The iThemba LABS Radioactive Ion Beam Project

"South African Centre for Exotic Beams"

Robert Bark
iThemba LABS, South Africa

ACE BEAMS

ACE ISOTOPES

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

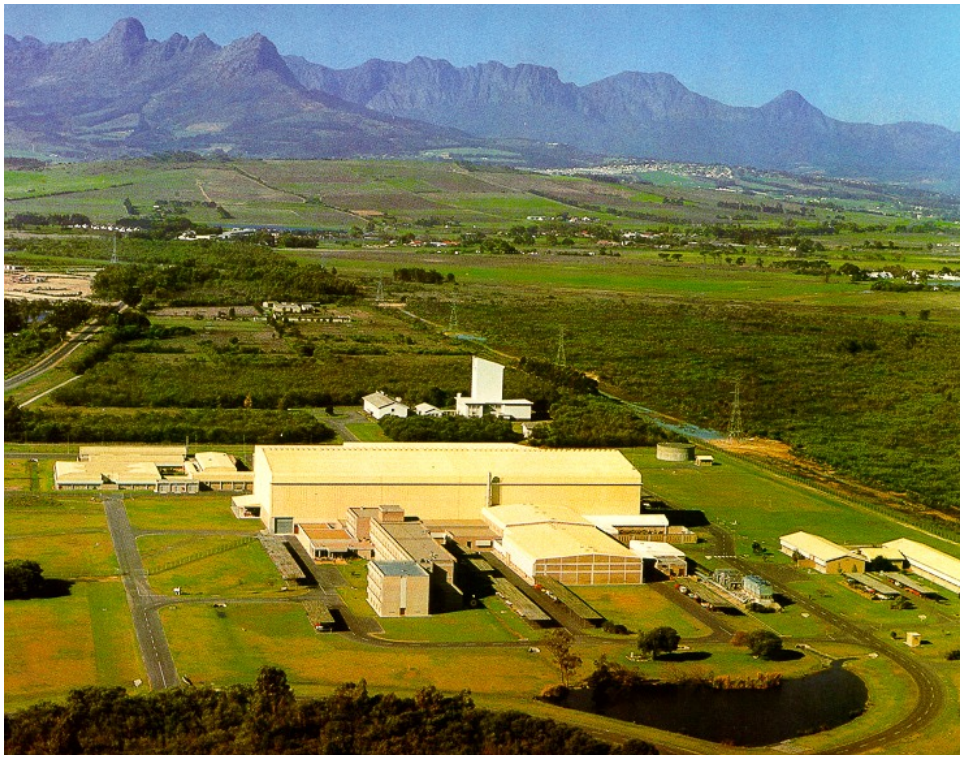
Inpc 2016
International Nuclear Physics Conference
Adelaide Convention Centre, Australia
11-16 September 2016

NRF National Research Foundation
iThemba LABS Laboratory for Accelerator Based Sciences

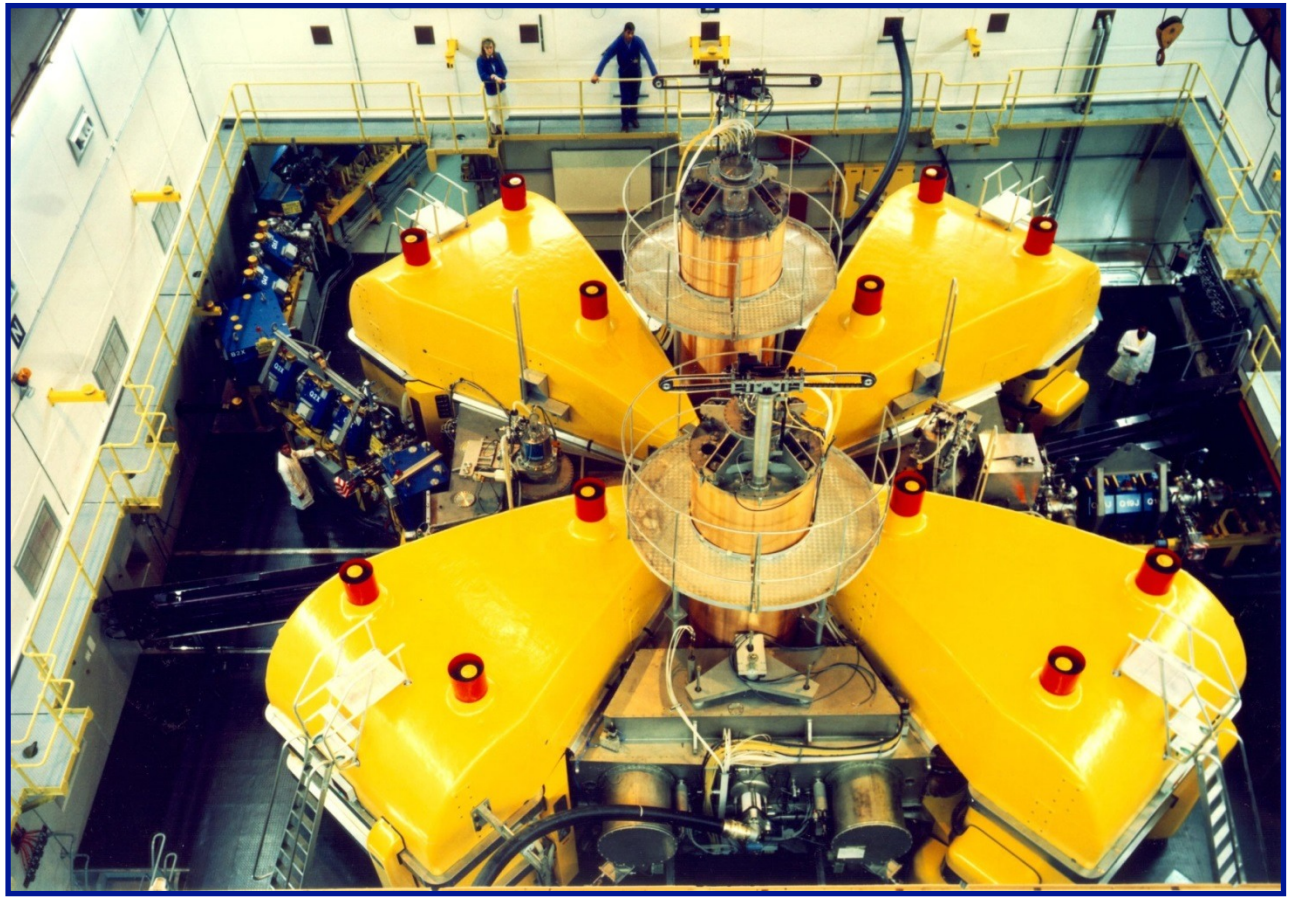
Update on iThemba LABS Radioactive-Ion Beam Project

ACE Beams

ACE Isotopes



The k=200 Separated Sector Cyclotron (SSC)

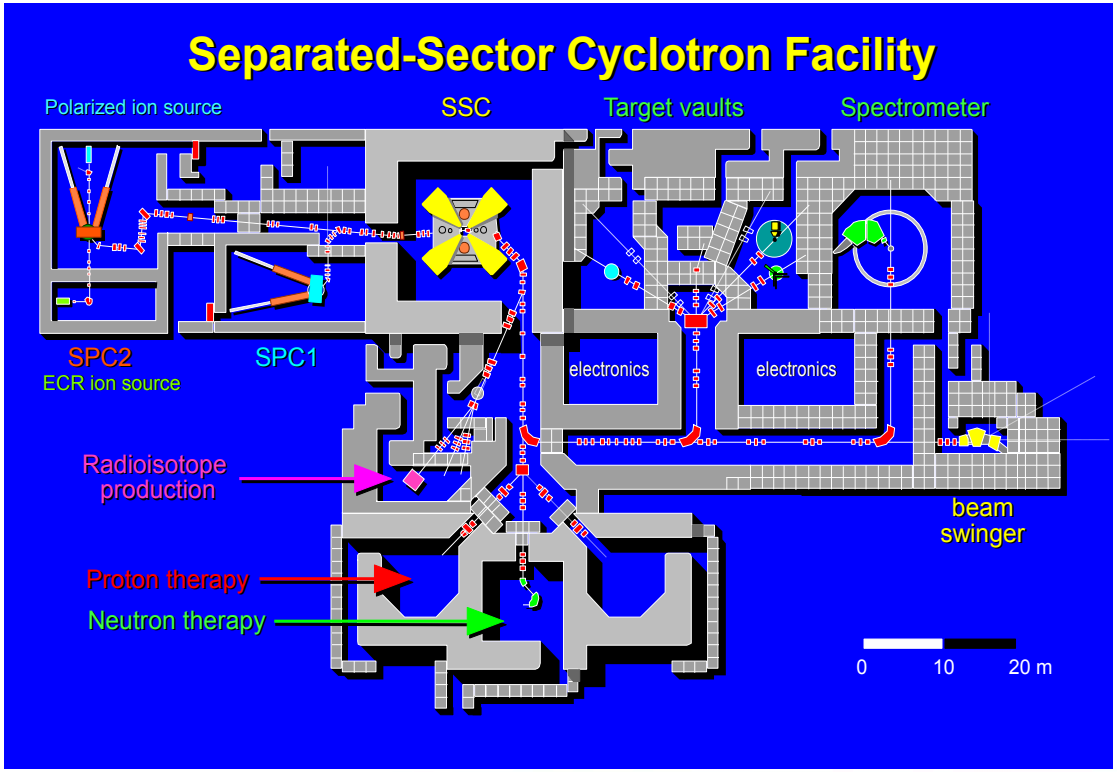


Beams:
p, d, α - since 1986
(66 MeV p @ 300μA)

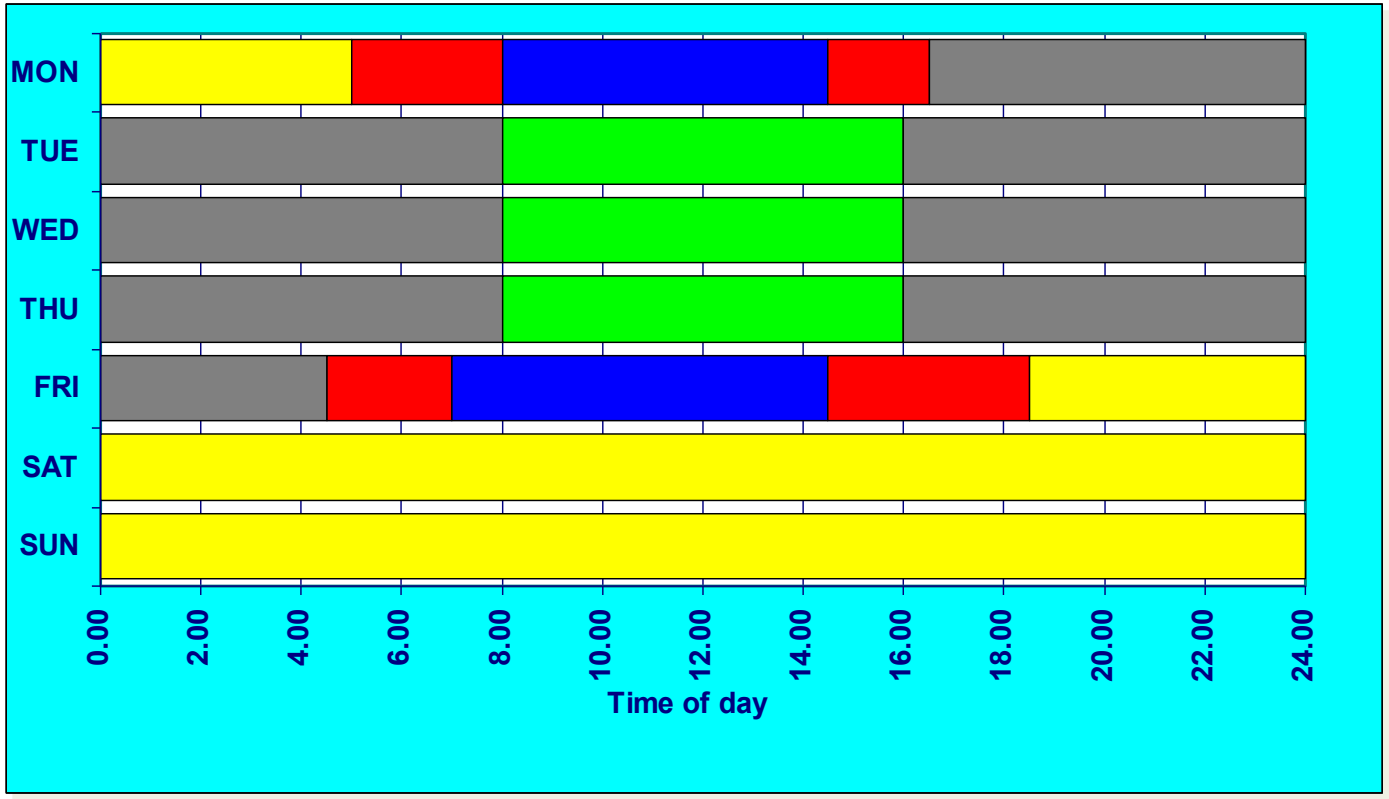
Heavy ions since ~1990

iThemba LABS: 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



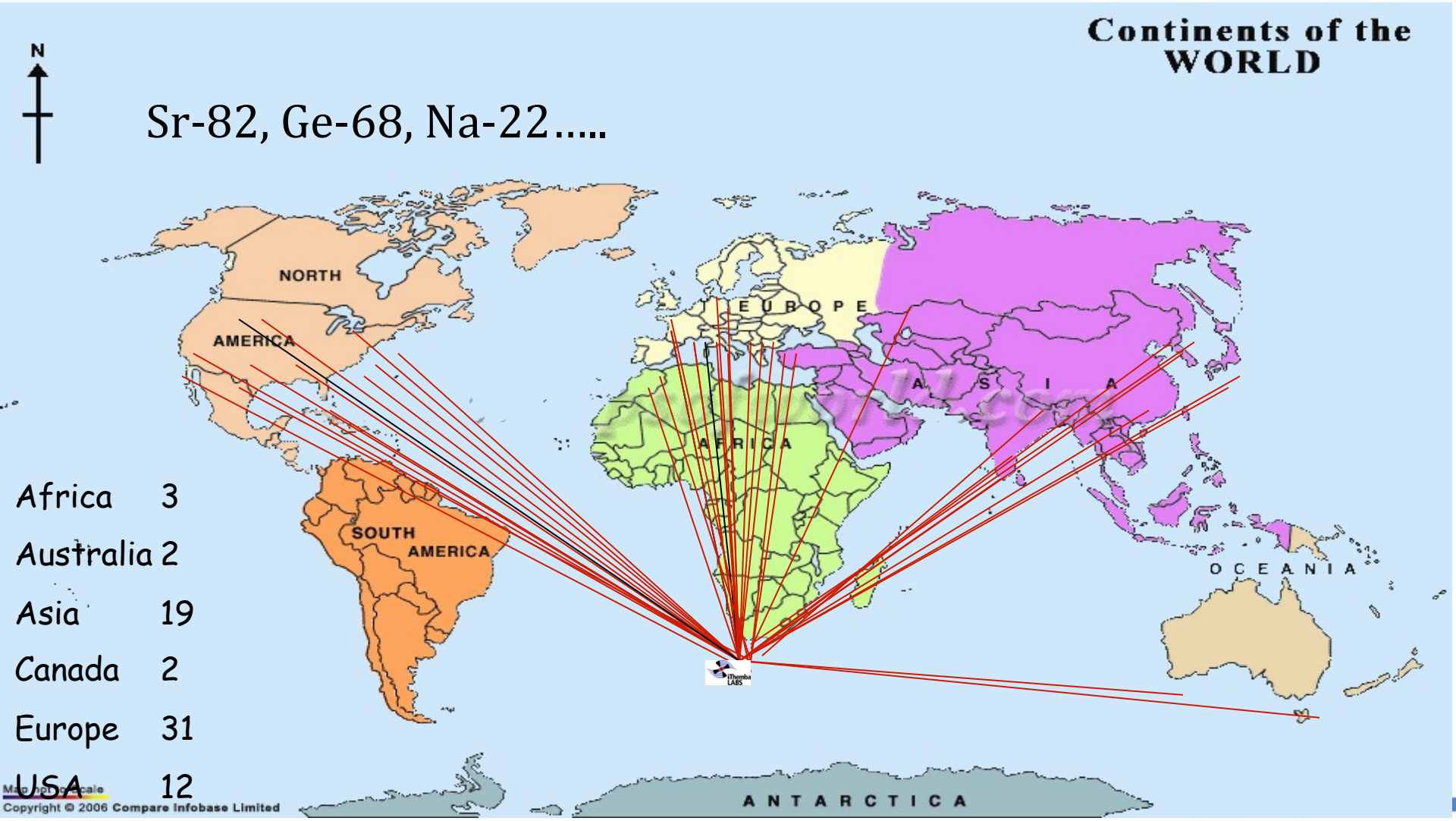
SSC Beam Schedule



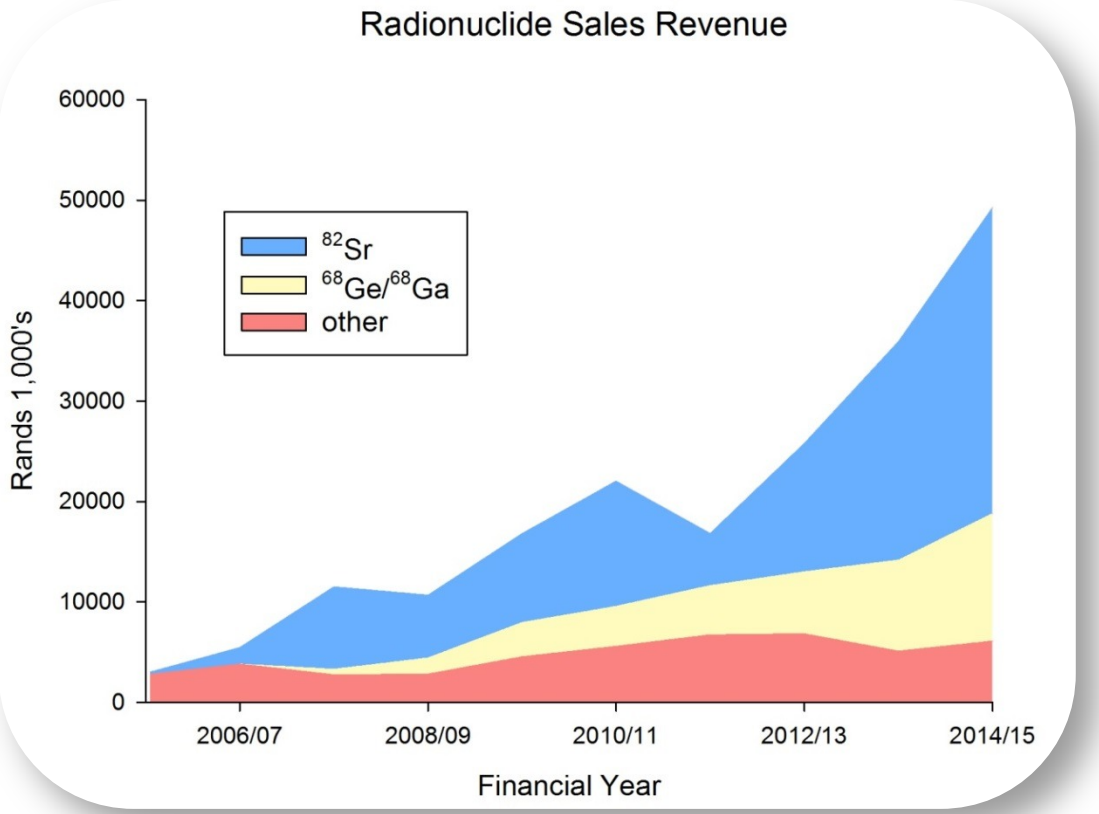
- ◊ Nuclear Physics
- © Neutron Therapy
- © Proton Therapy
- © Energy Change
- © Isotope Production

SSC Weekly Beam Schedule

Radionuclide Distribution Network

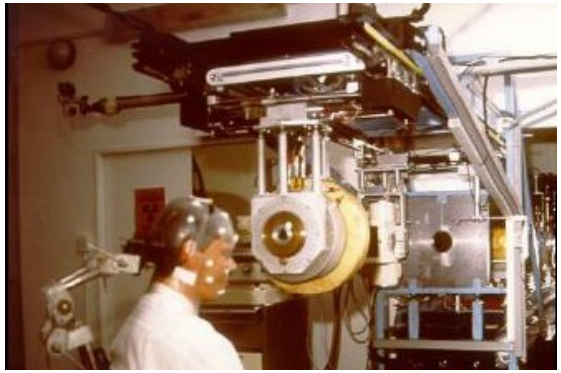


Radionuclide Production



Made Possible by Flat-topping in SPC1 and SSC and splitting 350μA of 66 MeV protons over two target stations

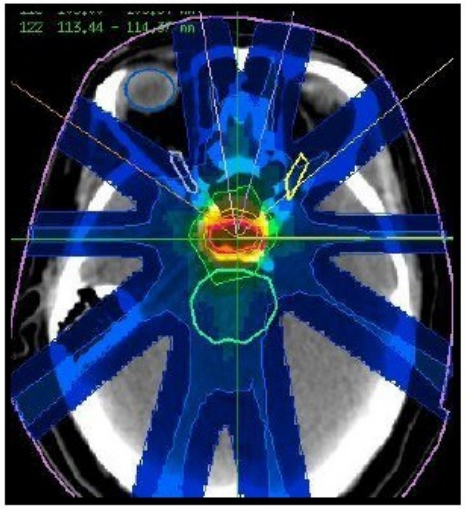
Neutron Therapy



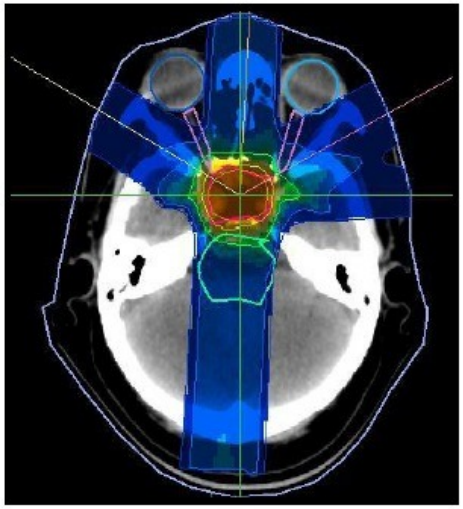
Proton Therapy

– unable to give proper fractions

PROTON PLANS:
PITUITARY ADENOMA



Plateau irradiations



COMBINATION
Plateau and SOBP irradiations

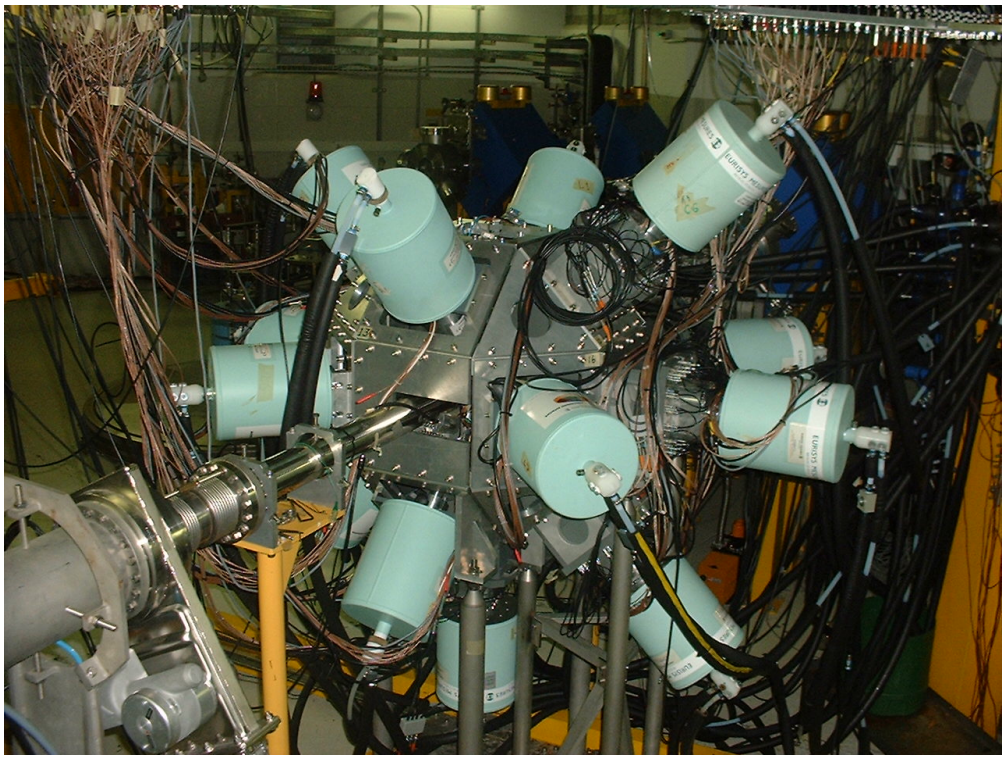
Nuclear Physics Research

- Nuclear Structure
  - Vibrational States
  - Pairing Isomers
  - Shape-Coexistence
  - Nuclear Clusters
  - Chirality
  - Giant Resonances
  - Strength Functions
- Nuclear Reactions
  - Astrophysical reactions
  - Production of intermediate mass fragments

The AFRODITE γ-detector Array to be UPGRADED

9 Compton suppressed Clover detectors
(+ 8 Planar Ge)
Efficiency 1.8 %
2G [W]–[W] events/weekend

+3 Clovers in 2017 (funded)
(+4 Clovers in ~ 2018 funding request submitted)
Eventual Efficiency 3.2%
1 G [W]–[W]–[W] events/ weekend



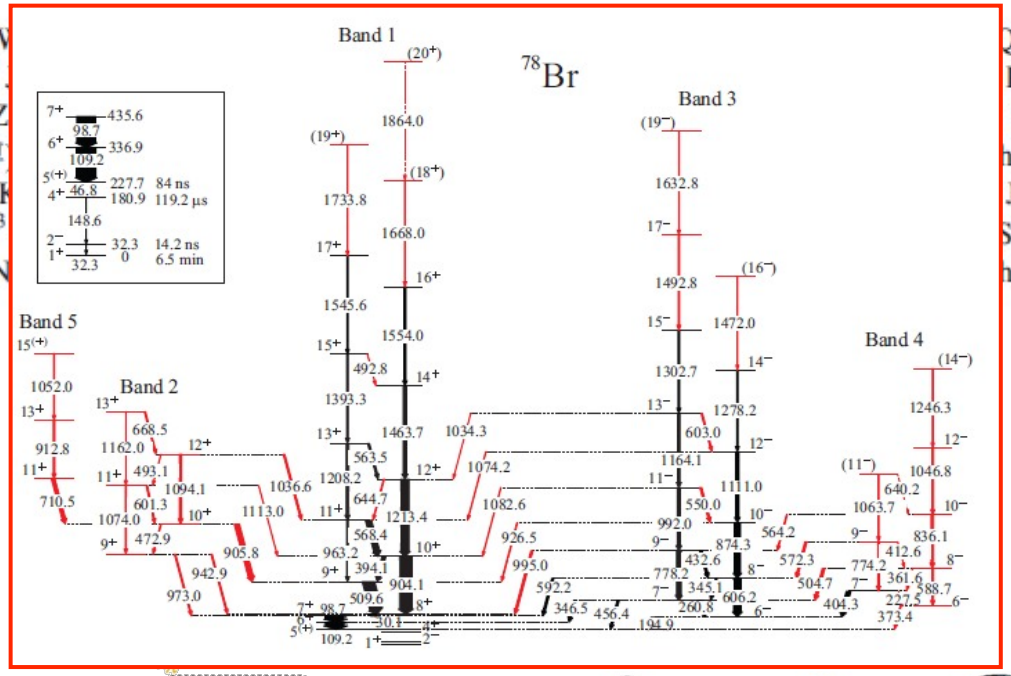
1 "TIGRESS" type segmented Clover

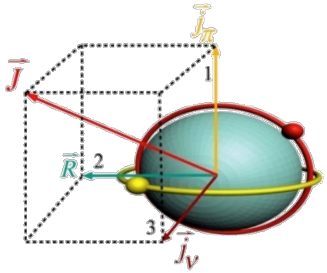
Studies of Nuclear Chirality

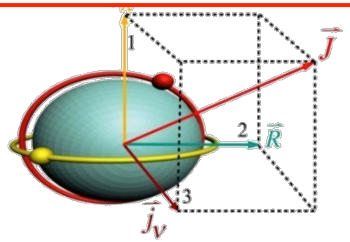
PRL 116, 112501 (2016) PHYSICAL REVIEW LETTERS week ending 18 MARCH 2016

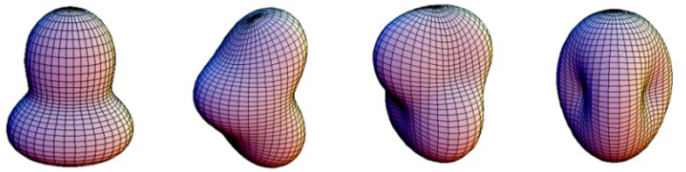
Evidence for Octupole Correlations in Multiple Chiral Doublet Bands

C. Liu (刘晨),[1] S. Y. W... Qi (亓斌),[1] P. Jones,[2]
S. M. Wyngaardt,[5] ... P. Sun (孙大鹏),[1]
L. Liu (刘雷),[1] Z... H. Hua (华辉),[3]
Q. B. Chen (陈启博... her,[2,5] T. Dinoko,[2,10]
J. Easton,[2,10] K... J. J. Lawrie,[2]
S. N. T. Majola,[2,13] ... S. S. Ntshangase,[12]
B. M. N... hole,[2,10]









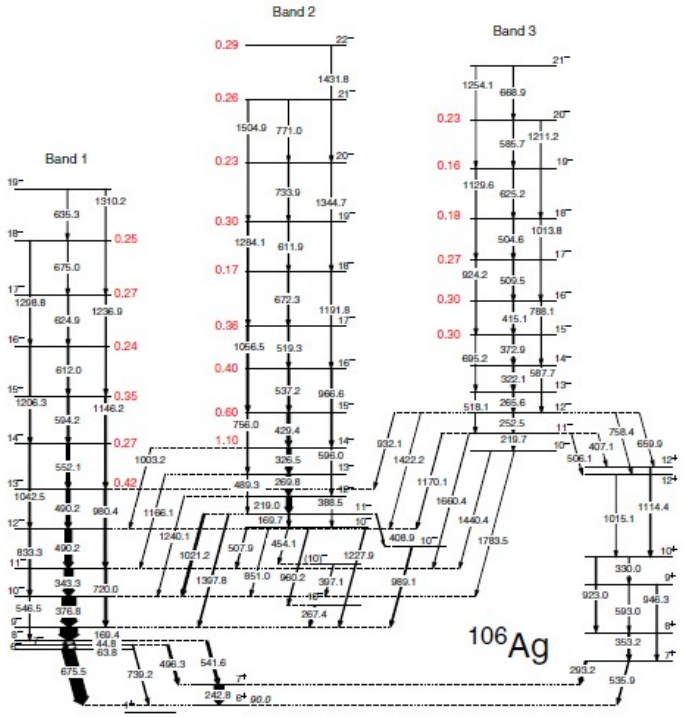
$Y_{20}+Y_{30}$ $Y_{20}+Y_{31}$ $Y_{20}+Y_{32}$ $Y_{20}+Y_{33}$

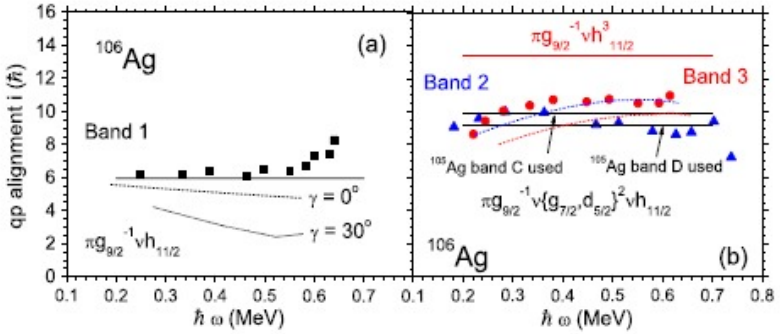
Studies of Nuclear Chirality

PRL 112, 202502 (2014) PHYSICAL REVIEW LETTERS week ending 23 MAY 2014

Resolution of Chiral Conundrum in ^{106}Ag: Doppler-Shift Lifetime Investigation

E. O. Lieder,[1,2] R. M. Lieder,[1,*] R. A. Bark,[1] Q. B. Chen,[3] S. Q. Zhang,[3] J. Meng,[3,4,5] E. A. Lawrie,[1] J. J. Lawrie,[1] S. P. Bvumbi,[1] N. Y. Kheswa,[1] S. S. Ntshangase,[1] T. E. Madiba,[1] P. L. Masiteng,[1] S. M. Mullins,[1] S. Murray,[1] P. Papka,[1] D. G. Roux,[6] O. Shirinda,[1] Z. H. Zhang,[3] P. W. Zhao,[3] Z. P. Li,[7] J. Peng,[8] B. Qi,[9] S. Y. Wang,[9] Z. G. Xiao,[10,11] and C. Xu[3]



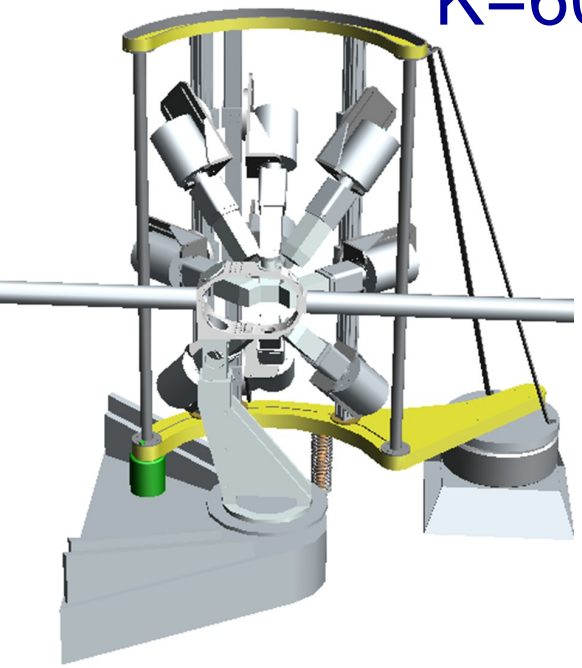


K=600 magnetic spectrometer
a high resolution QDD spectrometer for light ions

Upgraded for operation at zero degrees (0-2°) and small angles (3-5 °)

K=600 magnetic spectrometer

Recent improvements

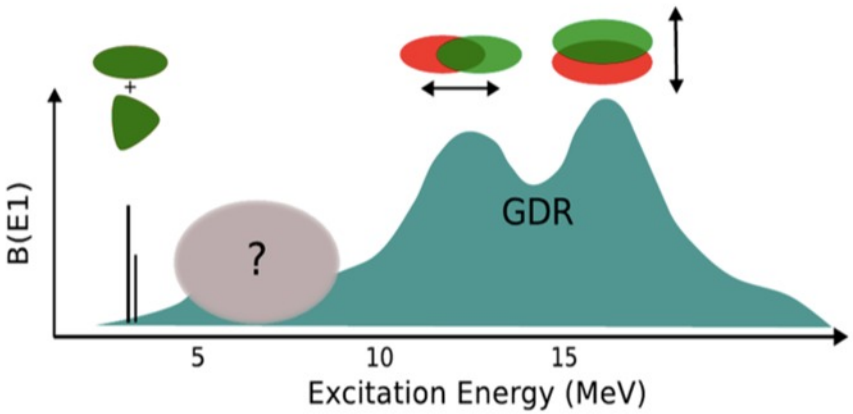


Particle -γ coincidence with K600 at 0°

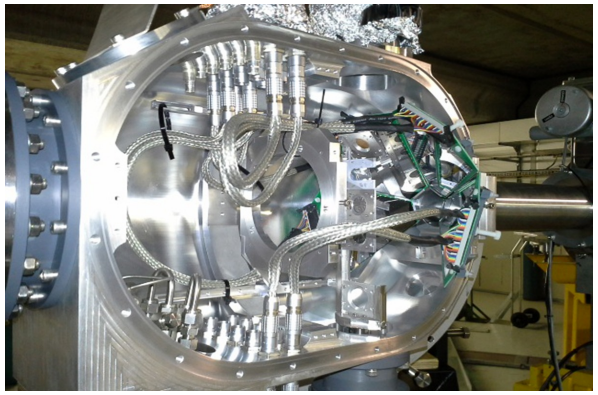
8 Clovers at 17 cm from target: ε = 0.6%

Study PDR in deformed ^{154}Sm via inelastic α-scattering

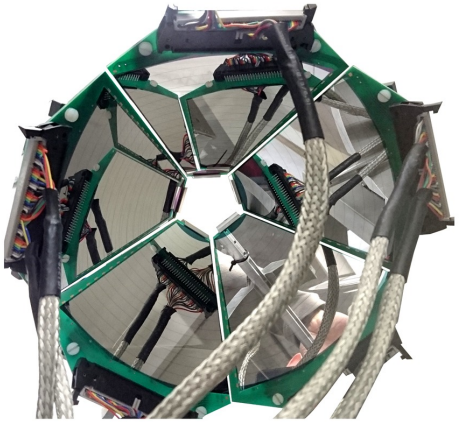
γ-ray detection allow the identification of E1 strength



K=600 magnetic spectrometer
Recent improvements



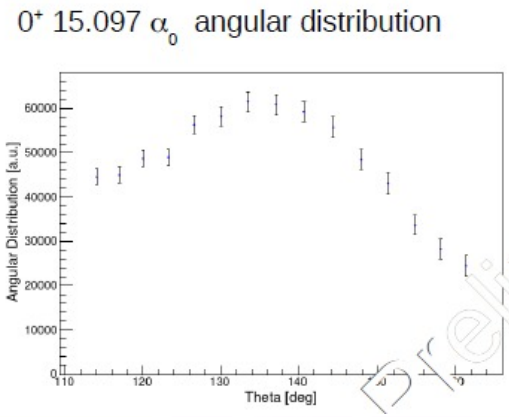
A small chamber:
Coincidence experiments
with K600 at 0 – 4°
5 DSSSDs cover 26% of 4π
114 to 166 degrees
7 MeV p, 28 MeV α

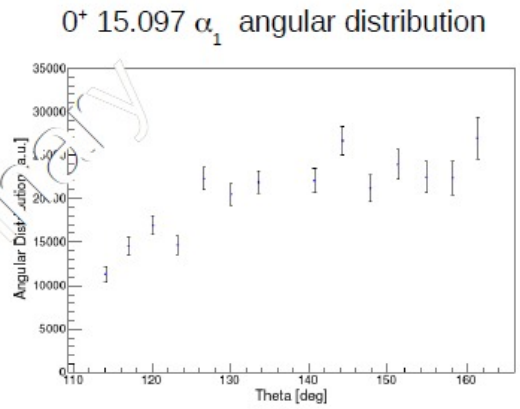


Search for Hoyle-like
States in ^{16}O

(see Kevin Li's
Talk tomorrow)

15.097 MeV angular distributions

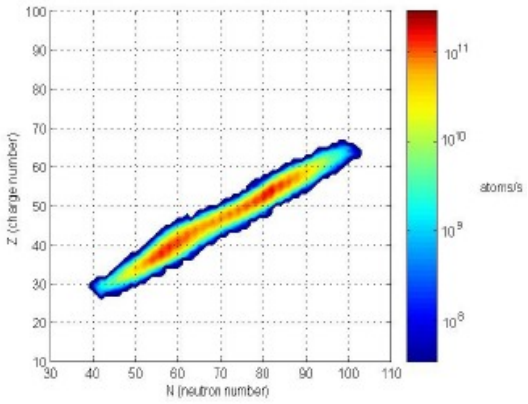




ACE Beams & ACE Isotopes

- Proton Therapy to a hospital
- Isotope Production off SSC and onto new cyclotron
- Free SSC for use by Physics
- More than doubles physics beamtime
- Production of radioactive beams using the ISOL method
- In-flight production of RIBs?

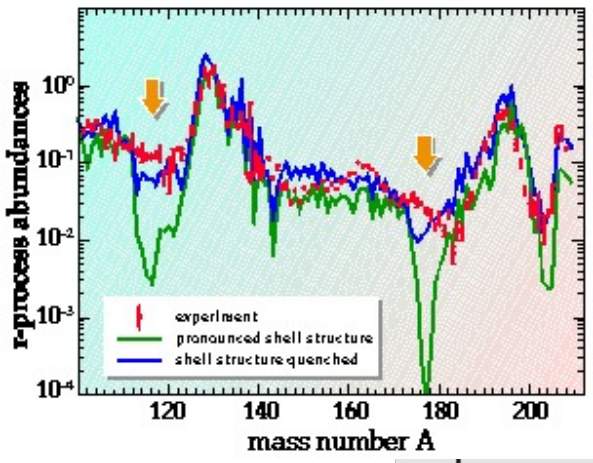
Making Radioactive Beams at iTL



(p,xn), (p,yp,xn), (p, za, xn) .....

Proton induced Fission of Uranium

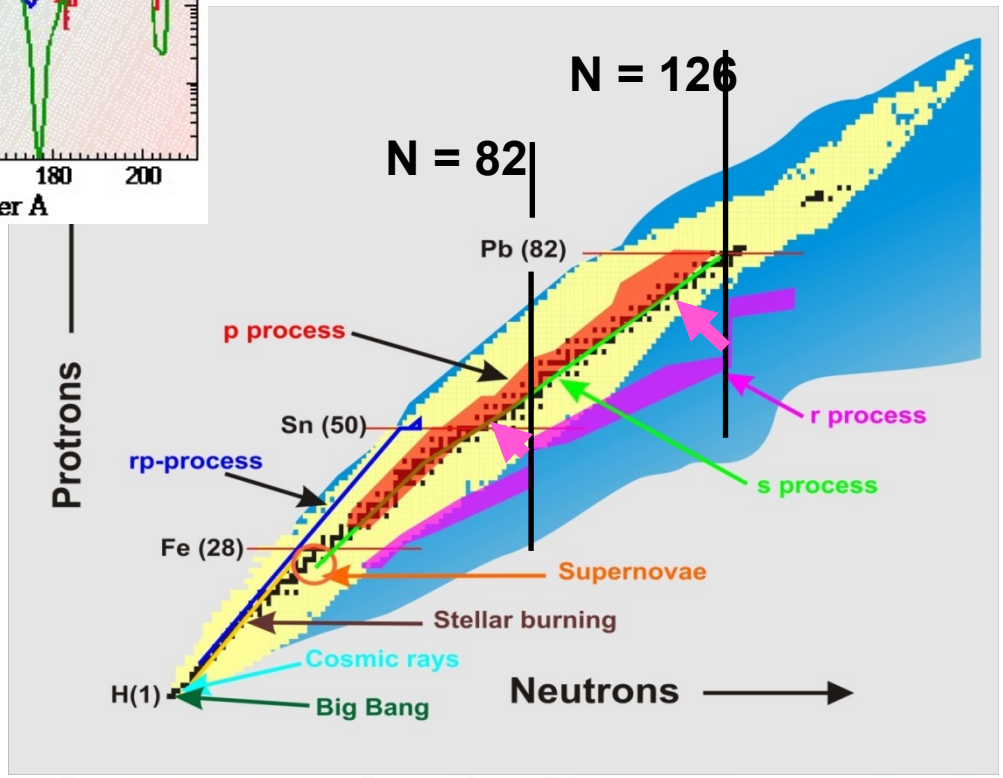
Synthesis of the elements



Freiberghaus APJ 518(98)

Astrophysical r-process

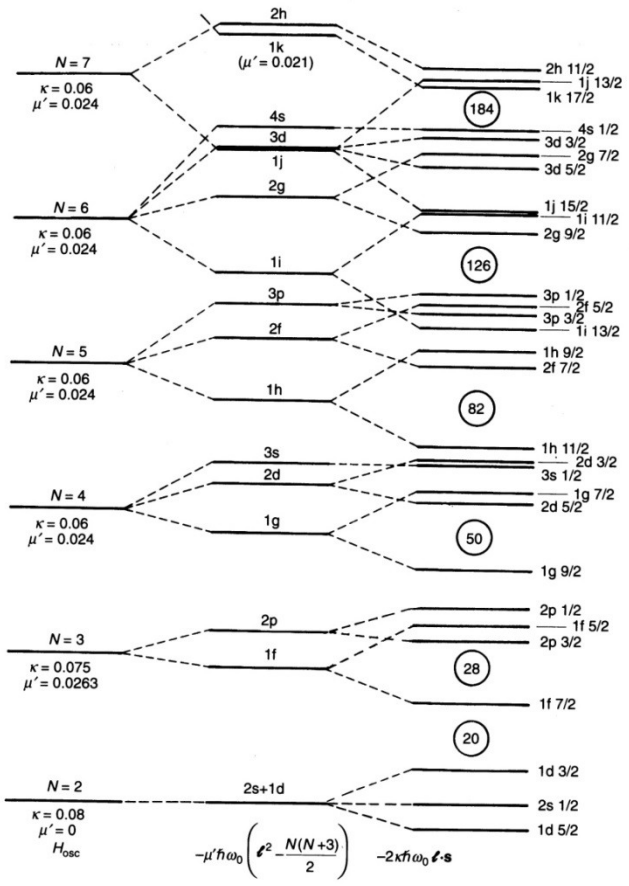
Massive neutron bombardment in Supernova



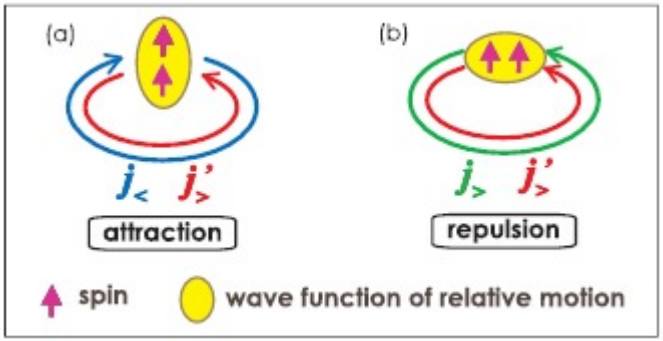
Understanding the Synthesis of the Elements
r-process

- Rapid neutron bombardment in e.g. supernova
- Need to know (n,γ) reaction rates
- Must measure:
  - Level densities
  - Photon strength functions
  - Pygmy resonances
- Need to measure Gamov-Teller Strength distributions (β-decay)

Shell Model of 1949 needs fixing



- 3 body forces
- Importance of Tensor Force in the n-rich!

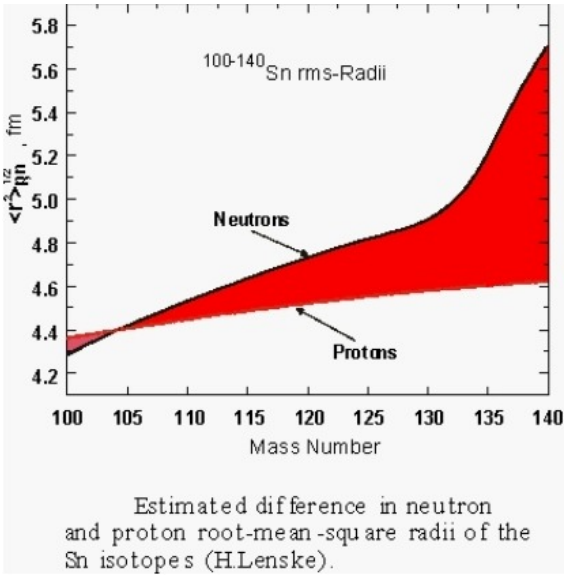


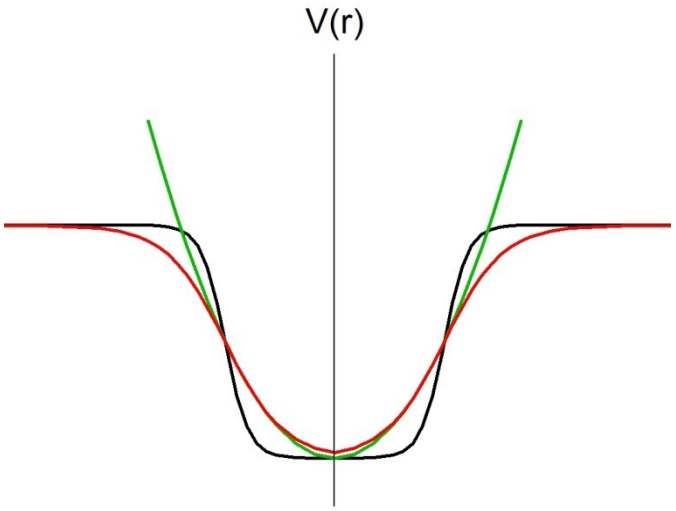
(Takaharu Otsuka)

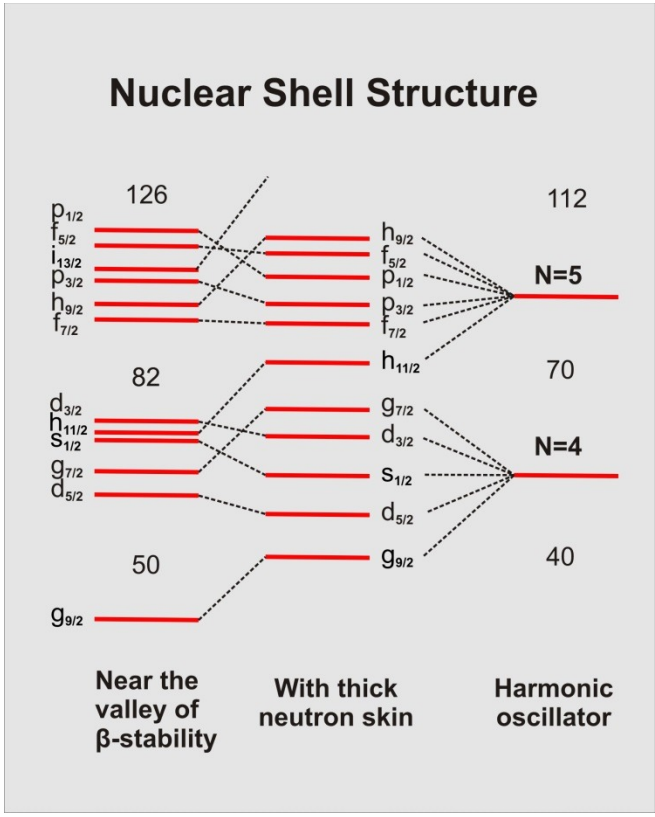
- Neutron Skin

Neutron Rich: Neutron Skin!

Drastic Changes of Shell Structure far off stability!





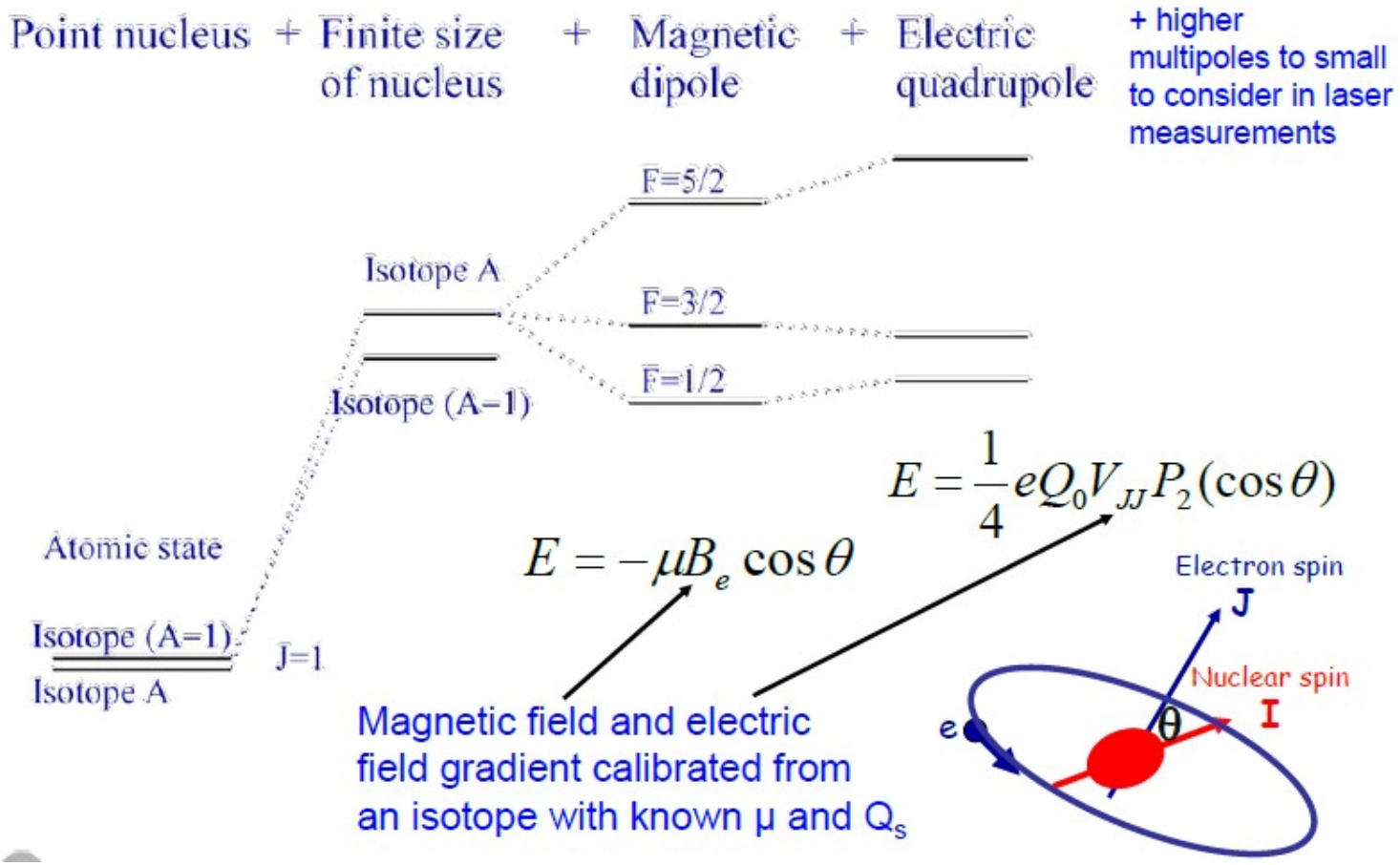


Softening of the nuclear potential:
High-l pushed upward and
Spin-Orbit splitting reduced

$$V_{S.O.} \propto dV(r)/dr\ \vec{l}.\vec{s}$$

Materials Analysis with RIBs

Hyperfine Structure

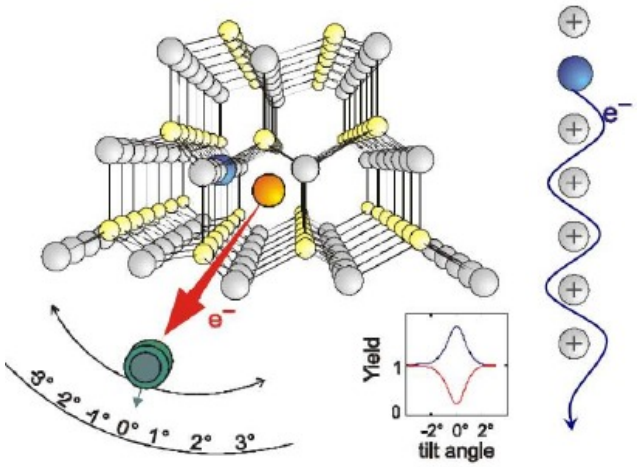


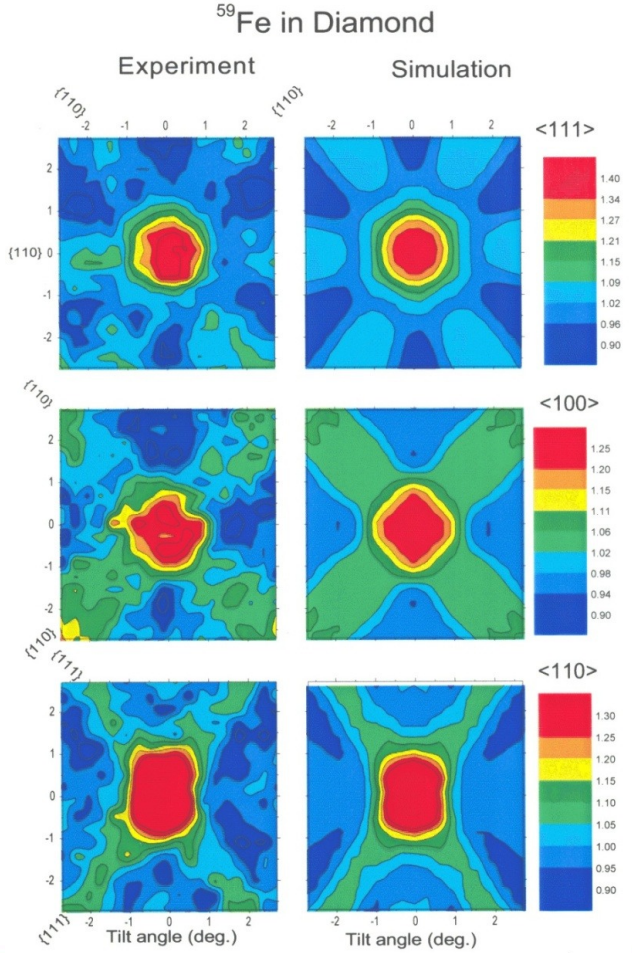
Solid State Physics at ISOLDE, CERN

K. Bharuth-Ram et al

^{59}Fe β-decays with $t_{1/2}$ = 45 days

Lattice location of Fe in Diamond





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

ACE Phases

Phase 0: (Funded 2.8m Euro)

- Design Study (0.6m Euro)
- Test Ion Source/"Demonstrator" (2.2m Euro)

(using 66 MeV p from SSC)

Phase 1:

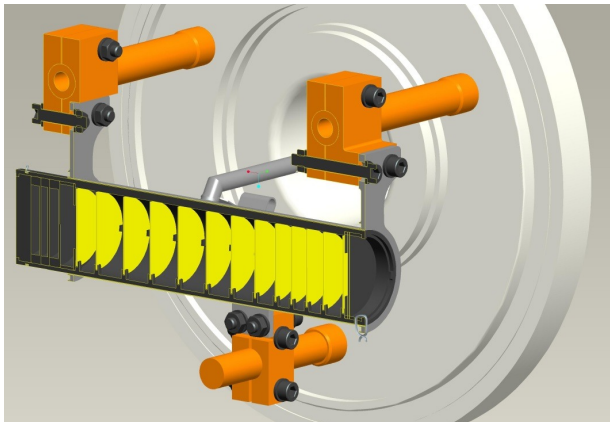
- 70 MeV Cyclotron and beam lines
- Isotope Production Target Stations

Phase 2:

- ISOL target stations
- Laser Ionization, mass separation, charge breeding
- Post-acceleration (existing SPC2 and SSC)
- Experimental Facilities

Phase 0: Based on SPES RIB Target and Ion source

Collaboration with INFN Legnaro
SPES direct target designed for 40 MeV at 200 μA
Upgraded to 70 MeV beam



Power in this design :
P = 70 MeV x 150 μA
= 10.5 kW

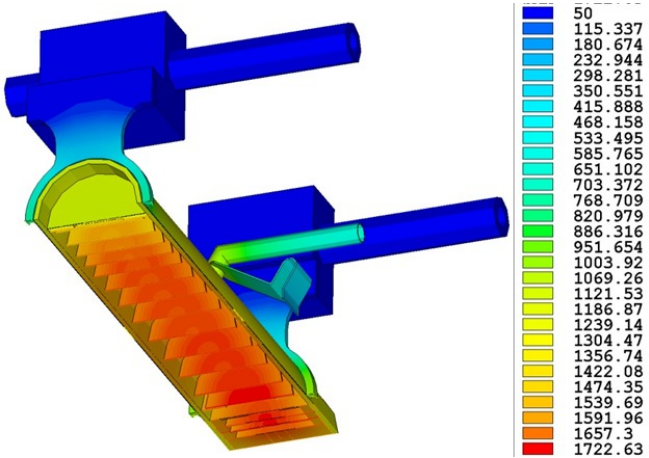
UC_x or SiC target discs

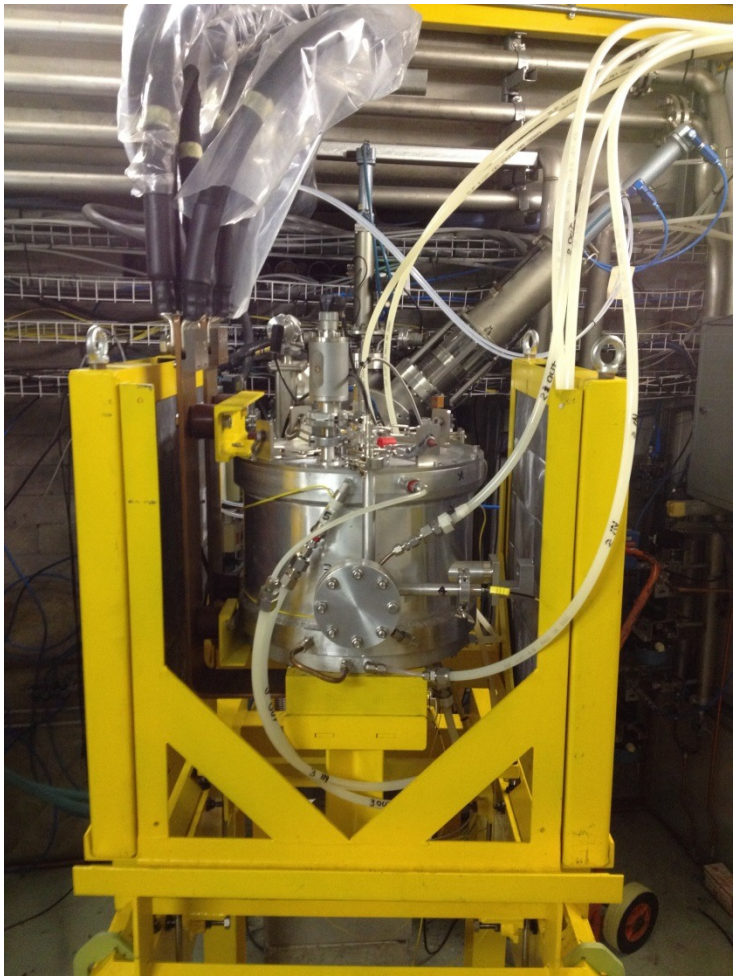
fission yield ~ 2 x 10^{13}

"Front-End" to be delivered this year

Validation of SPES targets
High – Power Test of SiC Target

60 μA, 66MeV = 4 kW

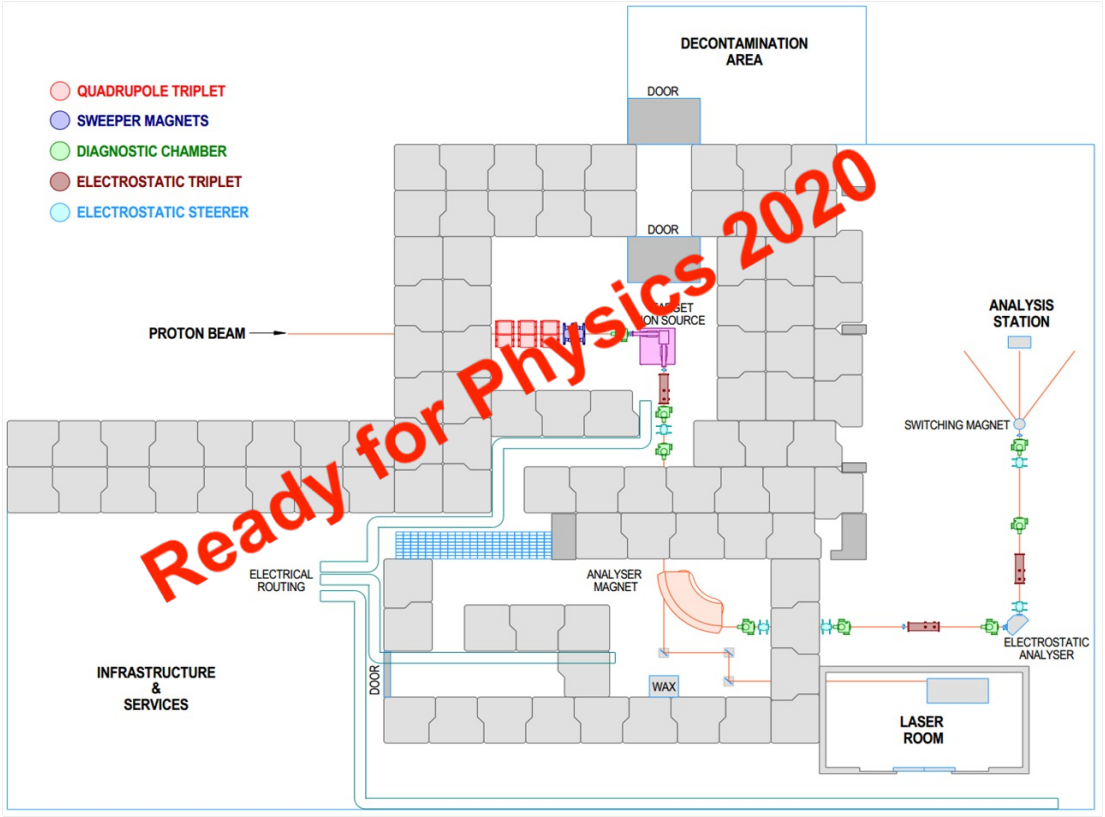




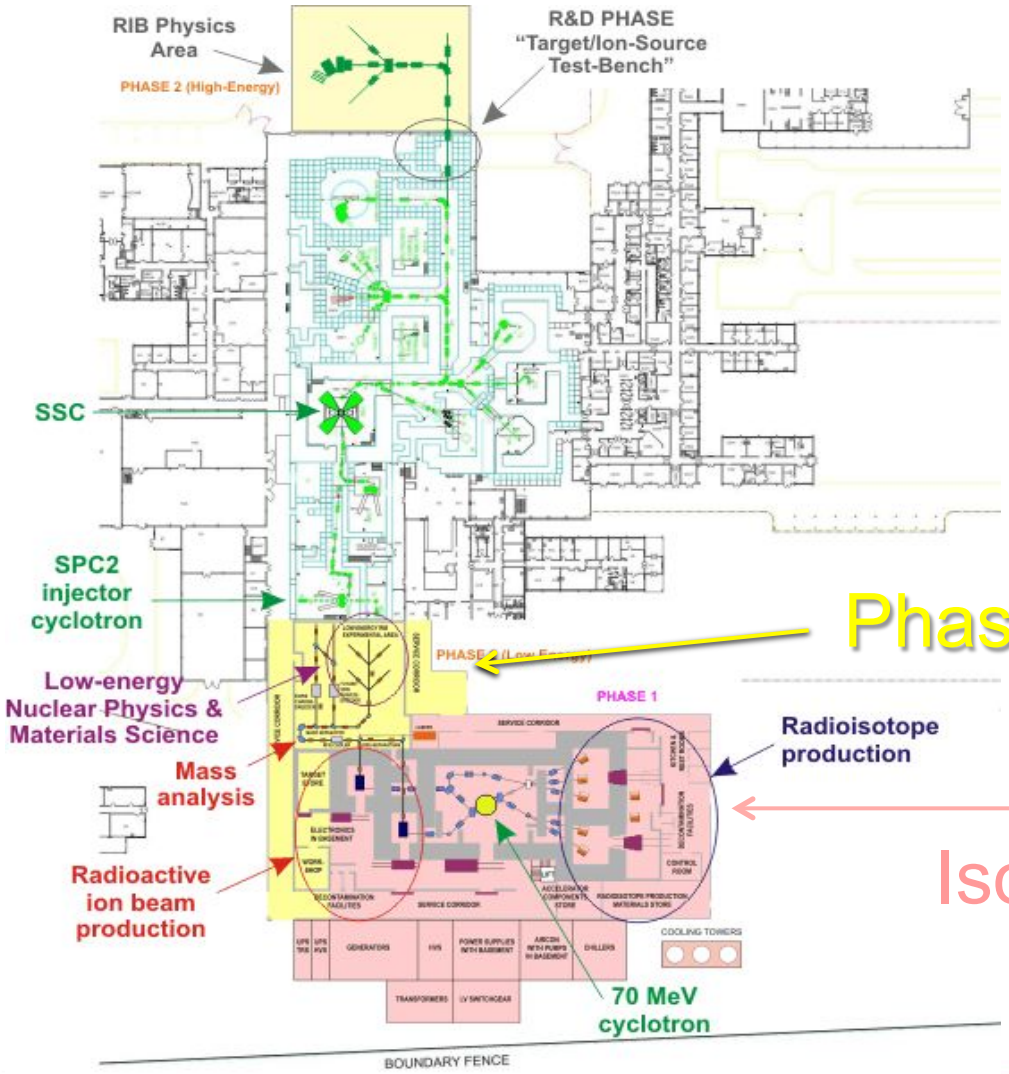
Monetti, Bark, et al EPJ A52(2016) 168

iThemba LABS RIB Test Facility "Demonstrator" (Funded:R25M)

First Beams 2018



RIB Design Study



2 weeks isotope production from the 70 MeV H$^-$minus cyclotron (2x 200μA)

2 weeks RIB with the 70 MeV H-minus cyclotron as driver

Phase 2 RIB Production

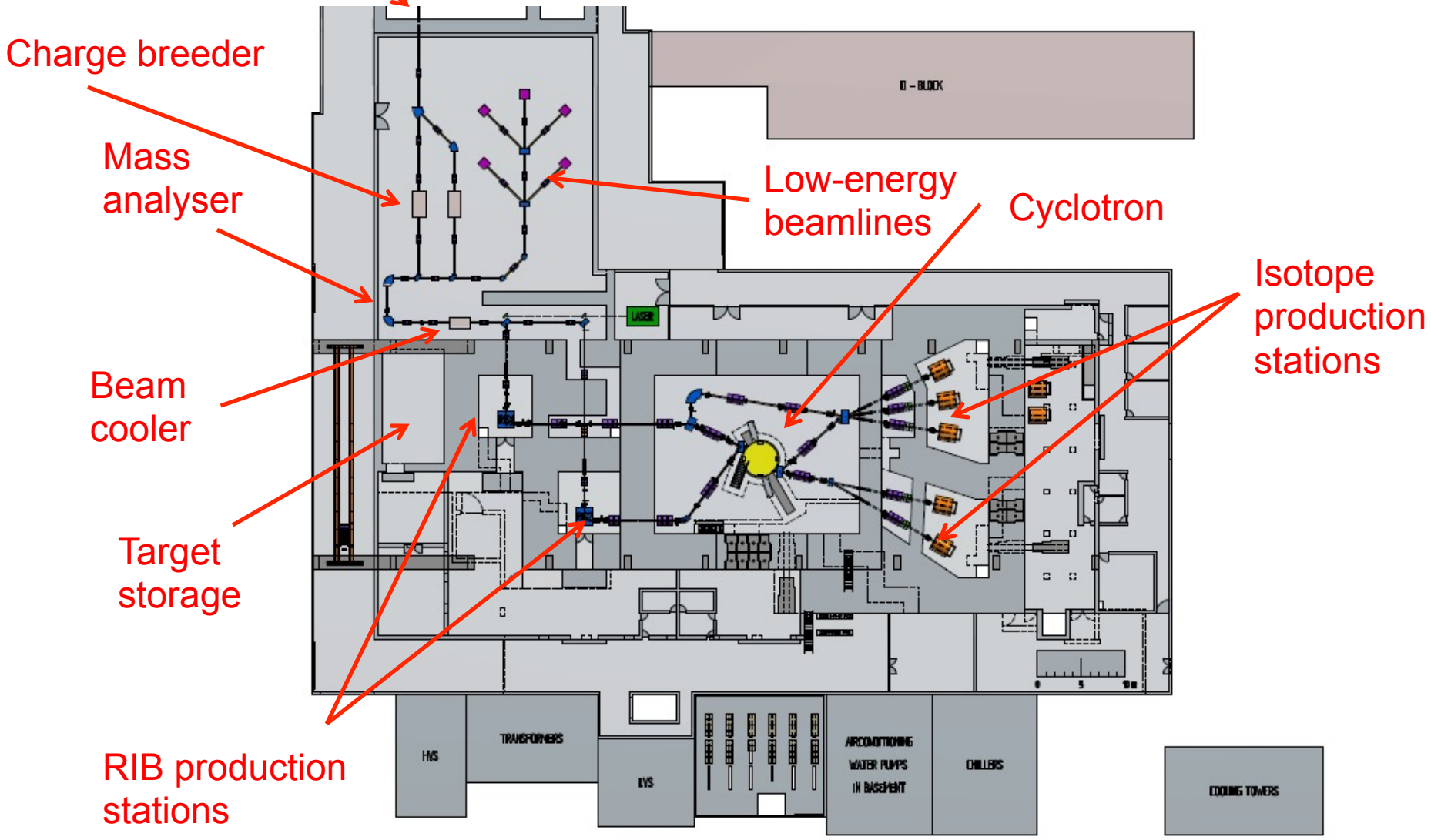
Phase 1
Isotope production

BEST Cyclotron under installation at INFN Legnaro

Dual extraction H^- machine.

Up to 350 μA protons of 70 MeV per port.

Floor Plan (plan "A")



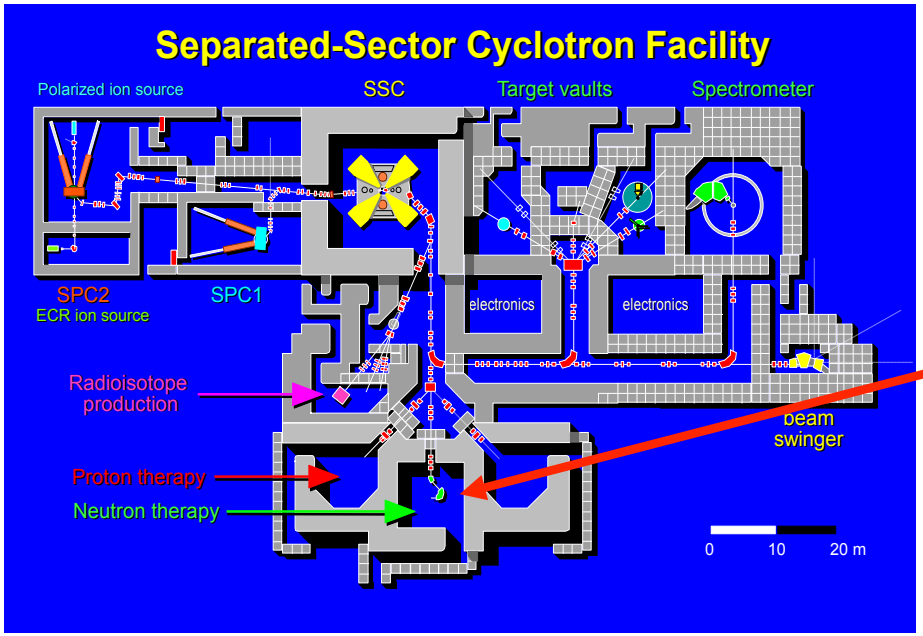
Late 2015

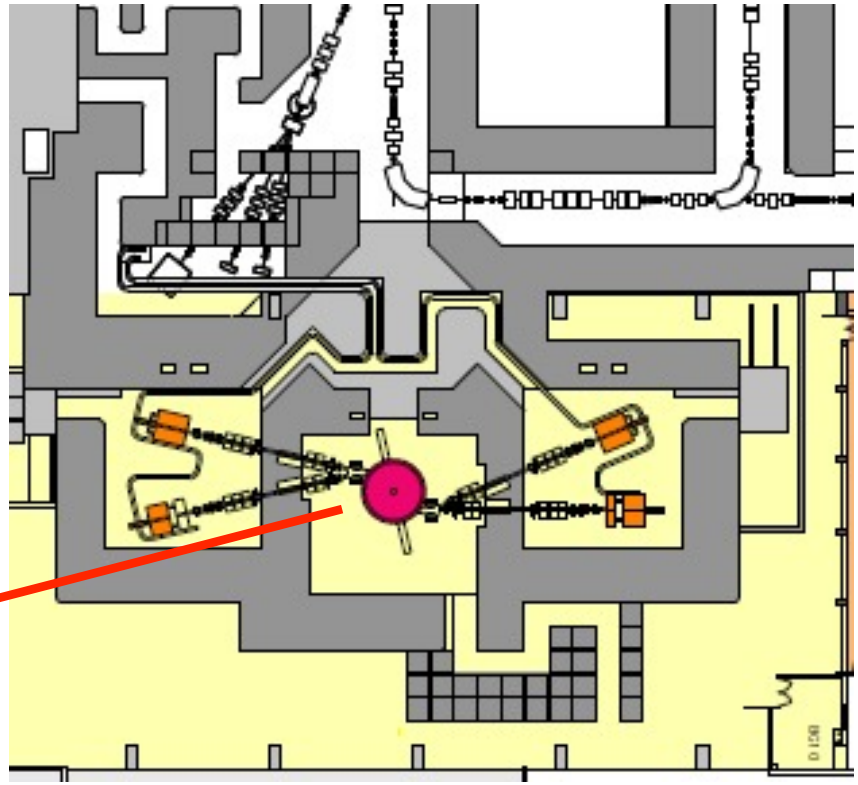
- South African Rand Crashed
- Fears that the upfront cost was too high to start the project
- Civil construction would take too long/ too difficult
- But.. NRF might be able to “find” the cash to fund a cyclotron alone. If we could find a place to put it….

Enter Plan “B”

“Plan B:” New Proposal for 70 MeV Cyclotron placement

Cyclotron placed in existing therapy vault

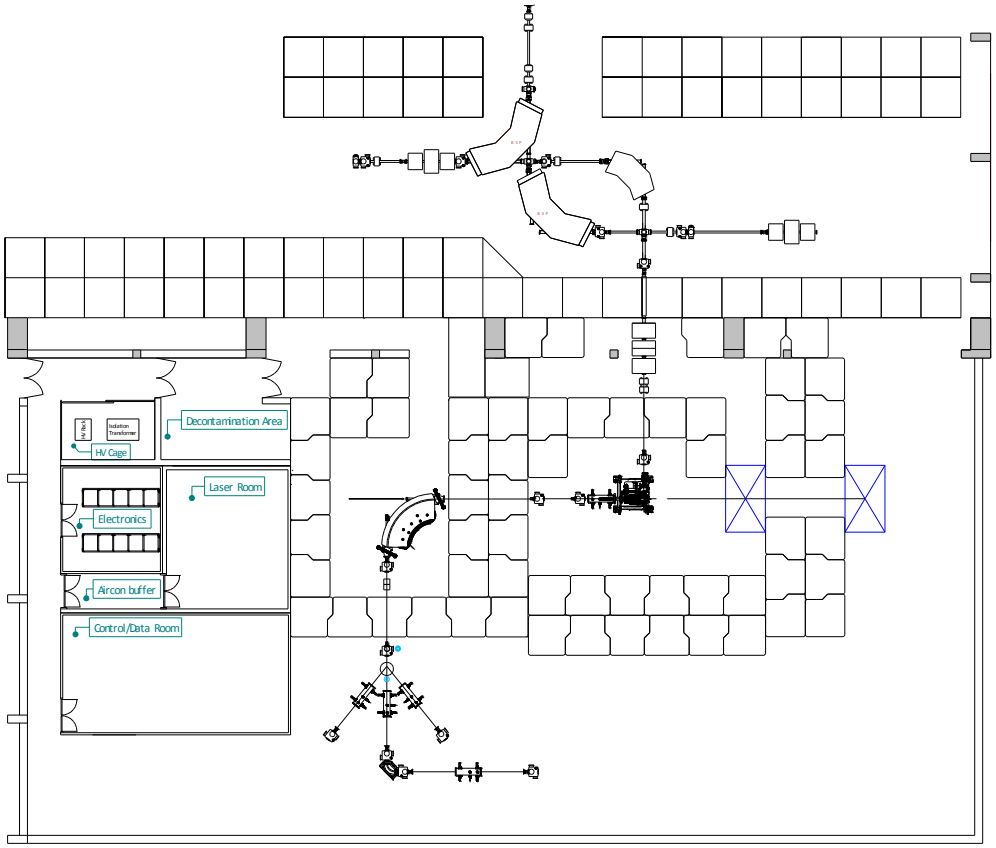




Advantages of “Plan B”

- a much lower start-up cost (Phase 1)
- a much shorter construction time (Phase 1)
- the maximum net annual revenue from isotope production of R158M realized
- it allows the low-energy test-facility to be used far sooner as a competitive research platform
- Isotope production completely separated from research with the SSC

The “Demonstator” Project to be Upgraded: Low Energy RIB Facility

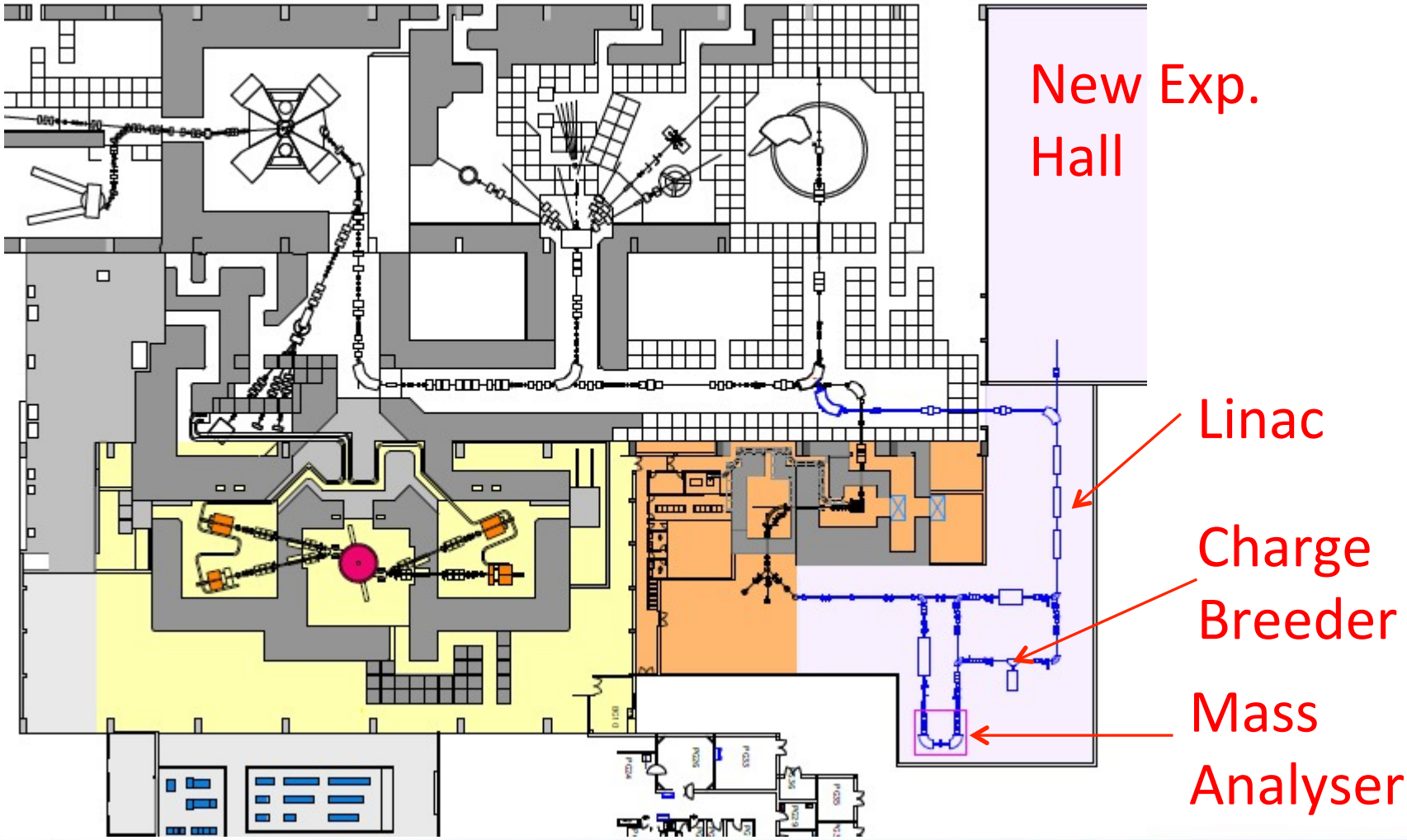


Designed to be permanent – first vault of Phase 2

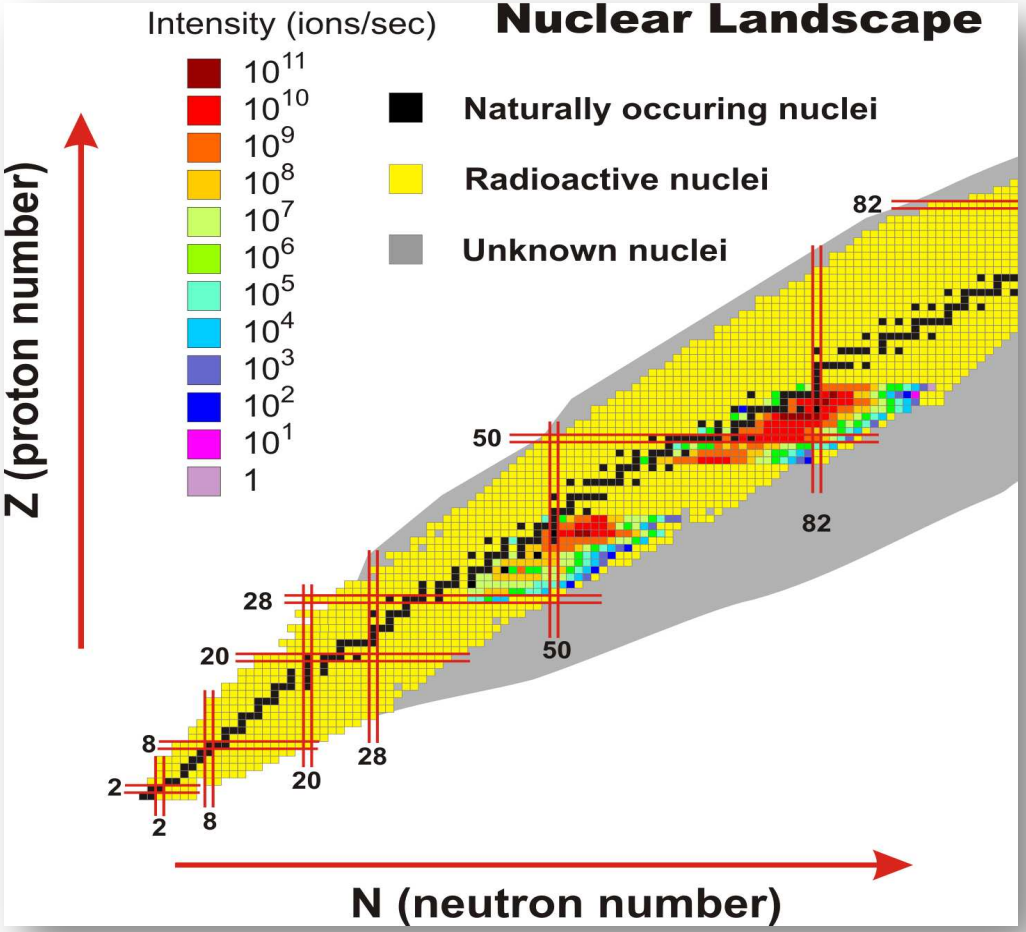
Used for

- β-decay studies
- Testing fundamental symmetries (lifetimes)
- Materials sciences (Mössbauer, Emission channelling)
- Use existing Ge detectors + Tape station

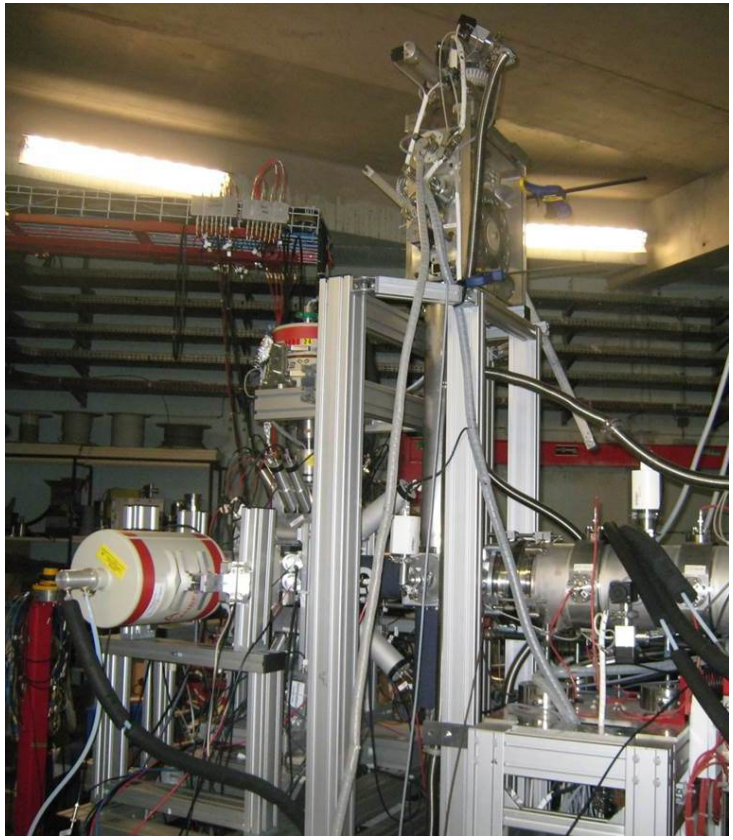
ACE Beams ACE Isotopes



“Unaccelerated” (60 keV)
Beam Intensities with 150μA 70 MeV protons ~ 2 x 10^{13} f/s



-decay Tape Stations



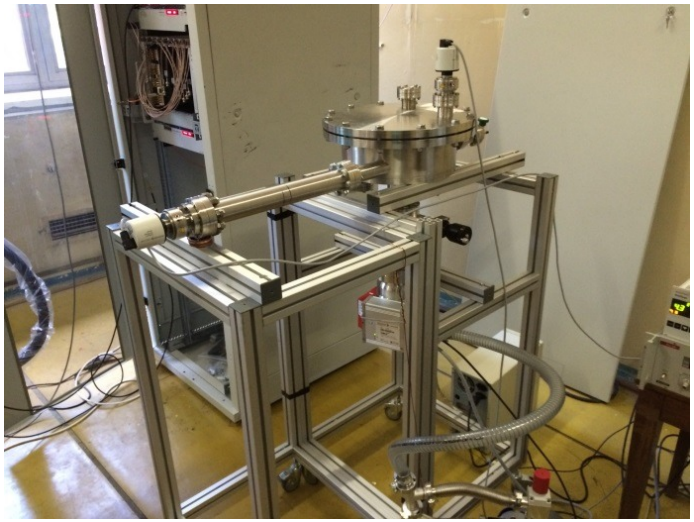
Collaboration between

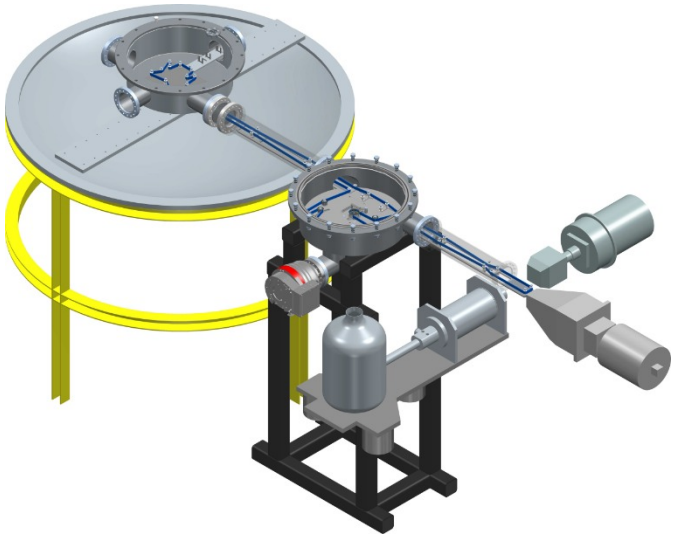
Orsay,
Legnaro
and iThemba LABS

to build copies of the
BEDO Tape Station at
ALTO

BEDO Tape Station Orsay

-decay Tape Stations



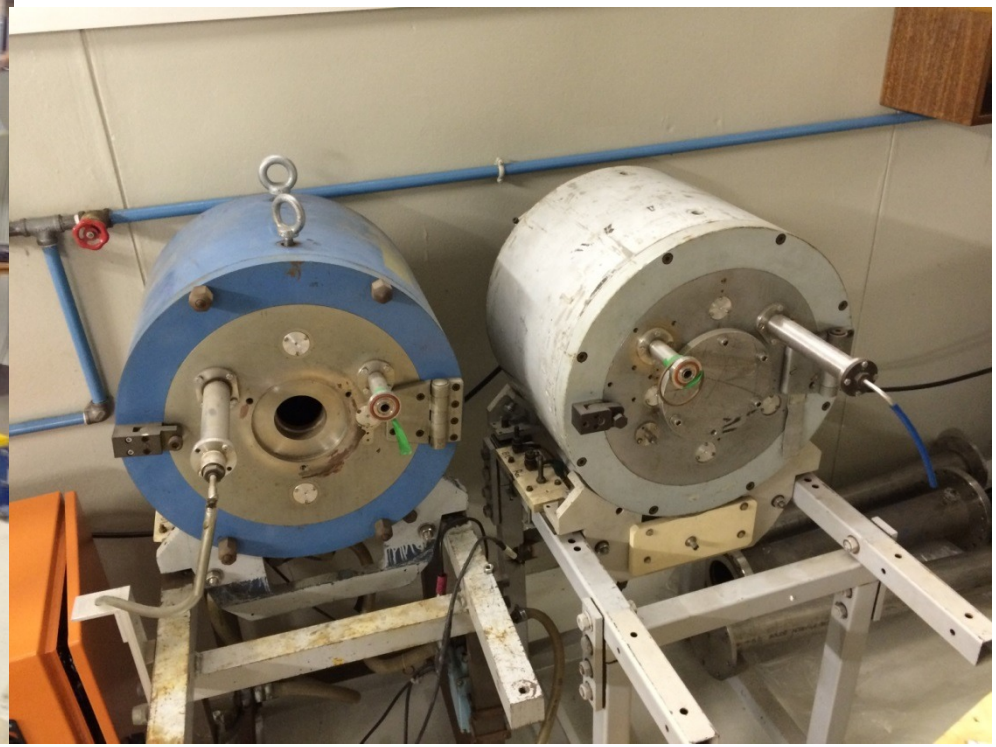


Slovakia Tape Station (TATRA)
Martin Venhart

Similar station be tested with beam at iThemba LABS in 2017
Later to be used with GALS
- See Sergey Zemlyanoy poster

Detectors

AFRODITE Clovers, LEPS, TIGRESS
Orsay & Bonn Electron Spectrometers
8 $LaBr_3$



Conclusions

- AFRODITE array to be upgraded
- Experiments with AFRODITE on K600 spectrometer
- Low Energy RIBs within 4 years ~ 10^{13} fissions/s
- New Plan for 70 MeV cyclotron
  - can be operational 4 years after securing funding
  - Thus SSC fully utilized for research
  - Increased revenue to fund development
- ReDesign of Phase 2 for accelerated RIBs to commence

Thank You

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