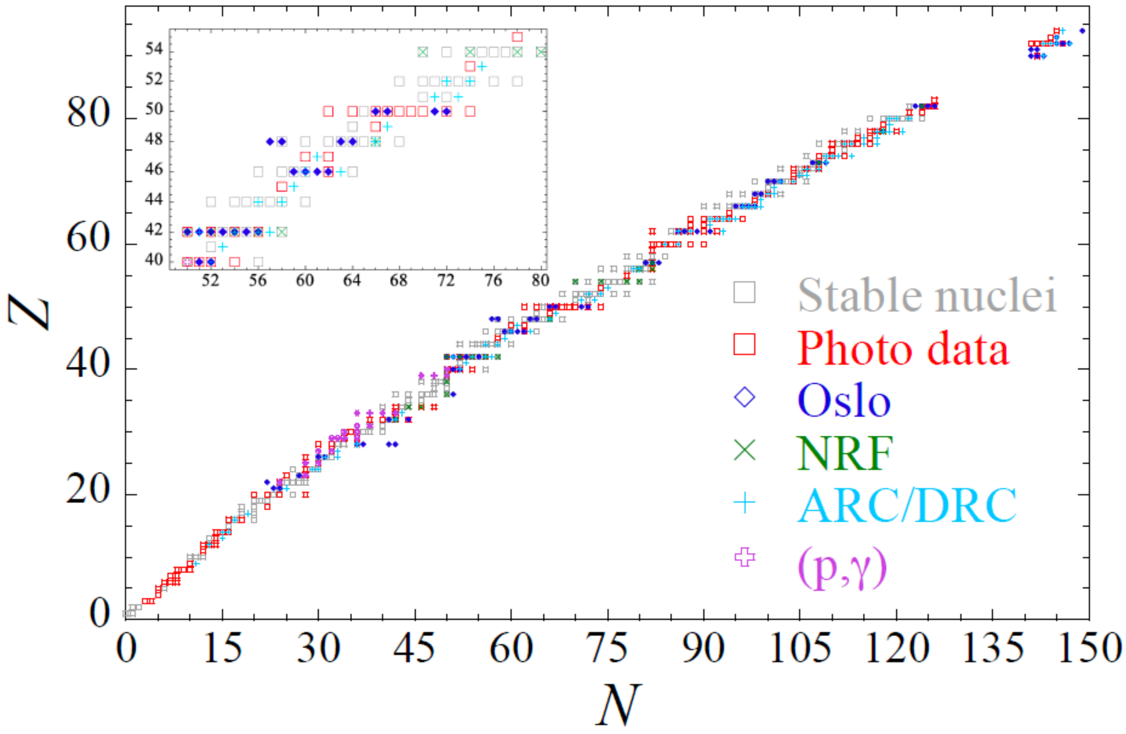
Photon Strength Function from proton capture reactions

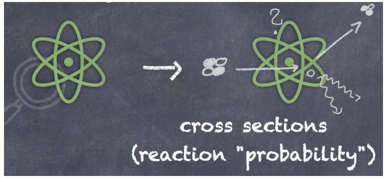
Kgashane L. Malatji
Nuclear Data Program, LBNL & Nuclear Engineering Department, UCB
klmalatji@berkeley.edu
http://nucleardata.berkeley.edu

Supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contracts No. DE-AC02-05CH11231 and the US Nuclear Data Program.

ECT* workshop on Neutron Capture Reactions for Astrophysical Processes, Nov. 3-7, 2025

Quasi-continuum data is critical for applications and basic sciences





Nucleosynthesis

Nuclear Structure

Fission

Waste transmutation

Nuclear Medicine: Radioisotope Production

Homeland security: Nuclear forensics

Non-proliferation of nuclear weapons

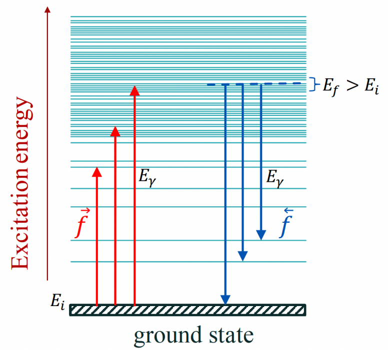
Generation IV reactors, e.g. decay heat

Advanced Nuclear Fuel Cycles and others…

✓ To date, experimental measurements of PSFs exist for ~ 330 unique nuclides

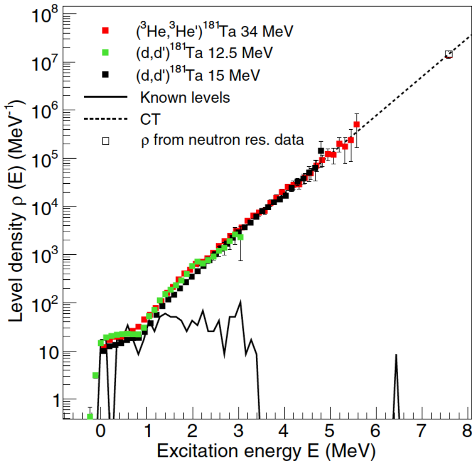
Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J A 55, 172 (2019)

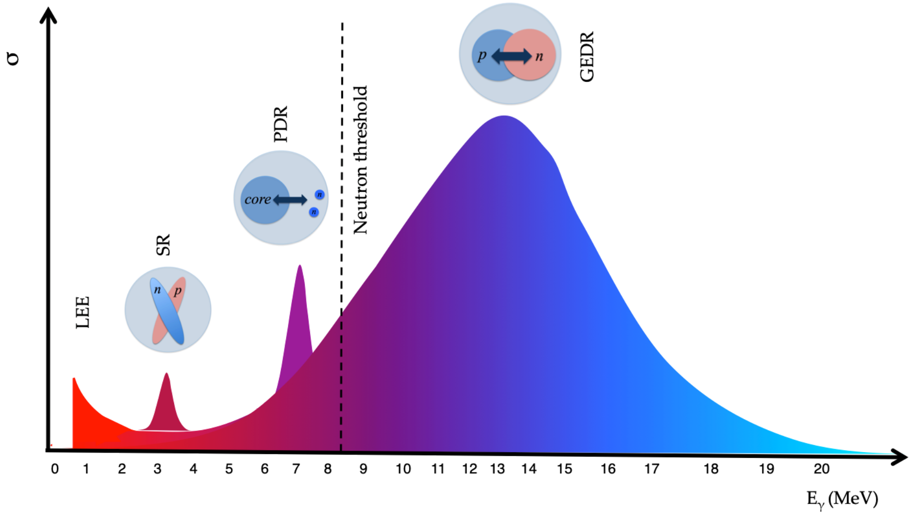
Quasi-continuum data: NLD & PSF



PSF represents the distribution of average reduced widths Γ_γ for XL-type transitions (E for electric, M for magnetic) over γ-ray energies E_γ.

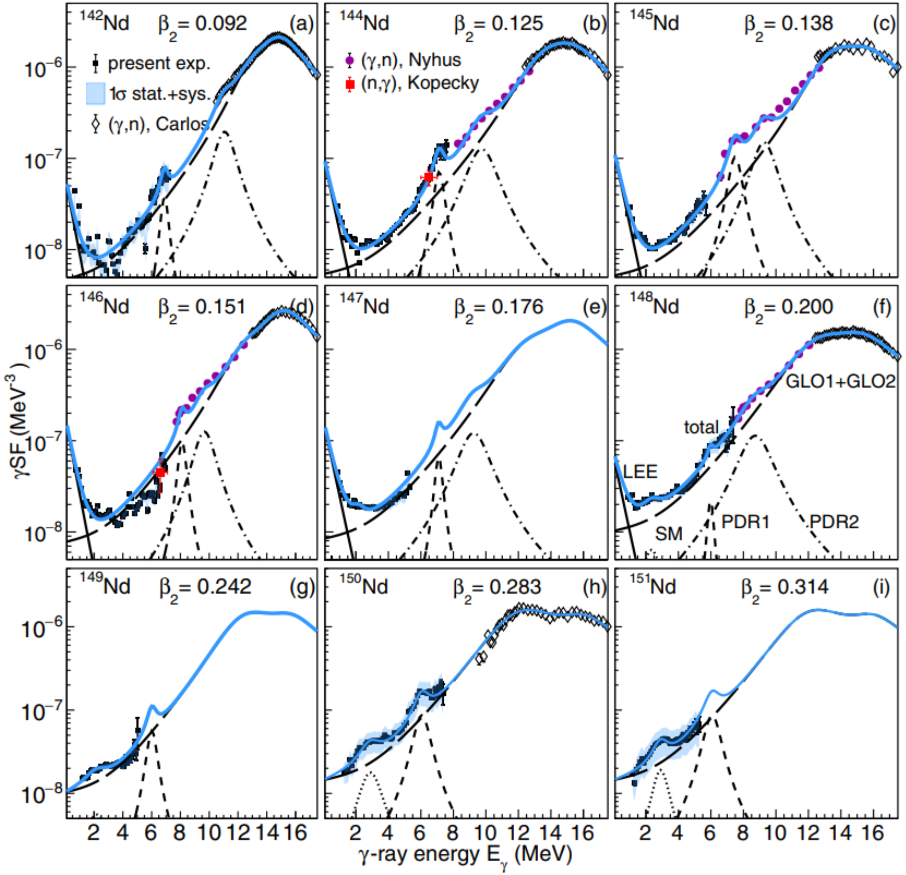
$$\boxed{f^{J}_{i\to f,XL}(E_\gamma) = \frac{\bar{\Gamma}^{J}_{i\to f,XL}}{E_\gamma^{2L+1}} \cdot \rho^{J}(E_i),}$$



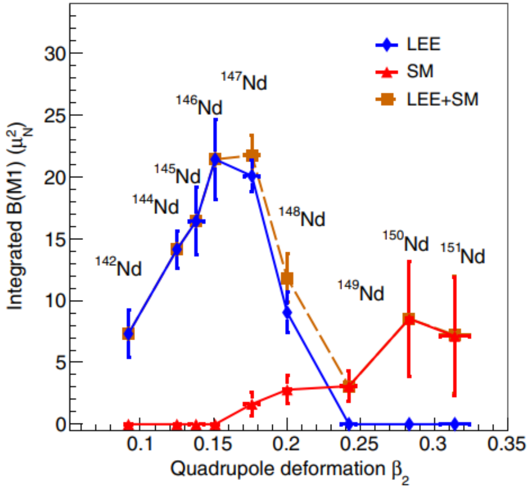


Brits, Malatji, Wiedeking, et al., Phys. Rev. C. 99, 054330 (2019)

Impact on nuclear structure

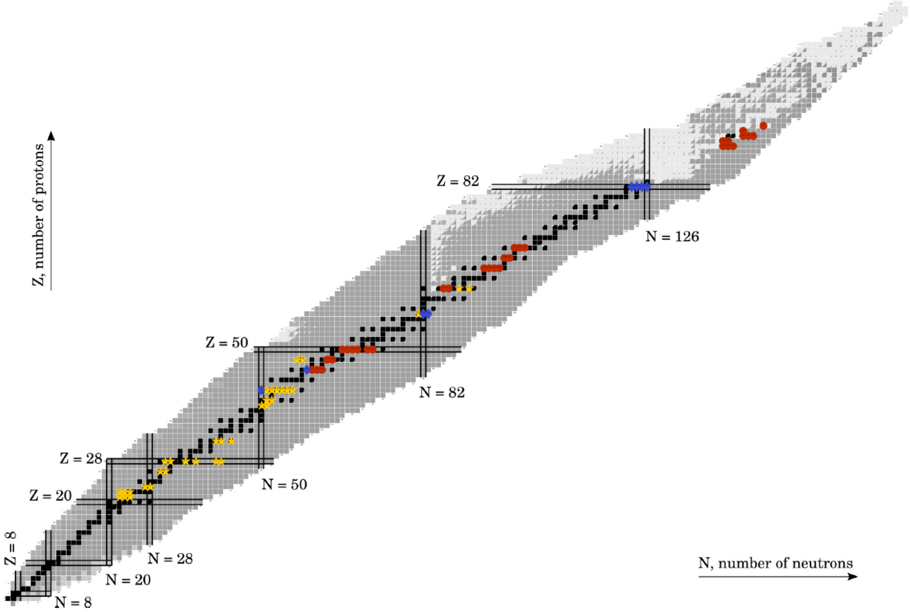


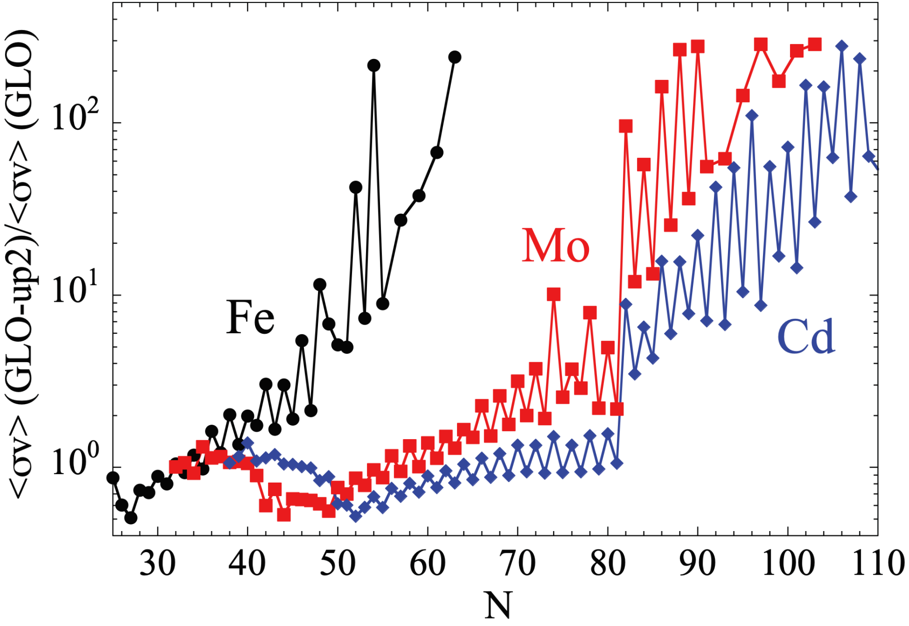
- ✓ Study the underlying physics and evolution of nuclear structure effects: Pygmy Dipole Resonance (PDR), Scissors Resonance (SR) & Low-Energy Enhancement (LEE).
- ✓ Dependence of deformation



Guttormsen, Ay, Ozgur, et al., Phys. Rev. C. 106, 034314 (2022)

Impact on reaction rates



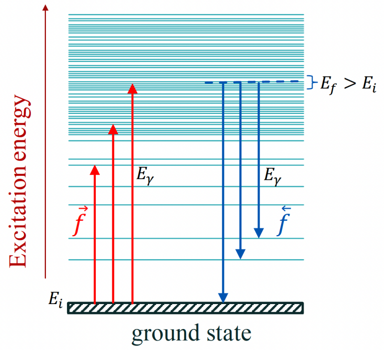


✓ LEE has proved to potentially enhance the r-process (n,g) reaction rates by up-to 2 orders of magnitude for the very neutron-rich nuclei.

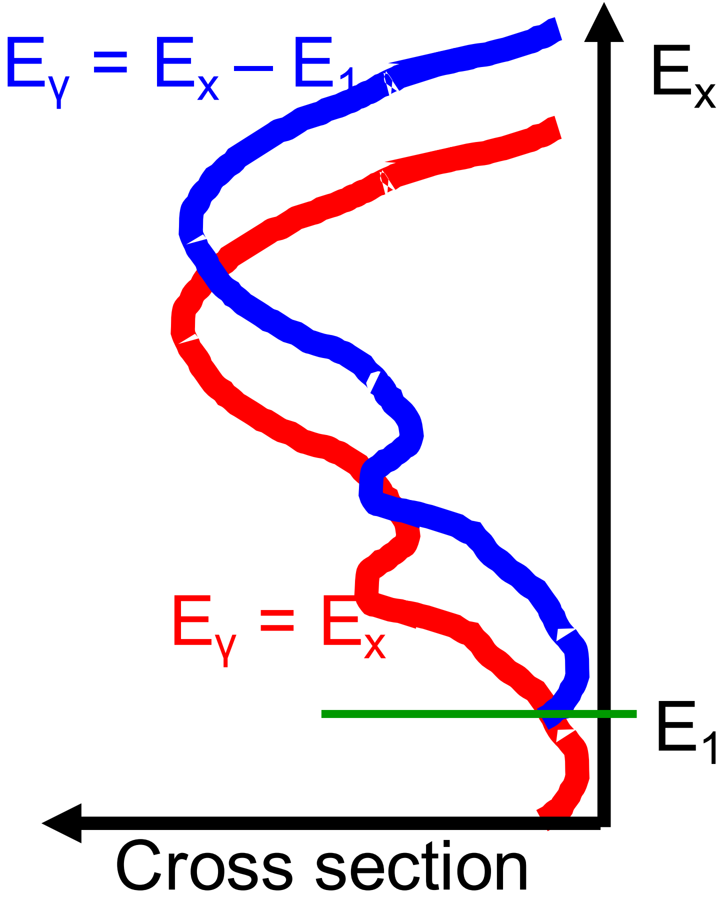
Midtbø, Larsen, Renstrøm, *et al.*, Phys. Rev. C. 98, 064321 (2018)
Larsen and Goriely, Phys. Rev. C. 82, 014318 (2010)

Brink-Axel Hypothesis

- ✓ Photoabsorption cross section (and, therefore, γSF) of the GDR is independent of the detailed structure of the initial state [1].
- ✓ Further generalized to both γ-absorption and emission processes [2].



- ✓ Photo-excitation should be identical to average electromagnetic decay (i.e. photo-deexcitation).
- ✓ GBA has implications e.g; for low-energy E1 & M1 strength functions for calculations (n,γ) cross-section for various applications.



[1] D. M. Brink, Ph.D. thesis, Oxford University, 1955
[2] P. Axel, Phys. Rev. 126, 671 (1962)

Brink-Axel Hypothesis

Physics Letters B 788 (2019) 225–230

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

The concept of nuclear photon strength functions:
A model-independent approach via $(\vec{\gamma}, \gamma'\gamma'')$ reactions

J. Isaak [a,b,c,*], D. Savran [b], B. Löher [a,b], T. Beck [a], M. Bhike [d], U. Gayer [a], Krishichayan [d], N. Pietralla [a], M. Scheck [e], W. Tornow [d], V. Werner [a], A. Zilges [f], M. Zweidinger [a]

the Brink–Axel hypothesis is not strictly fulfilled in the excitation-energy region below the neutron separation threshold

PRL 118, 022502 (2017) PHYSICAL REVIEW LETTERS week ending 13 JANUARY 2017

Simultaneous Microscopic Description of Nuclear Level Density and Radiative Strength Function

N. Quang Hung,[1,*] N. Dinh Dang,[2,3,†] and L. T. Quynh Huong[4,5]

It also invalidates the assumption based on the Brink-Axel hypothesis in the description of the RSF.

PHYSICAL REVIEW LETTERS 127, 182501 (2021)

Comprehensive Test of the Brink-Axel Hypothesis in the Energy Region of the Pygmy Dipole Resonance

M. Markova,[1,*] P. von Neumann-Cosel,[2,†] A. C. Larsen,[1,‡] S. Bassauer,[2] A. Görgen,[1] M. Guttormsen,[1] F. L. Bello Garrote,[1] H. C. Berg,[1] M. M. Bjørøen,[1] T. Dahl-Jacobsen,[1] T. K. Eriksen,[1] D. Gjestvang,[1] J. Isaak,[2] M. Mbabane,[1] W. Paulsen,[1] L. G. Pedersen,[1] N. I. J. Pettersen,[1] A. Richter,[2] E. Sahin,[1] P. Scholz,[3,4] S. Siem,[1] G. M. Tveten,[1] V. M. Valsdottir,[1] M. Wiedeking,[5,6] and F. Zeiser[1]

GSFs are shown to be independent of excitation energies and spins of the initial and final states, … in the energy region of the pygmy dipole resonance.

Eur. Phys. J. A (2023) 59:147
https://doi.org/10.1140/epja/s10050-023-01067-8

THE EUROPEAN PHYSICAL JOURNAL A

Letter

Brink-Axel hypothesis in the pygmy-dipole resonance region

K. Sieja[1,2,a]

[1] Université de Strasbourg, IPHC, 23 rue du Loess, 67037 Strasbourg, France
[2] CNRS, UMR7178, 67037 Strasbourg, France

using microscopic Configuration Interaction method, … dipole photo-absorption cross section at low energy is dependent on the excitation energy and deviations from the Brink-Axel hypothesis are particularly large for the ground state of an even-even system.

GBA has significant implications for PSF, which is one of the key input in radiative (n,γ) cross-section calculations for nucleosynthesis modeling.

Brink-Axel Hypothesis

Physics Letters B 788 (2019) 225–230

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

The concept of nuclear photon strength functions: A model-independent approach via $(\vec{\gamma}, \gamma'\gamma'')$ reactions

J. Isaak [a,b,c,*], D. Savran [b], B. Löher [a,b], T. Beck [a], M. Bhike [d], U. Gayer [a], Krishichayan [d], N. Pietralla [a], M. Scheck [e], W. Tornow [d], V. Werner [a], A. Zilges [f], M. Zweidinger [a]

the Brink–Axel hypothesis is not strictly fulfilled in the excitation-energy region below the neutron separation threshold

PHYSICAL REVIEW LETTERS 127, 182501 (2021)

Comprehensive Test of the Brink-A... sis in the Energy Region of the Pyg... ce

M. Markova,[1,*] P. von Neumann-... ssauer,[2] A. Görgen,[1] M. Guttormsen,[1] F. L. Bello Garrote,[1] H. C. ... -Jacobsen,[1] T. K. Eriksen,[1] D. Gjestvang,[1] J. Isaak,[2] M. Mbabane,[1] ... N. I. J. Pettersen,[1] A. Richter,[2] E. Sahin,[1] P. Scholz,[3,4] S. ... alsdottir,[1] M. Wiedeking,[5,6] and F. Zeiser[1]

GSFs ... dependent of excitation energies and ... and final states, … in the energy region of the ... resonance.

PRL 118, 022502 (2017) PHYSICAL REVIEW LETTE... ARY 2017

Simultaneous Microscopic Descri... nsity and Radiati...

N. Quang Hung[1,*] ... uynh Huong[4,5]

It also invalidates the ass... sed on the Brink-Axel hypothesis in the descripti... the RSF.

Eur. Phys. J. A (2023) 59:147
https://doi.org/10.1140/epja/s10050-023-01067-8

THE EUROPEAN PHYSICAL JOURNAL A

Letter

Brink-Axel hypothesis in the pygmy-dipole resonance region

K. Sieja[1,2,a]

[1] Université de Strasbourg, IPHC, 23 rue du Loess, 67037 Strasbourg, France
[2] CNRS, UMR7178, 67037 Strasbourg, France

using microscopic Configuration Interaction method, … dipole photo-absorption cross section at low energy is dependent on the excitation energy and deviations from the Brink-Axel hypothesis are particularly large for the ground state of an even-even system.

70 years later…, no clear consensus

GBA has significant implications for PSF, which is one of the key input in radiative (n,γ) cross-section calculations for nucleosynthesis modeling.

NLD & PSF: How are these data measured?

Techniques for NLD

Primary γ spectra with the Oslo methods (Ex < Sn)

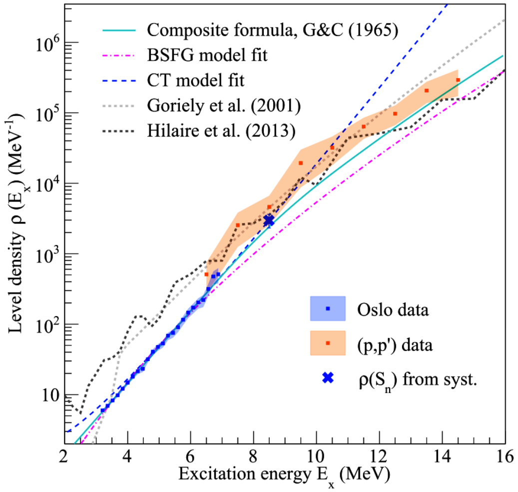
Discrete levels (Ex < 2 - 3 MeV or < 50 - 100 levels/MeV)

Neutron/proton resonances (Ex = Sn or Sp)

Spin/parity resolved level densities from (p,p´) or (e,e´)

Particle evaporation spectra (Ex = 4 - 15 MeV)

Ericson fluctuations (Ex ~ 15 MeV)



Markova, Larsen, von Neumann-Cosel, et al., Phys. Rev. C 106, 034322 (2022)

Techniques for PSF

Primaries from charged particle reactions (<S_n): OM, iOM, bOM

Ratio/Shape Methods (<S_n)

Nuclear Resonance Fluorescence (<S_n)

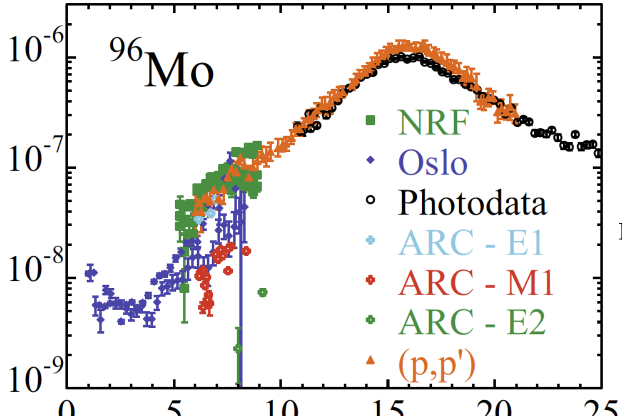
Inelastic p scattering with polarized beam (<S_n and >S_n)

Primaries from p-capture (>S_p and <S_n)

Two-step cascade, n/p capture (<S_n)

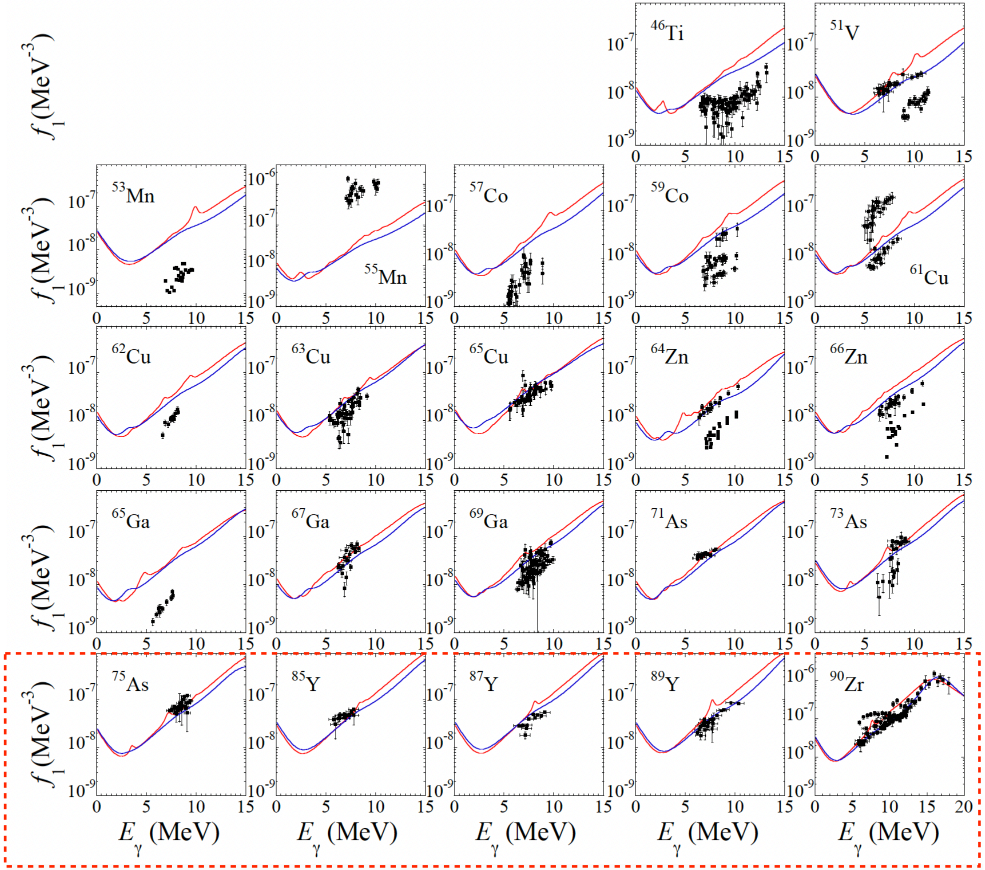
Photonuclear Reactions (>S_n)

Primaries from n-capture (>S_n)



Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J. A 55, 172 (2019)

PSF from (p, γ) reactions

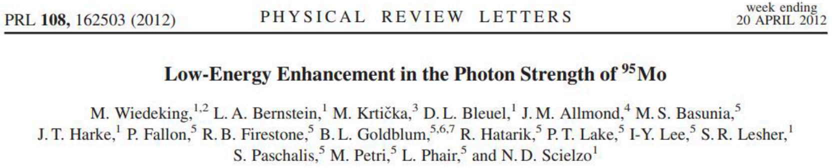


- ✓ Experimental PSFs from (p, γ) data and SMLO (blue lines) and D1M+QRPA+0lim (red lines) models for the 22 nuclei for which data exist.
- ✓ Poor agreement for some Mn, Co, Cu and Zn isotopes.

- ✓ There's a need to remeasure ARC PSF using state-of-the-art arrays
- ✓ Previous measurements performed with E_p~1 - 4 MeV
- ✓ Measured up-to A ≤ 90 for which (p,γ) cross-sections can be measured with good statistics
- ✓ Increasing Coulomb barrier (A ≥ 90) ⇔ decreasing (p,γ) XS
- ✓ Need higher NLD (A ≥ 50) ⇒ statistical decays
- ✓ S_n of compound needs to be much higher than S_p, to cover E_x/E_γ range

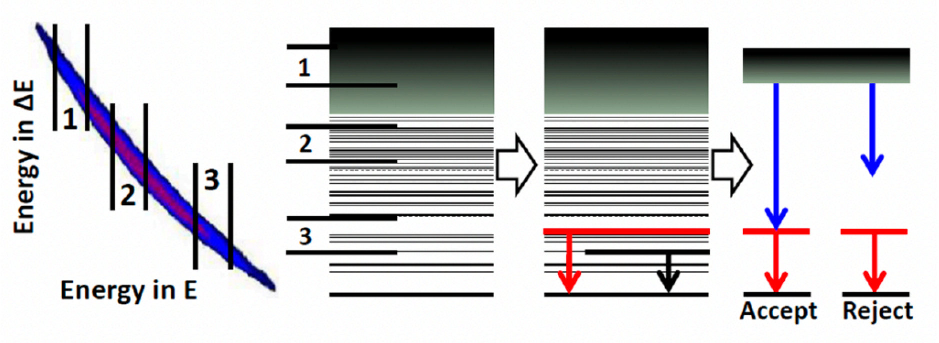
Goriely, Dimitriou, Wiedeking et al., Eur. Phys. J A 55, 172 (2019)

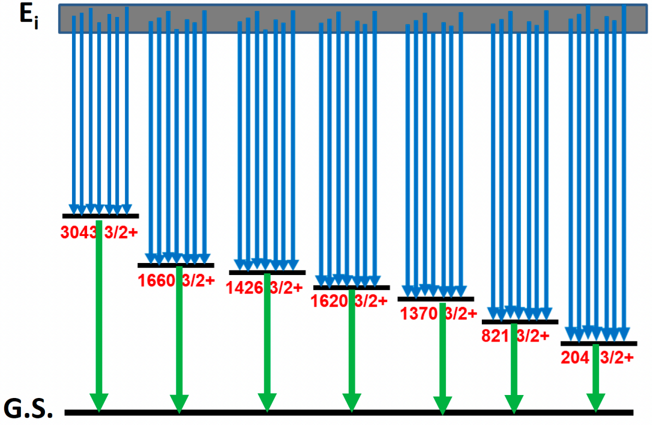
Shape Method in a 


PRL 108, 162503 (2012) PHYSICAL REVIEW LETTERS week ending 20 APRIL 2012

Low-Energy Enhancement in the Photon Strength of ^{95}Mo

M. Wiedeking,[1,2] L. A. Bernstein,[1] M. Krtička,[3] D. L. Bleuel,[1] J. M. Allmond,[4] M. S. Basunia,[5] J. T. Harke,[1] P. Fallon,[5] R. B. Firestone,[5] B. L. Goldblum,[5,6,7] R. Hatarik,[5] P. T. Lake,[5] I-Y. Lee,[5] S. R. Lesher,[1] S. Paschalis,[5] M. Petri,[5] L. Phair,[5] and N. D. Scielzo[1]





credit: M. Wiedeking

- ✓ Extract primary transitions from the well-defined excitation energies to discrete low-lying levels
- ✓ Primaries corrected for Efficiency, Branching Ratios and E_γ^3

$$\overleftarrow{f}_{XL}(E_\gamma) = \frac{\bar{\Gamma}_{J^\pi}(E_i,E_\gamma)\rho_{J^\pi}(E_i)}{E_\gamma^{2L+1}}$$

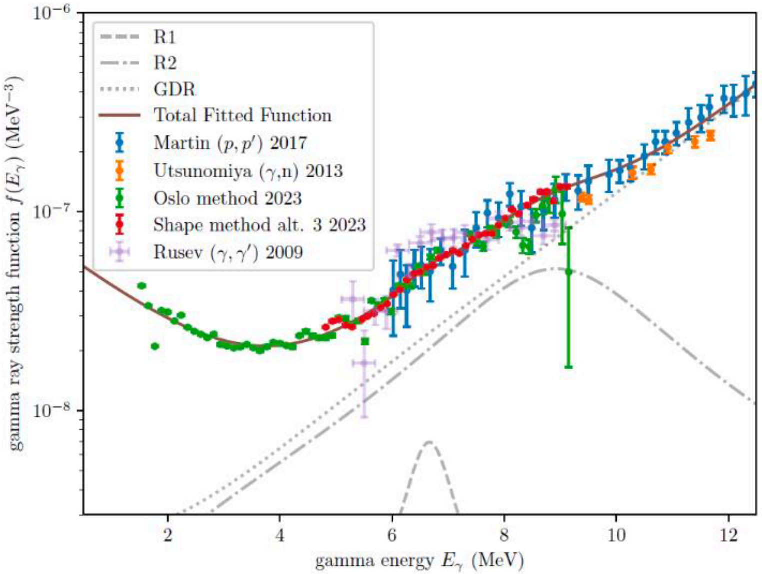
$$N_{L_j}(E_i) \propto \sum_{J^\pi} \sigma(E_i)\bar{\Gamma}_{J^\pi}(E_i,E_\gamma)\rho_{J^\pi}(E_i)$$

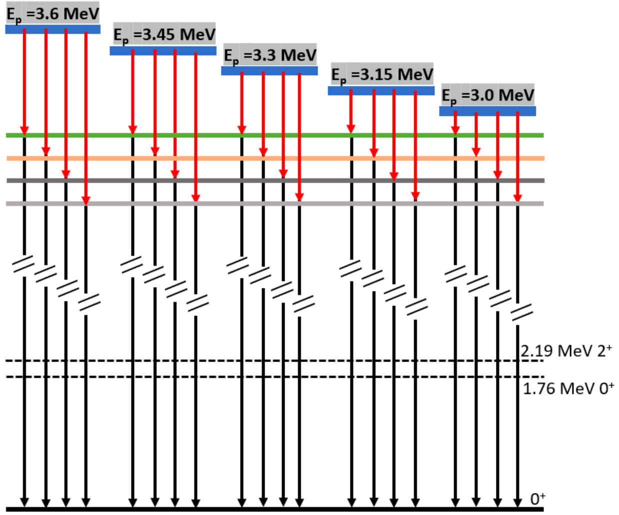
$$N_{L_j}(E_i) \propto f(E_\gamma)E_\gamma^3 \sum_{J^\pi} \sigma(E_i)$$

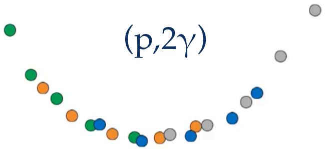
$$f(E_{\gamma 1}) \propto \frac{N_{L_1}(E_1)}{E_{\gamma 1}^3}$$

$$f(E_{\gamma 2}) \propto \frac{N_{L_2}(E_1)}{E_{\gamma 2}^3}$$

Low-energy enhancement in the unexplored energy regime: $^{89}Y(p,\gamma)^{90}Zr$







(p,2γ)

Experimental Setup and Goals:

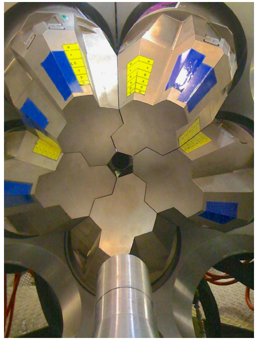
✓ **Targets:** ^{89}Y, 2 mg/cm², energy Loss > 110 keV

✓ **E$_p$:** 3.15 – 3.6 MeV, beam current ~ 0.4 – 1 μA

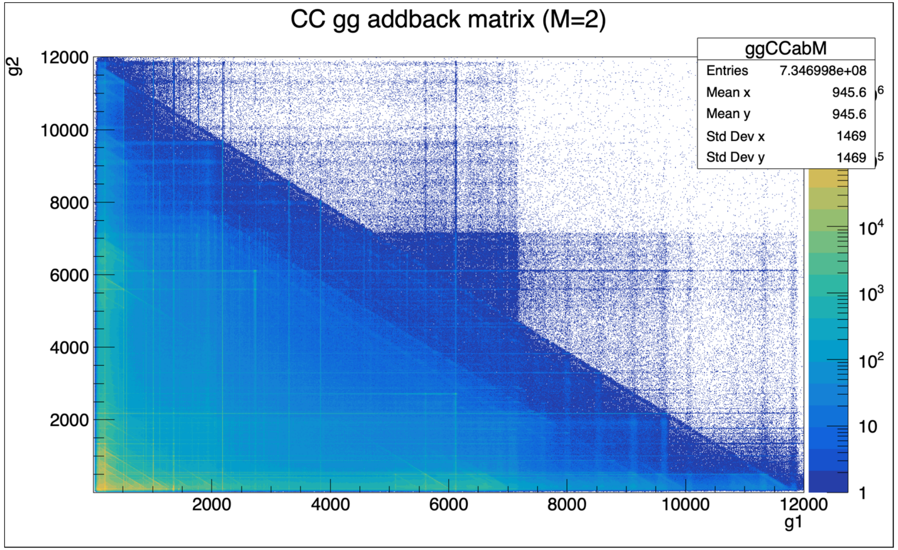
✓ Measure γ-decay using **GRETINA** at **ATLAS** (stand-alone mode, Nov. 2024)

✓ **Configuration:** ~ 10.5 quads (42 HPGe crystals used in the experiment)

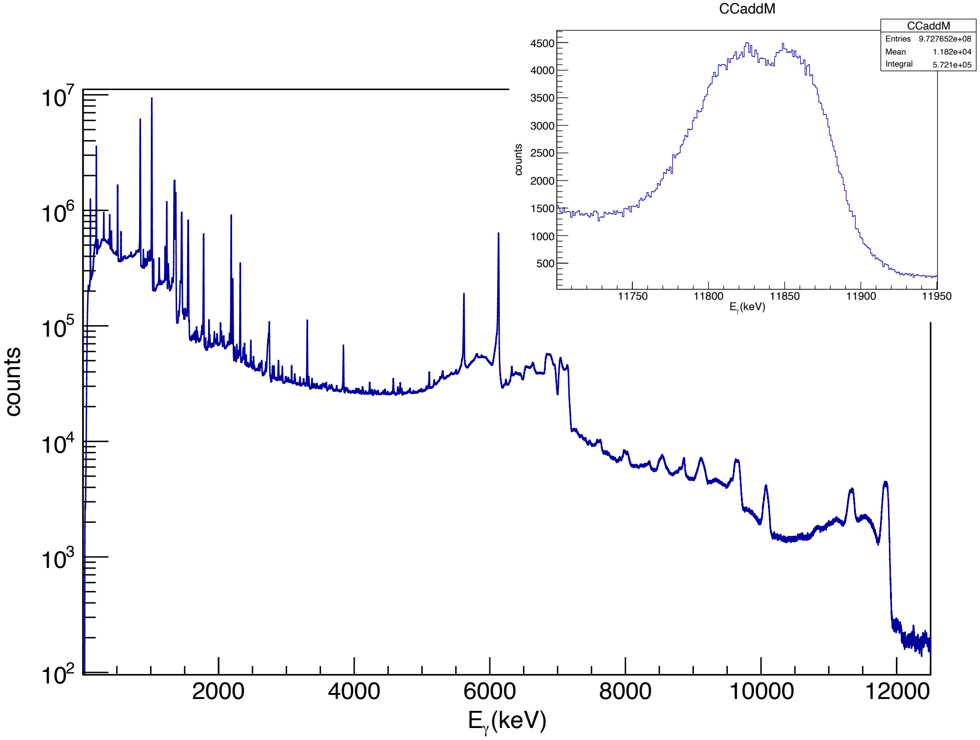
✓ **Objective:** Investigate the low-energy enhancement (LEE) down to ~ 100 keV



Low-energy enhancement in the unexplored energy regime: $^{89}Y(p,\gamma)^{90}Zr$

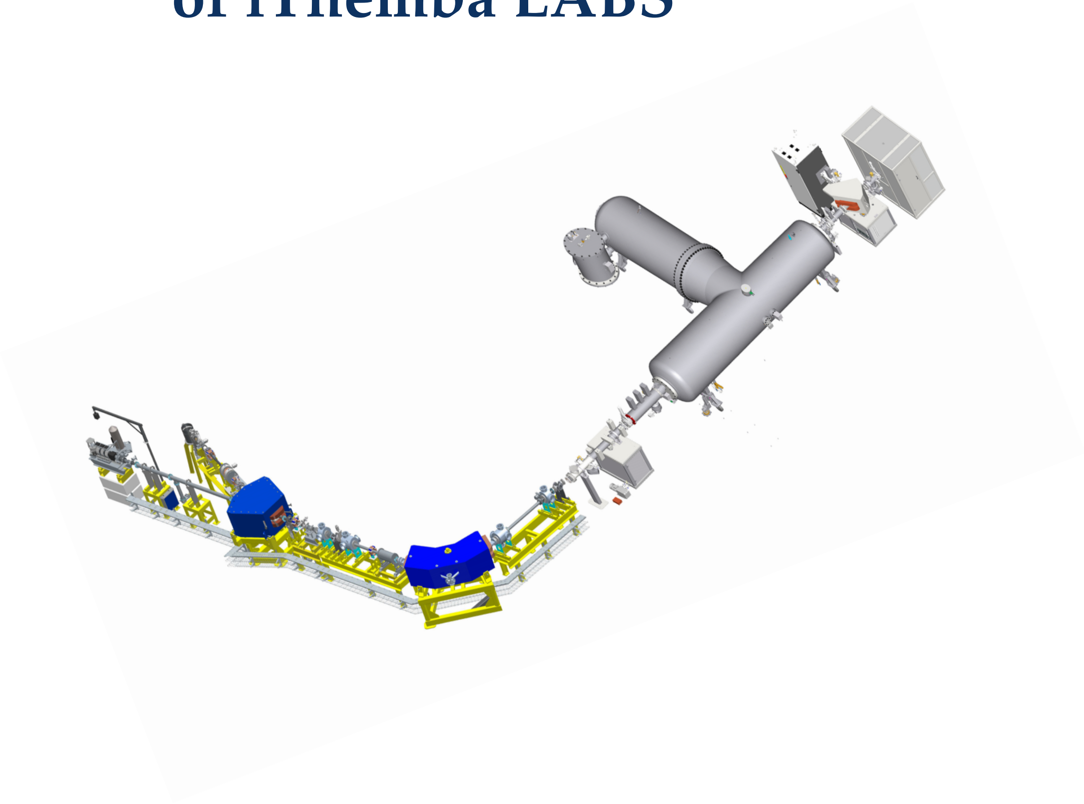


- ✓ γ-γ matrix for M=2 events only
- ✓ 50% of the data for $E_p = 3.6$
- ✓ Competing background



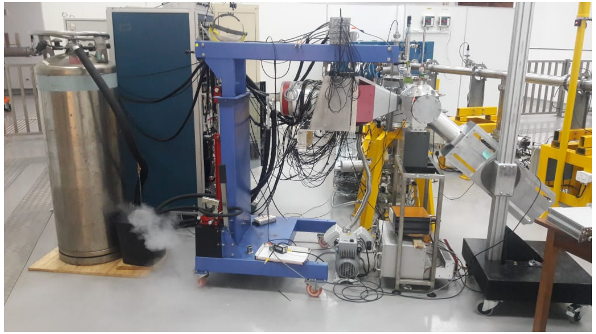
E(level) (keV)	J^{π}(level)	$T_{1/2}$(level)	E(γ) (keV)	M(γ)	Final Levels	
0	0+	STABLE				
1760.74 *14*	0+	61.3 ns *25*	1760.70 *20*	E0	0	0+
2186.273 *14*	2+	87.9 fs *21*	425.5 *2* 2186.242 *25*	[E2] E2	1760.74 0	0+ 0+
2319.000 *9*	5-	809.2 ms *20* % IT = 100	132.716 *18* 2318.959 *25*	E3(+M4) E5	2186.273 0	2+ 0+
2739.29 *5*	(4)-		420.28 *5*		2319.000	5-
2747.875 *16*	3-	15.2 ps *28*	429.0 *3* ? 561.604 *11* 2747.47 *5*	[E2] E1 E3	2319.000 2186.273 0	5- 2+ 0+

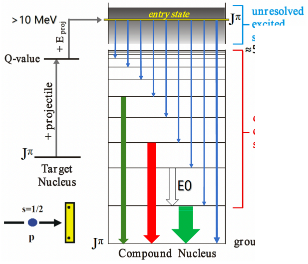
Low-energy nuclear physics beamline at the Tandetron Laboratory of iThemba LABS



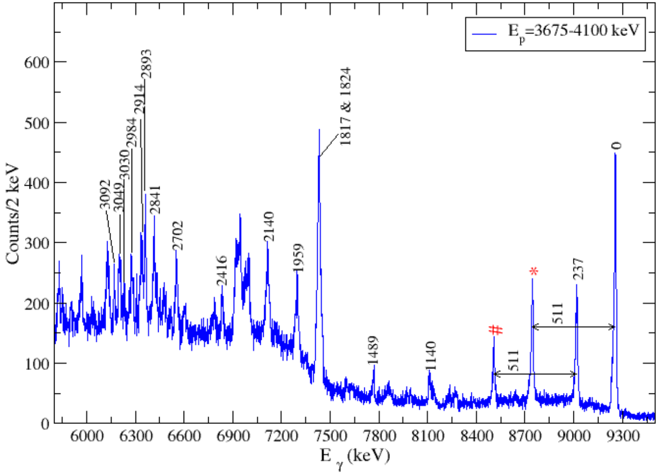
Proof-of-principle experiment: $^{50}Cr(p, \gamma)^{51}Mn$

Adivhaho Netshiya
PhD submitted
(WITS)





Credit: S. Harissopulos



- ✓ 200-350 $\mu g/cm^2$ ^{50}Cr targets.
- ✓ 1 Compton-suppressed Clover detector.
- ✓ 3 MV Tandetron: E_p = 2.5 - 3 MeV & 3.7 - 4.5 MeV in 20-25 keV intervals.
- ✓ A total of 64 γ-ray spectra were collected.

Apply Average Resonance Proton Capture [1]

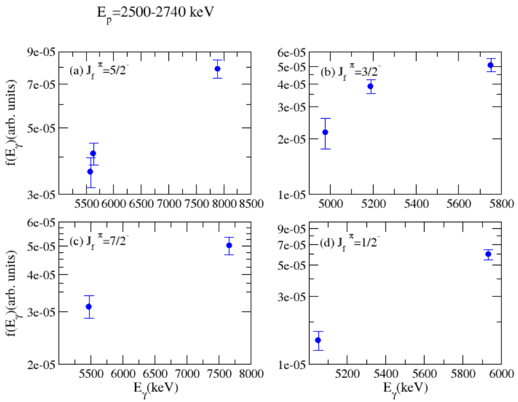
- ✓ Sum the spectra into bins of 260 and 825 keV, minimize statistical fluctuations.

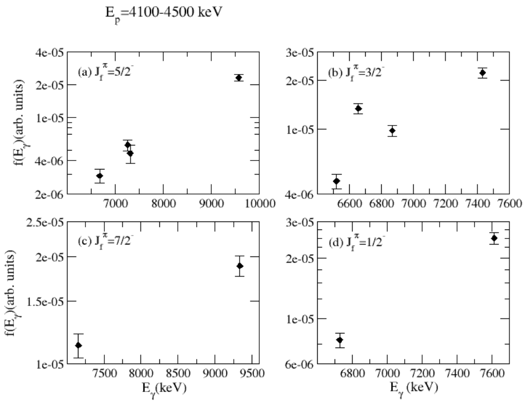
Apply Shape Method [2]

- ✓ Identify pairs of primary γ transitions from the same initial Ex to specific discrete states with same J^π.

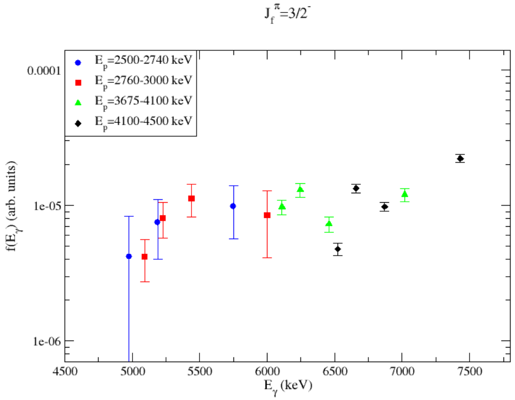
[1] Goriely, et al., Eur. Phys. J. A 55, 172 (2019)
[2] Wiedeking et al., Phys. Rev. C., 104 014311 (2021), Phys. Rev. Lett., 108 162503 (2012).
[3] Netshiya, et al., J. Phys. Conf. Ser. 2586, 012111 (2023)

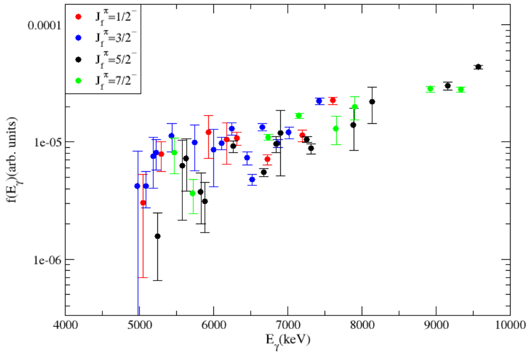
Shape of PSF from $^{50}Cr(p, \gamma)^{51}Mn$ reaction



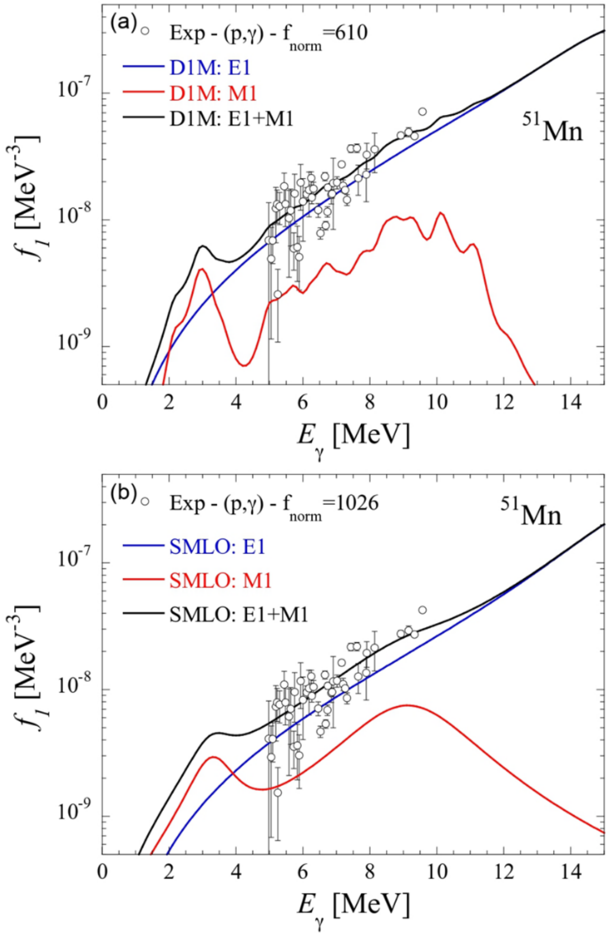


- ✓ Pairs of primary γ transitions from the same initial Ex to specific discrete states of the same J^{π}
- ✓ Add pairs from different initial Ex and scaled w.r.t. each other

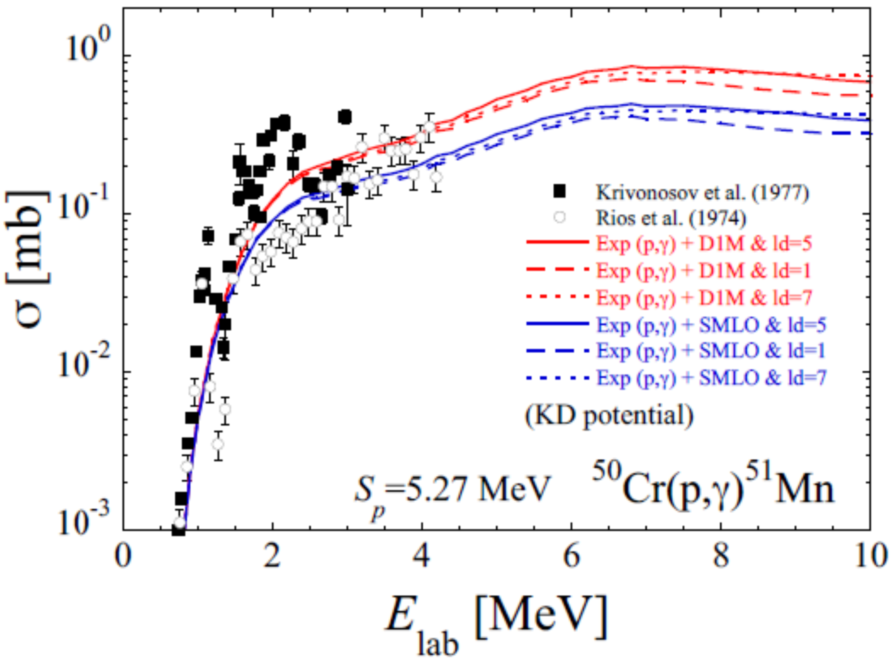




PSF from $^{50}Cr(p, \gamma)^{51}Mn$



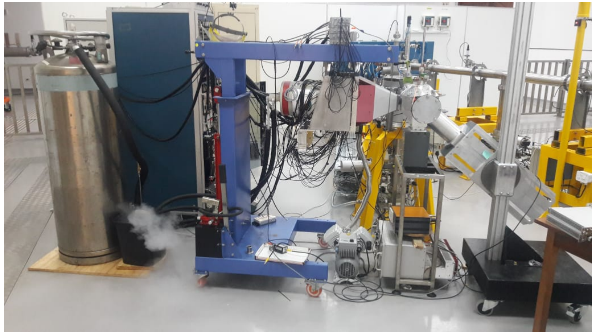
Courtesy of S. Goriely

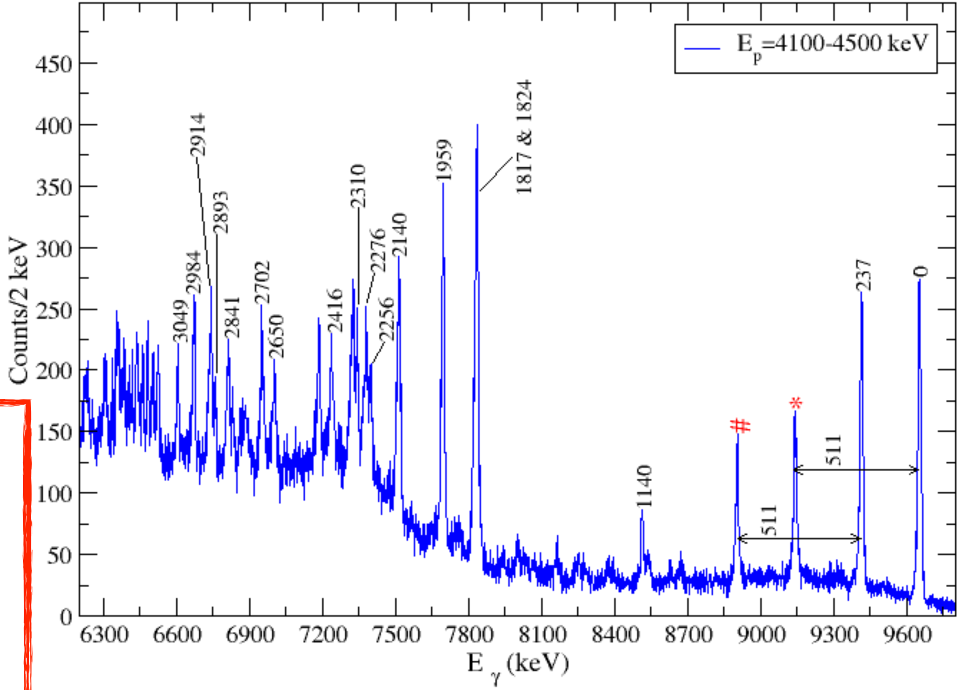


Calculations varied different NLDs, PSFs and OMPs.

Proof-of-principle experiment: $^{50}Cr(p, \gamma)^{51}Mn$

Adivhaho Netshiya
PhD submitted
(WITS)





- ✓ 1 HPGe segmented clover detector (TIGRESS).
- ✓ From total of 64 γ-ray spectra collected, 171 γ-rays and 37 energy levels were newly observed.
- ✓ Relative intensities of all 171 γ-rays were measured for the first time.
- ✓ Possible multipolarities were assigned to 17 γ-ray transitions.

Netshiya, et al., In Preparation (2026)

Nuclear astrophysics beamline at the iThemba LABS Tandetron

Ion sources (up to 700 uA):

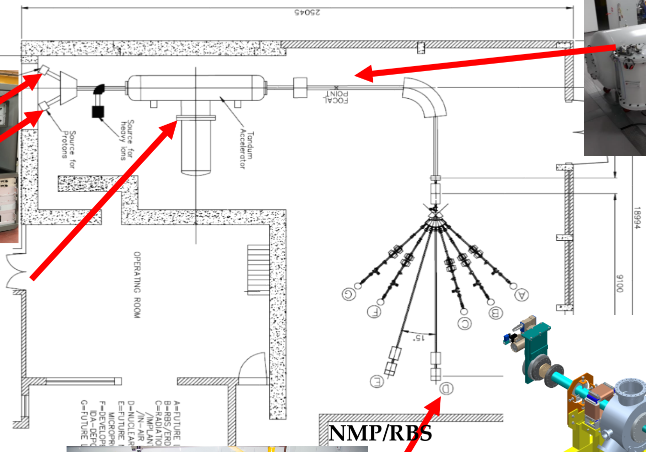
- He Multicusp Model SO130 positive extraction
- H- and D- Multicusp Model SO120 direct negative extraction

2017 : Replacement of the 52 year old Van de Graaff with 3MV Tandetron

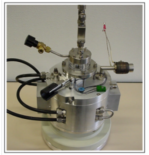
$_1$H+ : 150 eμA @ TV = 200 kV
$_1$H+ : 200 eμA @ TV = 1.0 MV
$_1$H+ : 200 eμA @ TV = 3.0 MV

$_2$D+ : 150 eμA @ TV = 200 kV
$_2$D+ : 200 eμA @ TV = 1.0 MV
$_2$D+ : 200 eμA @ TV = 3.0 MV

$_4$He+ : 8 eμA @ TV = 200 kV
$_4$He2+ : 25 eμA @ TV = 1.0 MV
$_4$He2+ : 25 eμA @ TV = 3.0 MV



NEGATIVE SPUTTER ION SOURCE
Model 860A and 860C



Features

- Easy operation and maintenance
- High intensity ion beams of almost all elements in the periodic table
- Beam currents up to 150 μA
- Low beam emittance
- Easy cesium reservoir loading
- Lifetime cesium charge > 1000 hours
- Easy (ex)change of source materials

Radius	1.5 m
Maximum field	1.28T
Pole gap	45 mm
Maximum mass energy product $(M_{inj}E_{inj}/q^2)$	165 MeV amu
Maximum energy Silver 4+	25.3 MeV

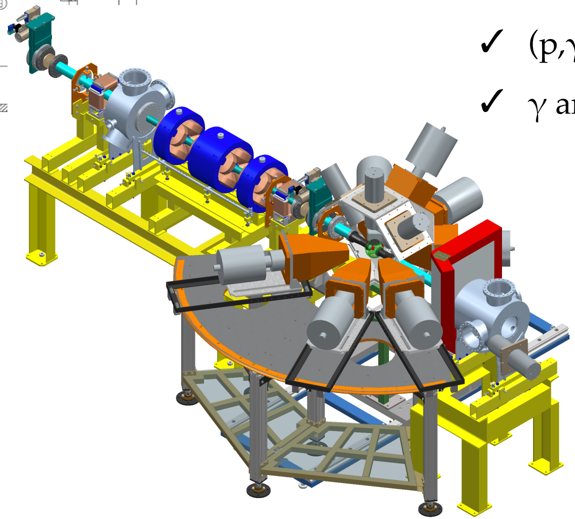
$^{11}B^-$	10 μA
$^{12}C^-$	100 μA
$^{16}O^-$	100 μA
$^{28}Si^-$	100 μA
$^{31}P^-$	30 μA
$^{58}Ni^-$	30 μA
$^{63}Cu^-$	20 μA
$^{75}As^-$	15 μA
$^{197}Au^-$	80 μA

NMP/RBS

RBS/ERDA

Dedicated Nuclear Physics Beamline:

- ✓ PSF measurements
- ✓ Tests of Brink-Axel hypothesis
- ✓ (p,γ) and (α,γ) cross sections
- ✓ γ and particle emission widths



Z.M. Khumalo *et al.*, 2025 *JINST* **20** T06001

Nuclear astrophysics beamline at the iThemba LABS Tandetron

Beam Left: Half-AFRODITE frame, Slide ~1.3 meter (in-) outward

✓ 6 **HPGe clover** or 9 large Volume (3.5″×8") **$LaBr_3$:Ce** detectors

✓ 4 Small (2″×2") $LaBr_3$:Ce detectors

✓ Angular range (45, 90, 135 deg)

Beam Right: Angular Distribution Table, 3 detectors on carriages for multiple angles (~ 26-141 deg)

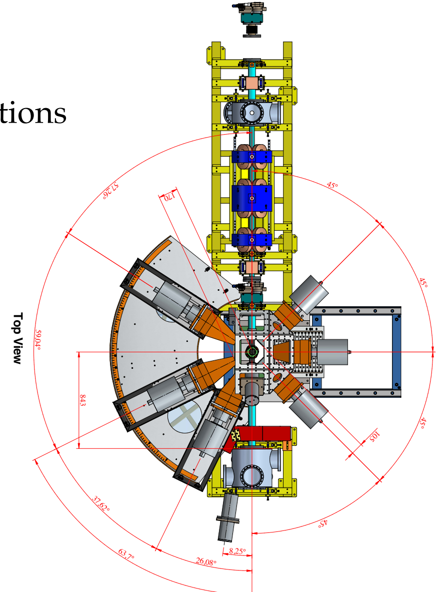
Target Ladder/Chamber: Depends on user specifications

Auxiliary detectors: Depends on user specifications

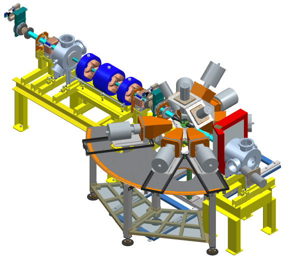
Beams: p, α & in the future ^{3}He

Energies: 0.5 - 6 MeV protons & 1 - 9 MeV alphas

Intensities: 20 nA - 10 μA

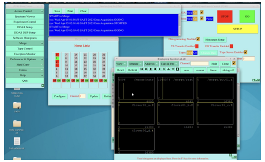


Nuclear astrophysics beamline at the iThemba LABS Tandetron

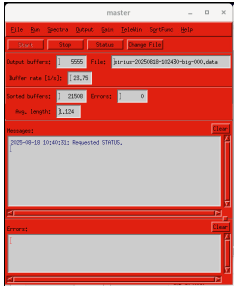


16-bit, 100 | 500 MHz
XIA fast digitizers

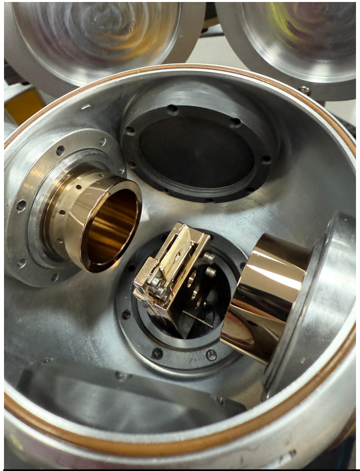
MIDAS DAQ



MASTER (UiO), since 2025



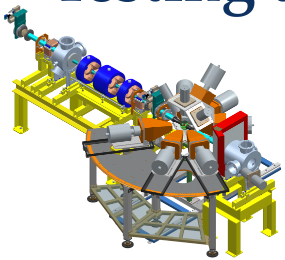
Gold plated collimator and target ladder to improve background reduction



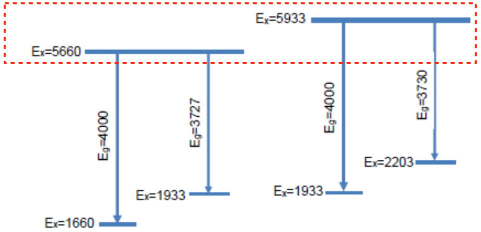
Thanks to Kevin Li (UiO)

LaBr$_3$:Ce detectors (stand-alone Mode)

Testing the validity of the Brink-Axel Hypothesis: $^{60}Ni(p,\gamma)^{61}Cu$



Tshegofatso Modise
PhD ongoing University of Botswana)

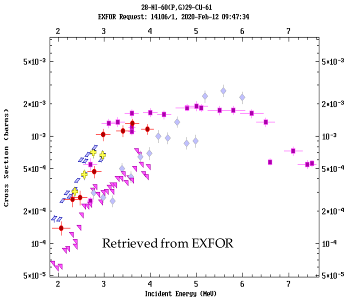


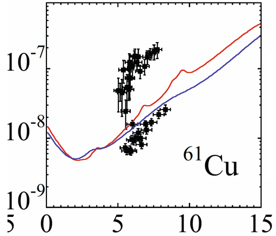
Set	Energy of level 1 (keV)	Energy of level 2 (keV)	Energy difference (keV)	Spin difference
1	970	1394	424	0
2	1310	1733	423	0
3	1904	2336	432	2
4	1660	1933	273	0
5	2203	1933	270	1
6	1733	1943	210	0
7	2472	2684	212	0
8	2089	2295	206	4
9	2203	2399	195	1
10	1394	2472	502	1
11	475	970	495	2
12	1394	1904	508	0

- ✓ ^{61}Cu has definite spin and parity assignments
- ✓ States populated sufficiently in (p,γ) reactions unto $E_x < 3$ MeV
- ✓ ^{61}Cu has well separated energies
- ✓ Use Shape/Ratio Method
- ✓ Double Ratio is independent on efficiencies of primary γ-rays

$$R = \frac{f_1(E_i - E_{f_1})}{f_1(E_i - E_{f_2})} = \frac{I(E_i - E_{f_1})(E_i - E_{f_1})^3}{I(E_i - E_{f_2})(E_i - E_{f_2})^3}$$

- ✓ Proton beam of 2.23-4.32 MeV in 60-80 keV steps (~ 31 spectra)
- ✓ Target: 1 mg/cm² ^{61}Ni
- ✓ $^{60}Ni(p,\gamma)$ at energies below Coulomb barrier (6.8 MeV).
- ✓ *Ex* determined directly from *Ep*..

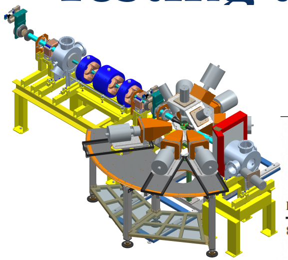




Goriely, et al., Eur. Phys. J. A 55, 172 (2019)

Testing the validity of the Brink-Axel Hypothesis: $^{60}Ni(p,\gamma)^{61}Cu$

Commissioning Exp. Aug 2023

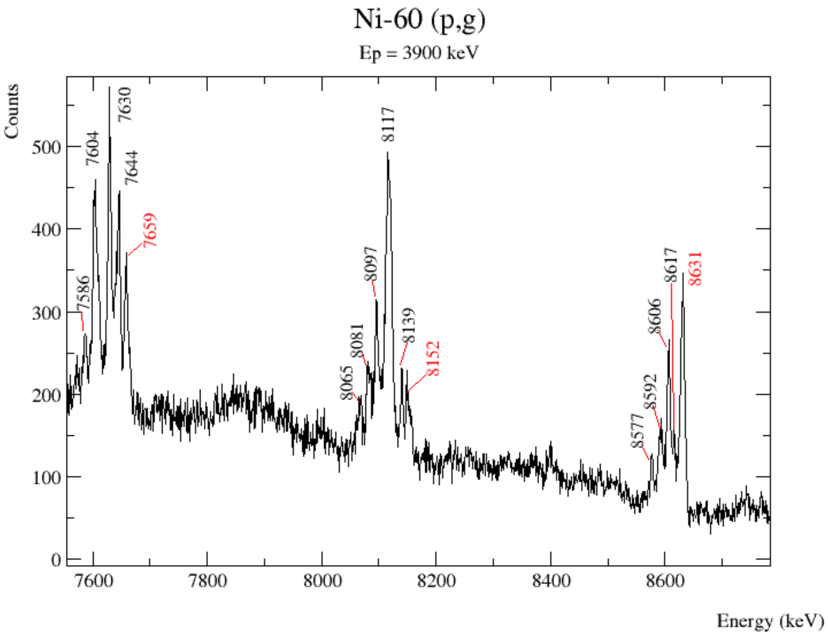


^{60}Ni(p,γ):resonances (continued)

$\gamma(^{61}$Cu) (continued)

E_i(level)	J^π_i	E_γ[#]	I_γ[@]	E_f	J^π_f	E_i(level)	J^π_i	E_γ[#]	I_γ[@]	E_f	J^π_f
8481.5	$9/2^+$	4348[&]	4[&]	4132.8	$9/2^+$	8492.4	3/2	7181.4	18 *4*	1310.88	$7/2^-$
		4500[&]	2[&]	3980.6				7521.9	22 *4*	970.00	$5/2^-$
		5759[&]	78[&]	2721.2	$9/2^+$			8015.9	27 *4*	475.84	$1/2^-$
		5853[&]	8[&]	2627.2	$11/2^-$			8491.7	33 *4*	0	$3/2^-$
		7169[&]	4[&]	1310.88	$7/2^-$	8499.9	5/2	6766.2	36 *4*	1733.1	$7/2^-$
8485.0	$9/2^+$	3233[&]	1[&]	5251.7				7188.3	25 *4*	1310.88	$7/2^-$
		4103[&]	2[&]	4382.0?				8499.6	39 *4*	0	$3/2^-$
		4352[&]	8[&]	4132.8	$9/2^+$	8503.7		8503.1	100	0	$3/2^-$
		4504[&]	1[&]	3980.6		8507.3	1/2	8506.7	100	0	$3/2^-$
		5468[&]	3[&]	3016.6	$11/2^-$	8508.1	1/2	6603.1[j]	20 *7*	1904.4	$5/2^-$
		5482[&]	4[&]	3002.4	5/2			6846.9	25 *6*	1661.09	$3/2^-$
		5763[&]	55[&]	2721.2	$9/2^+$			8031.6	12 *5*	475.84	$1/2^-$
		5857[&]	2[&]	2627.2	$11/2^-$			8507.4	43 *6*	0	$3/2^-$
		6148[&]	2[&]	2336.9	$9/2^-$	8509.9		6306[j]	9 *2*	2203.2	$5/2^-$
		6189[&]	1[&]	2295.6	$9/2^-$			6576	10 *2*	1933.0	$3/2^-$
		6542[&]	7[&]	1943.2	$7/2^-$			6848.8	5 *2*	1661.09	$3/2^-$
		6751[&]	9[&]	1733.1	$7/2^-$			7199.0	5 *3*	1310.88	$7/2^-$
		7173[&]	5[&]	1310.88	$7/2^-$			8509.3	71 *4*	0	$3/2^-$
8489.9	1/2	6828.7	33 *4*	1661.09	$3/2^-$	8515.4		8039.0	100	475.84	$1/2^-$
		8013.4	15 *5*	475.84	$1/2^-$	8522.6	1/2,3/2	8046.2	35 *5*	475.84	$1/2^-$
		8489.2	52 *5*	0	$3/2^-$			8522.0	65 *5*	0	$3/2^-$

[†] From level energy difference (1983Si06).
[‡] From 1983Si06.
[#] From level energy difference.
[@] Relative branching from each level. Decay of resonances from 1973Tr06, 1974Tr03, 1974Kr26, 1975Kr05, 1976Be30, 1979Bo09.
[&] From 1990Sz01.
[a] From 1974Kr26.
[b] From 1974Ad06.
[c] From 1976Be30.
[d] From 1974Tr03.
[e] From level energy difference (1988Iz01).
[f] From $\gamma(\theta)$ measurements, see δ.
[g] Dipole-quadrupole mixing, 1974Tr03, 1976Kr19, 1981By03, 1988Iz01. When there are two solutions, only the smaller δ has been given.
[h] From 1988Iz01.
[i] From p$\gamma\gamma(\theta)$ data of 1965Go02.
[j] Placement of transition in the level scheme is uncertain.



At $E_{p,cm}$= 4278 keV ⇒ E_γ = 9040 keV (~ **518** keV above tabulated resonances)

Additional Experiments

Studying the astrophysically crucial $^{12}C(\alpha, \gamma)^{16}O$ reaction at high temperatures

Motivation:

- ✓ **Measure cross section on and of resonances regions of interest (6 weeks of beam-time, Aug/Sep 2025)**
- ✓ Develop neutron-γ discrimination capabilities
- ✓ Target: Enriched ^{12}C targets
- ✓ Beam: $E_\alpha = 4–9.0$ MeV,
- ✓ 12 * large volume $LaBr_3(Ce)$ detectors,
- ✓ Target thickness 22 & 24 $\mu g/cm^2$

$^7Li(p, \gamma)^8Be$: Testing conventional explanations for the X17 anomaly (2 weeks, Oct 2023)


EPJ Web of Conferences **275**, 01012 (2023) https://doi.org/10.1051/epjconf/202327501012
11th European Summer School on Experimental Nuclear Astrophysics

Investigation of a light Dark Boson existence : The New JEDI project

Beyhan Bastin[1,*,**,***], *Jürgen* Kiener[2,**,***], *Isabelle* Deloncle[2,**], *Alain* Coc[2,**], *Maxim* Pospelov[3,**], *Jaromir* Mrazek[4,**], *Livio* Lamia[5,6,**], *Dieter* Ackermann[1], *Philip* Adsley[7,8,***], *Charles-Olivier* Bacri[2], *Jérôme* Bourçois[2], *Vaclav* Burjan[4], *Anastasia* Cassisa[4], *Giuseppe* D'agata[4,5,6], *Gilles* De France[1], *Alessia* Di Pietrio[6], *Yasmine* Demane[9], *François* De Oliveira[1], *Lindsay* Donaldson[7,8,***], *Corinne* Donzaud[10], *Jean-Eric* Ducret[1], *Clarisse* Hamadache[2], *Fairouz* Hammache[2], *Pete* Jones[6], *Marco* La Cognata[6], *Adrien* Laviron[2], *Marek* Lewitowicz[1], *Kgashane* Malatji[8], *Antonio* Massara[6], *Cyril* Pitrou[11,12], *Rosario Gianluca* Pizzone[6], *Giovanni Luca* Guardo[6], *Marek* Płoszajczak[1], *Giuseppe* Rapisarda[5,6], *Bernadette* Rebeiro[9,14], *Brigitte* Roussière[2], *Domenico* Santonocito[6], *Nicolas* de Séréville[2], *Maria Letizia* Sergi[5,6], *Eva* Simeckova[4], *Olivier* Sorlin[1], *Christelle* Stodel[1], *Vincent* Tatischeff[2], *Jean-Charles* Thomas[1], and *Aurora* Tumino.[6,13]

Additional Experiments

Studying the astrophysically crucial $^{12}C(\alpha, \gamma)^{16}O$ reaction at high temperatures

Motivation:

- ✓ **Measure cross section on and of resonances regions of interest (6 weeks of beam-time, Aug/Sep 2025)**
- ✓ Develop neutron-γ discrimination capabilities
- ✓ Target: Enriched ^{12}C targets
- ✓ Beam: $E_\alpha = 4$–9.0 MeV,
- ✓ 12 * large volume $LaBr_3(Ce)$ detectors,
- ✓ Target thickness 22 & 24 $\mu g/cm^2$

$^{7}Li(p, \gamma)^{8}Be$: Testing conventional explanations for the X17 anomaly (2 weeks, Oct 2023)

EPJ Web of Conferences **275**, 01012 (2023) https://doi.org/10.1051/epjconf/202327501012
11th European Summer School on Experimental Nuclear Astrophysics

Investigation of a light Dark Boson existence : The New JEDI project

Beyhan Bastin[1,*,**,***], *Jürgen* Kiener[2,**,***], *Isabelle* Deloncle[2,**], *Alain* Coc[2,**], *Maxim* Pospelov[3,**], *Jaromir* Mrazek[4,**], *Livio* Lamia[5,6,**], *Dieter* Ackermann[1], *Philip* Adsley[7,8,***], *Charles-Olivier* Bacri[2], *Jérôme* Bourçois[2], *Vaclav* Burjan[4], *Anastasia* Cassisa[4], *Giuseppe* D'agata[4,5,6], *Gilles* De France[1], *Alessia* Di Pietrio[6], *Yasmine* Demane[9], *François* De Oliveira[1], *Lindsay* Donaldson[7,8,***], *Corinne* Donzaud[10], *Jean-Eric* Ducret[1], *Clarisse* Hamadache[2], *Fairouz* Hammache[2], *Pete* Jones[6], *Marco* La Cognata[6], *Adrien* Laviron[2], *Marek* Lewitowicz[1], *Kgashane* Malatji[8], *Antonio* Massara[6], *Cyril* Pitrou[11,12], *Rosario Gianluca* Pizzone[6], *Giovanni Luca* Guardo[6], *Marek* Płoszajczak[1], *Giuseppe* Rapisarda[5,6], *Bernadette* Rebeiro[9,14], *Brigitte* Roussière[2], *Domenico* Santonocito[6], *Nicolas* de Séréville[2], *Maria Letizia* Sergi[5,6], *Eva* Simeckova[4], *Olivier* Sorlin[1], *Christelle* Stodel[1], *Vincent* Tatischeff[2], *Jean-Charles* Thomas[1], and *Aurora* Tumino.[6,13]

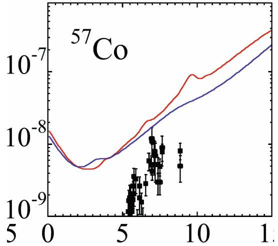
NEW JEDI

$^{56}Fe(p,\gamma)^{57}Co$: Low-energy γ-ray decay at high excitation energies (Sep 2024)

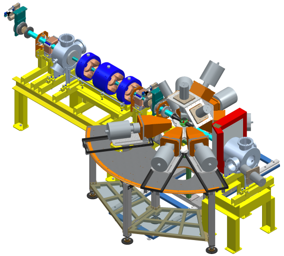
Motivation:

- ✓ **Measure γ-decay from (p,γ) for studying the LEE (2 weeks of beam-time, Sep 2025)**
- ✓ $E_p = 3$, 4 & 5 MeV
- ✓ 4 HPGe clover detectors
- ✓ Target thickness: 4 mg/cm^2

Goriely, et al., Eur. Phys. J. A 55, 172 (2019)



Summary and Outlook



Average Resonance Capture Measurements

✓ **^{89}Y(p, γ)^{90}Zr**: Low-energy enhancement in the unexplored energy regime (down to~ 100 keV)

Low Energy Nuclear Physics Array @ iThemba LABS

✓ **^{50}Cr(p, γ)^{51}Mn**: Shape of PSF from (p, γ) reactions

✓ **^{60}Ni(p,γ)^{61}Cu**: Testing the validity of the Brink-Axel Hypothesis

✓ Studying the astrophysically crucial **^{12}C(α, γ)^{16}O** reaction at high temperatures

✓ **^{56}Fe(p,γ)^{57}Co**: Low-energy γ-ray decay at high excitation energies

✓ **^{7}Li(p, γ)^{8}Be**: Testing conventional explanations for the X17 anomaly

Thanks to my collaborators

P. Adsley[4,5], A. Bahini[1], **T. Bokhutlo**[1,2], J.A.C. Bekker[2], S.D. Binda[2], **D. Bleuel**[11], **L.M. Donaldson**[1], S. Hart[6], L. Jafta[7], P. Jones[1], **S. Jongile**[1], B.V. Kheswa[1,7], T.C. Khumalo[1,2], S.P.E. Magagula[2], **K.L. Malatji**[1,10], **T. Modise**[13], R.E. Molaeng[2], **A.A. Netshiya**[1,2,8], **R. Neveling**[1], L. Pellegri[1,2], **M. Wiedeking**[1,2,3]

[1] iThemba LABS, South Africa,

[2] Department of Physics, University of the Witwatersrand, Johannesburg, South Africa,

[3] Lawrence Berkeley National Laboratory, Berkeley, California, USA,

[4] Cyclotron Institute, Texas A&M University, College Station, Texas, USA,

[5] Department of Physics and Astronomy, Texas A&M University, College Station, Texas, USA,

[6] Department of Physics, University of Cape Town, Cape Town, South Africa,

[7] Physics Department, University of the Western Cape, Bellville, South Africa,

[8] Department of Applied Physics and Engineering Mathematics, University of Johannesburg, Johannesburg, South Africa,

[9] Department of Chemical and Physical Sciences, Walter Sisulu University, Mthatha, South Africa

[10] University of California, Berkeley, California, USA

[11] Lawrence Livermore National Laboratory, Livermore, California, USA

[12] Department of Physics and Astronomy, Botswana International University of Science and Technology, Palapye, Botswana

[12] Department of Physics, University of Botswana, Botswana

Thank You!

PSFs from proton capture reactions

Kgashane L. Malatji, M. Wiedeking *et al.*,

Nuclear Data Program, LBNL & Nuclear Engineering Department, UCB

klmalatji@berkeley.edu

http://nucleardata.berkeley.edu

Supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contracts No. DE-AC02-05CH11231 and the US Nuclear Data Program.