# Statistical Model Calculations with TALYS for p-induced reactions on Sn isotopes

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# Motivation

Sensitivity of element abundance to nuclear reaction rates which in turn depends on the reaction cross section.

The reaction rates determine the balance of feeding and depletion flows for each nucleus.

Puzzling origin of p-nuclei and their relatively small abundance among other isotopes.

Description of entire synthesis process for *p*-nuclei require a comprehensive reaction network involving about 2000 nuclei connected by more than 20000 reactions.

Experimental data are scarce.

Contributions from all branches have to be considered in order to account for correct abundance.

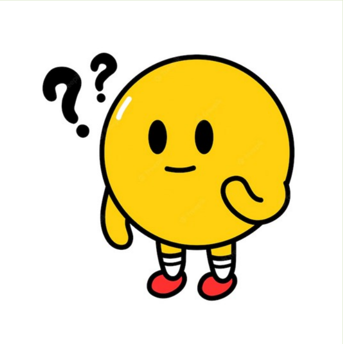
**Most of the involved nuclei are not accessible in the laboratory.**

**Theoretical Models**

**At astrophysical energies, charged particle cross sections are small.**

To test the predictive reliability of statistical models in astrophysical scenarios.

# Why Sn



- Tin has large number of isotopes from A=112 to 124.

- Includes a variety of *r*-, *s*- and *p*-process contributions.
  **$^{112}$Sn and $^{114}$Sn - *p*-process**
  **$^{116}$Sn - *s*-process**
  **$^{122}$Sn and $^{124}$Sn - *r*-process**
  **$^{117, 118, 119, 120}$Sn – mixture of *s*- and *r*-process**
  **$^{115}$Sn – mixture of *p*-, *r*- and *s*-process**

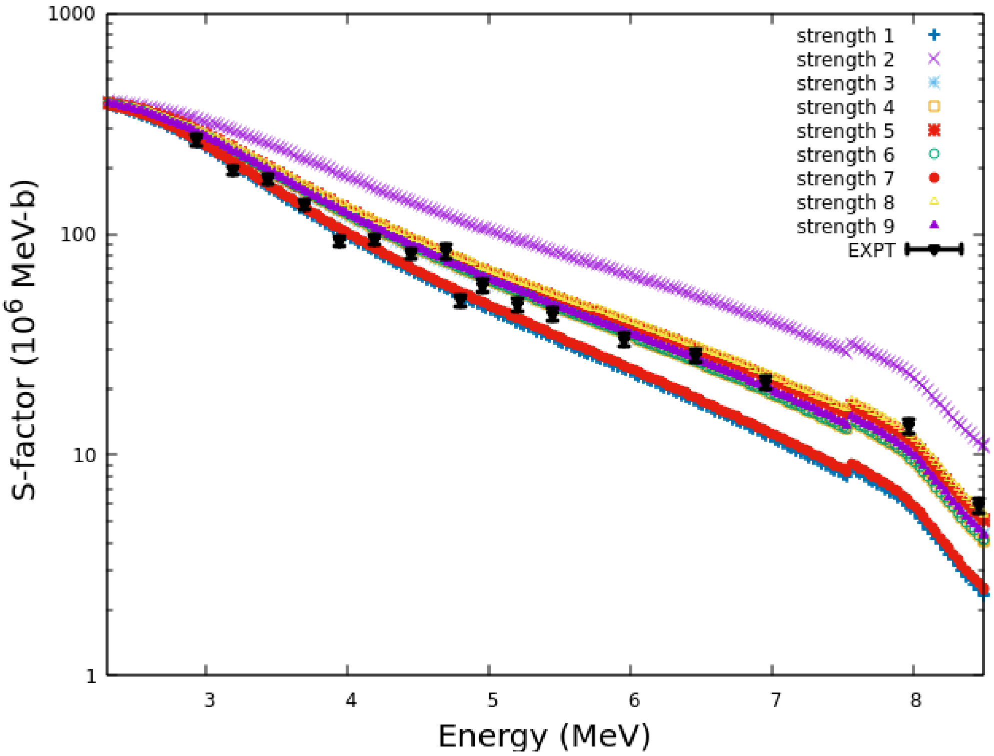
- Discrepancy in elemental abundance of tin is still alive.

- A fruitful element for identification of possible isotope anomalies.

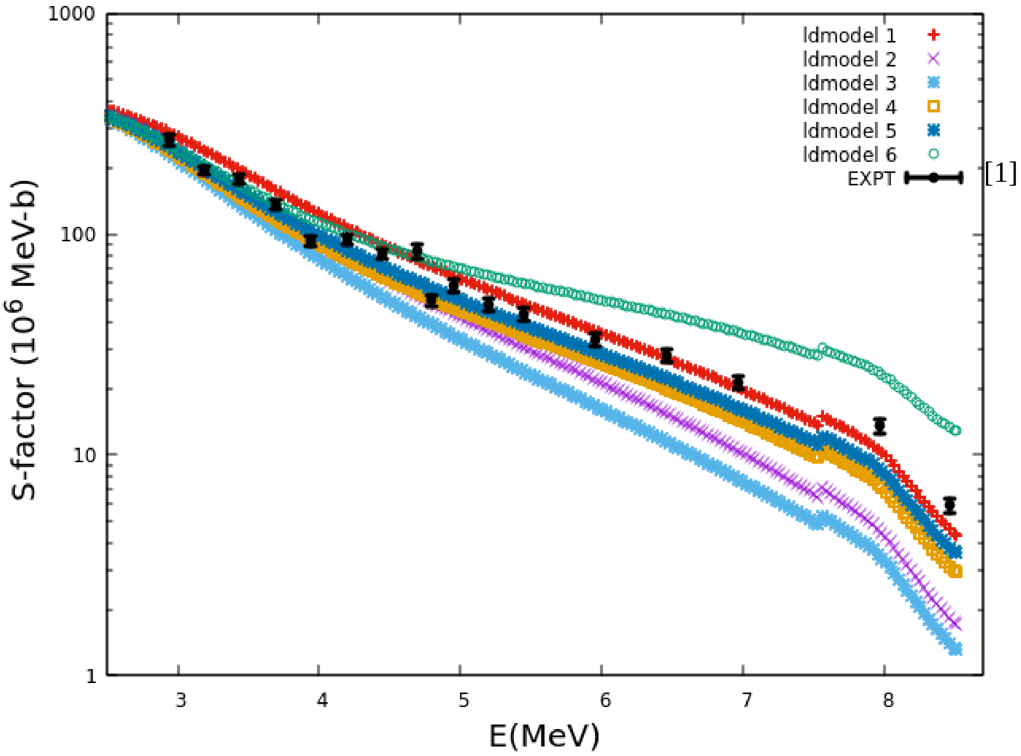
- Minor isotopes of tin are used to delineate between various models of *p*-process nucleosynthesis.

- Locating astrophysical site of their production.

# TALYS Calculations for $^{112}Sn(p,\gamma)^{113}Sb$

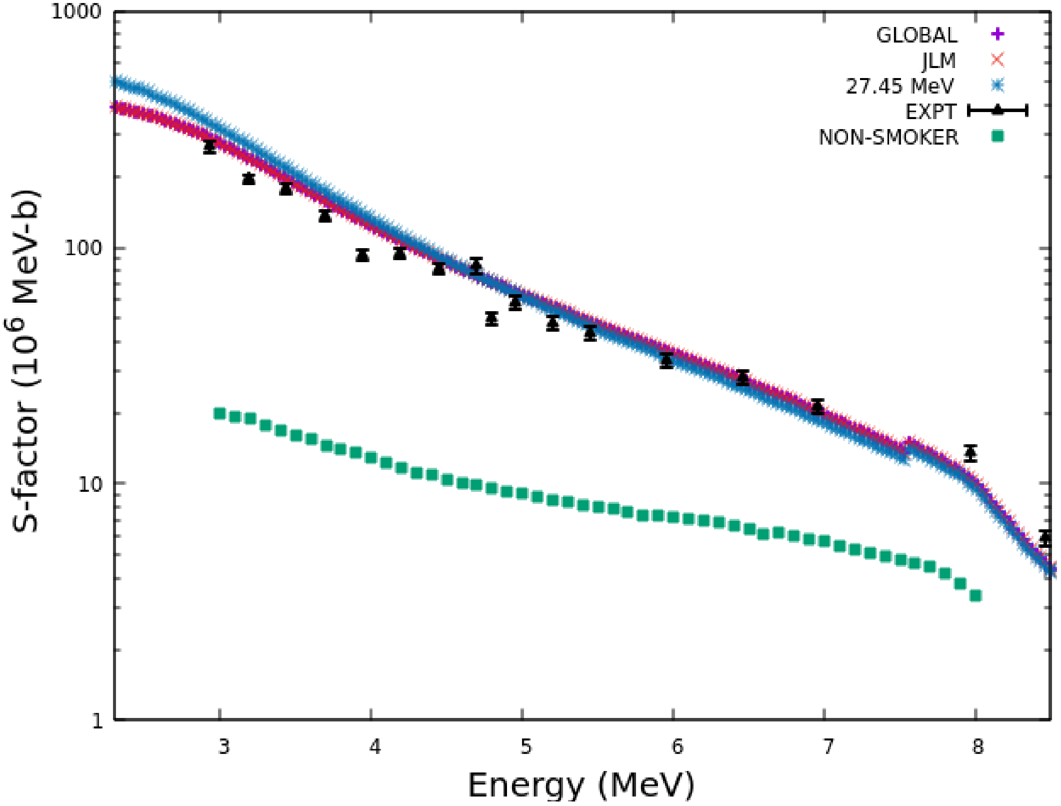



With different Gamma Strength Function models




With different Nuclear Level density models


*[1] F.R. Chloupek et al., Nuclear Physics A652, 391-405 (1999).*



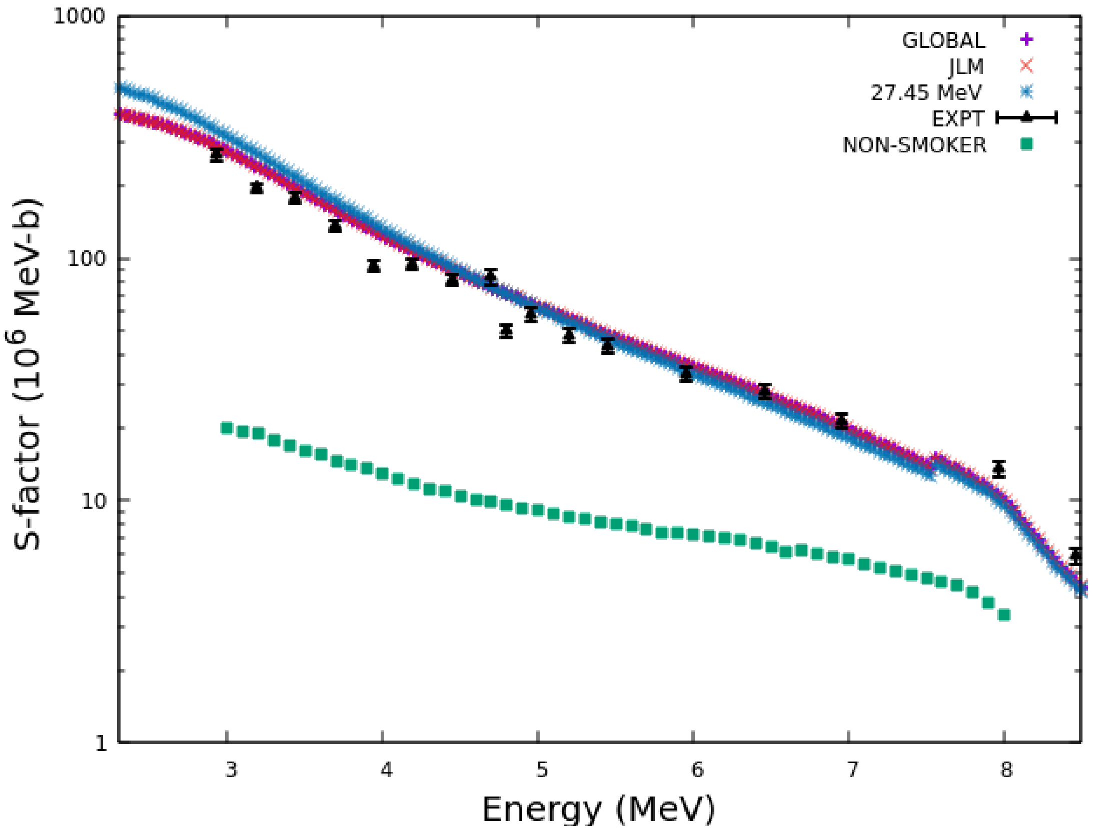

**With different Optical Potential models :**

[2] **-> Global**
[3] **-> Semimicroscopic JLM potential**

**-> Local Potential parameters fitted with elastic scattering of proton on $^{112}Sn$ at 27.45 MeV.**

| $E_{lab}$ | $V_o$ | $r_v$ | $a_v$ | W | $r_w$ | $a_w$ |
|---|---|---|---|---|---|---|
| 27.45 | 51.92 | 1.17 | 0.75 | 7.5 | 1.32 | 0.51 |

*[2] P.J.Biankert et al., Nuclear Physics A356, 74-96 (1981).*
*[3] W. Makofske et al., Physical Review , Vol 174, No. 4 (1968).*




[2]
[3]

**With different Optical Potential models :**

**-> Global**
**-> Semimicroscopic JLM potential**

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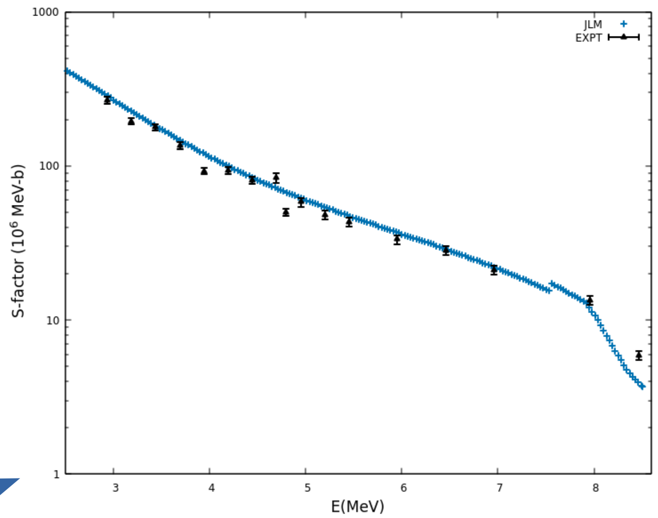
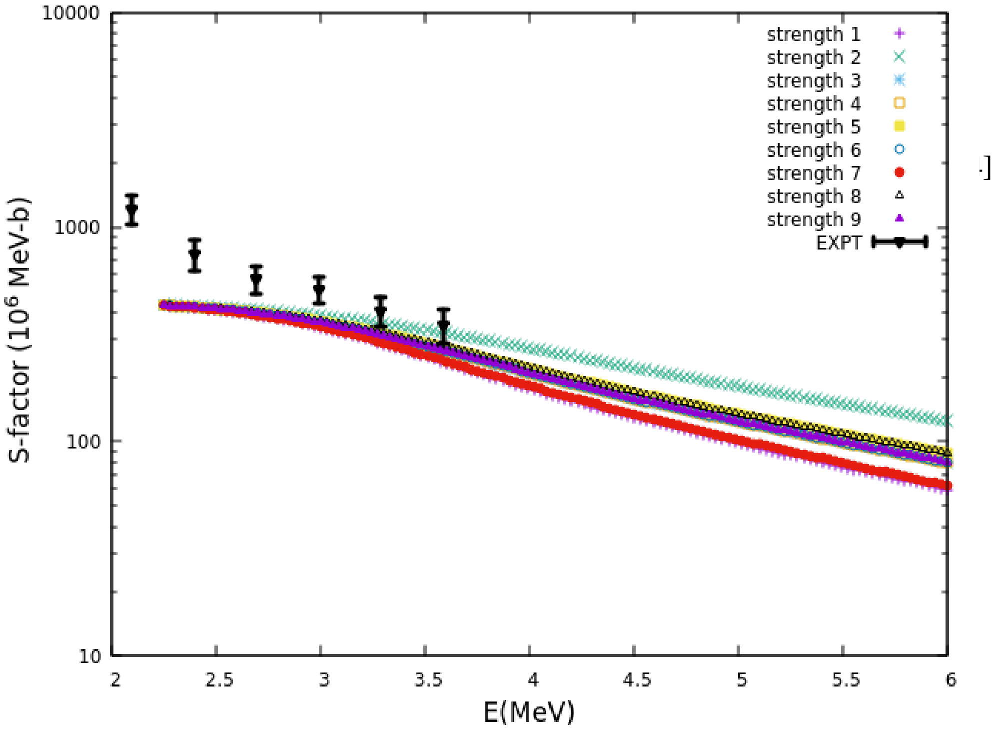
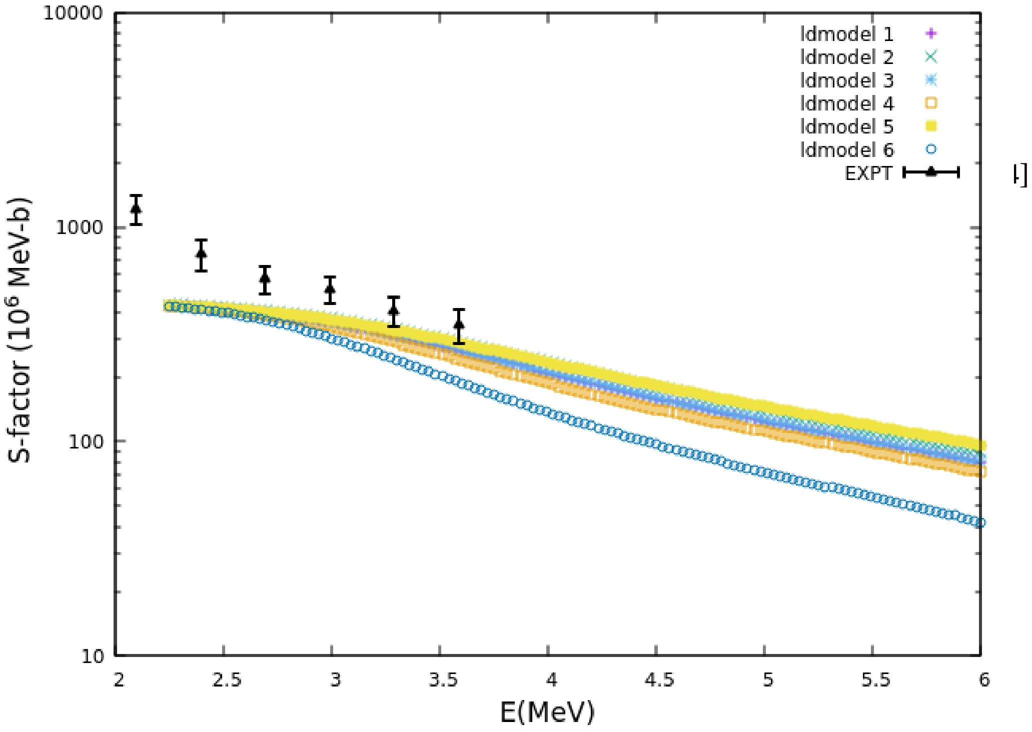



**With semi microscopic JLM potential**

# TALYS Calculations for $^{114}Sn(p,\gamma)^{115}Sb$

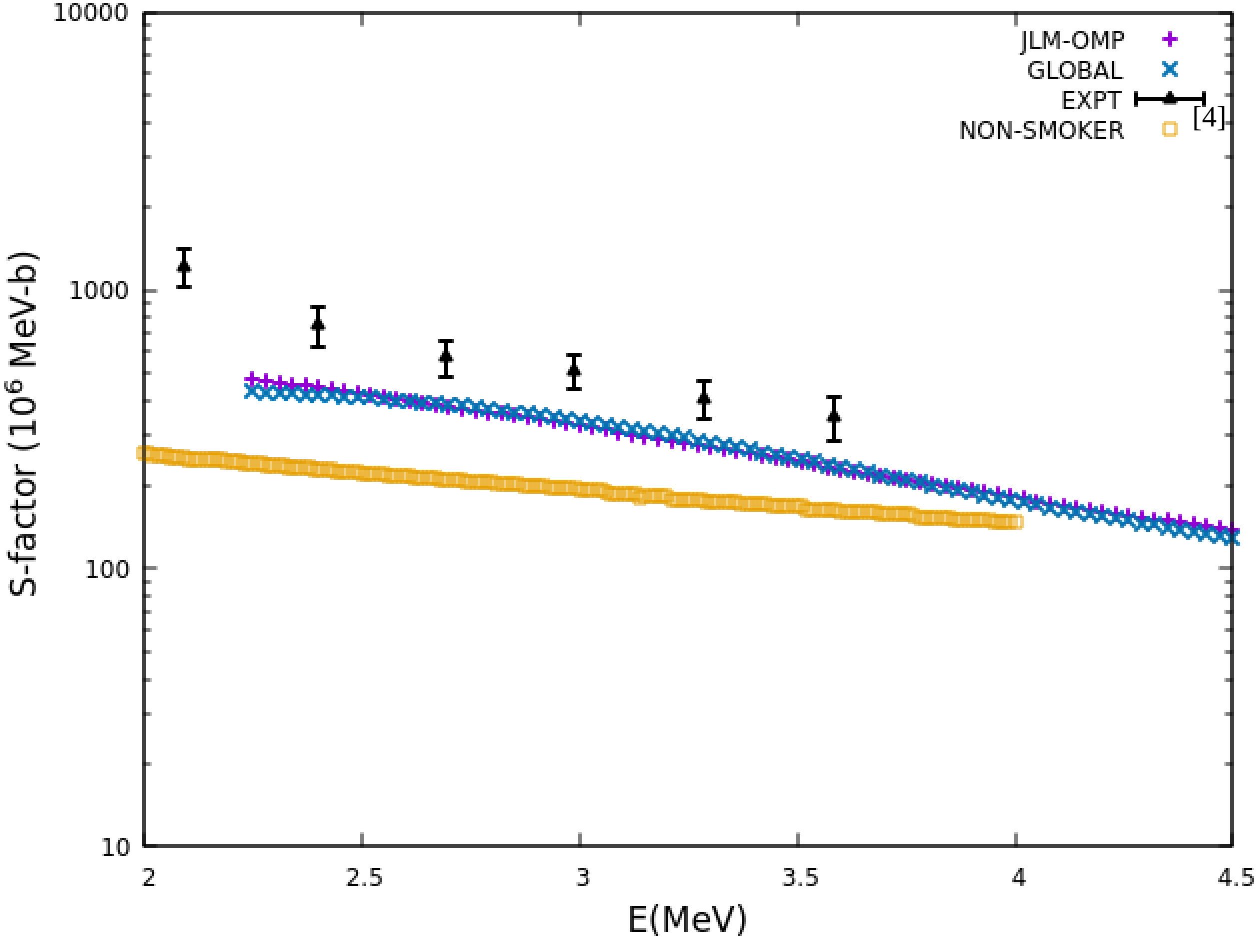



With different Gamma Strength Function models



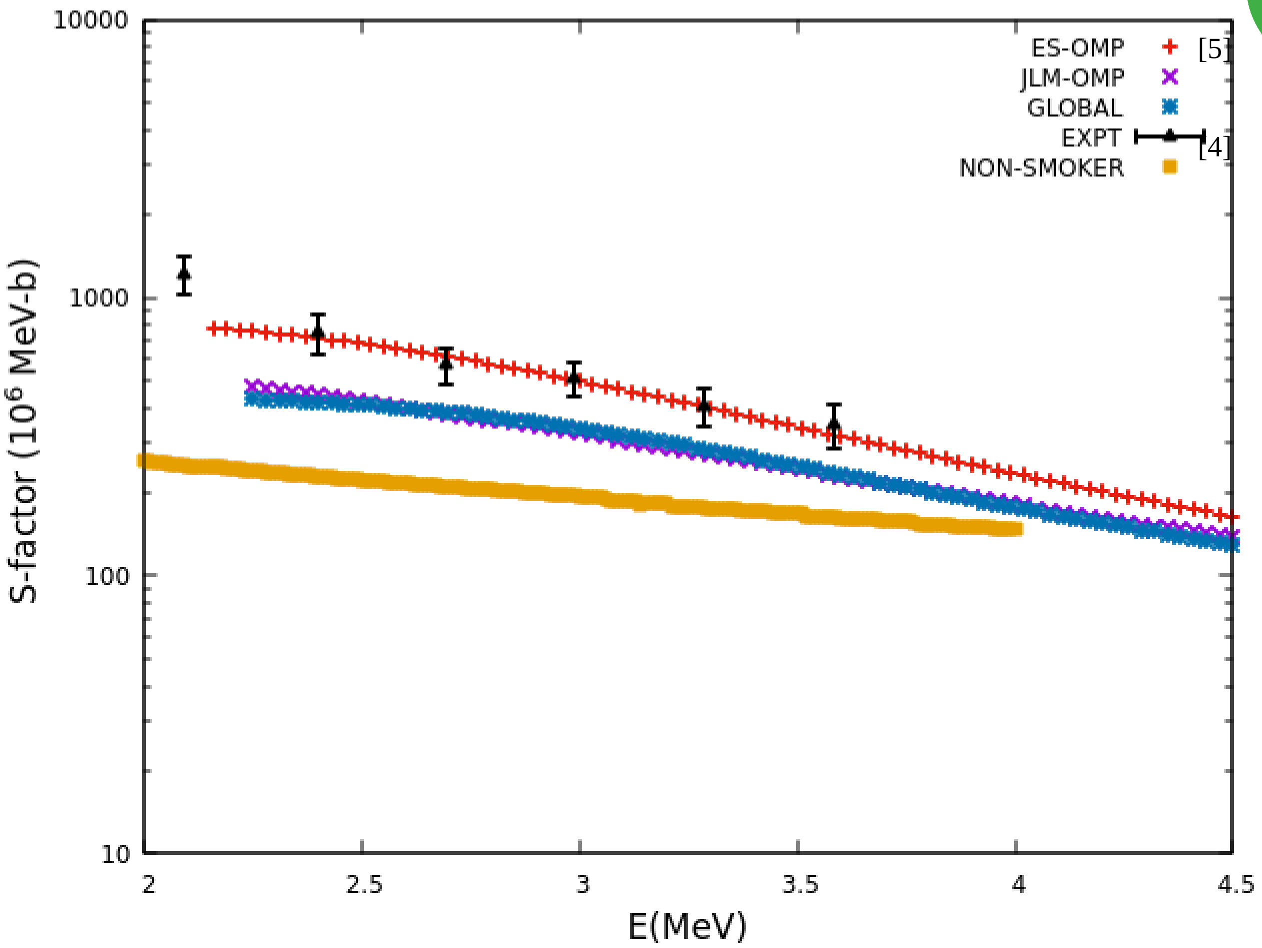

With different Nuclear Level density models


*[4] Michael A. Famiano et al., Nuclear Physics A802, 26-44 (2008).*




**Comparison of Experimental data with the default Optical Potentials : Global and Semi microscopic JLM potential and NON-SMOKER predictions.**

***Explains the experimental data much better***



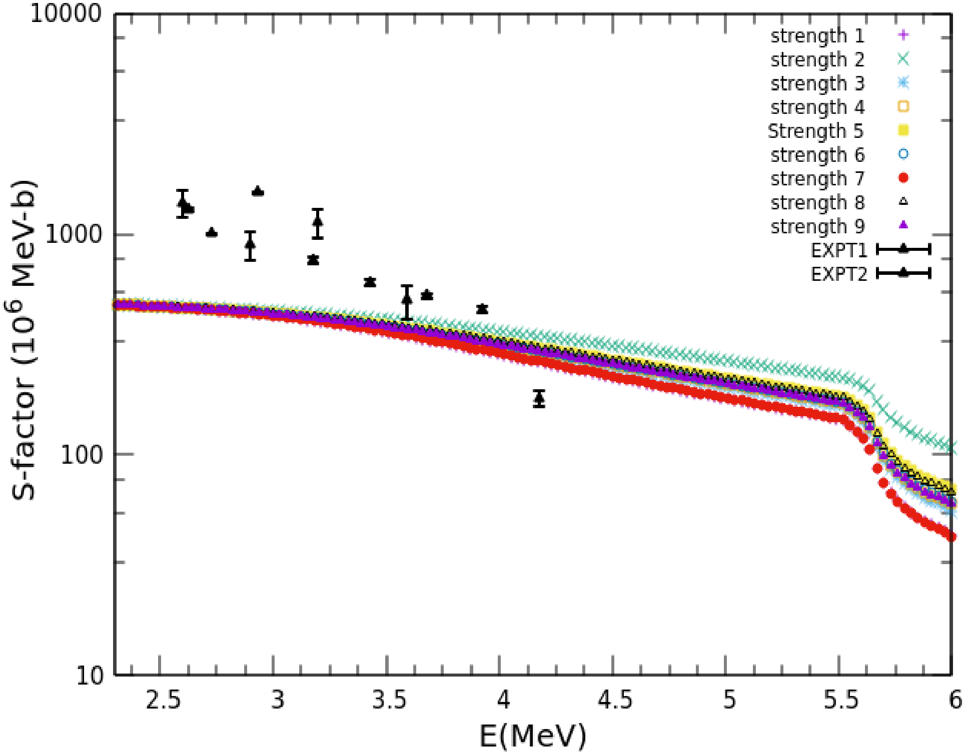

Optical Model Parameters by fitting proton elastic scattering data on $^{114}Sn$:

$E_{lab}$= 22.00 MeV

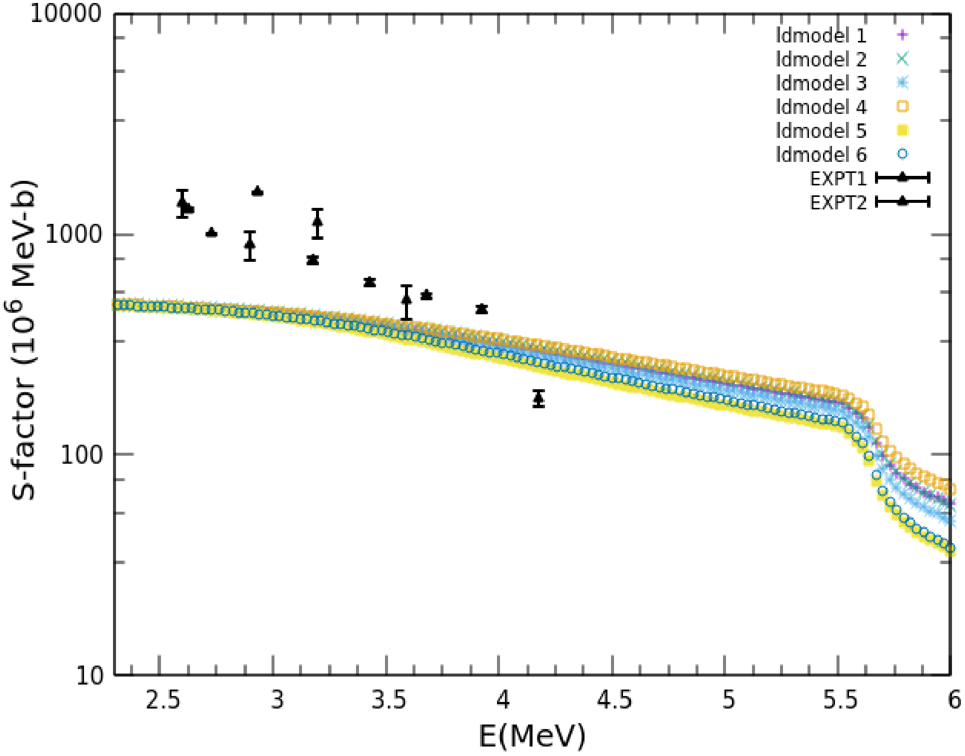
$V_o$= 50.0 MeV
r= 1.25 fm
a= 0.65 fm
$W_D$= 10.0 MeV
r’= 1.30 fm
a’= 0.6 fm

*[5] P. Guazzoni et al., Physical Review C 85, 054609 (2012).*

# TALYS Calculations for $^{116}Sn(p,\gamma)^{117}Sb$



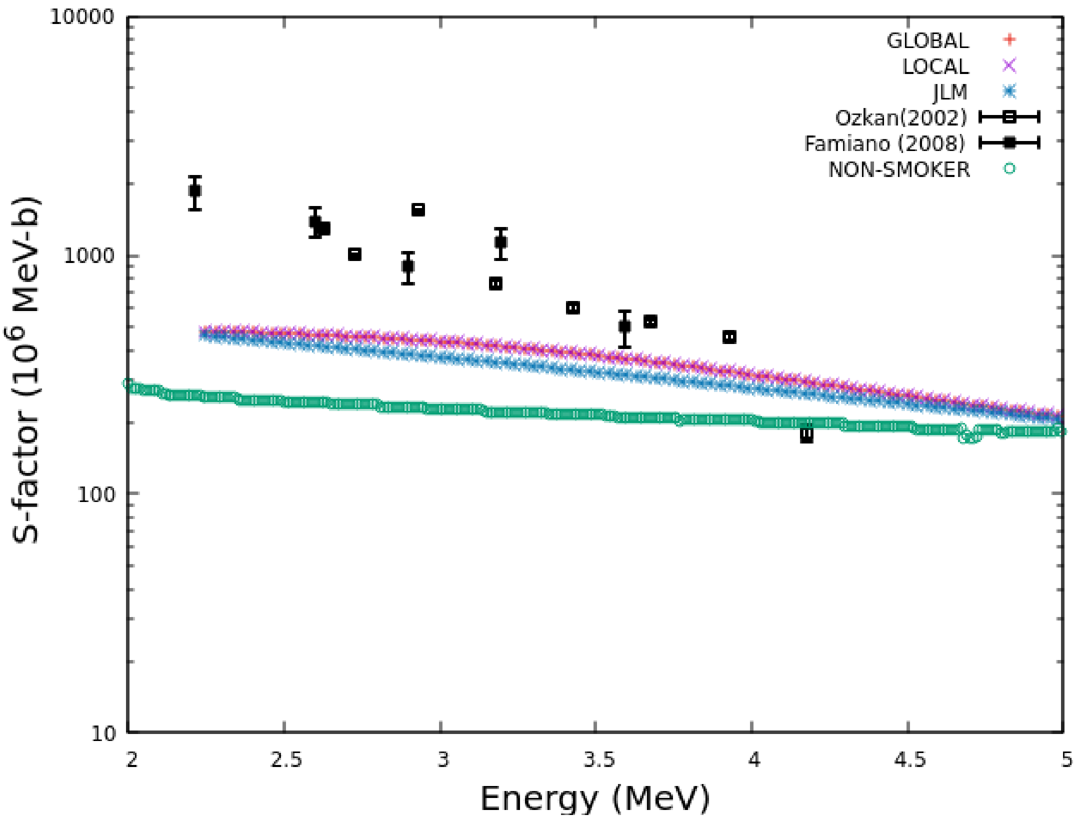

With different Gamma Strength Function models



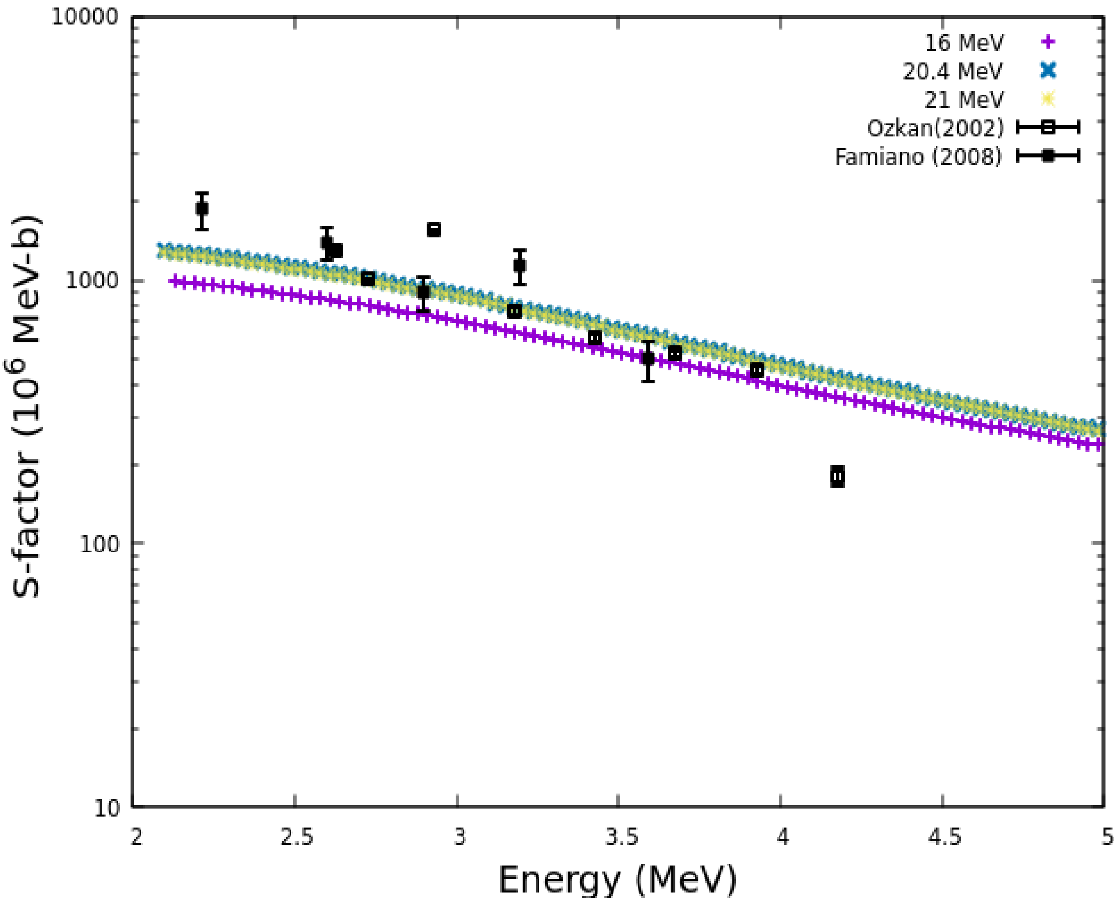

[4,6]

With different Nuclear Level density models


*[4] Michael A. Famiano et al., Nuclear Physics A802, 26-44 (2008).*
*[6] N.Ozkan et al., Nuclear Physics A710, 469-485 (2002).*




**With different Optical Potential models inherent to TALYS and a comaprison with NON-SMOKER results**




# Optical Model Parameters by fitting experimental data of elastic scattering of proton on $^{116}Sn$:

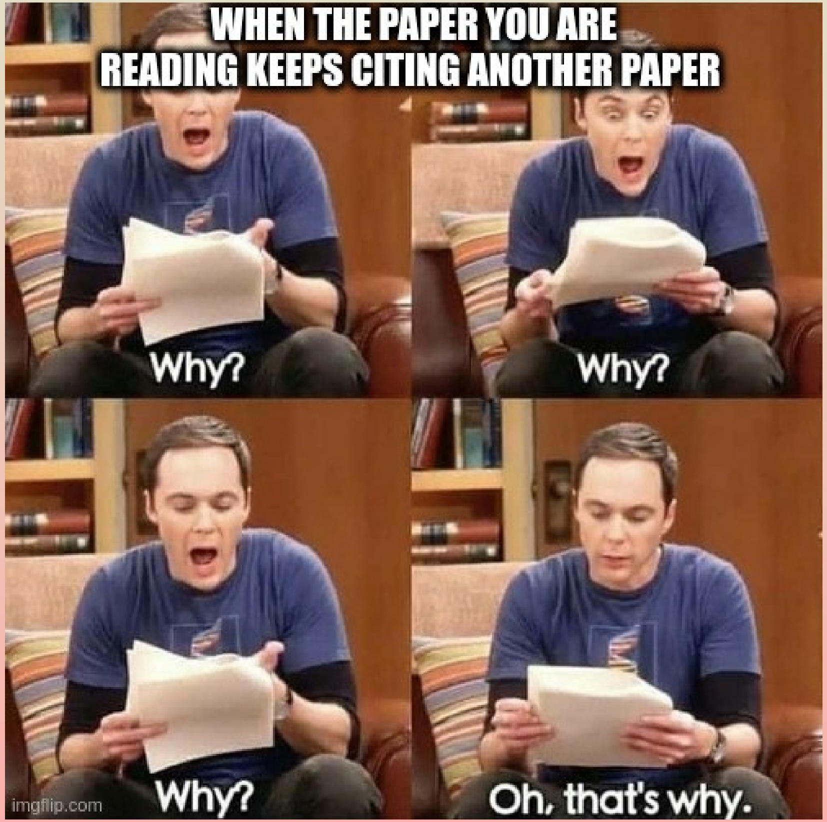
| $E_{lab}$ | $V_o$ | $r_v$ | $a_v$ | W | $r_w$ | $a_w$ |
|---|---|---|---|---|---|---|
| 16 | 55.25 | 1.2 | 0.7 | 10.73 | 1.25 | 0.65 |
| 20.4 | 53.71 | 1.194 | 0.713 | 8.85 | 1.265 | 0.675 |
| 21 | 53.9 | 1.18 | 0.71 | 10.6 | 1.26 | 0.66 |

[7]
[8]
[9]
[4,6]

*[7] W. Makofske et al., Physical Review, Vol 174, No. 4 (1968).*
*[8] S.D.Wassenaar et al., J. Phys. G: Nucl. Part. Phys.* ***15*** *181 (1989)*
*[9] Norton baron et al., Physical Review, Vol 180, No. 4 (1969)*

# SUMMARY

- Hauser Feshbach statistical model calculations were performed to describe the experimental cross sections of $^{112}$Sn(p,γ)$^{113}$Sb ,$^{114}$Sn(p,γ)$^{115}$Sb and $^{116}$Sn(p,γ)$^{117}$Sb using TALYS.
- Effect of different models for GSF, NLD and various sets of OMP parameters in the energy domain of the present study, namely 2-9 MeV for all three reactions were studied.
- Several OMP parameter sets optimized with proton elastic scattering data were used to calculate cross sections.
- Astrophysical S-Factor was plotted against proton lab energy and compared with literature data.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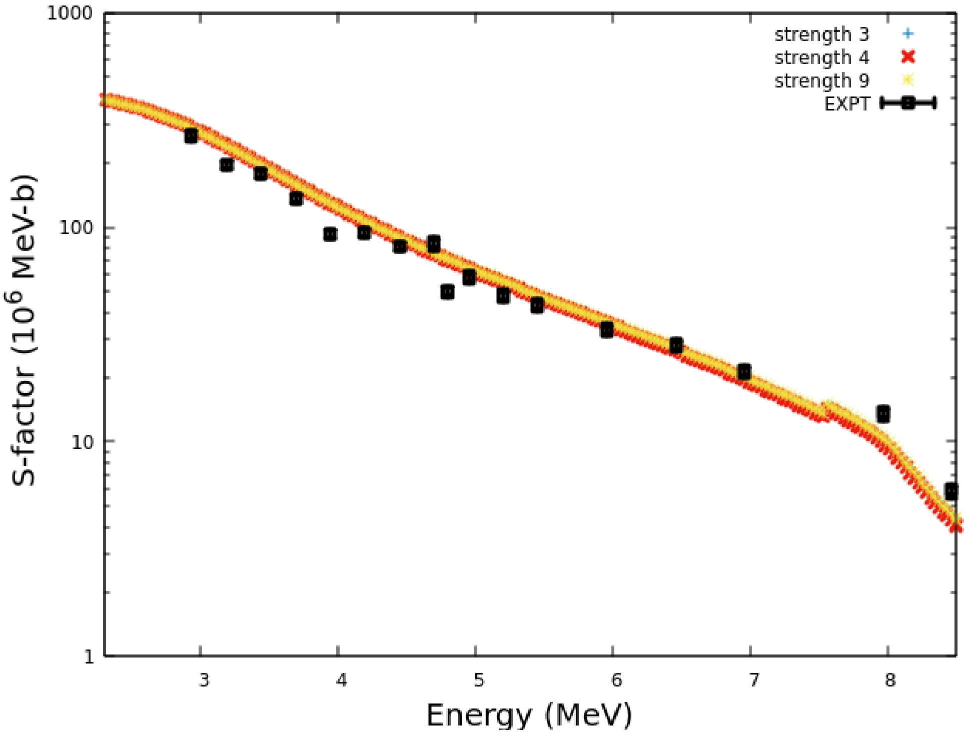
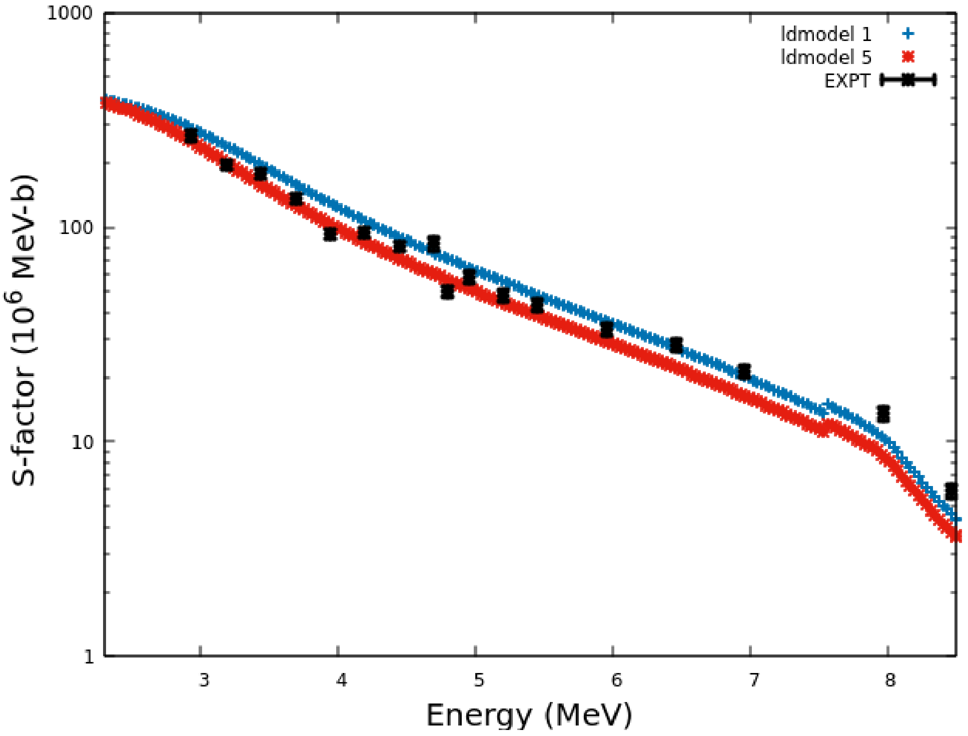
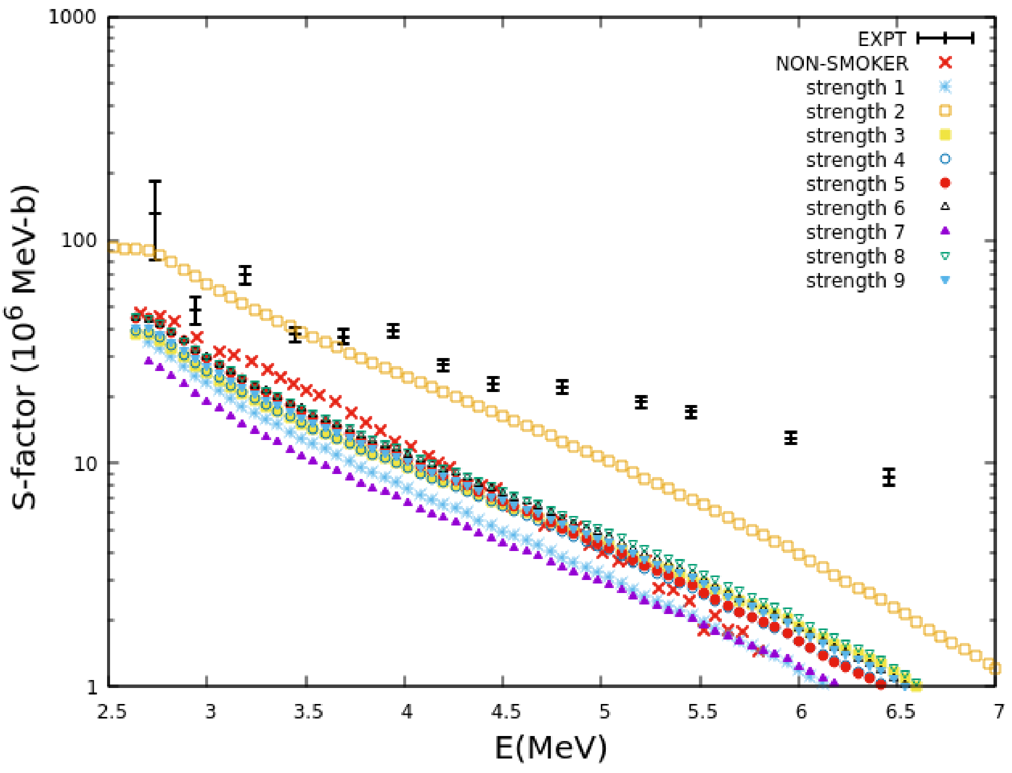



$^{112}$Sn Sfactors with GSF models, S3,4,9
Default model - S9



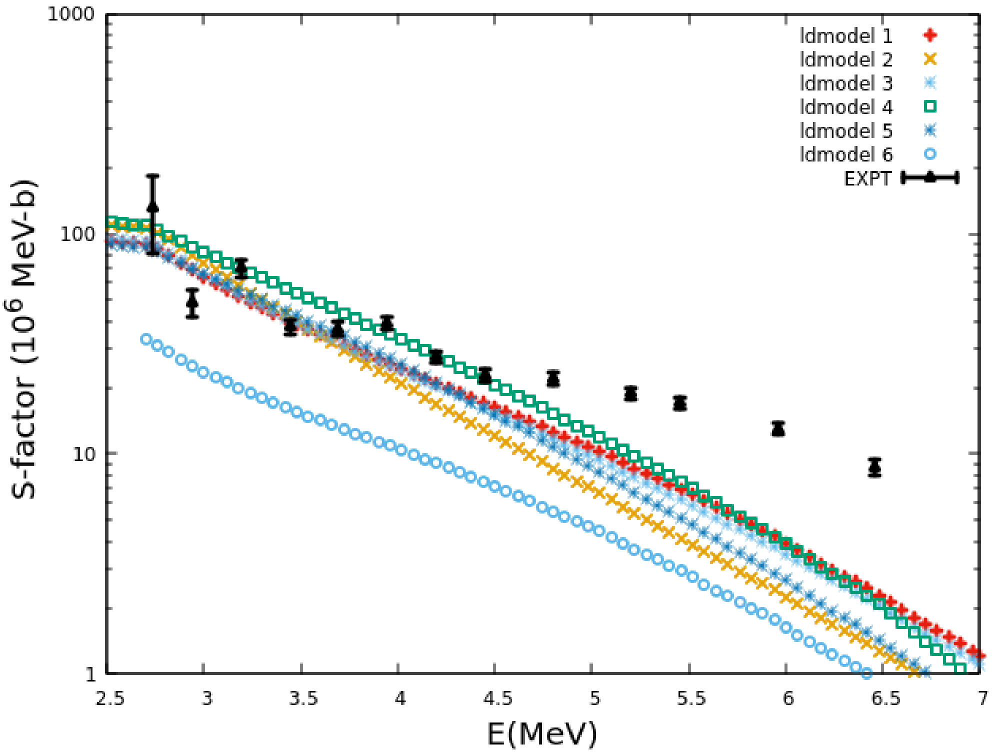

$^{112}$Sn Sfactors with NLD models, LD 1 and 5
Default model – LD1

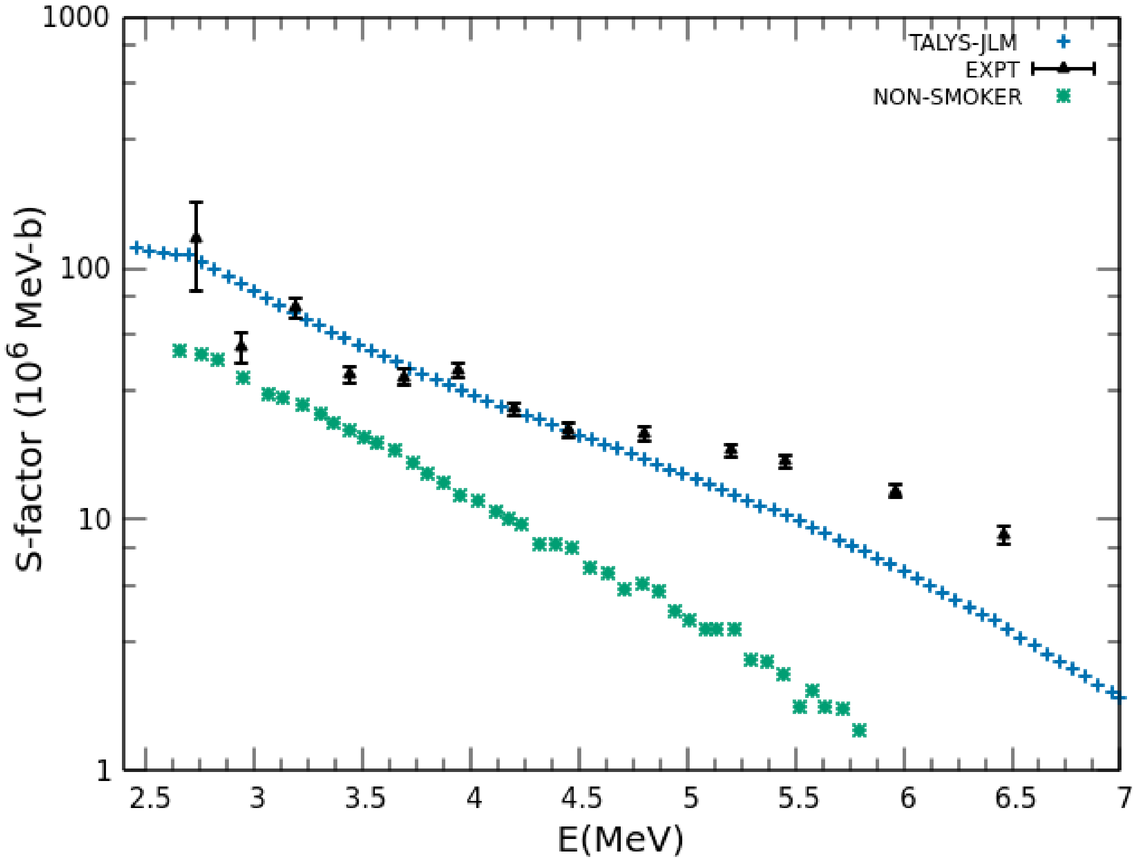
# TALYS Calculations for $^{119}Sn(p,\gamma)^{120}Sb$




With different Gamma Strength Function models

With different Nuclear Level density models






**Comparison of Experimental data with the default Optical Potentials : Global and Semi microscopic JLM potential and NON-SMOKER predictions.**

# List of 35 *p*-nuclei

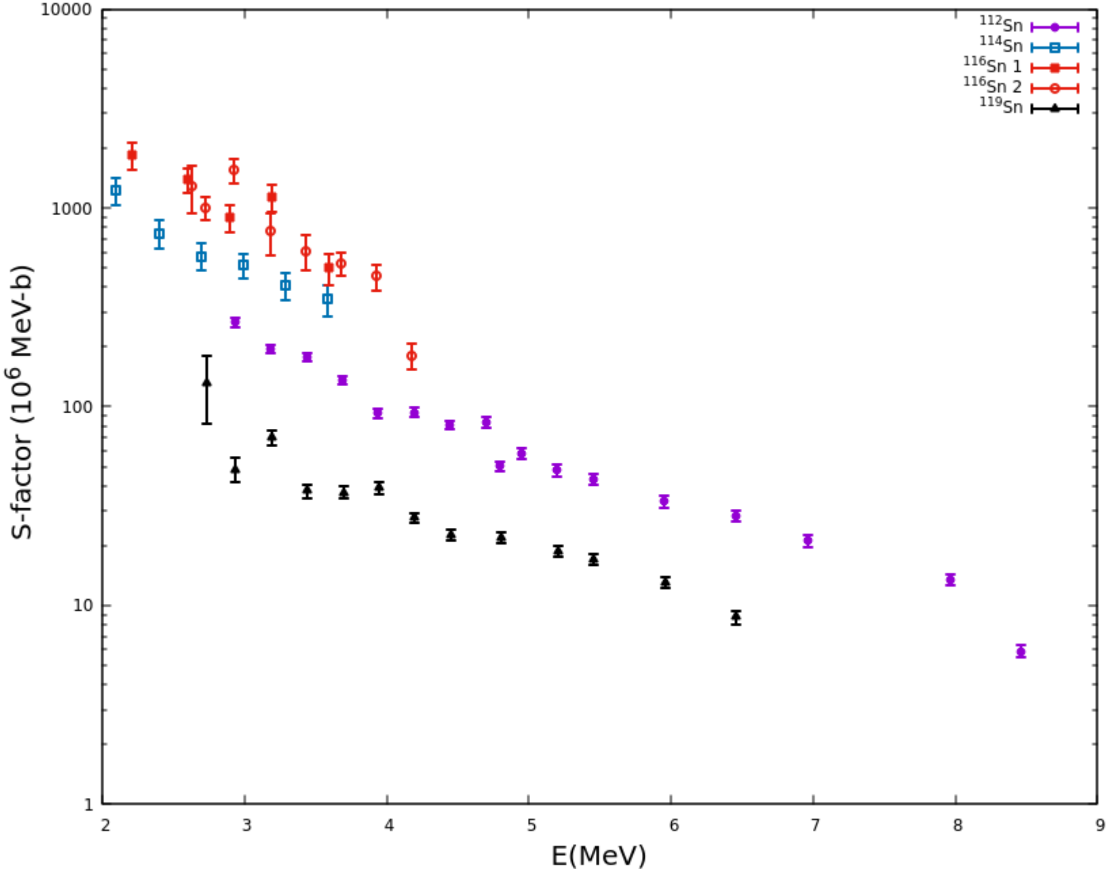
$^{74}$Se, $^{78}$Kr, $^{84}$Sr, $^{92}$Mo, $^{94}$Mo, $^{96}$Ru, $^{98}$Ru, $^{102}$Pd, $^{106}$Cd, $^{108}$Cd, $^{112}$Sn, $^{113}$In, $^{114}$Sn, $^{115}$Sn, $^{120}$Te, $^{124}$Xe, $^{126}$Xe, $^{130}$Ba, $^{132}$Ba, $^{136}$Ce, $^{138}$La, $^{138}$Ce, $^{144}$Sm, $^{152}$Gd, $^{156}$Dy, $^{158}$Dy, $^{162}$Er, $^{164}$Er, $^{168}$Yb, $^{174}$Hf, $^{180}$Ta, $^{180}$W, $^{184}$Os, $^{190}$Pt, and $^{196}$Hg

TABLE IX. Maxwellian averaged neutron capture cross sections of $^{114}$Sn, $^{115}$Sn, $^{116}$Sn, $^{117}$Sn, $^{118}$Sn, and $^{120}$Sn for thermal energies from 10 to 100 keV (the 1.5% uncertainty of the gold standard is not included here since it cancels out in most applications of relevance for nuclear astrophysics).

| $kT$ (keV) | $^{114}$Sn (mb) | $^{115}$Sn (mb) | $^{116}$Sn (mb) | $^{117}$Sn (mb) | $^{118}$Sn (mb) | $^{120}$Sn (mb) |
|---|---|---|---|---|---|---|
| 10 | 249.2±8.4 | 550.7±42 | 171.6±2.6 | 549.4±13 | 126.6±3.1 | 73.2±1.7 |
| 12 | 226.2±6.3 | 512.4±33 | 155.4±2.1 | 506.6±10 | 112.4±2.3 | 65.1±1.3 |
| 20 | 169.9±3.0 | 413.2±16 | 116.1±1.3 | 395.5±6.5 | 80.3±1.1 | 46.7±0.7 |
| 25 | 149.3±2.2 | 373.2±11 | 102.1±1.1 | 351.8±5.5 | 69.7±0.8 | 40.5±0.6 |
| 30 | 134.4±1.8 | 342.4±8.7 | 91.9±0.9 | 318.8±4.8 | 62.6±0.6 | 36.4±0.5 |
| 40 | 114.6±1.4 | 298.5±6.3 | 78.6±0.7 | 271.4±4.0 | 53.3±0.6 | 31.1±0.4 |
| 50 | 102.3±1.2 | 268.8±5.2 | 70.5±0.7 | 239.1±3.5 | 47.8±0.4 | 27.9±0.3 |
| 52 | 100.4±1.2 | 263.9±5.0 | 69.2±0.6 | 233.7±3.4 | 46.9±0.4 | 27.5±0.3 |
| 60 | 94.1±1.1 | 247.4±4.5 | 65.1±0.6 | 215.0±3.1 | 44.1±0.4 | 25.9±0.3 |
| 70 | 88.4±1.1 | 231.3±4.0 | 61.2±0.6 | 196.4±2.8 | 41.7±0.4 | 24.5±0.3 |
| 80 | 84.3±1.1 | 218.5±3.8 | 58.4±0.6 | 181.5±2.7 | 39.9±0.5 | 23.4±0.4 |
| 90 | 81.0±1.1 | 208.0±3.4 | 56.5±0.6 | 169.3±2.5 | 38.5±0.5 | 22.6±0.3 |
| 100 | 78.6±1.3 | 198.9±3.3 | 54.7±0.7 | 159.1±2.6 | 37.5±0.5 | 22.0±0.4 |

ISOTOPIC ABUNDANCES OF TIN

| Isotope | Absolute Abundance (atom percent) | Solar Abundance (atoms per $10^6$ Si) | Solar Abundance (ppm) |
|---|---|---|---|
| 112 ........... | 0.973 | 0.0372 | 0.0163 |
| 114 ........... | 0.659 | 0.0252 | 0.0107 |
| 115 ........... | 0.339 | 0.0129 | 0.0057 |
| 116 ........... | 14.538 | 0.555 | 0.244 |
| 117 ........... | 7.672 | 0.293 | 0.129 |
| 118 ........... | 24.217 | 0.925 | 0.407 |
| 119 ........... | 8.587 | 0.328 | 0.144 |
| 120 ........... | 32.596 | 1.245 | 0.548 |
| 122 ........... | 4.632 | 0.177 | 0.0778 |
| 124 ........... | 5.787 | 0.221 | 0.0972 |
| Total ....... | 100.00 | 3.82 | 1.68 |




***Systematic study of proton capture on Sn isotopes in the astrophysical energy range***

***Experimental cross sections available at energies from 2 – 9 MeV***

***$^{119}$Sn shows a peculiar trend***