XXI INTERNATIONAL BALDIN SEMINAR ON HIGH ENERGY PHYSICS PROBLEMS

Studies of Deuteron and Neutron Cross-sections Important for ADS Research

(XXI Baldin seminar)

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for collaboration "Energy plus transmutation"

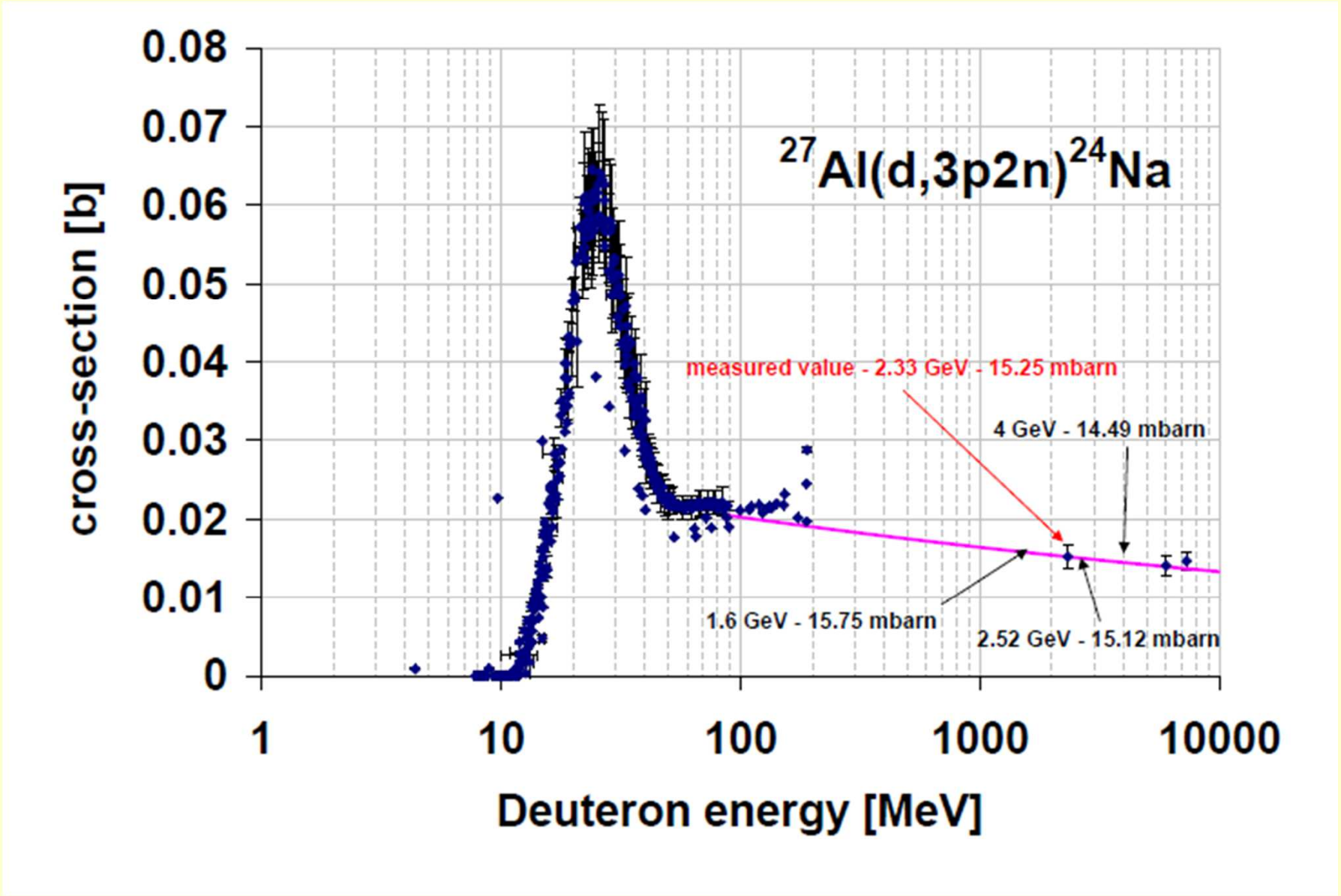
(Russia, Belarus, Germany, Greece, Poland, Ukraine, Czech Republic …)

Deuteron reaction cross-section measurements

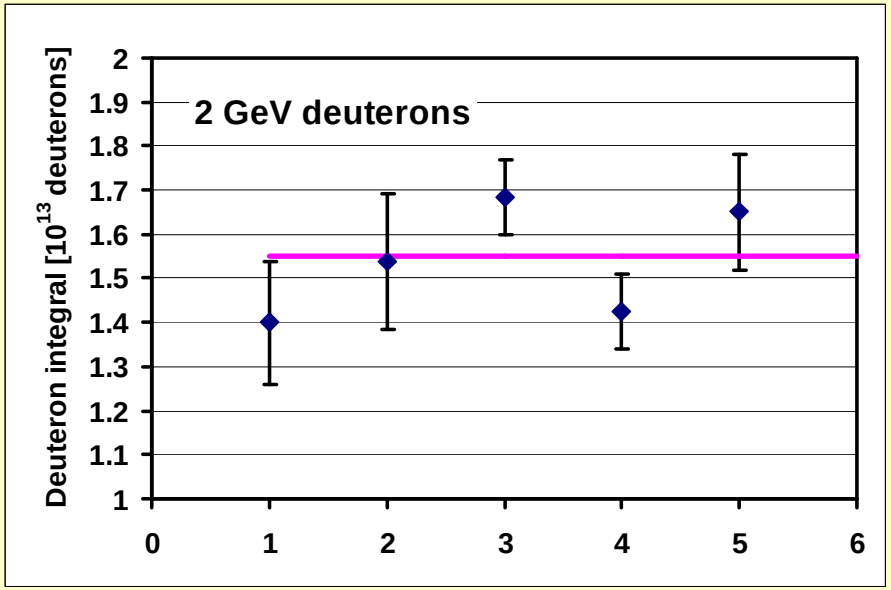
Neutron reaction cross-sections measurements

Production of ^{24}Na on aluminum foil by deuteron beam

Only about this reaction are cross-section data, but only scarce. → uncertainty 10 %



Beam integral determination by means of aluminum foils

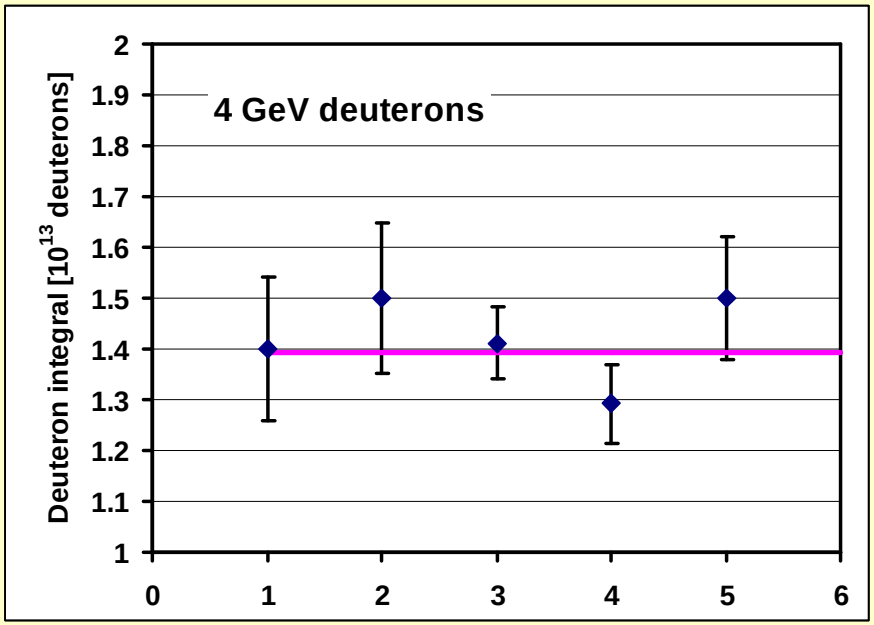


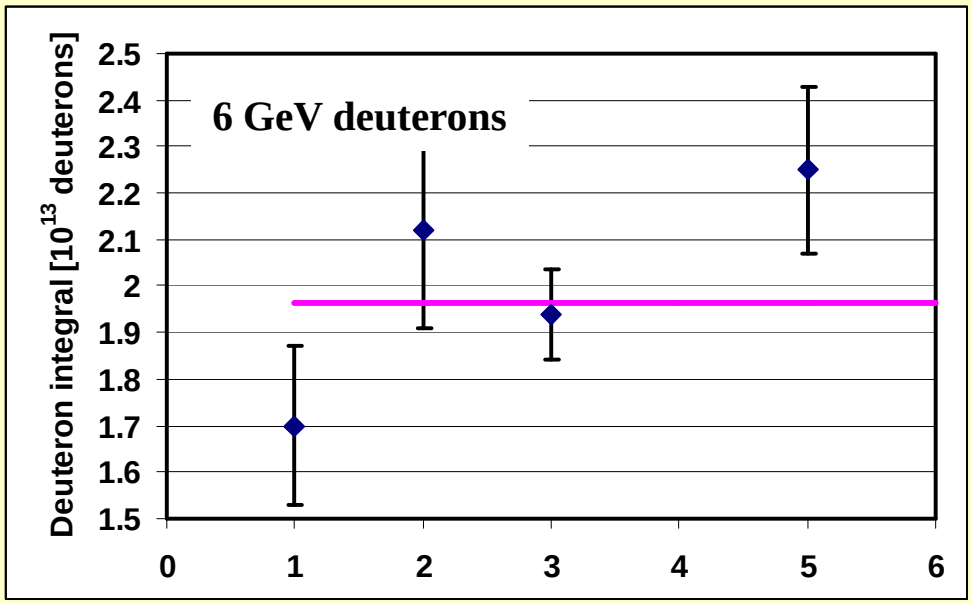
December 2011 set of QUINTA irradiations

Very good agreement – we have approved values

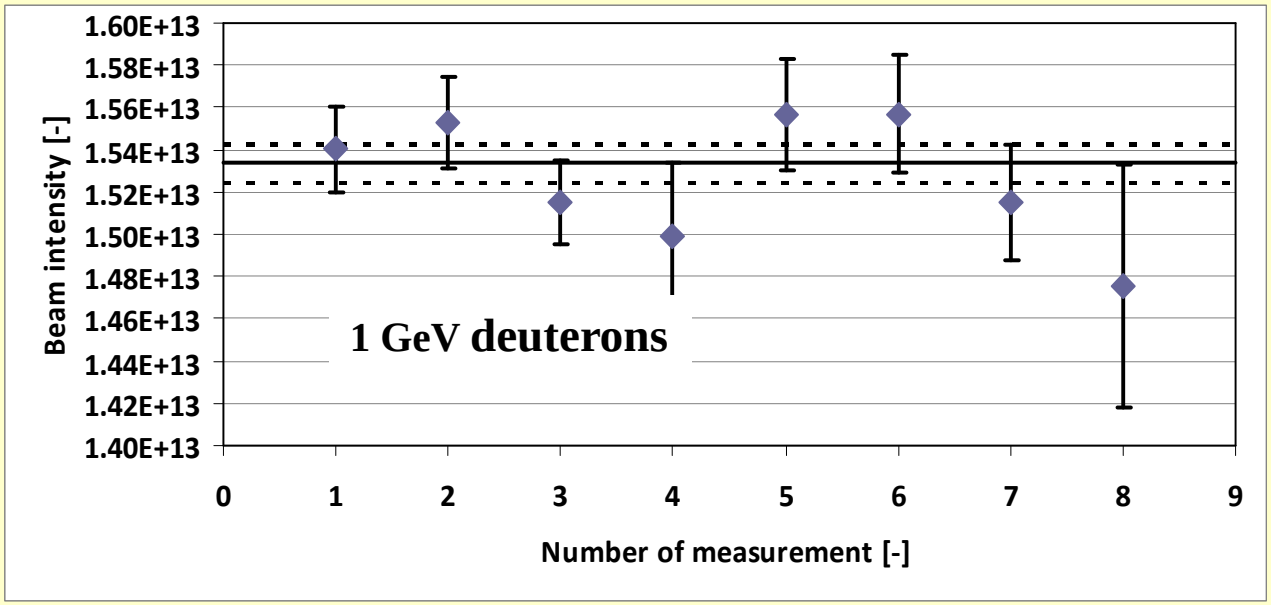
2 GeV	$1.54(7)\cdot 10^{13}$ deuterons
4 GeV	$1.39(4)\cdot 10^{13}$ deuterons
6 GeV	$1.97(10)\cdot 10^{13}$ deuterons

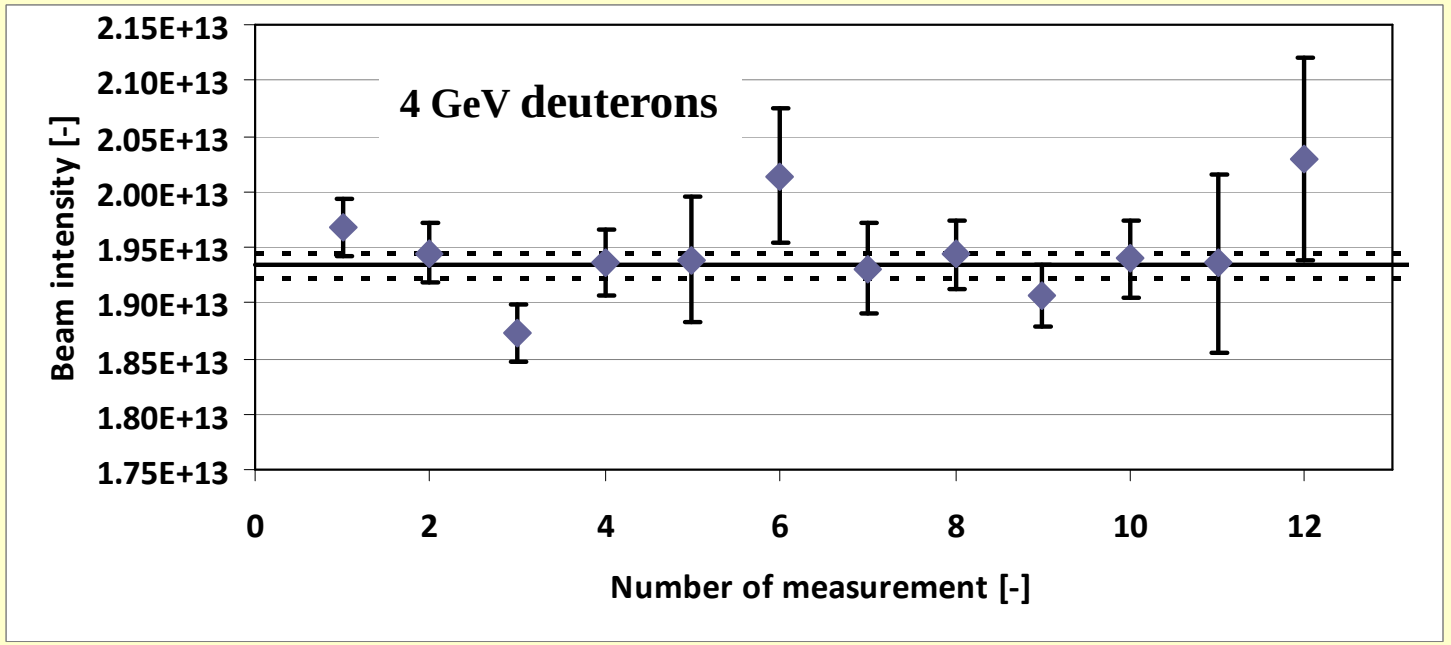
Cross-section uncertainty – 10 %





December 2011 irradiations





1 GeV $1.533(9)\cdot 10^{13}$ deuterons

4 GeV $1.932(10)\cdot 10^{13}$ deuterons

Only statistical uncertainties

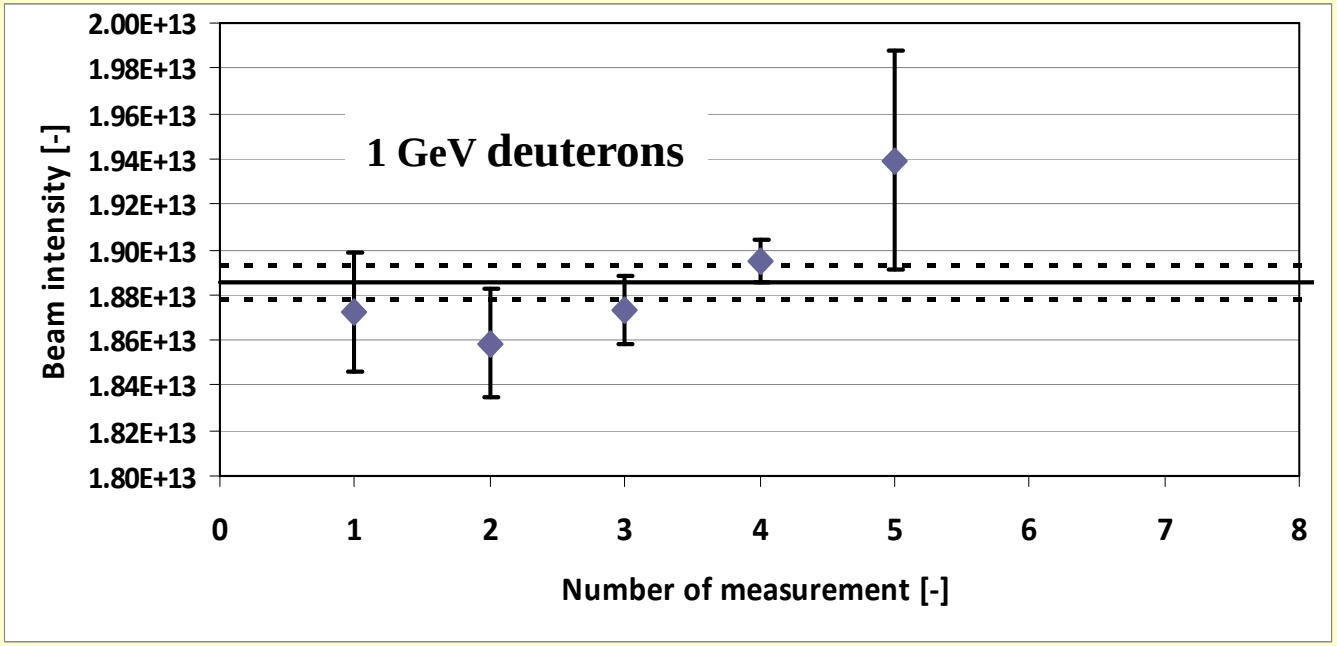
Zhuk:

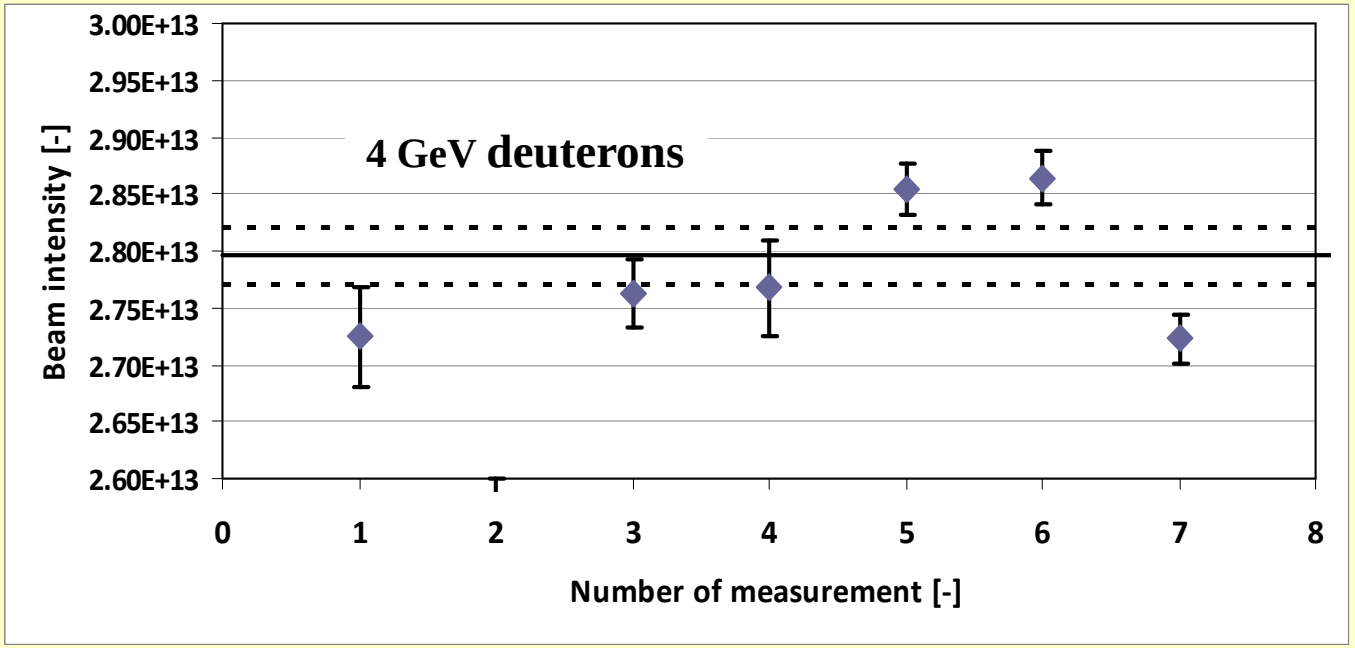
1 GeV $1.47\cdot 10^{13}$

4 GeV $1.96\cdot 10^{13}$

Necessary – all data with uncertainties
Description of all correction calculation (coincidences, self absorption, size of sample)

March 2012 irradiations



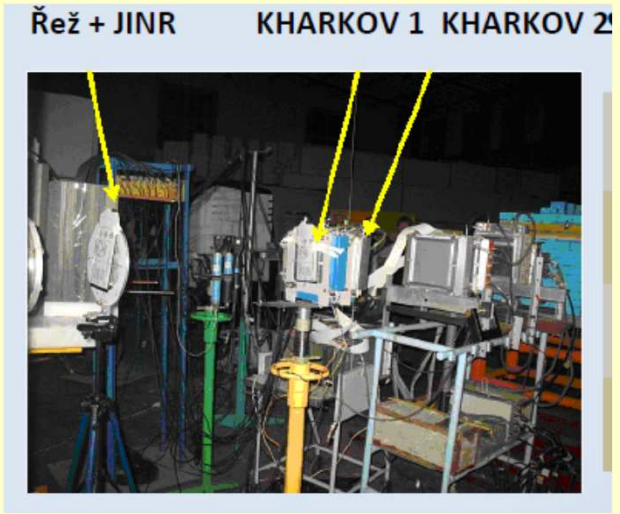


Energy	Number of deuterons
1 GeV	$1.886(8)\cdot 10^{13}$
4 GeV	$2.796(26)\cdot 10^{13}$
8 GeV	$0.565(6)\cdot 10^{13}$

Preliminary

Only statistical uncertainties

	1 GeV	4 GeV	8 GeV
Zhuk	1.9	2.7	0.37
KH1	1.8	3.5	0.49
KH2	1.8	2.7	0.37
JINR	1.87(10)	2.65(13)	0.55(4)



Studies of relativistic deuteron reactions on natural copper

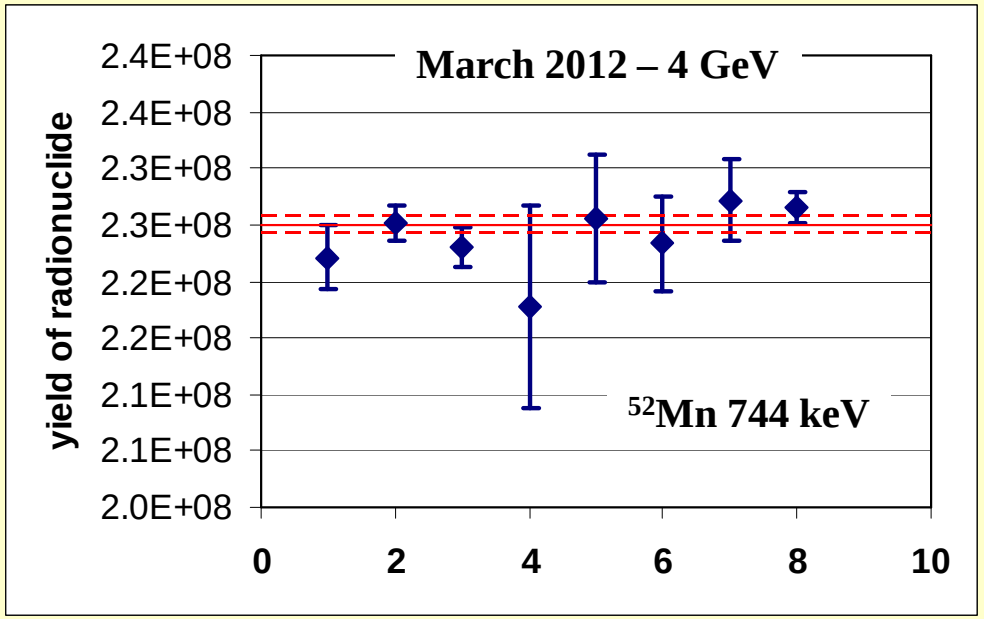
Common irradiation of aluminum and copper foils

Production of different radionuclides

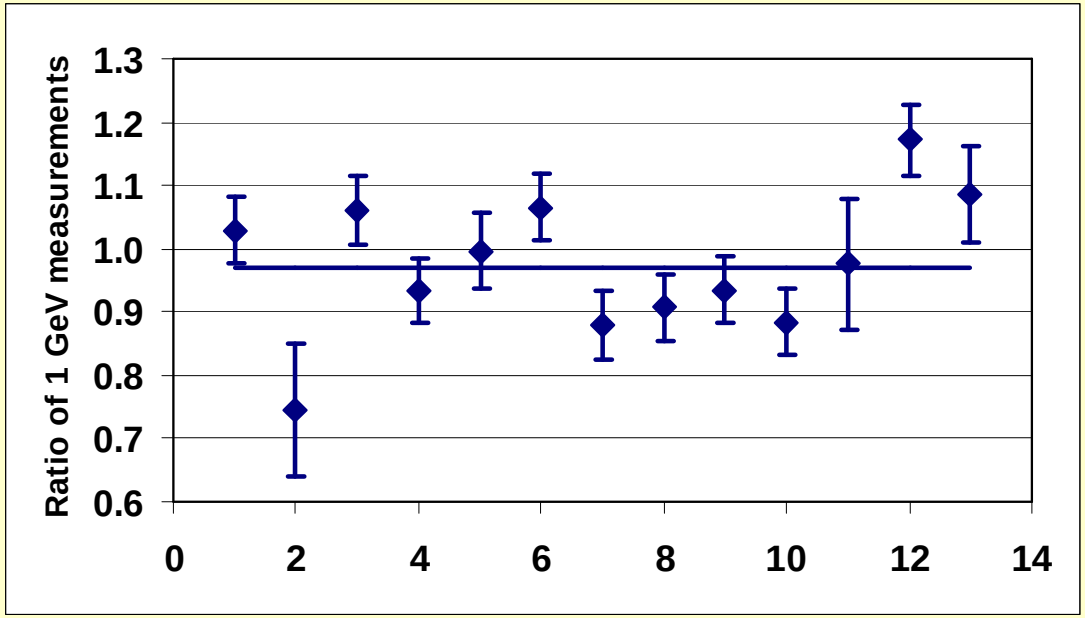
Some deuteron energies were measured more times

Energy range of deuteron beam from 1 GeV up to 8 GeV

More measurements of copper sample in different times (possibility split influence of short lived and long lived isotopes with the same energy line – ^{43}K and ^{43}Sc, ^{56}Co and ^{56}Mn, ^{48}Sc and ^{48}V) and on different detectors with different geometry (suppression of systematic uncertainties influence)

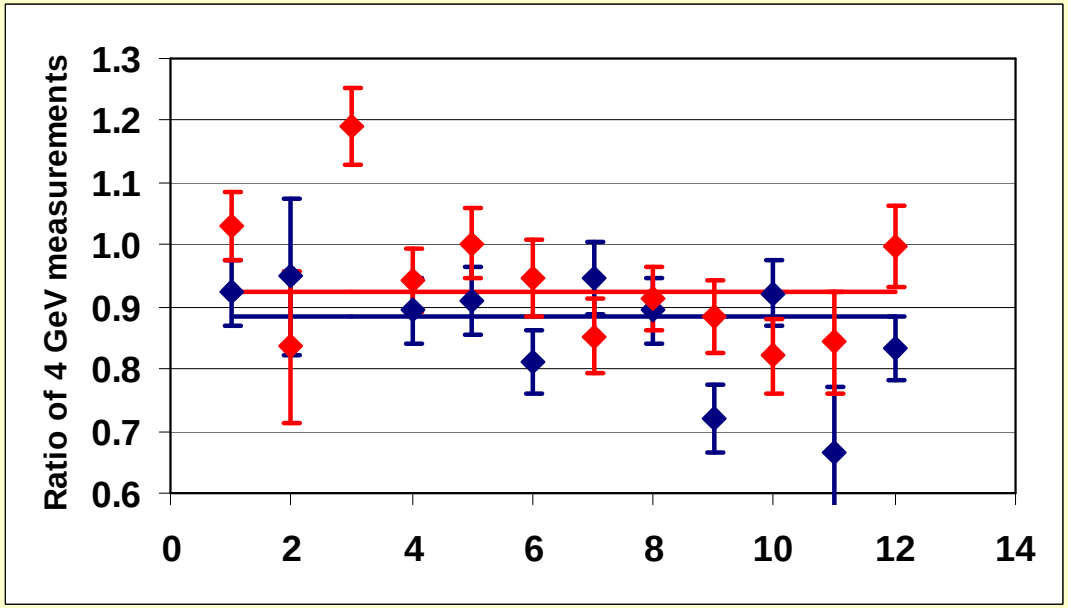


Comparison of different measurements with the same deuteron energy



Comparison of two measurements with 1 GeV neutron beam
1. December 2011
2. March 2012

Mean value of ratio: 0.969

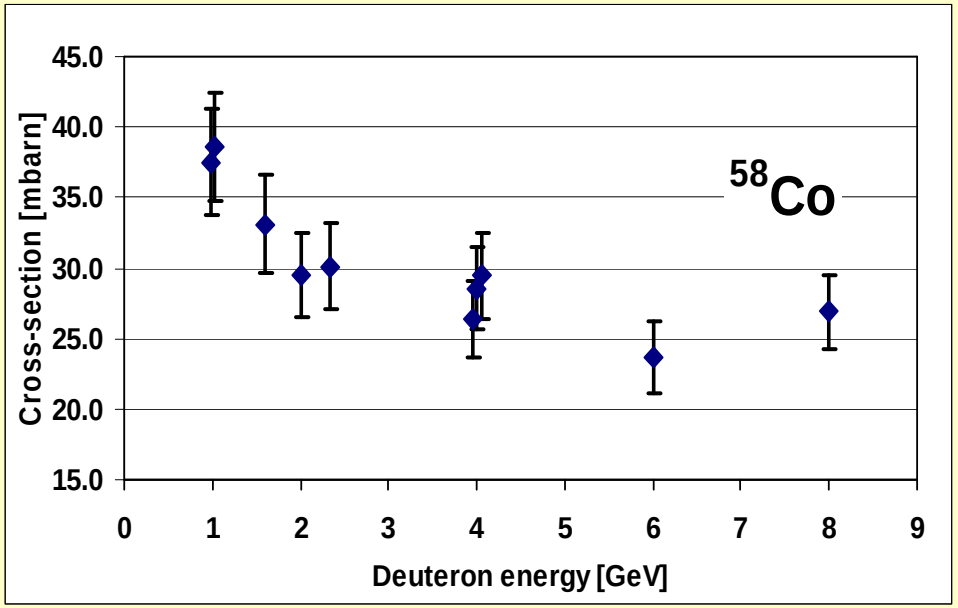


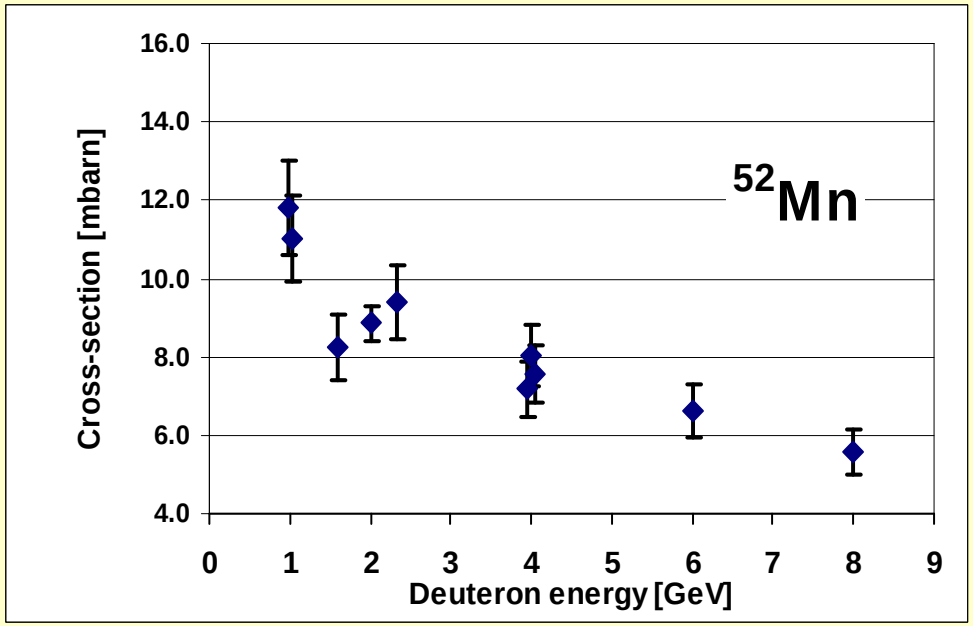
Comparison of three measurements with 4 GeV neutron beam
1. March 2011
2. December 2011
3. March 2012

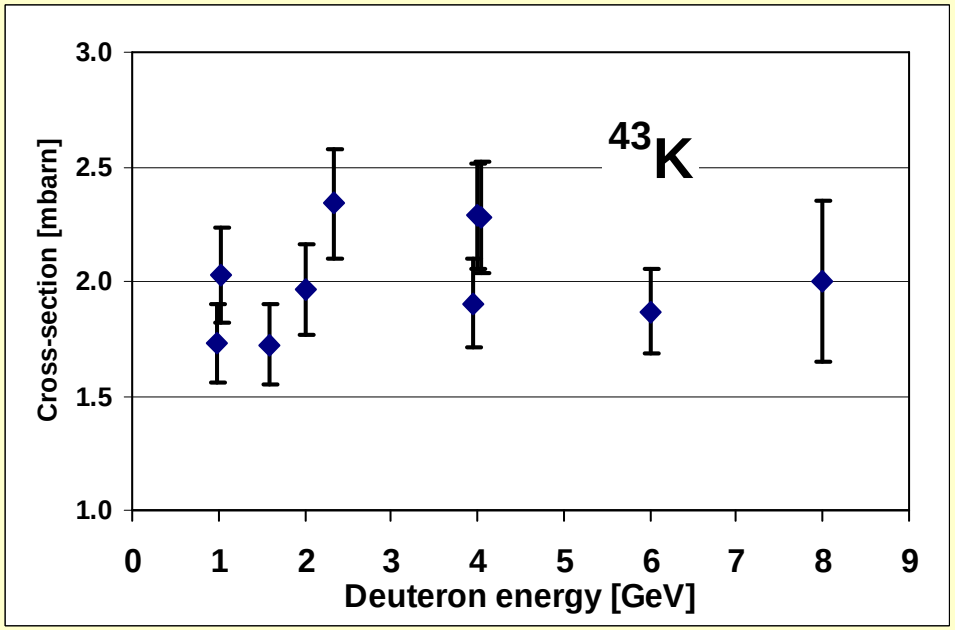
Mean value of ratio:
1./2. 0.884
3./2. 0.926

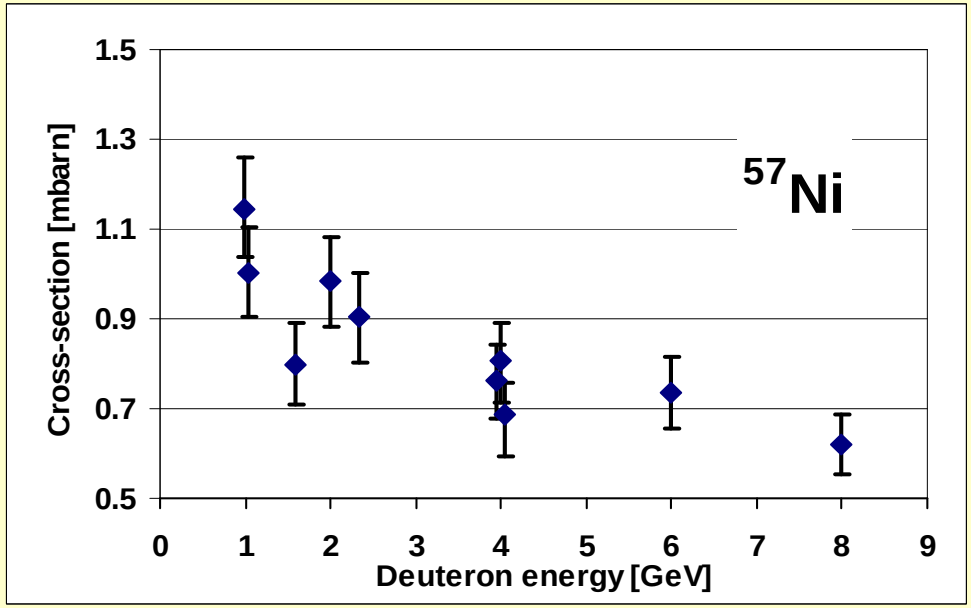
Obtained deuteron reaction cross-sections on natural copper

^{57}Ni, ^{58}Co, ^{56}Co, ^{55}Co, ^{56}Mn, ^{52}Mn, ^{48}Cr, ^{48}V, ^{48}Sc, ^{47}Sc, ^{44m}Sc, ^{43}Sc and ^{43}K



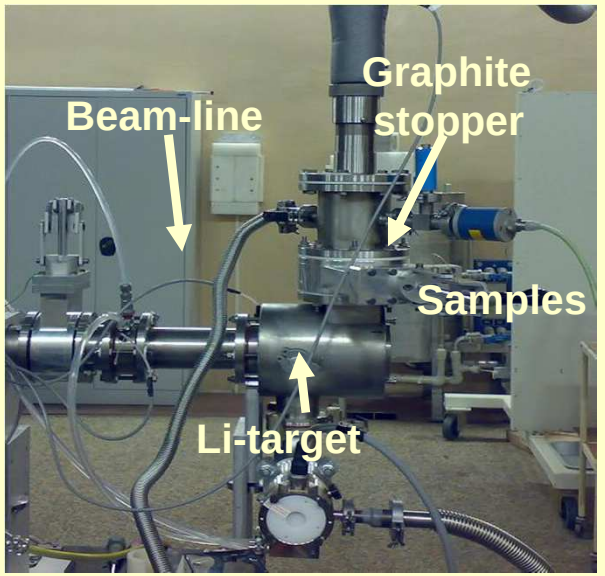






Measurement of neutron reaction cross/sections

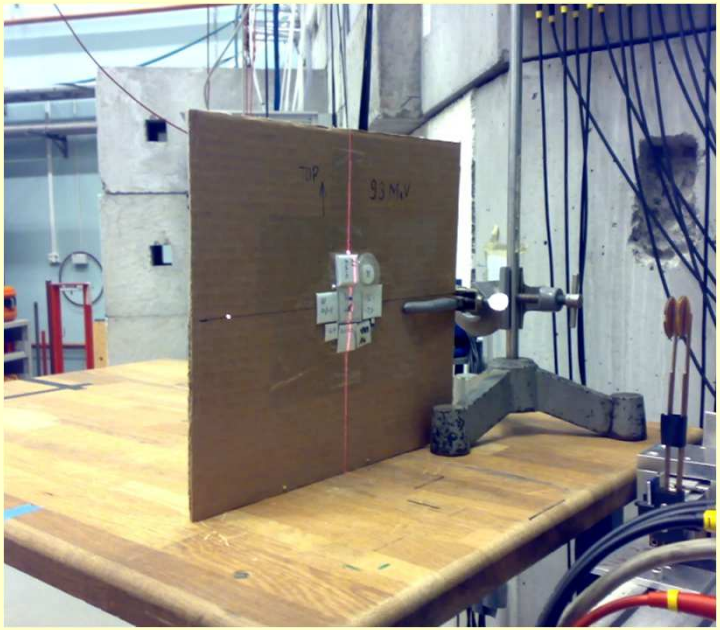
Quasi-monoenergetic neutron source:
protons from cyclotron + lithium target

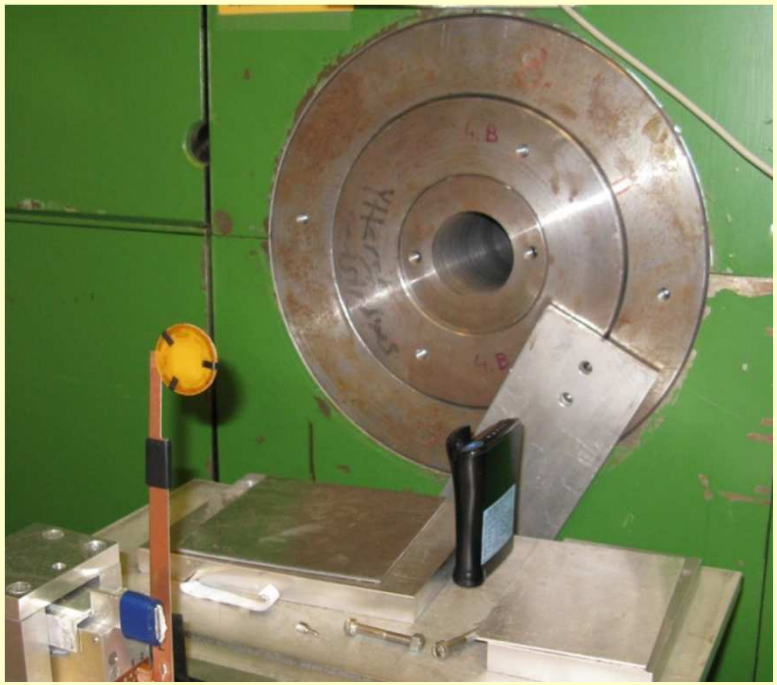


NPI ASCR Řež: **Energy range 18 -37 MeV,**
neutron intensity ~ 10^8 neutron cm^{-2} s^{-1}

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**





Yttrium cross-section measurement

Methodical measurement – neutron energy 32.5 MeV (only reactions (n,2n) and (n,3n)), May 2011, to prepare systematic study of yttrium reactions using the NPI neutron source

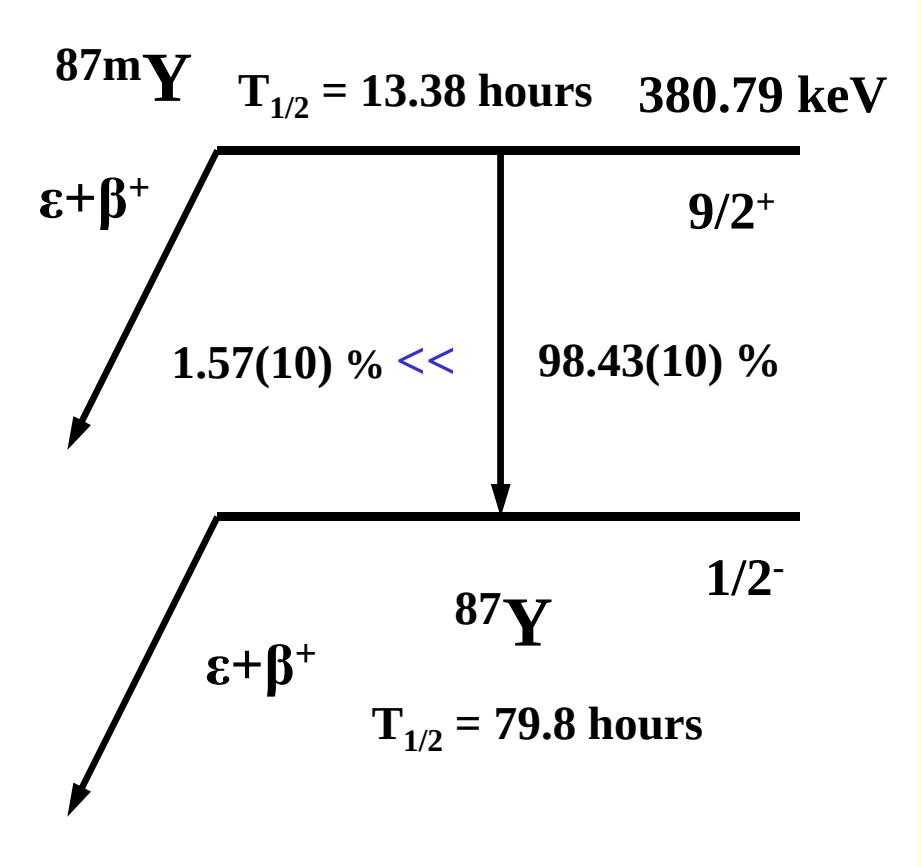
Yttrium – good material for activation detector
Used by "Energy+Transmutation" collaboration

Very scare data about cross-sections

No data about cross-sections of isomeric state production

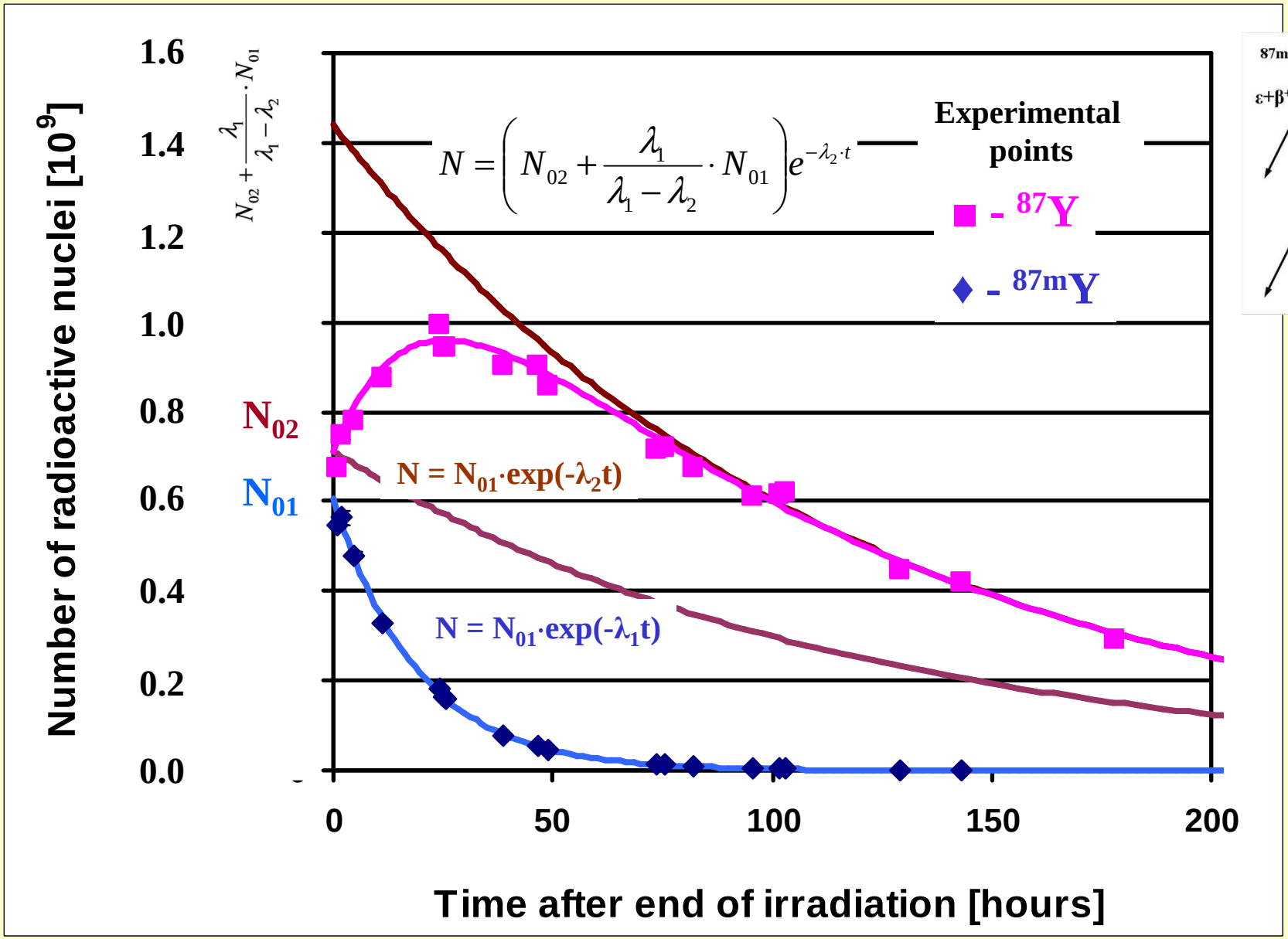
Long irradiation, intensive beam, only limited number of samples → possibility to measure yttrium sample many times to study systematic uncertainties of gamma measurements

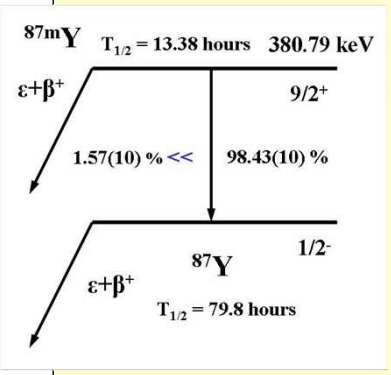
Concentration on isomeric state ^{87m}Y



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

^{87m}Y $N_1 = N_{01} e^{-\lambda_1 \cdot t}$ **^{87}Y** $N_2 = \left(N_{02} + \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} \right) e^{-\lambda_2 \cdot t} - \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} e^{-\lambda_1 \cdot t}$





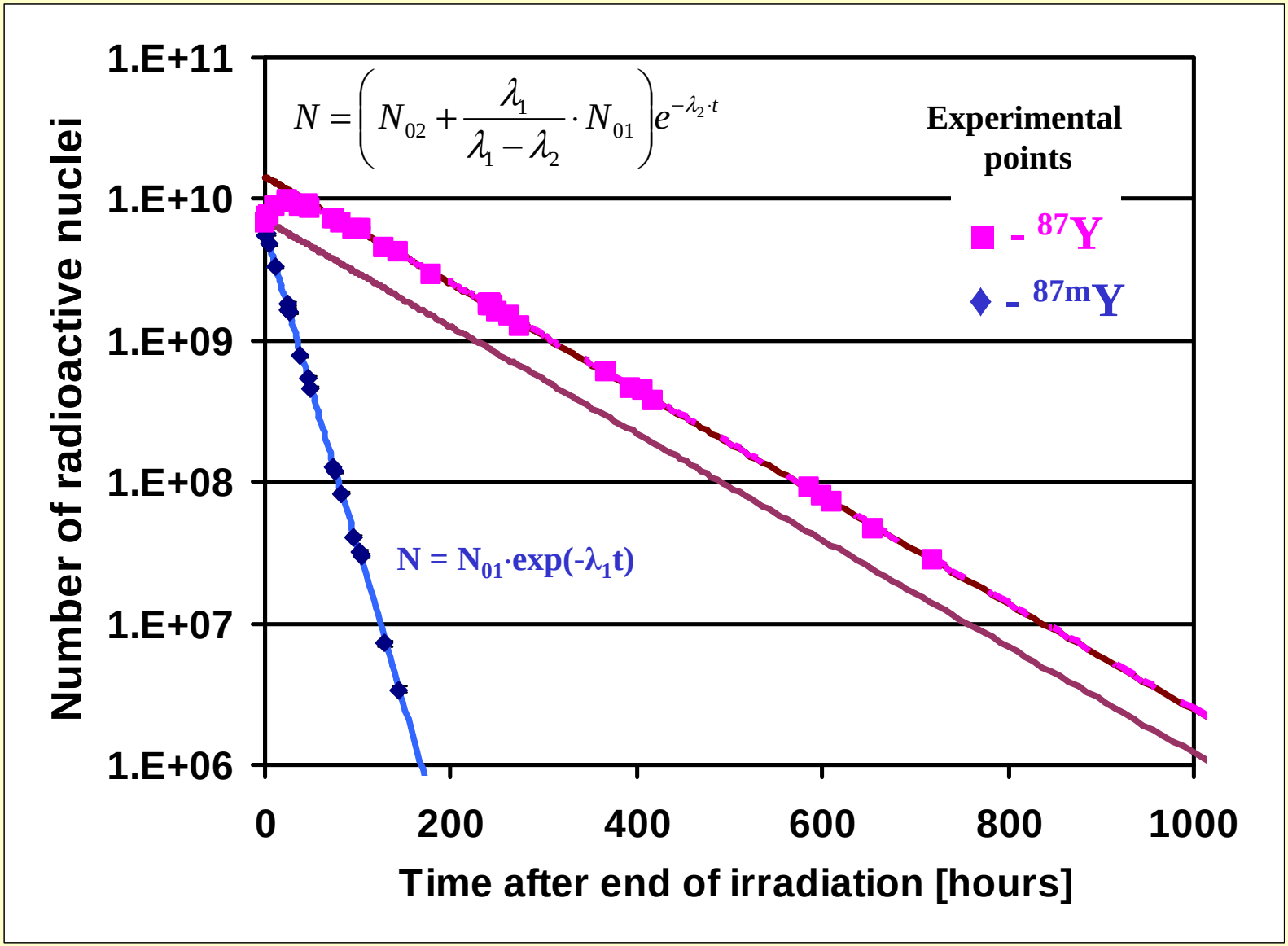
^{87m}Y $N_1 = N_{01} e^{-\lambda_1 \cdot t}$

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

$N_{01} = 6.05(8) \cdot 10^9$

$N_{02} + \frac{\lambda_1}{\lambda_1 - \lambda_2} \cdot N_{01} = 14.38(11) \cdot 10^9$

$N_{02} = 7.12(21) \cdot 10^9$



Cross-section of ^{87m}Y and ^{87g}Y

Higher threshold near to neutron energy → 93 % of radioactive nuclei is produced by peak, only 7 % by background

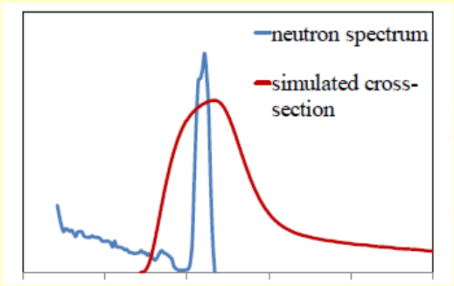
Uncertainties of proton beam integral and neutron spectra description are about 10 - 15 % > gamma spectroscopy uncertainties

$\sigma(^{87m}Y)$ = 578(56) mbarn

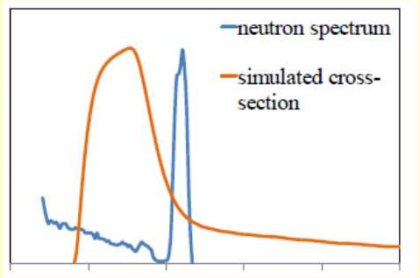
$\sigma(^{87g}Y)$ = 203(25) mbarn

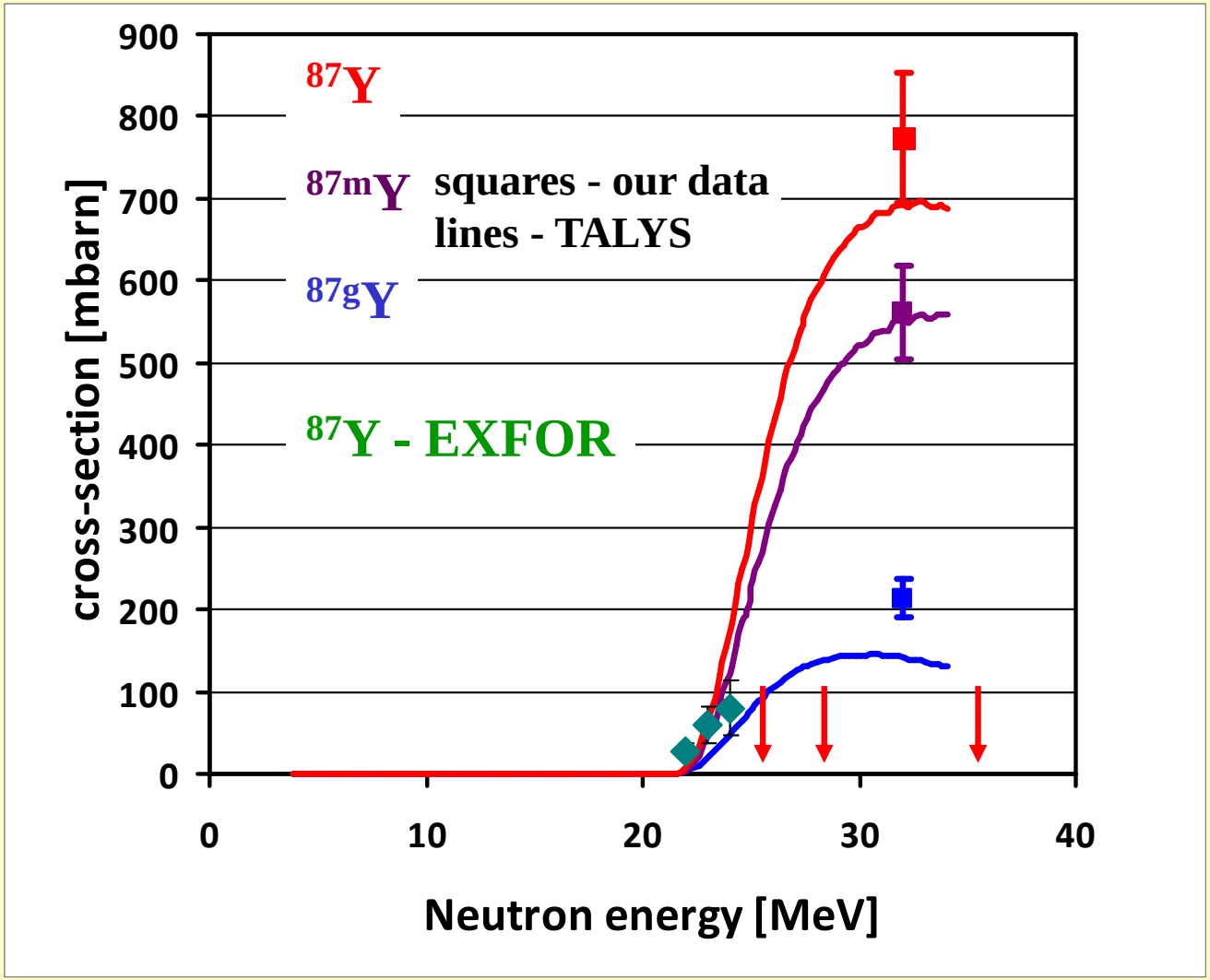
Background production subtraction

^{89}Y(n,3n)^{87}Y case



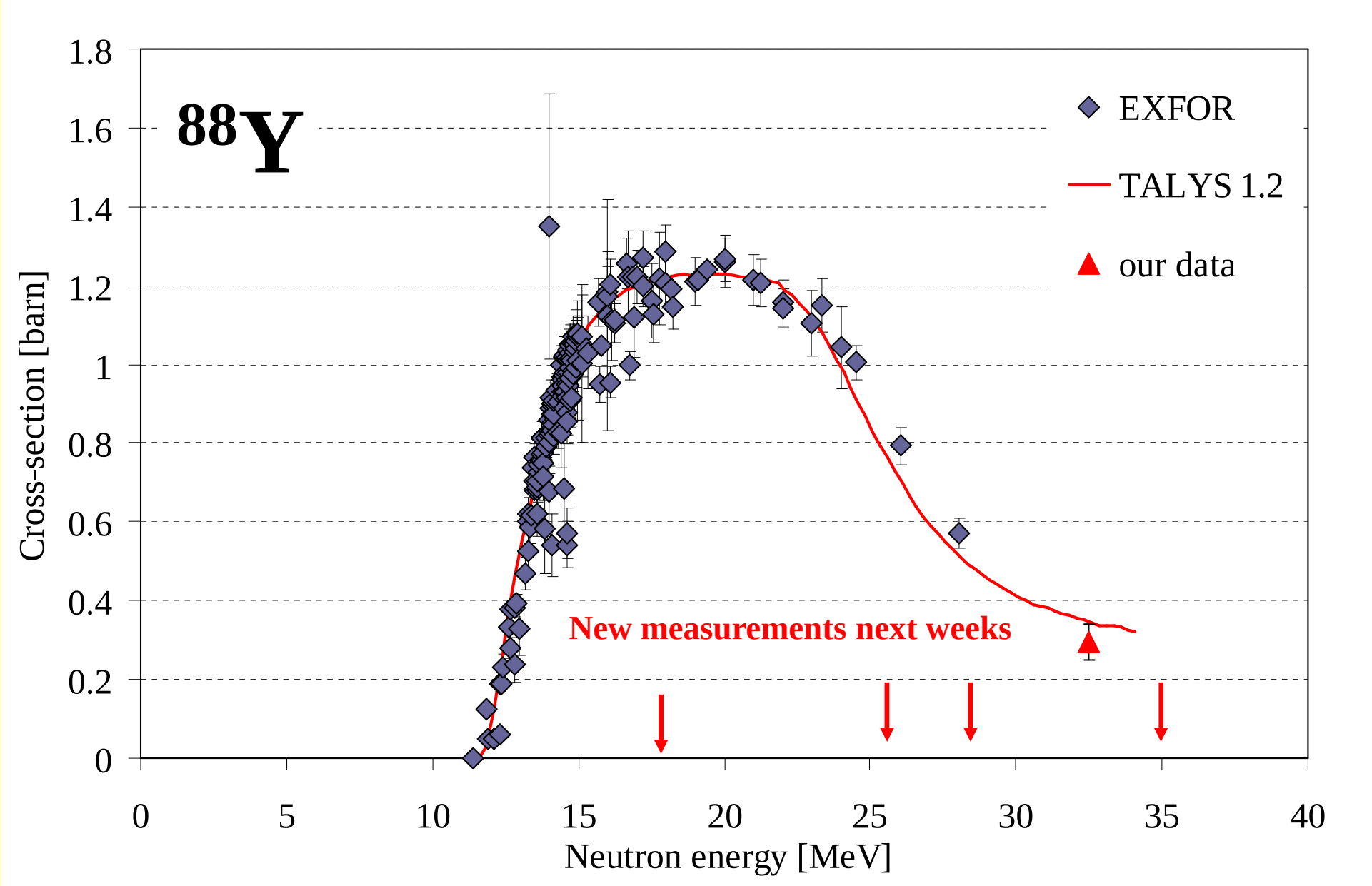
^{89}Y(n,2n)^{88}Y case





Reaction $^{89}Y(n,2n)^{88}Y$

Neutron peak - only 34.8 % of production, 65.2 % of radioactive nuclei produced by background



New measurements of neutron cross-section on yttrium together with Polish colleagues

Improvements:

1) Every irradiations two yttrium samples, one foil and one pressed tablet
2) Big number of measurements of every sample (very important for isomeric state measurement)
3) Measurement in different sample distance to detector

Measurement is in the framework of ERINDA

Four irradiations:

First two during weekend:

Energies 18 and 35 MeV

Next two during first half of October:

Energies 26 and 29 MeV

Conclusions

- **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.**
- **The crucial is determination of beam integral (for all data). The common analysis of all monitor data and determination of common final of beam integral is necessary. We made this only fo first Quinta irradiation (March 2011)**
- **The set of thirteen reactions on copper was studied and cross-sections were determined within energy range from 1 GeV up to 8 GeV.**
- **The quasimonoenergy neutron sources are ideal possibility to obtain cross-sections of reactions which we use for activation measurement of neutron field.**
- **We started set of measurements of yttrium samples together with our Polish colleagues. The ERINDA project and NPI Rez neutron source are used.**

BIG THANKS

to students

Diploma and PhD students:

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Petr Chaloupka

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Daniel Wagner

and also all colleagues

and JINR Dubna Nuclotron people