



Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Studies of shape coexistence at TRIUMF-ISAC

Adam Garnsworthy

ARIEL Principal Scientist and TRIUMF Research Scientist, TRIUMF

SSNET 2016, Orsay, France

2016 November 8th

Excitation energies

- Peaks at magic numbers
- Smooth transition as move away from magic numbers

Key Question: What mechanisms drive the transition from spherical, single-particle structures to deformed, collective excitations?

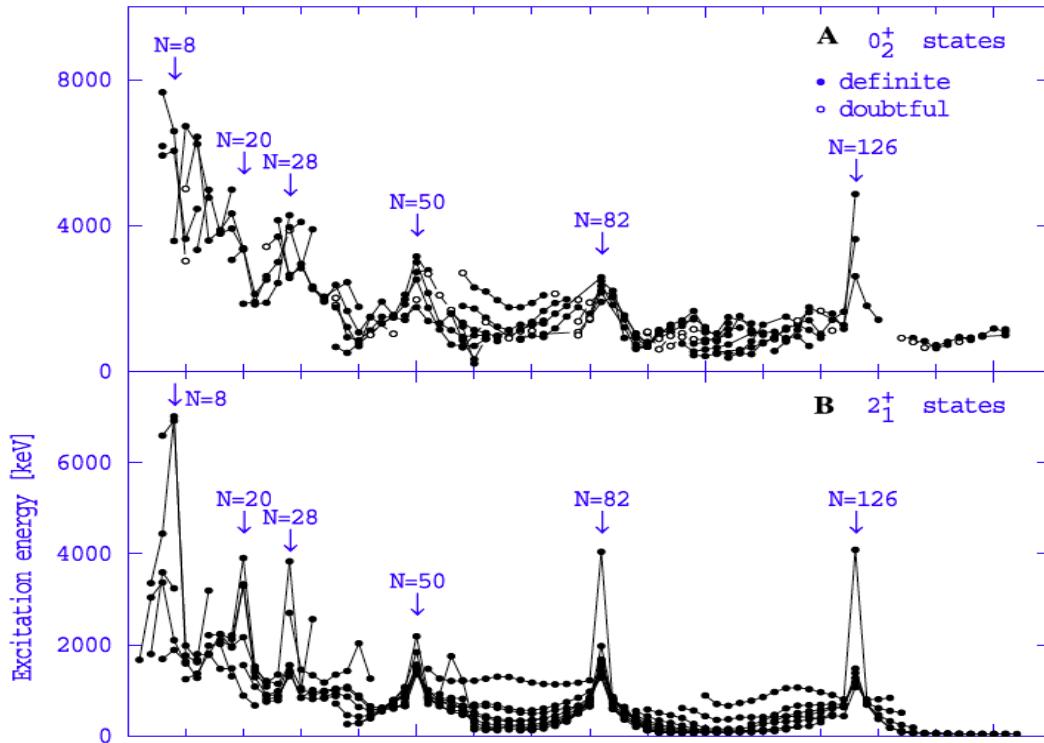
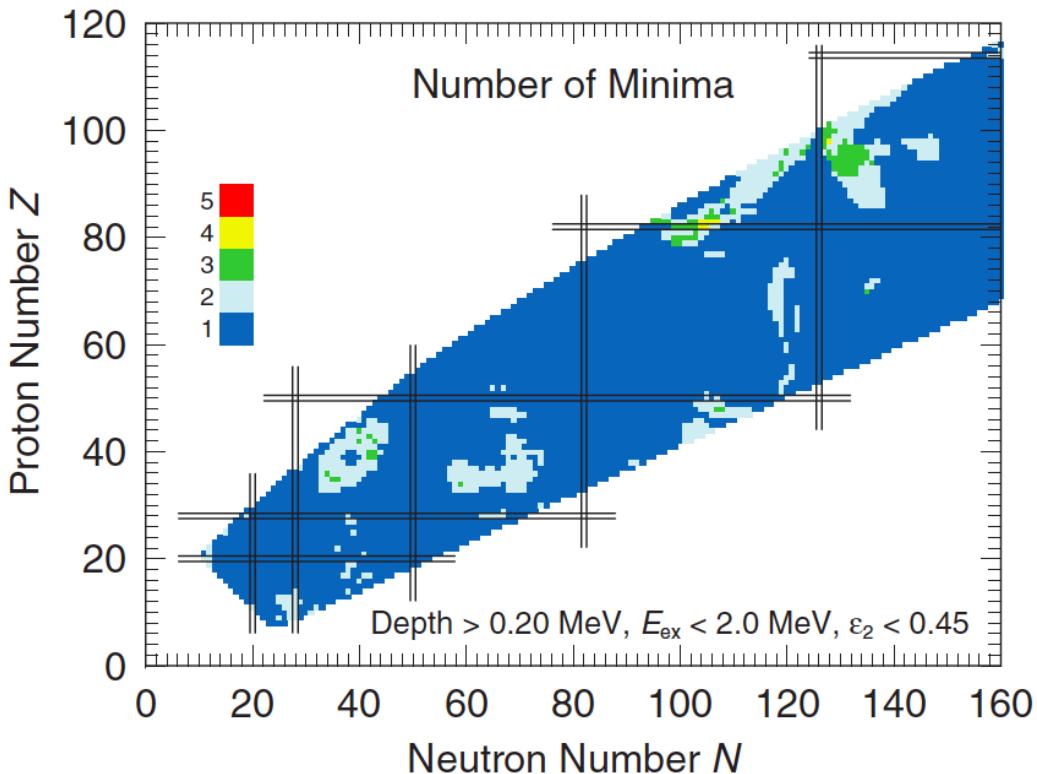
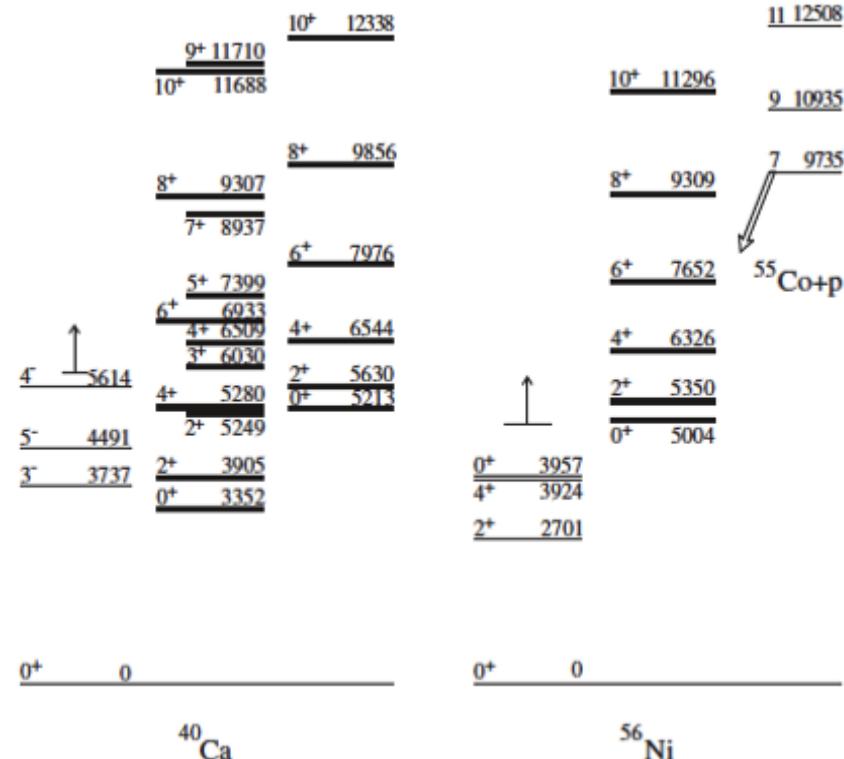


Figure from T. Kibédi and R.H. Spear, Atomic Data and Nuclear Data Tables 89, 77 (2005).



Potential-Energy Surfaces calculated using the Macroscopic-Microscopic Finite-Range Liquid Drop Model (FRLLDM), taken from P. Möller et al, PRL 103, 212501 (2009)

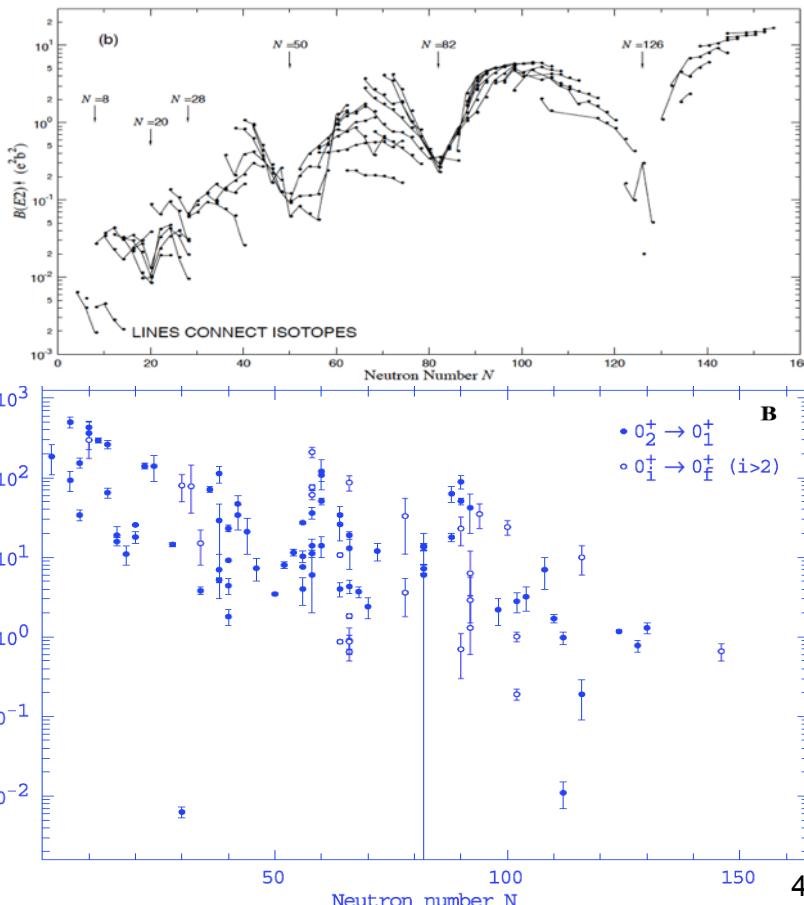
Figure from K. Heyde and J.L. Wood, Rev. Mod. Phys. 83, 1467 (2011).

Transition strengths:

- Dips at magic numbers
- Smooth transition away from magic numbers

Key Question: What mechanisms drive the transition from spherical, single-particle structures to deformed, collective excitations?

Figures from S. Raman, C.W. Nestor, JR., P. Tikkanen, Atomic Data and Nuclear Data Tables 78, 1 (2001), and T. Kibédi and R.H. Spear, Atomic Data and Nuclear Data Tables 89, 77 (2005).



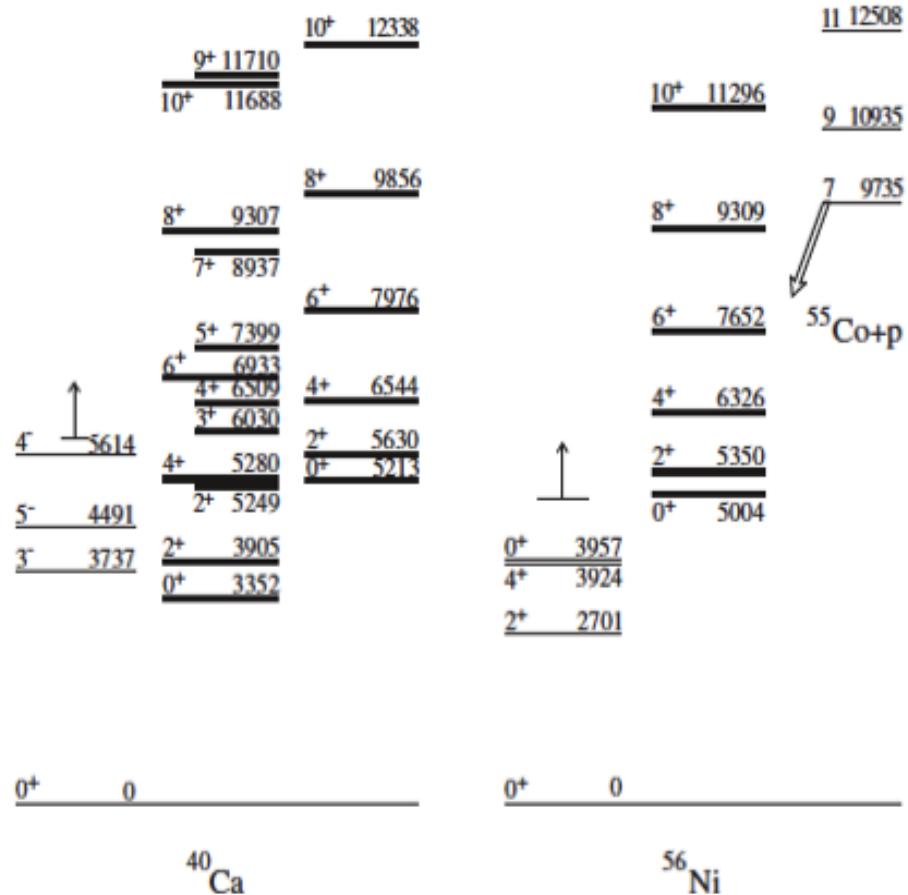


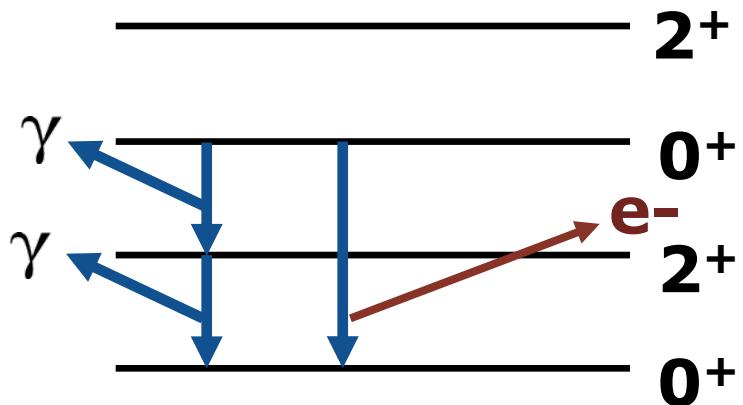
Figure from K. Heyde and J.L. Wood, Rev. Mod. Phys. 83, 1467 (2011).

Nuclei demonstrating shape coexistence are a unique laboratory.

See recent review by Heyde and Wood, Reviews of Modern Physics 83, 1467 (2011)

lack of data to make firm conclusions:
 -particle transfer
 -mean square charge radii
 - $B(E2)$, $\langle Q^2 \rangle$
 - $E0$ strengths

- **8 π , GRIFFIN**
 - High-statistics γ - γ coincidence data – Branching ratios
 - PACES: conversion electrons – $E0$ strengths
 - LaBr₃: Lifetimes, transition matrix elements
- **TIGRESS**
 - Coulomb excitation – quadrupole moments
 - Transfer reactions – spectroscopic factors
 - TIP plunger: Lifetimes, transition matrix elements
 - SPICE: conversion electrons – $E0$ strengths



$$M(E0) = \sum_k e_k r_k^2$$

e_k = effective charge

r_k = radius of k th nucleon

- Between **0⁺** states, decay only via **E0** transitions
- γ -ray decay forbidden in **E0** transitions due to angular momentum selection rules

$$\rho^2(E0) = \frac{1}{\Omega_k \tau_k}$$

$\rho^2(E0)$ is dimensionless,
given in milliunits ($\times 10^3$)

$E0$ transition strength

$$\rho^2(E0) = \frac{I_K(E0)}{I_K(E2)} \times \frac{\alpha_K(E2)}{\Omega_K(E0)} \times \frac{BR(E2_\gamma)}{\tau}$$

Lifetime of parent state

$$q^2(E0/E2) = \frac{I_K(E0)}{I_K(E2)}$$

Atomic
theory

Branching ratio of $E0/E2$ transitions

R.S. Hager & E.C. Seltzer, Nucl. Data Tables 6 (1969)

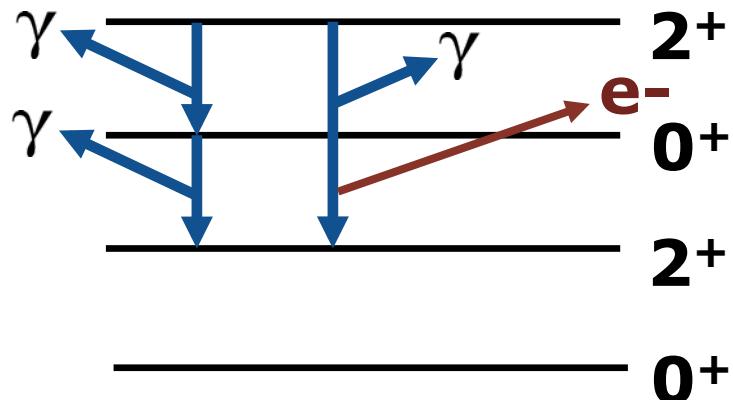
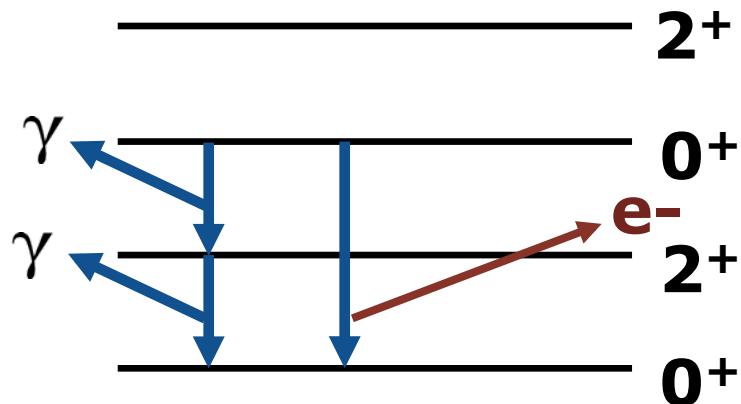
T. Kibédi *et al.*, NIM A 589 (2008)

202-229: <http://bricc.anu.edu.au/>

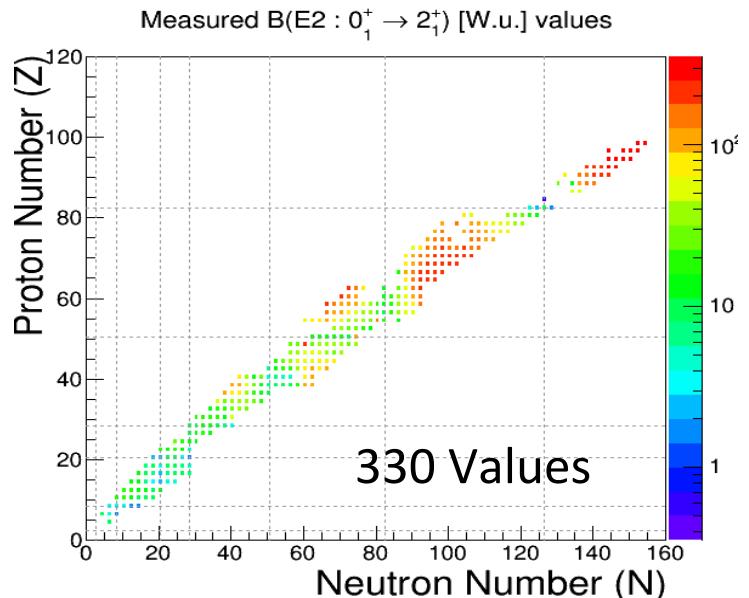
8 Nov 2016

$$\rho(E0) = \frac{\langle f | M(E0) | i \rangle}{eR^2}$$

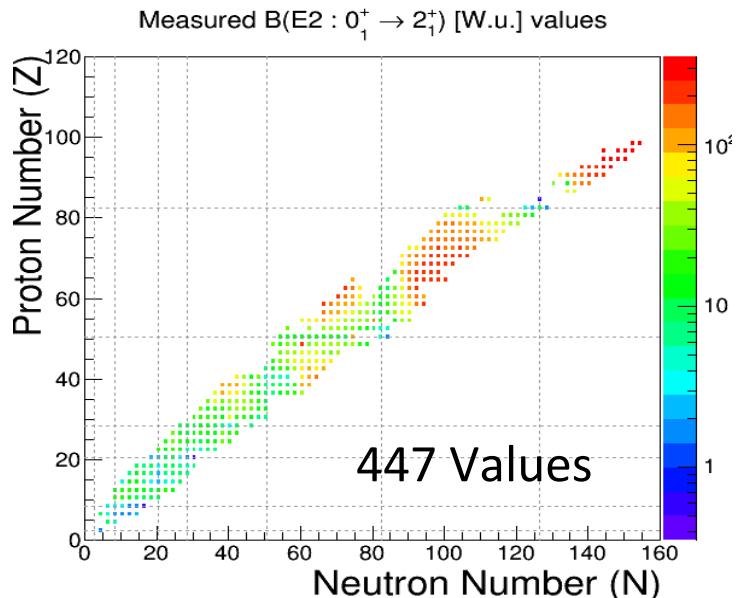
$E0$ Nuclear matrix element



- Between 0^+ states, decay only via $E0$ transitions
- γ -ray decay forbidden in $E0$ transitions due to angular momentum selection rules
- Between J^+ states, decay via $E0+M1+E2$
(γ -rays only emitted in $M1+E2$)

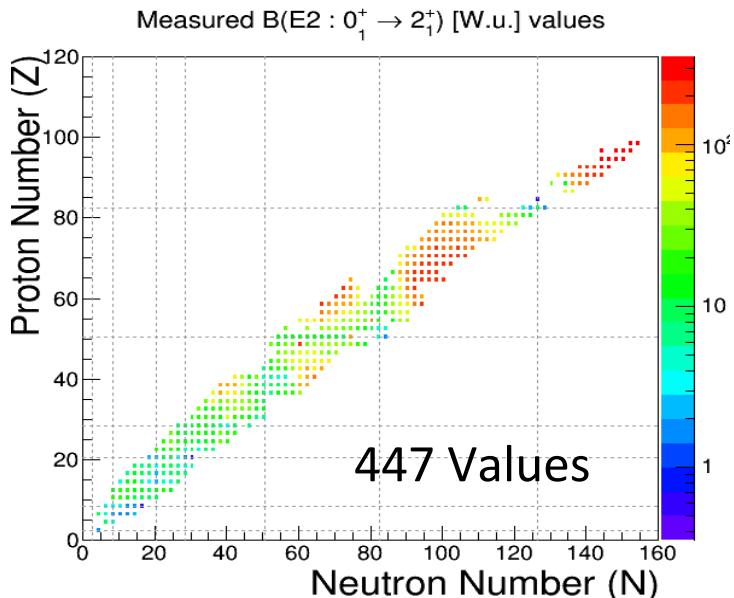


Raman *et al.*, Data Nucl. Data Tables, 78 (2001)



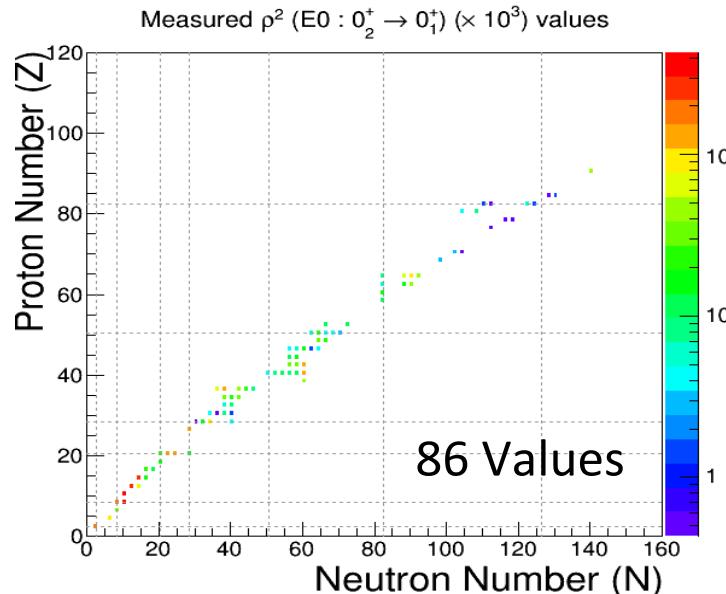
Pritychenko *et al.*, Atomic Data & Nucl. Data Tables, 107 (2016)

~120 new values in 15 years



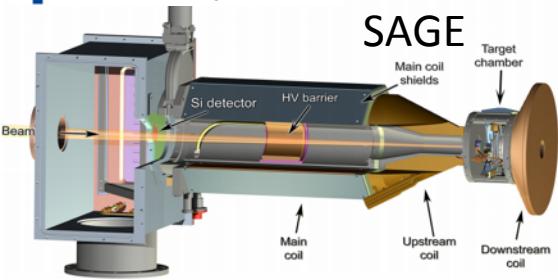
Pritychenko *et al.*, Atomic Data & Nucl. Data Tables, 107 (2016)

~120 new values in 15 years

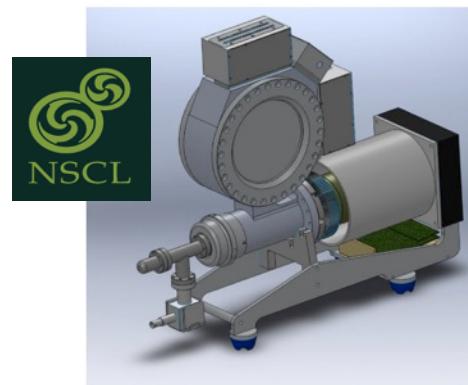


Kibédi & Spear, Data Nucl. Data Tables, 89 (2005)

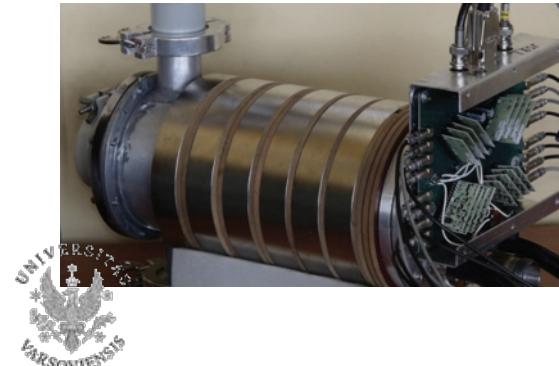
J. Pakarinen, P. Papadakis *et al.*, EPJ A 50 (2014)



N. Larson, S.N. Liddick *et al.*, NIM A 727 (2013)



Perkowski *et al.*, Rev. Sci. Instrum. 85 (2014).



S. Ketelhut, L.J. Evitts *et al.*, NIM A 753 (2014)



SSNET2016

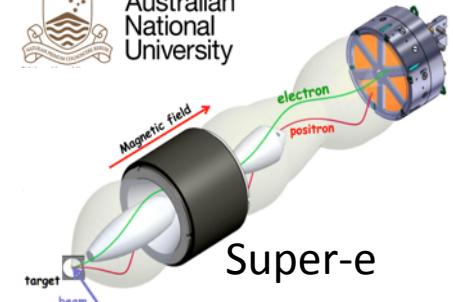
P. Papadakis, J. Pakarinen *et al.*, JPS 6 (2015)

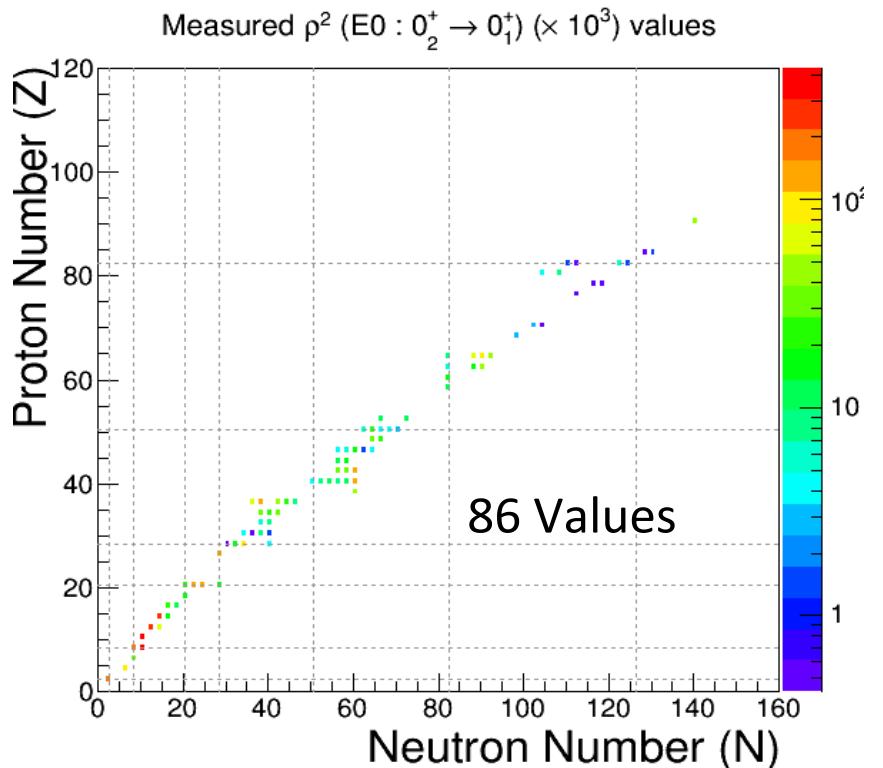


T. Kibedi, A.E. Stuchbery *et al.*, EPJ WoC 35 (2012)



Australian
National
University





15 measured $\rho^2(E0)$ in $2_2^+ \rightarrow 2_1^+$ transitions

Nuclide	$\rho^2(E0) \times 10^3$	Nuclide	$\rho^2(E0) \times 10^3$
		^{174}Hf	27(13)
^{114}Cd	36(5)	^{176}Hf	52(9)
^{150}Sm	100(40)	^{188}Os	0.7(6)
^{152}Sm	69(6)	^{194}Pt	0.46(16)
^{152}Gd	35(3)	^{196}Pt	1.0(6)
^{154}Gd	74(9)	^{230}Th	50(20)
^{156}Gd	55(5)	^{232}Th	63^{+53}_{-37}
^{172}Yb	3.1(15)	^{238}Pu	180(110)

J.L. Wood *et al.*, Nucl. Phys. A, 651 (1999) 323-368

A lot more data exists but has not been evaluated!

Spectroscopic information on pure E0 and mixed E0+E2+M1 transitions [\[edit \]](#)

Recommended evaluated and published values are from:

Pure E0: T. Kibédi and R.H. Spear, [At. Data and Nucl. Data Tables 89 \(2005\) 77](#)

E0+E2+M1: J.L. Wood, E.F. Zganjar, C. De Coster and K. Heyde, [Nucl. Phys. A651 \(1999\) 323](#)

Additional entries are from:

[J.L. Wood from available ENSDF data](#)

New review of *E0* transition strengths being undertaken by Garnsworthy, Kibédi, Wood.

Available ENSDF data has the relevant Nuclear Data Sheets citation.

Nuclide	E _i	T _{1/2}	J _i – J _f	E0	E2	δ(E2/M1)	α _K (exp)	q _K ² (E0/E2)	X(E0/E2)	10 ³ × p(E0) ²	Source	Reference
4_2He_2	20210	5.3 fs	$0^+_2 - 0^+_1$	20210	[1]					185 (77)	2005Ki02	1968Fr04 1970Wa09
$^{10}_4Be_6$	6179.3	0.8 (3) ps	$0^+_2 - 0^+_1$	6179.3	2811.3			3.4 (14)	1.1 (4)	93 (26)	2005Ki02	1969Al17 1979En05
$^{12}_6C_6$	7654.2	0.054 (7) fs	$0^+_2 - 0^+_1$	7654.2	3215.3			2.8 (4)	2.4 (4)	500 (81)	2005Ki02	1977Al31 1977Ro05
$^{14}_6C_8$	6589.4	3.0 (4) ps	$0^+_2 - 0^+_1$	6589.4	[1]					34 (5)	2005Ki02	1980To05 1991Aj01

$^{182}_{74}W_{108}$	1135.8		$0^+_2 - 0^+_1$	1135.8	1035.7			1.8 (7)	0.09 (4)		2005Ki02	1976Ki09 1995Si04
	1257.4	1.71 (13) ps	$2^+_3 - 2^+_1$	1157.3		-9 ⁺³ ₋₆	0.0092 (5)	2.31 (18)	0.162 (13)	11.8 (13)	2015Wood 2010Sl13	2015Wood 2010Sl13

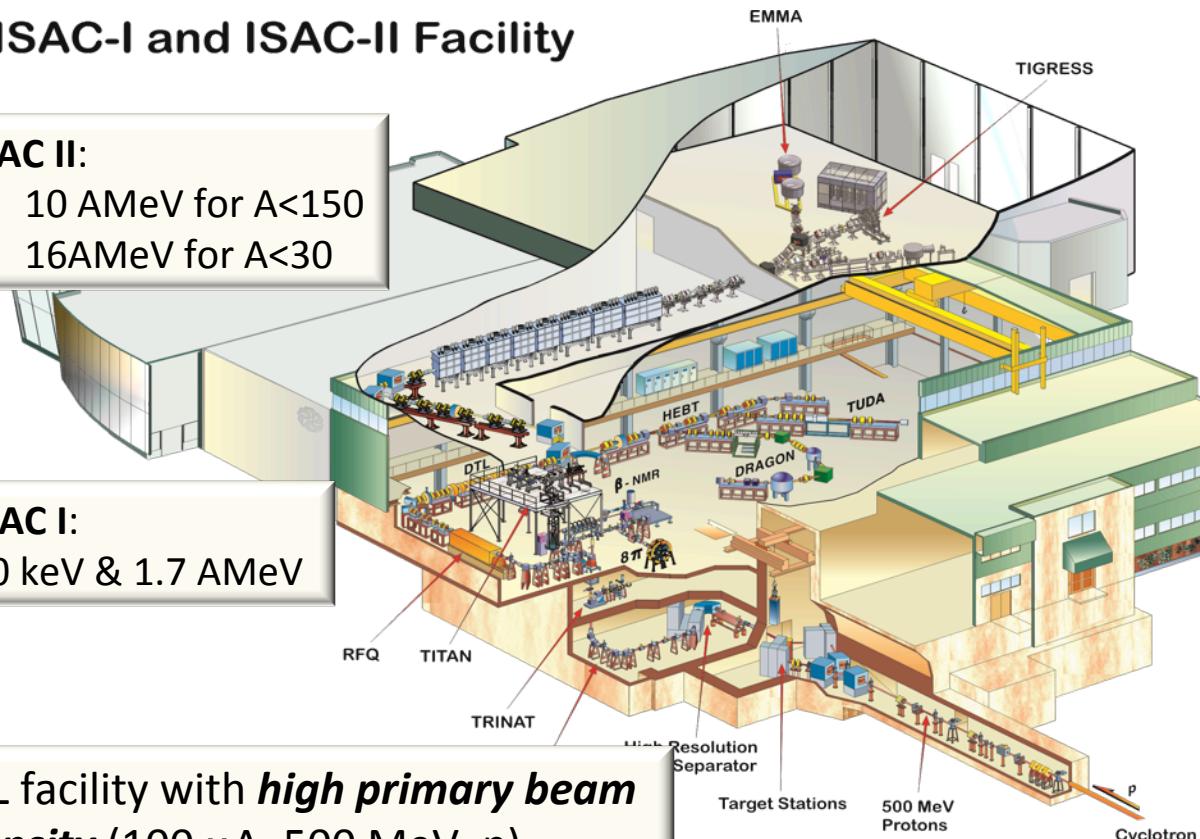
ISAC-I and ISAC-II Facility

ISAC II:

- 10 AMeV for $A < 150$
- 16 AMeV for $A < 30$

ISAC I:

60 keV & 1.7 AMeV



ISOL facility with ***high primary beam intensity*** (100 μ A, 500 MeV, p)
Delivering RIBs since 1999.

Programs in

- Nuclear Structure & Dynamics
- Nuclear Astrophysics
- Electroweak Interaction Studies
- Material Science
- 18 permanent experiments



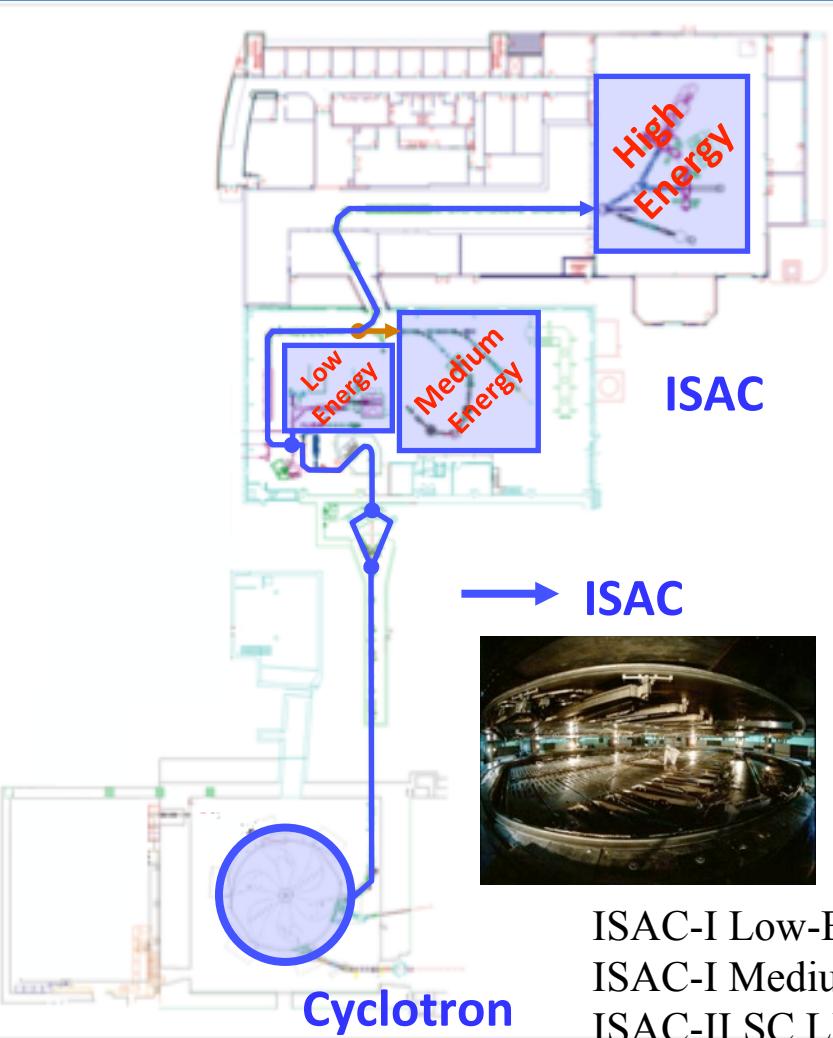
TRIUMF-ISAC

Isotope Separator and ACcelerator

1 RIB delivery to experiments

500MeV p⁺ at 100μA on ISOL target

SiC, NiO, Nb, ZrC, Ta, UC_x Targets
Surface, FEBIAD, IG-LIS ion sources



ISAC-I Low-Energy <60keV

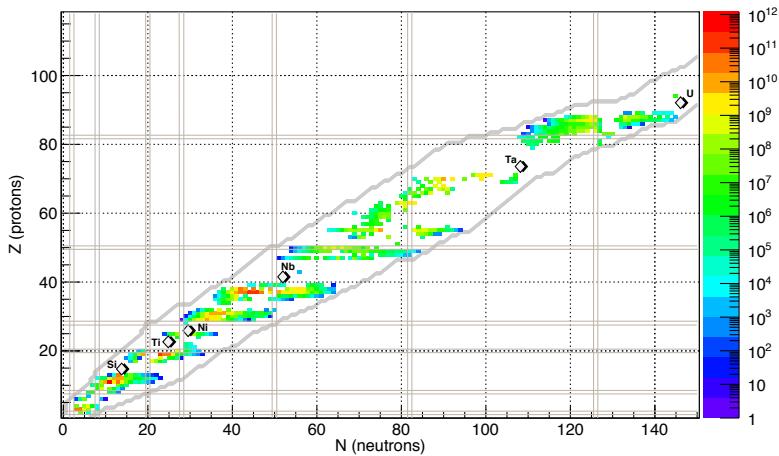
ISAC-I Medium E <1.5MeV/u

ISAC-II SC LINAC <10MeV/u

Ground state + decay, material science

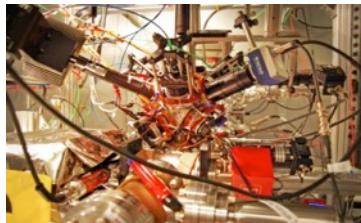
Astrophysics

Nuclear reactions and structure

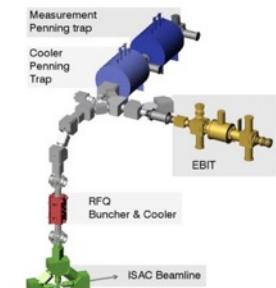
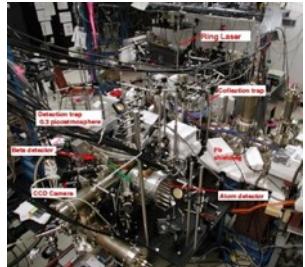


Low energy RIBs
< 60 keV

FRANCIUM MOT
(PNC, anapole moment)



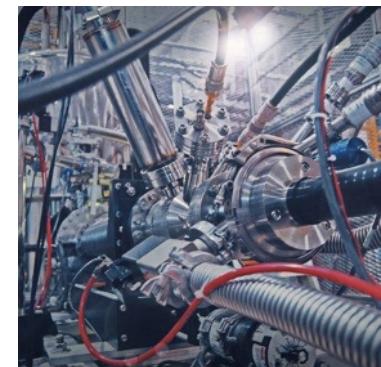
TRINAT
Neutral Atom Trap
($\beta\nu$ -neutrino correlations)



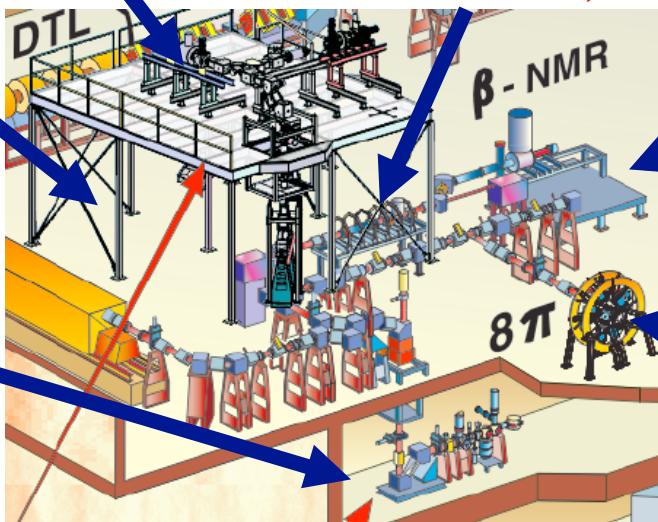
TITAN
Penning Traps
(masses,
in-trap decay)



Polarizer beamline
Laser spectroscopy, MTV
CPT test, betaNMR

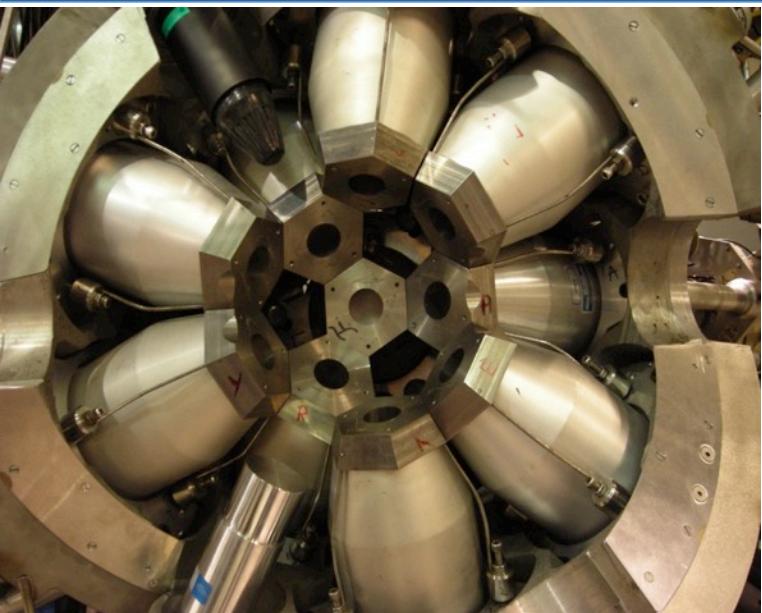


Beta-NMR
Material science



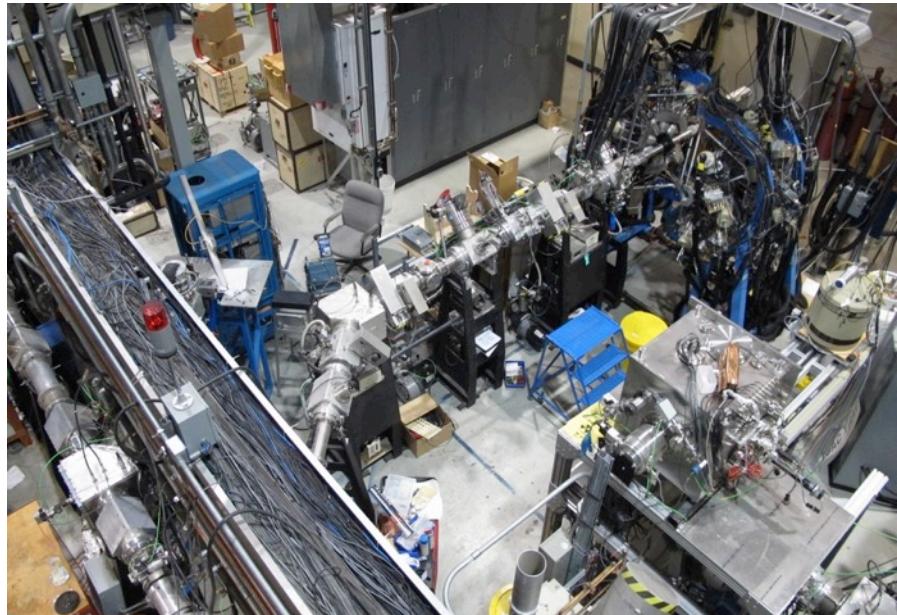
GRIFFIN
Gamma & Electron
spectrometer
(decay spectroscopy,
superallowed decays)





Researchers from 24 institutions
from 8 countries.
25 post-docs,
5PhD, 12MSc, 1MPhys
Many Grad. Students in progress

Performed decay spectroscopy at
TRIUMF-ISAC-I from 2000 to 2013



GRiffin Facility at TRIUMF



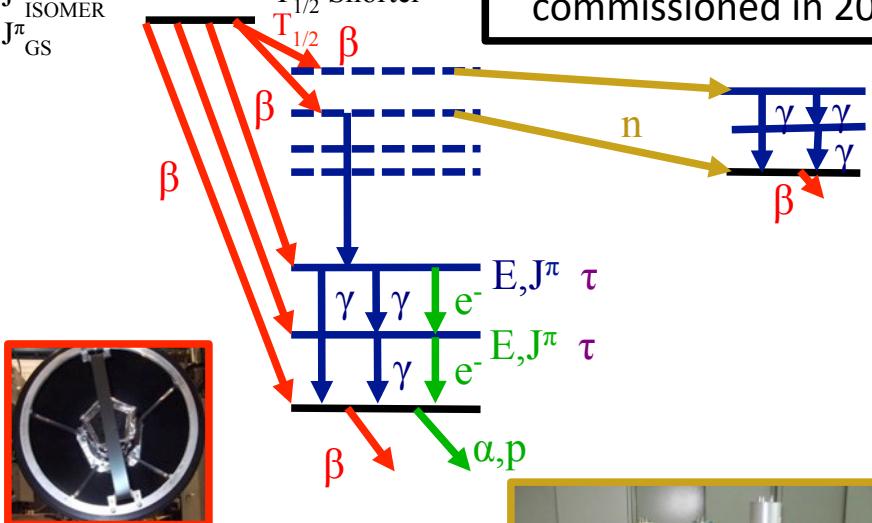
Fast, in-vacuum tape system
Enhances decay of interest

ISOBAR
 J^π ISOMER
 J^π_{GS}

— $T_{1/2}$ Longer
— $T_{1/2}$ Shorter
 $T_{1/2}$ β

See C.Andreoiu
talk tomorrow!

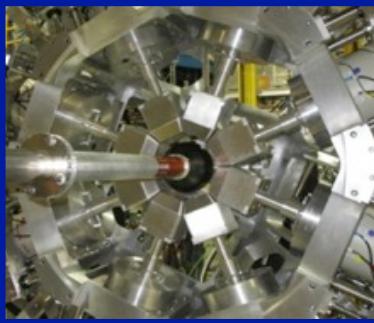
Initial operation in
fall 2014. Fully
commissioned in 2015



SCEPTAR: 10+10 plastic
scintillators
Detects beta decays and
determines branching ratios



DESCANT Neutron array
Detects neutrons to measure beta-delayed neutron branching ratios



HPGe: 16 Clovers
Detect gamma rays and
determines branching ratios,
multipolarities and mixing ratios

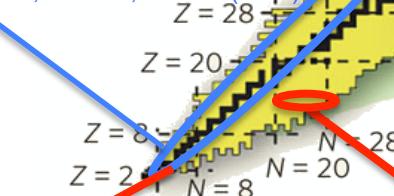


Zero-Degree Fast scintillator
Fast-timing signal for betas



PACES: 5 Cooled Si(Li)s
Detects Internal Conversion
Electrons and alphas/protons

Superallowed/Mirror Beta Decay
 ^{10}C , ^{14}O , ^{18}Ne , ^{19}Ne , ^{26m}Al , ^{38m}K , ^{62}Ga , ^{74}Rb
M.R. Dunlop et al., PRL 116, 172501 (2016).
A.T. Laffoley et al., PRC 92, 025502 (2015)
G.C. Ball, Hyp. Int 225, 133 (2014)
R. Dunlop et al., PRC 88, 045501 (2013)
G.F. Grinyer et al., PRC 87, 045502 (2013)
A.T. Laffoley et al., PRC 88, 015501 (2013)
P. Finlay et al., PRC 85, 055501 (2012)
S. Triambak et al., PRL 109, 042301 (2012)
P. Finlay et al., PRL 106, 032501 (2011)
G.F. Grinyer et al., NIM A622, 236 (2010)
P. Finlay et al., PRC 78, 025502 (2008)
K.G. Leach et al., PRL 100, 192504 (2008)
G.F. Grinyer et al., PRC 77, 015501 (2008)
G.F. Grinyer et al., PRC 76, 025503 (2007)
G.F. Grinyer et al., NIM A579, 1005 (2007)
E.F. Zganyar et al., Acta Phys.Pol. B38, 1179 (2007)
B. Hyland et al., PRL 97, 102501 (2006)
B. Hyland et al., AIP Conf.Proc. 819, 105 (2006)
B. Hyland et al., J. Phys. G31, S1885 (2005)
G.F. Grinyer et al., PRC 71, 044309 (2005)
A. Piechaczek et al., PRC 67, 051305 (2003)



^{11}Li beta-delayed neutron emission

C.M. Mattoon et al., PRC 80, 034318 (2009)
F. Sarazin et al., PRC 70, 031302 (2004)

High-statistics studies of Cd, Sn, Xe

B. Jigmeddorj et al., Eur. Phys. J. A 52, 36 (2016).
B. Jigmeddorj, et al., EPJ Web Conf. 107, 03014 (2016).
A.J. Radich et al., PRC 91, 044320 (2015)
P.E. Garrett et al., PRC 86, 044304 (2012)
P.E. Garrett et al., Acta Phys.Pol. B42, 799 (2011)
P.E. Garrett et al., AIP Conf.Proc. 1377, 211 (2011)
K.L. Green et al., PRC 80, 032502 (2009)

Half Life of geochronometer, ^{176}Lu

G.F. Grinyer et al., PRC 67, 014302 (2003)

Isomer decay in ^{174}Tm , ^{178}Hf , ^{179}Lu

R.S. Chakrawarthy et al., PRC 73, 024306 (2006)
R.S. Chakrawarthy et al., EPJ. A 25, S1, 125 (2005)
M.B. Smith et al., NPA746, 617c (2004)
M.B. Smith et al., PRC 68, 031302 (2003)

Large Beta-Delayed neutron branching ratio observed from ^{102}Rb

Z.M.Wang et al., PRC 93, 054301 (2016).

Shape coexistence in neutron-rich Sr, Zr

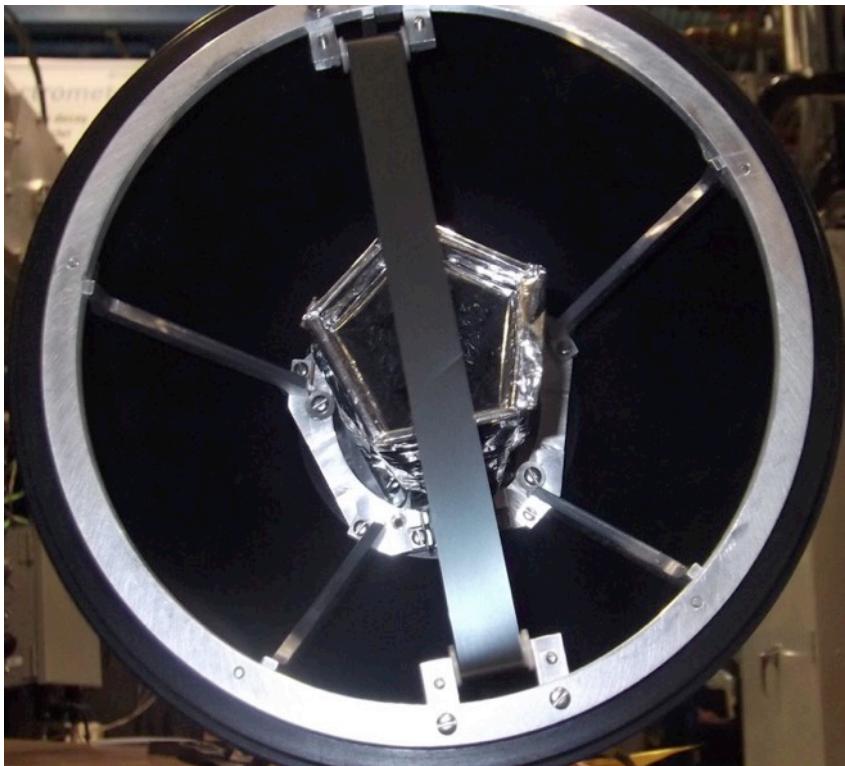
J. Park et al., PRC 93, 025802 (2016).
A. Chakraborty et al., PRL 110, 022504 (2013)

Technical and Overview Publications

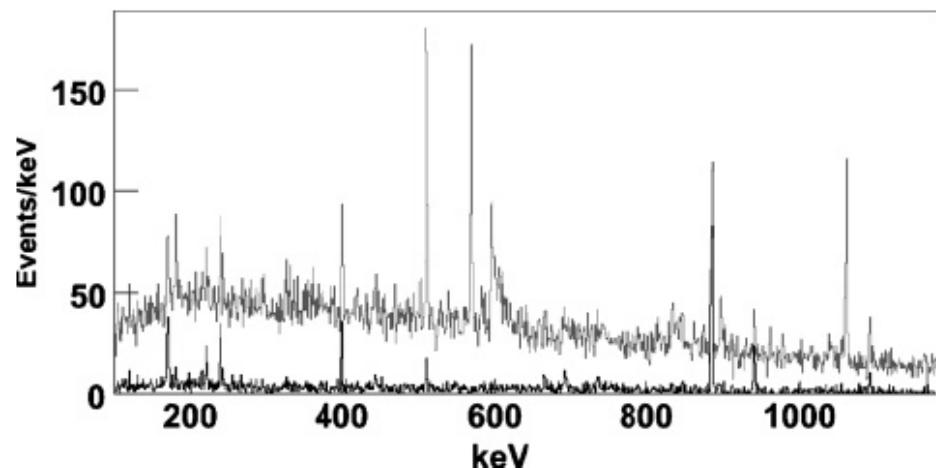
A.B.Garnsworthy, EPJ Web of Conf.s 93, 01032 (2015)
P.E. Garrett et al., J. of Phys. Conf. Series 639, 012006 (2015).
A.B. Garnsworthy and P.E. Garrett, Hyp. Int. 225, 121 (2014)
G.C. Ball et al., J.Phys.:Conf.Ser. 387, 012014 (2012)
D S Cross et al., JINST 6, P08008 (2011)
P.E. Garrett et al., NIM Phys.Res. B261, 1084 (2007)
G.C. Ball et al., J.Phys.(London) G31, S1491 (2005)
S.J. Williams et al., J.Phys.(London) G31, S1979 (2005)
C.E. Svensson et al., NIM Phys. Res. B204, 660 (2003)

Island of inversion, ^{32}Mg

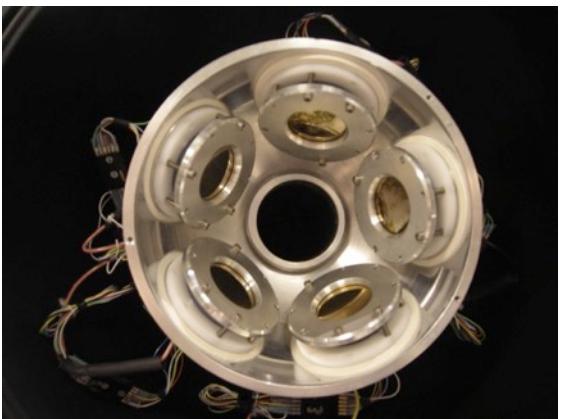
C.M. Mattoon et al., PRC 75, 017302 (2007)



- Two hemispheres of 10 plastic scintillators
- Detects beta particles with ~80% solid angle coverage
- Improves peak-to-background of HPGe spectra



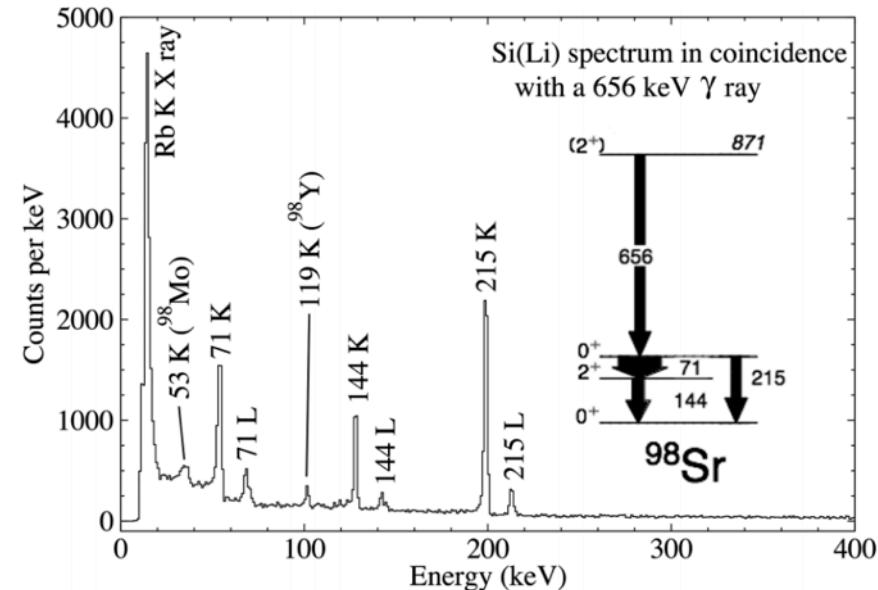
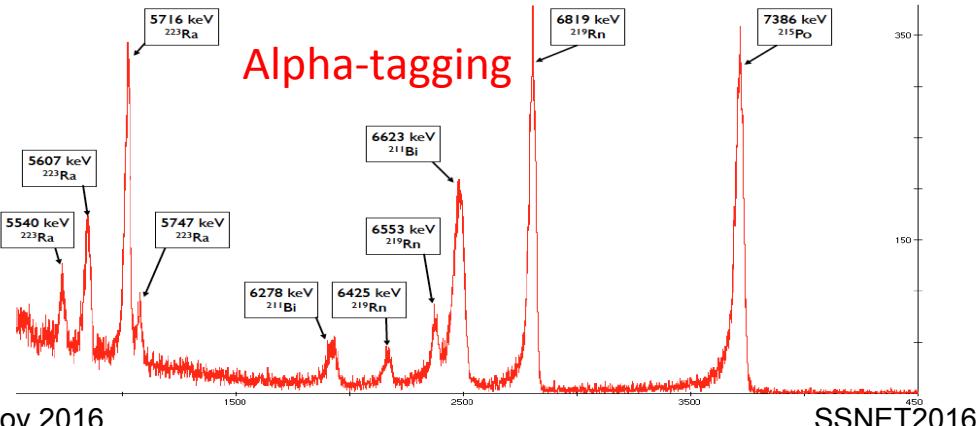
C.M.Mattoon et al., PRC75, 017302 (2007)

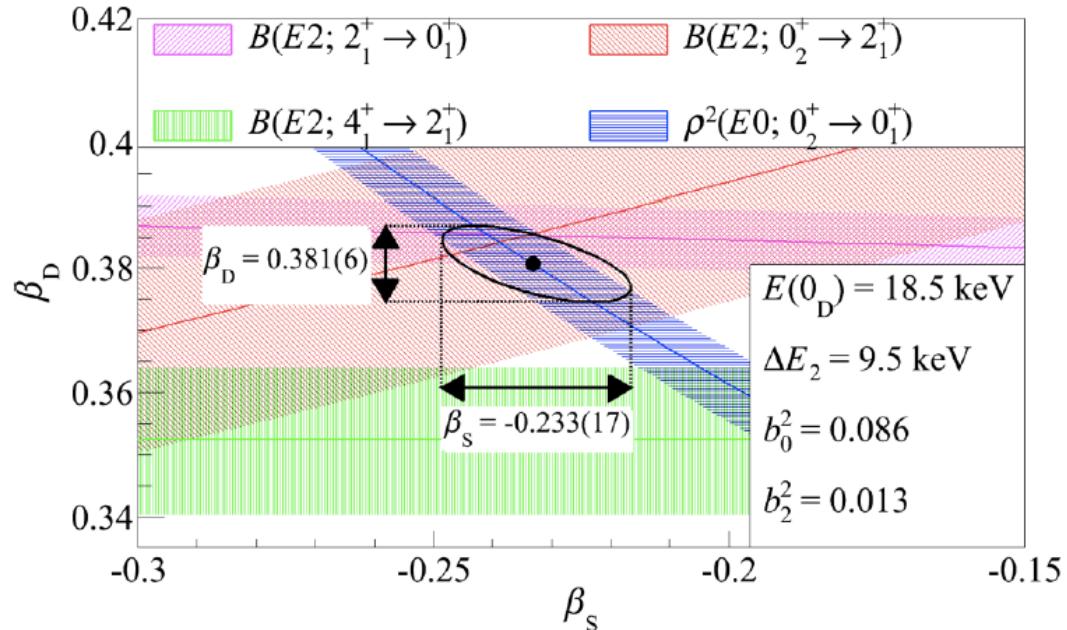
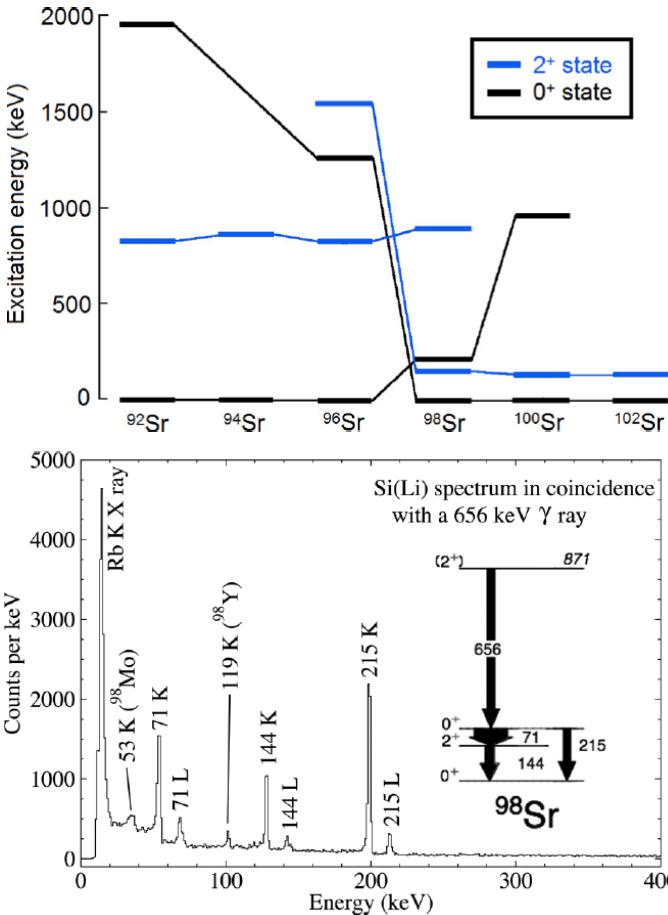


Five 5mm thick, 200mm² Si(Li), LN₂-cooled Si diode and FET

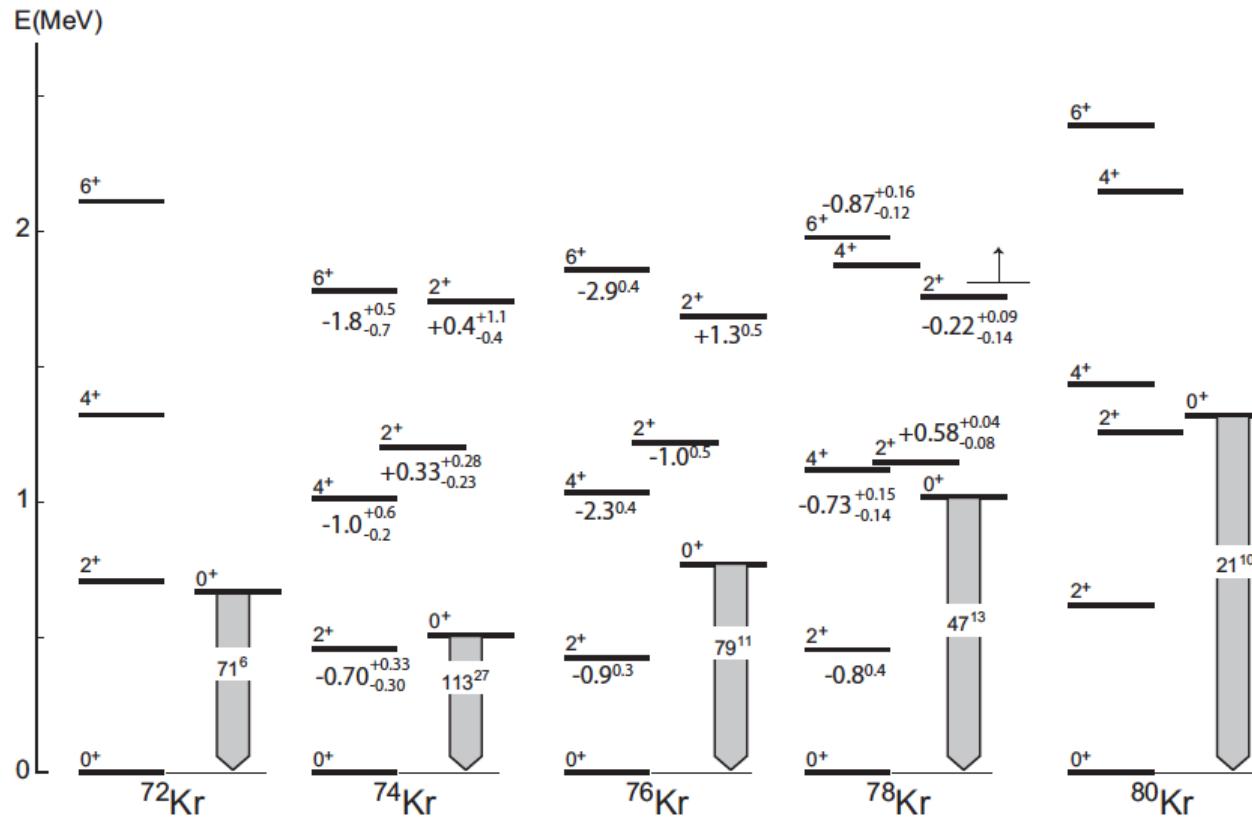
Solid angle coverage: 1.4% each, 7% total

~2keV resolution for electrons





Minimization in two-state mixing using all available experimental data indicates:
9% mixing of 0^+ state, 1.3% in 2^+ states.
Deformation difference in β of 0.38.



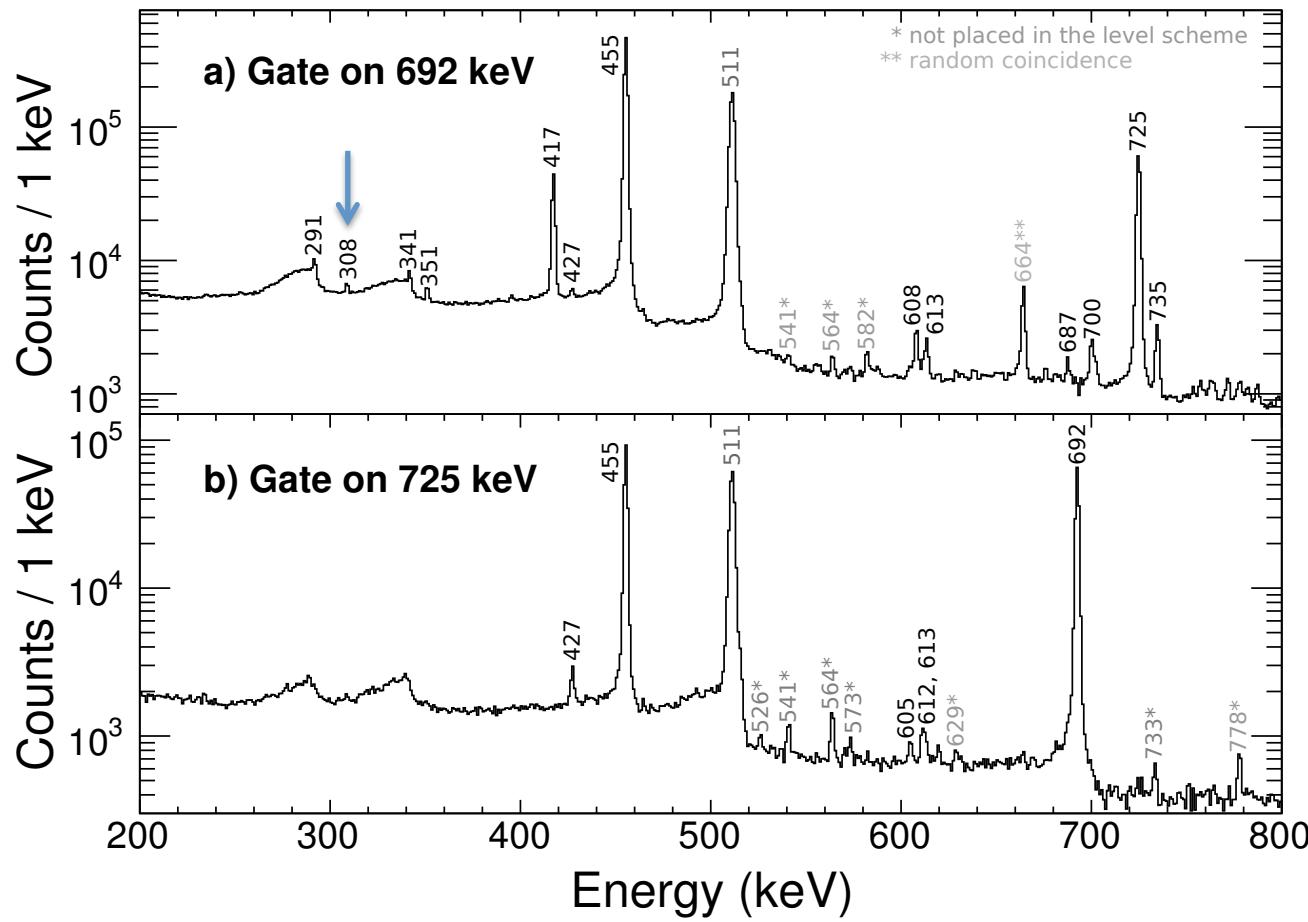
E. Clement *et al.*, Phys. Rev. C 75, 054313 (2007).

F. Becker *et al.*, Nucl. Phys. A 770, 107 (2006).

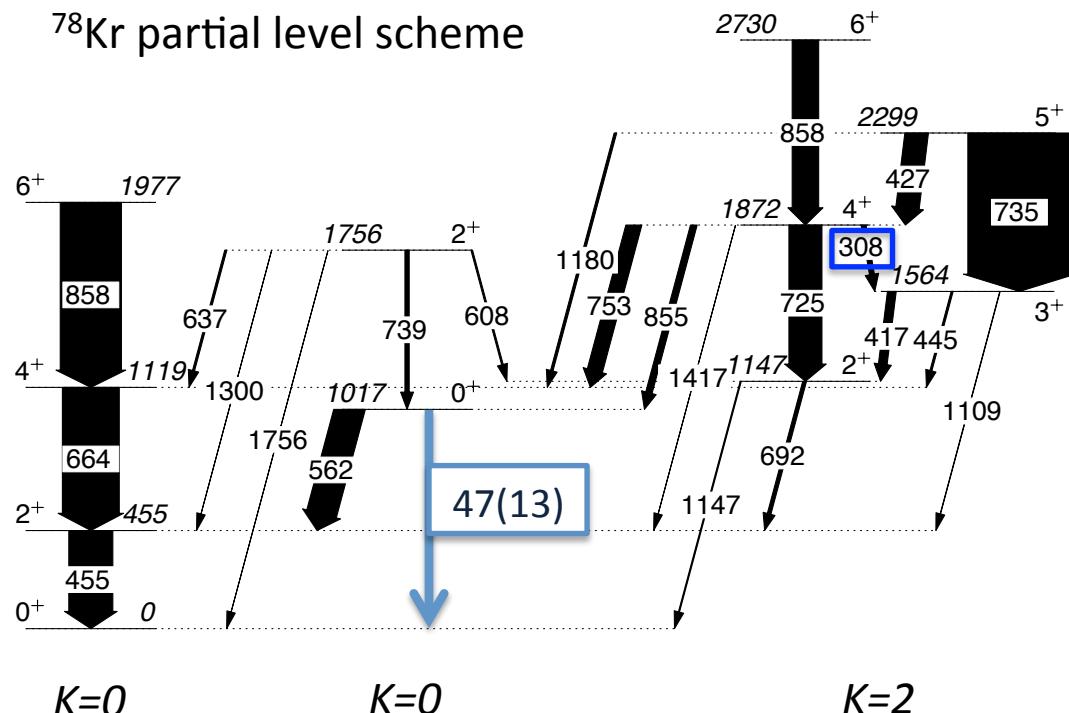
8 Nov 2016

SSNET2016

25



308keV is 0.07%
the intensity of
the 455keV 2-0

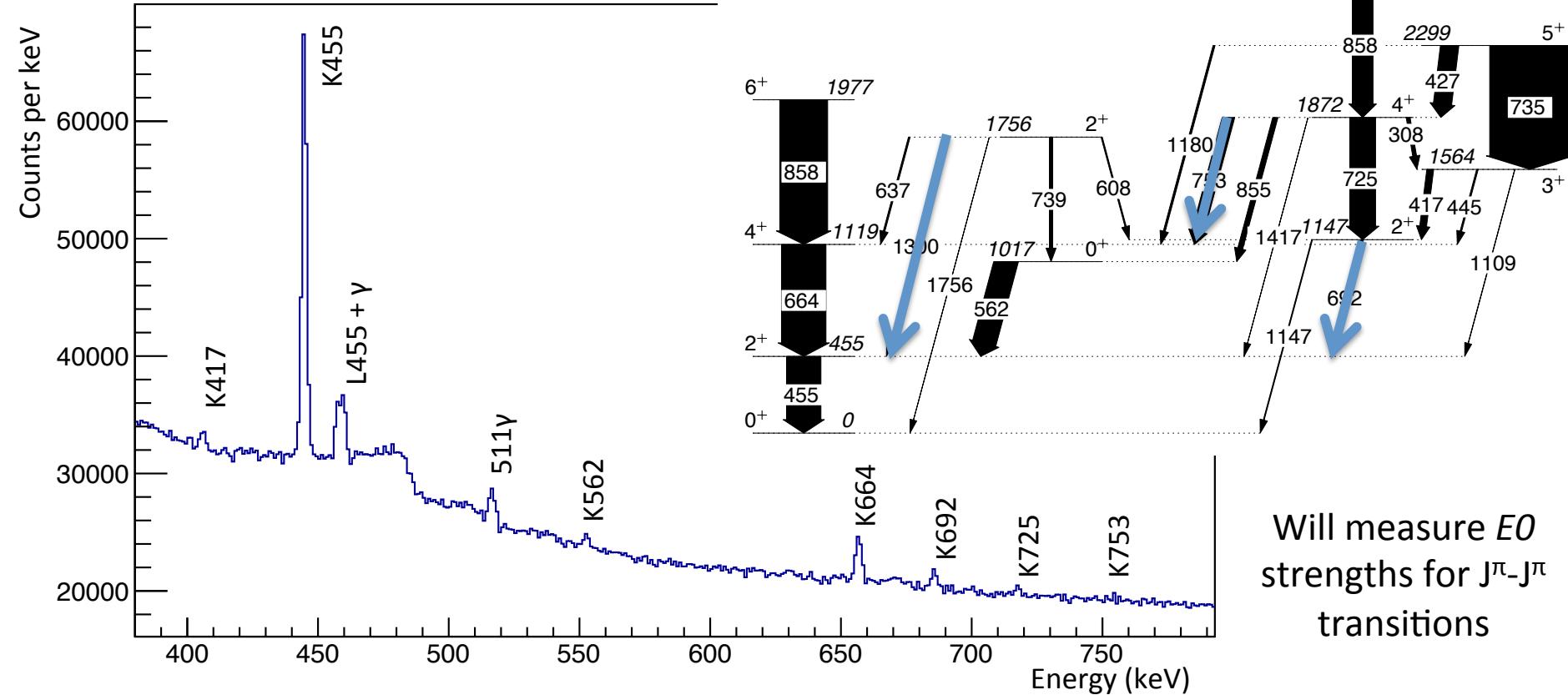
^{78}Kr partial level scheme

Observed 308keV transition for first time.

Mostly confirmed branching ratios from previous beta decay study. Some revised.

No evidence found for the $K=2$ band actually being a $K=0$ band.

Electron singles in PACES



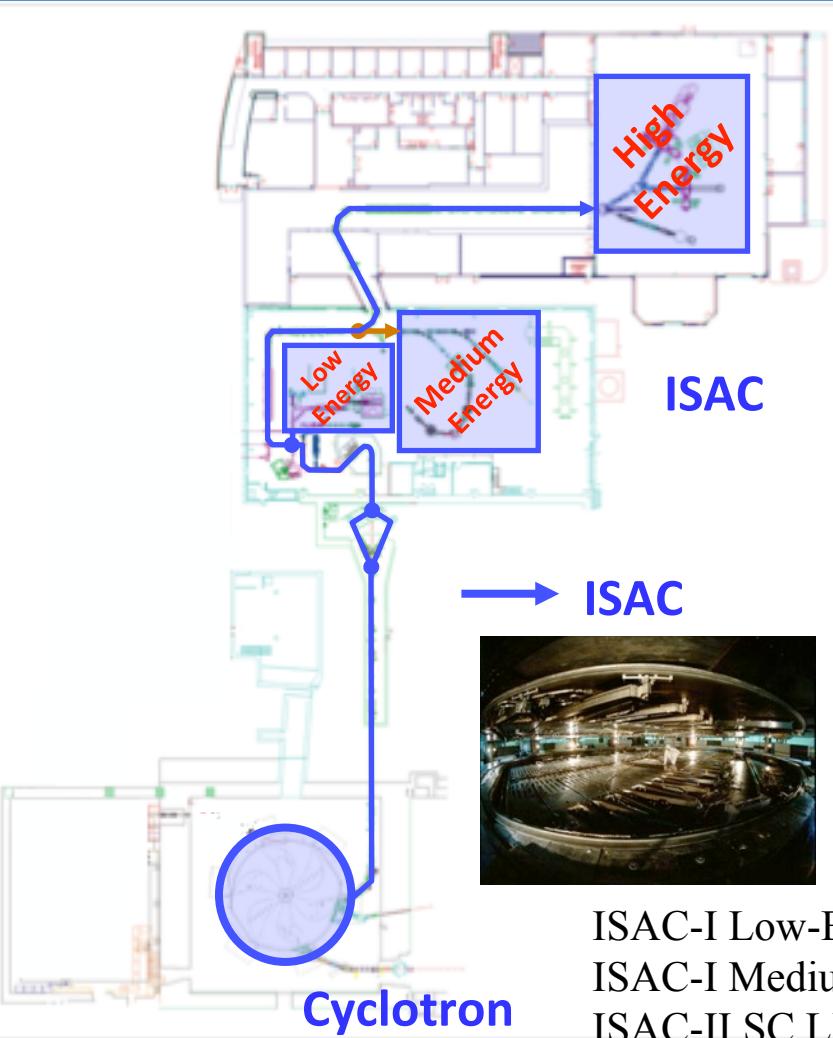
TRIUMF-ISAC

Isotope Separator and ACcelerator

1 RIB delivery to experiments

500MeV p⁺ at 100μA on ISOL target

SiC, NiO, Nb, ZrC, Ta, UC_x Targets
Surface, FEBIAD, IG-LIS ion sources



ISAC-I Low-Energy <60keV

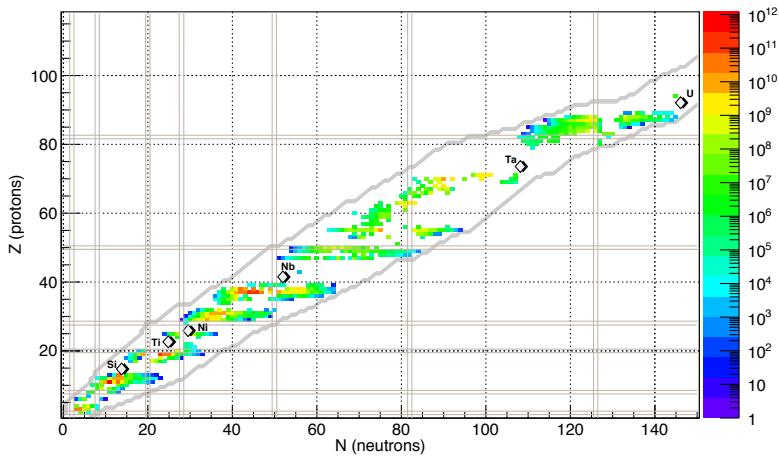
ISAC-I Medium E <1.5MeV/u

ISAC-II SC LINAC <10MeV/u

Ground state + decay, material science

Astrophysics

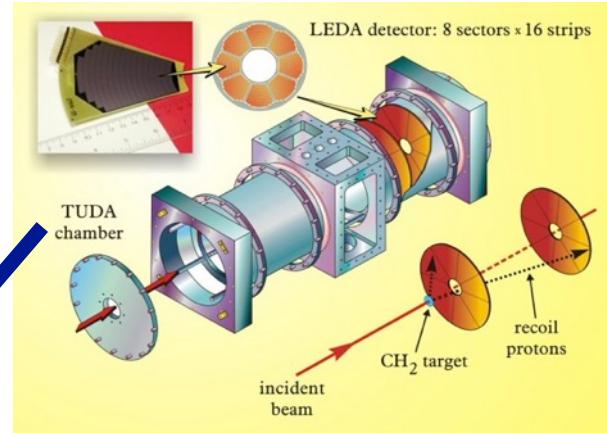
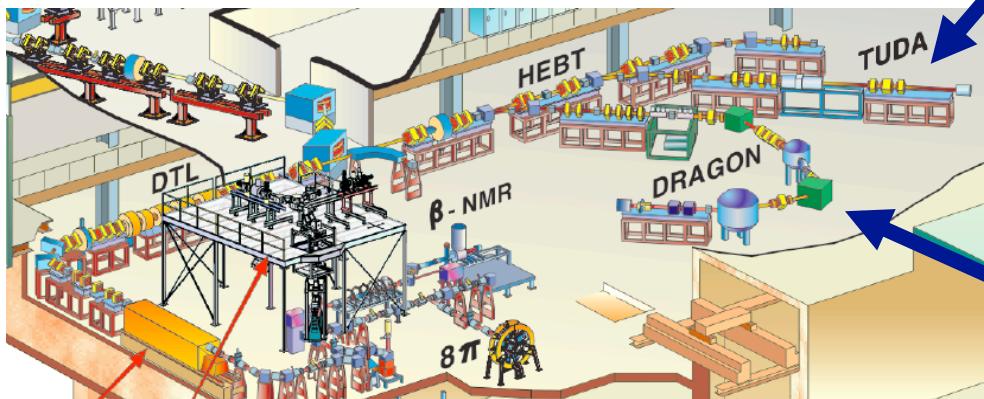
Nuclear reactions and structure



Medium energy RIBs
~ 0.15 - 1.7 AMeV

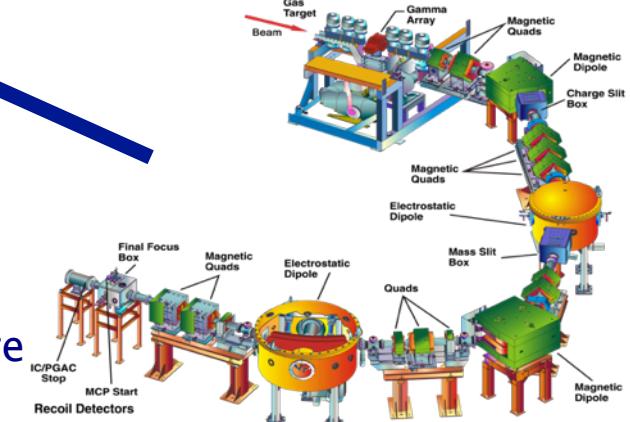
TUDA

Astrophysical charged particle reactions



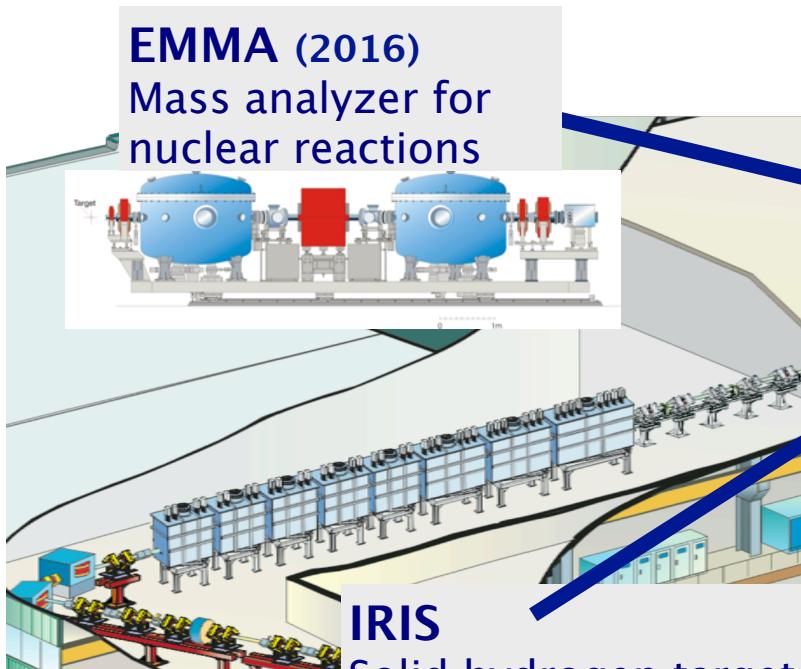
DRAGON

Astrophysical capture reactions



High-energy RIBs > 6 AMeV

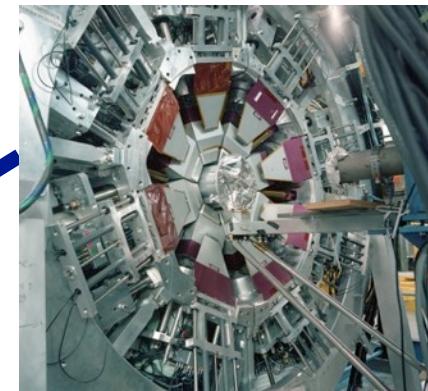
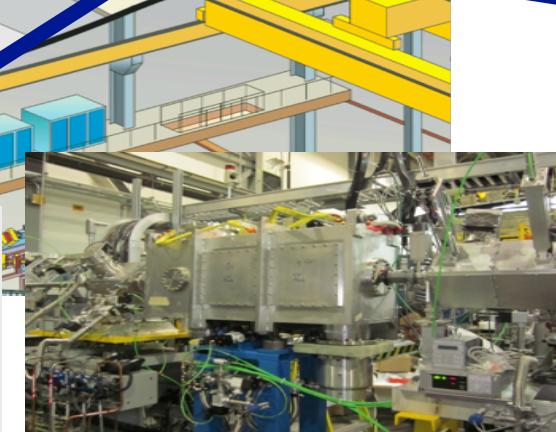
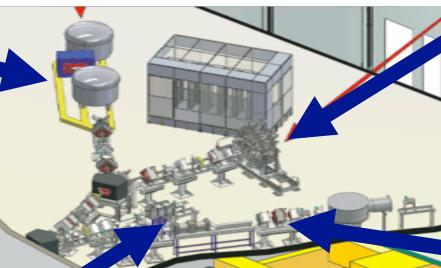
EMMA (2016)
Mass analyzer for
nuclear reactions



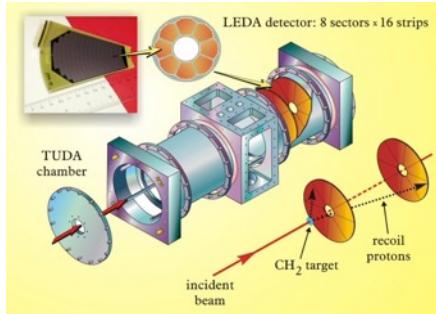
IRIS
Solid hydrogen target
for direct nuclear
reactions

TIGRESS + auxiliary detectors

HPGe γ -ray spectrometer
in-beam spectroscopy of
nuclear reactions



TUDA
Scattering array
for direct reactions



16 Compton-Suppressed segmented HPGe Clovers with digital DAQ

SHARC Silicon barrel

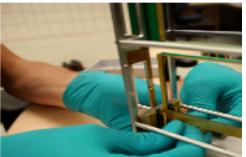
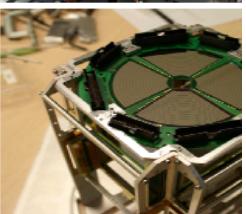
Studies with accelerated RIBs 0.5-15MeV/u

downstream of reaction target (York Micron).

- Length: 72 mm (24 strips)
- Width: 48 mm (48 strips)
- Upstream 1000 μm
- Downstream 140 μm + 1500 μm .

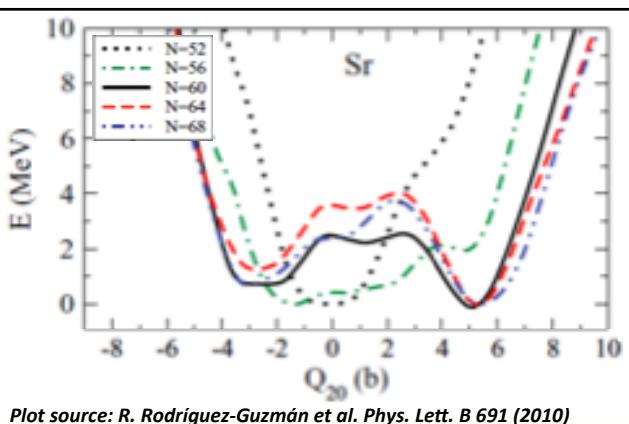
Iron QQQ2 CD detector (A.A. Chen, Master)

- 4 sectors, active area:
- 9.0 mm to 41 mm radius (16 rings)
- 81.6° (24 radial strips)
- Thickness: 300–400 μm .



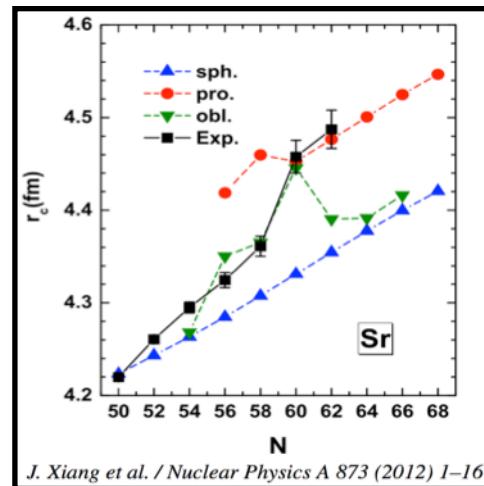
Shape Coexistence at Z~40 N~60

- Beyond mean field calculations predict binding energy as a function of deformation.
- Measurements of single particle levels in $^{95,96,97}\text{Sr}$ essential for a detailed description of this transitional region.



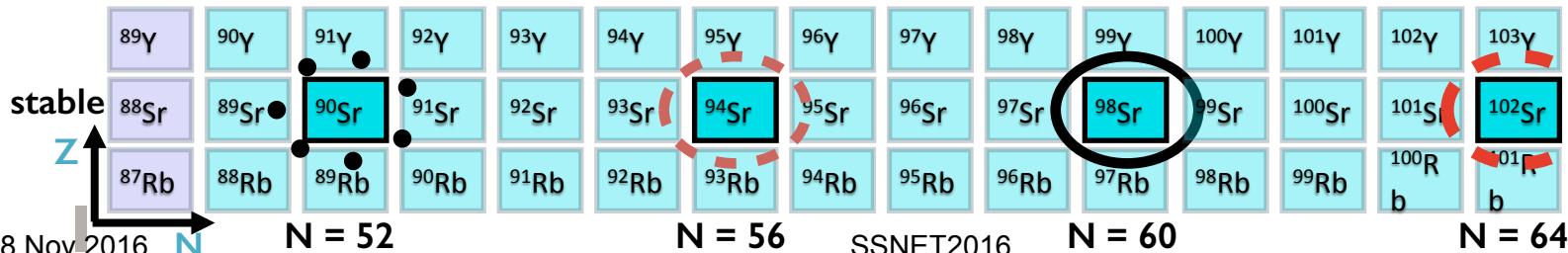
Predicted

Binding energy curves predict almost degenerate potential minima at $N = 60$.



Observed

Sudden increase in charge radius suggests change of ground state shape

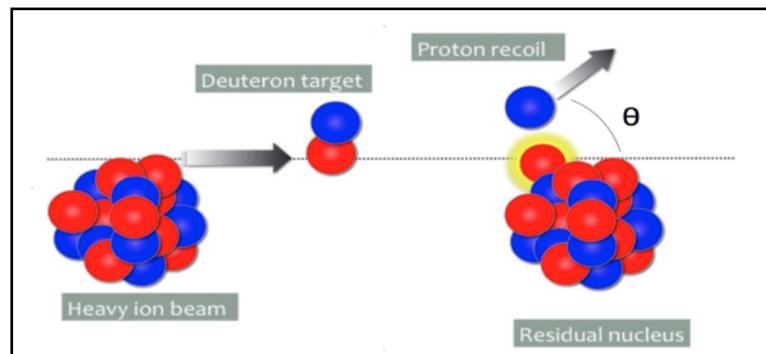


neutron drip line $A > 107$

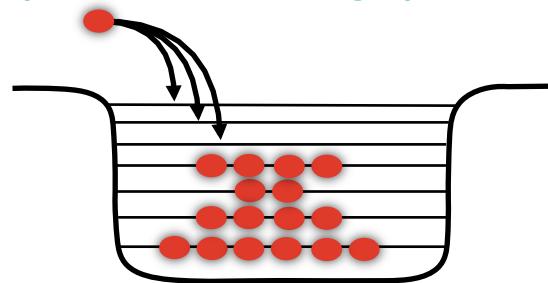
$^{94,95,96}\text{Sr}(d,p)\text{Sr}$ reactions to study evolution of structure in Sr through low energy single particle states.

Aims

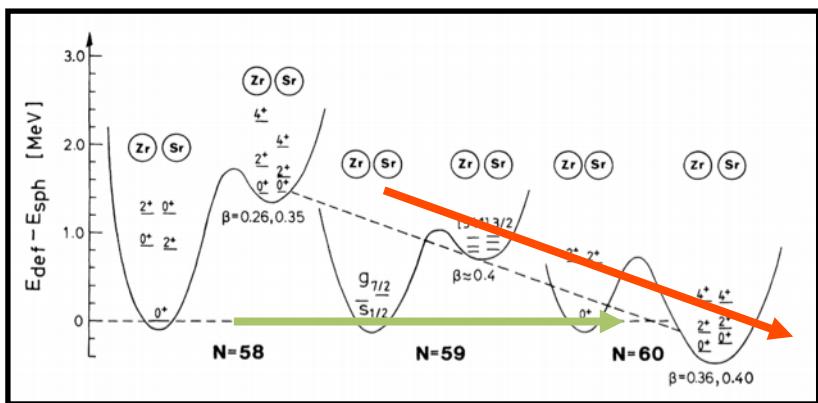
- Measure angular momentum transfer of Sr states ($d\sigma/d\Omega$).
- Measure cross section, which gives a orbital occupation number.
- Compare occupation numbers to large scale shell model calculations that will be carried out in collaboration with shell model experts.



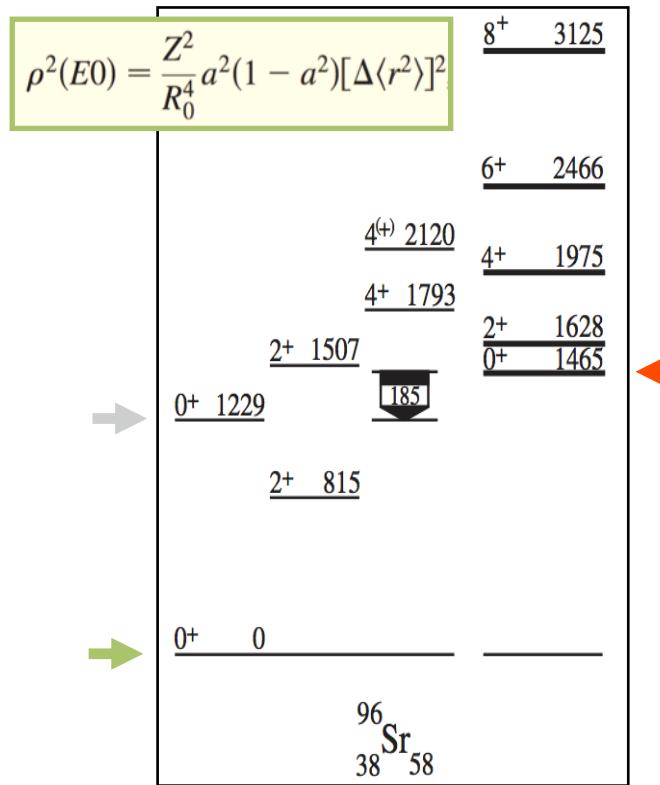
Neutron populates one of the single particle orbitals



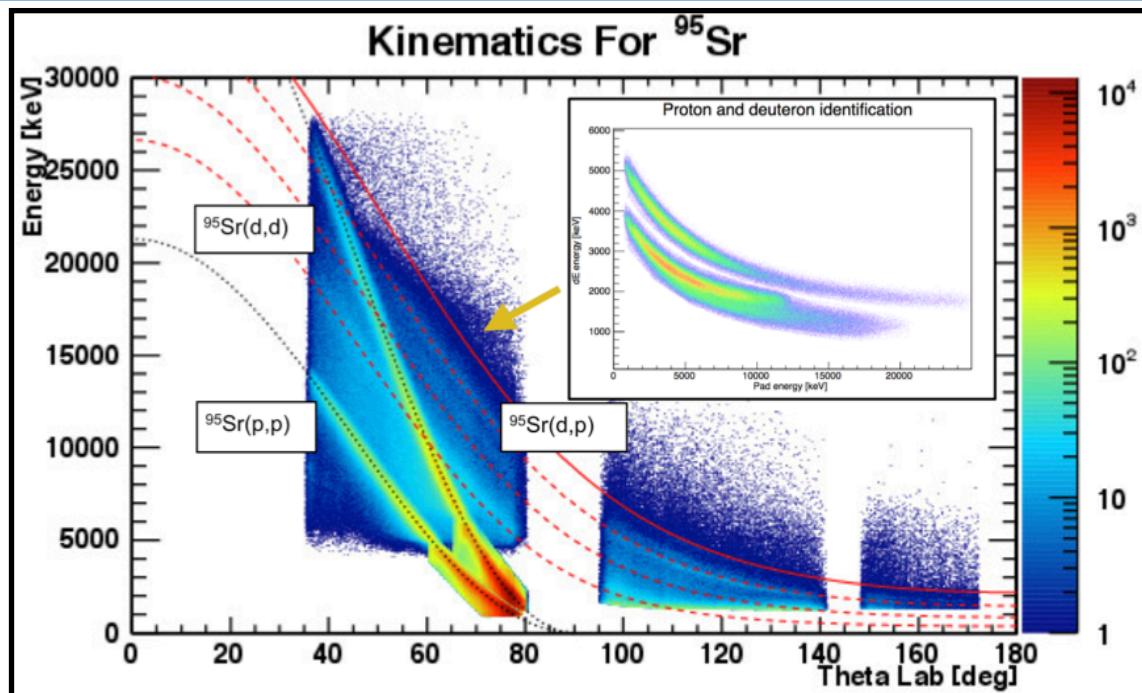
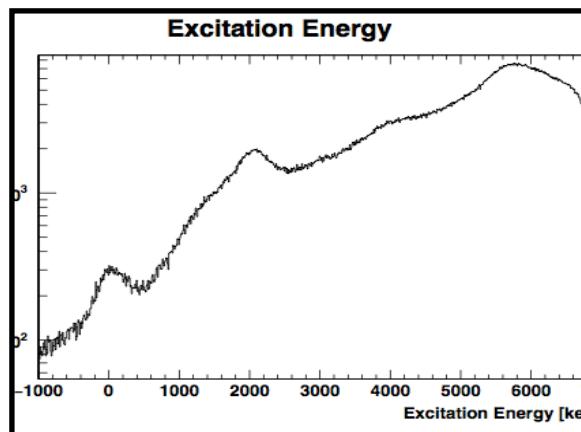
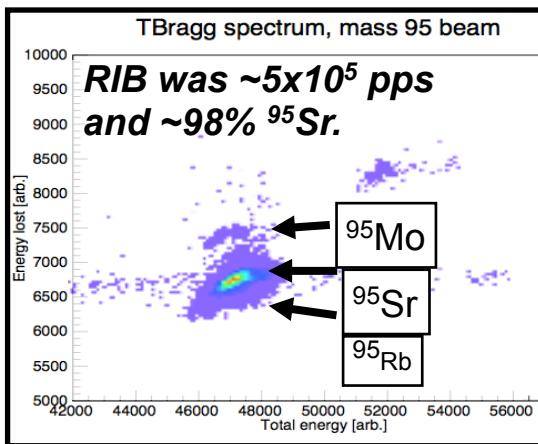
- The strong 0_3^+ (1465 keV) $\rightarrow 0_2^+$ (1229 keV) E0 transition is characteristic of coexisting shapes.
- The deformed 0_3^+ state at 1465 keV is expected to be the same structure as the ^{98}Sr ground state.



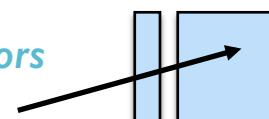
G. Lhersonneau *et al.*, Phys. Rev. C 49, (1994) 1379

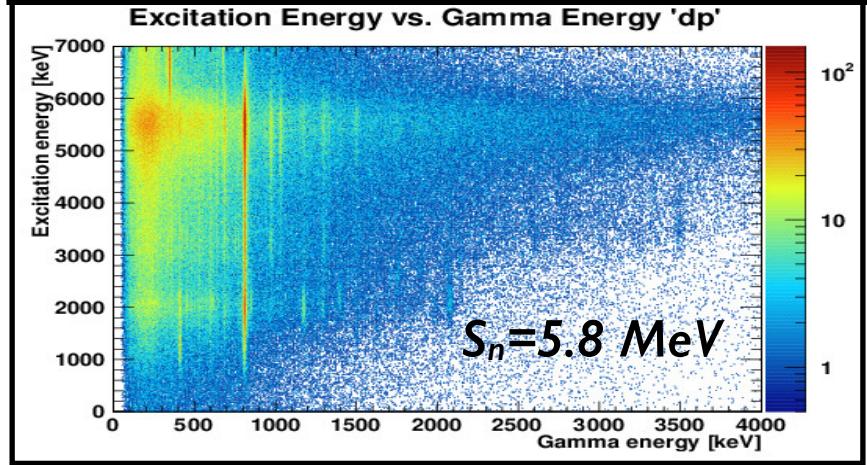
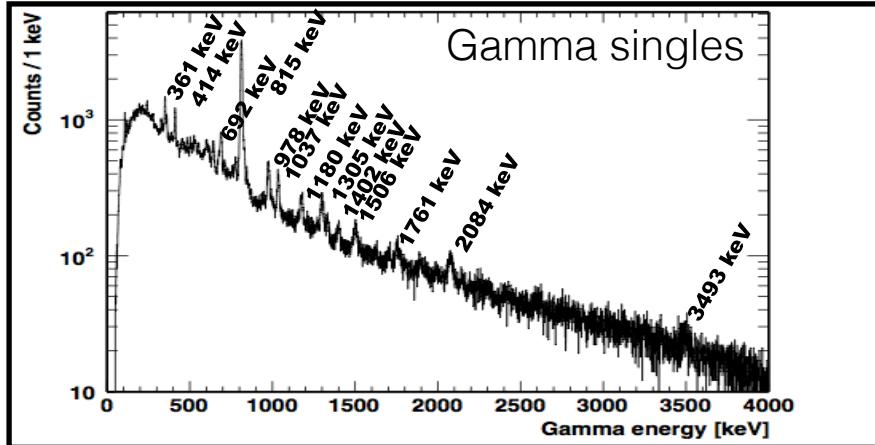
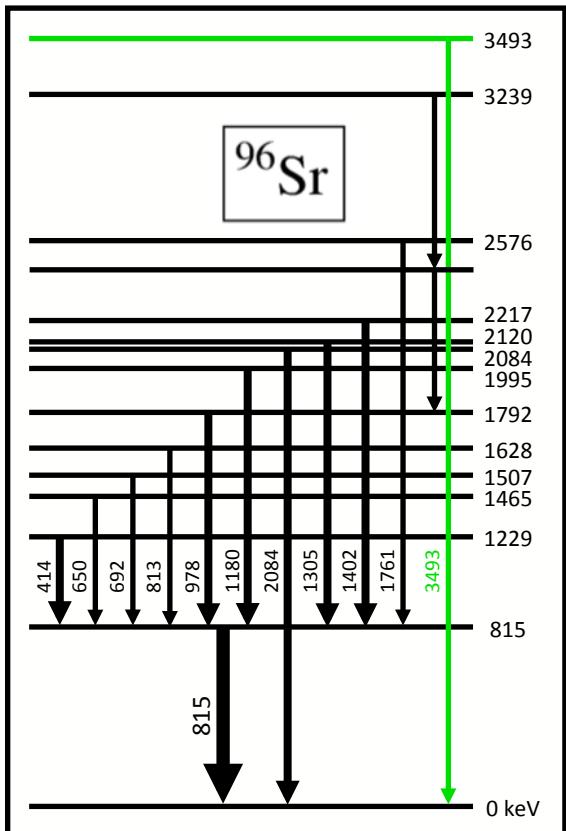


Shape coexistence in atomic nuclei
[Rev. Mod. Phys. 83, 1467 (2011)]

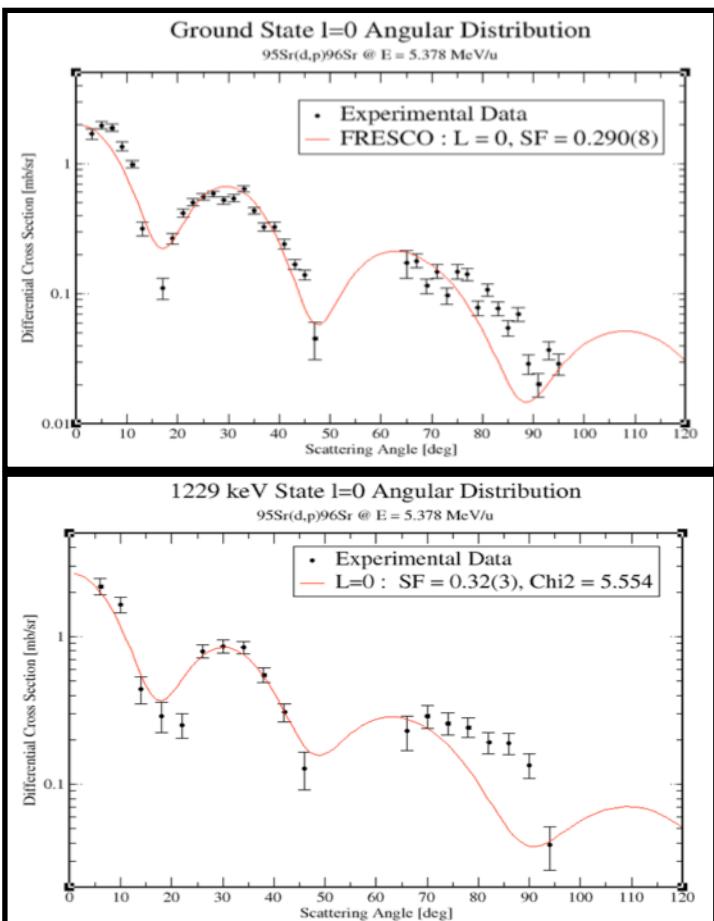
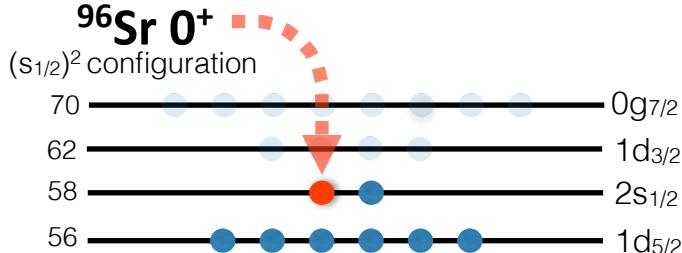


Particle ID from dE-E detectors



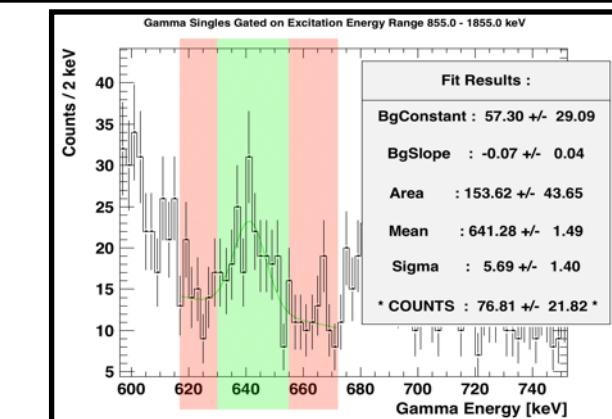
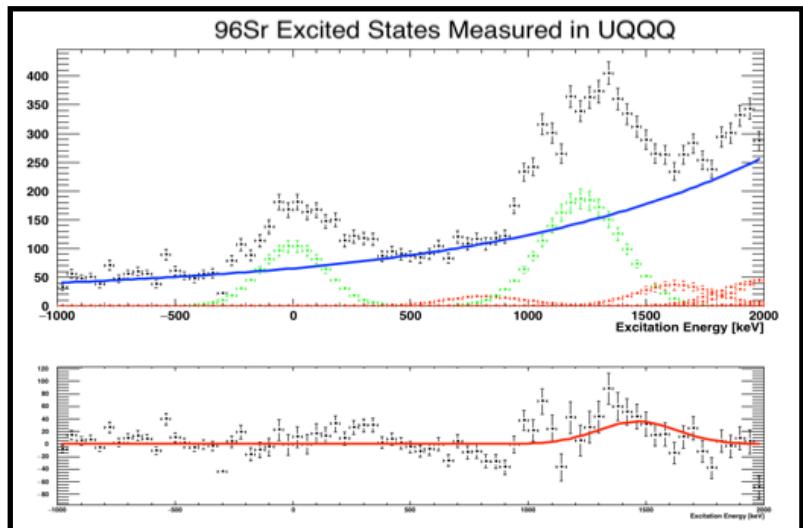


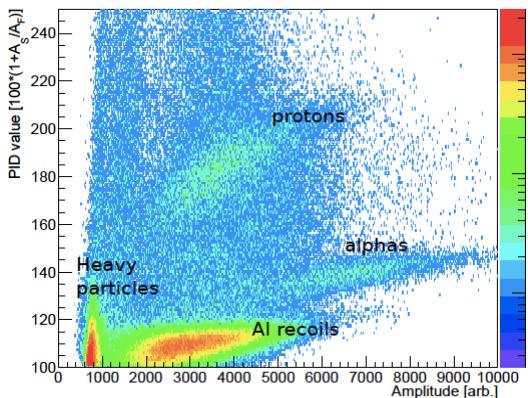
- Clear $\ell=0$ character.
- Spectroscopic factors are similar, and tell us that the ^{96}Sr $0_{1,2}^+$ states are not pure $[\text{s}_{1/2}]^2$ configurations.
- TIGRESS gate used on 414 keV transition to select 1229 keV state.
- Pair scattering of neutrons in ^{95}Sr would affect the cross section for this reaction.
- Shell model calculations for $^{95,96}\text{Sr}$ to follow shortly.



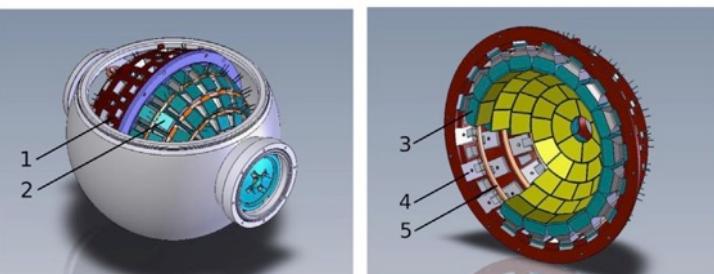
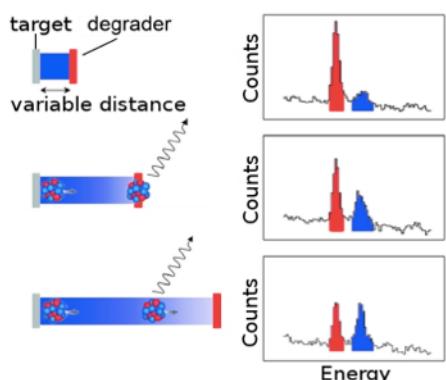
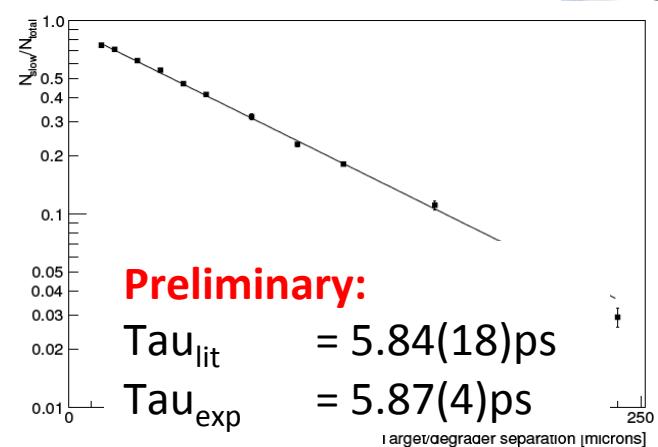
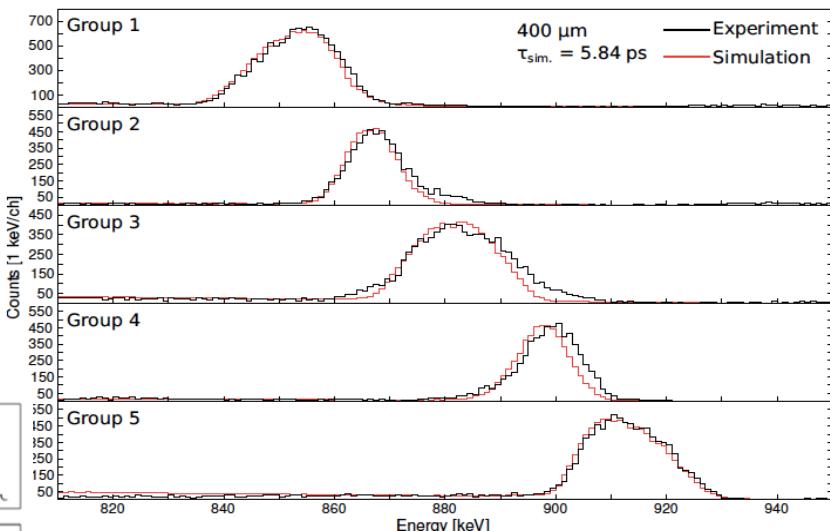
- γ gate on isomeric decay of 1465 keV 0₃⁺ state and compare to 0₂⁺ population strength.
- Mixing amplitude of 0₃⁺: 0₂⁺ states, $a = 50 \pm 10\%$.
- Smaller [s_{1/2}]² contribution in 0₃⁺ than 0₂⁺.
- This suggests a different structure in 0₃⁺ compared to 0₂⁺:

$$\rho^2(E0) = \frac{Z^2}{R_0^4} a^2 (1 - a^2) [\Delta \langle r^2 \rangle]^2$$





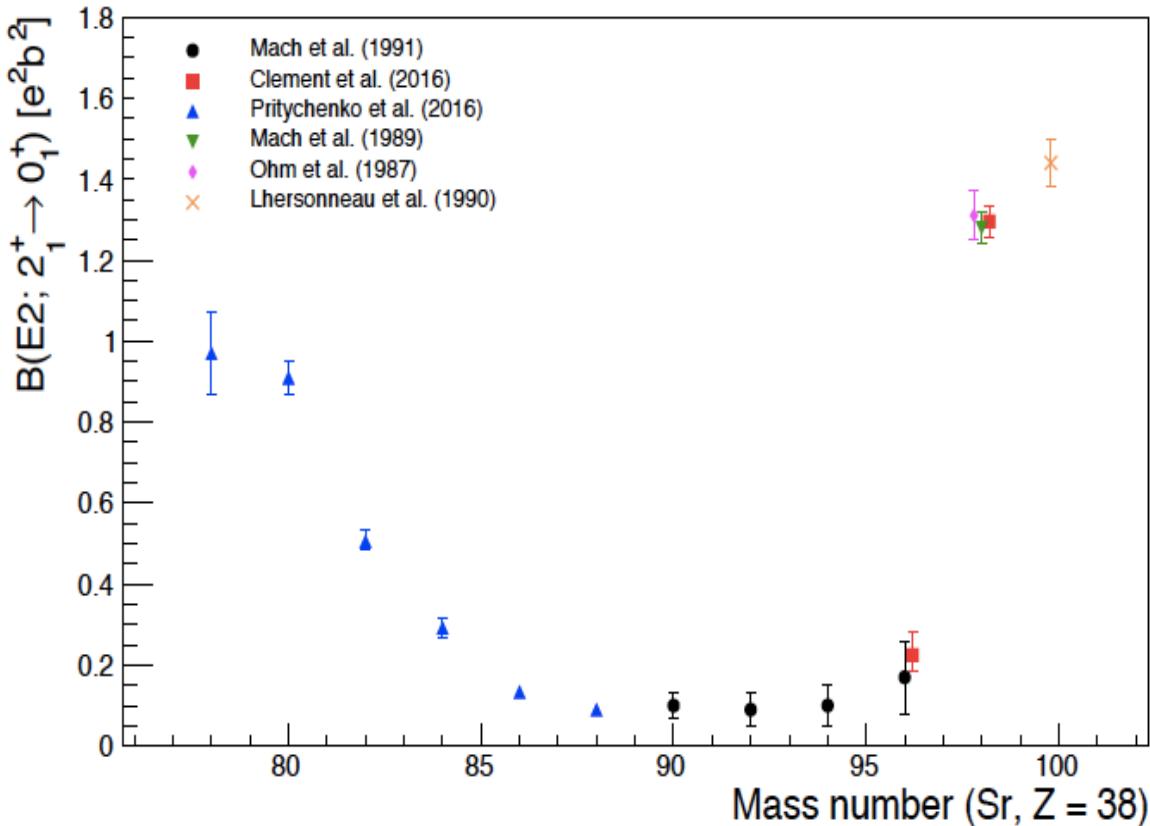
First 2⁺ state populated in Coulomb excitation of ⁸⁴Kr beam

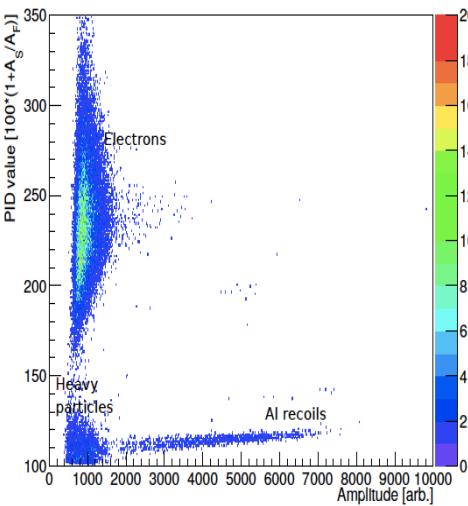


A. Chester, K. Starosta SFU *et al.*

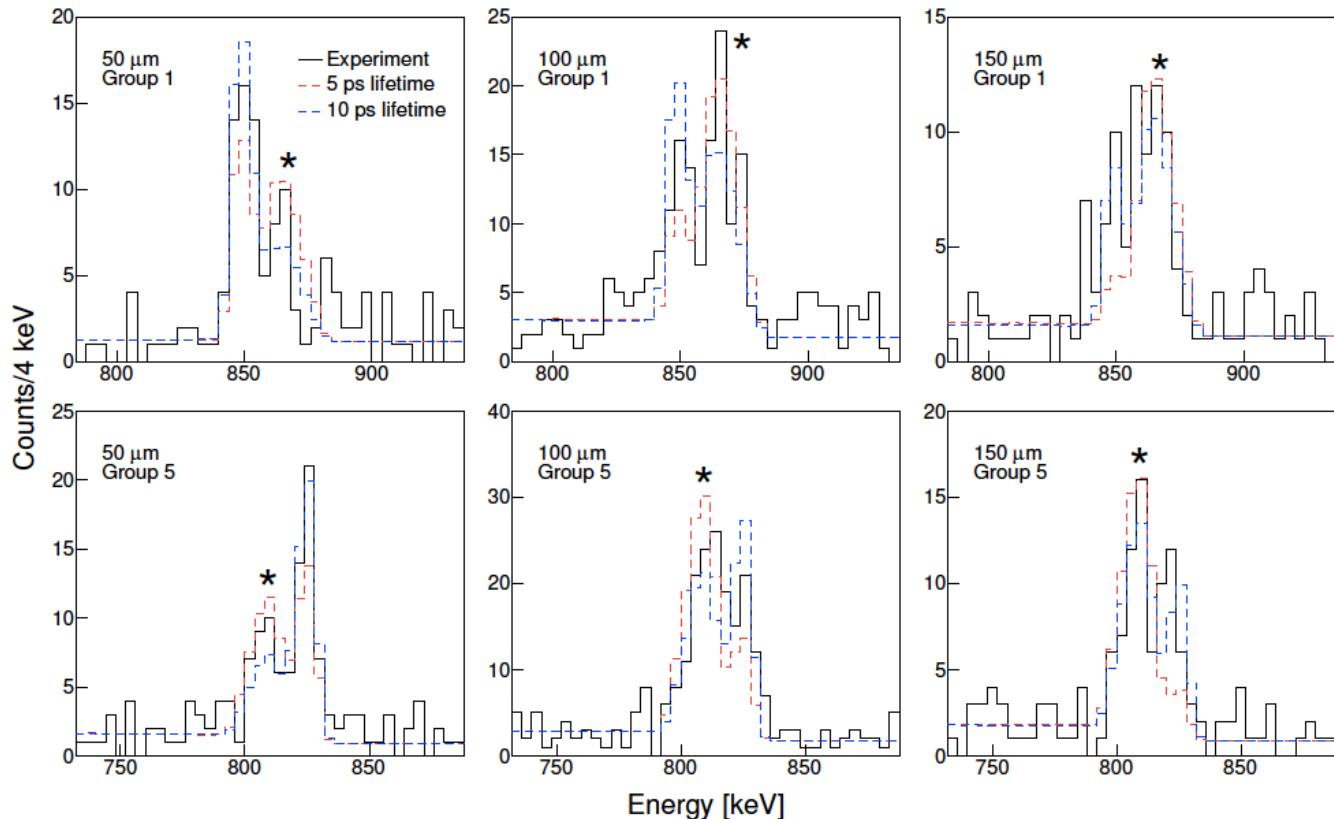
Very sudden change in ground-state structure observed at $N=60$.

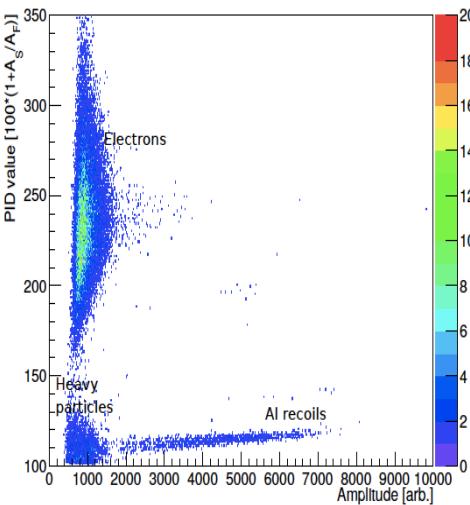
$B(E2)$ values from coincidence timing measurements and from Coulex.



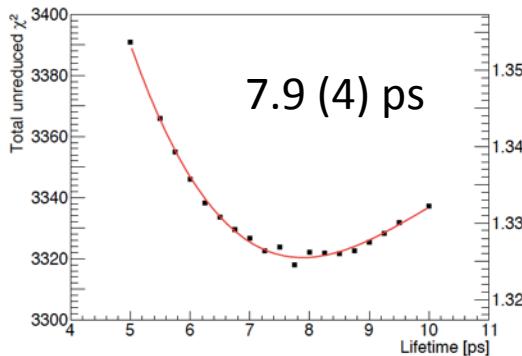
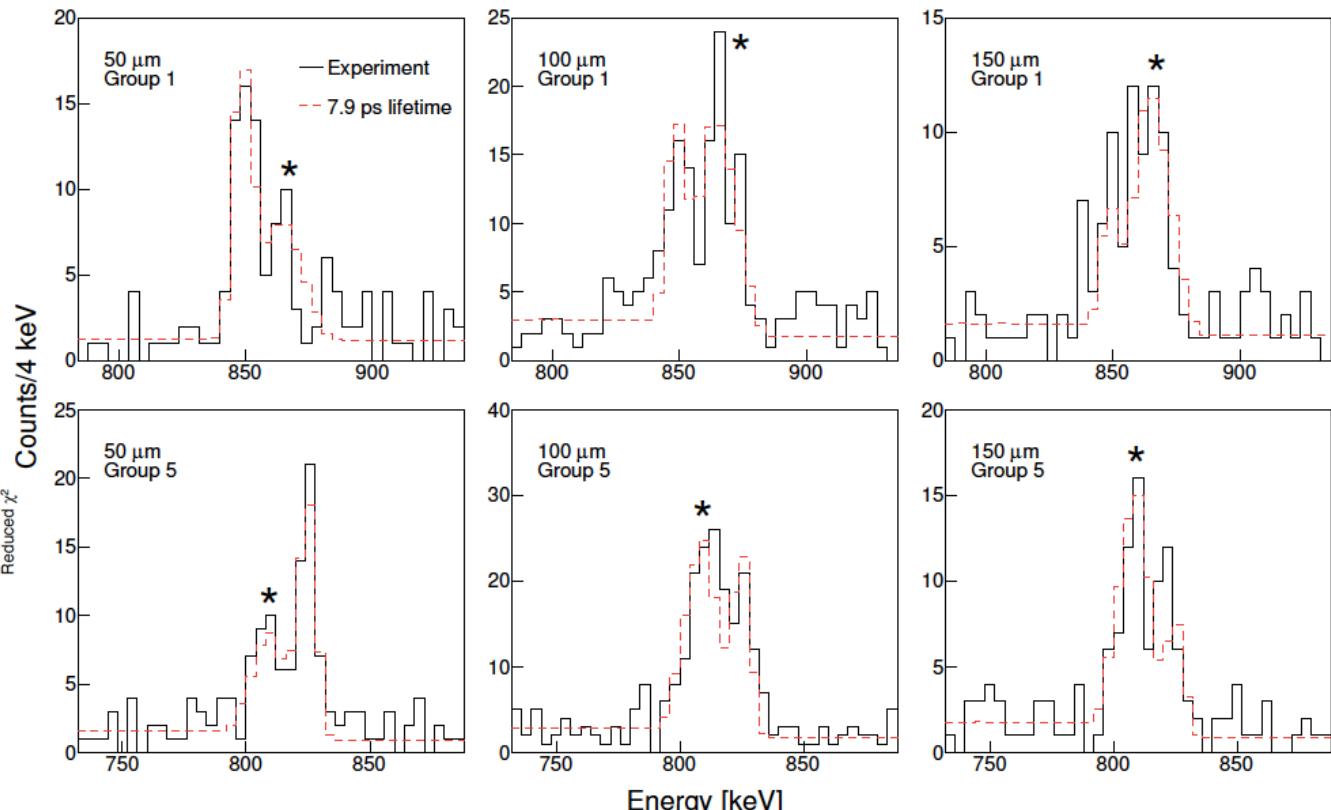


First 2^+ state populated in unsafe Coulex of ^{94}Sr beam



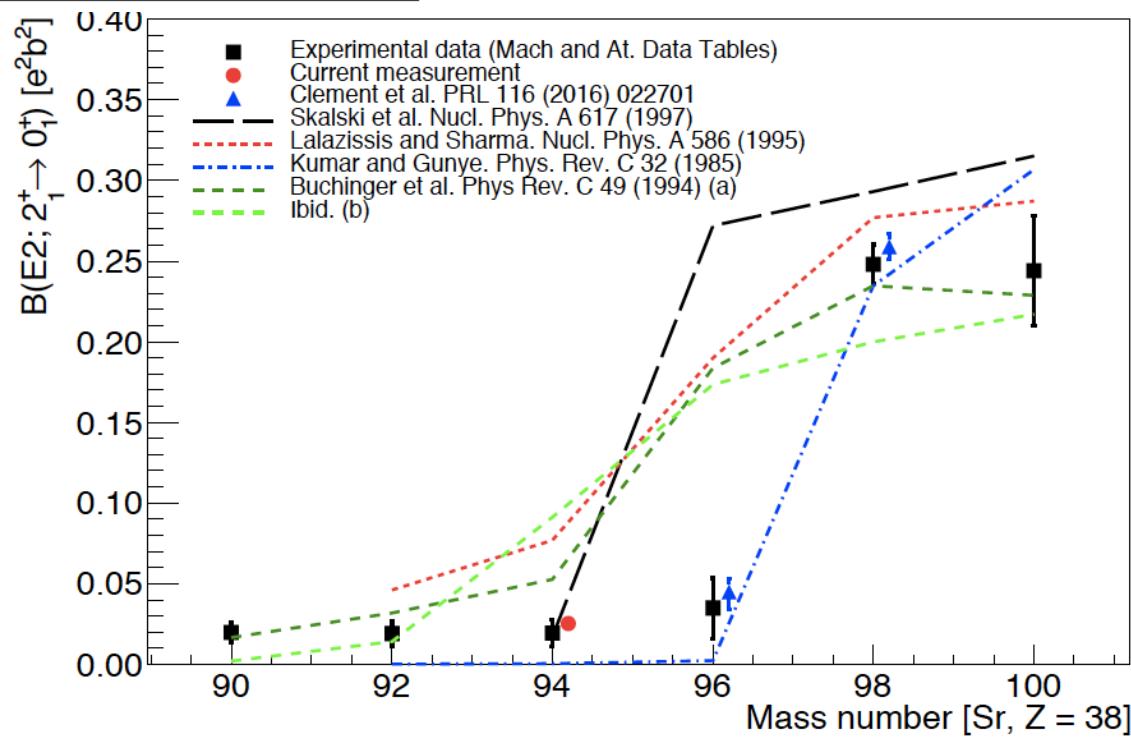


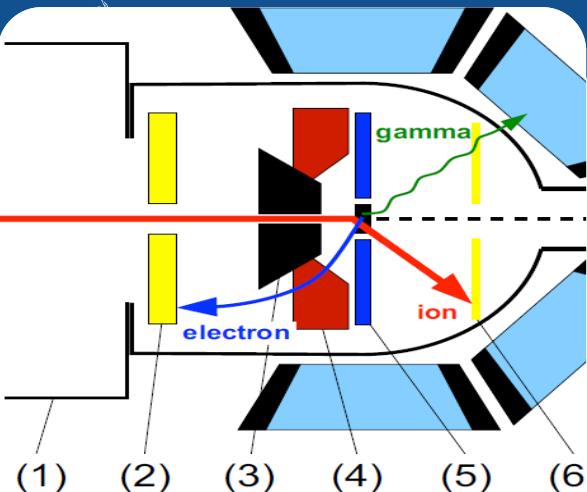
First 2^+ state populated in unsafe Coulex of ^{94}Sr beam



Reference	Technique	Lifetime τ [ps]	$B(E2)$ [$e^2 b^2$]
Current work	RDM	7.9 ± 0.4	0.0252_{-13}^{+14}
Mach <i>et al.</i>	Fast timing	10 ± 4	0.020 ± 0.008

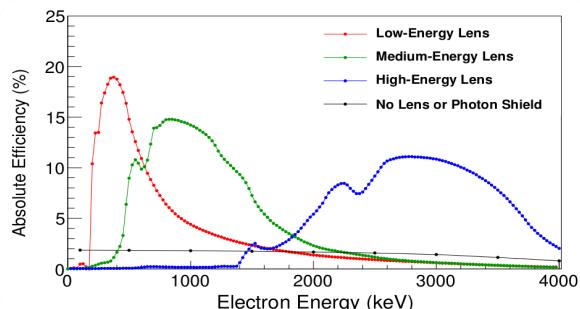
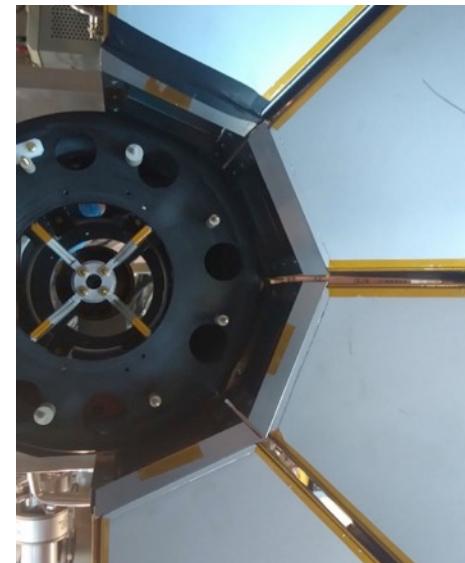
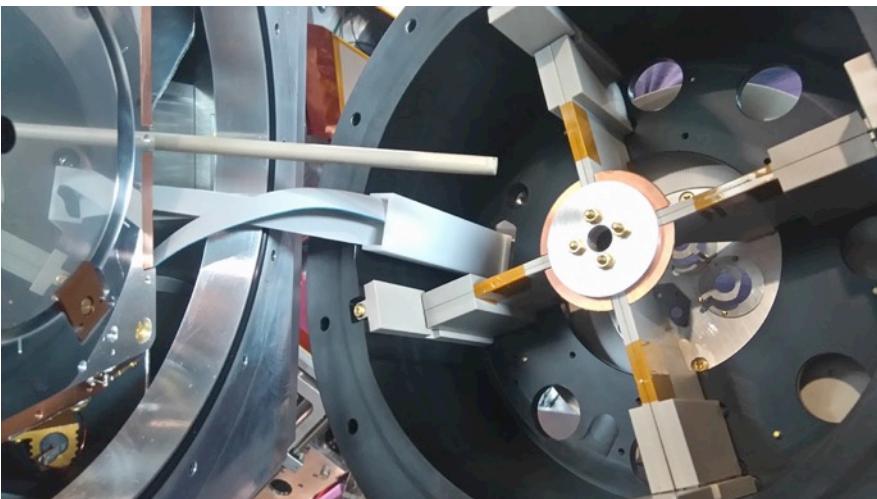
- Improves uncertainty in the $B(E2)$ value from 40% to <6%.
- Confirms sudden onset of deformation in ground-state structure.
- In preparation for publication.

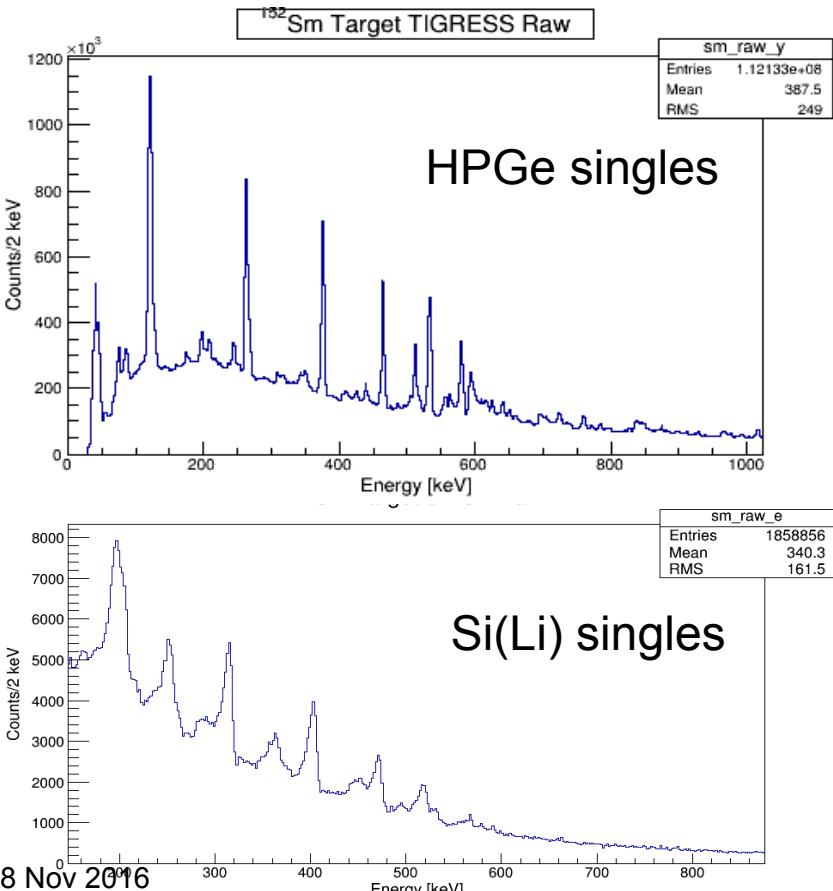




Garnsworthy, Smallcombe *et al.*

1. Vacuum vessel
2. Si(Li)
3. Photon-shield
4. Magnetic lens
5. Target wheel
6. DSSD
- 7. HPGe (TIGRESS)**



J.Smallcombe *et al.*

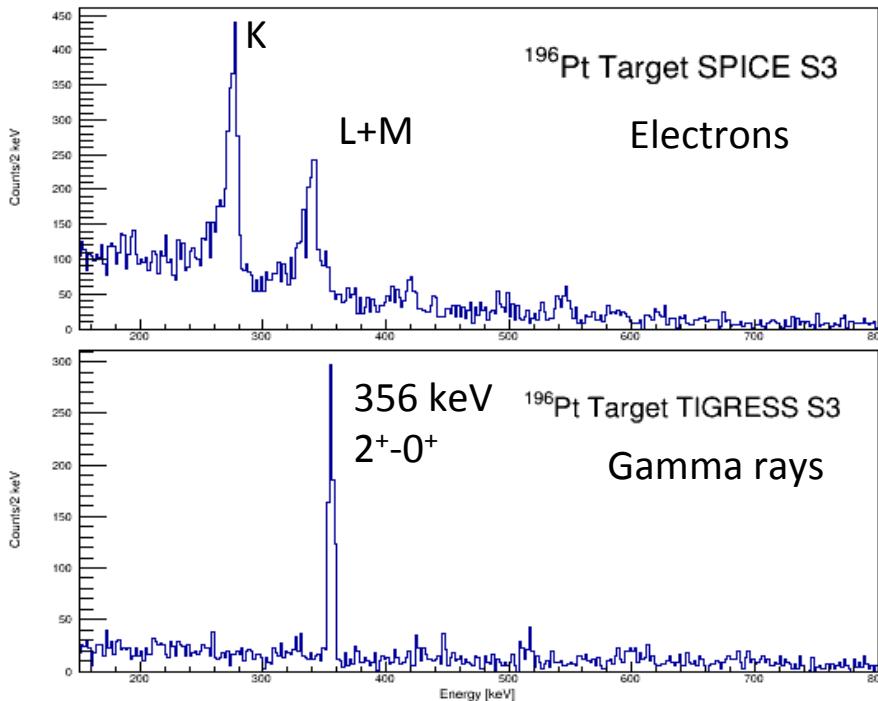
68 MeV ^{12}C beam,
4 mg/cm² ^{152}Sm , 300 ppA,
13.5 hours,

Coulex:
 $^{152}\text{Sm}(\text{^{12}C}, \text{^{12}C})^{152}\text{Sm}^*$

Fusion evaporation:
 $^{152}\text{Sm}(\text{^{12}C}, 4\text{n})^{160}\text{Er}^*$

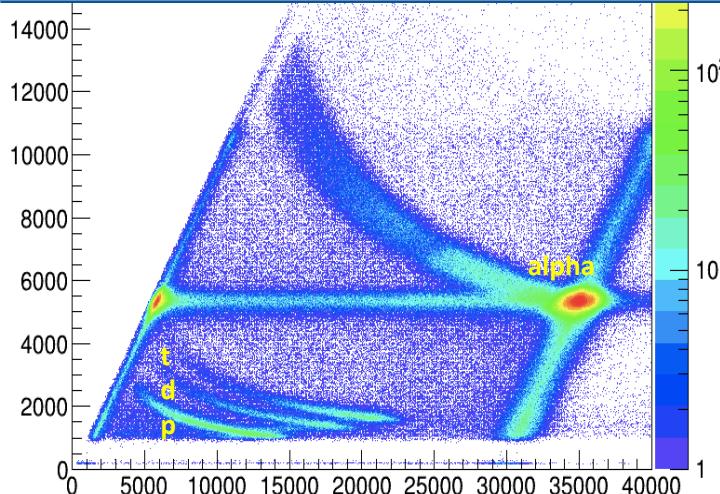
J.Smallcombe *et al.*

68 MeV ^{12}C beam, 2.9 mg/cm² ^{196}Pt , 10 ppA, 2 hours, $^{196}\text{Pt}(^{12}\text{C}, ^{12}\text{C})^{196}\text{Pt}^*$



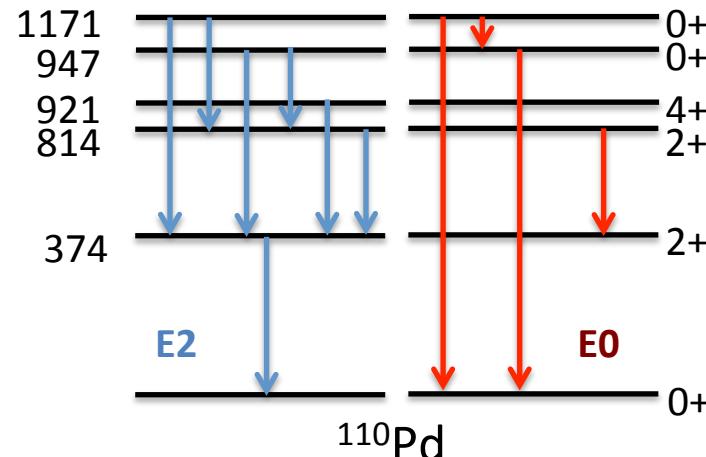
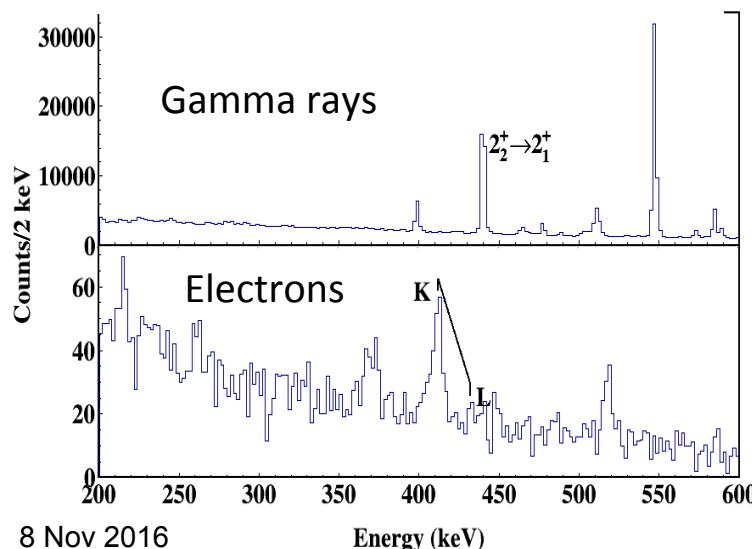
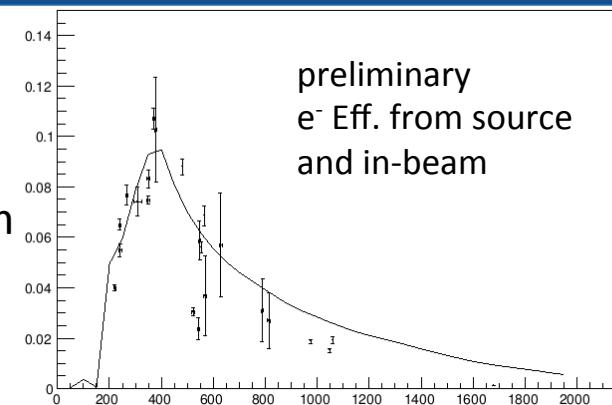
Coincidence with heavy-ion recoil in S3 detector

SPICE run:



$\Delta E - E$ telescope
140um and 1mm S3

250ppA 36MeV alpha beam
on 1.6mg/cm² ¹¹⁰Pd target



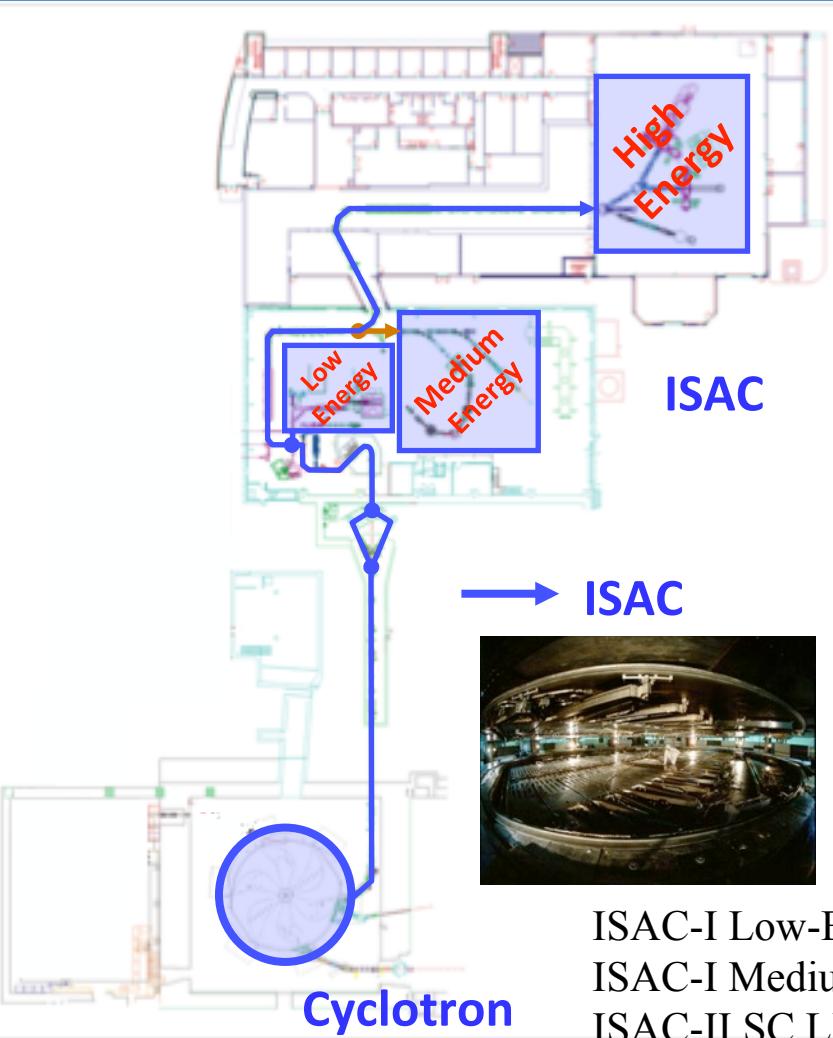
TRIUMF-ISAC

Isotope Separator and ACcelerator

1 RIB delivery to experiments

500MeV p⁺ at 100μA on ISOL target

SiC, NiO, Nb, ZrC, Ta, UC_x Targets
Surface, FEBIAD, IG-LIS ion sources



ISAC-I Low-Energy <60keV

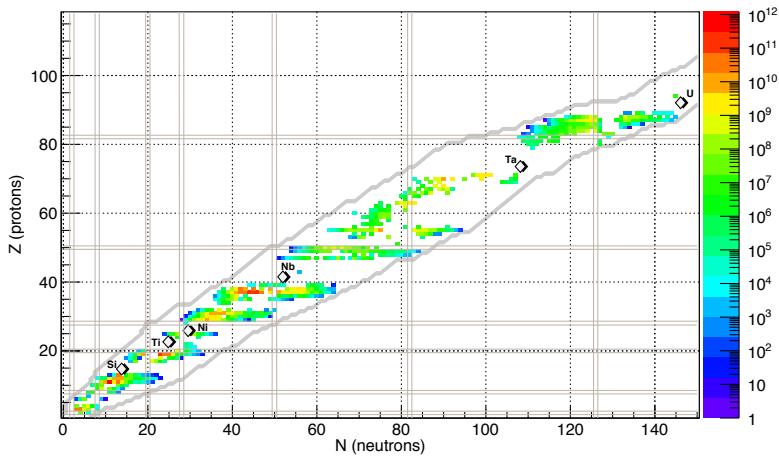
ISAC-I Medium E <1.5MeV/u

ISAC-II SC LINAC <10MeV/u

Ground state + decay, material science

Astrophysics

Nuclear reactions and structure



TRIUMF-ARIEL

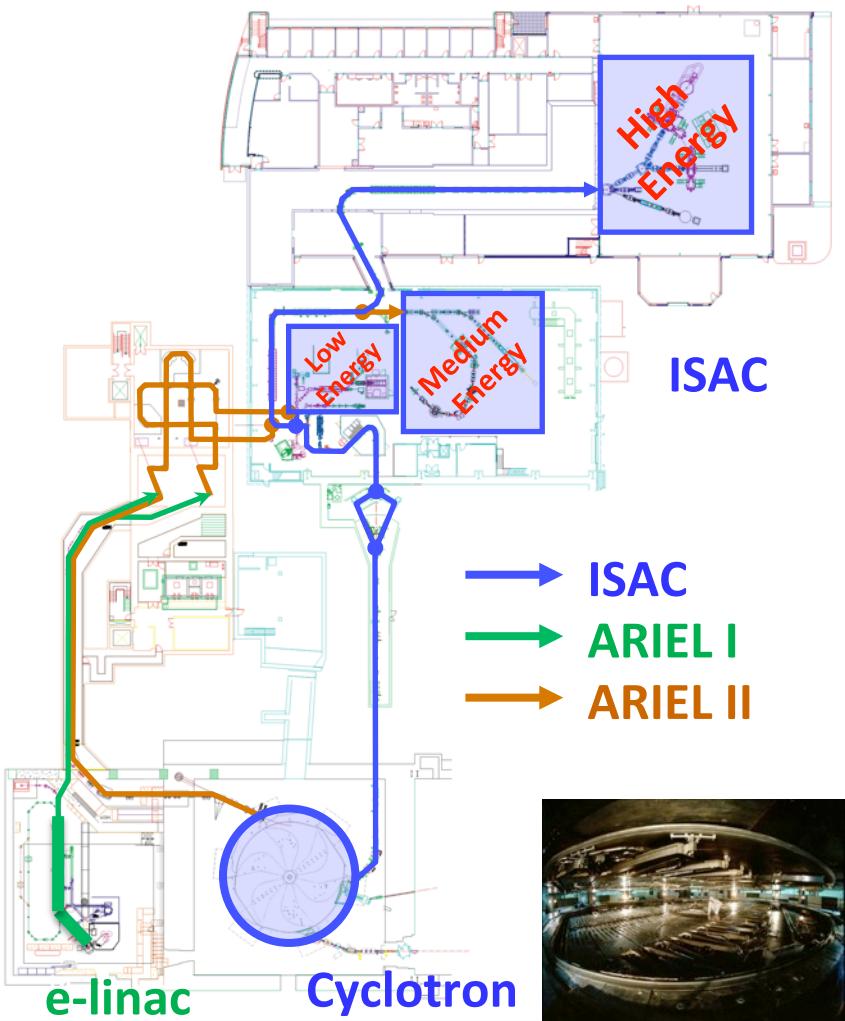
Advanced Rare-IsotopE Laboratory

1 RIB → 3 simultaneous RIBs

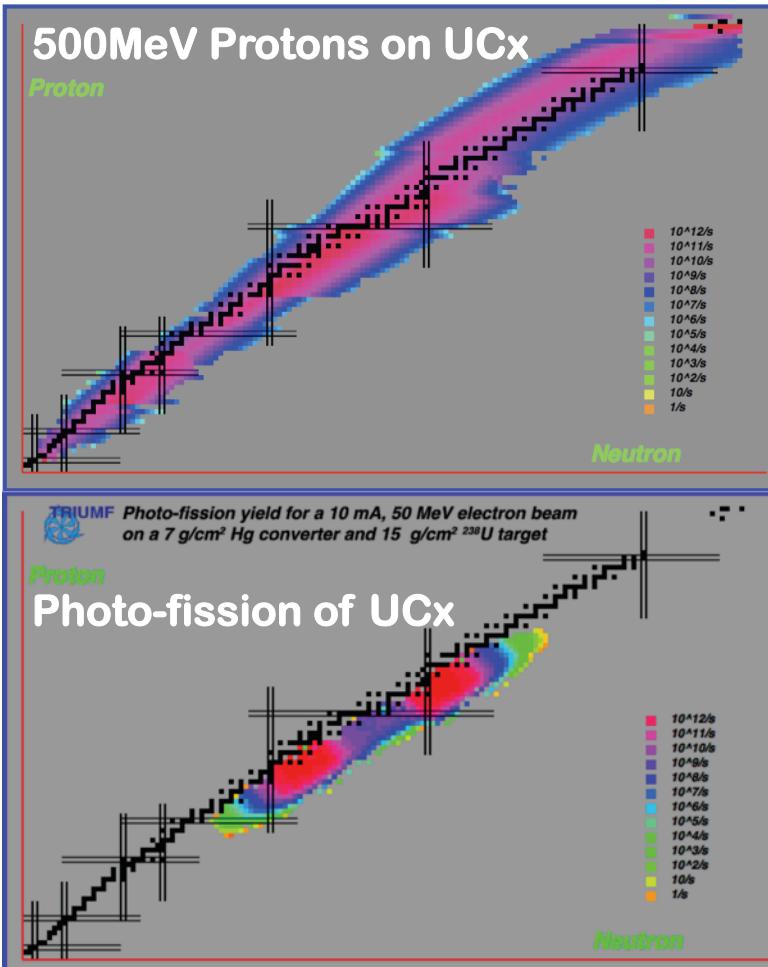
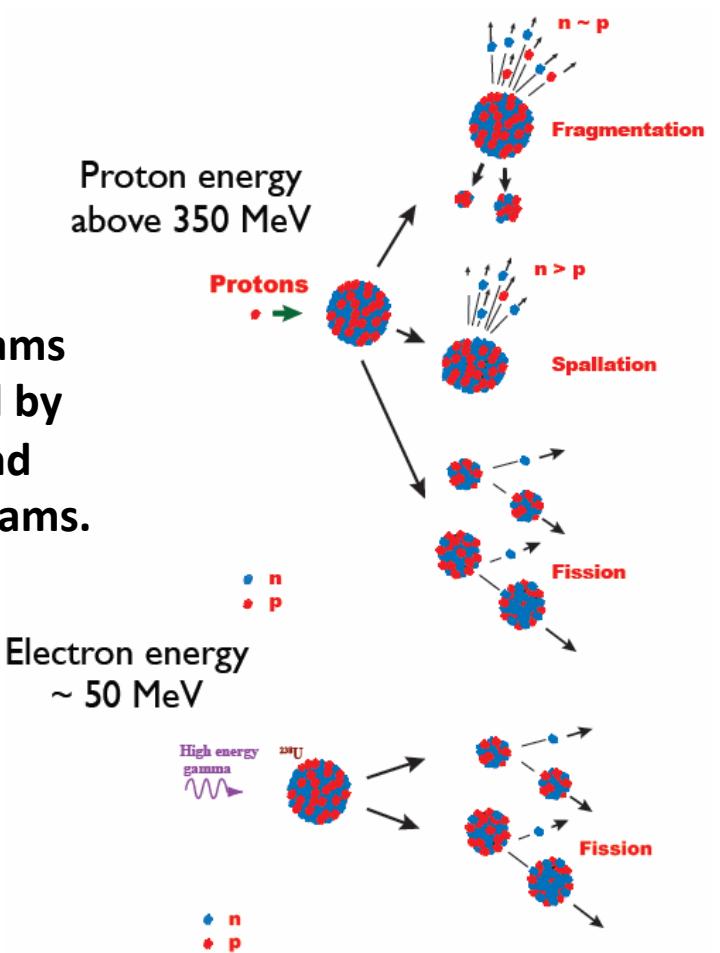
ARIEL Project:

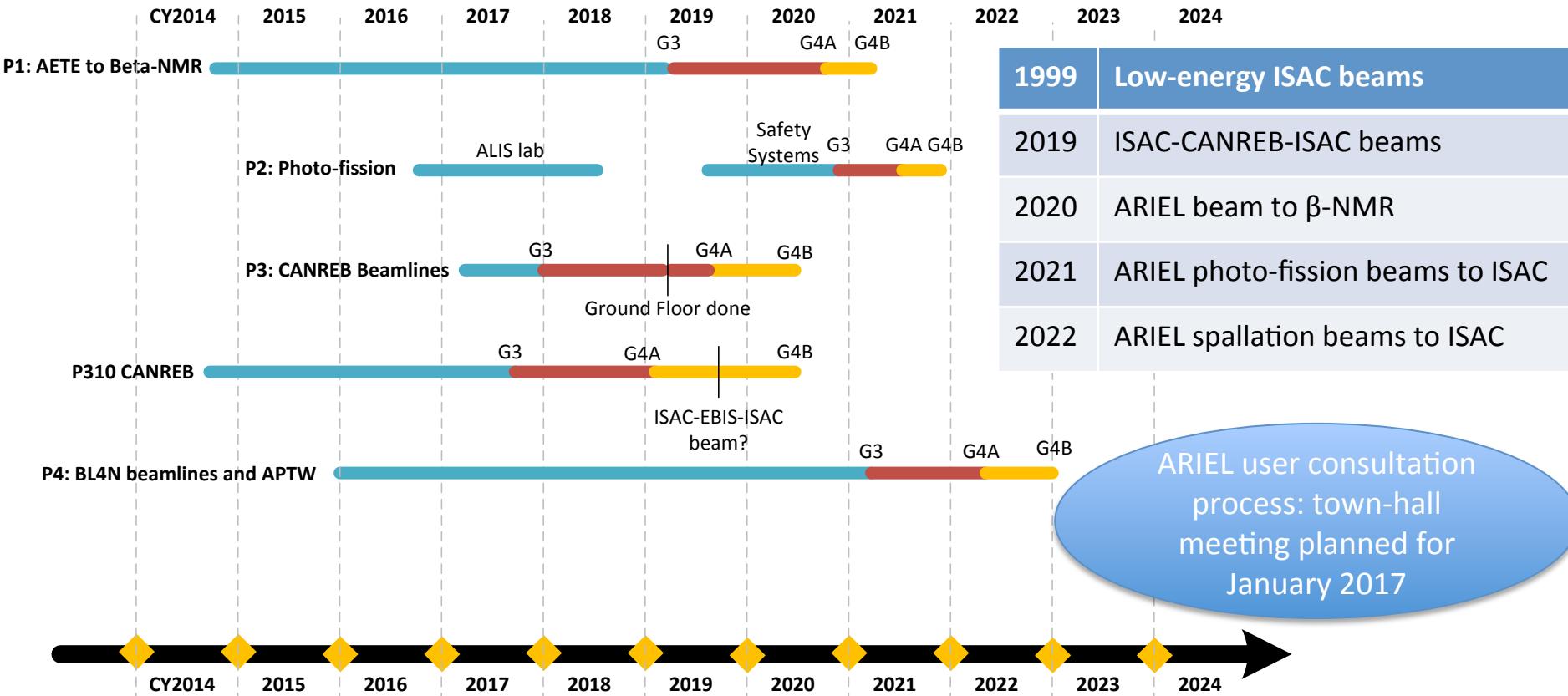
- new electron linac driver for photo-fission
- new target stations and front end
- new proton beamline

E-linac and electron beamline
Sept. 2014



Rare-isotope beams will be produced by from proton and electron driver beams.





- **8 π**
 - ^{98}Sr and ^{78}Kr $E0$ transition strengths
 - GRIFFIN dramatically increases coincidence efficiency
- **TIGRESS**
 - (d,p) reactions in $^{94,95,96}\text{Sr}$, in the future (t,p)
 - TIP plunger: precision $B(E2)$ measurement in ^{94}Sr
 - SPICE: Now commissioned in-beam, Coulex of ^{78}Kr next week
- **ARIEL** will bring more beamtime to ISAC experiments

G.C. Ball, T. Ballast, C. Bartlett, P. Bender, N. Bernier, D. Bishop, M. Bowry, D. Brennan, T. Bruhn,
R. Caballero, A. Cheeseman, R. Churchman, S. Ciccone, B. Davids, L. Evitts, I. Dillmann, S. Georges,
G. Hackman, S. Hallam, J. Henderson, R. Kokke, R. Kruecken, K. Leach, Y. Linn, C. Lim,
L. MacConnachie, D. Miller, W.J. Mills, L.N. Morrison, M. Moukaddam, C.A. Ohlmann, O. Paetkau,
J. Park, C.J. Pearson, M.M. Rajabali, P. Ruotsalainen, B. Shaw, J. Smallcombe, J.K. Smith, D. Southall,
C. Unsworth, Z.M. Wang, S. Wong, *TRIUMF, Canada*;

H. Bidaman, V. Bildstein, P. Boubel, C. Burbadge, G. Deng, A. Diaz Varela, R.A. Dunlop,
M. Dunlop, P.E. Garrett, B. Hadina, B. Jigmeddorj, D. Kisliuk, A. Laffoley, A. MacLean,
E. McGee, B. Olaizola Mampaso, A. Radich, E.T. Rand, C.E. Svensson, J. Turko, T. Zidar,
University of Guelph, Canada;

C. Andreoiu, A. Chester, F. Garcia, J.L. Pore, U. Rizwan, K. Starosta, P. Voss, J. Williams,
Simon Fraser University, Canada

J-P. Martin, *Universite de Montreal, Canada*;

E. Peters, S. Yates
University of Kentucky, USA

E. Padilla Rodal, UNA Mexico

and the other members of the TIGRESS and GRIFFIN collaborations





Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

A dark blue-tinted photograph of a complex, multi-layered detector structure, likely a particle detector, with numerous cylindrical and rectangular components.

Thank you! Merci!

TRIUMF: Alberta | British Columbia | Calgary |
Carleton | Guelph | Manitoba | McGill | McMaster |
Montréal | Northern British Columbia | Queen's |
Regina | Saint Mary's | Simon Fraser | Toronto |
Victoria | Western | Winnipeg | York

Follow us at [TRIUMFLab](#)

