EPICS-based control system for compact-ERL and iBNCT

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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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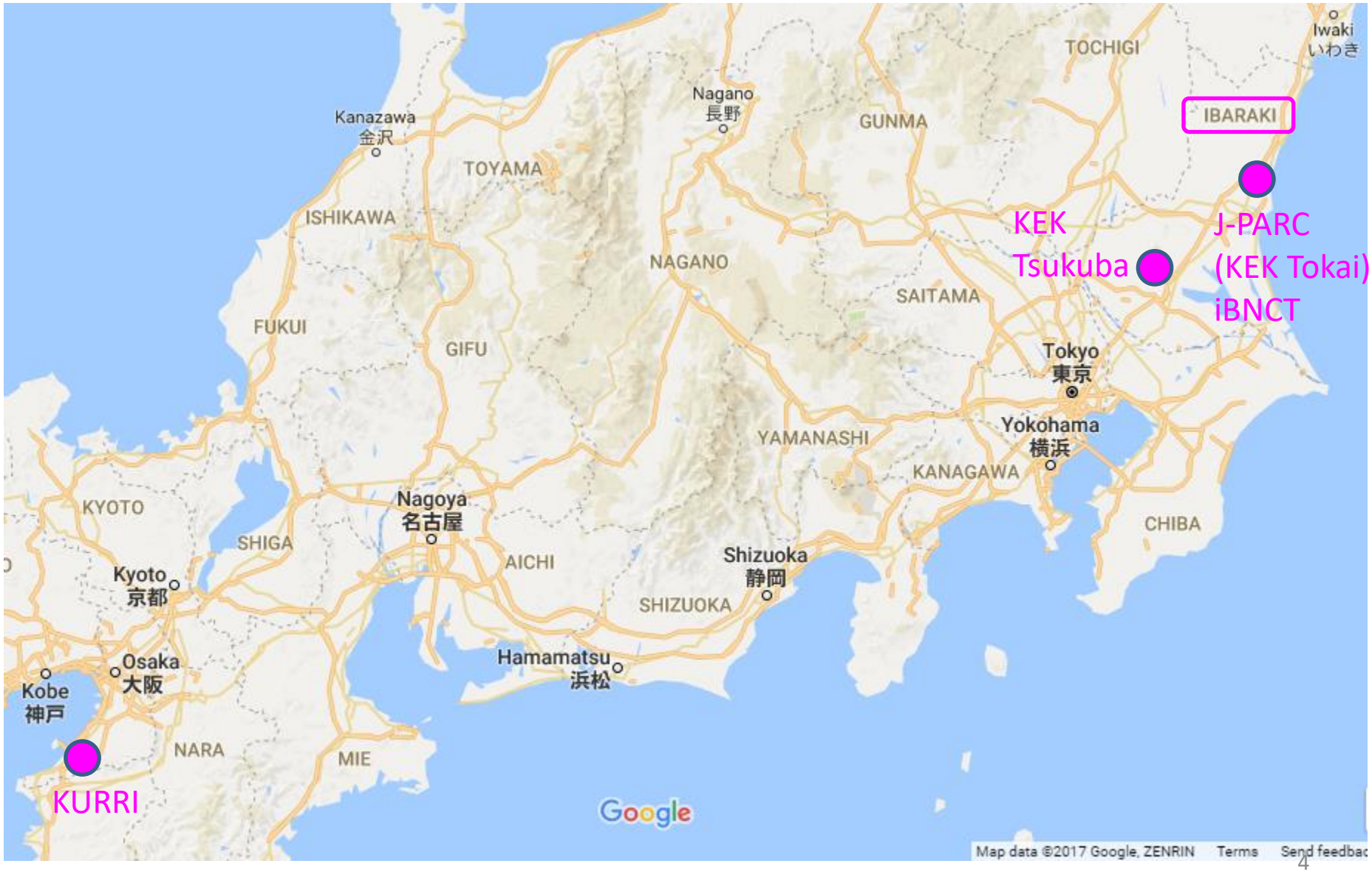
Location


Iwaki
いわき
TOCHIGI
IBARAKI
Nagano
長野
Kanazawa
金沢
GUNMA
TOYAMA
ISHIKAWA
KEK
Tsukuba
J-PARC
(KEK Tokai)
iBNCT
NAGANO
SAITAMA
FUKUI
GIFU
Tokyo
東京
Yokohama
横浜
YAMANASHI
KANAGAWA
KYOTO
Nagoya
名古屋
CHIBA
SHIGA
AICHI
Shizuoka
静岡
Kyoto
京都
SHIZUOKA
Hamamatsu
浜松
Osaka
大阪
Kobe
神戸
NARA
MIE
KURRI
Google
Map data ©2017 Google, ZENRIN
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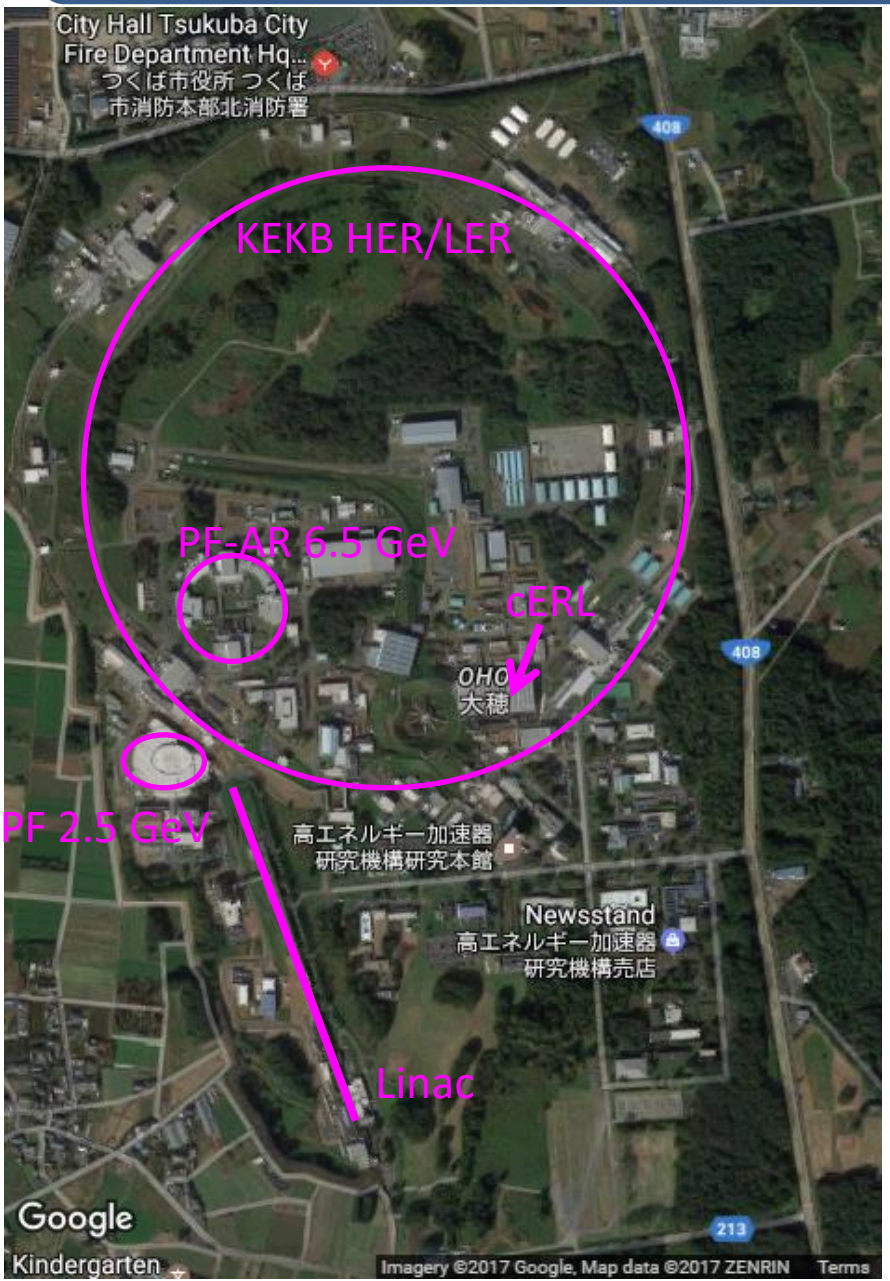
Send feedbac

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)

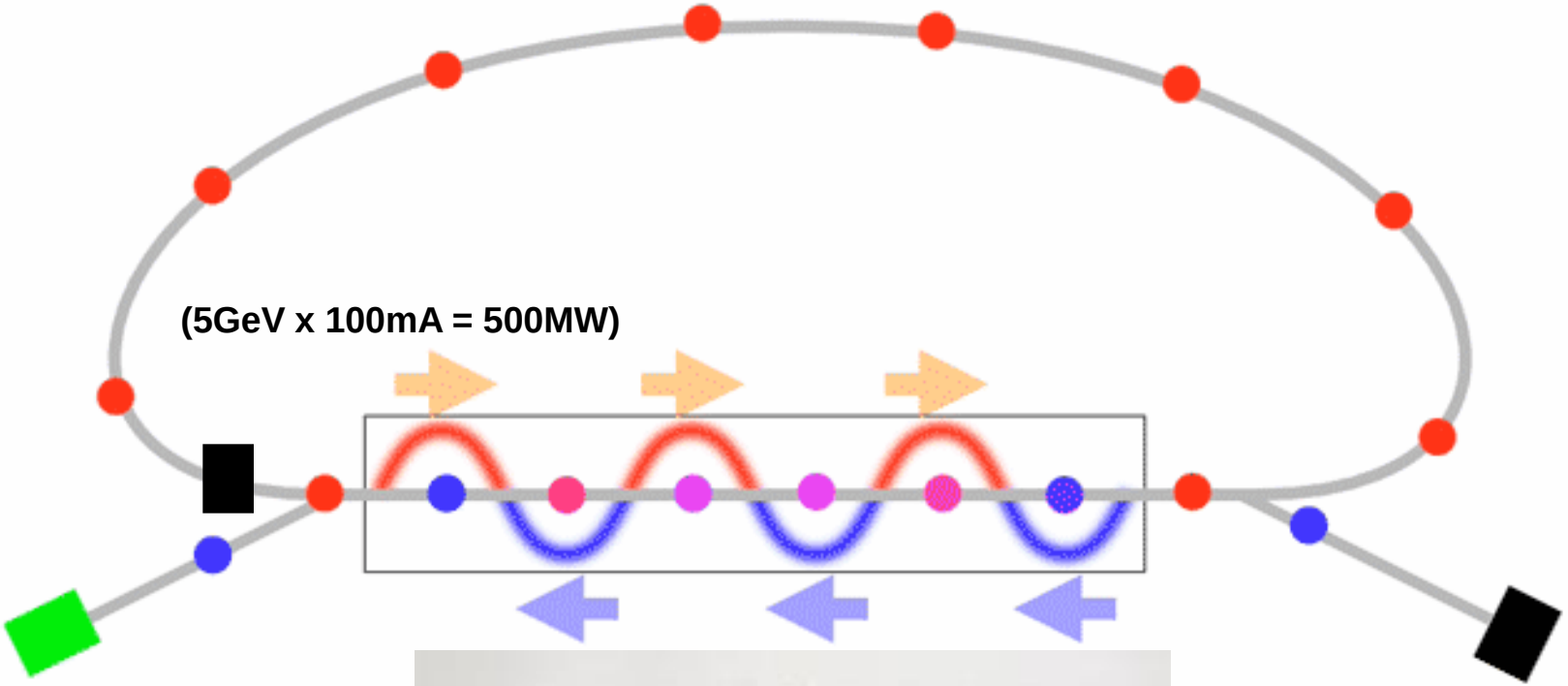
(Relatively) compact accelerator:

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



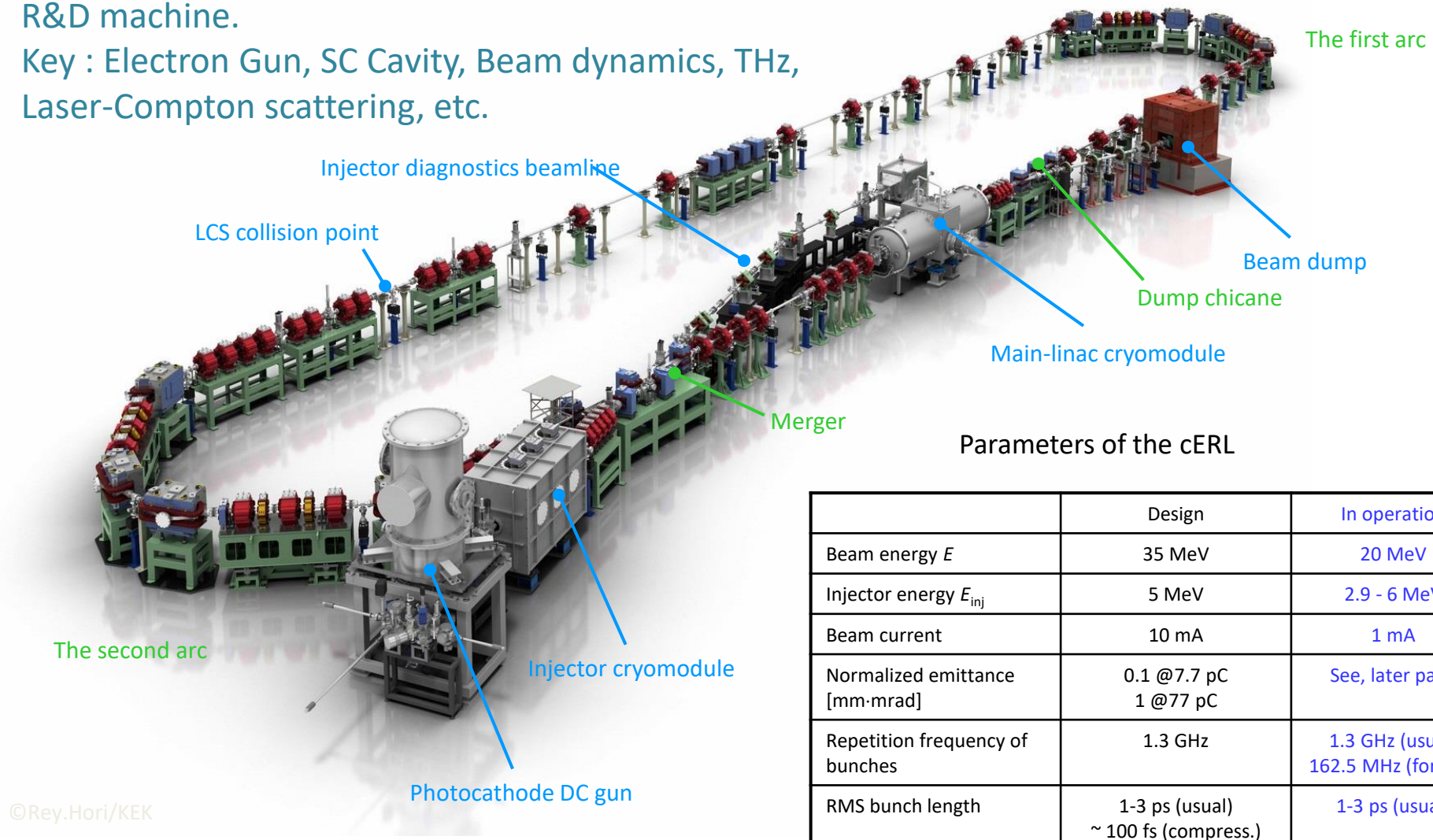
High brilliant electron gun

Super conducting cavity for Acceleration and deceleration

Beam Dump
(10MeV x 100mA = 1MW)

compact ERL at KEK

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

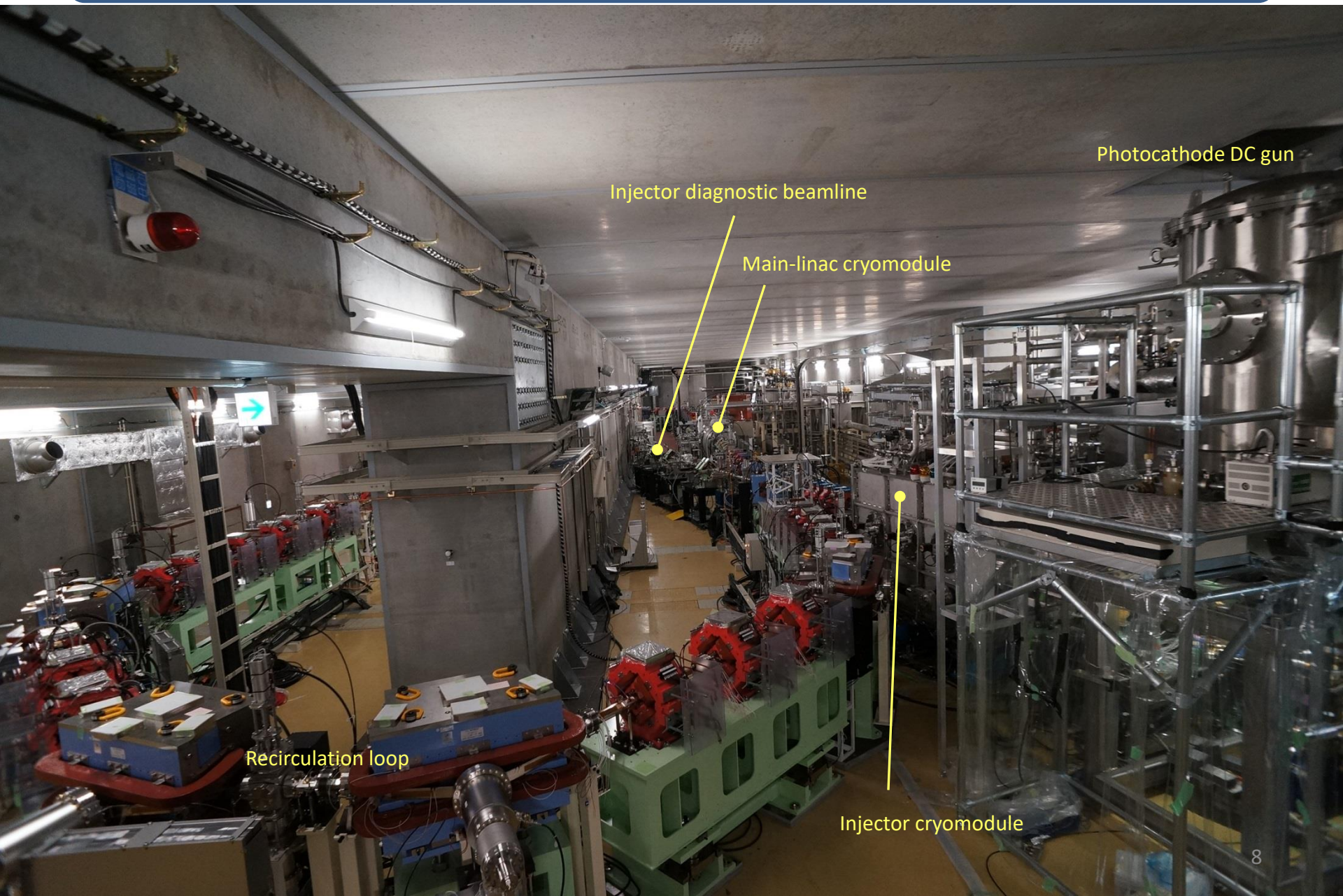


Circumference: ~ 90 m

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

Picture of cERL



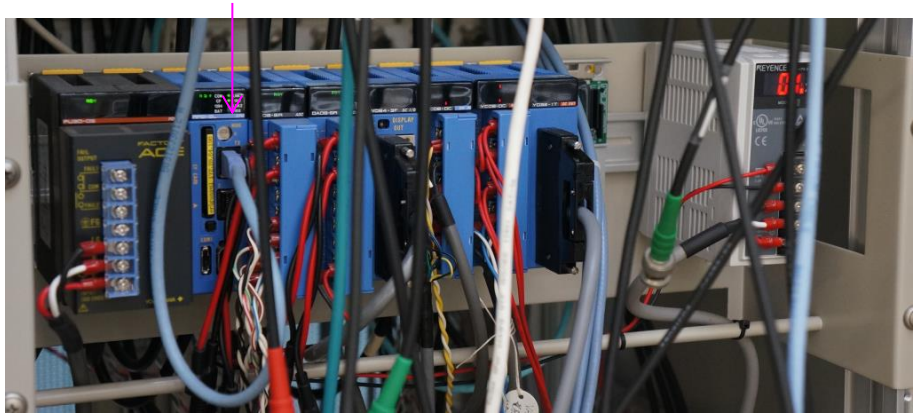
Control System : "Standard" Field Bus

- 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

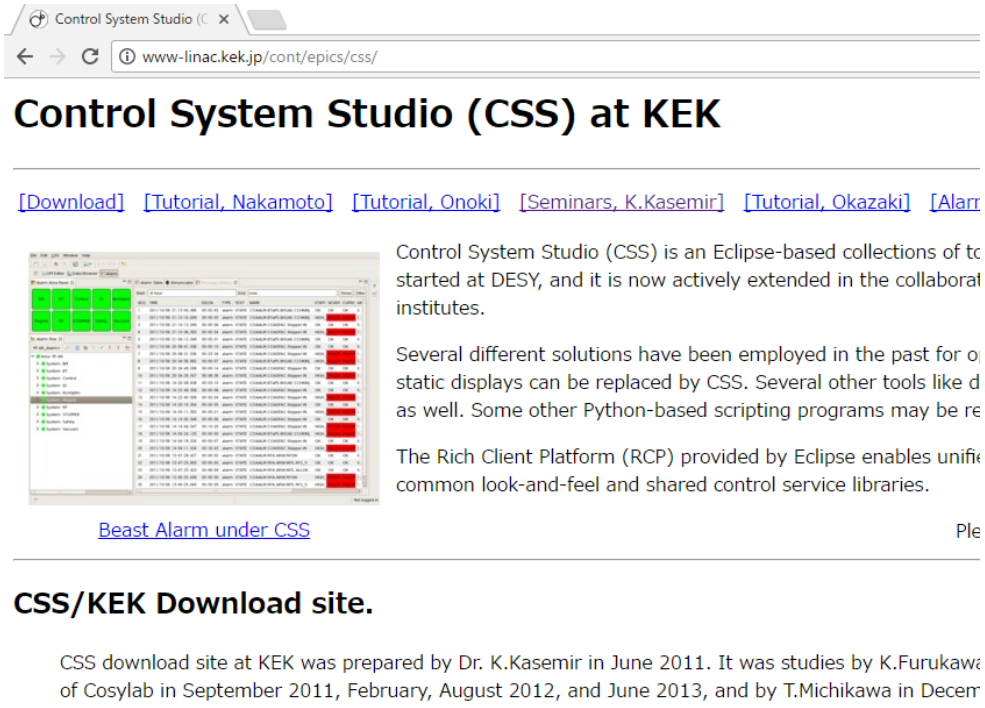
- Two projectors to the wall
  - mainly for demonstration (for Guests/visitors)
- Desktop 27-inch display is mainly used for accelerator tuning.
  - 2 PCs for operation/ Beam tuning.

Software tools used

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

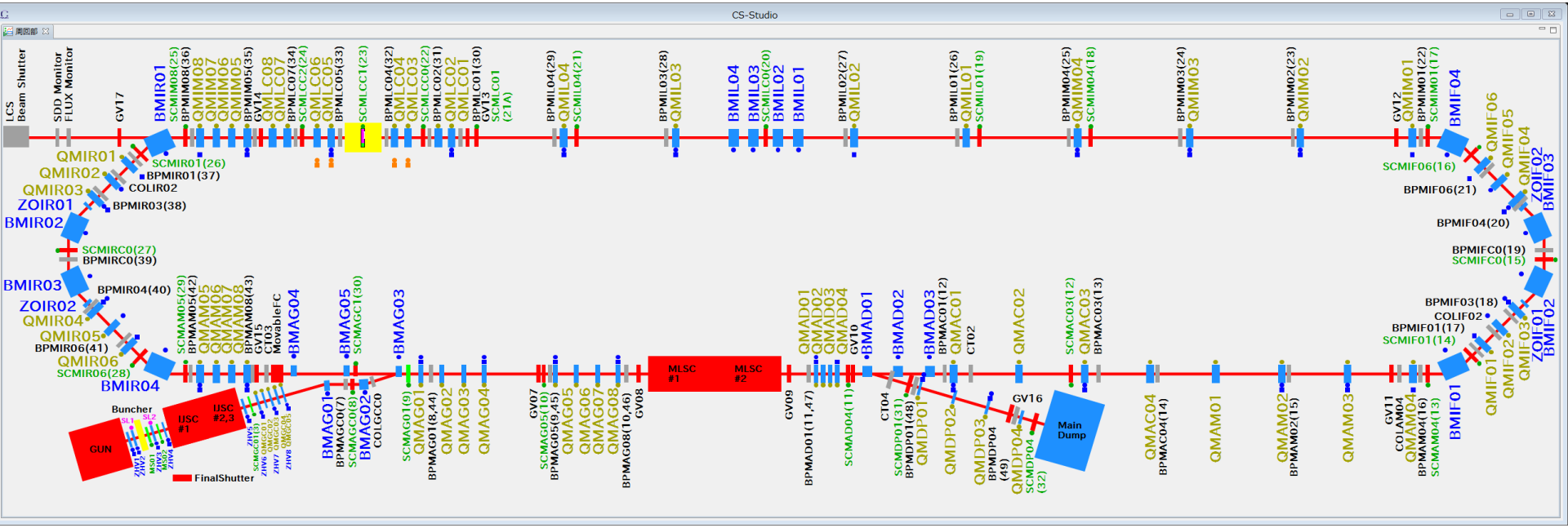


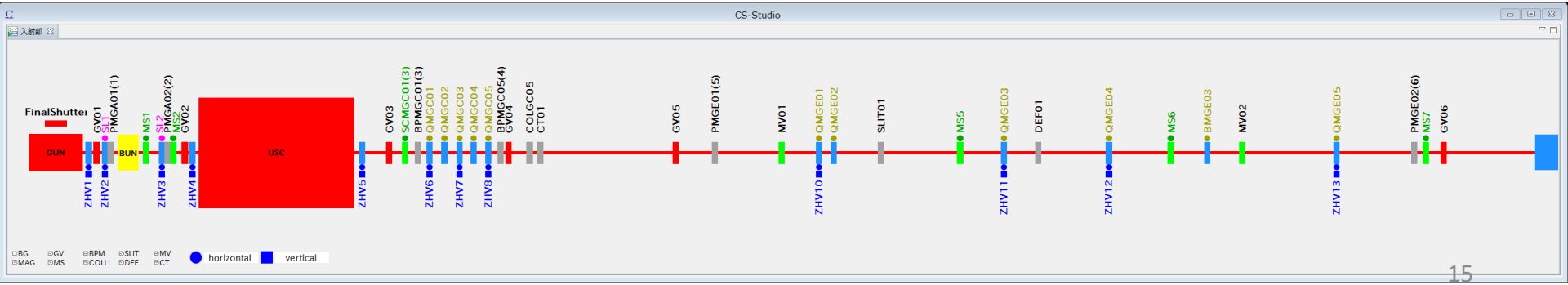
wiki

- 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

Machine Status Panel

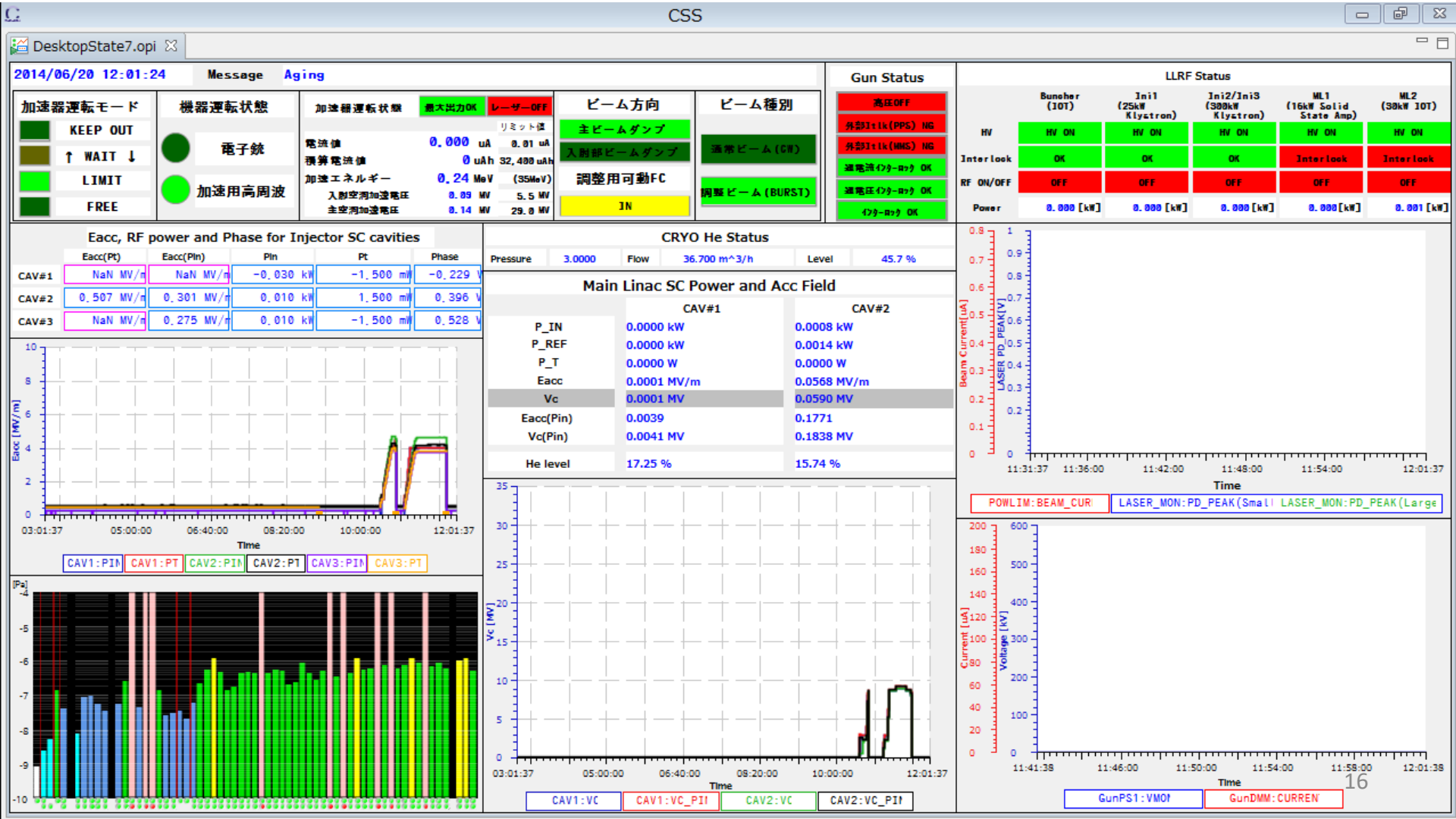
- Figure





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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What is iBNCT?

- Location

map

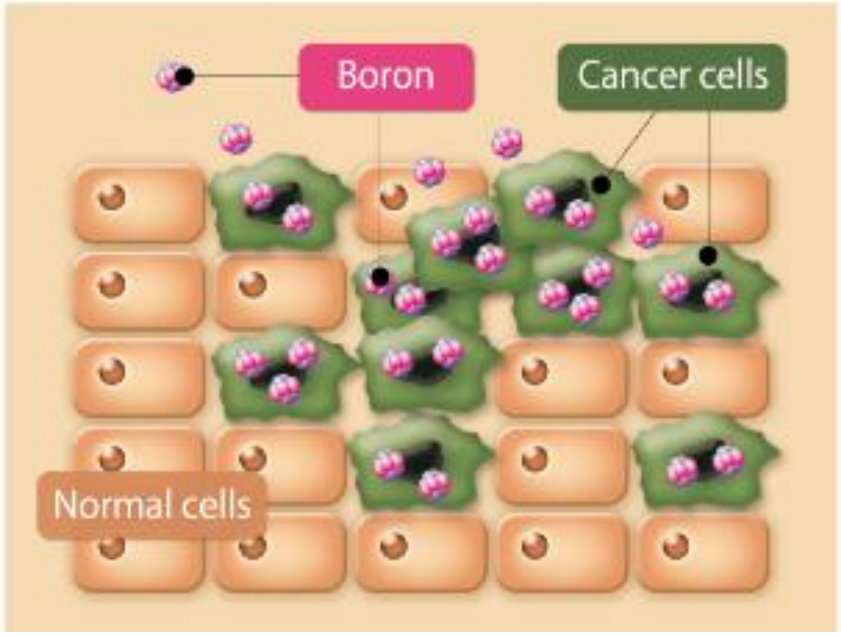
- iBNCT Location : near the entrance of J-PARC

What is iBNCT?

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

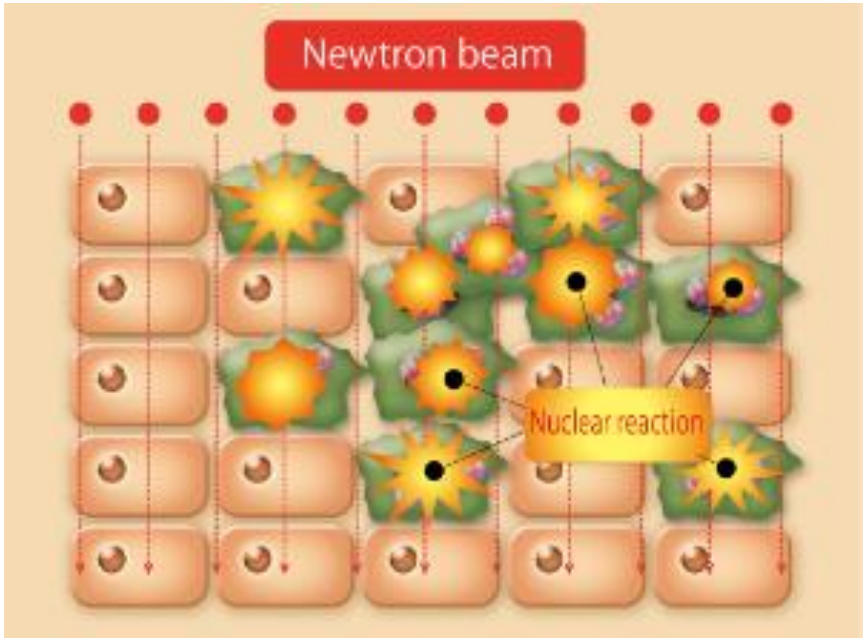
①Administer boron-containing drug:

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.

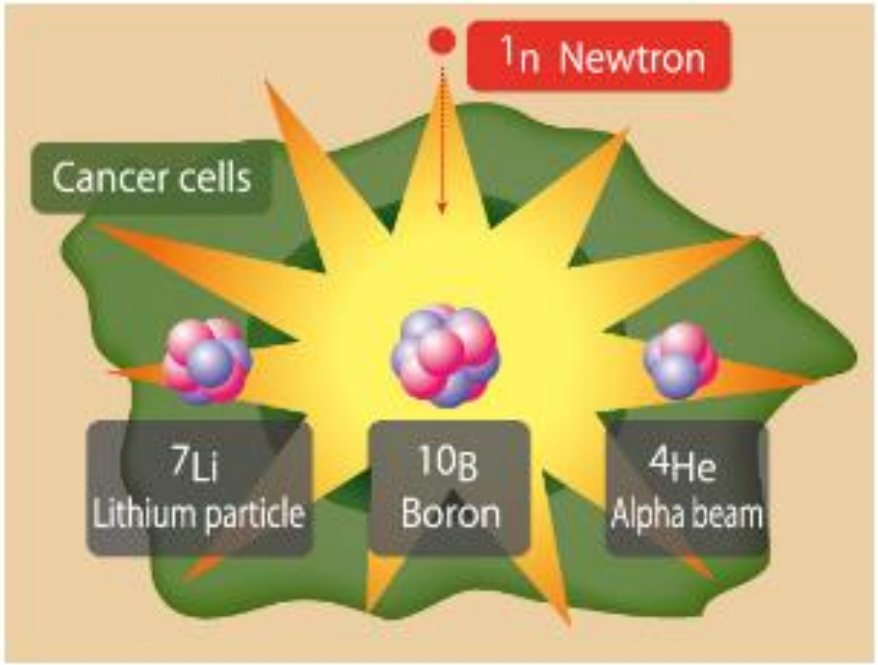


Courtesy Dr. Kumada, University of Tsukuba

Principle (cont.)

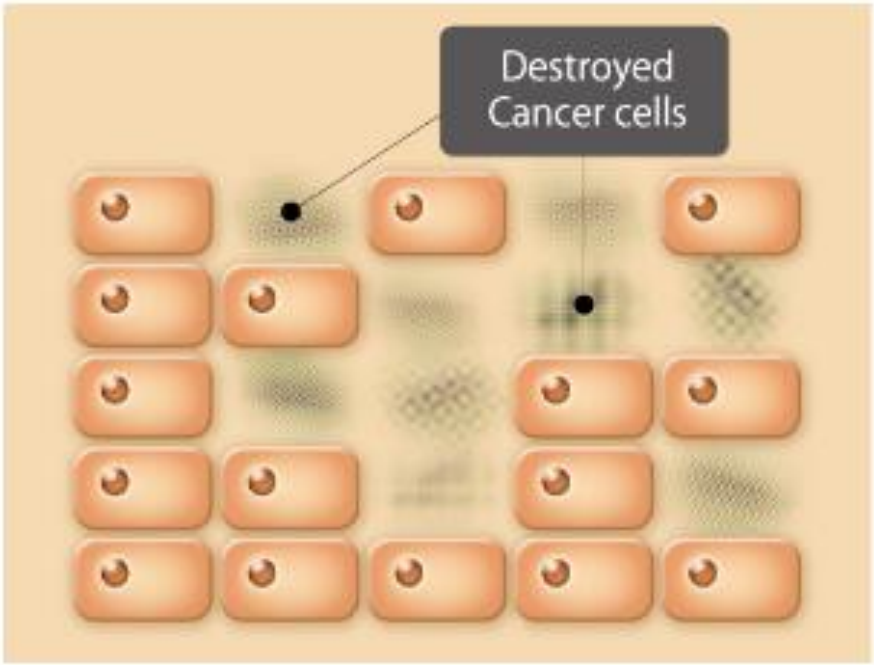
③Neutrons react with boron:

emitted alpha beam and lithium particles destroy cancer cells.



④Cancer cells are destroyed:

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

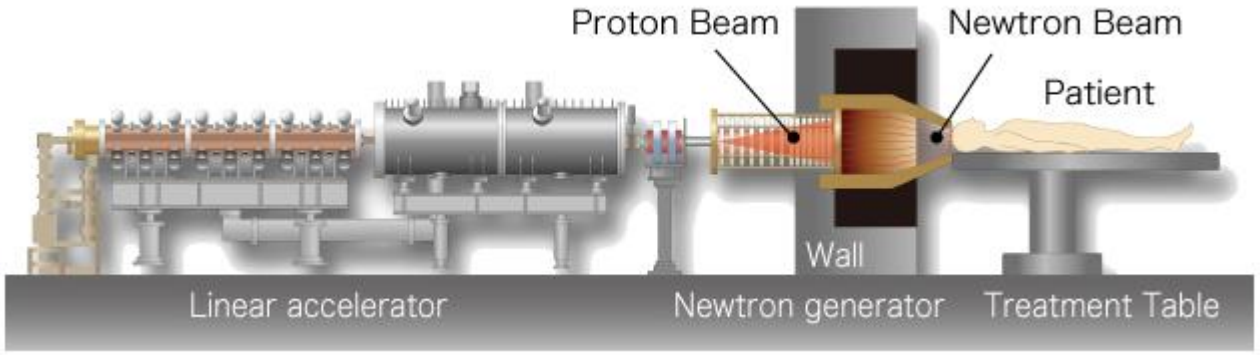


$$n + B(10) = Li + \alpha + \gamma$$

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

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/controlsheet_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

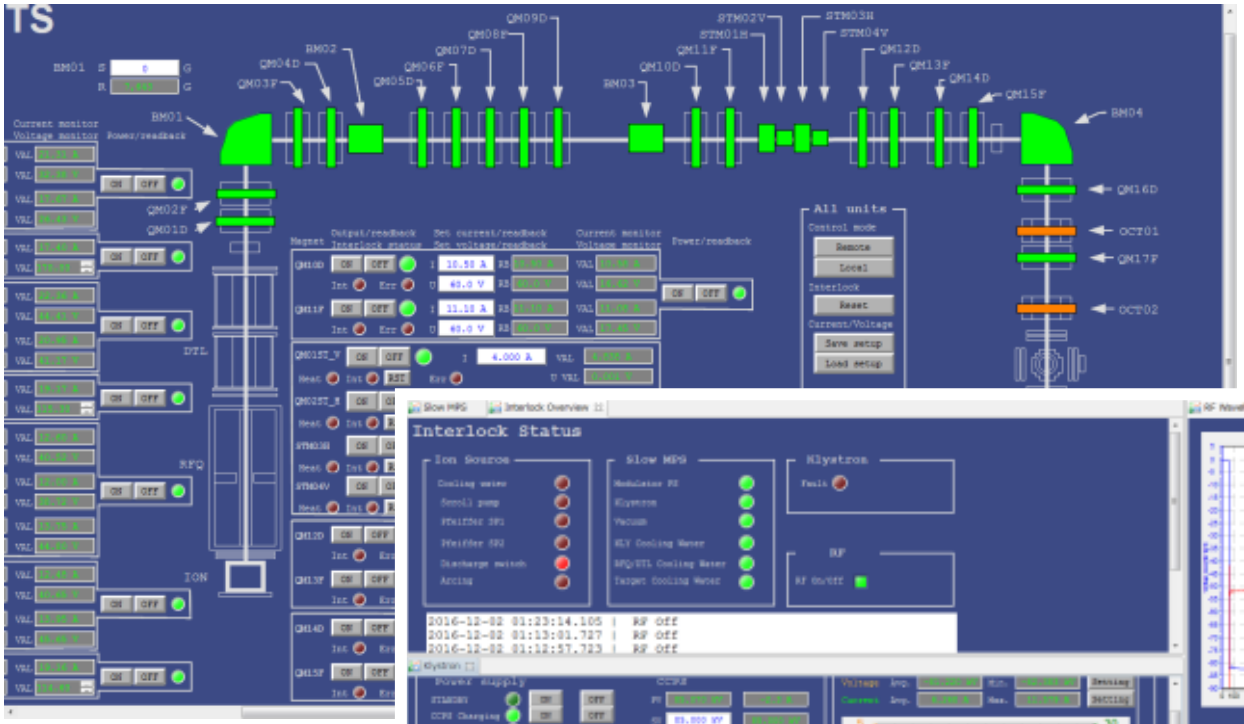
- Yokogawa PLC
  - most of the accelerator equipment are controlled by PLC.
  - Ladder CPU + WideField (development environment)

- Yokogawa SL1000
  - CT, BPM, Loss Monitor, etc
  - VXI-11 protocol

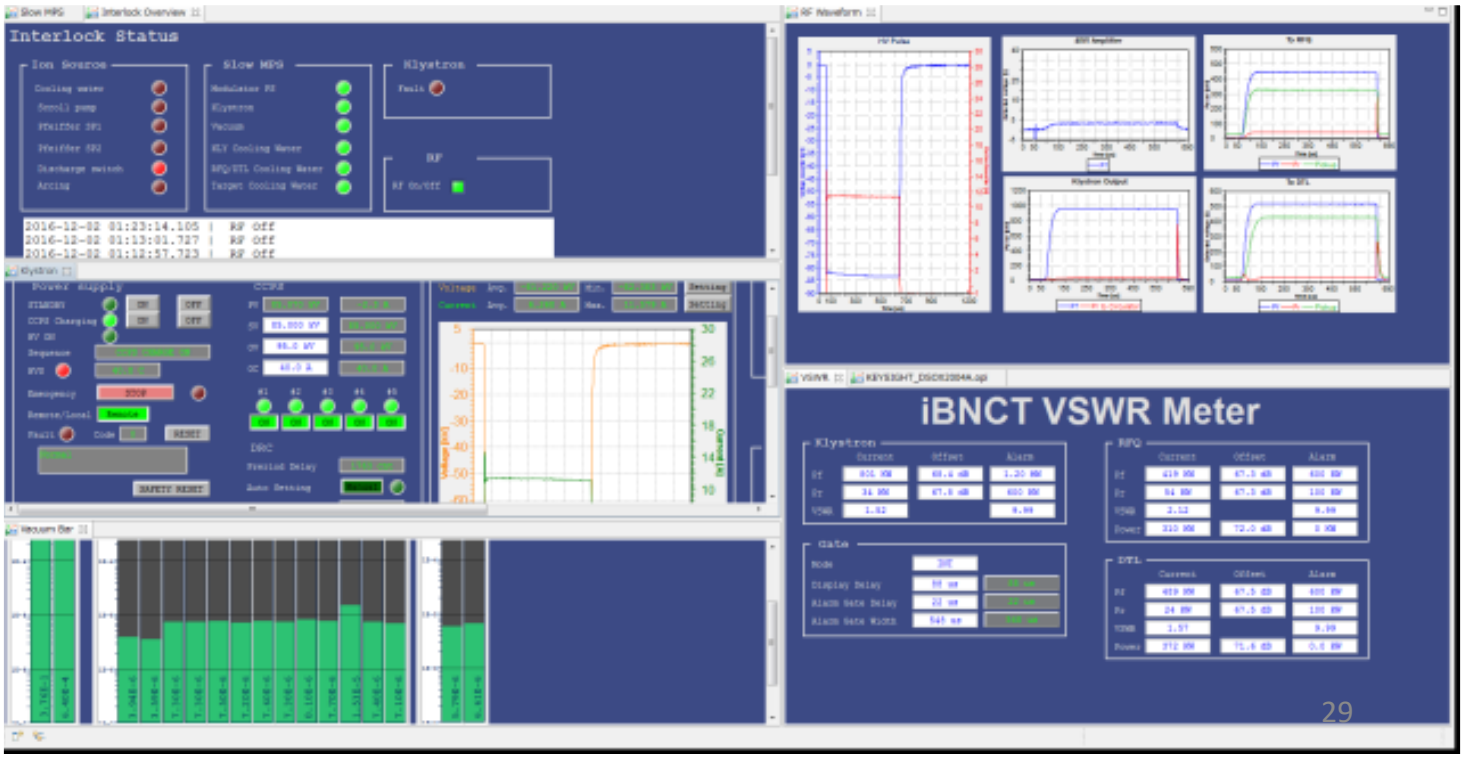
- EVG/EVR (mrf) for timing system

GUI Example

- Magnet status/direct set (Cosylab)



Status Panel (Cosylab)



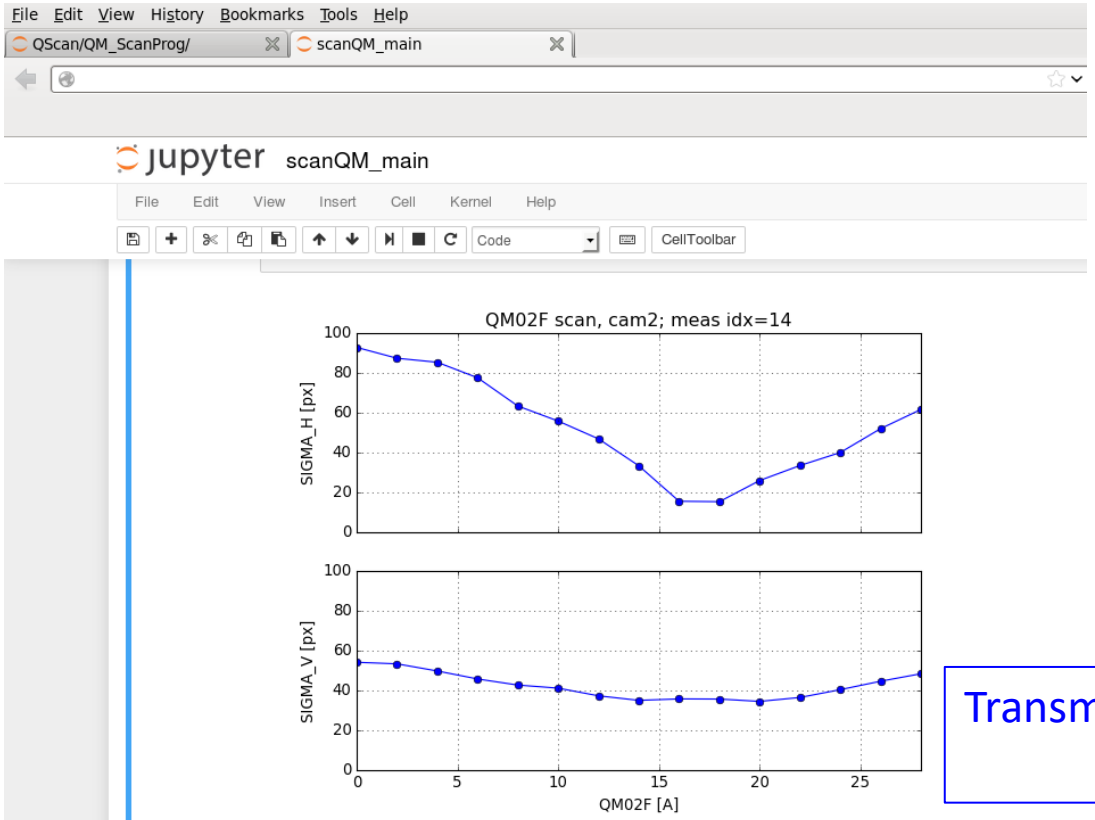
Number of PVs, Archiver, etc

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)

iBNCT passed the radiation facility safety inspection in December 2016

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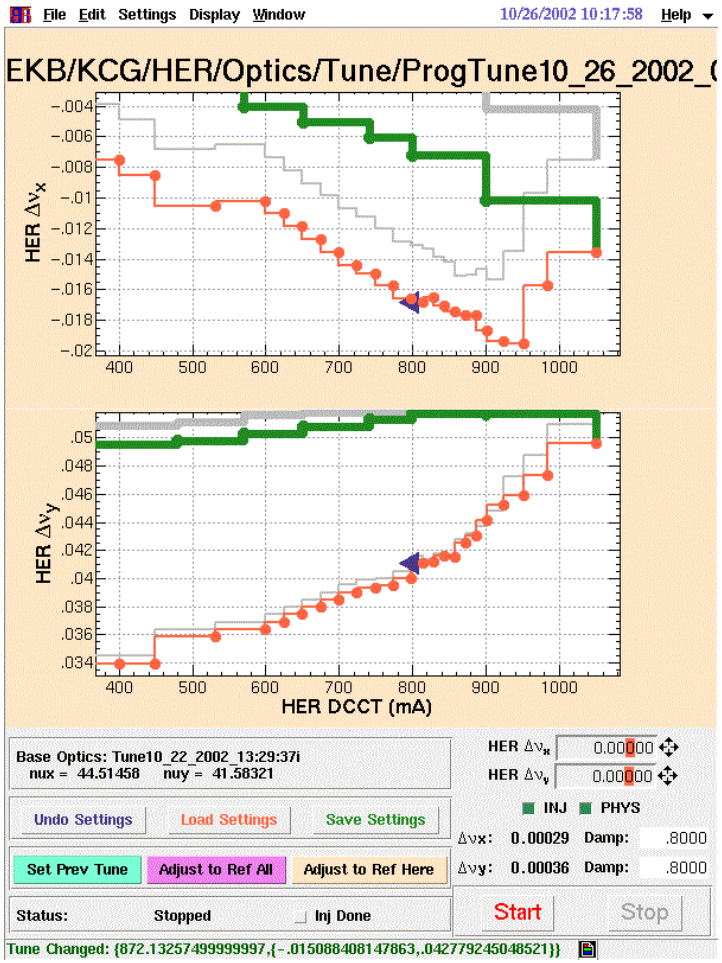
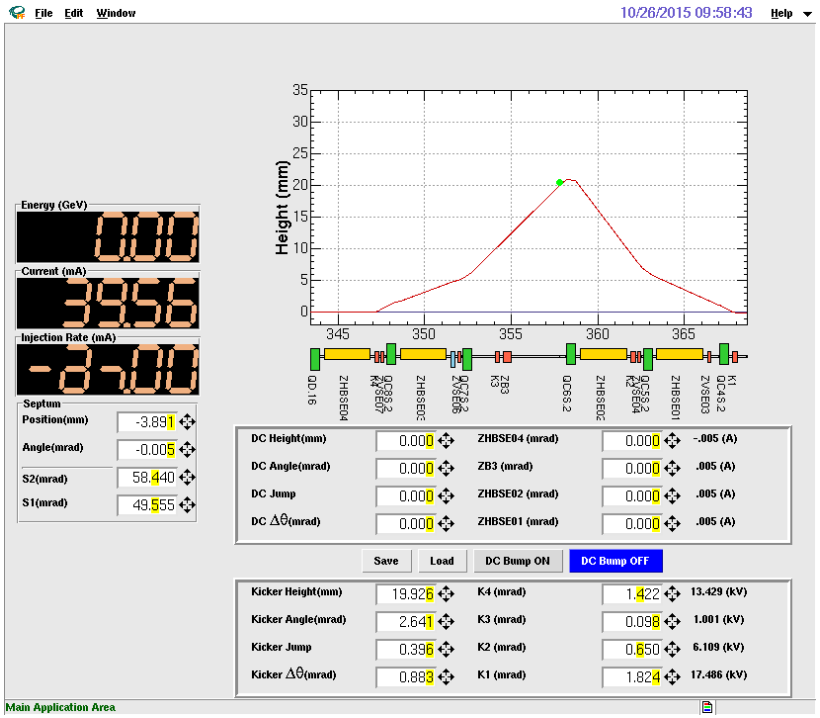
High Level Application : Software for beam tuning

- In case you need accelerator optics knowledge : Use SAD

KEKB Optics (Tune) Panel



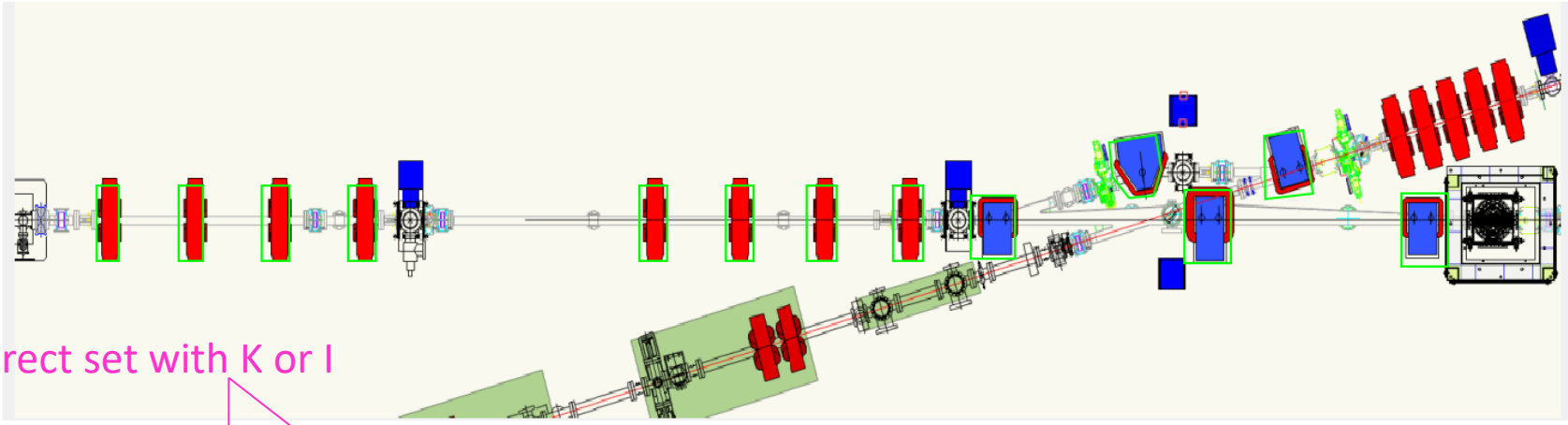
PF-AR Injection bump panel



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

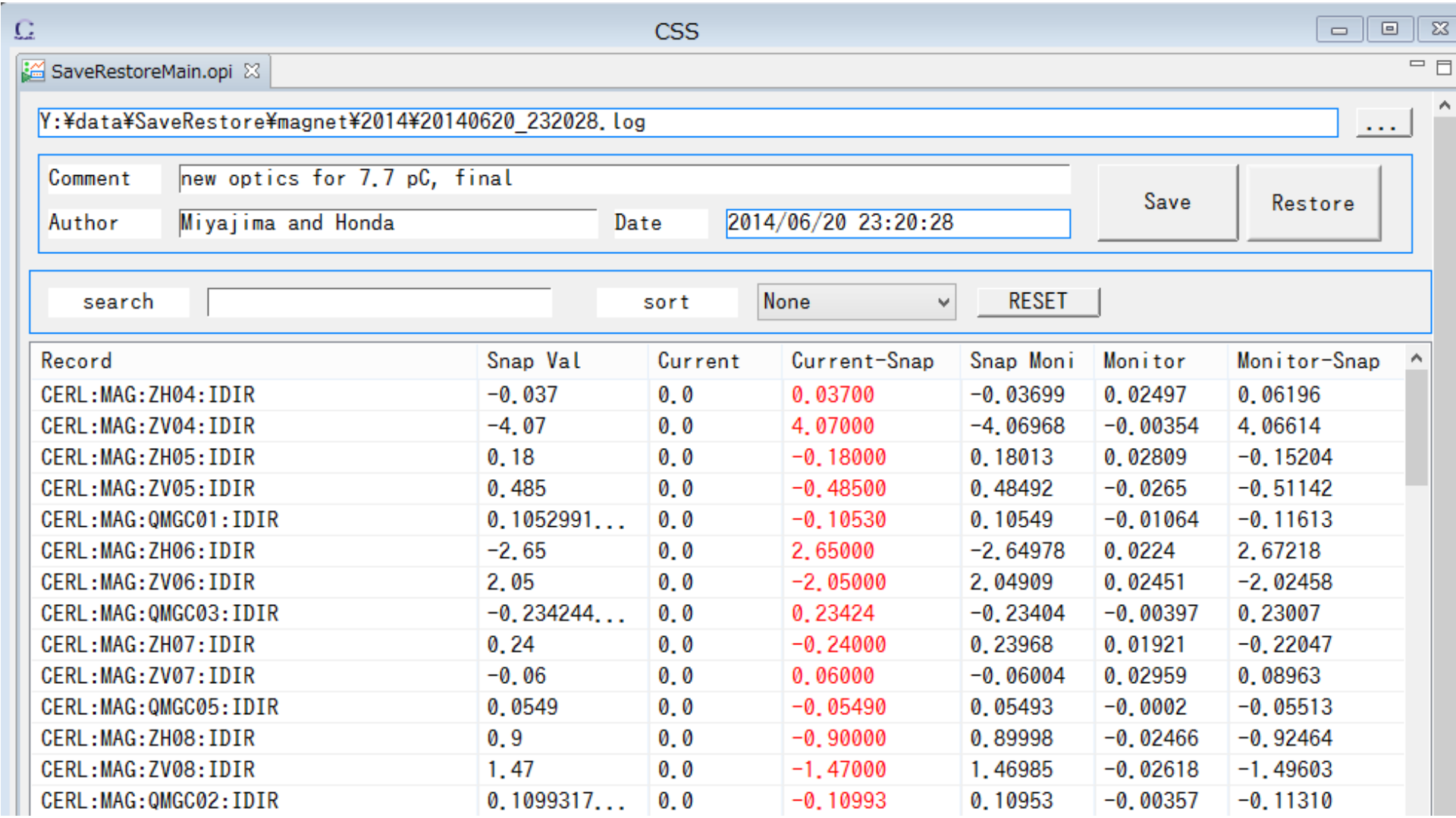
	Q			H			V		
	K set	I set	I mon	K set	I set	I mon	K set	I set	I mon
QMAG01	0 0.050	0 0.050	-0.000	0 0.050	0 0.050	-0.025	0 0.050	0 0.050	0.029
QMAG02	0 0.050	0 0.050	0.000						
QMAG03	0 0.050	0 0.050	0.001						
QMAG04	0 0.050	0 0.050	-0.009	0 0.050	0 0.050	-0.024	0 0.050	0 0.050	-0.025
QMAG05	0 0.050	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

ZHBMAG01	0 0.050	0 0.050	-0.018
ZHBMAG02	0 0.050	0 0.050	-0.026
ZHBMAG03	0 0.050	0 0.050	0.006
ZHBMAG04	0 0.050	0 0.050	0.031
ZHBMAG05	0 0.050	0 0.050	0.029

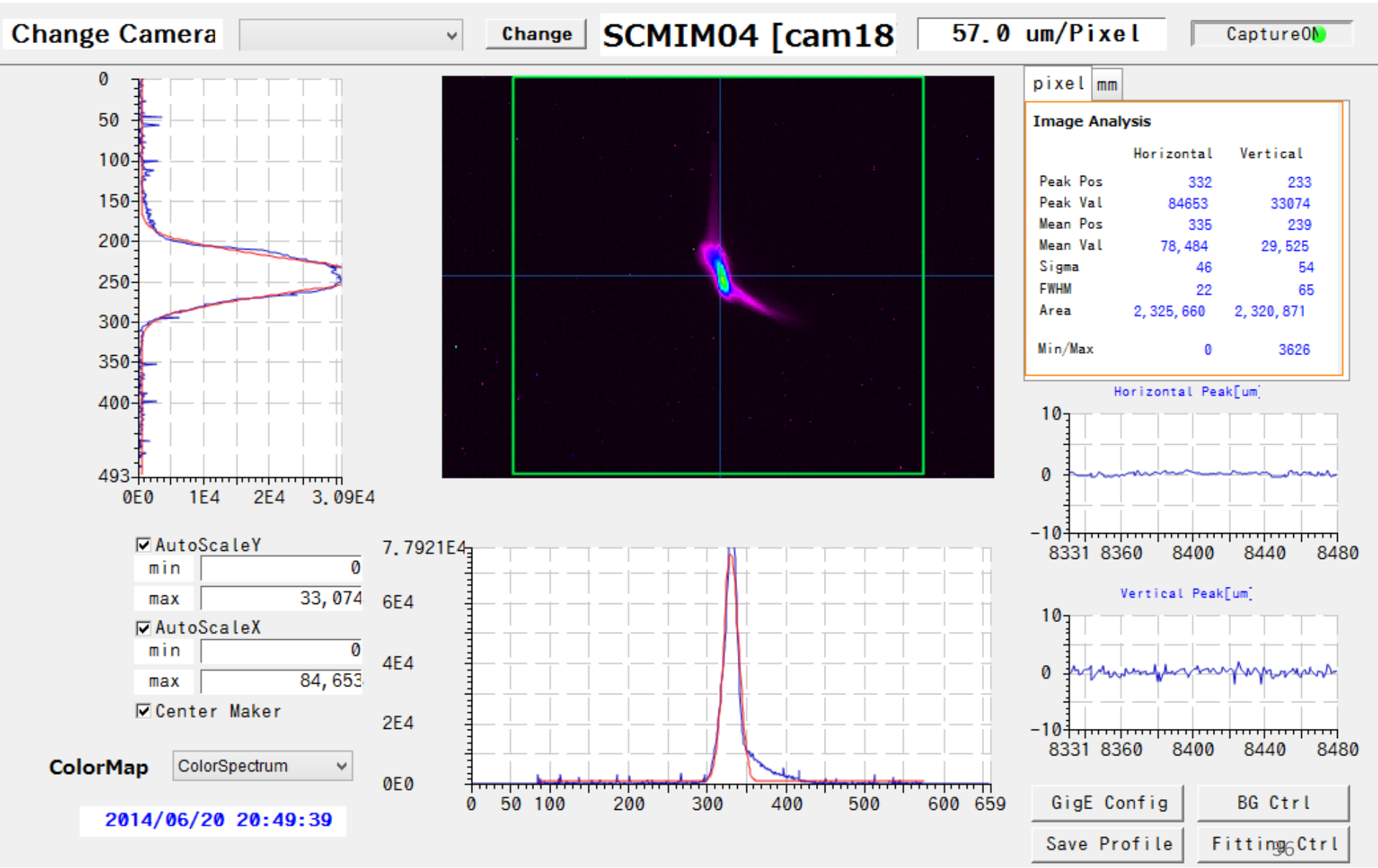
Direct Diff monitor value

save/restore



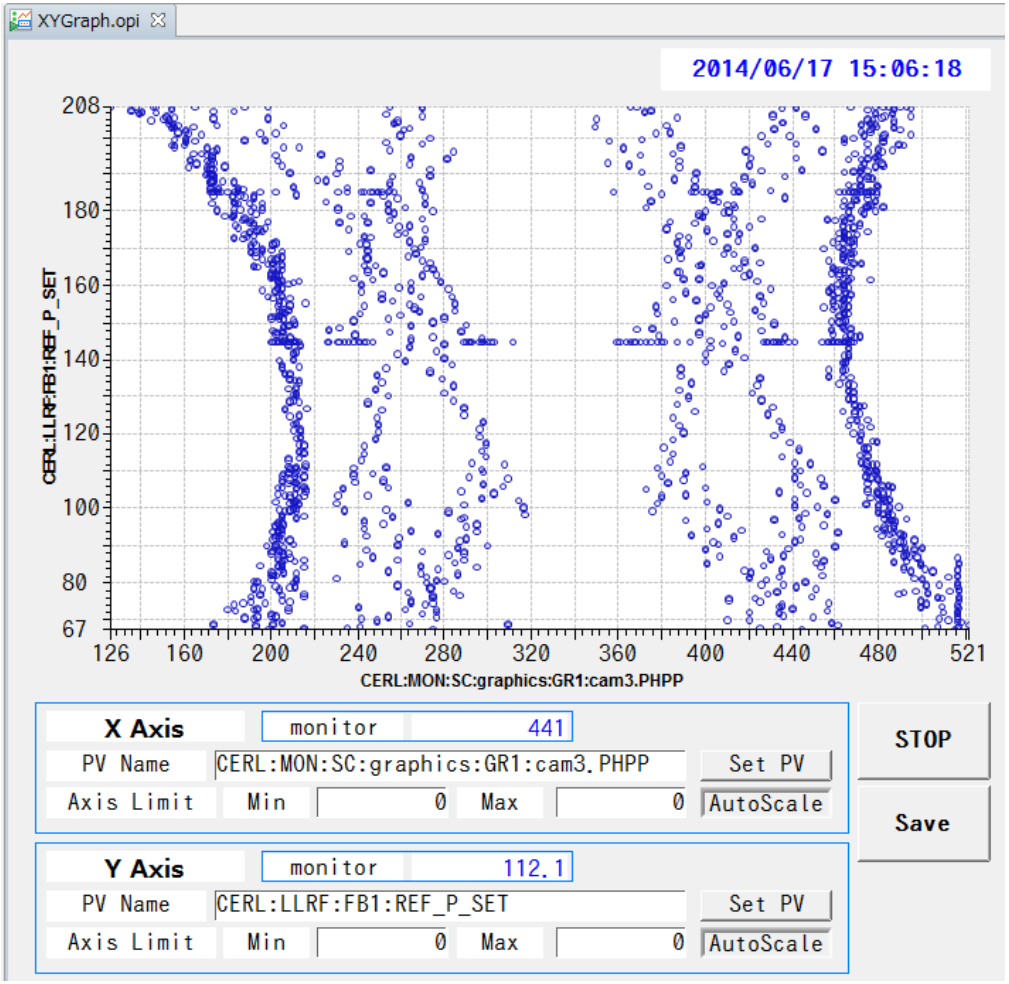
Record	Snap Val	Current	Current-Snap	Snap Moni	Monitor	Monitor-Snap
CERL:MAG:ZH04:IDIR	-0.037	0.0	0.03700	-0.03699	0.02497	0.06196
CERL:MAG:ZV04:IDIR	-4.07	0.0	4.07000	-4.06968	-0.00354	4.06614
CERL:MAG:ZH05:IDIR	0.18	0.0	-0.18000	0.18013	0.02809	-0.15204
CERL:MAG:ZV05:IDIR	0.485	0.0	-0.48500	0.48492	-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



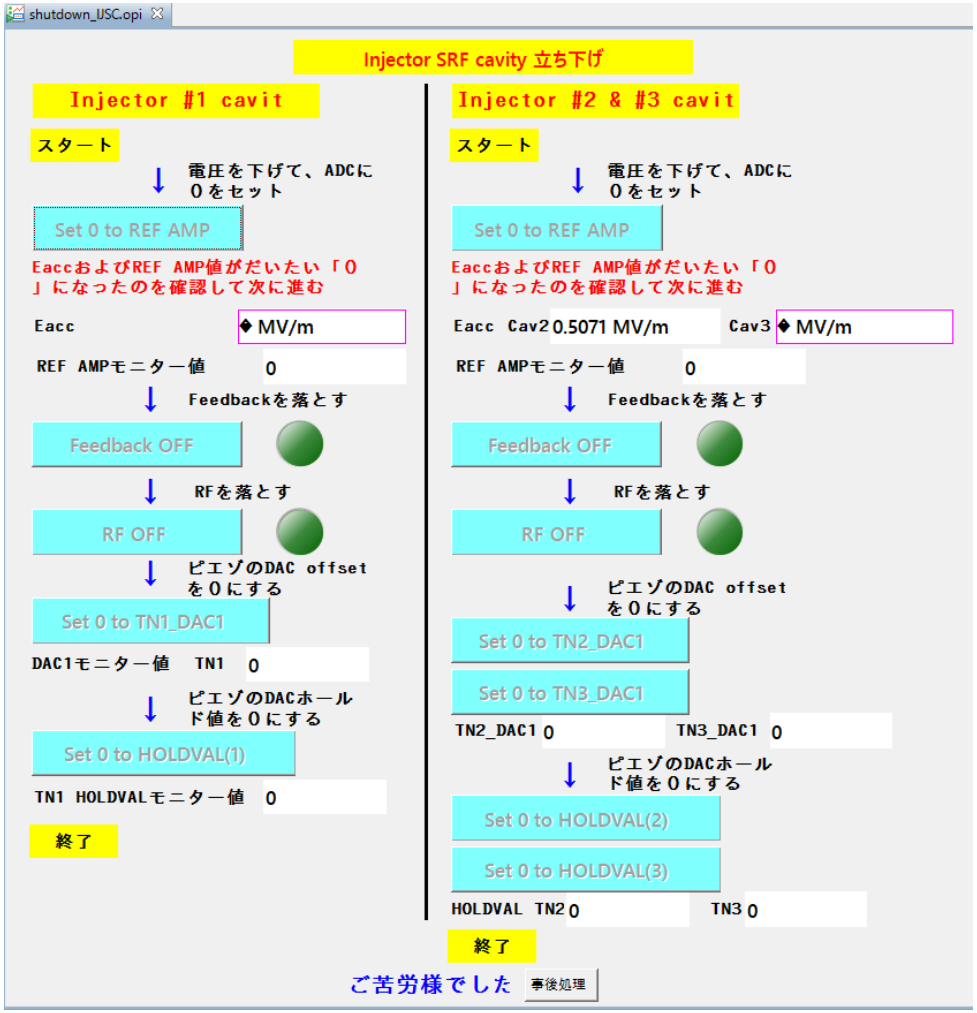
X-Y plot OPI : (example : RF Phase scan)

- 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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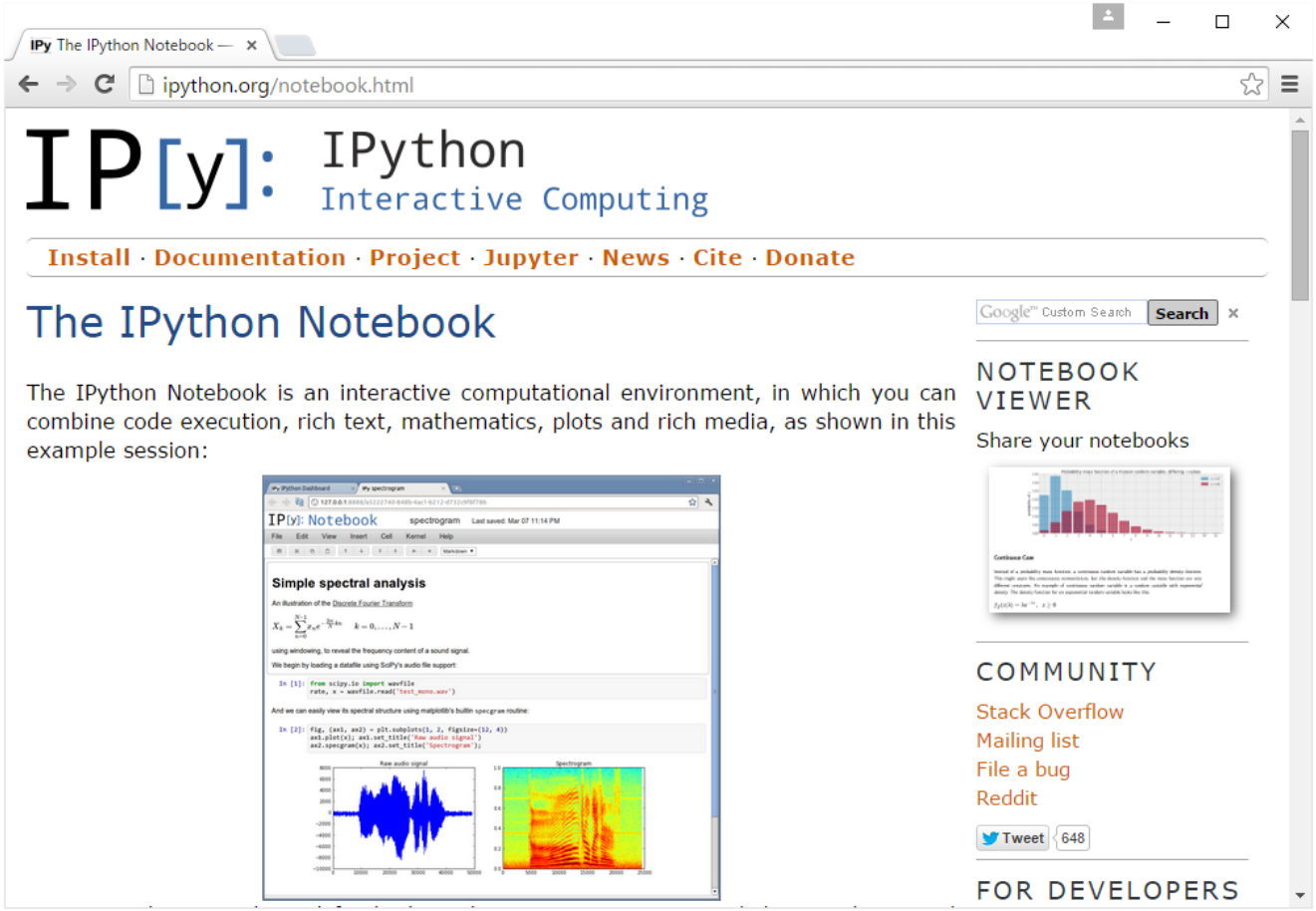
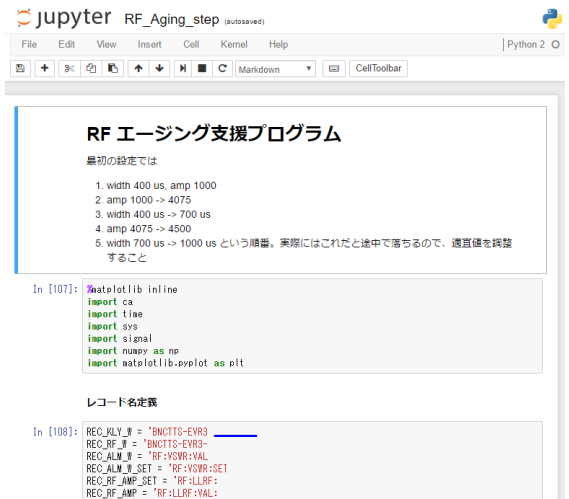
IPython (Jupyter) Notebook

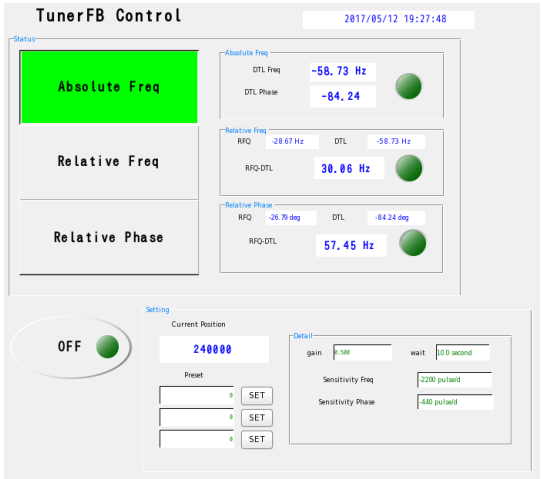
- Suitable for equipment control that does not need Accelerator optics.
- IPython core is running on server machine, client use web browser only.
- Intensively used in cERL and iBNCT



Rapid prototyping with IPython Notebook

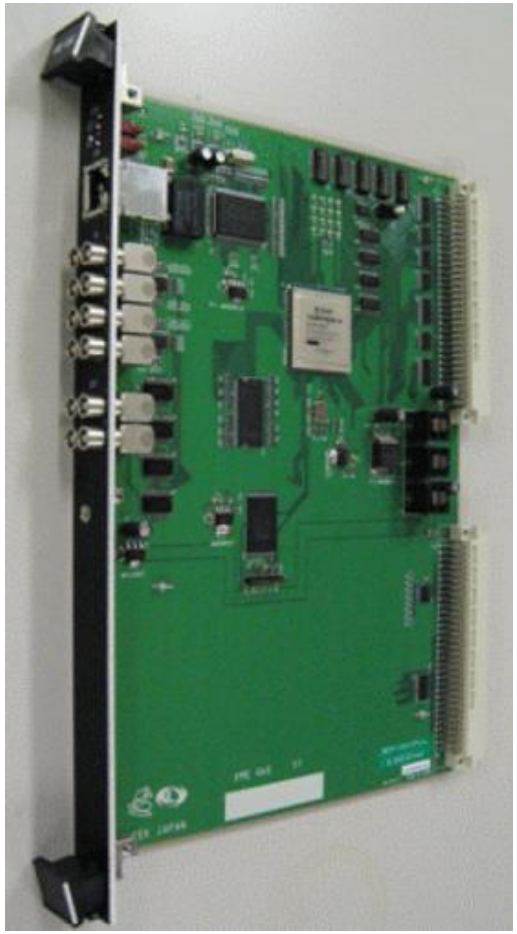
- ex: RF conditioning and DTL tuner (slow) feedback control for iBNCT
- Need to adjust input voltage and pulse height, repetition rate, etc.
  - monitoring tuner position, RF frequency, power, ... and many other parameters.
  - Some patterns have been tried at the beginning.
  - "Quick and Dirty" approach 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".



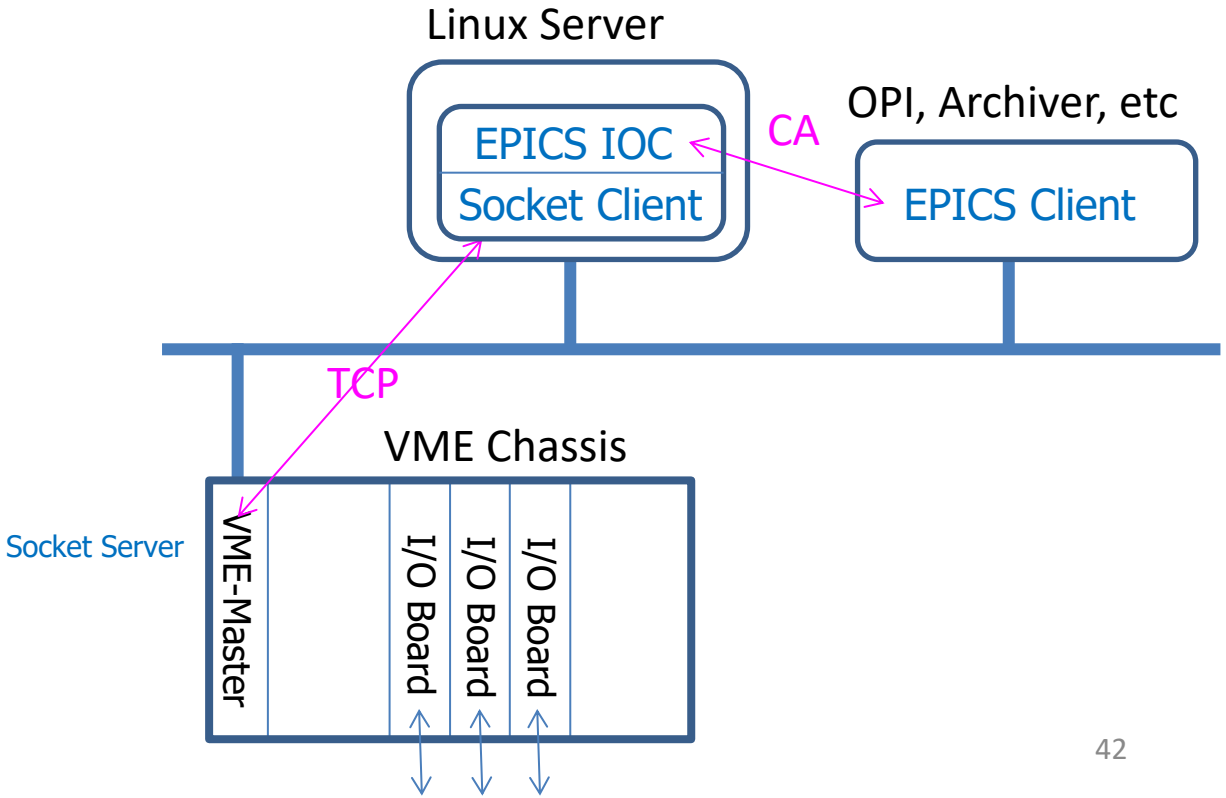


Misc. Hardware : VME-Master

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

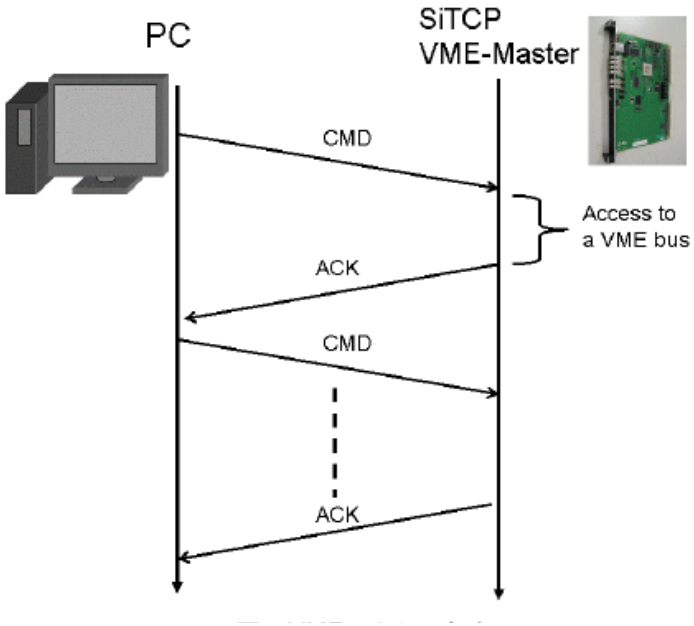


We can use VME boards like a network-attached I/O module.
Standard "Stream Device/Asyn" for communication.

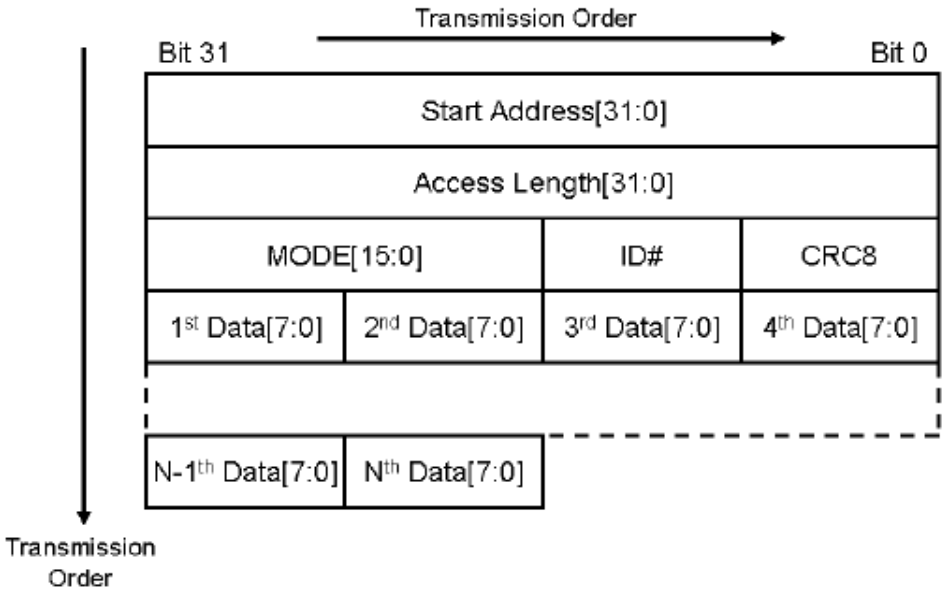


Outline of operation procedure

- Please refer to the manual for details.



VME access flow



Packet Format

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