CYC2022

23rd International Conference on Cyclotrons and their Applications

Dec. 5 - 9, 2022 • Beijing, China

Hosted by

China Institute of Atomic Energy & Huazhong University of Science and Technology

China Institute of Atomic Energy

CYC'2022 Summary

Yuri Bylinskii, TRIUMF

Joachim Grillenberger, PSI

CYC2022

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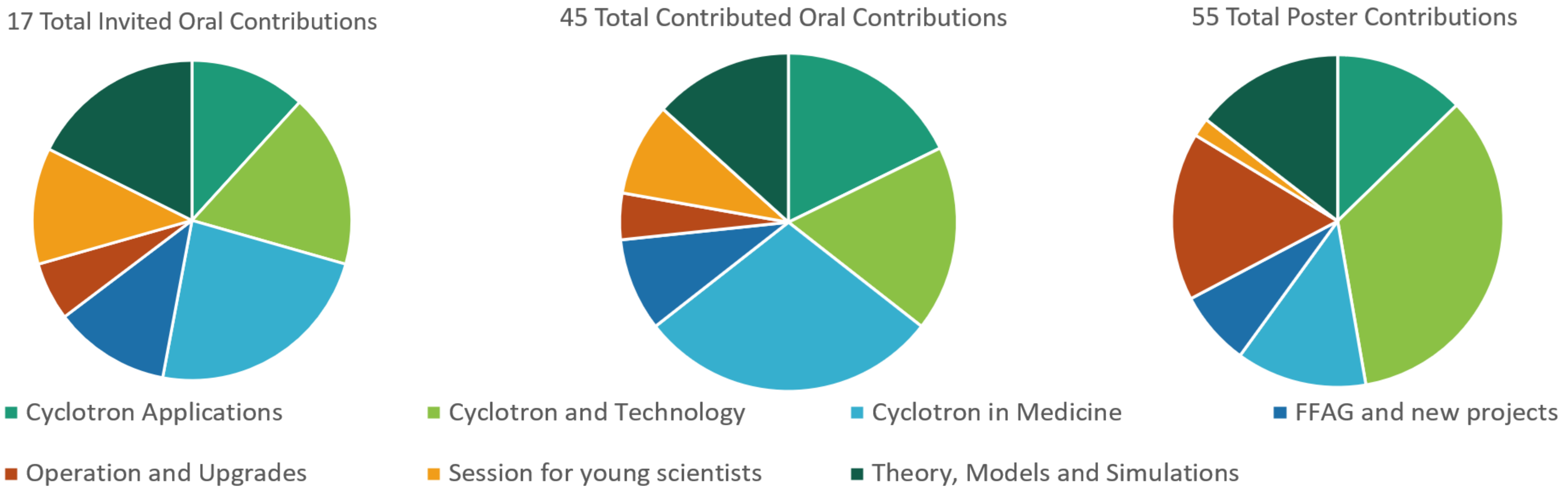
18 Invited talks, 45 Contributed orals and 55 Posters, in total, 118 Contributions



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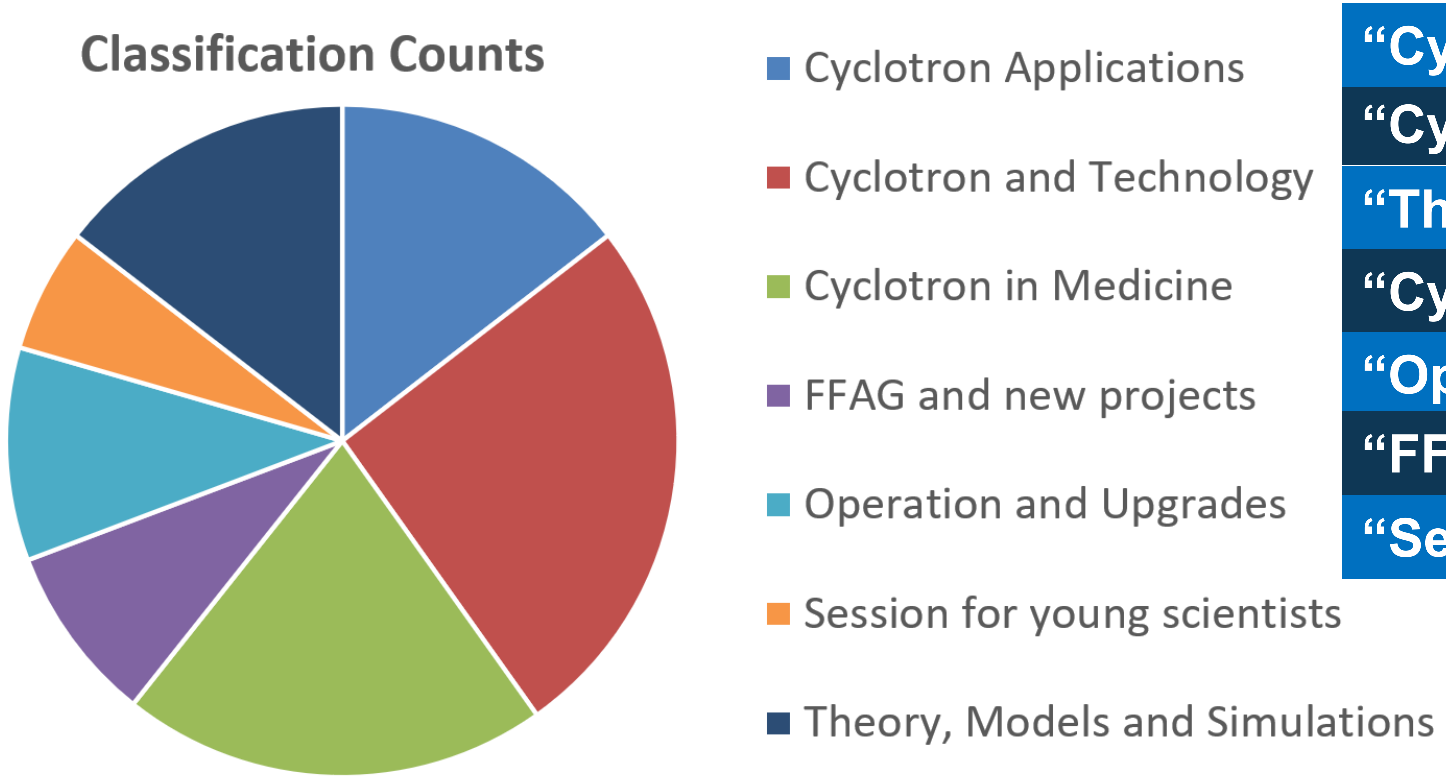
IOC Meeting

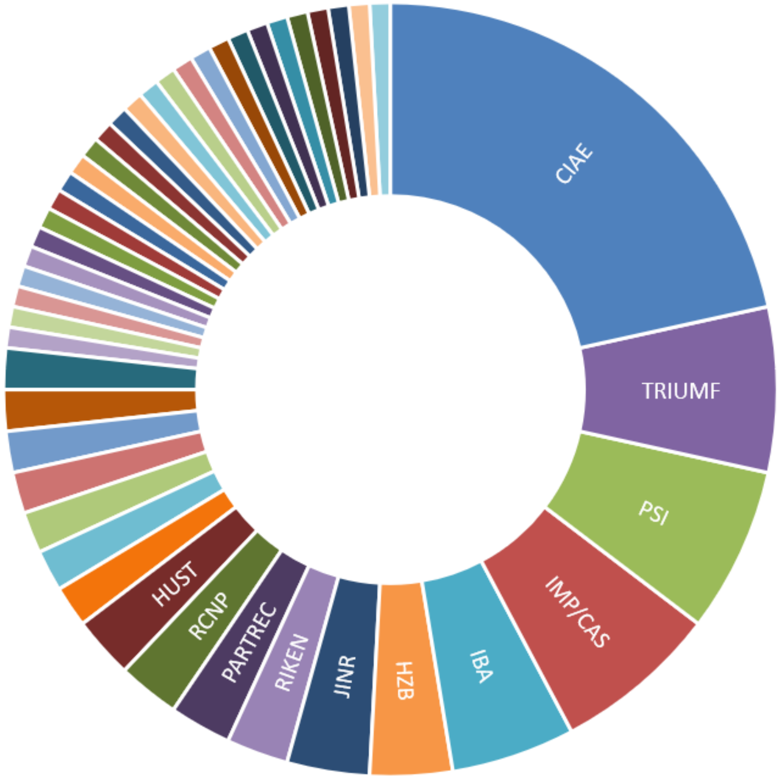
7 topics for the conference



- "Cyclotron and Technology" - 30 papers
- "Cyclotron in Medicine" - 24 papers
- "Theory Models and Simulations" - 17 papers
- "Cyclotron Applications" - 18 papers
- "Operation and Upgrades" – 12 papers
- "FFAG and new projects" – 10 papers
- "Session for young scientists" – 7 papers

The conference abstracts come from 45 different affiliations

Contribution Counts by Affiliation



CIAE - 25 abstracts

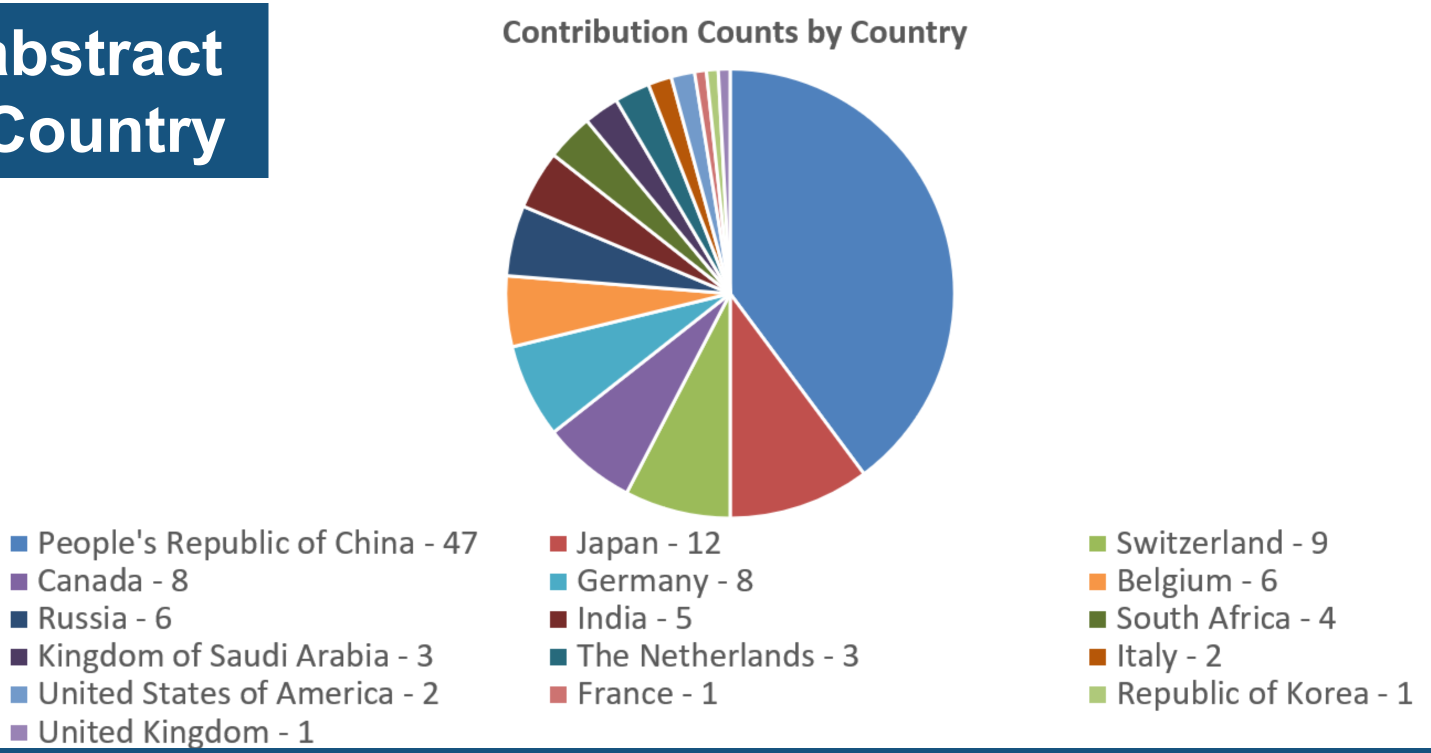
Followed by **IMP**, **PSI,** and **TRIUMF** - 8 abstracts each

IBA has 6, and **JINR** and **HZB** - 4 abstracts each

HUST, RCNP, PARTREC, and **RIKEN** - 3 abstracts each

Others - 1 or 2 abstracts

Statistics of the abstract submissions by Country



The abstracts are coming from 16 countries.
Among them, China submitted 47 abstracts, about two-fifths of the total.

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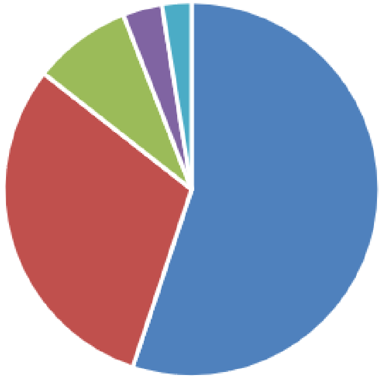
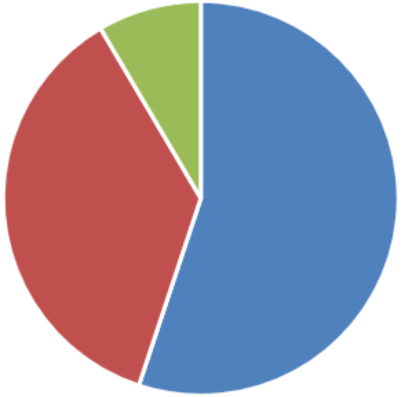
Statistics of the abstract submissions by Region and Super Region

Contribution Counts by Region



Contribution Counts by Super Region



Registration Statistics

Grand total: 237 participants

Canada		12
United States of America		8
North America		**20**
Americas		**20**
India		8
Japan		23
People's Republic of China		84
Republic of Korea		1
Asia		**116**
Asia		**116**
Mali		1
South Africa		6
Africa		**7**

> 40 students attended the conference

Albania		1
Belgium		13
Finland		2
France		5
Germany		22
Italy		11
Russia		9
Switzerland		23
The Netherlands		3
United Kingdom		2
Europe		**91**
Kingdom of Saudi Arabia		3
Middle East		**3**
Europe		**101**
Grand Total		**237**

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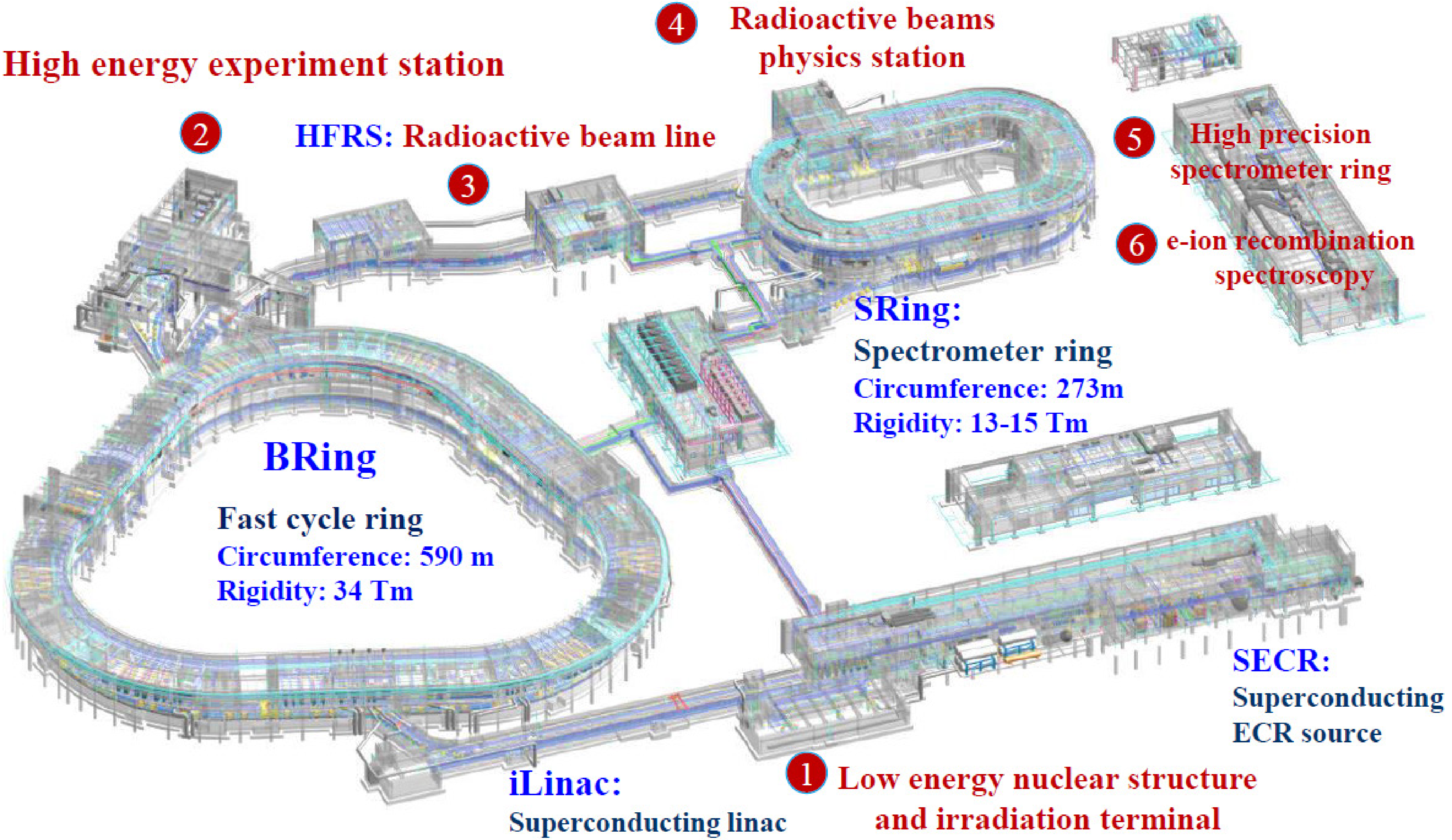
Conference Highlights

New Projects & Proposals

Brief introduction of the HIAF

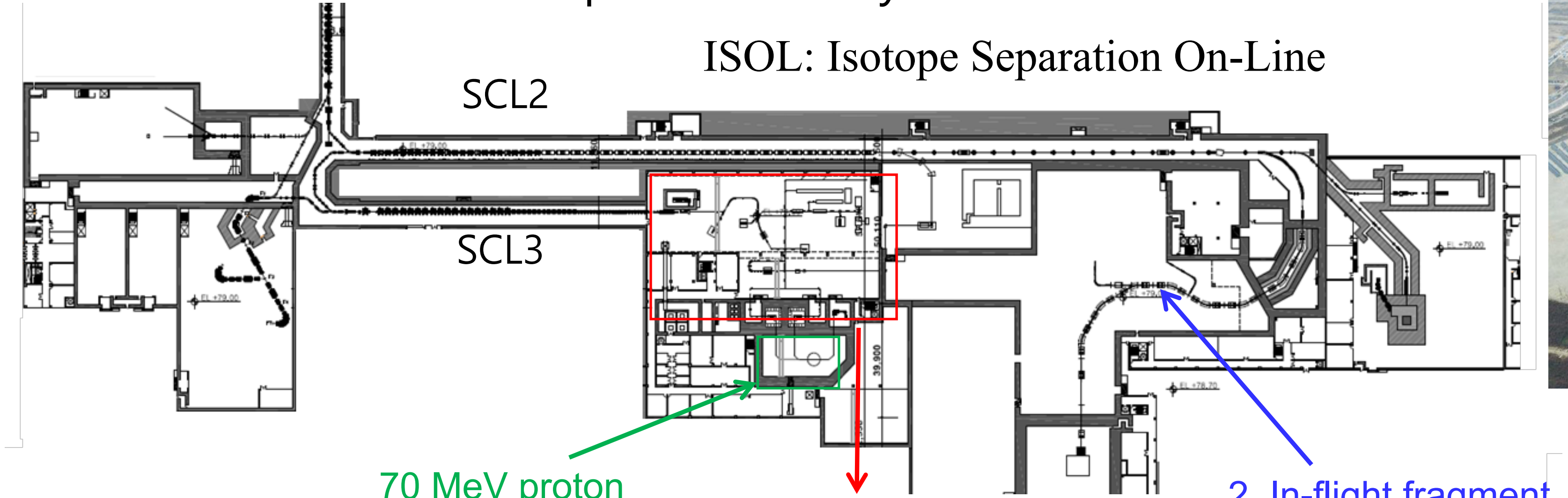
Accelerator components and experiment terminals



Institute for Basic Science, Korea

RI beam production by ISOL method for RISP

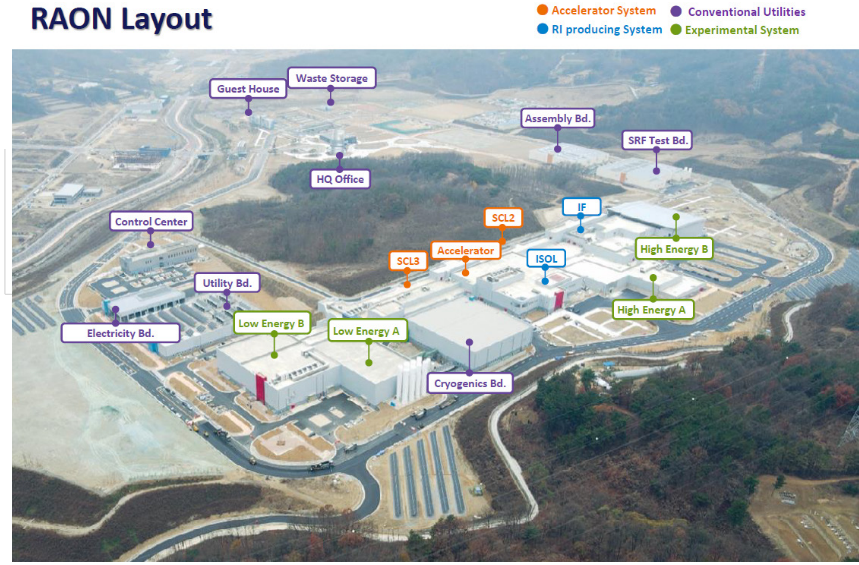
ISOL: Isotope Separation On-Line



70 MeV proton Cyclotron

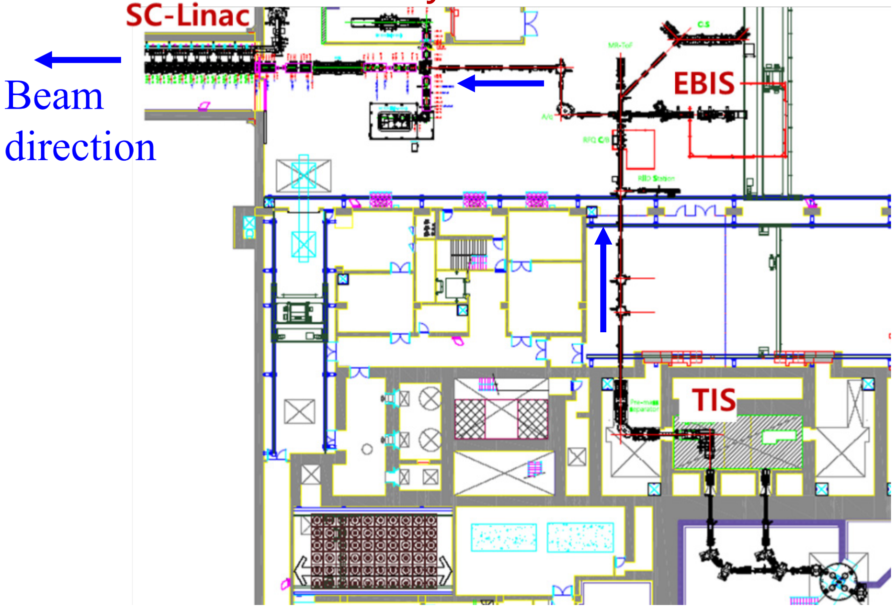
1. ISOL system

2. In-flight fragment separator



Period: 2011.12~ 2022.12
Budget: ~1.3 billion USD (~0.9 billion for building and land)
Total area: ~0.95 km^2

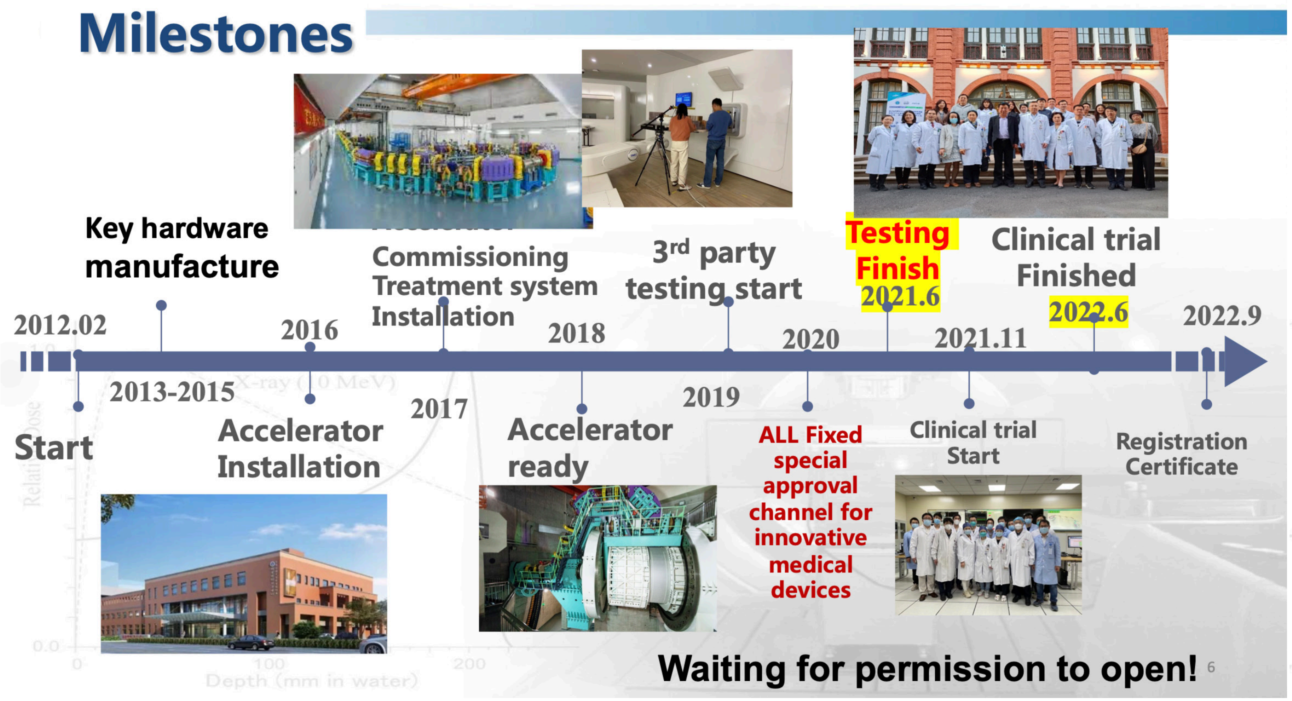
Layout of ISOL

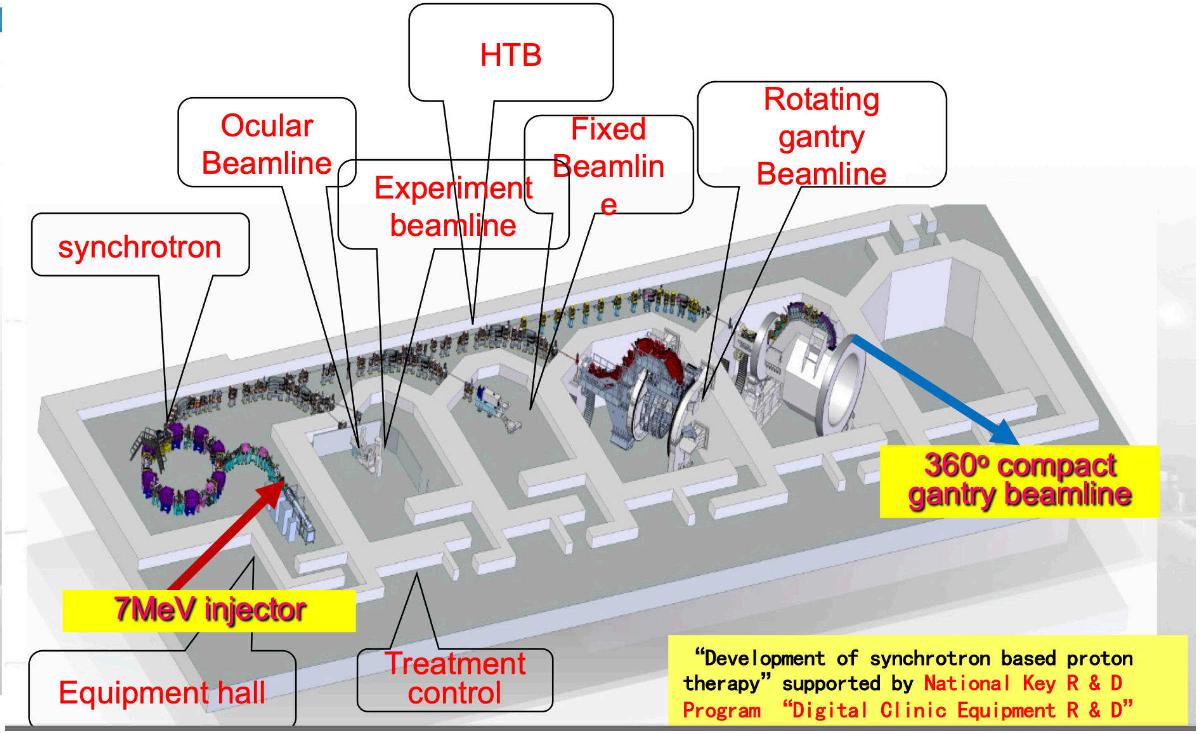


IBA C70 cyclotron

THB1-3: SAPT- A synchrotron based proton therapy
Manzhou Zhang

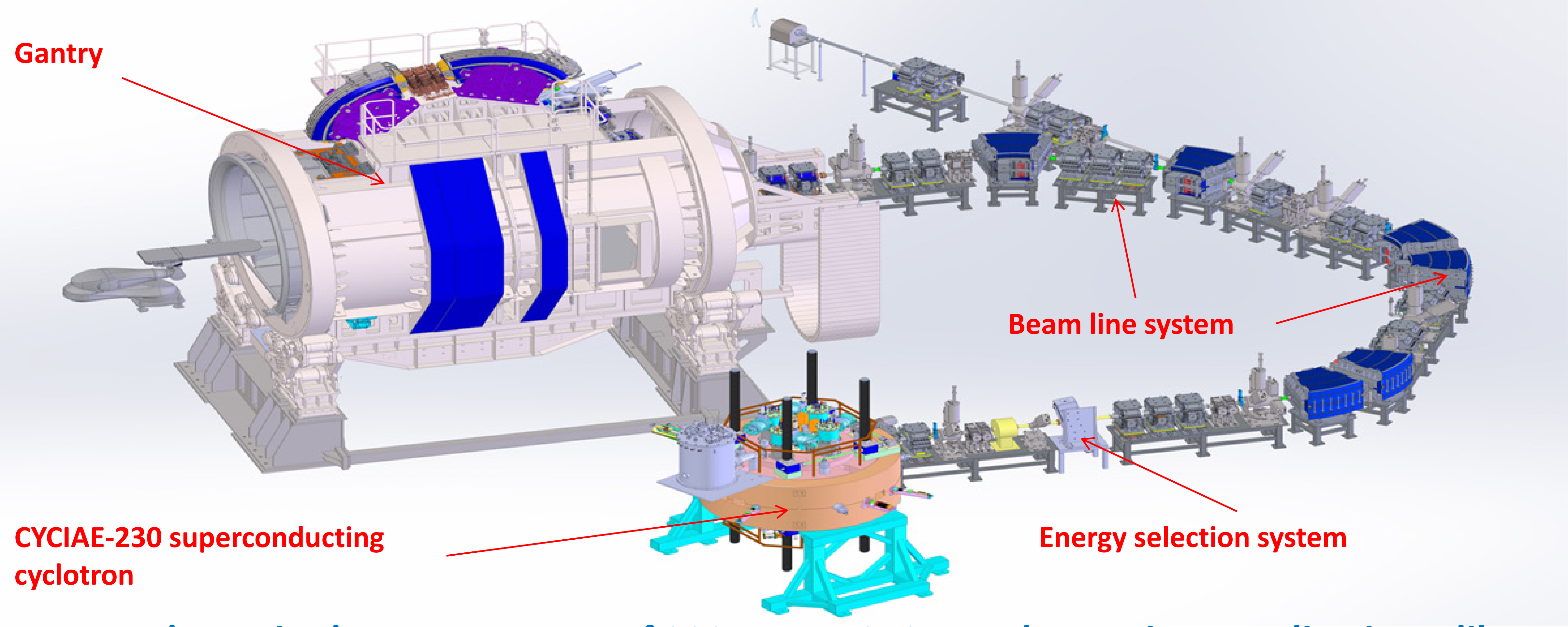
A very nice overview of the synchrotron based proton therapy center in Shanghai. It is amazing what they acheived in such short time. The hardware devolopment started in 2014 and the clinical trials where finished ahead of schedule. The facility is not much larger than a cyclotron based facility. Therefore, this talk proofs that synchrotrons are serious competitors to cyclotrons. It is a pity they still have to wait for the permisson to open. Could have been invited, too.





Introduction to CYCIAE-230

Granted by CNNC, the cyclotron project was launched in 2016. The rest of the proton therapy system was granted by Ministry of Industry and Information Technology in 2017.



Proton beam in the energy range of 200 MeV – 250 MeV has various applications, like proton therapy, SEE test and radiation hardening of microchips, etc.

■China's carbon ion therapy facility-HIMM

Heavy Ion Medical Machine

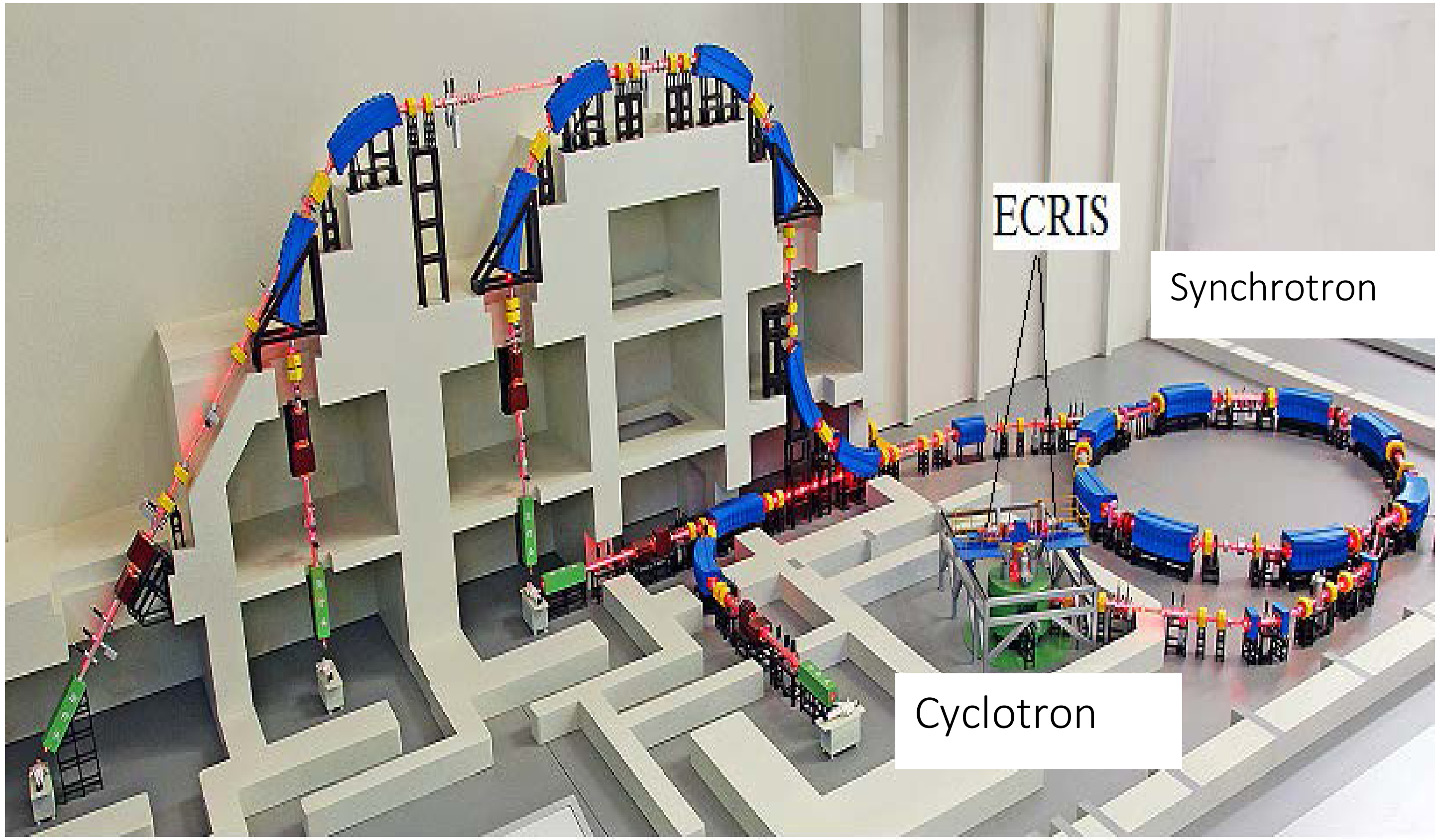
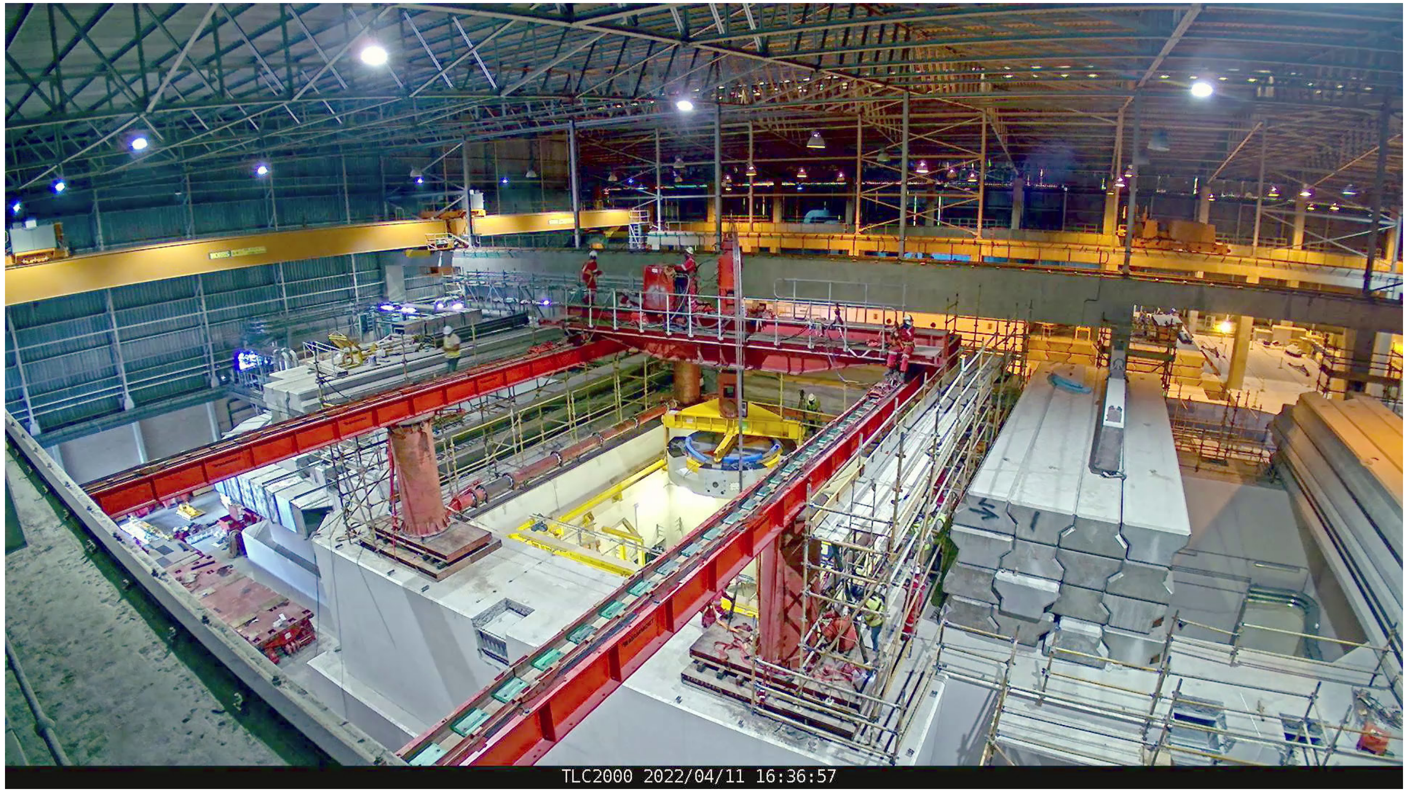


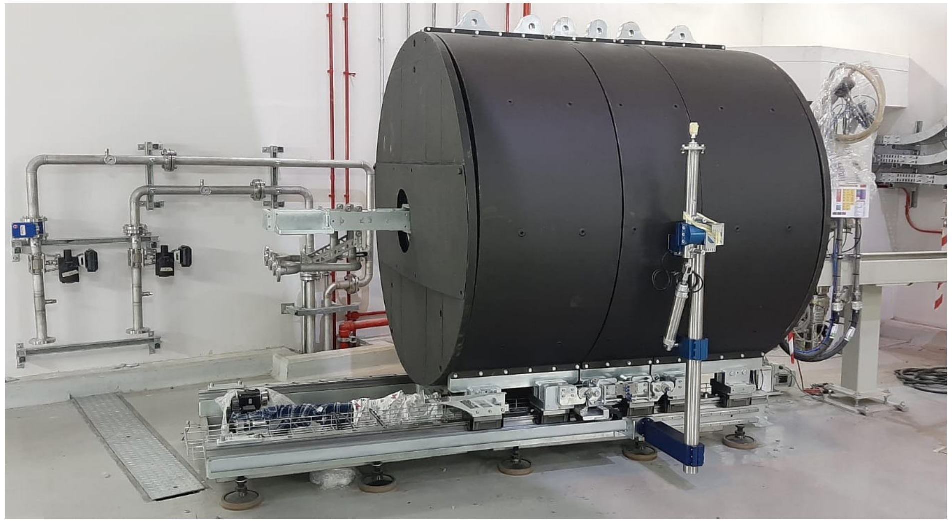
Fig.1 Schematic view of HIMM

- 2 ECR ion sources
- Compact Cyclotron:
  - 2.92m Diameter
  - No Trimming coils
  - ~7MeV/u, 10 μA, 12C5+
- 120-400 MeV/u Synchrotron
- 4 Treatment terminals
- 5 fixed irradiation ports
- Maximum particle number in the terminal (ppp) : 1.2E9

WEB1-1: : An overview of the south African ISOTOPE FACILITY(SAIF) PROJECT
Izak Le Roux Strydom

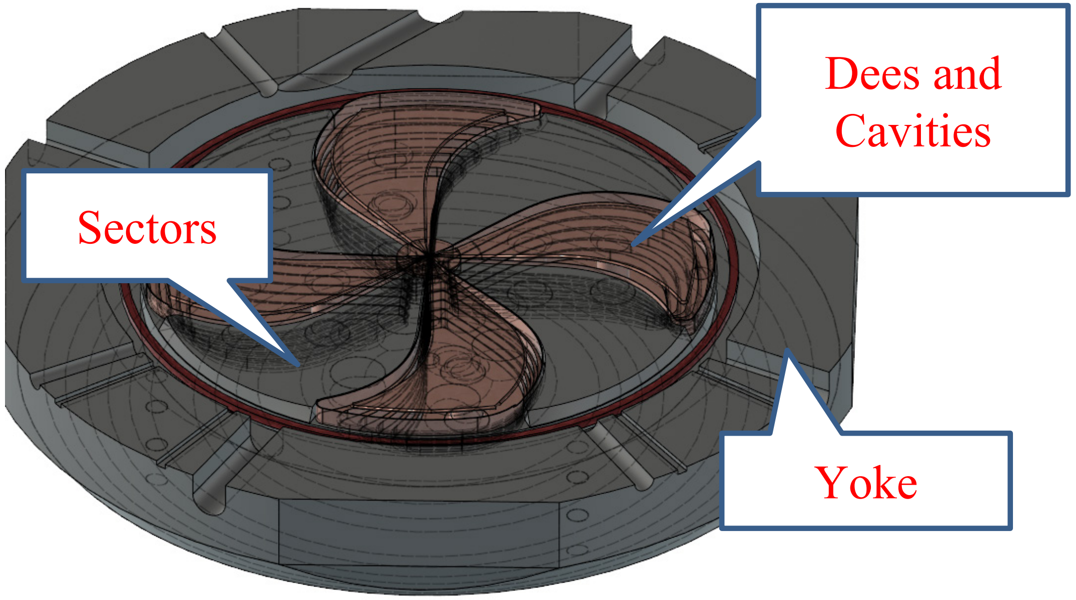
Really nice and impressive overview over the Isotope Production at iThemab Labs. Slide 5 for the installation of the magnet, and slide 8 showing the target system are impressive in particular.





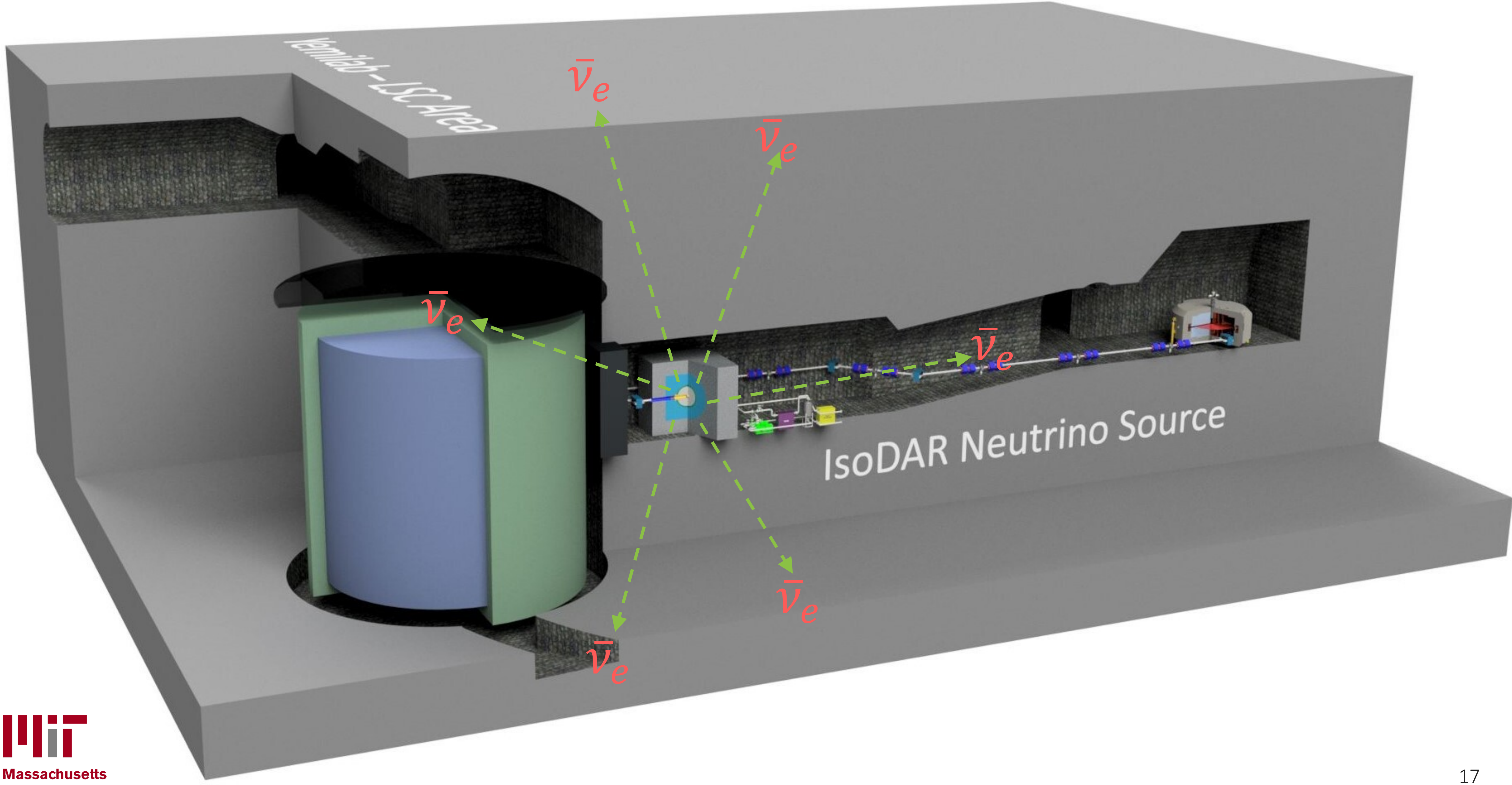
Installation of C70 cyclotron and beam transport lines at iThemba

MSC230 – Medical Superconducting Cyclotron



Inside the MSC230

Accelerated Particles	Protons
Magnet Type	Compact, SC coil, warm yoke, B≈1.5 T
Number of Sectors	4
Number of RF Cavities	4
Ion Source	Internal, PIG
Final Energy	230 MeV
Number of Turns	600

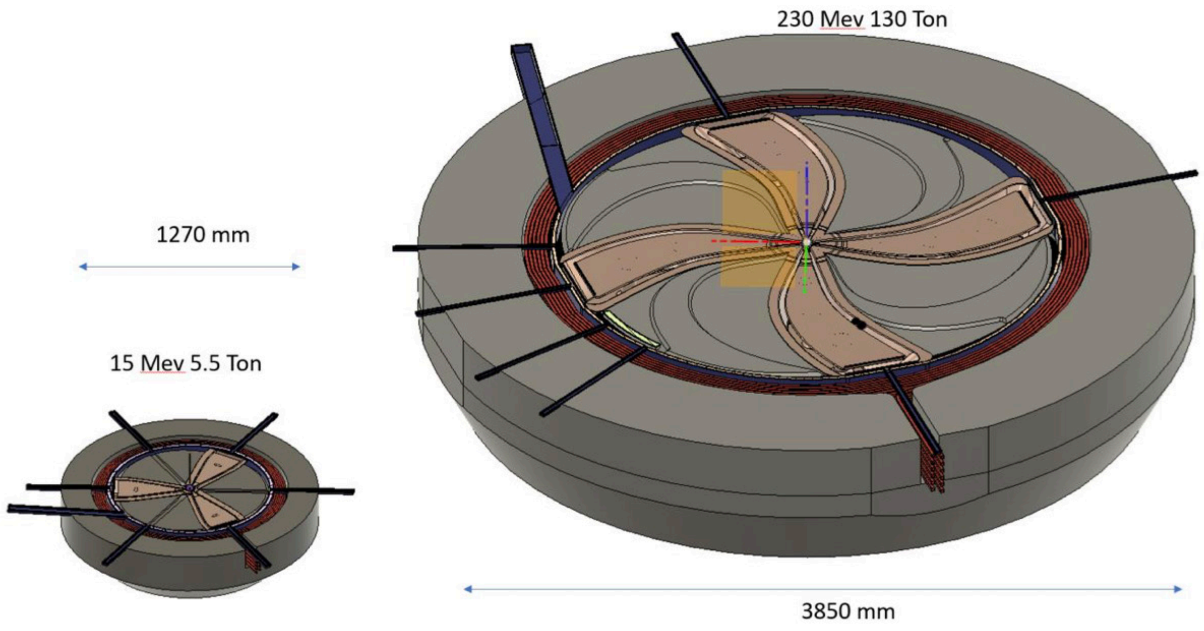


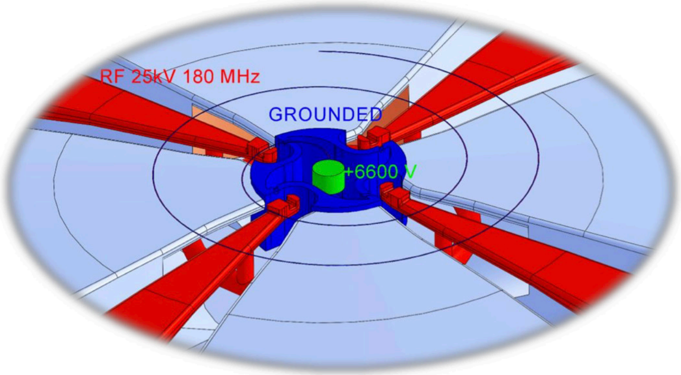
Massachusetts Institute of Technology

THB1-2: A new concept of cyclotrons for medical applications

Oleg Karamyshev

The goal of this interesting study is the design of a more compact and lighter design of a cyclotron for medical and industrial applications. In the past, the trend was to increase the B field and thus the decrease the pole radius. This approach intends to make RF and Coil more compact by increasing RF frequency, decreasing the dimensions of the valley, which leads to less A-turns in magnet, thus making the coil smaller, which will lead to smaller yoke.
The concept would lead to a lower poer consumption and smaller footprint of such a machine, thus lower cost. Very interesting for industry.





Central region. Interesting solution for the capture issue at high frequency by putting the ion source on +6.6kV. 8th harmonic acceleration mitght be difficult, though.

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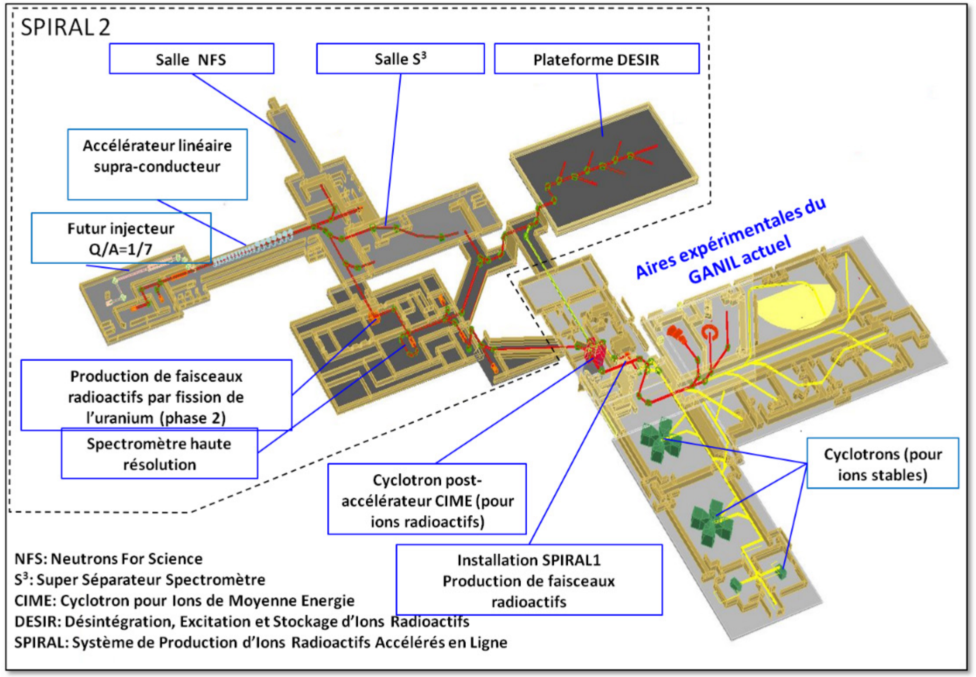
Status reports

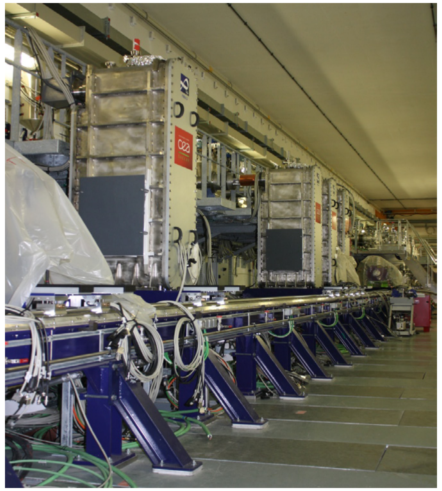
SPIRAL2 Project

2005 : Project launched



Original project, including post-acceleration of fission products in CIME

2011 : excavation

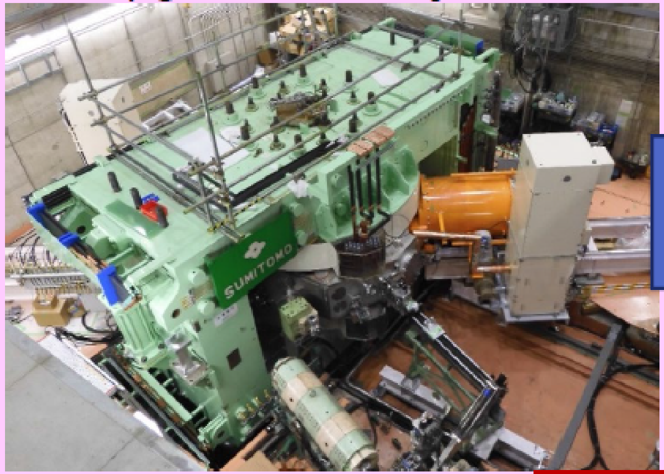


2015: 1st beam in RFQ

October 28th, 2019 : 1st beam in the LINAC

Upgrade of the RCNP AVF Cyclotron

Upgraded AVF cyclotron

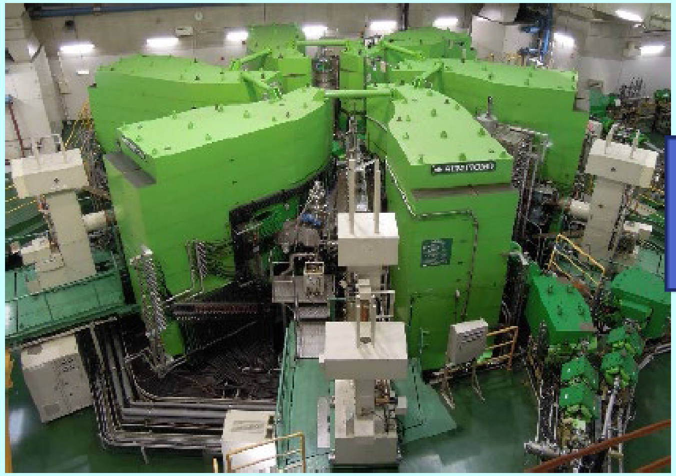


Stand alone mode

Injector mode

High-intensity
High-quality

Ring cyclotron



1. Production of RIs — Several tens to 100 μA
   - Increase of proton and deuteron beam intensity
     → Short-lived RI supply platform
   - Increase of helium beam intensity
     → Targeted alpha-particle therapy
     （Trial treatment started in March 2022)

2. Production of secondary particle beam — > 10 μA
   - Increase of 400 MeV proton beam intensity
     → Muons produced by MuSIC
     → White neutrons for soft-error-rate testing
     → Mono-energetic neutrons

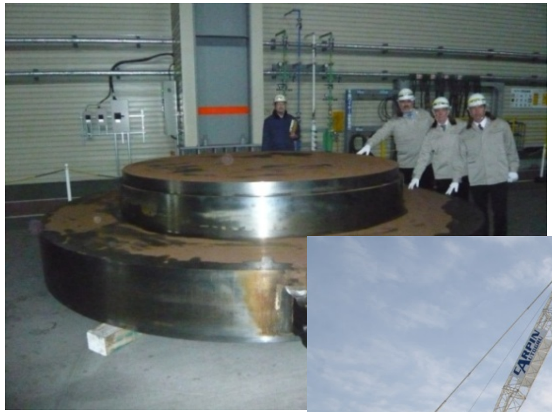
3. High quality beam — $\Delta E/E \sim 10^{-4}$
   - Increase of high-quality light ion beam intensity
     → Hyper-quality, halo-free beam
     → highly-polarized beam

4. Unstable heavy ion beam
   - Increase of heavy ion beam intensity
     → Unstable nuclear beam
     → CAGRA + Grand-RAIDEN

Status of SPES Cyclotron at Laboratori Nazionali of Legnaro -INFN

2011-2014 Study, Design ,Construction and factory tests

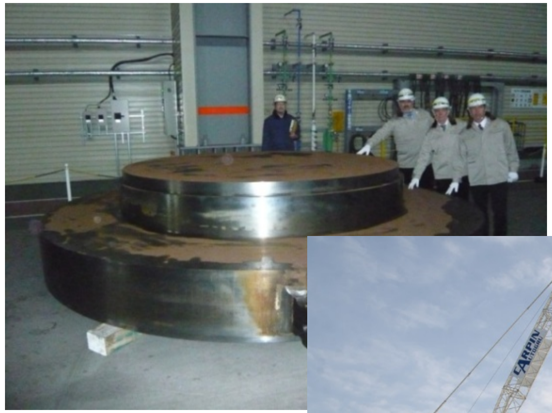
Status of SPES Cyclotron at Laboratori Nazionali of Legnaro -INFN



2011-2014 Study, Design ,Construction and factory tests

2015
Installation at LNL

Status of SPES Cyclotron at Laboratori Nazionali of Legnaro -INFN

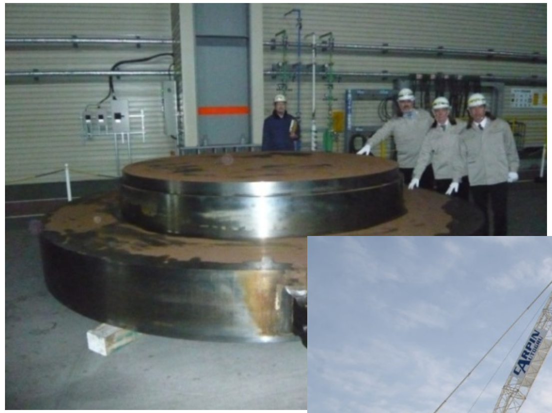


2011-2014 Study, Design ,Construction and factory tests

2015
Installation at LNL

2016
First beam and commissioning

Status of SPES Cyclotron at Laboratori Nazionali of Legnaro -INFN



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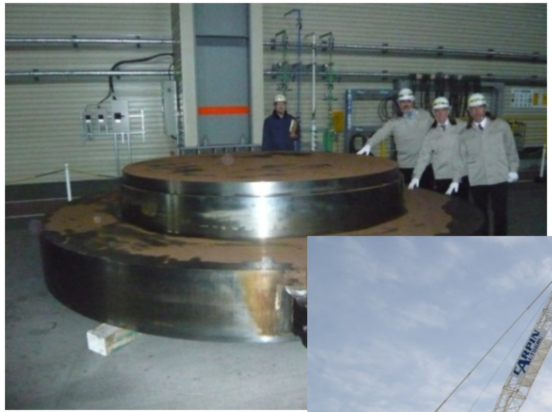

2011-2014 Study, Design ,Construction and factory tests

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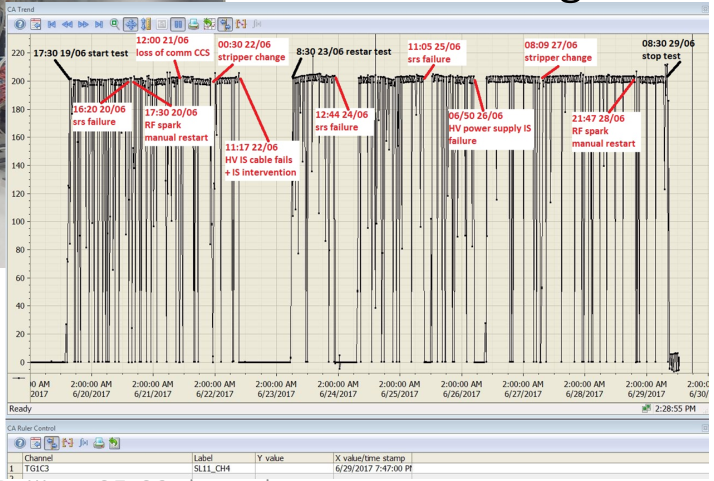
First beam and commissioning



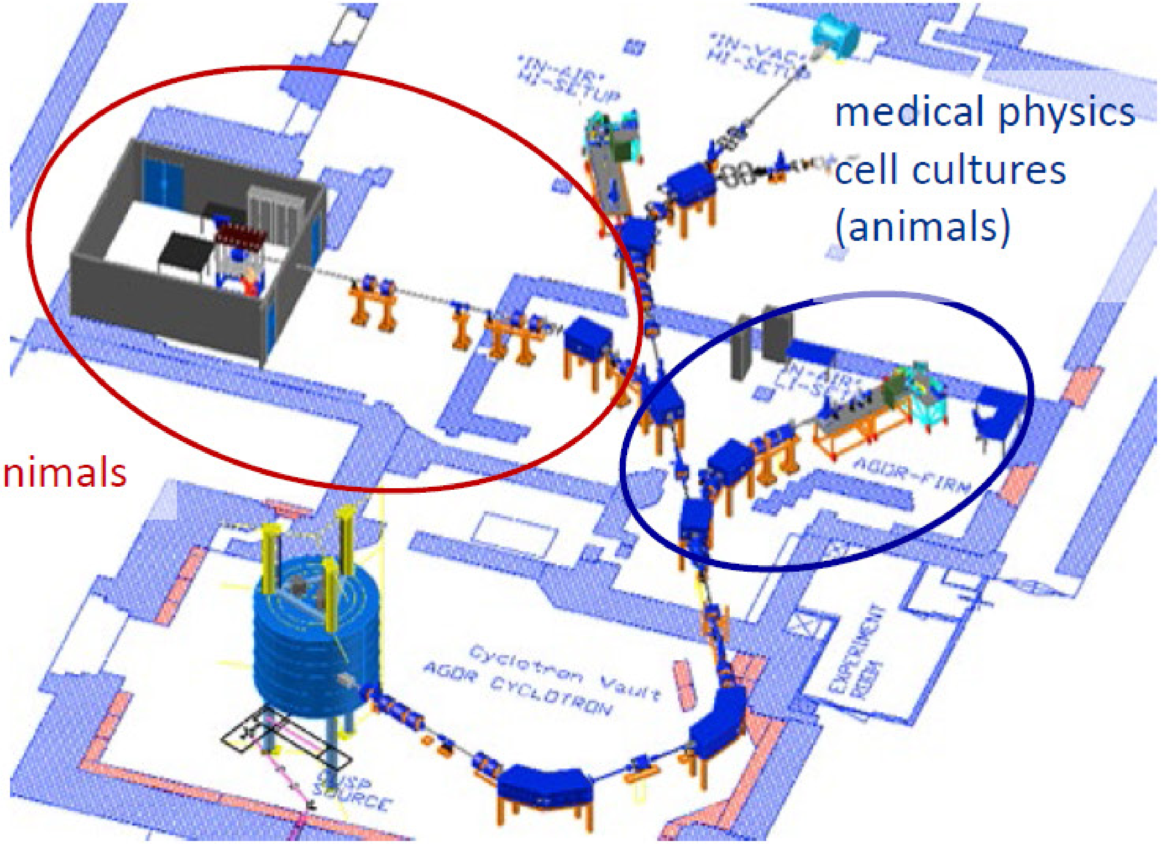
2017
Site Acceptance Test and final delivery

2018
INFN operation

partrec

Ongoing Upgrades

- Radiation hardness testing is expanding
- In 2018 funding has been obtained for further expansion of the biomedical research as well as for a project investigating the properties of neutron-rich heavy nuclei
- Image guidance
- Individual planning
- Multiple modalities
  - PBS/scattering
  - Shoot through/SOBP
  - Grid (Microbeam)
  - FLASH
  - Protons; helium



animals

university of groningen

University Medical Center Groningen

Status of the HZB Cyclotron

Major Event: Repair of Extraction

- time consuming:
  - opening of cyclotron (extraction valley) necessary
  - open all the feed-throughs for phase probes
  - after repair: pumping and conditioning of electrostatic elements

Status of the HZB Cyclotron

Major Event: Repair of Extraction

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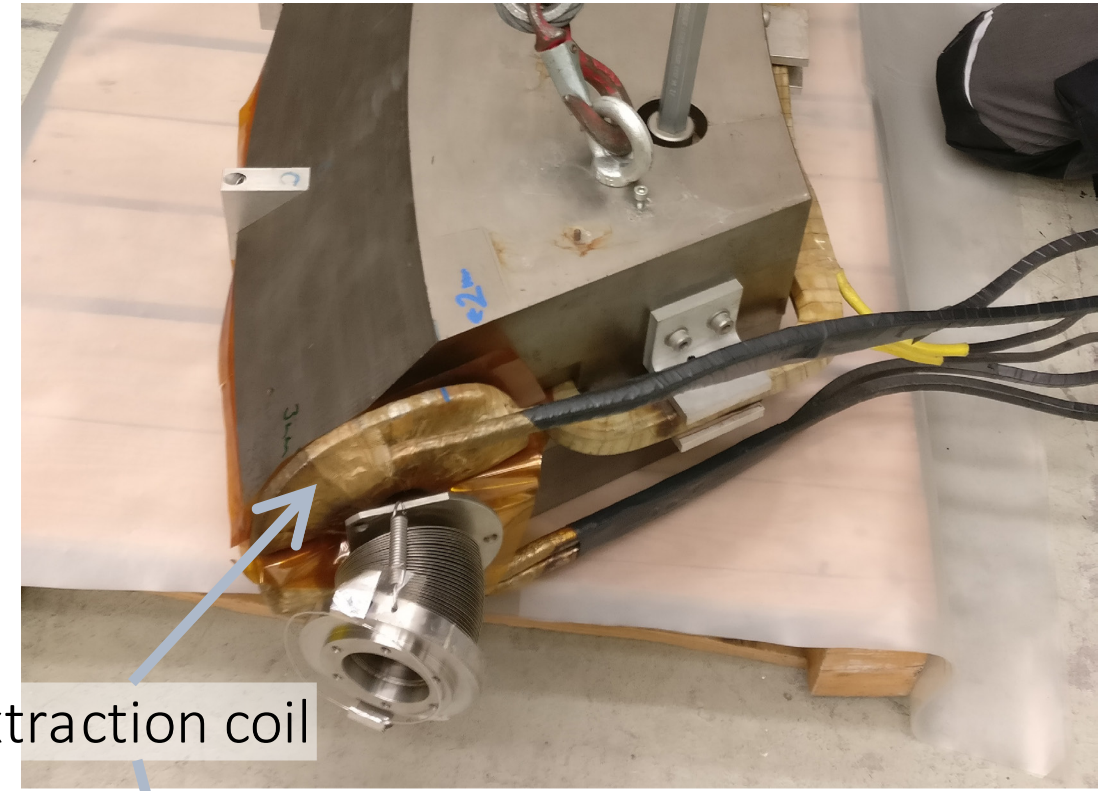
- our luck: spare extraction coil according to original drawings already ordered and at HZB



extraction coil

Status of the HZB Cyclotron

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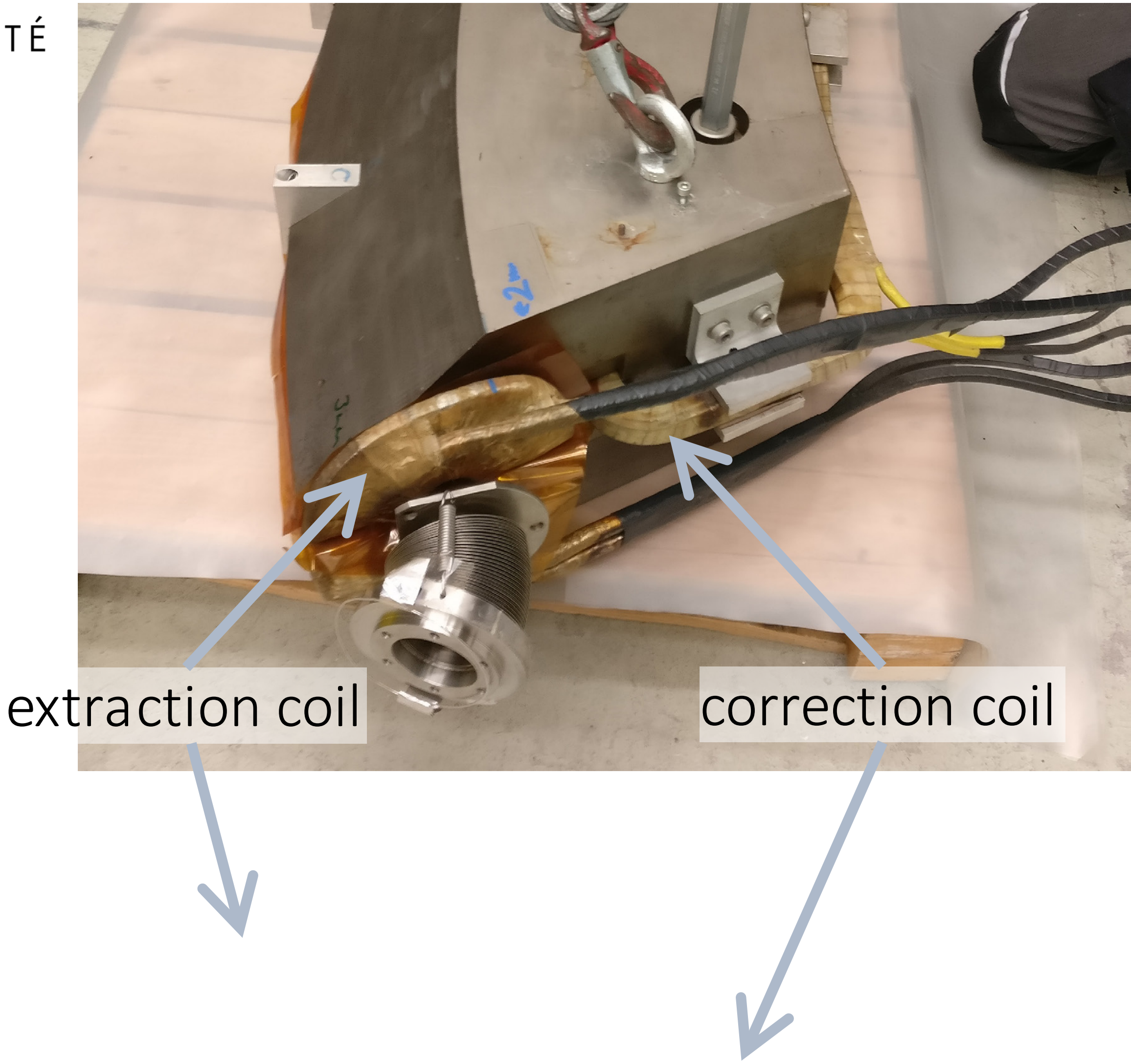
- our luck: spare extraction coil according to original drawings already ordered and at HZB
- since several decades: correction coil never used, even not connected!



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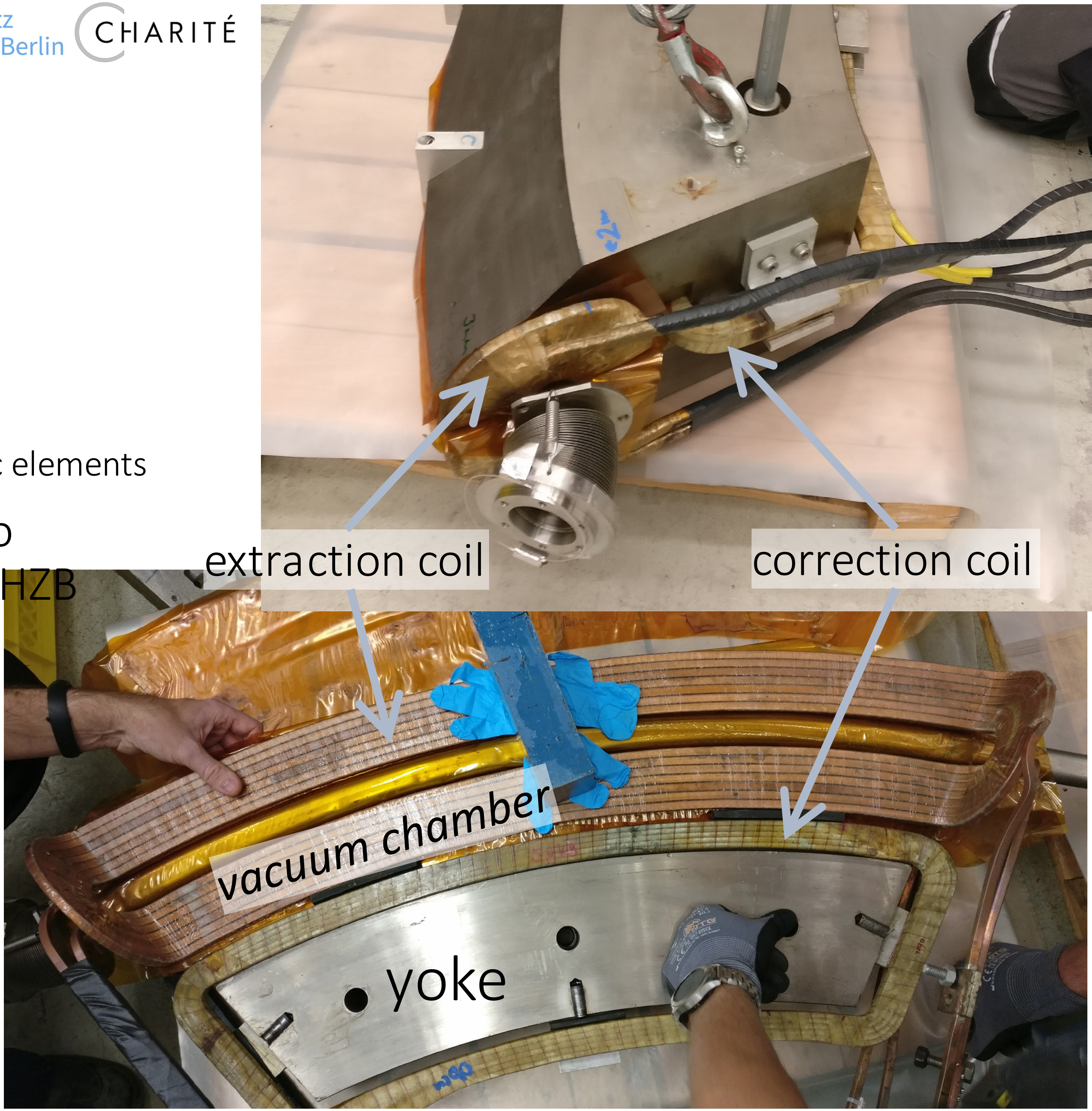

HZB Helmholtz Zentrum Berlin CHARITÉ

Status of the HZB Cyclotron

Major Event: Repair of Extraction

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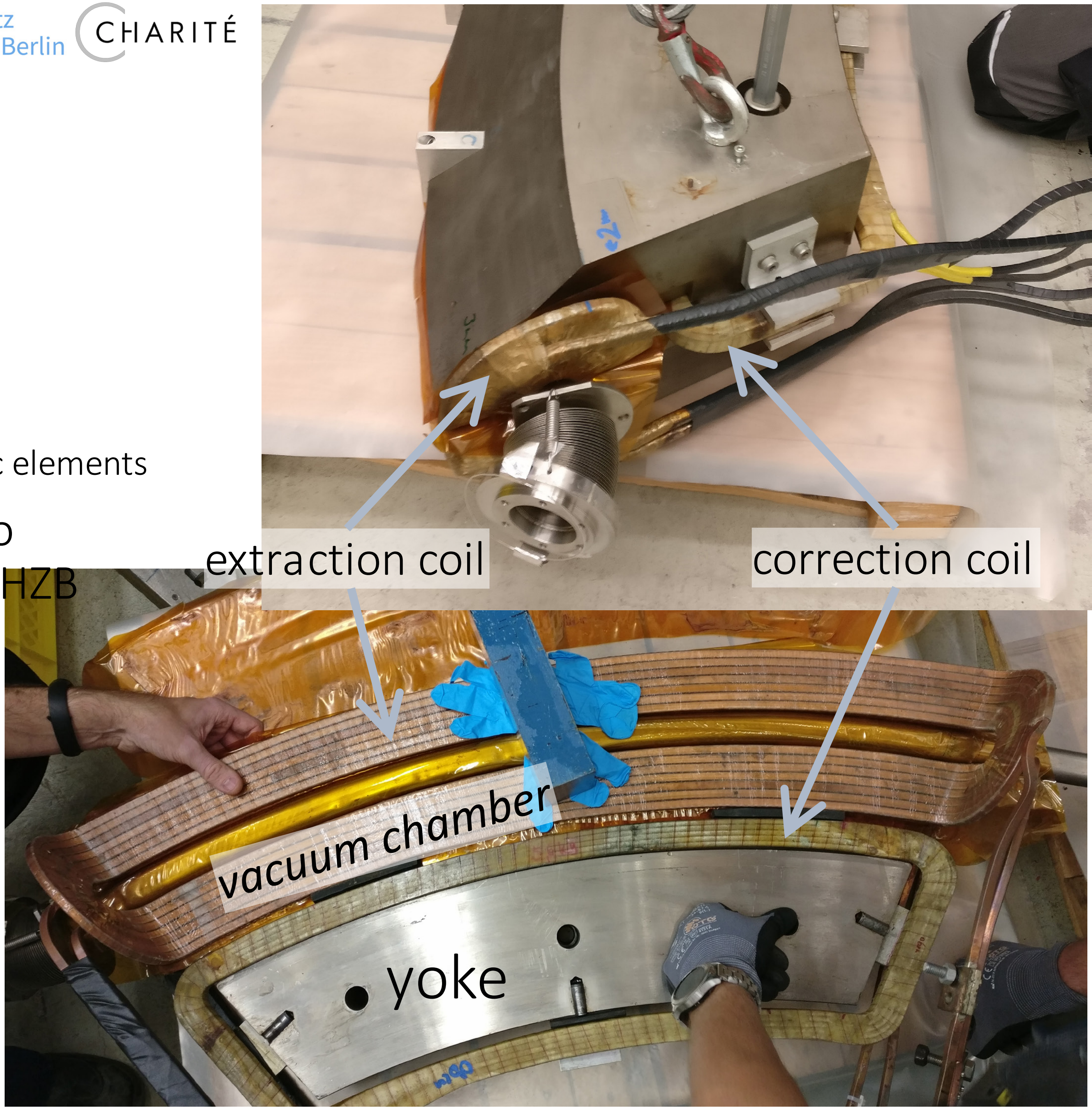
- our luck: spare extraction coil according to original drawings already ordered and at HZB
- since several decades:
  correction coil never used,
  even not connected!
- now: correction coil necessary,
  otherwise no extraction possible!



HZB Helmholtz Zentrum Berlin CHARITÉ

Status of the HZB Cyclotron

Major Event: Repair of Extraction

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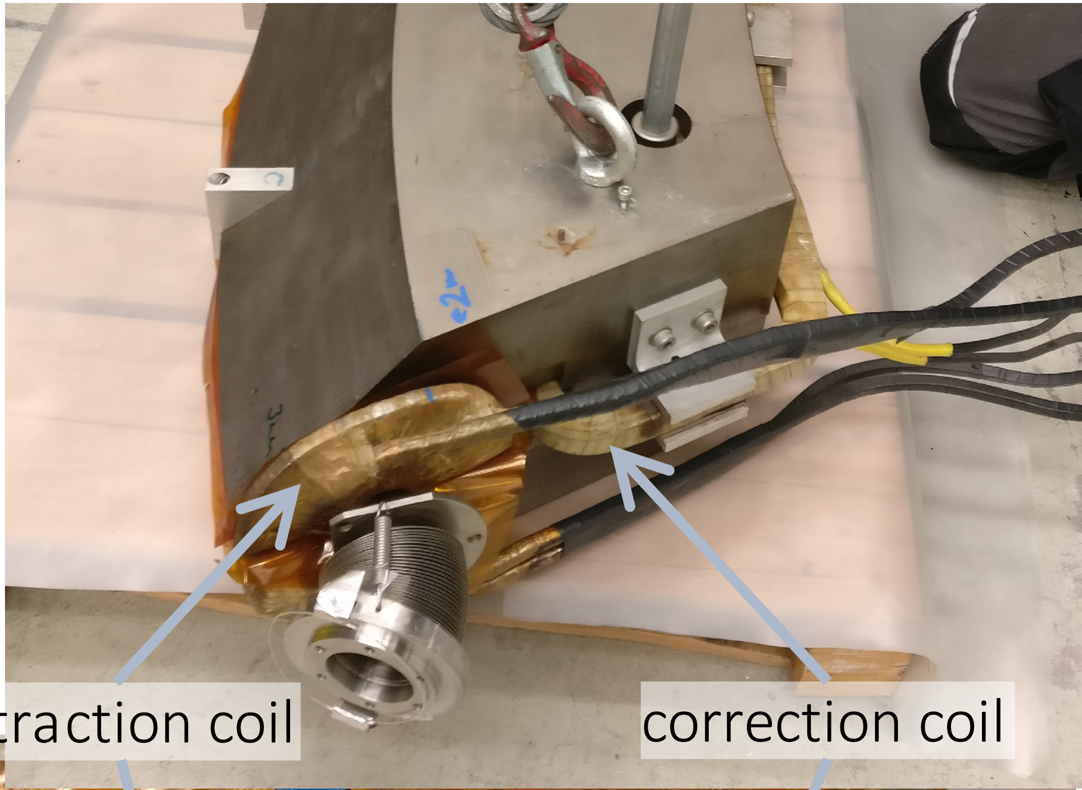
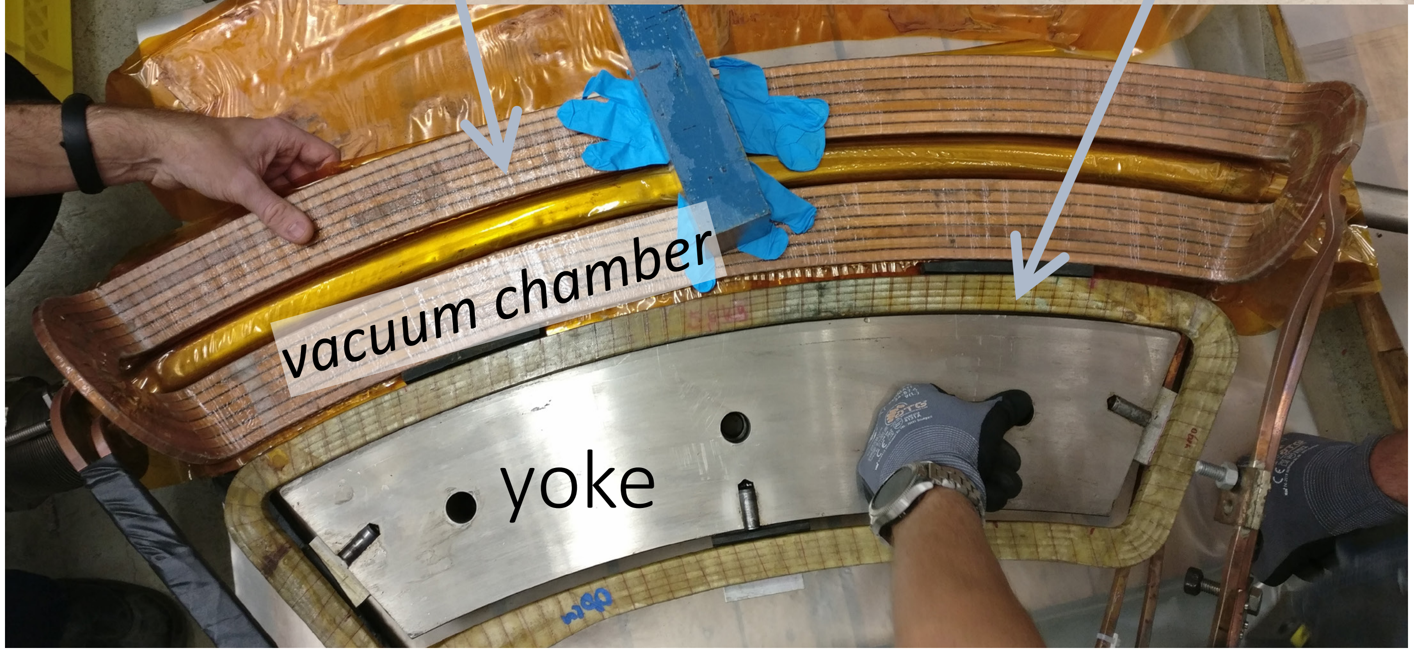
- our luck: spare extraction coil according to original drawings already ordered and at HZB
- since several decades:
  correction coil never used,
  even not connected!
- now: correction coil necessary,
  otherwise no extraction possible!
- most likely: slightly different position of vacuum chamber



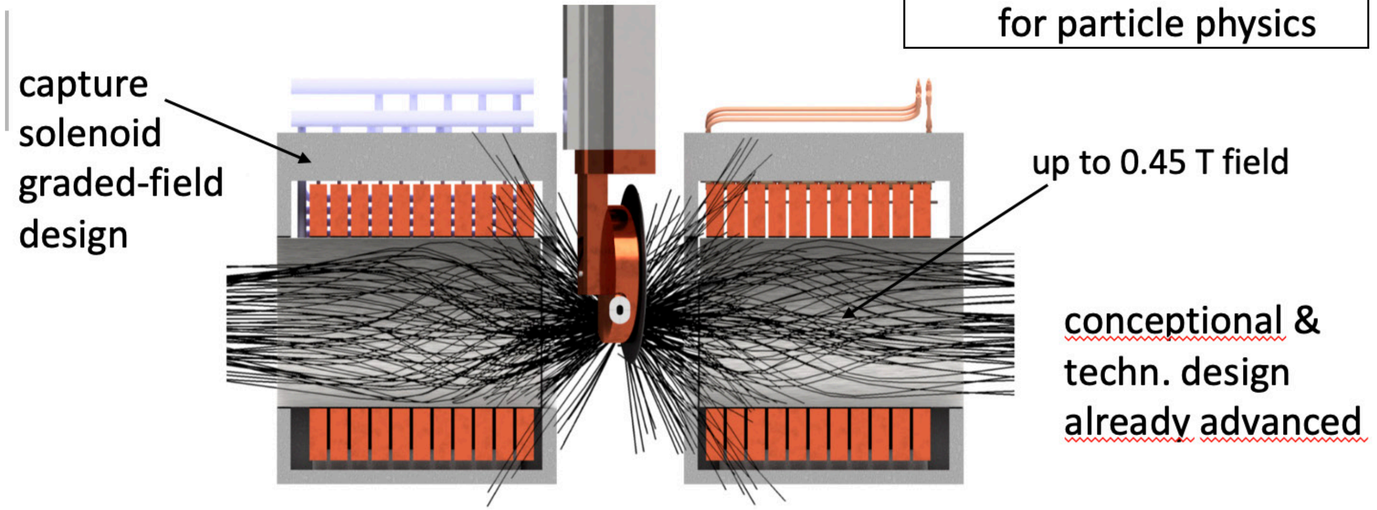


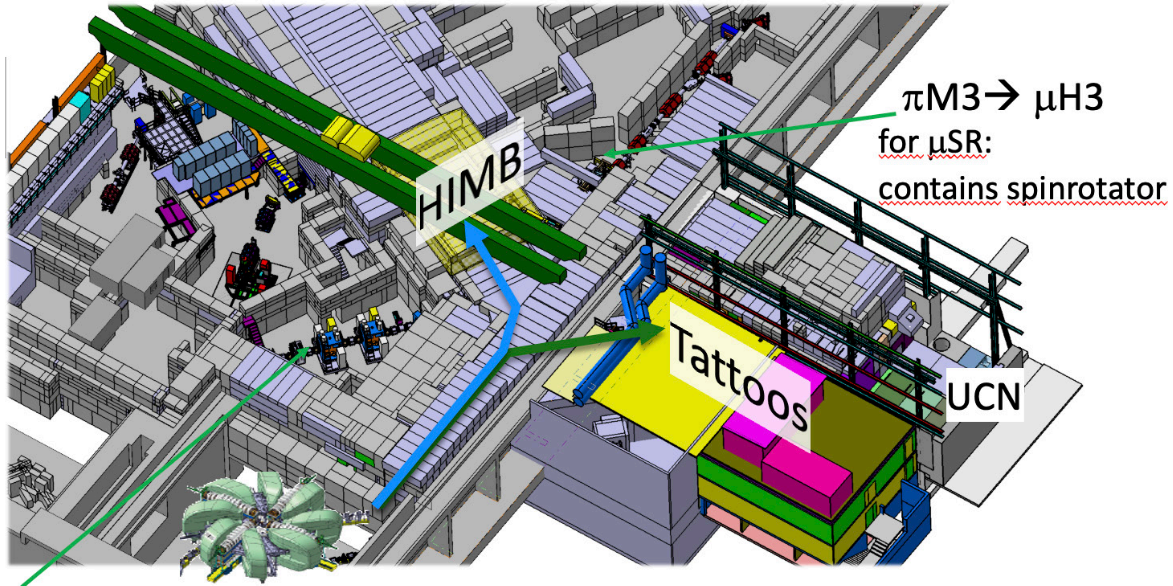
MOB2-2: IMPACT: A Substantial Upgrade to the HIPA Infrastructure at Paul Scherrer Institute (we are biased of course)
D. Kiselev

A very nice summary on the new foreseen project IMPACT at PSI. It nicely demonstrates that even 50 year old facilities still represents an attractive playground for scientists.
With the HIMB project the muon rates at the Meson production target M are predicted to be a factor of 100. A factor, the accelerator beam power can not compete with.
The Tattoos project is an impressive isotope production facility that will receive beam currents of up to 0.1mA at full beam energy of 590 MeV. It will be used for research on cancer treatment and diagnostics at the same time with the isotope ^{161}Tb.
First beam studies proofed that it is possible to split of 0.08mA from the main Megawatt beam.

HIMB = High-Intensity Muon Beams

goal: 10^{10} surface muons/s for particle physics





FFA's

CIAE:
High Energy and High Current Isochronous Proton Accelerator

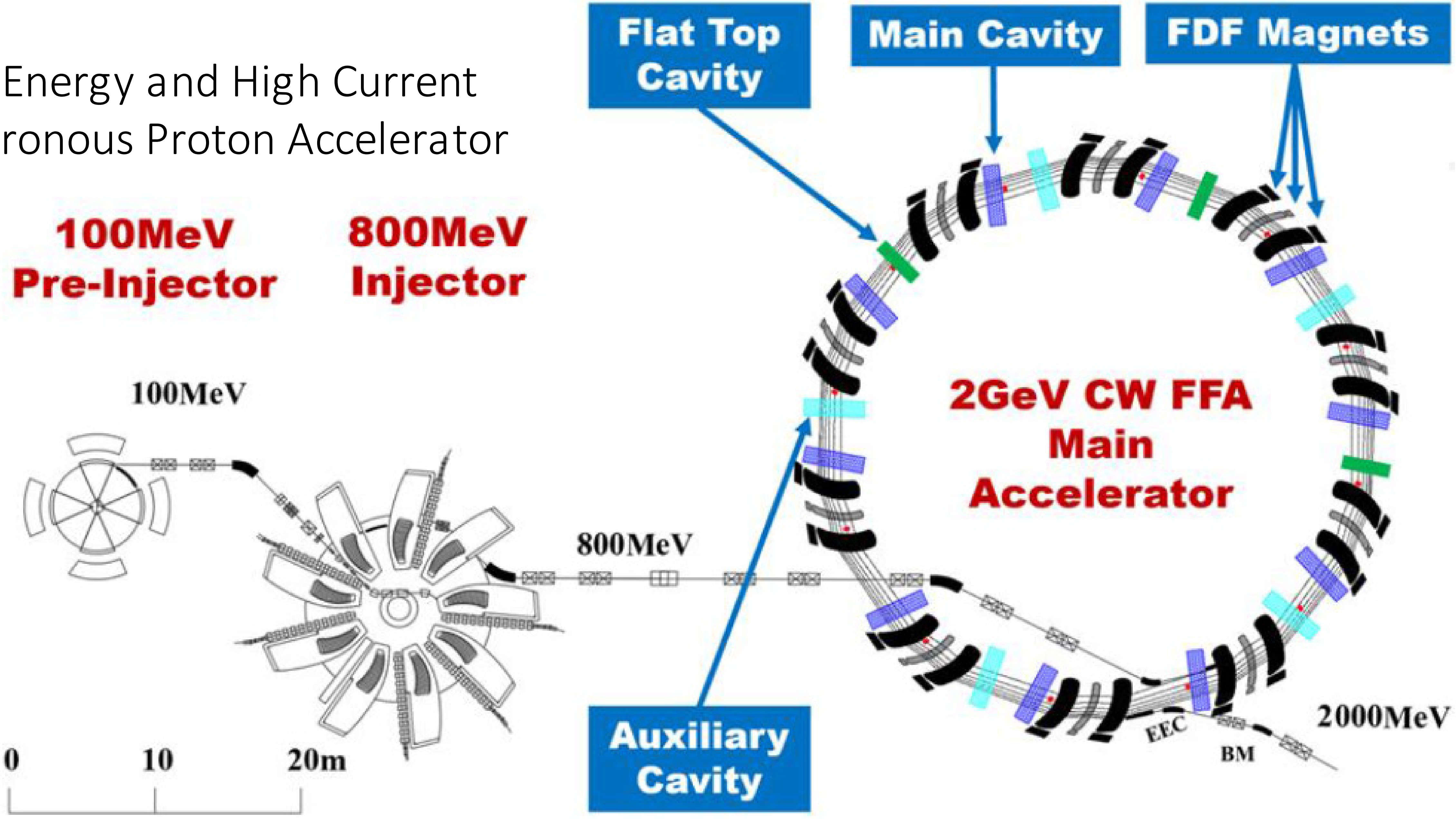


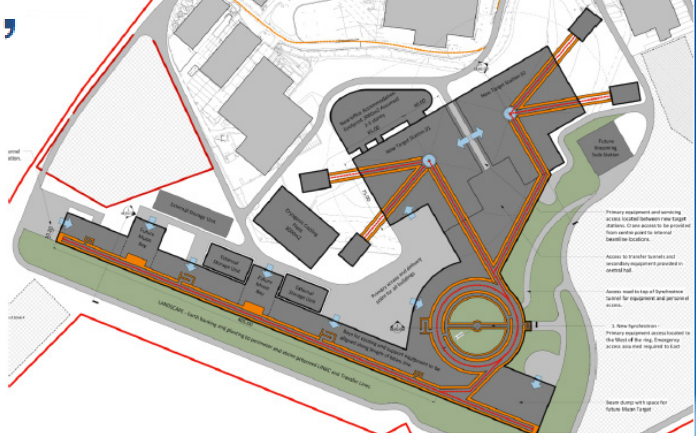
Figure 1-1 The layout of the 2 GeV CW FFA complex.

FFA demonstrator

FETS: Front End Test Stand

ISIS upgrade, "ISIS-II"

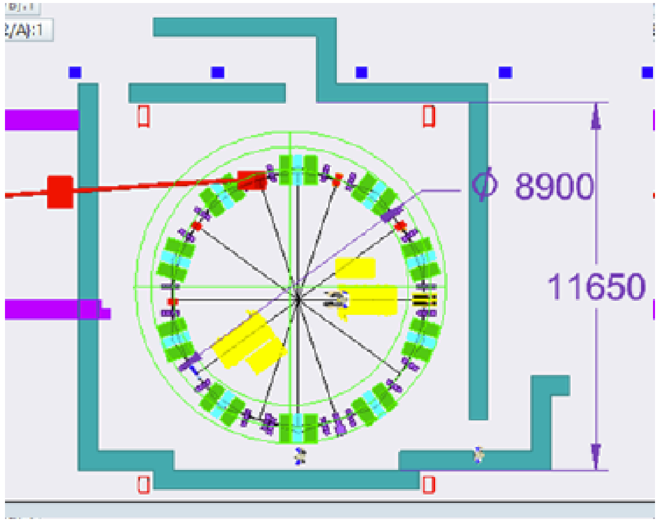
Beam power	1.25 - 2.50 MW
Beam energy	1.2 GeV



- Cyclotron is a good candidate. But why not a scaling **FFA?**
  - However, FFA needs a demonstrator of high intensity operation.
  - A prototype FFA, "**FETS-FFA**" as a demonstrator of FFA based ISIS-II proton driver.
- FFA is a pulsed accelerator, like a synchro-cyclotron.
  - A similar challenge as high intensity synchrotron, not like a CW cyclotron.

beam energy	3 - 12 MeV
ave. radius	4 - 4.2 m
repetition	100 Hz
number of proton per bunch	3×10^{11}
average current	~ 5 micro A
average beam power	~ 60 W
space charge tune shift	-0.25

FETS-FFA in R9



Science and Technology Facilities Council

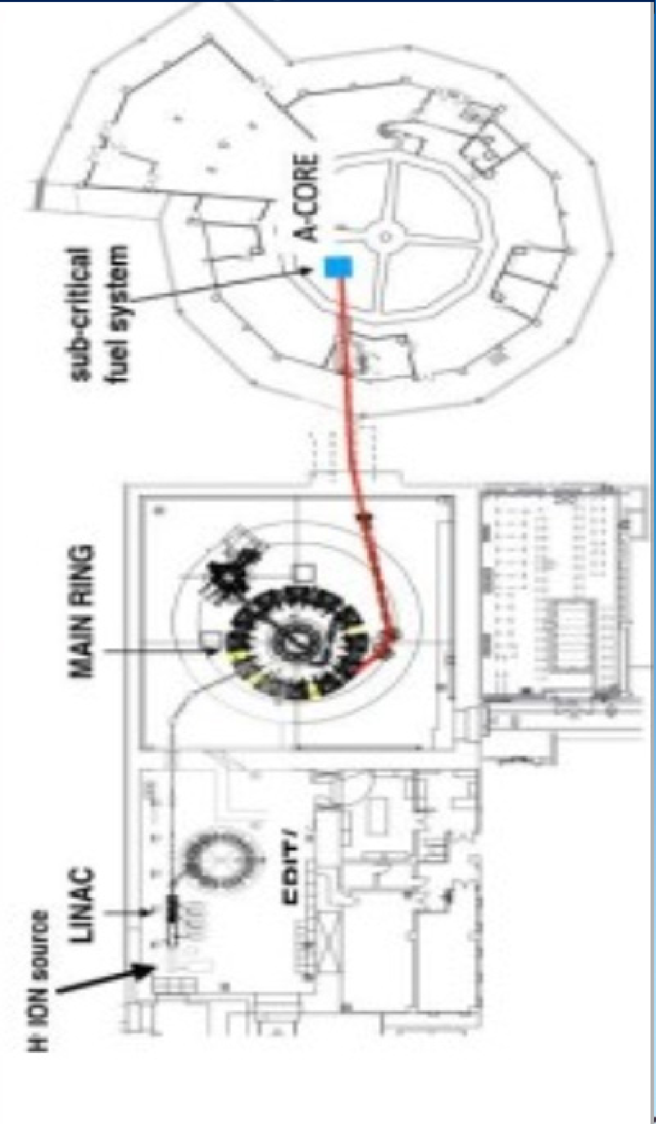
CYC2022

23rd International Conference on

FFAG Activity in Japan and Future Projects

Y.Ishi, T.Uesugi, Y. Mori
(Institute for Integrated Radiation and Nuclear Sciences, Kyoto University)

FFA complex at KURNS



ERIT(Energy Recovery Internal Target)

reaction rate at a thick target
(energy dependent cross section)

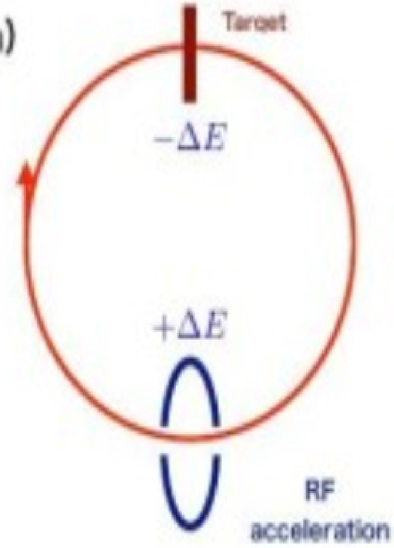
$$\varepsilon = \frac{N_A}{A}\int_{E_t}^{E_b} \frac{\sigma(E)}{S(E)}dE.$$

$\sigma(E)$: cross section, $S(E)$: stopping power

η : statistical weight for specific reaction

E_t : threshold energy, E_b : beam energy

N_A : Avogadro number, A : Atomic number

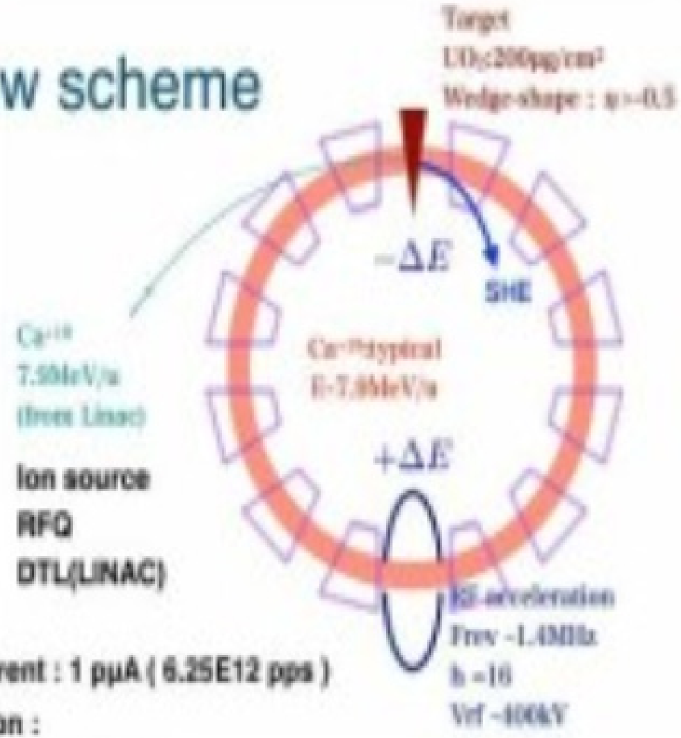


$\varepsilon = 1$ for ERIT (in principle)

# of reactions ∝ # of turns

Super Heavy Elements Production

new scheme



Injection current : 1 pμA (6.25E12 pps)

assumption :

1000 turn survival

target thickness 200μg/cm2

detection efficiency 10%

Continuous injection

continuous production

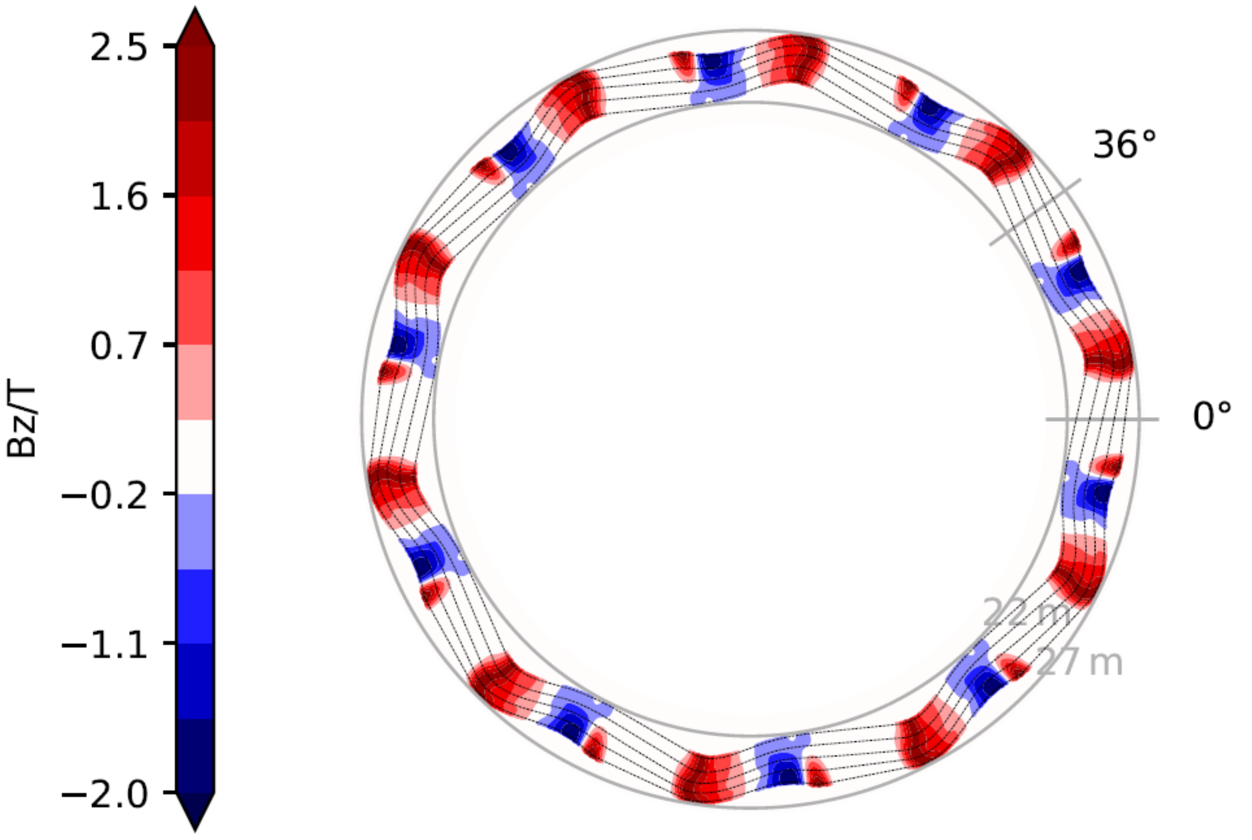
continuous extraction

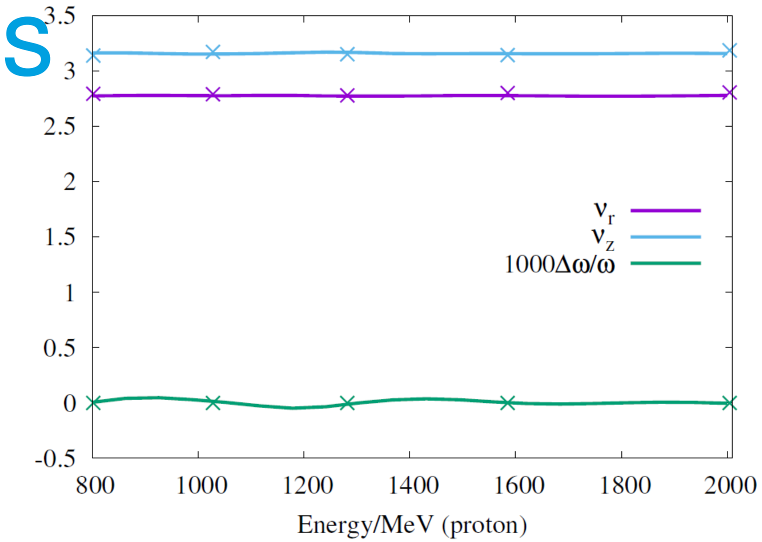
Can detect 1 SHE in every 38 days

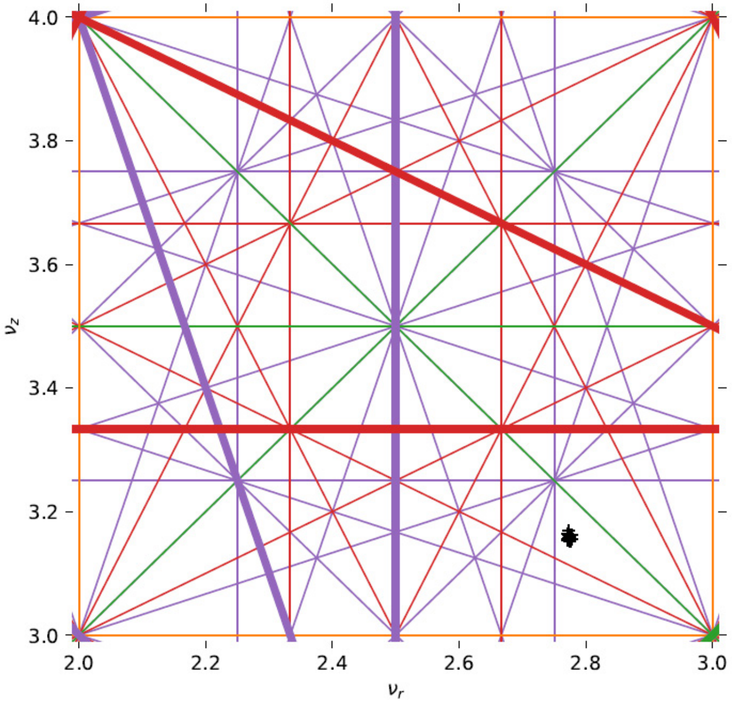
Constant Tune Cyclotrons

Richard Baartman

Constant-tune 2 GeV Cyclotron $B(r,\theta)$







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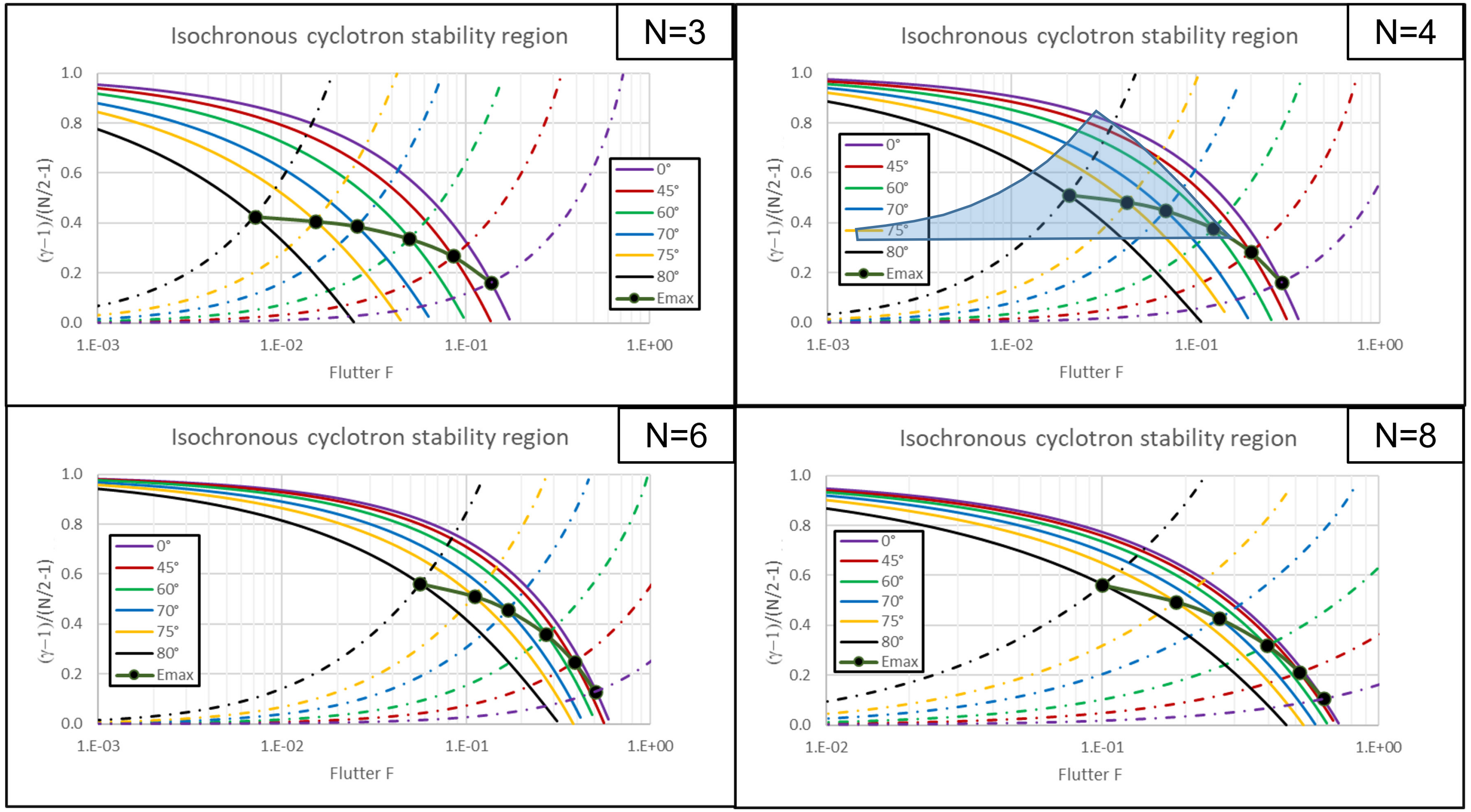
Beam Physics

On the Energy Limit of Compact Isochronous Cyclotrons

Wiel Kleeven

Cyclotron stability region



- Vertical focusing limit (n_z=0, dashed curve) and resonance limit (g_1, solid curve) as function of flutter *F* (logaritmic scale) for a number of the sector spiral angles ξ

$$\tan\xi = \varphi'$$

- Focusing limit monotonically increases with *F* and ξ
- $2n_r$=*N* limit monotonically decreases with *F* and ξ
- Stable area is area below both limits (green area in *N*=4, ξ=80° plot)

- The intersections between focusing and resonance limits represents the energy limit for a given symmetry number *N* and a given spiral angle ξ
- These are the solid dots in the plot.

PSI Ring: Gradient Correctors (2)

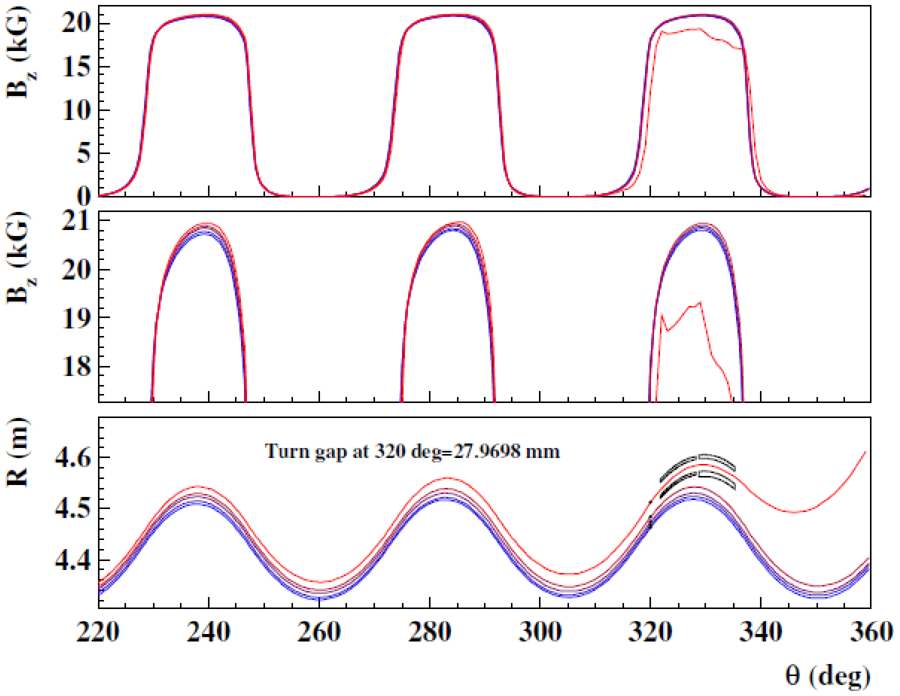


Figure: The last turns of the ring cyclotron with gradient corrector. Turn number (and energy) increases from blue to red. Top/middle: Field seen by the orbit. Bottom: Radius vs. Angle.

- Fast extraction: The field gradient is positve or zero up to the last sector.
- Gradient corrector is required, but only on one sector.
- Actual turn separation 18 mm [6], by acceleration with gradient corrector 28 mm.
- Note: Gradient corrector generates first harmonic (not compensated).

Need for gradient correctors, calculated for PSI Ring cyclotron:

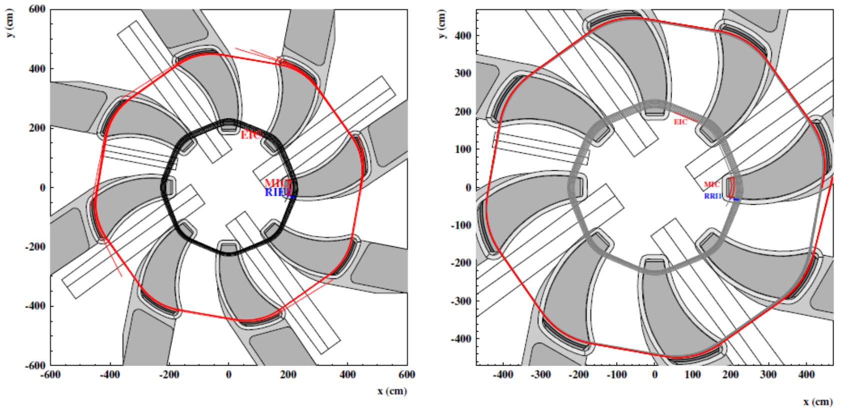
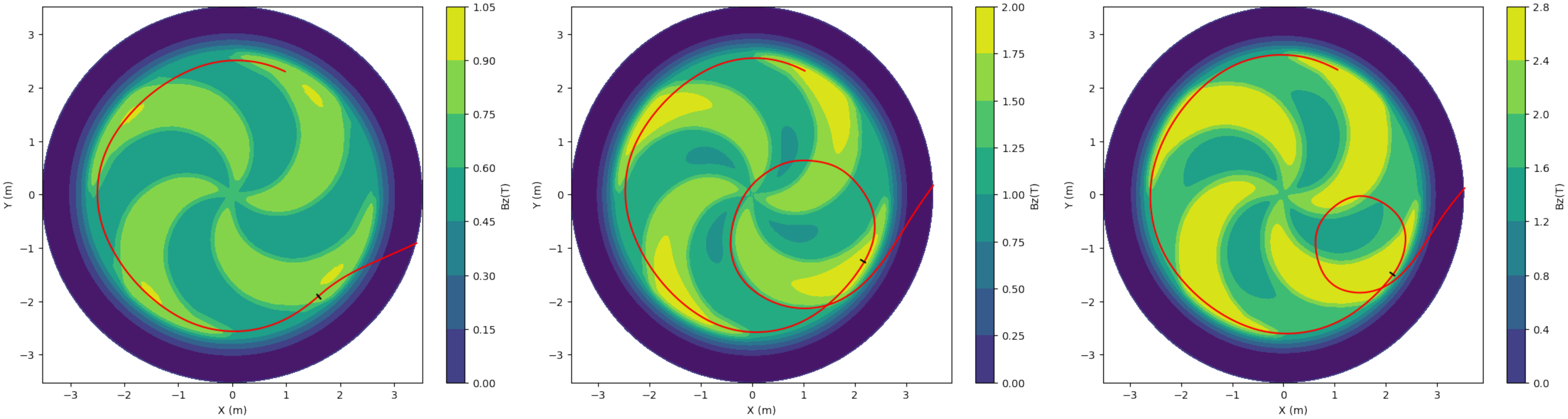
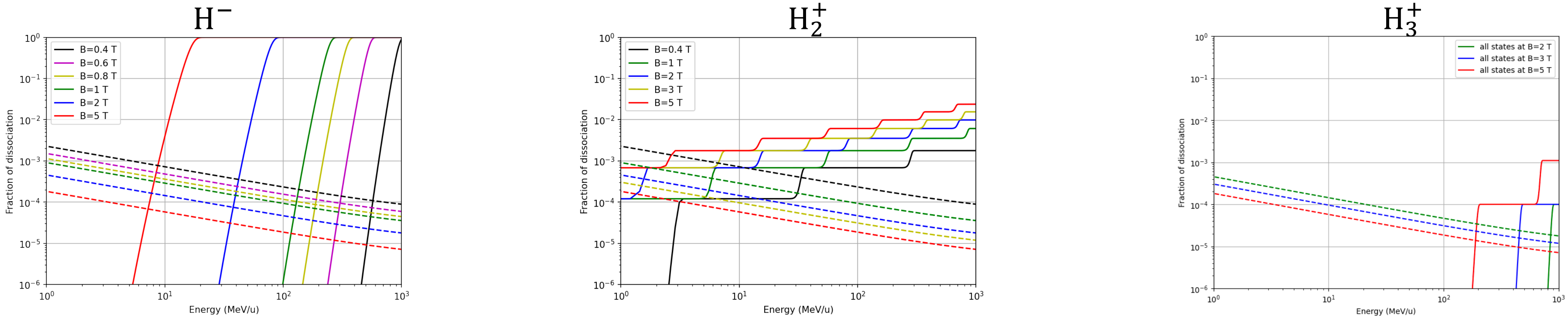


Figure: Some tracks with slightly different starting conditions in R, P_r, E and rf phase τ. Left: Without gradient corrector. Right: With passive magnetic channels as gradient correctors.

Stripping Extraction and Lorentz Dissociation

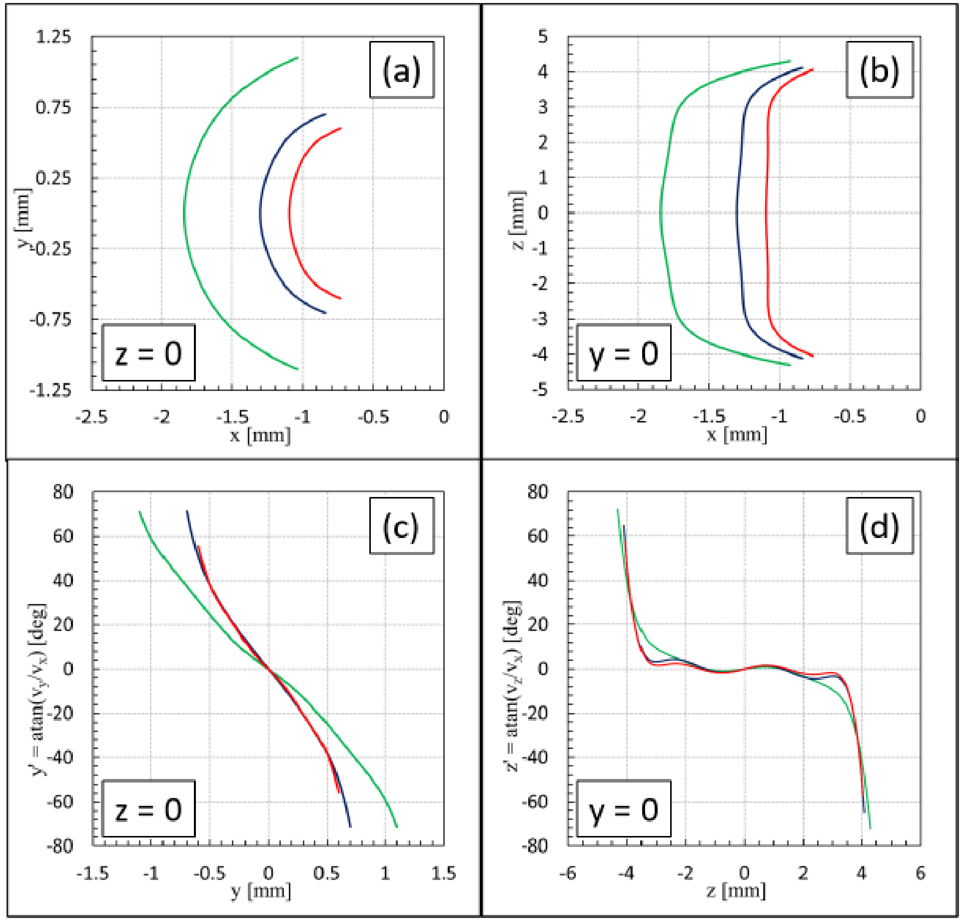
Hui Wen Koay



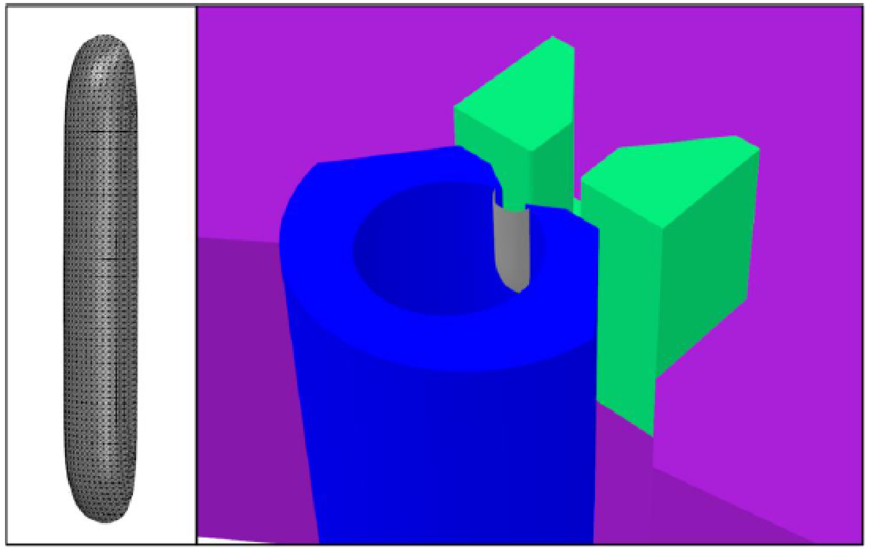


Self-consistent simulation of the plasma meniscus and the space charge dominated beam

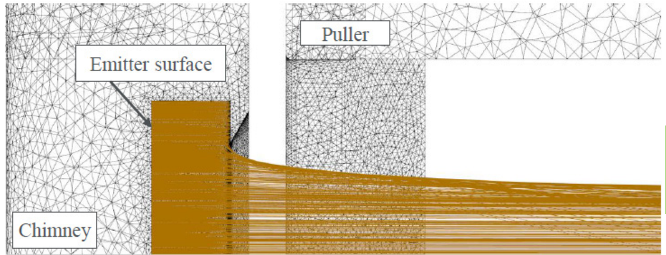
G. D’Agostino and W. Kleeven



Green: V_{dee} = 38.9 kV, J_{emit} = 0.4 A/cm^2
Blue: V_{dee} =18.8 kV, J_{emit} = 0.4 A/cm^2
Red: V_{dee} = 38.9 kV, J_{emit} = 2 A/cm^2



- The meniscus surface is modelled in OPERA as a wire-edge structure with a triangular mesh.
- The TOSCA model of the central region is solved by putting the meniscus surface at ground potential.



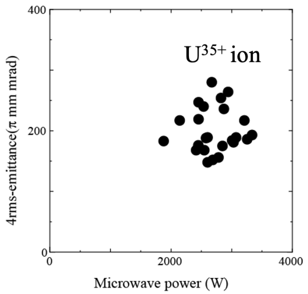
Subsystems

High performance ECR ion sources development at RIKEN and their impact to heavy ion accelerators.

Takahide Nakagawa RIKEN

Time evolution of the U^{35+} ion beam intensity

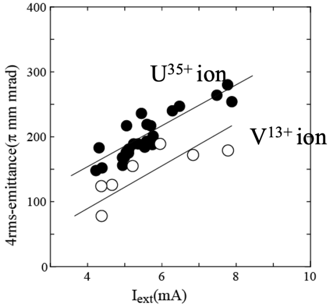
Emittance vs. microwave power

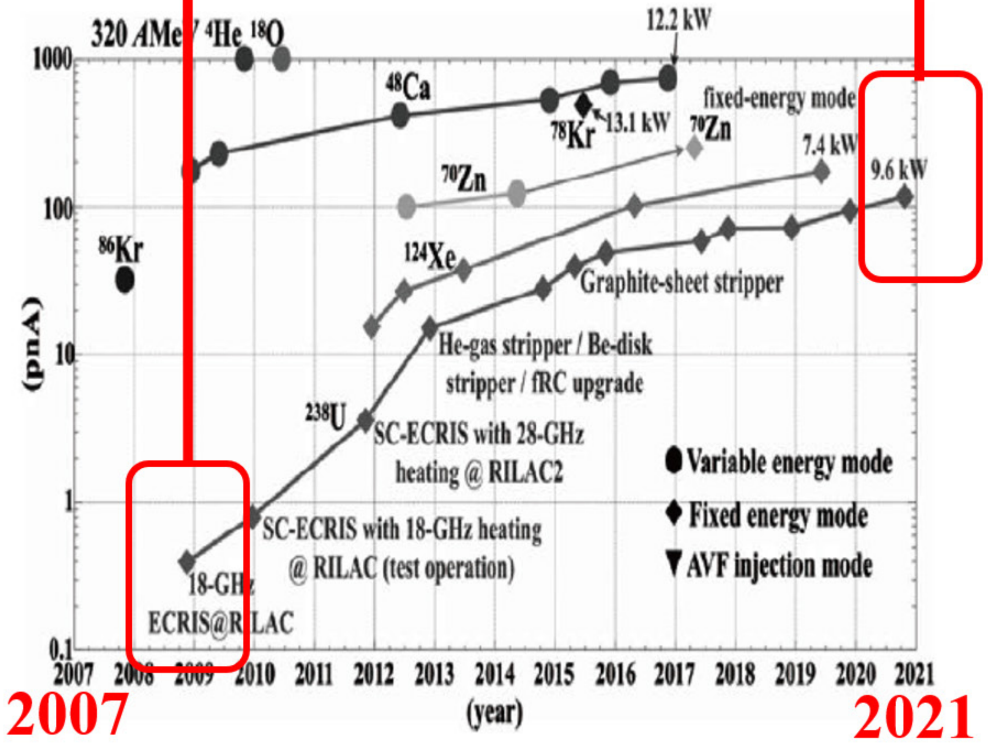


It seems that the no relevance between the emittance and the microwave power

The emittance becomes larger with increasing the extraction current (space charge effect?)

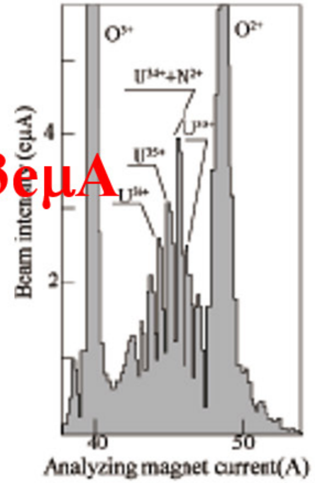
Emittance vs. extraction current





18GHz ECRIS

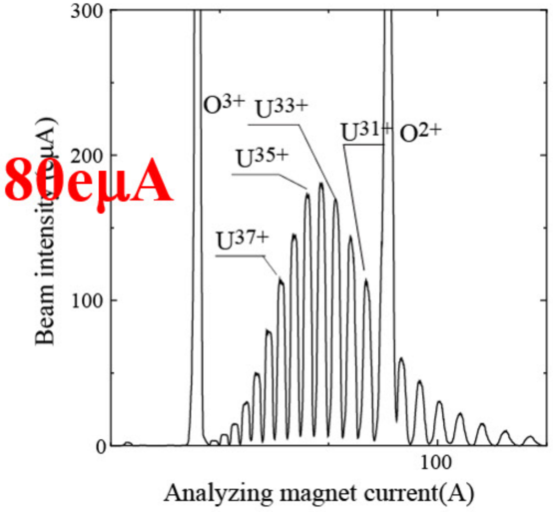
~3eμA



T. Nakagawa, JPASJ 4, 180,(2007)

28GHz SC-ECRIS

~180eμA



A novel multi-harmonic buncher

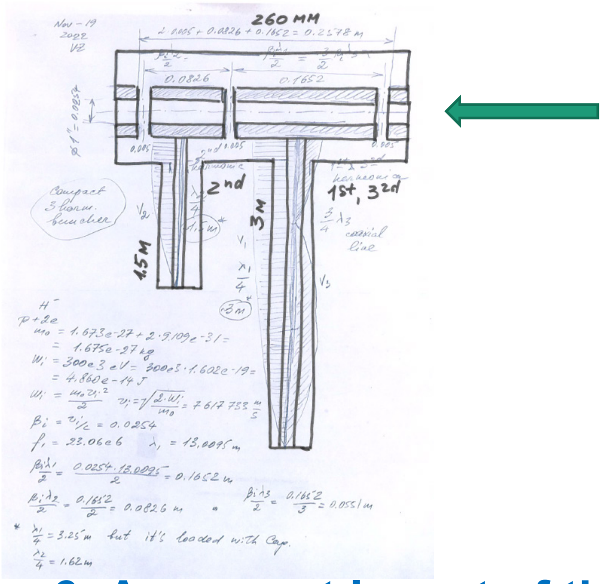


Fig. 6: A concept layout of the multi-harmonic buncher cavity *

Aperture radius	1.27 cm
1st harmonic	23.06 MHz
2nd harmonic	46.12 MHz
3rd harmonic	69.18 MHz
Re-buncher	23.06 MHz

Table:3 New multi-buncher

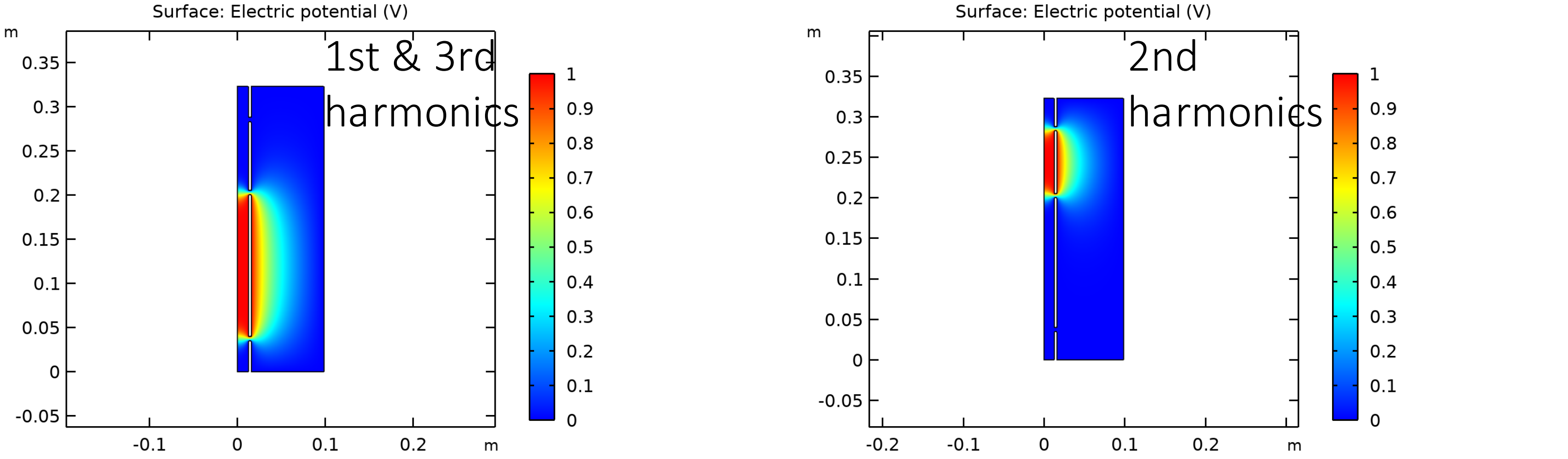


Fig. 7: Calculated electrostatic potential contour by using the code COMSOL

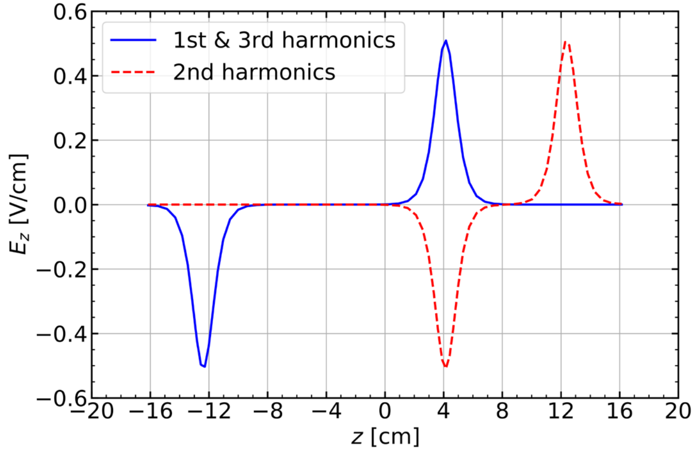


Fig. 8: Calculated electric field along the axis of the buncher with an applied potential of 1 V.

Courtesy: * proposed by V. Zvyangintsev

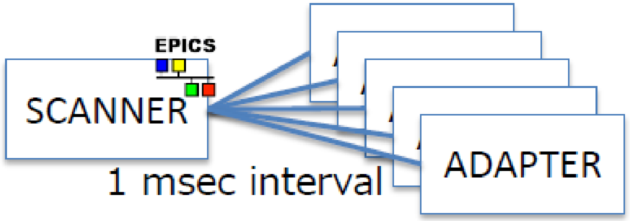
Evaluation of PLC-Based EtherNet/IP Communication for Upgrade of Electromagnet Power Supply Control at RIBF

Akito Uchiyama RIKEN Nishina Center

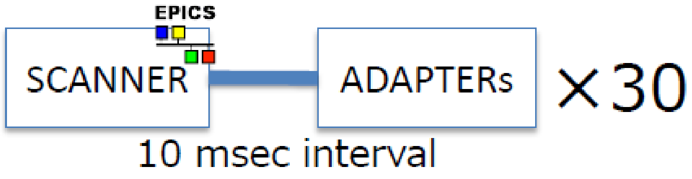
great way to modernize control system parts

Evaluation of PLC-based EtherNet/IP

- In requested packet interval is 1 msec, EtherNet/IP connection takes 2.3 msec to deliver the signal.
- We had an FL-net-based application with the minimum number of nodes before.
- About response time of EtherNet/IP, the performance was comparable to FL-net.
- While the transmission time of FL-net becomes proportionally slower as the number of connected nodes increases.
- The jitter is only about 0.7 ms larger via EtherNet/IP, though soft realtime system.
- Sufficient performance as an interlock signal to be output when stopping the beam due to power supply problems.
- It is possible to transmit interlock signals to distant locations via a general-purpose network switches.



In requested packet interval is 1 msec, SCANNER handles 5 ADAPTERs.



In requested packet interval is 10 msec, SCANNER handles 30 ADAPTERs without interlock signal.

CYC2022

23rd International Conference on Cyclotrons and their Applications

Dec. 5 - 9, 2022 • Beijing, China

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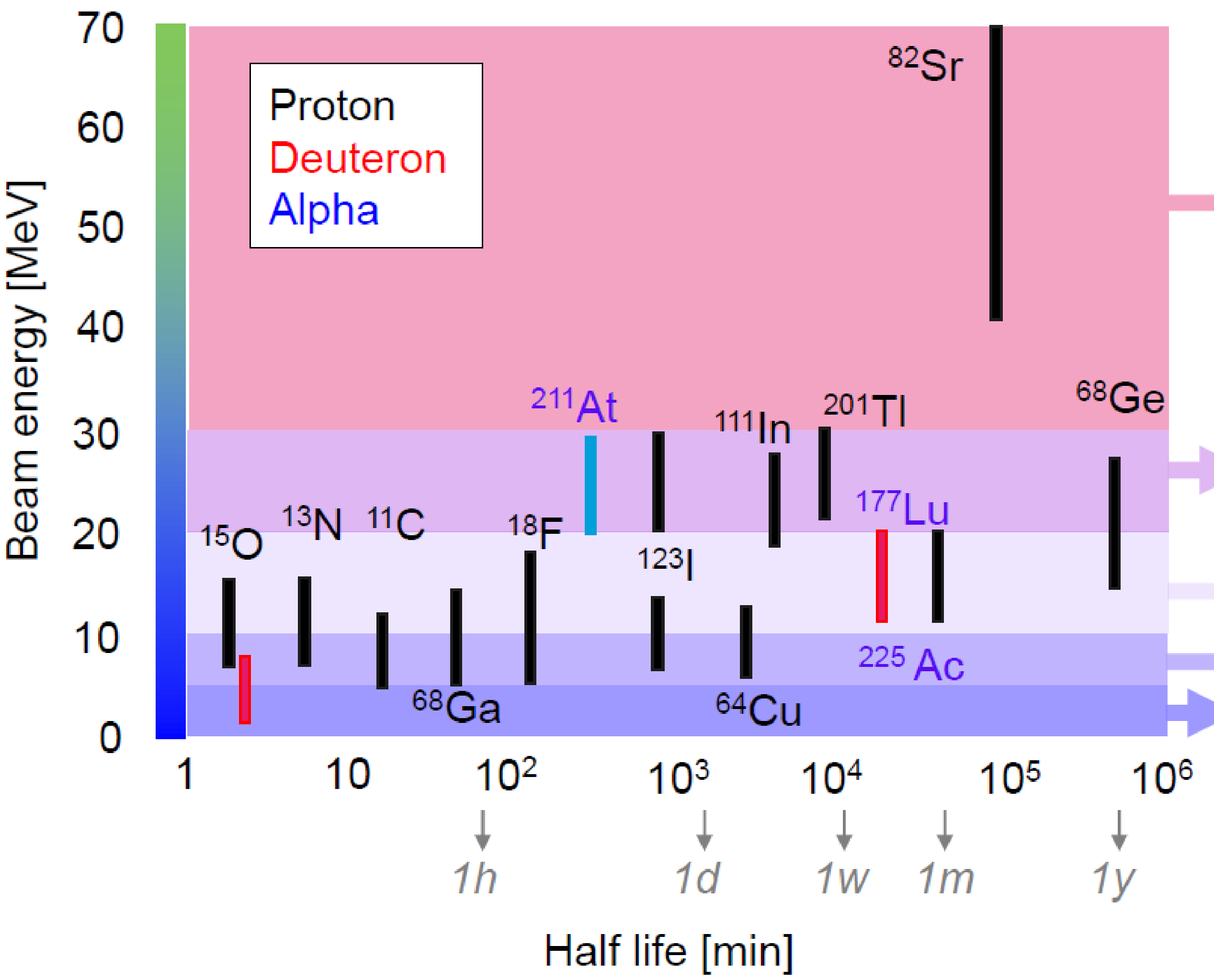
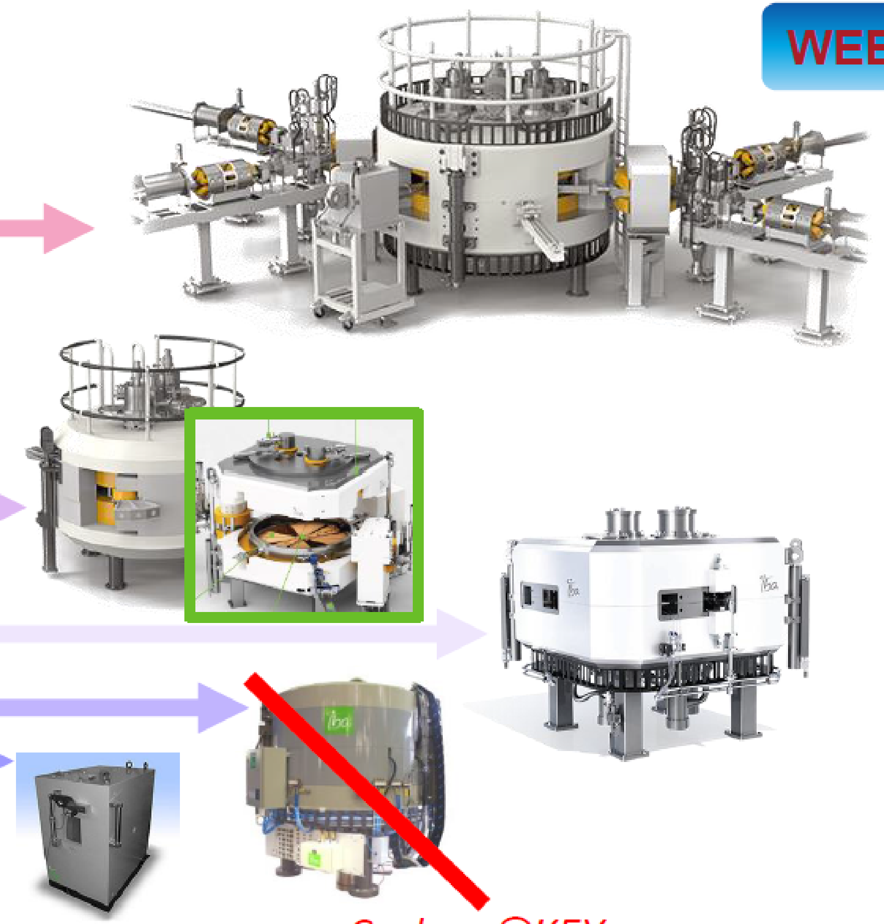
Industrial Cyclotrons

High Intensity Cyclotrons for Production of Medical Radioisotopes

See iThemba : **WEBI1**

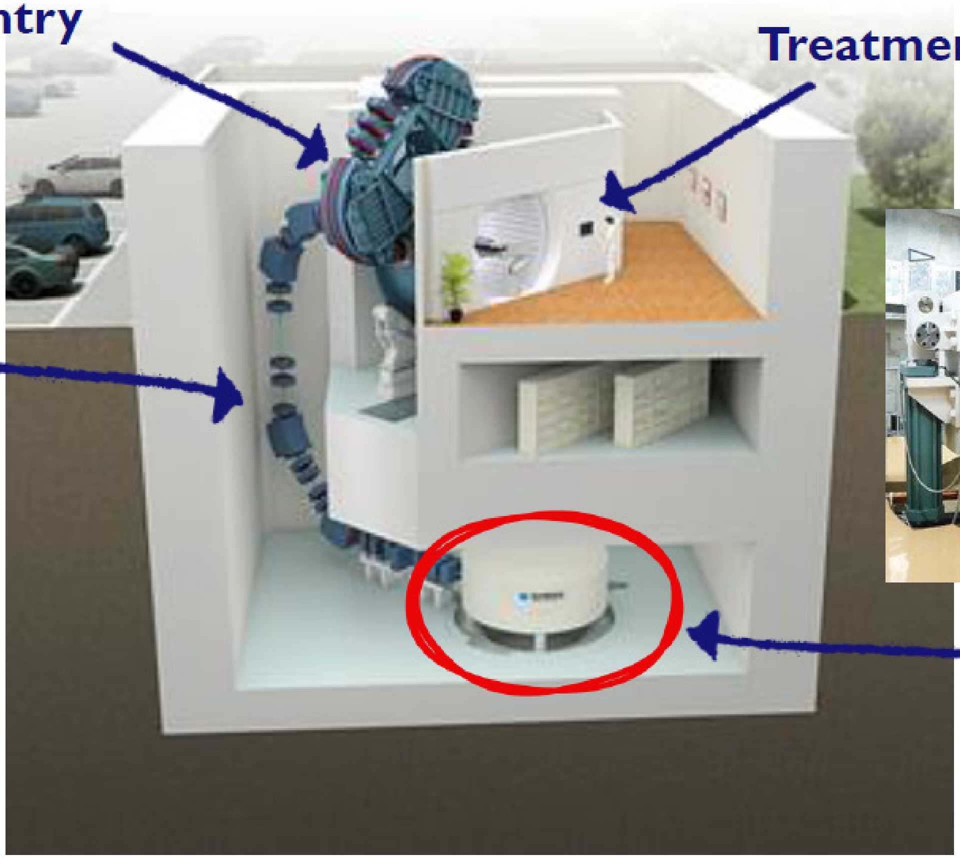




Cyclone®KEY : **WEAO3**

PT system

SHI's PT system

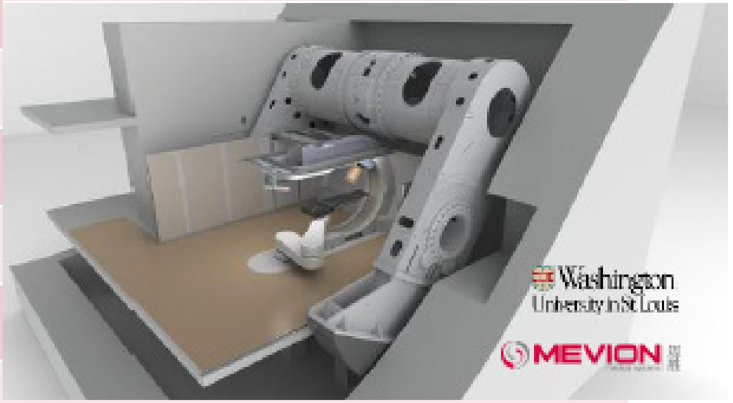


The large device size limits its use in hospitals.
Manufacturers have been miniaturized components in recent years.

MEVION
medical systems

A Compact 10 Tesla Superconducting 250 MeV Synchrocylotron for Cancer Therapy

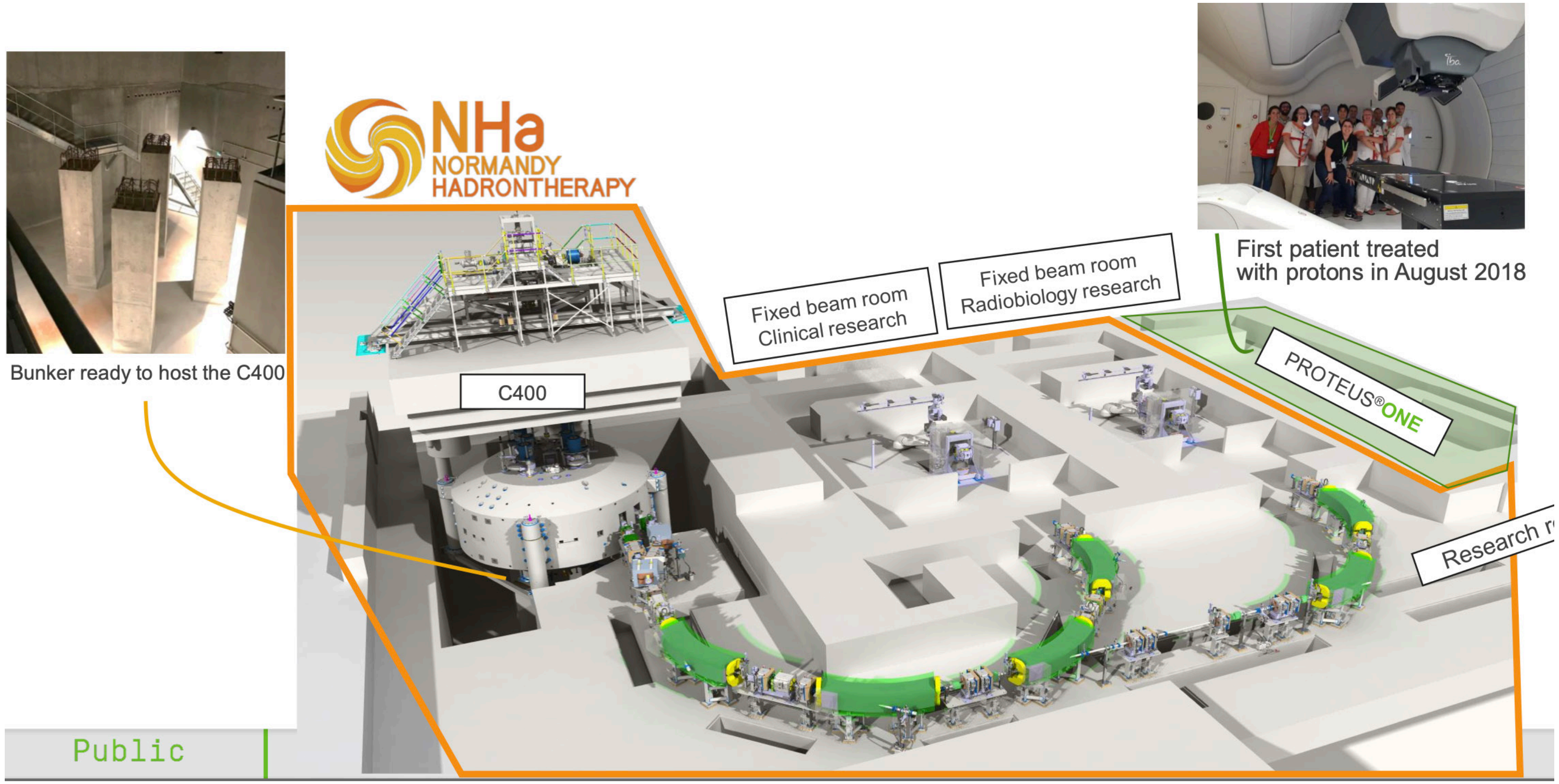
Parameter	Value
Maximum Energy	230 MeV or 250 MeV
Beam Current Range	0 to 20+ nA
Radius	1.8 m
Weight	15 tons
Coil	Nb_3Sn
Magnetic Field	10 T
Average Power	15 kW
Cooling	4
Time Structure	Pulsed at 750 Hz
RF	Single dee, ¾ wave resonator
Extraction	Passive regenerative
Ion Source	PIG cold cathode
Vacuum	Dry system



THB1-1: Carbon cyclotron for particle therapy

Jerome Mandrillon

Very professional talk about the NHa C400 Cyclotron for Hadrontherapy. The design of the C400 of 2009 was not changed but all subsystems were reviewed. The machine has three ion source for H_2^+, $^4He^{2+}$, and $^{12}C^{6+}$
The dual extraction system is used to extract H2+ via stripping and $^4He^{2+}$, and $^{12}C^{6+}$ with an electrostatic deflector.
The medical advantage of treating cancer with heavier ions to justify such a large cyclotron needs more studies.



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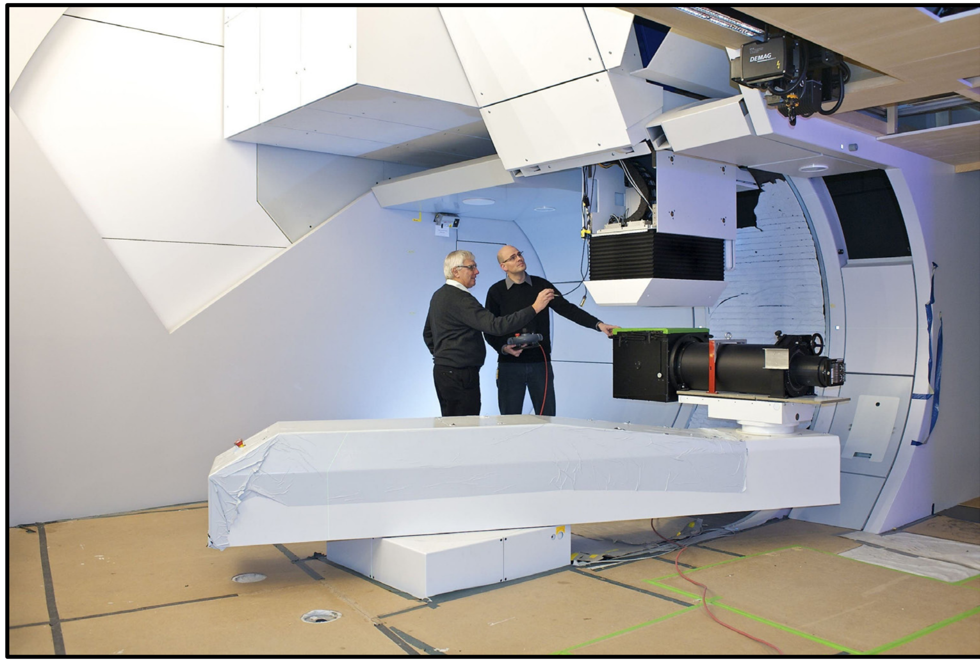
Cyclotron Applications

The most "sexy" medical research:

FLASH!

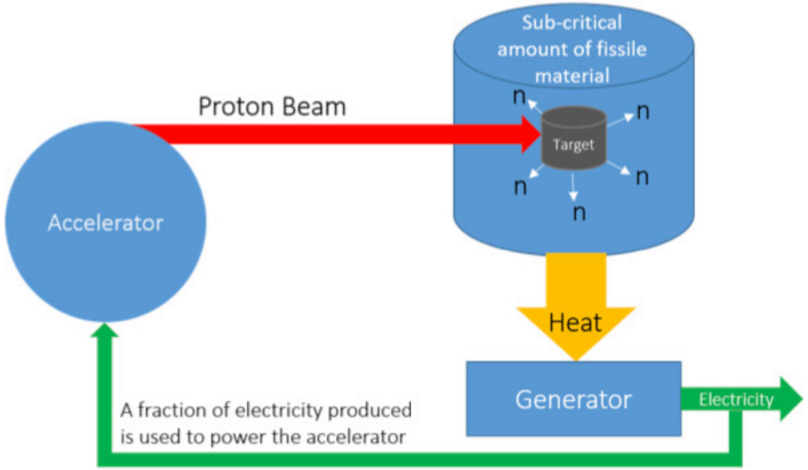
WEBO5: Upgrade of a Clinical Facility to Achieve a High Transmission and Gantry Angle-Independent Flash Tune

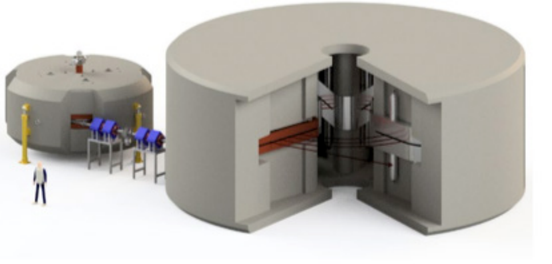
- PSI succesfully upgraded their clinical facility to achieve a high transmission and gantry angle-independent FLASH tune on the Gantry 2
- The 90° dipole was upgraded for energies up to MeV 250 MeV
- The desired beam quality with small, symmetric and gantry angle independent beam size, as required for FLASH PBS, was achieved
- The clinical Gantry 2, will provide a unique setting for researching FLASH-PT and demonstrating FLASH's adaptability in the clinic.



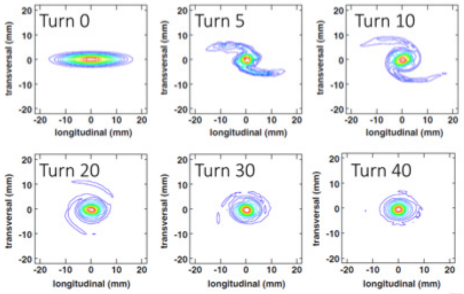
MOB1-1: Summary of Snowmass'21
D. Winklehner

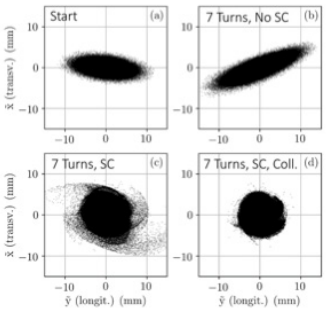
A very informative summary of Snowmass'21 once again shows the importance of cyclotron technology in research, industry, and human health. The talk also pointed out the challenges the cyclotron community will be facing in the future. There is an ever increasing demand for higher beam power, reliability, and nowadays also for energy efficiency. This not least due to the current energy crisis but also for the idea to use cyclotrons for energy production. Therefore, cyclotrons play an important role in Nuclear and Particle Physics. The talk also pointed out new ideas e.g. for the injection and extraction of particles from a cyclotron. A notorious problem in cyclotrons. (Slide 18/Injection and Slide 19/Extraction).

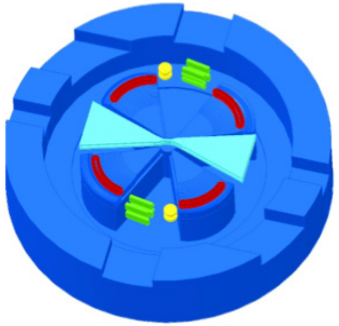


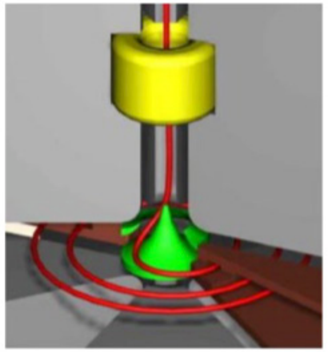


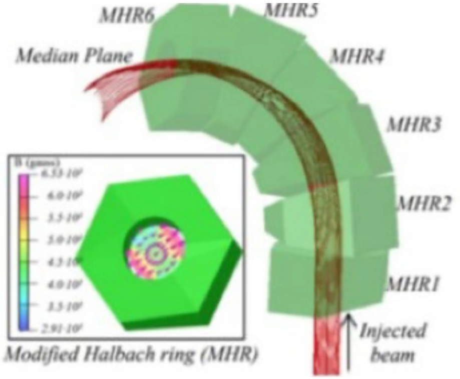
DAEdALUS Two-Stage H_2^+







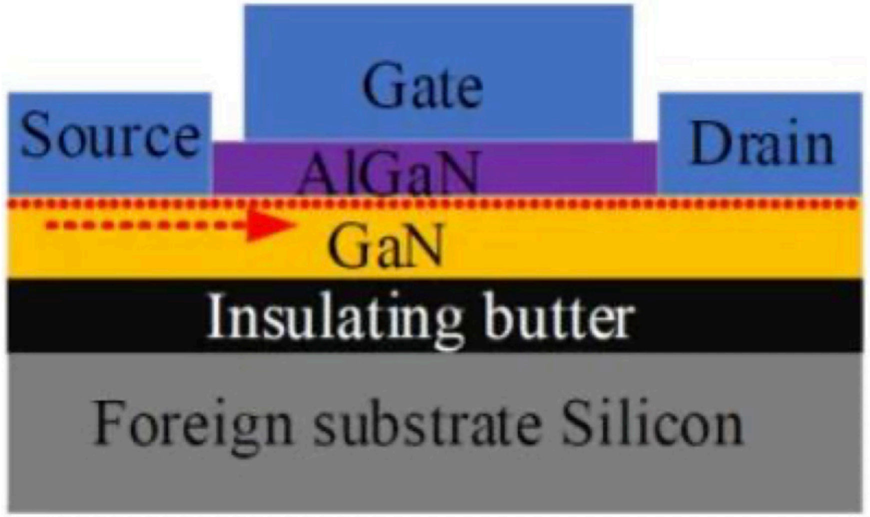




MOB2-4: : Experimental study on proton irradiation effect of gallium nitride high electron mobility transistor
Zheng Zhang

Very interesting results on GaN-based transistor. Radiation hardness of semiconductor based electronic devices has always be a notorious problem for the accelerator community. Radiation defects in conventional Silicon based devices do not allow the use of such devices in radiation environment. Slow, »analogue» device still need to be used. The wide-band gap Semiconductor GaN, with it’s superior electric properties, e.g. electron mobility and high breakdown voltage, has the potential to be used as the material of choice in the future for radiation hard electronic devices. It has been proven that the material can withstand high radiation doses as present close to accelerator and it exhibits a certain self-annealing effect. After 10 days at room temperature the electrical paramaters of the device were restored.

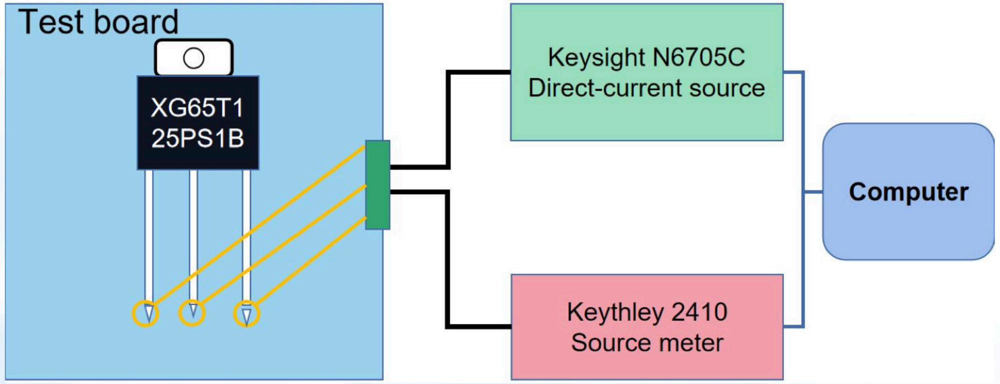
GaN HEMT structures



Proton irradiation

Parameter	Vaule
Energy	30,40,60,90MeV
fluence rate	10^8 p/cm2•s
total fluence	10^{12} p/cm^2

Test system



There should be more of such special contributions in CYC. Solid State Physics, especially semiconductors, had the greatest impact on society in the past century.

Real time determination of the range and Bragg peak of protons with a depth profile camera at HZB
Alina Dittwald Helmholtz-Zentrum Berlin für Materialien und Energie

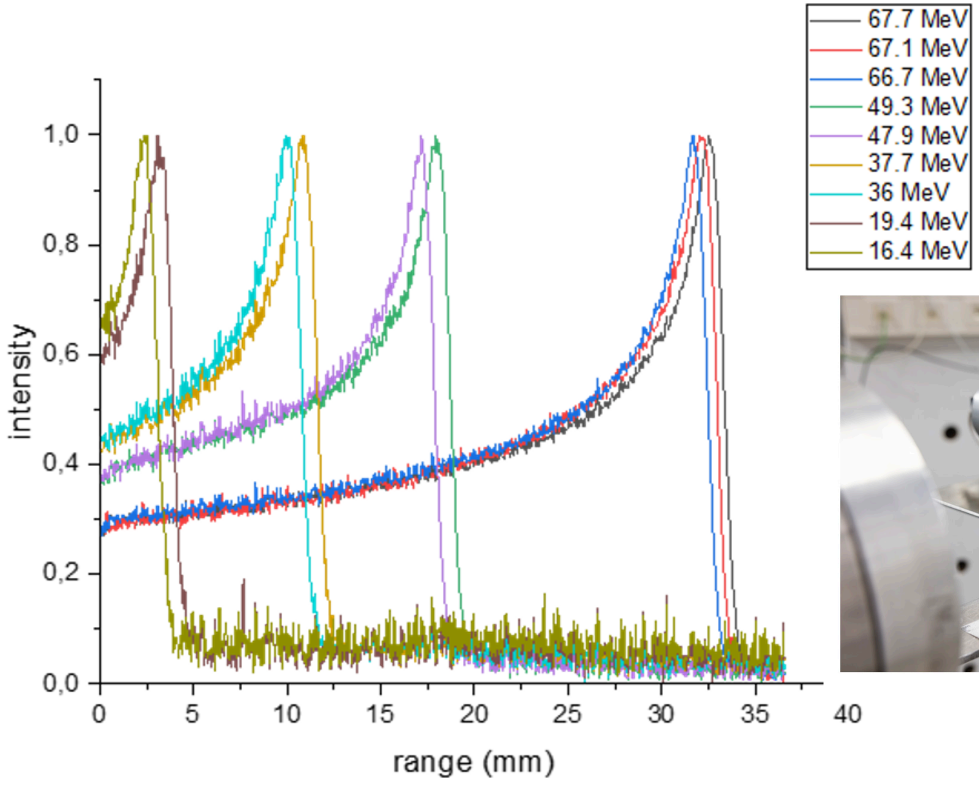
inexpensive and rapid measurement of depth profiles

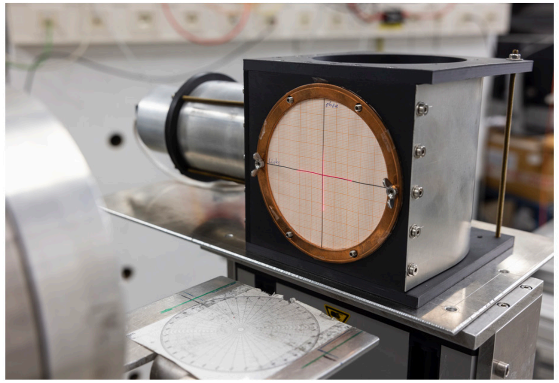
HZB Helmholtz Zentrum Berlin

different energies of the proton beam

- proton beam energies from 68 MeV down to 16 MeV, achieved with absorber plates
- Bragg-peak of beam with different energies directly visible
- small steps of 400 keV are clearly discernible
- differences between measured and theoretical values are larger at lower energies

energy	camera range [mm]	PSTAR range [mm]
67.1	32.96	32.61
66.7	32.46	32.20
19.4	3.86	3.45
16.4	3.02	2.57





- ranges are taken at 80% of the Bragg-peak

- PSTAR: https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

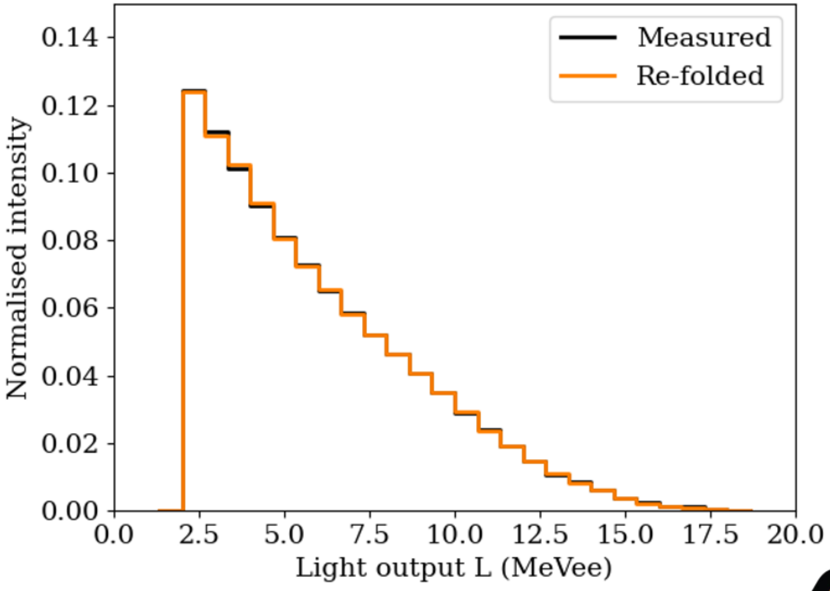
Measurement of Detector Response Functions for Fast Neutron Spectroscopy With Organic Scintillators

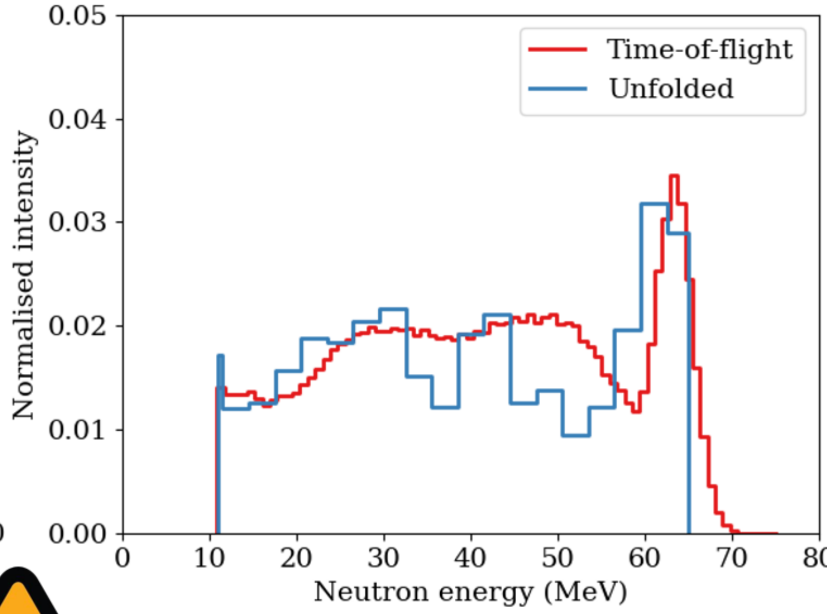
Tanya Hutton Department of Physics, University of Cape Town

Making detectors independent from time signals

Spectrum unfolding with measured detector response functions

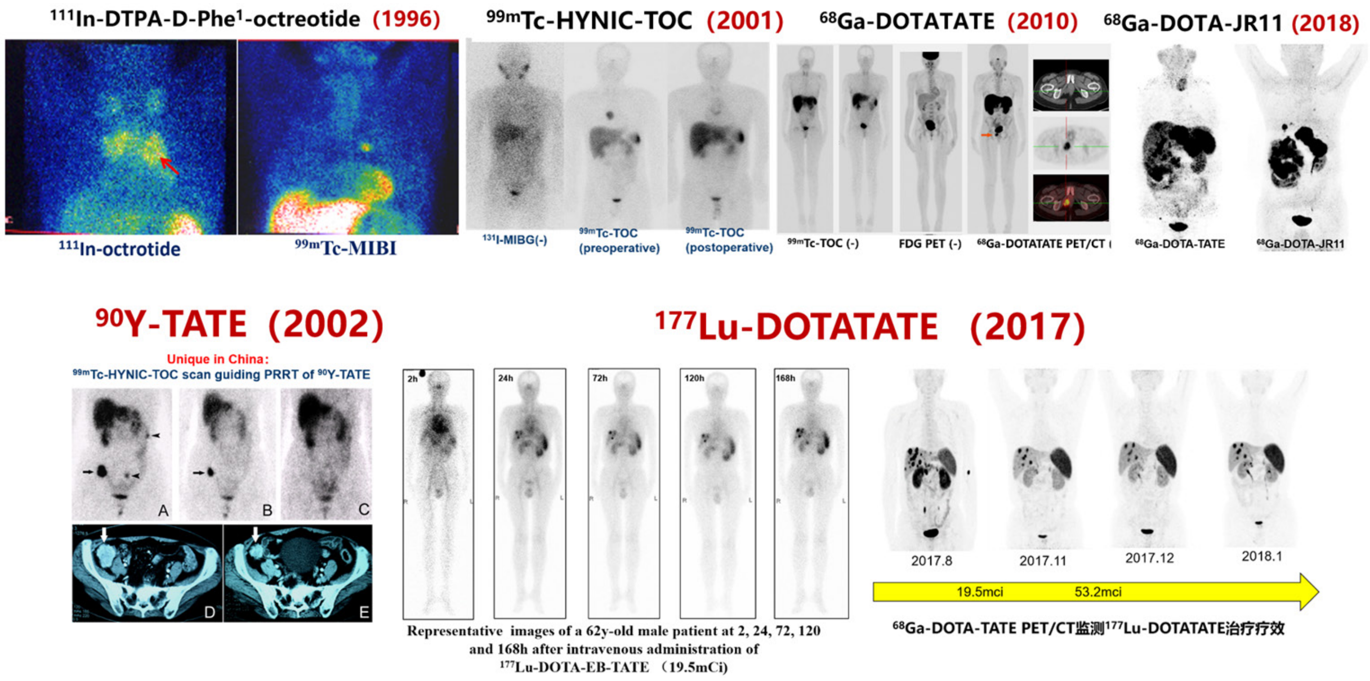
Neutron light output spectrum measured at 16° with EJ-276 for a 66 MeV proton beam on 8.0 mm Li target

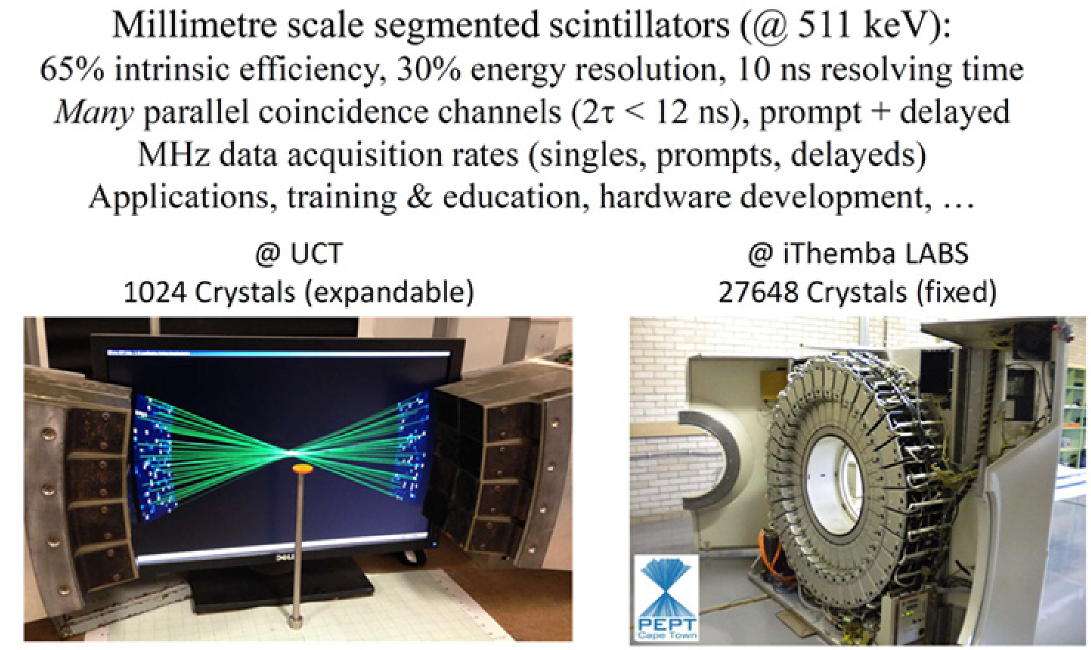




- **Li Huo from Beijing hospital reported that series translational nuclear medicine research on somatostatin receptor, which has demonstrated quite good diagnostic level and treatment effect.**

- **T.Leadbeater from University of Cape Town presented a BGO positron cameras (UCT and iThemba LABS) with quite good performance.**

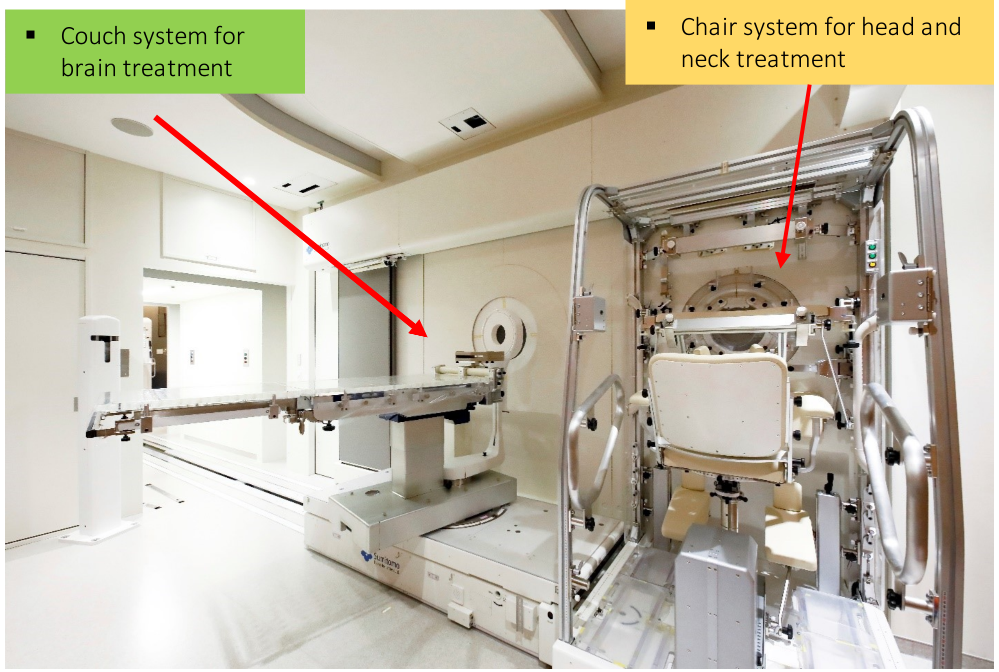




WEBI2: Compact accelerator based epithermal neutron source and its application for cancer therapy

We received an excellent overview of the principle and the history of BNCT and the specific features, (dis-)advantages and optimization requirements of accelerator based BNCT systems.

- The Kansai BNCT medical center founded at the Osaka Medical and Pharmaceutical University (OMPU) was opened in 2018. Their NeuCure® system is the world's first BNCT system as a medical device that has now treated over 100 patients



WEBO6: Accelerator and detector developments for the production of theranostic radioisotopes with solid targets at the Bern medical cyclotron

- The team of Saverio Braccini successfully develops, tests, qualifies, and improves existing and new methods for production of theragnostic radioisotopes, such as Ga-68, Sc-44 and others, with the Bern medical cyclotron.
- Their work on precise measurements of cross-sections, production yields and radioisotope purity, for a wide range of nuclear reactions, stimulates further use of such isotopes for cancer diagnostics and treatment

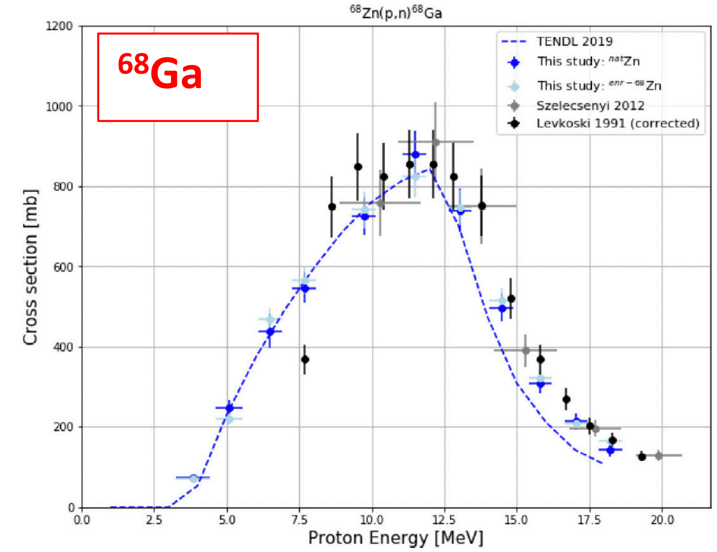


Fig. 4. ^{68}Zn(p,n)^{68}Ga cross section measured from natural and enriched ^{68}Zn targets with the isotopic composition marked as (A) in Table 1.

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Thank you for participation!