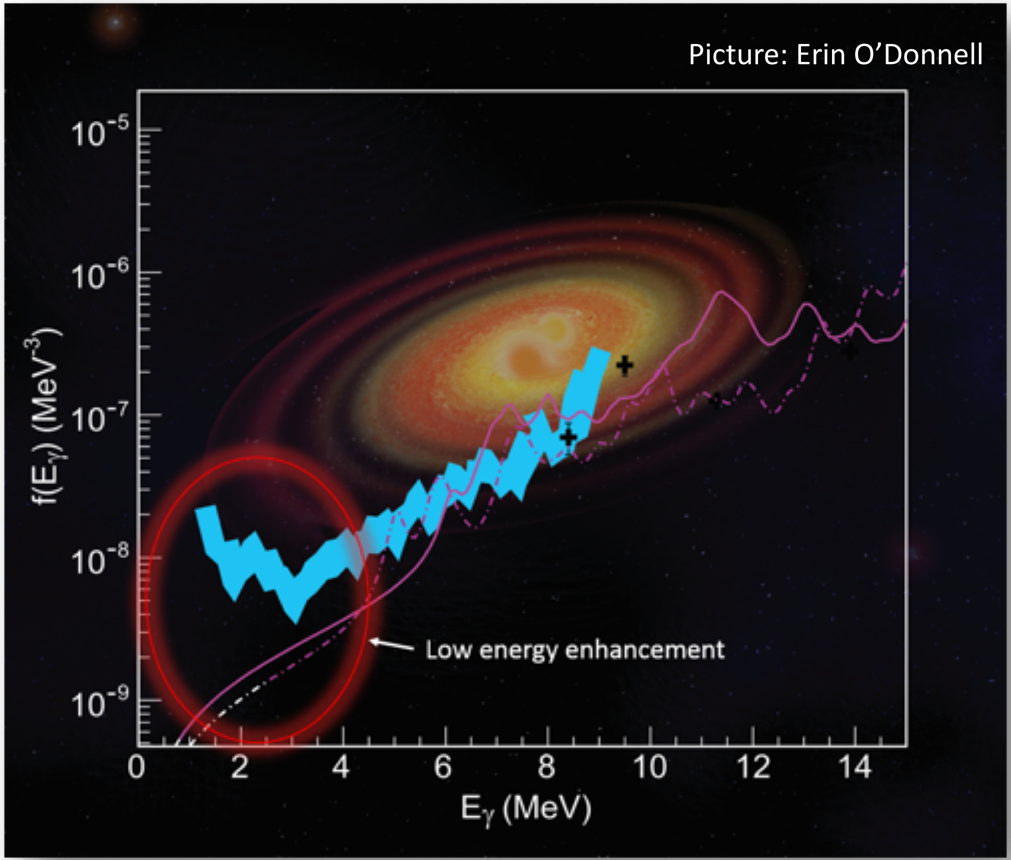
Mini workshop on the beta-Oslo method: case study of ^{70}Ni



Thursday, Aug 1, and Friday, Aug 2, 2019

Magne Guttormsen m.s.guttormsen@fys.uio.no

Ann-Cecilie Larsen a.c.larsen@fys.uio.no

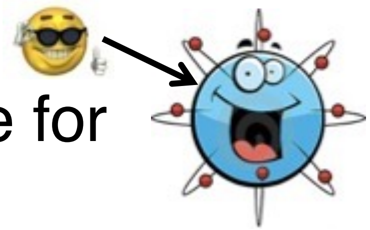
Content

1. Introduction/motivation
2. Case study: ^{70}Ni
3. E_x and Eγ unfolding using MaMa
4. Extraction of first-generation γ rays using MaMa
5. Getting the level density and γ-ray transmission coefficient using *rhosigchi.f*
6. Normalization of the level density (and the slope of the γ-ray transmission coefficient) using *counting.c*
7. Normalization of the γ-ray transmission coefficient and getting the dipole γ-ray strength function using *normalization.c*
8. Fit of the γ-ray strength function to generate TALYS E1 and M1 tables (Root script)
9. TALYS input file for calculating (n,γ) cross sections and rates
10. Some Root <-> MaMa scripts

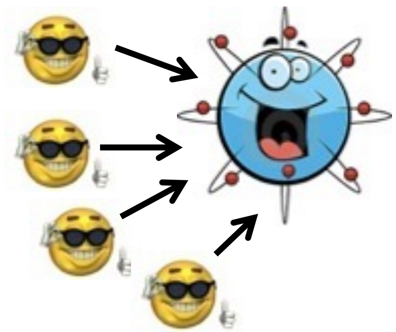
1. Introduction/motivation

Nuclear input for radiative-capture rates

What's the chance for

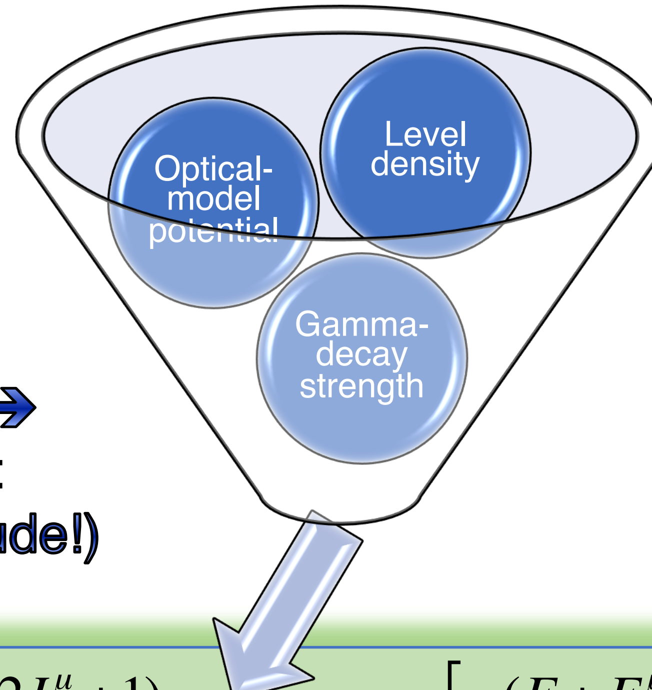


or



to happen?

Uncertain input →
Uncertain output
(orders of magnitude!)



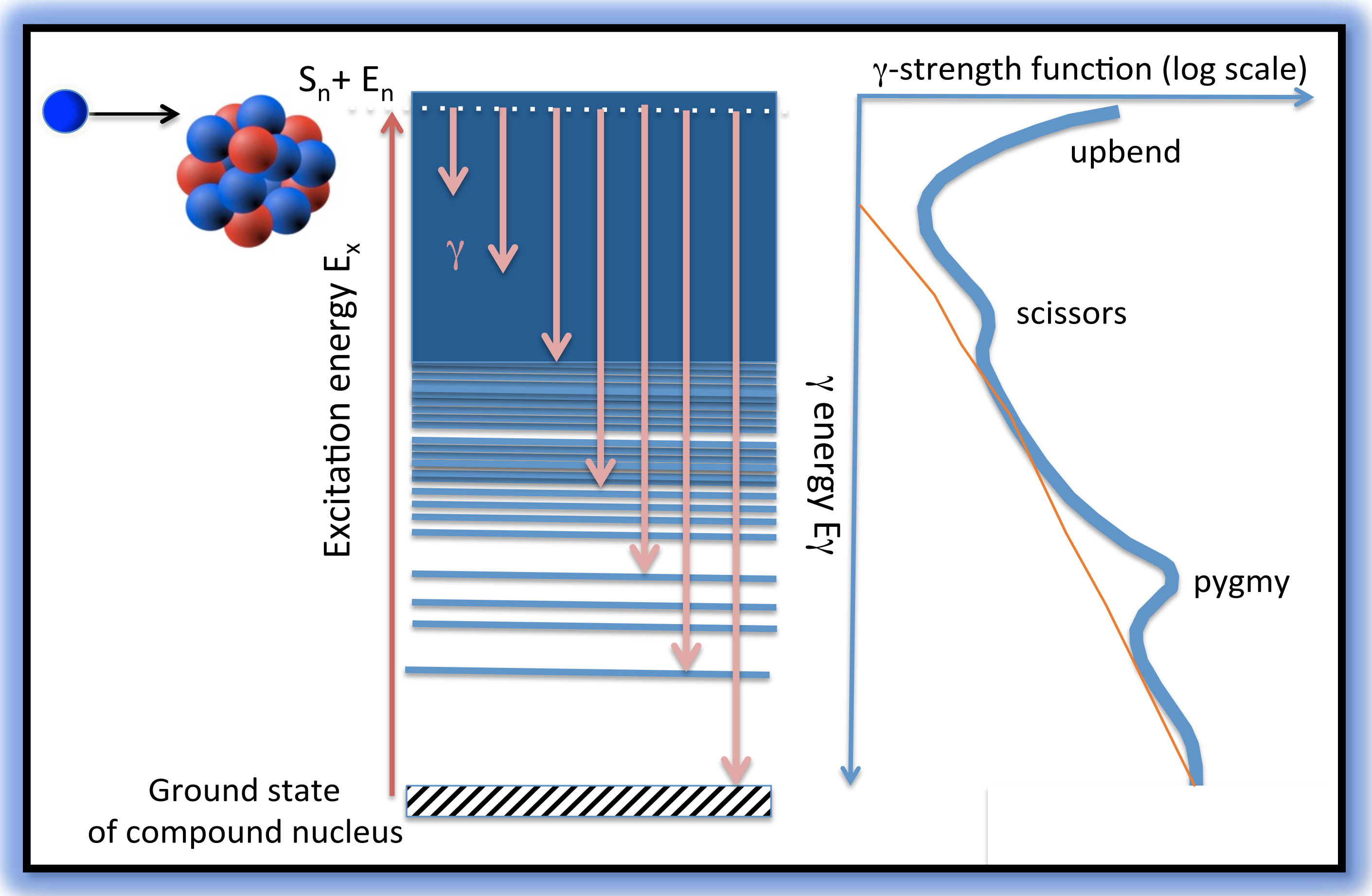
$$N_A\langle\sigma v\rangle(T) = \left(\frac{8}{\pi m}\right)^{1/2} \frac{N_A}{(kT)^{3/2} G(T)} \int_0^\infty \sum_\mu \frac{(2I^\mu+1)}{(2I^0+1)} \sigma^\mu(E)\, E \exp\left[-\frac{(E+E_x^\mu)}{kT}\right] dE$$

$$G(T) = \sum_\mu (2I^\mu+1)/(2I^0+1)\exp(-E_x^\mu/kT)$$

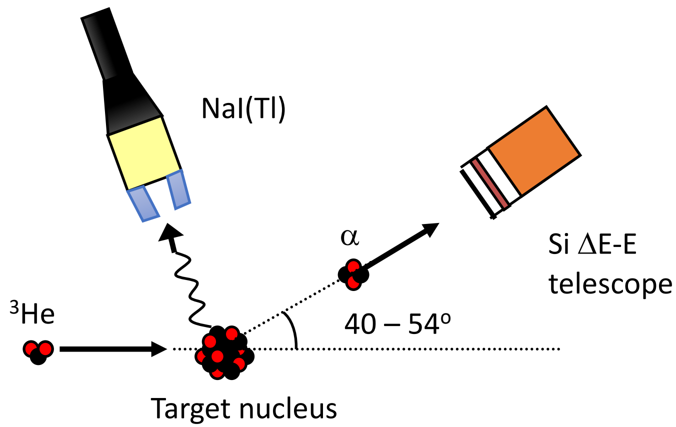
Nuclear input for radiative-capture rates

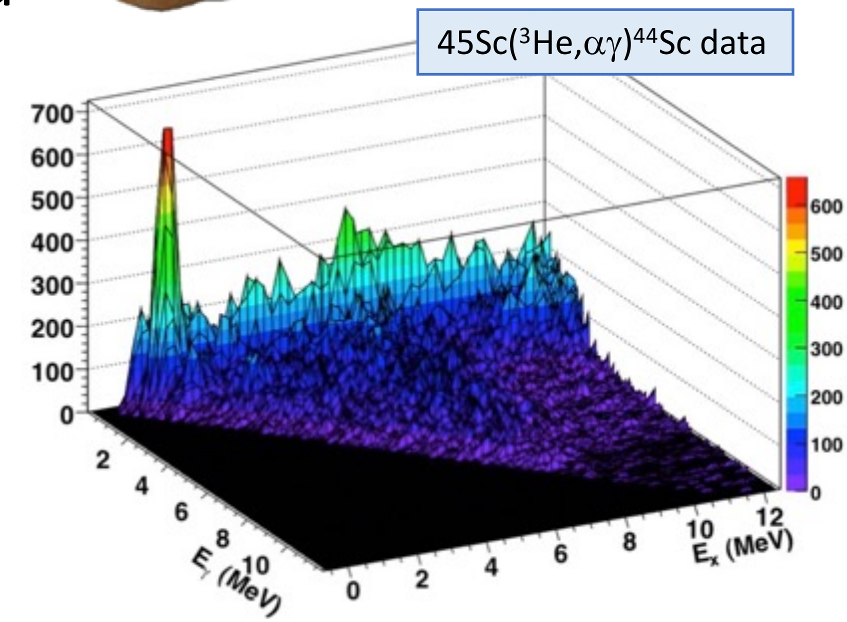
Level density: Available quantum levels at a given excitation-energy bin per energy unit

Gamma strength: The nucleus' ability to emit electromagnetic radiation when other known dependencies are removed (level density, E_g^3 factor for dipole radiation) -> directly connected to reduced transition probabilities



The Oslo method in a 

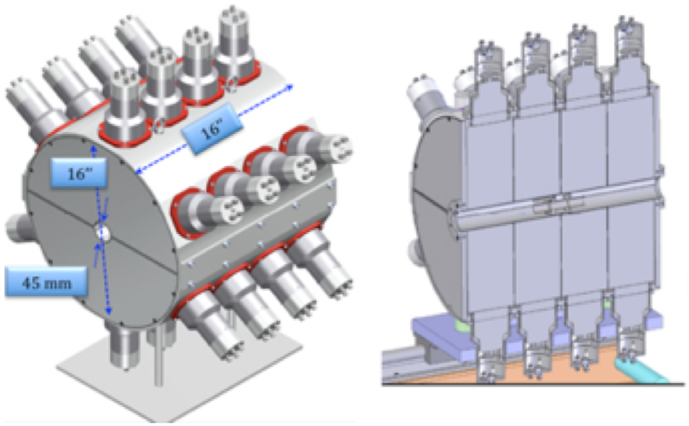




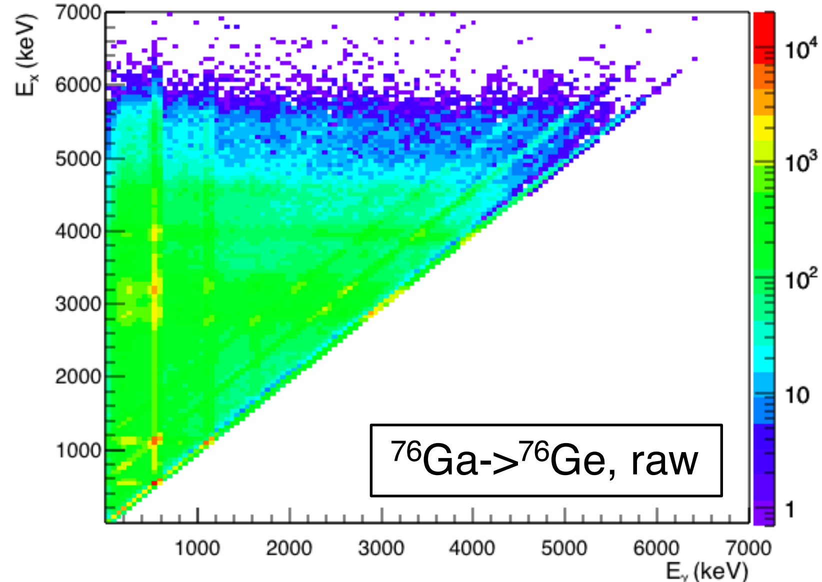
0. Get a hold of an (Eγ,Ex) matrix (~30-40 000 coincidences)
1. Correct for the NaI response [Guttormsen et al., NIM A 374, 371 (1996)]
2. Extract *distribution of* primary γs for each Ex [Guttormsen et al., NIM A 255, 518 (1987)]
3. Get level density and γ-strength from primary γ's [Schiller et al., NIM A 447, 498 (2000)]
4. Normalize & evaluate systematic errors [Schiller et al., NIM A 447, 498 (2000), Larsen *et al.*, PRC **83**, 034315 (2011)]

Data and references: **ocl.uio.no/compilation/**
Analysis codes and tools:
github.com/oslocyclotronlab/oslo-method-software
New Python Oslo-method package: **OMPy** by J.E. Midtbø, F.Zeiser, E. Lima

The beta-Oslo method in a 



[A. Simon, S.J. Quinn, A. Spyrou et al, NIM A 703, 16 (2013)]



Recipe:

1) Implant a neutron-rich nucleus in a segmented total-absorption spectrometer (preferably with $Q_{beta} \approx S_n$)
2) Measure β-particle in coincidence with γ rays from the daughter nucleus
3) Apply Oslo method to the E_x-E_γ matrix to extract level density & γ-ray strength

A. Spyrou, S.N. Liddick, A.C.Larsen, M. Guttormsen et al., Phys. Rev. Lett. **113**, 232502 (2014)

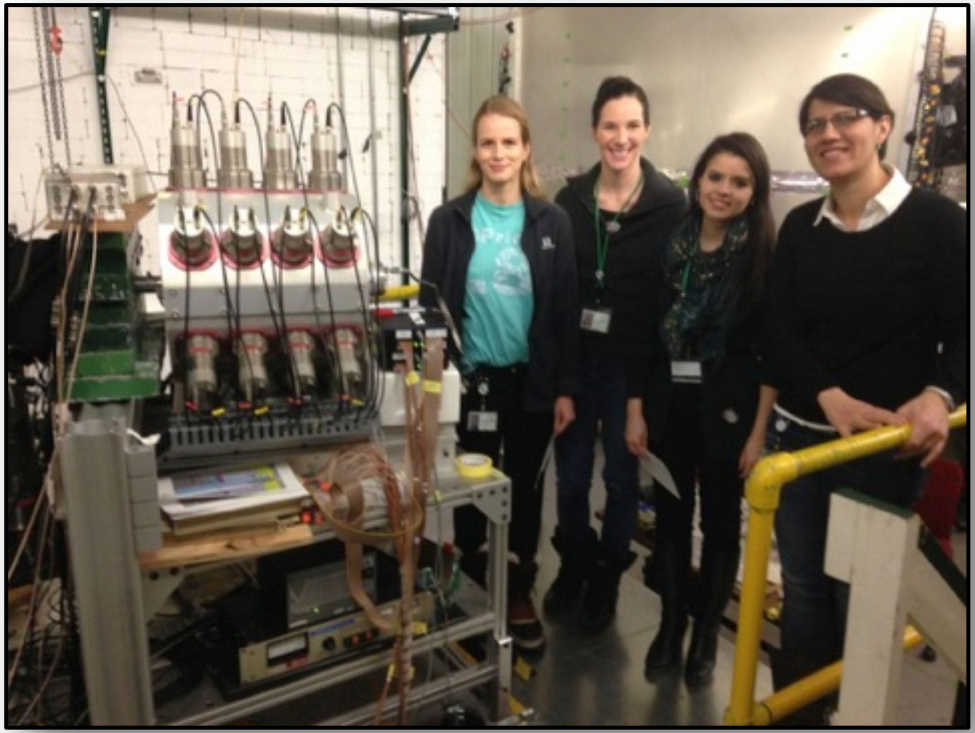
NSCL +

2. Case study: ^{70}Ni

Some experimental details, ^{70}Ni

Discretionary beam time @ NSCL/MSU, February 2015; ^{70}Co -> ^{70}Ni
^{86}Kr primary beam, 140 MeV/nucleon on thick Be target producing ^{70}Co ++
A1900 mass separator optimized for ^{70}Co
DSSD inside SuN for detecting ^{70}Co & β^-

^{70}Co $T_{1/2}$: 112 ms
^{70}Co $I^\pi = (6^-,7^-)$ and isomer $(2^+,3^+)$
Beta-decay Q-value: 12.3 MeV
S_n, ^{70}Ni: 7.3 MeV



S.N. Liddick et al., Phys. Rev. Lett. **116**, 242502 (2016)

A.C. Larsen et al., Phys. Rev. C **97**, 054329 (2018)

The ^{70}Ni analysis steps

1. Unfold the raw matrix on the excitation energy axis
2. Unfold the E_x-unfolded matrix on the γ-energy axis
3. Extract primary γ rays for each excitation-energy bin
4. Extract level density and γ-ray transmission coefficient (which is directly proportional to the γ-strength function) from the primary γ-ray matrix
5. Normalize the level density to known discrete levels and Hartree-Fock-Bogoliubov calculations of Stephane Goriely et al. at high E_x (consider the populated spin range…)
6. Normalize the γ-ray transmission coefficient and get the γ-ray strength function
7. Use the level-density and γ-strength data to guide models to be used as input in the nuclear reaction code TALYS
8. Calculate the ^{69}Ni(n,γ)^{70}Ni cross section and reaction rate with the data-constrained input for the level density and γ strength

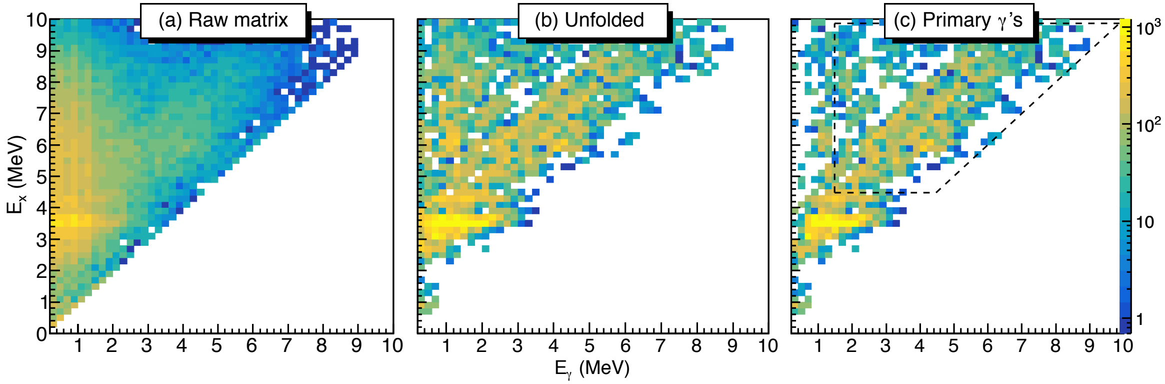
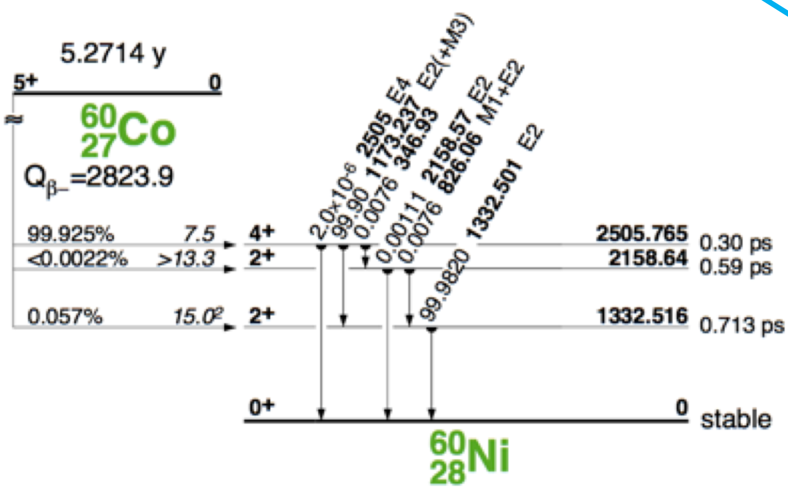


Figure from A.C. Larsen et al., Phys. Rev. C **97**, 054329 (2018)

3. E_x and E_γ unfolding using MaMa

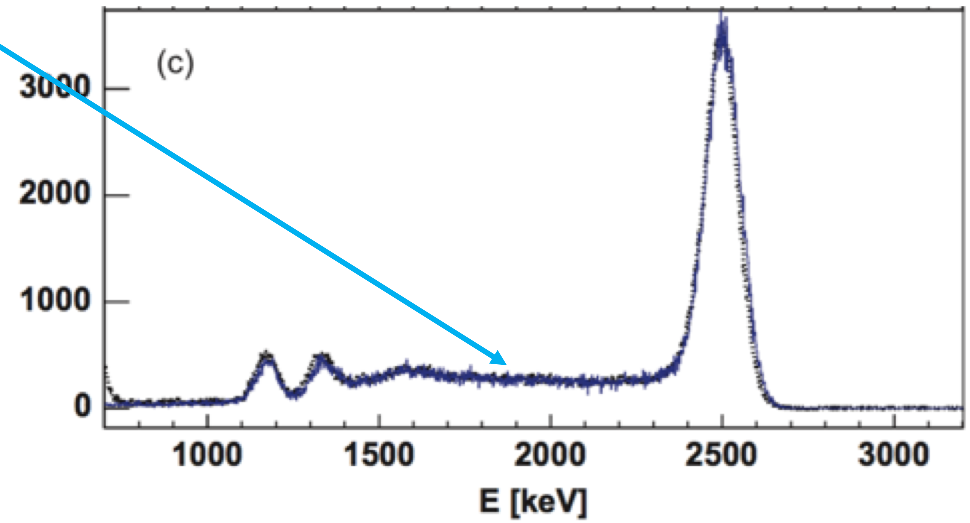
Incomplete summing: what is it?

Note the “tail” towards low E_x!



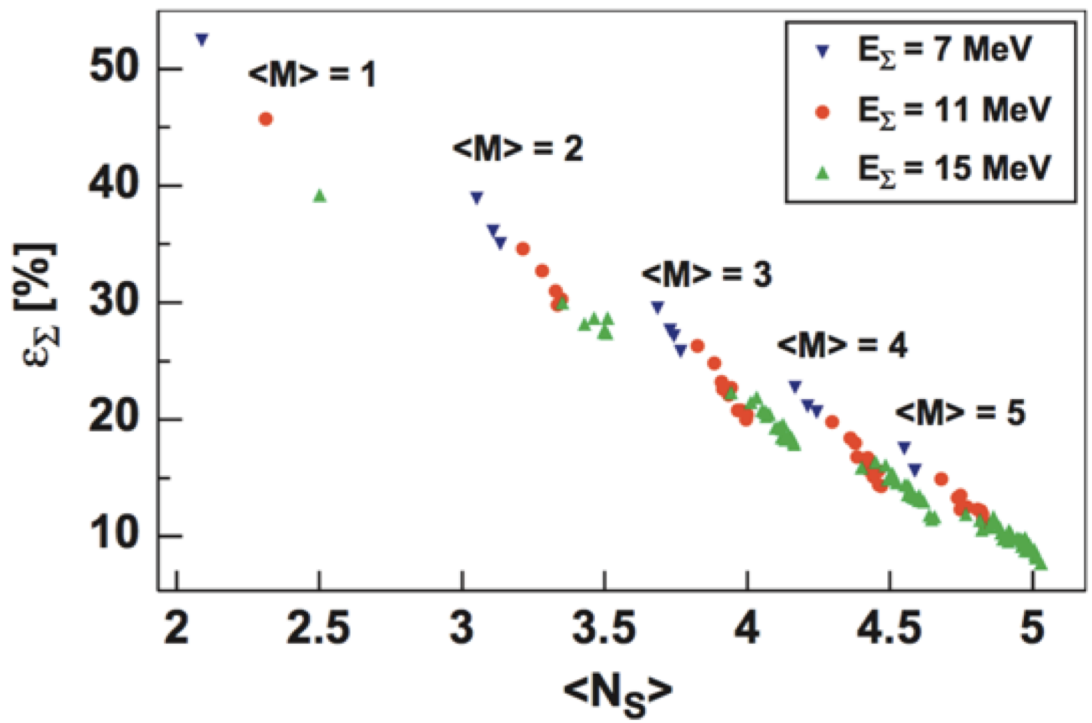
[From Table of isotopes, R.B. Firestone]

Sum of all segments, ^{60}Co source (1173keV+1332keV)



[A. Simon, S.J. Quinn, A. Spyrou et al, NIM A 703, 16 (2013)]

Summing efficiency and multiplicity



Summing efficiency of the SuN detector as a function of the average number of hits $\langle N_S \rangle$ for various sum-peak energies

[A. Simon, S.J. Quinn, A. Spyrou et al, NIM A 703, 16 (2013)]

E_x unfolding, ^{70}Ni

In the β-Oslo method, the sum of all segments gives the initial E_x, but:

-> if incomplete summing, the obtained E_x is not correct

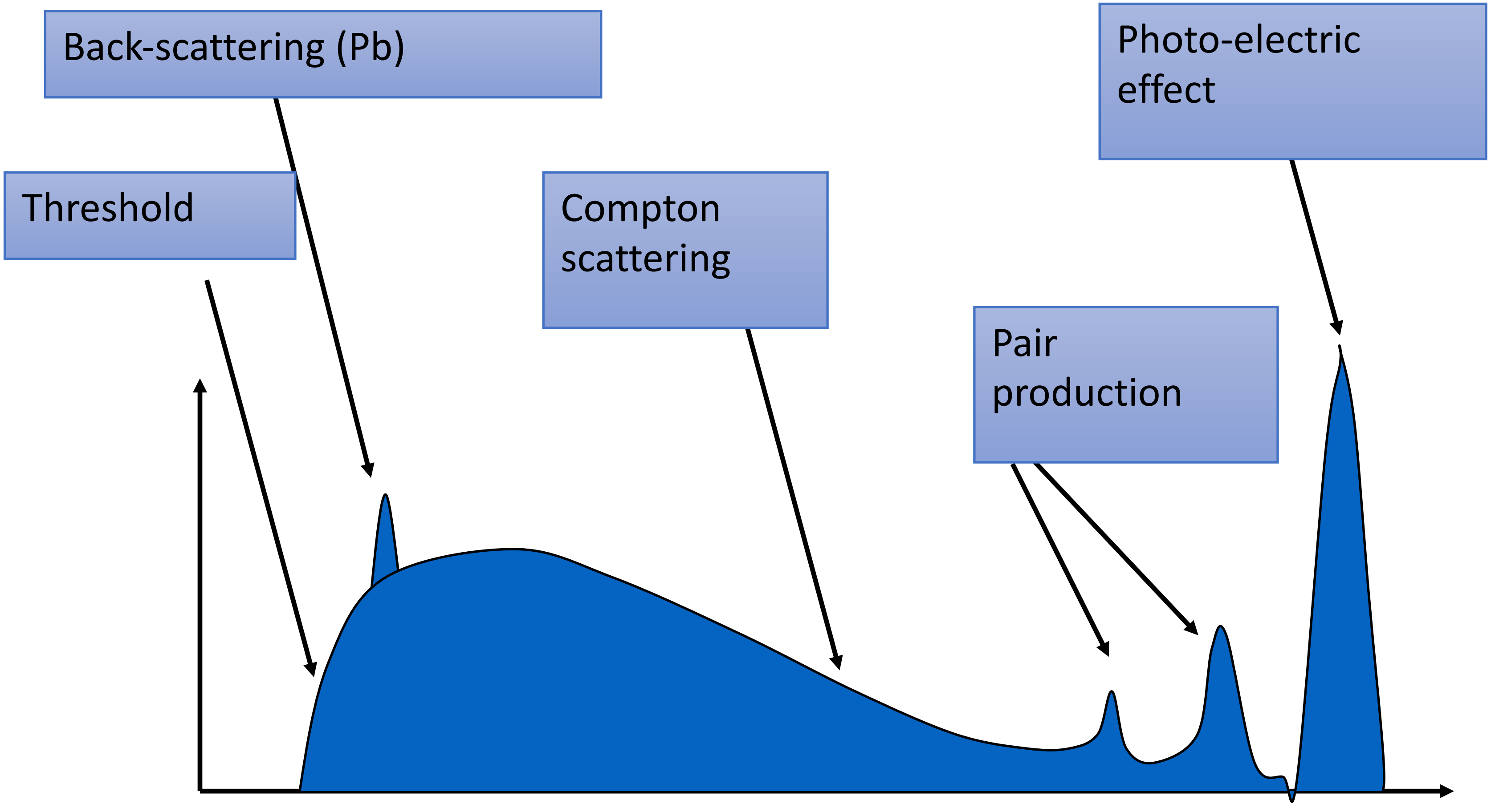
-> the higher the γ multiplicity, the lower the SuN efficiency

-> the high Q_β value gives a background from electrons interacting with SuN

$\Rightarrow$We need to unfold the E_x axis

The next slides are from Magne's presentation at a nuclear-physics group meeting in Oslo, 2017

One crystal NaI response function



The unfolding algorithm

We know how to fold: $$\mathbf{f} = \mathbf{R}\mathbf{u}$$

(i) First trial function: $\mathbf{u}^0 = \mathbf{r}$

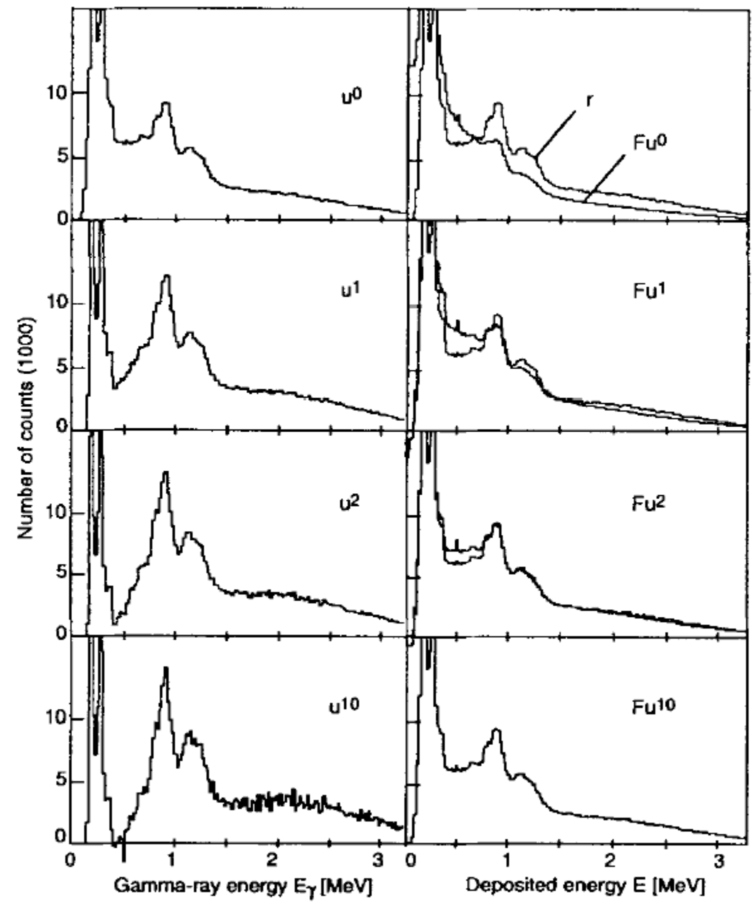
(ii) First folded spectrum: $\mathbf{f}^0 = \mathbf{R}\mathbf{u}^0$

(iii) Correct for how much we fail: $\mathbf{u}^1 = \mathbf{u}^0 + (\mathbf{r} - \mathbf{f}^0)$

(iv) Second folded spectrum: $\mathbf{f}^1 = \mathbf{R}\mathbf{u}^1$

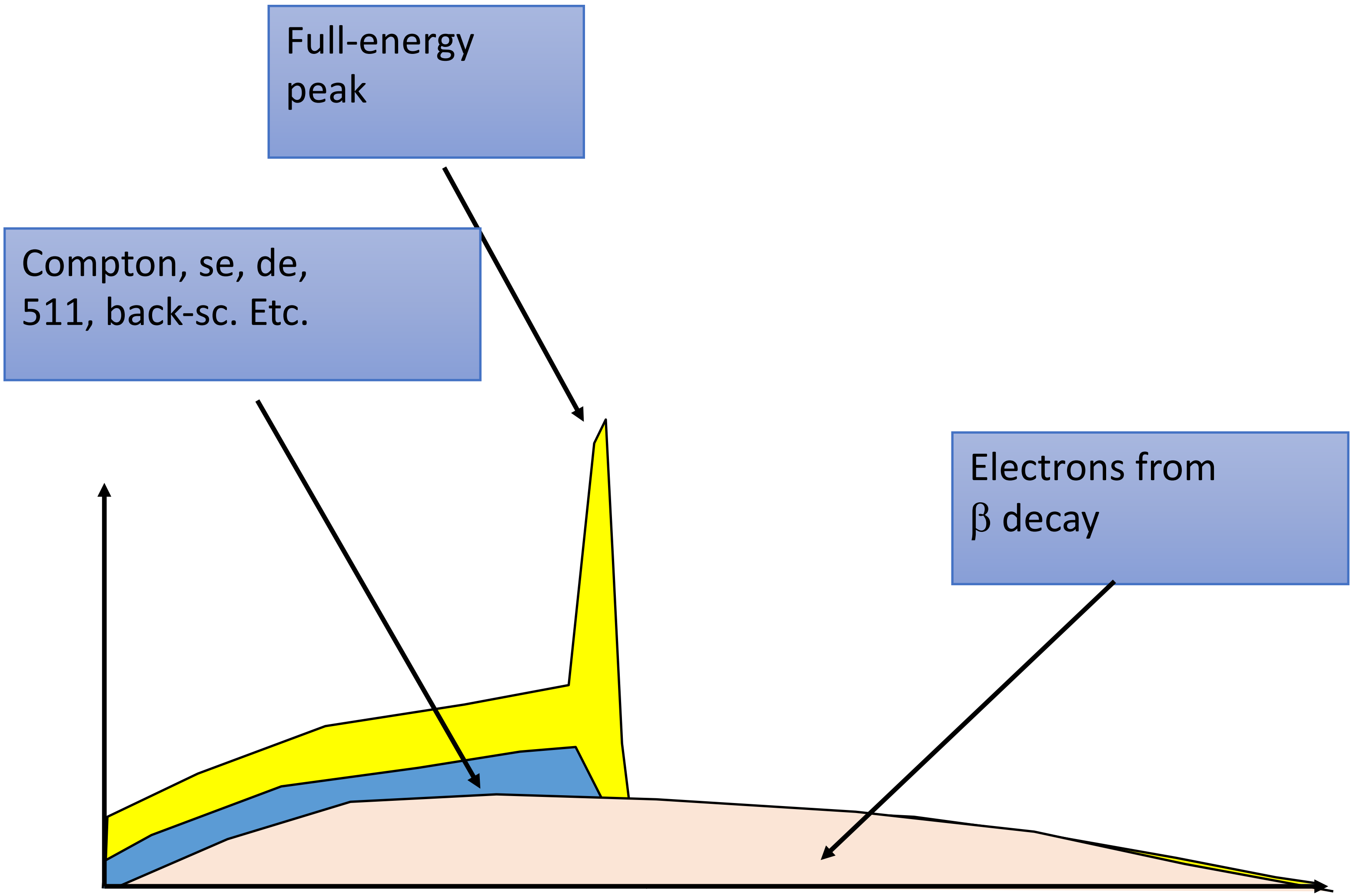
(v) The third trial function: $\mathbf{u}^2 = \mathbf{u}^1 + (\mathbf{r} - \mathbf{f}^1)$

and so on until $\mathbf{f}^i \approx \mathbf{r}$.



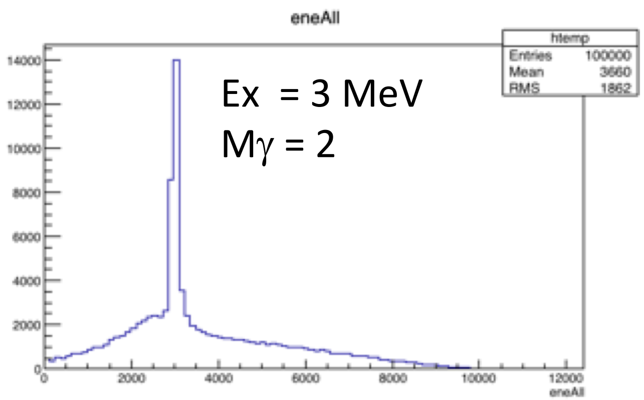
Guttormsen et al., NIM A 374, 371 (1996)

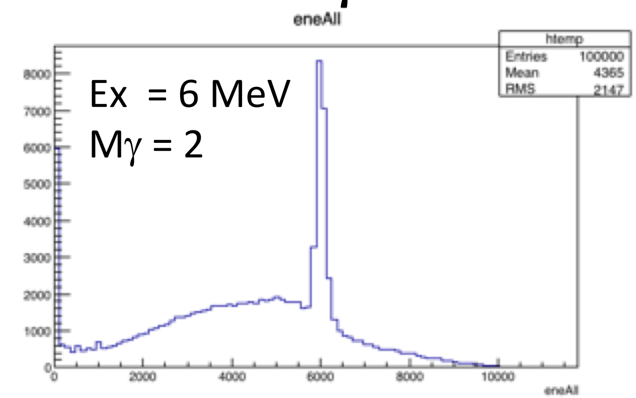
$E_x = \Sigma\ E_\gamma$ NaI response

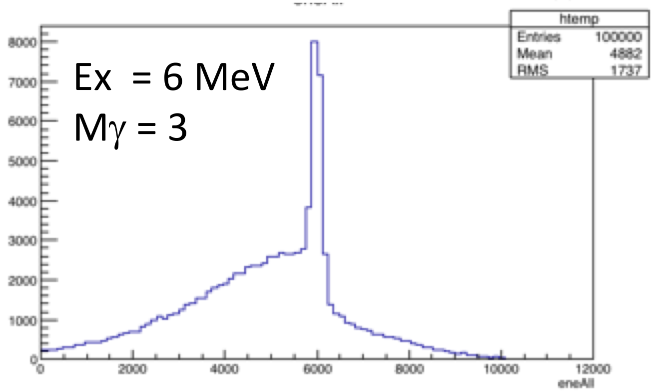


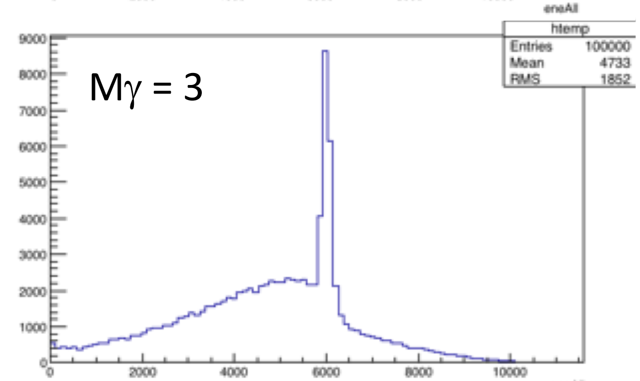
Dependence on E_x and M_γ

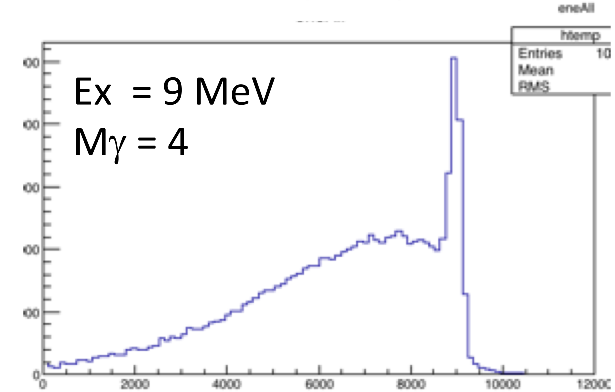
(GEANT4 simulations by Artemis Spyrou)

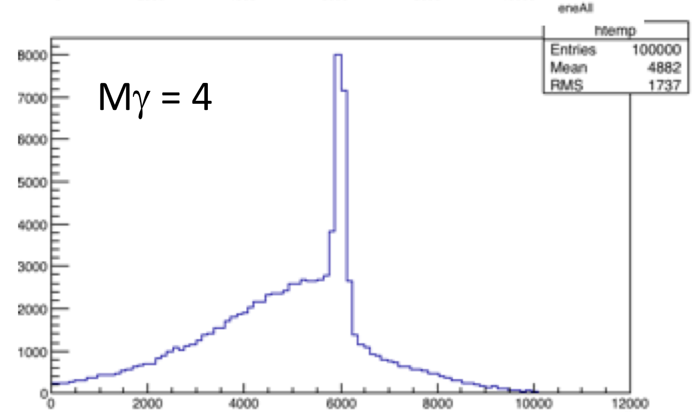










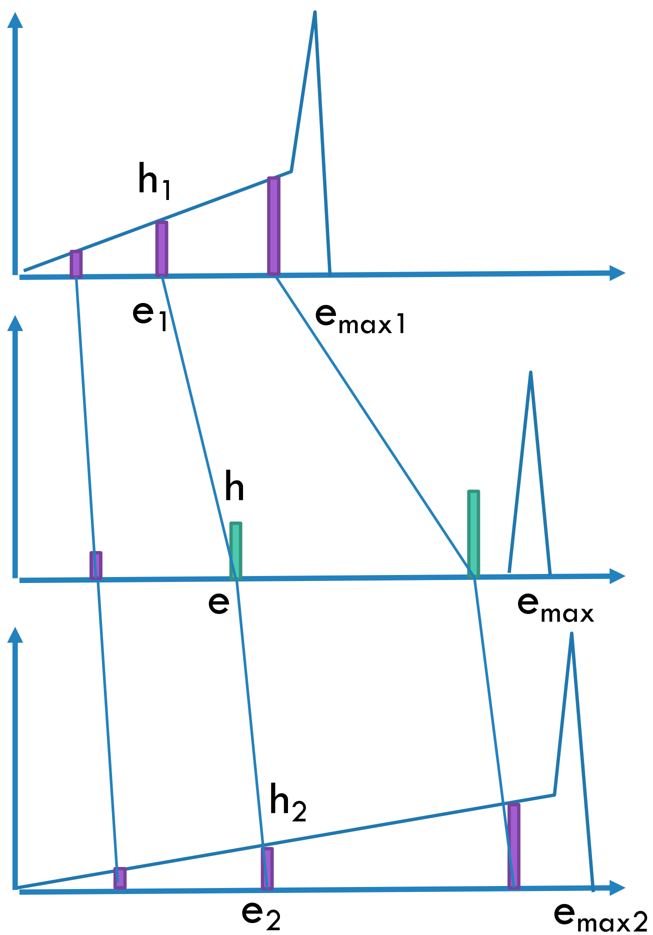


Multiplicity interpolation

Weigths:
$wm_1 = (m_2 - m)/(m_2 - m_1)$
$wm_2 = 1 - wm_1$

For all h's at the same Ex:
$h(e) = wm_1\, h_{m1}(e) + wm_2\, h_{m2}(e)$

E_x interpolation below the full-energy peak



Channel energy:

$e_1 = e\ (e_{max1}\ /e_{max})$

$e_2 = e\ (e_{max2}\ /e_{max})$

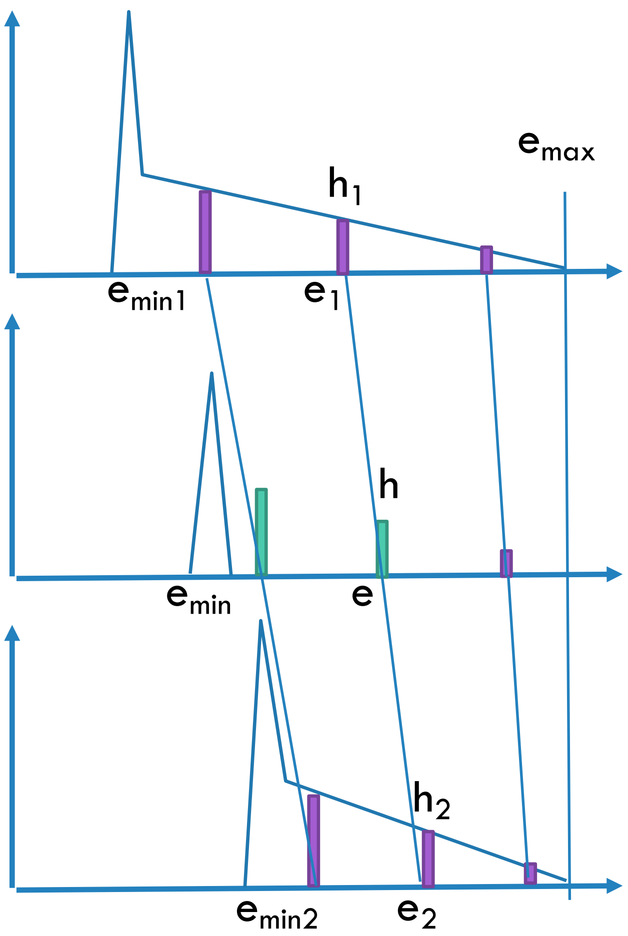
Weigths:

$we_1 = (e_{max2} - e)/(e_{max2} - e_{max1})$

$we_2 = 1 - we_1$

$h(e) = we_1\ h_1(e_1) + we_2\ h_2(e_2)$

E_x interpolation above the full-energy peak



$e_{max} = 12$ MeV

Channel energy:

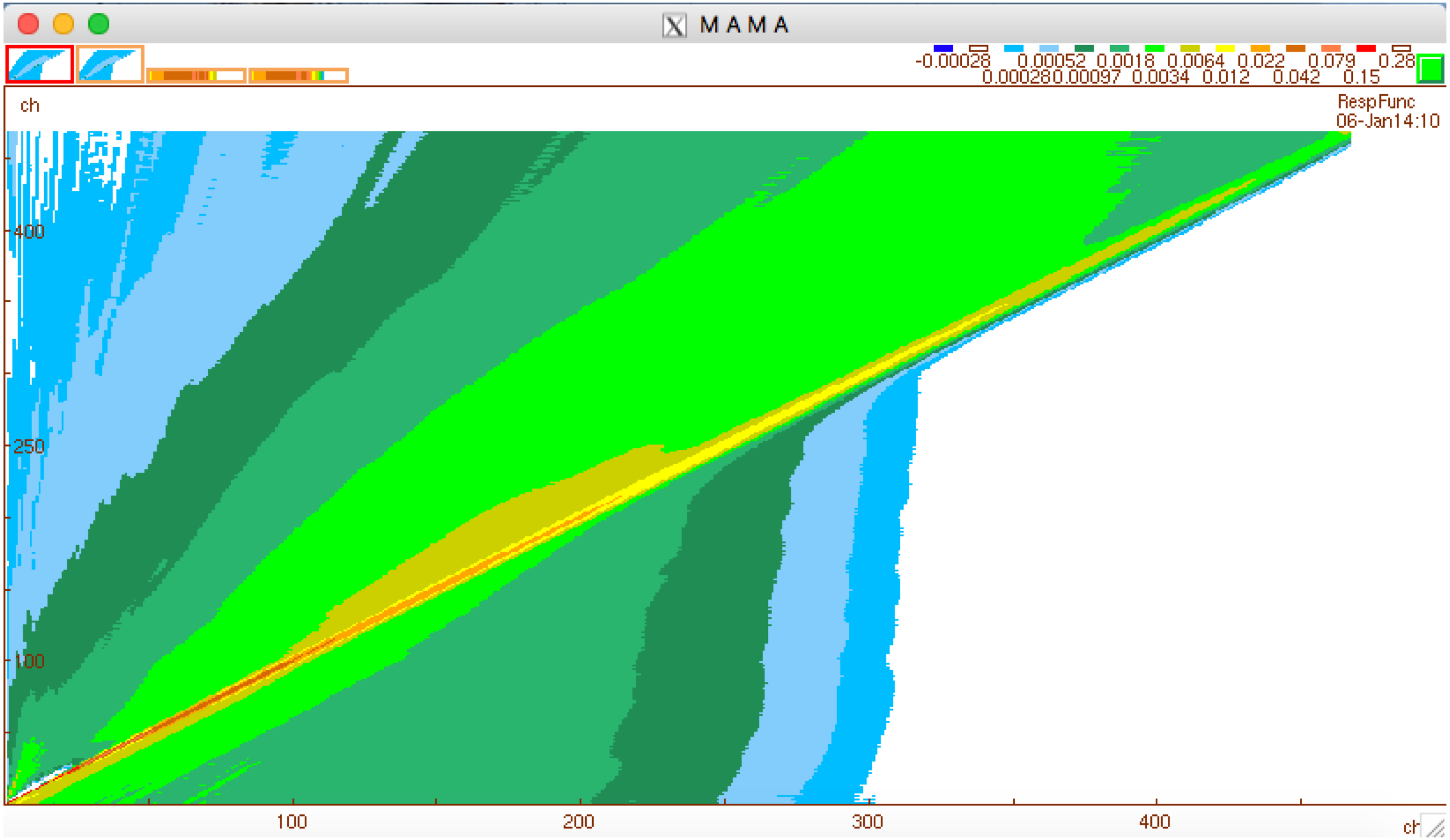
$e_1 = e_{min1} + (e - e_{min})(e_{max} - e_{min1})/(e_{max} - e_{min})$

$e_2 = e_{min2} + (e - e_{min})(e_{max} - e_{min2})/(e_{max} - e_{min})$

$h(e) = we_1\, h_1(e_1) + we_2\, h_2(e_2)$

The E_x response matrix

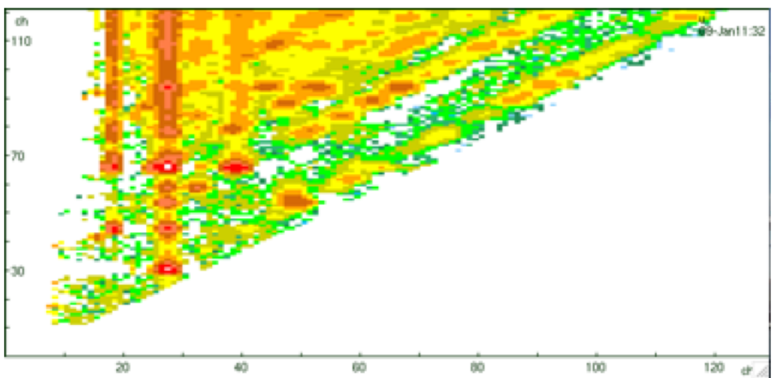
The y-axis is the true Ex populated. The x-axis is the Ex values detected by SuN.
Note that we observe values below (incomplete summing) and above (electron energies) the true Ex value.



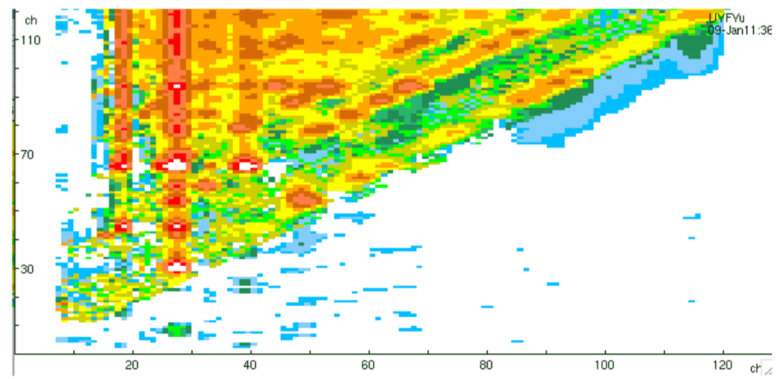
Folding and unfolding the E_x axis

Starts with an unfolded 92Zr matrix U0 from (p,p) reaction with Oslo method. Then fold along y-axis Fy(U0) and finally unfold back again, so that U0 = Uy(Fy(U0)). Note all the “curtains” hanging down below the Ex=Eg diagonal.

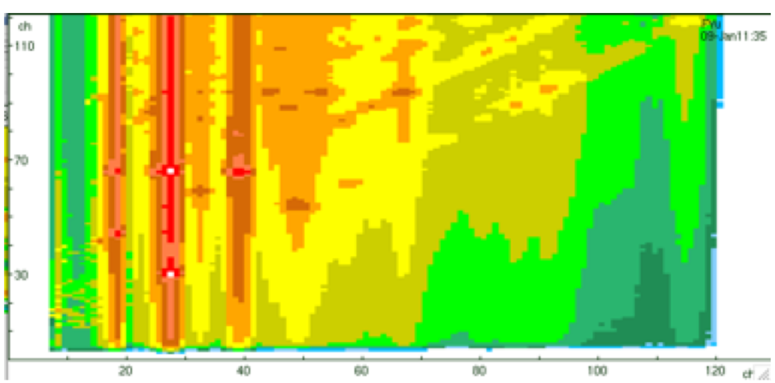
U_0



$U_y\,(F_y\,(U_0))$



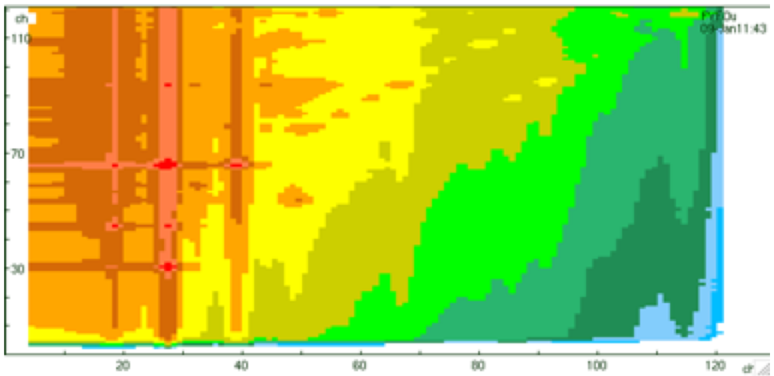
$F_y\,(U_0)$



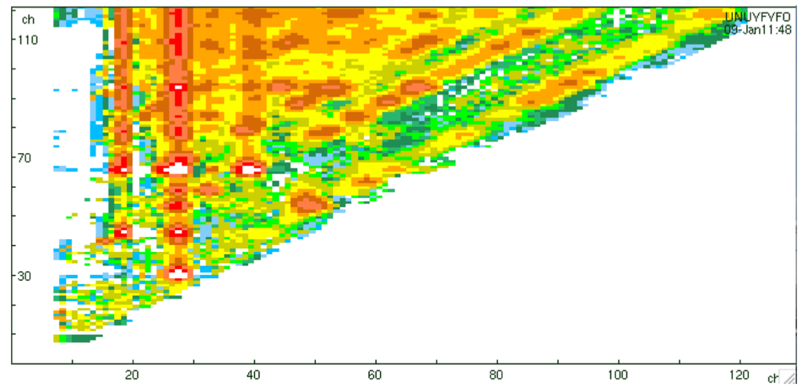
Folding and unfolding E_x and E_γ axis

Starts with U0 folded along Eg and Ex axis: Fy(Fx(U0)). Then unfolding along Ex-axis: Uy(Fy(Fx(U0))). Then unfold Eg-axis in order to obtain the original the U0 matrix: so that U0 = Ux(Uy(Fy(Fx(U0))).

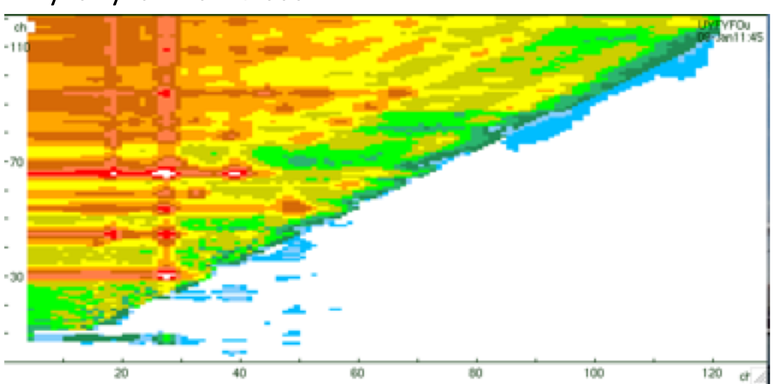
$F_y(F_x(U_0))$

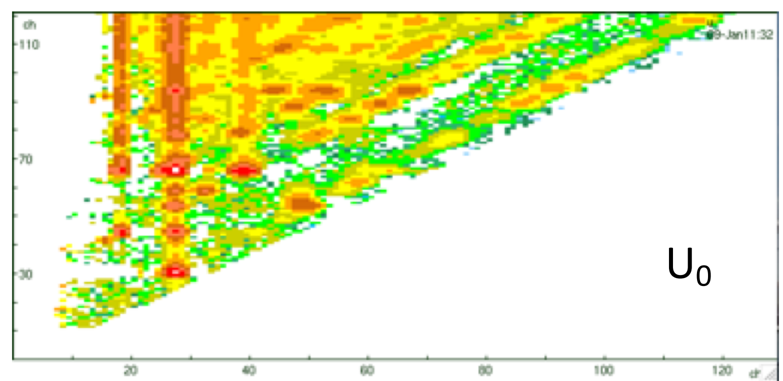


$U_x(U_y(F_y(F_x(U_0))))$



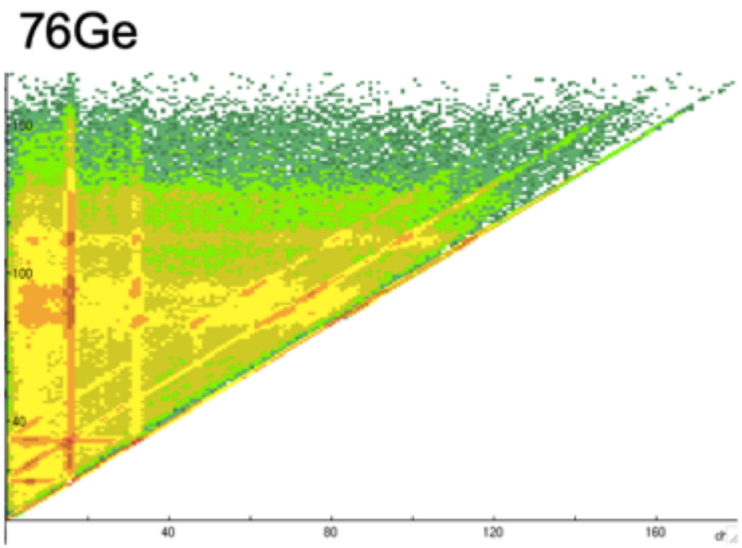
$U_y(F_y(F_x(U_0)))$

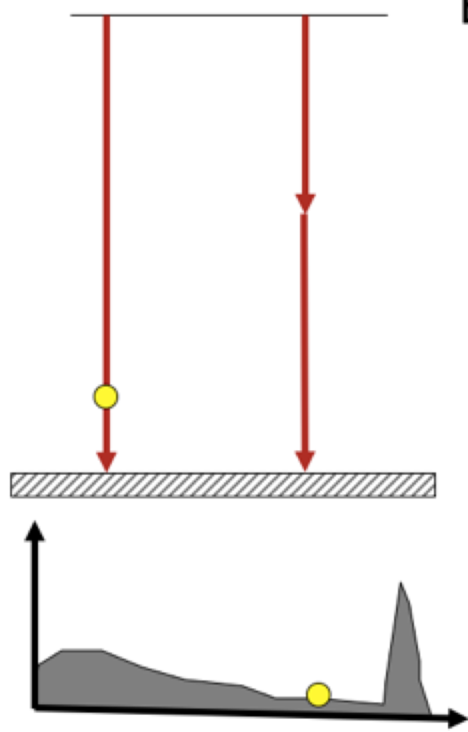


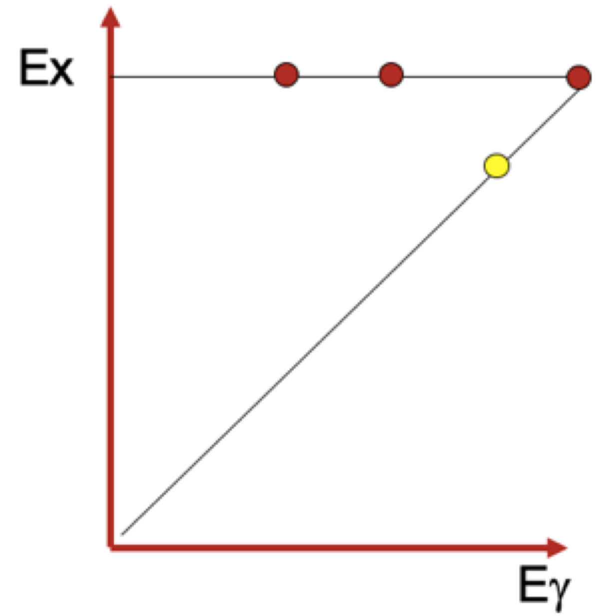


U_0

Correlations between E_x and E_γ – not taken into account so far



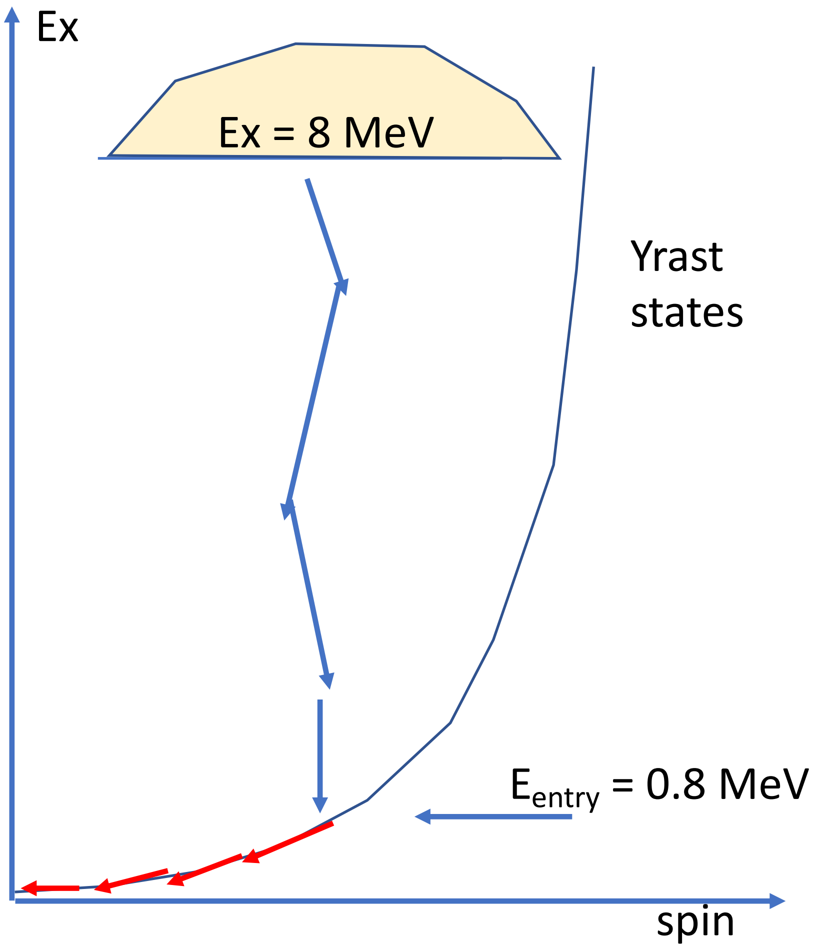




4. Extraction of 1st generation γ rays using MaMa

The 1st-generation method

- We want to isolate the distribution of the primary γ rays from all possible decay cascades at a given excitation-energy bin (i.e. branching ratios) [M. Guttormsen, T. Ramsøy, and J. Rekstad, NIM A255, 518 (1987)]



Total gamma-multiplicity:

$M_{tot} = M_{stat} + M_{yras}t = 4 + 4 = 8$

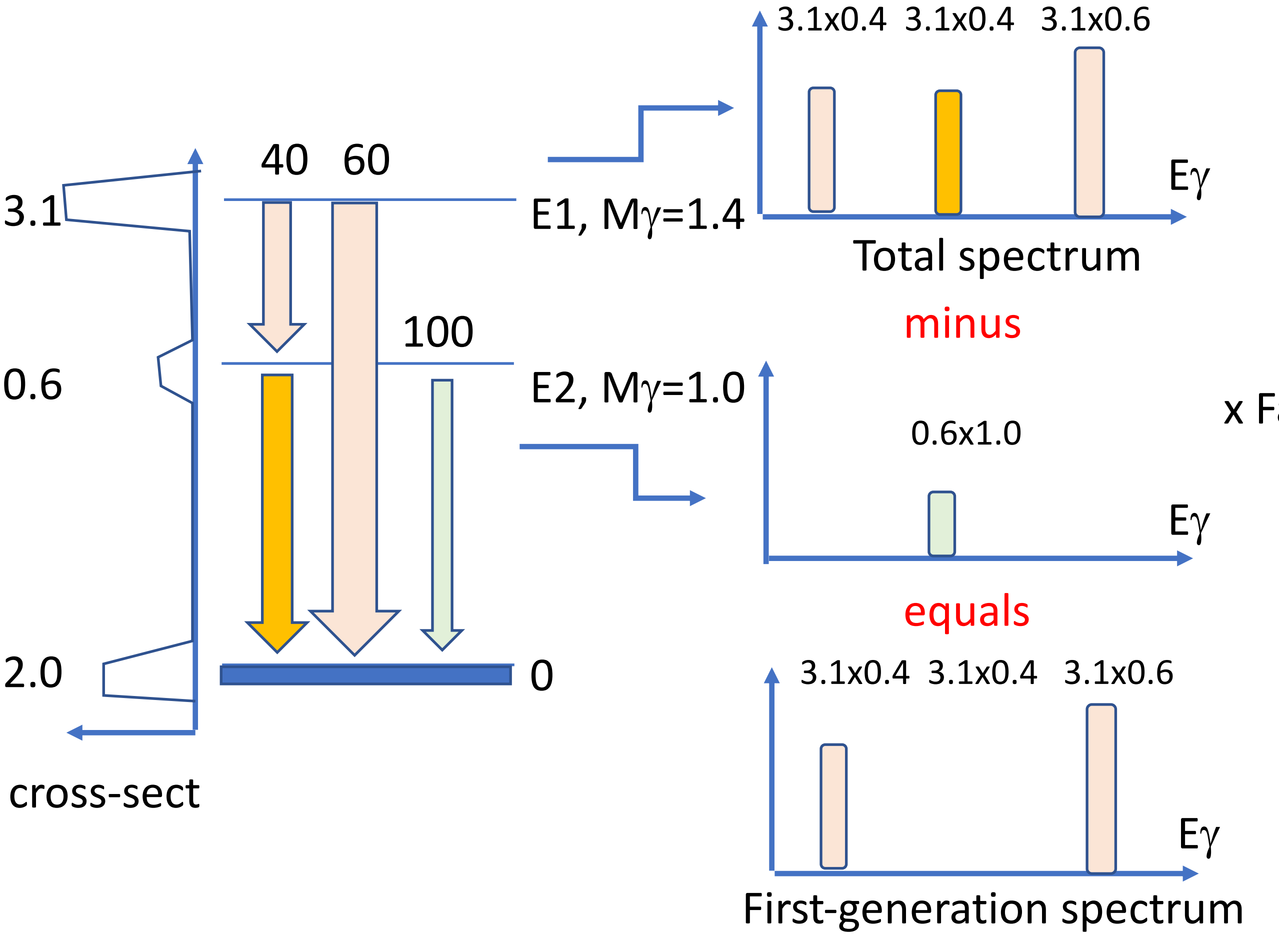
$M_{tot} = Ex/\langle E\gamma\rangle = 8/1 = 8$

$M_{stat} = (Ex-E_{entry})/\langle E\gamma\rangle_{stat} = (8-0.8)/1.8 = 4$

We only use M_{stat} with an artificial ground state of E_{entry} (instead of M_{tot}) if we cannot determine accurately the intensities of the yrast transitions.

M_{stat} is typically used for rotational rare earth nuclei

Simple example, 1st gen. method



x Factor

Cross sections:
Factor= 3.1x.4/0.6x1
= 2.07

Multiplicity:
Factor=(3.1x1.4-3.1x1)/0.6x1
=2.07

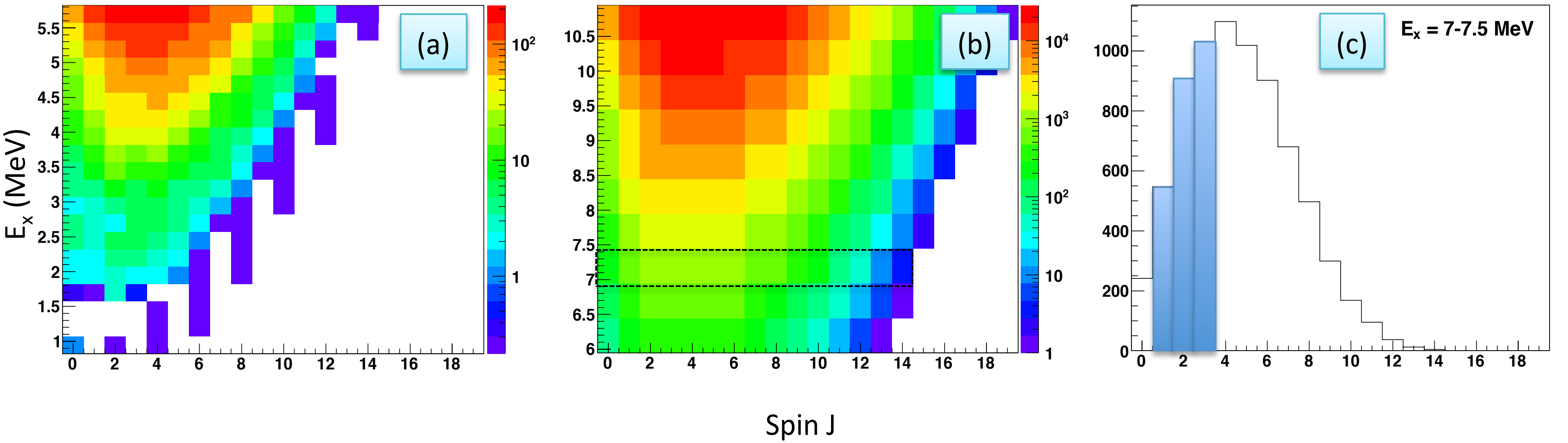
What about spin population?

Assumption behind the first-generation method:
[M. Guttormsen, T. Ramsøy, and J. Rekstad, NIM A255, 518 (1987)]

The present method is based on the assumption that states populated after the first γ-transition have the same decay properties as states populated directly in the particle reaction at that excitation energy. Using the

A possible culprit

- Populated spins in the standard Oslo method: J ≈ 0-10 both directly and from decay from above (and still we have some trouble!!)
- Beta-decay populates a few spins, much more selective (mainly Gamow-Teller, i.e. same parity as the mother nucleus and spins $J_{initial} = J_{mother}-1, J_{mother}, J_{mother}+1$)



Spin distribution for ^{76}Ge from Goriely et al. [PRC 78, 064307 (2008)]
(a) for Ex ≈ 1-5.8 MeV, (b) for Ex ≈ 6-10.9 MeV, and
(c) for a projection for Ex ≈ 7-7.5 MeV. **Blue** histograms: $J_{initial}$ of ^{76}Ge.

Information saved to figegaout.dat

Average gamma multiplicity – this gets better with larger Ex bins (200 keV/ch instead of 50 keV/ch)

```
figegaout.dat

 Parameters used:

First geneneration spectra extracted for
excitation energies between 11000.-    0. keV
corresponding to y-channels   220 -    0
 Number of spectra=  221
 Ax0 =      0.0 Ax1 =     50.0 Ay0 =      0.0 Ay1 =     50.0
 AxW0=      0.0 AxW1=      0.0 AyW0=      0.0 AyW1=      0.0
 Weighting: 0 Level density parameter a= 7.6 Exponent n=4.2
 Normalization= 2 Stat/Tot= 2 Areacorr.= 1
 Experimental lower gamma threshold:      300.0 keV (ch=   6)
 Upper threshold for statistical gammas:  300.0 keV (ch=   6)
 Average energy entry point in g.s. band:  300.(stat)  2000.(tot)
 Sliding threshold given by Ex*R, with R = 0.30
 Multiplicities: MA = Af/Afg and ME = (Ex-ExEntry)/<Eg>

Iteration number:   1
Y-ch   Ex          Af         Ag        Afg  Mult    Sing Alpha MATot METot MASta MESta
220 11000.         0.         0.         0. 0.00       0  1.15  0.00  0.00  0.00  0.00
219 10950.        48.        26.        22. 2.22    1000  0.89  2.22  2.22  2.22  2.64
218 10900.         0.         0.         0. 0.00    1000  0.89  0.00  0.00  0.00  0.00
217 10850.        45.        30.        15. 1.74    1000  0.85  2.98  1.74  2.98  2.07
216 10800.        51.        29.        22. 2.34    1000  0.99  2.34  2.34  2.34  2.79
215 10750.         0.         0.         0. 0.00    1000  0.99  0.00  0.00  0.00  0.00
214 10700.        64.        27.        38. 3.71    1000  1.15  1.71  3.71  1.71  4.44
213 10650.        50.        27.        22. 2.06    1000  0.85  2.23  2.06  2.23  2.47
212 10600.       109.        60.        49. 2.06    1000  0.85  2.22  2.06  2.22  2.47
211 10550.        37.        21.        16. 2.30    1000  0.98  2.30  2.30  2.30  2.76
210 10500.       140.        76.        65. 2.08    1000  0.85  2.17  2.08  2.17  2.50
209 10450.       112.        62.        50. 2.26    1000  0.95  2.26  2.26  2.26  2.71
208 10400.       218.       124.        94. 1.96    1000  0.85  2.31  1.96  2.31  2.36
207 10350.         3.         1.         2. 8.04    1000  1.15  1.23  8.04  1.23  9.68
206 10300.        41.        26.        15. 1.73    1000  0.85  2.76  1.73  2.76  2.08
205 10250.        39.        32.         7. 1.33    1000  0.85  5.82  1.33  5.82  1.60
204 10200.       142.        84.        58. 2.45    1000  1.13  2.45  2.45  2.45  2.96
203 10150.       118.        71.        47. 1.81    1000  0.85  2.52  1.81  2.52  2.18
202 10100.       130.        69.        62. 2.12    1000  0.88  2.12  2.12  2.12  2.56
```

Correction factor to the weighting function. Can only deviate from 1 by 15%. If it is at its limits (0.85 or 1.15), it indicates that the primary spectrum at this Ex is not fully reliable

5. Getting the level density and γ-ray transmission coefficient using *rhosigchi.f*

The principle

Ansatz: primary γ matrix can be factorized into two independent functions (vectors)

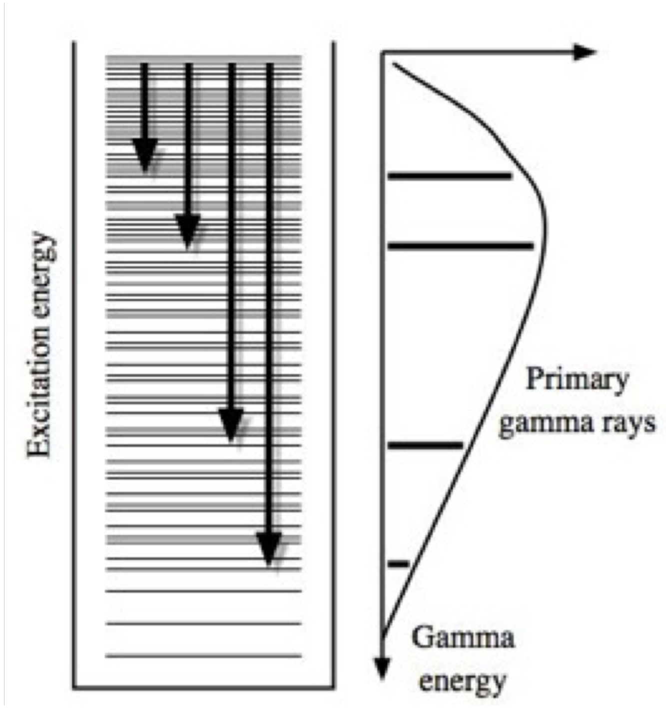
[Schiller et al., NIM A 447, 498 (2000)]

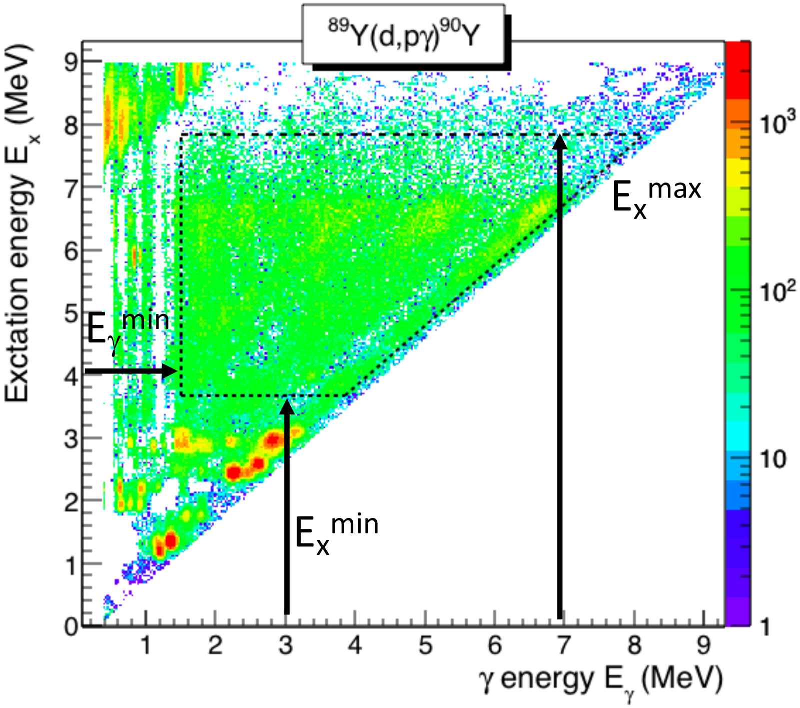
Assumes: (i) Compund-state *decay*

(ii) The Brink hypothesis

$$P(E_i, E_\gamma) \propto \rho(E_i - E_\gamma)\tau(E_\gamma)$$

$$f(E_\gamma) = \tau(E_\gamma) / 2\pi E_\gamma^3$$





Formalism, *rhosigchi.f*

- Normalize $P(E_i,E_\gamma)$ so that $\sum_{E_\gamma=E_\gamma^{\min}}^{E_i} P(E_i,E_\gamma)=1.$

- Theoretical estimate of experimental primary γ matrix:

$$P_{th} = \frac{\tau(E_\gamma)\rho(E_i - E_\gamma)}{\sum_{E_\gamma=E_\gamma^{\min}}^{E_i} \tau(E_\gamma)\rho(E_i - E_\gamma)}$$

- First trial function: $\rho^{(0)} = 1,$

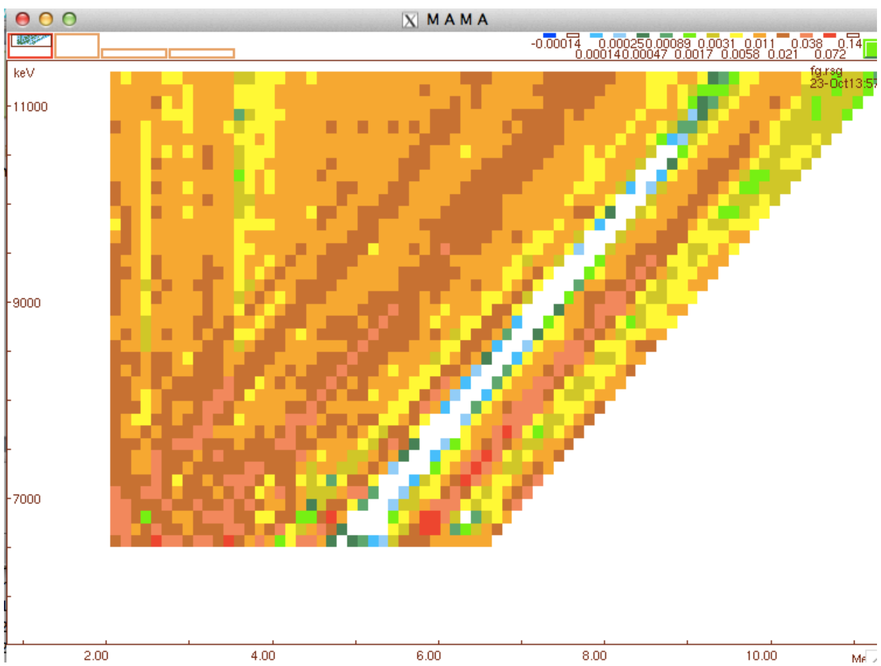
$$P(E_i,E_\gamma) = \frac{\tau^{(0)}(E_\gamma)}{\sum_{E_\gamma=E_\gamma^{\min}}^{E_i} \tau^{(0)}(E_\gamma)}$$

Note: there is no *a priori* assumption that the level density has a Fermi gas or constant-temperature shape!

Formalism, *rhosigchi.f*

- Higher-order estimates through a least χ^2- minimization:

$$\chi^2 = \frac{1}{N_{free}} \sum_{E_i=E_{\min}}^{E_{\max}} \sum_{E_\gamma=E_\gamma^{\min}}^{E_i} \left[\frac{P_{th}(E_i,E_\gamma) - P(E_i,E_\gamma)}{\Delta P(E_i,E_\gamma)} \right]^2$$



^{56}Fe, fg.rsg
[see also Larsen et al., JPhysG (2017)]

Each vector element in ρ and τ is treated as a free parameter

^{56}Fe(p,p') example:
Data points ("pixels"): 2052
Free parameters: 184

$$\mathbf{N_{free} << N_{data}}$$

Typically ≈10-20 iterations, but converges after ~4-5 iterations

Comparison, input/output

ANALYSIS OF POSSIBLE SYSTEMATIC ERRORS IN THE . . . PHYSICAL REVIEW C **83**, 034315 (2011)

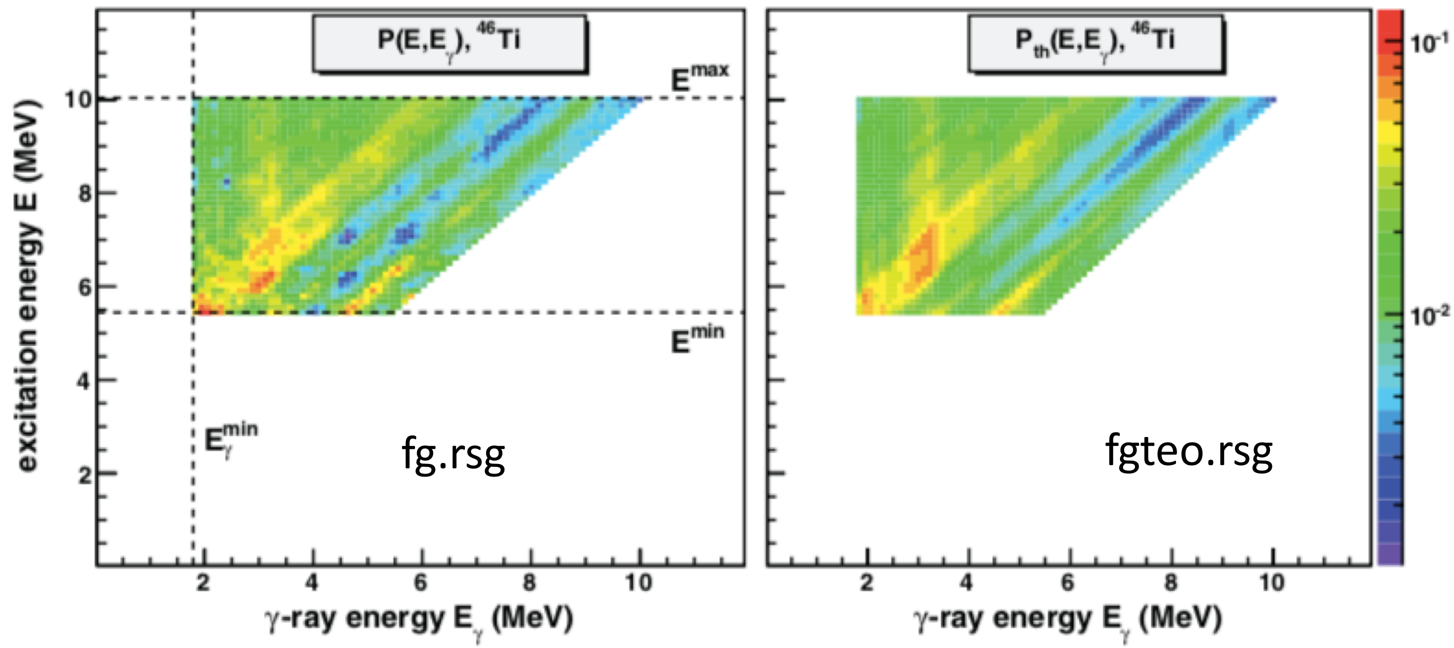
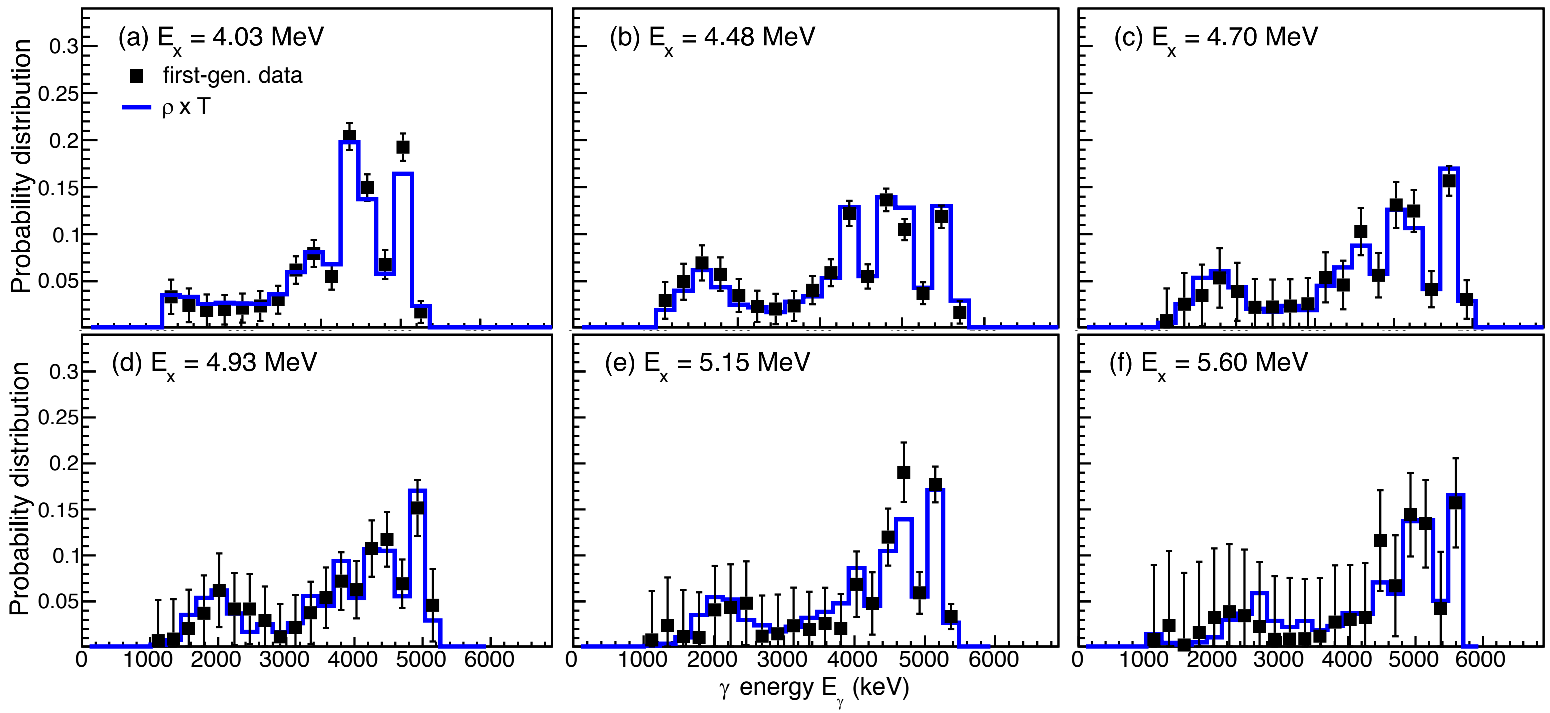


FIG. 5. (Color online) Experimental first-generation matrix $P(E, E_\gamma)$ (left) and the calculated $P_{th}(E, E_\gamma)$ (right) of ^{46}Ti from the iteration procedure of Schiller *et al.* [25]. The dashed lines show the limits set in the experimental first-generation matrix for the fitting procedure. The data are taken from the experiment presented in Ref. [15].

[From Larsen *et al.*, PRC **83**, 034315 (2011)]

Does it work? ^{76}Ge example

- Extracted level density and γ-ray trans.coeff. from the whole region within E_x^{min}, E_x^{max}, E_γ^{min} tested against primary γ spectra from individual bins (see Root script does_it_work_51Ti_NSCL.cpp)



[From the supplemental material, A. Spyrou, S.N. Liddick, A.C. Larsen, M. Guttormsen et al., PRL **113**, 232502 (2014)]

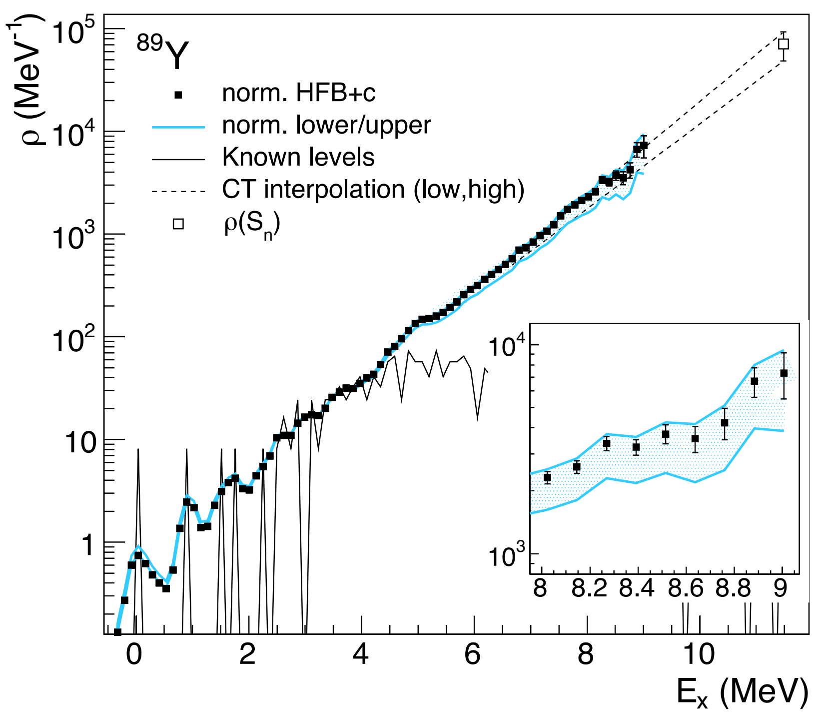
6. Normalization of the level density (and the slope of the γ-ray transmission coefficient) using *counting.c*

For nuclei at/near stability

Low E_x: known, discrete levels
High Ex: calculate total level density from the neutron-resonance spacing D_0

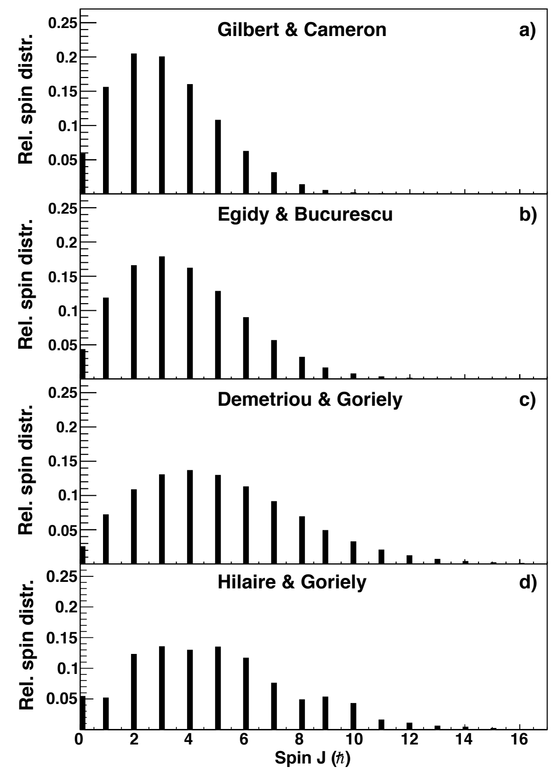
From Ericson (1960):

$$g(E_x, J) \cong \frac{2J+1}{2\sigma^2}\exp[-(J+1/2)^2/2\sigma^2]$$



[From A.C. Larsen et al., PRC **93**, 045810 (2016)]

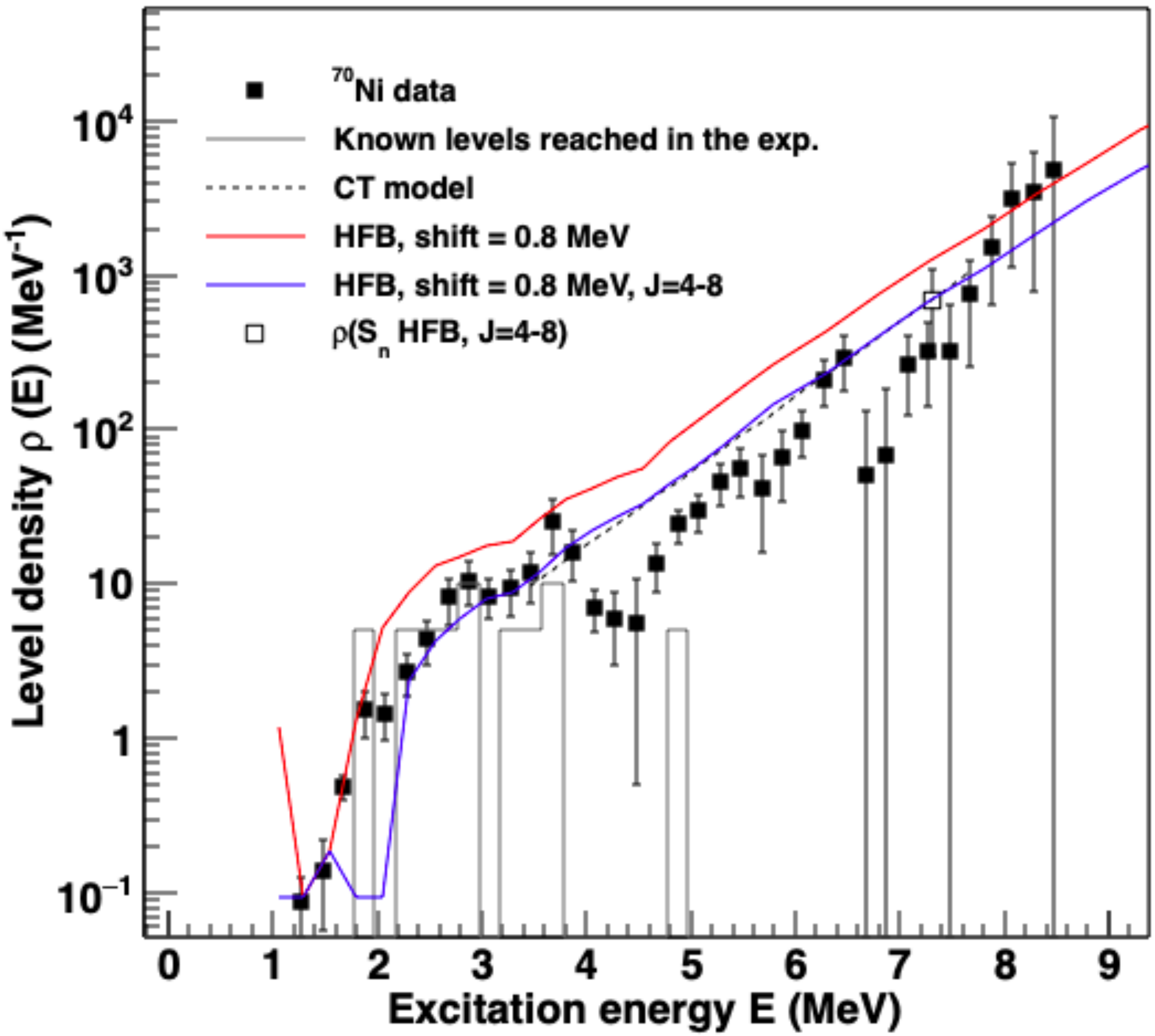
CHALLENGE: usually no experimental data on the spin distribution at high E_x!



Level-density normalization, ^{70}Ni

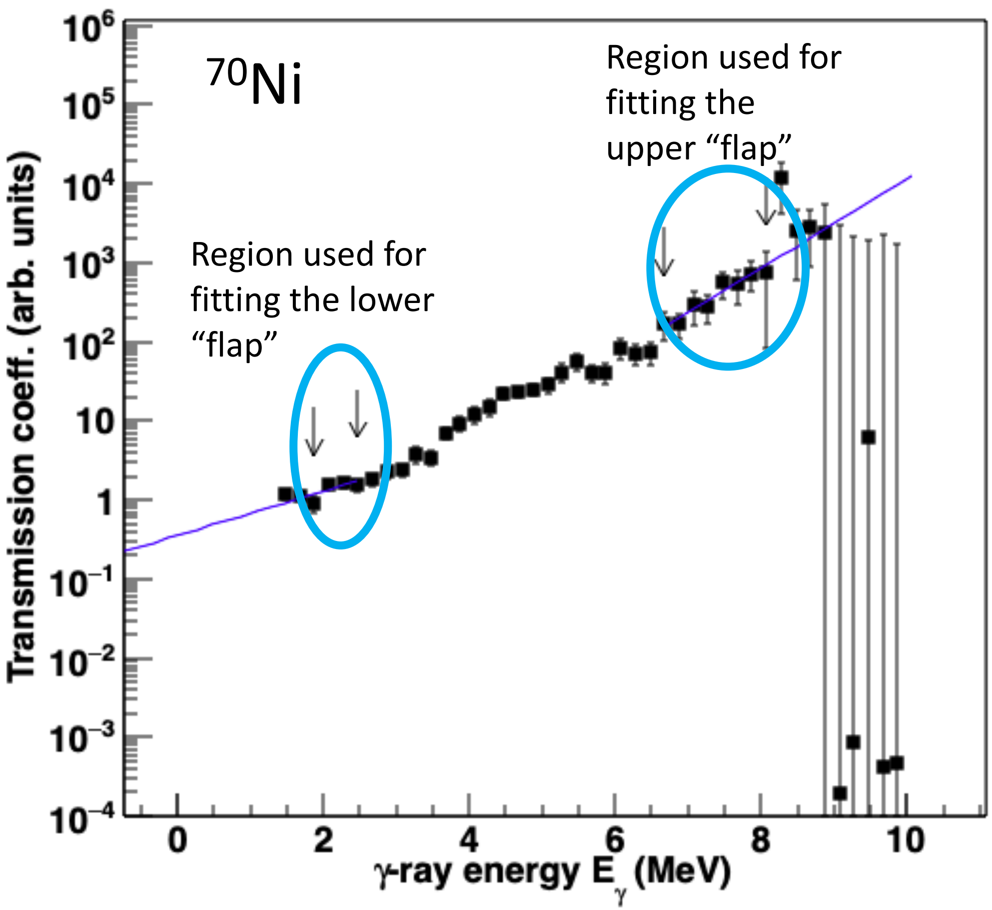
- Discrete levels for both parities within the spin range J=4-8 ($J_{initial}$ = 5^-,6^-,7^-, assuming one dipole transition to reach both parities and spins 4-8)
- Using Goriely's HFB tables (calculations from 2008), adding together both parities for spins J=4-8, and shift them to match the discrete levels
- This gives the level density for this r*estricted* spin range => gives the correct slope for the γ-transmission coefficient
- Note that the *total* level density should be used in the TALYS calculations (TALYS figures out the spins reached in n-capture, and needs the total level density for all spins as input)

Level-density normalization, ^{70}Ni



counting.c also normalizes the slope of the γ-ray transmission coefficient

- … and makes "flaps" [credit: Stephanie Lyons ☺] on "both sides" of the experimental data



Note:
This figure was made with an older version of counting.c. The current one on Github gives a steeper decline on the lower "flap", to get an approx. exponential low-energy component in the γ strength function

7. Normalization of the γ-ray transmission coefficient and getting the dipole γ-ray strength function using *normalization.c*

For nuclei near/at stability

We only got the slope from the level density normalization, and need to determine the scaling factor B by normalizing to the average, total radiative width measured for s-wave neutron resonances:

$$\langle \Gamma_\gamma (S_n, I_t \pm 1/2, \pi_t) \rangle$$
$$= \frac{B}{4\pi \rho(S_n, I_t \pm 1/2, \pi_t)} \int_{E_\gamma=0}^{S_n} dE_\gamma \mathscr{T}(E_\gamma)$$
$$\times \rho(S_n - E_\gamma) \sum_{J=-1}^{1} g(S_n - E_\gamma, I_t \pm 1/2 + J),$$

We assume (and have measured!) dominance of dipole radiation, so that

$$B\mathscr{T}(E_\gamma) = B \sum_{XL} \mathscr{T}_{XL}(E_\gamma) \approx B[\mathscr{T}_{\mathrm{E1}}(E_\gamma) + \mathscr{T}_{\mathrm{M1}}(E_\gamma)]$$

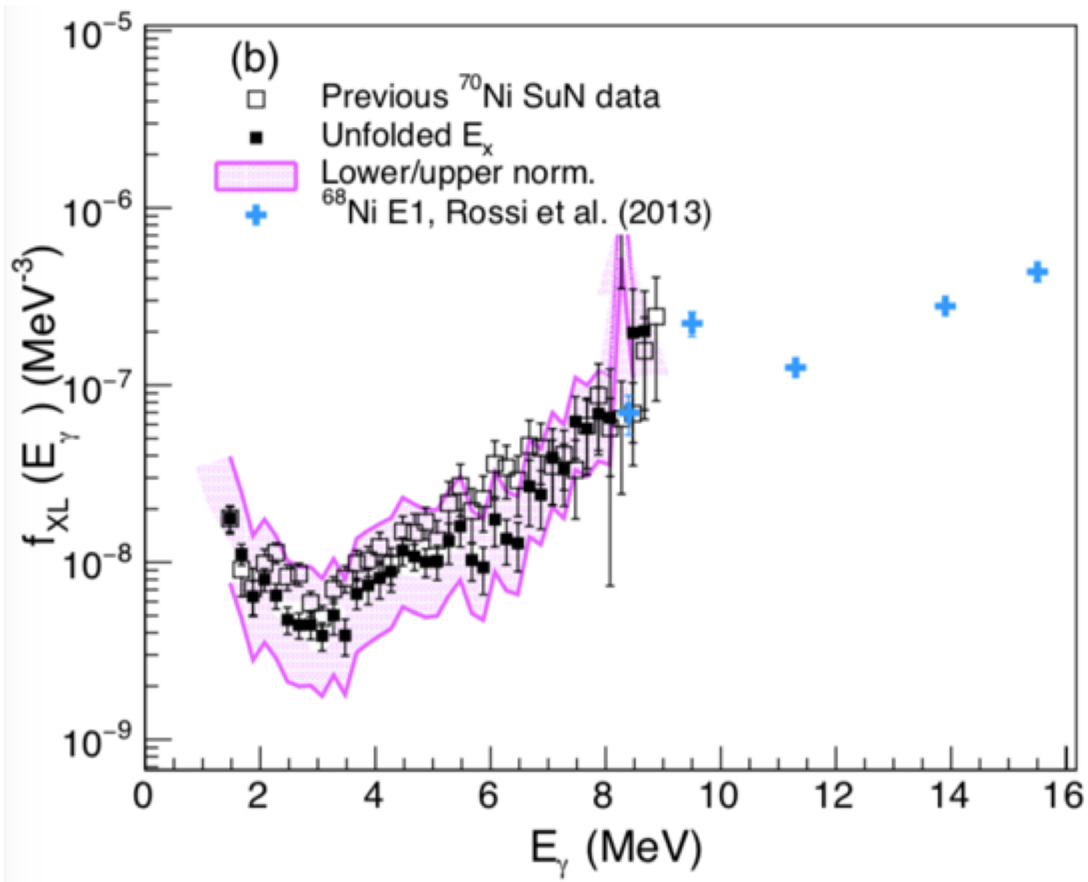
and $f(E_\gamma) = \frac{1}{2\pi E_\gamma^3} B\mathscr{T}(E_\gamma)$

Normalizing the γ strength of ^{70}Ni

No neutron-resonance data available (obviously)

⇒ Used Coulomb-dissociation data of ^{68}Ni measured at GSI (Rossi et al., PRL (2013))

⇒ Scaled the radiative width (used as a free parameter in normalization.c) until best match with the GSI data at ≈8.5 MeV

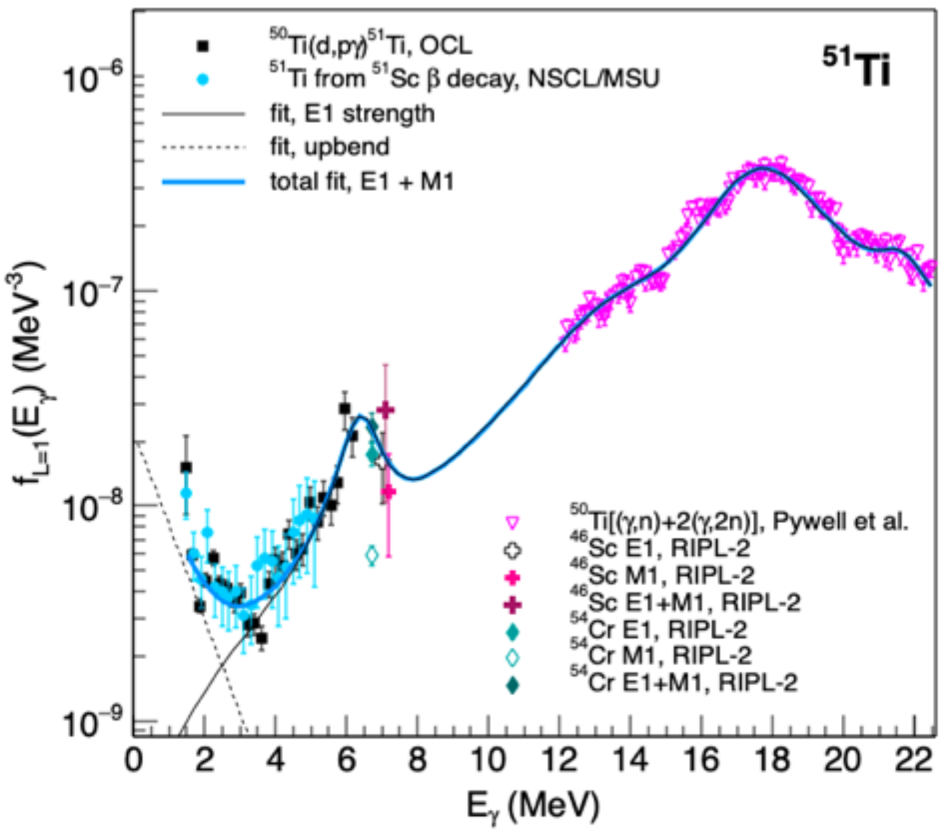


8. Fit of the γ-ray strength function to generate TALYS E1 and M1 tables (Root script)

Using ^{51}Ti as an example

Root script fitexample_gSF_51Ti.cpp (input files also provided) makes a fit of

- the ^{50}Ti(d,pγ)^{51}Ti data from Oslo
- the ^{51}Sc->^{51}Ti beta-decay data from NSCL
- (γ,n) + 2(γ,2n) photonuclear data from Pywell et al
- E1 and M1 strengths from RIPL-2 for ^{46}Sc and ^{54}Cr



The fit includes:

- Generalized Lorentzian (two components), E1
- One Standard Lorentzian around Eγ = 14 MeV, E1
- One Standard Lorentzian around Eγ = 6 MeV, E1
- Upbend as an exponential function (assumed to be M1)

E1 and M1 strength functions printed to files (TALYS format)

```
// Print E1 and M1 strengths to file, to use in the TALYS calculations
// REMEMBER that the TALYS functions are given in mb/MeV (Goriely's tables)
// so we must convert with the factor const double factor   = 8.6737E-08;   // const. factor in mb^(-1) MeV^(-2)
FILE *E1file, *M1file;

E1file = fopen("E1_gsf_51Ti_TALYSformat.txt","w");
fprintf(E1file," Z=  22 A=  51\n");
fprintf(E1file,"  U[MeV]  fE1[mb/MeV]\n");
double dummy = 0.1;
//cout << " E1 strength:" << endl;
for(i=0;i<300;i++){
    fprintf(E1file,"%9.3f%12.3E\n",dummy,(plot_strength_E1->Eval(dummy))/factor);
    //cout << dummy << " " << (plot_strength_E1->Eval(dummy)) << endl;
    dummy += 0.1;
}
fclose(E1file);

M1file = fopen("M1_gsf_51Ti_TALYSformat.txt","w");
fprintf(M1file," Z=  22 A=  51\n");
fprintf(M1file,"  U[MeV]  fM1[mb/MeV]\n");
dummy = 0.1;
//cout << " M1 strength:" << endl;
for(i=0;i<300;i++){
    fprintf(M1file,"%9.3f%12.3E\n",dummy,(plot_strength_upbend->Eval(dummy))/factor);
    //cout << dummy << " " << (plot_strength_upbend->Eval(dummy)) << endl;
    dummy += 0.1;
}
fclose(M1file);

cout << " Modeled strength functions for 51Ti written in TALYS format. " << endl;
```

9. TALYS input file for calculating (n,γ) cross sections and rates

Using again ^{51}Ti as an example

input_ng_51Ti_example.txt

```
#
# TALYS input file, 50Ti(n,g)51Ti
# Date: Tue 13 March, 2018
# Recommended normalisation
# Additional comments added on Aug 6, 2019
# Cecilie

projectile n
ejectiles g
element ti
mass 50
energy energies.txt
massmodel 2

transeps 1.00E-15
xseps 1.00E-25
popeps 1.00E-25
preequilibrium y
fileresidual y

# CT model with parameters T = 1.227 MeV, E0 = 0.007 MeV
# I have copied the table generated by counting.c found in the
# output file talys_nld_cnt.txt into the Goriely tables contained
# in /talys/structure/density/ground/goriely/Ti.tab for Z= 22 A= 51
ldmodel 4
ptable 22 51 0.0
ctable 22 51 0.0

# Use first 14 discrete levels
Nlevels 22 51 14


# Gamma strength: tables for the E1 and M1 components
# generated with the Root script fitexample_gSF_51Ti.cpp
E1file 22 51 E1_gsf_51Ti_TALYSformat.txt
M1file 22 51 M1_gsf_51Ti_TALYSformat.txt
gnorm 1.
```

10. Some Root <-> MaMa scripts

To ease the conversion between Root and MaMa formats:

- th22mama.C: taking a Root TH2 and converting to a MaMa matrix
- th22mama_hist.C: taking a Root TH1 and converting to a MaMa spectrum
- mamatoroot_70Niexample.cpp: takes a MaMa matrix and converts to Root, writes to a Root file

Remaining challenges 🤔

1. We need a better way to unfold on the Ex axis to include correlations between Ex and Eγ
2. The spin distribution of the initial and final levels is different -> problems with the 1st generation method?
3. How can we reliably normalize the level density and γ strength far away from stability? [Some ideas are on the way…]
4. …
5. …

… and probably many more ☺

From iStock