THE ACCELERATOR FACILITIES OF THE NATIONAL RESEARCH FOUNDATION IN SOUTH AFRICA

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RuPAC 2008

18-09-08 - 03-10-08 Zvenigorod

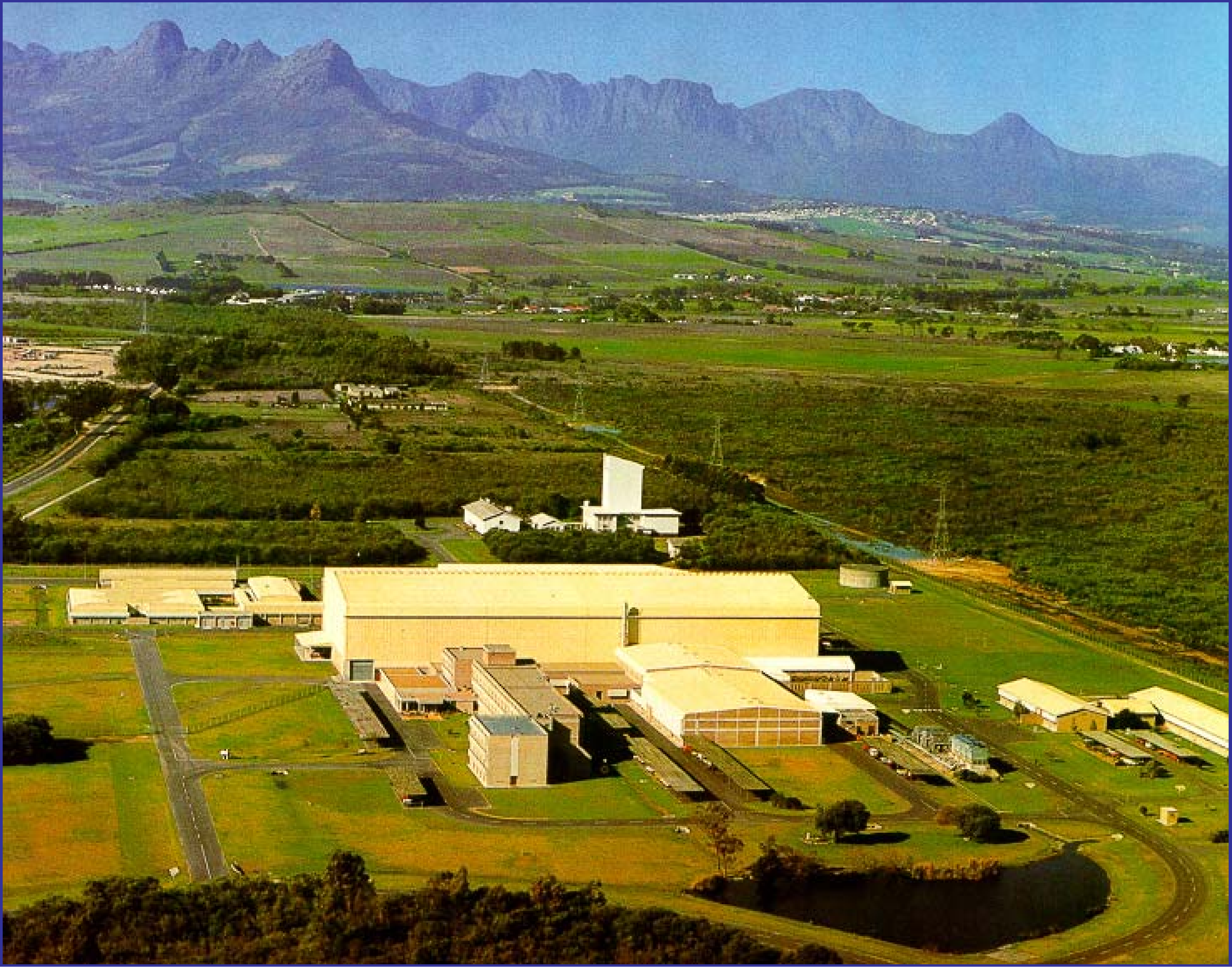
iThemba LABS and the NRF

iThemba L(aboratory) for A(ccelerator)-B(ased) S(ciences) is a multi-disciplinary research centre, operated by the NRF (National Research Foundation). It provides accelerator and ancillary facilities for:

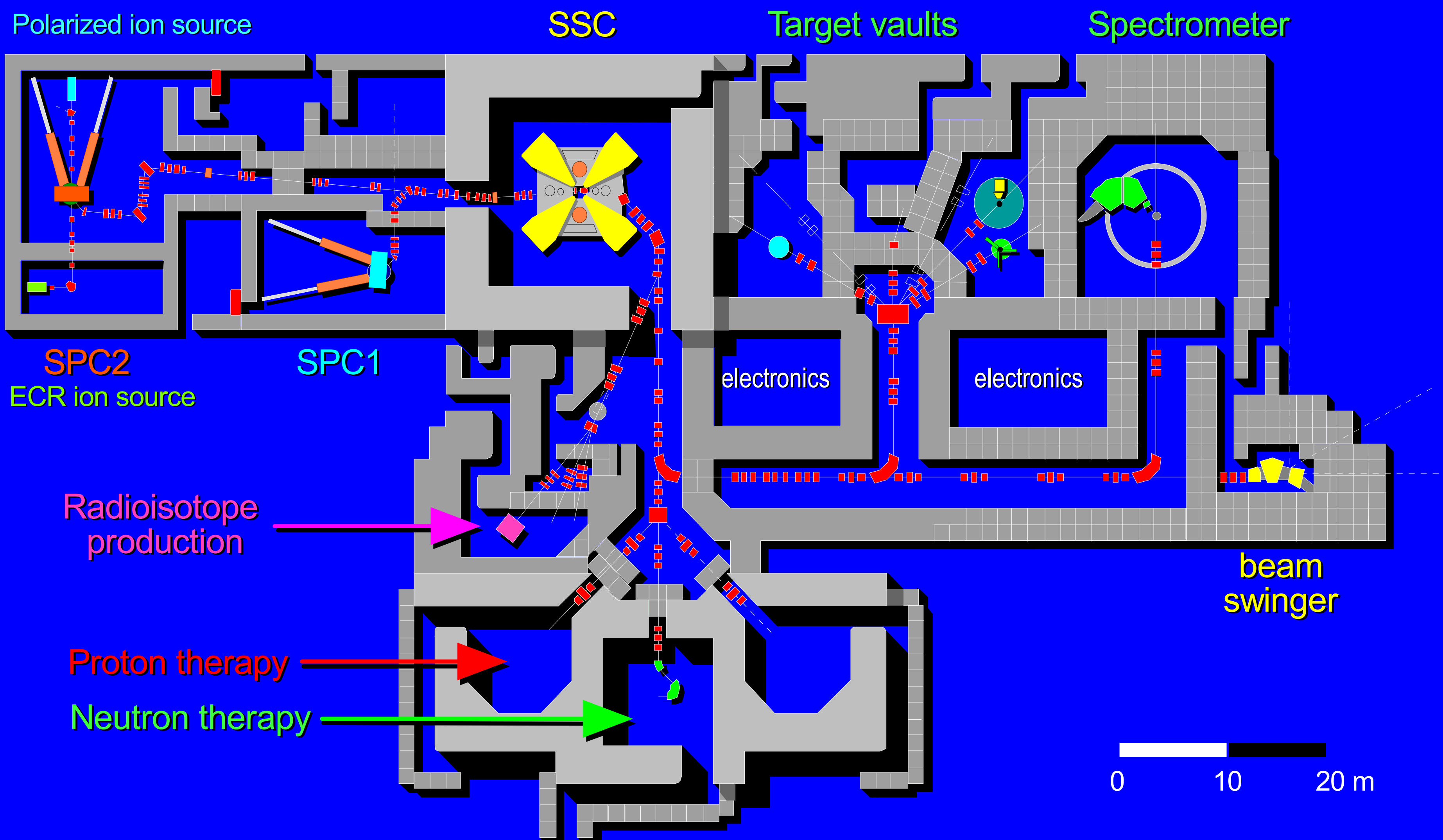
- Research and training in the physical, biomedical and material sciences
- Treatment of cancer patients with energetic neutrons and protons and related research
- Production of radioisotopes and radiopharmaceuticals for use in nuclear medicine, research and industry and related research

Outline of the talk

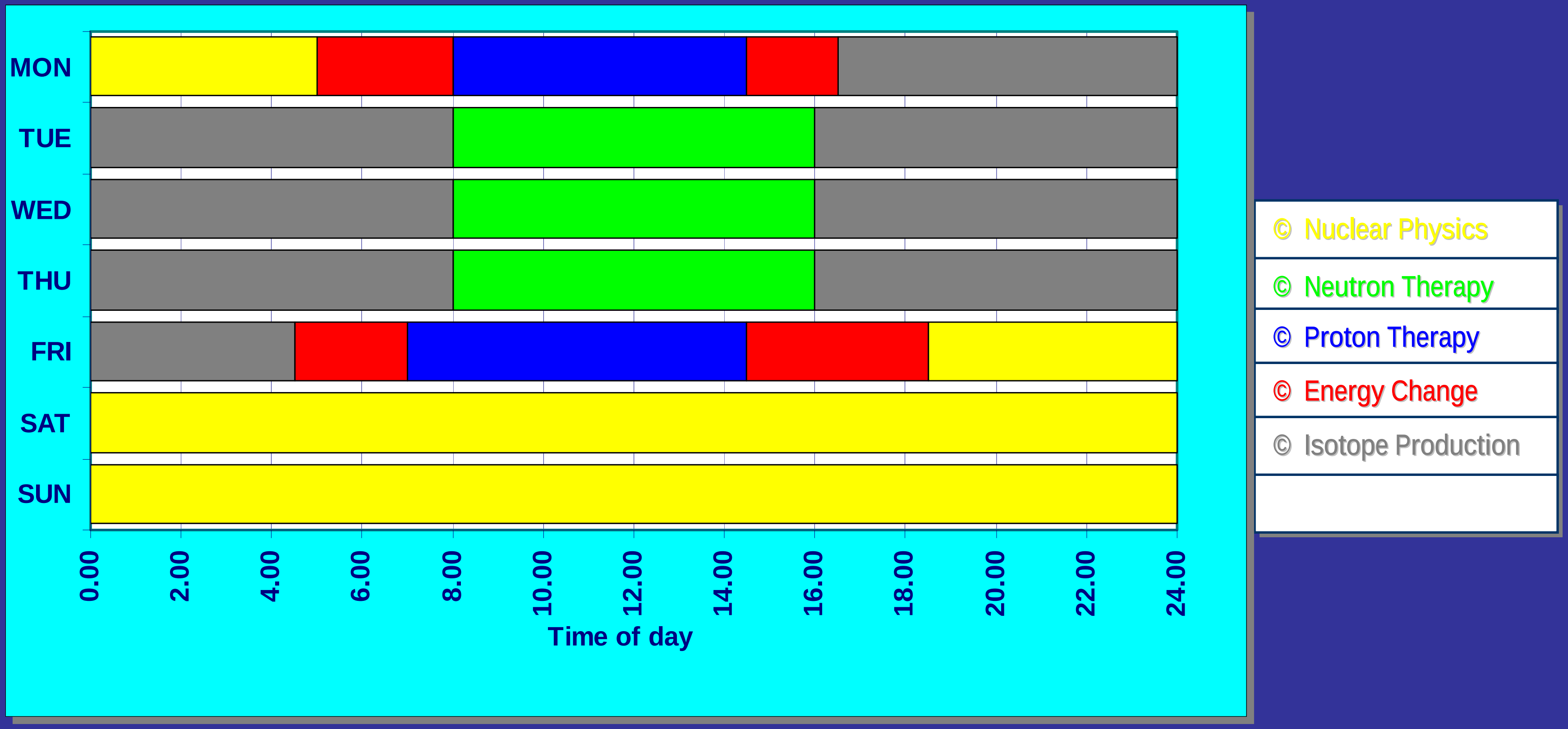
- Status and the cyclotron facilities
- Status of the electrostatic accelerators
- New Projects



Separated-Sector Cyclotron Facility



BEAM SCHEDULE



Beams delivered at iThemba LABS

Some beams at iThemba LABS			
Element	Mass	Energy range MeV	
		from	to
H	1	11.5	227
He	4	25	200
B	11	55	60
C	12	58	400
C	13	75	82
N	14	140	400
O	16	73	400
O	18	70	110
Ne	20	110	125
Ne	22	125	125
Al	27	150	349
Si	28	141	141
Cl	37	205	250
Ar	40	280	280
Zn	64	165	280
Kr	84	450	530
Kr	86	396	462
I	127	730	730
Xe	129	750	790
Xe	136	750	750

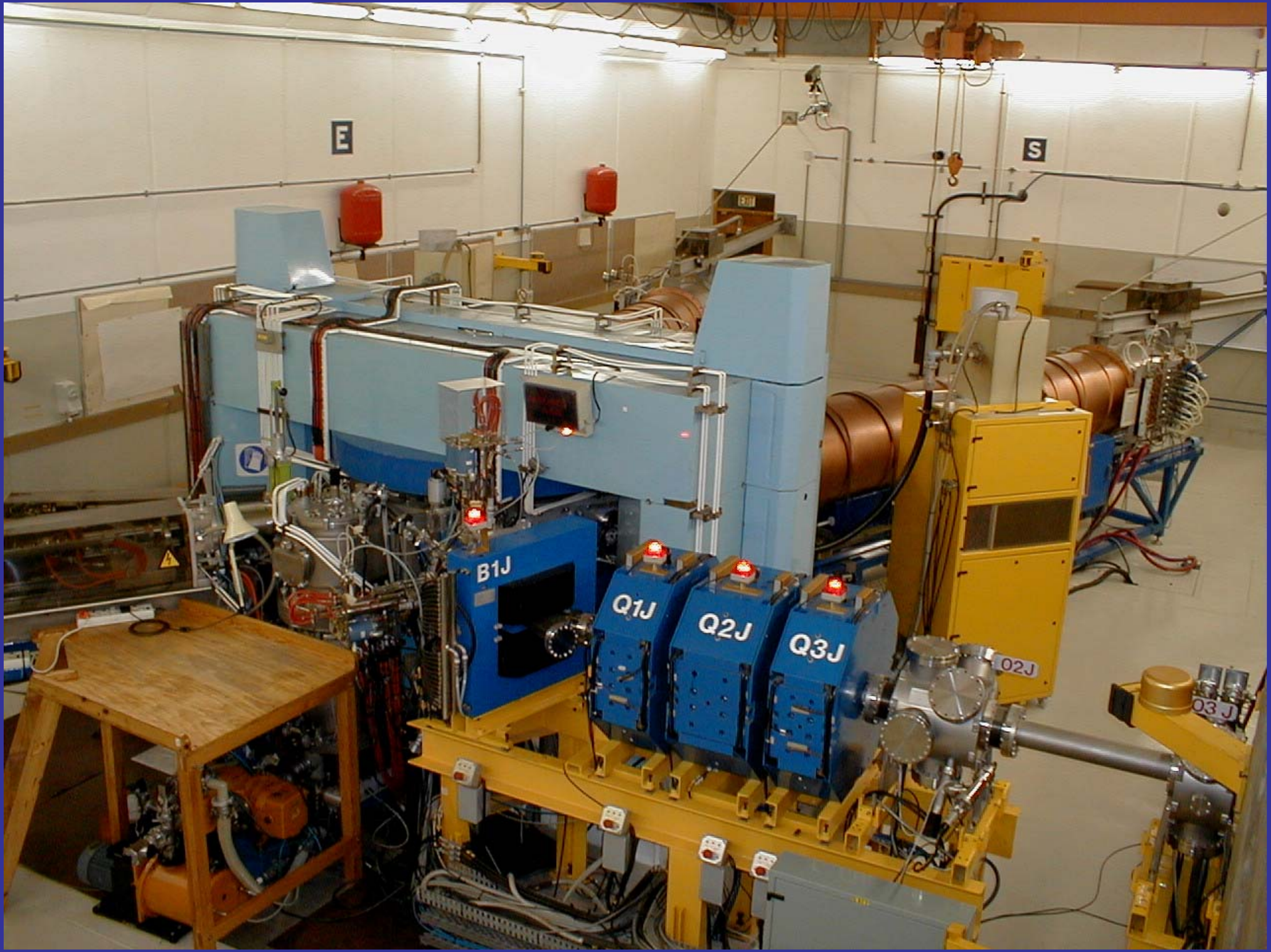
66 MeV Proton Beam

- **Beam current on target: 250 μA**
- **Transmission efficiency through the SSC:**

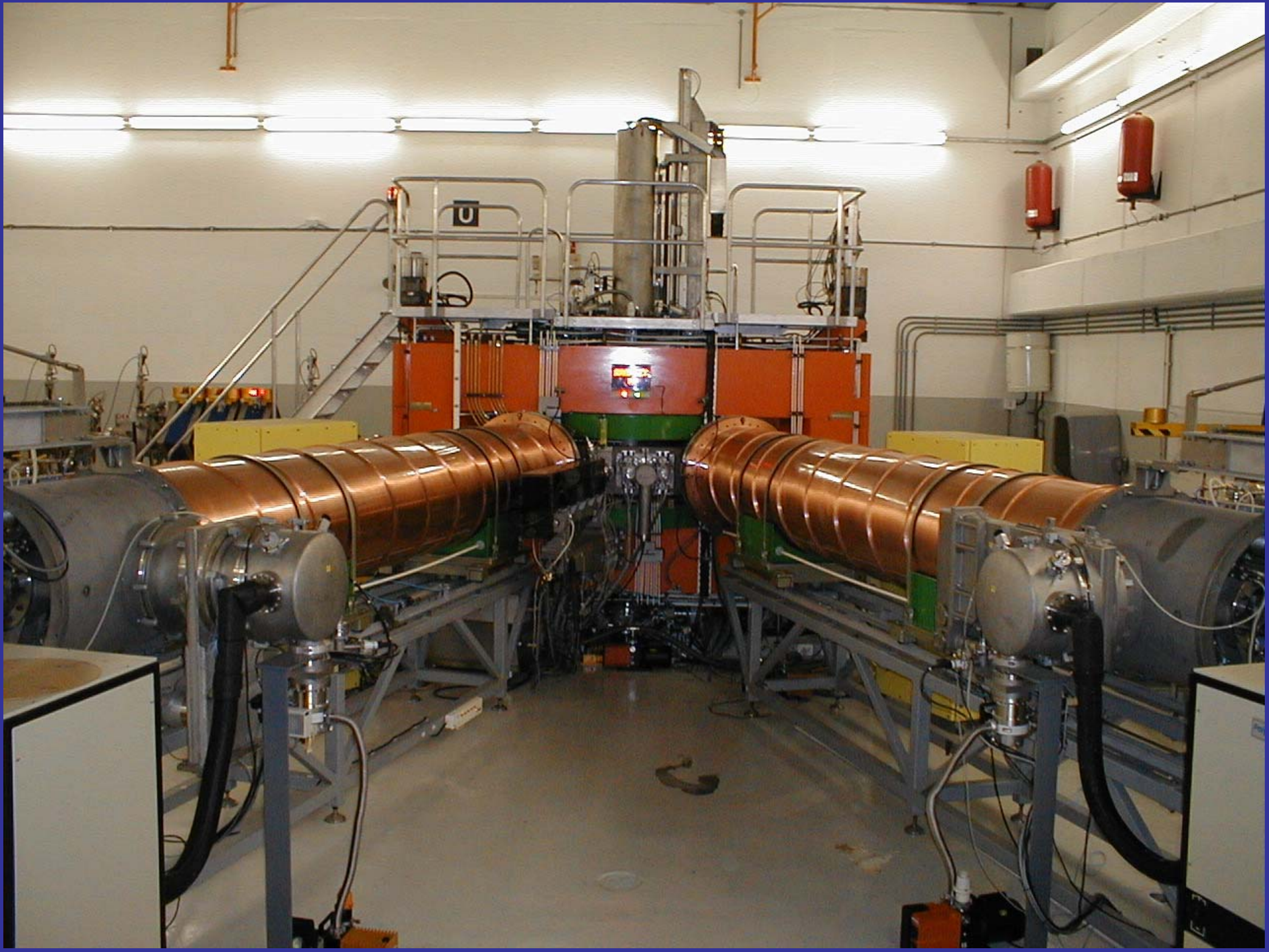
99.8%

UPS

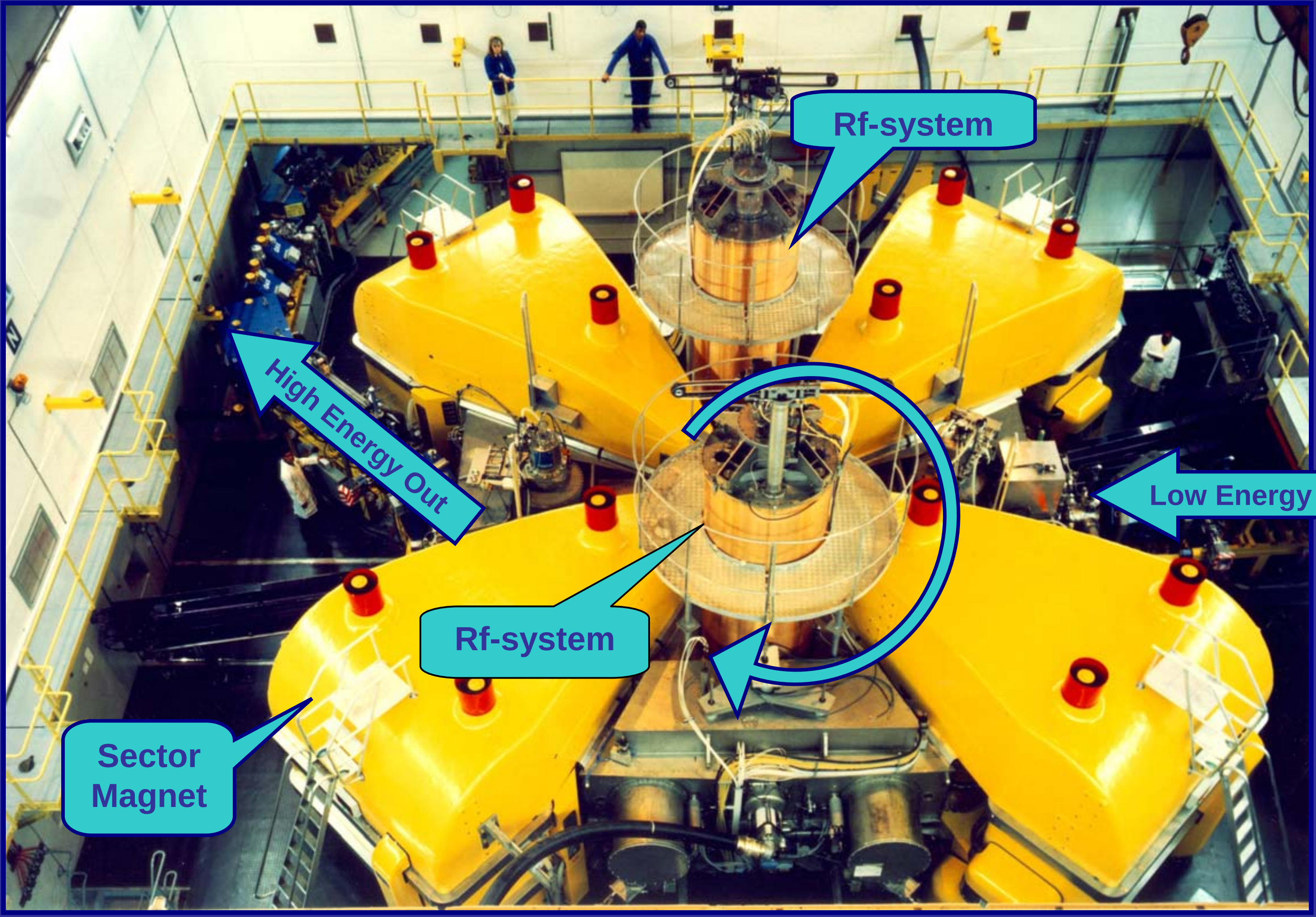
Solid-pole injector cyclotron 1 (SPC1)



Solid-pole injector cyclotron 2 (SPC2)



The SSC

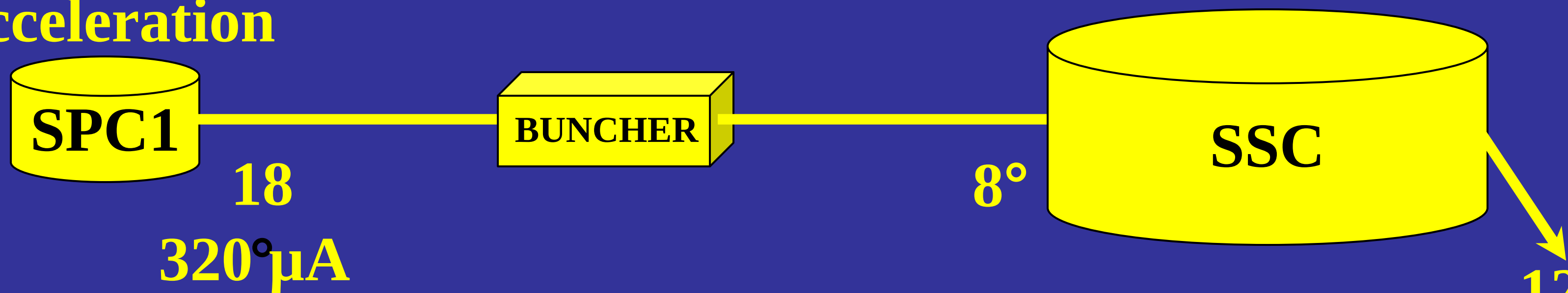


Rf-system
High Energy Out
Low Energy In
Rf-system
Sector
Magnet

FLAT-TOPPING AT iTHEMBA LABS

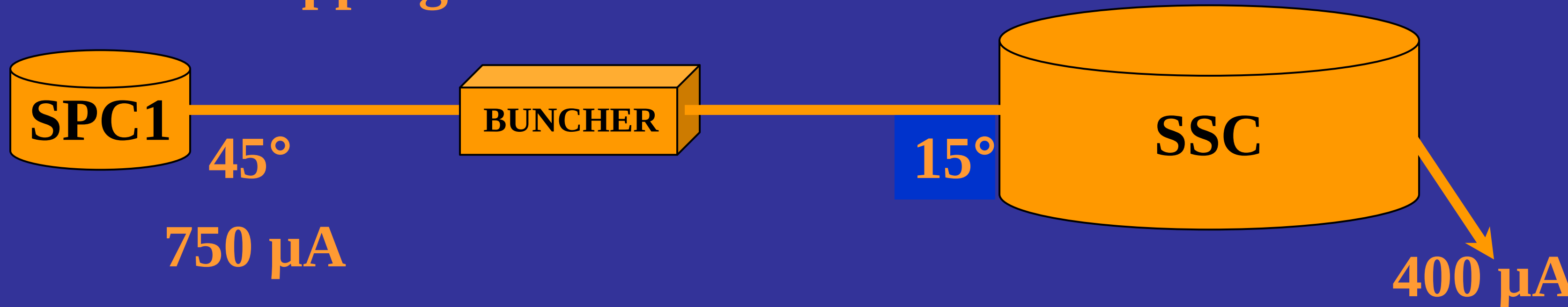
➢TO IMPROVE BOTH THE QUALITY AND INTENSITY OF THE 66 MeV PROTON BEAM FOR RADIOISOTOPE PRODUCTION

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

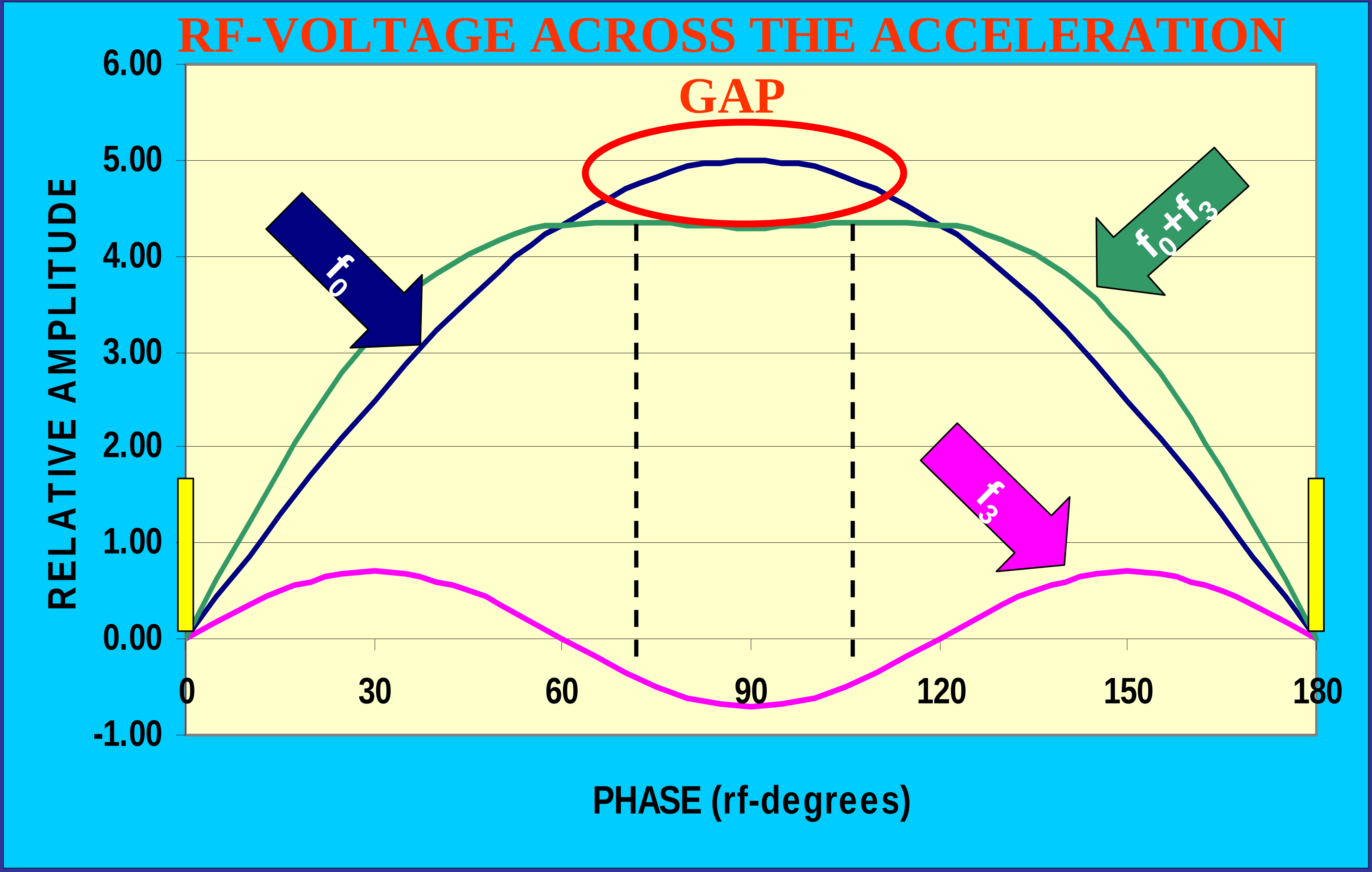


120 µA

With Flat-topping



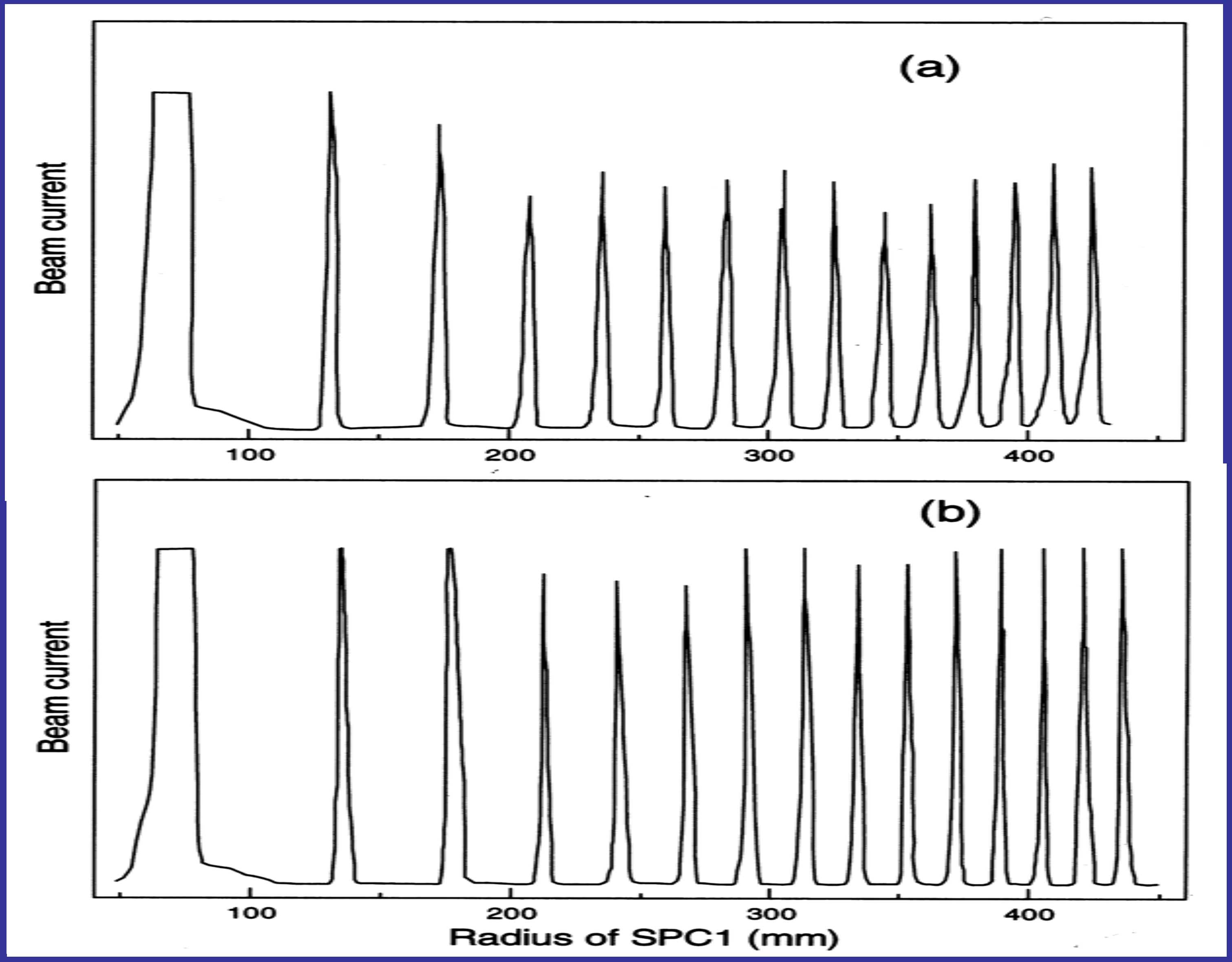
THE EFFECT of FLAT-TOPPING

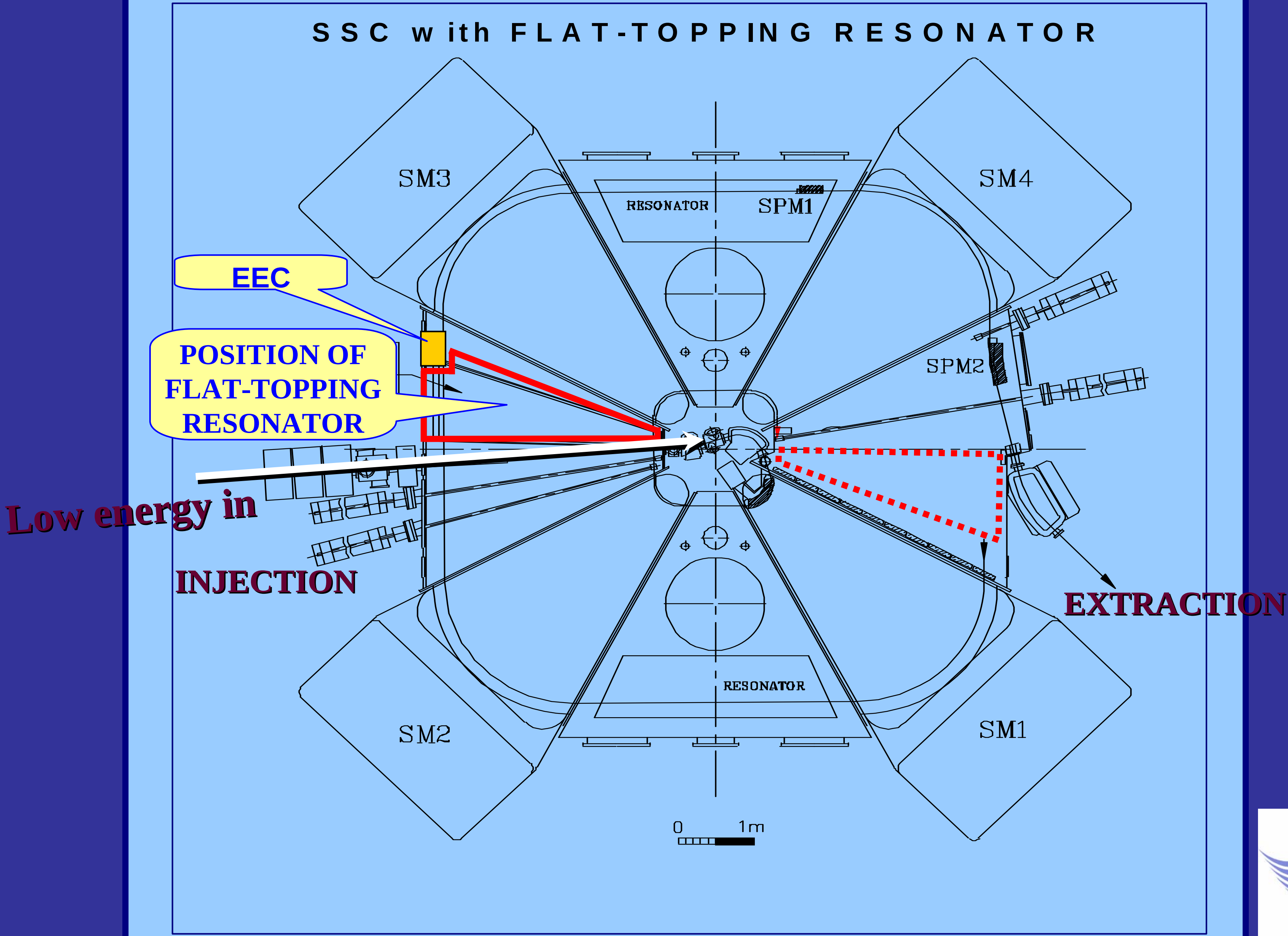


Two SPC1 flat-top resonators

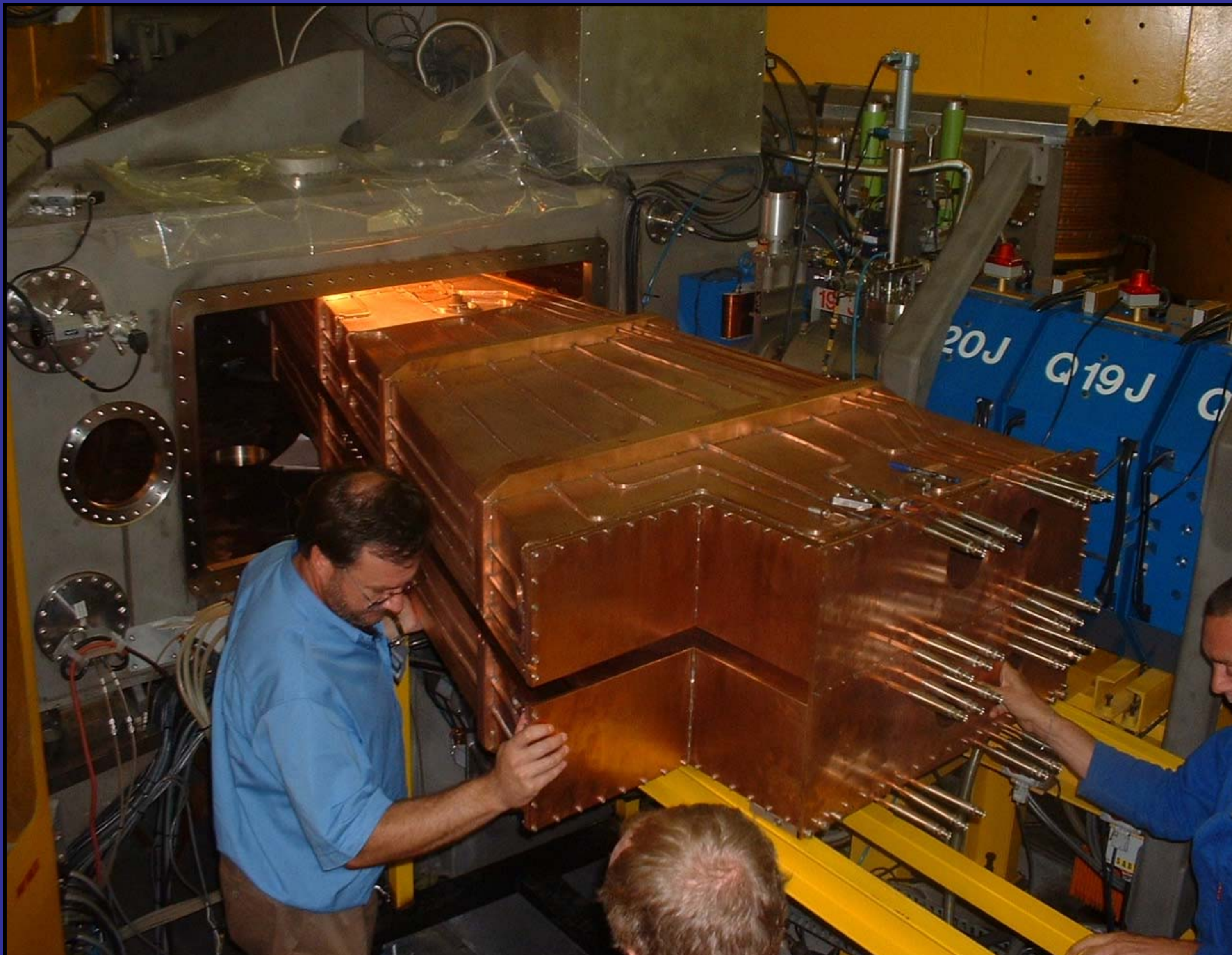
iThemba LABS

The orbit patterns without and with flat-topping

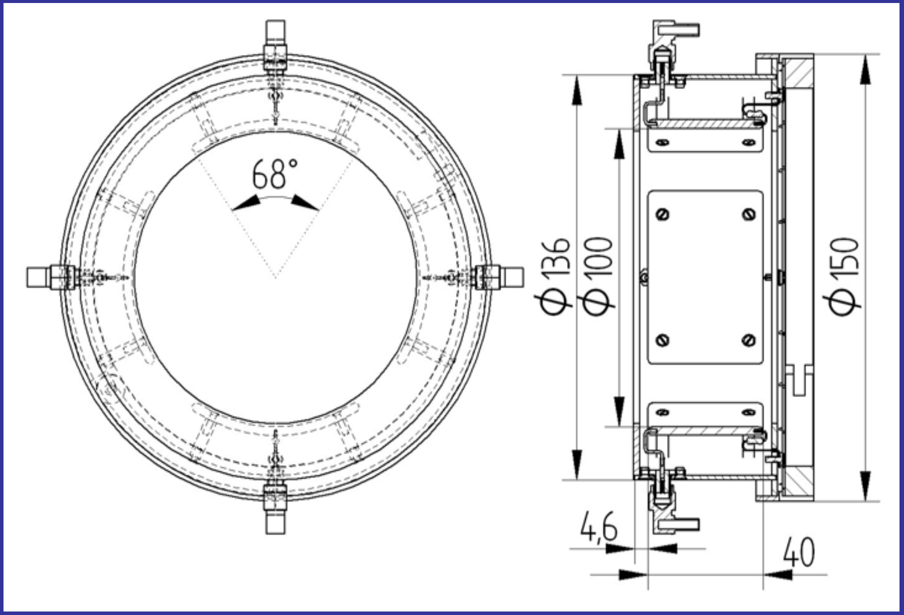



S S C w ith F L A T - T O P P I N G R E S O N A T O R
SM3
SM4
RESONATOR
SPM1
EEC
POSITION OF FLAT-TOPPING RESONATOR
SPM2
Low energy in
INJECTION
EXTRACTION
RESONATOR
SM2
SM1
0
1m

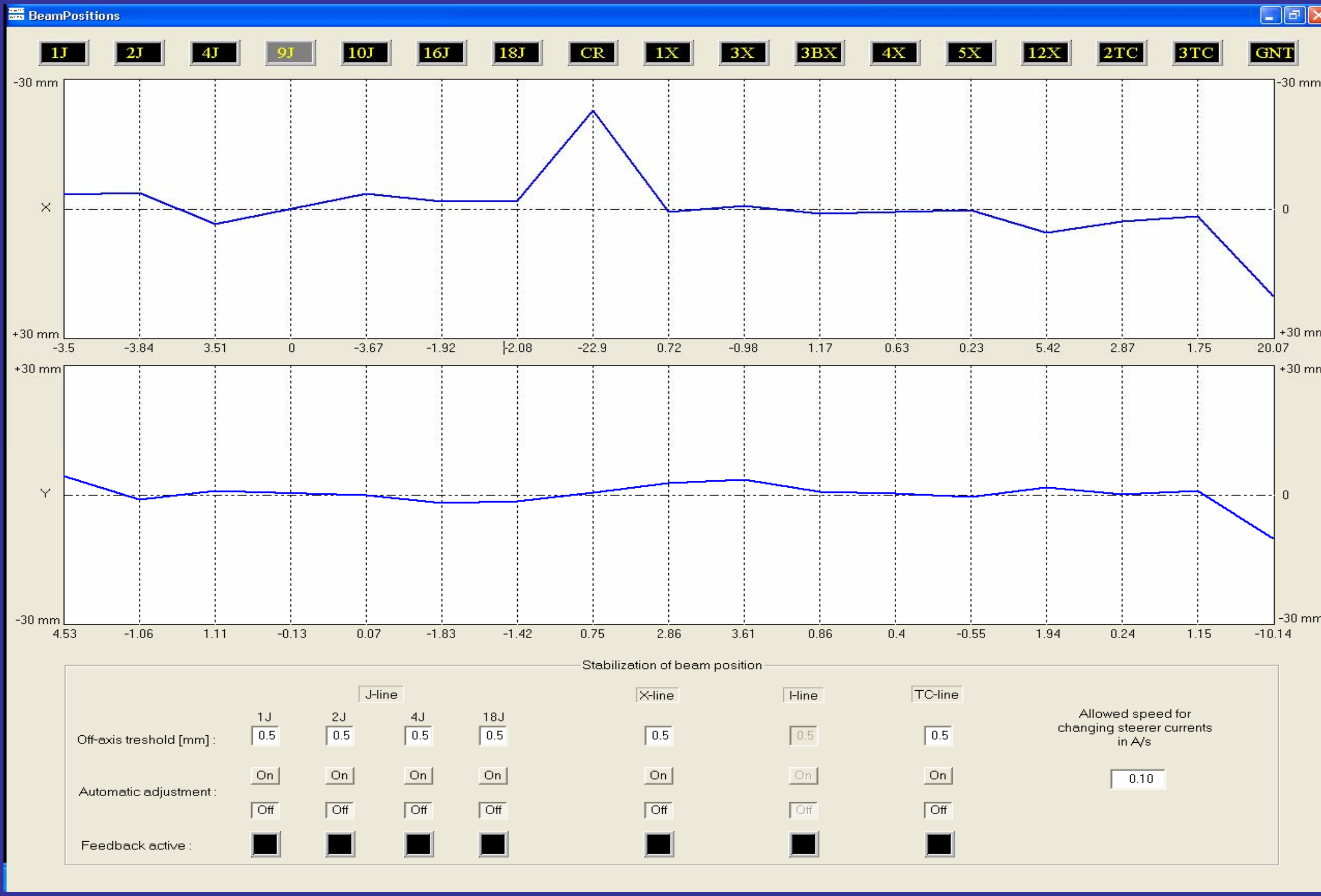
Installation of the Flat-top Resonator



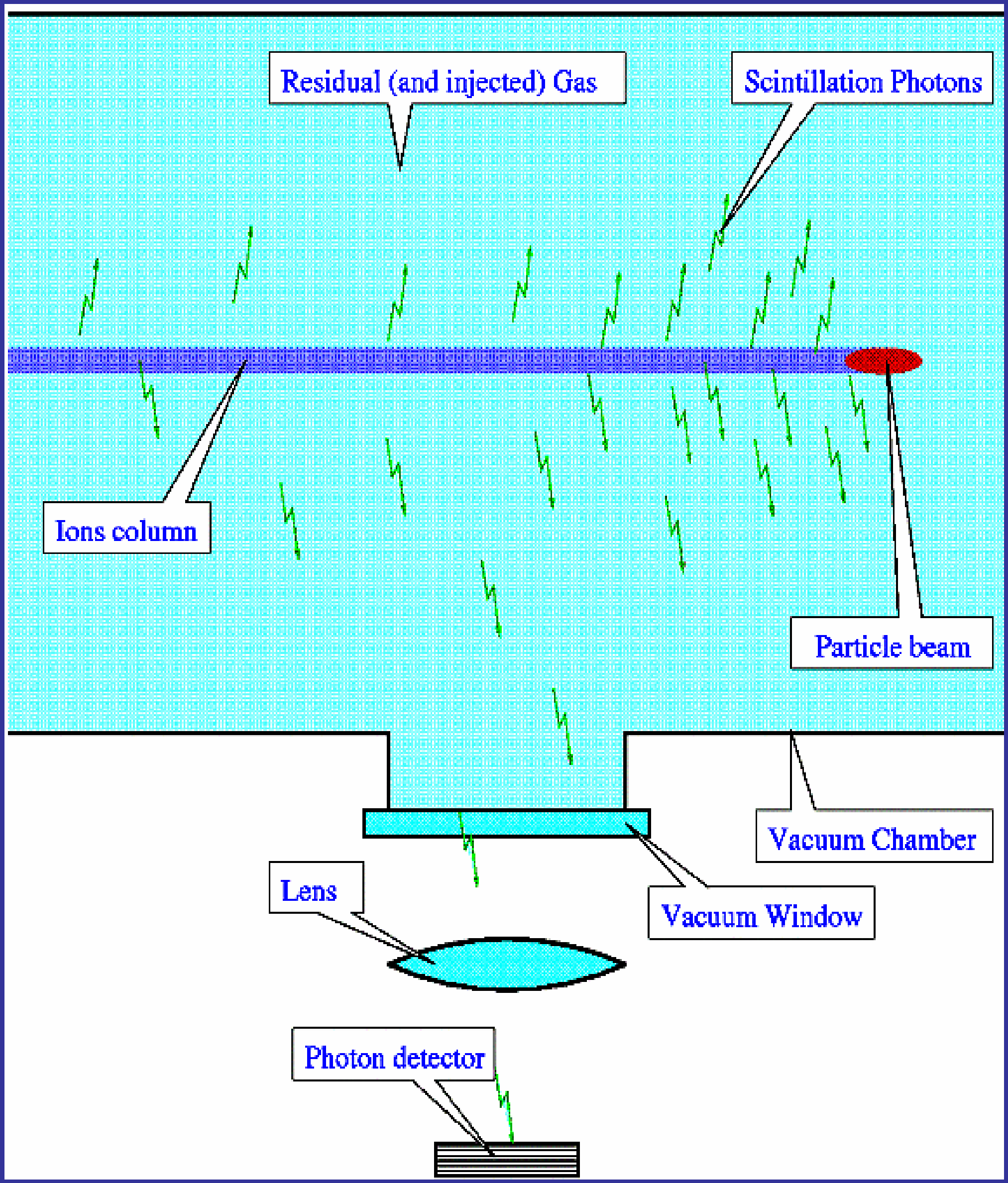
The beam position monitor



Beam Alignment on x– and y– axes



Residual gas fluorescence monitor



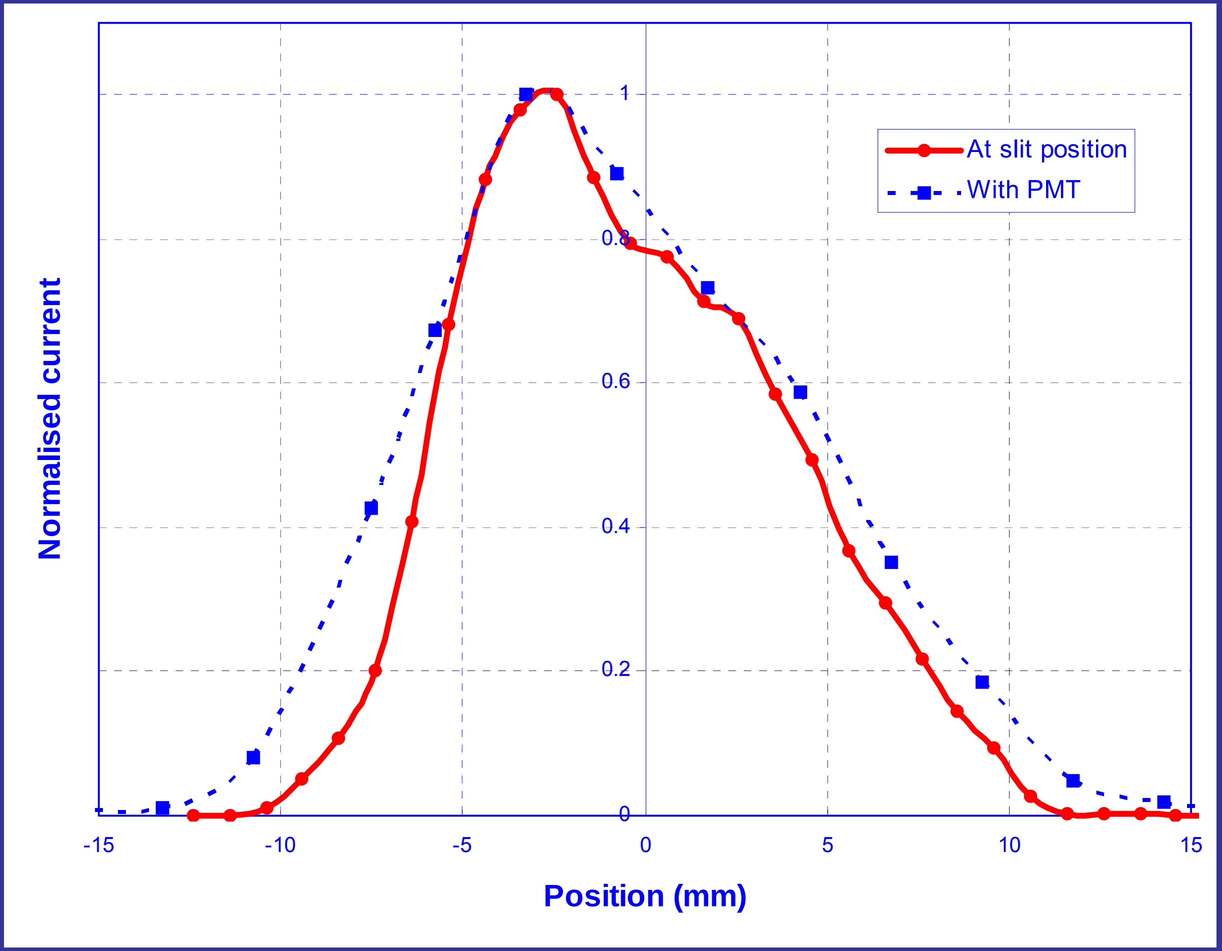
Gas molecules in the beam pipe,from either residual or injected gas, interact with the passing particle beam.

Electrons are promoted to excited states.

When the electrons fall to lower energy orbitals, photons are emitted.

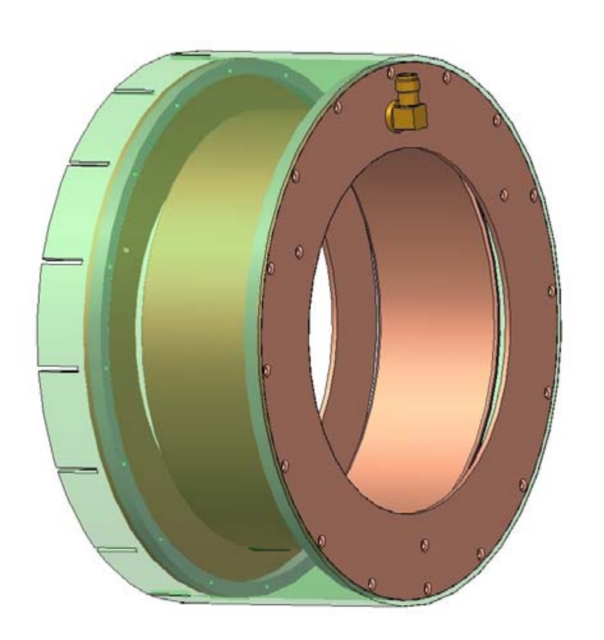
Photons are collected to measure the profile.

M.Plum, BIW2004, Knoxville

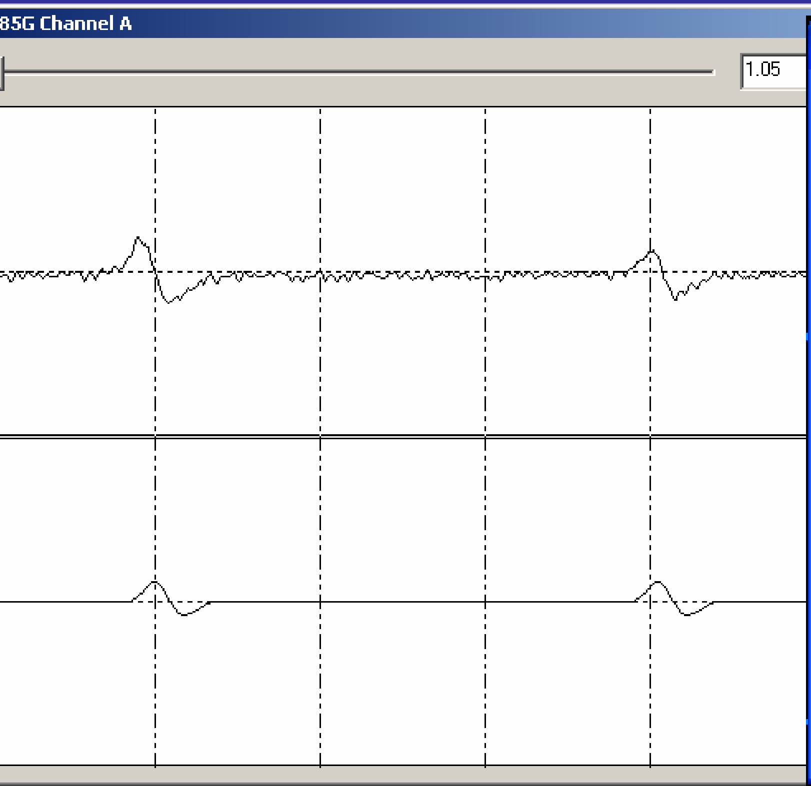


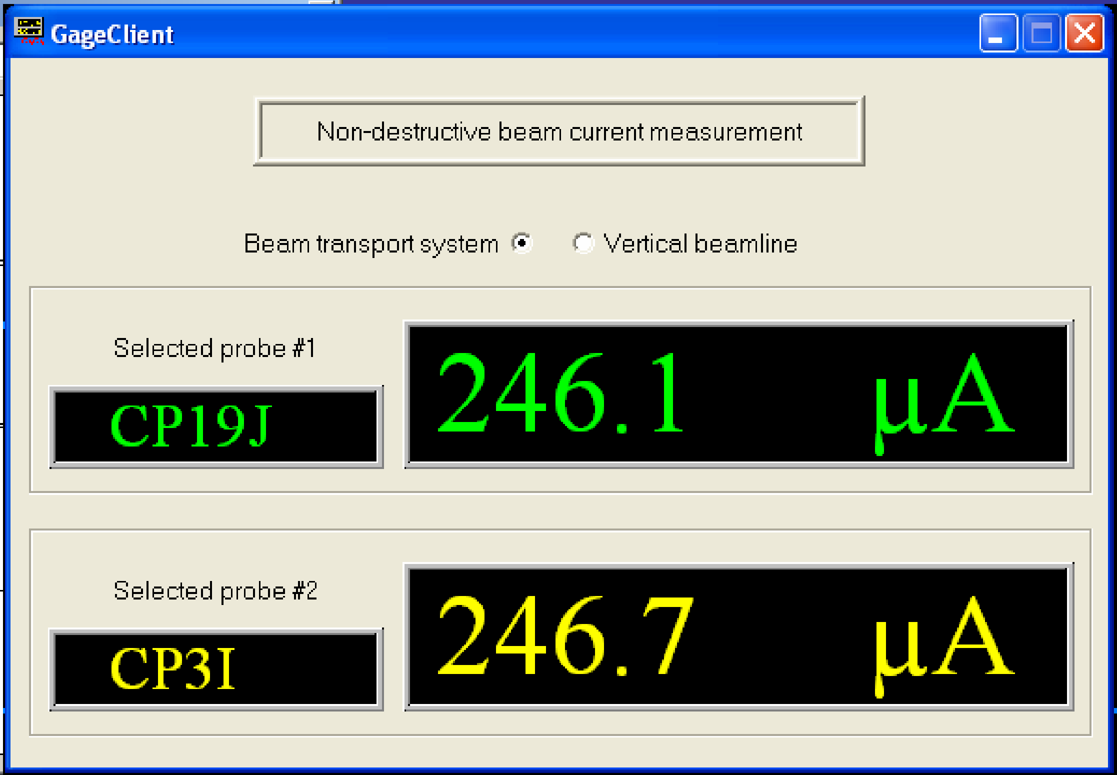
There is good agreement between the beam profiles measured with a 420 μA, 3.14 MeV proton beam at the PMT (broken line) and slit positions (solid line) that are 257 mm apart

Non-Destructive beam Current Measurement

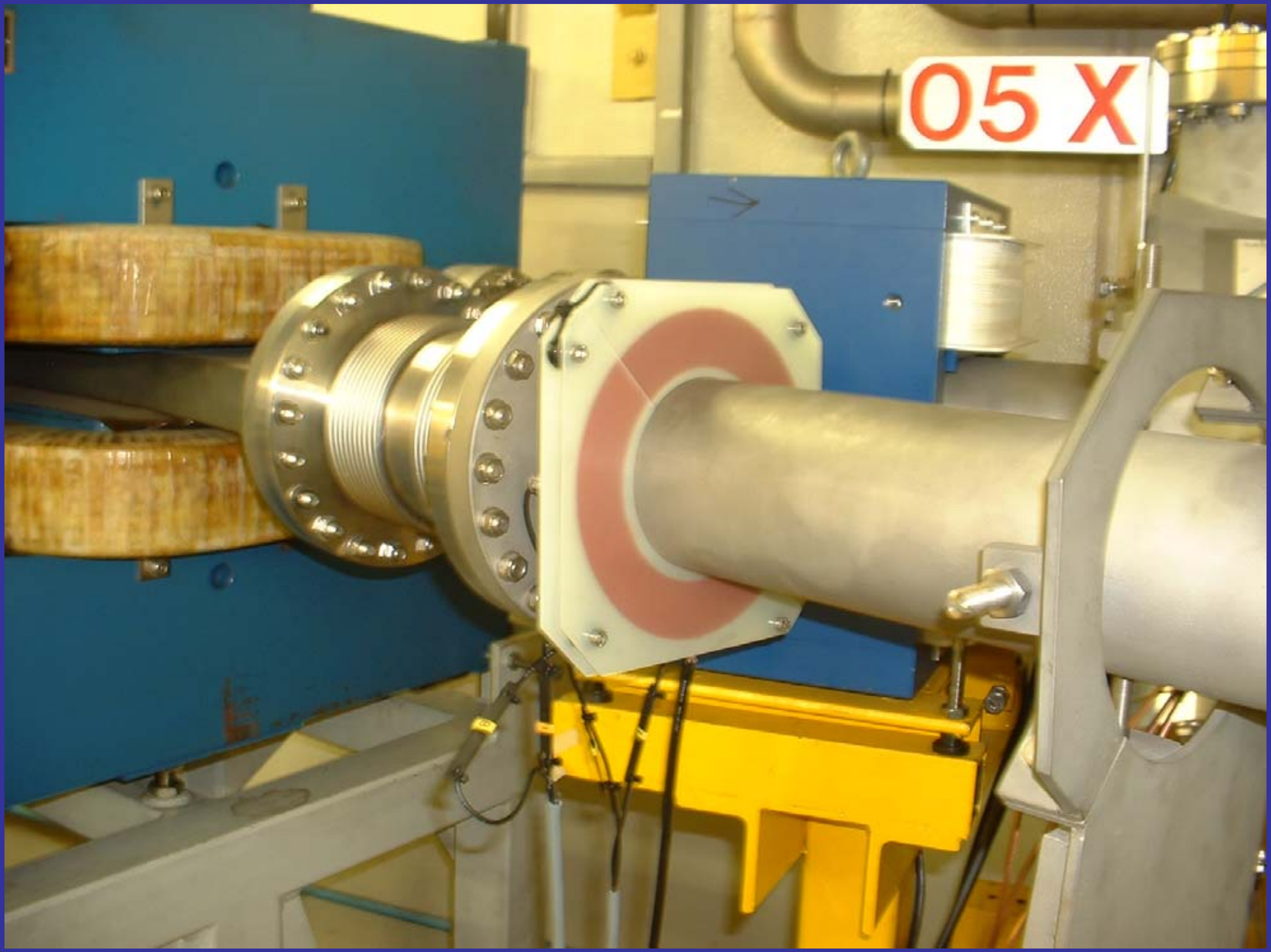


Capacitive probe

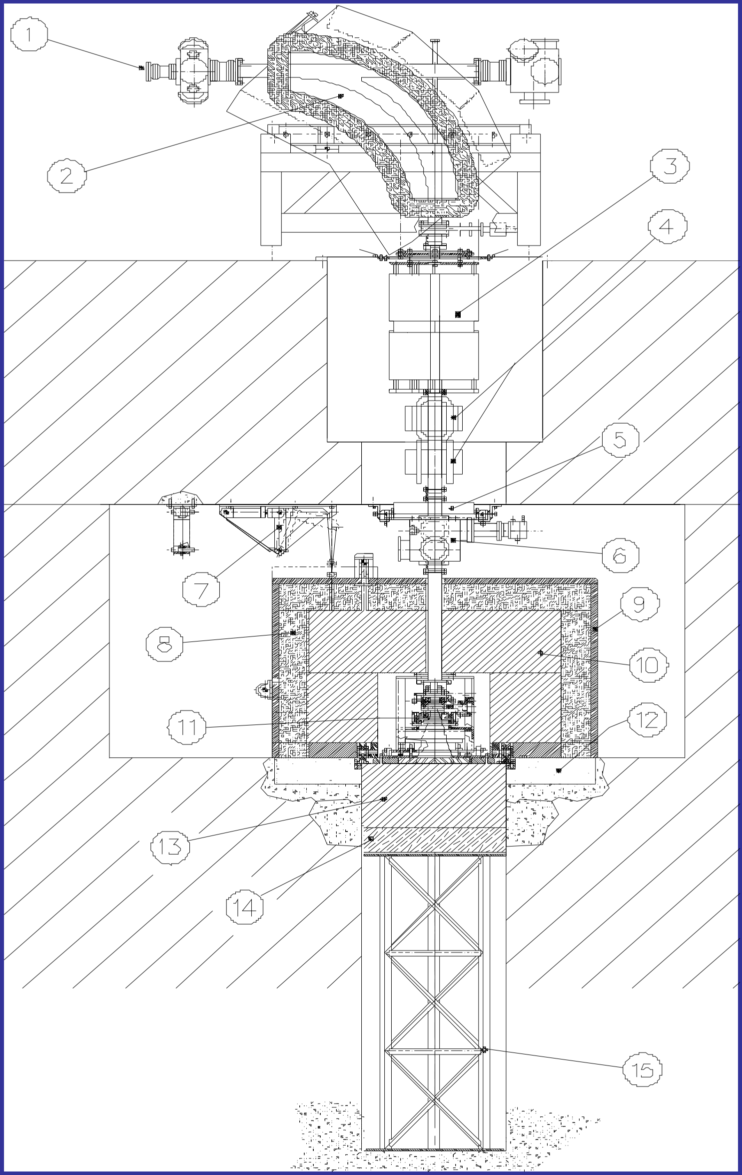




Halo Monitors to monitor beam loss along the beamlines



The new vertical beam line for Radionuclide production



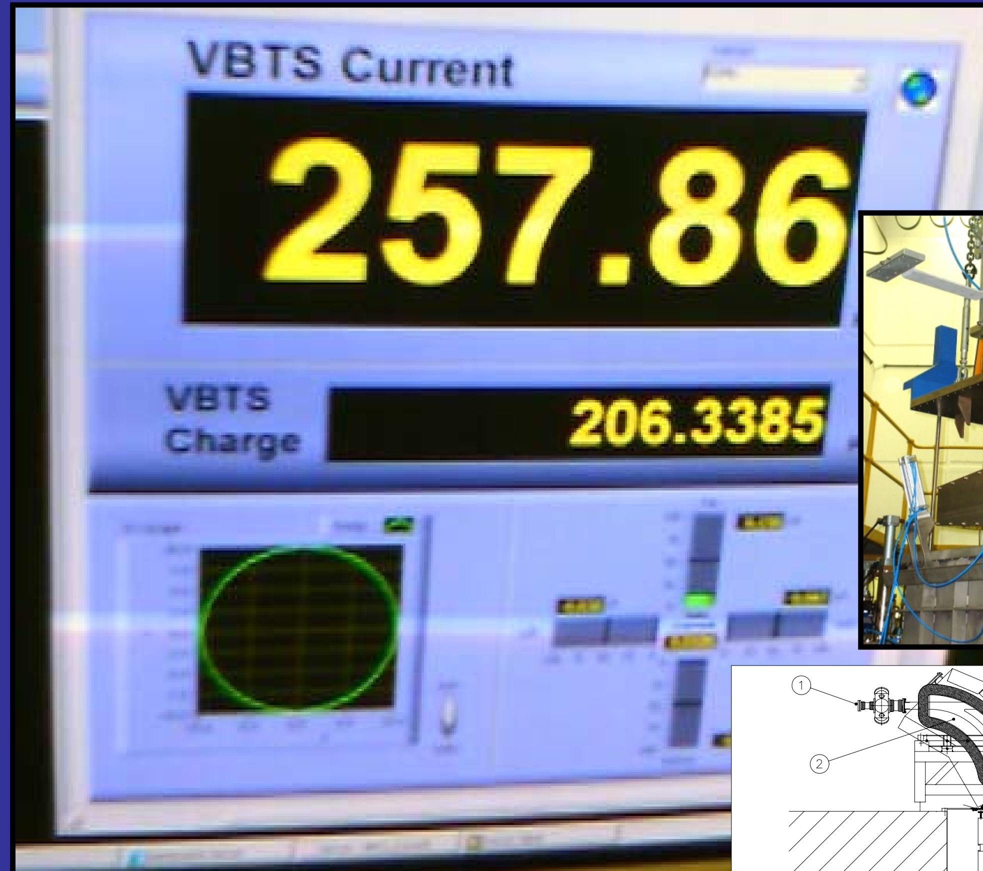
1. the horizontal beam line
2. the 90° bending magnet
3. two quadrupole magnets
4. sweeper magnets
5. steerer magnet
6. vacuum chamber for diagnostic equipment with a Faraday cup, harp and capacitive probe for current measurement
7. shielding lift mechanism for target exchanges

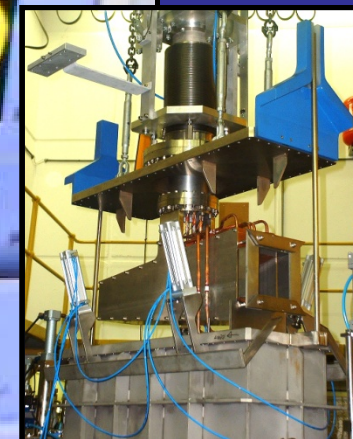
8. 9. and 10. inner iron shield

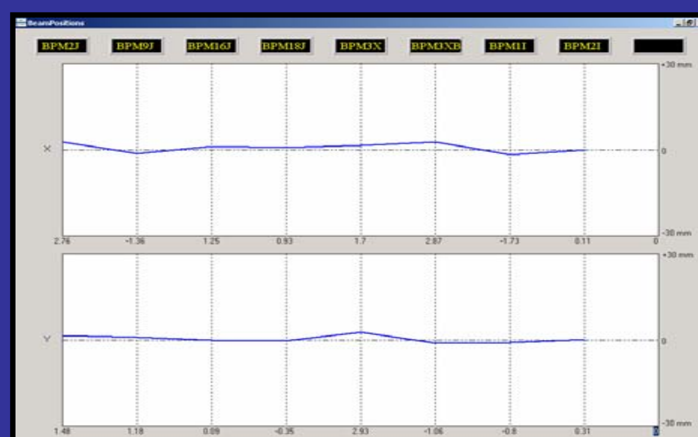
11. target
12. water tanks with a 4% ammonium pentaborate solution
13. iron shield
14. borated paraffin-wax shield
15. support structure.

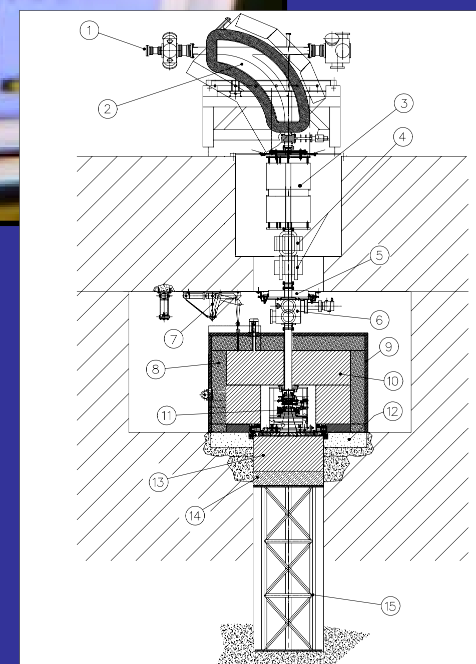
iThemba LABS


20J
Q19J

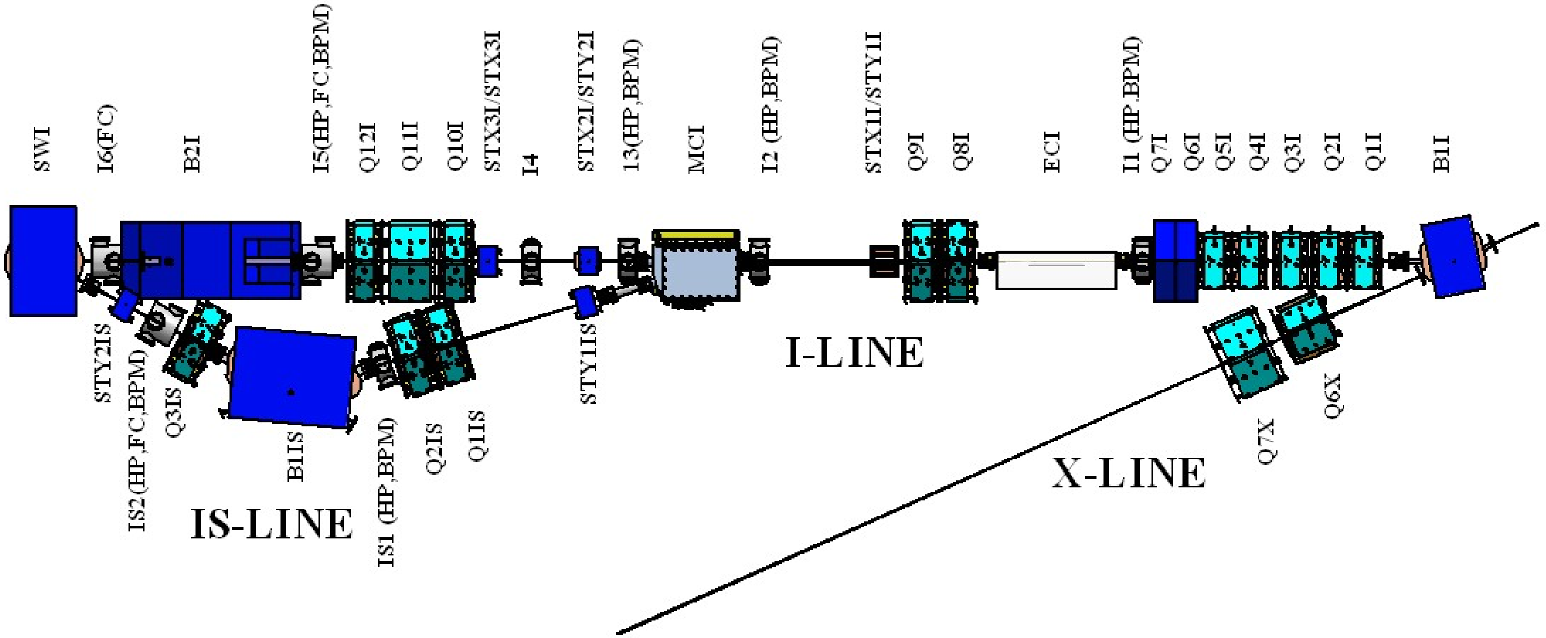

VBTS Current
257.86
VBTS Charge
206.3385




BPM2J
BPM9J
BPM16J
BPM18J
BPM3X
BPM3XB
BPM1I
BPM2I

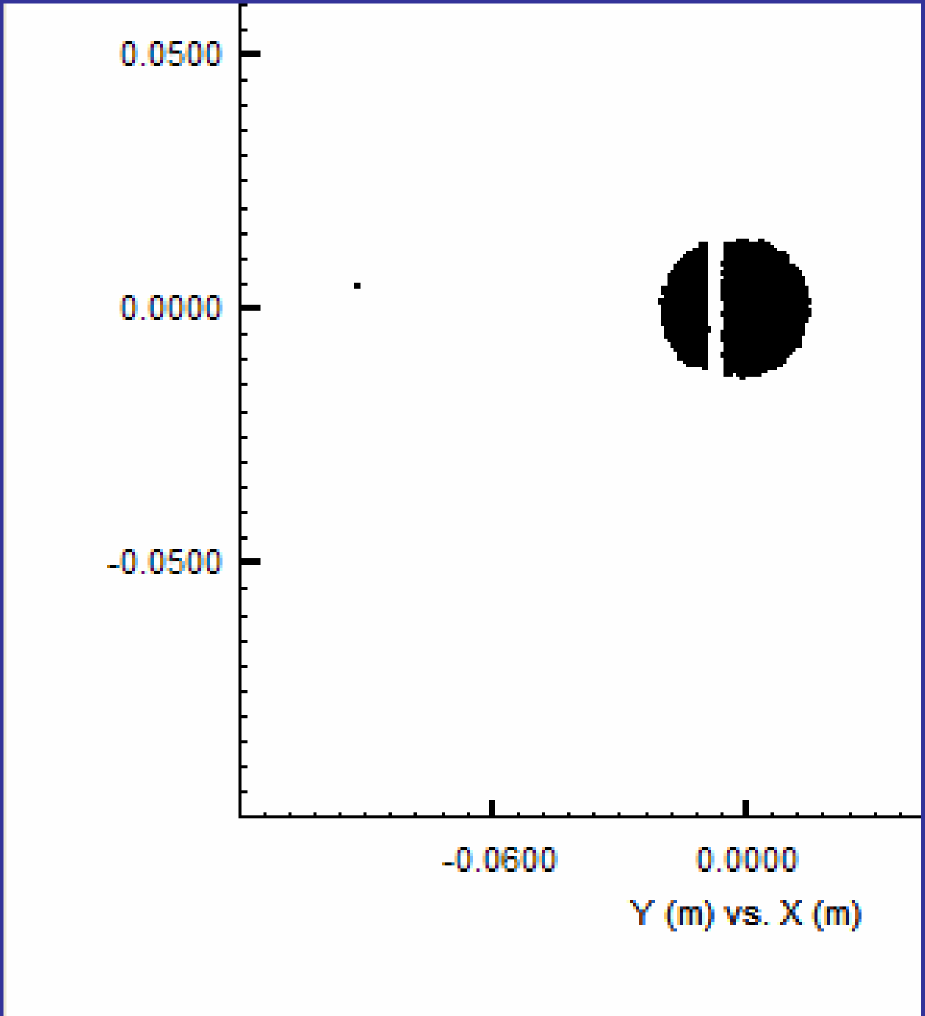

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

LAYOUT OF BEAM SPLITTER LINE

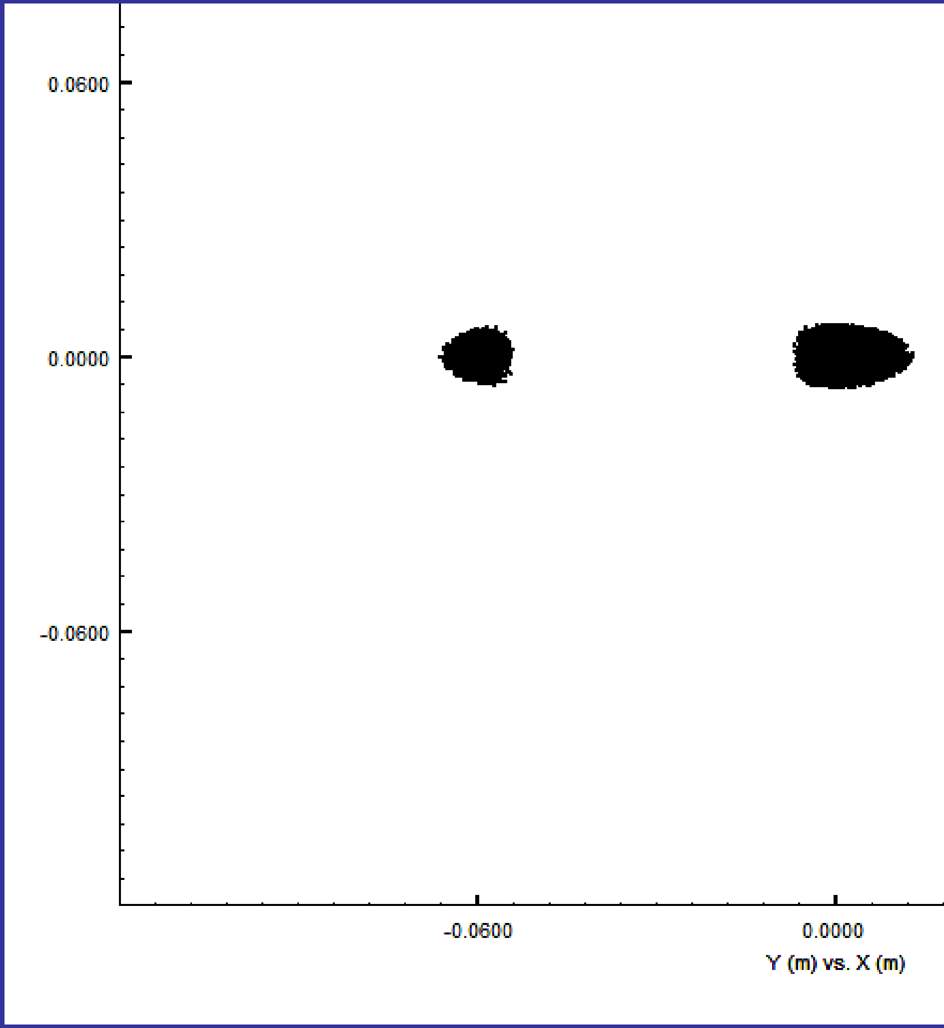


HP = HARP
FC = FARADAY CUP
BPM = BEAM POSITION MONITOR

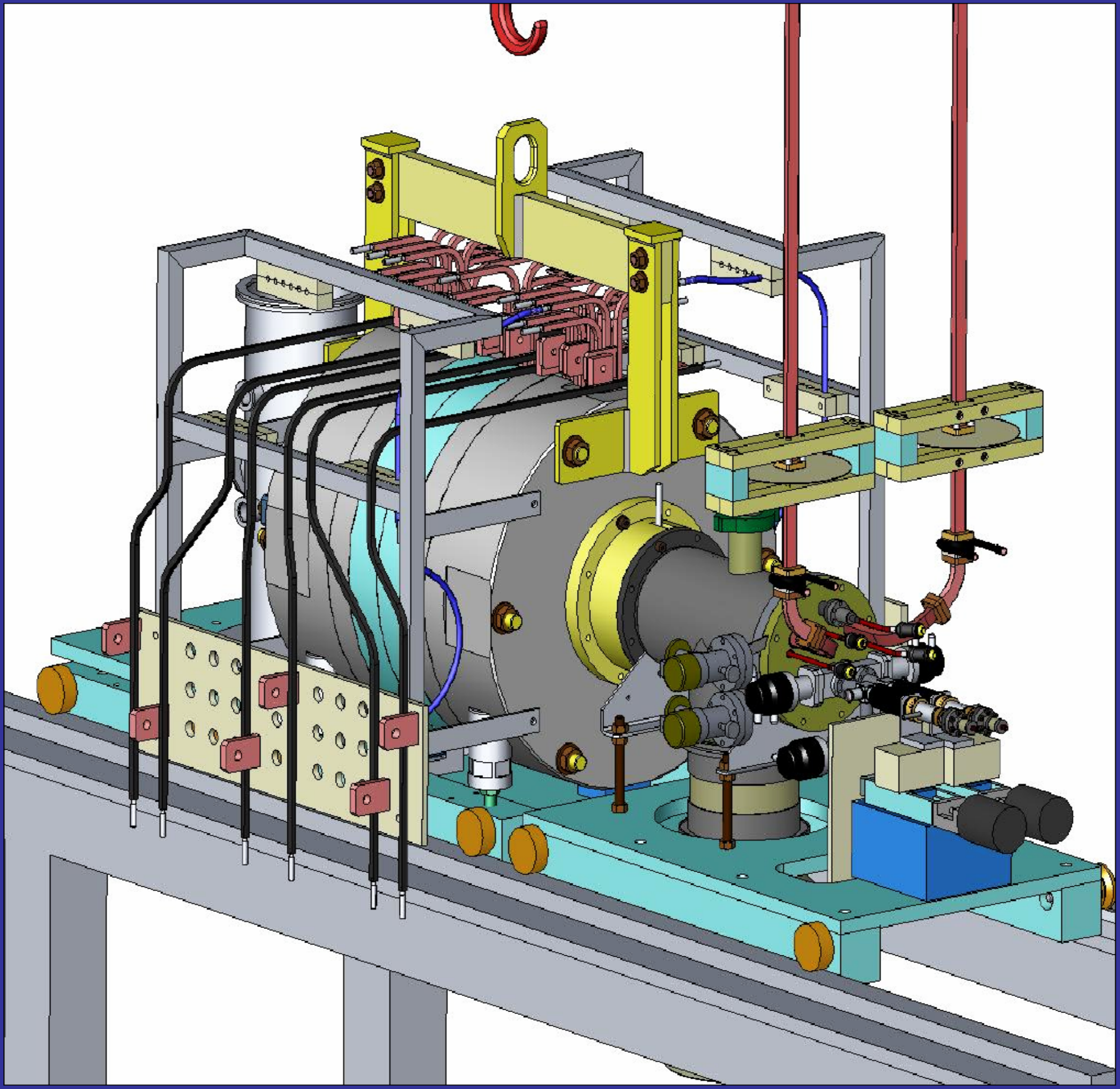
Beam direct behind the electrostatic channel



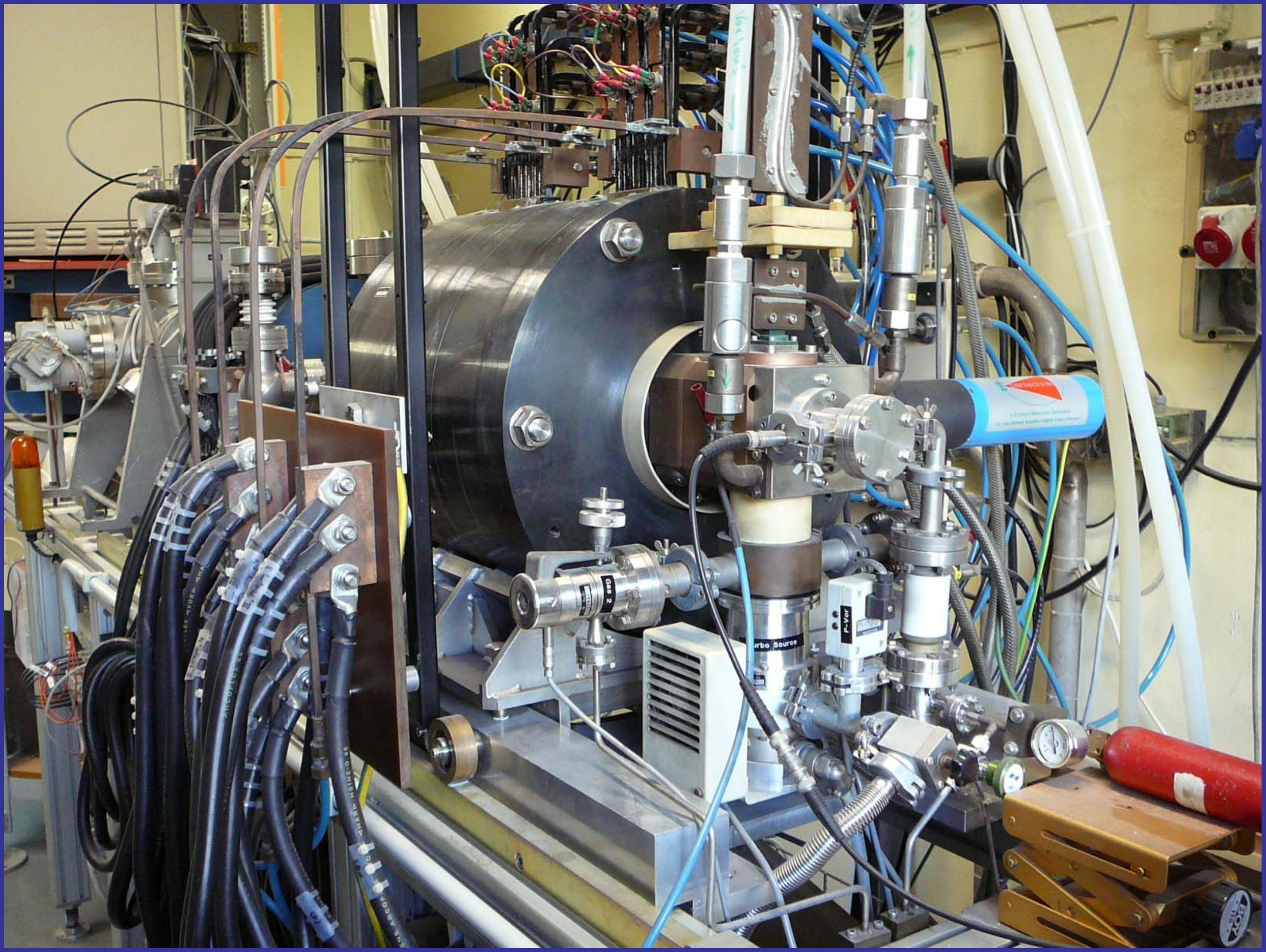
Beam in front of the magnetic channel



Grenoble GTS 14 GHz and 18 GHz ECR Ion Source



HMI 14.5 GHz ECR Ion Source



Radioisotopes produced at iThemba LABS

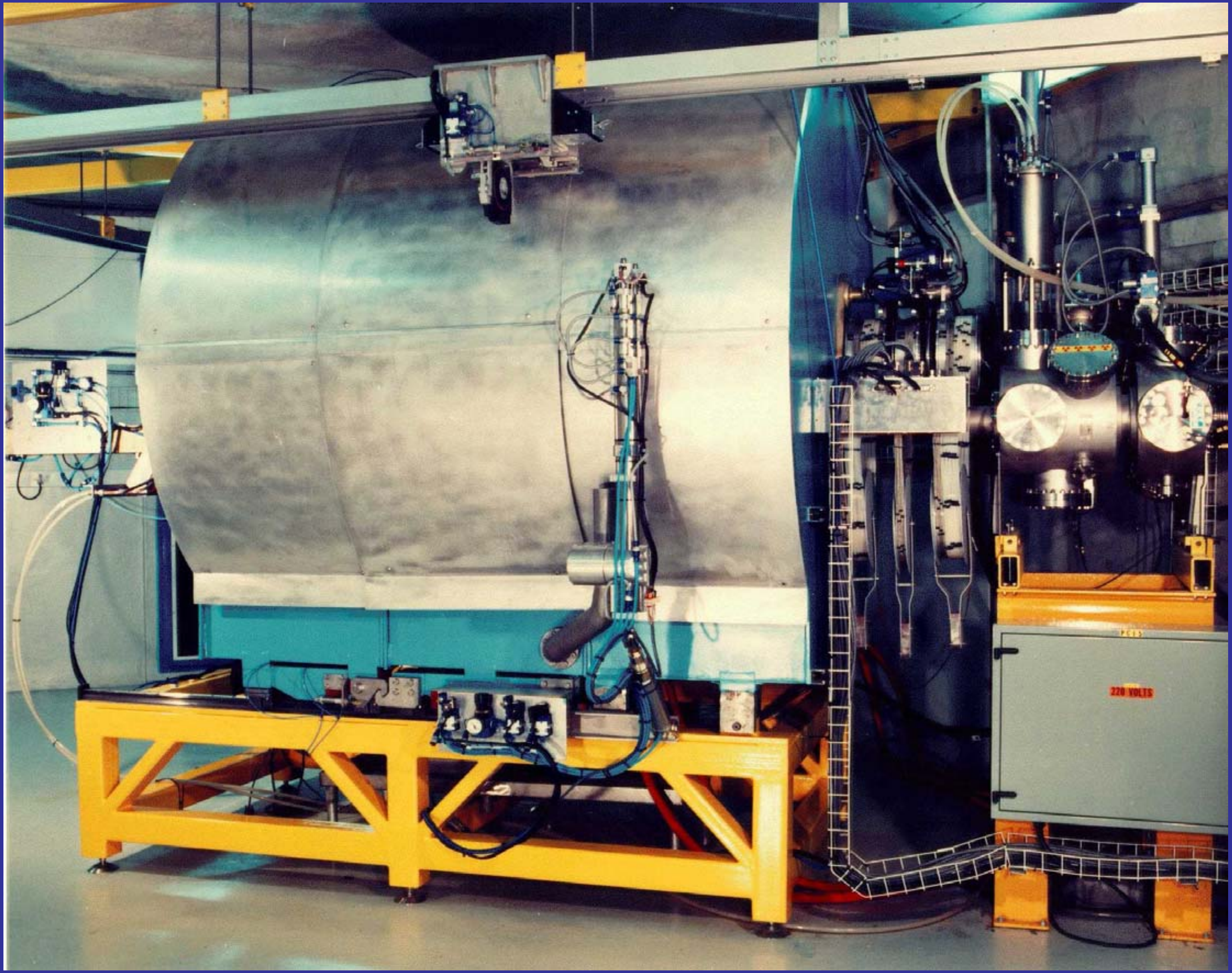
- Currently, iThemba LABS weekly produces the medical radioisotopes ^{67}Ga, ^{123}I and ^{81}Rb for the preparation of radiopharmaceuticals for local users

- ^{68}Ge and ^{82}Sr are produced for the Department of Energy (DOE) of the United States of America for use in medical generators to obtain the PET radioisotopes ^{68}Ga and ^{82}Rb, respectively

- ^{22}Na is produced for the manufacture of ^{22}Na positron sources

- Other radioisotopes, such as ^{52}Fe, ^{55}Fe, ^{88}Y, ^{103}Pd, ^{111}In, ^{133}Ba, ^{139}Ce, and ^{201}Tl are also be produced on order,

Bombardment station 1



The k=600 Magnetic Spectrometer

A kinematically corrected QDD spectrometer for light particles

70 mrad acceptance

Resolution: 26 keV at 200 MeV
Dispersion matched
"Faint beam method"

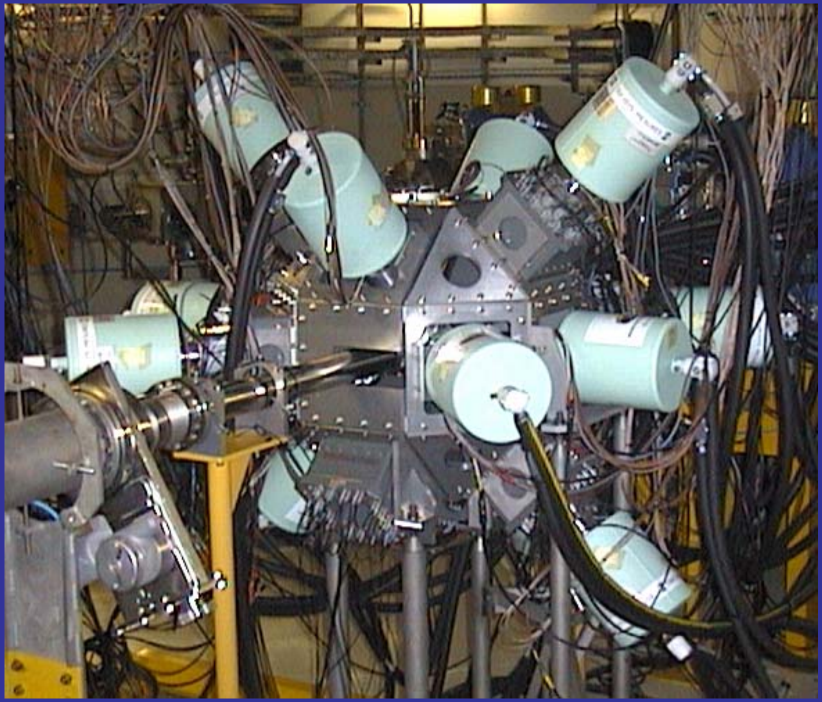
Developing a zero degree mode of operation for proton inelastic scattering

•Studies of M1 transitions in (p,p')

Experiments:

•High resolution knock-out reactions e.g. (p,2p) and (p,pα)
•Decay of giant resonances in (p,px) for x=n,p, α
•Fine structure in giant resonances with ^{208}Pb,^{90}Zr(p,p')
•Study of mixed symmetry state

Afrodite γ-detector array



8 escape suppressed clover detectors
Efficiency: 1.6% at 1.33 MeV

8 segmented planar Ge detectors
Efficiency: 6% at 100 keV

γ- Spectroscopy Experiments:

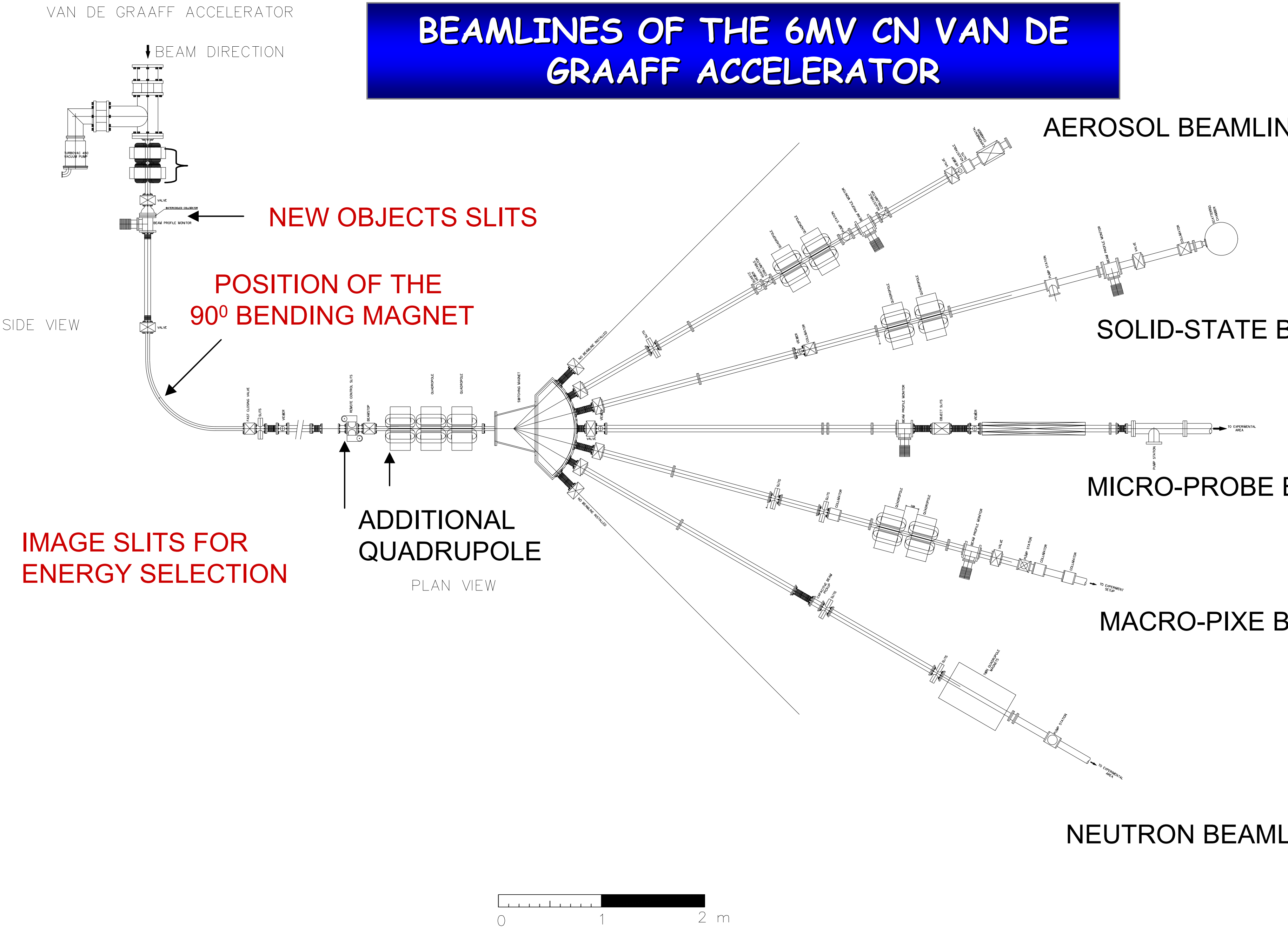
- Dipole bands in ^{195,197}Bi
- Searches for chirality
- Signature splitting and inversion in ^{164,165}Ta
- Low energy transitions in ^{197,198}Tl
- Lifetimes of ns isomers

New development for AFRODITE

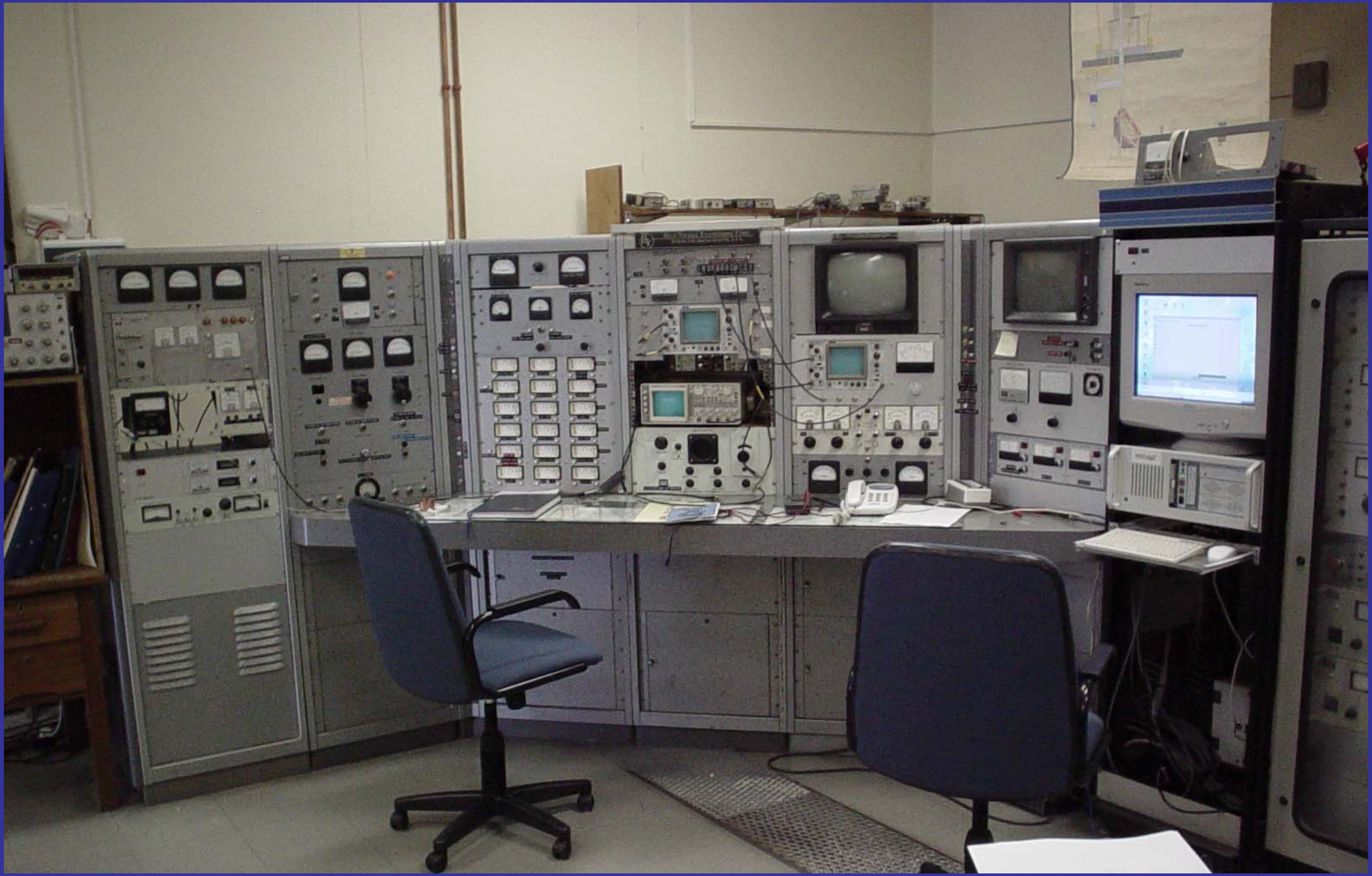
- DIAMANT (*4π array of CsI detectors for particle-γ coincidences)* on loan for short periods (collaboration with ATOMKI (Hungary)
- *Electron spectrometers (from Orsay) for e^{-} -γ coincidences*
- *Recoil detector for exit channel selection*

Neutron Therapy

BEAMLINES OF THE 6MV CN VAN DE GRAAFF ACCELERATOR

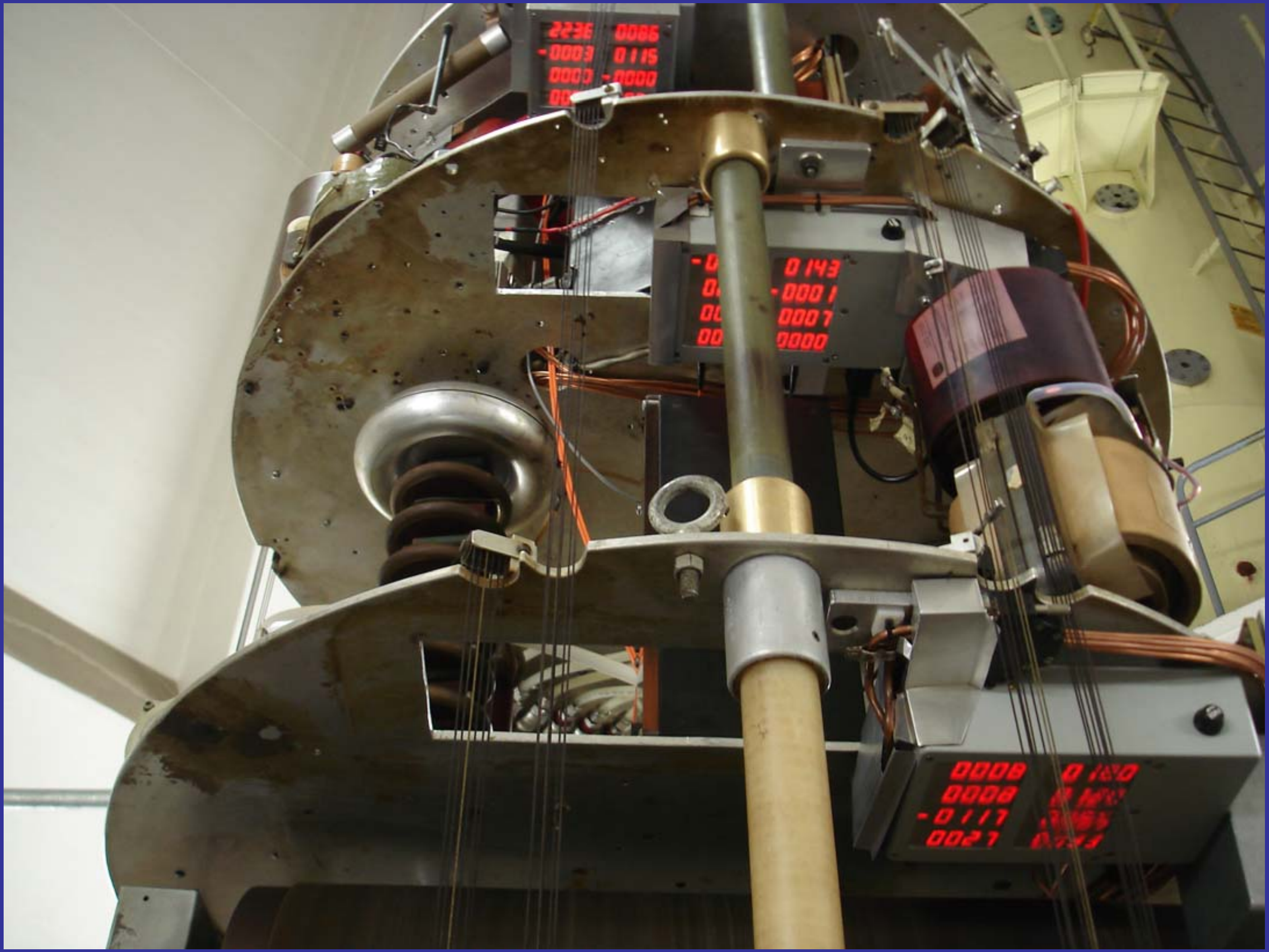


Control room 6MV Van de Graaff 2003

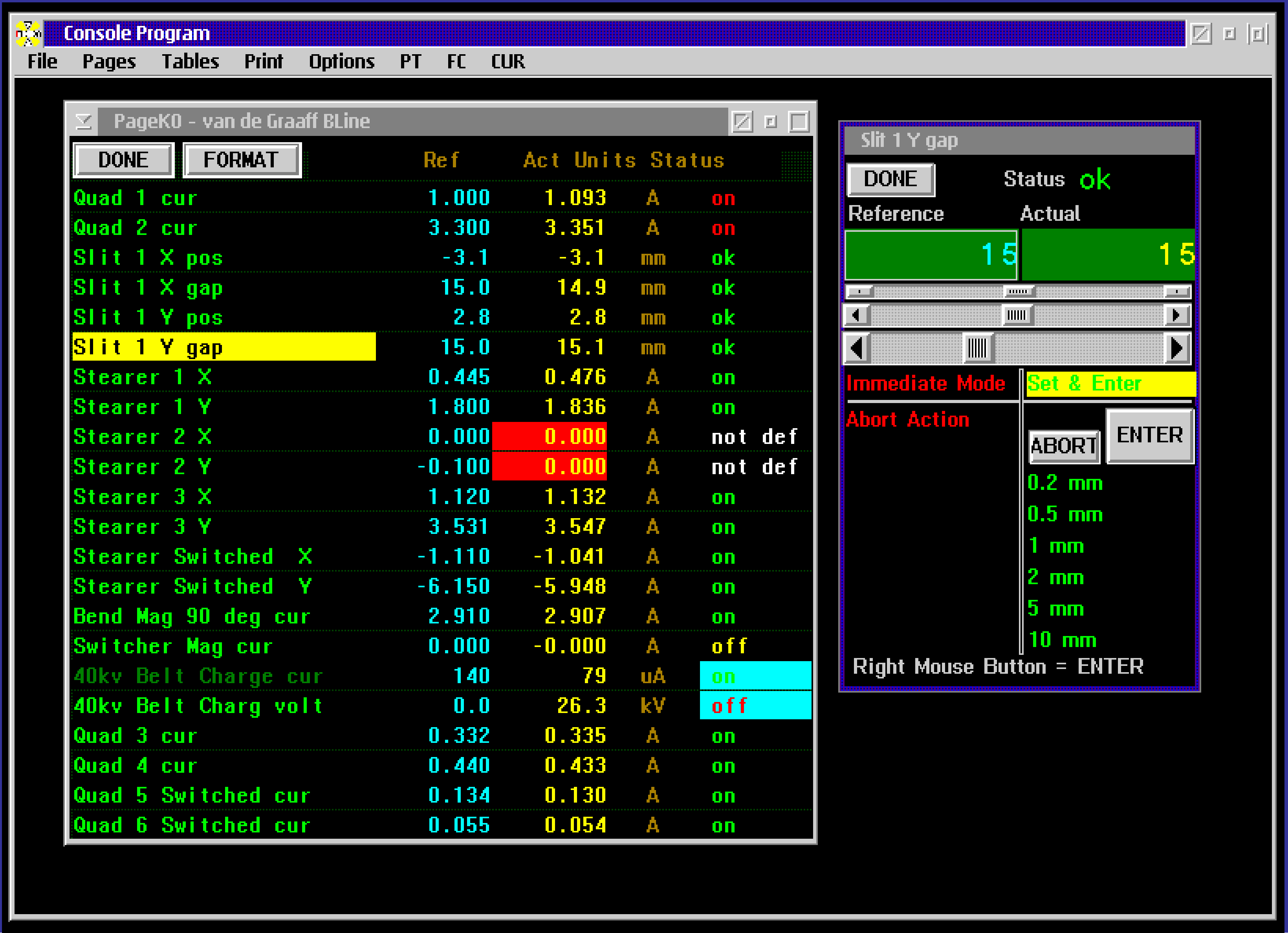


Control room Van de Graaff accelerator 2007

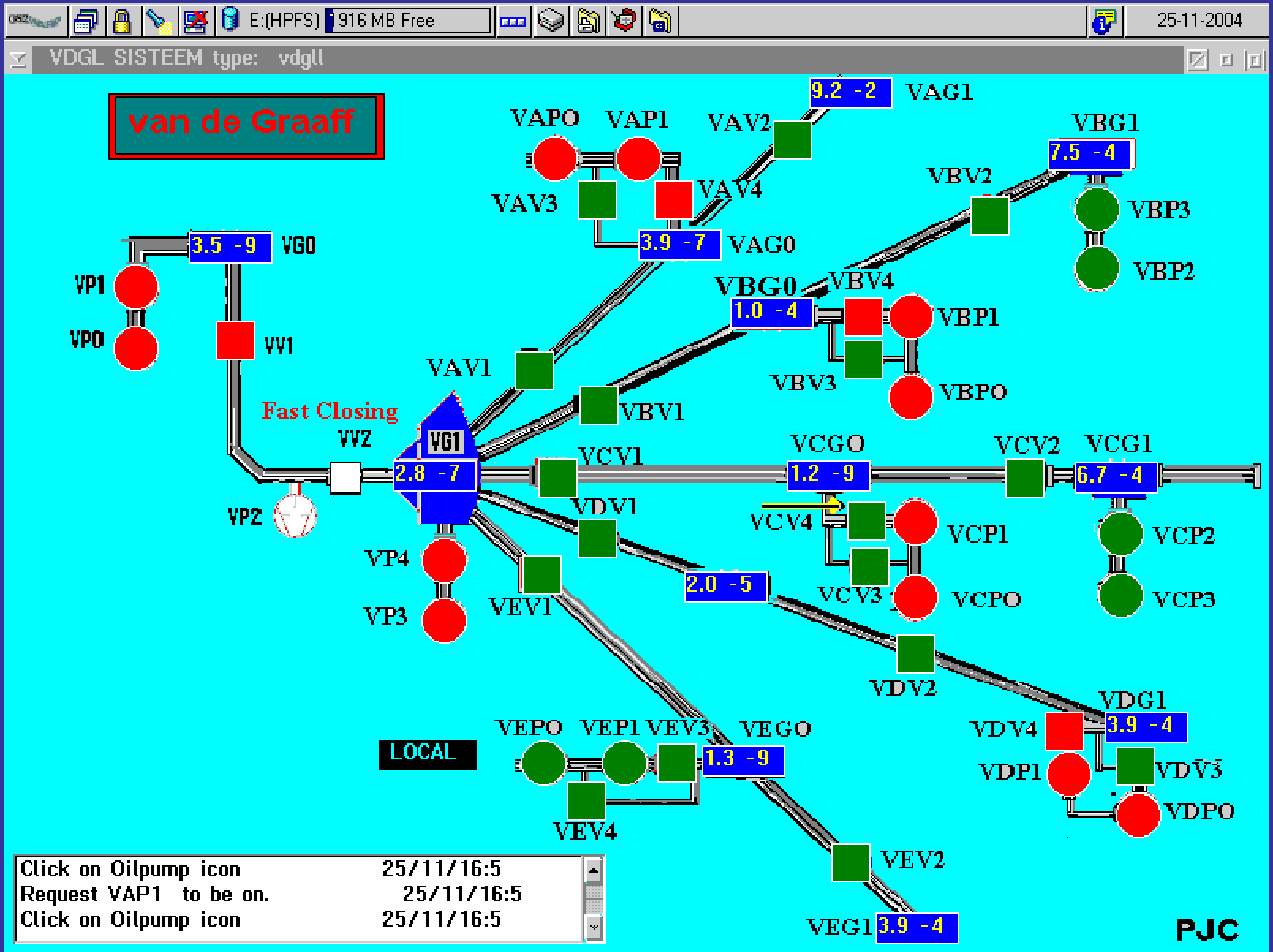
24 Digital meters installed in the terminal of the 6 MV CN Van De Graaff



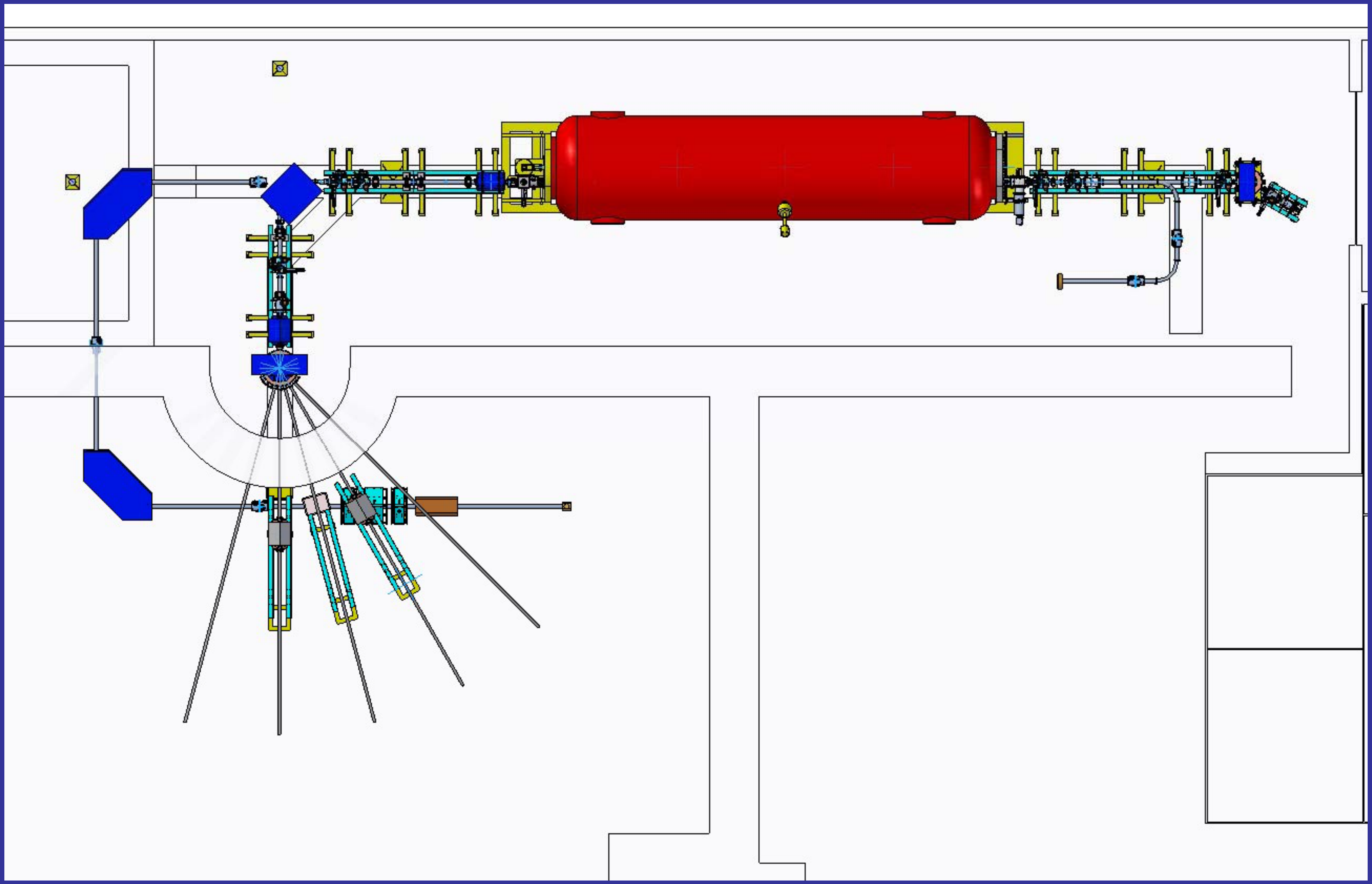
Control page for the power supplies and slits



Control page of the vacuum system



Proposed layout of beam lines for AMS of the 6MV EN tandem accelerator

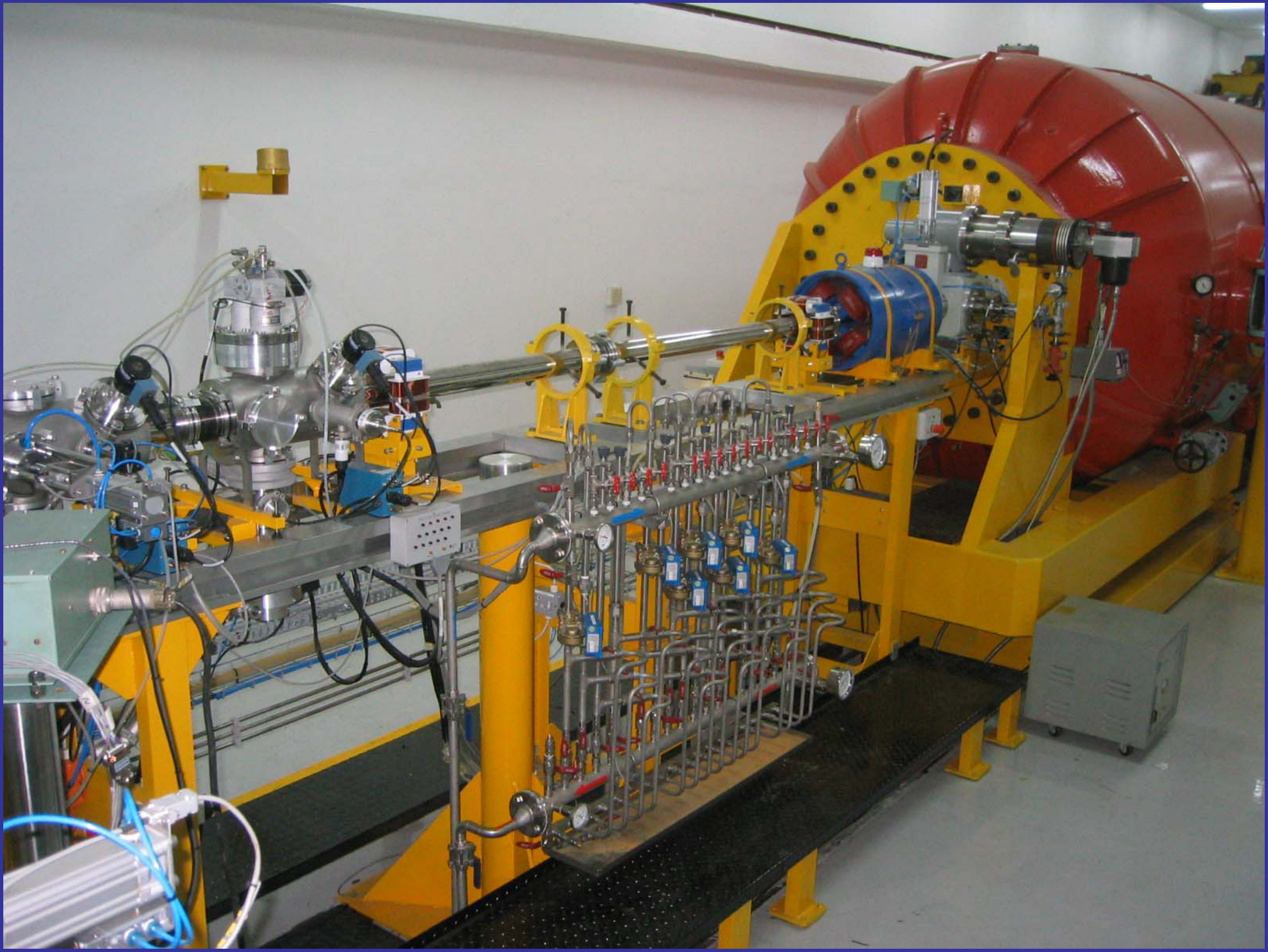


Extraction side of the 6 MV EN Tandem before the refurbishment

Accelerator injection

Injection side of the tandem accelerator after refurbishments

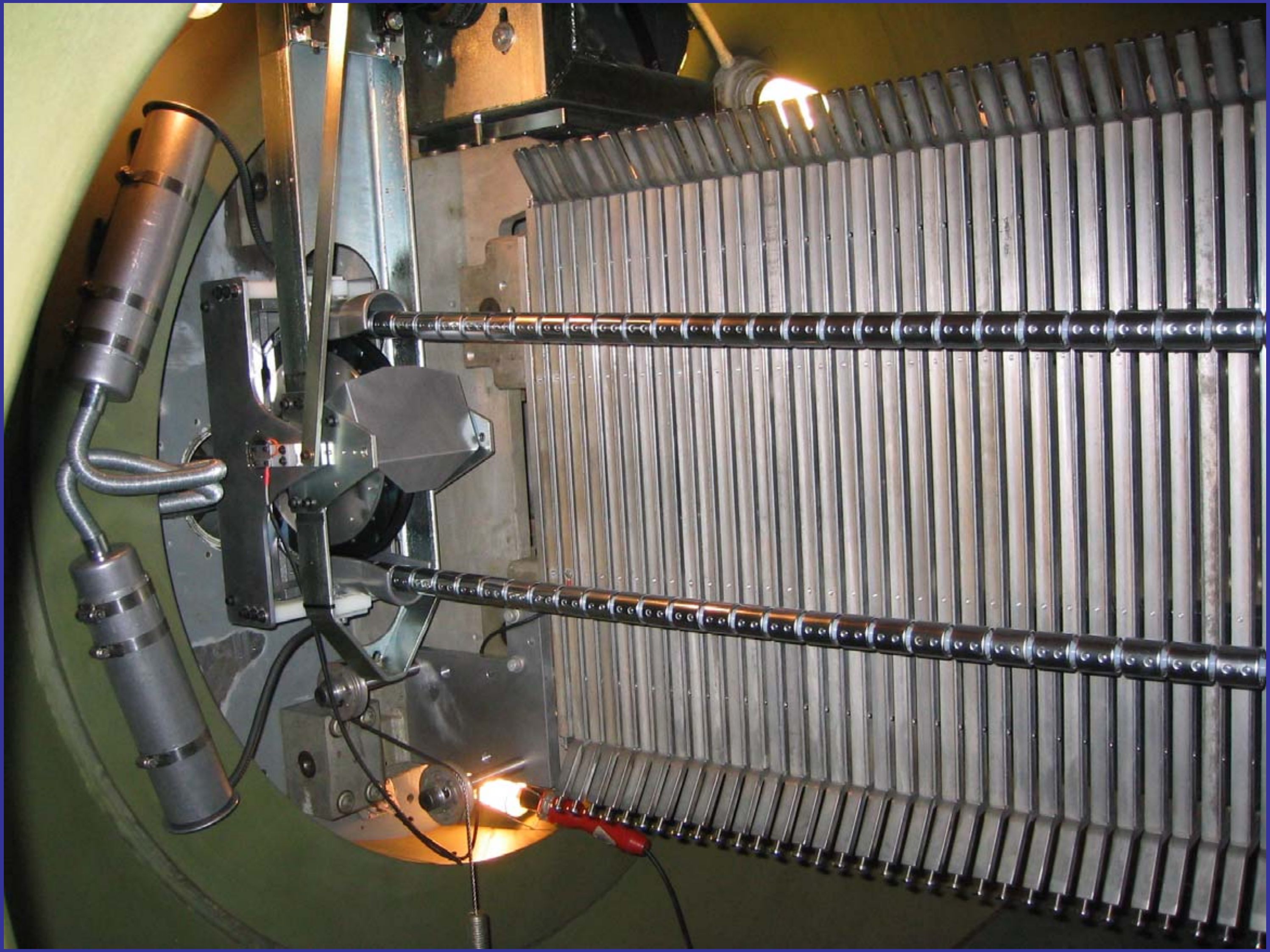
Extraction beam line of tandem accelerator



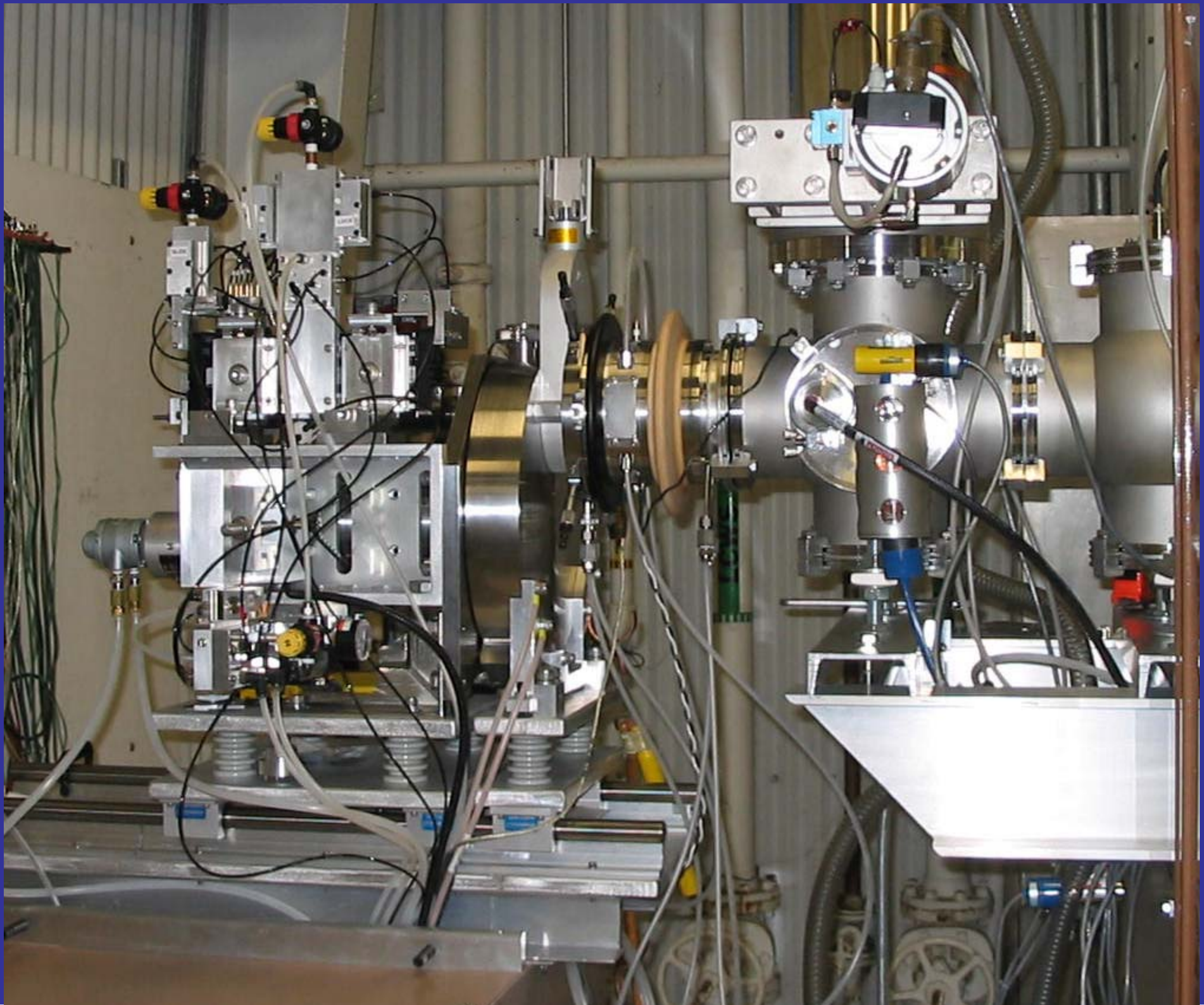
Removing the tubes of the tandem

The resistor chain

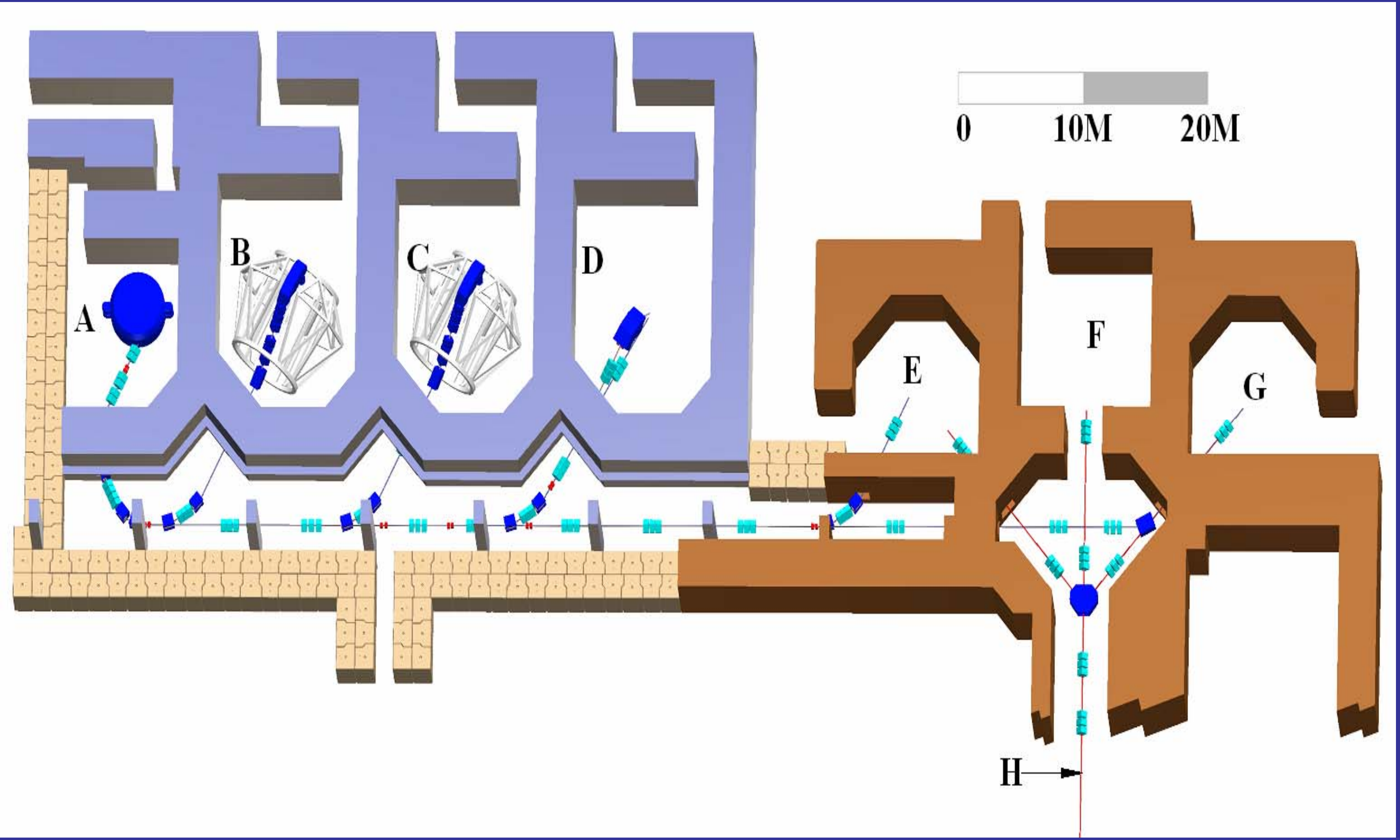
Pelletron Chain



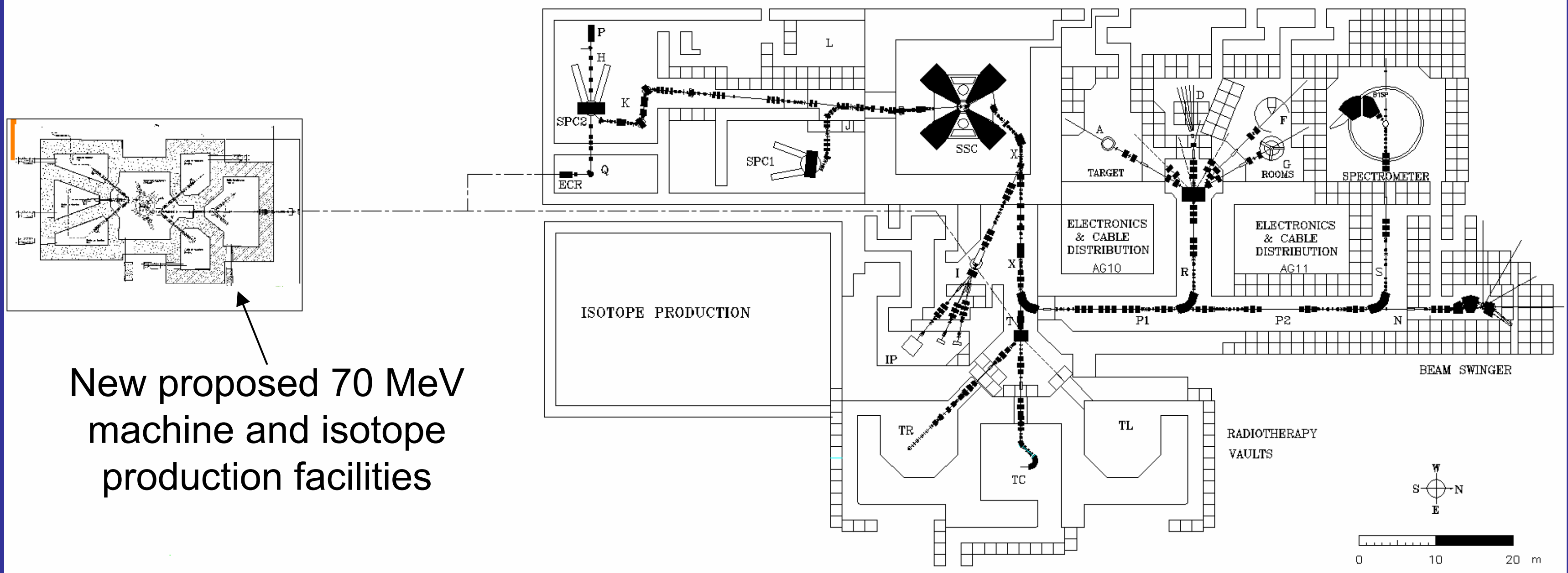
We are in the process of building a Multi cathode Source of Negative Ions by Cesium Sputtering base on the LLNL design (foto) for AMS



New dedicated facility for proton therapy

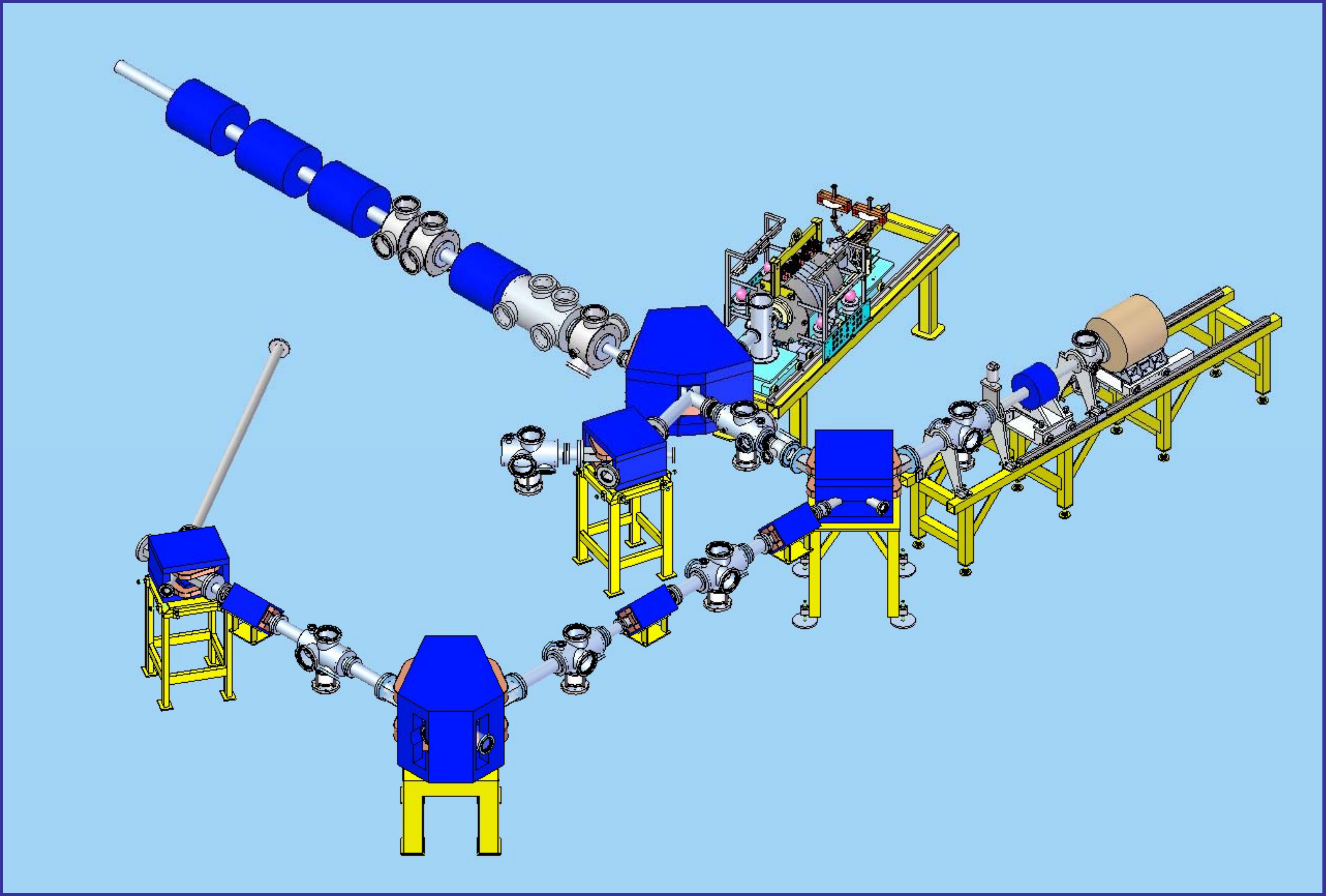


Future dedicated 70 MeV H$^-$ accelerator for isotope production, neutron therapy and radioactive beams



New proposed 70 MeV machine and isotope production facilities

ECR vault layout



Display of the Halo Monitors

Radioisotopes produced with high-energy beams

iThemba LABS is one of a few facilities that utilises proton beam energies significantly above 30 MeV for large-scale production of radioisotopes.

High-energy proton accelerators have a definite use for the production of radioisotopes, e.g.

- ^{68}Ge: (p,4n) nuclear reaction on ^{71}Ga – increases production yield of ^{68}Ge significantly when added to the yield of the (p,2n) reaction on ^{69}Ga
- ^{82}Sr: (p,4n) nuclear reaction on ^{85}Rb
- ^{123}I: (p,5n) nuclear reaction on ^{127}I via the ^{123}Xe precursor
- ^{22}Na: (p,xn) nuclear reaction on ^{nat}Mg; ^{25}Mg(p,α)^{22}Na; ^{26}Mg(p,nα)^{22}Na
- ^{67}Ga: (p,4n) nuclear reaction on ^{nat}Ge (in tandem with Zn gives 2.5 times more activity than only a Zn target)

Radioisotopes produced at iThemba LABS

- Currently, iThemba LABS produces weekly the medical radioisotopes ^{67}Ga, ^{123}I and ^{81}Rb and these radioisotopes are used to prepare radiopharmaceuticals for the local users

- ^{68}Ge and ^{82}Sr are produced for the Department of Energy (DOE) of the United States of America for use in medical generators to obtain the PET radioisotopes ^{68}Ga and ^{82}Rb, respectively.

- ^{22}Na is produced to manufacture ^{22}Na positron sources.

- Other radioisotopes, such as ^{52}Fe, ^{55}Fe, ^{88}Y, ^{103}Pd, ^{111}In, ^{133}Ba, ^{139}Ce, and ^{201}Tl can also be produced on order,

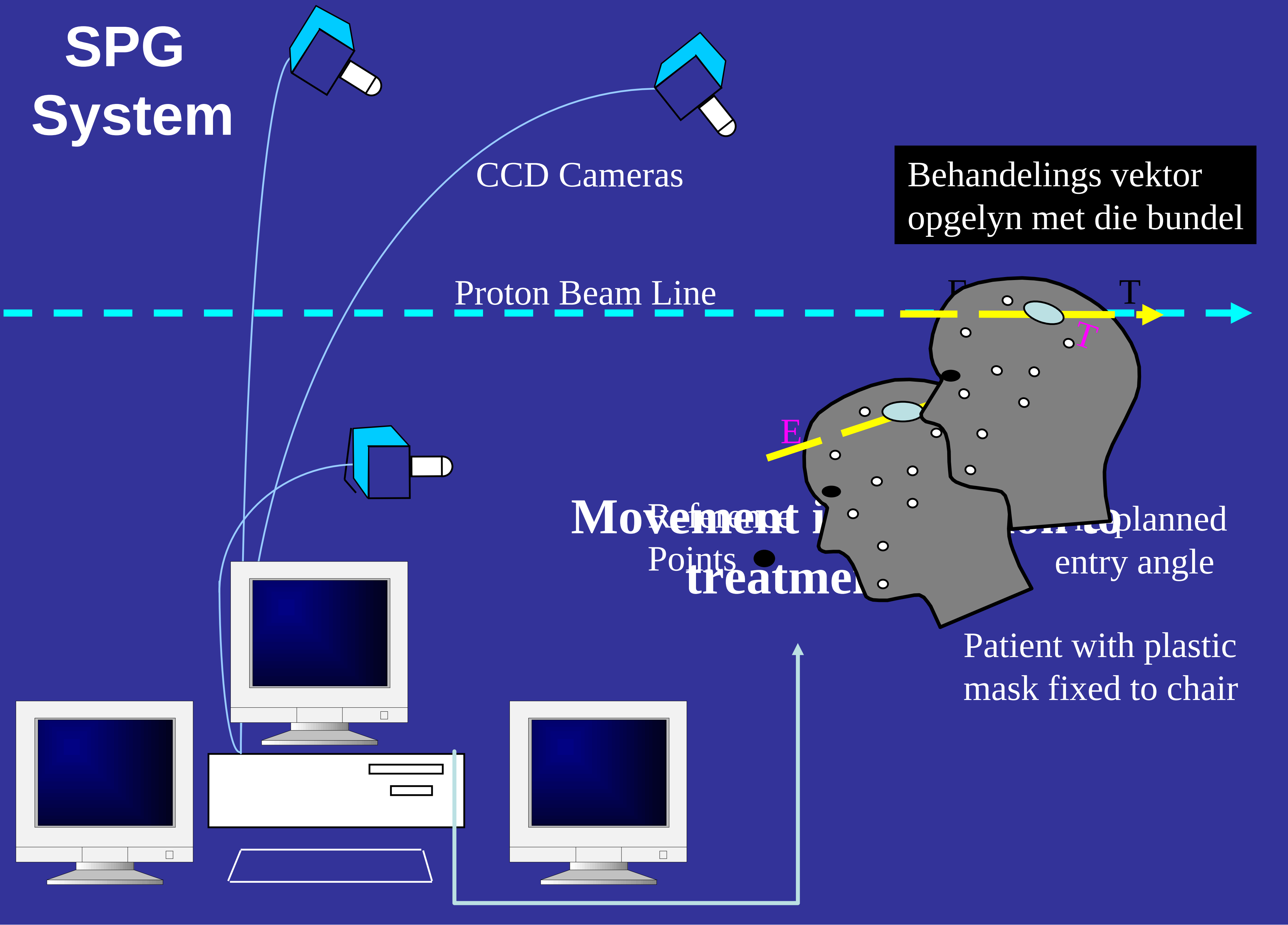
- A wider range of radionuclides will be produced when the new vertical beam target station (VBTS) becomes operational.

Summary of current status

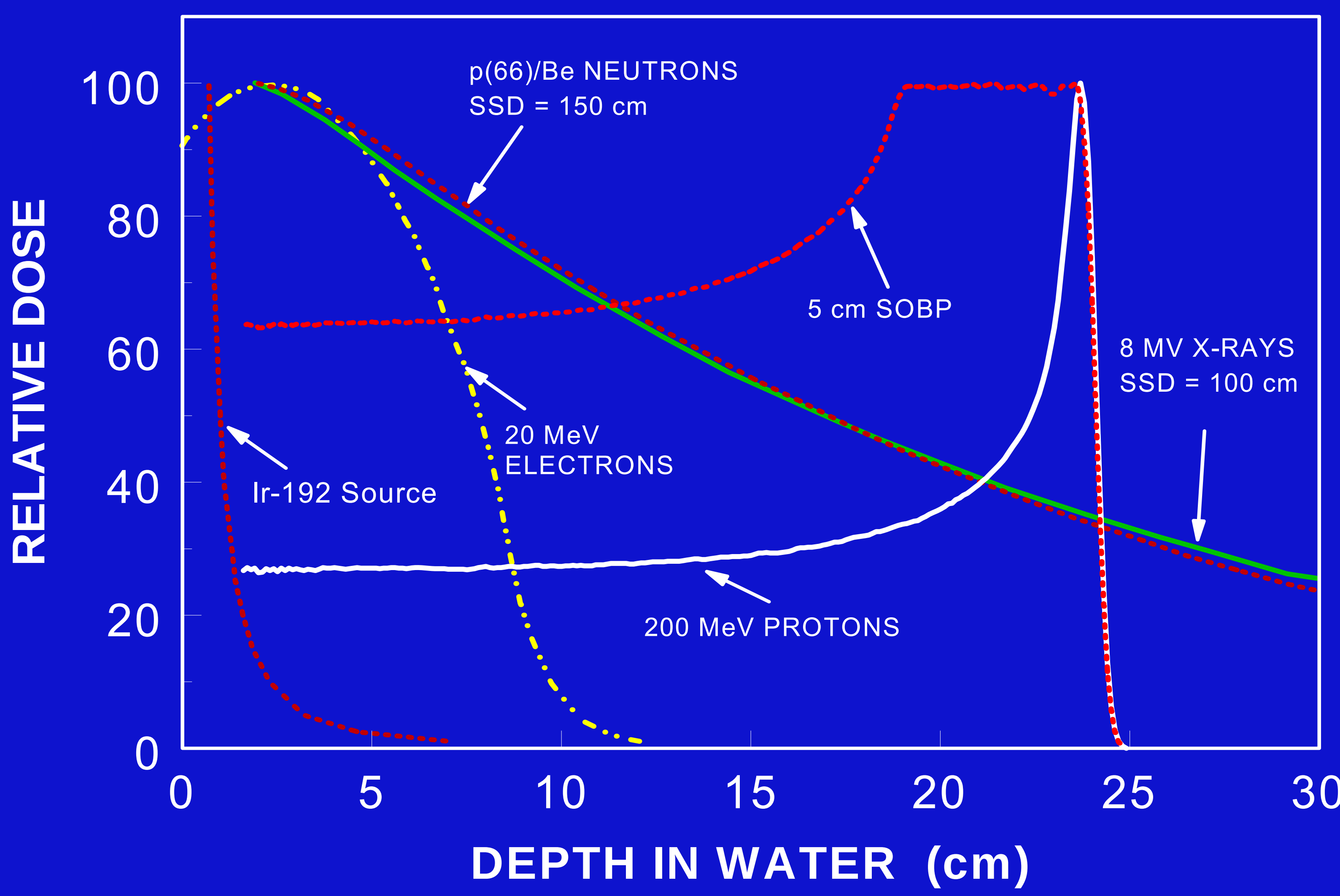
Refurbishment is now 98% completed First beam delivered, up to the faraday cup in front of experimental setup on the 31 May 2007. The official inauguration of the upgrade facility was on the 3 June 2007.

- Charging belt replaced with Pelletron Charging System
- New acceleration tubes installed
- Gas stripper being converted to recirculating gas stripper
- Voltage grading resistors renewed
- Terminal Potential Stabilizer (TPS) system installed
- Beam optics calculated and beamlines remodeled
- New diagnostic equipment designed (Faraday Cup, Slits)
- New vacuum chambers manufactured and installed
- Vacuum system automated and improved
- New central computer control system 95% completed
- Complete the project within the budget
- Completed the two year project three month behind schedule due to additional task which was not initially part for refurbishment.

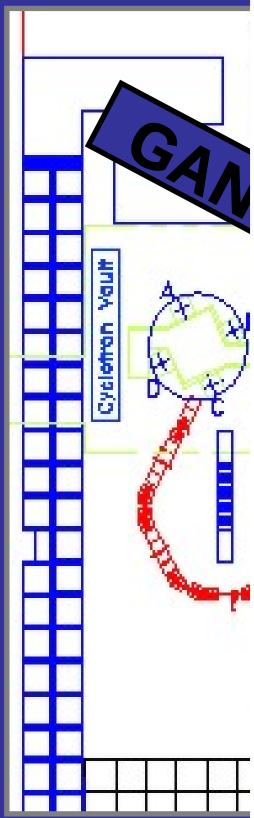
SPG System

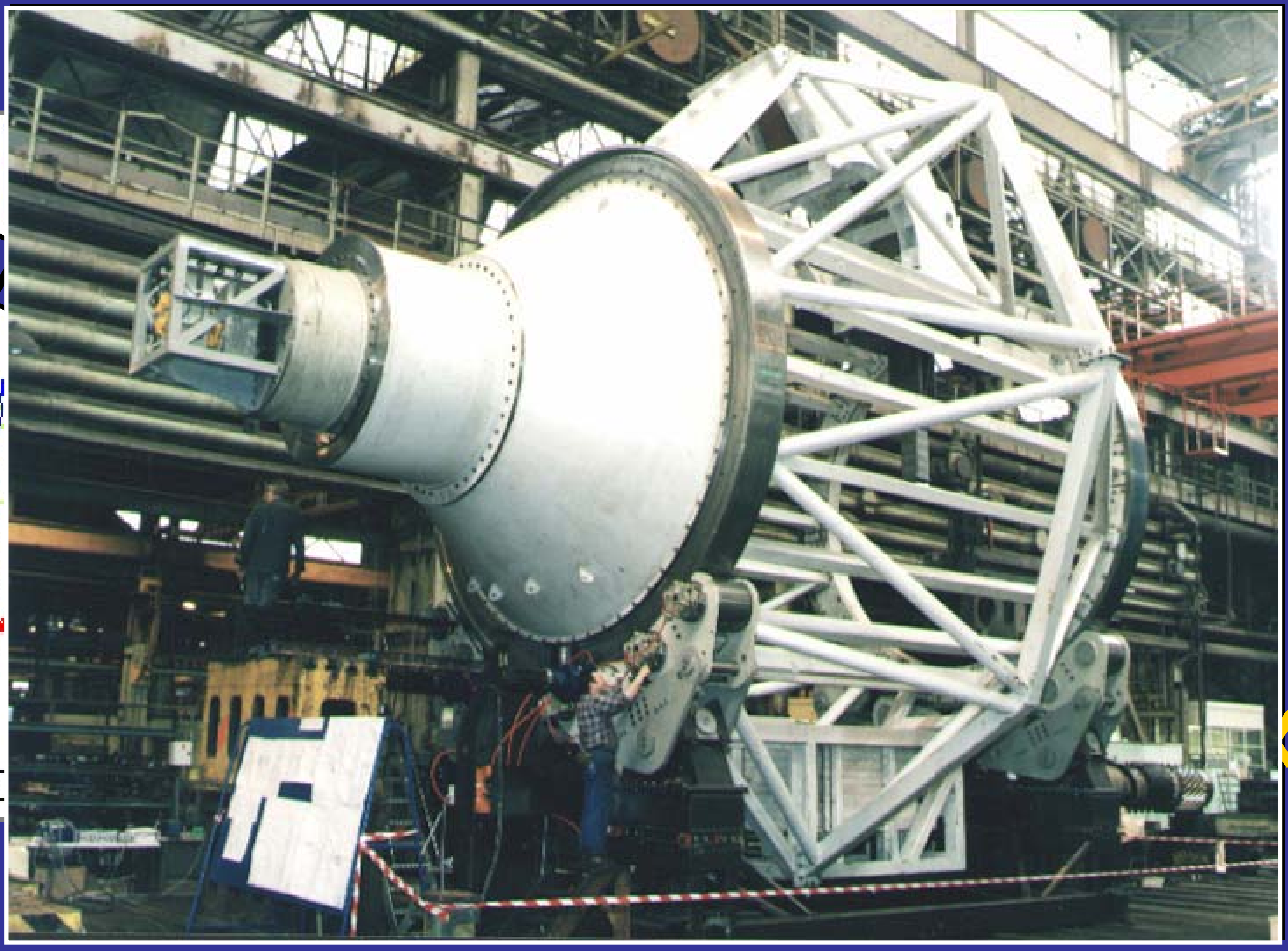

CCD Cameras
Behandelings vektor opgelyn met die bundel
Proton Beam Line
T
E
T
Reference Points
planned entry angle
Patient with plastic mask fixed to chair

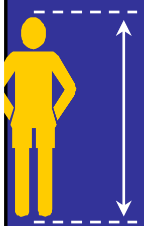
Depth dose curves for different treatment modalities



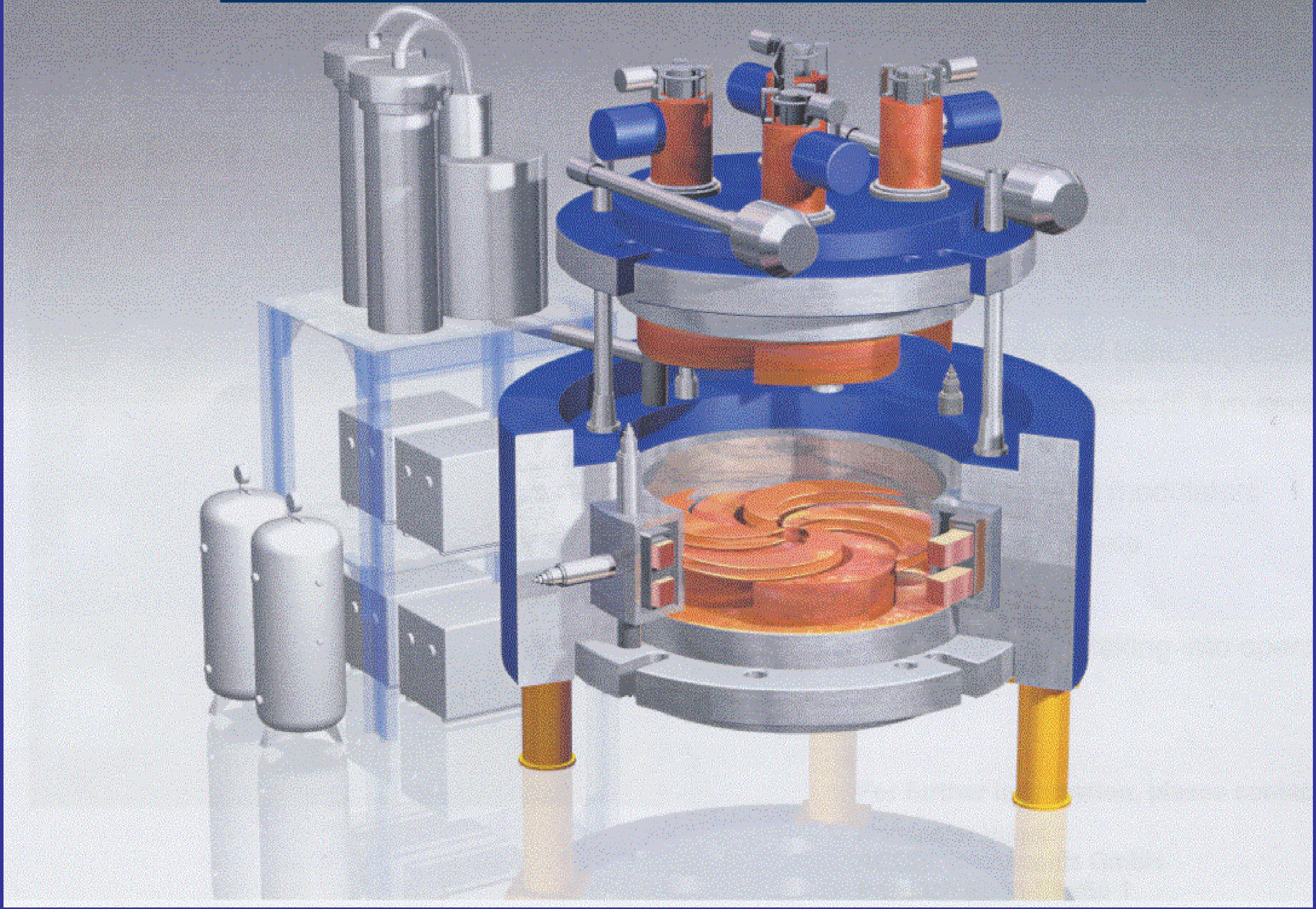
Isosentriese Gantry



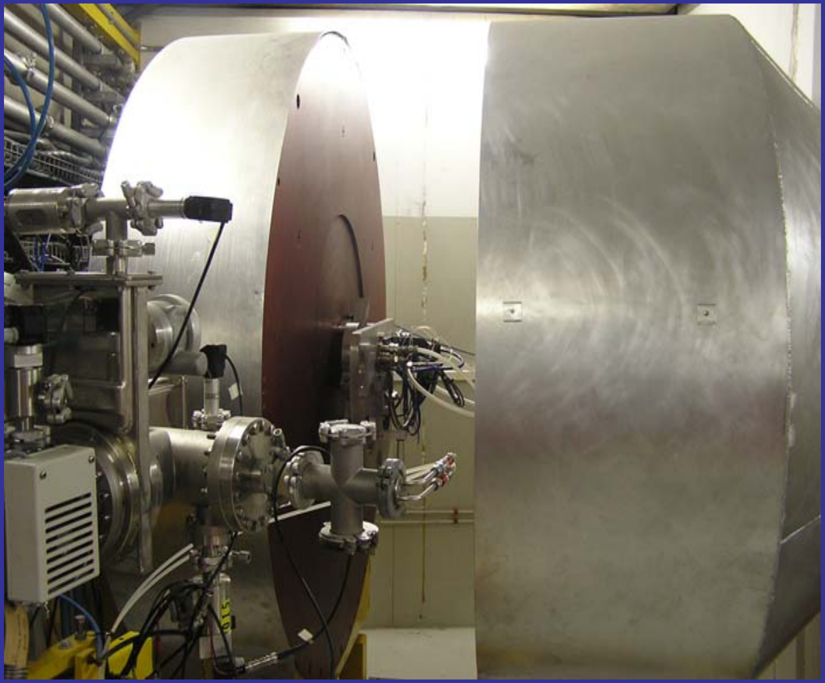




Superconducting 250 MeV cyclotron - ACCEL

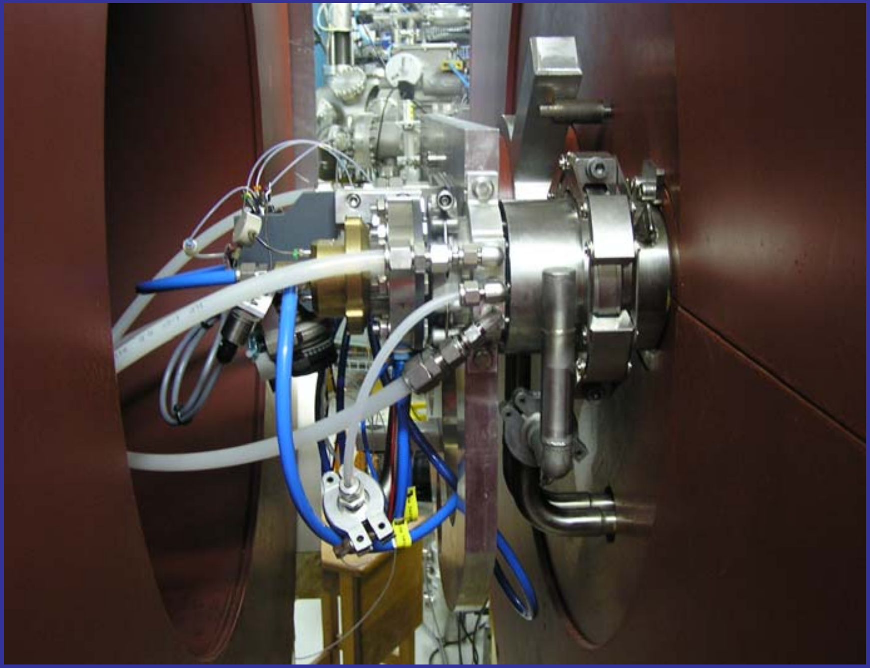


Bombardment Station - ^{18}F



^{18}F Target Station

Produce: ^{18}F



Enriched water target

Chemical Processing Facilities

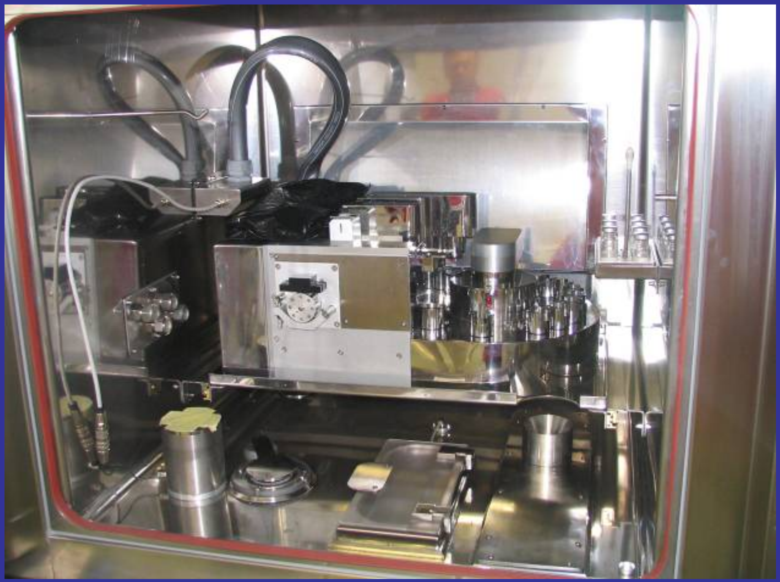
^{18}F-Automated Chemical Processing Hot Cells

Manual Manipulator Hot Cells

Transport system

Dispensing / Quality Control Facilities

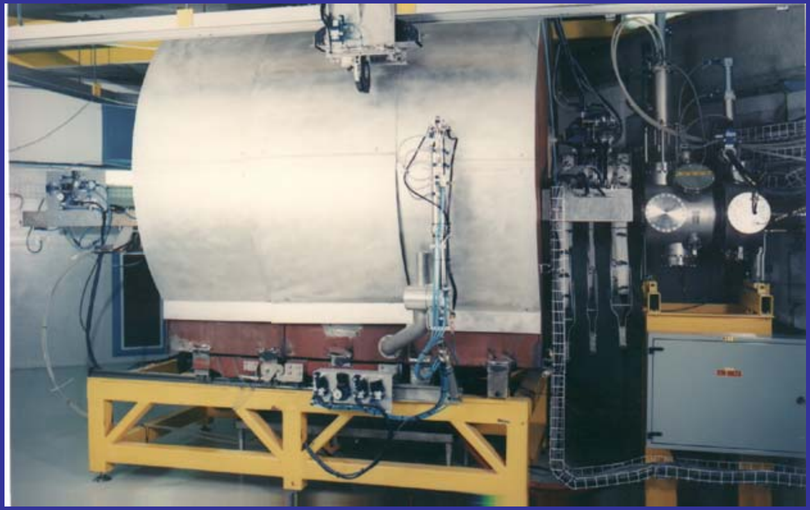
^{18}F-FDG Dispensing Clean Room



^{18}F-FDG Automated Dispensing Unit

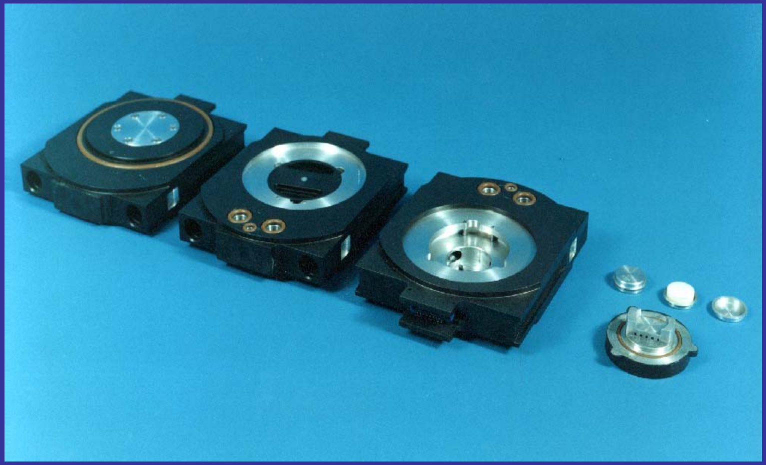
Quality Control

Bombardment Station-HBTS



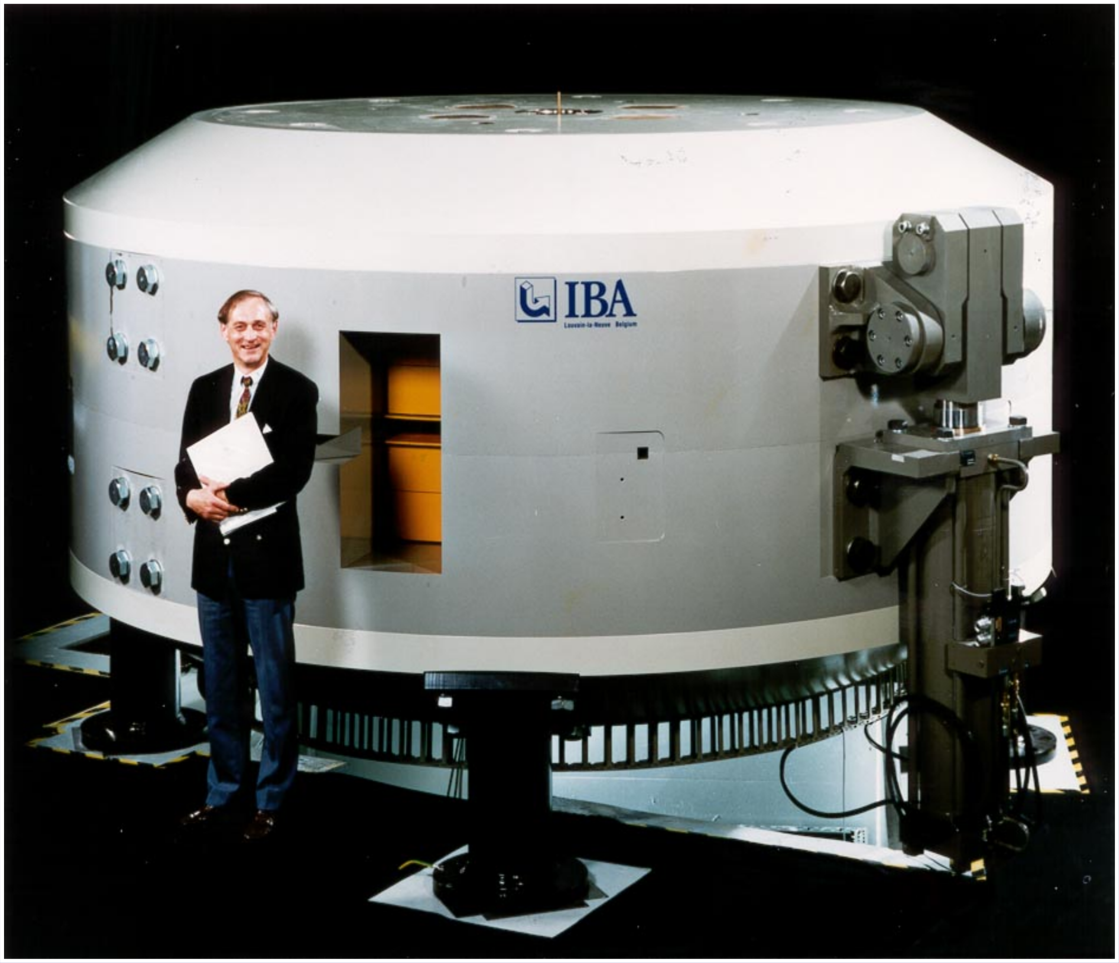
Horizontal Beam Target Station (HBTS)

Produce: ^{67}Ga, ^{123}I, ^{81}Rb, ^{22}Na, ^{88}Y, ^{57}Co and ^{109}Cd,



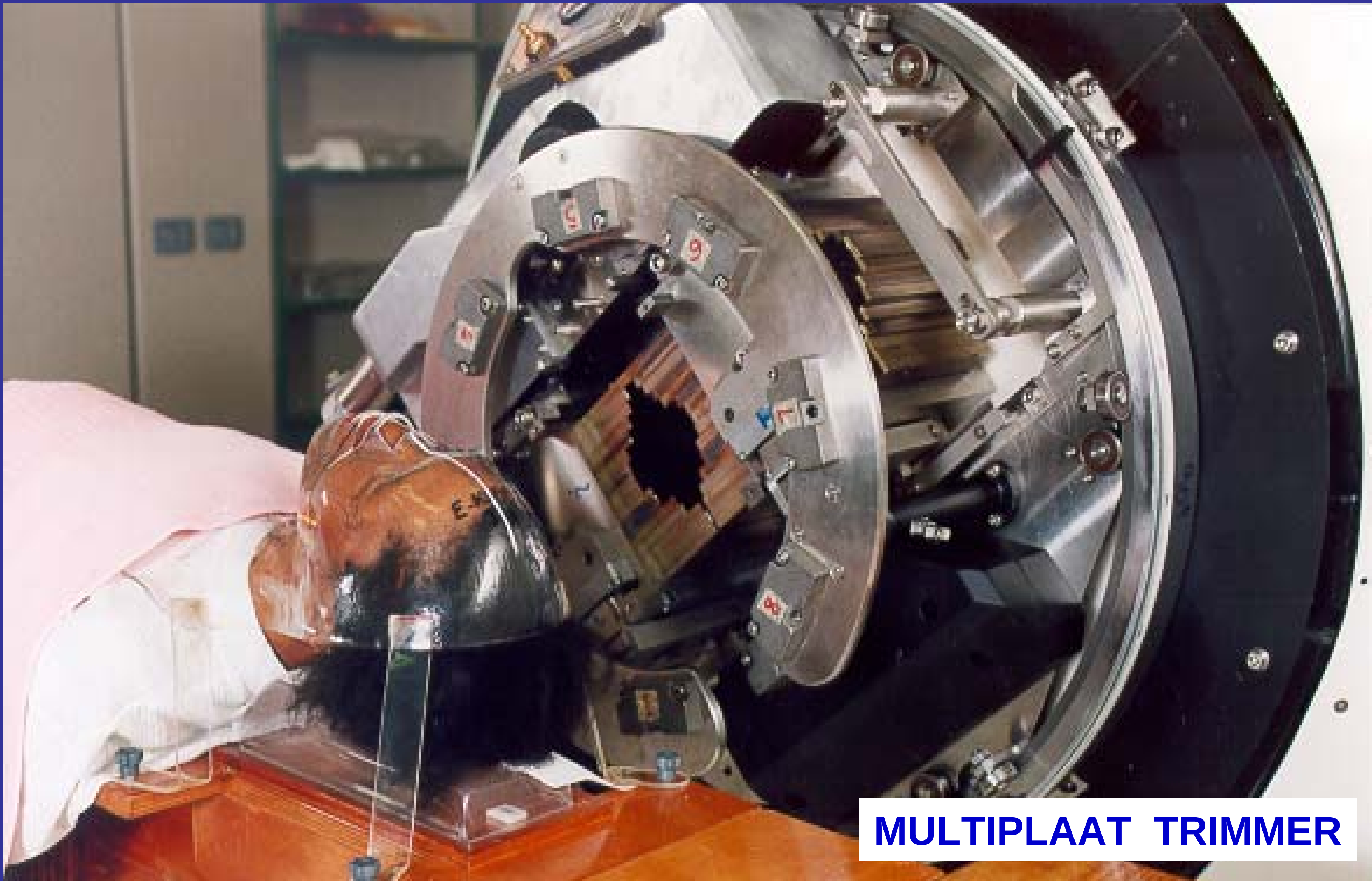
HBTS Target and target holders

230 MeV room-temperature cyclotron from IBA



Control room Van de Graaff accelerator

Injection side of the tandem accelerator after refurbishments



MULTIPLAAT TRIMMER

Bombardment Station-VBTS

Vertical Beam Target Station (VBTS)

Produce: ^{82}Sr and ^{68}Ge in tandem

VBTS Thick Target Holders

Radioisotopes produced with high-energy beams

iThemba LABS is one of a few facilities that utilises proton beam energies significantly above 30 MeV for large-scale production of radioisotopes.

High-energy proton accelerators have a definite use for the production of radioisotopes, e.g.

- ^{68}Ge: (p,4n) nuclear reaction on ^{71}Ga – increases production yield of ^{68}Ge significantly when added to the yield of the (p,2n) reaction on ^{69}Ga
- ^{82}Sr: (p,4n) nuclear reaction on ^{85}Rb
- ^{123}I: (p,5n) nuclear reaction on ^{127}I via the ^{123}Xe precursor
- ^{22}Na: (p,xn) nuclear reaction on ^{nat}Mg;
  $^{25}Mg(p,\alpha)^{22}Na$; $^{26}Mg(p,n\alpha)^{22}Na$
- ^{67}Ga: (p,4n) nuclear reaction on ^{nat}Ge (in tandem with Zn gives 2.5 times more activity than only a Zn target)

Current Radiopharmaceuticals in routine production

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

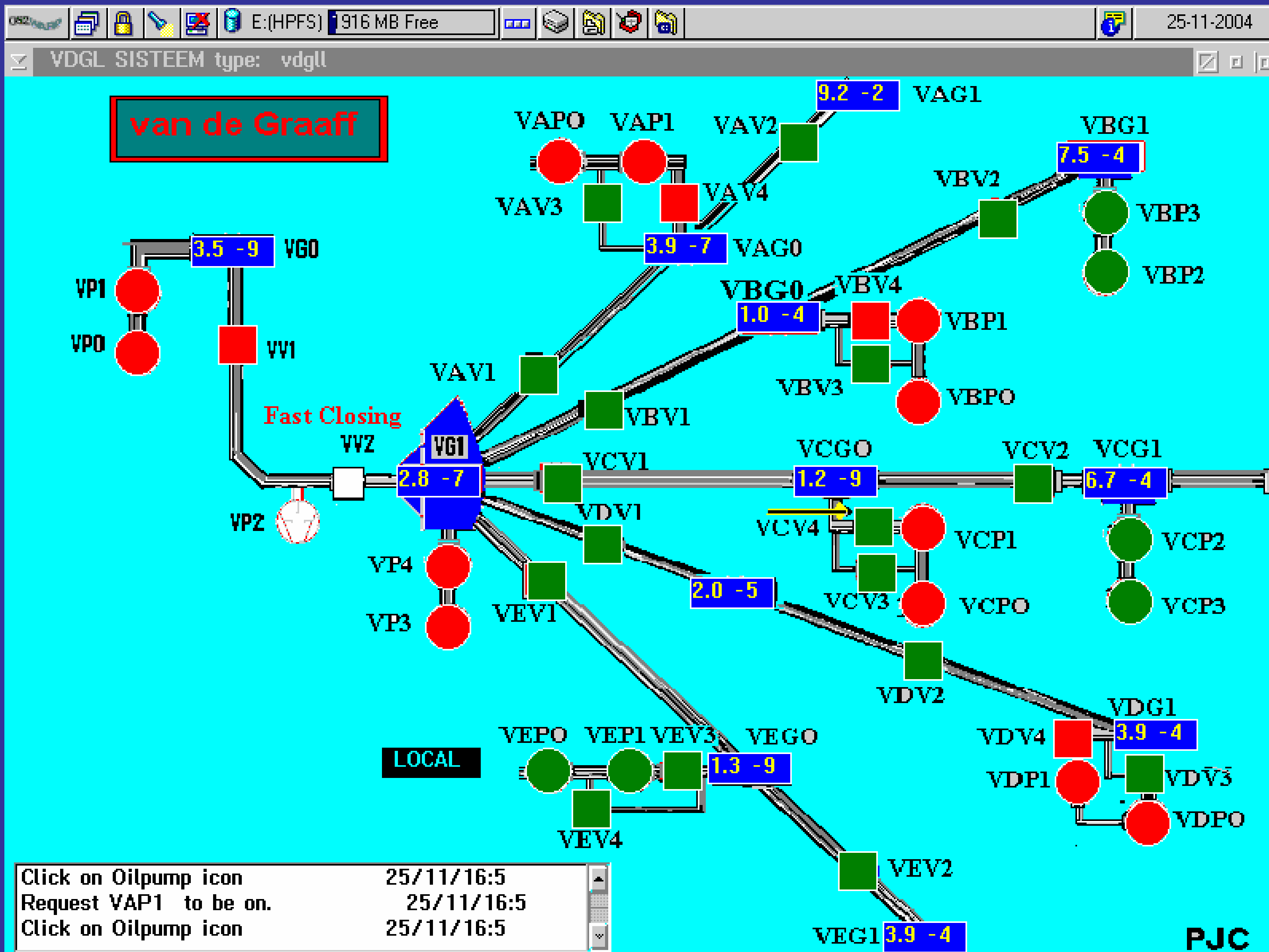
Current Radionuclides in routine production list continue

Radionuclide	Half-Life (days/years)	Nuclear Reaction	Product	Main Use
^{82}Sr	25 days	$Rb(p,xn)^{82}Sr$	Produced as a radionuclide	Used to manufacture $^{82}Sr/^{82}Rb$ generators
^{68}Ge	271 days	$Ga(p,xn)^{68}Ge$	Produced as a radionuclide	Used to manufacture $^{68}Ge/^{68}Ga$ generators or used for calibration of gamma camera's or PET CT scanners
^{88}Y	106.6 days	$Sr(p,xn)^{88}Y$	Produced as a radionuclide	Non –medical application
^{109}Cd	453 days	$Ag(p,xn)^{109}Cd$	Produced as a radionuclide	Non-medical application
^{22}Na	2.602 years	$Mg(p,n)^{22}Na$	Produced as a radionuclide	Positron Annihilation Studies

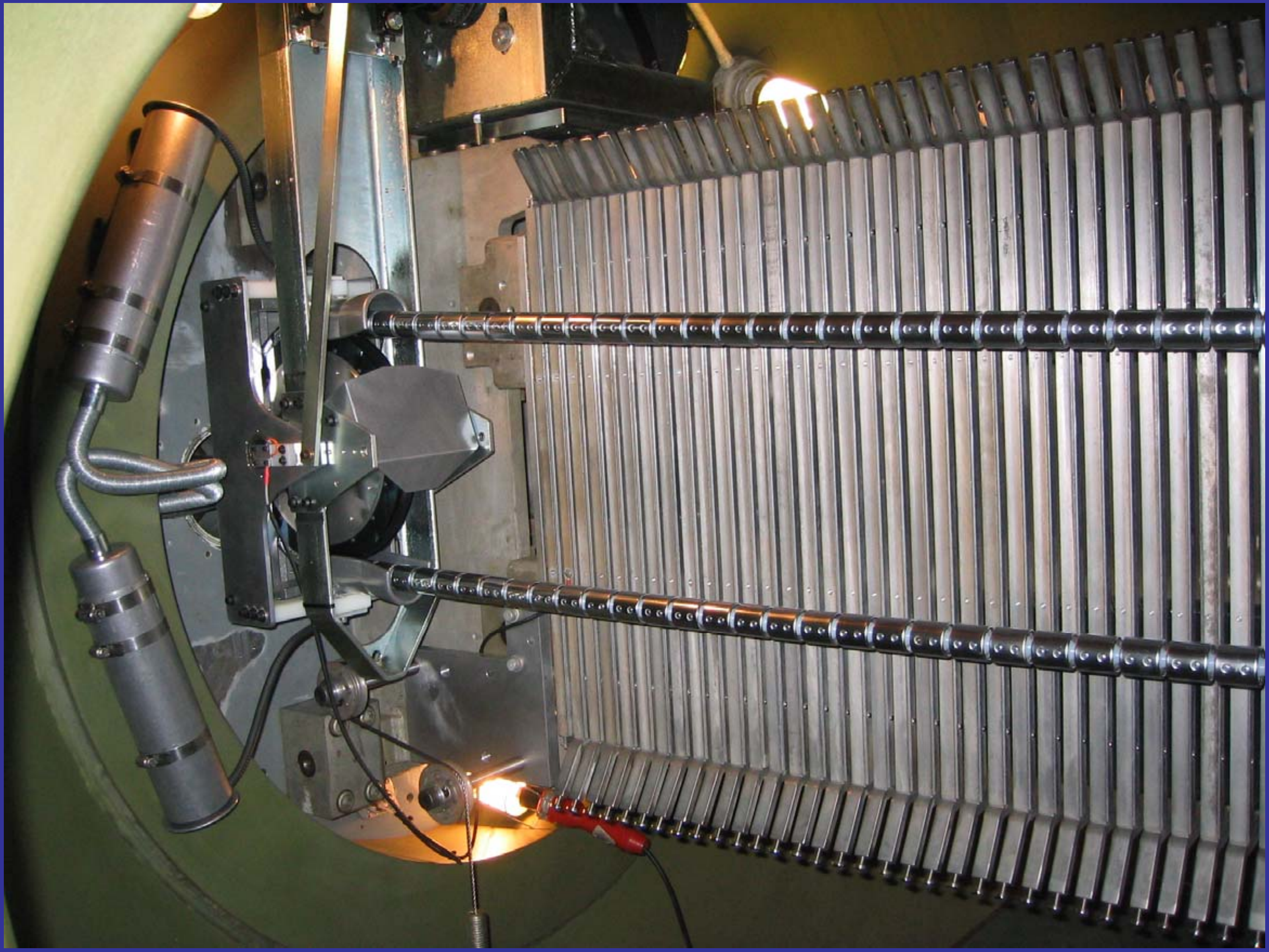
6 MV CN Van de Graaff Accelerator

- Manufactured by High Voltage Engineering – USA.
- Installed in 1963
- Vertical machine, Voltage range: 0.6 to 6 MV
- Tank 18 ton. Pressure: 16 Bar, Gas: N_2=80% and CO_2=20%
- Gas compressor, dryer and storage tank.
- Opening cycle 27 hours
- Current: DC 20 uA max. 1.5 nS, Pulsed @ 2 MHz 5 uA
- Drive motor 10 kW 60 Hz 1700 RPM, Belt speed 60 km/h
- Terminal generator 115 V 400 Hz 2 kW max
- Column/accelerating tube: 2 tubes with 132 insulated rings in total, with a resistor chain of 10^{11} ohm

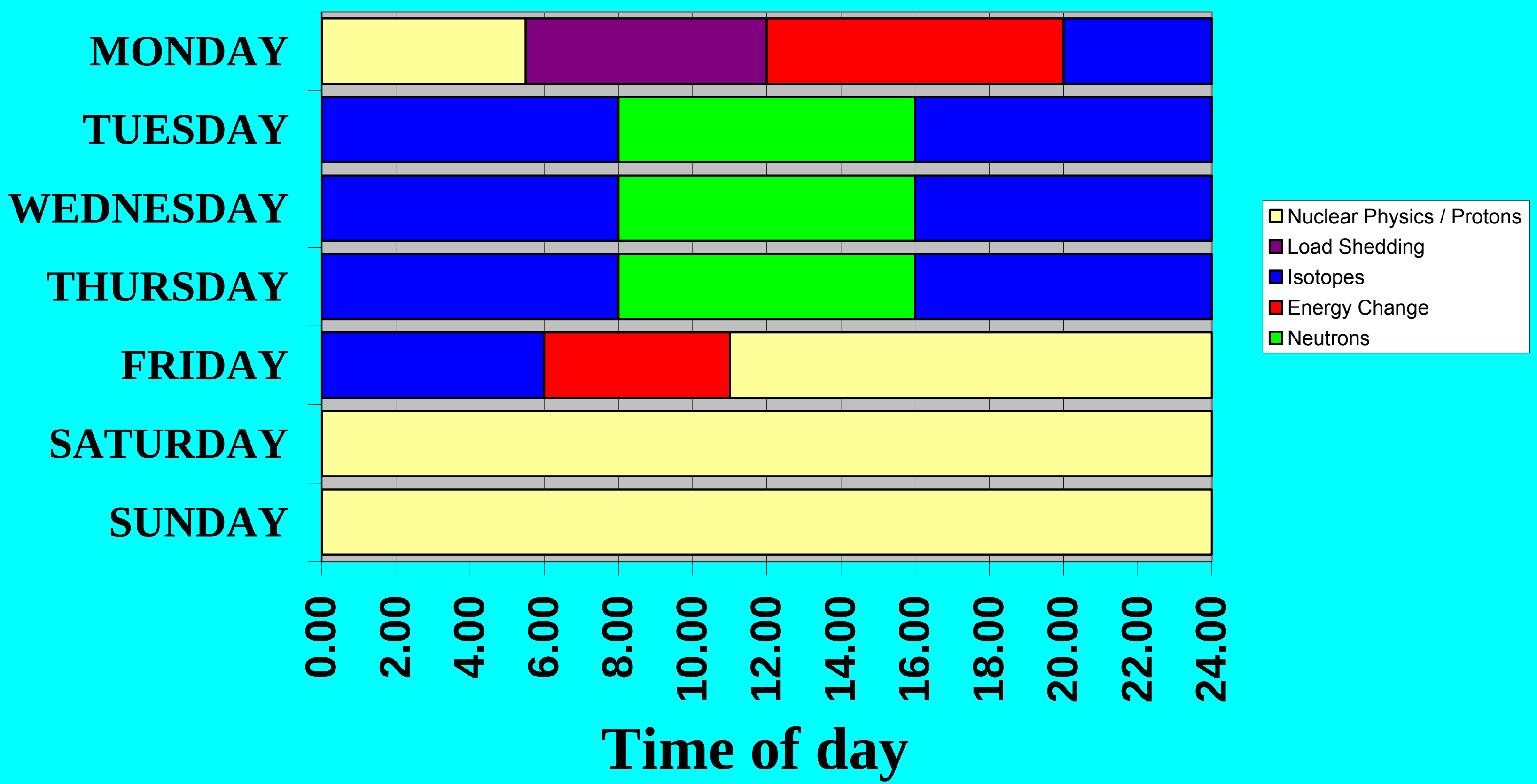
Control page of the vacuum system



Pelletron Chain



CYCLOTRON OPERATING SCHEDULE



NEUTRON AND PROTON THERAPY

Compared with conventional radiations (photons, electrons):

- Neutrons have similar physical characteristics to x-rays and are more effective for treating radioresistant tumors, usually large and/or slow-growing, such as salivary gland tumours, advanced prostate cancer

Neutrons are used because of their BIOLOGICAL EFFECTS

- Protons have more favorable dose distributions (fixed range, little scattering) which can easily be controlled and are used to treat well-delineated lesions (benign and malignant) close to critical structures, which can easily be avoided, such as brain lesions, early prostate cancer

Protons are used because of their PHYSICAL PROPERTIES