1st East-Asian Miniworkshop on High Intensity p Accelerator-RFQ

Dec.10&11 2002 @ KEK

J-PARC Front-End Group
Akira UENO(KEK)
Kiyoshi IKEGAMI(KEK)
Yasuhiro KONDO(JAERI)
Hidetomo OGURI(JAERI)

Design of a Front-End System for the J-PARC

(0) Drawing of a Front-End System for the J-PARC

(1) Ion Source Beam Dynamics Design with BEAMORBT & Electron and H^- Beam Axis Trajectory Calculation

*BEAMORBT:1D ion extractor simulation code by Y. OKUMURA of JAERI for NBI
*3D magnetic field analysis with OPERA-3D

(2) Principle of Energy Modulation Type Pre-Chopper & Beam Dynamics Design of LEBT with TRACE2D

(3) Beam Dynamics Design of RFQ with KEKRFQ and PARMTEQm

*KEKRFQ:RFQ design code by A. UENO
*PARMTEQm:standard RFQ simulation code (2D space-charge & z-domain) by K. CRANDALL

(4) Cavity Structure Design of 4-vane RFQ with PISL by using SUPERFISH & MAFIA

*PISL(π-mode Stabilizing Loop):accelerating-mode stabilizer against dipole-mode mixing, invented for J-PARC RFQ's & adopted in SNS-RFQ
*SUPERFISH:2D RF field analysis code by K. HALBACH
*MAFIA:3D RF field analysis code by T. WEILAND

(5) RF-Window Design for Loop Type Coupler with HFSS

*HFSS:3D RF field analysis code

Front-End Design
(0)Drawing
(1)IS Optics
(2)LEBT Optics
(3)RFQ Optics
(4)RFQ Cavity
(5)Loop Coupler

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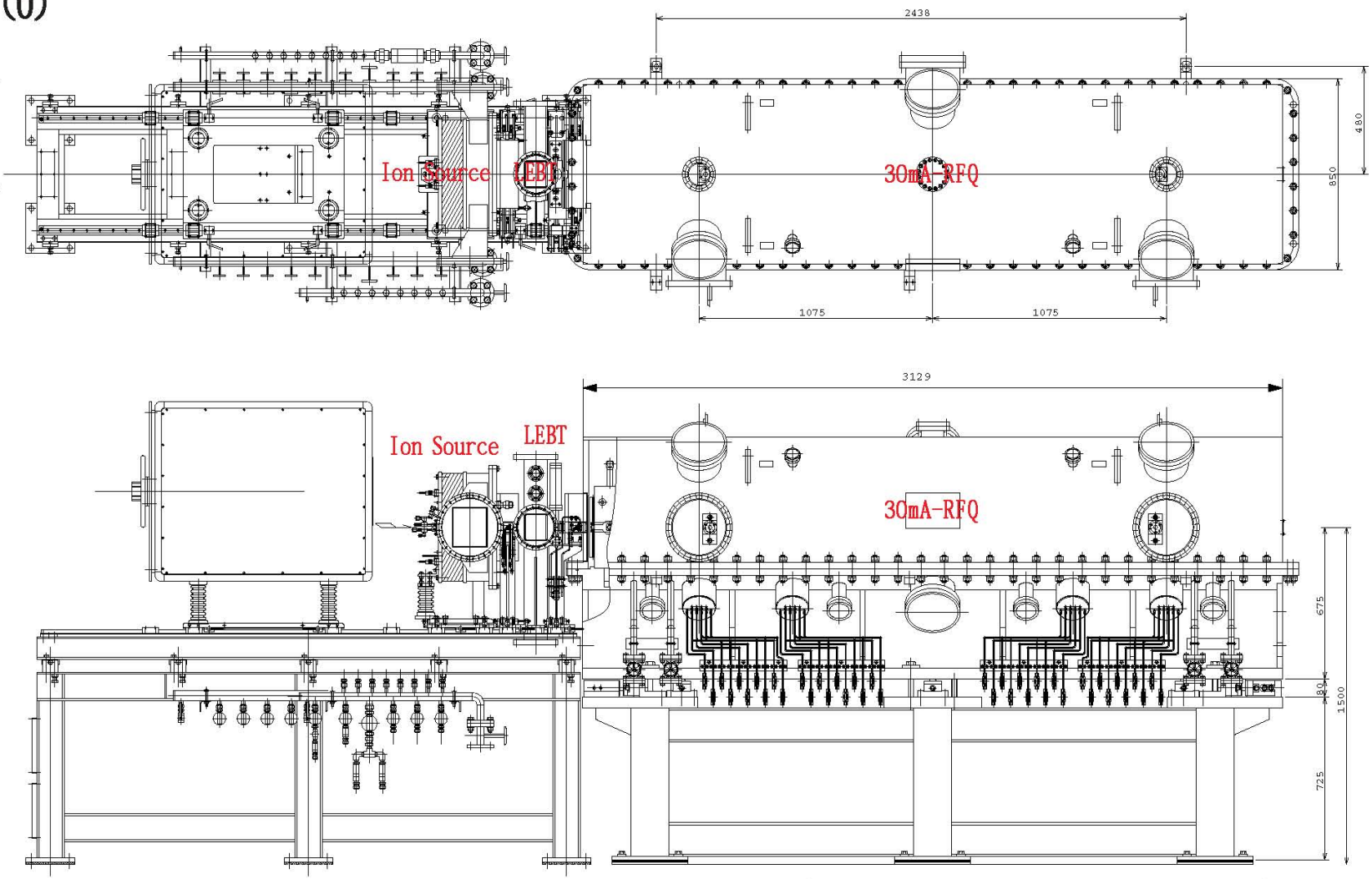

Drawing of a front-end system for the J-PARC (before installing pre-chopper).

Front-End Design
(0)Drawing
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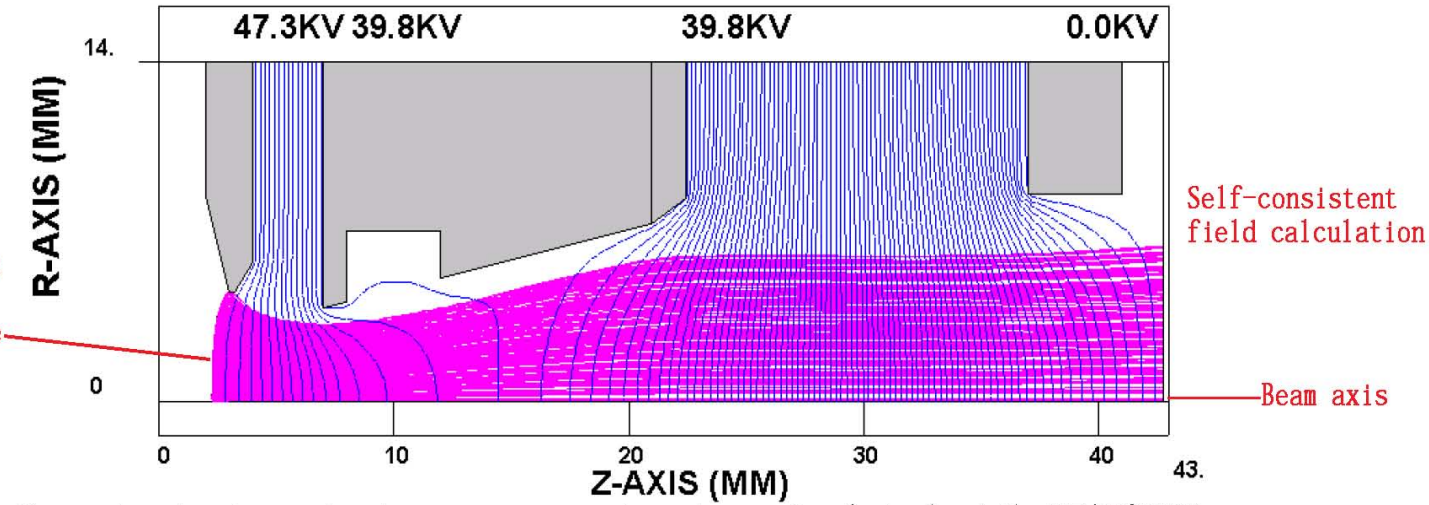
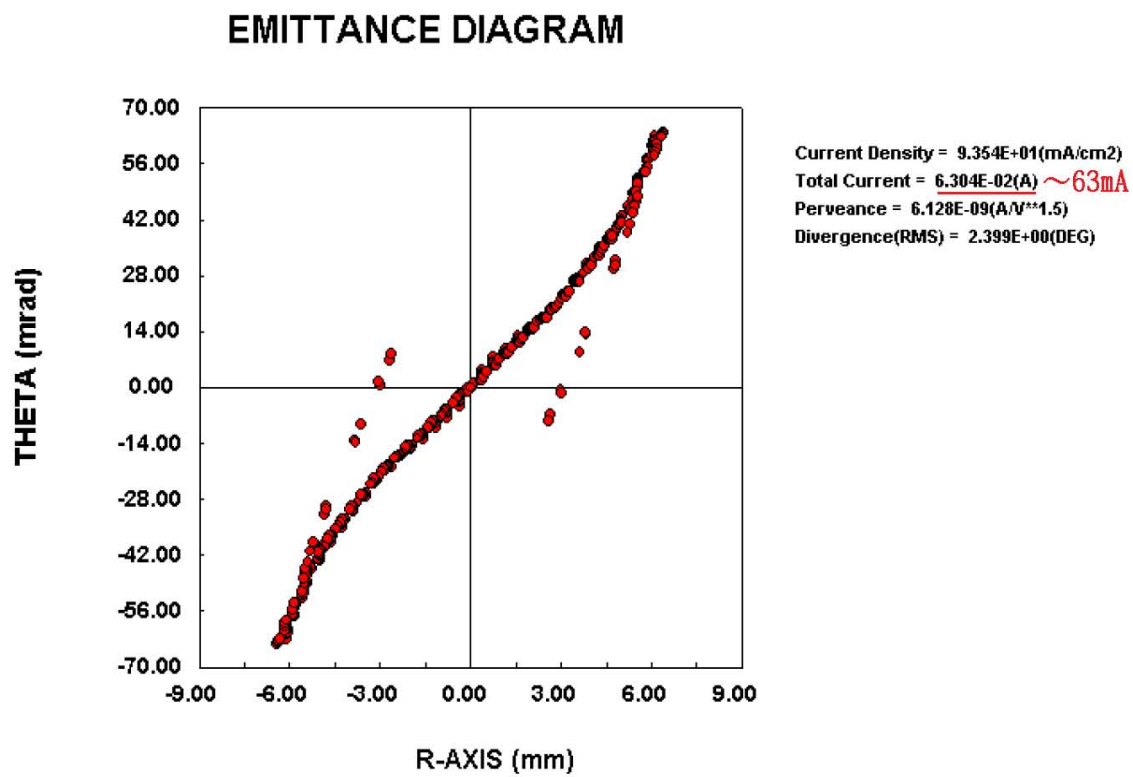


Beam trajectory in ion source extractor simulated with BEAMORBT.



Beam emittance at exit of ion source extractor simulated with BEAMORBT.

Front-End Design
(0)Drawing
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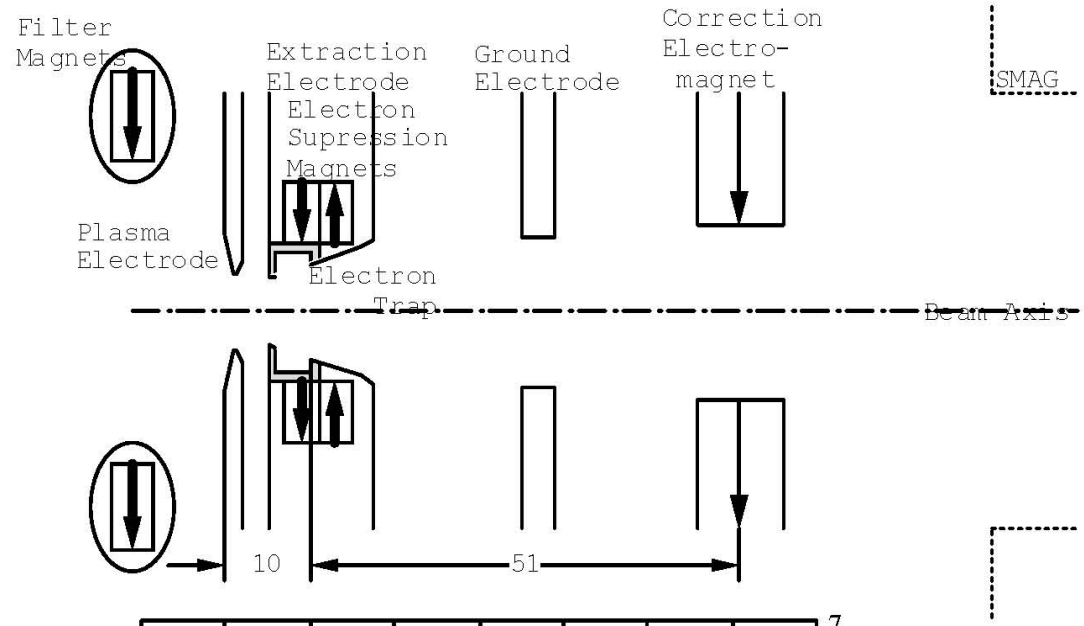
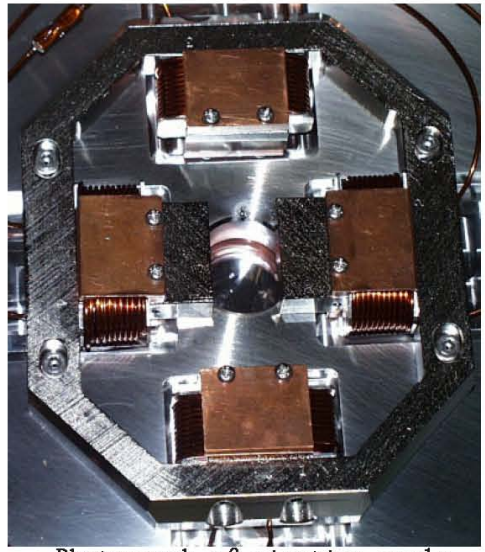


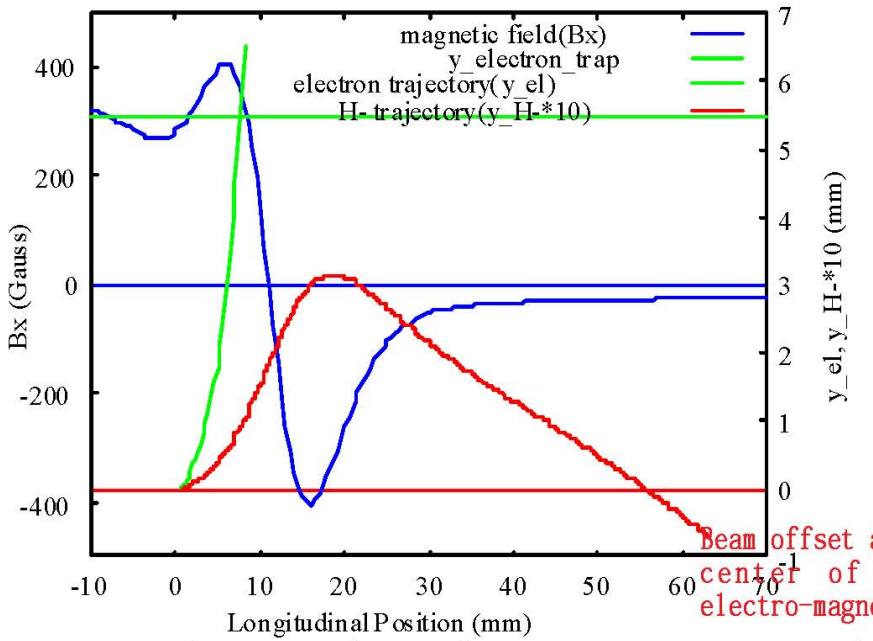
Parameters of ejection angle correction electro-magnet. (4-poles & 2-currents)

Pole thick.	24mm
Turns/pole	22
Pole-gap(hor.)	20mm
Bend. angle(ver.)	0~27mrad
Pole-gap(ver.)	70mm
Bend. angle(hor.)	0~1.35mrad

*Max. coil current is 10A for vertical or horizontal.



Photograph of ejection angle correction electro-magnet.



Beam offset at the center of correction electro-magnet ～50 μm

Positions and sizes of axial asymmetric magnets for beam extractor (upper figure). Magnetic field on beam axis without correction magnet field and calculated trajectory of centers of H^- beam and electron beam (lower figure).

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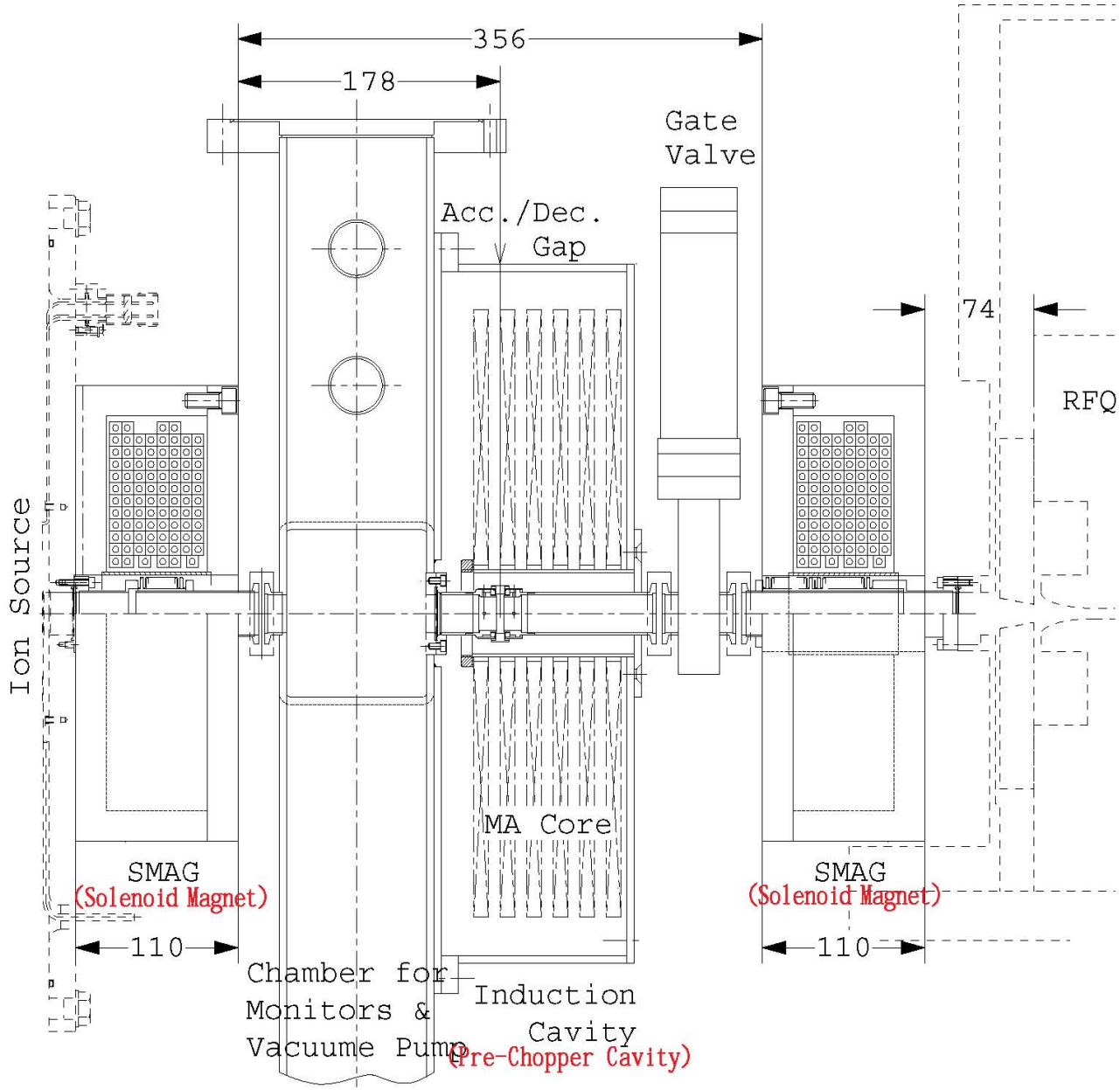

Front-End Design
(0)Drawing
(1)IS Optics
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Schematic darawing of LEBT with pre-chopper cavity (induction cavity with MA cores).

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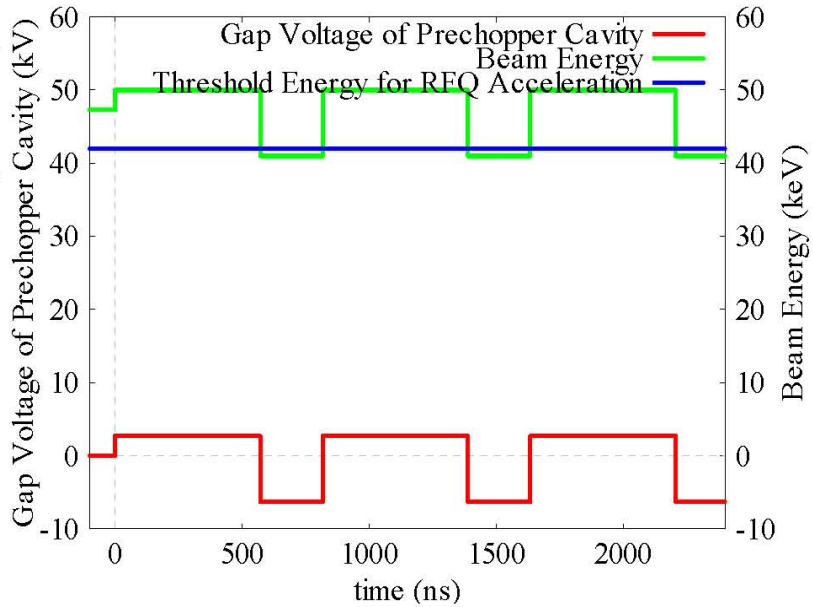
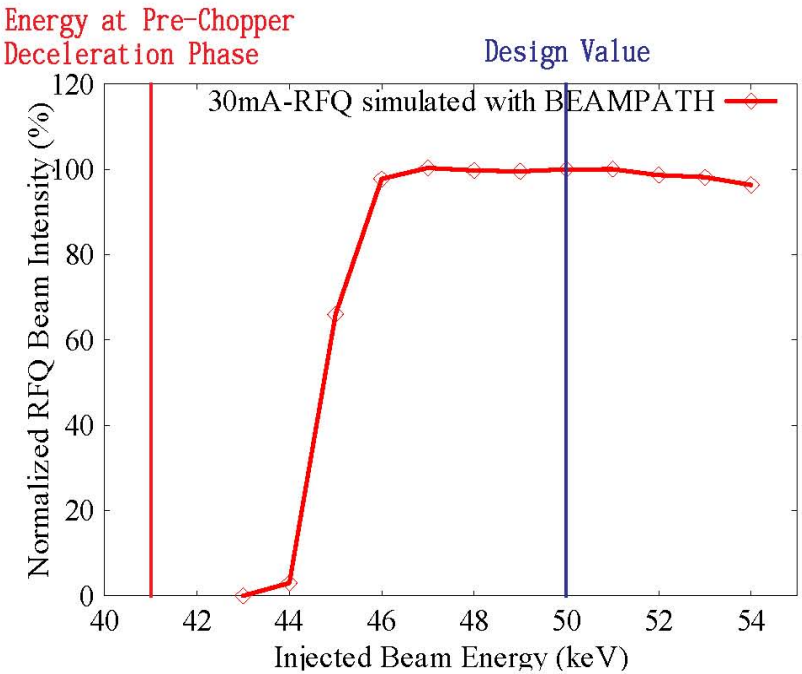


Principle of energy modulation pre-chopper.



Relationship between RFQ beam intensity and injected beam energy simulated with BEAMPATH.

*BEAMPATH:time domain 3D PIC code by Y. BATYGIN of RIKEN

Pre-chopper parameters for 70% chopping operation.

Rise/fall time	～50 ns
Injected beam energy	47.3 keV
Vacc	+2.7 kV
dt_Vacc	515 ns
Vdec	-6.3 kV
dt_Vdec	221 ns

*Beam energy ejected from LEBT=50 keV or 41 keV,
*Vacc*dt_Vacc= Vdec*dt_Vdec to avoid core saturation

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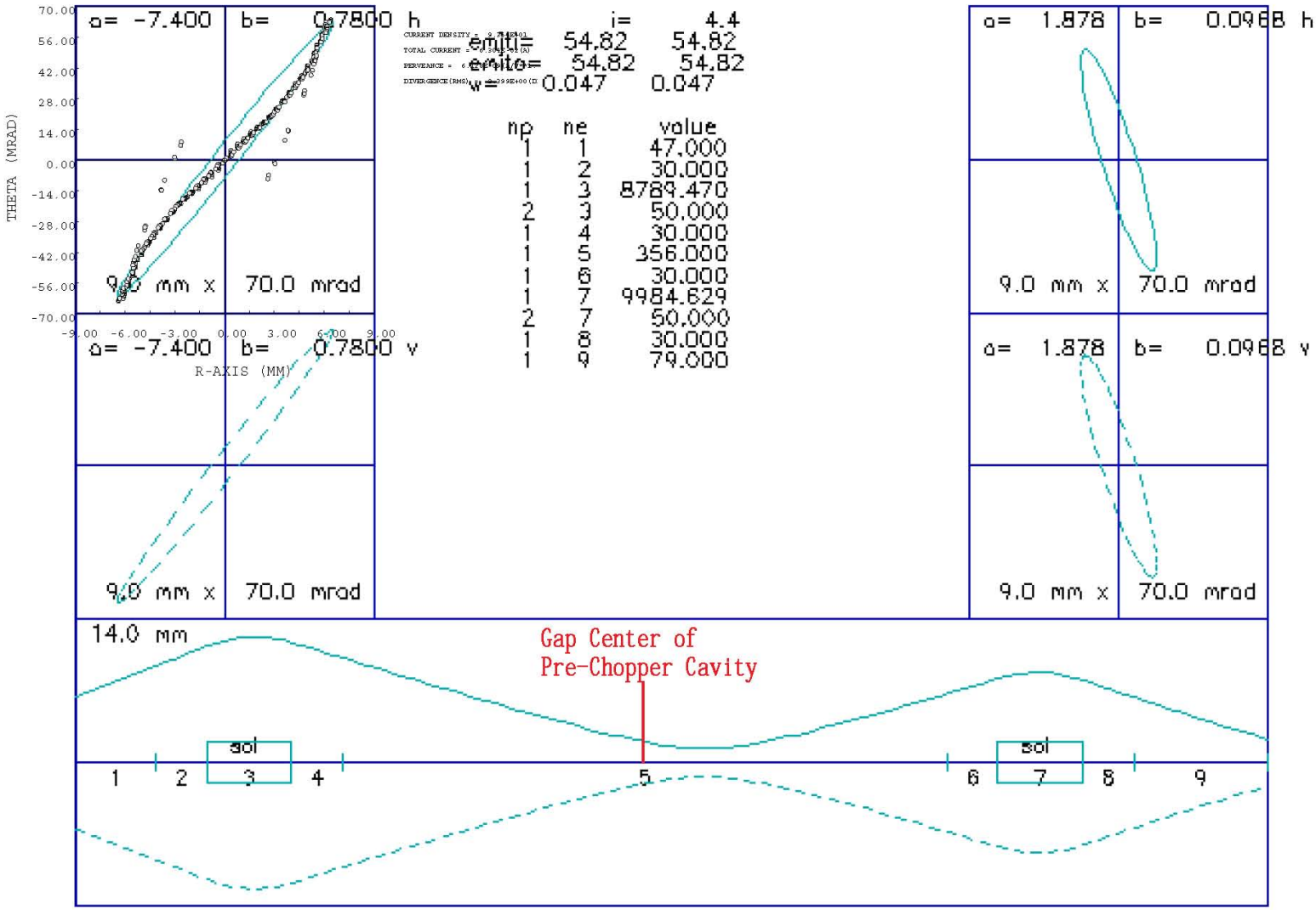
(2) EMITTANCE DIAGRAM



np	ne	value
1	1	47.000
1	2	30.000
1	3	8789.470
2	3	50.000
1	4	30.000
1	5	356.000
1	6	30.000
1	7	9984.629
2	7	50.000
1	8	30.000
1	9	79.000

Front-End Design
(0)Drawing
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Initial and final emittances and beam envelopes in LEBT calculated with TRACE2D.

*1st candidate for LEBT optics in design stage for samaller transit time factor & smaller transverse focusing effect of pre-chopper accelerating gap.
→lower RFQ transmission (～75%): possible causes (1)lower space charge newtrarizaion (2)transverse parameter of beam and/or RFQ matched parameter different from simulations

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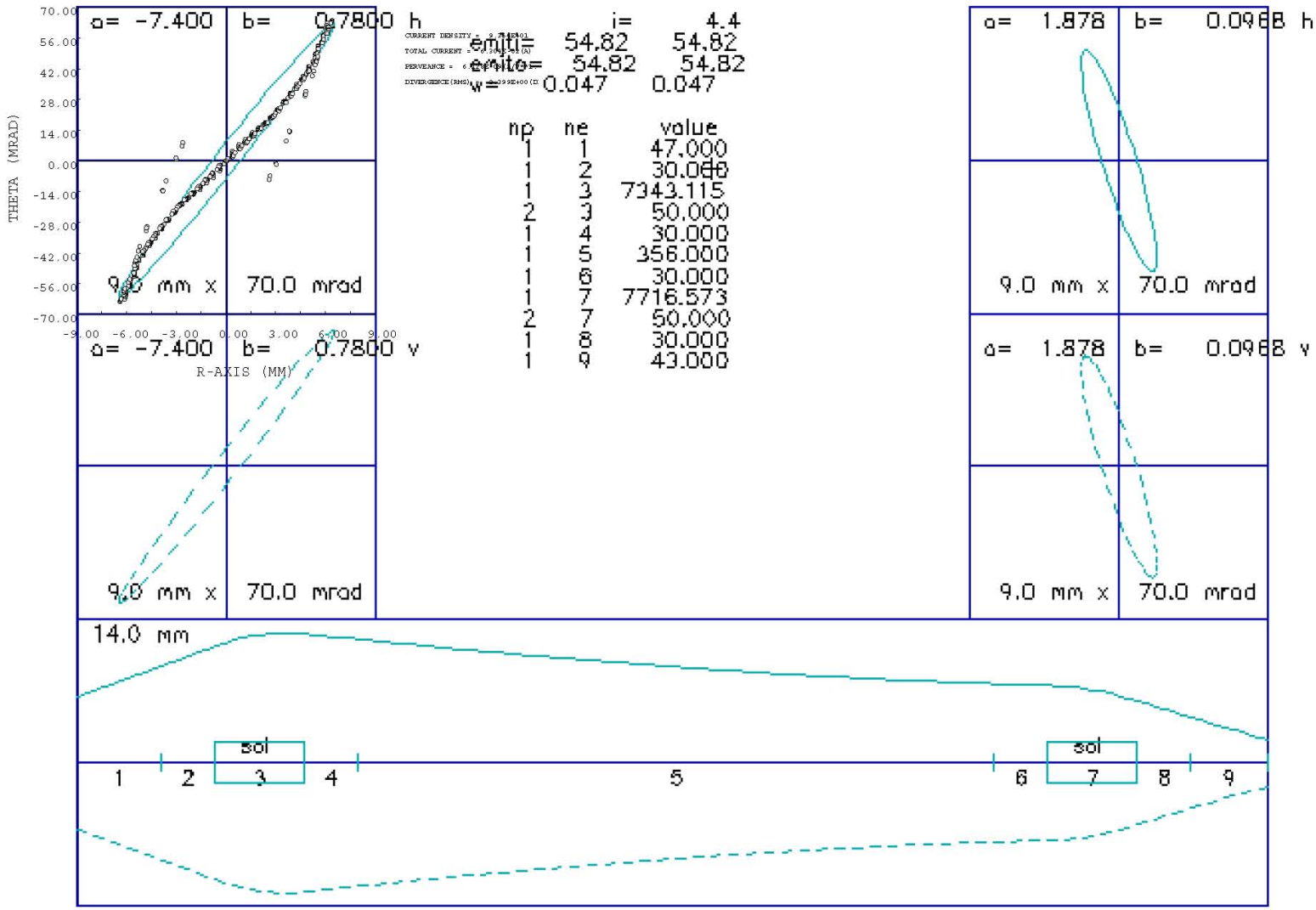

Front-End Design
(0)Drawing
(1)IS Optics
(2)LEBT Optics
(3)RFQ Optics
(4)RFQ Cavity
(5)Loop Coupler

Initial and final emittances and beam envelopes in LEBT calculated with TRACE2D.

*2nd candidate for LEBT optics will be tested on January 2003.
With similar optics (before installing pre-chopper), in which only distance between 2 SMAG's was different (150mm shorter), RFQ transmission more than 90% was observed.

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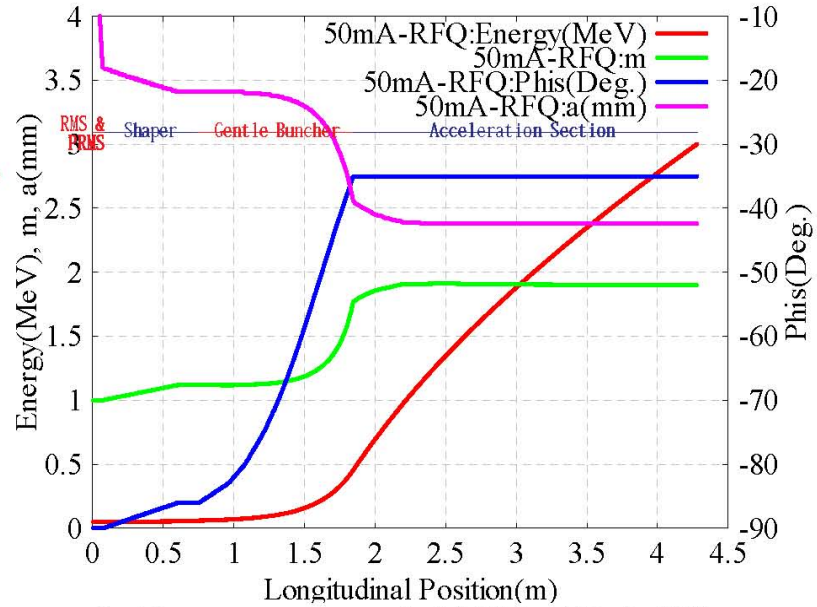
a) KEKRFQ Design Criteria
Gentle Buncher (ϕ s_30mA/50mA=−88/86° →−30/35°)
: constant longitudinal acceptance
→ longitudinal capture suitable for pre-chopper
Acceleration Section (ϕ s_30mA/50mA=−30/35°)
: constant transverse acceptance
→efficient acceleration = shorter length
*Many sets of cell parameter by KEKRFQ were simulated with PARMTEQm and best one was adopted.

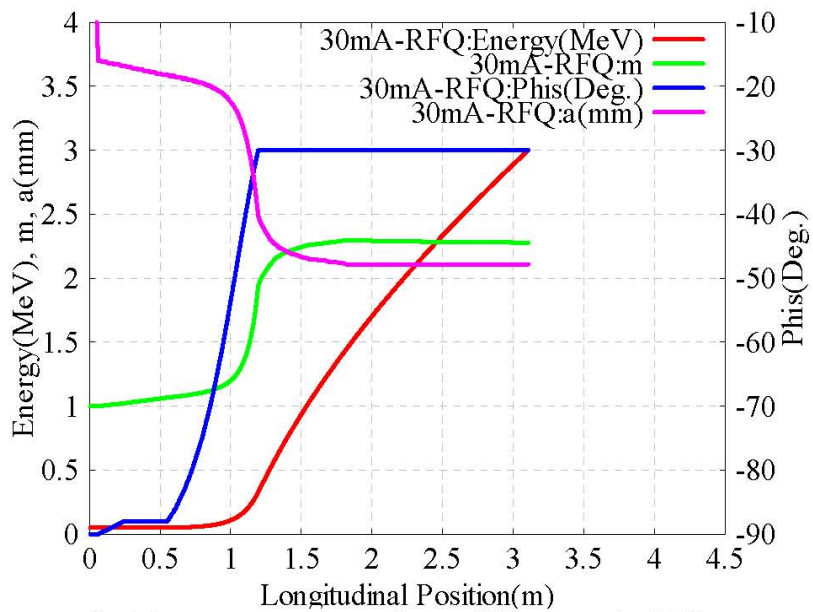
b) Constant Bore Radius (r_0) for 2-dimentional machining by using rotating concave cutter (Vane Tip Curvature ρ =0.89r_0).

c) 8-cell Post Radial Matching Section (B=B/2→B)
→Reduce Convergence Angle of Matched Beam.
*L. Young's Idea used in LEDA-RFQ Design.

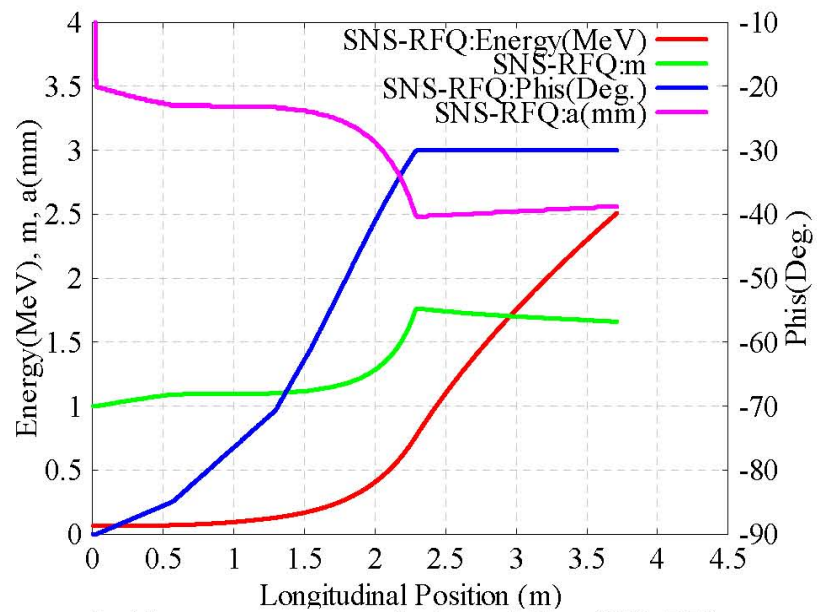
d) Es < 1.8EKPL = 32.08MV/m



Cell parameter of 324MHz-50mA-RFQ.



Cell parameter of 324MHz-30mA-RFQ.



Cell parameter of 402.5MHz-SNS-RFQ.

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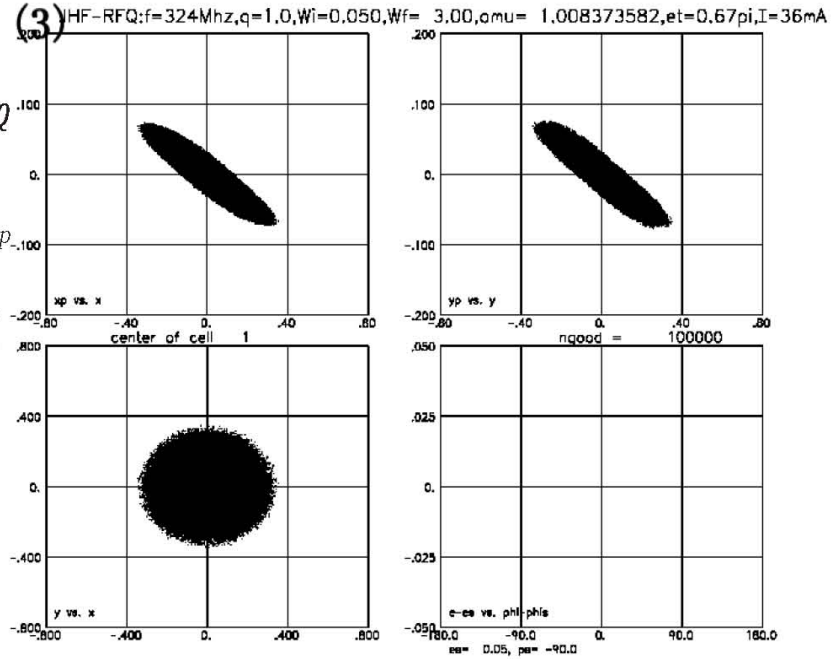
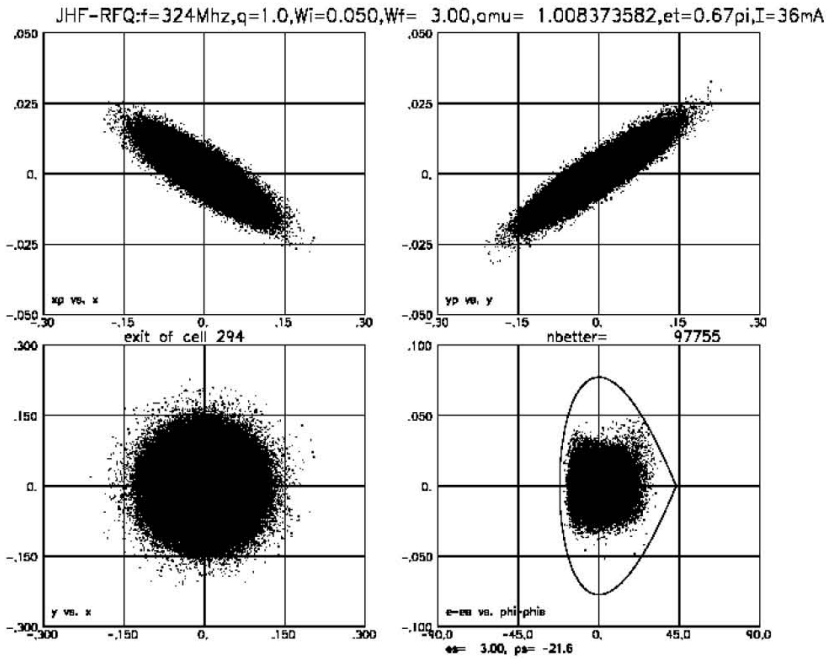
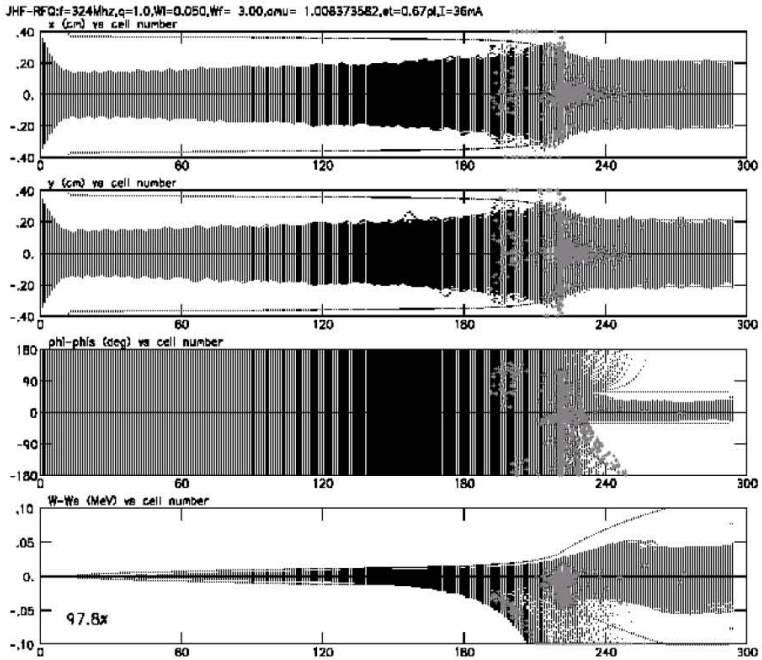


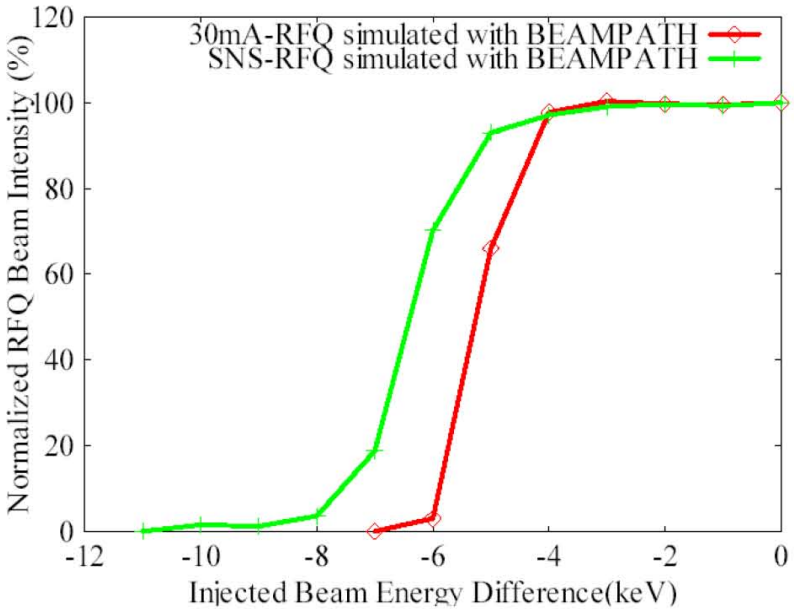
30mA-RFQ PARMTEQm result:injected beam emittances



30mA-RFQ PARMTEQm result:final beam emittances



30mA-RFQ PARMTEQm result:trajectory of each particl



Relationship between RFQ beam intensity and injected beam energy simulated with BEAMPATH.

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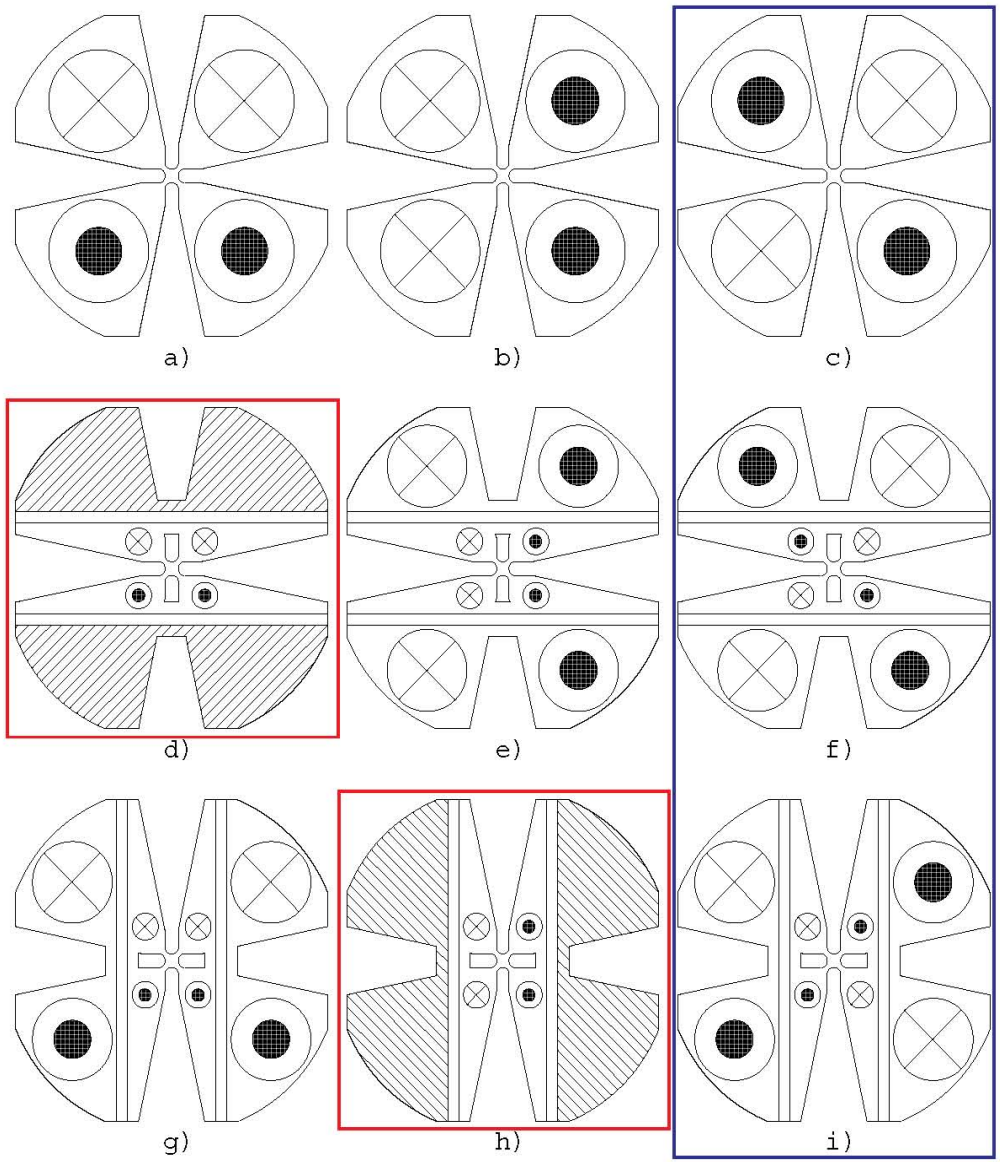

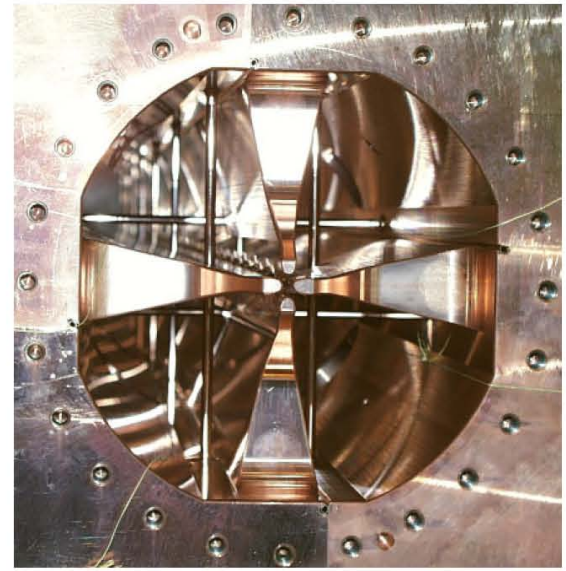

Inside view of the 30mA-RFQ cavity stabilized against dipole-mode mixing with PISL's.
π (PI)-mode Stabilizing Loop

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Principle of the PISL:
Frequency of one of 2 degenerated dipole modes {a)d)g)} increased by horizontal PISL, that of the other {b)e)h)} increased by vertical PISL with small effects for accelerating mode {c)f)i)}.

From Maxwell Equations,

$$\int_{S(loop_inside)} B(x,y)dxdy = 0$$

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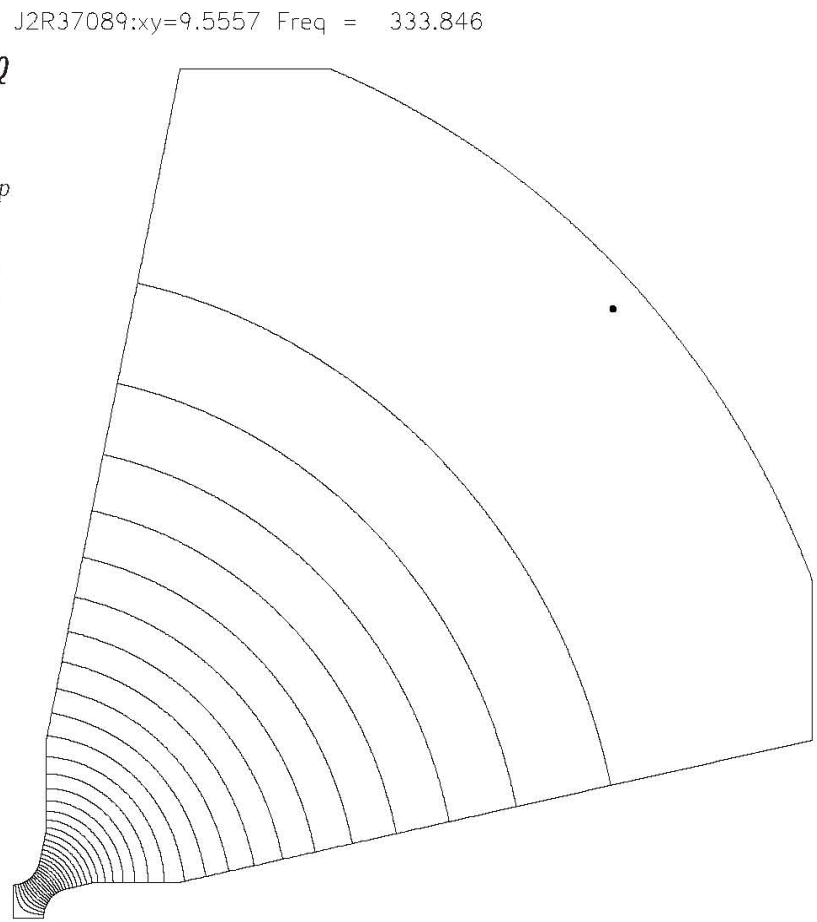
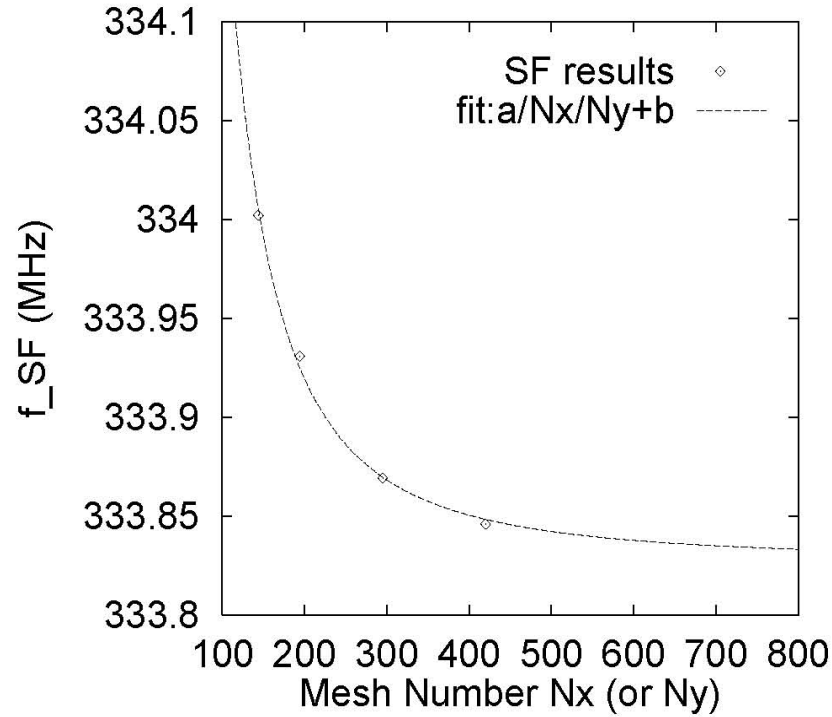


30mA-RFQ electric field calculated by using SuperFish. Mesh number Nx(or Ny)=420, minimum mesh size dx(or dy)=0.07mm and calculated resonant frequency f_SF=333.846 MHz.



Most probable resonant frequency was calculated by fitting several results for different mesh size on a equation f_SF(N)=a/Nx/Ny+b. f_SF(N=∞)=333.827 ± 0.03 MHz.

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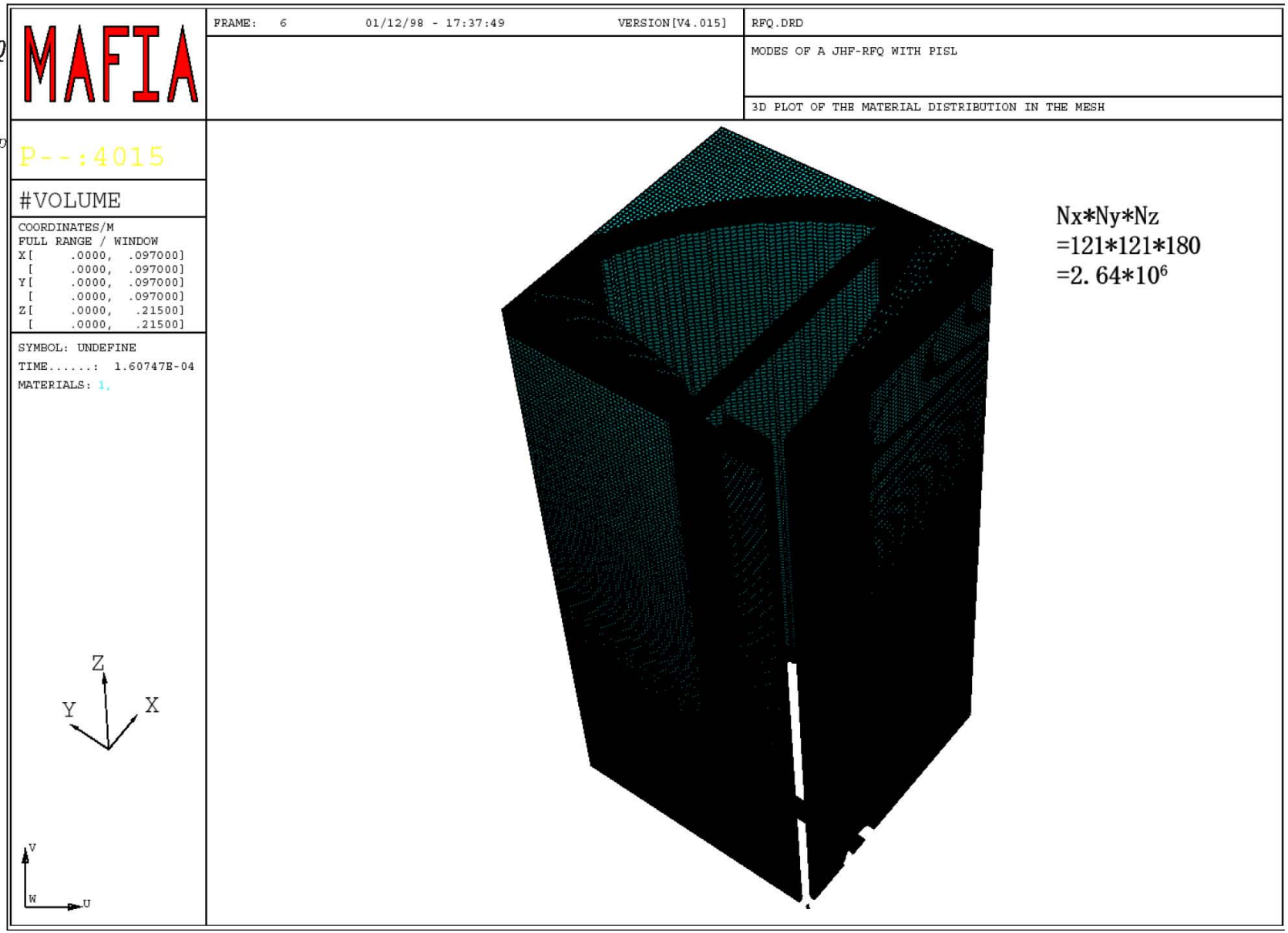

MAFIA Mesh Plot of 30mA-RFQ Unit Cell (1 PISL Period of Quadrant Cavity)

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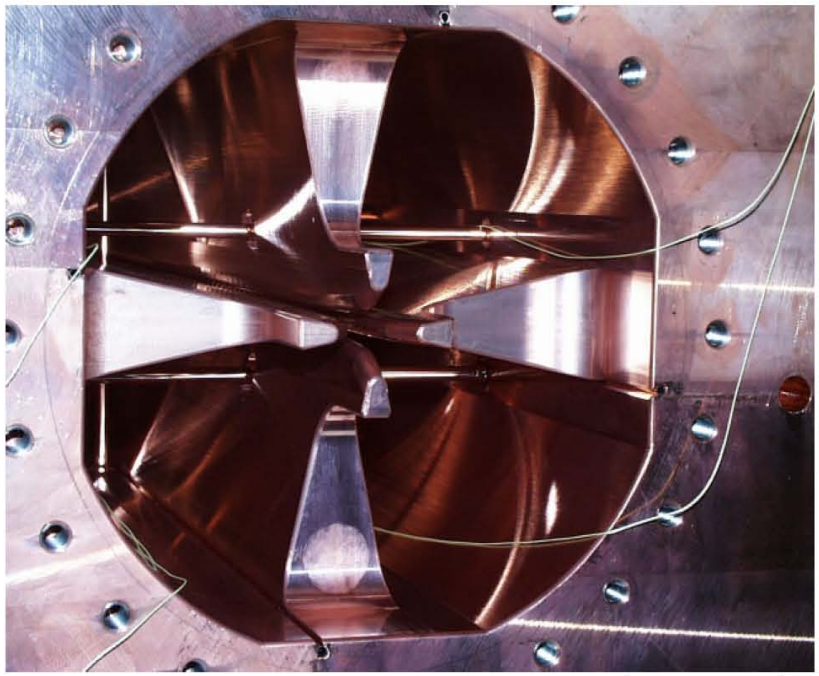
Summary of SuperFish and MAFIA Analyses of 30mA-RFQ

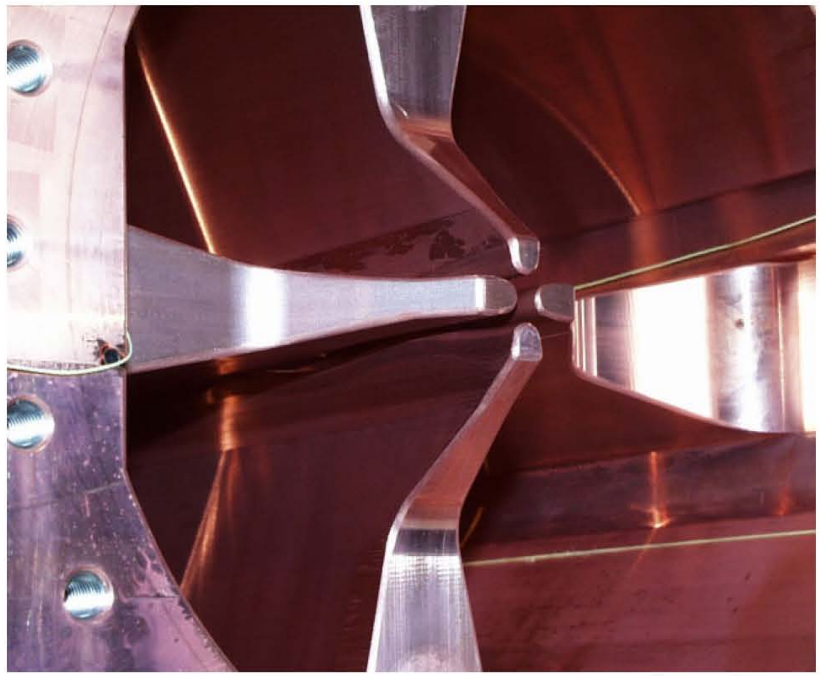
SuperFish (without PISL)	f_SF(MHz) & Q_SF	333.827 & 11276
MAFIA_STD (without PISL)	f_MFS(MHz) & Q_MFS	330.675 & 10812
MAFIA_PISL	f_MFP(MHz) & Q_MFP	320.782 & 10264

∴ f_design=f_SF-(f_MFS-f_MFP)=333.827-(330.675-320.782)=323.934 MHz

*The larger Nx/y, the smaller Q_MF. Problem on fine mesh power dissipation calculation in MAFIA.



Photograph of 30mA-RFQ vane-end (entrance).



Photograph of 30mA-RFQ vane-end (exit).

Vane-end shapes, with which the resonant frequency became that in unit cell calculation and the electric field reproduce that used around beam axis became almost same with those in unit cell cal-

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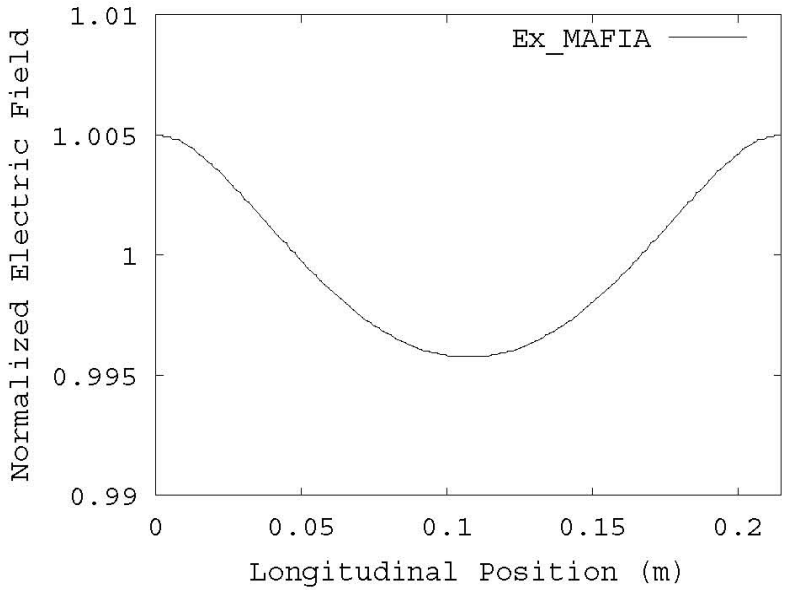
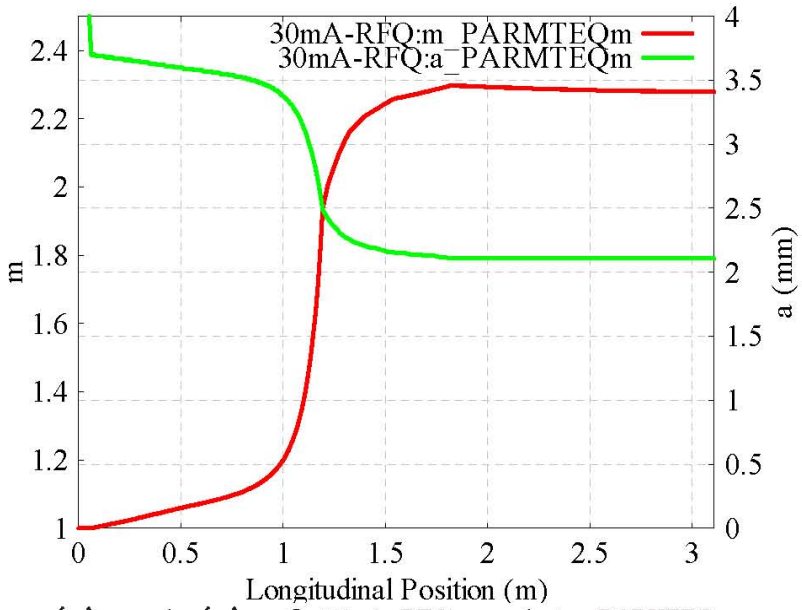
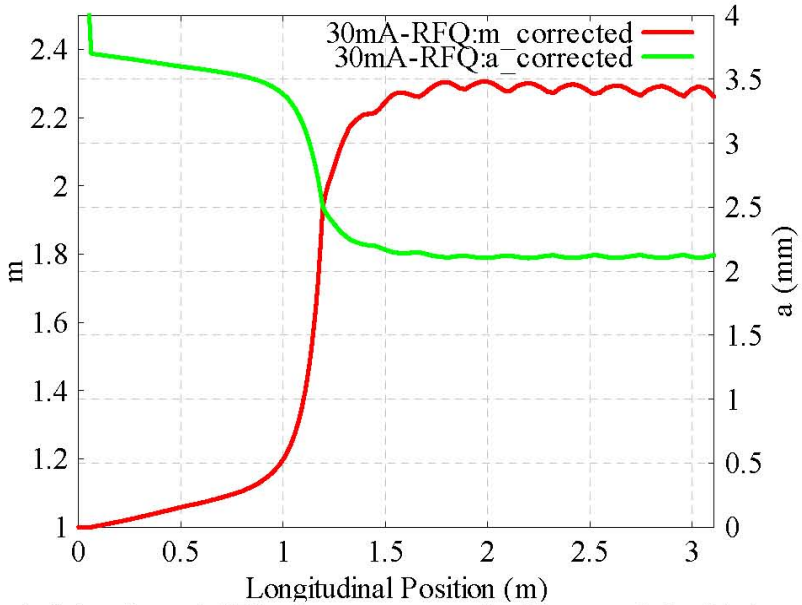


Electric field distribution near beam axis between two neighboring PISL's calculated with MAFIA.



'm' and 'a' of 30mA-RFQ used in PARMTEQm.



'm' and 'a' of 30mA-RFQ after corrected effects of field distortion due to PISL's and incorrect PARMTEQm approximation.

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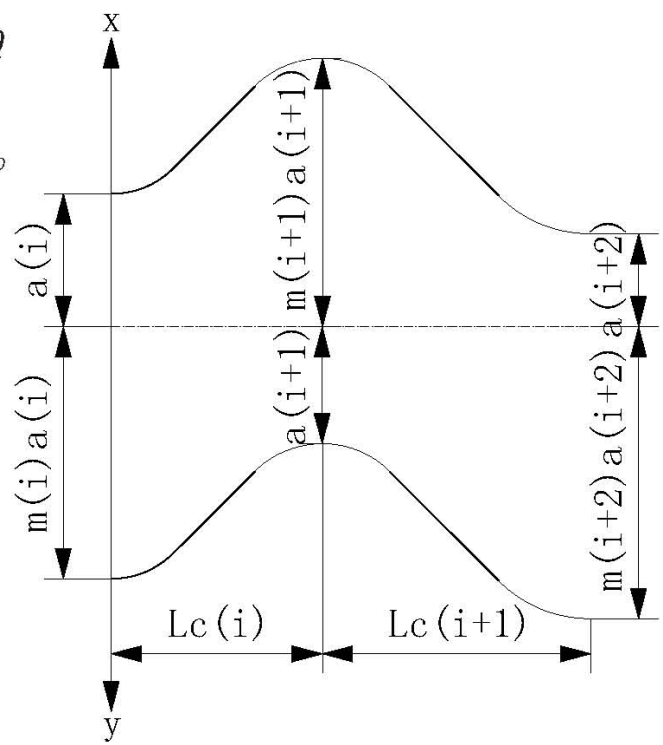

m :modulation factor
a :minimum bore radius
Lc:cell length
x :horizontal direction
y :vertical direction

Amplitude of acceleration field $E_z = \frac{\pi AV}{2L_c} I_0(\frac{\pi r}{L_c}) \sin\frac{\pi z}{L_c} \equiv Ae(L_c, z)$

where, $$A = \frac{m^2 - 1}{m^2 I_0(\frac{\pi a}{L_c}) + I_0(\frac{\pi ma}{L_c})}$$

(1)Approximation used in PARMTEQm

$$E_z(z) = \{A(i) + \frac{A(i+1) - A(i)}{L_c(i)} dz\} e(L_c(i), z)$$

where, $$A(i) = \frac{m(i)^2 - 1}{m(i)^2 I_0(\frac{\pi a(i)}{L_c(i)}) + I_0(\frac{\pi m(i) a(i)}{L_c(i)})}$$

*Incorrect cell length Lc(i+1) is used to calculate A(i+1).

(2)More acculrate approximation

$$E_z(z) = \{A_0(i) + \frac{A_1(i) - A_0(i)}{L_c(i)} dz\} e(L_c(i), z)$$

where, $$A_0(i) = \frac{m(i)^2 - 1}{m(i)^2 I_0(\frac{\pi a(i)}{L_c(i)}) + I_0(\frac{\pi m(i) a(i)}{L_c(i)})}$$

$$A_1(i) = \frac{m(i+1)^2 - 1}{m(i+1)^2 I_0(\frac{\pi a(i+1)}{L_c(i)}) + I_0(\frac{\pi m(i+1) a(i+1)}{L_c(i)})}$$

Front-End Design
(0)Drawing
(1)IS Optics
(2)LEBT Optics
(3)RFQ Optics
(4)RFQ Cavity
(5)Loop Coupler

*CRANDALL agrred with this, but thinks the effect is negligible.
*Vanes of J-PARC-RFQ's are cut with corrected 'm' and 'a' to reproduce energy gain in each cell used in PARMTEQm simulation, since 'm' and 'a' of KEKRFQ design change more rapidlly compared with ordinally design.

J-PARC Front-End Group
Akira UENO(KEK)
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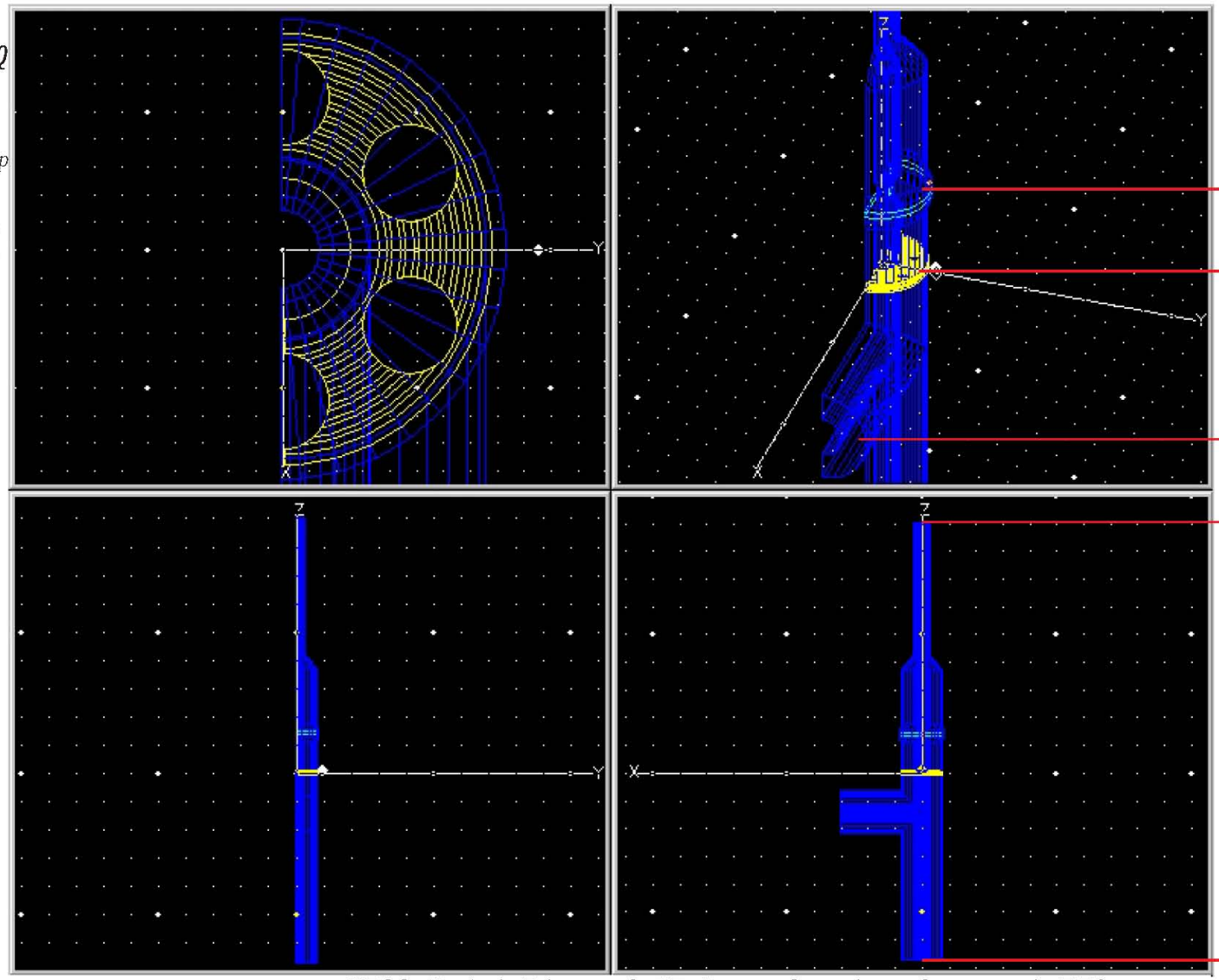
Hidetomo OGURI(JAERI)

(5)



HFSS Model Plot of RF Loop Coupler for 30mA-RFQ

Front-End Design
(0)Drawing
(1)IS Optics
(2)LEBT Optics
(3)RFQ Optics
(4)RFQ Cavity
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1st East-Asian Miniworkshop on High Intensity p Accelerator-RFQ

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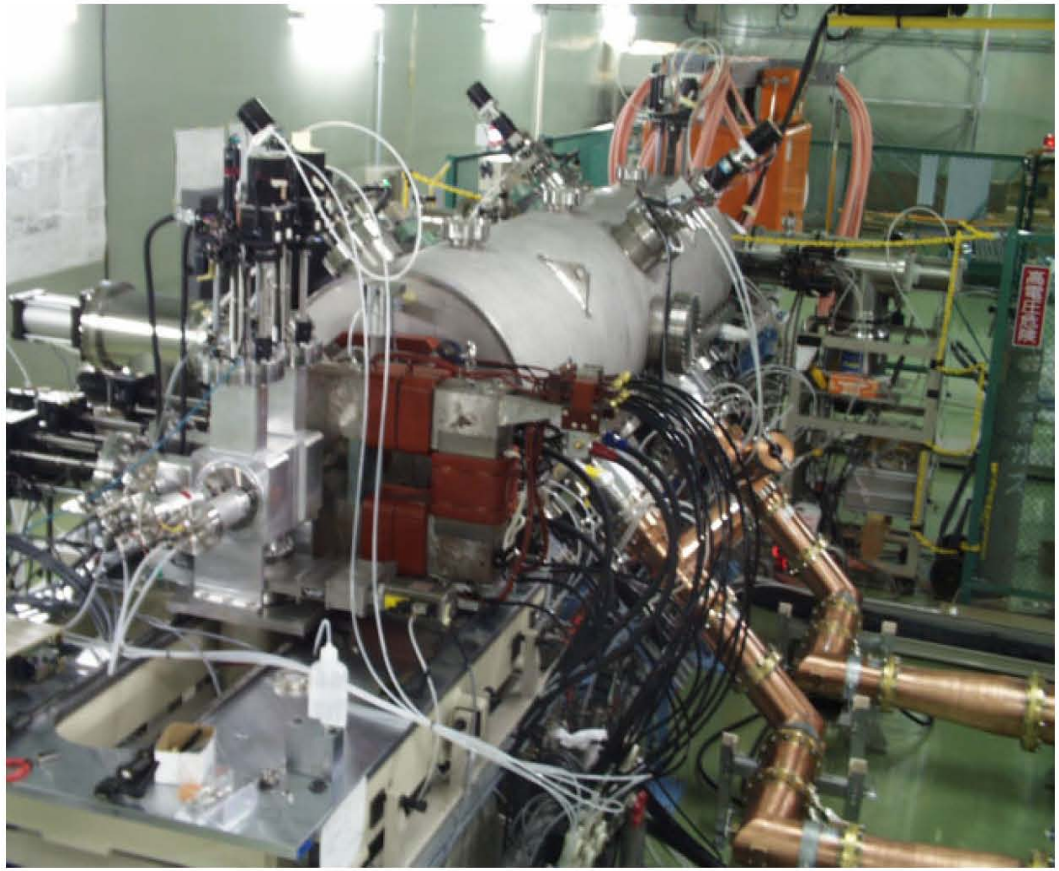
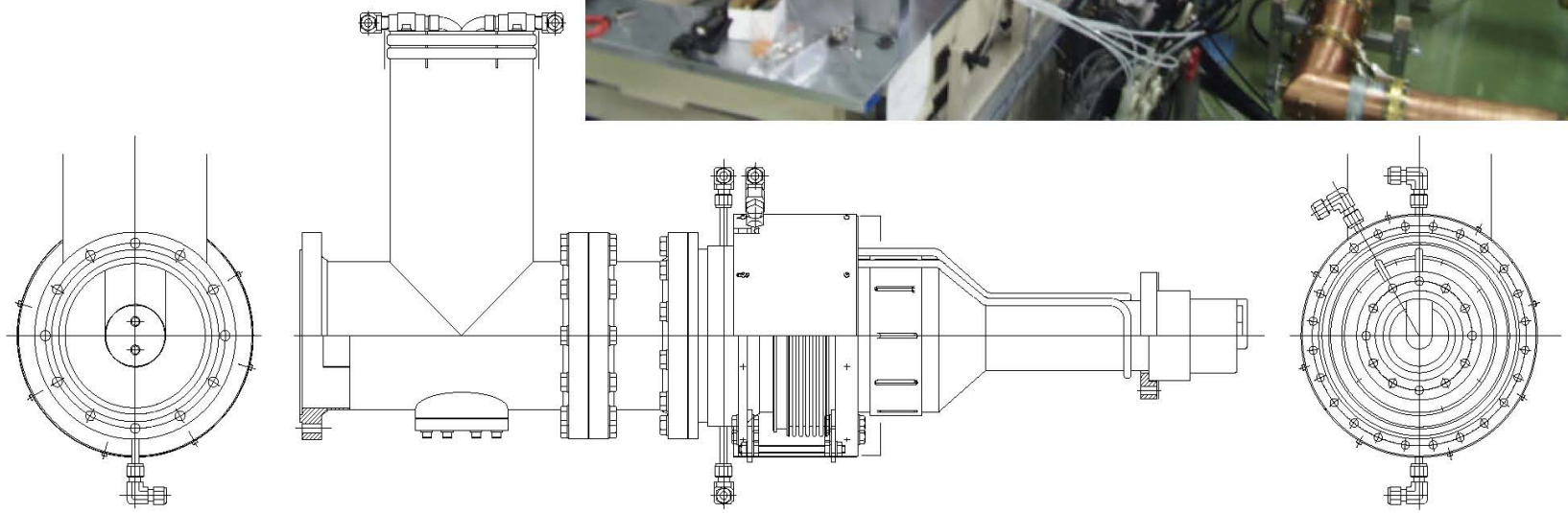
Two RF couplers are installed on 30mA-RFQ. Each coupler is rotated about 45° .





Drawing of RF Loop Coupler for 30mA-RFQ

Loop shape was determined by testing model couplers with various loop shapes on 30mA-RFQ cavity.

Front-End Design
(0)Drawing
(1)IS Optics
(2)LEBT Optics
(3)RFQ Optics
(4)RFQ Cavity
(5)Loop Coupler