UNIQUE FEATURES OF THE J-PARC LINAC AND ITS PERFORMANCE - LESSONS LEARNT -

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Outline of Talk

(1) Overview of J-PARC linac

(2) Surface Production Dominating Cs-Free H^- IS
with Magnetic Focus LEBT

(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods

(4) RF-Chopper & RFQ Operation Parameter Suitable for It

(5) Transverse Matching with TRACE3D PMQ Element

(6) DTQ-Coil & Cavity Plating Using PR Electroforming

(7) 2 Cavity Behavior of SDTL Driven by One Klystron

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(1) Overview of J-PARC linac

Accelerated Particle :H^-

Energy :IS 50keV, RFQ 3MeV, DTL 50MeV, SDTL 181MeV

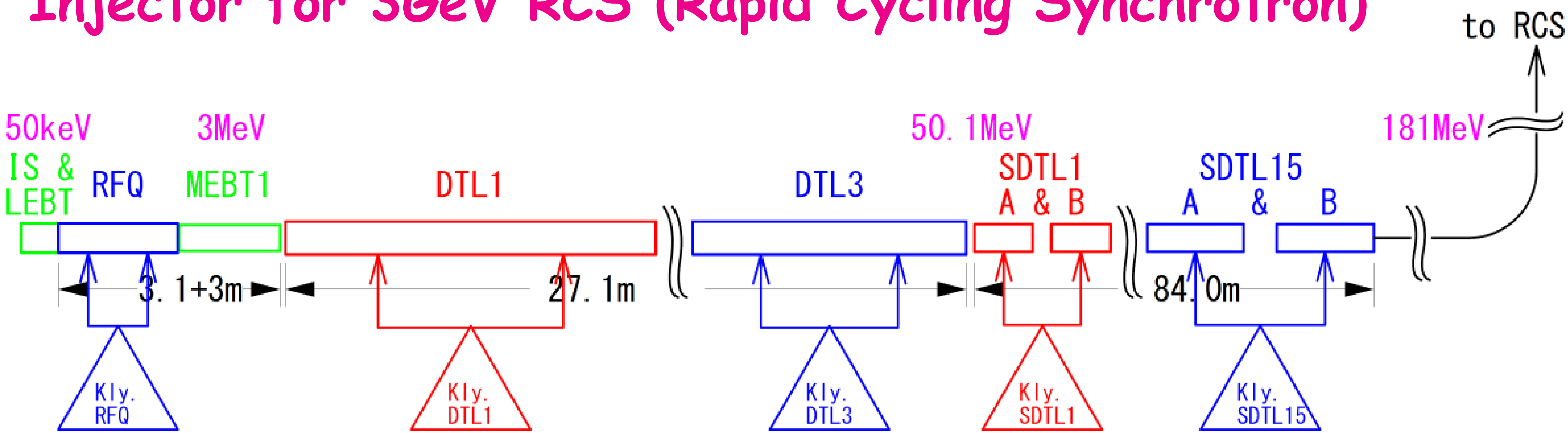
34 Accelerating Cavities :RFQ, DTL1~3, SDTL1A~15B

*SDTLnA&B are driven by one klystron.->19 klys. for acc.

Peak Intensity:30mA at 1st stage (in 2nd stage 50mA)

Beam Duty :500μs * 25Hz (in 3rd stage 500μs * 50Hz)

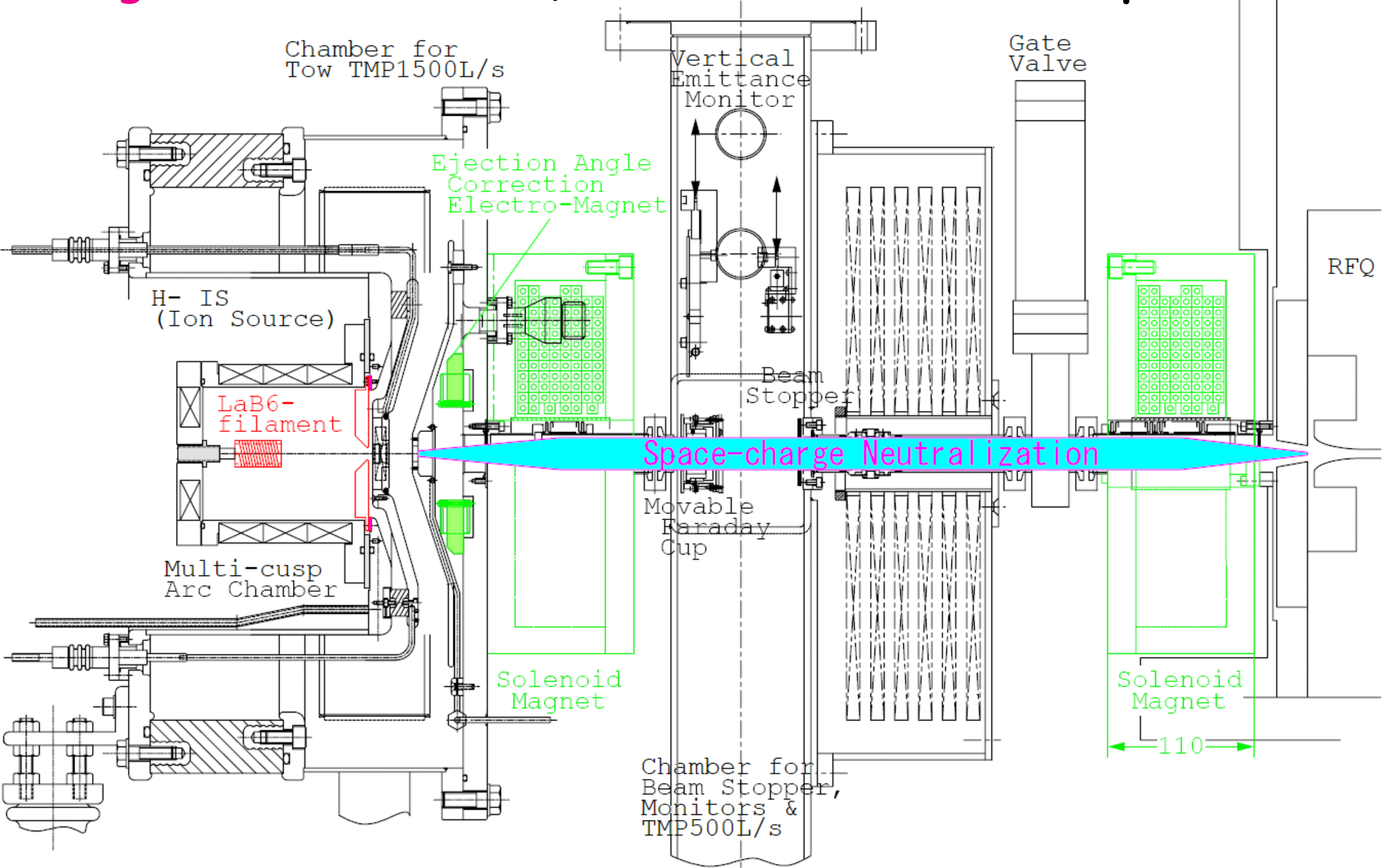
*Injector for 3GeV RCS (Rapid Cycling Synchrotron)



(2)Surface Production Dominating Cs-Free H⁻ IS(Ion Source) with Magnetic Focus LEBT(Low Energy Beam Transport)

i) For stable(easy constant intensity&against sparking) operation, Cs-free IS

ii) To minimize emittance growth, use SCN(Space-Charge Neutralization) by magnetic focus LEBT (measured SCN >90% *Reported in LINAC1996)



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(2) Surface Production Dominating Cs-Free H^- IS

Previously, 16mA H^- by Iarc=220A & Arc Chamber with D150mm*L150mm.

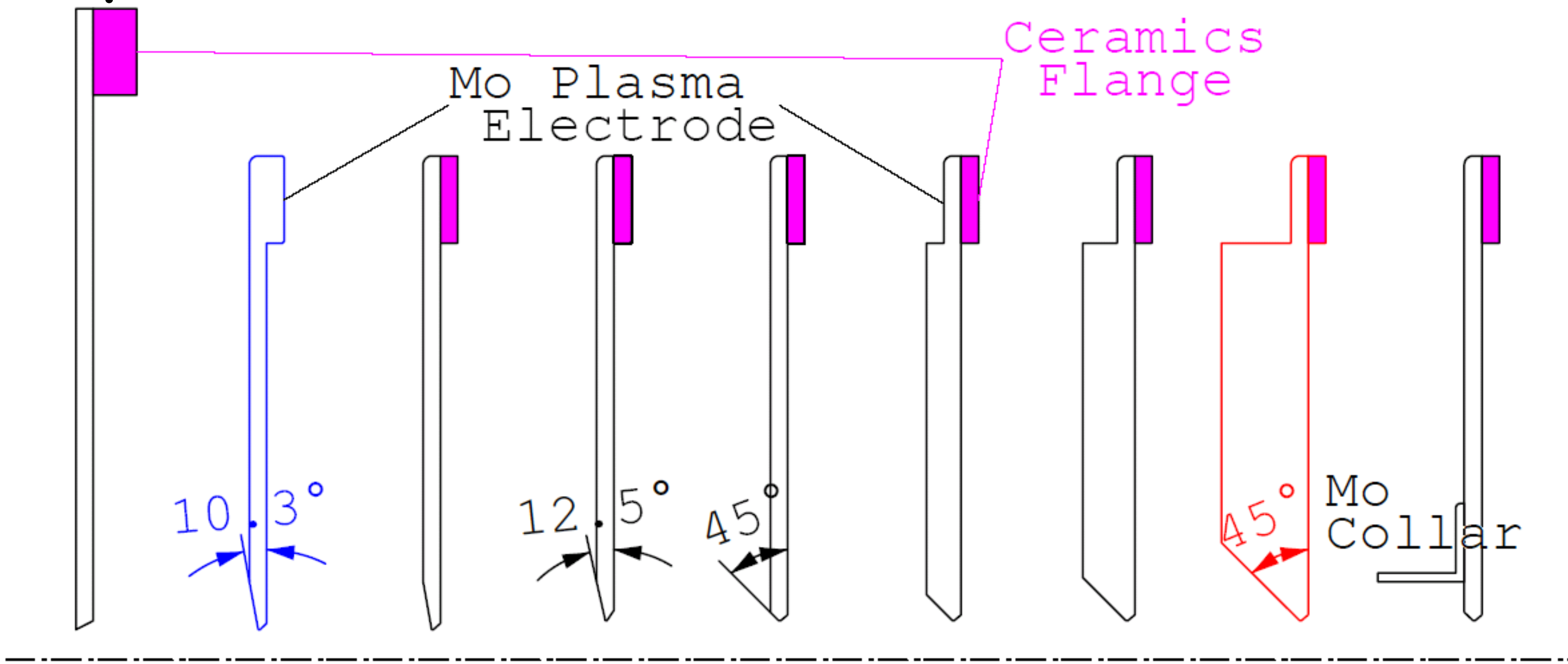
For 2years from R&D start, 16mA by Iarc=290A&A.C.with D100mm*L120mm

Difference (w/wo ceramics flange) : Temperature of Mo Plasma Electrode

(b) without c.f.16mA->(c) with c.f.20mA(D7mm)->(d) with c.f.25mA(D9mm)

∴Surface Production : angle & area->(h) with c.f.38mA(D9mm, 45°, T10mm)

*Measured Temperature of Mo PE~500°C->Deoxidization of Mo in H_2 gas



	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
Cut. Angle	*JHP	10.3°	10.3°	12.5°	45°	45°	45°	45°	45°
Thickness	T2mm	T2mm	T2mm	T2mm	T2mm	T4mm	T6mm	T10mm	T2mm
Diameter of Beam Hole	D7mm	D7mm	D7mm	D9mm	D9mm	D9mm	D9mm	D9mm	D9mm
Iarc(A)	220	290	290	290	290	290	290	290	290
I_H-(mA)	16	16	20	25	26	30.6	34.4	38	30

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(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods

i) Macro-Beam-Pulse Shaping with RFQ Long. Accep. by Mod. IS Potential

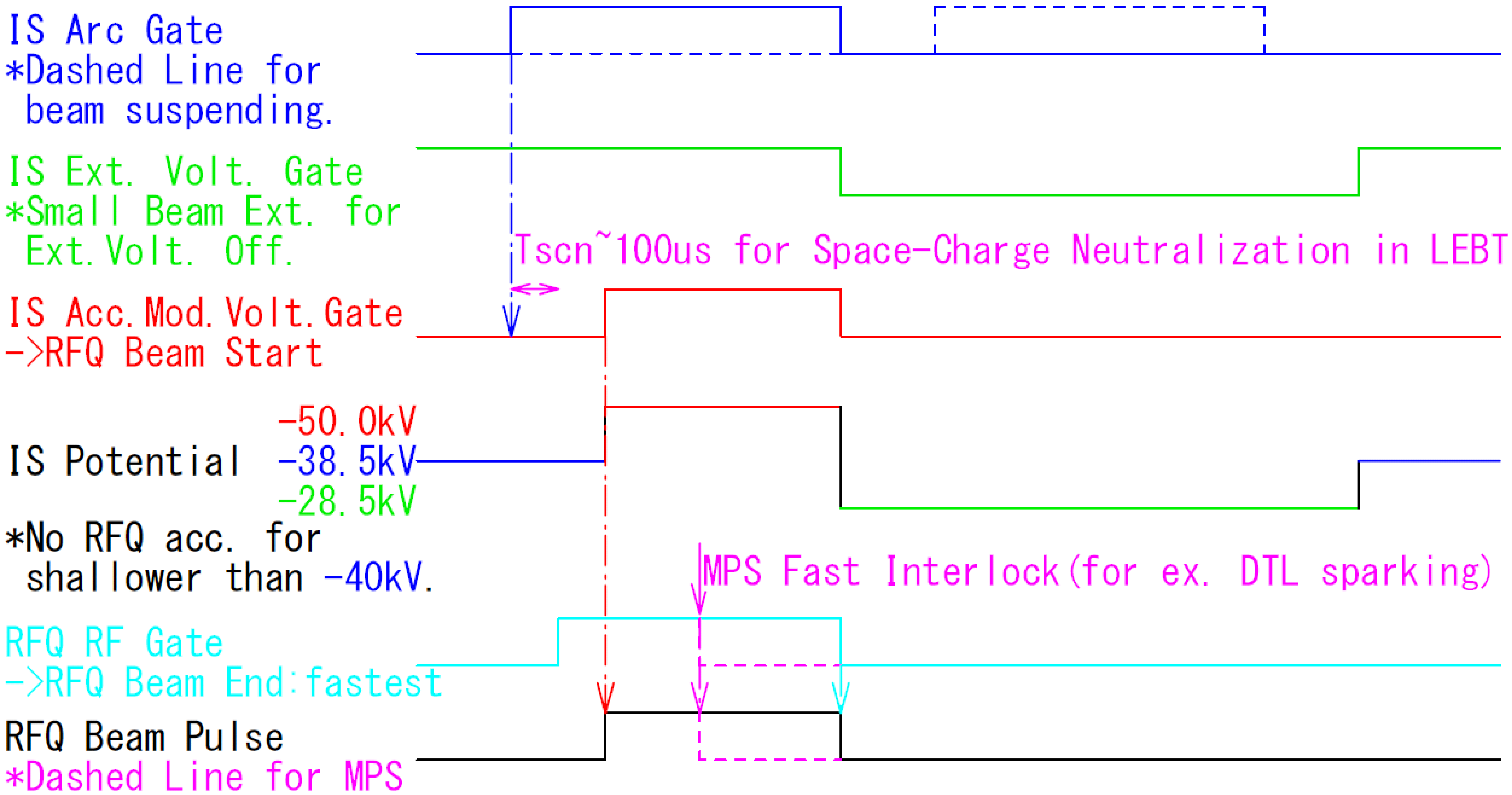
Problem of magnetic focus LEBT : emittance rotation in SCN rise-time

->Low-Energy Unacc. Beam Establish SCN ~100μs Before RFQ Acceleration

*RFQ RF-off Settle Beam End (Fastest)->MPS Fast Interlock within Pulse

ii) Beam Suspending by Delaying IS Arc Gate Only

All High Power Devices Work Full Duty->Stable One-Shot Operation etc.



(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods

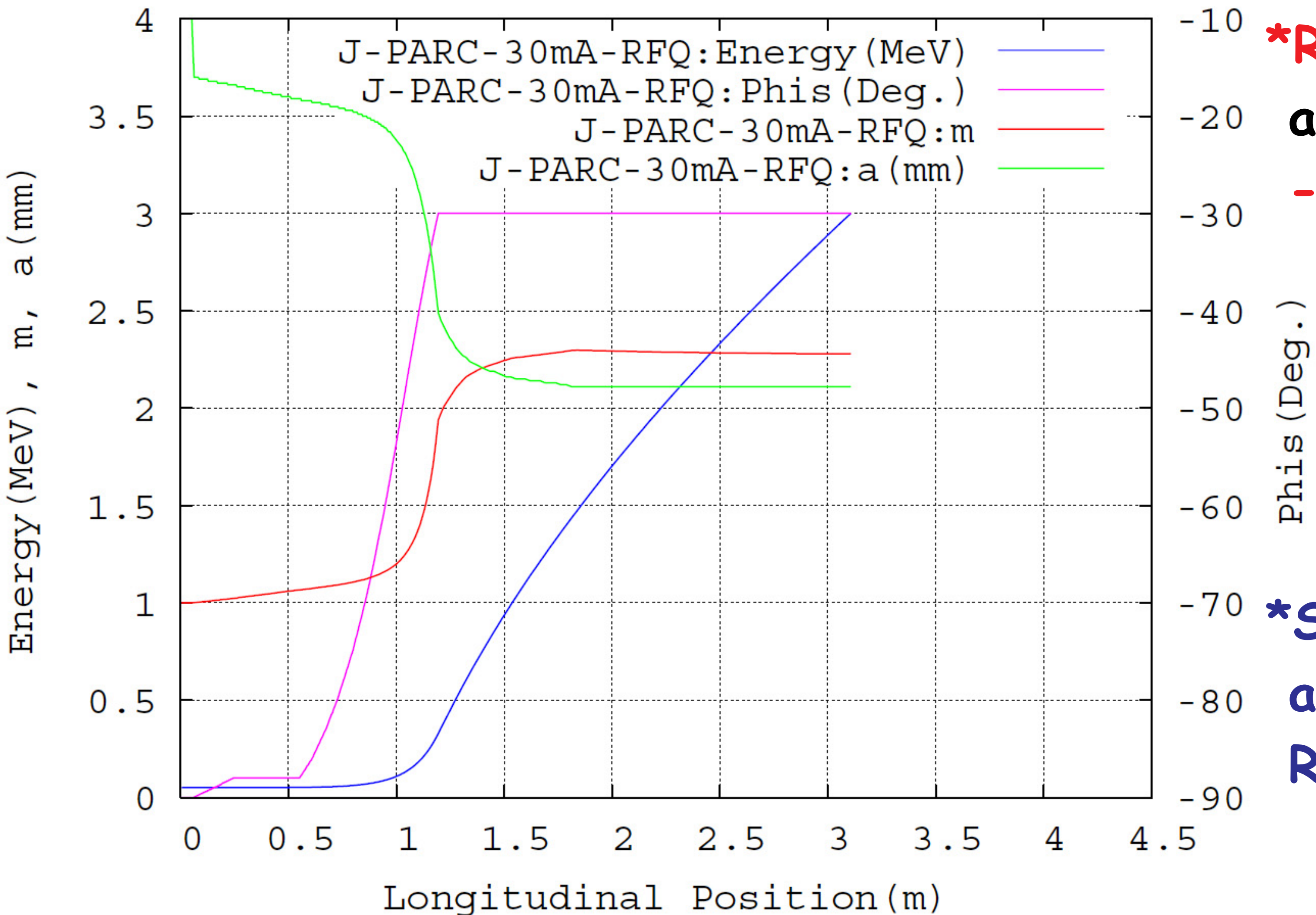
J-PARC 30mA-RFQ Design by Design Code KEKRFQ & PARMTEQm

Criteria of KEKRFQ to Minimize Long. Emit. and Making RFQ Emit. Filter

i) Constant Long. Accep. at Gentle-Buncher (ϕ_s=-88°->-30°)

ii) Constant Trans. Accep. at Accelerator Section (ϕ_s=-30°)

*Both Accep. Include Space-Charge Effects



*Rapid Change of 'm' & 'a' at Gentle-Buncher ->Accelerating Field should be Accurate.

*Small Long. Emittance is also Indispensable for RF-Chopper.

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(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods

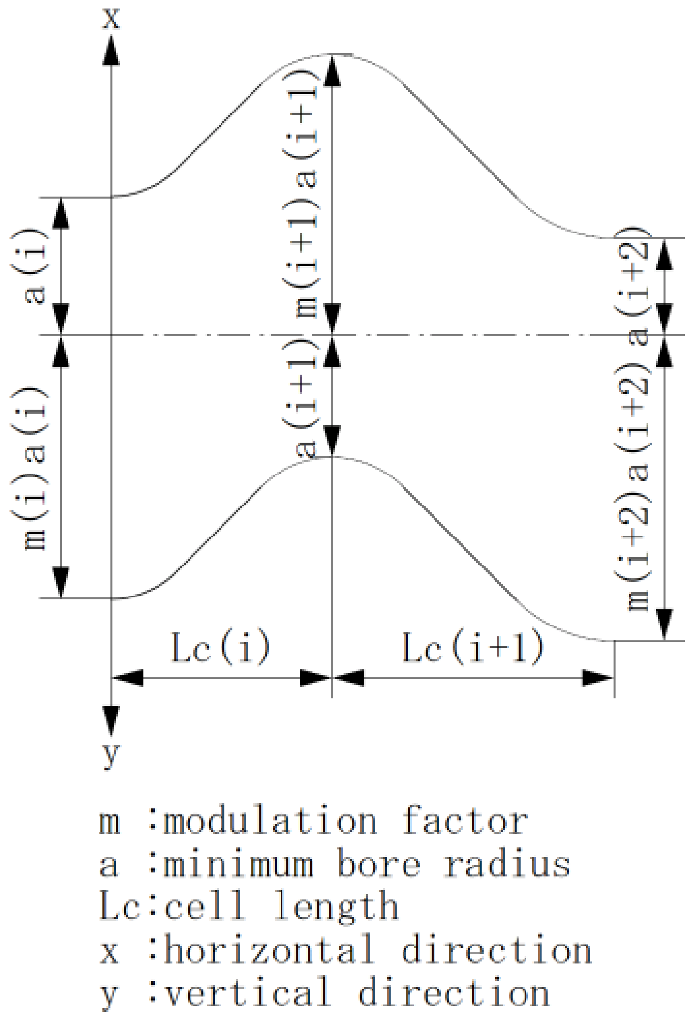
J-PARC 30mA-RFQ Manufacturing for Accurate Accelerating Field

i) Correction of PARMTEQm Approximation

$$E_z(z) = \{A(i) + \frac{A(i+1) - A(i)}{L_c(i)} dz\} e(L_c(i), z) \quad \text{where} \quad A(i) = \frac{m(i)^2 - 1}{m(i)^2 I_0(\frac{\pi a(i)}{L_c(i)}) + I_0(\frac{\pi m(i) a(i)}{L_c(i)})} \qquad (1)$$

*Incorrect cell length Lc(i+1) is used in A(i+1) calculation.

->More accurate Approximation



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

where

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

and

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

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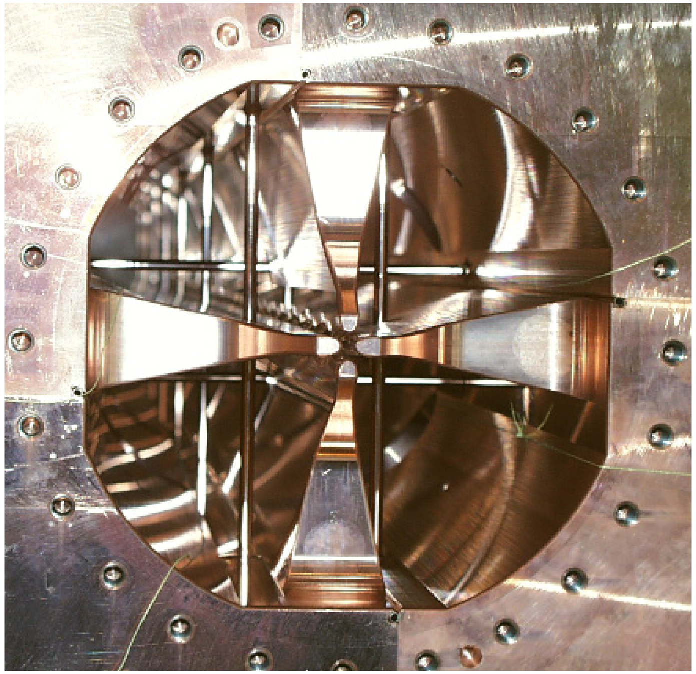
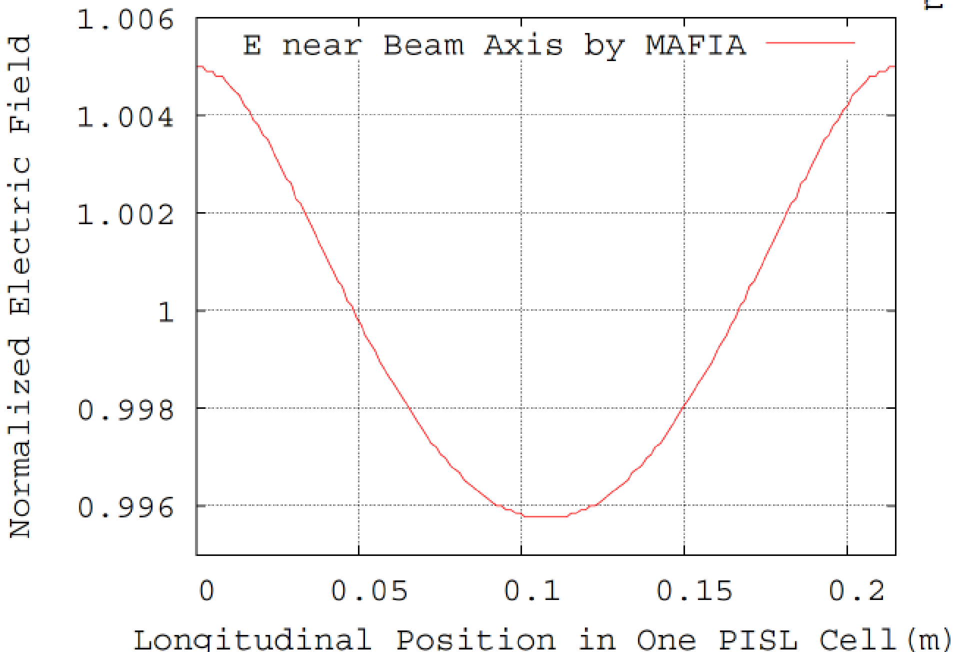
(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods

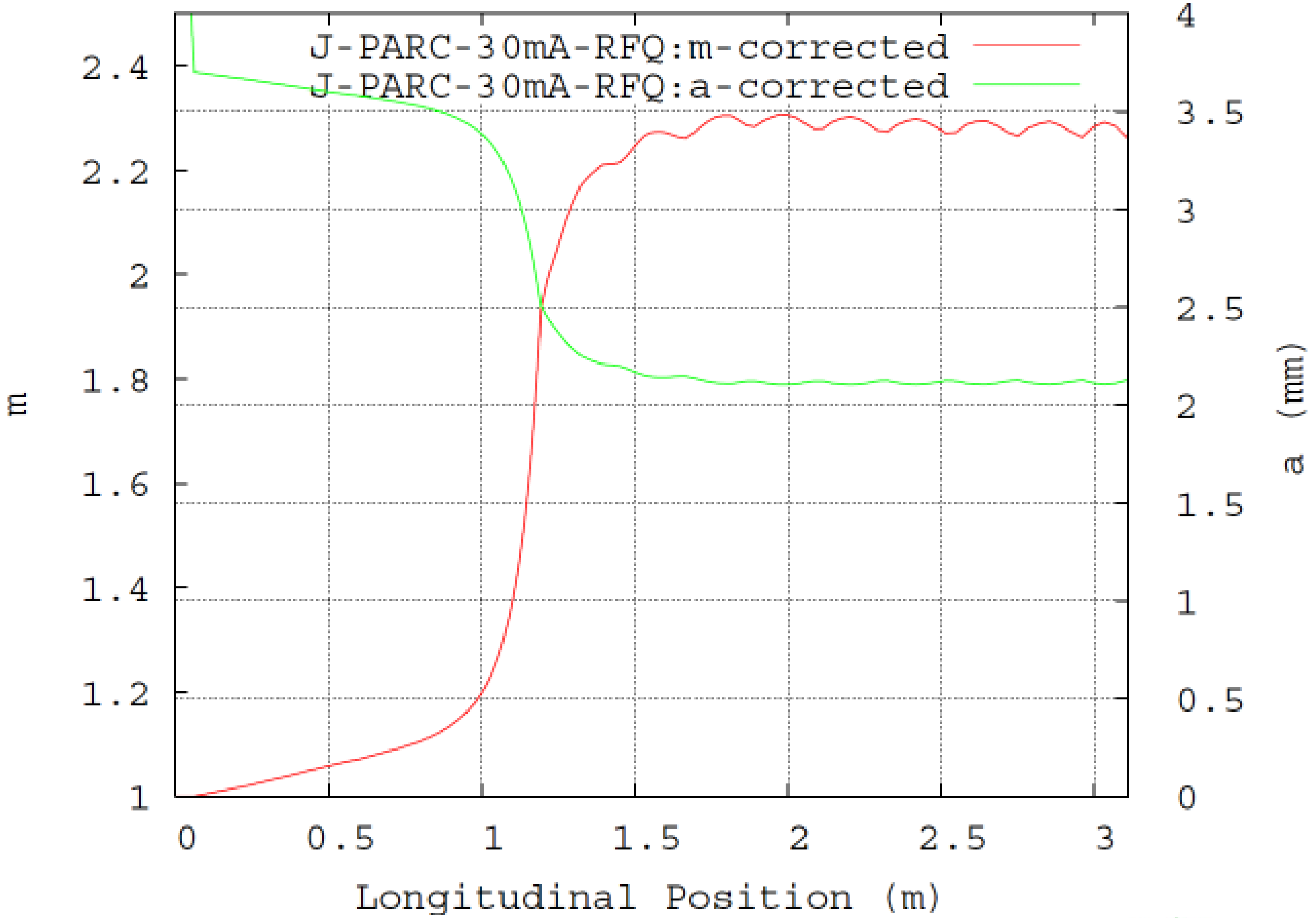
J-PARC 30mA-RFQ Manufacturing for Accurate Accelerating Field

ii) Correction of Field Distribution due to PISL (π-mode Stabilizing Loop)

*Field Stabilizer against Dipole-Mode Mixing







'm' & 'a' after correction i) & ii)
*manufactured

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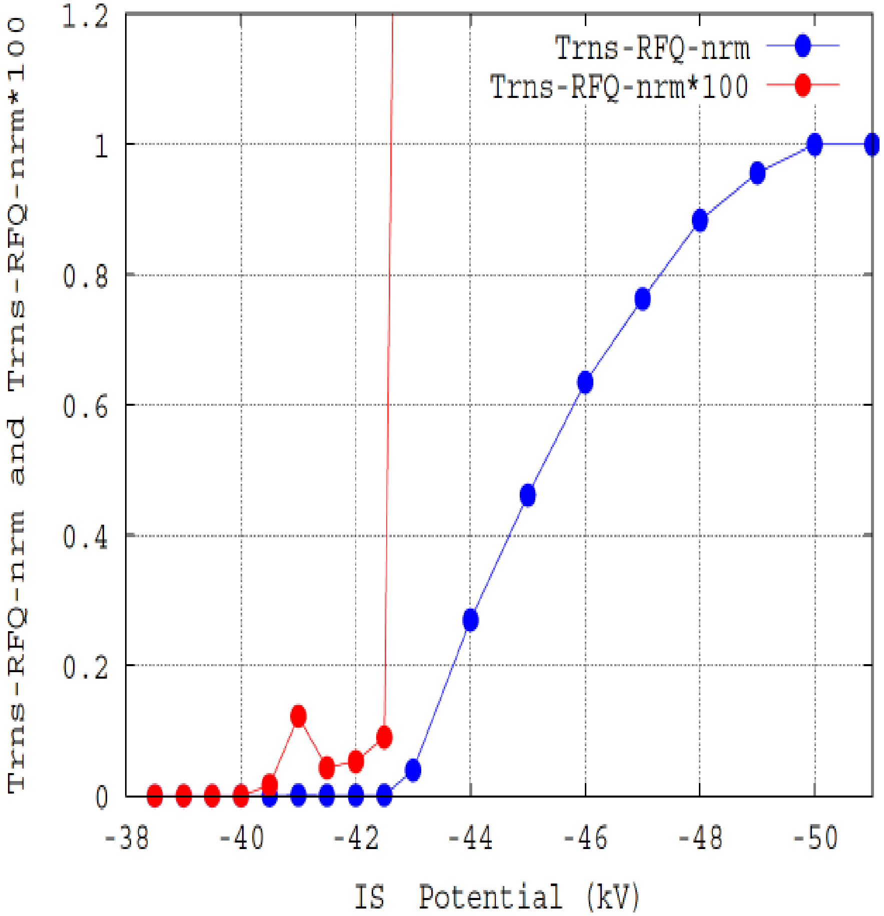
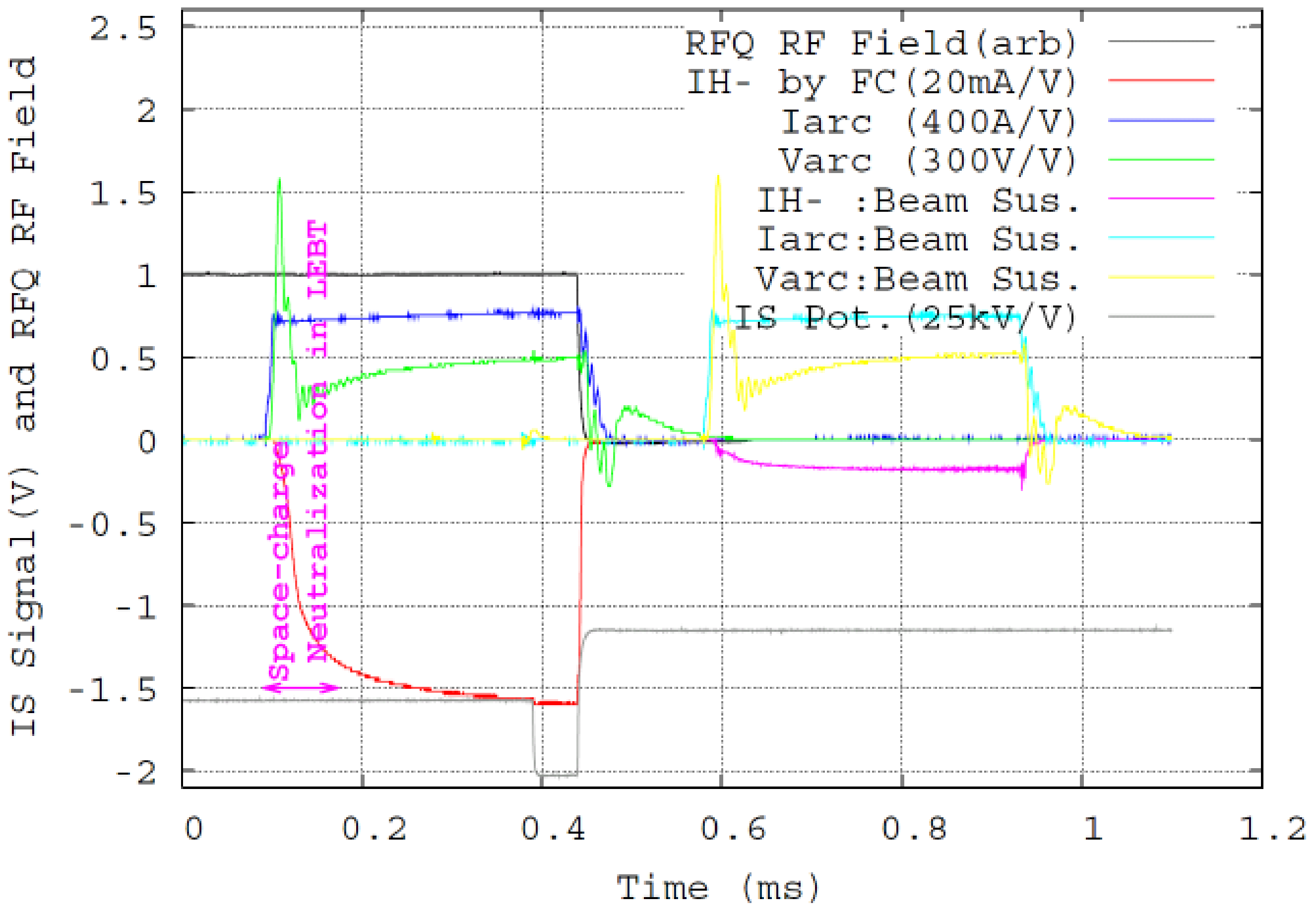
(3) Macro-Beam-Pulse Shaping & Beam Suspending Methods





RFQ Transmission as Function of IS Potential

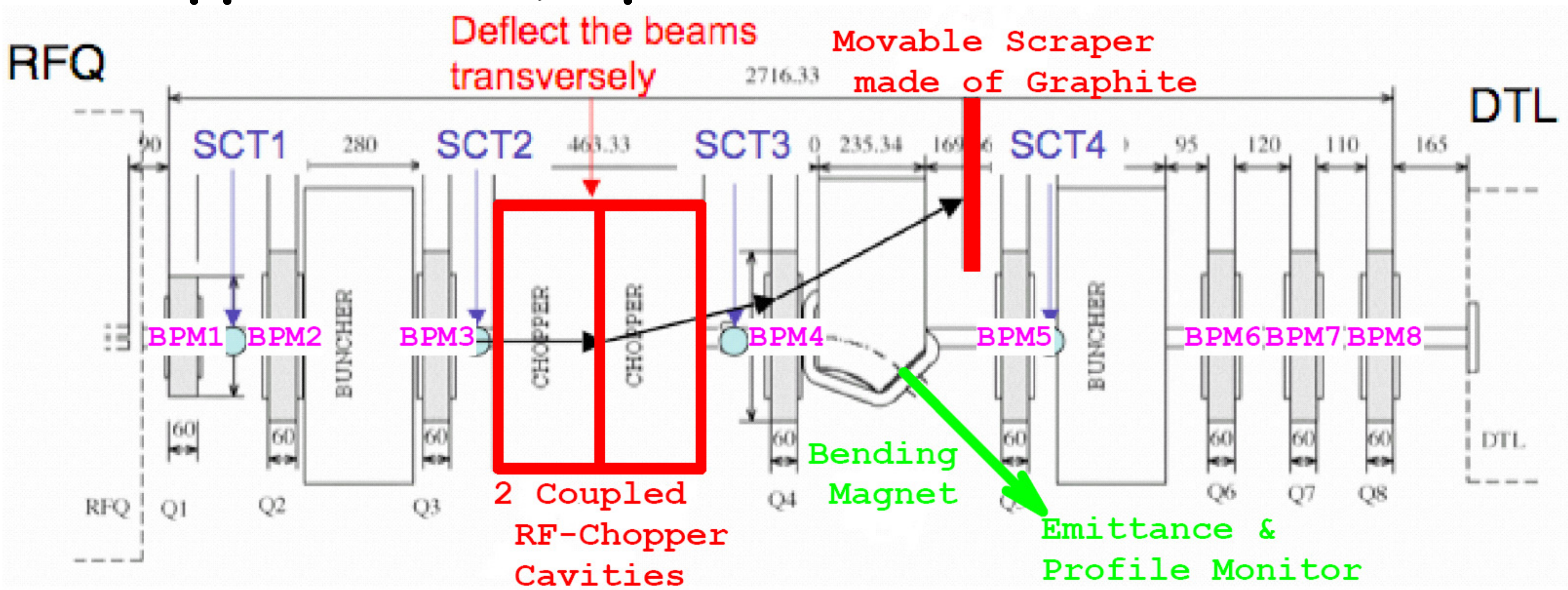
*Design: -50kV

*Vmod: -11.5kV(38.5keV)

RFQ RF, IH⁻ by F.C., Iarc, Varc, IS Pot. Waveforms (Operation & Beam Suspending)

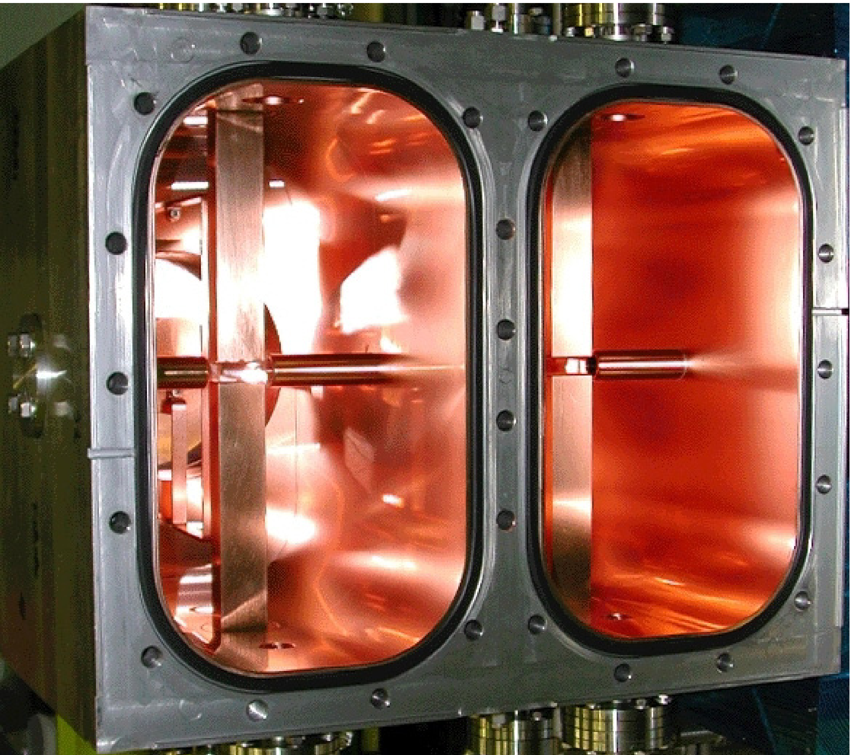
*In Case of 50μs Macro-Beam-Pulse

(4) RF-Chopper & RFQ Operation Parameter Suitable for It



Schematic Drawing of MEBT1

- Beam is deflected by RF-Chopper Cavity 1&2 and Q4 and Dumped on Graphite Scraper
- By Switching RF, Arbitrary Width and Number of Intermediate-Beam-Pulses
- Experimentally Confirmed that Graphite Stands for 1st Stage Duty(30mA*270μs*25Hz)



<-Inside-view of 2 Coupled RF-Chopper Cavities

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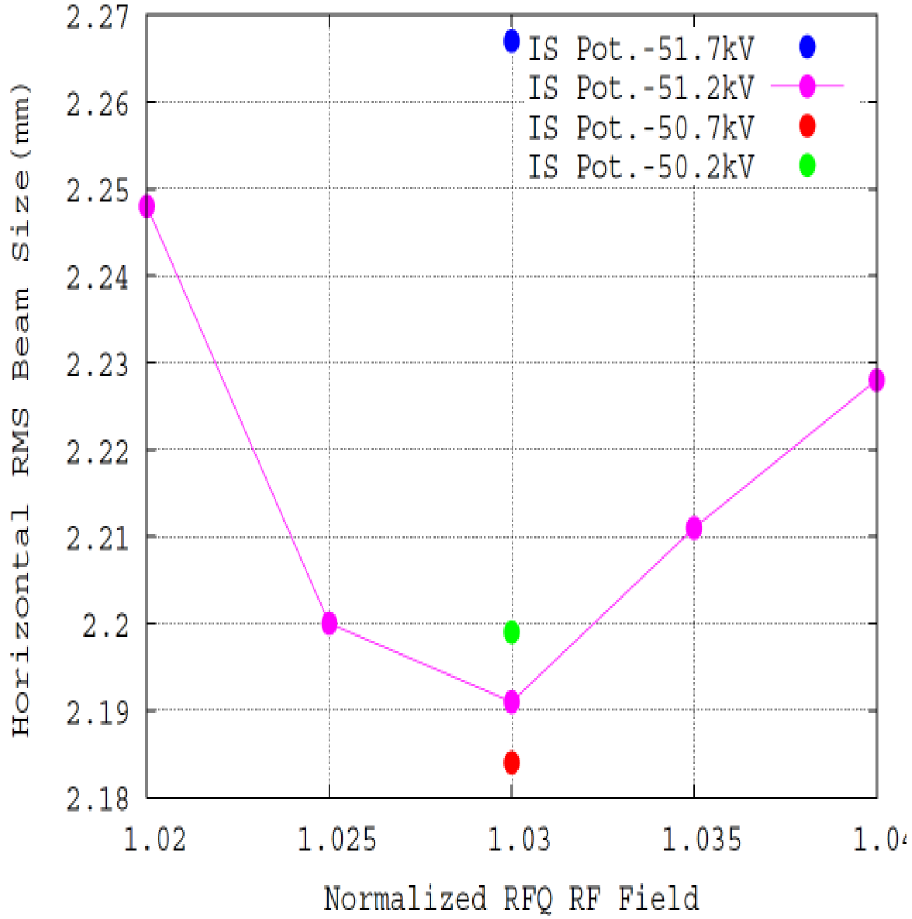
(4) RF-Chopper & RFQ Operation Parameter Suitable for It

'Remaining Beam':Deflected by RF-chopper but Accelerated by DTL&SDTL

Early in J-PARC linac Commissioning, Difficult to Reduce 'Remaining Beam':

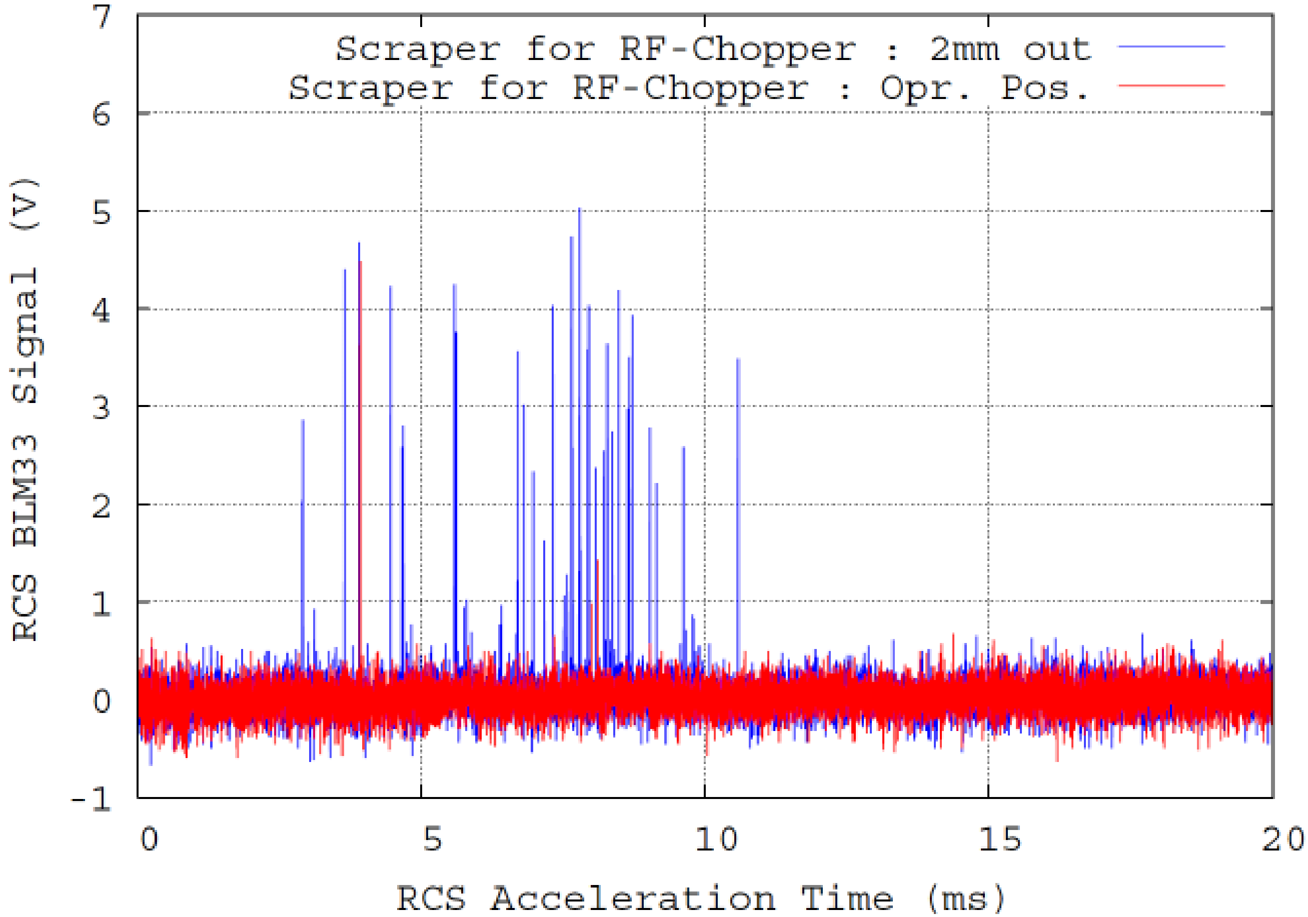
Smaller than Measurement Accuracy by linac WSM(Wire Scanner Monitor)



Horizontal Beam Size as Functions of RFQ RF-Field & IS Potential

∴RFQ RF 103% & IS Pot.-50.7kV

->Smaller than WSM Sensitivity



RCS BML (Beam Loss Monitor) Signal during Acceleration Time at Position with Dispersion. *Most Sensitive

162MHz RF-Chopper will Elimi.

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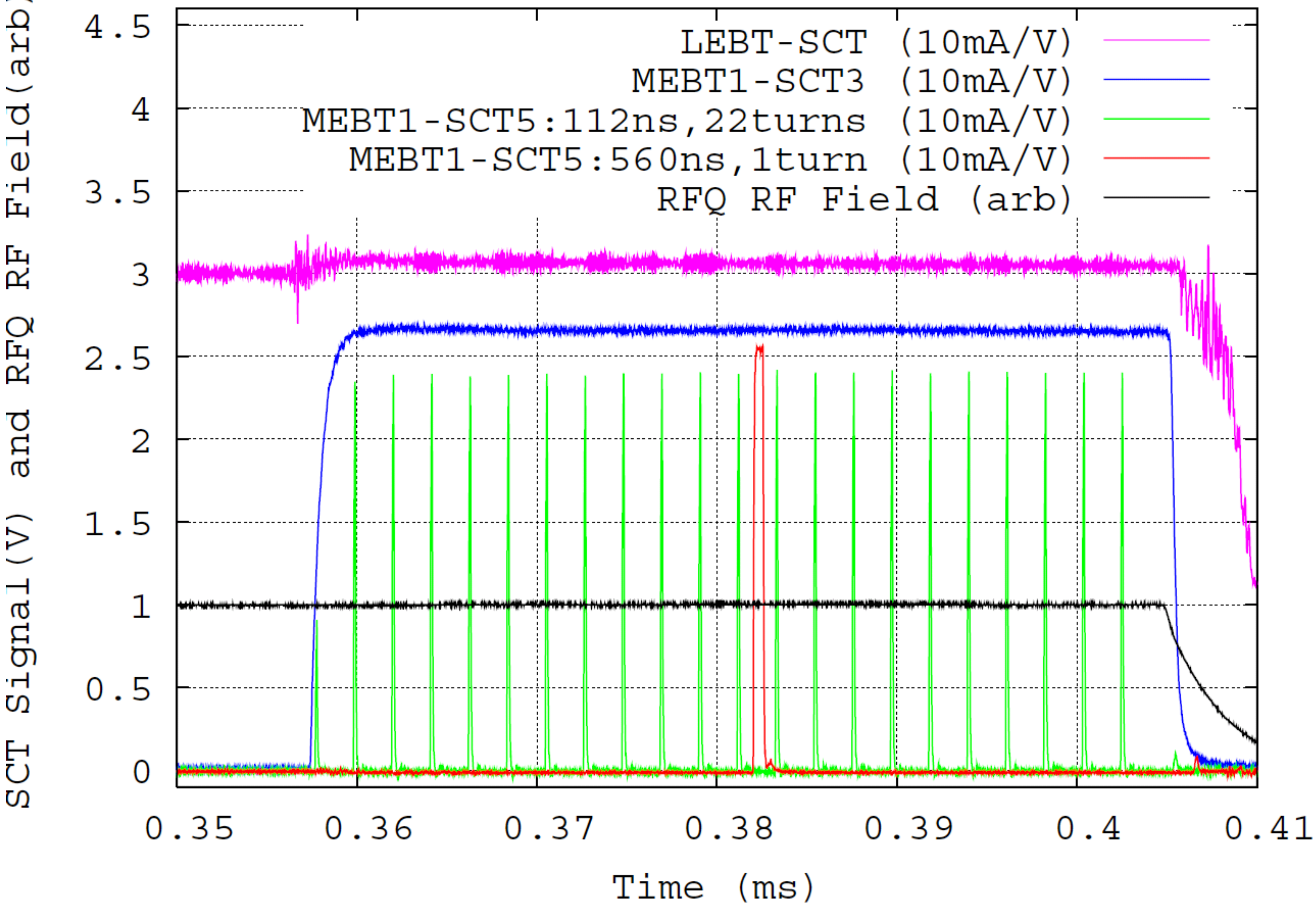
(4) RF-Chopper & RFQ Operation Parameter Suitable for It



LEBT & MEBT1 SCT(Slow Current Transformer) Signals and RF-Chopper RF

Macro-Beam-Pulse 50μs(Risetime 3μs~T_Vaccmod, Falltime 1μs~80%RFQ RF)

112ns & 22turn and 560ns & 1turn Intermediate-Beam-Pulse

LEBT-SCT~200μs

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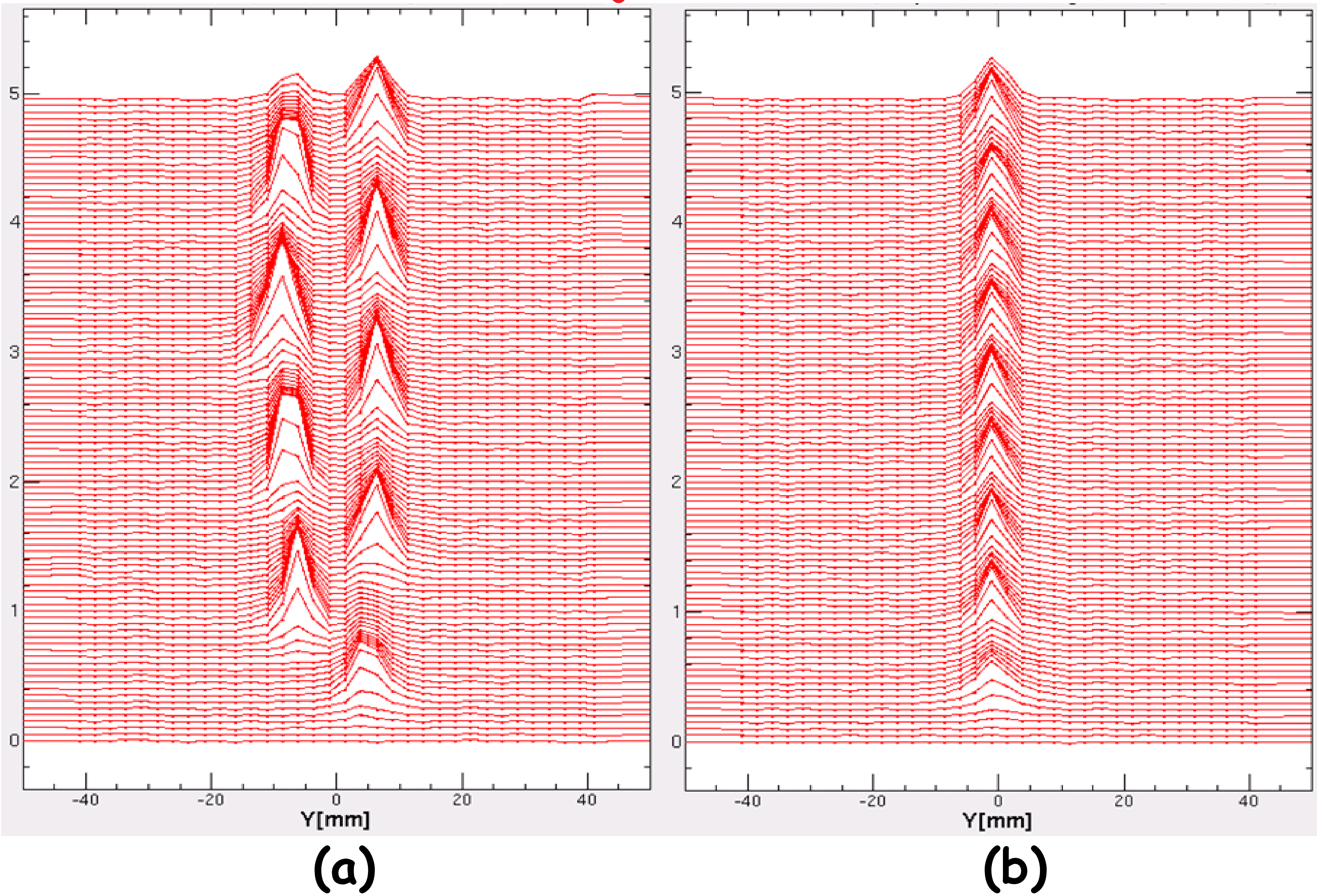
(4) RF-Chopper & RFQ Operation Parameter Suitable for It

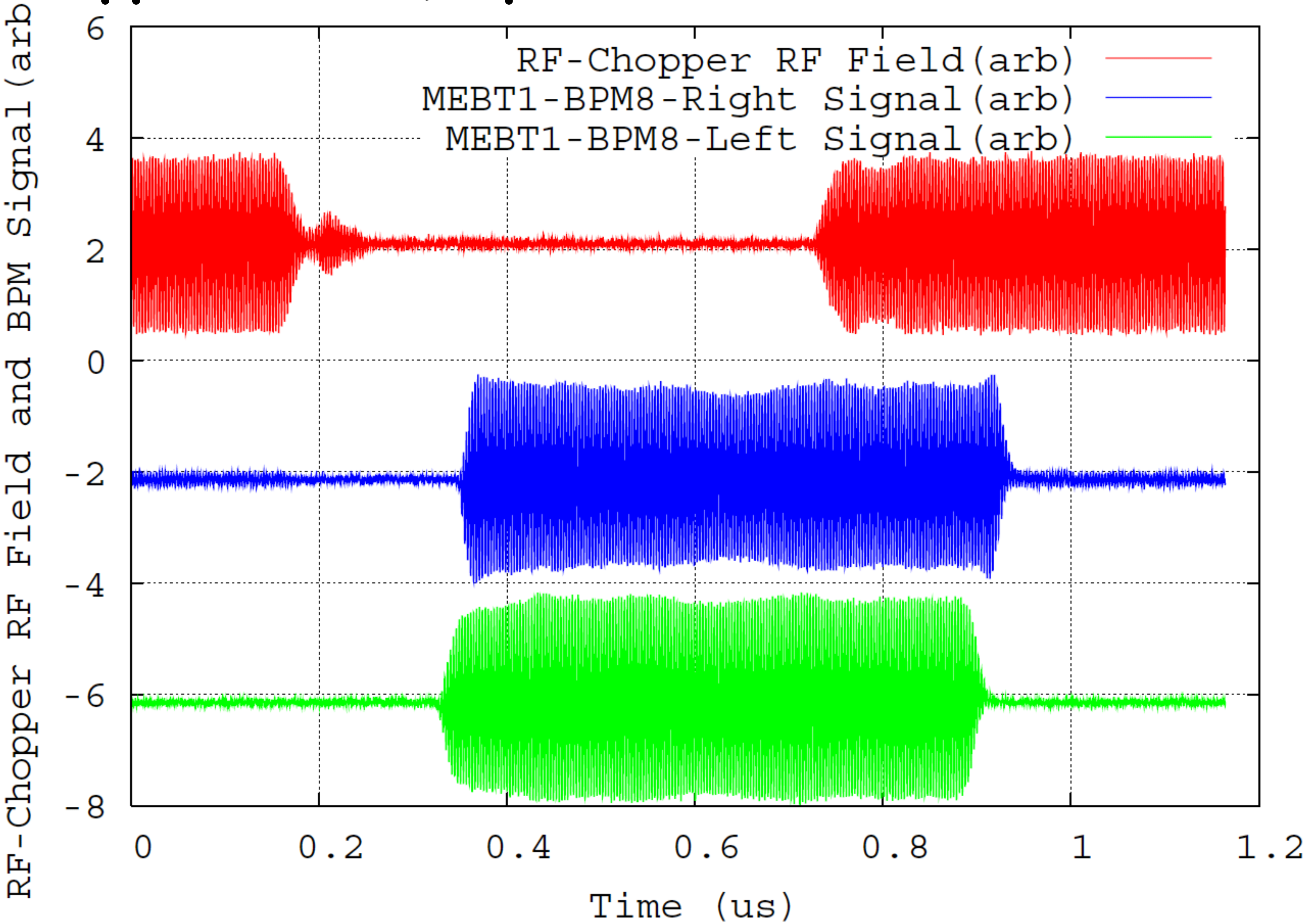
One Turn Injection into RCS



Mountain Plots of RCS Vertical IPM(residual gas Ionization Profile Monitor) Signals (Turn by Turn) before (a) and after (b) Injection Error Correction

*First 9turns

(4) RF-Chopper & RFQ Operation Parameter Suitable for It

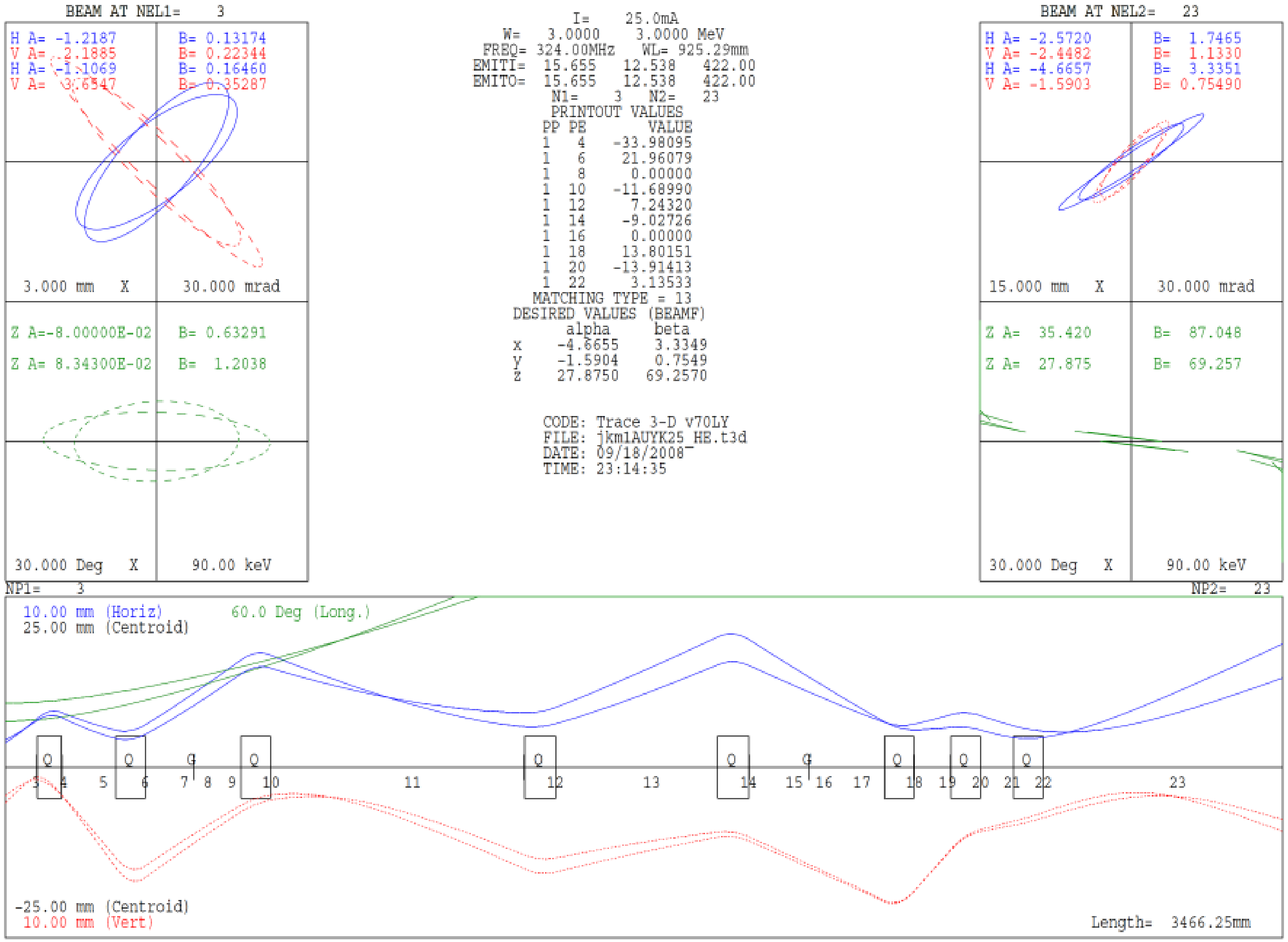


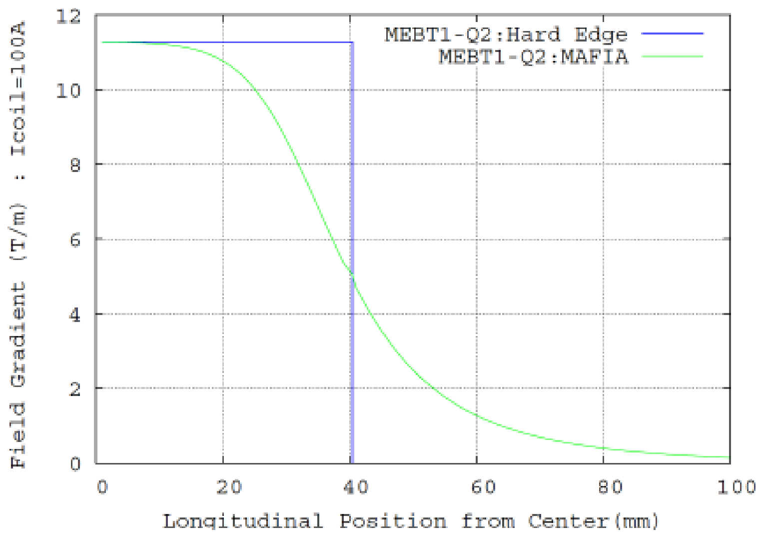
Ringing of RF-field of RF-Chopper at RF on/off Transient-Time

*RF-Power Flow between 2-Coupled Cavities (Inevitable)->2 RF-Sources

MEBT1-BPM8-Right & Left : Beam Position is Changed

(5) Transverse Matching with TRACE3D PMQ Element

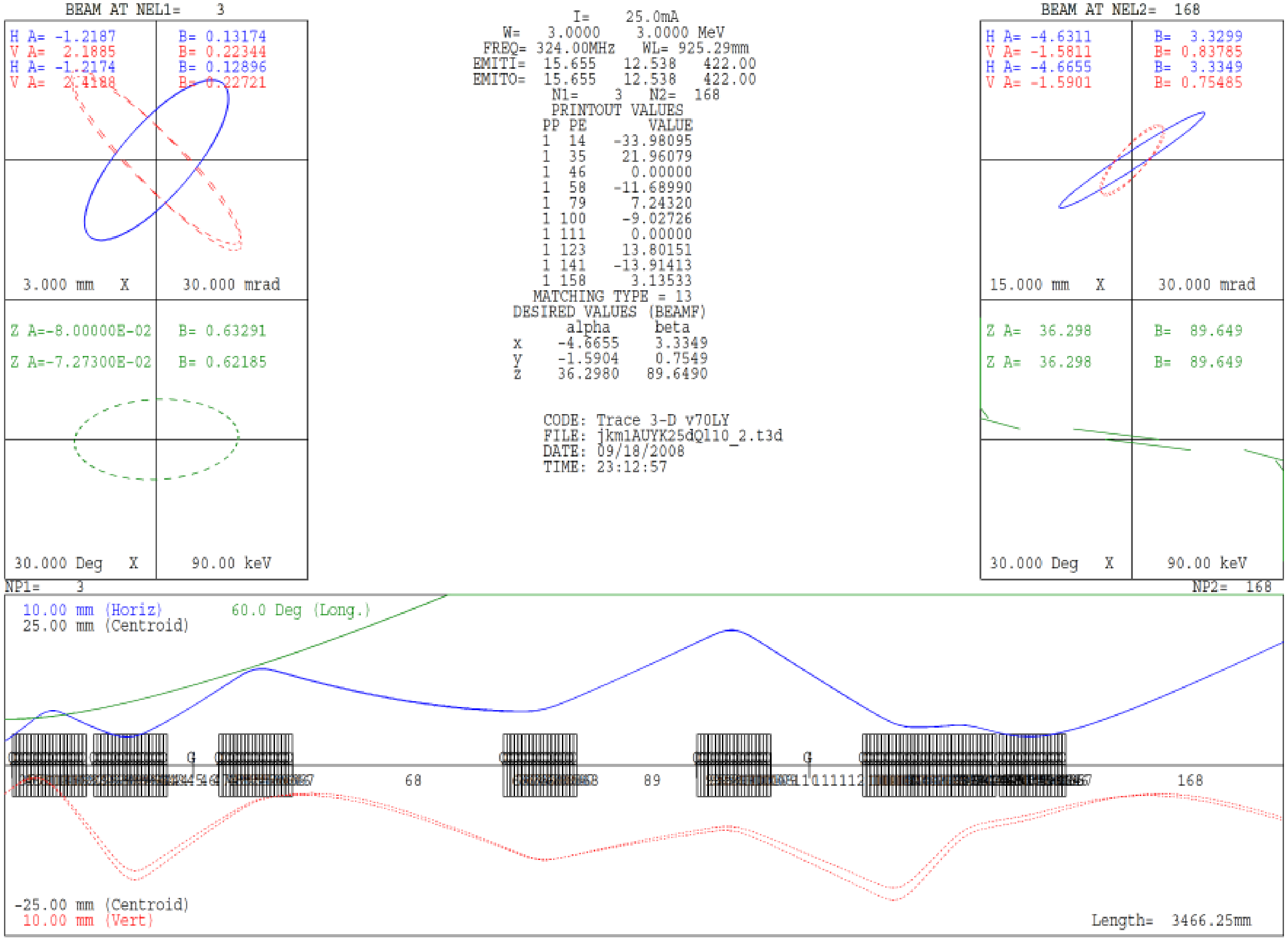


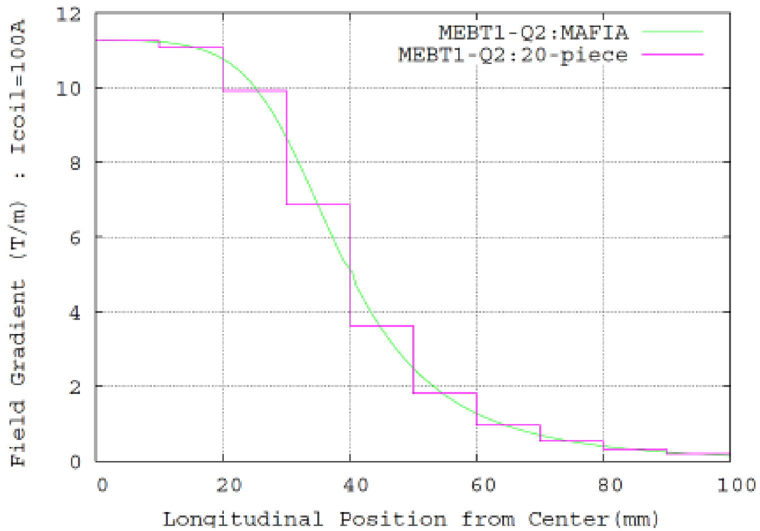


Field Distributions of MAFIA & Hard-Edge of MEBT1-Q2

Large Discrepancy between Measured Ellipses and Simulated Ellipses with Hard-Edge Q-magnets.

(5) Transverse Matching with TRACE3D PMQ Element





Field Distributions of MAFIA & 20-pice Hard-Edge Q-mags of MEBT1-Q2

Measured Ellipses is well Represented with 20-piece Hard-Edge Q-mags. for each Q-magnets.

***Reported in LINAC2002**

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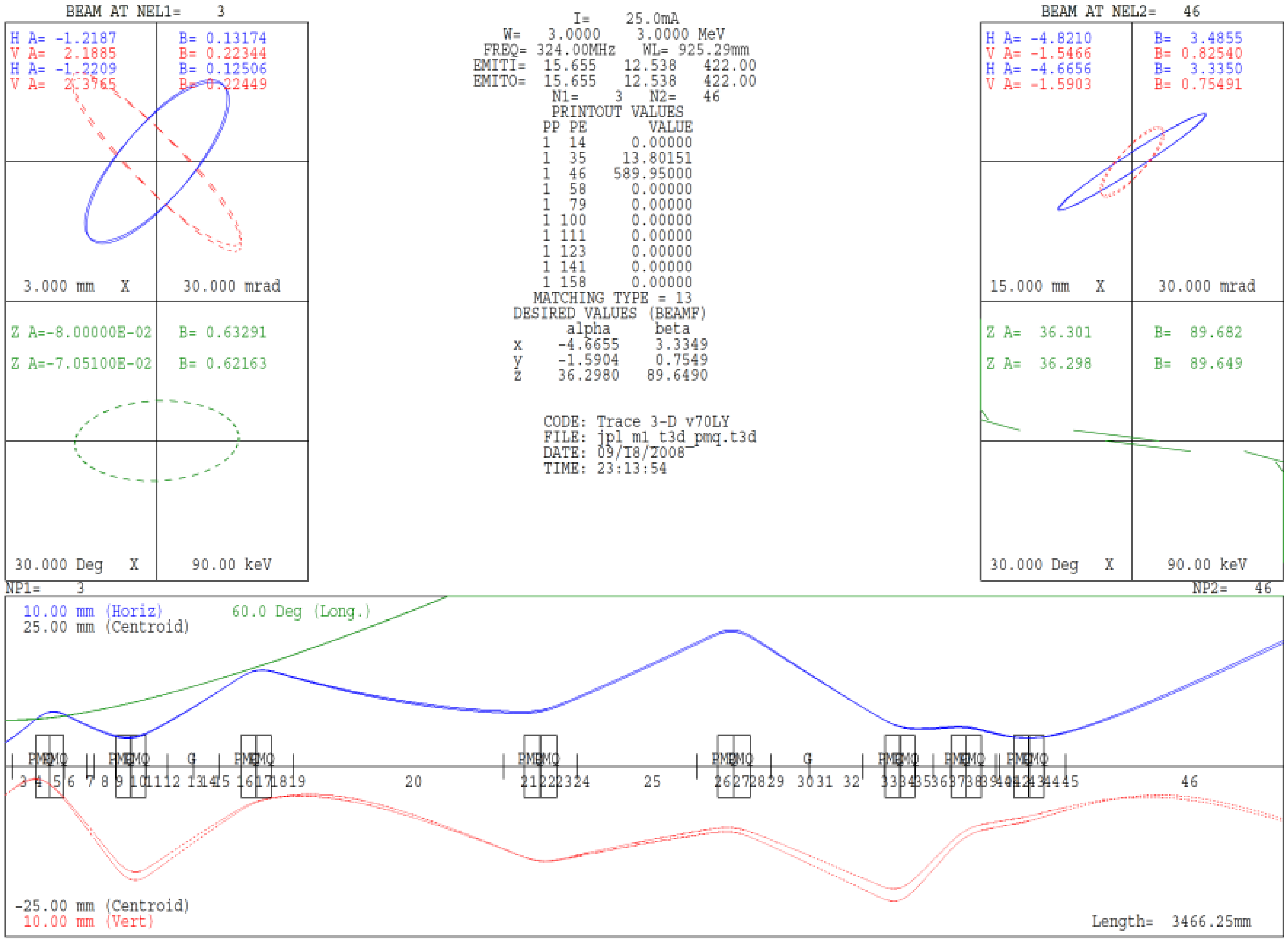
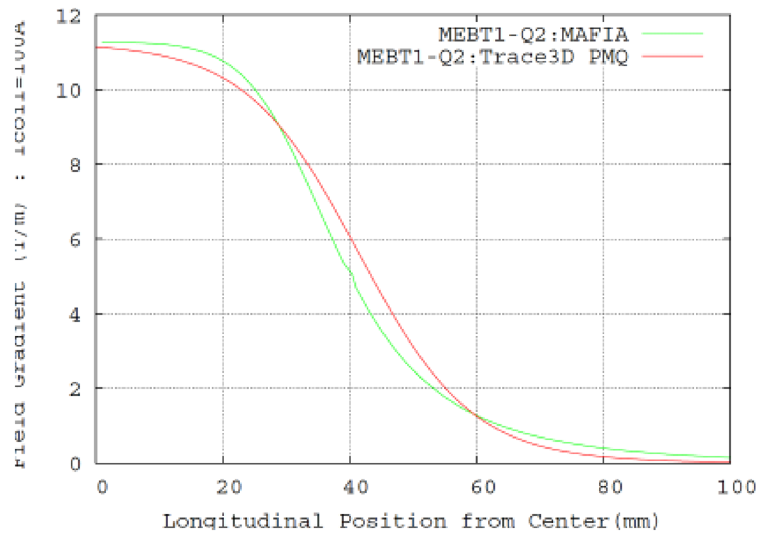
(5) Transverse Matching with TRACE3D PMQ Element





Field Distributions of MAFIA & TRACE3D PMQ of MEBT1-Q2

Measured Ellipses is well Represented with TRACE3D PMQ-magnets too.

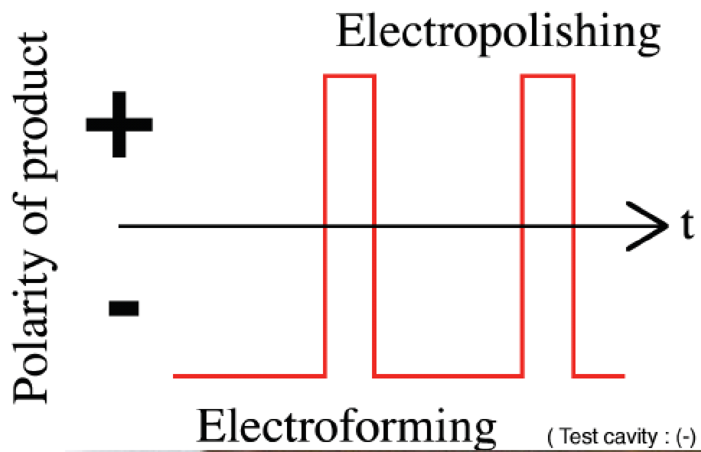
->All of J-PARC linac Q-magnets are treated as PMQ's.

*J-PARC linac is controlled with XAL, in which PMQ is transplanted.

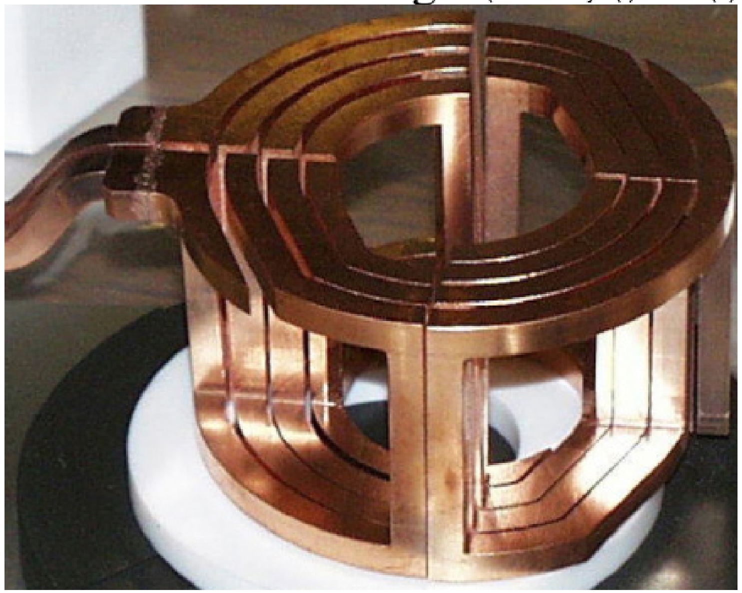
(6) DTQ-Coil & Cavity Plating Using PR Electroforming

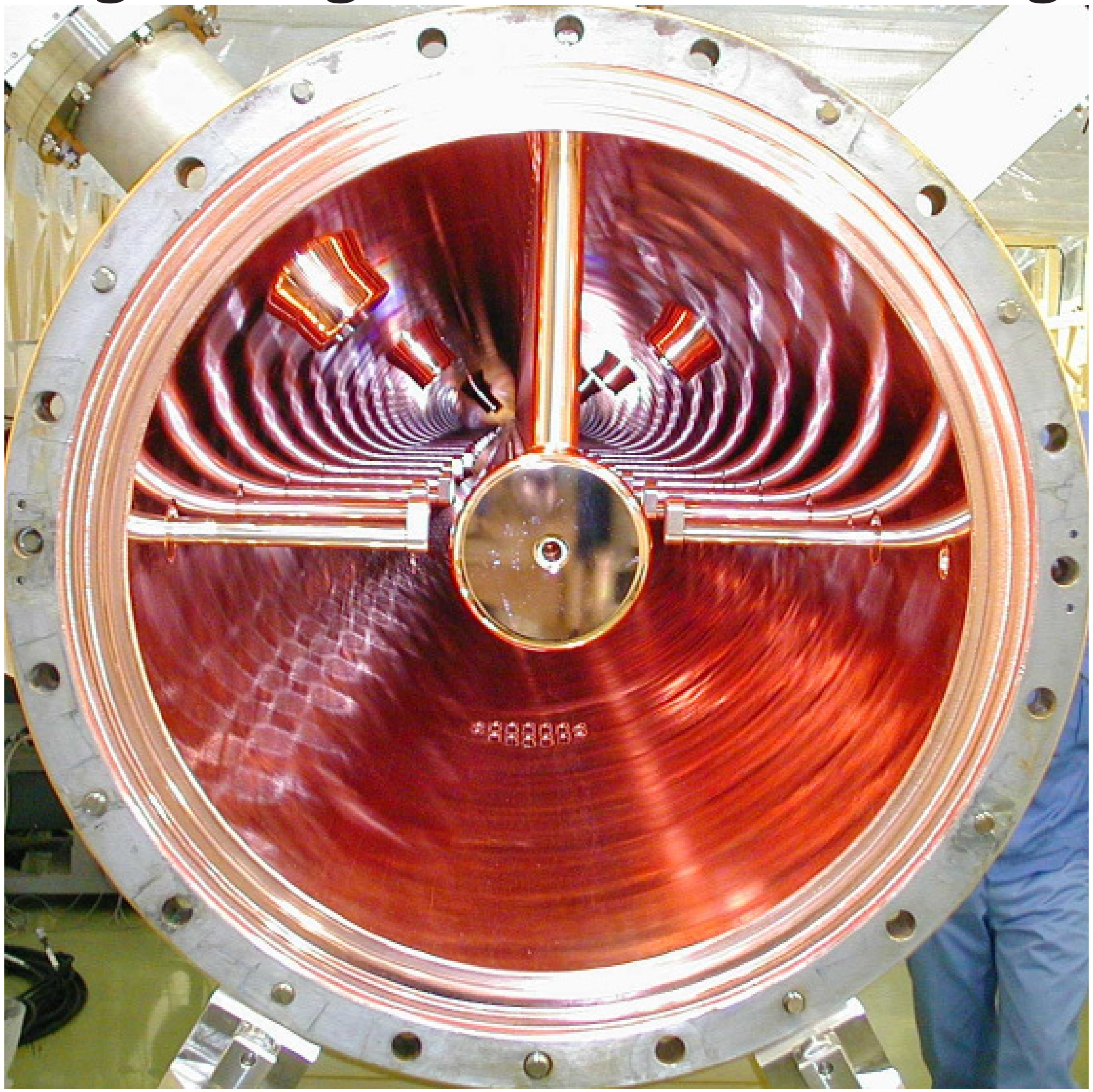
----> Periodic Reverse (PR) Electroforming

without brightning agent ~ OFC



(Test cavity : (-) 20 sec (+) 4 sec)



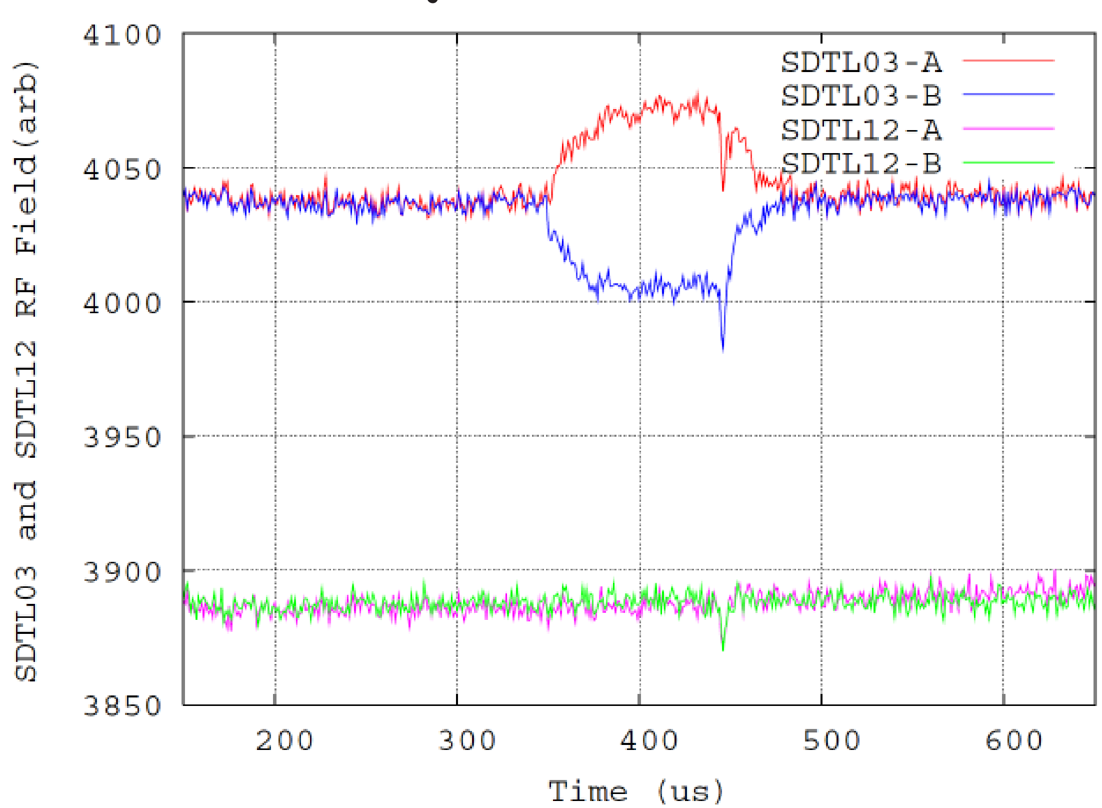


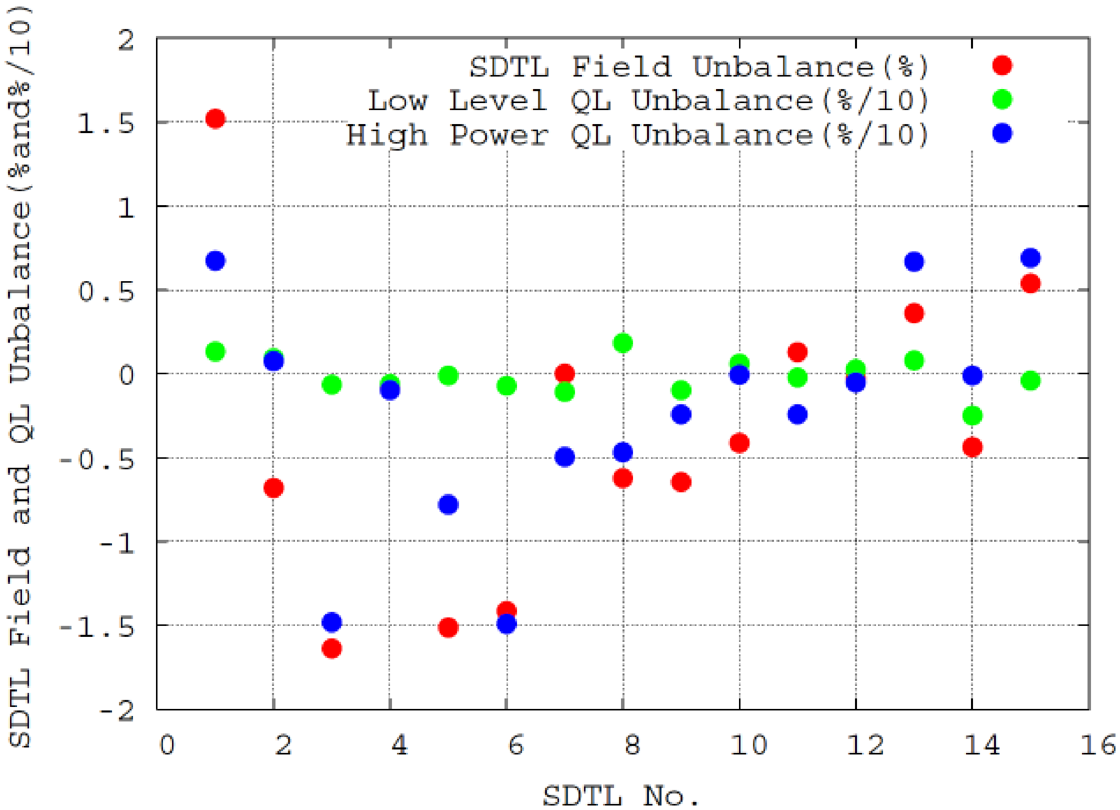
PR (Periodic Reverse) Electroforming->Thick Pure (~OFC) Plating

->Compact & High-duty (3.5turn, 600A, DC) DTQ-Coil

->High-Q-Value & Low Sparking Rate Plating for DTL & SDTL

(7) 2 Cavity Behavior of SDTL Driven by One Klystron





RF-Fields of SDTL03A&B (Max. Unbal. due to 28mA & 100μs Beam Loading :Unexpectedly Large Unbal.) and SDTL12A&B (Min.Unbal.)

RF-Field Unbal., Low Level QL (Loaded Q-Value) Unbal. and High-Power QL (Preliminary) Unbal. of Each SDTL pair (A&B).

*Although Accurate Measurement of High-Power QL's are necessary, High-Power QL (Preliminary) may have Relationship with RF-Field Unbalance. If this is correct, it may be due to multipacting.

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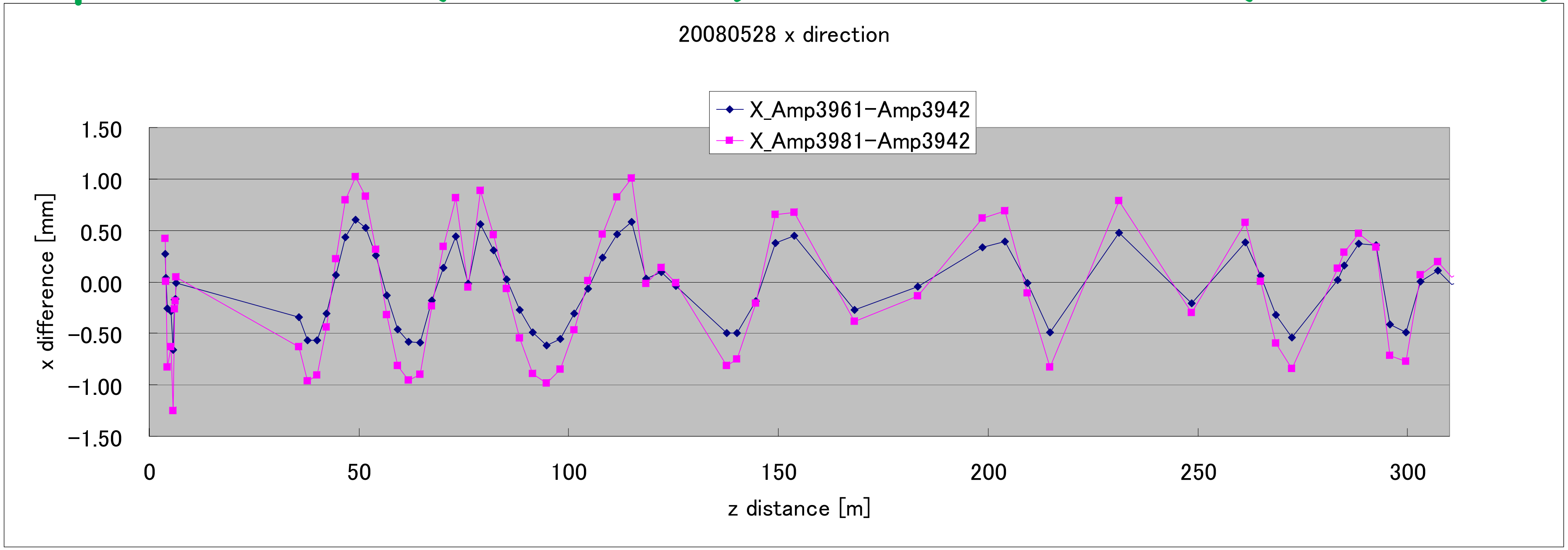
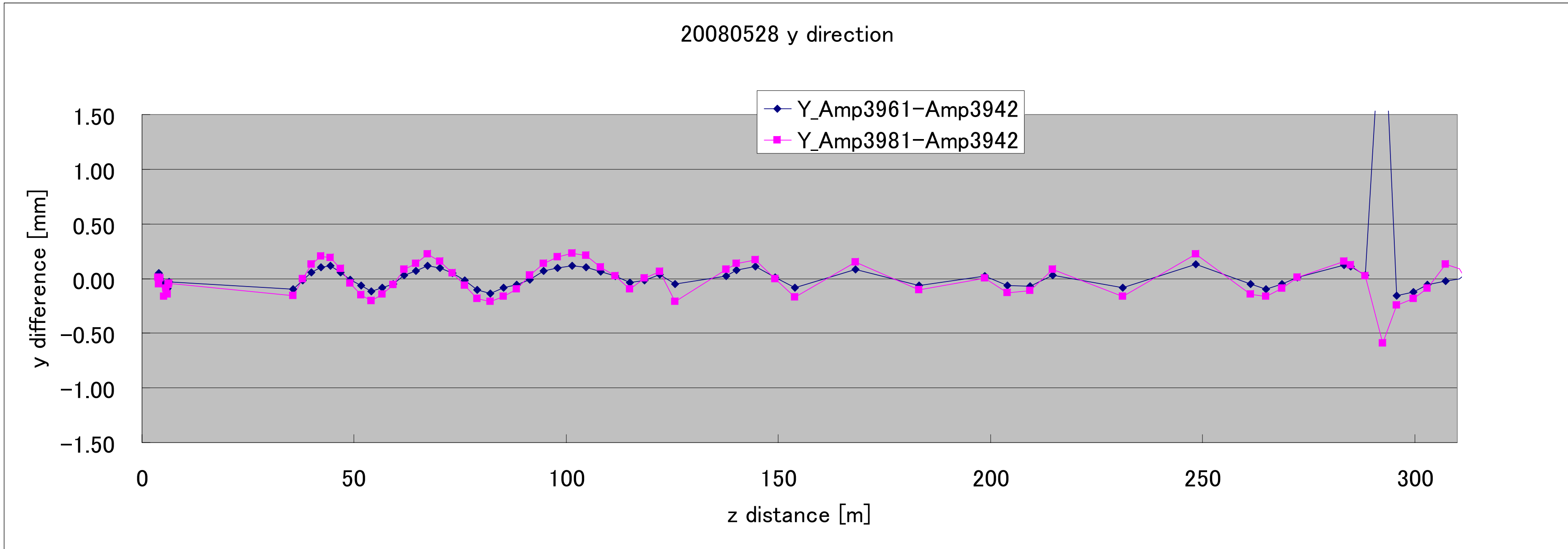
SUMMARY

- Surface Production Dominating Cs-Free H^- IS:Stable Operation with~30mA
- Macro-Beam-Pulse Shaping using RFQ Long. Accep.
  :Risetime of 3μs (SCN Established) & Falltime of 1μs (80% RFQ RF-Field)
- Beam Suspending by RFQ RF Off (for Fast MPS) & IS Arc Gate Delay
  (for Stable One-Shot Operation etc.)
- RF-Chopper & RFQ Operation Parameter Suitable for It:At Optimum RFQ
  RF-Field(103%) & IS Pot.(-50.7kV), 'Remaining Beam' is Acceptable at Present
  ->Slight 'Remaining Beam' will be Eliminated by 162MHz RF-Chopper Cavities,
  Consequent 2 Scrapers Stands for J-PARC 2nd Stage Beam Power.
  *RF-Chopper RF Field Ringing can be Eliminated by 2 RF-Sources.
- Transverse Matching with TRACE3D PMQ Element
  :PMQ Field well Represent Measured Ellipses->Treat All Q-mags as PMQ.
- PR (Periodic Reverse) Electroforming
  ->Compact & High-duty (3.5turn, 600A, DC) DTQ-Coil
  ->High-Q-Value & Low Sparking Rate Plating for DTL & SDTL
- 2 Cavity Behavior of SDTL Driven by One Klystron
  *Unexpectedly Large RF-Field Unbal. of SDTLnA&B due to Multipacting?

Measured Beam Orbit Variation due to RFQ RF-Field Change

Top : Horizontal (+0.5%&+1%), Bottom : Vertical (+0.5%&+1%)





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