Accelerator Facilities and EPICS Activities at KEK

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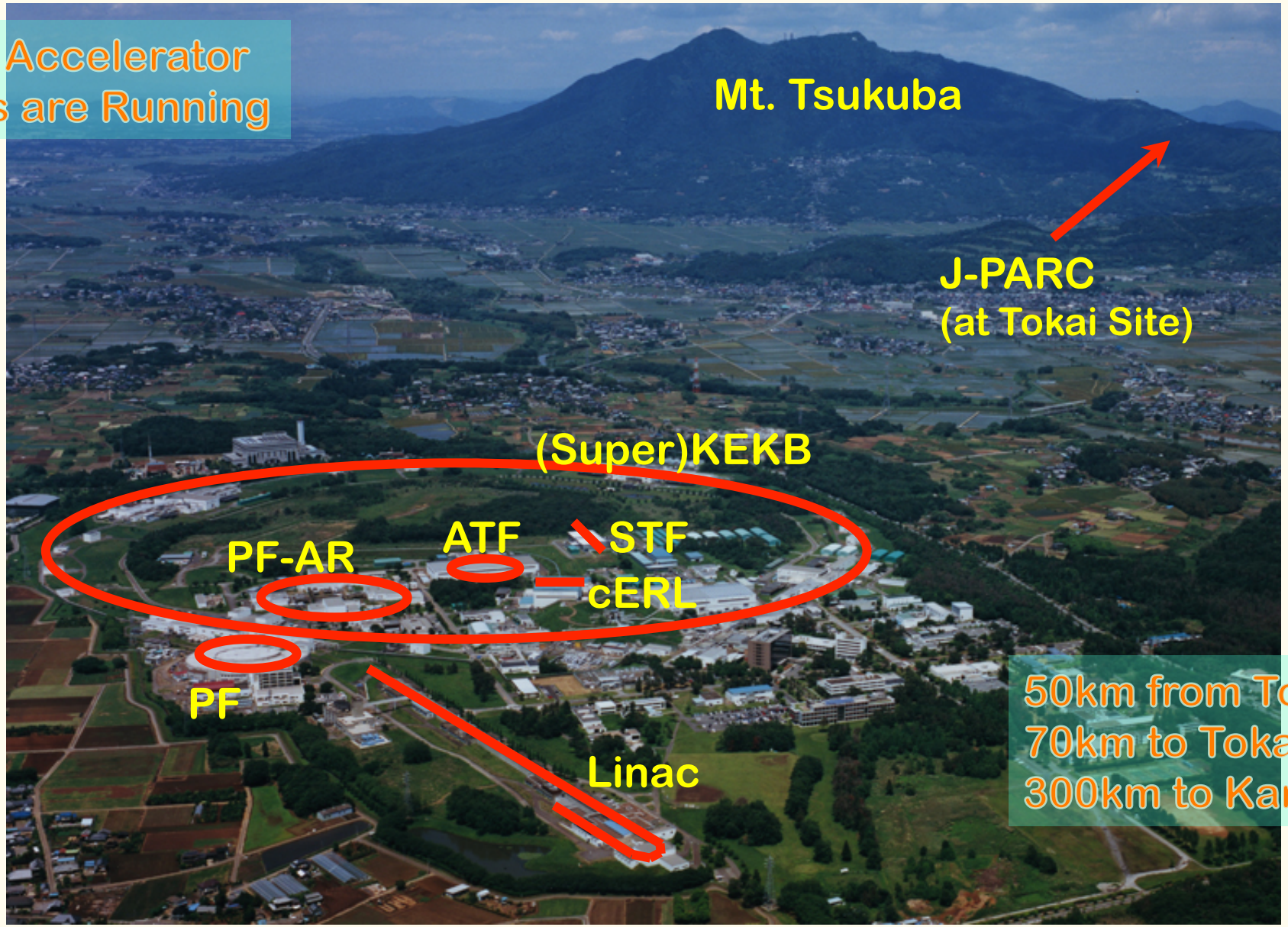
for Control groups at KEK

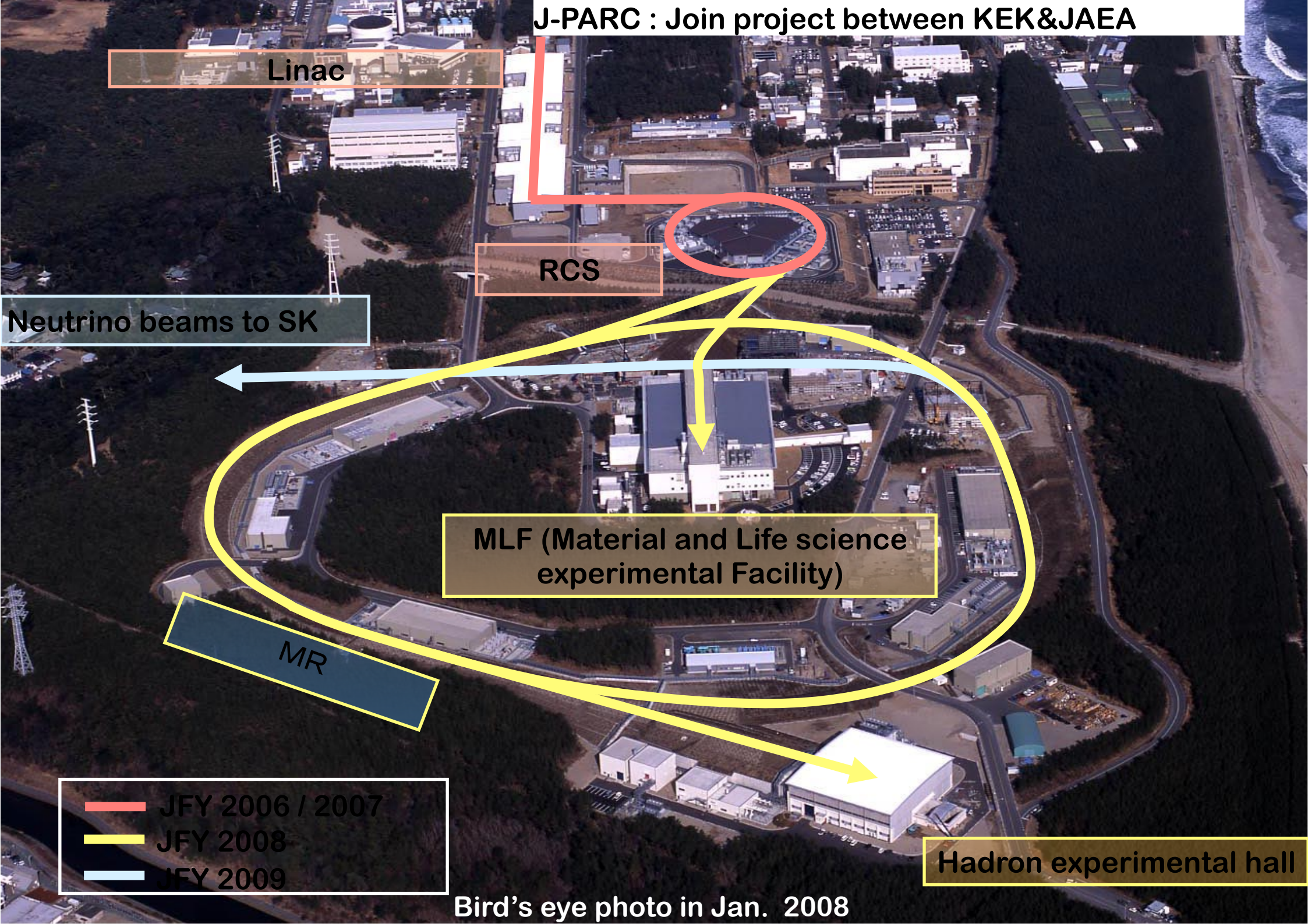
Contents

- Accelerators projects at KEK
- Base control components
- Control concepts
- Some more details
- Conclusions

Particle accelerators at KEK

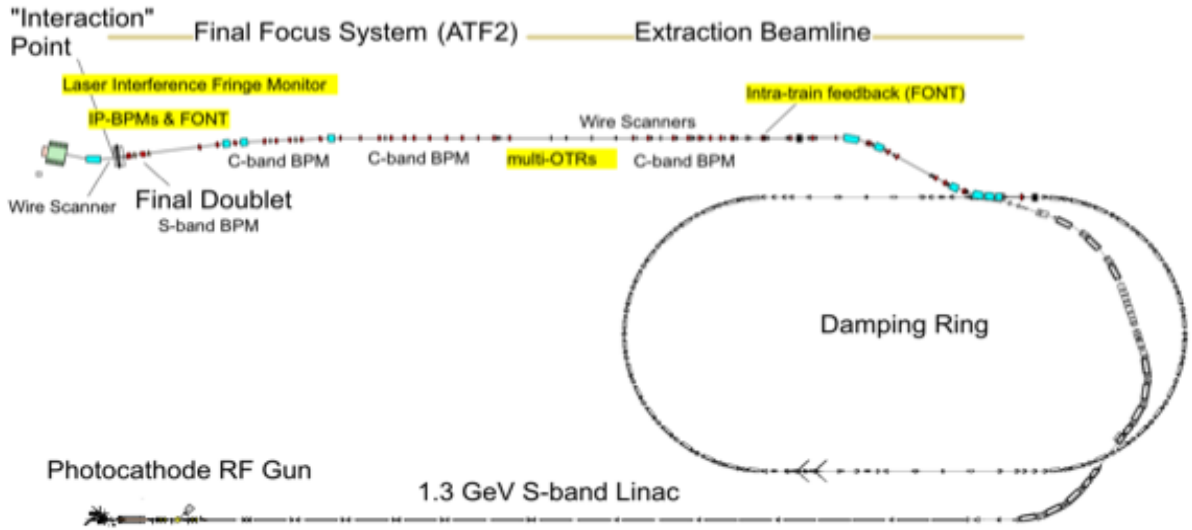
Several Accelerator Projects are Running




J-PARC : Join project between KEK&JAEA
Linac
RCS
Neutrino beams to SK
MLF (Material and Life science experimental Facility)
MR
Hadron experimental hall
JFY 2006 / 2007
JFY 2008
JFY 2009
Bird's eye photo in Jan. 2008

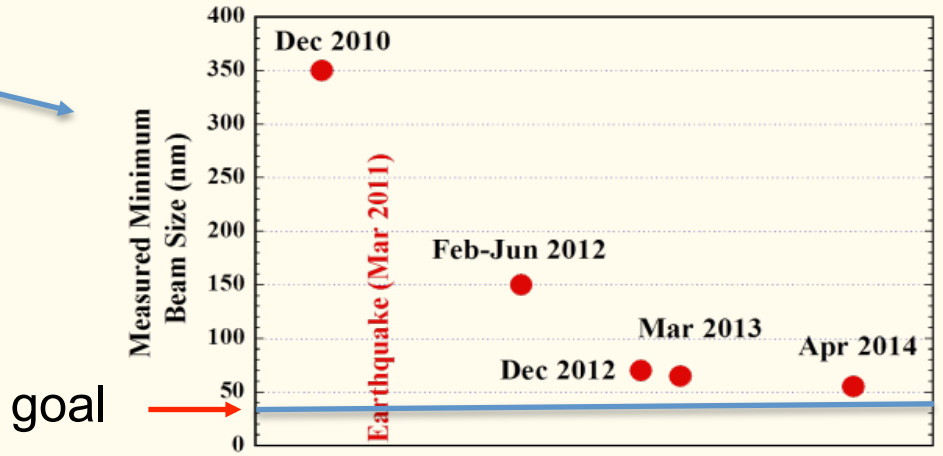
ATF

Goal1 focus the vertical beam size to 37 nm with a local chromaticity correction scheme,
Goal2 control its vertical position within a few nanometers at the final focus point.



R&D items

- **Beam size monitor for ATF2-IP**
- **Beam position monitor for ATF2-IP**
- **Multiple OTR**
- **FONT (Intra-train beam orbit feedback)**
- **Polarized positron source**



History of beam size measured by IP-BSM

Upgrade plan of direct beam transport line for PF-AR

The purpose of this upgrade is to achieve 6.5 GeV full energy injection and top-up operation in PF-AR.

Linac SY3

3GeV → 6.5 GeV acceleration

Present beam transport

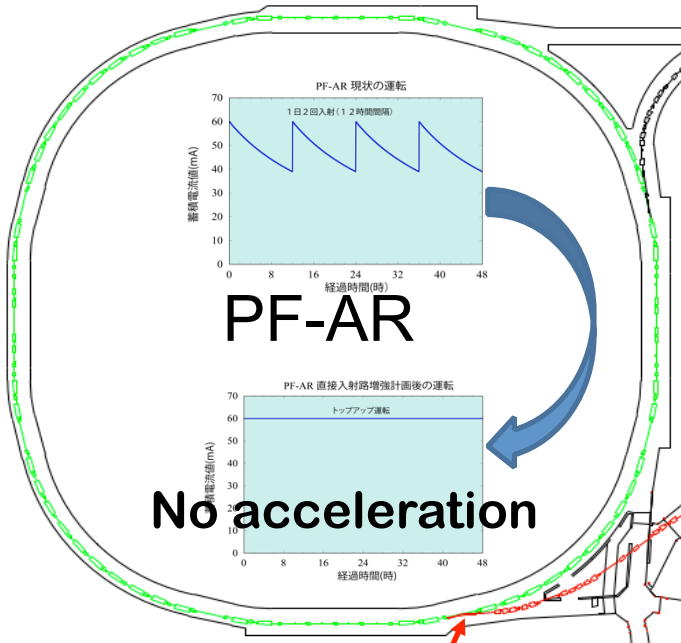
PF-AR 3GeV e-

SKEKB
7GeV e-, 4GeV e+

Injector Linac

6.5GeV e-

New direct beam transport

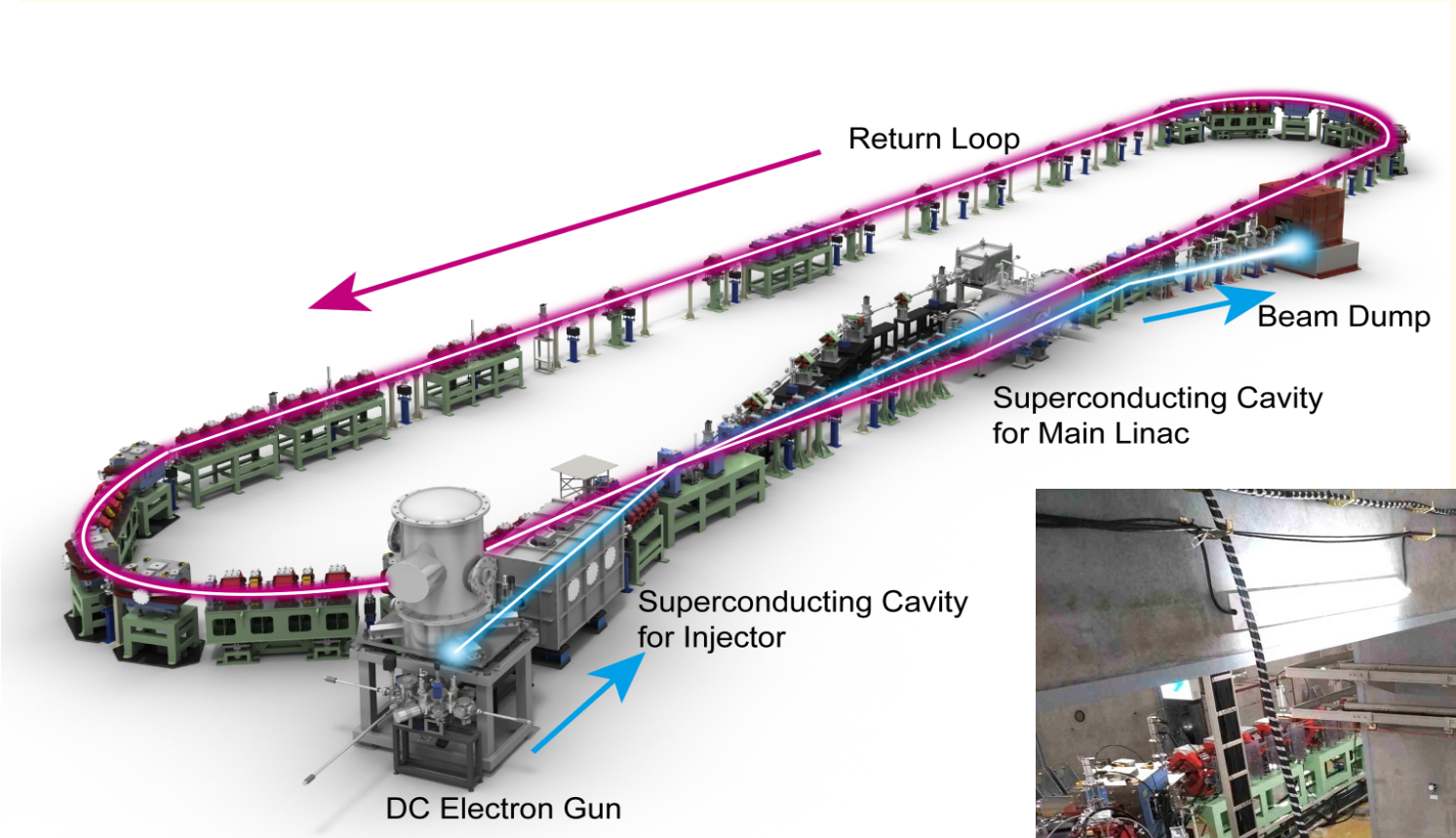


New tunnel is going to construct

New injection point

Fast switching delivery of injection beam is required among PF ring , PF-AR and SuperKEKB (LER, HE

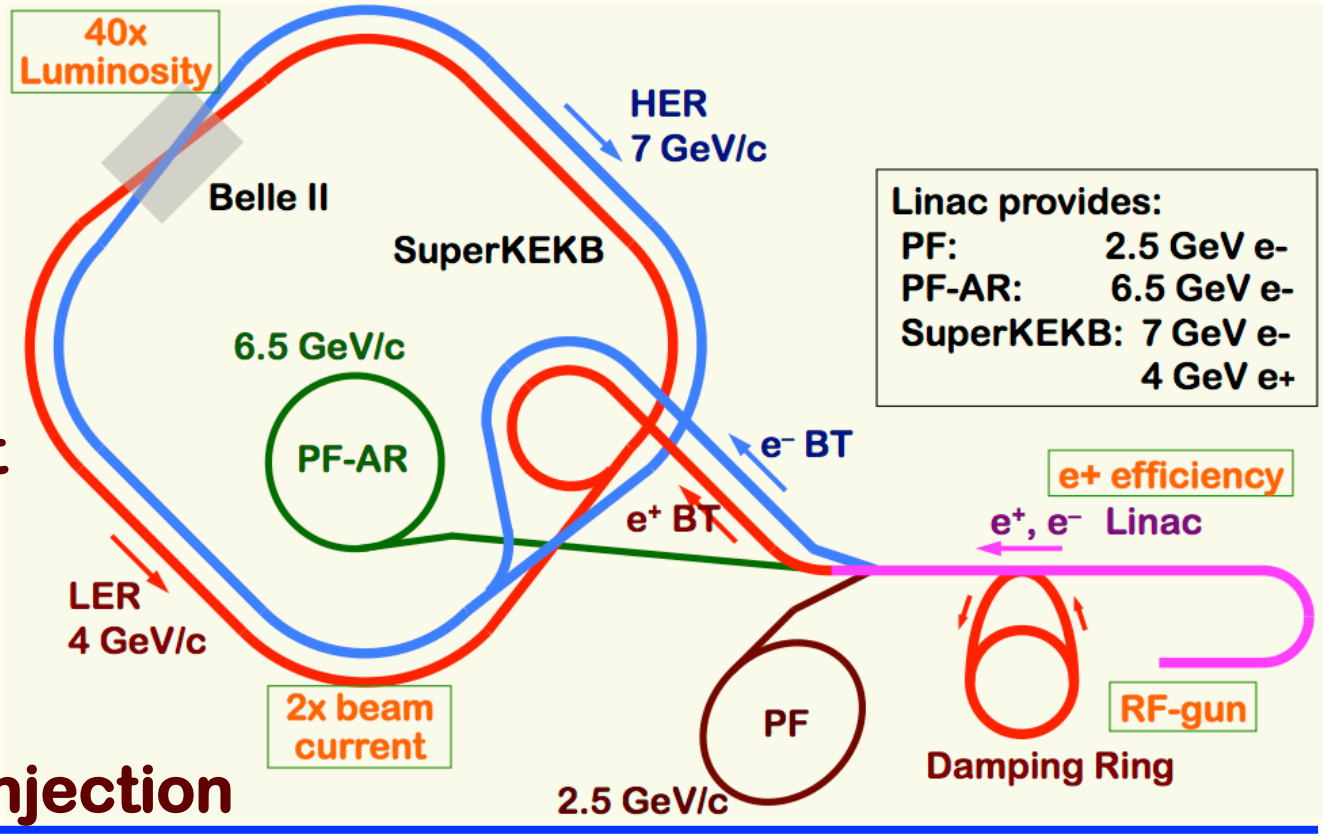
The Compact ERL succeeded in beam recirculation and energy recovery



The cERL injector was constructed with its diagnostic line in April 2013 and successfully commissioned from 22 April to 28 June in 2013. Construction of the cERL recirculation loop including the merger and the dump line started in July and ended in November.

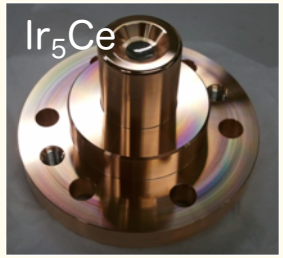
Mission of SuperKEKB and electron/positron Injector

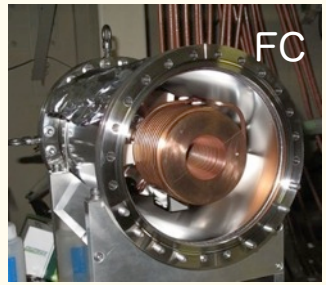
- **40-times higher Luminosity**
  - Twice larger storage beam → Higher beam current at Linac
  - 20-times higher collision rate with nano-beam scheme
    - → Low-emittance even at first turn → Low-emittance beam from Linac
    - → Shorter storage lifetime → Higher Linac beam current
- **Linac challenges**
  - Low emittance e-
    - with high-charge RF-gun
  - Low emittance e+
    - with damping ring
  - Higher e+ beam current
    - with new capture section
  - Emittance preservation
    - with precise beam control
  - 4+1 ring simultaneous injection

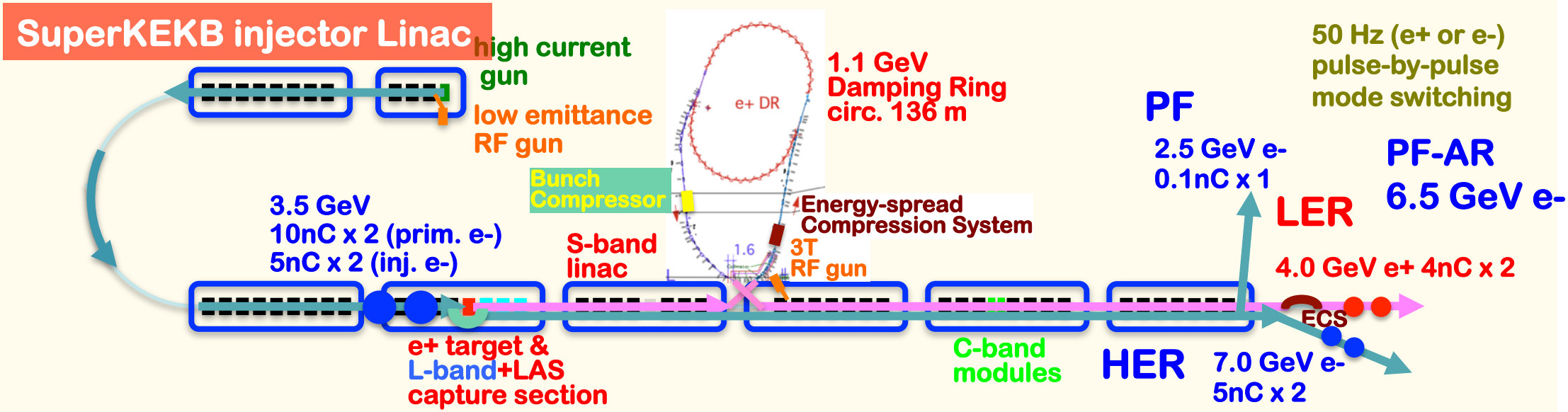


Linac Upgrade for SuperKEKB

- **Lower-emittance Injection Beam**
  - To meet nano-beam scheme in the ring
  - Positron with a damping ring, Electron with a photo-cathode RF gun
  - Emittance preservation by alignment and beam instrumentation
- **Higher Injection Beam Current**
  - To meet larger stored beam current and shorter beam lifetime in the ring
  - 4~8-times larger bunch current for electron and positron
  - Reconstruction of positron capture section and electron gun
- **Quasi-simultaneous injections into 4 storage rings (PPM)**
  - SuperKEKB e^-/e^+ rings, and light sources of PF and PF-AR
  - Improvements to beam instrumentation, low-level RF, controls, timing, etc

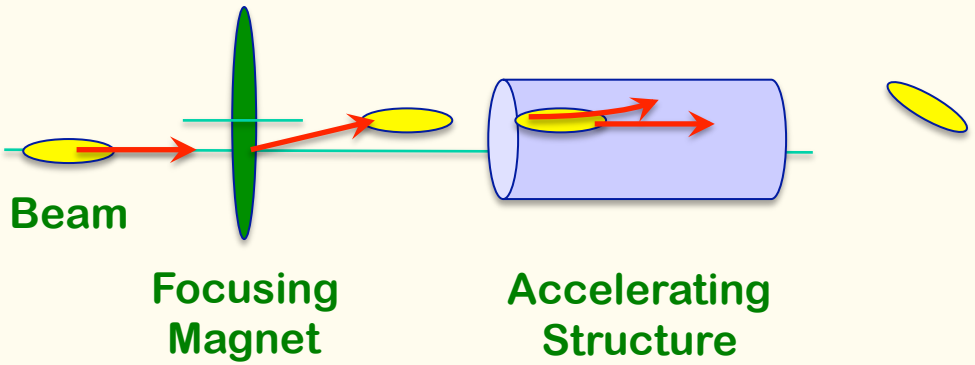






Emittance Preservation

- If Device is off center of the beam
  - Focusing magnet (quad) kicks the beam bunch
  - Accelerating structure (cavity) excites wakefield, to bend the tail
- Distorted bunch in banana shape
  - Emittance dilution or blow-up
  - Depending on the beam optics and the beam charge
- Orbit correction and alignment management are crucial to preserve the emittance along linac



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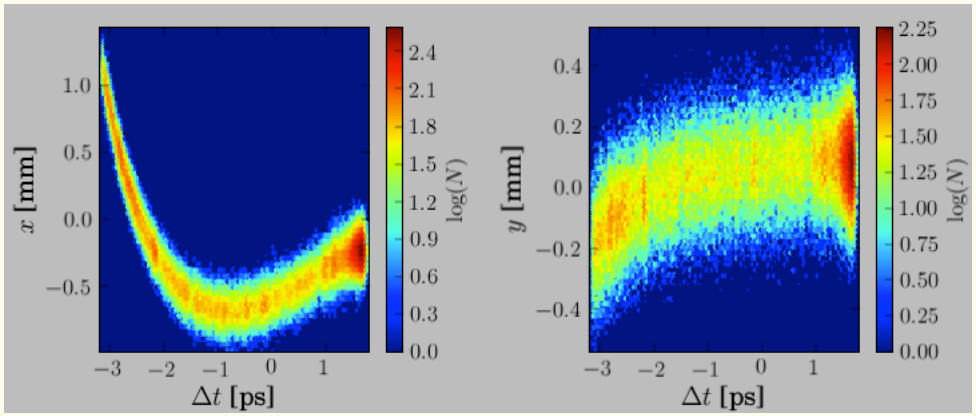


Transverse distribution in time direction

Base Control Components at KEK

- **Platform and Hardware IOCs**
  - VME MVME5500 (mostly) at Linac and SuperKEKB
  - Japanese PPC CPU and GE Fanuc Intel CPU at J-PARC
  - Yokogawa's Linux PLC CPU (F3RP61) at all facilities
  - MicroTCA Vertex-5 PPC core at STF, cERL, SuperKEKB
  - Windows embedded IOC on Oscilloscopes at Linac, etc
- **Archiver**
  - CSS archiver with partitioning at Linac, cERL and SuperKEKB
  - KEKBlog archiver at SuperKEKB
  - Channel archiver at J-PARC, PF, PF-AR

Base Control Components at KEK (2)

- **Display managers**
  - **SADscript for most of beam operations**
    - At all facilities
    - Mathematica-like language without symbolic manipulation
    - Numeric manipulation including non-linear fit etc.
    - Various plotting, Tk interactive widgets, Channel access
  - **Python (with mostly Tk) for other operations**
    - At all facilities
      - Originally Tcl/Tk at Linac, mostly rewritten
  - **CSS at cERL, SuperKEKB, PF-AR, etc**
  - **MEDM, EDM at KEKB, J-PARC**

Base Control Components at KEK (3)

- **Alarm handler**
  - KEKBAlarm (in SADscript) at KEKB
  - CSS Alarm at Linac, PF-AR, SuperKEKB
- **Operation log**
  - Postgresql and Flex elog at Linac
    - Can search data since 1995
  - Zlog (zope and postgresql) at other facilities
    - EPICS related information is linked from <http://www-linac.kek.jp/cont/epics/>

Main features of controls at KEKB

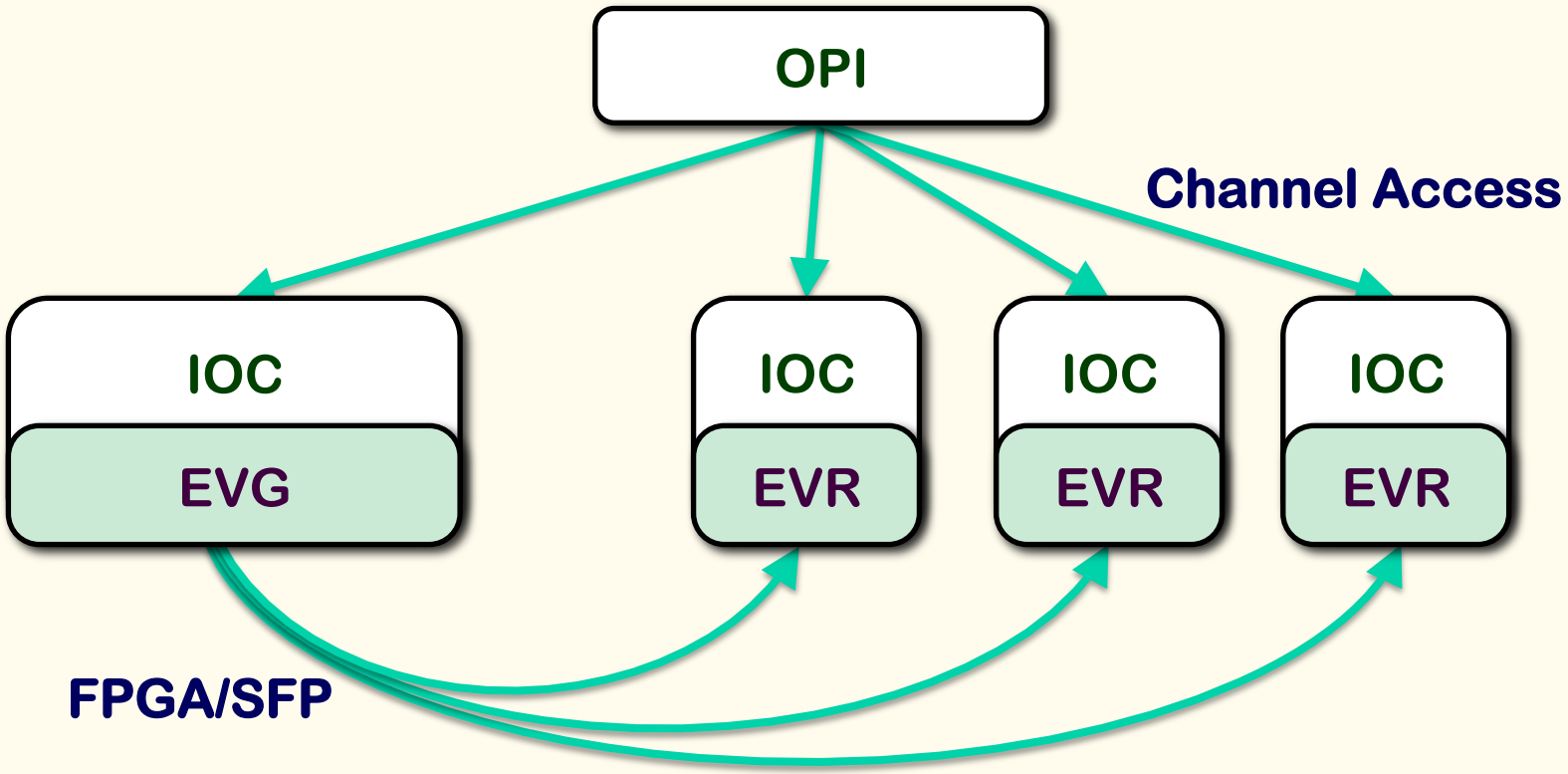
- **EPICS as Main control Software Toolkit**
  - Provided a robust basis of equipment controls
  - Reduced software design efforts much
- **Scripting Languages for Operational Software**
  - SADscript/Tk, Python/Tk, Tcl/Tk used much
    - Especially, SADscript as a bridge btw. Accelerator simulation, Numeric manipulation, Graphic interface and EPICS controls
  - Bright new idea in the morning meeting could make the operation much advanced in the evening
    - Great tool to optimize the operation

SuperKEKB Controls

- **Inherit Good part of KEKB Controls**
  - EPICS
  - Scripting languages
- **EPICS Channel Access (CA) Everywhere**
  - Embed EPICS control software (IOC) everywhere possible
  - Reduce efforts on protocol design, testing, etc
- **Dual Tier: Another layer in addition to EPICS/CA**
  - Event system helps EPICS with another channel/layer
  - Additional functionality, synchronization and speed

Dual-tier Controls

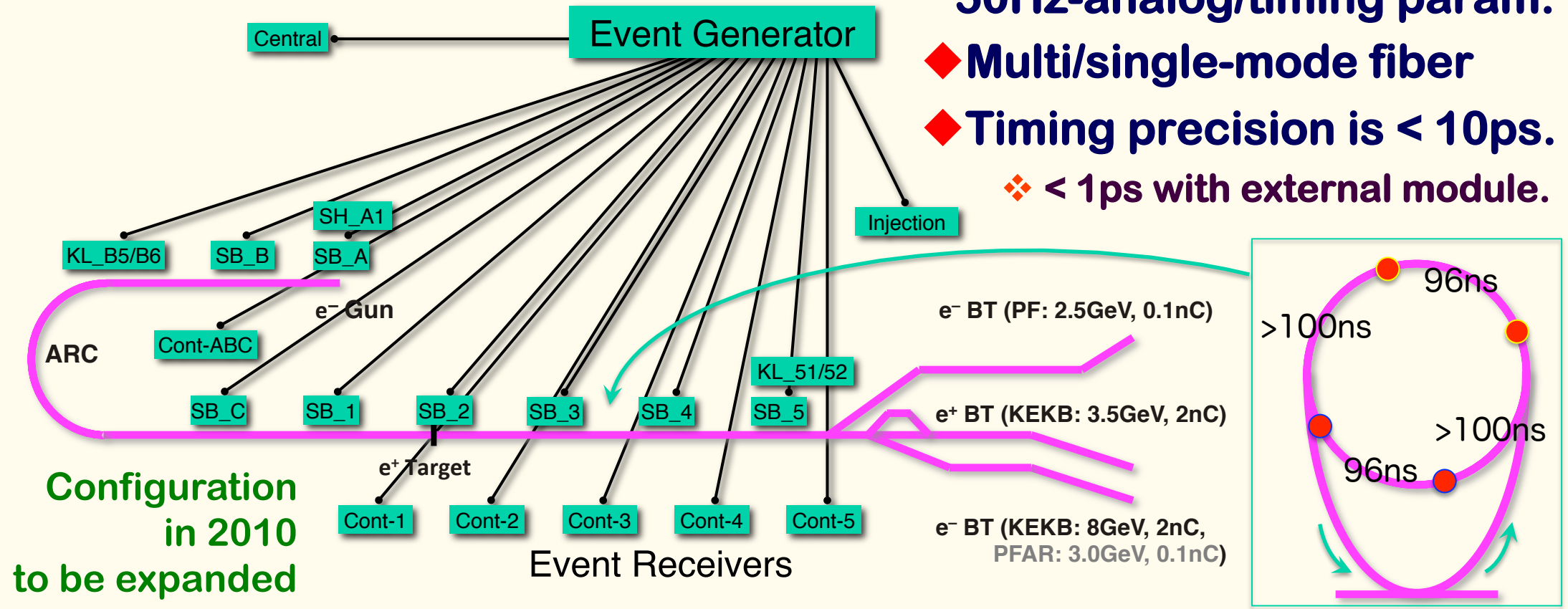
- IOC controls via Conventional EPICS CA
  - Above 1ms, ordered controls
- Fast FPGA controls via SFP/Fiber (MRF)
  - 10ps ~ 100ms, 114MHz synchronous controls



Fast, Global, and Synchronous Controls

- MRF's series-230 (and SINAP's) Event Generator / Receivers
- VME64x and VxWorks v5.5 / v6.8
- EPICS R3.14.x with mrfioc1/2
- 18 event receivers in KEKB
- More Home-grown receivers

- 114.24MHz event rate, 50Hz fiducial
- ~200 dynamic 50Hz-analog/timing param.
- Multi/single-mode fiber
- Timing precision is < 10ps.
  - < 1ps with external module.

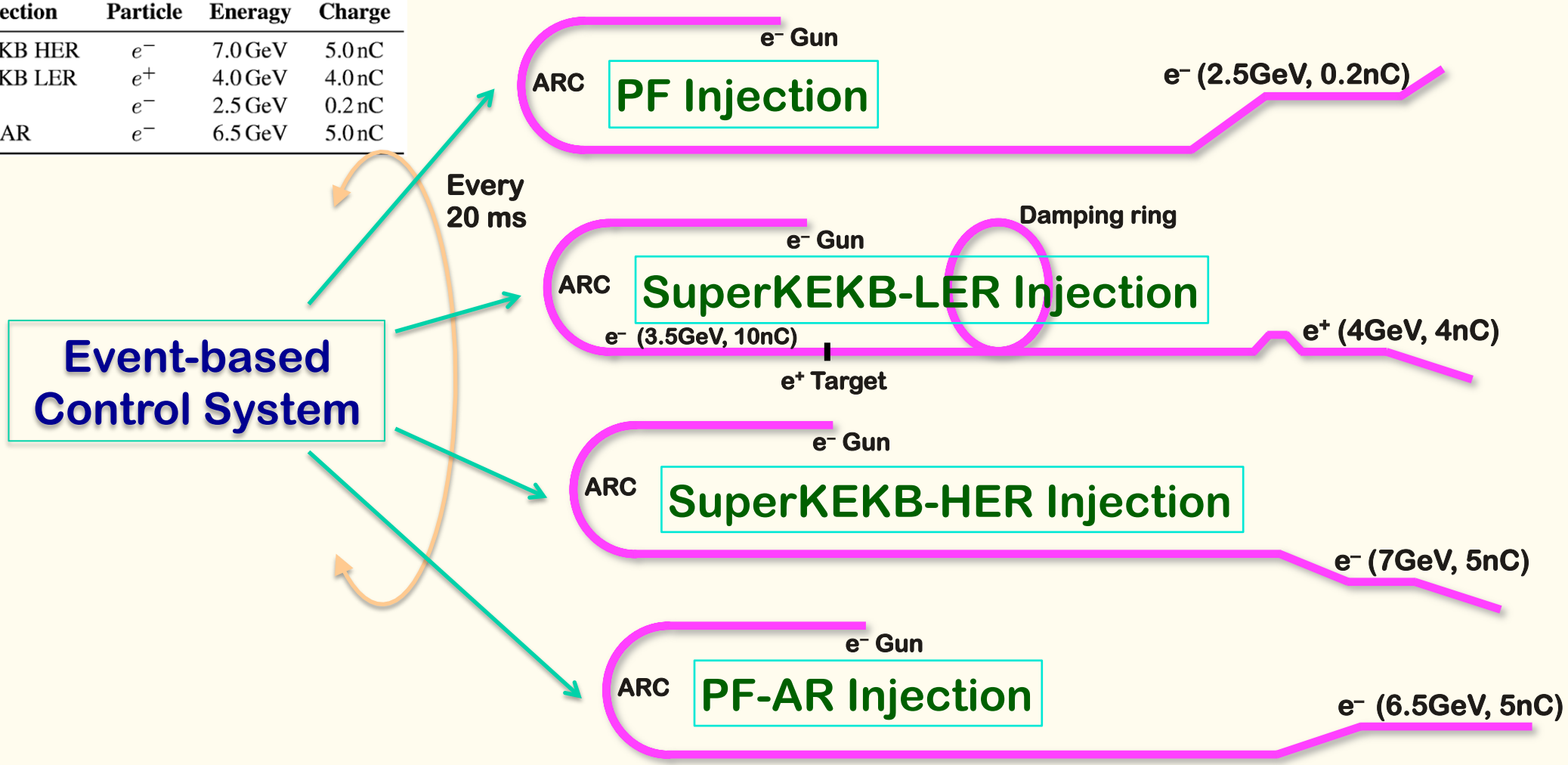


Configuration in 2010 to be expanded

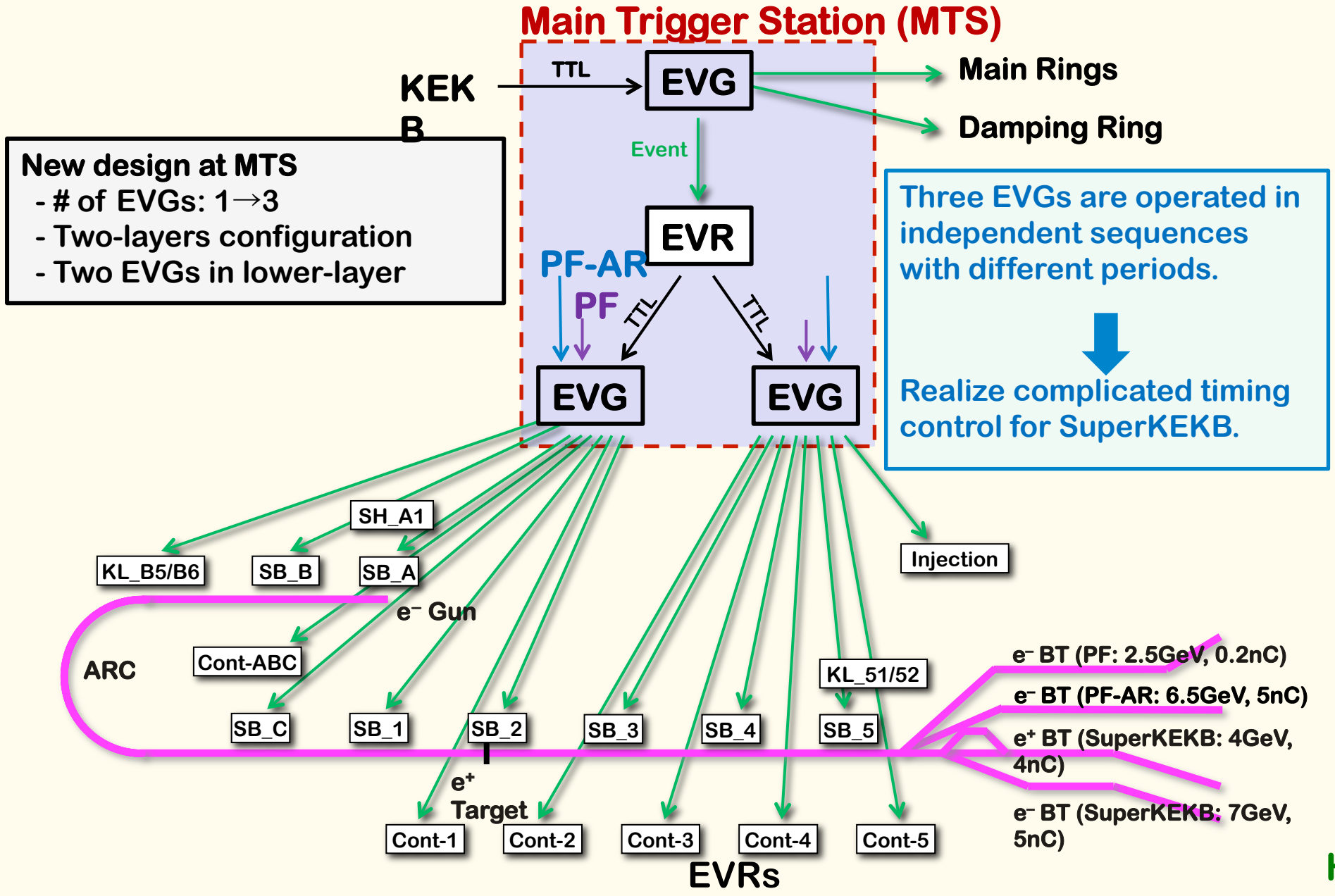
Single Machine, Multiple Virtual Accelerators (VAs)

- Pulse-to-pulse modulation (PPM), one of the VAs is active at a time
- Independent parameter set for each VA, ~200 parameters are switched every 20ms pulse

Direction	Particle	Energy	Charge
KEKB HER	e^-	7.0 GeV	5.0 nC
KEKB LER	e^+	4.0 GeV	4.0 nC
PF	e^-	2.5 GeV	0.2 nC
PF-AR	e^-	6.5 GeV	5.0 nC



Possible Configuration for SuperKEKB

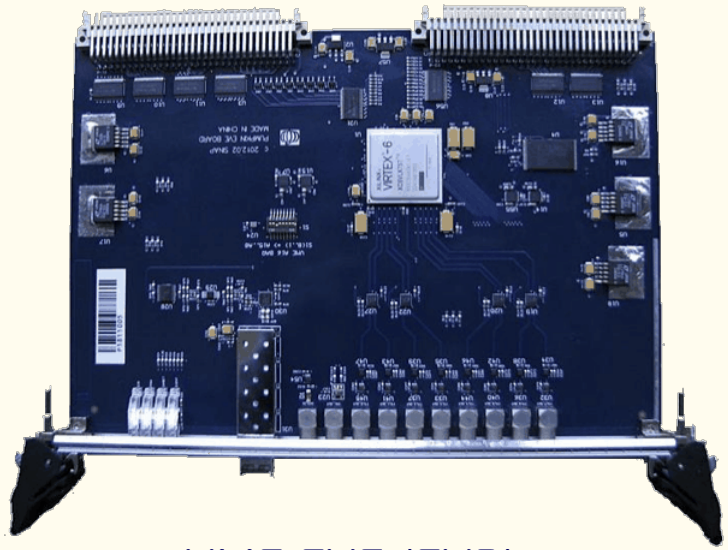


H. Kaji

Compatible MRF-Event Hardware

- **RF monitor system**
  - Embedded EVR for event sync. with Vertex-6 and SFP
- **LLRF system for damping ring**
  - MicroTCA LLRF module with Vertex-5 and SFP
- **Detector interface**
  - Possible embedded EVR in fast detector-veto system
- **SINAP VME and PLC modules for damping ring**

VME EVO (EVG)



VME EVE (EVR)

PLC EVR

Two kinds of Virtual Accelerators (VAs)

- **Virtual Accelerator Models (VAs)**

- **PPM VAs, that represent independent accelerator views for different purposes**
  - **by using dual-tier controls**

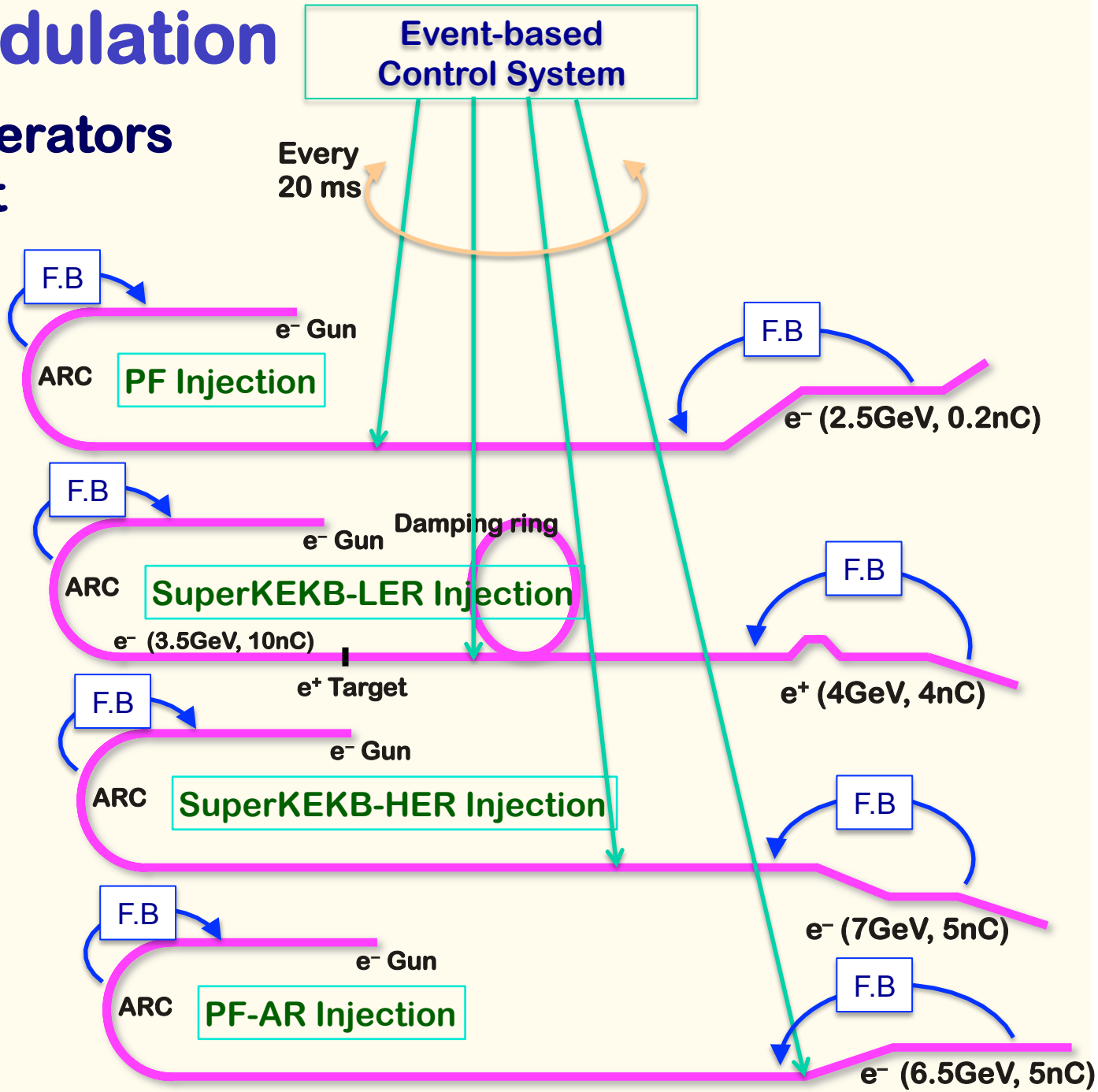
- **Simulation VAs, that represent physics models of accelerators in simulation codes**
  - **by using SADscript codes through EPICS CA, normally**
  - **even before the machine completion**

Pulse-to-pulse modulation

- **Four PPM virtual accelerators for SuperKEKB project**

maybe with additional PPM VAs for stealth beam measurements

based on Dual-tier controls with EPICS and event-system



EPICS on PLC

- Modular system is preferable in accelerator controls
  - Not too fast, industrial I/O modules, commercial availability
  - Difficult to find modules nowadays in VME or MicroTCA form-factors
- Single vender support PLC modules
  - Reliable
  - Yokogawa's IO-open provide facility for user-defined modules (flexible)
- Yokogawa starts to provide Linux (2.6) on PLC CPU
  - Brave enough to choose open source environment
    - We negotiate with Yokogawa to remove any license issues
  - PREEMPT_RT realtime was included for <100μs response
  - Odagiri/KEK, Uchiyama/SHI-RIKEN, Yamada/KEK made much effort to realize the implementation, (but no need for asynchronous records)
  - Takuya-Nakamura/MSC-KEK tailored the environment for KEKB
    - Procserv, pcmon, NFS, …

F3RP61 (e-RT3 2.0)

Linux 2.6.24 (PREEMPT_RT)

PPC 533MHz

128Mbyte RAM

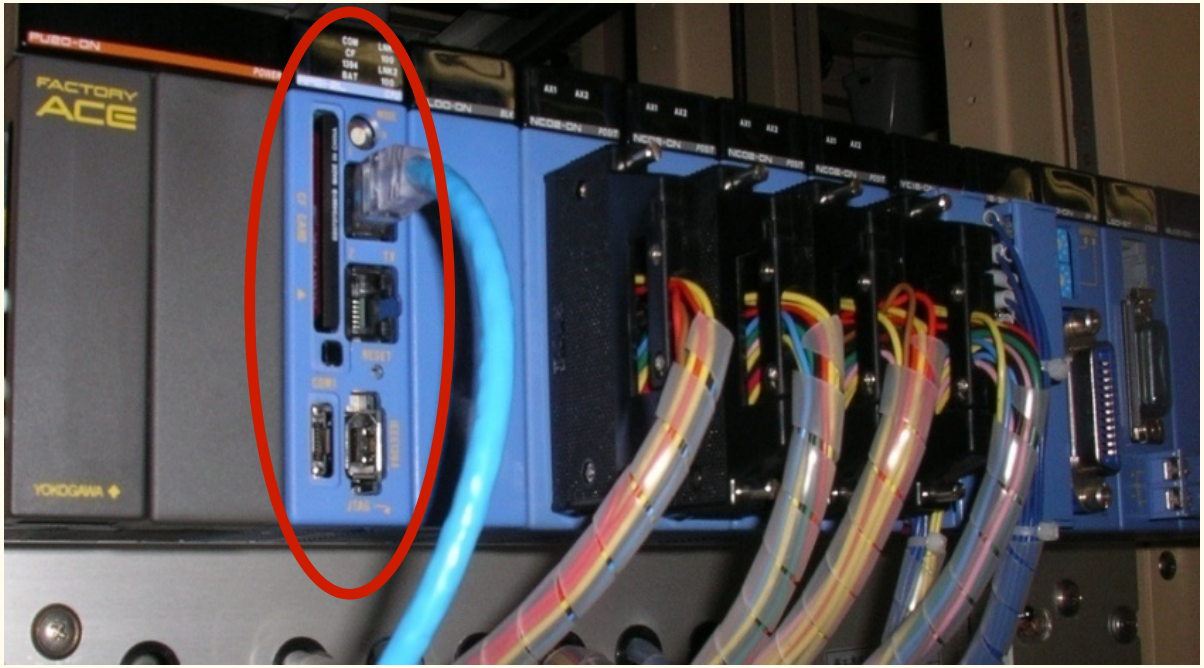
100BaseTx x 2

USB

IEEE1394

Serial

PCI



KEKB Beam mask controller

I/O Bus for FAM3 Module Interface

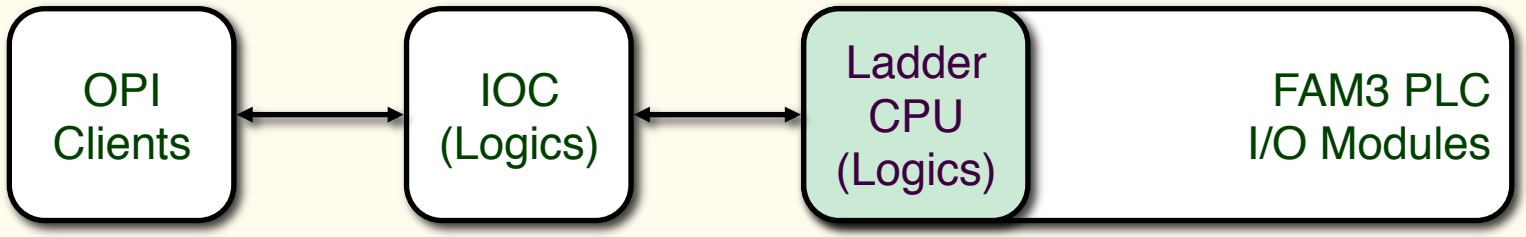
can access to mature FAM3 I/O Modules

Can be combined with conventional ladder CPU

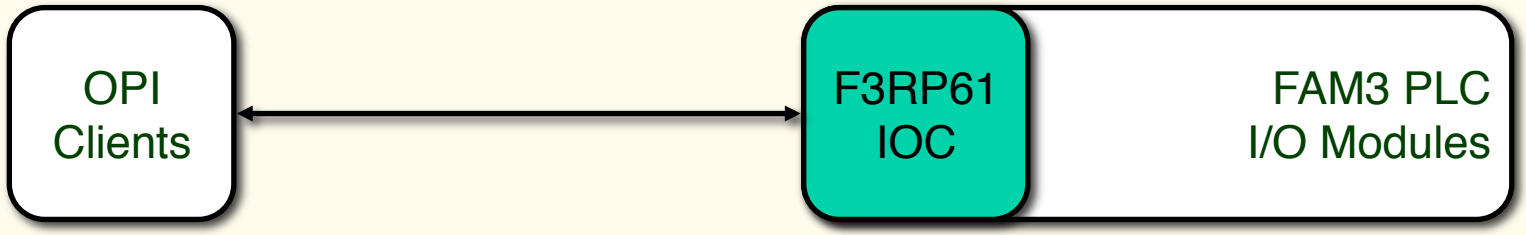
Software development environment (ELDK)

Simple Usage under EPICS

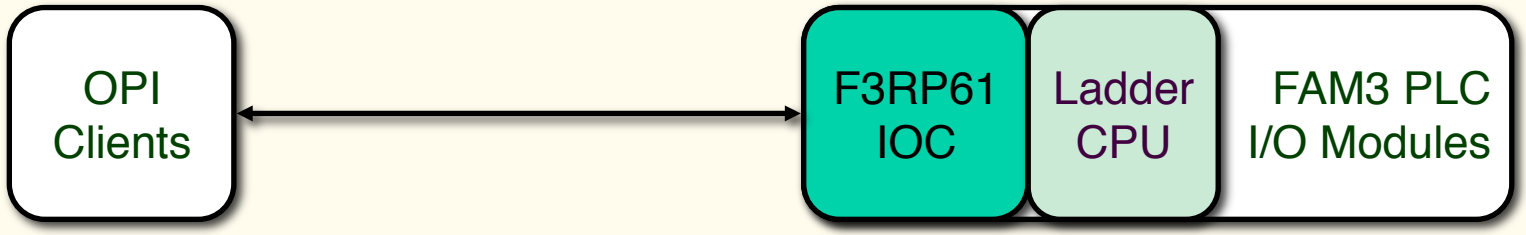
Conventional PLC usage with asynchronous access



PLC usage with F3RP61 with only synchronous access and maybe with sequencer

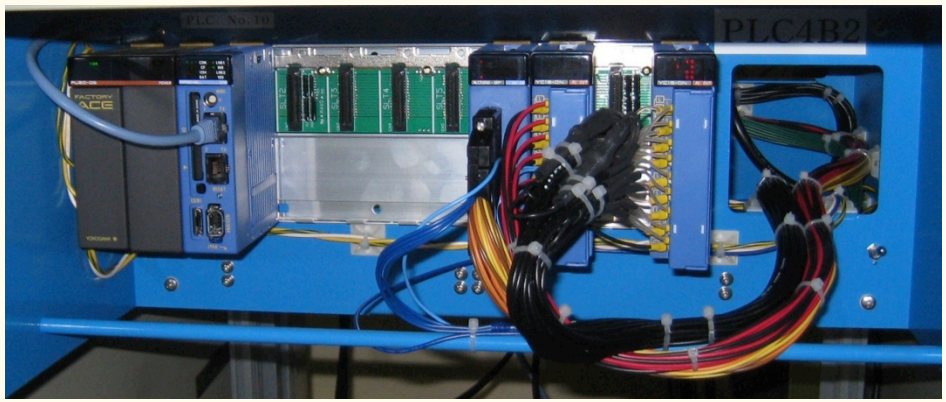


If necessary, we can combine



Device Support and Applications

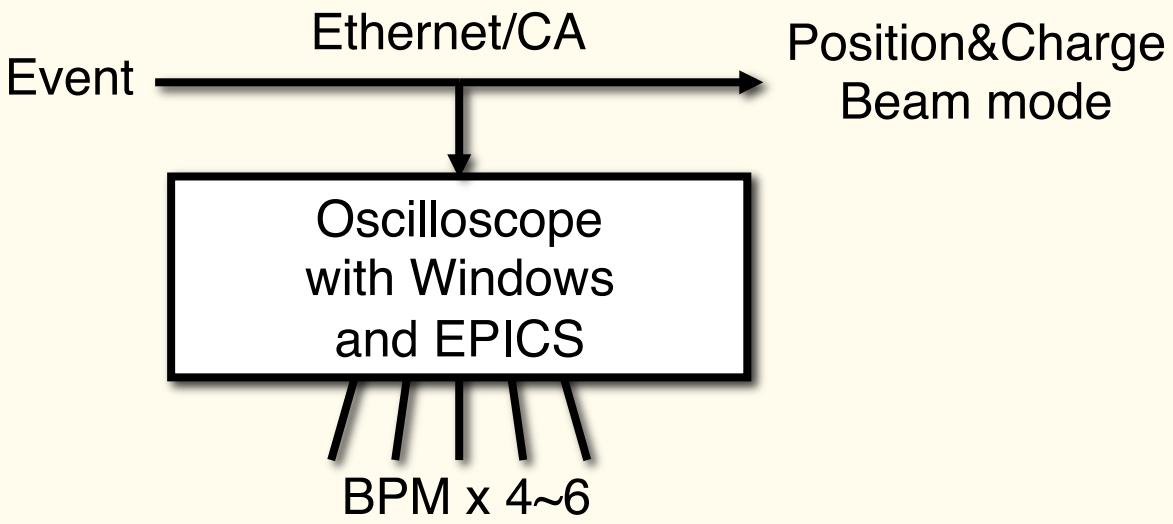
- No need for asynchronous access
  - Direct access to all I/O modules
- Can access to registers on ladder CPU if necessary
- Interrupts also possible
- Logics can be database links or sequencers
- Did extend the number of EPICS developers
- About 80 installations now



- Source code and documents
  - http://www-linac.kek.jp/cont/epics/f3rp61/

Beam Instrumentations – Linac BPM

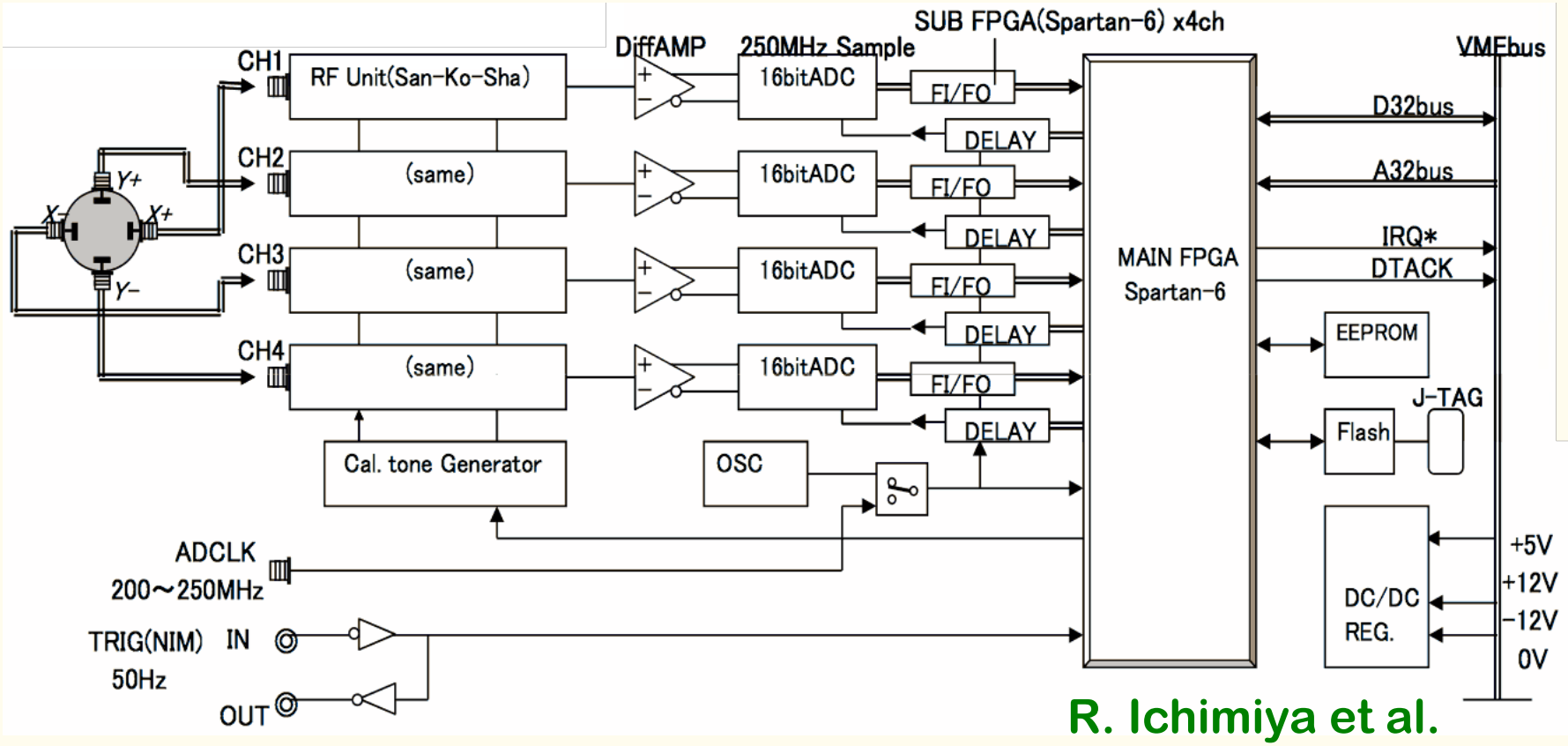
- **Beam position monitor**
  - 50Hz 2-bunch positions, ~100micron → <10micron
- **Oscilloscope-based**
  - 2005 ~ now
  - Cost-effective
  - Embedded EPICS

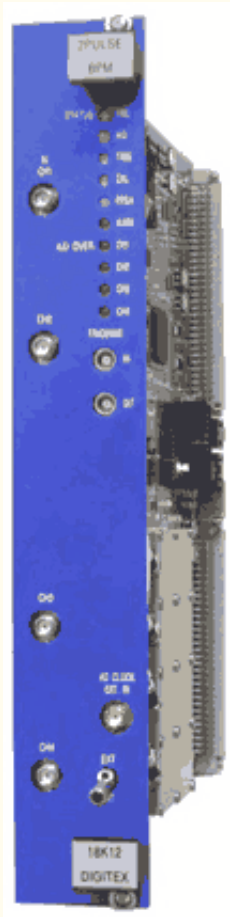


- **New development with FPGA, fast-ADC, etc**
  - 2015 ~
  - for higher resolution

New BPM Readout

- **VME, 2-stage BPF, 16bit 256Ms/s, FPGA**
  - **Accept 96-ns dual-bunch, provide <10micron precision**
  - **Synchronize to MRF event – EVR-230RF**





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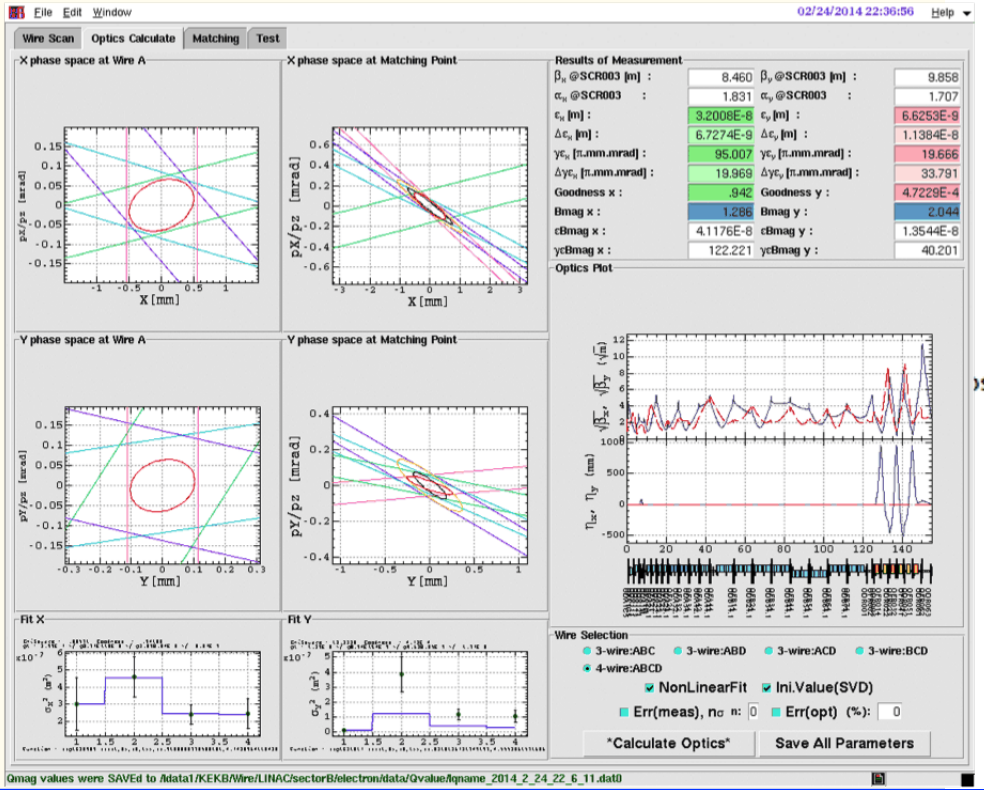
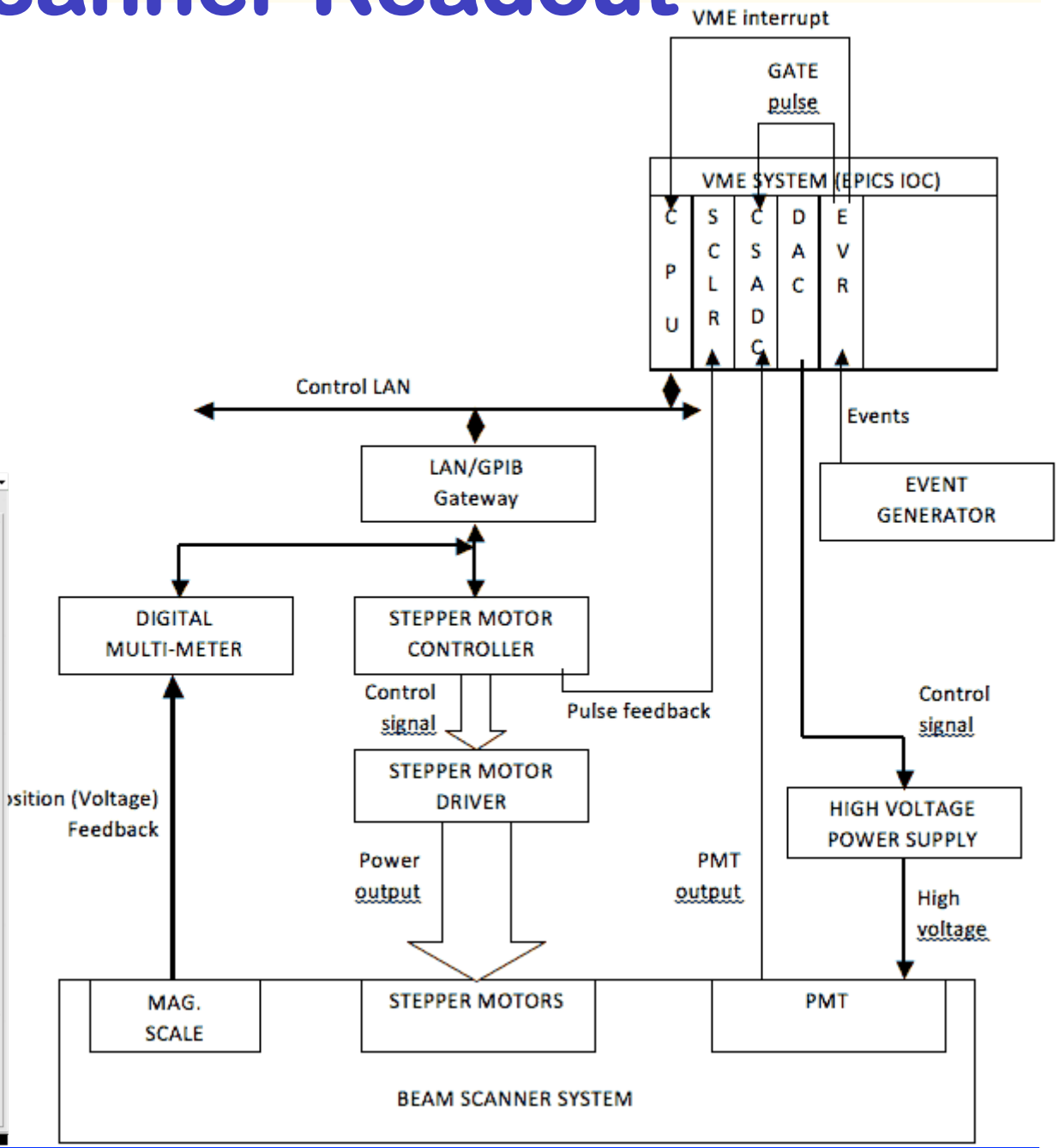
New Wirescanner Readout

- Event synchronization
- CAMAC elimination
- Correction with BPM
- Speed optimization, etc

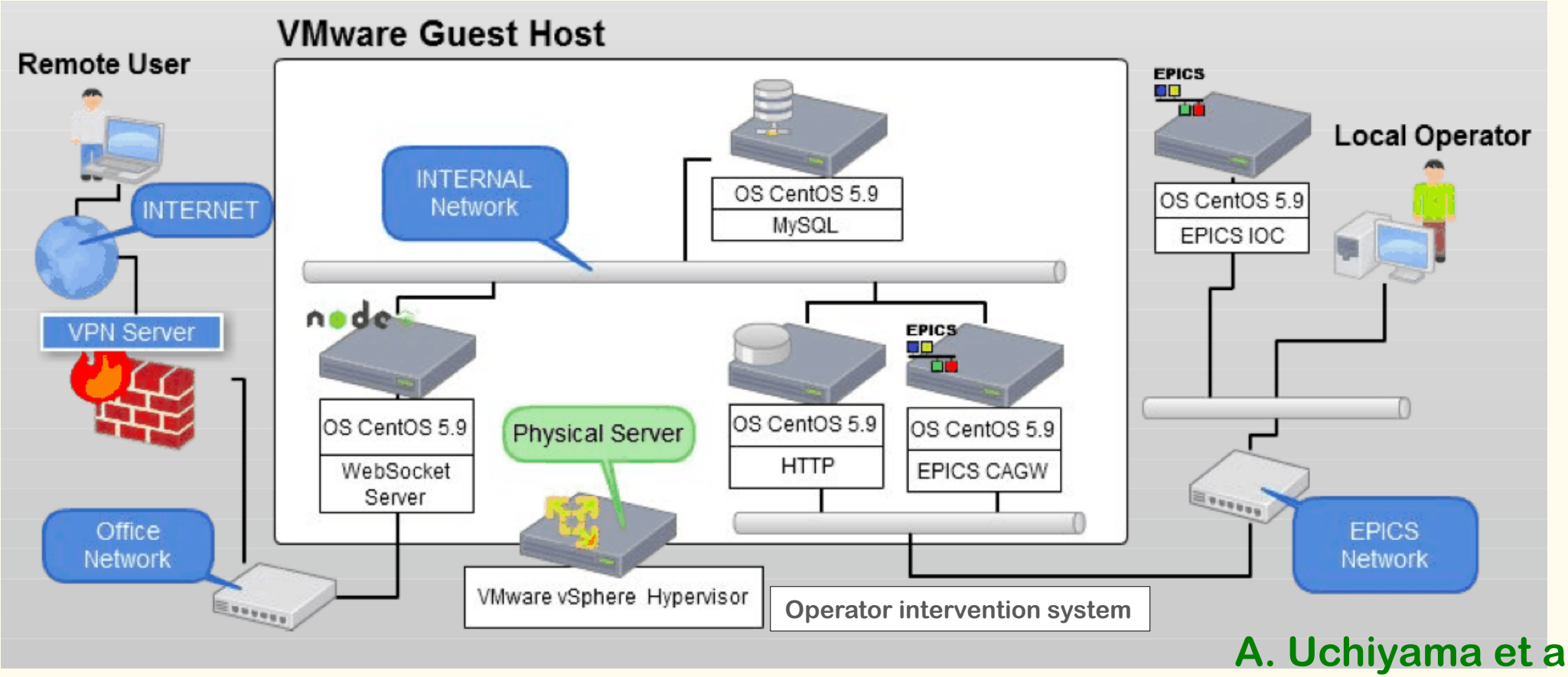
A. Roy et al.





Remote operation diagnosis

- If expert is abroad …
  - Websocket secure channel access interface
  - Operator intervention system



A. Uchiyama et al.

Challenges

- **Security**
  - Windows-XP have to be identified by the institute
- **Development management**
  - Partially managed by equipment group
  - Not enough time to negotiate on the specifications
- **Broadcast, multicast packets**
  - Network separation to manage broadcasts
  - new protocols like MDNS for automation may bother devices
- **More FPGA – SFP systems?**
  - No developers in control group
- **CSS and other Java developments**
  - EPICS community prefers because of Java developer population but we …