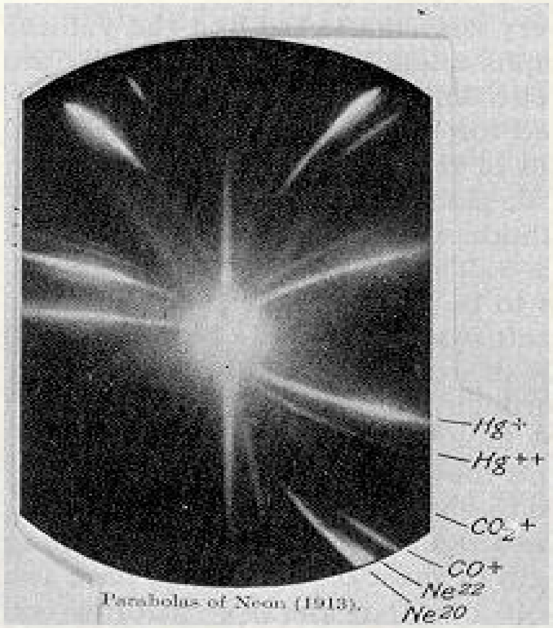
The Morinaga-Ikeda Nucleus

Neon (New in Greek) Challenge to Mean Field, Cluster and Collective Models

^{20}Ne is the fifth most abundant nucleus in the universe…and yet unknown



First discovery of isotopes of stable atoms by J. J. Thompson (1913)

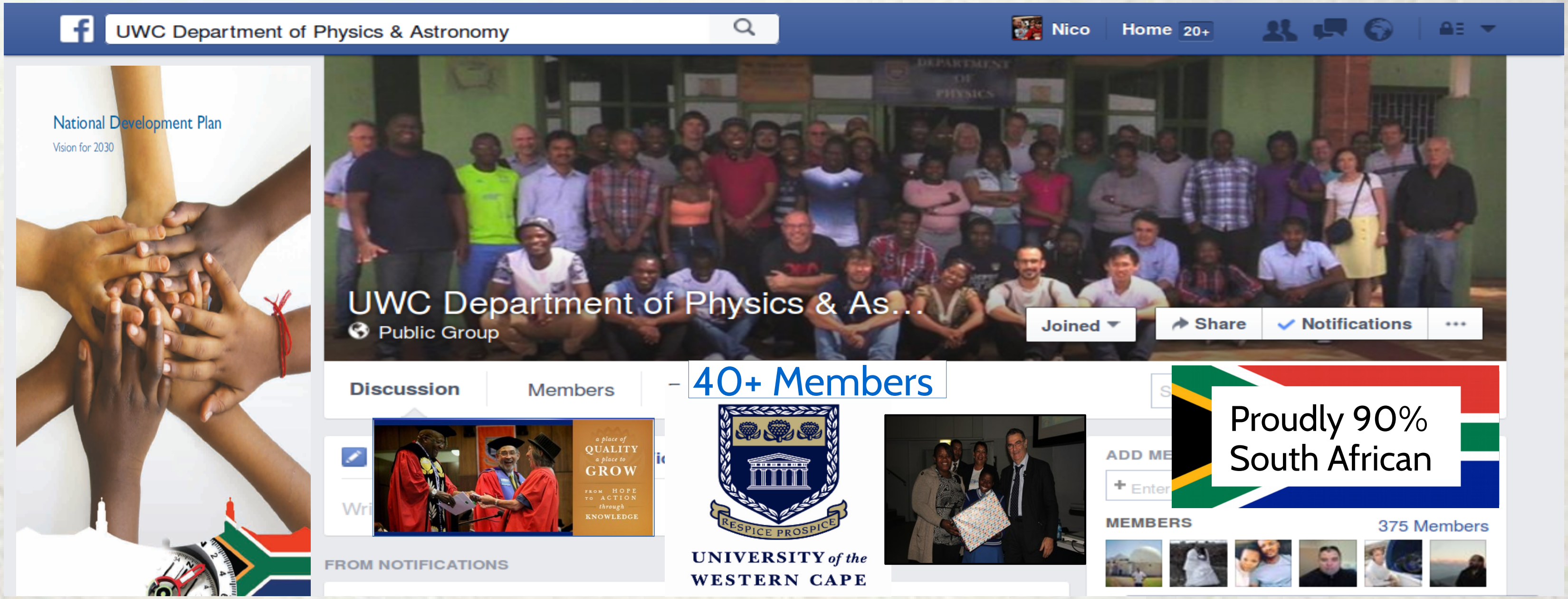
Senamile Masango, Craig Mehl and collaborators

ISOLDE Workshop Dec 2018

UNIVERSITY of the WESTERN CAPE

2018-2019 Fundamental Nuclear Physics & Applications @ UWC

Experiments @ UWC, iThemba LABS, HIE-SOLDE, Washington, MLL & TRIUMF



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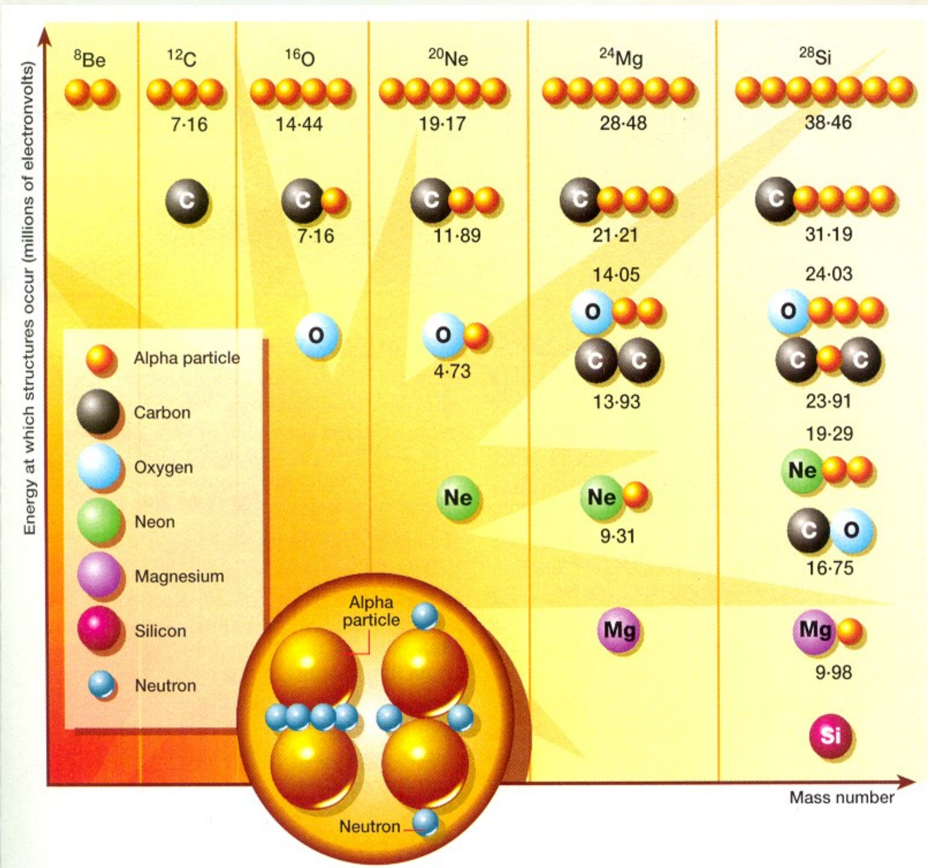
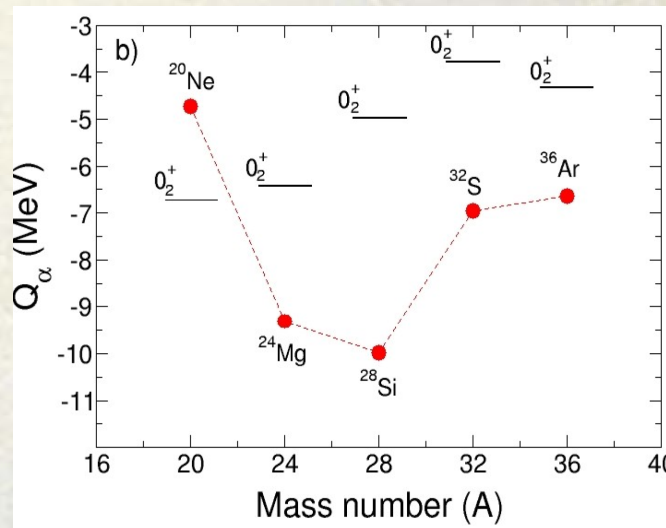
https://nuclear.uwc.ac.za

The Morinaga-Ikeda Nucleus

α clusters can emerge gradually as the internal energy of the nucleus increases and are fully realized at the α threshold



``^{20}Ne is probably the best example of a clustered nucleus" (Martin Freer)



Only self-conjugate nucleus with α threshold below second 0^+ excitation

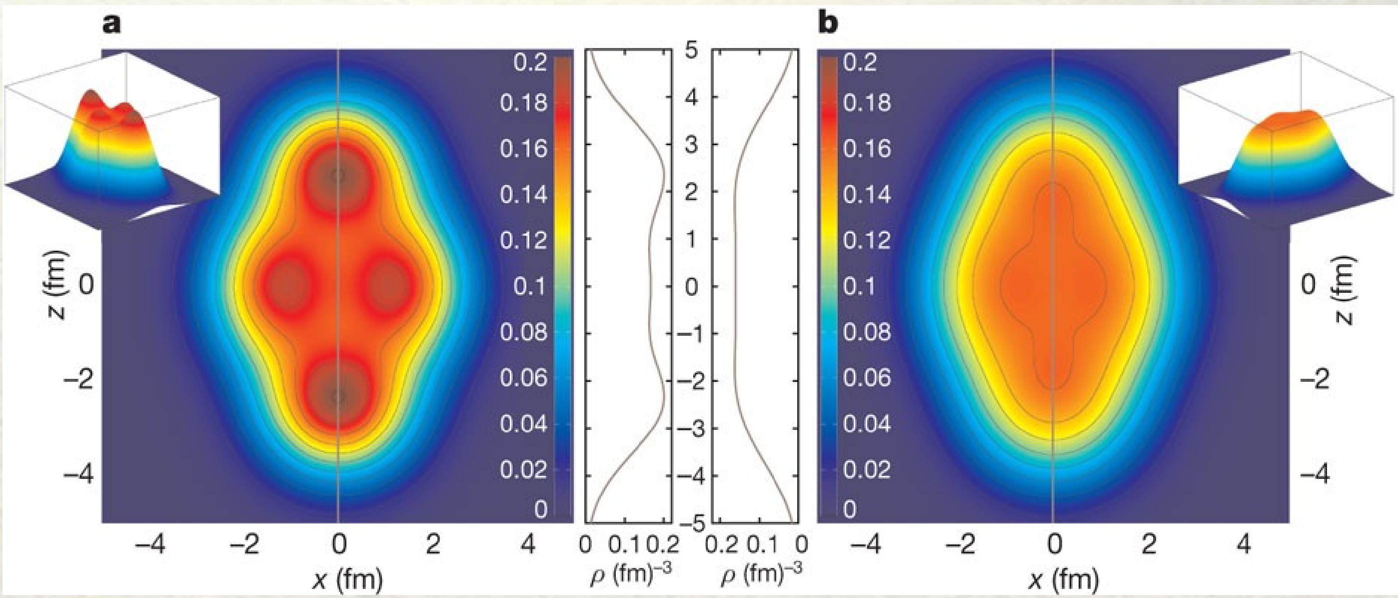
H. Morinaga, Phys. Rev. **101**, 254 (1956)
Ikeda, K., N. Takigawa, and H. Horiuchi, Prog. Theor. Phys. Suppl. **E68**, 464 (1968)

How atomic nuclei cluster

Ground state of ^{20}Ne may already present a cluster structure

Fully microscopic description based on energy-density functionals (EDFs)

Ebran, Khan, Nikšić & Vretenar, Nature **487**, 341 (2012)



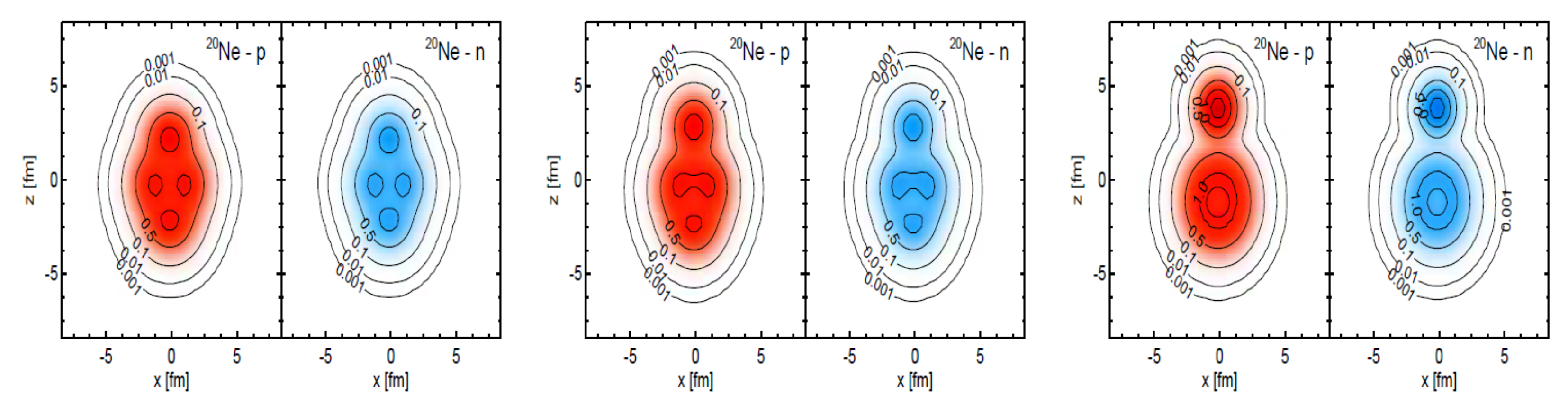
Self-consistent ground-state densities of ^{20}Ne: a) relativistic DD-ME2 and b) Skyrme SLy4

Assumption: The mixing with α clusters congurations may have a pronounced effect on the shape of mean-field states at lower excitation energies

The Morinaga-Ikeda Nucleus

The mean-field state has a sizable cluster character
(agrees with largest E0 strength in nature)

- $Q_s(2^+) = -0.126$ eb standard mean-field calculations (HFB)
- $Q_s(2^+) = -0.153$ eb including cluster configurations
- $Q_s(2^+) = -0.23(3)$ eb from reorientation-effect measurements



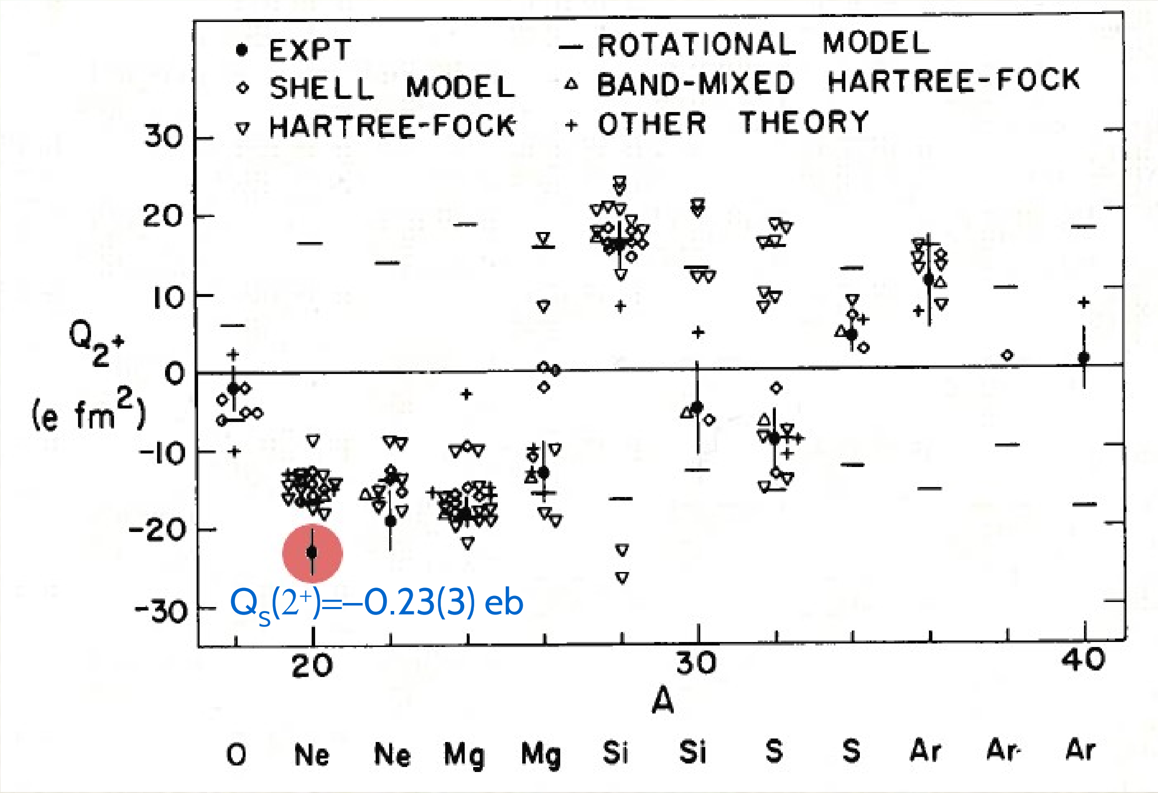
α clusters can emerge gradually as the internal energy of the nucleus is increased

Thanks to Thomas Neff, Fermionic-Molecular Dynamic Calculations of ^{20}Ne

^{20}Ne: a 45 year-old puzzle

ALL calculations (mean field (HFB, shell model), rotor, cluster models)

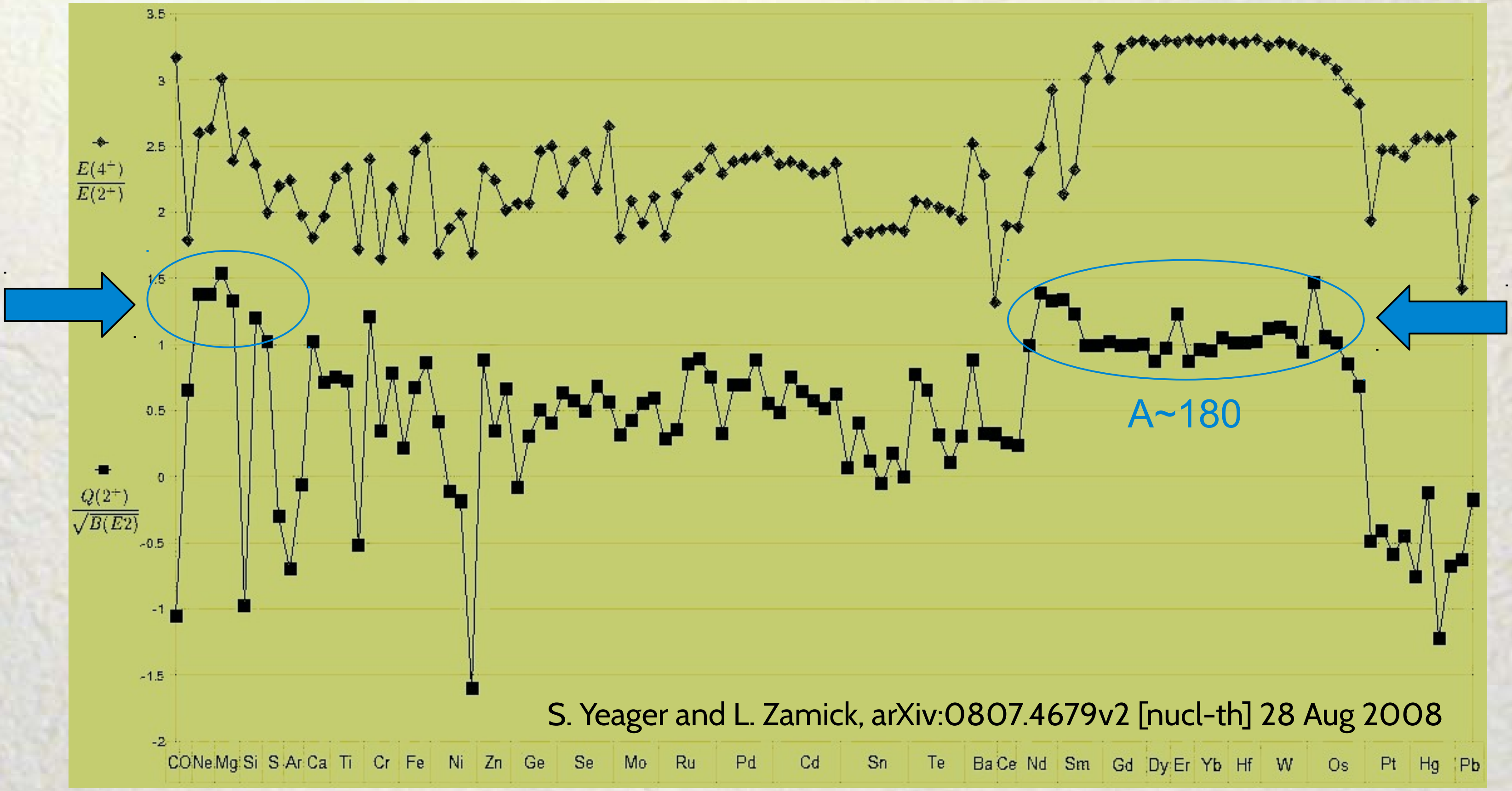
fail to describe the spectroscopic quadrupole moment of the first 2^+ state in ^{20}Ne



R.H. Spear, Phys. Rep. **73**, 369 (1981)

The quadrupole moment ratio: 1 for rotors, 0 for vibrators

$$\frac{Q_0(S)}{Q_0(B)} = -\frac{7}{2}\sqrt{\frac{5}{16\pi}}\frac{Q(2^+)}{\sqrt{B(E2)}} = -1.1038705\frac{Q(2^+)}{\sqrt{B(E2)}}$$



^{20}Ne is one of the few known cases in the nuclear chart where $Q_S(2^+)_{B(E2)} = -0.165(5)$ eb and $Q_S(2^+)_{RE} = -0.23(3)$ eb disagree at the 2σ confidence level

Spectroscopic Quadrupole Moment of the first 2^+ state in ^{20}Ne

"A new measurement is desirable." R. H. Spear (1981)

4.2. *The nucleus ^{20}Ne (table 4.2)*

There are only 3 RECE measurements, and none of them is recent. The paucity of data is largely due to the difficulty of producing negative Ne ions and the consequent unavailability of Ne beams from tandem accelerators. Two of the measurements [20, 24] included in their analysis data obtained at disturbingly high bombarding energies (corresponding to distances of closest approach as small as approximately 4 fm in each case), and none of them demonstrated convincingly that their maximum bombarding energies were safe. In addition, the analysis of Nakai et al. required assumptions about the electric quadrupole moments of the target nuclei, and the error quoted for the result of Schwalm et al. is unusually large. A new measurement is desirable. The adopted value is obtained by simply weighting the RECE results in inverse proportion to the squares of their stated errors.

R.H. Spear, Phys. Rep. **73**, 369 (1981)

Spectroscopic Quadrupole Moment of the first 2^+ state in ^{20}Ne

"A new measurement is desirable." R. H. Spear (1981)

Separation between nuclear surfaces, $S_{min} > 6.5$ fm

Experimental determinations of Q_{2^+} for ^{20}Ne ($E_x = 1.634$ MeV)

Author [ref.]	Year	Q_{2^+} (e fm^2)	Projectile/Target	Method	Details	s_{min} (fm)
Nakai [20]	1970	-24 ± 3	^{20}Ne/^{120}Sn, ^{130}Te, ^{148}Sm	RECE	PγC; $\theta = 90°, 160°$	3.8
Horikawa [21]	1971	-17 ± 1	e/Ne	(e, e′)	Assumes rotational model	
Schwalm [22]	1972	-23 ± 8	^{32}S/^{20}Ne	RECE	DBγLS(0°); gas target	7.1
Rebel [23]	1972	-13 ± 1	^{4}He/^{20}Ne	CCEIS	$E = 104$ MeV; assumes rotational model	
Olsen [24]	1974	-20 ± 5	^{20}Ne/Pt, Au	RECE	γAD	4.2
Gross [25]	1978	-27 ± 3	^{20}Ne/^{208}Pb	CCEIS	$E = 131$ MeV; assumes rotational model	

Adopted value: $-23 \pm 3\ e$ fm^2

R.H. Spear, Phys. Rep. **73**, 369 (1981)

^{20}Ne: a 45 year-old puzzle

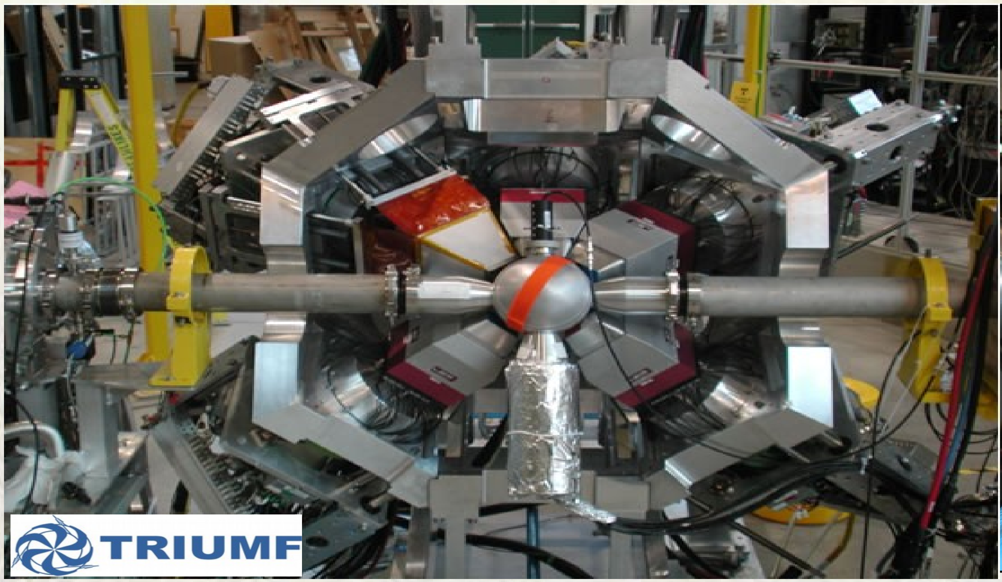
Forget the N_pN_n scheme, ^{20}Ne is the most deformed nucleus in the *sd* shell and beyond!

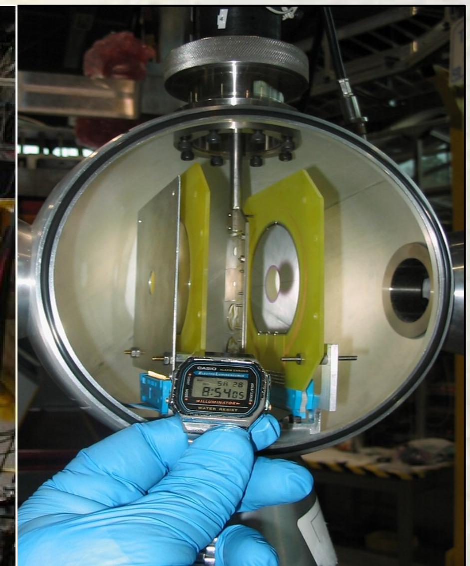
	$Q(2_1^+)$ $[e\ \mathrm{fm}^2]$	$B(E2)$ $[e^2\ \mathrm{fm}^4]$	$\lvert Q_0(S)/Q_0(B)\rvert$	$E(4_1^+)/E(2_1^+)$
^{20}Ne	−23 (3)	340 (30)	1.38 (19)	2.600
^{22}Ne	−19 (4)	230 (10)	1.38 (28)	2.634
^{24}Mg	−16.0 (8)	432 (12)	0.85 (4)	3.012
^{28}Si	+16 (3)	326 (12)	0.98 (18)	2.596
^{32}S	−15 (2)	300 (13)	0.96 (13)	2.000
^{36}Ar	+11 (6)	340 (40)	0.66 (36)	2.240
^{40}Ar	+1 (4)	330 (39)	0.06 (24)	1.980

S. J. Q. Robinson, A. Escuderos, L. Zamick, P. von Neumann-Cosel, A. Richter and R. W. Fearick, Phys. Rev. C **73**, 037306 (2006)

B(E2) measurement @ TIGRESS (S. Masango, MSc)

$^{110}Pd(^{20}Ne,^{20}Ne^{*})^{110}Pd^{*}$ @ 64.7 MeV (extremely safe with $S_{min} = 9.3$ fm @ 49.1^{o})





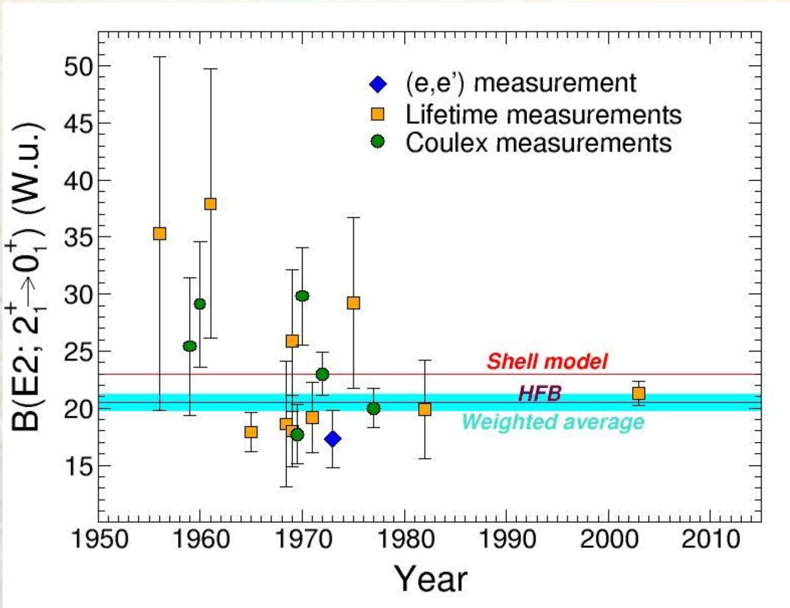
Particle-gamma coincidence measurement

6 TIGRESS detectos + silidon S3 detector covering forward angles [20.9^{o}, 49.1^{o}]

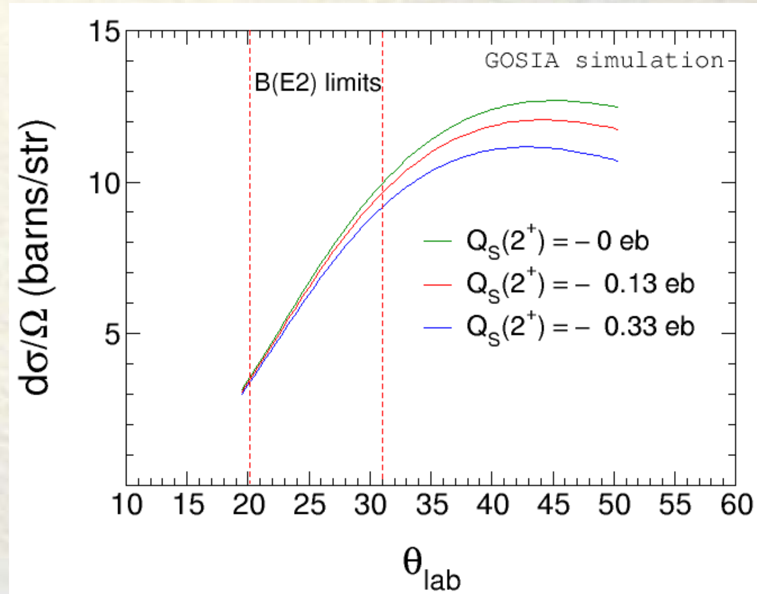
B(E2) measurement @ TIGRESS (S. Masango, MSc)

$^{110}Pd(^{20}Ne,^{20}Ne^{*})^{110}Pd^{*}$ @ 64.7 MeV (extremely safe with S_{min} = 9.3 fm @ 49.1°)

$$\sigma_{E2} = \sigma_R[k_1(\vartheta,\xi)B(E2)(1 + k_2(\vartheta,\xi)Q_s(2_1^+))]$$



Previous measurements



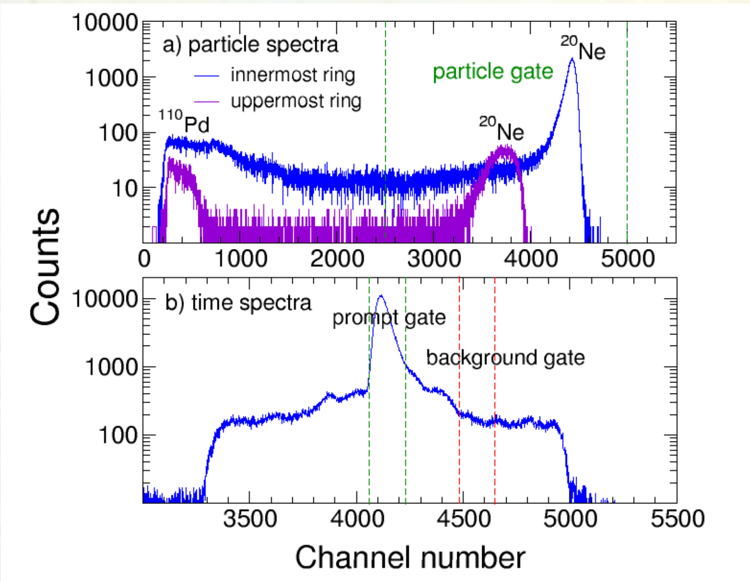
New Coulex measurement < 3% second-order contribution

Particle-gamma coincidence measurement

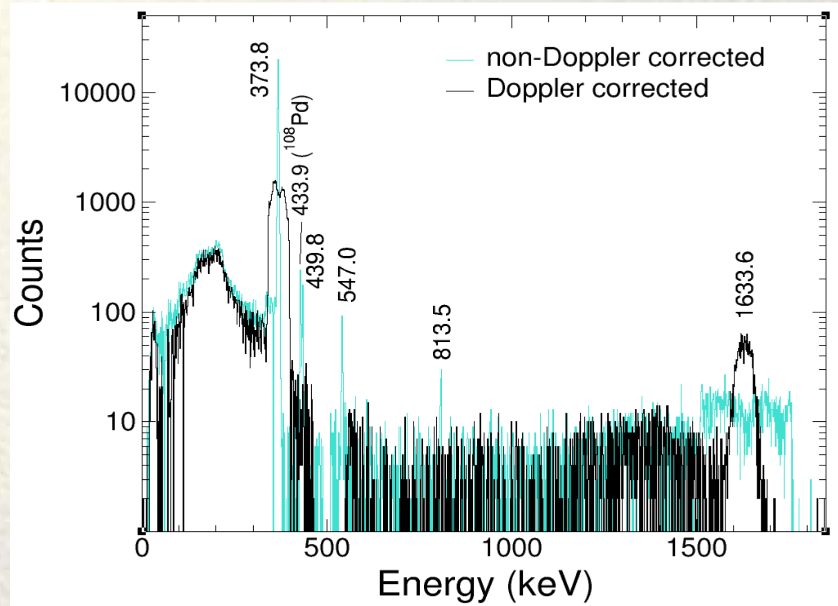
6 TIGRESS detectos + silidon S3 detector covering forward angles [20.9°, 49.1°]

B(E2) measurement @ TIGRESS (S. Masango, MSc)

$^{110}Pd(^{20}Ne,^{20}Ne^{*})^{110}Pd^{*}$ @ 64.7 MeV



Particle + time spectra



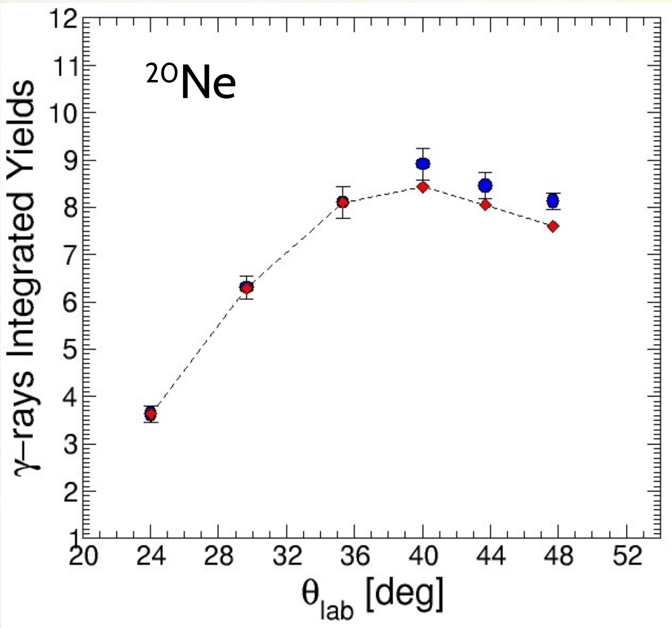
Gamma spectra

Particle-gamma coincidence measurement

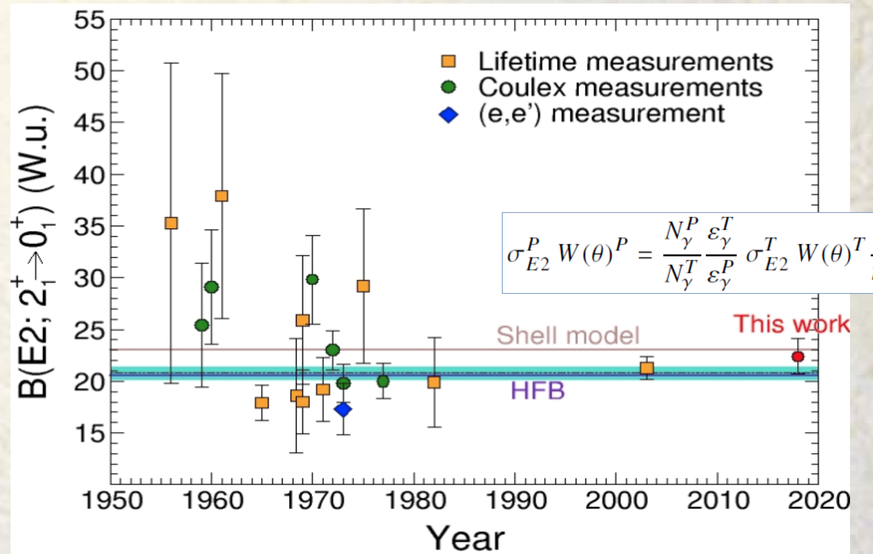
6 TIGRESS detectos + silidon S3 detector covering forward angles [20.9°, 59.1°]

B(E2) measurement @ TIGRESS (S. Masango, MSc)

$^{110}Pd(^{20}Ne,^{20}Ne^{*})^{110}Pd^{*}$ @ 64.7 MeV



Angular distribution (arbitrary units)



New B(E2) measurement
B(E2)=22.4(1.7) W.u.

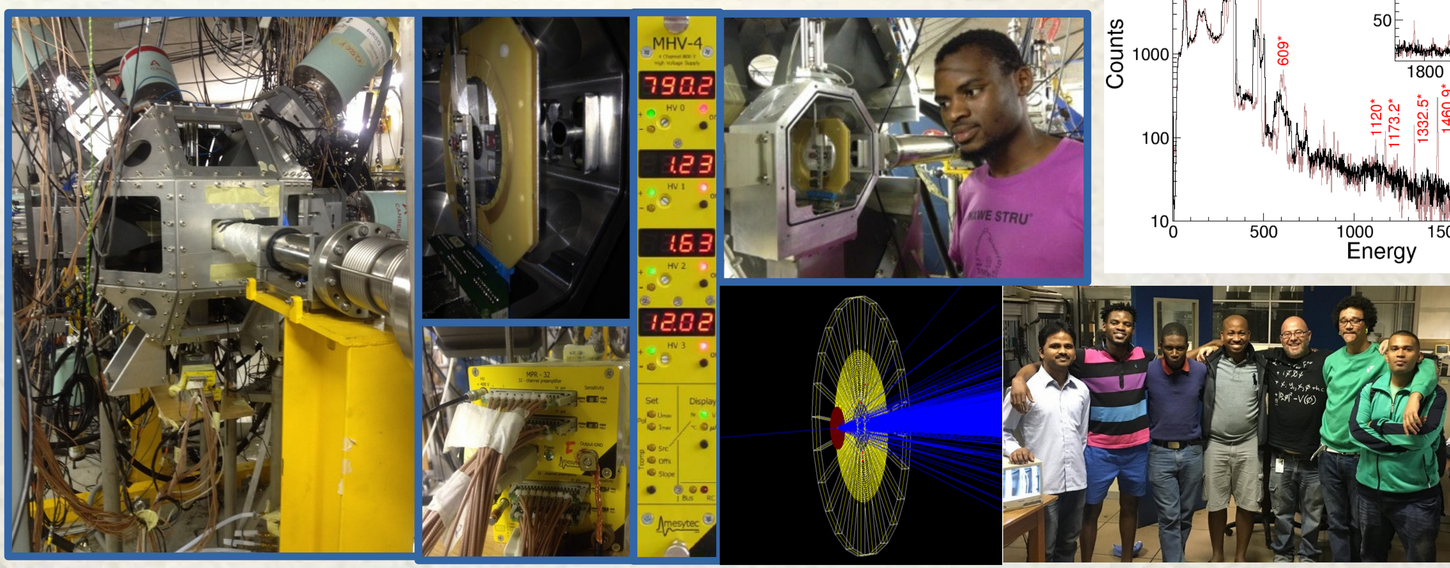
Particle-gamma coincidence measurement

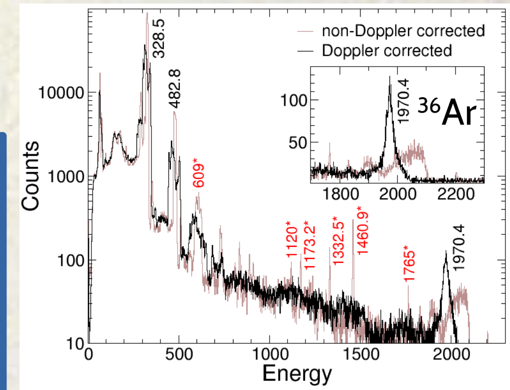
6 TIGRESS detectos + silidon S3 detector covering forward angles [20.9°, 49.1°]

New pipeline for Coulomb-excitation measurements using particle-gamma coincidences @ iThemba LABS

Two-month RE campaign April-May 2016: ^{20}Ne, ^{32}S, ^{36}Ar and ^{40}Ar

$^{194}Pt(^{20}Ne,^{20}Ne^{*})^{194}Pt^{*}$ @ 73 MeV; $S(150^{o})_{min} = 6.6$ fm



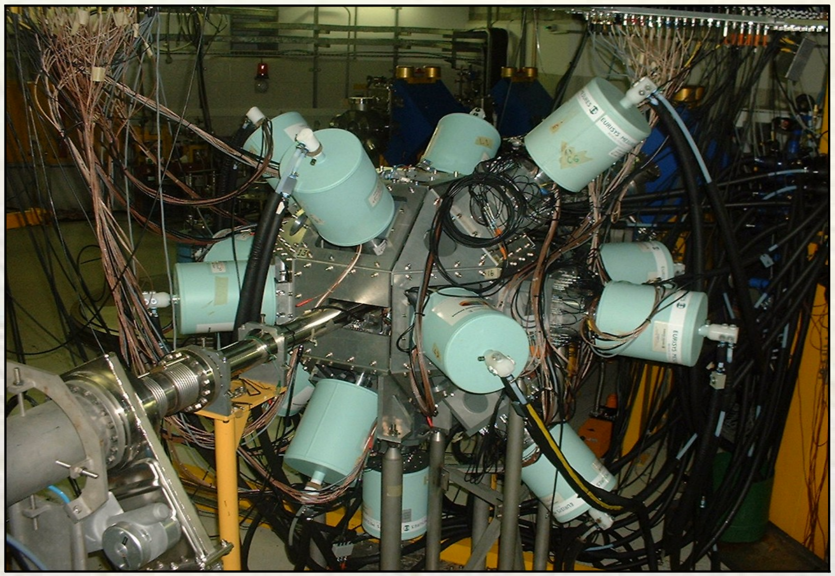


3xS3 detectors + adapters, 6xMPR-32 preamps, 1xMHV-4, feedthrough cables, computers, sorting codes, GEANT, GOSIA (Magda, Dan), ^{20}Ne, ^{36,40}Ar, ^{32}S proposals, 3 postdocs, flexible chamber+ extension (Mathis & Paul) + feedthroughs, new beam development ($^{60-62}$Ni, ^{102}Ru, Ntombi, Rainer Thomae), DAQ digital system (Pete)

RE measurement @ iThemba LABS (C. Mehl, PhD)

First safe RE measurement of ^{20}Ne beams

$^{194}Pt(^{20}Ne, ^{20}Ne^{*})^{194}Pt^{*}$ @ 73 MeV; $S(150^{o})_{min} = 6.6$ fm

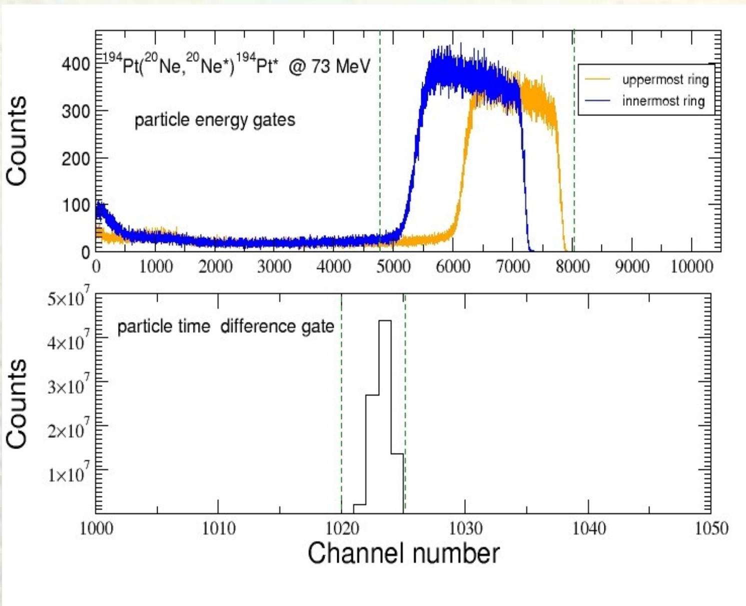


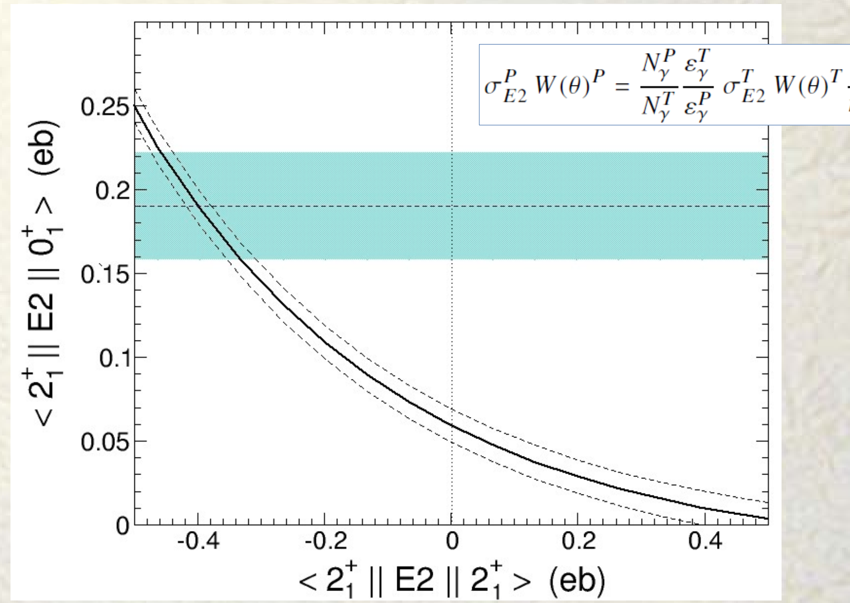
Particle-gamma coincidence technique

AFRODITE + S3 CD-type silicon @ [120°, 150°]

RE measurement @ iThemba LABS (C. Mehl, PhD)

First safe RE measurement of ^{20}Ne beams (preliminary results)





$Q_s(2^+) = -0.29(5)$ eb

In agreement with previous work $Q_s(2^+) = -0.23(3)$ eb

The large static quadrupole moment in ^{20}Ne is confirmed

Shape Coexistence back to SA through measurements using GAMKA

What about second 2^+states? Generally no statistics for angular distribution

Physics breakthroughs will ultimately come from both HIE-ISOLDE and iThemba LABS

UNIVERSITY of the WESTERN CAPE

UNIVERSITY OF ZULULAND

NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

UNIVERSITEIT STELLENBOSCH UNIVERSITY

GAMKA – Gamma-ray AsyMmetric spectrometer for Knowledge in Africa
PI: Nico Orce

The extended angular coverage and high statistics of the new GAMKA array will allow precise lifetime and mixing ratio measurements of high-lying 2^+ states

Future work and Conclusions

- Clear discrepancy with old and modern nuclear models!
- New cluster calculations being done by Maveric, Khan et al.
- Coulomb-excitation program @ iThemba LABS has been established (new digital electronics + DAQ developed @ UWC)
- First data analysis completed for ^{12}C, ^{20}Ne, ^{32}S, ^{36}Ar, ^{40}Ar (^{12}C published in Phys. Lett. B (2018).
- Future projects: study of nuclear shapes at low and high excitation using GAMKA (60-62Ni, 100-102Ru, etc)
- Including complementary lifetime + mixing ratio measurements (e.g., ^{66}Ge, ^{70}Se, etc).

Acknowledgements

Evidence for clustering in ^{20}Ne: the Morinaga nucleus

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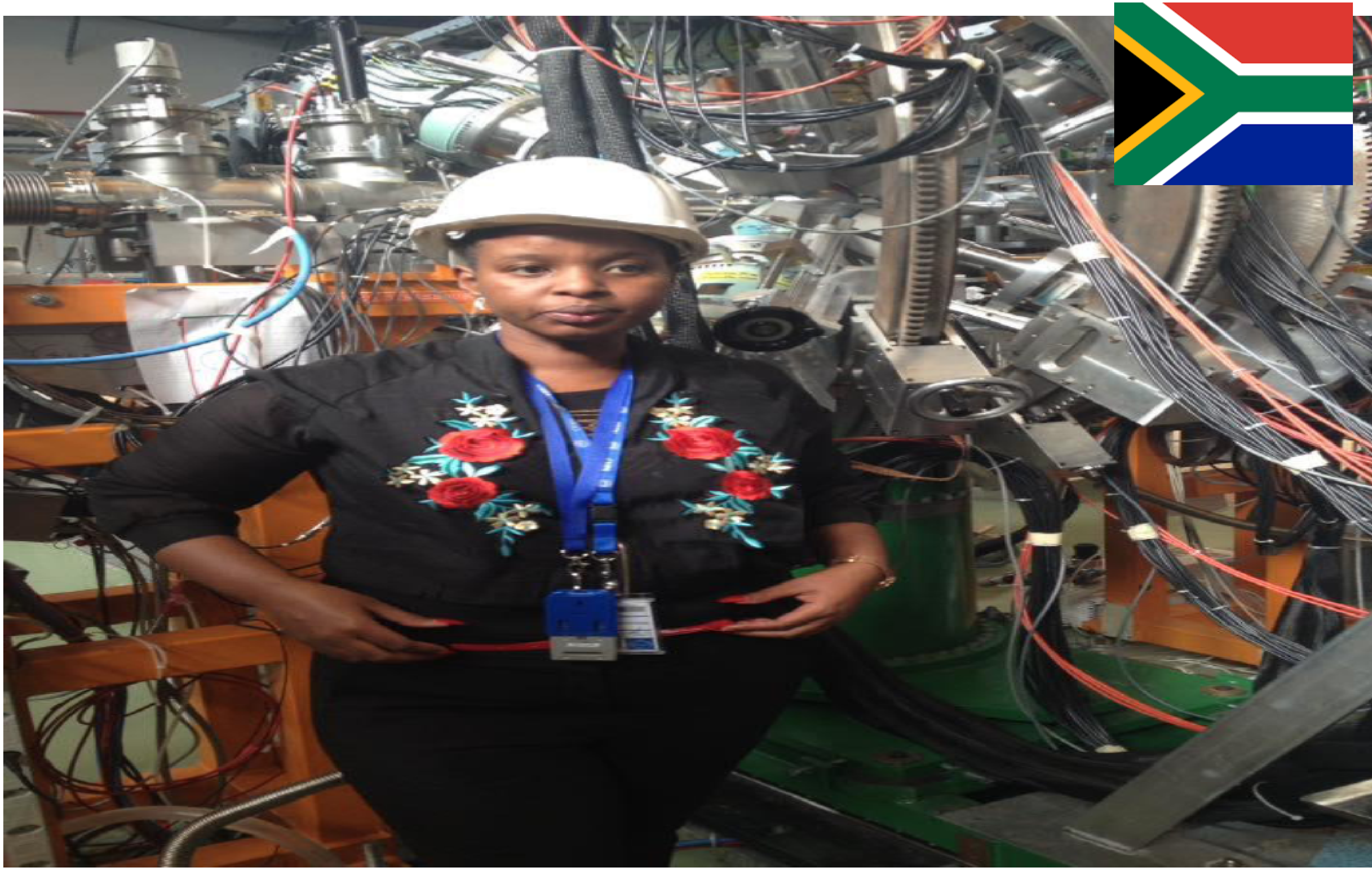
(Dated: November 25, 2018)

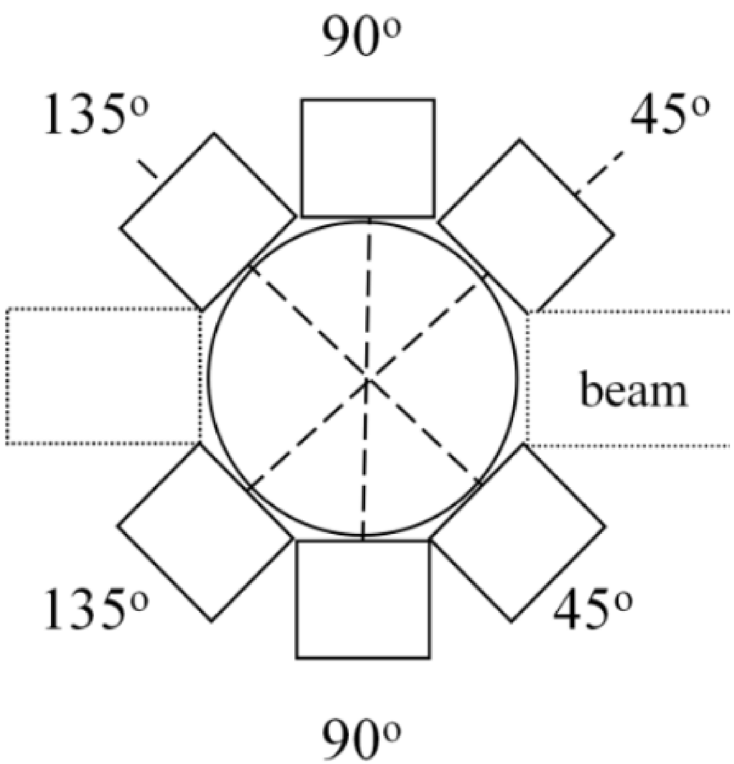
Ngiyabonga ! Imibuzo noma Imibono



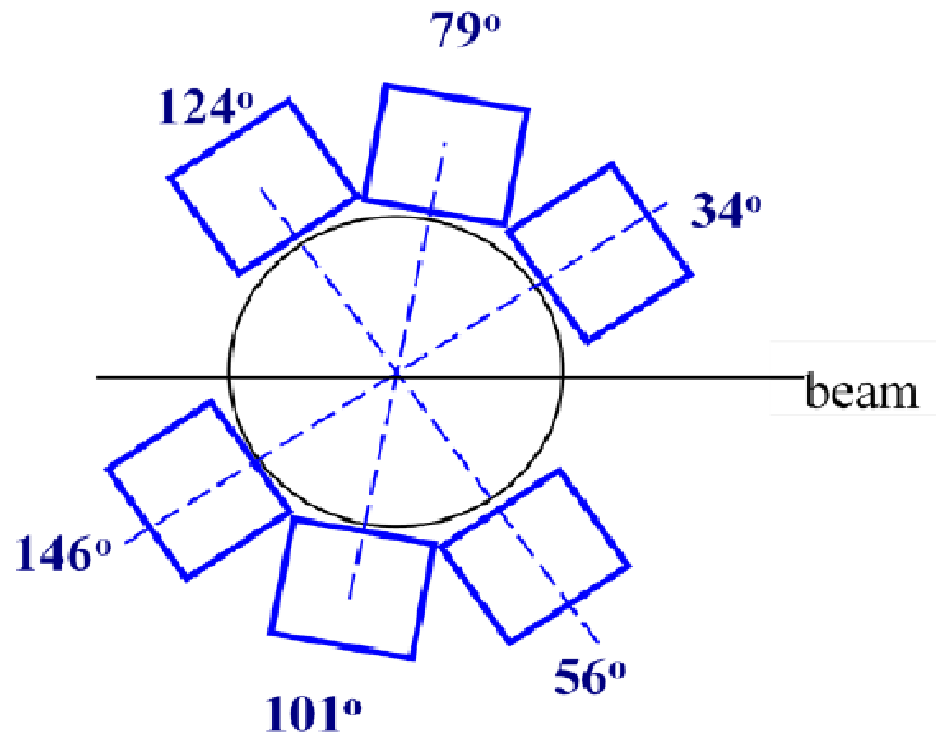
Thank you! Questions or comments

GAMKA: assymetric array at iThemba LABS

<u>How nuclei decay:</u> Transition probabilities, lifetimes, mixing ratios,...



current AFRODITE



GAMKA

GAMKA – Gamma-ray AsyMmetric spectrometer for Knowledge in Africa