FFAG Accelerators
Experimental Results

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Operational FFAGs

- PoP FFAG (KEK): world first proton FFAG

  scaling, radial sector(DFD), E=0.5(1)MeV, com'd 2000

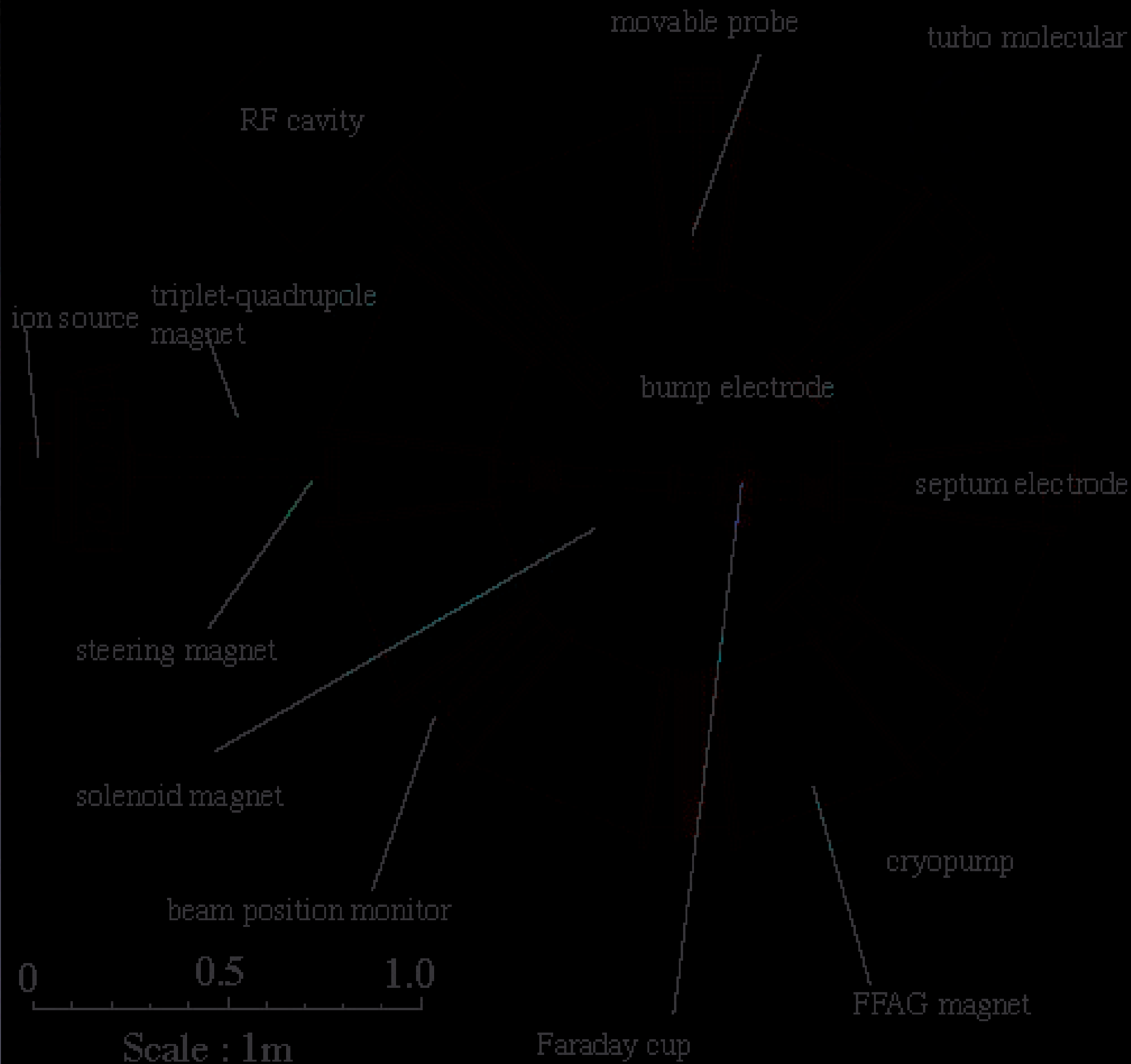
- 150MeV FFAG (KEK)

  scaling, radial sector(DFD), E=100(150)MeV, 2003

- Injector of KURRI FFAG chains

  scaling, spiral sector, E=2.5MeV, 2006, Jan. 1st.

PoP-FFAG



PoP-FFAG parameter table

Particle	proton
Type of magnet	radial sector type
No.of sector	8
Field index	k=2.5
Energy	50keV => 500keV
Repitition rate	1kHz
Magnetic field	
Focus-mag.	0.14 - 0.32 T
Defocus-mag.	0.04 - 0.13 T
Radial of closed orbit	0.81 - 1.14m
betatron tune	
horizontal	2.17 - 2.22
vertical	1.24 - 1.26
RF frequency	0.61 - 1.38MHz
RF voltage	1.3 - 3.0kVp

World First
Proton FFAG Accelerator

- PoP(proof-of-principle) FFAG :KEK 2000

Fundamental Parameters
as experimental evidences

- Transverse

  chromaticity: Qx (Qz) vs. energy

  tunability: Qx, Qz vs. F/D ratio

- Longitudinal

  synchrotron osc. : fs vs. energy

- Closed orbit change

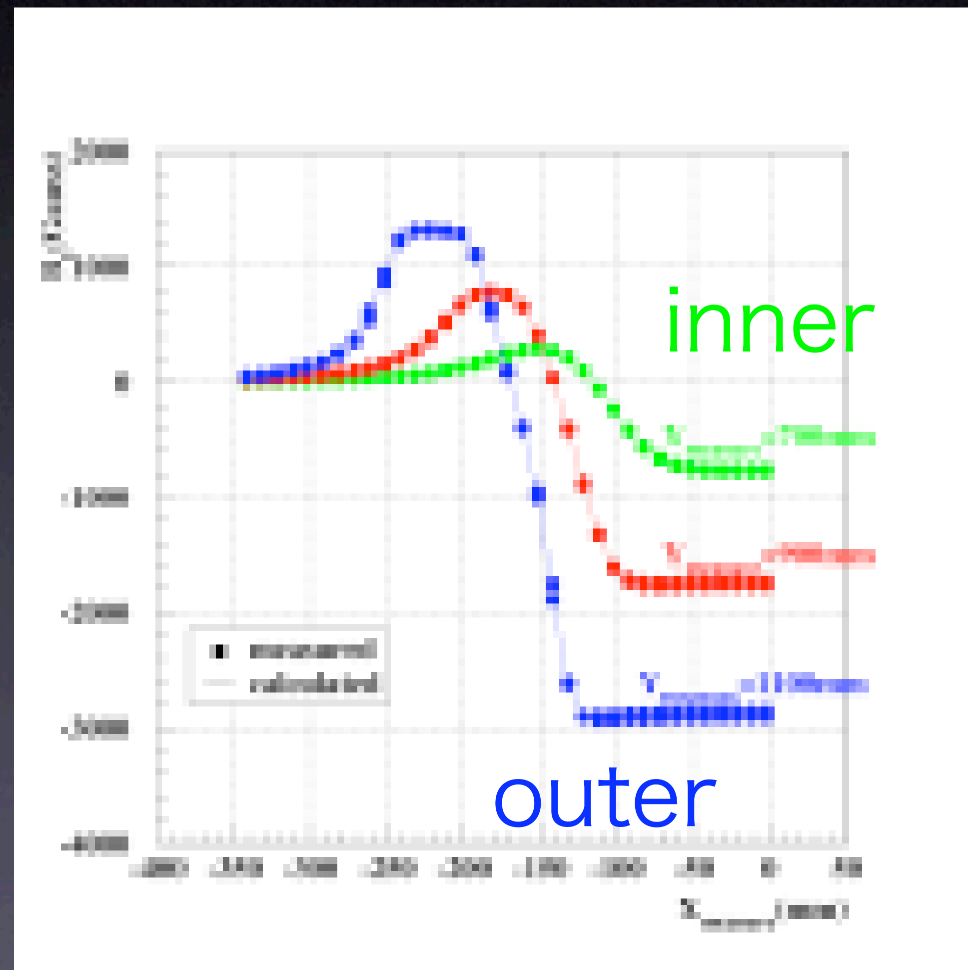
Field Optimization

Scaling

$$B \propto r^k$$

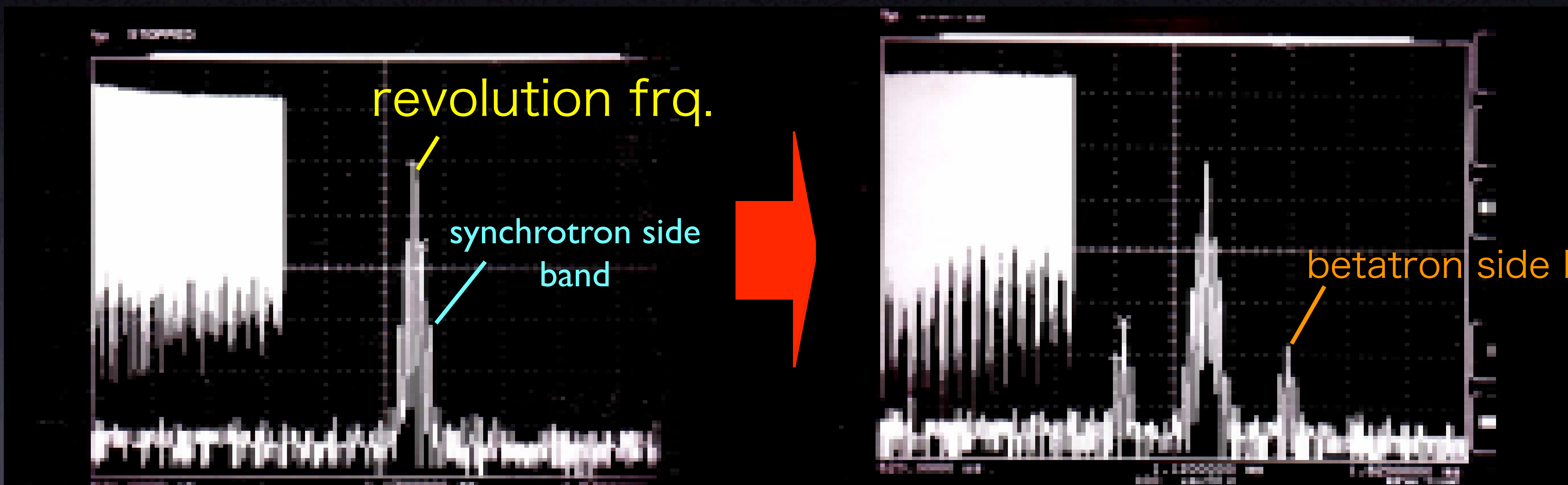
including length

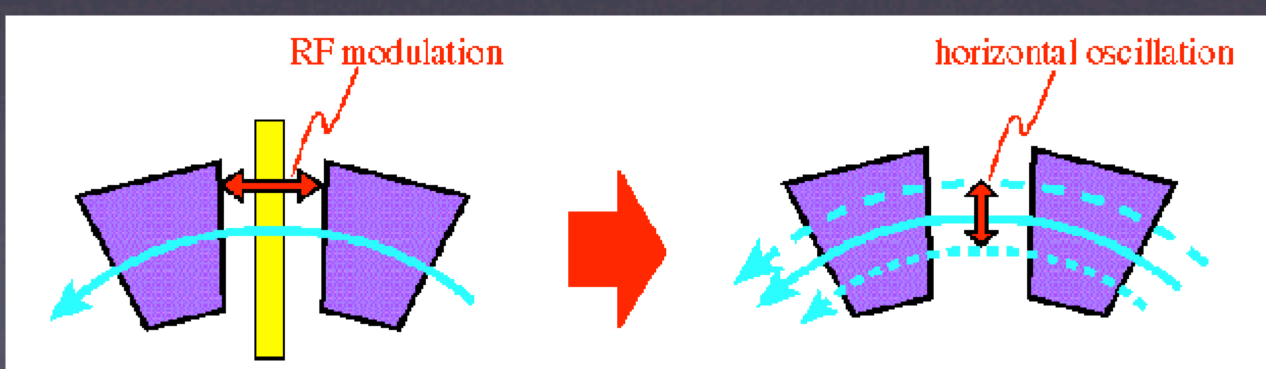
$$Bl \propto r^{k+1}$$



Tune Measurement

- RF knock-out

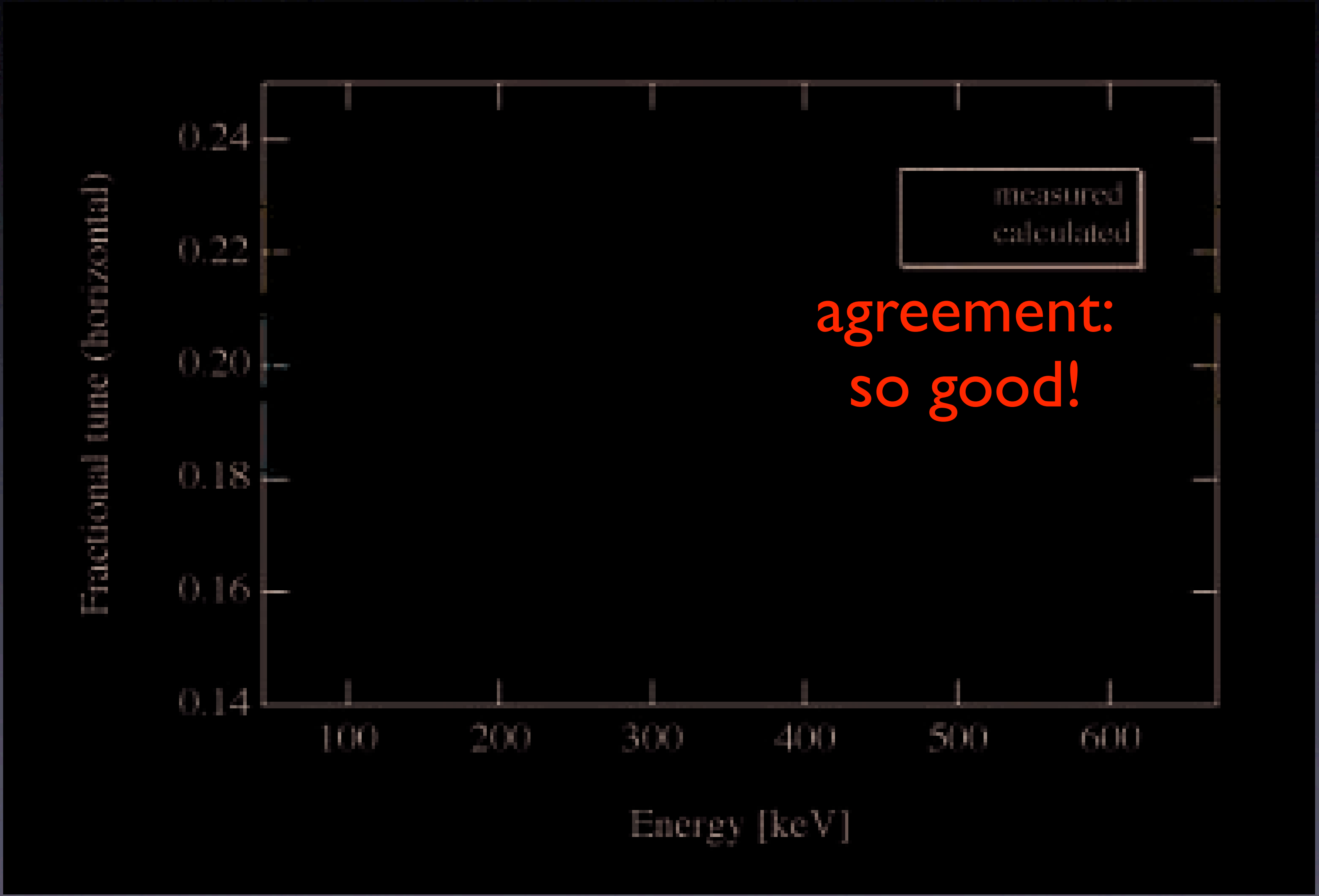




$$pQ_h + qQ_v = \pm m \pm \frac{f_{rf}}{f_{rev}}$$

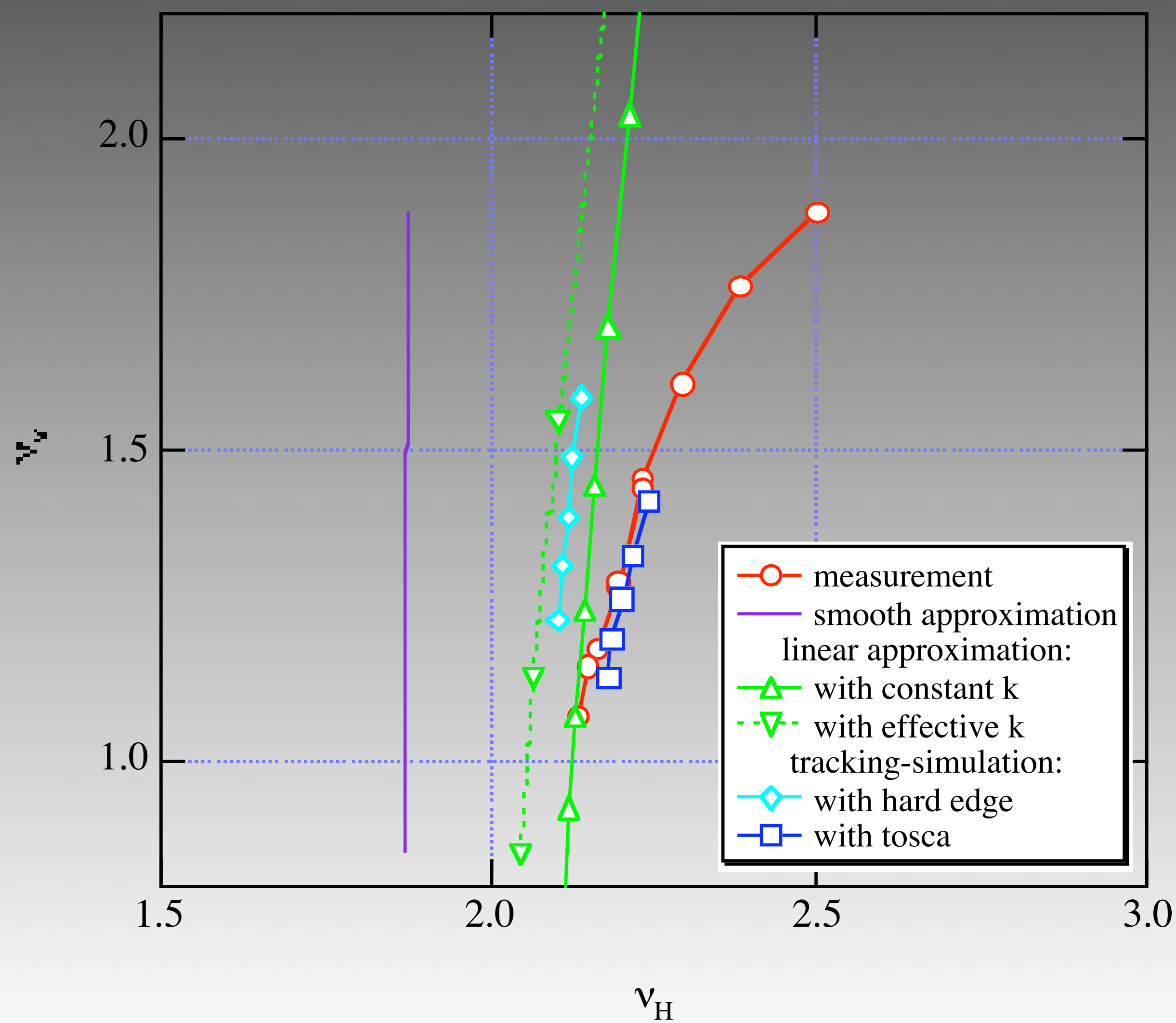
Betatron Tunes

-design vs. measurement-

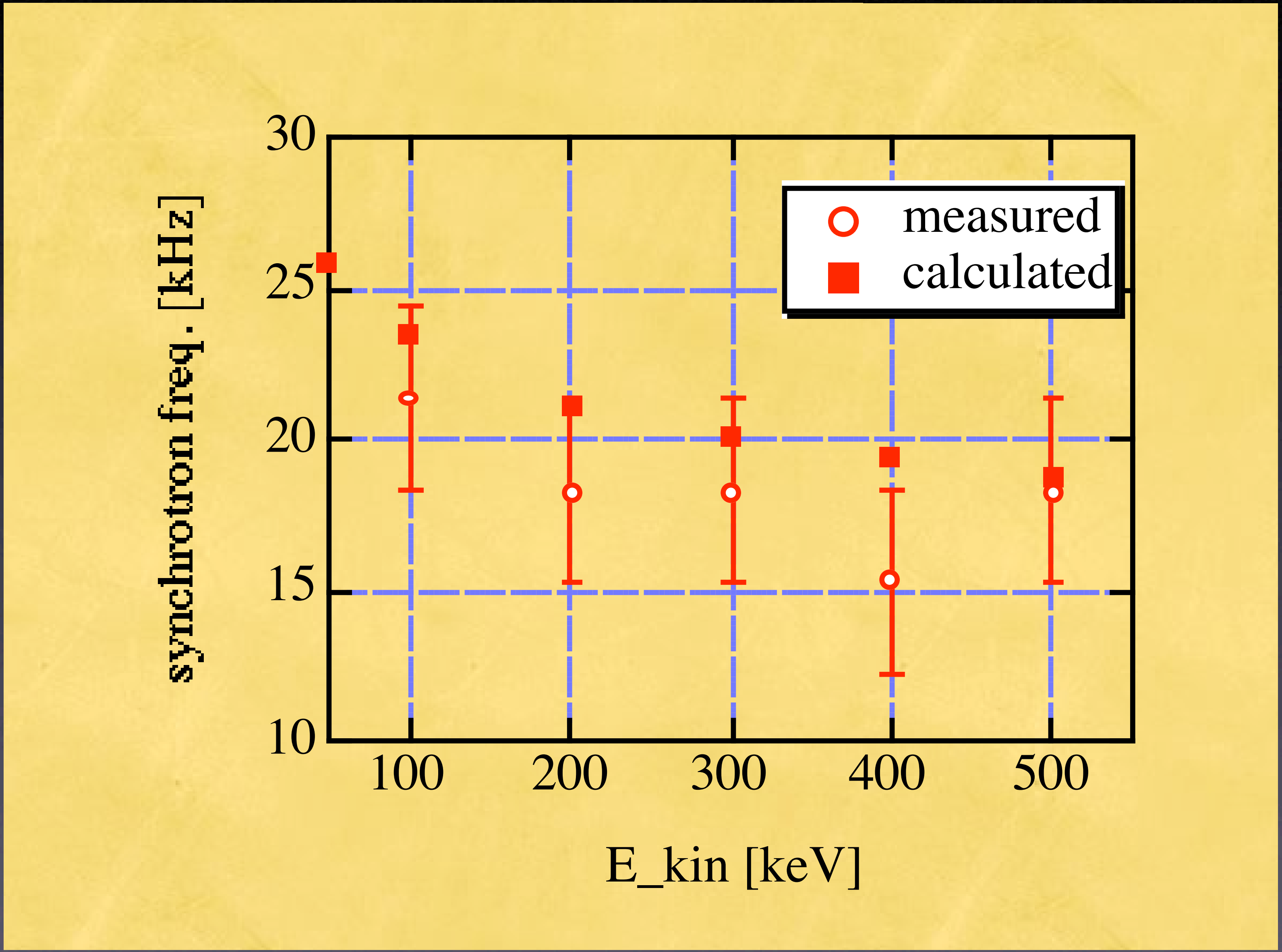


Betatron Tunes for various F/D ratio at injection energy of PoP FFAG

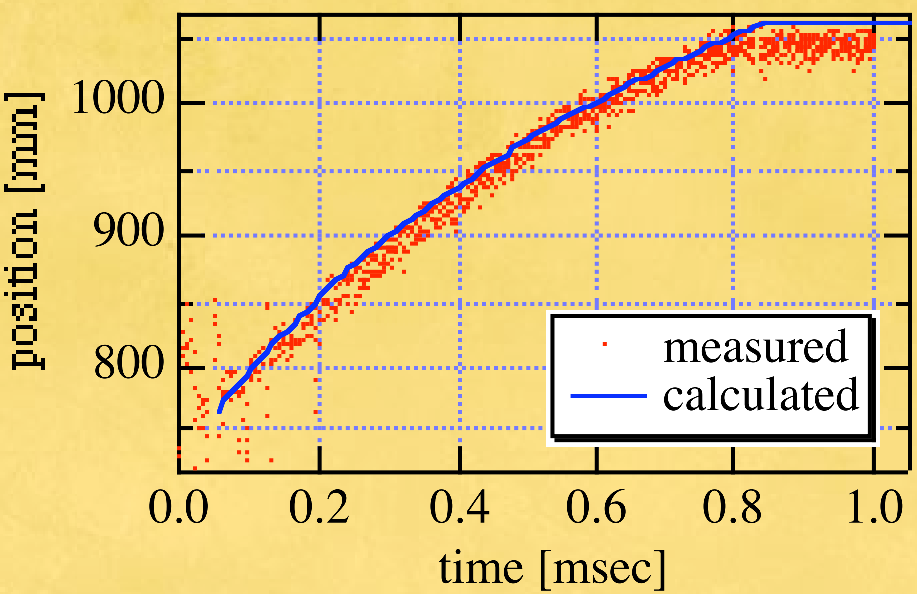
@ Injection Energy



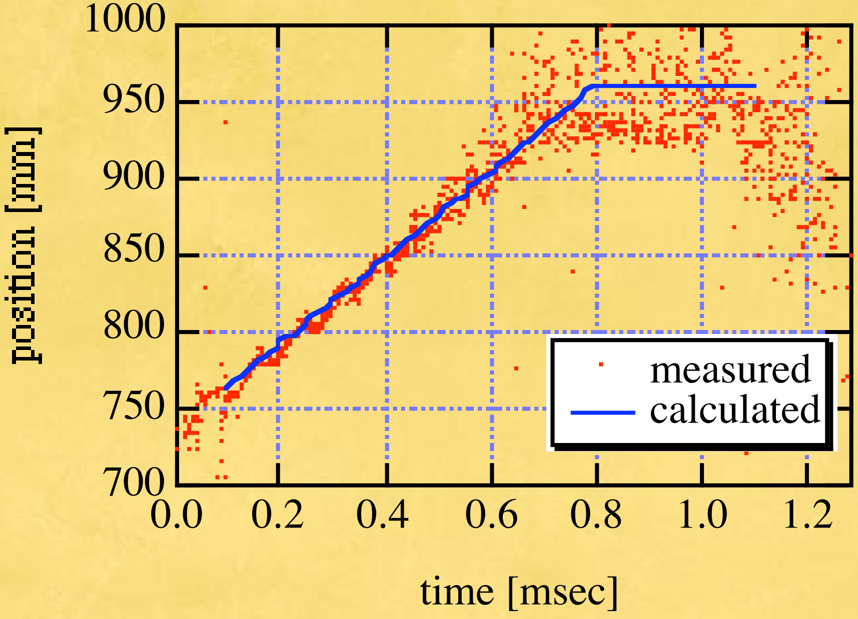
Synchrotron Frequency



Closed Orbit Change



energy gain/turn=const.



dr/dt=const.

Beam Intensity

- Injected beam

  Ip=0.5mA, $\Delta T = 3\mu$sec (4-turn injection)

  Np=Ip x ΔT / e =1 x 10^{10}ppp

- Accelerated Beam ; Np ~2-3 x10^{9}ppp

  No adiabatic capture process

  Neutralization (H^{+} -> H^{0}) at injection energy

  Looks no beam loss after rf capture.

150-MeV FFAG

- Unexpected difficulties
- Lower Injection beam energy -reduced field

  -Opereating tunes are drastic changed.

  Need field correctors to avoid dangerous resonances
- Large magnetic field at straight section.

  - Large COD by magnetic devices(rf cavity, kicker etc.) which break periodicity and excite unwilling non-structure resonances.

  Need non-ferromagnetic kicer, bumper and COD corrector for rf cavity.

  - Shunt impedance drop of rf cavity.

  Need large rf power and cooling for cavity

150-MeV FFAG beam intensity

- Injected beam

  Energy 10 MeV (not 12 MeV)

  Repetition rate 100Hz

  Intensity Ip=10 μA at injection septum

  Turn number 3turns(max.) : ΔT=2.5 μsec

  Np=1.6 x 10^8ppp, Ip=2.5nA

- Extraced beam after acceleration

  Energy 100MeV

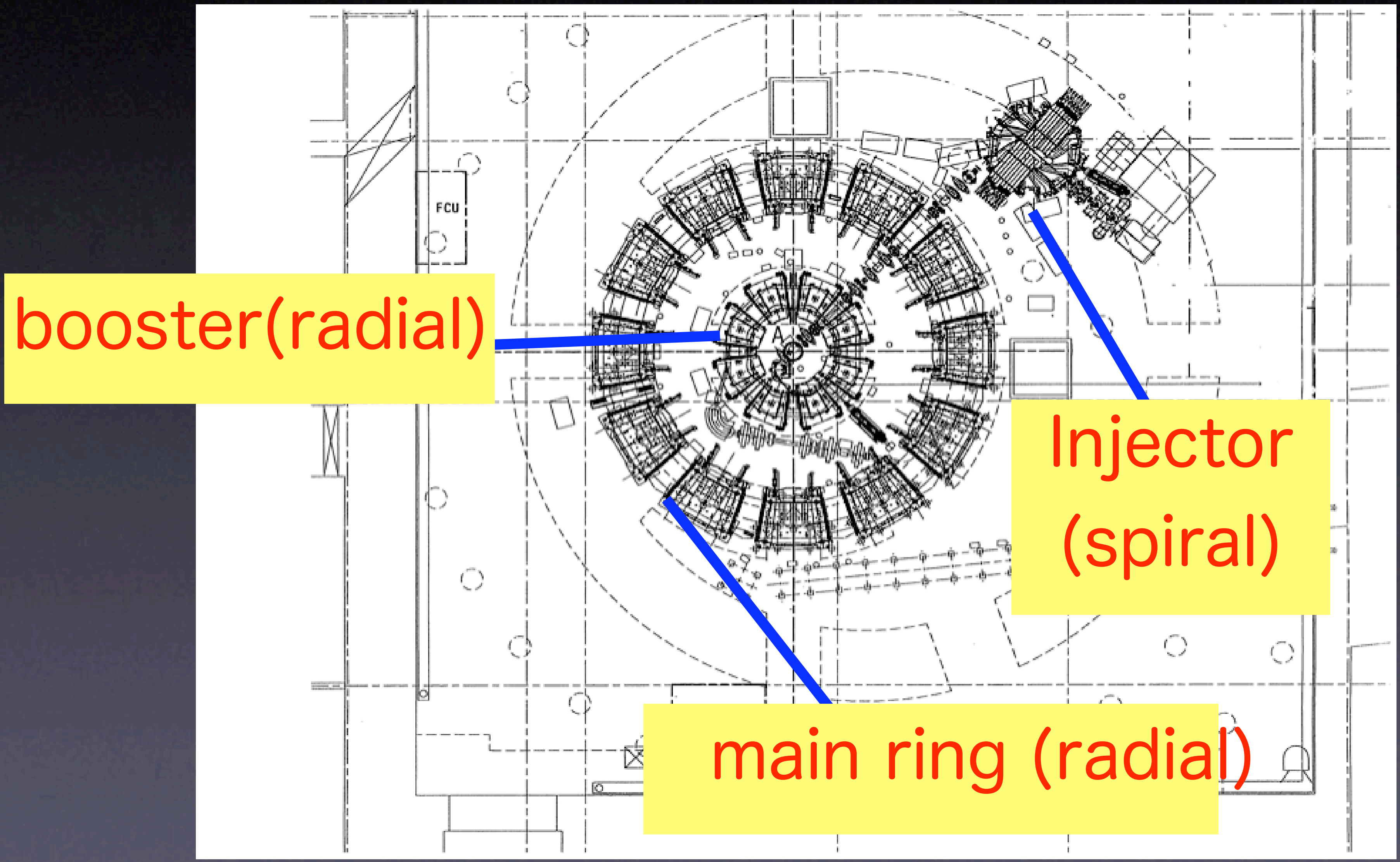
  Intensity Ip=1.5nA after beam extraction, Efficiency: ~60%

  Adiabatic capture effecitve but not perferct.

  Looks small beam loss after rf capture.

FFAGs for ADS project

Kyoto University Research Reactor Institute (KURRI)



Parameters of the Accelerator Complex

	Injector	Booster	Main ring
Einj	100keV	2.5MeV	20MeV
Eext	2.5MeV	20MeV	150MeV
Lattice type	Spiral -	Radial DFD	Radial DFD
Acc. scheme	Induction	rf	rf
# of cells	8	8	12
k value	0-2.5	4.5	7.6
coil/pole	coil	coil	pole
Pext/Pinj	5.00	2.84	2.83
Rinj	0.60m	1.42m	4.54m
Rext	0.99m	1.71m	5.12m

Injector - spiral

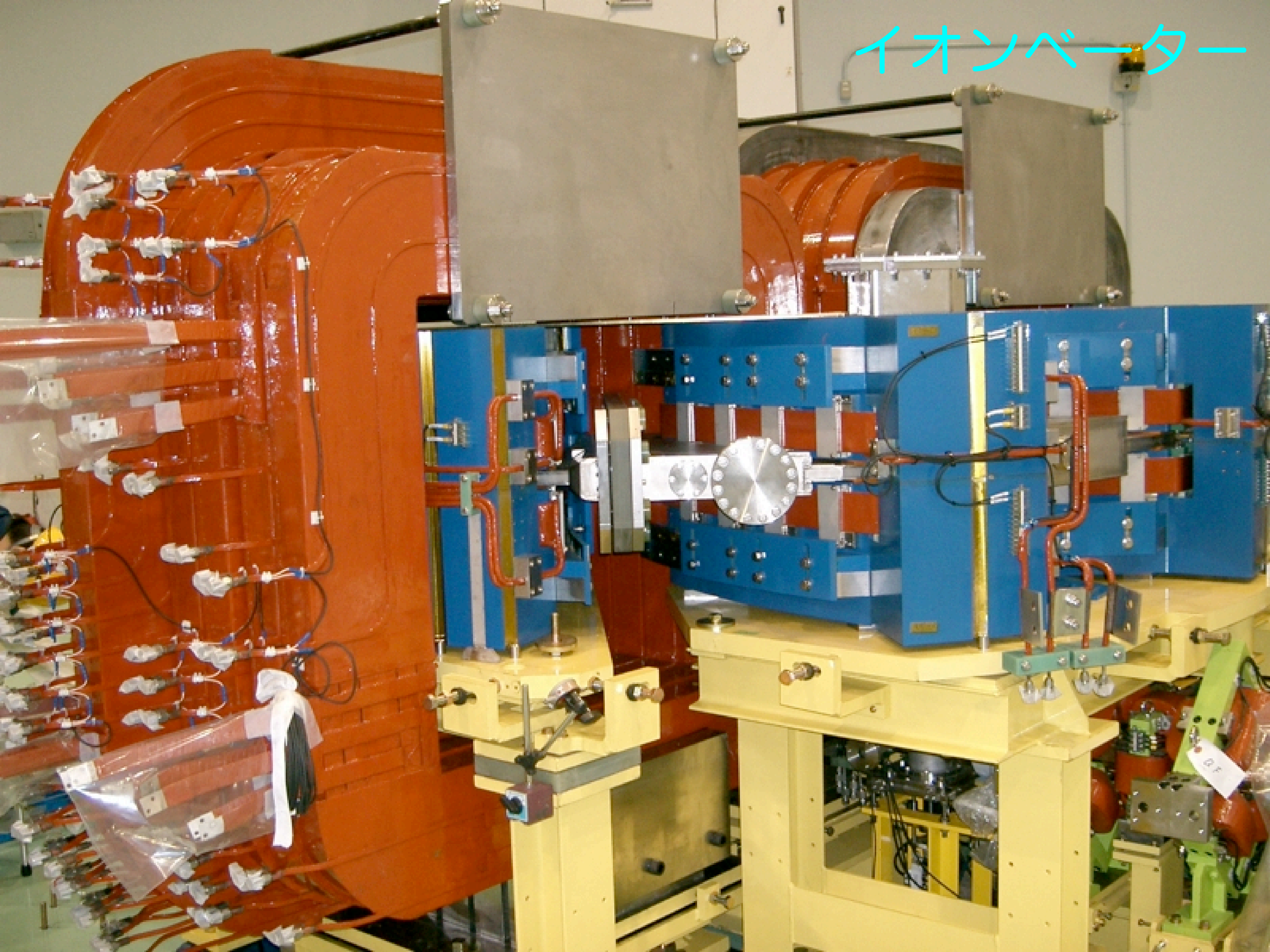
- Features

  Spiral sector   8-fold symmetry

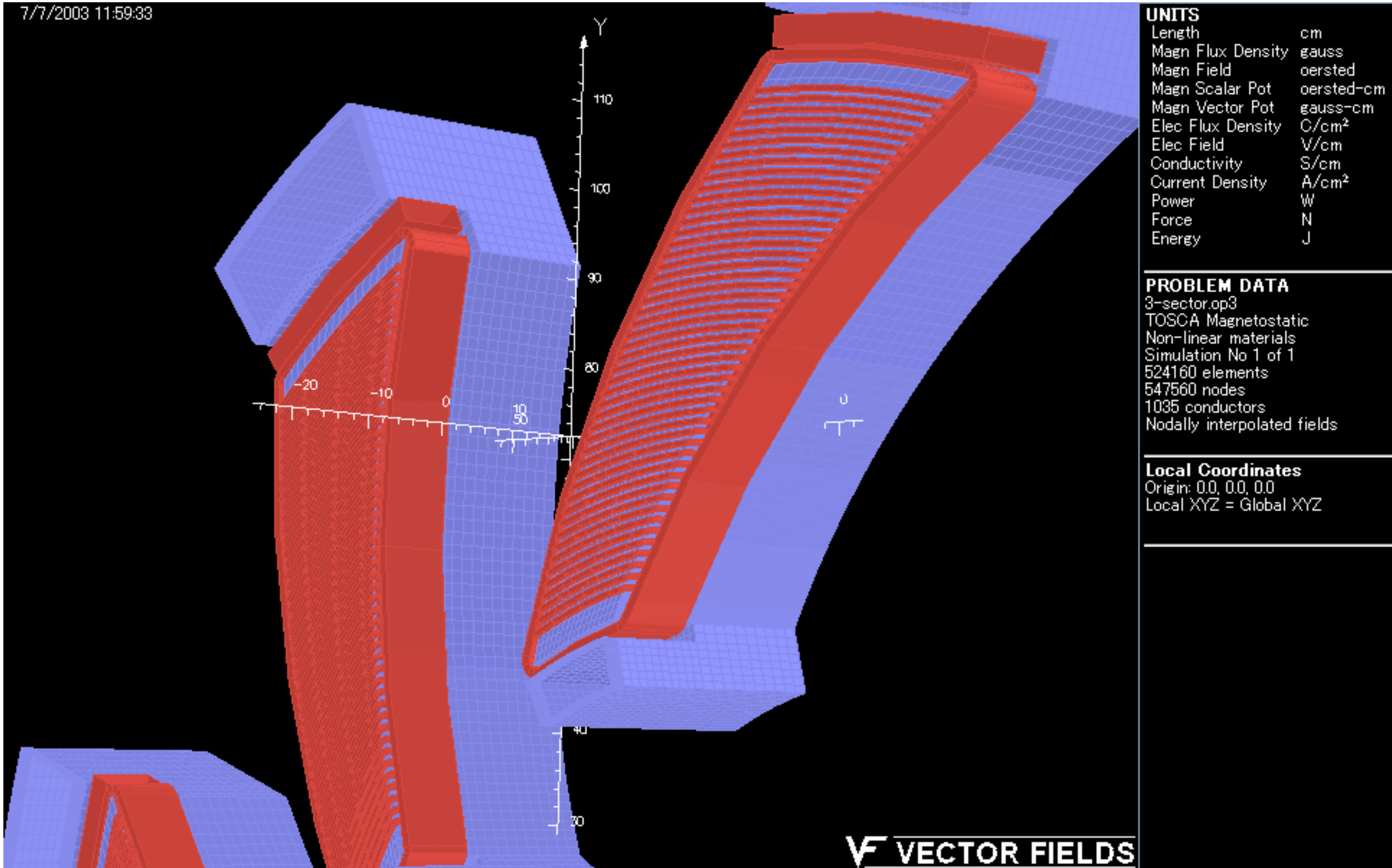
  Field index changeable   k=0 - 2.5

  energy variable   E=0.25 -2.5 MeV

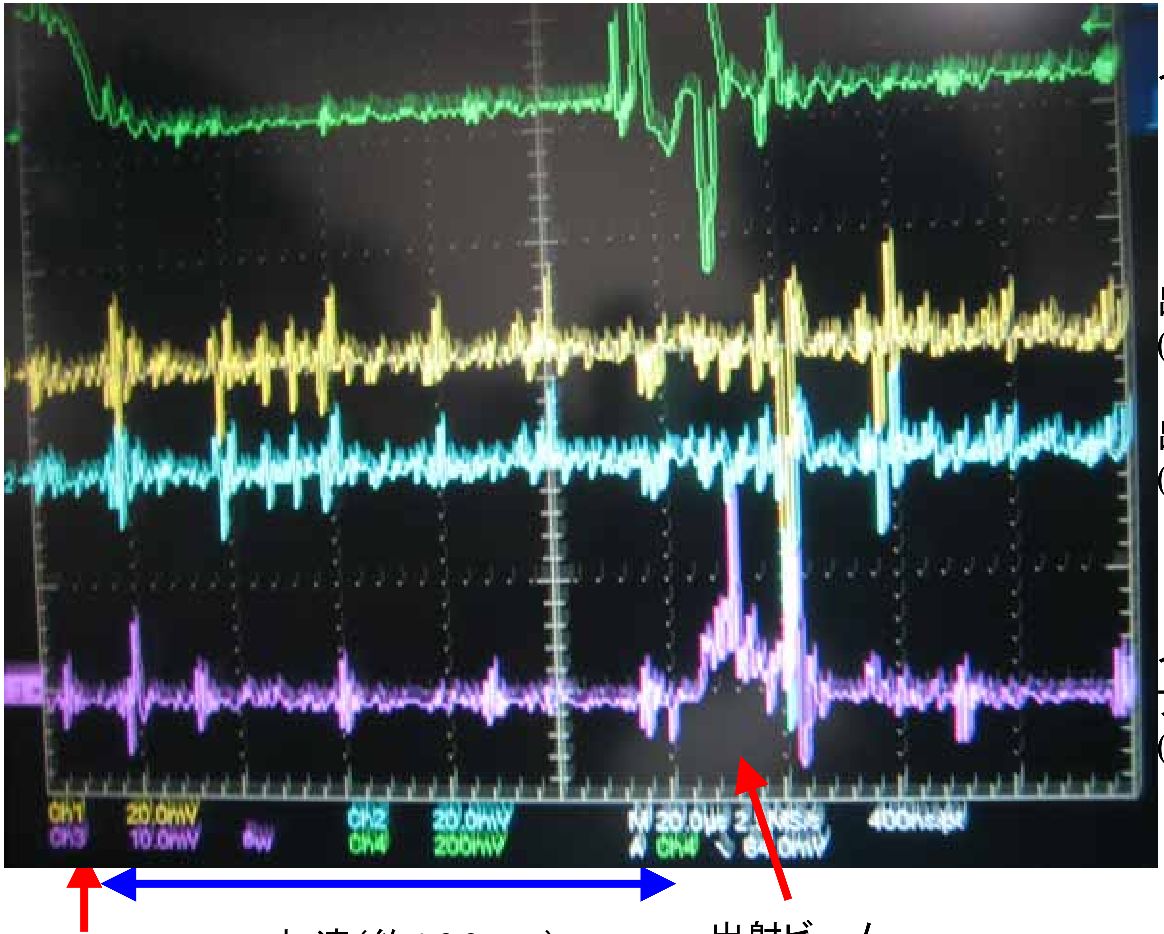
- Commissioning was successfully completed. Jan. 17, 2006.


イオンベーター

スパイラル磁石形状(モデル1:48分割)



FFAGイオンベータからビーム出射に成功

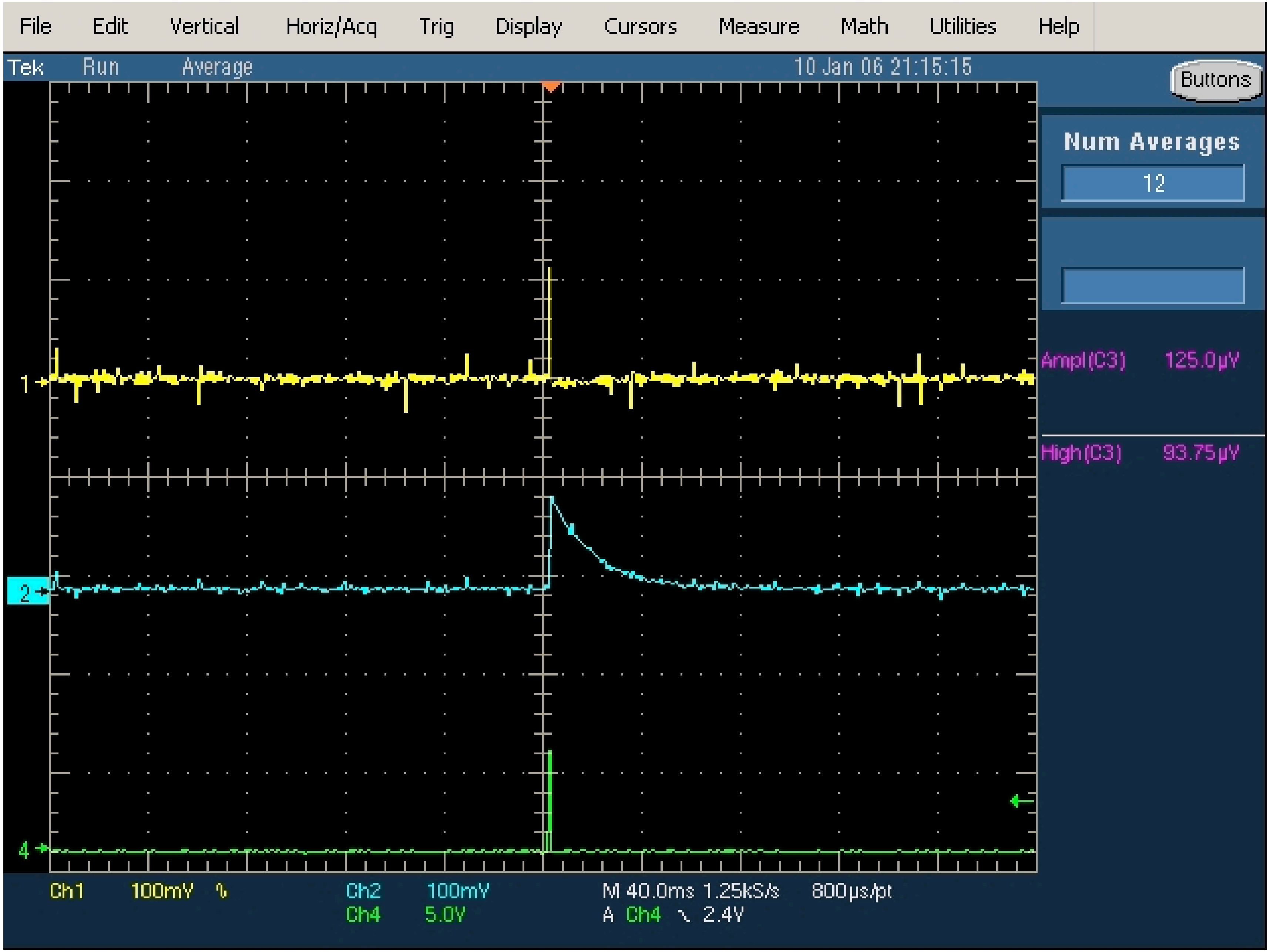


２００５年６月１４日（月）１６時００分

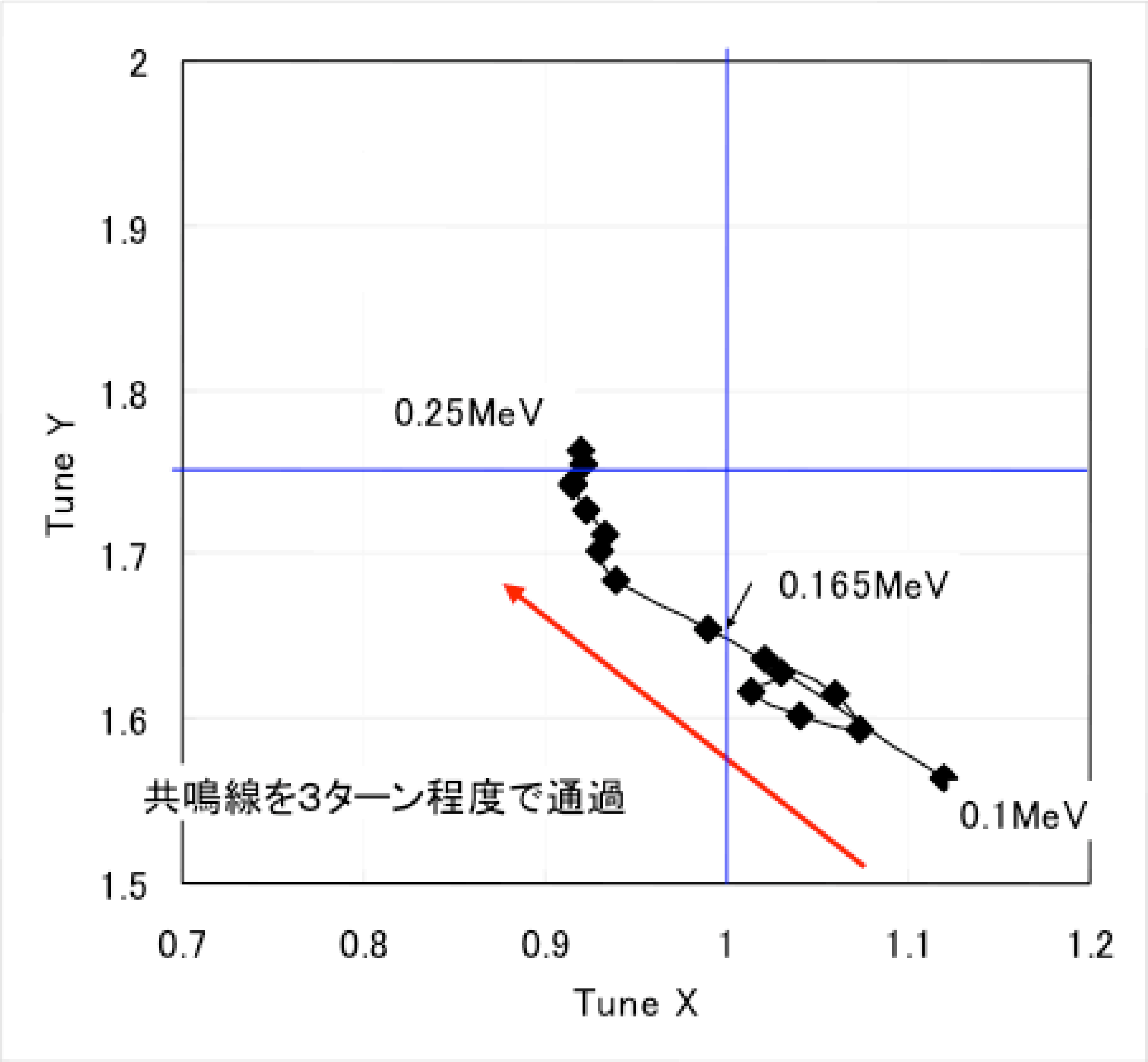
入射エネルギー100keV、加速エネルギー250keV、加速ビーム電流0.25mA、出射ビーム電流0.12mA

加速電圧：入射時(7μｓ）2.6kV、加速時(120μｓ）0.9kV、出射時(7μs)2.6kV

Extracted beam from injector (ion-beta), Jan. 15th, 2006 k=2.3



イオンβ（トリムなし）コミッショニングの軌道解析



三菱電機・先端総研・田中
2005-3-26

①100keV入射で250keV程度までビーム加速可能

②165keVで水平方向線形共鳴を通過する