The GAMKA spectrometer

UNIVERSITY *of the* WESTERN CAPE

RESPICE PROSPICE

GAMKA

THE LION

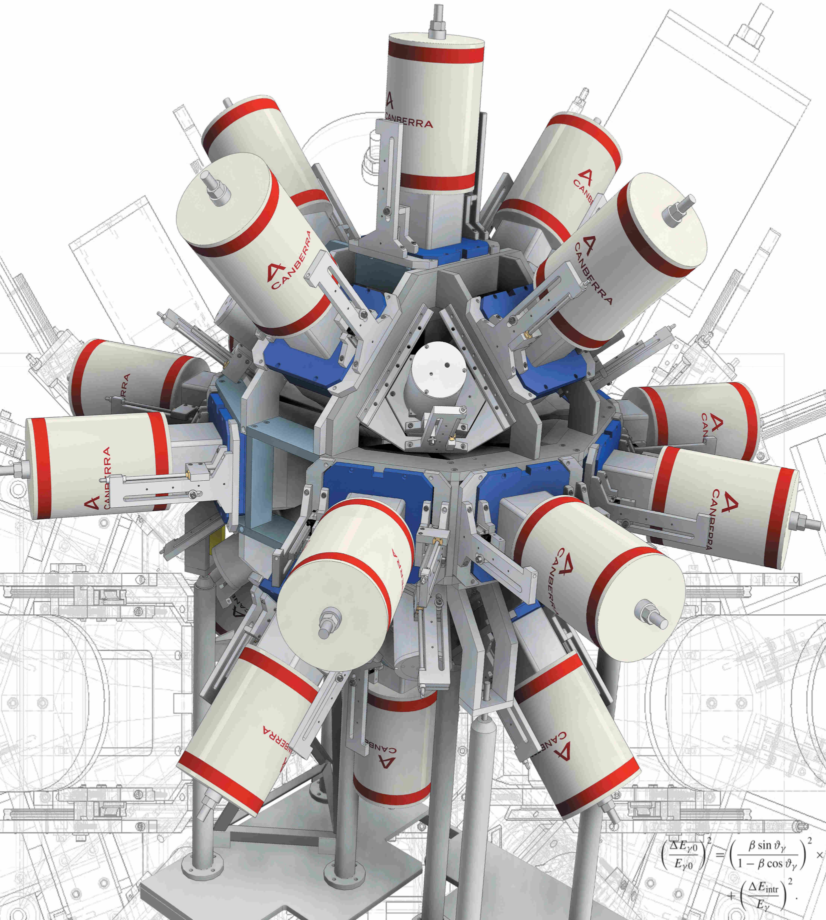
$$df_{E\lambda}(\vartheta,\xi) = \frac{4\pi^2}{(2\lambda+1)^3}\sum_{\mu}\left|Y_{\lambda\mu}\left(\frac{\pi}{2},0\right)\right|^2 \times |I_{\lambda\mu}(\vartheta,\xi)|^2 \sin^{-4}\frac{\vartheta}{2}d\Omega$$

$$\omega = \frac{v}{r} = \frac{qB}{m}$$

$$E^2 = (pc)^2 + \left(m_0c^2\right)^2$$

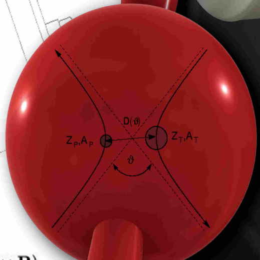
$$\frac{E_\gamma}{E_{\gamma 0}} = \frac{\sqrt{1-\beta^2}}{1-\beta\cos\vartheta_\gamma},$$

$$\sigma_{E\lambda} = \left(\frac{Z_1 e}{\hbar v}\right)^2 a^{-2\lambda+2}B(E\lambda)f_{E\lambda}(\xi)$$



$$\mathcal{F} = NI$$

$$\frac{mv^2}{r} = qvB$$



$$\mathbf{F} = q(\mathbf{E} + \mathbf{v}\times\mathbf{B})$$

$$\mathcal{F} = \oint \mathbf{H}\cdot \mathrm{dl}.$$

$$\left(\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}}\right)^2 = \left(\frac{\beta\sin\vartheta_\gamma}{1-\beta\cos\vartheta_\gamma}\right)^2 \times (\Delta\vartheta_\gamma)^2 + \left(\frac{\beta-\cos\vartheta_\gamma}{(1-\beta^2)(1-\beta\cos\vartheta_\gamma)}\right)^2 \times (\Delta$$

$$+\left(\frac{\Delta E_{\mathrm{intr}}}{E_\gamma}\right)^2.$$

Nico Orce

INTRANS 2024 WORKSHOP

UNIVERSITY of the
WESTERN CAPE

GAMKA
THE LION
THE GAMMA-RAY SPECTROMETER FOR KNOWLEDGE IN AFRICA

First University for coloured people in South Africa (founded in 1960)

UNIVERSITY of the WESTERN CAPE

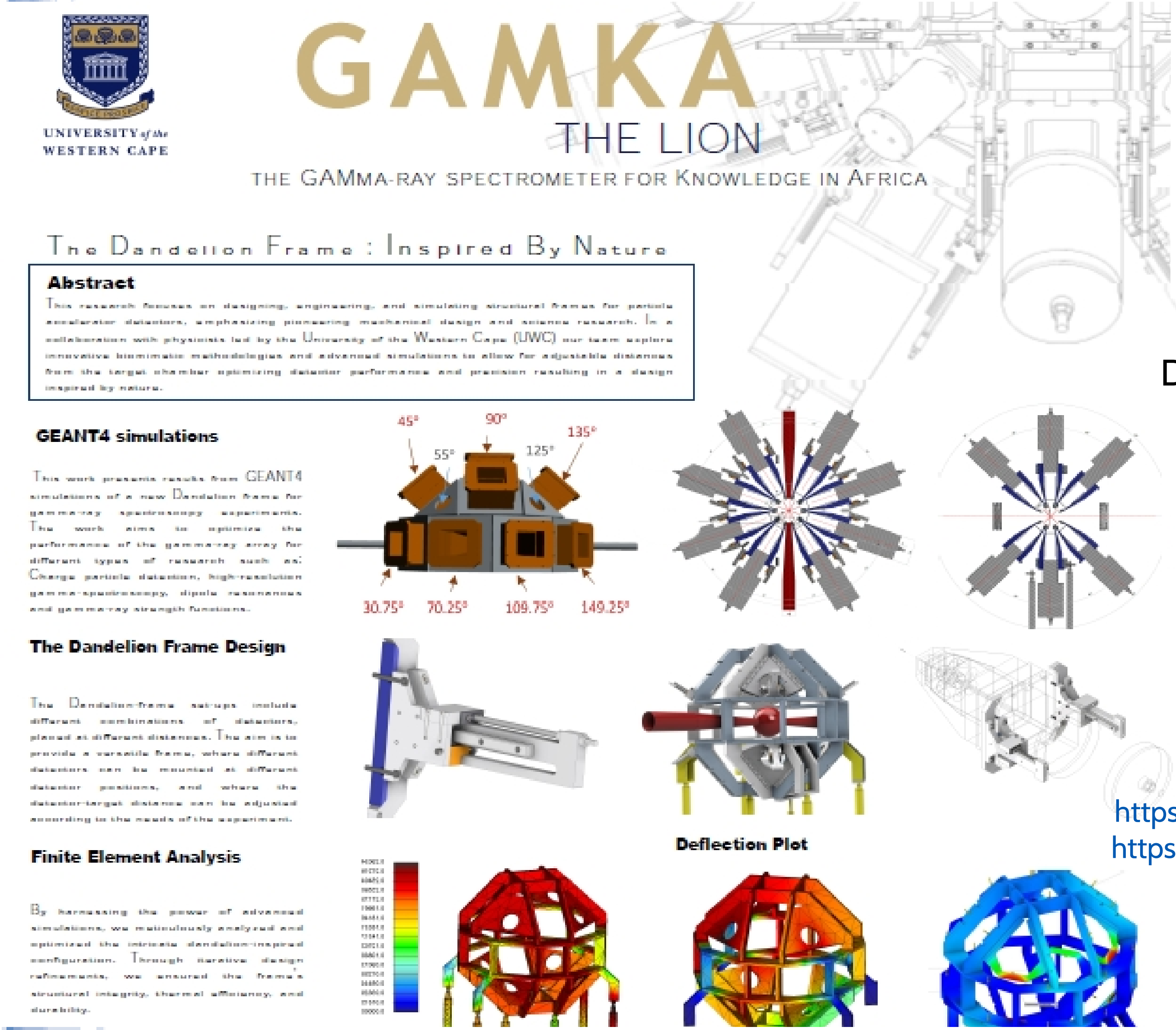
GAMKA

THE LION

THE GAMMA-RAY SPECTROMETER FOR KNOWLEDGE IN AFRICA

Largest single grant given by the NRF in a competitive call (+2M€) for a new γ-ray spectrometer
New funding instrument for Strategic Research Equipment (SRE). PI: Nico Orce

The name GAMKA (Lion in Khoisan language) was elected by the Physics Users in 2012.
A name that symbolized decolonization, SA pride and ownership



INTRANS 2024 Workshop
22-25 january 2024
Auditorium P. Lehmann - bldg 200

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

cnrs

université PARIS-SACLAY

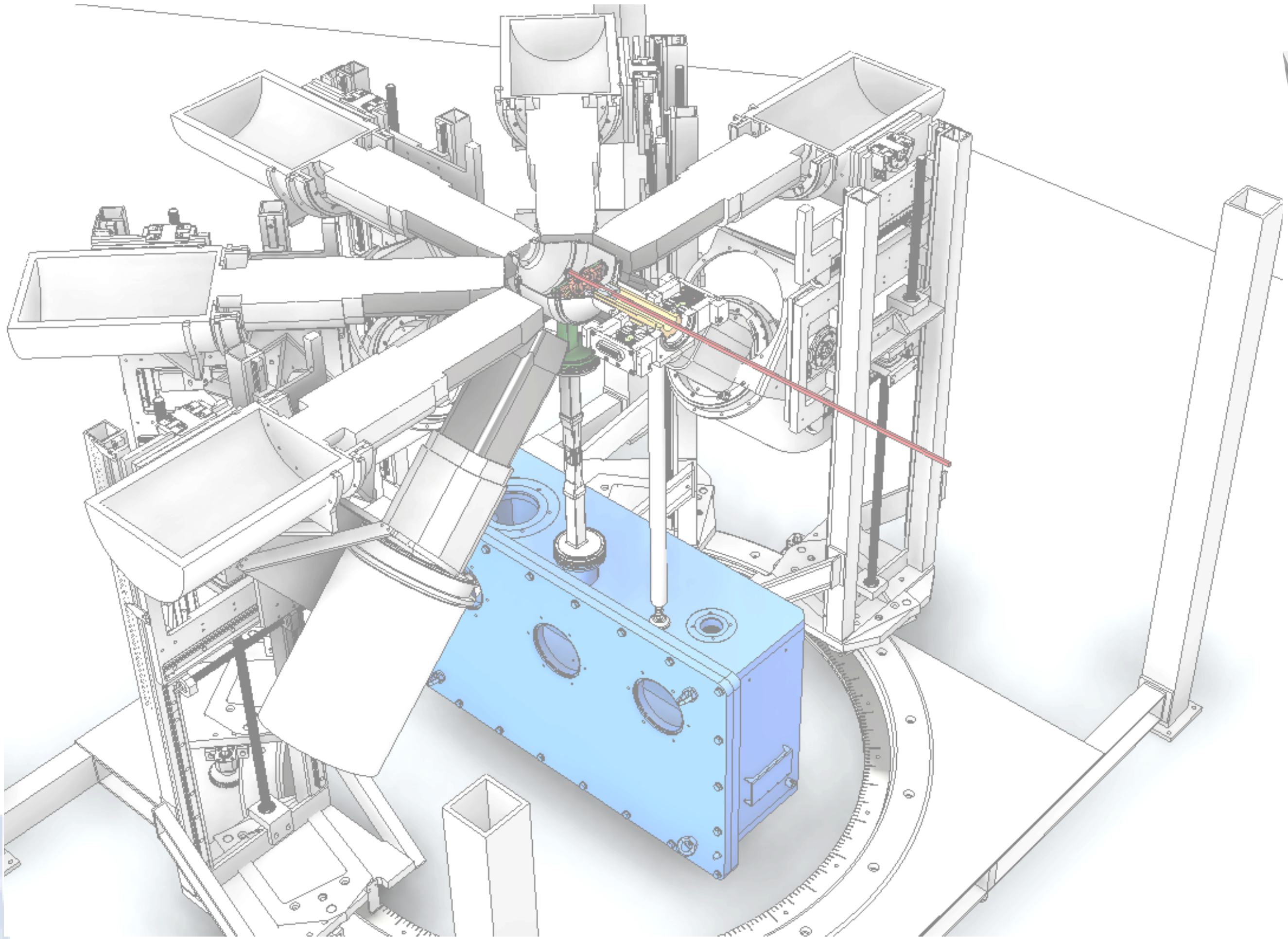
InTraNS

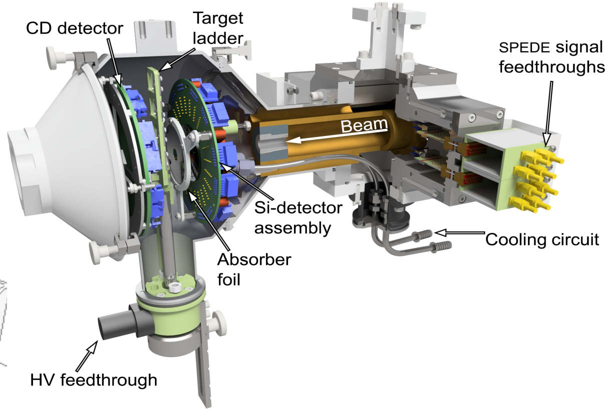
EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

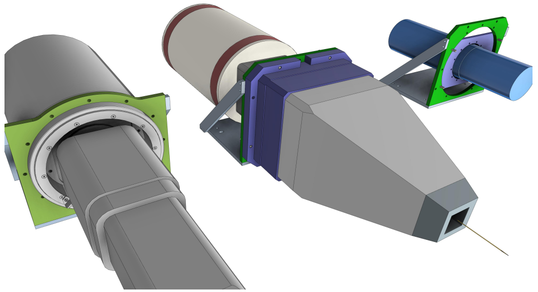
Design of the Dandelion ('dent de lion') Frame: Poster by Shaun Hendricks

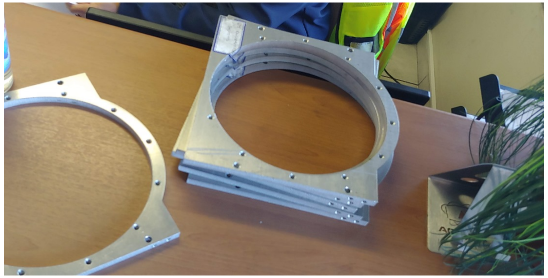
https://www.youtube.com/watch?v=ucnCQDrpNQk
https://www.youtube.com/watch?v=wxLRLOtXwmM
https://github.com/UWCNuclear/
https://nuclear.uwc.ac.za/

Shaun's further involvement @ IDS/CERN





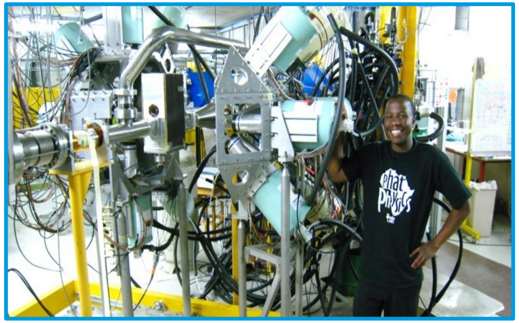




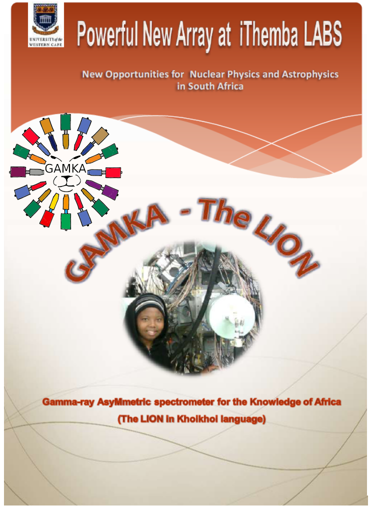
Once upon a time

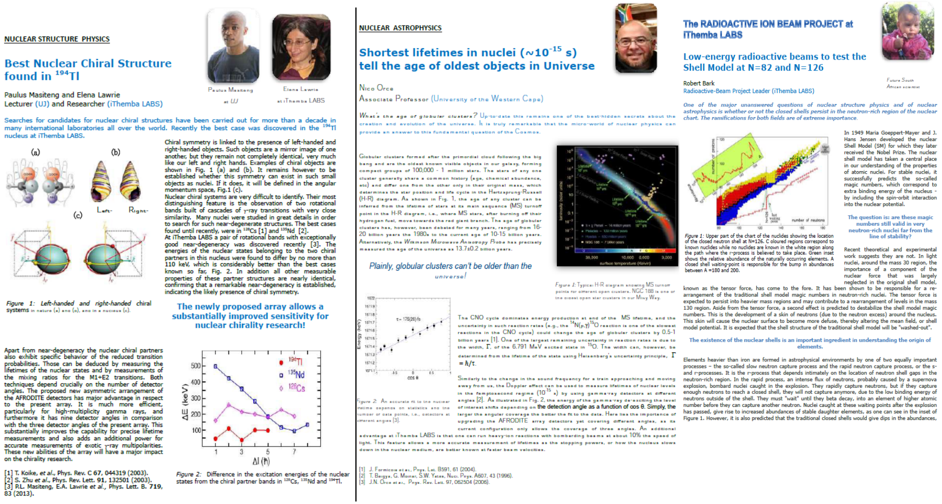
In October 2012 I was elected by the Physics Users @ iThemba LABS
with the mandate to lead the design/building/funding of a new γ-ray spectrometer

AFRODITE ~20 years old



Needed a new array
to be competitive worldwide



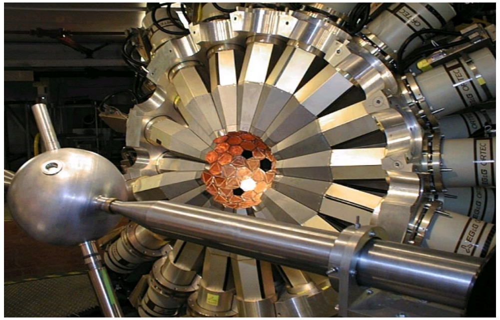


Combination of **high-resolution + high-efficiency gamma detectors** in flexible configurations to accommodate a wide range of nuclear physics and nuclear astrophysics phenomena: nuclear deformation and collectivity, high spin, short nuclear lifetimes, angular distributions, photon strength functions, nuclear polarizability and giant dipole resonances → NEP rejected (too much money!)

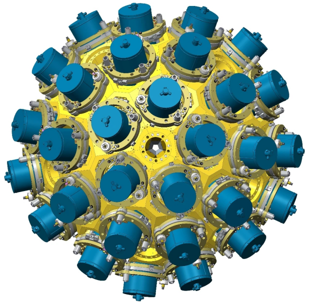
“Keep the dream alive”, late Danny Adams

(Chief Director: Basic Sciences & Infrastructure@ DSI)

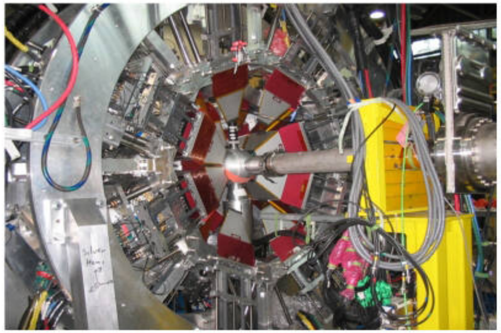
Gammasphere



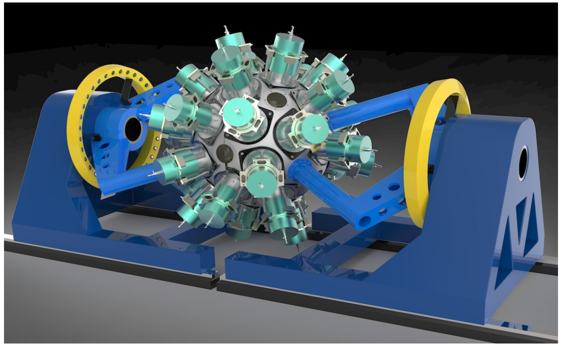
AGATA @ GANIL, LNL, GSI

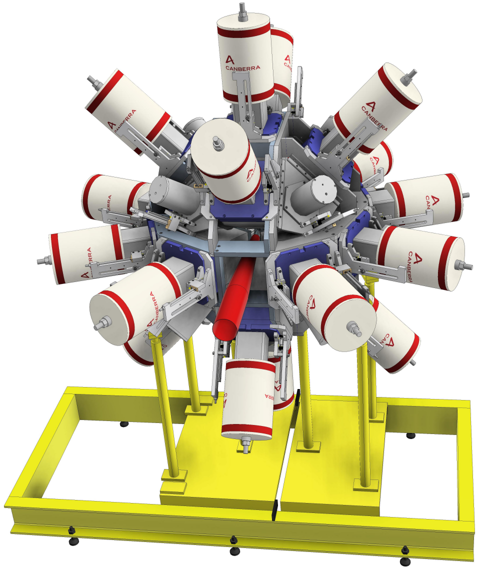


TIGRESS



GRETA @ FRIB, ANL





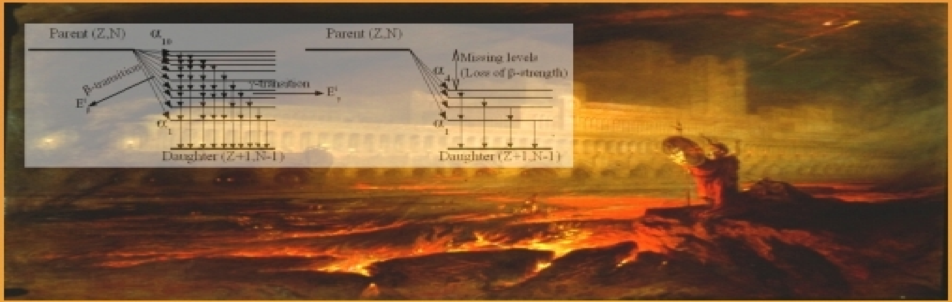
GAMKA @ iThemba LABS

Followed by Beta-Decay Workshop - Nov 6

Let's do Physics!

V Tastes of Nuclear Physics

November 4 - 6, 2015



Pandemonium: a place or scene of riotous uproar or utter chaos

New Physics with GAMKA [the Lion] and RIBs

No Registration Fees
Free Coffee & Lunch
Tastes Braai
9:30-16:30 @ Room 1.35
Physics Dept @ UWC

World-Class Lecturers

Maria Garcia Borge (CERN, Switzerland)
Alejandro Algora (Valencia, Spain)
Paul Garrett (Guelph, Canada)
Andreas Görgen (Oslo, Norway)
Emanuele Vardaci (Napoli, Italy)
John Wood (Georgia Tech, USA)
Steve Yates (Kentucky, USA)
With Special Talks By Our Own Students!

Timely Topics

Mathematics for Advanced QM
Beta Decay
Coulomb Excitation
Nuclear Lifetimes
Statistical Model
Physics @ ISOLDE (CERN)
Physics with the 8pi (TRIUMF)
Nuclear Astrophysics

Sponsors

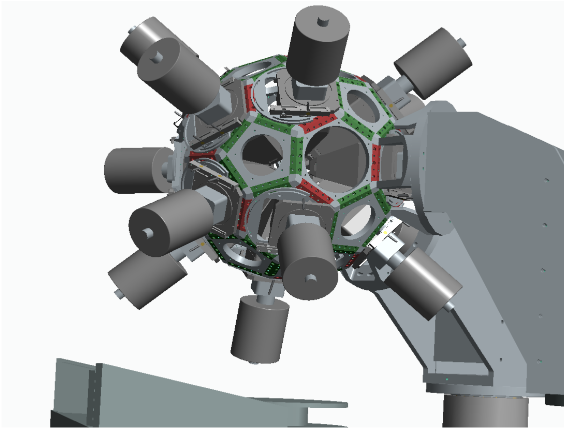
science & technology — Department: Science and Technology, REPUBLIC OF SOUTH AFRICA
UNIVERSITEIT STELLENBOSCH UNIVERSITY
NRF National Research Foundation — iThemba LABS Laboratory for Accelerator Based Sciences
Bio-teknik CANBERRA
UNIVERSITY of the WESTERN CAPE

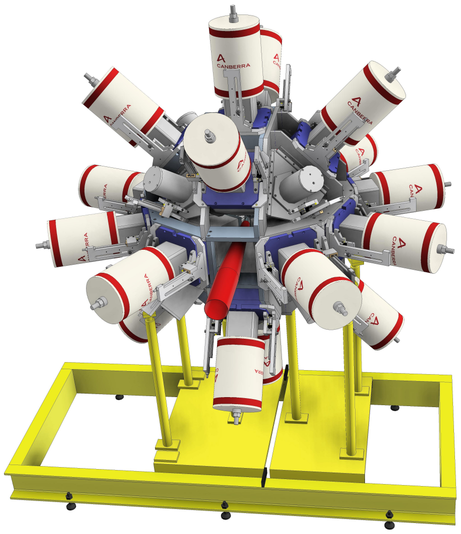
Tastes of Nuclear Physics @ UWC/SU/UZ

John Wood, Steve Yates, Berta Rubio, Maria Garcia Borge, Alejandro Algora, Paul Garrett, Magda Zielinska, Dan Doherty, David Jenkins, Mark Riley, Paul-Henri Heenen, Kike Nacher, Peter Butler, Eric Norman, Emanuele Vardaci, John Sharpey-Schafer, Elena Lawrie, Nico Orce, Kobus Lawrie, Pawel Napiorkowski, Ale Pastore, Alexis Diaz Torres, Xavier Roca-Maza, Jorge Piekarewicz, Calors Bertulani, Adriana Banu, Krish Baruth-Ram, Mitch Allmond, Werner Richter, Paul Papka, Sifiso Ntshangase, our students and others

New GAMKA spectrometer: proposal

- 4 clovers and 3 BGO shield → making up to 17 shielded clovers (including factory refurbishment of clovers)
- 17 large (89 mm diameter x 203 mm) $LaBr_3$ detectors → making up to 23 $LaBr_3$
- 2 frames for two different beam lines: K600 line (Soccerball frame) and AFRODITE (Dandelion frame)
- XIA digital electronics (500 MHz)
- HV, LN2 liquefier system





Frames:

- versatile
- shielded (unshielded) clovers
- large $LaBr_3$ for efficiency
- small $LaBr_3$ for lifetimes
- LEPS (segmented Planar HPGe) for low-energy gammas
- optimized for clover efficiency, clover + $LaBr_3$ efficiency, number of independent angles, clover P/T

Target Chambers:

- smaller 170mm diameter for increased efficiency
- larger, 200mm diameter to hold Si detectors

GEANT4 Simulations (by Elena Lawrie, Walid Yahia-Cherif, Kobus Lawrie)

Aim: To optimize the performance of the gamma-ray array for different types of research.

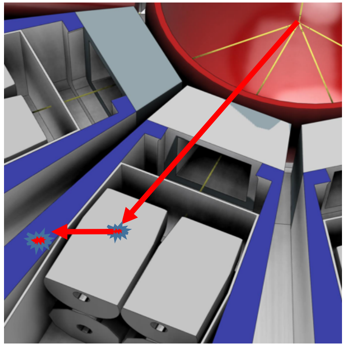
Construct Geometry
- different detectors
- positions in space (for different combinations and angles)

Emit γ rays
- γ rays at 1, 5 and 10 MeV
- Isotropic sources (^{60}Co, ^{152}Eu)
- coincident γ rays – cascades or sources (^{60}Co, ^{152}Eu) with any given angular distribution

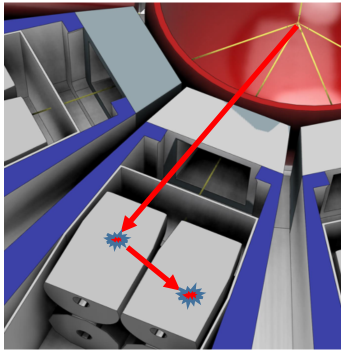
Track interaction in all materials
- (Photo electric effect, Compton scattering , Pair formation)

Record energy deposition
- for each detector and for sum of all
  - clovers with or without Compton suppression
  - clovers with or without add-back
    - (add-back: summed energy over 4 crystals in a clover)

Compton Scattering

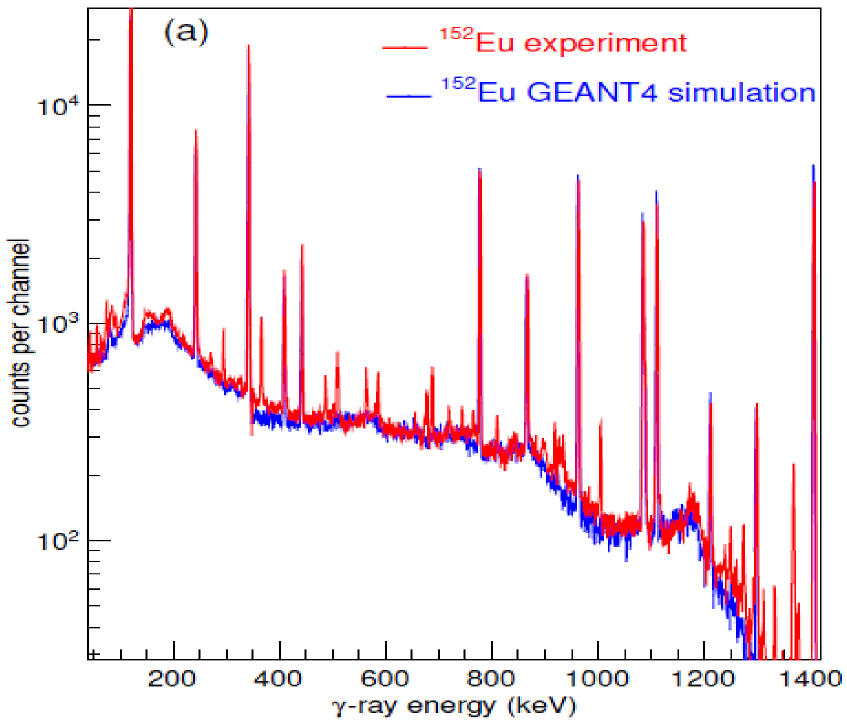


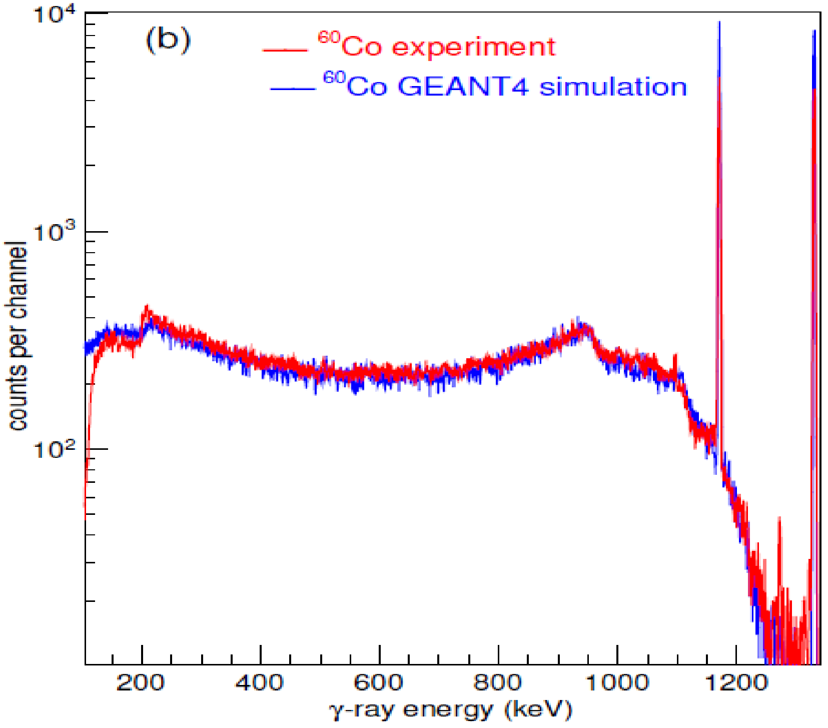
Escape Suppression



Add-back

GEANT simulation of sources





Dandelion – option 1

Detectors:

✓ 18 suppressed clovers
✓ 8 large or small $LaBr_3$ or LEPS

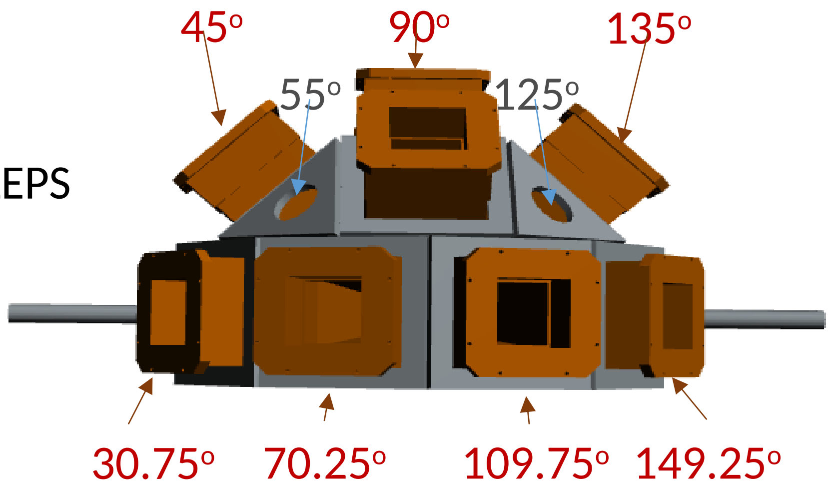
Distances:

Clovers @ 194mm to crystal (102mm to collimator)
Large $LaBr_3$: at 183mm to cap
Small $LaBr_3$: at 102mm to cap

Chamber: 200mm diameter

Beam pipe: 40 mm diameter

Peak/Total at 1 MeV:
35x35mm Collimator 67.4%
40x40mm Collimator 66.7%



Physics:

- High-spins states, spins, parity, mixing ratios, matrix elements
- Clovers + S3 silicon detectors for Coulomb Excitation

EFFICIENCY	1 MeV	5 MeV	10 MeV
17 Clovers Collimator 35x35 Collimator 40x40	 4.85% 5.59%	 1.32% 1.47%	 0.56% 0.59%
8 Large $LaBr_3$	4.48%	1.93%	1.13%
8 Small $LaBr_3$	1.92%		

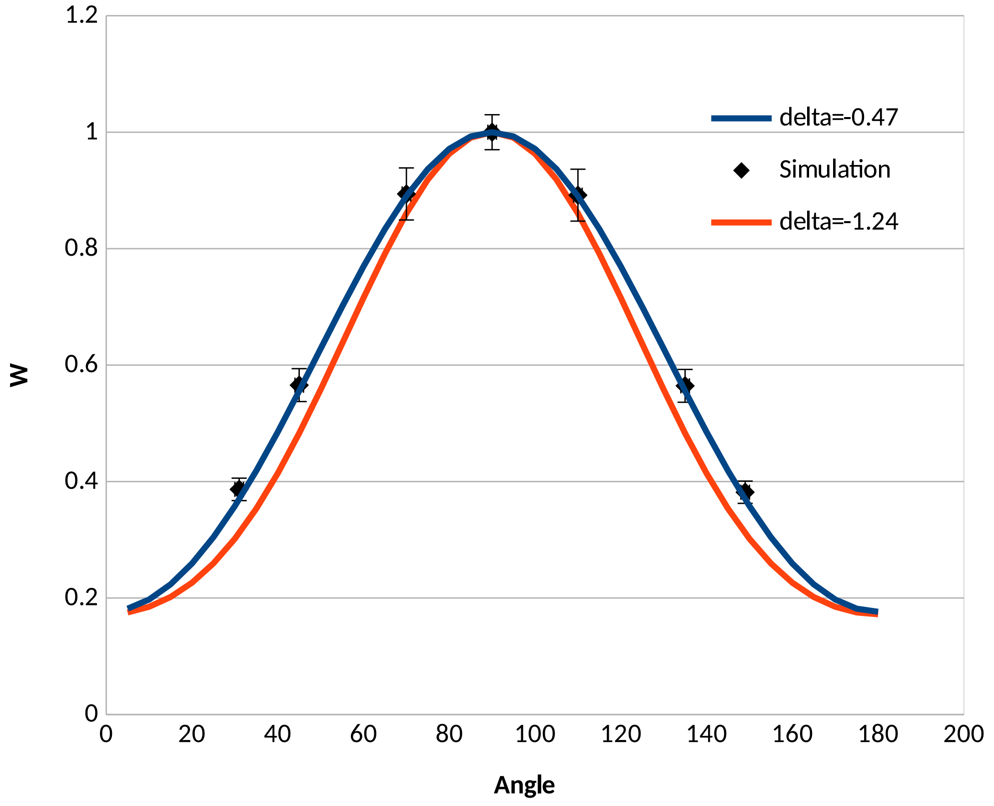
Angular Distribution Simulation (by Elena Lawrie, Kobus Lawrie, Gugu Mtembu)

$W(\theta) = a_0 + a_2 P_2(\cos\theta) + a_4 P_4(\cos\theta)$

747 keV $17/2^- \longrightarrow 15/2^-$ in ^{135}Pr
M1/E2 with δ = -0.47 and -1.24
(two possible values that give different interpretations)

Calculated a_2 and a_4 for δ =-0.47
Simulate emission with calculated $W(\theta)$ for 18 clovers in dandelion frame with 5% error

Compare with calculated $W(\theta)$ for
δ =-0.47 and -1.24



GAMKA Business Plan for Strategic Research Equipment (SRE)

100s of pages, thousands of files, sections, subsections, appendixes, various science cases, finances, steering, OC, NRF, UWC meetings, reports, NRF defense,…, many years of solid work.

NRF National Research Foundation | RISA Research and Innovation Support and Advancement

Funding Instrument:	Strategic Research Equipment
Functional Domain:	Human and Infrastructure Capacity Development
Type of Equipment:	Multiple Complimentary Instruments
Document:	ANNEXURE A: Revised Management Plan
Date:	March 2018

Table of Contents

APPENDIX A (Reproduced from Phase II Business Plan p 17-19)

Technical capabilities/applications

Technical capabilities

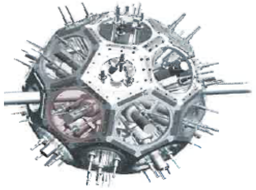
- The GAMKA gamma-ray spectrometer will be comprised of high-resolution clover-type HPGe detectors and high-efficient $LaBr_3$:Ce detectors. The technical capabilities and applications for the clover detectors were explained in our Phase 1 application.
- Four clover detectors will be used to complement the existing AFRODITE gammaray array. This will provide 16 detectors that constitutes the maximum number of detectors that can be accommodated in the present geometry and would give the largest possible coverage of the full 4pi solid angle. The expected efficiency at 1.3 MeV would be 2.72% with an energy resolution of 2.1 keV and a peak-to total ration 40%. The increase from the present 9 detectors to 16 will increase the probability of detecting coincidences of more than 3 simultaneous gamma rays by a factor of 4, thus allowing much superior selectivity particularly where gamma transitions with similar energies exist in the same isotope or in contaminants isotopes.
- The 17 new large volume (89x203mm) and high-efficient LaBr3:Ce detectors, that supplemented 6 identical detectors that have been ordered. These have an energy resolution of ~3% (40 keV at 1.3 MeV and 180 keV at 6 MeV). However the photopeak efficiency, particularly at high gamma energy, is much higher than that of Ge detectors as can be seen in the table below.
- The GAMKA array of high-resolution clover and high-efficiency $LaBr_3$:Ce detectors could be mounted in flexible configurations that makes provision for 30 detectors. . Two possible configurations that could make up the GAMKA array are shown in Fig. 1. Additional electronics for data processing to supplement the existing system at iThemba LABS are included in this proposal.

Gamma-Ray Energy (MeV)	Efficiency for one HPGe clover detector (%)	Efficiency of AFRODITE (nine Clovers) (%)	Efficiency for one $LaBr_3$:Ce detector (%)	Efficiency for 23 $LaBr_3$:Ce detectors (%)
1.3	0.20	1.8	0.38	8.74
6.0	0.05	0.45	0.16	3.68
10.0	0.03	0.27	0.10	2.30

- Coupled with other particle detection devices (such as the K600 spectrometer, silicon detectors, etc), GAMKA detectors will provide a unique combination with each detector

20

ifferent aspects of nuclear properties. As evident from the Br_3:Ce detectors will provide a huge increase in efficiency at , thus allowing cutting edge science to be performed.



s of the GAMKA array comprising (top) 30 $LaBr_3$:Ce detectors and Ce detectors.SU

aBr_3:Ce and clover detectors are delivered they will be available for experiments, an approach which utilizes the ility without delay and further commissioning.

, such as the study of resonances and strength functions, research projects, will benefit from the availability of large

2.3.1 all communications between the Consortium and the NRF as a point of contact;

2.3.2 submission to the NRF of an annual report, from date of grant award to ten (10) years post commissioning of the equipment under signature of the Chairperson of the Advisory Committee and the designated DvC from the lead institution (if different);

2.3.3 establishing the SRE as a national resource in leading the scientific and research themes of the Proposal and in the management of the day-to-day operational activities;

2.3.4 the development of the strategy;

2.3.5 the development of the Annual Business Plan;

2.3.6 Annual Progress Reports (APRs);

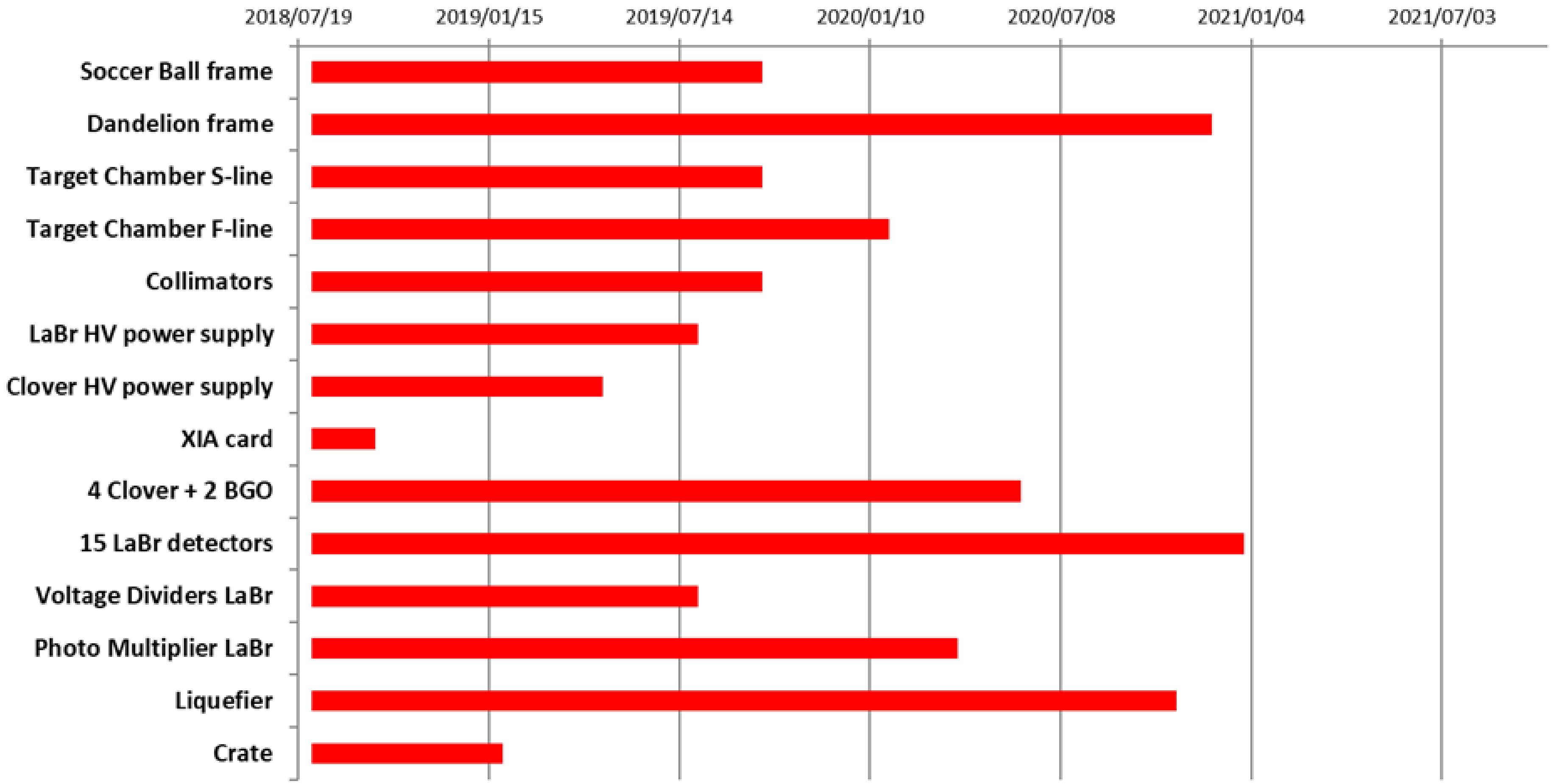
2.3.7 the financial management of the SRE Consortium funds; and

2.3.8 the preparation and provision of all other consolidated reports for submission to the NRF.

2.4 The provisions of this Agreement supersede any other related provisions contained in earlier Agreements between the Parties, which pertain to the management and operation of the **DST - NRF SRE Consortium**.

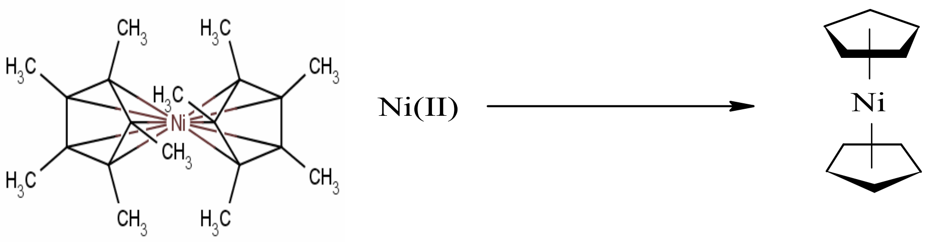
2.5 This Agreement will operate as from the Effective Date and will remain in force for a maximum period of ten (10) years, or until the winding up of the SRE Consortium as hereinafter provided, or as otherwise agreed between the Parties, or terminated in terms of the **Clause 9**, whichever occurs first, subject to the provisions of this Agreement.

GAMKA gantt chart – according to plan



Development of new beams @ iThemba LABS

Organometallic Chemistry using MIVOC method to accelerate exotic stable beams

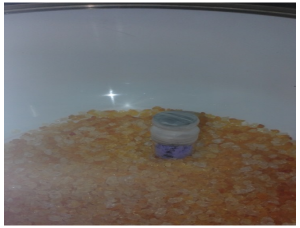


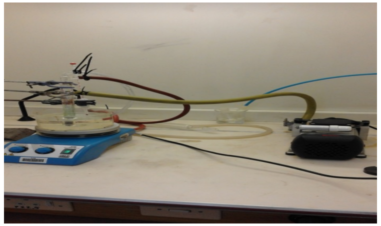
- Enriched isotopic material in powder form needed (Rainer Thomae)
- Organometallic chemistry (new chemistry lab available @ TLABS)
- Inject enriched compound into the new injection system of the HMI ECRIS4 ion source
- Lots of new beams (Ni, Ru, Pd, Pt, Sm, Mg, etc)
- New Physics (lifetimes in inverse kinematics, second-order effects in Coulomb excitation, strength functions, etc)

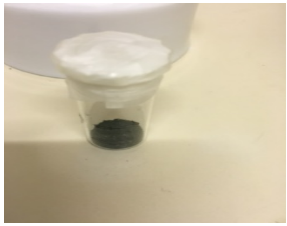
Ntombi Kheswa (PhD), Rainer Thomae and the Accelerator Group at iThemba LABS, Rudolph Nchodu (iThemba LABS), Salam Titinchi (Chemistry, UWC) and Nico Orce (UWC)

Chemistry lab @ TLABS (Ntombi's PhD)

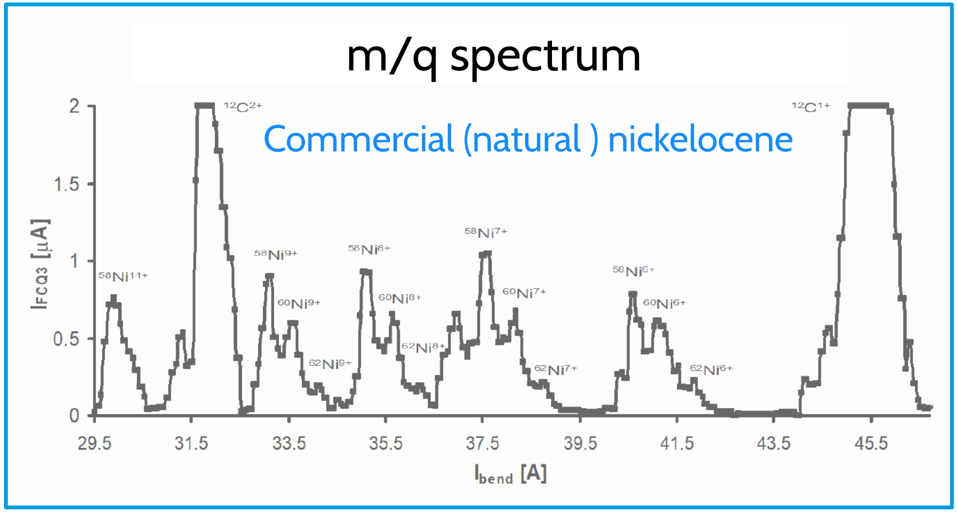
Nickelocene step by step synthesis from Nickel Chloride to Hexaaminenickelchloride to nickelocene

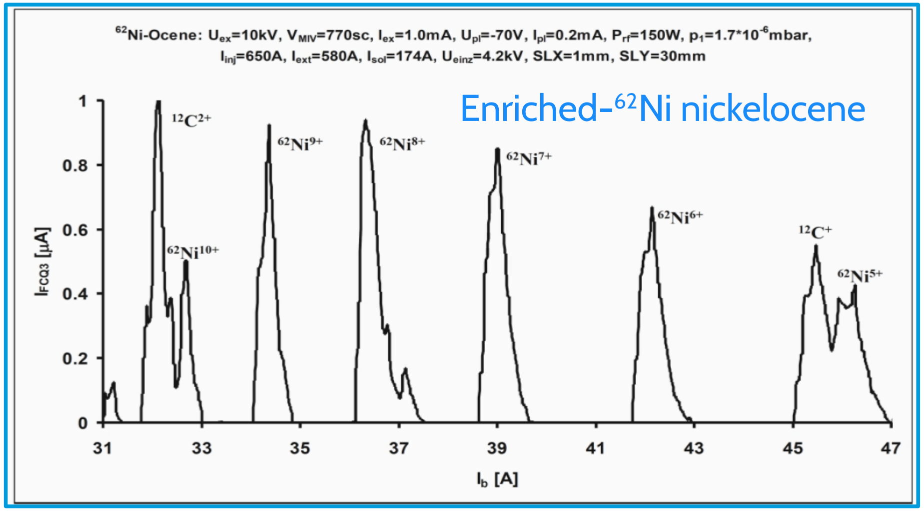






Synthesising samples characterised by investigating their crystal structure and bonding arrangements by X-ray diffraction (XRD), Fourier Transform Infrared (FT-IR) spectroscopy, and ^{1}H NMR

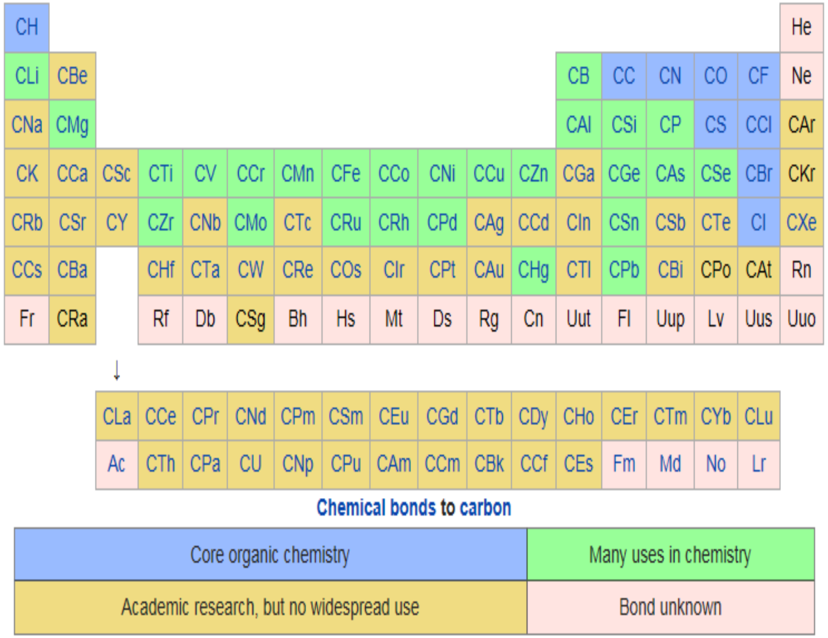


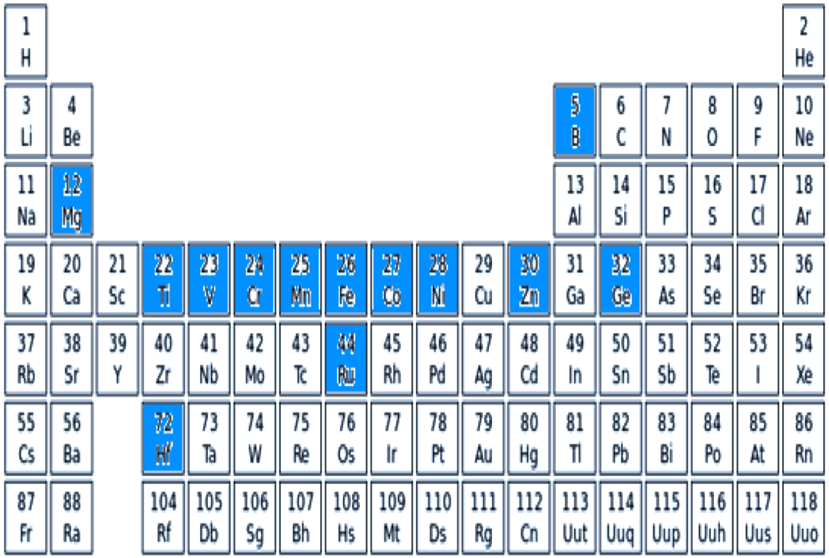


Beam currents ~ 30 μA for both ^{60}Ni and ^{62}Ni → optimum for physics measurements!

Possible organometallic materials for MIVOC method

Lots of new beams (Ni, Ru, Pd, Pt, Sm, Mg, etc) though MIVOC method with enriched isotopic material ($^{60-62}$Ni beams by N. Kheswa, PhD @ UWC/iThemba LABS)



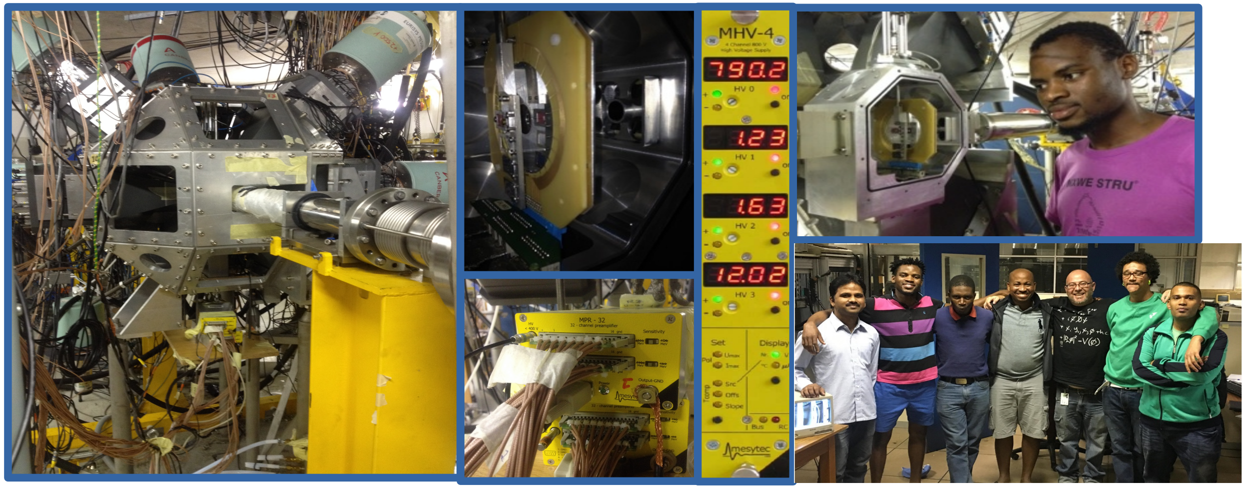


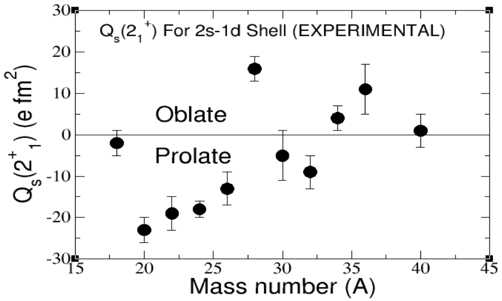
Some of the enriched metal ion beams produced in JYFL (Finland), GANIL (France) and JINR (Russia) using metallocenes

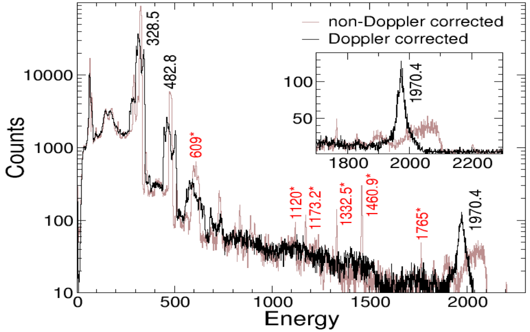
Broadening the Science Cases for MScs and PhDs @ iThemba LABS

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

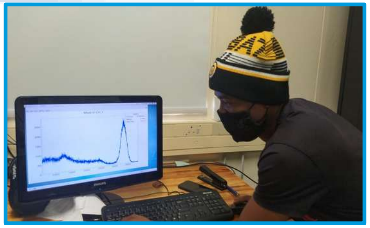
First successful measurements in April-May 2016
Orce et al., PRC 104, L061305 (2021) → Proof of Principle

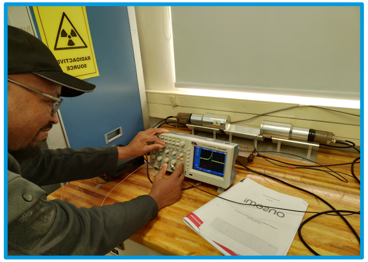






3xS3 detectors + adapters, 6xMPR-32 preamps, 1xMHV-4, feedthrough cables, computers, sorting and Coulomb-excitation codes, GEANT, GOSIA, ^{20}Ne, ^{36,40}Ar, ^{32}S, ^{60,62}Ni experiments, 4 postdocs, flexible chamber+ extension + feedthroughs, new beam development ($^{60\text{-}62}$Ni, ^{102}Ru), PIXIE-16, DAQ digital system, +15 completed MSc+PhD theses (machine learning, big data, academia,...)





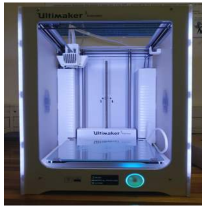
Modern African Nuclear DEtector LAboratory

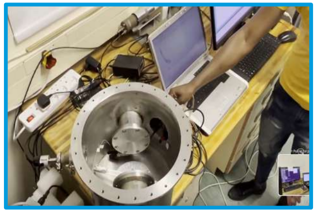
Global Challenge Research Funds (STFC/UK/York)

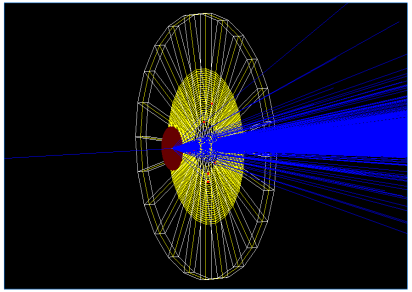
Modern nuclear laboratories built @ UWC and UZ

MANDELA partly to support GAMKA-based research

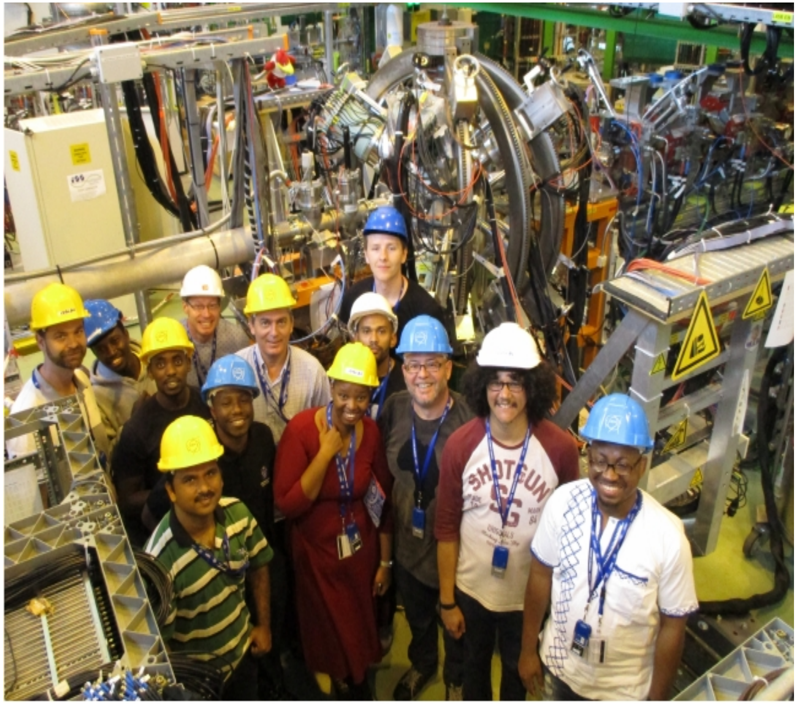
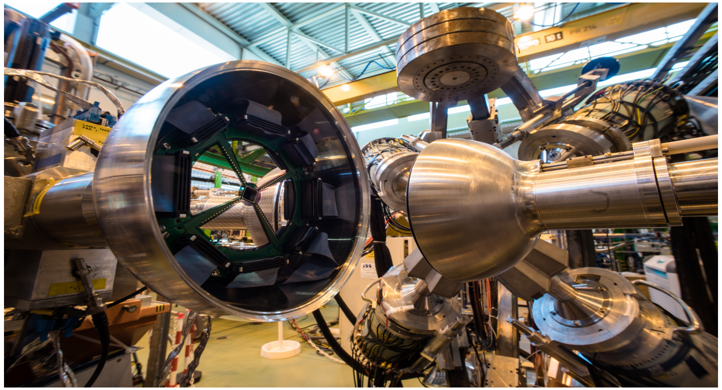
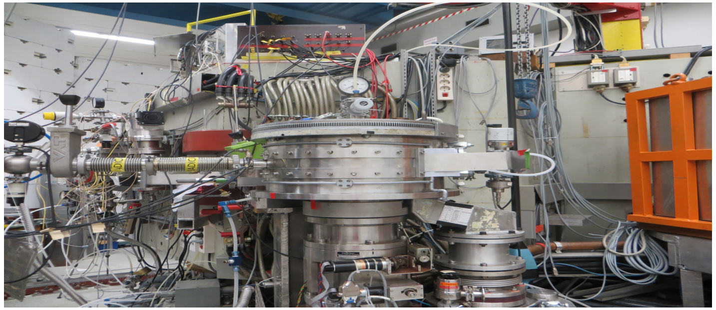
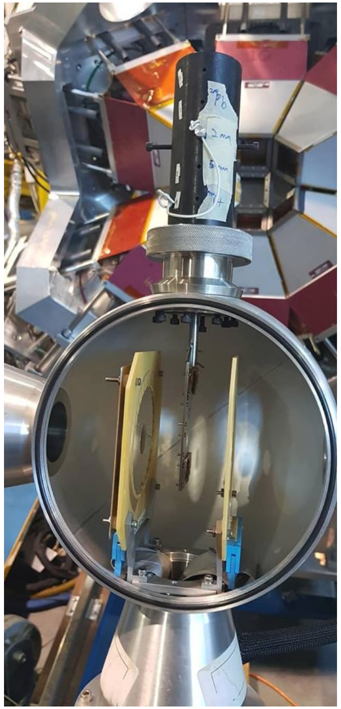
- Digitizers: XIA Pixie-16 250 MHz 12bit,
- CAEN DT5730S 500 MS/s, DT5742 5 GS/s
- Ionization chamber (beam purity, beam energy loss)
- PET scanners for nuclear imaging
- GEANT on the Cloud
- CsI array @ forward angles
- Segmented SiC detectors







Other Coulomb-excitation measurements @ HIE-ISOLDE, TRIUMF, MLL

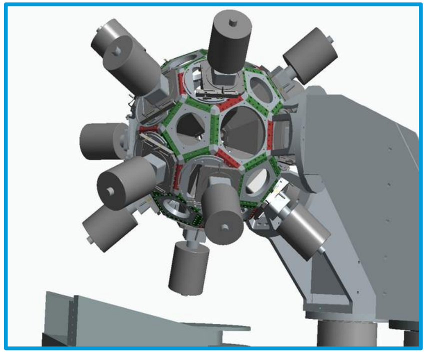





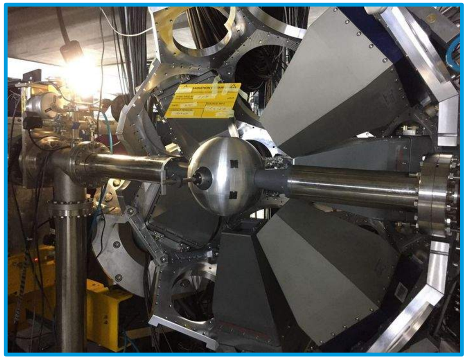
Nine well-trained SA students came to CERN in July 2017 to run what CERN called the Ubuntu experiment. PhD awarded to Kenzo Abrahams (2021)

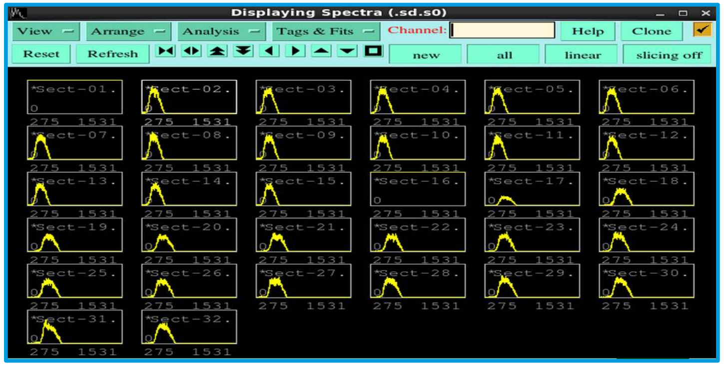
https://home.cern/news/news/experiments/ubuntu-powerful-motto-important-experiment

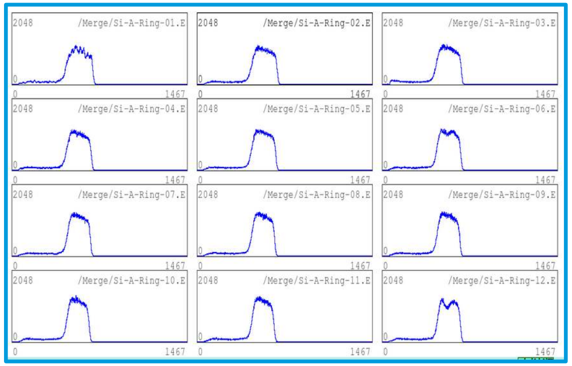
First Pre-GAMKA experiments with the soccerball frame

designed by Paul Papka and manufactured @ SAAO







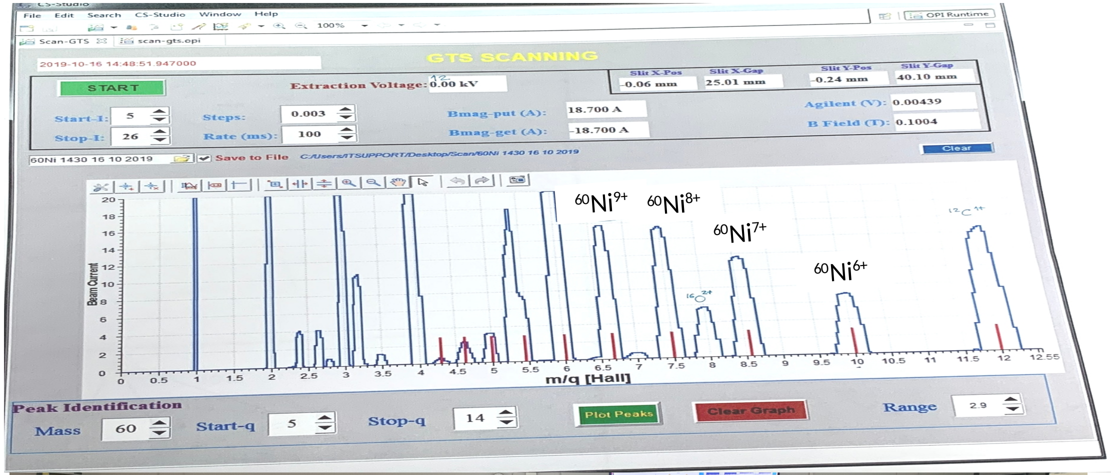


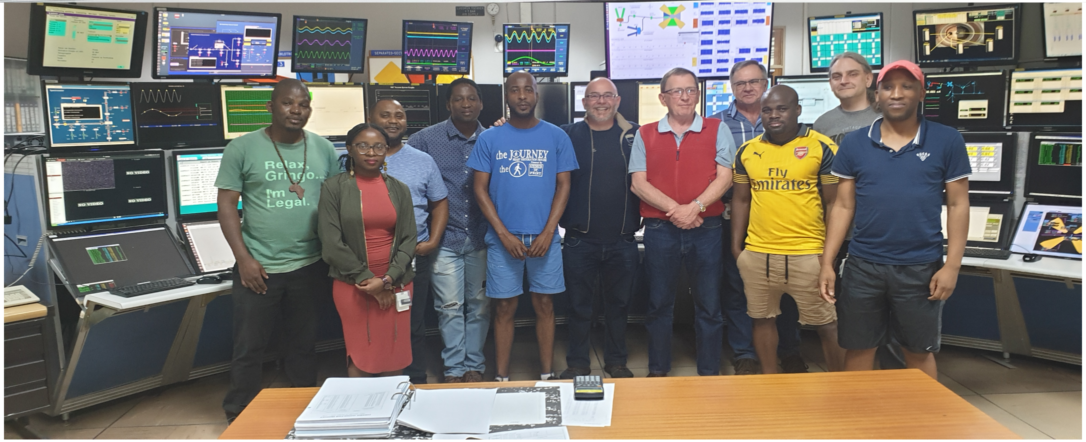
SEARCH FOR THE LOSS PARADIGM OF SURFACE VIBRATIONS.

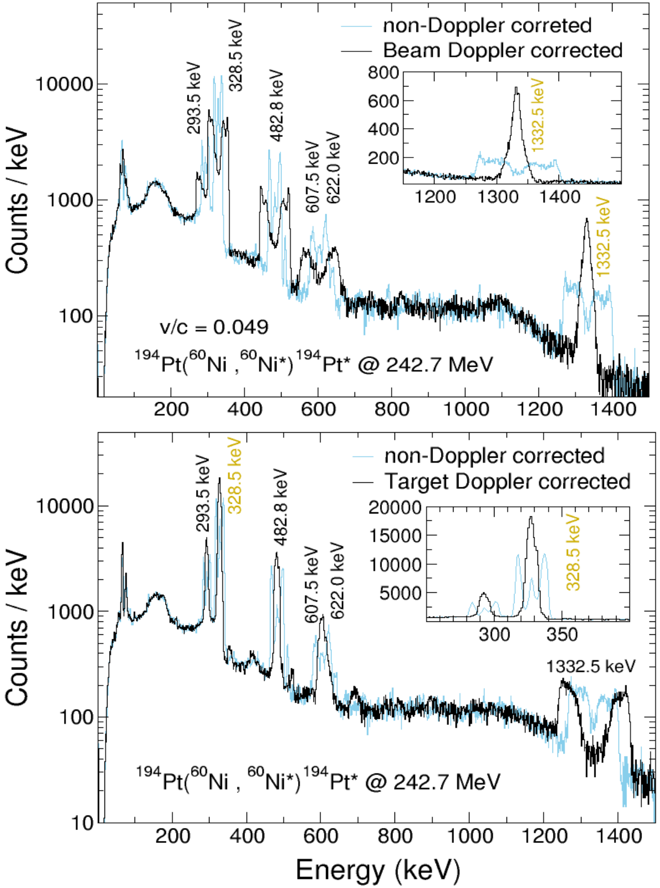
Spokesperson: Nico Orce

Successful delivery of enriched $^{60-62}$Ni beams in October-November 2019

Search for the loss paradigm of surface vibrations in the Ni isotopes







More data analysis

Paradigm of Surface Vibrations in ^{62}Ni

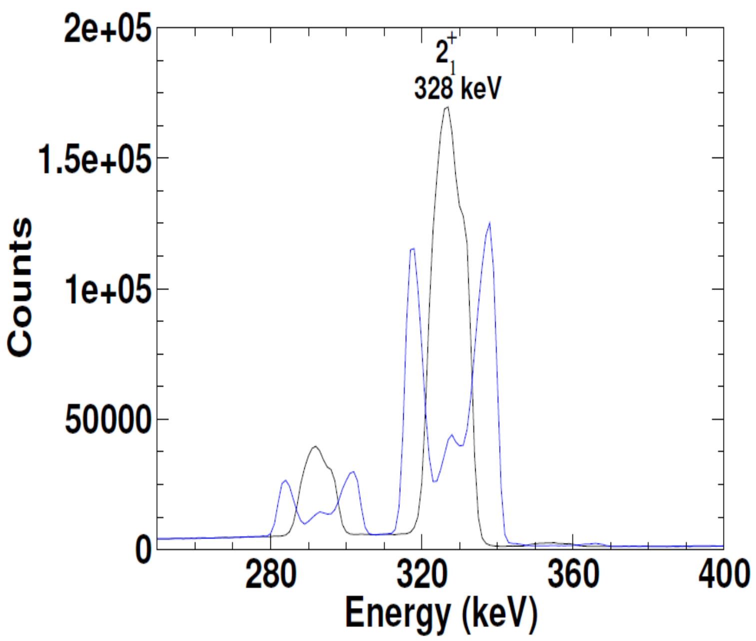
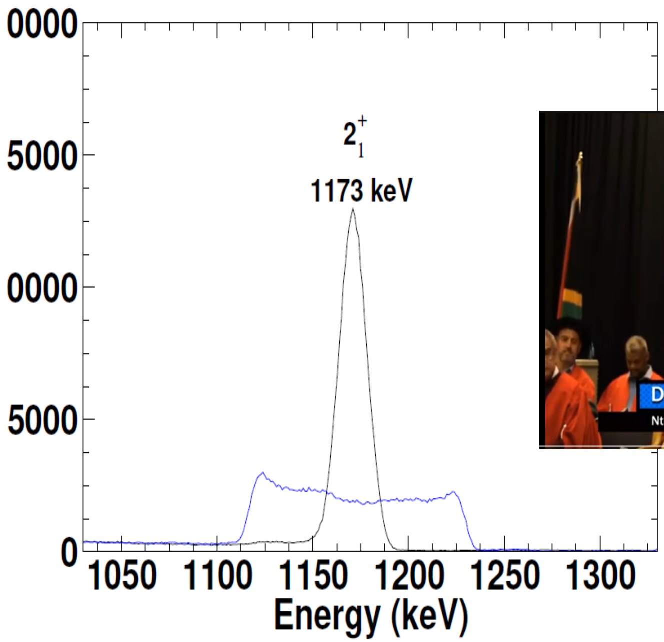
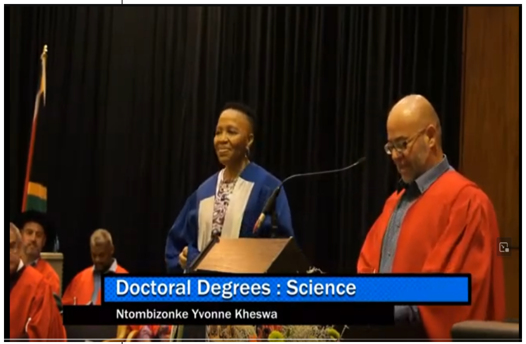


FIGURE 4.7: Non-Doppler corrected (blue) and Doppler corrected (black) spectra for ^{194}Pt using $\beta = \frac{v}{c} = 0.032$

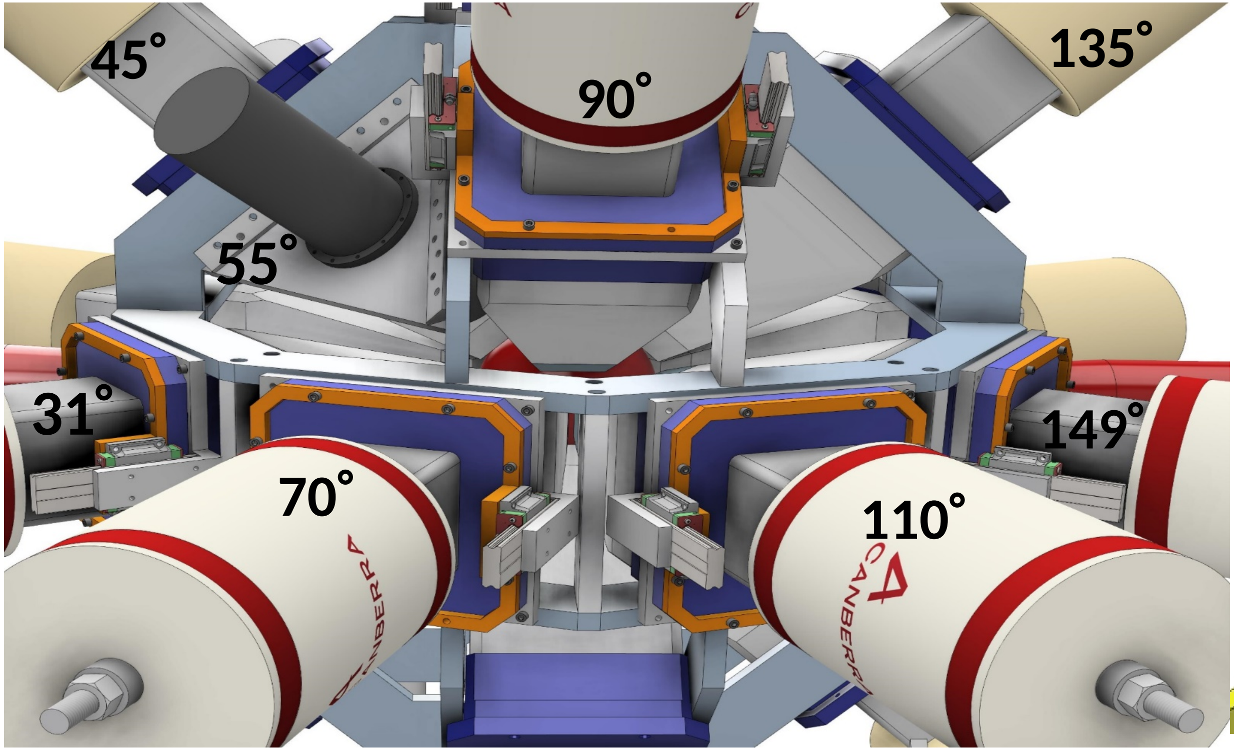


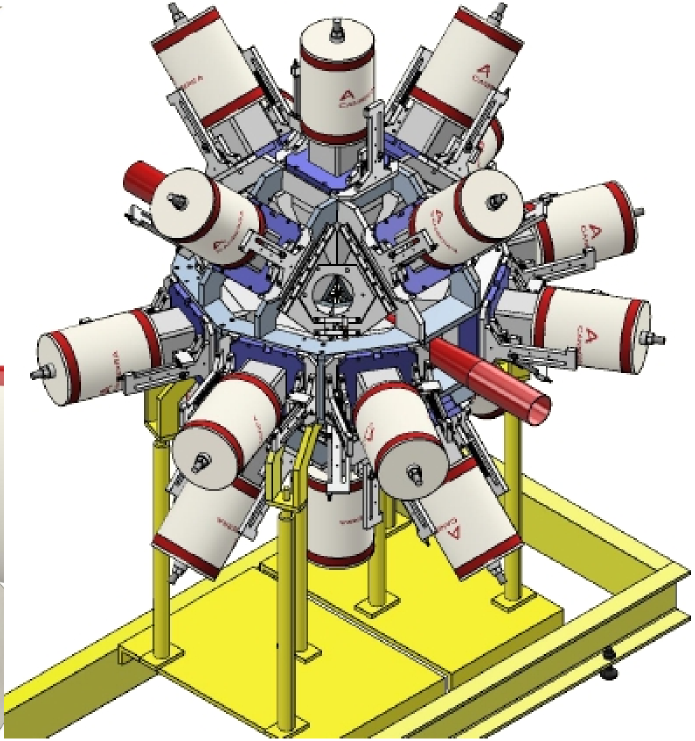


E 4.8: Non-Doppler corrected (blue) and Doppler corrected (black) spectra for ^{62}Ni using $\beta = \frac{v}{c} = 0.047$

Successful delivery of enriched $^{60-62}$Ni beams in October-November 2019
Proof of Principle (PhD awarded to Ntombi Kheswa)

Dandelion frame design & construction



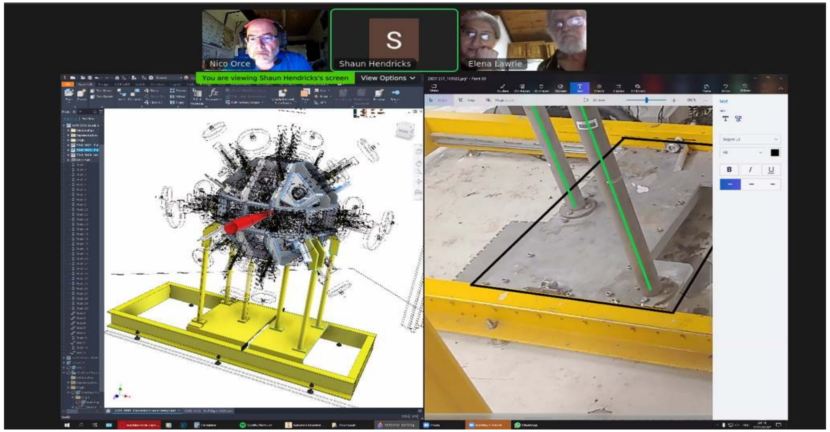


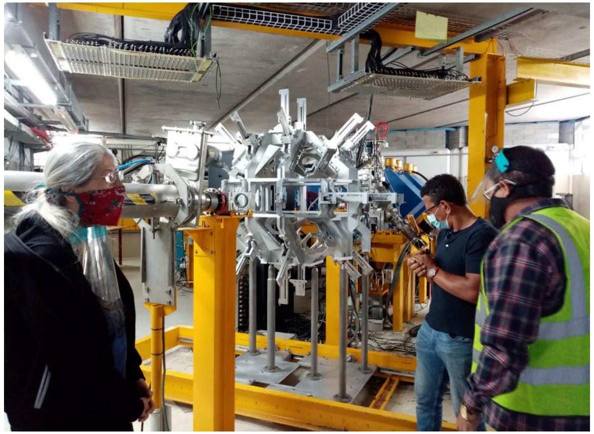
Design: Shaun Hendricks

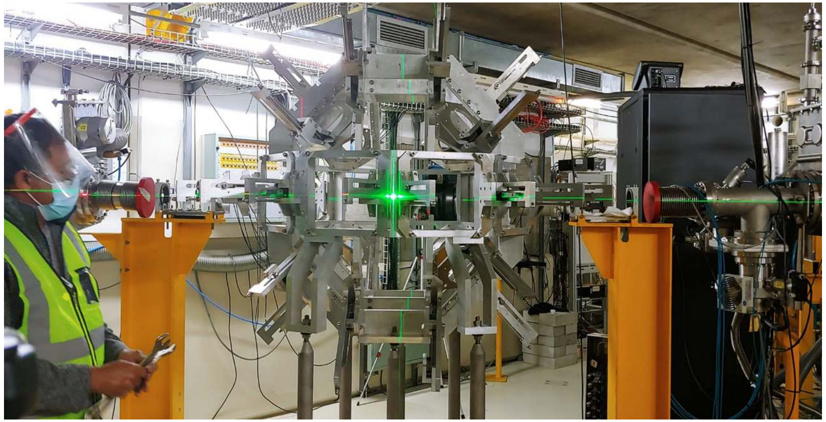
Construction: CJ Dustraction SYSTEMS ENVIRONMENTAL SOLUTIONS (Pty) Ltd.

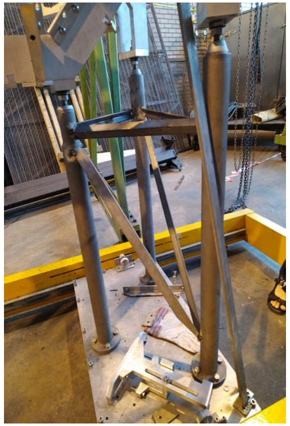
Commissioned in May 2021

Currently fixing the base and pillars









UNIVERSITY of the WESTERN CAPE

GAMKA
THE LION
THE GAMMA-RAY SPECTROMETER FOR KNOWLEDGE IN AFRICA

National Research Foundation NRF **in the News**
WEEK OF 31 MAY 2021

'the notable progress of the NRF-funded GAMKA project"

NRF-funded GAMKA Project makes South Africa potential world leader in nuclear physics research

Original source: University of the Western Cape

https://nuclear.uwc.ac.za/index.php/gamka

When UWC was awarded the single largest grant given by the NRF in a competitive call for a new nuclear spectrometer called the Gamma Ray Spectrometer for Knowledge in Africa (GAMKA), many people doubted if the project would ever see the light of day. But UWC ensured that the project was completed with great aplomb; bolstering the country's ability to perform cutting-edge nuclear research and attracting more world-class projects in the process.

The project was composed of a consortium led by Professor Nico Orce from the Department of Physics and Astronomy at UWC, and consisted of four South African universities – UWC, Stellenbosch University, the University of the Witwatersrand and the University of Zululand – as well as NRF-iThemba LABS operating as the final host of GAMKA. It also included enormous support from NRF officials, the review from experts and letters of support from SKA and CERN. The NRF awarded UWC a R35 million grant through the Strategic Research Equipment Programme to address the ageing of detection equipment; to become competitive worldwide; and enhance human capital development in South Africa.
GAMKA provides state-of-the-art equipment that will allow not only the consortium members, but also other researchers across the country and worldwide, to study a wide range of nuclear properties and phenomena.

This month, the final pieces - the liquifier and the dandelion-shaped frame, which houses the GAMKA detectors and, as a whole, forms the GAMKA spectrometer - have been completed after two years of extensive and vigorous work on the design and manufacturing. The first GAMKA experiment is scheduled to run in June.

According to Prof Orce, the GAMKA frames, now housed at NRF-iThemba LABS, were manufactured locally by SAAO and CJ Dustraction Systems in Kuils River, which has garnered international recognition. "Not only made in South Africa, but in one of the communities feeding UWC, too," **Read full article here.**

nature africa

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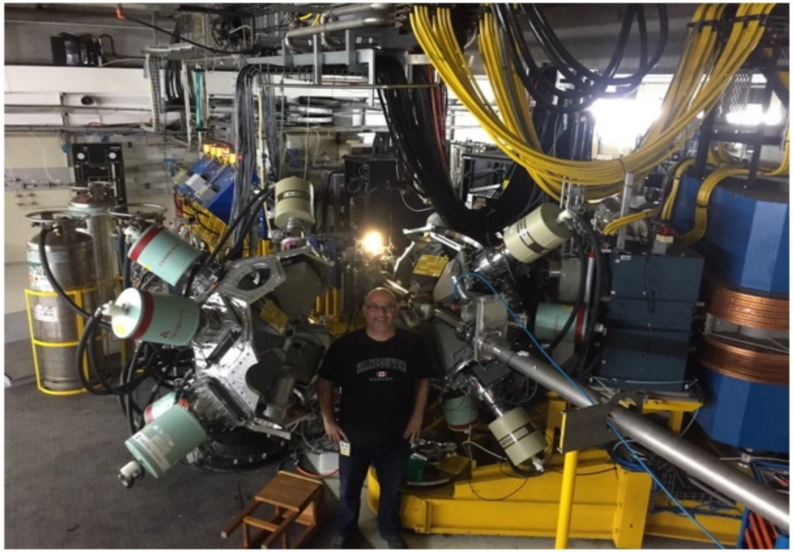
NEWS FEATURE | 20 October 2023

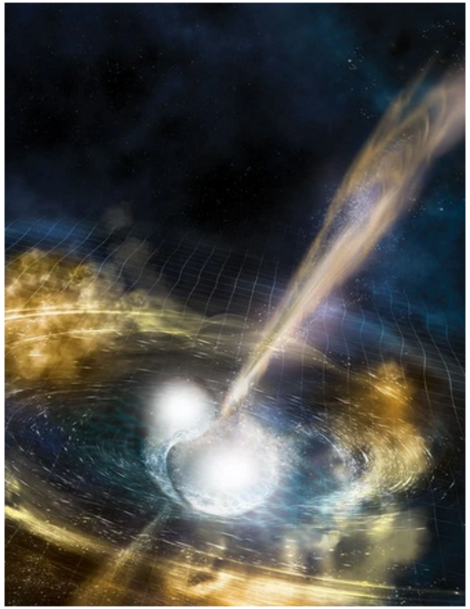
Understanding the universality of heavy elements

Groundbreaking research sheds light on scientific mystery.

Morgan Morris



As more neutrons are added to the nucleus, symmetry energy has a counterbalancing effect on the binding energy that holds the nucleus together. In this case, the greater the symmetry energy, the smaller the binding energy.



Artist's illustration of two merging neutron stars. The rippling space-time grid represents gravitational waves that travel out from the collision, while the narrow beams show the bursts of gamma rays that are shot out just seconds after the gravitational waves. Swirling clouds of material ejected from the merging stars are also depicted. The clouds glow with visible and other wavelengths of light. Credit: NSF/LIGO/Sonoma State University/A. Simonnet

The rise in symmetry energy found by the researchers is ascribed to a slight increase in the energy of giant dipole resonances (GDR). GDRs are the result of the collective 'excitation' – a specific type of jump in energy – of protons and neutrons oscillating out of phase, meaning that their waves are out of step with each other.

As such, GDRs represent the main contribution to the absorption and emission – the attraction and release – of electromagnetic radiation in a nucleus.

The jump in symmetry energy, the scientists argue, shrinks the 'neutron drip line', the boundary at which nuclei eventually become unbound. At this point, nuclei break up into their constituent neutrons and protons.

"It tells us we can't go too far capturing neutrons during the 'cooking' of elements," explains Orce.

Ultimately, the rise in symmetry energy impacts on the r-process. The r-process is responsible for the 'cooking' or nucleosynthesis of heavy elements. It is a set of nuclear reactions believed to create around half the known elements in the universe with an atomic weight heavier than iron.

OXFORD ACADEMIC

Monthly Notices of the Royal Astronomical Society

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JOURNAL ARTICLE

Enhanced symmetry energy may bear universality of r-process abundances

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José Nicolás Orce ✉, Balaram Dey ✉, Cebo Ngwetsheni, Srijit Bhattacharya, Deepak Pandit ✉, Brenden Lesch, Andile Zulu

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GAMKA THE LION

THE GAMMA-RAY SPECTROMETER FOR KNOWLEDGE IN AFRICA

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