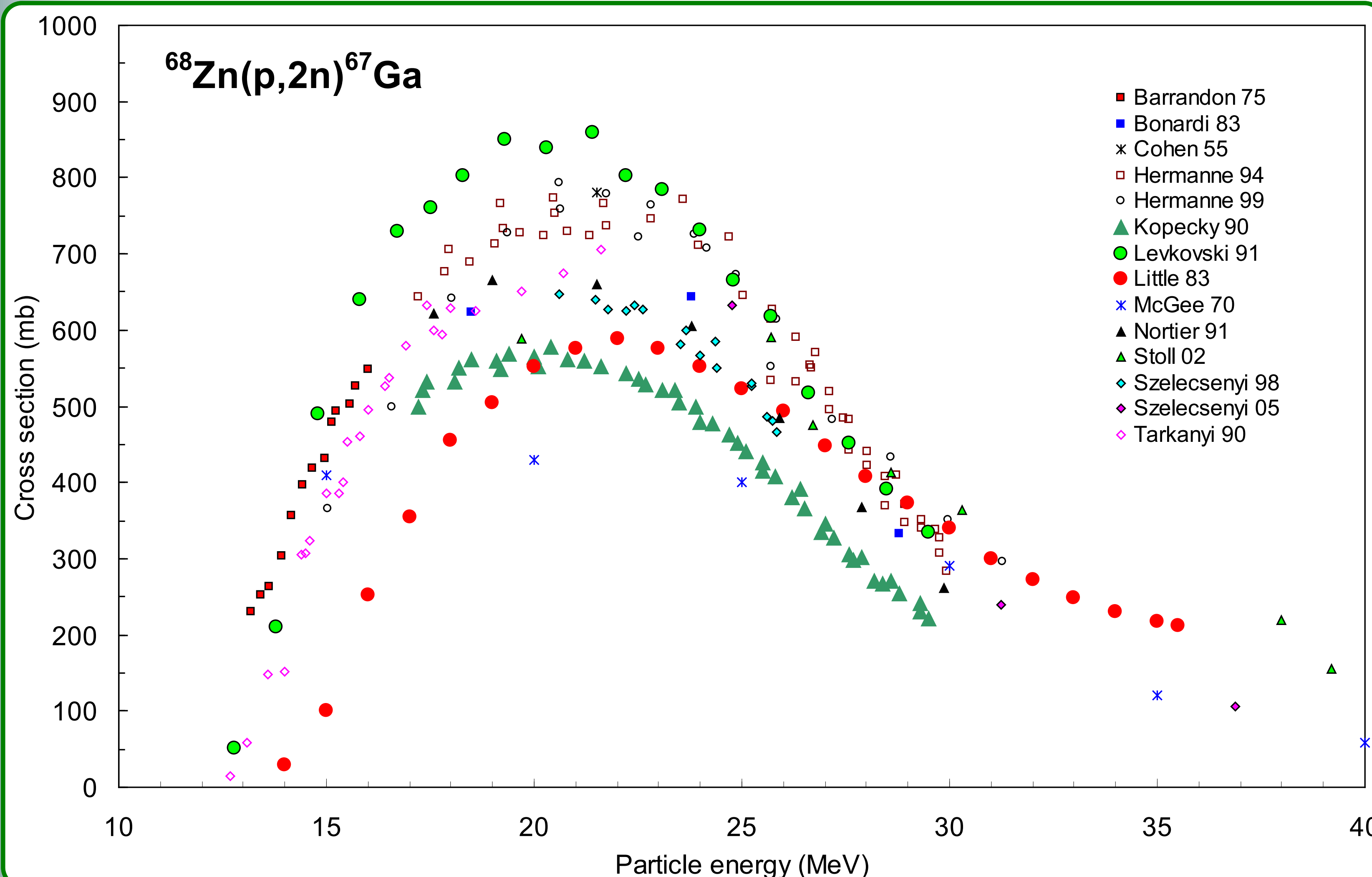
Cross section measurements of charged particle induced reactions: Possible systematic errors

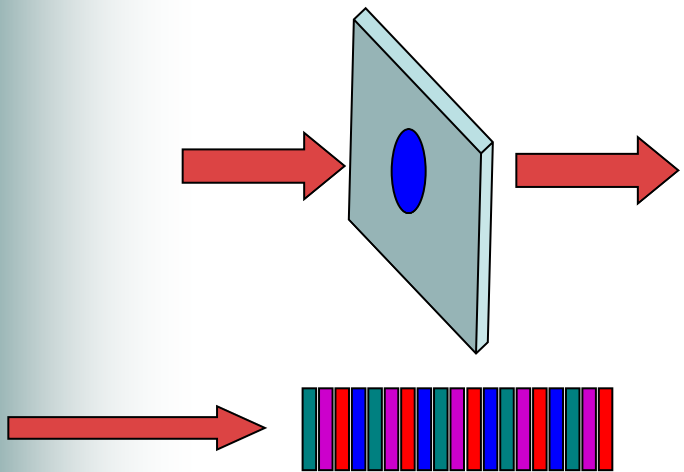
Sándor Takács

Institute for Nuclear Research, Hungarian Academy of Sciences (ATOMKI), Debrecen, Hungary

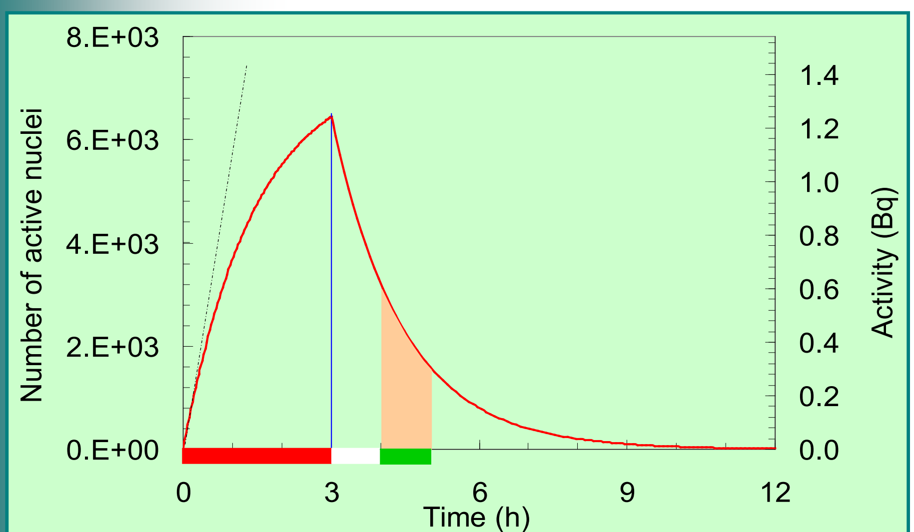
Evaluation of experimental data



Activation technique



$$N(t) = N_t N_b \sigma \frac{1}{\lambda}\left(1 - e^{-\lambda t_b}\right)$$

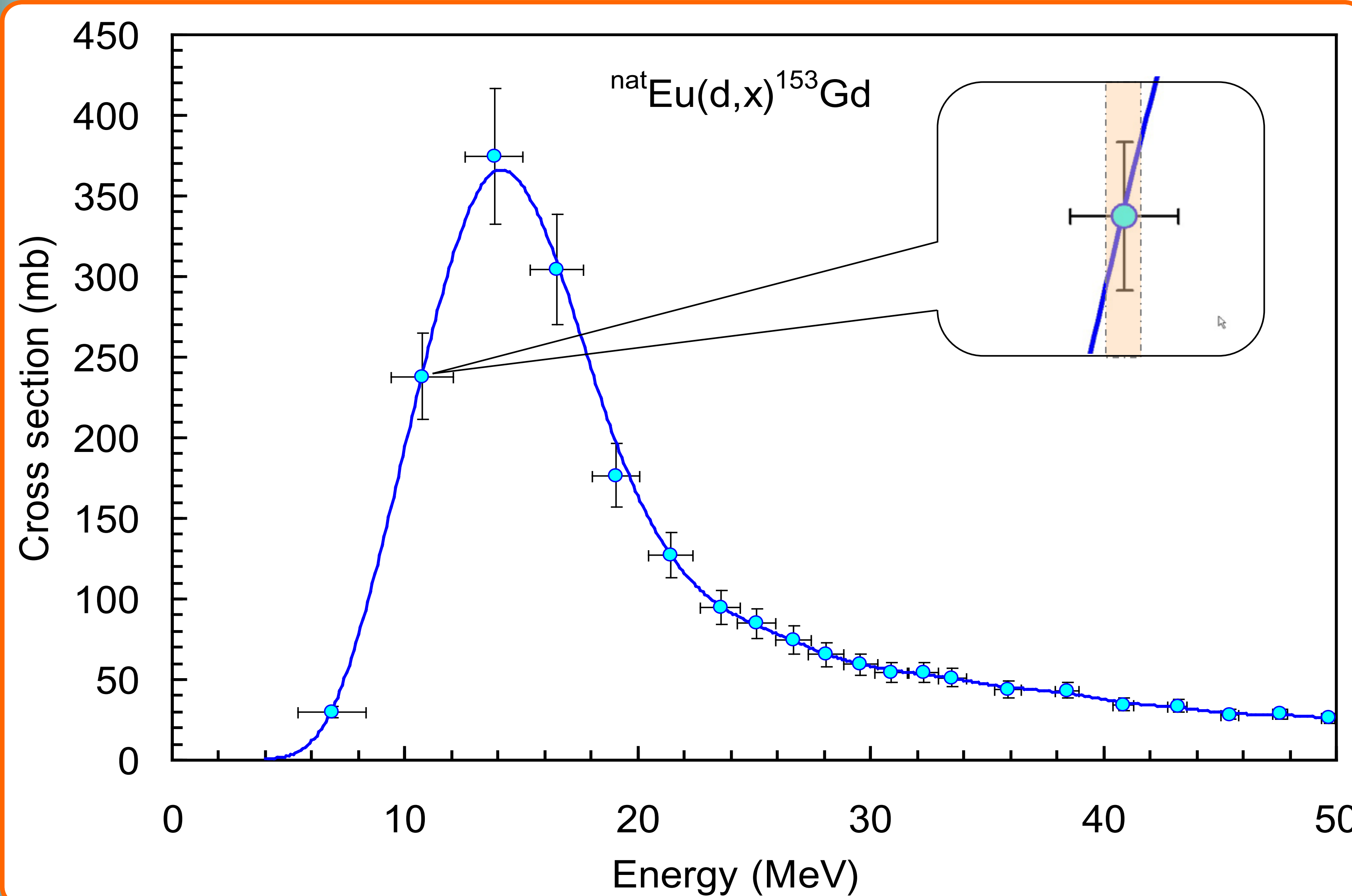


- N_t number of target nuclei on a unit area ($1/cm^2$)
- N_b number of bombarding particle for unit time (1/s) (constant)
- λ decay constant (1/s)
- t_b irradiation time (s)
- σ cross section (mb)

$$T_\gamma = \varepsilon_d \varepsilon_\gamma \Delta N$$

$$T_\gamma = \varepsilon_d \varepsilon_\gamma \Delta N = \varepsilon_d \varepsilon_\gamma N_t N_b \sigma \frac{1}{\lambda}\left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c}\left(1 - e^{-\lambda t_m}\right)$$

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c}\left(1 - e^{-\lambda t_m}\right)}$$



natEu(d,x)153Gd
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
450
0
10
20
30
40
50

How does the systematic error of different parameters influence the final result?

- Number of events counted ***N*** (peak area, background, interferences)
- Beam current ***I*** *(μA)* (black current, secondary electrons, fluctuation)
- Incident beam charge ***Q*** *(mC)*
- Incident energy ***E*** *(MeV)* (incident energy, stopping, straggling)
- Number of target nuclei per unit volume ***n*** $(1/cm^3)$ (density)
- Target thickness ***x*** *(cm)* (average thickness, surface roughness)
- Detector solid angle ***ΔΩ*** *(sr)*
- Detector efficiency ε_d (geometry factor)
- Irradiation time t_b *(s)*
- Cooling time t_c *(s)* (should be optimized)
- Measuring time t_m *(s)* (live time, real time, dead time)

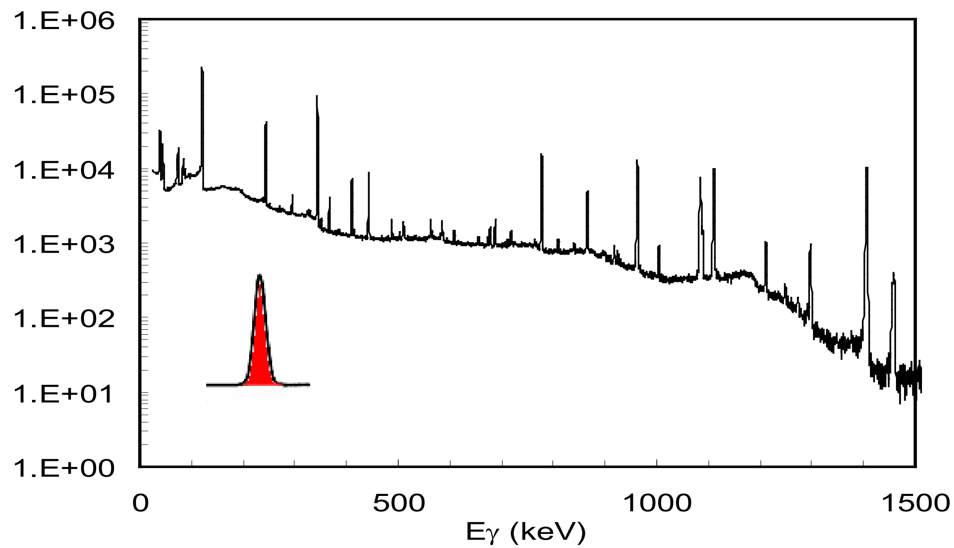
Nuclear data used

- Half life $T_{1/2}$ *(s)*
- Decay branching ratio ε_d (%)
- Gamma energy ***E*** *(MeV)*
- Gamma intensity I_γ *(%)*
- Target isotope abundance I_t *(%)*
- Reference cross sections (monitor reactions)

- *Data can be taken from different on-line libraries*

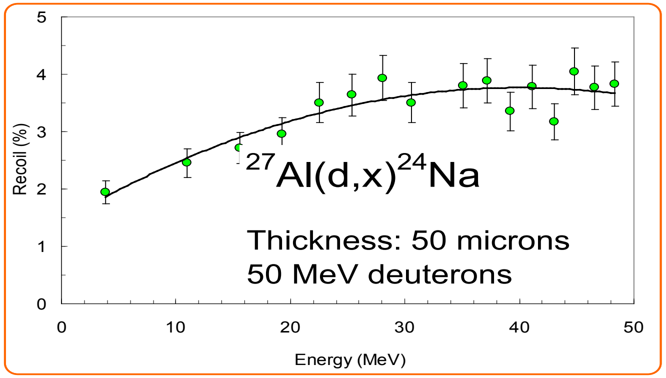
Peak area

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$



Corrected peak area:

- background
- dead time
- summing
- self-absorption
- random coincidence
- interference, etc.
- recoil effect



Peak area contributes linearly to the cross section,
Easy to correct during evaluation
Generally not published
Specific for the experiment

Detector efficiency

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Detector efficiency

For medical isotopes $E\gamma < 200$keV

General values 3 – 7 %

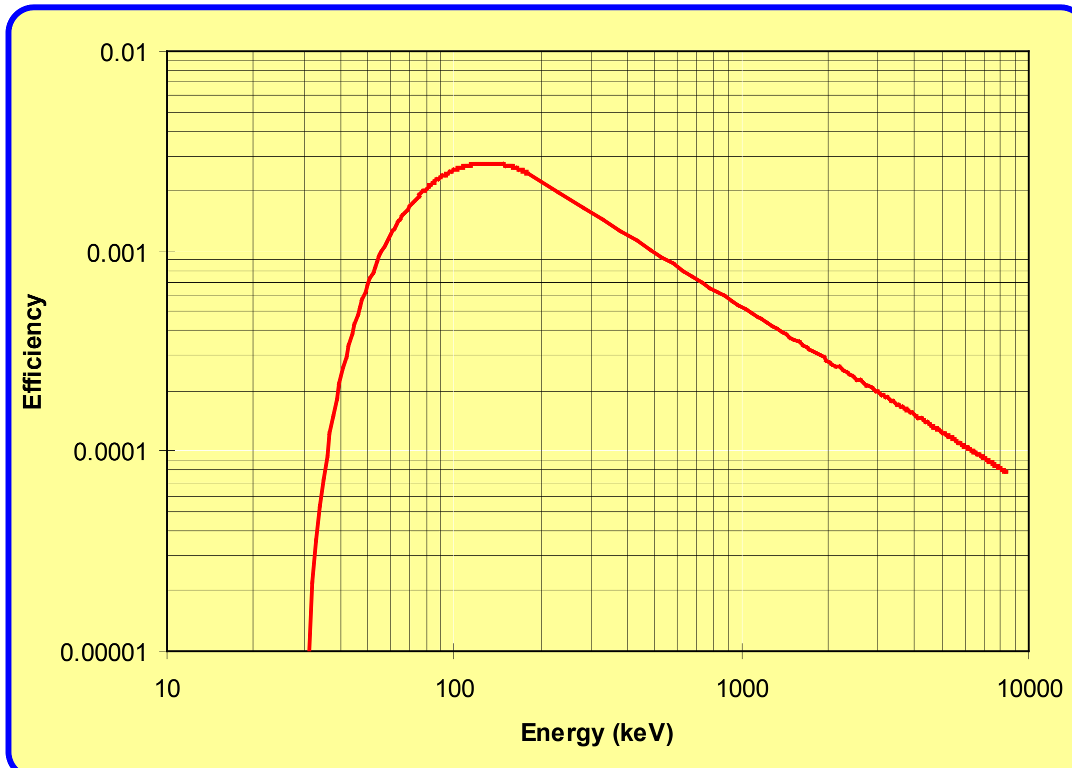
Low energy, can be above 10 %

Contributes linearly

Easy to correct

Generally not published

Specific for the experiment

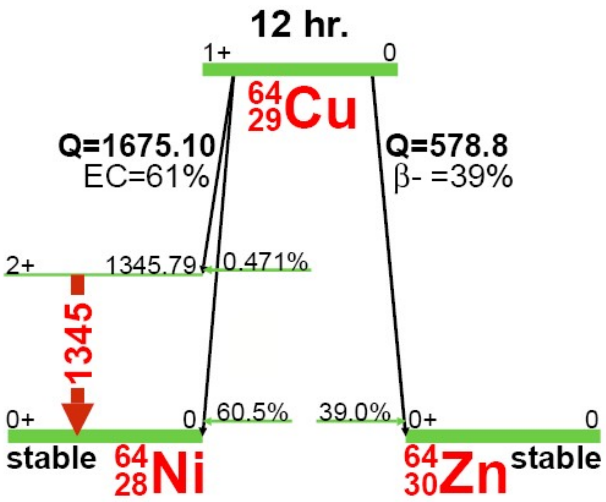


Branching ratios

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Gamma branching ratio

Taken from data libraries
Contributes linearly
Easy to correct
Generally published
Not experiment specific

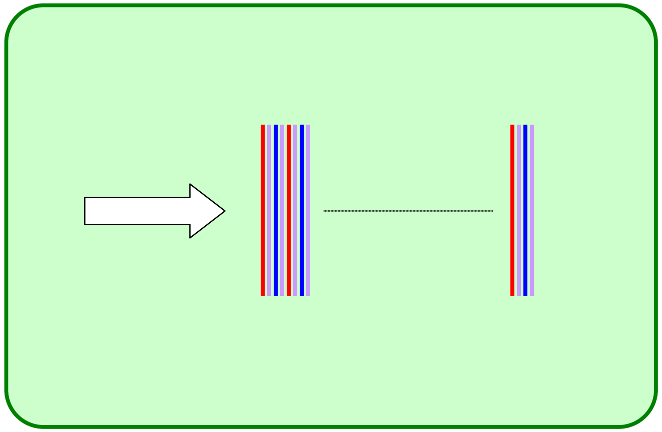


Target nuclides

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Number of target nuclides

Can be determined by different methods
Contributes linearly
Generally published
Average thickness, surface roughness, pin holes, cracks, deformation
Easy to correct (influences the energy scale)
Specific for the experiment

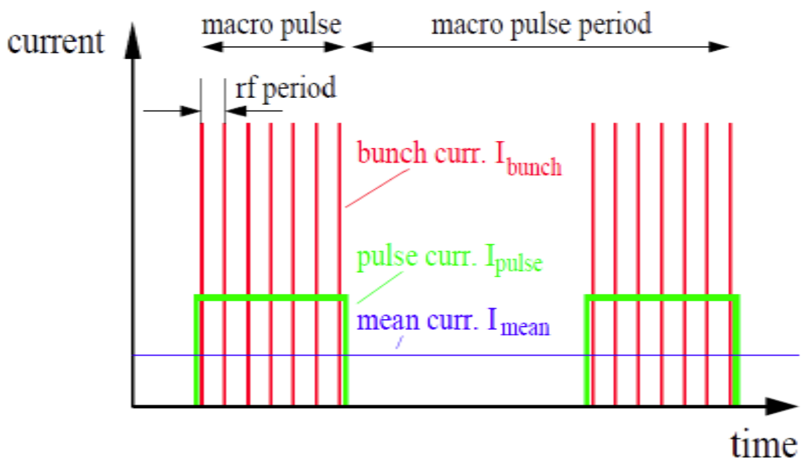


Beam current

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Number of bombarding particles

Determined from the
collected charge or beam current
Contributes linearly
Generally published
Easy to correct
Specific for the experiment



Time dependence

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Irradiation time
Cooling time
Measuring time

Do not contribute linearly

Generally t_b is given, t_c and t_m are not given

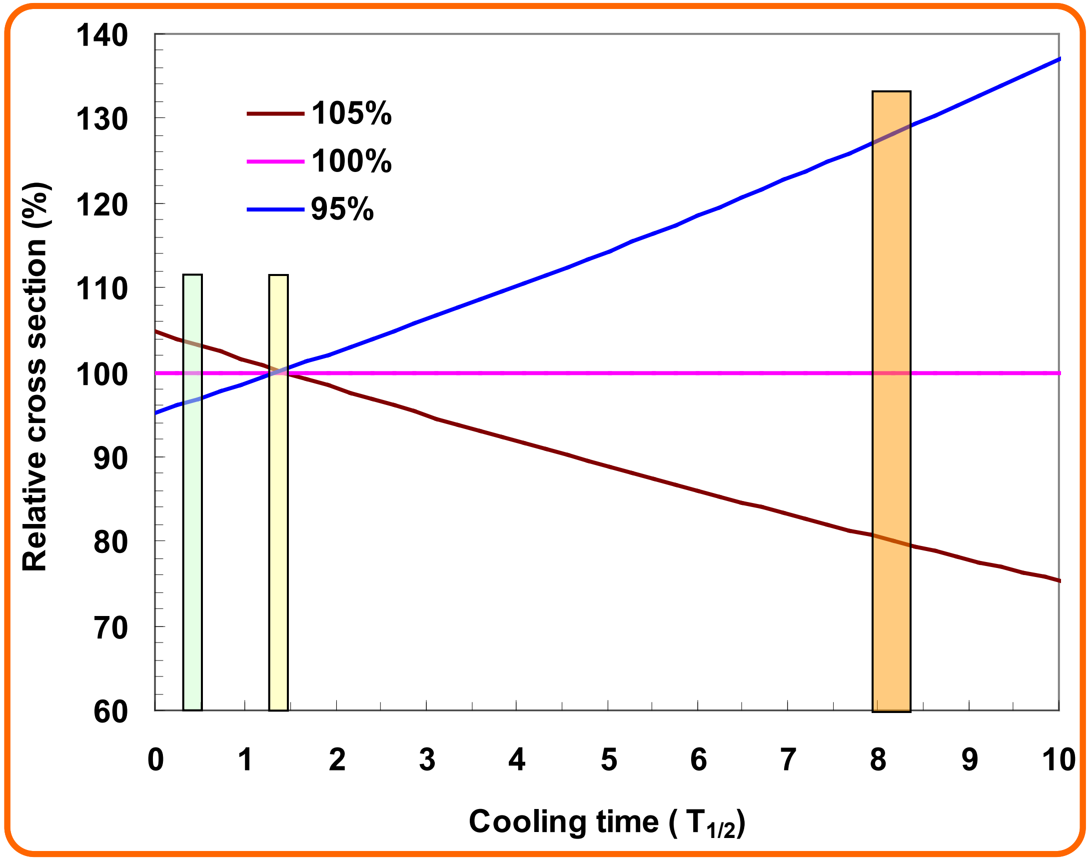
Correction is not easy

Considering the half lives of medical radio isotopes the possible systematic errors of time parameters is minimal.

Uncertainty of half life

$$\sigma = \frac{T_\gamma \lambda}{\varepsilon_d \varepsilon_\gamma N_t N_b \left(1 - e^{-\lambda t_b}\right) e^{-\lambda t_c} \left(1 - e^{-\lambda t_m}\right)}$$

Do not contribute linearly
Taken from data libraries
Generally published
In the lack of time information **correction is not easy**



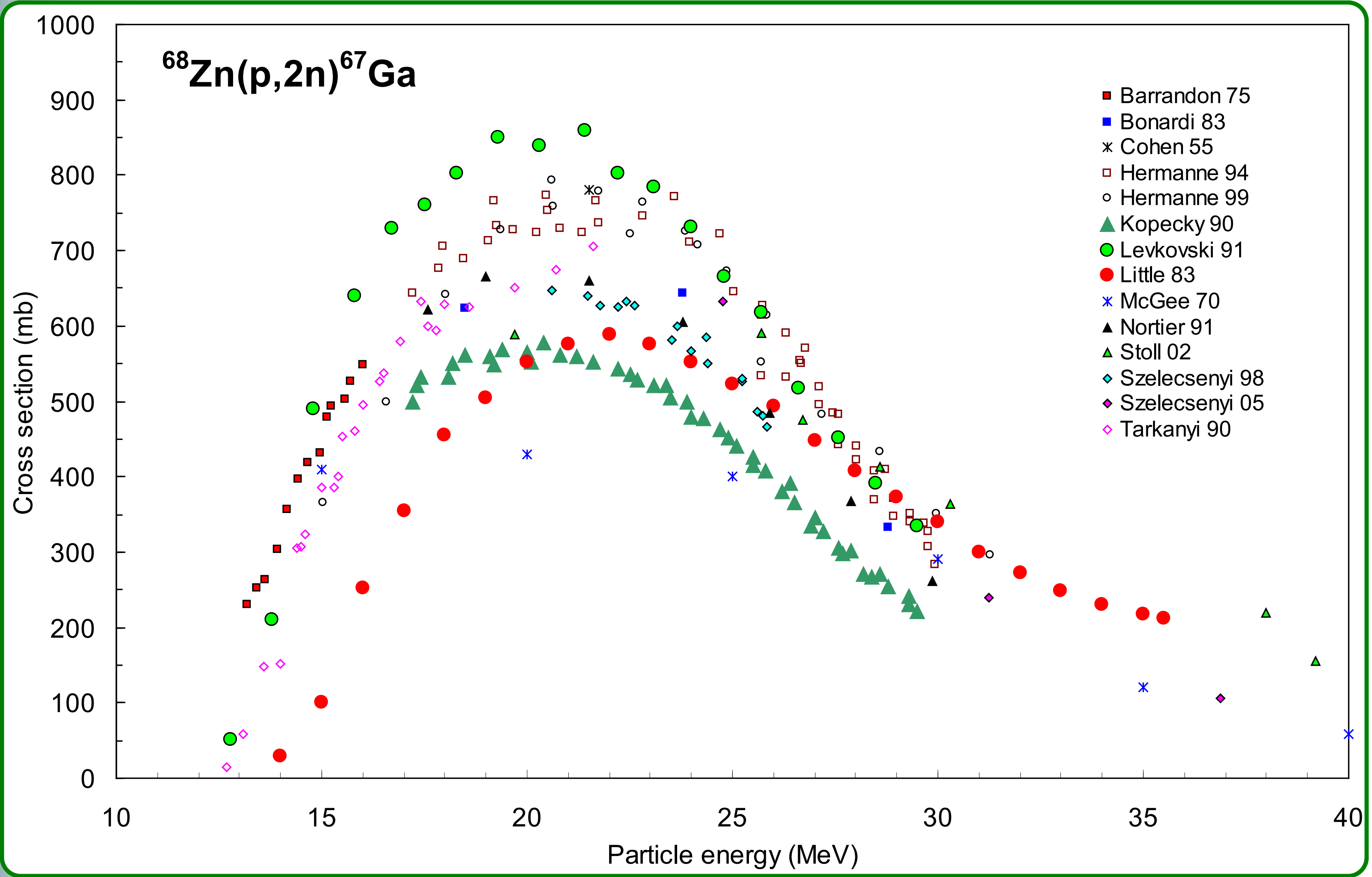
irradiation time: $0.1 * T_{1/2}$
measuring time: $0.1 * T_{1/2}$

Reactions for monitoring of proton beams

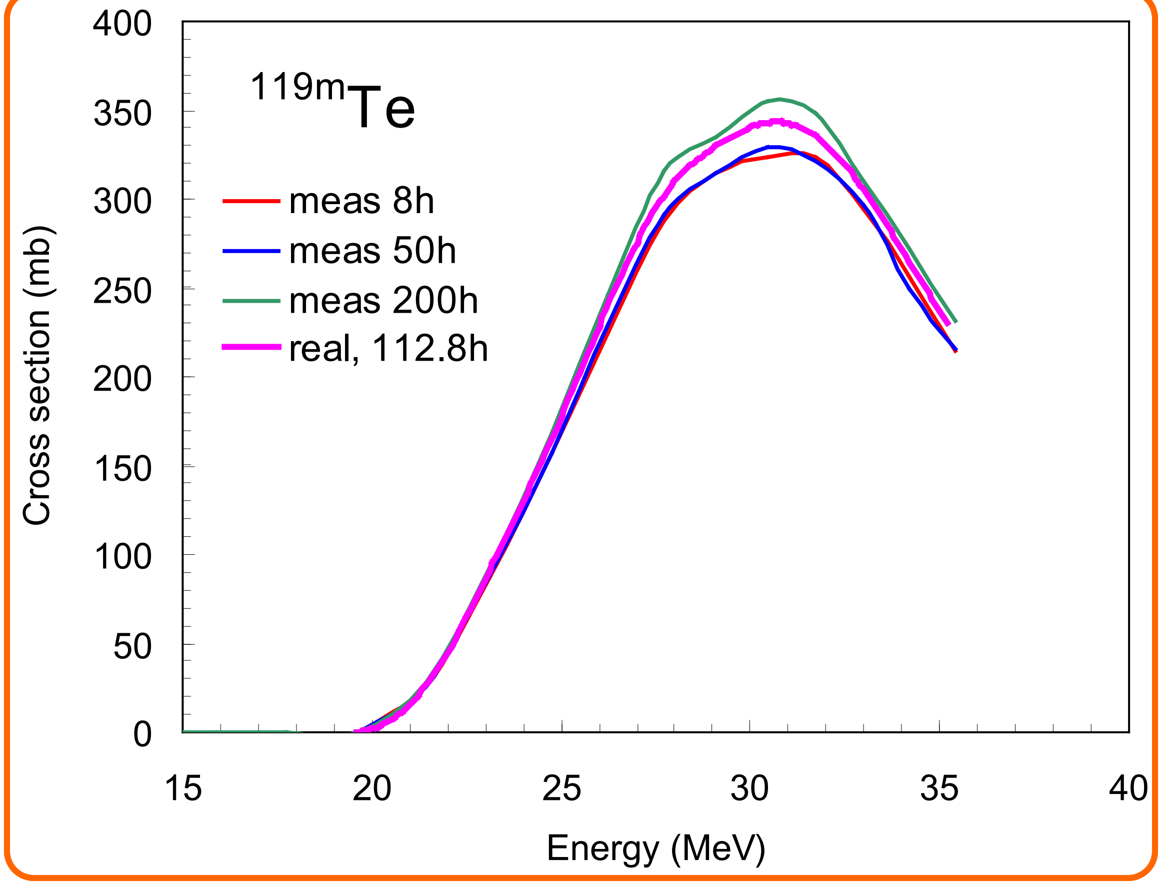
Reaction	$T_{1/2}$ of product nucleus		E_γ (MeV)	I_γ (%)		Useful range (MeV)
$^{27}Al(p,x)^{24}Na$	14.96 h	14.997 h	1368.6	100		30 - 100
$^{27}Al(p,x)^{22}Na$	2.6y		1274.5	99.94		30 - 100
$^{nat}Ti(p,x)^{48}V$	15.98 d		983.5 1312.0	99.99 97.49	99.98 98.2	4.5 - 30
$^{nat}Ni(p,x)^{57}Ni$	1.5 d	1.48 d	1377.6 127.2	77.9 12.9	81.7 16.7	15 - 50
$^{nat}Cu(p,x)^{63}Zn$	38.1 min	38.47 min	669.8 962.2	8.4 6.6	8.2 6.5	4.5 - 50
$^{nat}Cu(p,x)^{62}Zn$	9.26 h	9.18 h	596.7	25.7	26	14 - 60
$^{65}Cu(p,n)^{65}Zn$	244.1 d	243.93 d	1115.5	50.75	50.04	3 - 100

Changes in nuclear data TECDOC - NuDat2.7 (2013)

Experimental data with uncovered systematic errors

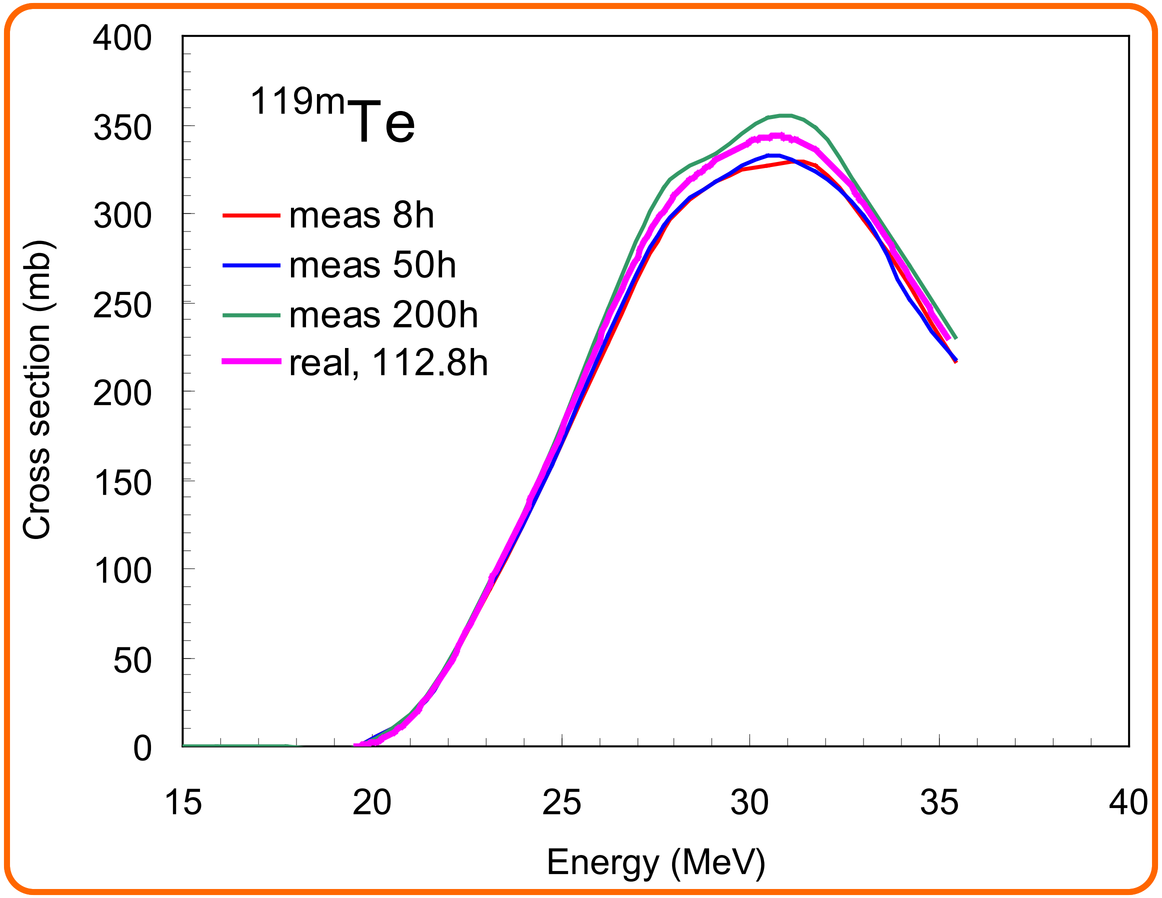


95%

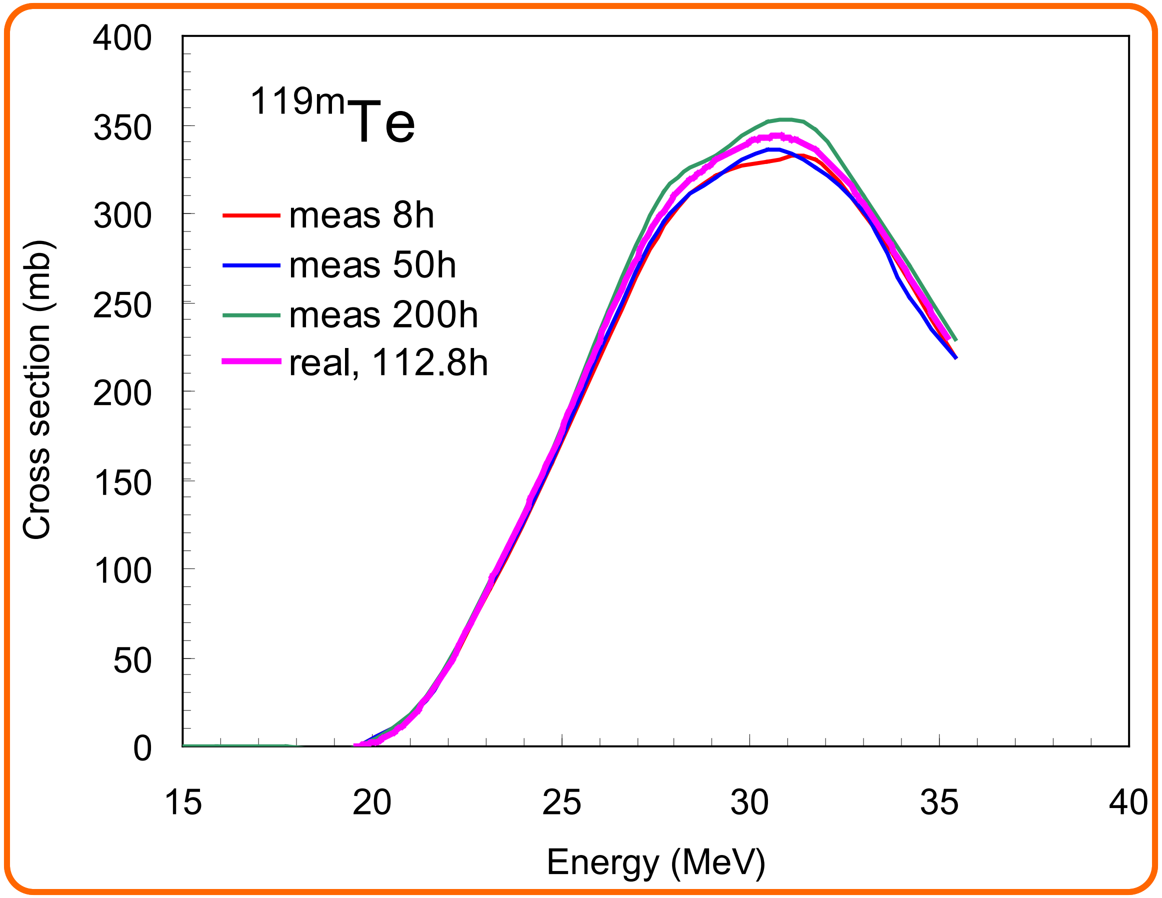


^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
400
350
300
250
200
150
100
50
0
15
20
25
30
35
40

96%

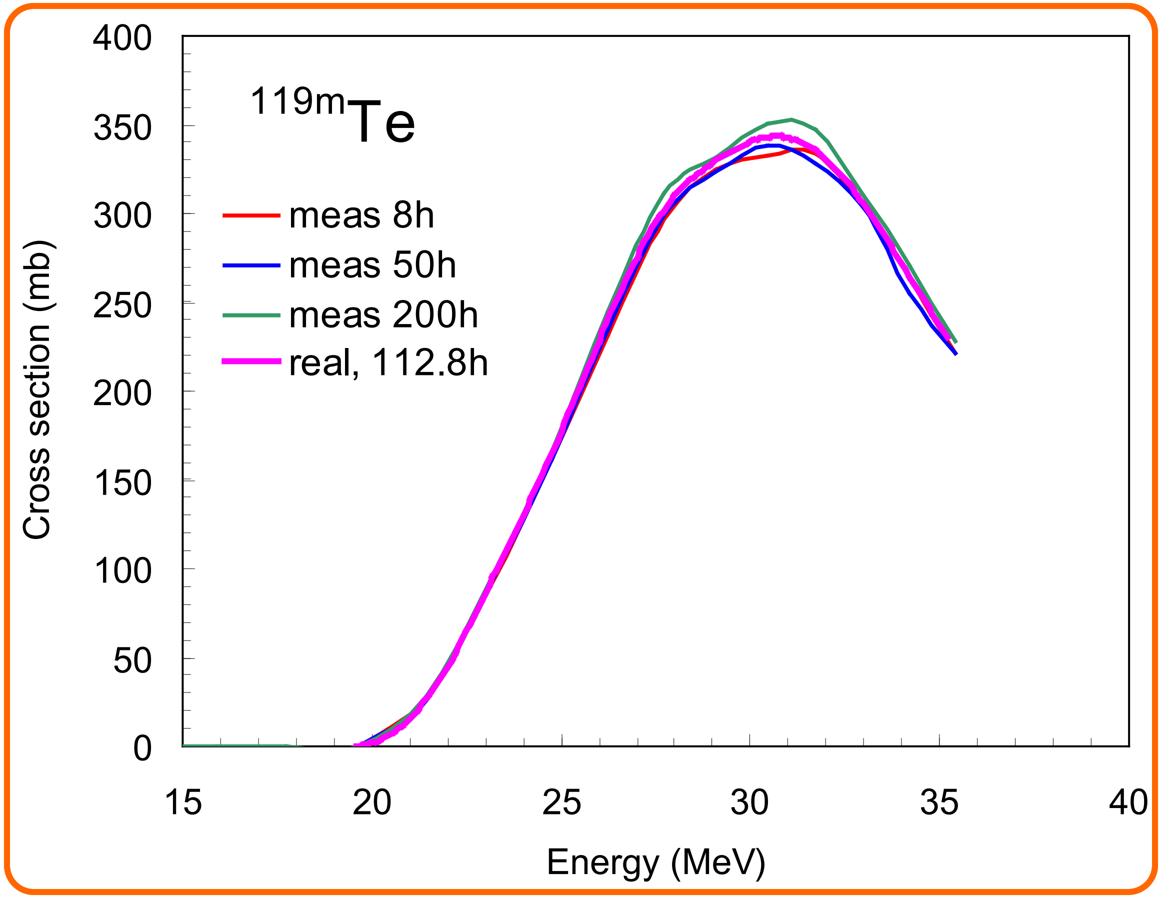

400
350
300
250
200
150
100
50
0
Cross section (mb)
^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
15
20
25
30
35
40
Energy (MeV)

97%



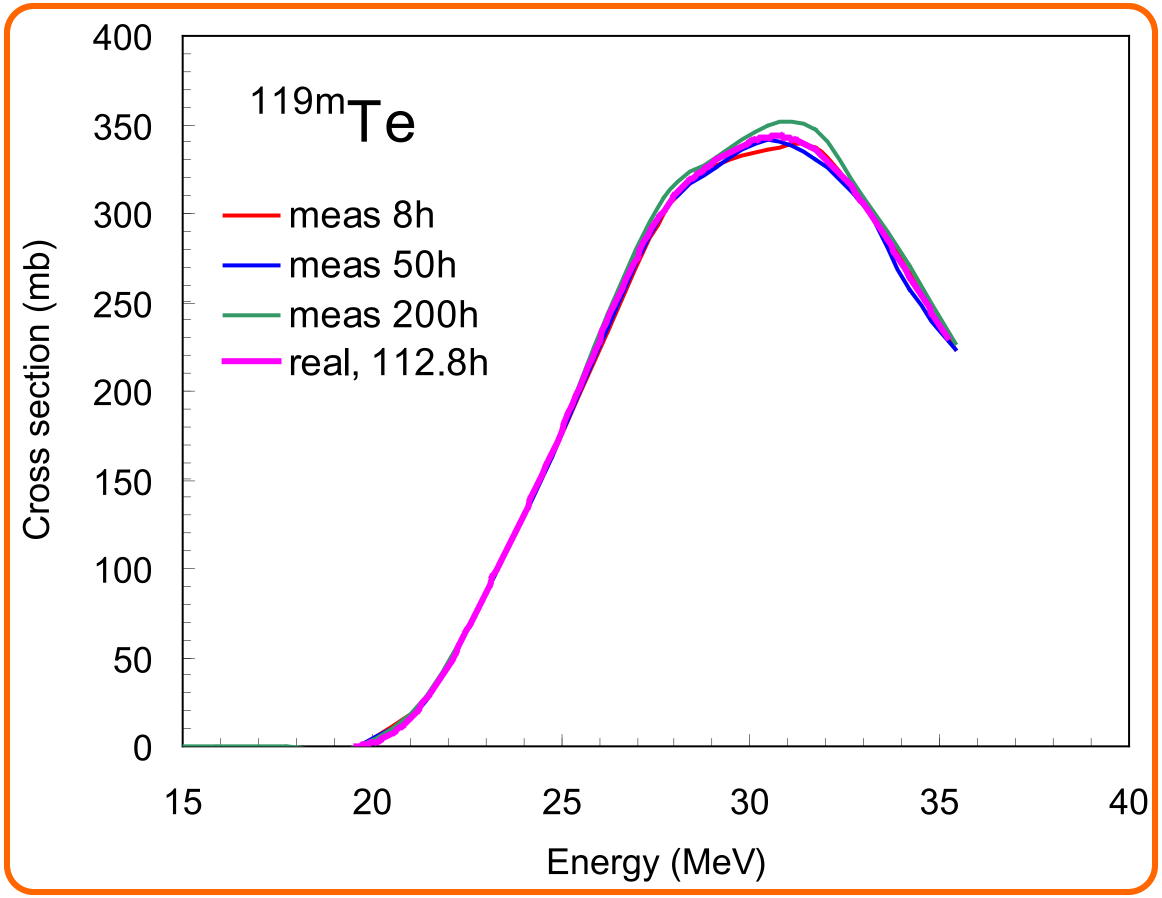
400
350
300
250
200
150
100
50
0
15
20
25
30
35
40
Cross section (mb)
Energy (MeV)
119mTe
meas 8h
meas 50h
meas 200h
real, 112.8h

98%



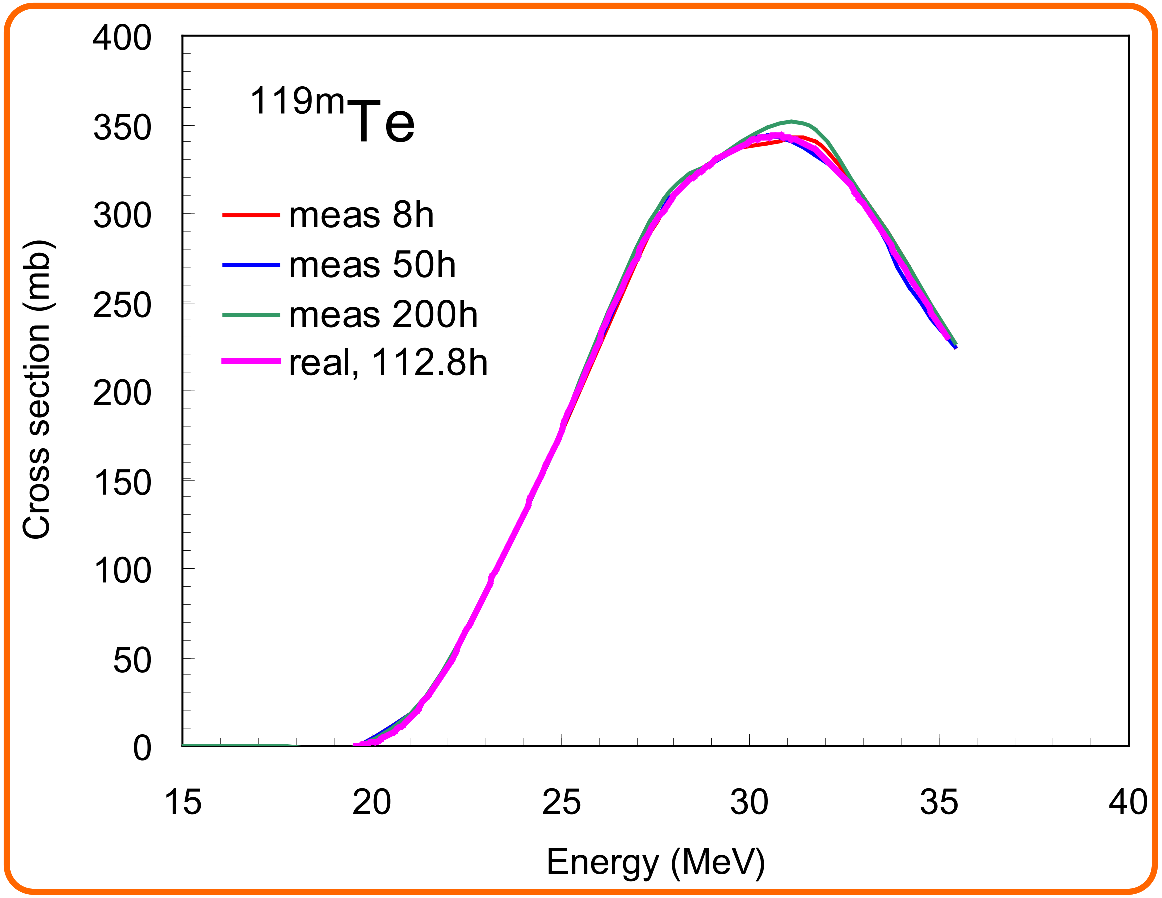
119mTe
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
15
20
25
30
35
40

99%



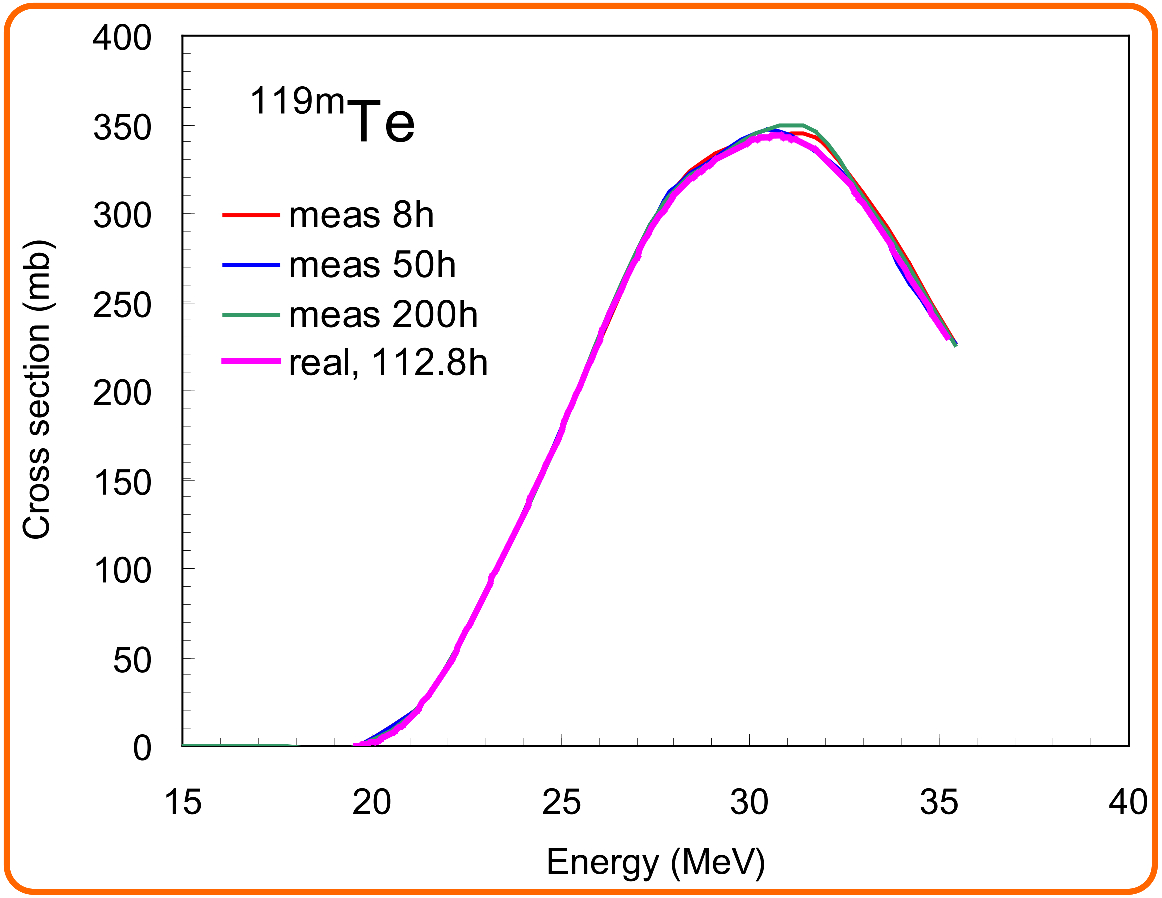
119mTe
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
15
20
25
30
35
40

100%



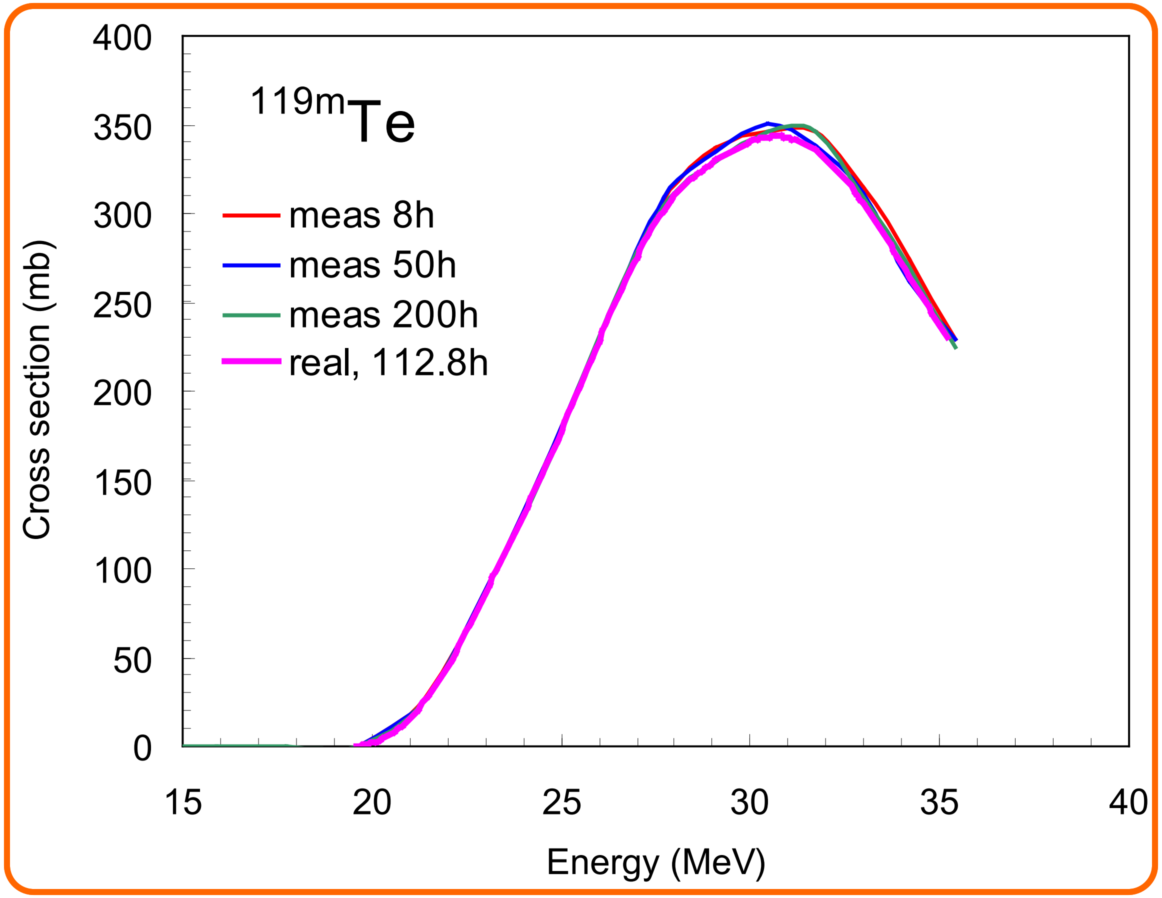
400
350
300
250
200
150
100
50
0
15
20
25
30
35
40
Cross section (mb)
Energy (MeV)
119mTe
meas 8h
meas 50h
meas 200h
real, 112.8h

101%



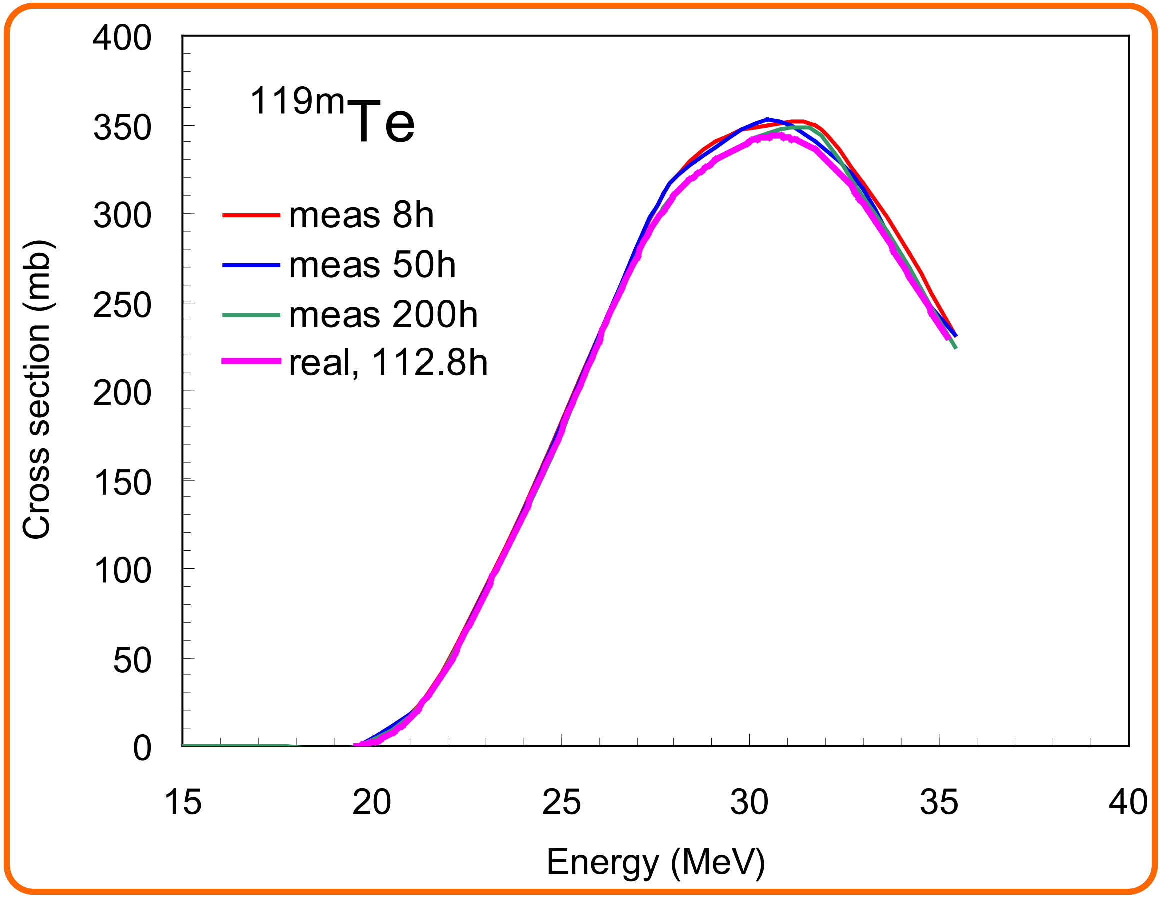
^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
15
20
25
30
35
40

102%



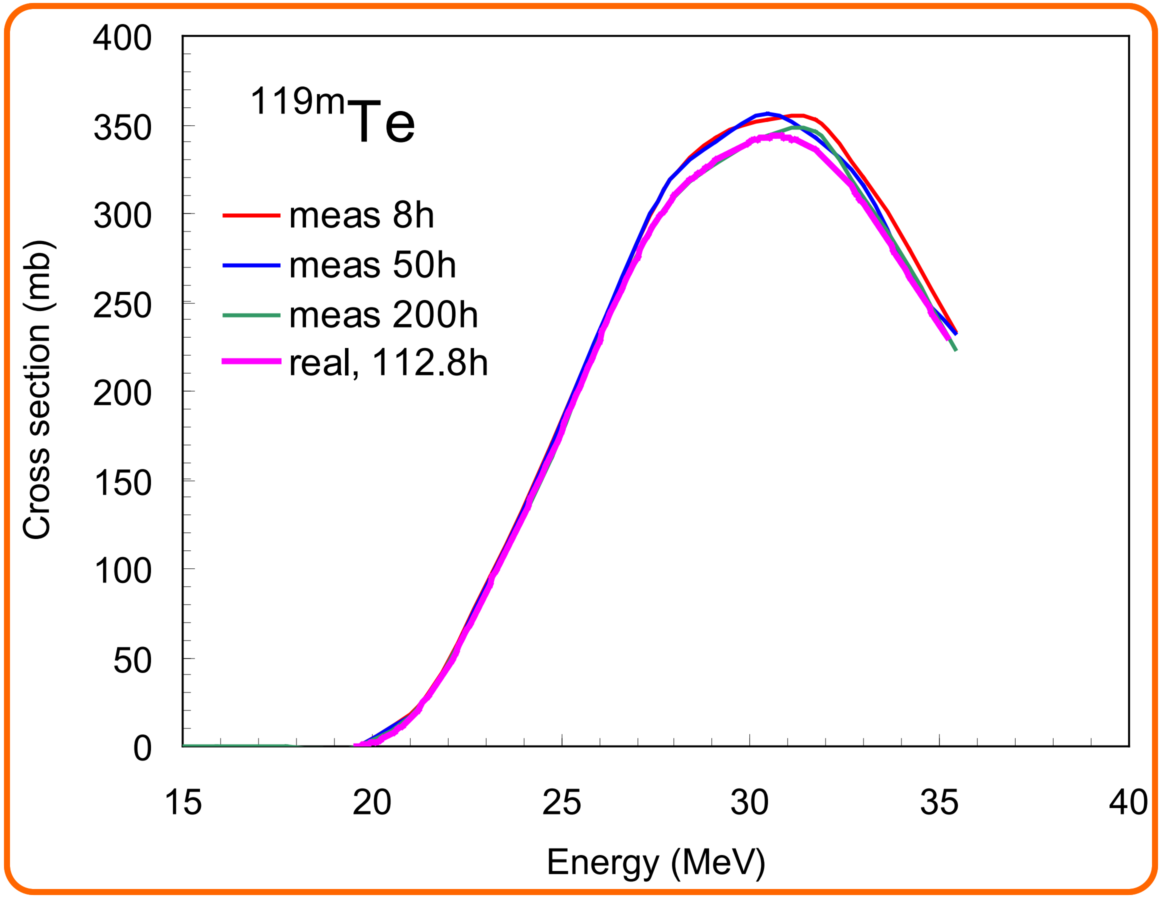
119mTe
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
15
20
25
30
35
40

103%



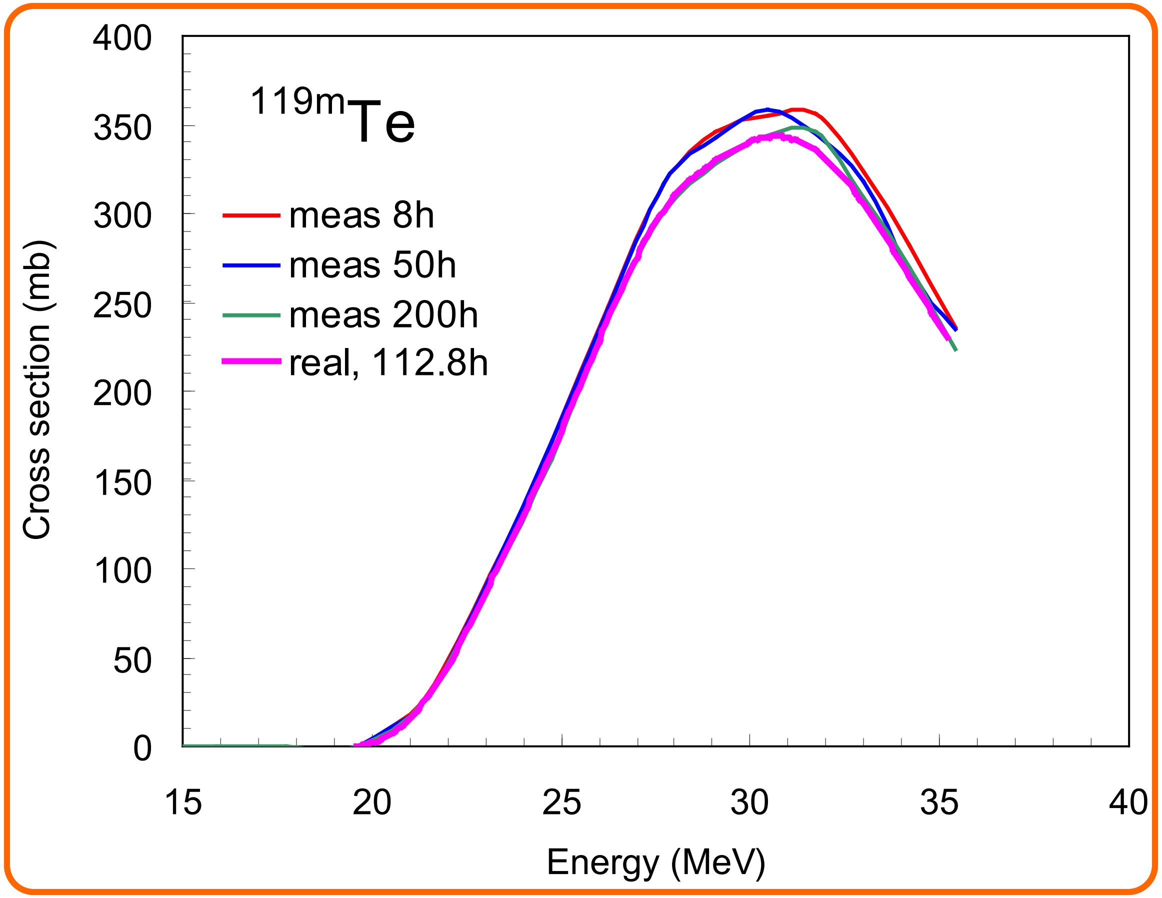
400
350
300
250
200
150
100
50
0
Cross section (mb)
^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
15
20
25
30
35
40
Energy (MeV)

104%



^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
0
50
100
150
200
250
300
350
400
15
20
25
30
35
40

105%



^{119m}Te
meas 8h
meas 50h
meas 200h
real, 112.8h
Cross section (mb)
Energy (MeV)
400
350
300
250
200
150
100
50
0
15
20
25
30
35
40

Thank you for your attention