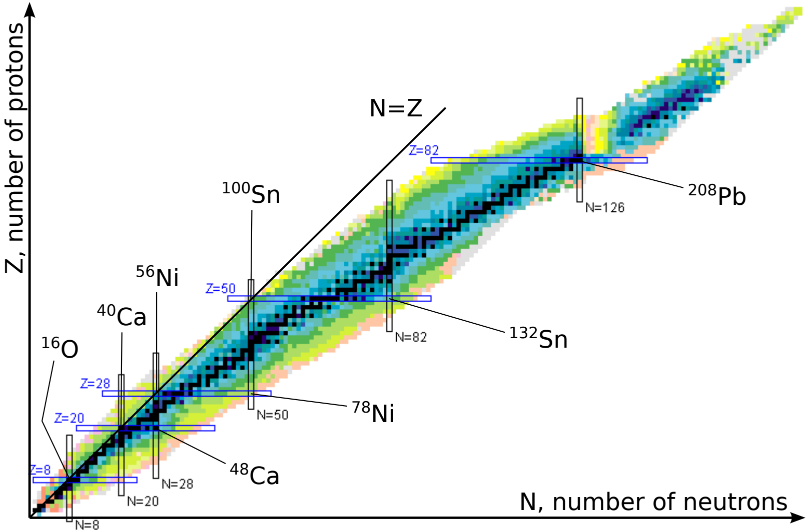
Doppler shift lifetime measurements using the TIGRESS Integrated Plunger device

Aaron Chester on behalf of the TIP and TIGRESS teams

PhD Candidate
Department of Chemistry
Simon Fraser University

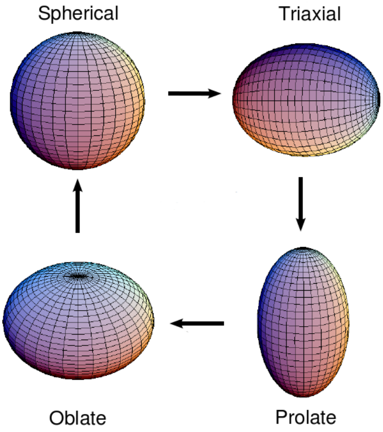
CAP Congress 2014
17 June 2014

Nuclear structure studies far from stability



Shape evolution along the $N = Z$ line

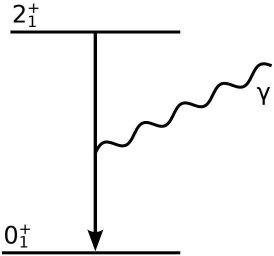
- Along the $N = Z$ line, shells open or close simultaneously and in the same way for protons and neutrons.
- Closed shells are spherical and inert.
- Proton-neutron interactions develop for partially filled proton and neutron shells, driving shape deformation.
- This gives rise to the phenomenon of shape evolution along the $N = Z$ line.



Shape evolution from ^{56}Ni to ^{100}Sn.

Studying nuclear structure using the electromagnetic force

- The electromagnetic force provides a convenient non-intrusive probe of nuclear systems bound by the strong force.
- Lifetime measurements using gamma-ray spectroscopy provide:
  1. An observable sensitive to nuclear structure.
  2. A sensitive benchmark for nuclear model calculations.



$$\tau(E2; 2_1^+ \to 0_1^+) = \frac{1}{\lambda(E2; 2_1^+ \to 0_1^+)}$$

$$\lambda(E2; 2_1^+ \to 0_1^+) \propto E(2_1^+)^5 \times B(E2; 2_1^+ \to 0_1^+)$$

$$B(E2; 2_1^+ \to 0_1^+) \propto \langle 2_1^+ || E2 || 0_1^+ \rangle^2$$

$$B(E2; 2_1^+ \to 0_1^+) \propto \beta^2$$

Motivation: Why ^{68}Se?

Model calculations

Model	Shell Model	Interacting Boson Model	Hartree-Bogoliubov	Self-consistent Collective Coordinate		Excited Vampir
$B(E2, 2_1^+ \rightarrow 0_1^+)$ [e^2fm^4]	100[1]	280[2]	500[3]	725[4]	834[4]	1048[5]

[1]M. Hasegawa et al. Phys. Lett. B **656** 51 (2007).; [2]F. Il. Khudair, Y. S. Li, G. L. Long, Phys. Rev. C **75** 054316 (2007).
[3]T. A. War et al. Eur. Phys. J. A **22** 13 (2004).; [4]N. Hinohara et al. Prog. Theor. Phys. (Kyoto) **119** 59 (2008).
[5]A. Petrovici et al. Nucl. Phys. A **710** 246 (2002).

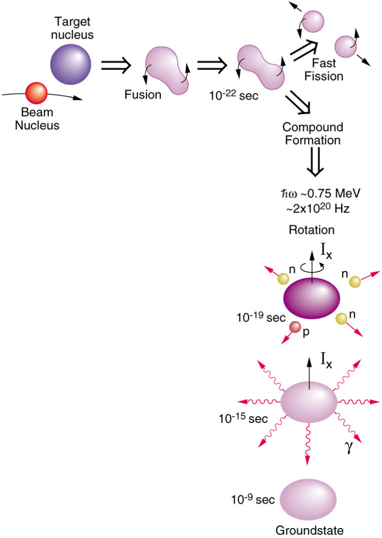
Recent measurements

Method	$B(E2, 2_1^+ \rightarrow 0_1^+)$ [e^2fm^4]	τ [ps]
Coulex[6]	432(58)	4.2(6)
RDM[7]	392(70)	4.60(82)

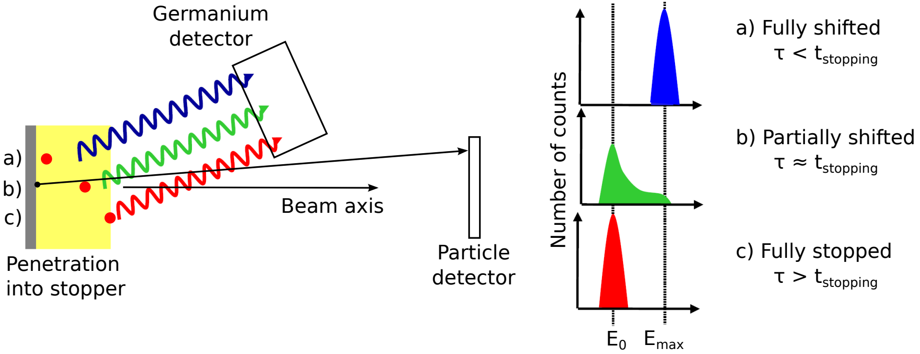
[6]A. Obertelli et al. Phys. Rev. C **80** 031304(R) (2009).; [7]A. J. Nichols et al. Phys. Rev. B **733** 52 (2014)

Producing exotic nuclei using fusion-evaporation reactions

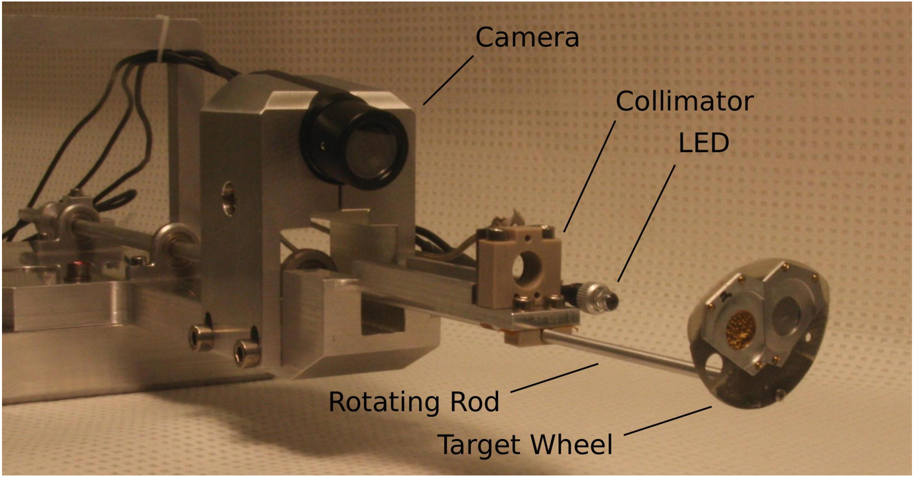
- A compound system forms with large angular momentum and recoil speed.
- The system decays first by the emission of particles, then by gamma-ray emission.
- Exotic recoil products can be studied provided a proper channel selection method is realized.



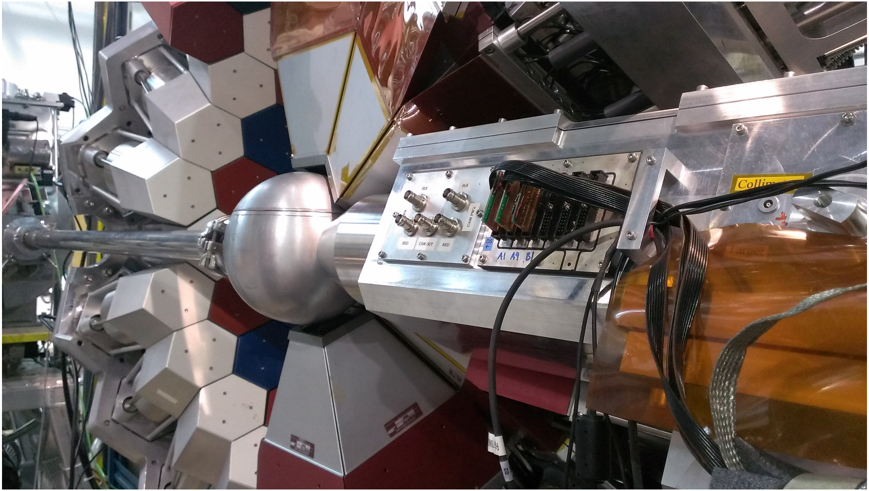
Doppler shift attenuation method lifetime measurements



TIP DSAM configuration



TIP DSAM configuration



TIP DSAM configuration

^{68}Se DSAM experiment summary

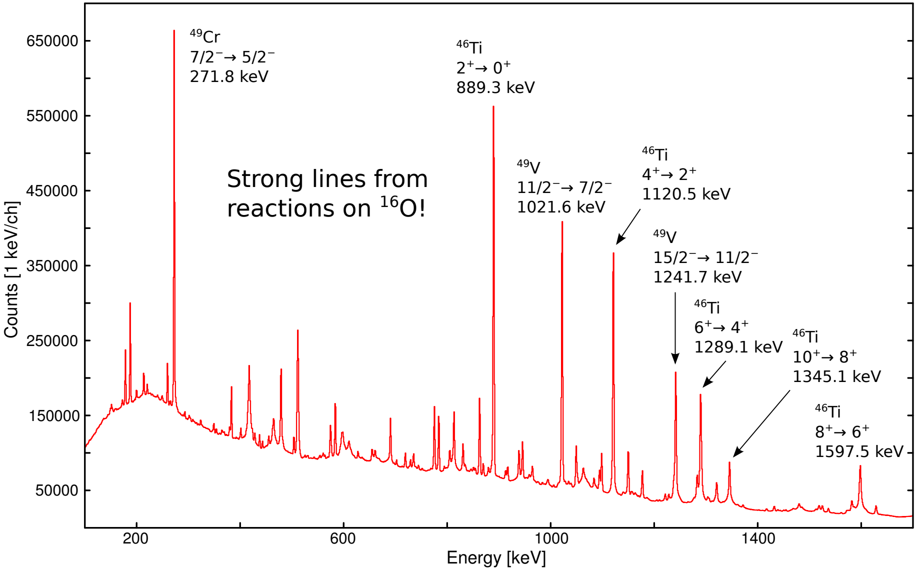
- Objective: Observation of ^{68}Se and possible lifetime measurement via DSAM.
- Detectors:
  - 24-element CsI(Tl) downstream wall for particle detection.
  - 13 TIGRESS HPGe and 3 GRIFFIN HPGe for gamma-ray detection.
- An ^{36}Ar beam was reacted on a ^{40}Ca target in a variety of backings and running conditions.
- The ^{76}Sr compound nucleus has 2α evaporation channel to ^{68}Se.
- Preliminary analysis is geared towards optimizing procedures for observation of ^{68}Se.

^{68}Se DSAM experiment summary

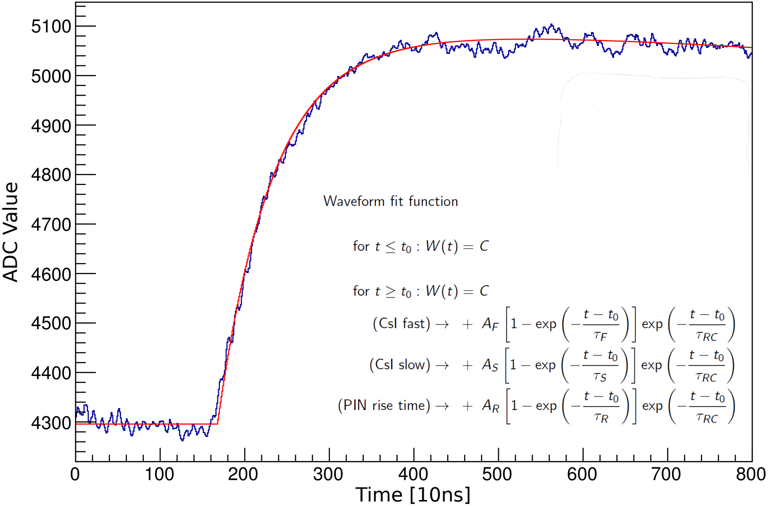
Beam energy	Target	Backing	Notes
100 MeV	250 $\mu g/cm^2$ Ca	21.7 mg/cm^2 Au	ox
110 MeV	250 $\mu g/cm^2$ Ca	21.7 mg/cm^2 Au	ox
110 MeV	**250 $\mu g/cm^2$ Ca**	**25.6 mg/cm^2 Pb**	**ox**
110 MeV	500 $\mu g/cm^2$ Ca	28.1 mg/cm^2 Pb	v. ox
110 MeV	134.2 $\mu g/cm^2$ Ca	24.36 mg/cm^2 Au	remade
105 MeV	134.2 $\mu g/cm^2$ Ca	24.36 mg/cm^2 Au	remade
115 MeV	250 $\mu g/cm^2$ Ca	27.6 mg/cm^2 Pb	remade
100 MeV	250 $\mu g/cm^2$ Ca	27.6 mg/cm^2 Pb	remade

- ox: target exhibited signs of oxidation
- v. ox: old target, very oxidized
- remade: remade by Micromatter with calcium "chunks" rather than grains

Gamma-ray spectrum: No particle identification

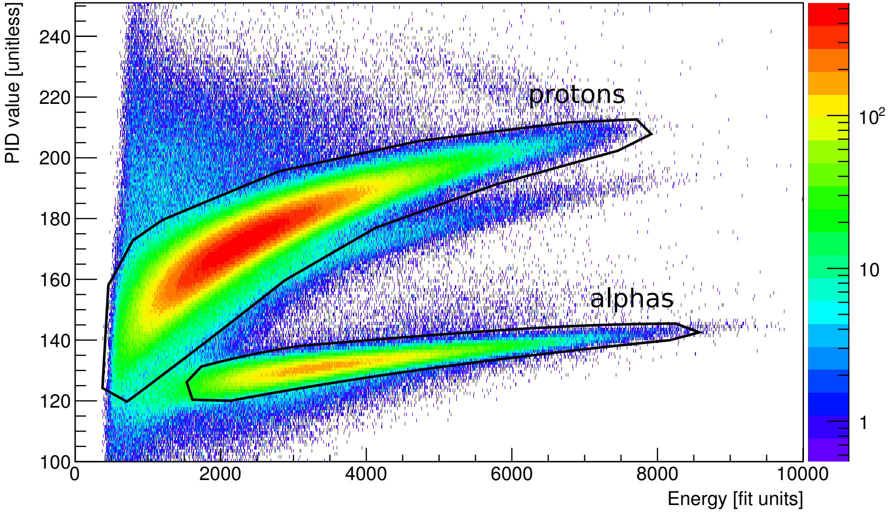


CsI(Tl) detector waveform fits

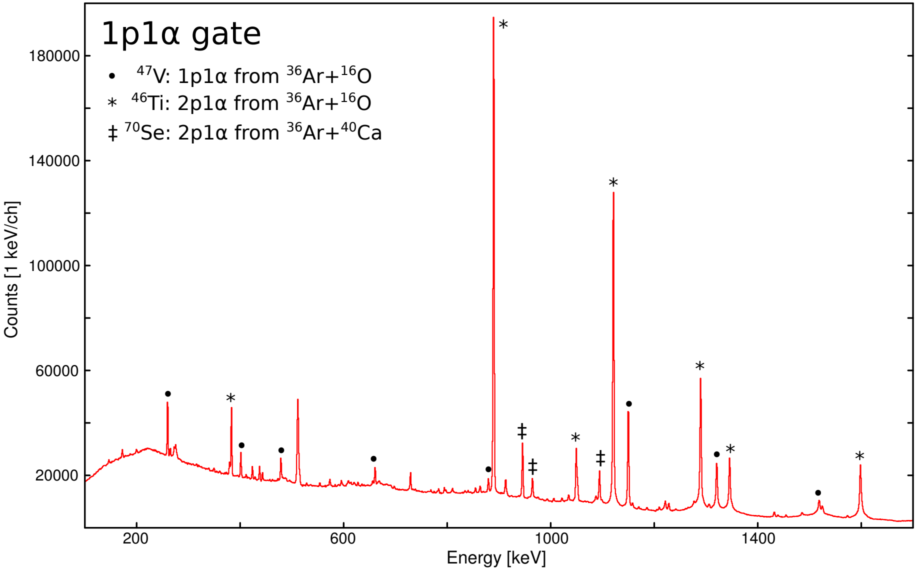


Particle identification using CsI(Tl) waveform fits

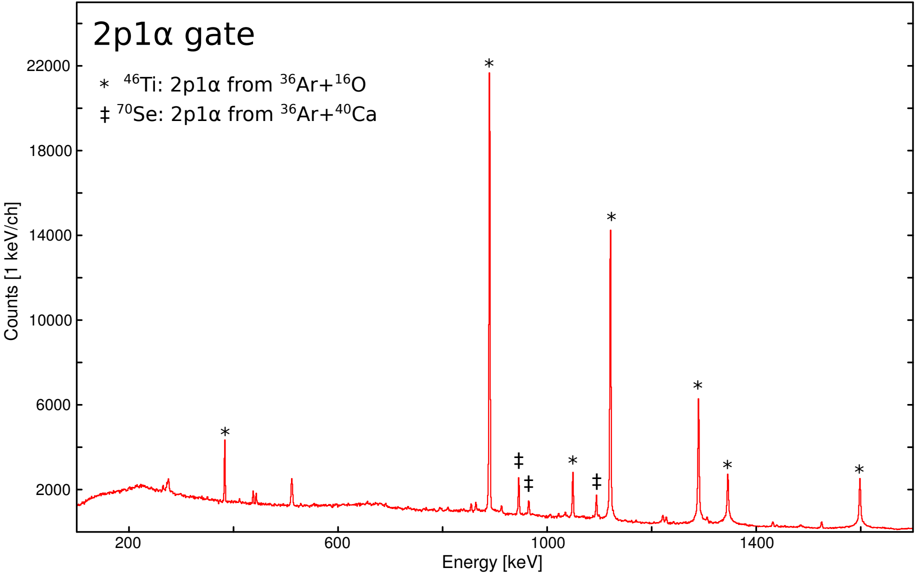
PID value = 100 × (1 + A_S/A_F)



1p1α gated gamma-ray spectrum



2p1α gated gamma-ray spectrum



Particle detection efficiency

$^{36}Ar + ^{16}O$

Particle type	eff. [%]
Proton	18.72(11)
Alpha	7(3)

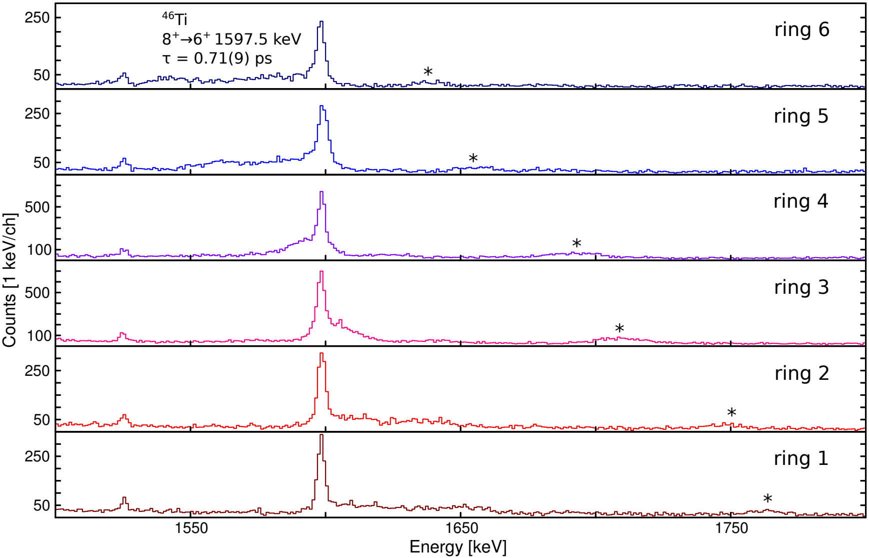
$^{36}Ar + ^{40}Ca$

Particle type	eff. [%]
Proton	14.8(4)
Alpha	5.5(1.5)

For comparison, the efficiency of Microball is ∼70% for protons and ∼45% for alpha particles under similar conditions.[8]

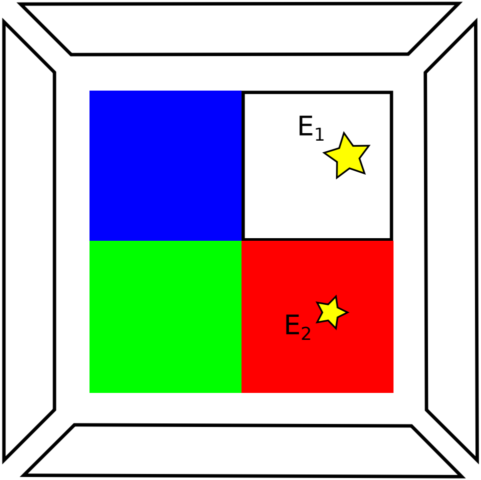
[8] K. Jonsson et al. Nucl. Phys. A. **645** (1999) 47–60.

DSAM lineshapes in the 2p1α gate



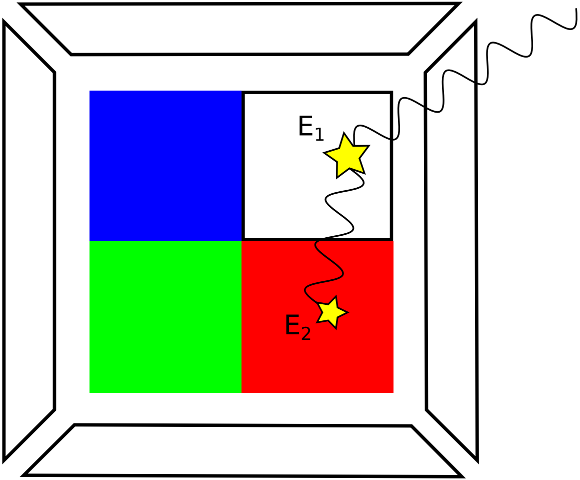
Add-back procedure

$E_1 > E_2$



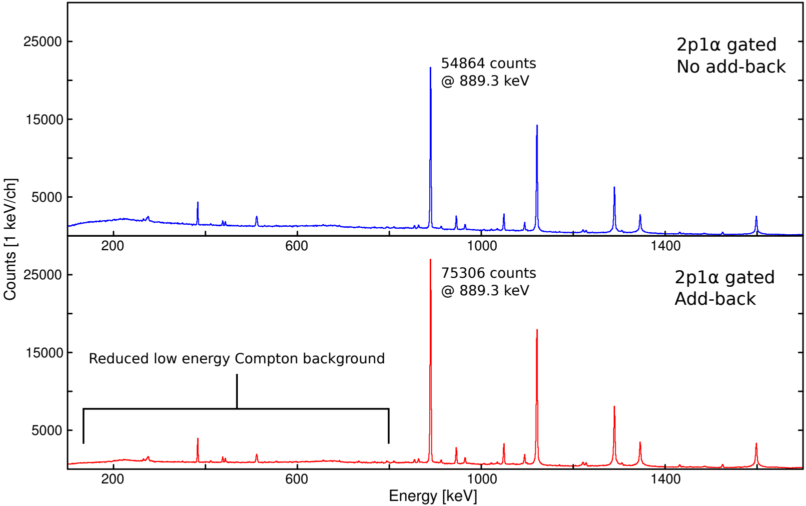
Add-back procedure

$E = E_1 + E_2$ assigned to white

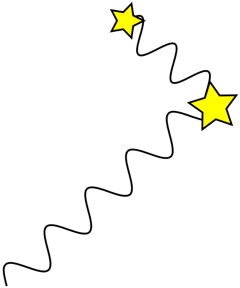


Add-back results

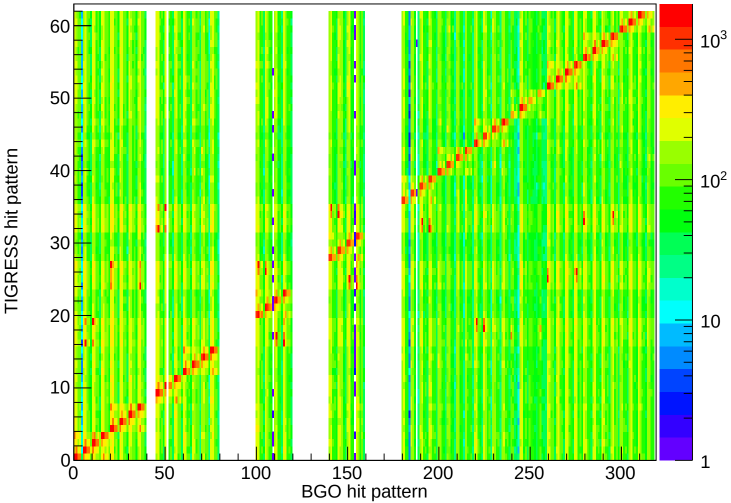
Add-back factor = 1.37 (37% more counts in add-back) at 889 keV.



Compton suppression with TIGRESS

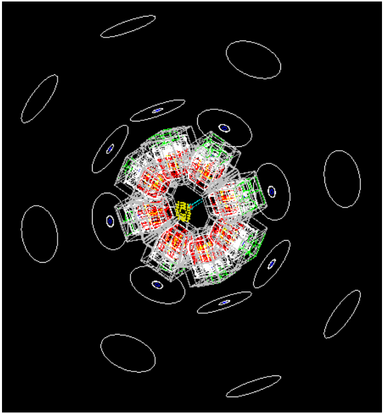


Compton suppression via TIGRESS/BGO hit pattern

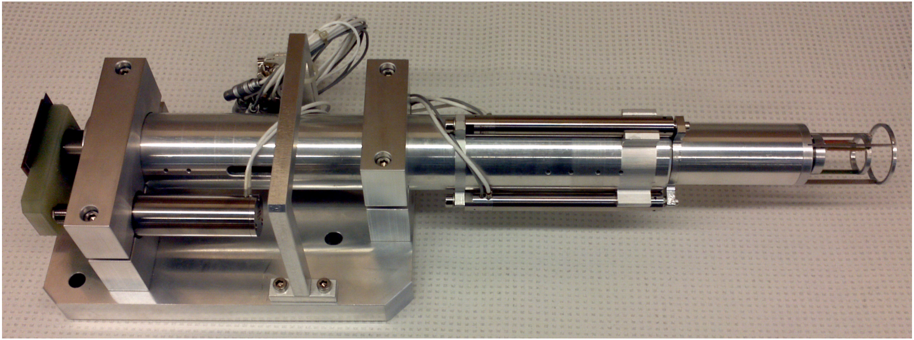


Future work: DSAM lineshape analysis code

- Geant4-based analysis code to extract lifetimes from DSAM lineshapes is under development.
- The TIGRESS array and TIP ancillary detectors have been implemented.
- Fusion-evaporation reaction kinematics must be implemented.
- Simulated lineshapes can be fit to experimental spectra and the best fit lifetime can be determined.

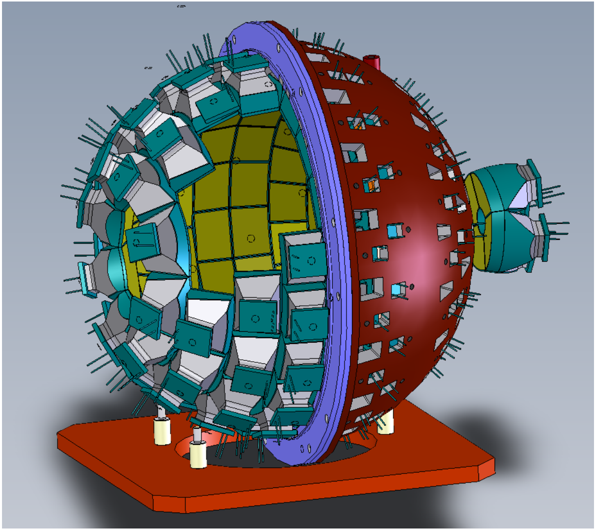


Future work: experiments with the TIP plunger



The TIP plunger device for RDM measurements, designed by Robert Henderson at TRIUMF.

Future work: TIP CsI(Tl) ball



The TIP CsI(Tl) ball, an $\sim 4\pi$ particle detector, designed by Robert Henderson at TRIUMF.

Conclusions and Summary

- Currently establishing data analysis procedures prior to attempting ^{68}Se identification.
- BGO suppression schemes are currently under investigation.
- The analysis will be geared towards identifying ^{68}Se and other nuclei where a contribution can be made by:
  1. Measuring lifetimes,
  2. building level schemes,
  3. measuring angular distributions,
  4. and measuring linear polarization.

Acknowledgements

TIP Design
R. Henderson, TRIUMF

Simon Fraser University
C. Andreoiu, R. Ashley, D. Cross, J. Pore, U. Rizwan, K. Starosta, P. Voss, J. Williams

SFU Science Machine & Electronics Shops
R. Holland, P. Kowalski, J. Shoults, K. Van Wieren

TRIUMF
G. Ball, T. Ballast, C. Bartlett, P. Bender, N. Bernier, A. Bey, C. Bolton, A. Cheeseman, S. Ciccone, A. B. Garnsworthy, G. Hackman, S. Ketelhut, R. Krücken, D. Miller, W. J. Mills, M. Moukaddam, C. Pearson, T. Proctor, M. Rajabali, E. Tardiff, C. Unsworth, Z.-M. Wang

University of Guelph
V. Bildstein, B. Hadina, B. Jigmeddorjj, A. T. Laffoley, K. G. Leach, E. T. Rand, C. Svensson

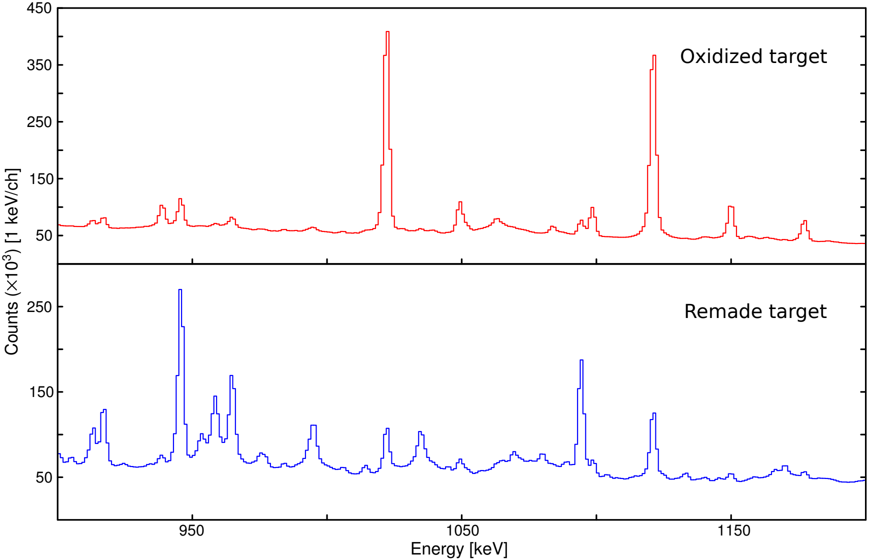
University of Toronto
T. E. Drake

University of Surrey
L. Evitts, L. Morrison

St. Mary's University
R. A. E. Austin

CINP ICPN Canadian Institute of Nuclear Physics Institut canadien de physique nucléaire
SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD
TRIUMF
NSERC CRSNG

Effect of target oxidation



Calculating particle detection efficiency: an example

- In general, if n particles are emitted, the probability to detect i is given by Eq. 1

$$P(i) = \binom{n}{i}\varepsilon^{i}(1-\varepsilon)^{n-i} \tag{1}$$

  where ε is the particle detection efficiency.

- The probability of detecting the two proton channel in the one proton gate is given by Eq. 2

$$P(\text{2p in 1p}) = \binom{2}{1}\varepsilon_{p}^{1}(1-\varepsilon_{p})^{2-1} = 2\varepsilon_{p}(1-\varepsilon_{p}) \tag{2}$$

  where ε_p is the proton detection efficiency.

- Similarly, the probability of detecting the two proton channel in the two proton gate is given by Eq. 3

$$P(\text{2p in 2p}) = \varepsilon_{p}^{2} \tag{3}$$

Calculating particle detection efficiency: an example

- Take the ratio of probabilities and solve for ε_p:

$$R = \frac{P(\text{2p in 2p})}{P(\text{2p in 1p})} = \frac{\varepsilon_p^2}{2\varepsilon_p(1-\varepsilon_p)} = \frac{\varepsilon_p}{2(1-\varepsilon_p)} \quad (4)$$

$$\Rightarrow \varepsilon_p = \frac{2R}{1+2R} \quad (5)$$

- We can calculate the proton detection efficiency for the ^{36}Ar+^{40}Ca reaction channel using the 1p1α and 2p1α gates.
- The detection probability is reflected in the number of observed gamma-rays from the nucleus of interest; in this case the 944 keV line in ^{70}Se.
- The alpha particle detection efficiency is fixed by examining the same alpha particle gate.
- 69141(437) counts in the 1p1α gate and 5996(121) counts in the 2p1α gate $\Rightarrow \varepsilon_p = 14.8(4)\%$ from Eq. 5.