Overview of iThemba LABS

Simon Mullins

iThemba LABS

National Research Foundation

iThemba LABS

Laboratory for Accelerator Based Sciences

Outline :

- Accelerator Mass Spectrometry (AMS) at iThemba LABS (Gauteng)
- Rare Isotope Beam (RIB) Project at iThemba LABS (Cape)

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Nuclear Research Facilities in South Africa

iThemba LABS in the Cape (Mother Ship)

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iThemba LABS in Gauteng (AMS about to fly)

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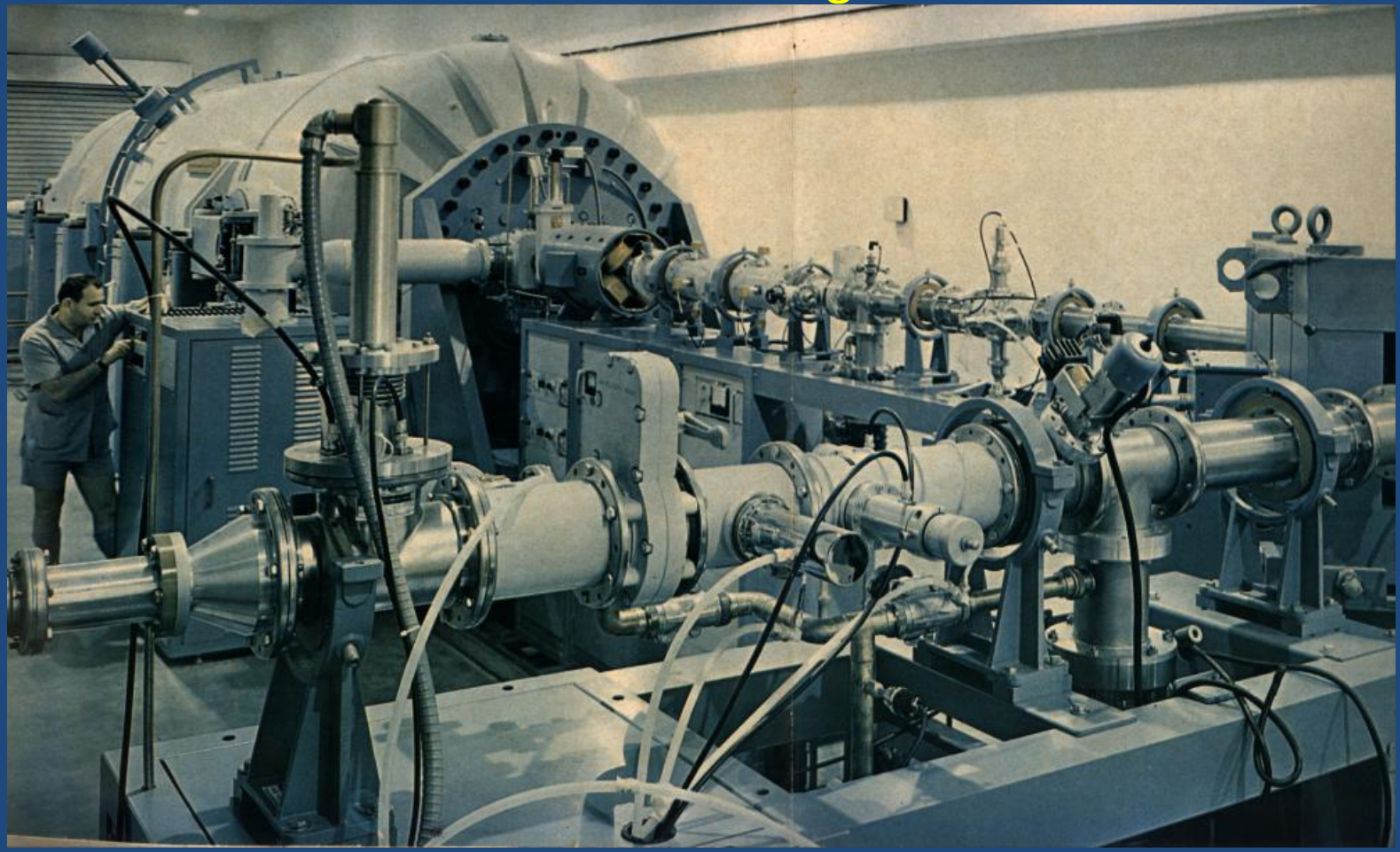
Tandem Accelerator beam-injection system at the (then) Schonland Research Institute along with Miklos Rebak.



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Old Injection System no more

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Injection Side of the Tandem Accelerator after Refurbishments

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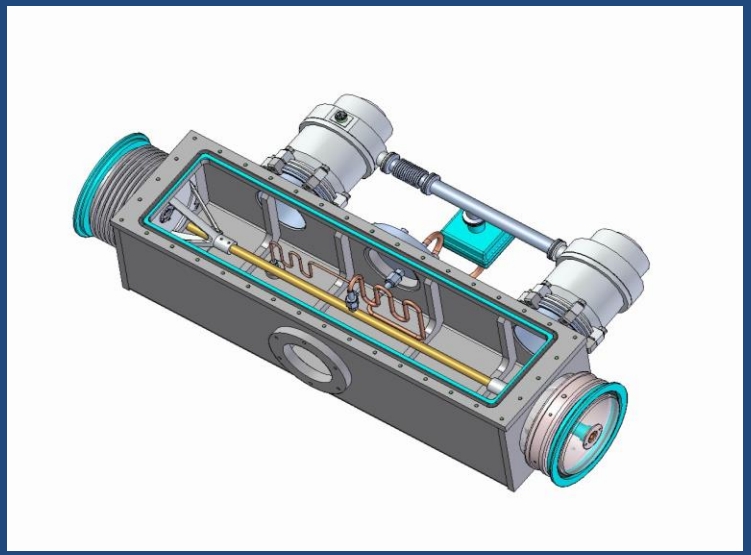
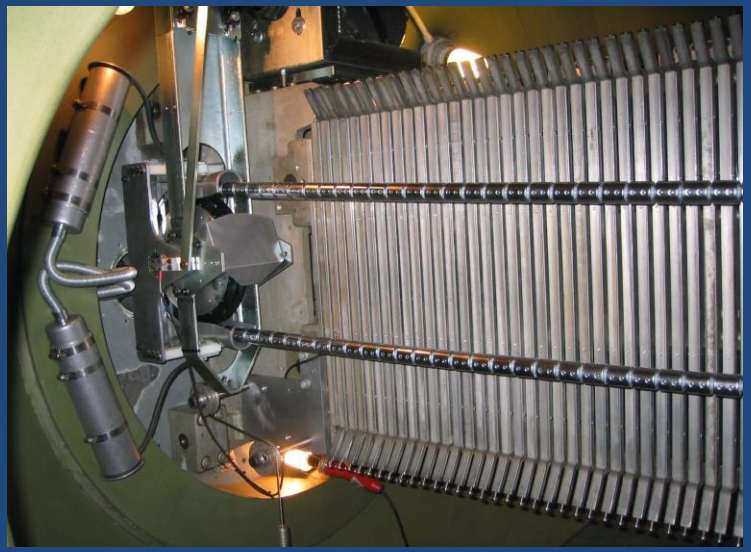
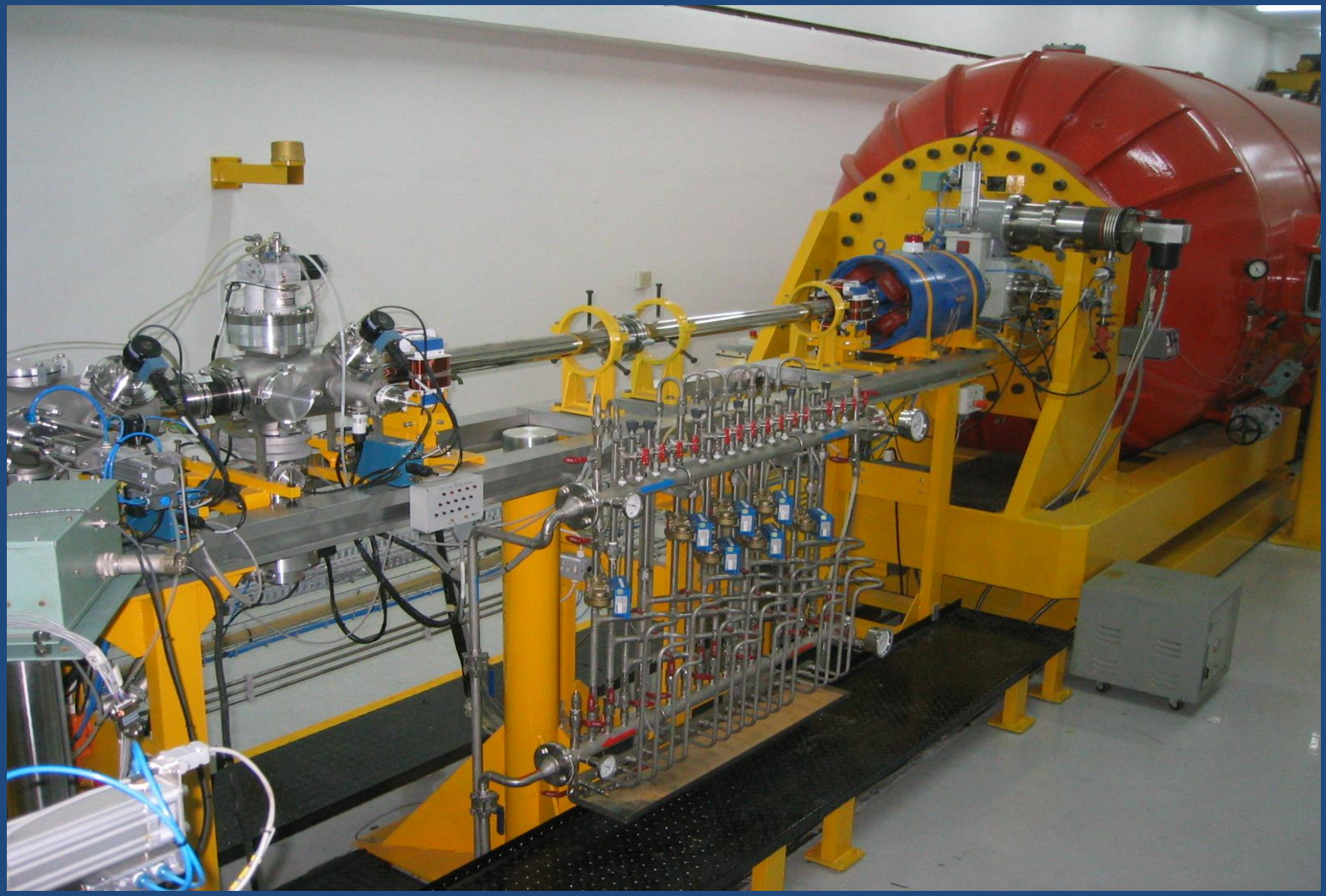
Pelletron & gas stripper box installation in 6 MV EN Tandem Accelerator





High Energy Extraction side of Tandem before the refurbishment

Extraction beam line of tandem accelerator post-refurbishment



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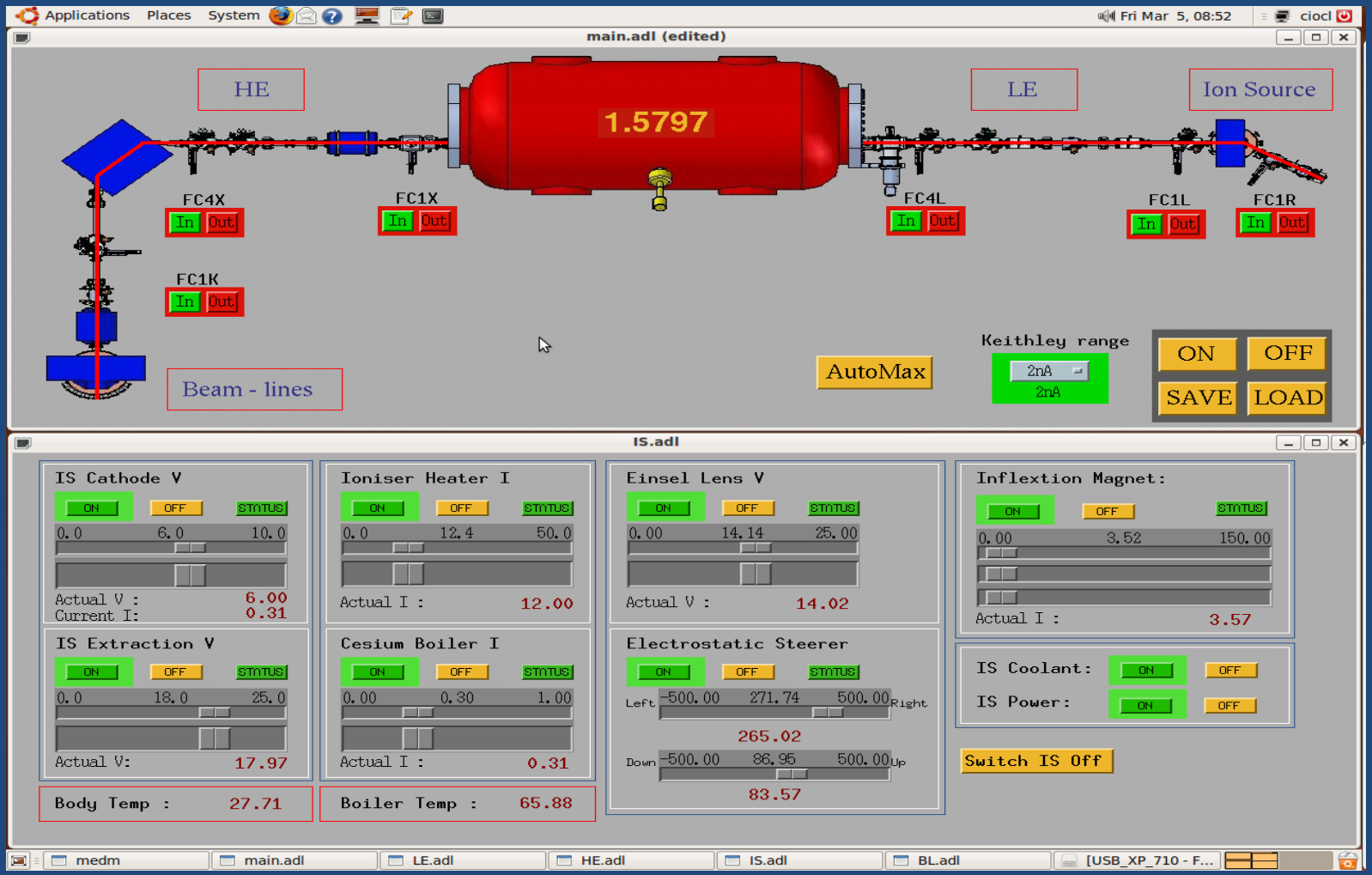
EPICS control system implemented for tandem accelerator



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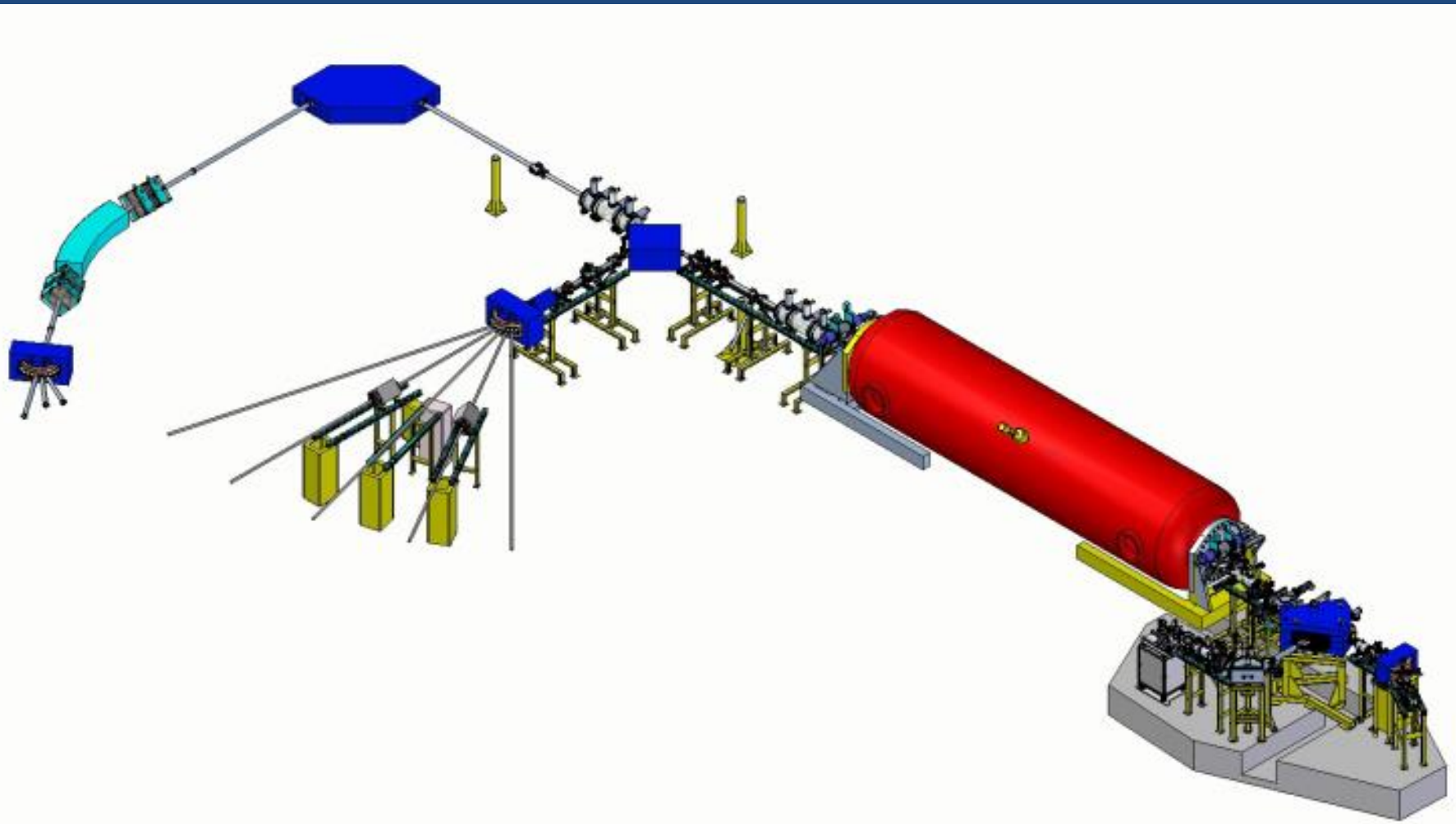
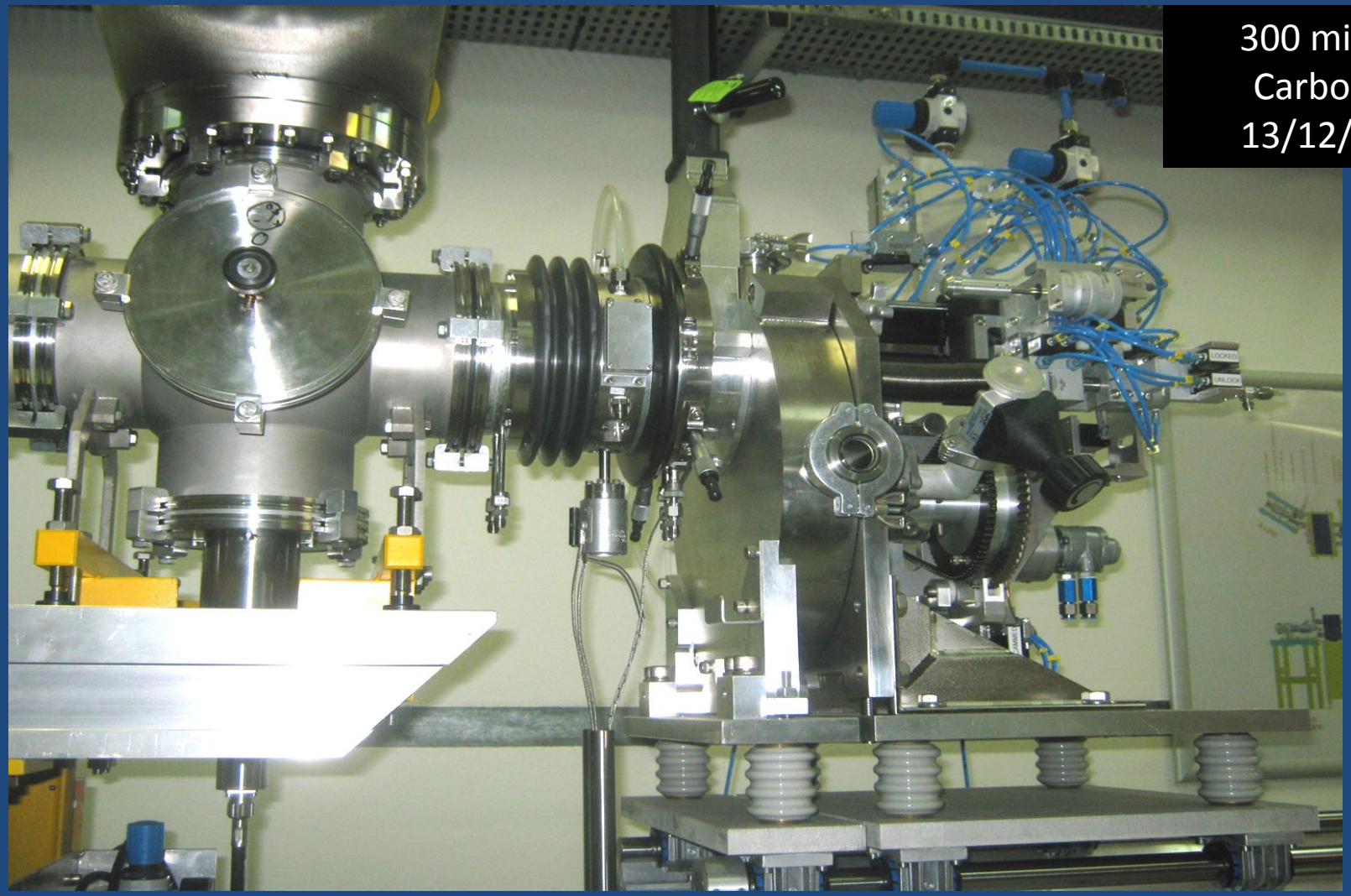
Layout of AMS system for iThemba LABS Gauteng



Negative Ion Source by Cesium Sputtering using the LLNL design (IAEA-funded)



300 micro A
Carbon 12
13/12/2009

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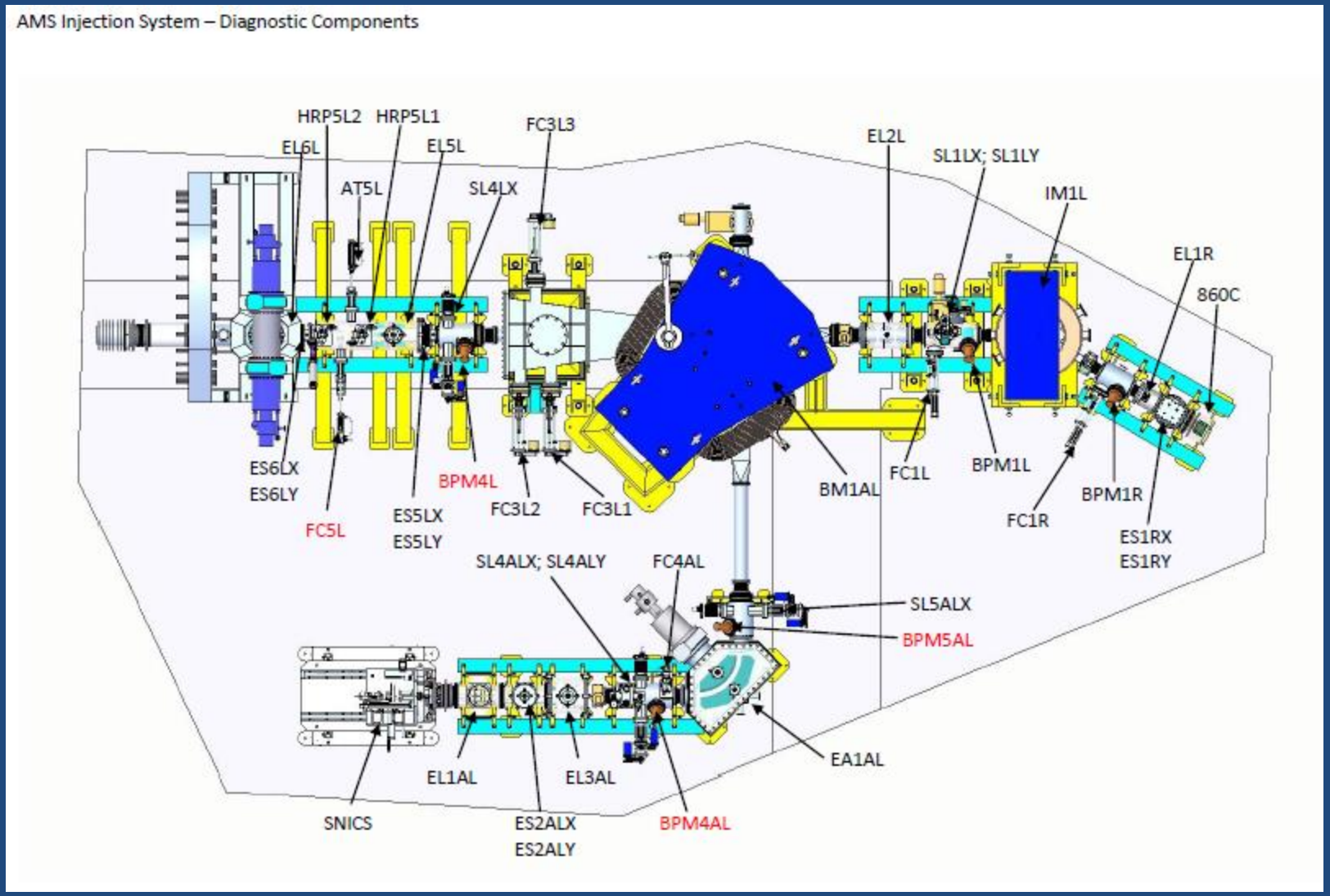
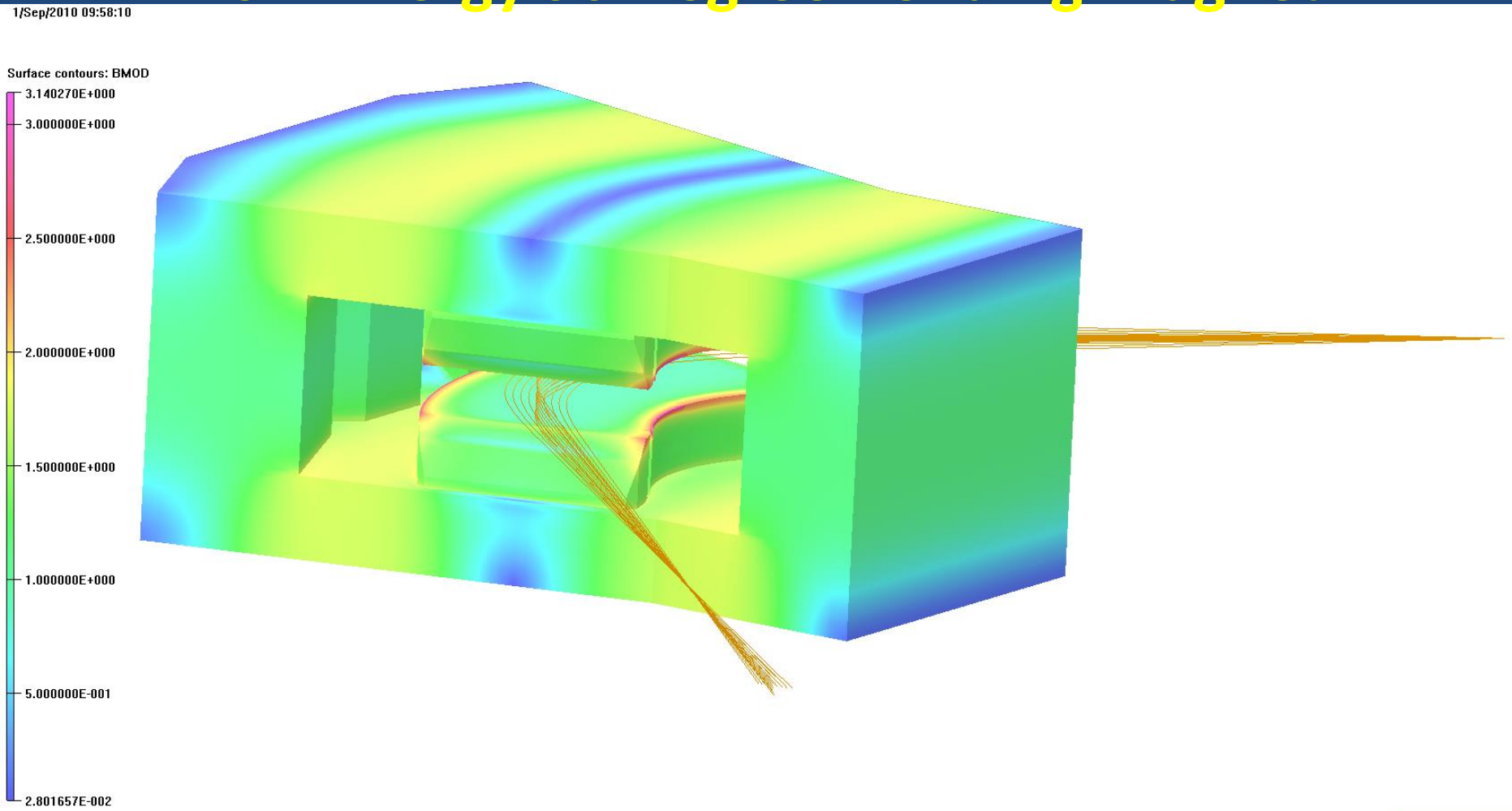
Plan view of Low-Energy Injection System with BPMs

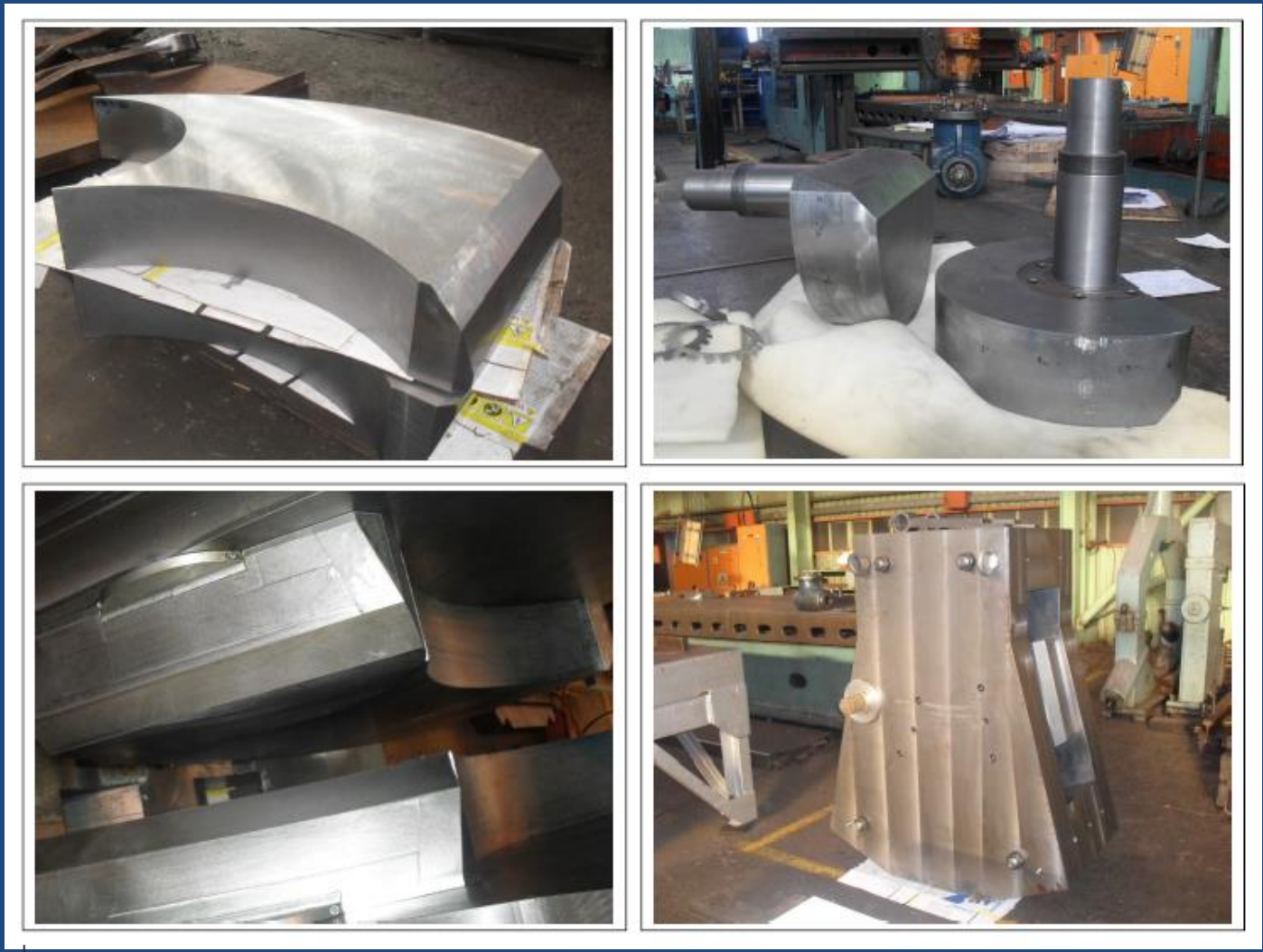


Low Energy 90 Degree Bending Magnet



Opera

Low Energy Injection Magnet manufactured in KZ-N



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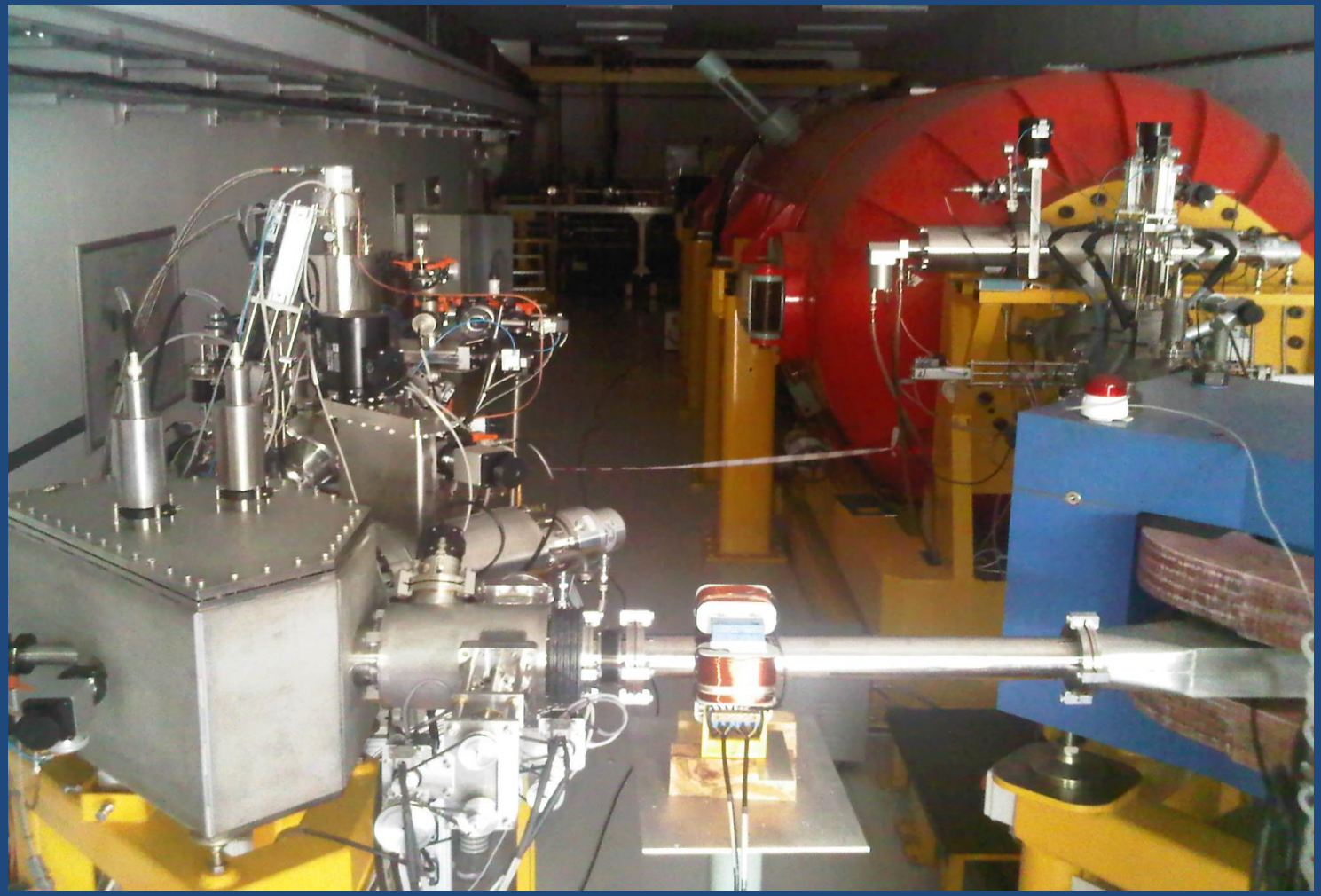
Low-Energy Injection System under commissioning Dec'2012/Mar 2013



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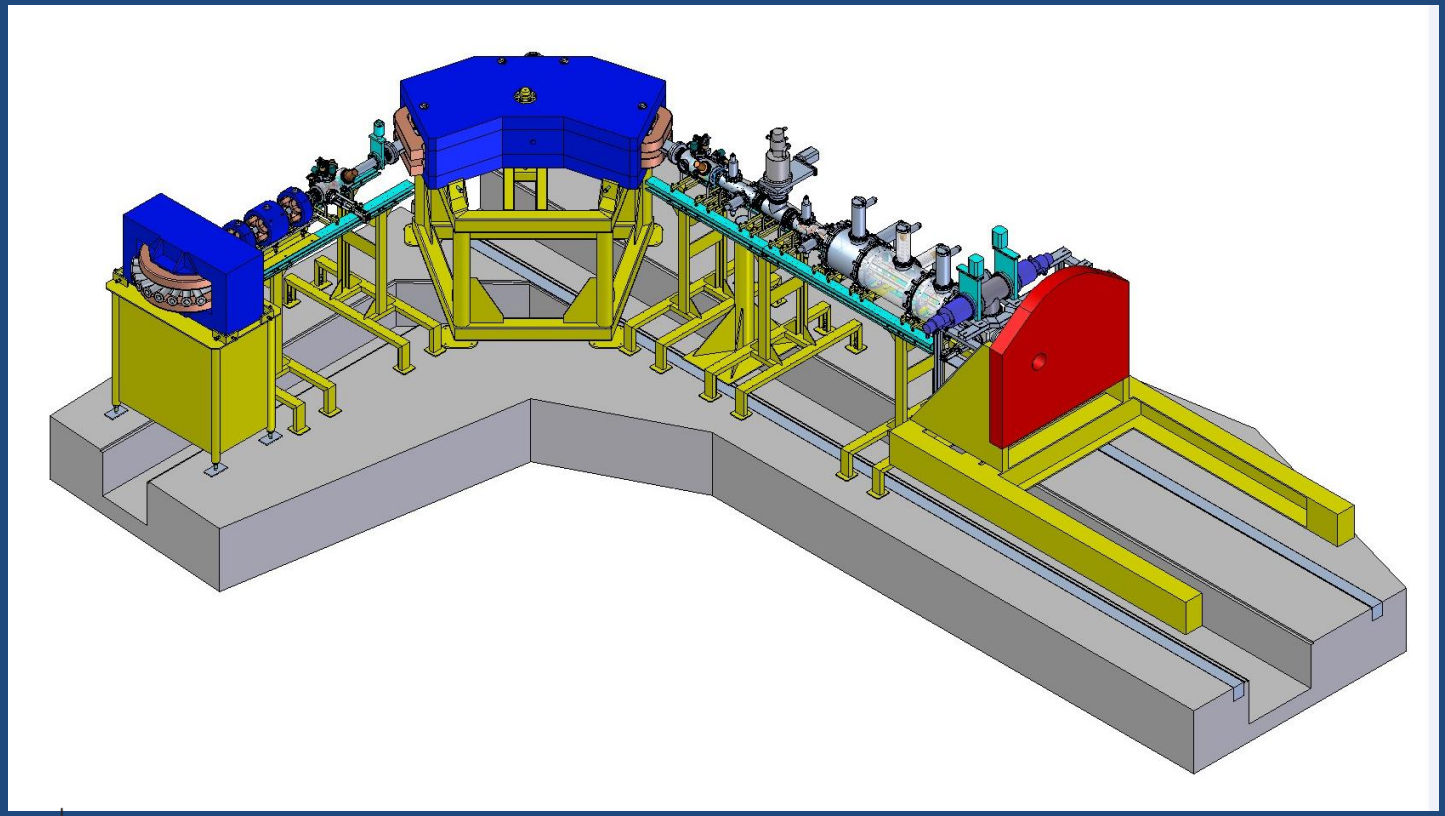
March 2014 : Further commissioning of LEIS

Rebuilt existing pre-AMS high energy beam lines:

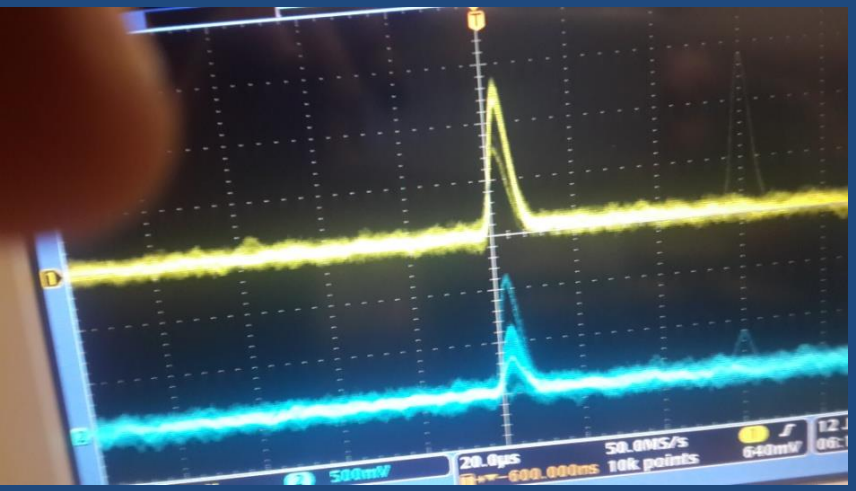
- Replaced analyzer magnet with larger magnet (better mass*energy product)
- Replaced magnetic elements with electrostatic devices – AMS requirement
- Replaced magnetic doublet after analyzer magnet with triplet arrangement

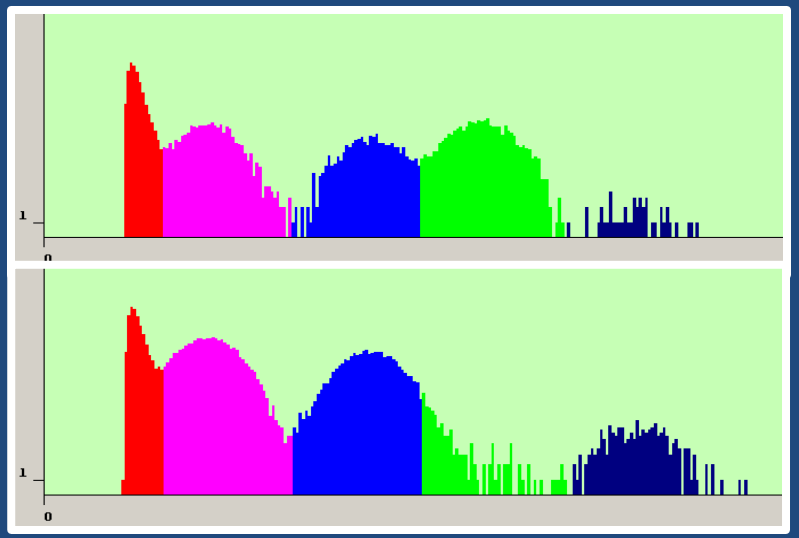


March 2014 : National Electrostatics Corporation (NEC) High Energy Analysis System under Installation (replica of SUERC system)

March 2014 : High Energy Analyzing Magnet under Installation

July 2014 : First commissioning of complete AMS system





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7th July 2014 : SAIP2014 AMS Workshop at iThemba LABS : opening address by the Hon. Mrs Naledi Pandor, Minister of Science and Technology, who later declared Africa's first AMS facility open

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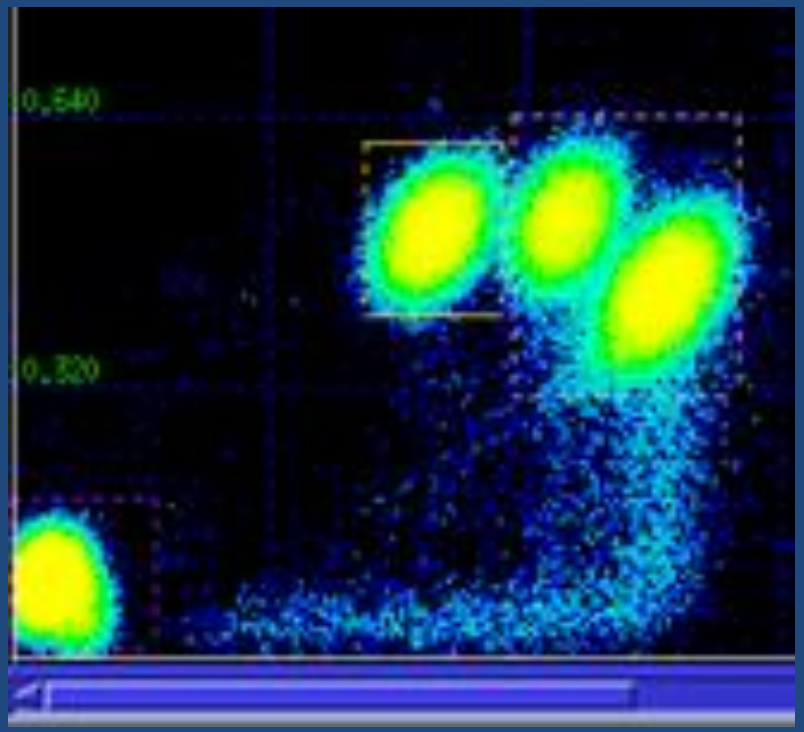
July 2014 : First fully operational detection of ^{14}C ions via AMS in Africa from Ox-II standard supplied by Tom Brown of CAMS, LLNL, USA

E →



ΔE →

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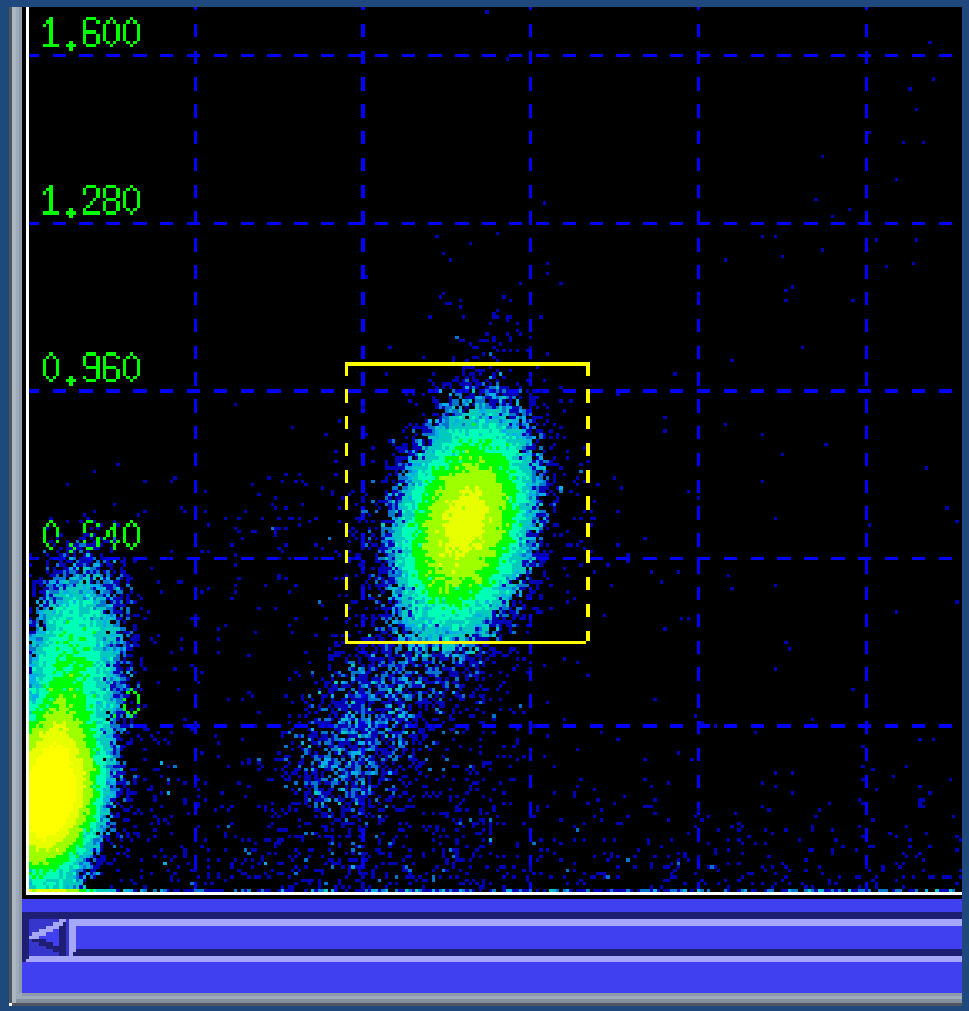
November 2014 : First detection of C14 ions by iThemba LABS AMS team (alone!)



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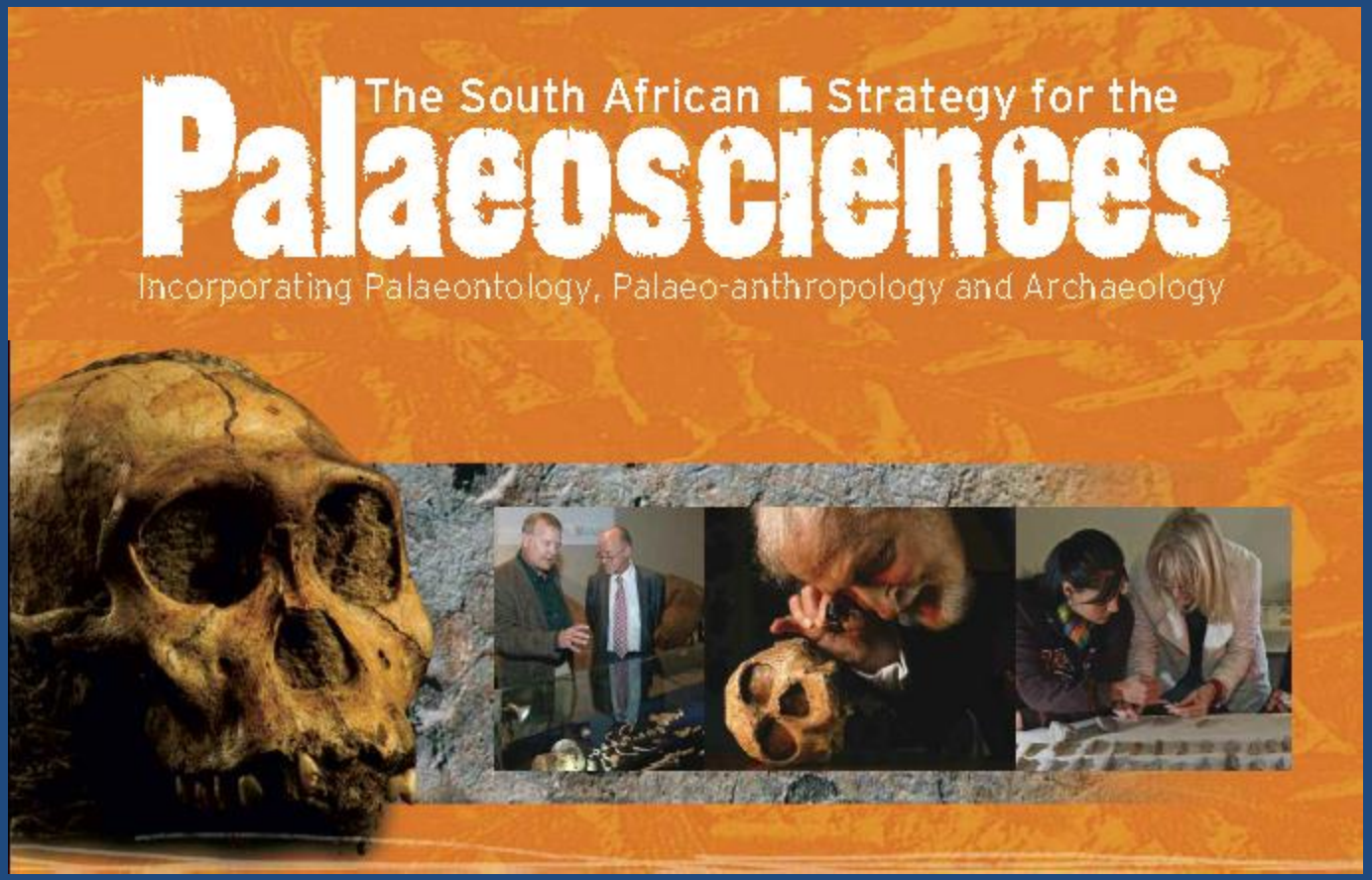
Users : Centre of Excellence for Palaeosciences (hosted by University of the Witwatersrand)



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Users : South Africa Antartic Programme (^{10}Be in ice-cores)

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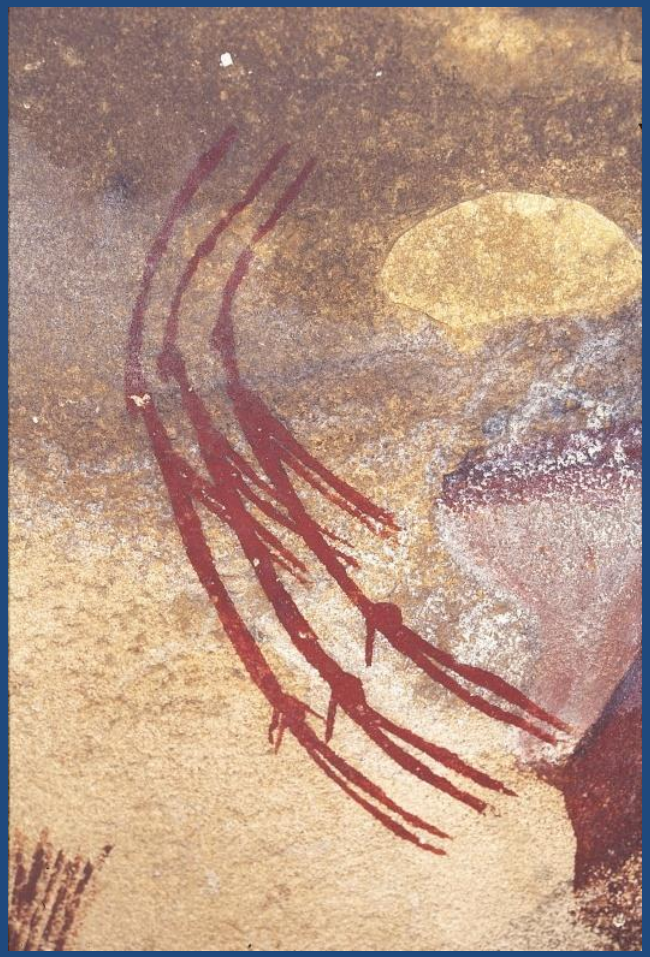
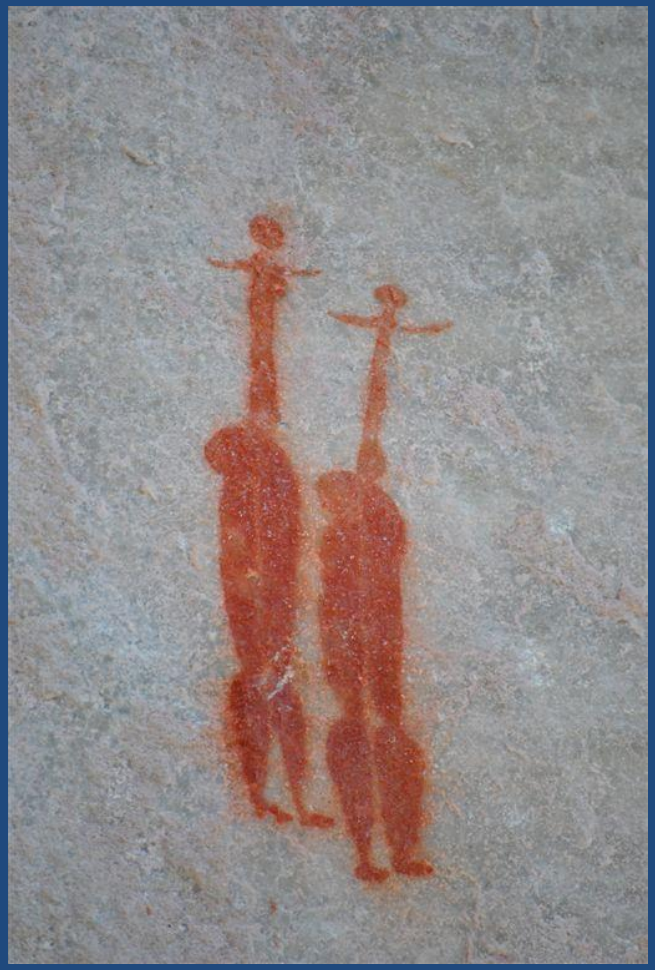
Users : Rock Art Research Institute (University of the Witwatersrand)





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Commissioning Africa's first AMS facility at iThemba LABS: Progress Report

(With Support from the NRF, the IAEA and the DST)

S.M. Mullins, A. Zondervan†, C.G. Badenhorst, K.F. Balzun, J.L. Conradie, J.G. Delsink, J.G. DeVilliers, D. Fourie, V.L. Mbele, A.S. Miller, O. Pekar, K.G. Sekonya, P. Van Schalkwyk, S.M. Woodborne

Introduction : refurbishments, upgrades and installations

The 6MV Tandem accelerator facility at the Gauteng site of iThemba LABS, South Africa, has been upgraded to enable AMS measurements to be undertaken. The upgrades and installations include:

1. The commissioning of a replica of the CAMS (LLNL) multi-cathode ion source funded by the IAEA.
2. In-house design and RSA manufacture of a 90° injection magnet with bouncing system.
3. Installation of a pelletron charging system and new high voltage resistors for stable TV up to 5MV.
4. Installation of a high energy analysis system (HEAS) from NEC based on the system at SUERC.
   - The HEAS includes a $ME/Z^2 = 176$ double focusing magnet (1.27 m radius) with $M/\Delta M = 725$ and a 20° electrostatic cylindrical analyzer (ECA) of 150° (3.81 m) radius with $E/\Delta E = 200$.
5. A multi-anode gas-ionization detector is installed with a further one obtained via the IAEA.
   - A radiocarbon sample preparation laboratory is under completion funded by the NRF and the IAEA.

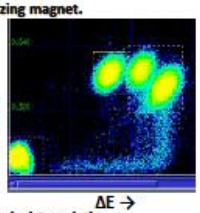
Figure 1. (Left) Schematic of the iThemba LABS AMS facility showing the refurbished 6MV Tandem Accelerator, the low energy injection system and the recently installed high energy analysis system.

First steps : the injection, acceleration, selection and detection of ^{14}C ions

The initial commissioning recently took place led by an IAEA expert mission† with these milestones achieved :

- ^{12}C transmission for 3^+ and 4^+ charge states was measured at a terminal voltage of 3.3 MV .
- ^{13}C and ^{12}C ions were detected in the Faraday cups after the high energy analyzing magnet.
- ^{14}C ions were identified in the gas ionization detector (see figure 2).

Figure 2. (Right) Screen-capture of E-ΔE spectrum showing the first AMS identification of ^{14}C ions (middle "blob" of the upper-right group of three) in Africa from an Ox-II standard (supplied by Tom Brown).



Next steps : quantitative measurements

Analyses with the fully commissioned facility have been requested by :

A The Rock Art Research Institute at Wits University and the PanAfrican Archeological Association.

B The DST/NRF Centre of Excellence in Palaeosciences hosted by Wits University.

C The South African National Antartic Programme (SANAP) for ice cores obtained from Queen Maud Land.

Acknowledgements

The development of the AMS facility was funded by the National Research Foundation (NRF) , the IAEA and iThemba LABS. Additional support has been received from Tom Brown (LLNL), Peter Steier (VERA), Ron Reimer (QUB) and John Southon (UCI).

August 2014 : Poster presented at AMS-13 conference in Aix-en-Provence, France

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Back to iThemba LABS in the Cape……

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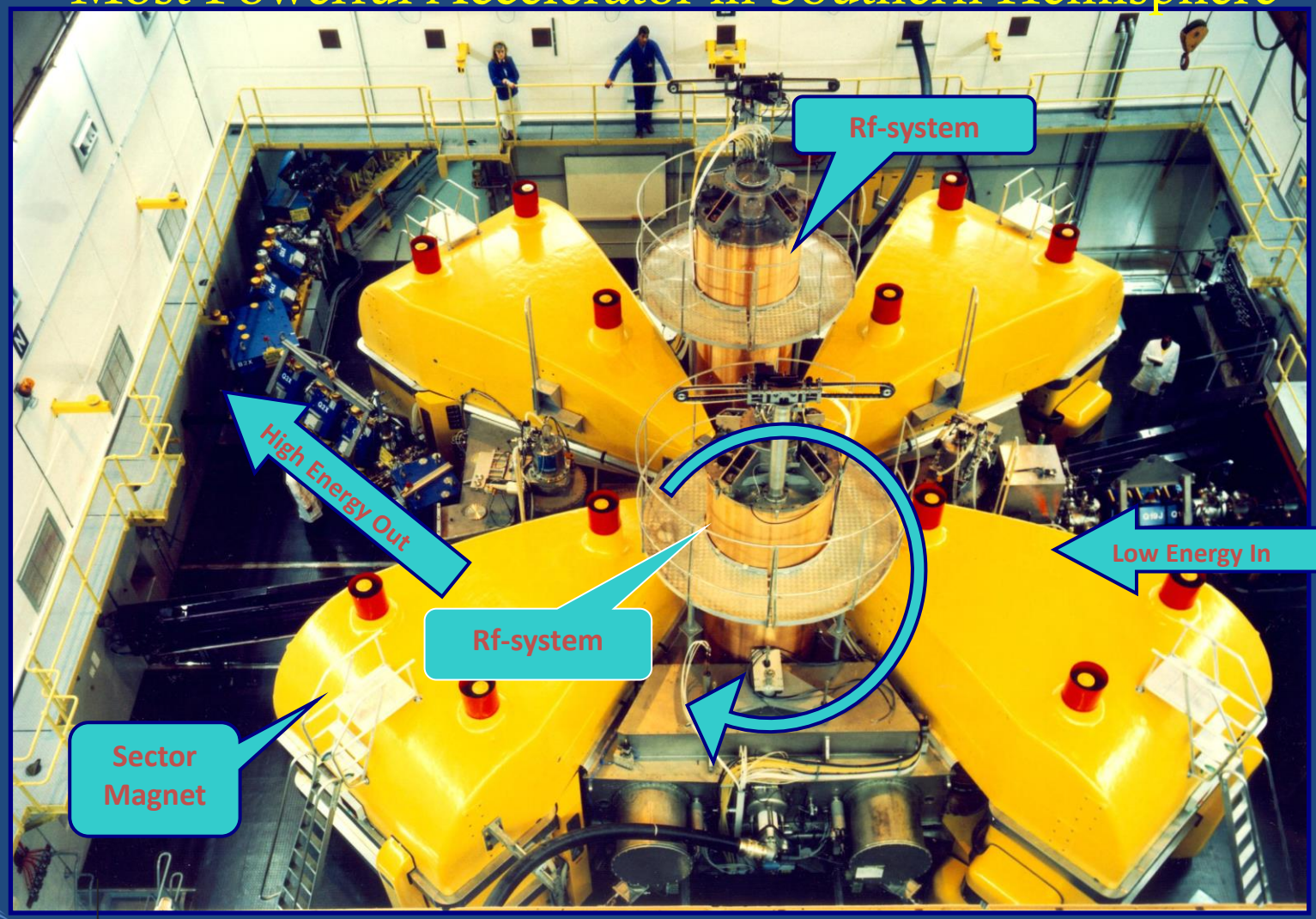
Separated-Sector Cyclotron (SSC)

Most Powerful Accelerator in Southern Hemisphere



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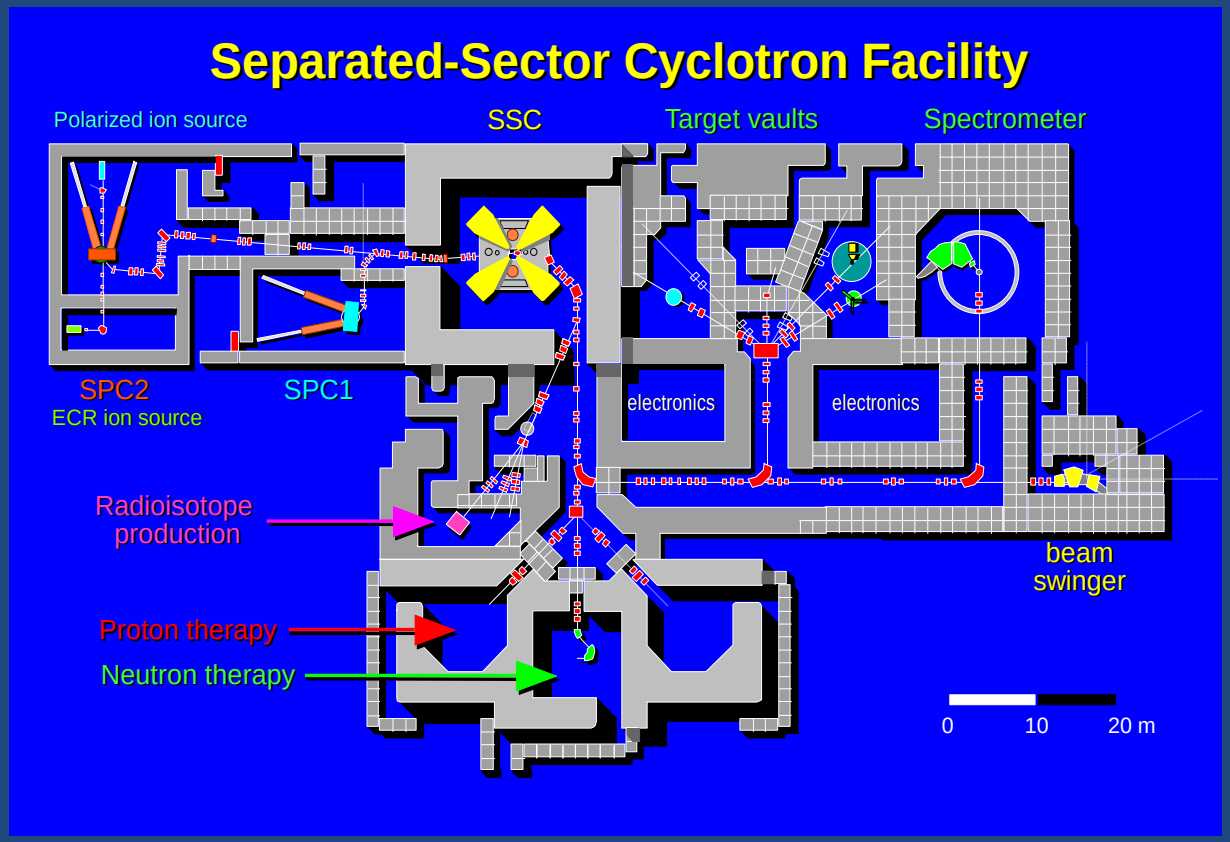
Multi-User Facility

- Proton Therapy: 200 MeV p
- Neutron Therapy: 66 MeV p, ~ 40μA
- Isotope Production: 66 MeV p, up to 350μA
- Nuclear Physics: various beams



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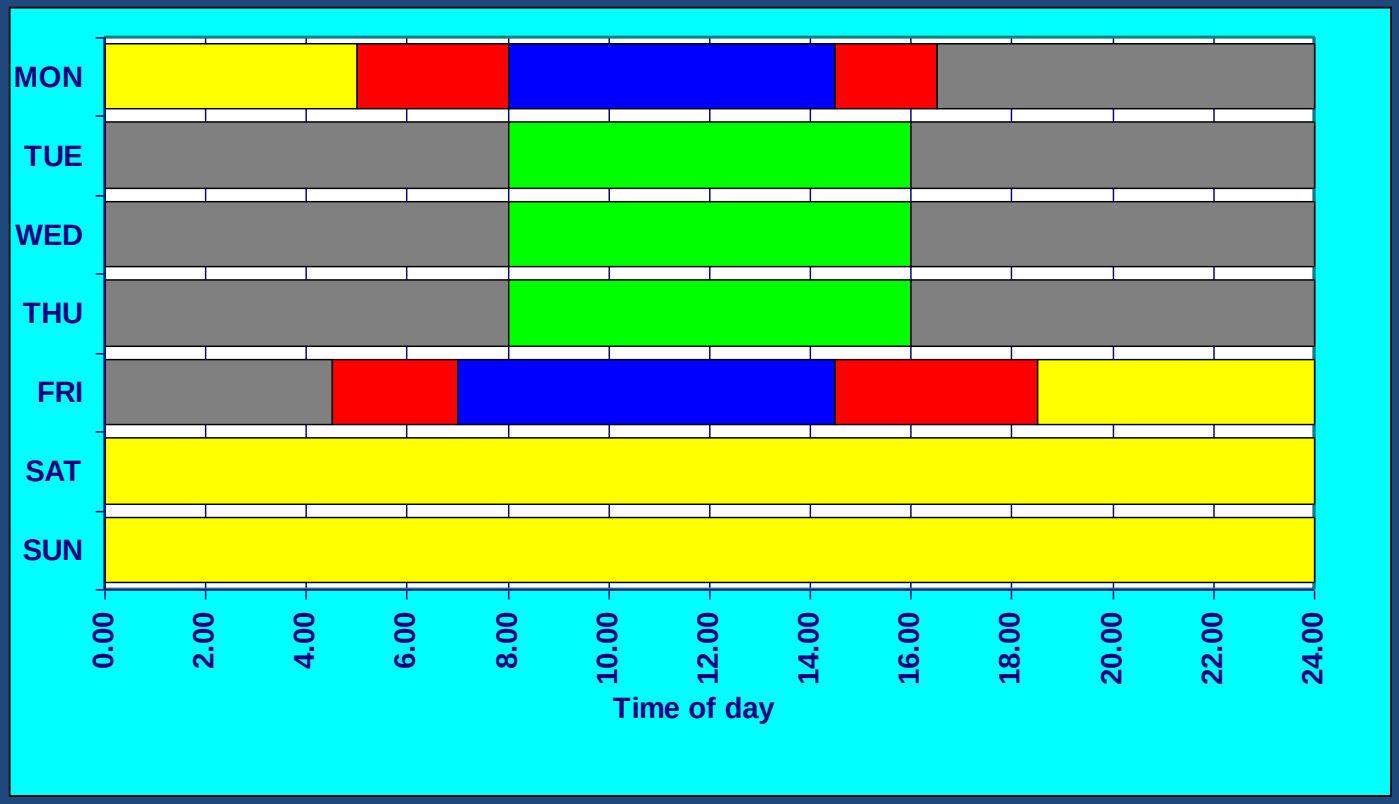
SSC Beam Schedule



◊ Nuclear Physics

© Neutron Therapy

© Proton Therapy

© Energy Change

© Isotope Production

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Proton Therapy

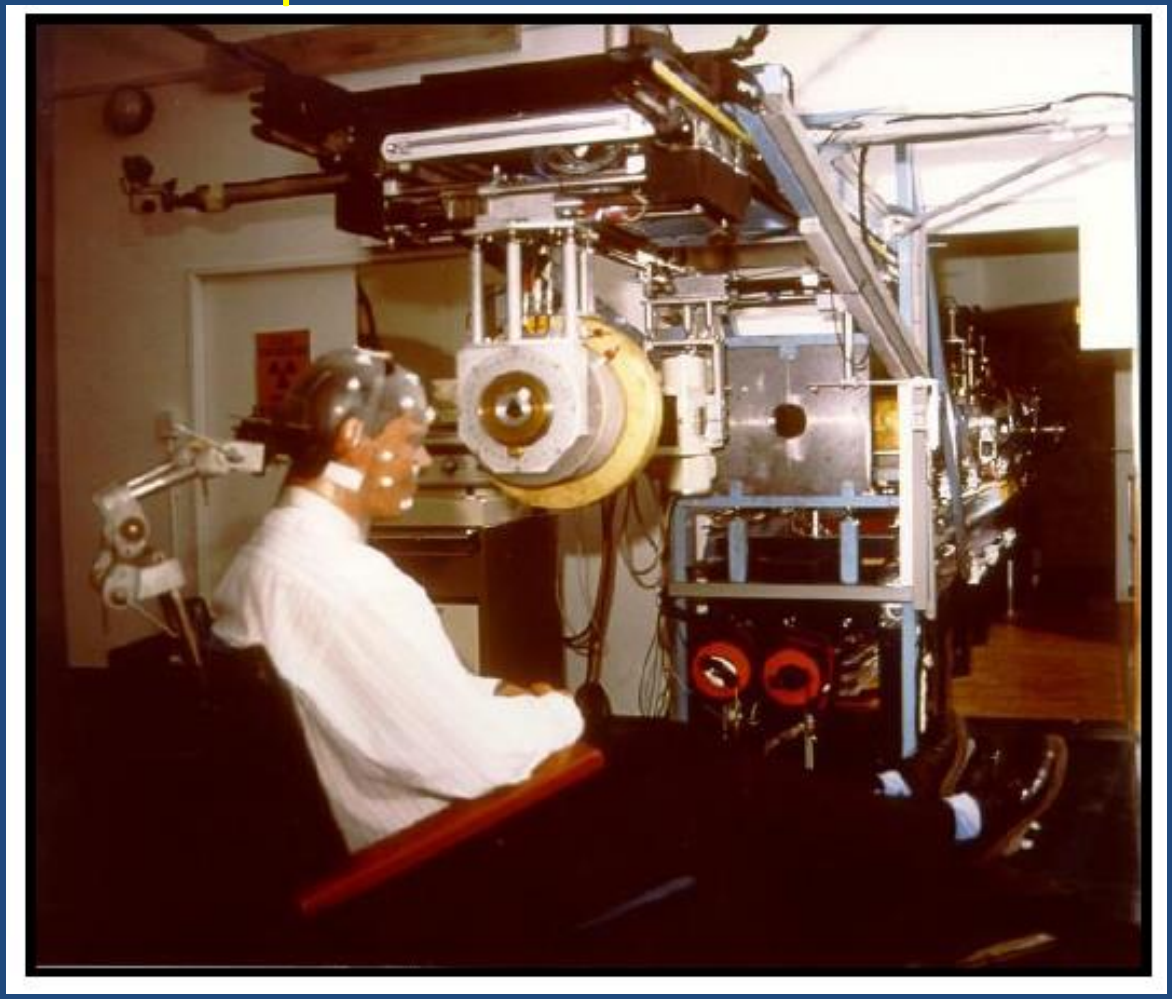
Present Schedule Restricted to 2 “Fractions” / week

- Brain tumours

If schedule allowed 5 “Fractions” / week

- Paediatric tumours
- Tumours close to critical structures
- Brain tumours
- Gastro-intestinal tumours (rectum, liver, pancreas)
- Prostate tumours
- Lung tumours
- Recurrent tumours

Proton-therapy computer-controlled treatment set-up at iThemba LABS



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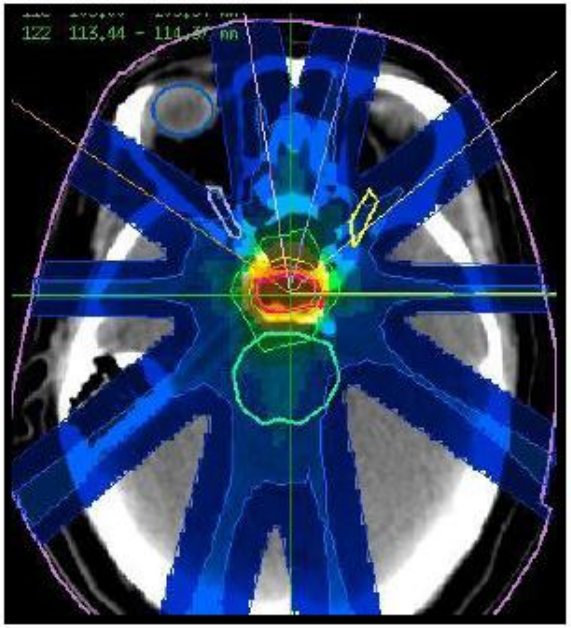
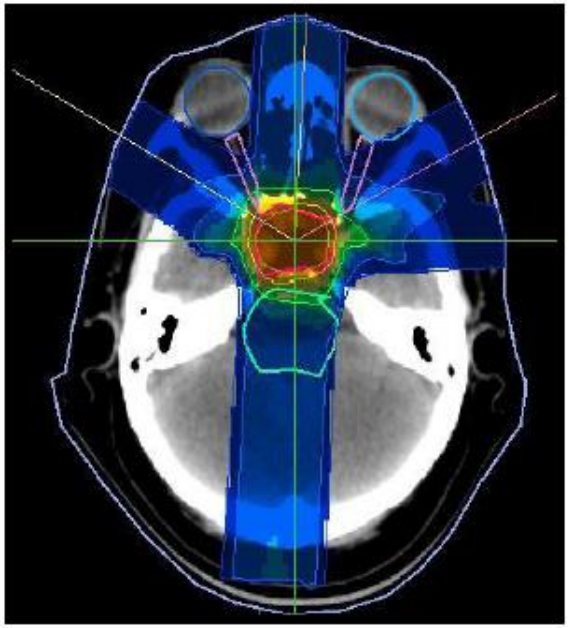
Proton Therapy : Delivered in “fractions”

PROTON PLANS: PITUITARY ADENOMA



Plateau irradiations



COMBINATION
Plateau and SOBP irradiations

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Neutron therapy treatment vault at iThemba LABS

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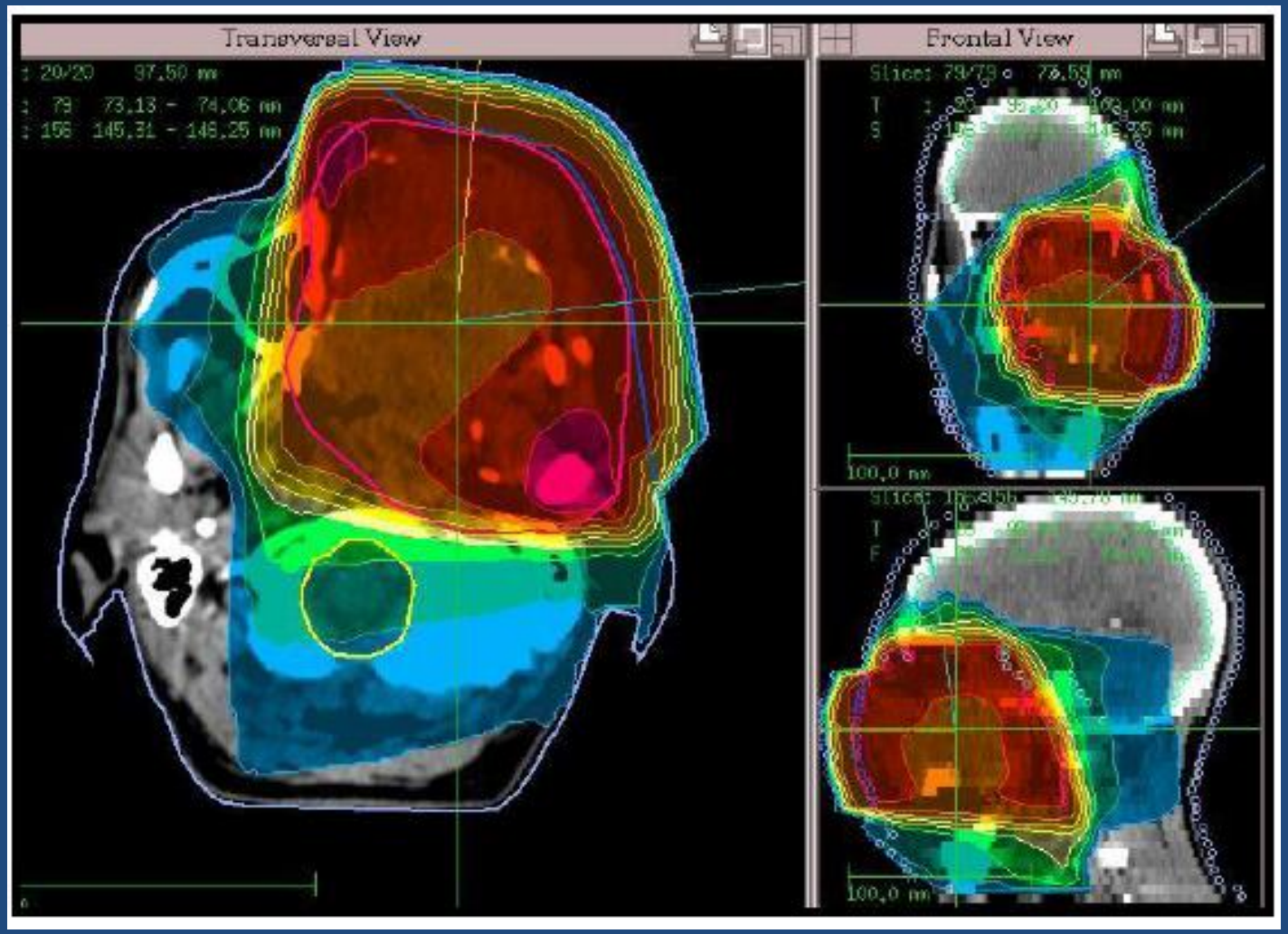
Neutron therapy treatment at iThemba LABS



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Nuclear Physics Research

- Nuclear Structure
  - Pairing Isomers
  - Pairing Vibrations
  - Tetrahedral Shapes
  - Hyperdeformation
  - Chirality
  - Giant Resonances
- Nuclear Reactions
  - Fusion Barrier Distributions
  - Incomplete Fusion
  - Astrophysical reactions
  - Production of intermediate mass fragments
  - Reaction Mechanisms

Nuclear Physics Research

K600 Spectrometer

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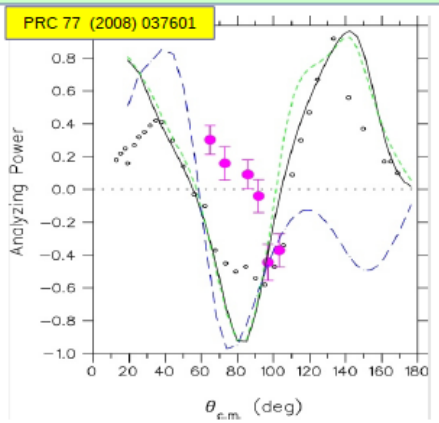
Research results published in high-impact, internationally-recognized journals :

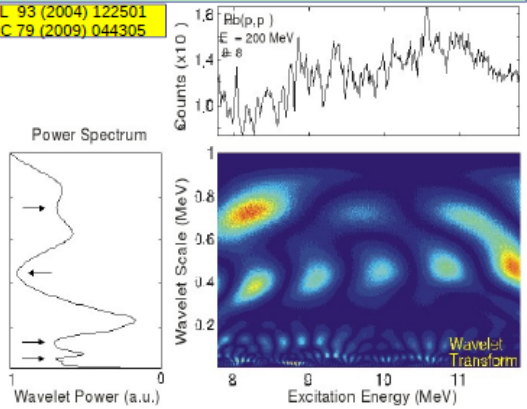
α cluster knockout in ^{40}Ca

PRC 77 (2008) 037601



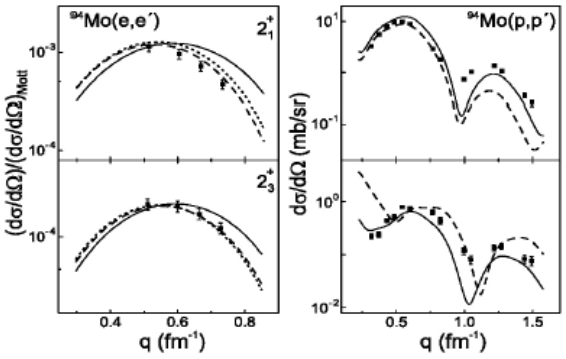
ISGQR fine structure

PRL 93 (2004) 122501
PRC 79 (2009) 044305



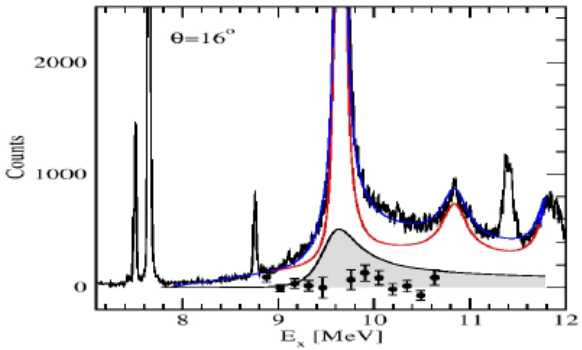
Mixed symmetry states

PRL 99 (2007) 092503



2^+ excitation of the ^{12}C Hoyle state

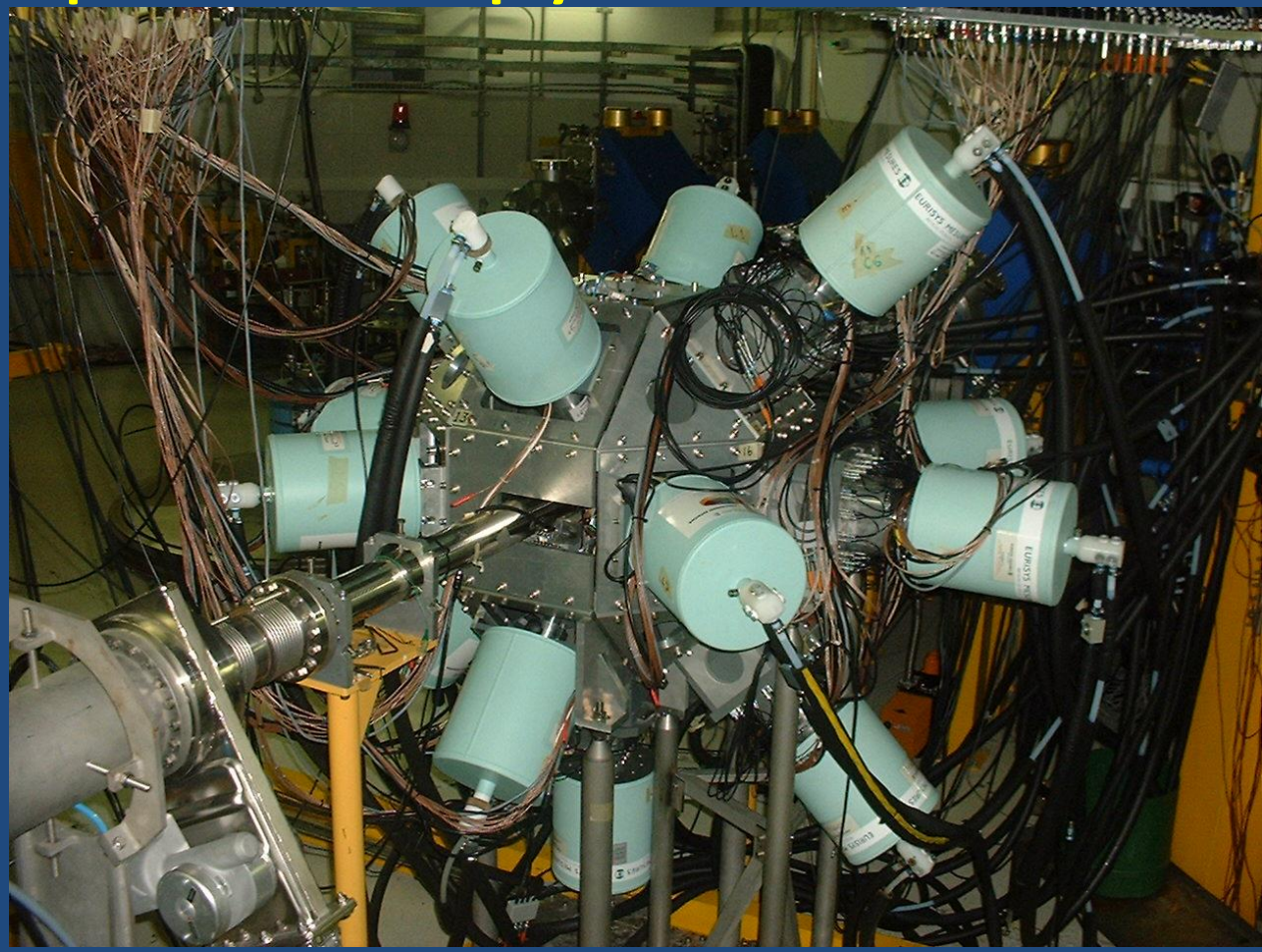
PRC 80(2009) 041303R



Nuclear Physics Research
AFRODITE at iThemba LABS γ-ray spectroscopy

9 Compton Suppressed Clover detectors

8 LEPS detectors



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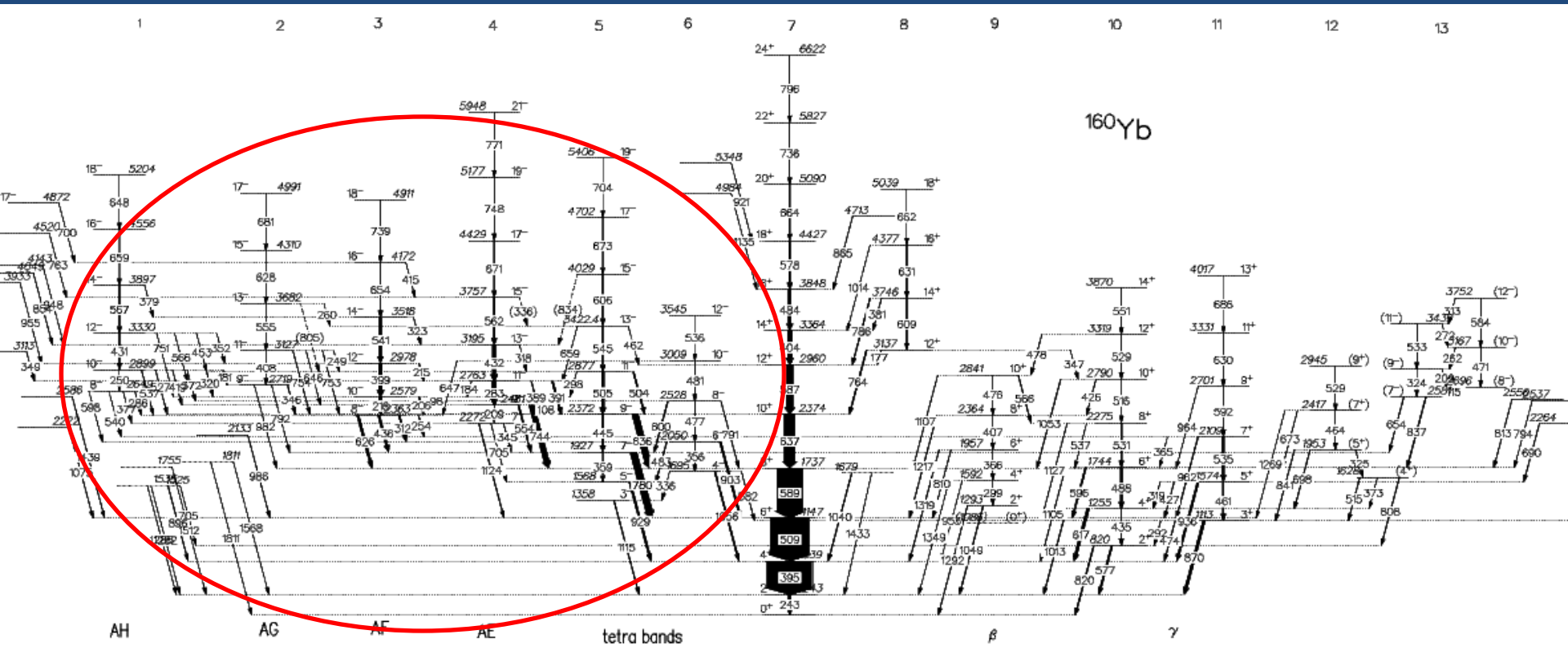
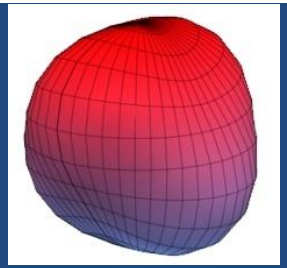
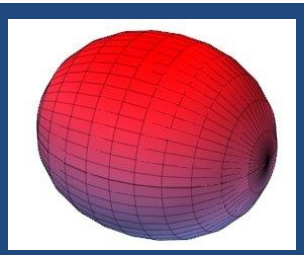
“search for a tetrahedral nucleus”

$^{147}Sm(^{16}O,3n)^{160}Yb$



?





The Future of ABS in SA : A New Cyclotron at iThemba LABS

- Isotope Production off SSC (uses 66 MeV p beam) (neutron therapy to be terminated?)
- Free SSC for use by Physics and proton therapy only (PT to get 230 MeV machine?)
- More than doubles physics beamtime
- Two accelerators allow the production of rare isotope beams using the ISOL method

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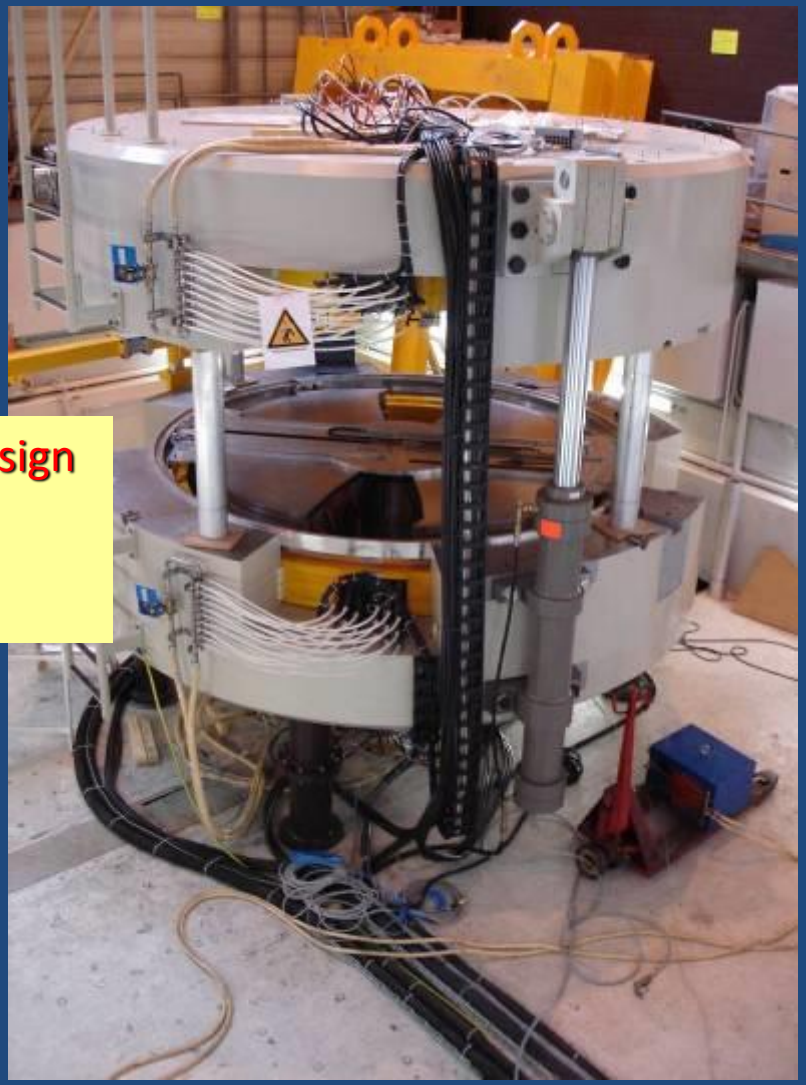
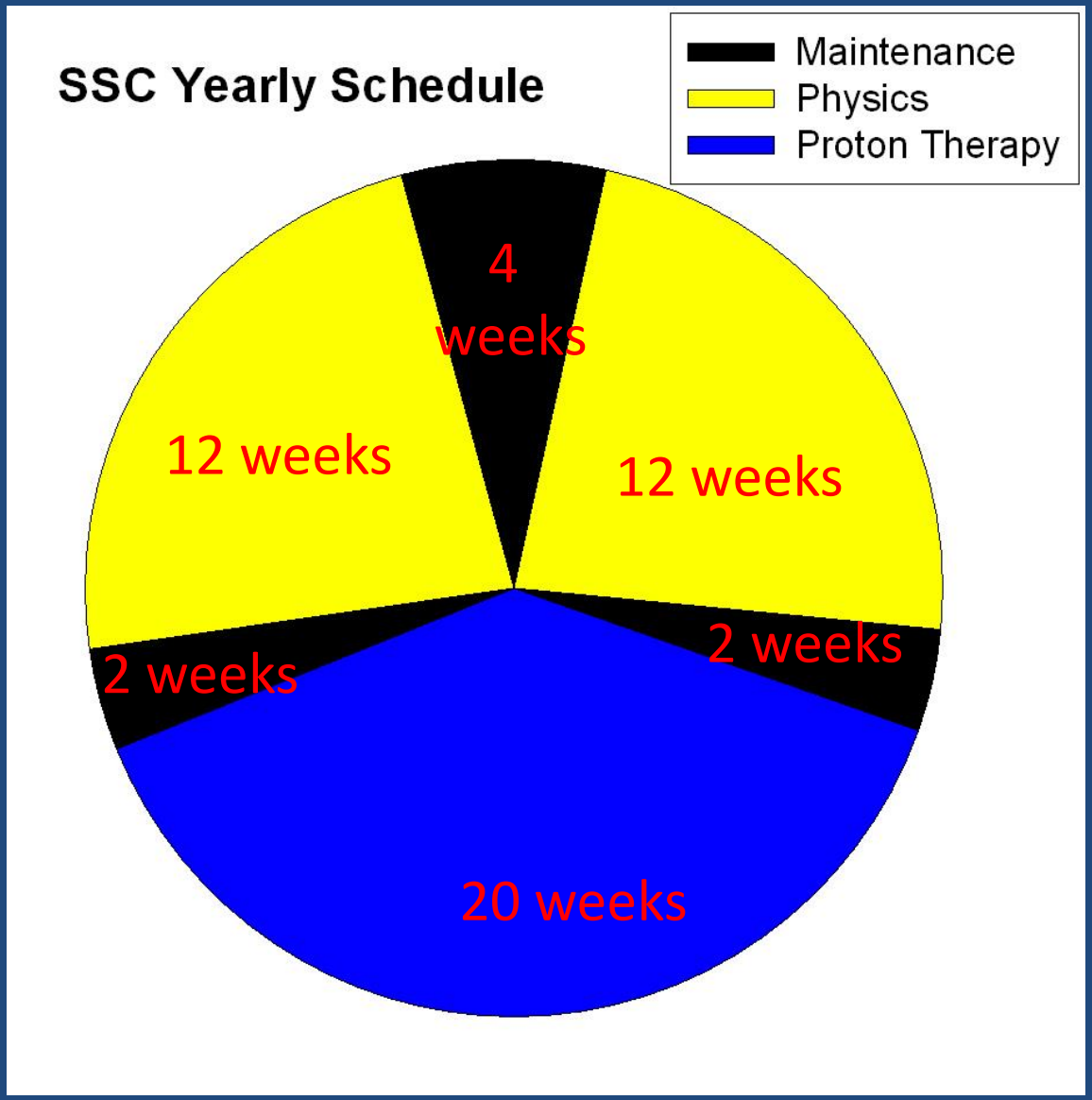
C70 GENERAL DESCRIPTION

- Diameter < 4m
- Weight > 120t
- Magnetic Gap: 30mm
- Magnetic field: 1.55T
- Extraction Radius: 1.2m
- 2 exit ports



SPES design

- Particles: H^- / D^- / He^{2+}/ HH^+
- **Variable Energy** : 15 MeV → 70 MeV
- extraction Systems:
  - **Stripper → H^- / D^-**
  - Deflector → He^{2+}/ HH^+
- Performances:
  - **750µA H^- → 70MeV** Current upgrade up to 1.5mA
  - 35µA He^{2+} → 70MeV



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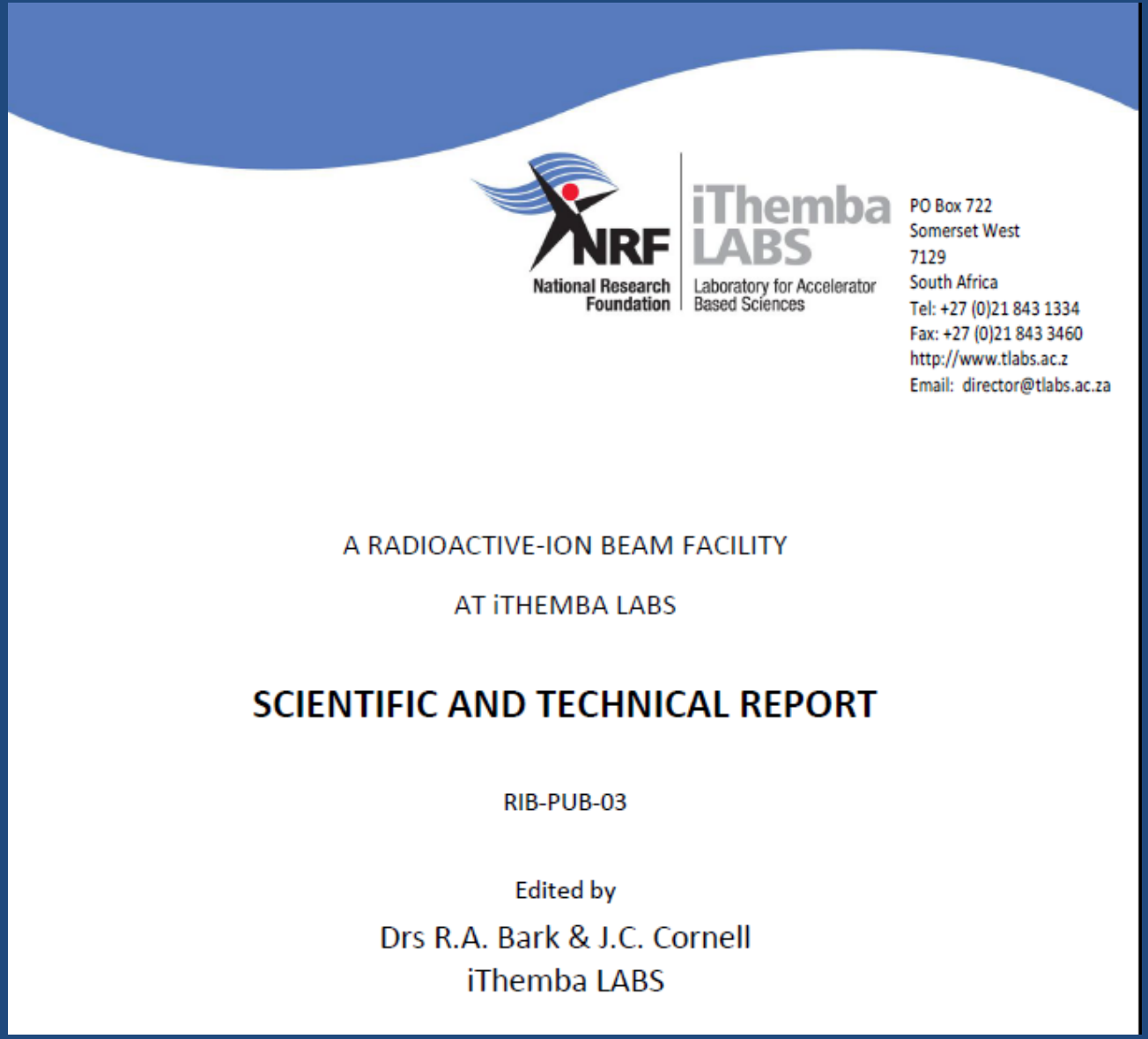

http://www.tlabs.ac.za/radioactive-ion-beam/

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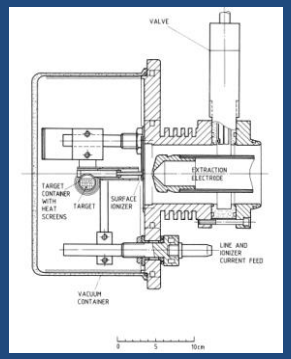
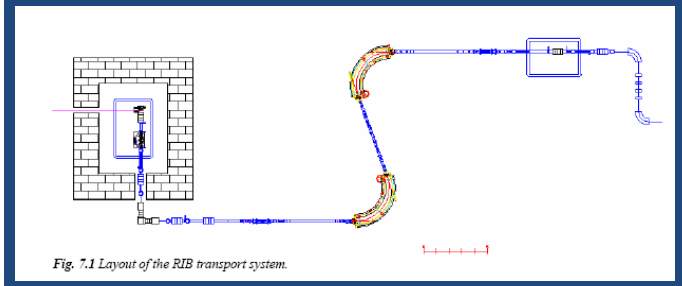
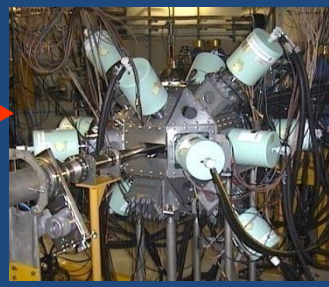
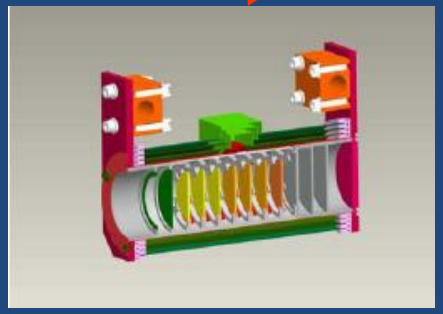
RIBs - HOW? - Isotope Separation Online : ISOL

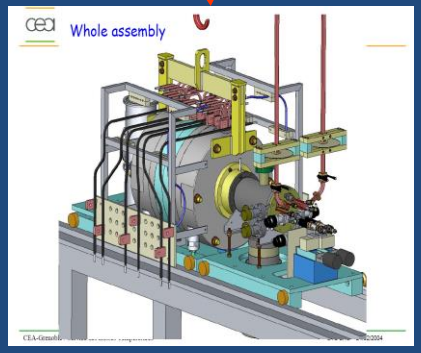




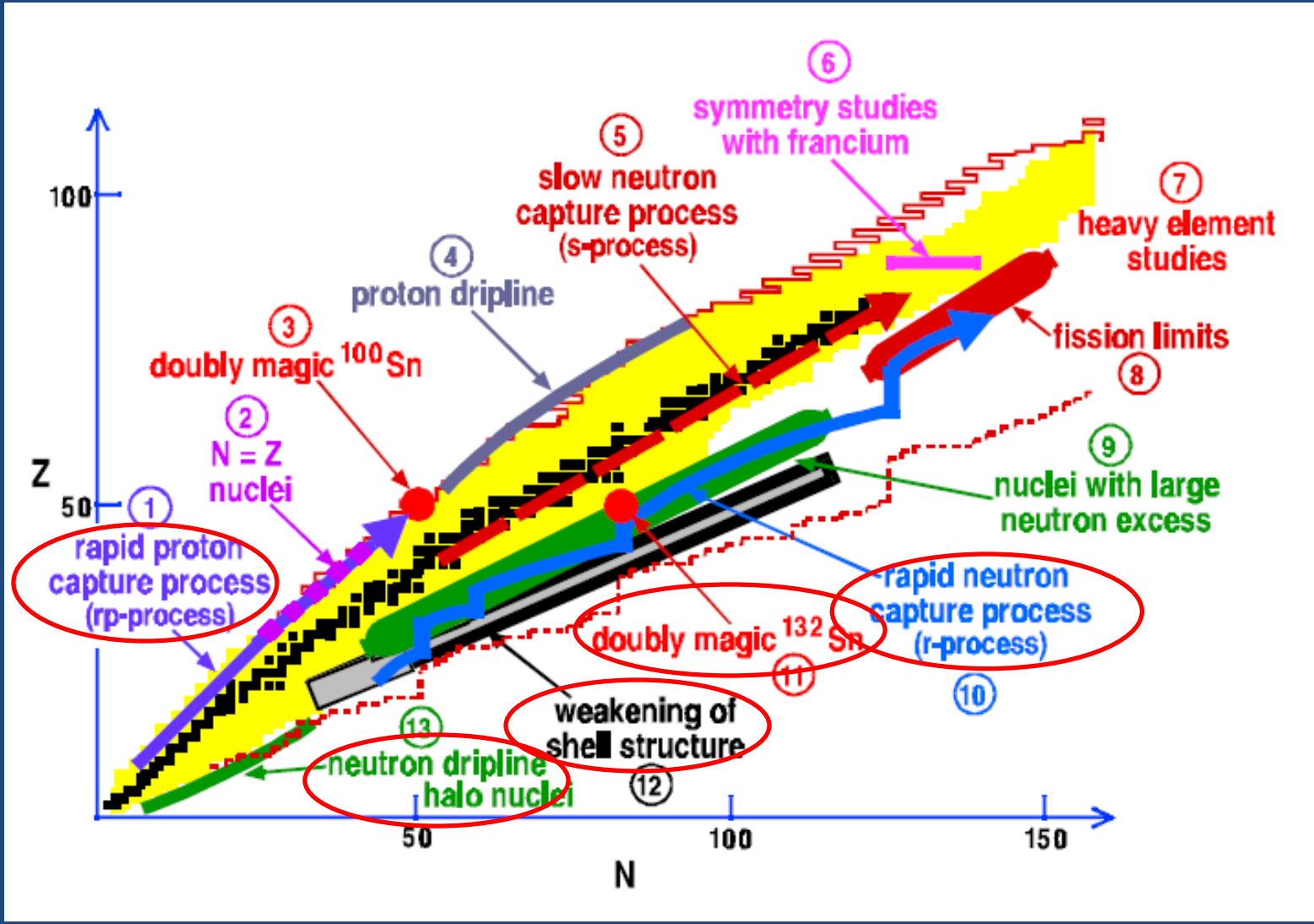
New Accelerator → RIB Production target → 1^+ ion – source & mass selector → Charge Breeder → injector → SSC → Experiment



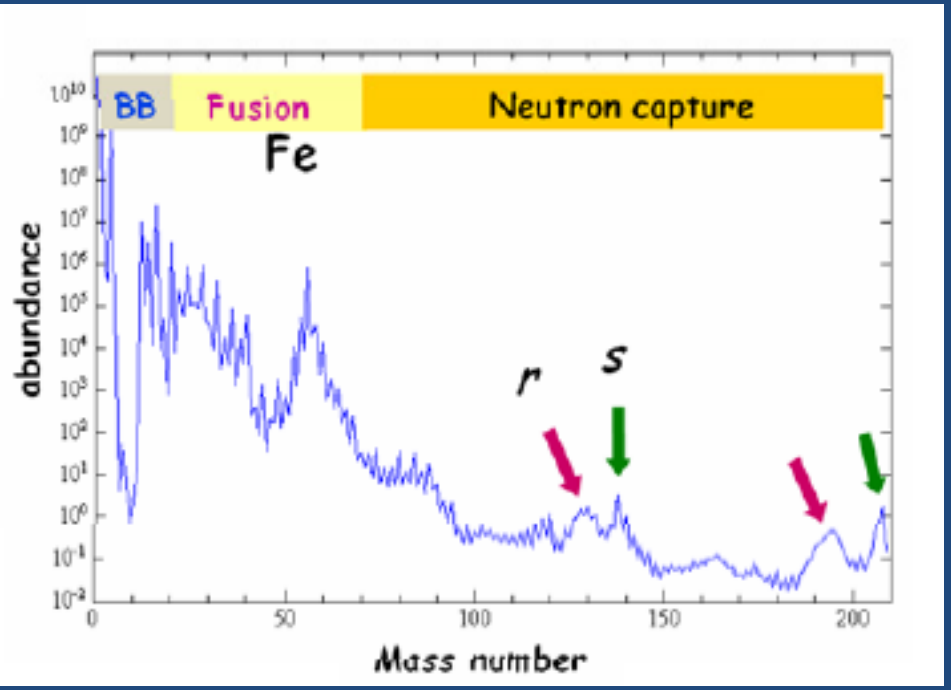


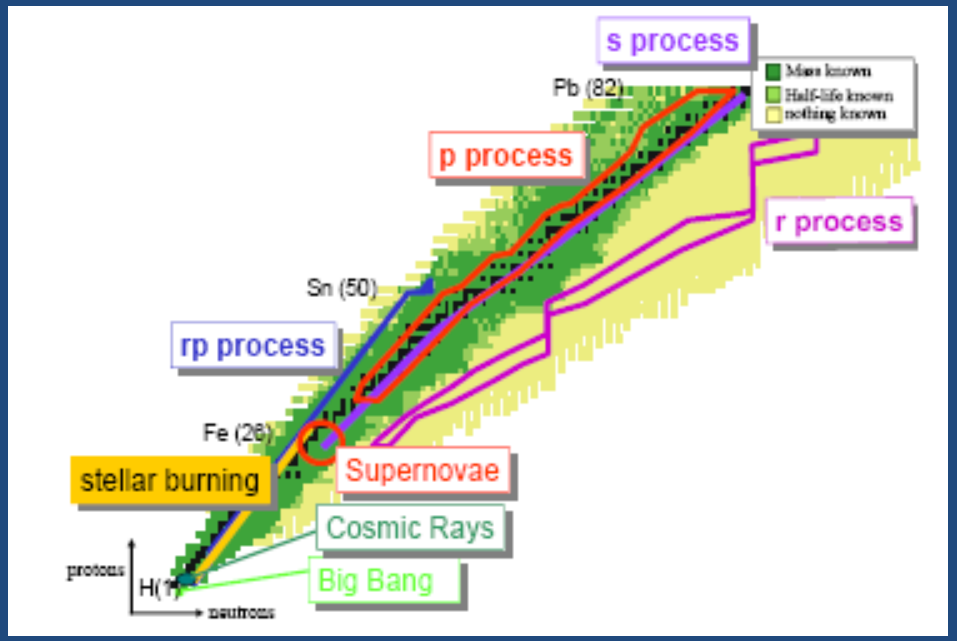


Nuclear Physics: Why Rare Isotope beams ?

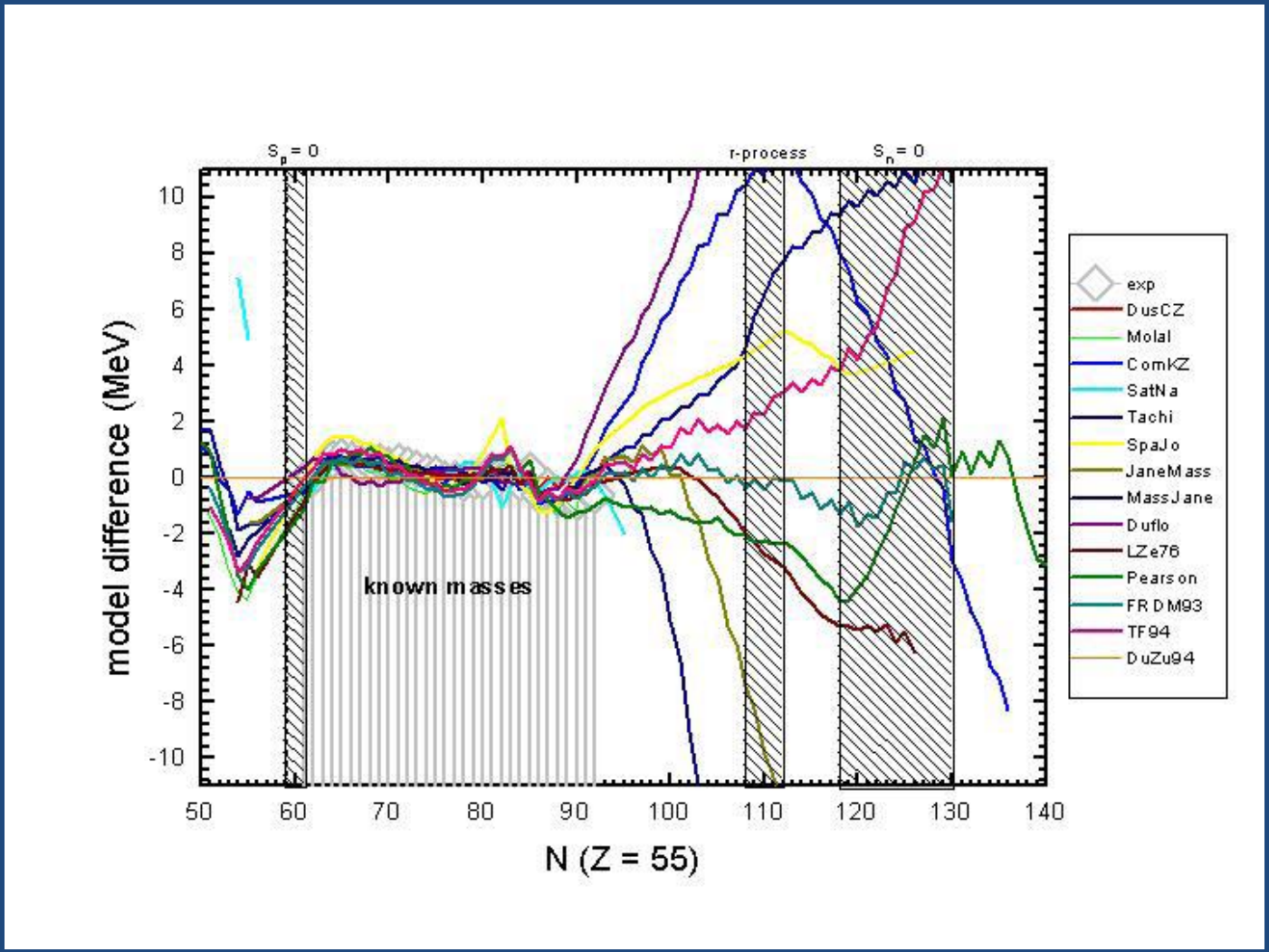


Origin of the elements: astrophysical r-process





Predictions of Nuclear Masses Compared with Experiment



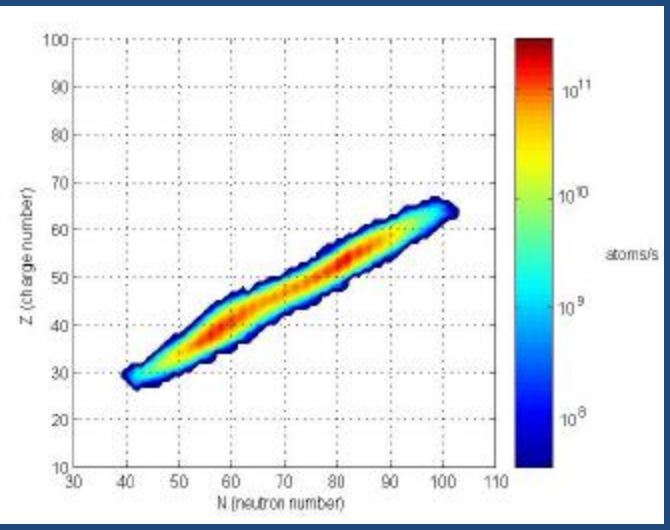
Which Rare Isotope Beams?

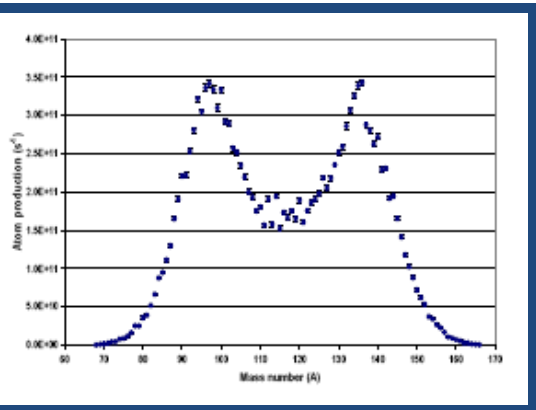
- Beams for material sciences
  - ^{7}Be, ^{22}Na, ^{28}Mg, ^{31}Si, ^{38}Cl, ^{47}V, ^{42}K, ^{43}K,
  - ^{65}Ni, ^{67}Cu, ^{67}Ga, ^{69}Ge, ^{71}As, ^{73}Ga, ^{110}Sn,
  - ^{111}Ag, ^{113}Ag, ^{117}Cd, ^{119}Sb
- ^{6,8}He
- Proton Rich ?
- Neutron Rich: Fission Target

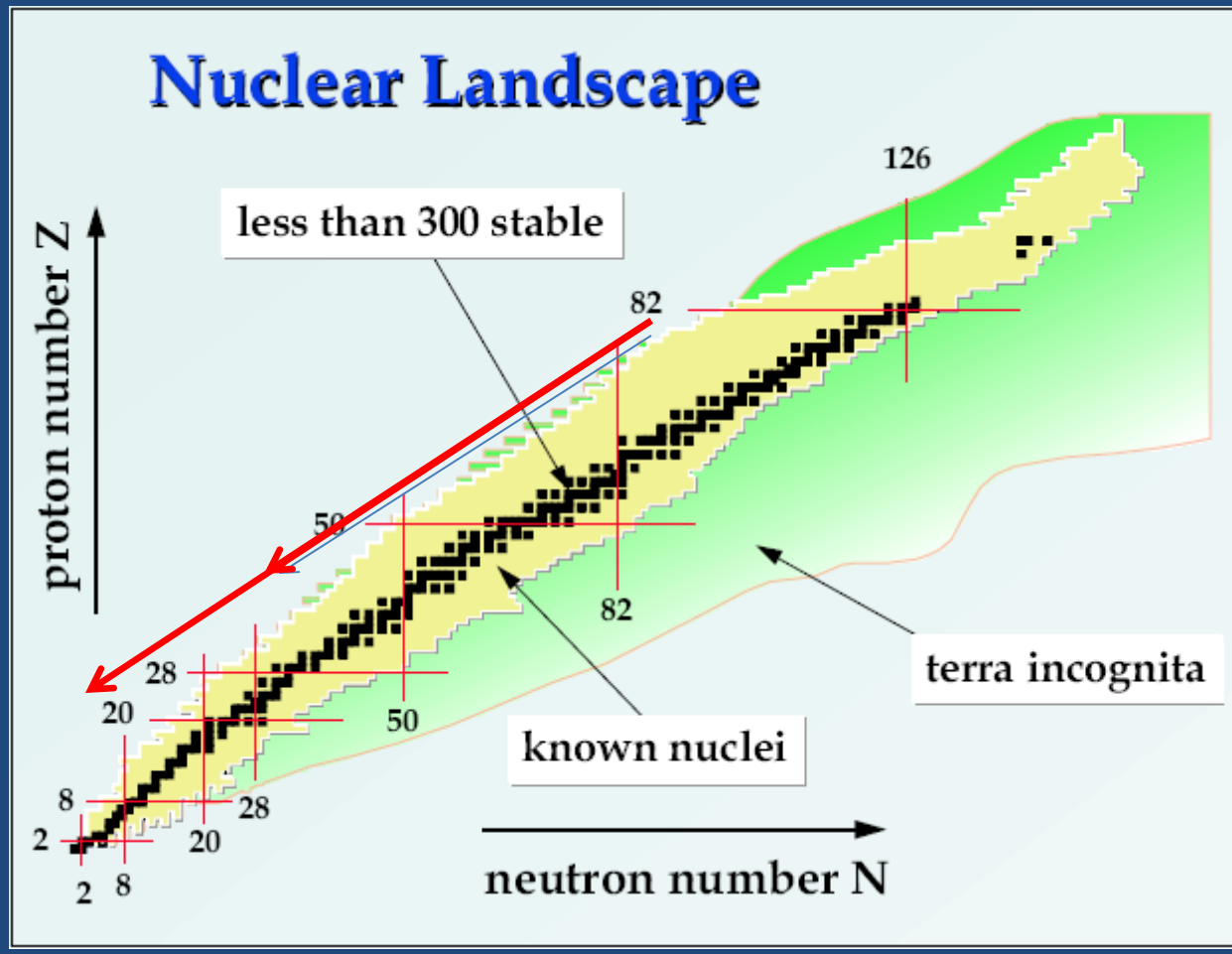
Proton –rich $\Rightarrow$different target per beam

Neutron-rich $\Rightarrow$ one ^{238}U target; 100 beams

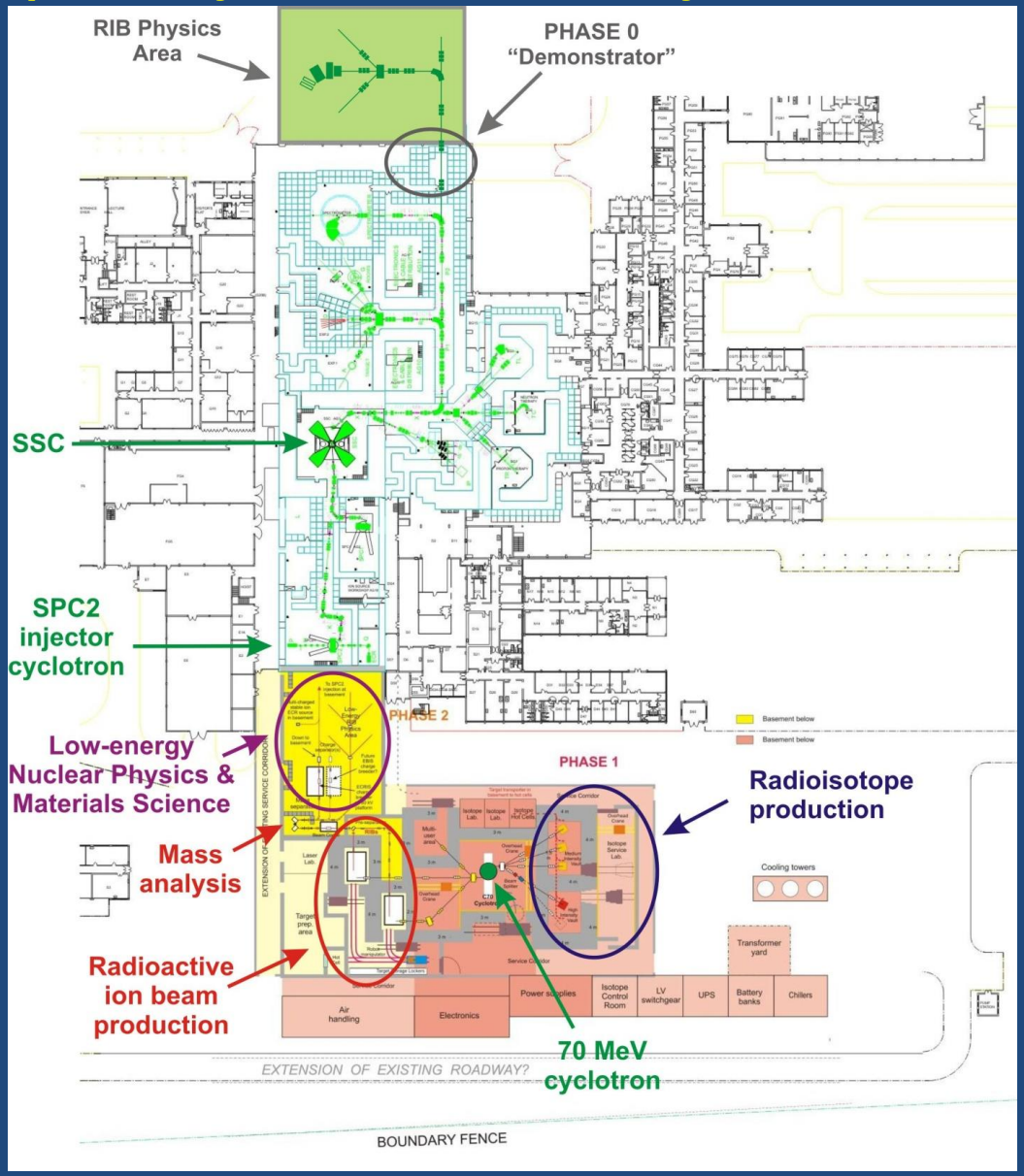
Reaching the neutron rich: FISSION URANIUM



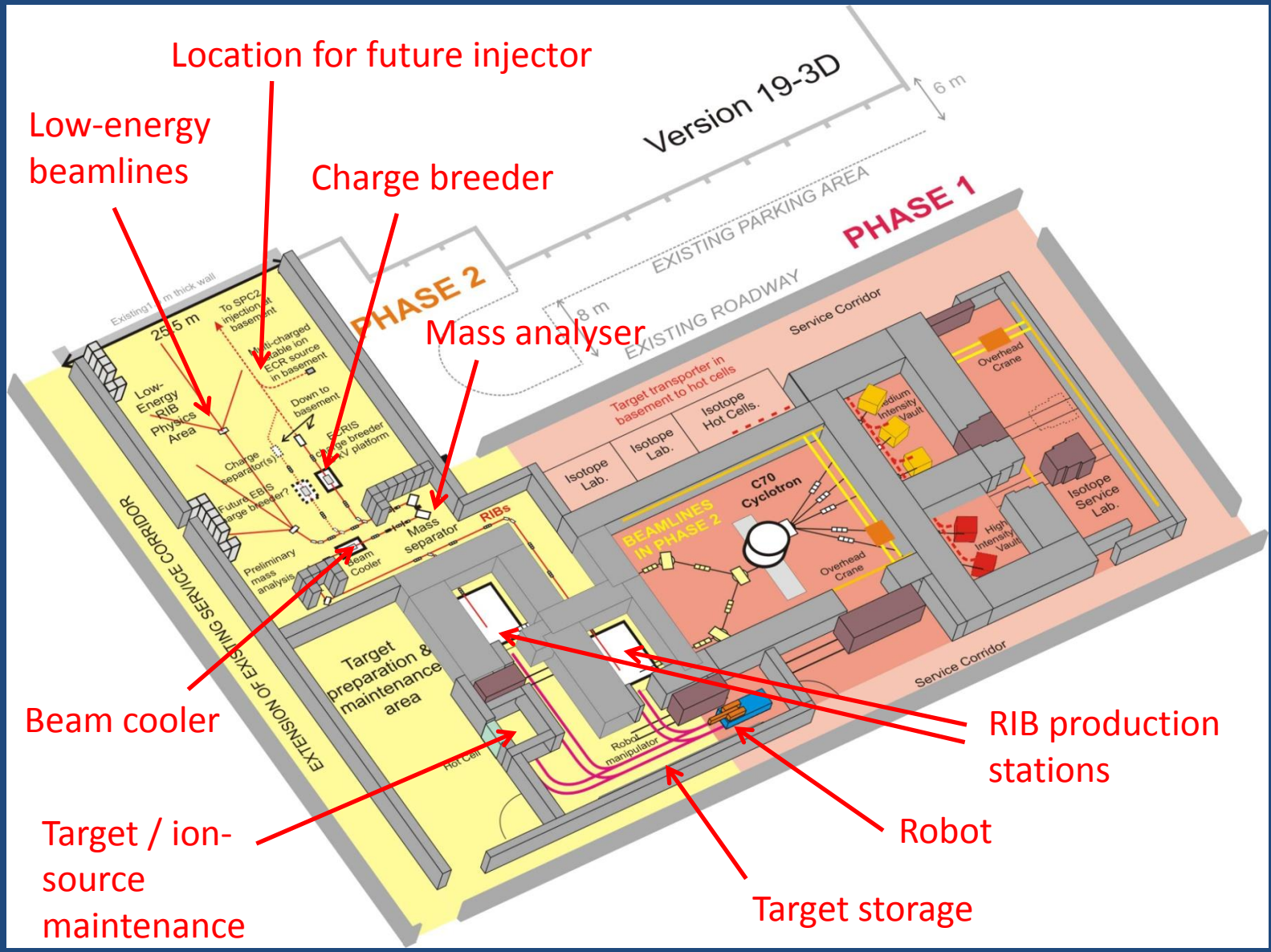




Proposed layout of the RIB facility at iThemba LABS

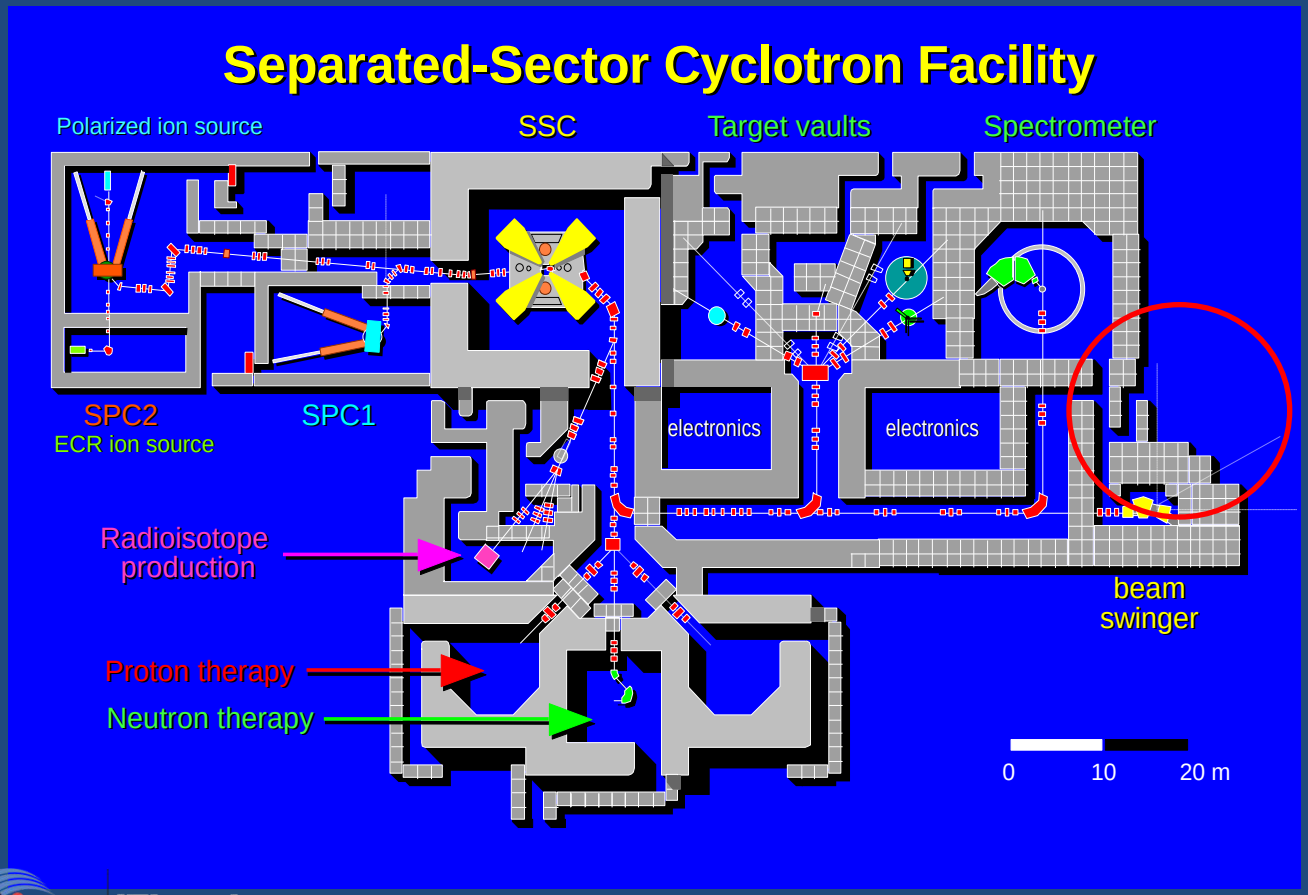


RIB production



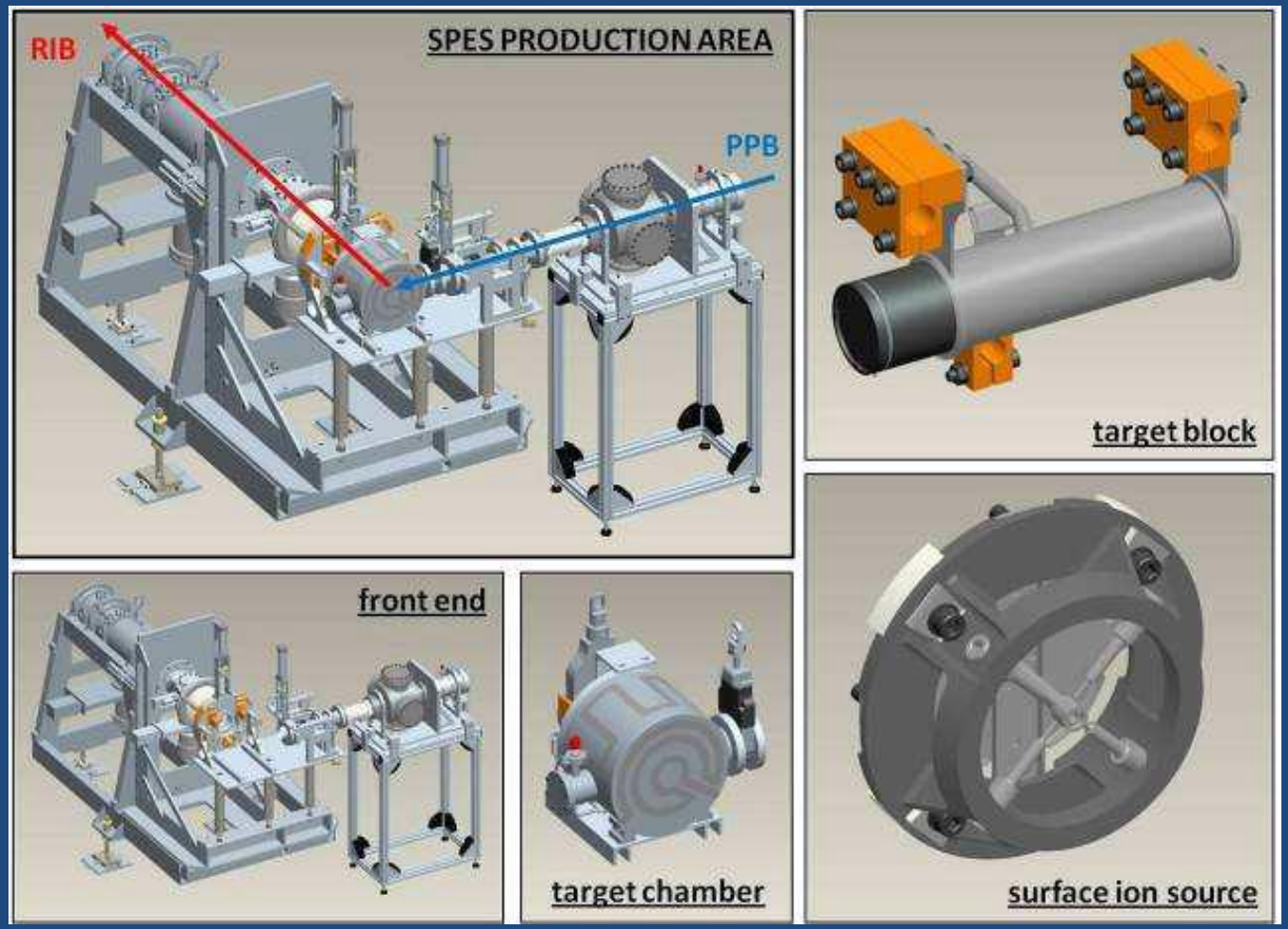
Demonstrator with “Unaccelerated” RIBs

RIB ion-source Test Station + β-decay + Materials

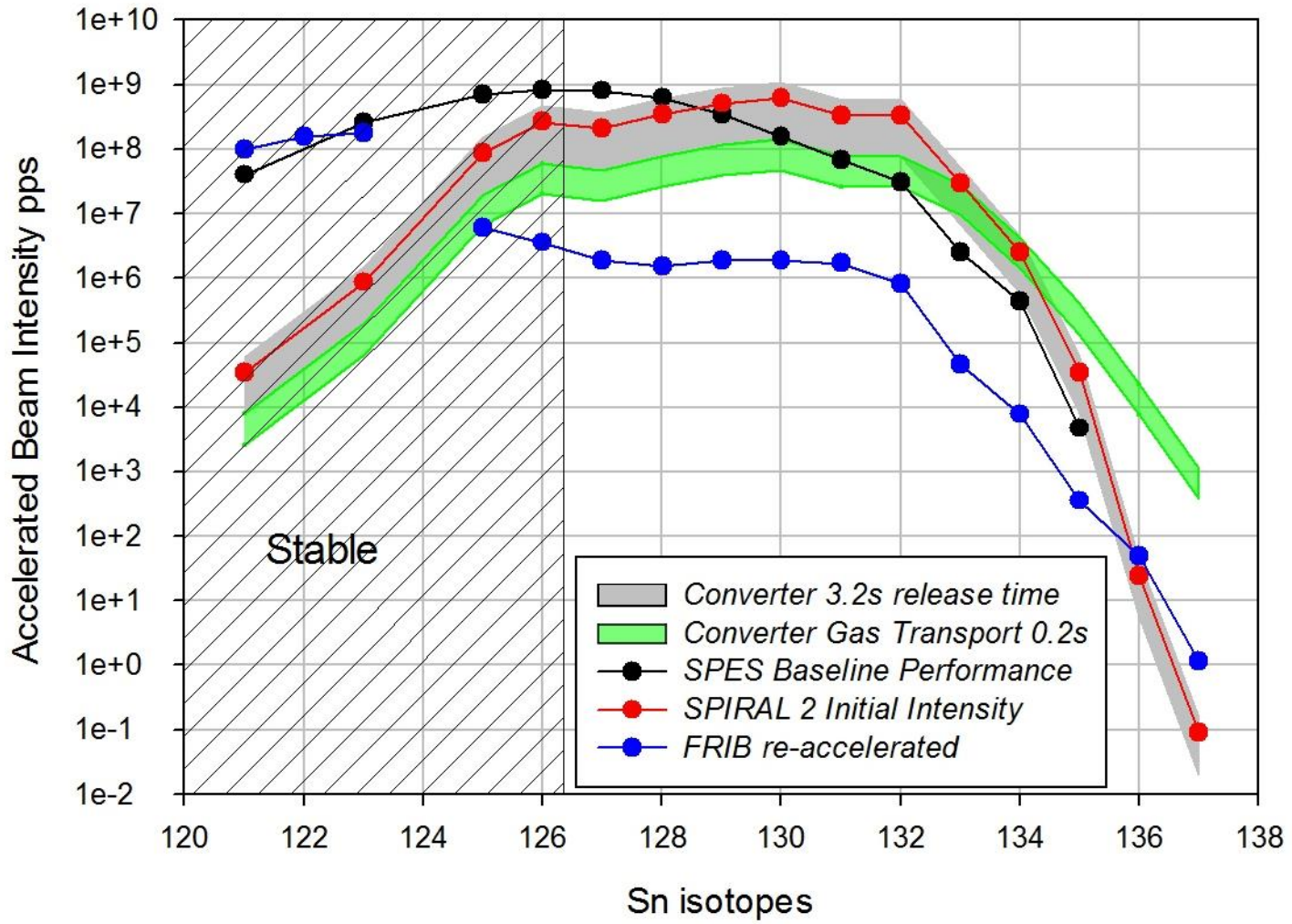


Possible location of RIB test ion-source

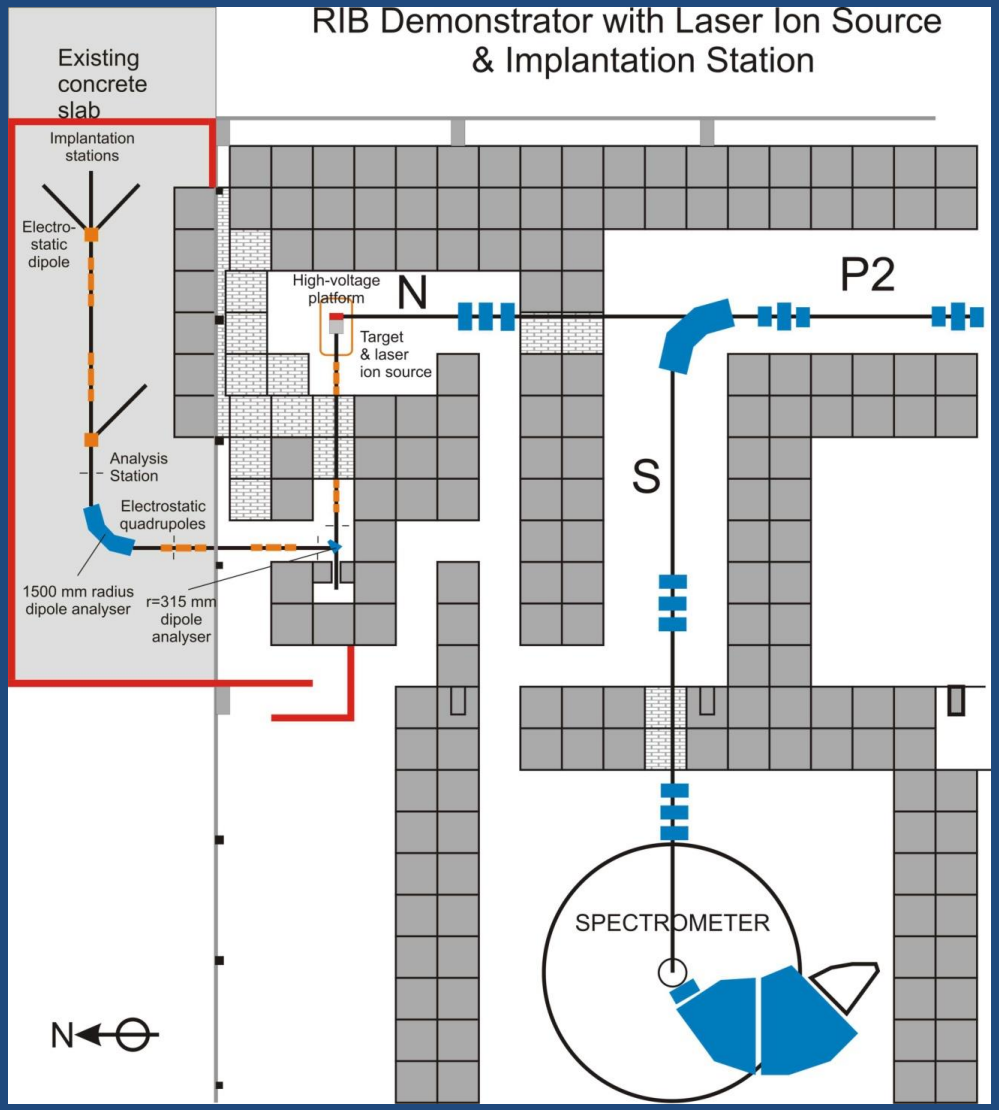
Demonstrator to test Legnaro SPES target/ion-source – under MoU



RIB Production 70 MeV protons 350 μA to 1 mA (shaded) compared with SPES, SPIRAL 2 and FRIB



RIB demonstrator : low energy (LE) Beams for Materials Research



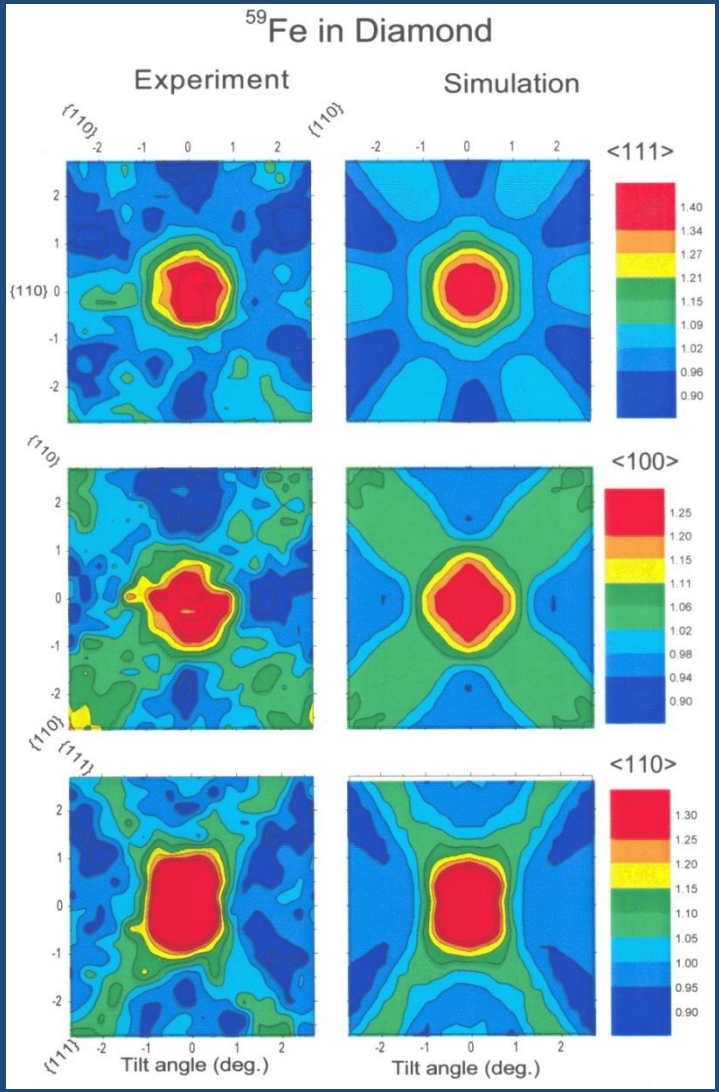
Example : Solid State Physics at ISOLDE (LE RIBs)

Lattice location of Fe in Diamond

K. Bharuth-Ram *et al.*

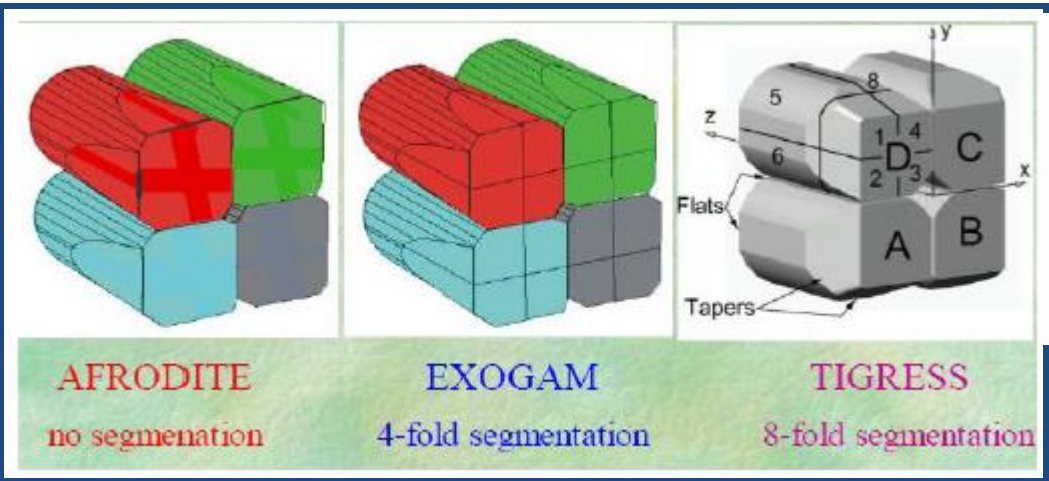
^{59}Mn ($t_{1/2}$ = 4.6s) implanted into Diamond, decays to ^{59}Fe which β-decays with $t_{1/2}$ = 45 days

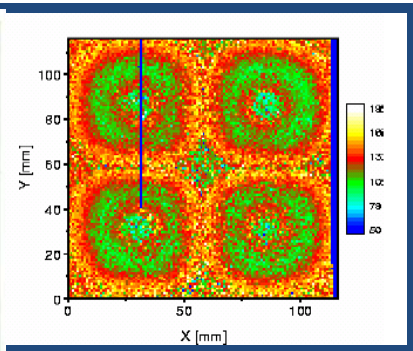
Electron emission channeling Measurements indicate that 65% of Fe atoms lie within 0.2 Å From a substitutional site



Instrumentation

Item	MR	MR
Nuclear physics:		124.00
TIGRESS type detectors (x8)	56.00	
Large-acceptance spectrometer	50.00	
Active target	11.00	
K600 spectrometer instrumentation	3.00	
Neutron Physics beamline (stable beams)	2.00	
Position-sensitive proportional avalanche counter	2.00	
Materials science equipment:		10.00
Total		134.00





First RIB test with SiC target : May 2014

Testing of Silicon Carbide (SiC) target successful (Radioactive Ion Beam Project)

On the 17th of May, team members of a collaboration between iThemba LABS and INFN Legnaro, Italy, conducted a high-power test of a Silicon Carbide (SiC) target, for Rare-Ion Beam production. Rare-Ion beams, produced artificially by a stable beam from a primary accelerator, are short-lived isotopes that represent the cutting edge of basic nuclear physics research and have applications in the material sciences. In a collaboration between the two laboratories, the target was designed by Alberto Monetti, while visiting the iThemba LABS Radioactive-Ion Beam group in 2012. The target was subjected to 4kW of primary beam power (60 µA of 66 MeV protons) from the Separated Sector Cyclotron of iThemba LABS for about an hour. The goal was not to extract rare-ions, but to test whether the target could withstand the power and stresses induced by the primary proton beam. The temperature and radioactivities of the target were monitored in a successful validation of the computer simulations of its performance. A SiC target is likely to be the first to be used on the Rare-Ion Beam test facility, funded by a Strategic Infrastructure Grant from the NRF, and in the early stages of implementation at iThemba LABS.

Special thanks to the members of the Accelerator & Engineering, Workshop, I.T., Isotope Production & Radiation Safety Departments, and to the supporters of the RIB project, for making it all possible !

Photo: team members monitoring the temperature probes on the target after reaching 60 µA of beam current.

Dr Robert Bark Leader,

Radioactive Ion Beam Project

iThemba LABS

www.tlabs.ac.za

tel: 021 843 1123

http://www.tlabs.ac.za/news-3/

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Summary:

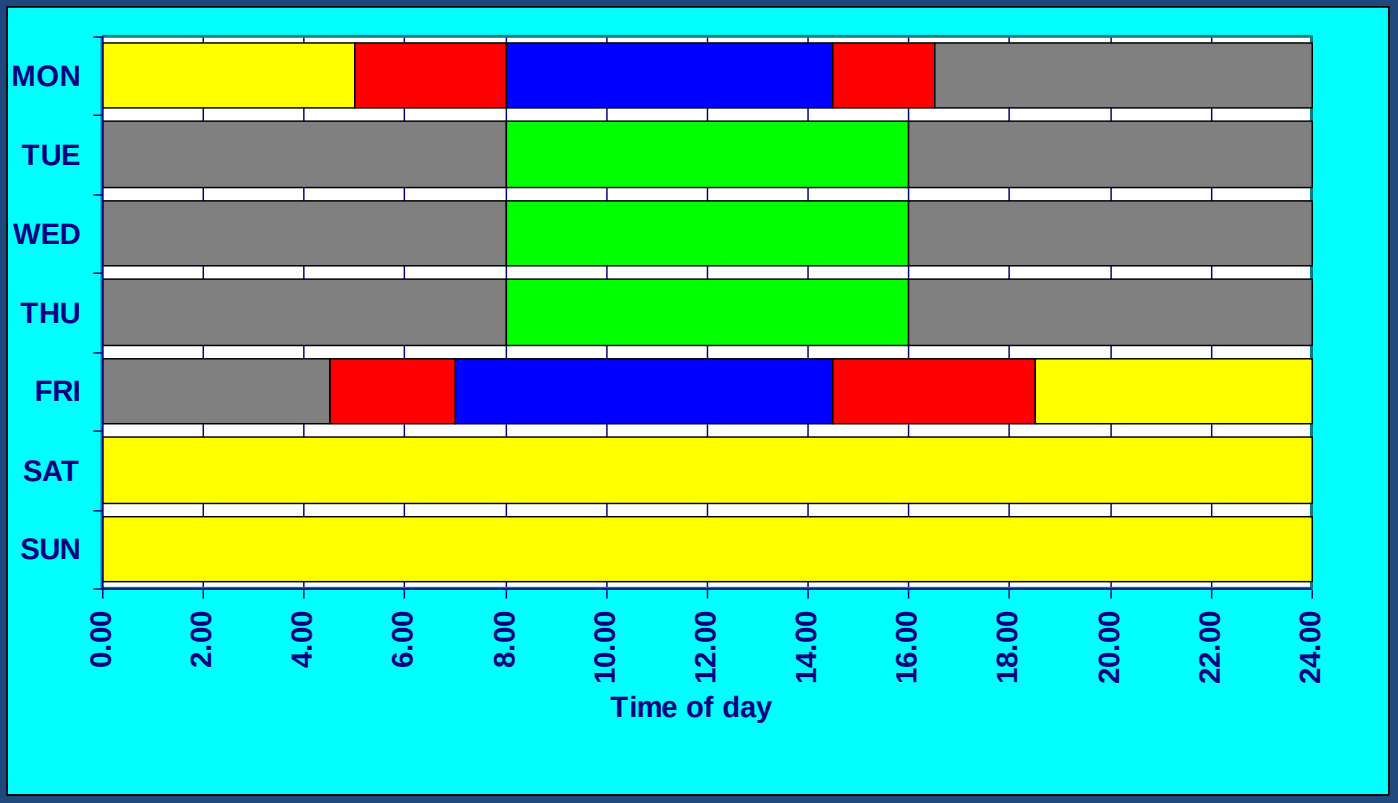
- There is world-class infrastructure and expertize in Accelerator-Based Nuclear Sciences in South Africa, but this needs to be funded at a level to continue to development and deliver
- Deliver what? High-impact research outputs and highly skilled people
- Partnerships between National Facilities (like iThemba LABS), HEIs and the Nuclear Power Sector need to be strengthened and expanded
- S/He who hesitates is lost! We need to start to invest now to enable these partnerships to deliver!

Acknowledgements:

- AMS : the NRF, the DST, the IAEA and colleagues at iThemba LABS (Cape and Gauteng)
- RIB : Dr Rob Bark (Project Leader)

Thank you for your attention

SSC Beam Schedule



◊ Nuclear Physics

© Neutron Therapy

© Proton Therapy

© Energy Change

© Isotope Production

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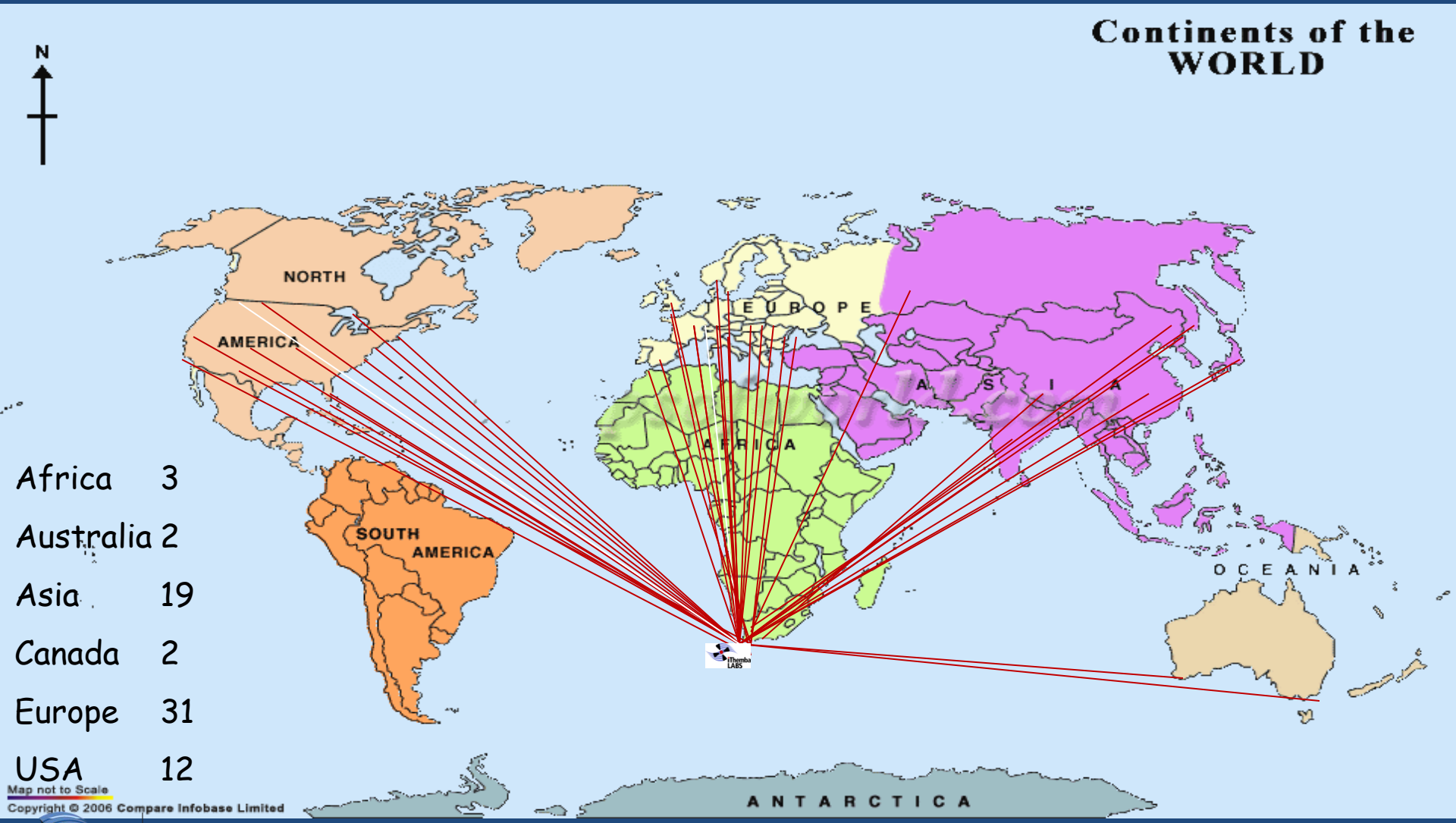
Laboratory for Accelerator Based Sciences

iThemba LABS
Radionuclide Distribution Network



Radio-Nuclide Production (primarily medical) [HoD : Dr Clive Naidoo]

- Many customers, both international & local
- How to boost production rate?
- Higher beam current (as long as targets can take it)
- “Flat-Topping”

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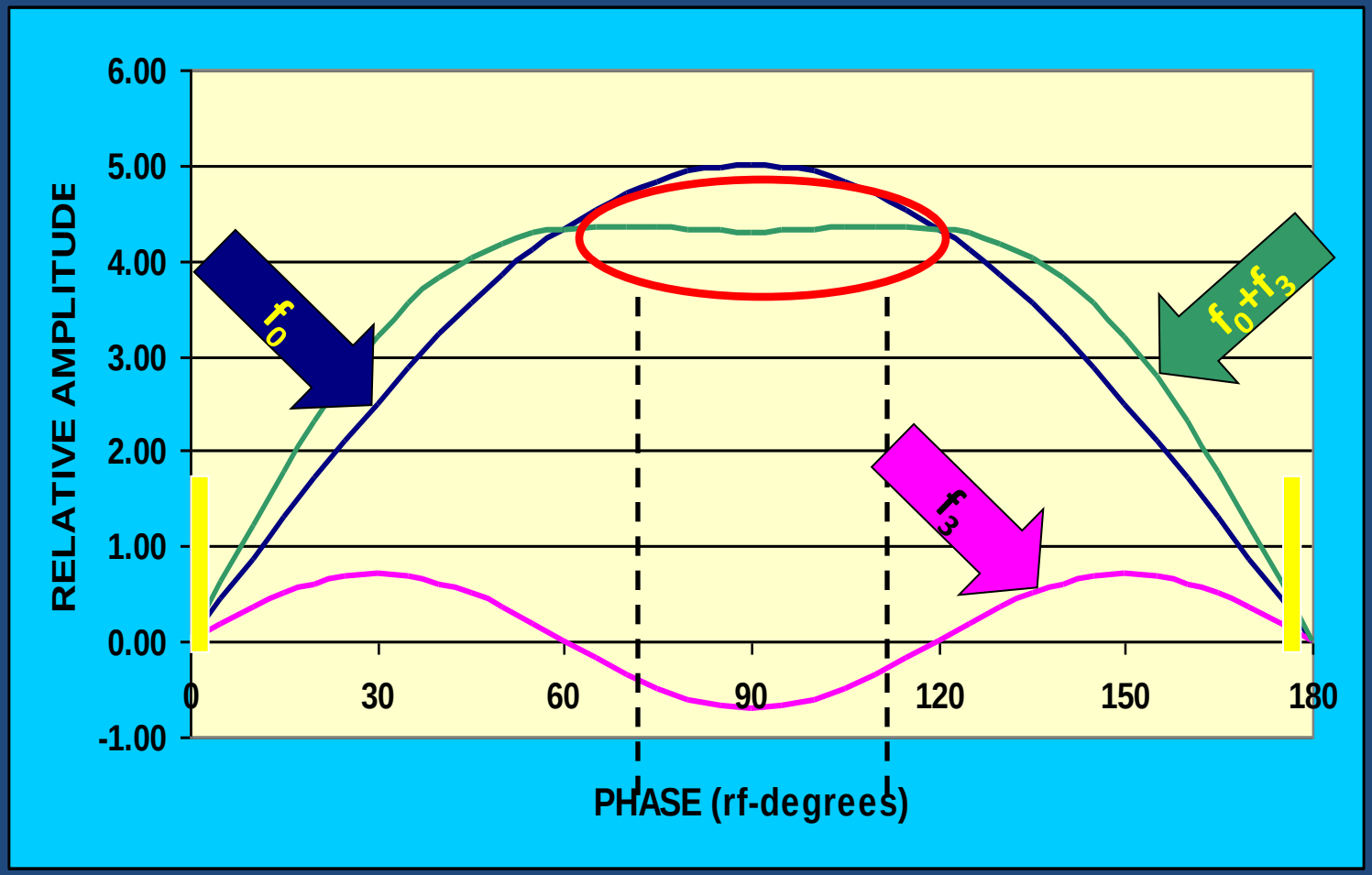
THE EFFECT of FLAT-TOPPING RF-VOLTAGE ACROSS THE ACCELERATION GAP



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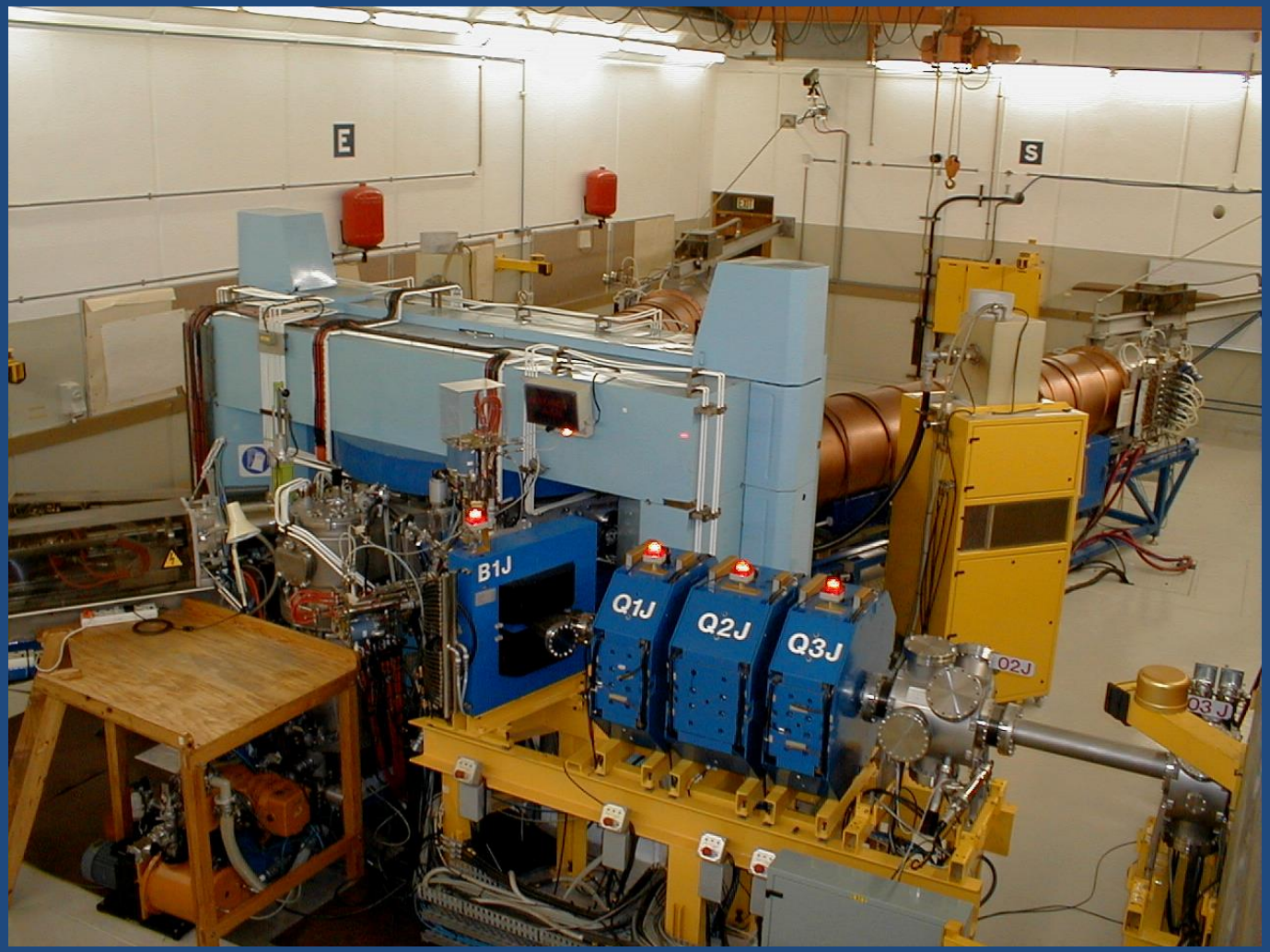
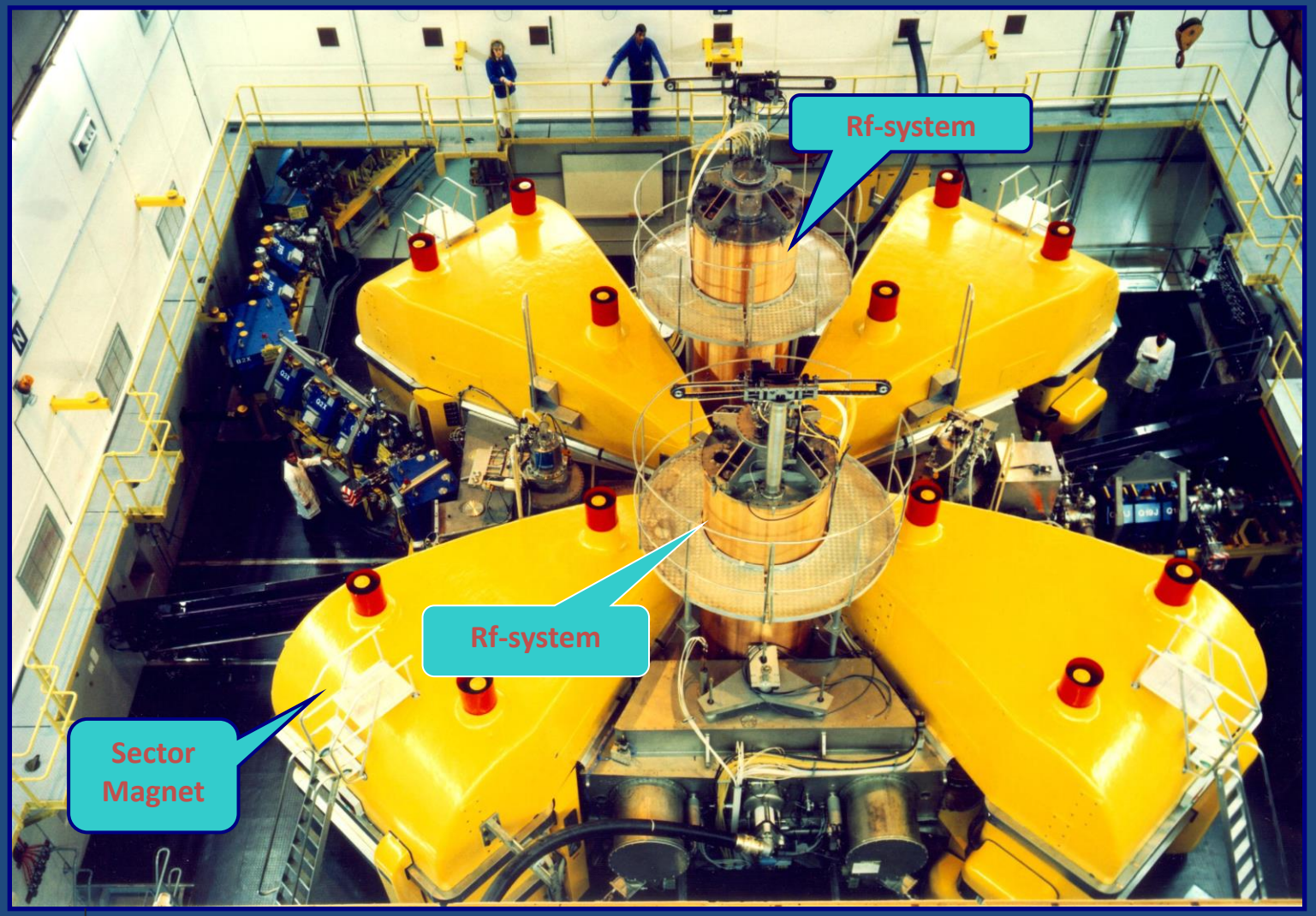
Solid-pole injector cyclotron 1 (SPC1)



Separated-Sector Cyclotron (SSC)



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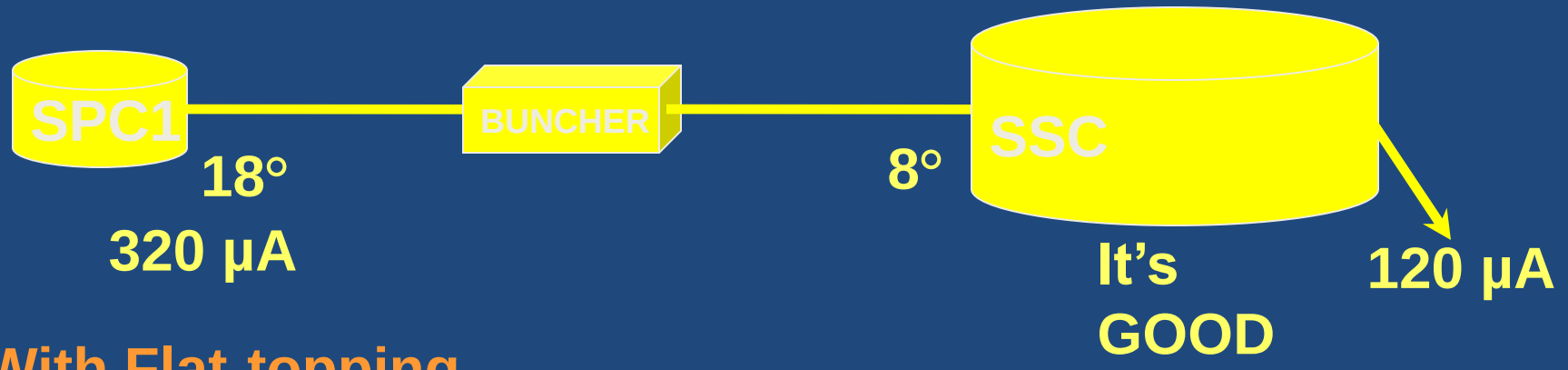
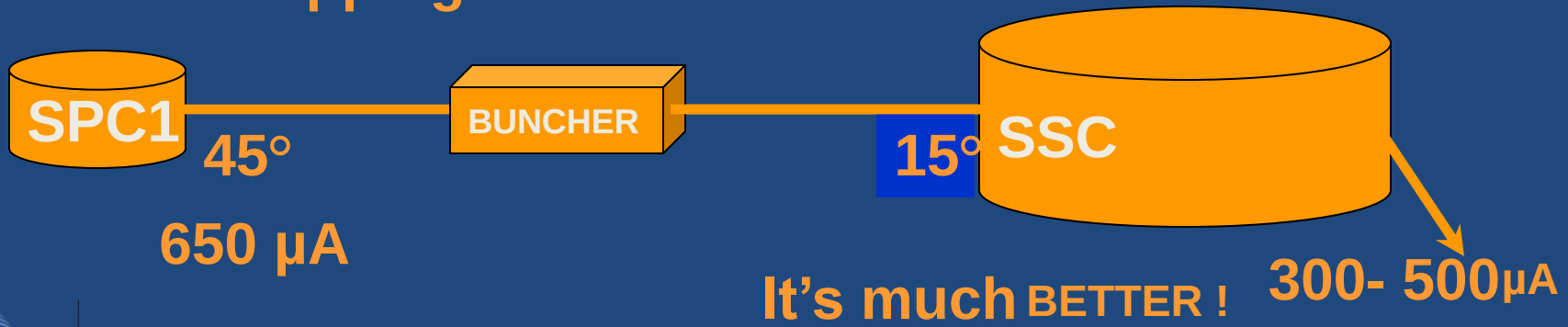
FLAT-TOPPING IN A NUTSHELL

IMPROVE BOTH THE BEAM QUALITY AND INTENSITY OF THE 66 MeV p^+ BEAM

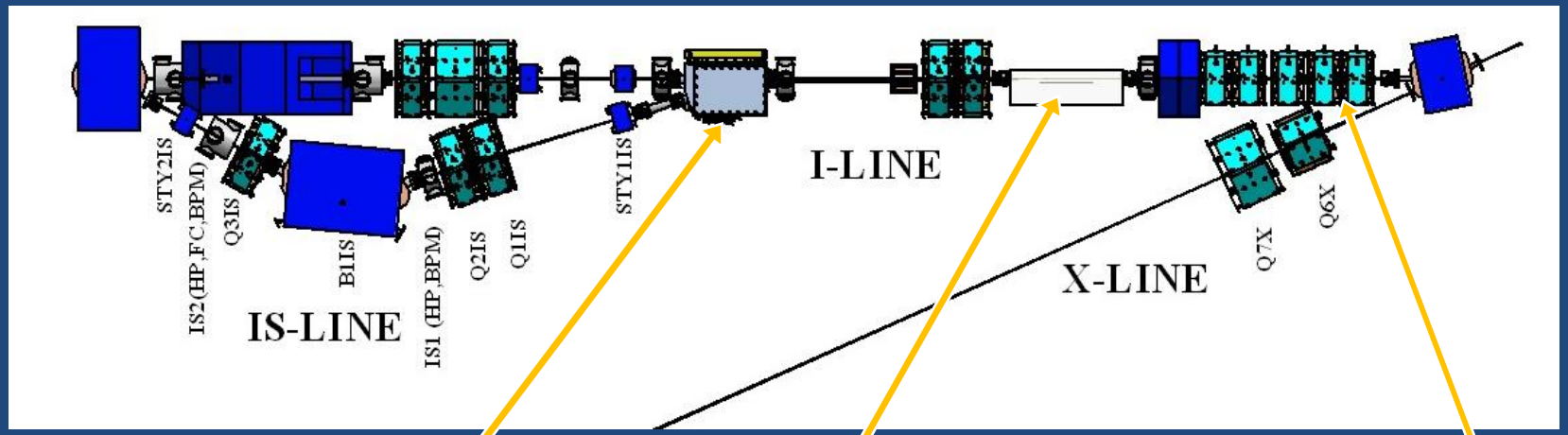
Without Flat-topping => pure sinusoidal rf-voltage for acceleration



With Flat-topping



Layout of the beam splitter



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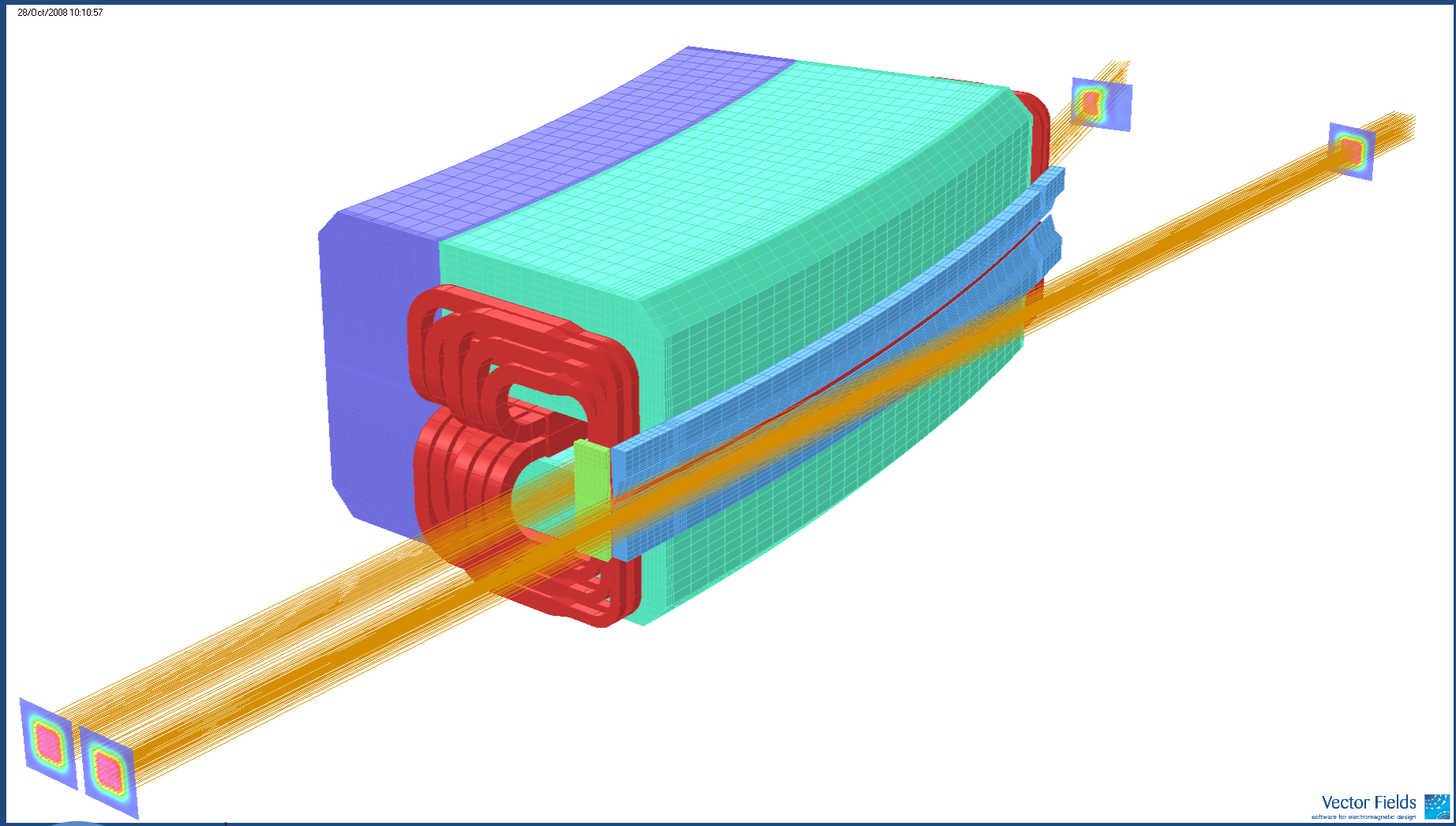
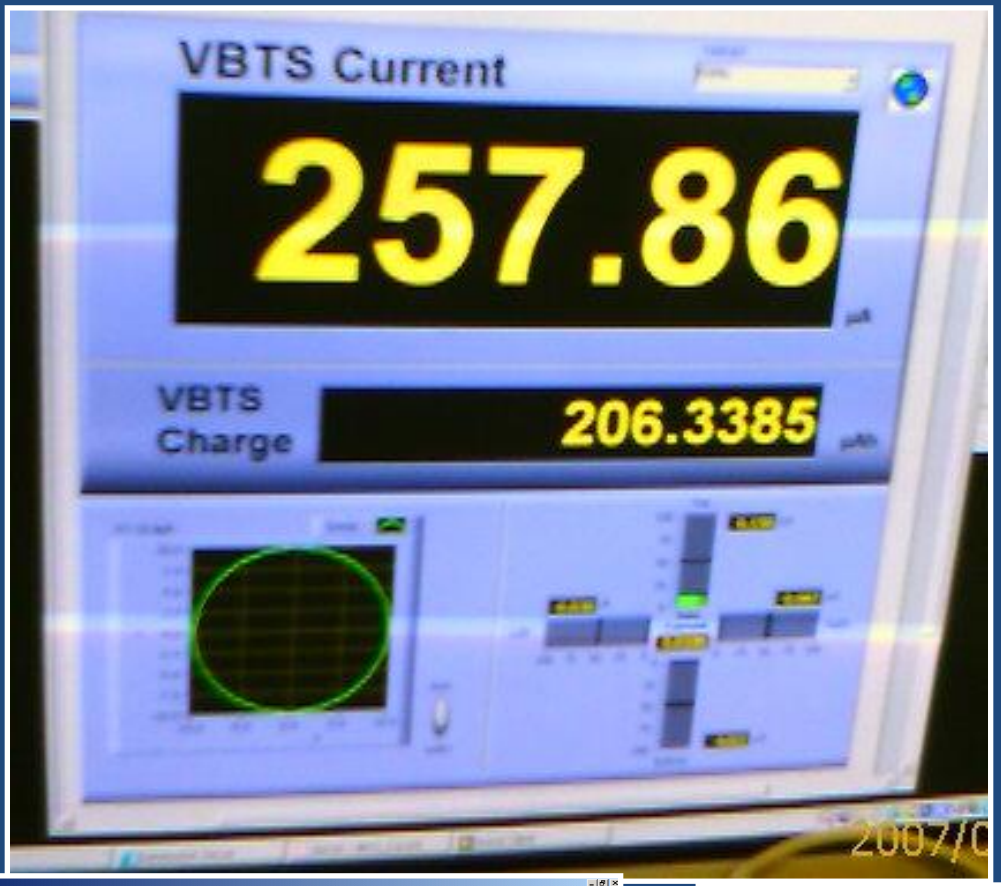
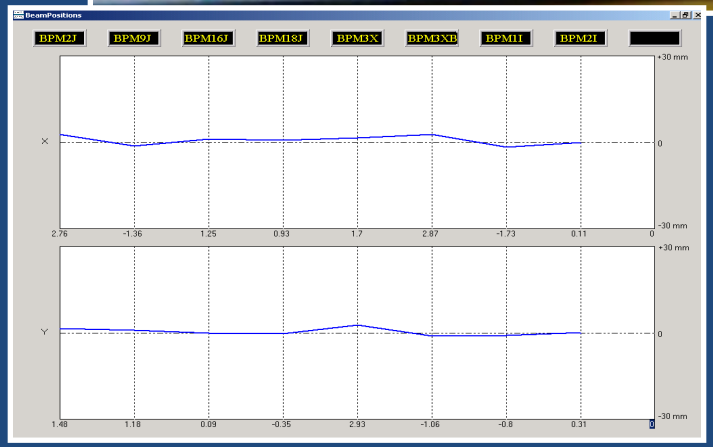
Electrostatic channel – a mirror image of PSI design

Magnetic channel







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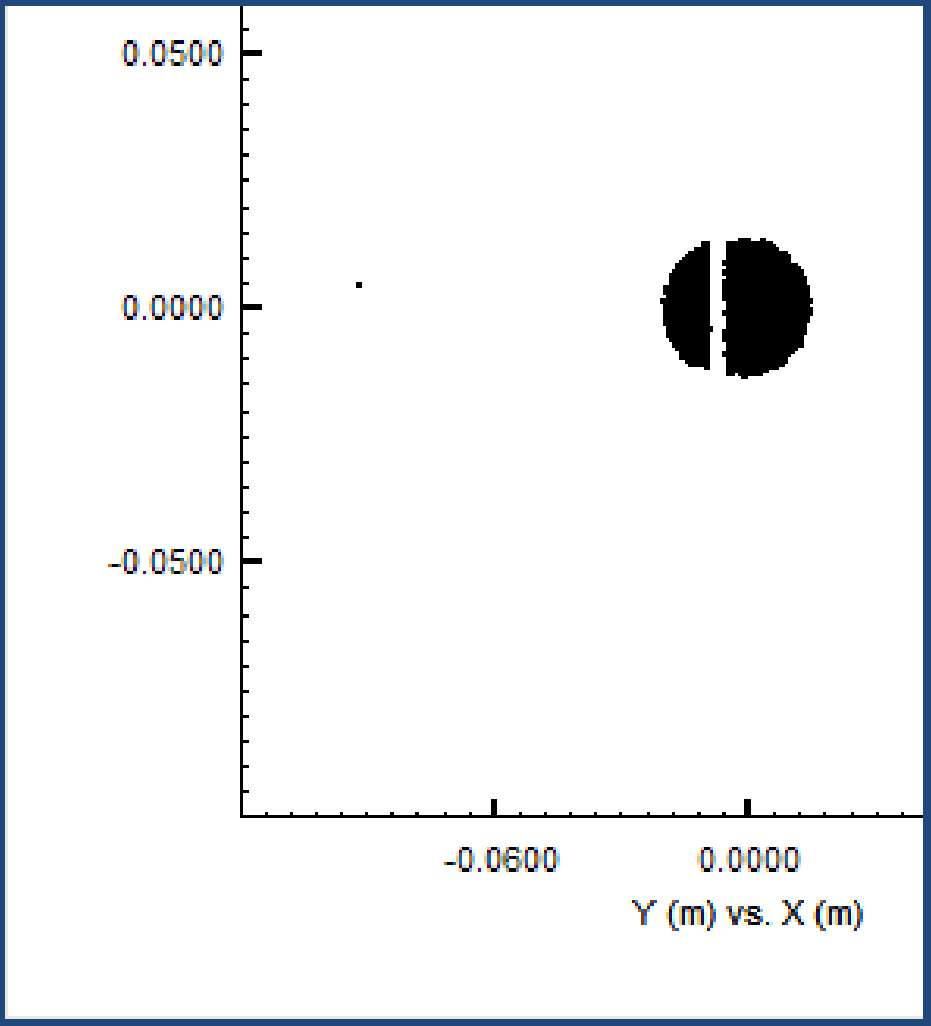
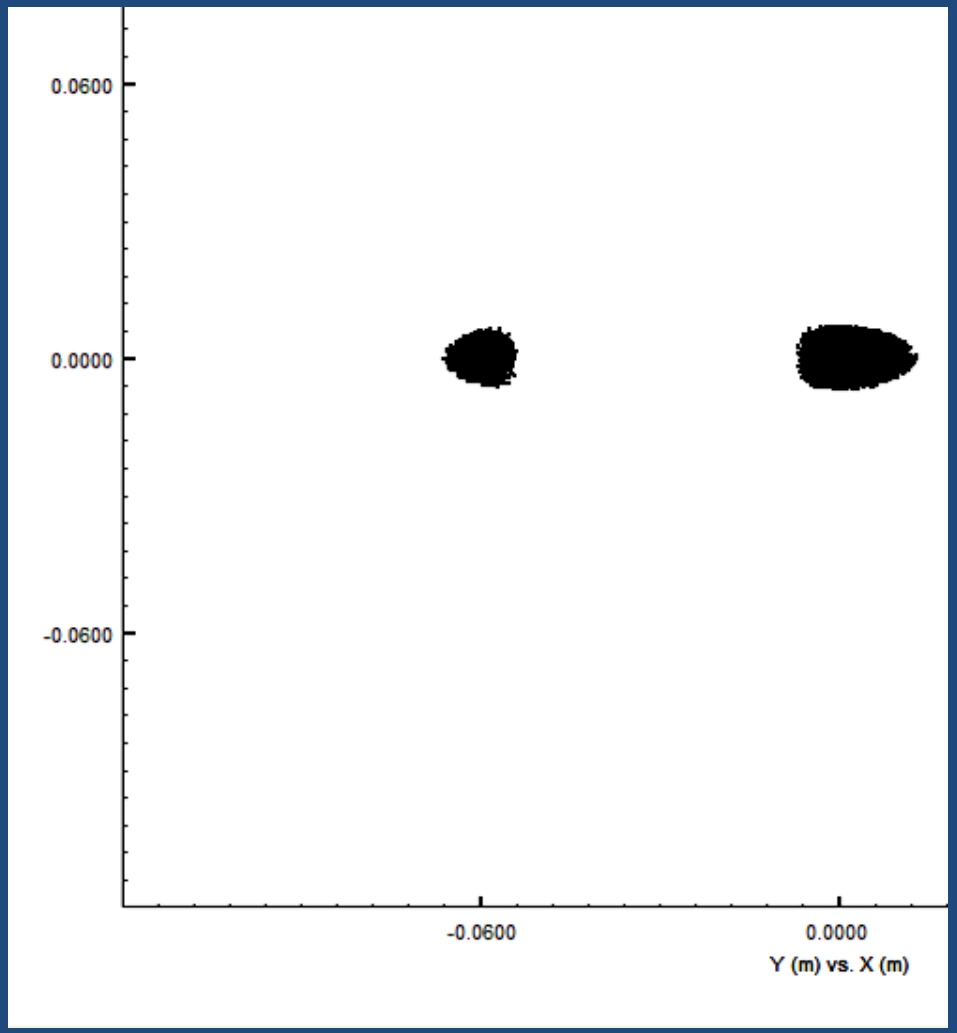
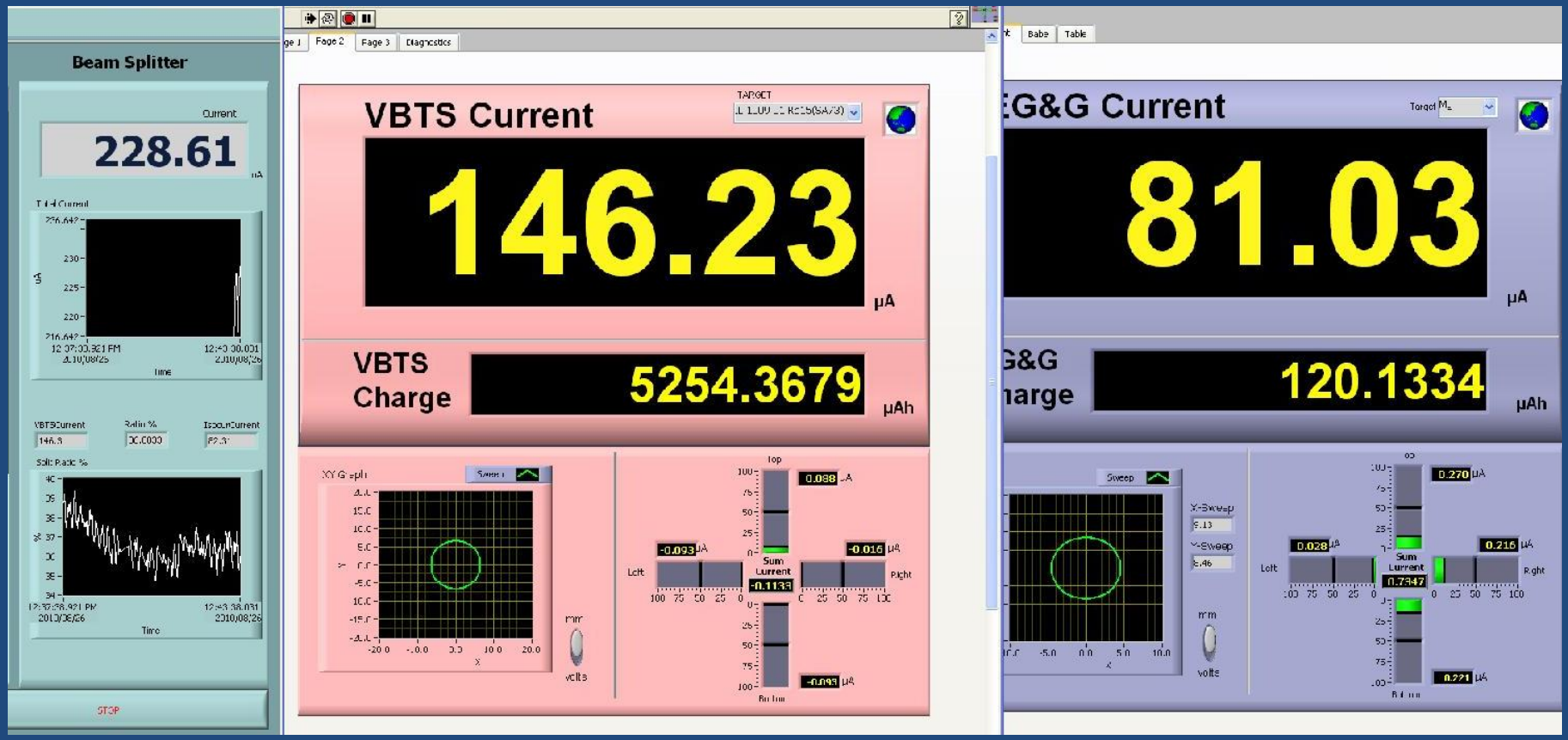
Beam direct behind the electrostatic channel



Beam in front of the magnetic channel



Measured beam current on the two target stations



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cGMP Radiopharmaceuticals

Supply over 60 local Nuclear Medicine Hospitals and Private Clinics

Radionuclide	Half-Life (hours)	Nuclear Reaction	Radiopharmaceutical Product	Main Use
^{18}F	1.83	$^{15}O(p,n)^{18}F$	^{18}F-FDG	Glucose metabolic studies
^{67}Ga	78.3	$Zn(p,xn)^{67}Ga$ $Ge(p,x)^{67}Ga$	^{67}Ga-citrate	Localization of certain tumours and inflammatory regions
$^{81}Rb/^{81m}Kr$	4.58	$Kr(p,xn)^{81}Rb$	$^{81}Rb/^{81m}Kr$ generator	Lung ventilation studies
^{123}I	13.2	$^{127}I(p,5n)^{123}Xe \rightarrow {}^{123}I$	^{123}I-sodium iodide ^{123}I-mIBG	Thyroid studies Localization of certain tumours such as neuroblastoma, pheochromocytoma
$^{68}Ge/^{68}Ga$ generator	^{68}Ge = 271 d ^{68}Ga = 68 min	$^{69}Ga(p,2n)^{68}Ge$	^{68}Ga –DOTA-peptides	Typically detection of neuroendocrine tumours

iThemba LABS
Long-Lived Radionuclides

Supply over 60 clients worldwide

Radionuclide	Half-Life (days/years)	Nuclear Reaction	Main Use
^{82}Sr	25 days	Rb(p,xn)^{82}Sr	Used to manufacture ^{82}Sr/^{82}Rb generators
^{68}Ge	271 days	Ga(p,xn)^{68}Ge	Used to manufacture ^{68}Ge/^{68}Ga generators and calibration sources for PET CT scanners
^{88}Y	106.6 days	Sr(p,xn)^{88}Y	Non –medical application –calibration sources
^{109}Cd	453 days	Ag(p,xn)^{109}Cd	Non-medical application-calibration sources
^{22}Na & ^{22}Na positron sources	2.602 years	Mg(p,n)^{22}Na	Used in Material Sciences -Positron Annihilation Studies

Targets for radionuclide production

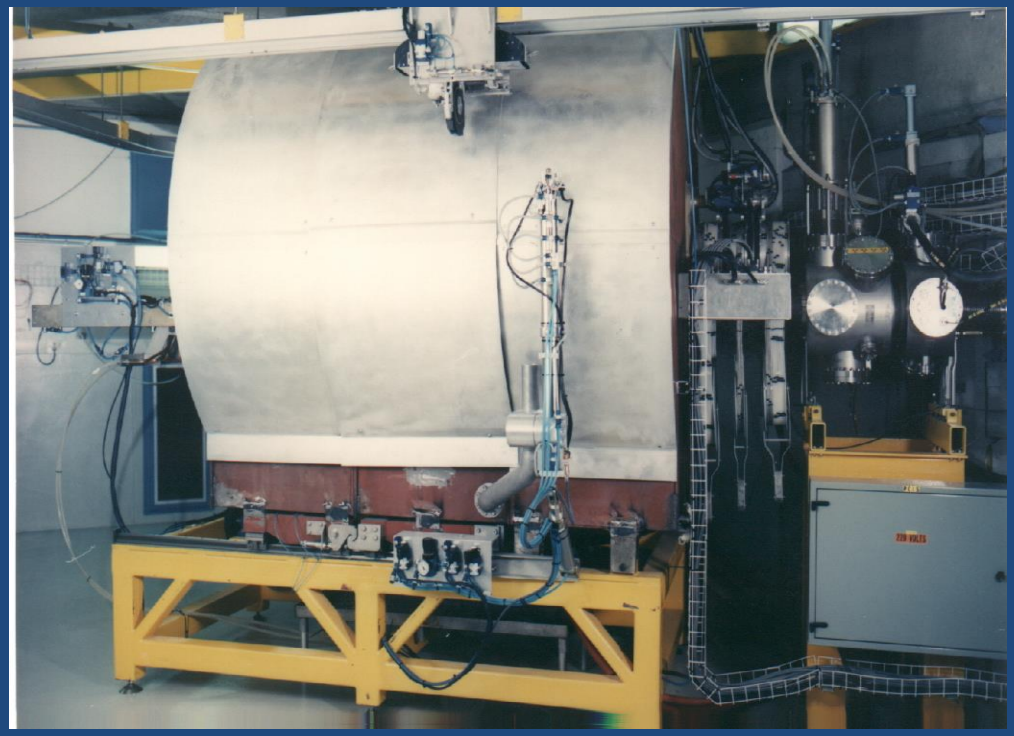
Radionuclide	Target	Energy window (MeV)
^{67}Ga	Zn Ge	34.3 → 18.1 60.7 → 38.7
^{68}Ge	Ga "Ga_2O"	34.0 → 2.4 34.0 → 0.0
^{81}Rb	RbCl	62.6 → 57.7
^{82}Sr	Rb	61.5 → 39.4
^{109}Cd	Ag	34.0 → 0.0
^{123}I	NaI	62.6 → 47.6
^{88}Y	SrCl	34.0→ 0.0
^{22}Na	Mg	61.5 → 40.0
^{18}F	[^{18}O]Water	18.0 → 0.0

Bombardment Station-HBTS

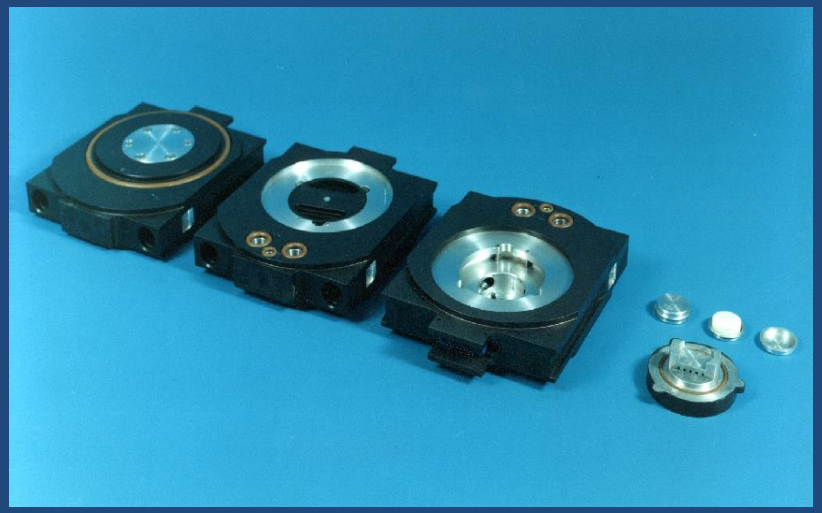
Produce:

^{67}Ga, ^{123}I and ^{81}Rb

^{68}Ge, ^{82}Sr, ^{22}Na, ^{88}Y, ^{57}Co and ^{109}Cd



Horizontal Beam Target Station (HBTS)



HBTS Target and target holders

66 MeV proton beam with an intensity of 80-90 µA

Bombardment Station-VBTS

Produce in Tandem
$^{82}Sr/^{68}Ge$
$^{22}Na/^{68}Ge$

Vertical Beam Target Station (VBTS)
66 MeV proton beam with an intensity of ~250 µA

VBTS Thick Target Holders

VBTS Tandem targets

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RNP Control Room

Automated Transport System

Upgrade of control systems such as cooling systems, interlocking systems and transport system.

Upgrade of Targetry Cooling Systems for dual beams

Helium Cooling Systems that can deliver 70 m^3/hr to operate two bombardment stations simultaneously

Water Cooling Systems that can deliver in total 300 L/min to operate two bombardment stations simultaneously

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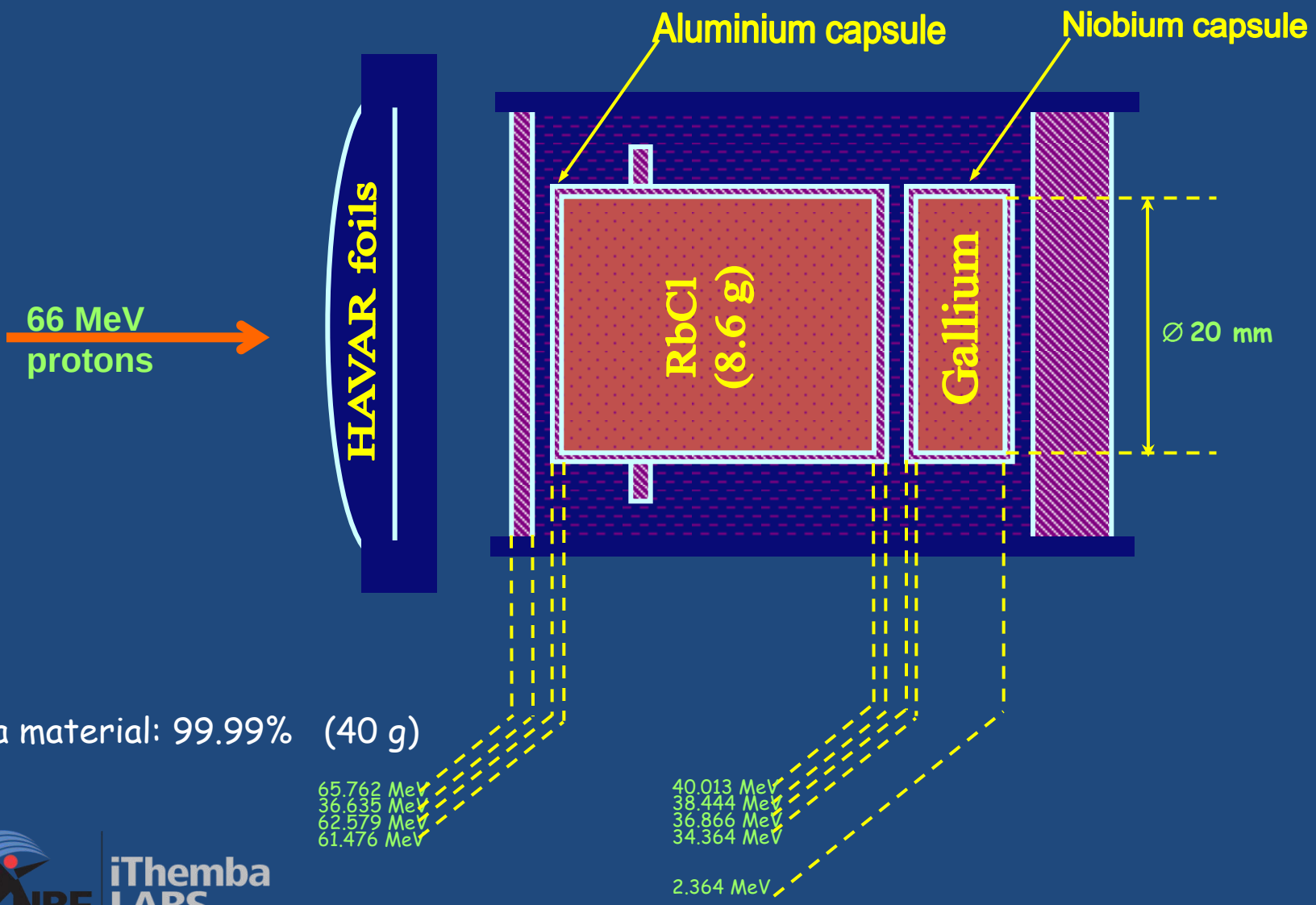
Tandem target for the production of ^{82}Sr and ^{68}Ge



Ga material: 99.99% (40 g)

Chemical Processing Facilities

^{18}F-Automated Chemical Processing Hot Cells

Manual Manipulator Hot Cells

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3 X Independent Clean Rooms

$^{68}Ge/^{68}Ga$

^{18}F-FDG

^{123}I /^{67}Ga

Dispensing Facilities

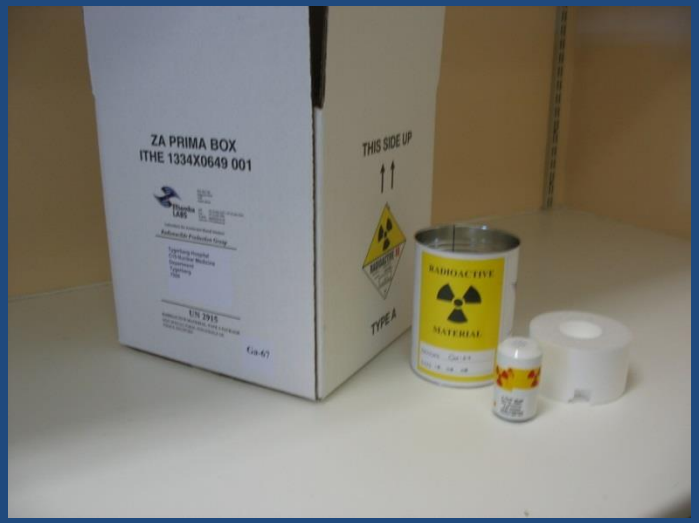
Comecer Hotcells & Timothea Dispensing Facilities

Quality Control Facilities

18F-FDG Quality Control

Quality Control Microlab

Packaging and Dispatch



As per IATA (International Air Transport Assoc') Regulations