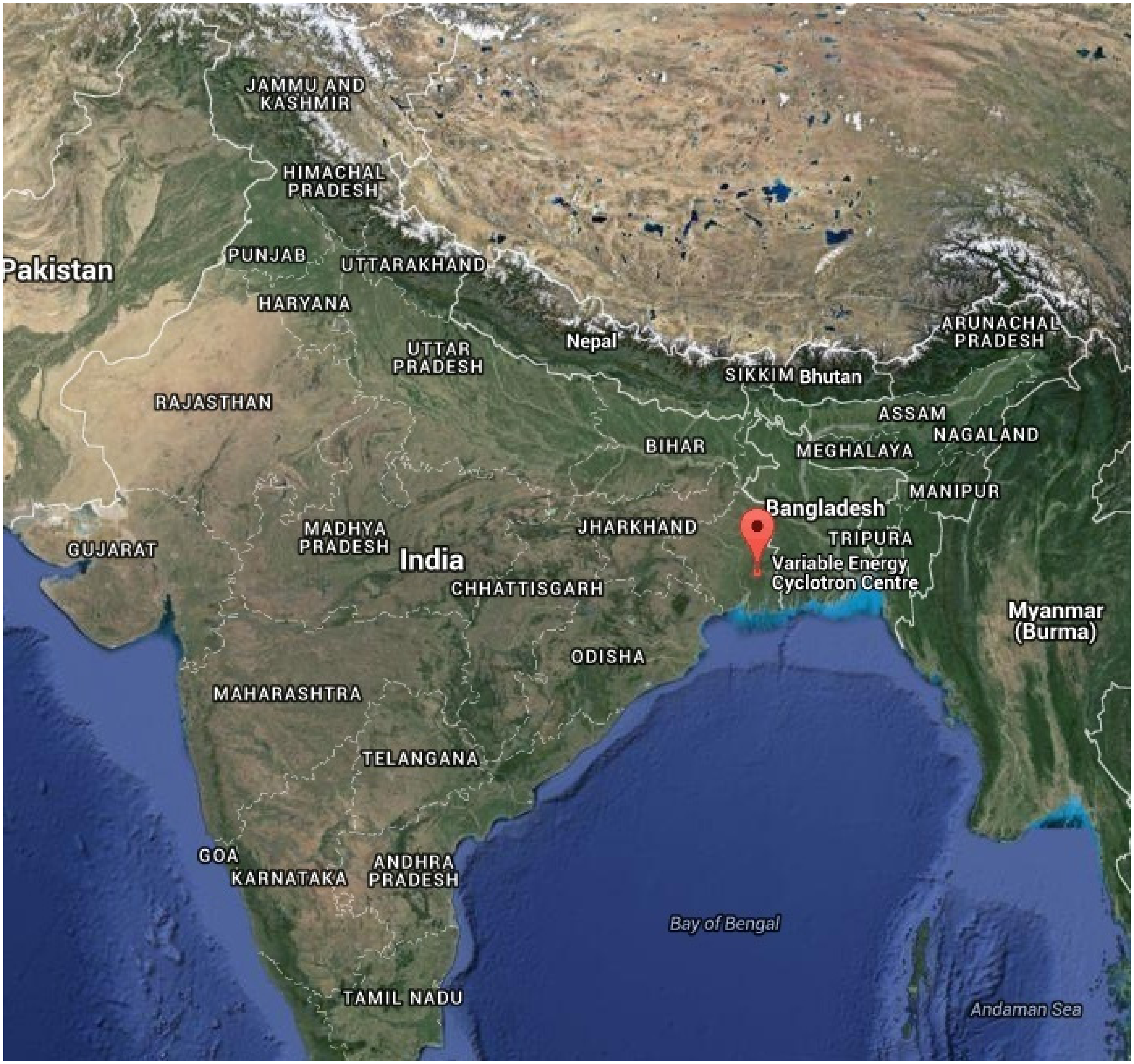
Radioactive Ion Beam Program at VECC-Kolkata

On behalf of the RIB team at VECC and the collaborators

Alok Chakrabarti

VECC, Kolkata, India

HIAT 2015


JAMMU AND KASHMIR
HIMACHAL PRADESH
Pakistan
PUNJAB
UTTARAKHAND
HARYANA
UTTAR PRADESH
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ARUNACHAL PRADESH
SIKKIM
Bhutan
RAJASTHAN
ASSAM
NAGALAND
BIHAR
MEGHALAYA
MANIPUR
Bangladesh
MADHYA PRADESH
JHARKHAND
TRIPURA
GUJARAT
India
Variable Energy Cyclotron Centre
CHHATTISGARH
Myanmar (Burma)
ODISHA
MAHARASHTRA
TELANGANA
GOA
KARNATAKA
ANDHRA PRADESH
Bay of Bengal
TAMIL NADU
Andaman Sea


VECC


SUPERCONDUCTING CYCLOTRON

Variable Energy Cyclotron Centre

(R&D institute under DAE; a part of HBNI)

(200 scientists and engineers, total staff: 600)

Activities/ Charter:

a) Accelerator design and development

b) Accelerator based nuclear physics, material science, isotope production, etc.

c) High Energy Physics: collaboration with CERN, RHIC, FAIR…

d) Theoretical physics (Nuclear and High Energy Physics)

e) PhD program for HBNI students

f) Societal: Radiation Medicine Centre, Medical Cyclotron, Educational aid for different groups, Summer training of basic science engineering students, Outreach program

Accelerators at VECC

- *K* = 130 Cyclotron: delivering beam to the users from 1980;
  Light ions (*p* and *α*) and Heavy Ions up to Argon

  New century brought some money to R&D

- SCC (*K*=500): Internal beam in 2009, beam extraction efforts in progress
- RIB activities: started in 1998 in a R&D/ Capacity building mode:

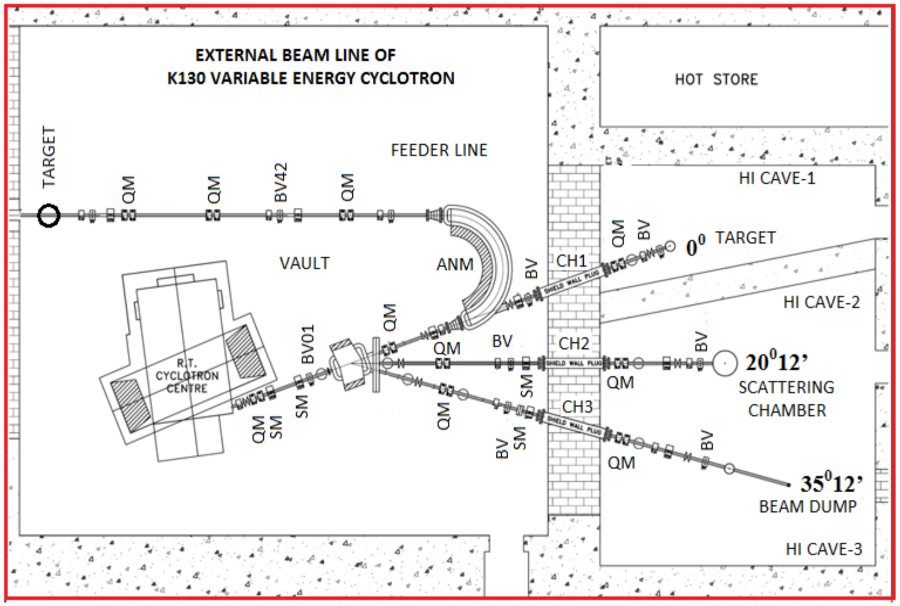
  2002 to 2012: 17 M USD: On-line ECR, 2 RFQs, 5 IH Linacs, Material Science beam line, Collinear Laser spectroscopy set up, development of RI beams, construction of small annexe building & infrastructure

- ANURIB (**A**dvanced **N**ational facility for **U**nstable and Rare Ion Beams): Estimated cost: 200 M USD; 2013 and beyond

  Sanction obtained in 2013: 30 M USD for e-linac, target, SCQWR (acc. from 1 to 2 MeV/u), liquid He, Phase-1 building

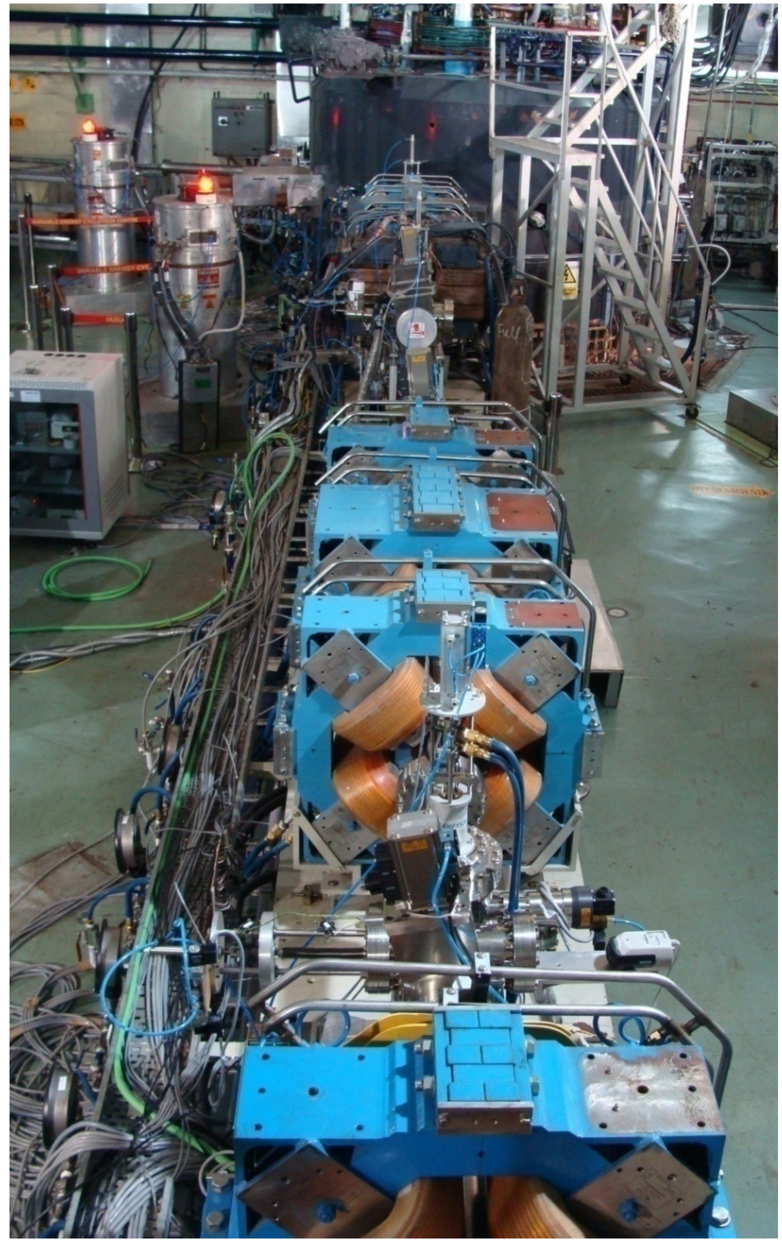
Room temperature Cyclotron

Internal beam : 16^{th} June, 1977; still operating as a user facility



- Accelerated particles : alpha, proton & deuteron with internal PIG Ion Source
- Light heavy-ions

Superconducting Cyclotron and Beam Line

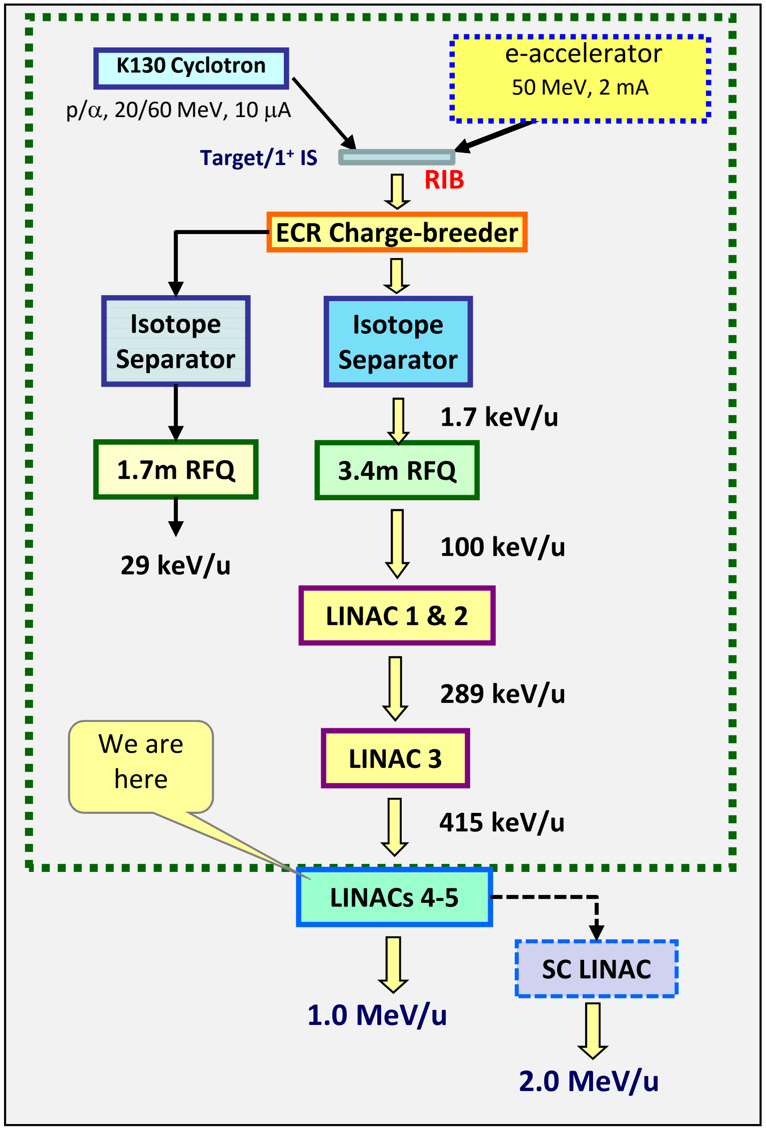


MOU between VECC & RIKEN (beginning of Acc. design for RIB)

- Physics design of accelerator components such as ECR ion-source, RFQ & heavy-ion Linac

- Exotic nuclei physics experiments at RIPS projectile fragment separator

RIB scheme at VECC- the plan & the status



- Developed 1st RFQ in the country (29 keV/u; 2005). Second RFQ commissioned in 2008 (100 keV/u). Fabricated in India.
- Developed 1st IH-Linac in the country. Linac-1 & 2 & 3 are already commissioned; Linac 4 & Linac 5 tested waiting to be installed in new annex building by 2015
- May 12, 2012 – First RIB : ^{14}O (71 sec) accelerated to 1.4 MeV through RFQ. Intensity after RFQ ~ 3300 pps; before RFQ ~ 4400 pps.
- Also produced RI beams of ^{42,43}K , ^{41}Ar, ^{111}In .
- Accelerated beams of $^{16}O^{4+}$ and $^{14}N^{4+}$ to 415 keV/u through Linac-3.
- Target R&D , on-line experiments ongoing.
- Superconducting Electron Linac, HI QWR, & Actinide target development started, in collaboration with TRIUMF Canada.
- Fragment Separator based experiment & PFS design (collaboration with RIKEN)
- Ion-beams from the facility being used for material science experiments.

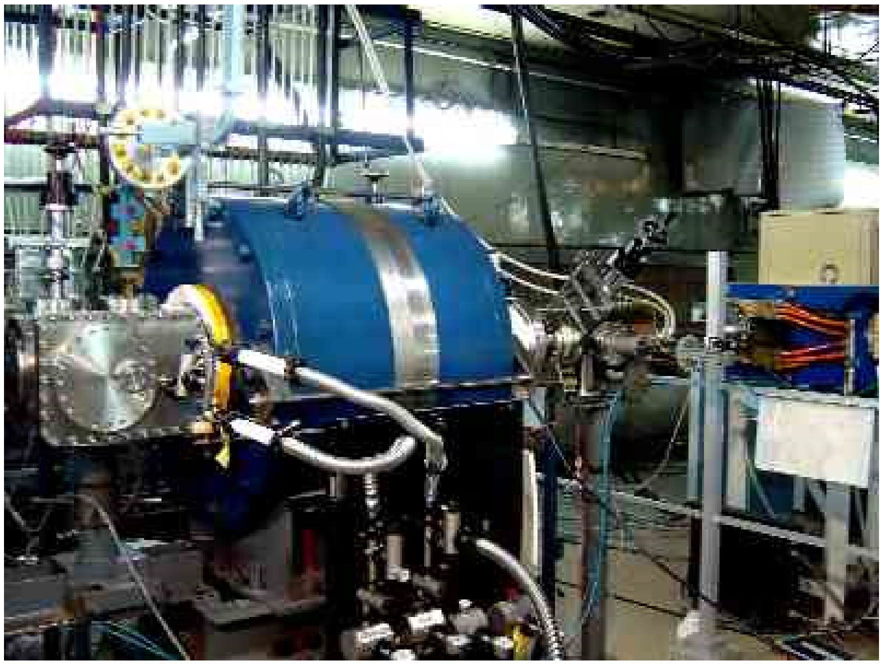
Milestones …

ECR ion source
year 2002

Vaishali Naik et.al., Nucl. Instrum. & Meth. A 447 (2000) 345 ;
Damayanti Naik et.al., Nucl. Instrum. & Meth. A547 (2005)270.

Separator (ECR-RFQ beam-line)
year 2002

Arup Bandyopadhyay et.al., Nucl. Instrum. & Meth. A562 (2006)41



6.4 GHz on-line ECR

ECR to RFQ beam-line

RFQ1: Sept 2005; 33.7 MHz, CW
Output energy = 29 keV/u

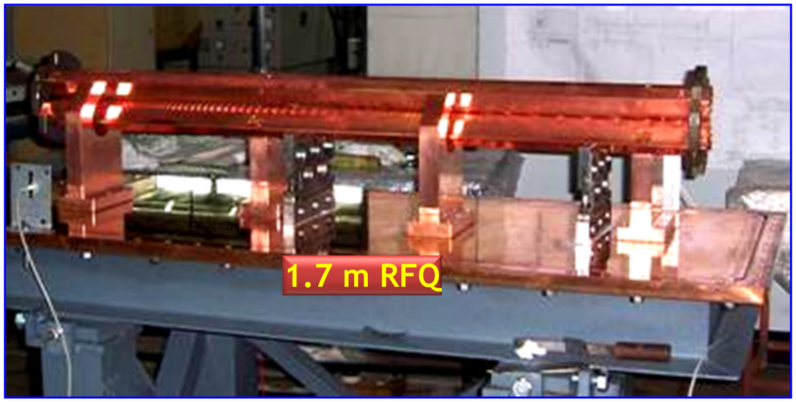
A.Chakrabarti et.al., RSI 78 (2007) 043303

A.Chakrabarti et.al., NIM A535 (2004)599

RFQ2: July 2008, 37.8 MHz, CW
Output energy = 100 keV/u

S. Dechoudhury et.al., RSI. 81 (2010) 023301

A. Chatterjee et.al., RSI. 80, (2009) 103303



First RFQ in the country

Linac1: 2008, energy = 187 keV/u

Linac2: 2010, energy = 289 keV/u

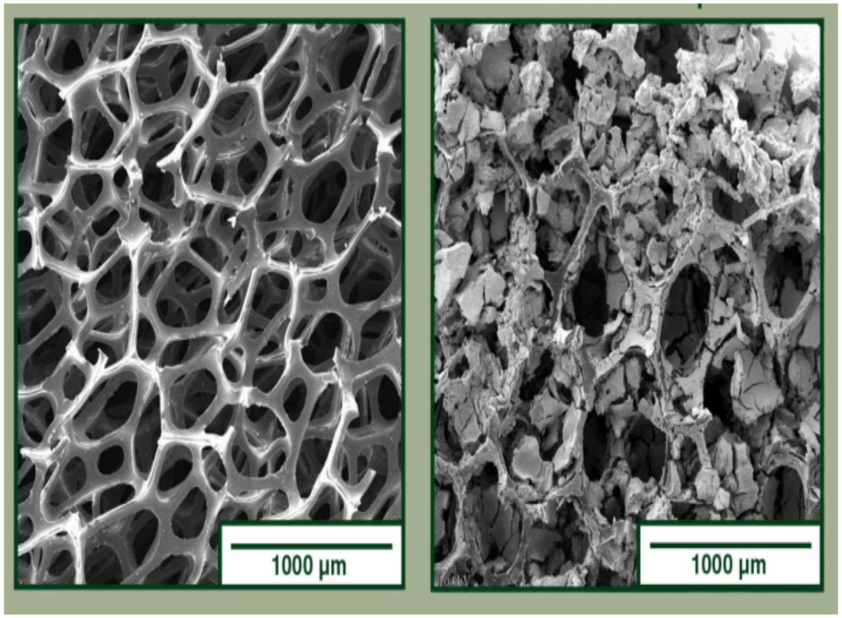
Linac3: 2011, energy = 414 keV/u

Linac4: 2012, energy = 718 keV/u

Nucl. Instrum. & Meth. A560 (2006)182
Nucl. Instrum. & Meth. A 631 (2011)

Development of Targets deposited on RVCF

The matrix chosen is Reticulated Vitreous Carbon Fiber (RVCF)



Properties of RVCF

Chemically inert over up to high temp.

Unusually large surface to volume ratio.

Porosity ~ 97% of the total volume

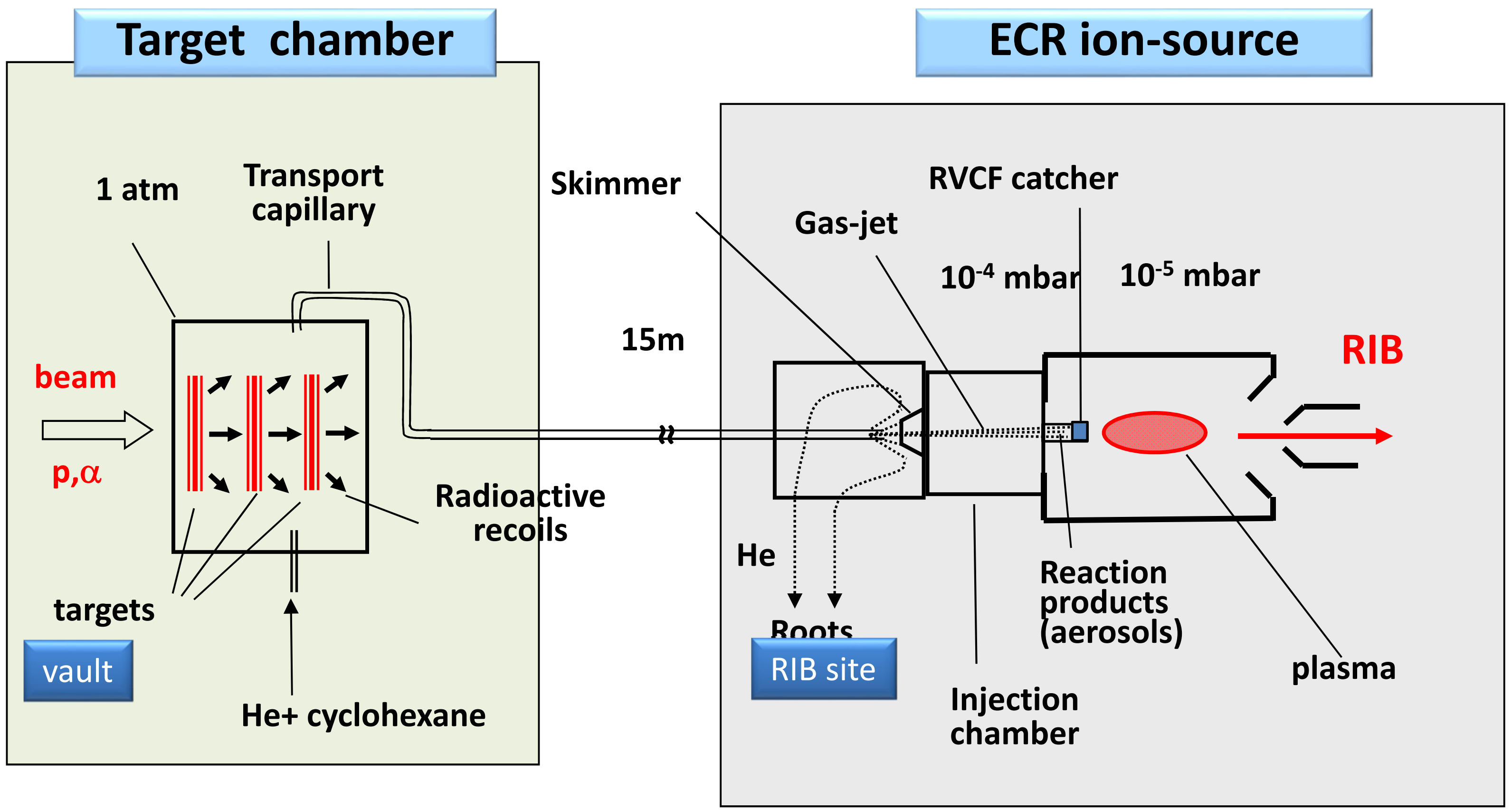
Density ~ 3% of the normal C-density.

Thermal conductivity is fairly good

1. *Ceramics International, (2011) 2679*
2. *Ceramics International, 34 (2008) 81*
3. *Nucl. Instrum. & Meth. A539 (2005)54*

Gas-jet based RIB production using RVCF as Catcher

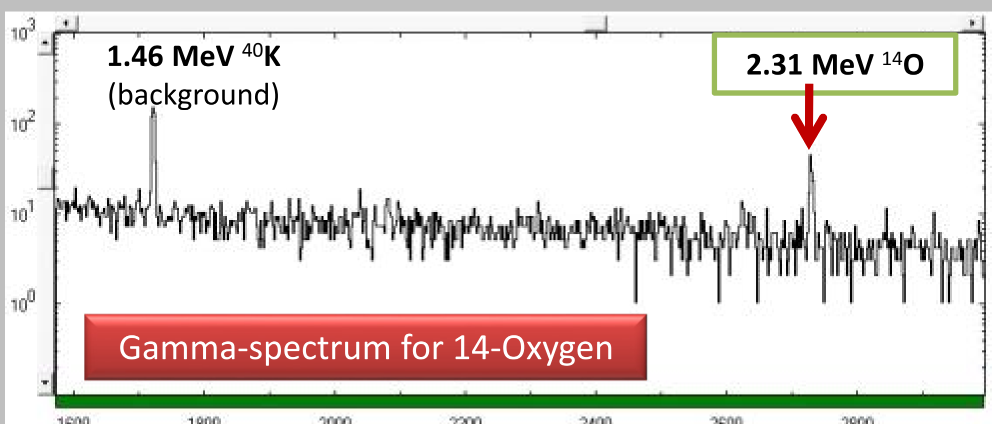
(No chemical selection, Helium helps in target cooling)



1. *V. Naik, et. al.,Rev. Sci. Instrum. Vol.84, (2013) 033301*. ***RIB acceleration***
2. *V. Naik, et.al., Nucl. Instrum. & Meth. B 317 (2013)227*. ***RIB acceleration***

RIBs produced

RIB	Prod. route	T1/2	I(pps) @ before RFQ	I(pps) @ after RFQ	Applications
^{14}O	^{14}N(p, n)	71 s	5.0 x 10^3	3.2 x 10^3	super-allowed beta decay, test of standard model; break-out reaction from hot CNO cycle to rp-process
^{42}K	^{40}Ar(α,pn)	12.36 hr	2.7 x 10^3	-	bio-medical tracer
^{43}K	^{40}Ar(α,p)	22.3 hr	1.2 x 10^3	-	bio-medical tracer
^{41}Ar	^{40}Ar(α,2pn)	109 min	1.3 x 10^3	-	tracer used in engineering ; wear studies
^{111}In	^{nat}Ag(α,xn)	2.8 days	1.6 x 10^3	-	Perturbed angular correlation spectroscopy, medical radio-tracer

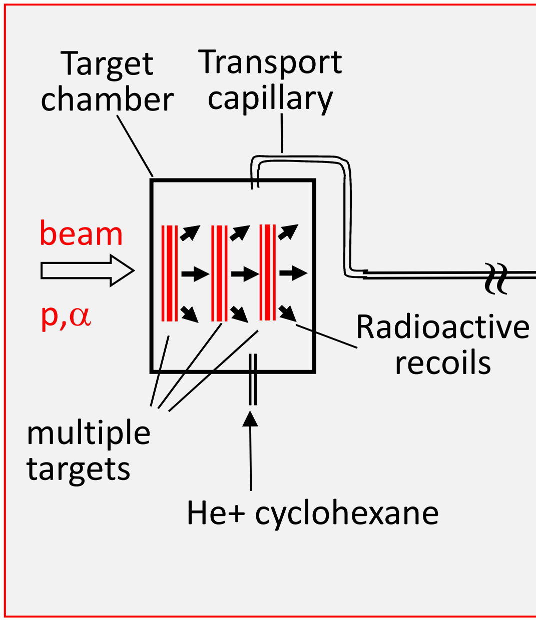


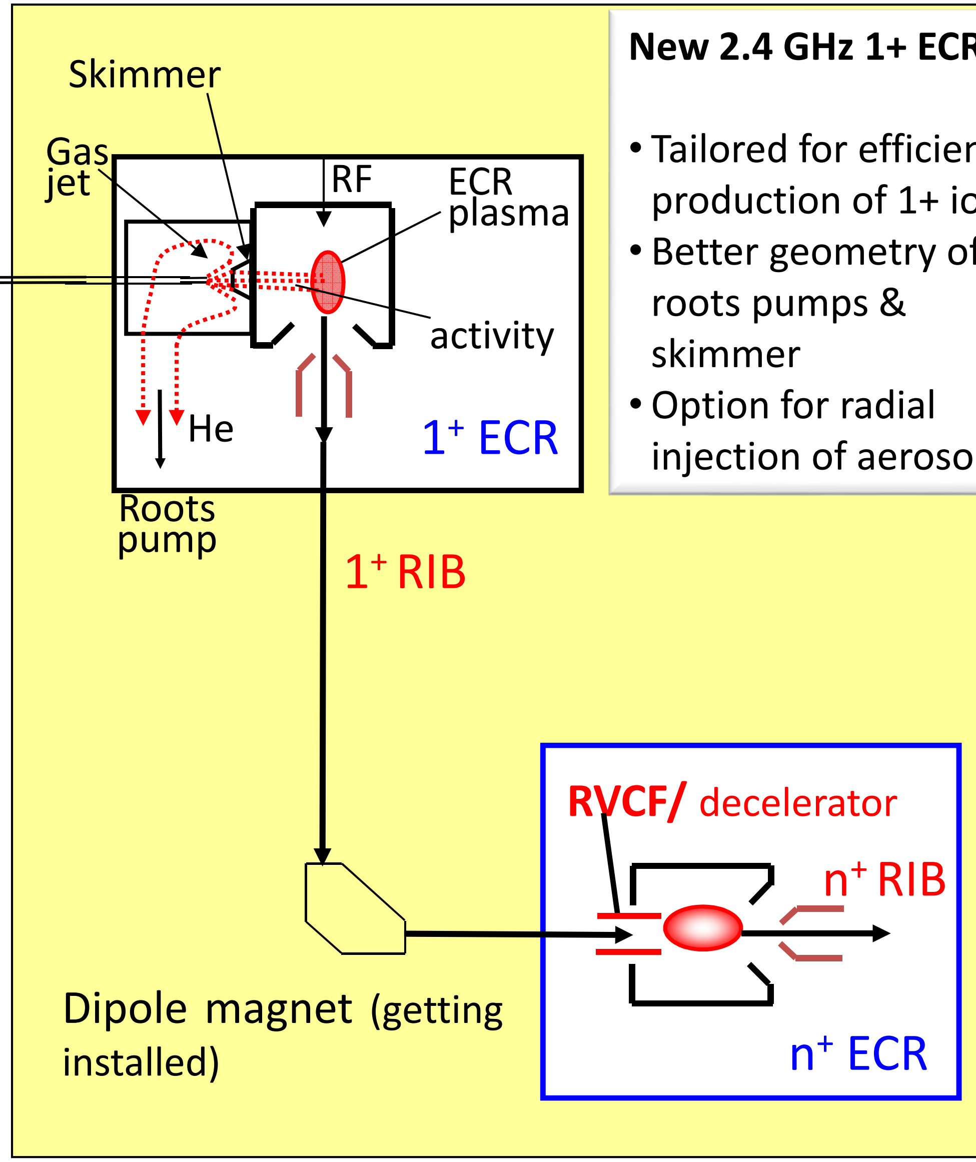
Gamma-spectrum for 14-Oxygen

Optimized parameter	value
beam	$^{14}O^{2+}$
ECR ext. vol.	12.3 kV
RFQ power	10 kW cw
RFQ vane vol.	27 kV

RFQ parameters for 14-Oxygen

Gas-jet based charge- breeder using RVCF as a catcher*





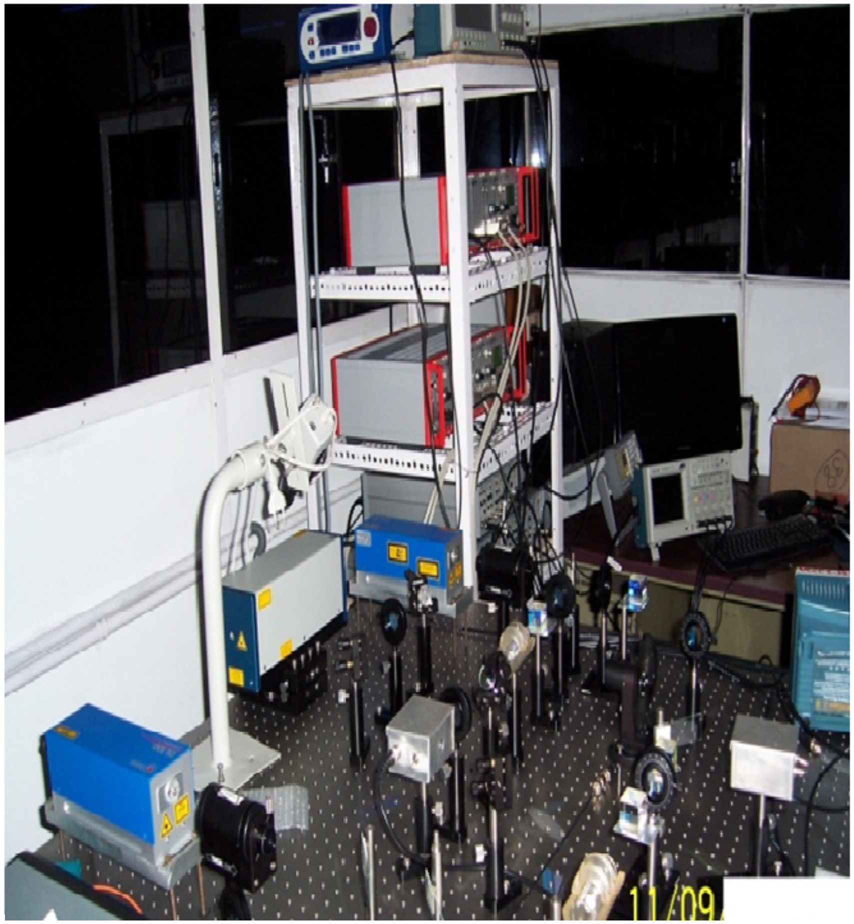
New 2.4 GHz 1+ ECR

- Tailored for efficient production of 1+ ions
- Better geometry of roots pumps & skimmer
- Option for radial injection of aerosols

* 1+ ion Source is absolutely necessary for fission/any reaction producing large number of isotopes

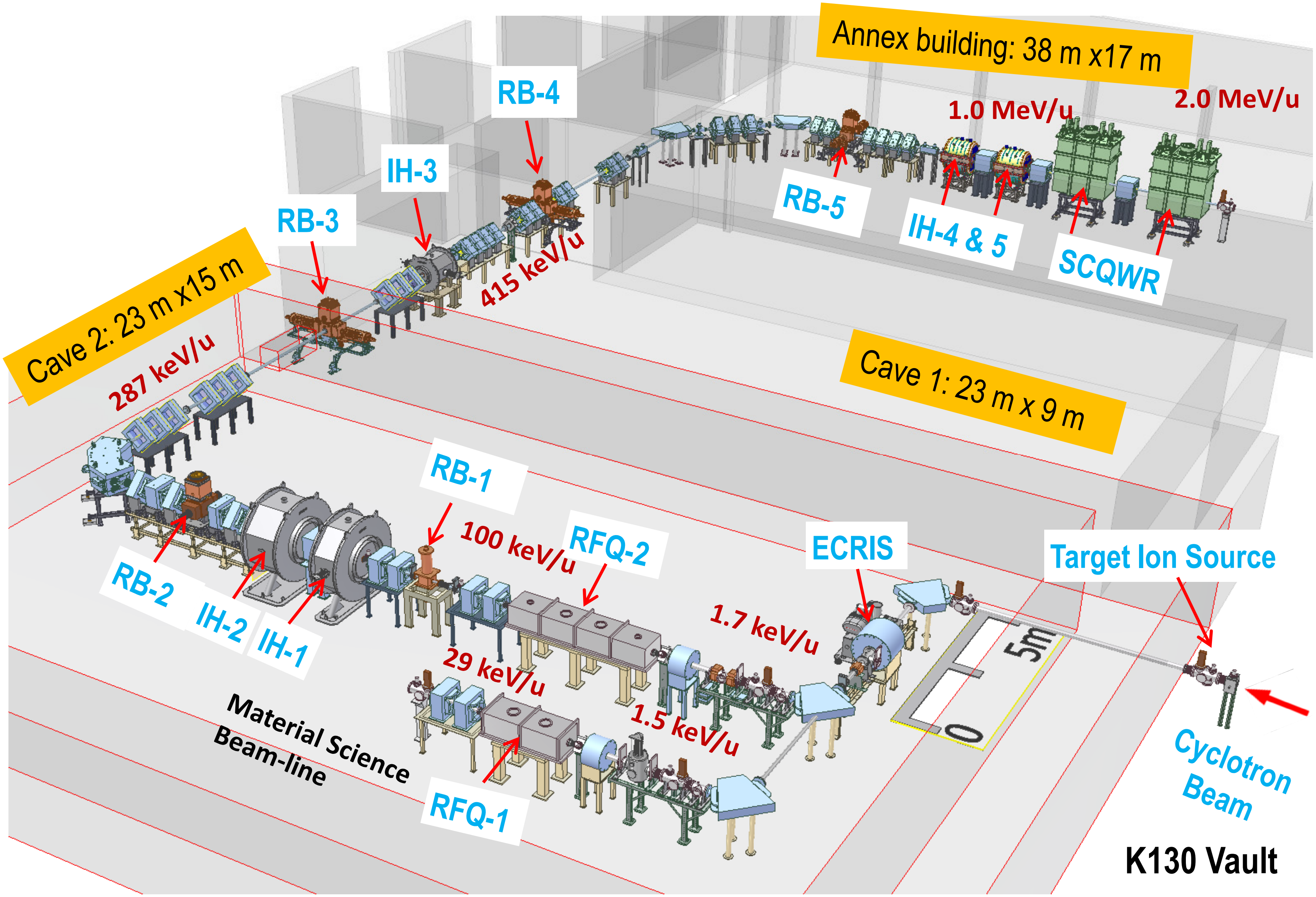
B. Collinear spectroscopy setup

The ISOL Beam Line

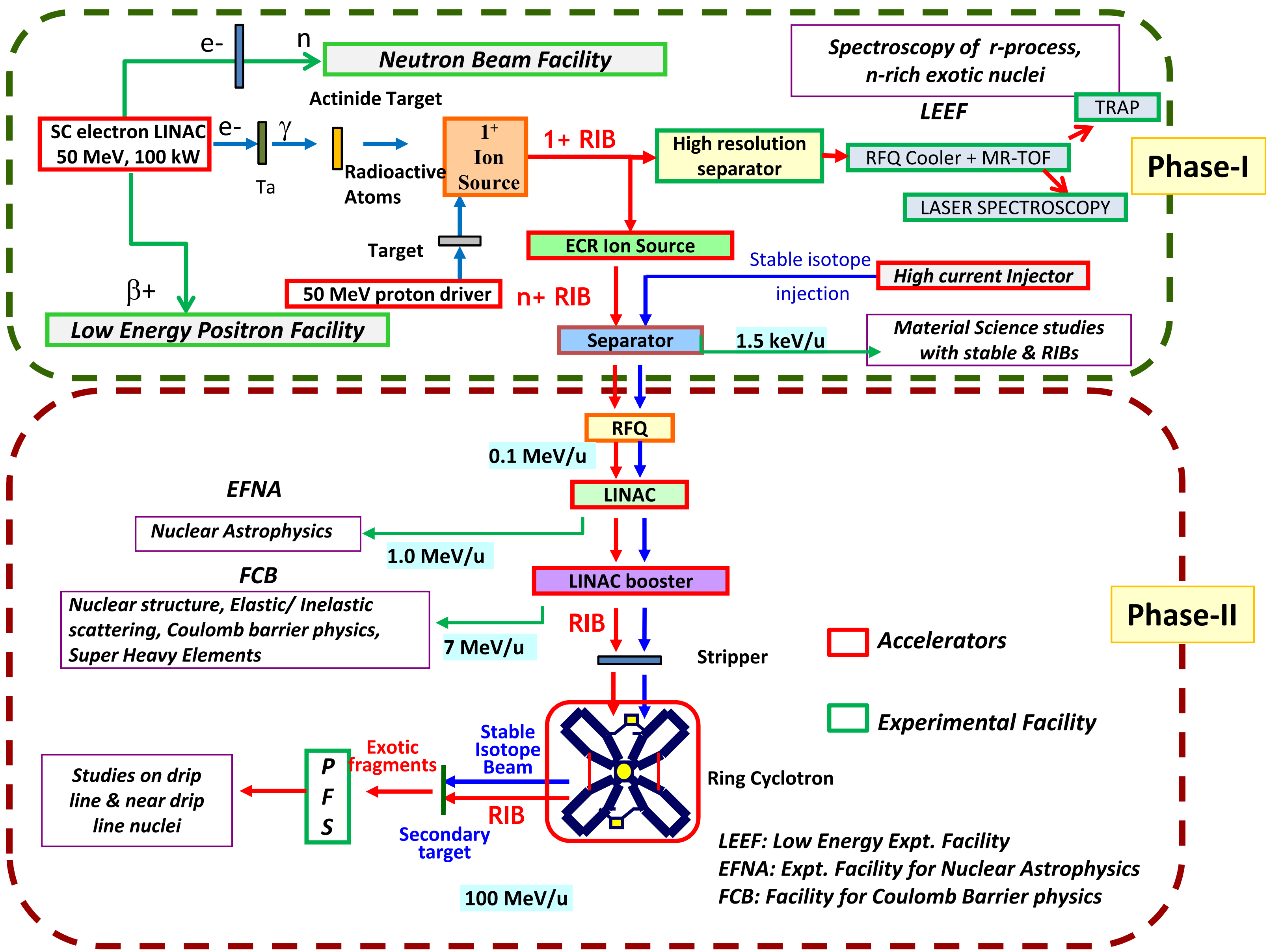


The Laser Hut

RIB facility at VEC Campus



ANURIB Schematic



Main features of ANURIB facility

1. Both ISOL and Projectile Fragment Separator type facility

2. Will accelerate both radioactive and high intensity stable isotope beams

3. **Two drivers:** 50 MeV, 2 mA electron linac photo-fission driver for production of neutron-rich RIBs & 50 MeV proton machine for production of p-rich nuclei

4. Neutron & Positron Facility in addition to facilities for nuclear physics and astrophysics

5. Fragmentation /fusion of radioactive ion beams to produce near drip-line n-rich /p-rich nuclei.

REPORT OF THE INTERNATIONAL ADVISORY COMMITTEE

Advanced National Facility for Unstable & Rare Isotope Beams - ANURIB

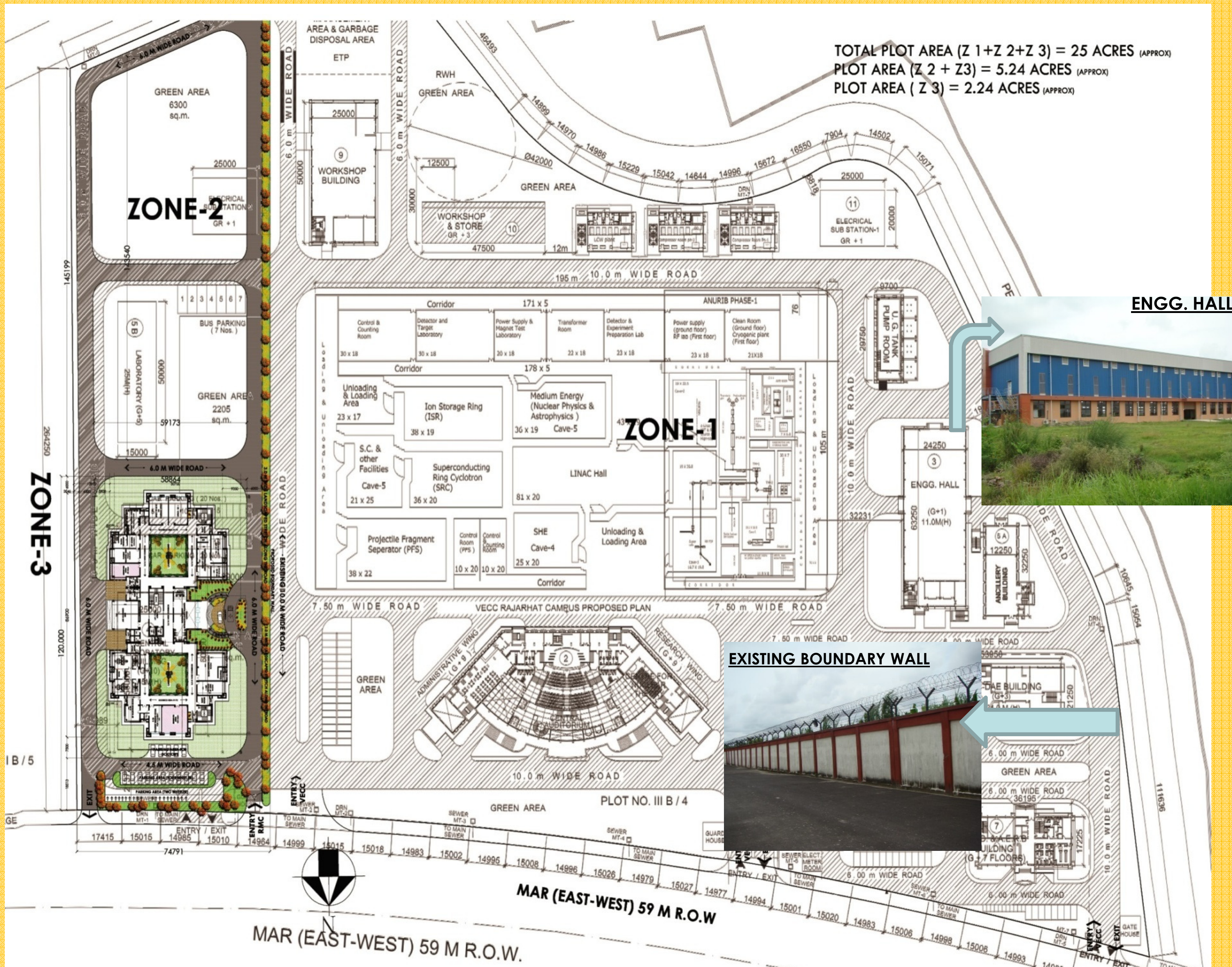
April 2012

1. Executive Summary

The International Advisory Committee (IAC) recognizes that ANURIB will be unique in the world and will attract a national and international user community. The IAC is confident that ANURIB will secure a science community with intimate knowledge of nuclear physics and will provide India with world class facilities. The committee is fully confident that the electron linac baseline design will achieve the performance required by the ANURIB science program. The IAC is confident that, with the planned enhanced project management support commensurate with this large facility, the VECC management team is well qualified to bring ANURIB successfully online.

IAC

Dr. Nigel Lockyer
Dr. Swapan Chattopadhyay
Dr. Yasushige Yano
Dr Lia Merminga
Dr. Andrew Hutton
Dr. Mats Lindroos
Joint Secretary R&D DAE
Dr. Bikash Sinha
Dr. R.K. Bhandari
Dr. Amit Roy
Dr. S. Kailas
Dr. Alok Chakrabarti
Dr. A.K. Sinha

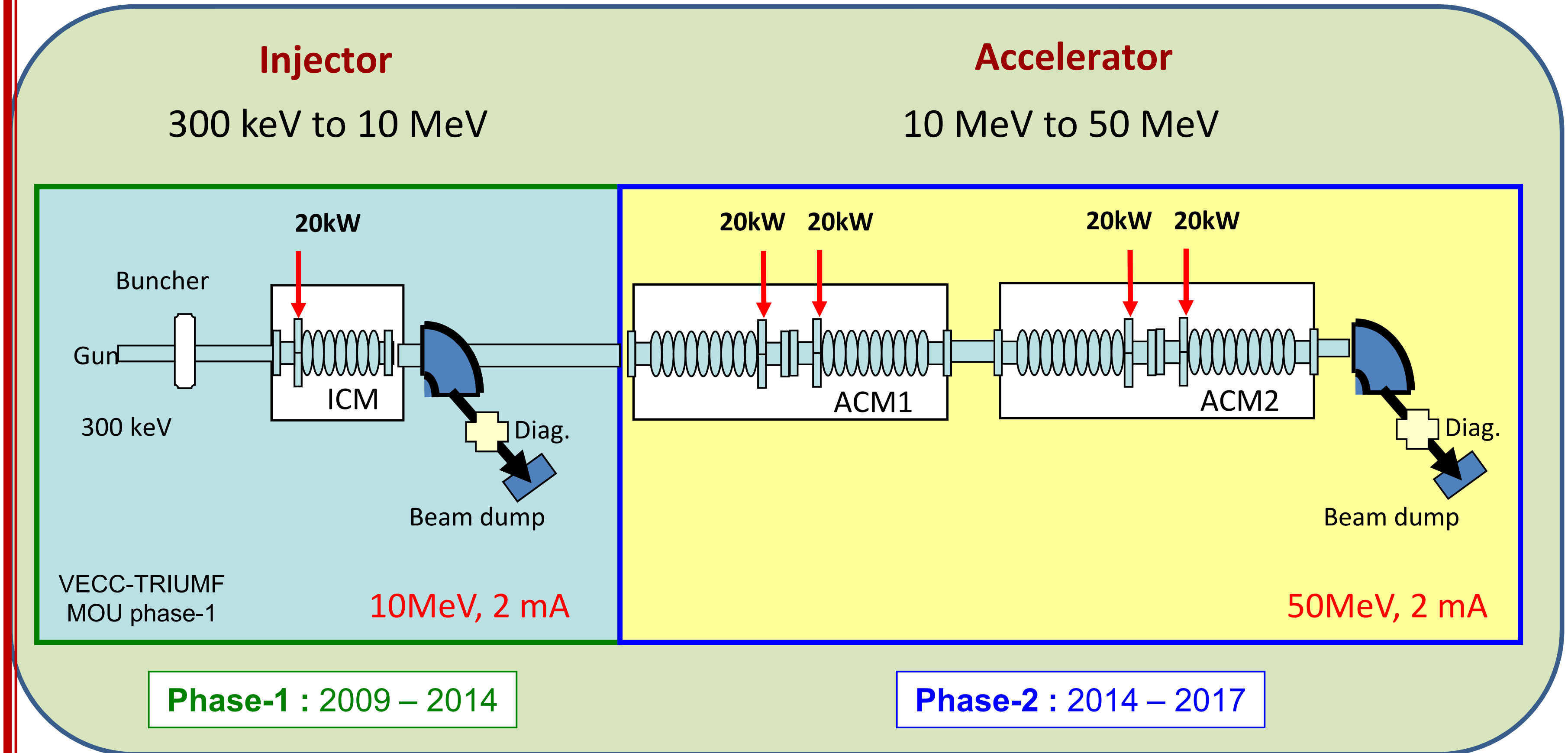

TOTAL PLOT AREA (Z 1+Z 2+Z 3) = 25 ACRES (APPROX)
PLOT AREA (Z 2 + Z3) = 5.24 ACRES (APPROX)
PLOT AREA (Z 3) = 2.24 ACRES (APPROX)
ZONE-1
ZONE-2
ZONE-3
ENGG. HALL
EXISTING BOUNDARY WALL
VECC RAJARHAT CAMPUS PROPOSED PLAN
AREA & GARBAGE DISPOSAL AREA
ETP
RWH
GREEN AREA
WORKSHOP BUILDING
WORKSHOP & STORE GR + 3
ELECTRICAL SUB STATION-1 GR + 1
U.G. TANK PUMP ROOM
10.0 m WIDE ROAD
7.50 m WIDE ROAD
6.0 M WIDE ROAD
4.5 M WIDE ROAD
GREEN AREA 6300 sq.m.
GREEN AREA 2205 sq.m.
BUS PARKING (7 Nos.)
LABORATORY (G+5)
ANURIB PHASE-1
Corridor
Control & Counting Room
Detector and Target Laboratory
Power Supply & Magnet Test Laboratory
Transformer Room
Detector & Experiment Preparation Lab
Unloading & Loading Area
Ion Storage Ring (ISR)
Medium Energy (Nuclear Physics & Astrophysics) Cave-5
S.C. & other Facilities Cave-5
Superconducting Ring Cyclotron (SRC)
LINAC Hall
Projectile Fragment Seperator (PFS)
SHE Cave-4
Loading & Unloading Area
ENGG. HALL (G+1) 11.0M(H)
ANCILLARY BUILDING
ADMINISTRATIVE WING (G + 9)
RESEARCH WING (G + 9)
CENTRAL AUDITORIUM
DAE BUILDING
PLOT NO. III B / 4
ENTRY / EXIT
GATE HOUSE
MAR (EAST-WEST) 59 M R.O.W
MAR (EAST-WEST) 59 M R.O.W.

Status of activities

DRIVER ACCELERATORS

- 50 MeV Electron Linac (for n-rich exotic nuclei)
- 50 MeV Proton machine (for p-rich nuclei)

50 MeV Superconducting Electron Linac – VECC-TRIUMF collaboration

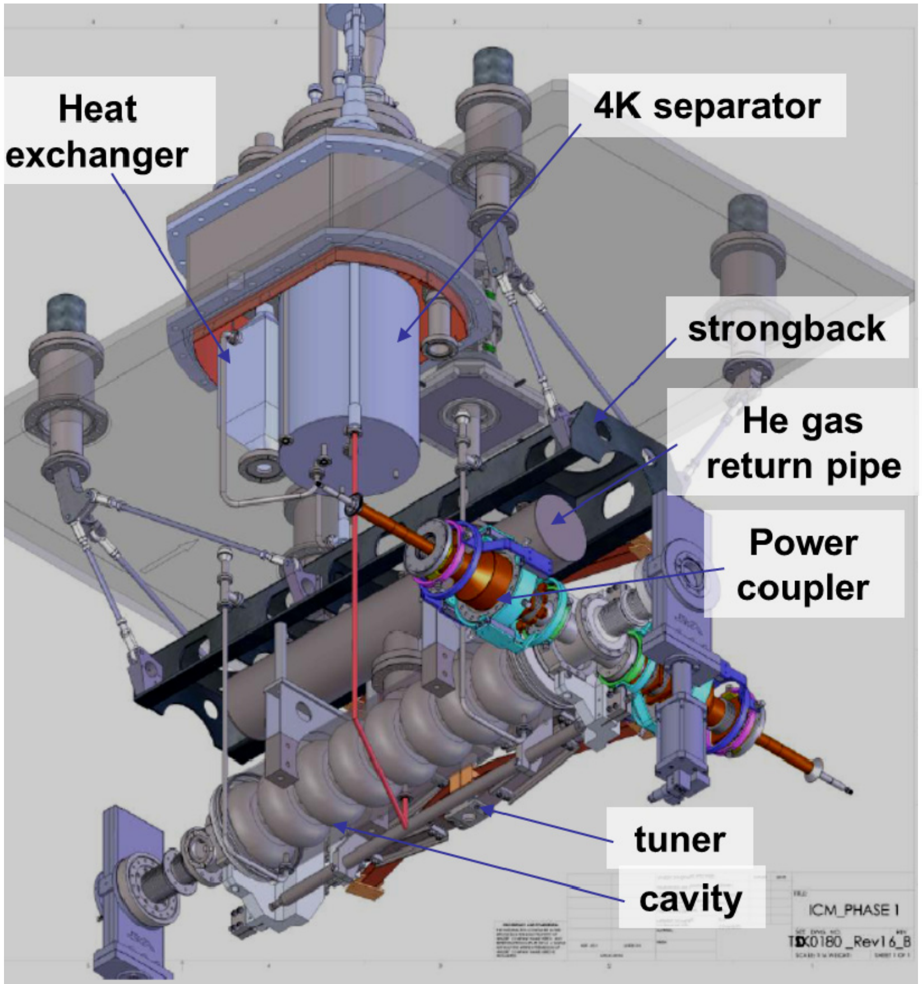


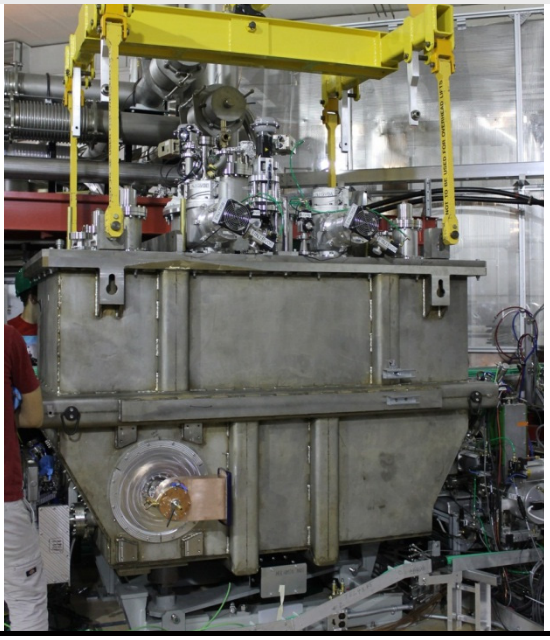
- 50 MeV, 2 mA; 100 kW CW, 1.3 GHz, 2 deg K; Being developed in collaboration with TRIUMF
- Production of neutron rich nuclei through photo-fission of Uranium
- based on 1.3 GHz, 2K Tesla SRF technology. High current CW acceleration – heavy beam loading, high cryogenic loads

MOU between VECC & TRIUMF

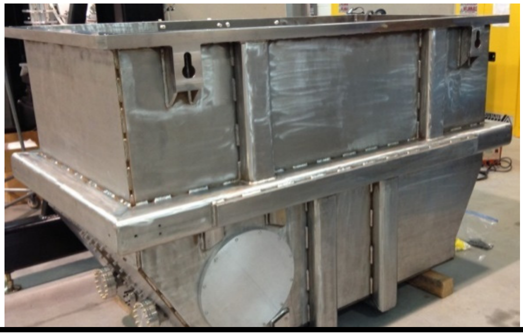
- For Design & Development of a Superconducting Electron Linac
- Starts with the Development of an Injector Cryo Module (ICM)

Injector Cryo Module (ICM)



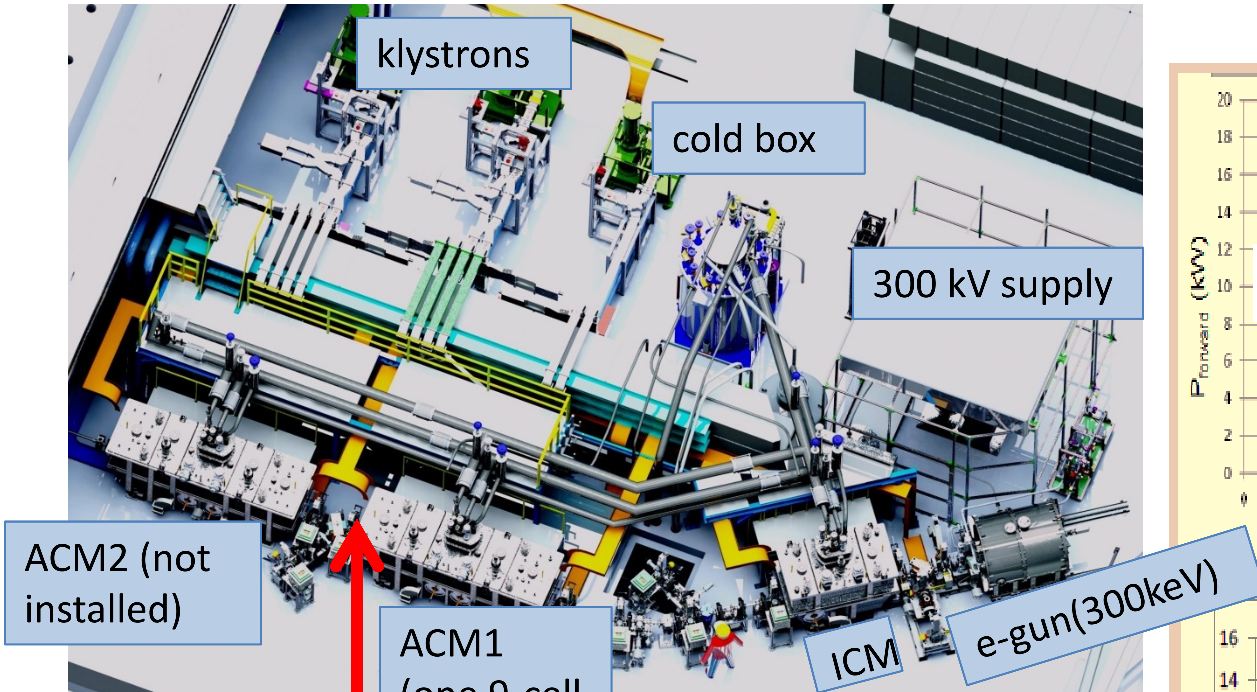


ICM1 – successful beam tests Sept’14

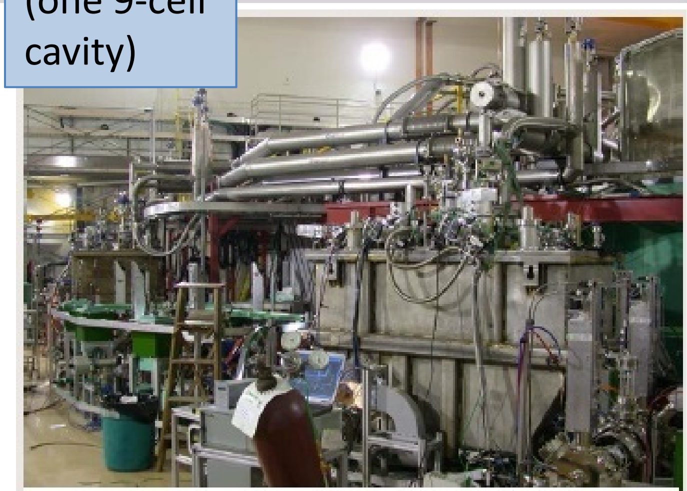


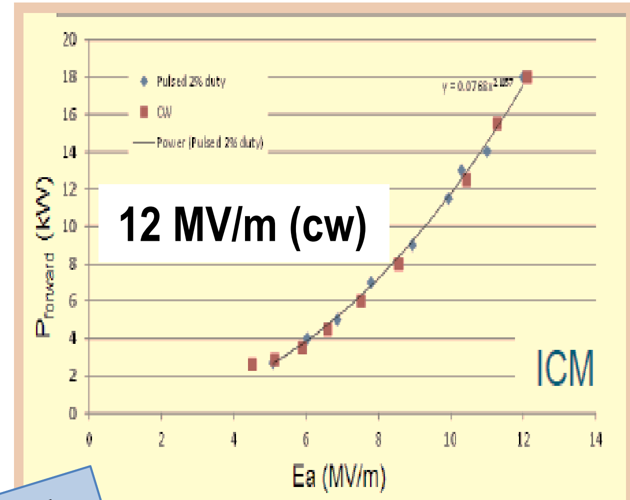
ICM2 assembly on-going at TRIUMF

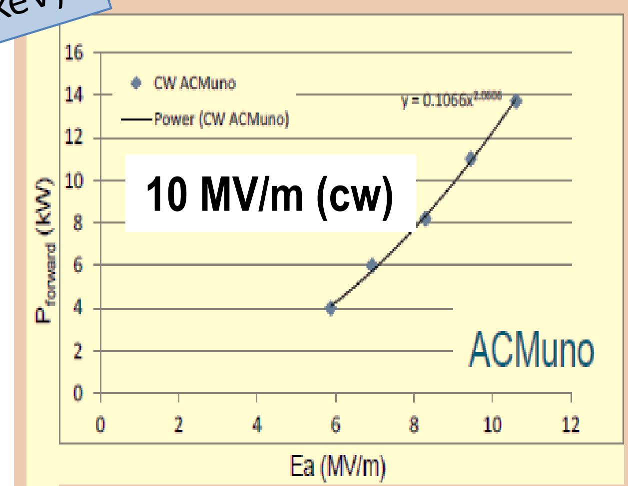
First beam accelerated to 23 MeV on 29th Sept 2014 at TRIUMF



23 MeV, 10 microAmp



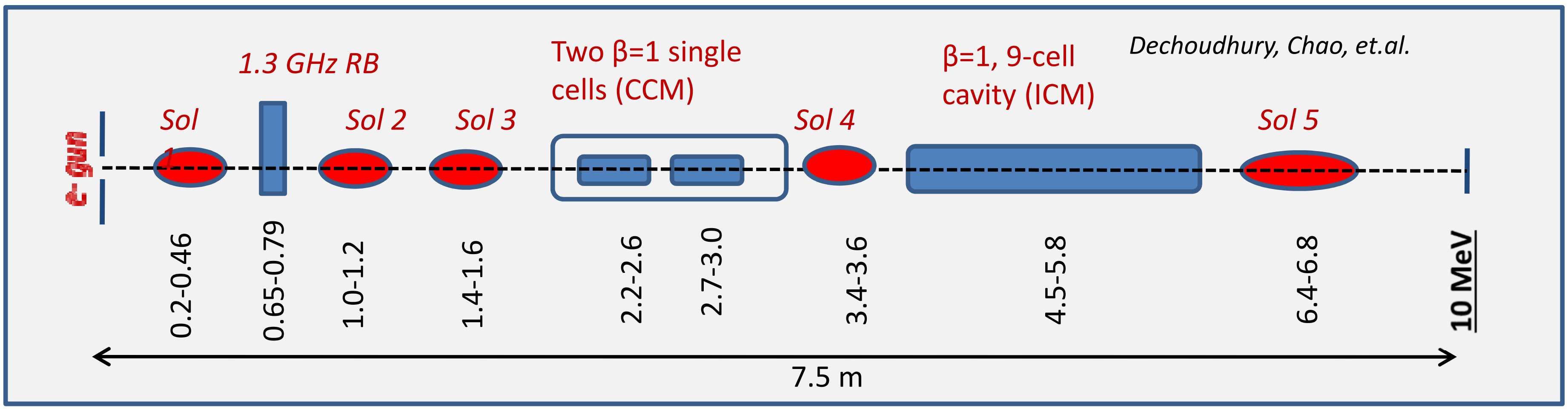




VECC ICM at TRIUMF – Aug 2015

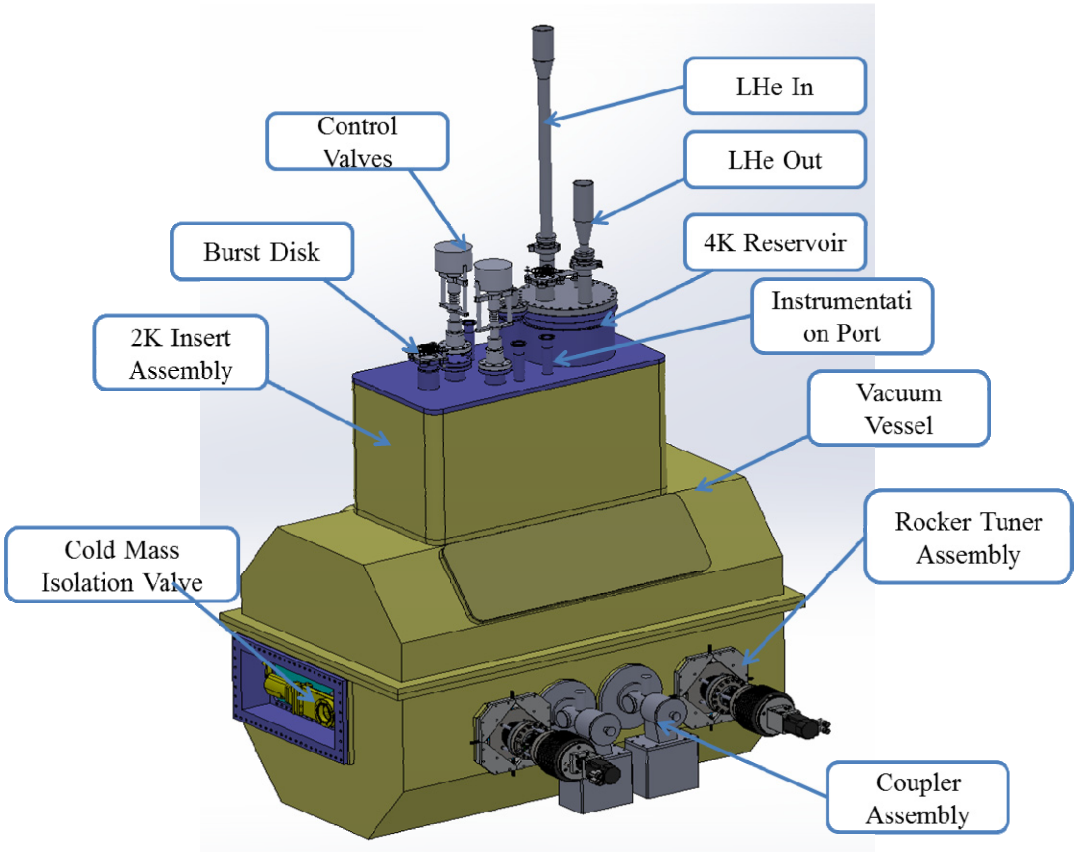
VECC: 10 MeV injector beam dynamics design

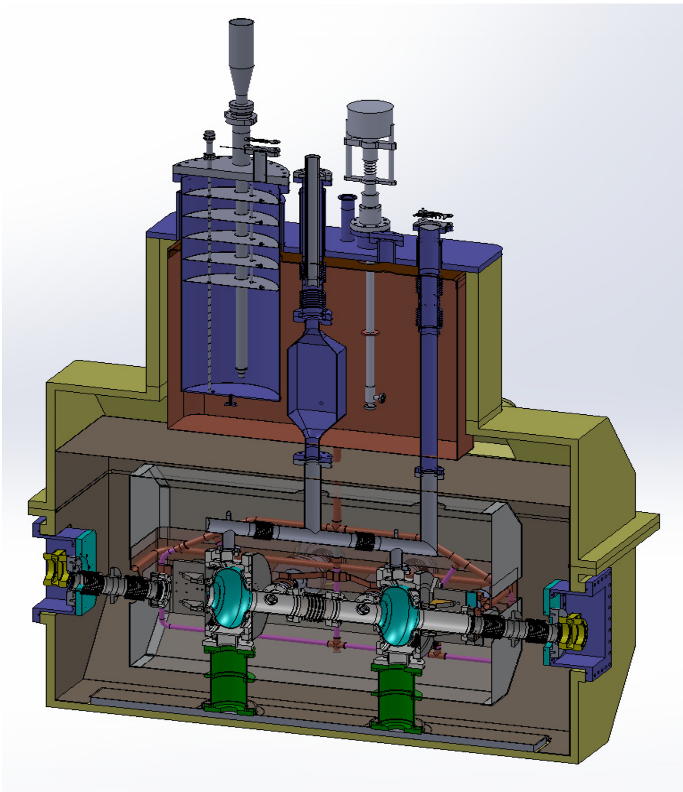
Parameter	Injection	Output @10 MeV
Bunch charge (pC)	~ 3	~ 3
Bunch rep' rate (MHz)	650	650
Transverse (norm) emittance (μm, 1σ)	5π	15π
Longitudinal 1σ emittance (keV.ps)	≤ 20π	≈ 750π
Bunch length (ps)	< 170 (FW)	≈ 8 (FW)
Energy spread	1 keV (FW)	≈ 100 keV (FW)



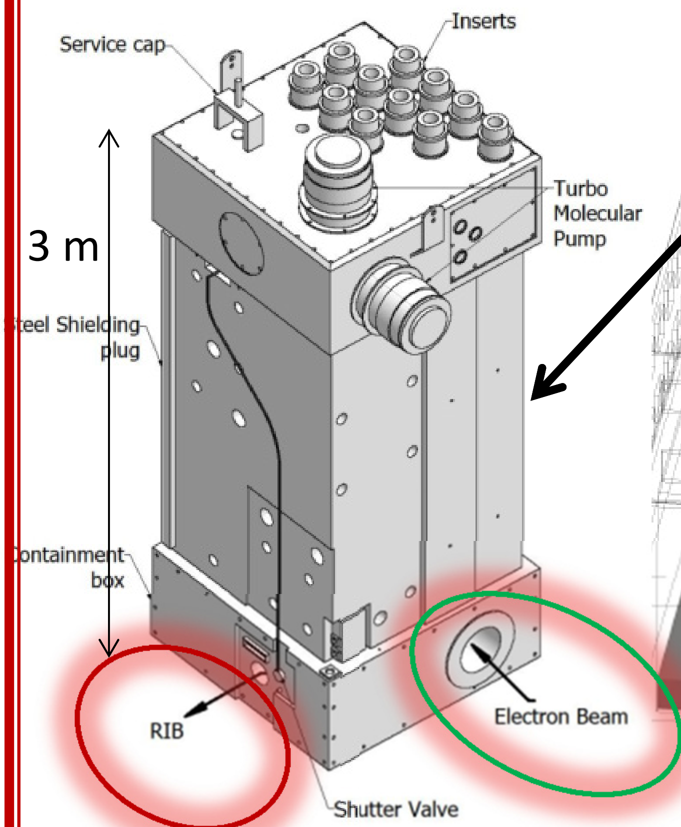
CCM mechanical design completed
to be built in Indian industry

VECC

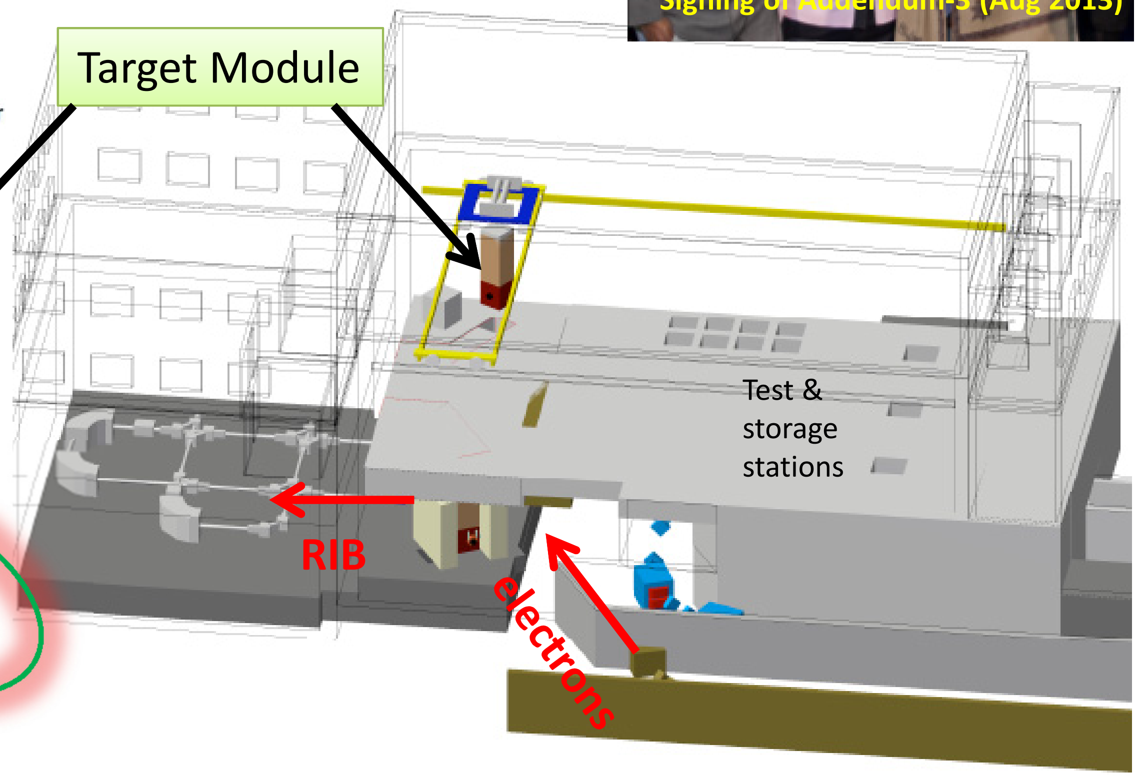


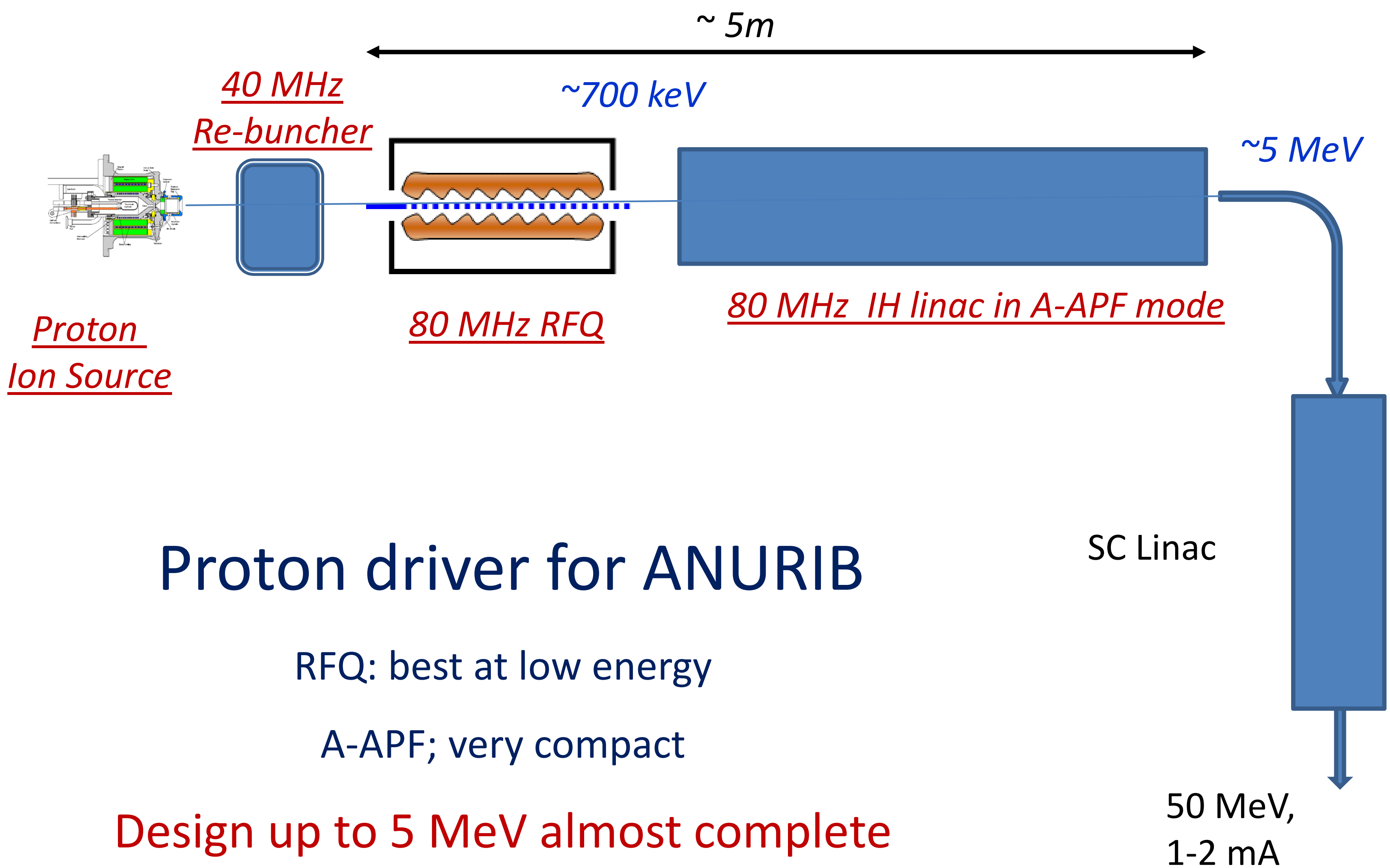


Target/Ion-source (TIS) Module (VECC-TRIUMF MoU Addendum-3)



Three Dimensional view of target/ion source module





Proton driver for ANURIB

RFQ: best at low energy

A-APF; very compact

Design up to 5 MeV almost complete

HI acceleration from 1 to 7 MeV/u in

SC LINAC BOOSTER

Beam dynamics design of SC QWRs for ANURIB facility (1.3 to 7 MeV/u)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 052001 (2013)

Alternate phase focusing in sequence of independent phased resonators as superconducting linac boosters

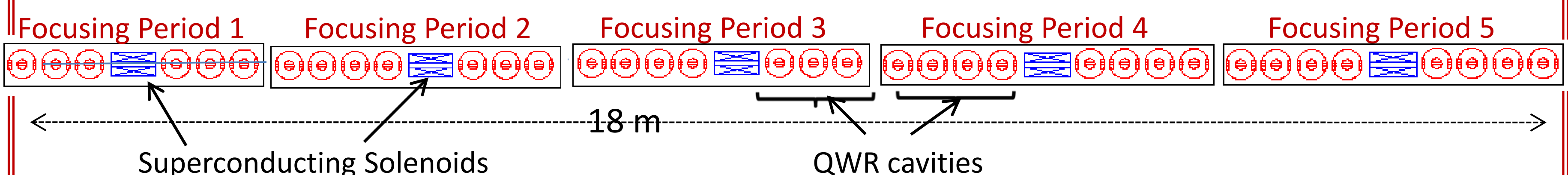
S. Dechoudhury* and Alok Chakrabarti

Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700 064, India

(Received 30 May 2012; published 20 May 2013)

Theoretical study of an alternate phase focusing (APF) structure, realized in a long chain of double gap quarter wave resonators, capable of accelerating heavy ions from 1.3 to 7 MeV/u has been carried out. Mathieu-Hill stability analysis for the focusing periods consisting of independent resonators with phase variation satisfying square-wave law has been used to evaluate parameters such as the electric field and phase for the resonators. Furthermore, a smooth approximation method taking into account the acceleration in the linac has been employed to find out the rf bucket parameters (energy and phase width acceptance) of the focusing periods. Corroborative particle tracking (longitudinal and transverse) has been carried out using simulated 3D fields for double gap quarter wave resonators (QWR). Steering effects in QWRs over the period have also been studied. In one APF period, the individual phase of resonators changes sign resulting in a vertical steering kick in a particular direction, which is less as compared to the case where all the individual resonators operate in the same phase.

DOI: 10.1103/PhysRevSTAB.16.052001 PACS numbers: 29.20.Ej, 29.27.−a



Energy (input–output) MeV/u	1.3–2.06	2.06–2.78	2.78–3.84	3.84–5.08	5.08–7.16
Length (m)	2.1	2.4	3.24	3.66	4.86
Number of QWR/β designed	6/0.06	7/0.06	7/0.1	8/0.1	8/0.15
Phase acceptance (deg)	131	158	117	124	128
Energy width (keV/u)	227	338	353	444	631

The A-APF design with QWRs for single charge state (1-7 MeV/u) depends on choice of phases so that operating point is at intersection of Cos(muL) = 0 and Cos(muT) =0.

Mathieu Hill Equations in terms of phase deviation $\psi = \phi - \phi_S$ and dimensionless radial parameter $\rho = r / L_f$

$$\frac{d^2\psi}{d\tau^2} + P_\psi(\tau).\psi = 0 \,;\, P_\psi(\tau) = 2B.\sin[\bar{\phi} + \tilde{\phi}(\tau)] \qquad P_\rho(\tau) \Rightarrow P_\rho(\tau+1)$$

$$\frac{d^2\rho}{d\tau^2} + P_\rho(\tau).\rho = 0 \,;\, P_\rho(\tau) = -B.\sin[\bar{\phi} + \tilde{\phi}(\tau) + \psi] \qquad P_\psi(\tau) \Rightarrow P_\psi(\tau+1)$$

with B as focusing parameter given by

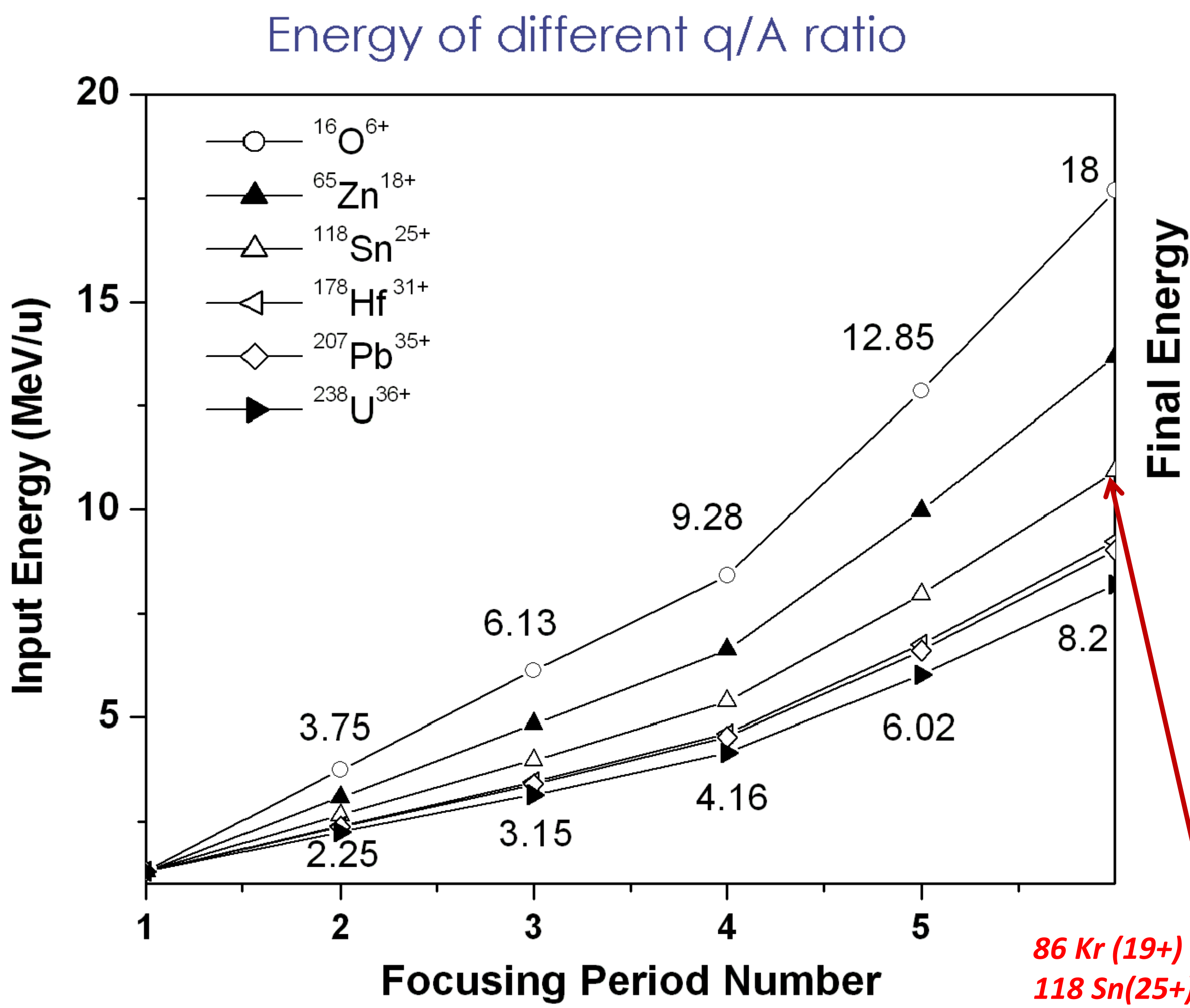
$$B = (\pi q E_m / A m_0 c^2)(L_f / \beta_s \lambda)^2 (1 - \beta_s^2)^{3/2}$$

For a different q/A, one can have similar efficiency in terms of simultaneous transverse & longitudinal focusing if one can keep {B(depends on q/A)x sin (phis)} over the period same as that for the designed q/A. Accordingly phase sequence for different q/A can be calculated.

Using the most probable charge state fraction (mpcst) after stripper ~ 1 MeV/u , and with above objective vis-à-vis AAPF efficacy, final energy for different q/A has been calculated

Kr (Z=36): Stable A = 78, mpcst: 19

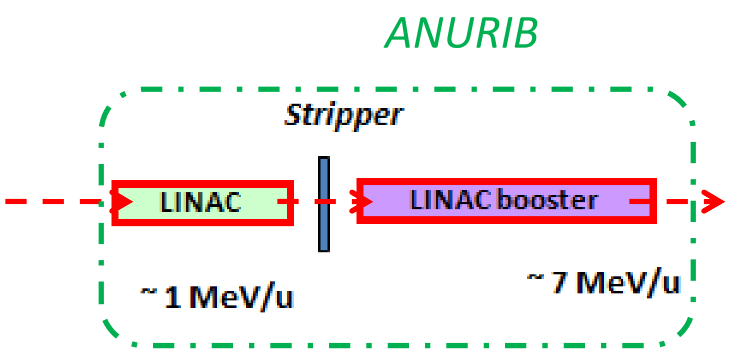
Charge states correspond to most probable charge state fraction after stripping @ ~1 MeV/u



86 Kr (19+) : q/A = 0.2118
118 Sn(25+) : q/A = 0.22
Energy ~ 10 MeV/u

Multiple charge acceleration in A-APF Structure

Motivation



▶Higher charge produced after stripper allows the optimal use of accelerating fields of SC cavities

▶ *Stripper induces a distribution of charge state about an equilibrium charge state*

^{238} U stripped at ~1 MeV/u: Distributed over 12 charge states about equilibrium charge of 37+ (*19 % of input beam*).

Simultaneous acceleration of multiple charge states results in much higher beam intensity

Multiple charge acceleration up to 6.2 MeV/u for Uranium

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 074201 (2014)

Multiple charge beam dynamics in alternate phase focusing structure

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Asymmetrical alternate phase (A-APF) focusing realized in a sequence of 36 superconducting quarter wave resonators (QWRs) has been shown to accelerate almost 81% of input uranium beam before foil stripper to an energy of 6.2 MeV/u from 1.3 MeV/u. Ten charge states from 34+ to 43+ could be simultaneously accelerated with the phase of resonators tuned for 34+. The A-APF structure showed the unique nature of a large potential bucket for charge states higher than that of the tuned one. Steering to QWRs can be mitigated by selecting appropriate phase variation of the APF periods and ion of solenoid field strengths placed in each of the periods. Thi

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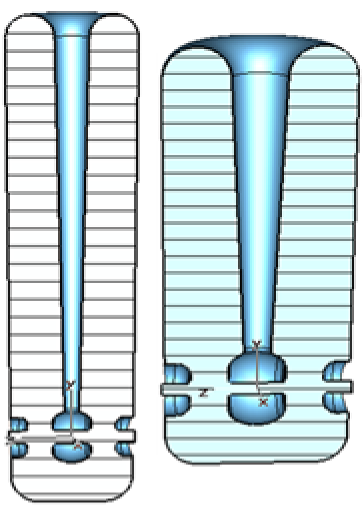
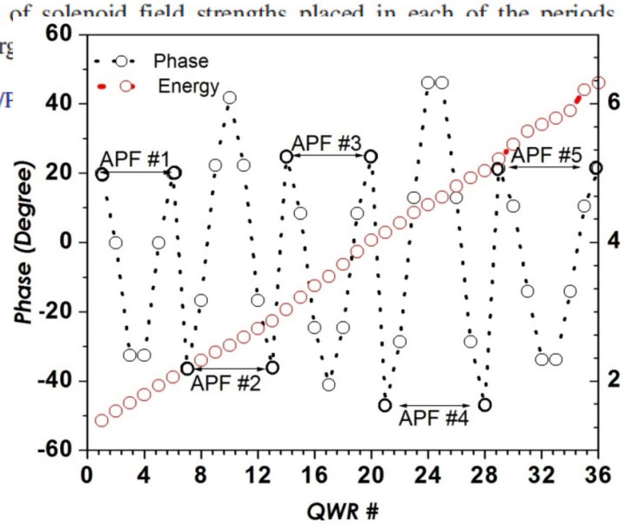
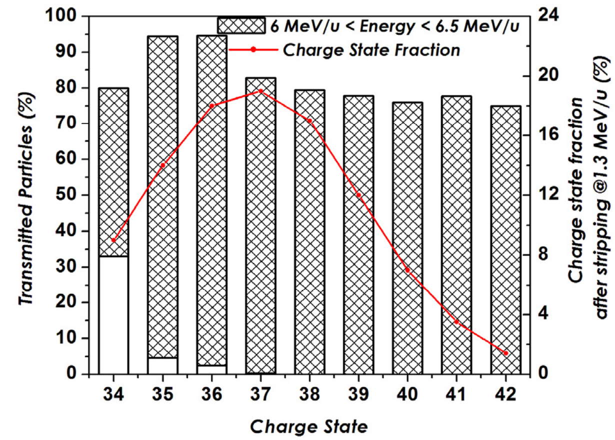




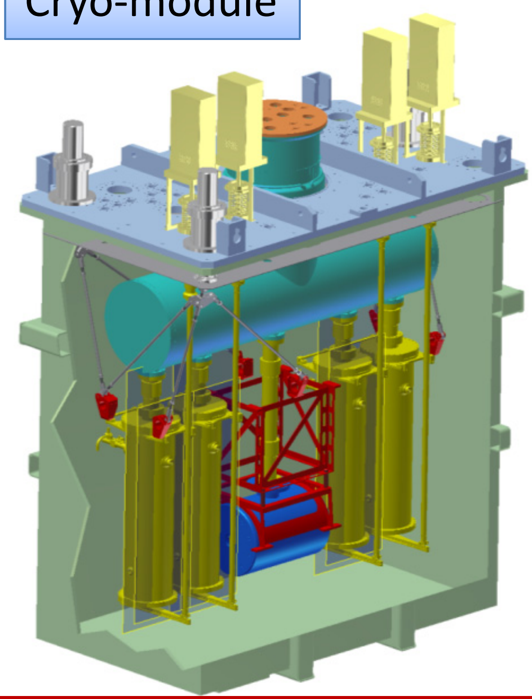


Higher intensity for SIB/RIB

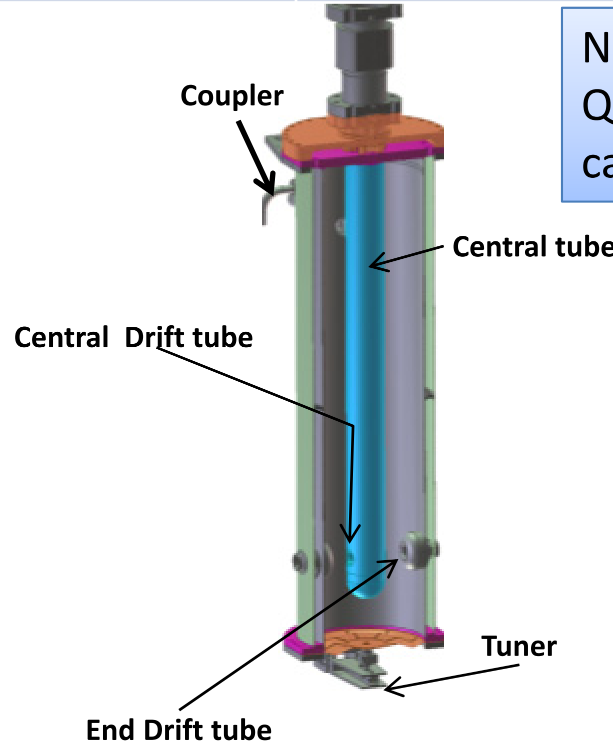
SC QWR Linac for heavy-ion beam acceleration (VECC-TRIUMF collaboration)

Frequency [MHz]	113.4
β_0 [%]	5.3
No. of resonators	8
E_{peak}/E_{acc}	~ 7.6
$B_{peak}/E_{\_acc}$ [G-m/MV]	~130
Initial/final energy (MeV/u)	1.04/2.0

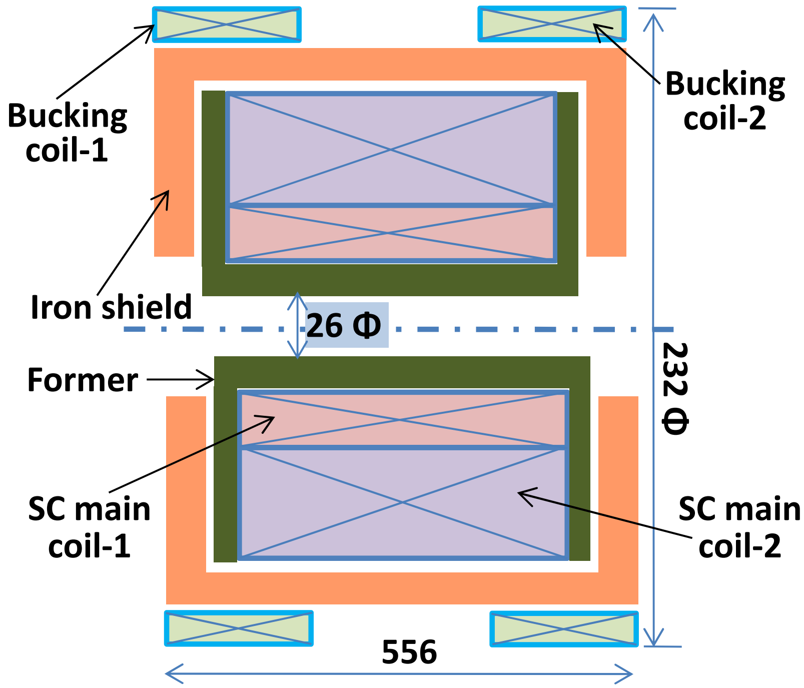
Cryo-module



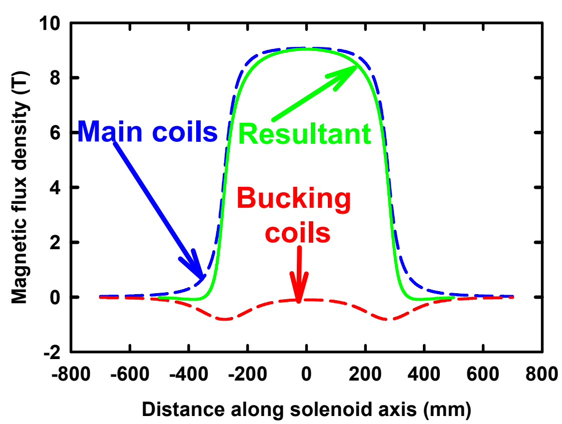
Niobium QWR cavity

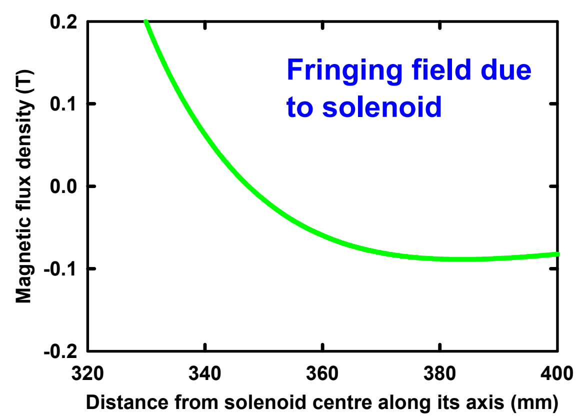


Design of internal superconducting solenoid for SC HI resonators

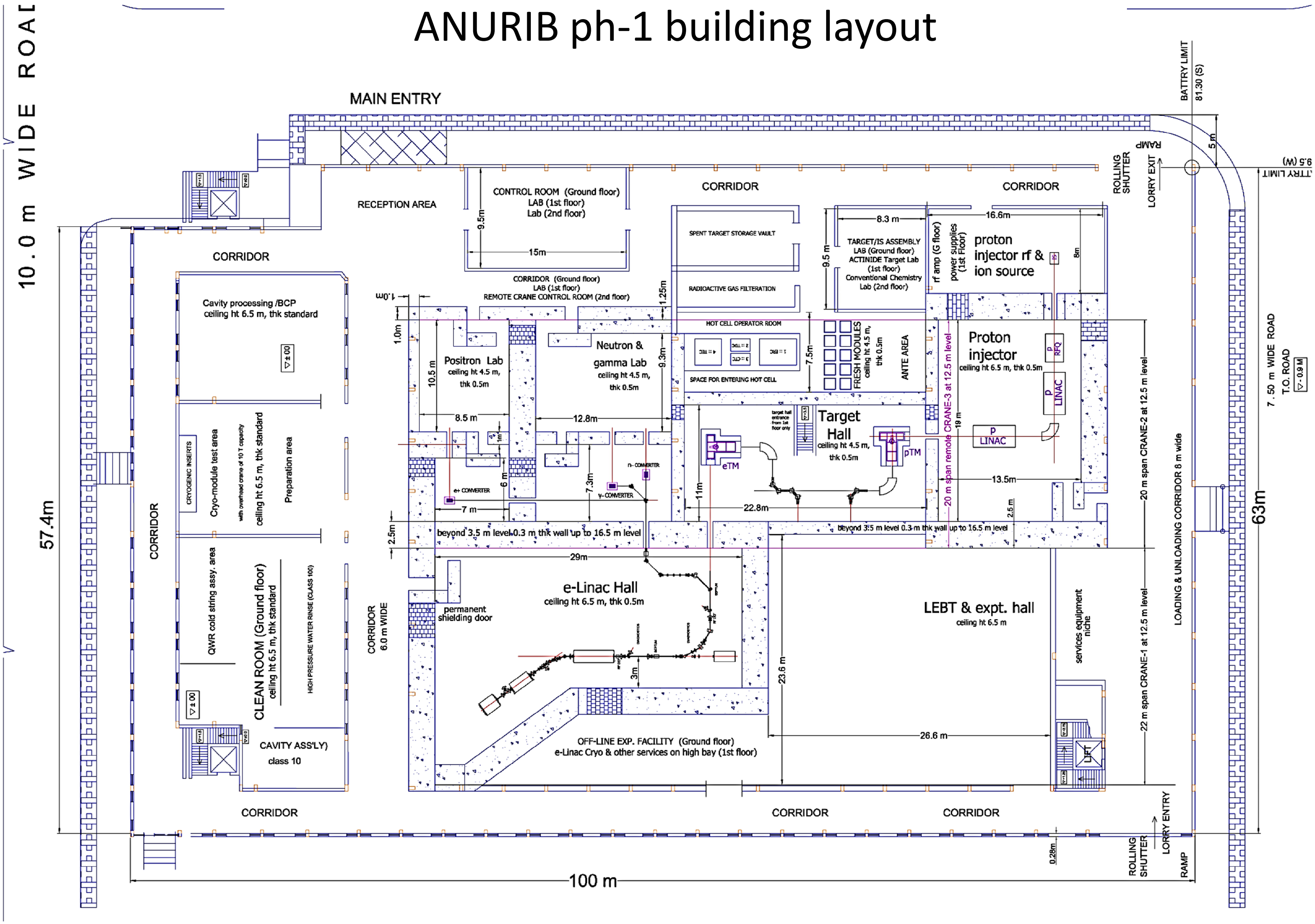


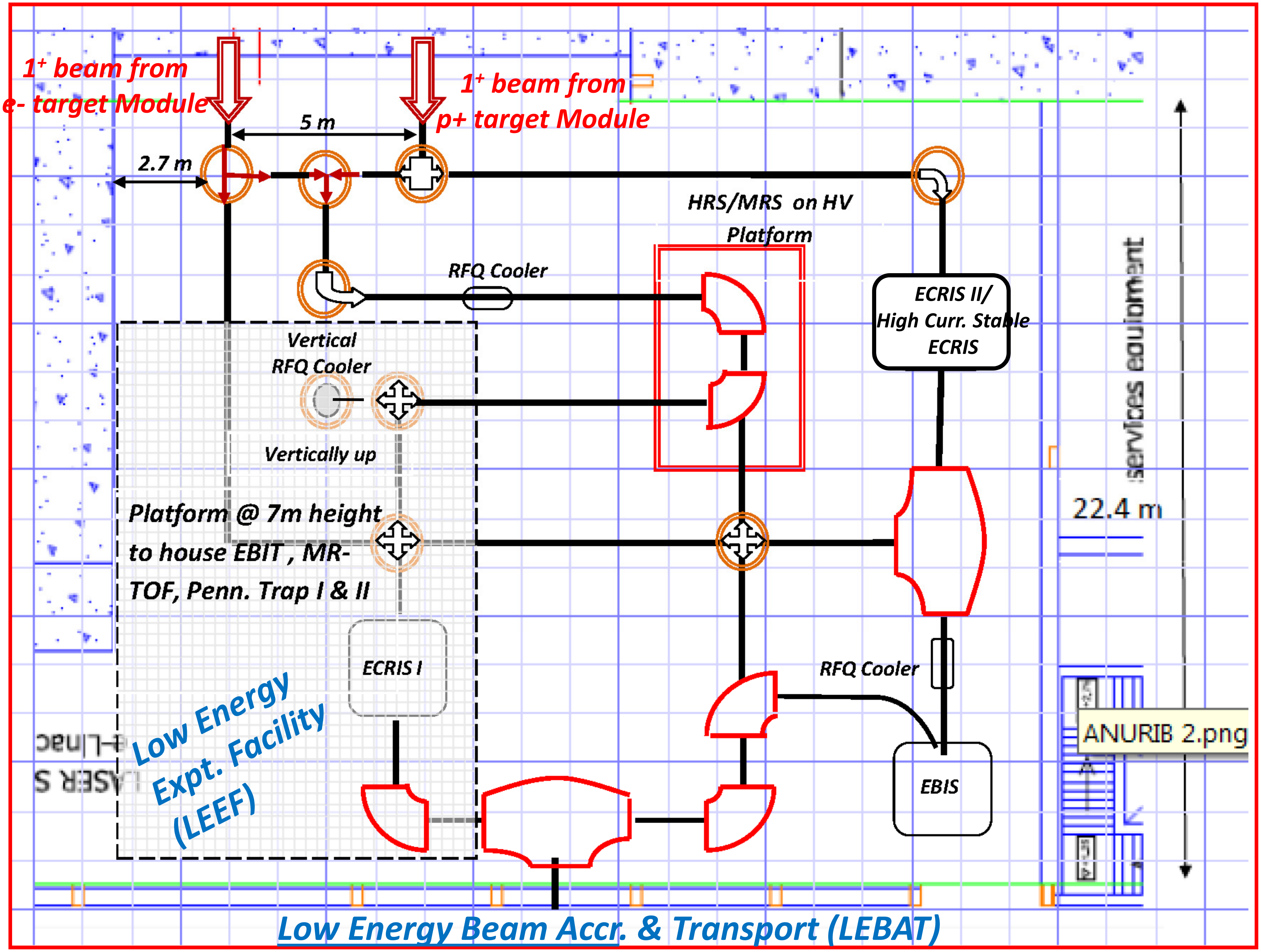
Effective Field Length [mm]	340
Physical Length [mm]	556
Max. Axial Field [T]	9
Fringing Field near QWR [T]	<0.13
Conductor	NbTi
Conductor size [mm x mm]	1.88 x 1.18
Critical current of conductor [A]	822 @ 8T



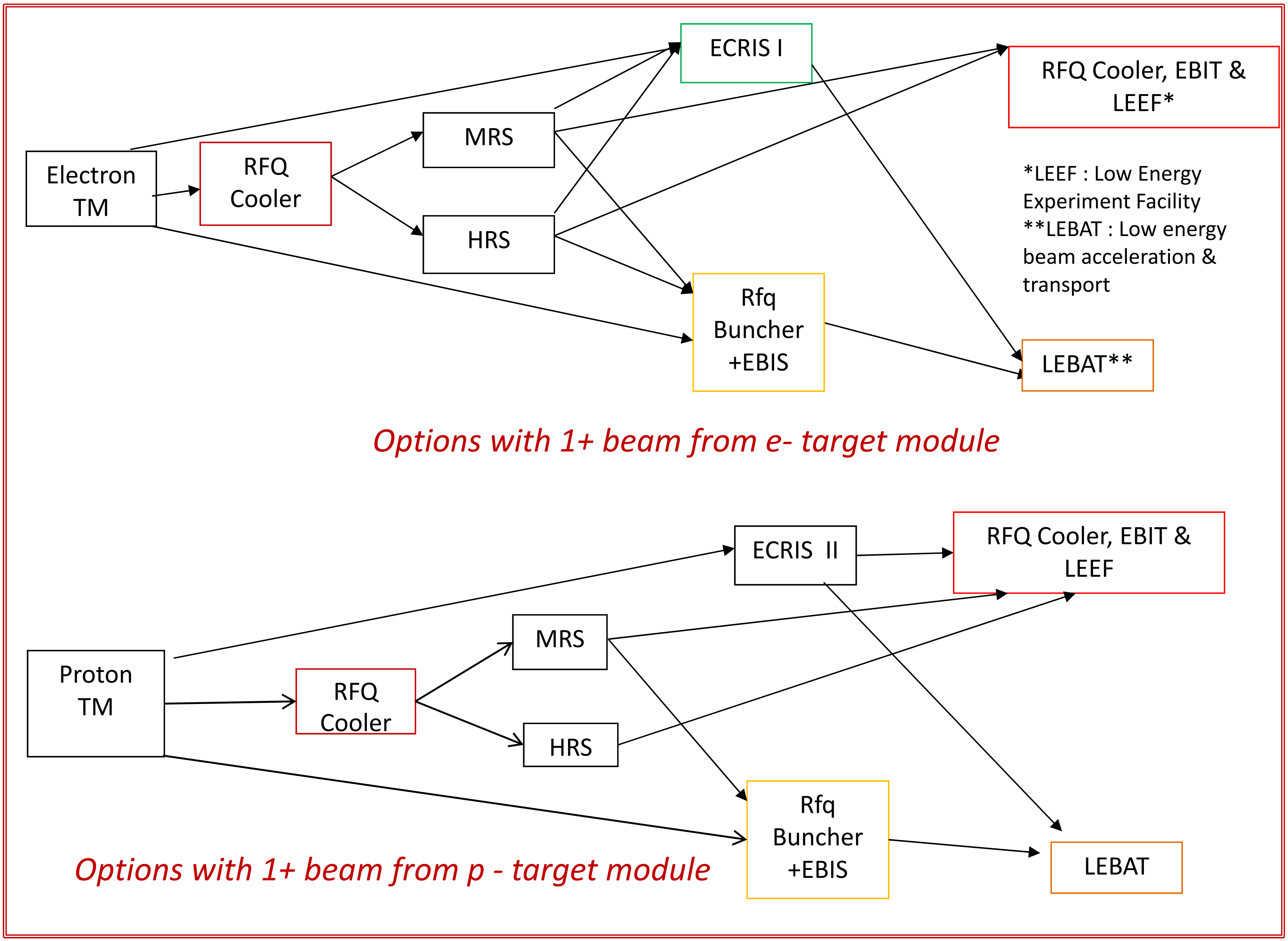


ANURIB ph-1 building layout





1+ beam from
e- target Module
1+ beam from
p+ target Module
5 m
2.7 m
HRS/MRS on HV
Platform
RFQ Cooler
ECRIS II/
High Curr. Stable
ECRIS
Vertical
RFQ Cooler
Vertically up
Platform @ 7m height
to house EBIT , MR-
TOF, Penn. Trap I & II
ECRIS I
Low Energy
Expt. Facility
(LEEF)
RFQ Cooler
EBIS
services equipment
22.4 m
ANURIB 2.png
Low Energy Beam Accr. & Transport (LEBAT)


ECRIS I
RFQ Cooler, EBIT & LEEF*
MRS
Electron TM
RFQ Cooler
HRS
*LEEF : Low Energy Experiment Facility
**LEBAT : Low energy beam acceleration & transport
Rfq Buncher +EBIS
LEBAT**
Options with 1+ beam from e- target module
ECRIS II
RFQ Cooler, EBIT & LEEF
MRS
Proton TM
RFQ Cooler
HRS
Rfq Buncher +EBIS
LEBAT
Options with 1+ beam from p - target module

HRD: Publications from RIB project (up to 2014)

Accelerator development

1. *Phys. Rev. ST AB 17 (2014) 074201. Linac Booster -ANURIB*
2. *Rev. Sci. Instrum. Vol.84, (2013) 033301. RIB acceleration*
3. *Nucl. Instrum. & Meth. B 317 (2013)227. RIB acceleration*
4. *Nucl. Instrum. & Meth. B 317 (2013)253. ANURIB*
5. *Phys. Rev. ST AB,16 (2013) 052001. Linac Booster -ANURIB*
6. *Ceramics International, (2011) 2679. Target*
7. *Nucl. Instrum. & Meth. A 631 (2011) 1 MEBT*
8. *Pramana 75 (2010) 485. MEBT*
9. *Rev. Sci. Instrum. 81, 023301 (2010); RFQ2*
10. *Rev. Sci. Instrum. 80, (2009) 103303. RFQ2*
11. *Ceramics International, 34 (2008) 81. Target*
12. *Nucl. Instrum. & Meth. B261(2007)1018. RIB facility status*
13. *Rev Sci Instrum. 78 (2007) 043303. RFQ1*
14. *Nucl. Instrum. & Meth. A562 (2006)41. Beam-line*
15. *Nucl. Instrum. & Meth. A560 (2006)182. Linac*
16. *Nucl. Instrum. & Meth. A547 (2005)270. Charge breeder*
17. *Nucl. Instrum. & Meth. A539 (2005)54. Target*
18. *Nucl. Instrum. & Meth. A535 (2004)599. RFQ1*
19. *Nucl. Instrum. & Method A 533 (2004) 37. RFQ1*
20. *Pramana 59 (2002) 923. RIB facility*
21. *Pramana 59 (2002) 957. RFQ1*
22. *Nucl. Instrum. & Meth. A 447 (2000) 345. charge breeder*

7 PhD theses so far

Nuclear Physics & Material Science Experiments

1. **Appl. Phys. Lett. 104, 231601 (2014).**
2. **Journal of Phys. D47 (2014) 025001**
3. **Applied. Phys. Lett. vol.103 (2013) 181601.**
4. **JOSA B, 30, 2436-2442 (2013)**
5. **Eur. Phys. J. D 67 (2013) 78.**
6. **J. Phys.: Condens. Matter 25 (2013) 385501**
7. **J. Opt. Soc. Am. B 30, 2436 (2013).**
8. **Nucl. Instr. & Meth. B278 (2012) 58.**
9. **J. Phys.: Condens. Matter 24 (2012) 325503**
10. **Applied Surface Science, 258 (2012) 4125**
11. **Materials Science Forum, 699 (2012) 1-38**
12. **J of Phys. Cond. Matt. 23 (2011) 155801**
13. **Appl. Surf. Sci. 257 (2011) 6775**
14. **Solid State Communications, 150, (2010) 2266.**
15. **J. Phys.: Condens. Matter 22 (2010) 175005**
16. **Nuclear Instru. & Method B267 (2009) 1783.**
17. **Phys. Rev. C 80, 044302 (2009)**
18. **Eur. Phys. J. A 42, 375-378 (2009)**
19. **J. of Phys: Cond. Matt. 21 (2009) 445902**
20. **Appl. Phys. Lett. 93, (2008) 103102.**
21. **Materials Characterization 60 (2009) 1014.**
22. **J. of Phys. D 41 (2008) 135006.**
23. **Appl. Phys. Letts. 93 (2008) 103102**
24. **J of Phys. C 20 (2008) 45217**
25. **J of Phys. D 41 (2008) 135006.**
26. **Phys. Lett. A371 (2007) 482.**
27. **J of Phys. C 19, (2007) 236218.**
28. **J of Phys. C 19, (2007) 236210.**
29. **J. of Mat. Sc. 40 (2005) 5265.**
30. **Physica C, Vol416, (2004) 25.**
31. **Nanotechnology 15 (2004) 1792.**
32. **Physica C 416 (2004) 25.**
33. **Phys. Rev. C 63 (2001) 024307.**
34. ***Eur. Phys. J. (2014) in press***

Thank You