# MEASUREMENTS RELEVANT TO HIGH ENERGY NEUTRON SPECTRUM BY APPLICATION YTTRIUM DETECTORS IN THE U/Pb-ASSEMBLY USING 4 GeV DEUTERON BEAM FROM JINR NUCLOTRON (DUBNA)

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(for collaboration „**Energy plus Transmutation**”)

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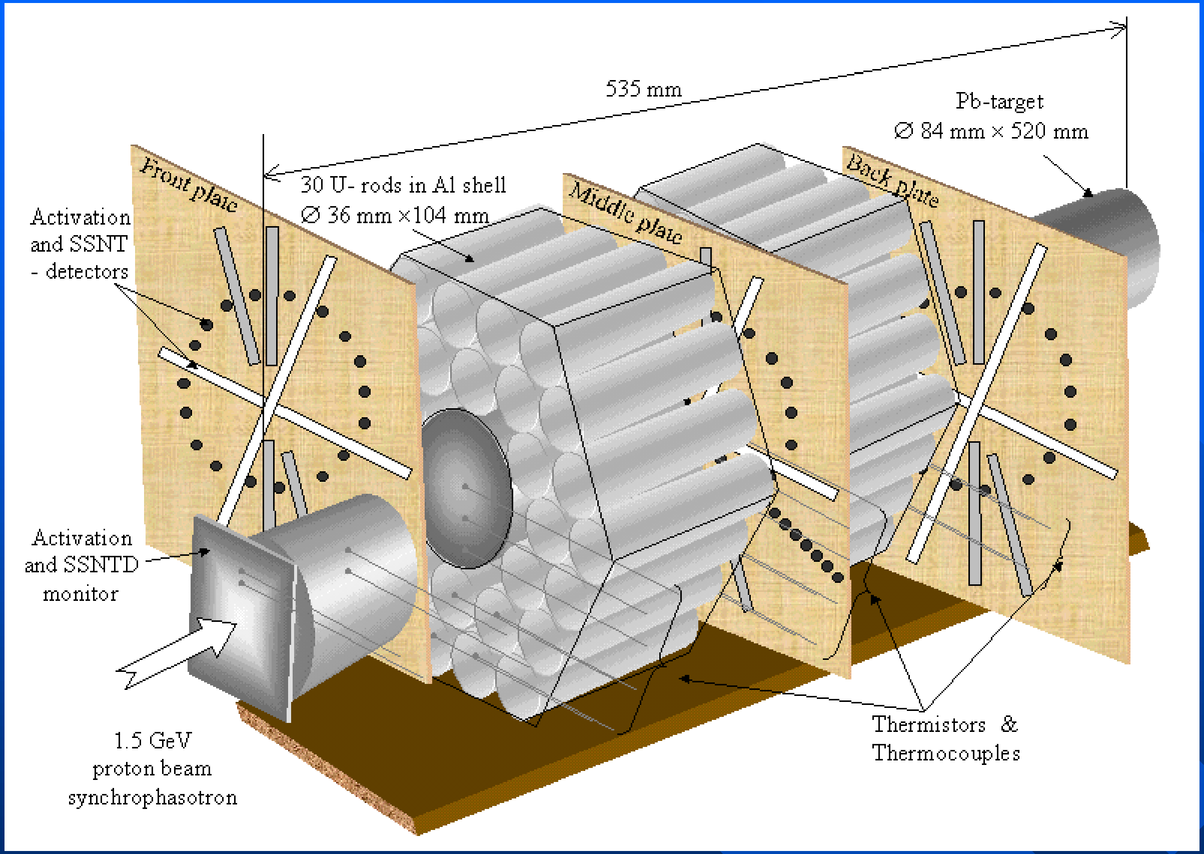
# Outline

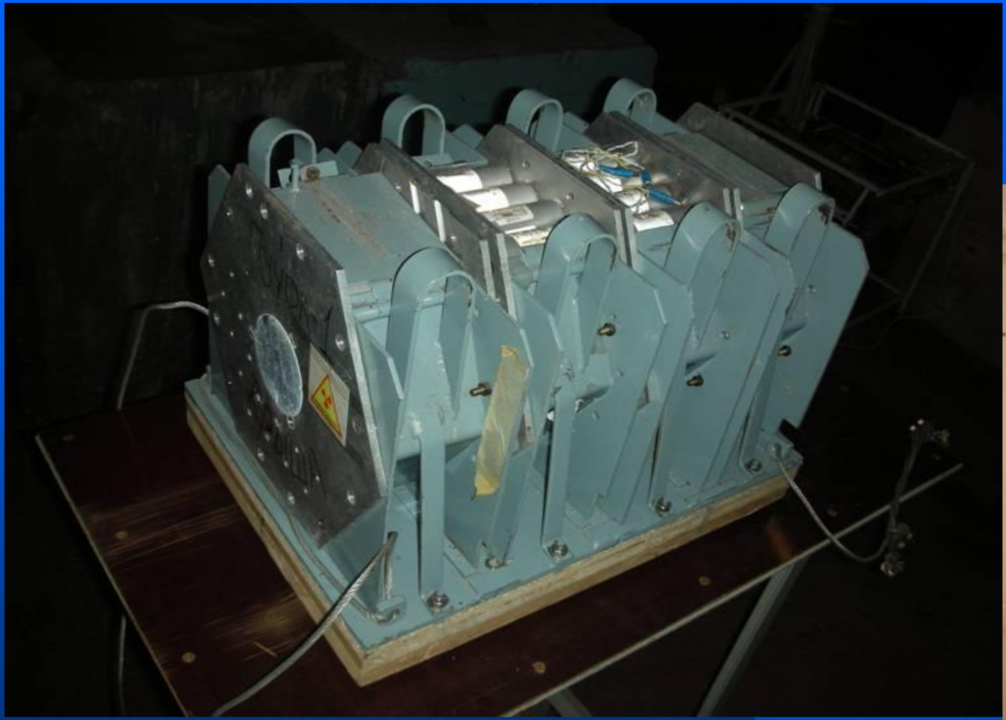
1. Some about the E+T Experiments History
2. 4 GeV Experimental data
3. Average neutron flux densities per deuteron for the three deuteron beams
4. Calculations Using Monte Carlo Methodology (MCNPX code)
5. Conclusions

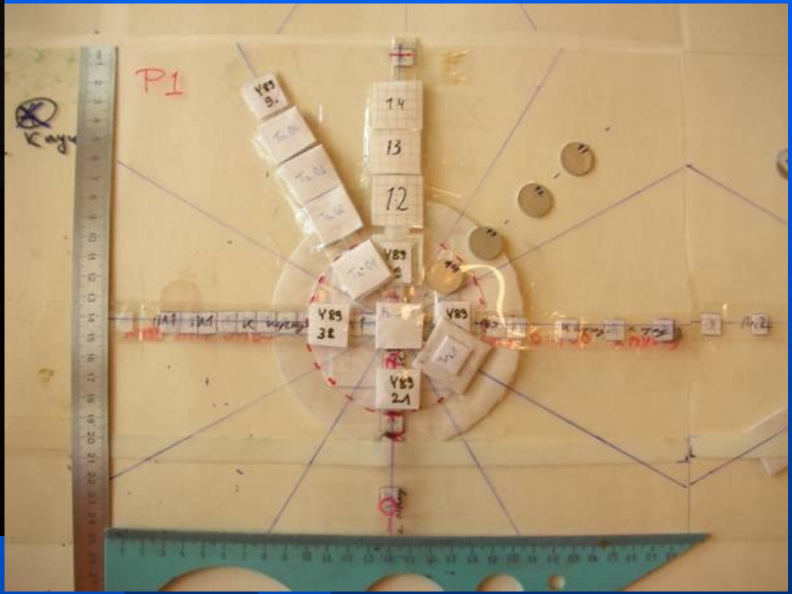
# 1. E+T History




First E+T 2-section Eksperimental Model with nonelastic foils

# Second Experimental setup «Energy plus Transmutation»





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

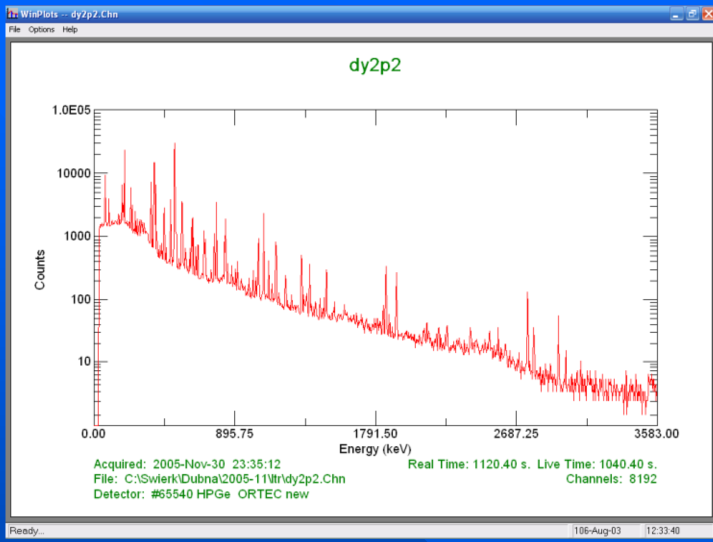
# Last E+T Experiments parameters

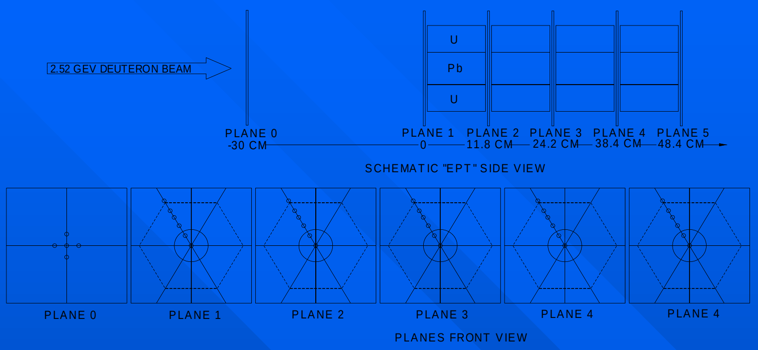
| | | | | |
|---|---|---|---|---|
| Accelerator: | JINR LWE Nuclotron | | | |
| Time: | June 2004 | Nov 2005 | Dec 2006 | Nov 2009 |
| Beam: | Proton | Deuteron | Deuteron | Deuteron |
| Energy: | 0,7 GeV | 2,52 GeV | 1,6 GeV | 4 GeV |
| Irrad. Time: | 31860 s | 21600 s | 22135 s | ~70000 s |
| Collected beem particles: | $2*10^{13}$ | $5.9*10^{12}$ | $2.08*10^{13}$ | $\sim 10^{13}$ |
| Target: | Model U/Pb assembly "Energy+Transmutation" | | | |
| Activation Detectors: | Yttrium 89 – disc shape, h ≅1-2 mm, d = 10 mm | | | |

# Some Activaction detectors [6]

| Material: | Co-59 | Bi-209 | Au-197 | Y-89 |
|---|---|---|---|---|
| (n,2n) MeV | 13,3 | 7,3 | 8,1 | 11,5 |
| | 78,82 d | 368000 y | 6,183 d | 106,65 d |
| (n,3n) MeV | 24,6 | 13,9 | 14,8 !!! | 20,8 |
| | 271,79 d | 31,55 y | 186,1 d | 79,8 h |
| (n,4n) MeV | 41,7 | 22,6 | 23,2 | 32,7 |
| | 77,27 d | 6,243 d | 38,02 h | 14,74 h |
| (n,5n) MeV | 56,2 | 29,6 | 30,2 !!! | 42,1 |
| | 17,53 h | 15,31 d | 17,65 h | 2,68 h |
| (n,6n) MeV | | 38,1 | 38,9 | 54,4 |
| | | 11,22 h | 4,94 h | 39,5 m |
| (n,7n) MeV | | 45,2 | 45,7 | |
| | | 11,76 h | 3,18 h | |
| | | to (n,9n) | | |

# Data from gamma spectrometer, analisys and corection.




- Sample 2 (plane 0, radius 0) gamma spectrum dY2p2 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

Spectrum lines in energy area 616 -- 617 keV

# Our 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:

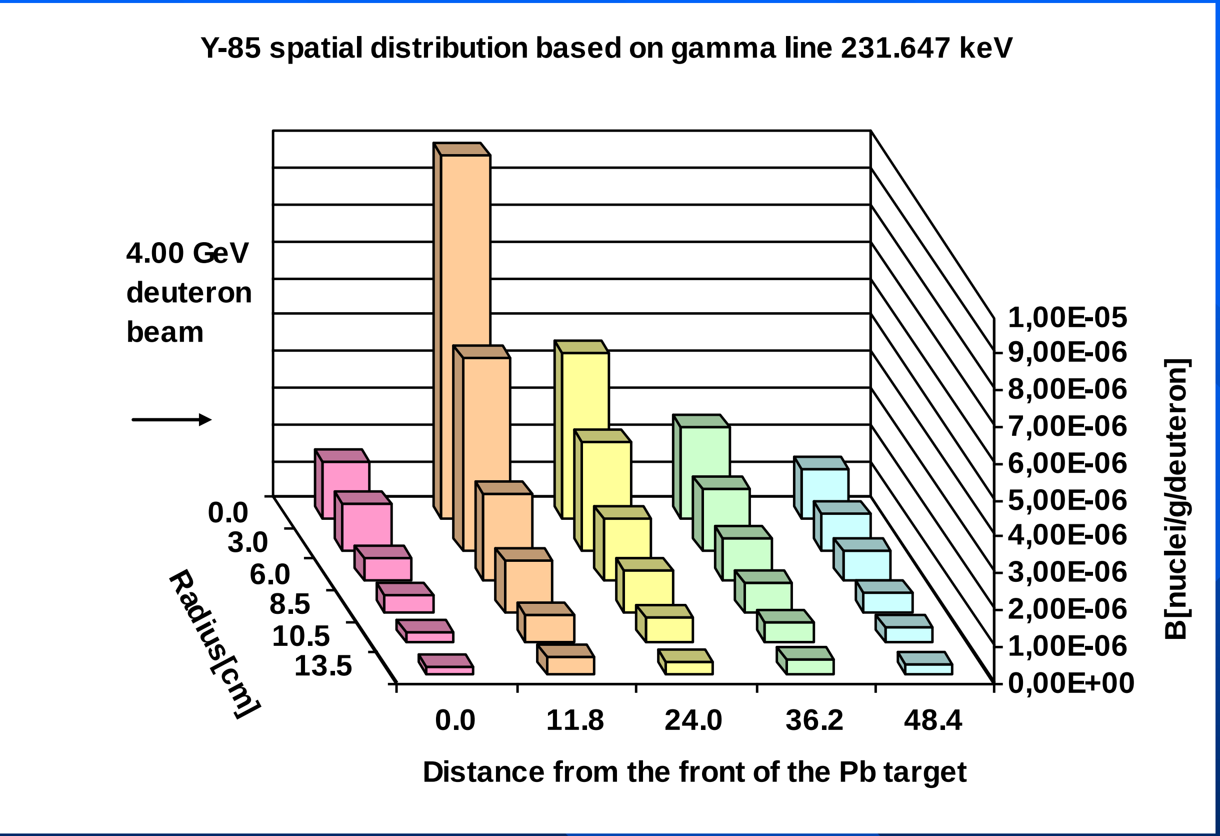
- B number of nuclei per gram of a sample material and per one primary deuteron

- $N_1$ 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), ΔS(G) 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

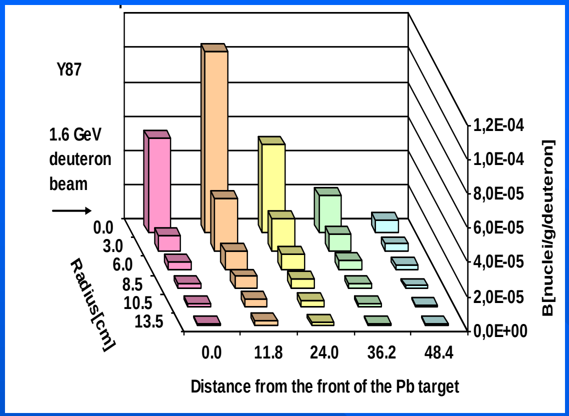
It was assumed that the main contribution to value B error came from statistical error, $\Delta N_1$.

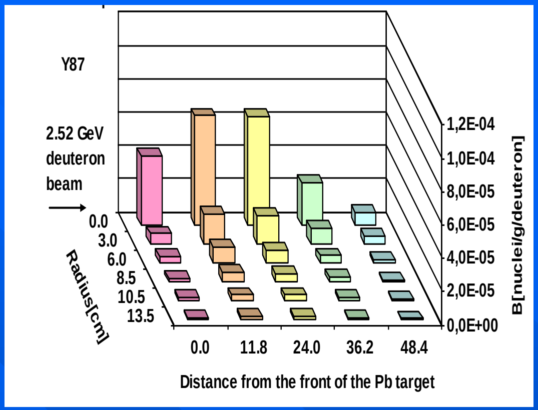
# 2. 4 GeV deuteron beam Experimental data

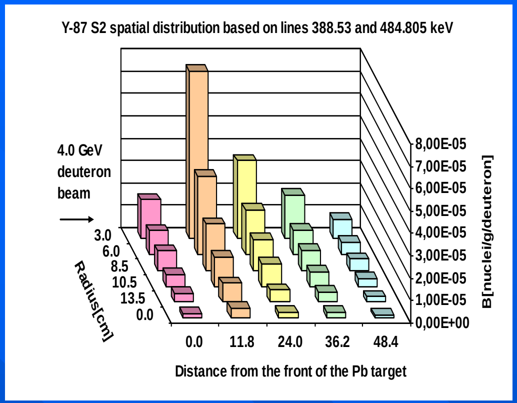



Spatial distribution (radial & axial) of Y85 production. The deuteron beam 4 GeV.

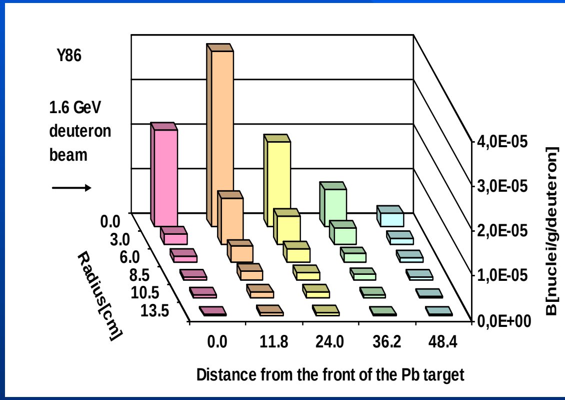
# Y-87 and Y-86 production spatial distribution comparison

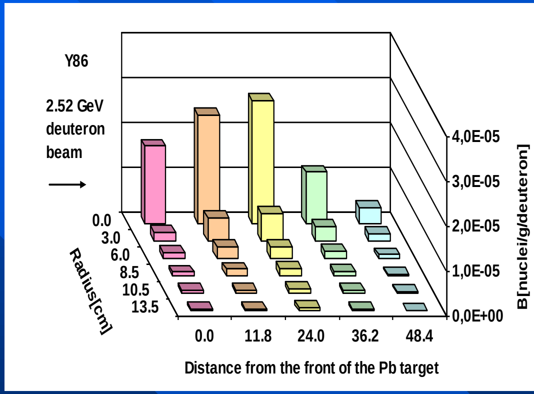


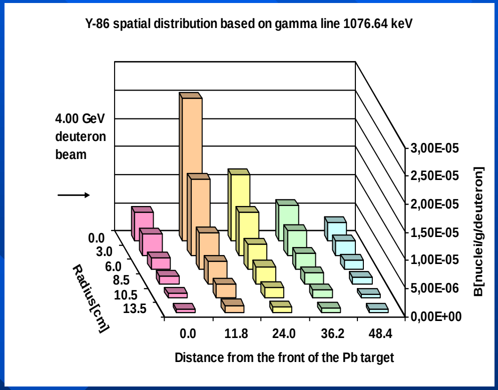




Y87



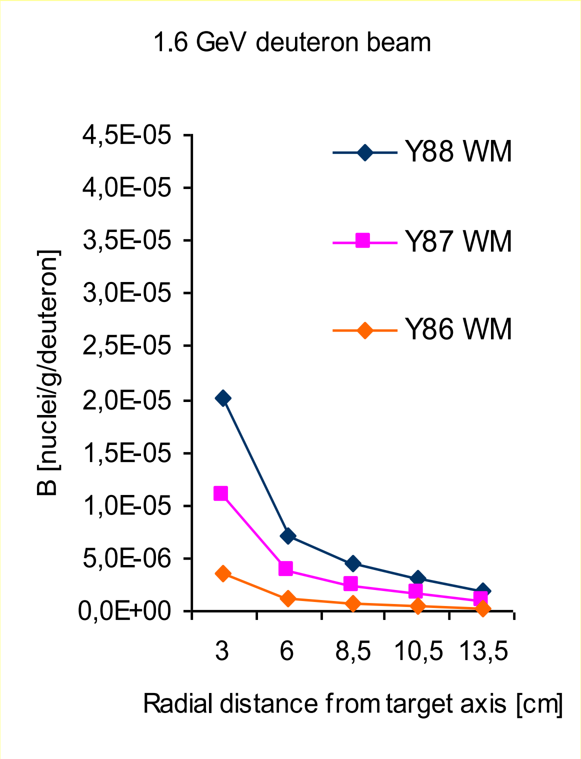



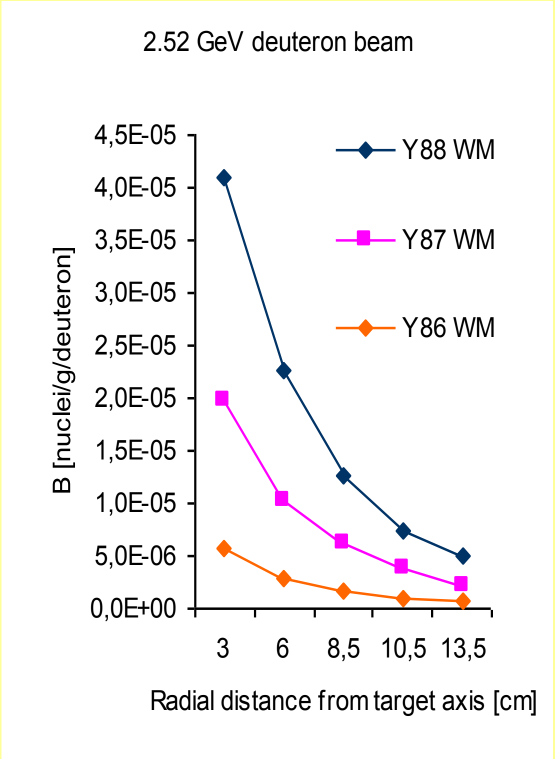

Y86

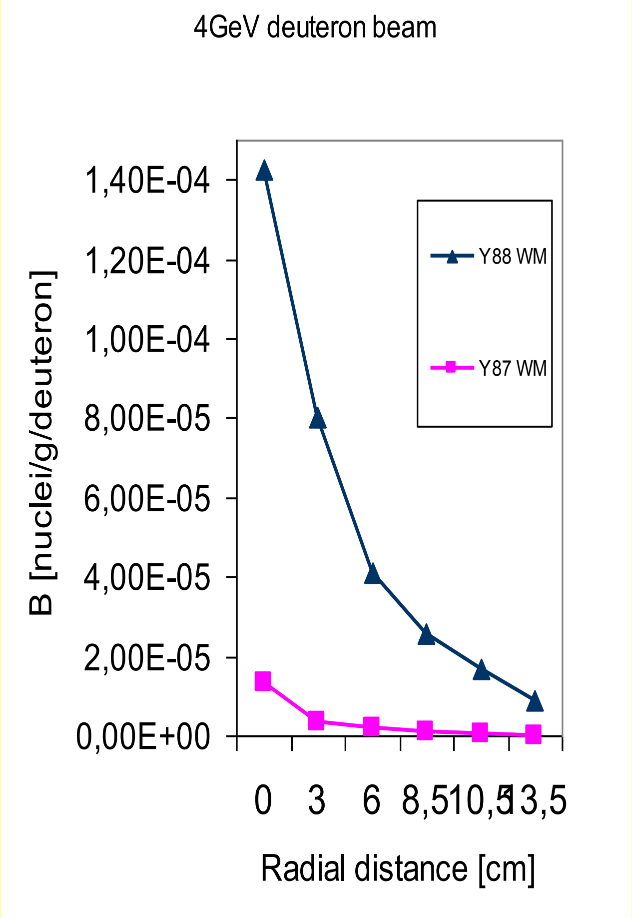
For Energy 1,6 GeV

For Energy 2,52 GeV

For Energy 4 GeV



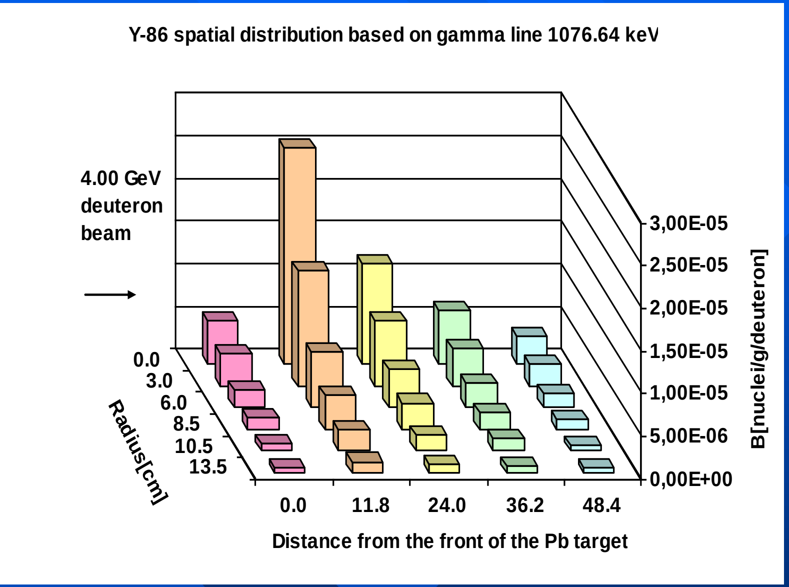




Radial distribution of the Y-88, Y-87 and Y-86 isotopes' production per beam particle at Plane 2 of the assembly. The lines connect the results of the same isotope.

# 4. Average neutron flux densities per deuteron for the three deuteron beams

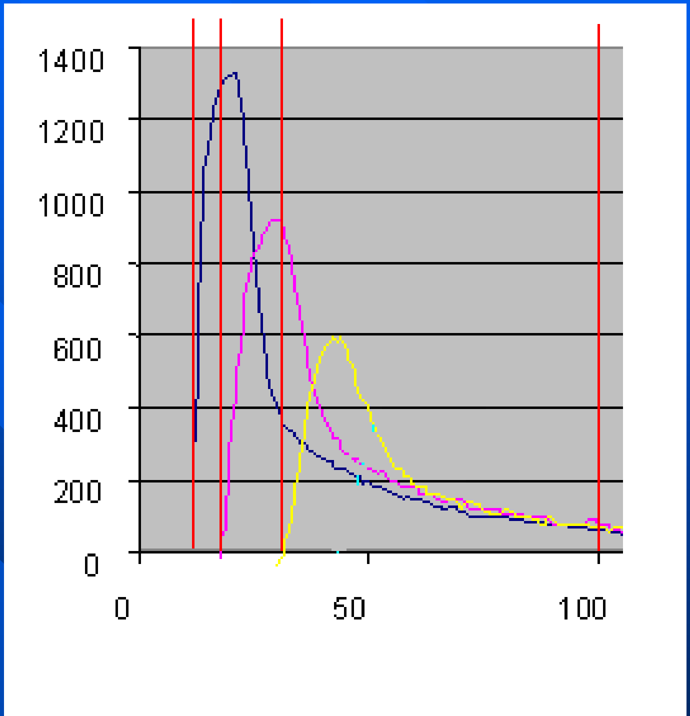
- Shape of the spatial distribution of Y-88, Y-87 and Y-86 isotopes of the yttrium-89 detectors in the U/Pb assembly produced by the neutrons generated in the assembly irradiated by the relativistic deuteron beam of 1.6 GeV (0.8 GeV/nucleon), 2.52 GeV (1.26 GeV/nucleon) and 4.00 GeV (2.0 GeV/nucleon) energies in general is the same but with small aberration for the deuteron of higher energy 2.52 GeV .



# 4. Average neutron flux densities per deuteron for the three deuteron beams

- In order to find explanation for the aberration of the neutron flux shape for the spatial distribution of the isotopes refering to the deuteron beam of energy equal to 2.52 GeV we have decided to compare the average neutron flux densities per deuteron for the three deuteron beams of energies equal to 1.6 GeV, 2.52 GeV and 4.0 GeV.

- 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



# Derivation of the average neutron flux formula

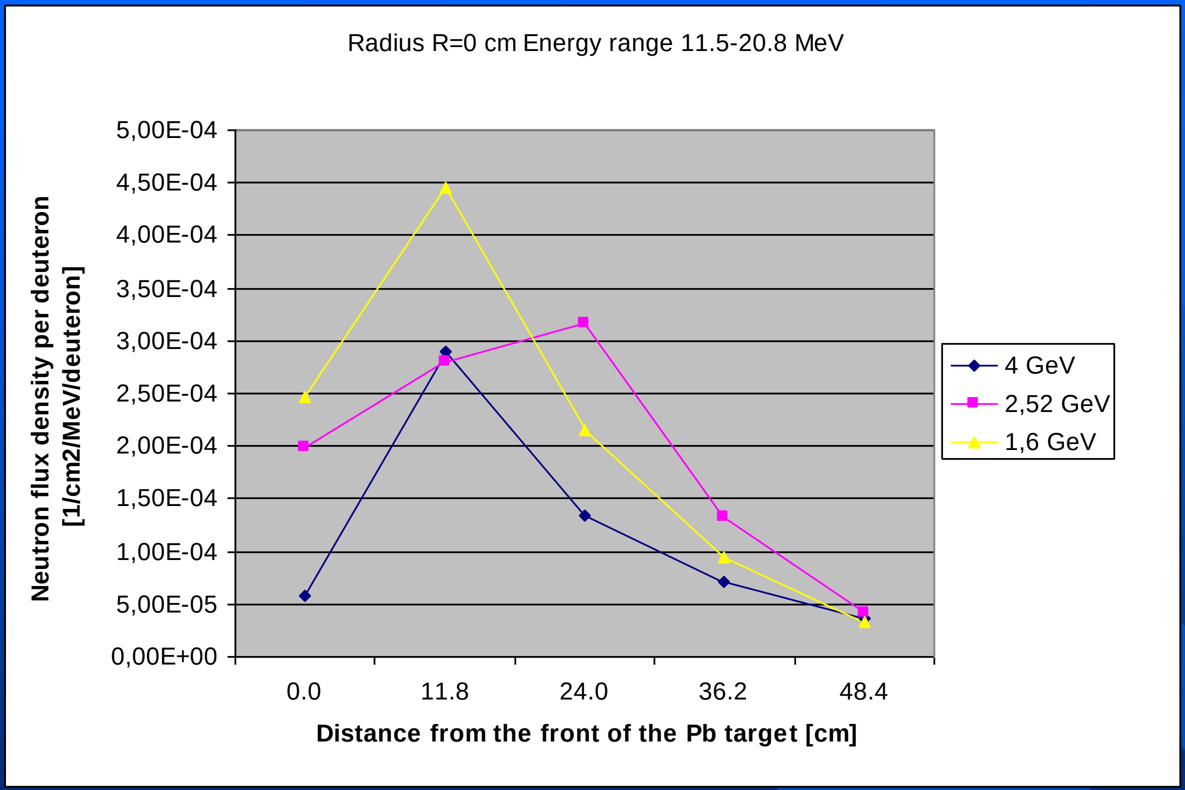
- Solution of three algebraic equations let us to evaluate the average neutron fluxes in the three energy ranges expressed in [n/cm2·s]:

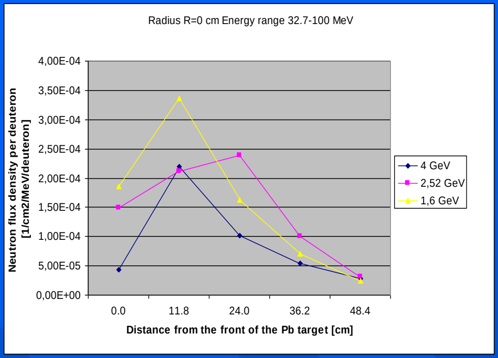
$$\overline{\phi_1} = \frac{C}{\sigma_{11}}[B^{88} - B^{87}\frac{\overline{\sigma_{12}}}{\sigma_{22}} + B^{86}(\frac{\overline{\sigma_{23}}\,\overline{\sigma_{12}}}{\sigma_{33}\sigma_{22}} - \frac{\overline{\sigma_{13}}}{\sigma_{33}})]$$

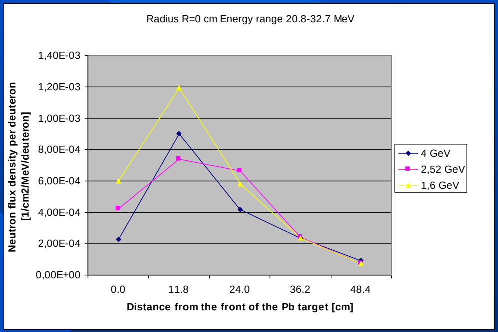
$$\overline{\phi_2} = \frac{C}{\sigma_{22}}[B^{87} - B^{86}\frac{\overline{\sigma_{23}}}{\sigma_{33}}]$$

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

# 4. Average neutron flux densities per deuteron for the three deuteron beams

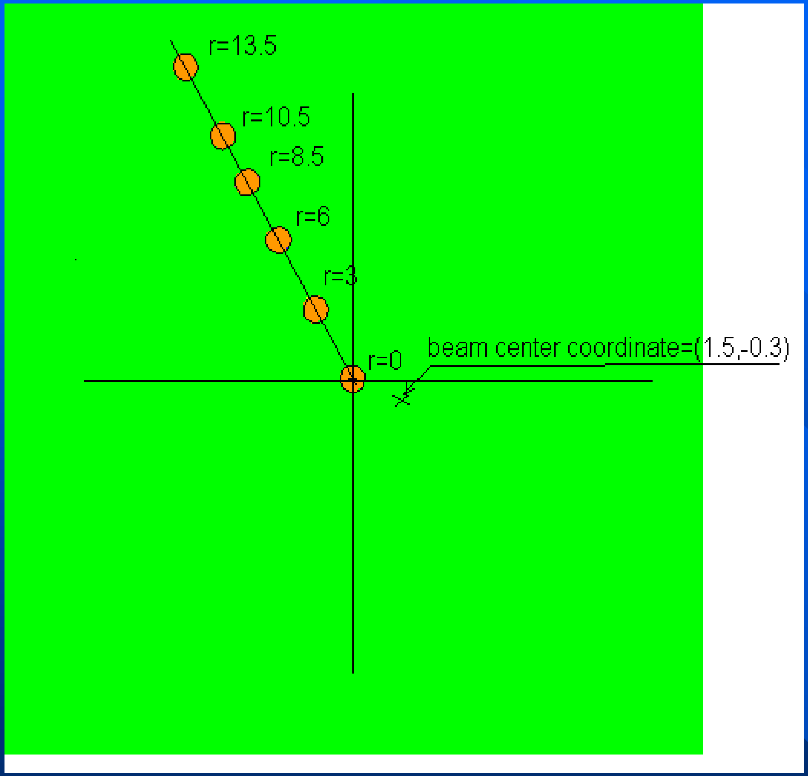


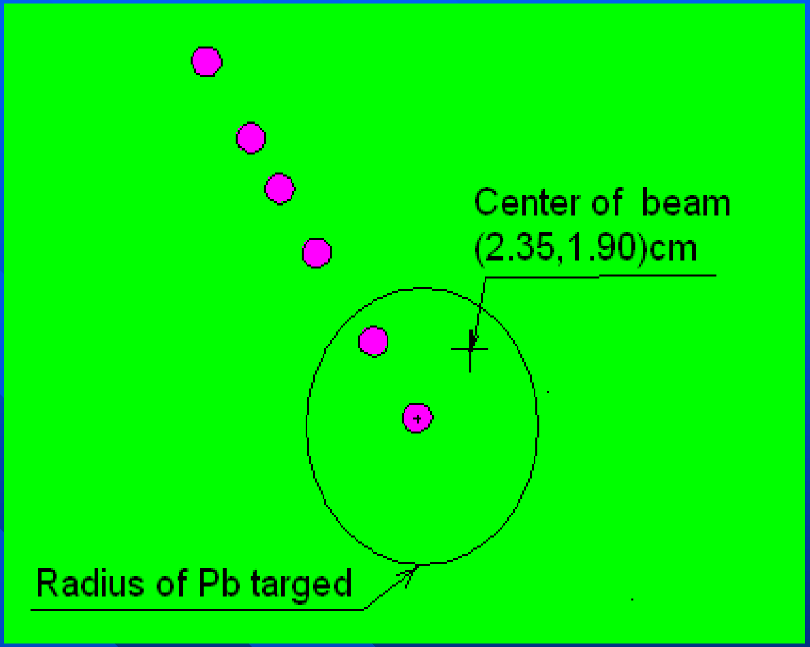




For radial distance R=0cm

# 4. Average neutron flux densities per deuteron for the three deuteron beams

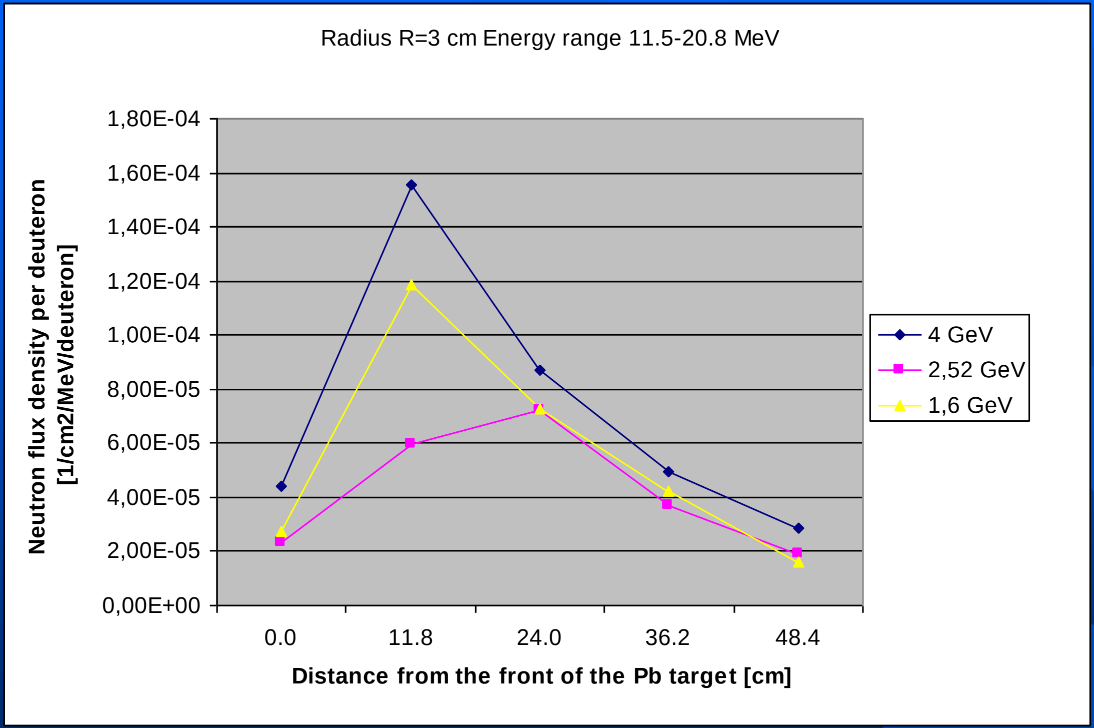


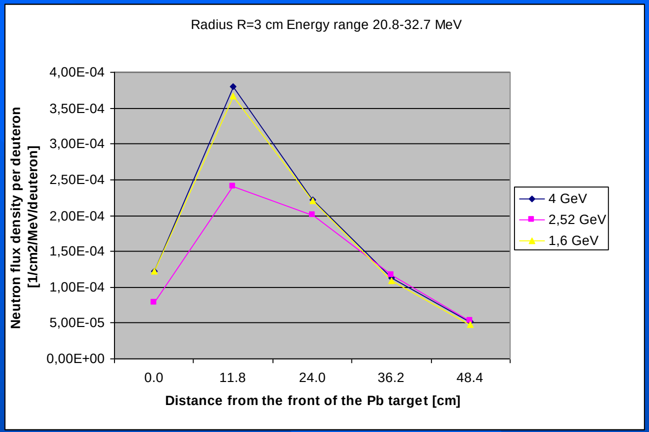

Displacement of 2.5 GeVdeuteron beam in relation to the center of Pb target

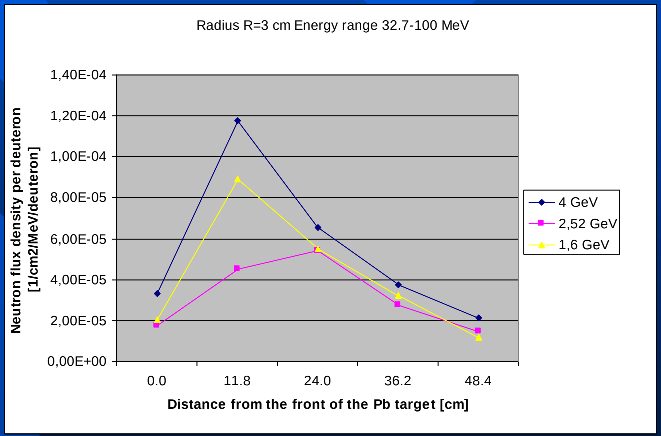



Displacement of 4 GeVdeuteron beam in relation to the center of Pb target

# 4. Average neutron flux densities per deuteron for the three deuteron beams

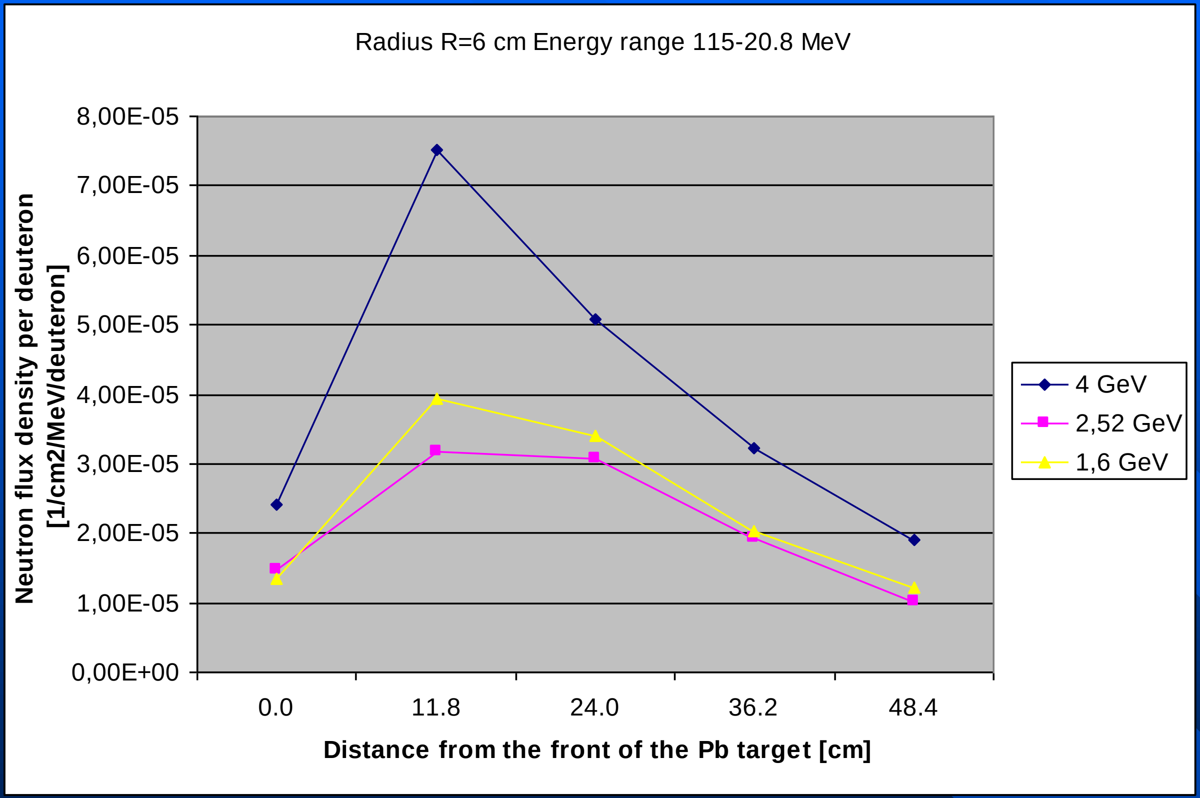


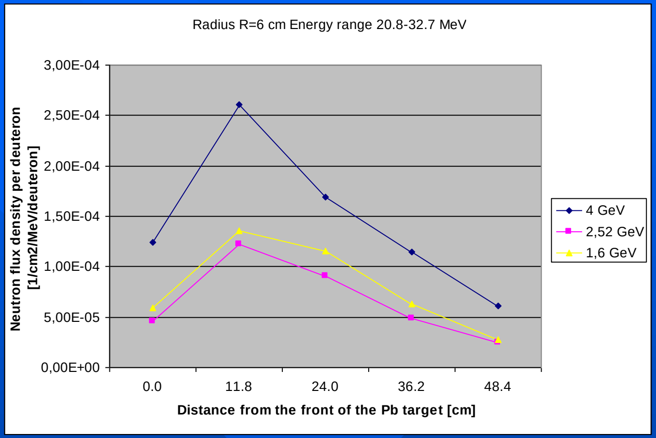



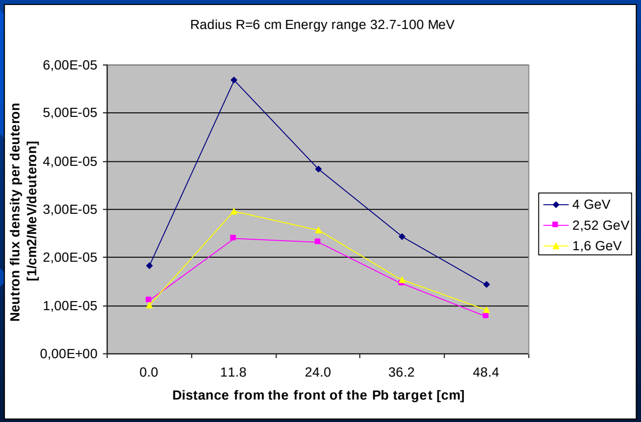




For radial distance R=3cm

# 4. Average neutron flux densities per deuteron for the three deuteron beams

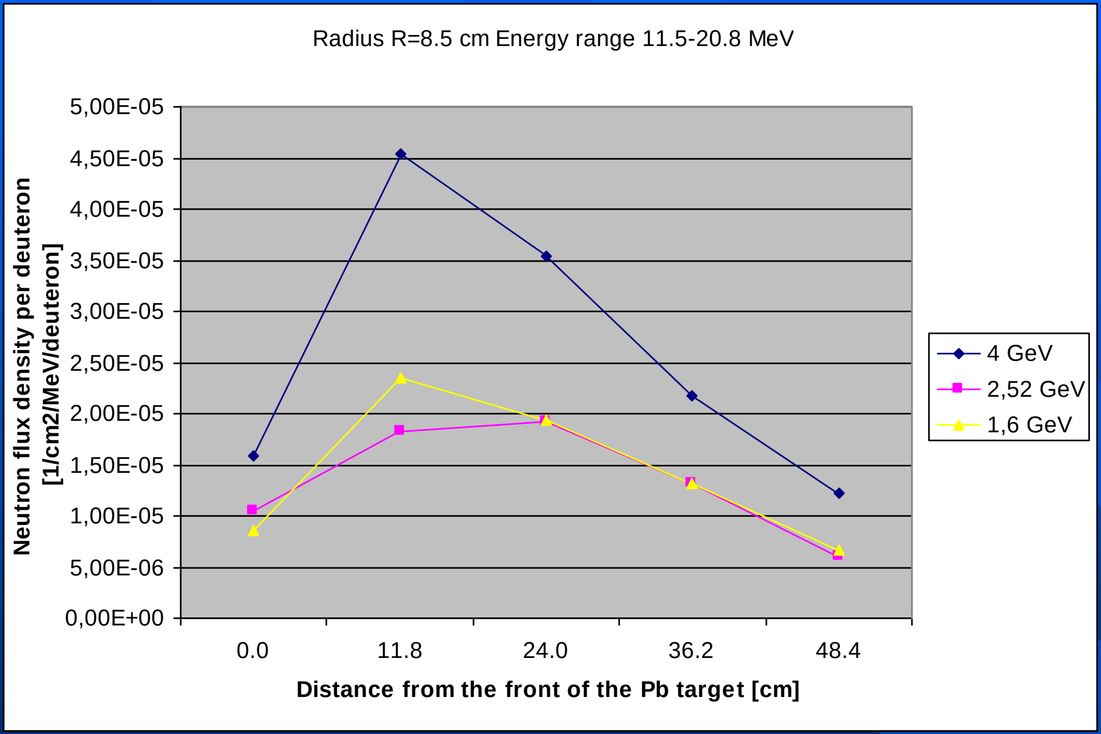


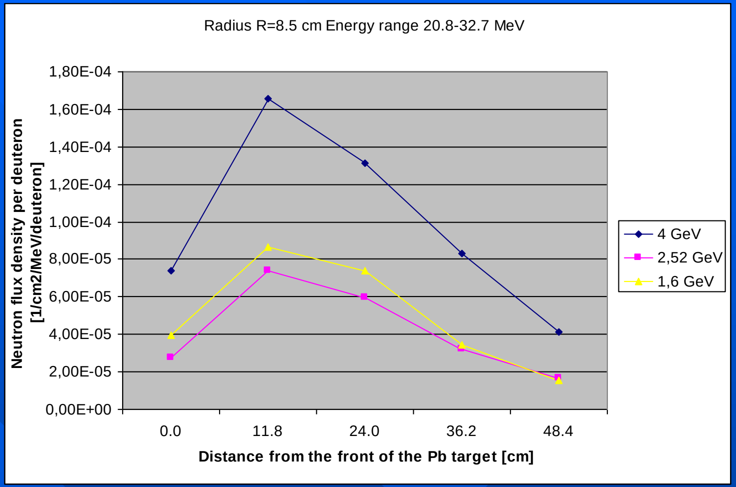



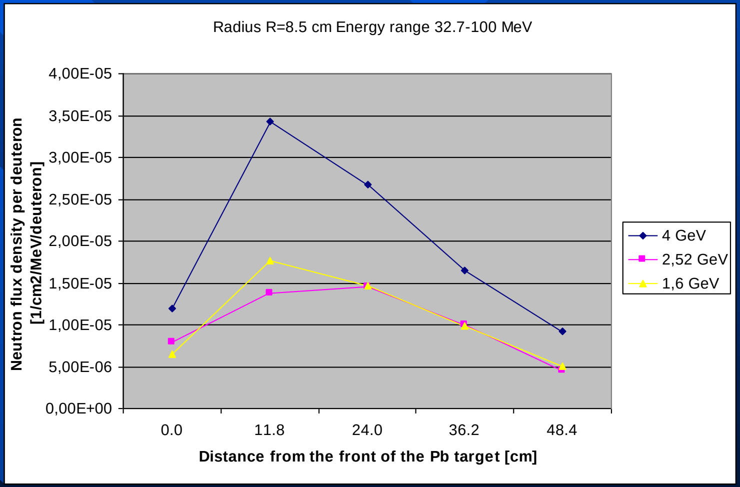

For radial distance R=6cm

# 4. Average neutron flux densities per deuteron for the three deuteron beams



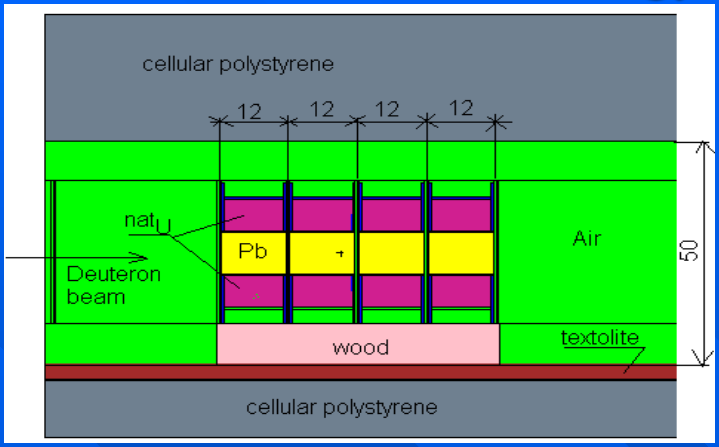




For radial distance R=8,5cm

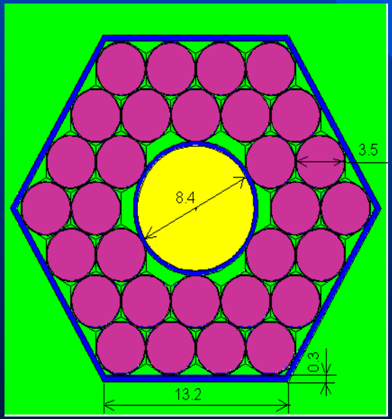


# 4. Calculations Made for the Energy plus Transmutation Experimental Facility Using Monte Carlo Methodology

- Defining each material with its density and composition we obtained the experimental Energy plus Transmutation facility simulation.
- We used for calculation the MCNPX 2.5. code. Number of (n,2n) reaction in detector 89Y was calculated using definition




$$n = \int_{E\,min}^{E\,max} \phi(E)\sigma(E)\rho dE$$



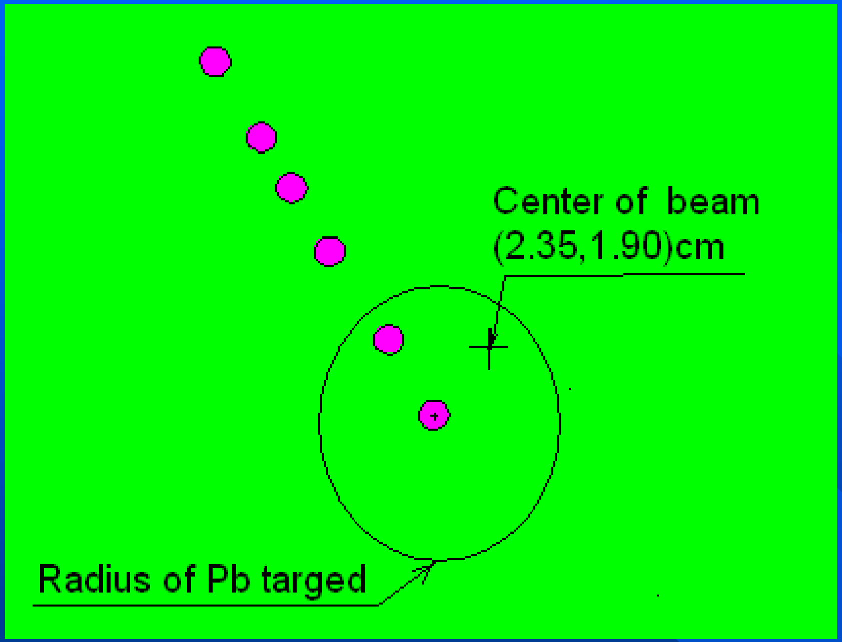

Emin, Emax - means threshold energy

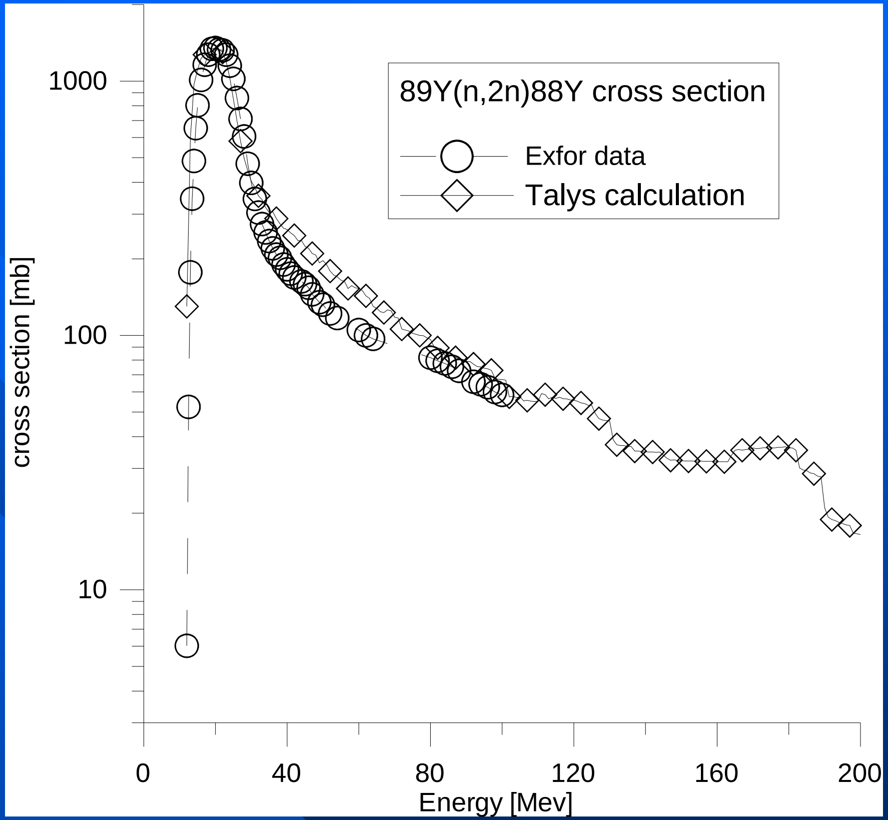
$\phi(E)$ was calculated using MCNPX code in detector

$\sigma(E)$ cross section for (n,2n) reaction. It was obtained from EXFOR data from range (1 - 100MeV) and interpolated.

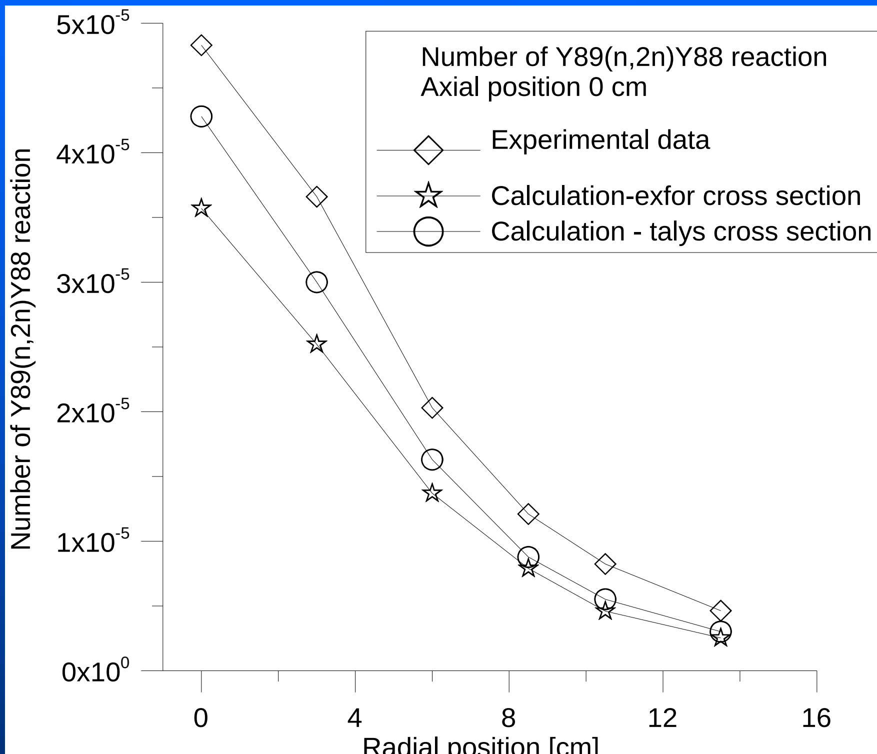
$\rho$ -density of 89Y.

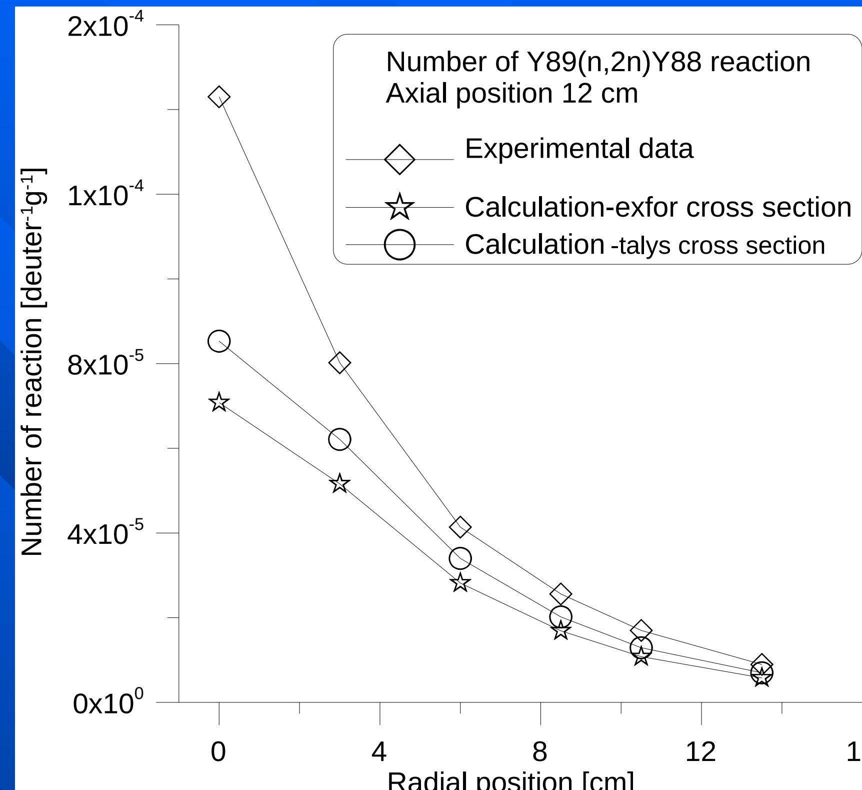
# Comparison with MCNPX calculations



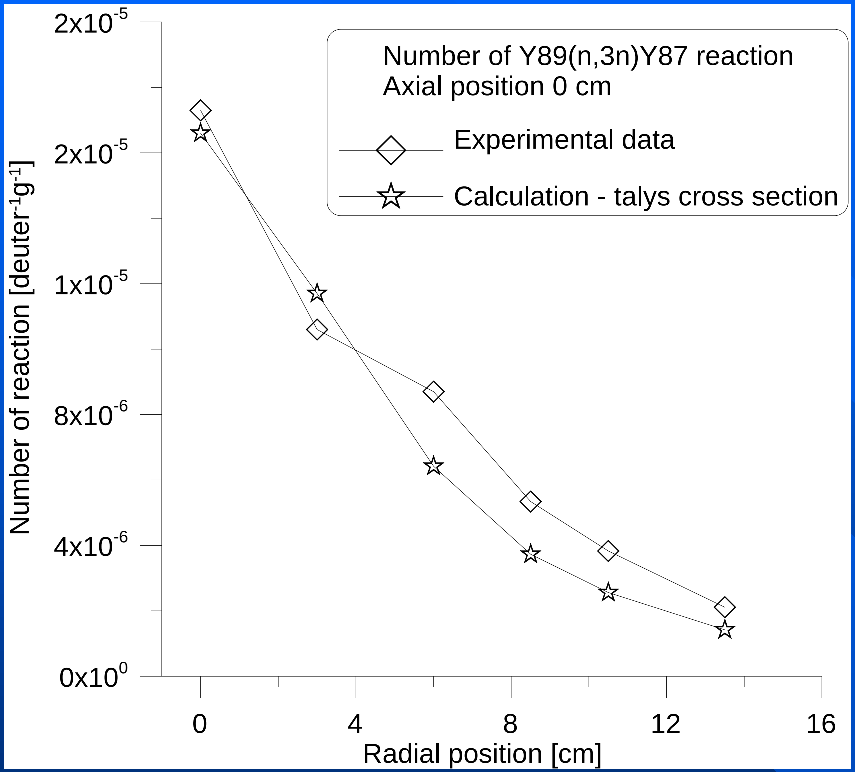



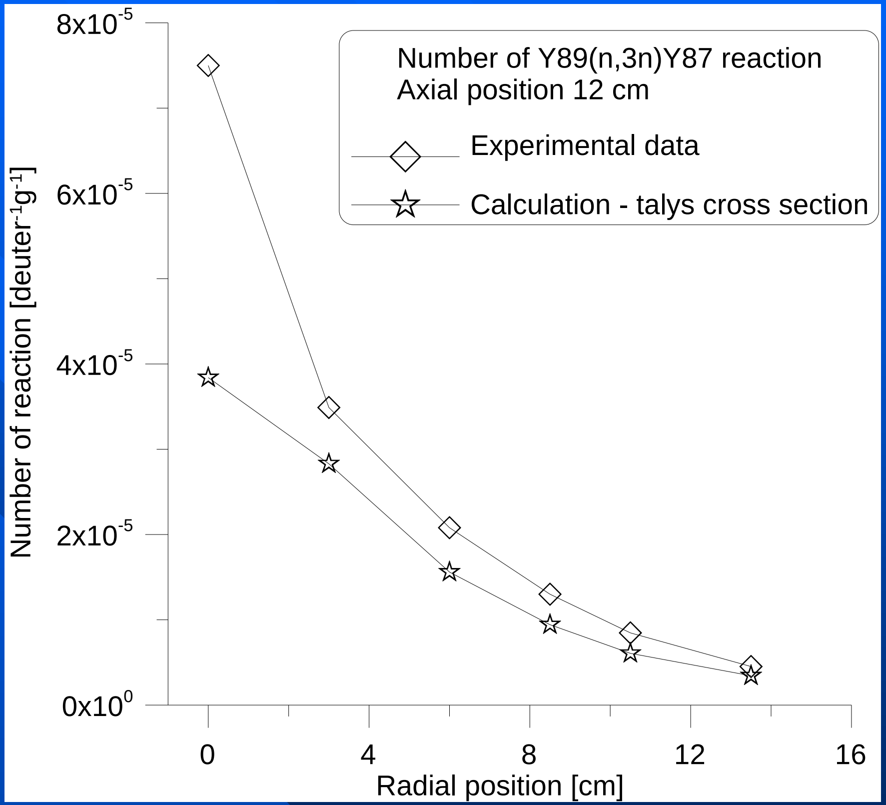
# 5. Comparison with MCNPX calculations



# Comparison with MCNPX calculations



# 5. Conclusions

- The average neutron flux density per deuteron in function of Pb target axis are equal within the evaluated error, as it was expected, starting from R=3 cm to R=13.5cm for the deuteron energies 1.6 and 2.52 GeV in the three neutron energy ranges (11.5-20.8, 20.8-32.7, 32.7-100 MeV) but at the distance 11.8 cm from the front of the Pb target and R=3cm what suggests that the measurements or detectors at the distance were mistaken. This surmise is supported by the fact that the shape of the flux density at the distance run away from the expected one.
- This that the average neutron flux density per deuteron in function of Pb target axis for the deuteron energy equal to 4.0 GeV does not overlap with the neutron flux density per deuteron for the deuteron energies equal to 1.6 and 2.52 GeV can be explained by a big deuteron beam misalignment with respect to the lead target axis.
- Measurements show that significant part of the deuteron beam had fallen on the uranium blanket what means that spallation occurred simultaneously in the lead and in the natural uranium. This suggests that the spallation effectiveness in the uranium target is higher than in the lead target and so this explains higher neutron flux density in the deuteron beam experiment of 4.0 GeV energy.

# 5. Conclusions

- Presented here results and inferences are not final ones and show just the tendencies and our suggestions have to be proved.
- Experiments without the uranium blanket of the E+T set-up for the same yttrium detectors location would be desired for dispelling the doubts.

# Thank you for the cooperation