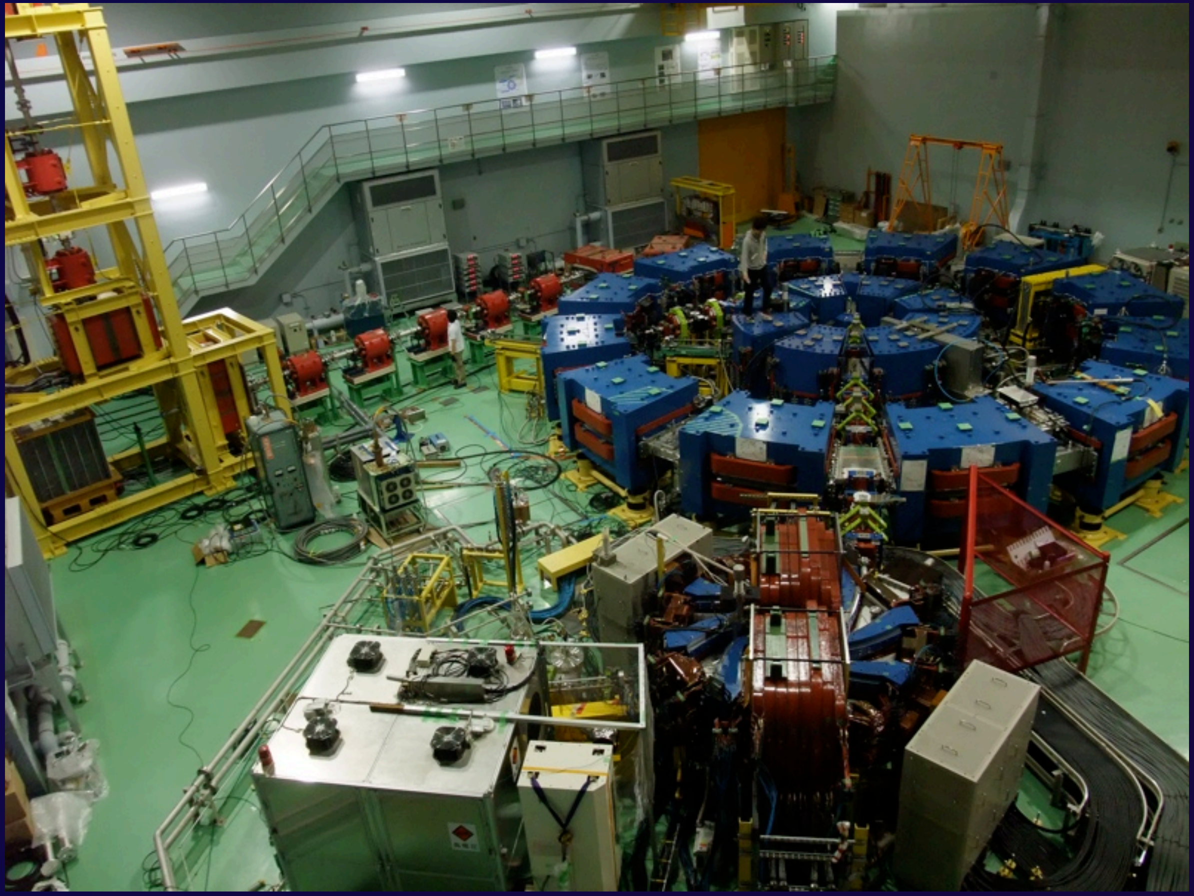
Present status and future of FFAG proton accelerators at KURRI

Y.Ishi (KURRI)



contents

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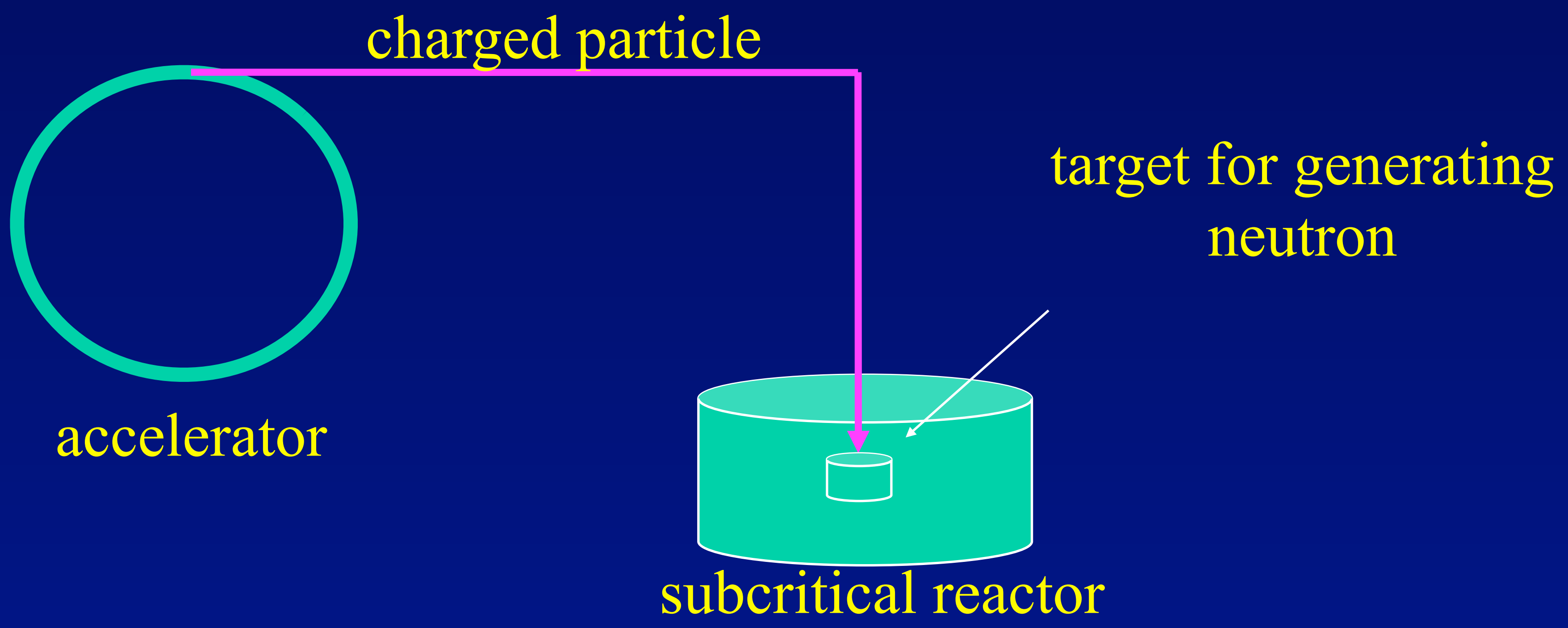
  - Ion-beta
  - Booster
  - Main ring
  - Beam transport systems
- Future plans
  - Intensity upgrade with existing setup
  - Replacement of injector system
  - Beyond 150MeV

What is ADSR?

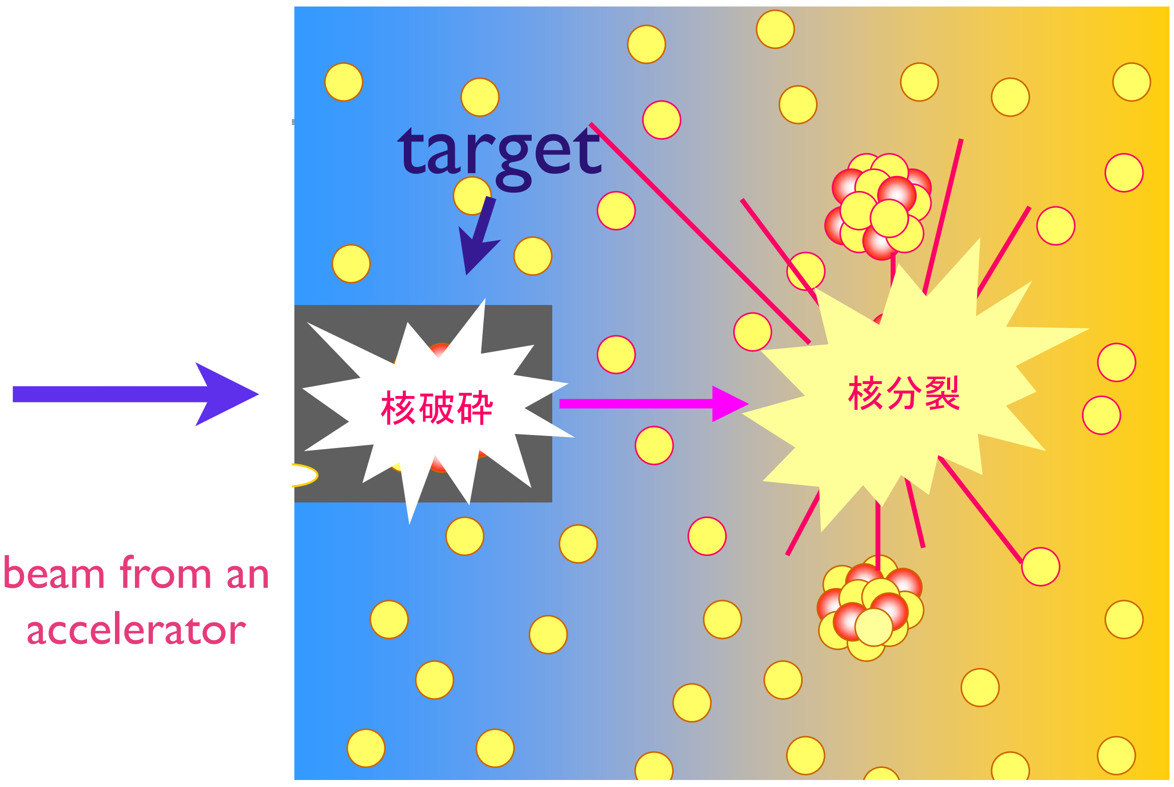
Accelerator Driven Subcritical Reactor

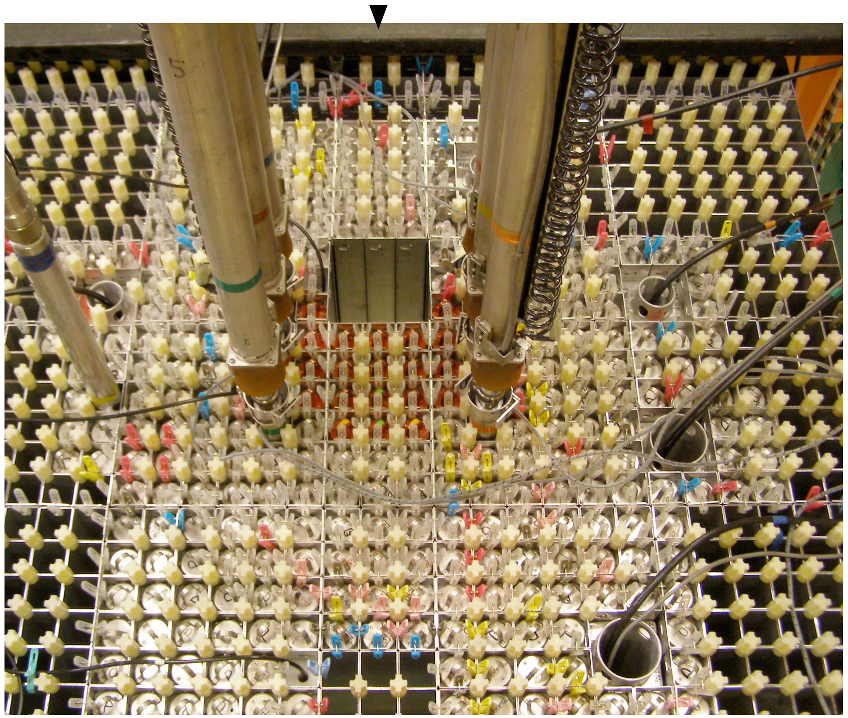


Beam off → chain reaction stops

Safer system !

Principle of ADSR





Feature of ADSR

$$P \sim \frac{S}{1 - k_{eff}}$$

P : ADSR output power

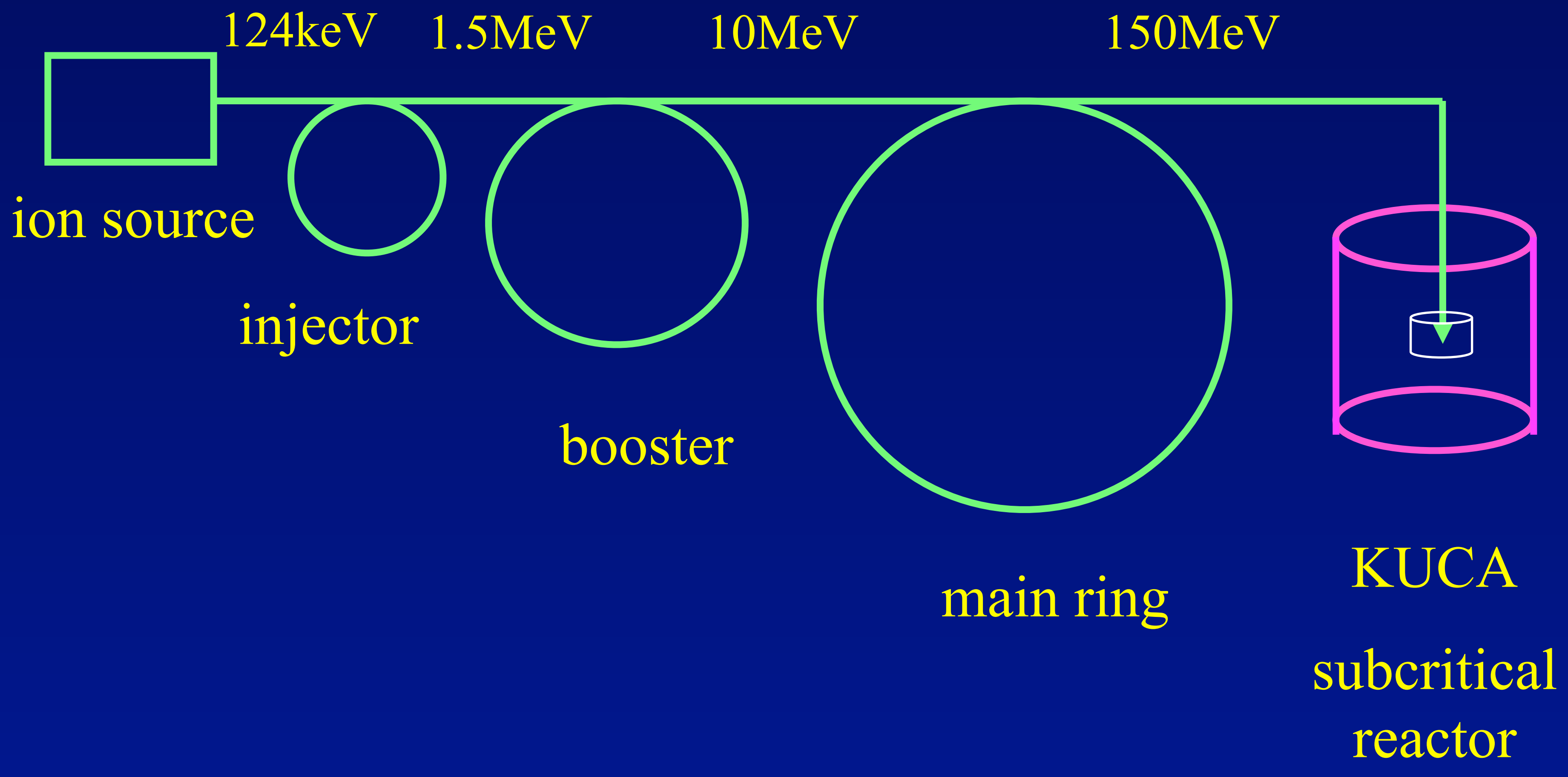
k_{eff} : effective multiplication factor of subcritical fuel system controlled by rods

S : neutron intensity   controlled by energy and/or intensity of the beam from the accelerators dynamically

Best choice for ADSR

	beam current	variable energy	high energy
Synch	× space charge	○	○
Cycl	○	△	△
FFAG	○ high rep.	○ trim coils long. stability	○ large k → compact

FFAG – KUCA ADSR system schematic diagram



ADSR Experiments of FFAG-KURRI

KUCAに構築した未臨界炉心で、炉物理の基礎研究をFFAG加速器からの陽子ビームを用いて実施する。

KUCA : 炉物理の研究炉　出力~10Wで運転

中性子増倍特性 $\alpha = \dfrac{1}{1-k_{eff}}$, $k_{eff} = 0.99$ なら $\alpha = 100$

ビームパワー　＜　0.1W であるべし

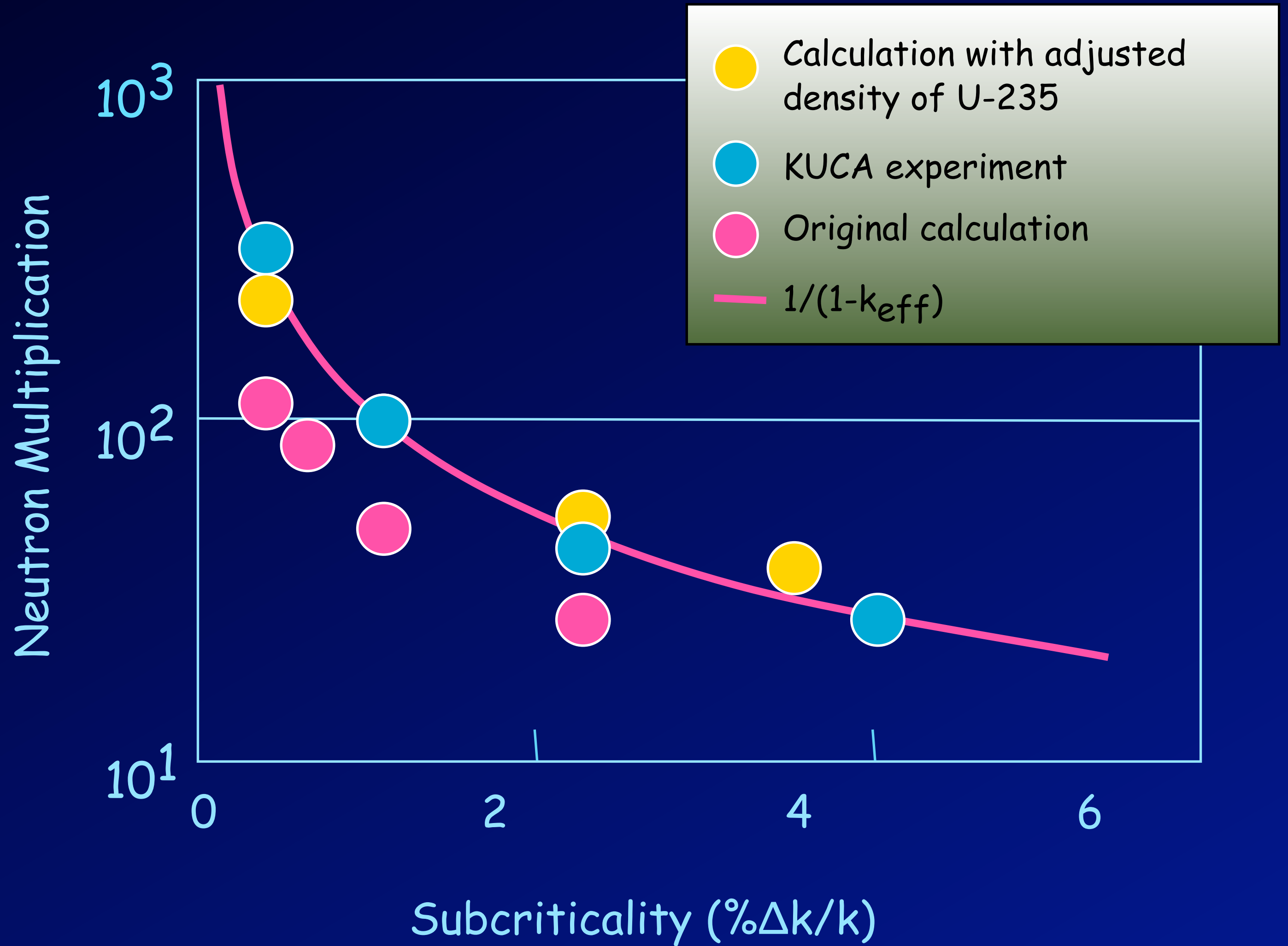
100MeV 陽子ビームだと電流は1nA以下

Basic parameters for ADSR experiments at KURRI

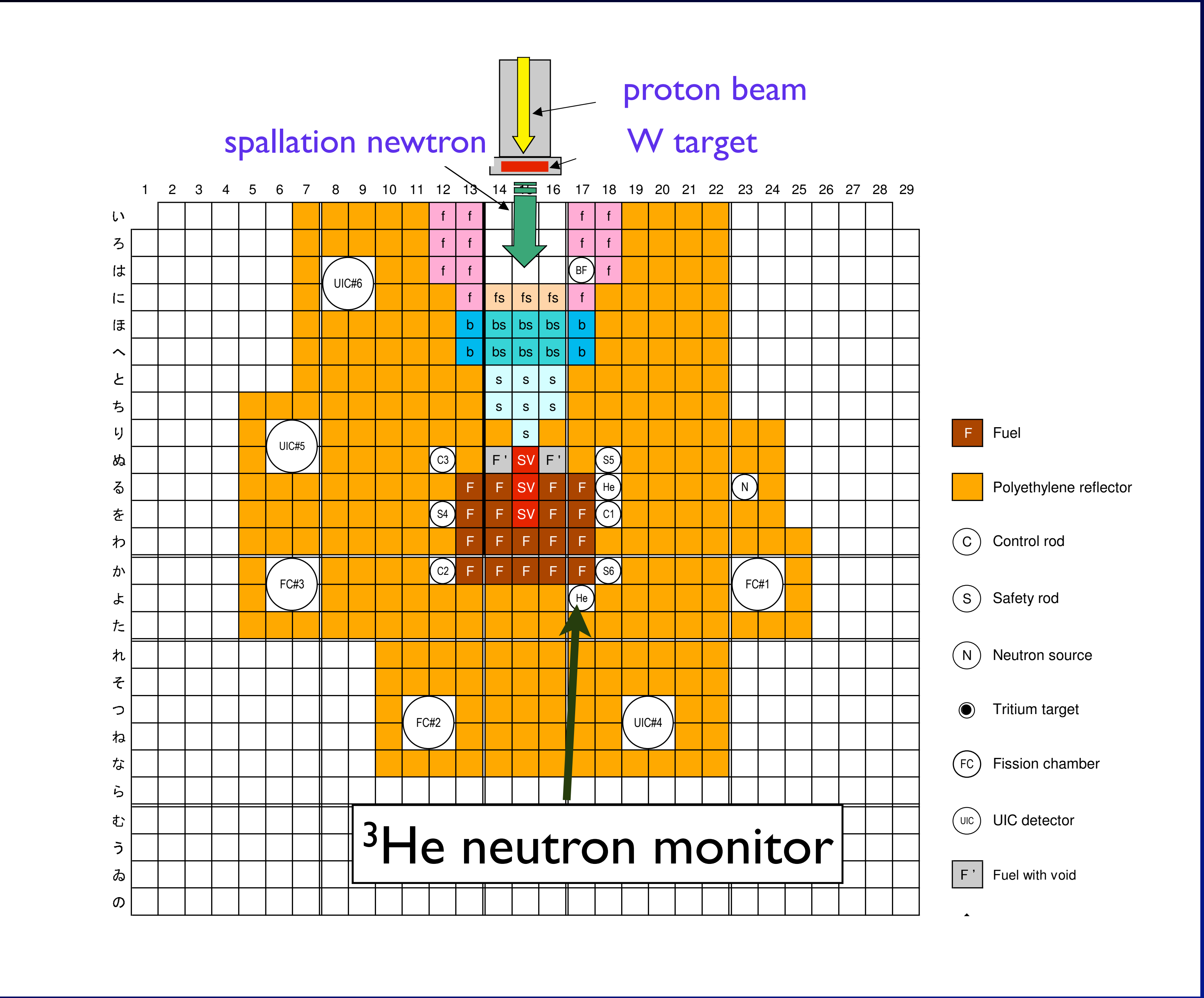
- Reactor output power ~10W
- Neutron multiplication <100(max.)
- Beam power of FFAG <0.1W
- Beam energy of FFAG 100-150MeV
- Beam current of FFAG <1nA

ADSR study with FFAG

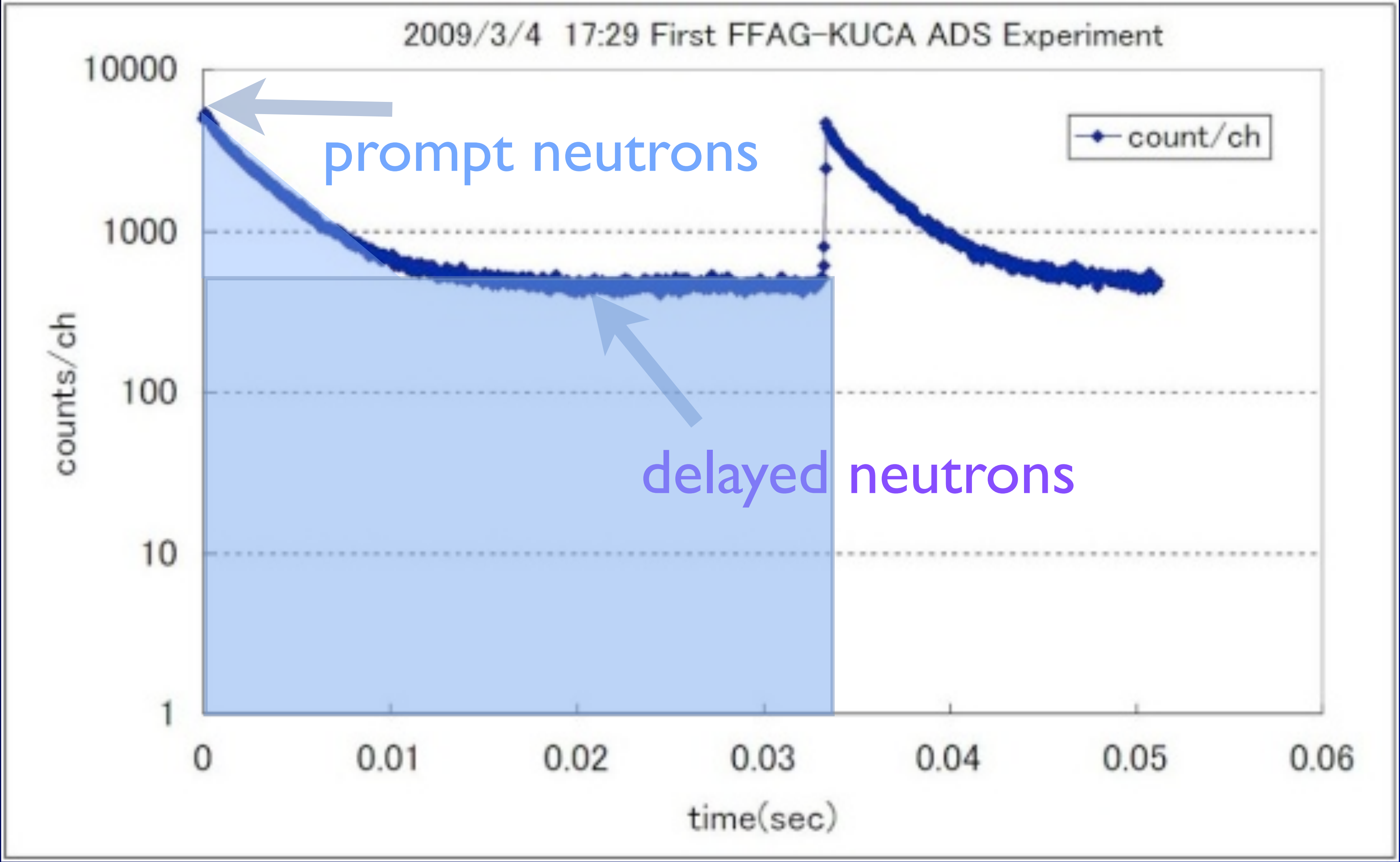
- Neutron multiplication for sub-criticality
- Effective critical factor for spectrum index (neutron portion of less than 1eV)



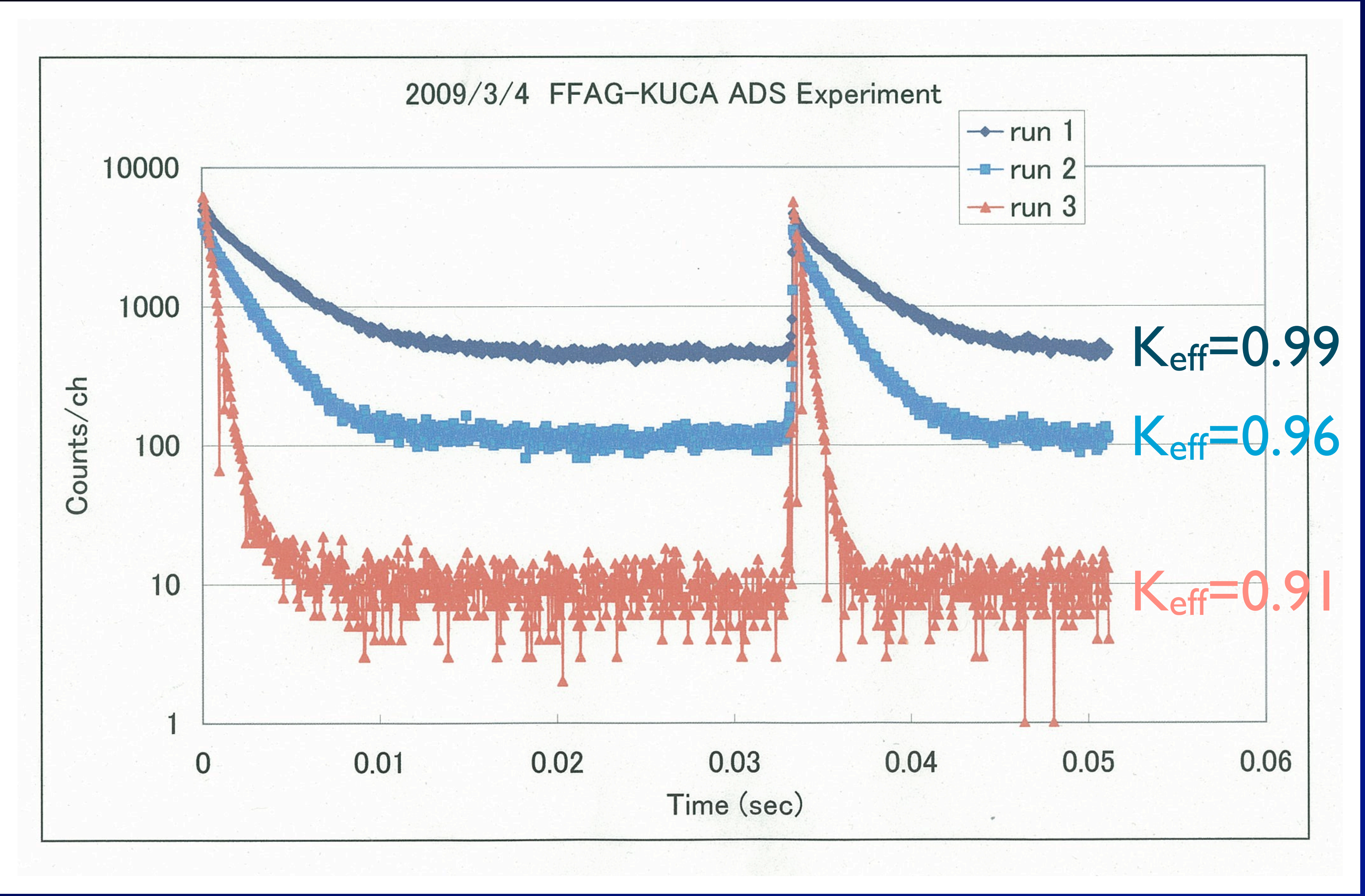
Reactor core in KUCA



First data of ADSR



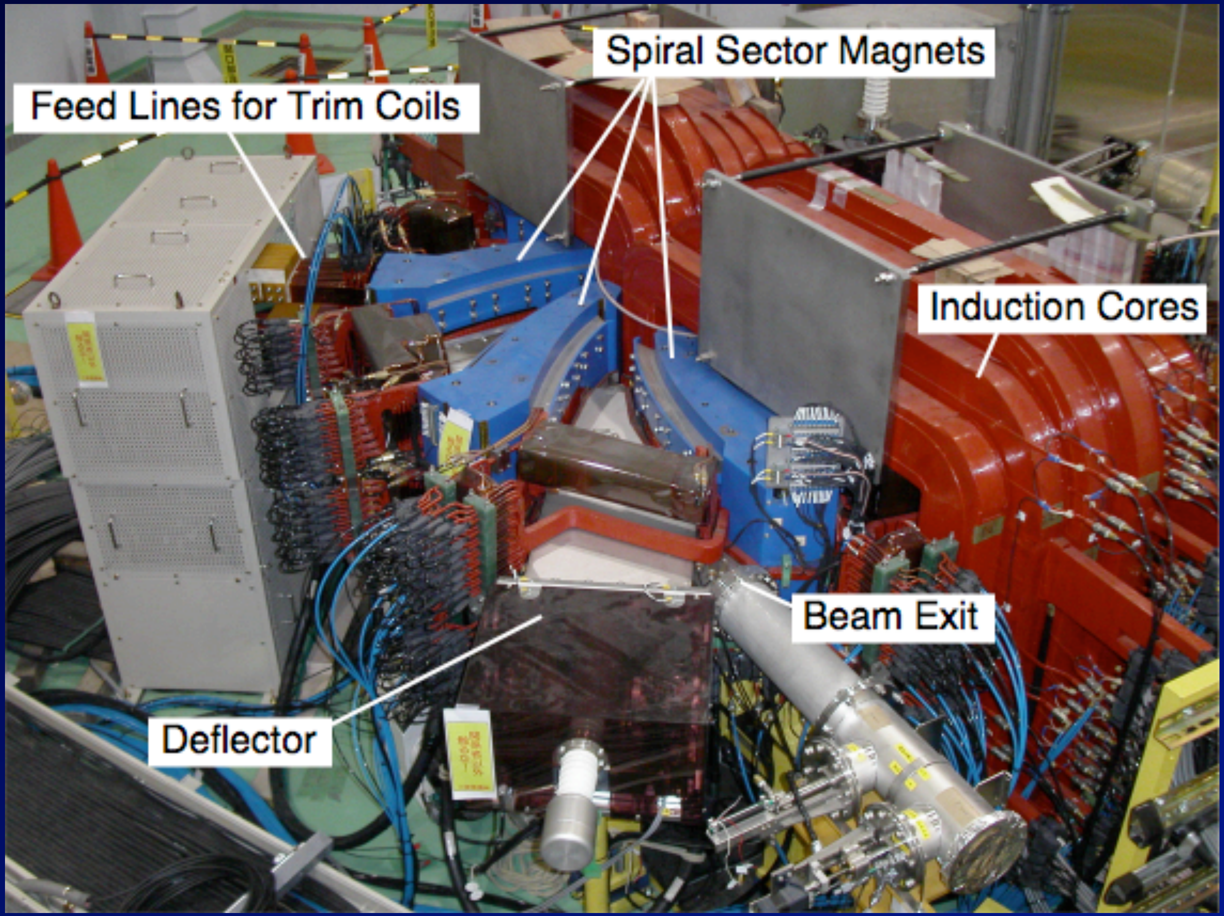
Neutron production vs time varying k_{eff}



Ion beta

World's first trials in proton FFAG:

- •Spiral secter magnet
- •Induction acceleration
- •Variable energy by using multi-pole fase winding coils

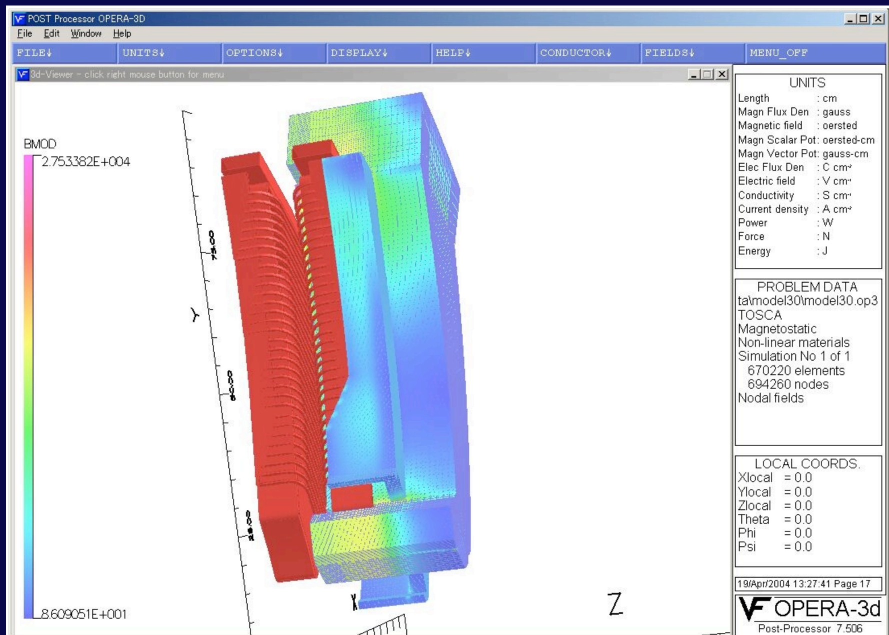


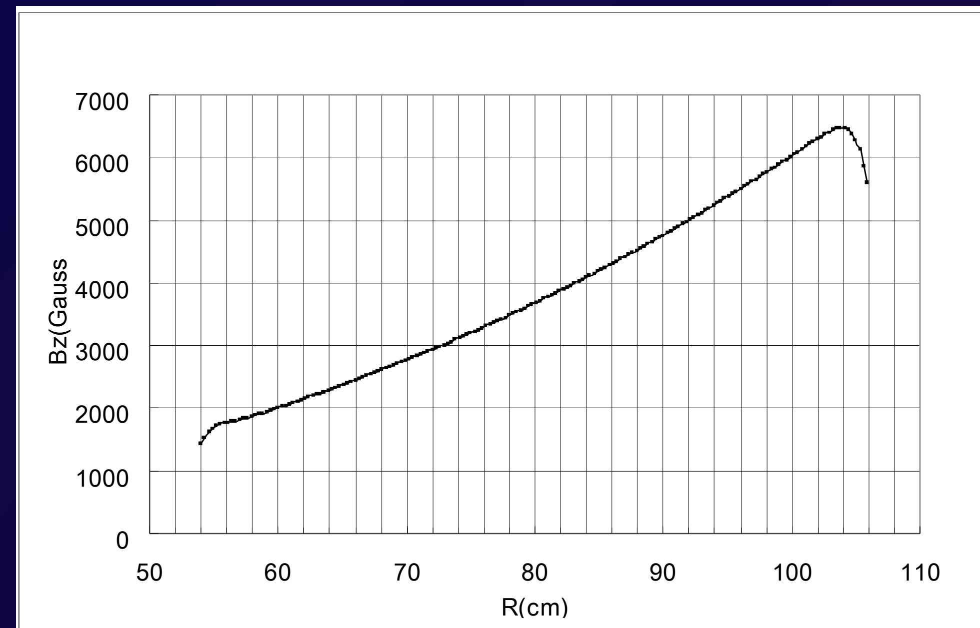
Independent 32 trim coils

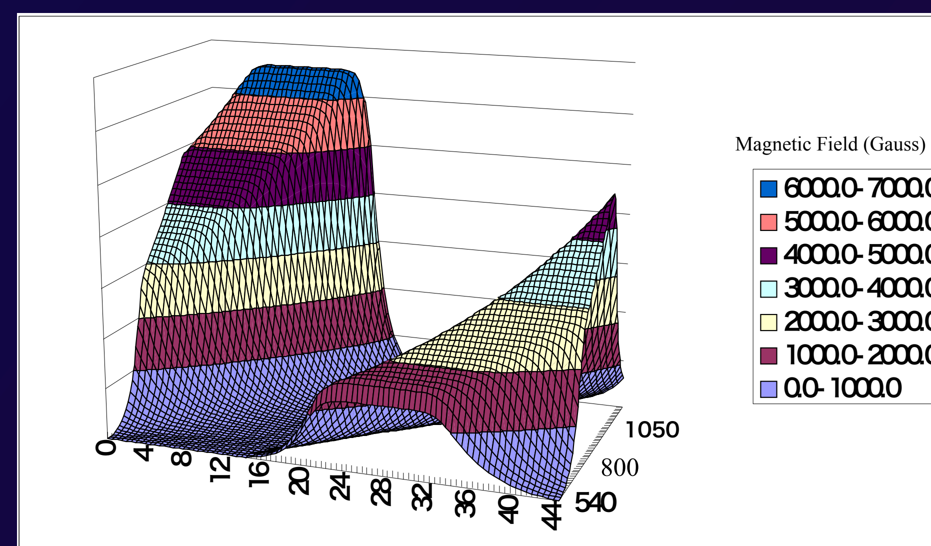
Specifications of Ion-Beta

item	design value
energu	2.5MeV
average current	20nA
rep. rate	120Hz
k	0-2
spiral angle	42°
# of cells	8
operating point	(1.85, 0.80)
inj. / ext. schemes	continuous inj./ext. during acceleration with inflector/deflector electrode
average radius	0.69 - 0.99 m

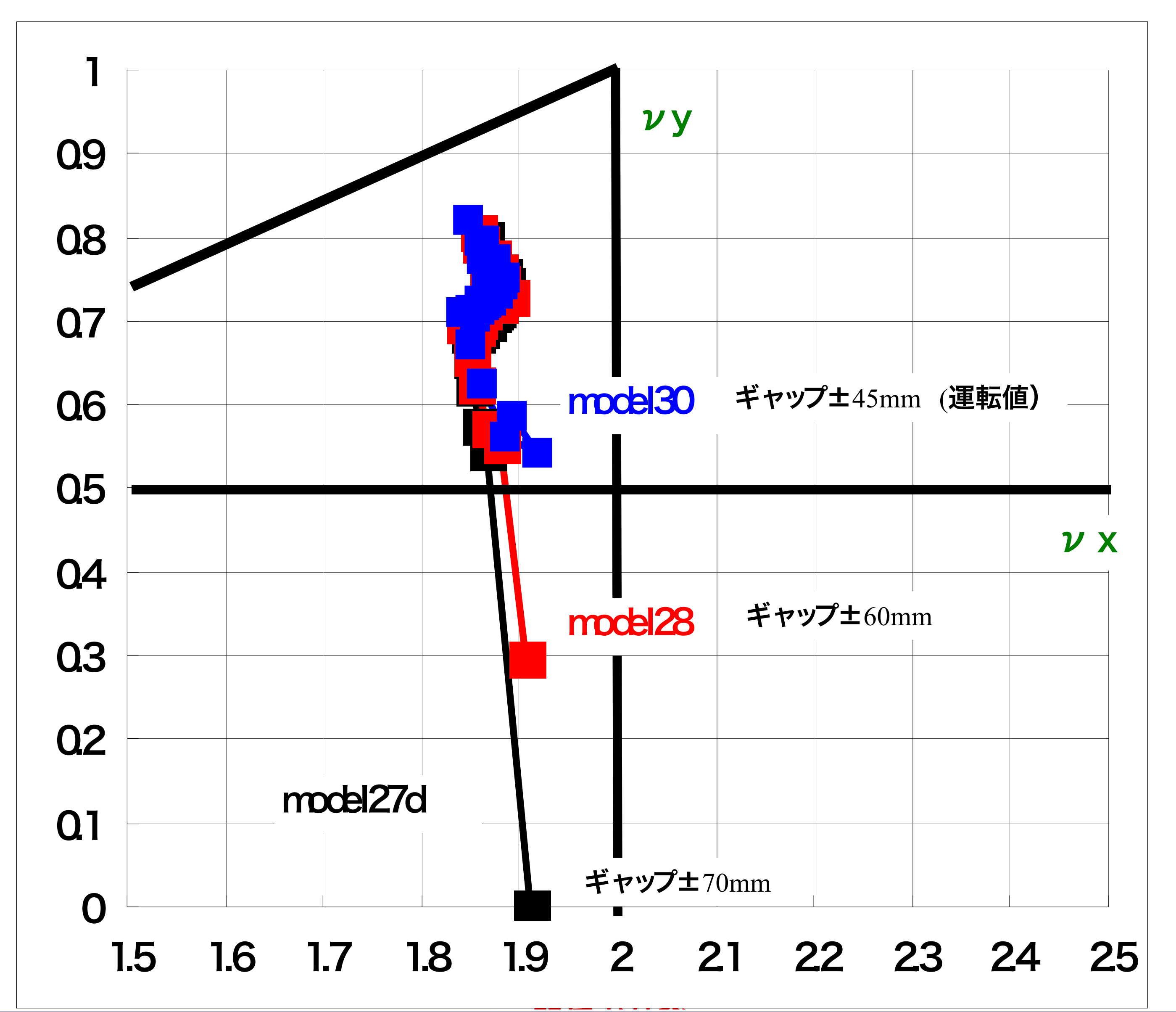
B Field by using multi coils





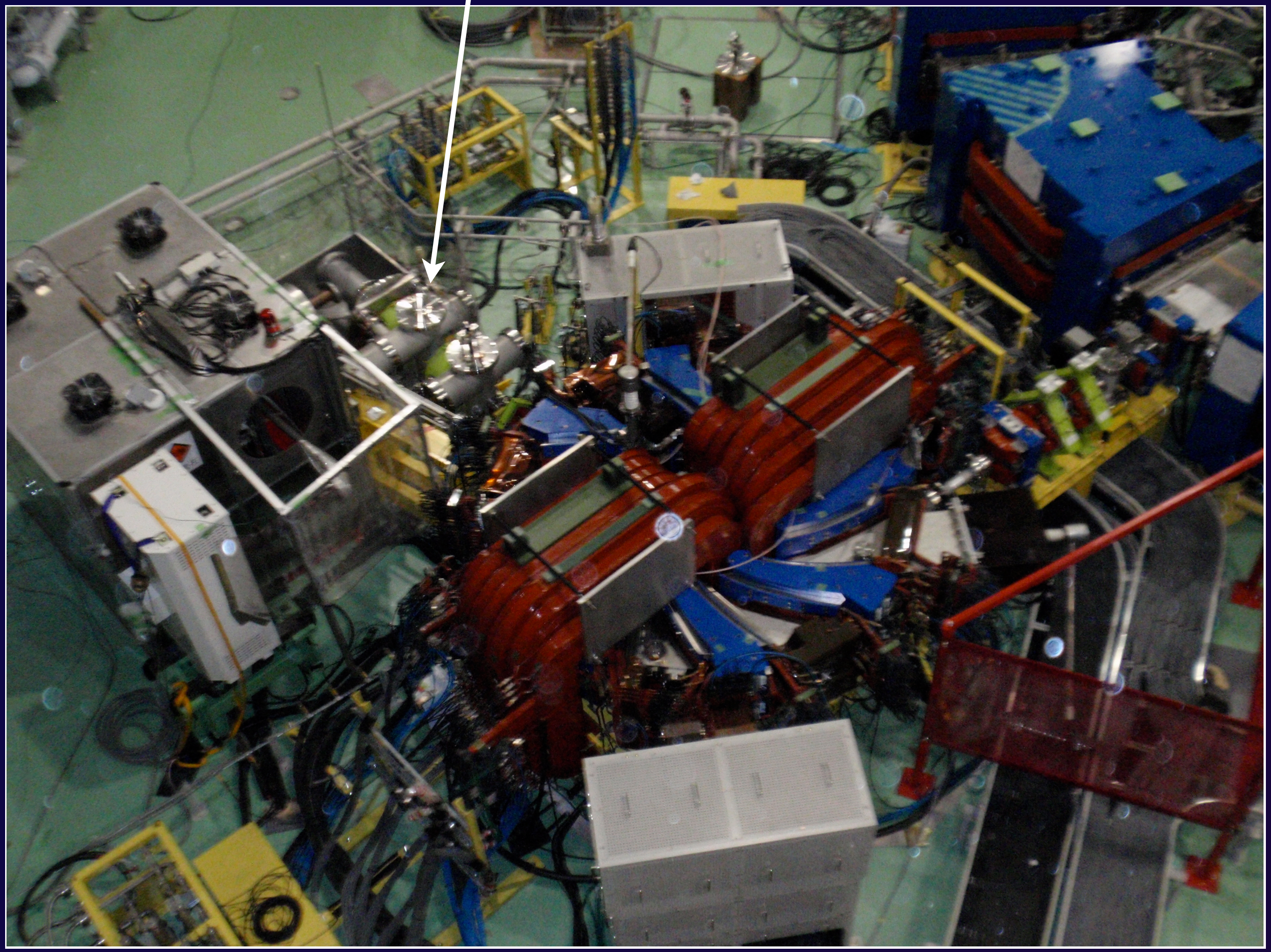


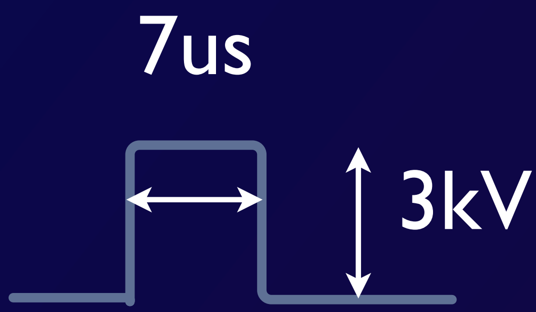
Operating points in Ion-beta



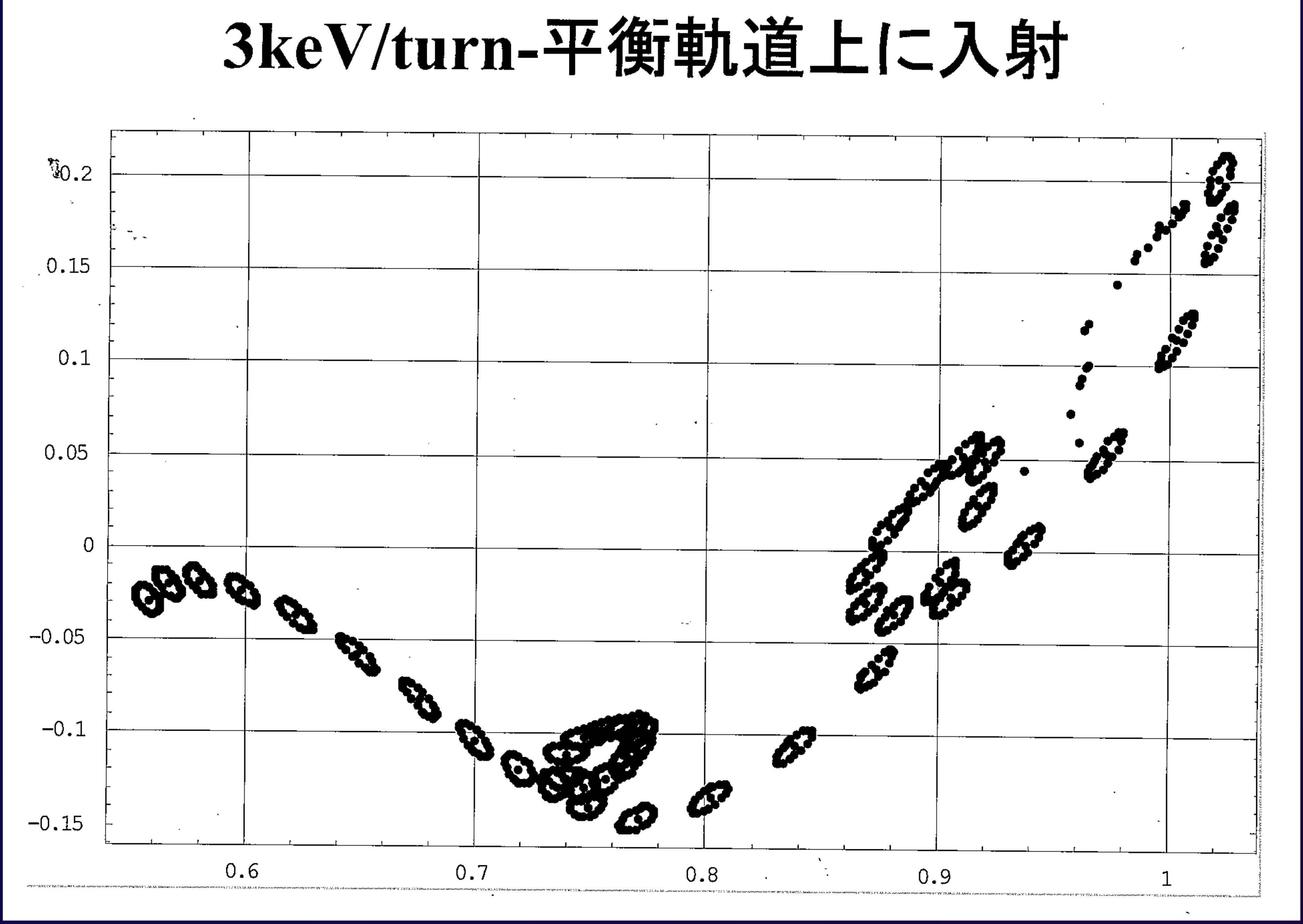
Injection beam shaping by using chopper

chopper electrode ： horizontal kick

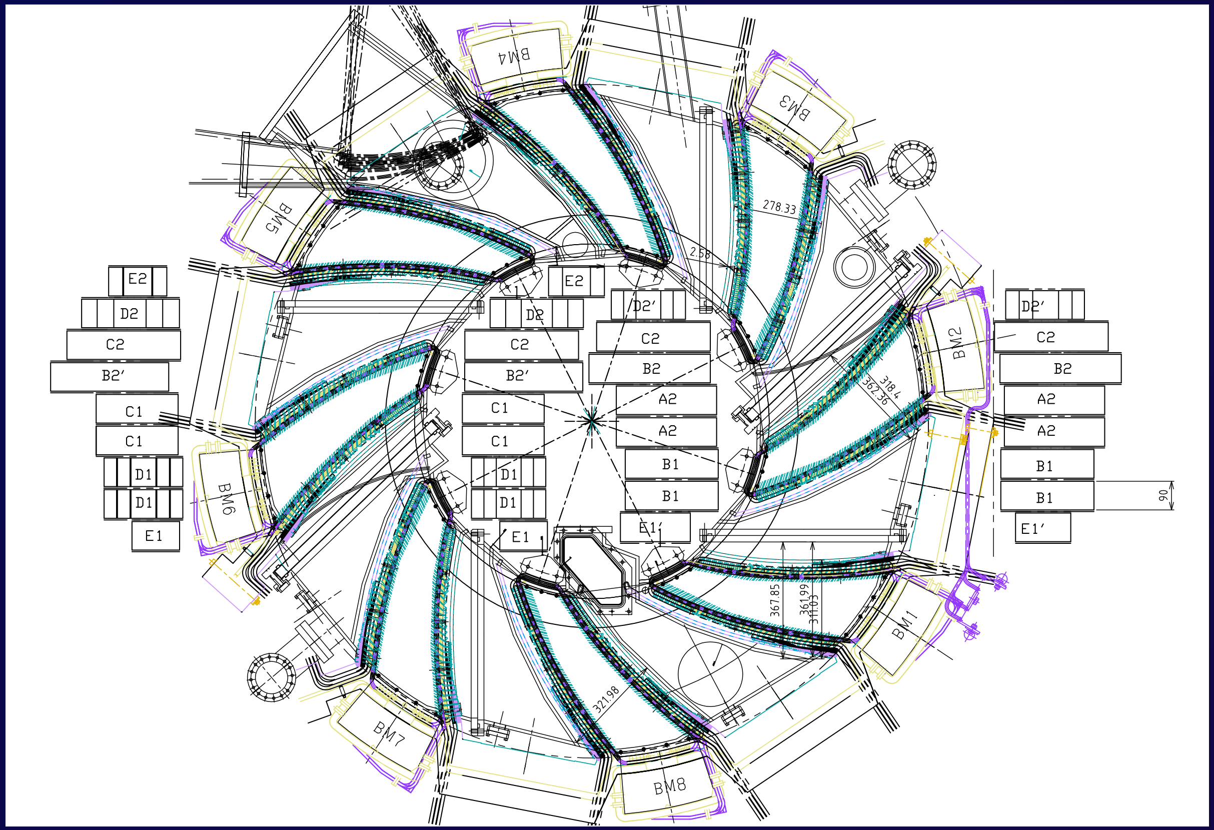




Phase space structure at injection

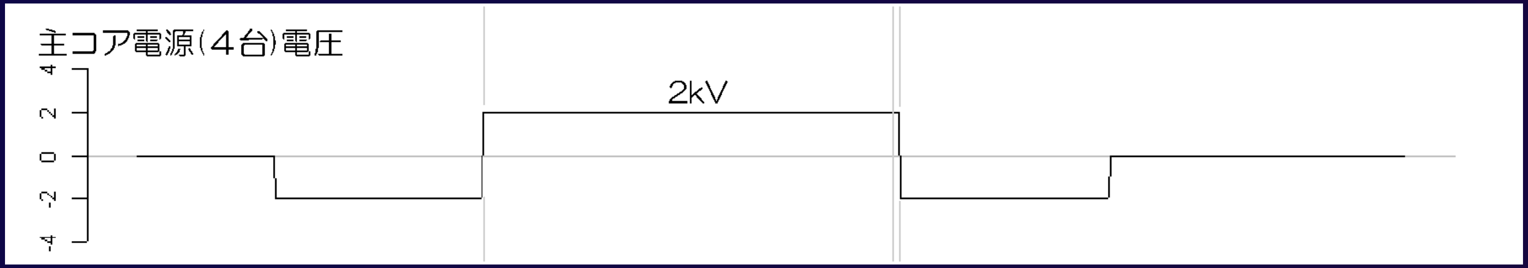


Induction accereration



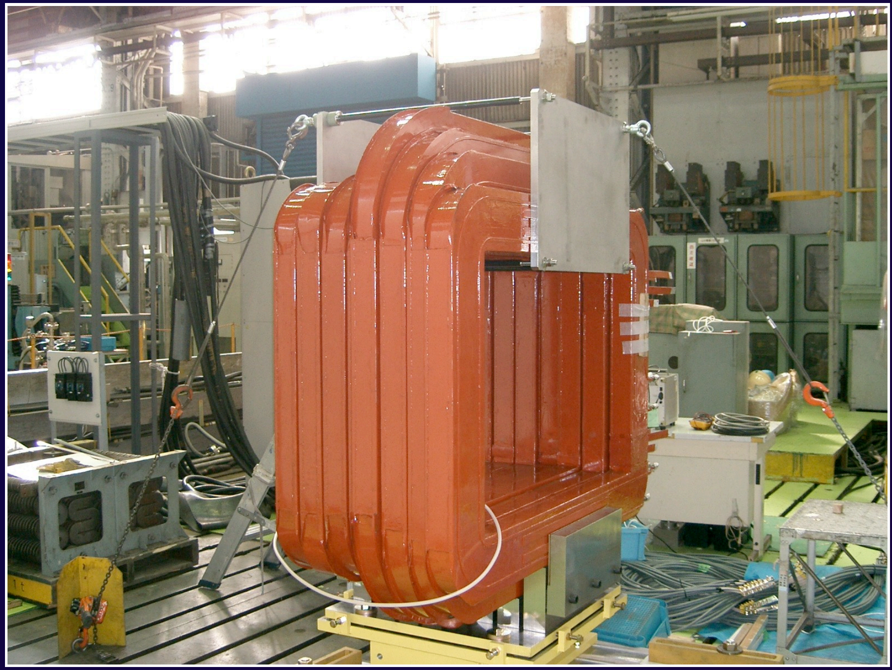
betatron core

Silicon coated iron steel thickness 0.23mm/0.05mm

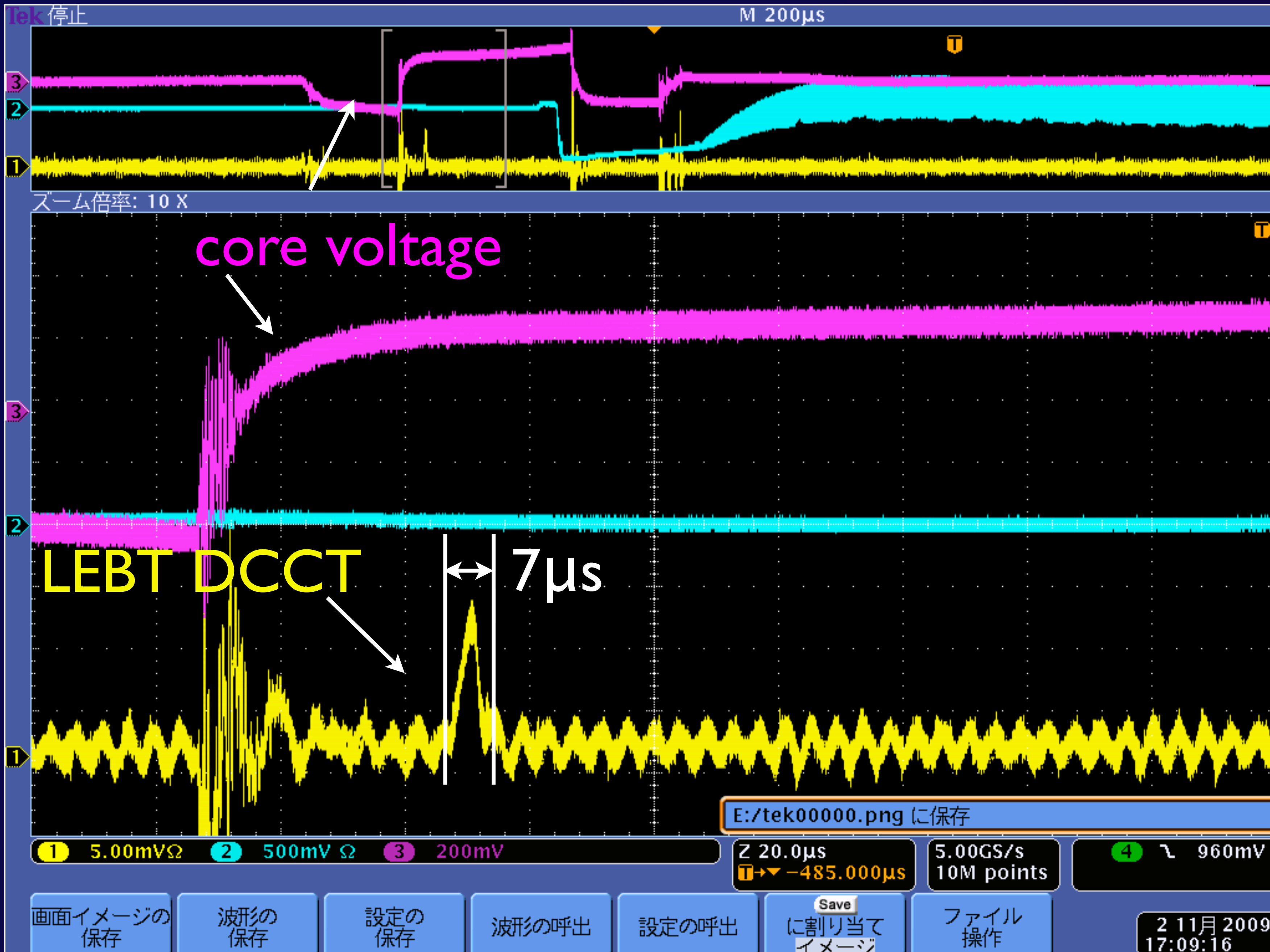


excitation pulse form

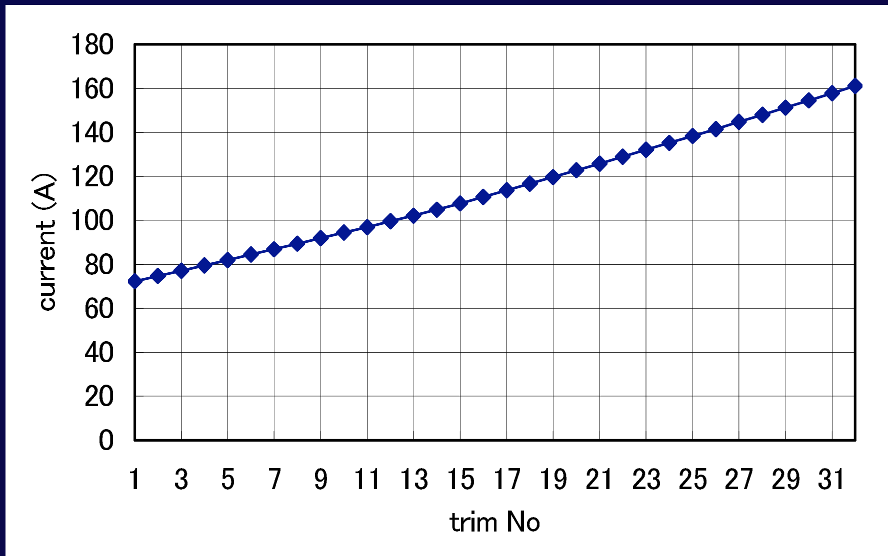
Production of betatron cores

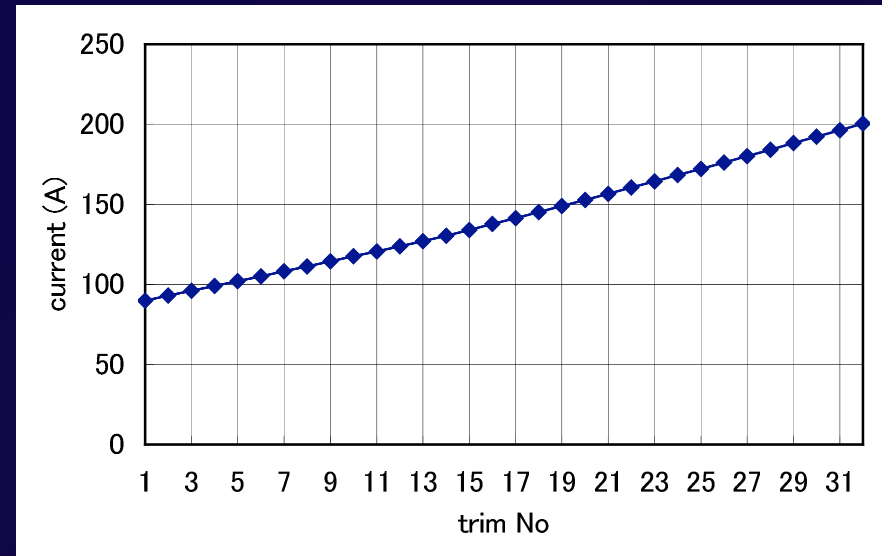


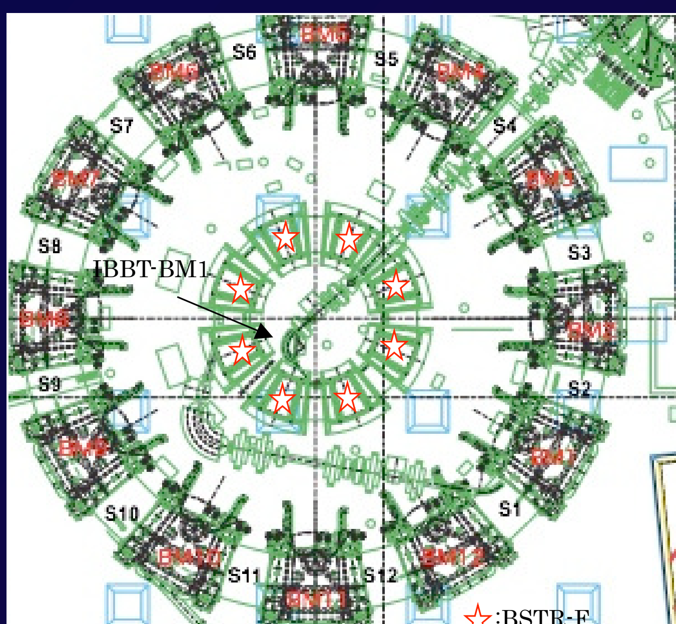
Injection beam signal and core voltage



Capability of varialbe energy







	パターン I	パターン II	ビーム運動量の比 (II/I)	ビームエネルギーの比 (II/I)
IBBT-BM1 (A)	380.9	438.9	1.152	1.302
BSTR-F (A)	112.9	128.8	1.141	1.279
周回周波数 (kHz)	1725.1	1962.0	1.142	1.282

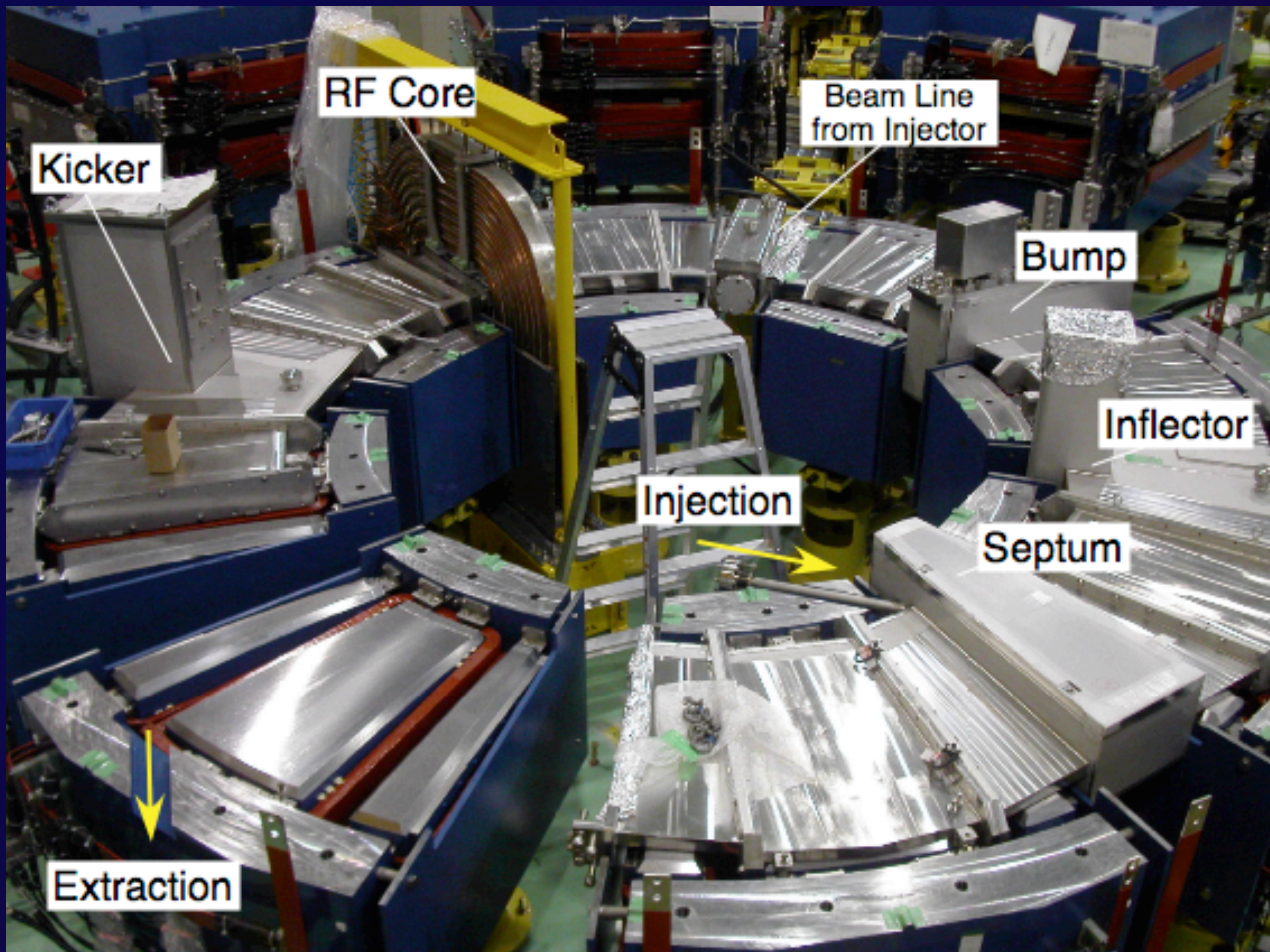
30% of energy variation
has been tested with different
pattern of trim coil excitation

Optimum parameters

injection energy	124.4KeV
extraction energy	2.5(1.5)MeV
injection efficiency	30%
acceleation efficiency	80%
extraction efficiency	90%
average current	20(7)nA
rep. rate	120(30)Hz

( ) parameter used in ordinary operation

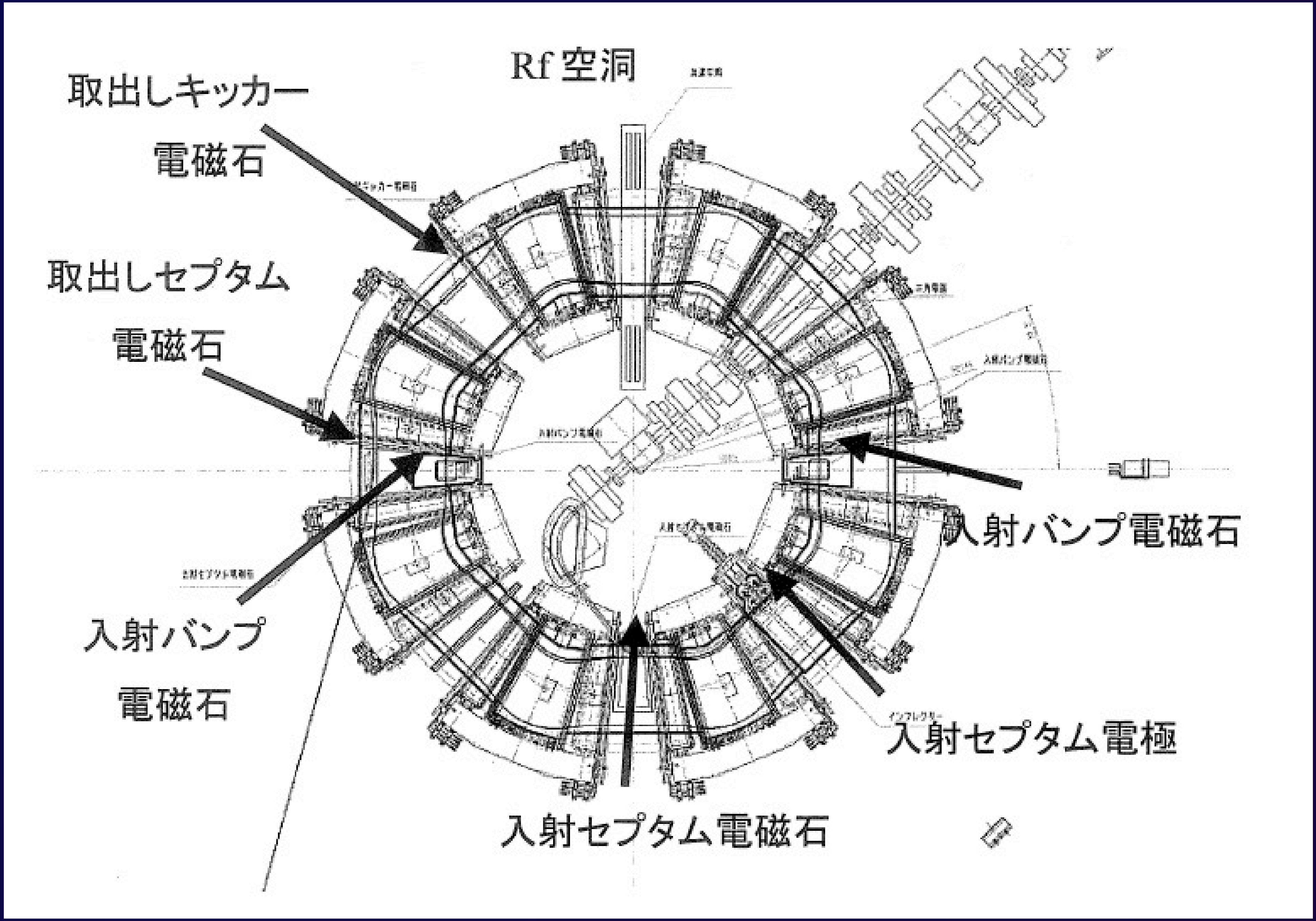
Booster


RF Core
Beam Line
from Injector
Kicker
Bump
Inflector
Injection
Septum
Extraction

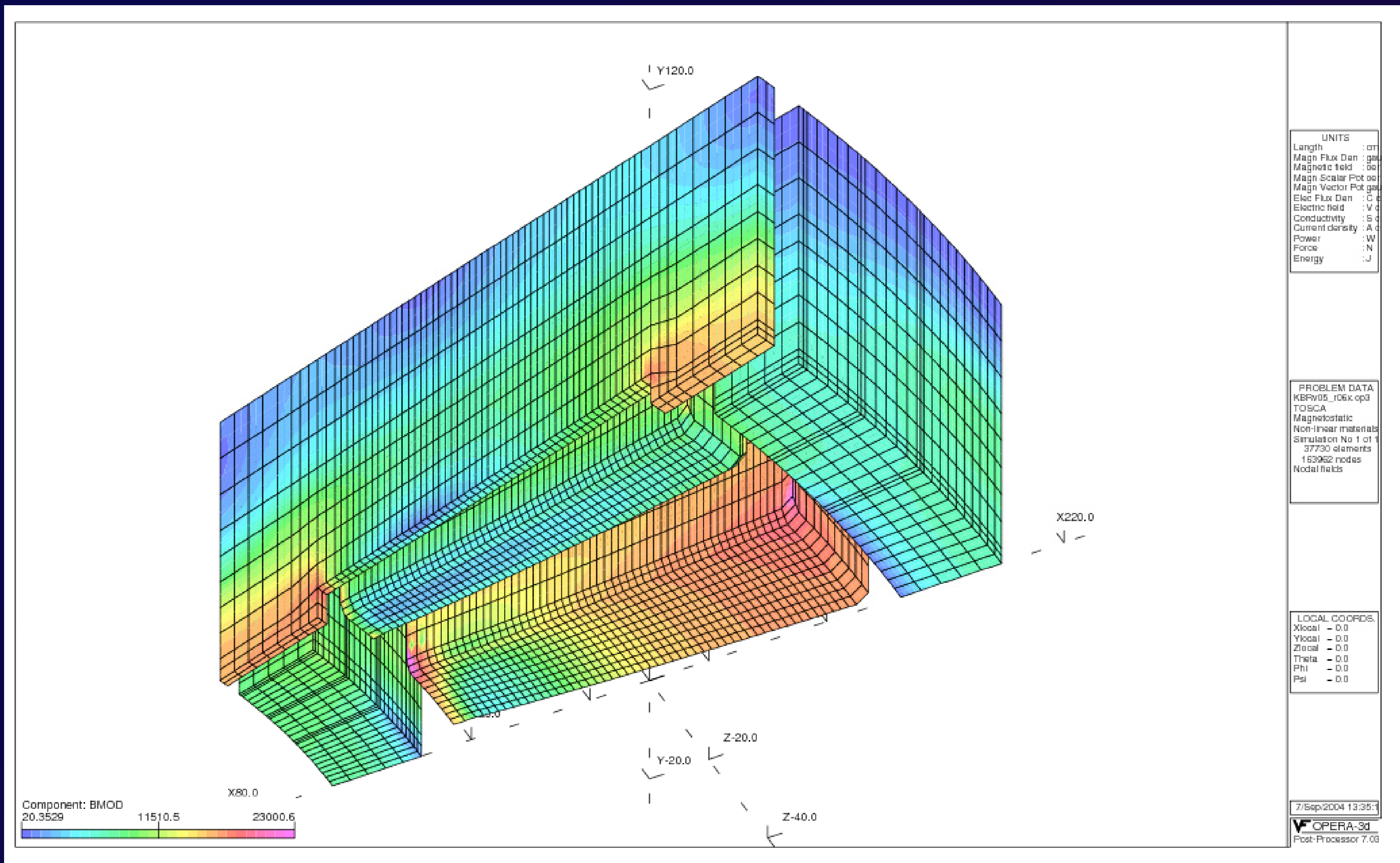
Specifications of Booster

item	design value
energy	20MeV
average current	1.5nA
rep. rate	120Hz
k	2.5
# of cells	8
operating point	(2.15, 1.38)
inj. scheme	multi-turn inj. （14 turns）
ext. scheme	fast extraction
average radius	1.42 - 1.71 m

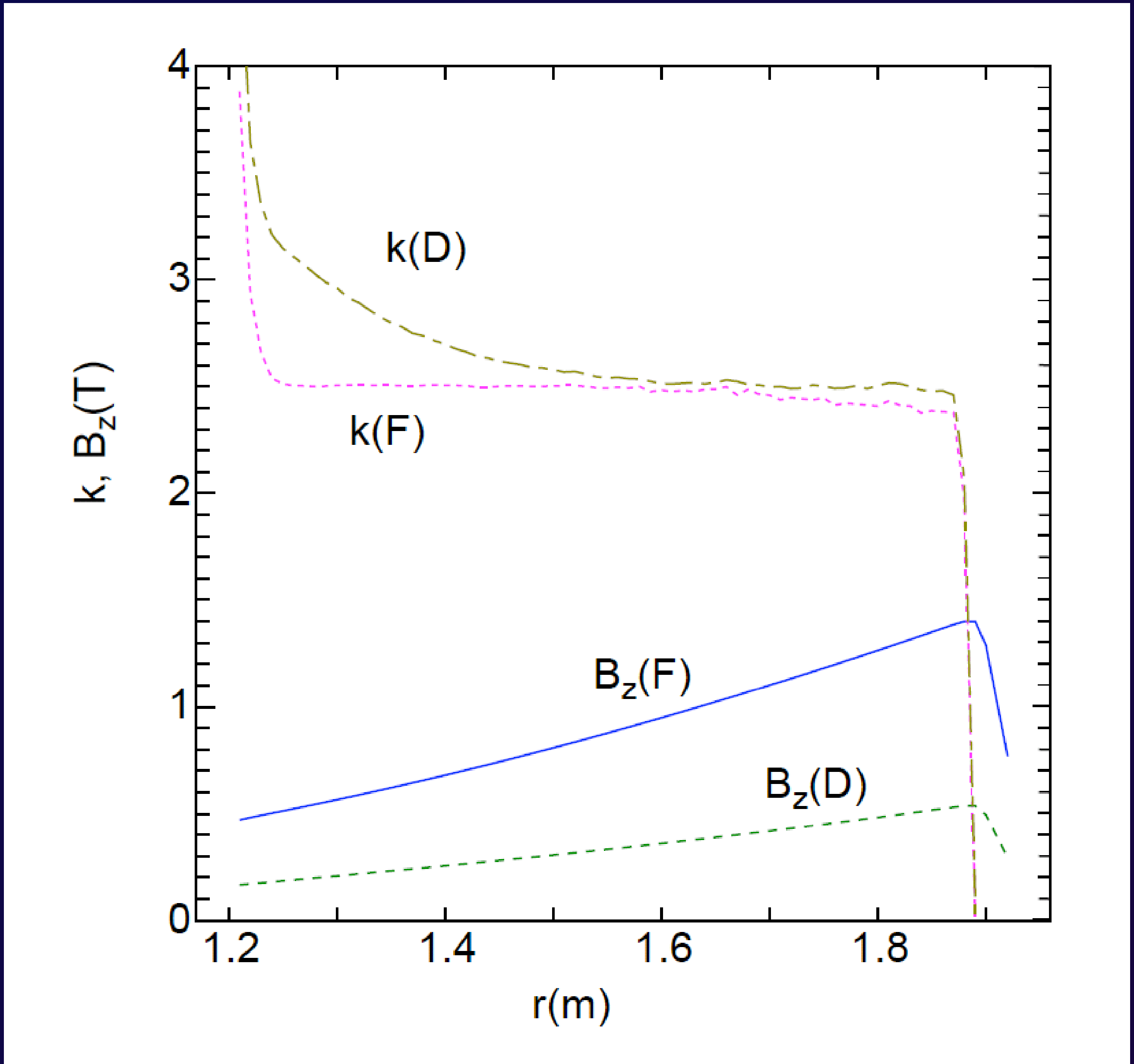
Layout of components of Booster



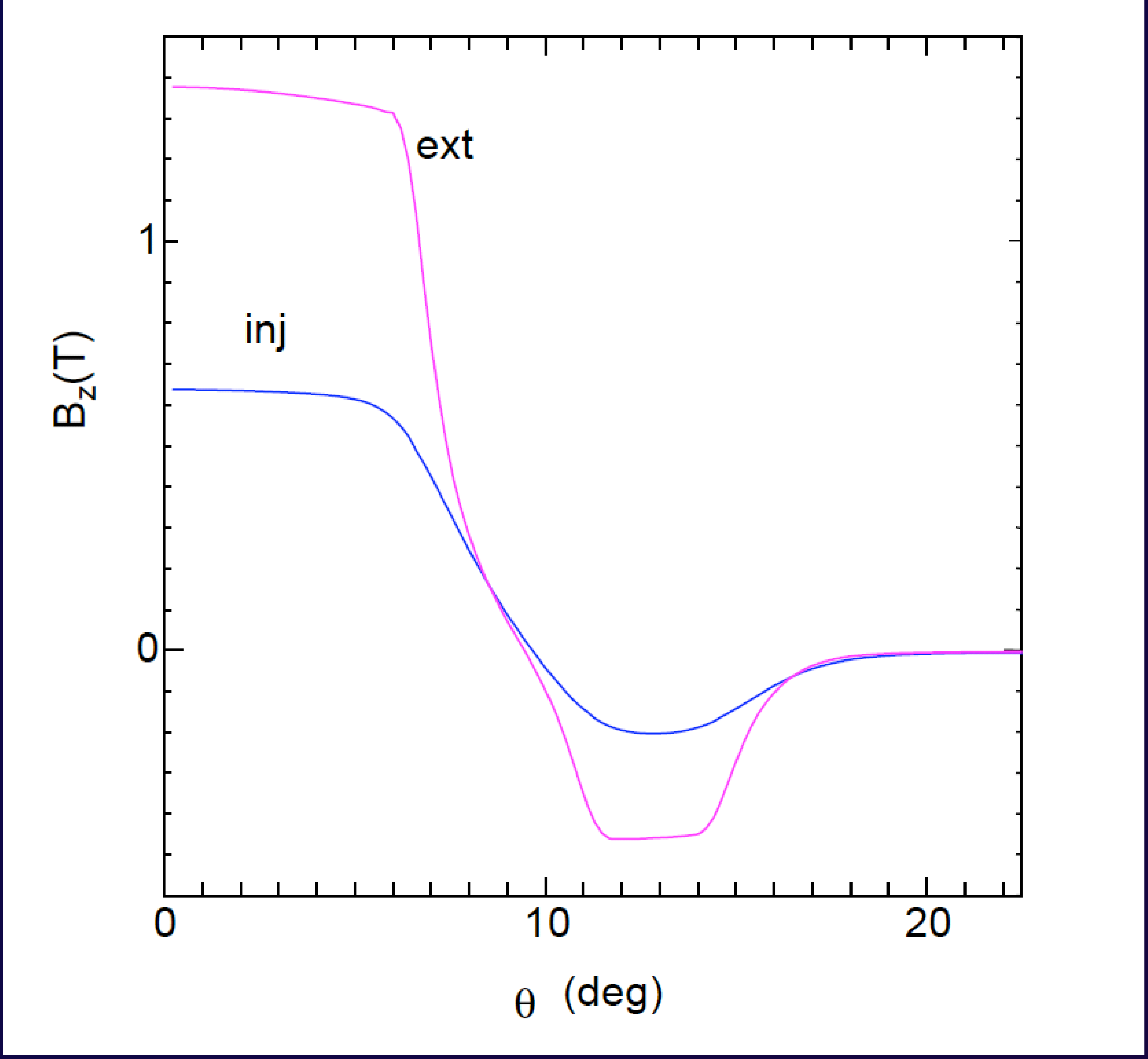
Main magnet of Booster



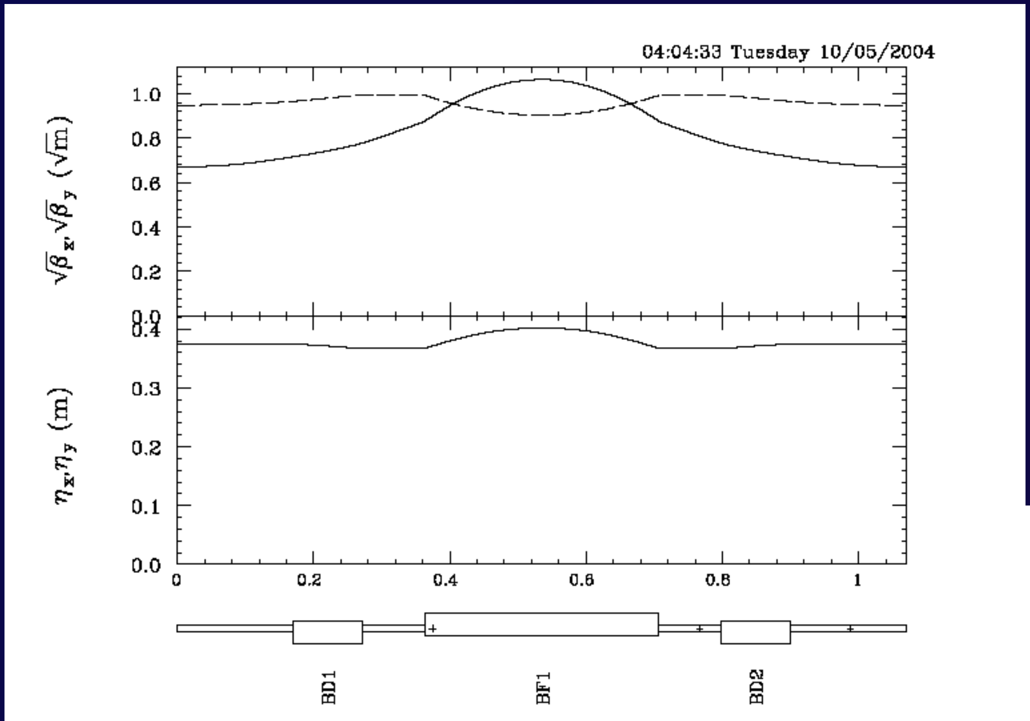
B field and k value vs radius



B field vs θ

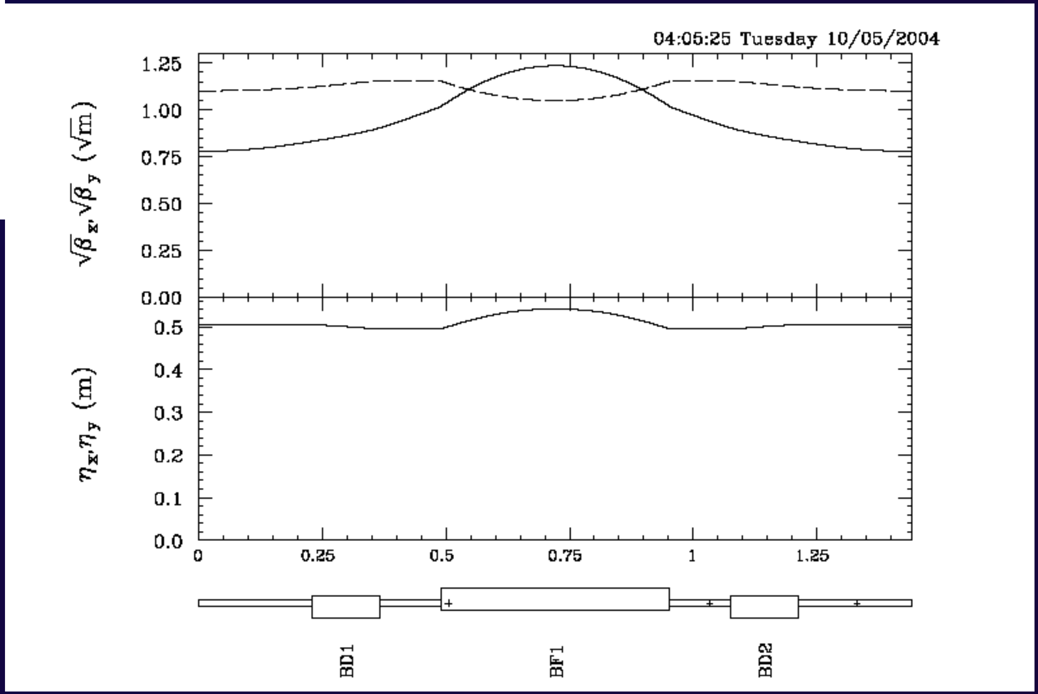


Lattice functions of booster

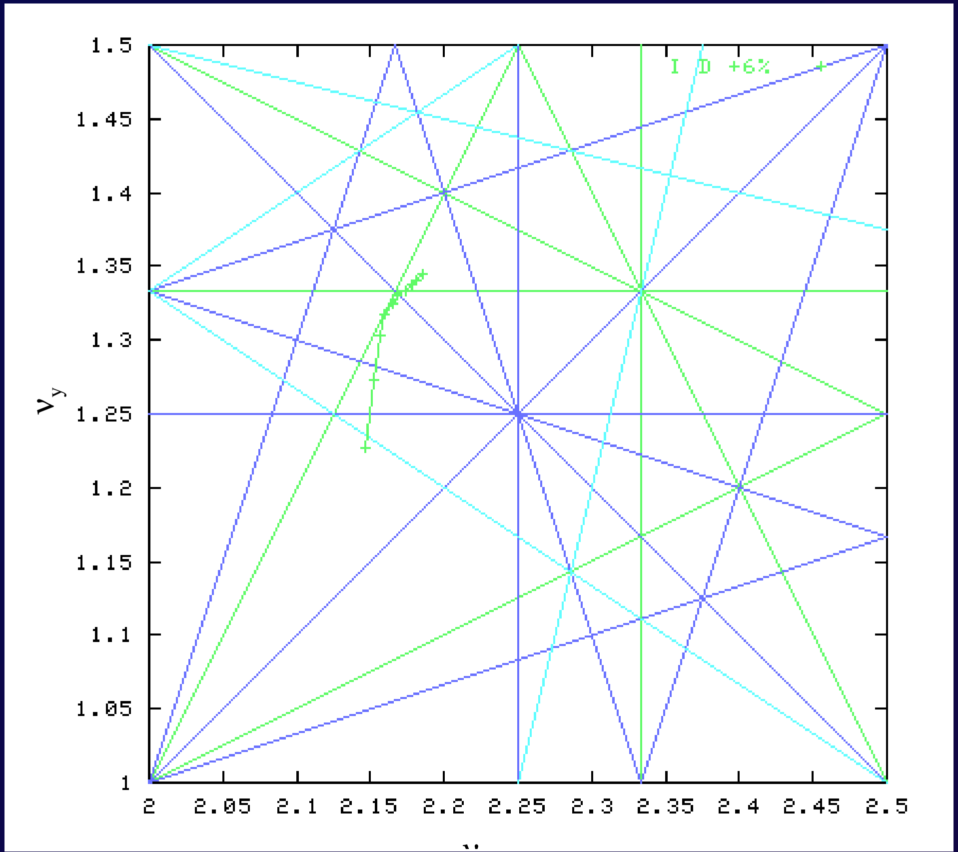


@injection

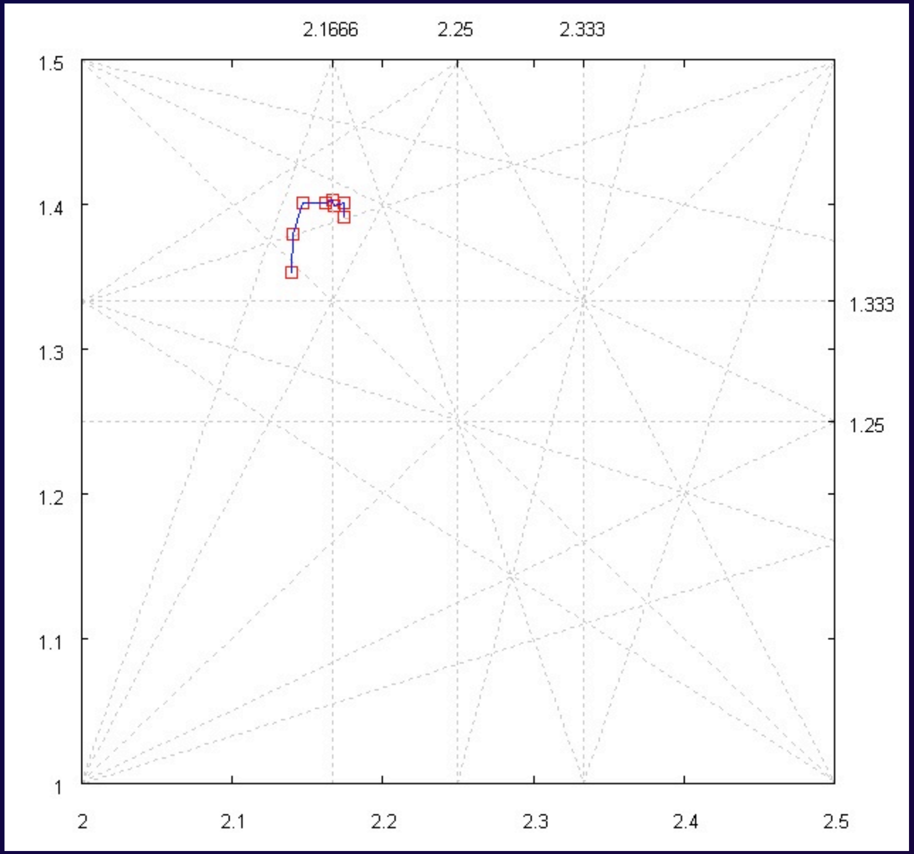
@extraction



Tune variation in booster



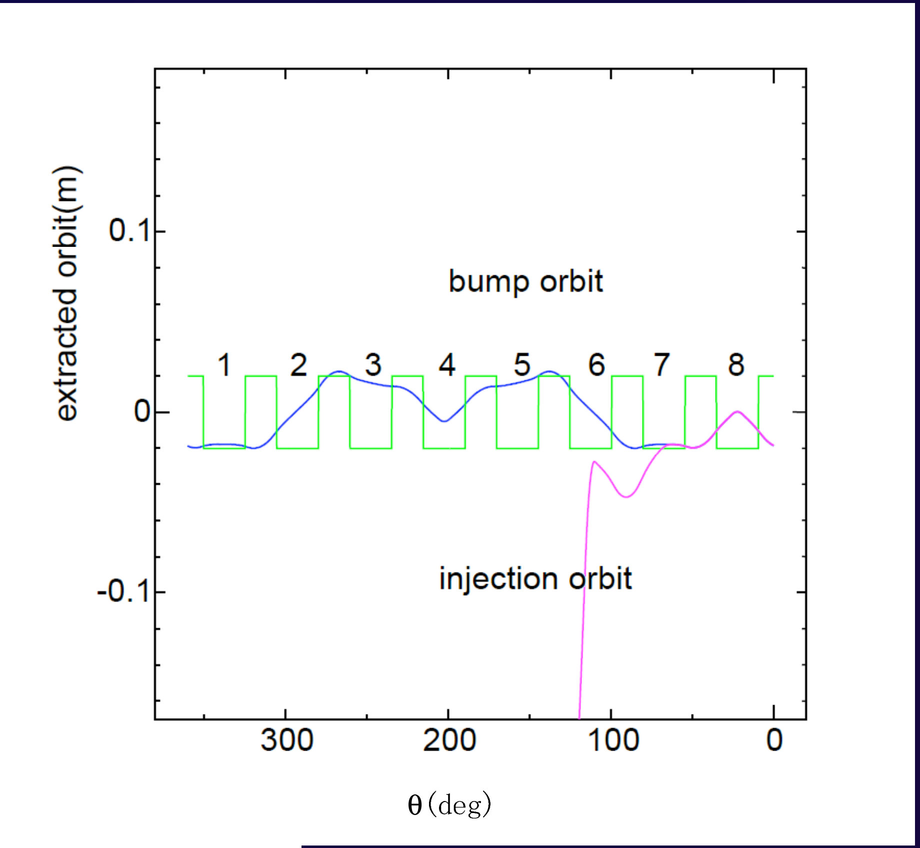
calculation(FFT with tracking data)

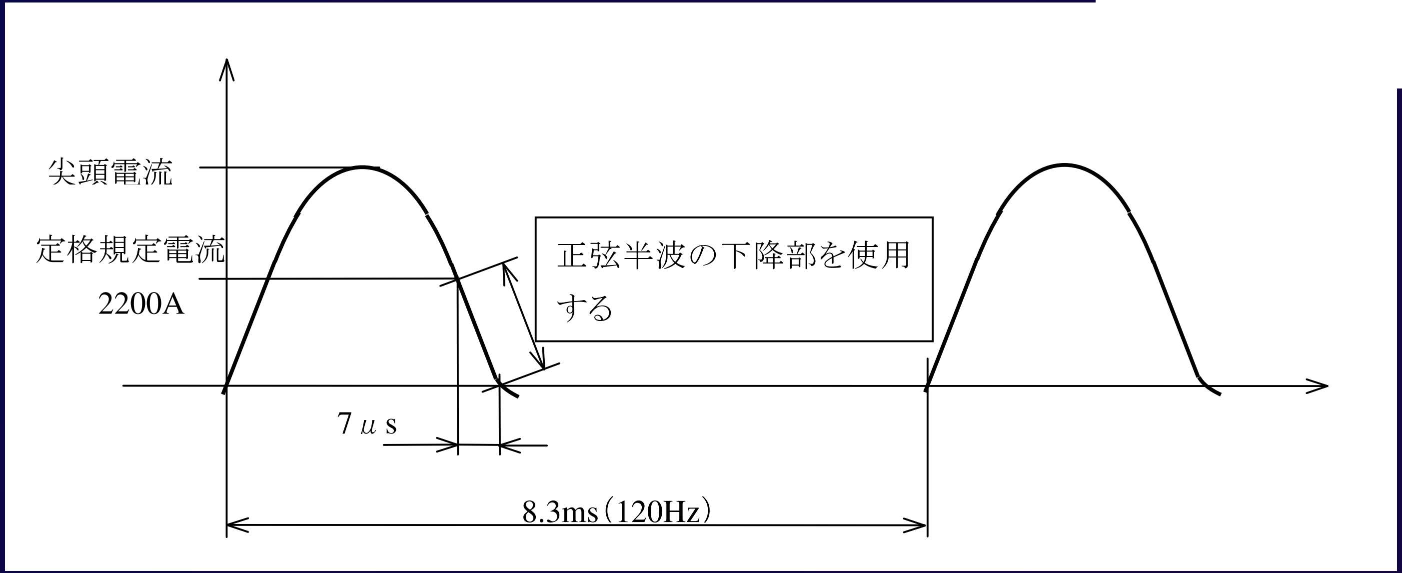


measurement

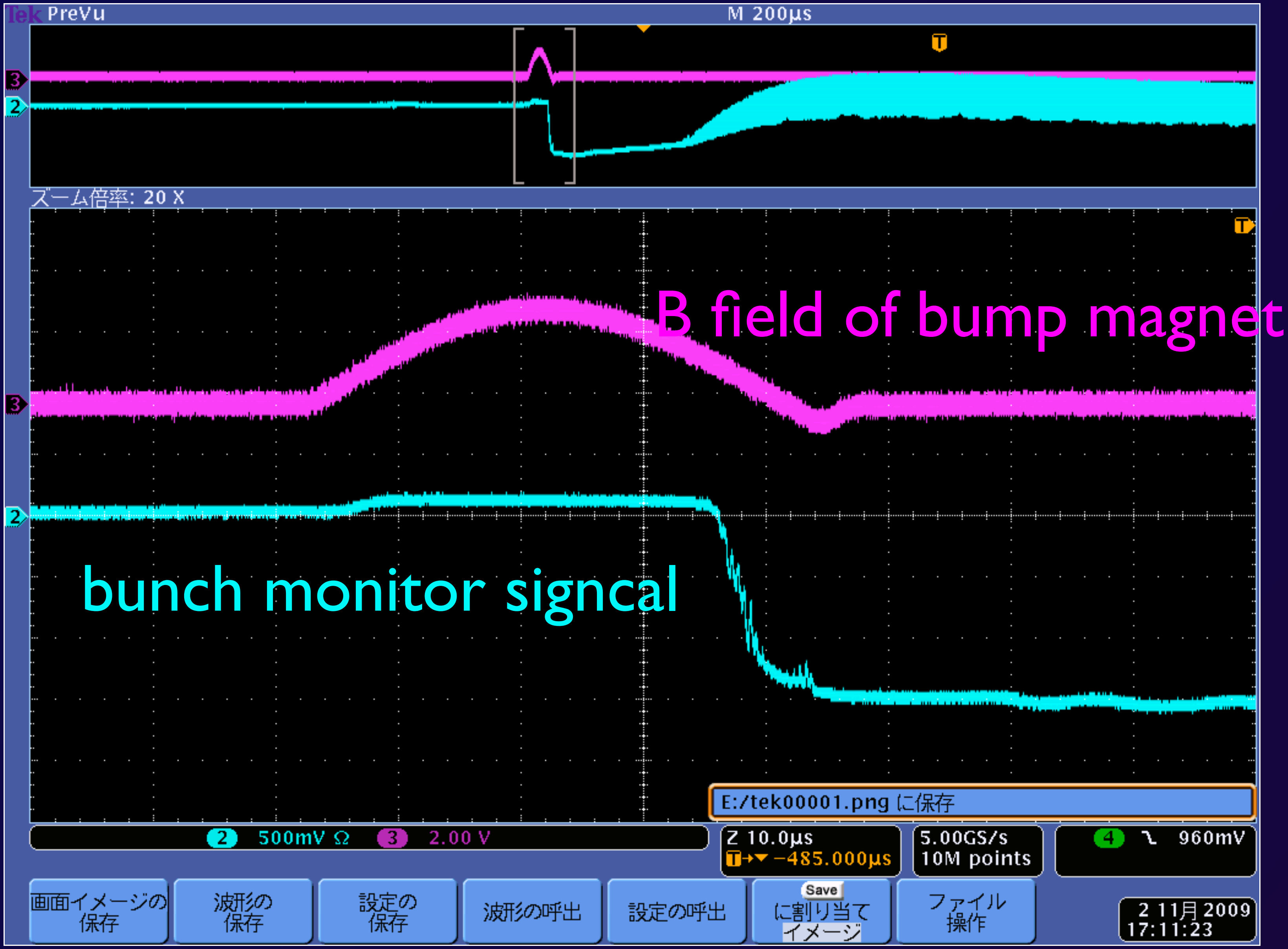
beam injection

- 14-turn injection
- 2-π bump scheme

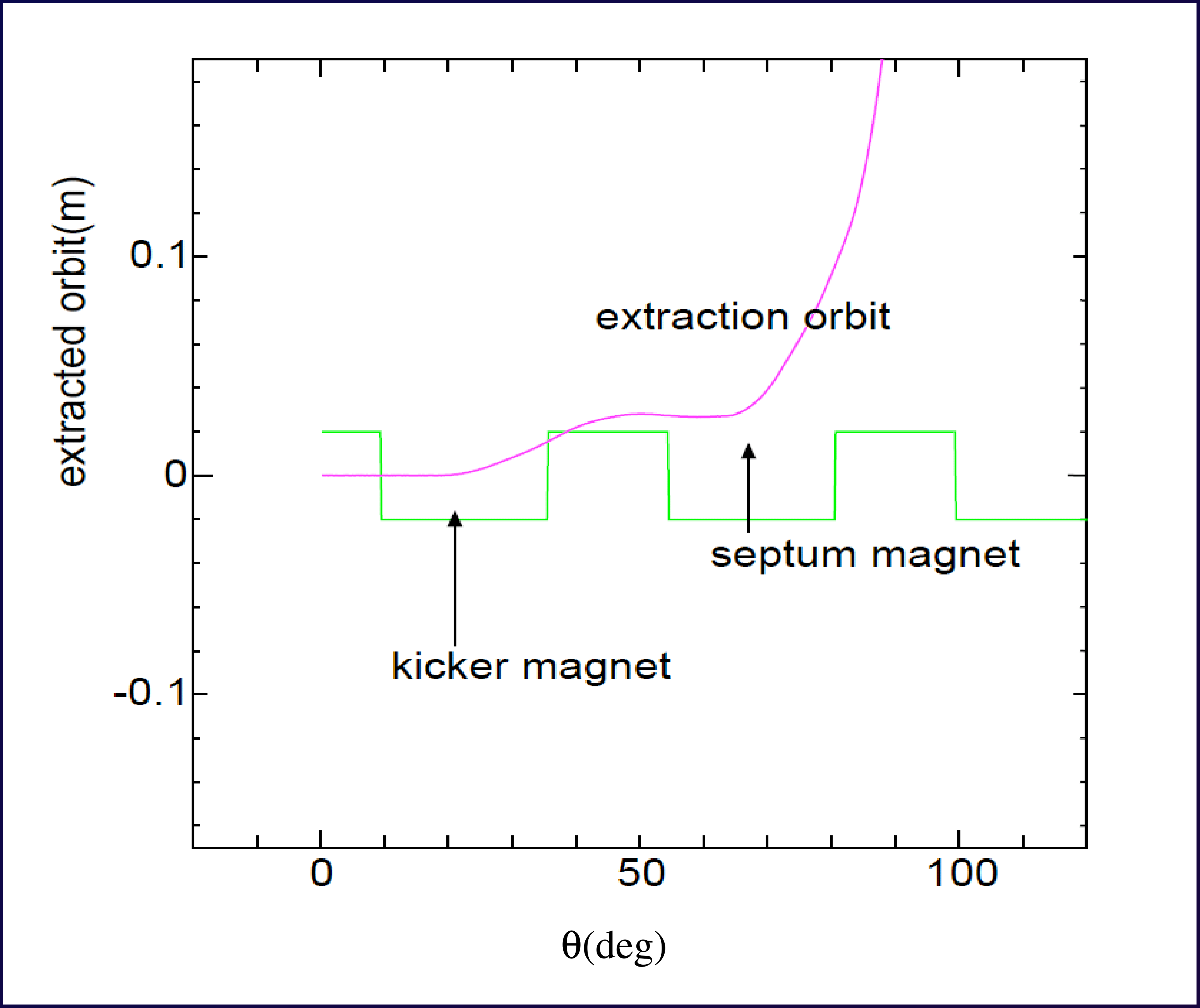




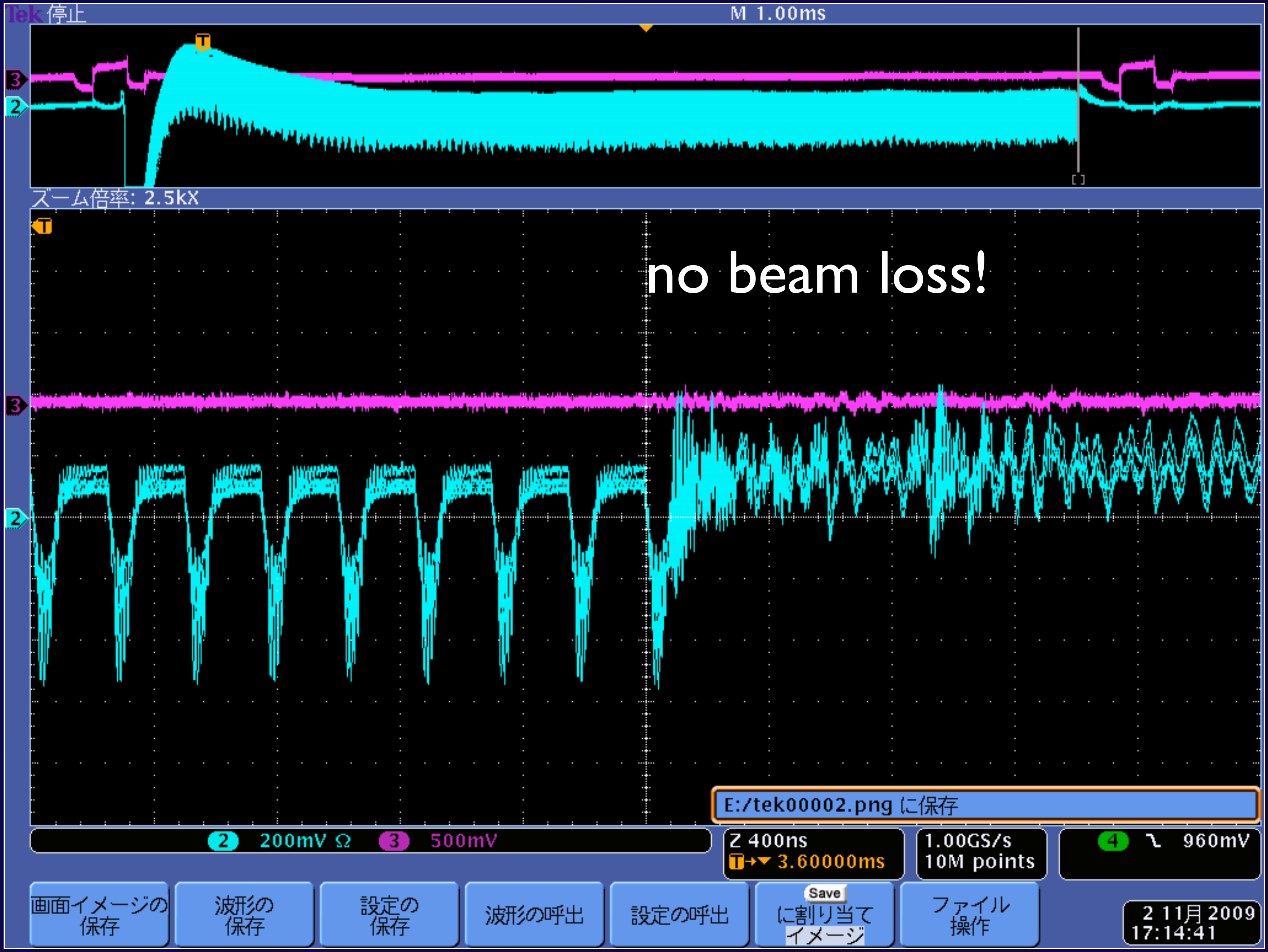
bunch monitor signal at injection



Extraction orbit



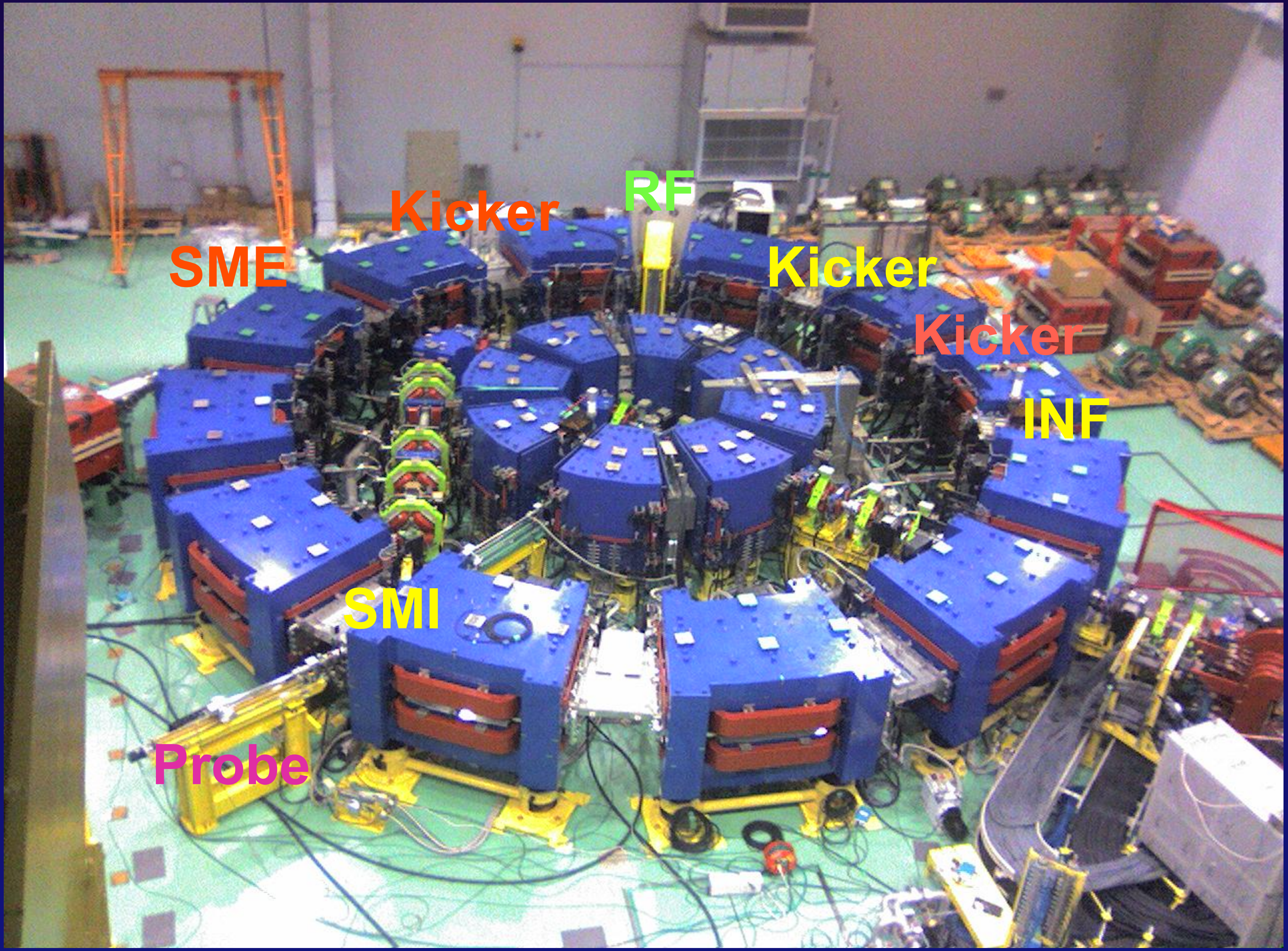
Bunch monitor signal thru acceleration



Optimum parameters

rep. rate	30Hz
inj. enerry	1.5MeV
ext. energy	11.5MeV
Pulse width of injected beam	7μs
injection efficiency	60%
acceleration efficiency	100%
extraction efficiency	90%

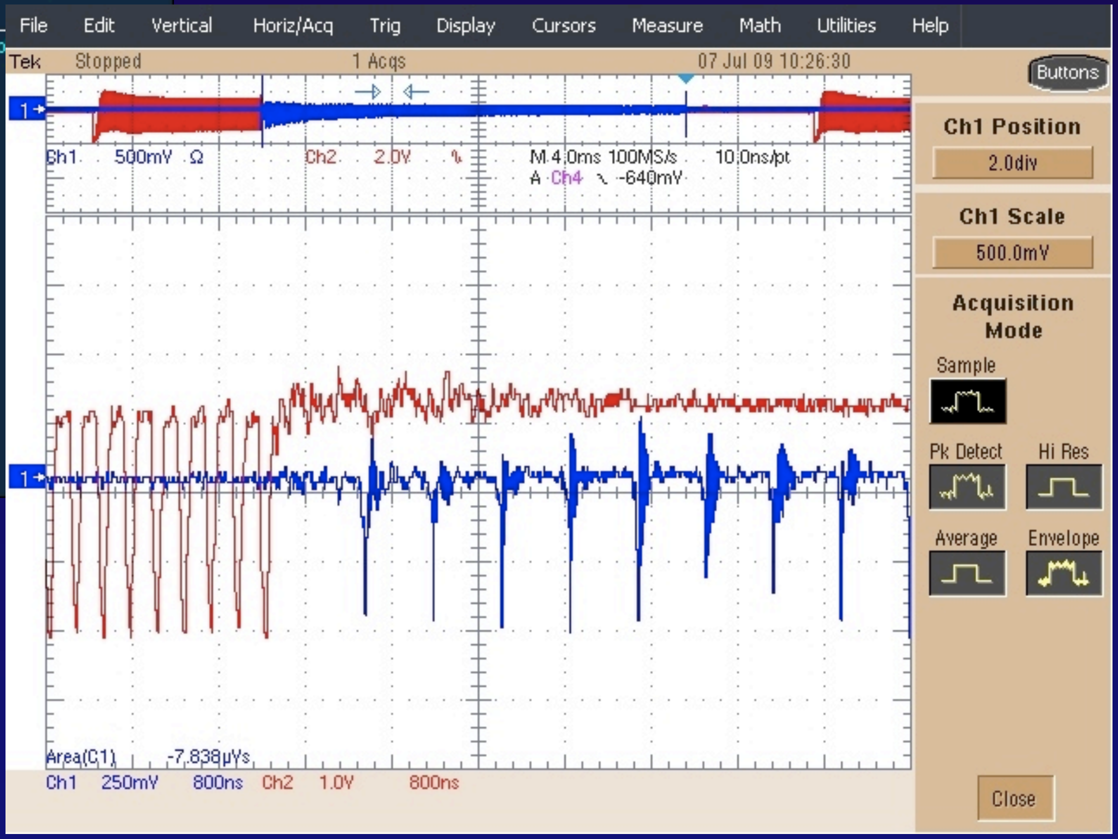
Main Ring



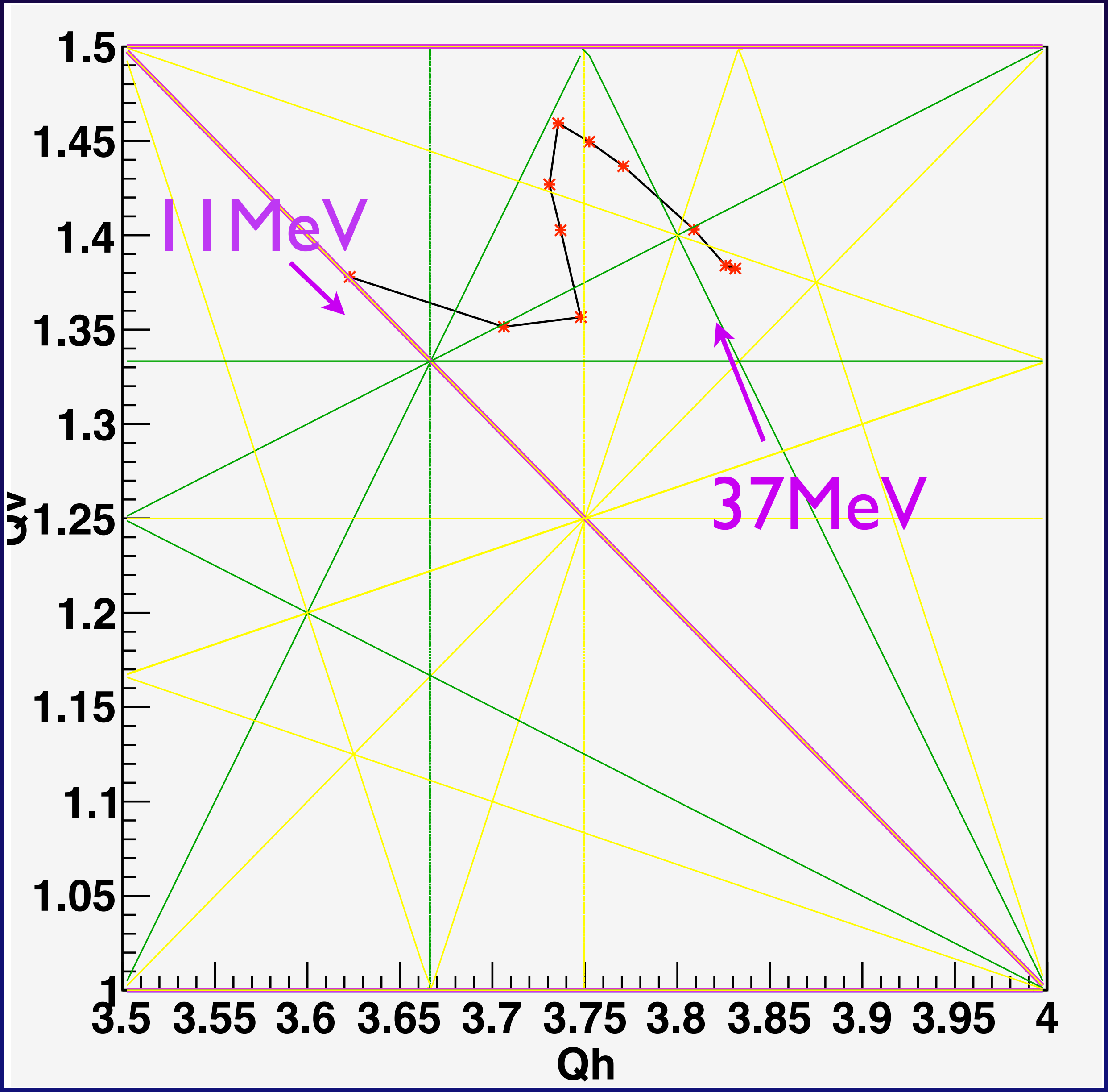
Specifications of Main Ring

item	design value
energy	150MeV
average beam current	1.0nA
rep. rate	120Hz
k	7.5
# of cells	12
operating point	(3.71, 1.38)
injection scheme	one-turn injection
extraction scheme	fast extraction
average radius	4.54 - 5.12 m

Bunch monitor signal at injection

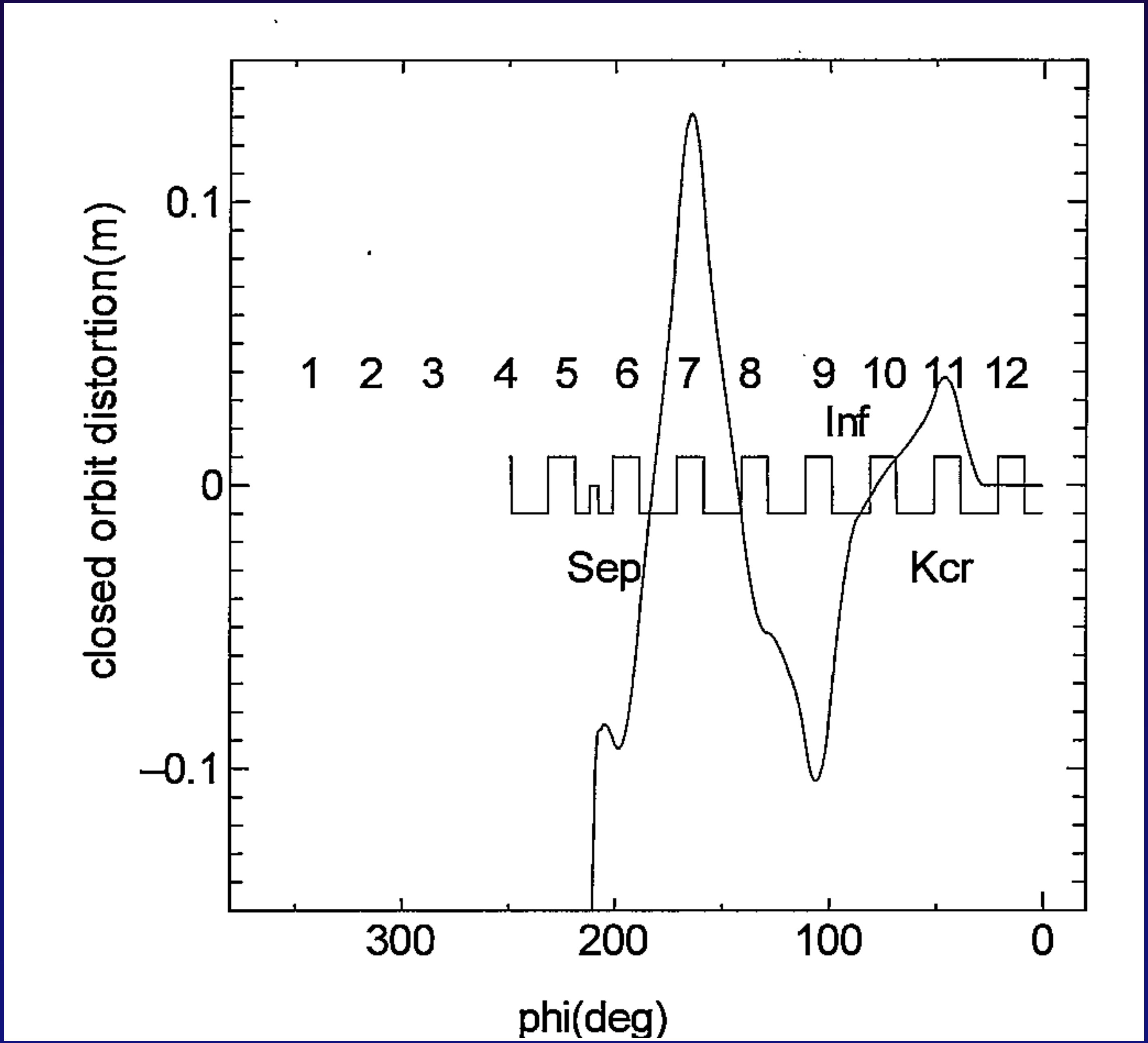


Tune variation in the Main Ring

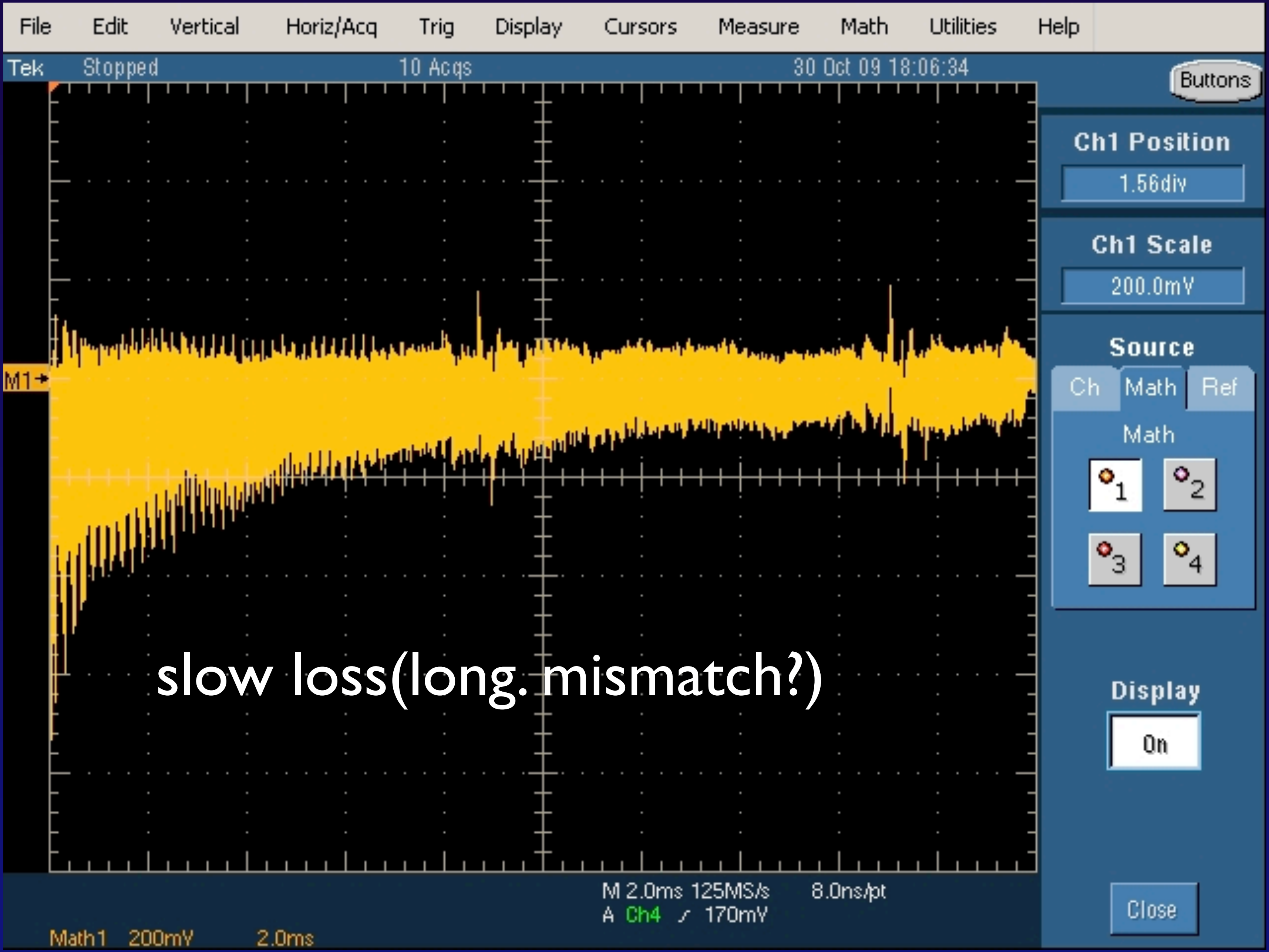


measurement

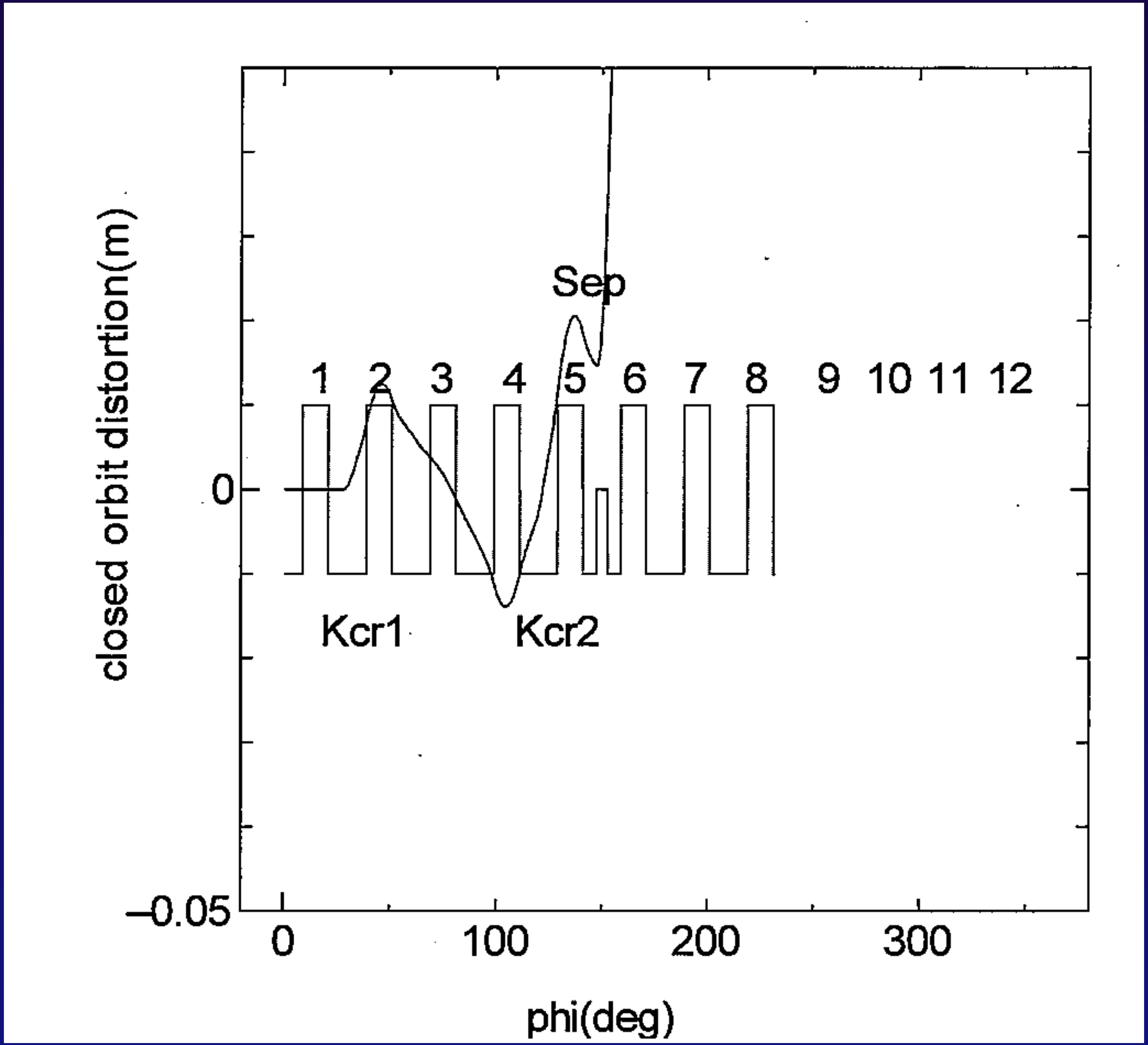
Injection orbit



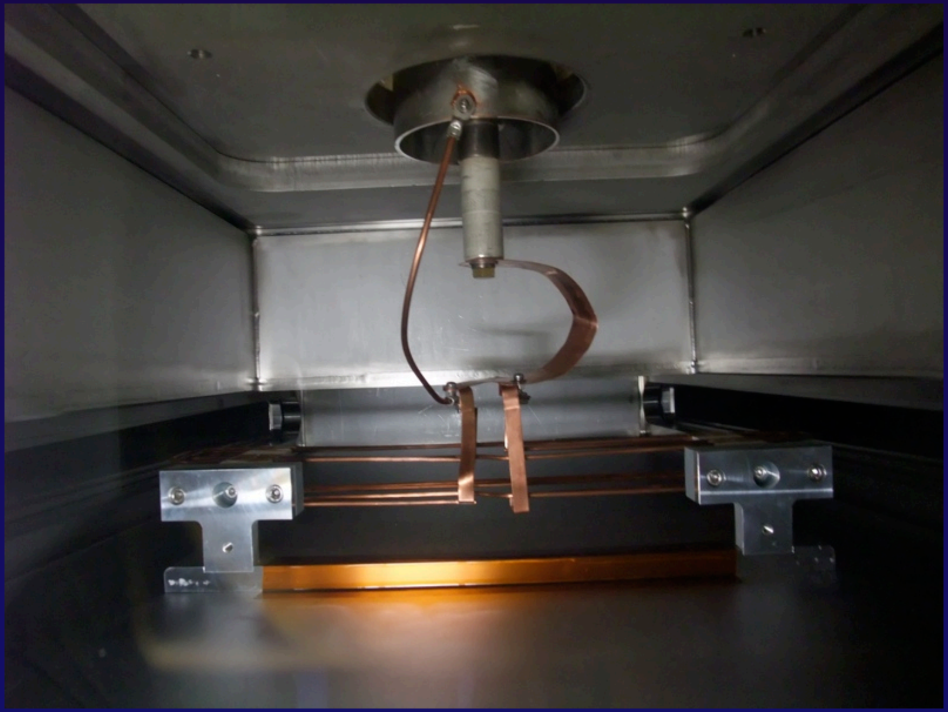
Bunch monitor signal thru acceleration

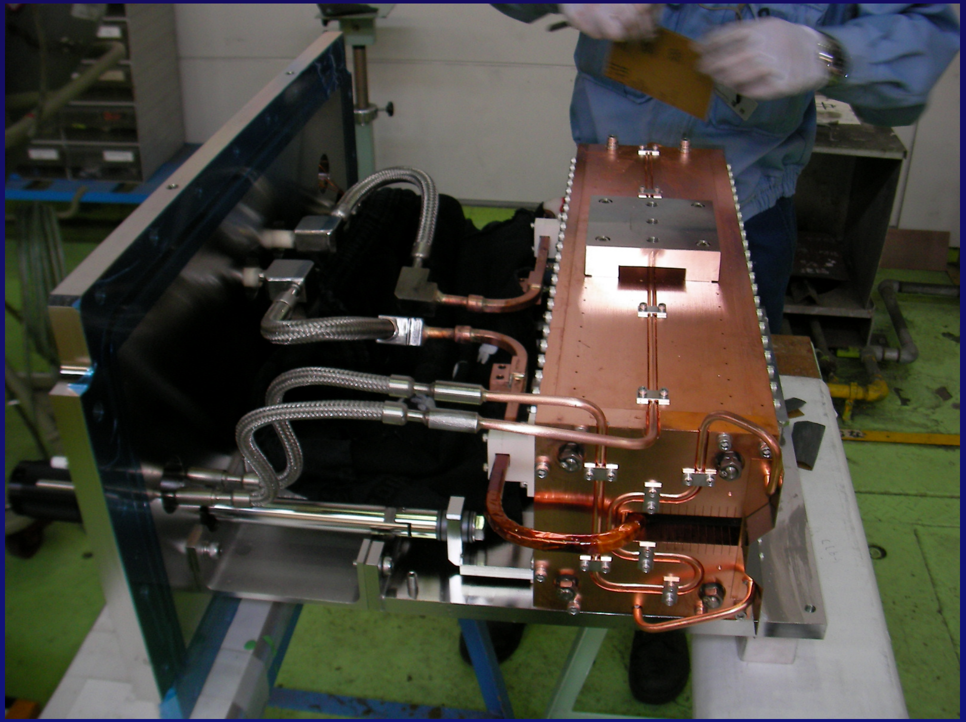


Extraction orbit



Extraction kicker and septum magnet





Optimum parameters

rep. rate	30Hz
injection energy	11.5MeV
extraction energy	100MeV*
injection efficiency	~100%
extraction efficiency	50%
beam intensity (@extraction orbit)	0.4nA
extraction efficiency	80%

* In order to increase energy up to 150MeV, the extraction orbit should be shifted outward by 13cm.

Status of rf system

Tom Uesugi will talk about it later ....

summary

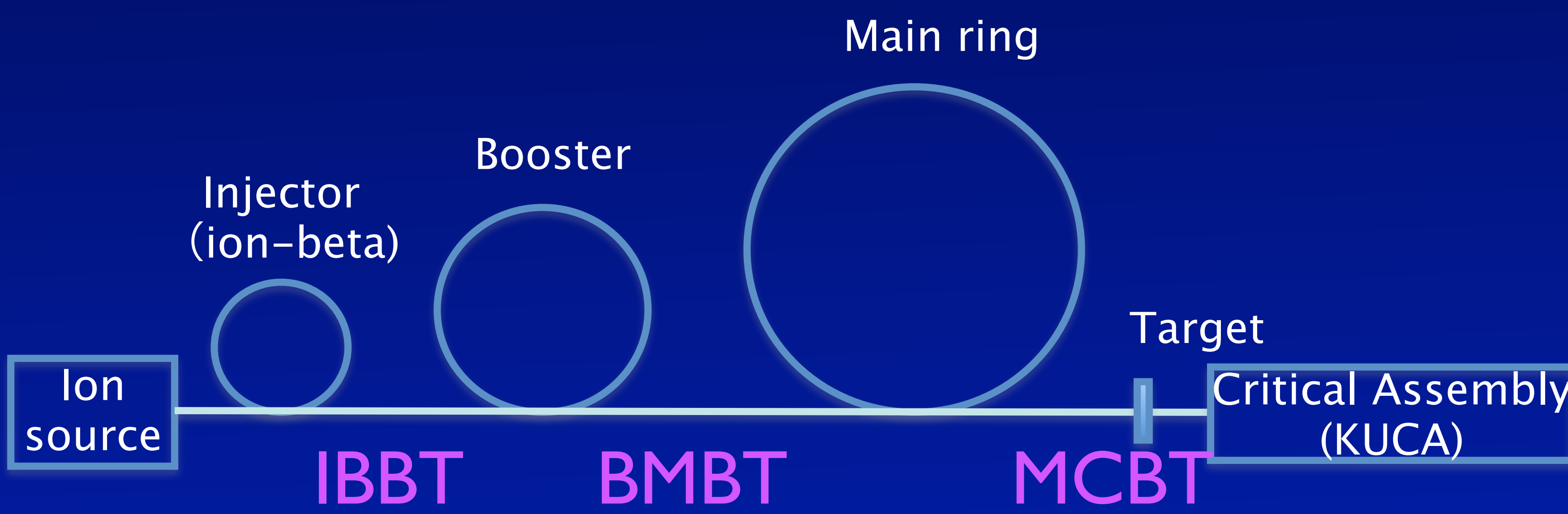
- Ion beta
  - Capability of variable energy has been demonstrated
- Booster
  - Stable beam performance has been obtained
- Main Ring
  - Difficulty in beam handling because of large stray field
  - Significant beam loss is observed at 4ms from injection
    - Mismatch of rf bucket →increase rf voltage
    - Transverse resonance→tune adjustment(F/D ratio, patch)

Beam transport systems

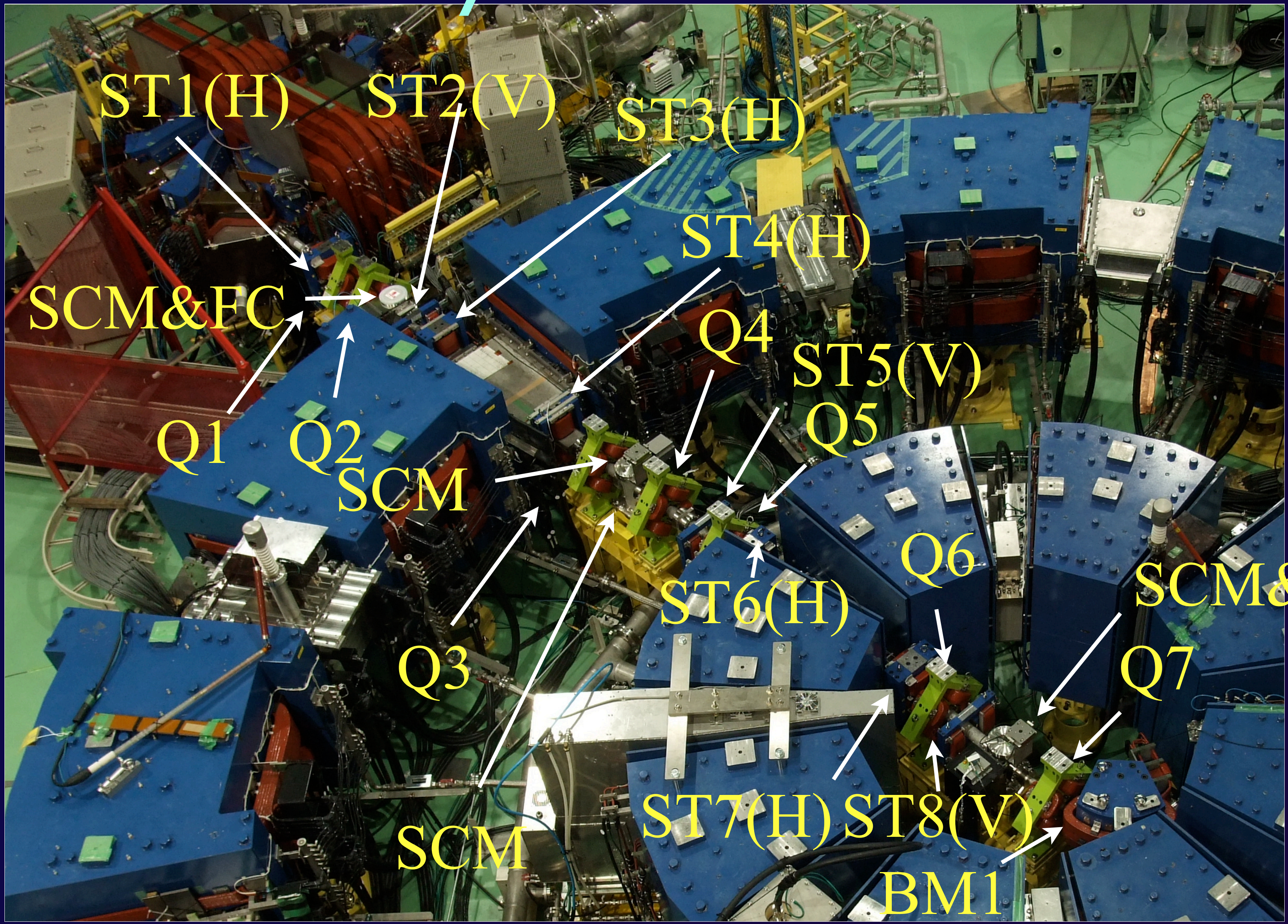
IBBT ION-BETA to BOOSTER Beam Transport system

BMBT BOOSTER to Main ring Beam Transport system

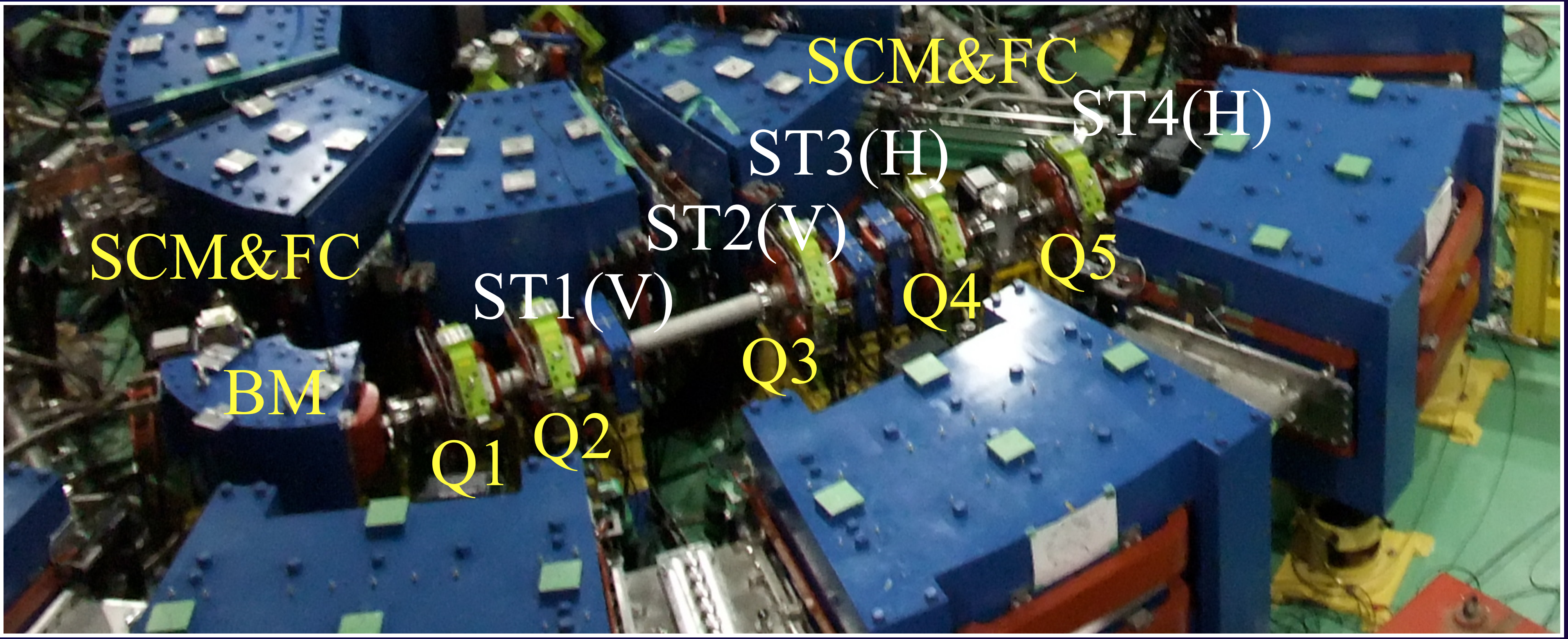
MCBT Main ring to CA Beam Transport system

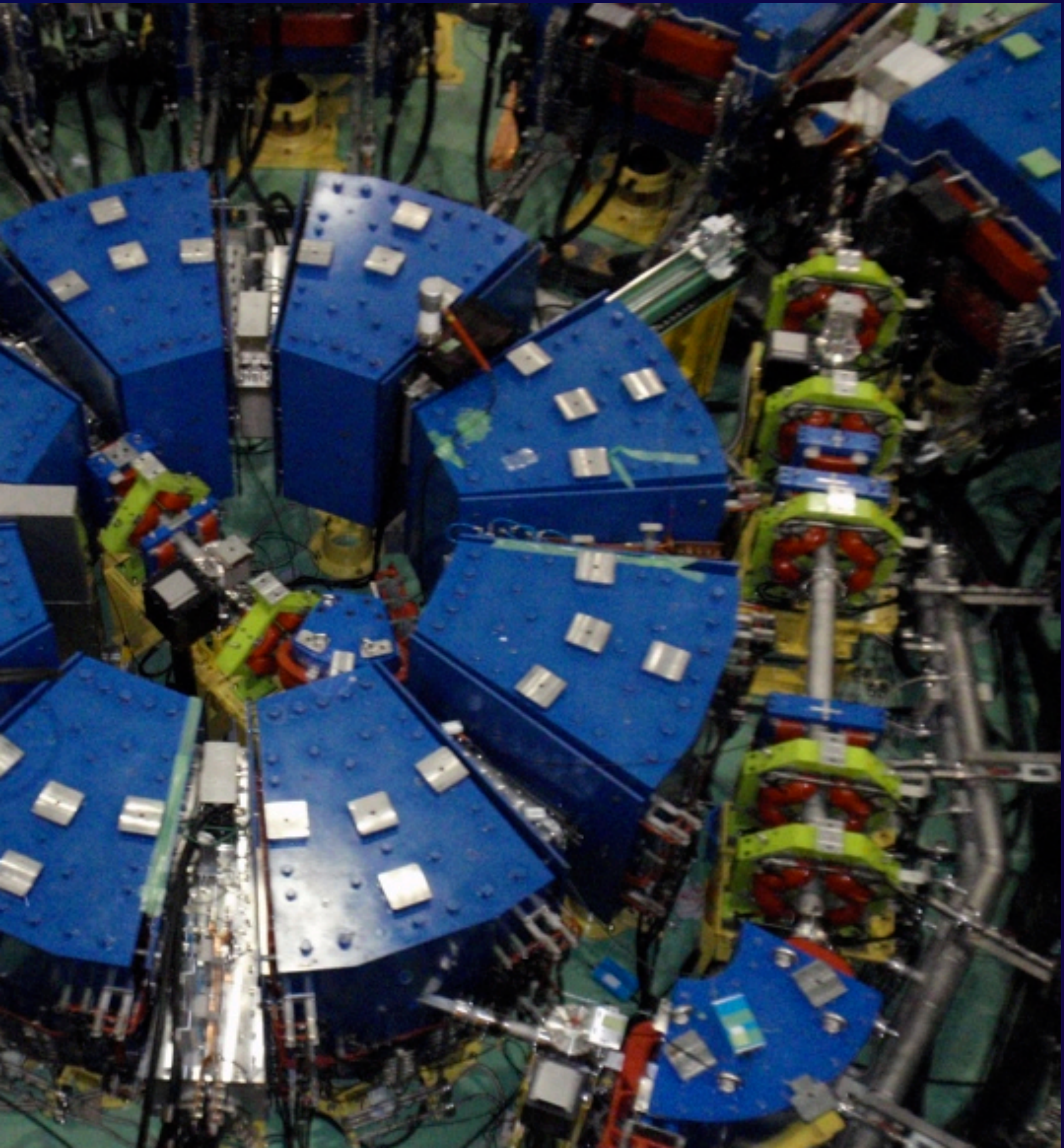


Layout of IBBT

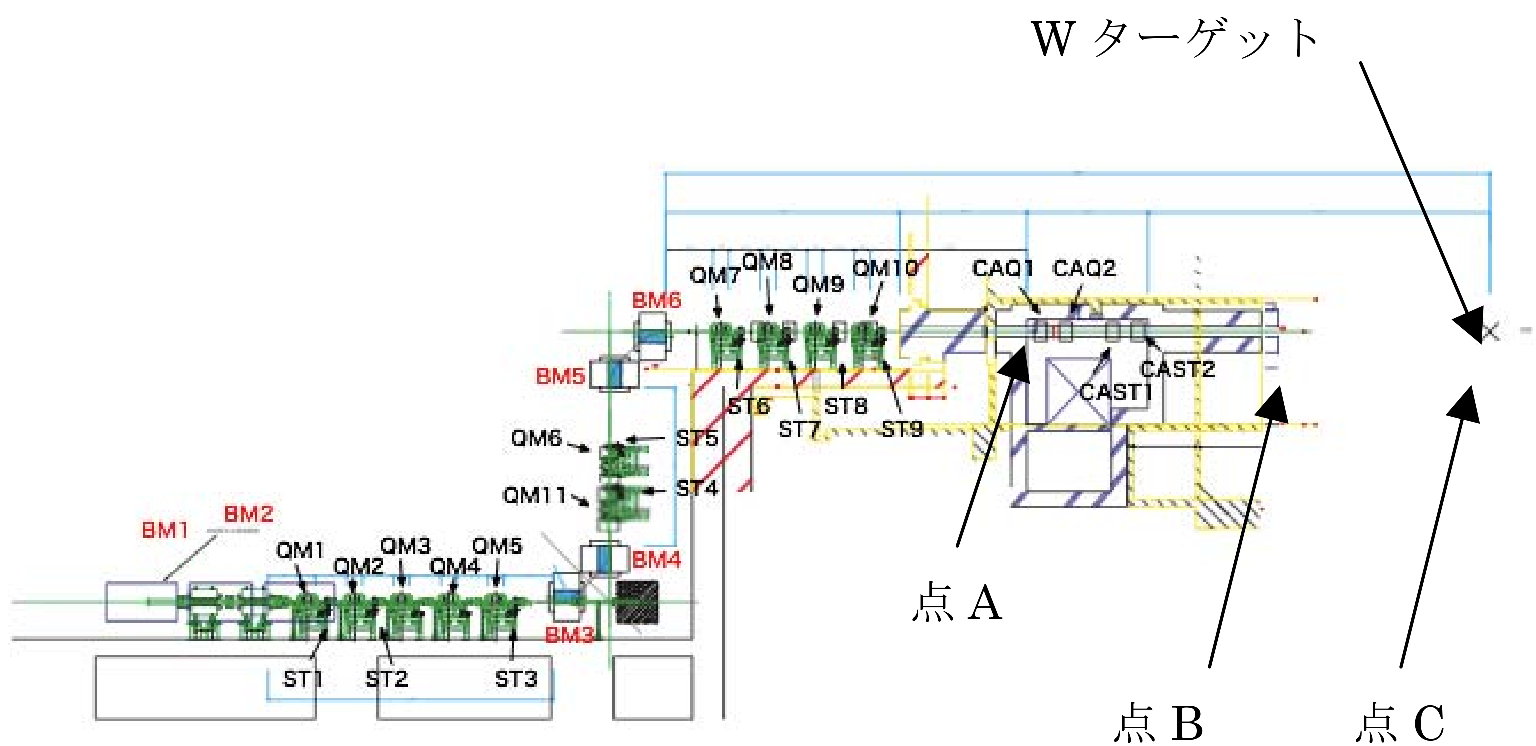


Layout of BMBT



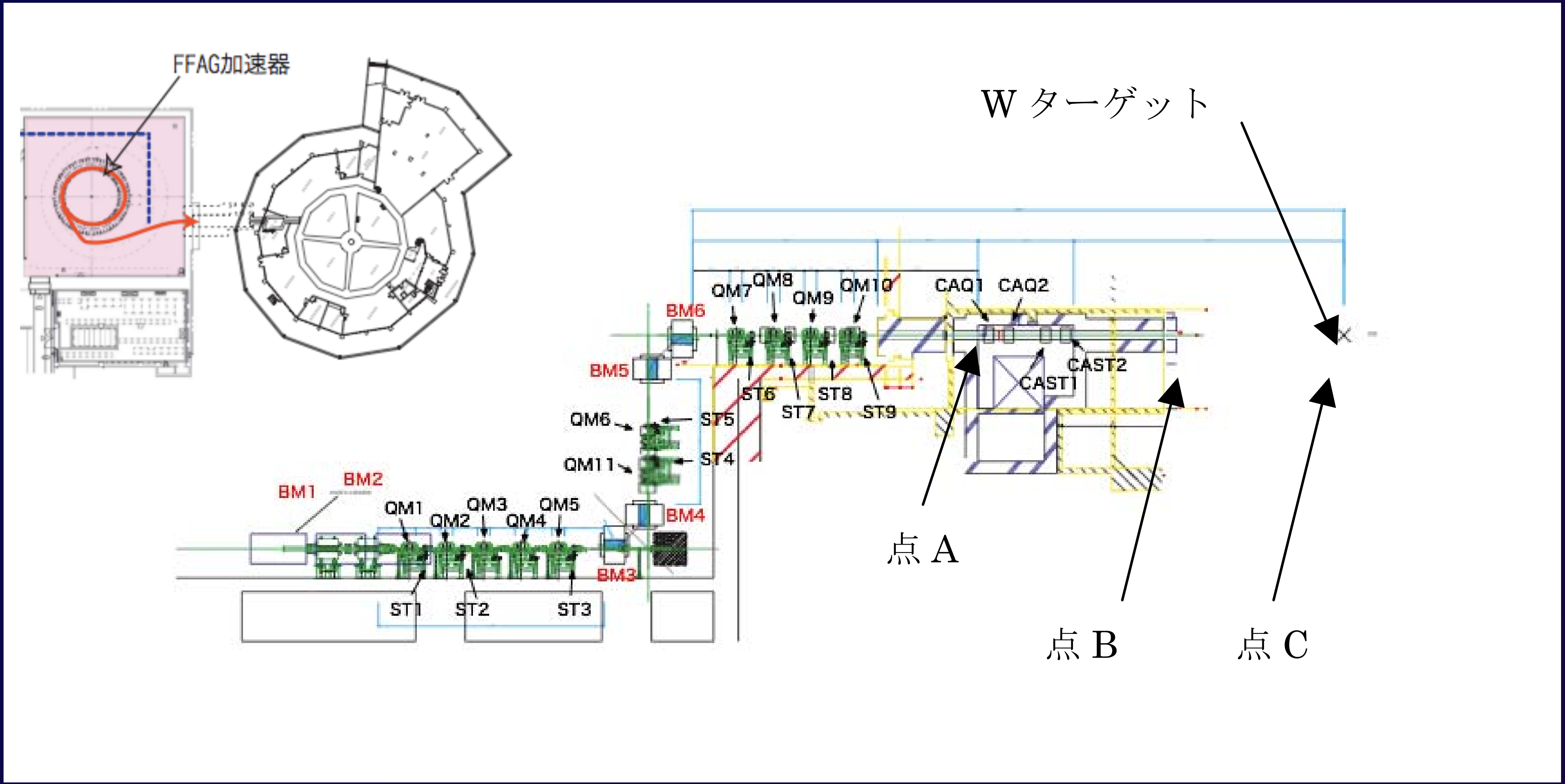


MCBT



W ターゲット
QM7
QM8
QM9
QM10
CAQ1
CAQ2
BM6
BM5
CAST2
CAST1
ST6
ST8
ST7
ST9
QM6
ST5
QM11
ST4
BM1
BM2
QM1
QM2
QM3
QM4
QM5
BM4
BM3
ST1
ST2
ST3
点 A
点 B
点 C

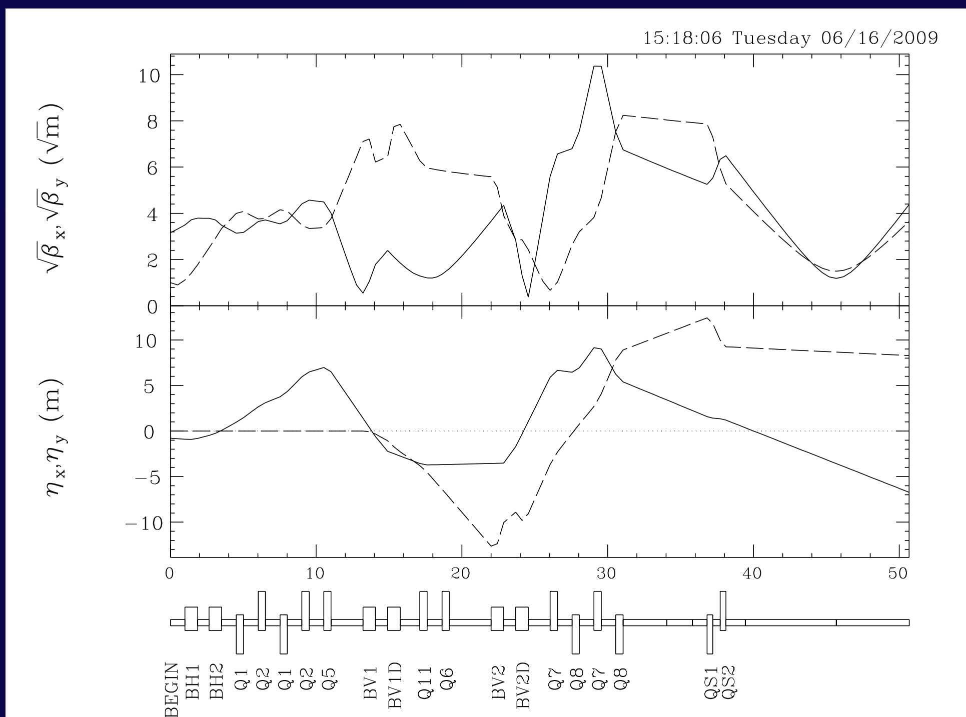
MCBT



FFAG加速器
Wターゲット
QM7
QM8
QM9
QM10
CAQ1
CAQ2
BM6
BM5
CAST2
CAST1
ST6
ST8
ST7
ST9
QM6
ST5
QM11
ST4
BM1
BM2
QM1
QM3
QM5
QM2
QM4
BM4
BM3
ST1
ST2
ST3
点A
点B
点C

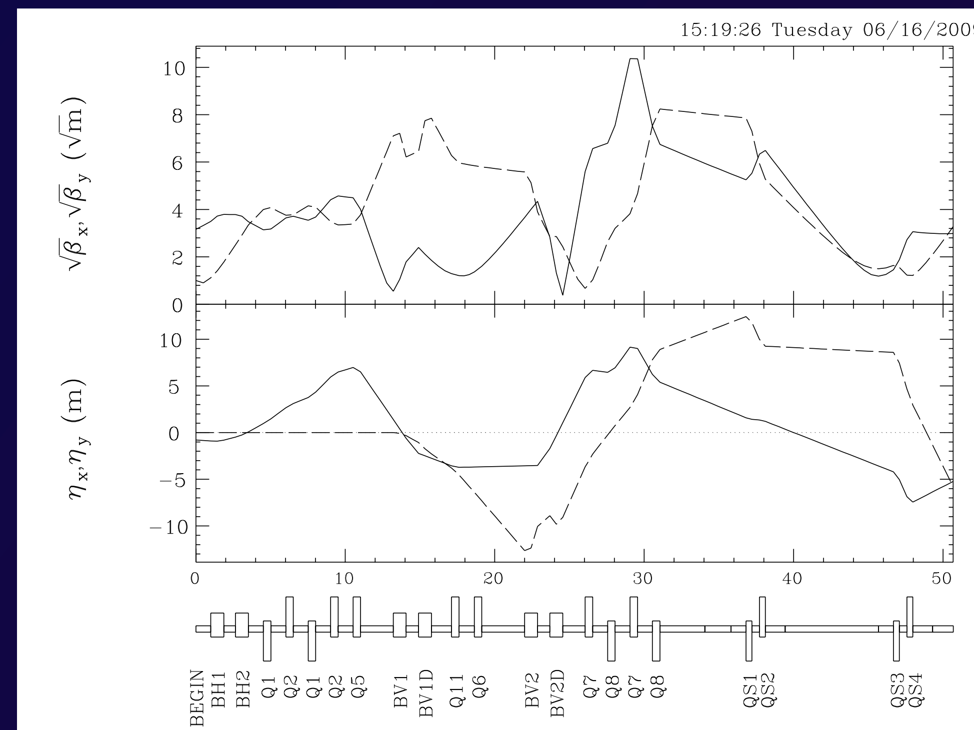
Lattice functions of MCBT

no QMs in the reactor



present ：large βη at the target

with doublet QMs in the reactor



plan to set QMs by the end of FY2009

problems and solutions

Main Ring	
efficiency	40% （acc. eff. 50%）
problems	slow beam loss because of mismatch of rf bucket betatron resonance because of tune variation
solutions	increase rf voltage tune adjustment (change F/D ratio, correction pole)
BMBT	
transport eff.	50%
problem	stray field from main magnets
solution	increase B of ST4 0.1T → 0.25T
MCBT	
transport eff.	10%
problems	misalignment of the pipe in the vertical line no final focusing in the reactor
solutions	add steering magnet in the vertical line set doublet of QMs in the reactor

present status

item	efficiency	beam current (nA)@30Hz	ppp
ext. from Booster		1.5	3.1E+08
BMBT trans.	0.5	0.8	1.6E+08
Main ring inj.	1.0	0.8	1.6E+08
Main ring acc.	0.5	0.4	7.8E+07
Main ring ext.	0.8	0.3	6.3E+07
MCBT trans.	0.1	0.03	6.3E+06

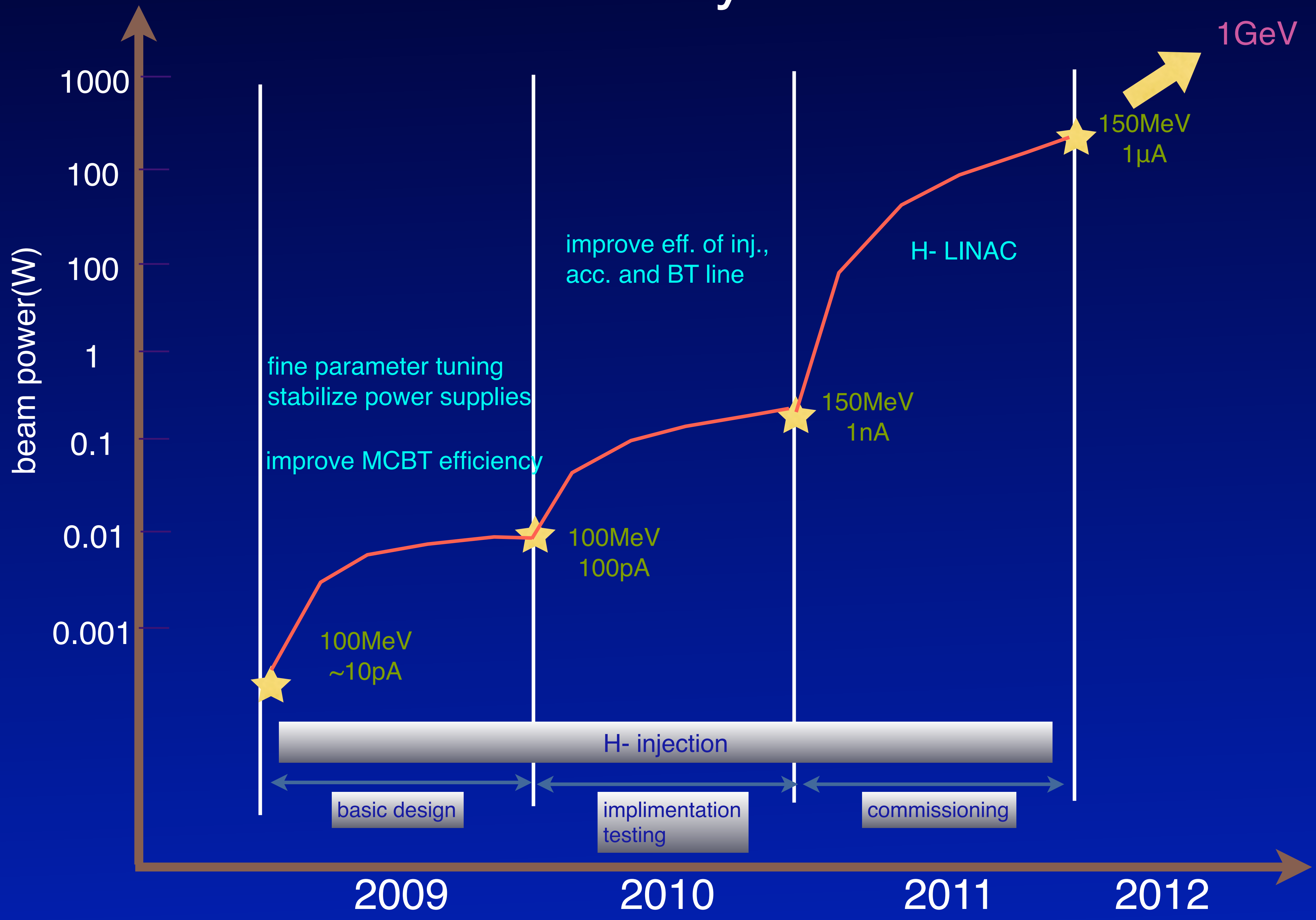
to 0.1nA

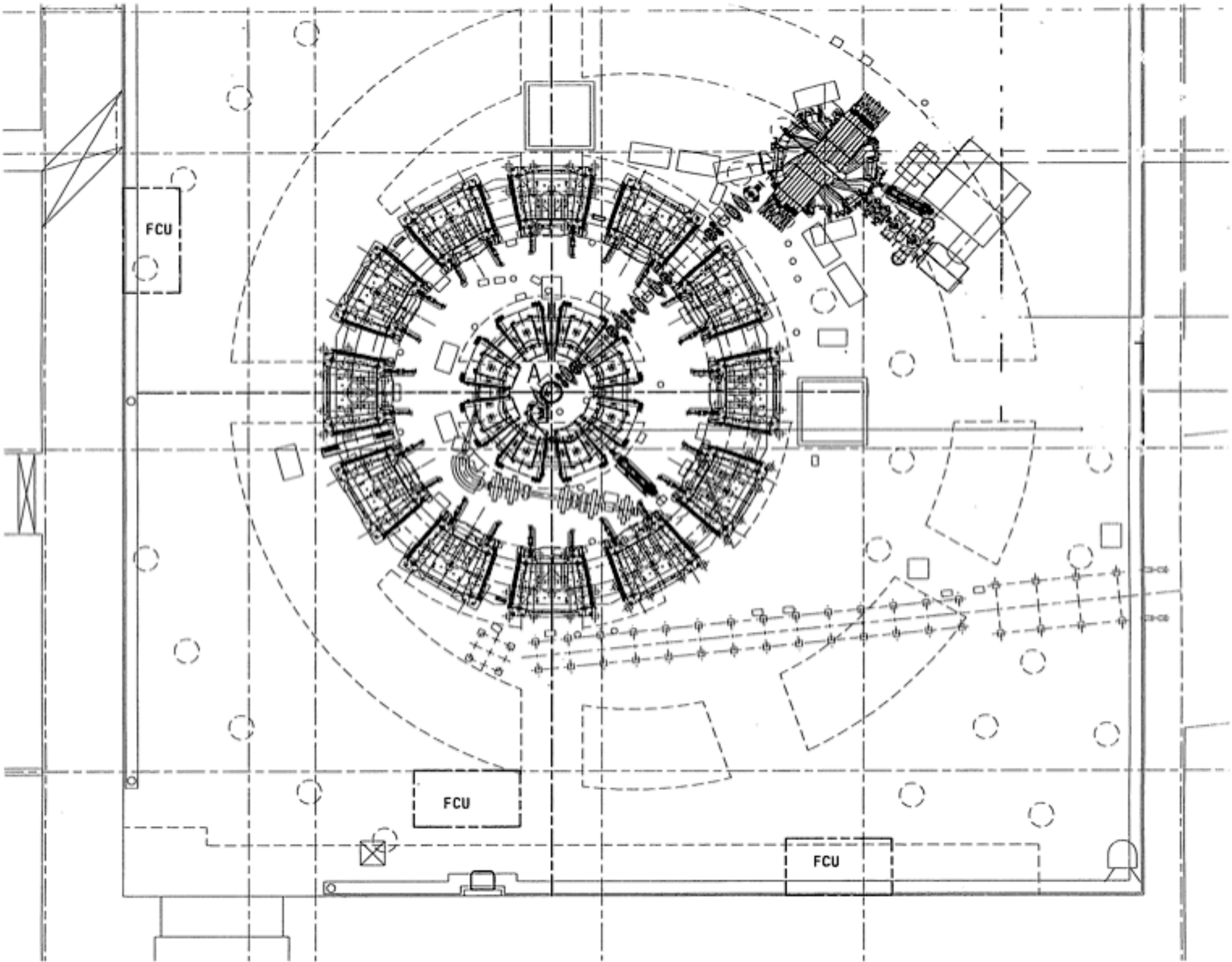
item	efficiency	beam current (nA)@30Hz	ppp
ext. from Booster		1.5	3.1E+08
BMBT trans.	0.5	0.8	1.6E+08
Main ring inj.	1.0	0.8	1.6E+08
Main ring acc.	0.5	0.4	7.8E+07
Main ring ext.	0.8	0.3	6.3E+07
MCBT trans.	0.3	0.09	1.9E+07

to 1.0nA

item	efficiency	beam current (nA)@30Hz	ppp
ext. from Booster		1.5	3.1E+08
BMBT trans.	0.9	1.4	2.8E+08
Main ring inj.	1.0	1.4	2.8E+08
Main ring acc.	0.9	1.2	2.5E+08
Main ring ext.	0.9	1.1	2.3E+08
MCBT trans.	0.9	0.98	2.1E+08

Plans to increase intensity for FFAGs at KURRI

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700MeV FFAG