Measurements of fast neutron spectrum in QUINTA assembly irradiated with 2,4 and 8GeV deuterons

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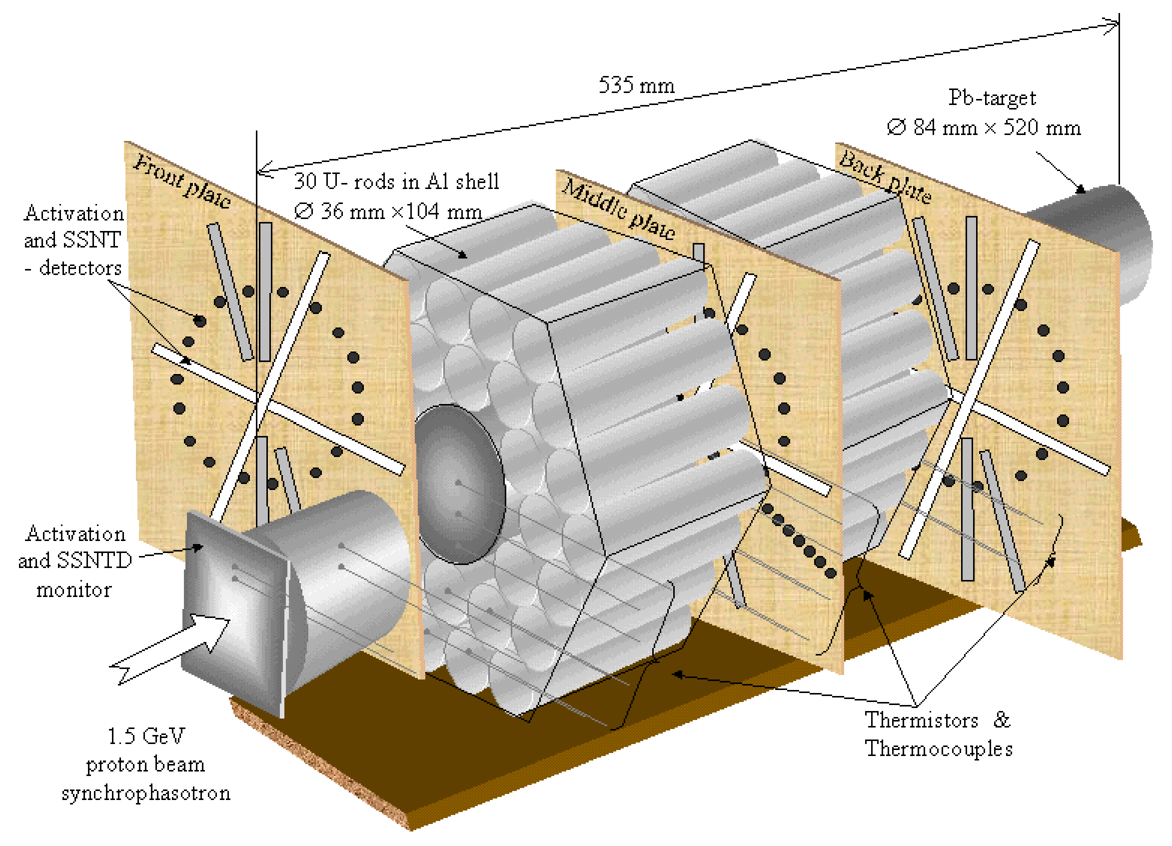
Outline

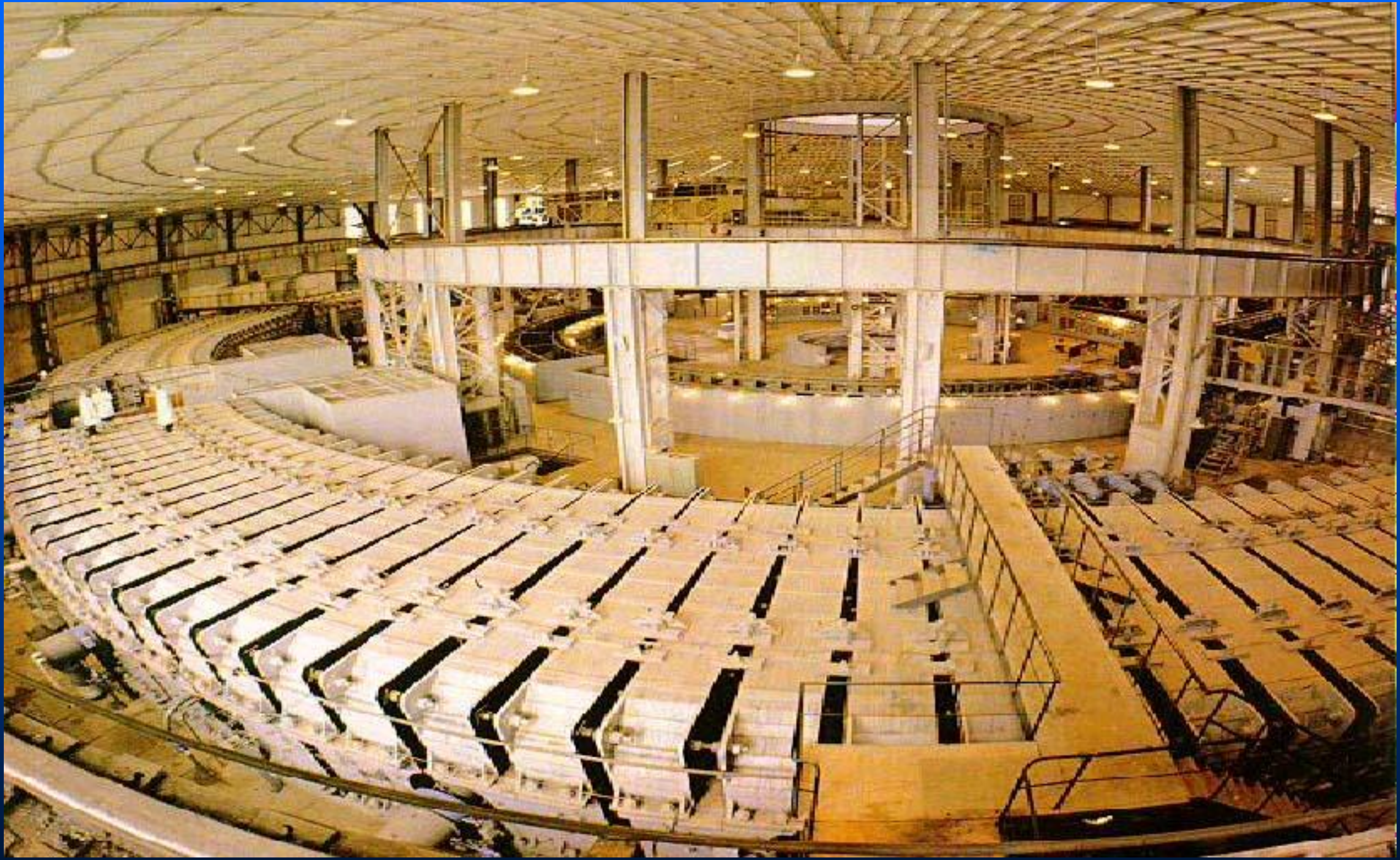
1. Short history (E+T and QUINTA)
2. Spatial distribution of yttrium isotope production.
3. Average neutron flux density per one deuteron from deuterons beams.
4. Cross-section ^{89}Y(n,xn) reaction measurements
5. Conclusions

1. E+T History (Experiments 2000-2003)



First E+T 2-section Experimental Model with non-elastic foils

1. Accelerators (Old sychrophasotron Dubna Russia)

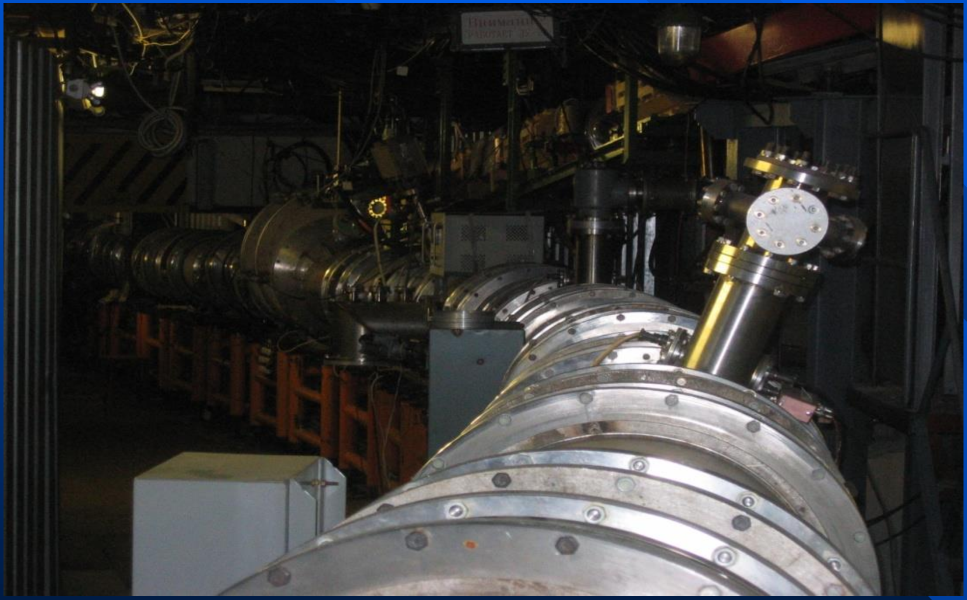


1. Accelerators (New Nuclotron – Dubna Russia)

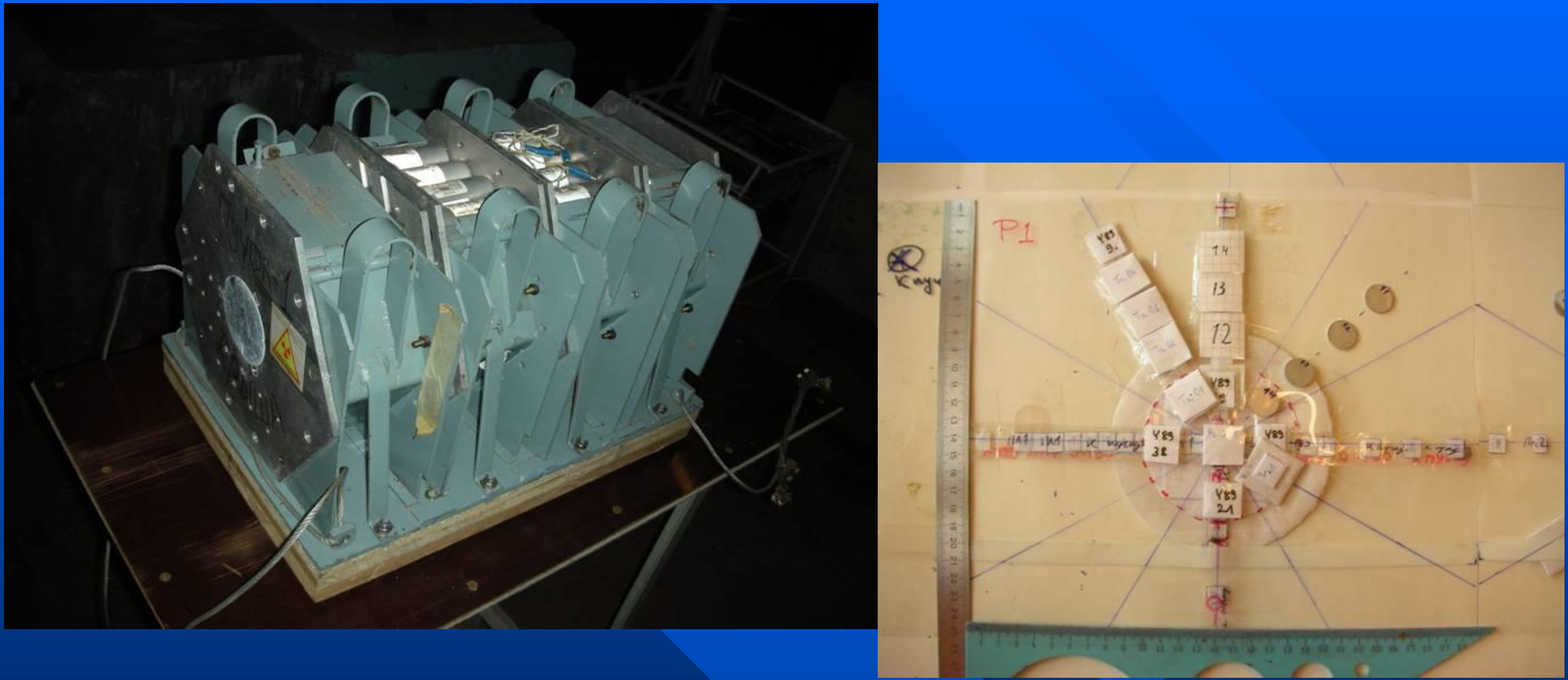
Used accelerators (JINR Dubna):

1) **Synchrohasotron (VBLHE) – advantage – wide spectrum of possible energies E_p = 500 MeV to 7 GeV, 10^{12} – 10^{13} protons per hours**

2) **Nuclotron (VBLHE) – advantage – wide spectrum of possible energies E_p = 500 MeV to 5 GeV, strong focusing, 10^{12} – 10^{13} protons per hours**

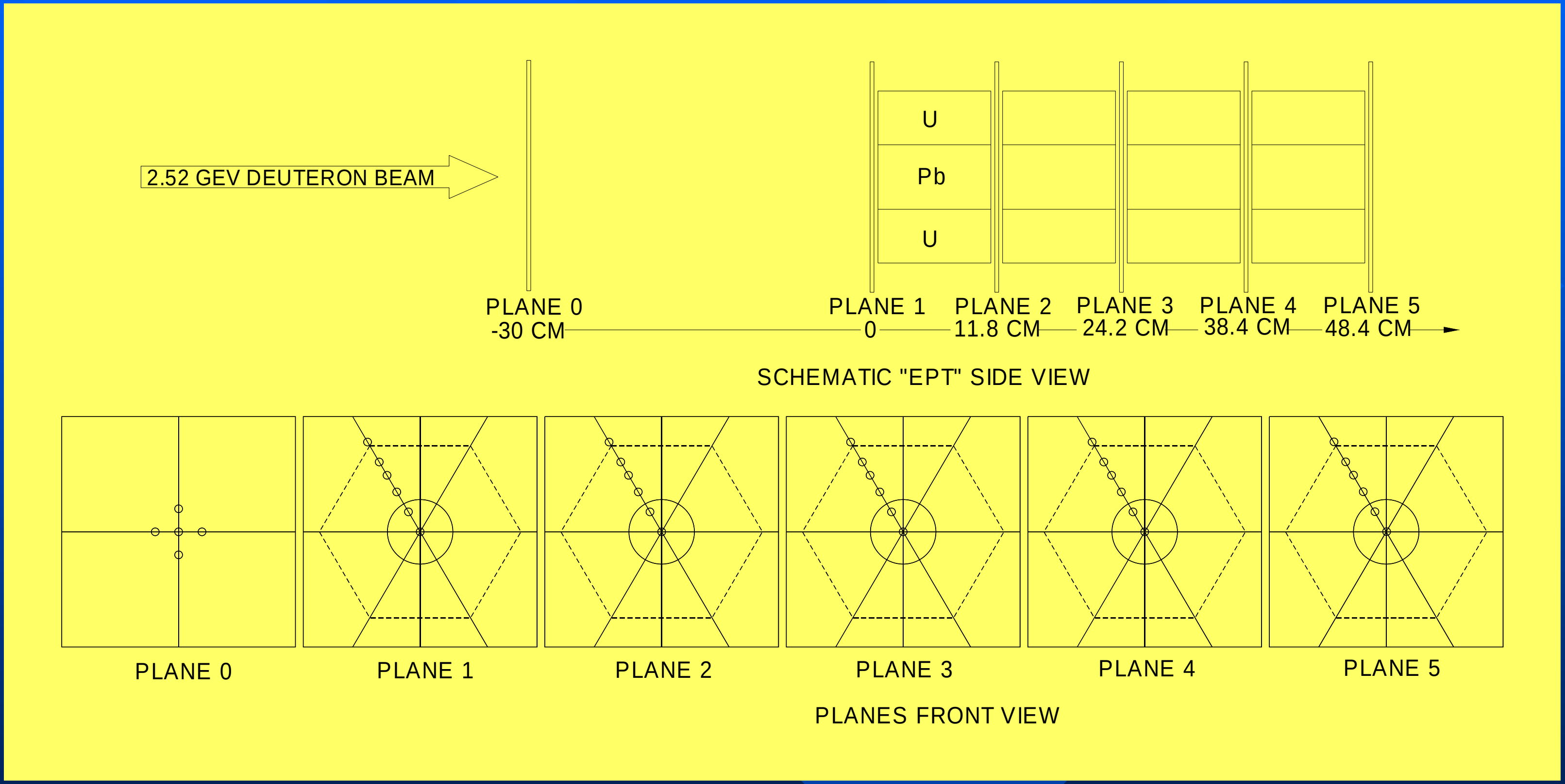


1. Second Experimental setup «Energy plus Transmutation» (2004 – 2009)



E+T 4-section Model and Elastic Foil which Detectors

1. Y-89 sample location in “Energy plus Transmutation” set-up.



1. Arrangement of the 89Y detectors on the detector plates in the QUINTA Assembly (2011 – 2013)

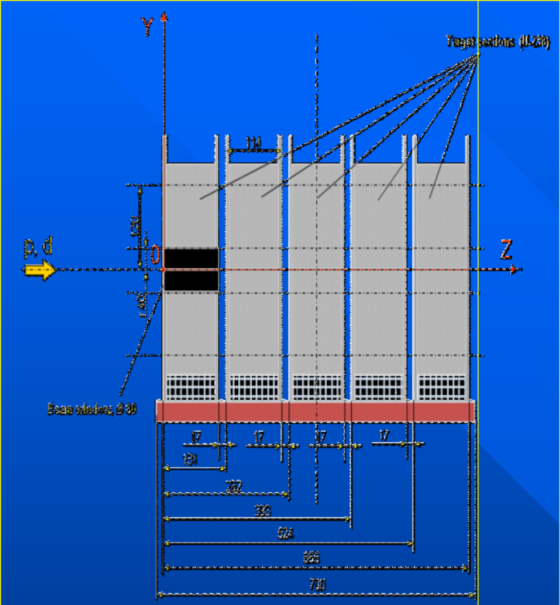


Fig. 1. Longitudinal view of the Quinta assembly

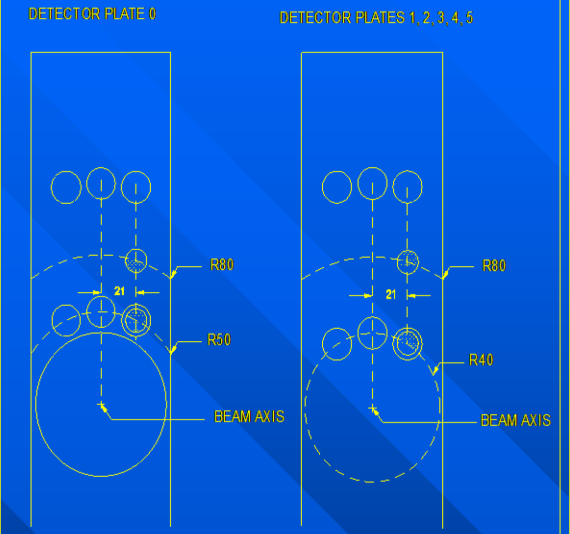
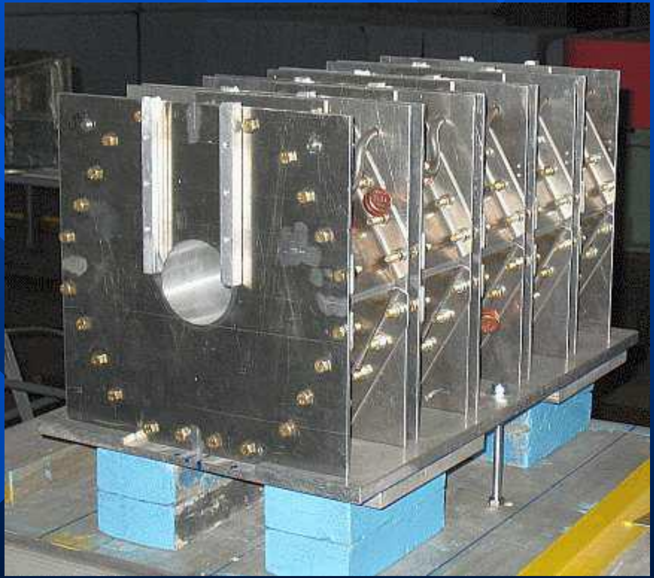


Fig. 1a Yttrium detectors location on the detector plates.



2. Spatial distribution of yttrium isotope production
QUINTA - 2012 y experiments parameters

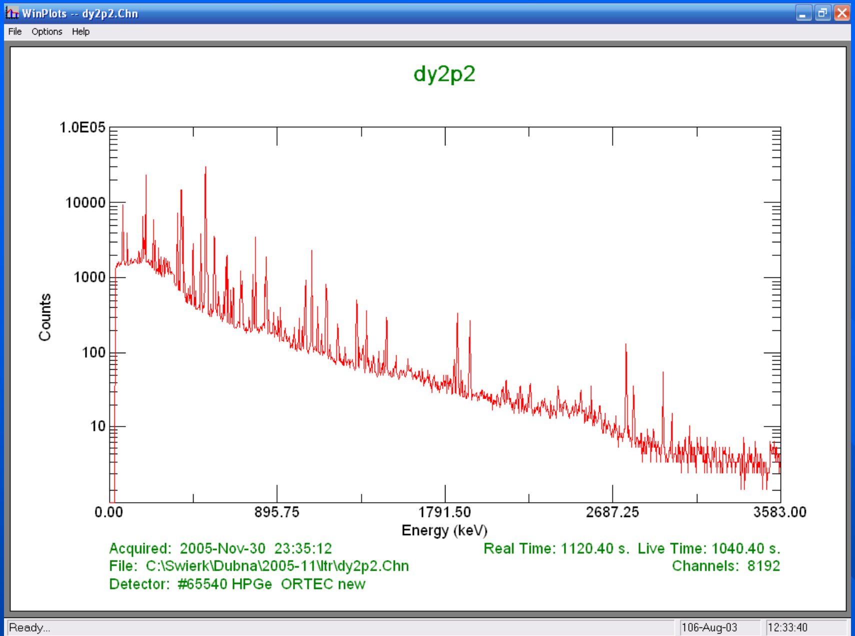
Accelerator: **JINR LWE Nuclotron**

Time:	**4 Dec 2012**	**13 Dec 2012**	**22 Dec 2012**
Beam:	**Deuteron**	**Deuteron**	**Deuteron**
Energy:	**2 GeV**	**4 GeV**	**8 GeV**
Irrad. Time:	**22 561 s**	**33 631 s**	**58 213 s**
Collected beem particles:	$3,05*10^{13}$	$3,57*10^{13}$	$1.39*10^{13}$

Target "QUINTA": **Model U/U + Pb shield**

Activation Detectors: **Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm**

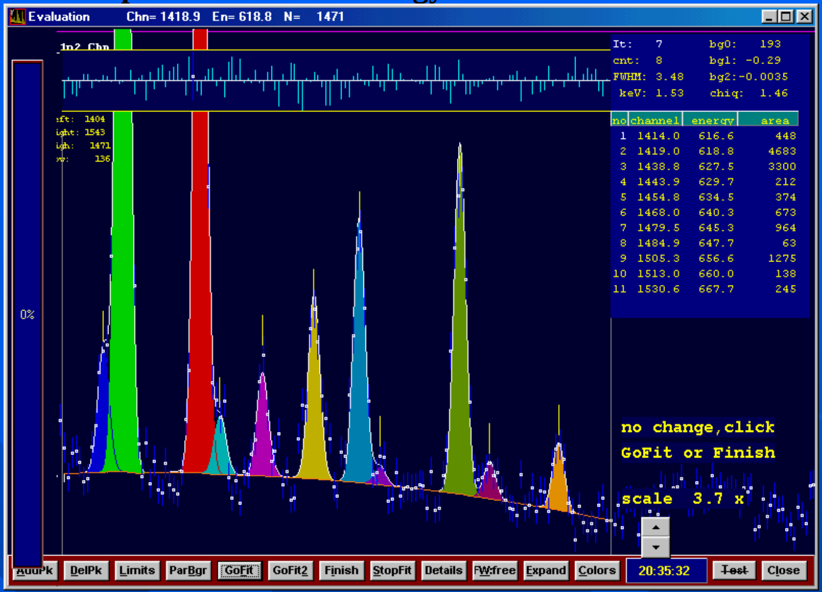
2. Data from gamma spectrometer, analysis and correction.



Acquired: 2005-Nov-30 23:35:12
File: C:\Swierk\Dubna\2005-11\ltr\dy2p2.Chn
Detector: #65540 HPGe ORTEC new

Real Time: 1120.40 s. Live Time: 1040.40 s.
Channels: 8192

Spectrum lines in energy area 616 -- 617 keV



Chn= 1418.9 En= 618.8 N= 1471

It: 7 bg0: 193
cnt: 8 bg1: -0.29
FWHM: 3.48 bg2: -0.0035
keV: 1.53 chiq: 1.46

no	channel	energy	area
1	1414.0	616.6	448
2	1419.0	618.8	4683
3	1438.8	627.5	3300
4	1443.9	629.7	212
5	1454.8	634.5	374
6	1468.0	640.3	673
7	1479.5	645.3	964
8	1484.9	647.7	63
9	1505.3	656.6	1275
10	1513.0	660.0	138
11	1530.6	667.7	245

no change, click GoFit or Finish

- Sample 2 as an example of experimental data.
- Spectra analysis with Czech program DEIMOS. Peak areas as a result.
- Correction for time, irradiation time, weight and so on by calibration formula

2. Calibration formula

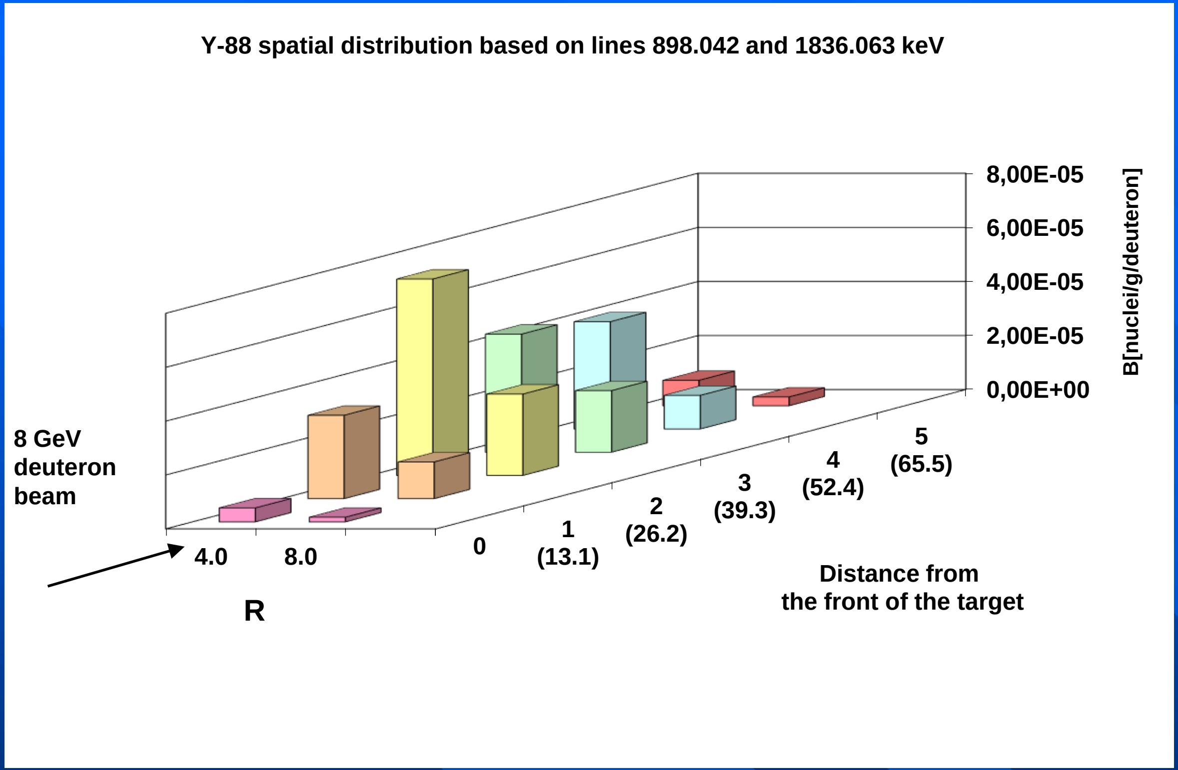
$$B = N_1 \cdot \frac{1}{m \cdot I} \cdot \frac{\Delta S(G) \cdot \Delta D(E)}{\frac{N_{abs}}{100} \cdot \varepsilon_p(E) \cdot COI(E,G)} \cdot \frac{(\lambda \cdot t_{ira})}{[1 - \exp(-\lambda \cdot t_{ira})]} \cdot \exp(\lambda \cdot t_+) \cdot \frac{\frac{t_{real}}{t_{live}}}{[1 - \exp(-\lambda \cdot t_{real})]}$$

where:

B	number of nuclei per gram of a sample material and per one primary deuteron
N_1	peak (line) area
N_{abs}	the absolute intensity of given line in percent [%]
$\varepsilon_p(E)$	detector efficiency function of energy (polynomial)
COI(E,G)	cascade effect coefficient function of energy and geometry
ΔS(G), ΔD(E)	calibrations function for thickness and shape of detectors
I	total number of primary protons
λ	decay constant ($\lambda = \ln(2)/t_{1/2}$)
$t_{1/2}$	half life time
t_{ira}	elapsed time of irradiation
t_+	time between the end of irradiation and the beginning of measurement
t_{real}	time of the measurement
m	mass of the sample (target) in grams

It was assumed that the main contribution to value B error came from statistical error, ΔN_1.

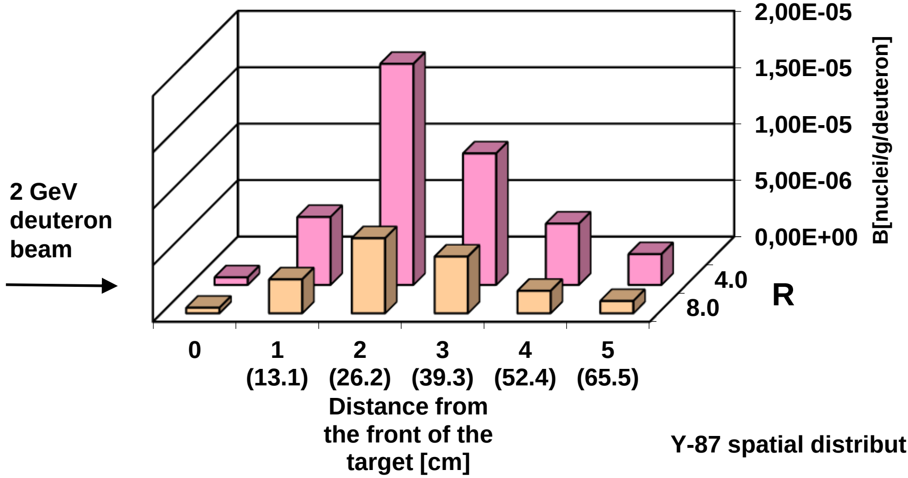
2. 8 GeV deuteron beam QUINTA Experimental data



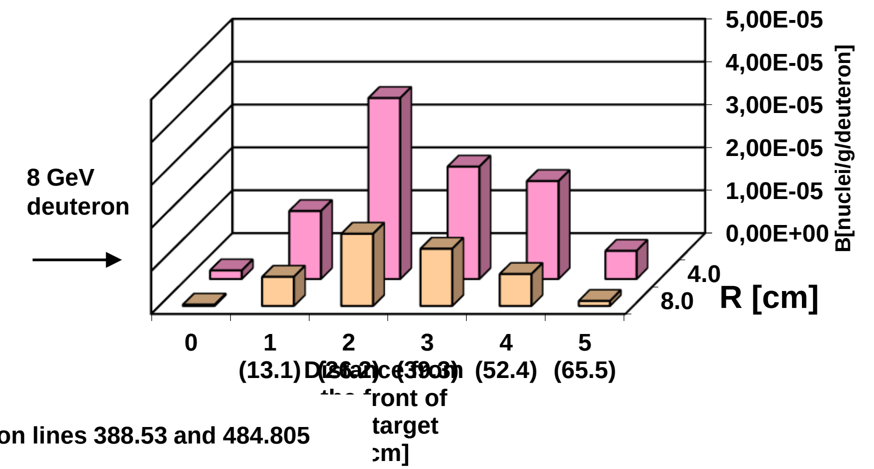
Spatial distribution (radial & axial) of Y88 production. The deuteron beam 8 GeV. The general feature of the experimental spatial distribution of 88Y, 87Y, 86Y and 85Y isotopes production is that the maximum yield is at about 26 cm from the front of the QUINTA assembly and about 13 cm from U238 spallation target and that the yield is decreasing with increasing radial distance from the target axis.

2. Y-87 production spatial distribution comparison. QUINTA Experiment XII.2012

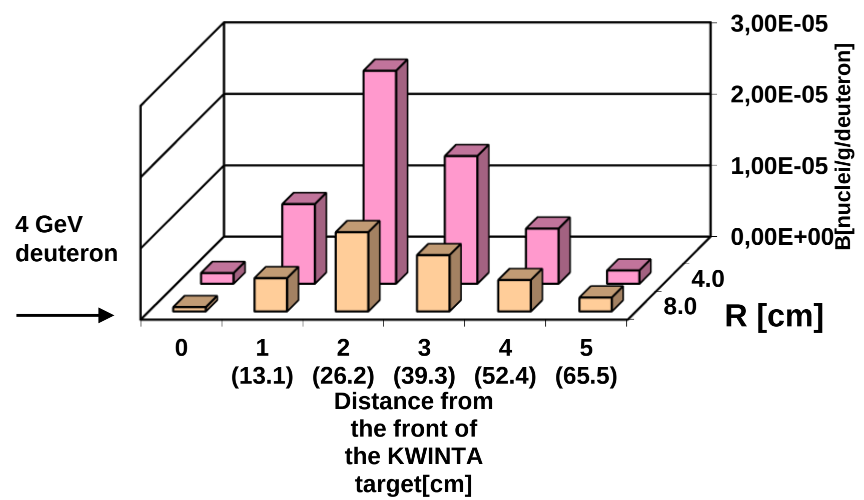
Y-87 spatial distribution based on lines 388.53 and 484.805 keV



Y-87 spatial distribution based on lines 388.53 and 484.805 keV



Y-87 spatial distribution based on lines 388.53 and 484.805 keV



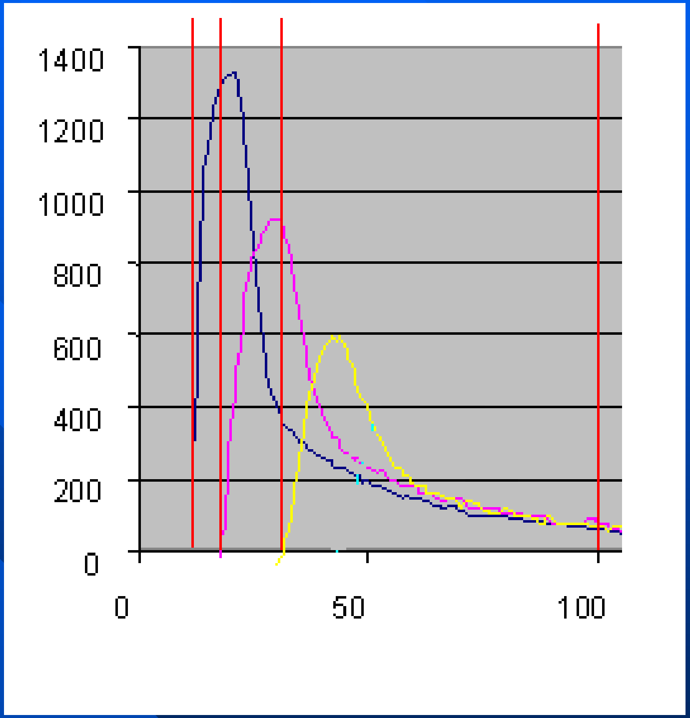
For Energy 2 GeV

For Energy 8 GeV

For Energy 4 GeV

3. Average neutron flux densities per one deuteron from deuteron beams

- It is expected that for the deuteron beam energies higher than 1GeV the average neutron flux densities per deuteron should be equal.
- Fig. on the right presents cross-sections of the three yttrium (n,xn) reactions – threshold energies: E1 = 11,5 MeV Y88 E2 = 20,8 MeV Y87 E3 = 32,7 MeV Y86



3. Average neutron flux densities per one deuteron from deuteron beams.

- Solution of three algebraic equations let us to evaluate the average neutron fluxes in the three energy ranges expressed in [n/cm2·s]:

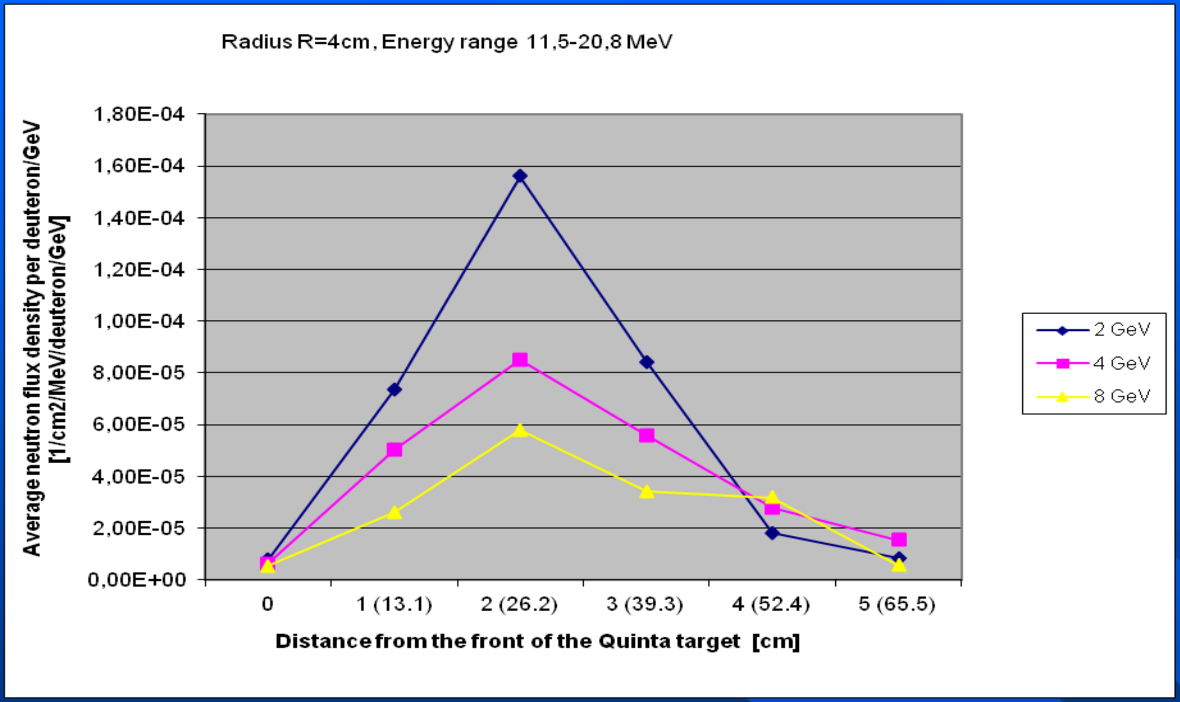
$$\overline{\phi_1} = \frac{C}{\overline{\sigma_{11}}}\left[B^{88} - B^{87}\frac{\overline{\sigma_{12}}}{\overline{\sigma_{22}}} + B^{86}\left(\frac{\overline{\sigma_{23}}}{\overline{\sigma_{33}}}\frac{\overline{\sigma_{12}}}{\overline{\sigma_{22}}} - \frac{\overline{\sigma_{13}}}{\overline{\sigma_{33}}}\right)\right]$$

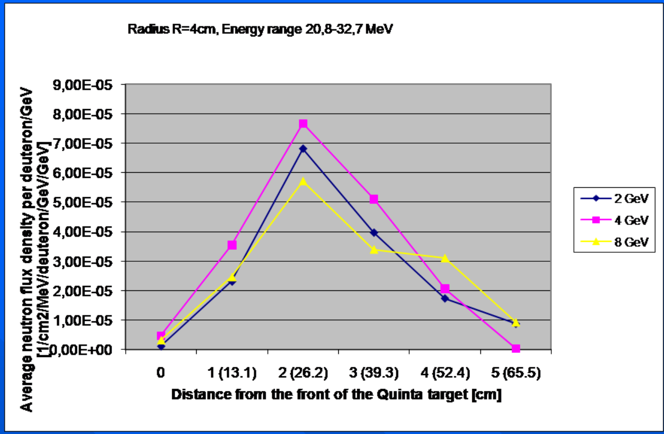
$$\overline{\phi_2} = \frac{C}{\overline{\sigma_{22}}}\left[B^{87} - B^{86}\frac{\overline{\sigma_{23}}}{\overline{\sigma_{33}}}\right]$$

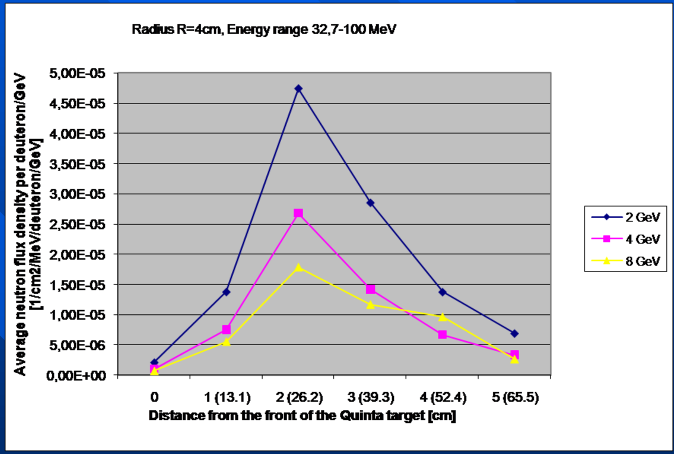
$$\overline{\phi_3} = \frac{C}{\overline{\sigma_{33}}}B^{86}$$

$$C = \frac{S\,G^{89}}{A\,t}$$

3. Average neutron flux densities per one deuteron from deuteron beams



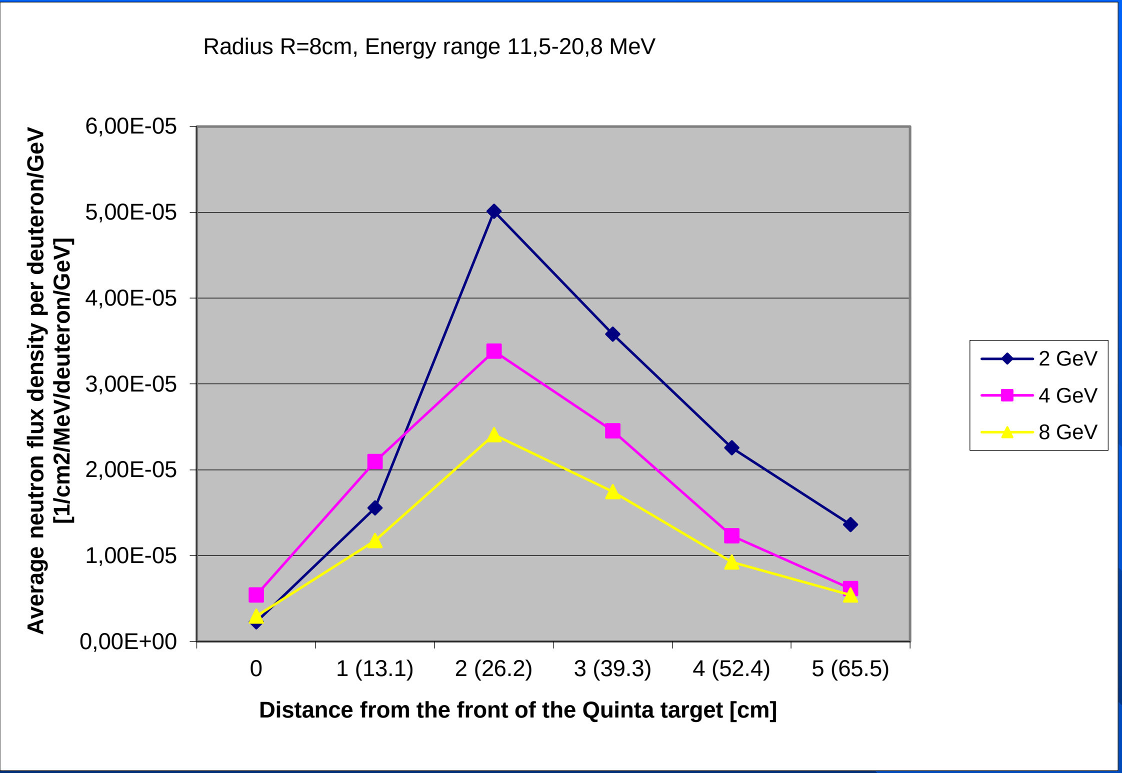


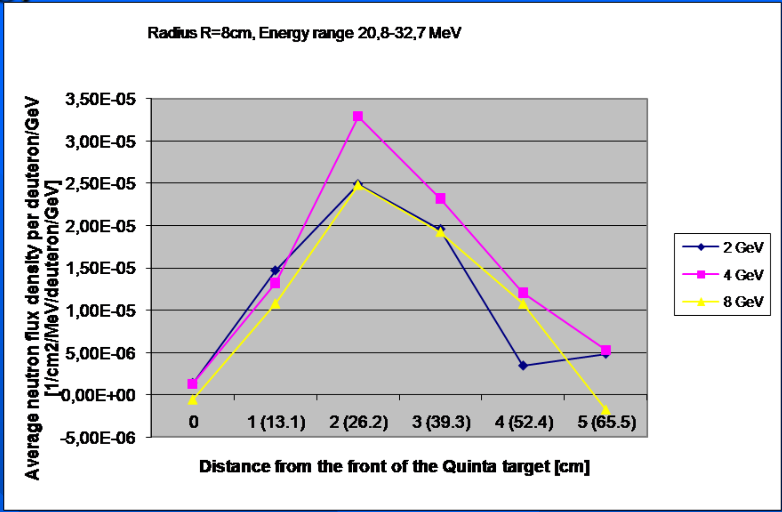


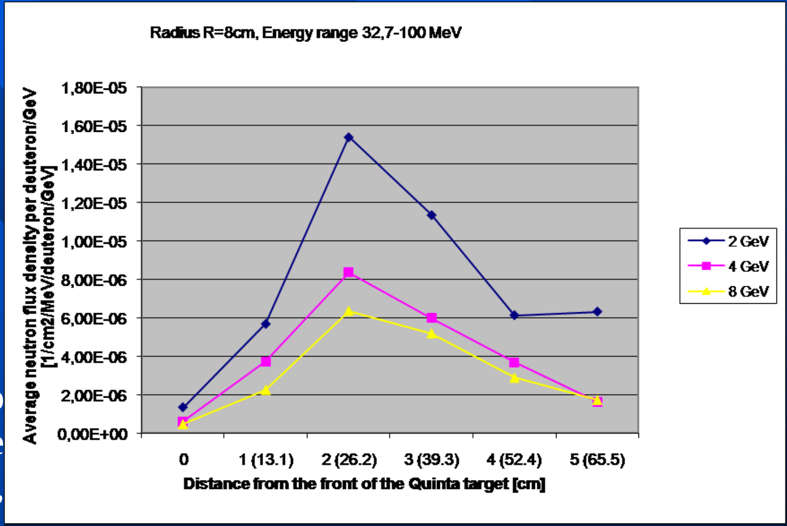
For radial distance R=4cm

The curves of the neutron flux density per deuteron and its energy overlap in the energy ranges 20.8-32.7 MeV, nearly overlap in the energy range 11.5-20.8 MeV and 32.7-100 MeV.. 8 GeV curve is belov the other., normaly was abave.

3. Average neutron flux densities per one deuteron from deuteron beams.





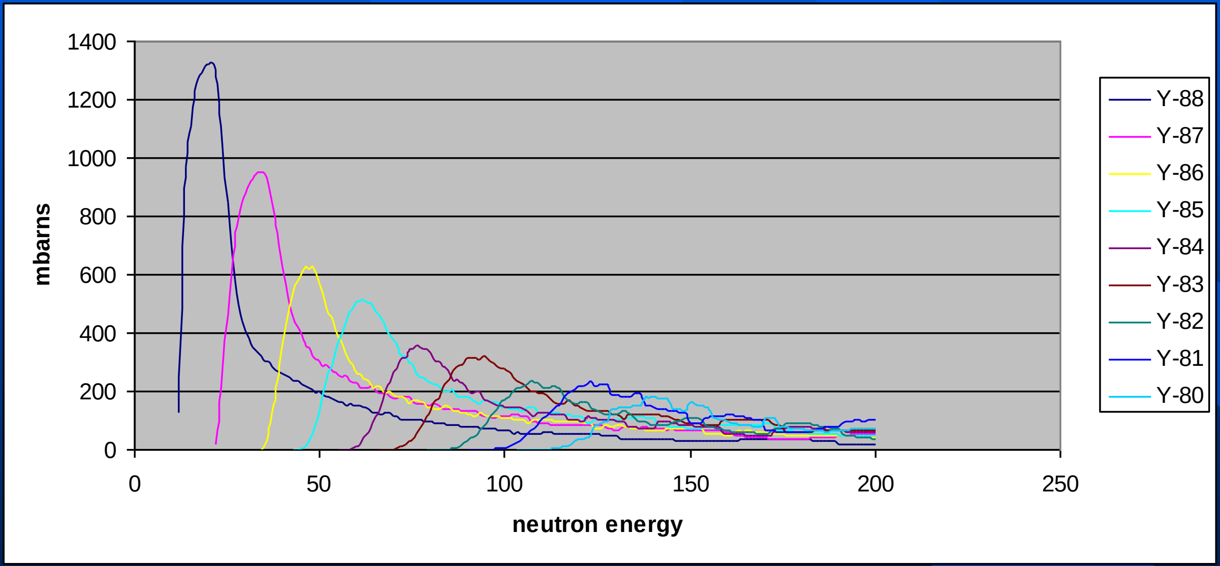


For radial distance R=8cm

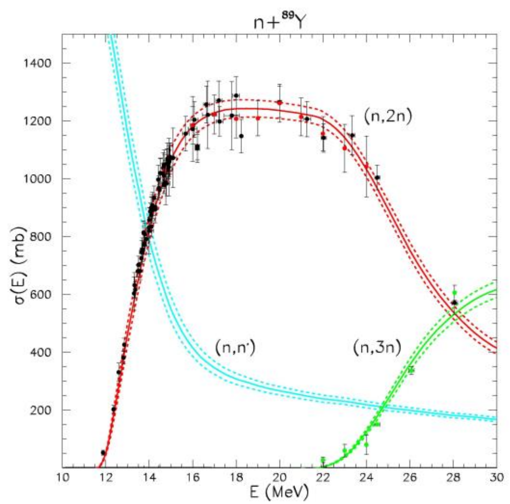
The curves of the neutron flux density per deuteron and its energy overlap in the energy ranges 20.8-32.7 MeV, nearly overlap in the energy range 11.5-20.8 MeV and 32.7-100 MeV.. 8 GeV curve is belov the other., normaly was abave.

4. Cross-section ^{89}Y(n,xn) reaction measurements

To evaluate the high energy neutron field we need to know the microscope cross section for the (n,xn) reaction of ^{89}Y. The available experimental data of microscopic cross section for the reaction ^{89}Y(n, 2n)^{88}Y and the small part for reaction ^{89}Y(n, 3n)^{87}Y are going from EXFOR data base. Since the nuclear data libraries are poor we have used TALYS code for calculation of (n,xn) reactions cross sections.



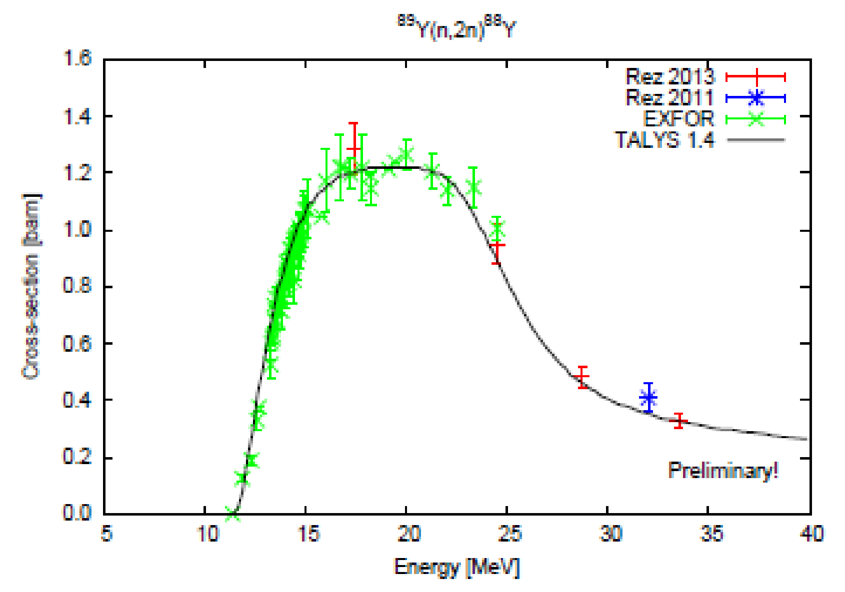
TALYS Microscopic cross sections for several ^{89}Y(n, xn) reactions.

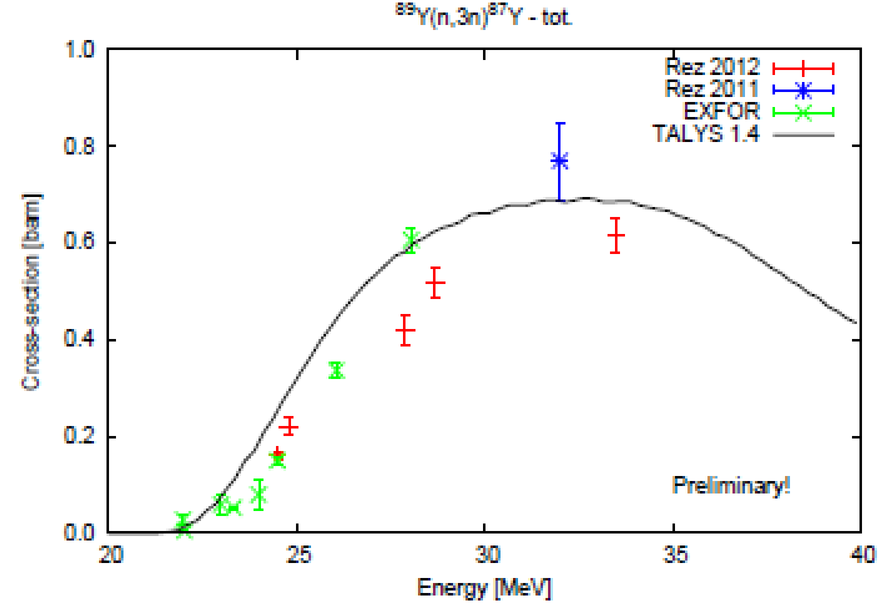


Experimental data from EXFOR data base

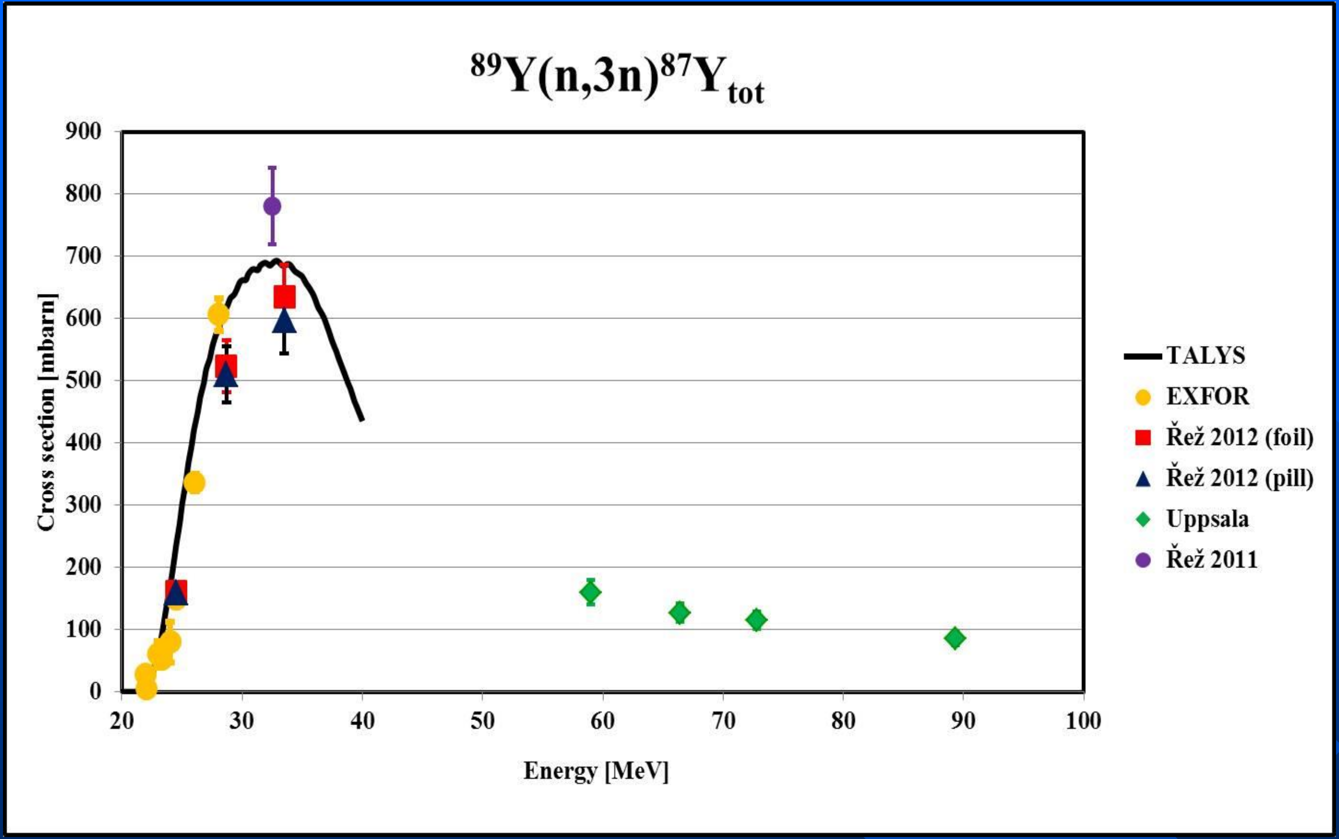
4. Cross-section ^{89}Y(n,xn) reaction measurements

We have performed measurement of neutron reaction cross-sections for selected energies of these reactions by means of quasi mono-energetic neutron sources at Nuclear Physics Institute (NPI) in Řež, Czech Republic (2012) and at The Svedberg Laboratory (TSL) in Uppsala, Sweden (2011 and 2015)





4. Cross-section ^{89}Y(n,xn) reaction measurements



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}

Total cross section of ^{87}Y production

5. Conclusions

- Yttrium detectors were irradiated in QUINTA setup with three deuteron beams – 2, 4 and 8 GeV to get (n,xn) reaction rate distributions.
- The experimental spatial distribution of 88Y, 87Y, 86Y and 85Y production has maximum at about 13 cm from the front of the U238 spallation target .
- The experimental neutron flux density has the maximum at about 26 cm as well (2 plate) from the front of QUINTA assembly and that it is decreasing with increasing radial distance from the target axis.
- The shape of neutron flux density is generally the same for 2 GeV, 4 GeV and 8 GeV deuterons
- At radial distances 4 and 8 cm the average neutron flux densities for deuteron beam of 8 GeV are less than for 2 and 4 GeV ones. We can not explain this phenomenon exactly yet.
- Reaction 89Y(n,xn) cross sections were measured in Rez Institute in frame of ERINDA project. The measurements will be continued.

References

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Thank you for the cooperation