

STUDY OF LASER – BEAM ARRIVAL TIME SYNCHRONIZATION TOWARDS SUB-PS LEVEL

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Joint Workshop of the TYL/FJPPN and FKPPN

May 22 – 24, 2024, KISTI, Daejeon, Korea

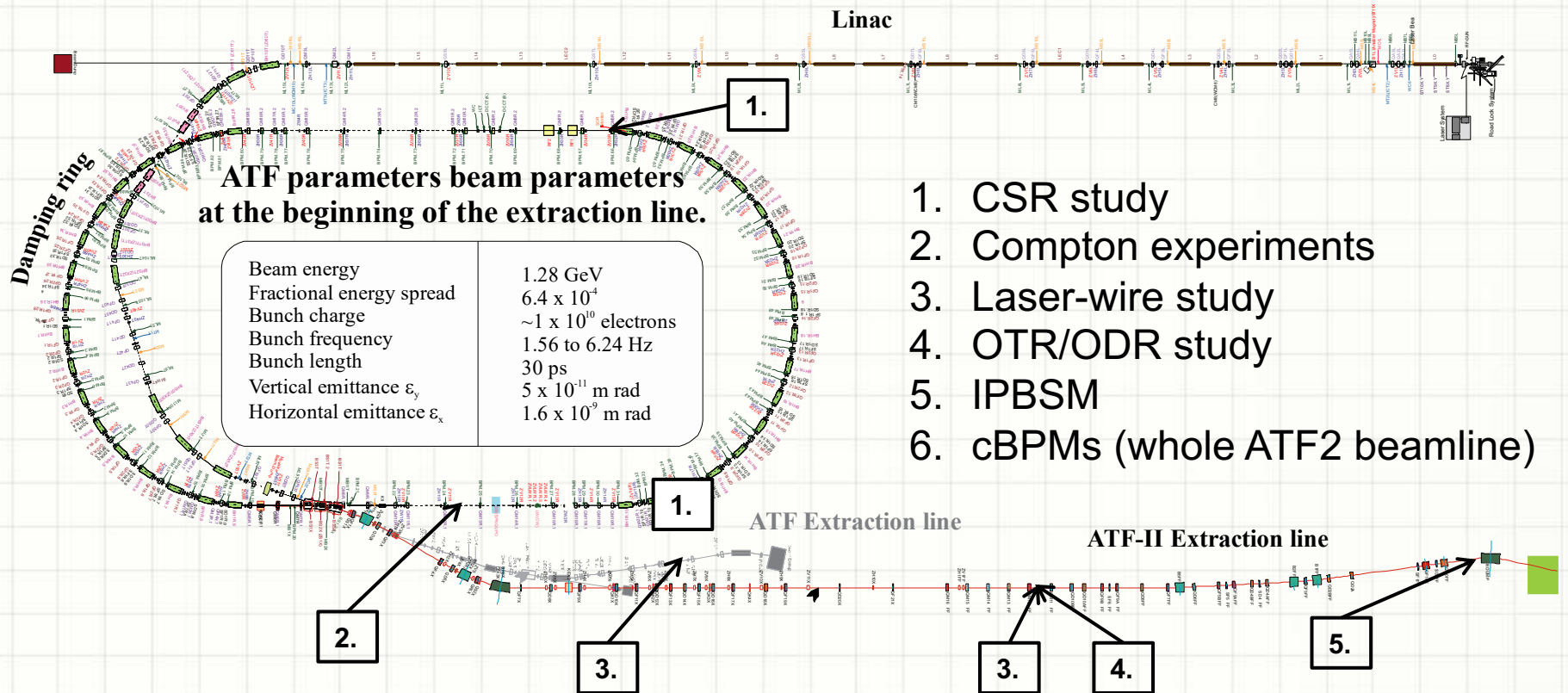
Outline

- Introduction
- ATF timing upgrade Motivation
- ATF timing upgrade Present status
- Polarized electrons in SuperKEKB
- Polarized electrons project status
- Summary and Future plans

Introduction



KEK ATF/ATF2, beam parameters

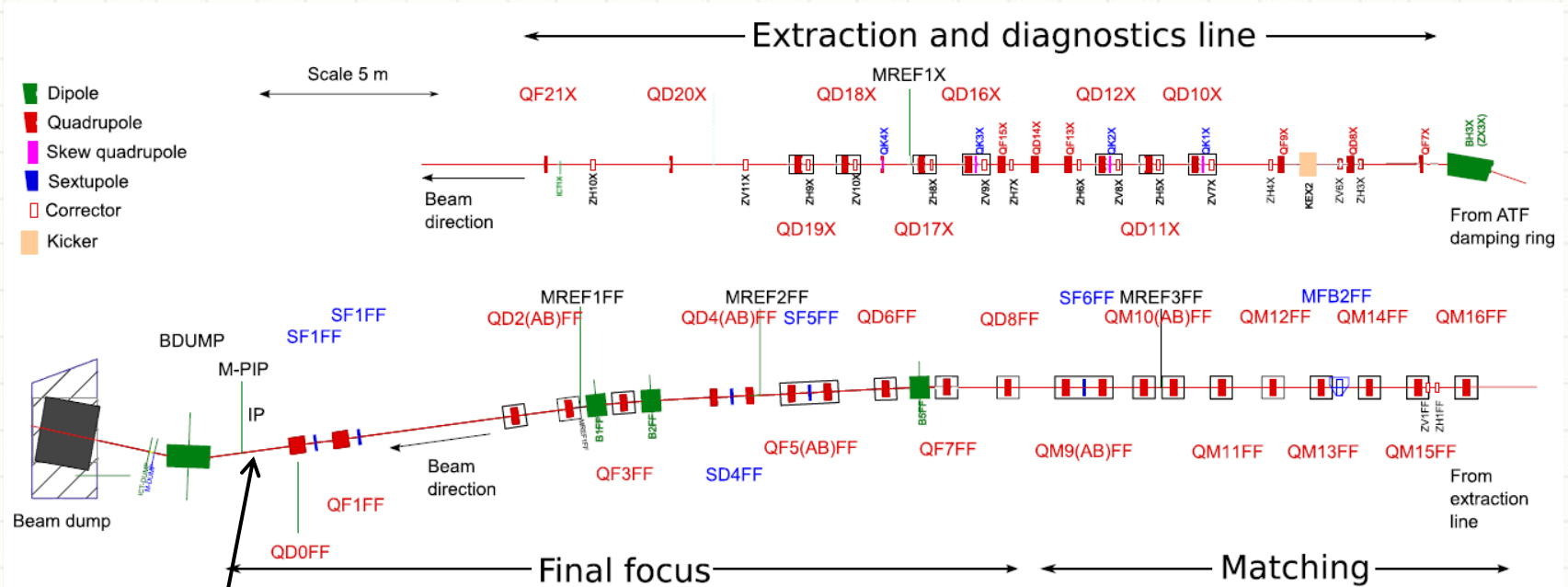


- Develop the nanometer beam technologies for ILC
- Key of the luminosity maintenance, 6 nm beam at IP (ILC)
- ATF2: Final Focus Test Beamline
 - Small beam (Goal: 37 nm) and Position stabilization in a few nm

ATF2 beam line

highlighting the quadrupoles containing cBPMs and IPBSM IP

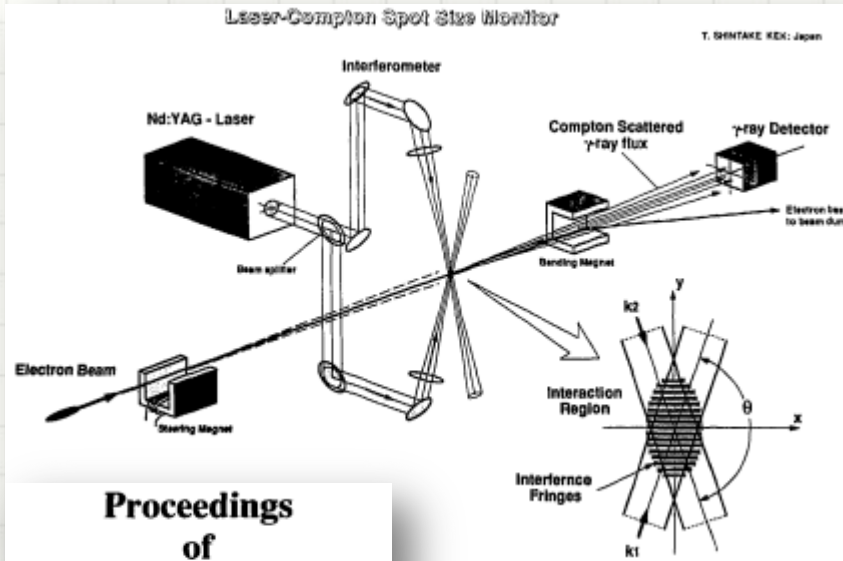
- Dispersion correction ➤ Orbit correction
- BBA



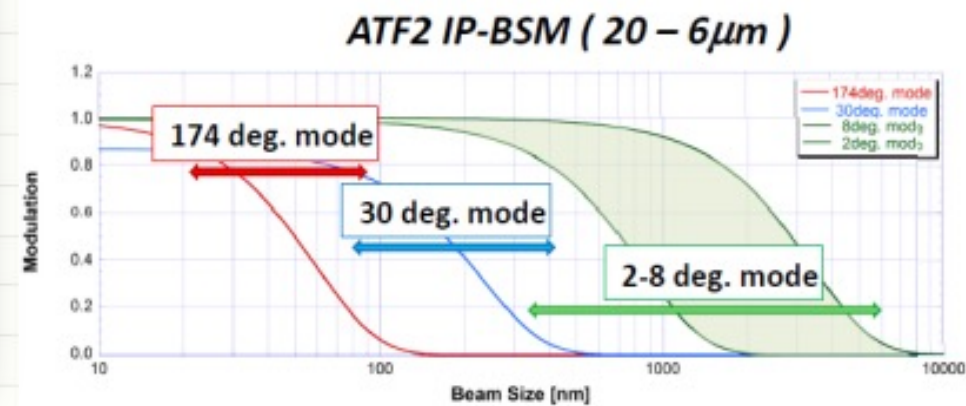
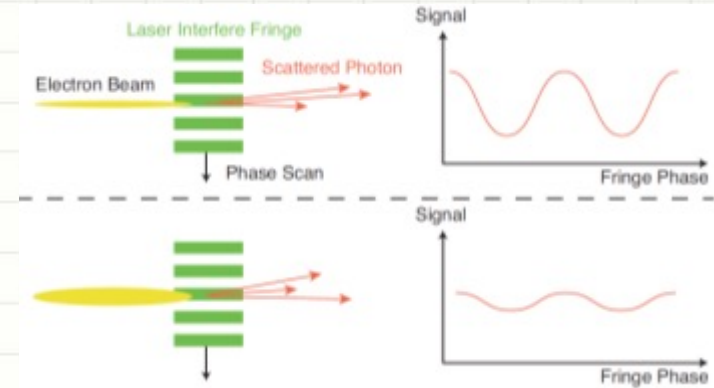
IPBSM-IP

Achieved 44 nm (2014) with a good repeatability.
Now the tuning method to reach 37 nm is under development.

ATF2, IPBSM



Proceedings
of
the Third Workshop
on
Japan Linear Collider
(JLC)
KEK, February 18 - 20, 1992



- Establish the ILC final focus method with same optics and comparable beamline tolerances
 - ATF2 Goal : 37 nm → ILC 6 nm
 - Achieved 41 nm (2016), obtained a good repeatability
- Continued:
- Establish the tuning method to 37 nm.
 - Study wakefields impact for ATF and ILC

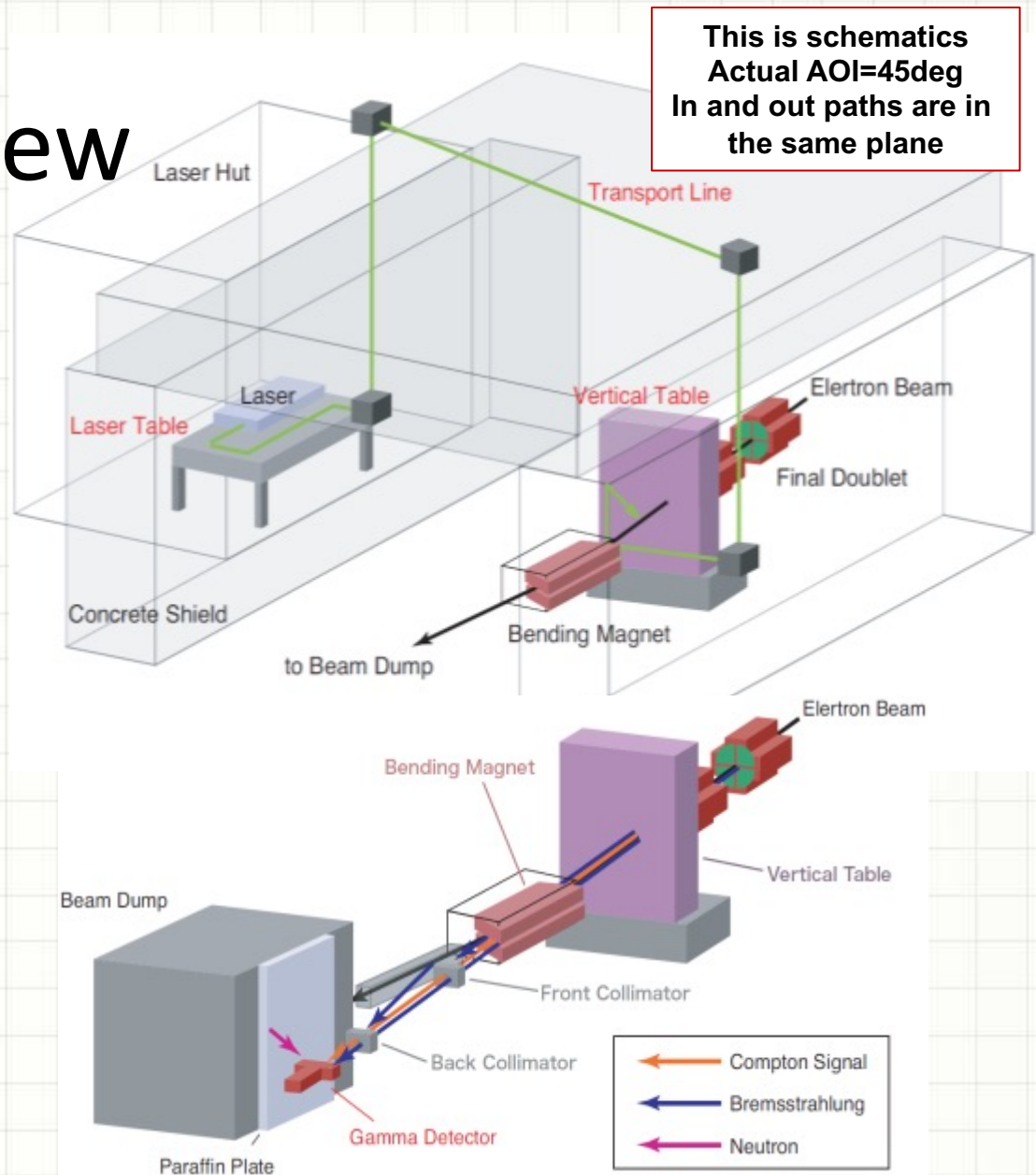
Original name:

“Laser-Compton Spot Size Monitor”

IP-BSM overview

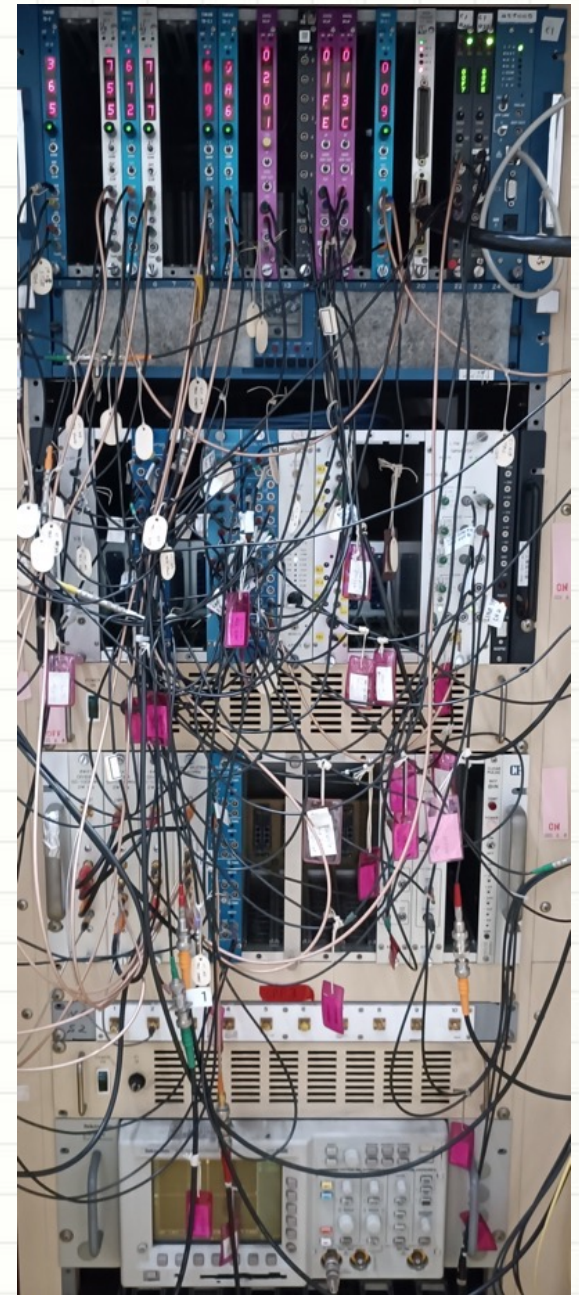
IP-BSM is not just a laser

- IP-BSM consists of:
 - Nd:YAG Laser
 - Laser Transport Line (LTL)
 - Vertical table (laser FF-IP)
 - Detection line:
 - Collimator
 - Detectors
 - DAQ
 - Timing system
 - Software



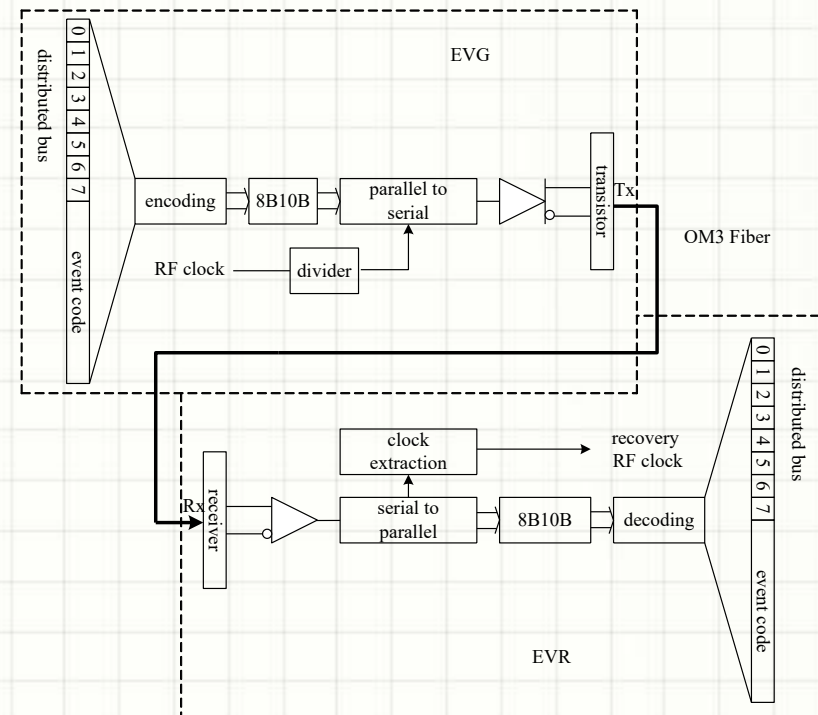
ATF timing Introduction

- Timing system provides:
 - Precise Synchronization between accelerator subsystems.
 - Triggers and Gates for DAQ.
 - Triggers for diagnostic systems.
 - Inhibit and Interlock signals.
- It is linked with LLRF system which includes:
 - RF generation/distribution for:
 - Accelerator cavities.
 - Digital delays.
 - Feedbacks
 - etc



Motivation and preliminary tests

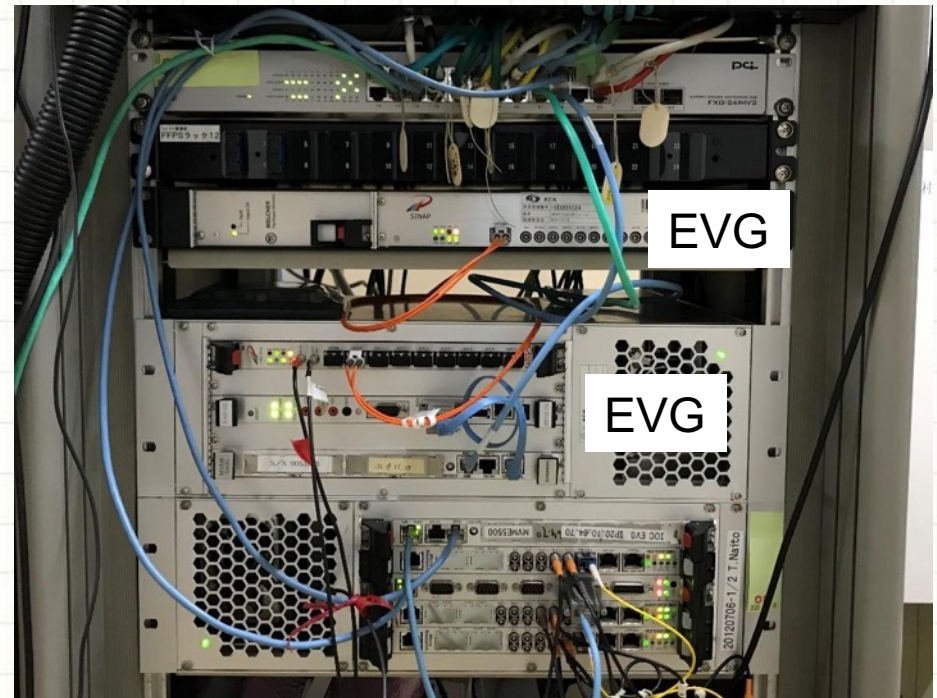
- Outdated key CAMAC and NIM components.
- Low precision.
- Short range of Digital Delay.
- Complexity of the system:
 - Distribution of Initial Trigger and RF clocks.
 - Sensitivity for electrical noise.
 - Legacy wiring/modules.
 - Constant maintenance.
- Since 2021 in a collaboration with KEKB we started a study on EVENT-based Timing system.

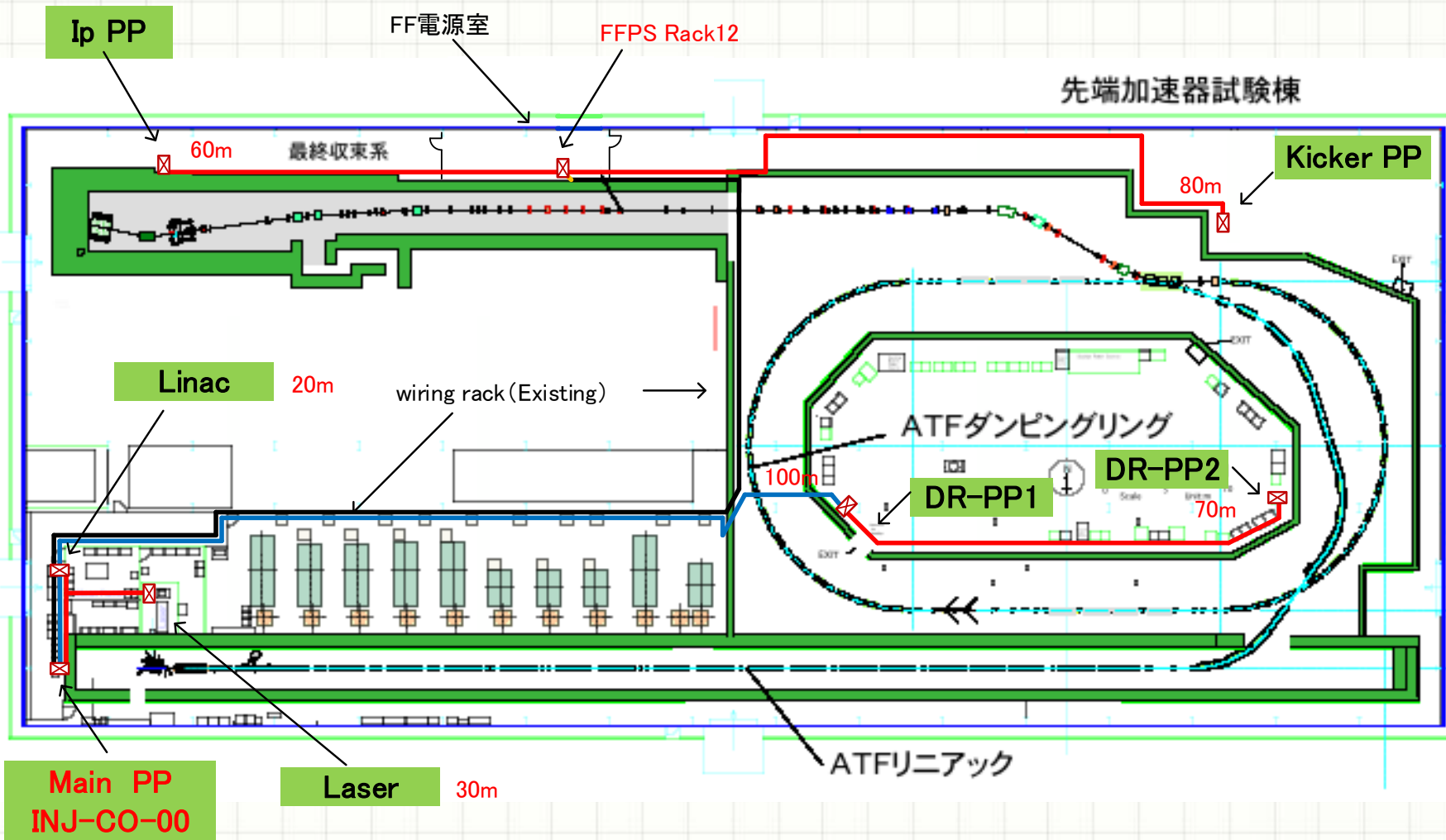


Preliminary tests

- After successful tests in the fall of 2021:
 - 12-core fiber cable was installed between ATF master timing and ATF FF local timing hut.
 - Event Generator connected to ATF master timing.
 - Event Receiver was installed to control ATF FF timing.
- 2022 operation shows better stability and higher precision of the new system.

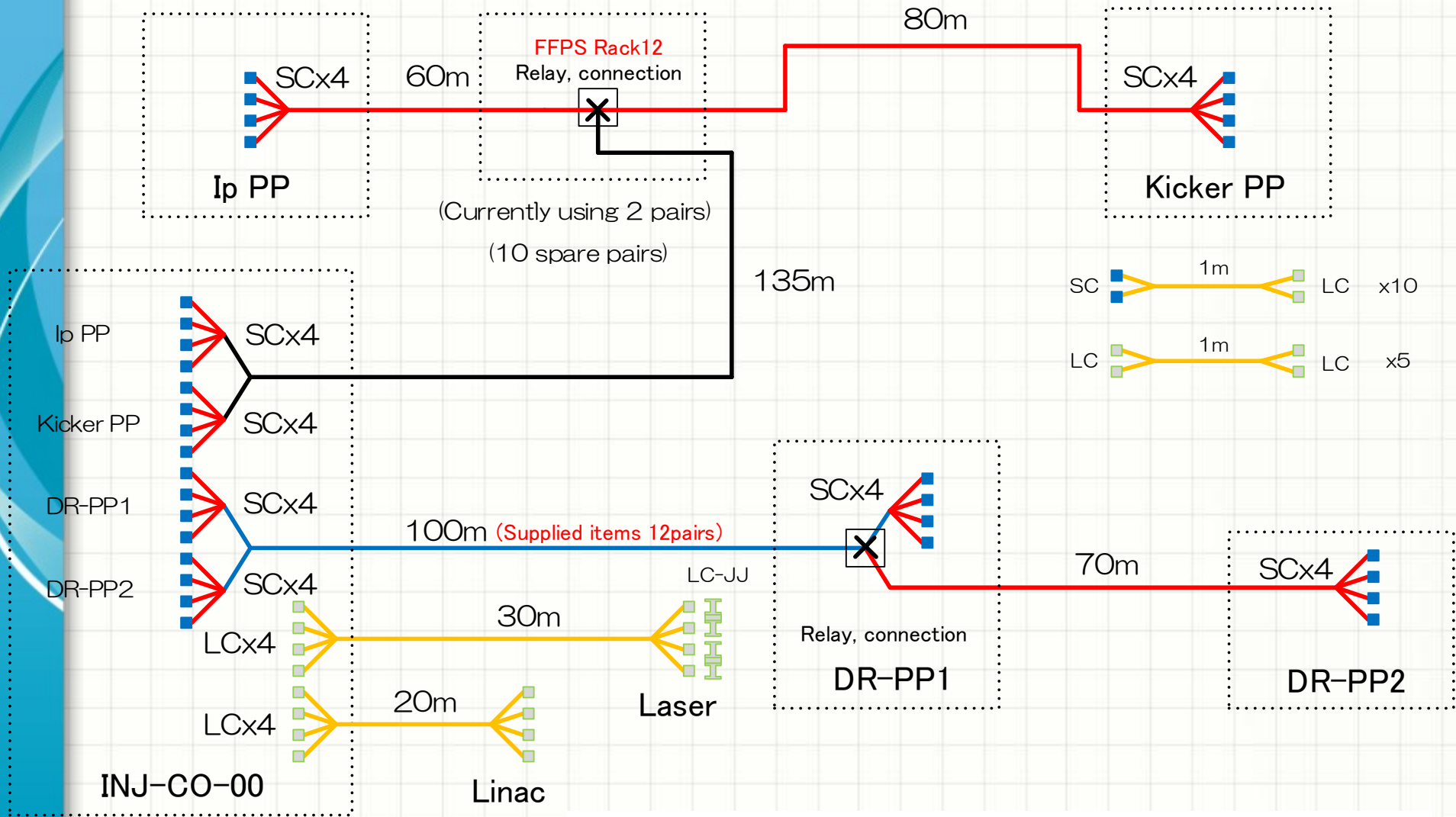
EVG – EVR testbench





- ☒ Control rack (Existing)
- Optical cable 12 pair (Existing)
- Optical cable 12 pair (Supplide item)
- Optical cable 2 pair (New)

Timing fiber distribution upgrade in 2023



Timing fiber distribution upgrade in 2023

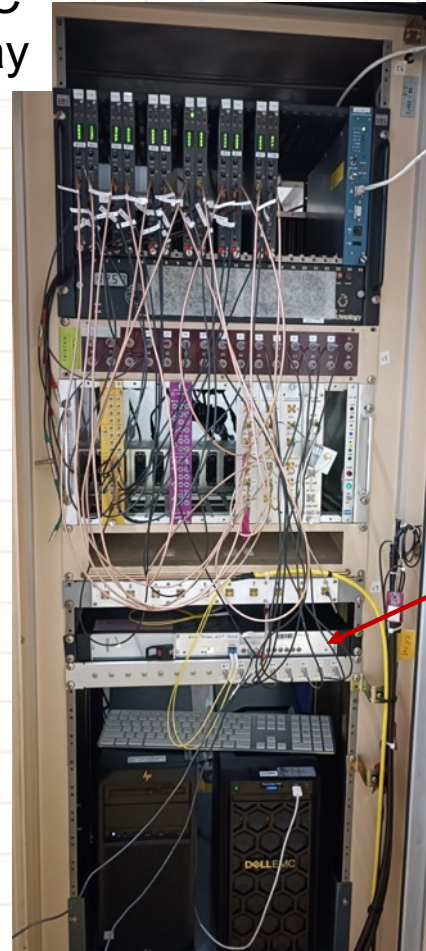
Present status: LINAC and RF Gun laser timing

2022

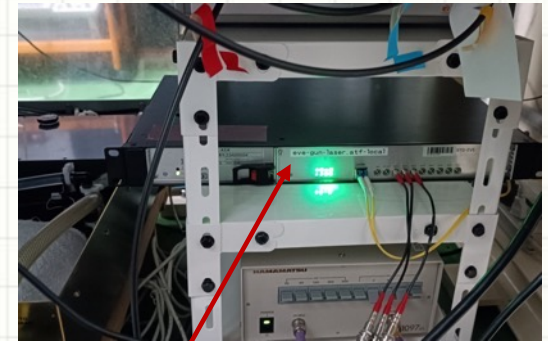


Old CAMAC
Digital Delay

Now



RF Gun laser hut



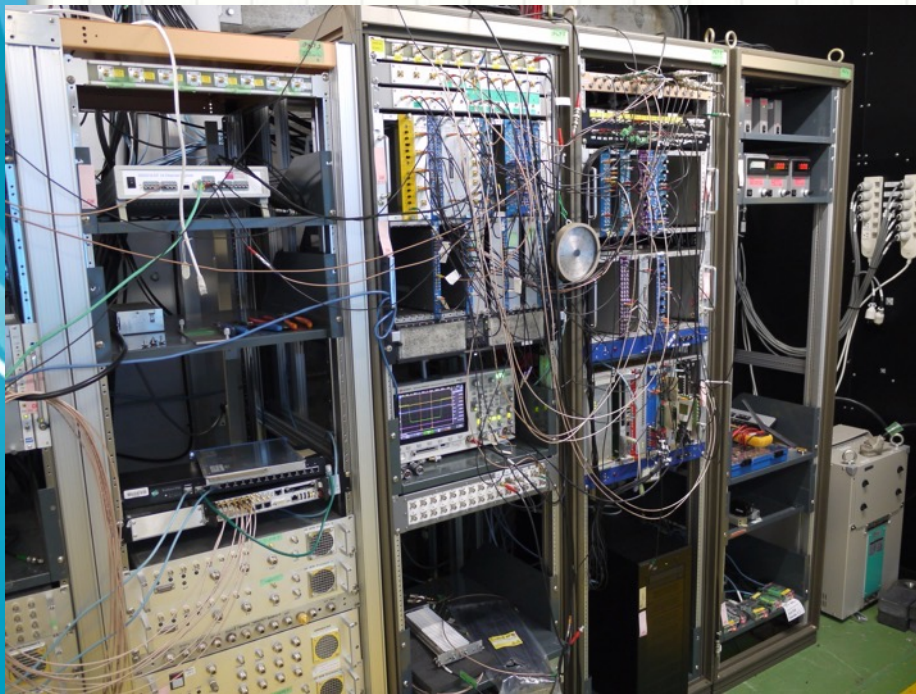
EVR

Both systems were tested with e-beam in March 2024

Present status: IP and IPBSM

ATF FF employs a new timing system since 2021

2022



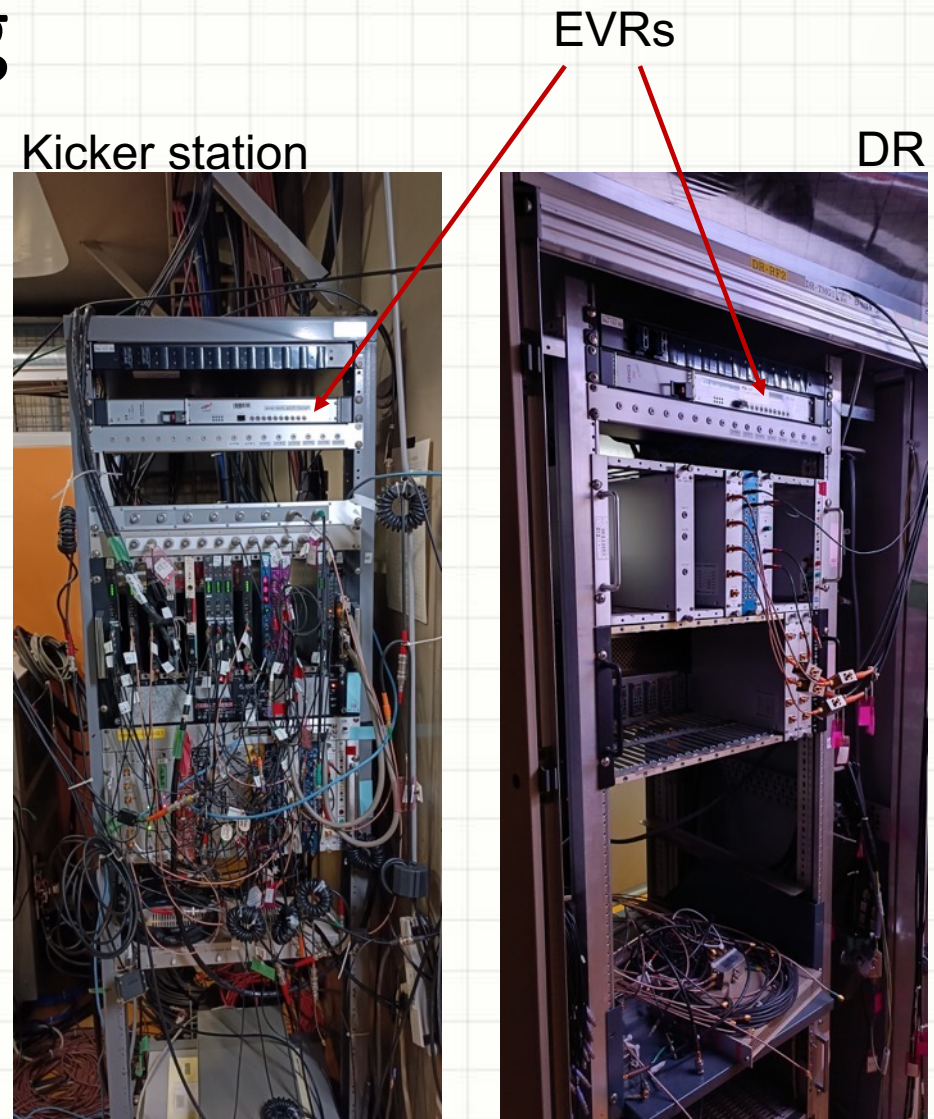
Now



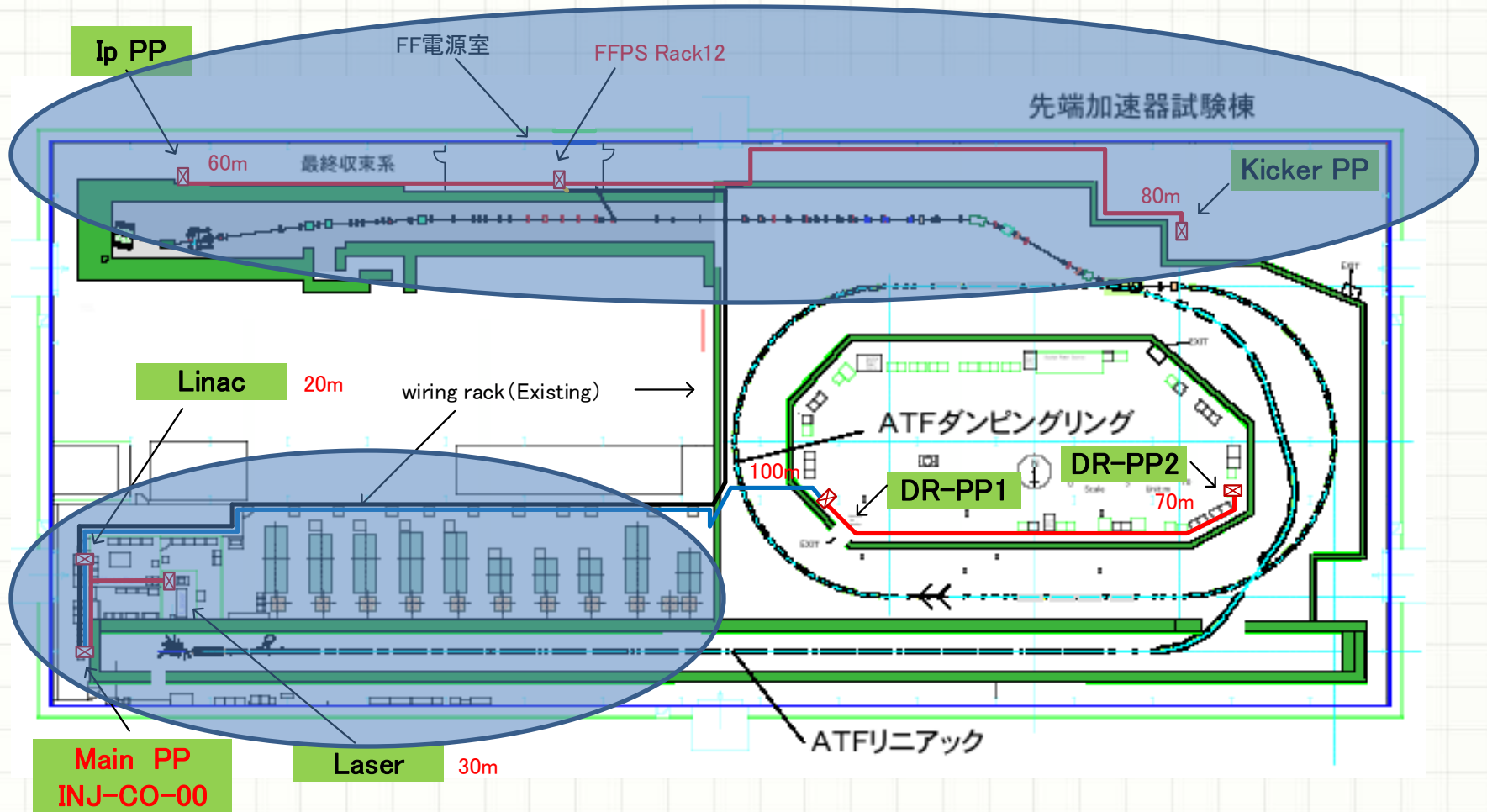
New system was tested with e-beam in January 2024

Present status: Kicker station and Damping Ring timing

- EVR is installed.
- At present the CAMAC based system in use.
- Switching is foreseen after careful revision of existing system.

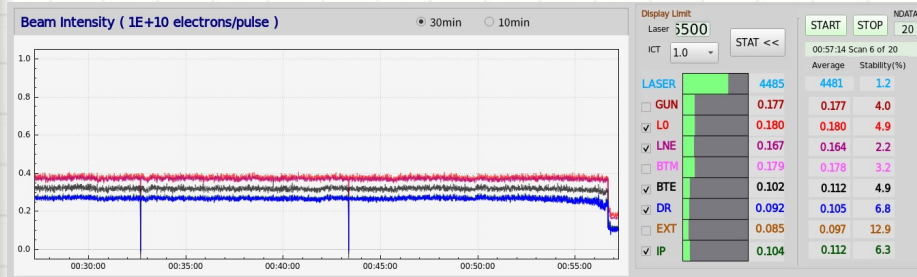


Summary: markers – EVG/EVR system



Short-term e- charge stability improvement

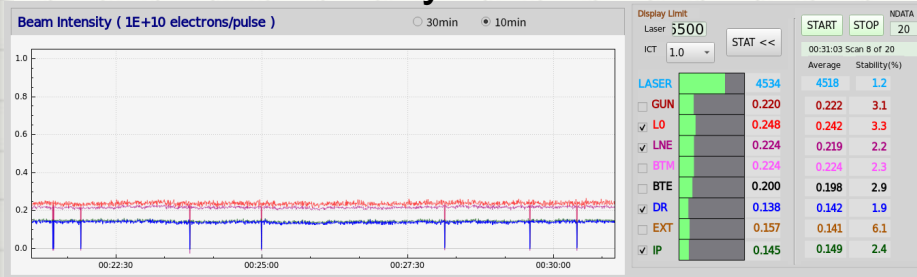
April 2023, only FF uses new timing system



- Stability data taken for ~ 30 minutes
- Transmission was ~ 100%
- Average charge ~0.15E10 e/bunch

Peak-to-Peak data below shows about 2 times improvement!

March 2024, RF Gun laser, Linac, FF, IP use new system



e- charge at:	2023	2024
Linac End	~0.01	~0.005
IP	~0.01	~0.005

Note: some beam “drops” suggest careful RF Gun laser timing tuning

ATF timing system upgrade summary

- Additional fibers and SINAP EVR modules with associated Patch Panels were installed in 2023.
- RF Gun Laser, LINAC, EXT, FF and IP already switched to a new timing system.
- Bucket selection (2-train operation mode) is now under study for a new timing system.
- Existing LLRF system is under review for potential upgrades.
- Completion of the timing system upgrade is foreseen in JFY 2024.

Why polarized electrons in SuperKEKB ?

With 70% polarized electron beam get unprecedented precision for neutral current vector couplings

Final State Fermion	SM g_v^f (M_Z)	World Average ¹ g_v^f	Chiral Belle σ 20 ab^{-1}	Chiral Belle σ 40 ab^{-1}	Chiral Belle $\sigma \sin^2 \Theta_W$ 40 ab^{-1}
b-quark (eff.=0.3)	-0.3437 \pm .0001	-0.3220 \pm 0.0077 (high by 2.8 σ)	0.002 Improve x4	0.002	0.003
c-quark (eff. = 0.3)	+0.1920 \pm .0002	+0.1873 \pm 0.0070	0.001 Improve x7	0.001	0.0007
Tau (eff. = 0.25)	-0.0371 \pm .0003	-0.0366 \pm 0.0010	0.0008	0.0006	0.0003
Muon (eff. = 0.5)	-0.0371 \pm .0003	-0.03667 \pm 0.0023	0.0005 Improve x 5	0.0004	0.0002
Electron (1nb acceptance)	-0.0371 \pm .0003	-0.03816 \pm 0.00047	0.0004	0.0003	0.0002

1 - Physics Report Vol 427, Nos 5-6 (2006), ALEPH, OPAL, L3, DELPHI, SLD
 $\sin^2 \Theta_W$ - all LEP+SLD measurements combined WA = 0.23153 ± 0.00016
 $\sin^2 \Theta_W$ - Chiral Belle combined leptons with 20 ab^{-1} have error ~ 0.00016

More info: <https://indico.cern.ch/event/1411959/contributions/5934685>

How ?

- Goal is ~70% polarization with 80% polarized source (SLC had 75% polarization at the experiment)
- Electron helicity would be chosen randomly pulse-to-pulse by controlling the circular polarization of the source laser illuminating a GaAs photocathode (similar to SLC source) **KEK+Hiroshima university**
- Inject vertically polarized electrons into the High Energy Ring (HER) - needs low enough emittance source to be able to inject.
- Rotate spin to longitudinal before IP, and then back to vertical after IP using solenoidal and dipole fields **TRIUMPF + U. Victoria + ANL + BNL**
- Use Compton polarimeter to monitor longitudinal polarization with <1% absolute precision, higher for relative measurements (arXiv:1009.6178) - needed for real time polarimetry **IJCLab+U.Manitoba**
- Use tau decays to get absolute average polarization at IP **U. Victoria**

Current status

Jinst

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Conceptual study of a Compton polarimeter for the upgrade of the SuperKEKB collider with a polarized electron beam

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ABSTRACT: The physics scope of the Belle II experiment currently acquiring data at the SuperKEKB collider will expand with a polarized electron beam upgrade, as recently proposed. Among the required elements for this upgrade, a real time diagnosis of the polarization is necessary to ensure it is large for all bunches in the accelerator during its regular operation. This will be realized by inserting a Compton polarimeter in the accelerator. Its conceptual design is described and no show-stopper for its integration has been identified. An estimation of the sensitivity of the polarimeter is made by means of toy Monte-Carlo studies. The proposed design accounts for the constraint to preserve the performance of the SuperKEKB accelerator and to cope with the short time separation of successive bunches. We show that the polarimeter will measure for each bunch the polarization within five minutes with a statistical precision below 1% and systematic uncertainties below 0.5%. It has the capability of providing this information online on a similar timescale. This work paves the way towards future implementation of real-time Compton polarimetry in several future projects.

First tests of polarization lifetime expected in 2025 in SuperKEKB (no modification to SuperKEKB yet)

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Snowmass 2021 White Paper Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation

April 13, 2022

US Belle II Group ¹

and

Belle II/SuperKEKB e- Polarization Upgrade Working Group ²

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BELLE2-REPORT-2023-001
DRAFT Version 2.1
22 December 2023
Submitted to BPAC

The Belle II Detector Upgrades Conceptual Design Report

Belle II Collaboration

2023 JINST 18 P10014

Compton polarimeter

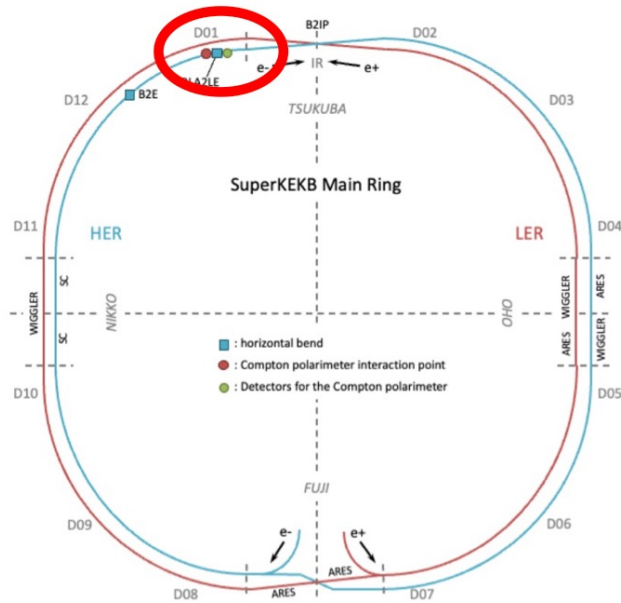
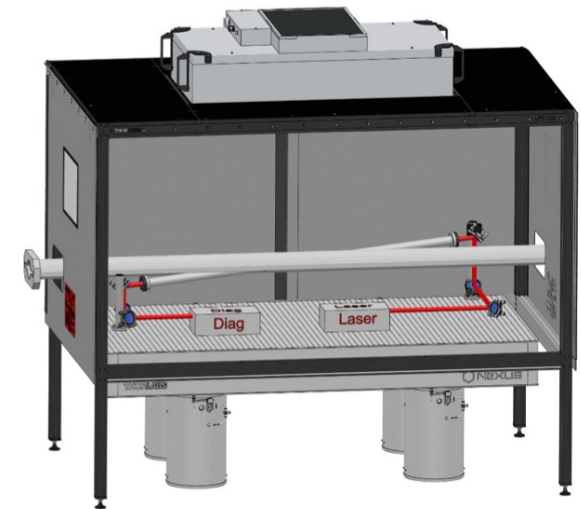


Figure 1. Schematic drawing of the main SuperKEKB ring, where the current B2E dipole to be replaced by spin rotators is identified. The location of the Compton polarimeter is also shown as well as Belle II interaction point.



2. Drawing of the laser and electron beams interaction chamber. Boxes named *laser* and *diag* are holders for the laser and the diagnostics for the laser light that will be used to ensure that alignment and operation of the laser are optimized. Not shown are electronics that will be located below the optical table that will be shielded against the ambient radiation of the accelerator.

Plans

- Key aspect of the project is the implementation of a laser in SuperKEKB
 - Not a easy task, but is simple to operate --> achievable
- Critical element to be validate well in advance is the **synchronisation of laser on the accelerator clock**
- Exploit the WhiteRabbit technology to precisely and simply transfer a clock from RF master oscillator to laser
- 2024-2025 plans:
 - Phase noise measurements at Orsay (ongoing)
 - Implementation of a first test clock transfer at KEK
 - Eventually implement synchronization of a laser on the RF clock, test may be easily done at the ATF
 - Validate performance
- Planned travels (Orsay→KEK): June and October



Acknowledgements

This work is partially supported by MEXT Development of key element technologies to improve the performance of future accelerators Program, Japan Grant Number JPMXP1423812204.



BACKUPS

Performance

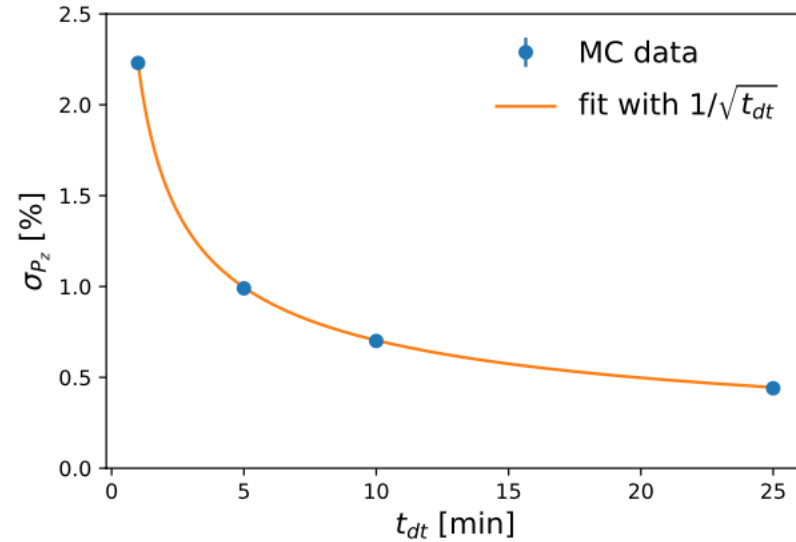
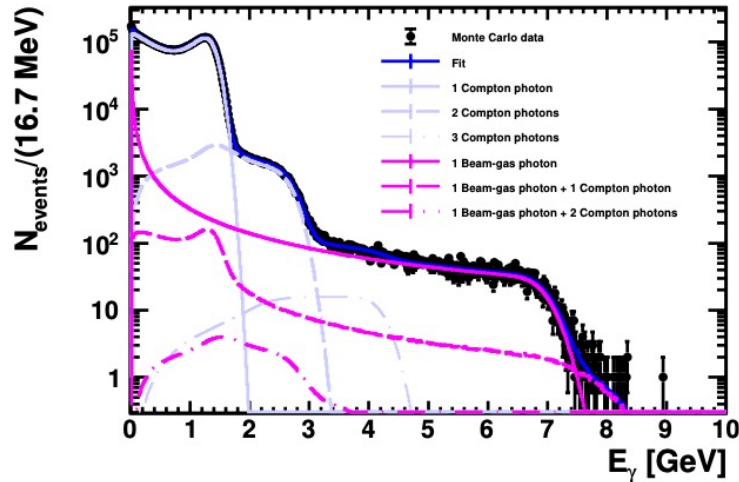
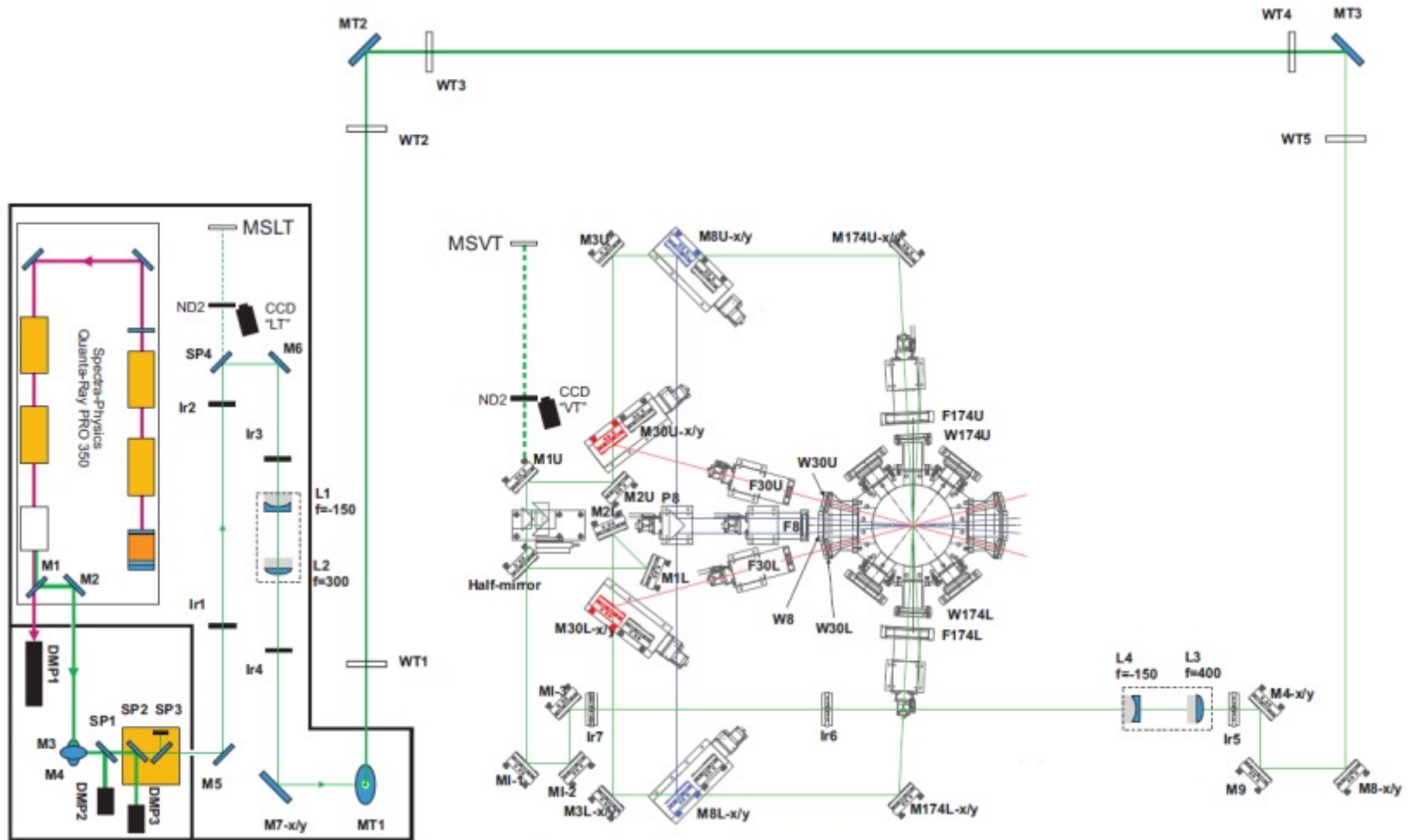


Table 4. Systematic uncertainties on the extraction of P_z , see text for details. Background modeling and absolute knowledge of the laser polarization dominates.

Source	Uncertainty on P_z (%)
Laser beam polarization	0.30
Backgrounds	0.16
Fit procedure	0.080
Beam energy	0.050
Spatial misalignment	0.015
Angular misalignment	0.015
Longitudinal misalignment	0.015
Transverse electron beam polarization	0.015
Total	0.35

<1% precision every 5min
for each bunch is
achievable

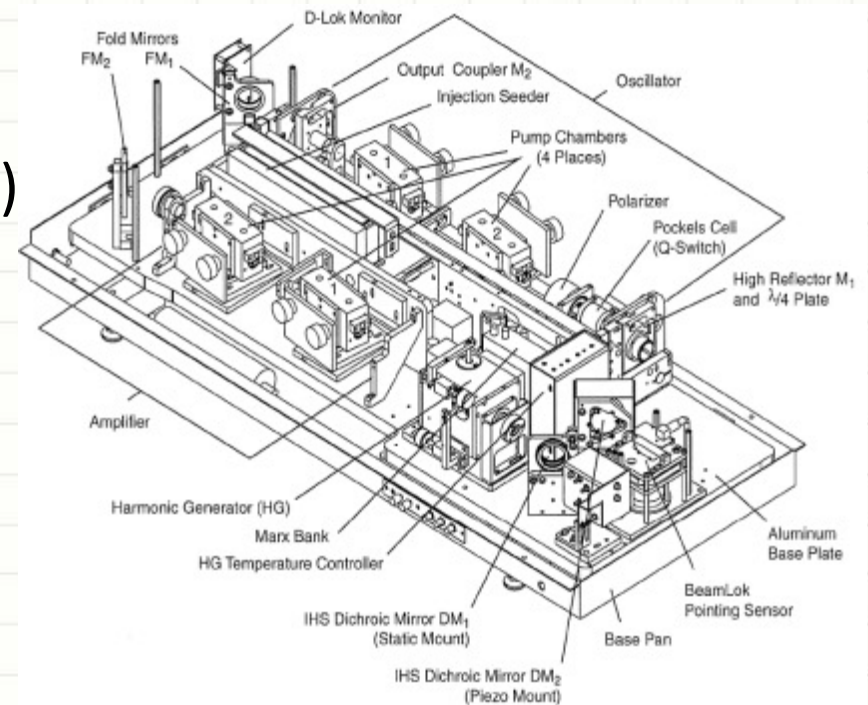
IP-BSM overview



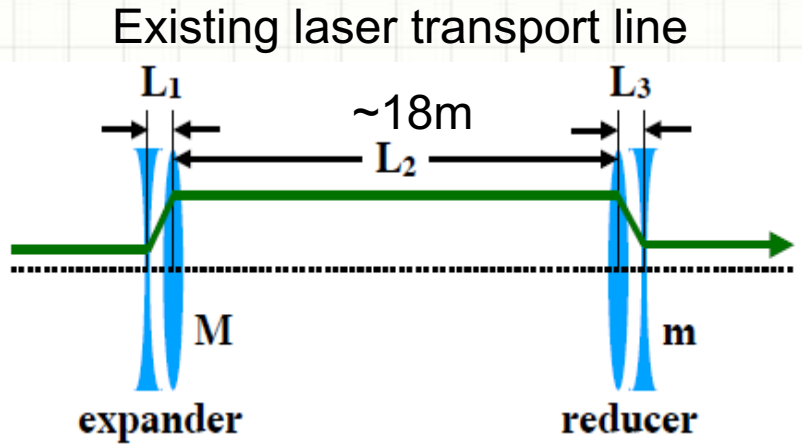
Spectra-Physics Quanta-Ray PRO 350

Right now it is discontinued

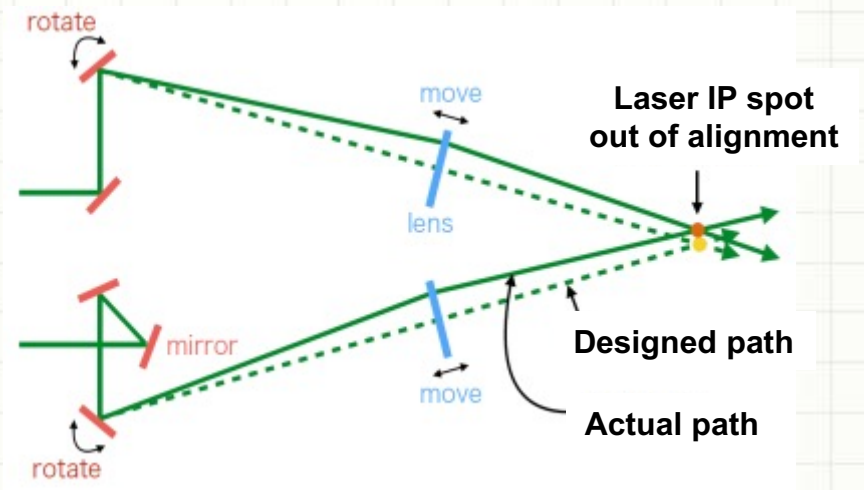
- **Company specs:**
 - Type: Nd:YAG Q-switched
 - $E_{532\text{nm}} = 1.4 \text{ J} \pm 3\%$
 - Pulse = $8\text{ns} \pm <0.5\text{ns}$ (FWHM)
 - Rep. rate = 6.24 Hz
 - M2 $\sim 1.8 - 2.2$ (vs tuning)
- **Requires regular actions:**
 - Cleaning
 - Tuning
 - Flash lamps replacement



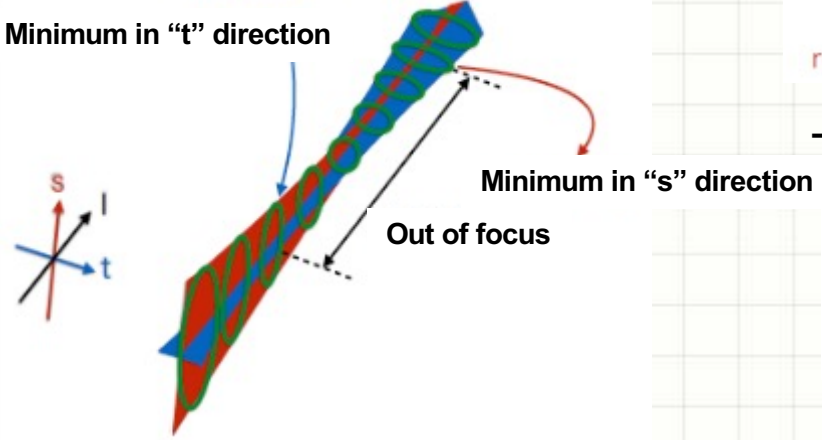
Expander – reducer, measurements



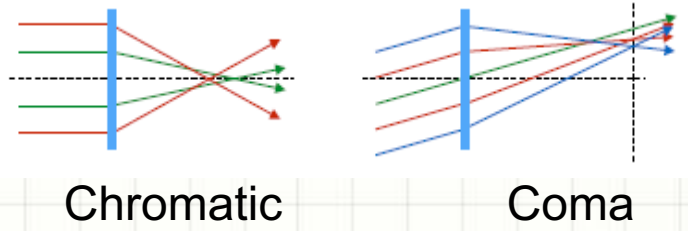
Not perfect laser path tuning result in aberrated profile at IP



Example of a strong astigmatism

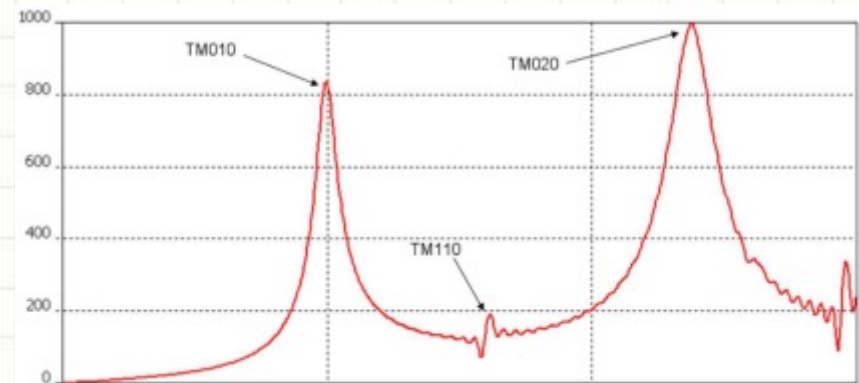
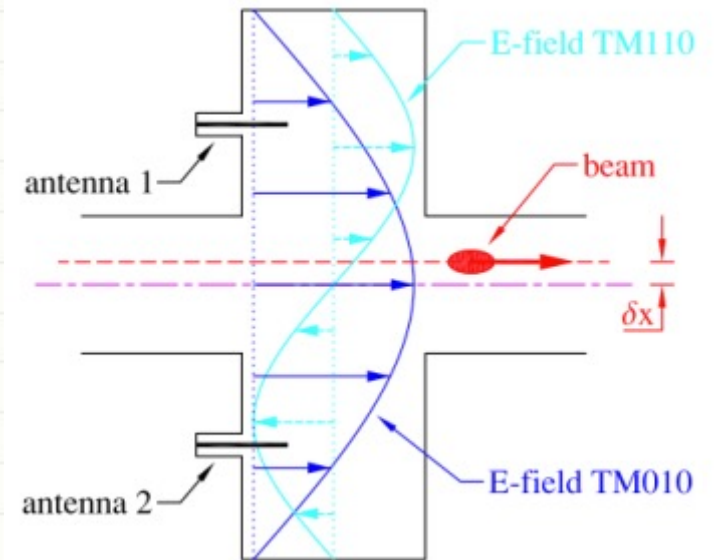
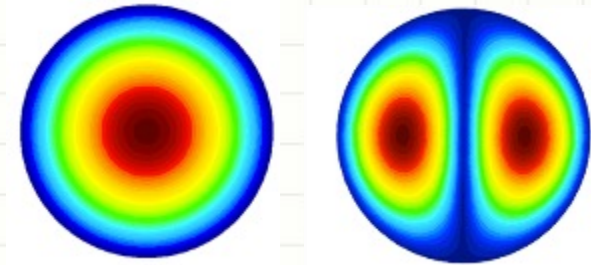


Types of aberrations we experience

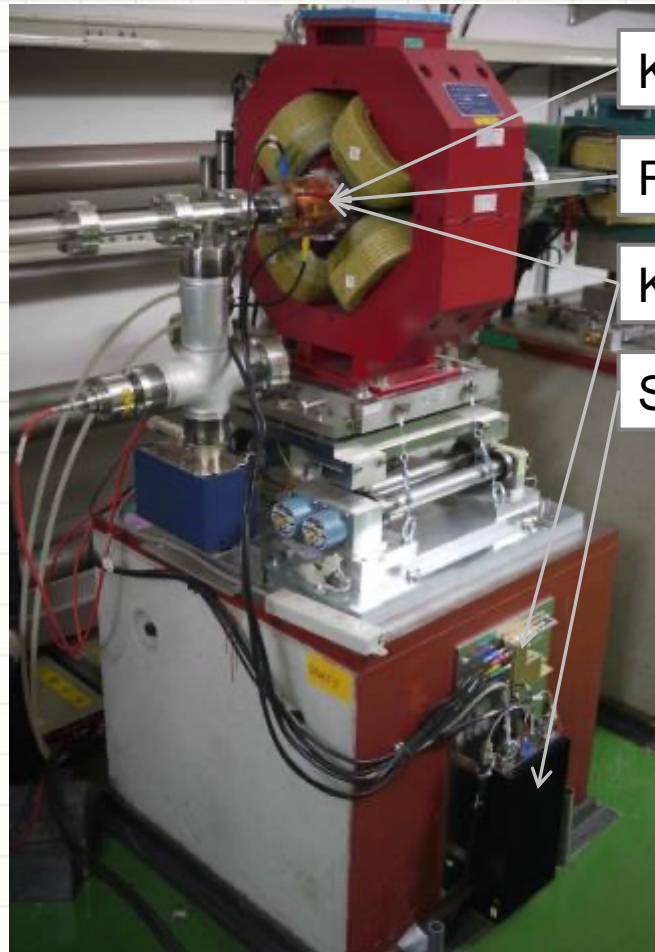


Cavity BPM Basics

- Centered beam excites monopole mode (TM_{010}).
 - Amplitude dependent on charge
- Away from the center, other modes are excited.
 - First order dipole mode (TM_{110}) depends **linearly on beam offset** and charge.
- TM_{110} splits in 2 orthogonal modes.
- Beam excites other unwanted higher order modes.
 - Requires suppression of unwanted modes.



Collaboration, signal processing



KNU

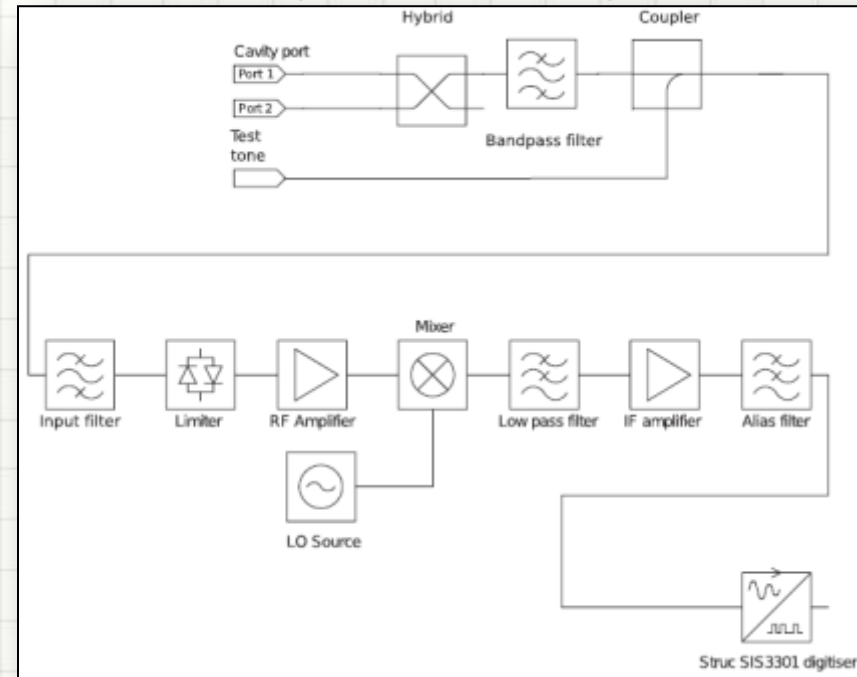
RHUL

KEK

SLAC

- There were 2 preliminary studies by KEK and SLAC
- At present, 25 cBPMs and 2 REFs are in use

Signal processing

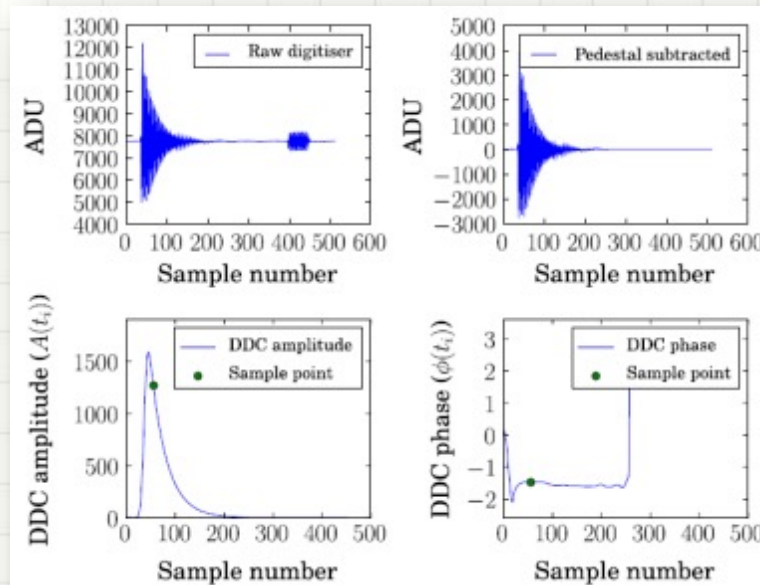


Signal calibration

A cavity's output signal $V(t)$ is an exponentially decaying sine wave containing 3 components with amplitudes proportional to the beam position d , beam trajectory angle d' , and bunch tilt θ :

$$V(t) = qe^{-t/\tau} e^{-i\omega t} (S_d d + S_{d'} d' e^{\pi i/2} + S_\theta \theta e^{-\pi i/2})$$

where ω is the cavity dipole mode frequency, τ is the decay time, q is the bunch charge, and S_d , $S_{d'}$, and S_θ are the cavity sensitivities to displacement, beam trajectory, and bunch tilt, respectively.



The beam position is calculated from the in-phase I and quadrature-phase Q components of the demodulated signal at the sampling point referenced to the nearest spatially and similar frequency reference cavity:

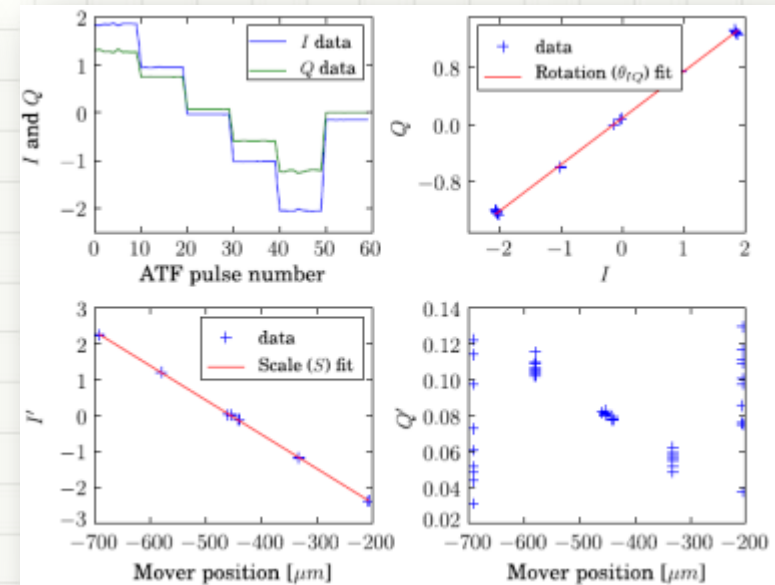
$$I = \frac{A_d(t_{\text{DDC},d})}{A_r(t_{\text{DDC},r})} \cos[\phi_d(t_{\text{DDC},d}) - \phi_r(t_{\text{DDC},r})]$$

$$Q = \frac{A_d(t_{\text{DDC},d})}{A_r(t_{\text{DDC},r})} \sin[\phi_d(t_{\text{DDC},d}) - \phi_r(t_{\text{DDC},r})]$$

$$I' = I \cos\theta_{IQ} + Q \sin\theta_{IQ}$$

$$Q' = -I \sin\theta_{IQ} + Q \cos\theta_{IQ}$$

$$d = SI'$$



Implementation

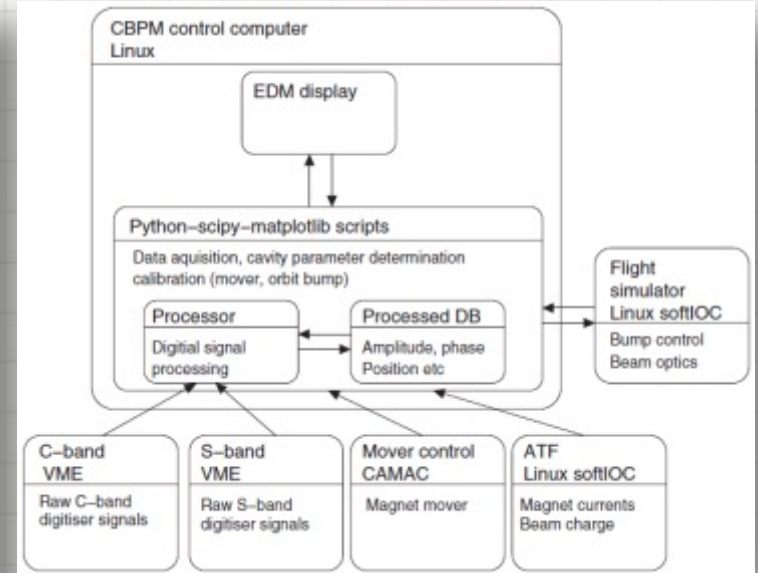
VME digitizers, LO and Calibration tone generators



LO and Calibration tone amplifiers



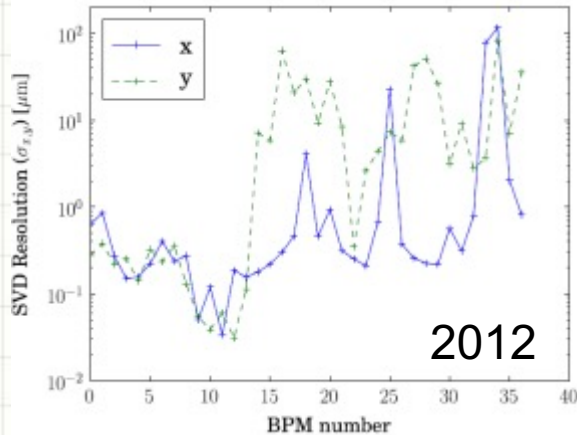
cBPM system Software



Also, parallel analysis for 2-4 bunch beam was tested



Current problems and solution



PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 15, 042801 (2012)

Cavity beam position monitor system for the Accelerator Test Facility 2

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- Slow calibration (4h/25 cBPMs)
 - Difficult scalability
 - Wakefields
 - Calibration tone into the cavities
 - Not a problem if above is implemented cavity
 - New cavity design
- Collaboration is ongoing with experimental studies.
 - Discussion about RHUL staff long-term invited fellow to KEK.