

# Progress of implementation of the GDH model in TALYS

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## Objective

**Discussion of implementation of the GDH model in  
the TALYS-1.74 code and results of test calculations**

## The hybrid and GDH model

J.J.Griffin, 1966 : exciton model

G.D.Harp, J.M.Miller, B.J.Berne, 1968 : master-equation approach

M.Blann, 1971 : "hybrid" model

M.Blann, 1972 : "geometry dependent hybrid" model

M.Blann, H.K.Vonach, 1983 : modification and basic improvements

J.Bisplinghoff, 1986 : critical analysis. Configuration mixing

1994 : cluster emission in GDH

M.Blann, 1996 : hybrid Monte Carlo simulation (HMS)

2005 : improvement of cluster emission calculation in GDH

C.A.Soares Pompeia, B.V.Carlson, 2006 : new analysis

2010-2014 : further improvements

# The GDH model

$$\frac{d\sigma}{d\varepsilon_x} = \pi \hat{\lambda}^2 \sum_{l=0}^{\infty} (2l+1) T_l \sum_{n=n_0}^{\infty} X_n \frac{\phi(p-1, h, U)}{\phi(p, h, E)} \frac{\lambda_x^e}{\lambda_x^e + \lambda_x^+} g D_n$$

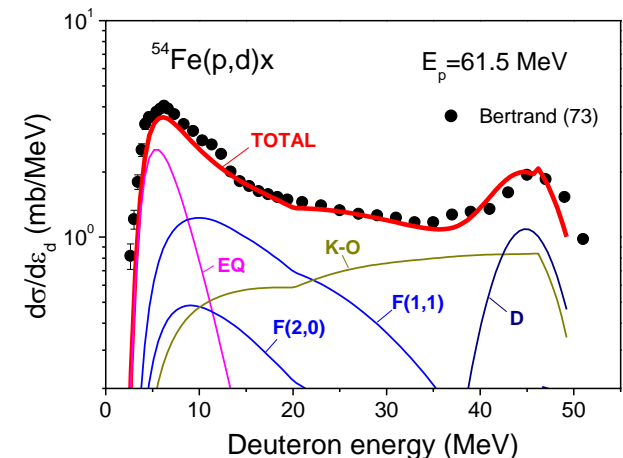
## Emission and transition rate

$$\lambda_x^e = \frac{(2S_x + 1) \mu_x \varepsilon_x \sigma_x^{\text{iny}}(\varepsilon_x)}{\pi^2 \hbar^3 g_x}$$

$$\lambda_x^+ = V \sigma_0(\varepsilon_x) \rho_l$$

## Cluster emission

$$\frac{d\sigma}{d\varepsilon_t} = \frac{d\sigma^{\text{P-U,C}}}{d\varepsilon_t} + \frac{d\sigma^{\text{K-O}}}{d\varepsilon_t} + \frac{d\sigma^{\text{D}}}{d\varepsilon_t}$$



## Exciton and hybrid model

different, sometimes close results

Uncertainty of calculated cross-sections, particle distributions etc.

## GDH + TALYS

TALYS-1.0, 2009

TALYS-1.2, 2011

TALYS-1.74

**TALYS-1.0**  
**(p,x) reactions, targets Z=12-83,**  
**E<sub>p</sub> up to 150 MeV, N = 16,045**

Factors	default models	GDH
$H = \left( \frac{1}{N} \sum_{i=1}^N \left( \frac{\sigma_i^{\text{exp}} - \sigma_i^{\text{calc}}}{\Delta \sigma_i^{\text{exp}}} \right)^2 \right)^{0.5}$	20.3	20.9
$R^{\text{CE}} = \frac{1}{N} \sum_{i=1}^N \frac{\sigma_i^{\text{calc}}}{\sigma_i^{\text{exp}}}$	1.24	1.27
$R^{\text{EC}} = \frac{1}{N} \sum_{i=1}^N \frac{\sigma_i^{\text{exp}}}{\sigma_i^{\text{calc}}}$	2.33	1.98
$S = 10 \left\{ \left[ \frac{\sum_{i=1}^N \left[ \lg(\sigma_i^{\text{exp}}) - \lg(\sigma_i^{\text{calc}}) \right]^2}{\sum_{i=1}^N \left[ \frac{\sigma_i^{\text{exp}}}{\Delta \sigma_i^{\text{exp}}} \right]^2} \right] \left[ \frac{\sum_{i=1}^N \left[ \frac{\sigma_i^{\text{exp}}}{\Delta \sigma_i^{\text{exp}}} \right]^2}{N} \right]^{-1} \right\}^{1/2}$	1.33	1.33

GDH in TALYS-1.74

added subprograms: 55

modified ALICE/ASH subprograms: 30

new subroutines: 10

modified TALYS subroutines: 6

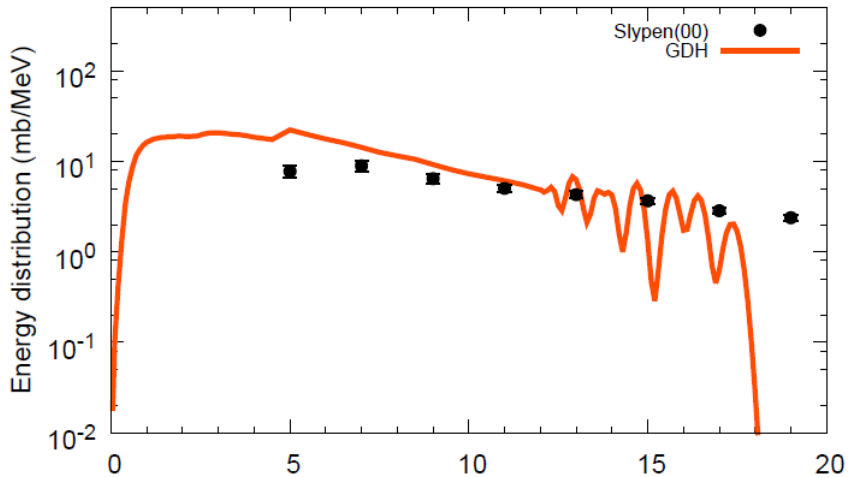
Memory load: +0.15 %

GDH: mpreeqmode=5

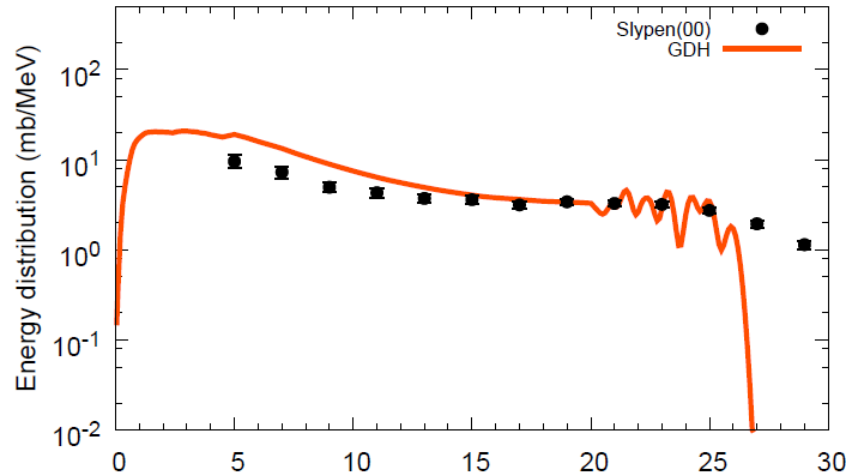
different GDH options: subroutine gdhinput

# Nucleon energy distributions

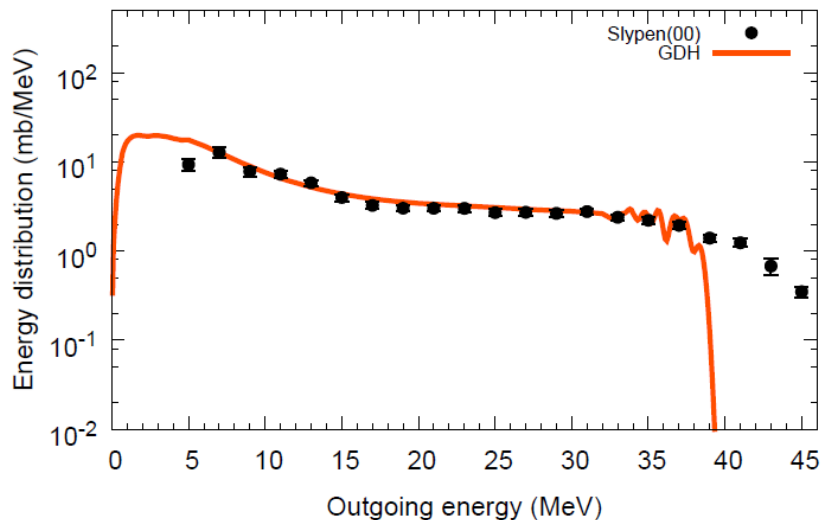
$^{12}\text{C}(n,xp)$ ,  $E_n=32.5$  MeV



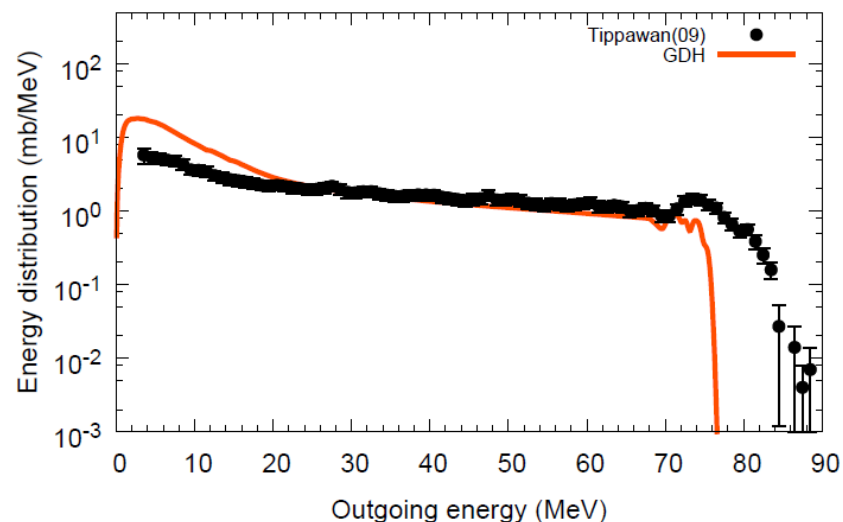
$^{12}\text{C}(n,xp)$ ,  $E_n=41.8$  MeV



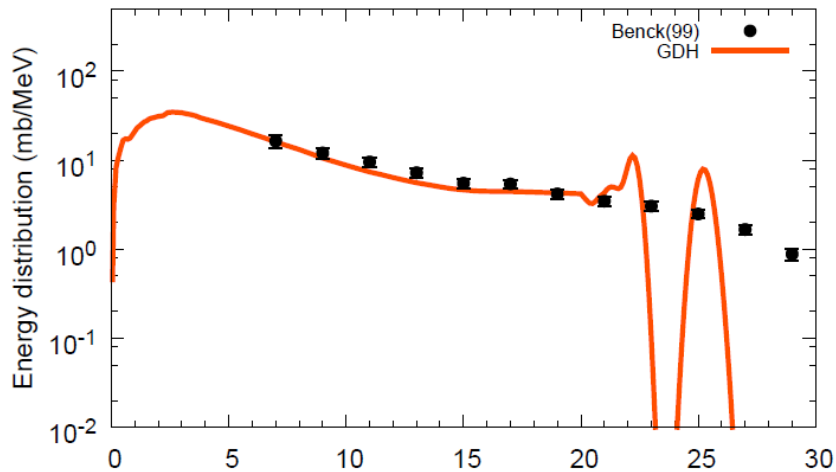
$^{12}\text{C}(n,xp)$ ,  $E_n=55.3$  MeV



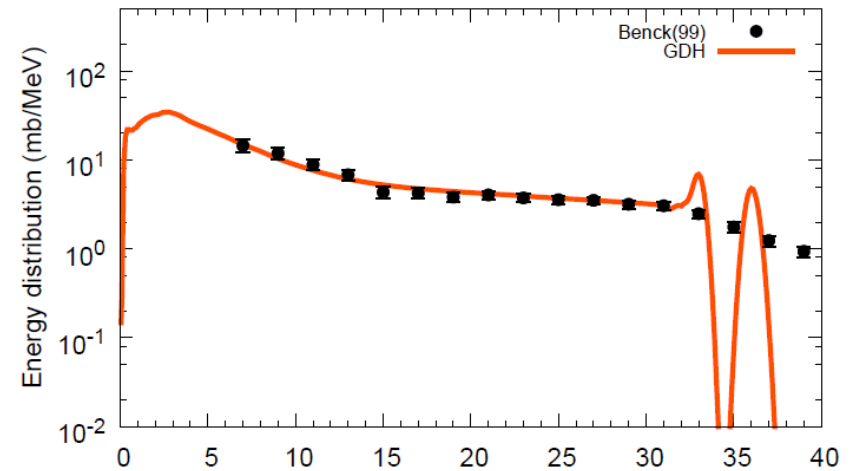
$^{12}\text{C}(n,xp)$ ,  $E_n=95.6$  MeV



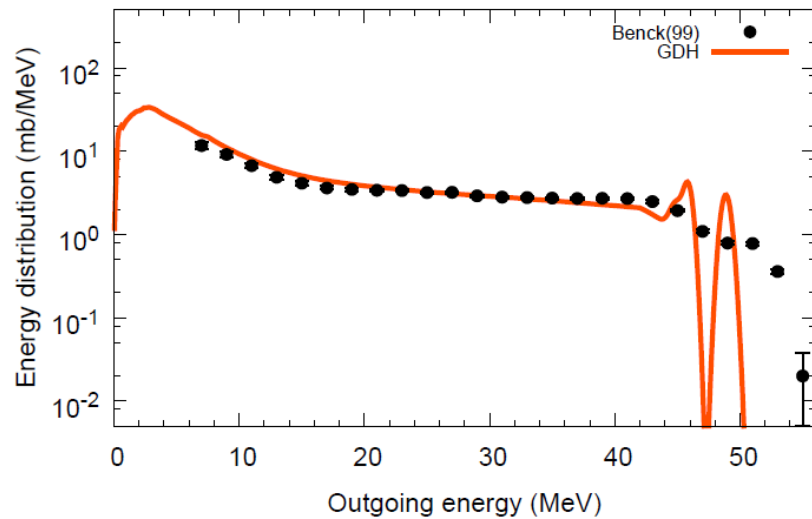
$^{16}\text{O}(n,xp)$ ,  $E_n=37.5$  MeV



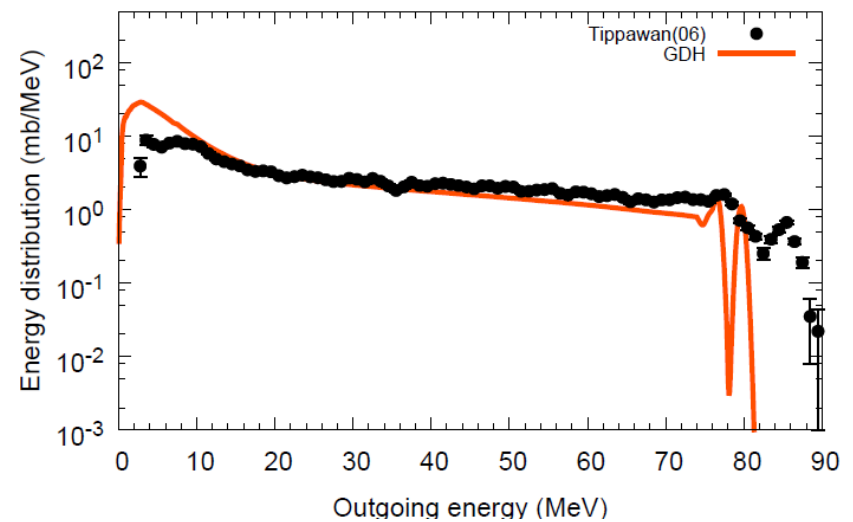
$^{16}\text{O}(n,xp)$ ,  $E_n=49$  MeV



$^{16}\text{O}(n,xp)$ ,  $E_n=62.7$  MeV

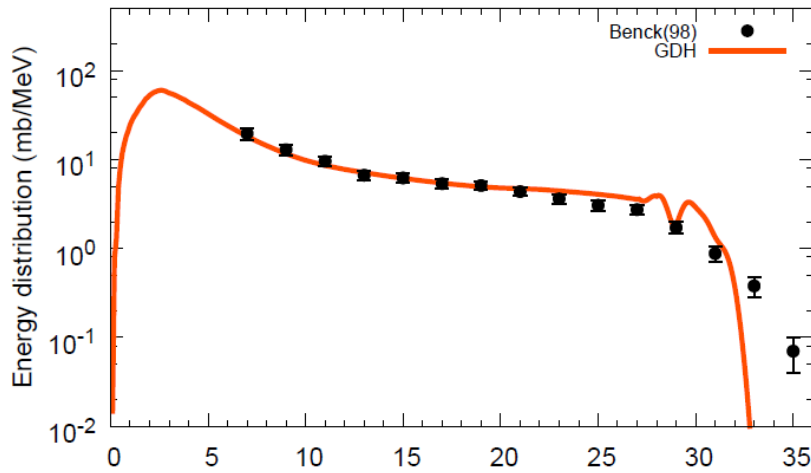


$^{16}\text{O}(n,xp)$ ,  $E_n=95.6$  MeV

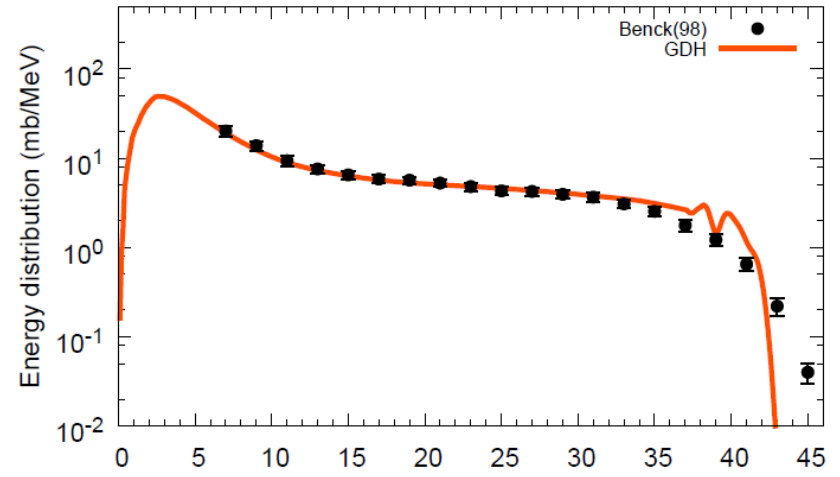




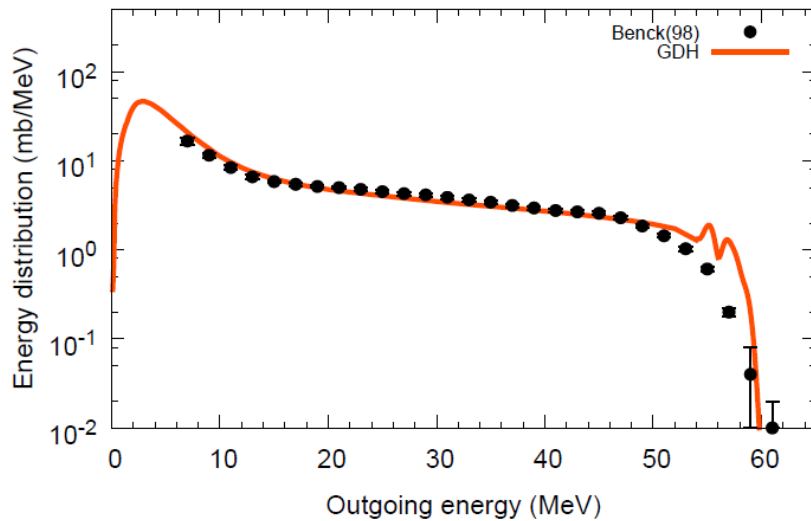
$^{27}\text{Al}(n, xp)$ ,  $E_n=34.5$  MeV



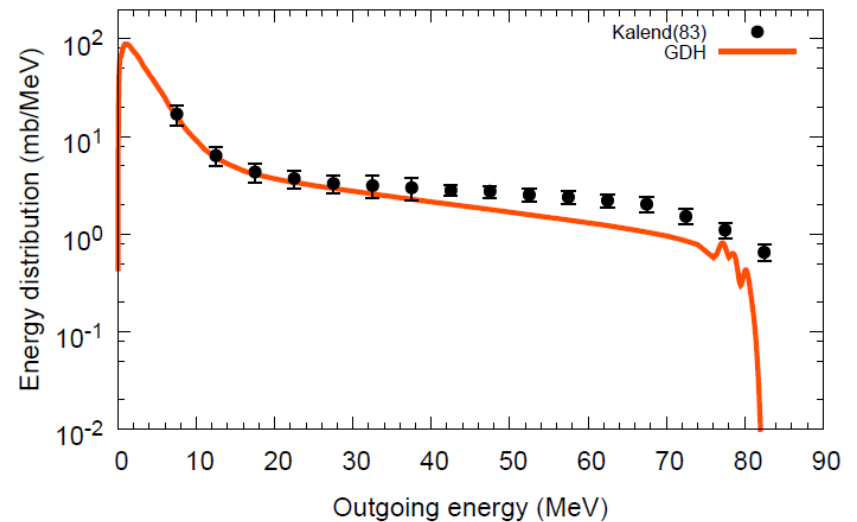
$^{27}\text{Al}(n, xp)$ ,  $E_n=45$  MeV



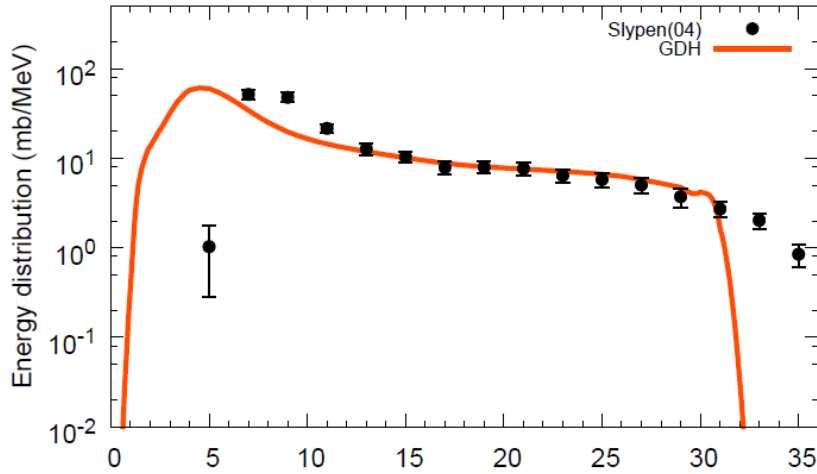
$^{27}\text{Al}(n, xp)$ ,  $E_n=62.7$  MeV



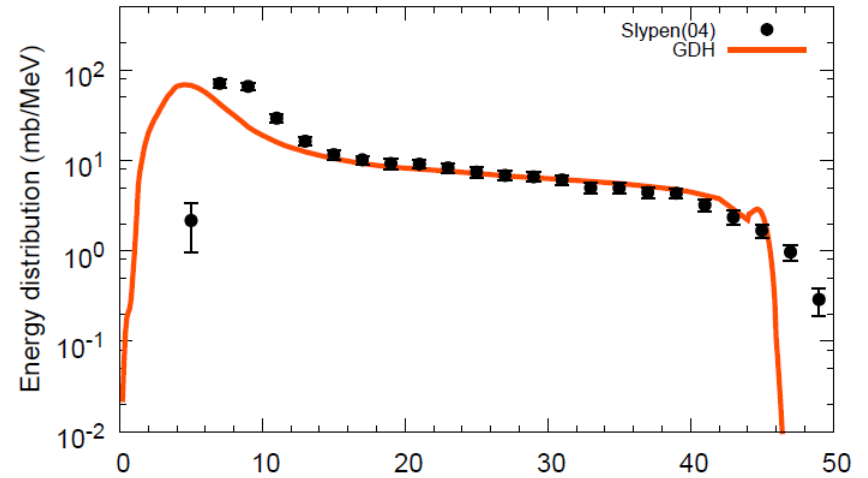
$^{27}\text{Al}(p, xn)$ ,  $E_p=90$  MeV



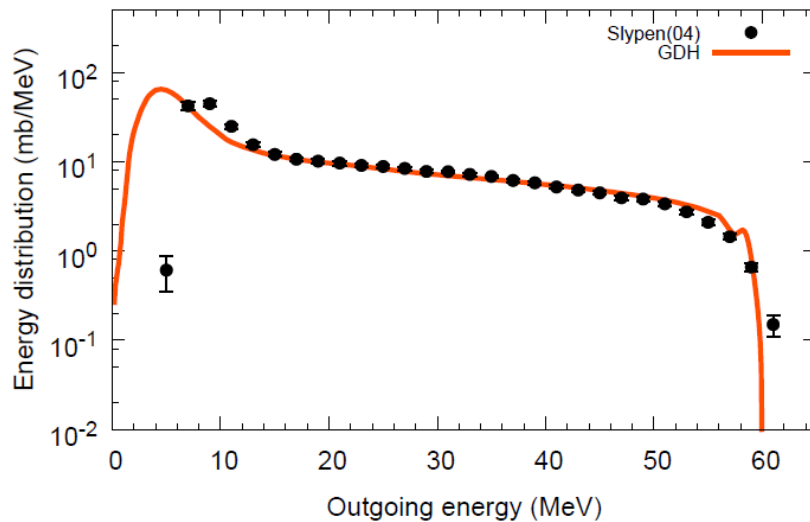
$^{56}\text{Fe}(n,xp)$ ,  $E_n=34.5$  MeV



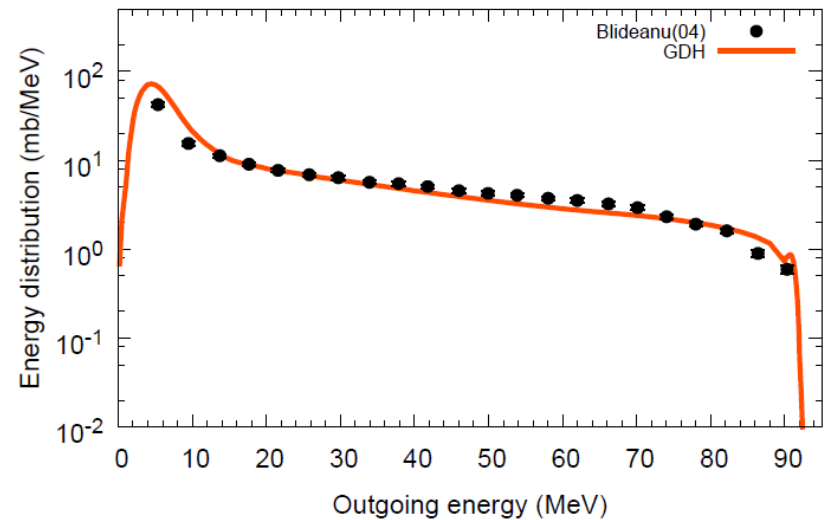
$^{56}\text{Fe}(n,xp)$ ,  $E_n=49$  MeV

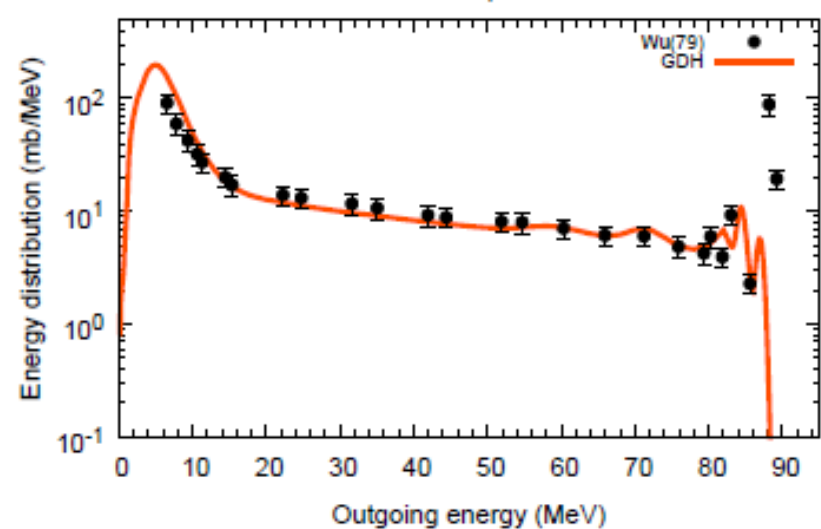
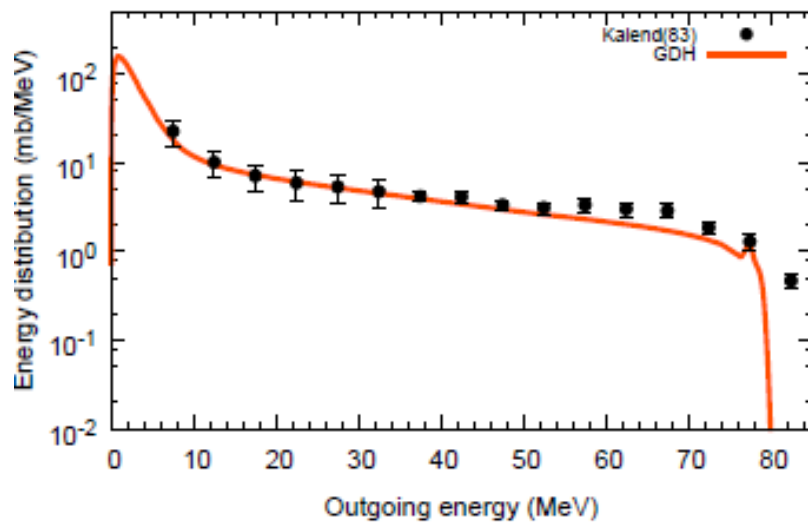
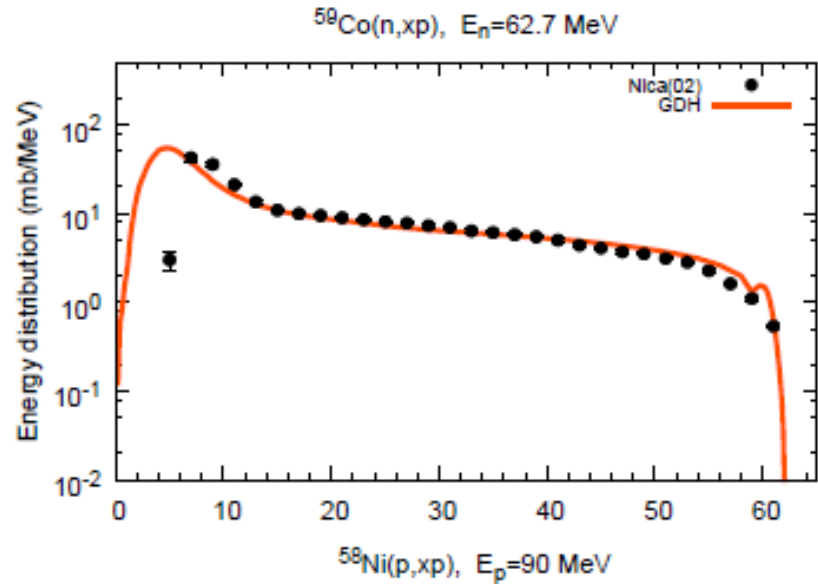
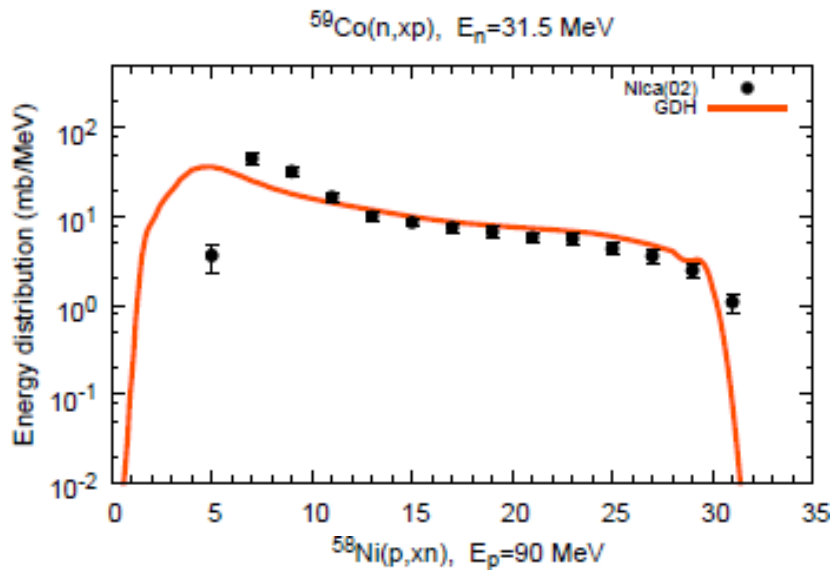


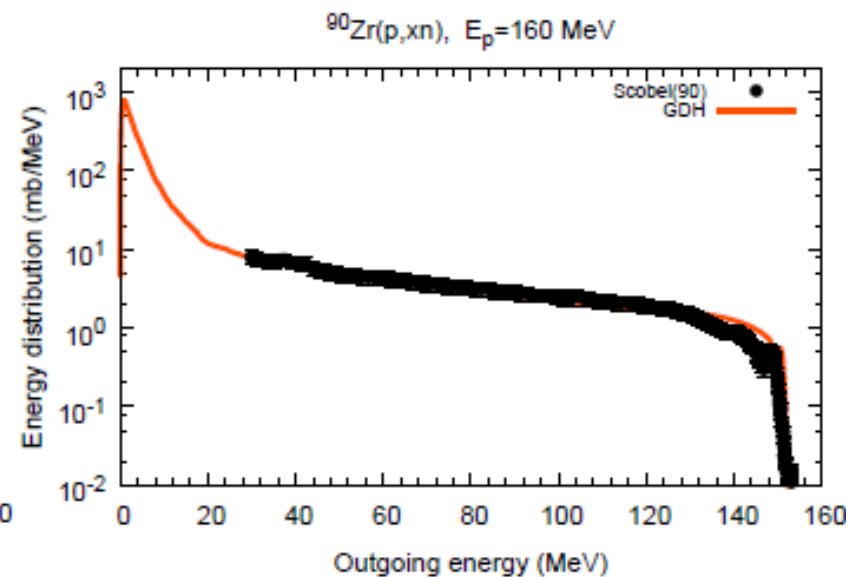
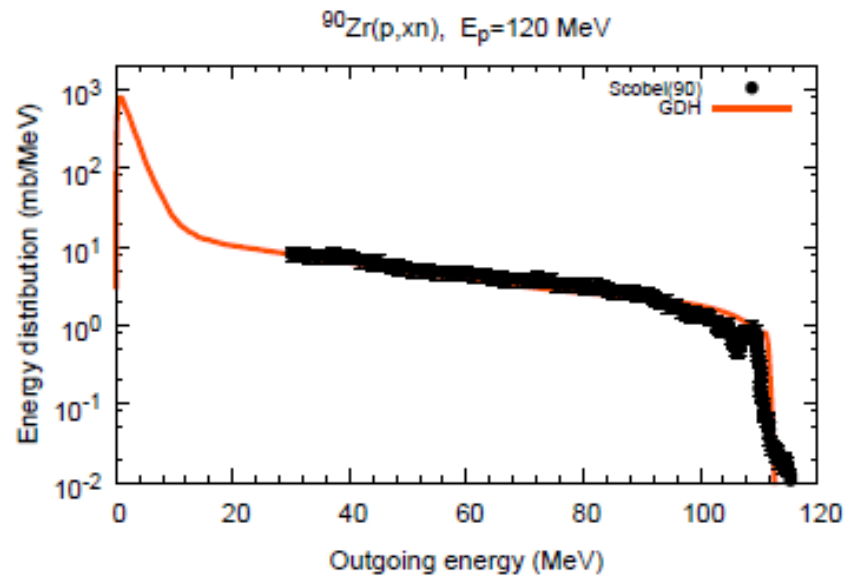
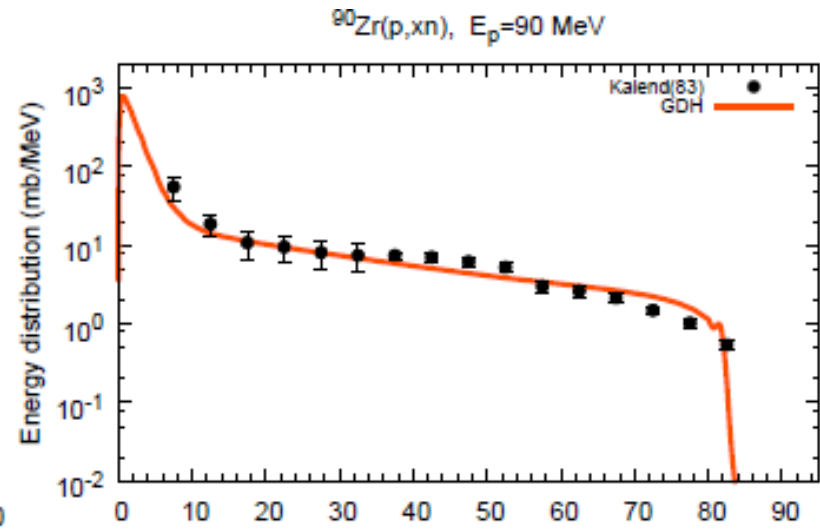
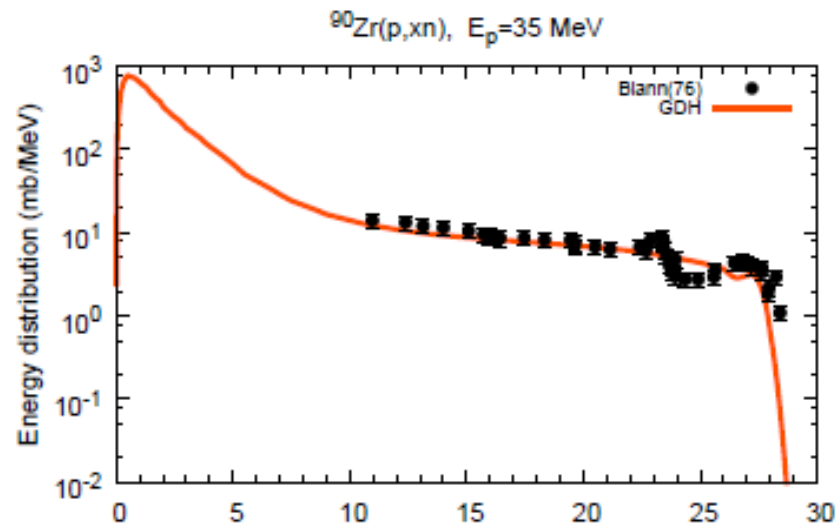
$^{56}\text{Fe}(n,xp)$ ,  $E_n=62.7$  MeV

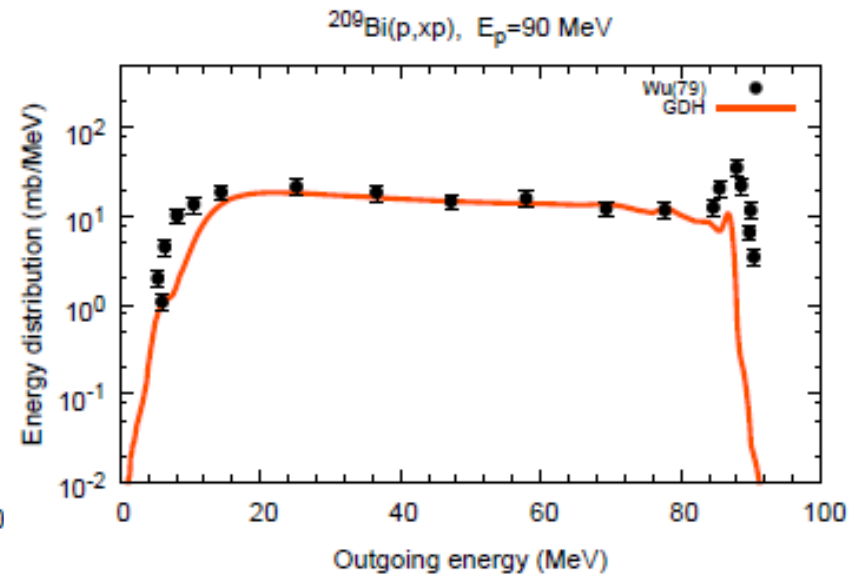
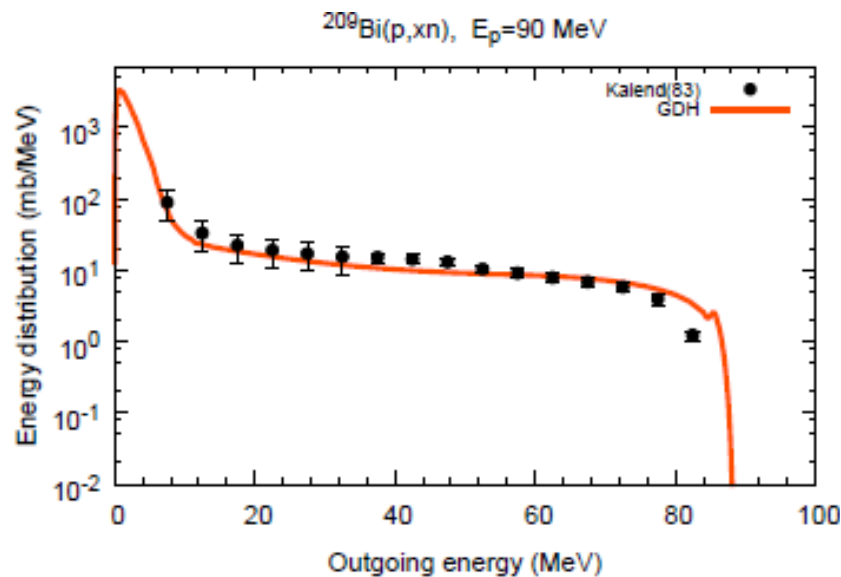
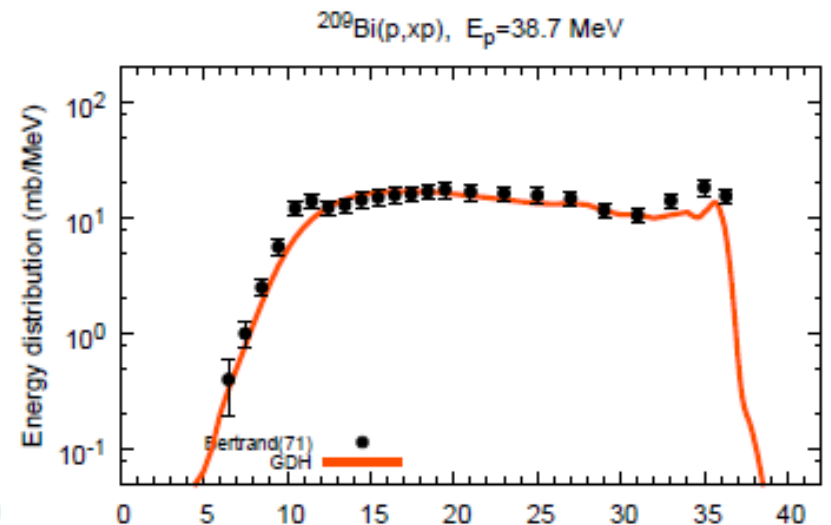
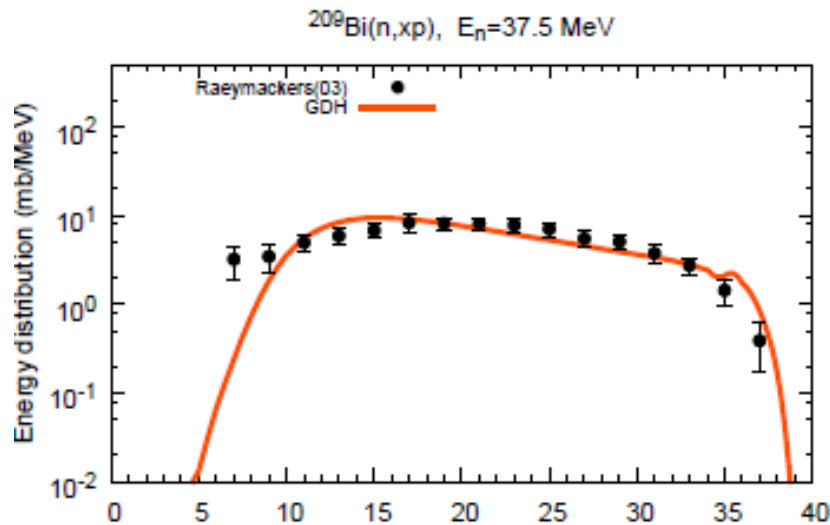


$^{56}\text{Fe}(n,xp)$ ,  $E_n=96$  MeV



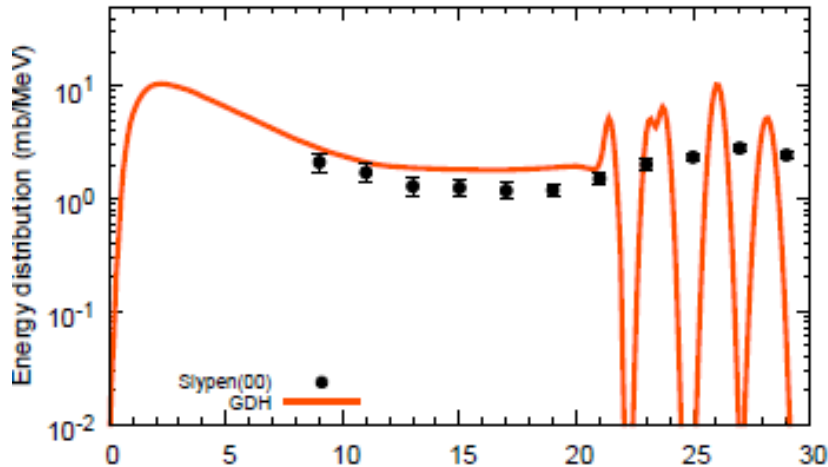




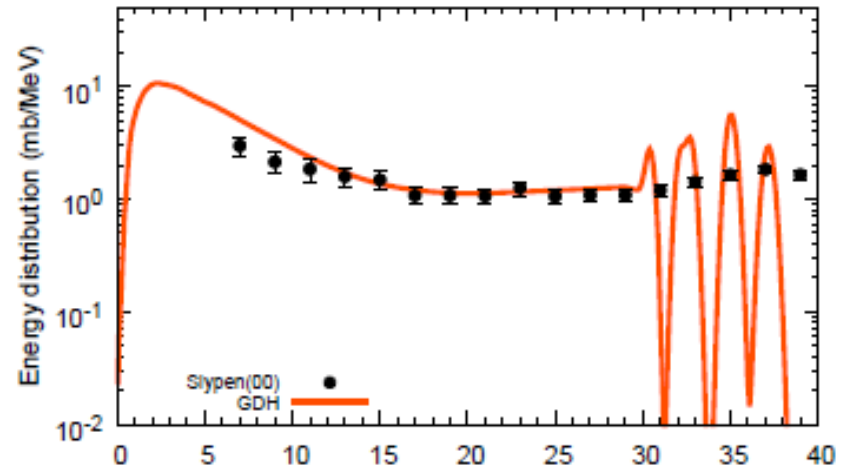


# Deuteron energy distributions

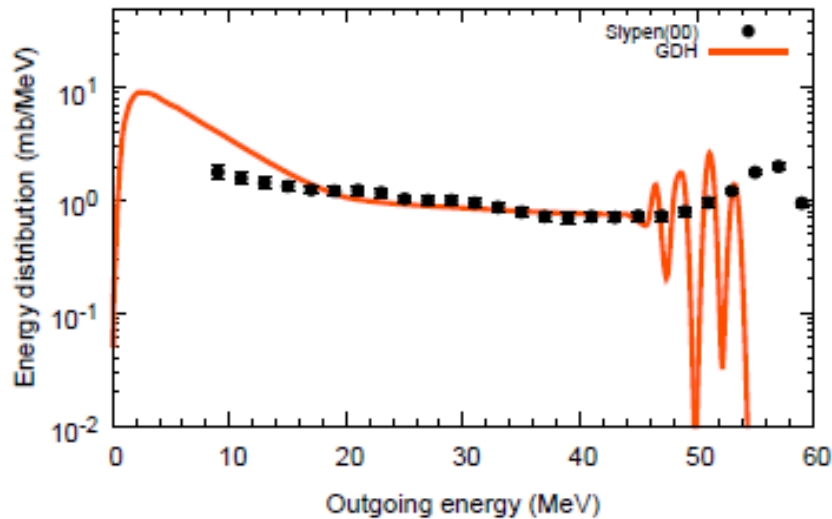
$^{12}\text{C}(n,xd)$ ,  $E_n=45.5$  MeV



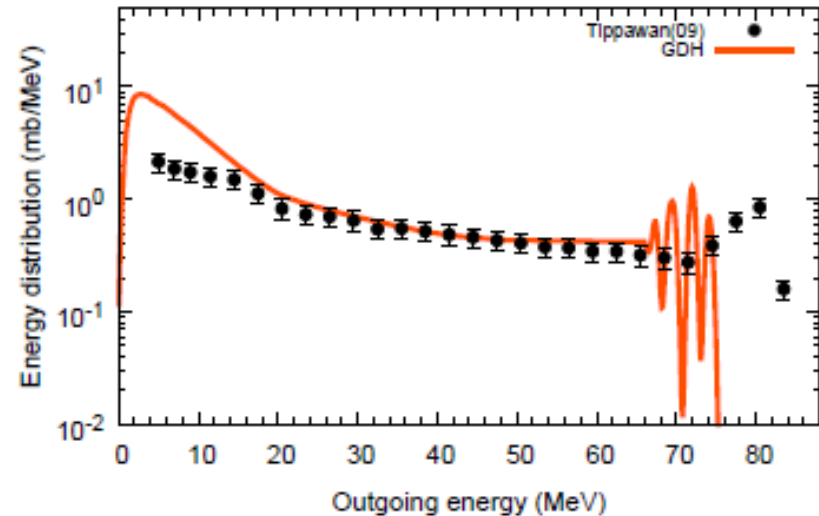
$^{12}\text{C}(n,xd)$ ,  $E_n=55.3$  MeV



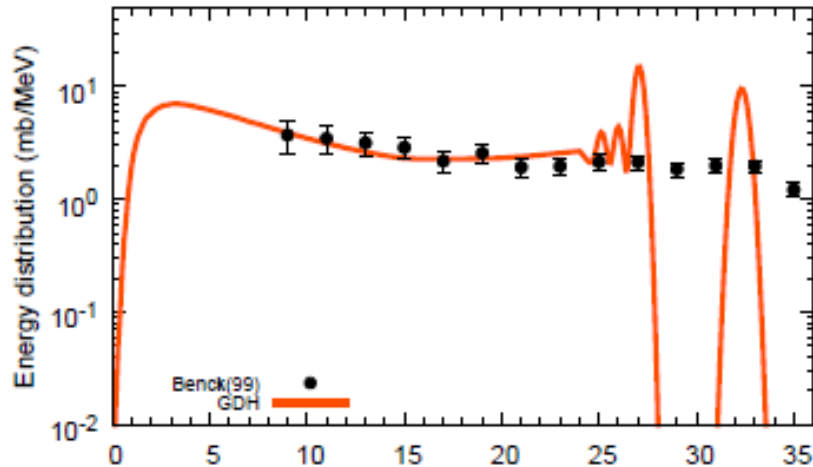
$^{12}\text{C}(n,xd)$ ,  $E_n=72.8$  MeV



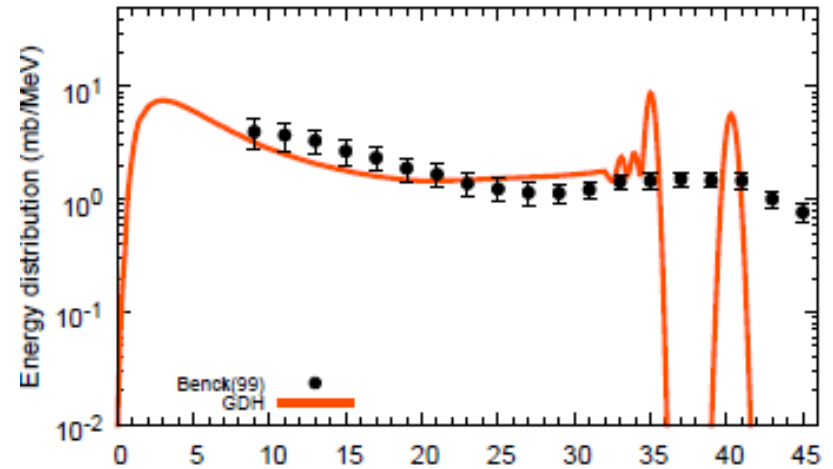
$^{12}\text{C}(n,xd)$ ,  $E_n=95.6$  MeV



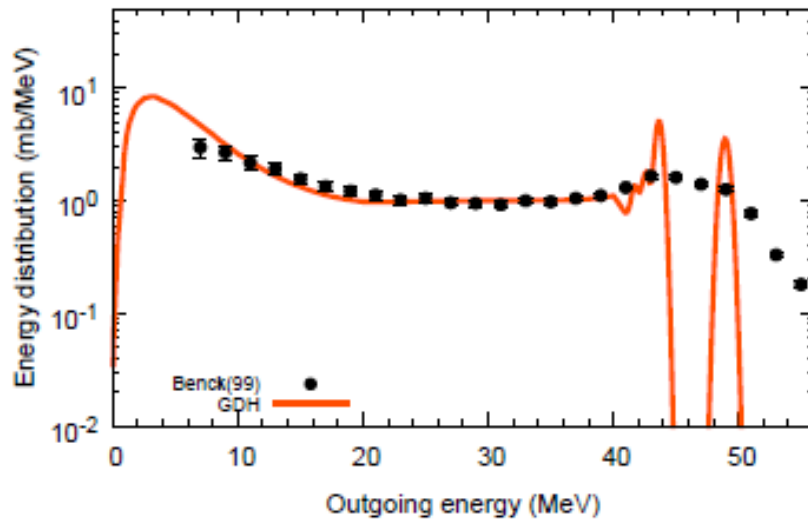
$^{16}\text{O}(n,xd)$ ,  $E_n=45$  MeV



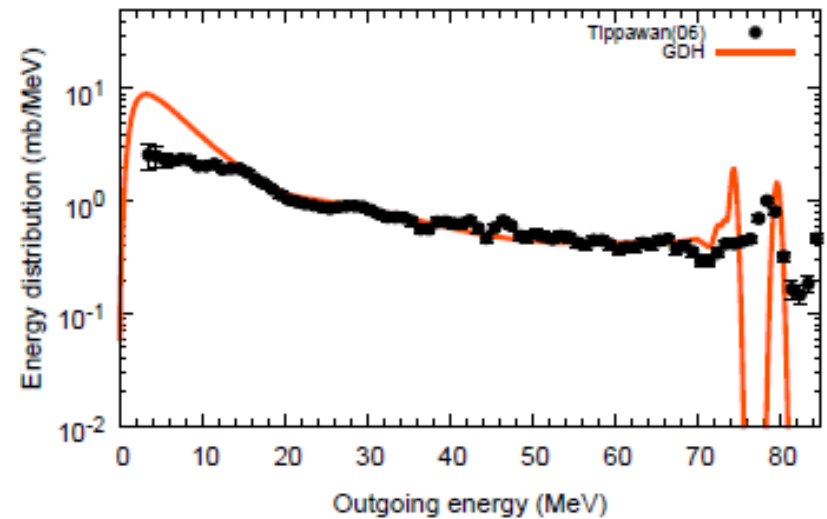
$^{16}\text{O}(n,xd)$ ,  $E_n=53.5$  MeV



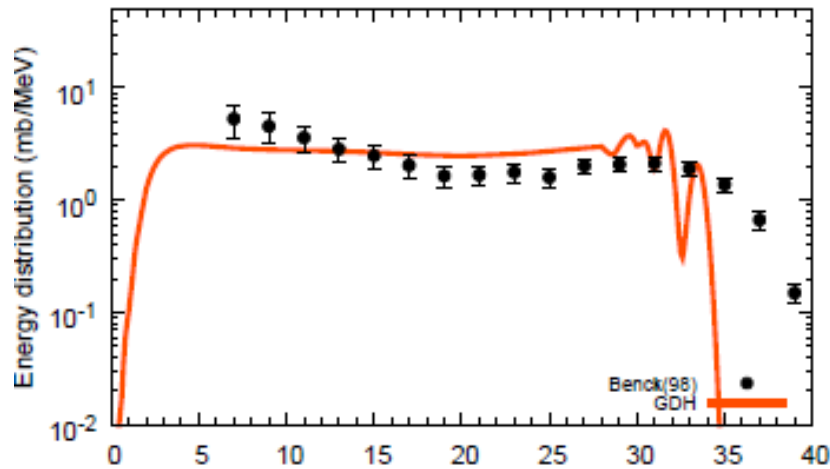
$^{16}\text{O}(n,xd)$ ,  $E_n=62.7$  MeV



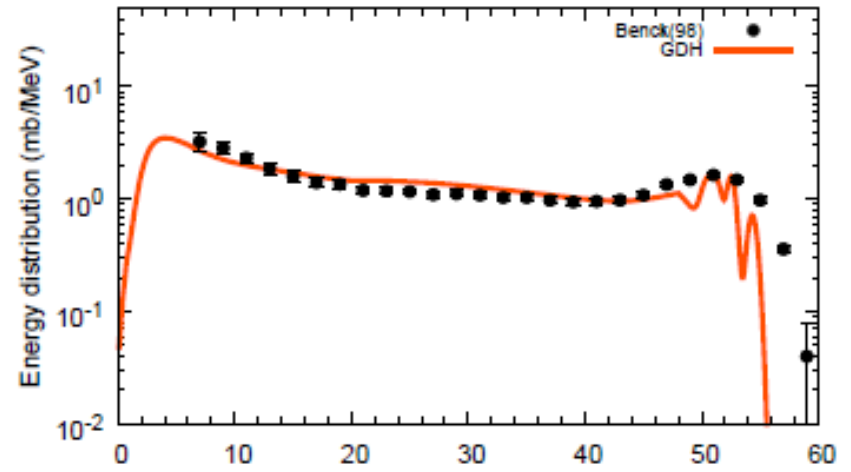
$^{16}\text{O}(n,xd)$ ,  $E_n=95.6$  MeV



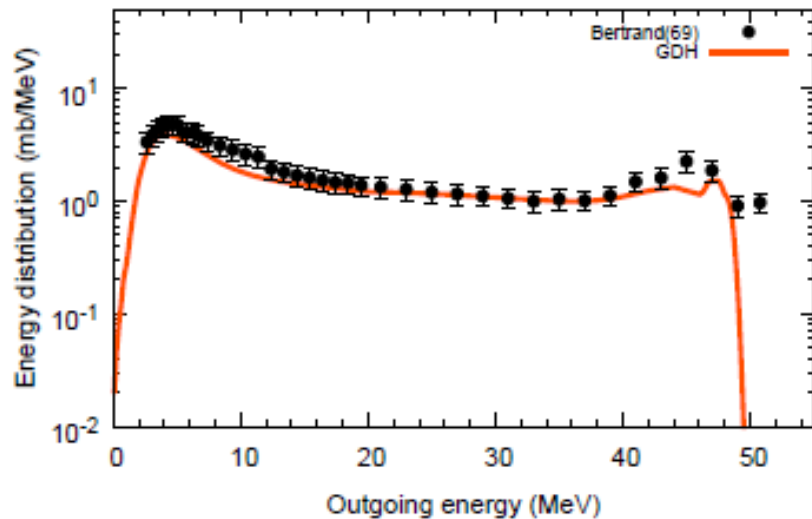
$^{27}\text{Al}(n,xd)$ ,  $E_n=41$  MeV



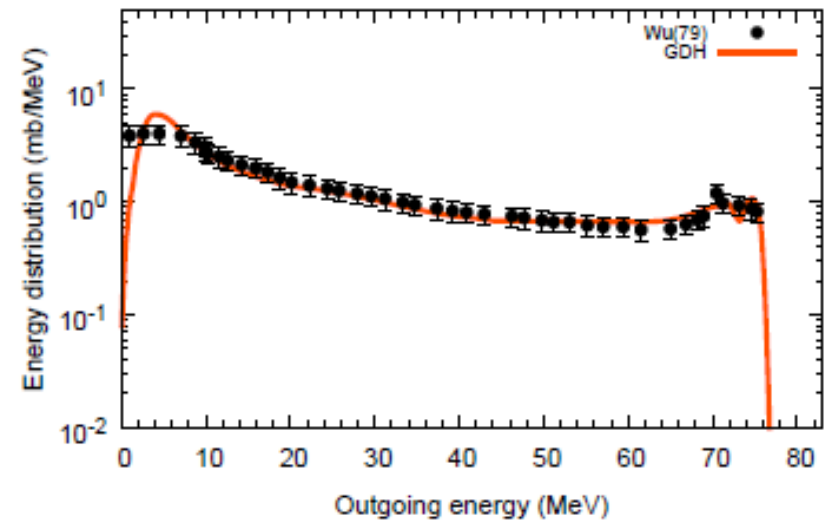
$^{27}\text{Al}(n,xd)$ ,  $E_n=62.7$  MeV



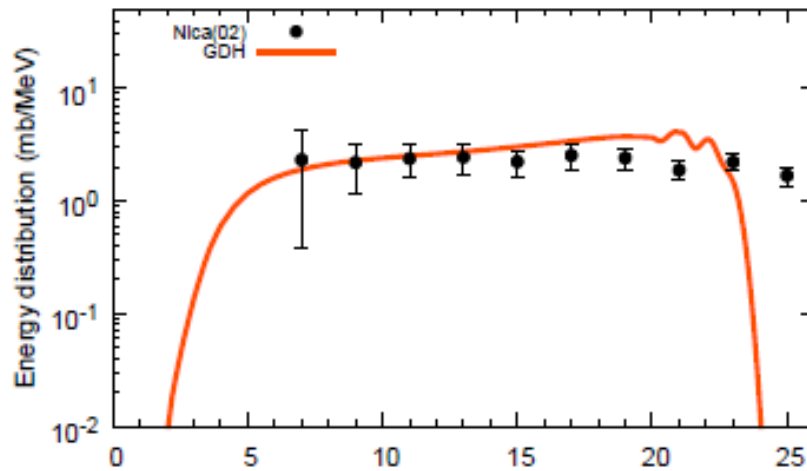
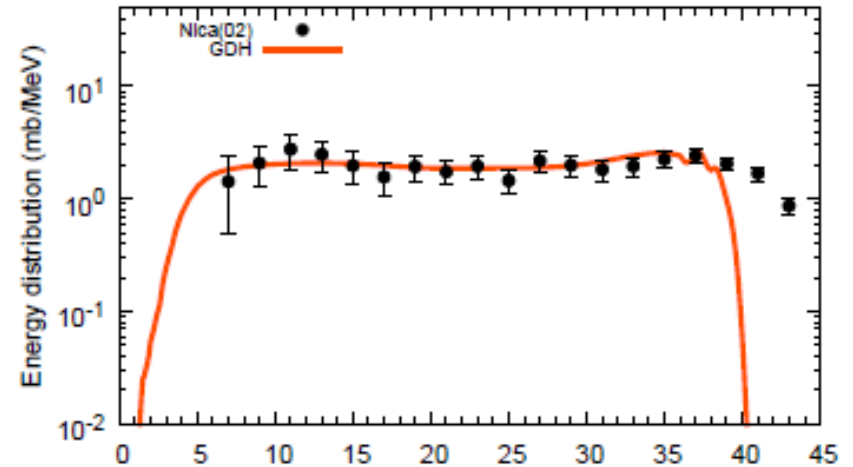
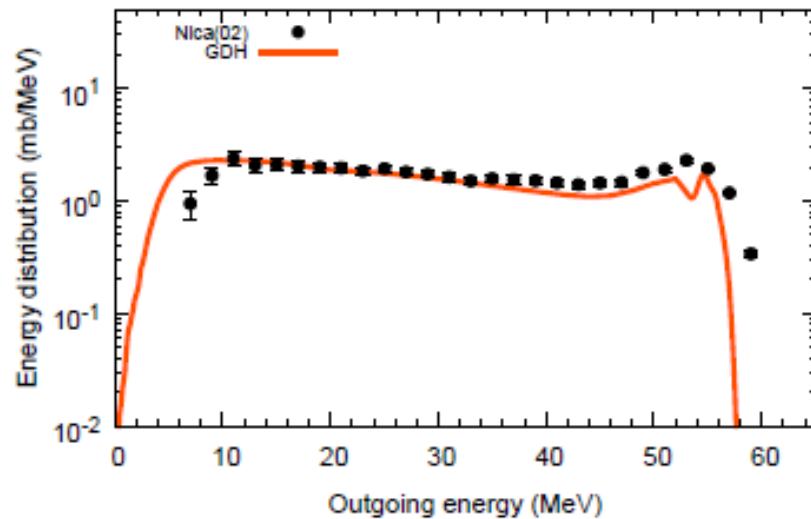
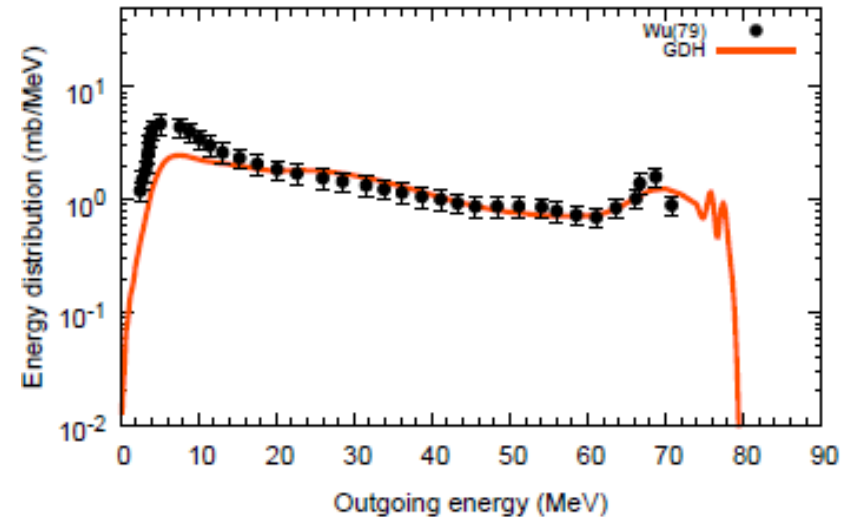
$^{27}\text{Al}(p,xd)$ ,  $E_p=61.7$  MeV



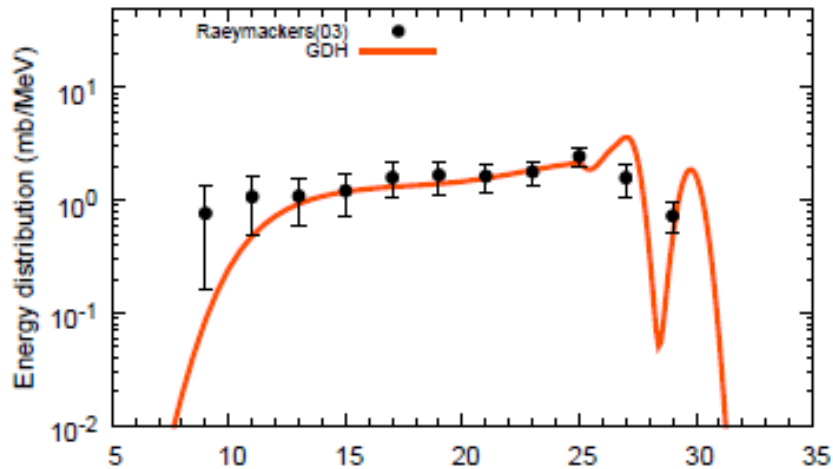
$^{27}\text{Al}(p,xd)$ ,  $E_p=90$  MeV



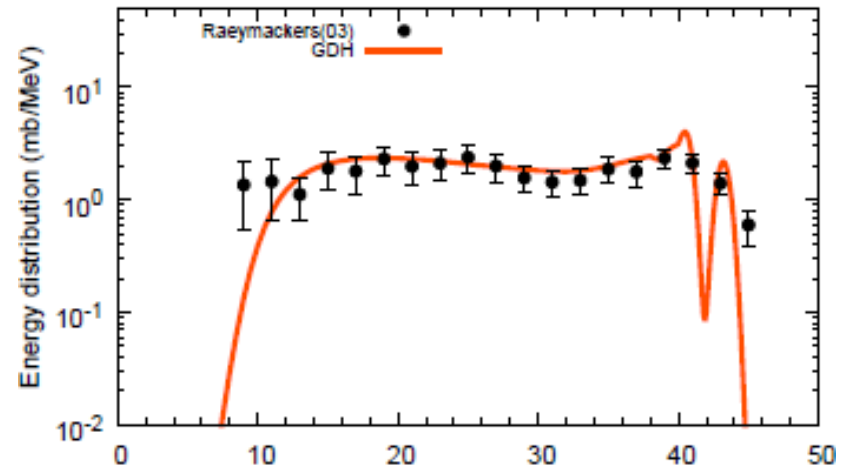


$^{59}\text{Co}(n,xd)$ ,  $E_n=28.5$  MeV

 $^{59}\text{Co}(n,xd)$ ,  $E_n=45$  MeV

 $^{59}\text{Co}(n,xd)$ ,  $E_n=62.7$  MeV

 $^{58}\text{Ni}(p,xd)$ ,  $E_p=90$  MeV


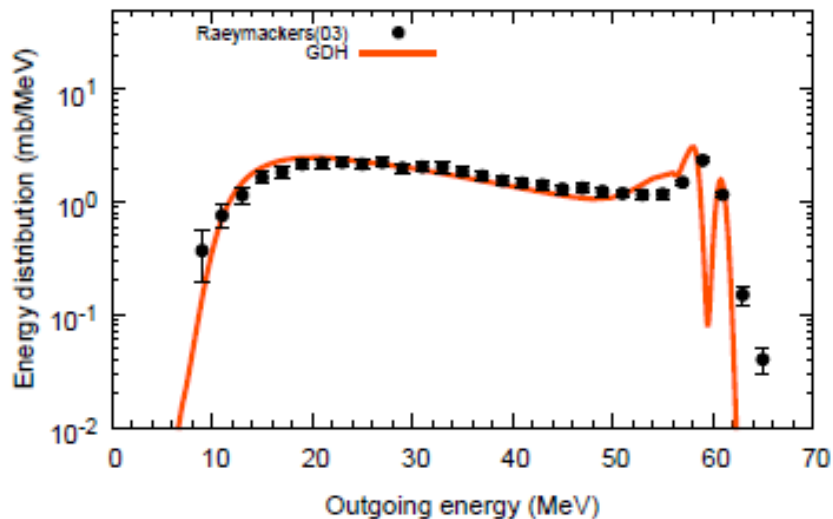
$^{209}\text{Bi}(n,xd)$ ,  $E_n=31.5$  MeV



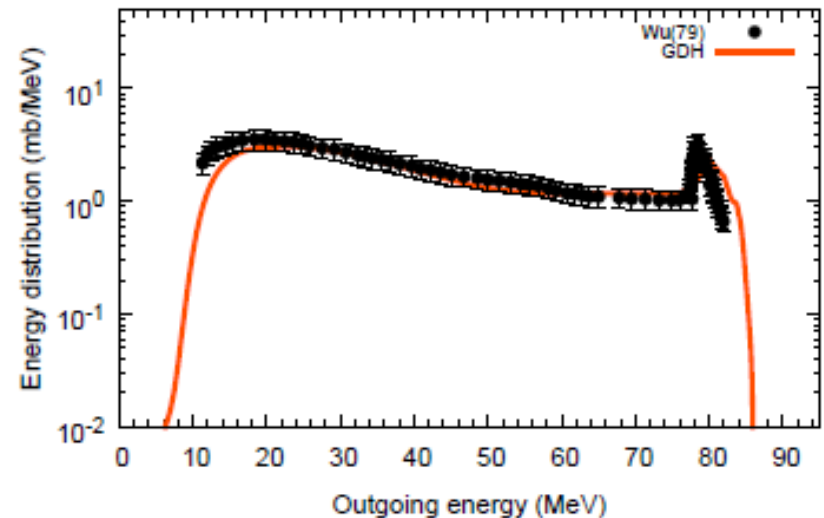
$^{209}\text{Bi}(n,xd)$ ,  $E_n=45$  MeV



$^{209}\text{Bi}(n,xd)$ ,  $E_n=62.7$  MeV

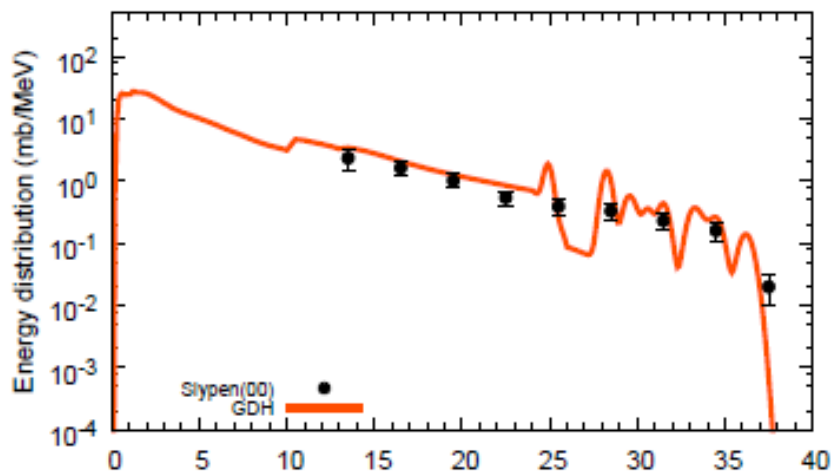


$^{209}\text{Bi}(p,xd)$ ,  $E_p=90$  MeV

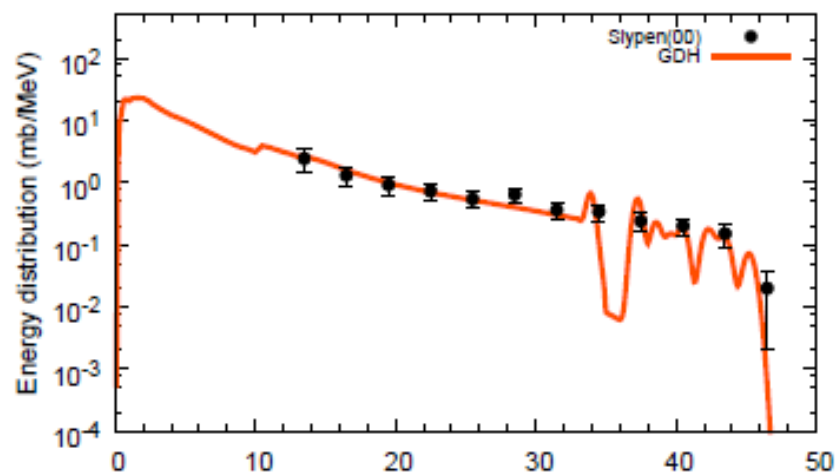


# $\alpha$ -particle energy distributions

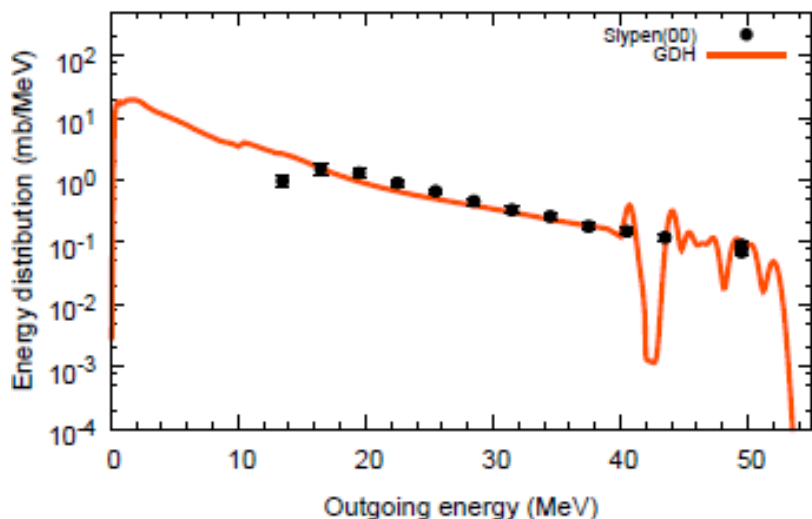
$^{12}\text{C}(n,\alpha^4\text{He})$ ,  $E_n=45.5$  MeV



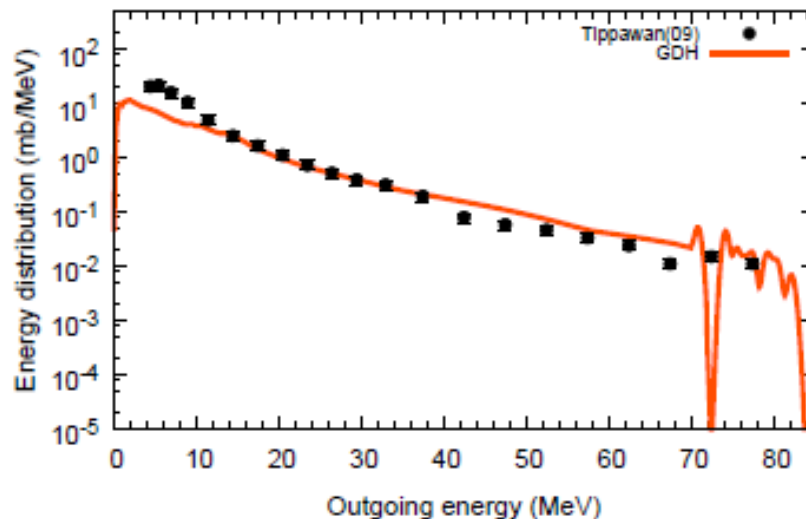
$^{12}\text{C}(n,\alpha^4\text{He})$ ,  $E_n=55.3$  MeV



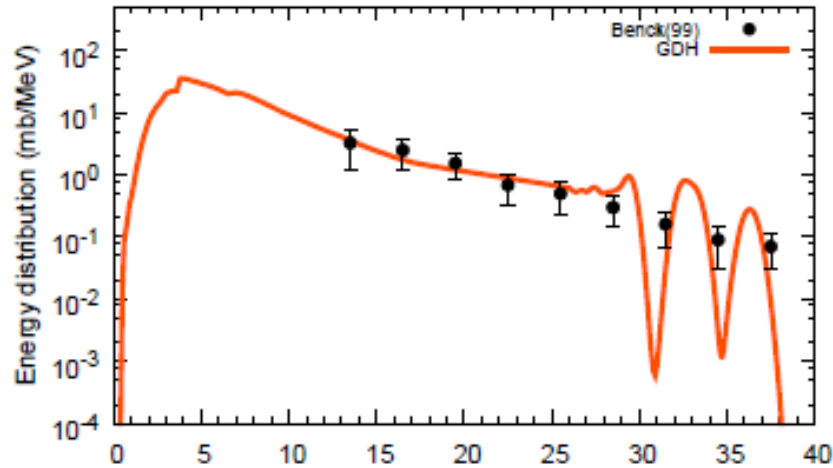
$^{12}\text{C}(n,\alpha^4\text{He})$ ,  $E_n=62.7$  MeV



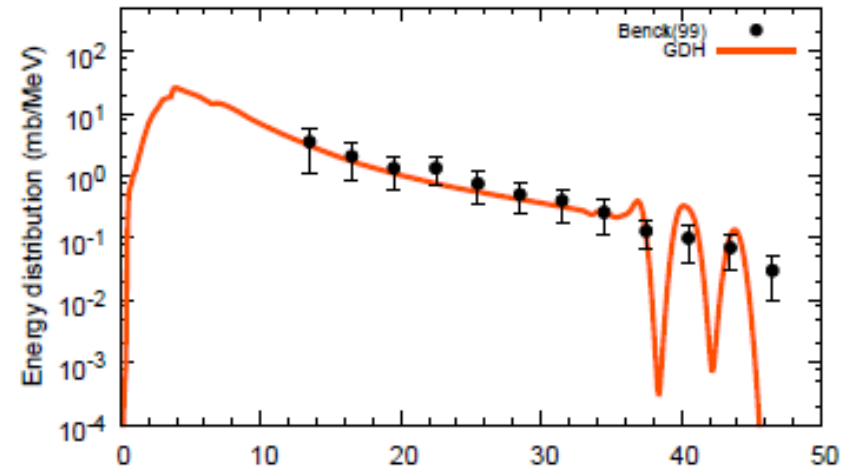
$^{12}\text{C}(n,\alpha^4\text{He})$ ,  $E_n=95.6$  MeV



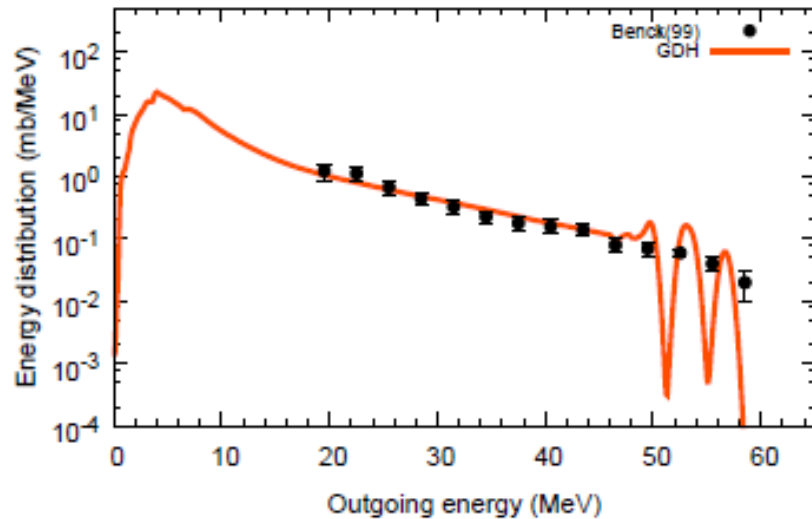
$^{16}\text{O}(n,x^4\text{He}), E_n=41\text{ MeV}$



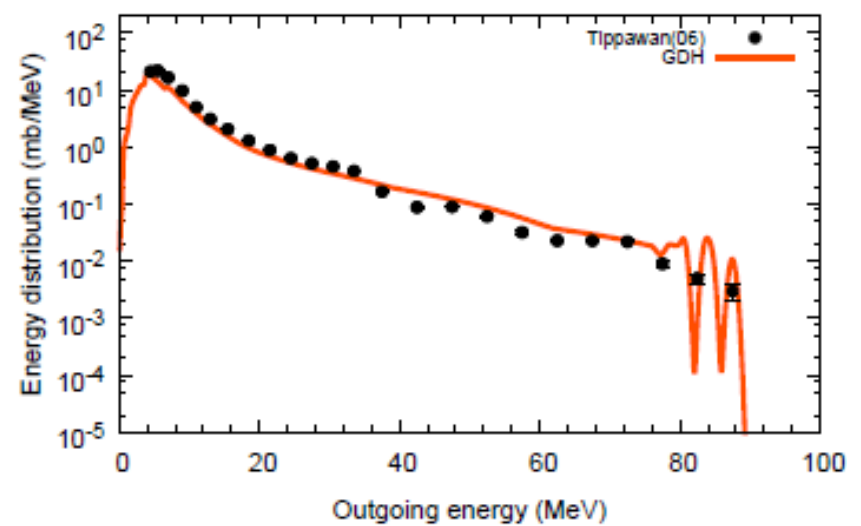
$^{16}\text{O}(n,x^4\text{He}), E_n=49\text{ MeV}$



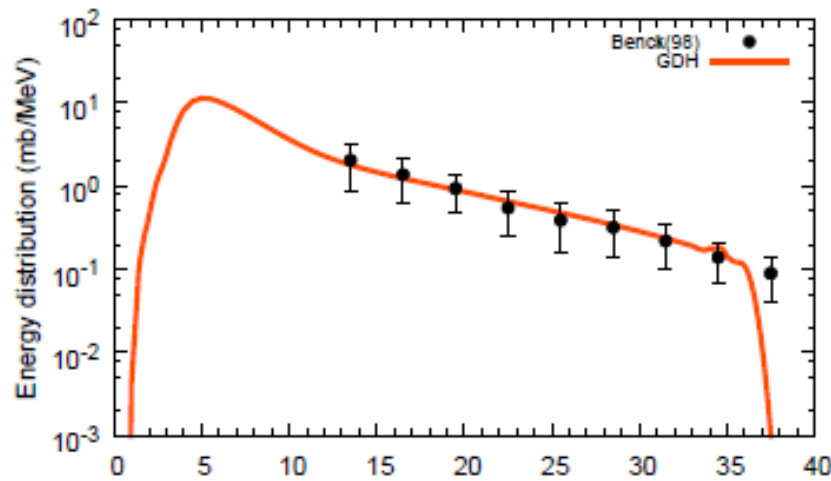
$^{16}\text{O}(n,x^4\text{He}), E_n=62.7\text{ MeV}$



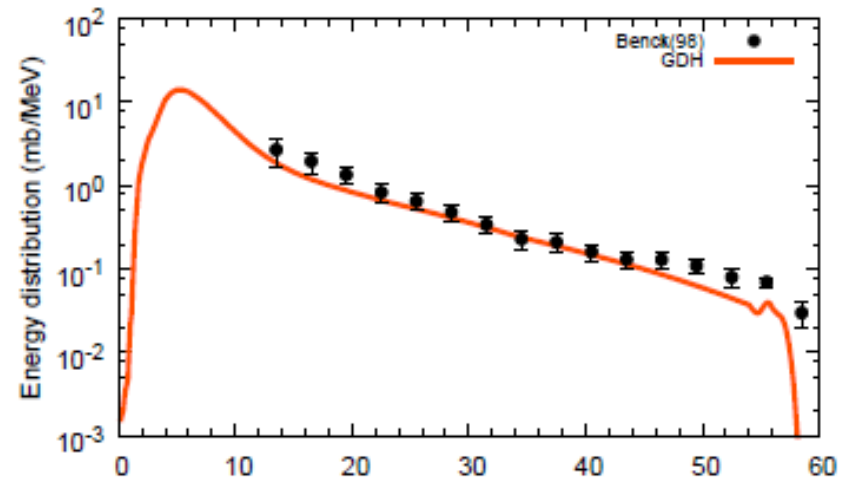
$^{16}\text{O}(n,x^4\text{He}), E_n=95.6\text{ MeV}$



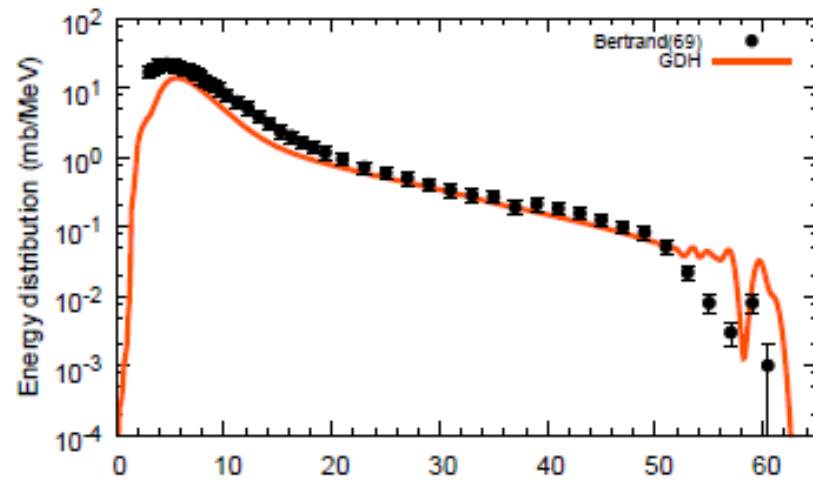
$^{27}\text{Al}(n,x^4\text{He}), E_n=41\text{ MeV}$



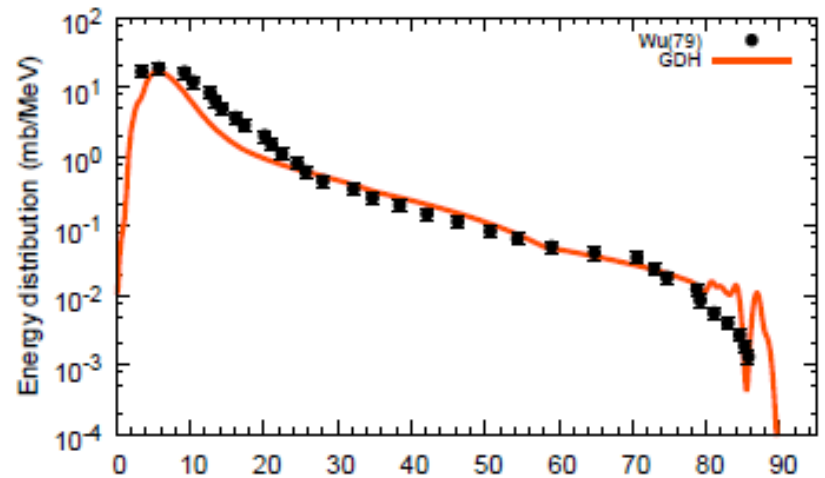
$^{27}\text{Al}(n,x^4\text{He}), E_n=62.7\text{ MeV}$



$^{27}\text{Al}(p,x^4\text{He}), E_p=61.7\text{ MeV}$



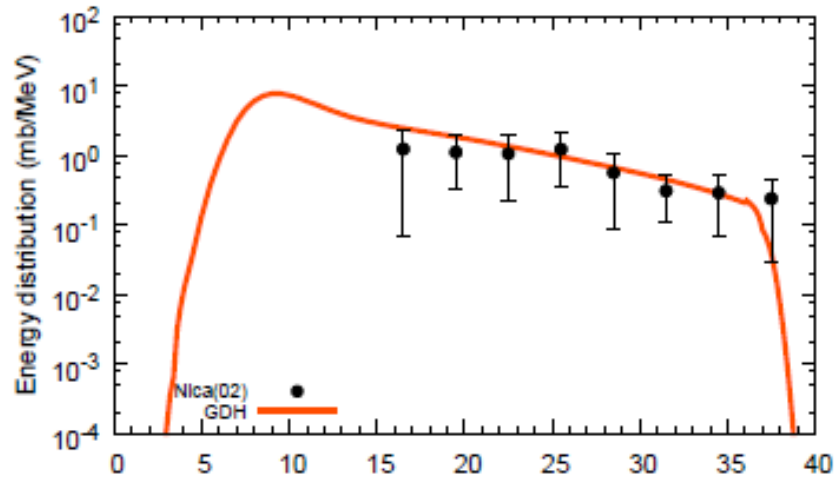
$^{27}\text{Al}(p,x^4\text{He}), E_p=90\text{ MeV}$



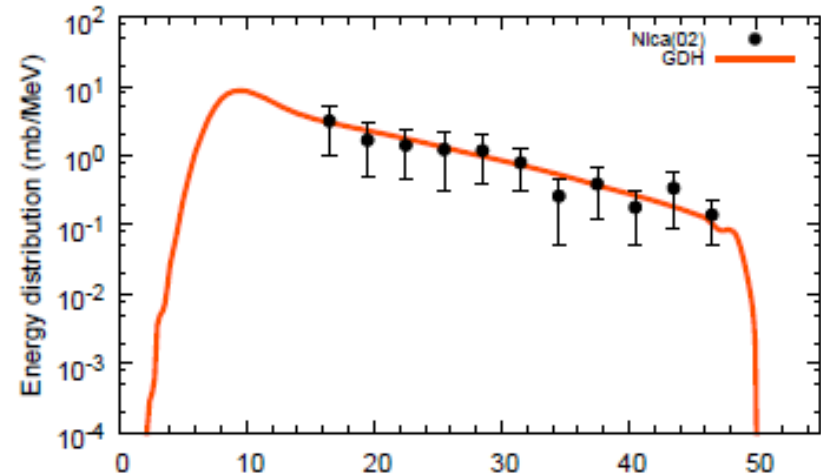
Outgoing energy (MeV)

Outgoing energy (MeV)

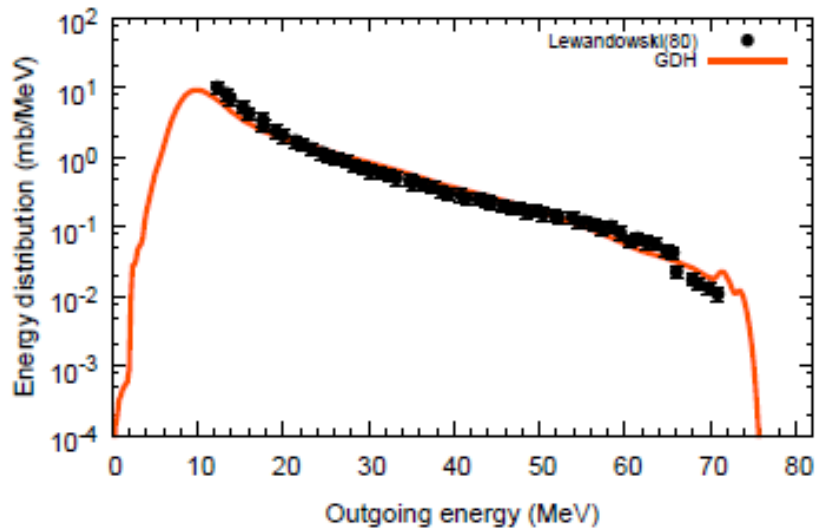
$^{59}\text{Co}(n,x^4\text{He}), E_n=37.5\text{ MeV}$



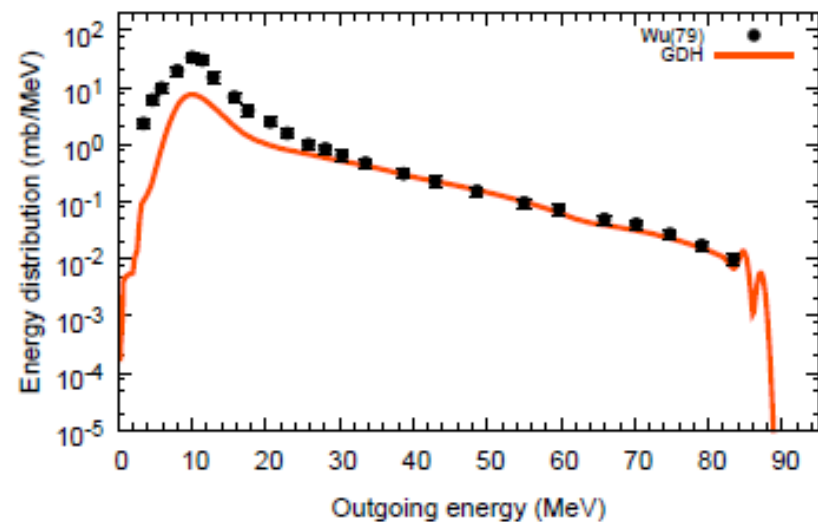
$^{59}\text{Co}(n,x^4\text{He}), E_n=49\text{ MeV}$

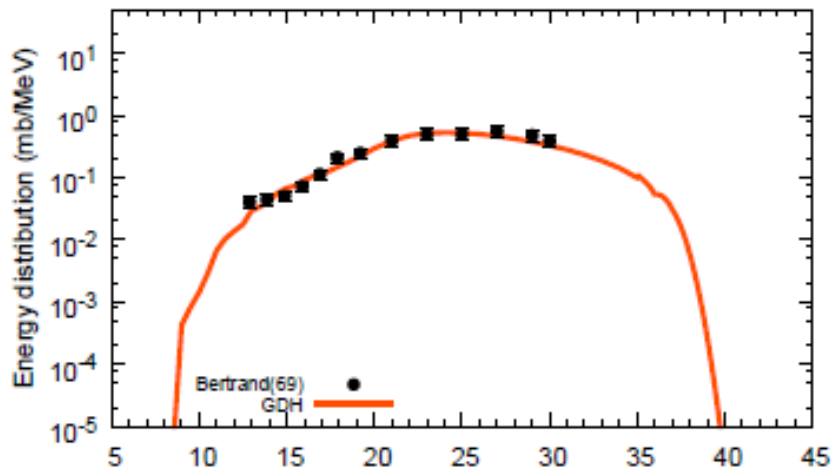
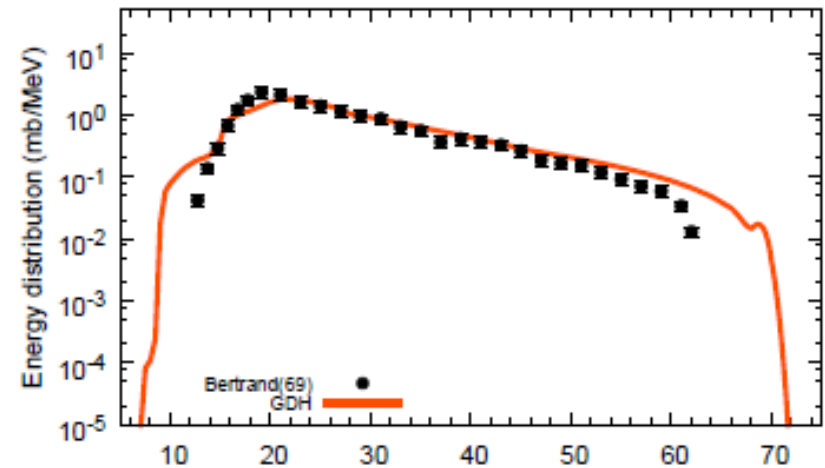
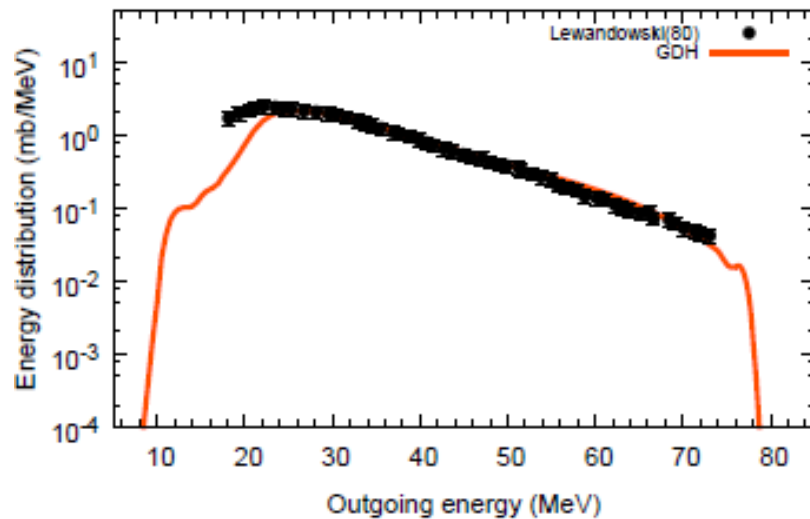
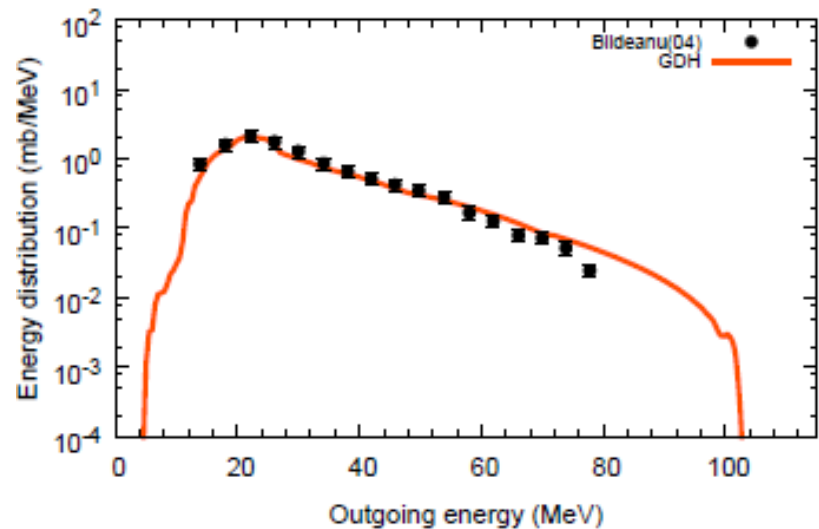


$^{59}\text{Co}(p,x^4\text{He}), E_p=72.3\text{ MeV}$



$^{58}\text{Ni}(p,x^4\text{He}), E_p=90\text{ MeV}$



$^{197}\text{Au}(p,x^4\text{He}), E_p=28.8\text{ MeV}$ 

 $^{197}\text{Au}(p,x^4\text{He}), E_p=61.5\text{ MeV}$ 

 $^{208}\text{Pb}(p,x^4\text{He}), E_p=70.7\text{ MeV}$ 

 $^{208}\text{Pb}(n,x^4\text{He}), E_n=96\text{ MeV}$ 


## Conclusion

The **GDH** model was implemented in **TALYS-1.74**

**First test calculations** were performed