Impact of the γ-Ray Strength Function to Elastic and Inelastic Photon Scattering

G. Rusev

Department of Physics, Duke University

Triangle Universities Nuclear Laboratory

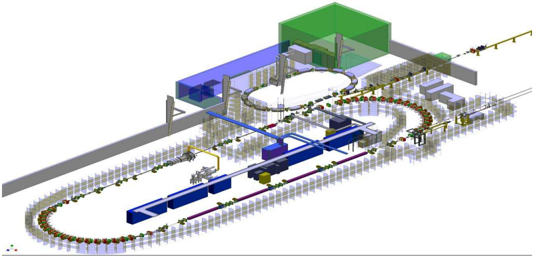
3$^{\mathrm{rd}}$ Workshop on Level Density and Gamma Strength

May 23, 2011

Outlook

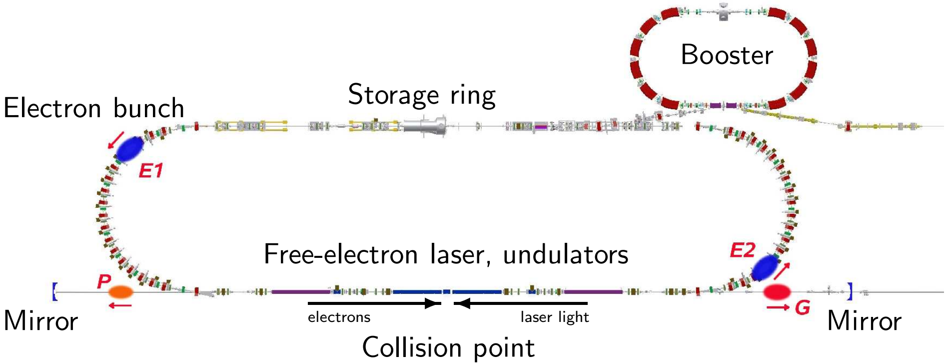
- High-Intensity γ-ray Source.
- Photon-scattering experiments on ^{89}Y, ^{90}Zr and ^{98}Mo.
  - $E1$ vs. $M1$ strength distributions.
  - Branching ratios for transitions to the ground state.
- Neutron-capture experiment on ^{87}Sr.

High-Intensity γ-ray Source (HIγS)



- 260 MeV electron accelerator
- 1.2 GeV storage ring
- Booster
- 2 free-electron lasers
- 1 – 100 MeV photon beams
- 0.5 – 5% energy spread
- linear or circular polarization

Inverse Compton scattering



Inverse Compton scattering

Compton scattering

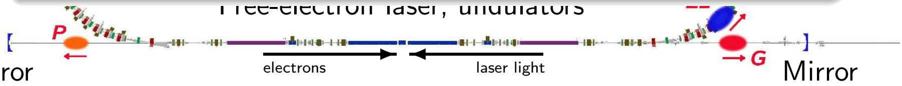
$$E_\gamma \approx \frac{4\gamma^2 E_p}{1+\gamma^2\theta_f^2+4\gamma^2 E_p/E_e}$$

$$\gamma = 1/\sqrt{1-\beta^2}$$

C. Sun *et al.*, Phys. Rev. ST Accel. Beams **12**, 062801 (2009)

Elec

Free-electron laser, undulators



Collision point

Inverse Compton scattering

Elec

Compton scattering

$$E_\gamma \approx \frac{4\gamma^2 E_p}{1+\gamma^2\theta_f^2+4\gamma^2 E_p/E_e}$$

$$\gamma = 1/\sqrt{1-\beta^2}$$

C. Sun *et al.*, Phys. Rev. ST Accel. Beams **12**, 062801 (2009)

Free-electron laser, undulators

Mir

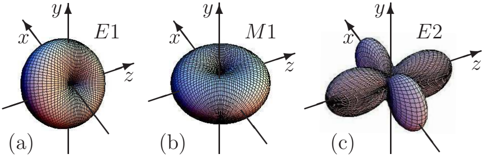
r

Photon-beam properties

Monochromaticity

Linearly polarized

Spin and Parity Determination: Even-Even Nuclei

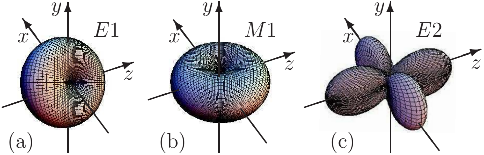


z axis: beam direction; x axis: vector of polarization

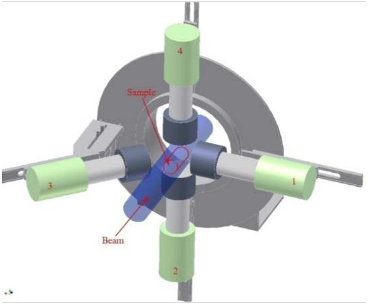
Angular distribution

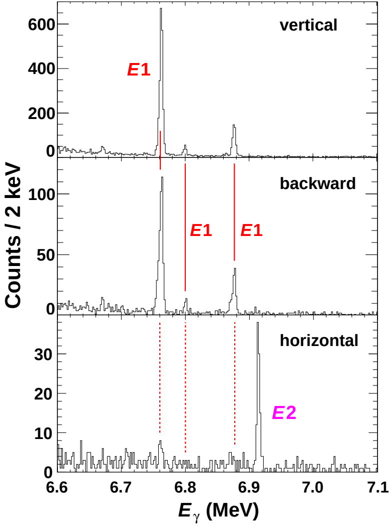
Measurement of the transition intensity at three different angles allows unique assignment of the e.m. character and multipolarity of the transition.

Spin and Parity Determination: Even-Even Nuclei (^{90}Zr)

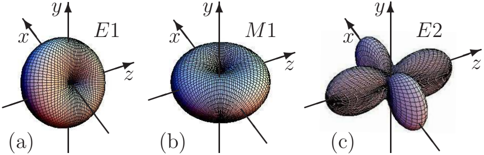


z axis: beam direction; x axis: vector of polarization

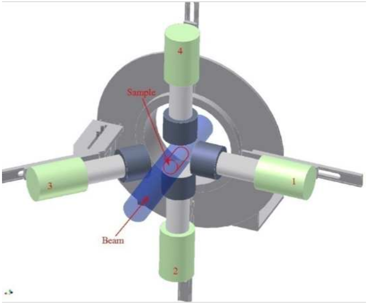


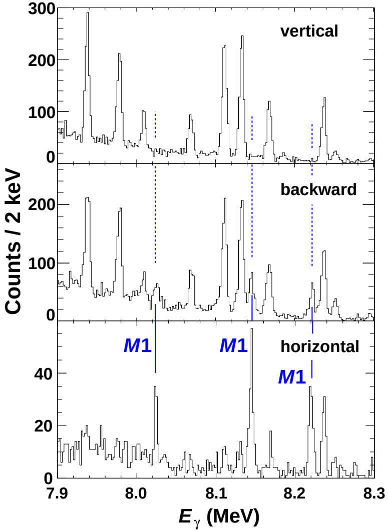


Spin and Parity Determination: Even-Even Nuclei (^{90}Zr)

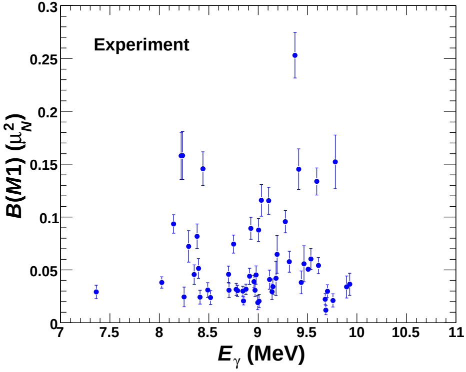


z axis: beam direction; x axis: vector of polarization

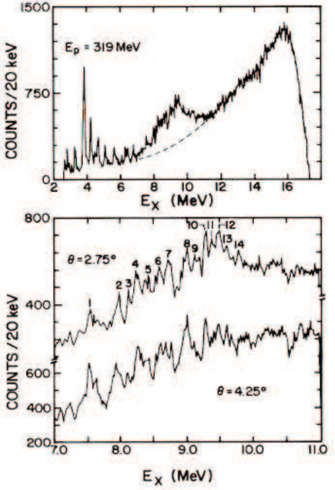




Giant $M1$ Resonance in ^{90}Zr

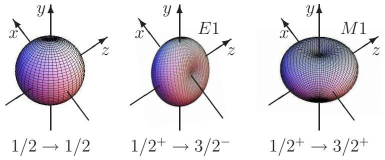


G. Rusev *et al.*, Phys. Rev. Lett. (2011), to be submitted

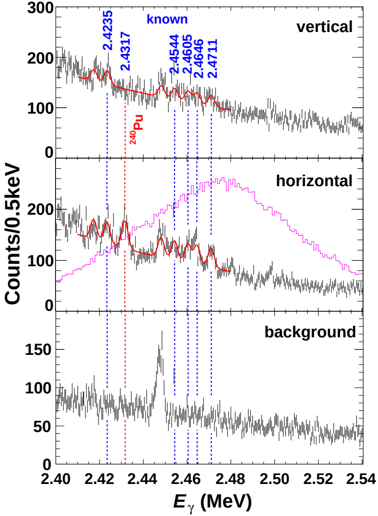


S. K. Nanda *et al.*, Phys. Rev. Lett. **51**, 1526 (1983)

Isotope Identification ($^{239/240}$Pu)

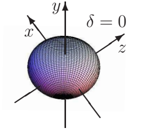


z axis: beam direction; *x* axis: vector of polarization



known: W. Bertozzi *et al.*, Phys. Rev. C **78**, 041601(R) (2008)

$M1/E2$ Multipole-Mixing Ratio (^{11}B)

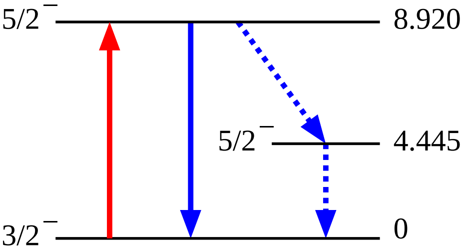


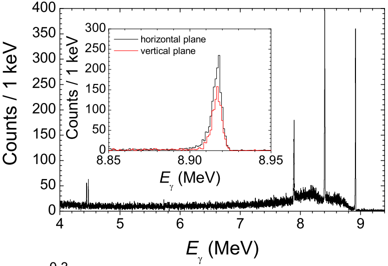
$3/2^- \to 5/2^- \to 3/2^-$

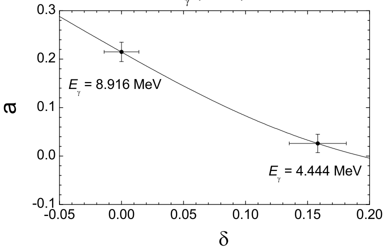
z axis: beam direction; x axis: vector of polarization

Asymmetry:

$$a = \frac{I_x - I_y}{I_x + I_y}$$

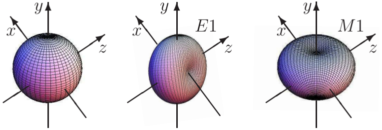






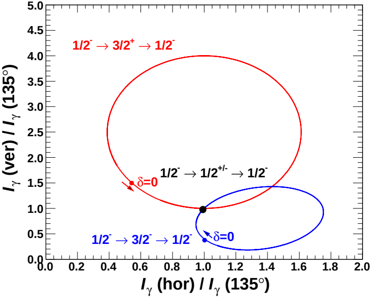
G. Rusev *et al.*, Phys. Rev. C **79**, 047601 (2009)

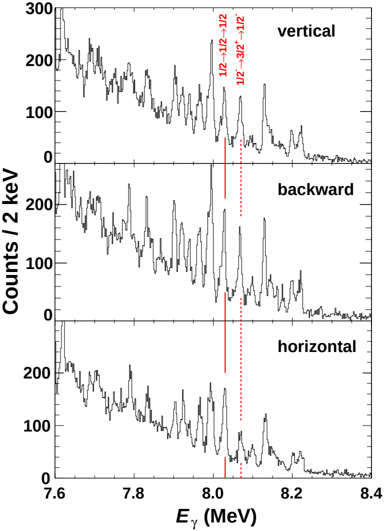
Spin and Parity Determination: Odd-Mass Nuclei (^{89}Y)



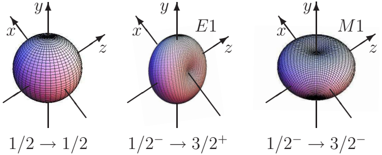
$1/2 \rightarrow 1/2$ $1/2^- \rightarrow 3/2^+$ $1/2^- \rightarrow 3/2^-$

z axis: beam direction; x axis: vector of polarization

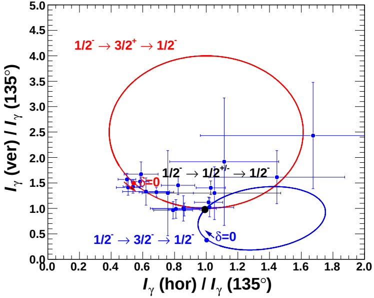


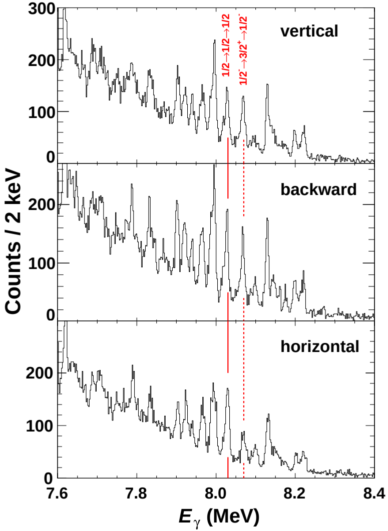


Spin and Parity Determination: Odd-Mass Nuclei (^{89}Y)

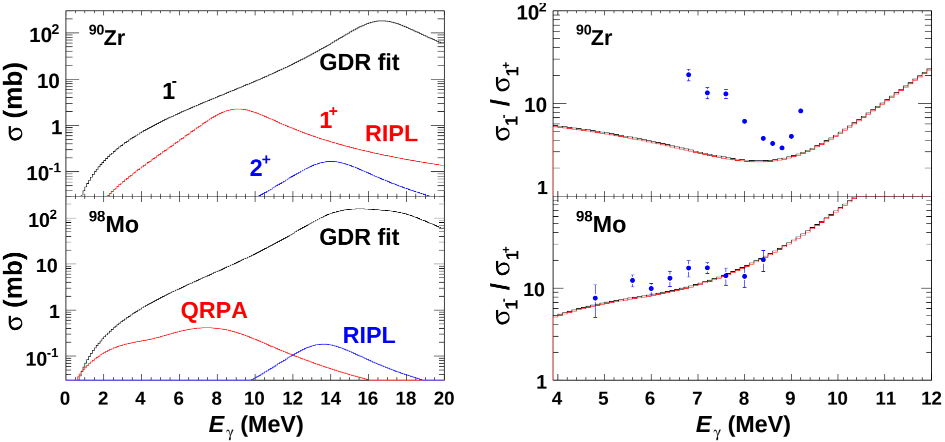


z axis: beam direction; x axis: vector of polarization



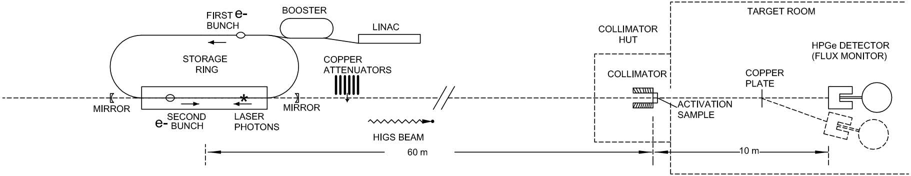


$\vec{f}_{E1}(E_\gamma)/\ \vec{f}_{M1}(E_\gamma)$ Ratio

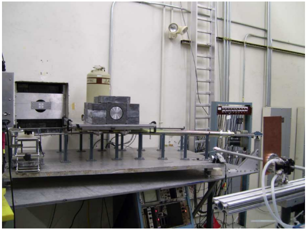


^{90}Zr: R. Schwengner *et al.*, Phys. Rev. C **78**, 064314 (2008)
^{98}Mo: G. Rusev *et al.*, Phys. Rev. C **77**, 064321 (2008)

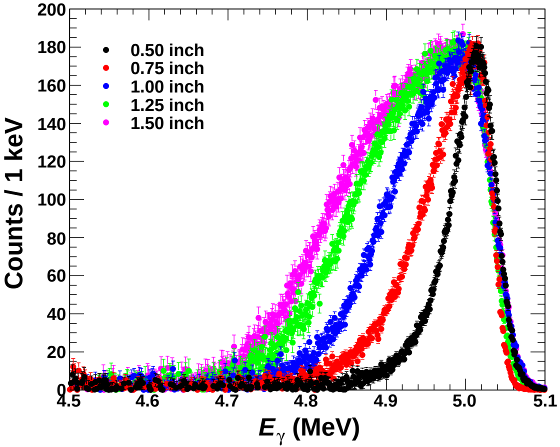
Measurement of the Beam-Energy Distribution



- Large volume HPGe detector.
- Cu attenuators placed 40 m away from the HPGe detector.

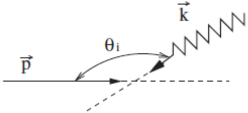


Photon-Beam Distribution

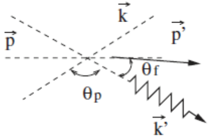


Compton scattering process:

before scattering

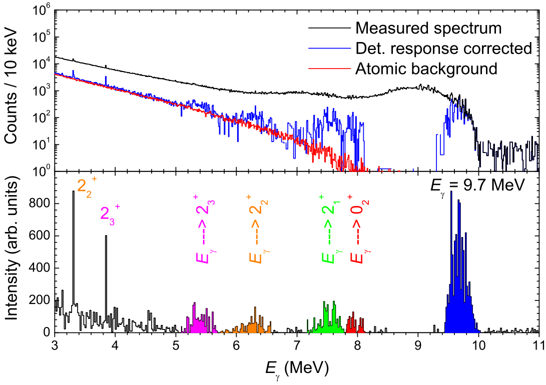


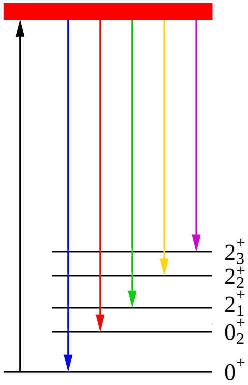
after scattering



C. Sun *et al.*, Phys. Rev. ST **12**, 062801 (2009)

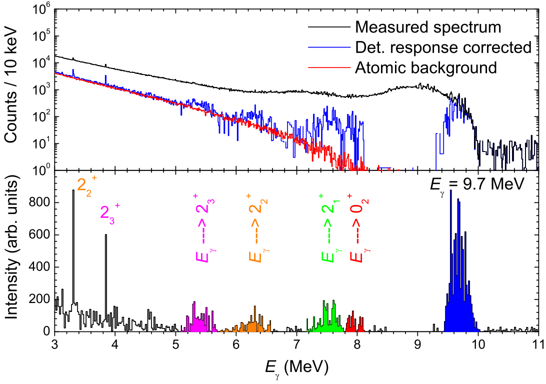
Branching Transitions to the Low-lying Levels in ^{90}Zr

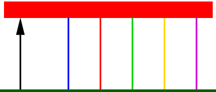




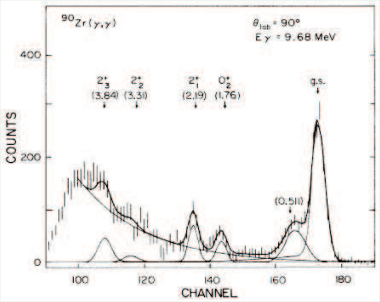
The monoenergetic beam provides separation of the ground-state transitions from the branching transitions.

Branching Transitions to the Low-lying Levels in ^{90}Zr





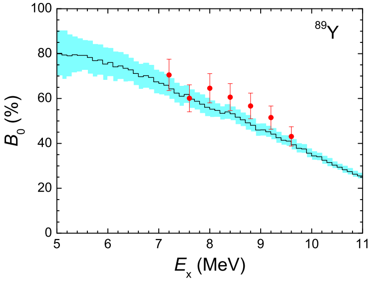
Previous work

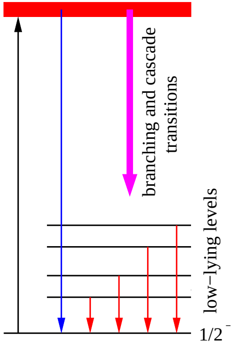


R. Alarcon *et al.*, Phys. Rev. C **36**, 954 (1987)

The monoenergetic beam provides separat
transitions from the branching transitions.

Branching Ratios for the Ground-State Transitions (^{89}Y)



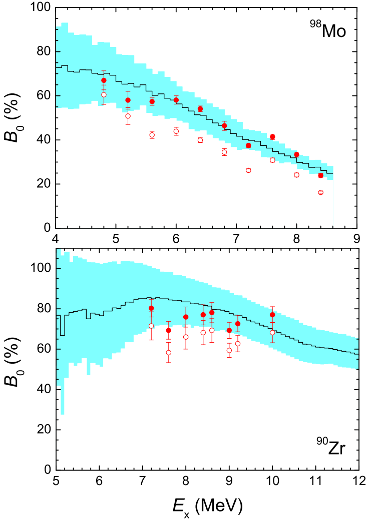


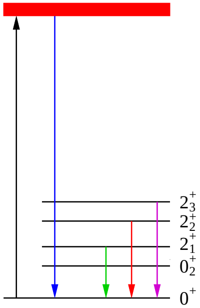
$$B_0 = \frac{I_{\mathrm{g.s.}}}{I_{\mathrm{g.s.}} + \Sigma I_{\mathrm{low-lying\ levels}}}$$

N. Benouaret *et al.*, Phys. Rev. C **79**, 014303 (2009)

No correction for bypass transitions applied!

Branching Ratios for the Ground-State Transitions



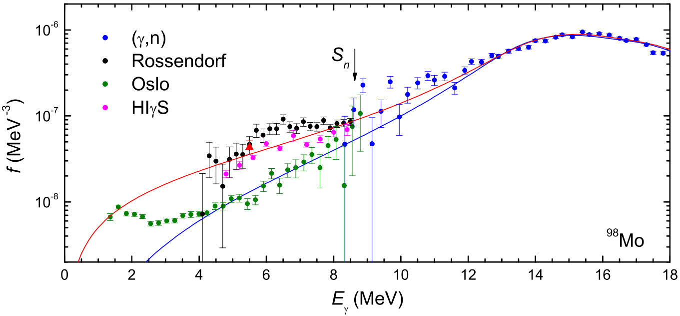


Filled circles: $B_0 = \frac{I_{g.s.}}{I_{g.s.} + I_{2_1^+} + I_{2_2^+} + I_{2_3^+}}$

Open circles: $B_0 = \frac{I_{g.s.}}{I_{g.s.} + 2I_{2_1^+} + I_{2_2^+} + I_{2_3^+}}$

No correction for bypass transitions applied!

Gamma-Ray Strength Function in ^{98}Mo



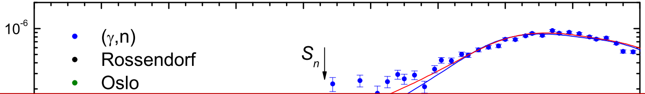
(γ, n) H. Beil *et al.*, Nucl. Phys. **A227**, 427 (1974)

(n, γ) J. Kopecky and M. Uhl, Proceedings of the NEA/ENEA and IAEA (1994)

(^{3}He,^{3}He$'\gamma$) M. Guttormsen *et al.*, Phys. Rev. C **71**, 044307 (2005)

(γ, γ') G. Rusev *et al.*, Phys. Rev. C **77**, 064321 (2008)

Gamma-Ray Strength Function in ^{98}Mo



Problems

- Different experiments provide different strength functions.
- $\Gamma_{n\gamma}^{tot}$ calculated from the (γ, γ') data is a factor of 2 larger than the measured from neutron resonances.

(γ, n) H. Beil *et al.*, Nucl. Phys. **A227**, 427 (1974)

(n, γ) J. Kopecky and M. Uhl, Proceedings of the NEA/ENEA and IAEA (1994)

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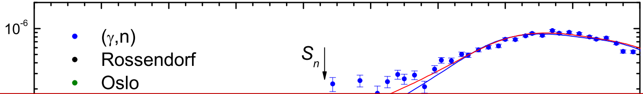
Gamma-Ray Strength Function in ^{98}Mo



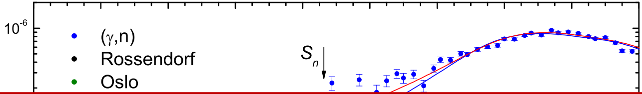
Problems

Experiments related to the $\vec{f}_{E1}\,(E_\gamma)$ in ^{98}Mo

- ^{98}Mo$(\gamma,\gamma')^{98}$Mo at HIγS (completed)
- ^{97}Mo$(n,\gamma)^{98}$Mo at the DANCE calorimeter at LANL (in progress, C. Walker)
- ^{98}Mo$(n,n'\gamma)^{98}$Mo at TUNL (pending)

(γ,n) H. Beil *et al.*, Nucl. Phys. **A227**, 427 (1974)
(n,γ) J. Kopecky and M. Uhl, Proceedings of the NEA/ENEA and IAEA (1994)
$(^3\mathrm{He},^3\mathrm{He}'\gamma)$ M. Guttormsen *et al.*, Phys. Rev. C **71**, 044307 (2005)
(γ,γ') G. Rusev *et al.*, Phys. Rev. C **77**, 064321 (2008)

Gamma-Ray Strength Function in ^{98}Mo



Problems

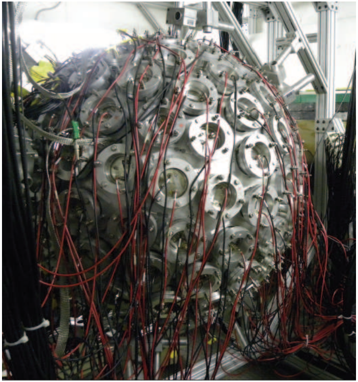
Experiments related to the $\vec{f}_{E1}(E_\gamma)$ in ^{98}Mo

- ^{98}Mo$(\gamma,\gamma')^{98}$Mo at HIγS (completed)

Experiments related to the $\vec{f}_{E1}(E_\gamma)$ in ^{88}Sr

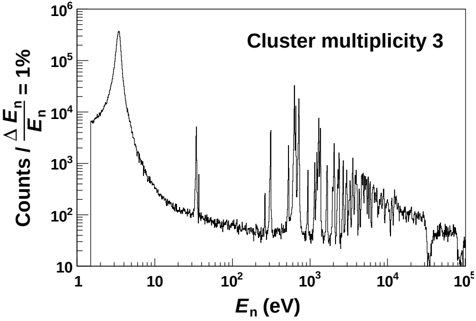
- ^{88}Sr$(\gamma,\gamma')^{88}$Sr at HIγS (completed)
- ^{87}Sr$(n,\gamma)^{88}$Sr at the DANCE calorimeter at LANL (in progress, G. Rusev)
- ^{88}Sr$(n,n'\gamma)^{88}$Sr at TUNL (REU project, summer 2011)

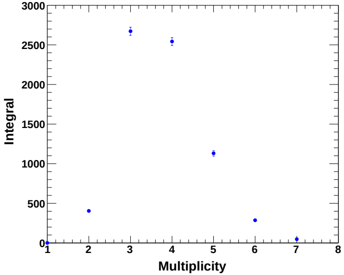
^{87}Sr(n,γ) Experiment at DANCE

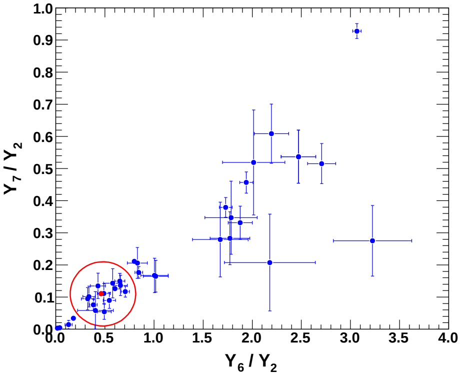


- Astrophysics:
  - Neutron density during the *s* process
  - ^{87}Rb—^{87}Sr chronometric pair
- Nuclear structure:
  - Pygmy resonance in ^{88}Sr
  - Low-energy tail of the GDR in ^{88}Sr

^{87}Sr$(n,\gamma)^{88}$Sr Experiment at DANCE





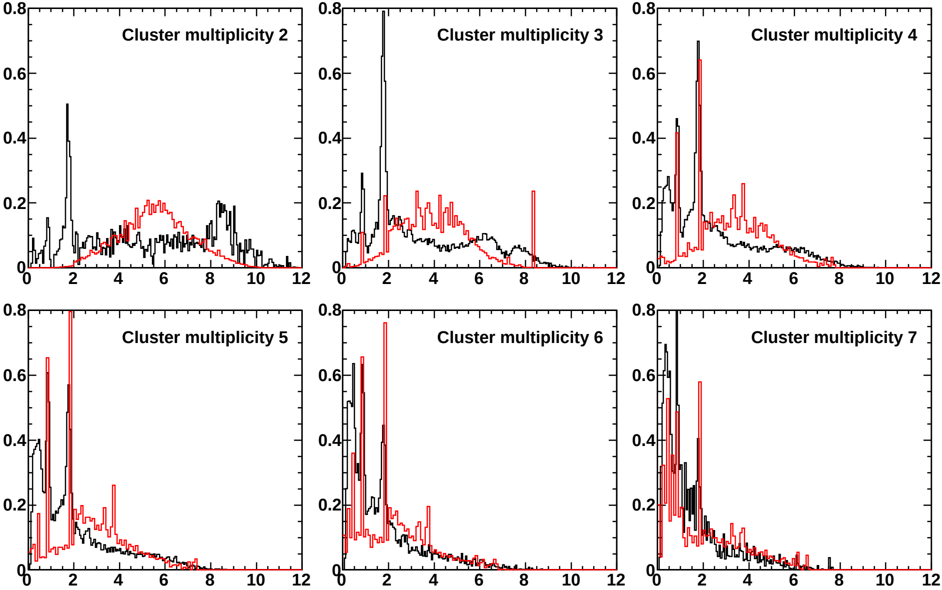


B. Baramsai, Ph. D dissertation, NCSU

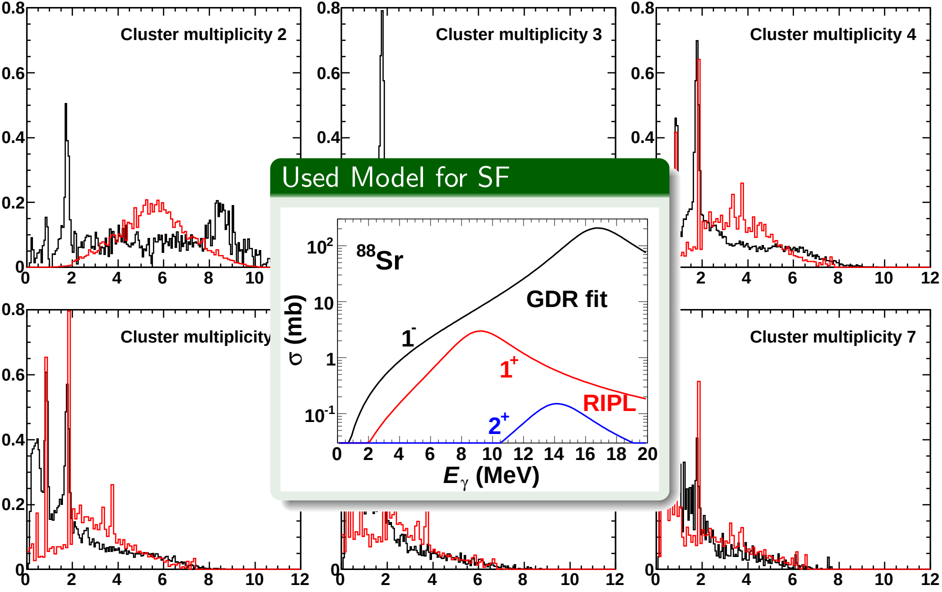
Spin Assignment

The resonances around the red data point have spin $J = 4$.

Experiment vs. Simulations



Experiment vs. Simulations



Summary

- Cascade simulations with standard assumptions for the level density (BSFG model) and strength functions (GDR fit, RPA calculations, RIPL) provide a good estimate for the branching ratios of transitions to the ground state.
- Measured ratios $\vec{f}_{E1}(E_\gamma) / \vec{f}_{M1}(E_\gamma)$ show that the $M1$ resonance in ^{90}Zr is narrower than that proposed in RIPL while the $M1$ strength in ^{98}Mo is spread over a wide energy range.
- The $E1$ strength below the neutron-separation energy follows the extrapolation of the Lorentzian fit of the GDR.
- The $E2$ strength seems to be important in (n, γ) reactions.

Acknowledgements

E. Kwan[1]
R. Raut
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C. Huibregse

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[1] Present address: Lawrence Livermore National Laboratory
[2] Present address: Oak Ridge National Laboratory
[3] Present address: Lawrence Berkeley National Laboratory