{44}Sc production cross-section determination



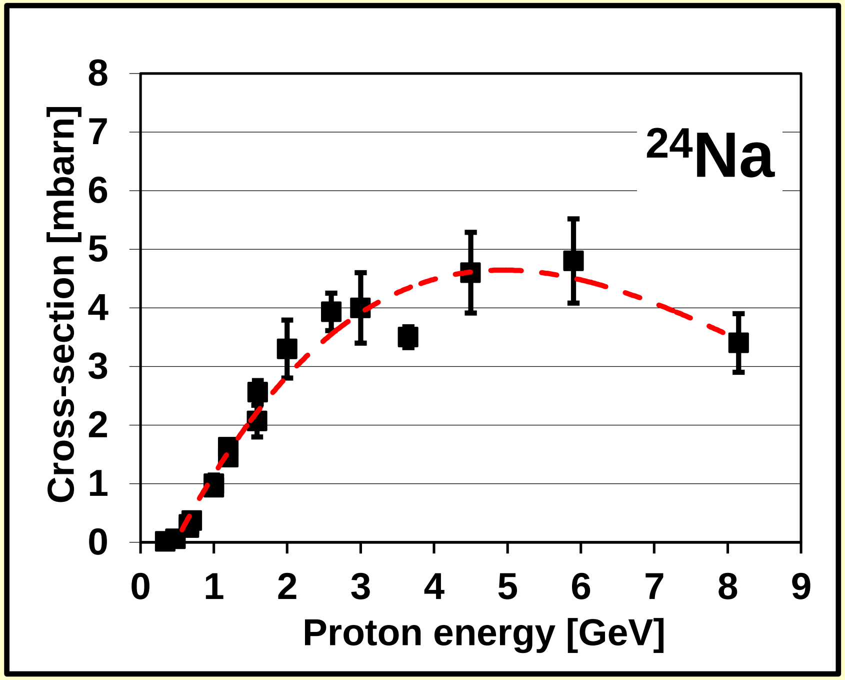


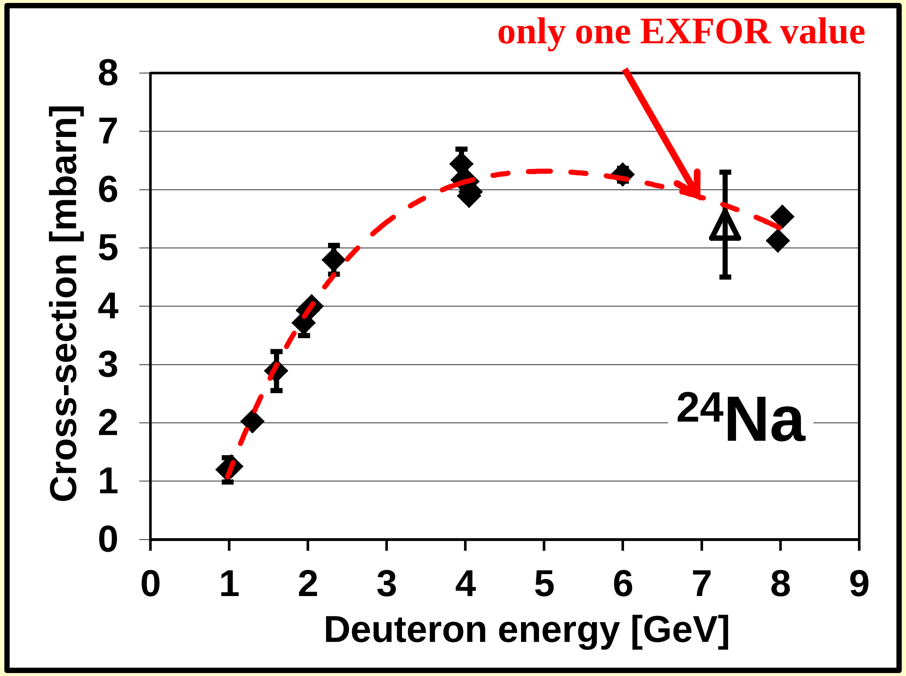


Without correction on beam integral uncertainty

with correction

Only one example of obtained cross-section data





Relativistic protons (EXFOR)

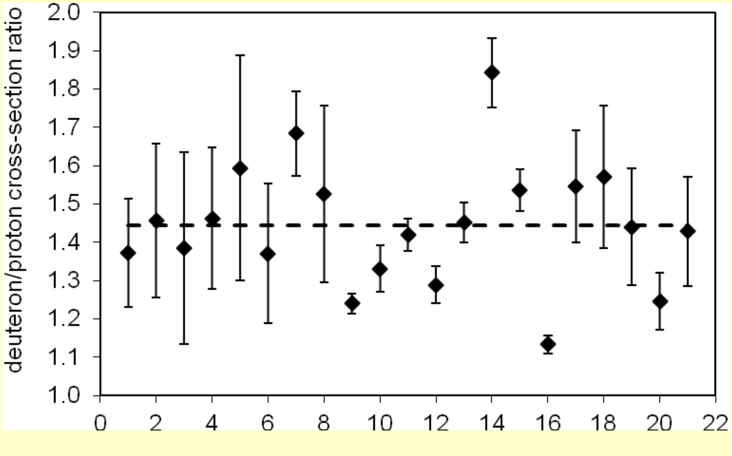
Relativistic deuterons (ours)

Ratio between deuteron and proton cross-sections:

1.3 – 1.6 → deuteron production is about 40 % higher

Only ratio for productions of the lightest nuclide (^{7}Be) is different (deuteron reaction cross-section is two times higher)

Detailed information – Martin Suchopar presentation



ERINDA (successor of EFNUDAT)
Transnational Access Activities

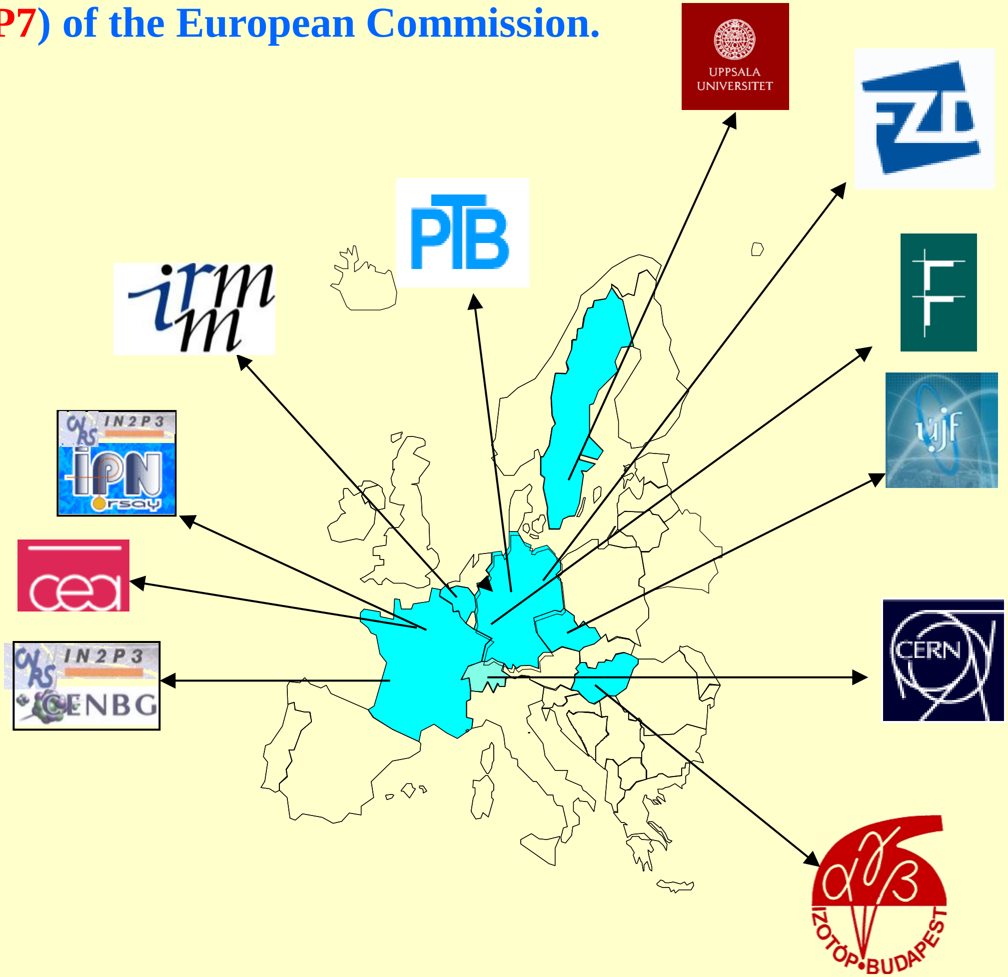
The **ERINDA** project is an Integrated Infrastructure Initiative (**I3**) funded under the 7th framework programme (**FP7**) of the European Commission.

The ERINDA Project

Start date: 1/1/2011
Duration : 4 years
Beam time: 2600 hours
Typical experiments: 26
Support: 80 manweeks

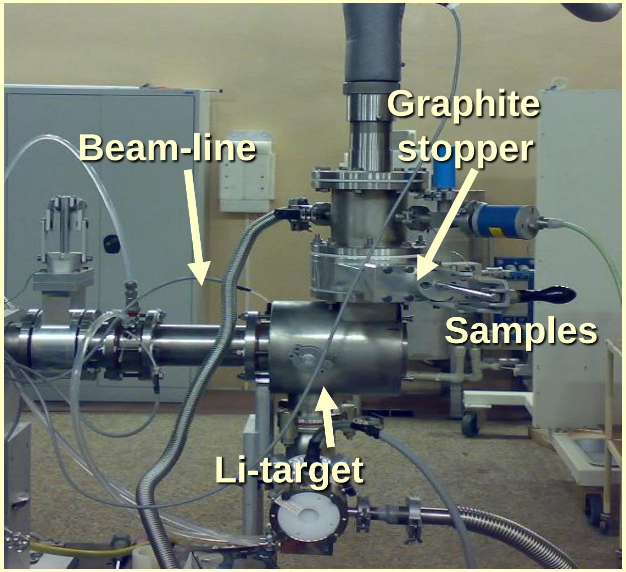
The ERINDA Consortium
13 partners- 13 facilities
hours for external users

Web-site: www.erinda.org
<u>Project Coordinator</u>: A. Junghans



Measurement of neutron reaction cross-sections

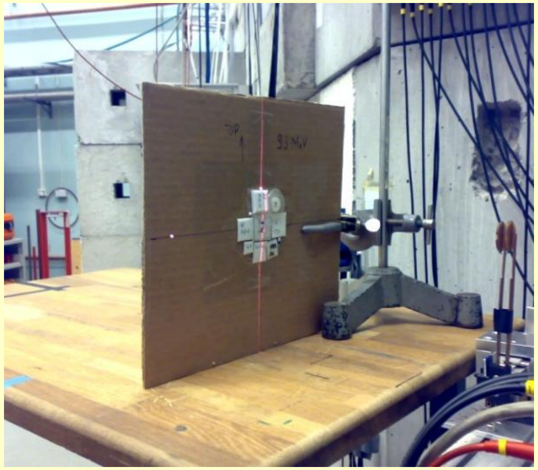
Quasi-monoenergetic neutron source: protons from cyclotron + lithium target

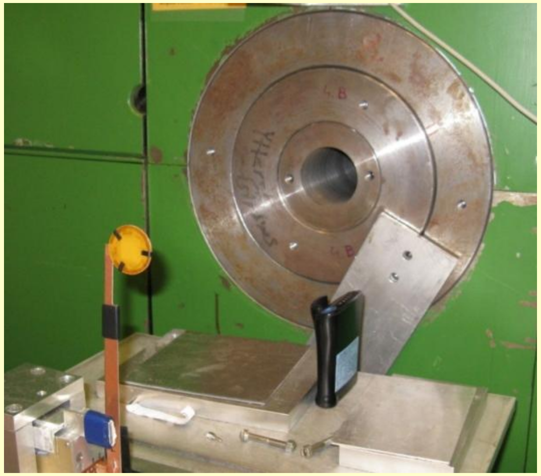


NPI ASCR Řež: Energy range 18 -37 MeV, neutron intensity ~ 10^8 neutron cm^{-2} s^{-1}

TSL Uppsala: Energy range 25 – 180 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





- **Nuclear Instruments and Methods in Physics Research - *Vol.726*, (2013) 84-90**

Yttrium cross-section measurement (ERINDA project)

Only reactions (n,2n) and (n,3n) for energy up to 38 MeV, systematic study of yttrium reactions using the NPI neutron source were done during last two years

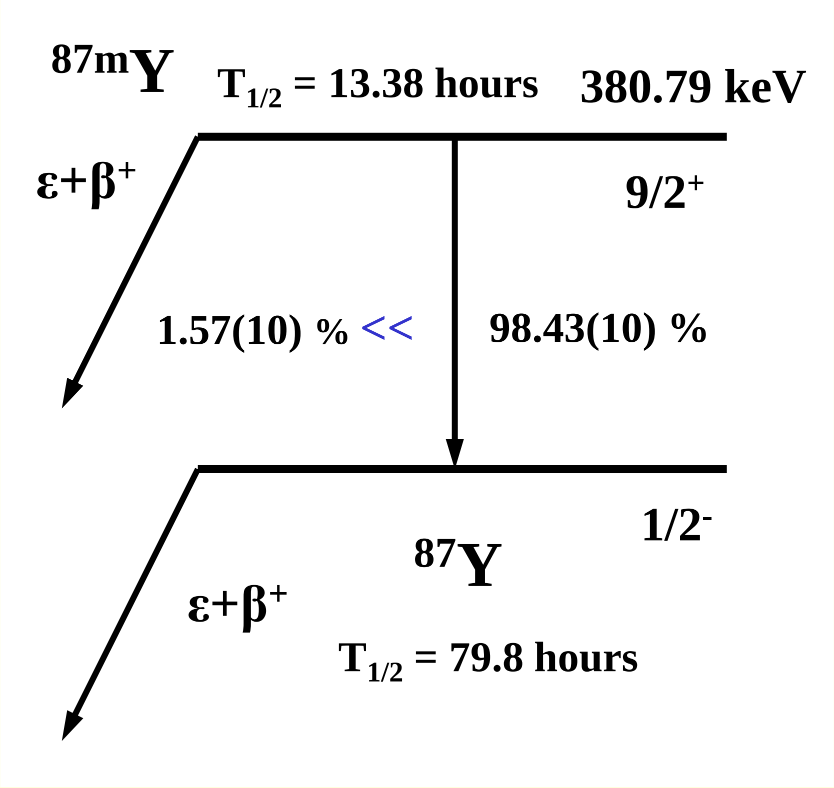
Yttrium – good material for activation detector
Used by "Energy+Transmutation" collaboration

Very scare data about cross-sections

No data about cross-sections of isomeric state production

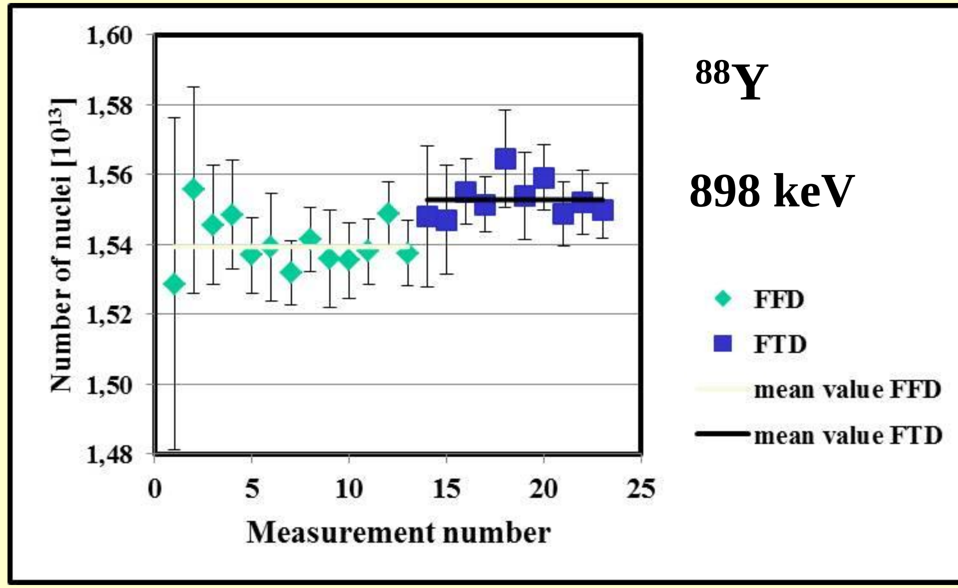
Long irradiation, intensive beam, only limited number of samples → possibility to measure yttrium sample many times to study systematic uncertainties of gamma measurements

Important - isomeric state ^{87m}Y study



Reaction (n,3n) - production of isomeric and ground state of ^{87}Y

Accuracy of gamma spectroscopy measurement



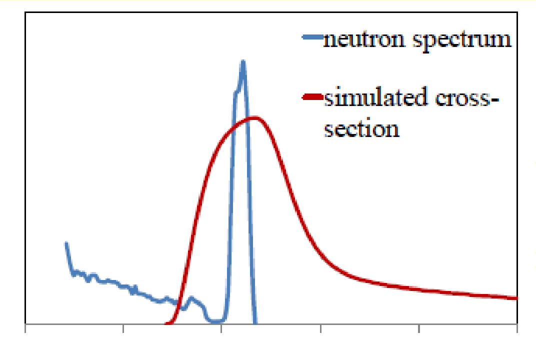
Source detector distance – **50 mm**

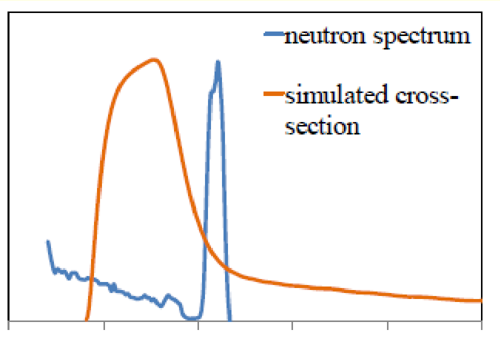
Yttrium – thicker sample (~ mm) →
if different side facing to the detector
→ small difference:

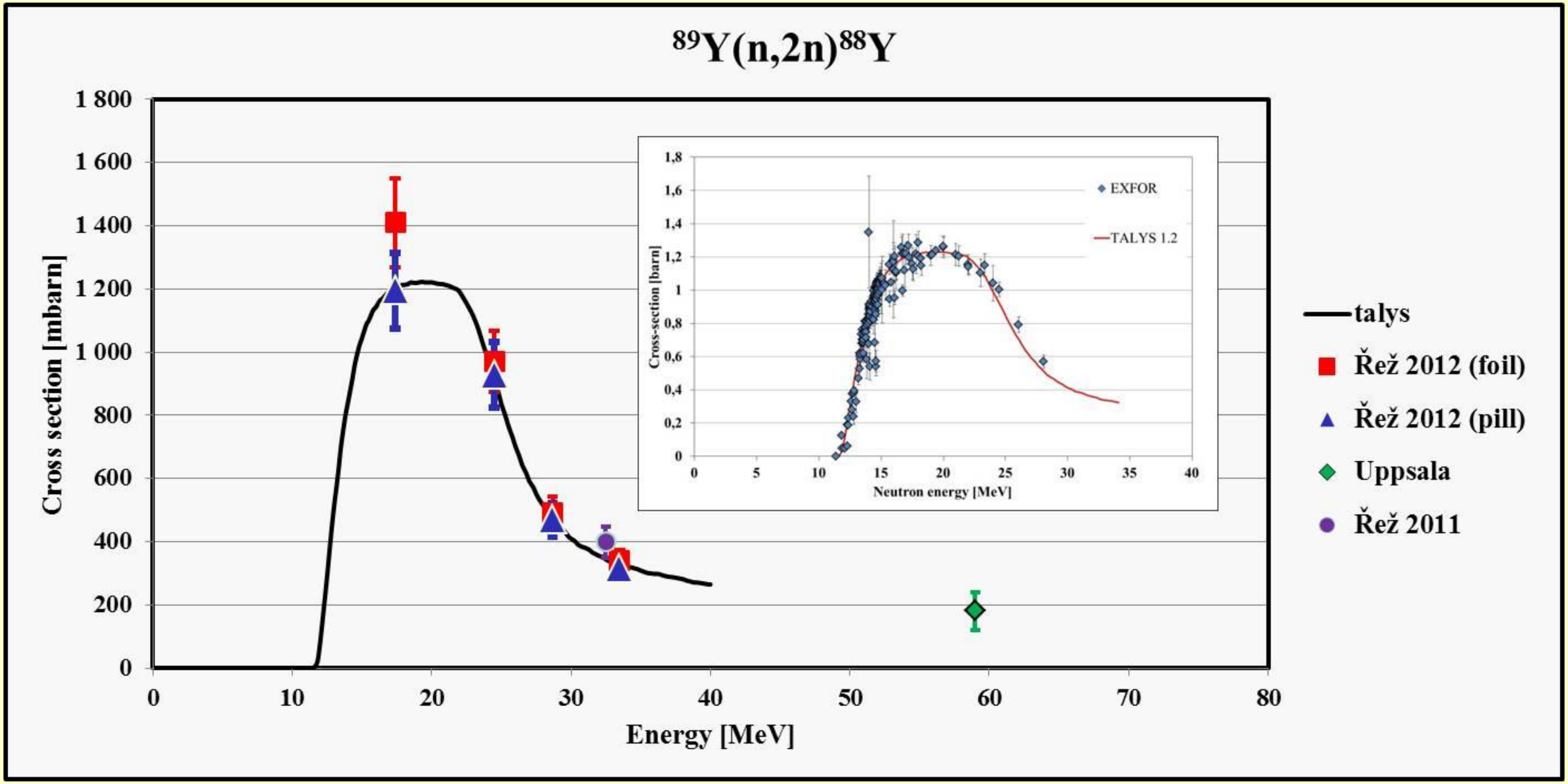
N(FFD) = $1.539(3)\cdot10^{13}$
N(FTD) = $1.553(3)\cdot10^{13}$
N(all) = $1.546(2)\cdot10^{10}$

difference
~ 0.9 %

Phenomena is quickly decreasing
with bigger source detector distances

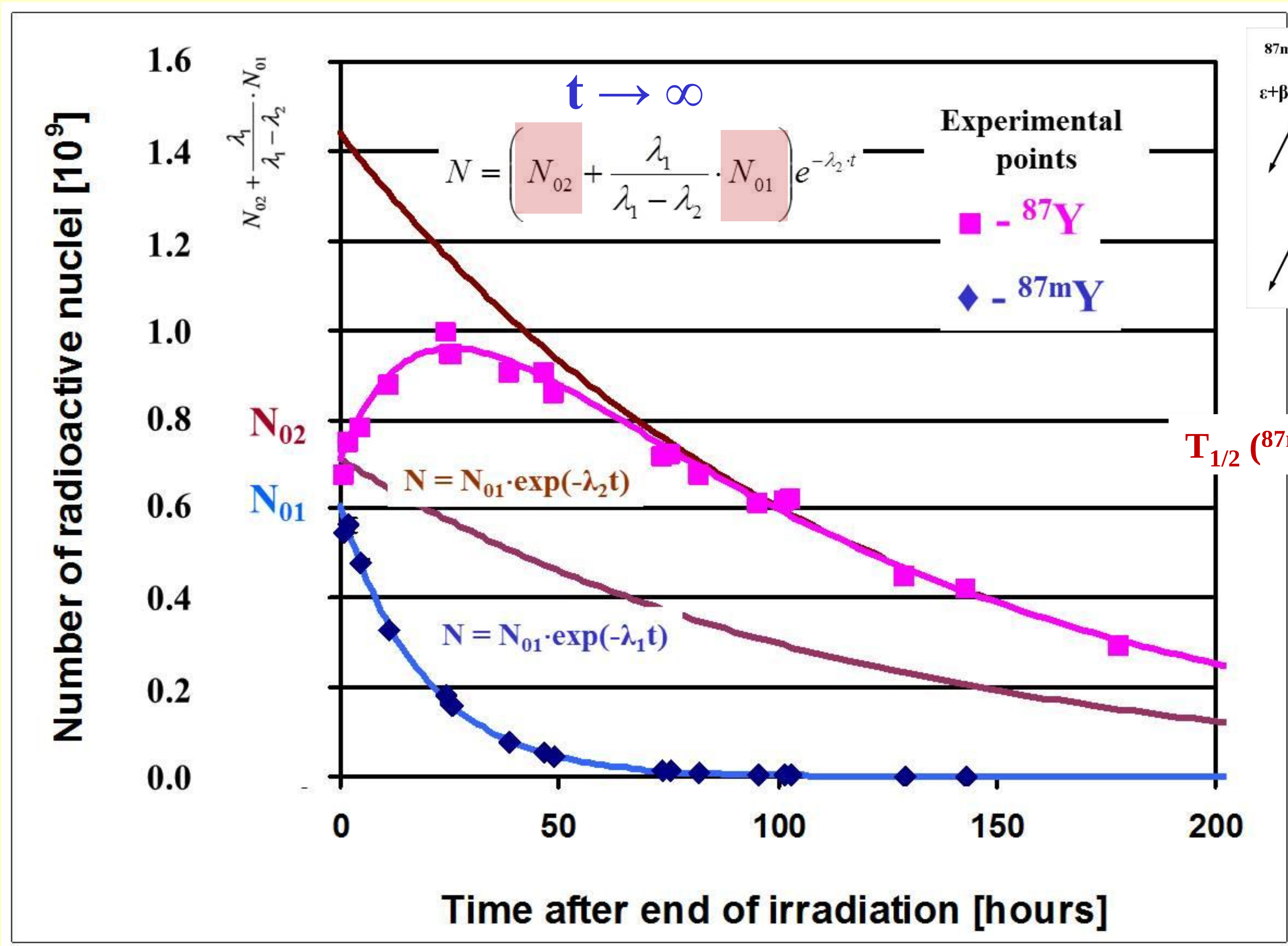

neutron spectrum
simulated cross-section

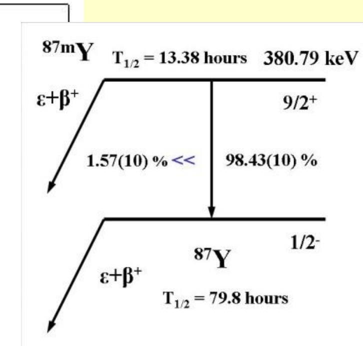

neutron spectrum
simulated cross-section


$^{89}Y(n,2n)^{88}Y$
Cross section [mbarn]
Energy [MeV]
0
200
400
600
800
1 000
1 200
1 400
1 600
1 800
0
10
20
30
40
50
60
70
80
EXFOR
TALYS 1.2
Cross-section [barn]
Neutron energy [MeV]
talys
Řež 2012 (foil)
Řež 2012 (pill)
Uppsala
Řež 2011

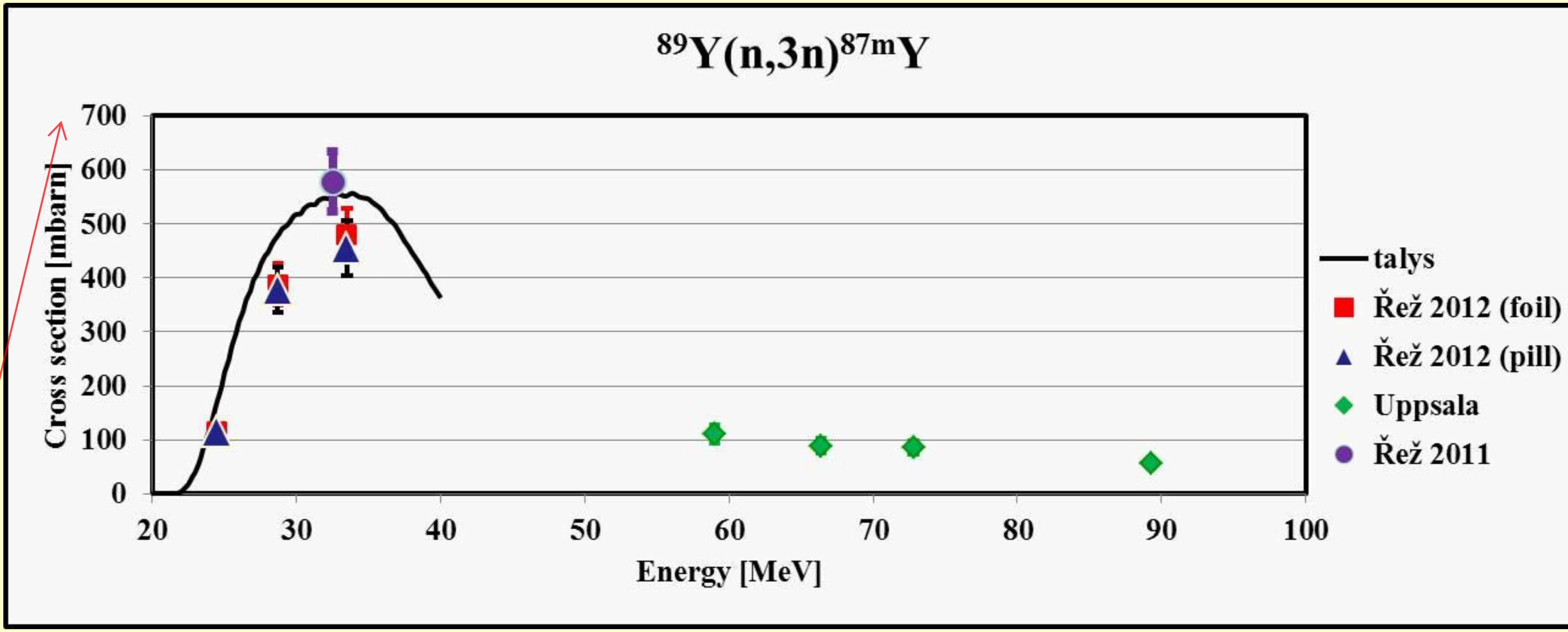
87mY $N_1 = N_{01} e^{-\lambda_1 \cdot t}$

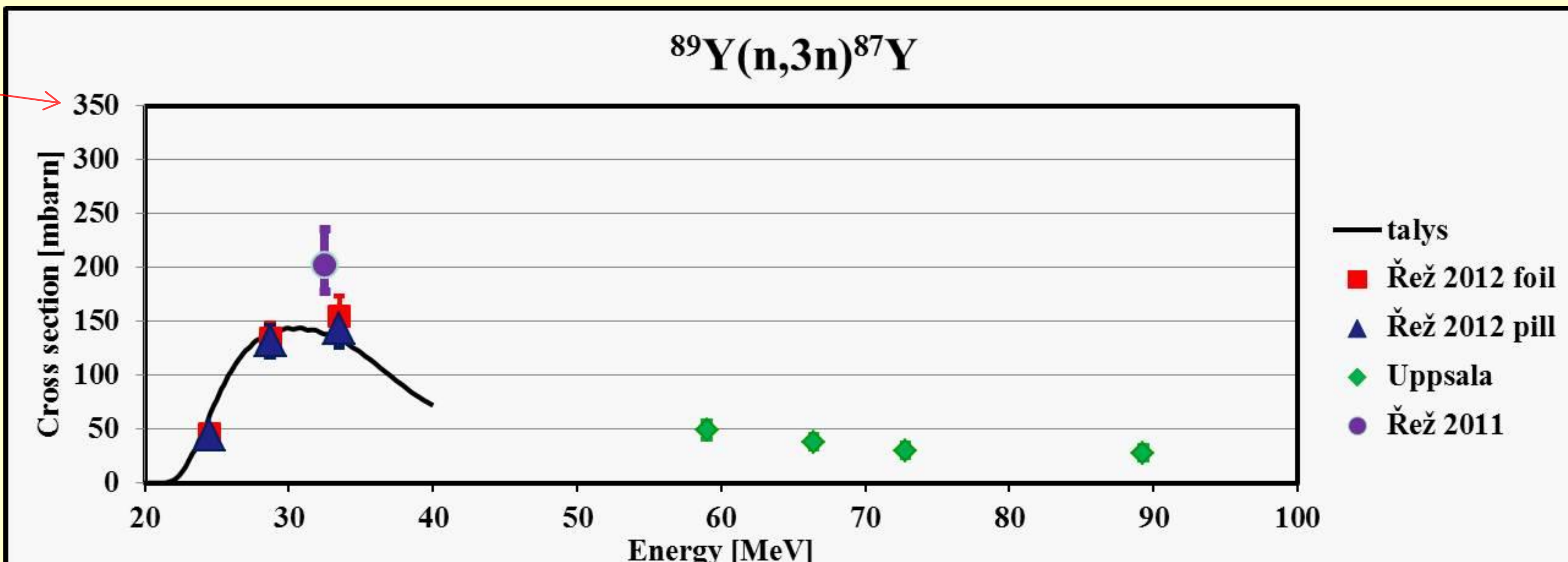
87Y $N_2 = \left(N_{02} + \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} \right) e^{-\lambda_2 \cdot t} - \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} e^{-\lambda_1 \cdot t}$





$T_{1/2}(^{87m}Y) << T_{1/2}(^{87}Y)$

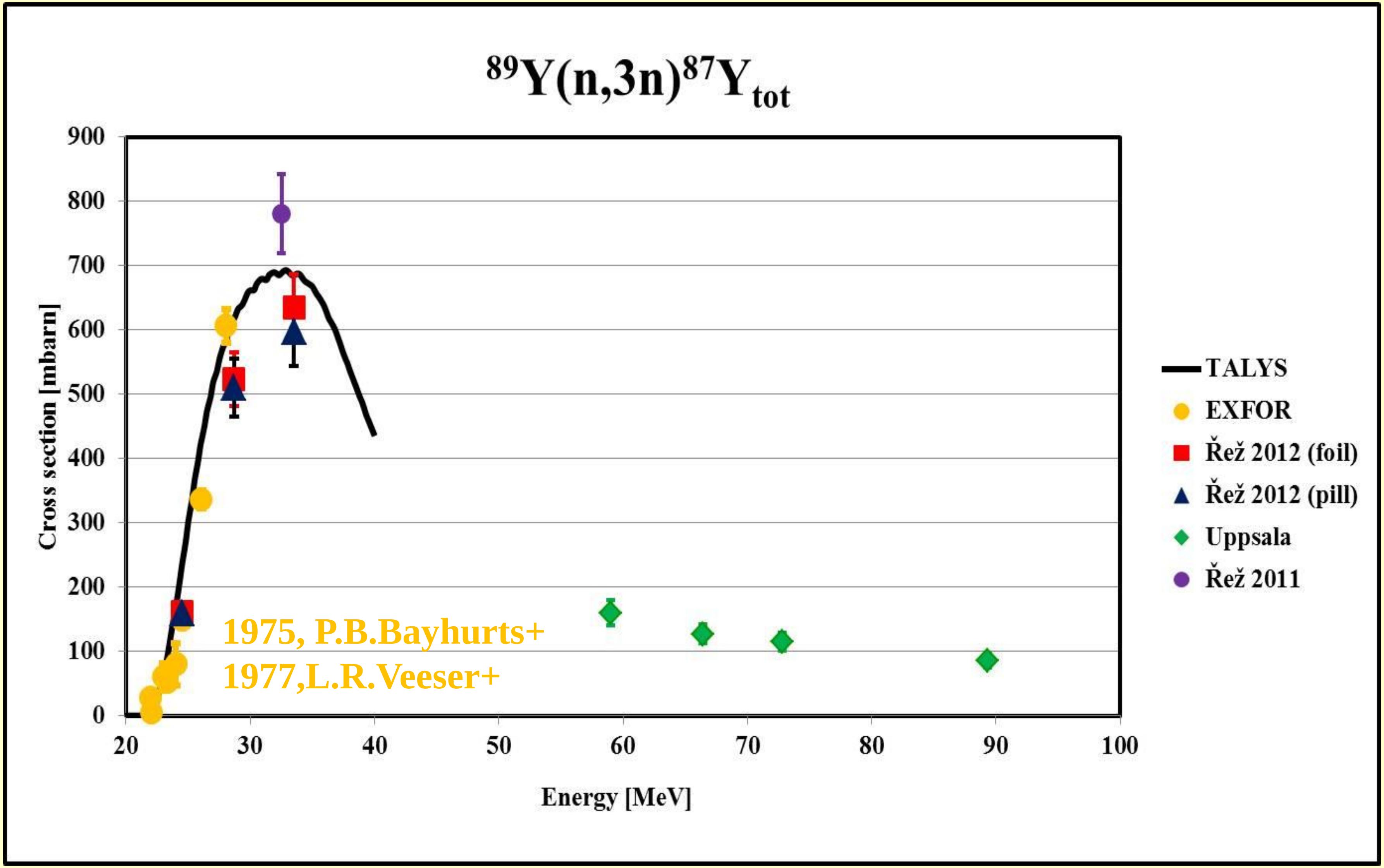




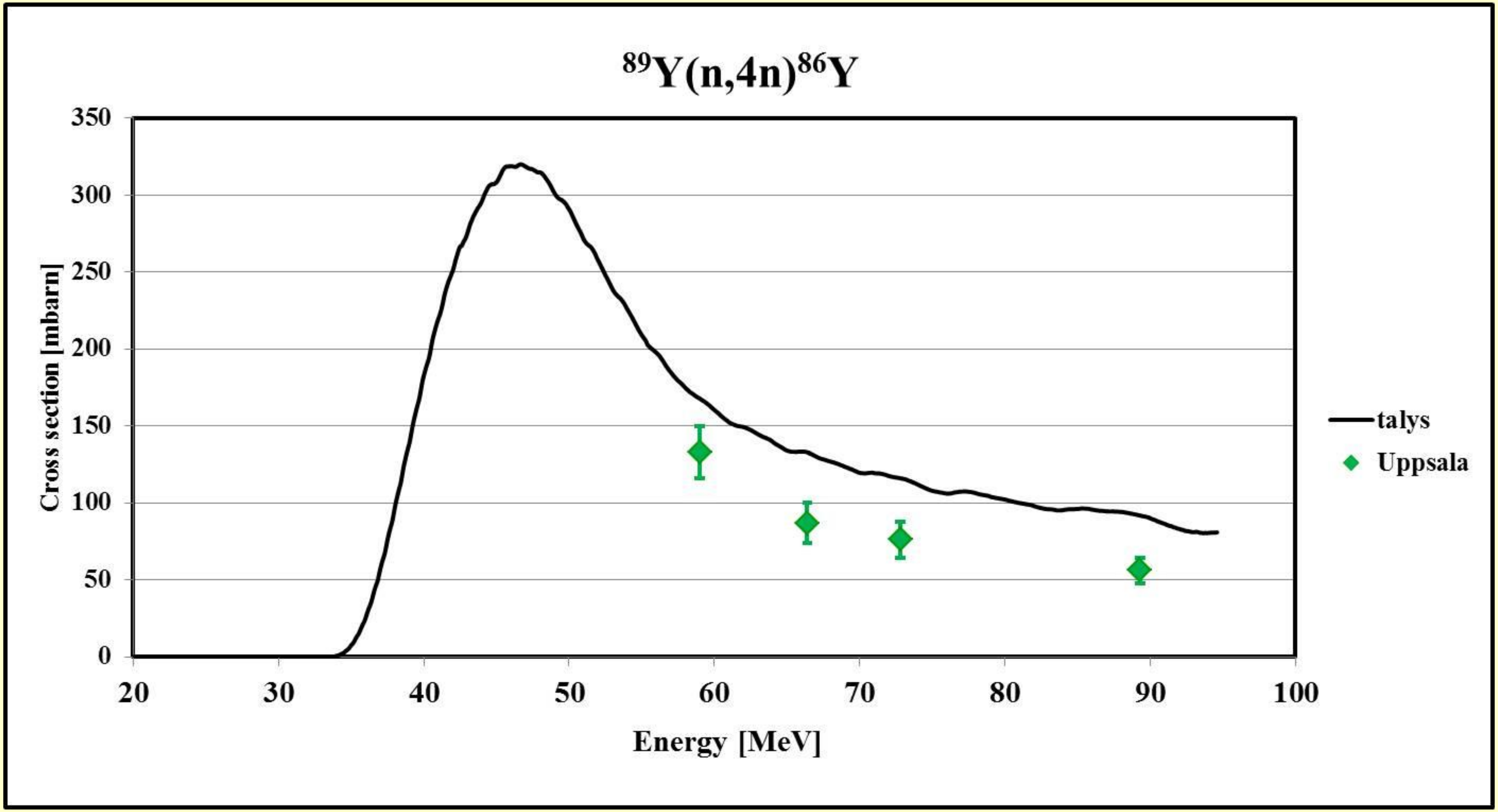
Scale 2times lower

Total cross section of ^{87}Y production

ERINDA Rez
EFNUDAT Uppsala

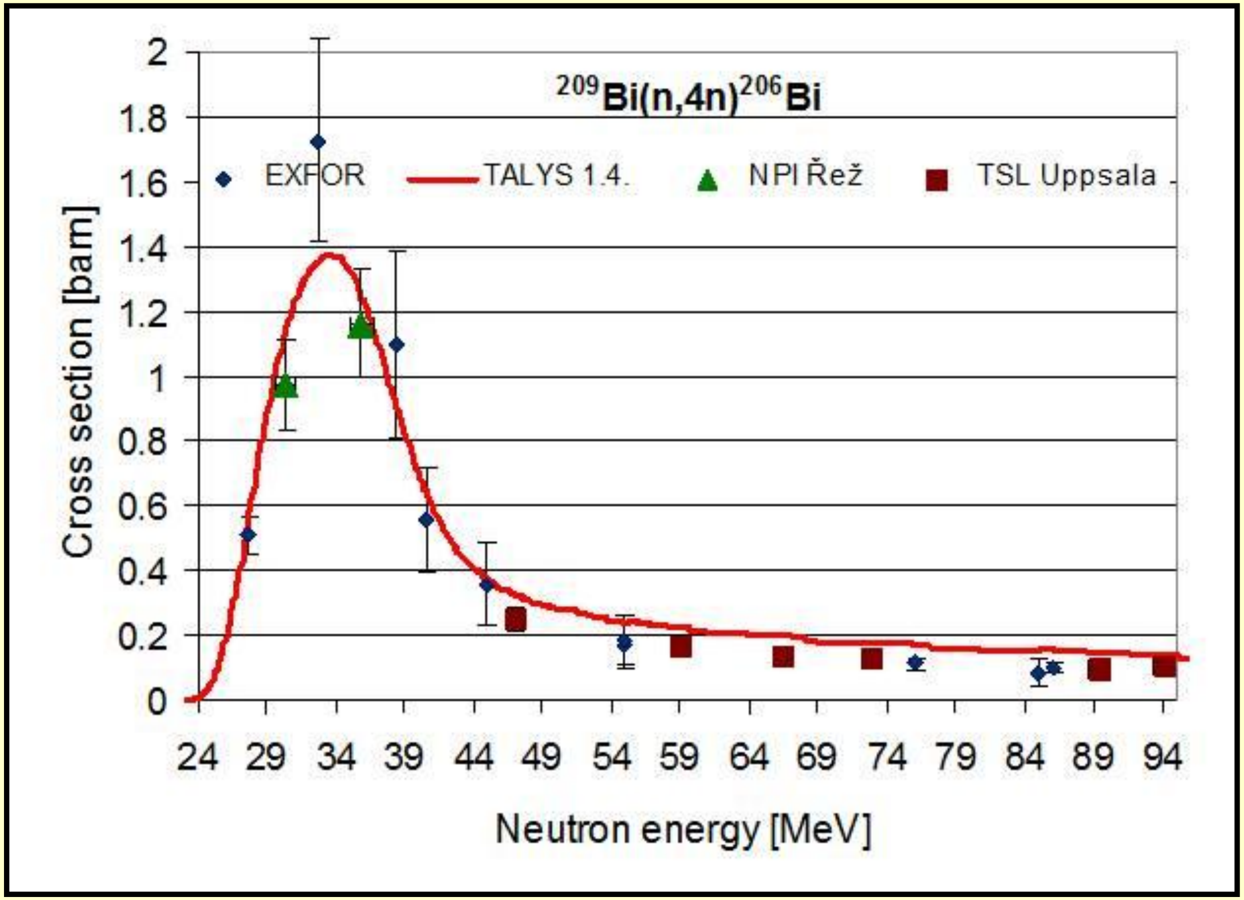


Cross section of ^{86}Y production EFNUDAT Uppsala

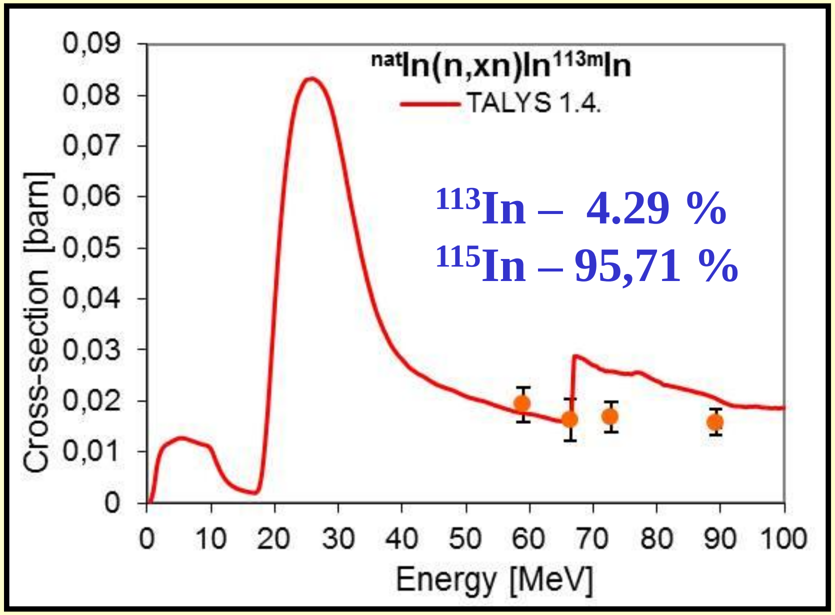


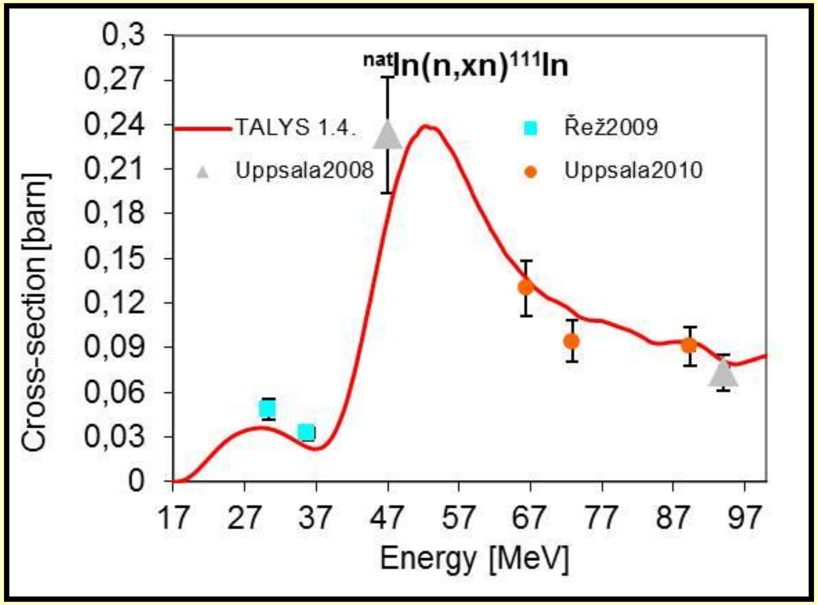
Systematic study of neutron cross sections (EFNUDAT)

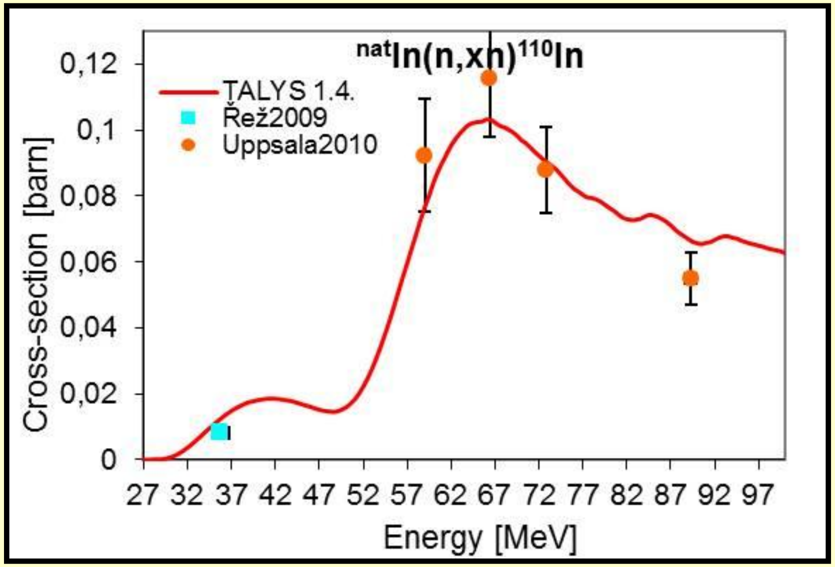
We measured threshold reactions on Au, Al, Bi, In, Ta, Ti, Y commonly used for such purposes and we also studied other materials: Cu, Fe, I, Mg, Ni, Zn.

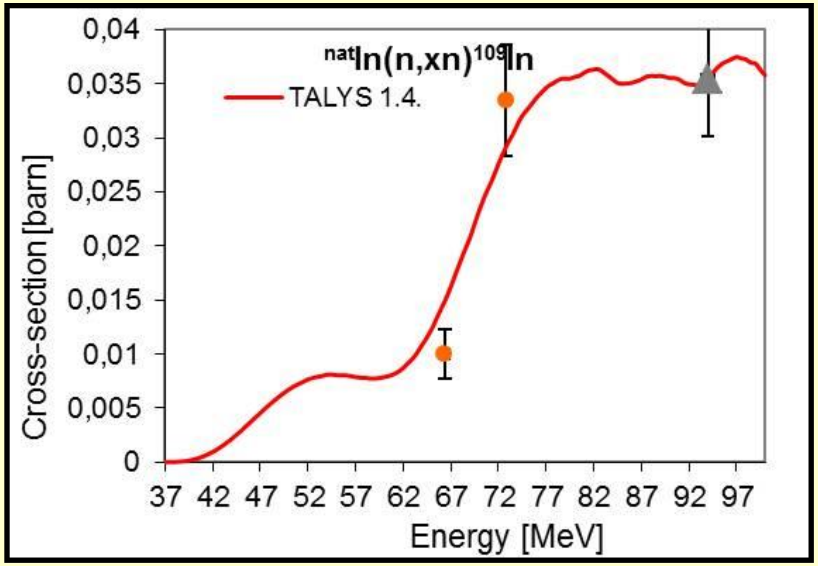


Comparison of cross-sections (n,xn) reactions on natural indium with TALYS

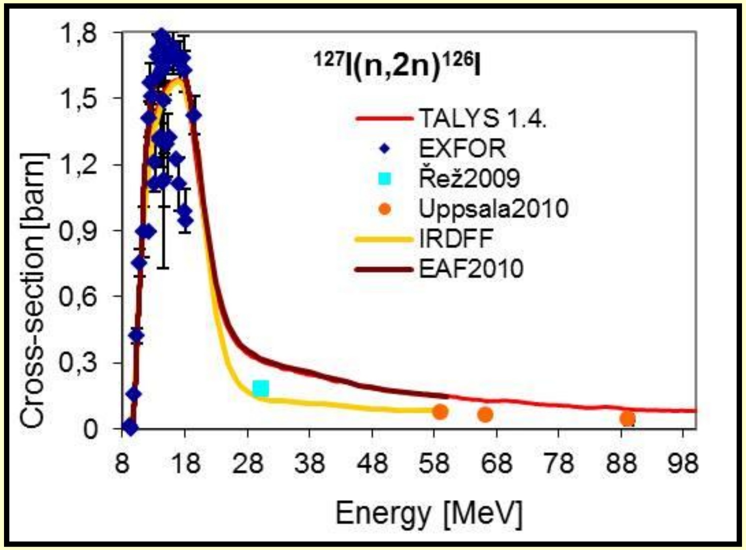


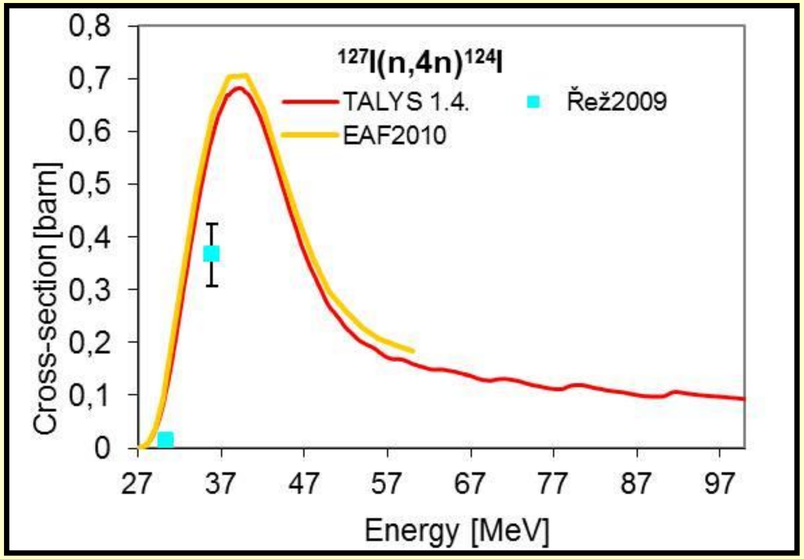


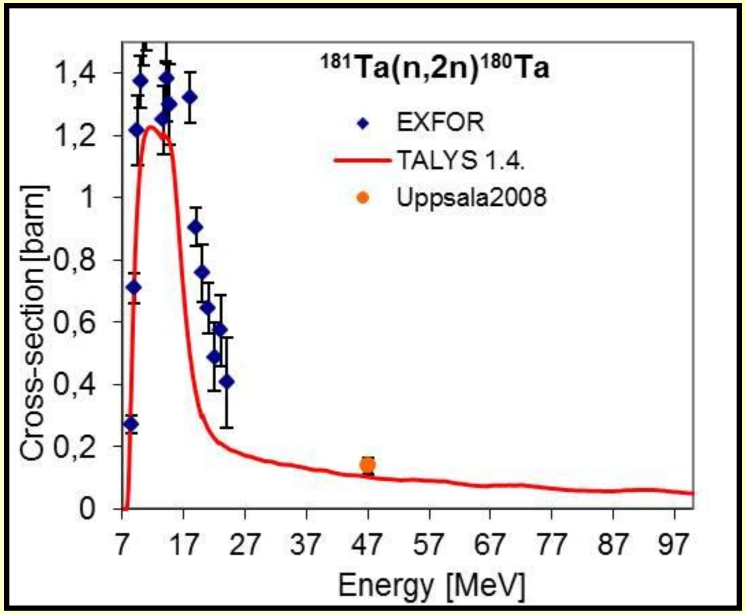


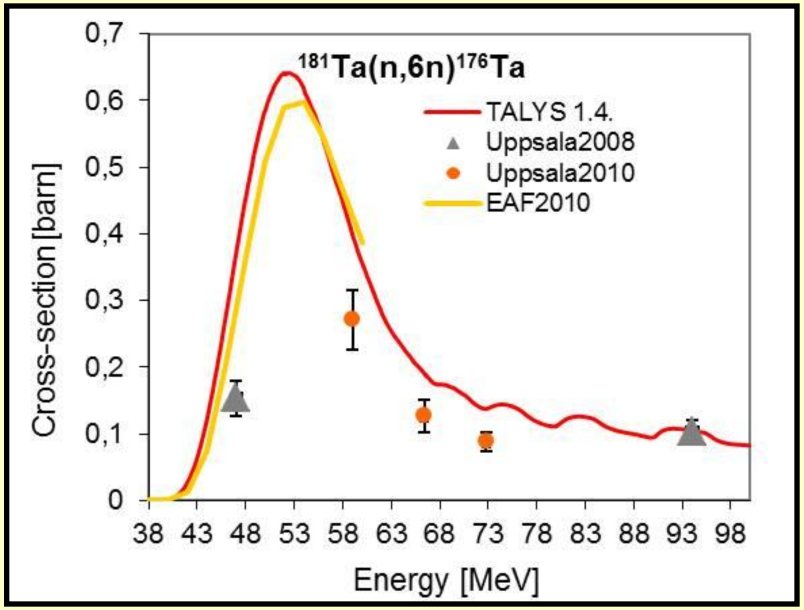


Comparison of cross-sections (n,xn) reactions on iodine and tantalum with EXFOR, TALYS and libraries of evaluated data

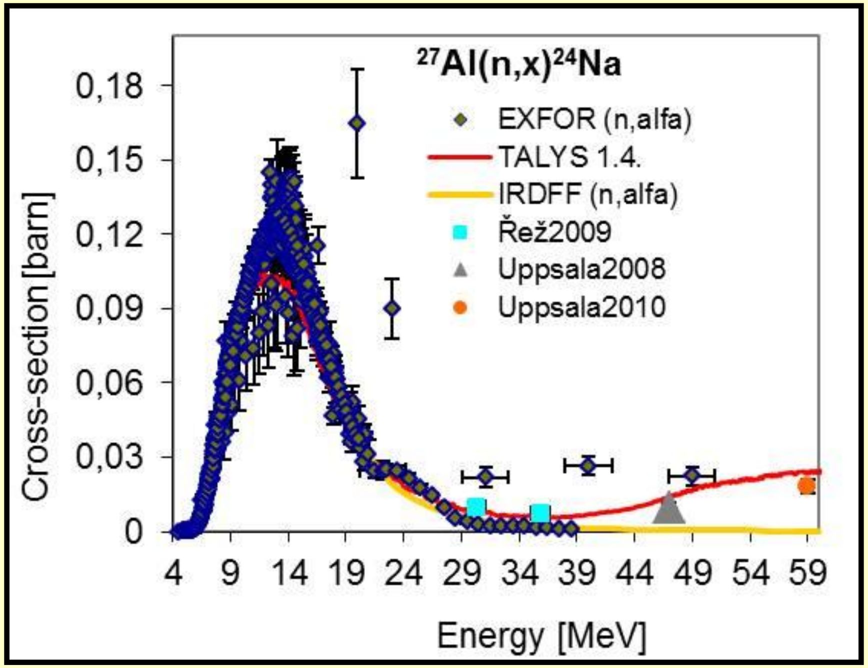


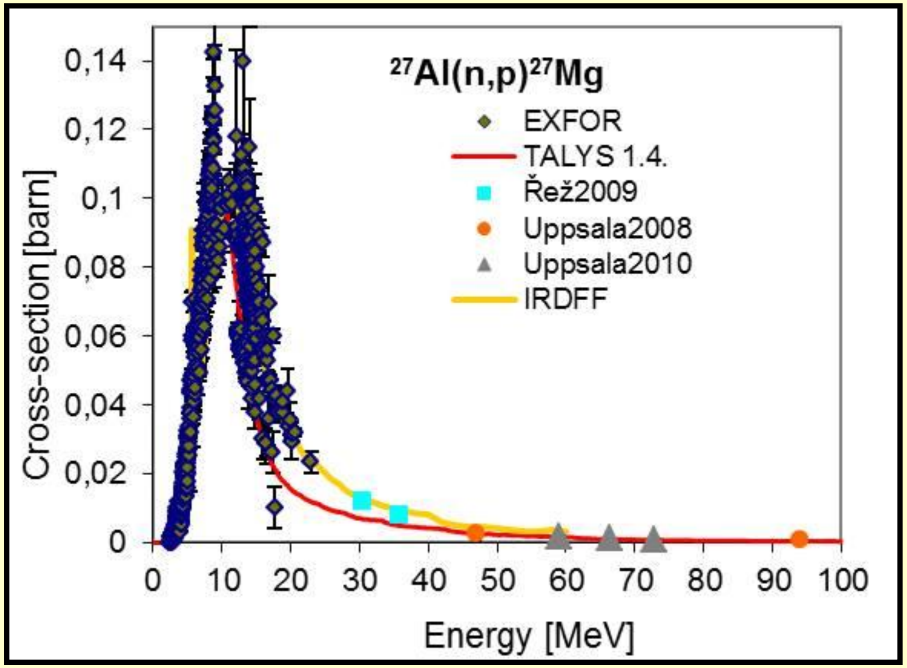






Comparison of cross-sections (n,x) reactions on aluminum with EXFOR, TALYS and libraries of evaluated data





Review of obtained data can be find in journal:

Nuclear Instruments and Methods in Physics Research - Vol.726, (2013) 84-90

Nice data obtained thanks to EFNUDAT, ERINDA and Řež and Uppsala neutron sources

CHANDA will be next opportunity

Test of single-crystal diamond detectors for fluency measurements

$n+{}^{12}C$	$\rightarrow {}^{9}Be+{}^{4}He$	-5.70 MeV
	$\rightarrow n'+{}^{12}C$	-4.44 MeV
	$\rightarrow n'+3a$	-7.27 MeV
	$\rightarrow p+{}^{12}B$	-12.59 MeV
	$\rightarrow d+{}^{11}B$	-13.73 MeV

NPI neutron source was used
(80 hours of irradiation)

Size: $4.7 \times 4.7 \times 0.5\ mm^3$

$E_{deposition} = Q + E_n - E_{n'}$

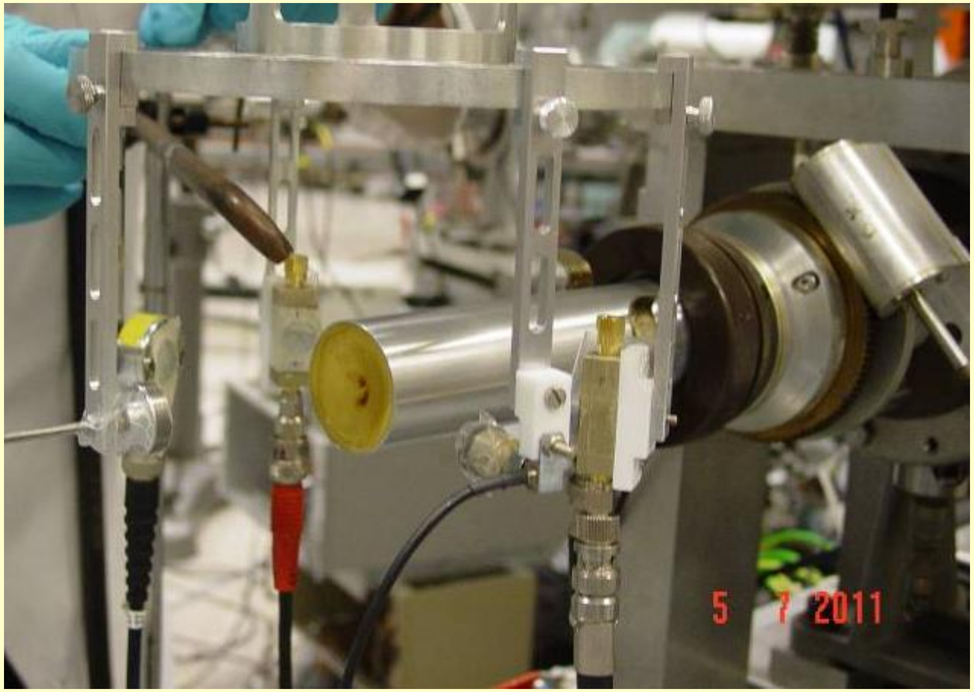
Sharp if no n' emitted:

E_n spectrometer

Antonín Krása
Arjan Plompen

(IRMM-JRC-EC)

ERINDA – PAC 2/3



from Arjan Plompen presentation

CHANDA
(New transnational Access EU Project)

CIEMAT, ANSALDO, CCFE, CEA, CERN, CNRS, CSIC, ENEA, GANIL, GSI, HZDR, IFIN-HH, INFN, IST-ID, JRC, JSI, JYU, KFKI, NNL, NPI, NPL, NRG, NTUA, PSI, PTB, SCK, TUW, UB, UFrank, UMainz, UMan, UPC, UPM, USC, UU, UOslo

Challenges in nuclear data for the safety of European nuclear facilities

Coordinator: Enrique Gonzalez
Infrastructure coord. & development

5.4 M€ EC contribution, ≈10M€ total
36 partners, 2013-2017

New neutron beams, new experimental equipment, new evaluation methods, Myrrha safety case, access to validation experiments, transnational access

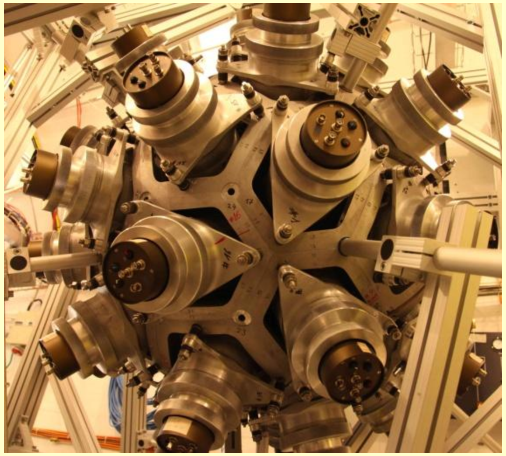
First CHANDA call for proposal

1) The Proposal for Testing and Improving the IAEA International Dosimetry Library for Fission and Fusion (IRDFF): irradiations at the TSL in Uppsala
2) Measurement of neutron yttrium reactions cross- section at Uppsala
3) Measurement of ^{197}Au(n,5n)^{193}Au ^{197}Au(n,6n)^{192}Au reaction cross-sections

Set proposals for TSL Uppsala neutron source was approved

New call for proposals will be during end of this year, please use it

Also n-TOF neutron source is participant device of CHANDA project:



Conclusions

- **Nuclear data are very important for future advanced nuclear systems. Many cross-sections of deuteron and neutron reactions with different materials are needed (very scarce data at experimental data bases).**
- **We used Quinta measurements to obtain cross-sections of relativistic deuterons reactions on copper.**
- **Excellent set of deuteron reactions on copper is possible to compare with data about proton reactions on copper. It is possible to use such data for benchmark of nuclear models and codes**
- **The quasi- monoenergetic neutron sources – ecellent tool for neutron reaction cross-section studies.**
- **The European projects EFNUDAT, ERINDA and CHANDA made possible to use effectively European neutron sources**
- **We are waiting for second call for proposals of CHANDA project**