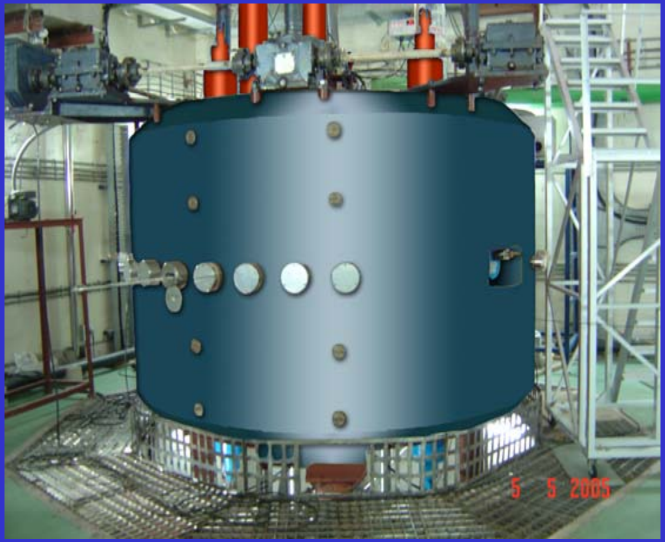
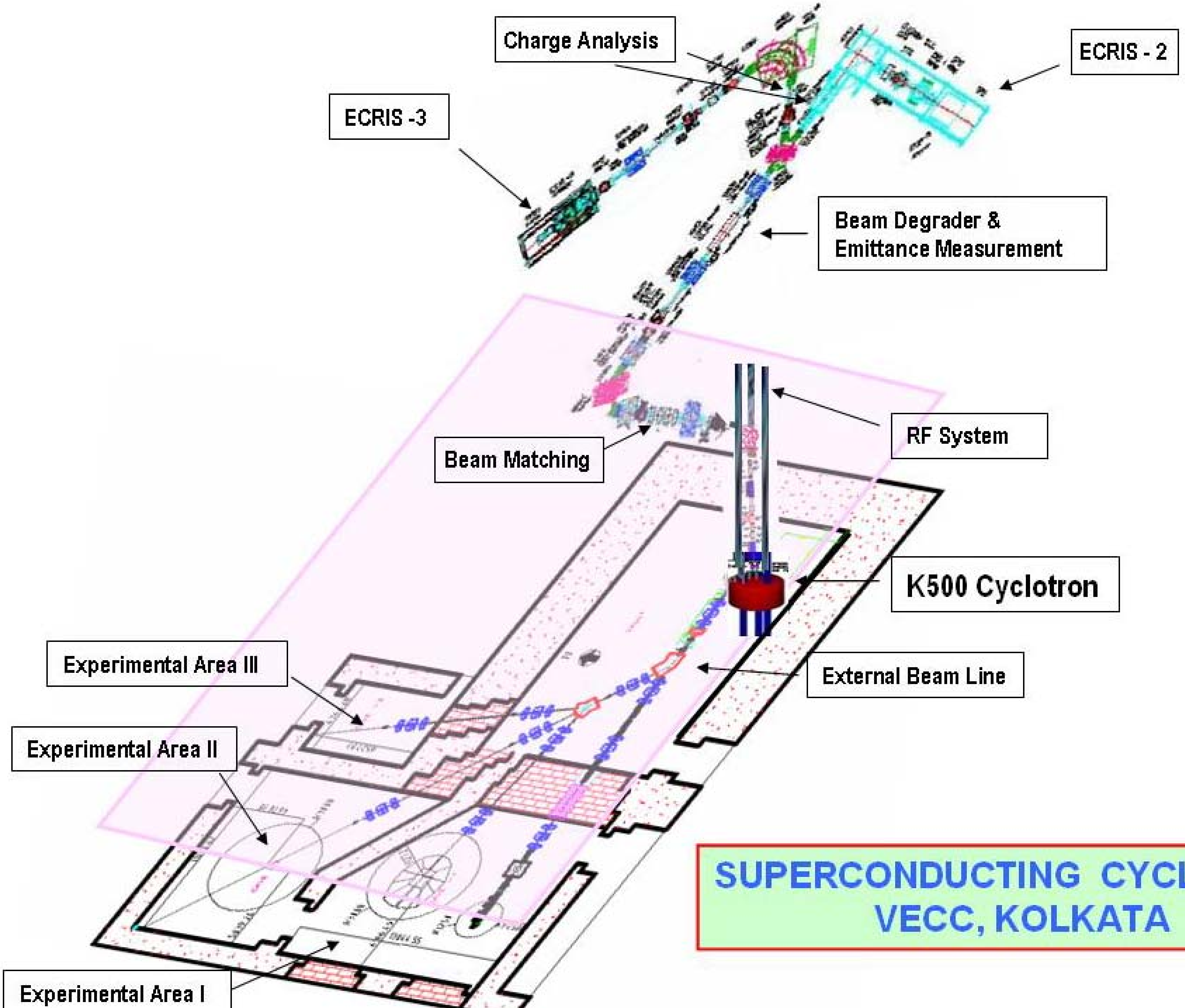
INJECTION
AND
EXTRACTION SYSTEM
OF
SUPERCONDUCTING CYCLOTRON

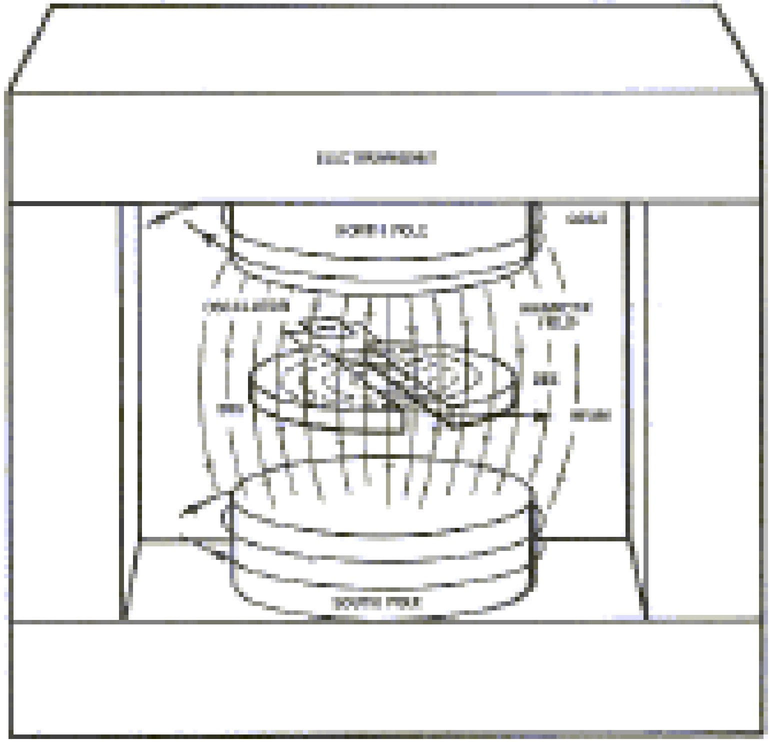


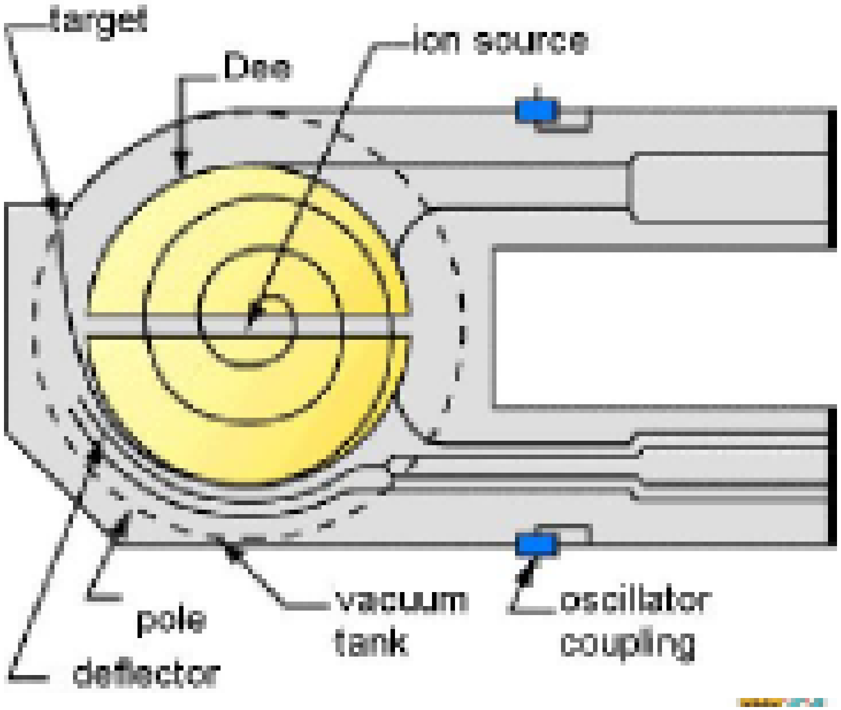
C. MALLIK
VECC
KOLKATA



SUPERCONDUCTING CYCLOTRON VECC, KOLKATA

$E(\text{Energy})=B^2 R^2 Q^2/2M$



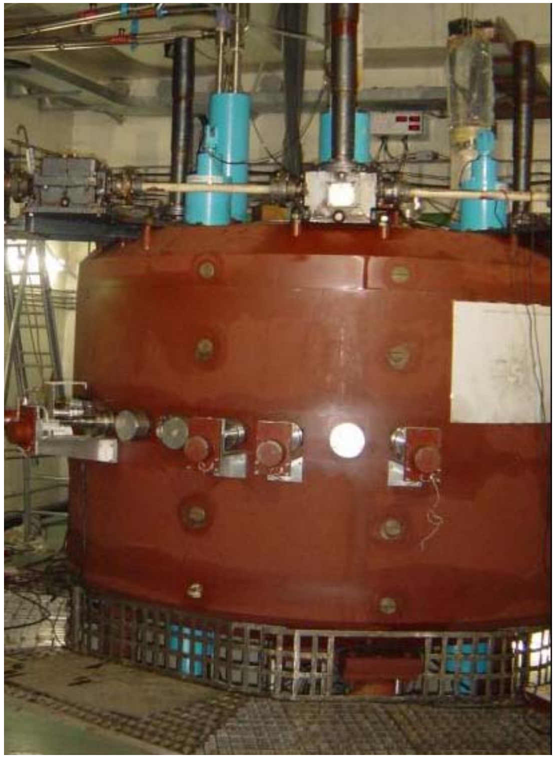


Superconducting cyclotron (1985)

- Most existing cyclotrons utilize room temperature magnets Bmax =2T (iron saturation)
- Beyond that, superconducting coils must be used: $B_{hill} \sim 6$ T
    1. Small magnets for high energy
    2. Low operation cost

VECC

SCC

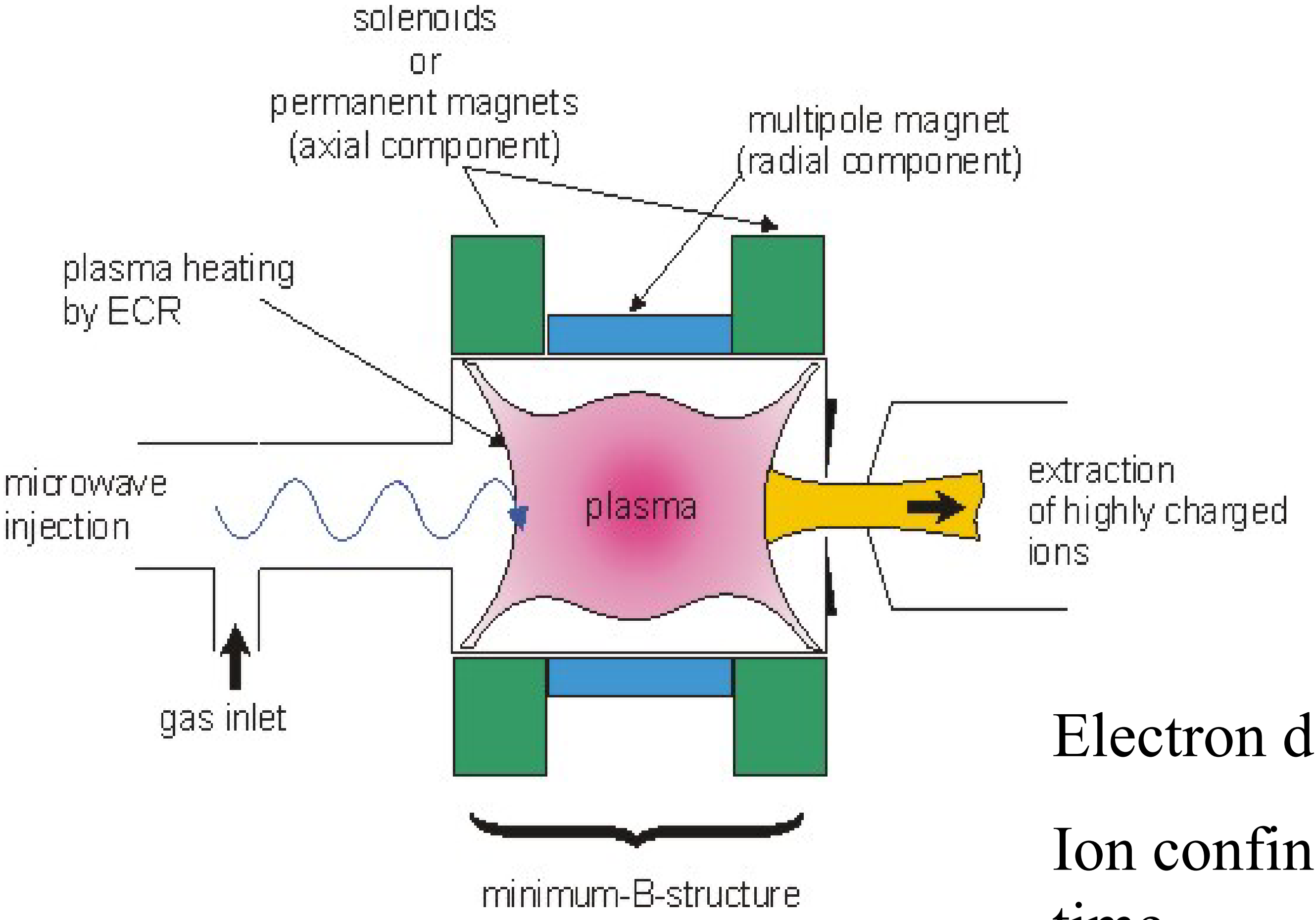


VECC	***SCC***
224 cm	142 cm
2.1Tesla	5.8 Tesla
450 KW	40KW
K130	K500

RF System Specification

Frequency range	9 – 27 MHz
Harmonics	1,2,3,4,5,7
Dee Voltage	100 kV max.
Frequency stability	1×10^{-7}
Amplitude stability	1×10^{-4}
Phase stability	$< 0.5^0$

$P=p-qA$



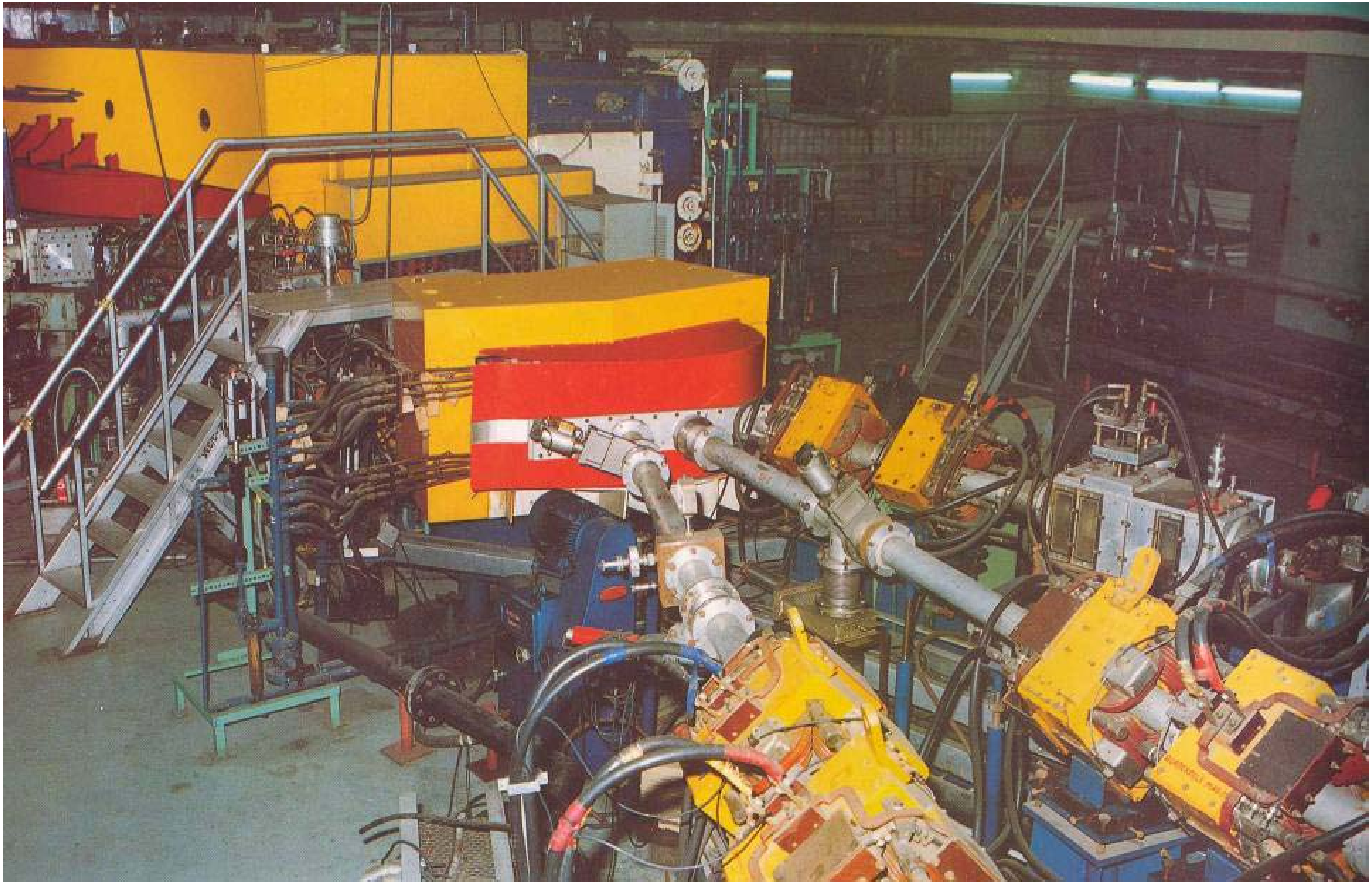
ECR ION SOURCE

Electron density

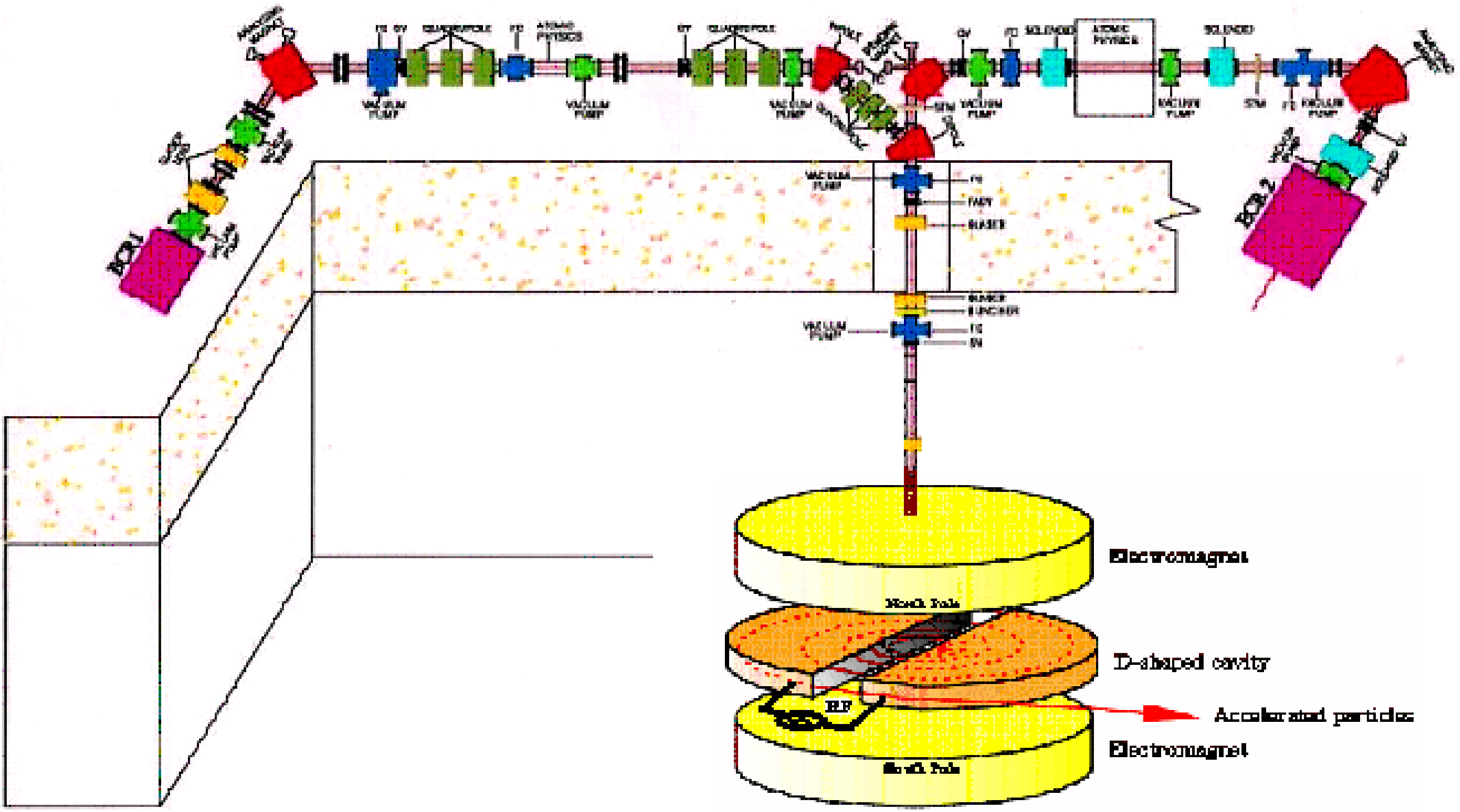
Ion confinement time

Electron temperature

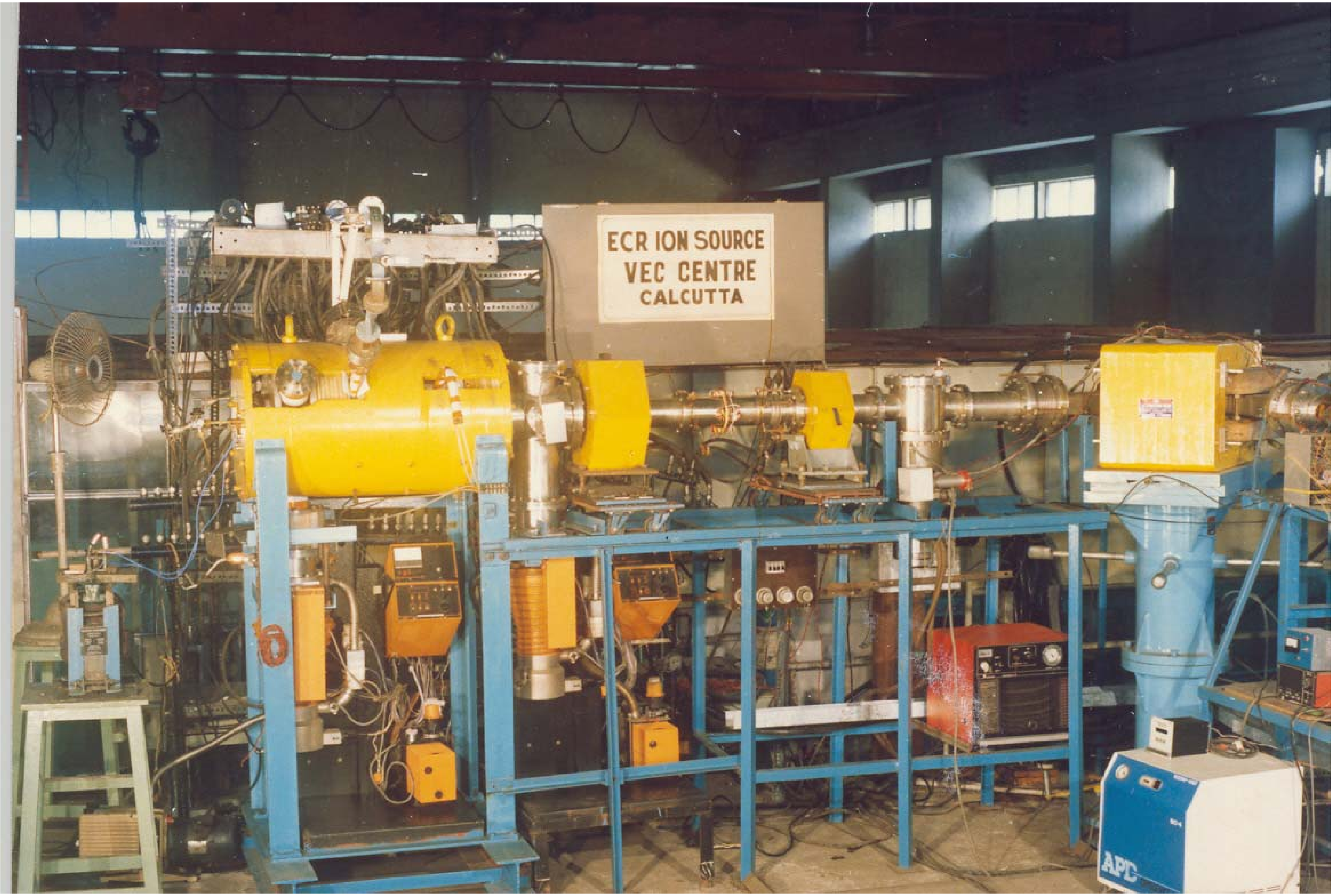
224cm Variable Energy Cyclotron



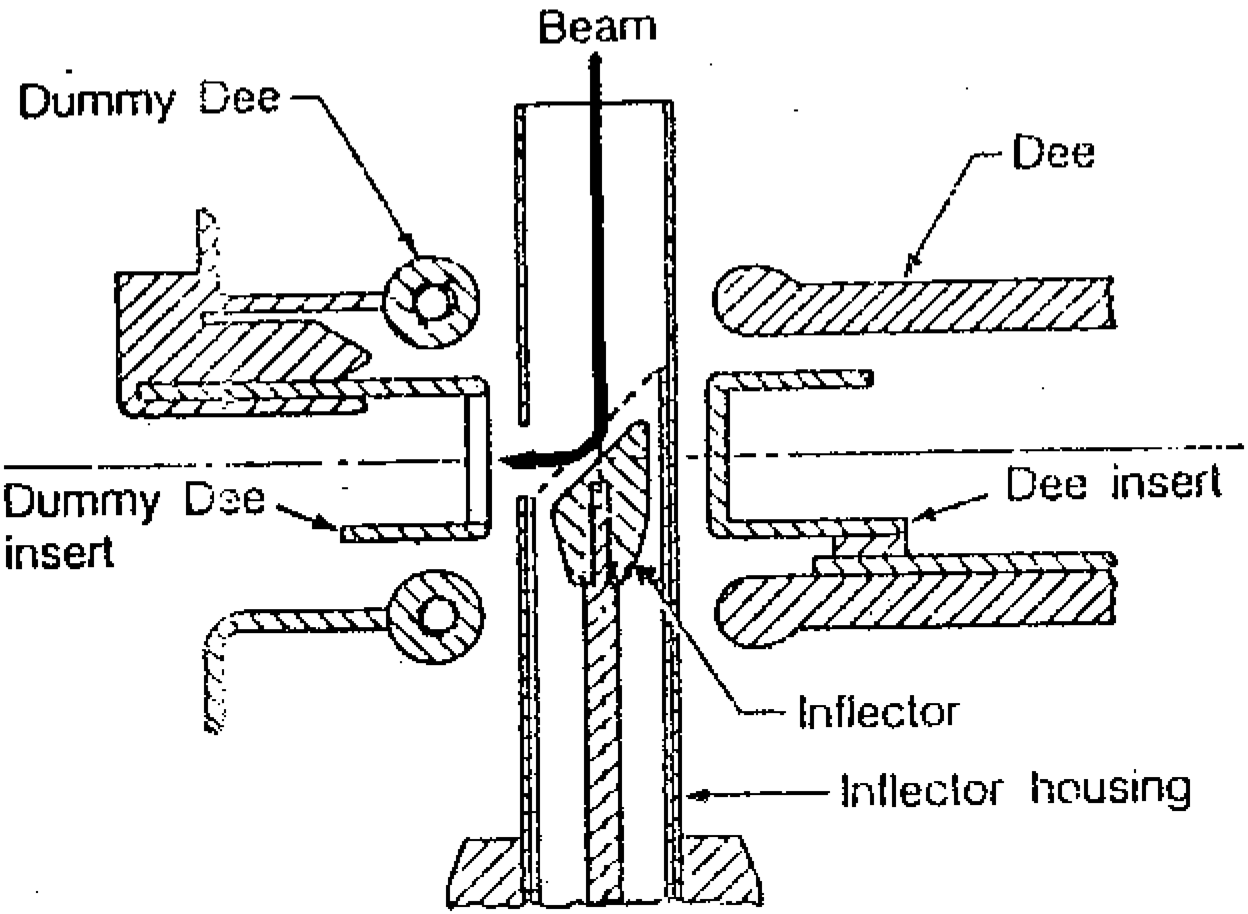
AXIAL INJECTION SYSTEM USING ECR 1 & 2
VARIABLE ENERGY CYCLOTRON CENTRE



ECR-1 AT VECC



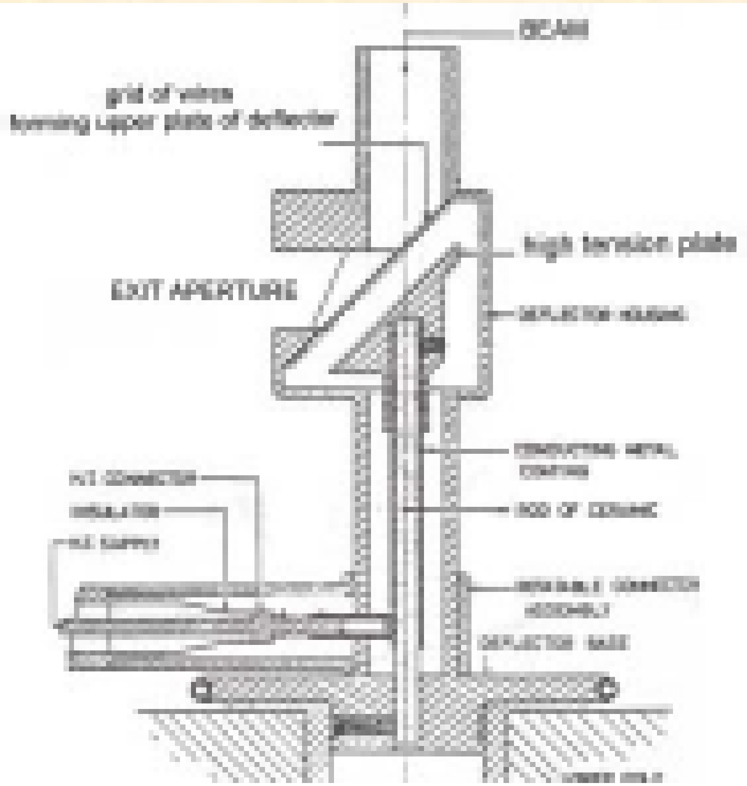

ECR ION SOURCE
ED12



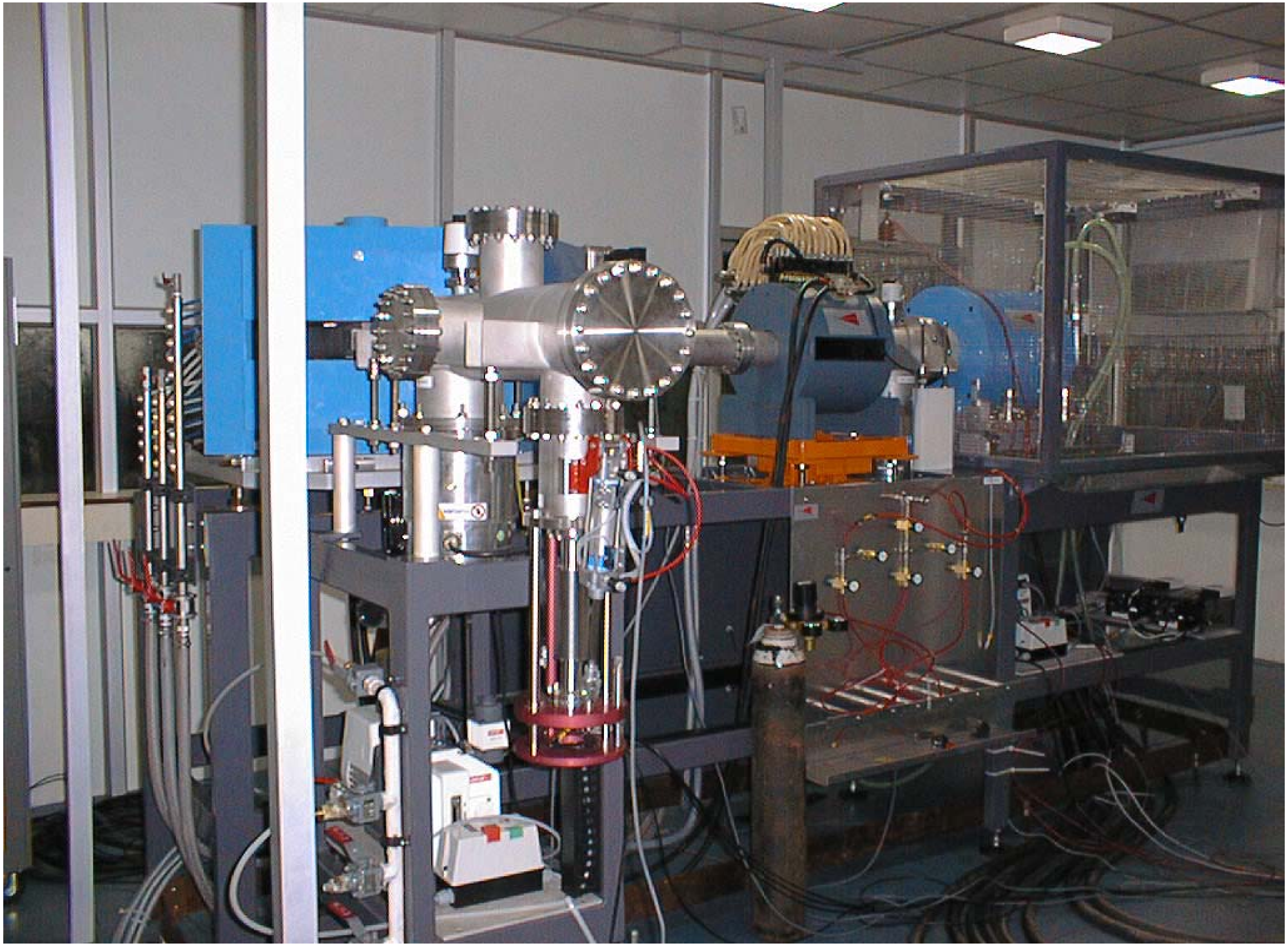
Schematic of central region modifications

Axial injection

1. The electrostatic mirror
   - Simpliest: A pair of planar electrodes which are at an angle of 45° to the incoming beam. The first electrode is a grid reducing transmission (65% efficiency).
   - smallest
   - High voltage

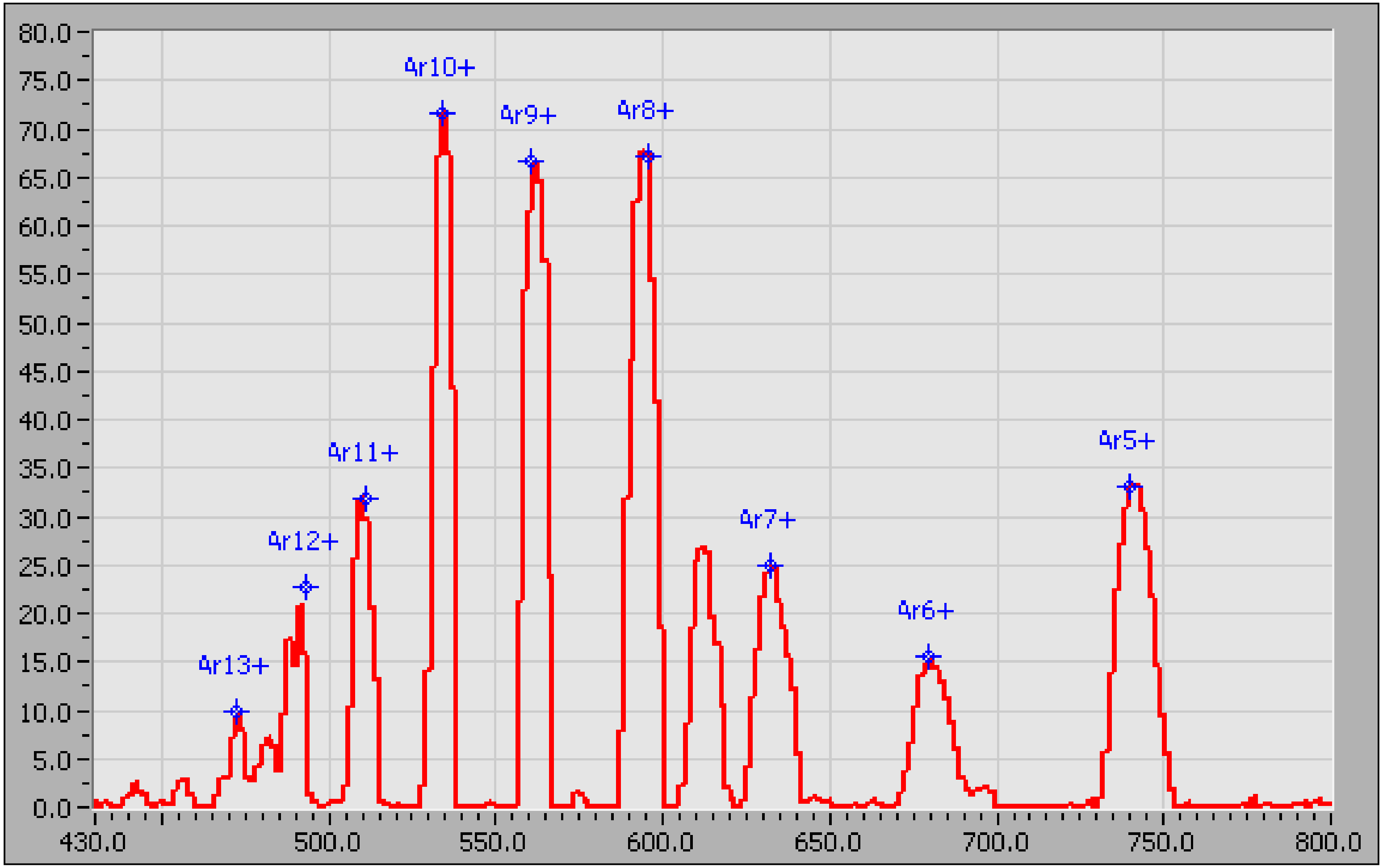


ECR ION SOURCE



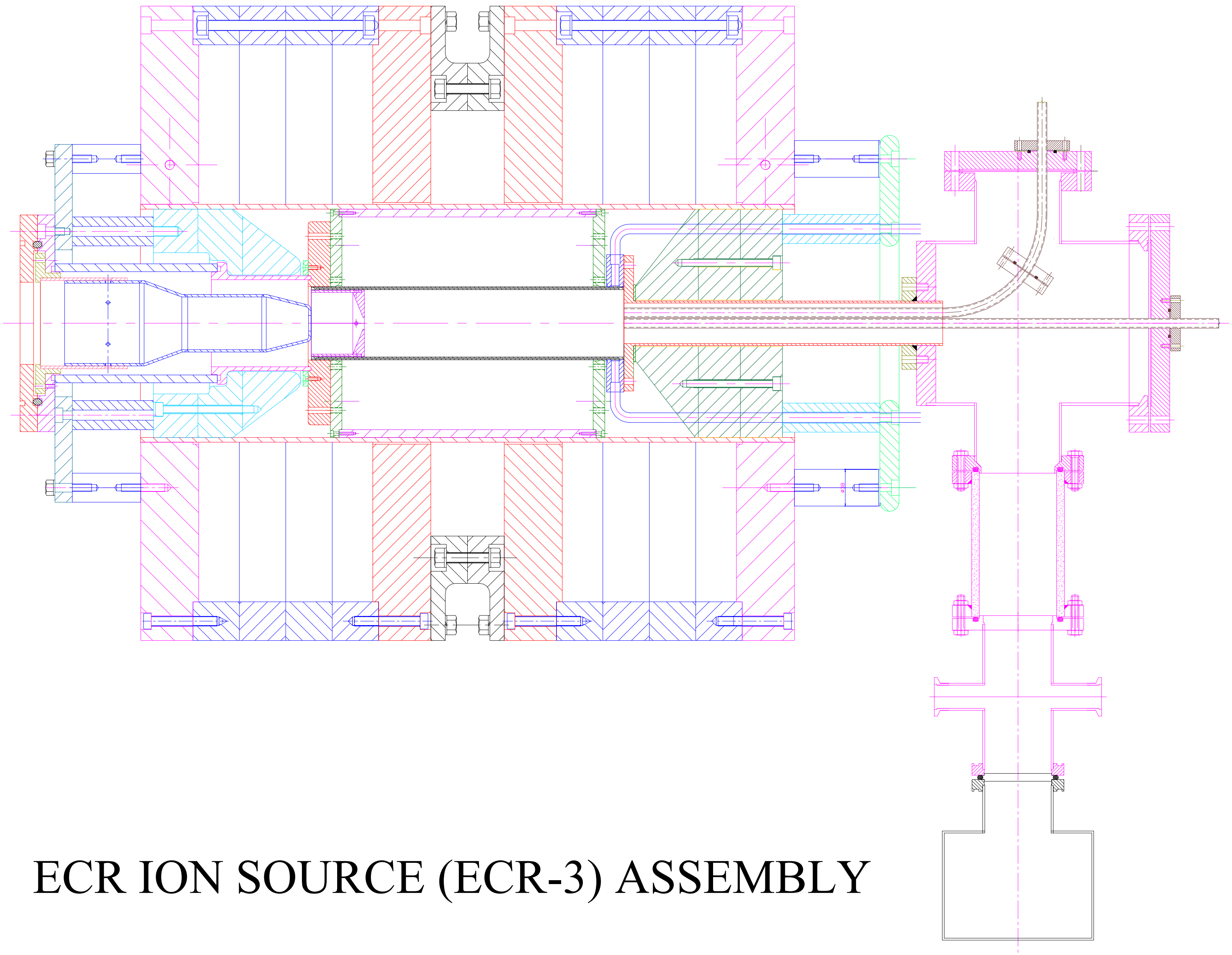
224 cm VARIABLE ENERGY CYCLOTRON - CALCUTTA - INDIA

Argon Beam Spectrum



ECR Ion Source

Fabrication Completed, Ready for Assembly



ECR ION SOURCE (ECR-3) ASSEMBLY

14 GHz ECR ION SOURCE

BEAM ENVELOPE FOR AXIAL INJECTION LINE

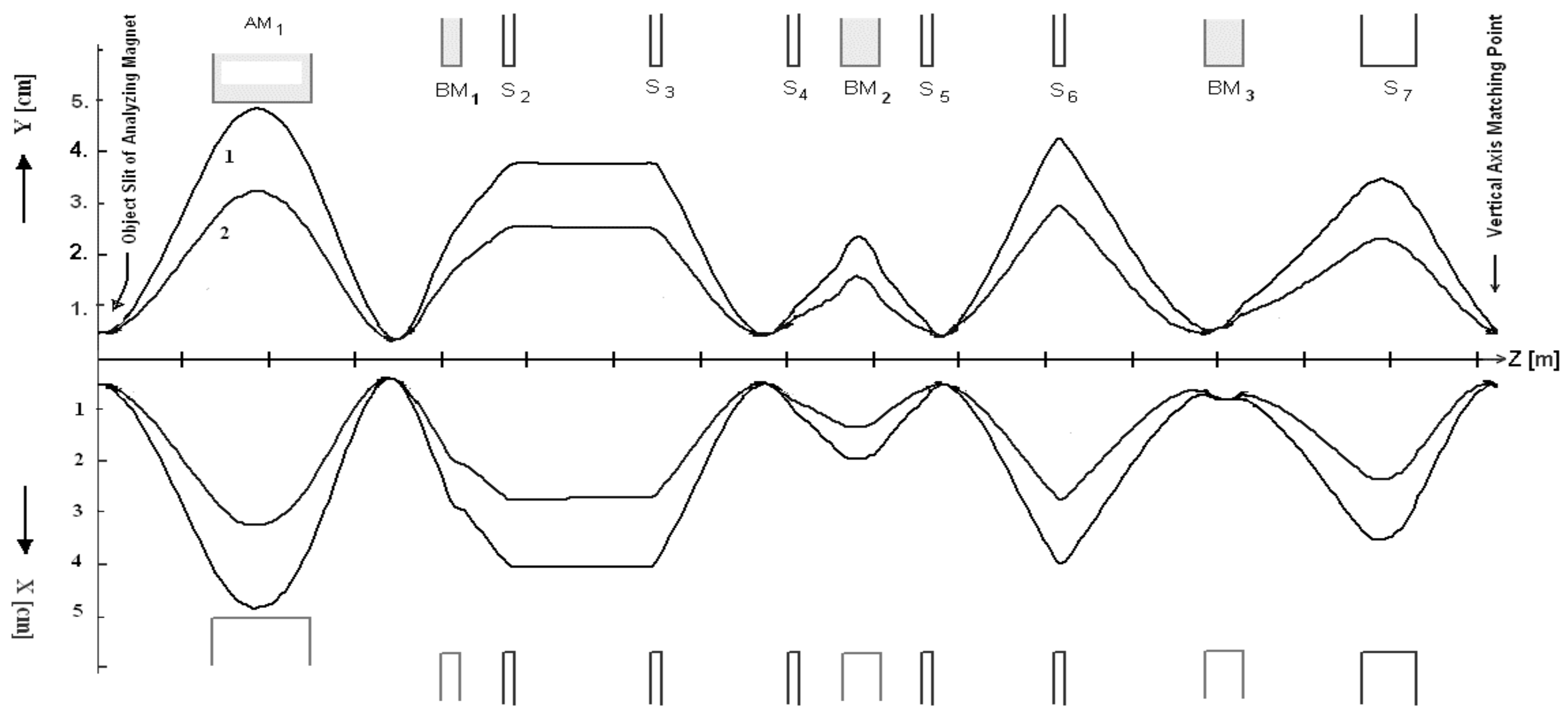
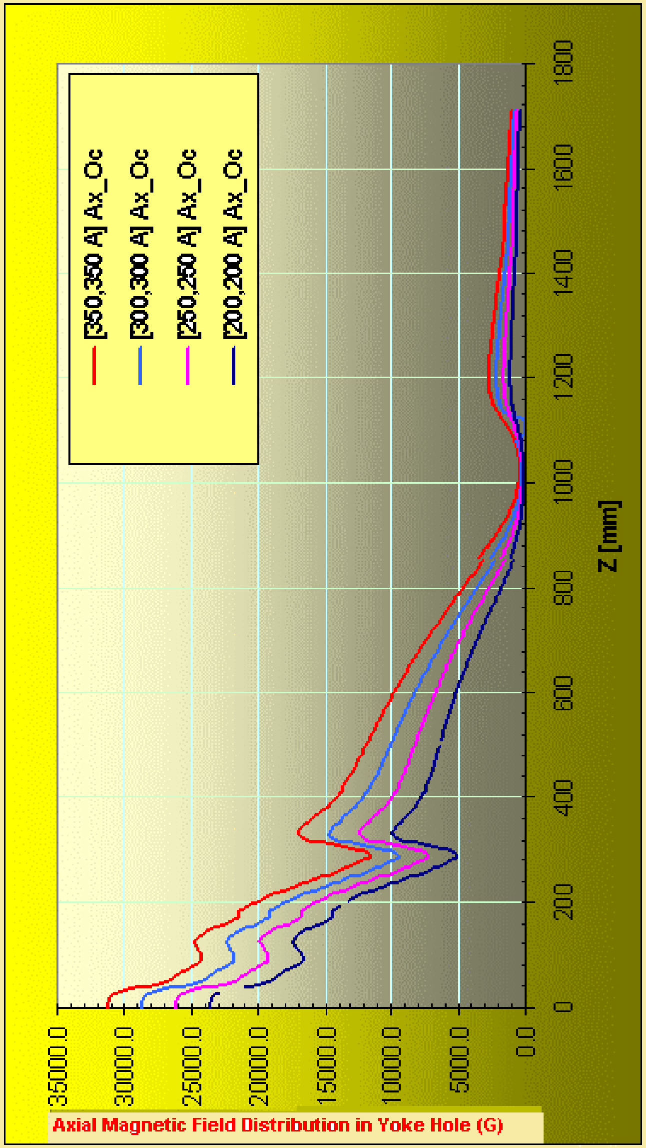
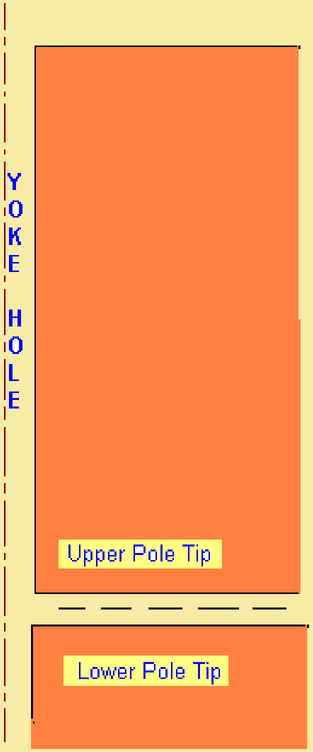
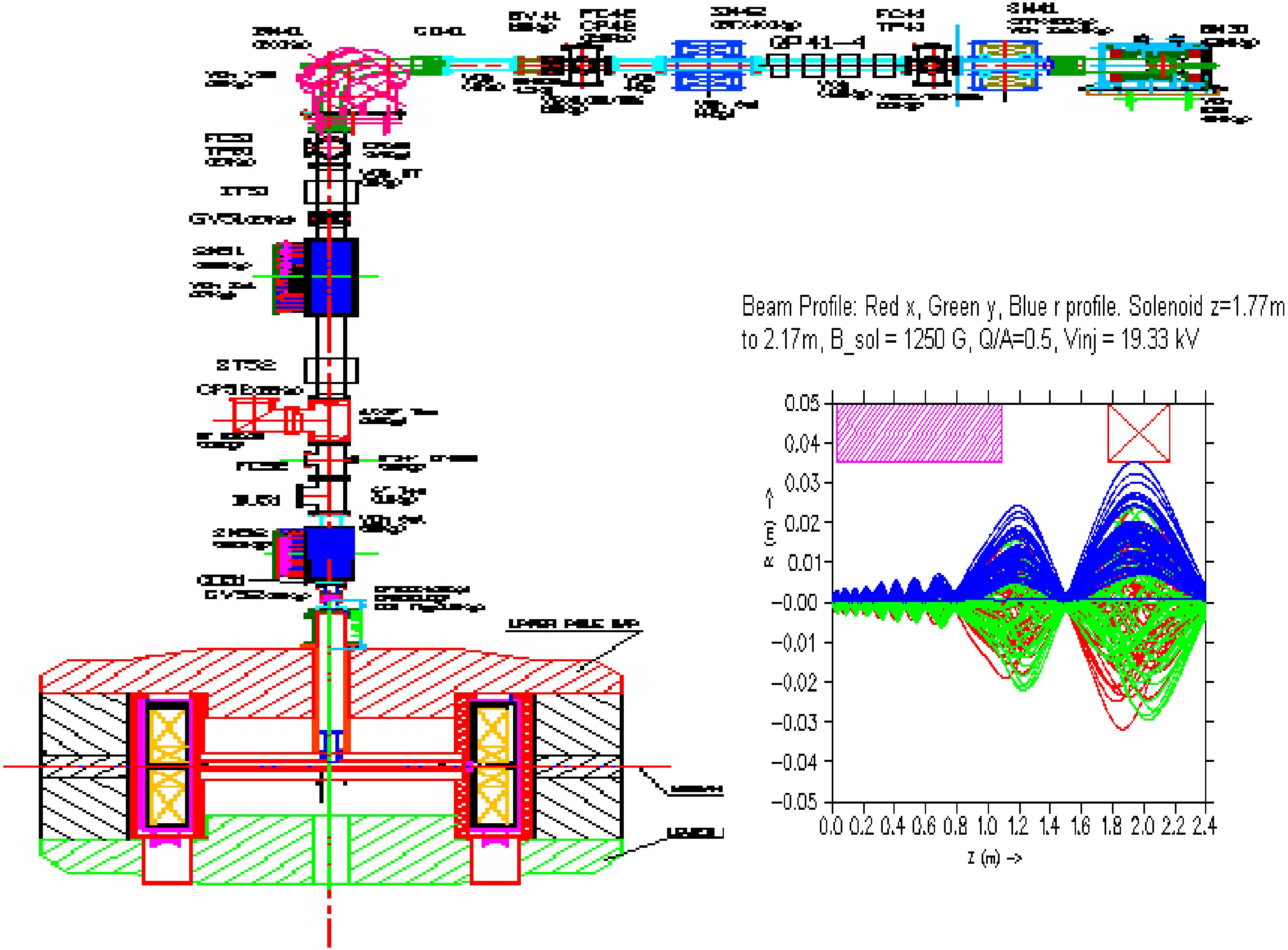


Figure 2. Beam envelopes for different emittances. (1) $\epsilon=150\ \pi$ mmmrad (2) $100\ \pi$ mmmrad.

MAGNETIC FIELD IN YOKE HOLE



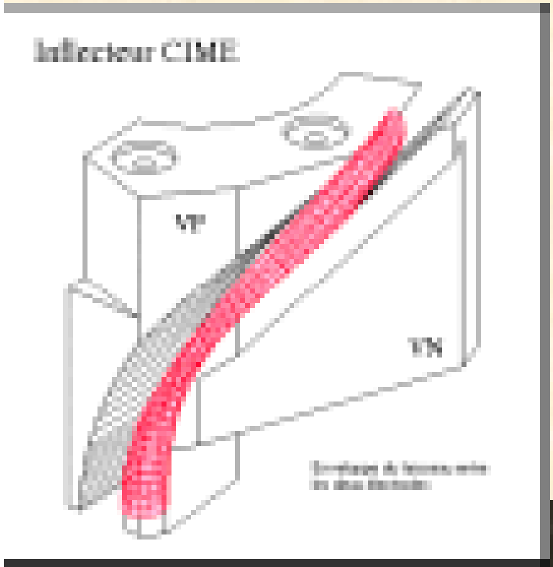




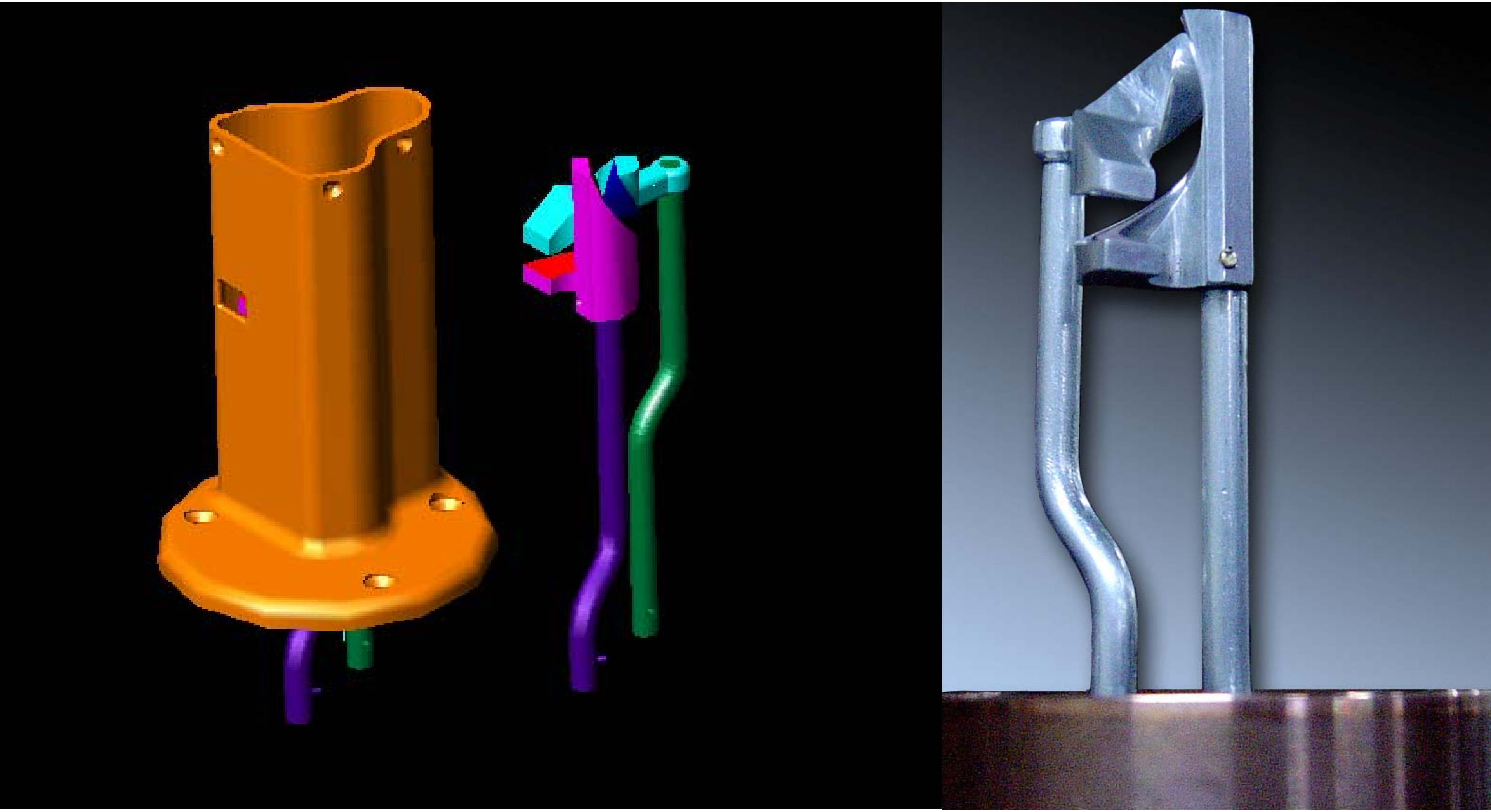
Beam Profile: Red x, Green y, Blue r profile. Solenoid z=1.77m to 2.17m, B_sol = 1250 G, Q/A=0.5, Vinj = 19.33 kV

LAYOUT OF VERTICAL SECTION OF INJECTION LINE FOR VEC K-500 SUPERCONDUCTING CYCCLOTRON

Spiral inflector



- First used in Grenoble (J.L. Pabot J.L. Belmont)
- Consists of 2 cylindrical capacitors which have been twisted to take into account the spiralling of the ion trajectory from magnet field.
- $\vec{v}_{beam} \perp \vec{E}$: central trajectory lies on an equipotential surface. Allows lower voltage than with mirrors.
- 2 free parameters (spiral size in z and xy) giving flexibility for central region design
- 100 % transmission



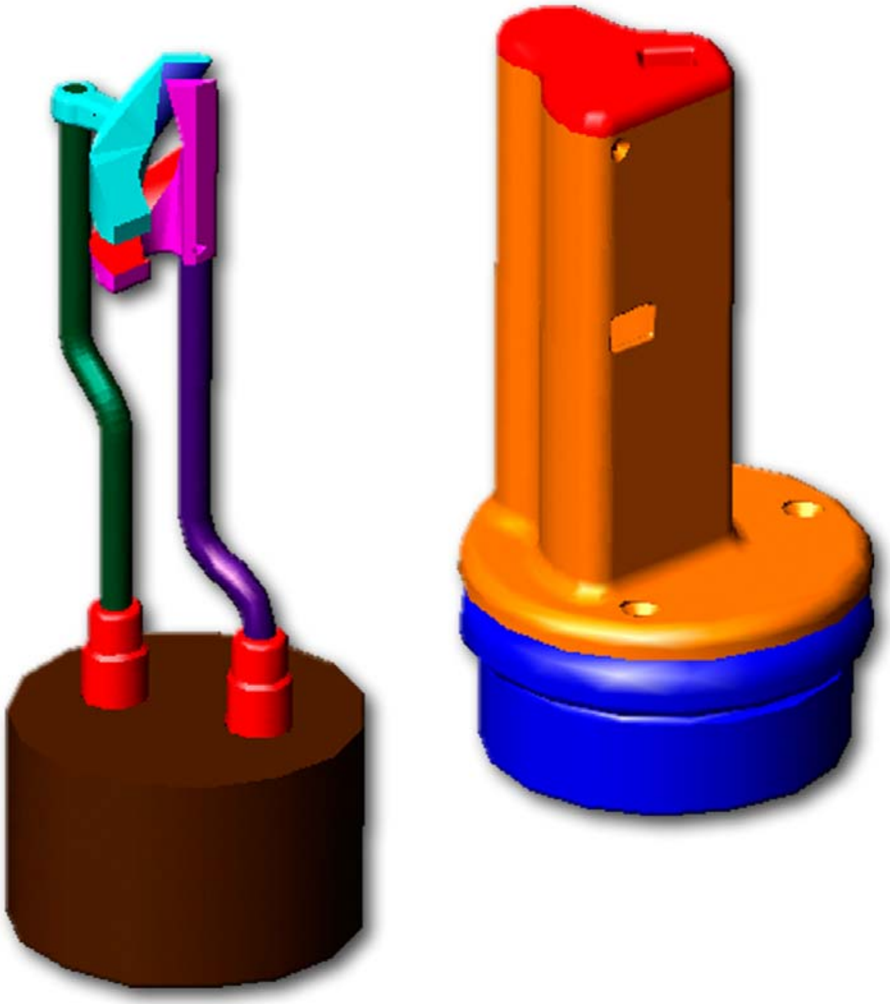
SPIRAL INFLECTOR

Fabrication work at CDM, BARC

$$\begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & K'/2 & K & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ -K'/2 & -K & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \quad \text{(varying axial field)}$$

$$\begin{pmatrix} 0 & 1 & -CK & 0 & 0 & 0 \\ -S^2K^2 & 0 & -SK/A & 0 & 0 & SK \\ CK & 0 & 0 & 1 & 0 & 0 \\ -SK/A & 0 & 0 & 0 & 0 & 2/A \\ -SK & 0 & -1/A & 0 & 0 & 1 \\ -CK/A & 0 & 0 & -1/A & 0 & 0 \end{pmatrix}, \quad \text{(spiral inflector)}$$

where $K = 1/\rho$, A is the inflector height, $S = \sin(s/A)$, $C = \cos(s/A)$, s is the independent variable and is set to zero at the inflector entrance. For the spiral inflector, the two transfer matrices



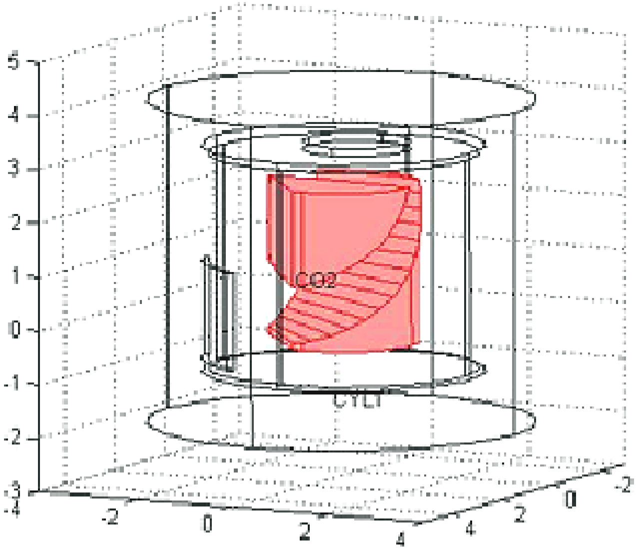
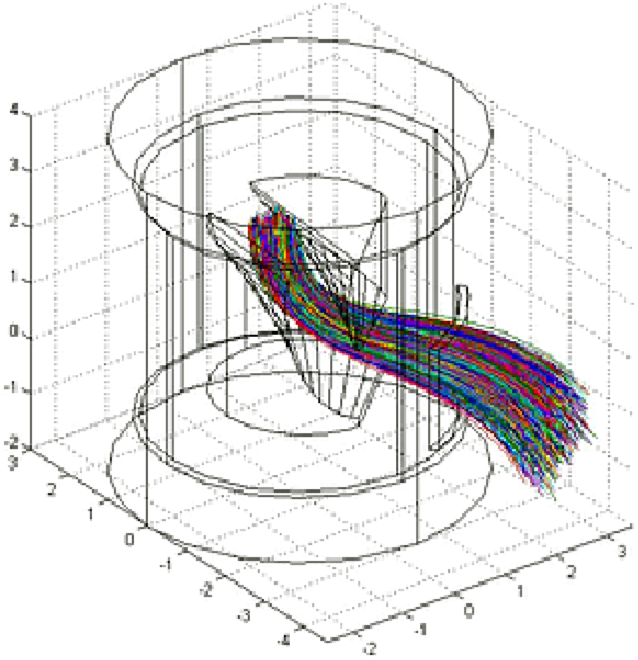
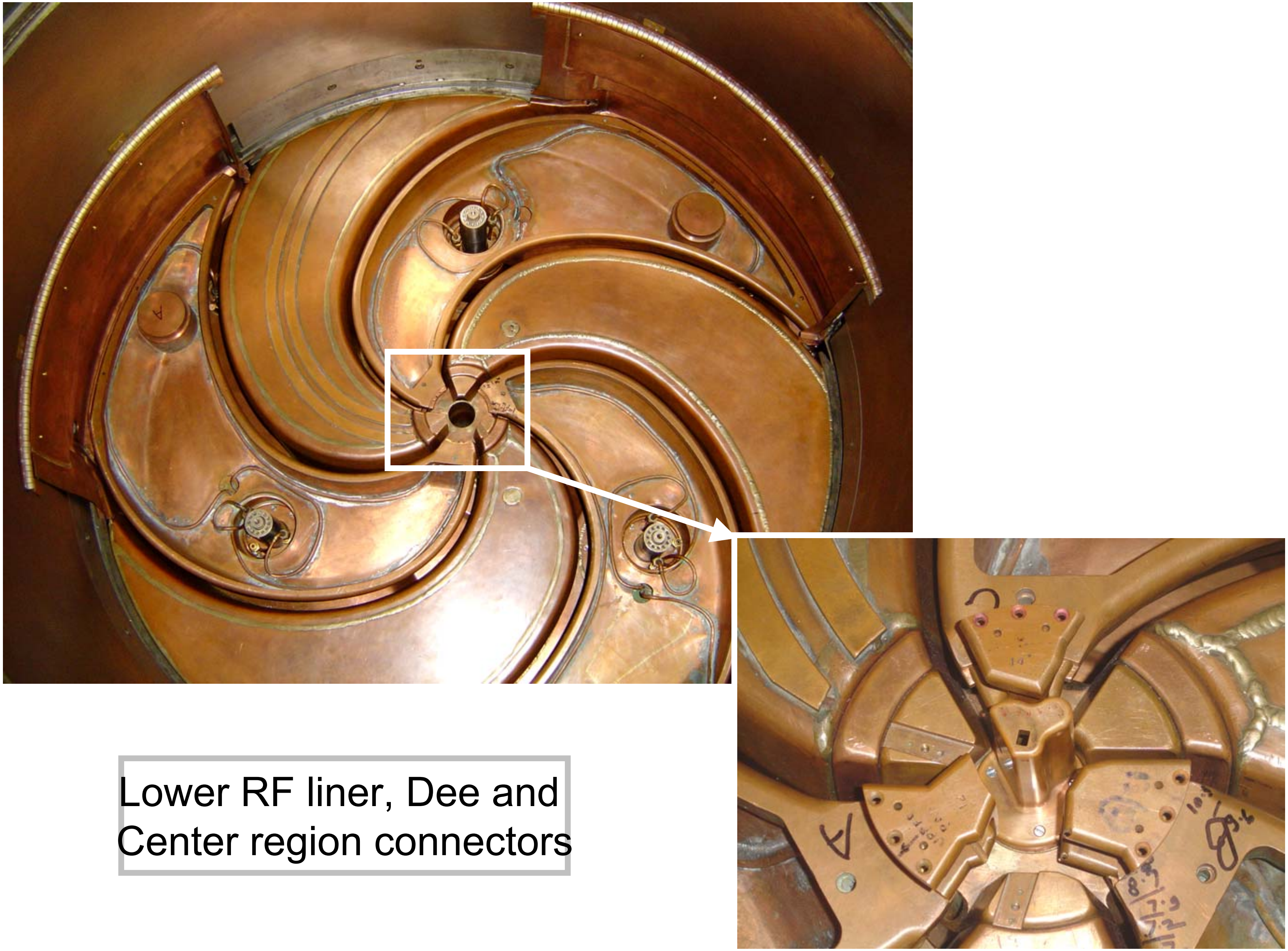
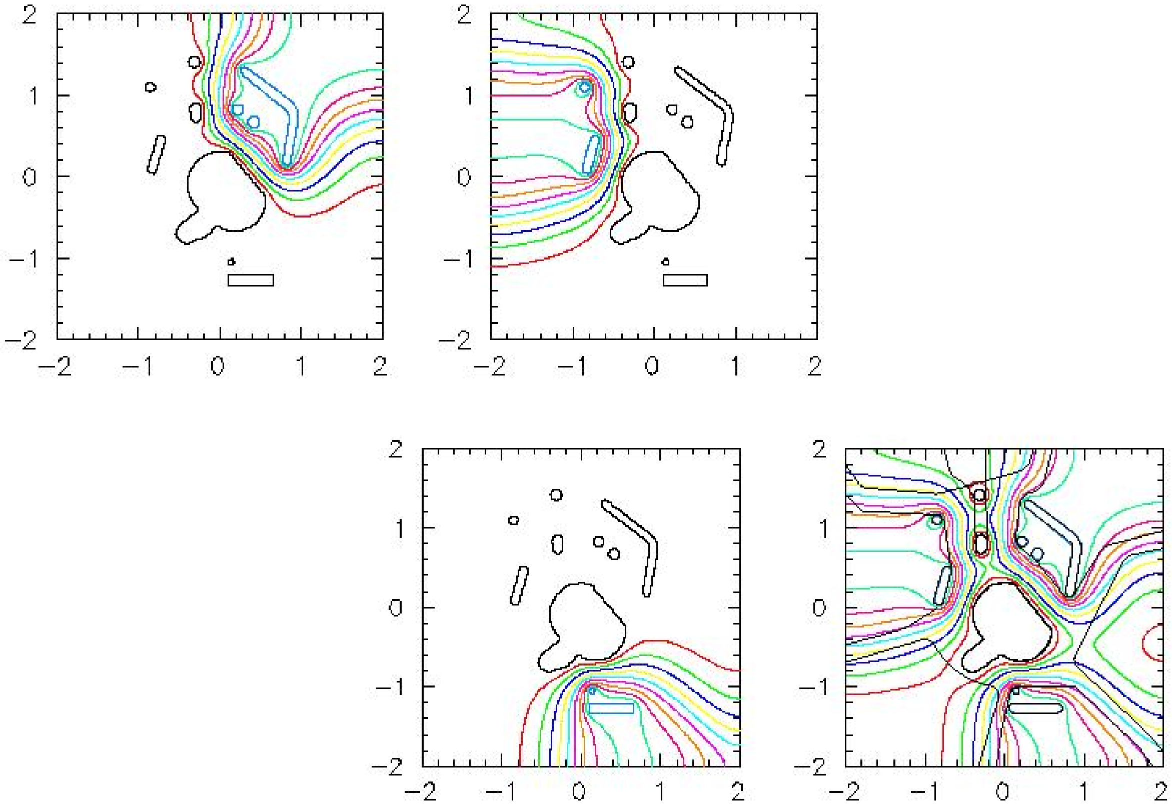


Figure 2: The spiral inflector.





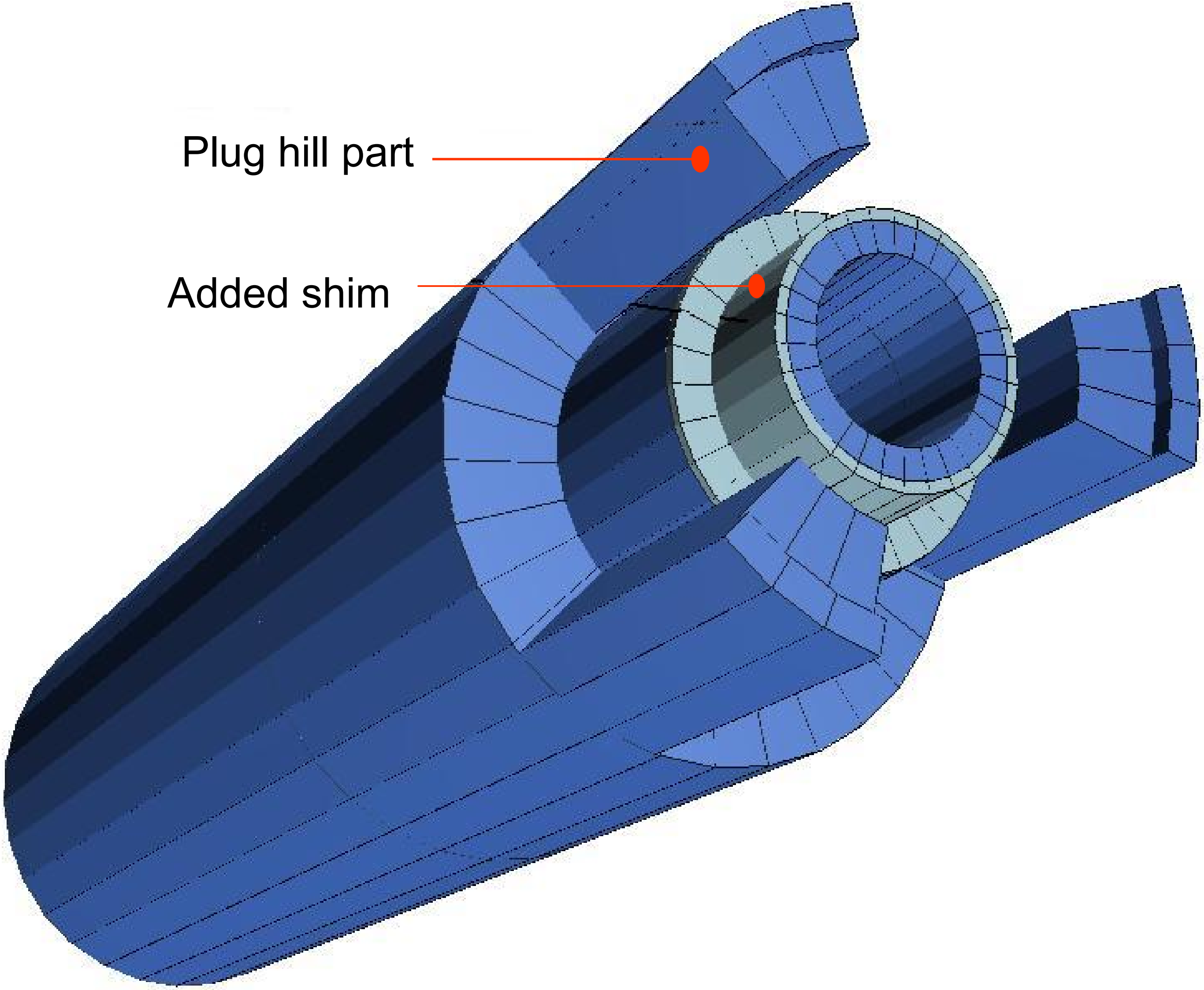
Lower RF liner, Dee and Center region connectors



Electric potential distribution for central region electrode structures as simulated with the code RELAX3D. (a) The equipotential contours for dee-1 kept at V_{dee} and other electrodes grounded. (b) and (c) shows the similar picture for dee-2 and dee-3 kept at V_{dee} respectively while others grounded. (d) shows the distribution when all the dees are at V_{dee}; the dees, dummy dees and posts are also shown.

RELAX3D,
ANSYS

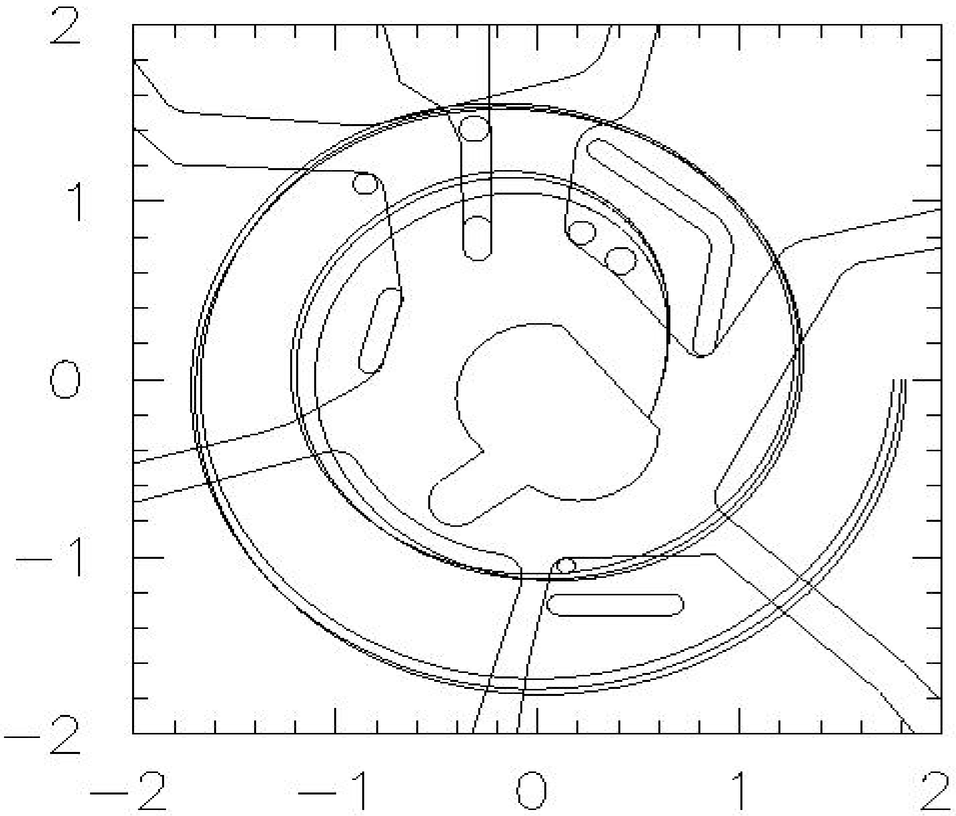
CENTRAL PLUG



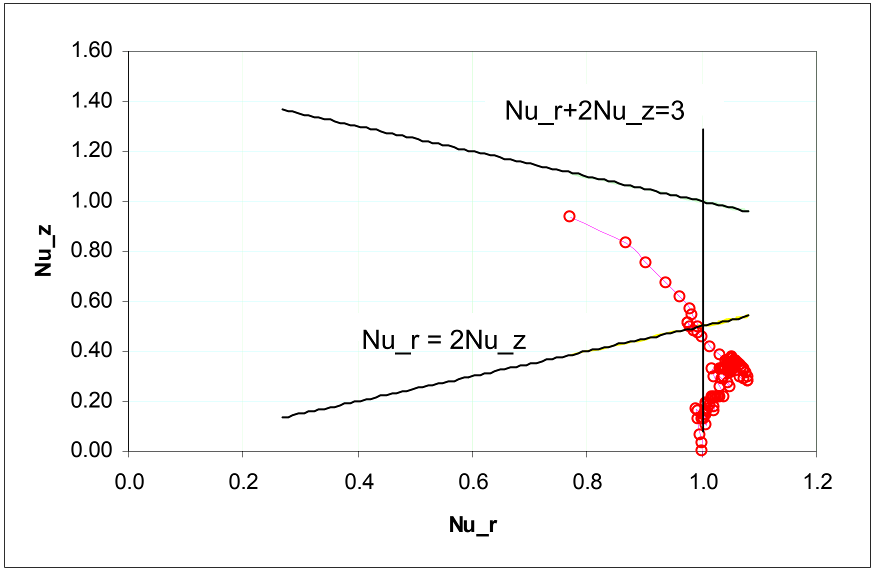
Plug hill part

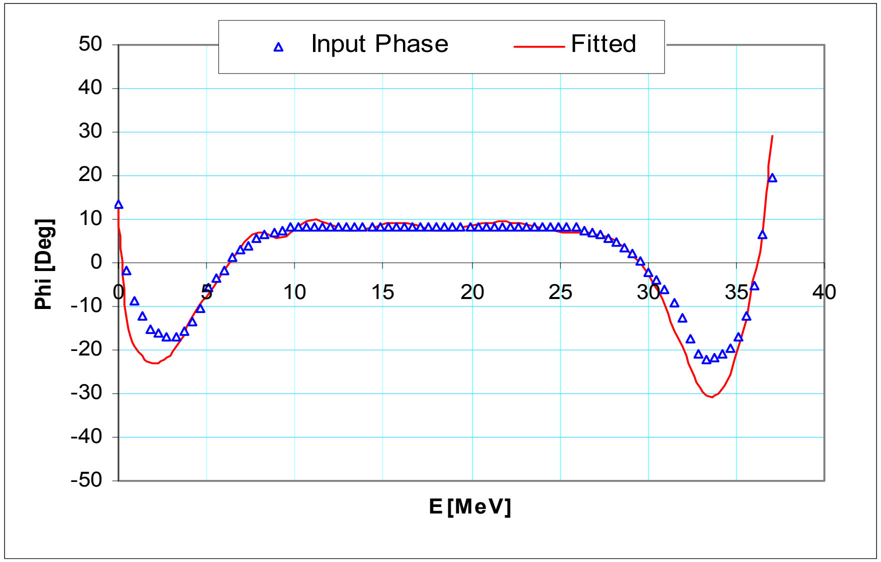
Added shim

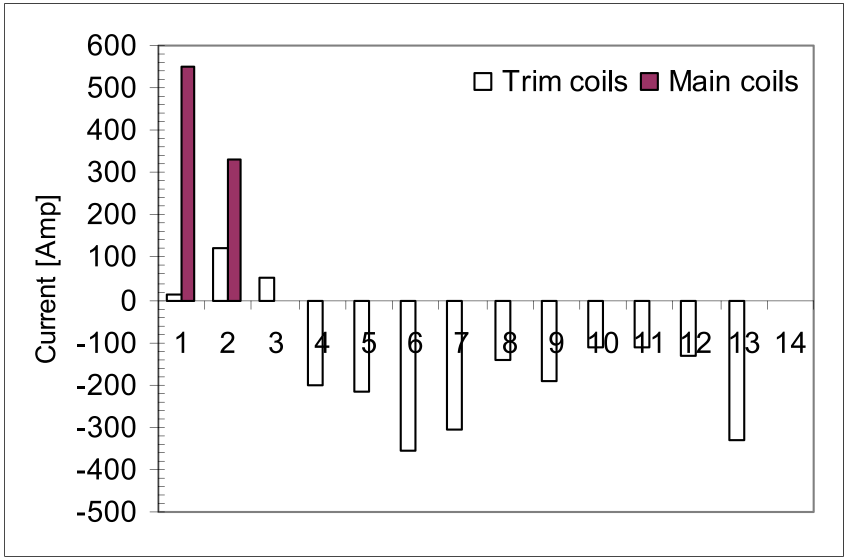
Central Region Electrode Structure and Reference Trajectory

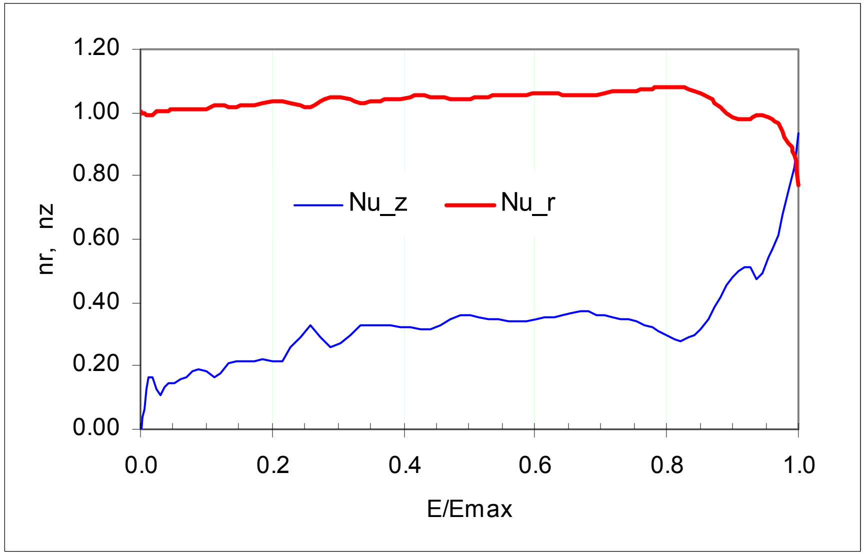


Q/A=0.37 37 MeV/n



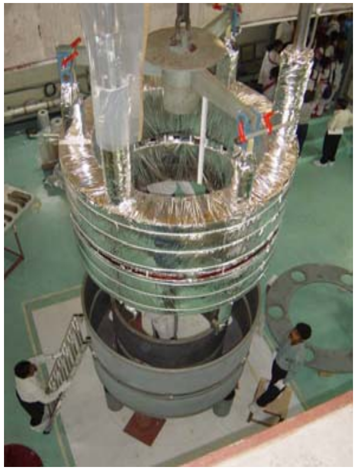


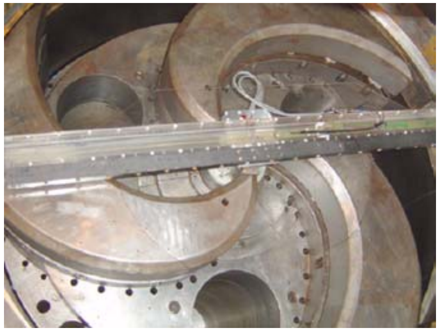





15 5 2004


7 14:32



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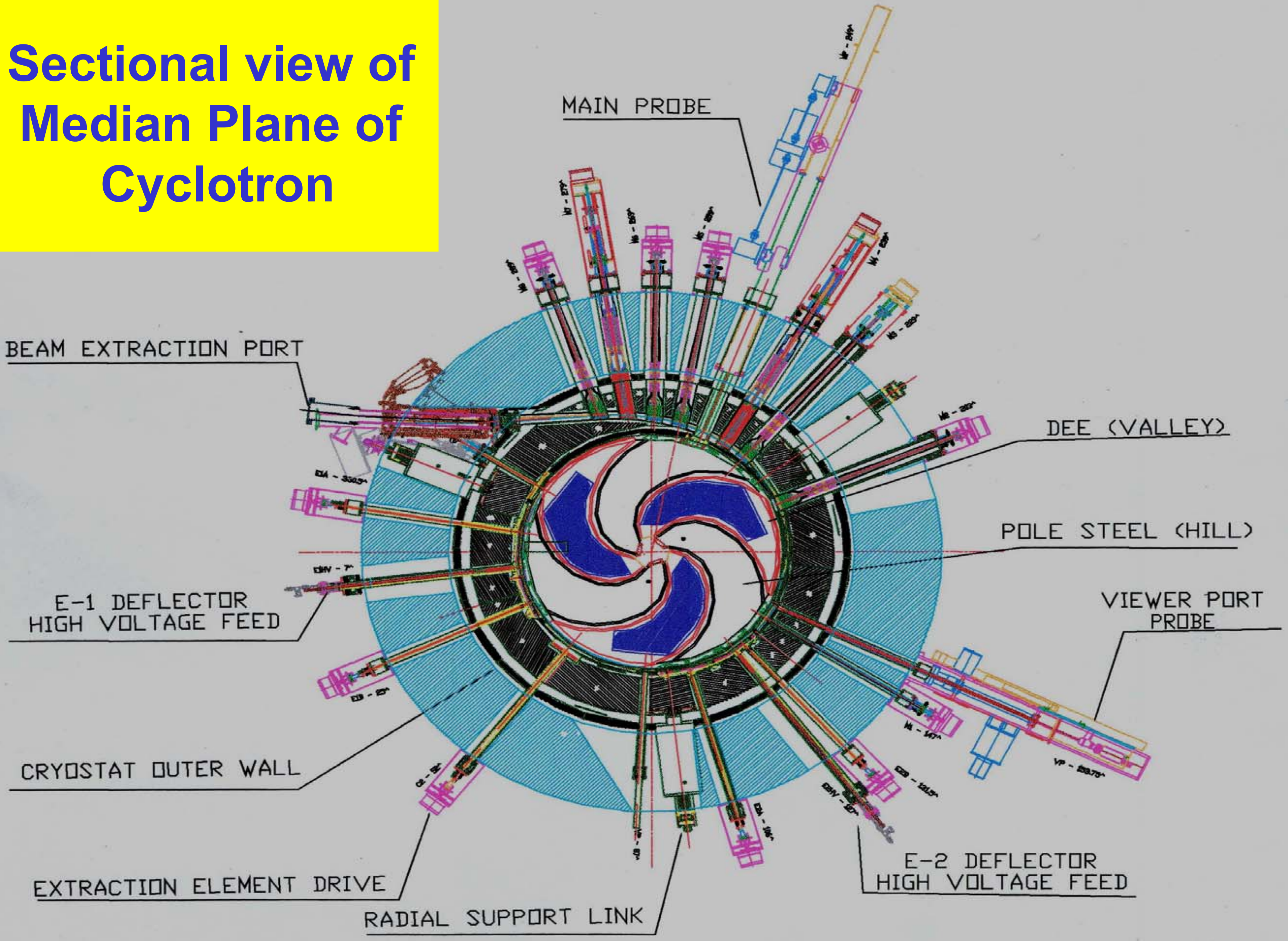
Sectional view of Median Plane of Cyclotron



Relativistic case

Isochronism and Lorentz factor

$$m = \gamma m_0 = \frac{m_0}{\sqrt{1-\beta^2}} \quad , \quad \beta = \frac{v}{c}$$

$$\boxed{\omega_{rev} = \frac{QB(r)}{\gamma(r) m_0}}$$

ω_{rev} constant if $B(r)=\gamma(r)B_0$ ↗ increasing field (n < 0)

Not compatible with a decreasing field for vertical focusing

Tunes

$$\nu_r^2 = 1 + \kappa, \text{ and } \nu_z^2 = -\kappa + F^2(1 + 2\tan^2\xi)$$

These expressions were originally derived by Symon, Kerst, Jones, Laslett, Terwilliger in the original 1956 Phys. Rev. paper about FFAGs.

Note: Since there is now a distinction between local curvature (ρ) and global (R), the definition of field index is ambiguous. The local index, used in the dipole transfer matrix, is $k = \frac{\rho}{B}\frac{dB}{d\rho}$, while the Symon formula uses $\kappa = \frac{R}{B}\frac{dB}{dR} \approx k\,\frac{R}{\rho}$. It is in fact this latter quantity which must be equal to $\beta^2\gamma^2$ for isochronism.

For isochronous machines, we therefore have

$$\nu_r = \gamma, \text{ and } \nu_z^2 = -\beta^2\gamma^2 + F^2\left(1 + 2\tan^2\xi\right)$$

Energy and focusing limits

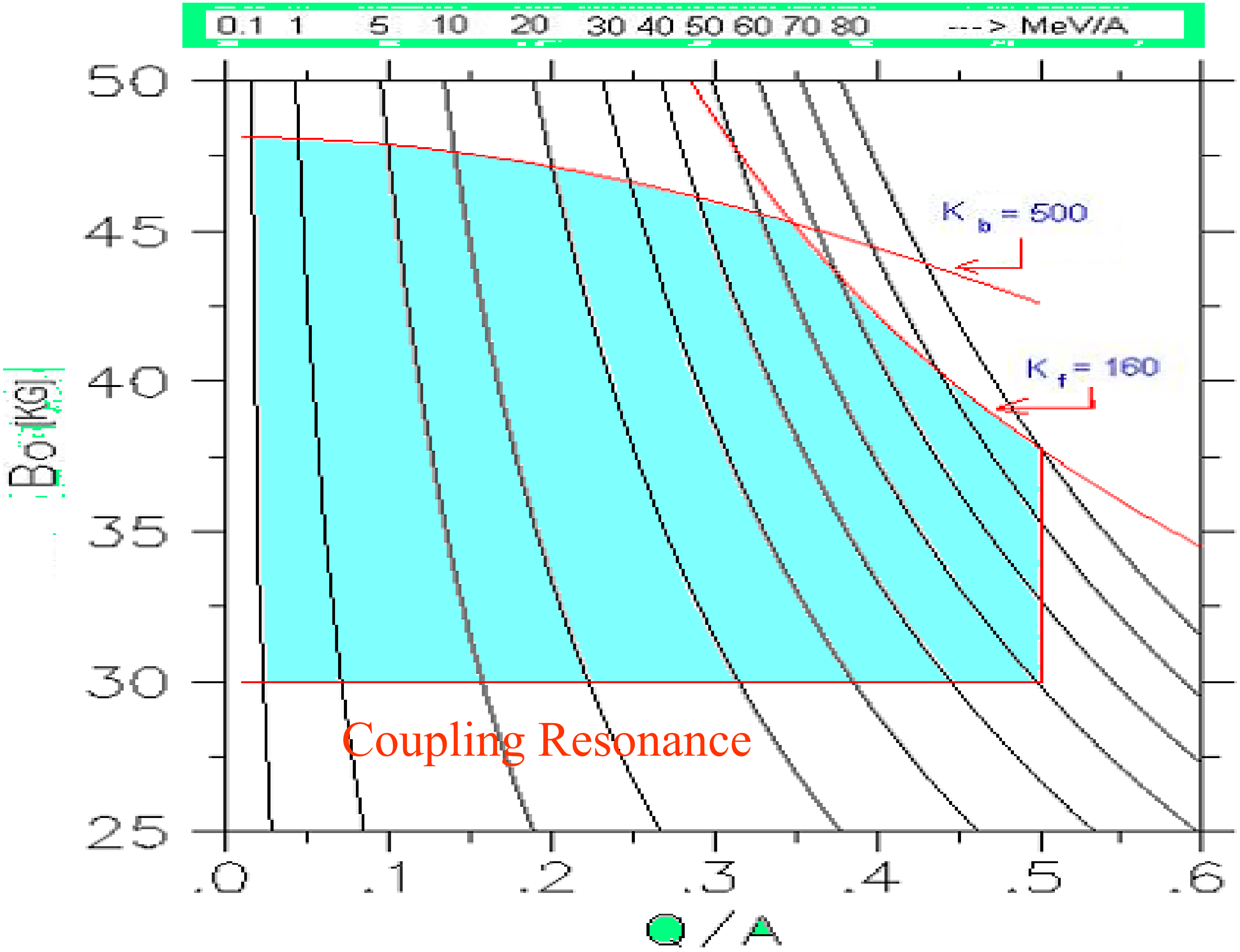
1. For conventional cyclotron, F increases for small hill gap (B_{hill} ↗) and deep valley (B_{val} ↘) but <u>does not depend</u> on the magnetic field level:

$$\boxed{F = \frac{\left(B_{hill} - B_{val}\right)^2}{8\langle B\rangle^2}}$$

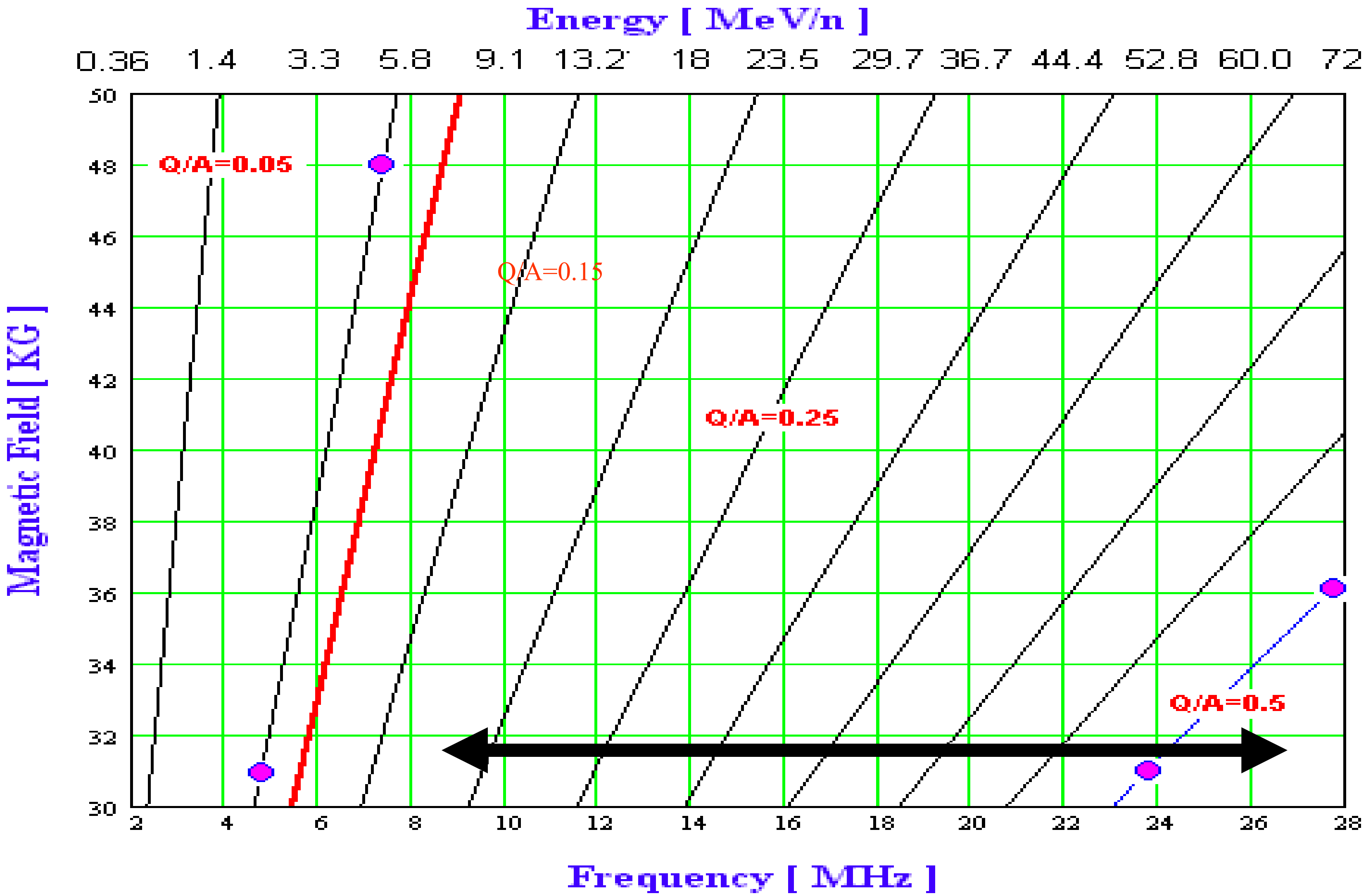
2. For superconducting cyclotron, the iron is saturated, the term $(B_{hill}-B_{val})^2$ is constant, hence $F \propto 1/\langle B\rangle^2$

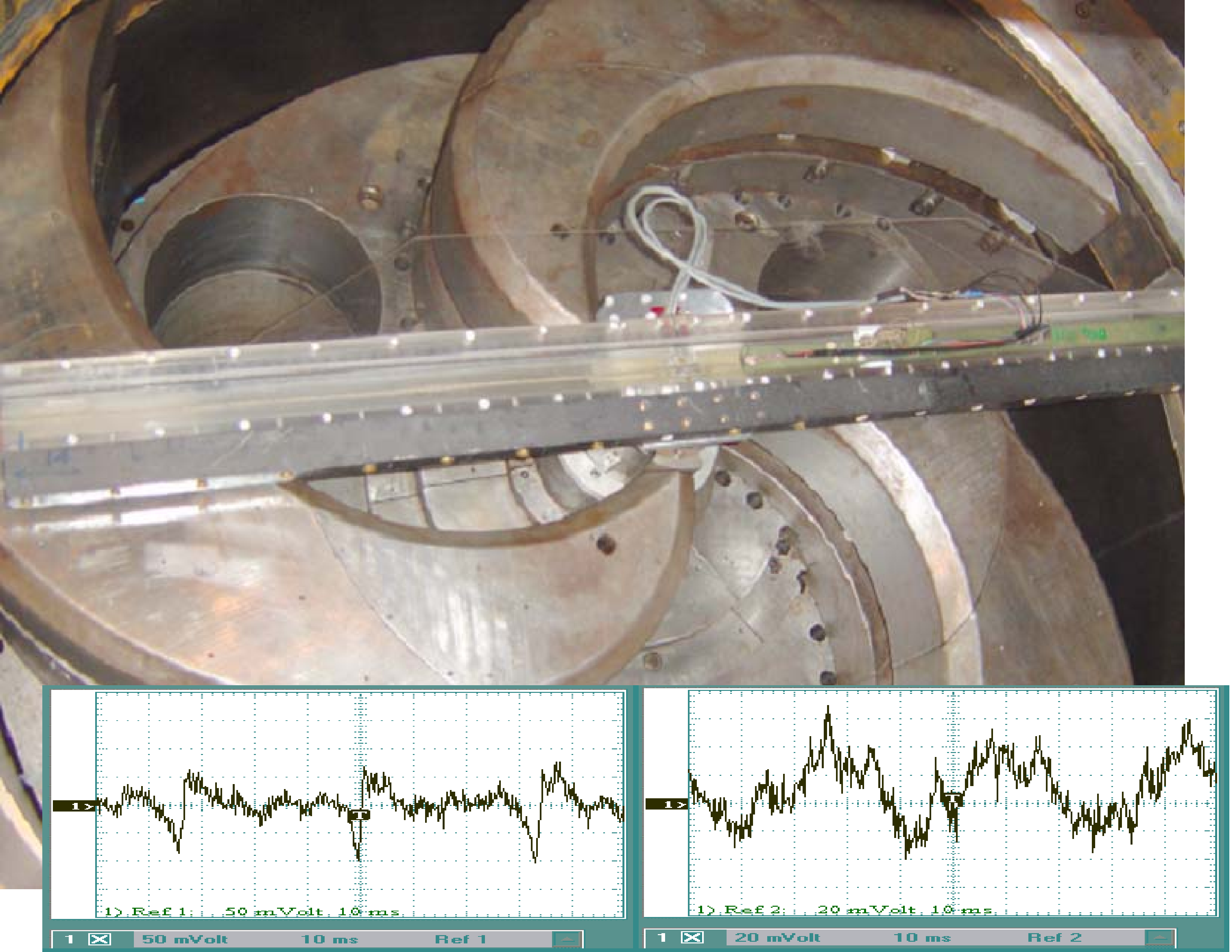
⇨ consequences on W_{max}

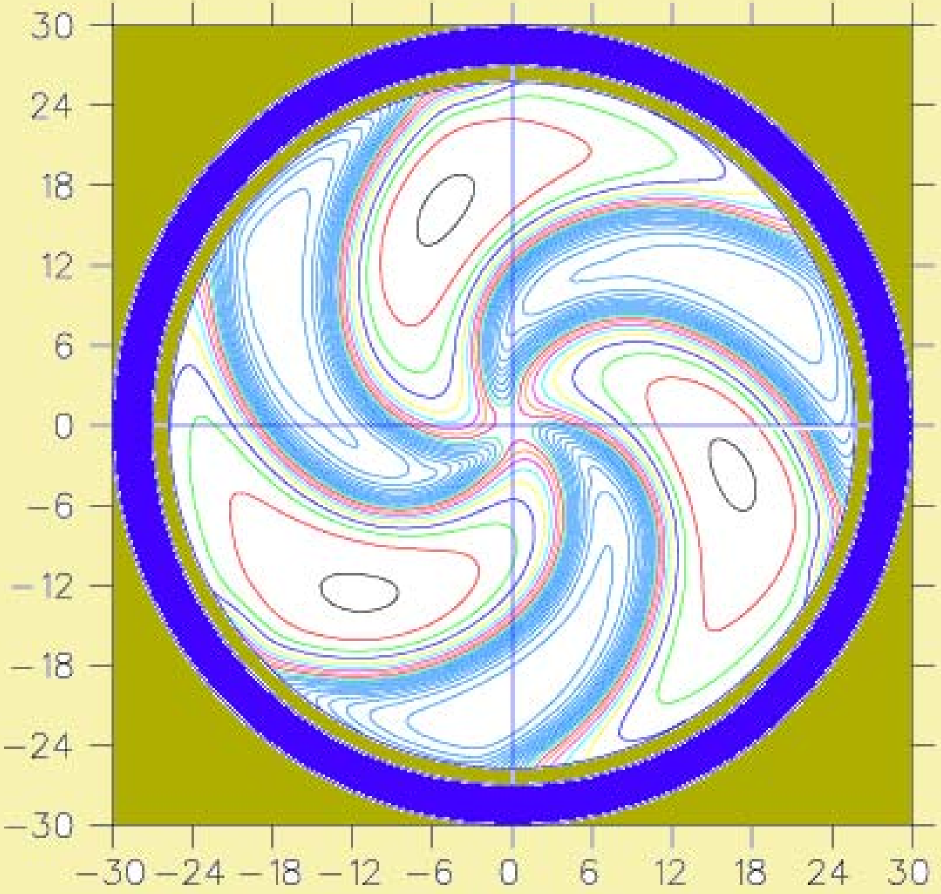
OPERATING DIAGRAM



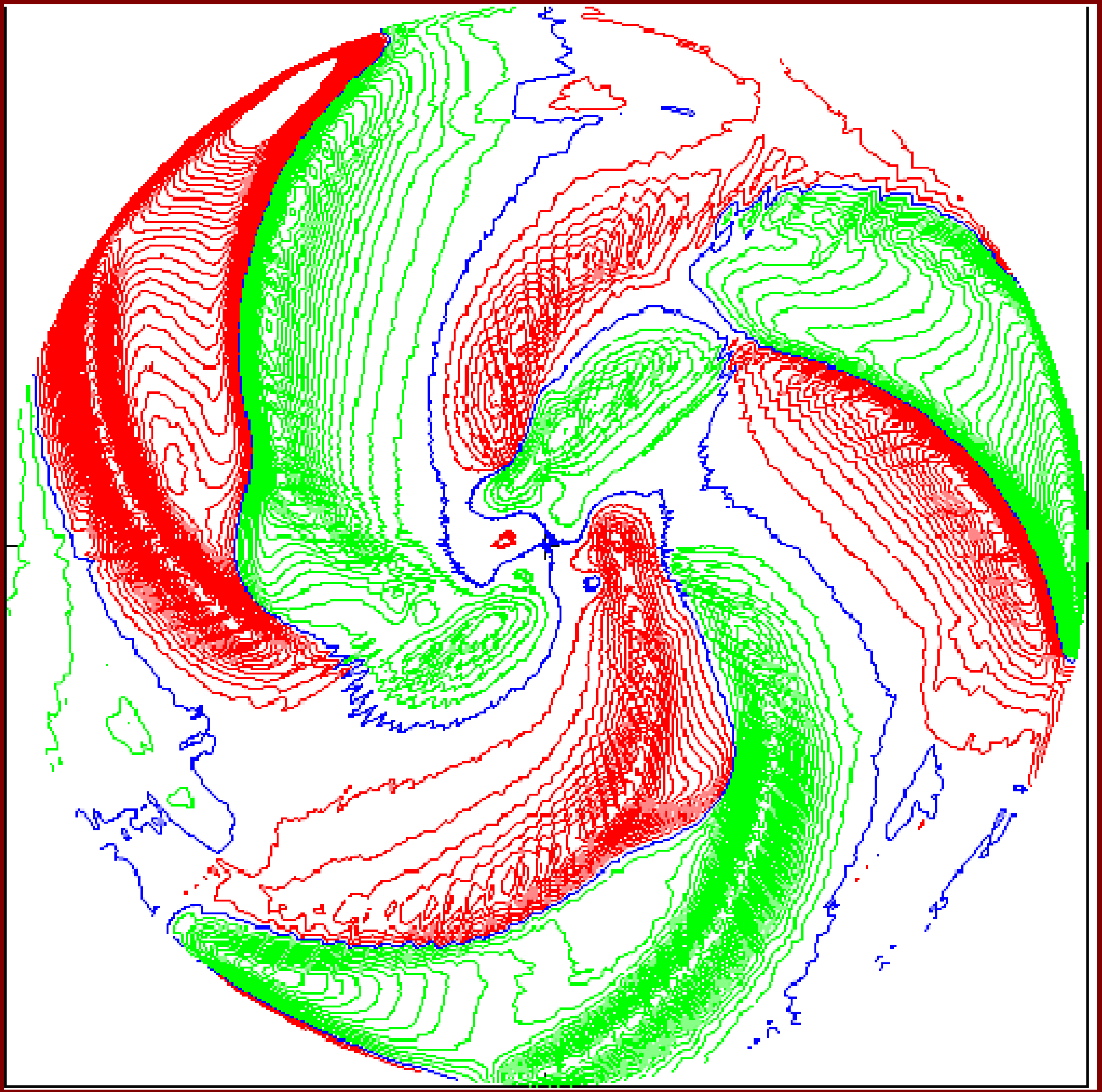
Energy-Field-Frequency Diagram




1)
T
1) Ref 1: 50 mVolt 10 ms
1 ☒ 50 mVolt 10 ms Ref 1
1)
T
1) Ref 2: 20 mVolt 10 ms
1 ☒ 20 mVolt 10 ms Ref 2



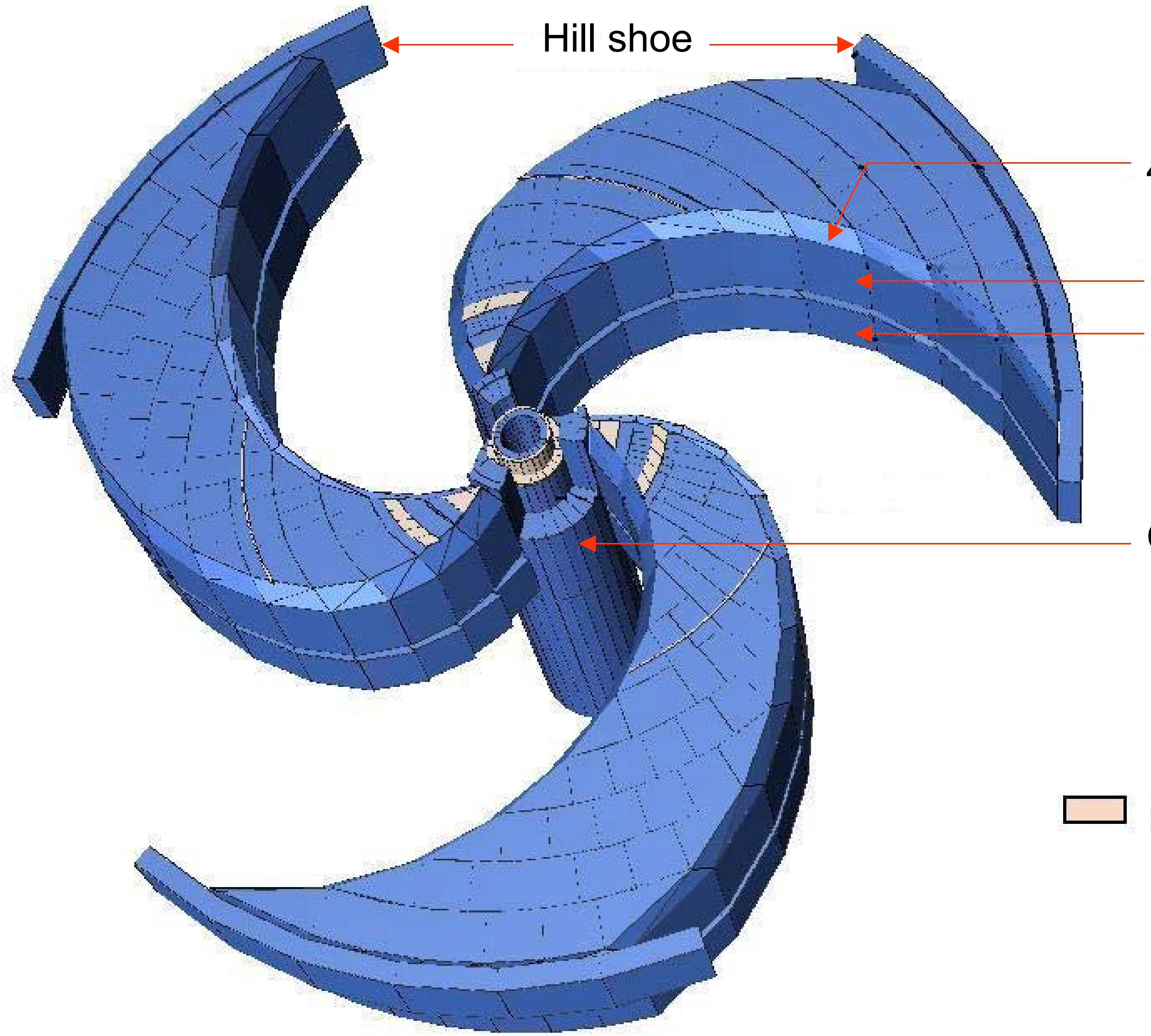
ISOGAUSS CONTOUR PLOT



DEVIATION FROM THREE FOLD SYMMETRY - CONTOUR PLOT

Step = 0.01 kG, Green: Negative, Blue: Zero, Red: Positive

SPIRAL POLE TIPS



Hill shoe

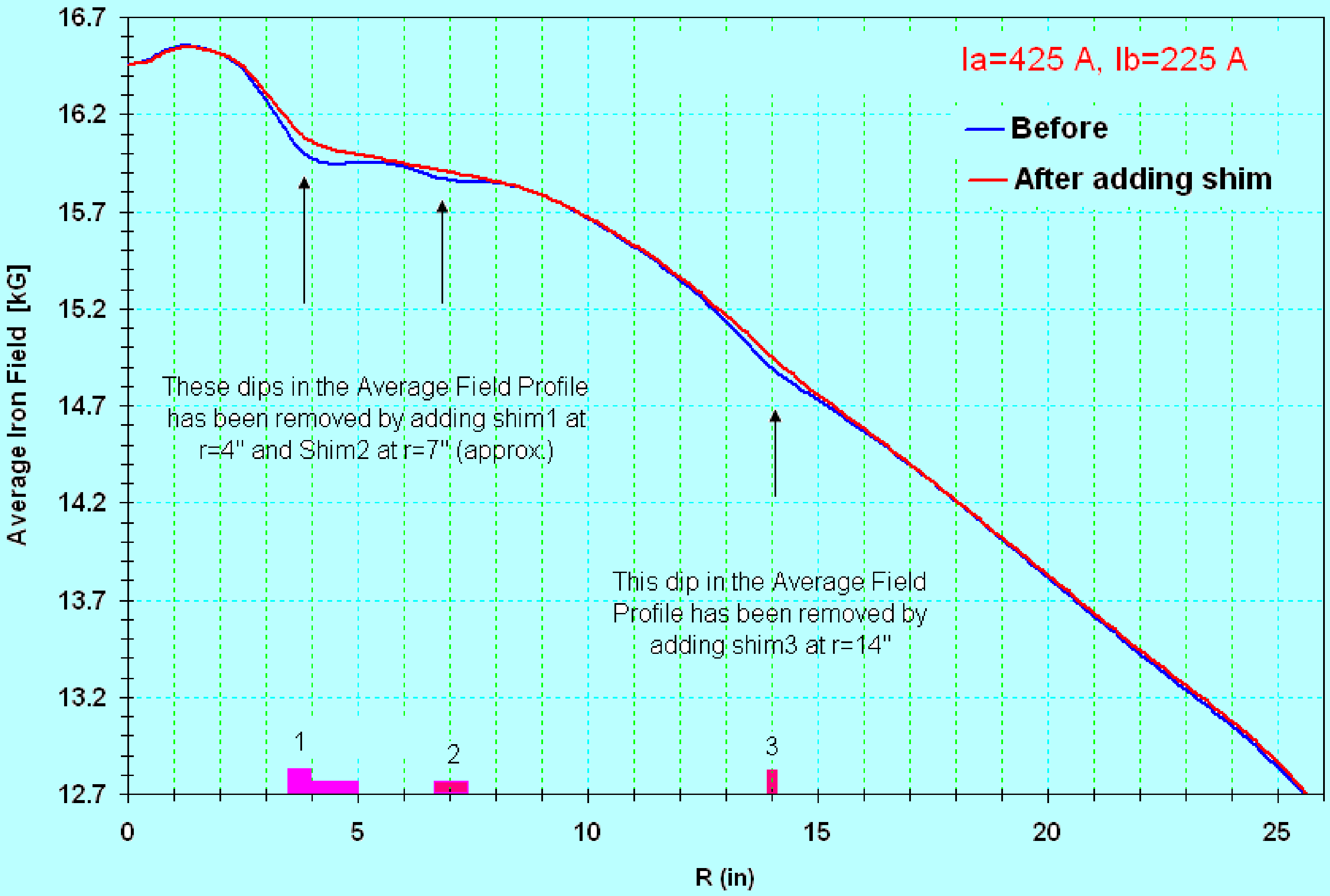
45º chamfered

Hill (upper part)

Hill (lower part)

Central plug

▭ Added shims



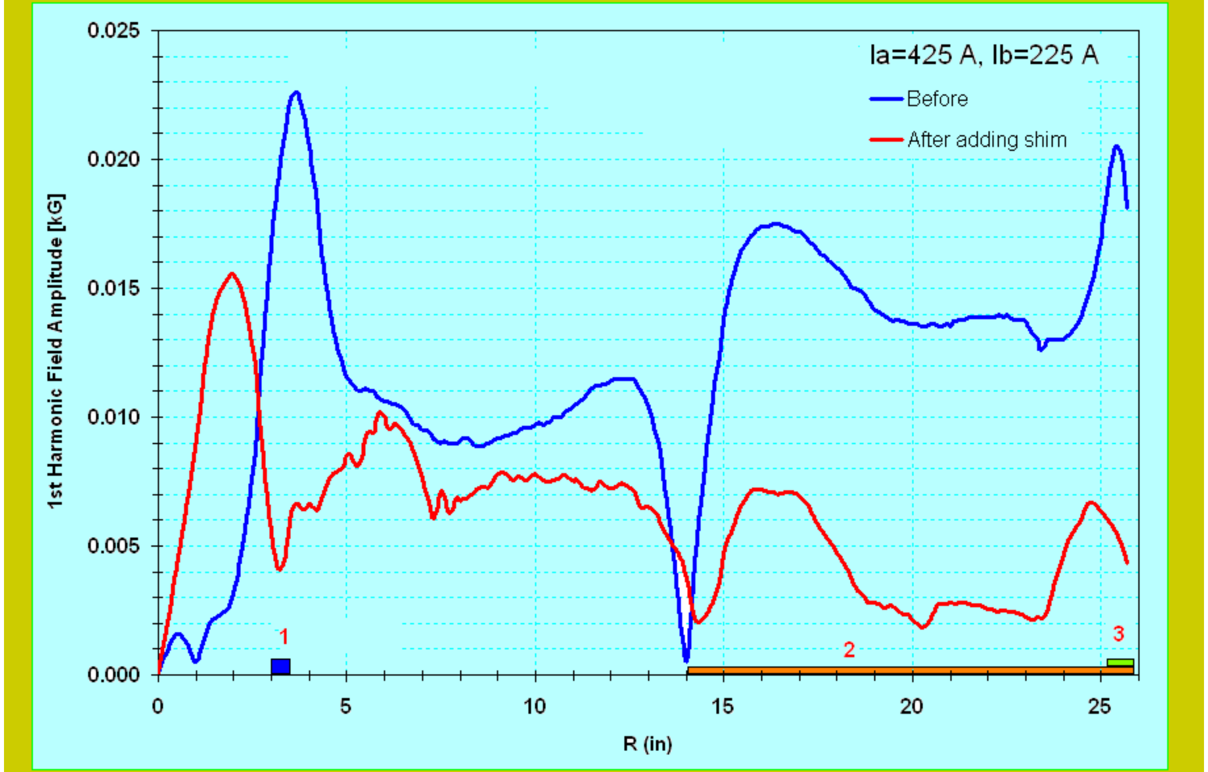
These dips in the Average Field Profile has been removed by adding shim1 at r=4" and Shim2 at r=7" (approx.)

This dip in the Average Field Profile has been removed by adding shim3 at r=14"

Shiming To Correct Average Field Profile

$$B(\theta) = B_{average} + B_1 \, \mathrm{Cos}(\theta) + B_2 \ldots\ldots\ldots$$

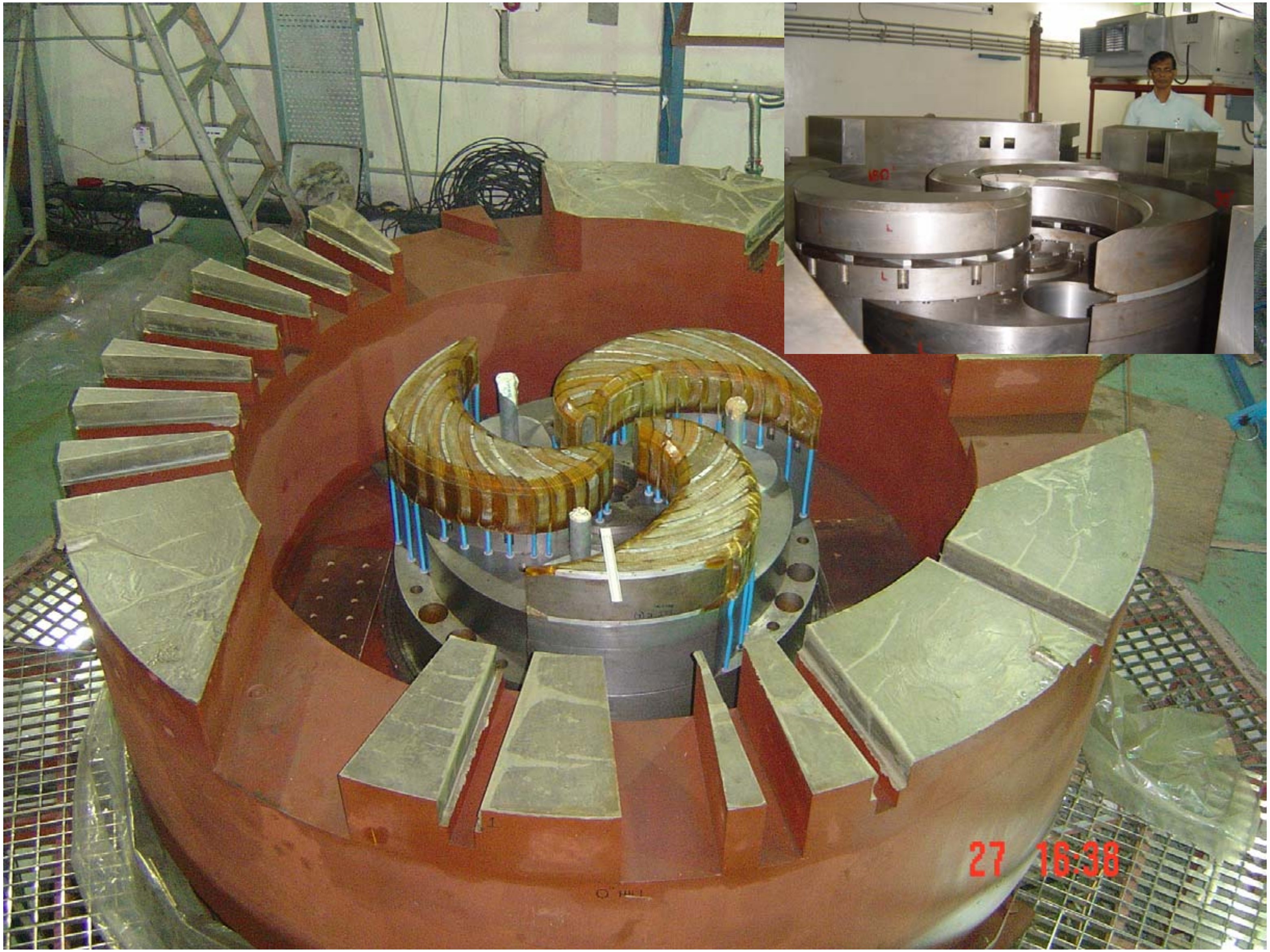
1^{st} Harmonic minimization

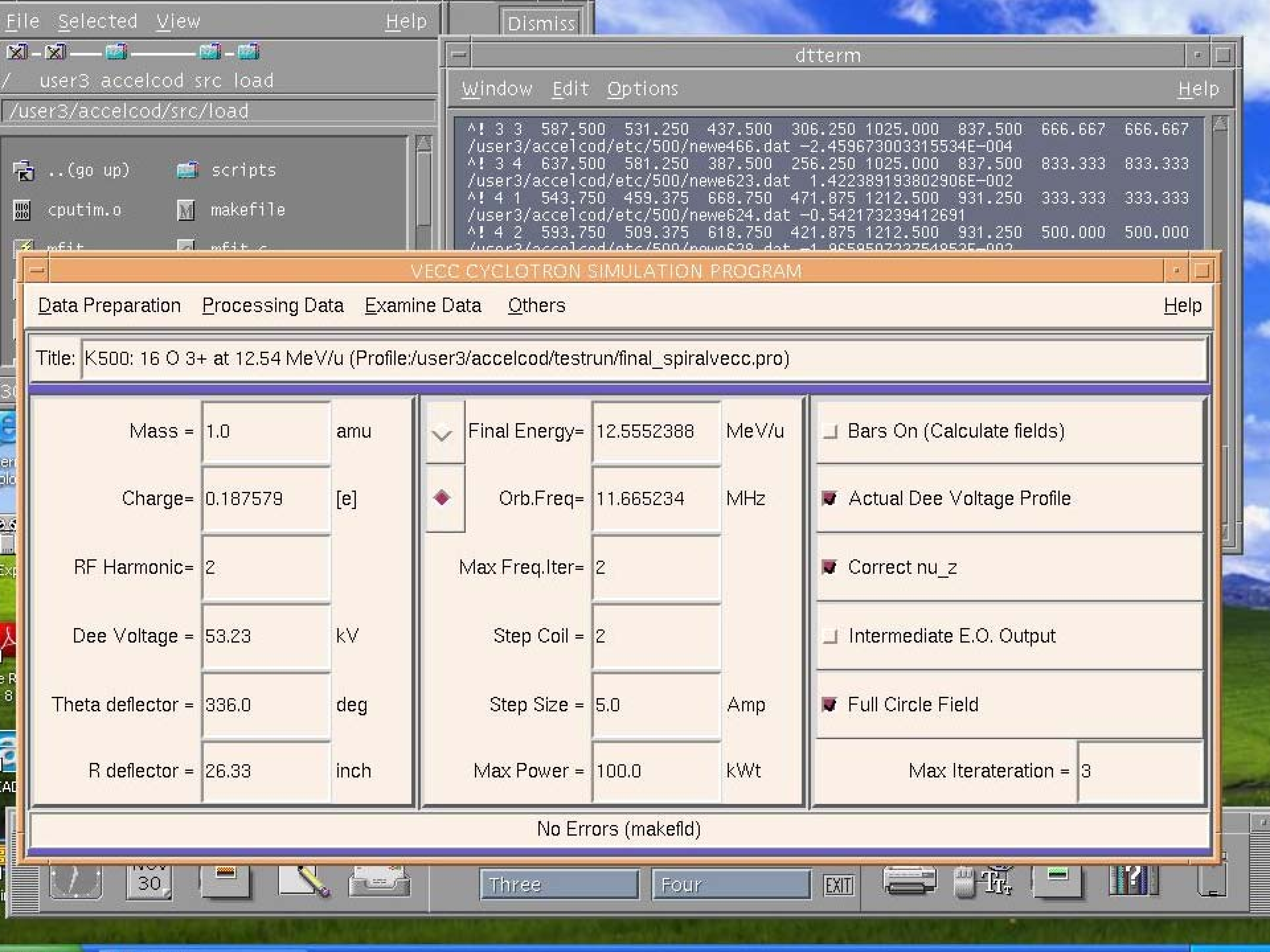


First Harmonic Minimization By Adding Iron Shims

FIRST HARMONIC DRIVES RESONANCES

TRIM COIL INSTALLATION





```
^! 3 3  587.500  531.250  437.500  306.250 1025.000  837.500  666.667  666.667
/user3/accelcod/etc/500/newe466.dat -2.459673003315534E-004
^! 3 4  637.500  581.250  387.500  256.250 1025.000  837.500  833.333  833.333
/user3/accelcod/etc/500/newe623.dat  1.422389193802906E-002
^! 4 1  543.750  459.375  668.750  471.875 1212.500  931.250  333.333  333.333
/user3/accelcod/etc/500/newe624.dat -0.542173239412691
^! 4 2  593.750  509.375  618.750  421.875 1212.500  931.250  500.000  500.000
```

Title: K500: 16 O 3+ at 12.54 MeV/u (Profile:/user3/accelcod/testrun/final_spiralvecc.pro)

Mass = 1.0 amu

Charge= 0.187579 [e]

RF Harmonic= 2

Dee Voltage = 53.23 kV

Theta deflector = 336.0 deg

R deflector = 26.33 inch

○ Final Energy= 12.5552388 MeV/u

● Orb.Freq= 11.665234 MHz

Max Freq.Iter= 2

Step Coil = 2

Step Size = 5.0 Amp

Max Power = 100.0 kWt

☐ Bars On (Calculate fields)

☑ Actual Dee Voltage Profile

☑ Correct nu_z

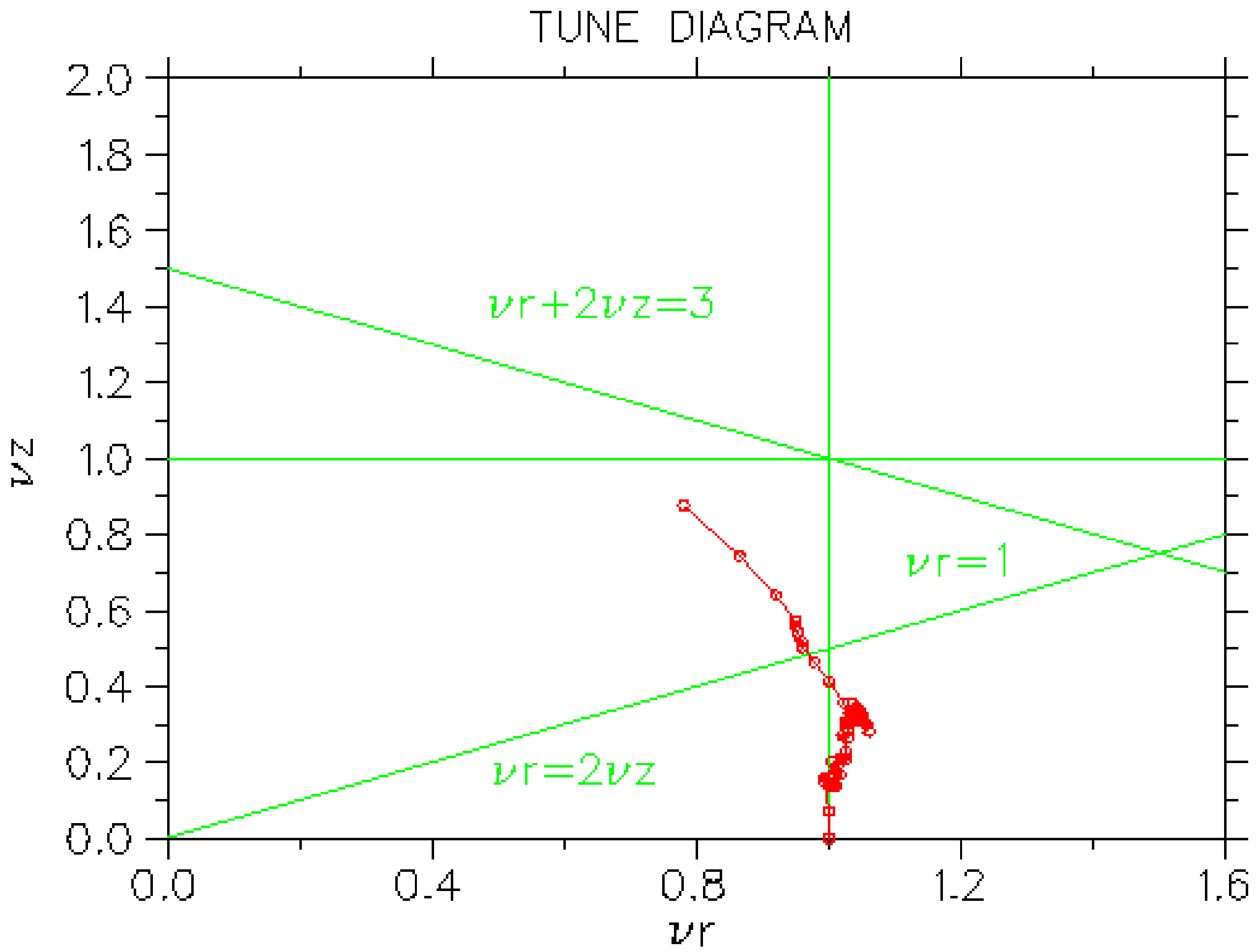
☐ Intermediate E.O. Output

☑ Full Circle Field

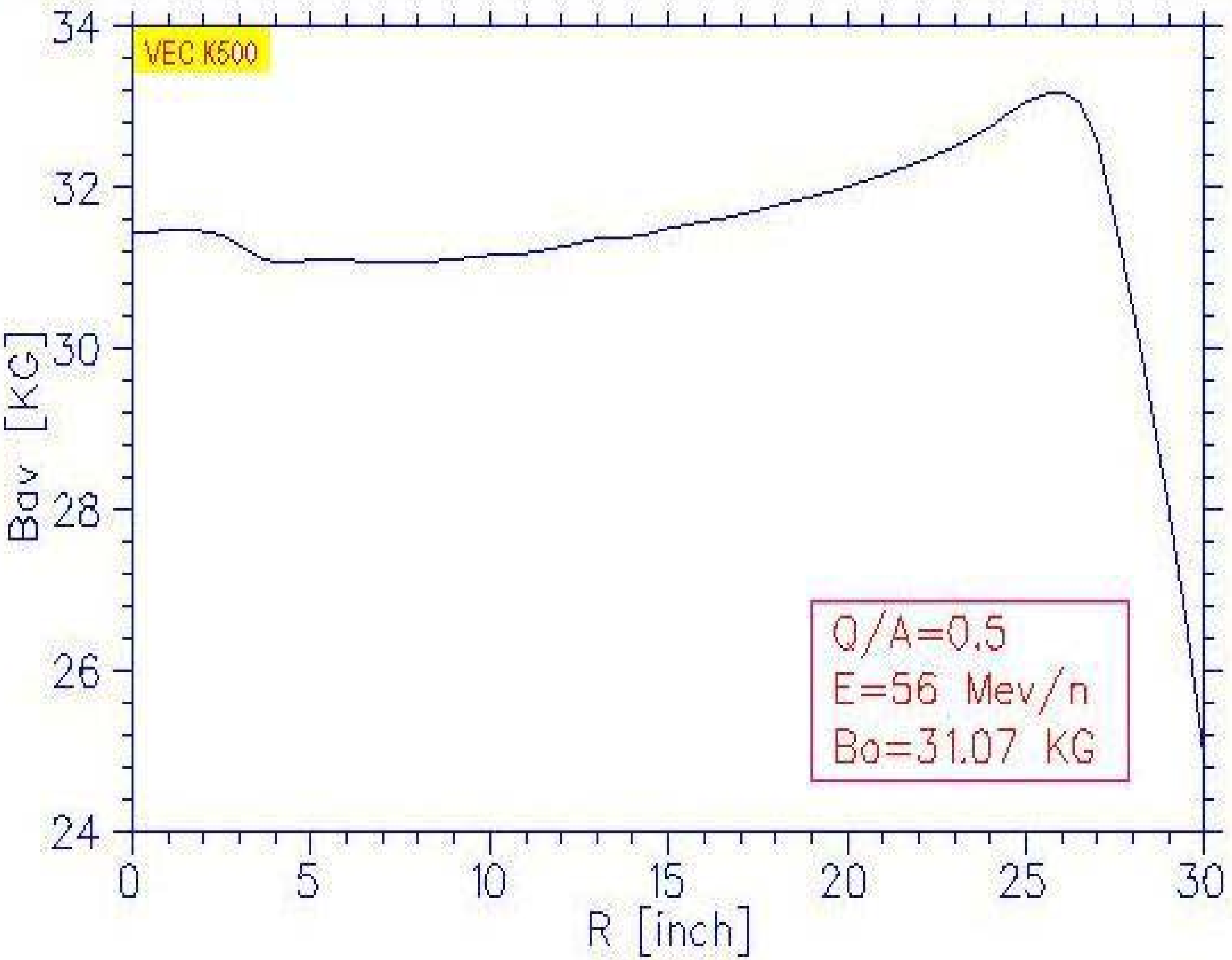
Max Iterateration = 3

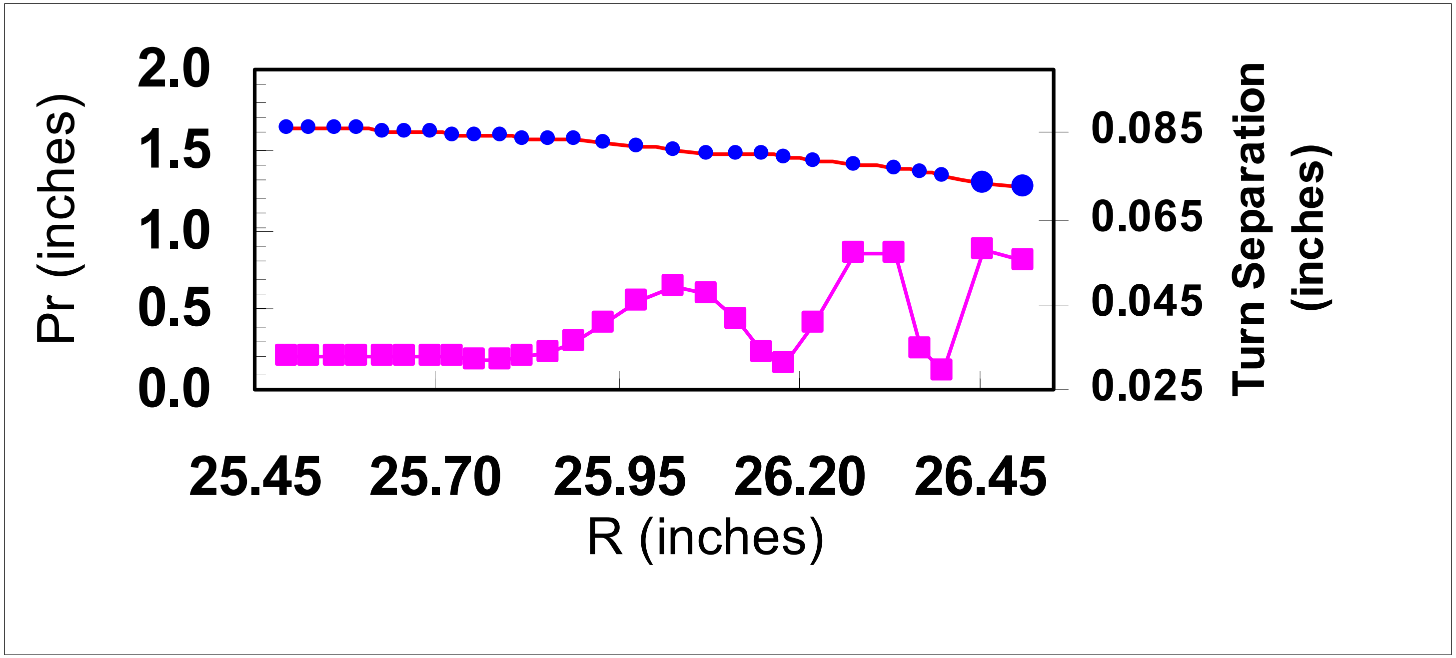
No Errors (makefld)

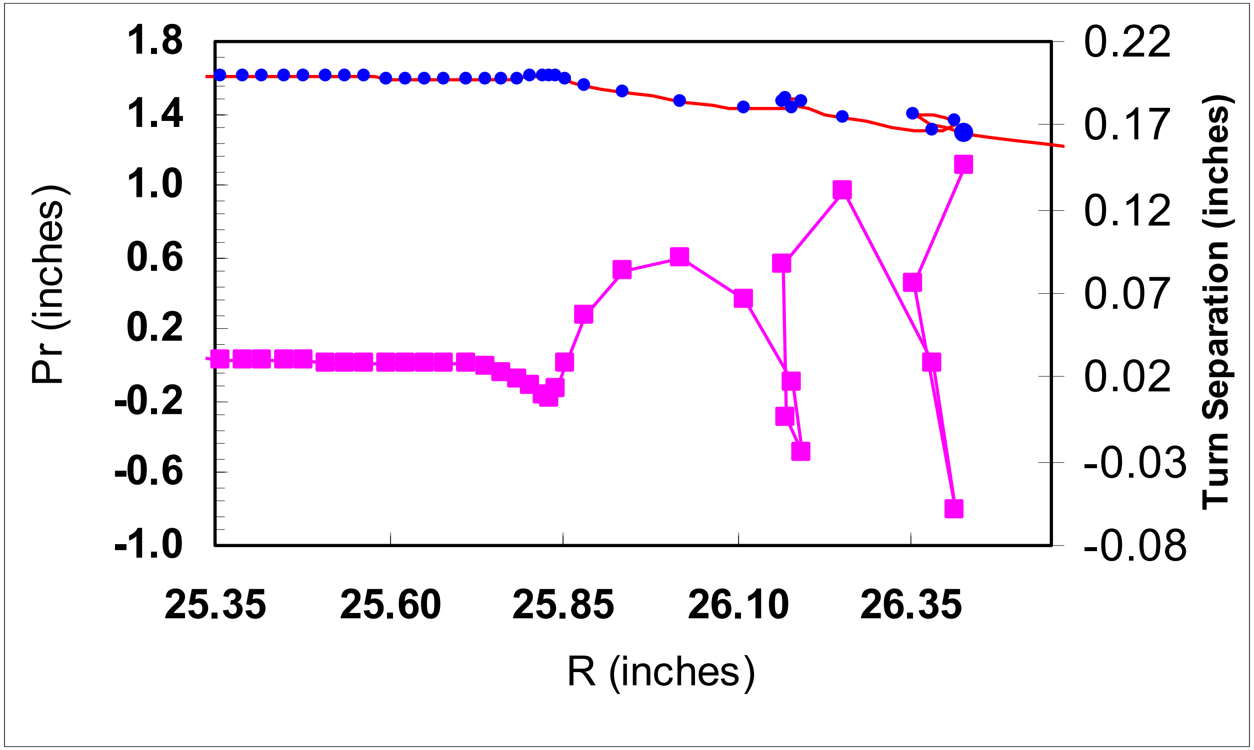
Nu_r vs. Nu_z plot , showing different resonances



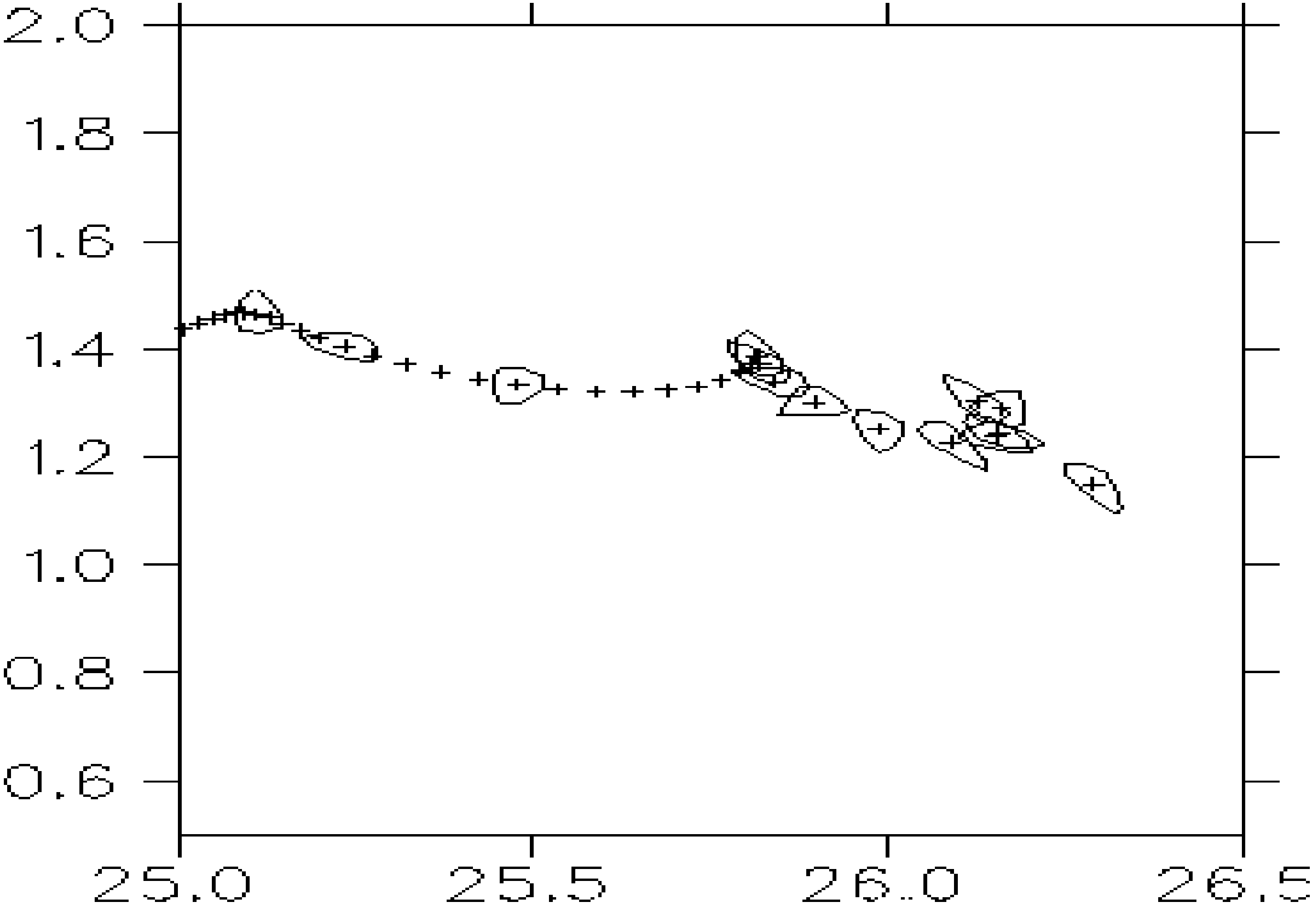
Calculated isochronous average field



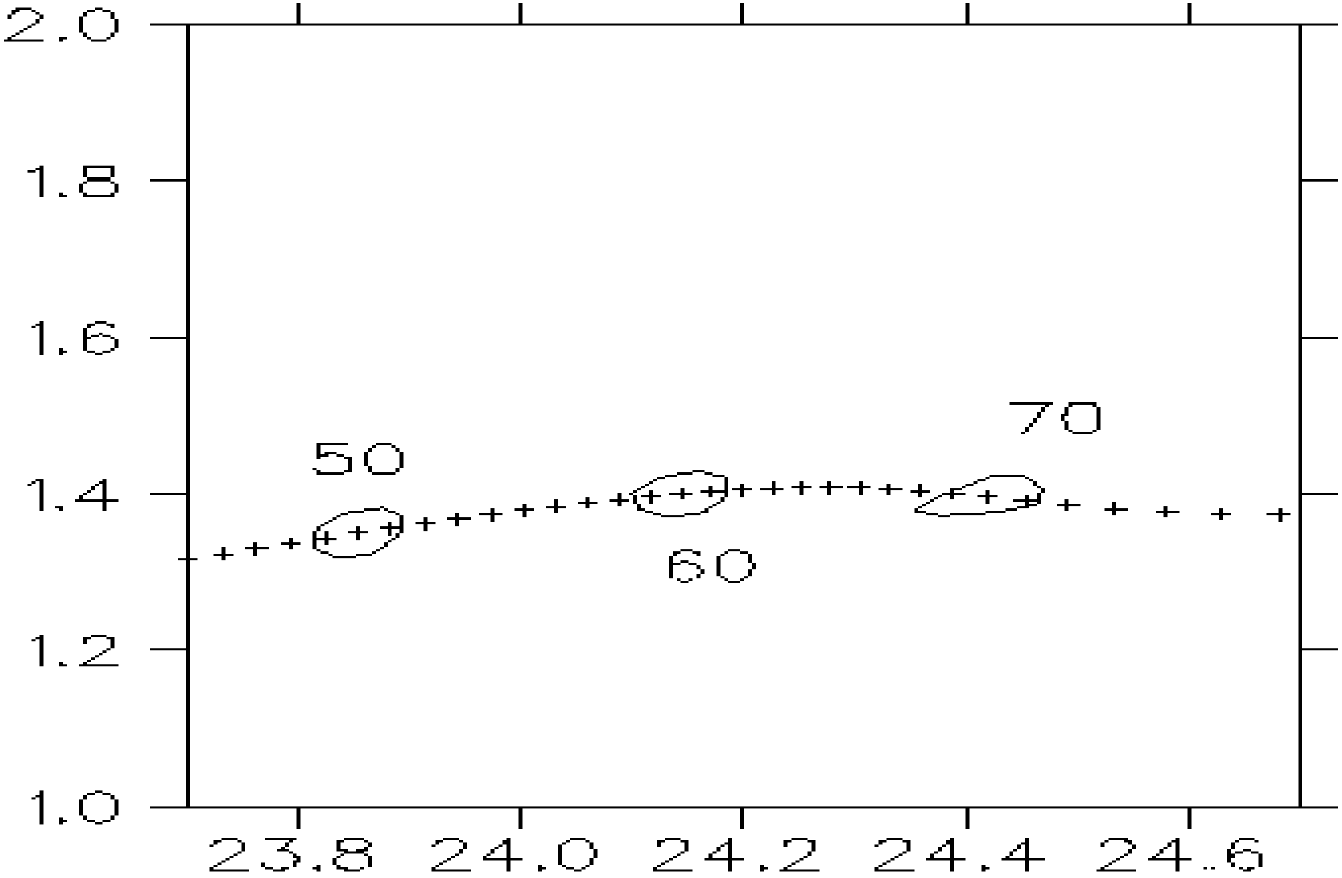

Pr (inches)
2.0
1.5
1.0
0.5
0.0
Turn Separation (inches)
0.085
0.065
0.045
0.025
25.45
25.70
25.95
26.20
26.45
R (inches)


Pr (inches)
1.8
1.4
1.0
0.6
0.2
-0.2
-0.6
-1.0
Turn Separation (inches)
0.22
0.17
0.12
0.07
0.02
-0.03
-0.08
25.35
25.60
25.85
26.10
26.35
R (inches)

Bump profile used for “Precissional Extraction”



Bump profile used for "Precissional Extraction"



Precessional Extraction

In the extraction region of cyclotron , drops through the

$$\nu_r = 1$$

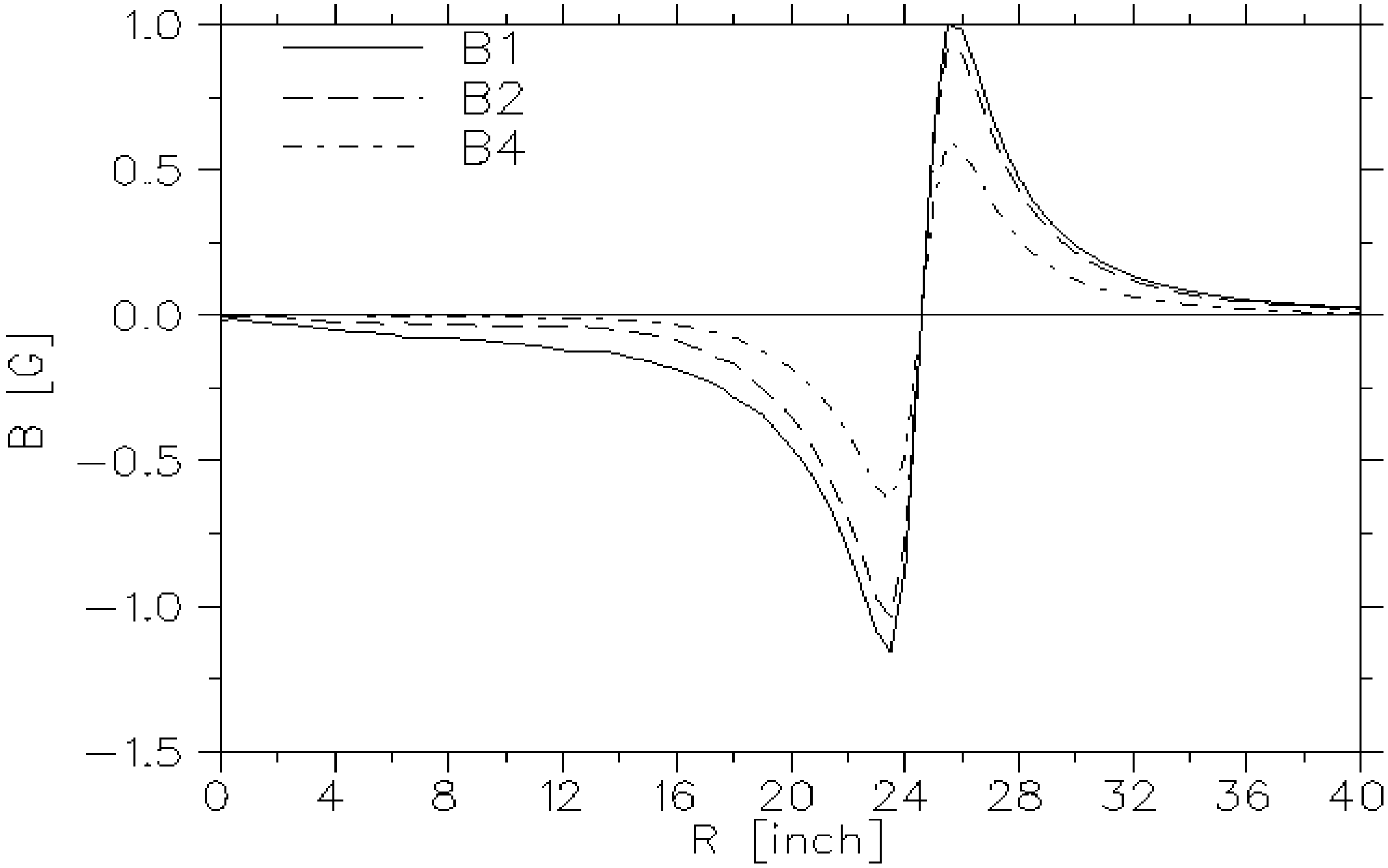
resonance. This passage produces a coherent amplitude

$$x_c = \frac{\pi R b_1}{B_o} \times \frac{1}{\sqrt{\frac{d\upsilon_r}{dn}}}$$

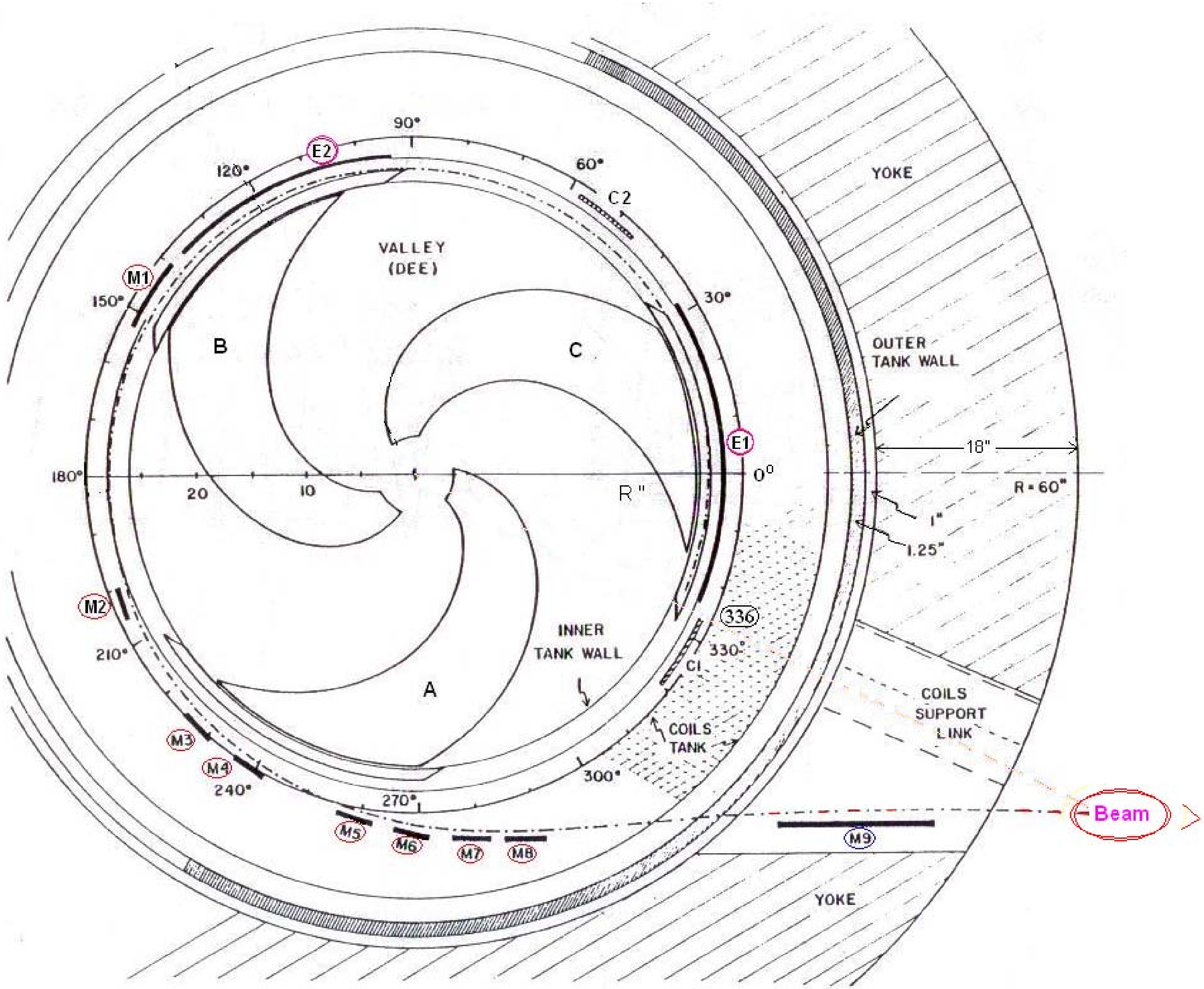
In the fringing field precession takes place giving additional turn separation

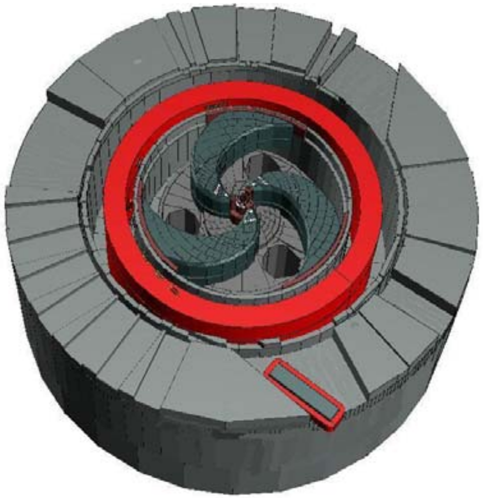
$$\frac{dR}{dn} = 2x_c \sin\pi(1-\nu_r)$$

Bump profile used for “Precissional Extraction”

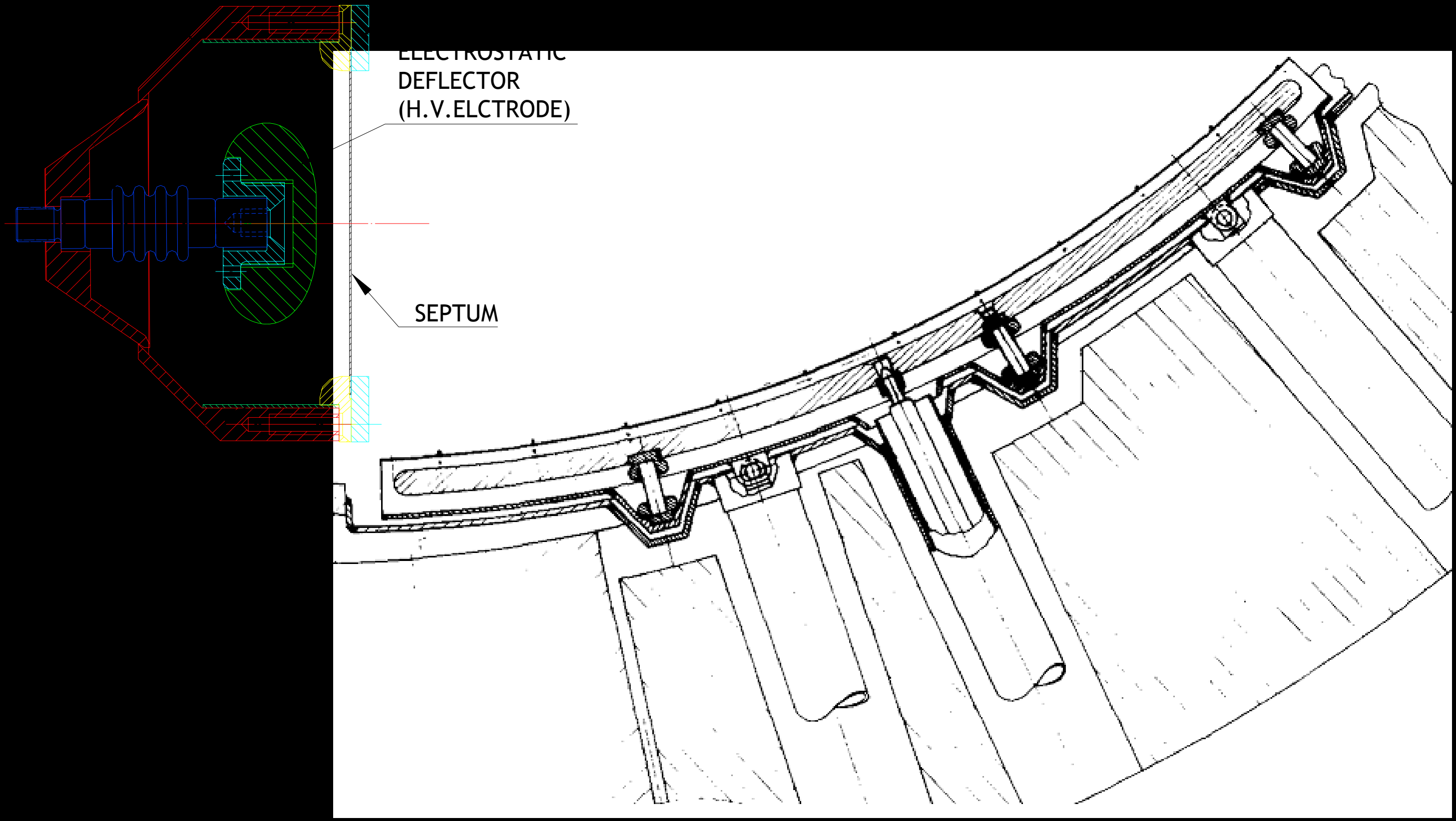


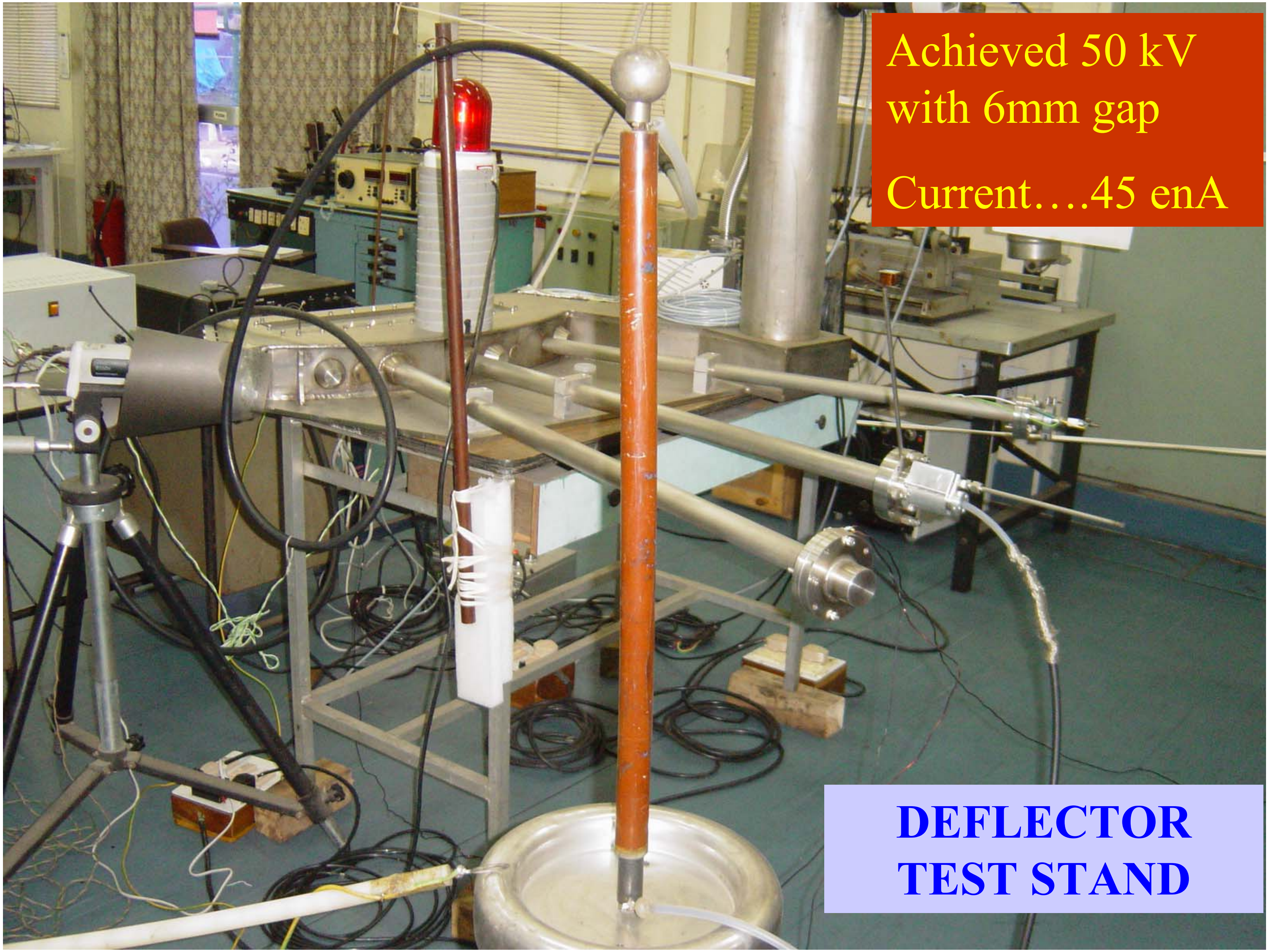
Median Plan View





Cross-section of Electrostatic Deflector





Achieved 50 kV
with 6mm gap

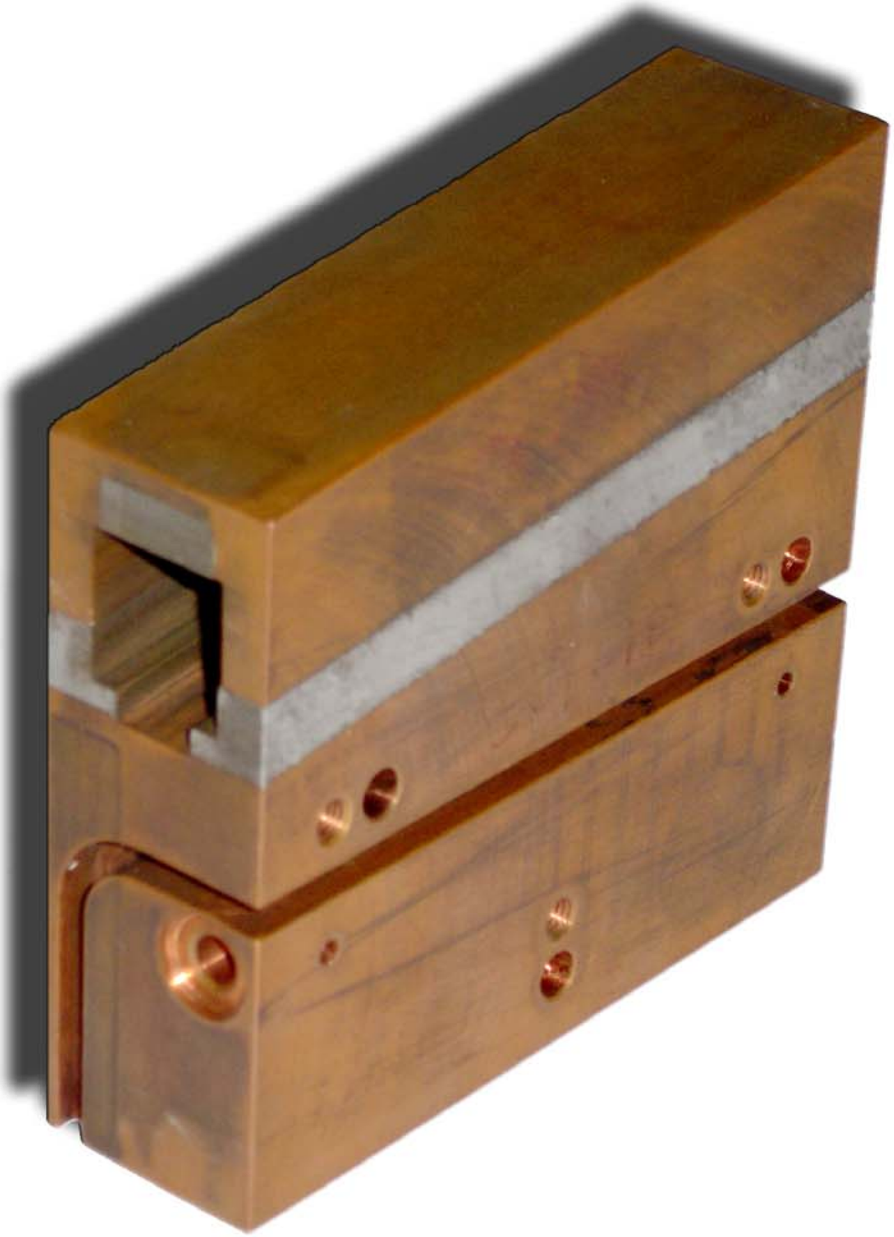
Current….45 enA

**DEFLECTOR
TEST STAND**

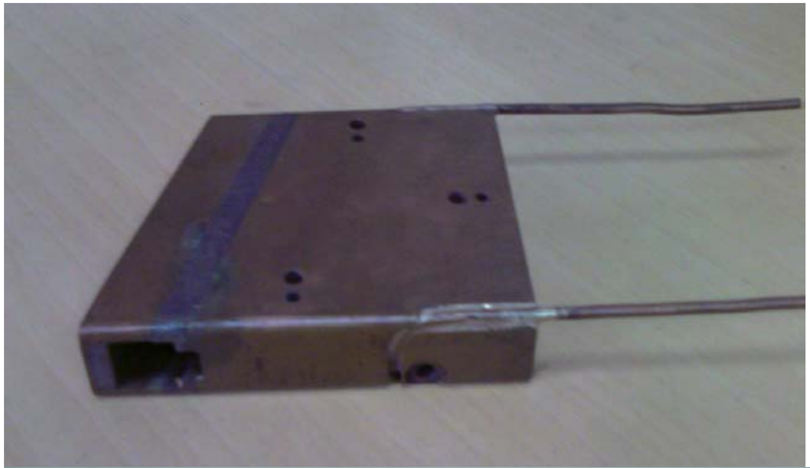
Electrostatic Deflectors

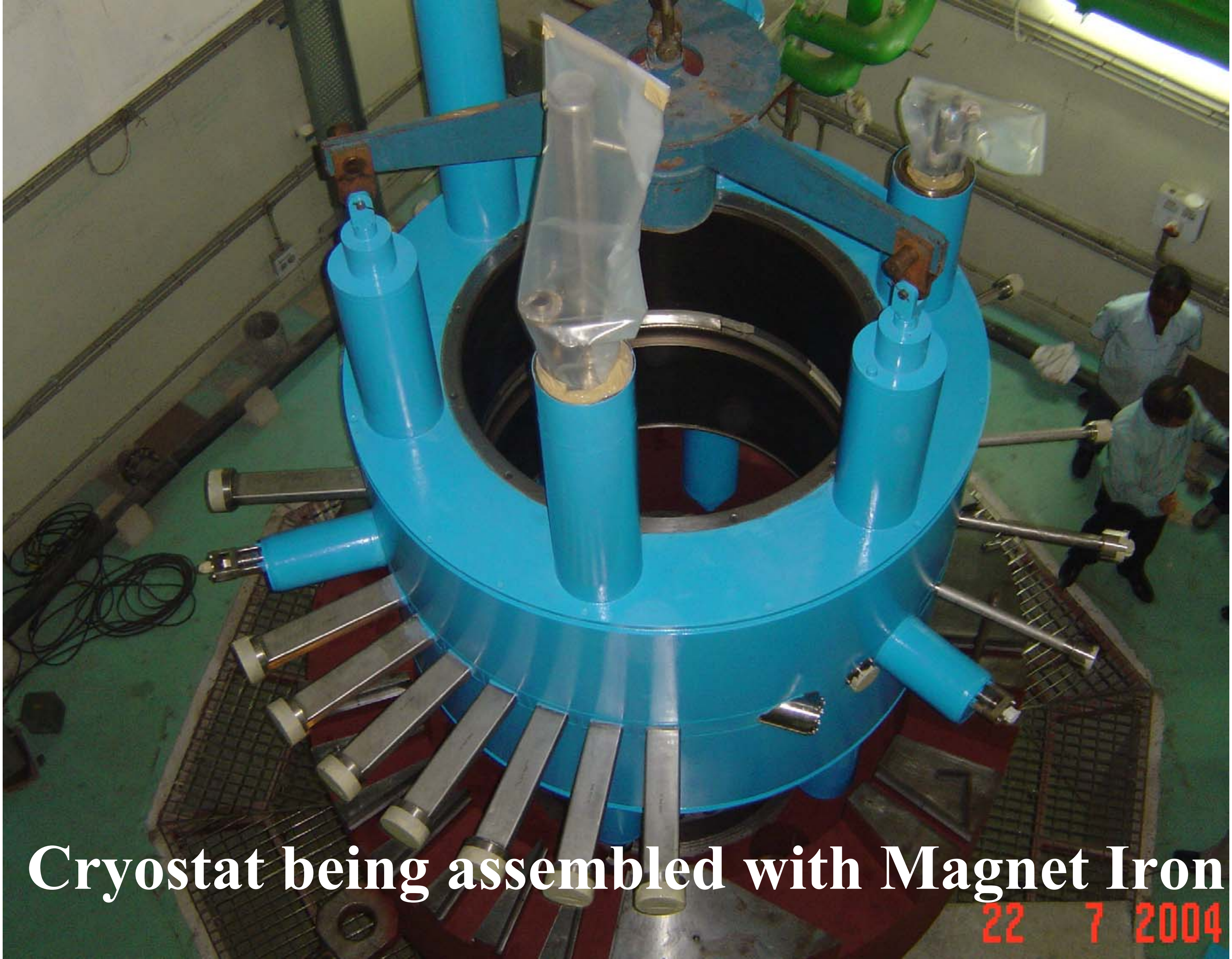
Electrostatic Deflector for SCC

- 2 Deflectors, 55^{o} and 43^{o}
- The High Voltage Electrode: special contour, made of Titatanium.
- Maximum applied Voltage ~100 kV
- Electrode is supported by three insulators
- Voltage Feed-through : Highly Insulated & Shielded
- Septum: Made of Tungsten, Very thin (0.3 mm)
- Power Supply : Remotely operated



Passive magnetic channels



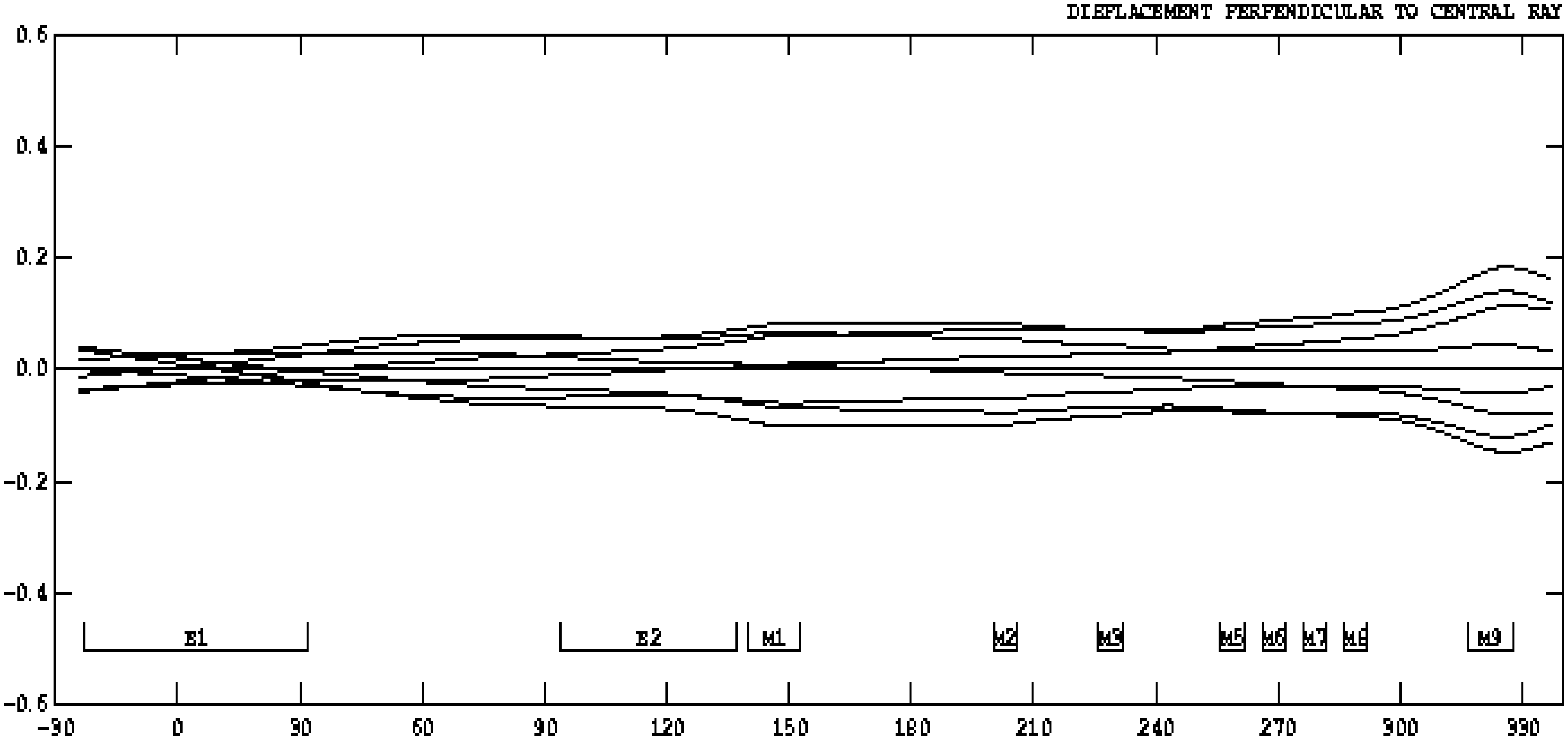


Cryostat being assembled with Magnet Iron

Magnetic Channels

- 8 Passive Magnetic Channel
- Made of Iron Bars in Copper box, Locally reduce magnetic field to facilitate Beam Extraction, Movable radialy to suit dynamics of different ion species.
- 1 Active Magnetic Channel in the Yoke-hole

Bump profile used for “Precissional Extraction”



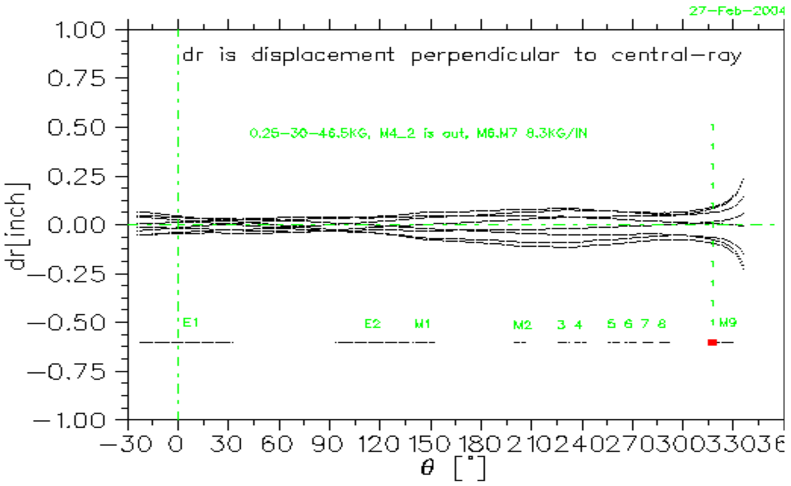


Fig. (6a) . Q/A = 0.25, E = 30 MeV/n, Bo = 46. KG

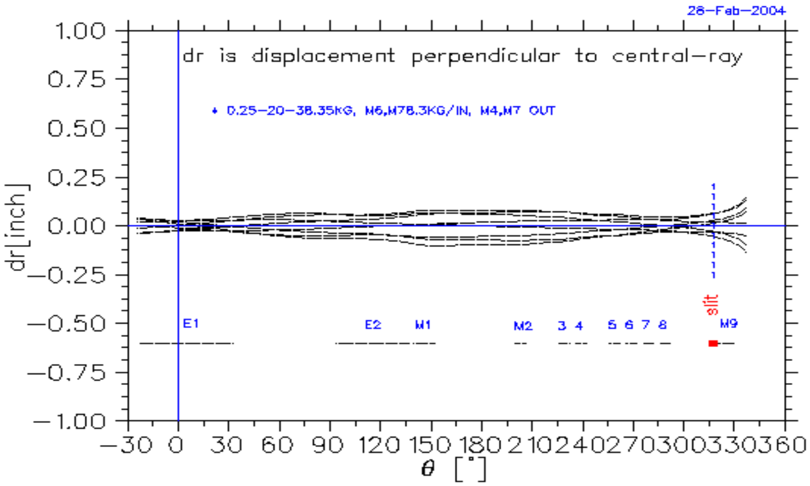


Fig. (6b). Q/A = 0.25, E = 20 MeV/n, Bo =38 KG

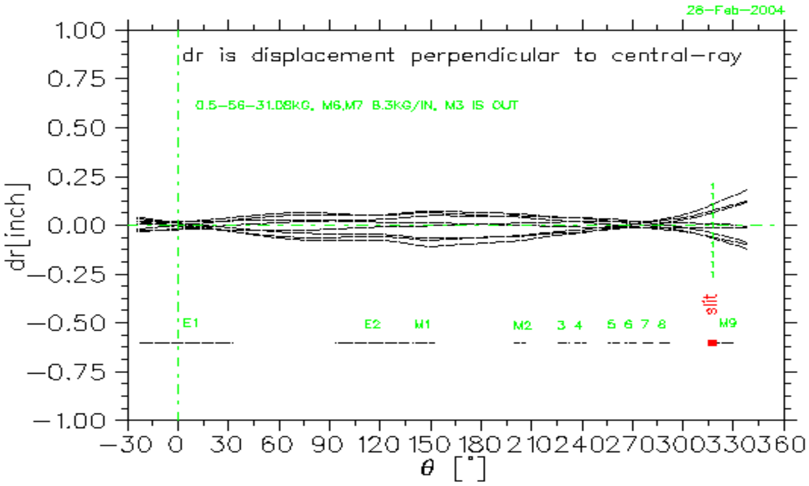
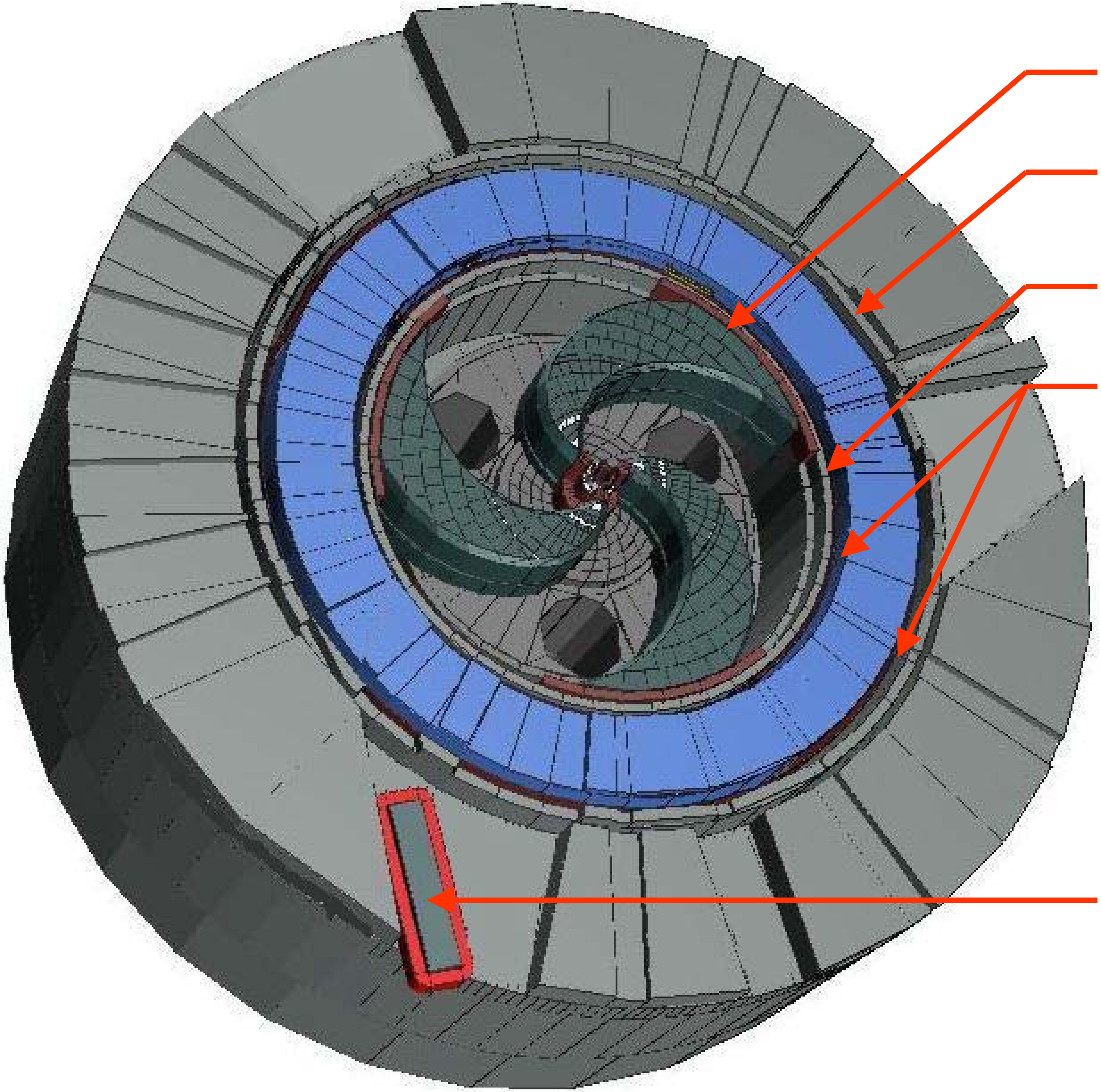


Fig. (6c). Q/A = 0.5, E = 56 MeV/n, Bo = 31 KG

Figures show horizontal beam width along the Extraction Path, Magnetic channels M1-M8 are passive.M9 is active. For M1, M2 dB/dx is 8.3 KG/inch, M3-M5 dB/dx=13.3 KG/in, M6,M7 8.3 KG/in, M8 is 11.6 KG/in. Simulated by code DEFINX for 3 different central magnetic field excitations.

MEDIAN PLANE VIEW



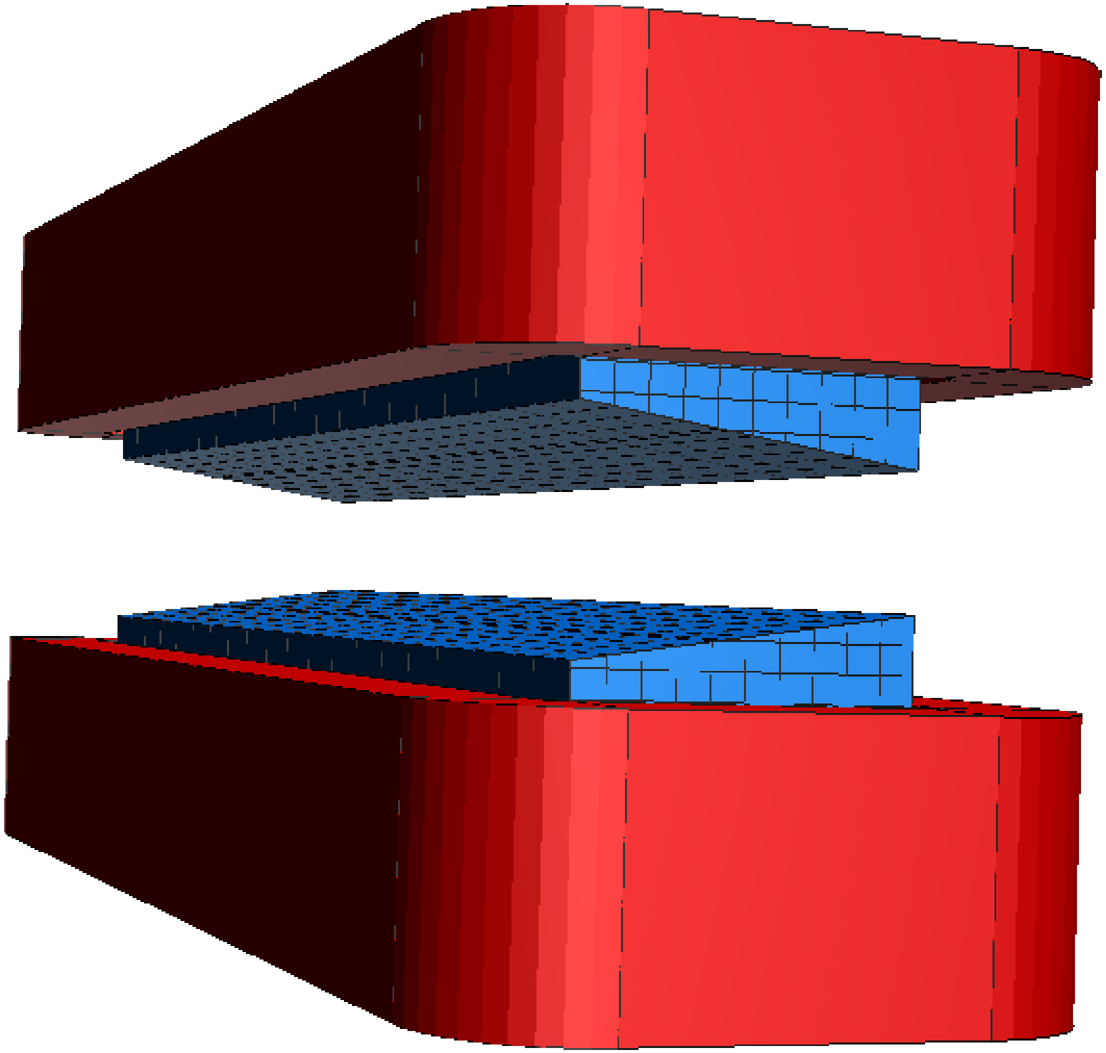
Liquid helium chamber

Outer coil tank

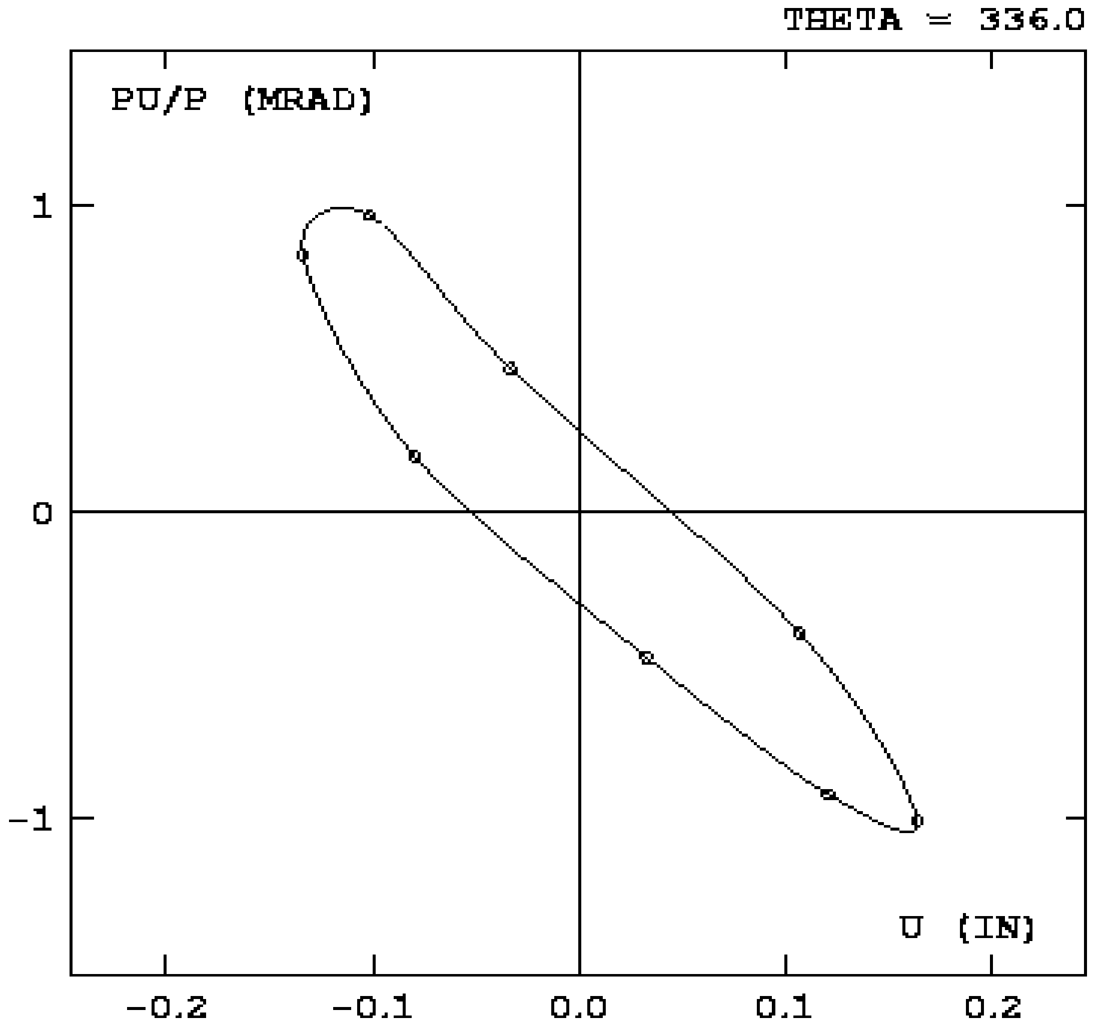
Inner coil tank

Radiation shield

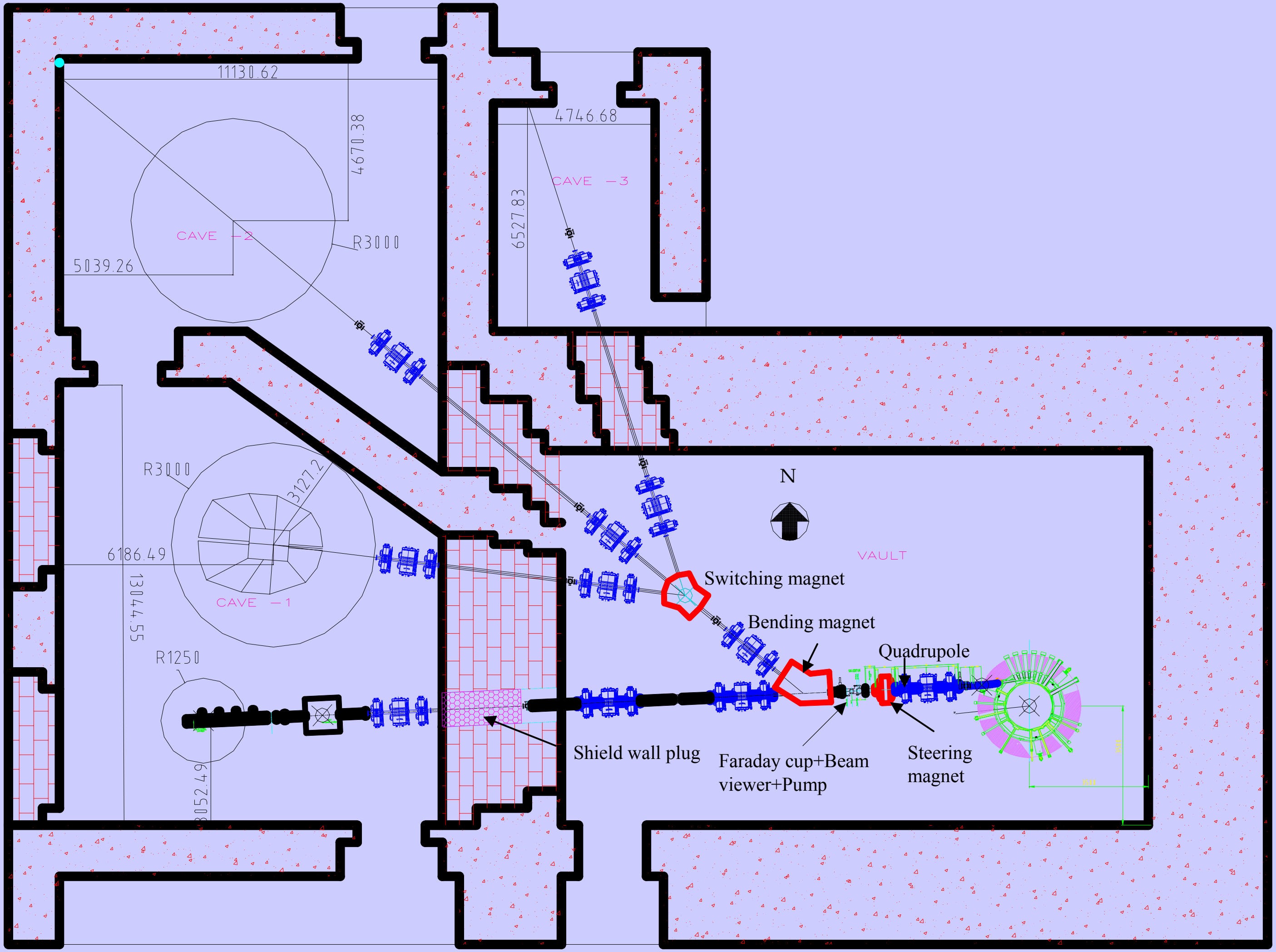
M9 channel



Bump profile used for "Precissional Extraction"

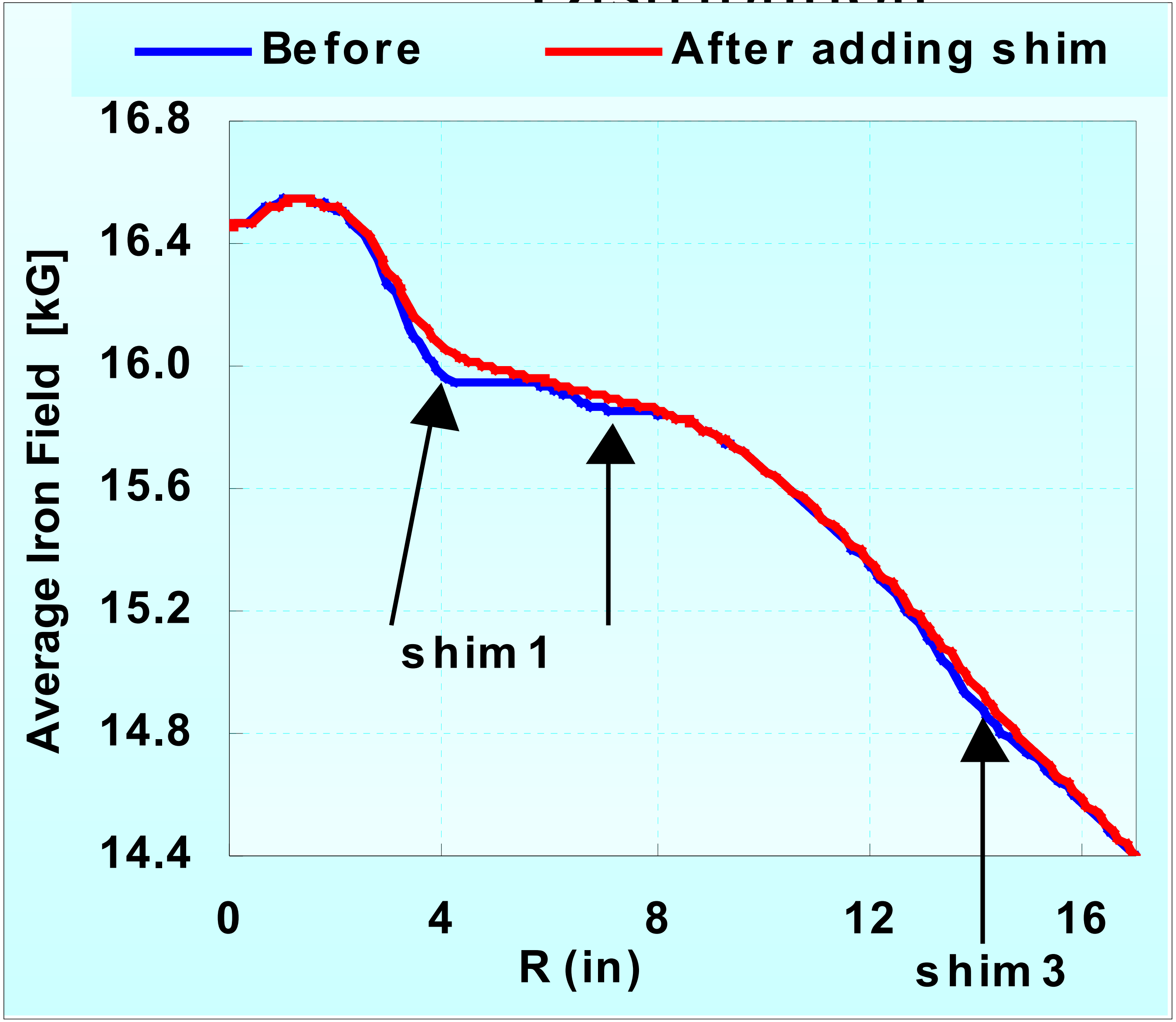


K500 SUPERCONDUCTING CYCLOTRON EXTERNAL BEAMLINE LAYOUT

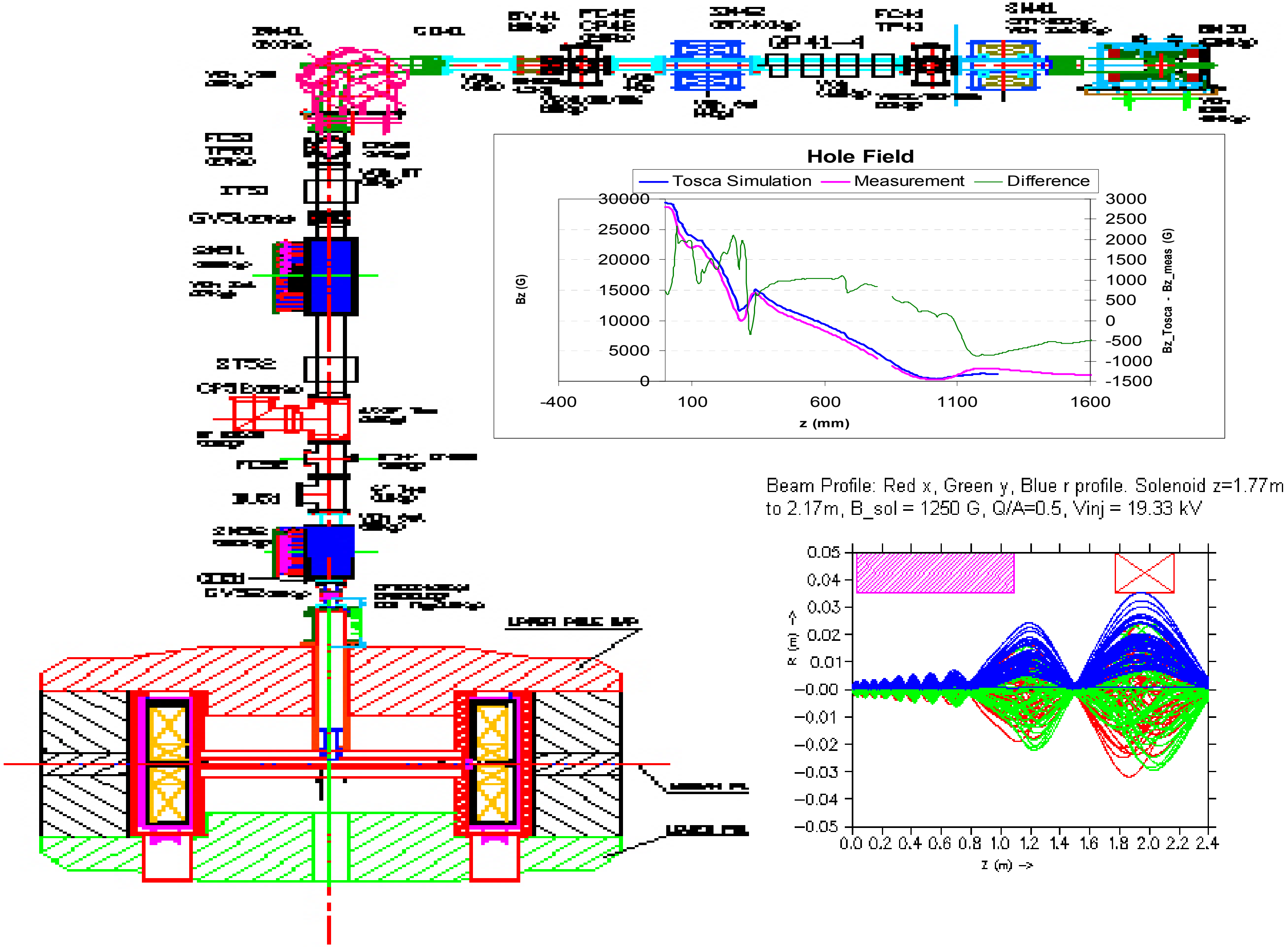


THANKS

Error Correction in Average Field Distribution



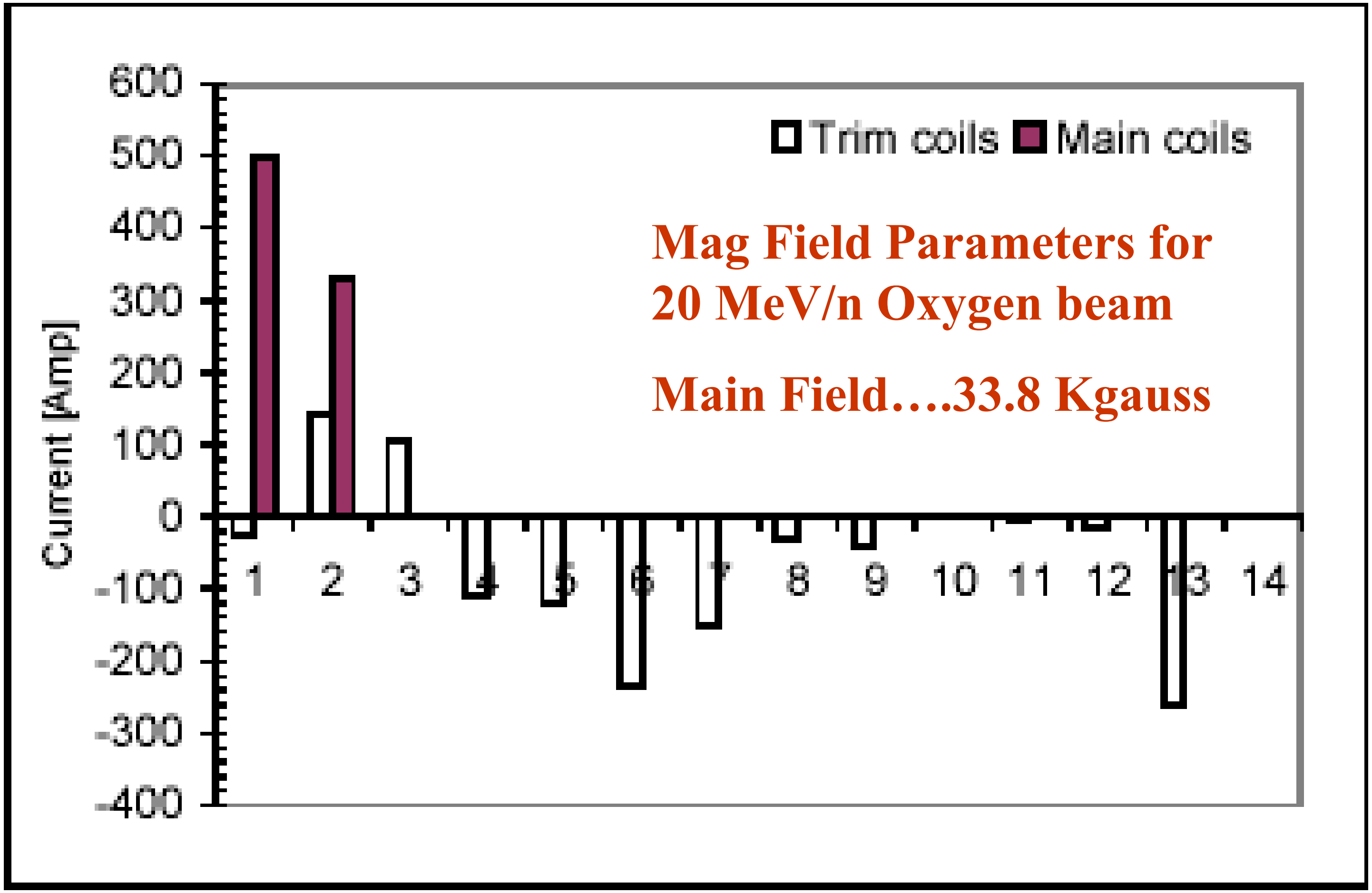
Iron shims were added to remove unwanted dips in the average iron field distribution at about 4", 7" and 14" radii



Beam Profile: Red x, Green y, Blue r profile. Solenoid z=1.77m to 2.17m, B_sol = 1250 G, Q/A=0.5, Vinj = 19.33 kV

LAYOUT OF VERTICAL SECTION OF INJECTION LINE FOR VEC K-500 SUPERCONDUCTING CYCCLOTRON

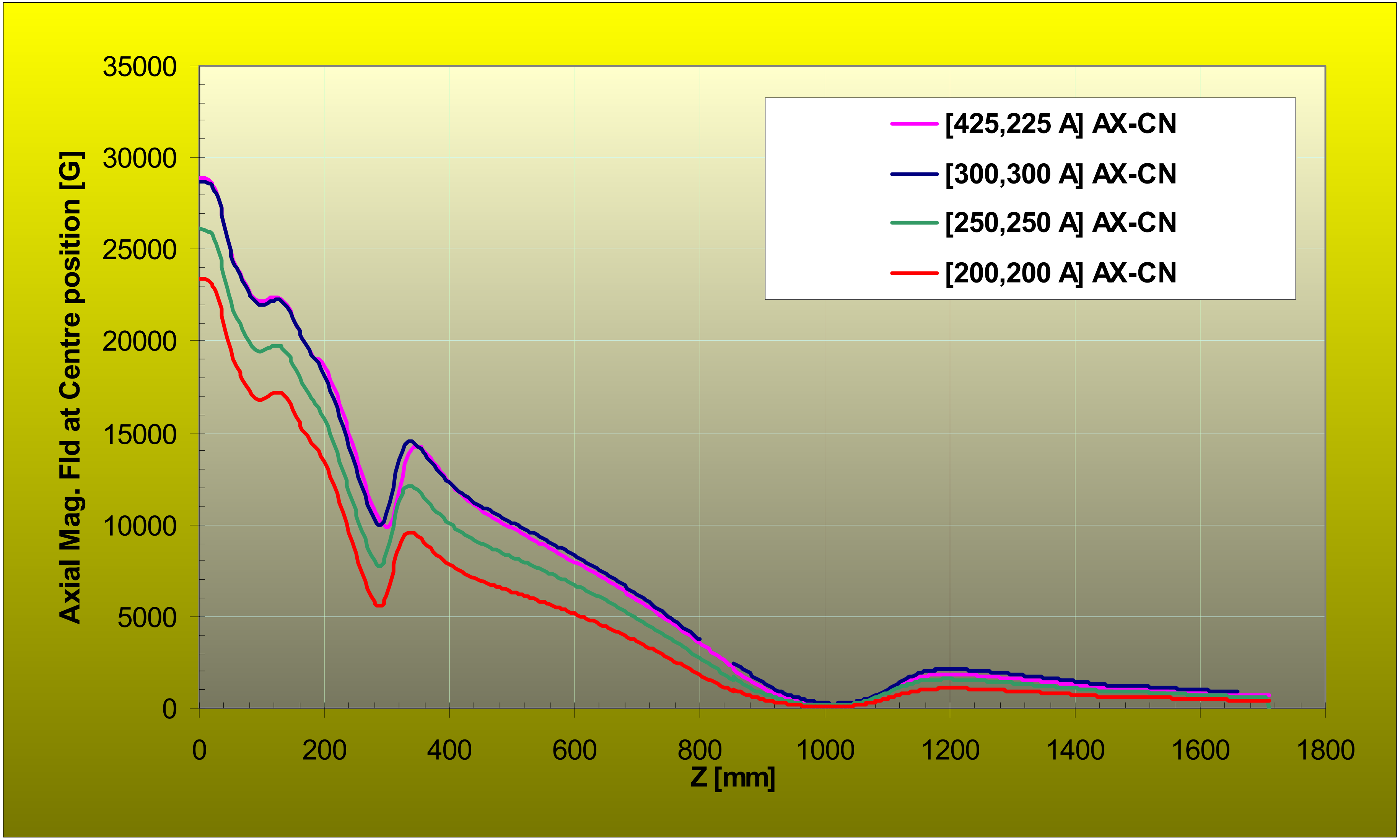
Possible Parameters for the FIRST BEAM

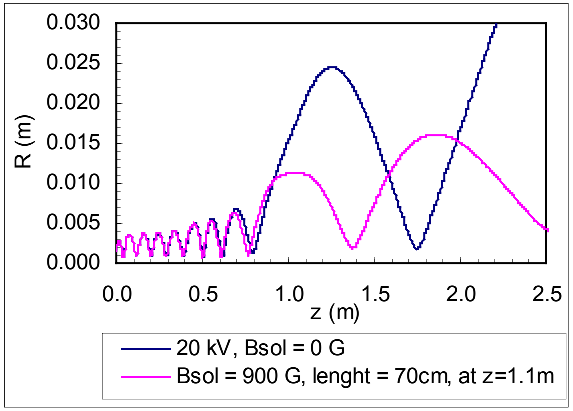


Mag Field Parameters for 20 MeV/n Oxygen beam

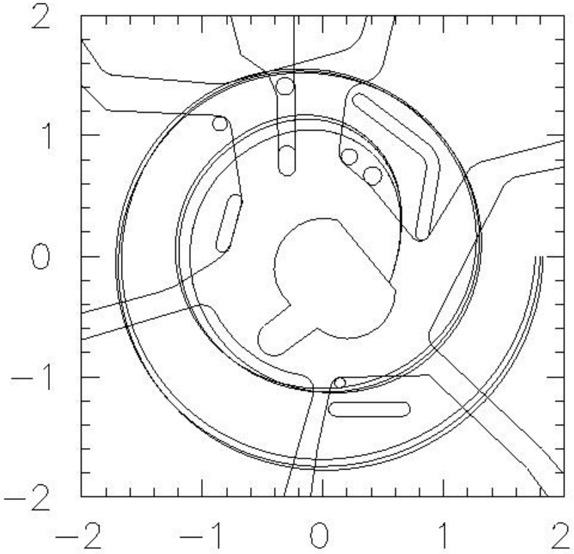
Main Field….33.8 Kgauss


19 9 2005


35000
30000
25000
20000
15000
10000
5000
0
Axial Mag. Fld at Centre position [G]
0
200
400
600
800
1000
1200
1400
1600
1800
Z [mm]
[425,225 A] AX-CN
[300,300 A] AX-CN
[250,250 A] AX-CN
[200,200 A] AX-CN



Beam envelope for Q/A=0.5, Vinj=20 kV.



2
1
0
−1
−2
−2
−1
0
1
2

cyclotron

- homogenous magnetic field isochronous (non-relativistic)

$$\frac{mv^2}{R} = qvB \quad R = \frac{mv}{Bq} \quad \nu_{orb} = \frac{Bq}{2\pi m}$$

- accelerate with RF electric field with $\nu_{RF} = \nu_{orb}$

- theory: homogeneous field ➡ no vertical orbit stability
  ➡ large beamlosses

- pratice: due to fringefield effects B_z decreases with radius
  ➡ marginal vertical orbit stability
- gradual loss of synchronism: energy limit

cyclotron

- relativistic effects $\frac{\gamma m v^2}{R} = qvB$ $R = \frac{\gamma m v}{Bq}$ $\nu_{orb} = \frac{Bq}{2\pi\gamma m} = f(R)$
- rapid loss of synchronism: energy limit ~ 20 MeV protons
  - only useful for ions ($m_p/m_e = 1836$)
- two solutions
  - vary ν_{RF} periodically: pulsed acceleration, synchro-cyclotron requires phase focussing (McMillan, Veksler; 1945)
  - restore isochronism $B_z(r) = \gamma(r)\,B_z(0)$: isochronous cyclotron B_z increases with radius ➡ no vertical stabilility introduce sectors in magnetic field (Thomas; 1938): "strong" focussing

Vertical focusing

AVF or Thomas focusing (1938)

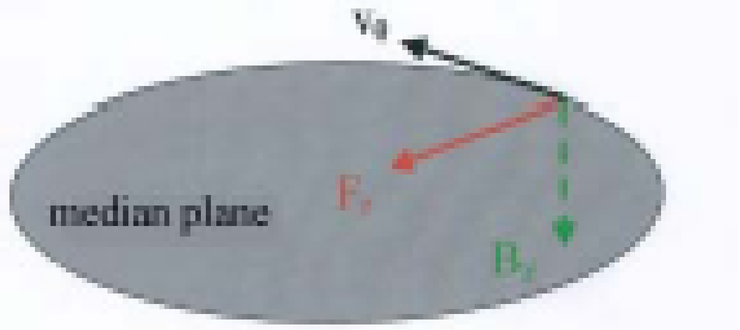
We need to find a way to increase the vertical focusing :

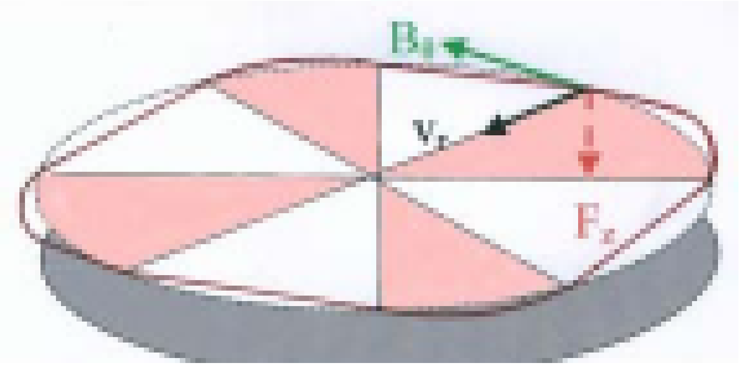
- F_r v_θ B_z : ion on the circle
- F_z v_θ B_r : vertical focusing (not enough)

Remains

- F_z with v_r , B_θ : one has to find an azimuthal component B_θ and a radial component v_r (meaning a non-circle trajectory)

➡ Sectors





Vertical focusing and isochronism

2 conditions to fulfil

- **Vertical focusing :** F$_z$ ~ ν_z^2
  - Field modulation: or flutter

$$\boxed{F = \frac{\langle B^2\rangle - \langle B\rangle^2}{\langle B\rangle^2} \approx \frac{\left(B_{hill} - B_{val}\right)^2}{8\langle B\rangle^2}}$$

where <B> is the average field over 1 turn

  - we can derive the betatron frequency:

$$\boxed{\nu_z^2 = n + \frac{N^2}{N^2-1}F + \dots > 0}$$

- **Isochronism condition :**

$$\overline{B}_z(r) = \gamma(r)\overline{B}_z(0) \Rightarrow \frac{\partial B_z}{\partial r} > 0 \Rightarrow \boxed{n = 1-\gamma^2 < 0}$$

The focusing limit is:

$$\boxed{\frac{N^2}{N^2-1}F > -n = \gamma^2 - 1}$$

Energy max for conventionnal cyclotrons

A cyclotron is characterised by its K_b factor giving its max capabilities

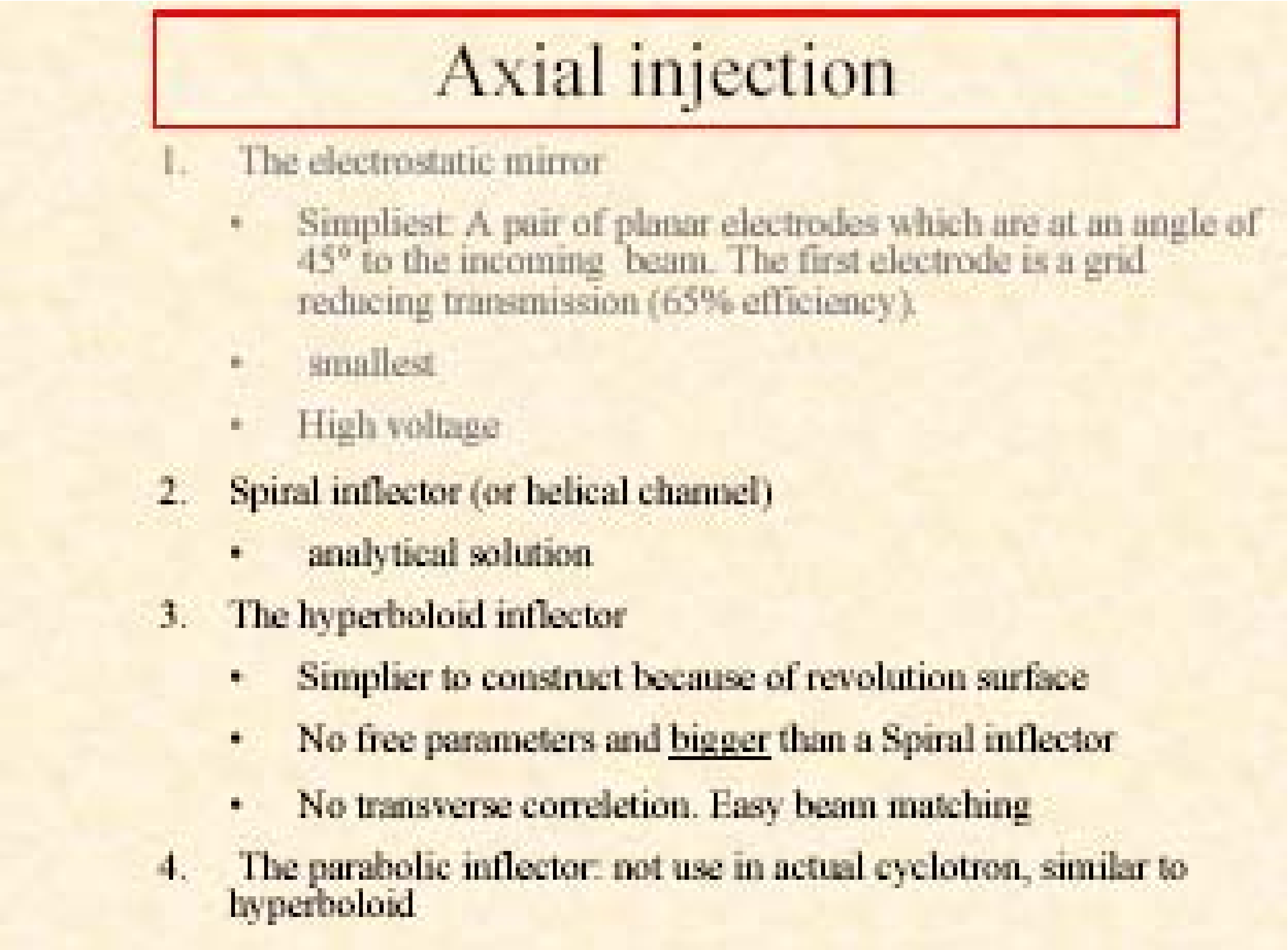
$$\boxed{W_{max}\left(MeV\ /\ nucleon\right)=K_b\left\{\frac{Q}{A}\right\}^2}\quad \text{with}\ K_b=48{,}244\left(\langle B\rangle r_{ej}\right)^2$$

- $W \propto r^2$: iron volume as r^3 ! → for compact $r_{extraction}$ ~ 2 m.
- For a same ion or isobar A=cst, W_{max} grows with Q^2 (great importance of the ion sources cf P. Spädtke)

Energy max for superconducting cyclotrons

Because of the focusing limitation due to the Flutter dependance on the B field:

$$W_{max}(MeV\ /\ nucleon) = K_f \left\{ \frac{Q}{A} \right\}$$



Axial injection

1. The electrostatic mirror
   - Simpliest: A pair of planar electrodes which are at an angle of 45° to the incoming beam. The first electrode is a grid reducing transmission (65% efficiency).
   - smallest
   - High voltage
2. Spiral inflector (or helical channel)
   - analytical solution
3. The hyperboloid inflector
   - Simplier to construct because of revolution surface
   - No free parameters and <u>bigger</u> than a Spiral inflector
   - No transverse correletion. Easy beam matching
4. The parabolic inflector: not use in actual cyclotron, similar to hyperboloid

Cyclotron resolution

An important figure for heavy ion cyclotrons is its mass resolution.

There is the possibility to have out of the source not only the desired ion beam (m_0, Q_0) but also pollutant beams with close Q/m ratio.

If the mass resolution of the cyclotron is not enough, both beams will be accelerated and sent to the physics experiments.

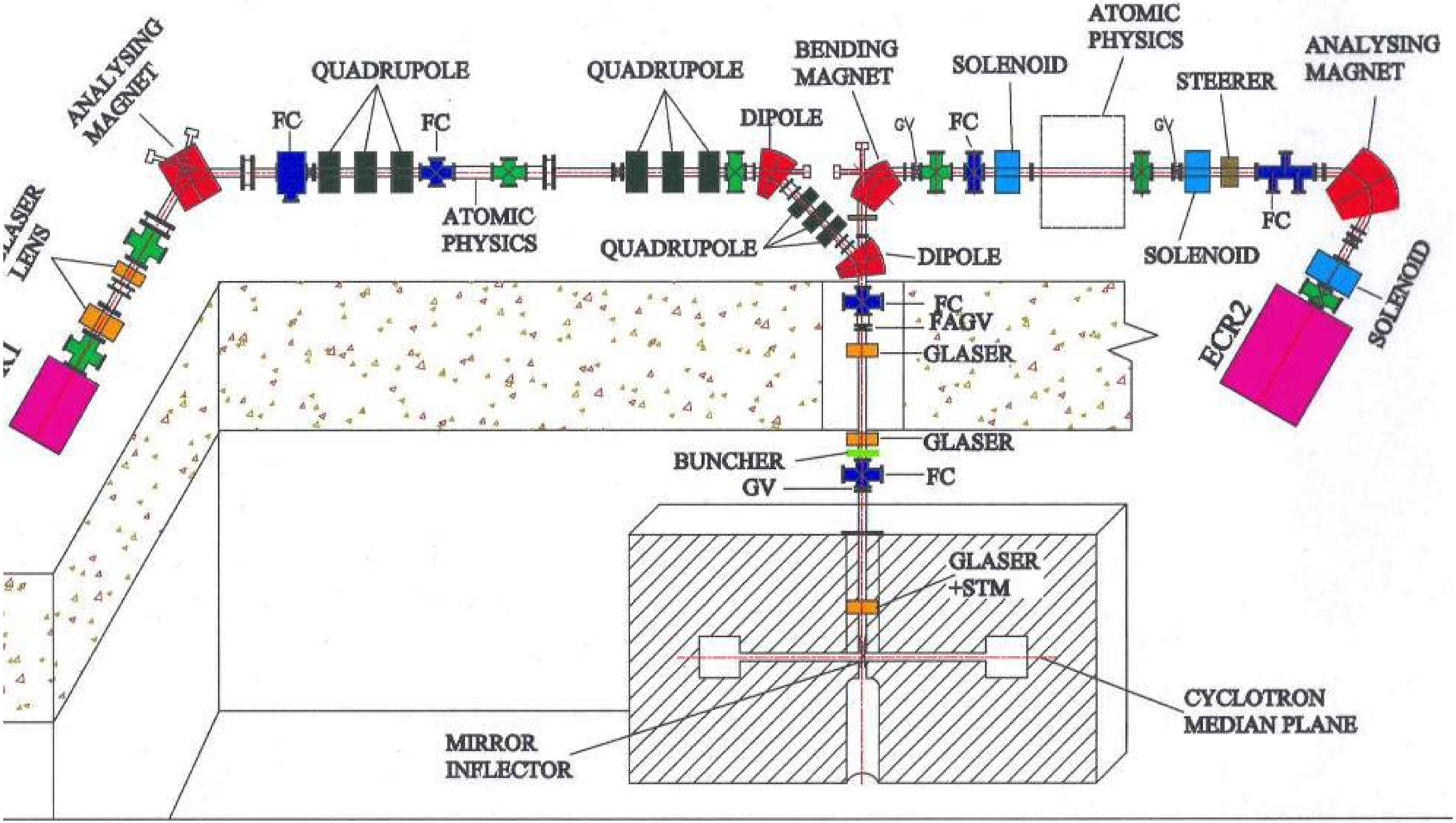
Mass resolution:

$$\boxed{R = \frac{\Delta\left(\frac{m}{Q}\right)}{\frac{m_0}{Q_0}} = \frac{1}{2\pi\ h N}}$$

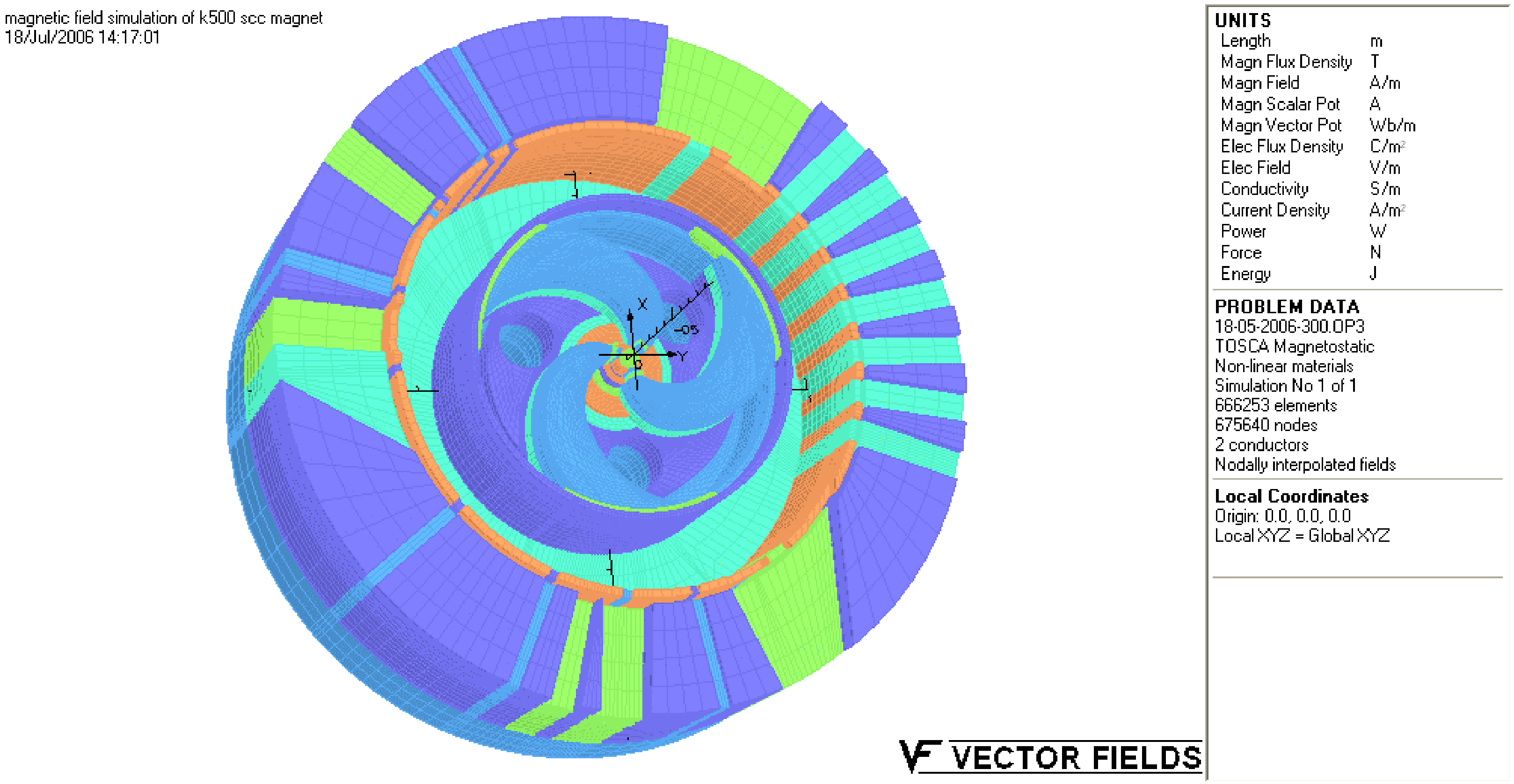
We want R small ⇨ seperation of close ion polluants

To have R small for a given harmonic h, the number of turn needs to be increase ⇨lowering the accelerating voltage ⇨small turn separation ⇨poor injection and/or extraction.

AXIAL INJECTION SYSTEM USING ECR-1 & ECR-2



Simulation of 3D Field Distribution with TOSCA



magnetic field simulation of k500 scc magnet
18/Jul/2006 14:17:01

UNITS

Length	m
Magn Flux Density	T
Magn Field	A/m
Magn Scalar Pot	A
Magn Vector Pot	Wb/m
Elec Flux Density	C/m^2
Elec Field	V/m
Conductivity	S/m
Current Density	A/m^2
Power	W
Force	N
Energy	J

PROBLEM DATA

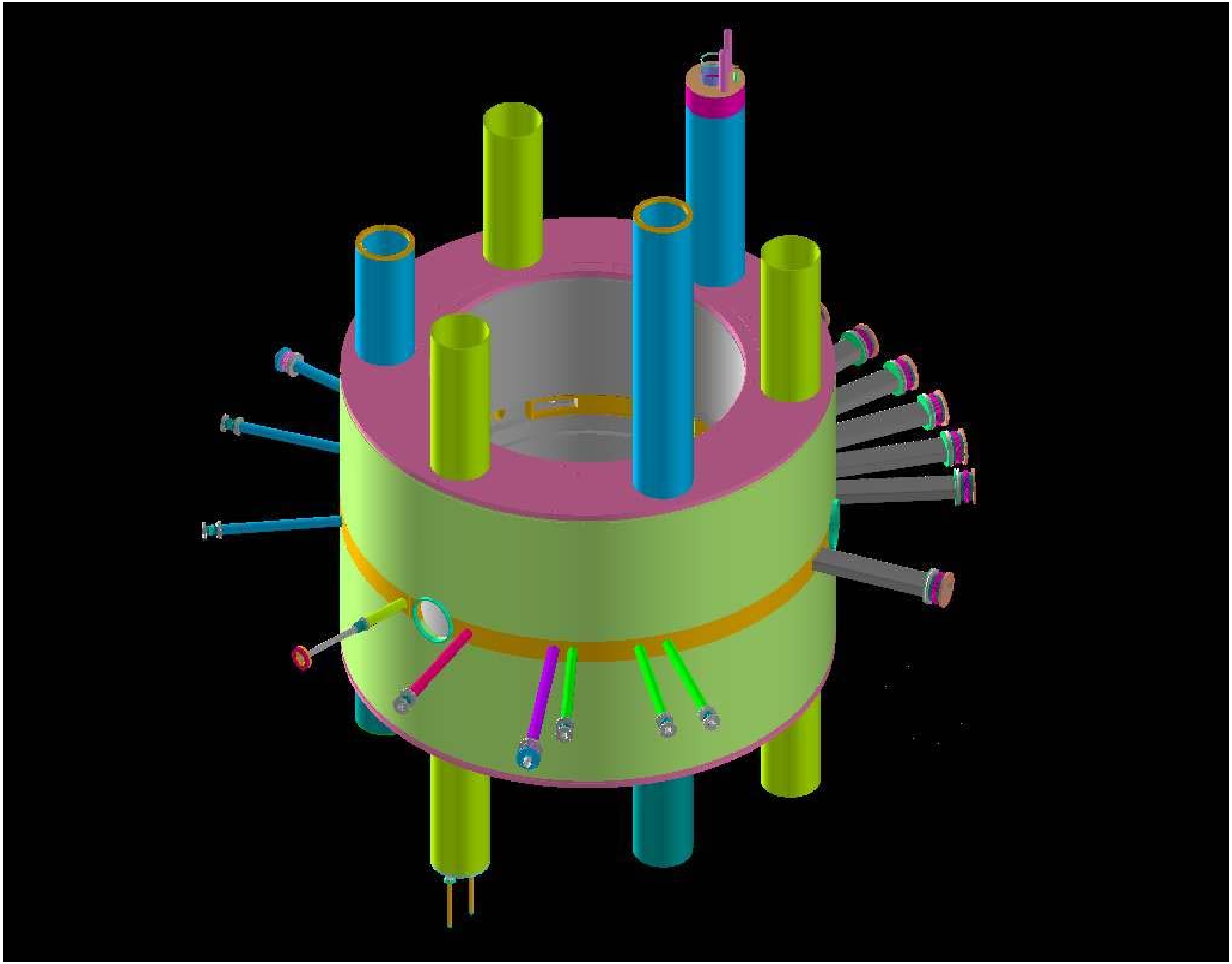
18-05-2006-300.OP3
TOSCA Magnetostatic
Non-linear materials
Simulation No 1 of 1
666253 elements
675640 nodes
2 conductors
Nodally interpolated fields

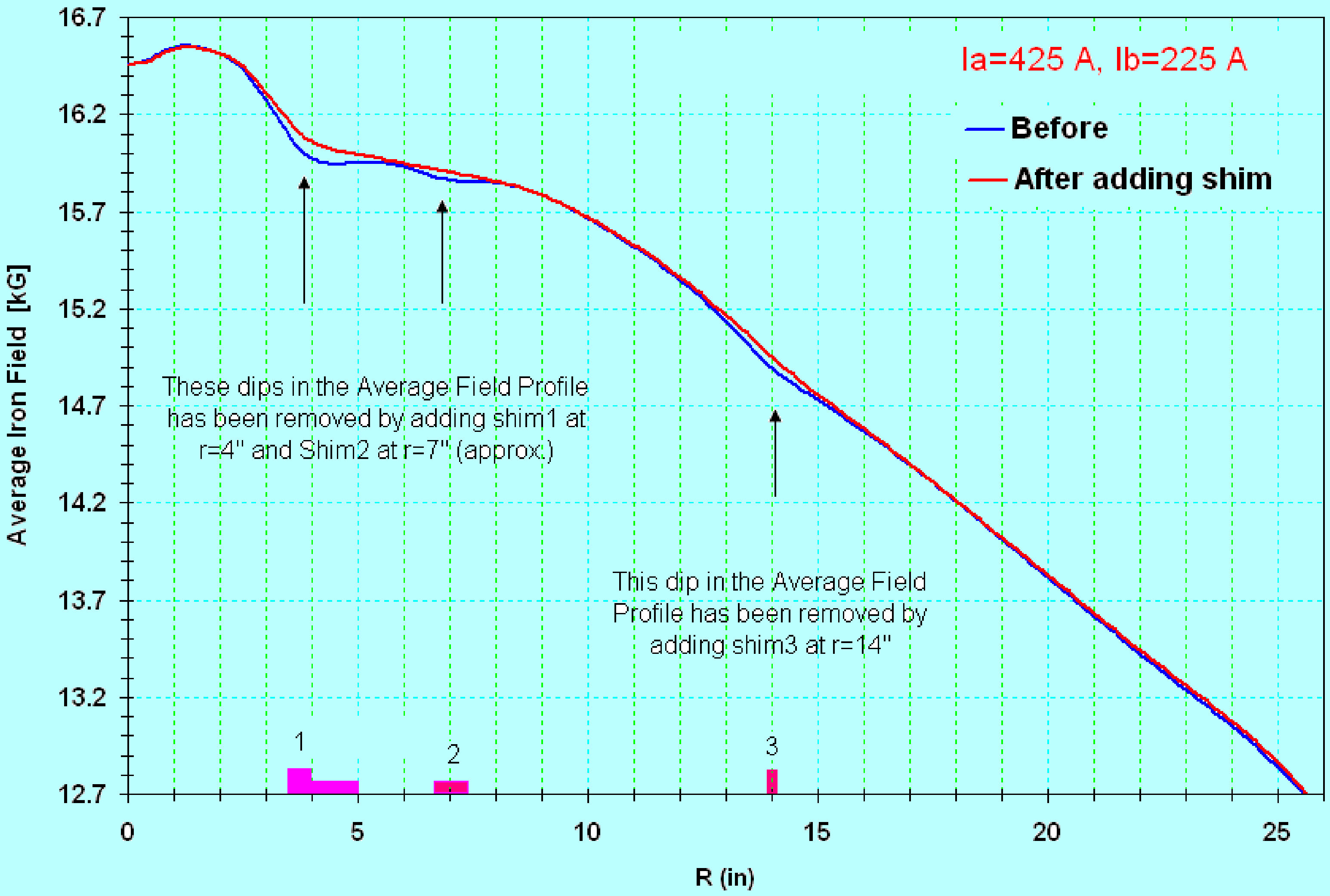
Local Coordinates

Origin: 0.0, 0.0, 0.0
Local XYZ = Global XYZ

Field measurement was not possible at all excitations and at all places due to inaccessibility. TOSCA simulation has been done to make up the data.

CRYOSTAT ASSEMBLY: COMPUTER MODEL



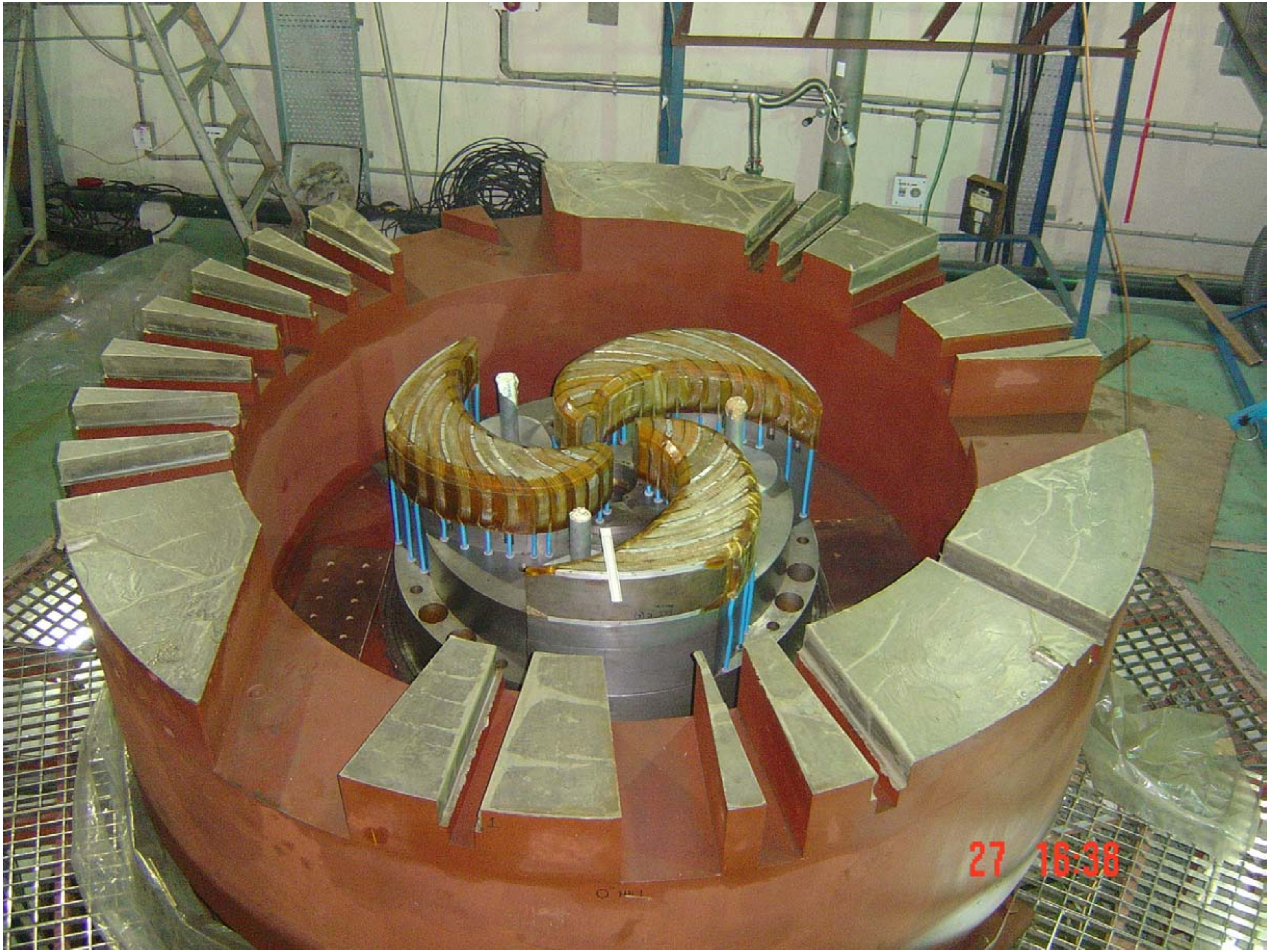


These dips in the Average Field Profile has been removed by adding shim1 at r=4" and Shim2 at r=7" (approx.)

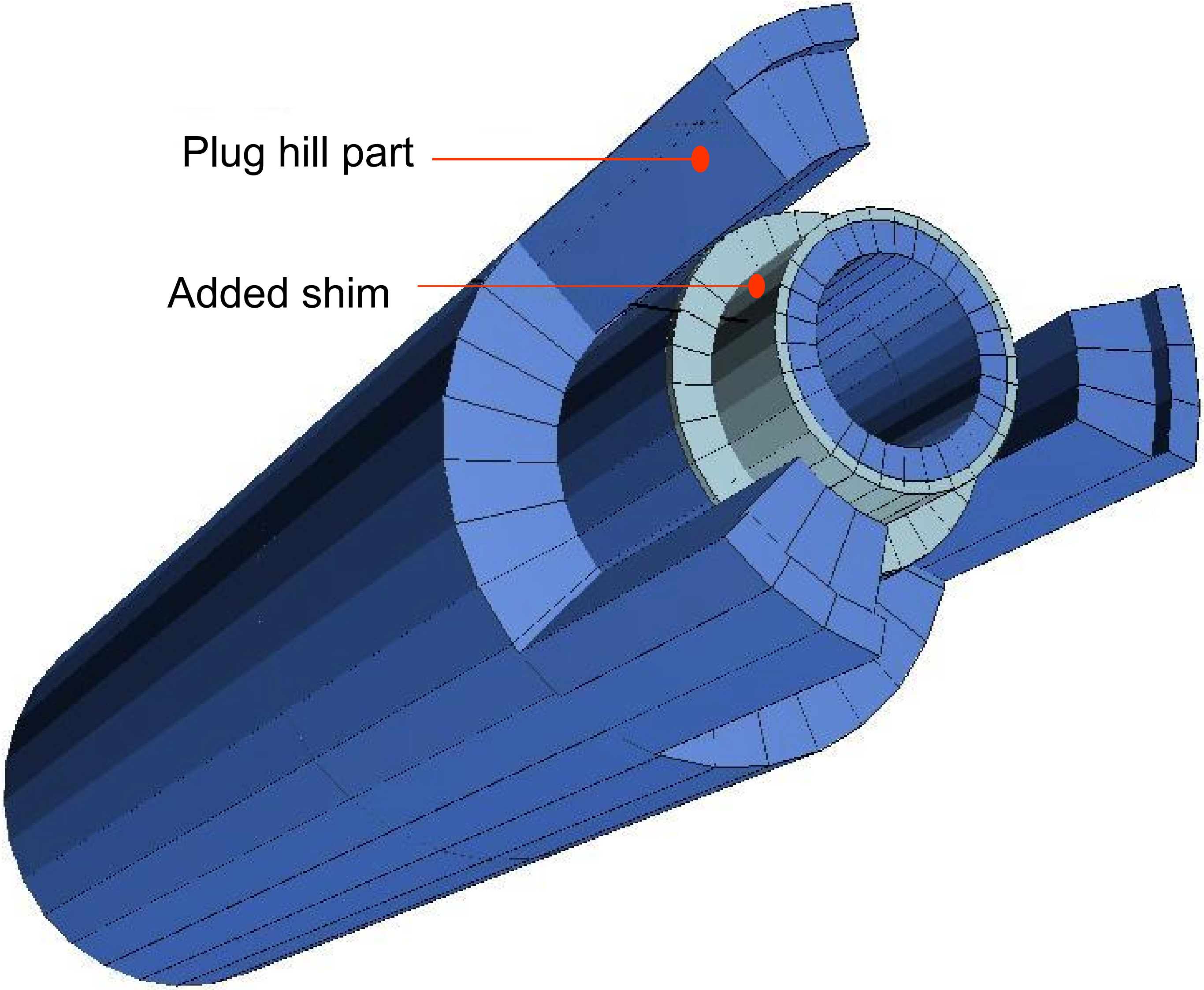
This dip in the Average Field Profile has been removed by adding shim3 at r=14"

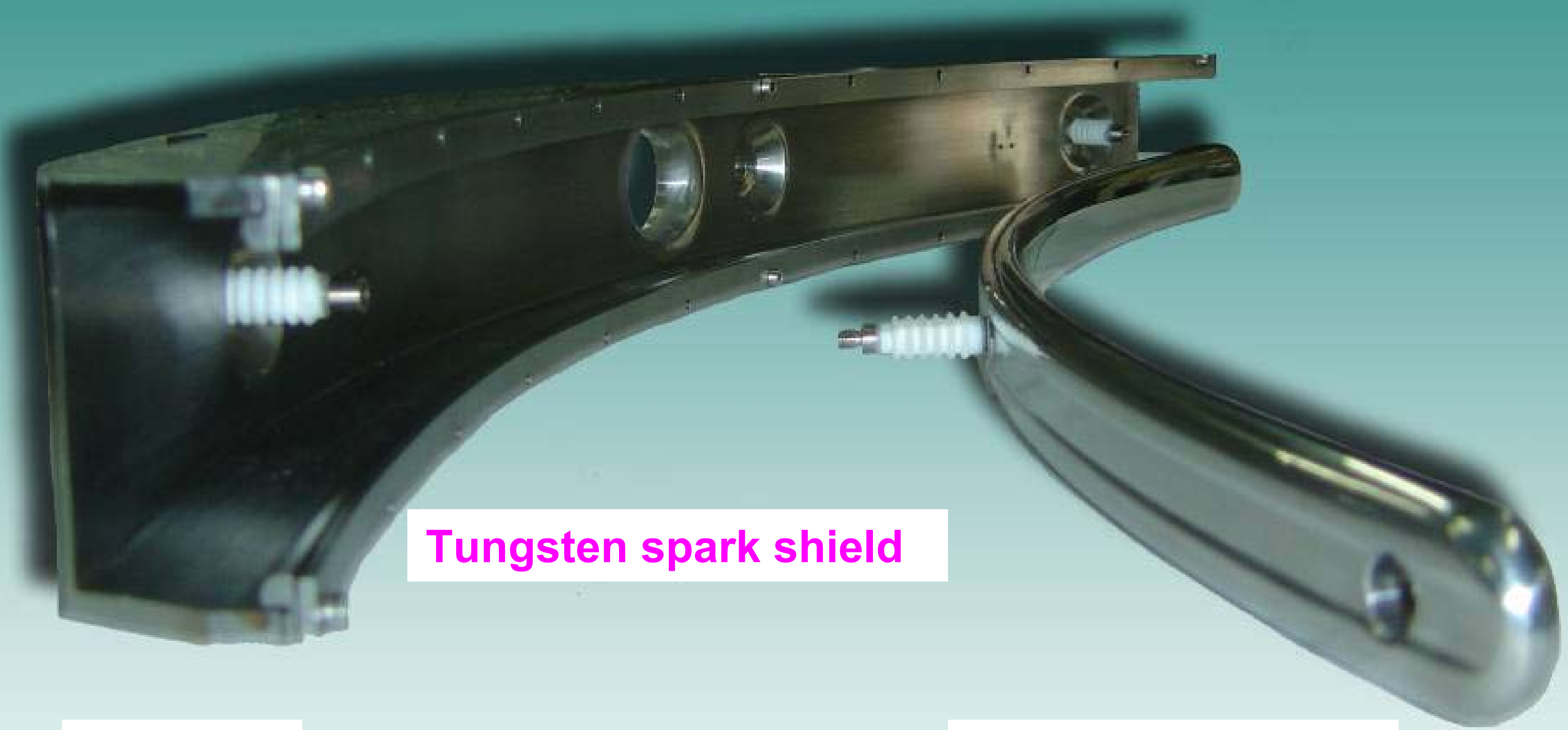
Shiming To Correct Average Field Profile

TRIM COIL INSTALLATION



CENTRAL PLUG





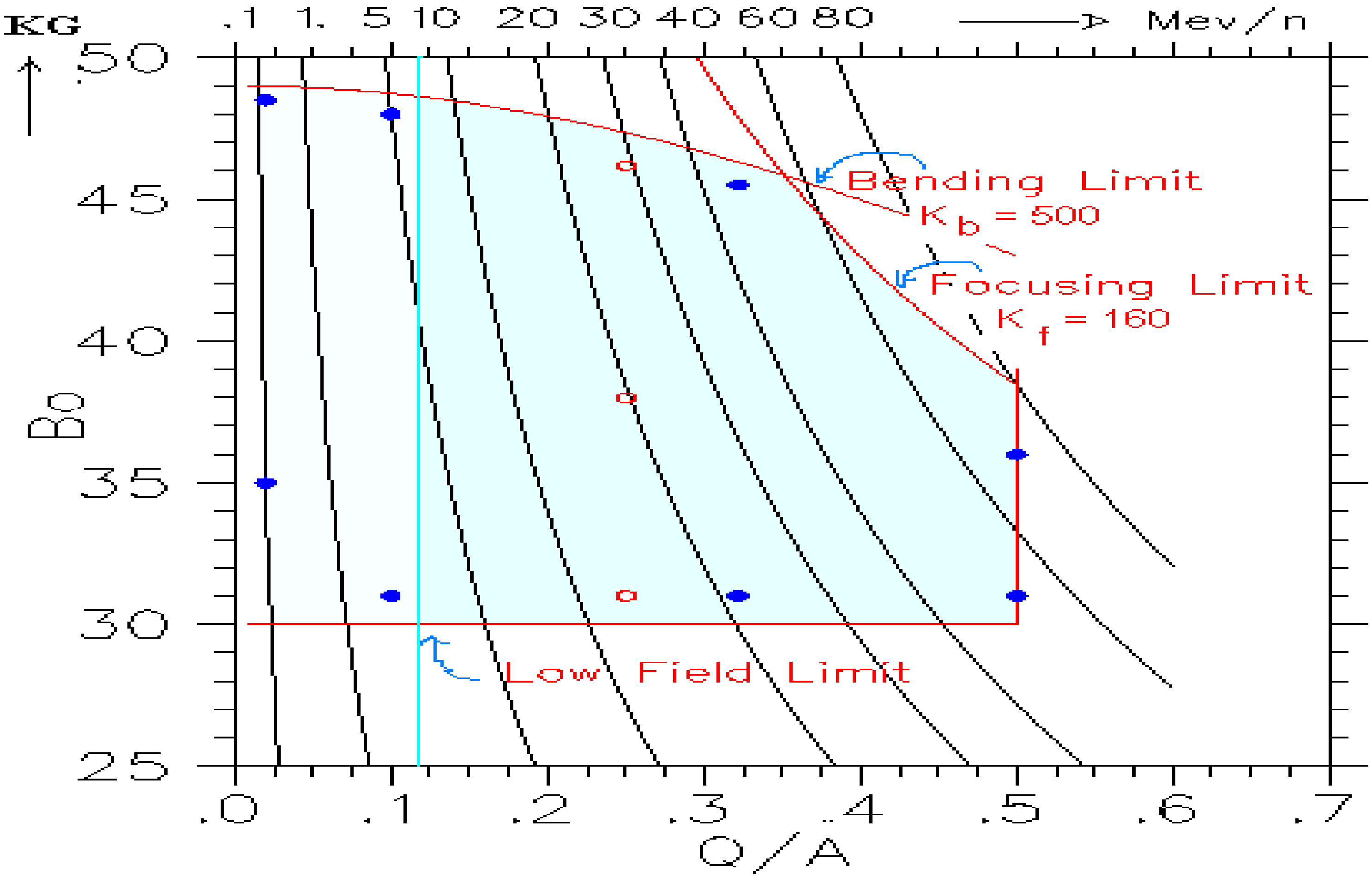
Tungsten spark shield

SS Body

Titanium electrode

Electrostatic deflector

OPERATING DIAGRAM
VECC K500 CYCLOTRON



Heavy Ion Acceleration

Bending Limit : $K_b = 520$

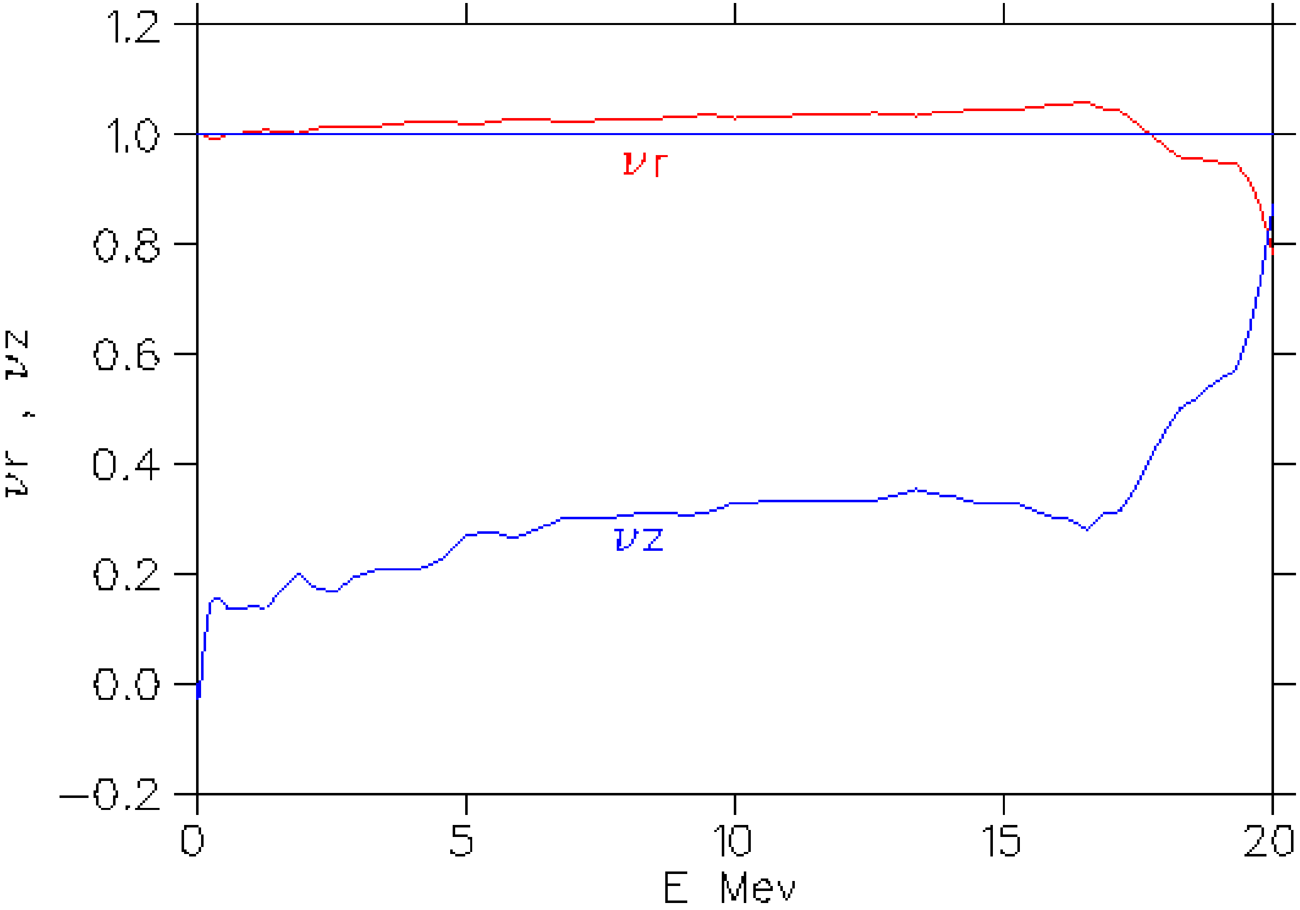
Focusing Limit : $K_f = 160$

- **Fully Stripped Heavy Ion Beams upto energy 80 MeV/A**
- **For Medium and Heavier Ion Beams Energy is limited to**
- **$520.Q^2/A^2$ MeV/A**
- **Protons cannot be accelerated but singly charged hydrogen molecular ion can be accelerated which can be stripped at extraction**
- **It is planned to operate the cyclotron in first harmonic mode. And hence energies below 10 MeV/n is ruled out. Experimentalists should plan above 15-20 MeV/n**

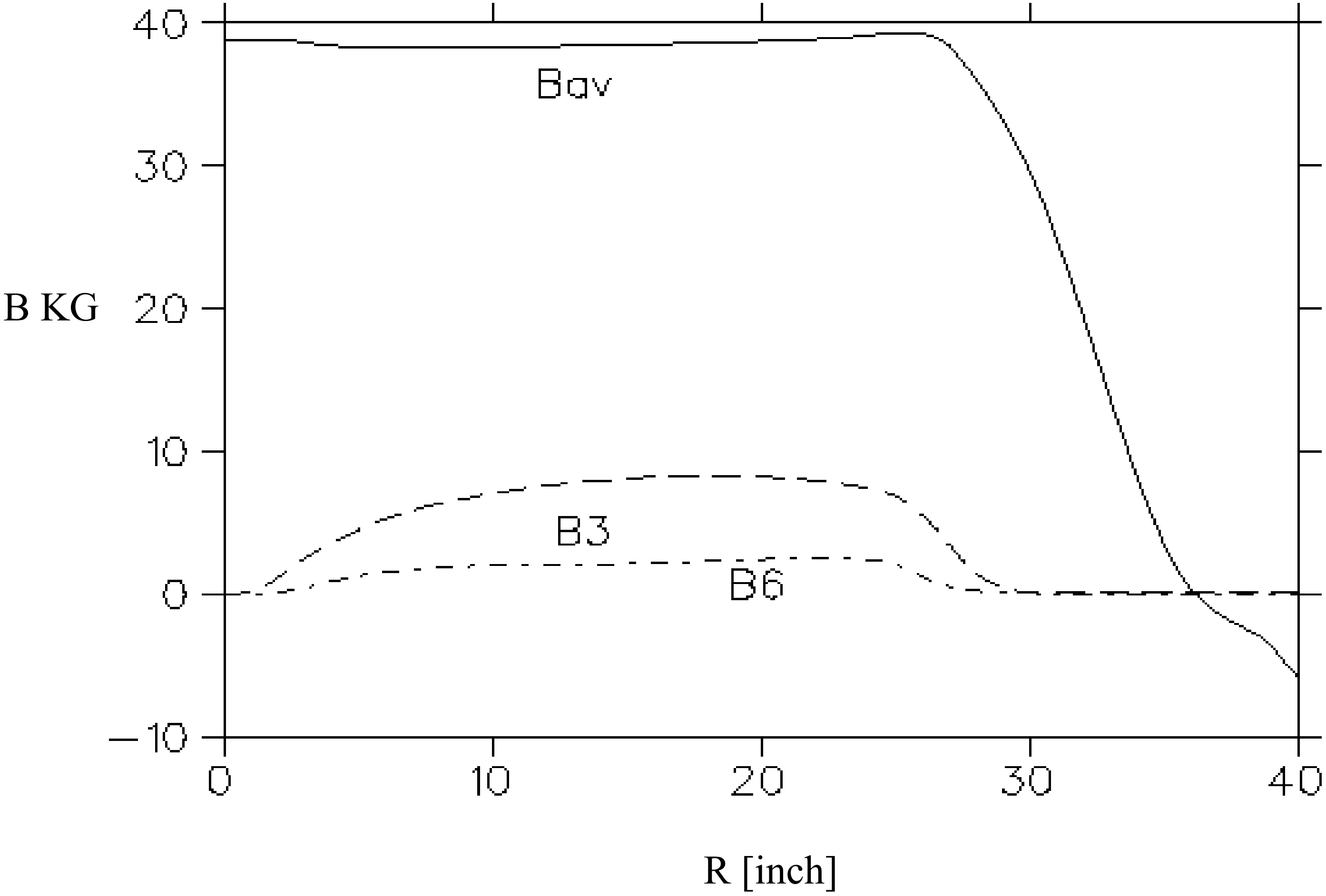
VECC K500 SCC

EXTRACTION SIMULATION

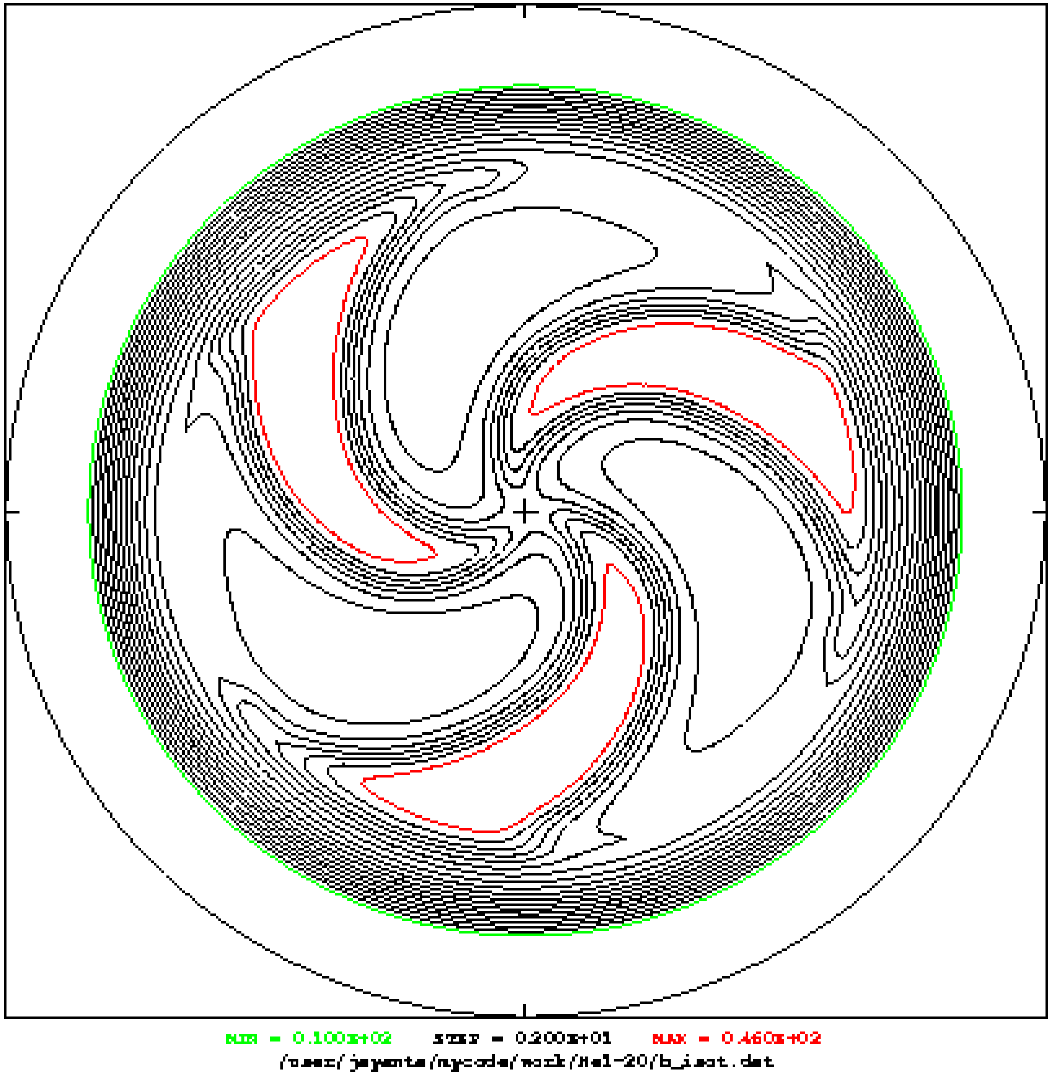
Energy vs. Nu_r, Nu_z plot , showing the values at E_{max}



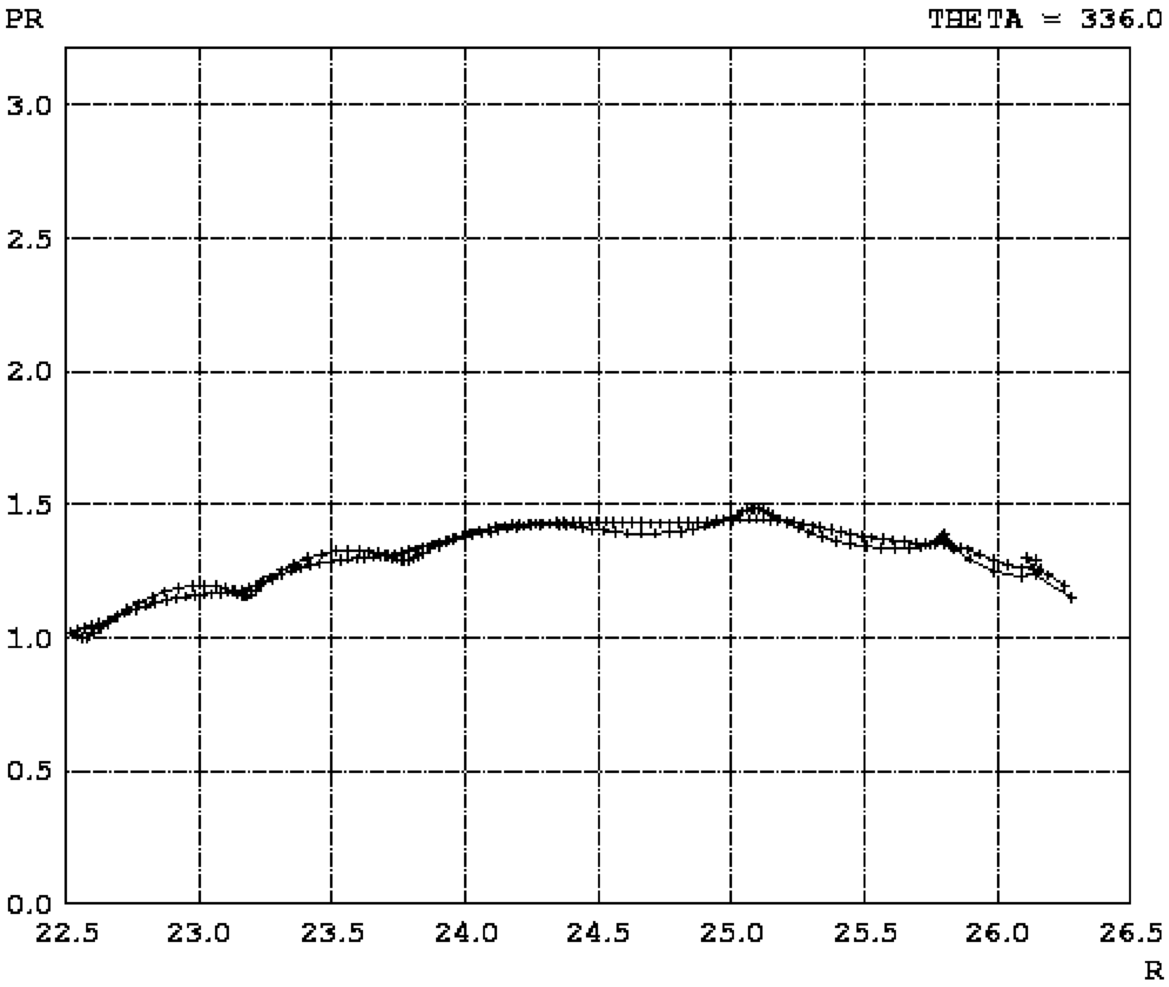
Fourier analysis of the isochronous field obtained from Trim coil fitting program.



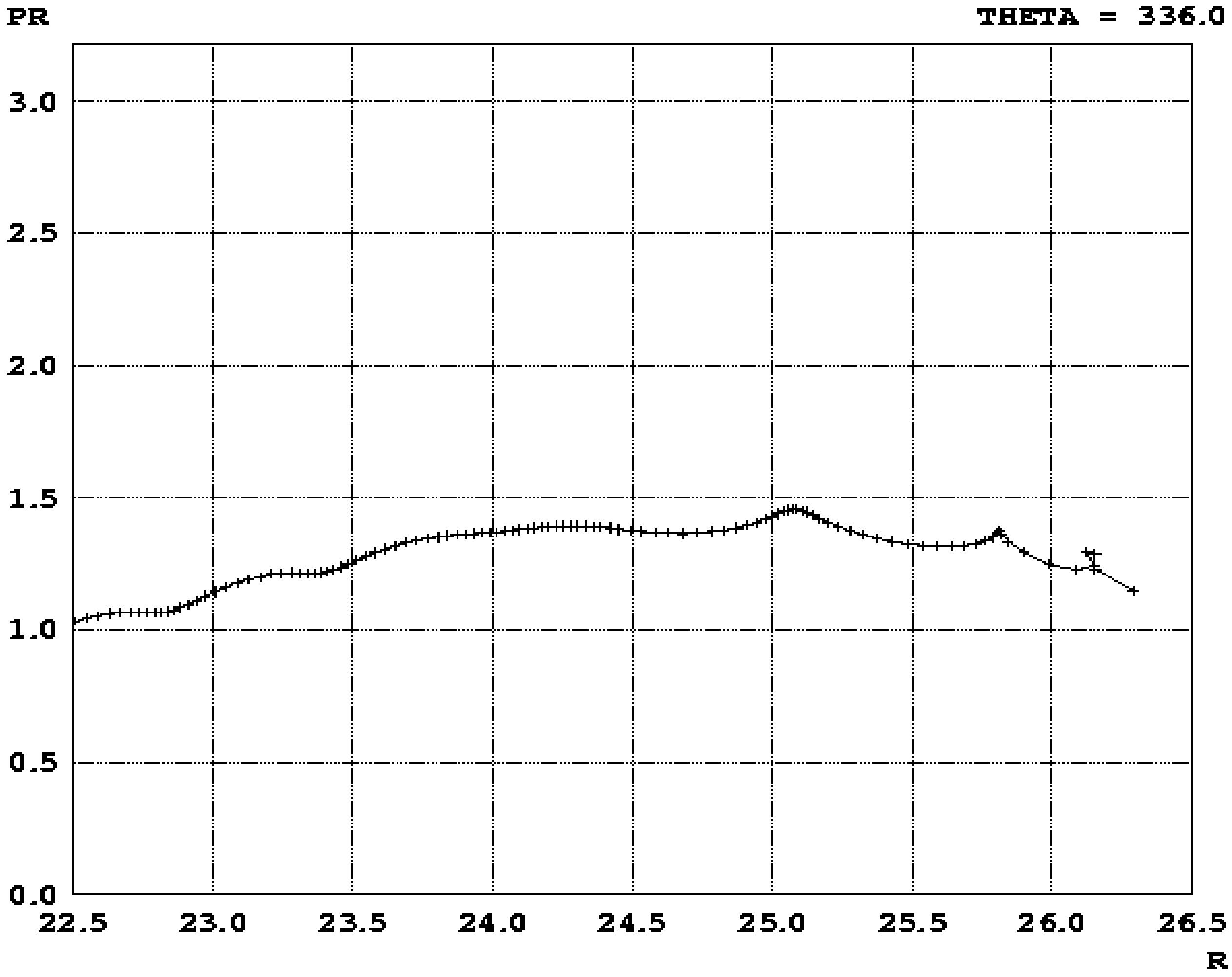
Contour plot of the isochronous field obtained from Trim coil fitting program.



Bump profile used for "Precissional Extraction"



Bump profile used for "Precissional Extraction"



```
DEF   TH BAR    R BAR   AL BAR    R RAY   AL RAY     X AV      -.25    X  +.25          -1.0     X  +1.0

  8  147.00   27.730    4.300   27.710    0.678    0.016
  9  147.00   27.730   -2.200   27.710    0.678    0.001
 10  203.00                     28.324    2.309
 11  229.00                     28.986    3.540
 12  239.00                     29.332    4.194
 13  259.00                     30.259    6.350
 14  269.00                     30.945    8.433
 15  279.00                     31.902   11.596
 16  289.00                     33.310   16.561
 17  322.84   49.624   51.243   49.431   51.719   -0.091
OFF FIELD AT TH =338.0      330.0 DEG DR =59.6604 ,DPR/P = 0.8737


R = 26.2900    PR =   1.1500    E =   20.00

DEF     TH1       TH2     TYP     E,B,R   DBR,AL   DE1,TH     DE2
  6   337.00     32.00     1     64.590    0.000    0.000    0.000
  7    94.00    137.00     1     64.590    0.000    0.000    0.000
  8   140.09    147.00     3     27.730    4.300    0.000    0.000
  9   147.00    152.91     3     27.730   -2.200    0.000    0.000
 10   200.00    206.00     2      1.150    8.300    0.000    0.000
 11   226.00    232.00     2      1.150    8.300    0.000    0.000
 12   236.00    242.00     2      0.000    0.000    0.000    0.000
 13   256.00    262.00     2      1.150    8.300    0.000    0.000
 14   266.00    272.00     2      1.150    8.300    0.000    0.000
 15   276.00    282.00     2      1.150    8.300    0.000    0.000
 16   286.00    292.00     2      1.150    8.300    0.000    0.000
 17   316.72    327.68     5     49.624   51.243  322.843    0.000
 18   319.51    326.50     4     27.776    3.000    0.000    0.000
 19   327.50    334.49     4     27.776   -3.000    0.000    0.000
 20    45.91     58.09     4     28.950    0.000    0.000    0.000
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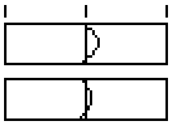

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DEF  TH BAR   R BAR  AL BAR   R RAY  AL RAY    X AV      -.25   X  +.25       -1.0    X  +1.0

  8  147.00  27.731   4.300  27.710   0.680   0.015
  9  147.00  27.731  -2.200  27.710   0.680   0.001
 10  203.00  28.304   2.300  28.326   2.312   0.009
 11  229.00  28.970   3.400  28.990   3.549   0.007
 12  239.00                  29.336   4.205
 13  259.00  30.244   6.600  30.266   6.368   0.009
 14  269.00  30.932   8.500  30.954   8.457   0.011
 15  279.00  31.898  11.600  31.915  11.633   0.007
 16  289.00  33.315  16.900  33.328  16.615   0.007
 17  322.84  49.624  51.243  49.530  51.795  -0.031
OFF FIELD AT TH =338.0     330.0 DEG DR =59.8010 ,DPR/P = 0.8740


R = 26.2900   PR =  1.1500   E =  20.00

DEF     TH1     TH2   TYP    E,B,R  DBR,AL  DE1,TH    DE2
  6  337.00   32.00     1   64.590   0.000   0.000   0.000
  7   94.00  137.00     1   64.590   0.000   0.000   0.000
  8  140.09  147.00     3   27.731   4.300   0.000   0.000
  9  147.00  152.91     3   27.731  -2.200   0.000   0.000
 10  200.00  205.98     3   28.304   2.300   0.000   0.000
 11  226.01  231.97     3   28.970   3.400   0.000   0.000
 12  236.00  242.00     2    0.000   0.000   0.000   0.000
 13  256.01  261.95     3   30.244   6.600   0.000   0.000
 14  266.01  271.94     3   30.932   8.500   0.000   0.000
 15  276.03  281.91     3   31.898  11.600   0.000   0.000
 16  286.10  291.82     3   33.315  16.900   0.000   0.000
 17  316.72  327.68     5   49.624  51.243 322.843   0.000
 18  319.51  326.50     4   27.776   3.000   0.000   0.000
 19  327.50  334.49     4   27.776  -3.000   0.000   0.000
 20   45.91   58.09     4   28.950   0.000   0.000   0.000
```
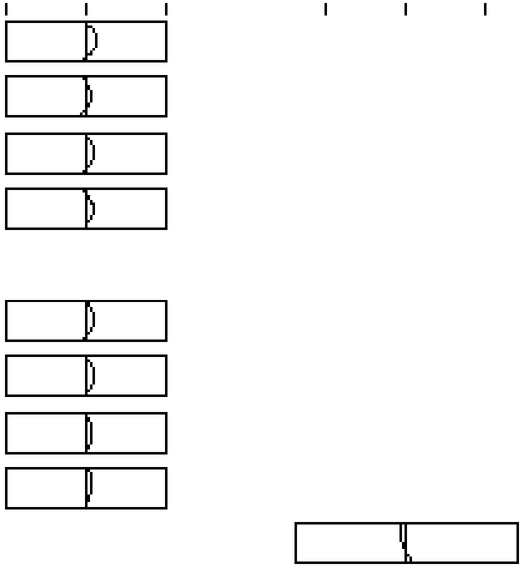
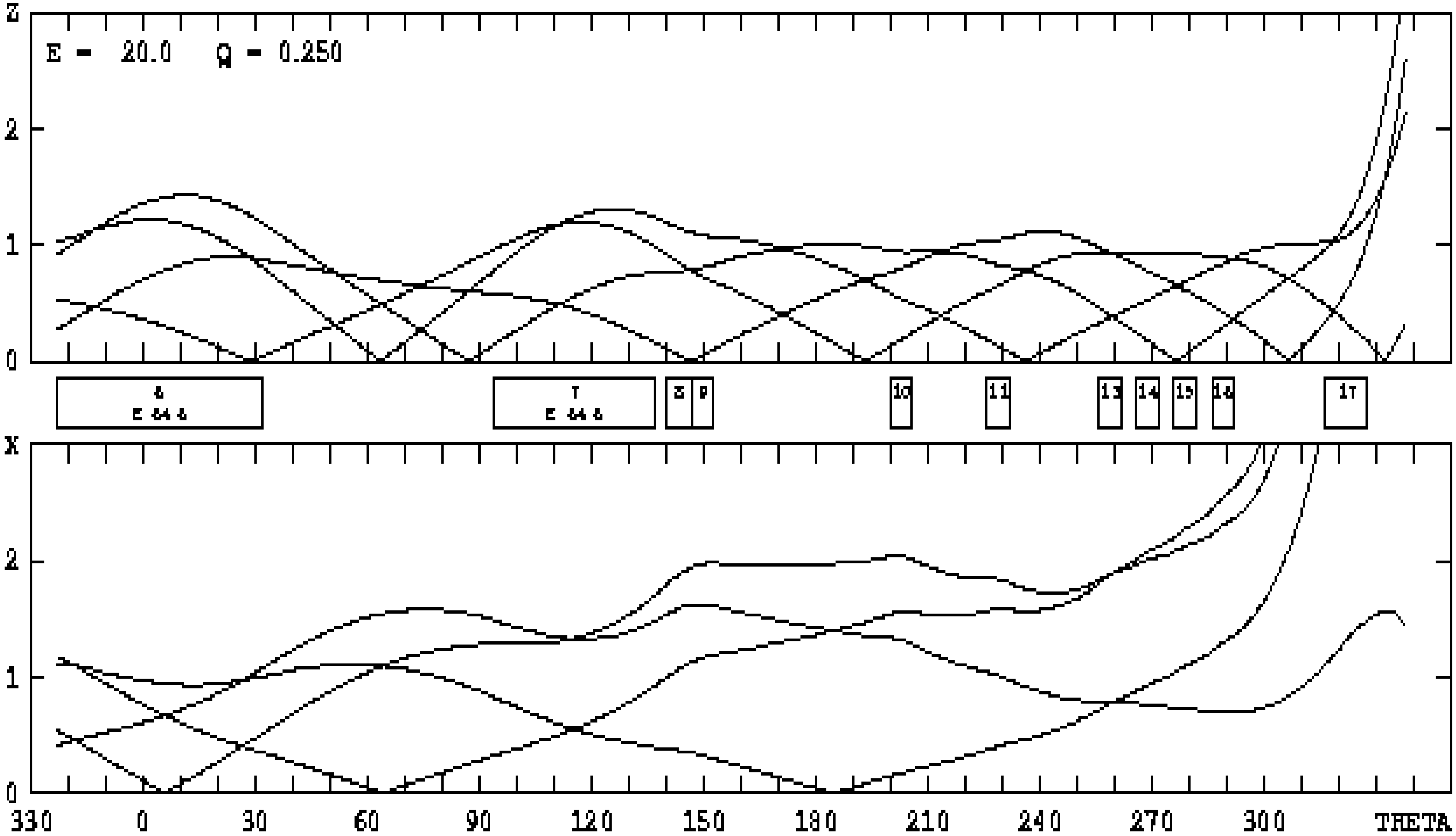
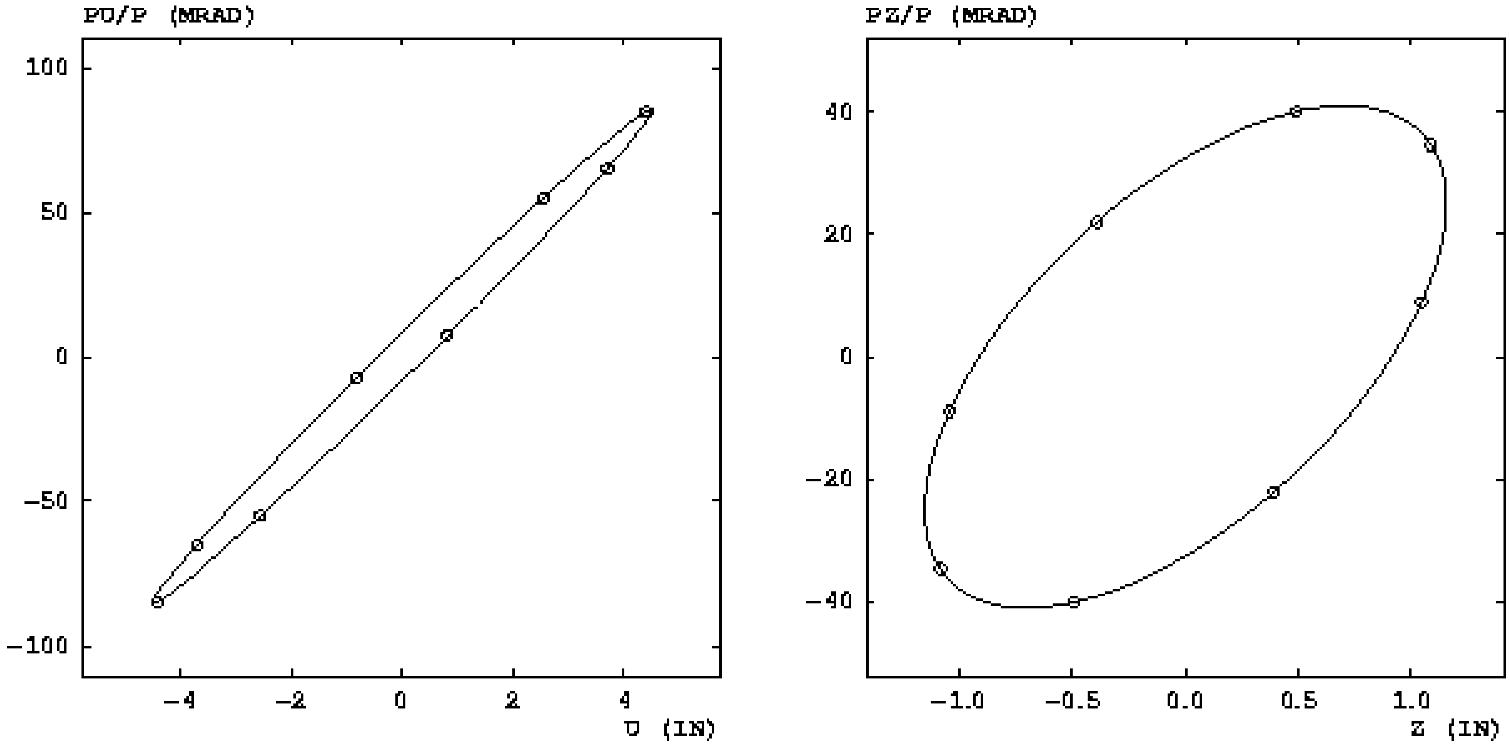



Trajectories through the Extraction system

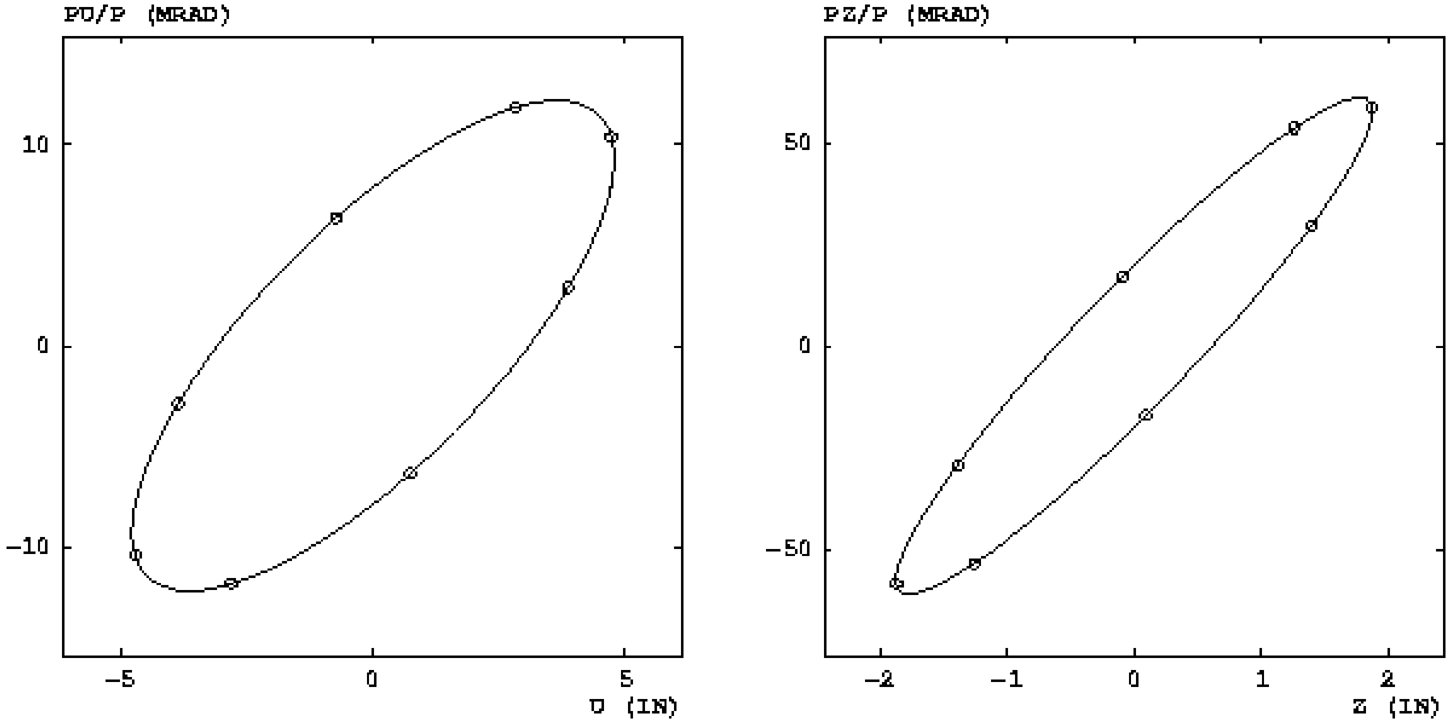


Bump profile used for “Precissional Extraction”



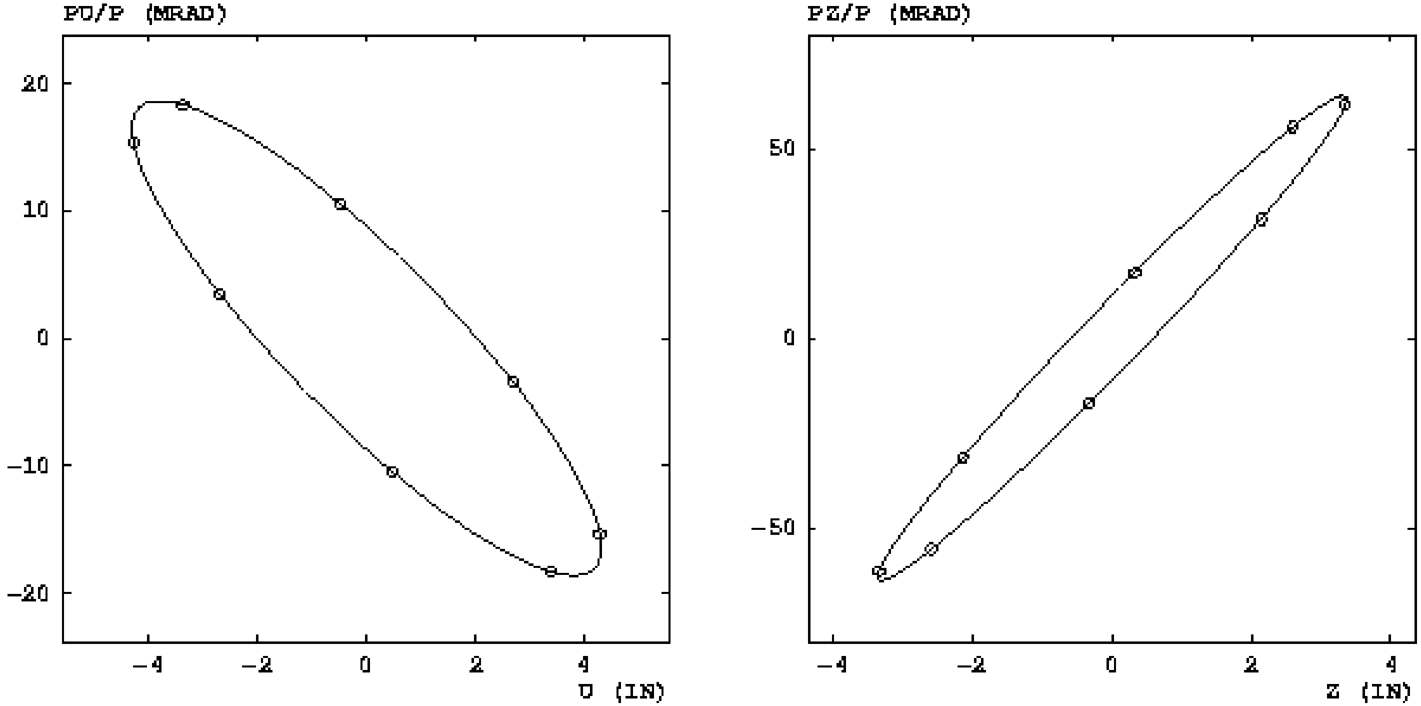
```
THETA (DEG) - 320.0   R (IN) -  46.676   PR/P - 0.747

U ELLIPSE
SQSIG11 (MM) -114.388   SQSIG22 (MRAD) - 85.270   R12 -  0.995
EMITTANCE (MM*MRAD) - 955.001*PI
BETA (M) - 13.701   GAMMA (1/M) -  7.614   ALPHA --10.164

Z ELLIPSE
SQSIG11 (MM) - 29.358   SQSIG22 (MRAD) - 41.083   R12 -  0.611
EMITTANCE (MM*MRAD) - 955.000*PI
BETA (M) -  0.903   GAMMA (1/M) -  1.767   ALPHA - -0.771
```

Bump profile used for “Precissional Extraction”



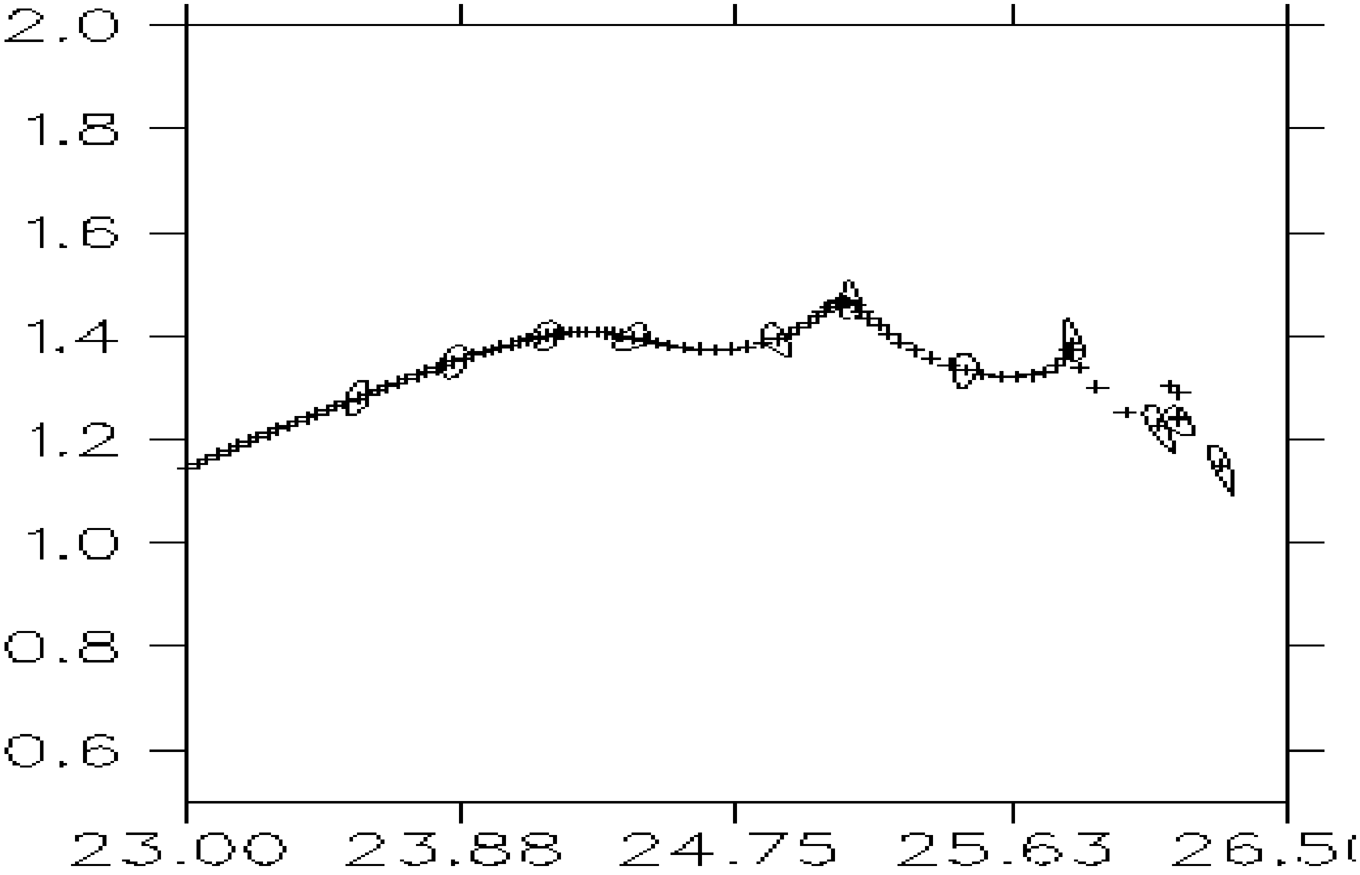
```
THETA (DEG) - 330.0   R (IN) -  59.801   PR/P - 0.874

U ELLIPSE
SQSIG11 (MM) -121.284   SQSIG22 (MRAD) - 12.170   R12 -  0.762
EMITTANCE (MM*MRAD) - 955.000*PI
BETA (M) - 15.403   GAMMA (1/M) -  0.155   ALPHA - -1.178

Z ELLIPSE
SQSIG11 (MM) - 47.700   SQSIG22 (MRAD) - 61.062   R12 -  0.945
EMITTANCE (MM*MRAD) - 955.001*PI
BETA (M) -  2.382   GAMMA (1/M) -  3.904   ALPHA - -2.881
```

Bump profile used for “Precissional Extraction”



```
THETA (DEG) - 338.0   R (IN) -  81.952   PR/P - 0.942

U ELLIPSE
SQSIG11 (MM) -109.367   SQSIG22 (MRAD) - 18.592   R12 - -0.883
EMITTANCE (MM*MRAD) - 955.000*PI
BETA (M) - 12.525   GAMMA (1/M) -  0.362   ALPHA -  1.880

Z ELLIPSE
SQSIG11 (MM) - 85.372   SQSIG22 (MRAD) - 63.792   R12 -  0.985
EMITTANCE (MM*MRAD) - 955.001*PI
BETA (M) -  7.632   GAMMA (1/M) -  4.261   ALPHA - -5.614
```

Bump profile used for “Precissional Extraction”



Median Plan View of the K-500 SCC VEC showing the Extraction Elements with the Extracted Beam [He^{+1} 20 Mev/A]