RECENT RESULTS OF EXPERIMENTS WITH MASSIVE URANIUM TARGET SETUP QUINTA AT NUCLOTRON.

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ISINN-20,Alushta,May 21-25,2012

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ISINN-20,Alushta,May 21-25,2012

INTRODUCTION

- **As it was reported at previous ISINN-19 the ADS project "Energy and Transmutation RAW" (E&T RAW) continued to run at JINR.**

- **The project is aimed at study of possibilities to use deep subcritical natural (depleted) uranium or thorium active core (AC) with very hard neutron spectrum inside for effective burning of the core material together with spent nuclear fuel (SNF).**

- **To preserve maximally hard neutron spectrum it is necessary to use high temperature helium cooling in primary circuit and large volume ("quasi-infinite") AC loaded by small size encupsulated fuel elements including these made from SNF without its preliminary radiochemical reprocessing**

- **The essential point of this ADS is direct use of the core load as a target for smeared incident beam with energy up to 10 GeV.**

- **The new approach to ADS outlined above is called the Relativistic Nuclear Technology (RNT) for utilization of spent nuclear fuel and energy production.**

- **At present very challenging problem of any ADS is a creation of powerful (~ 10-50 MWt) accelerator with good enough duty cycle.**

- **But creation of such accelerator as well as all RNT engineering problems are so far out of the current JINR project.**

JINR PROJECT "Energy&Transmutation RAW"

- **The objectives of project "E&T RAW" are to study during 2011-2013 the basic features of model ADS with quasi-infinite deep-subcritical AC irradiating by deuteron (proton) beam from JINR NUCLOTRON in incident energy range 1- 10 GeV**

JINR PROJECT "Energy&Transmutation RAW"

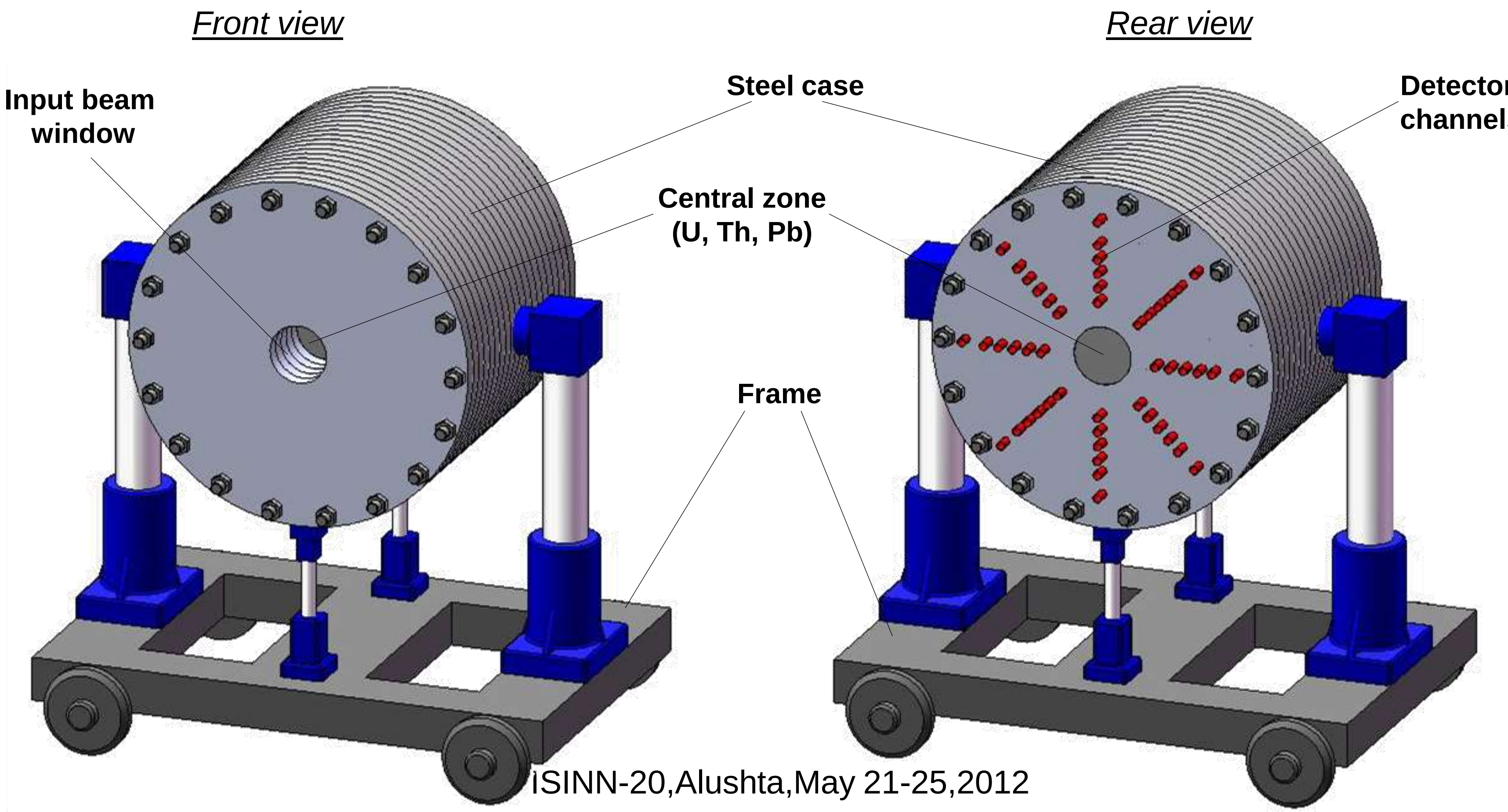
- **For realization of "E&T RAW" project there are two target assemblies at JINR :**

- semi-infinite (~20 tones) depleted uranium AC BURAN

- and smaller (~500kg) nat. U target assembly QUINTA modeling the central part of the larger AC

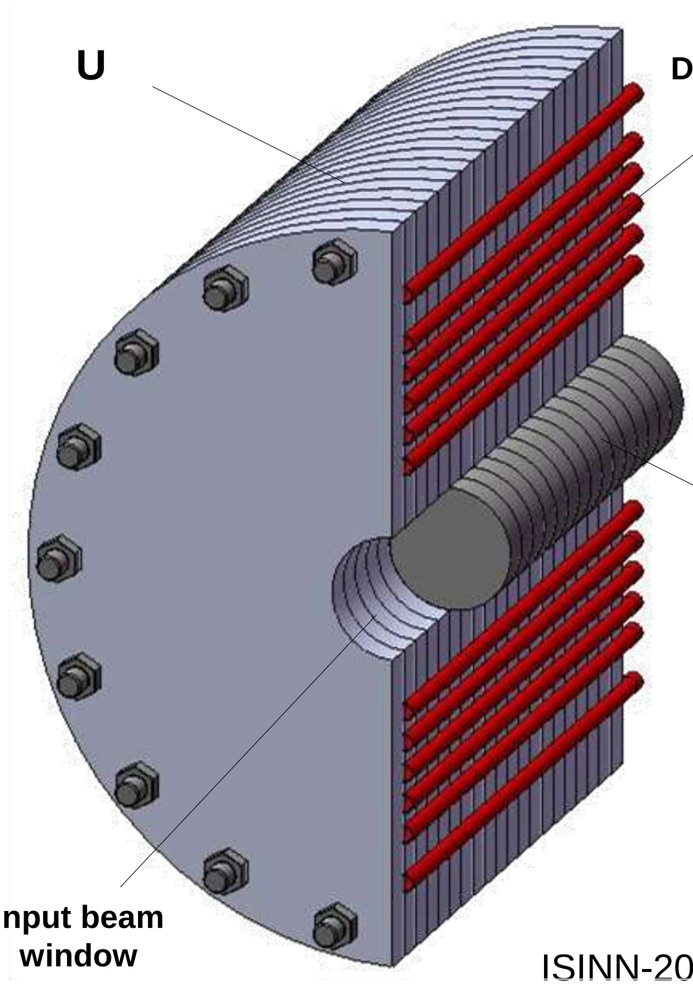
Quasi-infinite depleted uranium target (BURAN) with replacement central zone

Mass of uranium – 19.5 т. **Materials of central zone – U, Th, Pb.**
Diameter – 1,2 м. **Diameter of central zone – 0,2 м.**
Length – 1 м.



Quasi-infinite depleted uranium target (BURAN) with replacement central zone

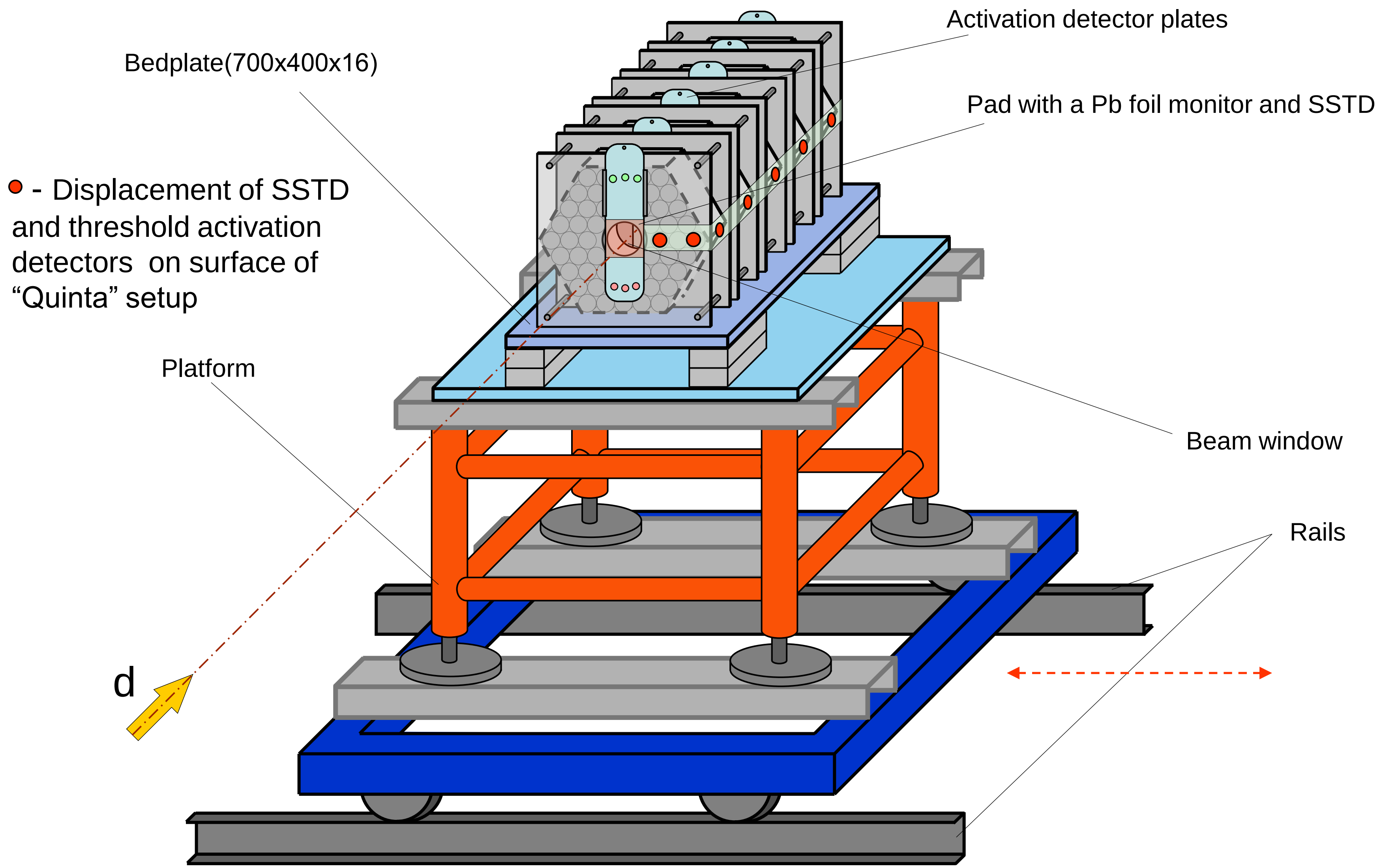
Longitudinal section of the BURAN together with central zone and detector sets



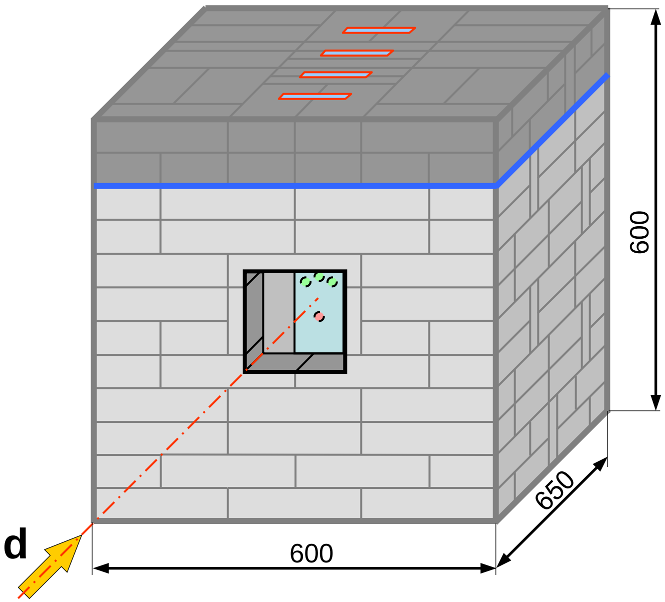
Front view photo

Rear view photo

Target assembly "Quinta" at the irradiation position (March 2011)



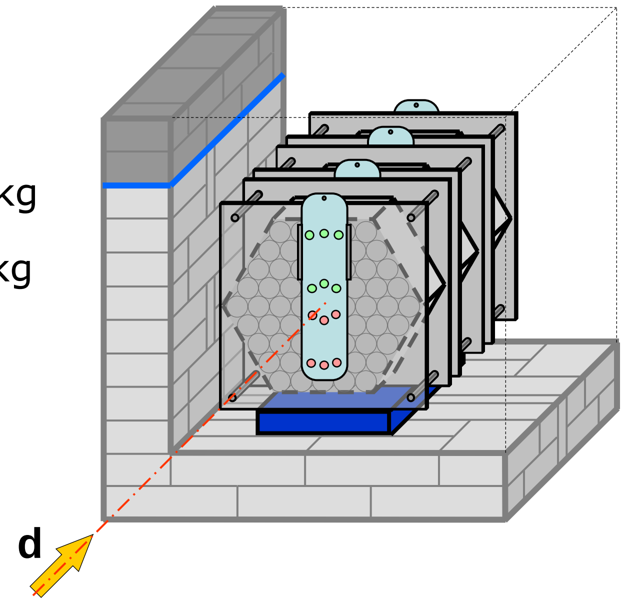
“Quinta” at the irradiation position
(June 2009, December 2011, March 2012)



m_U = 315 kg

m_{Pb} = 1780 kg

m_{Σ} = 2125 kg



JINR PROJECT “Energy&Transmutation RAW”

- **In present talk it’ll be discussed mainly the results of experiments carried out with target assembly QUINTA during 2011-2012 aimed at study basic physics of RNT**
- **Really these experiments are preparatory stage to future measurements with quasi-infinite AC planned for 2013**

- **It is appropriate to note that quasi-infinite subcritical AC from natural or depleted uranium were studied earlier:**

  - J.W. Weile et al.~20 tons nat. U+14 Mev neutrons (1961)
  - R.Vassil'kov et al. ~7 tons nat. U+660 MeV protons (1978)
  - Wang Dalun ~20 tons depl.U+14 MeV neutrons (1991)
  - C. Rubbia et al. ~3.6 tons nat.U+0.6-2.7GeVprotons (1995)

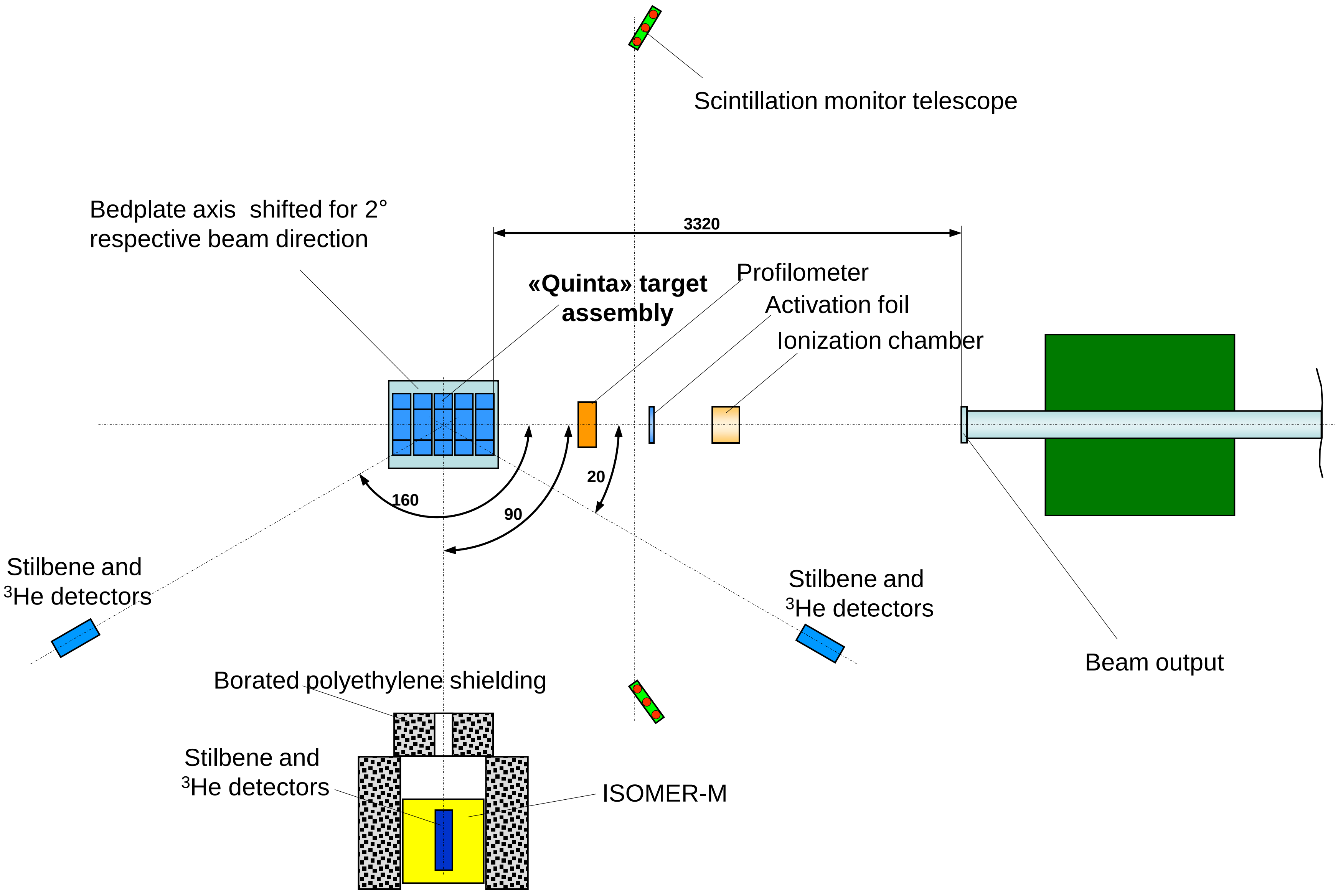
- **Only in three first experiments there was realized hard neutron spectrum**
- **In the fourth FEAT experiment U rods were embedded into light water moderator so real neutron spectrum was close to thermal one and neutron multiplicity coefficient k_{eff} of this system was near 0.9.**

- In experiment by Vasil'kov-Goldansky group on Dubna synchrocyclotron it was not used any moderator and was applied a special geometry so their 3.5 tons target was equivalent ~ 7 tones setup with rather small (<10%) neutron leakage.
- In this case of "quasi-infinite" AC maximally hard neutron spectrum has been realized with rather low $\boldsymbol{k_{eff}}$ ~ 0.4
- They obtained integral number of fission events N_f ~ 20 and produced ^{239}Pu nuclei $N_{n\gamma}$ ~ 45 per incident proton.
- It leads to the beam power gain (BPG) ~ 7 for 0.66 GeV protons at rather small ***k_{eff}~ 0.4***

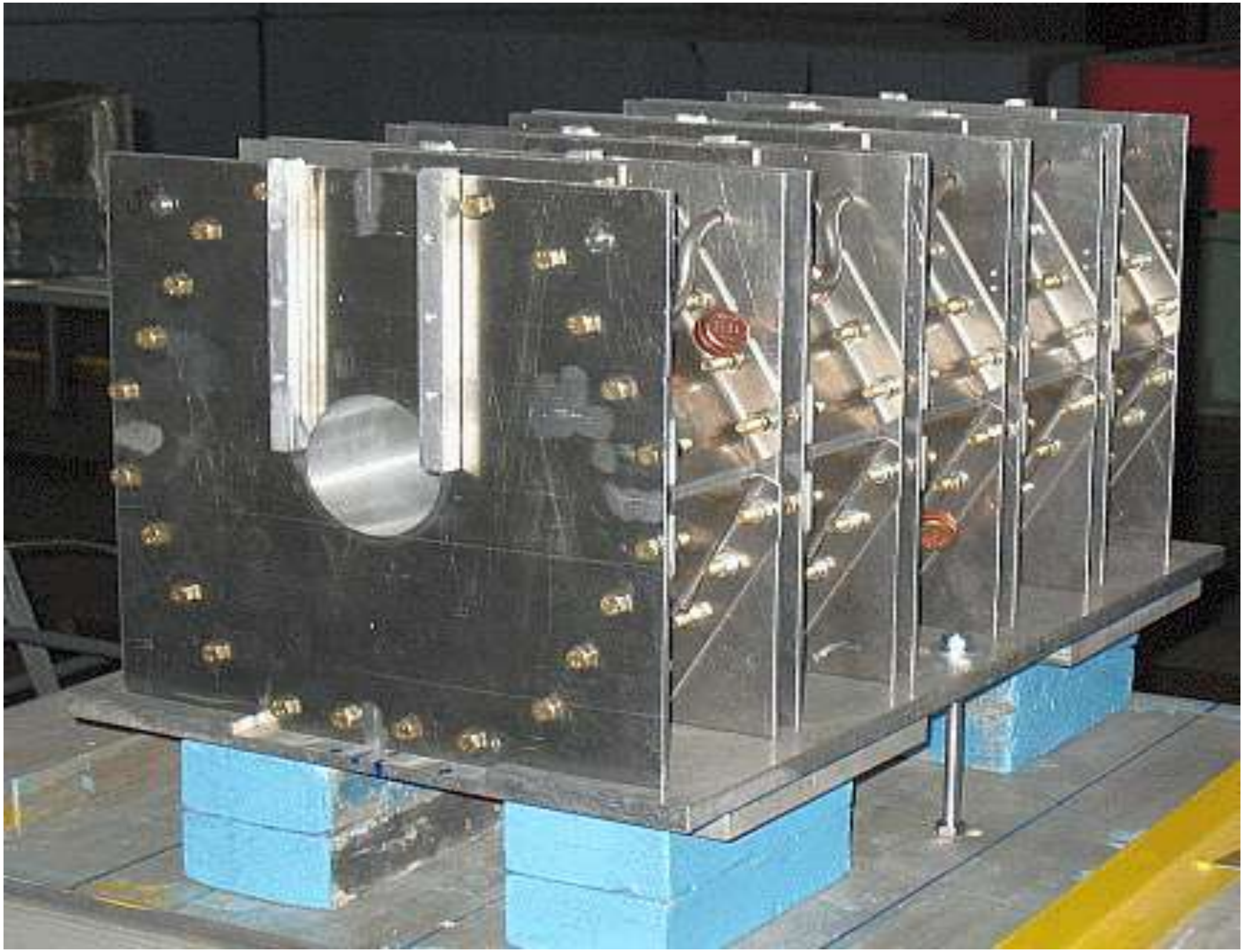
JINR PROJECT "Energy&Transmutation RAW"

- So it is very important to realize the experiment with quasi-infinite AC such as BURAN for more high energy (up to 10 GeV)
- The measurements with QUINTA target assembly allow us to test experimental technique planned to use for study of the AC BURAN properties and to clear out the basic characteristics of the central "neutron tube-like source" of this AC investigated in 2009 - 2012.

Scheme of experiment with "Quinta" setup, March 2011 run



Upgraded target assembly "Quinta" (front view)

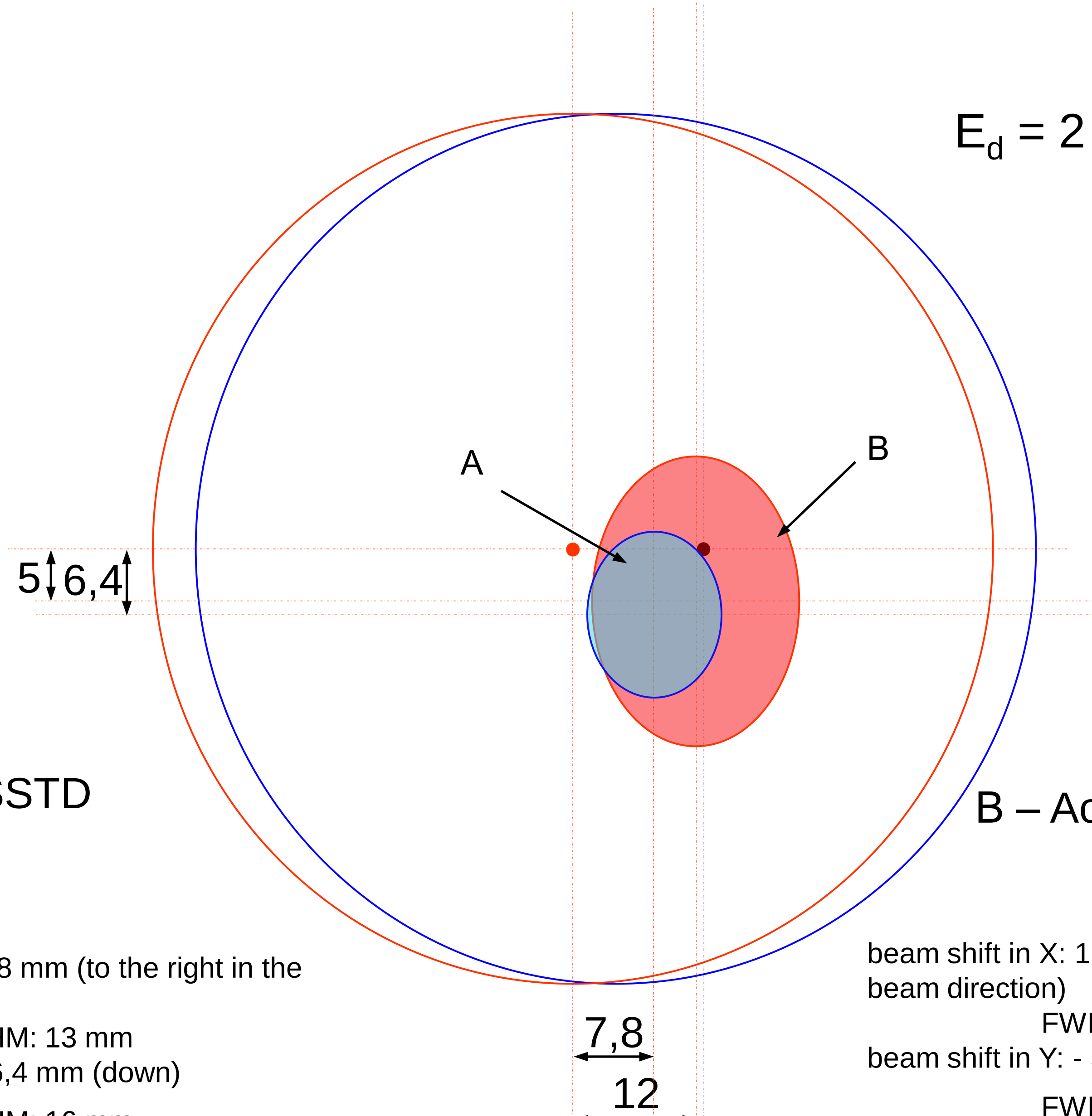


QUINTA at the irradiation position (front view)

General view of the experimental setup

Beam position into input window (front view)

$E_d = 2$ GeV



A – SSTD

B – Activation method

beam shift in X: 7,8 mm (to the right in the beam direction)

FWHM: 13 mm

beam shift in Y: - 6,4 mm (down)

FWHM: 16 mm

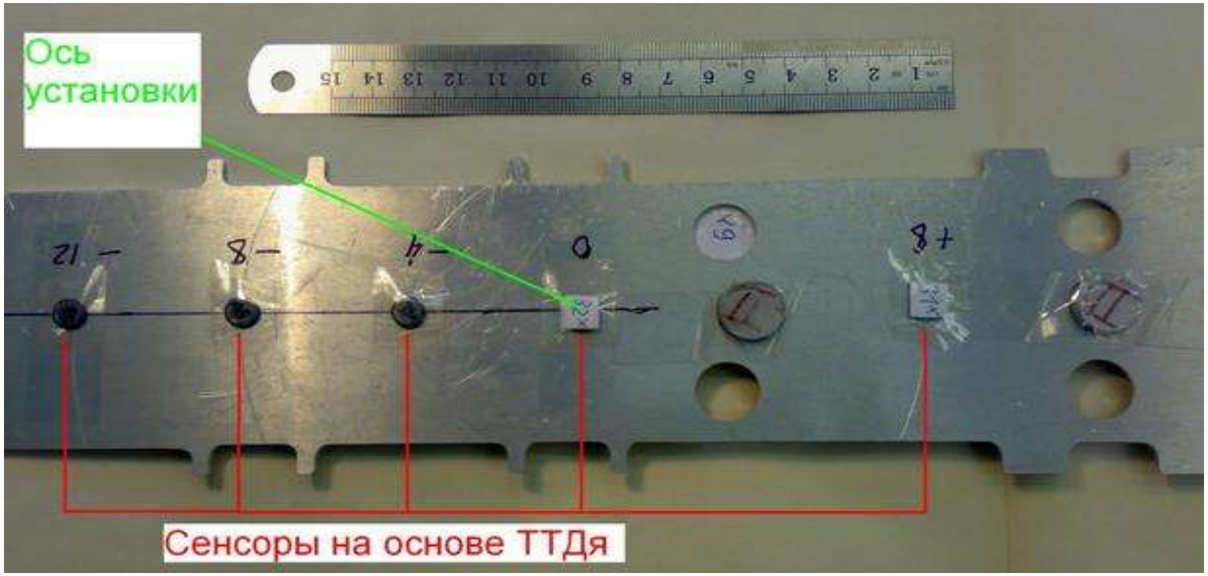
beam shift in X: 12 mm (to the right in the beam direction)

FWHM: 20 mm

beam shift in Y: - 5 mm (down)

FWHM: 28 mm

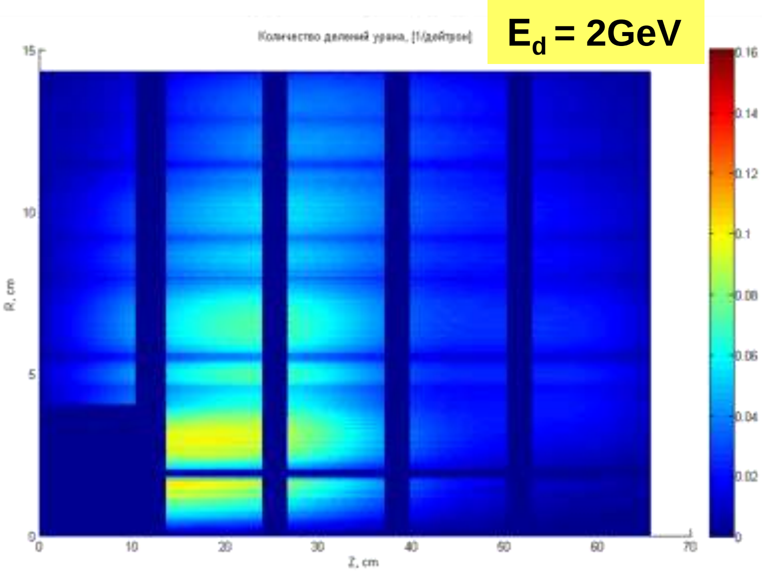
• M

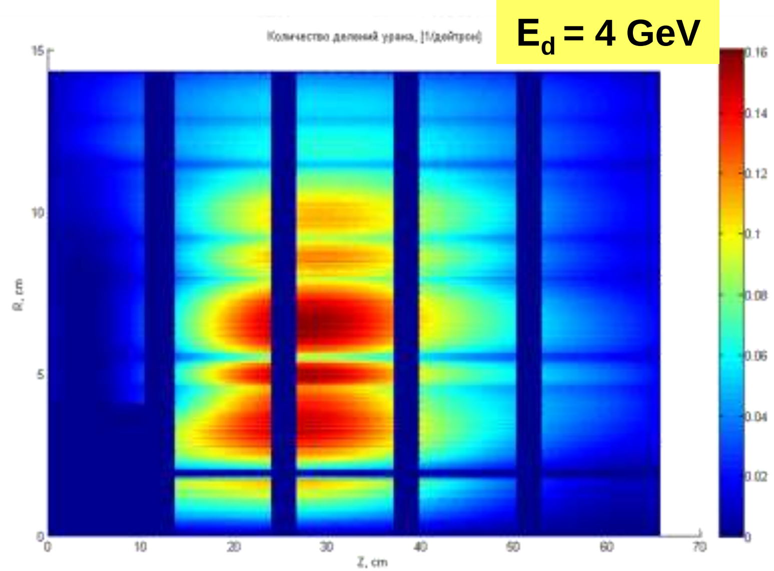

Ось
установки
-12
-8
-4
0
+8
Сенсоры на основе ТТДя

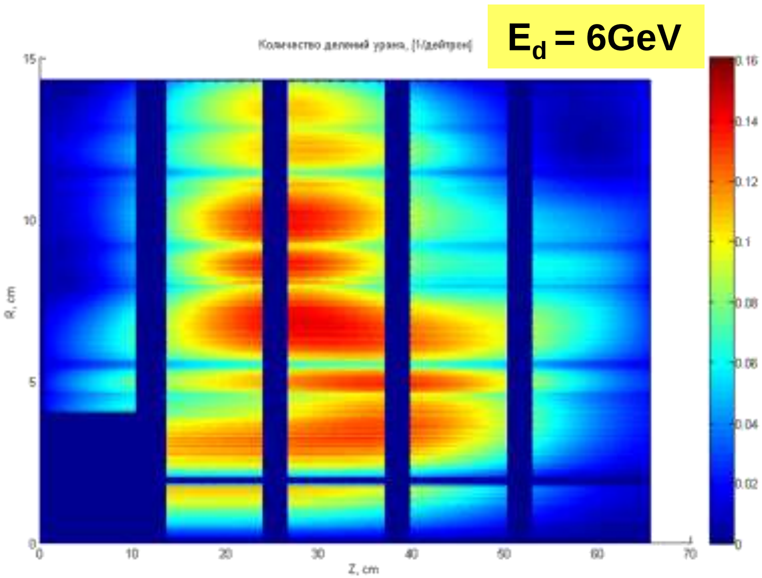

Сенсоры на основе ТТДя

Mica SSTD

Preliminary results of March 2011 experiments



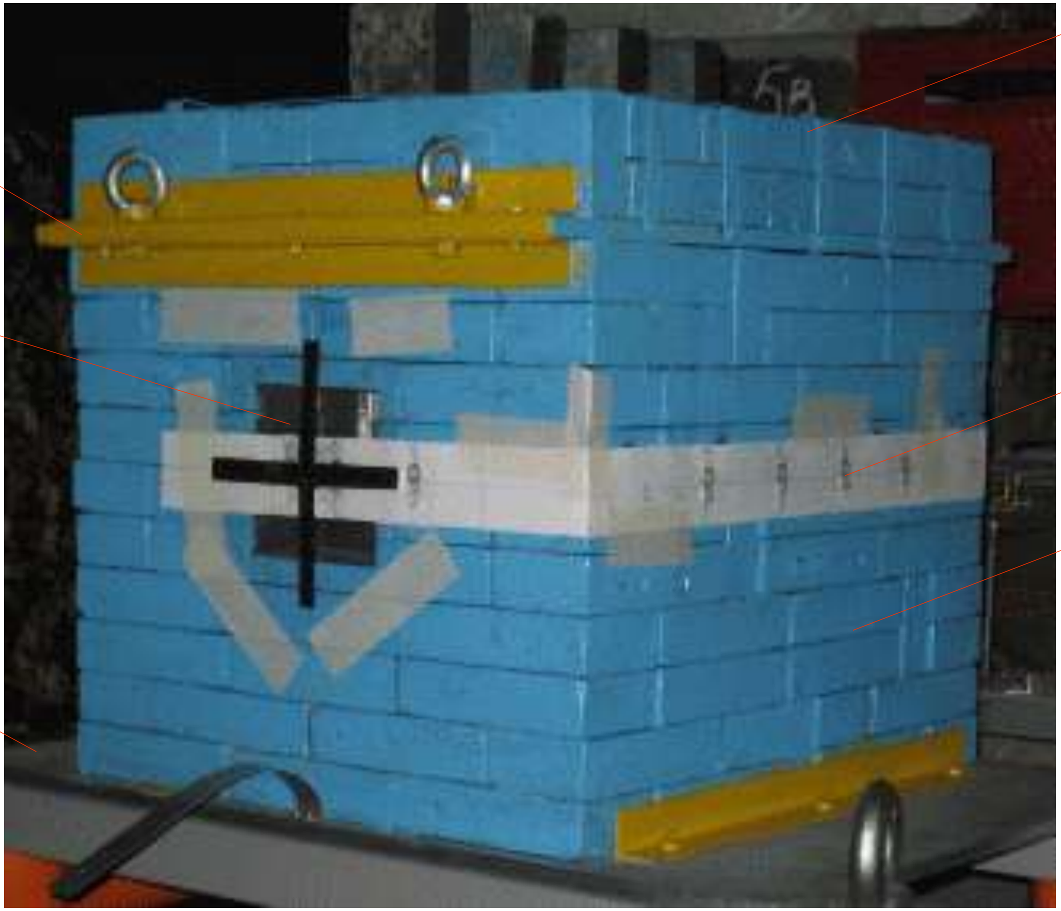


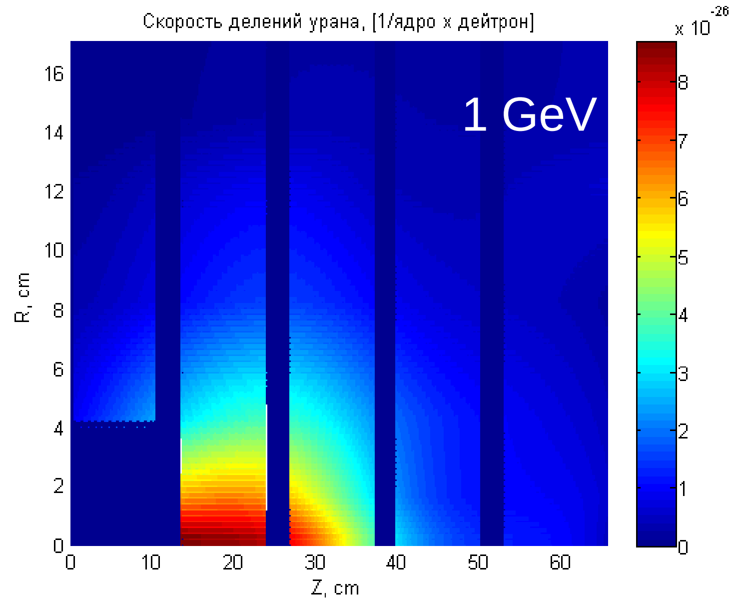


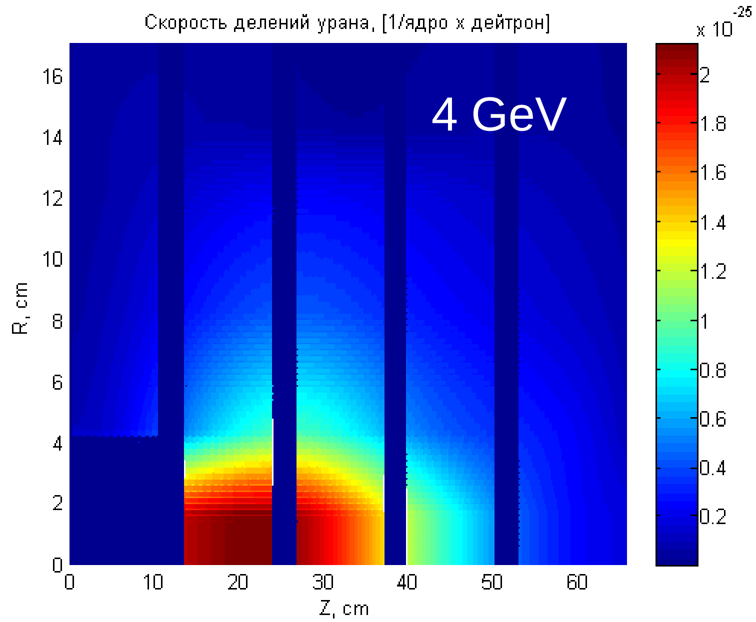
Spatial distributions of fission rates (in cm^3/one deuteron) for QUINTA setup irradiated by deuteron beam

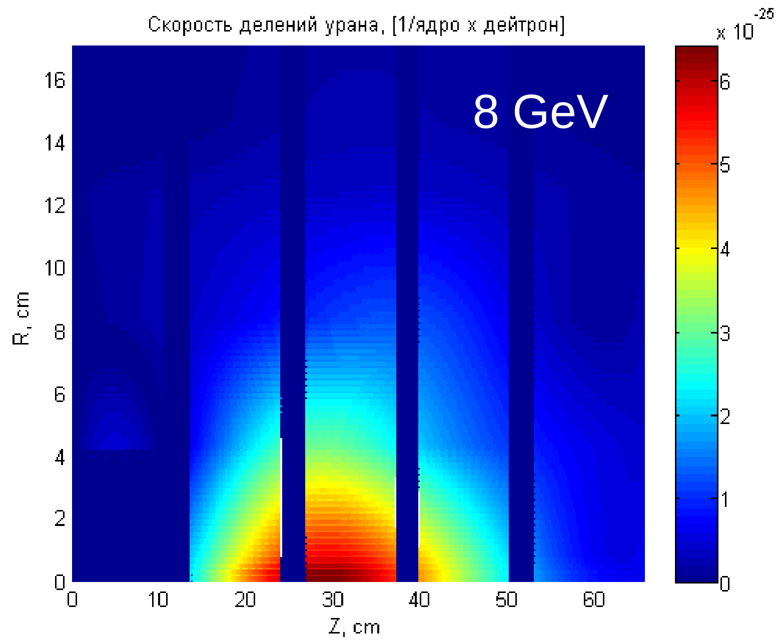
Measurements by solid state track detectors (SSTD)

“Quinta” at the irradiation position (June 2009 and March 2012)







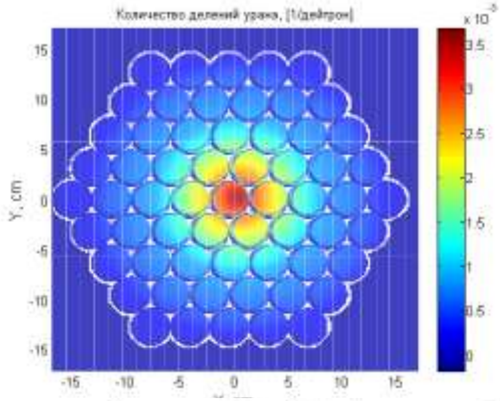


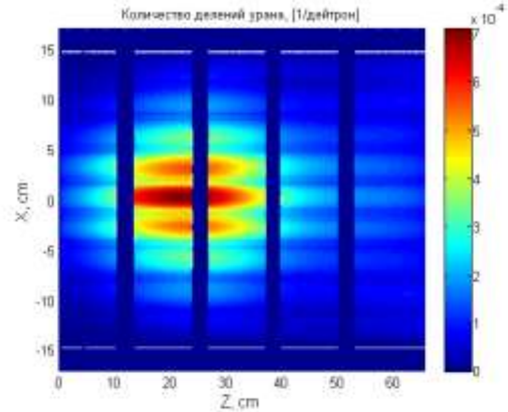
Fission rates

f/1nucleus/deuteron

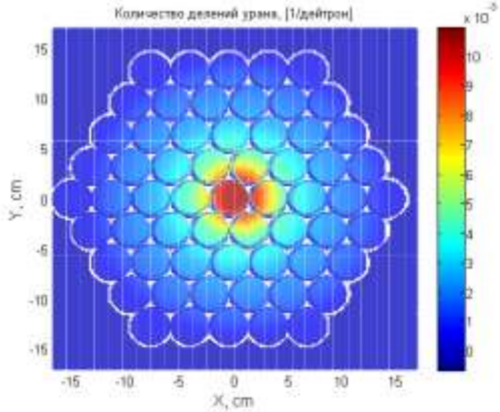
Measurements by solid state track detectors (SSTD) In March 2012

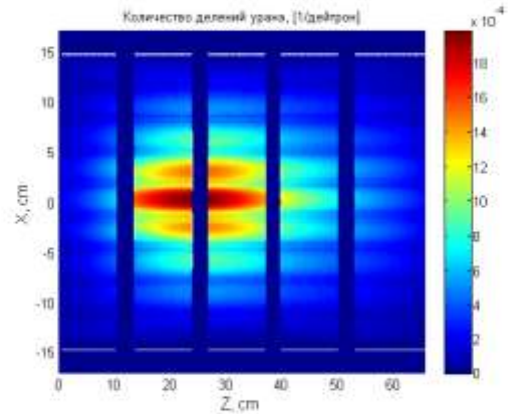
1 GeV



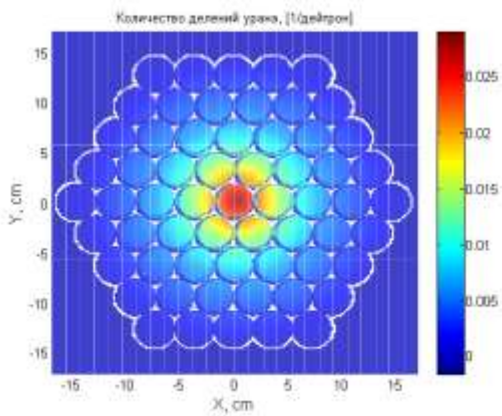


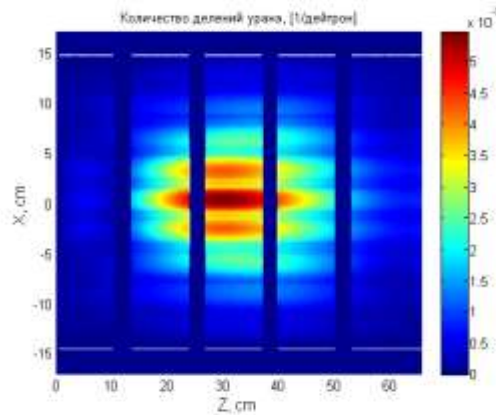
4 GeV





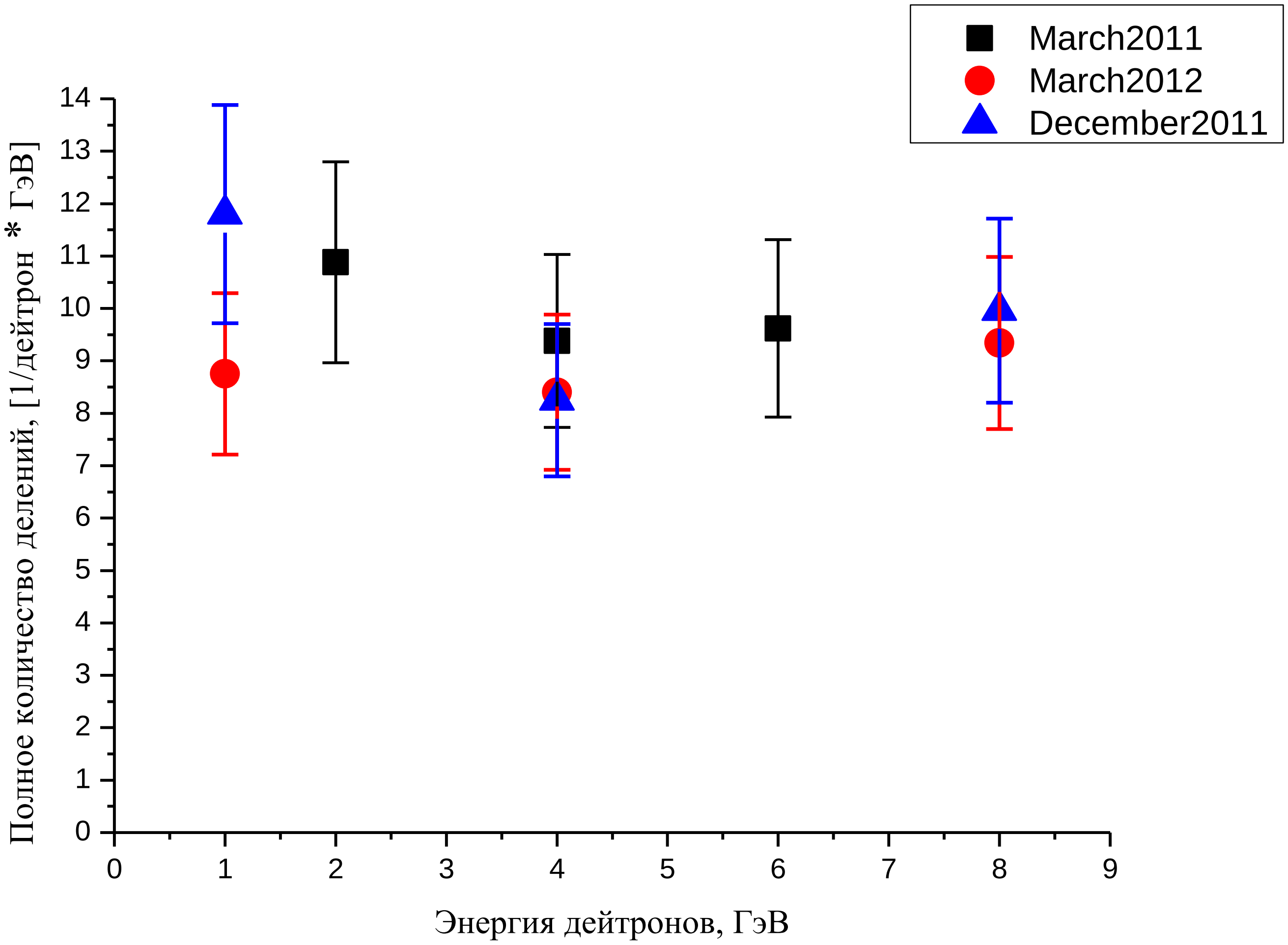
8 GeV





Distributions numbers of fissions integrated over Z axis- left over X axis -right

Total numbers of fissions from QUINTA per one deuteron and 1 GeV from SSTD



Plutonium production

$^{238}U(n,\gamma)^{239}U$ (23,54 min) β- $\rightarrow {}^{239}Np$ (2,36 days) β- $\rightarrow {}^{239}Pu$

277,6 keV γ-line from ^{239}Np

γ- detector calibrated with ^{60}Co, ^{54}Mn, ^{57}Co, ^{88}Y, ^{109}Cd, ^{113}Sn, ^{133}Ba, ^{137}Cs, ^{139}Ce, ^{152}Eu, ^{228}Th, ^{226}Ra standard sources.

Number of fissions defines by averaging of following fission product yields:

^{97}Zr (5.42%), ^{131}I (3.64%), ^{133}I (6.39%), ^{143}Ce (4.26%)

.

In brackets there are mean cumulative FP yields

For more details see M. Artωushenko's report later in this session

Total numbers (per 1 GeV) of produced nuclei ^{239}Pu (N_{Pu}) and fissions (N_f) of ^{nat}U into target assembly QUINTA

Run	E_d *GeV*	N_{Pu}	N_f
March 2011	**2**	**(7.0 ± 0.3) ± 0.8**	**(8.8± 0.4) ± 1.0**
(without	**4**	**(7.2± 0.4) ± 0.8**	**(8.8± 0.4) ± 1.0**
Pb blanket)	**6**	**(6.9± 0.3) ± 0.7**	**(8.3± 0.4) ± 0.9**
Dec. 2011	**1**	**(11.6± 0.6) ± 1.2**	**(10.2± 0.5) ± 1.1**
(with	**4**	**(10.9± 0.5) ± 1.1**	**(8.7± 0.4) ± 1.0**
Pb blanket)			
March 2012	**1**	**(11.2± 0.6) ± 1.2**	**(9.6± 0.5) ± 1.1**
(with	**4**	**(10.8± 0.5) ± 1.1**	**(8.8± 0.4) ± 1.0**
Pb blanket)	**8**	**(10.5± 0.5) ± 1.1**	**(9.8± 0.5) ± 1.1**

Comparison of DN and fission data

- *It is interesting to note that similar result was obtained in CERN experiment by C. Rubbia group for ~ 6 tons ^{nat}U target with fully thermalized neutron spectrum and $\boldsymbol{k_{eff}}$ ~ 0.9*

Main result of the FEAT experiment
(S. Andriamonje et al.,CERN/AT/94-45(ET))

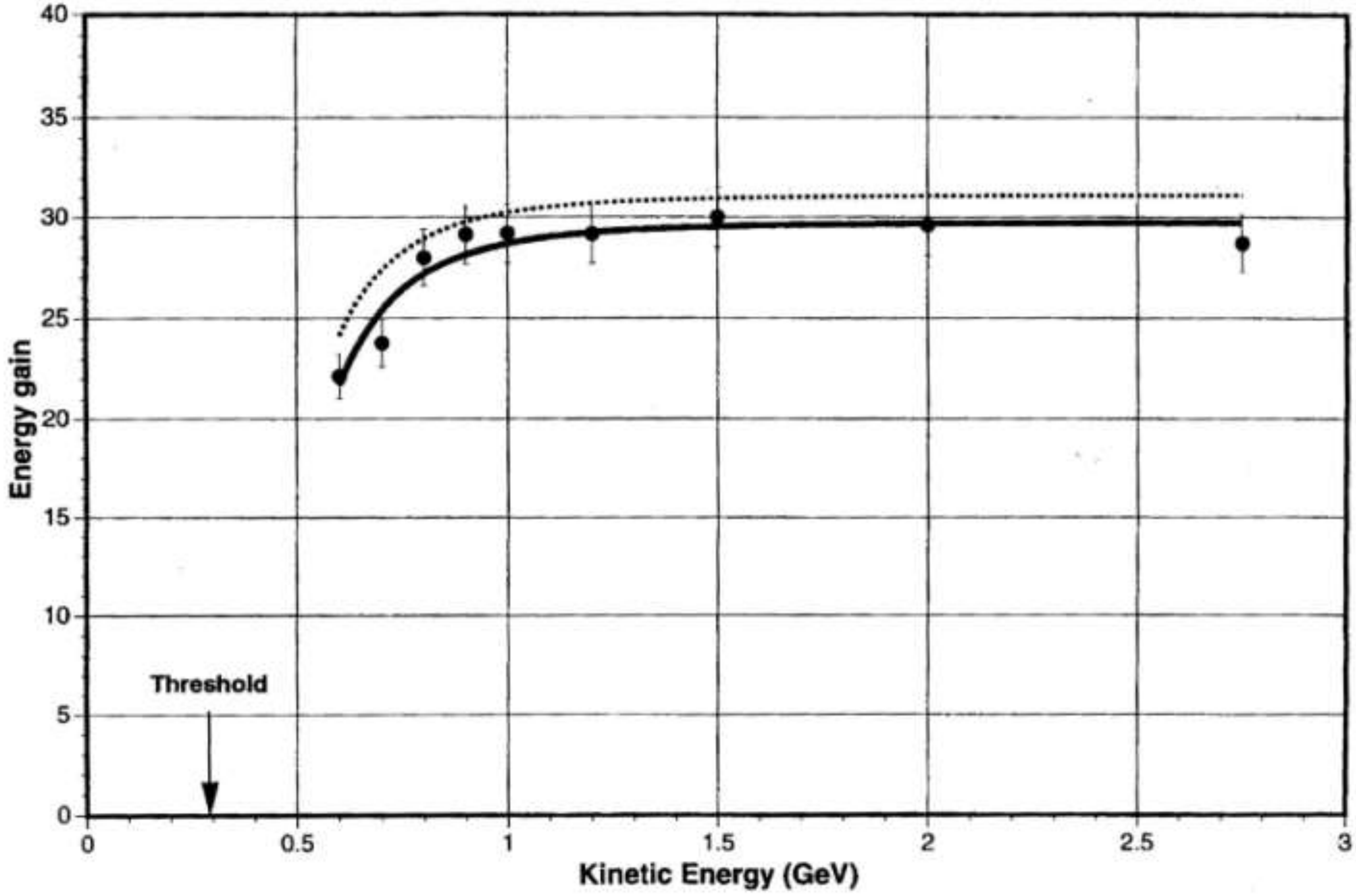
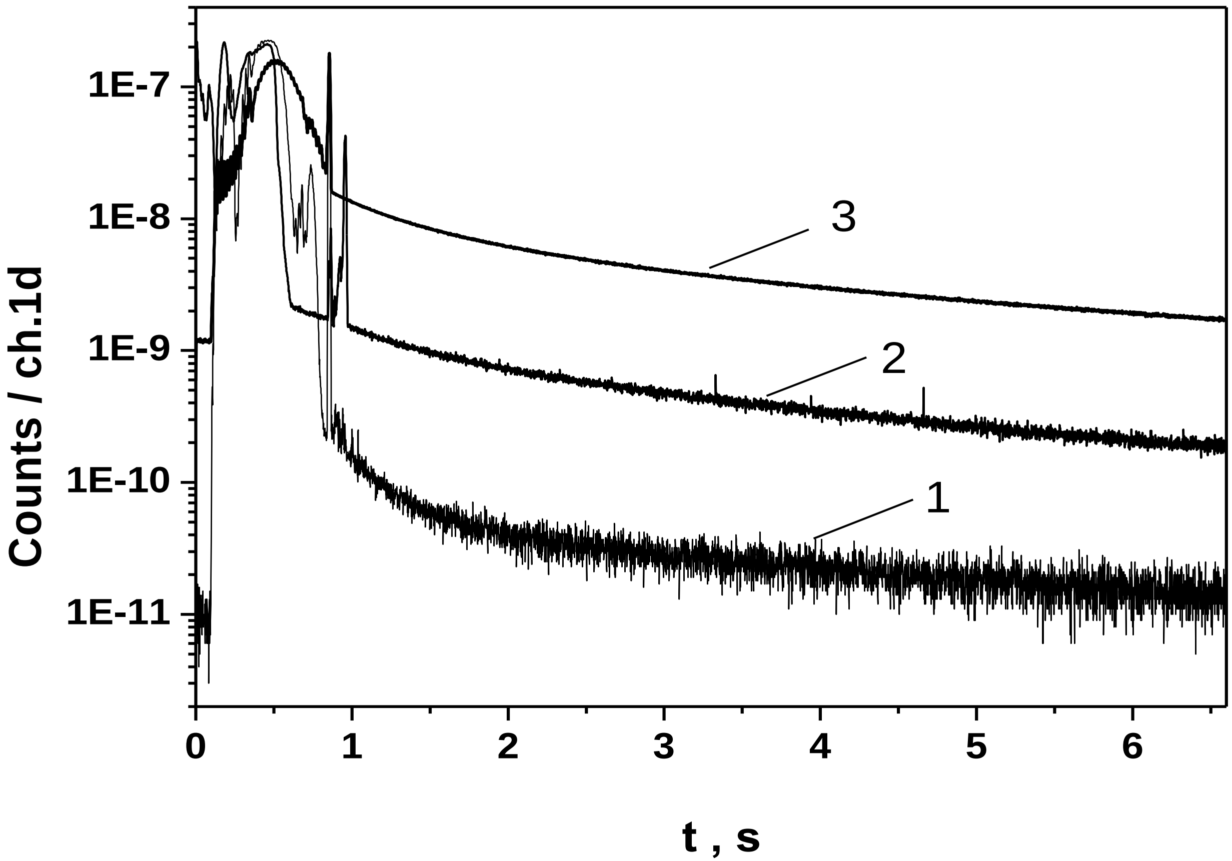


Figure 7

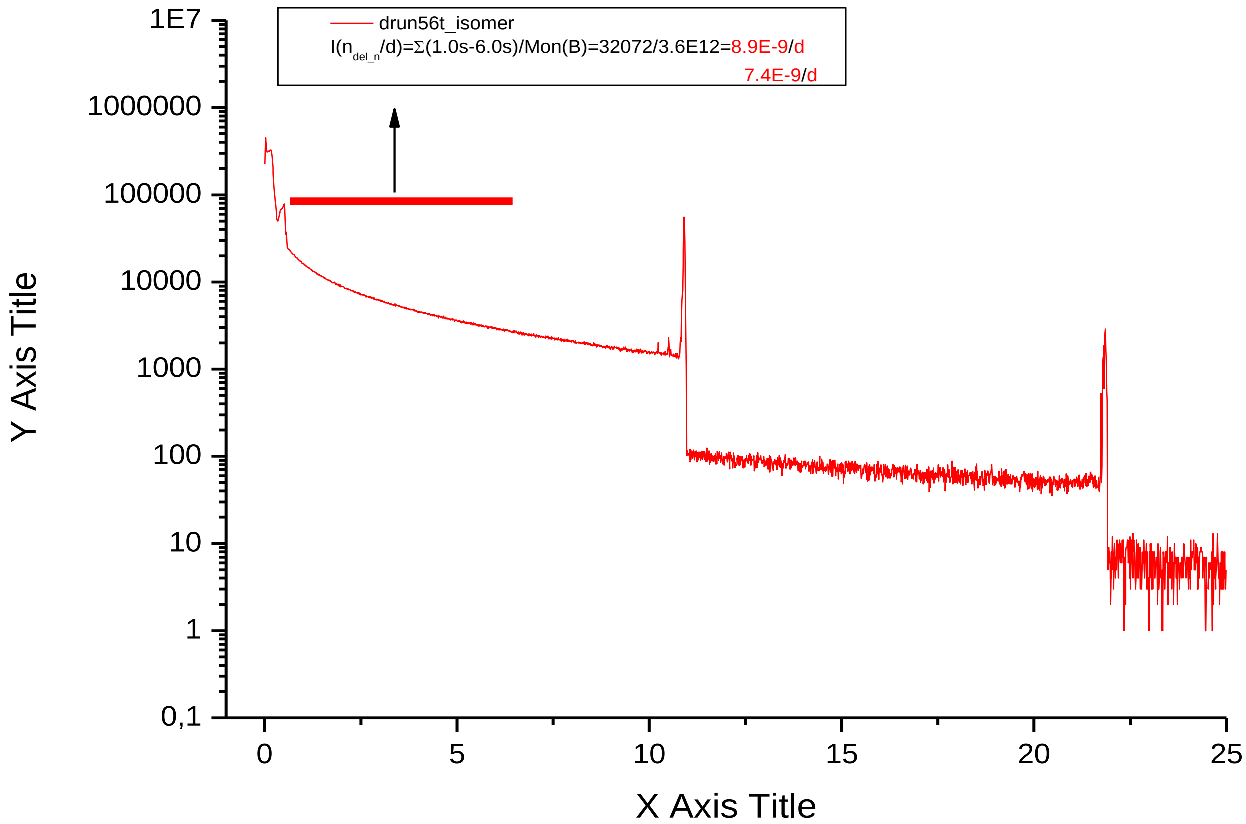
Neutron time spectra measured in June 2009



The time dependence of the neutron yield from the geometrically identical lead and uranium targets. 1 - (Pb+d) for E_d = 4 GeV; 2 and 3 (U+d) for E_d = 1 and 4 GeV.

Neutron time spectrum

E_d= 6 GeV, (T = 11 s, ΔT= 0.25 s), total DN yield I = (7.8±0.6)·10^{-9}/d



Comparison of DN and fission data

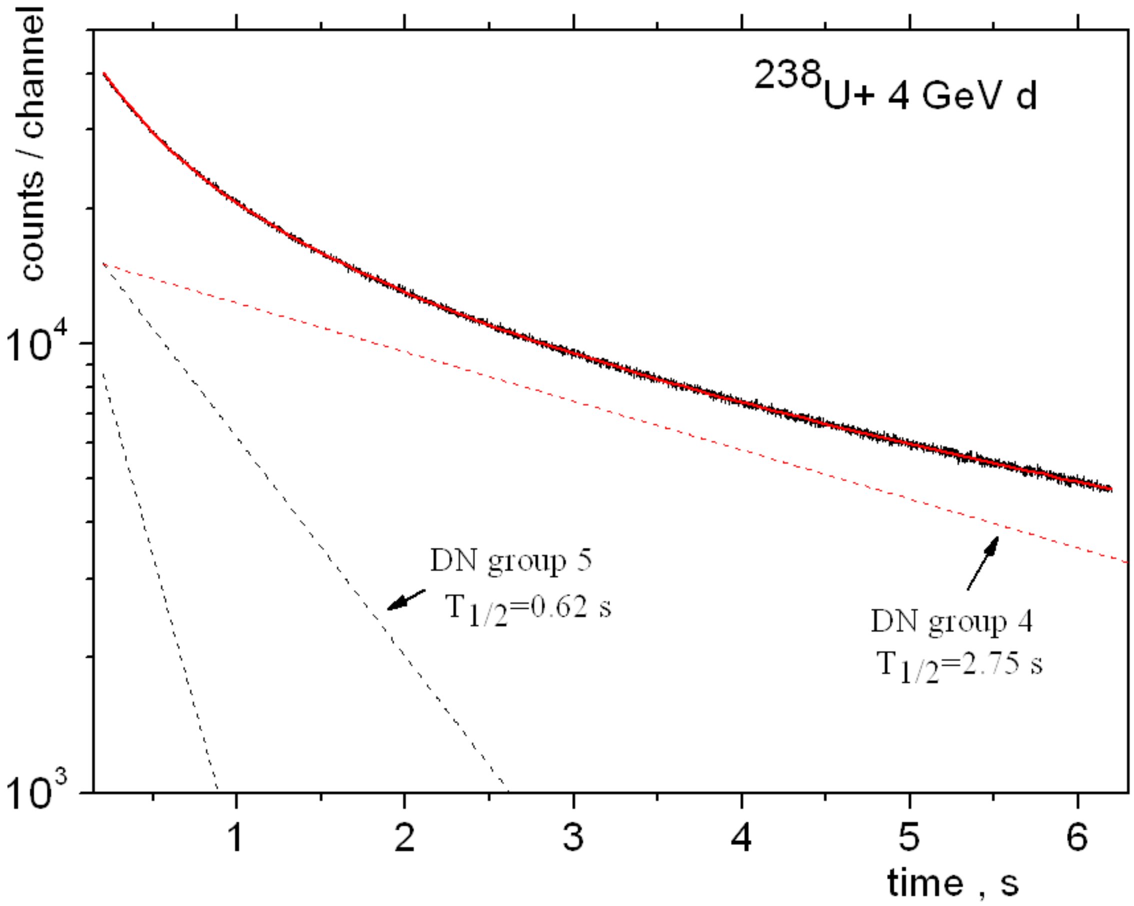
Run	1 Gev	2 GeV	4 GeV	6 GeV	8 GeV
SSTD					
03.12	8.8 ±**1.5**		8.4 ±**1.5**		9.3 ±**1.6**
03.11		11 ±**1.9**	9.4 ±**1.7**	9.6 ±**1.7**	
Activ.M					
03.12	9.6 ±**1.6**		8.8 ±**1.3**		9.8 ±**1.6**
DN					
03.12	11 ±**0.7**		10.3 ±**0.7**		14 ±**1.1**

V.G ~ 30

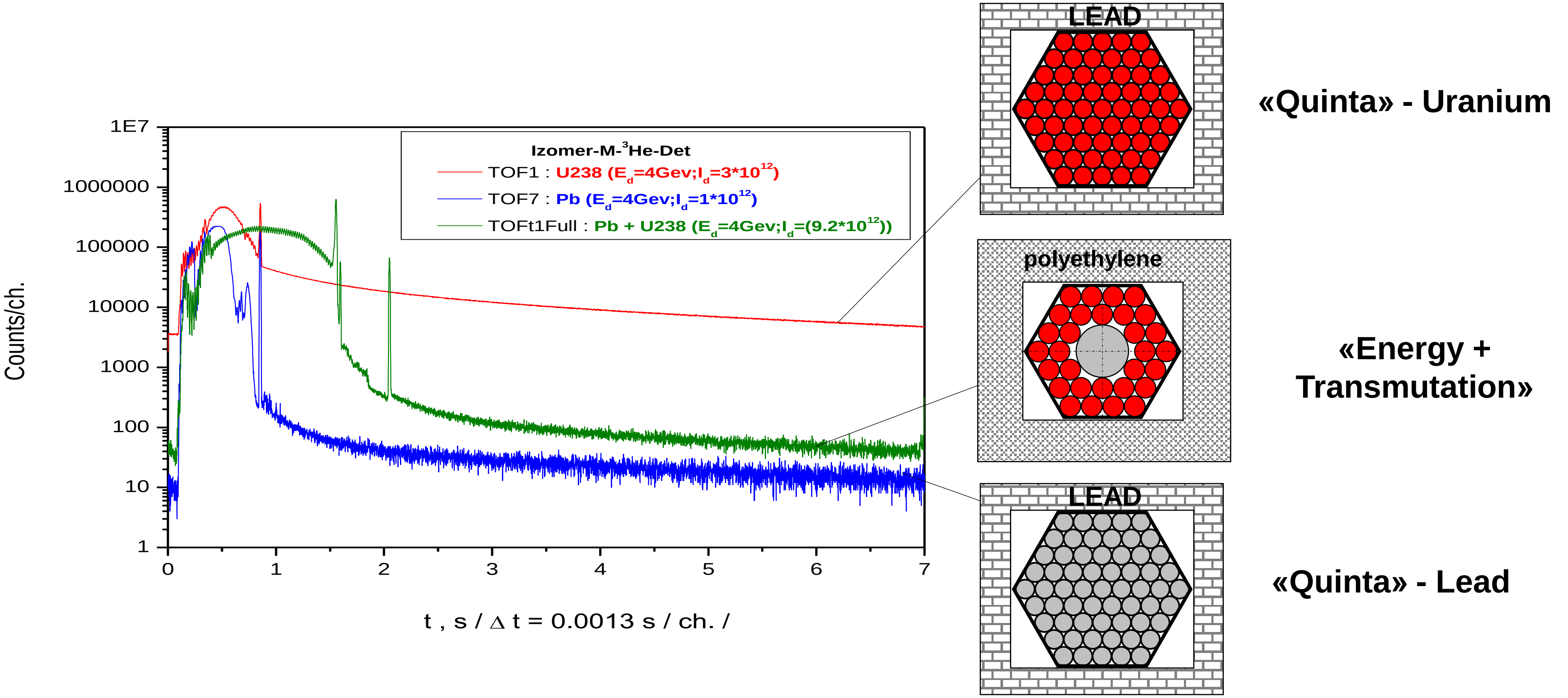
Comparison of DN and fission data

- ***The DN time spectra were obtained for three target assemblies irradiated by deuterons with energy 1, 2, 4, 6 and 8 GeV.***
- ***In parallel it was measured the spatial distributions of fission rates inside of uranium targets.***
- ***If total fission numbers (per one deuteron and 1 Gev) are constant in limits of experimental errors so similar relative DN total yields shows in contrast a slight increase. An essential increase of this yield observed in June 2009 could be caused by deficiency in monitoring of deuteron fluxes as it became clear now.***
- ***Difference in incident energy dependence of DN relative yields and total fission numbers is the subject for further experimental and theoretical study.***

Group analysis of DN time spectra

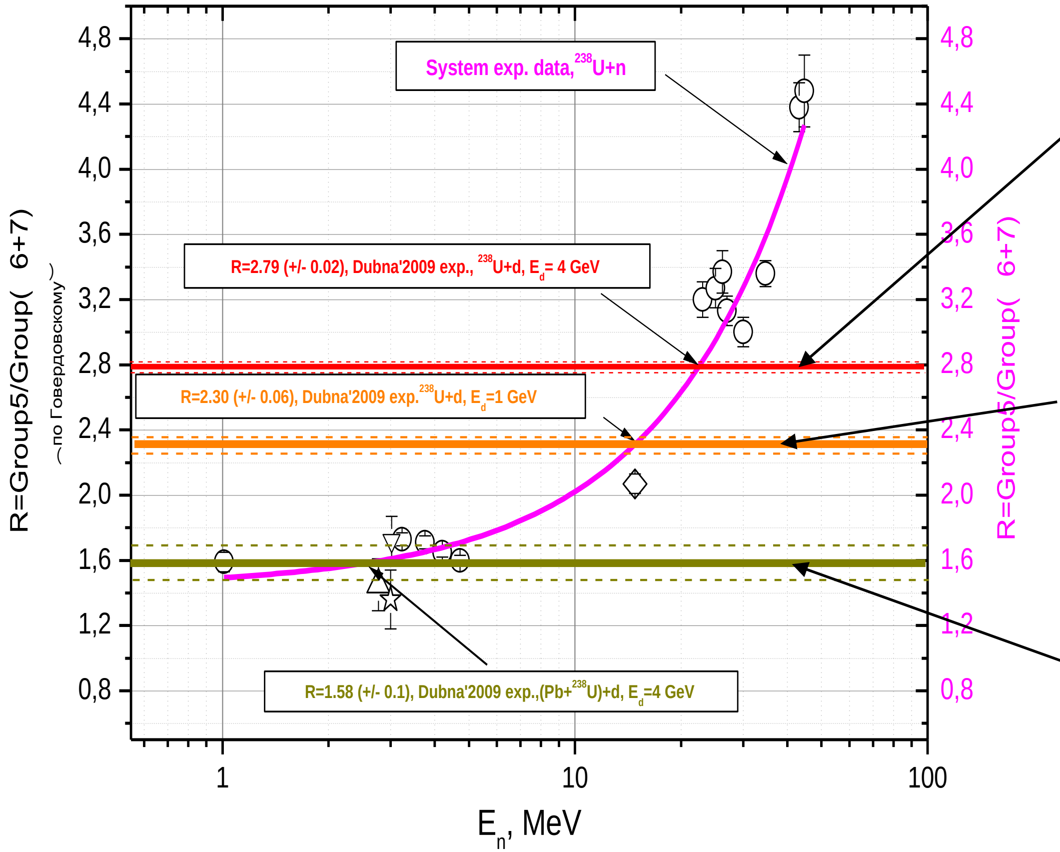


DN time spectra measured in June and November 2009



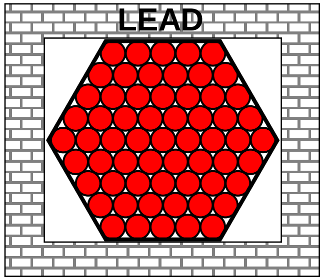
The time dependence of neutron yields from different target assemblies for E_d = 4 GeV.

Results of DN spectra analysis of June and November 2009 data



«Quinta» - Uranium

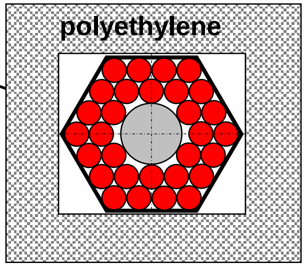
E_d = 4 GeV → $E_{n,f}$ ~ 25 MeV



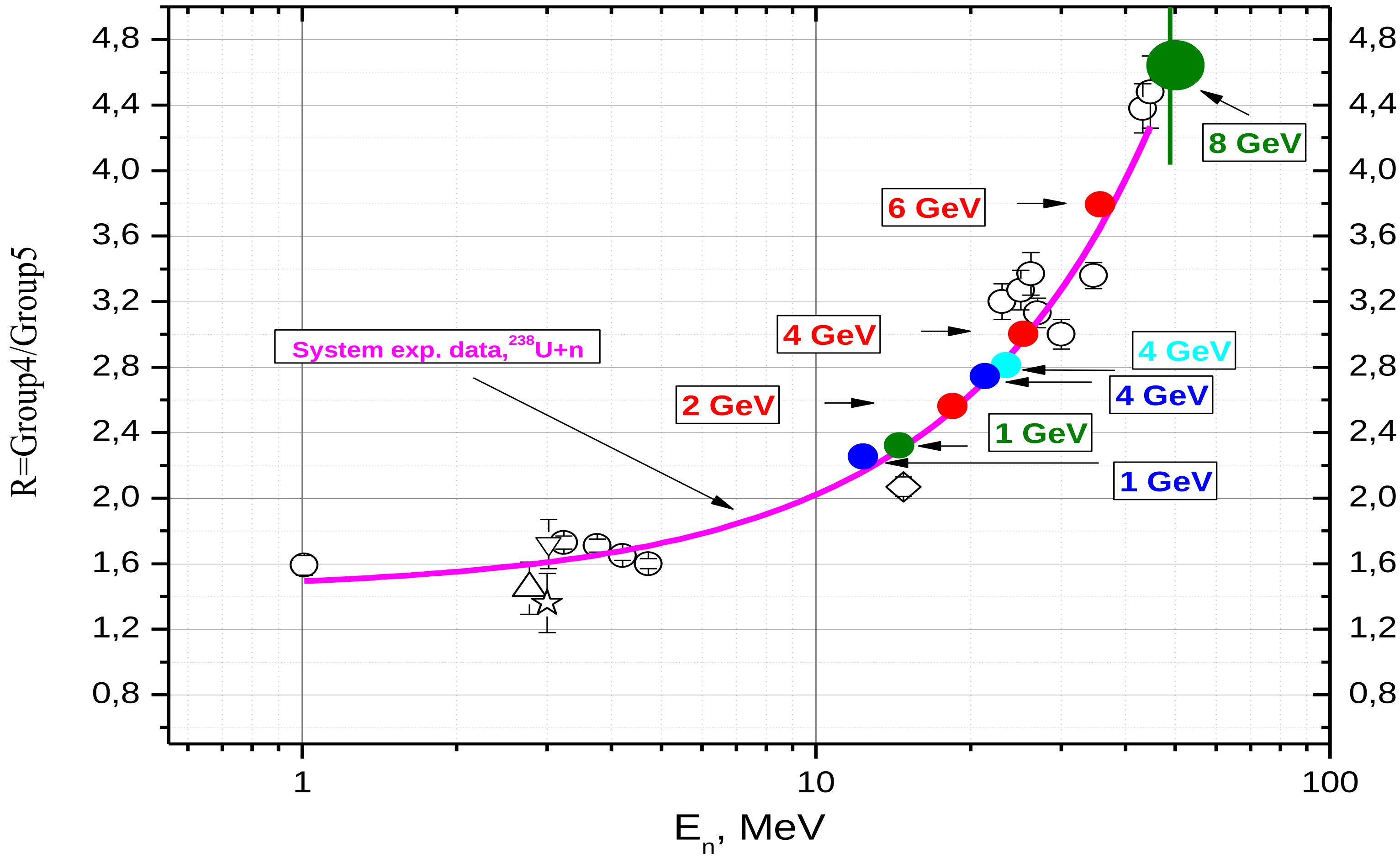
E_d = 1 GeV → $E_{n,f}$ ~ 15 MeV

«Energy + Transmutation»

E_d = 4 GeV → $E_{n,f}$ ~ 3 MeV



Comparison of neutron energy dependence of the weight ratios of 5-th to (4+3-th) DN groups from ^{238}U(n,f)-reaction and similar values extracted from DN time spectra measured in present work.



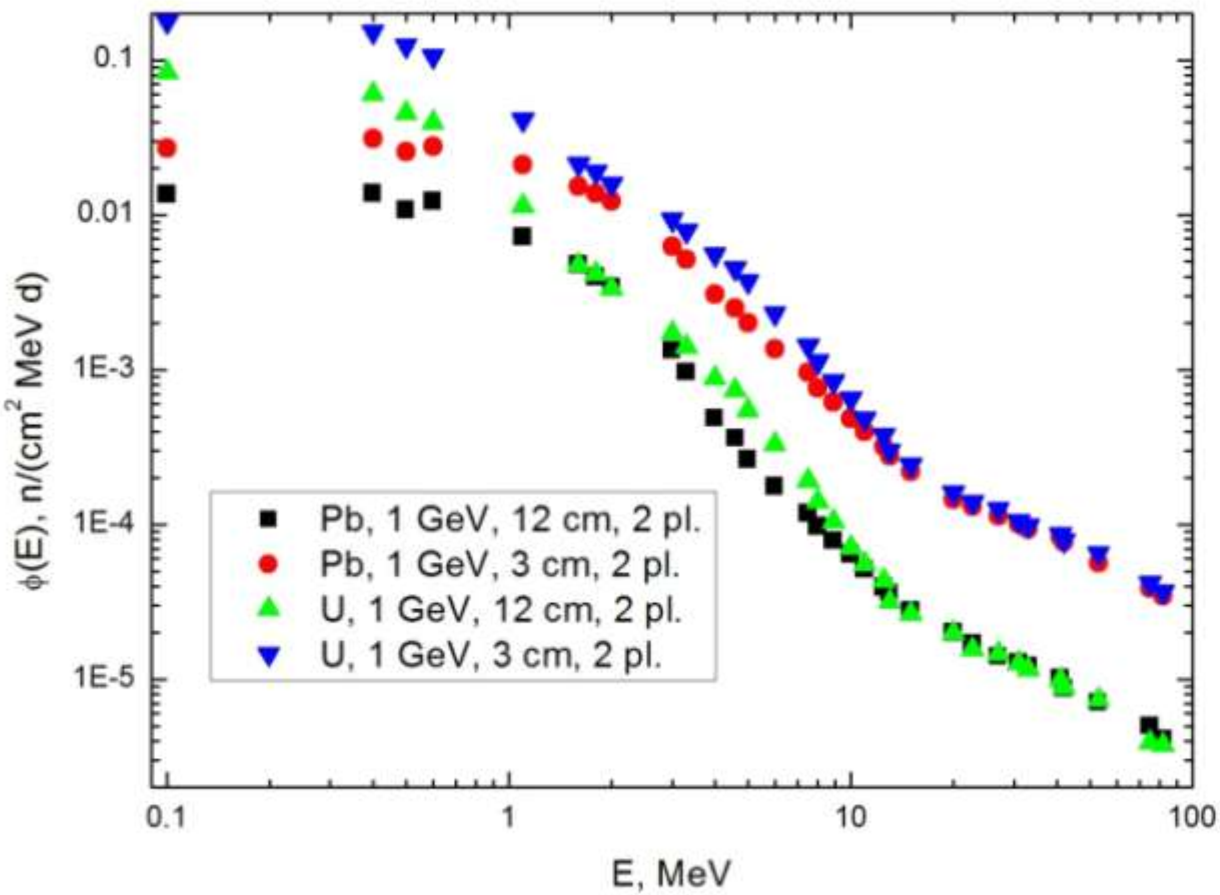
• - June 2009, • - March 2011, • - December 2011, • - March 2012

Analysis of DN time spectra

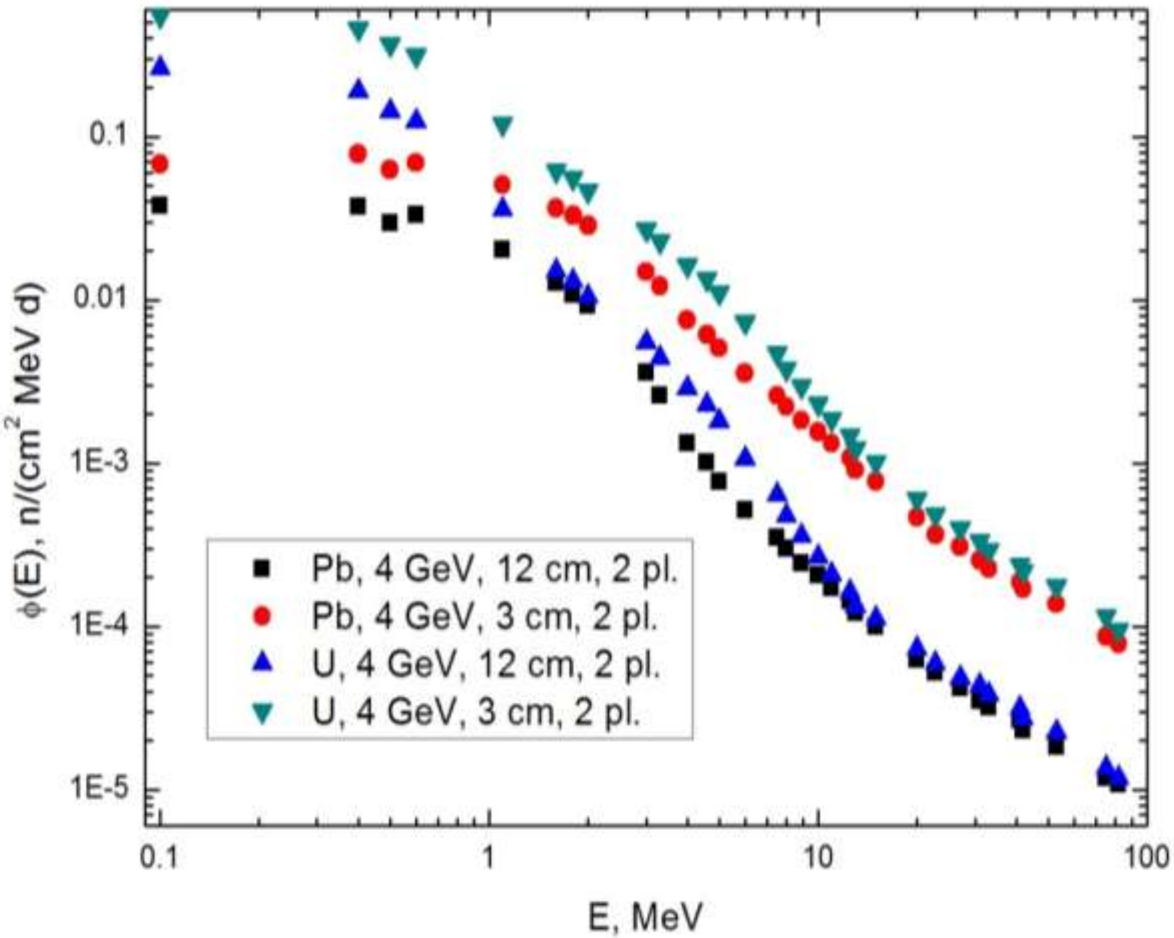
- *"Mean neutron energy" <En> inducing fission of ^{238}U that extracted from analysis of DN time spectra shows essential growth with increase of incident deuteron energy.*

- *<En> = (13 ± 3) MeV at Ed = 1 GeV*
- *<En> = ~ 40 MeV at Ed = 8 GeV*
- *Reason for this should be studied more*

Neutron energy spectra obtained in June 2009



Neutron energy spectra obtained in June 2009



Neutron energy spectra

- ***Obtained data for spatial distribution of neutron spectra and fluxes as well as main features of leakage neutrons should be a subject of subsequent analysis***

- ***It is planned to carry out of theoretical analysis of whole set of the obtained data aimed at verification and modification INC models in MC transport codes.***

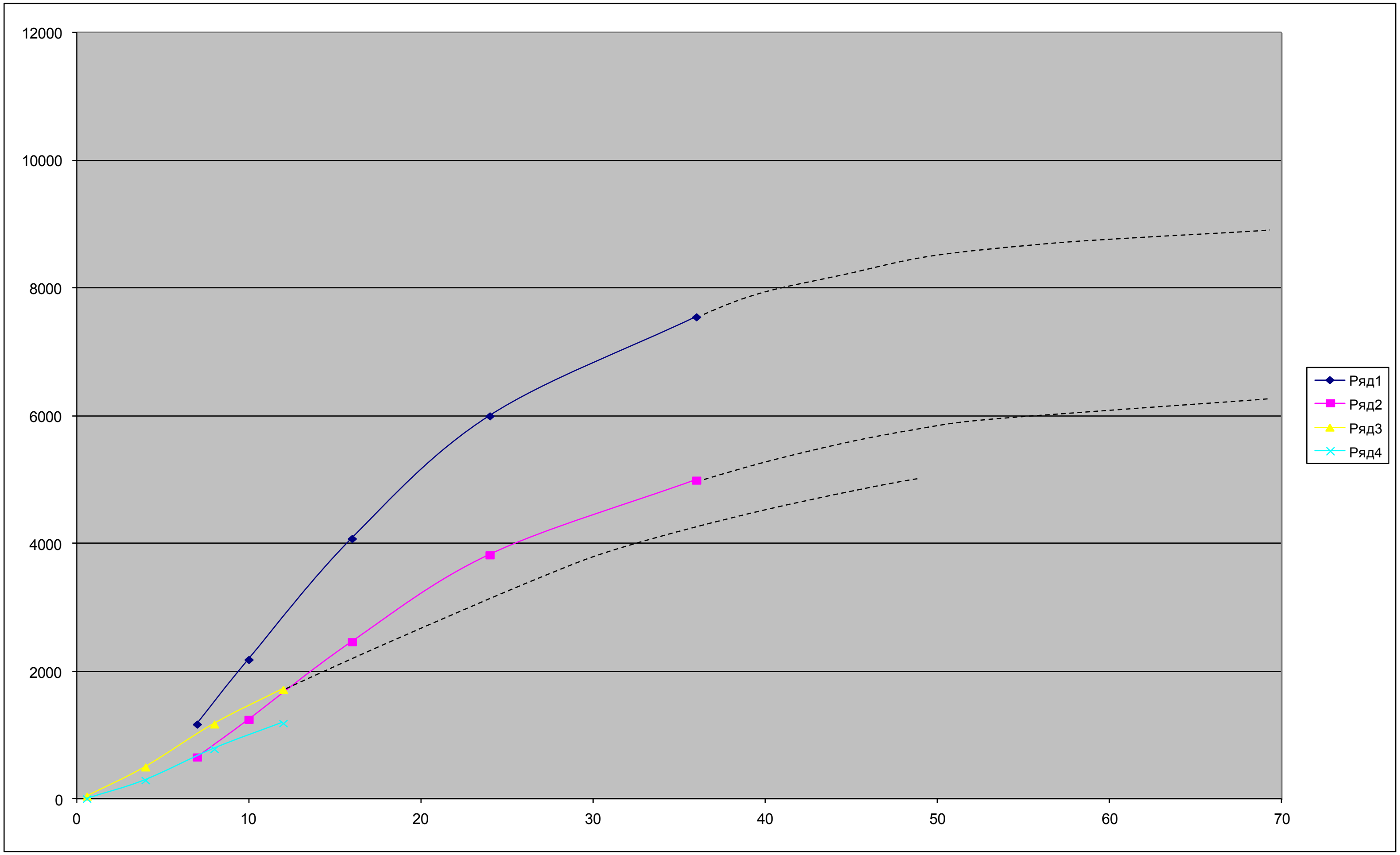
Reaction rates

I *x10(-27)*

1/s/GeV

Dec. 2011

E_{sh} MeV r cm	Ed = 1 GeV *I*	Ed = 4 GeV *I*	Ed = 8 Gev *I*
0.35			
4	59.2	97	73
12	214	453	201
34	678	687	292
11.05			
4	33	24	29
12	46	45	40
34	52	57	59
54.75			
4	11	7	7
12	12	12	14
34	14	15	15


12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
Ряд1
Ряд2
Ряд3
Ряд4

Thanks for your attention

Discussion of results

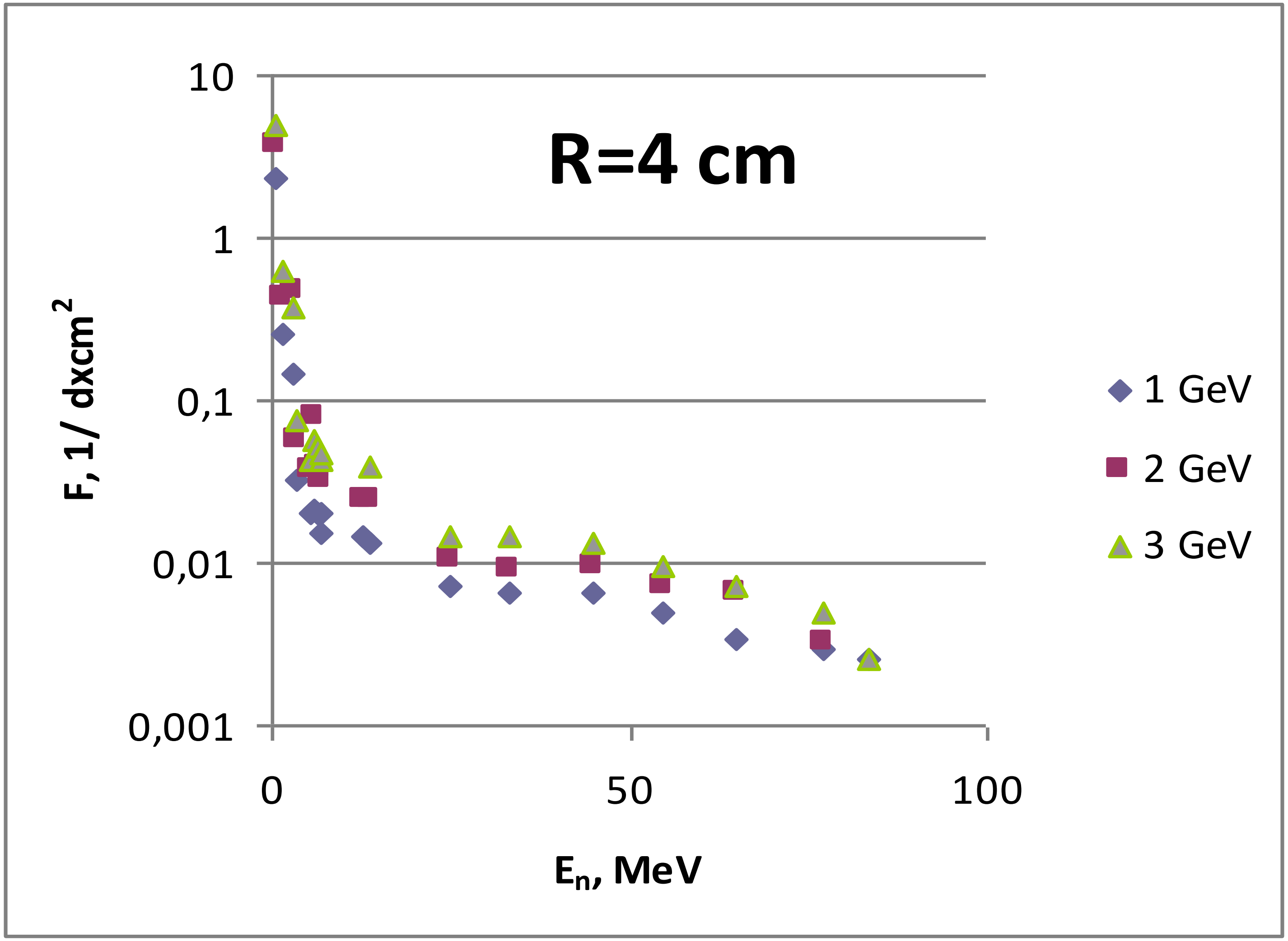
Number per one deuteron

Ed	0,66 GeV *(Vassil'kov et al)*	2 GeV	4 GeV	6 GeV
^{239}Pu production	46 4	17 1,7	30 3,0	45 4,5
$^{238}U(n,f)$	18,5 1,7	21 3,6	36 3,6	54 5,4
$^{238}U(n,f)$		20.4 3,8 2	32 6 3.2	44 7 4.4
DN relative yield normalized to fission data at 2 GeV		20 ± 1.4	69 ± 4.9	120 ± 8.4

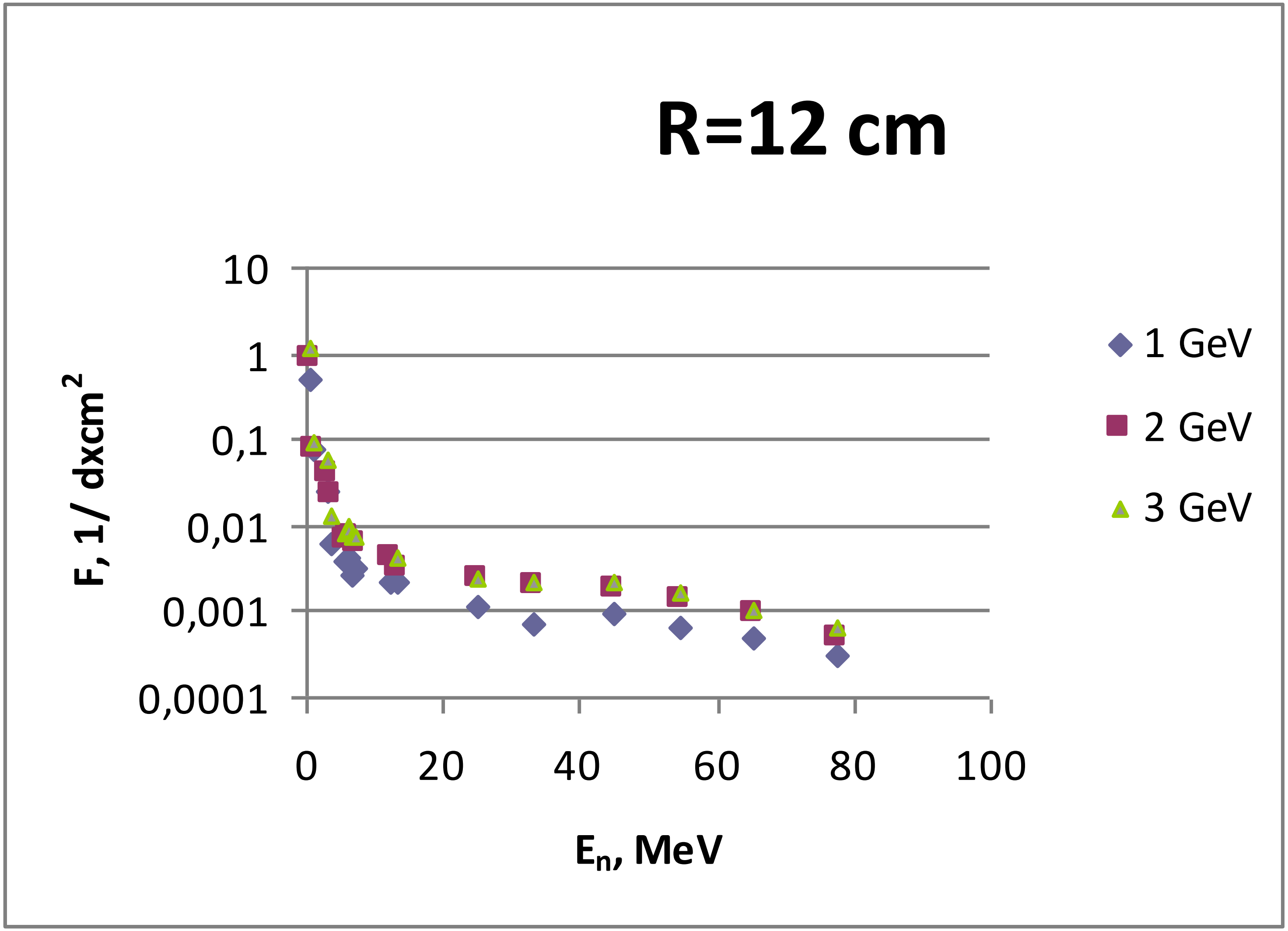
Analysis of neutron energy spectra

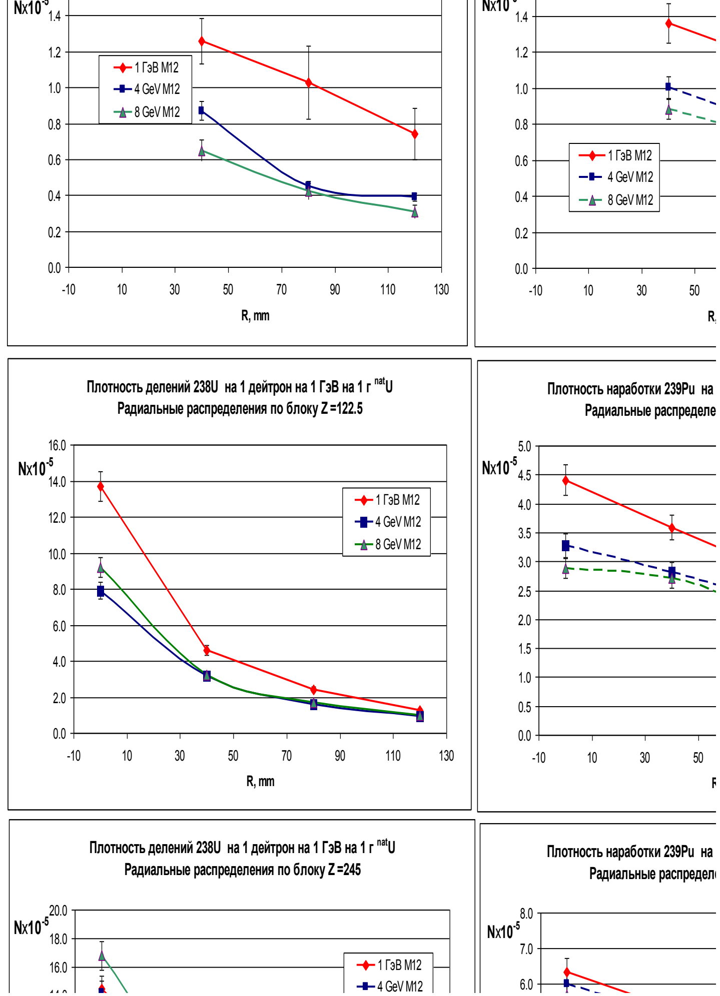
- The comparison of these total neutron spectra demonstrates the pronounced contribution of prompt fission neutrons for the uranium target in the energy range (1 – 10) MeV
- Role of these neutrons is more important for the central zone of the target than for peripheral regions of the target
- This effect becomes more pronounced with increasing incident deuteron energy
- More detailed analysis of obtained neutron spectra is a subject of following work

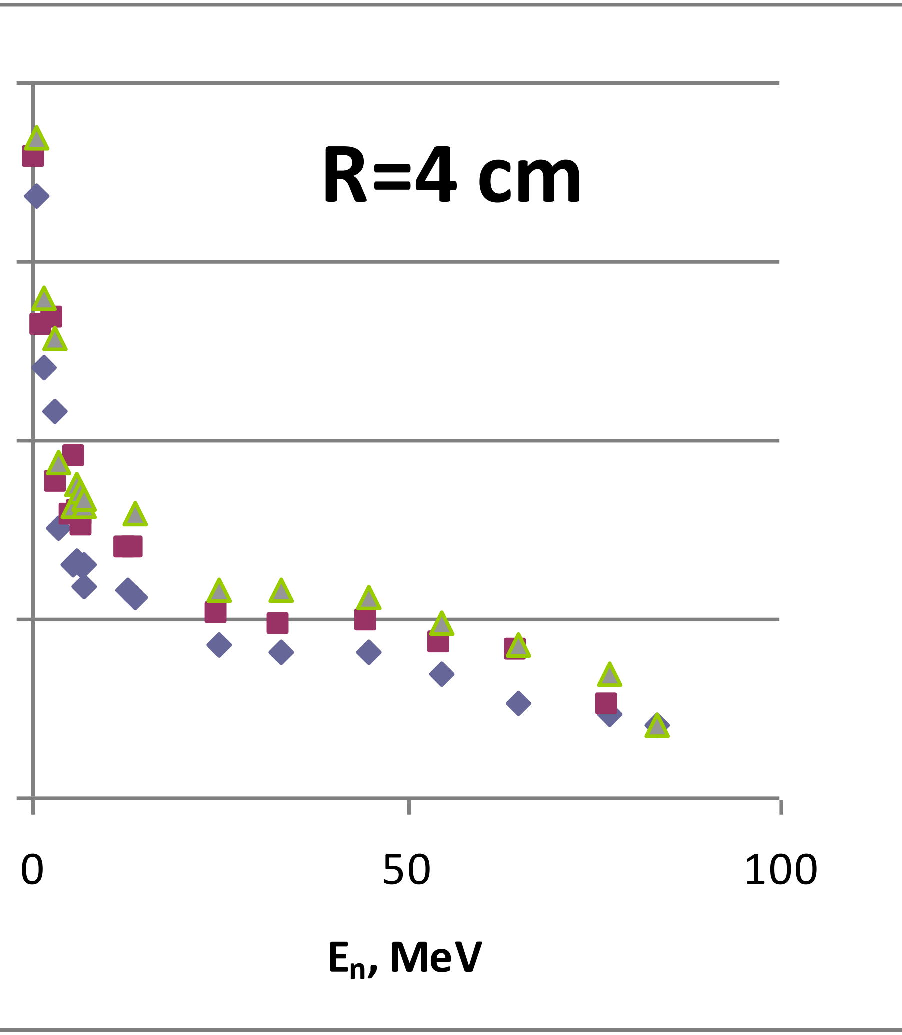
Results from threshold activation detectors (March 2011)

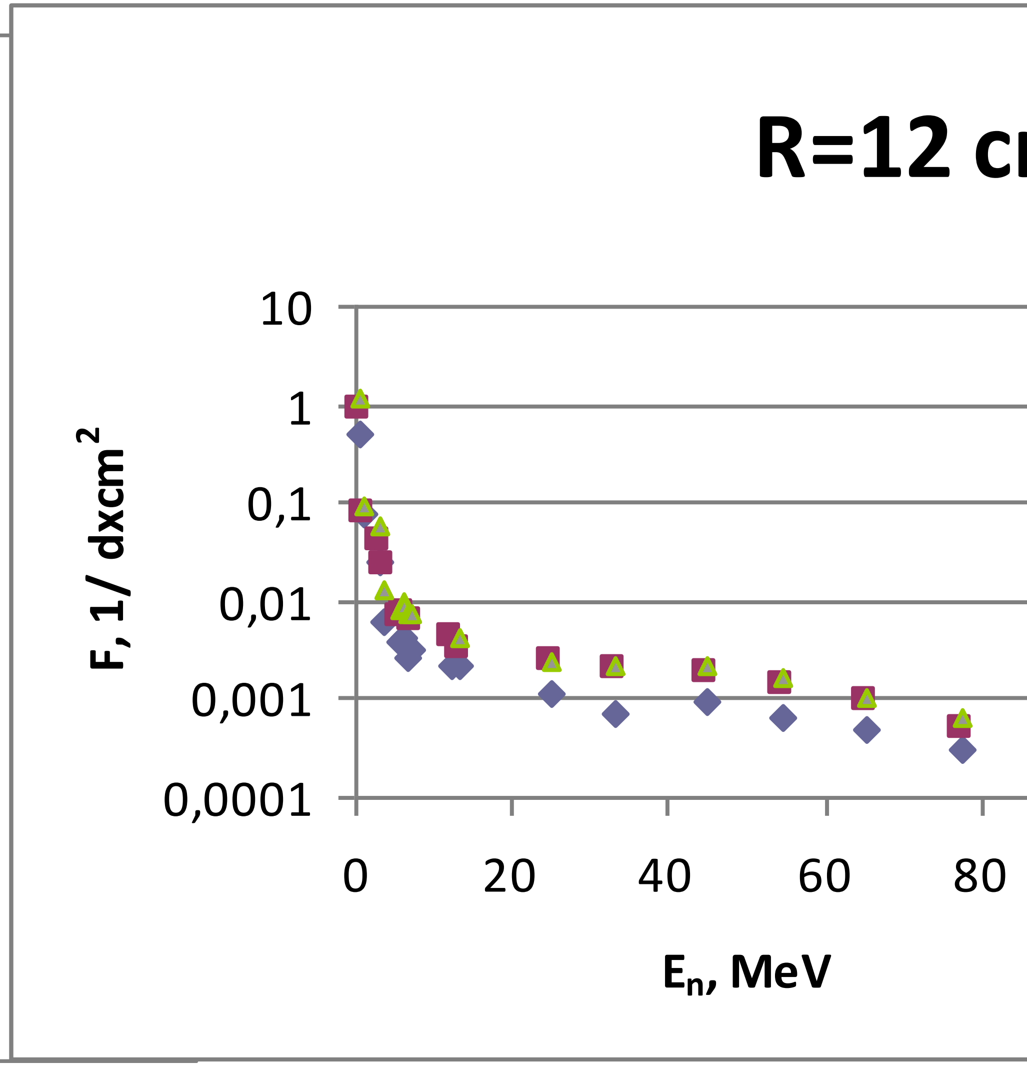


Results from threshold activation detectors (March 2011)




Nx10^-5
1 ГэВ М12
4 GeV M12
8 GeV M12
R, mm
Плотность делений 238U на 1 дейтрон на 1 ГэВ на 1 г natU
Радиальные распределения по блоку Z =122.5
Плотность наработки 239Pu на
Плотность делений 238U на 1 дейтрон на 1 ГэВ на 1 г natU
Радиальные распределения по блоку Z =245
Плотность наработки 239Pu на


R=4 cm
0
50
100
En, MeV


R=12 cm
10
1
0,1
0,01
0,001
0,0001
F, 1/ dxcm2
0
20
40
60
80
En, MeV

Preliminary results on DN yields (per deuteron and 1 GeV) from QUINTA target assembly

Number per one deuteron		E_d 1 GeV	E_d 2 GeV	E_d 4 GeV	E_d 6 GeV	E_d 8 GeV
DN total yield arbitrary units	**March 2011**		**20** *(7%)*	**69** *(7%)*	**94** *(7%)*	
	March 2012	**11 (6%)**		**41 (6%)**		**111 (6%)**