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Weisskopf
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old formula
new formula

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Comparison
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 Γ_a / Γ_n
 Γ_f / Γ_n

Level density parameter

A correction on CRISP

Motahareh Abbasi

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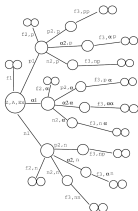


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Monte Carlo evaporation-fissions process

- **MCEF process**

- a competition between evaporation and fission

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- **MCEF process**

- a competition between evaporation and fission

- **Weisskopf model**

- calculation of probabilities of particles emission

Monte Carlo evaporation-fissions process

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- **MCEF process**

- a competition between evaporation and fission

- **Weisskopf model**

- calculation of probabilities of particles emission

- **Dostrovsky model**

- calculation of level density parameters

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- a competition between evaporation and fission

- **Weisskopf model**

- calculation of probabilities of particles emission

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- calculation of level density parameters

- **Bohr-Wheeler model**

- fission

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- Relative probability of emission of two particles i and j :

$$\frac{\Gamma_i}{\Gamma_j} = \frac{\gamma_i}{\gamma_j} \left(\frac{E_i}{E_j}\right) \frac{a_j}{a_i} \exp\{2[(a_i E_i)^{\frac{1}{2}} - (a_j E_j)^{\frac{1}{2}}]\}$$

a_i and a_j : level density parameters

Weisskopf model

Level density
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$$\frac{\Gamma_i}{\Gamma_j} = \frac{\gamma_i}{\gamma_j} \left(\frac{E_i}{E_j} \right)^{\frac{a_j}{a_i}} \exp\{2[(a_i E_i)^{\frac{1}{2}} - (a_j E_j)^{\frac{1}{2}}]\}$$

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$$\gamma_i = \frac{gm}{\pi^2 \hbar^3}$$

Correction

old formula

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- g : number of states for the spin of particle
- $g = 2$: for neutrons and protons
- $g = 1$: for α -particles
- m : mass of particle i
- $m_p \approx m_n$
- $m_\alpha \approx 4m_n$

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$$\gamma_i = \frac{gm}{\pi^2 \hbar^3}$$

- $g = 2$: for neutrons and protons
- $g = 1$: for α -particles
- $m_p \approx m_n$
- $m_\alpha \approx 4m_n$

$$\frac{\gamma_p}{\gamma_n} = \frac{g_p}{g_n} \times \frac{m_p}{m_n} = \frac{2}{2} \times \frac{1}{1} = 1$$

$$\frac{\gamma_\alpha}{\gamma_n} = \frac{g_\alpha}{g_n} \times \frac{m_\alpha}{m_n} = \frac{1}{2} \times \frac{4}{1} = 2$$

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$$\frac{\Gamma_i}{\Gamma_j} = \frac{\gamma_i}{\gamma_j} \left(\frac{E_i}{E_j} \right)^{\frac{a_j}{a_i}} \exp\{2[(a_i E_i)^{\frac{1}{2}} - (a_j E_j)^{\frac{1}{2}}]\}$$

$$\frac{\gamma_p}{\gamma_n} = 1 \quad \text{and} \quad \frac{\gamma_\alpha}{\gamma_n} = 2$$

↓

- For proton emission:

$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{1E_p}{E_n} \right) \left(\frac{a_n}{a_p} \right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

- For α -particle emission:

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n} \right) \left(\frac{a_n}{a_\alpha} \right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \left(\frac{a_n}{a_p}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \left(\frac{a_n}{a_\alpha}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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- a_n, a_p, a_α : level density parameters for neutrons, protons, alpha particles

$$a_n = \frac{A}{a_1} \left(1 - a_2 \frac{A - 2Z}{A^2}\right)^2$$

$$a_p = \frac{A}{a_3} \left(1 + a_4 \frac{A - 2Z}{A^2}\right)^2$$

$$a_\alpha = \frac{A}{a_5} \left(1 - \frac{a_6}{A}\right)^2$$

- a_1 to a_6 : fitted parameters

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Level density parameters in the old formula

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- Level density parameter for neutron emission:

$$a_n = (0.134A - 1.21) \times 10^{-4} A^2 \text{MeV}^{-1}$$

- Level density parameter for proton and α -particle emission:

$$a_j = r_j a_n$$

- where:

$$r_p = r_\alpha = 1 \quad \implies \quad \boxed{a_p = a_\alpha = a_n}$$

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$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \left(\frac{a_n}{a_p}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \left(\frac{a_n}{a_\alpha}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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$$a_p = a_\alpha = a_n$$

↓

$$\frac{a_n}{a_p} = \frac{a_n}{a_\alpha} = 1$$

Level density parameters in the old formula

Level density
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$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \left(\frac{a_n}{a_p}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \left(\frac{a_n}{a_\alpha}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{a_n}{a_p} = \frac{a_n}{a_\alpha} = 1$$

↓

$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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$$a_n = \frac{A}{a_1} \left(1 - a_2 \frac{A - 2Z}{A^2}\right)^2$$

$$a_p = \frac{A}{a_3} \left(1 + a_4 \frac{A - 2Z}{A^2}\right)^2$$

$$a_\alpha = \frac{A}{a_5} \left(1 - \frac{a_6}{A}\right)^2$$

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$$a_n \neq a_p \neq a_\alpha$$



$\frac{a_n}{a_p}$, $\frac{a_n}{a_\alpha}$ should not be omitted!

Level density parameters in the new formula

Level density
parameter

$$a_n \neq a_p \neq a_\alpha$$



- For proton emission:

$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \left(\frac{a_n}{a_p}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

- For α -particle emission:

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \left(\frac{a_n}{a_\alpha}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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- Comparison between:

$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

- and the corrected formulae:

$$\frac{\Gamma_p}{\Gamma_n} = \left(\frac{E_p}{E_n}\right) \left(\frac{a_n}{a_p}\right) \exp\{2[(a_p E_p)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

$$\frac{\Gamma_\alpha}{\Gamma_n} = \left(\frac{2E_\alpha}{E_n}\right) \left(\frac{a_n}{a_\alpha}\right) \exp\{2[(a_\alpha E_\alpha)^{\frac{1}{2}} - (a_n E_n)^{\frac{1}{2}}]\}$$

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Test done on CRISP

- Target Nucleus : Pb208
- Projectile : proton
- Initial Energy : 1000 MeV

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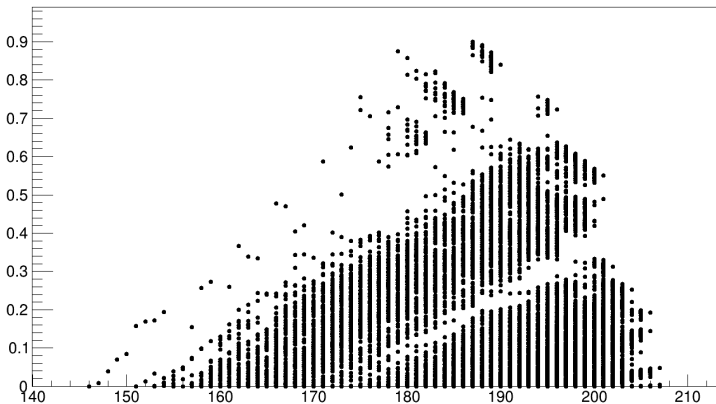
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● Results of CRISP:

$$\Gamma_a/\Gamma_n$$



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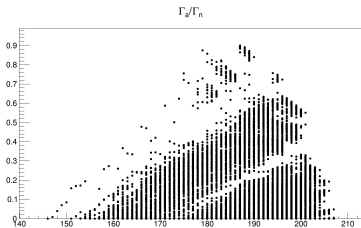
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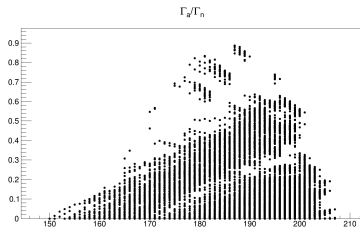
- Comparison of CRISP results:

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- new formula:



- old formula:



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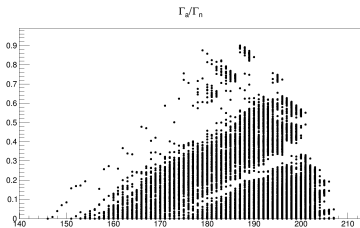
Γ_f/Γ_n

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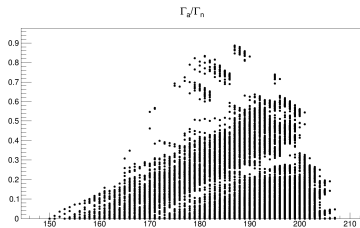
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- Comparison of CRISP results:

- new formula:



- old formula:



- Solution:

Averaging over the whole data for each mass number

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Averaging Code

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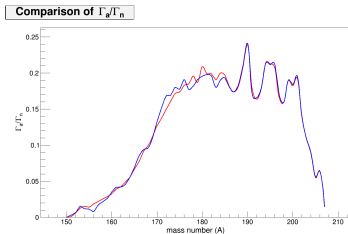
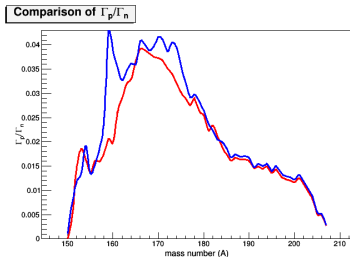
```
1 #include <iostream>
2 #include <fstream>
3 using namespace std;
4
5 int main(){
6     ifstream obj1("./A.txt");
7     ifstream obj2("./Gp.txt");
8
9     int A;
10    double Gp;
11    int B = 70774; // number of rows (data)
12    int k = 0;
13    int l = 0;
14    int j = 0;
15    double b[70][4]; // 70 - last A - first A + 1
16    int a[B];
17    double c[B];
18
19    ofstream writing("./output-Gp.xls");
20
21    while(obj1 >> A){
22        a[k] = A;
23        k++;
24    }
25
26    while(obj2 >> Gp){
27        c[l] = Gp;
28        l++;
29    }
30
31    for (int i = 0; i < B; i++)
32    {
33        if (i==0)
34        {
35            b[j][0] = a[i];
36            b[j][1] = 1;
37            b[j][2] = c[i];
38            b[j][3] = b[j][2] / b[j][1];
39        }else{
40            if(a[i]==a[i-1])
41            {
42                b[j][0] = a[i];
43                b[j][1]++;
44                b[j][2]=c[i];
45                b[j][3] = b[j][2] / b[j][1];
46            }else{
47                j++;
48                b[j][0] = a[i];
49                b[j][1] = 1;
50                b[j][2] = c[i];
51                b[j][3] = b[j][2] / b[j][1];
52            }
53        }
54    }
55    for (j=0; j < 70; j++)
56    {
57        writing << b[j][0] << " " << b[j][3] << endl;
58    }
59    return 0;
60 }
```

Comparison of Results before and after correction

● 39000 points:

— old formula

— new formula



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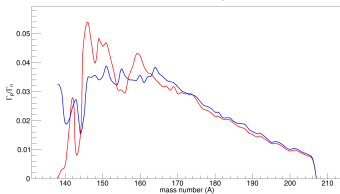
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● 71000 points:

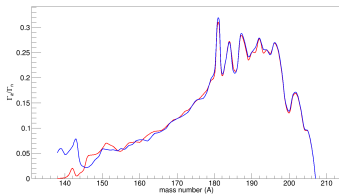
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Comparison of Γ_p/Γ_n



Comparison of Γ_d/Γ_n



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$$\Gamma_p/\Gamma_n$$

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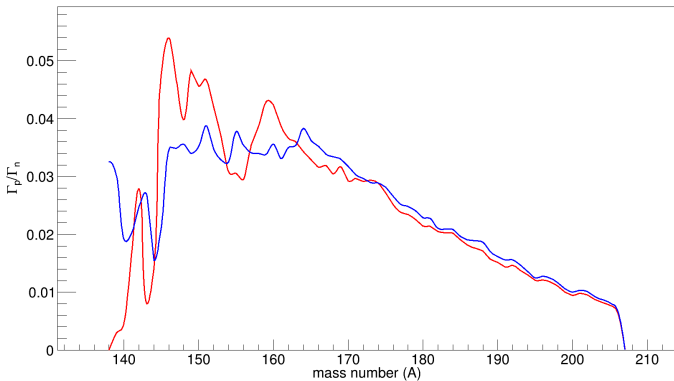
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$$\Gamma_p/\Gamma_n$$

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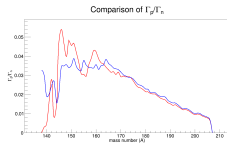
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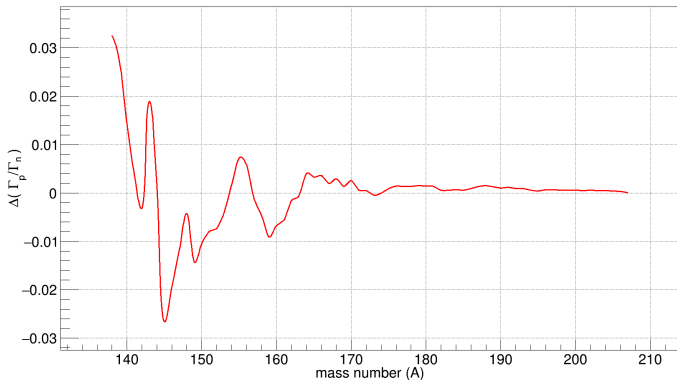
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Difference of Γ_p/Γ_n



$$\Gamma_a/\Gamma_n$$

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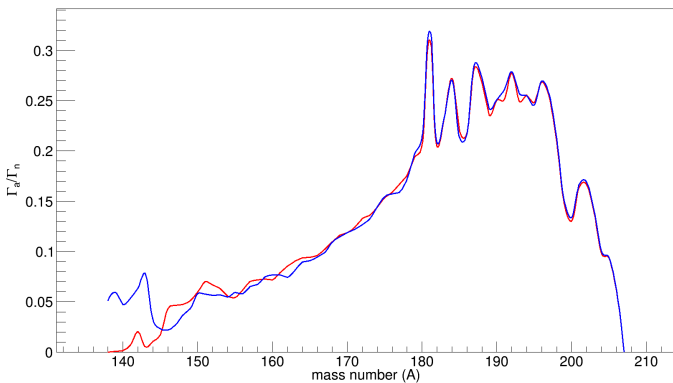
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Comparison of Γ_a/Γ_n



$$\Gamma_a/\Gamma_n$$

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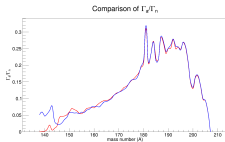
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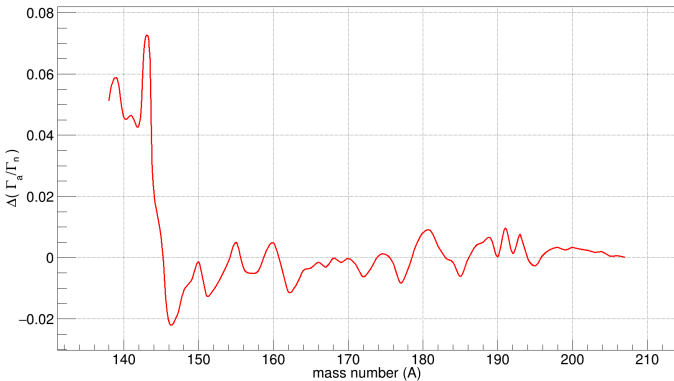
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Difference of Γ_a/Γ_n



$$\Gamma_f/\Gamma_n$$

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Correction

old formula

new formula

Results

Test

Results

Code

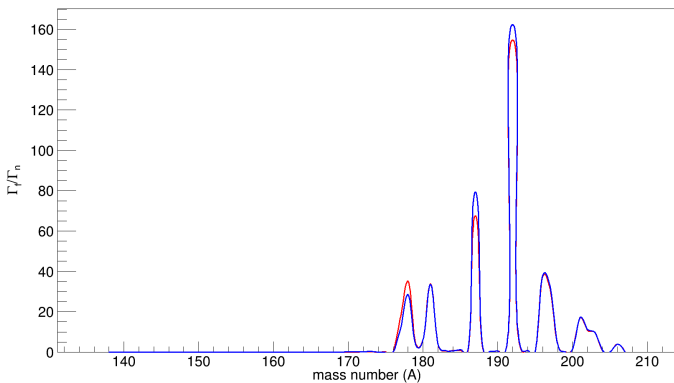
Comparison

Γ_p/Γ_n

Γ_a/Γ_n

Γ_f/Γ_n

Comparison of Γ_f/Γ_n



$$\Gamma_f / \Gamma_n$$

Level density
parameter

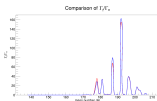
Level density
parameter

MCEF
Weisskopf
Dostrovsky

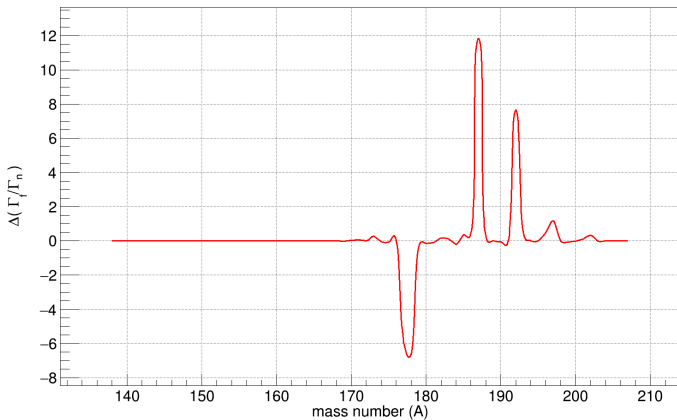
Correction
old formula
new formula

Results

Test
Results
Code
Comparison
 Γ_p / Γ_n
 Γ_a / Γ_n
 Γ_f / Γ_n



Difference of Γ_f/Γ_n



Thank you for your attention!

Level density
parameter

Level density
parameter

MCEF
Weisskopf
Dostrovsky

Correction

old formula
new formula

Results

Test
Results
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Comparison

Γ_p / Γ_n
 Γ_a / Γ_n
 Γ_f / Γ_n



Thank you for your attention!

Level density
parameter

Level density
parameter

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Results
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Γ_p / Γ_n
 Γ_a / Γ_n
 Γ_f / Γ_n

