Post-acceleration of RIBs – Important consideration and challenges

Arup Bandyopadhyay
VECC

Indo-Japan School on Advance Accelerators for Ions and Electrons

IUAC, New Delhi, Feb 16-18, 2015

Our Main Activities

- **Accelerator-based research in nuclear physics, material science, isotope production, radiochemistry, analytical chemistry etc., & development of large scale detectors and experimental facilities**

- **Accelerator design, development, construction, and operation**

- **Theoretical nuclear physics**

- **Collaborations at RHIC, LHC, INO, FAIR, TRIUMF, Fermi Lab, …**

- **Regional Radiation Medicine Centre**

224cm Variable Energy Cyclotron; Operating since 1977

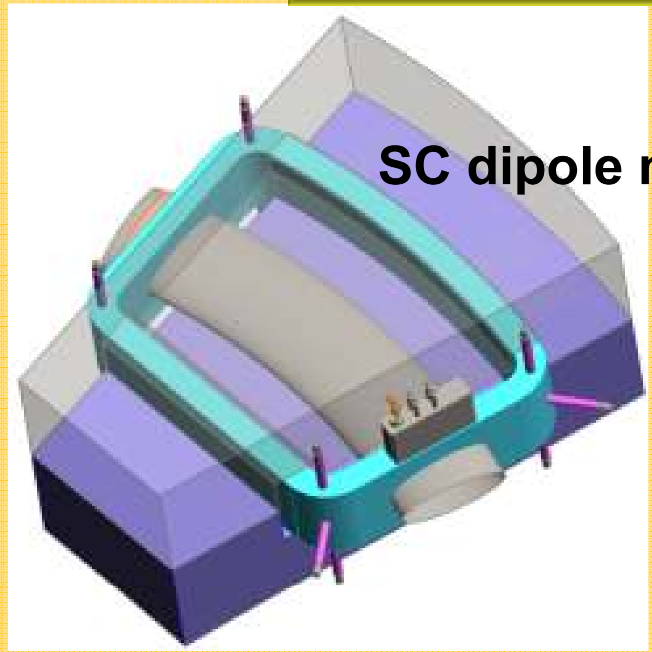
VECC SUPERCONDUCTING CYCLOTRON

- K_{bend}=520
- Accelerate heavy ion beams
- Energy
  - 80 MeV/nucleon for light ions
  - 8 MeV/nucleaon for heavy ions
- Radio-frequency system
  - 9-27 MHz
  - 80 kV maximum Dee voltage
- Superconducting magnet
  - Average magnetic field = 5 Tesla

  100 Tonnes magnet iron

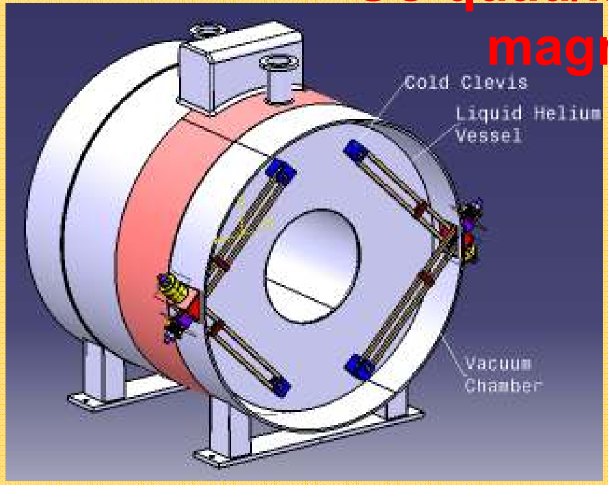
  12.5 Tonnes cryostat

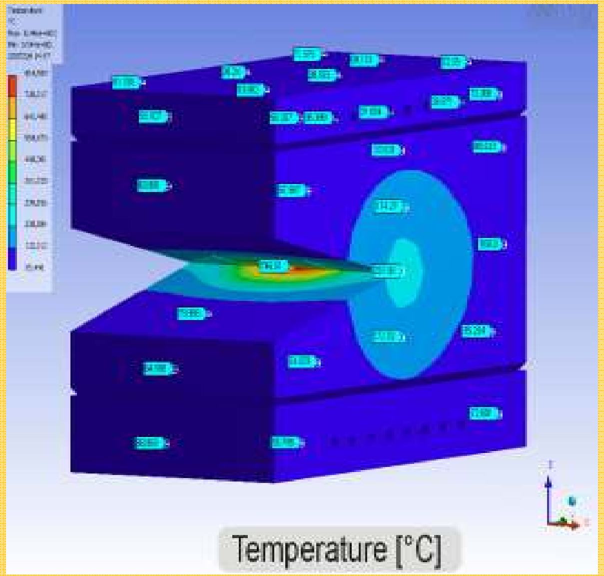
Indo-FAIR Collaboration



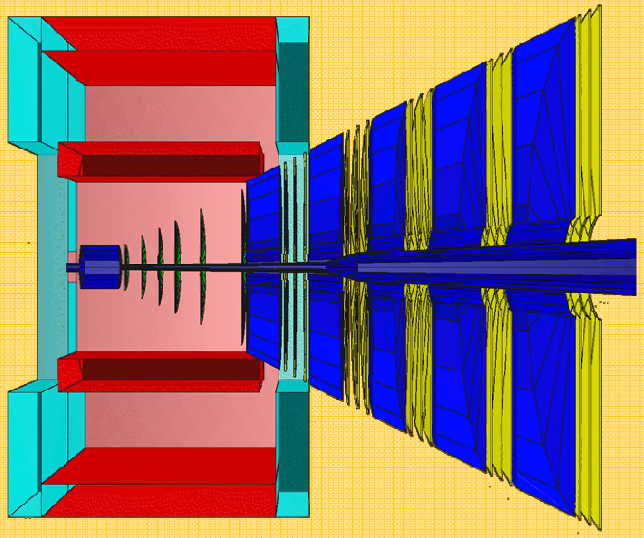
SC dipole magnets

SC quad/multipole magnets





Beam stoppers



MuCH : CBM expts.

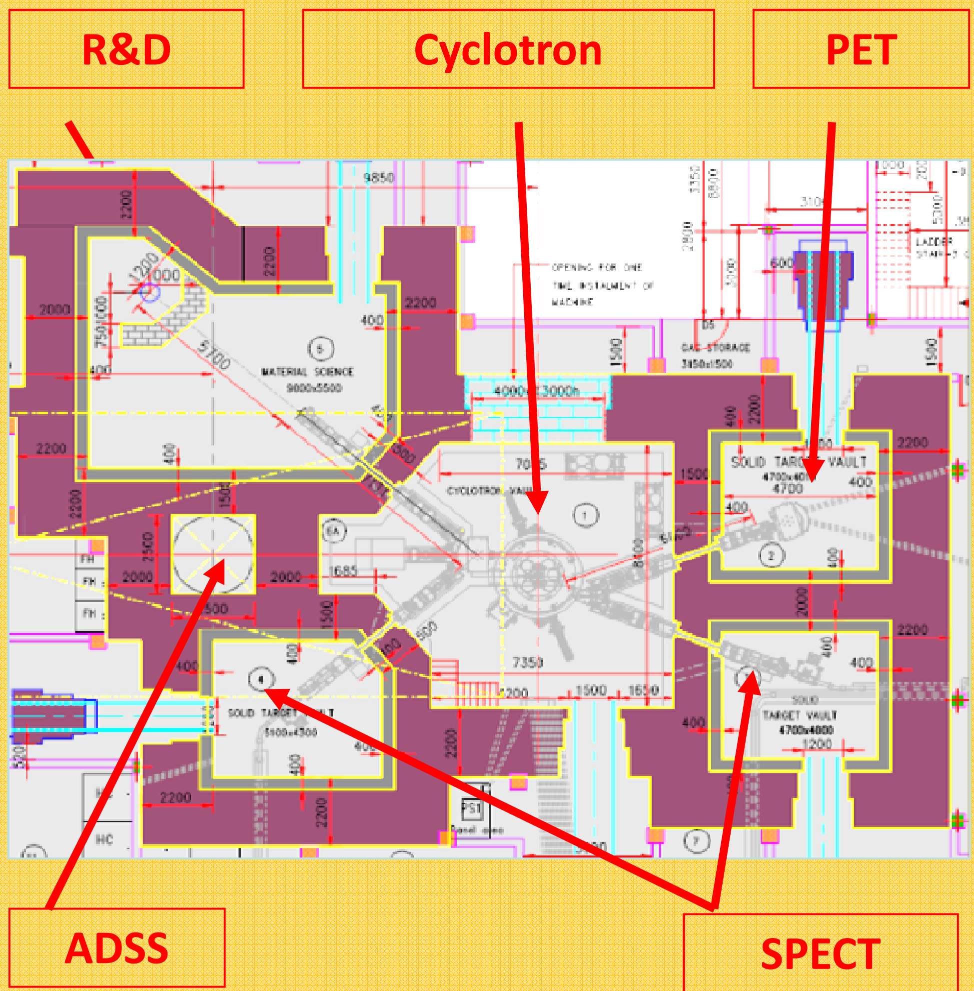
DAE Medical Cyclotron Project at Kolkata (30 MeV, 500μA p)

Importance in Atomic Energy Program:

- Material Science R&D on structural materials for Nuclear Reactor
- R&D on LBE target for ADSS

Societal Benefit:

Production of SPECT (Ga-67, Tl-201) and PET radio-isotopes and processing radio-pharmaceuticals used in nuclear imaging of cancerous tumors.

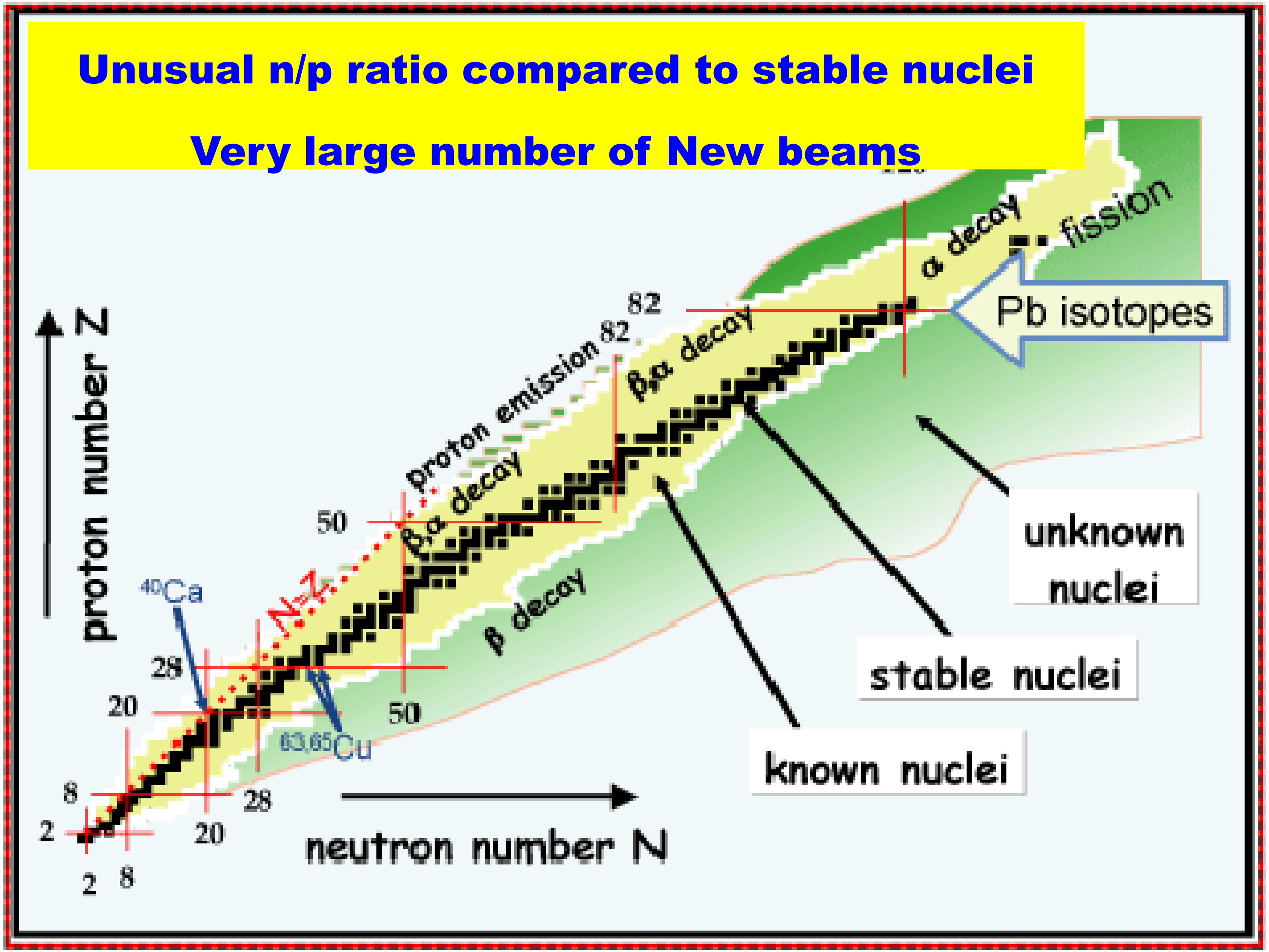


What is RIB ??

Ions of β-unstable nuclei

Proton Number								
Z		16Ne 9E-21 S 2P: 100.00%	17Ne 109.2 MS ε: 100.00% εp: 100.00%	18Ne 1.6670 S ε: 100.00%	19Ne 17.22 S ε: 100.00%	20Ne STABLE 90.48%	21Ne STABLE 0.27%	22Ne STABLE 9.25%
9	14F P	15F 1.0 MeV P: 100.00%	16F 40 KeV P: 100.00%	17F 64.49 S ε: 100.00%	18F 109.77 M ε: 100.00%	19F STABLE 100%	20F 11.07 S β-: 100.00%	21F 4.158 S β-: 100.00%
8	13O 8.58 MS εp: 100.00% ε: 100.00%	14O 70.620 S ε: 100.00%	15O 122.24 S ε: 100.00%	16O STABLE 99.757%	17O STABLE 0.038%	18O STABLE 0.205%	19O 26.88 S β-: 100.00%	20O 13.51 S β-: 100.00%
7	12N 11.000 MS ε: 100.00%	13N 9.965 M ε: 100.00%	14N STABLE 99.636%	15N STABLE 0.364%	16N 7.13 S β-: 100.00% β-α: 1.2E-3%	17N 4.173 S β-: 100.00% β-n: 95.1%	18N 620 MS β-: 100.00% β-α: 12.20%	19N 336 MS β-: 100.00% β-n: 41.80%
6	11C 20.334 M ε: 100.00%	12C STABLE 98.93%	13C STABLE 1.07%	14C 5700 Y β-: 100.00%	15C 2.449 S β-: 100.00%	16C 0.747 S β-: 100.00% β-n: 99.00%	17C 193 MS β-: 100.00% β-n: 32.00%	18C 92 MS β-: 100.00% β-n: 31.50%
	5	6	7	8	9	10	11	12

Neutron Number



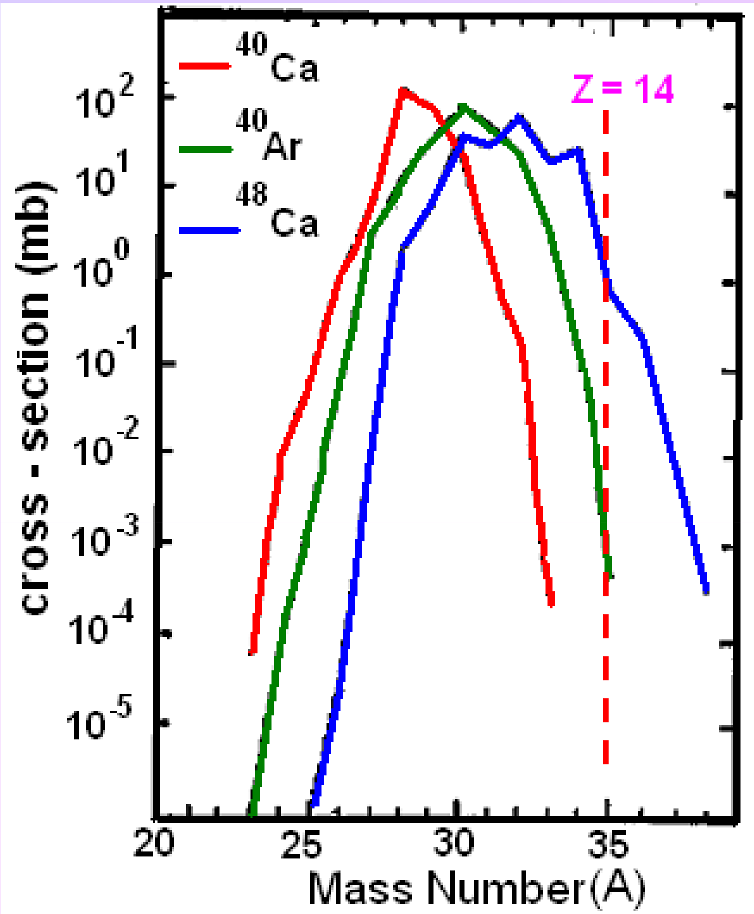
Unusual n/p ratio compared to stable nuclei
Very large number of New beams
proton number Z
neutron number N
proton emission
β,α decay
β,α decay
α decay
fission
β decay
N=Z
40Ca
63,65Cu
Pb isotopes
unknown nuclei
stable nuclei
known nuclei
82
82
50
50
28
28
20
20
8
8
2
2

Source : ORNL

Why we need RIB ??

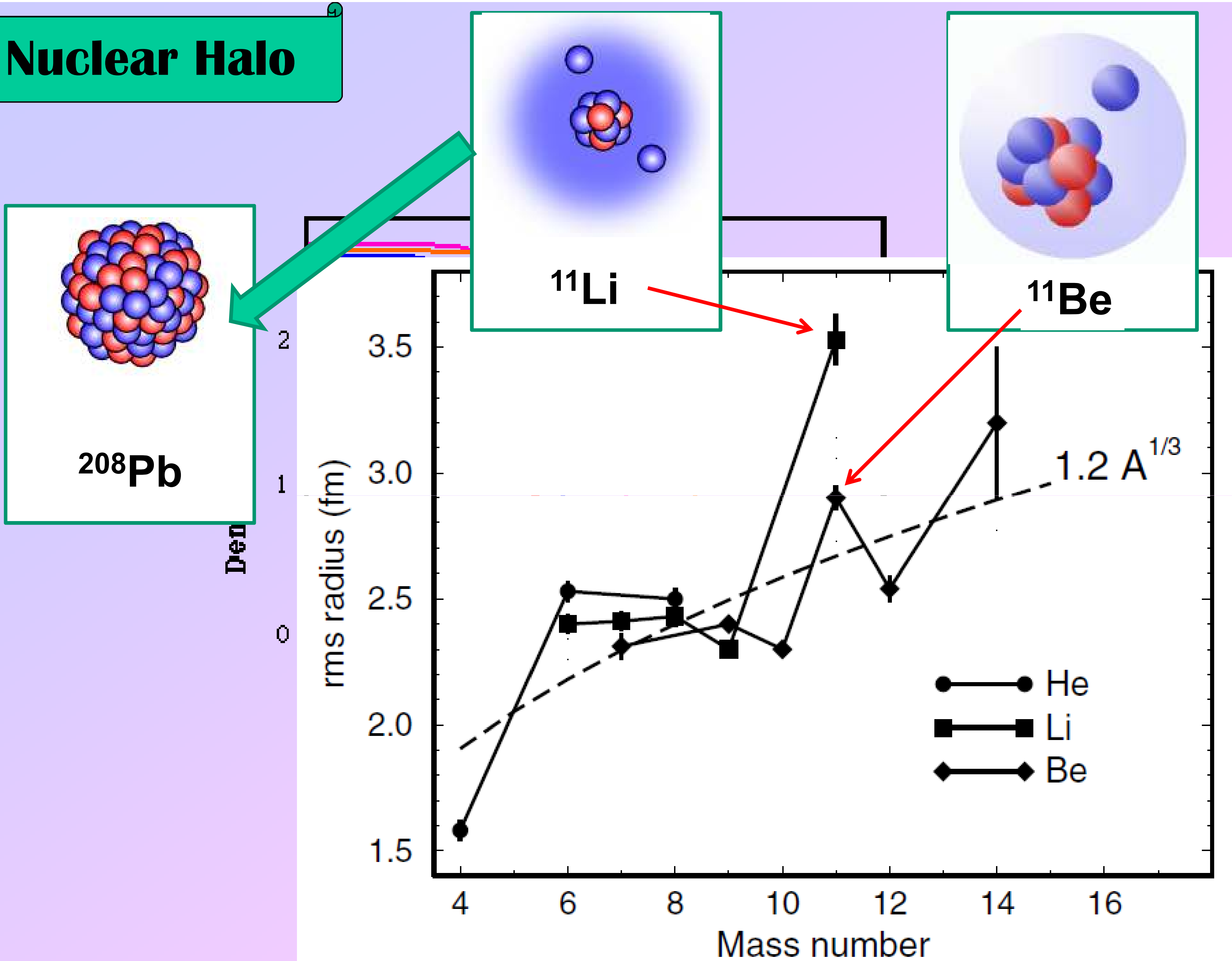
Using RIB it is possible to produce new nuclei.

Selecting a suitable combination of RIB & target it is possible to produce nuclei away from the stability line with a larger cross section compared to stable beams – this allows detailed study of nuclei



Exotic neutron-rich nuclei ^{35}Si produced with different projectiles using PF reaction.

Nuclear Halo



The magic of magic numbers not working

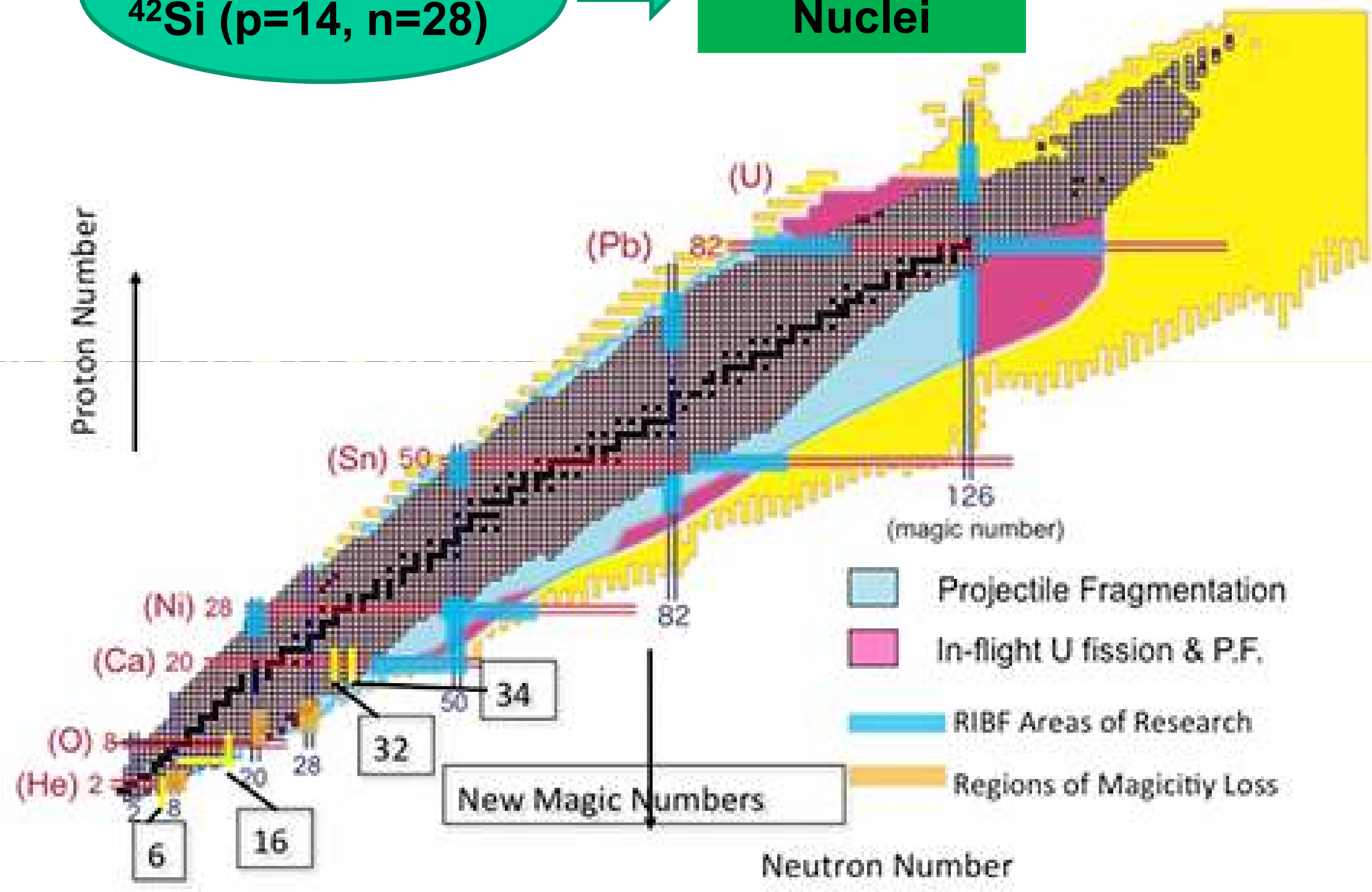
^{32}Mg (p=12, n=20)
^{42}Si (p=14, n=28)

→ **Deformed Nuclei**

Ma

Do

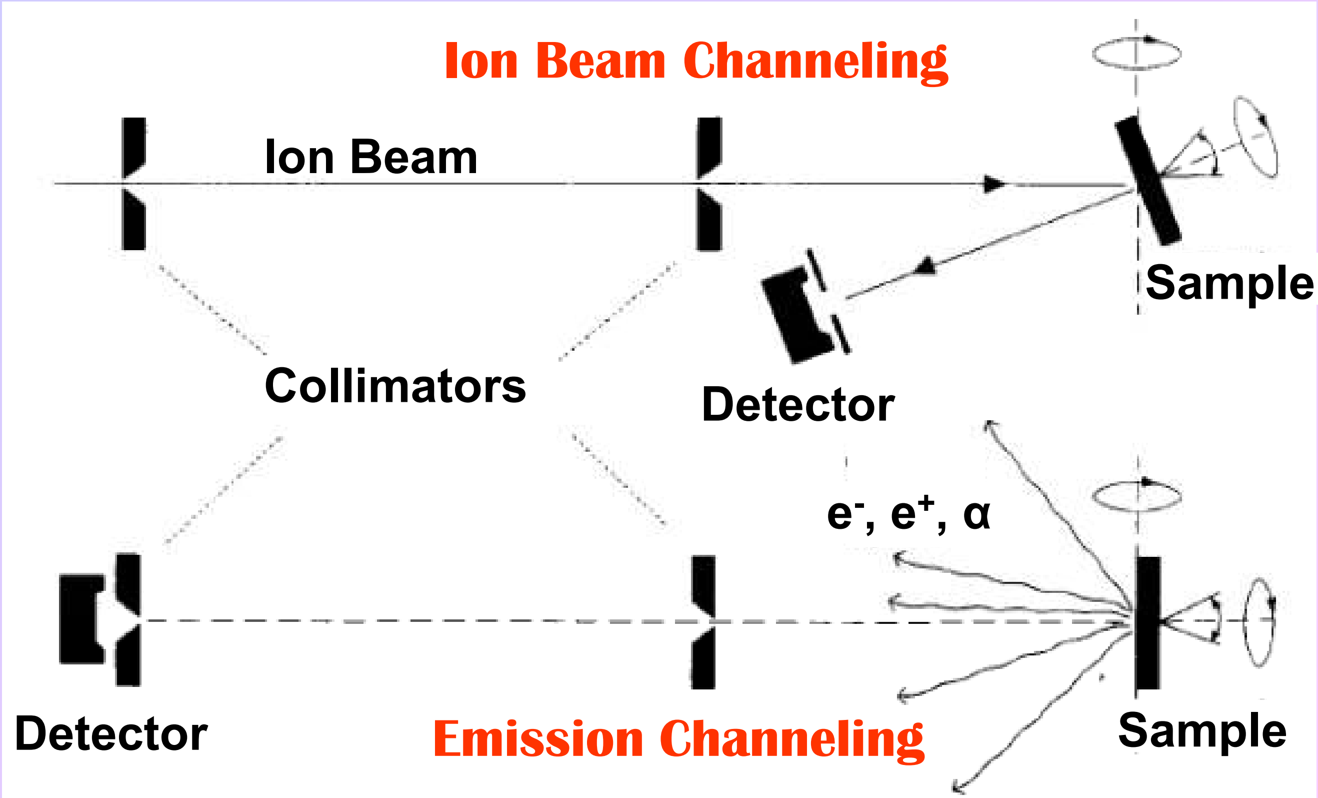
Wh ... clei
ass ... m
ma



Physics Motivation

Material Science

Study of formation & propagation of lattice defects by "Emission Challening" Technique.



- ➢Req. implantation dose of radioactive atoms is significantly lower than that of ion channeling experiment.
- ➢Radiation damage during channeling analysis negligible.
- ➢Sensitivity of EC >> higher than ion channeling tech. (1E13 & 1E18 /cc)

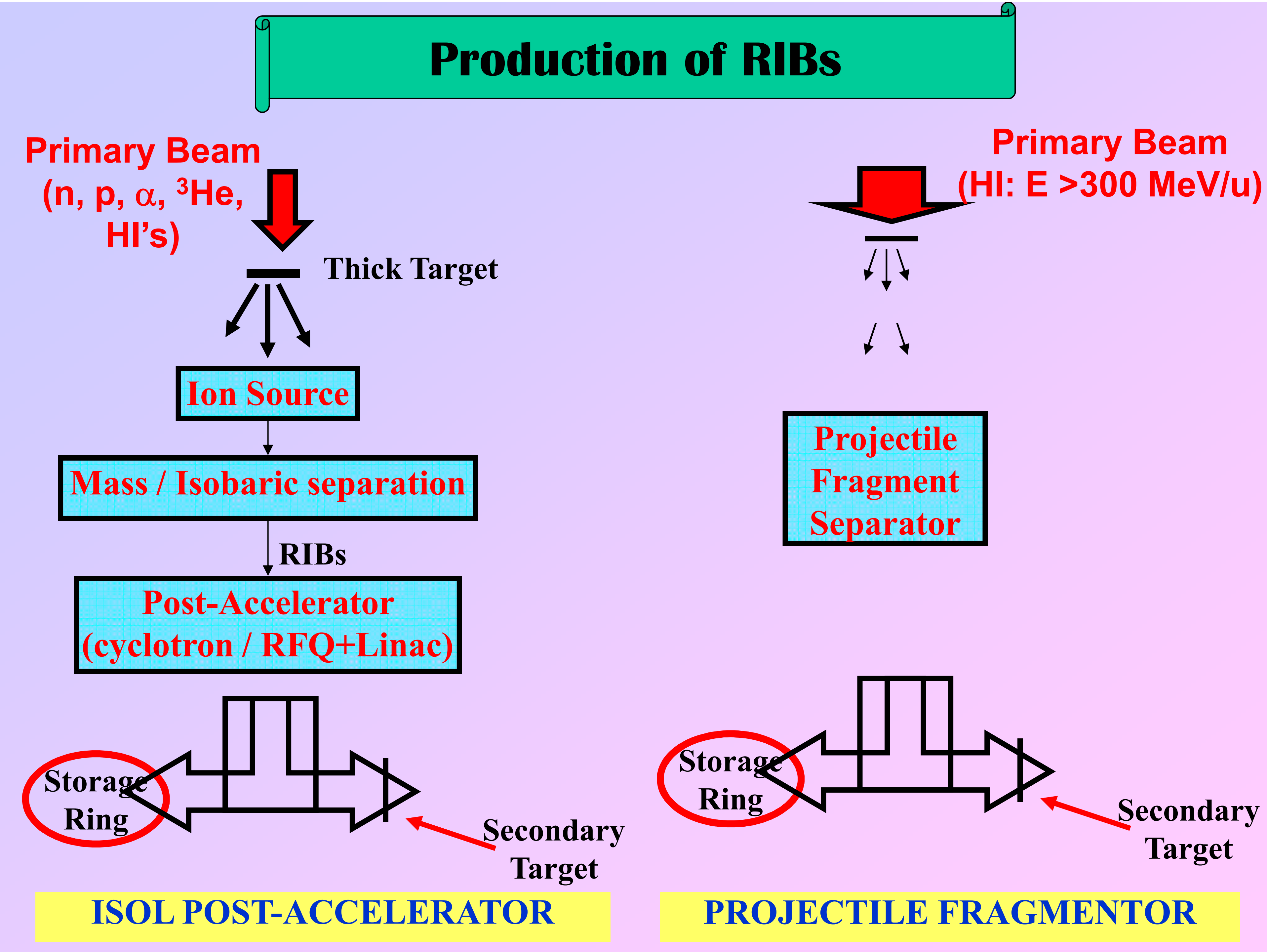
Physics Motivation

Medical research

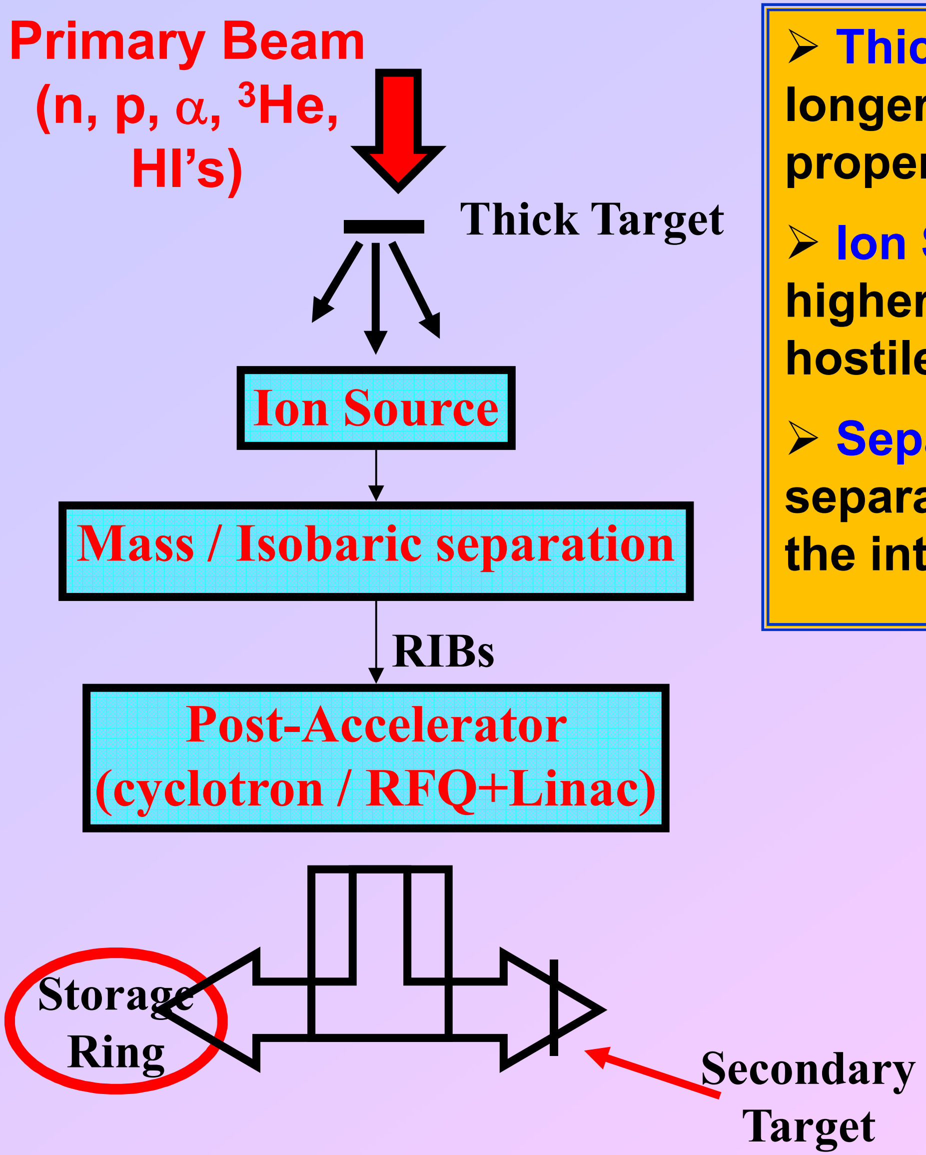
Radioisotope Therapy : A radionuclide is delivered to a tumor site using a biologically active molecule which decays via β^- or α.

Using RIB one can produce such nuclide with high specific activity as it will be carrier free or no-carrier-added form (suitable target+projectile & clean separation) + availability of new radioisotopes.

PET (Positron Emission Tomography) – medical imaging of tumors, mapping of human brain and heart function. Most of the PET isotopes are short lived for clinical use & research. Using RIB it is possible to produce longer lived PET isotopes (^{72}As : $T_{1/2}$~ 26 hours) which are carrier free i.e. high sp. Activity.


Production of RIBs
Primary Beam
(n, p, α, ³He, HI's)
Thick Target
Ion Source
Mass / Isobaric separation
RIBs
Post-Accelerator
(cyclotron / RFQ+Linac)
Storage Ring
Secondary Target
ISOL POST-ACCELERATOR
Primary Beam
(HI: E >300 MeV/u)
Projectile Fragment Separator
Storage Ring
Secondary Target
PROJECTILE FRAGMENTOR

Production of RIBs



ISOL POST-ACCELERATOR

- **Thick Target →** Sustain high current for longer duration / Fast & efficient release properties.
- **Ion Source →** High on-line efficiency for higher charge states for many elements in hostile environment of target.
- **Separation & Acceleration →** Isobaric separation and acceleration without sacrifycing the intensity.

Pros :

- **Beam Quality →** Clean beam / Small energy width.

Cons :

- **Half-life →** Lower threshold.

Production of RIBs

➢ **Primary Beam IS → High current for high charge states.**

➢ **Pri. Beam acceleration → Acceleration of HIs to high energy (≈ 300 MeV/u) W/O losing intensity.**

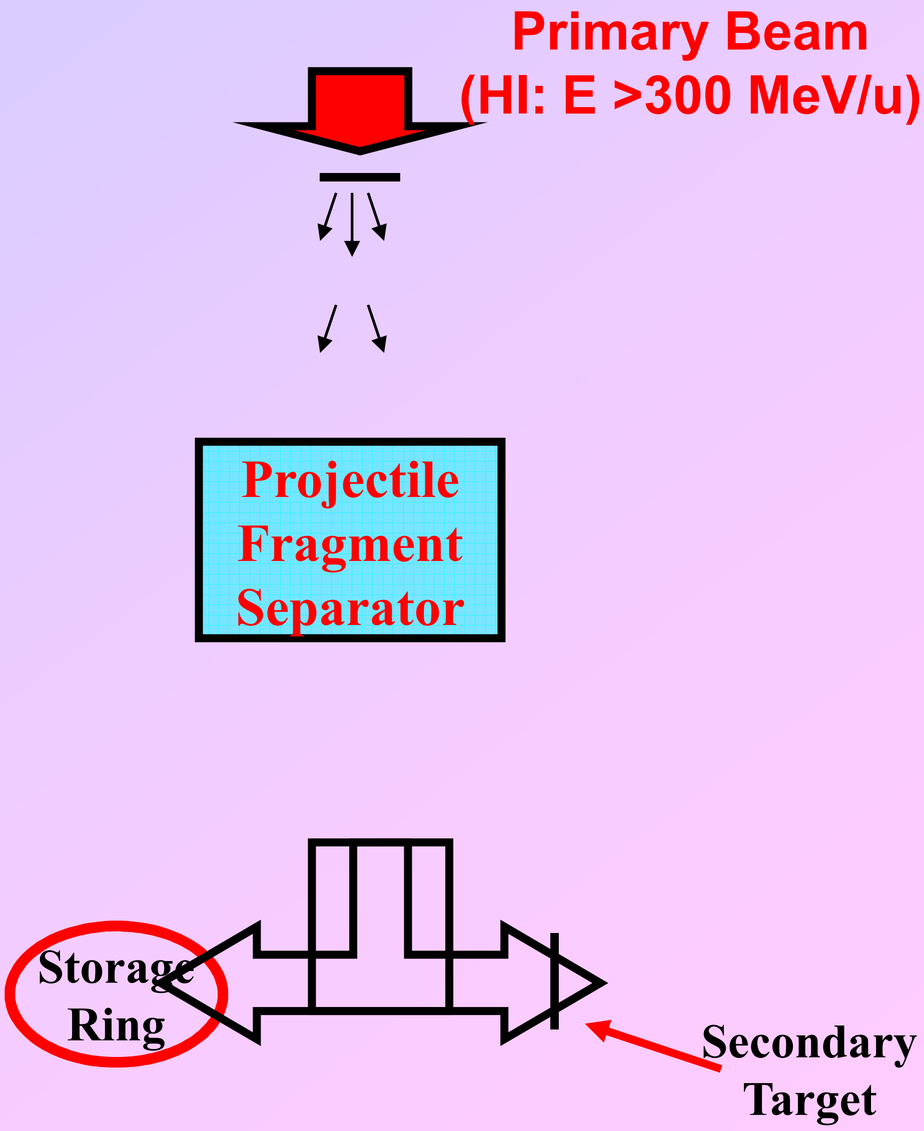
➢ **Separation → Clean separation of PFs.**

Pros :

- **Half-life → Even isomeric beams can be produced.**
- **Exoticity → Extremely exotic species can be produced.**

Cons :

Beam Quality → Mixed beam / Larger energy width.



PROJECTILE FRAGMENTOR

Production of RIBs in ISOL method

Beam (energy)	Reaction	Products
p / d / α (≤ 10 MeV/u)	CN Formation / Evaporation of nucleons	Mainly p-rich RIBs close to the stability line Adv : Few reaction channels
p / d / α (≥ 100 MeV/u)	Spallation / Fission	Mainly p-rich RIBs Adv : Exotic Products
HIs (≥ 100 MeV/u)	Projectile Fragmentation	Both p & n -rich RIBs Adv : Exotic Products
n / γ	Fission / Photo-fission	n -rich RIBs Adv : Exotic / High cross-section

Production of RIBs in ISOL method

$$I_{RIB} = I_{PRI} * N_{TARGET} * \sigma * \varepsilon_1 * \varepsilon_2 * \varepsilon_3 * \varepsilon_4$$

$$I_{PRI} = 1\mu A \sim 10^{13}\, pps$$

$$N_{TARGET} \sim 1 g/cm^2 \sim 10^{23}\, nuclei/cm^2$$

$$\sigma \sim 50 mb \sim 10^{-26}\, cm^2$$

$$I_{RIB} \sim 10^{10}\, pps (\varepsilon_1 * \varepsilon_2 * \varepsilon_3 * \varepsilon_4 = 1)$$

ε_1: RIB release & Transport

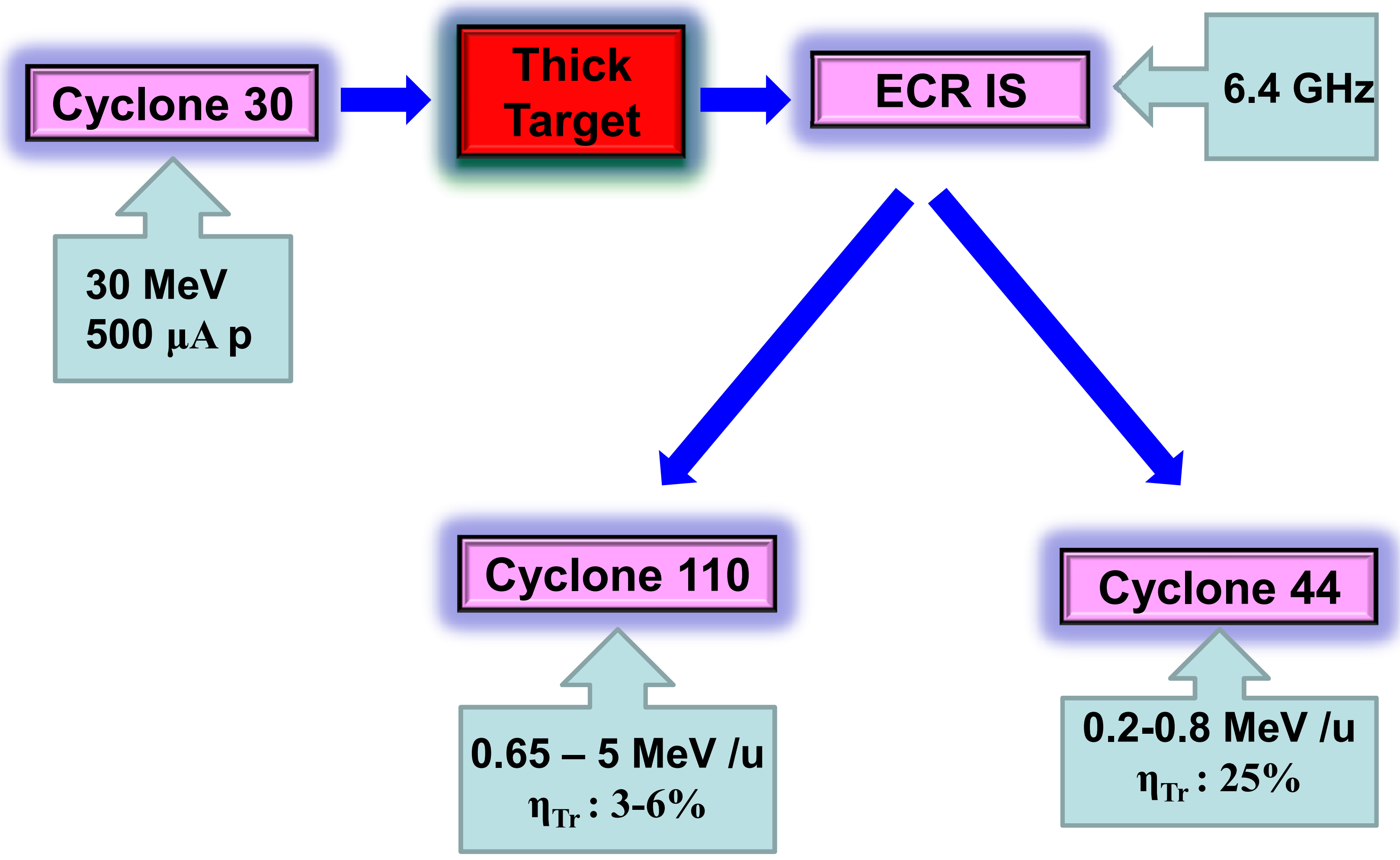
ε_2: Ion Source

ε_3: Decay Loss

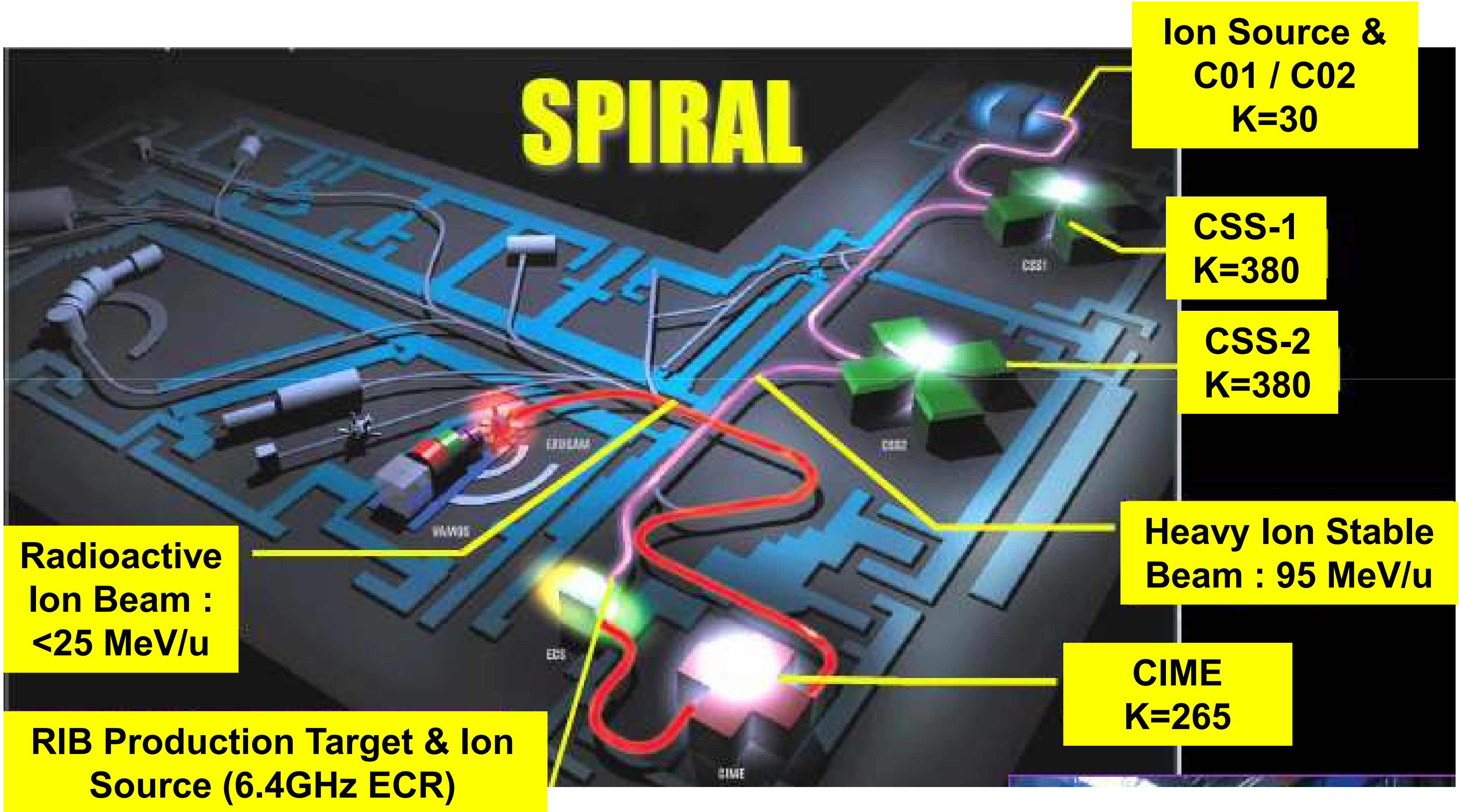
ε_4: Acceleration

It is important to maximise all the efficiency factors involved

Louvain-la Neuve - Belgium



GANIL - France



SPIRAL-II GANIL - France

RFQ 1 & 2
88 MHz

→

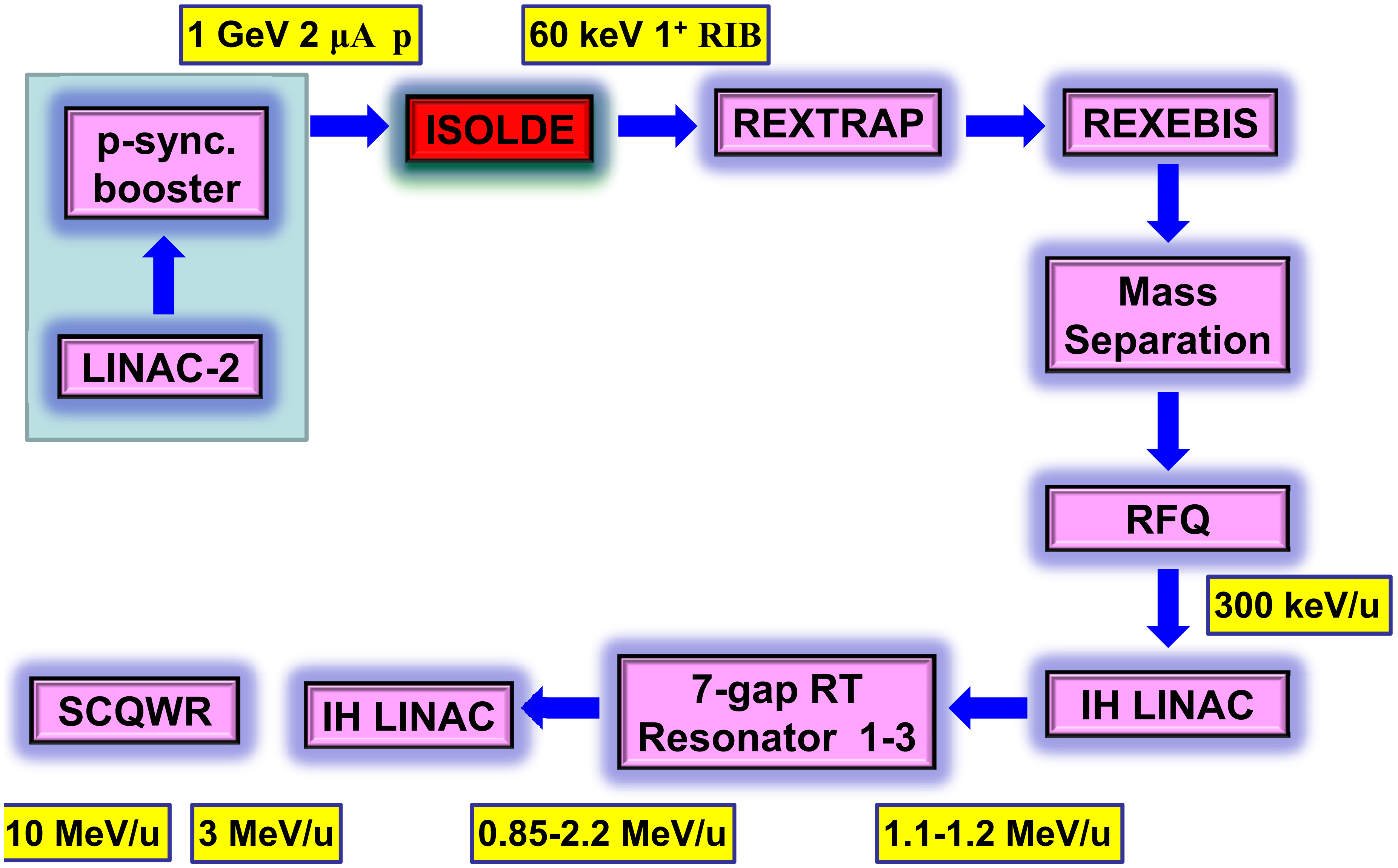
QWR @ 88 MHz
12 QWR, β=0.07

→

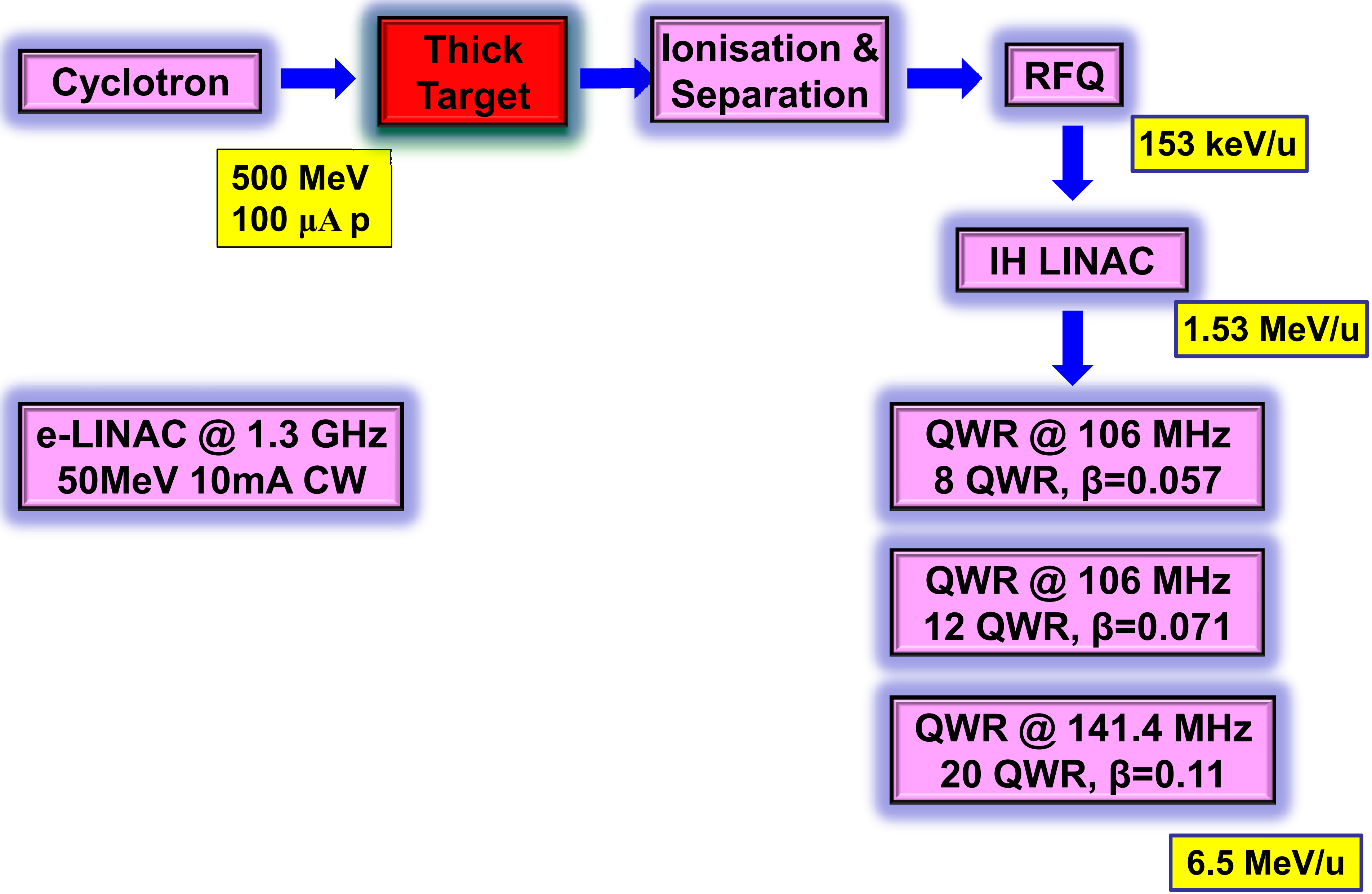
HWR @ 176 MHz
18 HWR, β=0.14

33 MeV p
40 MeV d @ 5mA
14.5 MeV/u HI @1mA

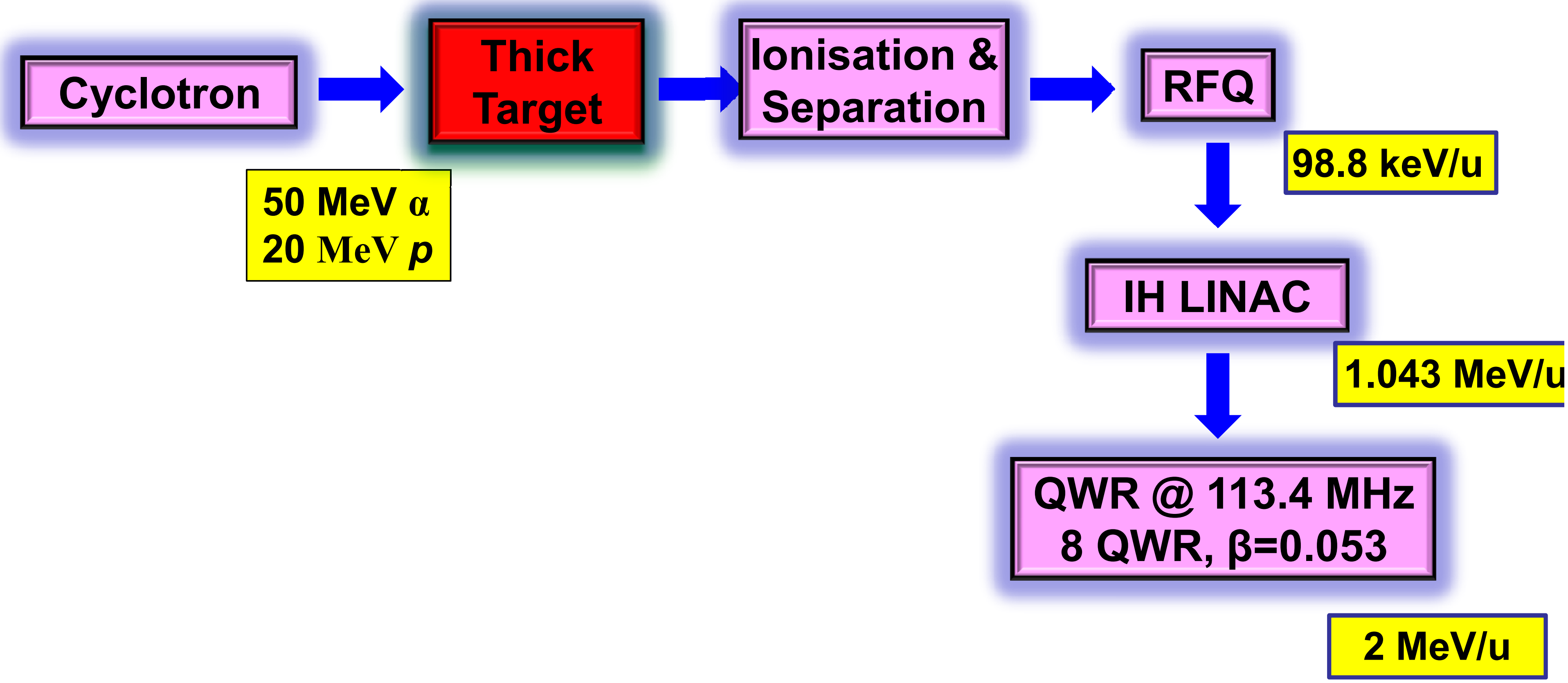
REX ISOLDE CERN - Geneva



ISAC TRIUMF - Canada

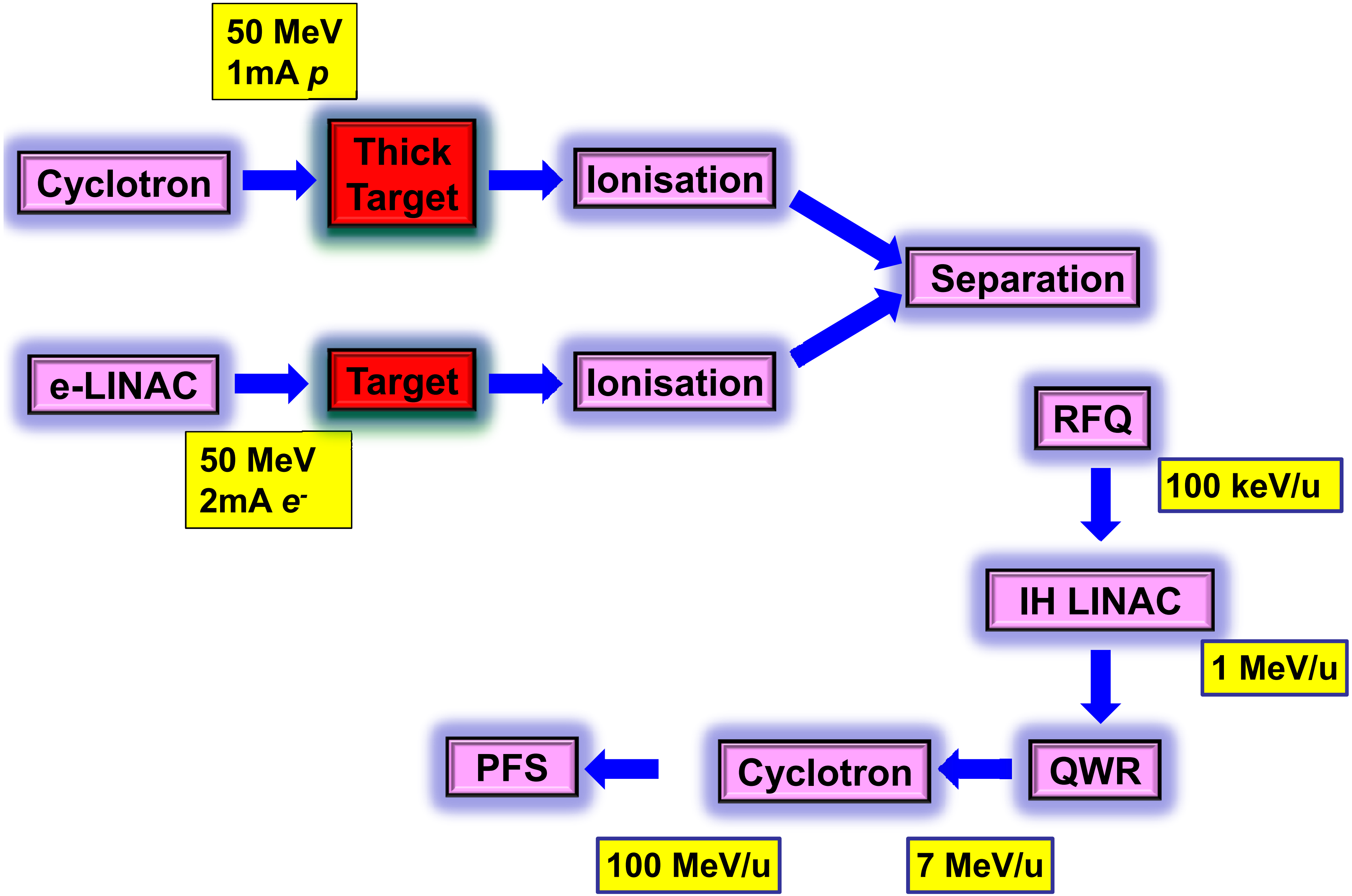


VECC - India



Cyclotron
Thick Target
Ionisation & Separation
RFQ
50 MeV α
20 MeV p
98.8 keV/u
IH LINAC
1.043 MeV/u
QWR @ 113.4 MHz
8 QWR, β=0.053
2 MeV/u

VECC ANURIB - India



Post-acceleration Schemes

Facility	Post-accelerator	RIB Energy (MeV/u)	Post-accln. Eff. (%)
Louvain-la Neuve	Cyclone 110	0.65-5	3-6
Louvain-la Neuve	Cyclone 44	0.2-0.8	25
SPIRAL	CIME (K=265)	25 (9 for Fission Fr)	
REX ISOLDE	RFQ + IH LINAC + 7-gap resonator + QWR	0.85-3 (10)	> 95%
ISAC TRIUMF	RFQ + IH LINAC + QWR	0.153-6.5 MeV/u	>95%
RIBF VECC	RFQ + IH LINAC + QWR	0.1-2 MeV/u	>85%

RFQ+IH LINAC+QWR is a better option from efficiency point of view – involves many RF systems and their synchroni-sation, cost and floor space

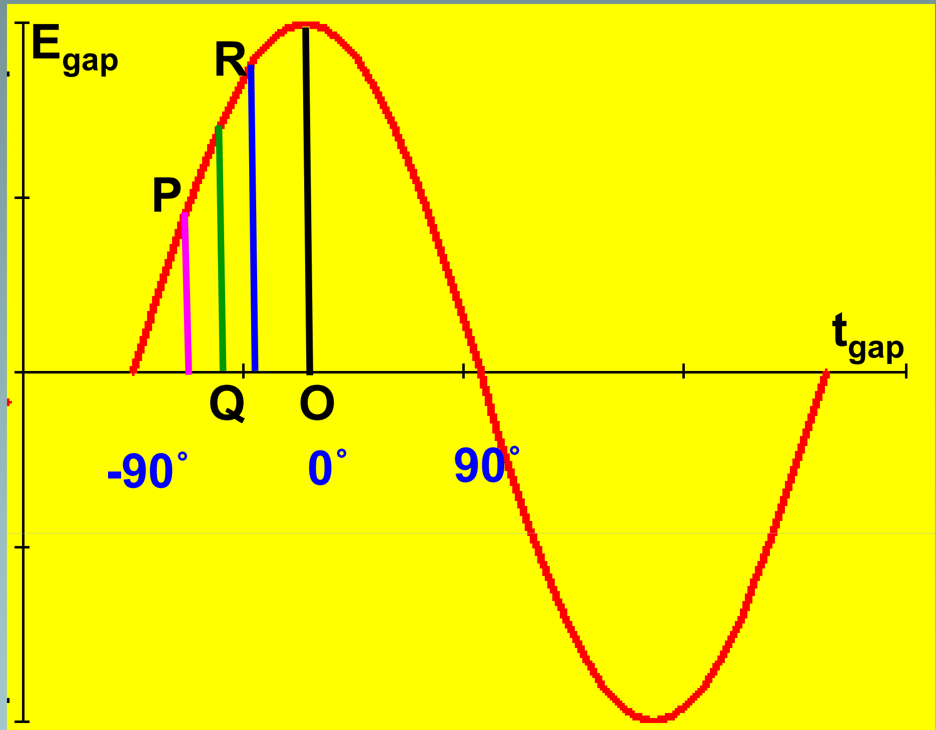
Synchronous Phase

Q : The synchronous ion

P (R) : An ion which reaches the gap centre at an earlier (later) time compared to the sync. Ion – say at time t_0-Δt (t_0+Δt)

P experiences less field and R more compared to Q : So, Δt will be less for both P & R in next gap

This is true for phases between -90˚ and 0˚ because RF field is increasing with time : longitudinal focusing.

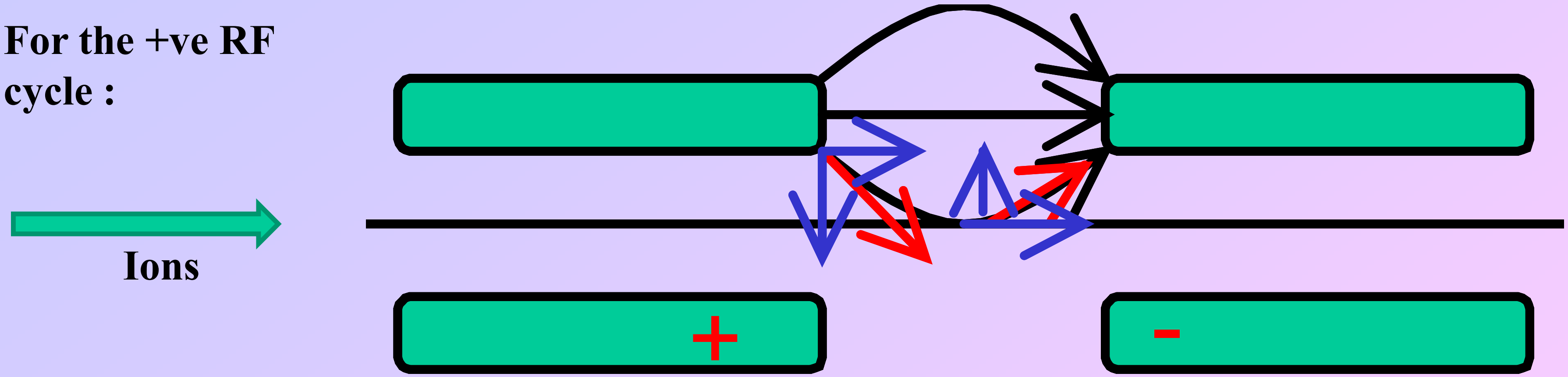


For $-90^\circ < \Phi_s < 90^\circ$ there will be ion acceleration

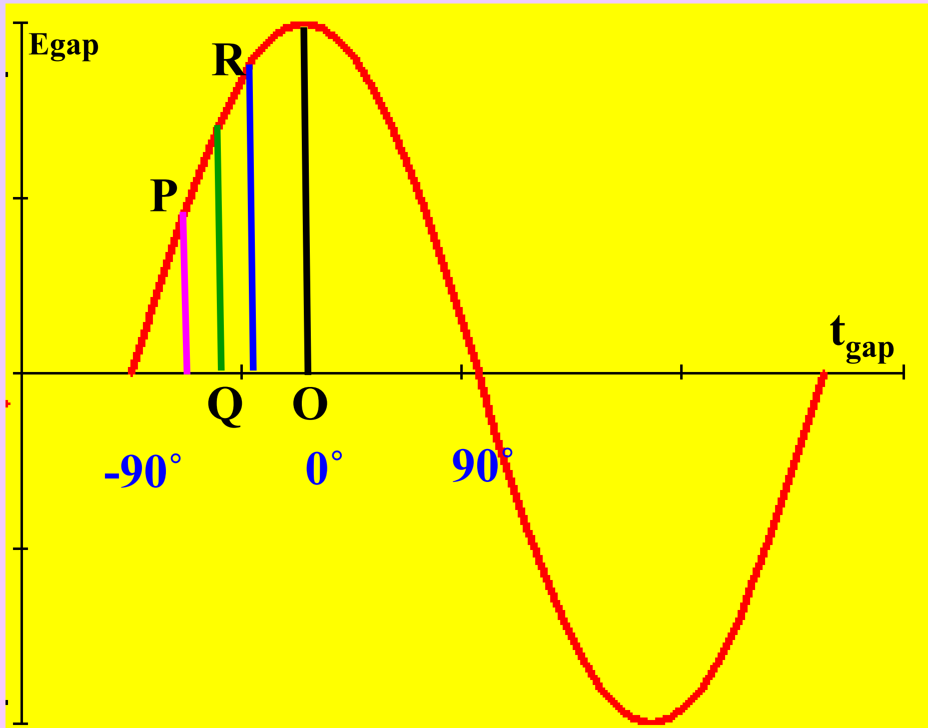
For $-90^\circ < \Phi_s < 0^\circ$ there will be longitudinal focusing during the acceleration and for $0^\circ < \Phi_s < 90^\circ$ there will be longitudinal defocusing

RF defocusing

For the +ve RF cycle :



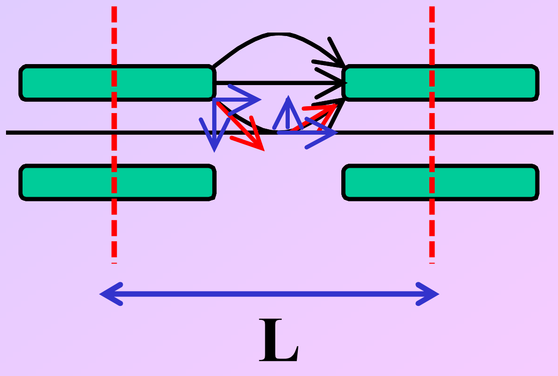
For negative synchronous phase ($-90^\circ < \Phi_s < 0^\circ$), the RF field in the gap increases with time when the ion bunch crosses the gap



This implies radial outward force at the exit of the gap will be stronger than radial inward force at the entrance of the gap : Net defocusing

Energy Gain across a gap

If the field across the gap is DC i.e. No time dependance and having the value equal to the field at the time the ion is at the gap centre then energy gain by the ion of charge ‘q’ can be expressed as :



$$\Delta w = q * (E_0 * \cos\Phi) * L = q * V_0 * \cos\Phi$$

When one considers the sinusoidal variation of the RF field then :

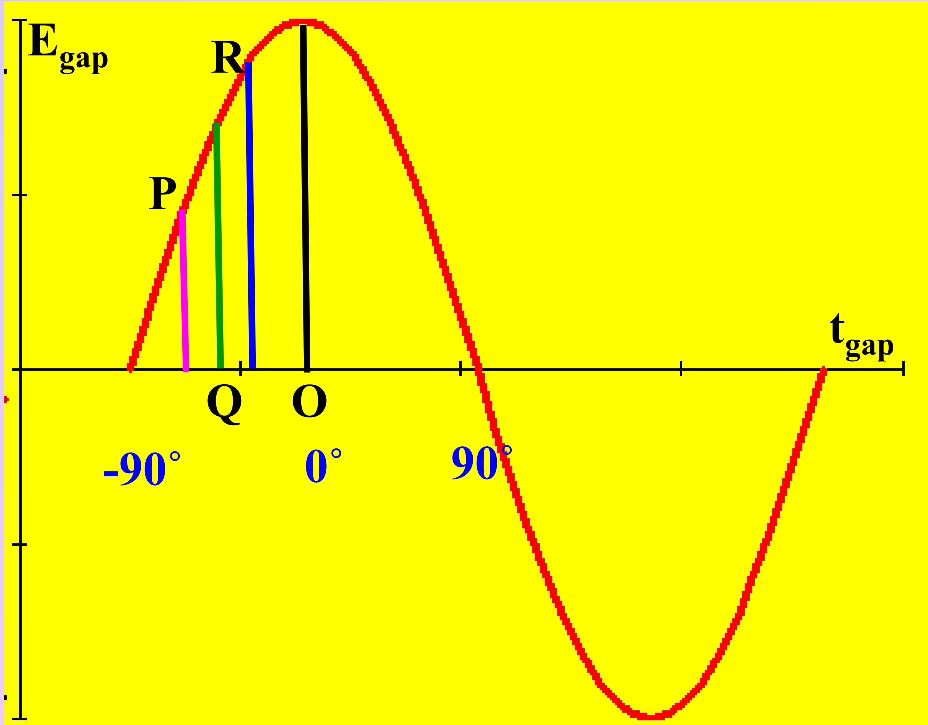
$$\Delta w = q * V_0 * T * \cos\Phi$$

Where ‘T’ is called transit time factor which depends on the field distribution across the gap and can be written as :

$$T = \int_{-L/2}^{L/2} E(r=0,z)\cos wt(z)\,dz \Big/ \int_{-L/2}^{L/2} E(r=0,z)\,dz$$

Choice of Synchronous Phase for Ion Acceleration

Synchronous phase (-90˚<Φ_s<0˚):



There will be longitudinal focusing / bunching of the beam

There will be acceleration of the beam given by

$$\Delta w = q * V_0 * T * \cos\Phi$$

There will be RF defocusing to be taken care of by other options

Synchronous phase Φ_s~0˚ :

Maximum Acceleration and minimum RF defocusing

No longitudinal focusing / bunching : to be taken care of by other options

Better beam quality

Shunt Impedance

Shunt impedance (Z) is the figure of merit of an accelerating structure in producing accelerating field per unit power loss within the structure and can be written as :

$$Z = \frac{\overline{E_z}^2}{P_{wall}/L}$$

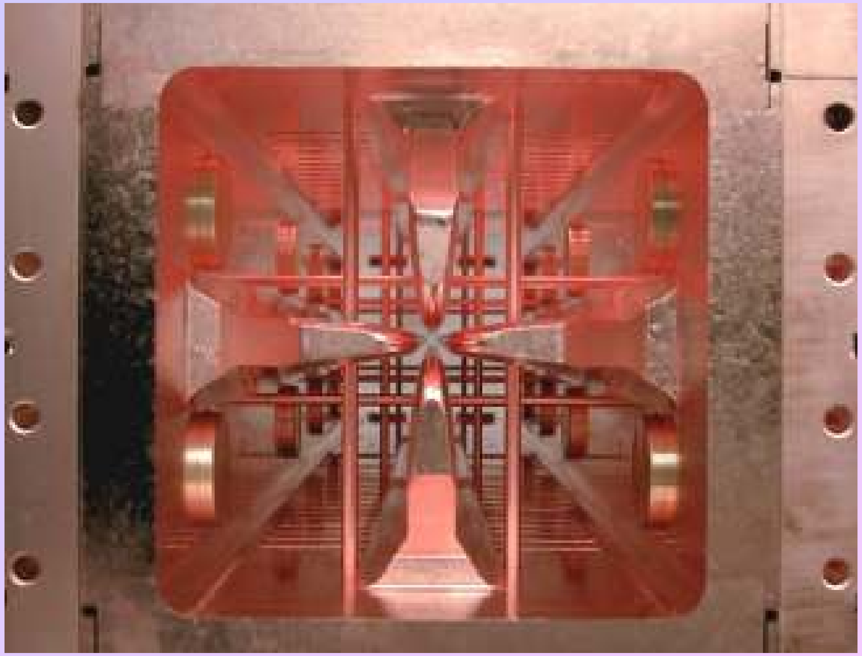
$$\overline{E_z} = \frac{1}{L}\int_0^L E_z dz$$

Is the average value of the Z component of the RF field and the integral to be taken over the entire structure length or an integral number of RF cell lengths. P_{wall} is the power loss within the RF structure over a length L.

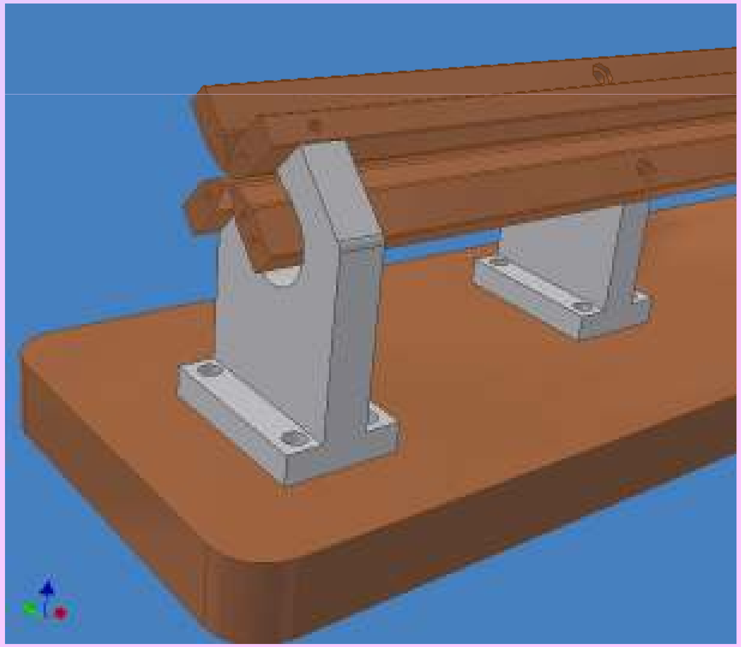
Radio Frequency Quadrupole (RFQ)

It is an accelerating structure which can provide radial focusing during the acceleration and also works as an excellent buncher. For heavy ions this is the preferred structure from a few keV/u to few hundreds of keV/u.

For Low β : magnetic focusing not that effective + little room for placing magnets



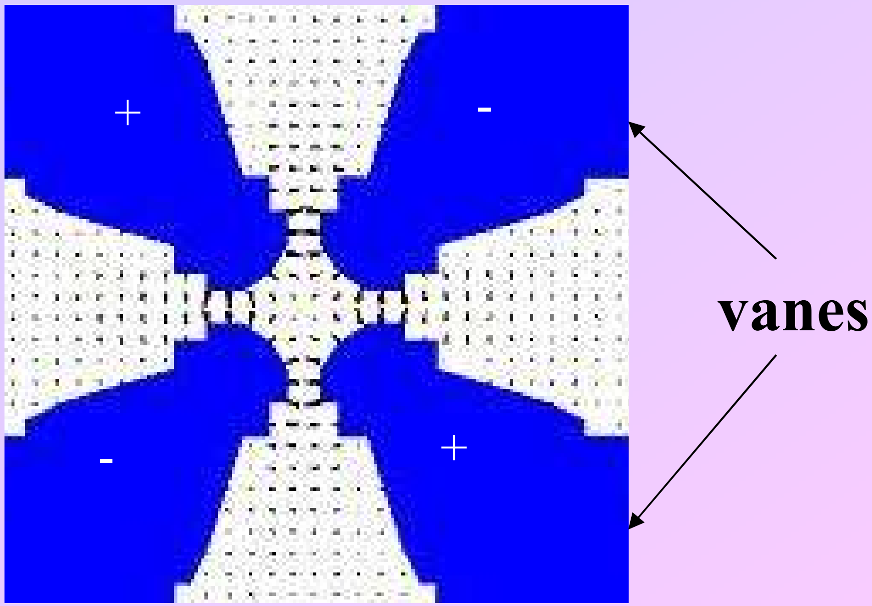
p/D RFQ Structure : Vane Type

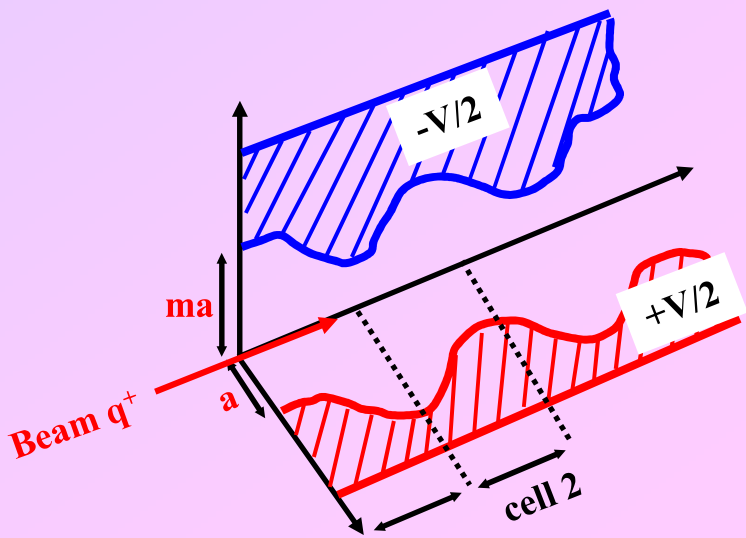


Heavy Ion RFQ : Rode type

Radio Frequency Quadrupole (RFQ) : Focusing

In a RFQ, the ions experience the action of a series of quadrupoles of alternate polarity along the entire RFQ length. It is possible to calculate the focusing strength of these quadrupoles from the RFQ potential and it turns out to be independent of z i.e. The direction of ion trajectory : Space uniform focusing

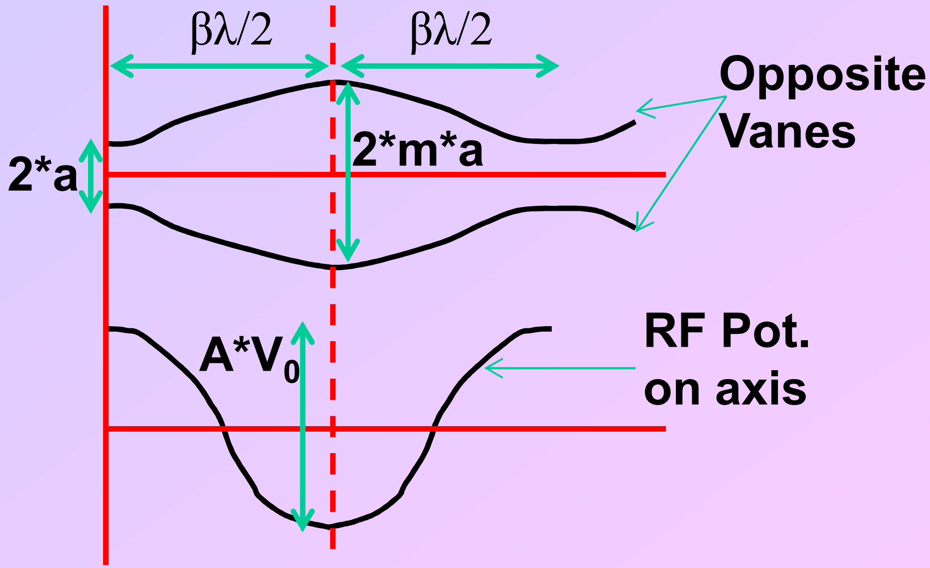


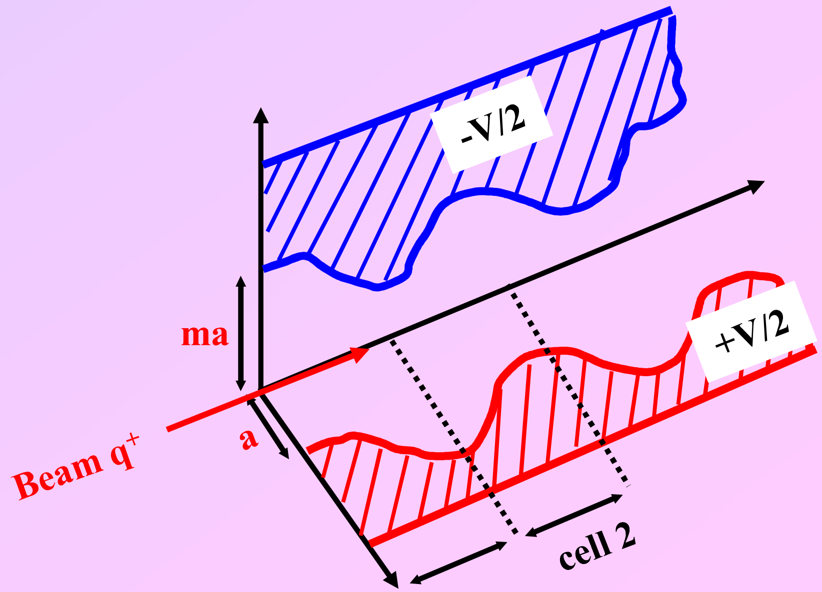


Radio Frequency Quadrupole (RFQ) : Acceleration

Due to vane/rod modulation, there is a component of RF field along the direction of the ion motion which accelerates the ions

If there is acceleration in the first cell, there will be deceleration in the second. However, the cell length is such that by the time the ions reach the second cell the RF phase changes by 180˚ i.e. Acceleration throughout.





Radio Frequency Quadrupole (RFQ) : Potential

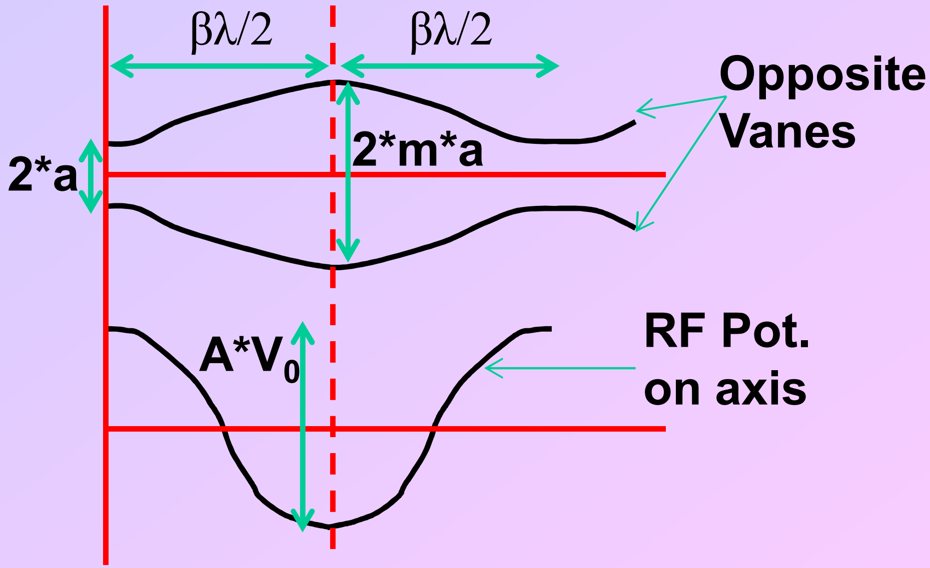
The electric potential among the vanes in the lowest order is expressed as :

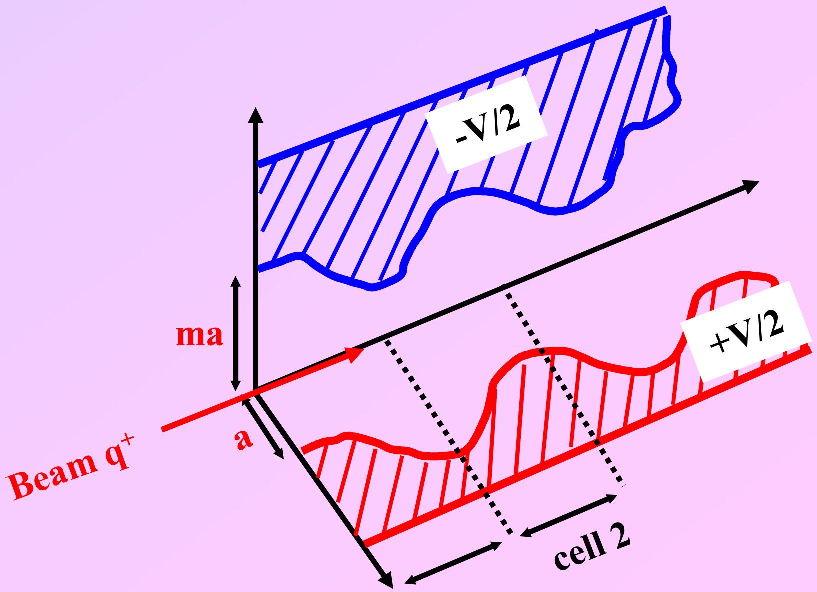
$$U(r,\theta,z)=\frac{V_0}{2}\left\{ X\left(\frac{r}{a}\right)^2\cos 2\theta + AI_0(kr)\cos kz \right\}$$

$$A=\frac{m^2-1}{m^2 I_0(ka)+I_0(mka)}\approx\frac{m^2-1}{m^2+1}$$

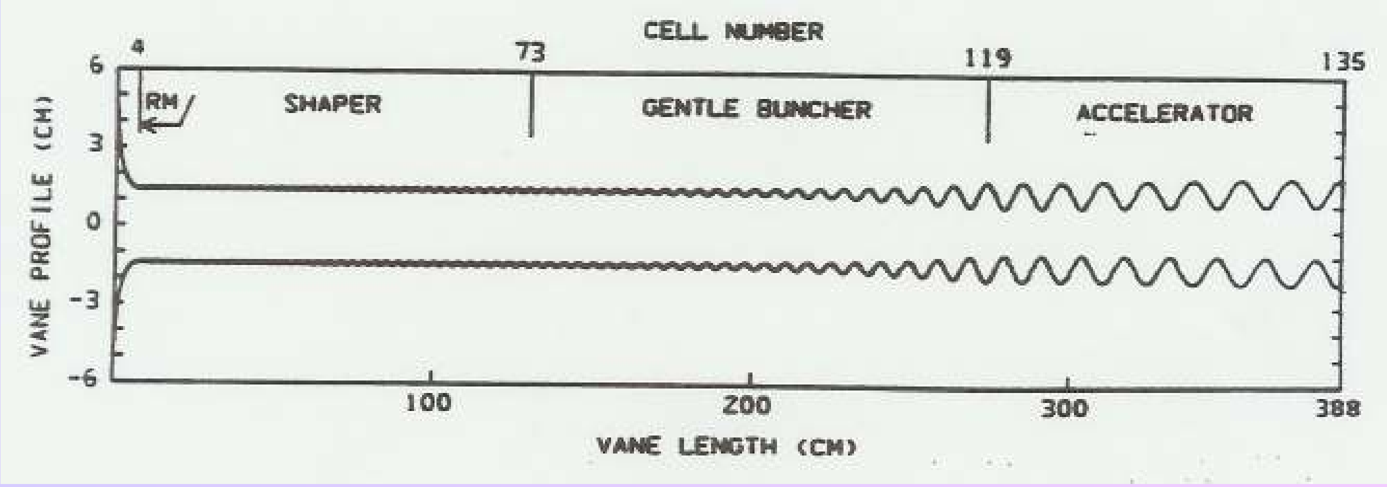
$$X=1-AI_0(ka)\approx\frac{2}{m^2+1}$$

a: Characteristic radius
A : Acceleration parameter
m : Modulation parameter
X: Focusing parameter





Radio Frequency Quadrupole (RFQ) : Cell parameters



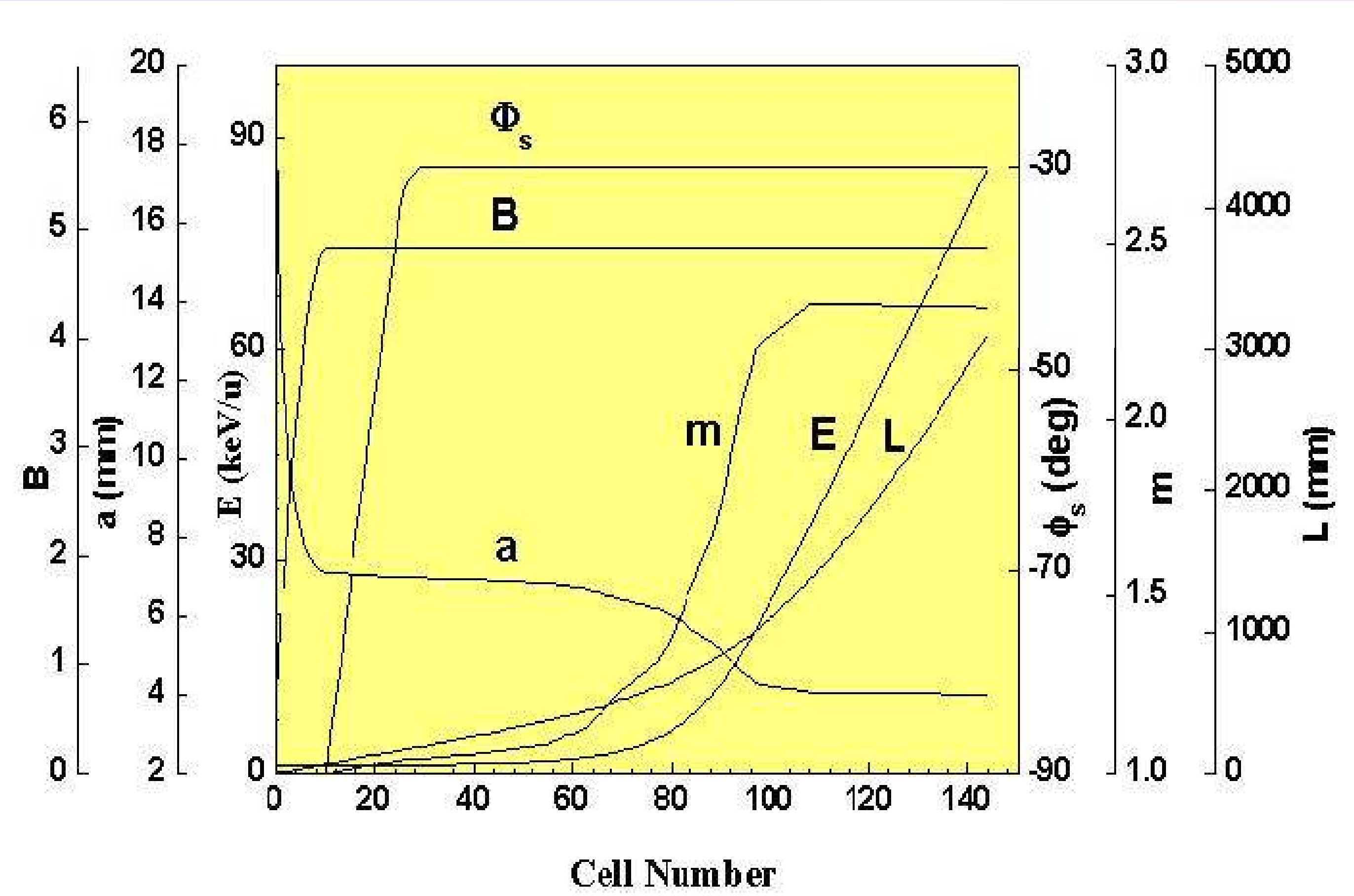
Radial Matching section : The transverse acceptance of a RF system is time dependent – the radial matching section makes the time dependent transverse acceptance of the RFQ time independent at its input

Shaping section : In this section the synchronous phase is slowly changed from -90˚ to -88˚ (say) to transform the DC beam to a bunched beam

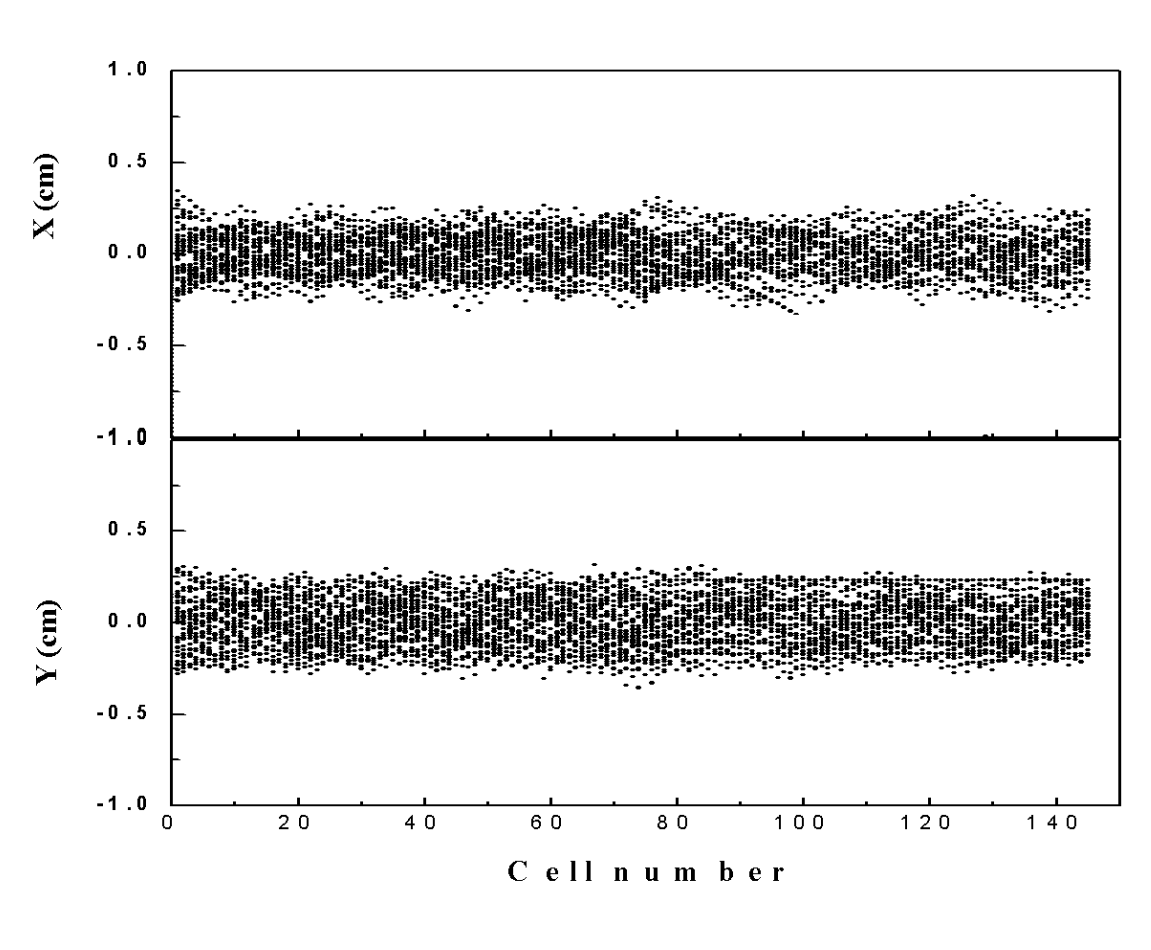
Gentle buncher : In this section the beam is bunched by changing the synchronous phase rapidly from -88˚ to -60˚ (say) without changing the allowed longitudinal phase space (separatrix) area

Acceleration setion : The sync. Phase is changed to its final desired value of -30˚ say and thereafter is is kept contant.

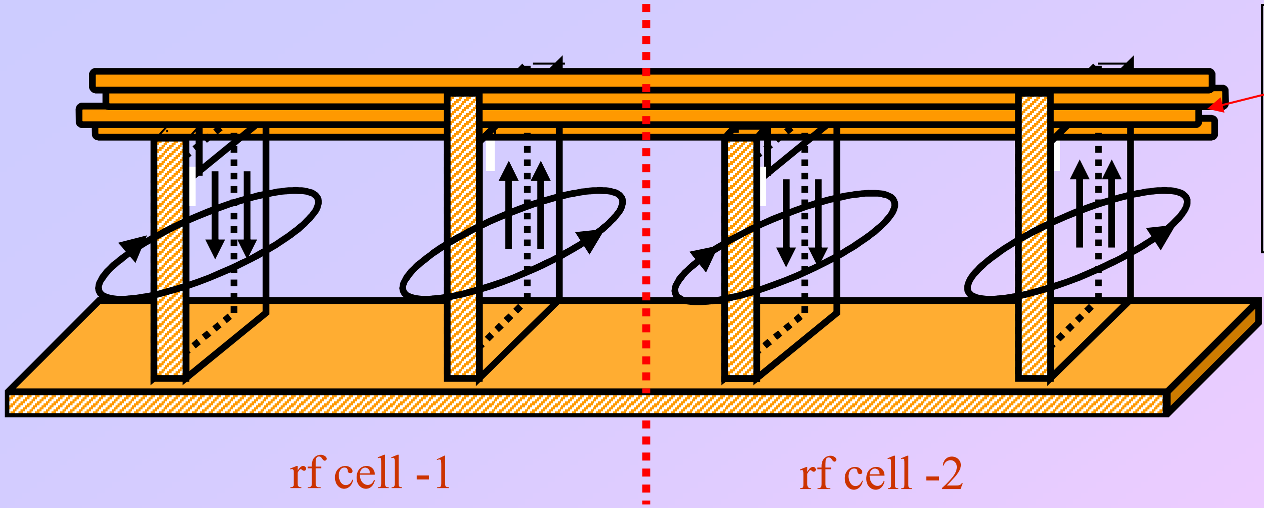
Radio Frequency Quadrupole (RFQ) : Cell parameters



Radio Frequency Quadrupole (RFQ) : Beam dynamics

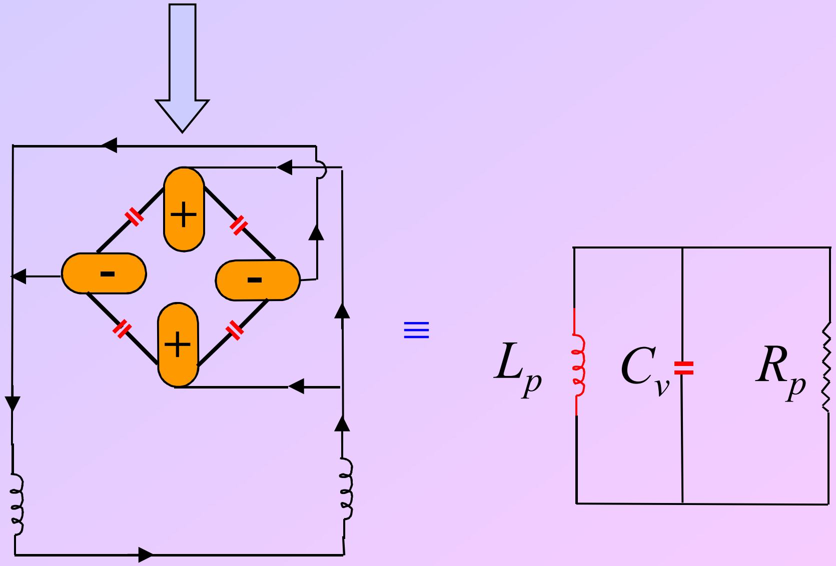


Radio Frequency Quadrupole (RFQ) : Posts



Vanes
≡
4-wire transmission-line
with open circuit termination

Post
≡
2-wire transmission-line
with short circuit termination



$$f = \frac{1}{2\pi\sqrt{L_p C_v}}$$

$$P = \frac{V^2}{2R_p}$$

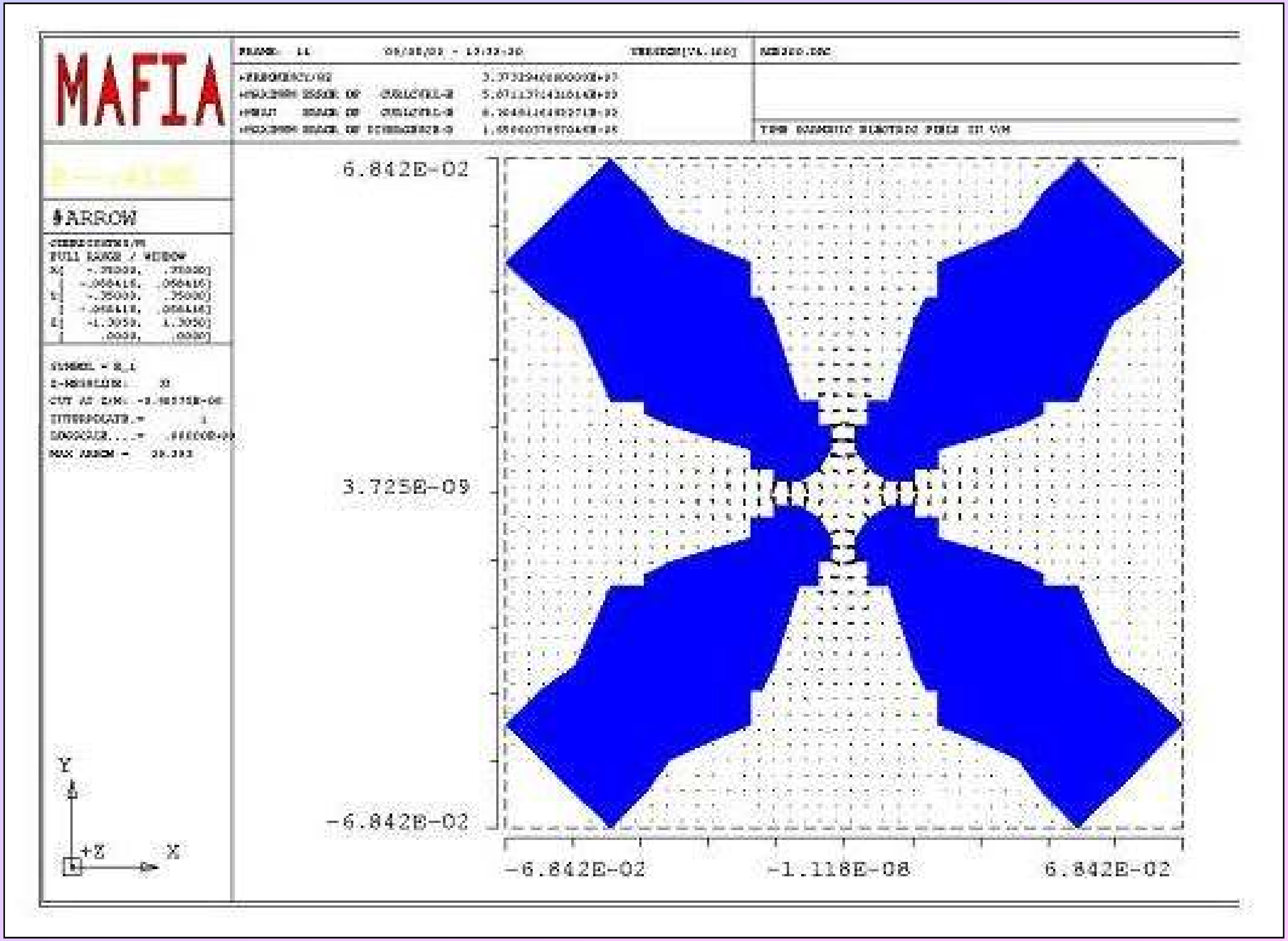
$$R_p \cong \frac{1}{\omega^2 C_v^2 R_s}$$

$$Q = \frac{energy\ stored}{energy\ loss}$$

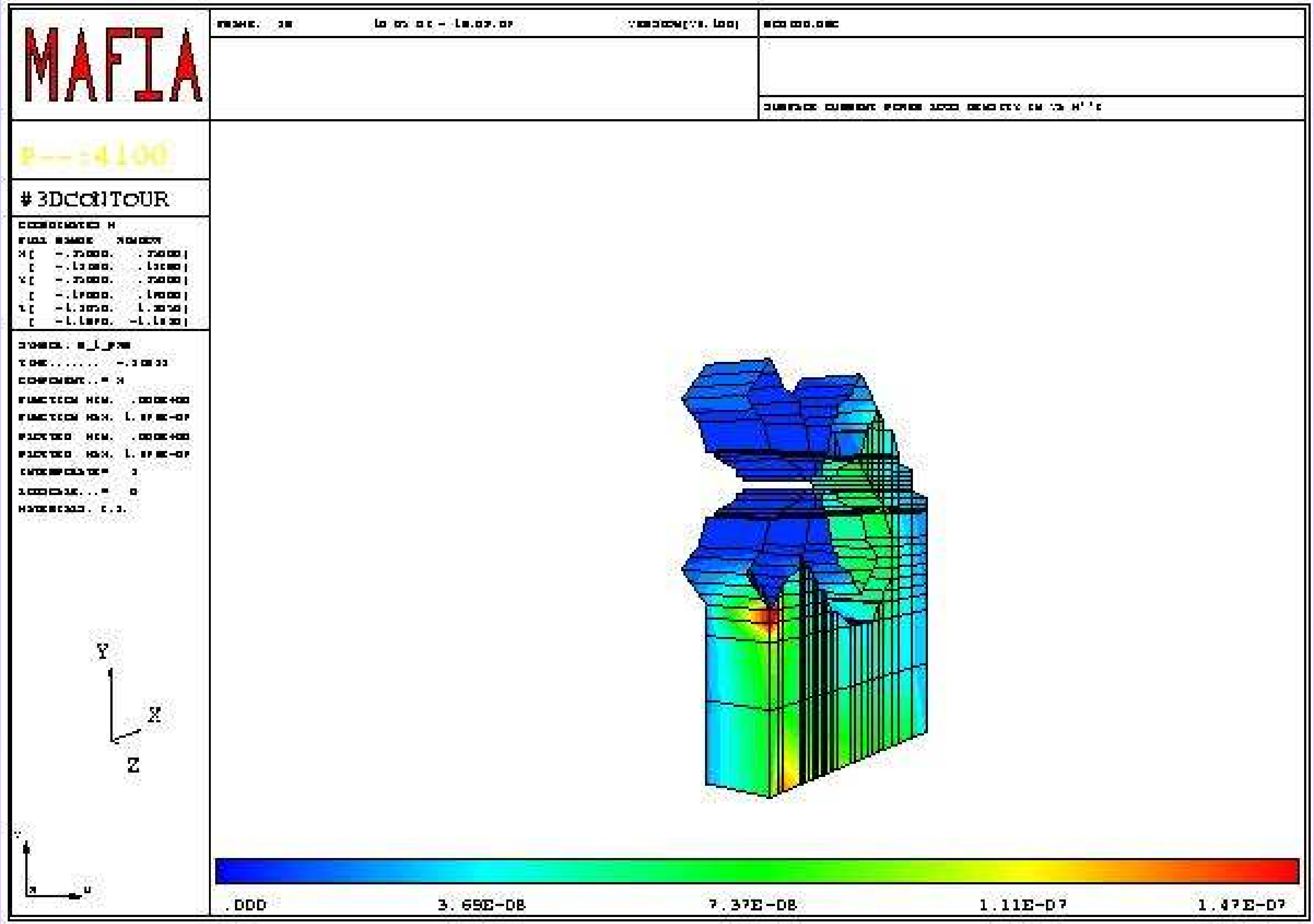
$$Q \propto R_p$$

Deflection of vanes !!!

Radio Frequency Quadrupole (RFQ) : RF simulation



Radio Frequency Quadrupole (RFQ) : RF simulation



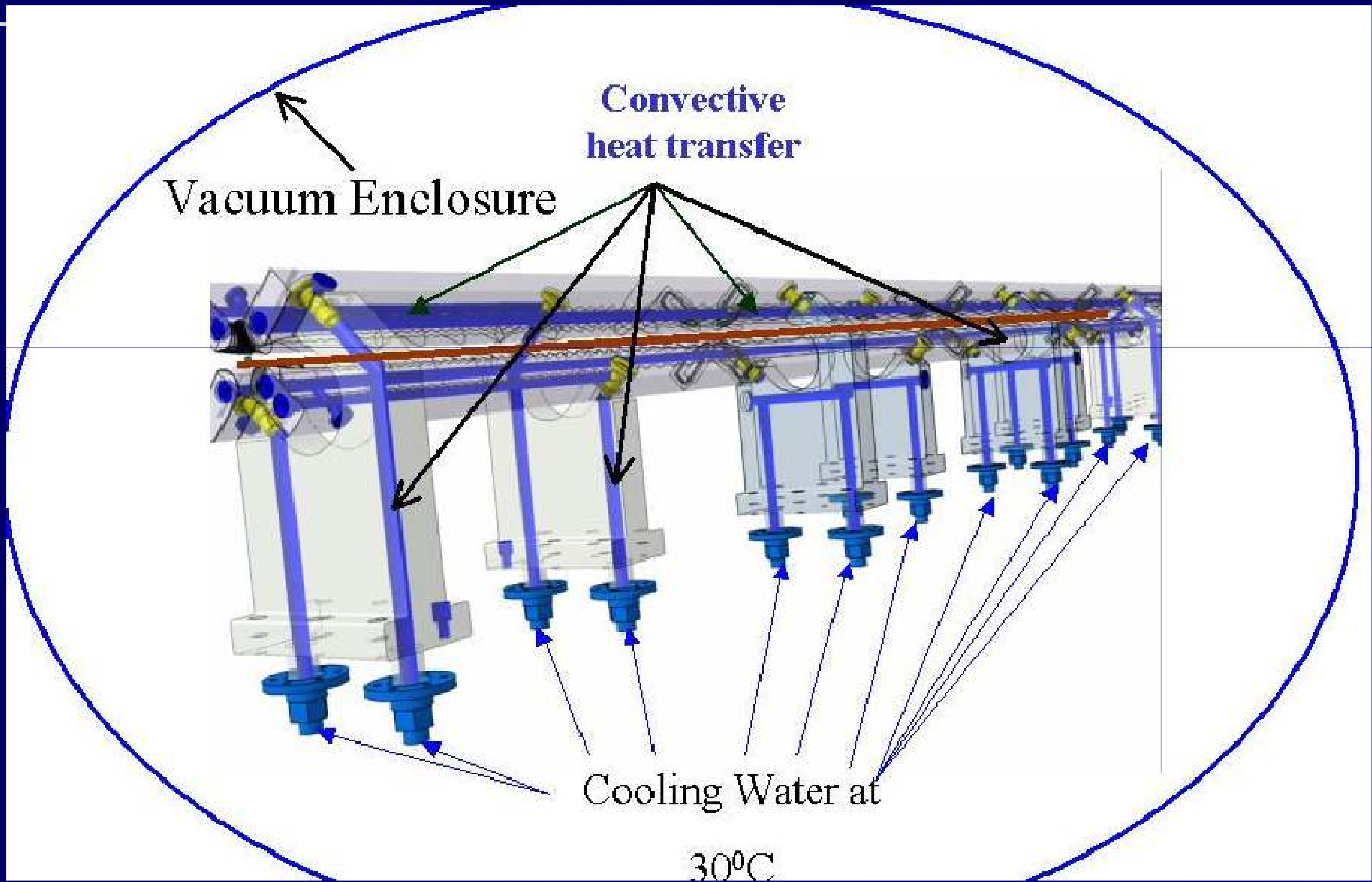
Radio Frequency Quadrupole (RFQ) : RF simulation

- f = 35.18 MHz
- Q = 9830
- R_p = 87.1 kΩ
- Power loss = 14.5 kW

Power loss distribution

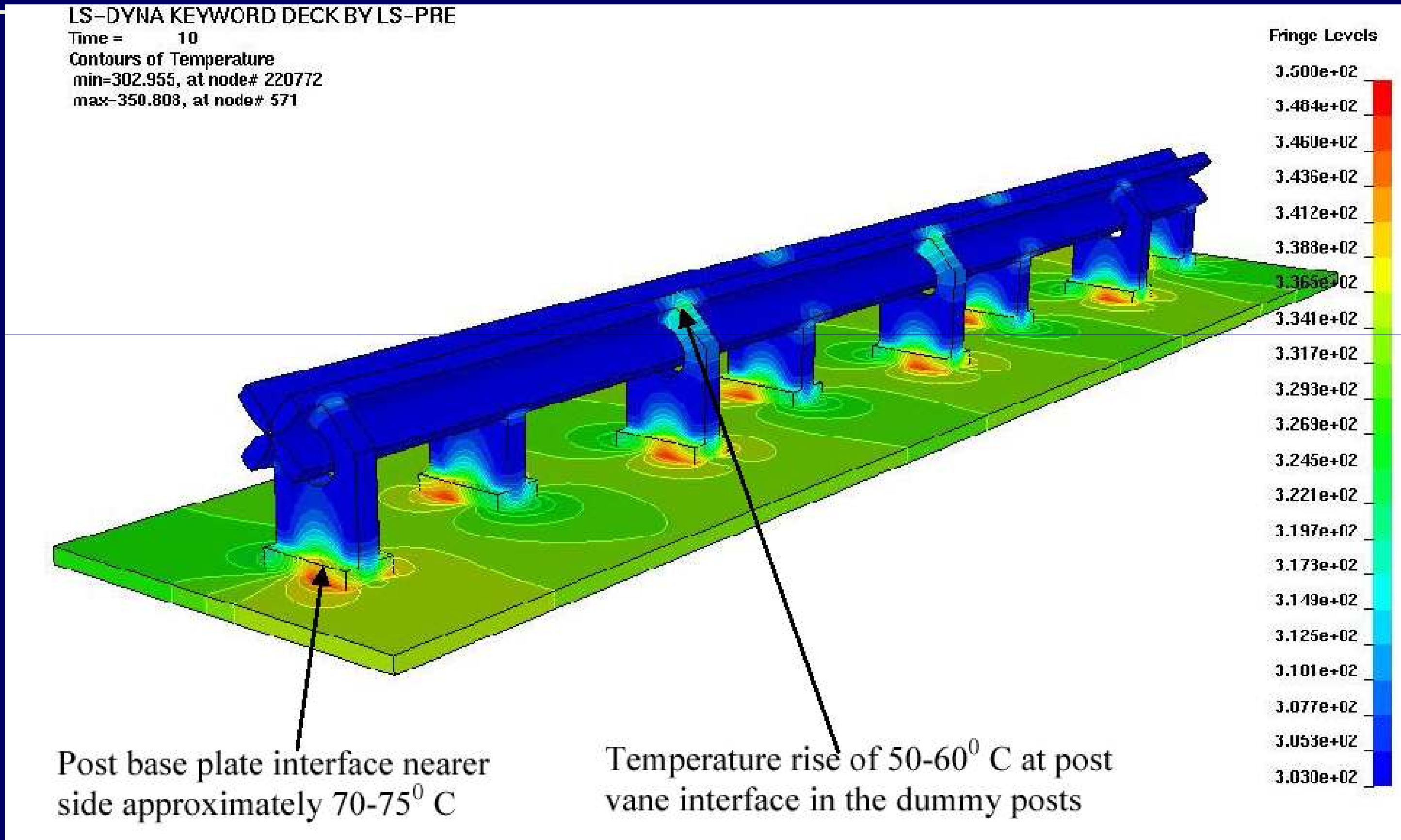
- cavity = 0.62 kW
- vane = 6.0 kW
- post + base plate = 7.87 kW

Radio Frequency Quadrupole (RFQ) : Thermal Management



Convective heat loss due to LCW water thru the cooling system

Radio Frequency Quadrupole (RFQ) : Thermal Management



Temperature distribution in RFQ structure

Radio Frequency Quadrupole (RFQ) : Machining

Vane profile from PARMTEQ

⇓

3D modeling of profile

⇓

X,Y,Z co-ordinates of ball-end mill cutter

⇓

Optimum tool path generation

⇓

Machining of vane

⇓

Check co-ordinates (CMM) & surface finish (Talysurf)

20 μm

Sample vane

~ 2 μm

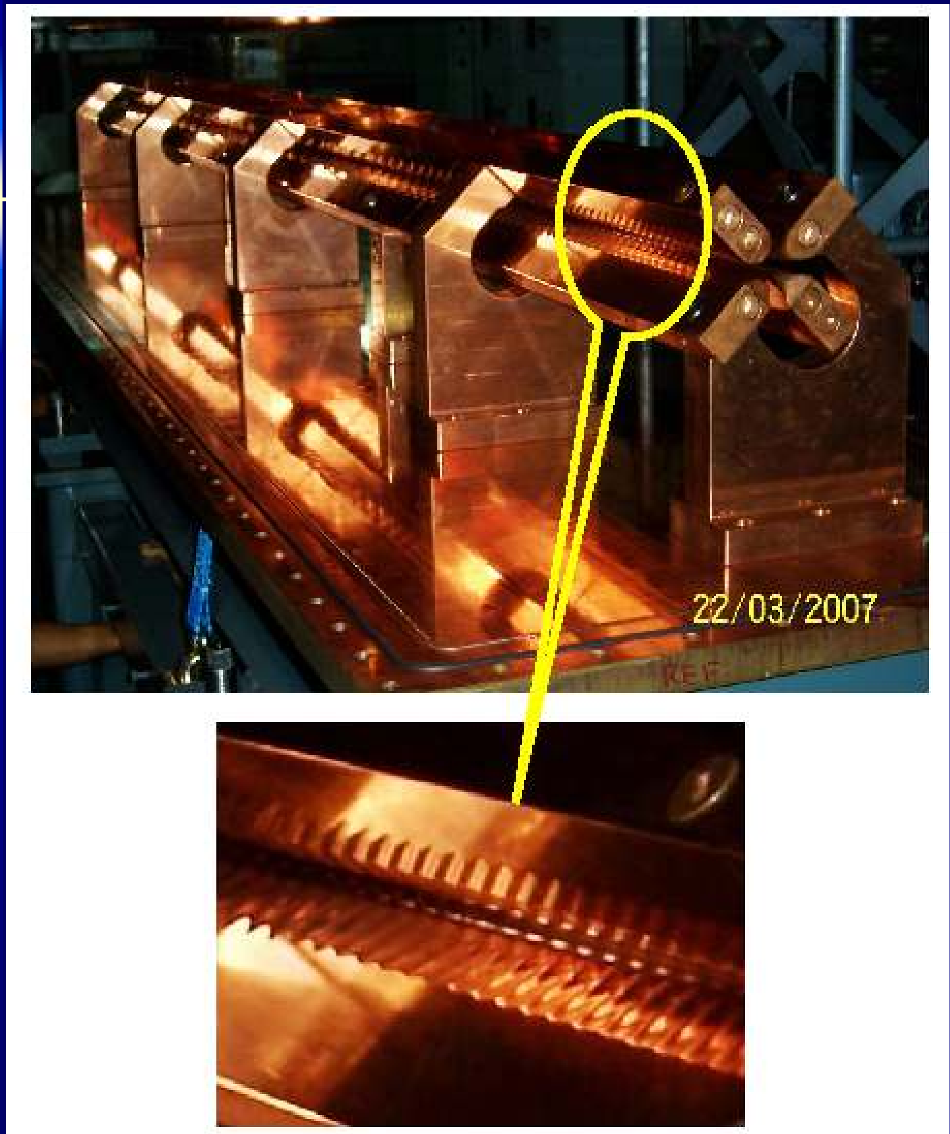
requirement

$\Delta / r_0 \leq 0.5\%$

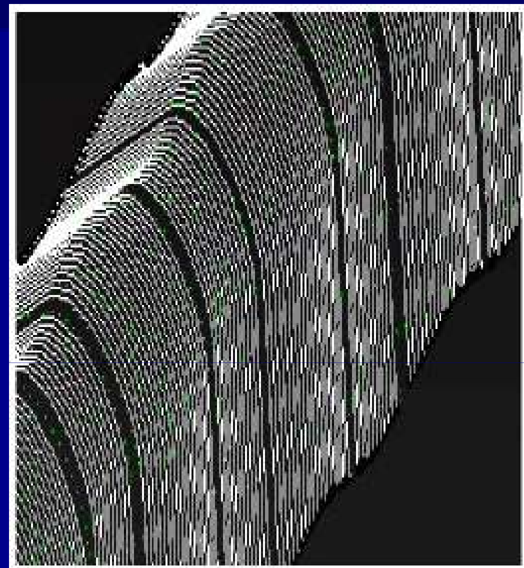
$\Delta \sim 30 \mu m$

$\delta \sim 11 \mu m$

MACHINING OF MODULATED VANE – CMERI , DURGAPUR

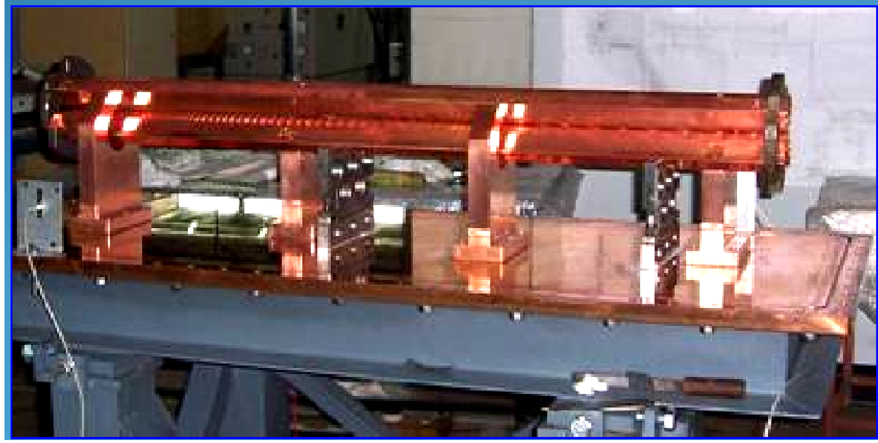


Machined vane in assembled condition



Cubical Spline interpolation

1.7m Long RFQ



Frequency : 33.7 MHz

q/A ≥ 1/16

Energy : 1.38 → 29 keV/u

Vane Length : 1.552 m

Vane Voltage : ± 45.9 kV

Characteristic radius r_0: 7.1 mm

Max. modulation : 1.935

Focusing strength : 4.83

Q: 9830

R_p: 174 kΩ

Commissioned in 2005

3.4m Long RFQ

VECC

Frequency : 37.8 MHz

q/A ≥ 1/14

Energy : 1.73 → 98.8 keV/u

No. of gaps : 9

Vane Length : 3.12 m

φ_s : -21.5°

Vane Voltage : ± 53.7 kV

Accln. grad. : 2.13 MV/m

R_p: 65 kΩ

Q: 8026

Commissioned in 2008

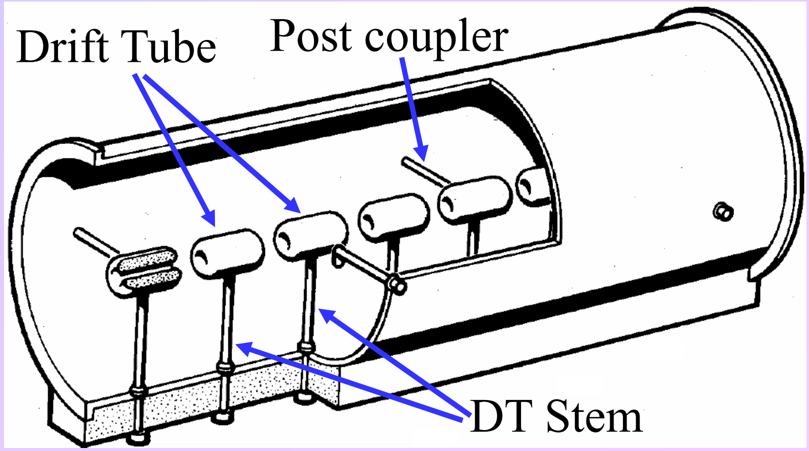
RFQ – Difficulties & Limitations

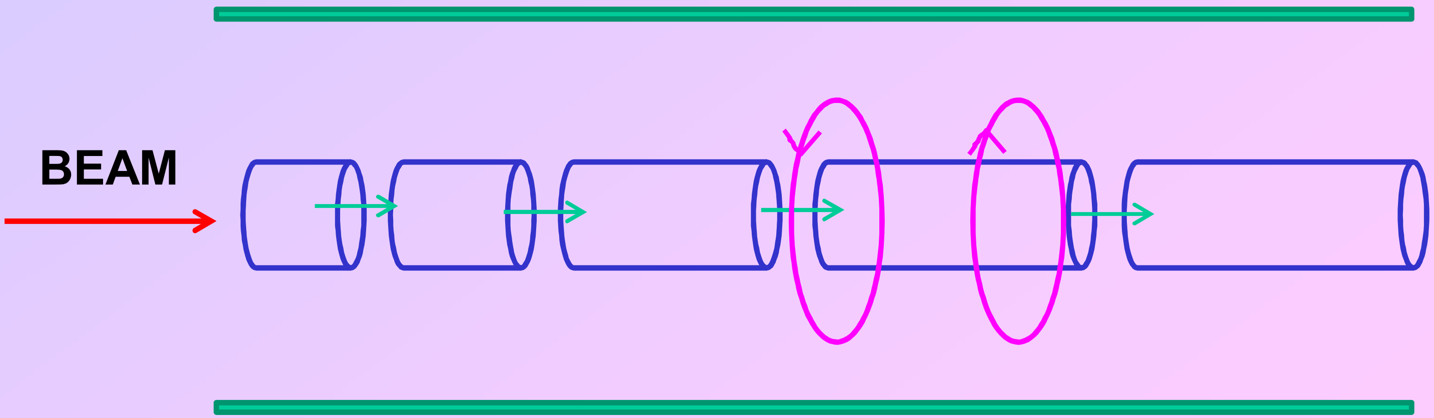
- **Critical machining requirement**
- **Very demanding alignment tolerance of the vanes**
- **Critical cooling requirement**
- **Low shunt impedance and acceleration gradient as part of power is used for providing transverse focusing**

So, one switches over to other linear accelerators as soon as it becomes practically feasible.

Drift Tube LINAC (DTL)

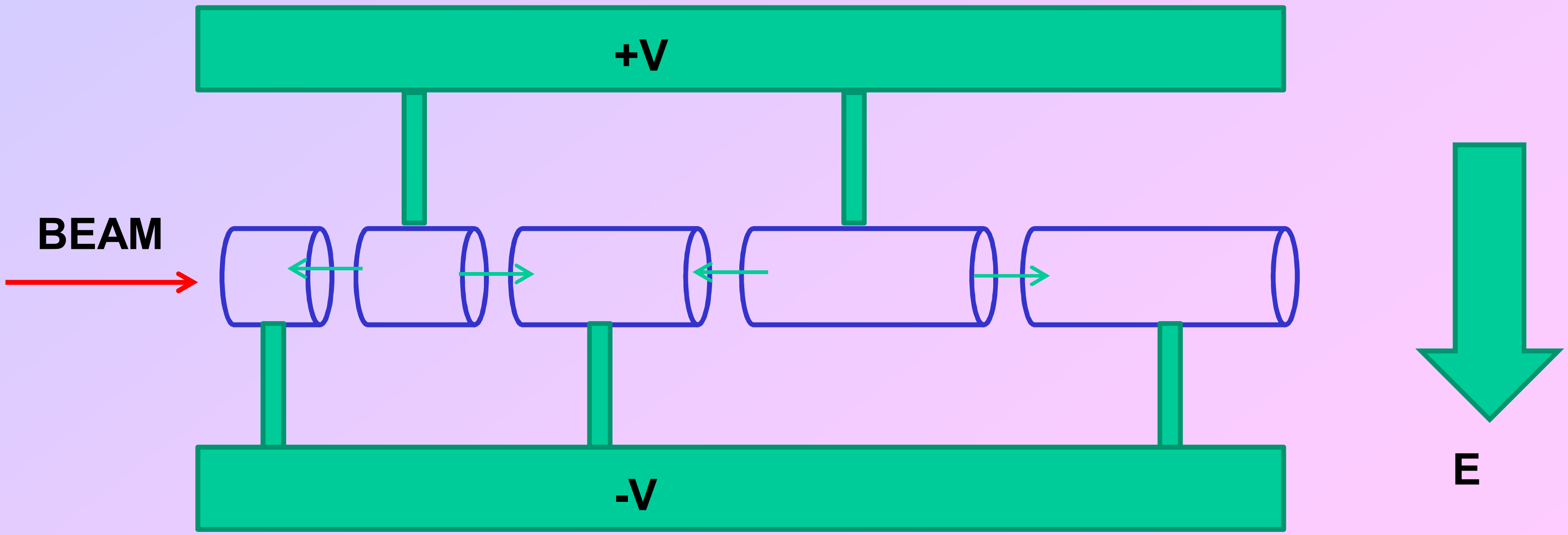
- Uses TM mode for acceleration
- Stems are mechanical support
- Post couplers to shift freq. of competing modes.
- Cell length βλ → E in all gaps are in phase (0-mode structure)
- Mainly used for the acceln. of p & HI for 5%<β<40%

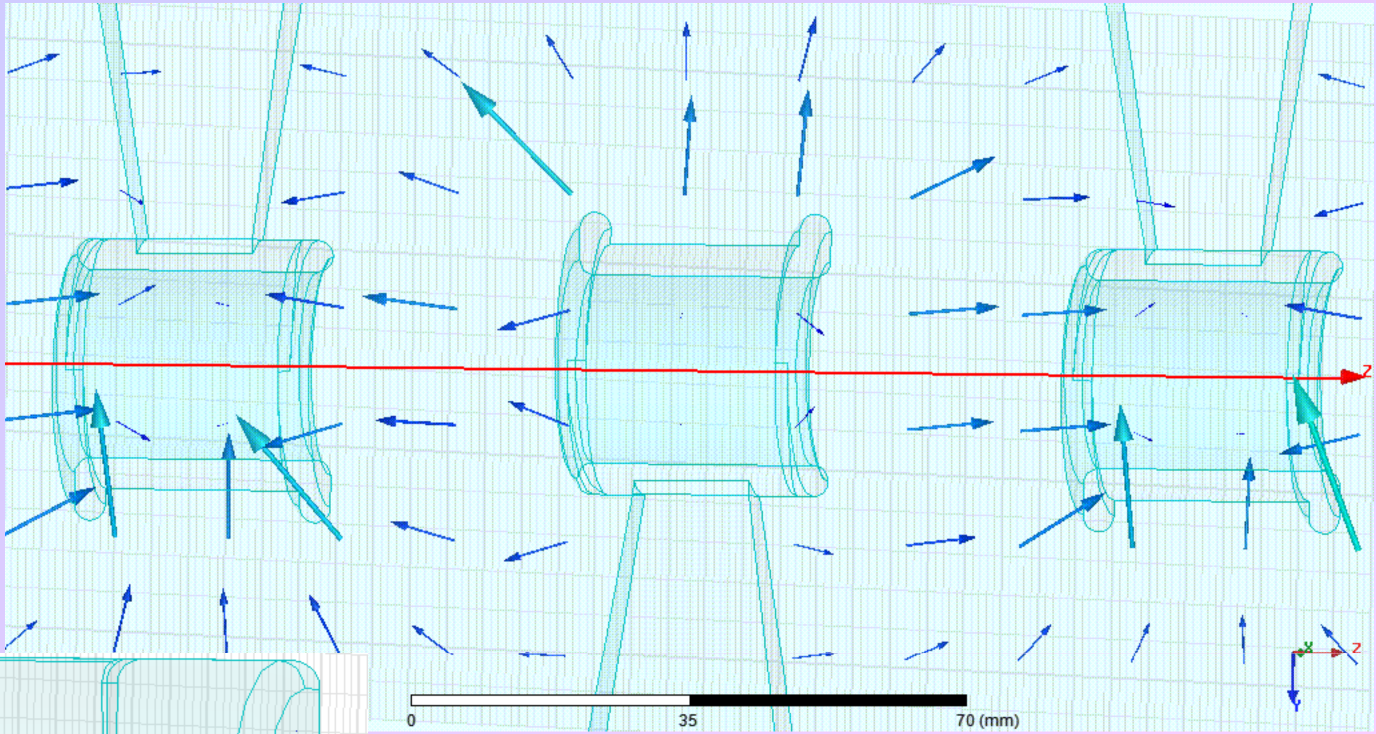


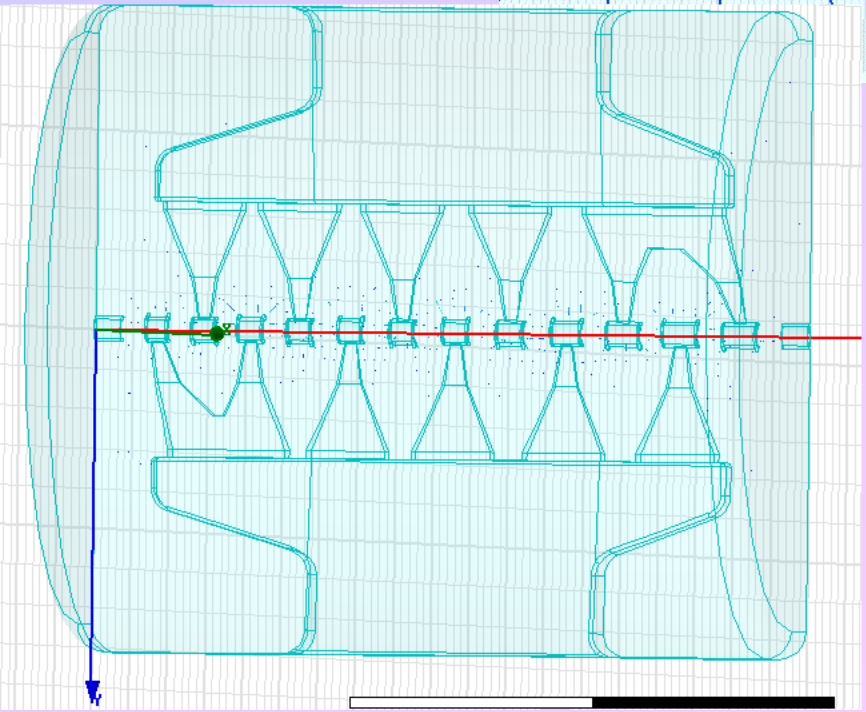


Interdigital H LINAC (IH)

- Uses TE mode for acceleration
- Cell length $\beta\lambda/2$ → E in adjacent gaps are in opposite phase (π – mode structure).
- High Z compared to DTL for $\beta < 10\%$.
- Much smaller transverse dimension (1/3rd) compared to DTL
- Mainly used for the acceln. Of HI for $10\% < \beta$. $Z \sim 1/\beta^2$

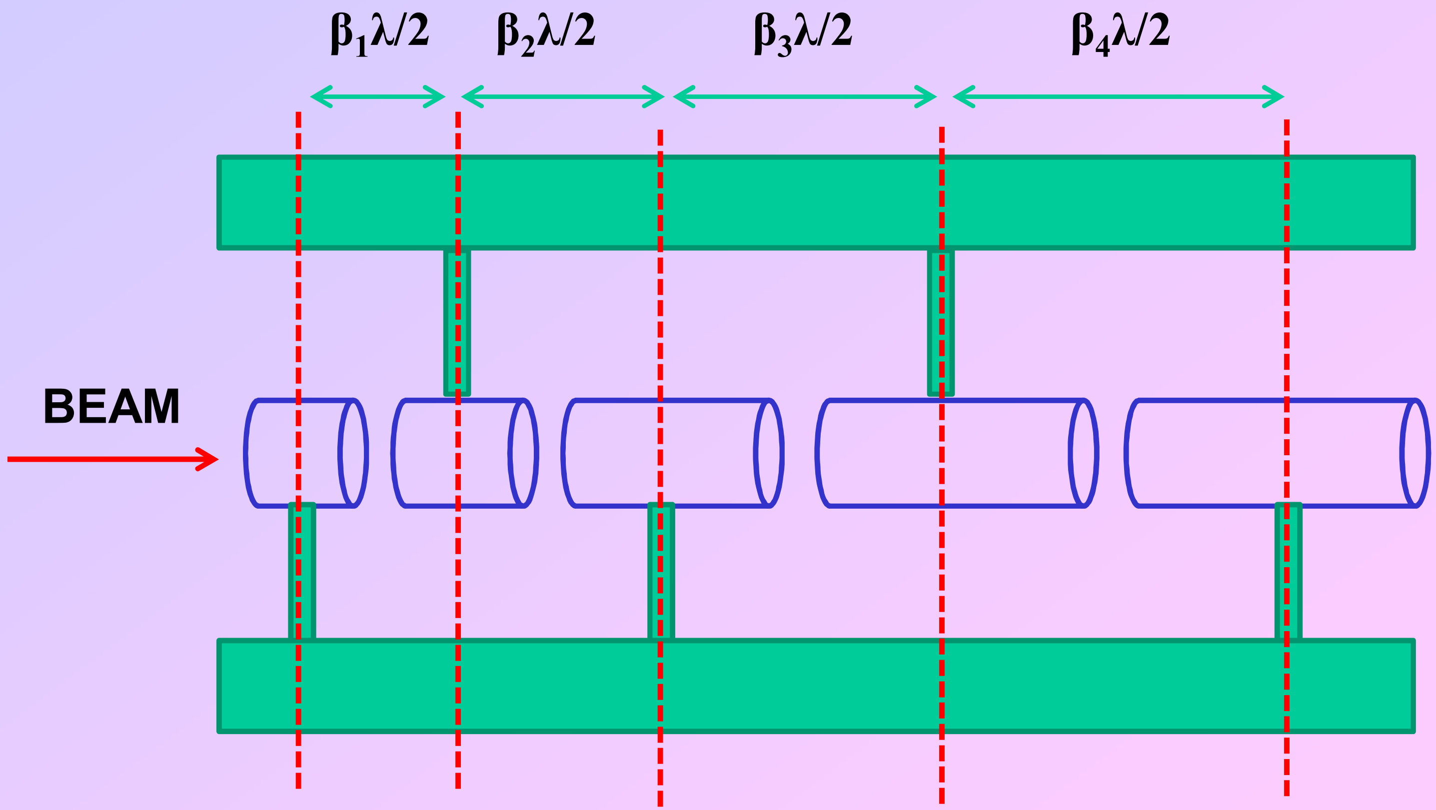



0
35
70 (mm)



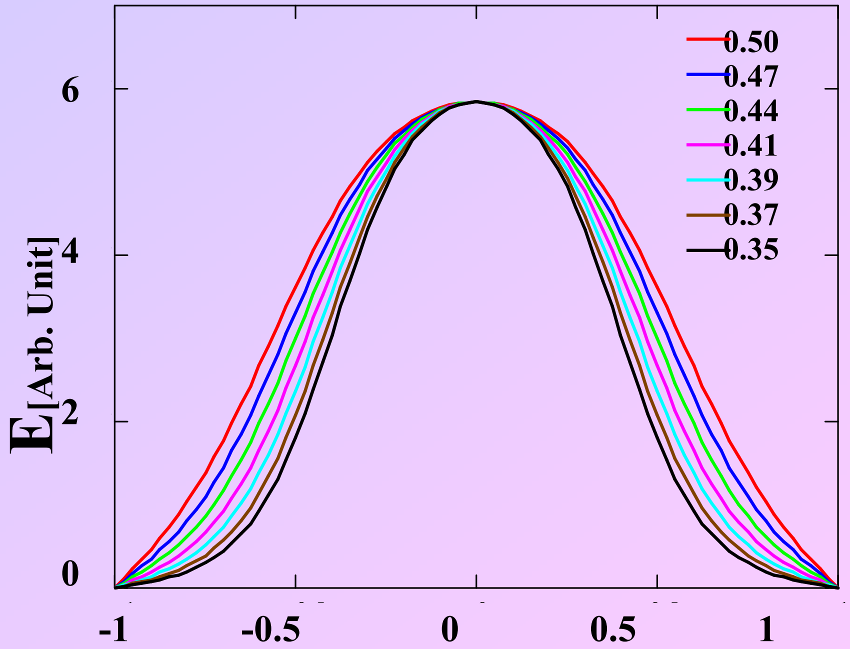
Finding the Correct Operating Field

Freq. [MHz]	E_Kil. MV/m	E_Kil.*1.3 MV/m	E_Kil.*1.4 MV/m
37.8	8.1	10.5	11.3
75.6	10.3	13.4	14.4



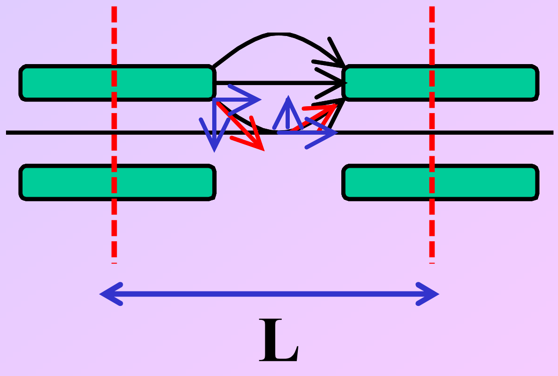
Finding the Correct Operating Field

2-D elctrostatic field for various gap to cell length ratios have been calculated – for intermediate gap to cell length ratios the fields have been interpolated – these fields have been used for the generation of cell geometry.



Energy Gain across a gap

If the field across the gap is DC i.e. No time dependance and having the value equal to the field at the time the ion is at the gap centre then energy gain by the ion of charge 'q' can be expressed as :



$$\Delta w = q * (E_0 * \cos\Phi) * L = q * V_0 * \cos\Phi$$

When one considers the sinusoidal variation of the RF field then :

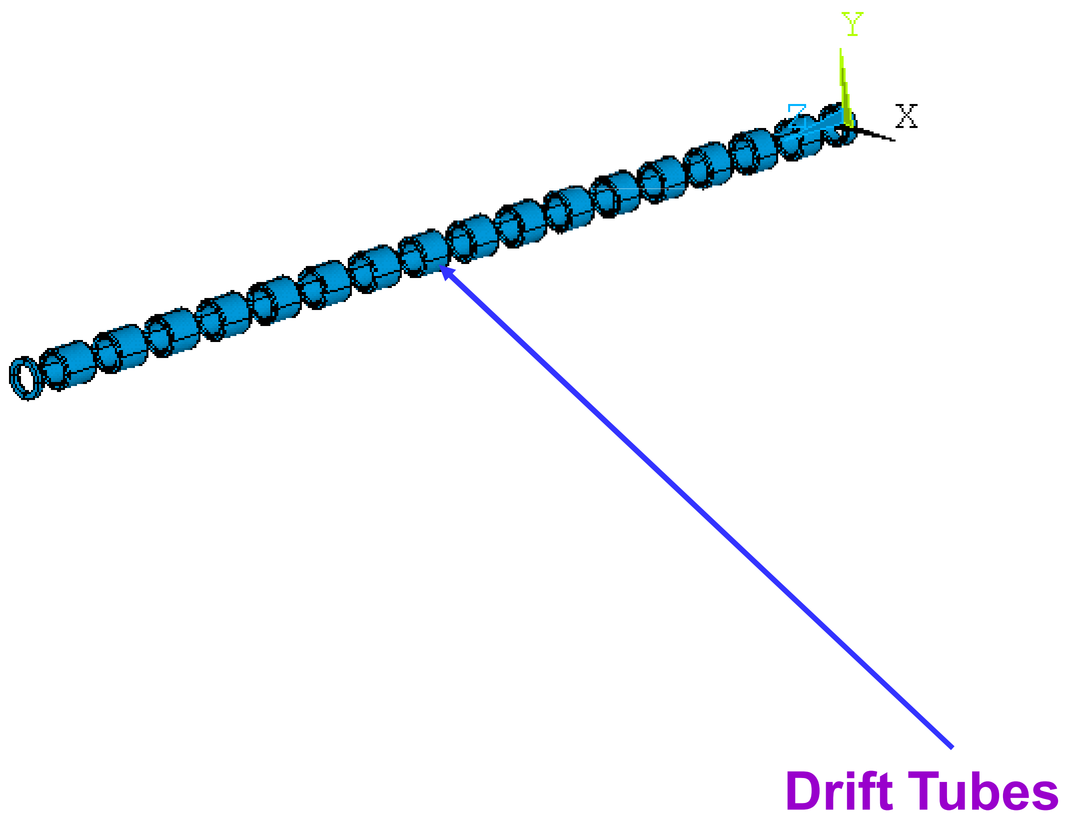
$$\Delta w = q * V_0 * T * \cos\Phi$$

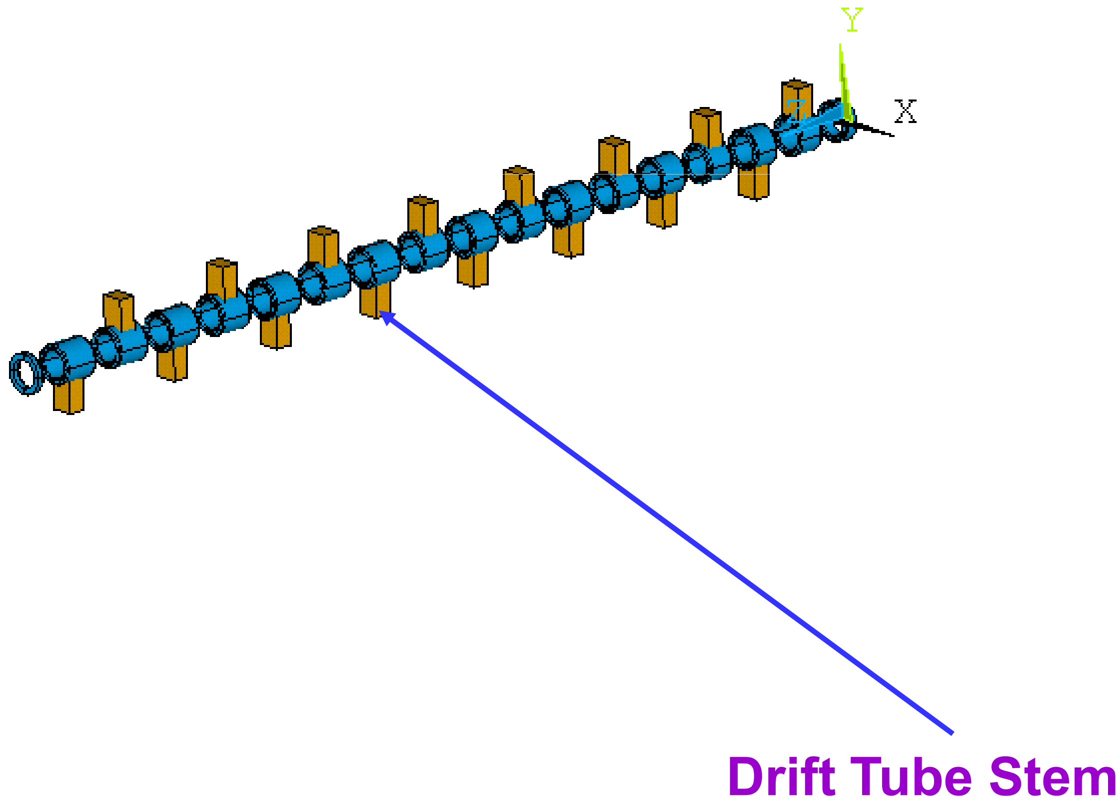
Where 'T' is called transit time factor which depends on the field distribution across the gap and can be written as :

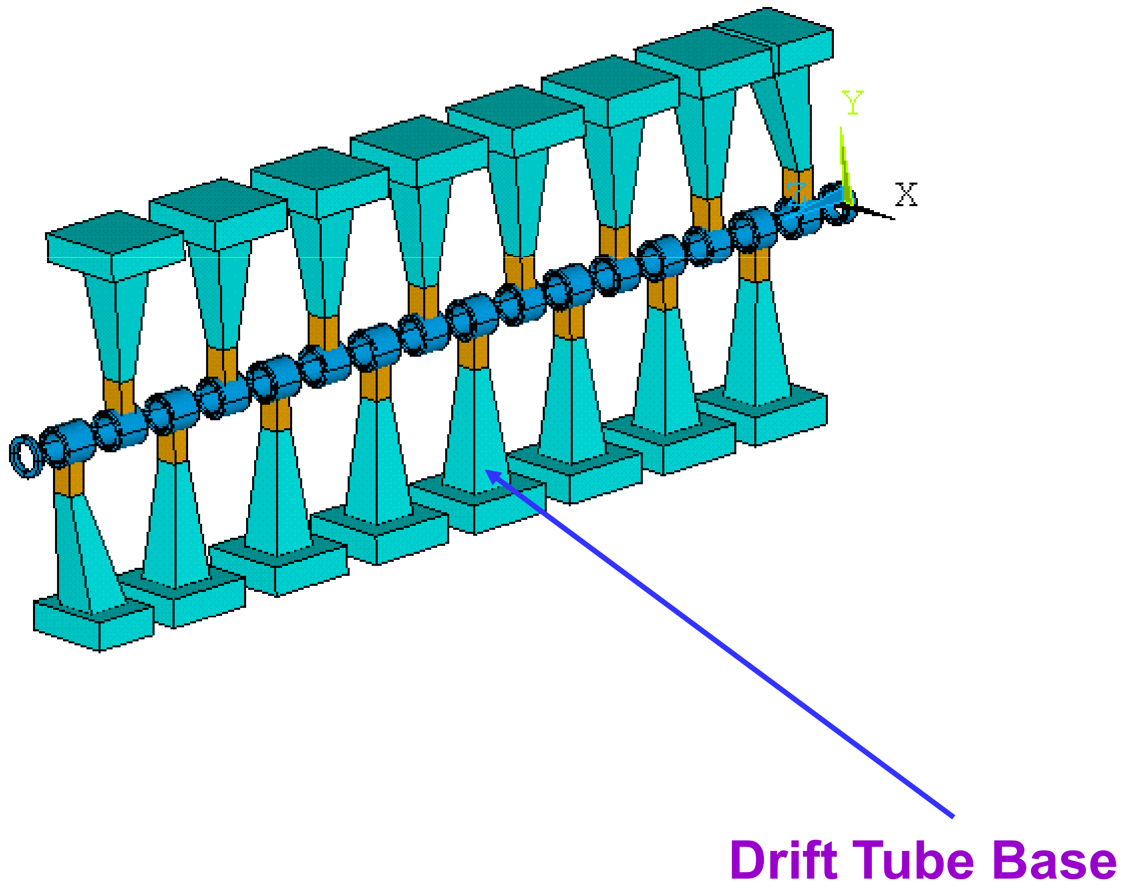
$$T = \int_{-L/2}^{L/2} E(r=0,z)\cos wt(z)\,dz \Big/ \int_{-L/2}^{L/2} E(r=0,z)\,dz$$

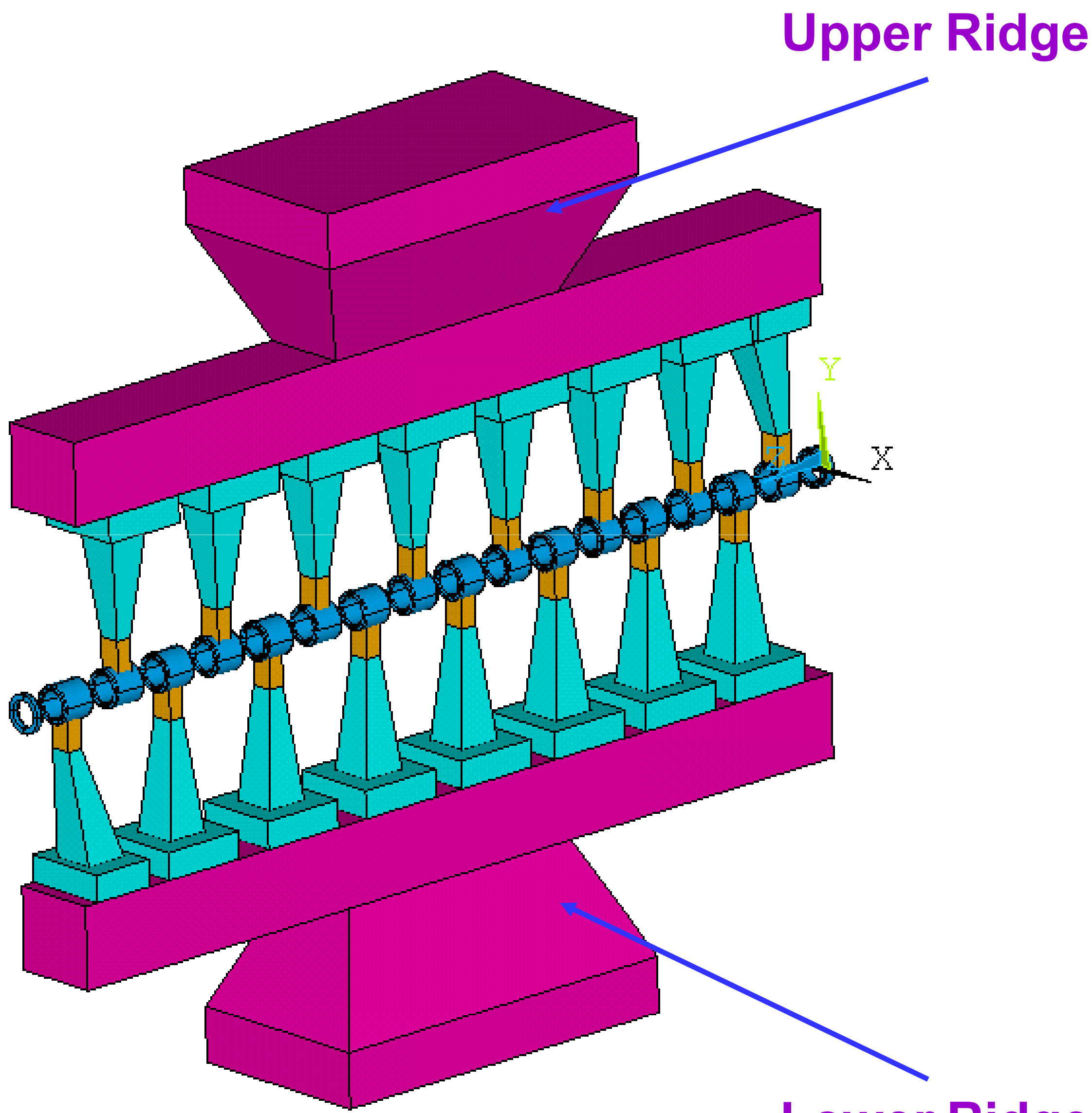
DD =

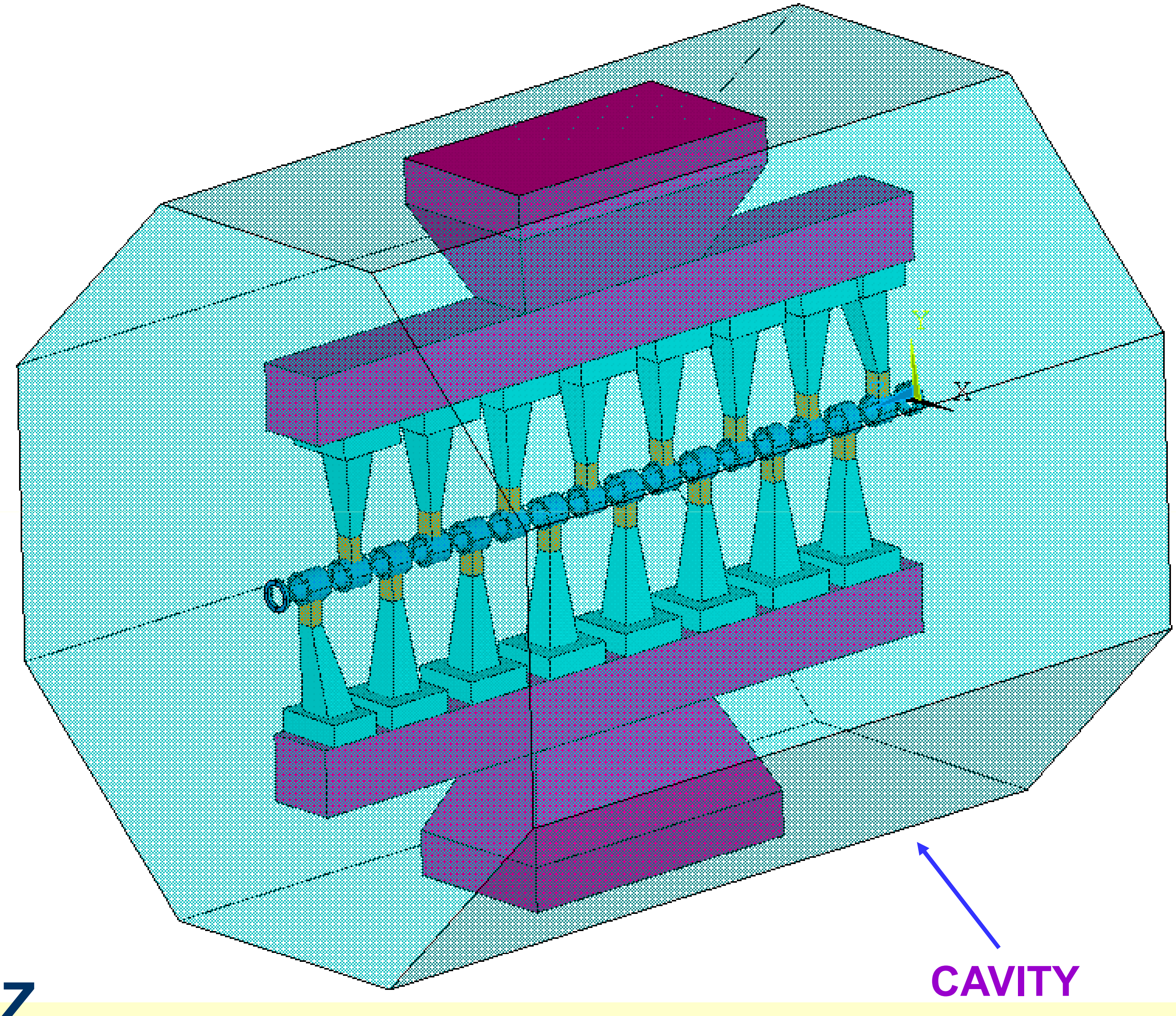
"T_in"	"T_out"	"Phase"	"L_cell"	"gap/cell"	"TT"	"V0*T"	"E0"
"MeV/u"	0	"Deg"	"mm"	"ratio"	"Fac"	"MV"	"MV/m"
0.0992	0.1045	−23.5326	58.4	0.5	0.7871	0.0805	1.7501
0.1045	0.1153	−21.9566	61	0.4787	0.7932	0.1638	3.3849
0.1153	0.1264	−21.7316	63.2	0.462	0.8052	0.1673	3.2883
0.1264	0.1377	−22.472	66.2	0.4411	0.8132	0.1702	3.1609
0.1377	0.149	−23.5682	68.6	0.4257	0.8205	0.1725	3.0645
0.149	0.1602	−24.9909	71.4	0.409	0.826	0.1743	2.9555
0.1602	0.1715	−25.9737	74.2	0.3935	0.8315	0.176	2.8518
0.1715	0.1828	−27.0485	76.4	0.3822	0.8365	0.1774	2.7756
0.1828	0.1884	−28.4081	78.8	0.3706	0.8399	0.0892	1.3471


Y
Z
X
Drift Tubes


Y
X
Drift Tube Stem

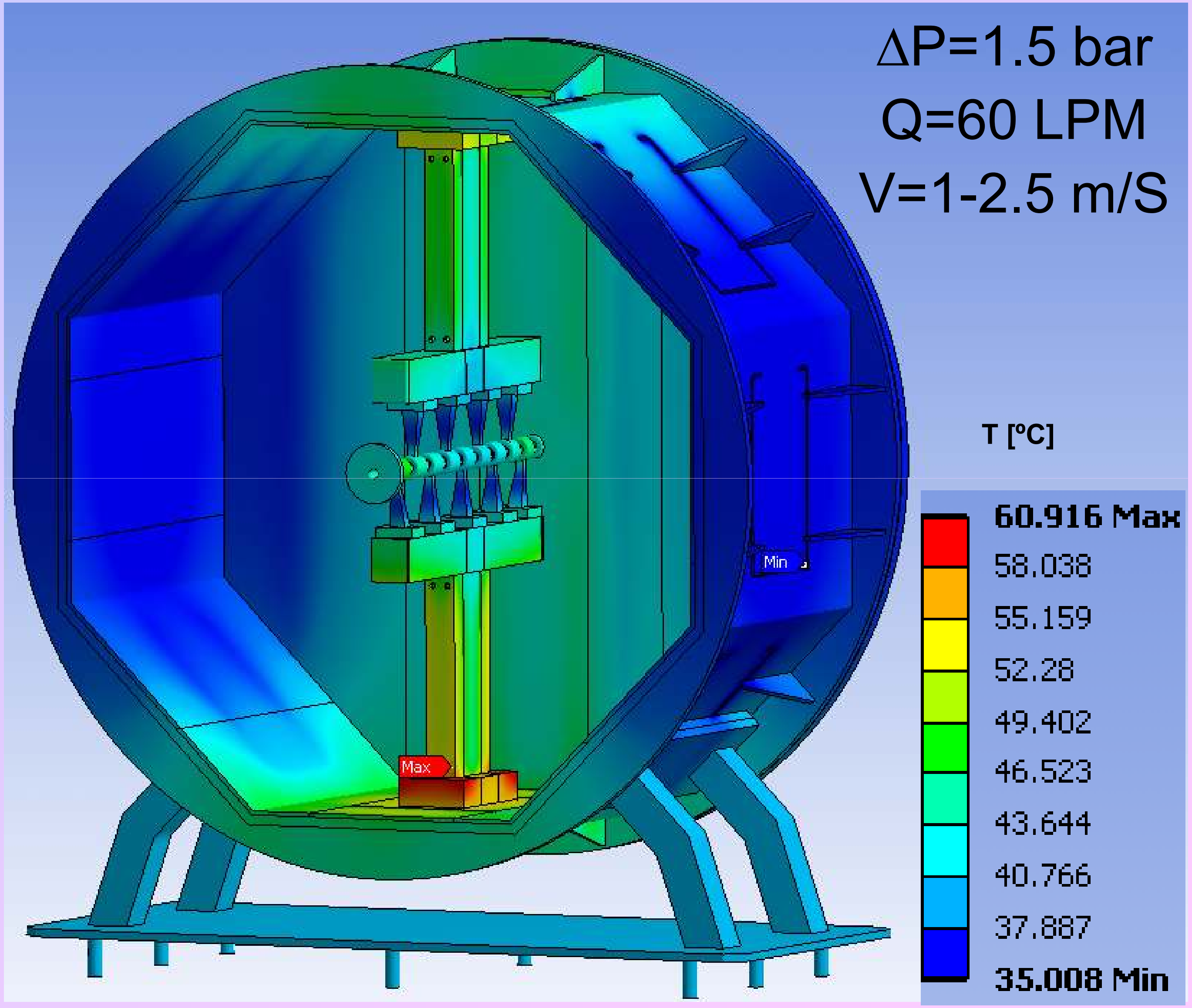

Y
X
Drift Tube Base


Upper Ridge
Y
X
Lower Ridge



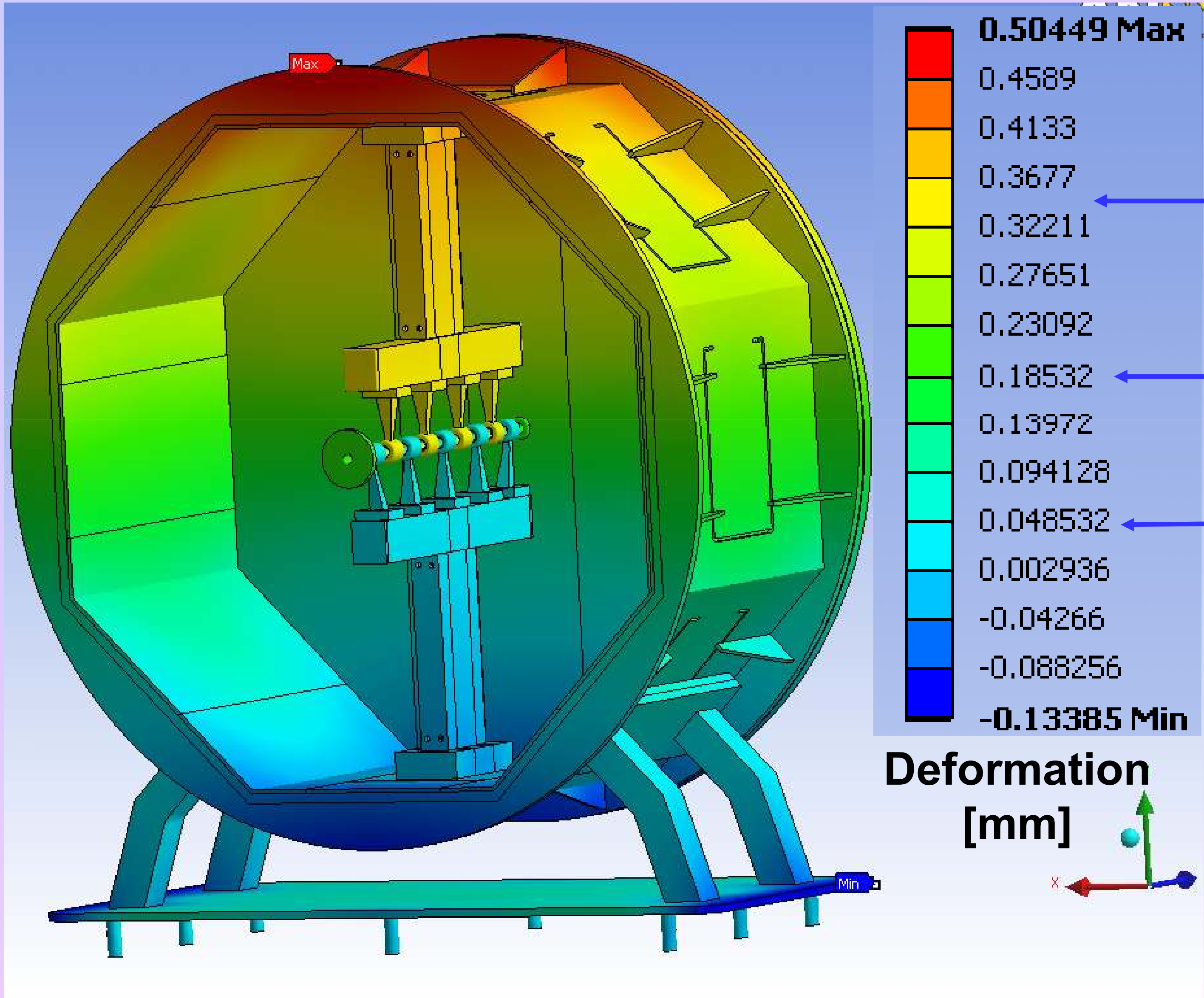
f & Z

Temperature distribution of LINAC-2



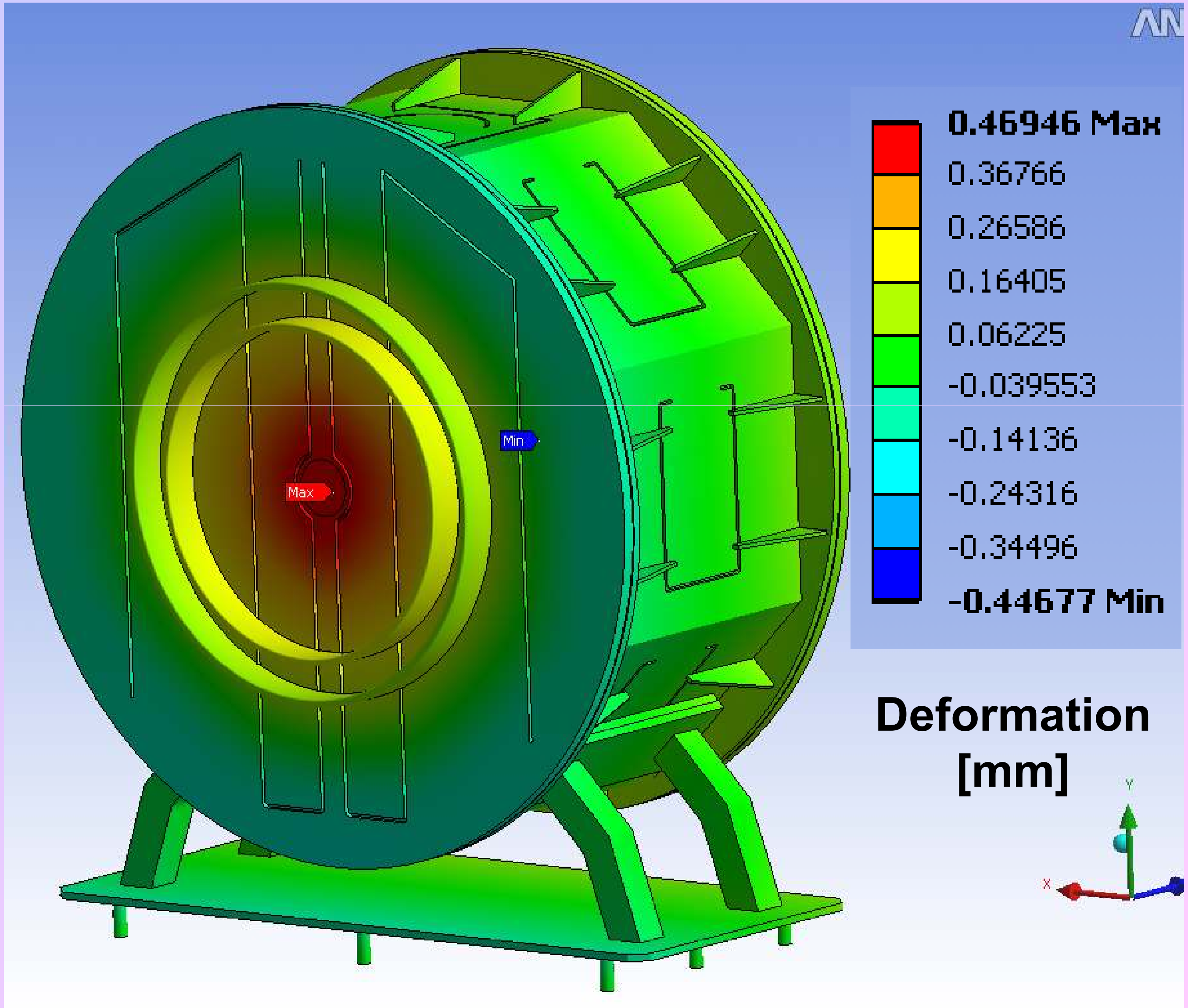
Vertical deformation of LINAC-2

- **Loads : Atm. Press. , Self weight , Thermal**



Axial deformation of LINAC-2

- **Loads : Atm. Press. , Self weight , Thermal**

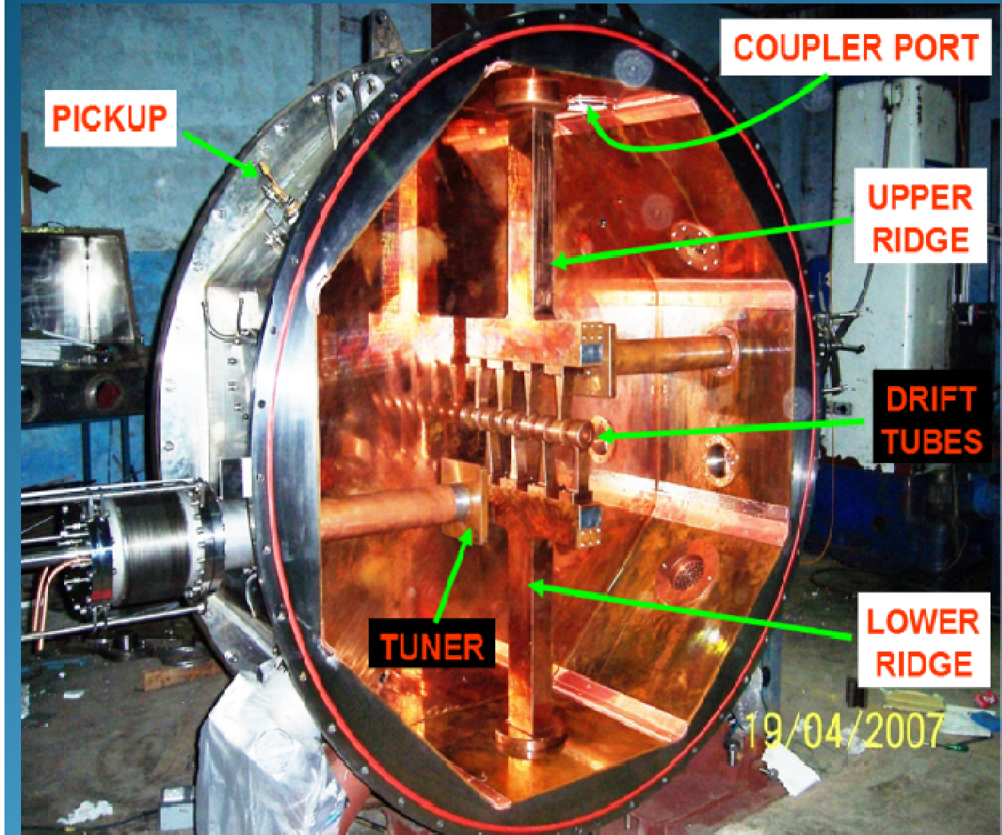


IH cavity - 1

Frequency : 37.8 MHz

q/A ≥ 1/14

Energy : 98.8 → 186.2 keV/u



NIM-A560(2006)182

IH cavity - 2

Frequency : 37.8 MHz

q/A ≥ 1/14

Energy : 186.2 → 289.1 keV/u

Rebuncher – 2 & 3

Frequency : 37.8 MHz

q/A ≥ 1/14

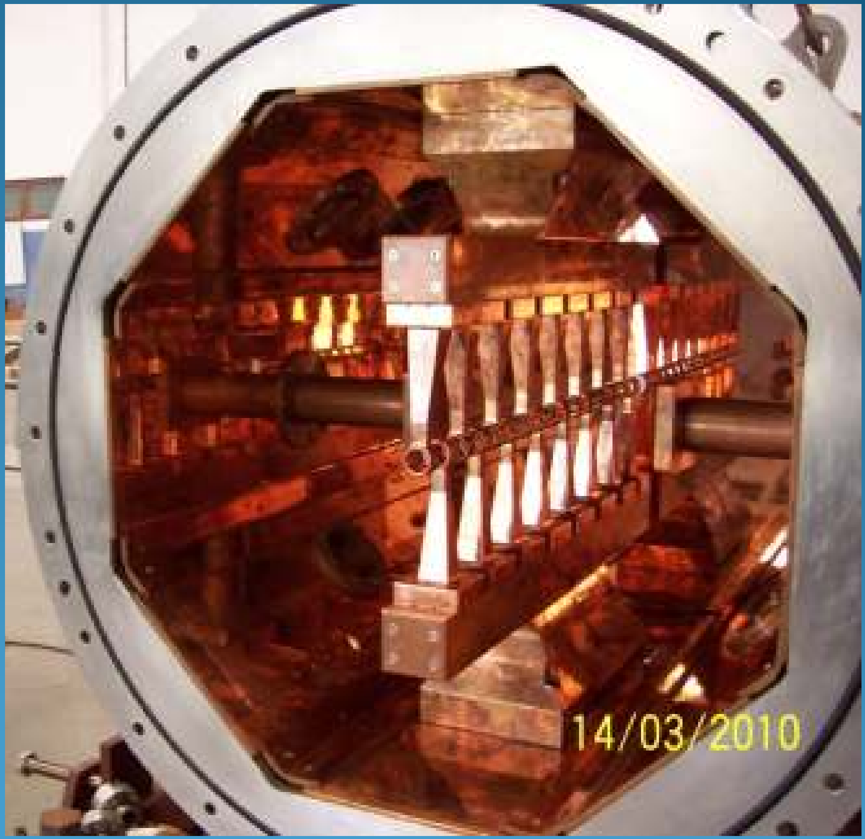
Energy : 289.1 → 289.1 keV/u

IH cavity - 3

Frequency : 75.6 MHz

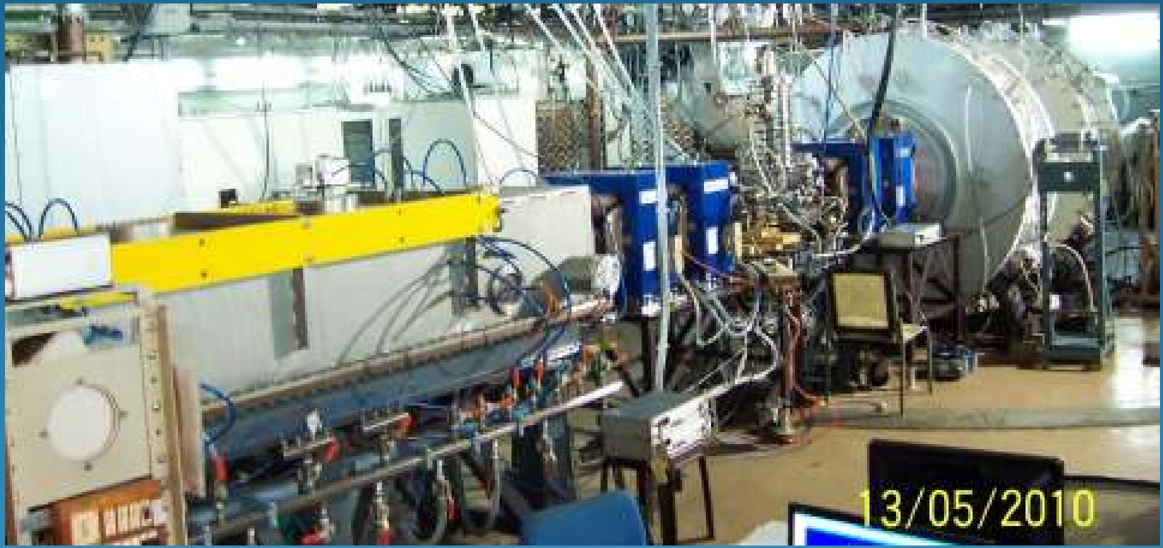
q/A ≥ 1/14

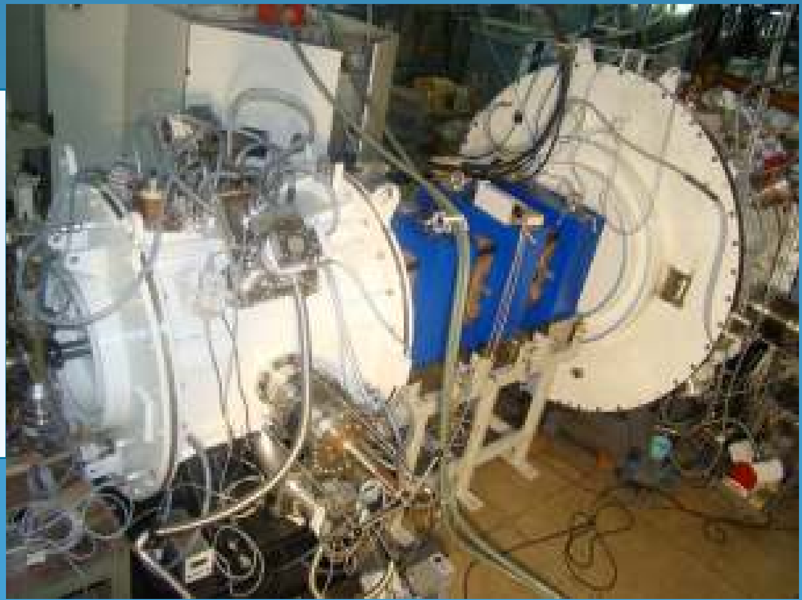
Energy : 289.1 → 413.9 keV/u



All these accelerators are operated as and when required

Transmitters developed by SAMEER, Mumbai





Measured Tr. Efficiency :

RFQ ~ 90%

RFQ-LINAC1-LINAC2 ~ 66%

RFQ-LINAC1-LINAC2-LINAC3 ~ 50%

IH cavity - 4

Frequency : 75.6 MHz

q/A ≥ 1/7

Energy : 413.9 → 717.8 keV/u

IH cavity - 5

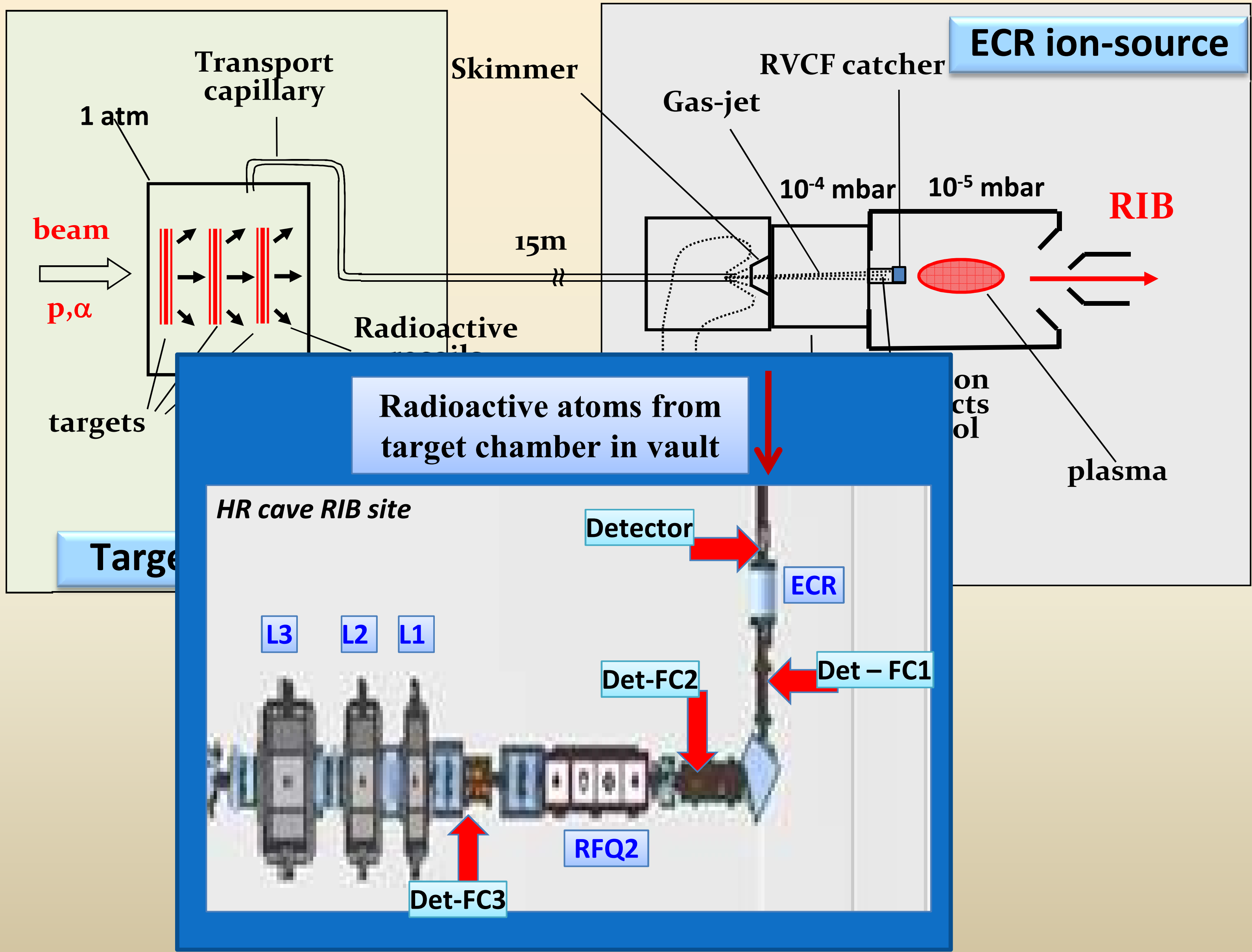
Frequency : 75.6 MHz

q/A ≥ 1/7

Energy : 717.8 → 1043 keV/u

Activity	Commissioning
n^+ ECR source	2002
1.7m Long RFQ	2005
3.4m Long RFQ	2008
IH LINAC cavity - 1	2009
IH LINAC cavity - 2	2010
IH LINAC cavity - 3	2011-12
First acceleration of RIB	2012
IH LINAC cavity - 4	2013
1^+ ECR source - only PMs	2013
Rebuncher 2 & 3	2014
IH LINAC cavity - 5	March 2015

Production & Acceleration of RIBs



Production & Acceleration of RIBs

List of RIBs Produced				
RIB	Prod. route	T1/2	PPS at FC1	PPS at FC2
^{42}K	$^{40}Ar(\alpha,pn)$	12.36 hr	3.1×10^4	2.7×10^3
^{43}K	$^{40}Ar(\alpha,p)$	22.3 hr	2.0×10^4	1.2×10^3
^{41}Ar	$^{40}Ar(\alpha,2pn)$	109 min	4.6×10^3	1.3×10^3
^{14}O	$^{14}N(p, n)$	71 s	6.7×10^4	5.0×10^3

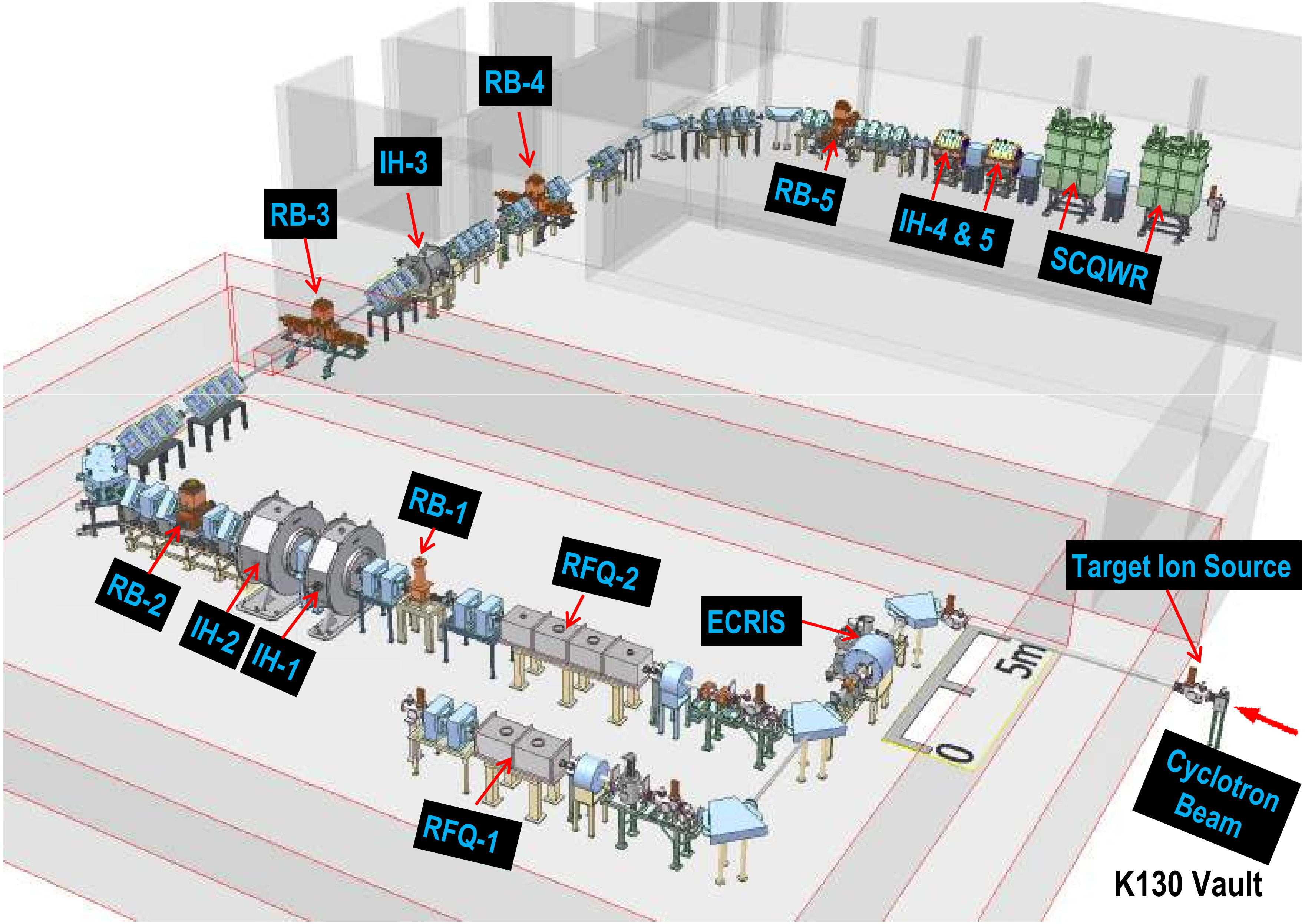
NIM-B317(2013)227

RSI-84(2013)033301

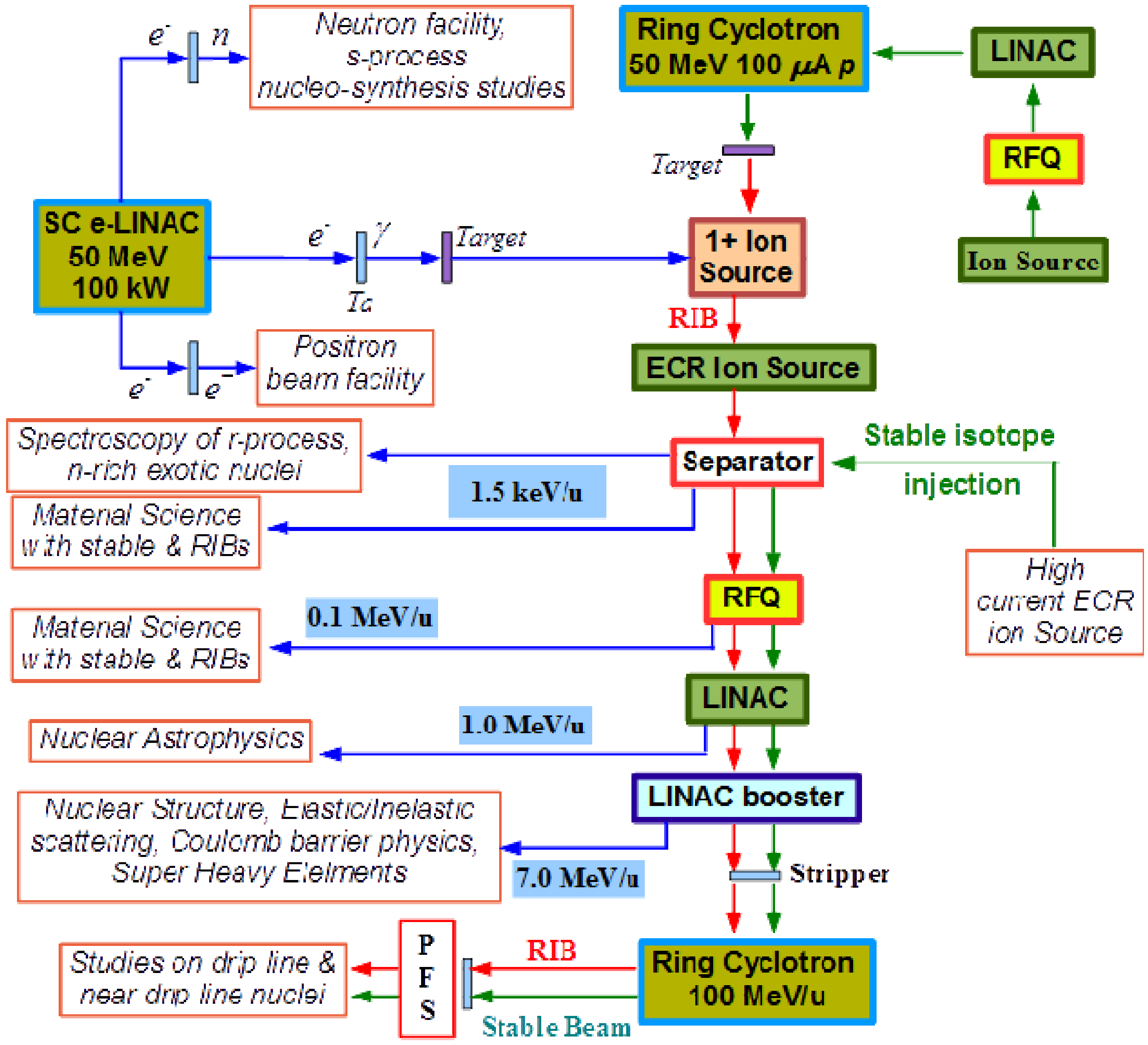
Acceleration of ^{14}O through RFQ to 1.4 MeV

RIB	Prod. route	Primary beam energy (MeV)	T1/2	pps @ ECR exit (FC1)	pps @ before RFQ (FC2)	pps @ after RFQ (FC3)
^{14}O	$^{14}N(p, n)$	11	71 s	6.7×10^4	5.0×10^3	3.2×10^3

Actual Layout of the Facility



Advanced National Facility for Unstable and Rare Isotope Beams (ANURIB)



e-LINAC for producing n-rich RIBs

Cyclotron for producing p-rich RIBs

Both ISOL & PFS type RIB facility

Both RIB & stable isotope beams

Fragmentation of RIBs for producing near drip-line nuclei

APPROVED	
12th plan allocation	42.15 Cr. ₹
13th plan allocation	30.14 Cr. ₹
Total	72.29 Cr. ₹

Acknowledgement :

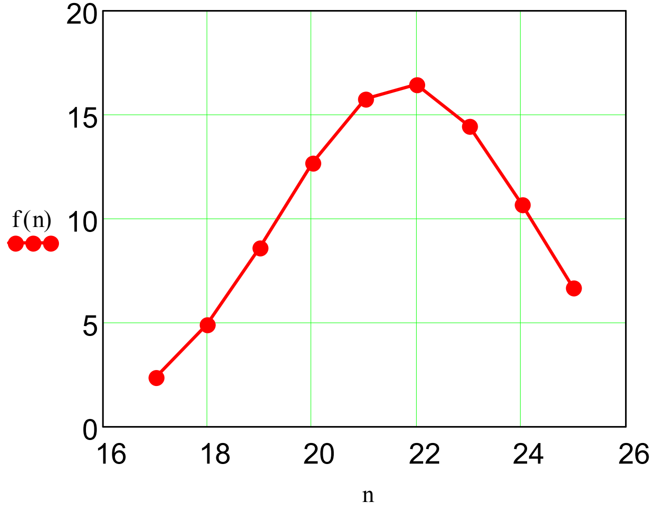
- RIKEN Accelerator Research Facility (RARF), Japan
- TRIUMF, Vancouver, Canada
- CMERI, Durgapur, India
- SAMEER, Mumbai, India
- SAMEER Centre for Electromagnetics, Chennai, India


THANK
YOU

Charge Stripping

q/A=1/7=0.143

Charge Fraction after stripping



Elelment"	"At. No."	"Mass #"	"q-after-stripping"	"Charge fraction"	"(q/A)_new"
"F"	9	17	6	44	0.353
"F"	9	18	6	44	0.333
"Ne"	10	19	6	40	0.316
"Ar"	18	35	9	33	0.257
"K"	19	38	10	33.4	0.263
"Ga"	31	64	14	21.8	0.219
"As"	33	70	14	22.3	0.2
"Ga"	31	78	14	21.8	0.179
"Ge"	32	80	14	22.3	0.175
"As"	33	83	14	22.4	0.169
"Se"	34	85	15	21.8	0.176
"Br"	35	88	15	22.9	0.17
"Kr"	36	90	15	23.3	0.167
"Rb"	37	93	16	22.5	0.172
"Ag"	47	118	20	22.1	0.169
"In"	49	123	21	21.1	0.171
"I"	53	133	22	18.9	0.165
"Xe"	54	135	21	18	0.156
"Cs"	55	138	22	17.1	0.159
"Ba"	56	140	22	16.7	0.157
"La"	57	143	22	16.5	0.154
"Ce"	58	145	22	16	0.152
"Pr"	59	148	22	16.2	0.149
"Nd"	60	150	22	16.4	0.147