The investigations of reaction rates in Th interacted with neutrons in QUINTA subcritical assembly irradiated by 2, 4, and 6 GeV deuterons.

"Energy and transmutation RAW" collaboration

Joint Institute for Nuclear Research at Dubna, Moscow region, Russia

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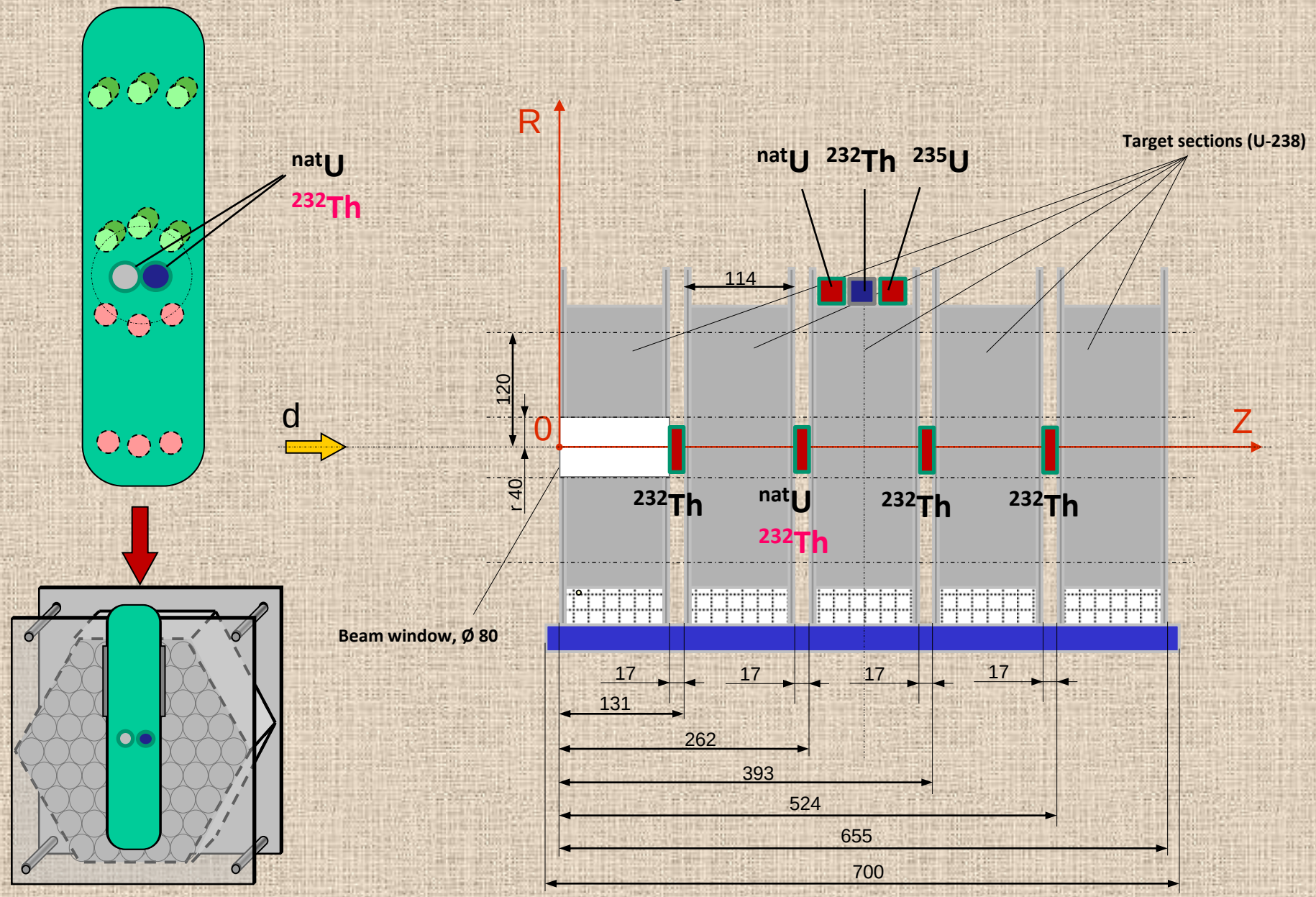
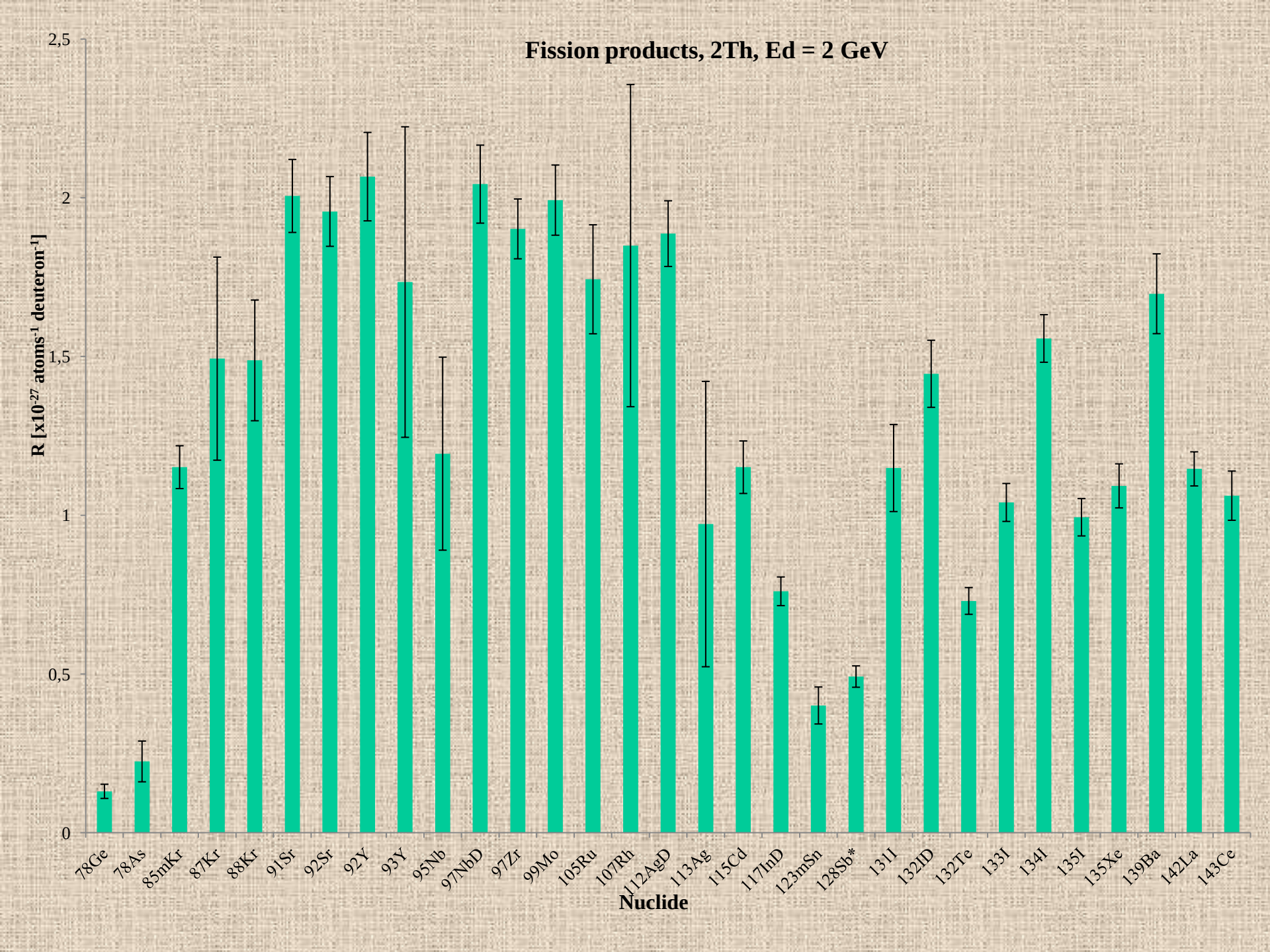
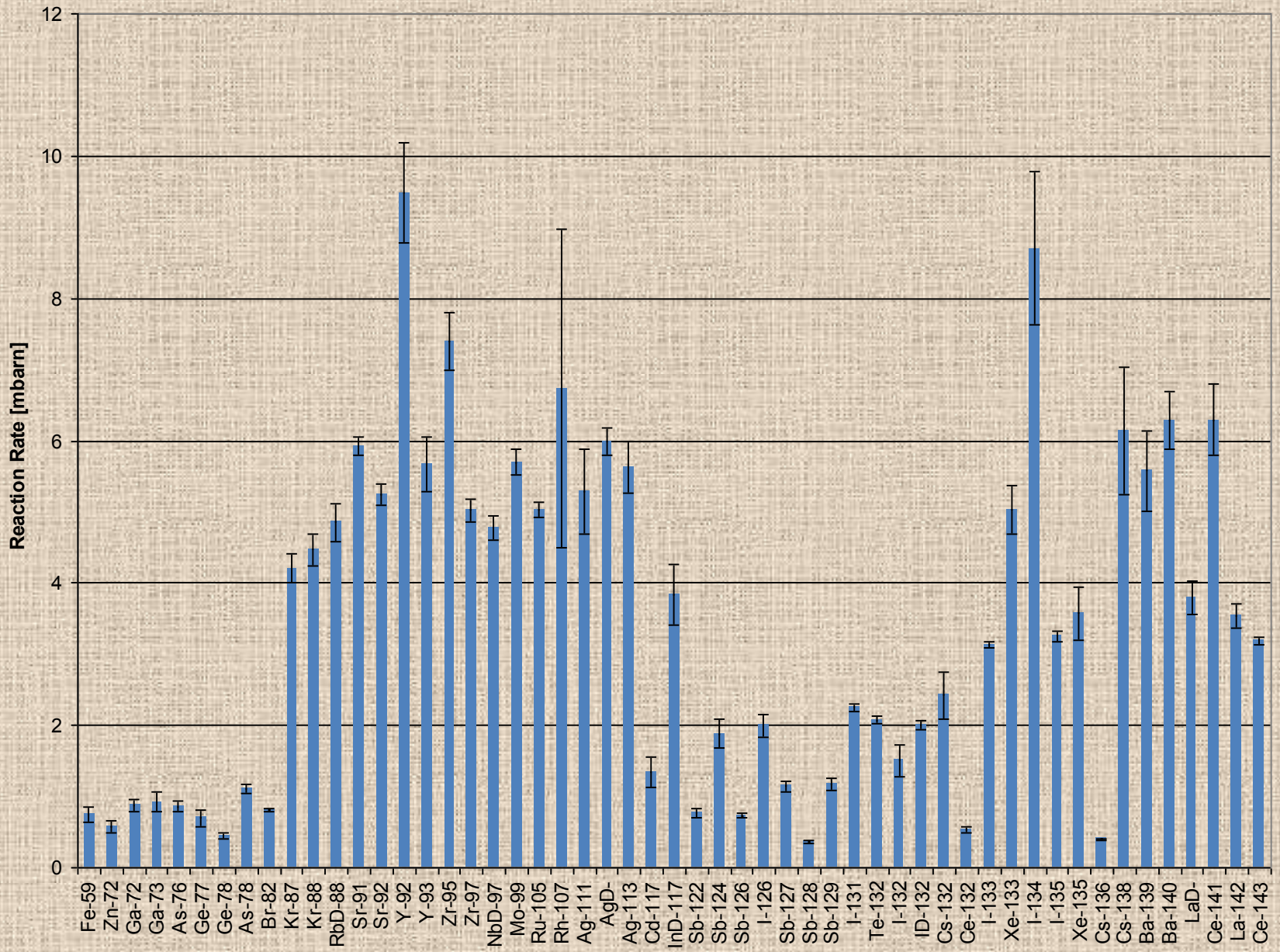
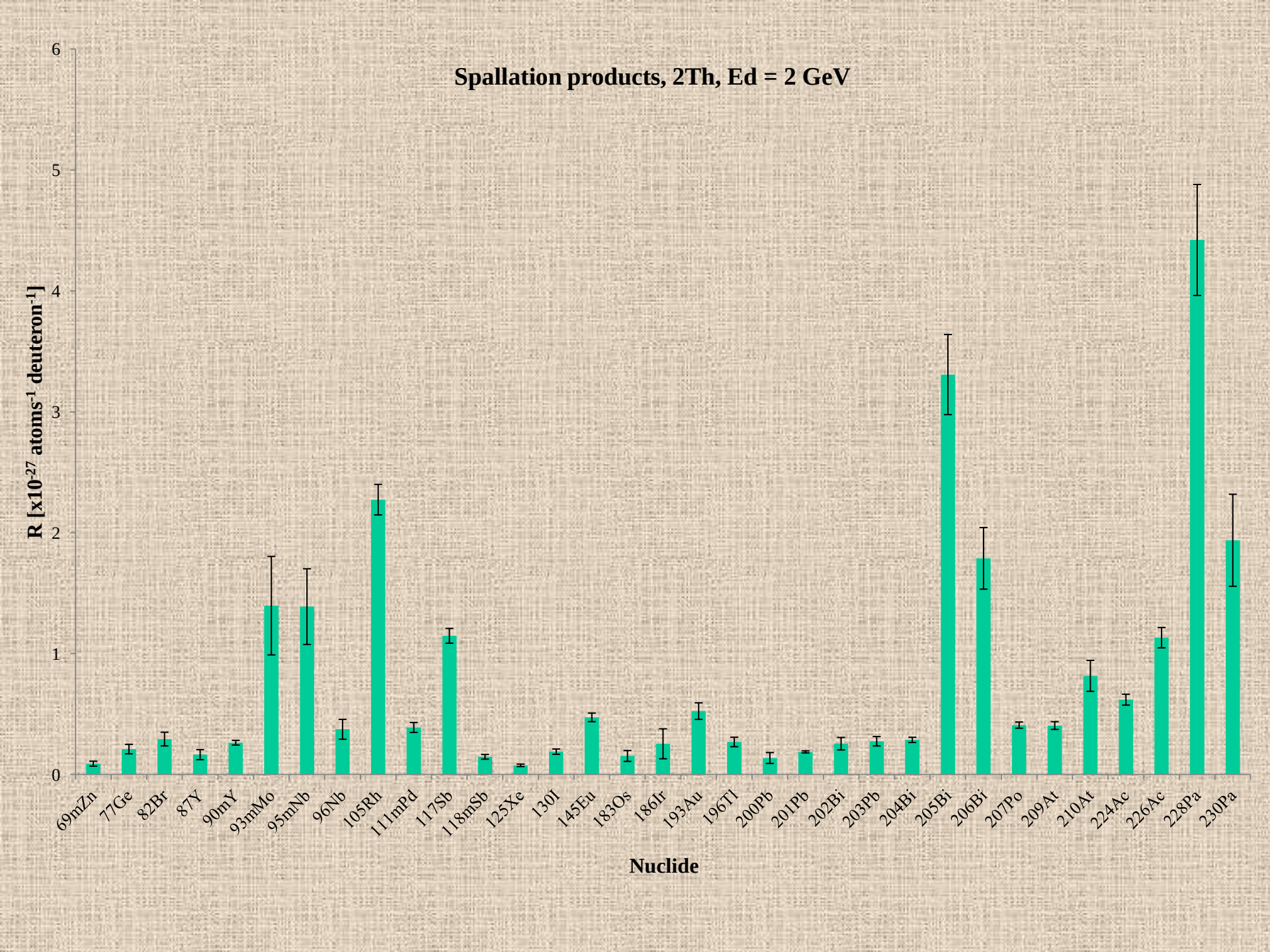
- ***Gesellschaft for Kernspektrometrie, Germany***
- ***GGS University, New Delhi, India***
- ***School of Physics University of Sydney, Australia***

«Quinta-M» target cross-cut

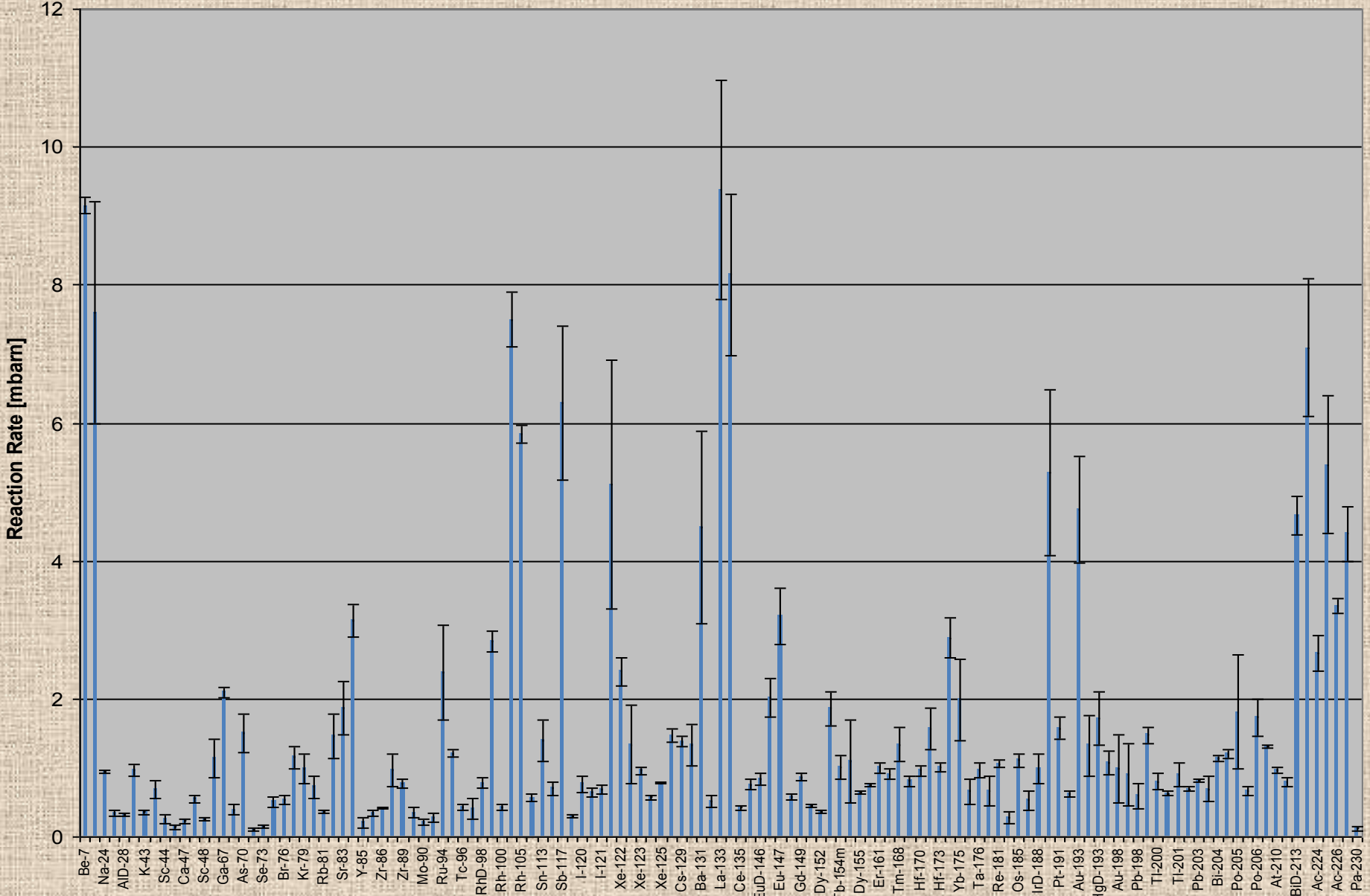


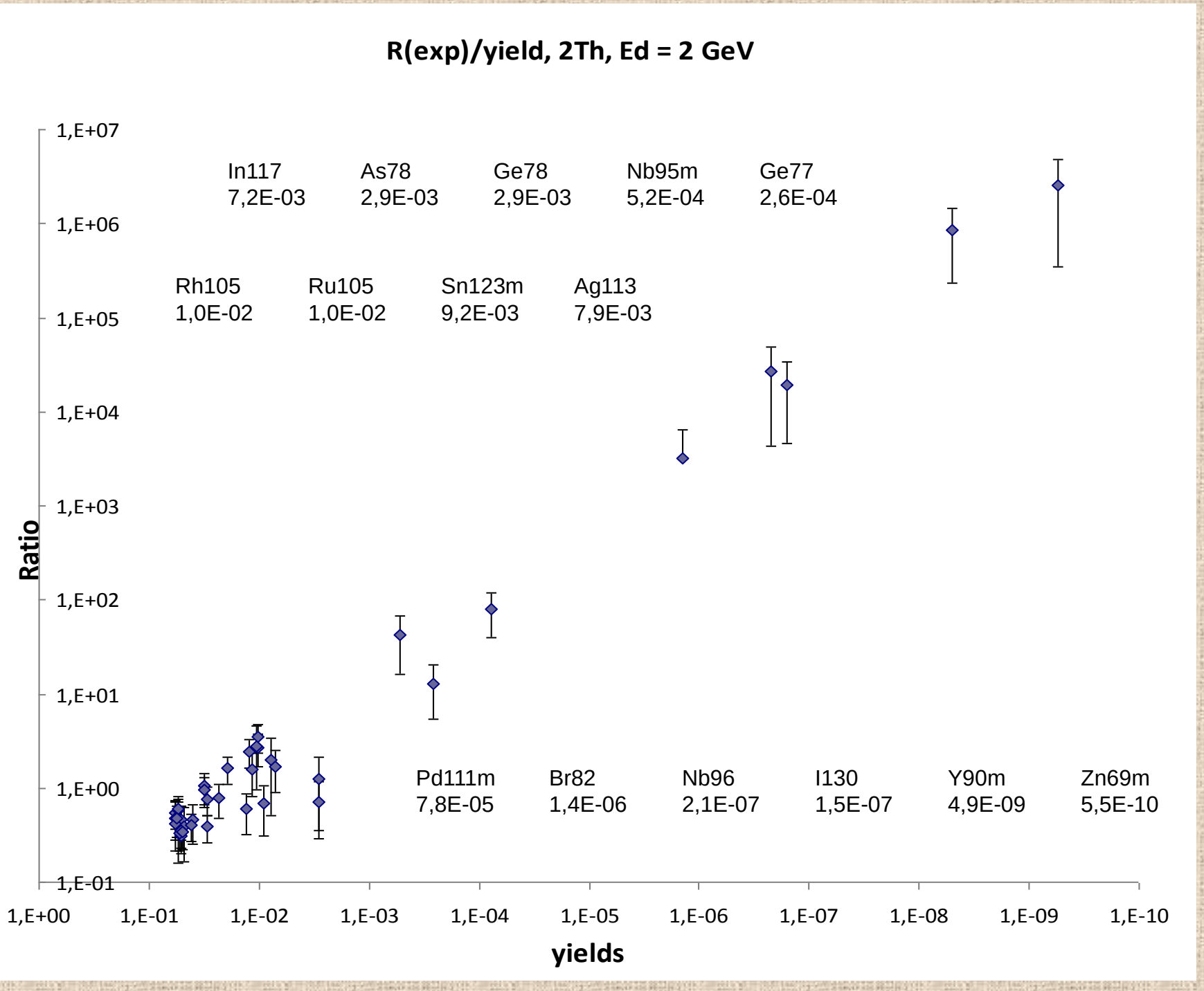

Fission products, 2Th, Ed = 2 GeV
R [x10-27 atoms-1 deuteron-1]
2,5
2
1,5
1
0,5
0
78Ge
78As
85mKr
87Kr
88Kr
91Sr
92Sr
92Y
93Y
95Nb
97NbD
97Zr
99Mo
105Ru
107Rh
112AgD
113Ag
115Cd
117InD
123mSn
128Sb*
131I
132ID
132Te
133I
134I
135I
135Xe
139Ba
142La
143Ce
Nuclide

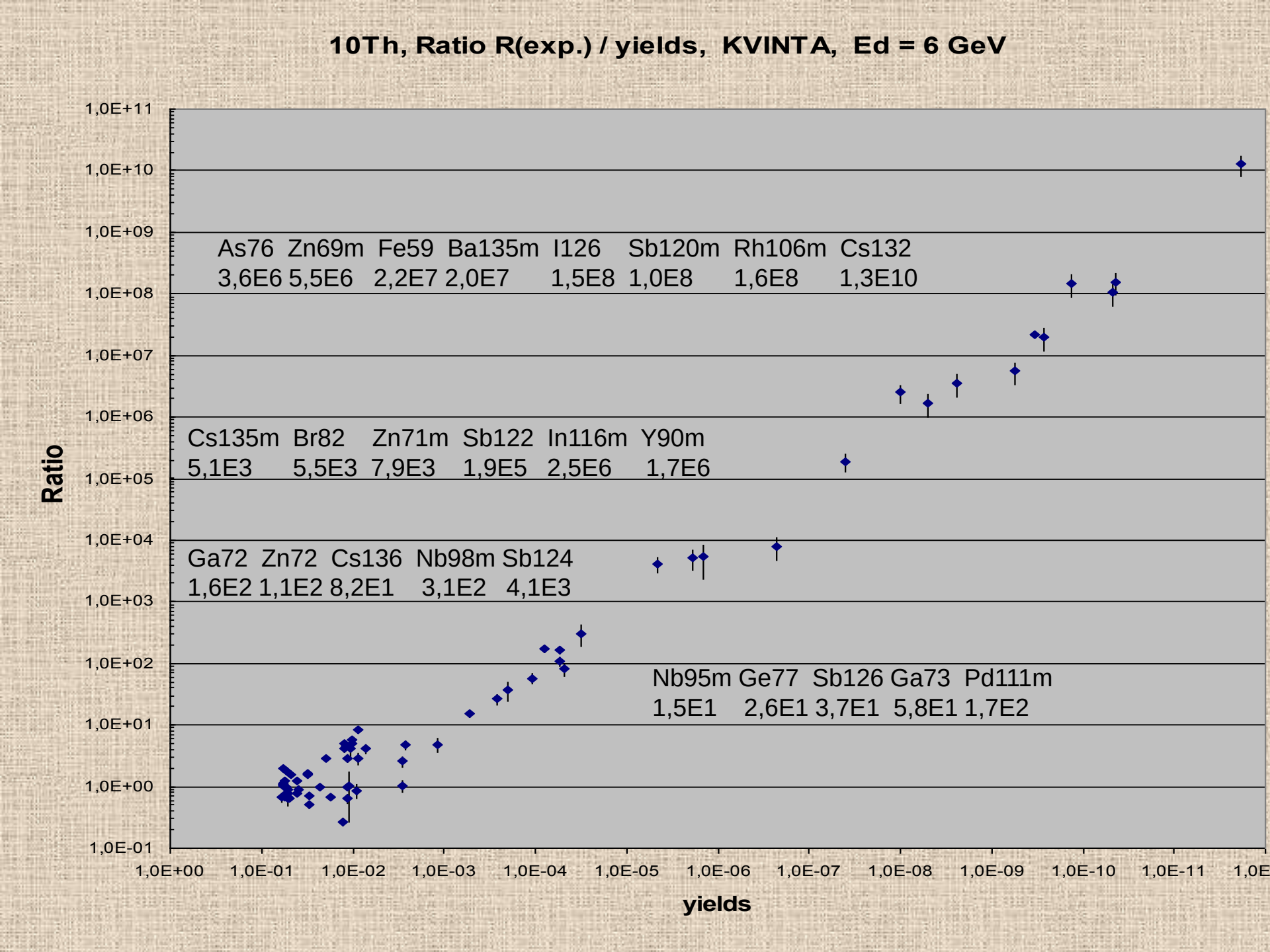

10Th, Ed = 6 GeV, FISSION
Reaction Rate [mbarn]
0
2
4
6
8
10
12
Fe-59
Zn-72
Ga-72
Ga-73
As-76
Ge-77
Ge-78
As-78
Br-82
Kr-87
Kr-88
RbD-88
Sr-91
Sr-92
Y-92
Y-93
Zr-95
Zr-97
NbD-97
Mo-99
Ru-105
Rh-107
Ag-111
AgD-
Ag-113
Cd-117
InD-117
Sb-122
Sb-124
Sb-126
I-126
Sb-127
Sb-128
Sb-129
I-131
Te-132
I-132
ID-132
Cs-132
Ce-132
I-133
Xe-133
I-134
I-135
Xe-135
Cs-136
Cs-138
Ba-139
Ba-140
LaD-
Ce-141
La-142
Ce-143

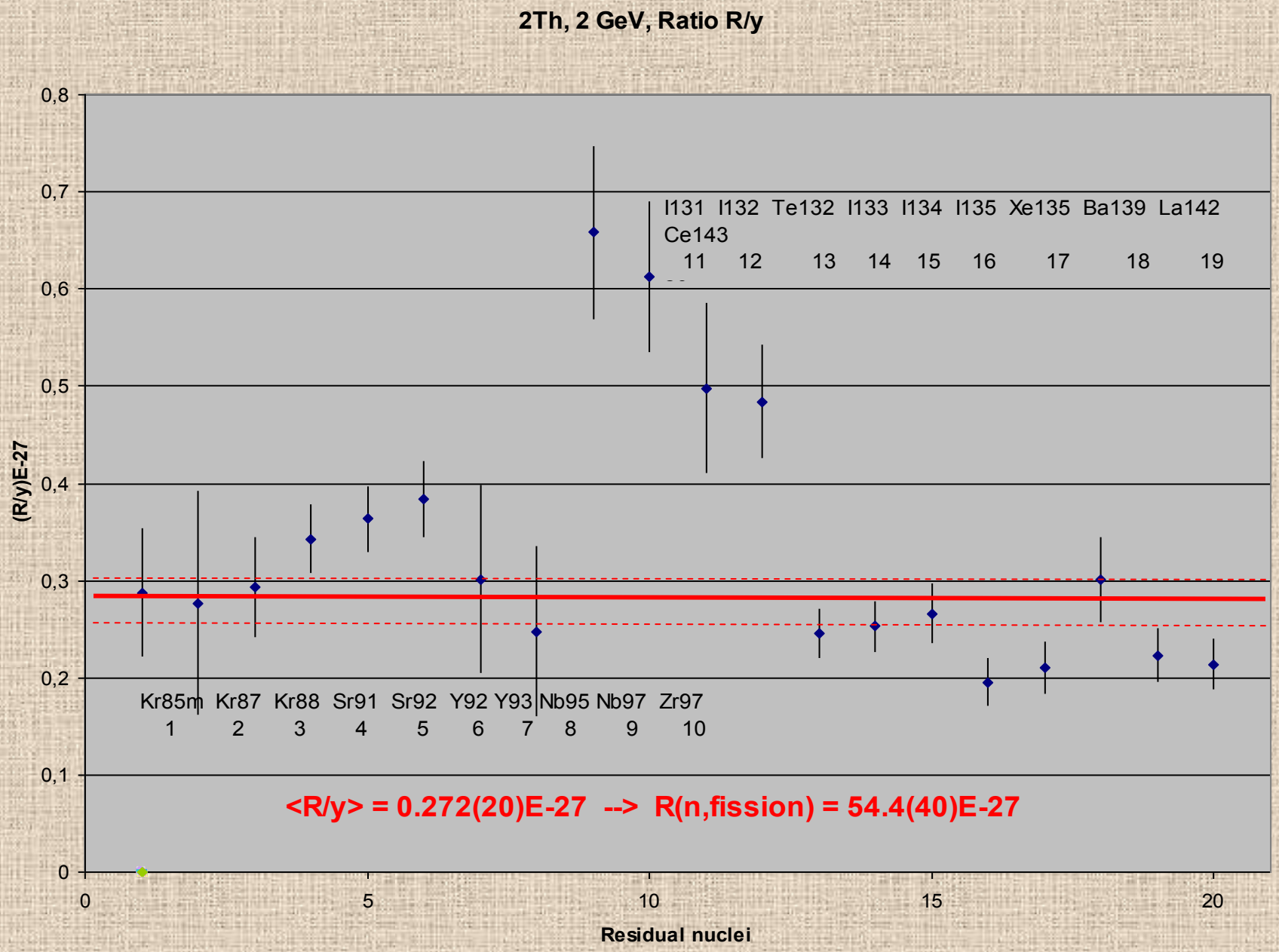

Spallation products, 2Th, Ed = 2 GeV
R [x10-27 atoms-1 deuteron-1]
0
1
2
3
4
5
6
69mZn
77Ge
82Br
87Y
90mY
93mMo
95mNb
96Nb
105Rh
111mPd
117Sb
118mSb
125Xe
130I
145Eu
183Os
186Ir
193Au
196Tl
200Pb
201Pb
202Bi
203Pb
204Bi
205Bi
206Bi
207Po
209At
210At
224Ac
226Ac
228Pa
230Pa
Nuclide

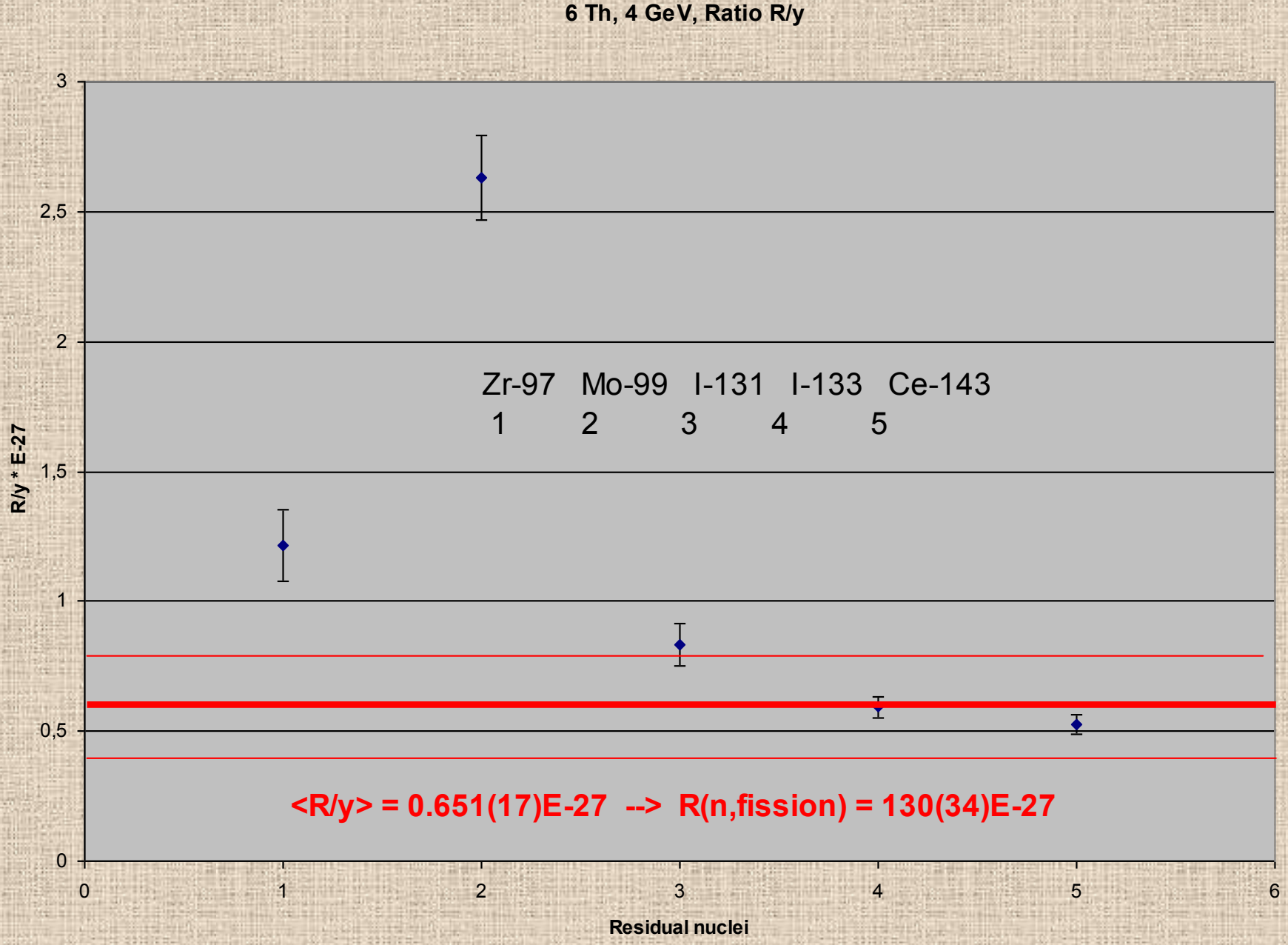
10Th, Ed = 6 GeV, SPALLATION

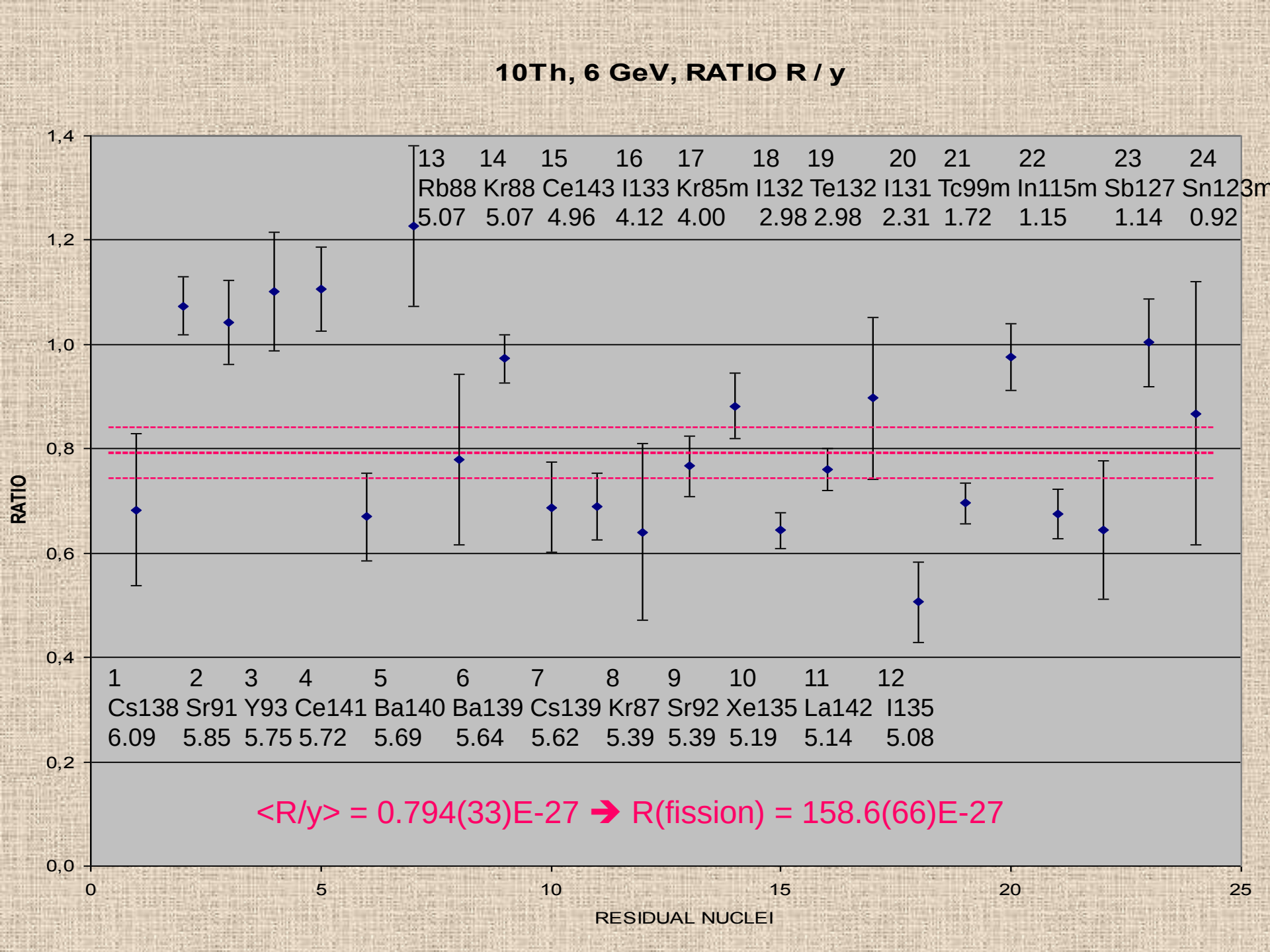



R(exp)/yield, 2Th, Ed = 2 GeV
In117
7,2E-03
As78
2,9E-03
Ge78
2,9E-03
Nb95m
5,2E-04
Ge77
2,6E-04
Rh105
1,0E-02
Ru105
1,0E-02
Sn123m
9,2E-03
Ag113
7,9E-03
Pd111m
7,8E-05
Br82
1,4E-06
Nb96
2,1E-07
I130
1,5E-07
Y90m
4,9E-09
Zn69m
5,5E-10
Ratio
1,E+07
1,E+06
1,E+05
1,E+04
1,E+03
1,E+02
1,E+01
1,E+00
1,E-01
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-10
yields


10Th, Ratio R(exp.) / yields, KVINTA, Ed = 6 GeV
Ratio
yields
1,0E+11
1,0E+10
1,0E+09
1,0E+08
1,0E+07
1,0E+06
1,0E+05
1,0E+04
1,0E+03
1,0E+02
1,0E+01
1,0E+00
1,0E-01
1,0E+00
1,0E-01
1,0E-02
1,0E-03
1,0E-04
1,0E-05
1,0E-06
1,0E-07
1,0E-08
1,0E-09
1,0E-10
1,0E-11
As76 Zn69m Fe59 Ba135m I126 Sb120m Rh106m Cs132
3,6E6 5,5E6 2,2E7 2,0E7 1,5E8 1,0E8 1,6E8 1,3E10
Cs135m Br82 Zn71m Sb122 In116m Y90m
5,1E3 5,5E3 7,9E3 1,9E5 2,5E6 1,7E6
Ga72 Zn72 Cs136 Nb98m Sb124
1,6E2 1,1E2 8,2E1 3,1E2 4,1E3
Nb95m Ge77 Sb126 Ga73 Pd111m
1,5E1 2,6E1 3,7E1 5,8E1 1,7E2

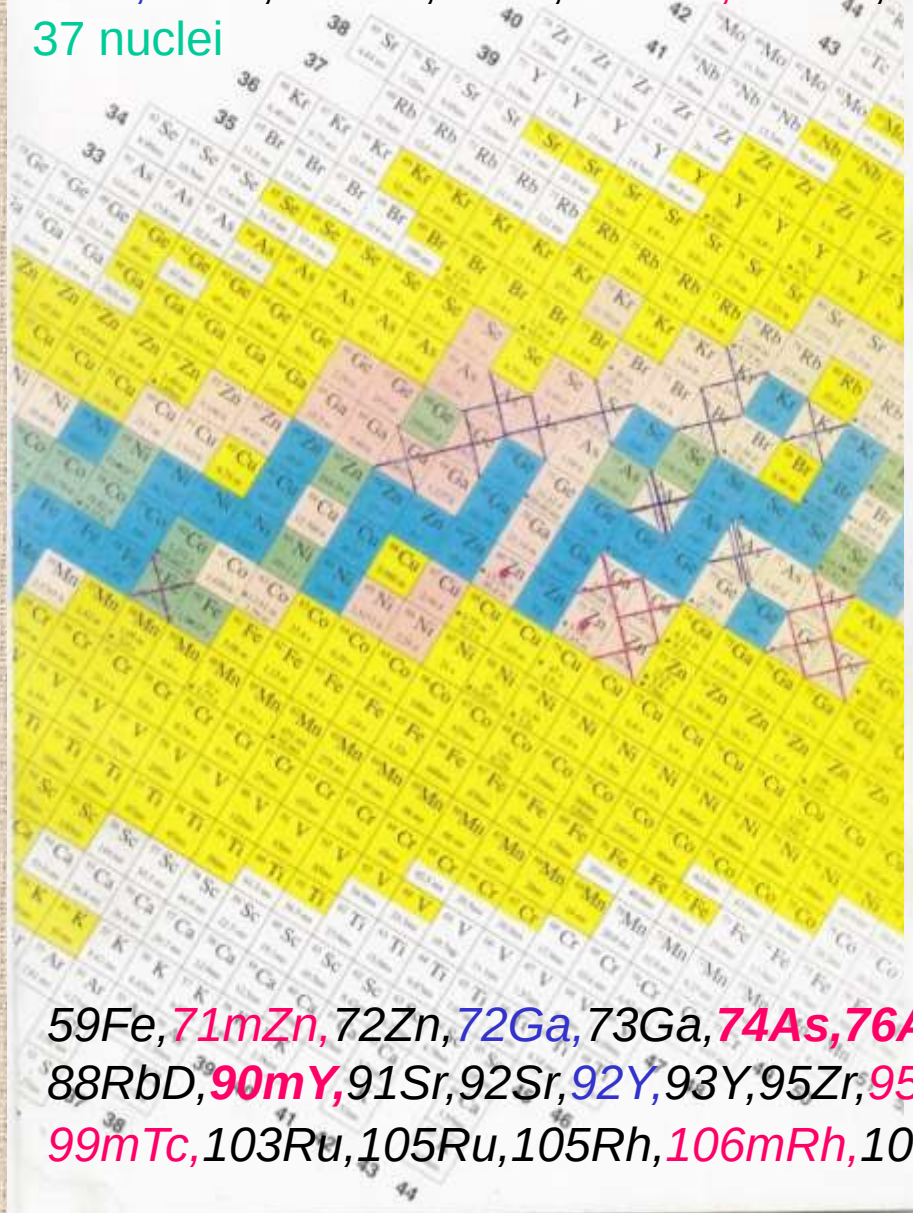

2Th, 2 GeV, Ratio R/y
(R/y)E-27
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
5
10
15
20
Residual nuclei
Kr85m 1
Kr87 2
Kr88 3
Sr91 4
Sr92 5
Y92 6
Y93 7
Nb95 8
Nb97 9
Zr97 10
I131 11
I132 12
Te132 13
I133 14
I134 15
I135 16
Xe135 17
Ba139 18
La142 19
Ce143
<R/y> = 0.272(20)E-27 --> R(n,fission) = 54.4(40)E-27

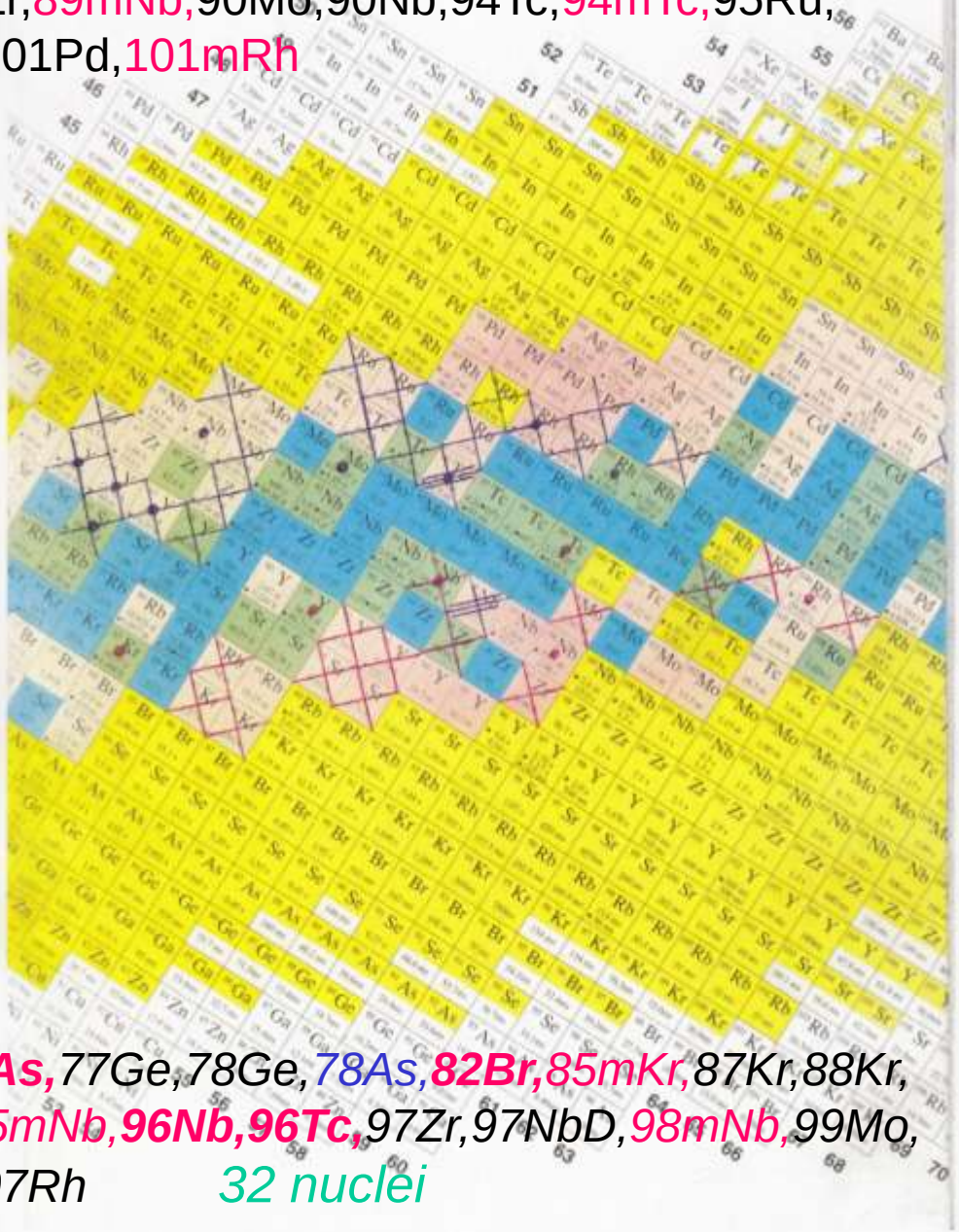

6 Th, 4 GeV, Ratio R/y
R/y * E-27
3
2,5
2
1,5
1
0,5
0
Zr-97 Mo-99 I-131 I-133 Ce-143
1 2 3 4 5
<R/y> = 0.651(17)E-27 --> R(n,fission) = 130(34)E-27
0 1 2 3 4 5 6
Residual nuclei


10Th, 6 GeV, RATIO R / y
RATIO
RESIDUAL NUCLEI
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0
5
10
15
20
25
13 Rb88 5.07
14 Kr88 5.07
15 Ce143 4.96
16 I133 4.12
17 Kr85m 4.00
18 I132 2.98
19 Te132 2.98
20 I131 2.31
21 Tc99m 1.72
22 In115m 1.15
23 Sb127 1.14
24 Sn123m 0.92
1 Cs138 6.09
2 Sr91 5.85
3 Y93 5.75
4 Ce141 5.72
5 Ba140 5.69
6 Ba139 5.64
7 Cs139 5.62
8 Kr87 5.39
9 Sr92 5.39
10 Xe135 5.19
11 La142 5.14
12 I135 5.08
<R/y> = 0.794(33)E-27 ➔ R(fission) = 158.6(66)E-27

67Ga,69Ge,70As,71As,73Se,76Br,77Kr,79Kr,80Sr,81Rb,83Sr,83Rb,85mY,85Y,85Sr,
85mSr,86Zr,86Y,86mY,87Y,87mY,88Y,89Zr,89mNb,90Mo,90Nb,94Tc,94mTc,95Ru,
95Tc,97Ru,98RhD,99Rh,99mRh,100Rh,101Pd,101mRh

37 nuclei



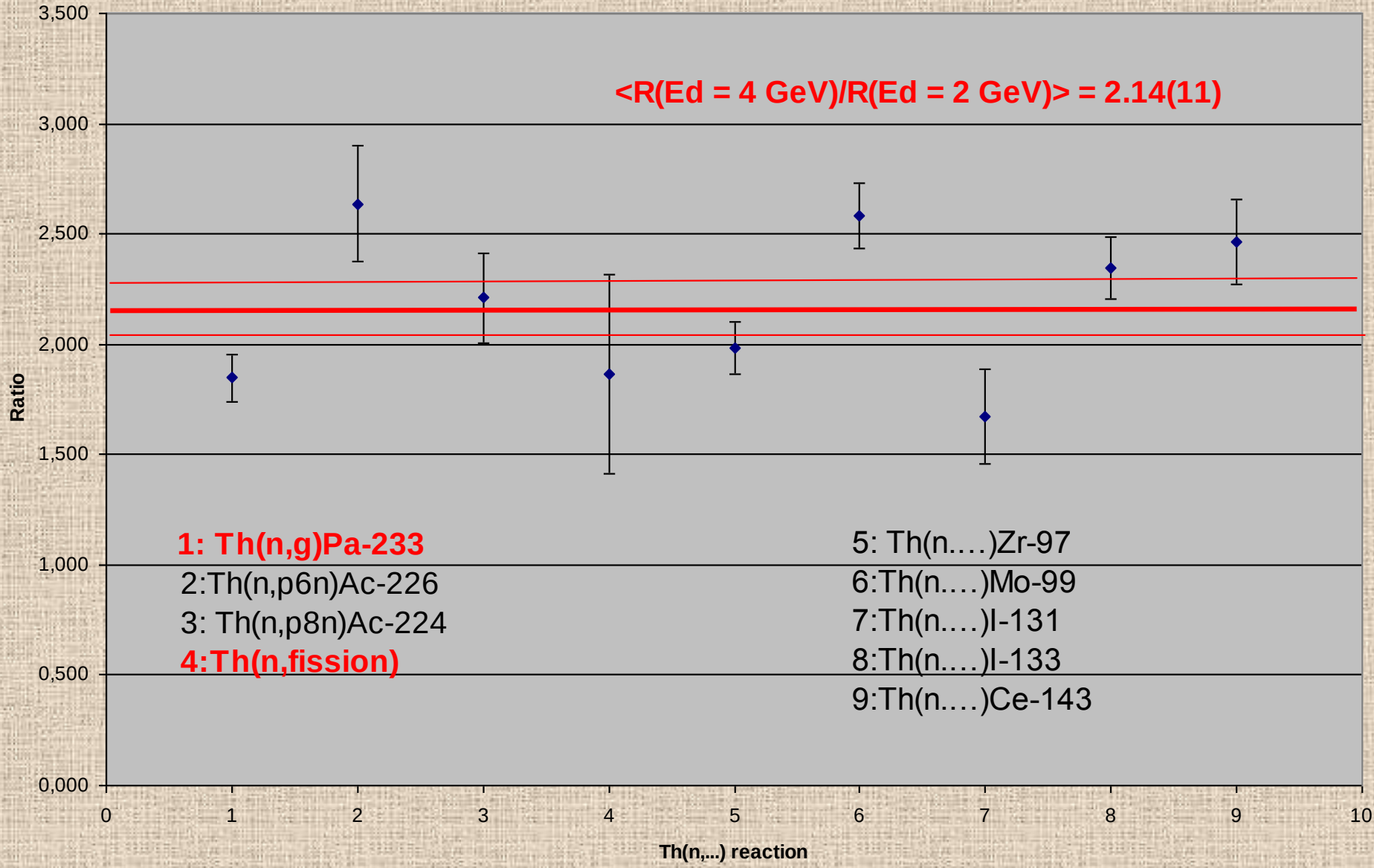


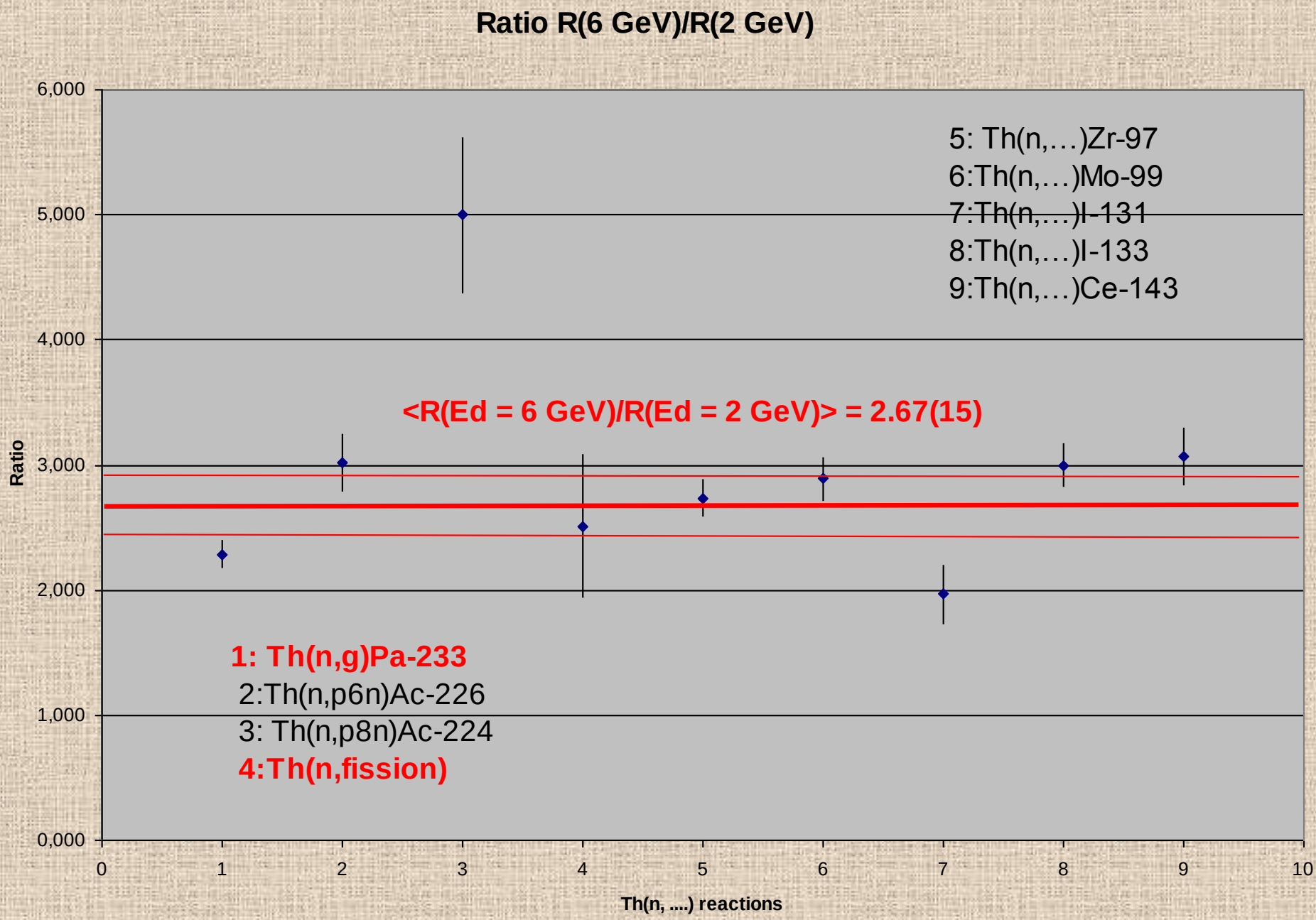
*59Fe,71mZn,72Zn,72Ga,73Ga,**74As,76As,**77Ge,78Ge,78As,**82Br,**85mKr,87Kr,88Kr,*
*88RbD,**90mY,**91Sr,92Sr,92Y,93Y,95Zr,95mNb,**96Nb,96Tc,**97Zr,97NbD,98mNb,99Mo,*
99mTc,103Ru,105Ru,105Rh,106mRh,107Rh

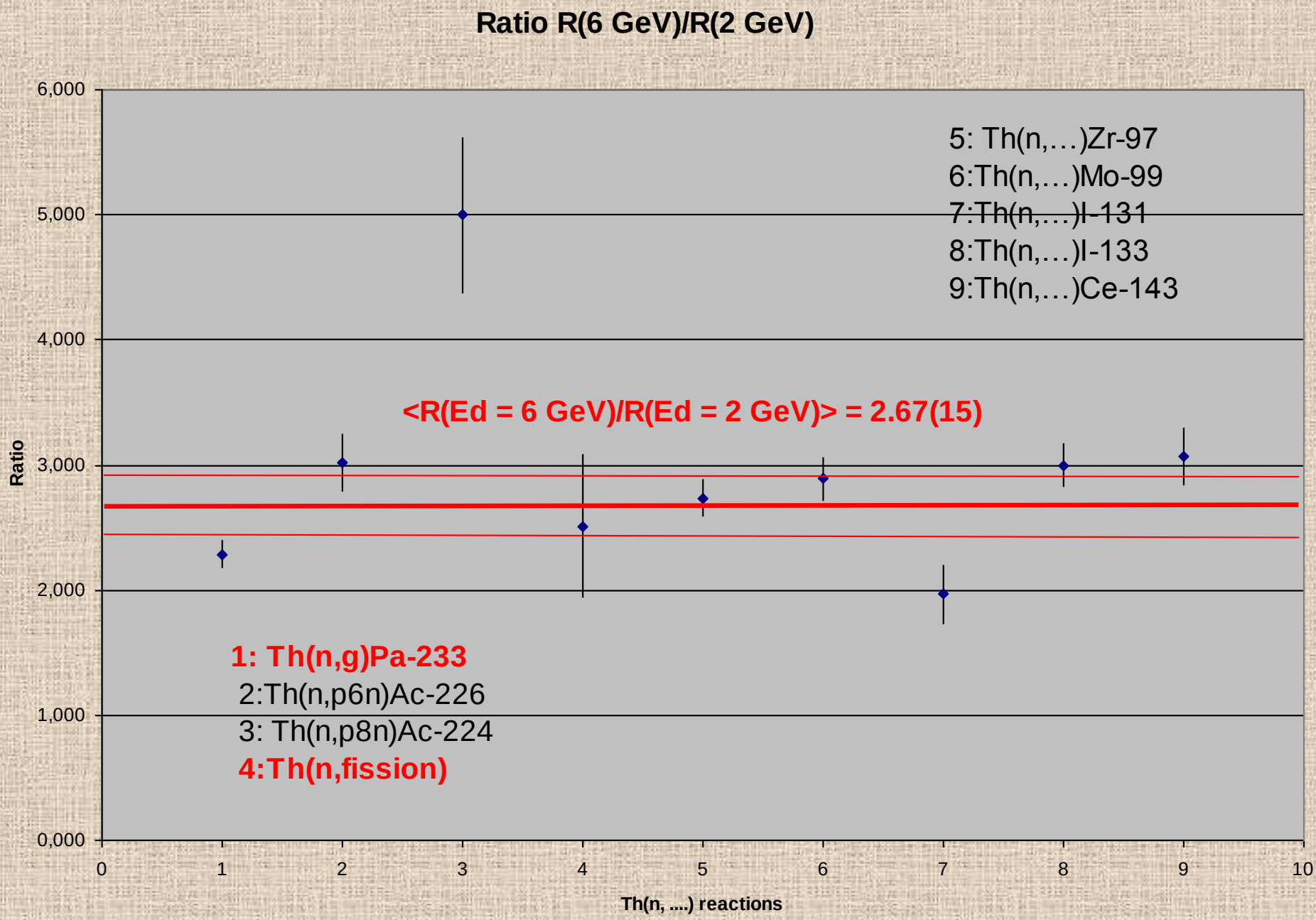
32 nuclei

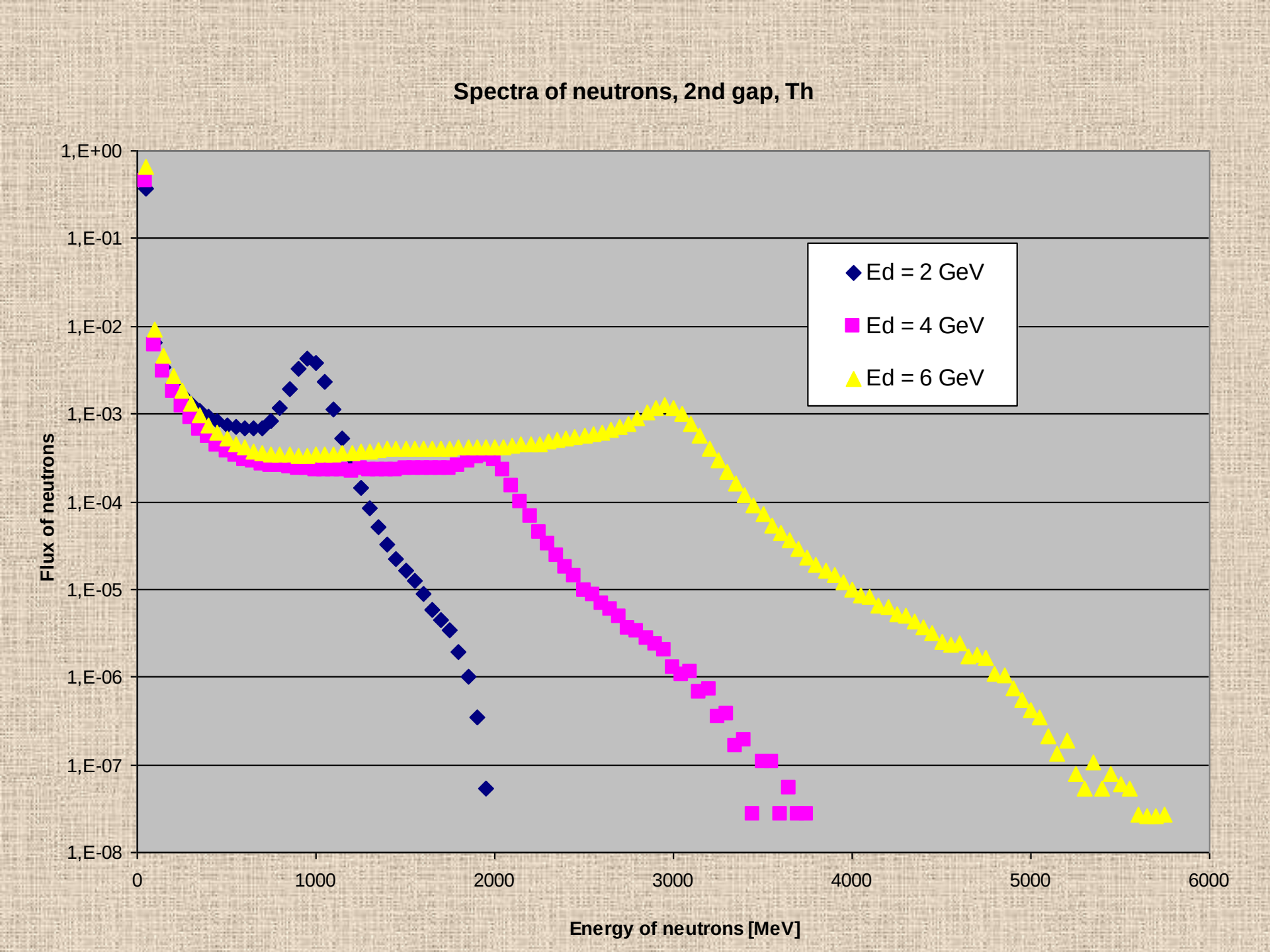

111In,113Sn,116SbD,117Sb,118mSb,119Te,119mTe,120I,120mI,121I,121Te,122Xe,
123Xe,123Xe,123I,124I,125Xe,126I,127Cs,129Ba,129Cs,131Ba,132Cs,132Ce,132La,
132mLa,133La,135Ce,137mCe,138mPr,139NdD,139mNd,145Eu,146Gd,146EuD,
147Eu,147Gd,149Gd,152Dy,152Tb,154Tb,154mTb,155Dy,155Tb,157Dy,161Er,105Ru,
105Rh,106mRh,107Rh 50 nuclei
111mPd,111Ag,112AgD,113Ag,115Cd,115mIn,116mIn,117Cd,117mCd,117InD,120mSb,
122Sb,123mSn,124Sb,126Sb,127Sb,128Sb,129Sb,130I,131I,132Te,132I,132ID,133I,
133Xe,133mXe,134I,135I,135Xe,135mCs,135mBa,136Cs,138Cs,139Ba,140Ba,140LaD,
142La,143Ce 38 nuclei

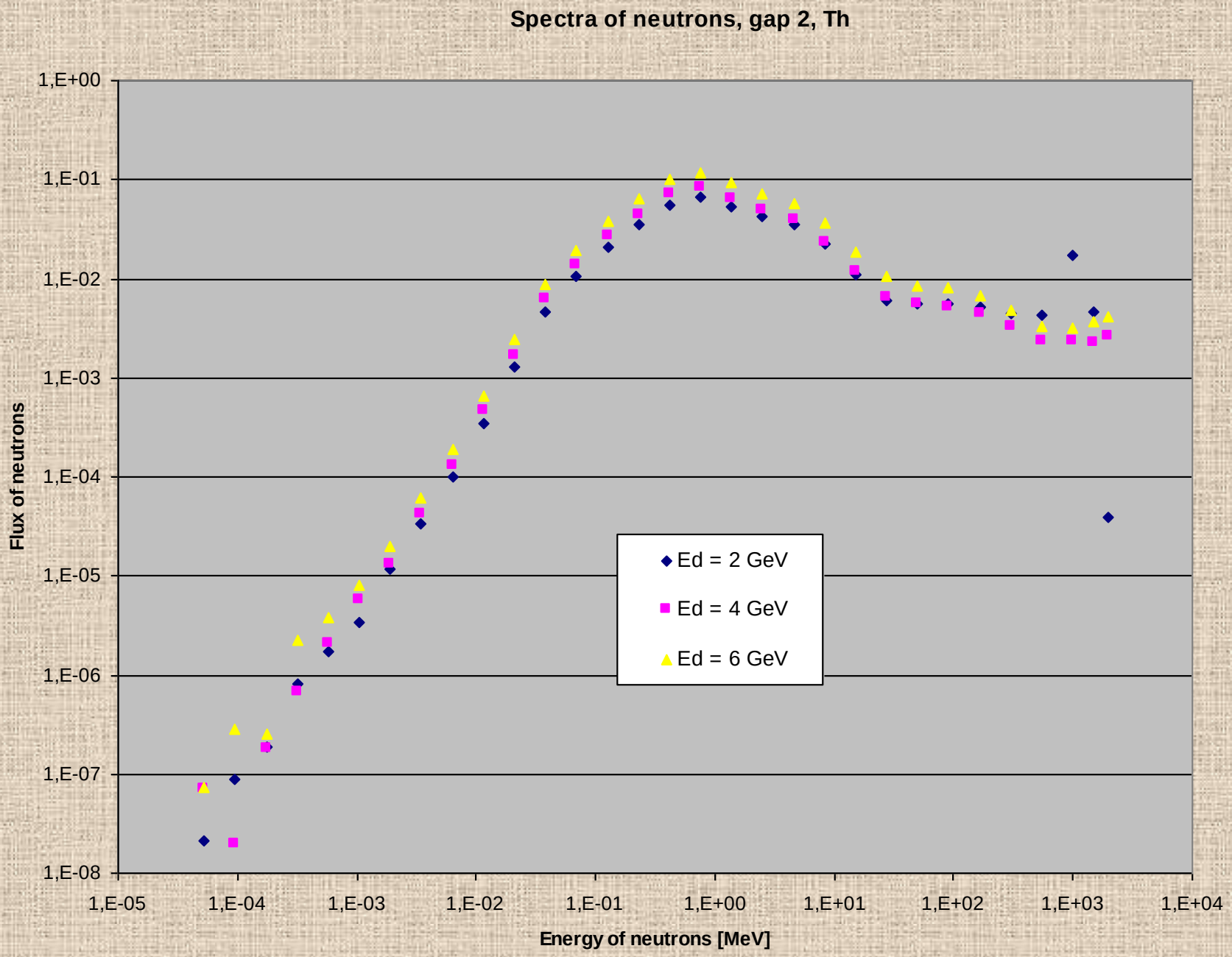
Ratio of R(4 GeV)/R(2 GeV)

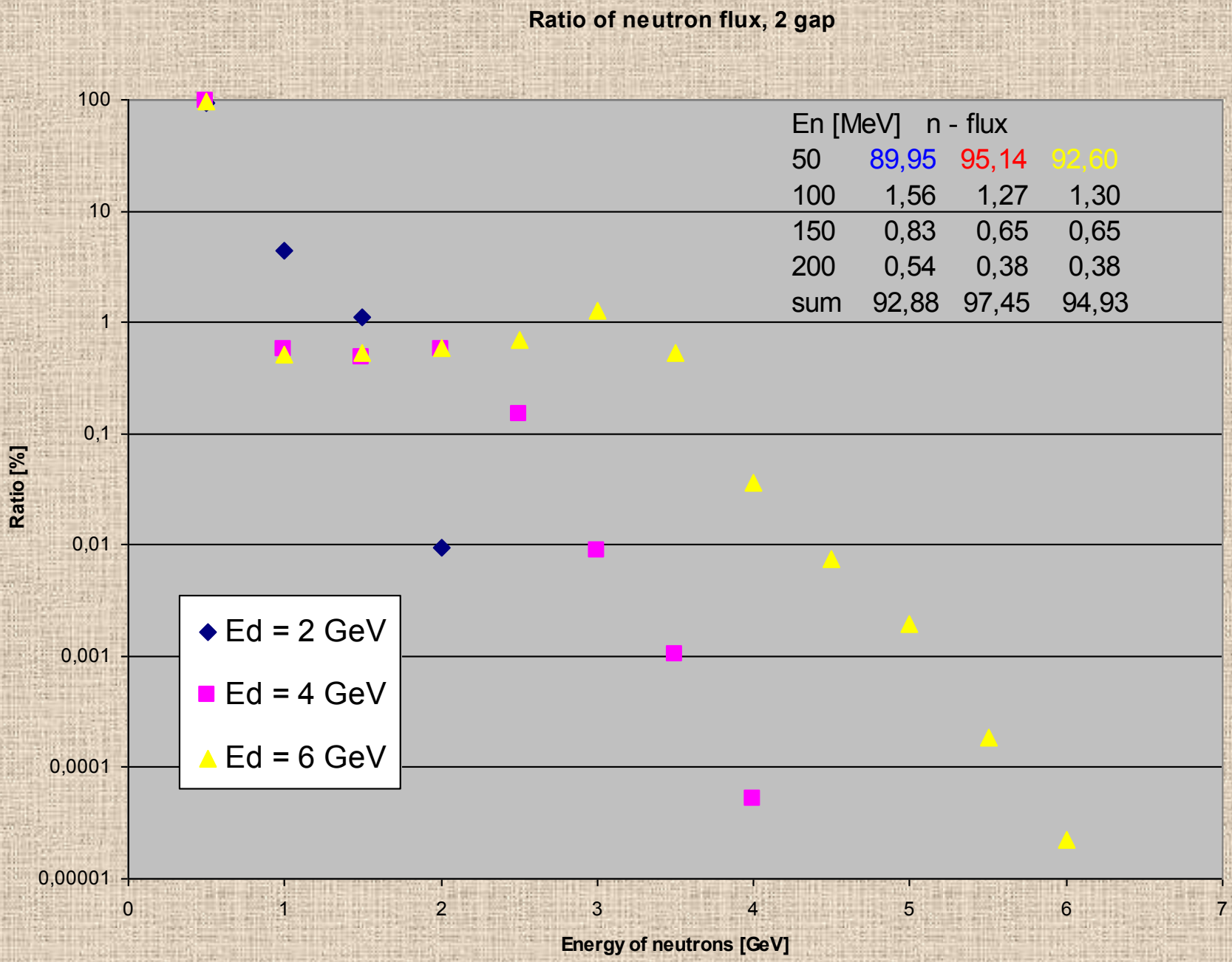



Ratio R(6 GeV)/R(2 GeV)
6,000
5,000
4,000
3,000
2,000
1,000
0,000
Ratio
0
1
2
3
4
5
6
7
8
9
10
Th(n, ...) reactions
5: Th(n,…)Zr-97
6:Th(n,…)Mo-99
7:Th(n,…)I-131
8:Th(n,…)I-133
9:Th(n,…)Ce-143
<R(Ed = 6 GeV)/R(Ed = 2 GeV)> = 2.67(15)
1: Th(n,g)Pa-233
2:Th(n,p6n)Ac-226
3: Th(n,p8n)Ac-224
4:Th(n,fission)


Ratio R(6 GeV)/R(2 GeV)
6,000
5,000
4,000
3,000
2,000
1,000
0,000
Ratio
0
1
2
3
4
5
6
7
8
9
10
Th(n, ...) reactions
5: Th(n,…)Zr-97
6:Th(n,…)Mo-99
7:Th(n,…)I-131
8:Th(n,…)I-133
9:Th(n,…)Ce-143
<R(Ed = 6 GeV)/R(Ed = 2 GeV)> = 2.67(15)
1: Th(n,g)Pa-233
2:Th(n,p6n)Ac-226
3: Th(n,p8n)Ac-224
4:Th(n,fission)


Spectra of neutrons, 2nd gap, Th
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
Flux of neutrons
0
1000
2000
3000
4000
5000
6000
Energy of neutrons [MeV]
Ed = 2 GeV
Ed = 4 GeV
Ed = 6 GeV


Spectra of neutrons, gap 2, Th
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
Flux of neutrons
1,E-05
1,E-04
1,E-03
1,E-02
1,E-01
1,E+00
1,E+01
1,E+02
1,E+03
1,E+04
Energy of neutrons [MeV]
Ed = 2 GeV
Ed = 4 GeV
Ed = 6 GeV


Ratio of neutron flux, 2 gap
En [MeV] n - flux
50 89,95 95,14 92,60
100 1,56 1,27 1,30
150 0,83 0,65 0,65
200 0,54 0,38 0,38
sum 92,88 97,45 94,93
Ed = 2 GeV
Ed = 4 GeV
Ed = 6 GeV
Ratio [%]
100
10
1
0,1
0,01
0,001
0,0001
0,00001
0
1
2
3
4
5
6
7
Energy of neutrons [GeV]

	Average energy [MeV]			Flux [h/d.cm^2]		
	n	p	pi	n	p	pi
• Gape 2						
• 2 GeV	106	631	270	4.1E-1	3.1E-2	2.1E-3
• 4 GeV	77	822	470	4.7E-1	1.4E-2	3.8E-3
• 6 GeV	143	1630	729	7.0E-1	3.7E-2	1.0E-2

REACTION RATE R(exp.)[E-27](err.)

Reaction products	Ed = 2 GeV Reza et al.	Ed = 4 GeV Adam et al.	Ed = 6 GeV Adam et al.
Th(n,g)**Pa-233**	76.9(39)	142(4)	176(3)
Th(n,2n)**Th-231**		51.4(15)	71.2(23)
Th(n,6n)**Th-227**		3.8(15)	4.4(4)
Th(n,p6n)**Ac-226**	1.13(8)	2.98(21)	3.41(11)
Th(n,p8n)**Ac-224**	0.62(5)	1.37(6)	3.1(3)
Th(n,**fission**)	**54.4(40)**	**118(10)**	**159(7)**
Th(n,…)**Zr-97**	1.9(9)	3.77(14)	5.2(17)
Th(n,…)**Mo-99**	1.99(11)	5.14(6)	5.75(18)
Th(n,…)**I-131**	1.15(14)	1.92(8)	2.26(6)
Th(n,…)**I-133**	1.04(6)	2.44(5)	3.12(5)
Th(n,…)**Ce-143**	1.06(8)	2.61(5)	3.25(6)
Th(n,**spallation**)	**17.9(25)**	**-**	**194(30)**

Reaction products	REACTION RATE R(exp.)[E-27](err.) Reza et al. Ed = 2 GeV	Adam et al. Ed = 4 GeV	Adam et al. Ed = 6 GeV
	REACTION RATE R(calc.)[E-27]		
Th(n,g)Pa-233	76.9(39)	142(4)	176(3)
	46.3	58.1	83.2
Th(n,2n)Th-231		51.4(15)	71.2(23)
	33.0	35.1	56.8
Th(n,6n)Th-227		3.8(15)	4.4(4)
Th(n,p6n)Ac-226	1.13(8)	2.98(21)	3.41(11)
Th(n,p8n)Ac-224	0.62(5)	1.37(6)	3.1(3)
Th(n,fission)	54.4(40)	118(10)	159(7)
	84.0	89.7	170.9

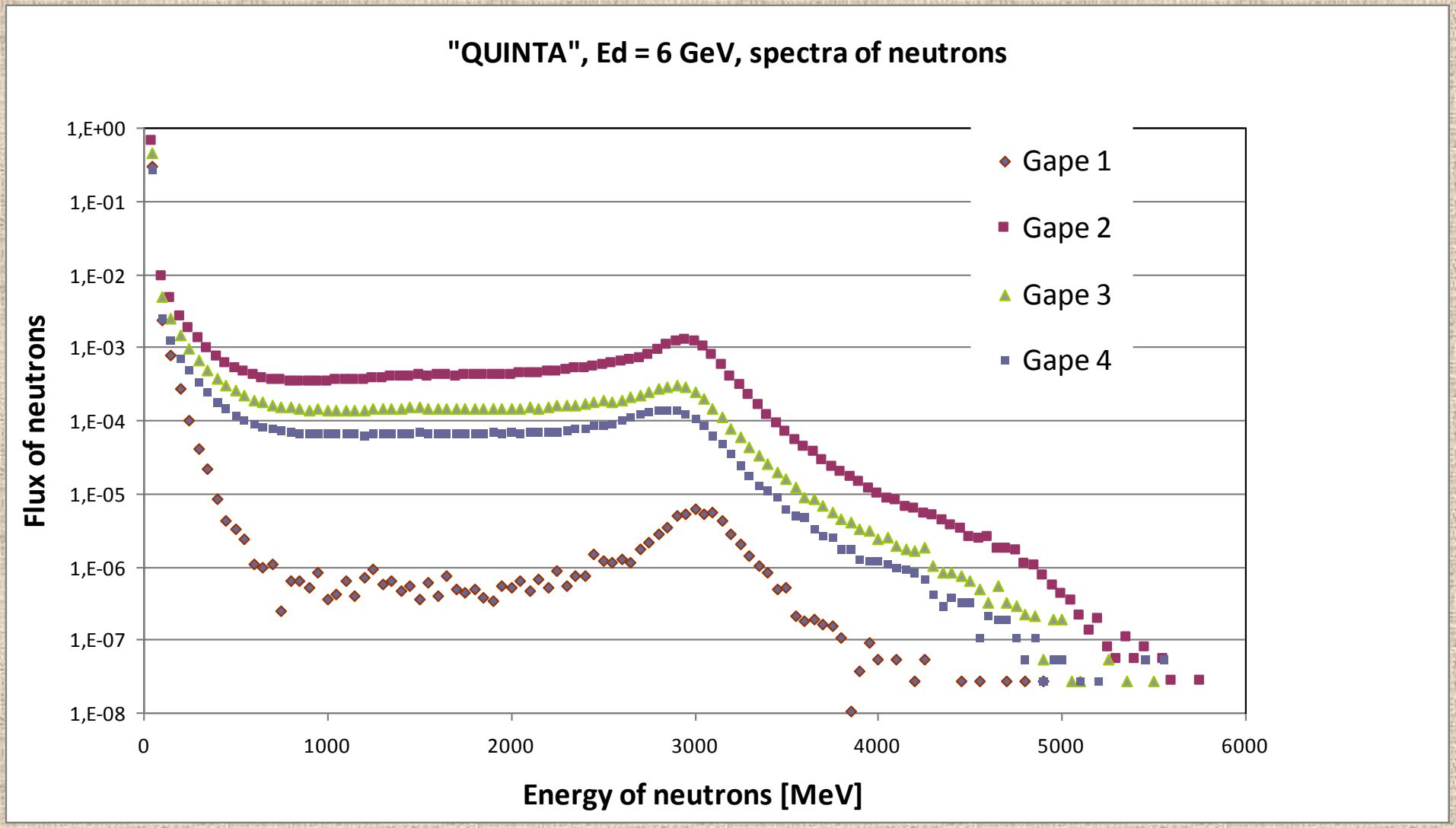
Conclusions

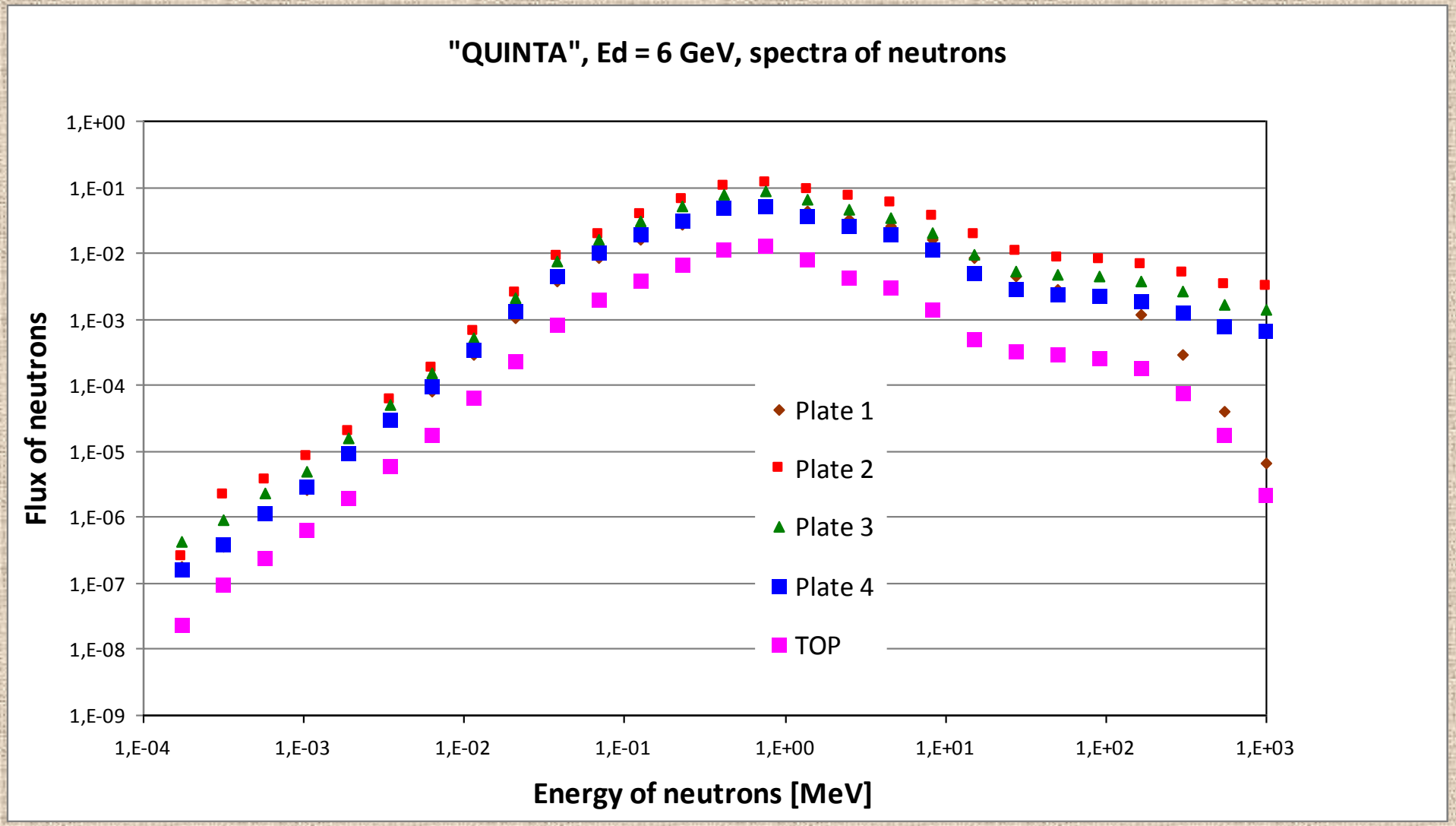
- 1. $R(n,x,E_d) / E_d \cong$ const., $x = f, \gamma, 2n$
  E_d from 2 GeV $\rightarrow$ 6 GeV

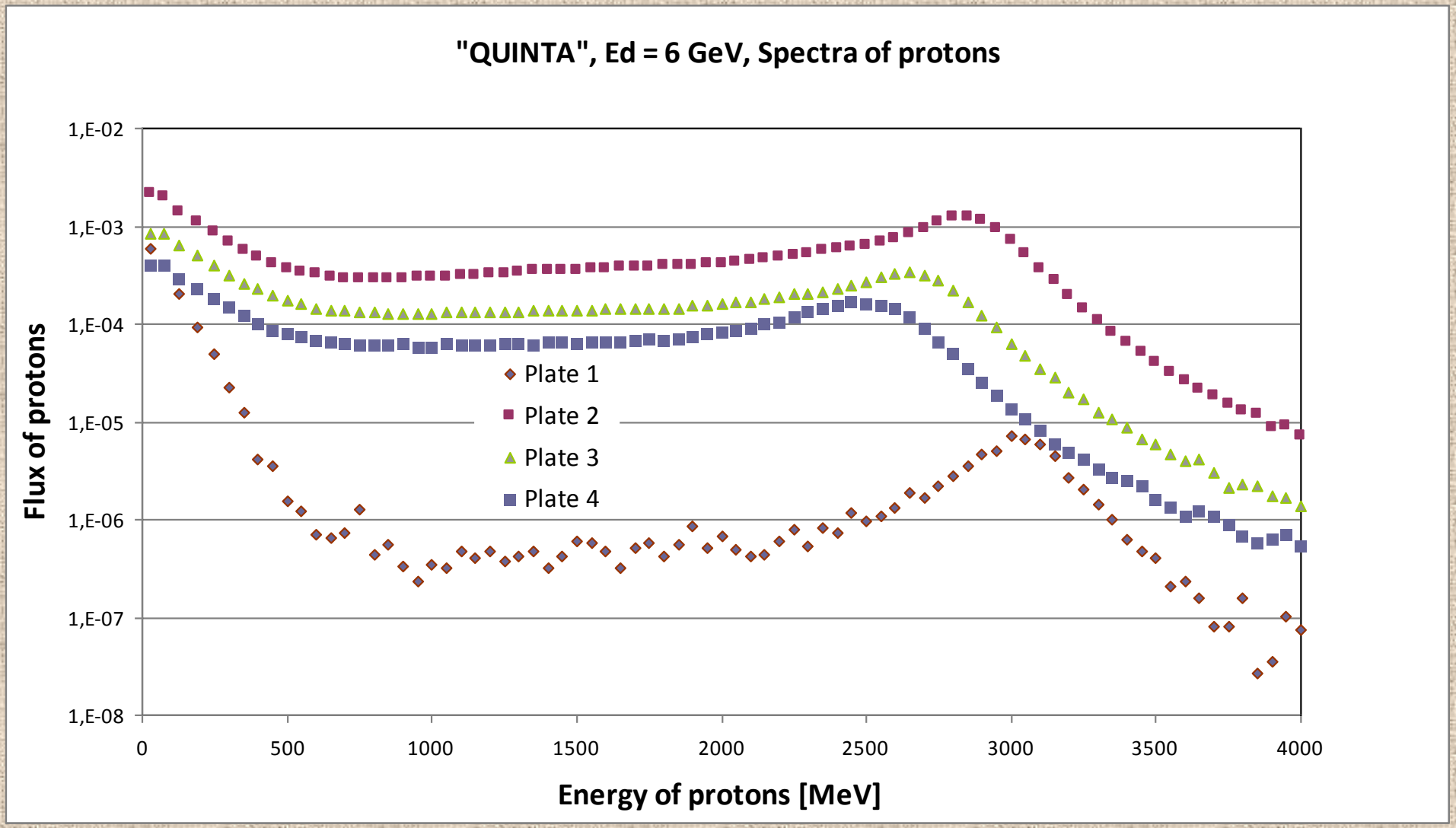
- 2. $R_{exp}(n,x) / R_{calc}(n,x) = 1.5 \pm 0.5$
  $x = f, \gamma, 2n$ E_d = 2, 4, and 6 GeV

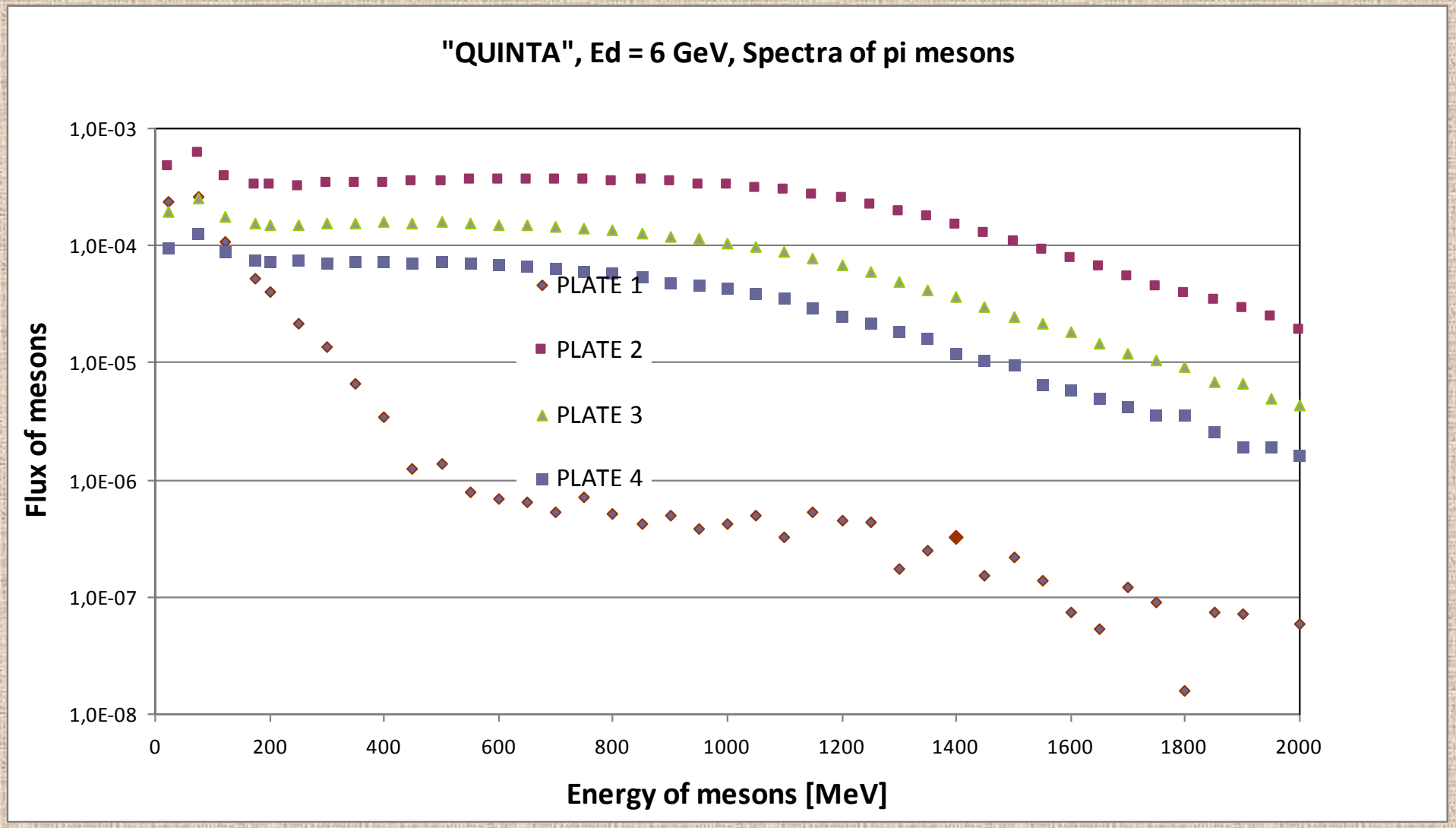
- 3. R(n,spallation) / R(n,fission)
  go up with E_d

THANK YOU FOR YOUR ATTENTION!


"QUINTA", Ed = 6 GeV, spectra of neutrons
Flux of neutrons
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
0
1000
2000
3000
4000
5000
6000
Energy of neutrons [MeV]
Gape 1
Gape 2
Gape 3
Gape 4


"QUINTA", Ed = 6 GeV, spectra of neutrons
Flux of neutrons
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
1,E-09
1,E-04
1,E-03
1,E-02
1,E-01
1,E+00
1,E+01
1,E+02
1,E+03
Energy of neutrons [MeV]
Plate 1
Plate 2
Plate 3
Plate 4
TOP

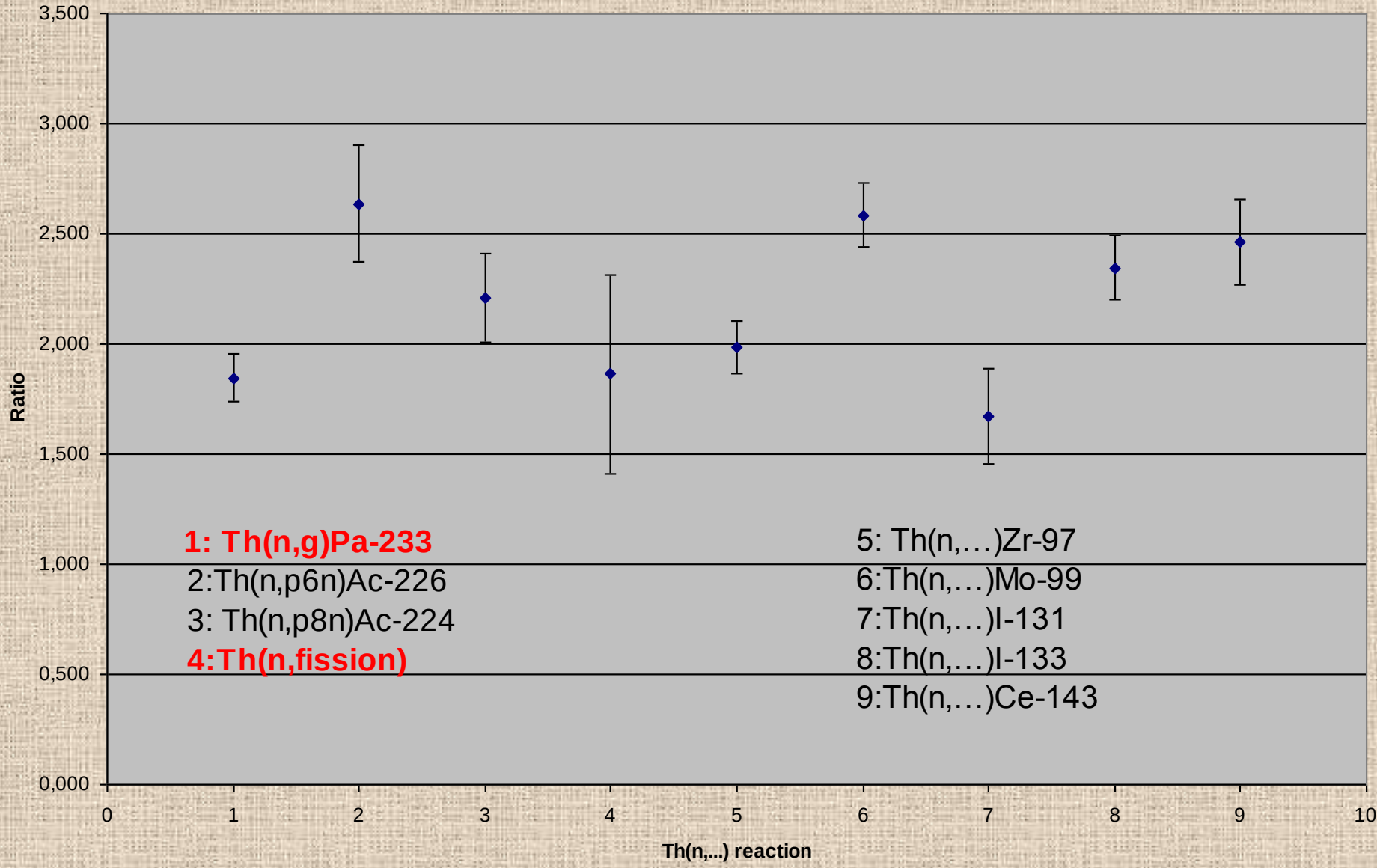

"QUINTA", Ed = 6 GeV, Spectra of protons
Flux of protons
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
0
500
1000
1500
2000
2500
3000
3500
4000
Energy of protons [MeV]
Plate 1
Plate 2
Plate 3
Plate 4

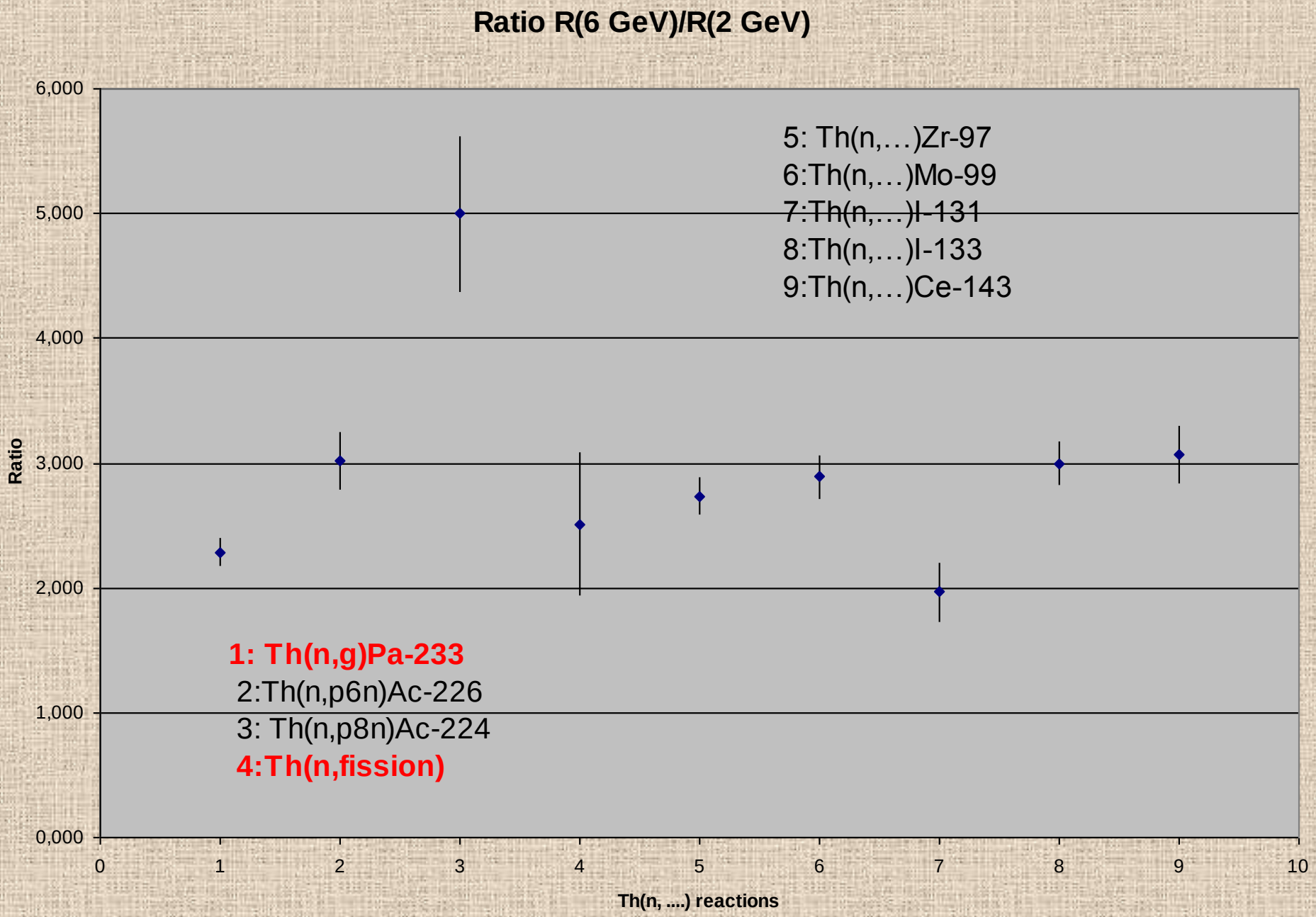

"QUINTA", Ed = 6 GeV, Spectra of pi mesons
Flux of mesons
1,0E-03
1,0E-04
1,0E-05
1,0E-06
1,0E-07
1,0E-08
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Energy of mesons [MeV]
PLATE 1
PLATE 2
PLATE 3
PLATE 4

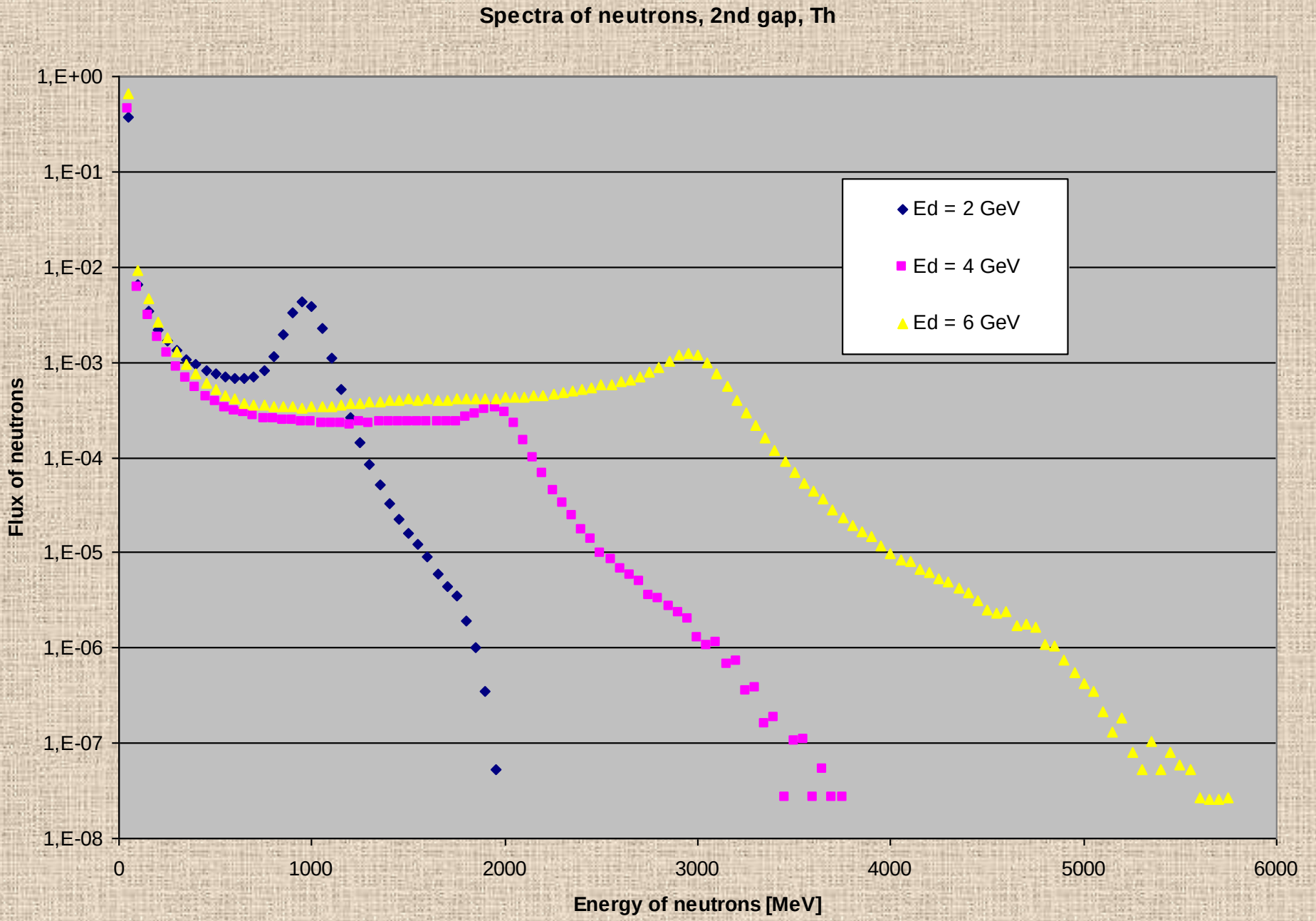
Ed = 6 GeV

	Average energy [MeV]			Relative Flux		
	n	p	pi	n	p	pi
• Gape 1	51.6	225	110	420	2.1	1.1
• Gape 2	143.0	1630	729	1000	53	14.8
• Gape 3	91.4	1360	634	680	19	5.5
• Gape 4	83.4	1310	592	400	8	2.4

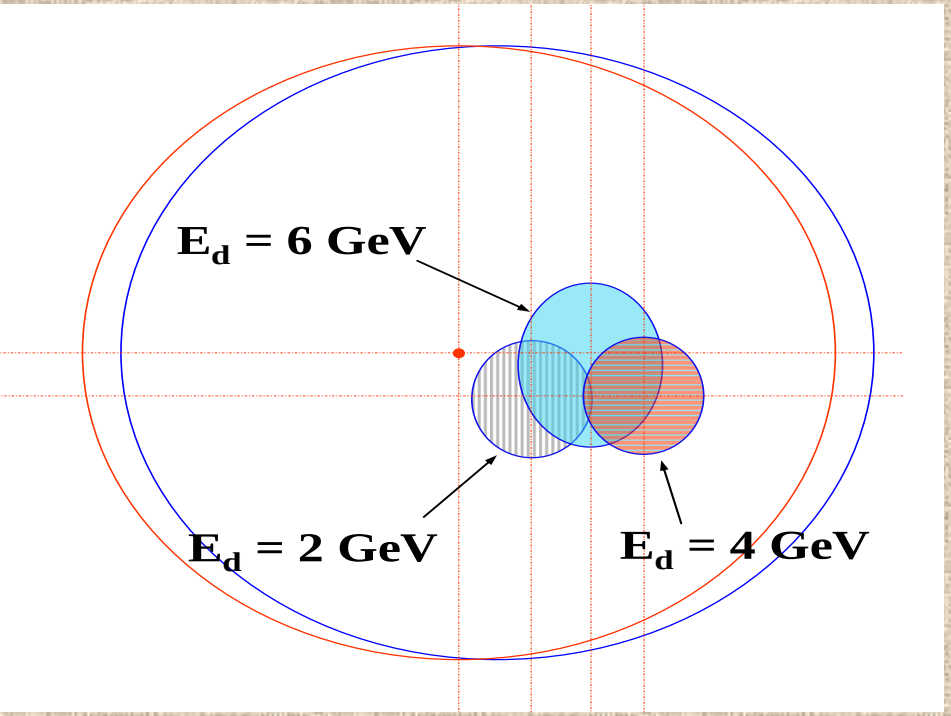
Ratio of R(4 GeV)/R(2 GeV)




Ratio R(6 GeV)/R(2 GeV)
6,000
5,000
4,000
3,000
2,000
1,000
0,000
Ratio
0
1
2
3
4
5
6
7
8
9
10
Th(n, ...) reactions
5: Th(n,…)Zr-97
6:Th(n,…)Mo-99
7:Th(n,…)I-131
8:Th(n,…)I-133
9:Th(n,…)Ce-143
1: Th(n,g)Pa-233
2:Th(n,p6n)Ac-226
3: Th(n,p8n)Ac-224
4:Th(n,fission)

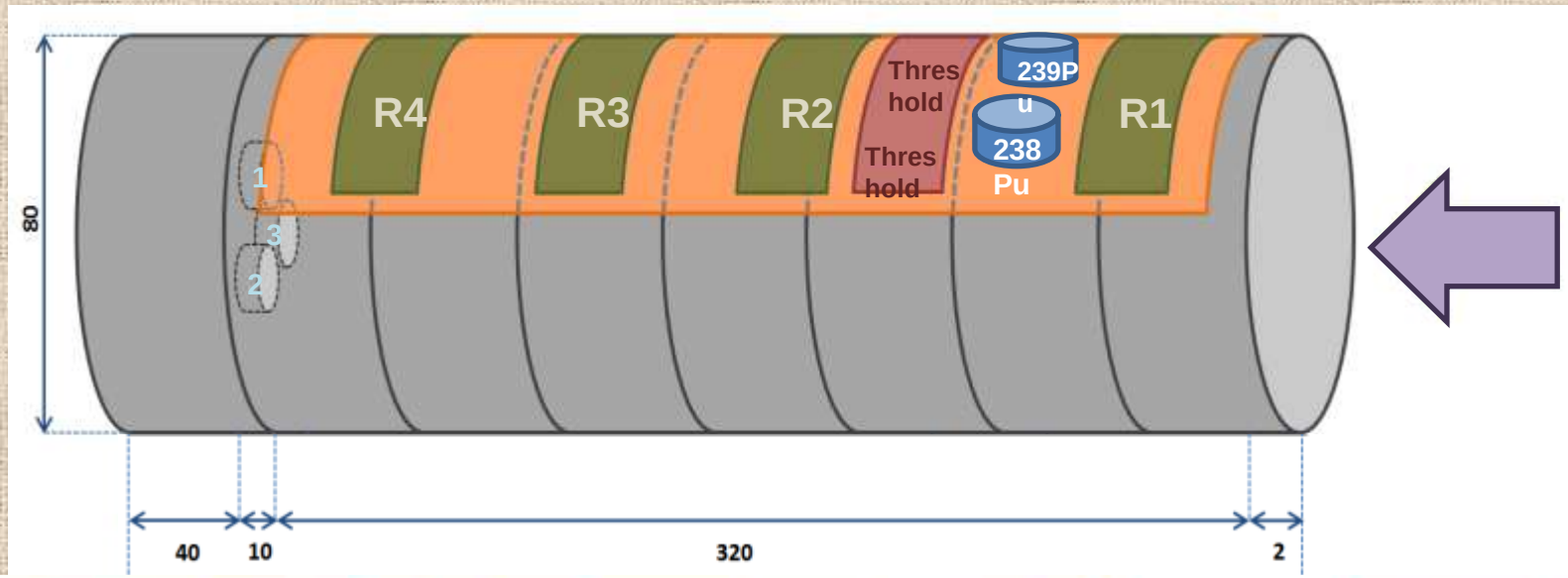

Spectra of neutrons, 2nd gap, Th
1,E+00
1,E-01
1,E-02
1,E-03
1,E-04
1,E-05
1,E-06
1,E-07
1,E-08
Flux of neutrons
0
1000
2000
3000
4000
5000
6000
Energy of neutrons [MeV]
Ed = 2 GeV
Ed = 4 GeV
Ed = 6 GeV

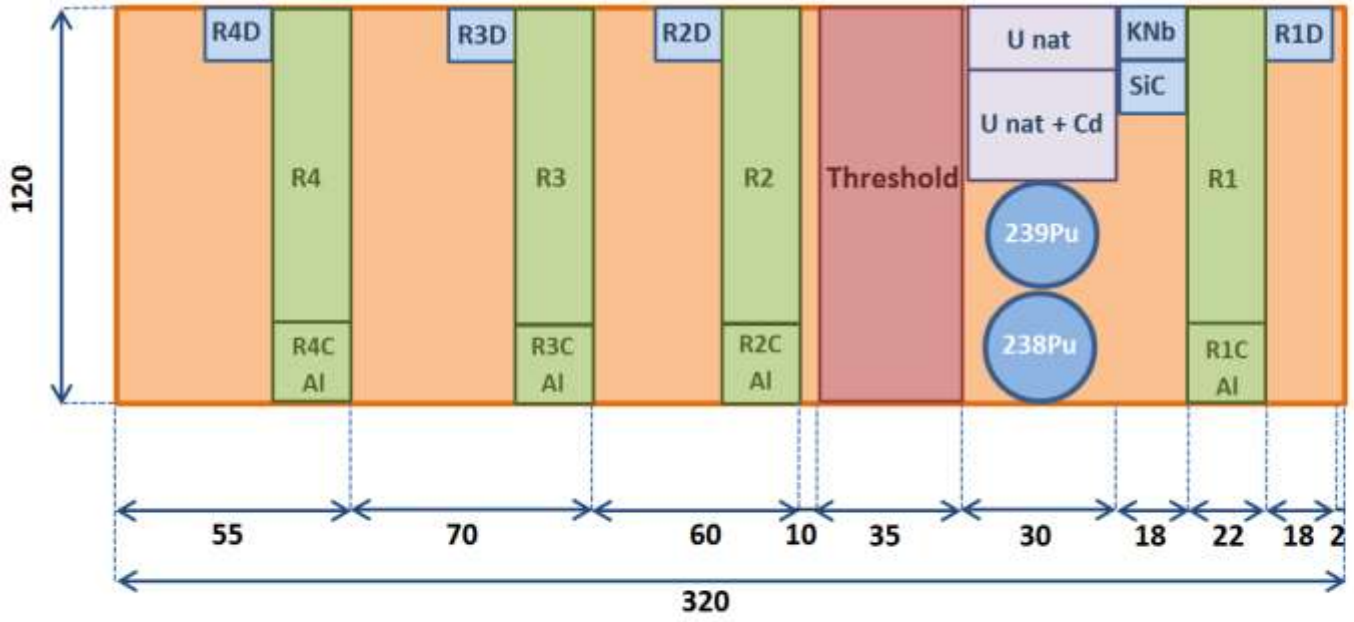
Results obtained by SSNTD method (Patapenka et al.)

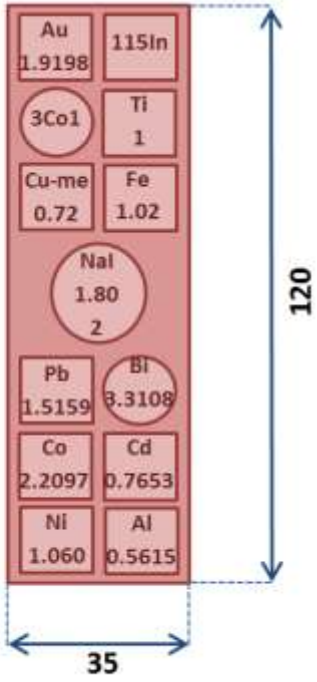


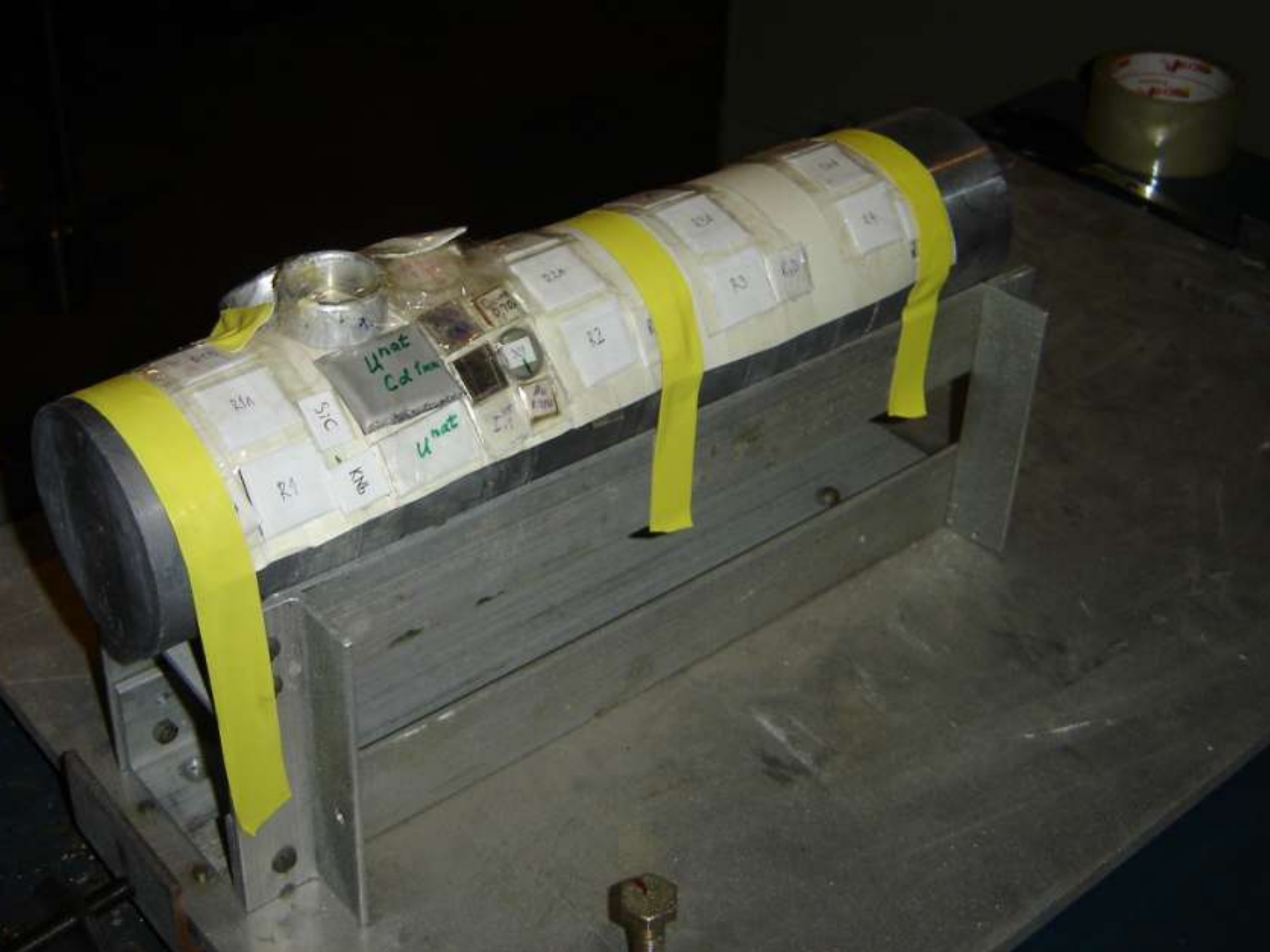
E, GeV	FWHM of distributions (mm)		Beam shift (mm)	
	X direction	Y direction	in X	in Y
2	13	16	7.8	6.4
4	13	16.1	20	5.9
6	15.6	22.4	14.2	1.8

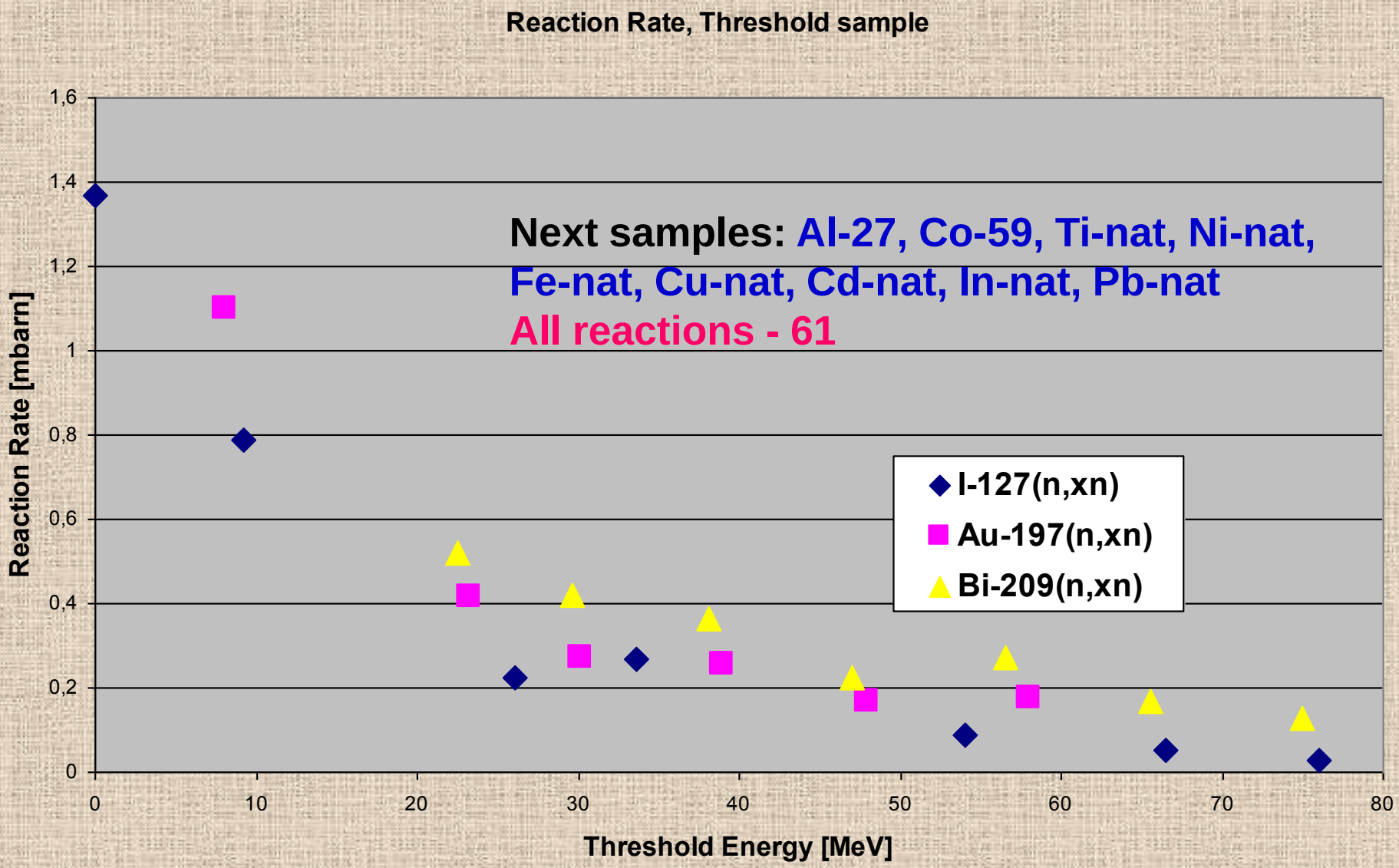
PHASOTRON 12th Feb 2011



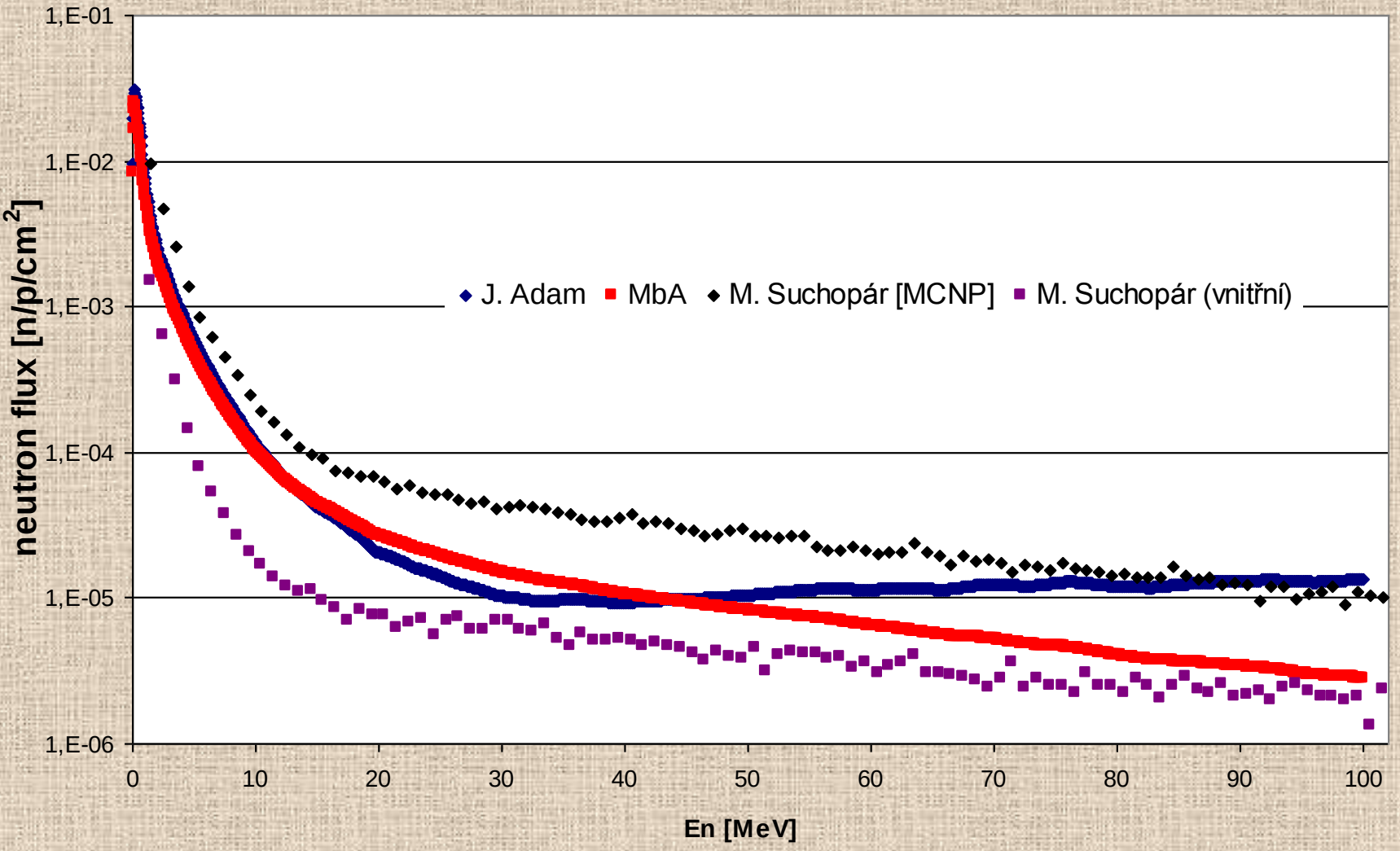





Unat
Cd 1mm
Unat
SiC


Reaction Rate, Threshold sample
Next samples: Al-27, Co-59, Ti-nat, Ni-nat, Fe-nat, Cu-nat, Cd-nat, In-nat, Pb-nat
All reactions - 61
I-127(n,xn)
Au-197(n,xn)
Bi-209(n,xn)
Reaction Rate [mbarn]
Threshold Energy [MeV]
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
0
10
20
30
40
50
60
70
80

Спектры нейтронов, восстановленные и расчетные



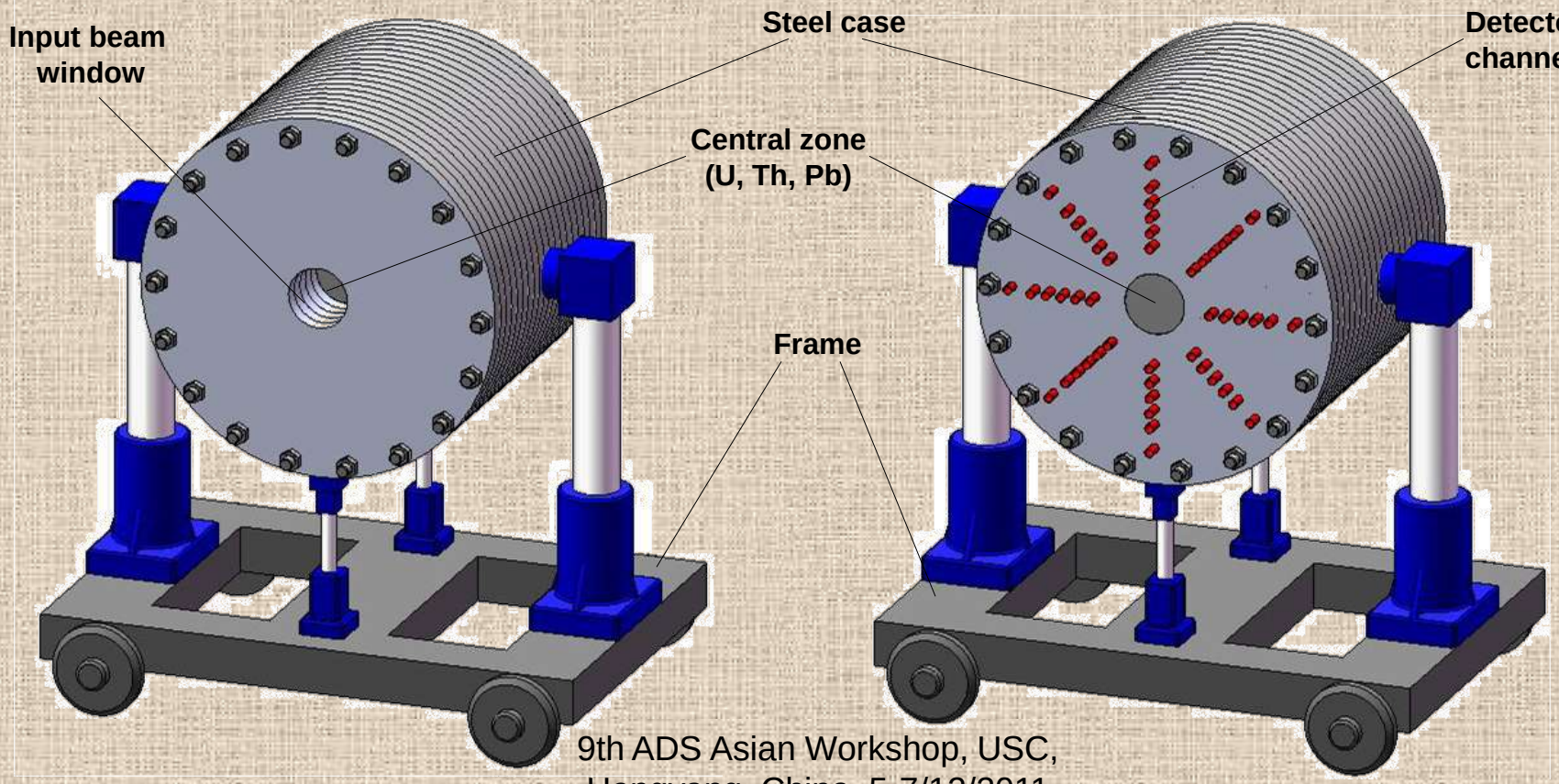
Quasi-infinite depleted uranium target (QIUT) with replacement central zone

Mass of uranium – 22 т.
Diameter – 1,2 м.
Length – 1 м.

Materials of central zone – U, Th, Pb.
Diameter of central zone – 0,2 м.

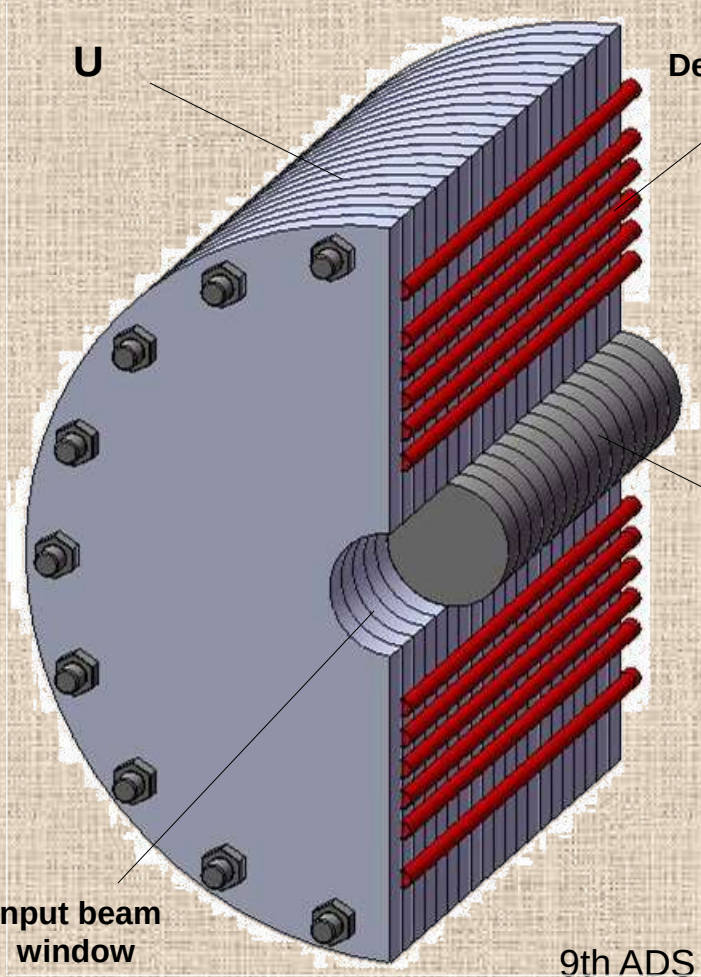
Front view

Rear view



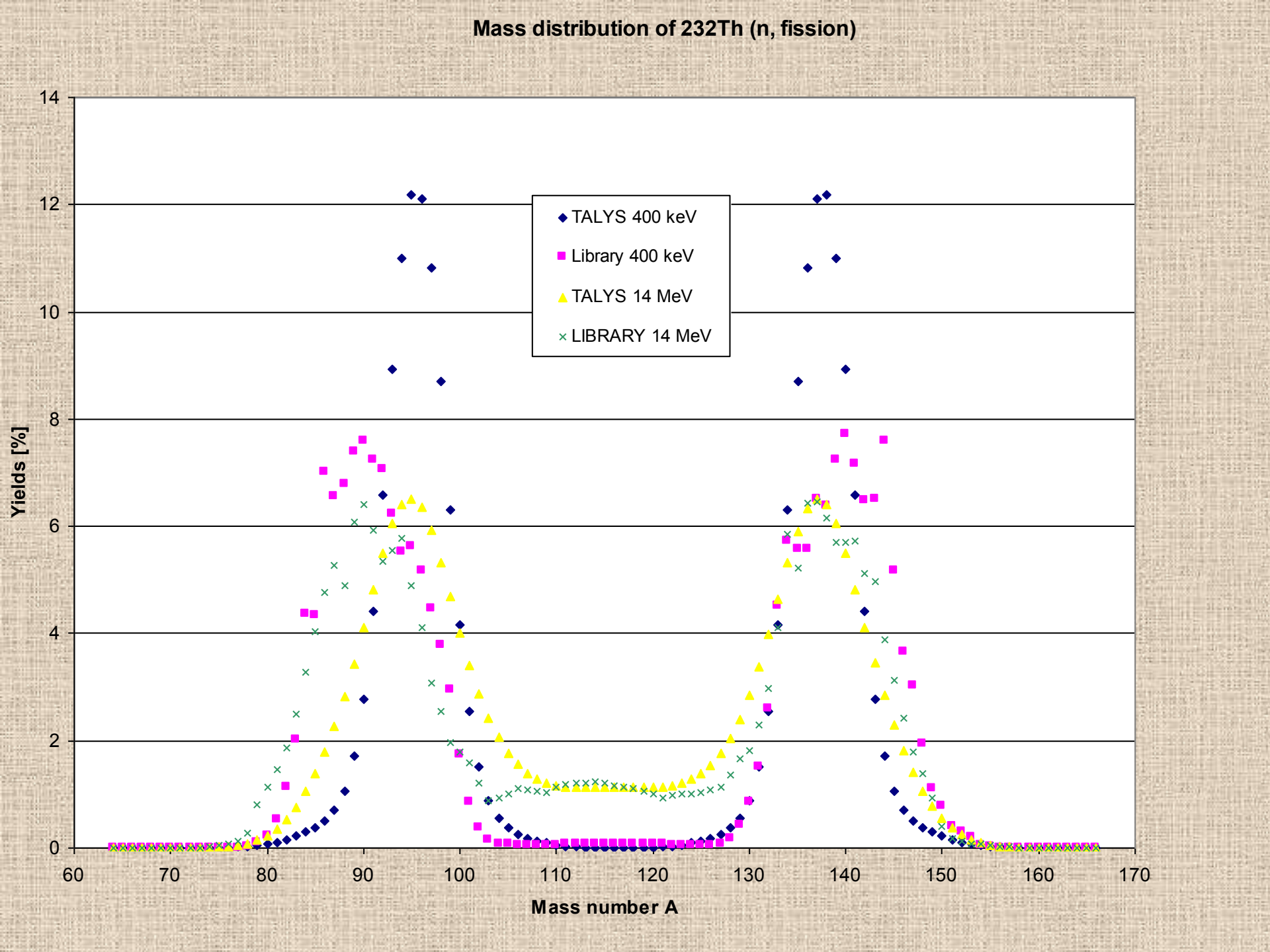
Quasi-infinite depleted uranium target (QIUT) with replacement central zone

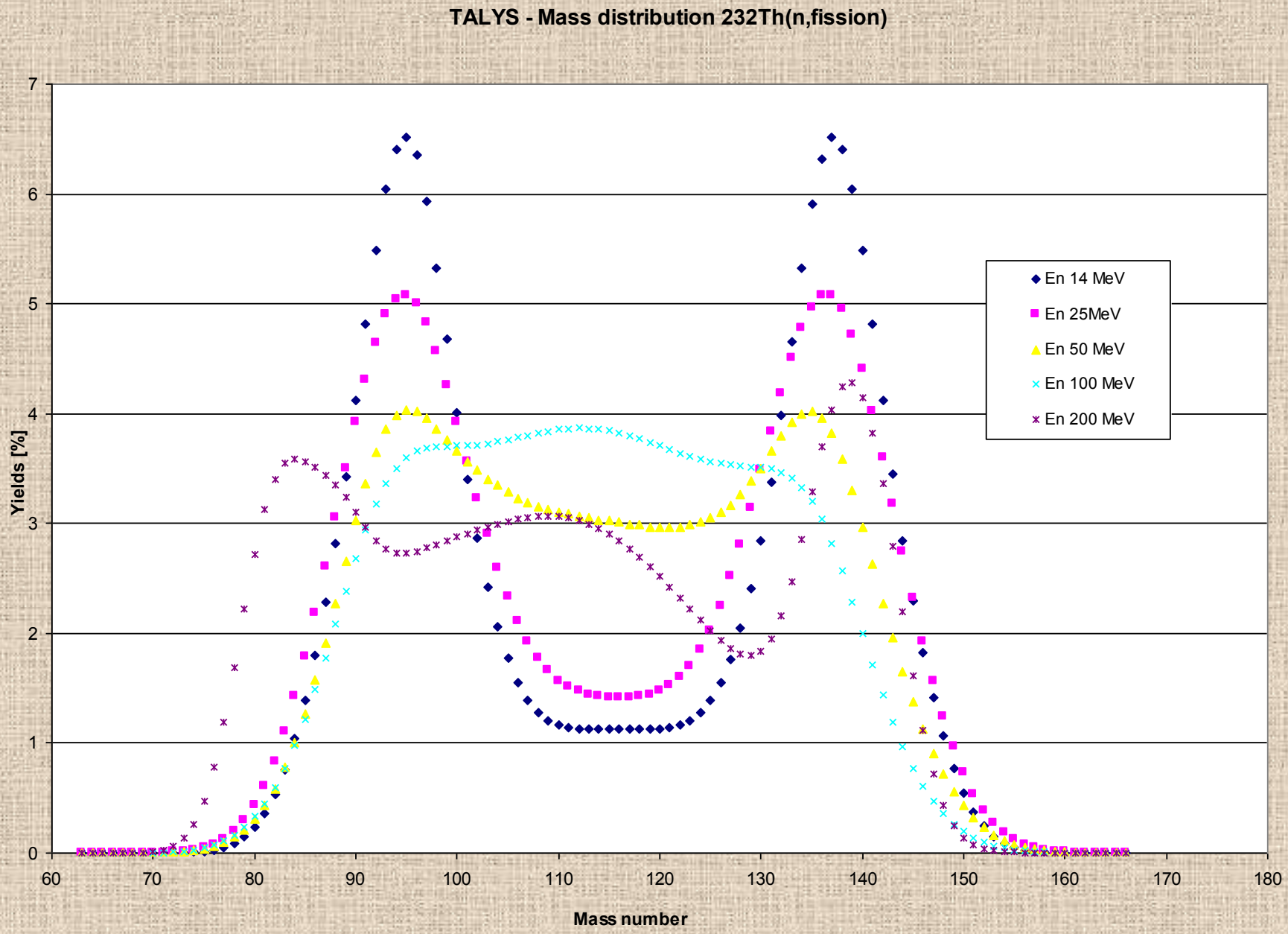
Longitudinal section of the QIUT together with central zone and detector sets



Front view photo

Rear view photo


Mass distribution of 232Th (n, fission)
TALYS 400 keV
Library 400 keV
TALYS 14 MeV
LIBRARY 14 MeV
Yields [%]
Mass number A
0
2
4
6
8
10
12
14
60
70
80
90
100
110
120
130
140
150
160
170


TALYS - Mass distribution 232Th(n,fission)
Yields [%]
Mass number
0
1
2
3
4
5
6
7
60
70
80
90
100
110
120
130
140
150
160
170
180
En 14 MeV
En 25MeV
En 50 MeV
En 100 MeV
En 200 MeV