A new look at the low-energy enhancement in photon strength

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Part of this work was performed under the auspices of the U.S. Department of Energy, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48 and under Contract No. DE-AC52-07NA27344.

Outline

i. Motivation.

ii. Experimental approach to study the region of high-level density.

iii. Experimental results.

iv. Comparison of the strength function data to the Oslo data (Oslo and Goriely Normalizations).

v. What does our data tell us about the existence of the low-energy enhancement?

vi. Concluding remarks.

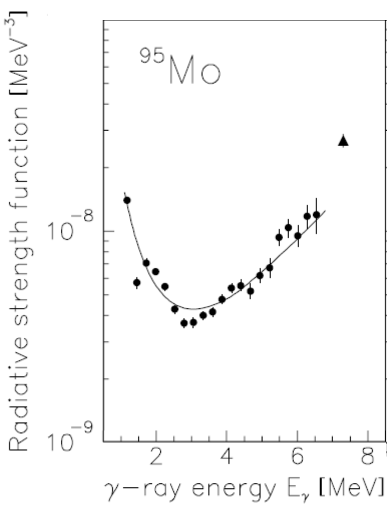
Motivation

VOLUME 93, NUMBER 14 PHYSICAL REVIEW LETTERS week ending 1 OCTOBER 2004

Large Enhancement of Radiative Strength for Soft Transitions in the Quasicontinuum

A. Voinov,[1,2,*] E. Algin,[3,4,5,6] U. Agvaanluvsan,[3,4] T. Belgya,[7] R. Chankova,[8] M. Guttormsen,[8] G. E. Mitchell,[4,5] J. Rekstad,[8] A. Schiller,[3,†] and S. Siem[8]

First report of enhancement
E. Tavukcu, Ph.D. thesis, North Carolina State University, 2002.



PHYSICAL REVIEW C 71, 044307 (2005)

Radiative strength functions in $^{93-98}$Mo

M. Guttormsen,[1,*] R. Chankova,[1] U. Agvaanluvsan,[2] E. Algin,[2,3,4,5] L. A. Bernstein,[2] F. Ingebretsen,[1] T. Lönnroth,[6] S. Messelt,[1] G. E. Mitchell,[3,4] J. Rekstad,[1] A. Schiller,[2] S. Siem,[1] A. C. Sunde,[1] A. Voinov,[7,8] and S. Ødegård[1]
[1]*Department of Physics, University of Oslo, N-0316 Oslo, Norway*
[2]*Lawrence Livermore National Laboratory, L-414, 7000 East Avenue, Livermore, California 94551*

Continued observations of low energy enhancement for light and medium mass nuclei. Debates over the years if the enhancement is real.

PHYSICAL REVIEW C 79, 024301 (2009)

Test of the statistical model in ^{96}Mo with the $BaF_2\gamma$ calorimeter DANCE array

S. A. Sheets,[1] U. Agvaanluvsan,[2] J. A. Becker,[2] F. Bečvář,[3] T. A. Bredeweg,[4] R. C. Haight,[4] M. Jandel,[4] M. Krtička,[3] G. E. Mitchell,[1] J. M. O'Donnell,[4] W. Parker,[2] R. Reifarth,[4] R. S. Rundberg,[4] E. I. Sharapov,[5] J. L. Ullmann,[4] D. J. Vieira,[4] J. B. Wilhelmy,[4] J. M. Wouters,[4] and C. Y. Wu[2]

Some say there may or may not be an enhancement.

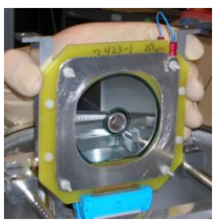
Others argue: the low energy enhancement does not exist.

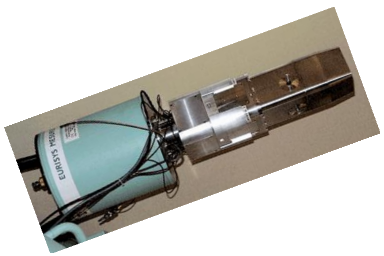
Motivation

Much debate about the existence of the
low-energy enhancement and its origin.

Needed: New approach and independent look at the enhancement.

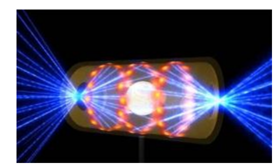
Independence on level density is desirable to study statistical properties.





R&D grant at LLNL to explore use of Clover and Silicon detectors to extract statistical properties.

Application: Statistical studies to understand data from NIF.

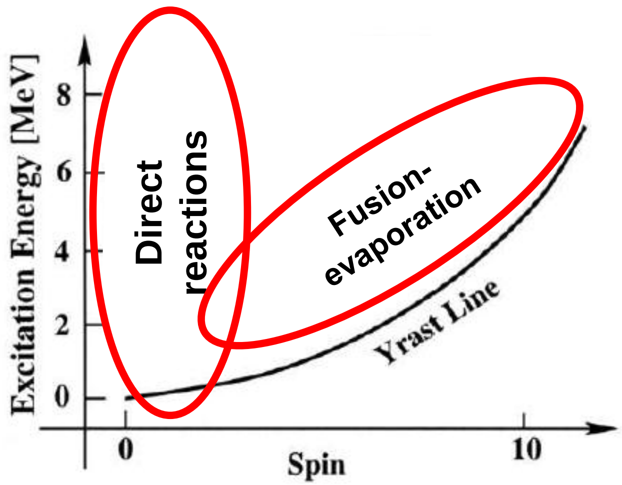


Physics: Does the low-energy enhancement exist and what is its origin?
Validity of the Axel-Brink Hypothesis? Pygmy resonances, etc.…

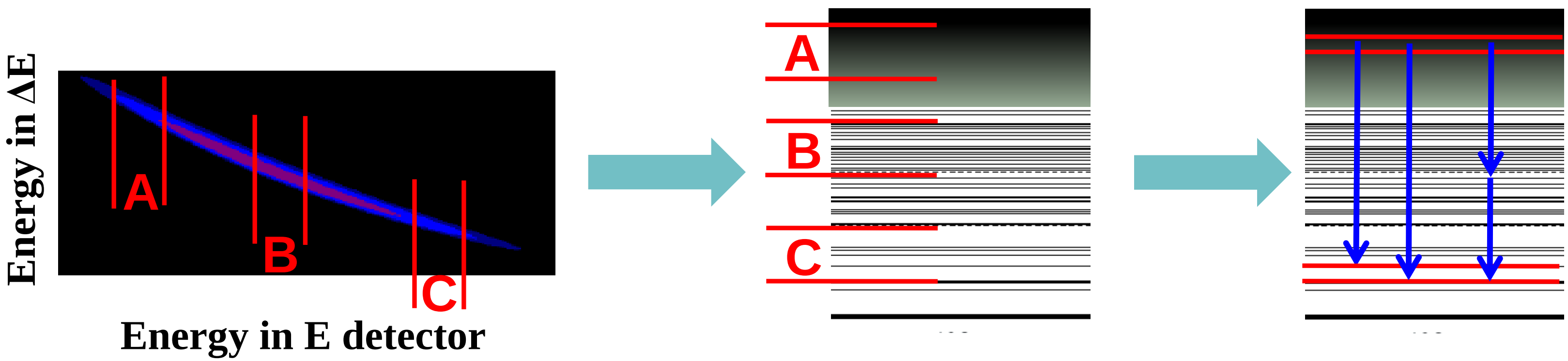
Development of method was tedious and littered with pitfalls. In the end it turned out to be fruitful.

Experimental Approach

Use direct reactions $^{94}Mo(d,p)^{95}Mo$ at 11 MeV to populate states with high excitation energy away from yrast line rather than fusion-evaporation which follows along the yrast line.

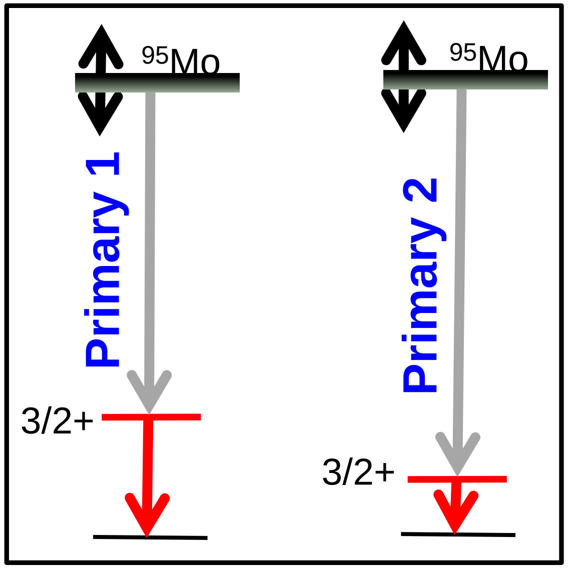


Charged particles will be used to specify entrance excitation energy into the system and γ -rays in coincidence are studied e.g feeding, lifetime.



Feeding information

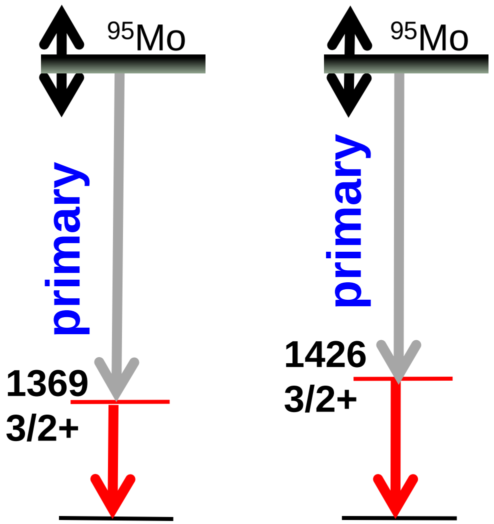
- Study feeding to by gating on discrete gamma transitions
- Originate from same excitation energy region
→ from the same level density.
- Study the feeing by varying the entrance excitation energy and discrete level.
- Scanning and efficiency corrections are done event by event. Sums of 1 MeV bins is performed afterwards.
- The number of counts are converted to strength.
- Take ratios to the same spin: These are independent of cross section, level density and systematic errors.
- 7x$3/2^+$, 2x$9/2^+$, 2x$7/2^+$, 2x$1/2^+$ states for ratios in ^{95}Mo.
- Compare our results to Oslo strength function data.

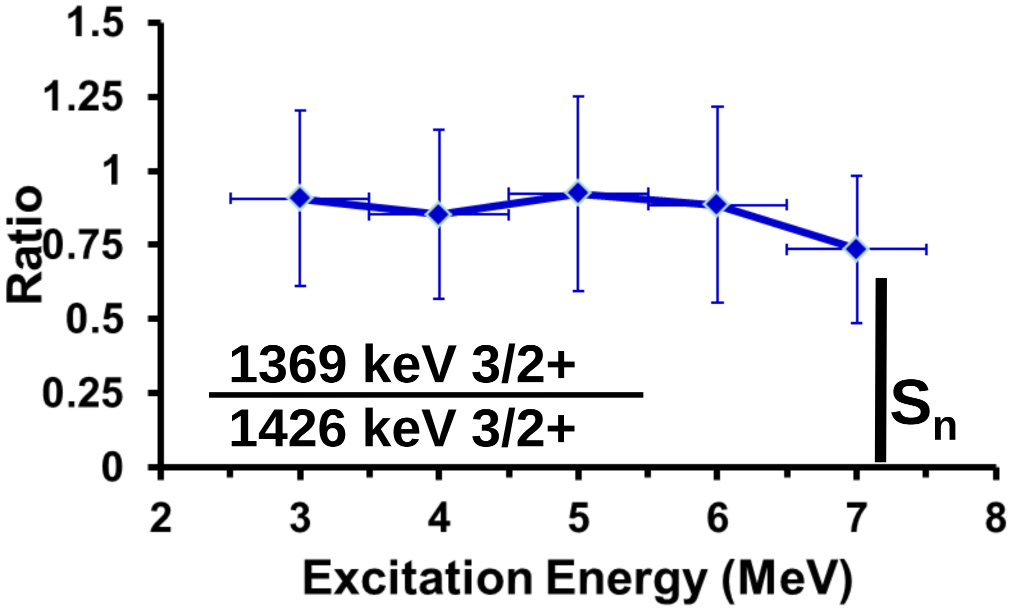


$$f_{(E_x-E_d)} = \frac{\sigma_{(E_x-E_d)}}{(3(\pi\hbar c)^2 E_{(E_x-E_d)}} = \frac{\Gamma_{(E_x-E_d)}\rho_{(E_x)}}{E^3_{(E_x-E_d)}} \Bigg\} \quad \frac{f_{1(E_x-E1_d)}}{f_{2(E_x-E2_d)}} = \frac{N_{1(E_x-E1_d)}E_2{}^3{}_{(E_x-E2_d)}}{N_{2(E_x-E2_d)}E_1{}^3{}_{(E_x-E1_d)}}$$

Total of 24 ratios

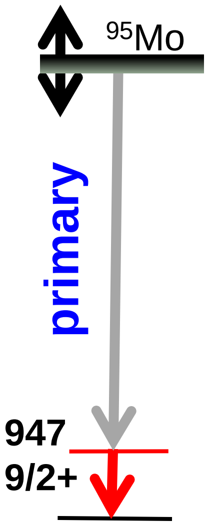
Ratio 1 of 24

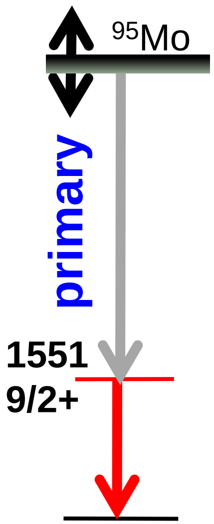


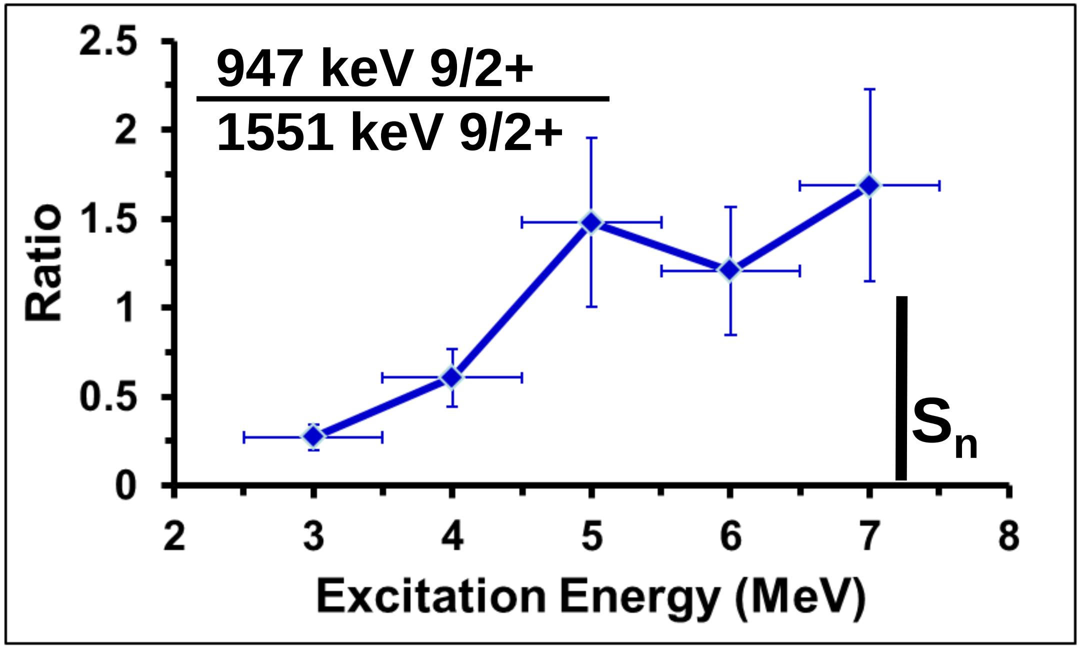


Ratios with value around 1.

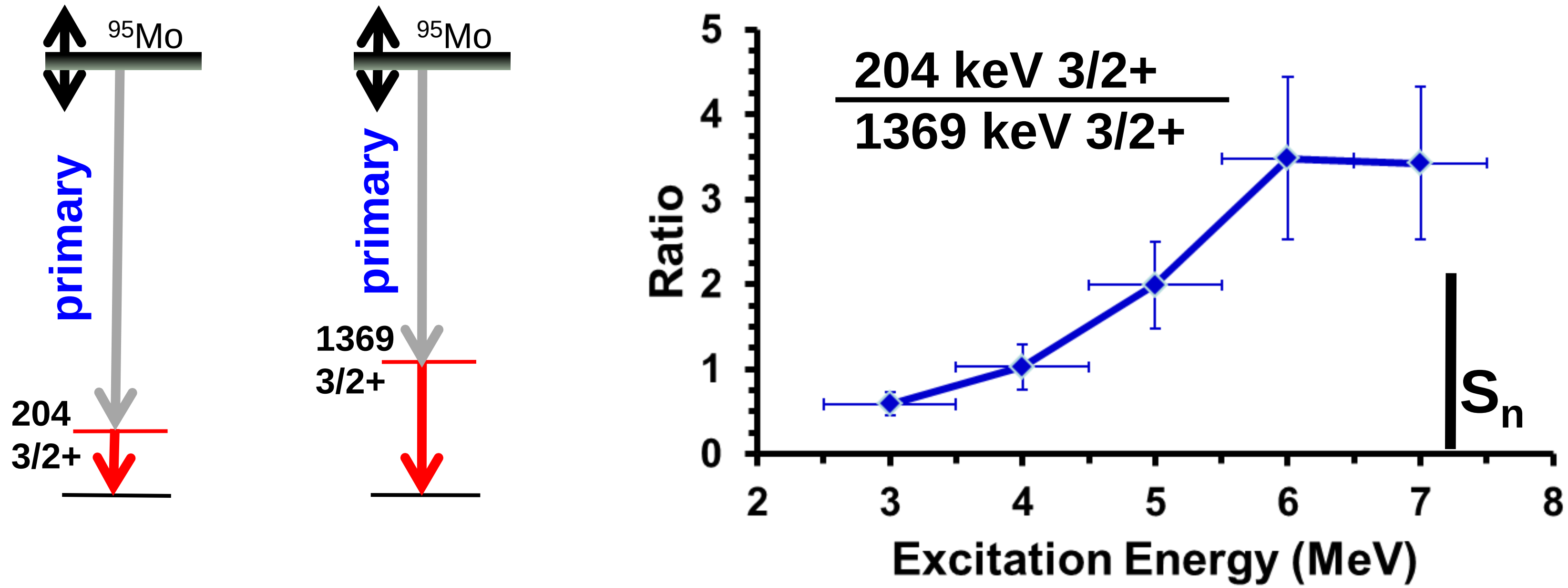
Ratio 10 of 24





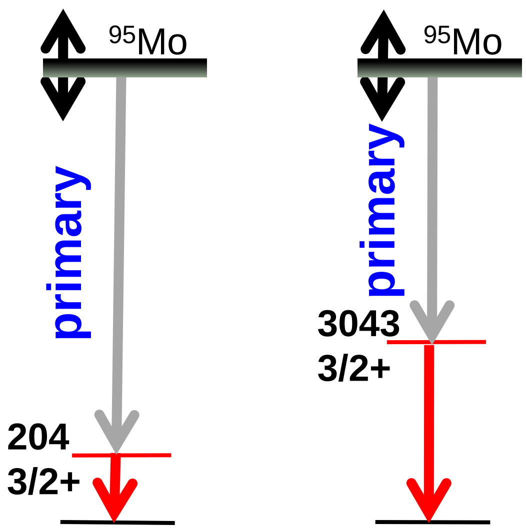


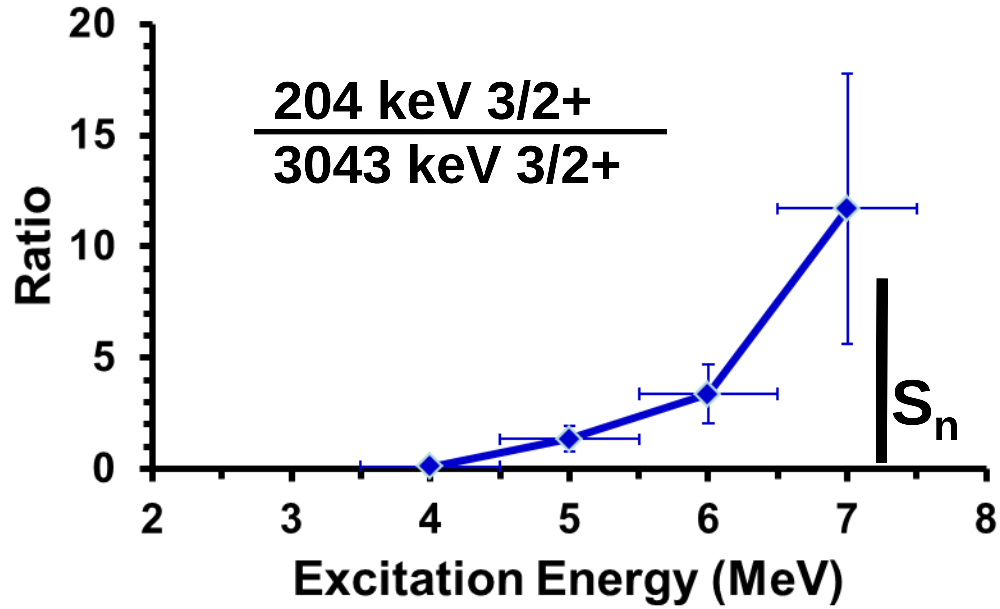
Ratio decreasing towards low excitation energy → Why?



Ratio decreasing towards low excitation energy → Why?

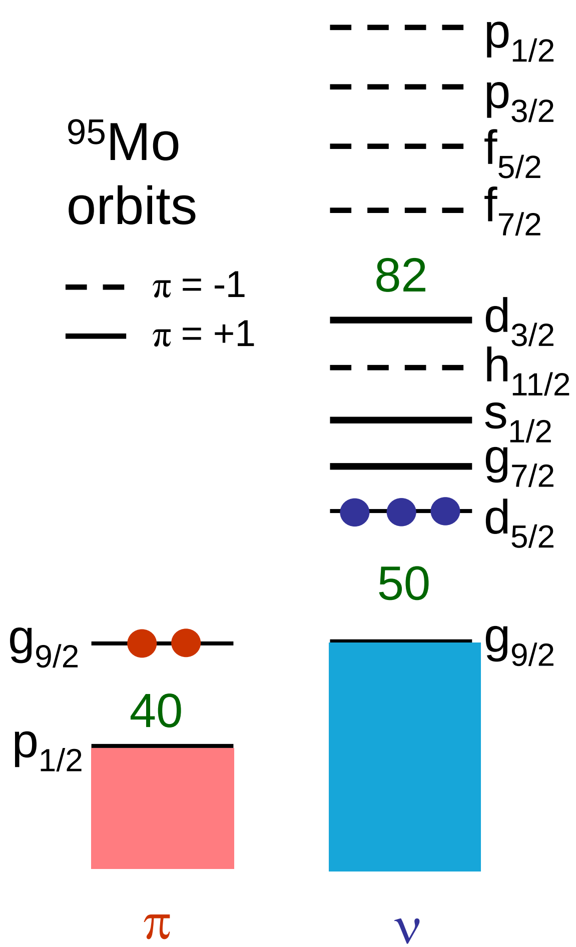
Ratio 23 of 24





Ratio decreases towards low excitation energy → Why?

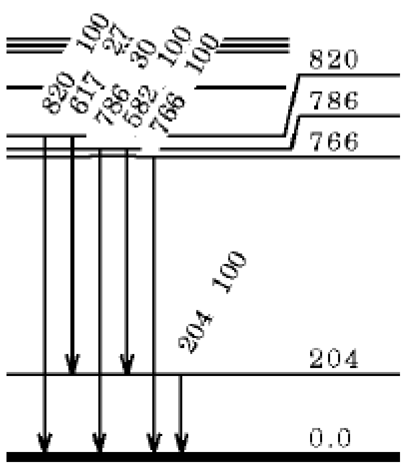
^{95}Mo: Structure details



- Assumption: The region of high-level density decays by E1 transitions only.
- Only gated positive-parity discrete levels are used.
- Single step feeding sensitive to negative-parity levels populated in the (d,p) reaction only i.e. the neutron enters the ^{95}Mo system via the negative-parity orbits $p_{1/2,3/2}$, $f_{7/2,5/2}$, $h_{11/2}$
- Also the spin window is defined by the gated discrete level.
- For multi step feeding these statements cannot be made.

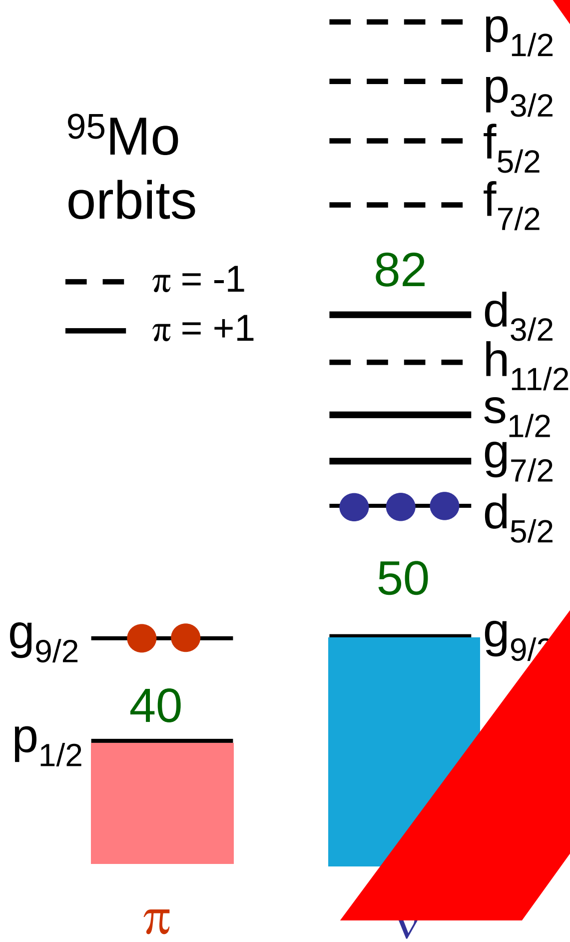
Spin construction from $d_{5/2}$ neutrons: $5/2^+$,$3/2^+$, and $9/2^+$
G.s., first-excited state at 204 keV, and the first $9/2^+$ level at 947 keV are pure $d_{5/2}$ neutron configurations [1].
Other levels involve higher-lying orbits and have mixed configurations.

Does the feeding from high-level density differentiate between mixed versus pure discrete configurations?



[1] P. Da R. Andrade et al, Nucl. Phys. 77, 298 (1966).

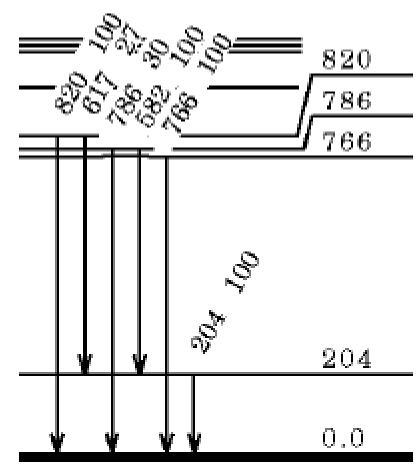
^{95}Mo: Structure details



Assumption: The regi… -level density decays by E1 …nsitions only.
… gated positi… …iscrete levels are used.
… step fee… …tive to negative-parity levels populated …p) rea… i.e. the neutron enters the ^{95}Mo system … orbits $p_{1/2,3/2}$, $f_{7/2,5/2}$, $h_{11/2}$
•A… …ow is defined by the gated discrete level.
•For… …ding these statements cannot be made.

S… … $d_{5/2}$ neutrons:
… and …
…st-excite… …204 keV, and …st 9/2⁺ level … are pure … neutron configu…
…ther levels involve … orbits and have mixed config…

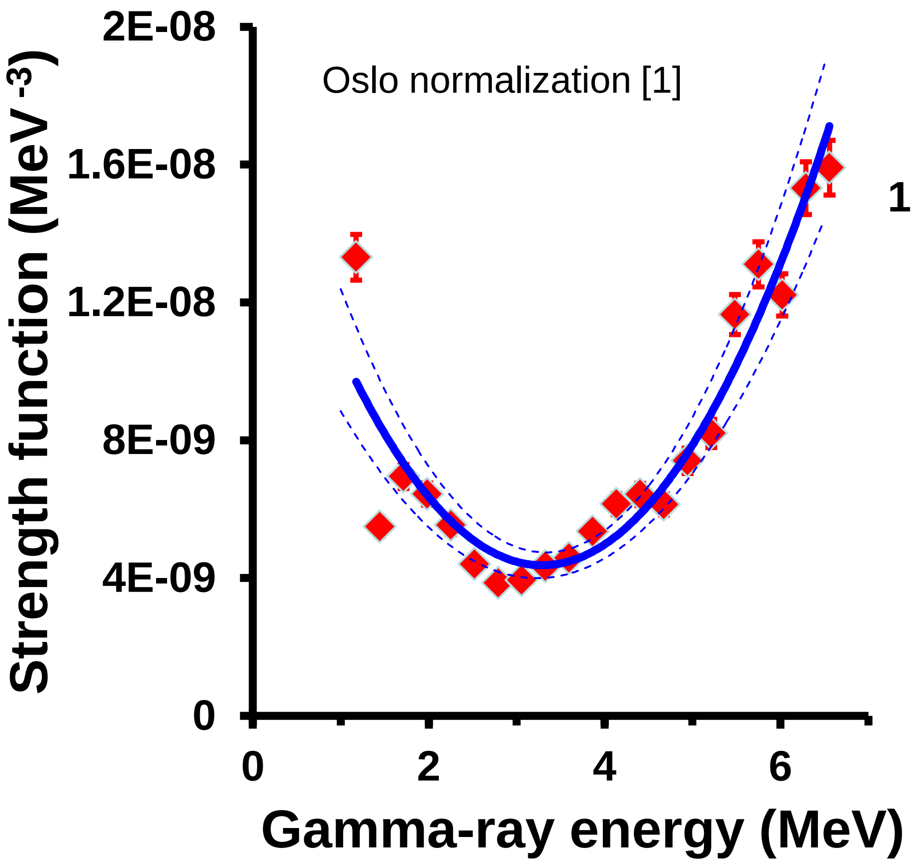
Does the feeding from high… …ity differentiate between mixed v… discrete configurations?

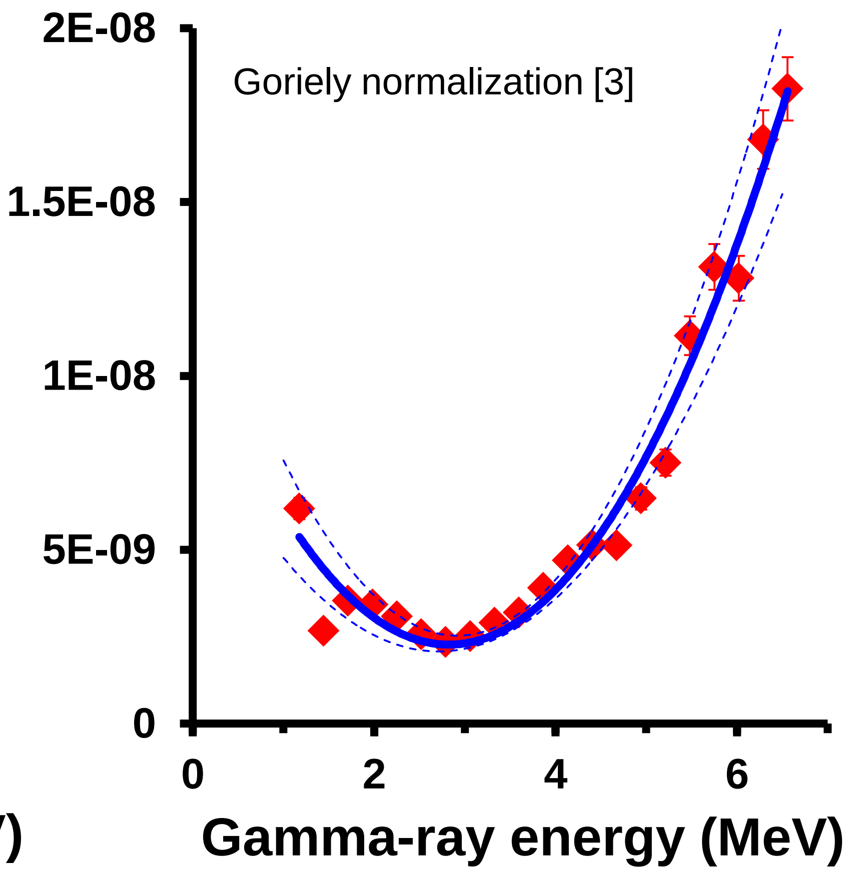


[1] P. Da R. Andrade et al, Nucl. Phys. 77, 298 (1966).

Continue the search…

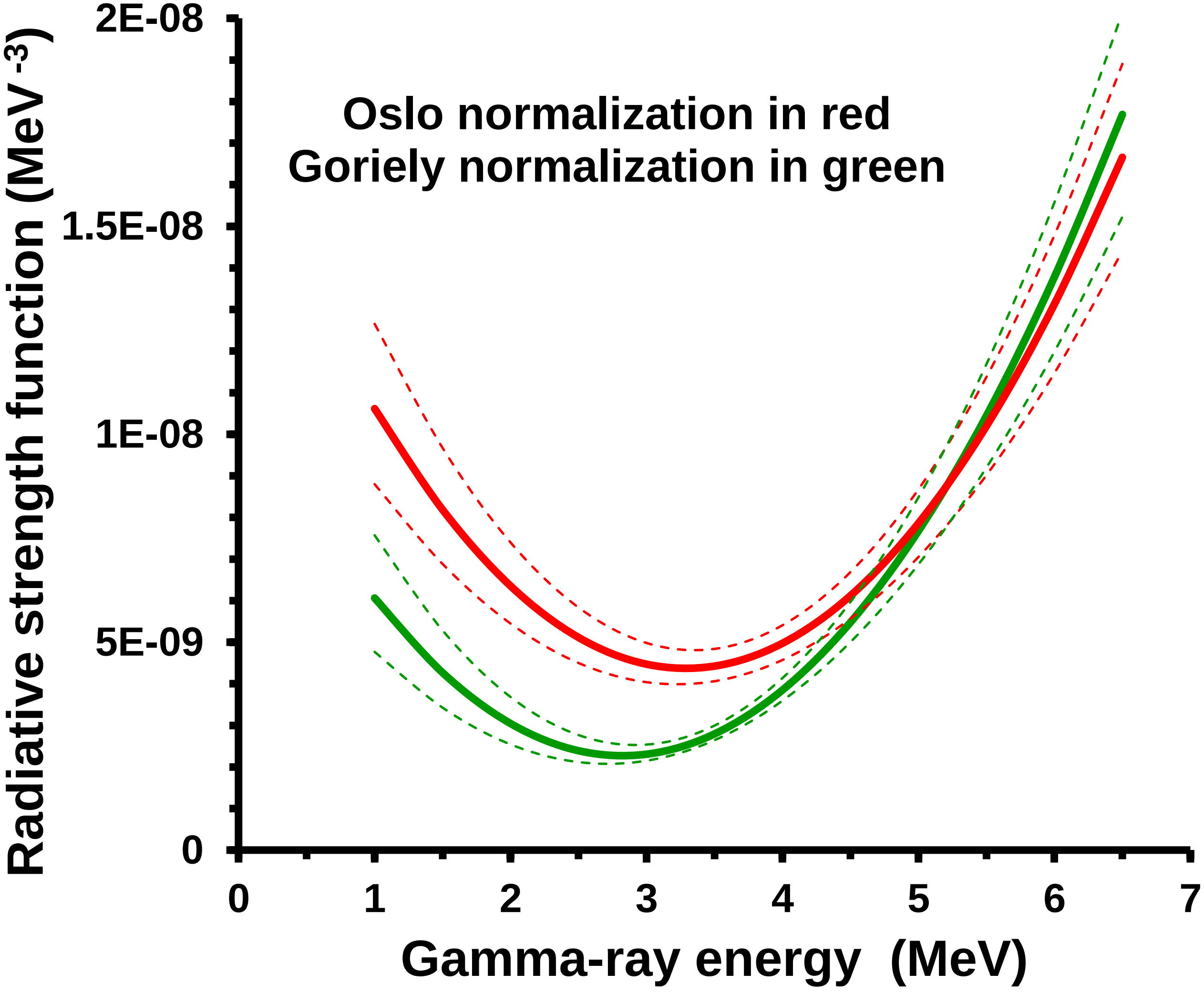
Nuclear structure is not responsible for the observed decrease at low excitation energy.
Oslo group has measured radiative strength function for ^{95}Mo [1]
Recent re-analysis using two different normalizations: Oslo and Goriely [2] (Data courtesy of AC Larsen).
Fit data and errors with polynomial function.



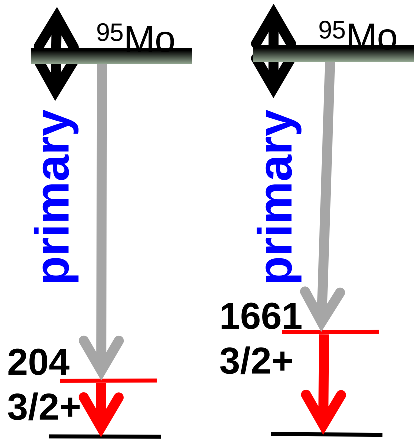


[1] Guttormsen et al., Phys. Rev. C71, 044307 (2005) [2] Larson & Goriely, Phys. Rev. C 82, 014318 (2010)
[3] Goriely *et al.*, Phys. Rev. C 78, 064307 (2008).

Oslo and Goriely

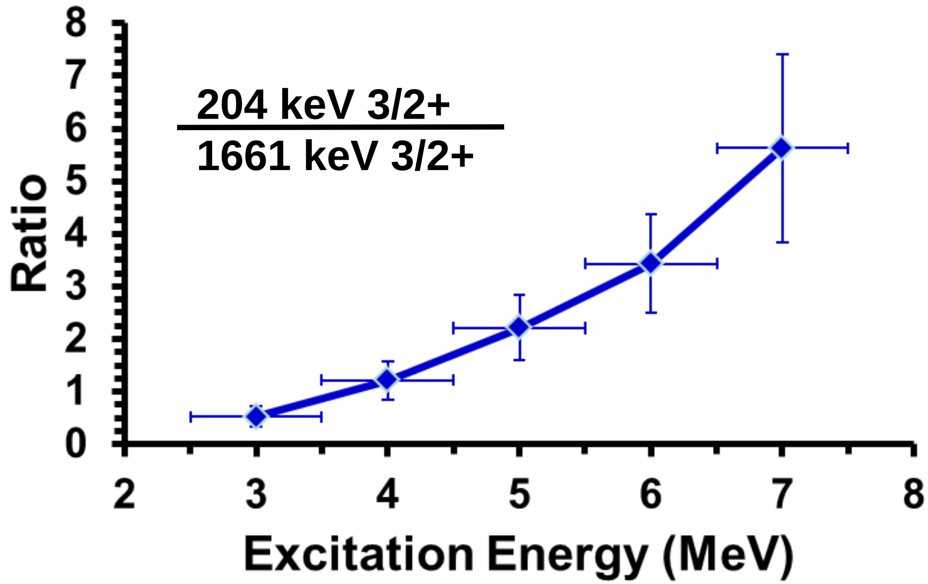


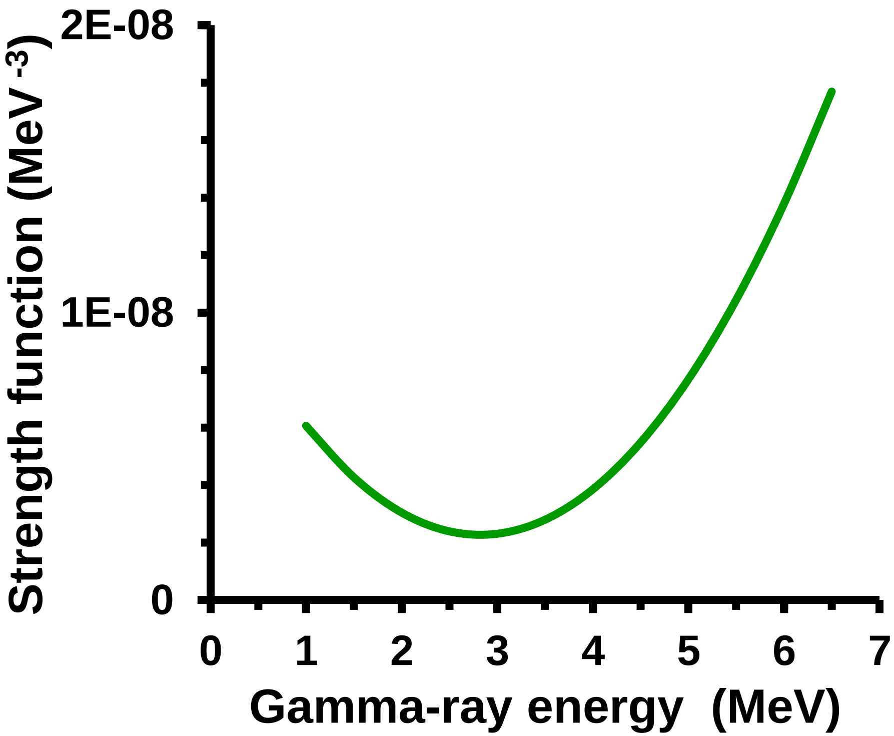
Comparison to our data



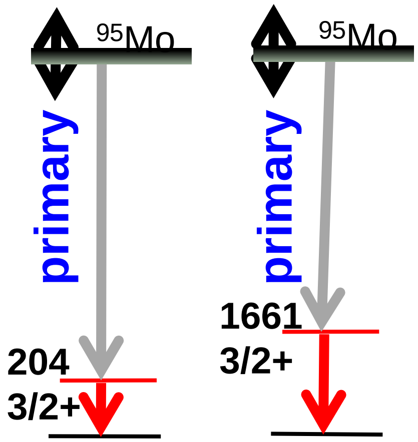
Our ratios are given in terms of Excitation Energy.
Need conversion to compare data to Oslo/Goriely

Exampe 1:



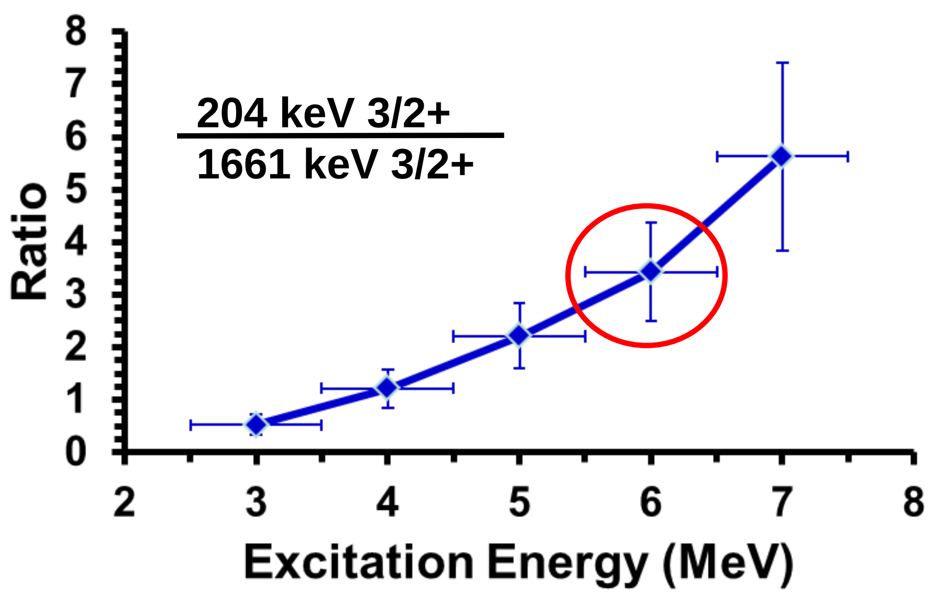


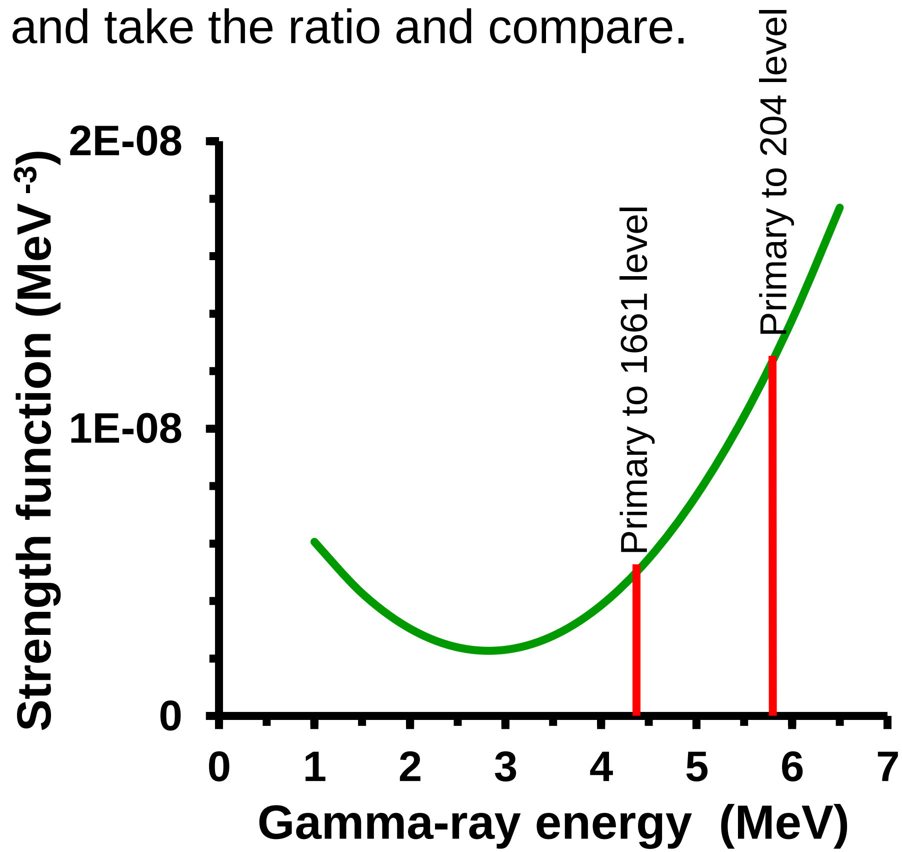
Comparison to our data



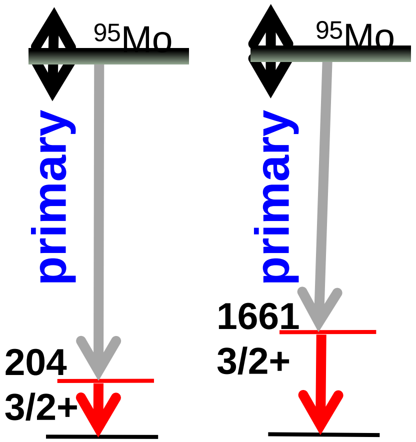
Our ratios are given in terms of Excitation Energy
Need conversion to compare data to Oslo/Goriely

Example 1: for E_x= 6 MeV
Primary to 204 keV level is 5796 keV
Primary to 1661 keV level is 4339 keV
Read off SF values and take the ratio and compare.



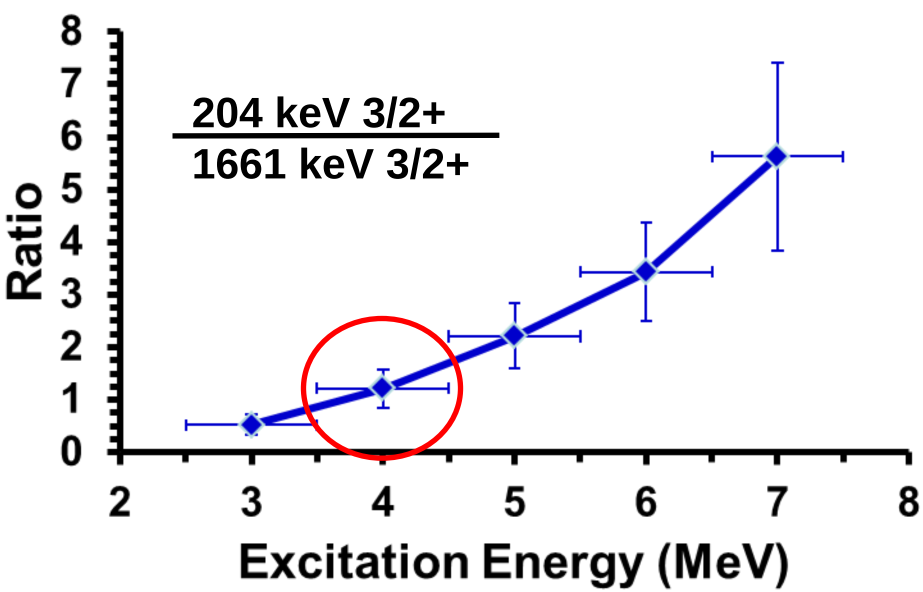


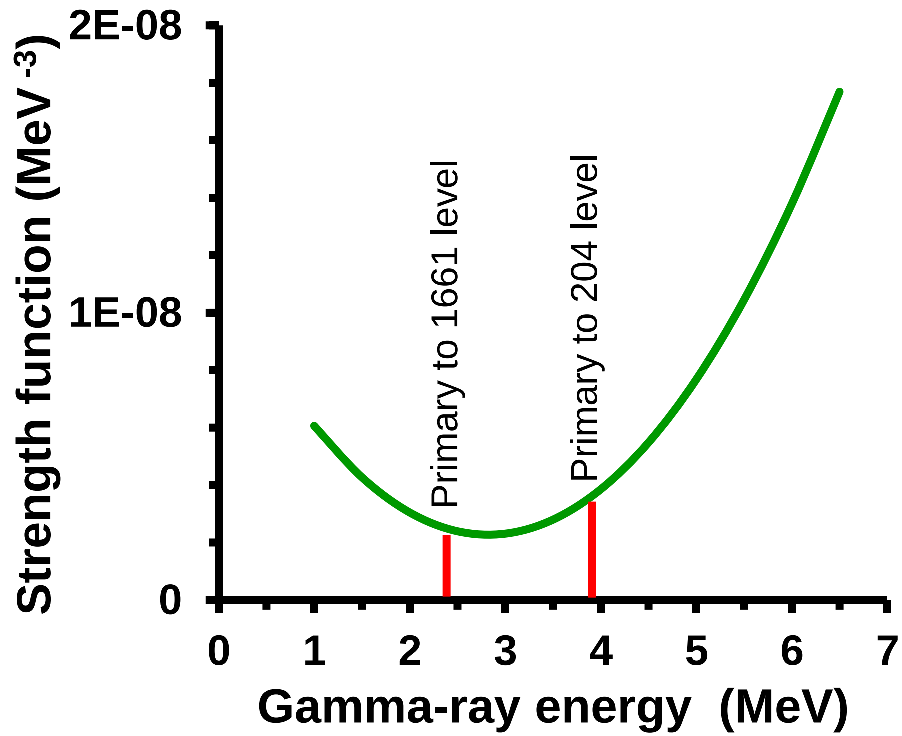
Comparison to our data



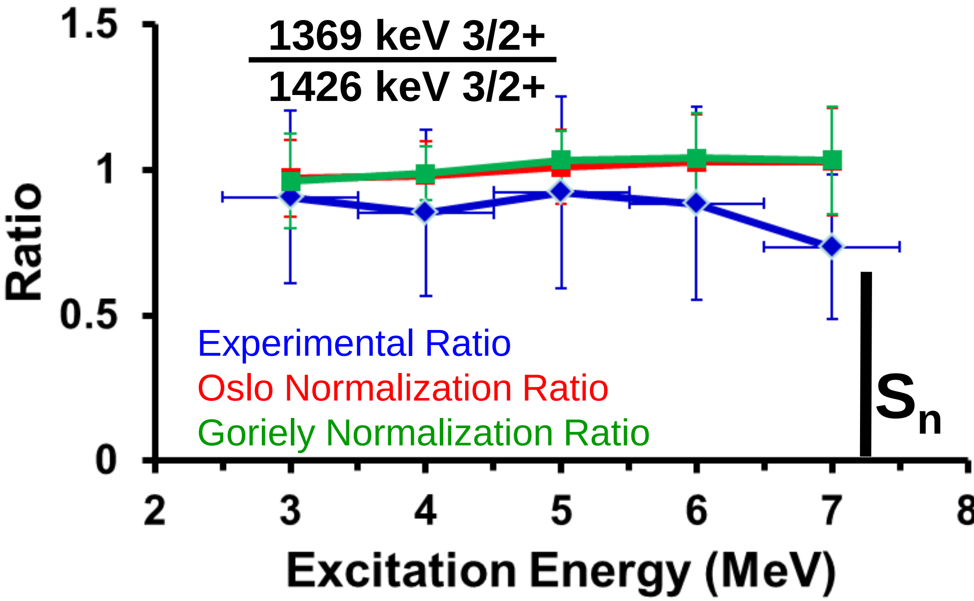
Our ratios are given in terms of Excitation Energy
Need conversion to compare data to Oslo/Goriely

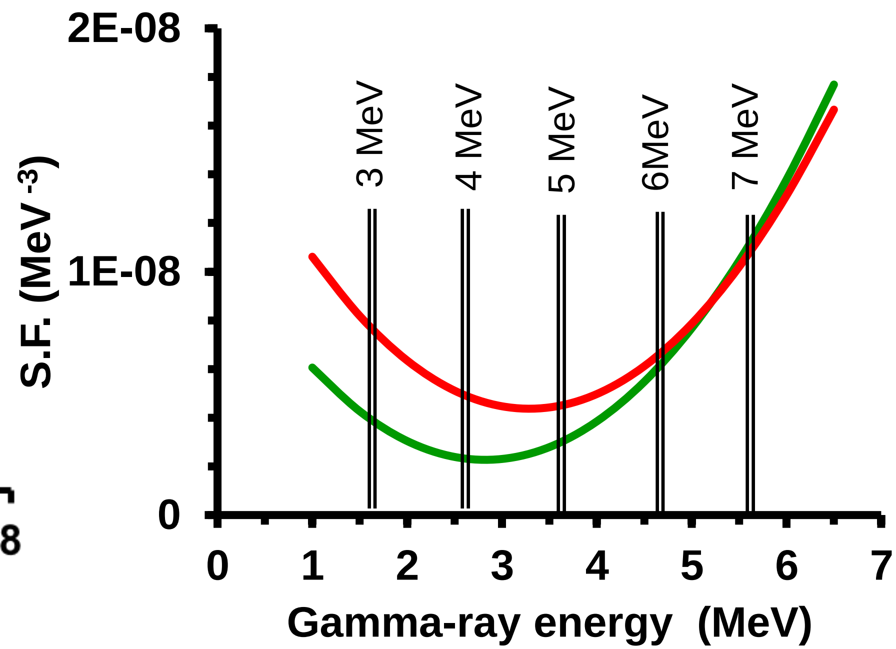
Example 2: for E_x= 4 MeV
Primary to 204 keV level is 3796 keV
Primary to 1661 keV level is 2339 keV
Read off SF values and take the ratio and compare.





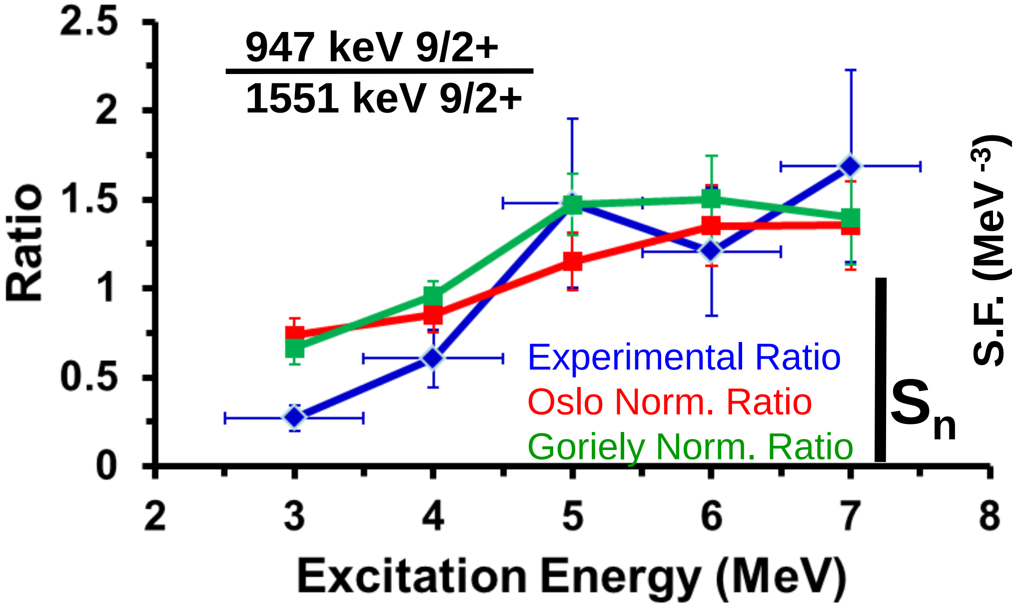
Ratio 1/24 comparison

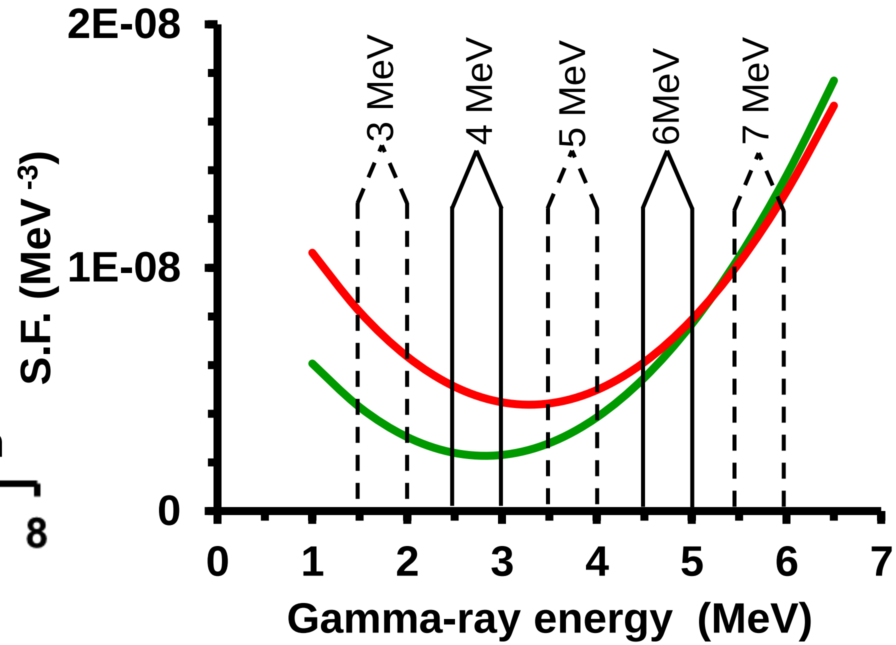




Oslo and Goriely normalization in agreement across all excitation energies.

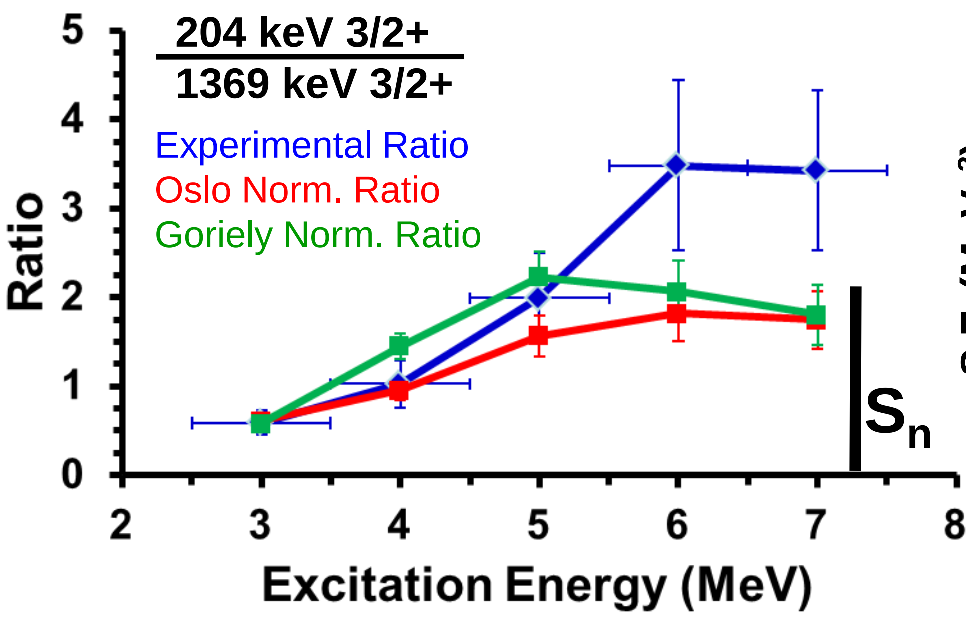
Ratio 10/24 comparison

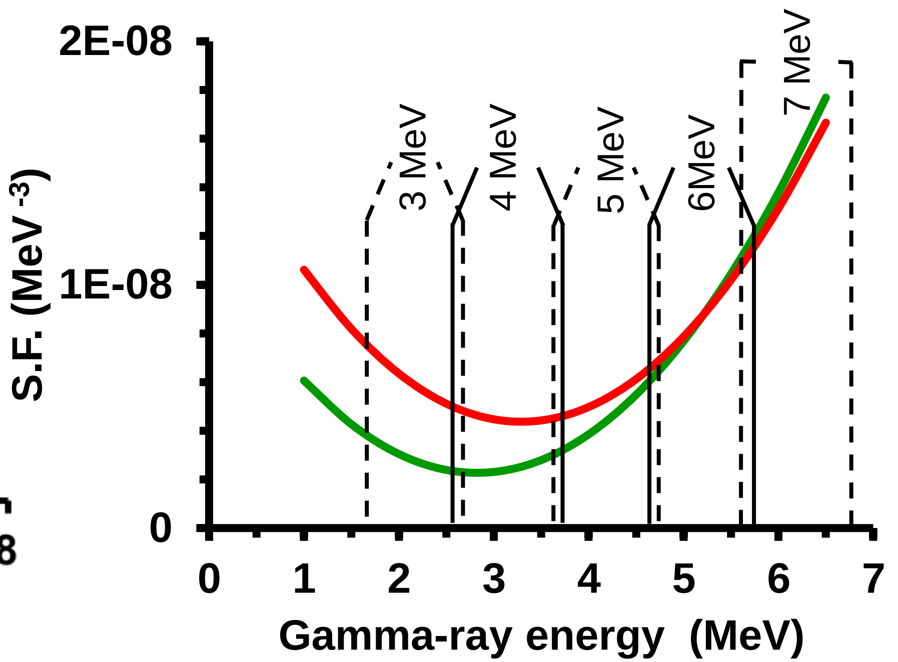




Oslo and Goriely Normalization in agreement within experimental errors bars.
Slightly off at 3 MeV but the general reducing trend is reproduced.

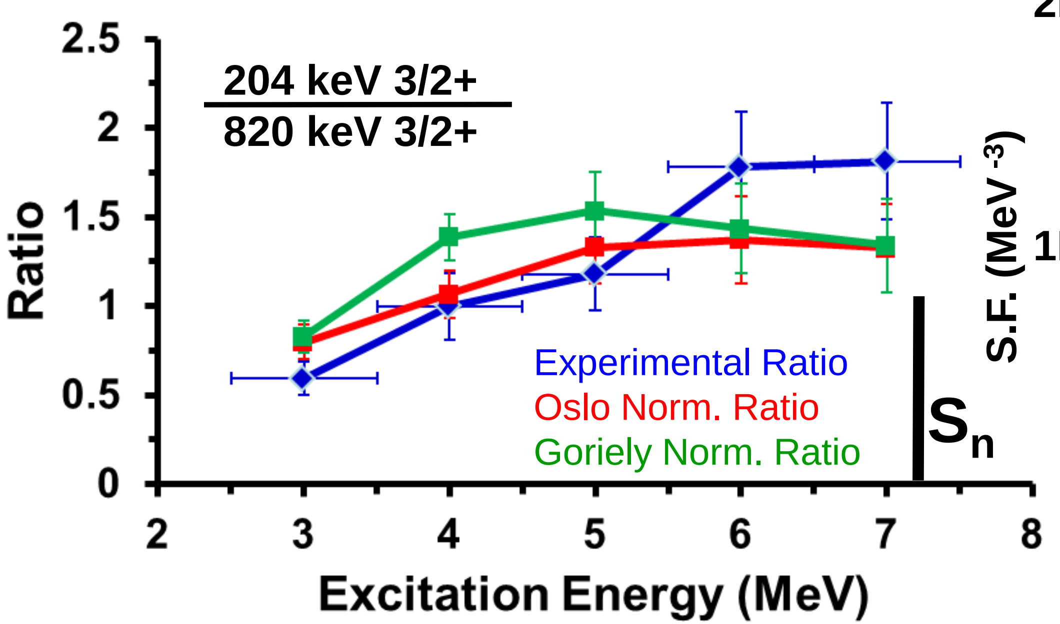
Ratio 14/24 comparison

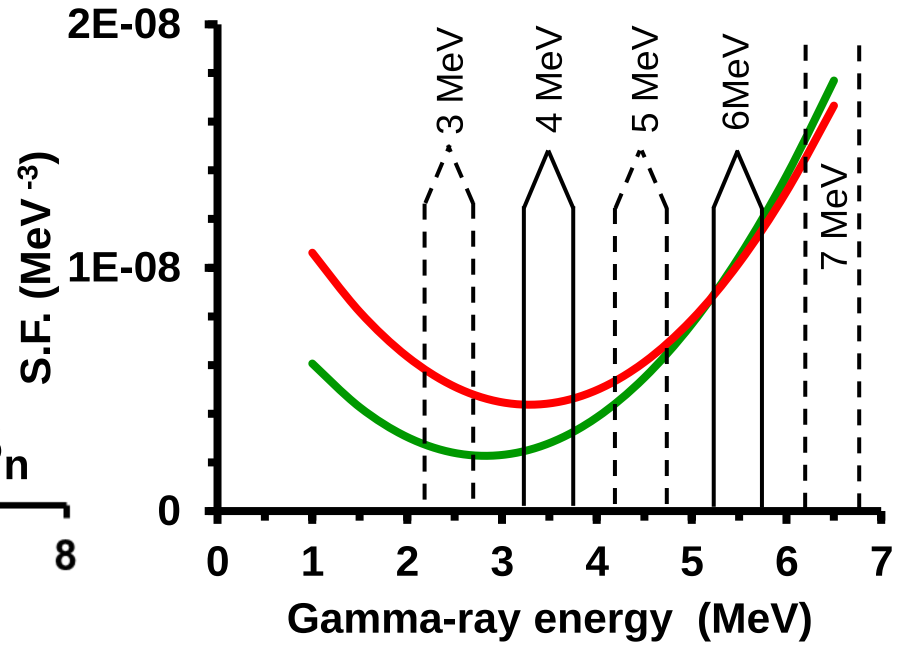




Oslo and Goriely normalization in agreement within experimental errors bars but underestimate at high excitation energies. The trend in reduction is reproduced towards low excitation energies.

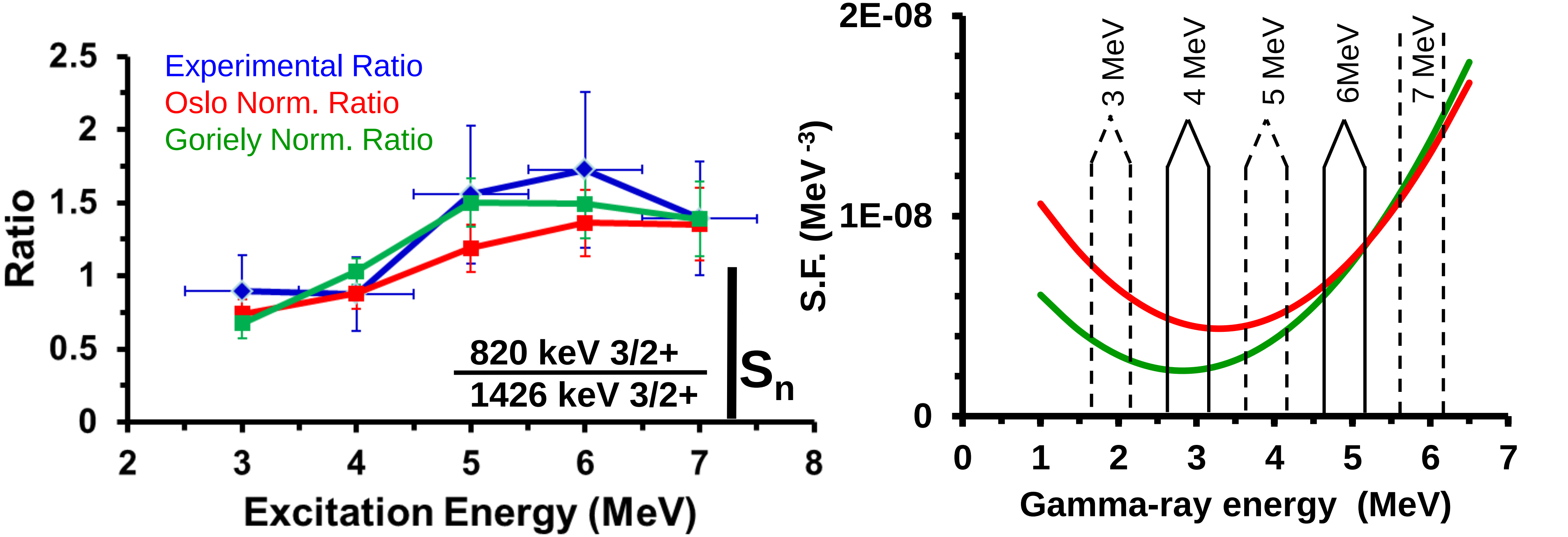
Ratio 9/24 comparison



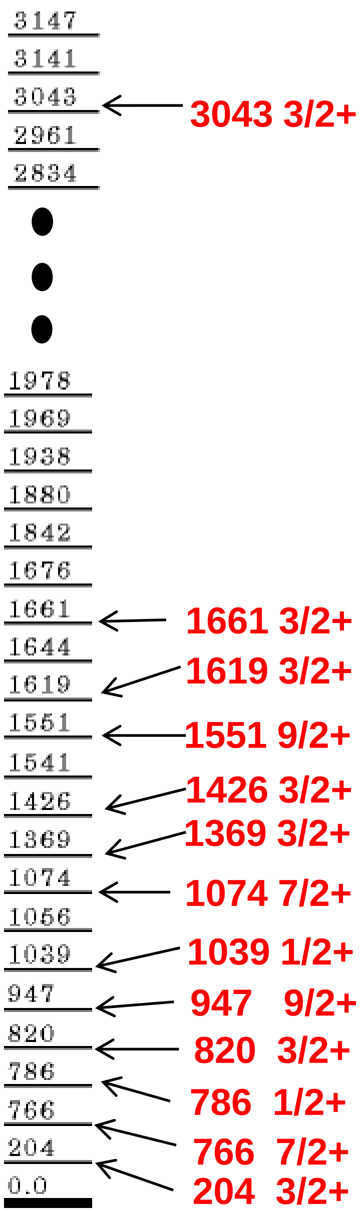


Oslo and Goriely normalization in agreement.
The trend towards low excitation energies is well reproduced.

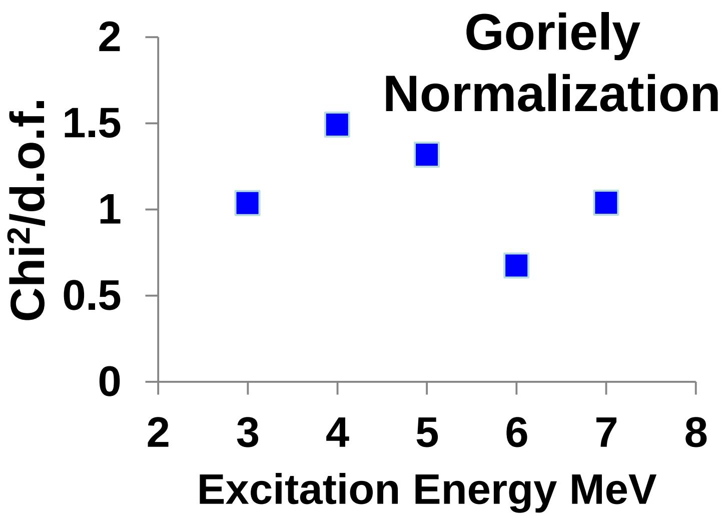
Ratio 3/24 comparison

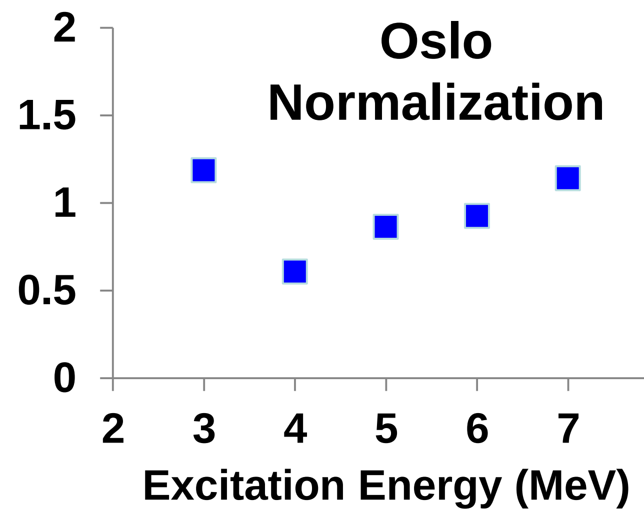


Chi^2/d.o.f.



Total of 24 ratios. Get a global picture in terms of Chi^2/d.o.f. At first exclude ratios containing 3043 keV which leaves a total of 18 ratios.

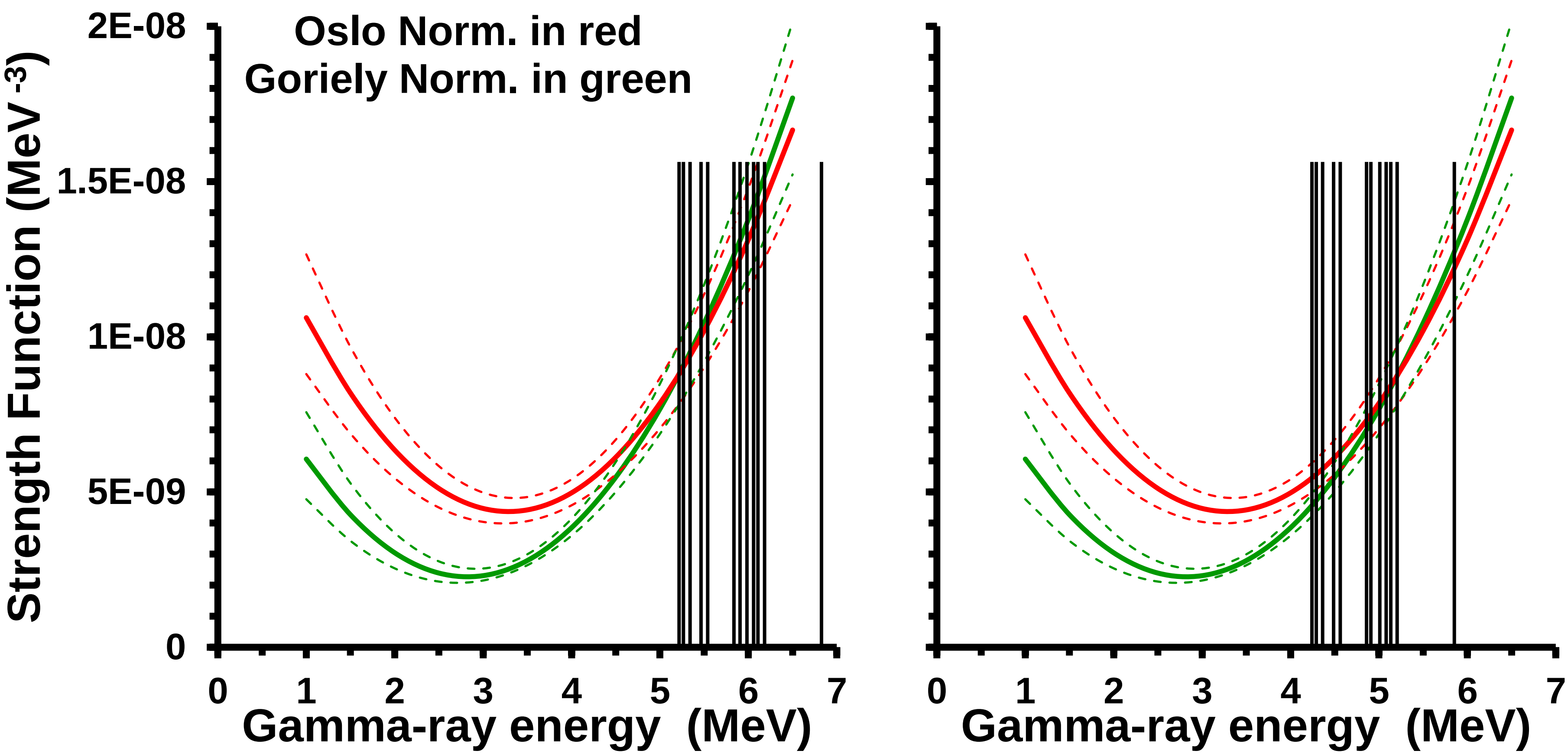




Oslo and Goriely Normalizations look very similar. Relatively constant above excitation energy of 3 MeV.

E_x at 6 and 7 MeV

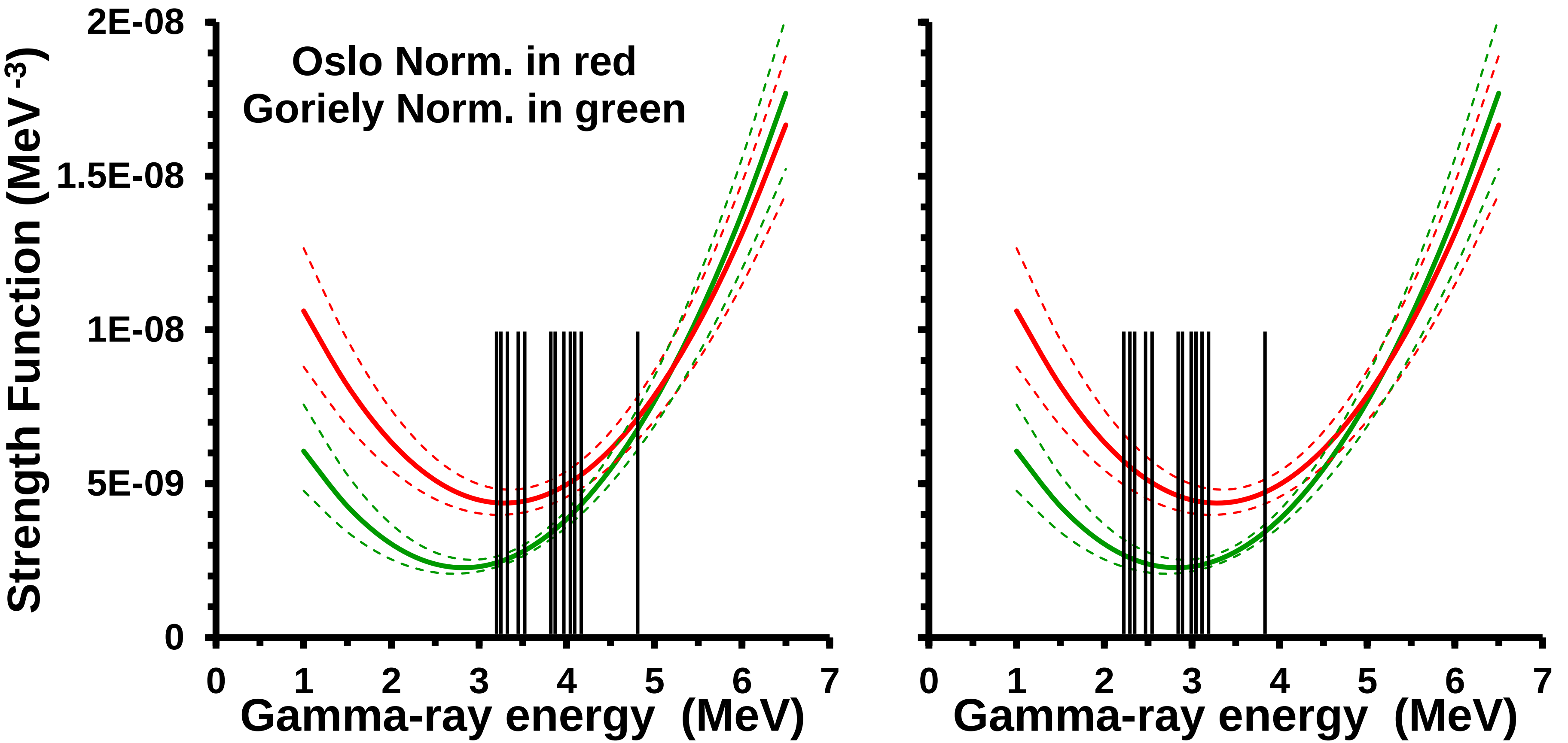
Ratios at 6 and 7 MeV excitation energy agree well.
Wide range of energies has been mapped out in the ratios.



The 6 and 7 MeV points map out the decrease in strength function with a decrease in gamma-ray energy. Unable to make statement if Oslo or Goriely Normalization is a better match with our error bars. This is not surprising since the curves look quite similar.

E_x at 5 and 4 MeV

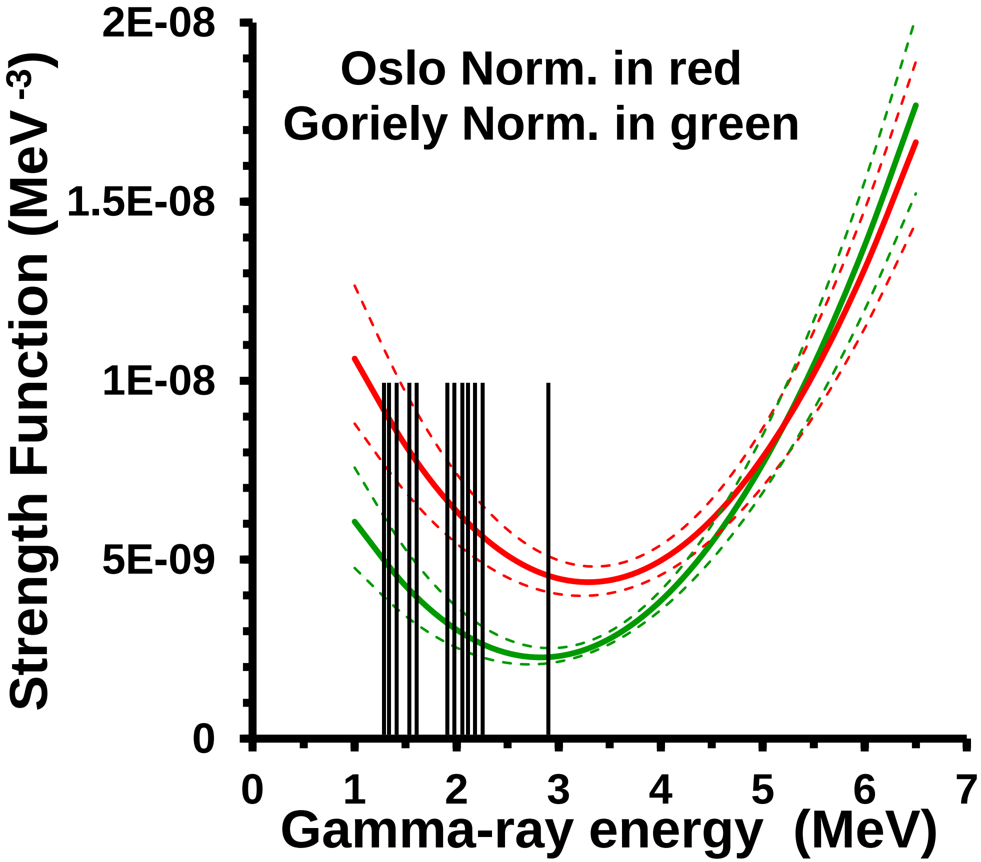
Ratios around 5 and 4 MeV excitation energy agree well.
Wide range of energies has been mapped out in the ratios.



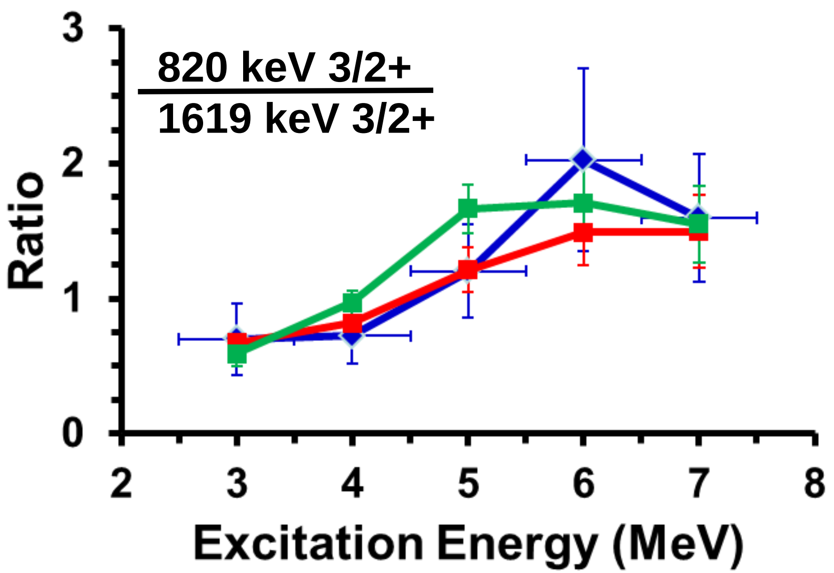
Here we map out the minima in both Oslo and Goriely normalization.
Our data confirms the picture of a leveling off in the strength function in this energy region.

E_x at 3 MeV

Ratios at 3 MeV excitation energy agree but not in all cases.
The Chi^2/d.o.f. increases to 3.5 to 4 in both normalizations.
Why is 3 MeV different?

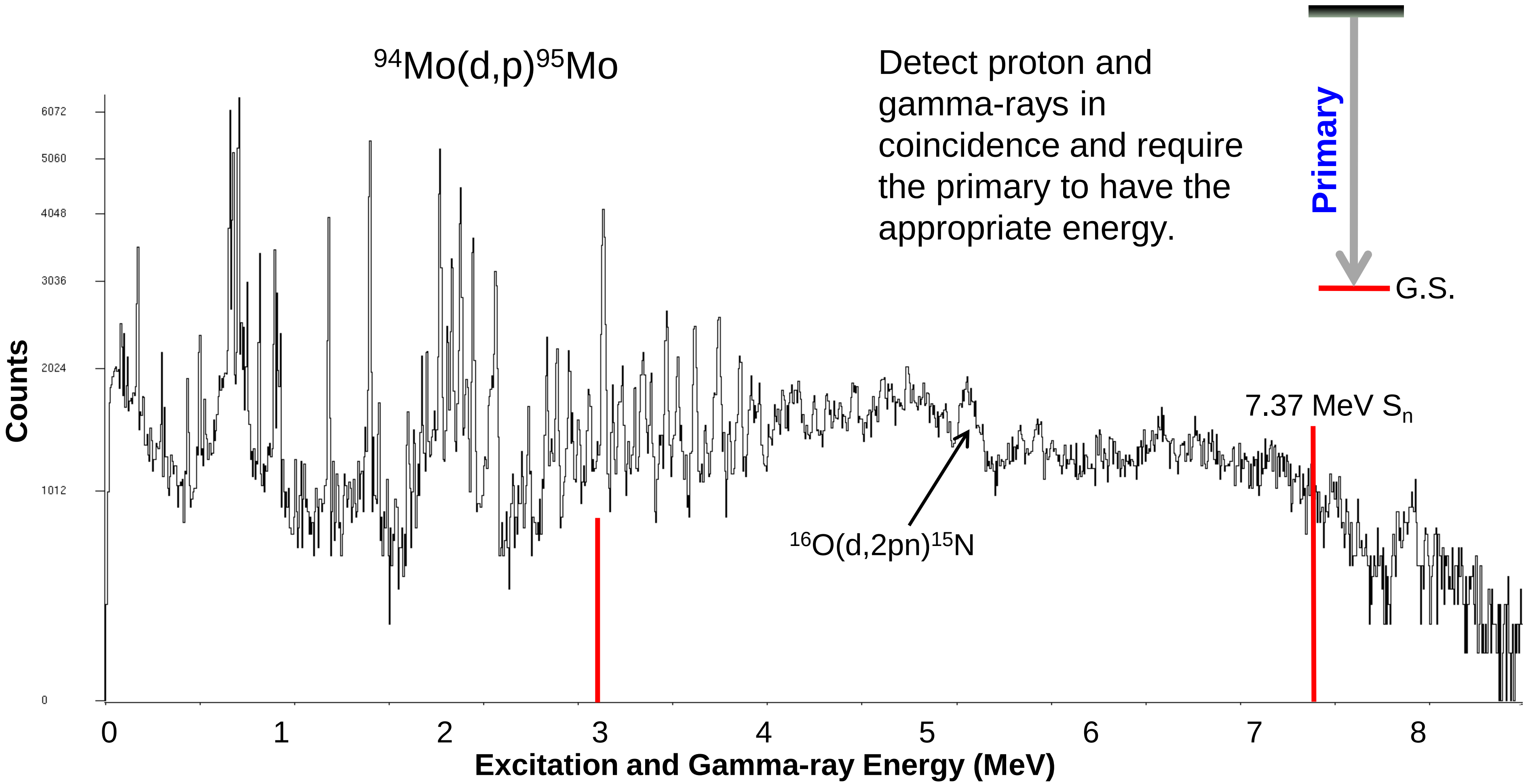


3 MeV maps out the increase of strength function out of the minima for both the Oslo and Goriely Normalizations.



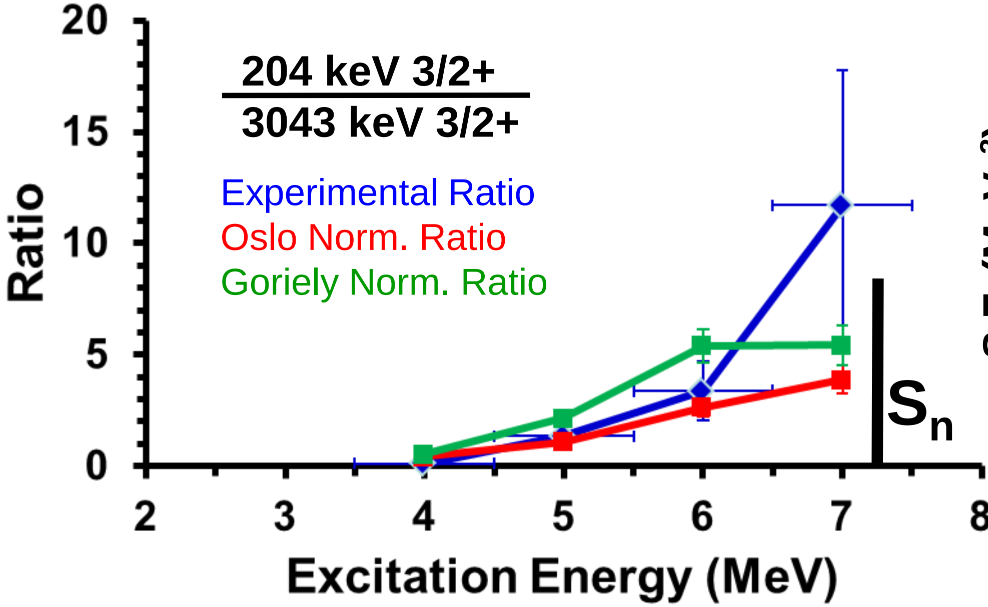
Primaries to the ground state

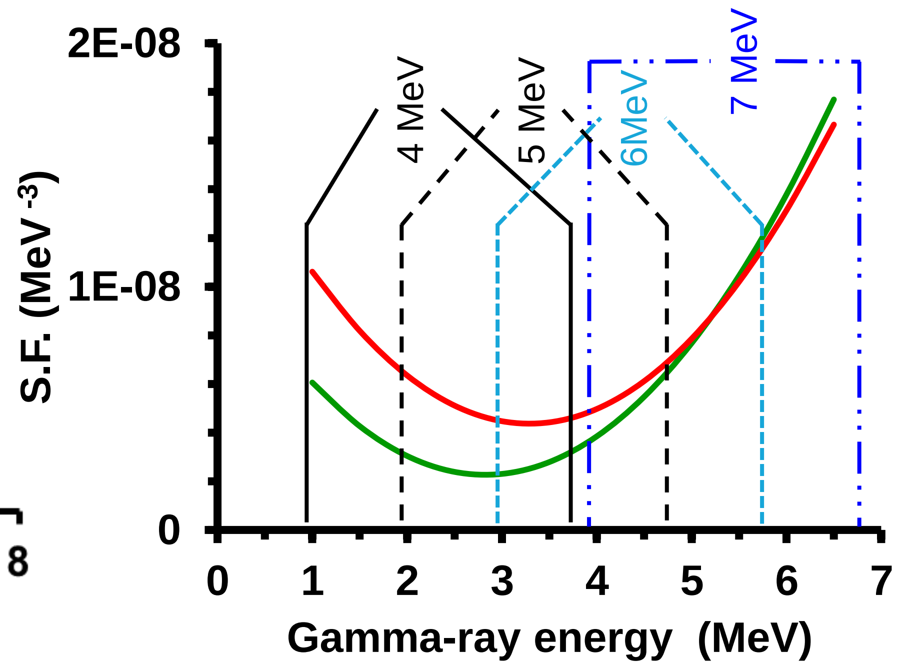
Detect proton and gamma-rays in coincidence and require the primary to have the appropriate energy.



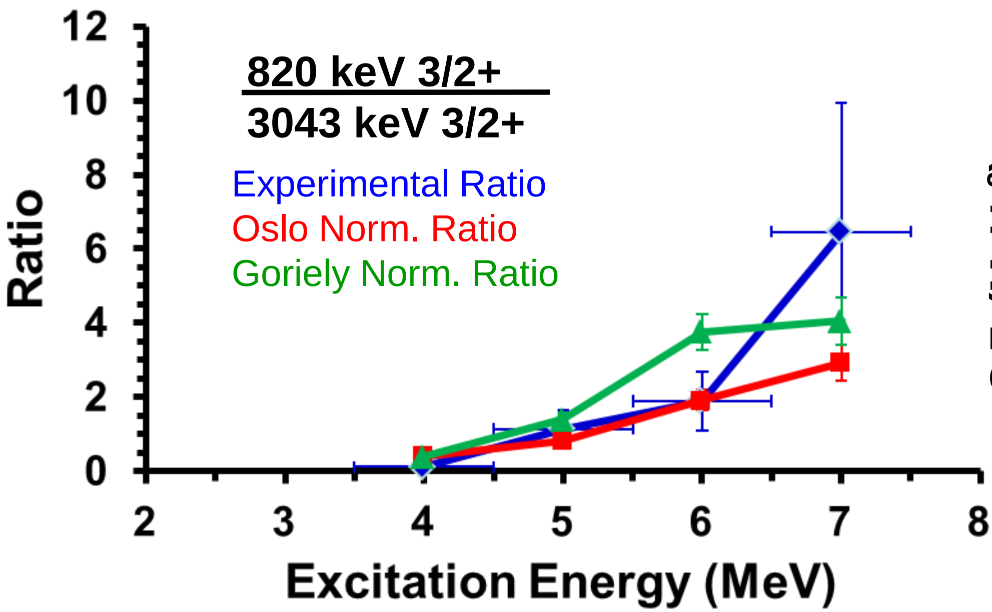
3043 keV Ratios

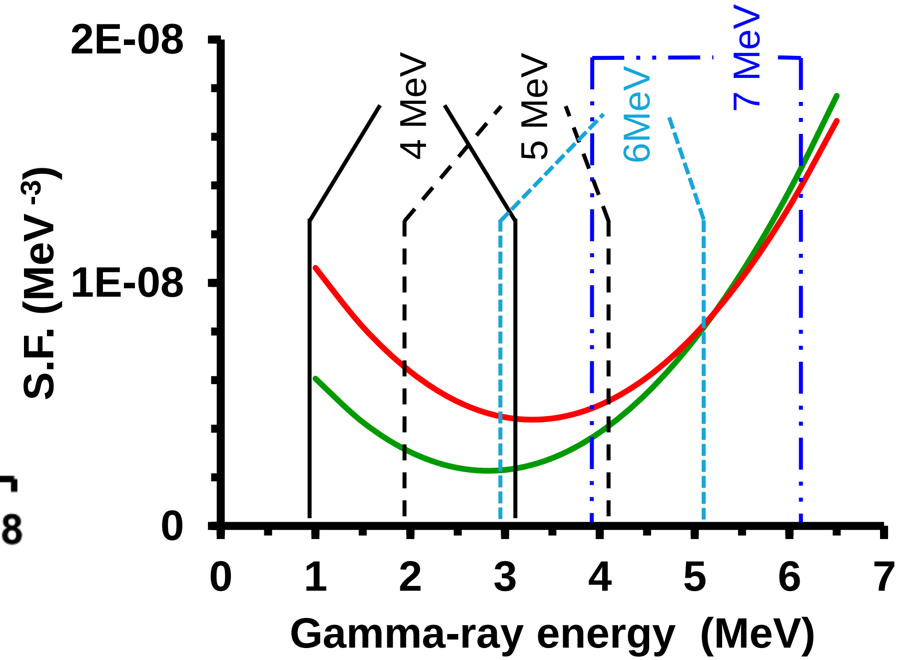
- Our data support the existence of a minima in the strength function.
- The 3043 keV is unique as it gives a large spread of gamma-ray energies to take ratios.
- These ratios map out a large range and do not include the 3 MeV energy region.





Low Energy Enhancement

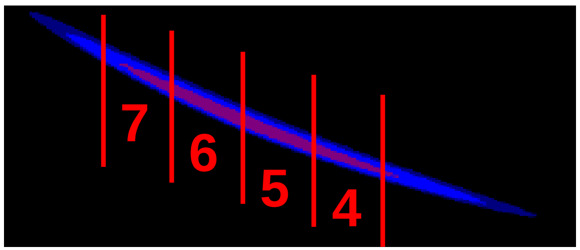




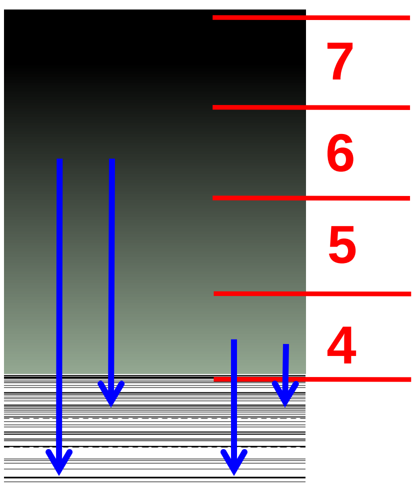
- Oslo and Goriely normalization agree with the steep decrease in ratio for low E_x.
- Difficult to imagine discrete unobserved feeding so strong to reach the Goriely ratio.
- It appears that the Oslo normalization works somewhat better
- Important region at 4 and 5 MeV as this maps out the minima and increase in strength.
- Both normalizations showing a steep decrease in ratio in agreement with our data.
- Data clearly confirms the minima and subsequent increase in radiative strength function.

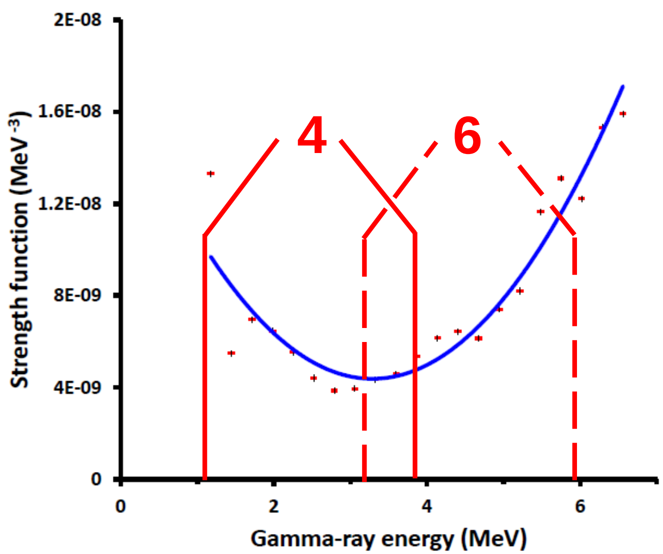
Enhancement Origin

- Our data confirms the minima and low-energy enhancement in the strength function.
- The stringent particle and gamma gates and sum energy requirements allows for a direct determination of the origin of the low-energy enhancement.



Each excitation energy gate probes a relatively large gamma-ray range.
The enhancement originates from the lower excitation energy region rather than from the higher regions.





Keeping in mind: In this work we do not look at low-energy gamma rays from high excitation energies.

Conclusion

i. Explored the quasi continuum experimentally using the STARS LIBERACE array and specific, stringent gating techniques.

ii. Characterization of feeding from the quasi-continuum to discrete states in ^{95}Mo by looking at ratios (independent of ρ).

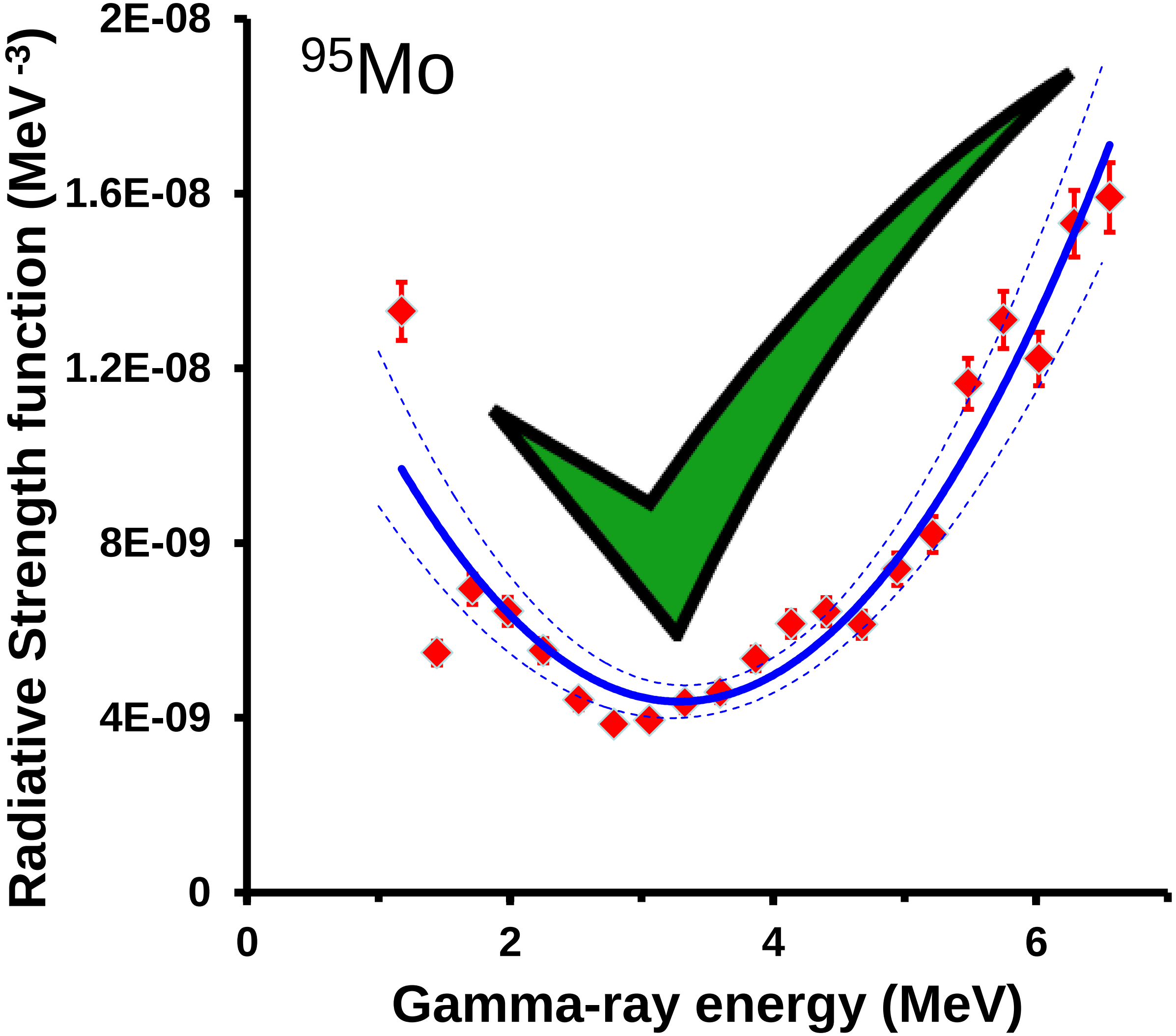
iii. Comparison of data to Oslo with the Oslo & Goriely normalizations.

iv. Ratios are insensitive to the difference in normalization except for 3043 for which the RSF shape from Oslo Normalization is probably favored.

v. Our data confirm the strength function minimum as has been measured by Oslo.

vi. Low-energy enhancement in the present study originates from low-excitation energies.

Summary



95Mo
Radiative Strength function (MeV-3)
2E-08
1.6E-08
1.2E-08
8E-09
4E-09
0
0
2
4
6
Gamma-ray energy (MeV)

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