

EPICS-based control system for compact-ERL and iBNCT

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Takashi OBINA

Control/Beam Diagnostics Group of Photon Factory and PF-AR
KEK, High Energy Accelerator Research Organization

Introduction

- I would like to talk about the control system of two accelerators:
 - Compact Energy Recovery Linac (cERL) at KEK Tsukuba
 - Ibaraki Boron Neutron Capture Therapy (iBNCT) at Tokai (near J-PARC)
- The reason for picking up the two accelerators are:
 - They use “EPICS”, of course
 - Both accelerators is (relatively) compact
 - Limited human resource
 - Both facilities uses similar hardware (Field Bus, console, server, etc)
 - I want to share the lessons learned with EPICS community...

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1. Introduction

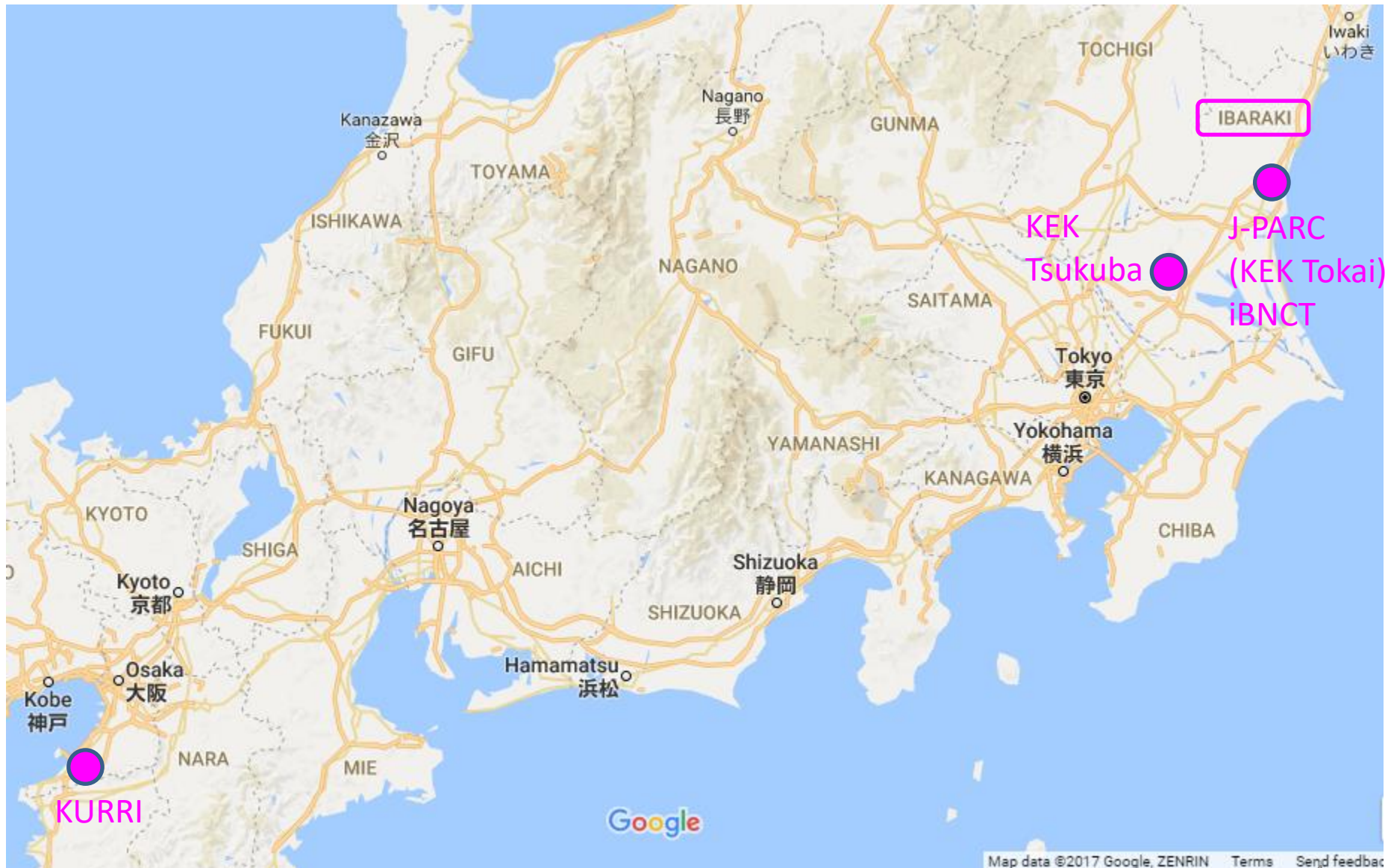
2. Outline of cERL at KEK

3. Outline of iBNCT at Tokai

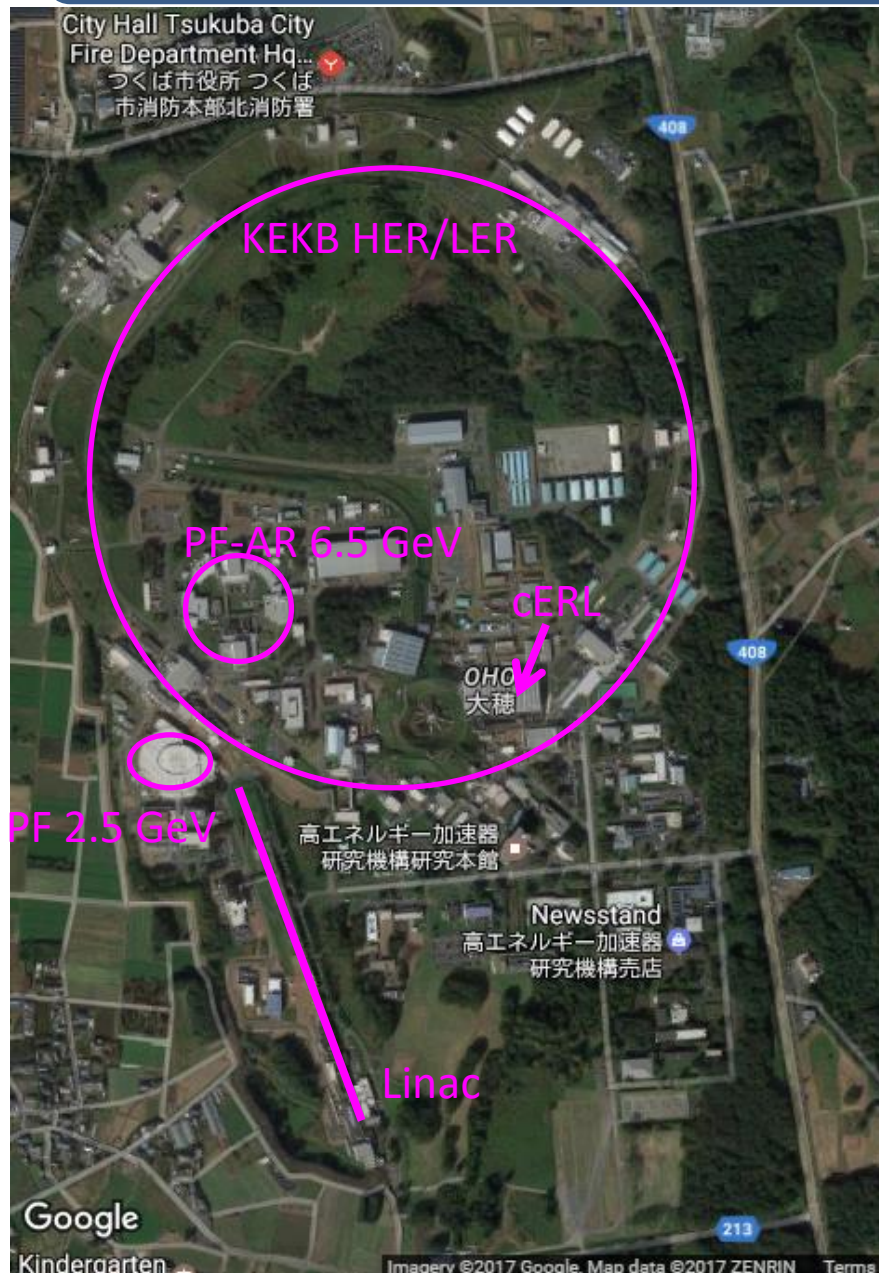
4. Commissioning, Tuning, Operation

- Various tuning panel
- CSS as an operation manual (procedure)
- Software for rapid prototype
- Hardware example : VME-Master

Location



KEK Tsukuba Campus



Large Accelerators:

- Linac
- KEKB : HER, LER ($C = 3$ km)

Synchrotron Radiation Facility

- PF-Ring : 2.5 GeV ($C = 187$ m)
- PF-AR : 6.5 GeV ($C = 640$ m)

(Relatively) compact accelerator:

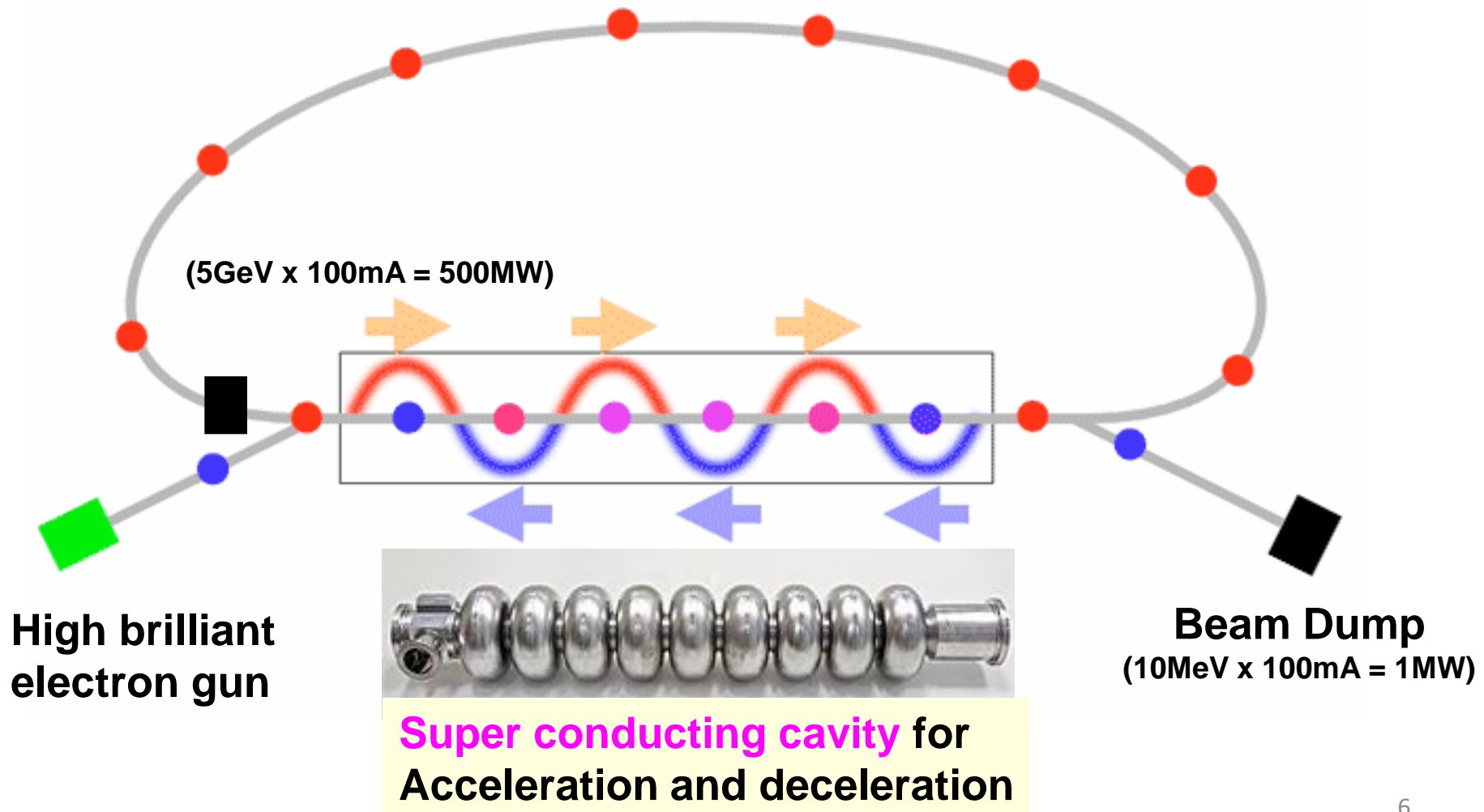
R&D Machine

compact ERL (~ 20 MeV, $C = 90$ m)

What is ERL?

Keyword : Linac-based, High Average Current, Brilliant electron source

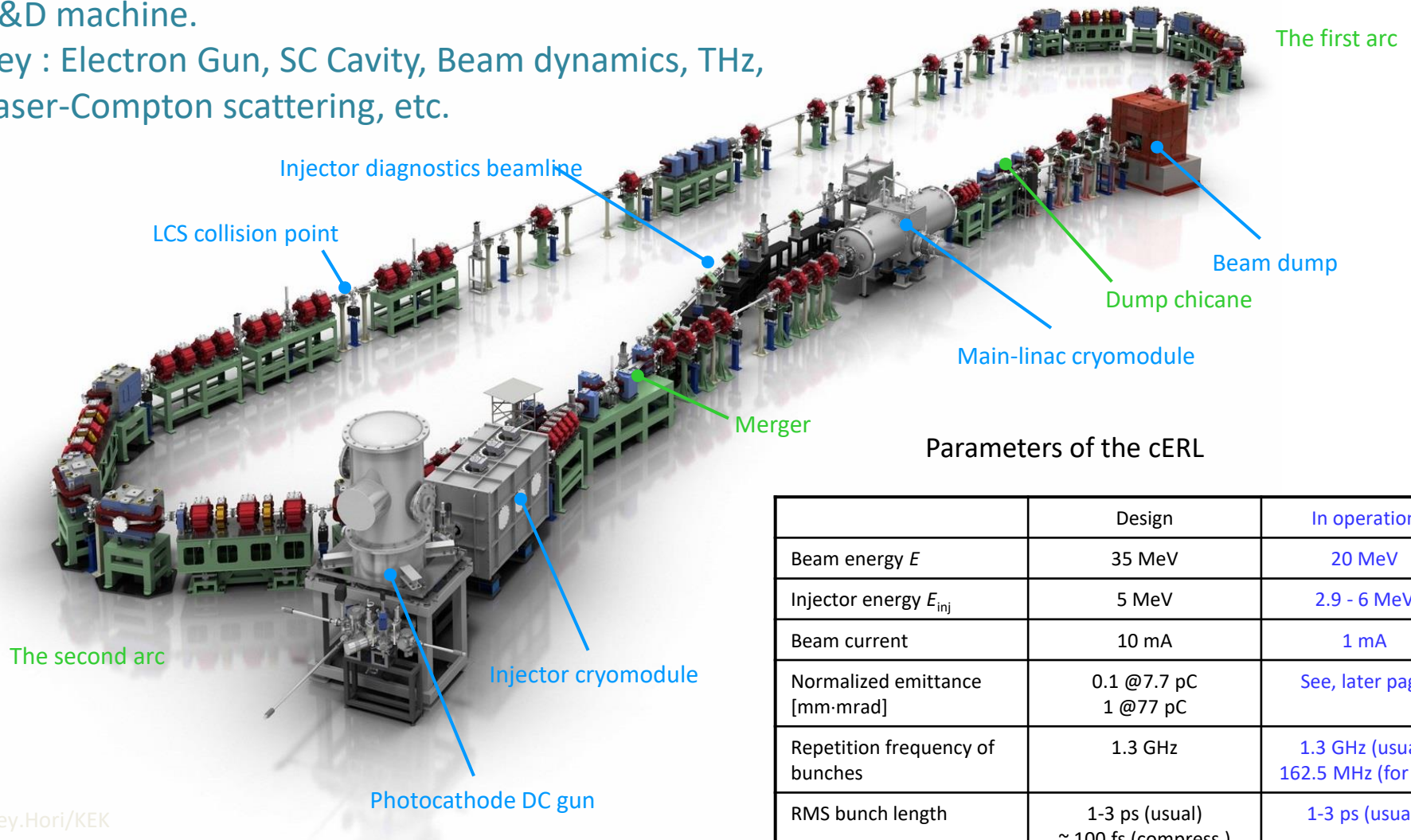
Application : Future Light Source, Electron Cooling, EUV-Lithography,... etc



compact ERL at KEK

R&D machine.

Key : Electron Gun, SC Cavity, Beam dynamics, THz,
Laser-Compton scattering, etc.

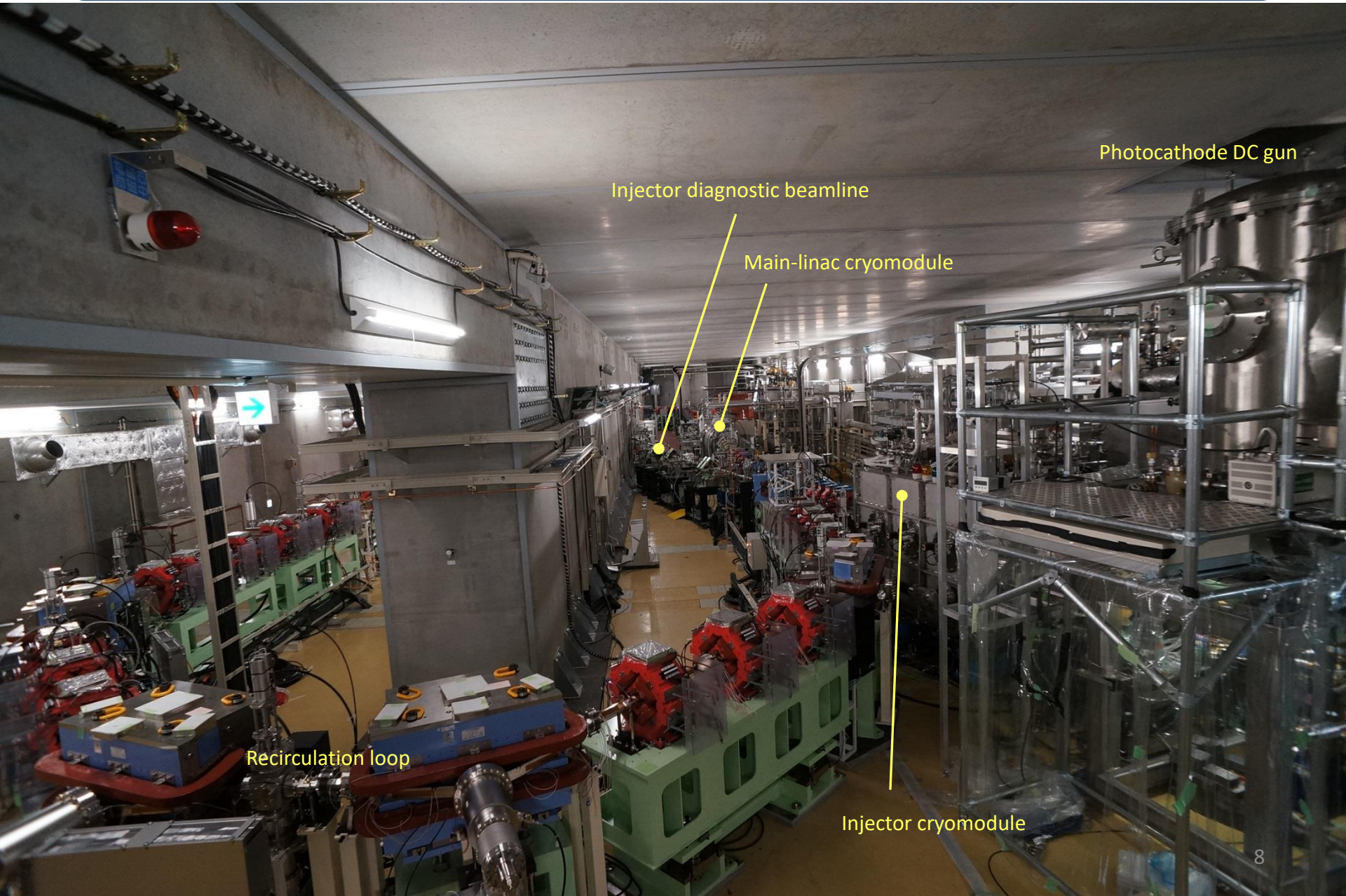


Parameters of the cERL

	Design	In operation
Beam energy E	35 MeV	20 MeV
Injector energy E_{inj}	5 MeV	2.9 - 6 MeV
Beam current	10 mA	1 mA
Normalized emittance [mm·mrad]	0.1 @ 7.7 pC 1 @ 77 pC	See, later page
Repetition frequency of bunches	1.3 GHz	1.3 GHz (usual) 162.5 MHz (for LCS)
RMS bunch length	1-3 ps (usual) ~ 100 fs (compress.)	1-3 ps (usual)
E_{acc} in main linac	15 MV/m	8.2 MV/m
Gun high voltage	500 kV	390 kV
Max. heat load at 2K	80 W	100 - 80 W

Circumference: ~ 90 m

Picture of cERL



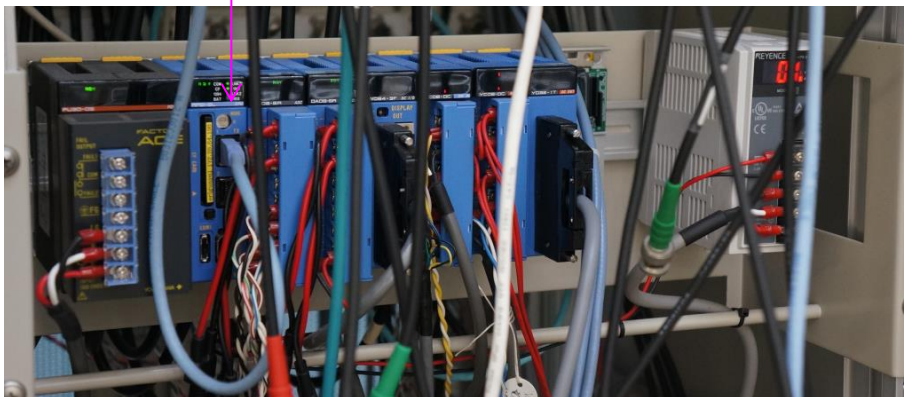
Control System : “Standard” Field Bus

- In General, it is very difficult to force everyone to use one specific hardware, while the control group wants to reduce the number of support hardware.

hardware selection depends on the requirement

- If there are no special reason, we ask development team to use Yokogawa PLC based module (FA-M3 Series) as a “standard” field bus.
 - Long hardware lifetime
 - Reliability
 - Easy development: EPICS Ready!, Many experiences in KEK
- Ladder CPU for Real-time (or safety) application
- Linux CPU (F3RP61) for EPICS IOC

Linux CPU



Ladder CPU

Linux CPU



Multichannel Data Logger

- For temperature sensor or analog voltage

- Yokogawa MW100

<http://tmi.yokogawa.com/products/data-acquisition-equipment/low-speed-daq-industrial-recorders/mw100-data-acquisition-unit/>



- Chino Network Logger

<http://www.chino.co.jp/products/component/ke.html>



- Graphtec data logger

http://www.graphtec.co.jp/site_instrument/instrument/index.html



EPICS device support or protocol files (Stream Device) for these equipment have been developed.

Magnet Power Supply

- CAENels
 - LiAM6005, SY3634
 - Each power supply directly attached to control network
 - ASYN + StreamDevice



Control Room Photo

- Two projectors to the wall
 - mainly for demonstration (for Guests/visitors)
- Desktop 27-inch display is mainly used for accelerator tuning.
 - 2 PCs for operation/ Beam tuning.



Software tools used

- Linux Server Machine / Windows console
- CSS for GUI, Archive/Retrieval, Alarm

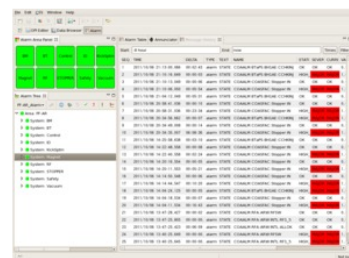
Thanks for Kay Kasemir for his great contribution!!

- EPISS 3.14
- CSS KEK version
 - <http://www-linac.kek.jp/cont/epics/css/>
 - Tutorial, documents, etc
 - Version 3.2.16 for cERL



Control System Studio (CSS) at KEK

[\[Download\]](#) [\[Tutorial, Nakamoto\]](#) [\[Tutorial, Onoki\]](#) [\[Seminars, K.Kasemir\]](#) [\[Tutorial, Okazaki\]](#) [\[Alarm\]](#)



[Beast Alarm under CSS](#)

Control System Studio (CSS) is an Eclipse-based collections of tc started at DESY, and it is now actively extended in the collaborat institutes.

Several different solutions have been employed in the past for o static displays can be replaced by CSS. Several other tools like d as well. Some other Python-based scripting programs may be re

The Rich Client Platform (RCP) provided by Eclipse enables unifi common look-and-feel and shared control service libraries.

Ple

CSS/KEK Download site.

CSS download site at KEK was prepared by Dr. K.Kasemir in June 2011. It was studies by K.Furukawa of Cosylab in September 2011, February, August 2012, and June 2013, and by T.Michikawa in Decem

wiki

- We want to share know-how in Japanese : EPICS Users JP wiki
 - <http://cerldev.kek.jp/trac/EpicsUsersJP>
 - For advanced researcher/programmer : send e-mail to tech-talk!!
 - Mailing List (in Japanese) ... not so active like tech-talk
 - epics-users@ml.post.kek.jp



The screenshot shows the EPICS-Users JP Japanese Wiki page. At the top, there is a logo for EPICS and the text 'EpicsUsersJP 日本語情報'. Below the logo is a navigation bar with links: Wiki, Timeline, Browse Source, View Tickets, and Search. The main content area has a title 'EPICS-Users JP 日本語情報' and a description: 'このサイトは、EPICS-Users Mailing List で取り上げられた話題や、過去にKEK内部向けのサイトに書いた日本語文書'. There are three main sections: 'MLに参加する方法', 'EPICS IOC関連', and 'CSS 関連'. Each section contains a list of links to various topics.

EPICS-Users JP 日本語情報

このサイトは、EPICS-Users Mailing List で取り上げられた話題や、過去にKEK内部向けのサイトに書いた日本語文書

MLに参加する方法

いまのところ自動登録ではありません。申し訳ありませんが、本家のML管理者(epics-users-request@ml.post.kek.jp)

EPICS IOC関連

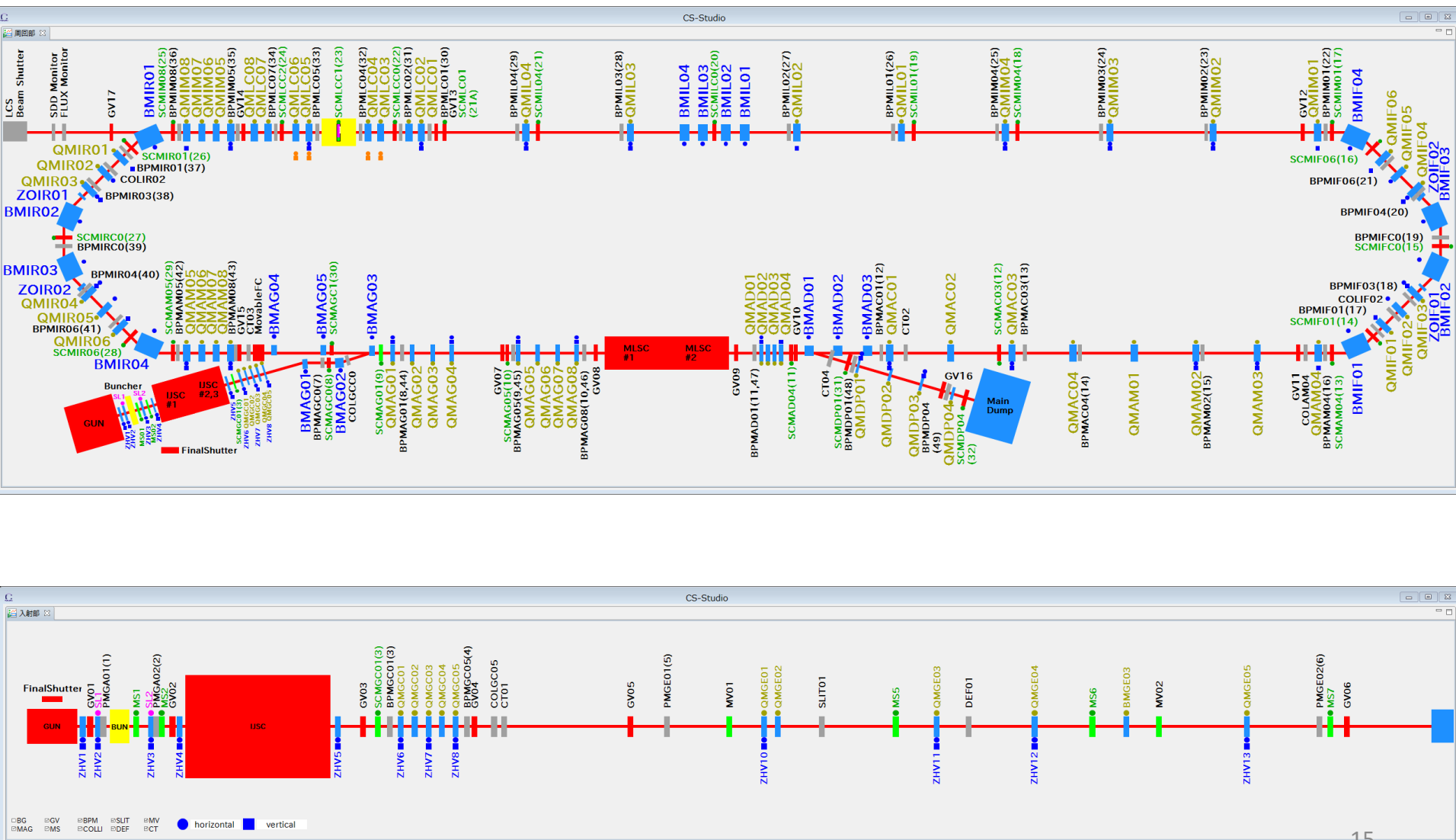
- [excasで試験用のCA Serverを実行する](#)
- [Timestampレコードについて](#)
- [compressレコードについて](#)
- [streamdeviceについて](#)
- [パルス出力を出したい](#)
- [Griffin Power MateをLinux&EPICSで使ってみる](#)
- [F3RP61ネタ集](#)
- [transferArrayレコードについて](#)
- [save/restore の使い方インストール方法と waveform の初期化例](#)

CSS 関連

- [フォント設定について](#)
- [Data Browserで表示されなかったら→IOCの時計合わせ](#)
- [BOY Examples をインストールしてもTable, Arrayの例が出てこない](#)

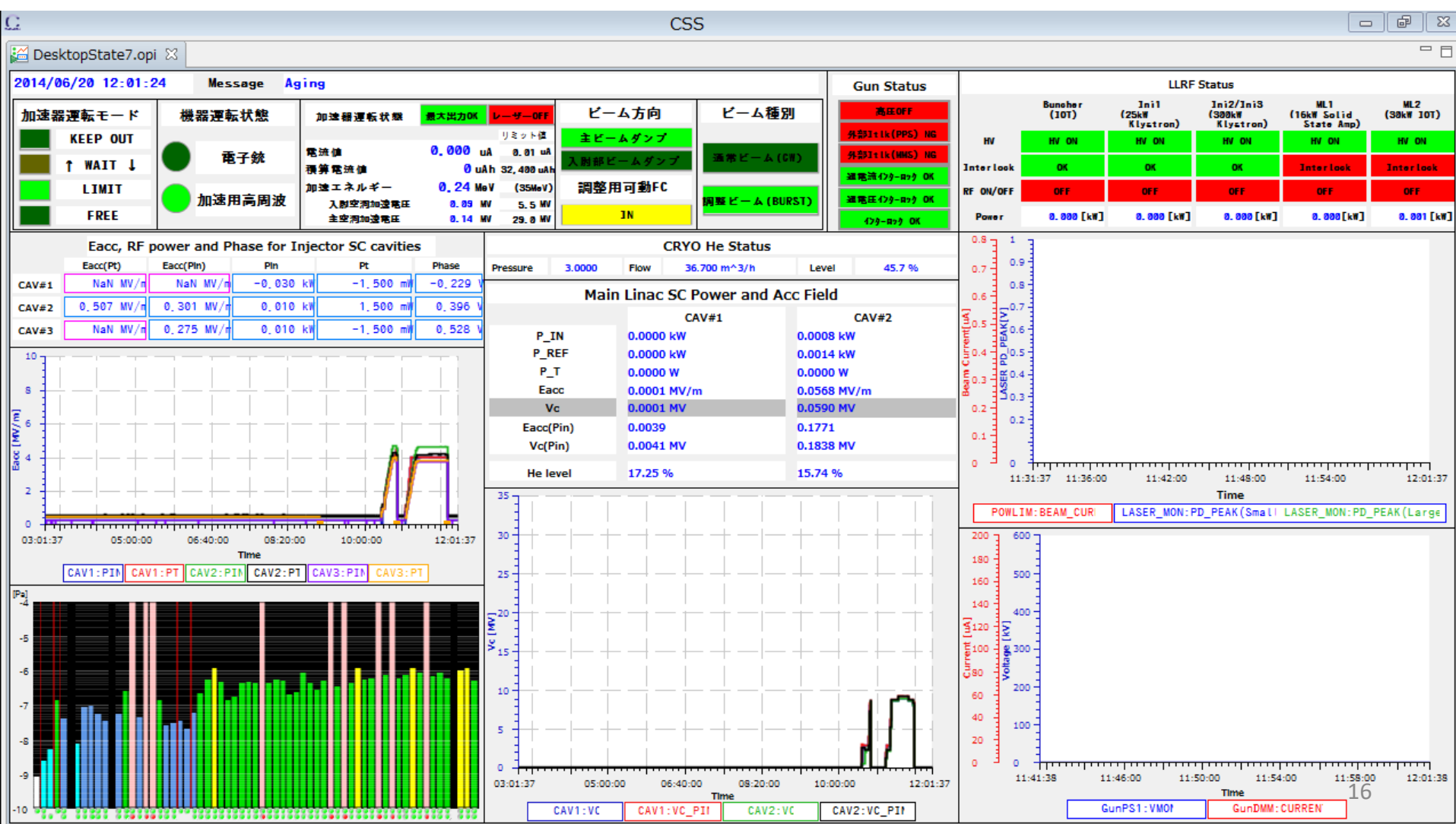
Machine Status Panel

- Figure



Status Panel Example

- Thanks for the Java environment, we can use Japanese on the panel.
 - nice feature for operator (not good for scientists from foreign countries)



Archive

- Almost 9,000 PVs are stored in archive

cERL

Archive Engine

Summary	
Version	3.2.1.201505261345
Description	cERL
HTTP Server	
State	RUNNING
Start Time	2015/08/25 15:16:58.164828722
Uptime	1.00 days
Workspace	/css/tmp/engcERL/
Groups	17
Channels	6900
Disconnected	1760
Batch Size	500 samples
Write Period	30 sec
Write State	OK
Last Written	2015/08/26 15:22:33.160811891
Write Count	26095 samples
Write Duration	3.2 sec
Idle Time	100.0 %
Memory	505.0 MB of 3555.5 MB used (14.2 %)

Disk usage:

2012 (1.7 TB)
2013 (3.5 TB)
2014 (4.5 TB)
2015 (6.1 TB)
2016 (3.0 TB)

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- Software for rapid prototype
- Hardware example : VME-Master

What is iBNCT?

- Location



map



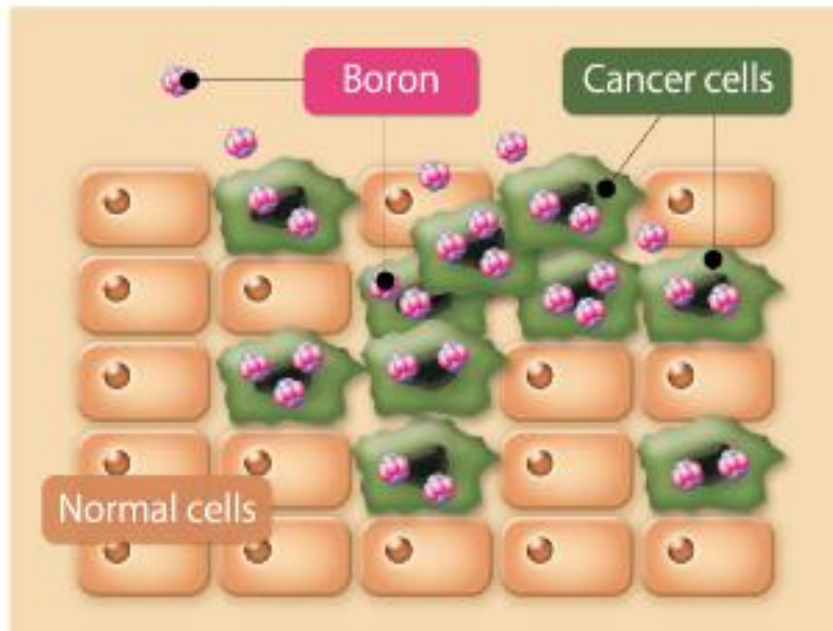
- iBNCT Location : near the entrance of J-PARC

What is iBNCT?

- Ibaraki Boron Neutron Capture Therapy
- Figures from : <http://bnct.kek.jp/eng/index.html>

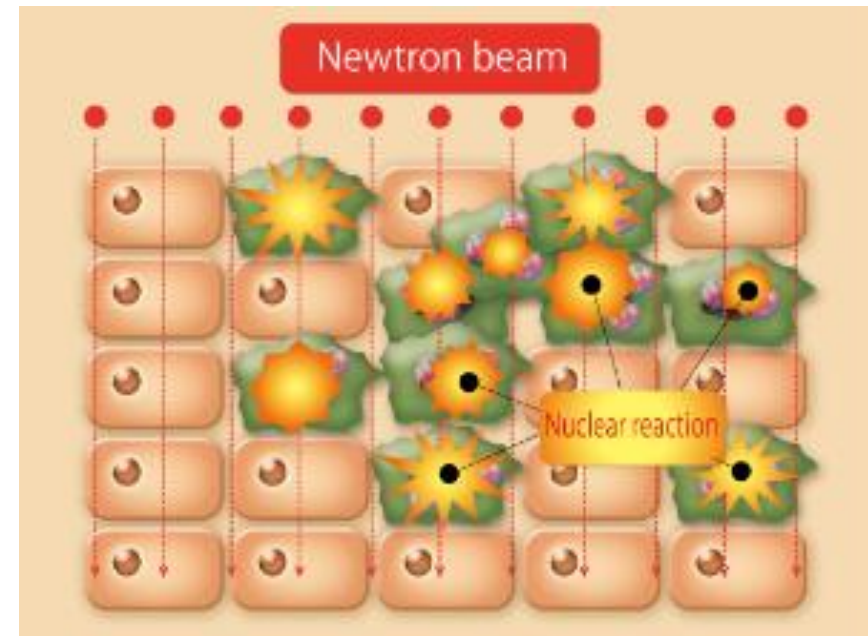
①Administer boron-containing drug:

a boron-containing drug that selectively accumulates in cancer cells is used.



②Neutron irradiation:

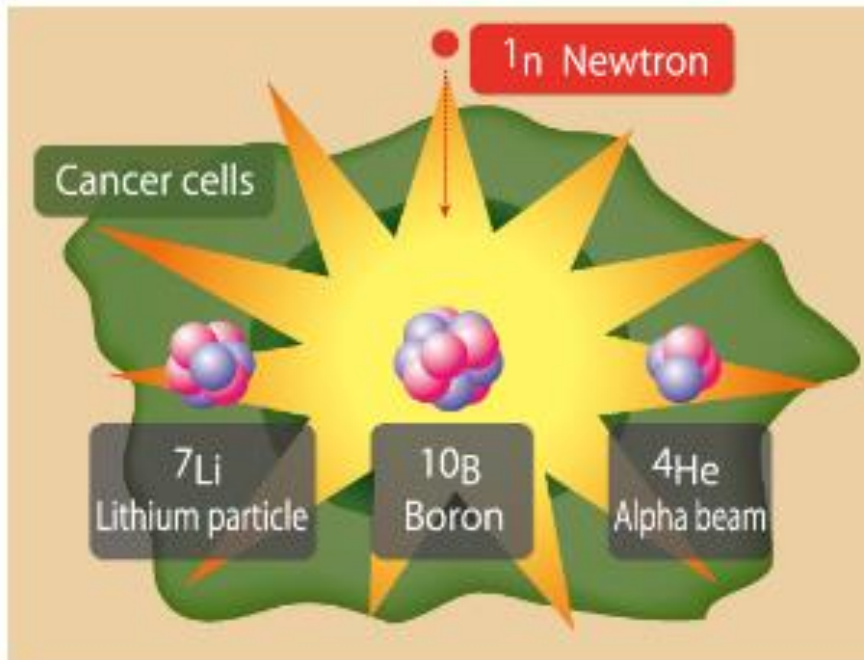
The affected site is irradiated with an energy-adjusted neutron beam.



Principle (cont.)

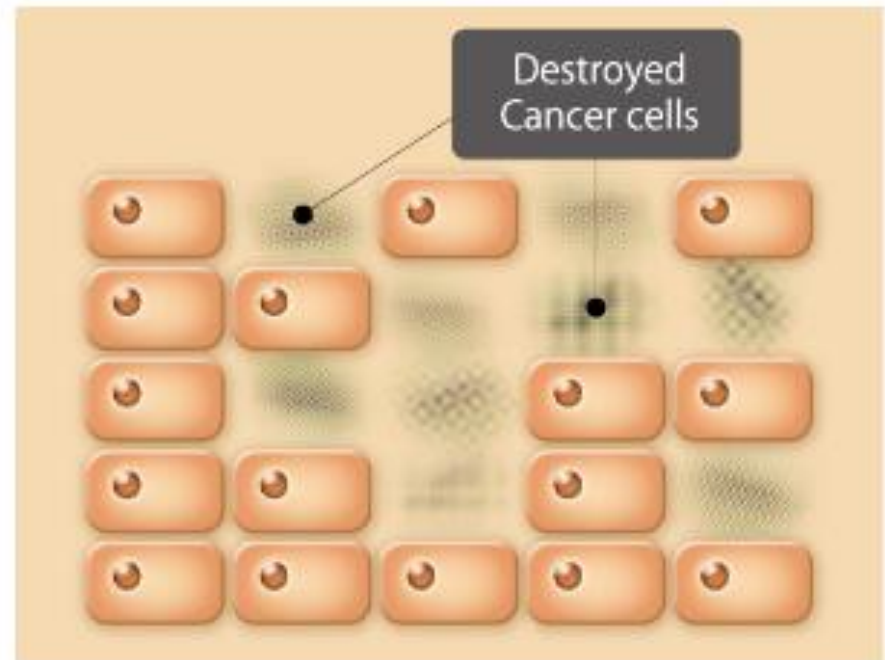
③ Neutrons react with boron:

emitted alpha beam and lithium particles destroy cancer cells.



④ Cancer cells are destroyed:

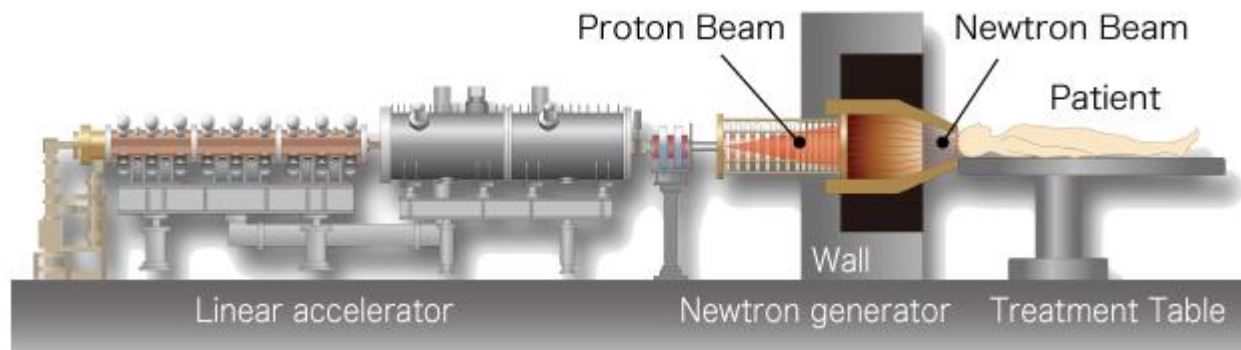
these particles only travel a distance of one cell width (about 10μm), allowing for cell-level treatment.



Brief History of BNCT

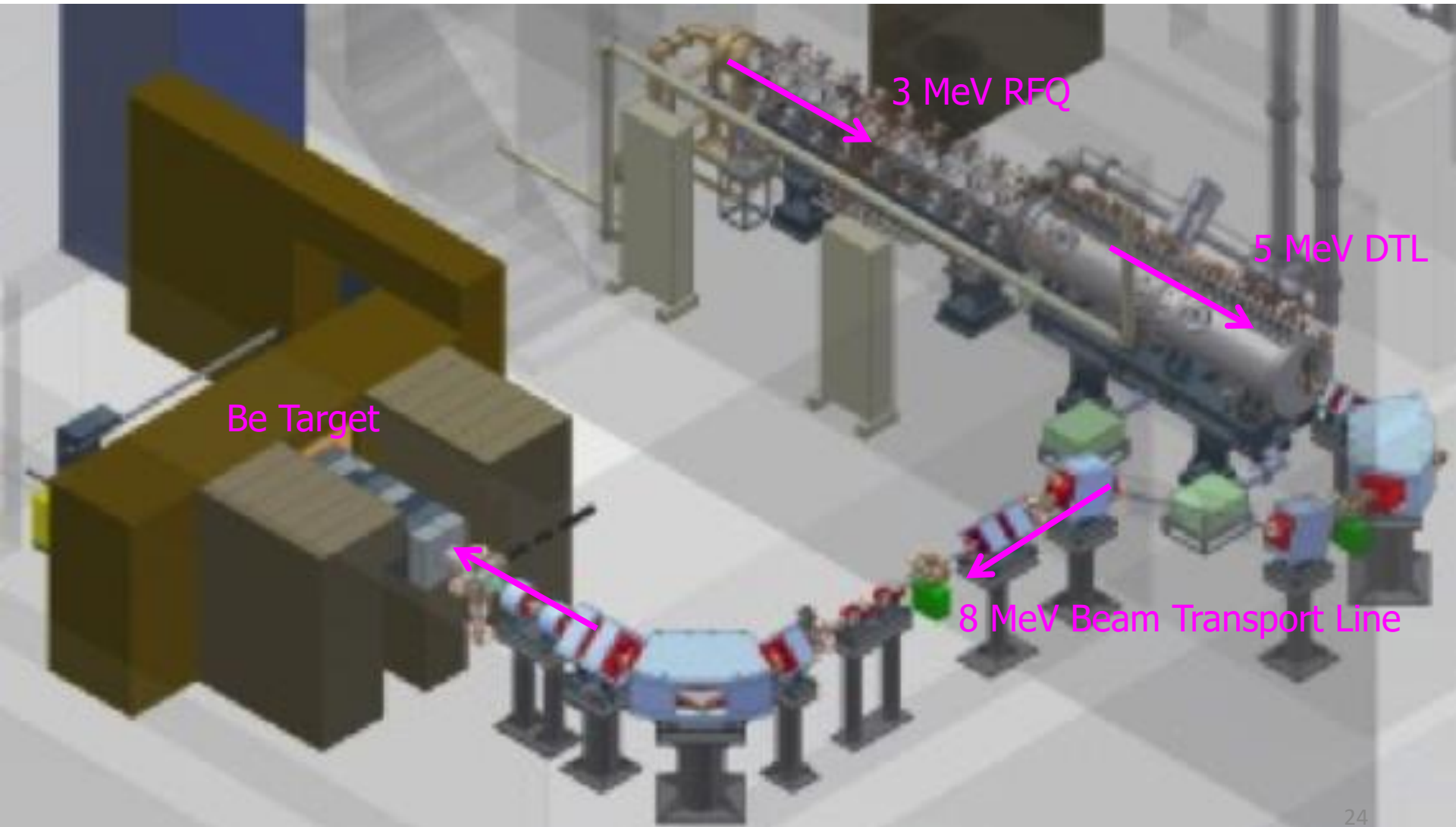
- KURRI is the leading facility
- Reactor-based BNCT → Accelerator-based BNCT [in the hospital](#)
- It is very difficult to develop new reactor-based facilities in Japan
- There are several candidates in energy, target material and moderator:
 - Cycrotron / Linac (RFQ or RFQ+DTL) : 2.5 MeV or 8 MeV or 30 MeV
 - Beryllium / Solid Lithium / Liquid Lithium
- There are no time to explain the detail today. Please refer to M. Yoshioka's talk at IPAC16 : "Review of Accelerator-based Boron Neutron Capture Therapy Machines", THXB01, Proc. IPAC2016, p 3171

Today, I would like to talk about control related topics of Ibaraki BNCT.
Machine layout: Ion Source + RFQ + DTL + (Transfer Line) + Be Target



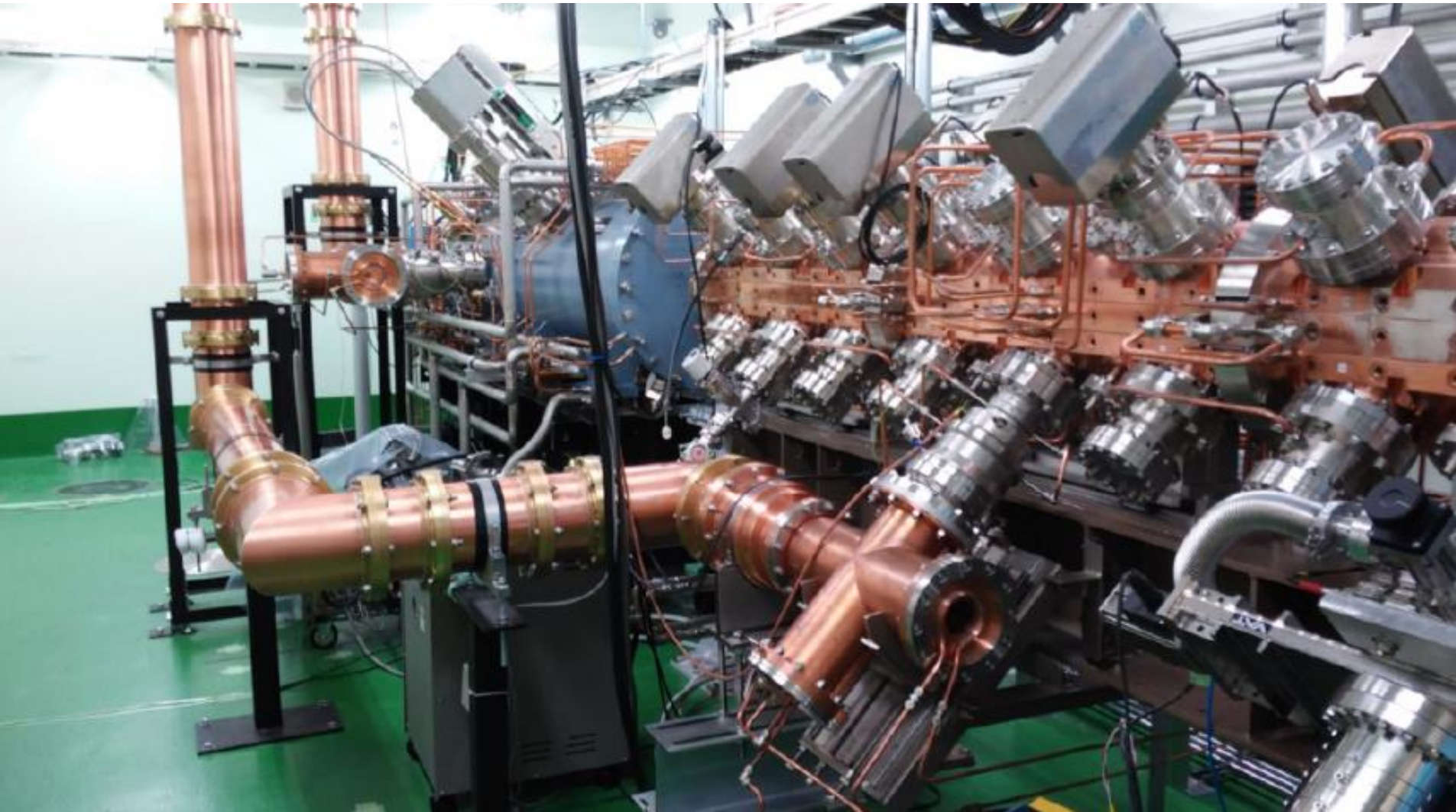
accelerator layout

50 keV Ion Source



Photo

- 3 MeV RFQ + 5 MeV DTL



Control room

- 2 PCs for Operation and beam tuning. Large (wall-mount) display for status



Control System

- Requirement for the control system is “Reliable System”
- Accelerator control system is developed by [Cosylab](#).
- First beam is reported in the Cosylab newsletter
 - T. Nakamoto and T. Zagar
 - http://www.cosylab.com/db/cosylab/file/controlsheets/controlsheets_2015-march-no22.pdf
- Excellent work done by the company
 - No major trouble in the basic control system
- I need to follow-up some software tools such as
 - Beam Loss monitors
 - Utilities for beam tuning
 - Software to share information : wiki, NAS, etc

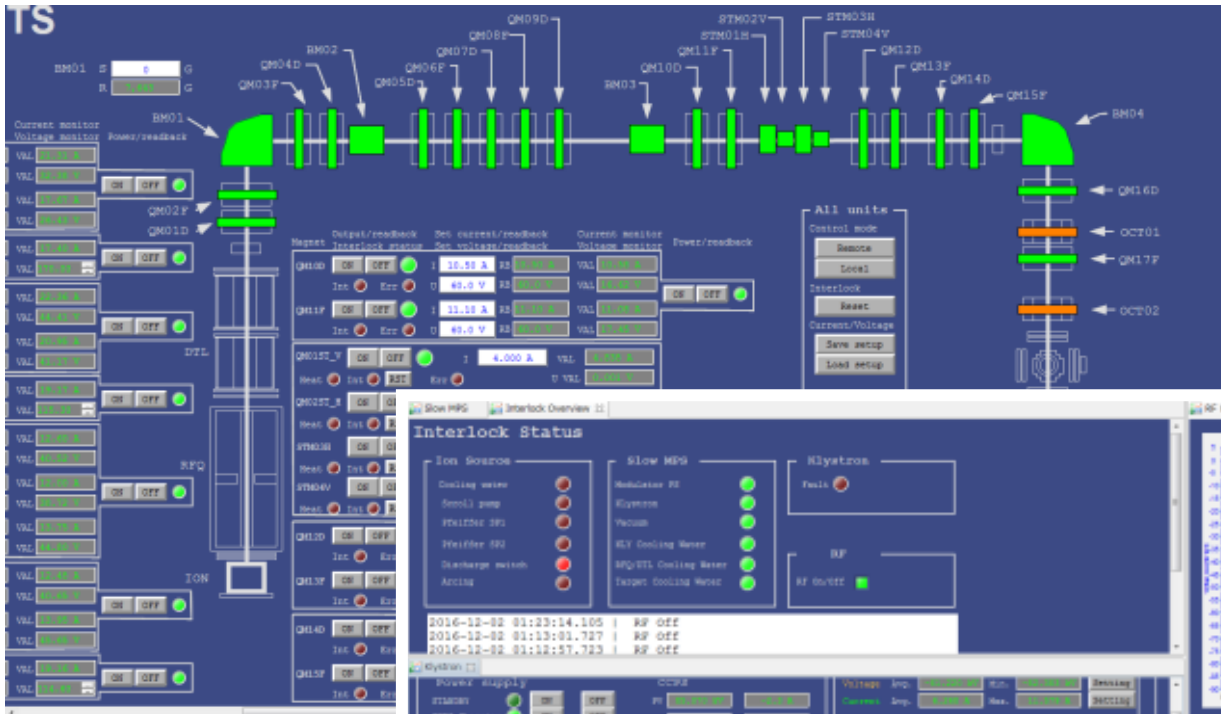
Fieldbus

- Yokogawa PLC
 - most of the accelerator equipment are controlled by PLC.
 - Ladder CPU + WideField (development environment)
- Yokogawa SL1000
 - CT, BPM, Loss Monitor, etc
 - VXI-11 protocol
- EVG/EVR (mrf) for timing system

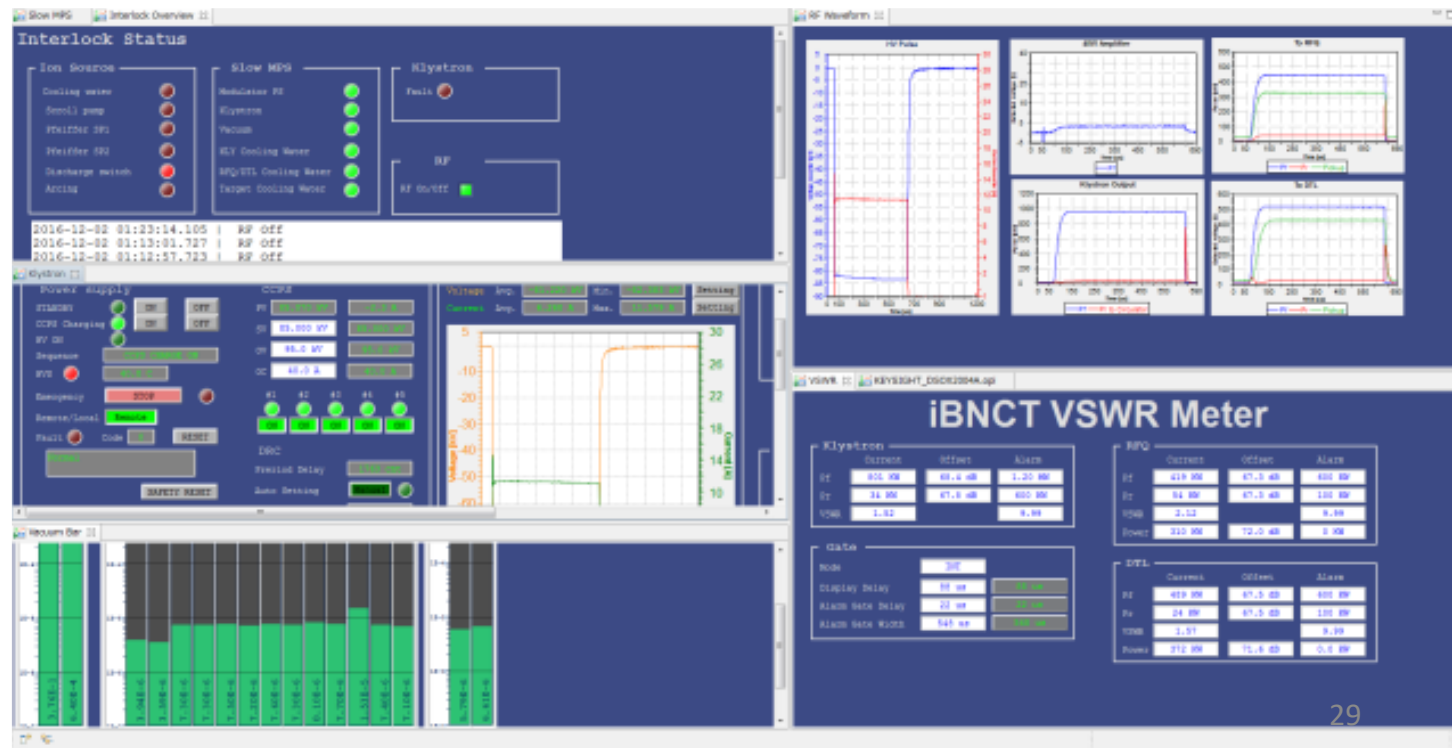


GUI Example

- Magnet status/direct set (Cosylab)



Status Panel (Cosylab)



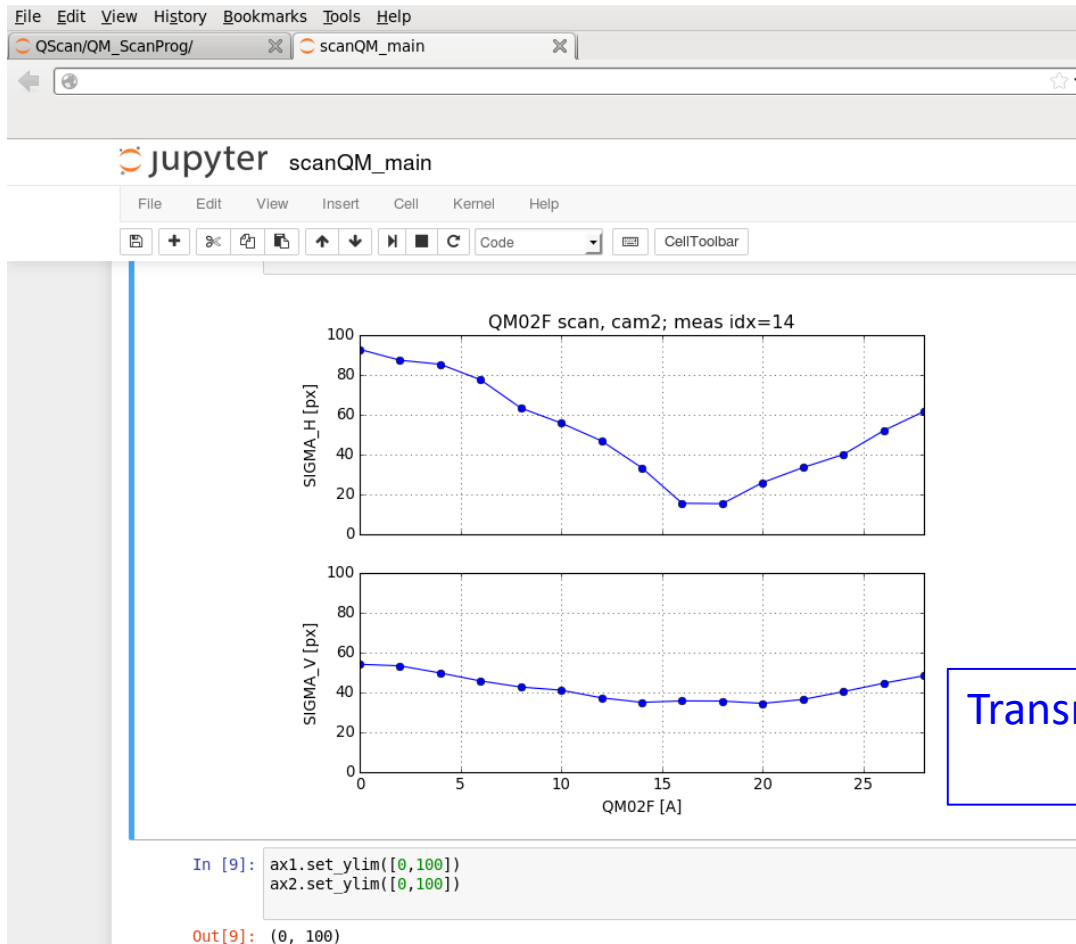
Number of PVs, Archiver, etc

Archive Engine

Summary	
Version	3.1.1.201305071351
Description	ibnct
HTTP Server	:4812
State	RUNNING
Start Time	2017/01/10 09:55:33
Uptime	123.07 days
Workspace	/workspace/
Groups	16
Channels	1615
Disconnected	16
Batch Size	500 samples
Write Period	30 sec
Write State	OK
Last Written	2017/05/13 11:37:06
Write Count	2914 samples
Write Duration	0.3 sec
Idle Time	100.0 %
Memory	4095.0 MB of 4095.0 MB used (100.0 %)

no disconn. channels during operation

Optics tuning (reduce beam loss)



Transmission rate after DTL → near 100%
(CT resolution)

save data



iBNCT passed the radiation facility
safety inspection in December 2016

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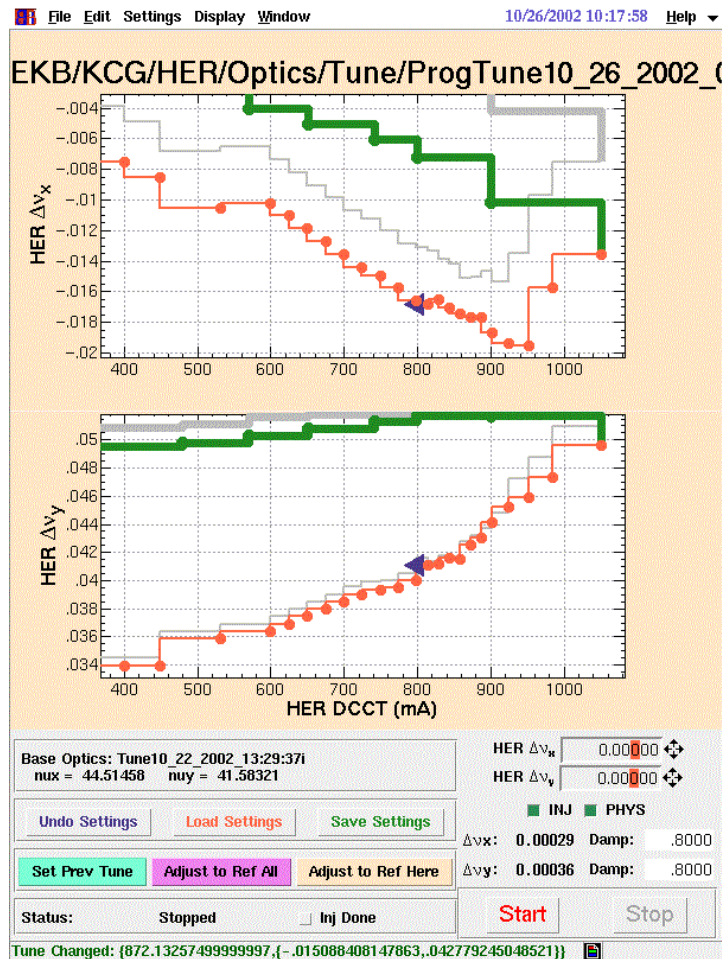
4. Commissioning, Tuning, Operation (for cERL and iBNCT)

- Example of tuning panel
- CSS as an operation manual (procedure)
- Software for rapid prototype
- Hardware example : VME-Master

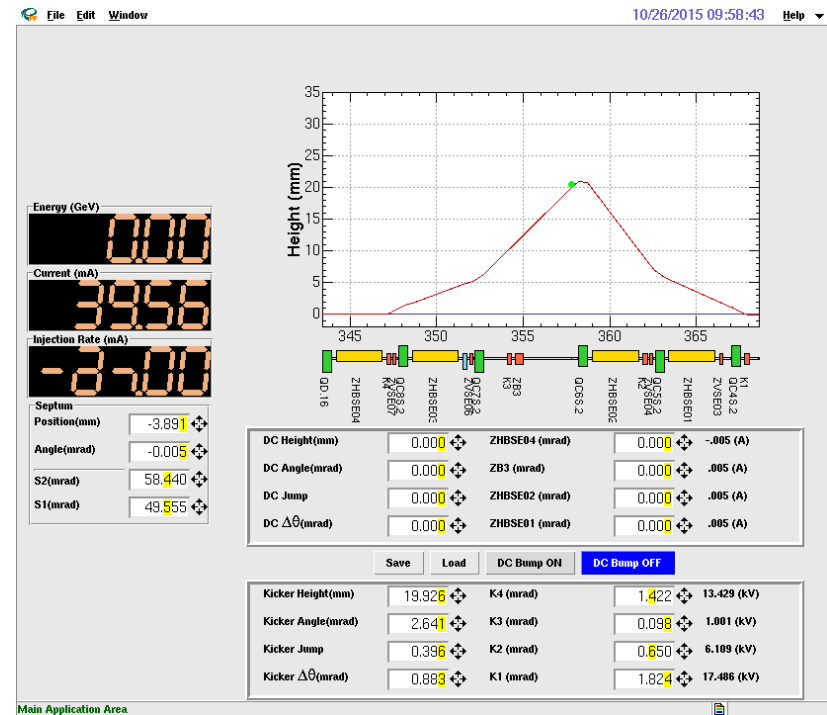
High Level Application : Software for beam tuning

- In case you need accelerator optics knowledge : Use SAD

KEKB Optics (Tune) Panel



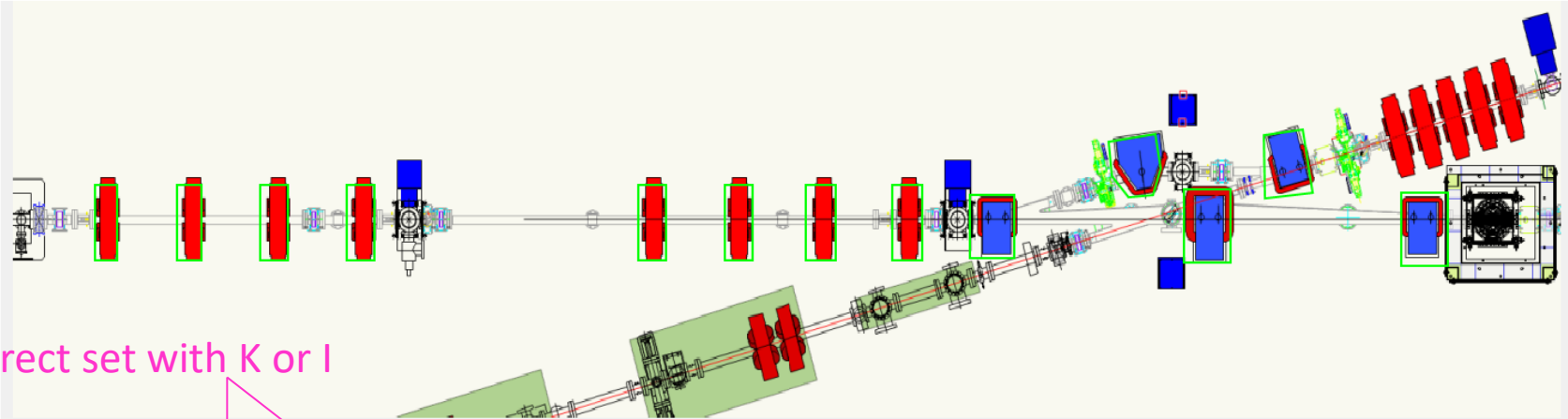
PF-AR Injection bump panel



other accelerator laboratories
may use elegant, matlab/AT, etc

Basic instruments control panel

Injection Diag Section1 Section2 Section3 Section4 Section5 Section6 Section7 Section8



Direct set with K or I

	Q			H			V		
	K set	I set	I mon	K set	I set	I mon	K set	I set	I mon
QMAG01	0 0.050	0 0.050	-0.000	0 0.050	0 0.050	-0.025	0 0.050	0 0.050	0.029
QMAG02	0 0.050	0 0.050	0.000						
QMAG03	0 0.050	0 0.050	0.001						
QMAG04	0 0.050	0 0.050	-0.009	0 0.050	0 0.050	-0.024	0 0.050	0 0.050	-0.025
QMAG05	0 0.050	0 0.050	-0.002	0 0.050	0 0.050	0.029	0 0.050	0 0.050	-0.007
QMAG06	0 0.050	0 0.050	0.013						
QMAG07	0 0.050	0 0.050	0.003						
QMAG08	0 0.050	0 0.050	-0.002	0 0.050	0 0.050	0.003	0 0.050	0 0.050	-0.013
BMAGPS1	0 0.050	0 0.050	-0.002						
BMAGPS2	0 0.050	0 0.050	-0.002						
ZHBAG01	0 0.050	0 0.050	-0.018						
ZHBAG02	0 0.050	0 0.050	-0.026						
ZHBAG03	0 0.050	0 0.050	0.006						
ZHBAG04	0 0.050	0 0.050	0.031						
ZHBAG05	0 0.050	0 0.050	0.029						

Direct

Diff

monitor value

save/restore

CSS

SaveRestoreMain.opi

Y:\data¥SaveRestore¥magnet¥2014¥20140620_232028.log

Comment

new optics for 7.7 pC, final

Author

Miyajima and Honda

Date

2014/06/20 23:20:28

Save

Restore

search

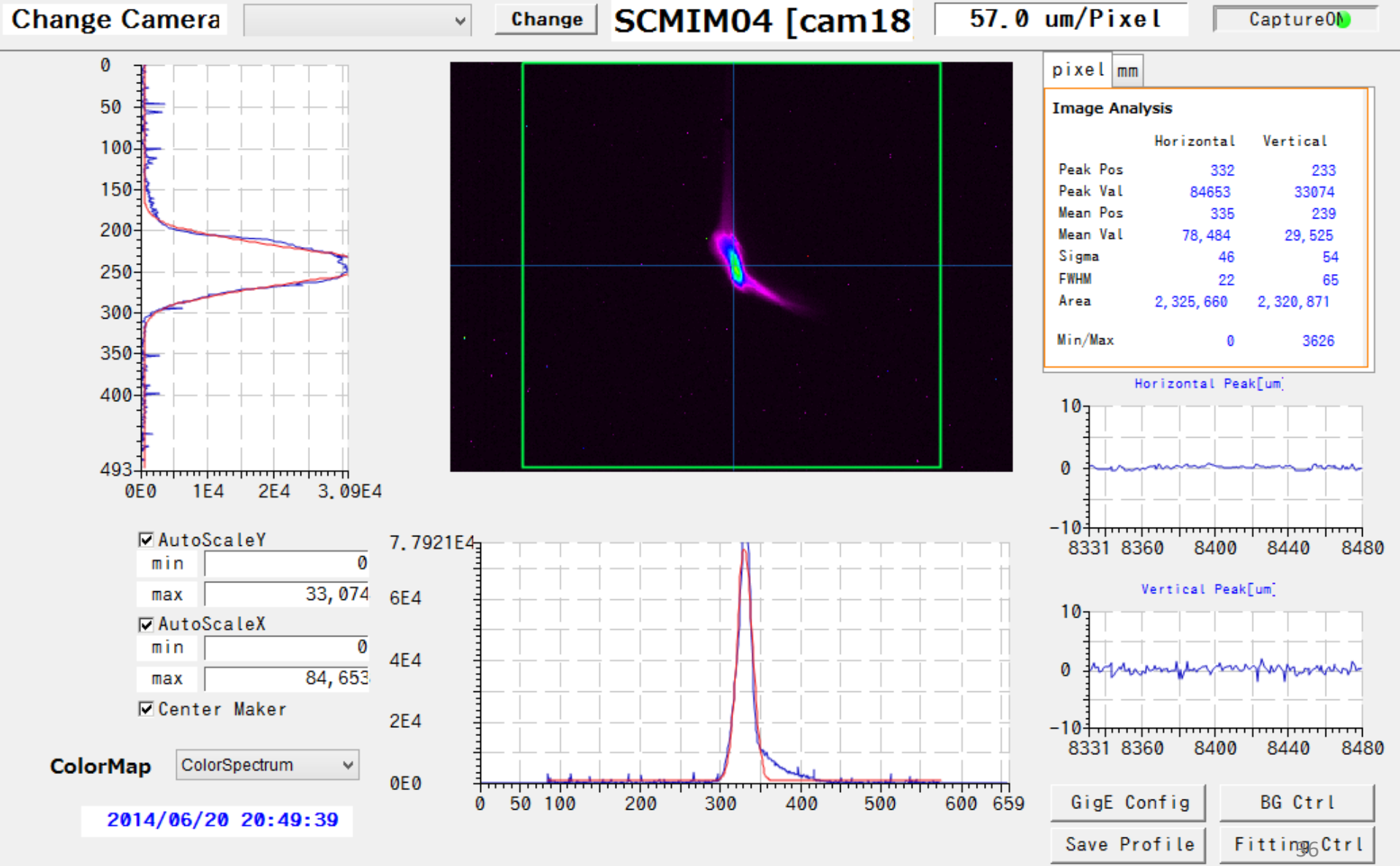
sort

None

RESET

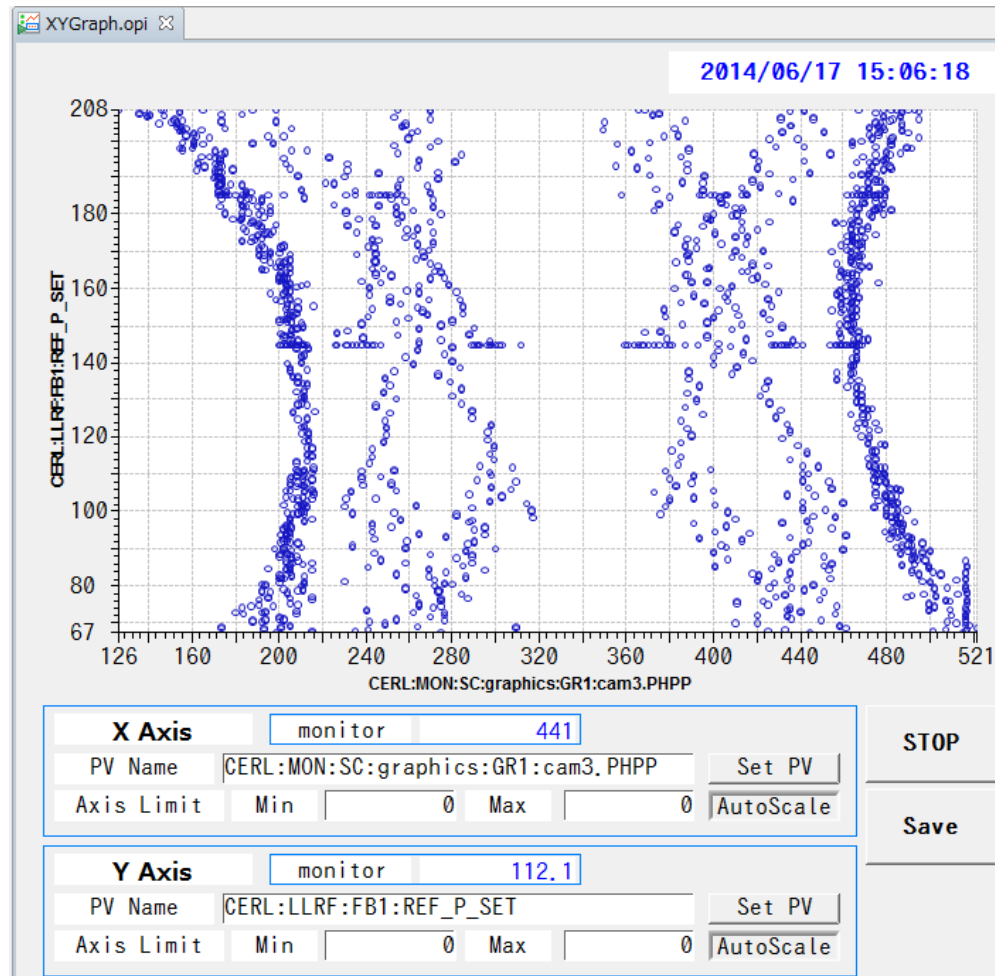
Record	Snap Val	Current	Current-Snap	Snap Moni	Monitor	Monitor-Snap
CERL:MAG:ZH04:IDIR	-0.037	0.0	0.03700	-0.03699	0.02497	0.06196
CERL:MAG:ZV04:IDIR	-4.07	0.0	4.07000	-4.06968	-0.00354	4.06614
CERL:MAG:ZH05:IDIR	0.18	0.0	-0.18000	0.18013	0.02809	-0.15204
CERL:MAG:ZV05:IDIR	0.485	0.0	-0.48500	0.48492	-0.0265	-0.51142
CERL:MAG:QMGC01:IDIR	0.1052991...	0.0	-0.10530	0.10549	-0.01064	-0.11613
CERL:MAG:ZH06:IDIR	-2.65	0.0	2.65000	-2.64978	0.0224	2.67218
CERL:MAG:ZV06:IDIR	2.05	0.0	-2.05000	2.04909	0.02451	-2.02458
CERL:MAG:QMGC03:IDIR	-0.234244...	0.0	0.23424	-0.23404	-0.00397	0.23007
CERL:MAG:ZH07:IDIR	0.24	0.0	-0.24000	0.23968	0.01921	-0.22047
CERL:MAG:ZV07:IDIR	-0.06	0.0	0.06000	-0.06004	0.02959	0.08963
CERL:MAG:QMGC05:IDIR	0.0549	0.0	-0.05490	0.05493	-0.0002	-0.05513
CERL:MAG:ZH08:IDIR	0.9	0.0	-0.90000	0.89998	-0.02466	-0.92464
CERL:MAG:ZV08:IDIR	1.47	0.0	-1.47000	1.46985	-0.02618	-1.49603
CERL:MAG:QMGC02:IDIR	0.1099317...	0.0	-0.10993	0.10953	-0.00357	-0.11310

Screen Monitor



X-Y plot OPI : (example : RF Phase scan)

- General-purpose plot tool
 - main part is written CSS python script
 - disadvantage : difficult to move newer version of CSS! → should be implemented in software sequencer or other IOC



CSS as operation manual?

- Operator (non-programmer, non- accelerator Physicist) can create panels.
- I surprised they start to create “operator manual” using CSS.
- Using “Japanese” is mandatory for them

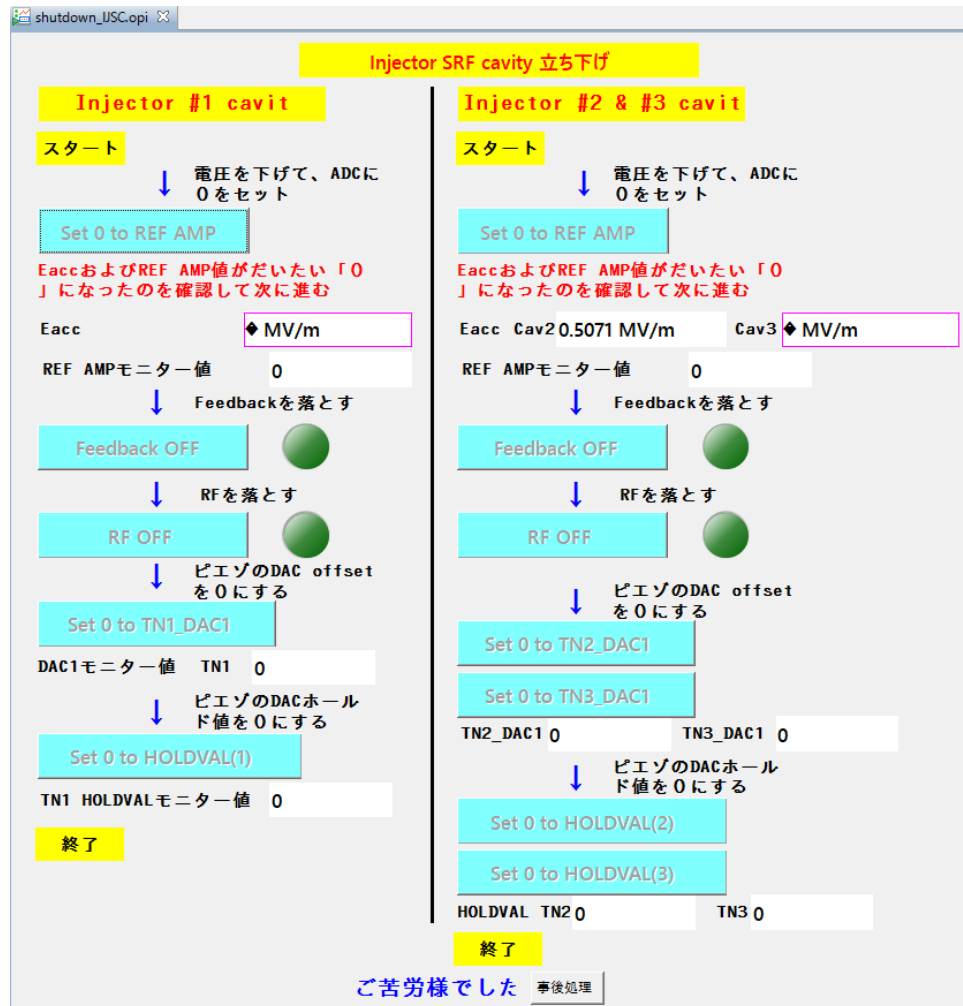


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- Hardware example : VME-Master

IPython (Jupyter) Notebook

- Suitable for equipment control that does not need Accelerator optics.
- IPython core is running on server machine, client use web browser only.
- Intensively used in cERL and iBNCT

The screenshot displays the IPython Notebook web interface in a browser window. The address bar shows `ipython.org/notebook.html`. The main heading is **IP[y]: IPython Interactive Computing**, with navigation links for [Install](#), [Documentation](#), [Project](#), [Jupyter](#), [News](#), [Cite](#), and [Donate](#).

The IPython Notebook

The IPython Notebook is an interactive computational environment, in which you can combine code execution, rich text, mathematics, plots and rich media, as shown in this example session:

Simple spectral analysis

An illustration of the Discrete Fourier Transform:

$$X_k = \sum_{n=0}^{N-1} x_n e^{-j2\pi k n / N} \quad k = 0, \dots, N-1$$

using windowing, to reveal the frequency content of a sound signal.

We begin by loading a dataset using SciPy's audio file support:

```
In [1]: from scipy.io import wavfile
data, sr = wavfile.read('test_audio.wav')
```

And we can easily view its spectral structure using matplotlib's builtin spectrogram routine:

```
In [2]: fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(10, 4))
ax1.plot(data) ax1.set_title('Raw audio signal')
ax2.spectrogram(data) ax2.set_title('Spectrogram')
```

The figure shows two plots: 'Raw audio signal' (a time-domain waveform) and 'Spectrogram' (a frequency-time plot).

NOTEBOOK VIEWER

Share your notebooks

COMMUNITY

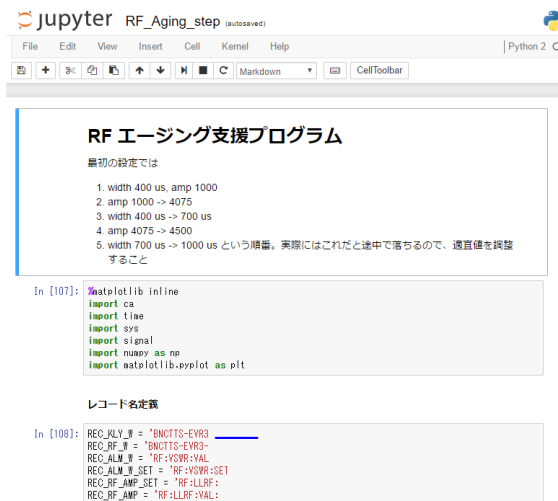
- [Stack Overflow](#)
- [Mailing list](#)
- [File a bug](#)
- [Reddit](#)

[Tweet](#) 648

FOR DEVELOPERS

Rapid prototyping with IPython Notebook

- ex: RF conditioning and DTL tuner (slow) feedback control for iBNCT
- Need to adjust input voltage and pulse height, repetition rate, etc.
 - monitoring tuner position, RF frequency, power, and many other parameters.
 - Some patterns have been tried at the beginning.
 - “Quick and Dirty” approach required
- IPython Notebook has nice feature such as
 - easy to understand (script).
 - can execute a part (block) or whole script
- After the parameters are fixed, the script is migrated to EPICS sequencer, then create a CSS panel.
- Notebook is used like a “requirement definition document” + “Prototype”.



The screenshot shows a Jupyter Notebook window titled "jupyter RF_Aging_step (autosaved)". The interface includes a menu bar (File, Edit, View, Insert, Cell, Kernel, Help) and a toolbar. The main content area displays a Japanese title "RF エージング支援プログラム" and a list of five steps for initial stabilization. Below the text, there are two code blocks. The first block, labeled "In [107]:", contains imports for matplotlib, ca, time, sys, signal, numpy, and np, along with a plot command. The second block, labeled "In [108]:", contains a series of EPICS record assignments for RF parameters.

```
RF エージング支援プログラム

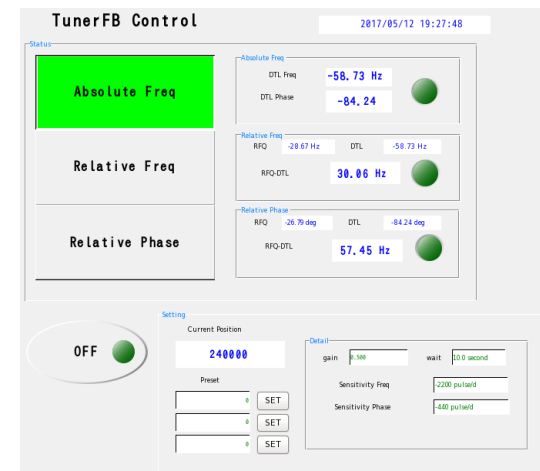
最初の設定では

1. width 400 us, amp 1000
2. amp 1000 -> 4075
3. width 400 us -> 700 us
4. amp 4075 -> 4500
5. width 700 us -> 1000 us という順番。実際にはこれだと途中で落ちるので、適宜値を調整
   すること

In [107]: %matplotlib inline
import ca
import time
import sys
import signal
import numpy as np
import matplotlib.pyplot as plt

レコード名定義

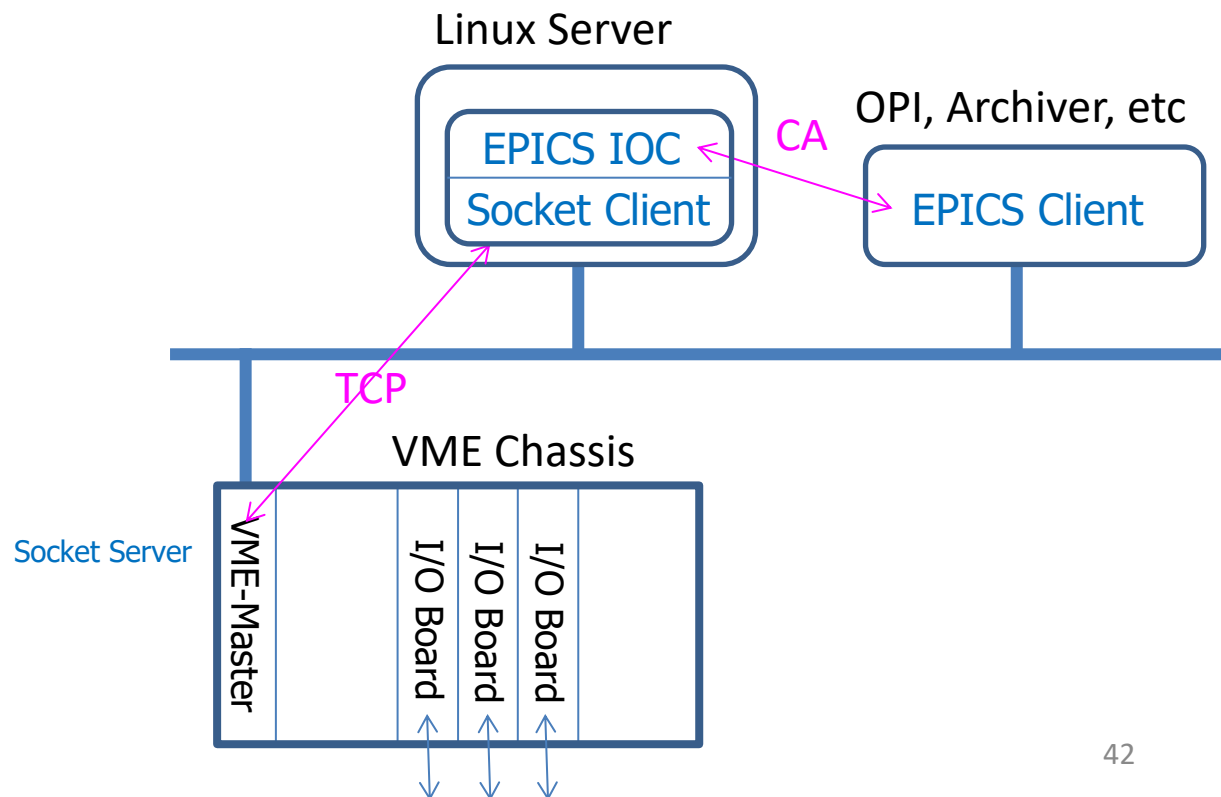
In [108]: REC_KLY_M = 'ENCTTS-EVR3
REC_RF_M = 'ENCTTS-EVR3-
REC_ALW_M = 'RF-VQVR:VAL
REC_ALW_SET = 'RF-VQVR:SET
REC_RFAMP_SET = 'RF-LLRF:
REC_RFAMP = 'RF-LLRF:VAL:
```



Misc. Hardware : VME-Master

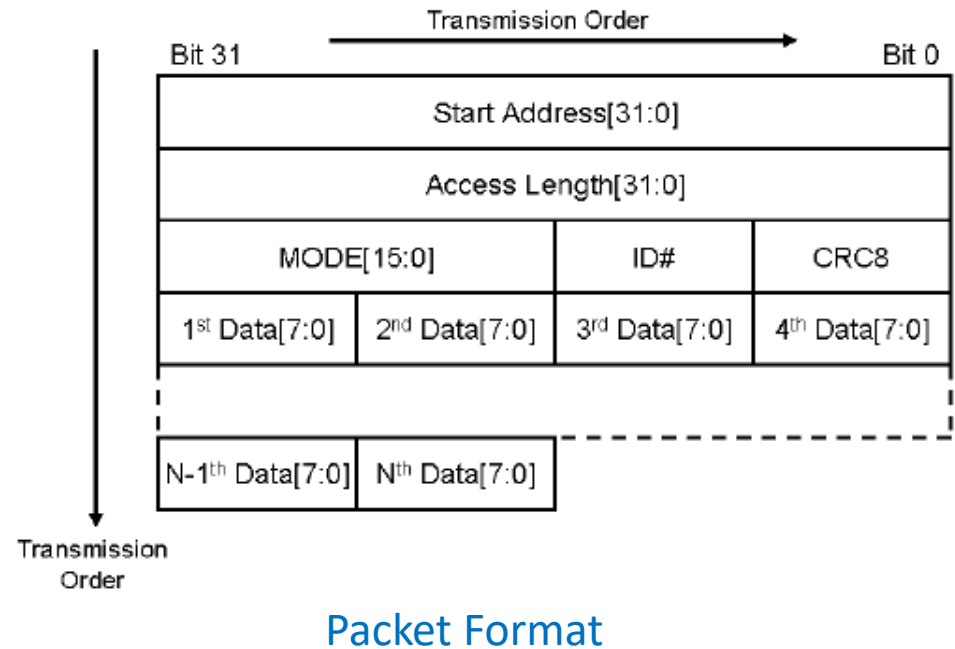
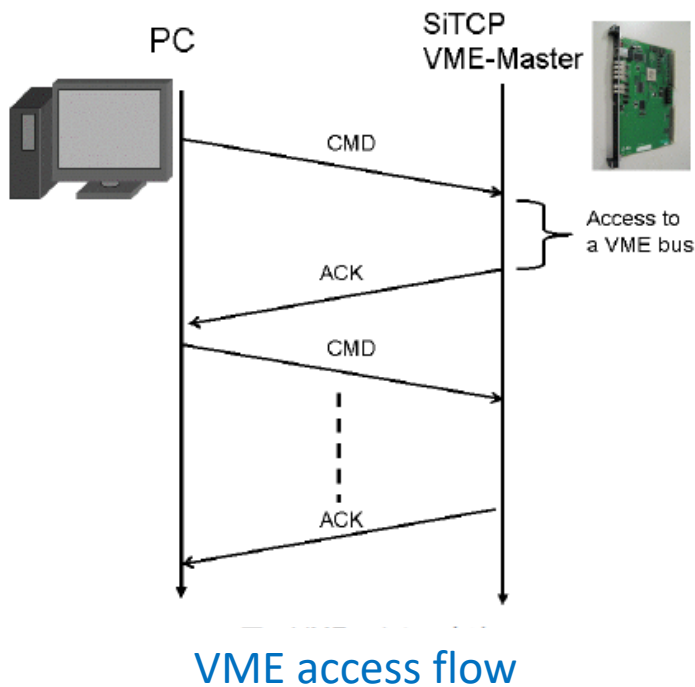
- Commercial Product of “BeeBeans Technologies” Co.
 - <http://www.bbtech.co.jp/> (KEK Venture Company)
- SiTCP (Silicon TCP in FPGA) for communication. **No operating system.**

We can use VME boards like a network-attached I/O module.
Standard “Stream Device/Asyn” for communication.



Outline of operation procedure

- Please refer to the manual for details.



Start Address :	VME Address
Access Length :	data length
MODE:	VME access mode read/write, A16/24/32, etc
ID#:	for verify CMD packet and ACK packet
CRC8:	for verify packet

protocol file example

- read pulse counter

```
# Example protocol file for VME-Master SiTCP
# REPIC 100MHz OCTAL CALER
#
addr      = 0x00 0x10 0x06 0x00;  # board base address 0x100600
leng      = 0x00 0x00 0x00 0x04;  # data length 4 byte
mode      = 0x05 0x40;             # mode
mode_r    = 0x05 0x48;
id        = 0x01;
#
getCounter {
    out $addr $leng $mode $id "%<crc8a>";
    in  $addr $leng $mode_r $id $crc_r "%4D";
}
```

Default CRC8 checksum uses different initial value from SiTCP format.
We defined a new checksum pseudo-converter.

Comments on VME-Master

- VME-Master has been used for cERL and iBNCT
- Very good for small experiment because...
 - We can utilize many old VME boards
 - No need to setup development environment . Just use a socket communication.
- Latest version can support VME **bus interrupt**.
- Fast enough for non-realtime application
- We plan to use the VME-Master board to replace magnet power-supply controller for KEK-PF electron storage ring in coming summer.
 - Present : Linux CPU (IOC, non-realtime) + VME Bus-Bridge
 - Total 10 VME chassis

Summary

- Introduction of two accelerator control system
 - cERL
 - iBNCT
- Overview of control room, field bus, other hardware
- Software for accelerator commissioning, tuning, operation
 - EPICS Application
 - CSS GUI
 - IPython notebook
- Some hardware (example : VME-Master)
- Other software/hardware (excluded from today's talk)
 - wiki for internal information sharing
 - Status display (CATV-like)
 - HipChat
 - Beaglebone Black as ioc
 - Yokogawa F3-HA12 module (12 channel 16 bit ADC)
 - and more