The iThemba LABS Facility:
Coulomb excitation studies and future plans at HIE-ISOLDE

J.N. Orce
University of the Western Cape
Isolde Workshop 2014

UNIVERSITY of the WESTERN CAPE

National Development Plan 2030

"By 2030 we seek to eliminate poverty and reduce inequality."

UNIVERSITY of the WESTERN CAPE

The University of the Western Cape

Coulomb excitation studies @ iThemba LABS & HIE-ISOLDE

[Nuclear Structure & Nuclear Astrophysics @ UWC]

Faculty: Nico Orce, Smarajit Triambak (1st Research Chair in Nuclear Science)
PhD Students: Bernadette Rebeiro, Nontobeko Khumalo, Nicholas Erasmus, Ntombi Kheswa
MSc Students: Craig Mehl, Luthedo Puthu, Bhivek Singh, Jeremy Makabata, Zandile Makiba, Sivuyile Xabanisa
Postdocs: Kumar Raju + two additional postdocs in 2015

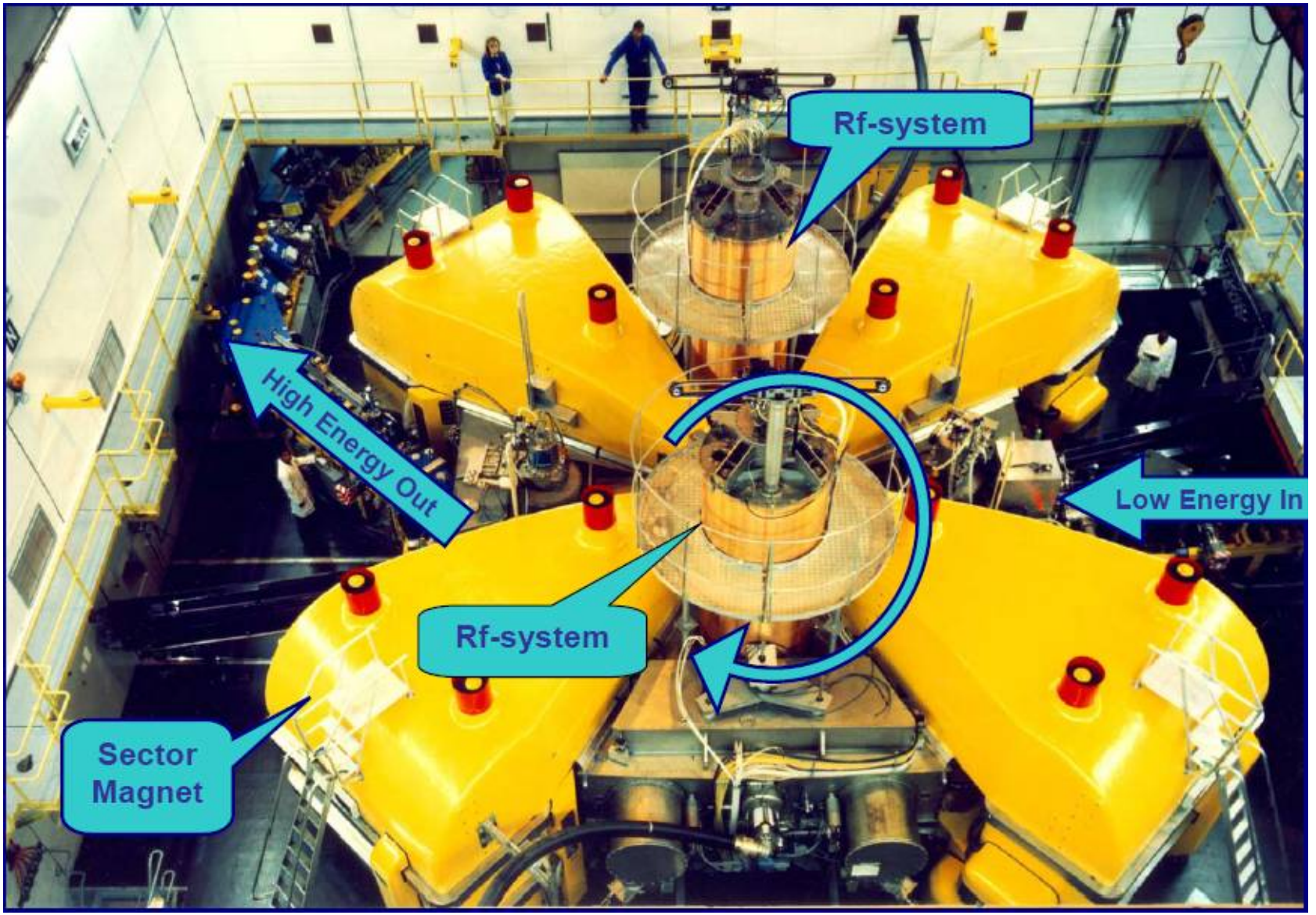
NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

Largest Science Facility in the Southern Hemisphere (a place of Hope)

Isotope Production, Medical Irradiation, Education and Training, Research. 3 accelerators (K200 cyclotron, 11 MeV cyclotron and 3MV van de Graaf for Materials Research)

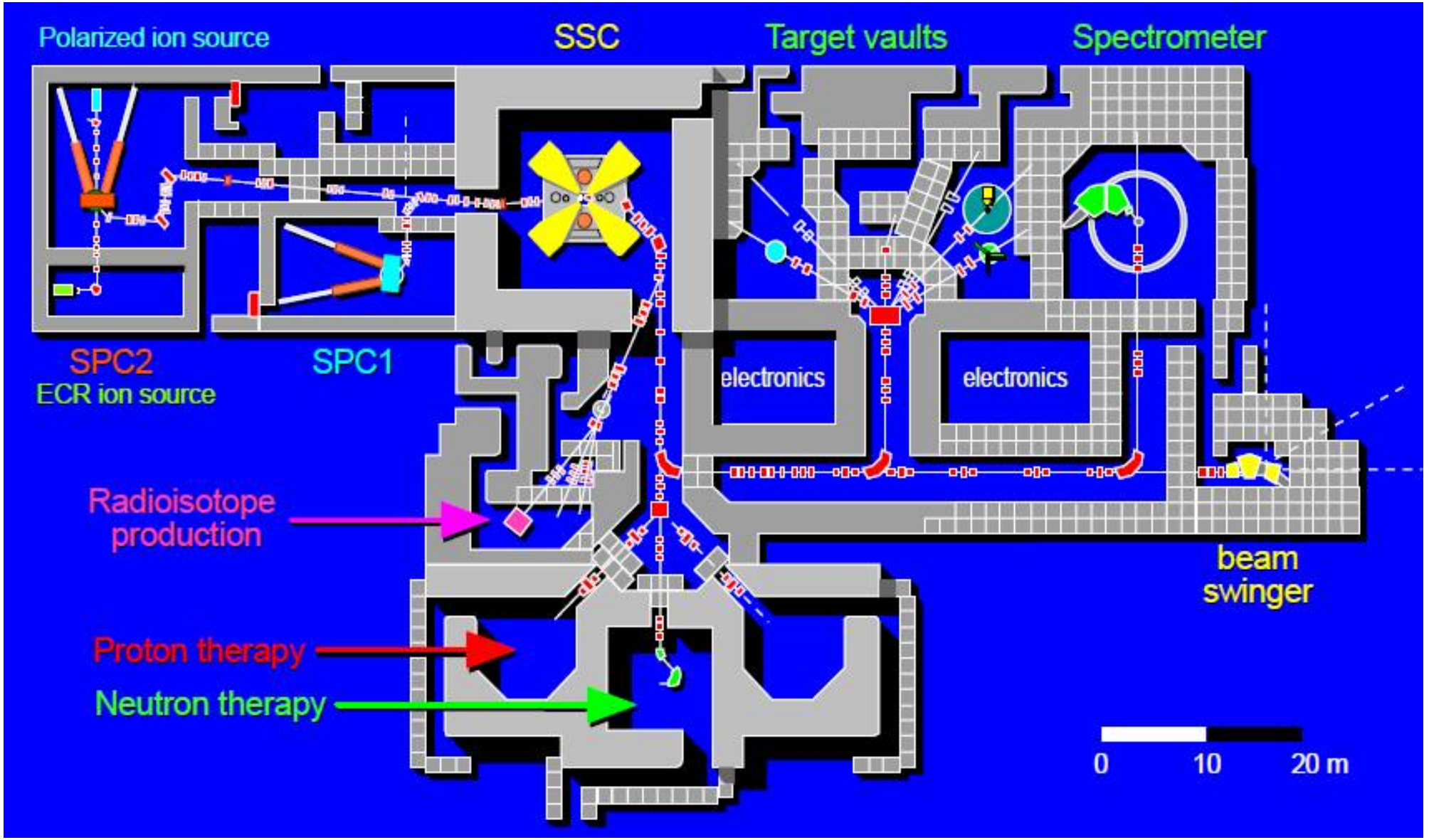
K200 Separated Sector Cyclotron

National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences



Separated-Sector Cyclotron Facility

Beam time is shared (Science in the weekend!)



Recent Innovation @ iThemba LABS

- New Physics recently found (no tetrahedral shapes, chiral symmetry, nuclear collectivity from GDR, Hoyle state, nucleosynthesis of ^{138}La,...)
- Broad range of nuclear reactions
  K600 high-resolution (FWHM~50 keV) zero-degree spectrometer:
  (p,t), (α,α'), (p,p'),^{12}C(^{20}Ne,α)^{28}Si
  Coulomb excitations (pipe line built)
  Lifetime measurements in inverse kinematics
  Fusion evaporation and (^{3}He,nγ) transfer reactions
- Digital Electronics (dead time, higher coincidence rate from 4 kHz to 40 kHz)
- New 3 MV Tandetrom (Material Sciences and Nuclear Astrophysics)
- Radioactive Ion Beam Facility
  RIB Demonstrator for β-decay studies funded.
- New 70 MV cyclotron (expands research time)?
- New ball of clover detectors (GAMKA)?

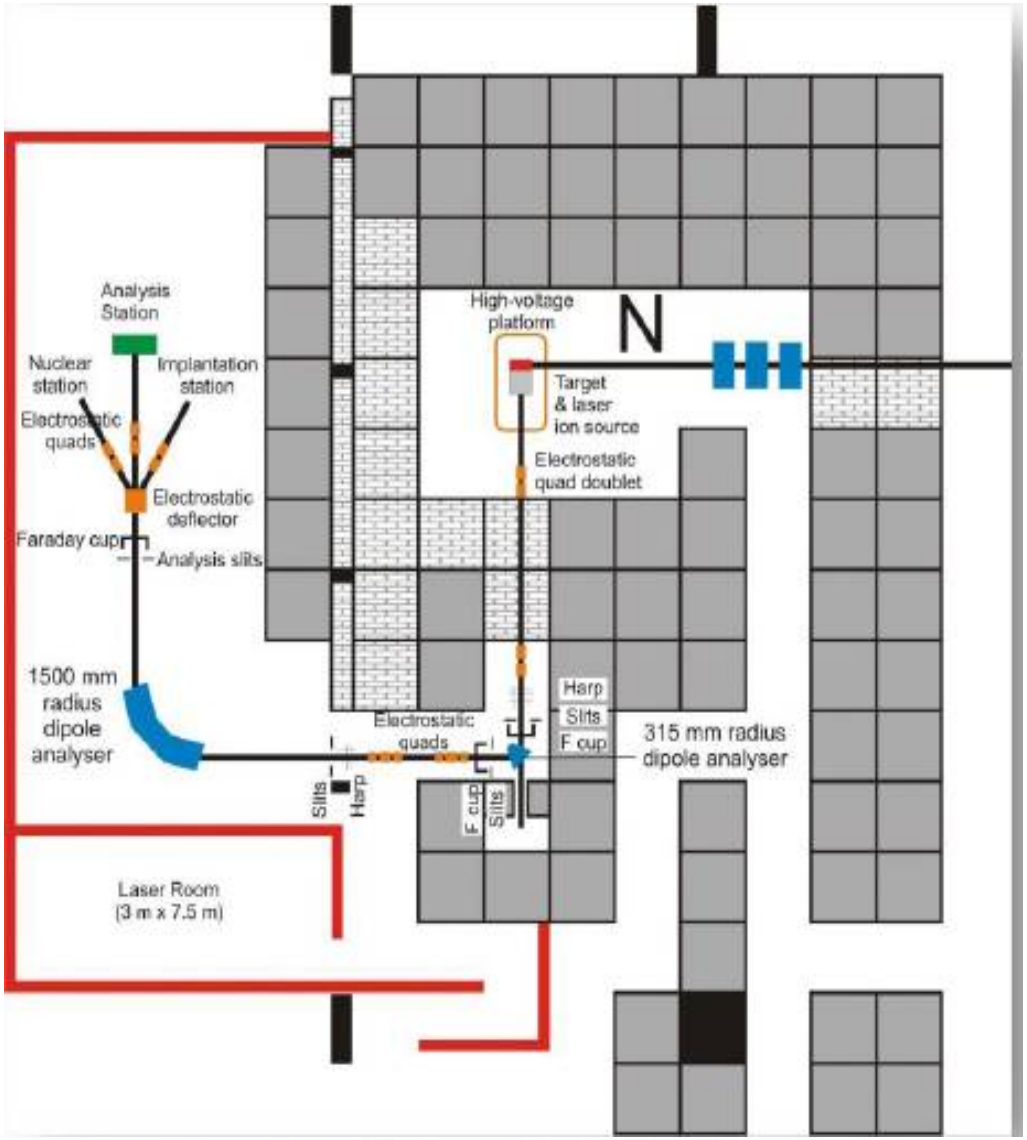
NRF National Research Foundation | iThemba LABS Laboratory for Accelerator Based Sciences

RIB Facility @ iThemba LABS (SPES @ INFN legnaro)

Rob Bark, John Cornell and the Accelerator Group

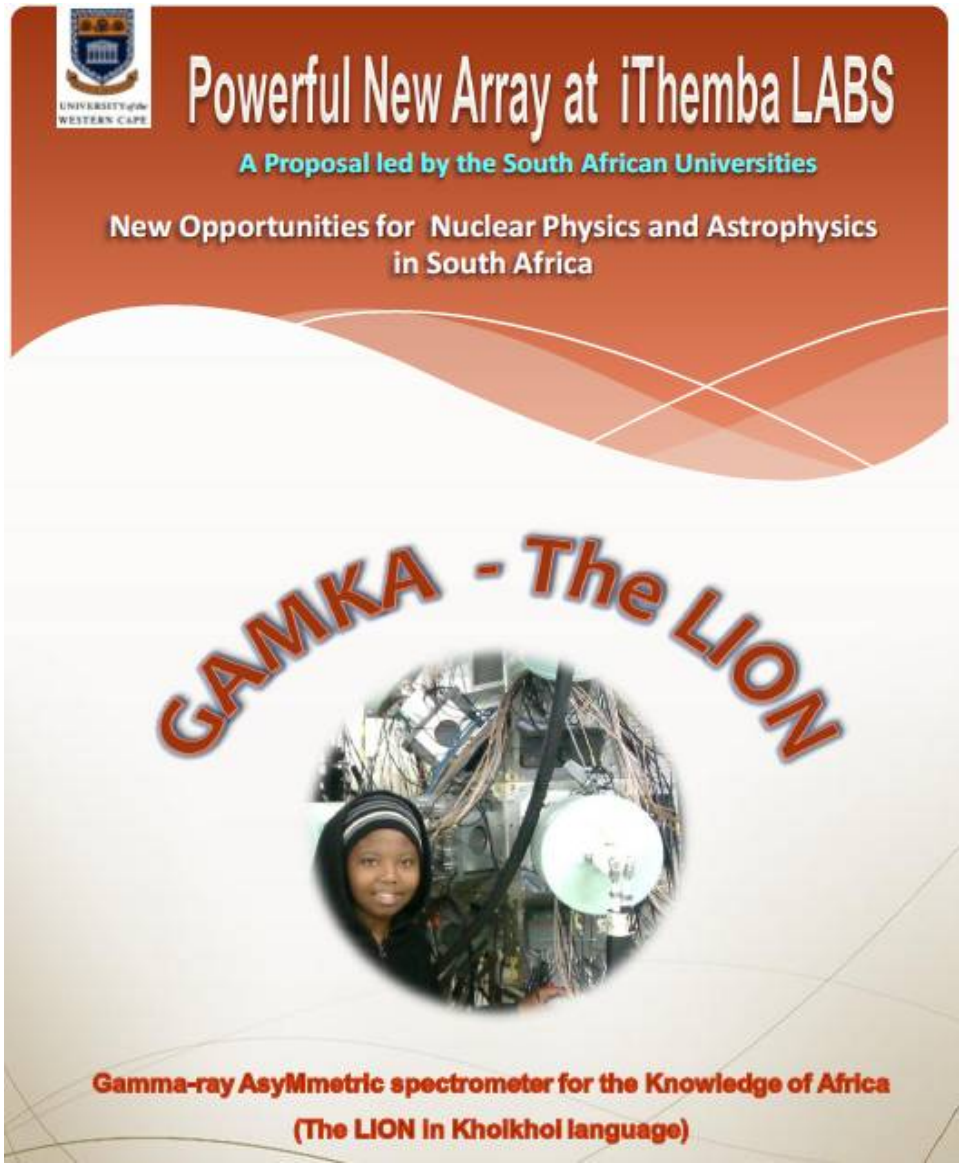
A successful high-power test of a SiC target performed last May 2014

- The SiC target was subjected to 4kW of beam power (60 μA of 66 MeV protons) for an hour.
- Monitor the temperature and radioactivities to validate computer simulations.
- It successfully performed to specifications!



GAMKA: NEP Application submitted August 2014 (R30M)

Supported by 8 Universities + iThemba LABS (ala MINIBALL or TIGRESS)



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UNIVERSITY OF ZULULAND

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

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UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

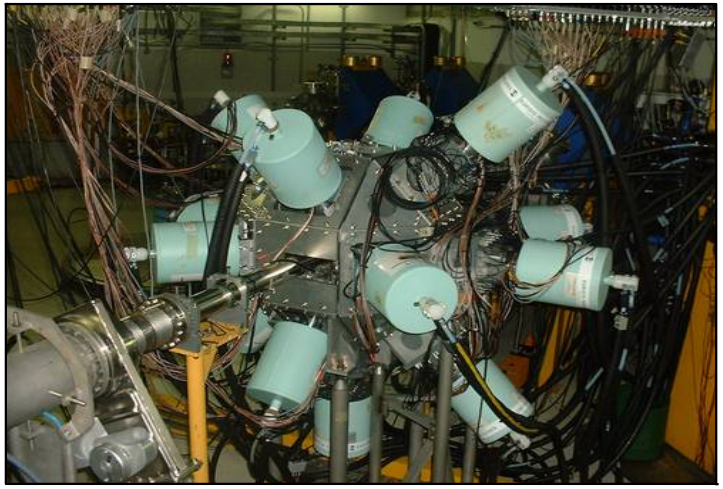
UNIVERSITY OF JOHANNESBURG

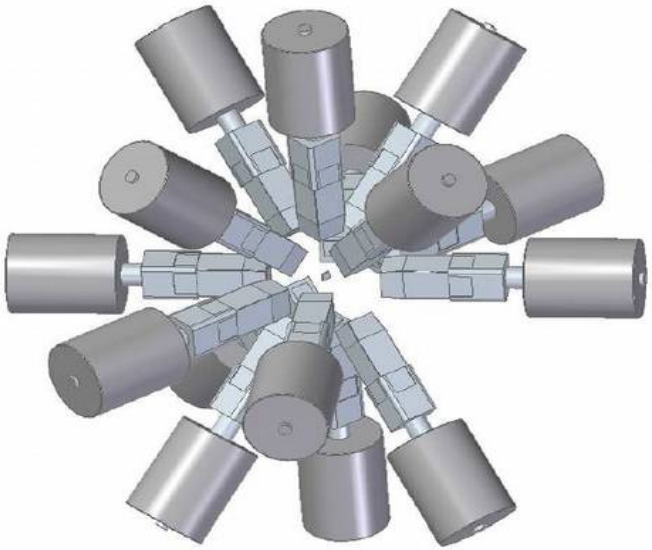
UNIVERSITEIT STELLENBOSCH UNIVERSITY

UNISA university of south africa

New GAMKA Array at iThemba LABS

GAMKA (15 clovers) versus current AFRODITE (8 clovers)





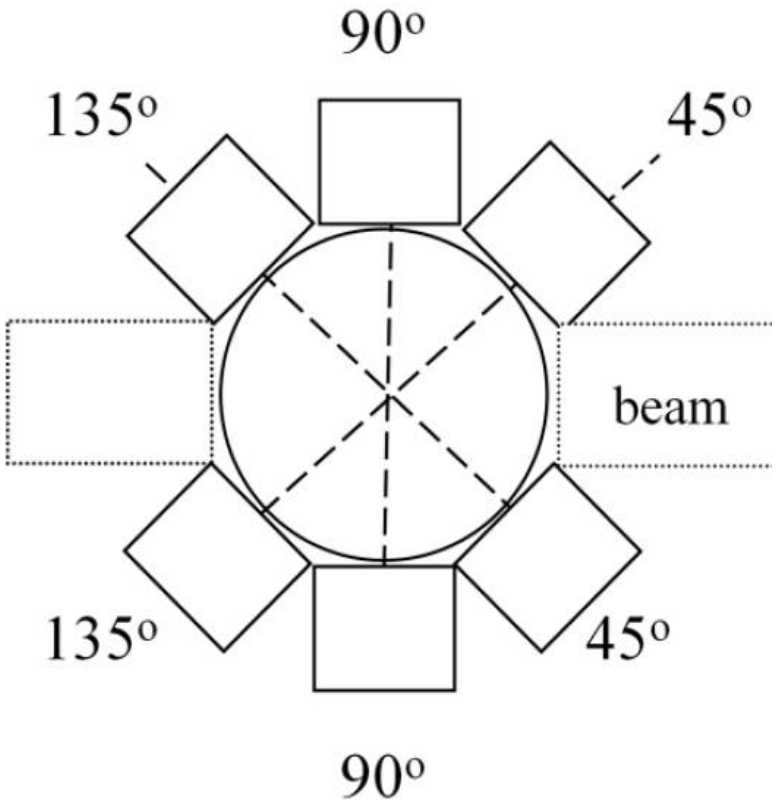
Improvements

- 7 more detectors will increase the efficiency by 3.3x for γ–γ coincidences, 6.6x for γ–γ–γ, etc
- Asymmetric configuration will broaden range of measurements
- We'll deliver New Science (some complementary science to HIE-ISOLDE)

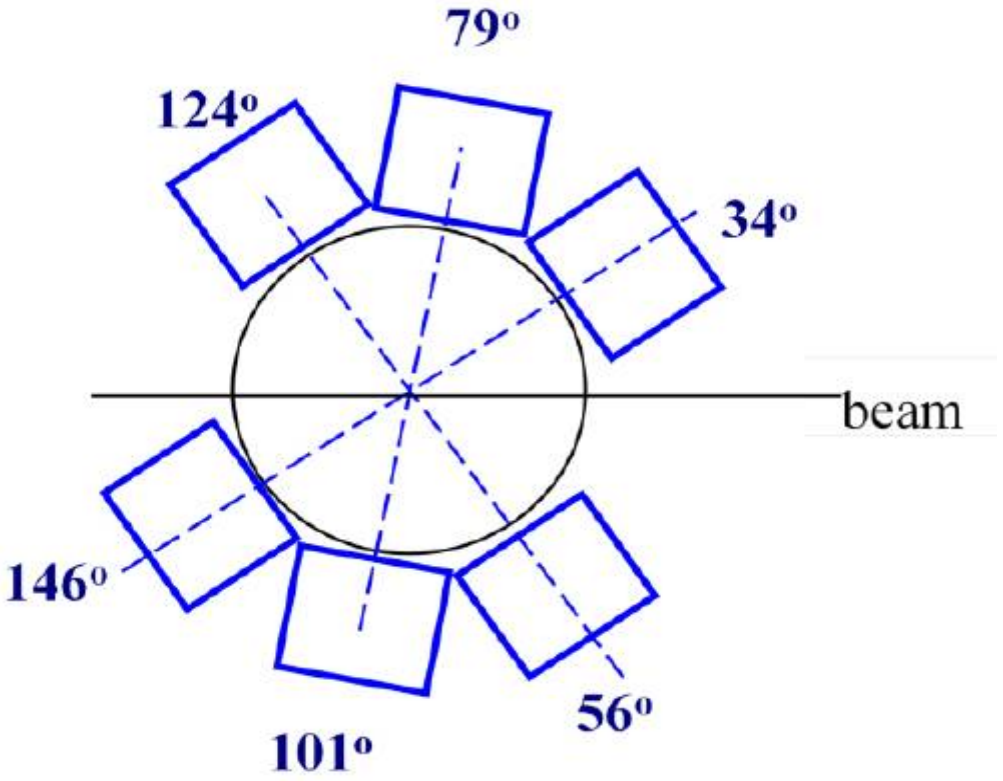
GAMKA – Gamma-ray AsyMmetric spectrometer for Knowledge in Africa

GAMKA: assymetric array at iThemba LABS

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



current AFRODITE



GAMKA

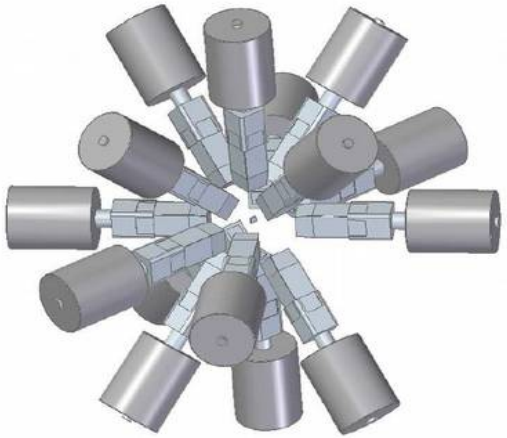
GAMKA – Gamma-ray AsyMmetric spectrometer for Knowledge in Africa

GAMKA coupled with other facilities + ancillary detectors at iThemba LABS

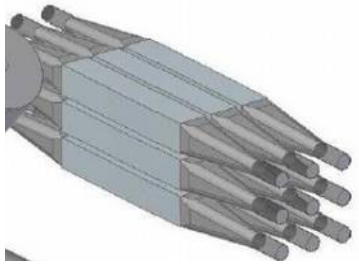
GAMKA offers flexibility

Silicon detectors

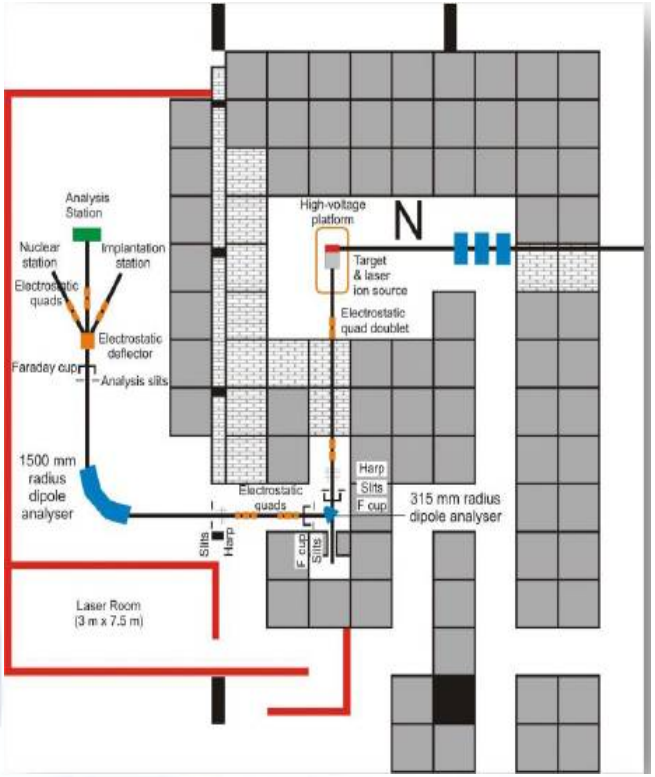
LEPS, Recoil detector, ($LaBr_3$),...



Neutron detector array
(WAFANA-WAFANA)



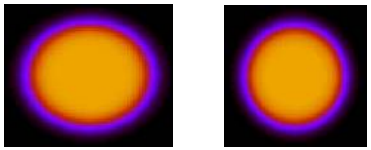
RIB Demonstrator

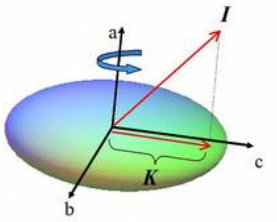


3 MV Tandetron
(approved)

K600 Spectrometer

Nuclear Physics @ iThemba LABS





Where are the low-energy vibrations?

How nuclei rotate?

Challenges to the shell model

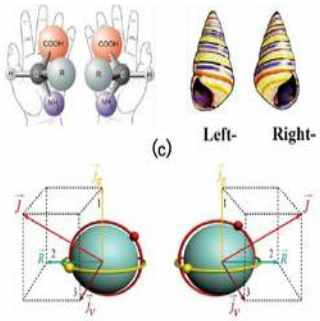
Nuclear clusters

Pygmy resonance

Nuclear Structure Physics

Address fundamental questions related to nuclear collectivity and move theory forward!

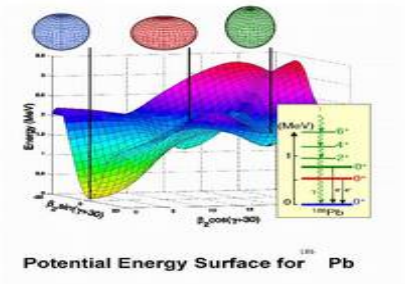
Nuclear chirality?

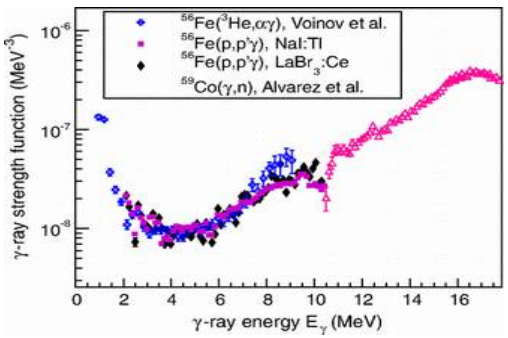


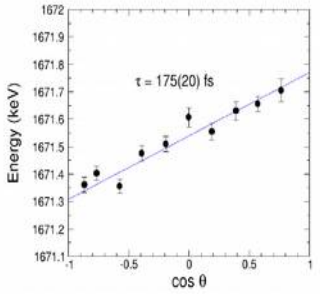
Shape coexistence and mixing

Level density & Gamma strength functions

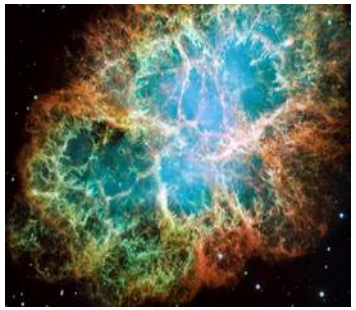
Lifetime measurements for nuclear structure

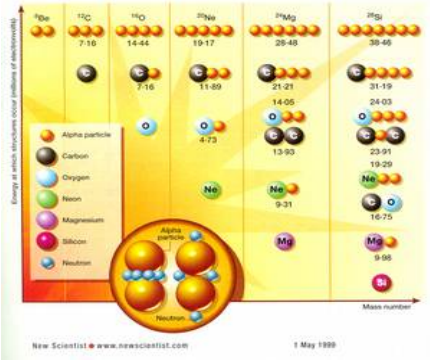






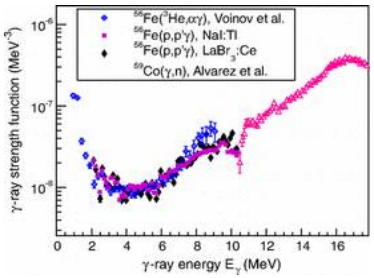
Nuclear Astrophysics @ iThemba LABS





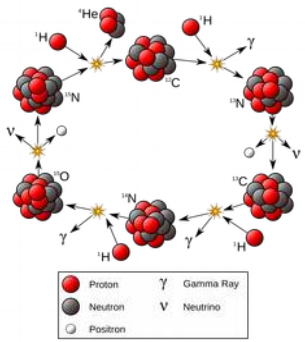
How the heavy elements are formed in supernova?

What's the origin of life? Or how carbon was created?



Nuclear Astrophysics

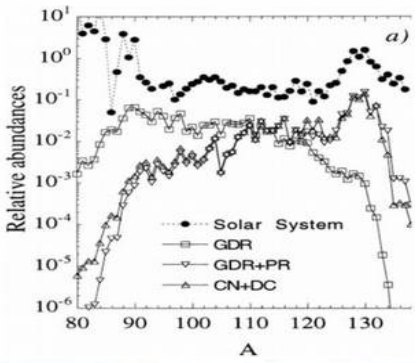
Address fundamental questions related to SKA and SALT

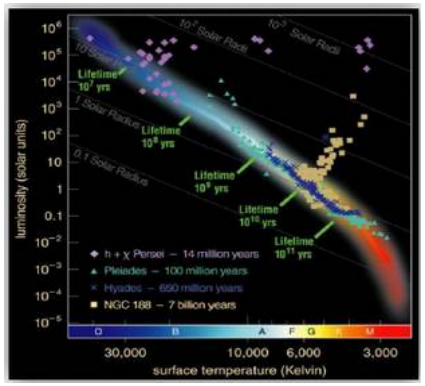


How resonances affect the abundance pattern

r vs s processes in metal-poor stars

What's the Age of the Universe

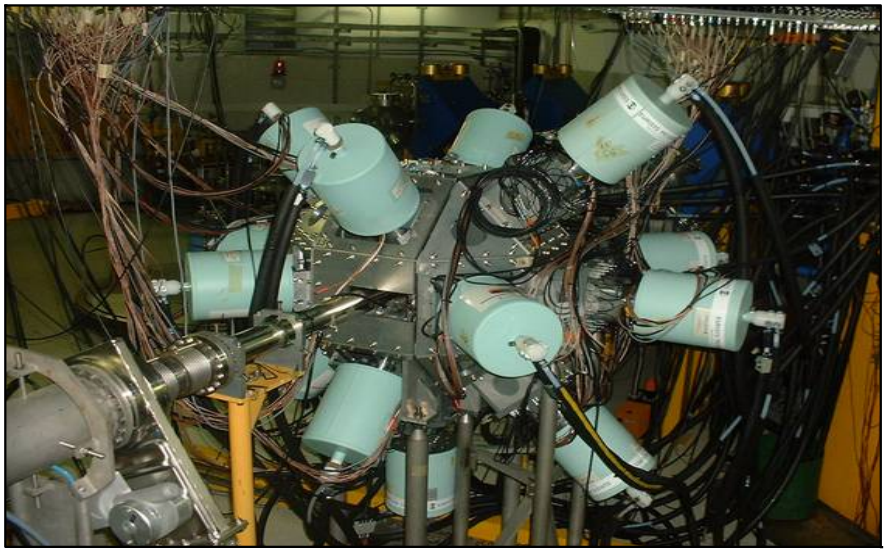




Experimental set up for Coulomb-excitation studies at iThemba LABS

Nicholas Erasmus, Craig Mehl, Kumar Raju, Jerry Makabata, Mathis Wiedeking, Dinesh Negi, Paul Papka, Pete Jones, Smarajit Triambak, Rudolph Nchodu, Elena Lawrie, Ntombi Kheswa

Pipe line built at iThemba LABS: S3 silicon detectors, flexible chamber, feedthrough cables, MPR-32 preamps, gomputers, Geant, Gosia, beam development, ^{60,62}Ni, ^{102}Ru, ^{20}Ne, ^{36,40}Ar, ^{32}S proposals



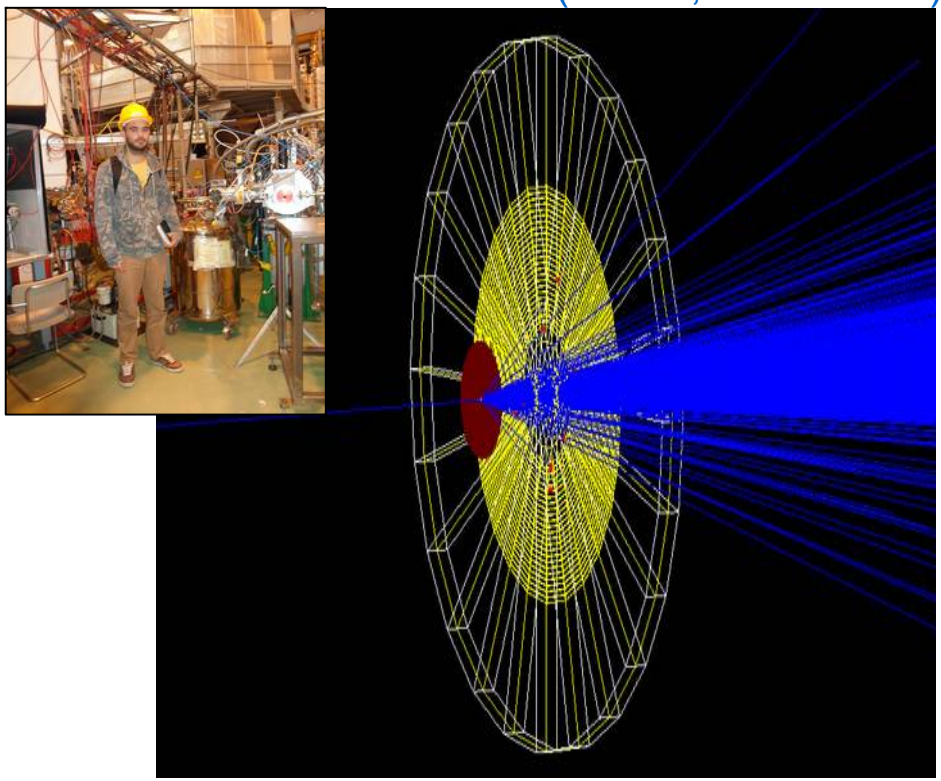
Particle-gamma coincidence technique

AFRODITE + S3 CD-type SiLi ([40°, 70°] & [113°, 143°])

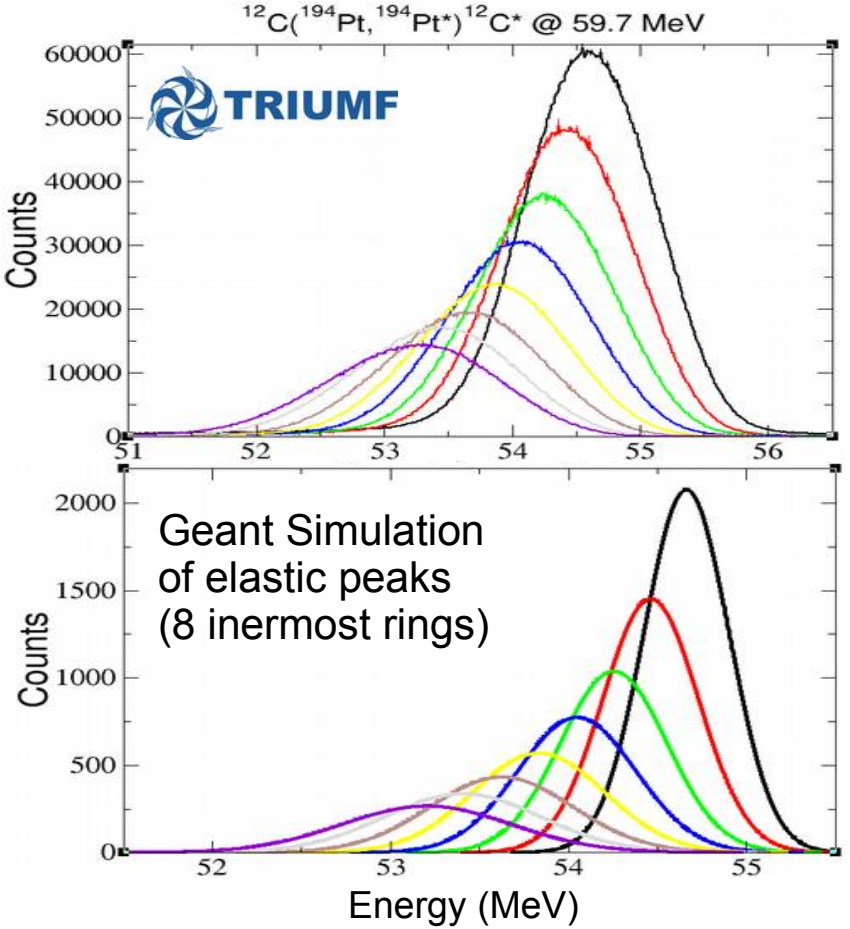
Geant 4.10 Simulations: Rutherford Scattering on S3 detectors

Nicholas Erasmus (MSc)

Thanks to Alexander Howard (CERN, ETH Zurich)



To be submitted to JINST



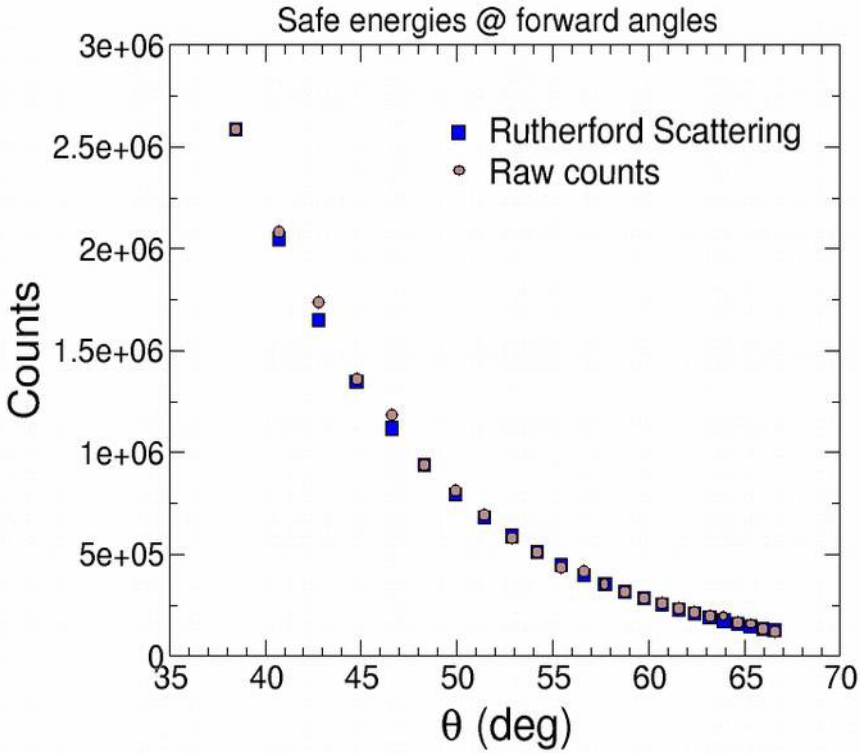
An accurate simulation of elastic peaks provides a cleaner particle-tagging, high-energy calibration points and the possibility of testing the experimental conditions including the target thickness, beam energy and linearity of electronic modules.

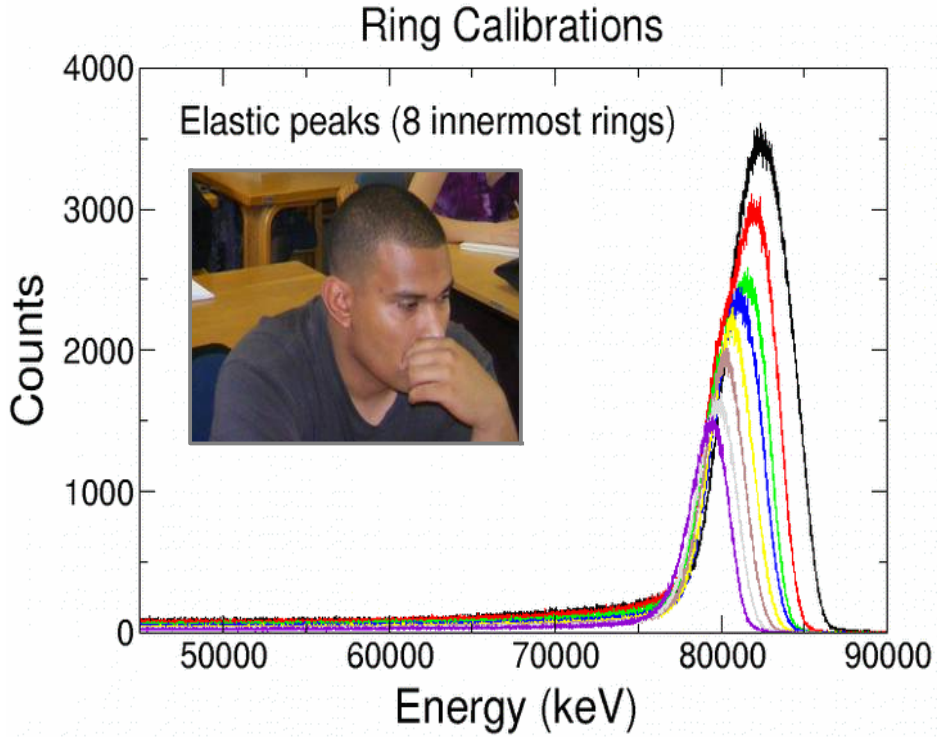
First Safe COULEX of ^{20}Ne Beams @ iThemba LABS

Successful run Dec 2013 (Craig Mehl)

^{194}Pt(^{20}Ne,^{20}Ne*)^{194}Pt* @ 73 MeV $S(142.6^{o})_{\mu\nu} = 6.6$ fm

^{194}Pt(^{20}Ne,^{20}Ne*)^{194}Pt* @ 95 MeV $S(66.8^{o})_{min} = 6.9$ fm





Geant Simulations, SimSort, MIDAS, Sortshell, ROOT, Kinematics, Stopping Powers, Geometry, GOSIA

First safe COULEX of ^{20}Ne beams @ iThemba LABS

Successful run Dec 2013

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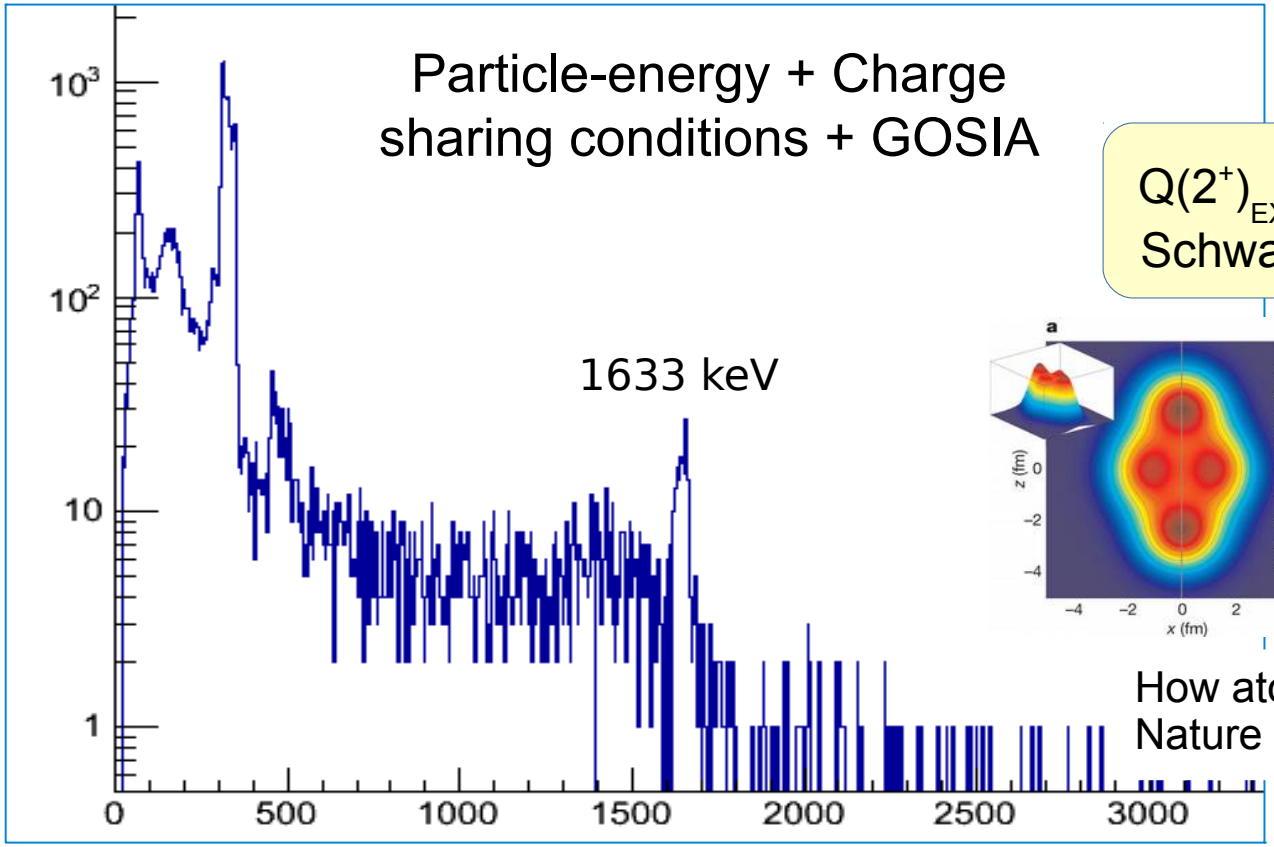
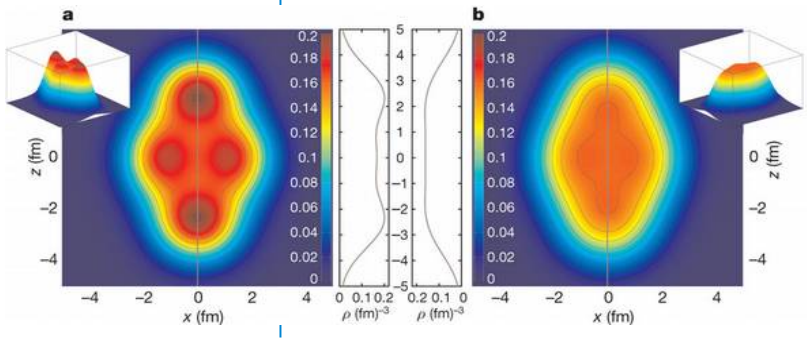


$Q(2^{+})_{EXP}$ = –23(8) efm^2
Schwalm (1972)



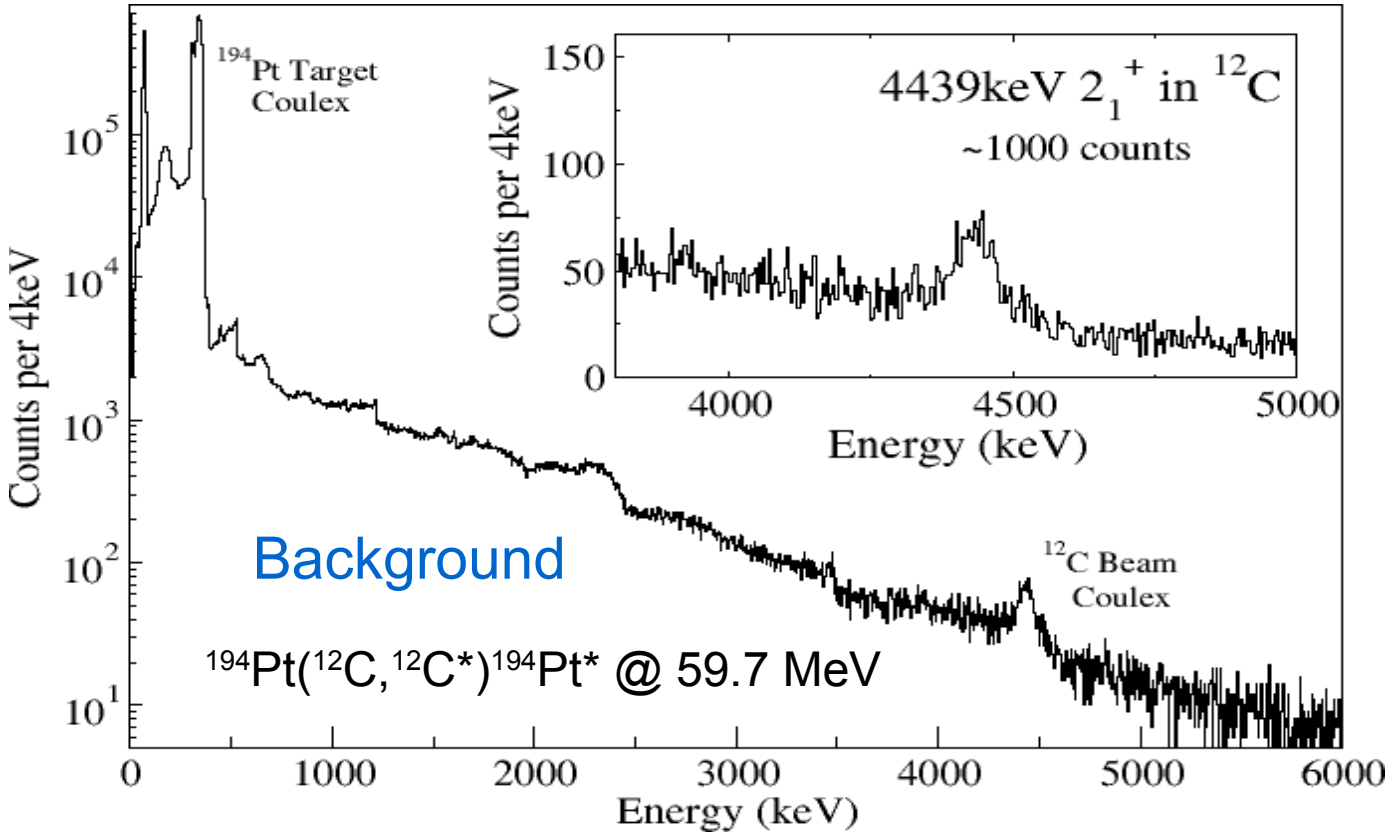
How atomic nuclei cluster
Nature (2012)

Preliminary results (sort-shell & SimSort, P. Papka)

^{12}C Coulex @ TIGRESS

Kumar Raju (Coulex data analysis)

Particle-energy + Charge sharing conditions + GOSIA

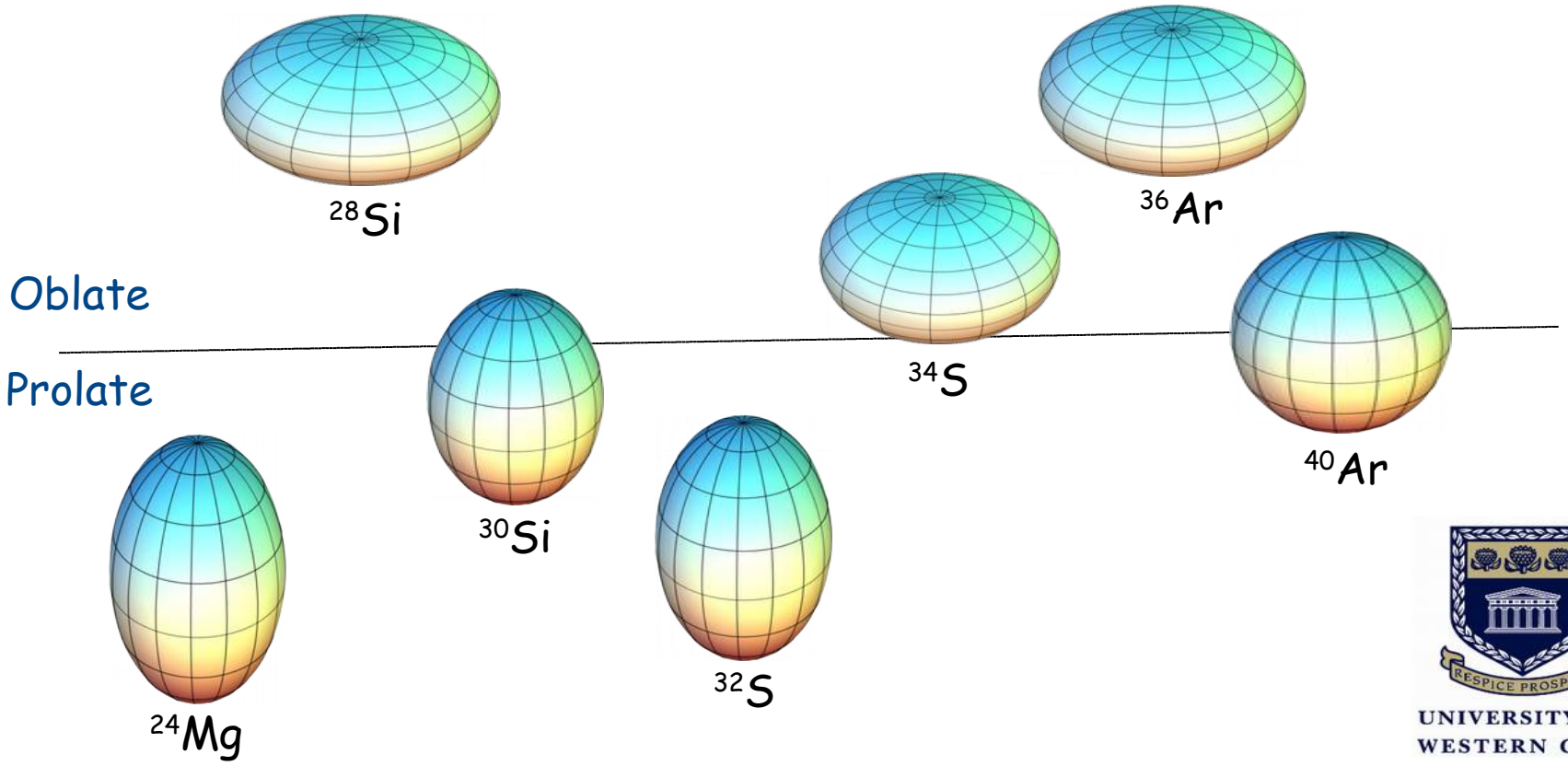


$Q(2^+)_{EXP} = +6(3)$ e fm^2 Vermeer *et al.* (1983) assuming k=1 from shell model

$Q(2^+)_{NCSM} = +6.0(4)$ e fm^2 Linear extrapolation in $1/N_{max}$ Forssen *et al.* (2014)

A Zig Zag of Shape Confusion @ iThemba LABS

Jerry Makabata (first safe Coulex of ^{40}Ar beams running in March 2015)



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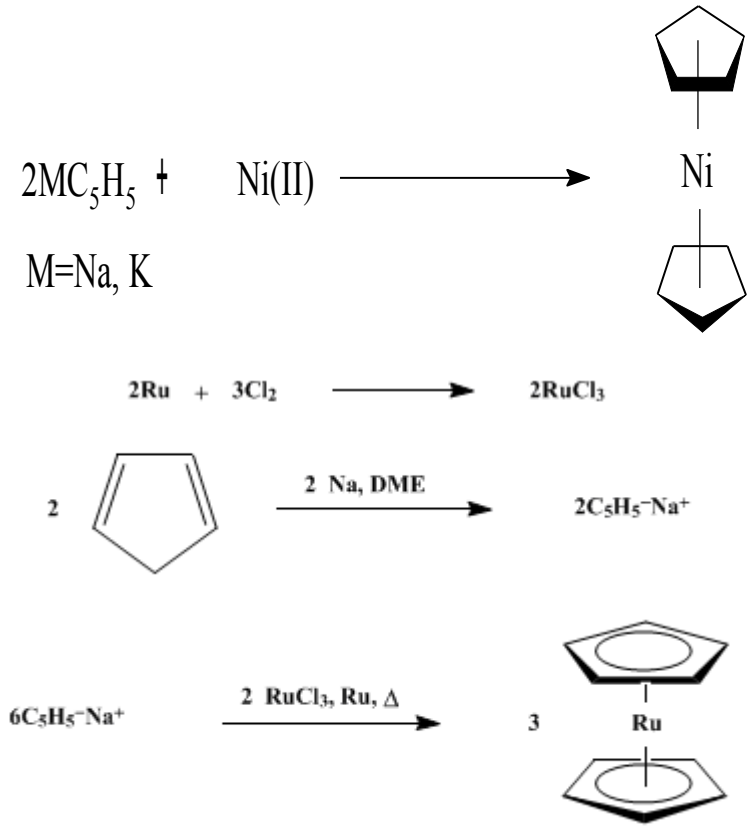
Other Coulex measurements are in the books (^{60,62}Ni, ^{102}Ru), but require beam development: organometallic chemistry

Ntombi Kheswa (PhD), Nico Orce, Rainer Thomae, Salam Titinchi, Rudolph Nchodu
and the UWC Nuclear Physics Group/iThemba LABS

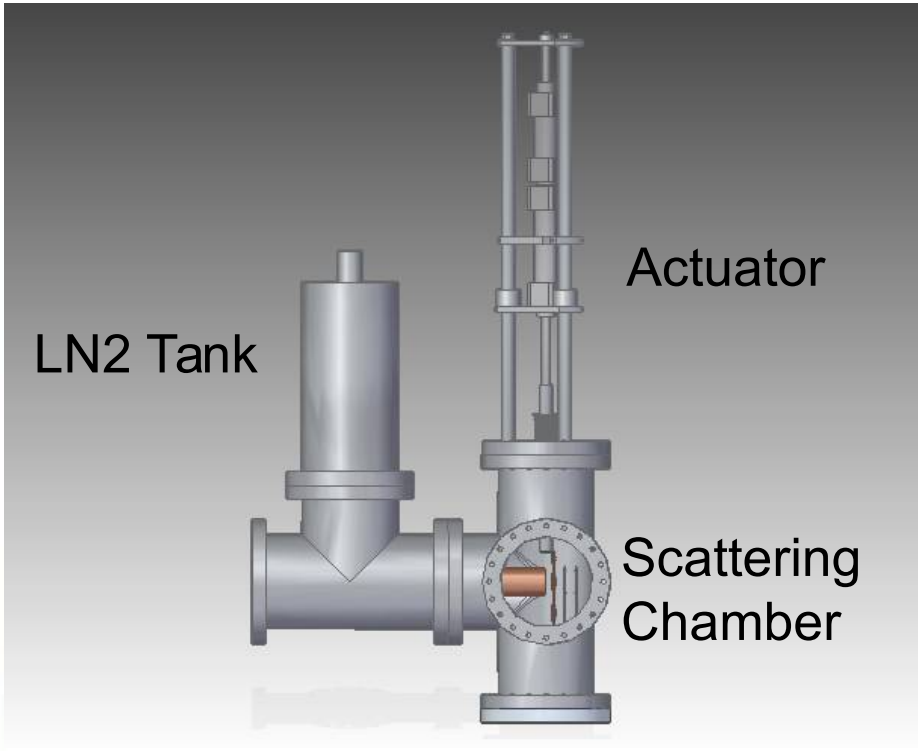


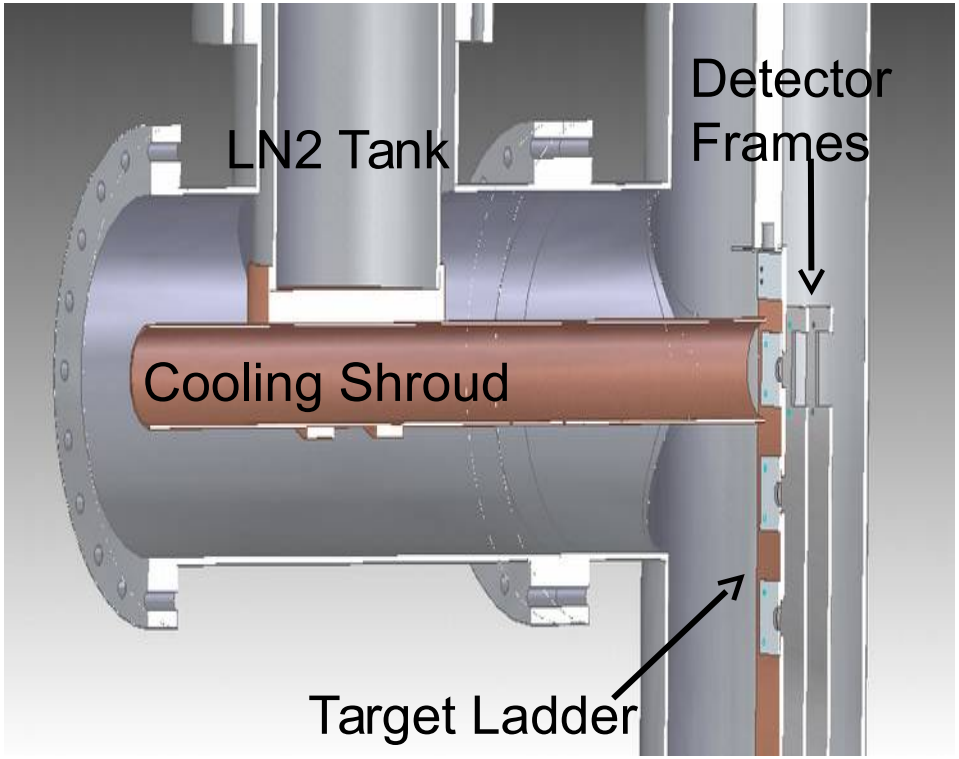
- Enriched material in powder form is needed (Rainer Thomae)
- Organometallic chemistry (new chemistry lab available)
- Inject enriched compound in the HMI ECR ion source
- Lots of new beams (Ni, Ru, Pd, Pt, Sm, Mg, etc)
- New Physics (lifetimes in inverse kinematics, Coulomb excitation, etc)

New Lifetimes Program @ iThemba LABS

Inverse kinematics (on ^{3}He implanted target) at forward angles (particle-γ)

Bhivek Singh, Smarajit Triambak, Nico Orce, Bernadette Rebeiro,...





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Scientific Committee Paper

Report number	CERN-INTC-2013-008 ; INTC-CLL-010
Title	**Solving the shape conundrum in ^{70}Se**
Project Manager/Technical Coordinator	Orce, Nico
Author(s)	Orce, Nico (Department of Physics, University of the Western Cape, South Africa) ; Jenkins, David (Department of Physics, University of York, York, United Kingdom) ; Warr, Nigel (Physik Department E12, Technische Universit\"at M\"unchen, Germany) ; Rapisarda, Elisa (Physics Department, CERN, Switzerland)
Corporate author(s)	CERN. Geneva. ISOLDE and neutron Time-of-Flight Experiments Committee ; INTC
Series	(Clarification Letter)
Submitted by	jnorce@uwc.ac.za on 29 May 2013
Subject category	Detectors and Experimental Techniques

15 shifts awarded

Email contact(s) : jnorce@uwc.ac.za

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Nuclear Physics in the Media

First African-led Experiment in Physics proposed at HIE-ISOLDE (CERN)

NANOTECHNOLOGY

BIG SCIENCE WITH TINY BUILDING BLOCKS

UWC drives the first South African-led experiment in physics at CERN

Prof Nico Orce

With dreams of attending a summer school at CERN thwarted, the young scientist remained undeterred. His path led him from Granada to the UK, USA and Canada, and now, here in the fairest Cape, those dreams of working with CERN have become a reality. Prof Nico Orce of UWC shares a personal story of his journey, leading him to the first South African-led experiment in physics at CERN.

Looking back

About fifteen years ago, as an undergraduate student in Spain, I convinced a few friends of mine to apply for a Summer School at CERN, the European Organization for Nuclear Research. With over 15,000 scientists and engineers from all over the world working in unison to reveal the secrets of nature, CERN is probably the most extraordinary research institution in the world. Getting there was our dream. The only thing that we needed was the consent and signature of a physics professor at the University of Granada in charge of student exchange programs. I sadly remember how the heads of my friends were going slowly down and down as such a "gentleman" was telling us, as a matter of fact, that "only the *crème de la crème*, students from MIT, Princeton, Oxford or Cambridge get to go to these kind of workshops. This is a small university and our students are not prepared for that." He did not sign the forms. I went to England to do a PhD in experimental nuclear physics. But that was not the end of the story.

CERN, the God Particle and the Big Bang

CERN has recently been the focus of breaking news worldwide with the discovery of the Higgs boson. Not only is the Higgs boson the particle credited with giving others mass (and helping us to understand how we come into being) but it might also be responsible for the existence of the mysterious dark energy, which keeps speeding our universe ever faster. CERN's breakthroughs are built upon the shoulders of a technological giant, the Large Hadron Collider (LHC), the highest-energy particle collider ever constructed. It goes around the entire city of Geneva in Switzerland and is one of the great engineering milestones of humankind. Other exciting high-energy physics programs at CERN concern the production of quark-gluon plasma that existed shortly after the Big Bang, finding clues for dark matter and the potentially missing antimatter.

Not only do CERN's scientists use the high-energy protons from the LHC and its booster accelerators to investigate the Big Bang, the Higgs boson and other high-energy physics; they also study the physics that addresses the origin of the low-energy interactions between nuclei – the strong nuclear force. The physics of interacting nuclei accounts for how the elements were (and are) created through nuclear reactions in explosive stellar scenarios – the physics of exotic materials that may lead to advanced technologies – the physics of creating a sustainable and safe energy supply by taming our sun, for example. This is the physics that has consumed, and still is consuming, more human hours than any other scientific question in the history of humankind. This is the physics that the Nuclear Physics and Nuclear Astrophysics Group at the University of the Western Cape is pursuing.

The MINIBALL gamma-ray spectrometer at the ISOLDE facility at CERN as seen from above, where UWC will carry out their measurements.

South African connection

ON CAMPUS

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UWC students streets ahead in JSE investment competition *page 9*

UWC heads CERN's first South African-led experiment *page 11*

A great golf day *page 16*

Your Source for University News

Science shows off its splendours, and a Nobel laureate

Prof Nico Orce (centre, bright blue shirt) with students from the UWC MANUS programme and other South African institutions during the 2012 Tastes of Nuclear Physics symposium at UWC.

UWC heads CERN's first South Africa-led experiment

A team from the University of the Western Cape will lead the first African experiment in nuclear physics – studying the mysteries of nuclei – to be granted beam time at the Isotope Separator On Line DEvice (ISOLDE) facility at the European Organisation for Nuclear Research (CERN) on the Swiss/French border.

While many South Africans are involved in studies on the CERN colliders, this is the first South African proposal in any field of physics greenlit for one of the booster accelerators of the famous Large Hadron Collider (LHC) at CERN. Experimental beam time on the ISOLDE facility is hard to come by, and only the most promising research proposals get the go-ahead.

It fell to UWC's Professor Nico Orce,

The MINIBALL gamma-ray spectrometer at the ISOLDE facility at CERN (as seen from above), where UWC researchers will carry out their measurements.

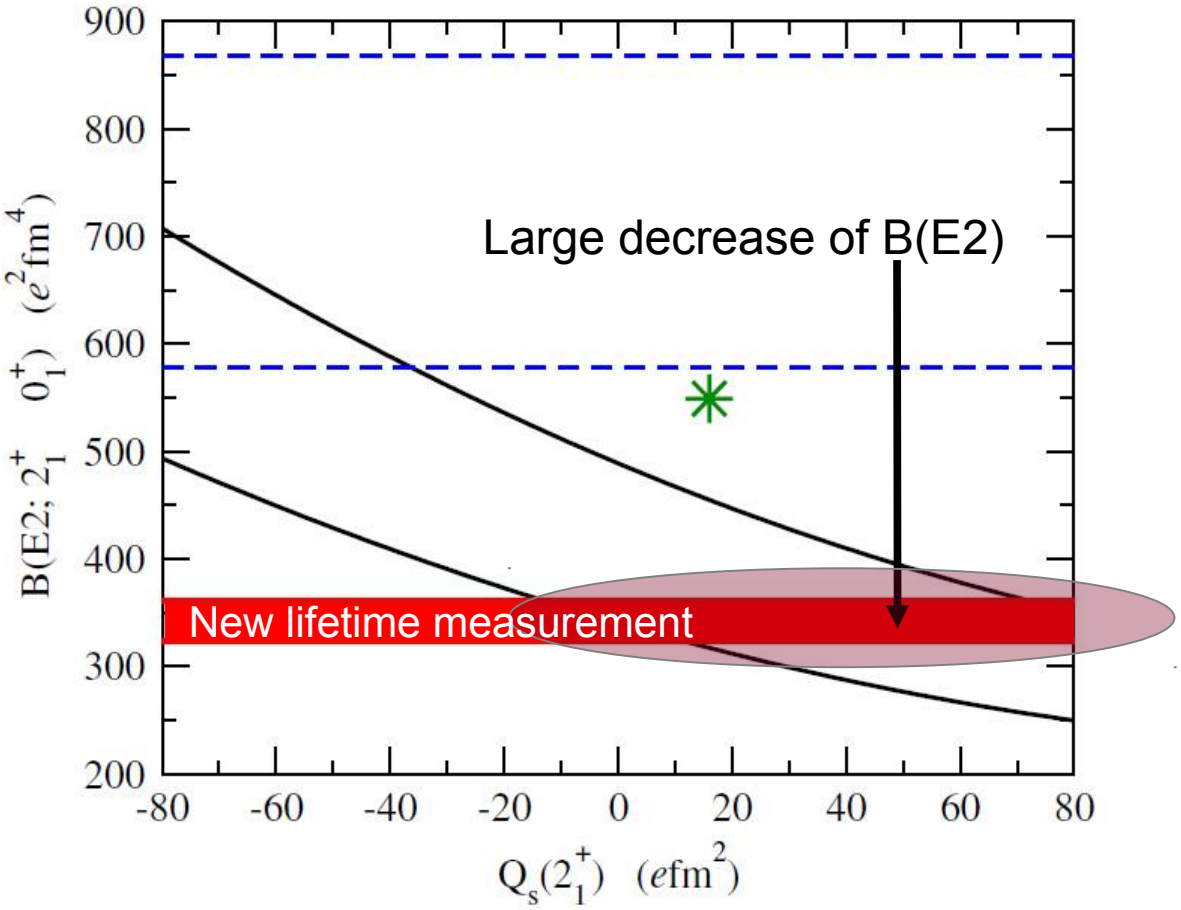
'shape conundrum' – how nuclei change their shape and how this may influence the its shape, moving from roughly cigar-shaped to a more rugby ball-like form or vice versa. How it does this is not understood, says Orce, but the nuclear shape affects the decay properties of nuclei – and thus the abundance of the elements as seen today.

UWC has been preparing for the project since launching its Master's in Accelerator and Nuclear Sciences and Material Sciences (MANuS/MatSci) programme in 2008, funded by the National Research Foundation (NRF). Students are lectured in the field of nuclear structure and nuclear reactions, and are trained to carry out experiments such as the one proposed at CERN.

UWC is, in fact, already running its first CERN-like experiments at iThemba LABS this November, and others will follow shortly, explains Orce.

Shape Coexistence in ^{70}Se

Spherical, Prolate or Oblate?

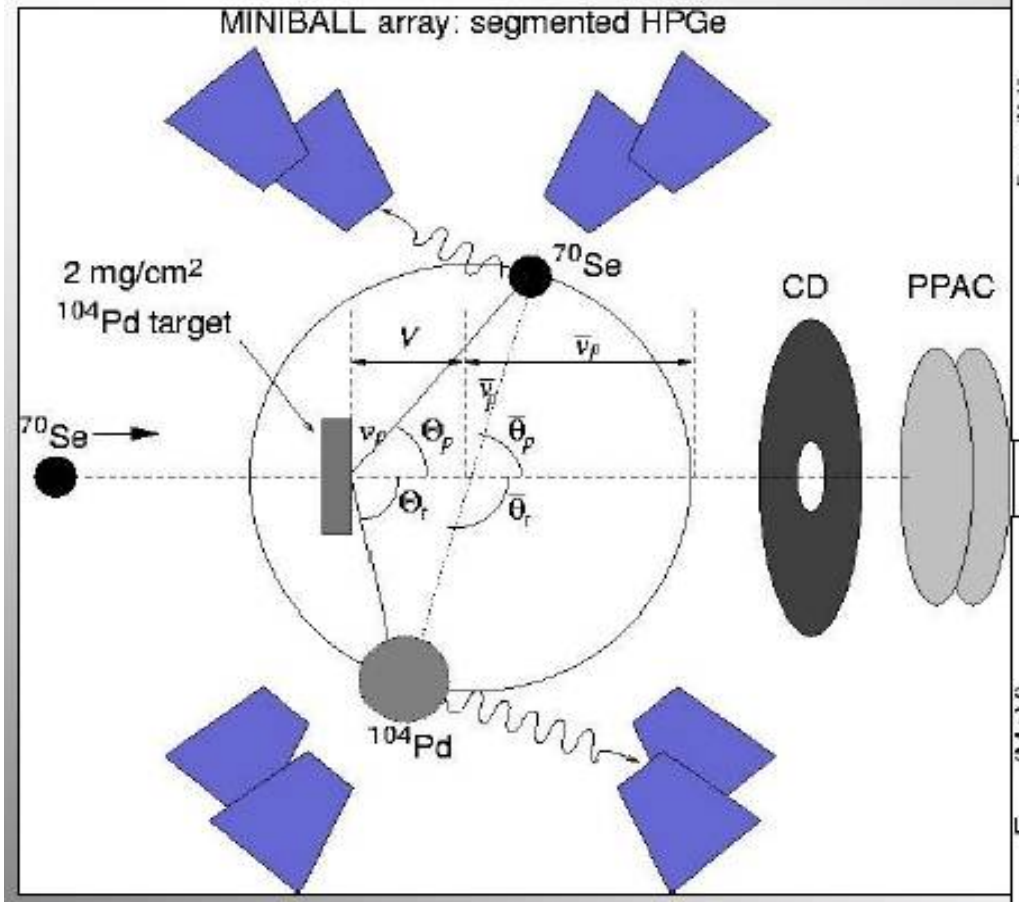


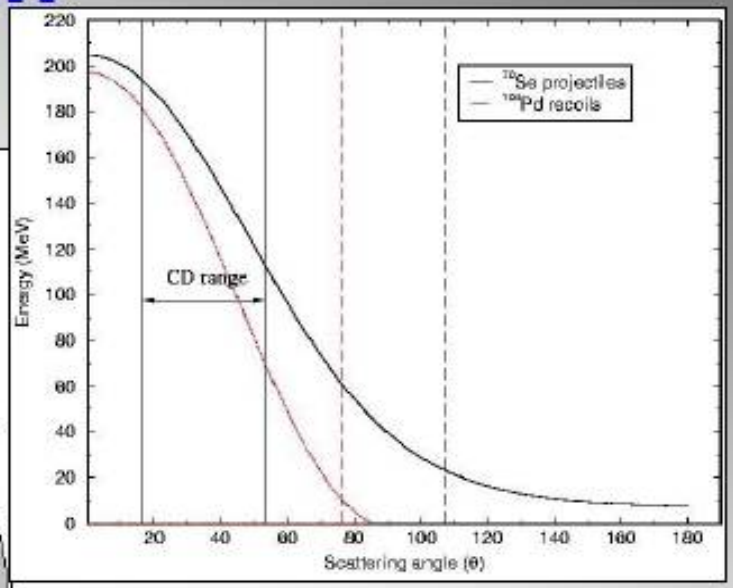
J. Ljungvall *et al.,* Phys. Rev. Lett. **100**, 102502 (2008)

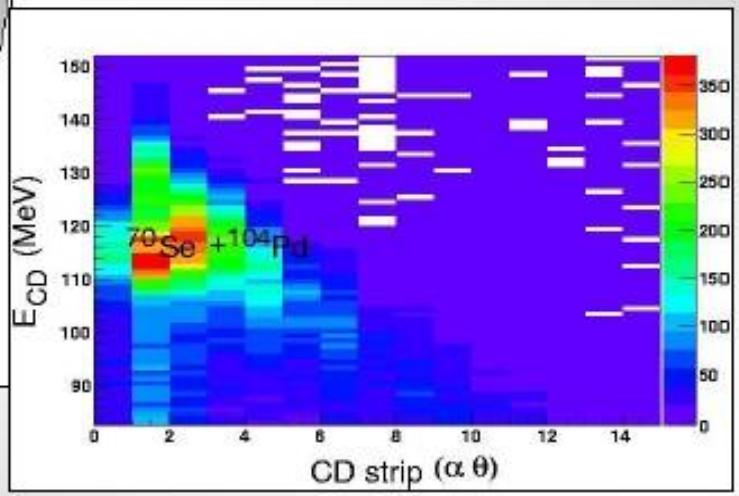
A. Hurst *et al.,* Phys. Rev. Lett. **98**, 072501 (2007)

Miniball

^{104}Pd(^{70}Se,^{70}Se) @ 2.94 MeV/u







"normal kinematics"

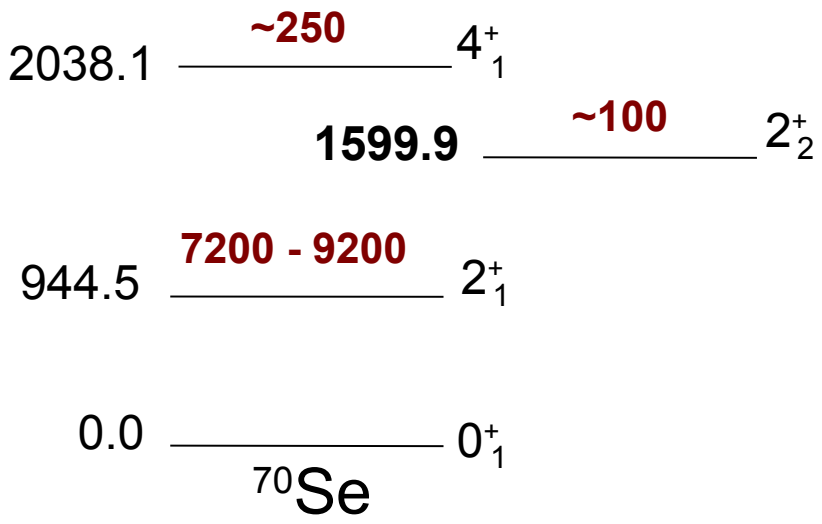
Pure ^{70}Se beams, but only 10^4 ions/s

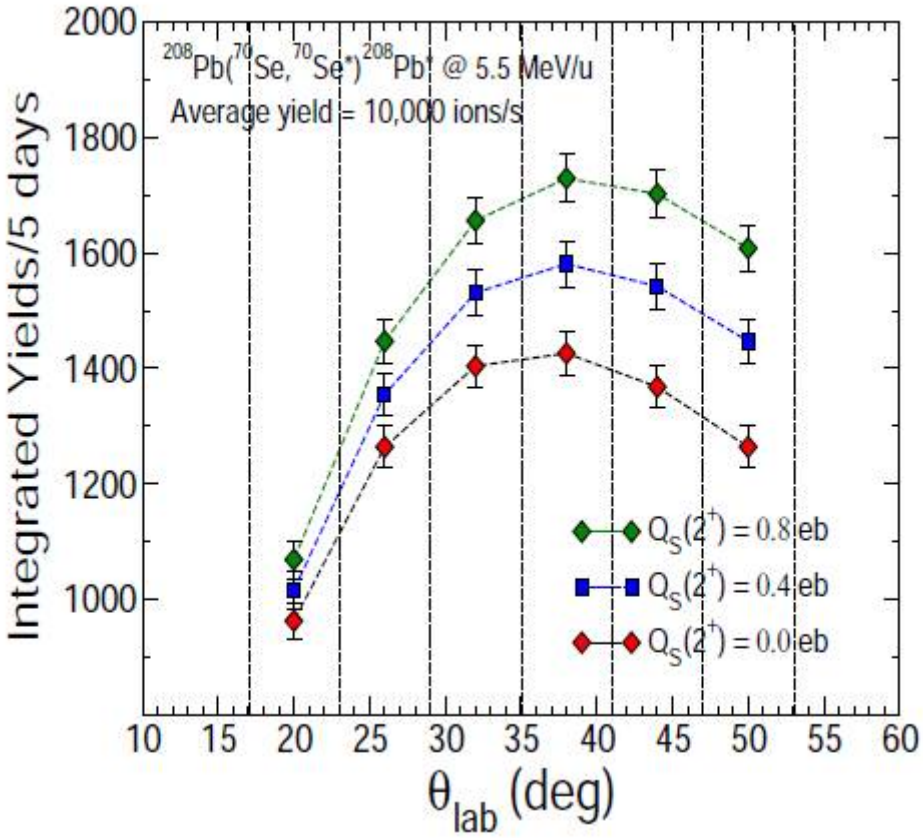
Google: 70Se + Peter Butler

Shape Coexistence in ^{70}Se

New Reorientation-effect measurement at HIE-ISOLDE

Counts/day (10^4 ions/s)





Angular distribution will tell us the shape

Shape Coexistence in ^{70}Se

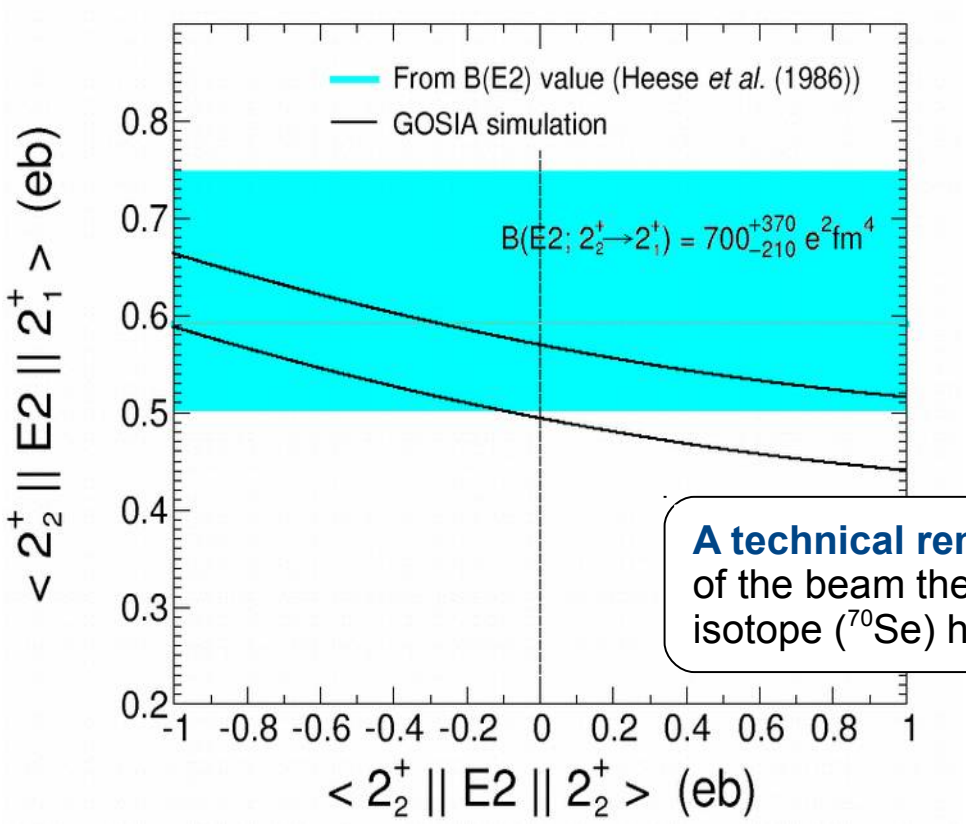
What about the second 2^+? No statistics for angular distribution

High excitation energy and 10^4 ions/s are limiting us

6x improvement at HIE-ISOLDE: higher proton intensity on target and 2 GeV protons

We could still do it, but...

it depends on NNDC lifetime (Heese *et al.*, ~27% uncertainty) and $\delta = -1.0^{+1}_{-2}$!!



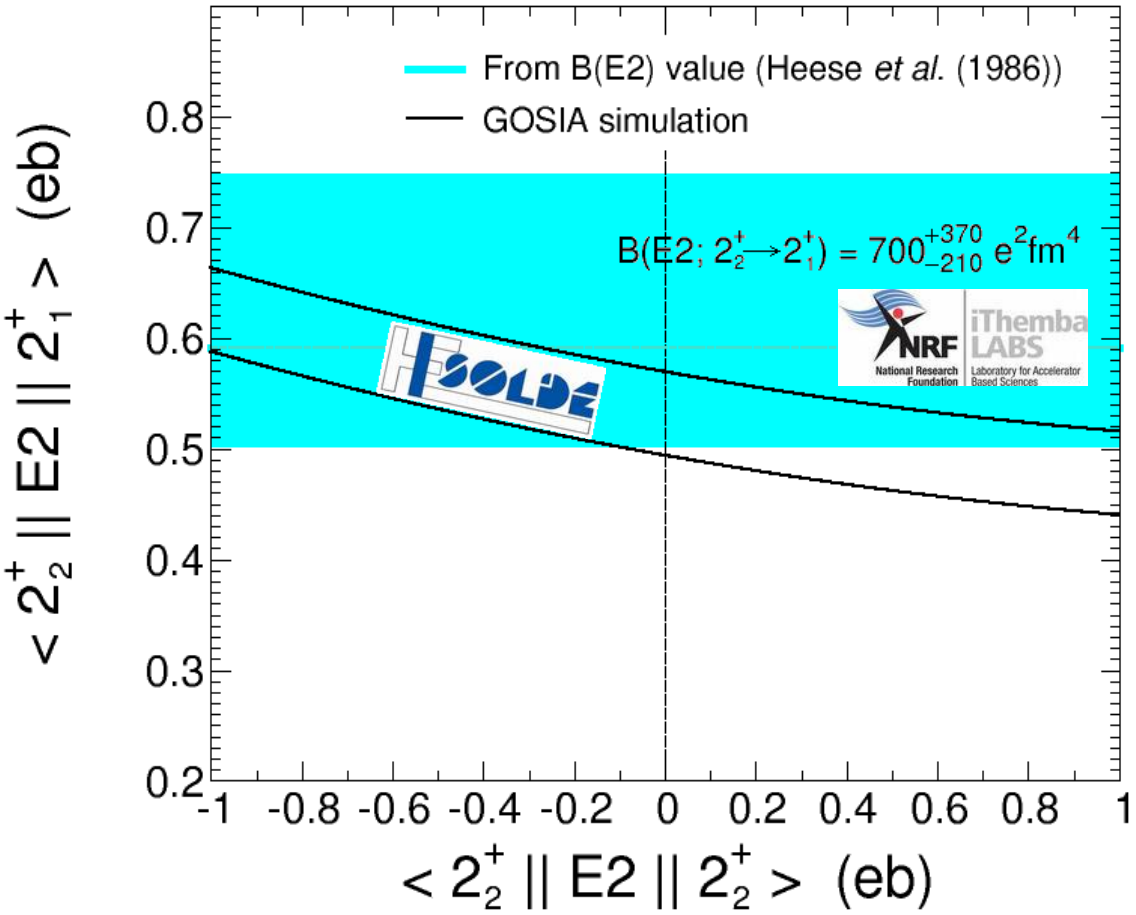
A technical remark: before the delivery of the beam the yield of the requested isotope (^{70}Se) has to be tested.

Shape Coexistence in ^{70}Se

What about the second 2^+? No statistics for angular distribution

Lifetime and mixing-ratio COMPLEMENTARY measurements at iThemba LABS

E.g., ^{58}Ni(^{14}N,pn) reaction at 39 MeV (Heese *et al* 1986) to avoid yrast population

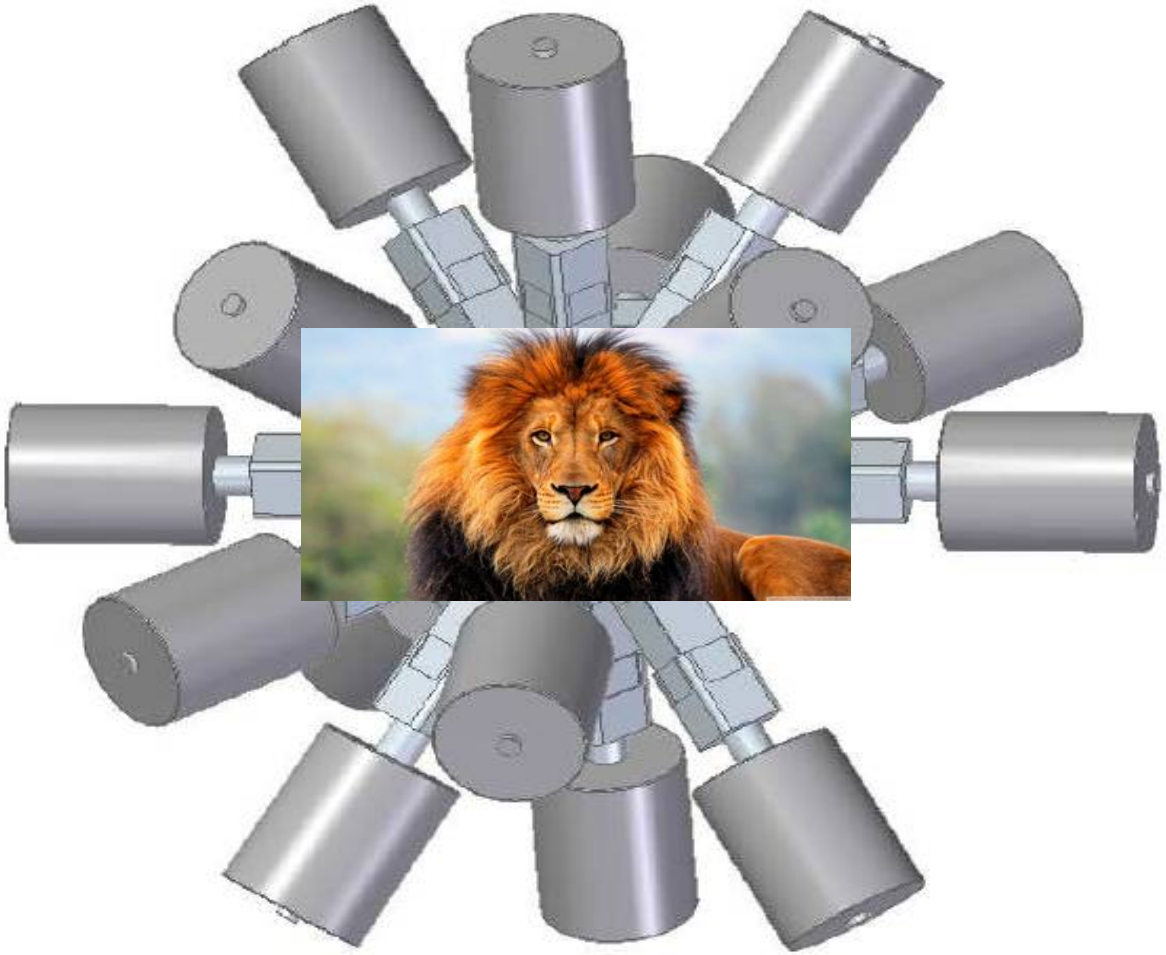


Shape Coexistence in ^{70}Se

What about the second 2^+? We need GAMKA!

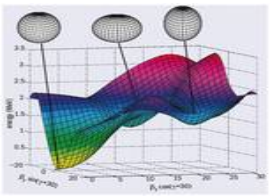
Lifetime and mixing-ratio COMPLEMENTARY measurements at iThemba LABS

E.g., ^{58}Ni(^{14}N,pn) reaction at 39 MeV (Heese *et al* 1986) to avoid yrast population



CONCLUSIONS & SUMMARY

- iThemba LABS is a vibrant facility with lots of possibilitites (K600, RIB, Tandetrom, AFRODITE + Ancillary Detectors)
- We've built a strong Coulomb-excitation program @ iThemba LABS
- A Lifetime program and GAMKA @ iThemba LABS
- HIE-ISOLDE full potential: ^{208}Pb(^{70}Se,^{70}Se*)^{208}Pb* @ 5.5 MeV/u
- Allows precise measurement (±0.1 eb) of $< 2_1^+ \,||\, E2 \,||\, 2_1^+ >$ (sperical, prolate or oblate?)
- Test of state-of-the-art beyond-, relativistic- mean field models
- $< 2_2^+ \,||\, E2 \,||\, 2_2^+ >$? Not enough statistics for angular distribution
- Complete Physics needs stable-ion-beam facilities such as iThemba LABS



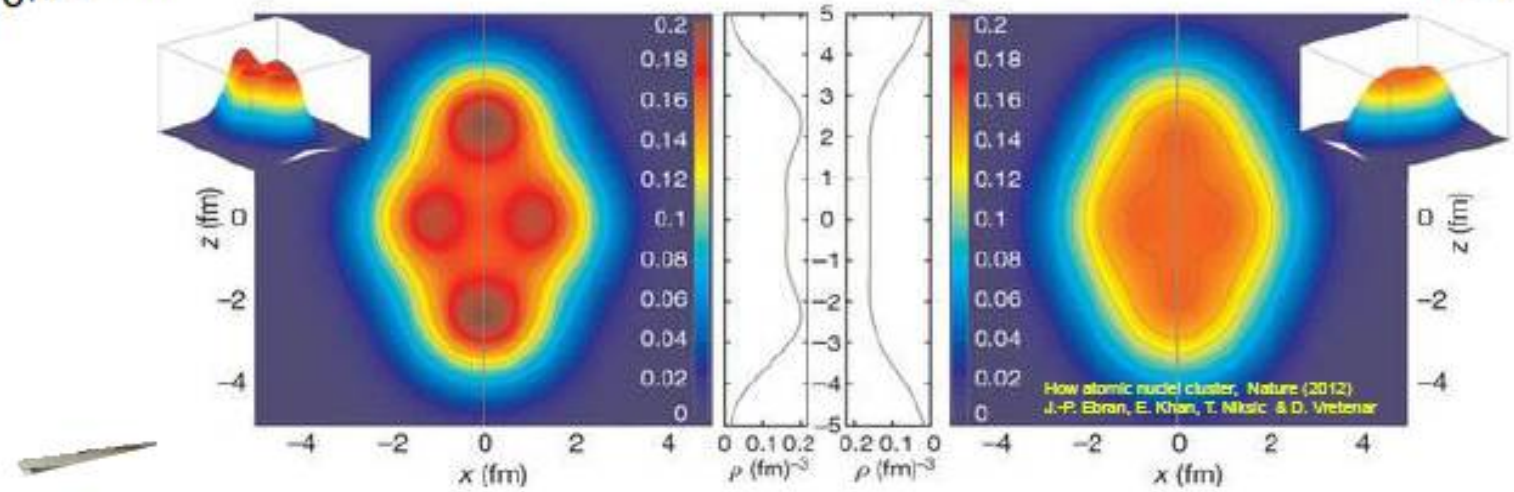
- Test of Shape coexistence is possible with combined efforts!

IV Tastes of Nuclear Physics

November 4 – 6, 2014

Nuclear Shapes
Beyond Mean Field

The Symplectic Model
Shape Coexistence



New Physics with GAMKA

Gamma-ray AsyMmetric spectrometer for the Knowledge of Africa

World-Class Lecturers

John Wood (Georgia Tech, USA)
Paul-Henri Heenen (Bruxelles, Belgium)
Andreas Görgen (Oslo, Norway)
David Jenkins (York, UK)
Nico Orce (UWC)

Timely Topics

Mathematics for Advanced QM
Beyond Mean-Field Model
Nuclear Shapes and Clusters
Shape Coexistence

No Registration Fees
Free Coffee & Lunch
10:00-16:00 @ Room 1.35
Physics Dept @ UWC

Sponsors

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Tastes of Nuclear Physics @ UWC

John Wood, Berta Rubio, Steve Yates, Andreas Gorgen, David Jenkins, Mark Riley, Paul-Henri Heenen, Carlos Bertulani, John Sharpey-Schafer, Mathis Wiedekings, Smarajit Triambak, Nico Orce, etc.

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