Beam Instrumentation Experience at ATF

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ATF international collaboration

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APAC07, Indore

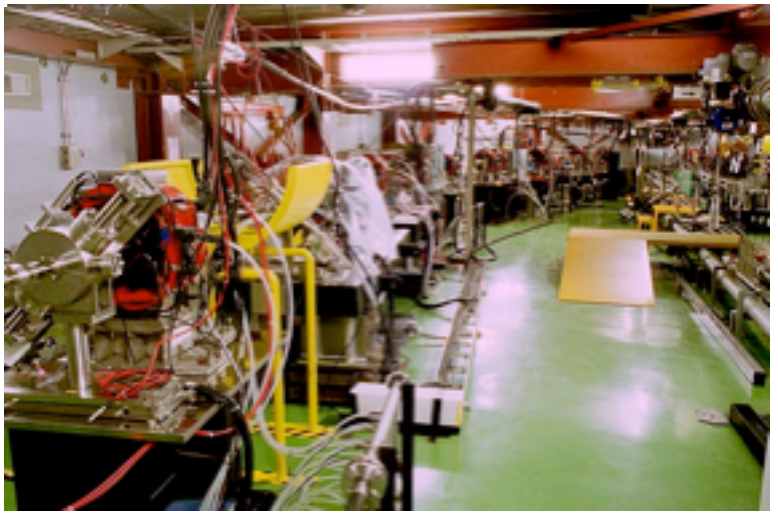
- Introduction
- Beam position monitors
- Beam size monitors
- Beam control

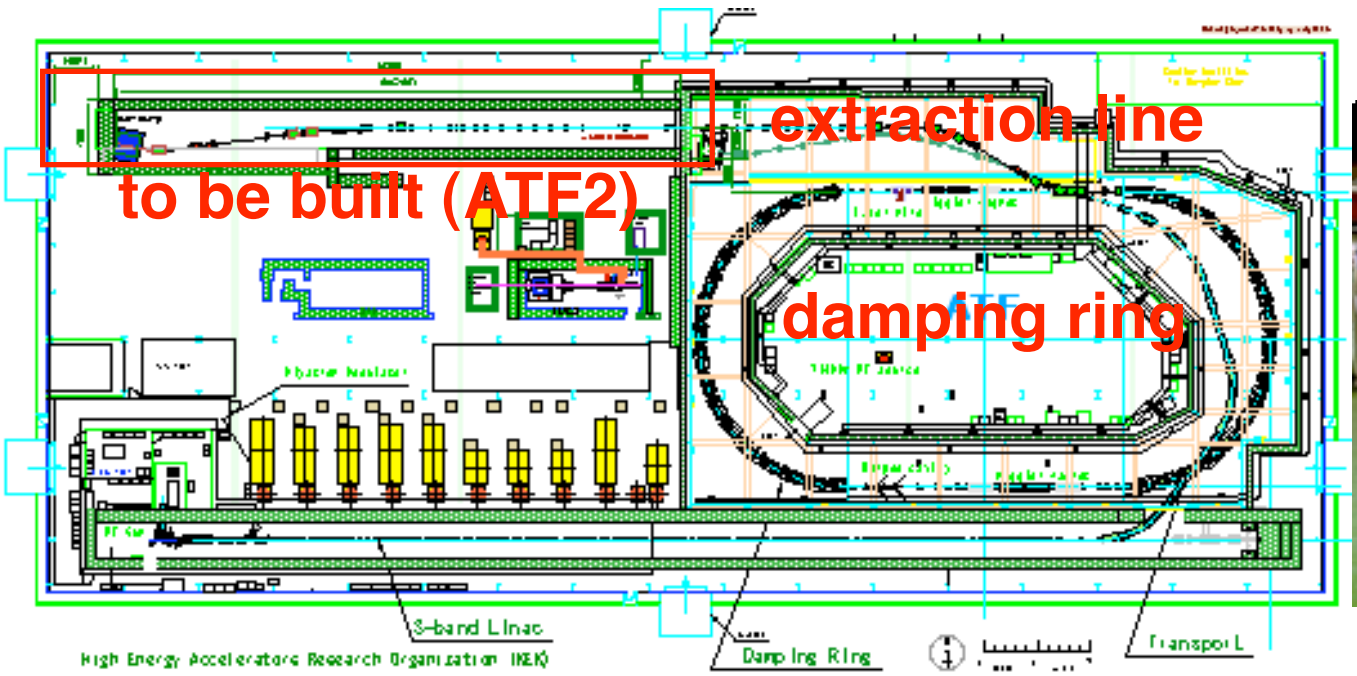
Introduction

ATF

- Accelerator Test Facility for LC
  - low-emittance Damping Ring
  - damped beam extraction line
- parameters
  - energy: 1.3GeV, DR circumference: 140m
  - rep. rate: 1.56Hz, bunch charge: 10^10e/bunch
  - emittance: 1nm rad (x), 10pm rad (y)
  - typical beam size: 100um(x), 10um(y)
- an unique facility to produce ILC-spec. beam

extraction line

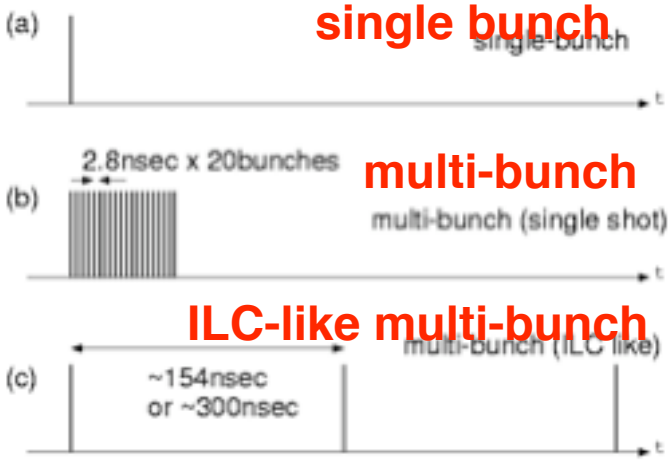


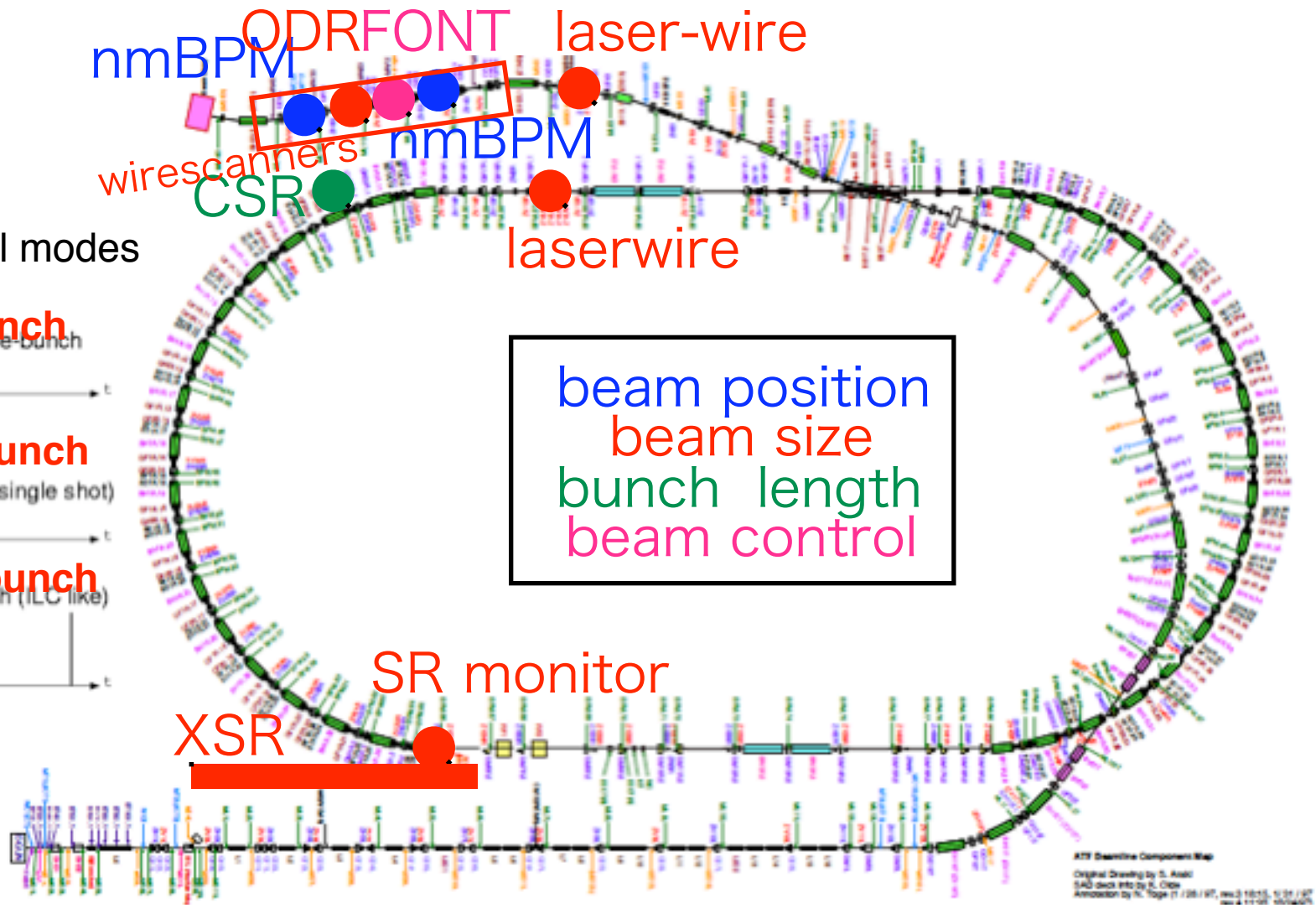


damping ring

Instrumentation R&D at ATF

- various operational modes



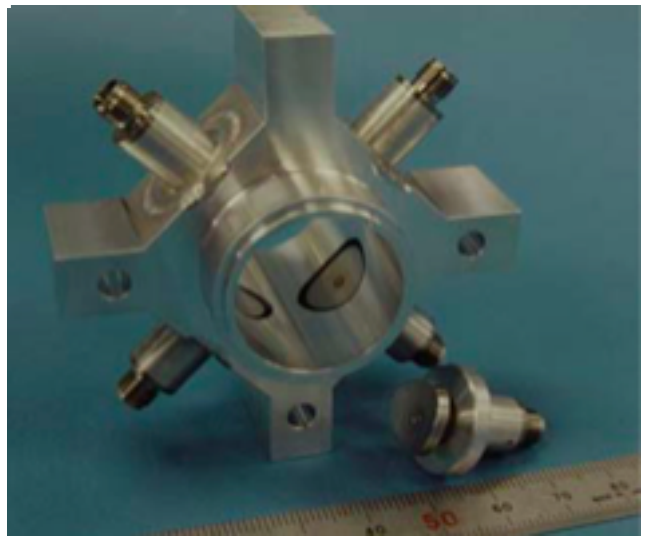


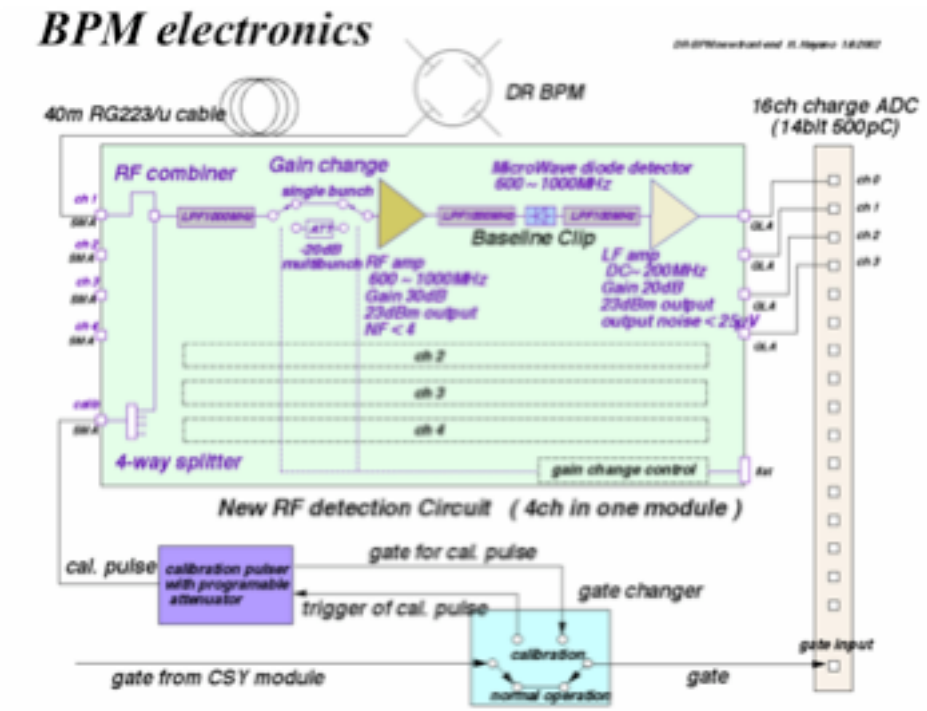
Beam Position Monitors

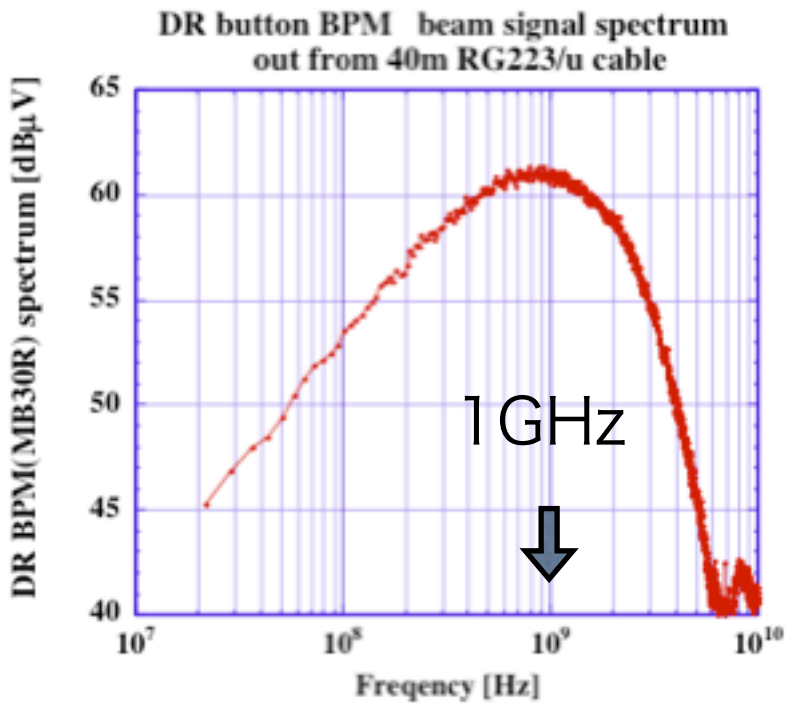
- pick-up BPM
- cavity BPM

Pick-up BPM

- BPM for usual beam operation
  - shot-by-shot orbit measurement
- BPMs
  - 96 buttun BPMs in DR
  - strip-line BPMs in linac and ext.line
  - beam duct diameter is 24mm
  - spectrum peak is at 1GHz (end of the cable)
- electronics
  - wide band detection (0.6~1GHz) , diode clipping



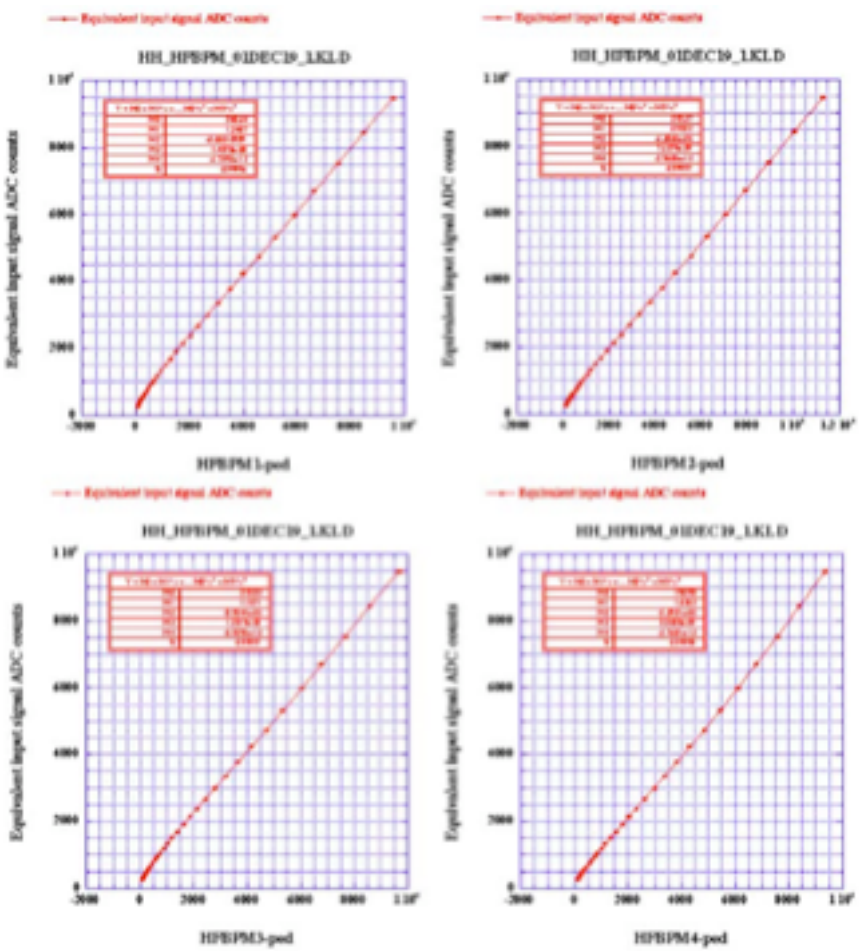




Pick-up BPM

- calibration of the electronics
  - using a dummy pulse
  - non-liniarity correction with a polynomial function

$$V_{pul} = a_0 + a_1 V_{cal} + a_2 V_{cal}^2 + a_3 V_{cal}^3 + a_4 V_{cal}^4$$



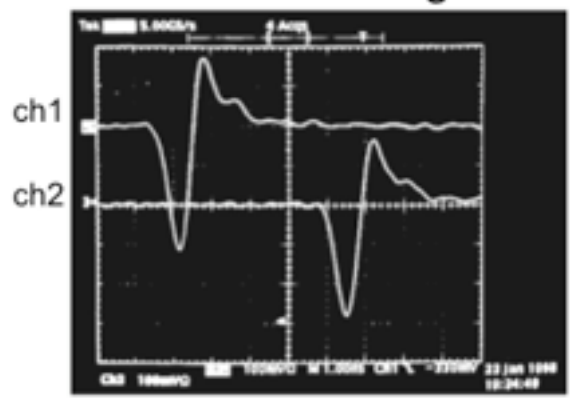
$$\begin{pmatrix} x \\ y \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \begin{pmatrix} x' \\ y' \end{pmatrix}$$

$$x' = S \frac{V_{pul(1)} - V_{pul(3)}}{V_{pul(1)} + V_{pul(3)}},$$

$$y' = S \frac{V_{pul(2)} - V_{pul(4)}}{V_{pul(2)} + V_{pul(4)}}$$

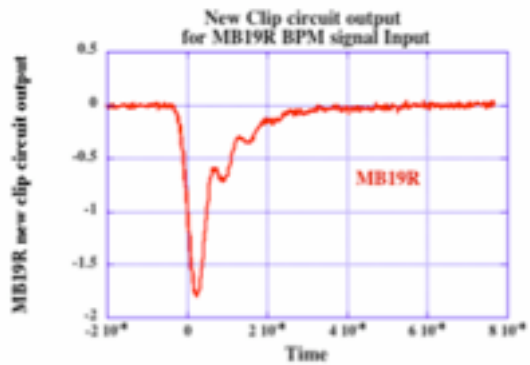
$$S \approx 6400\,\mu m$$

MB1R beam signal



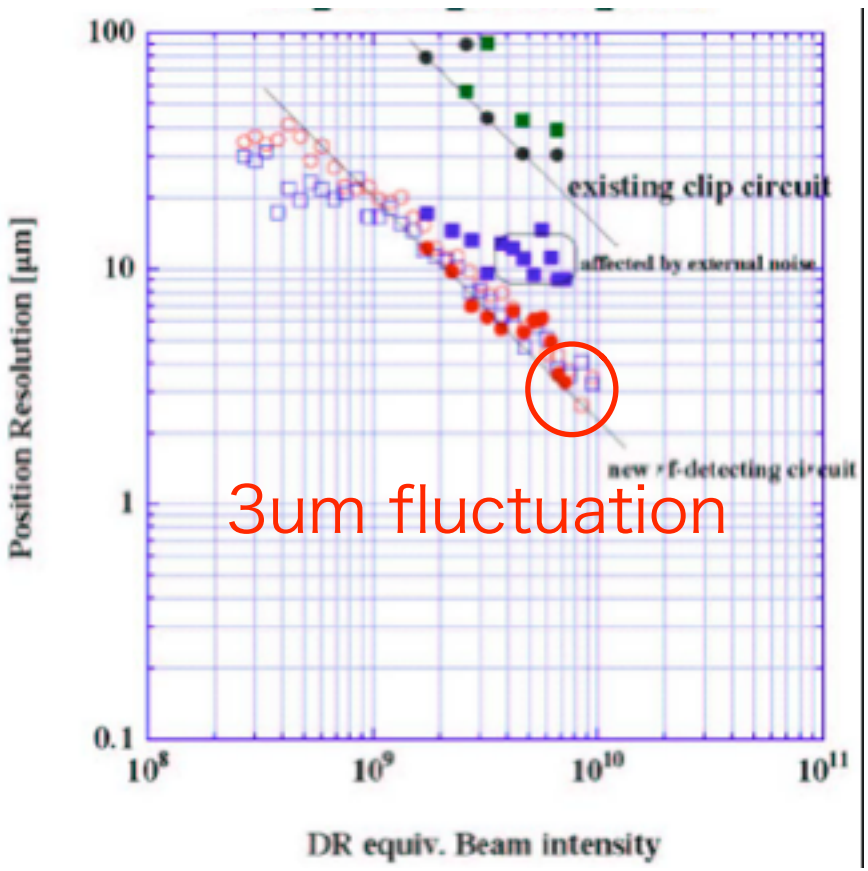
1GHz BW scope

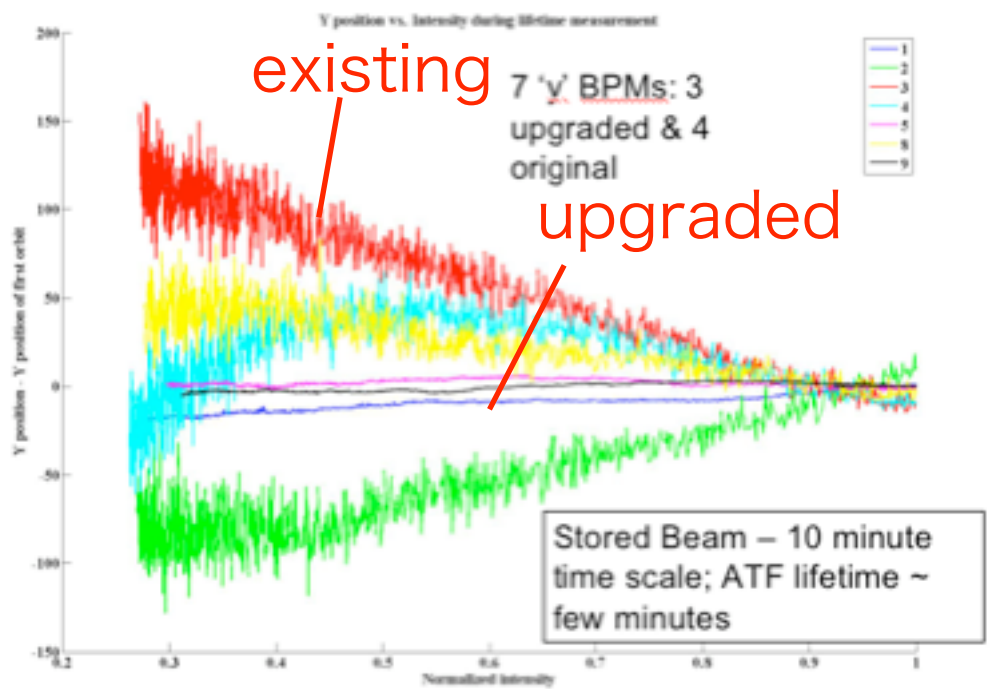
Clip circuit response (MB19R)



Pick-up BPM

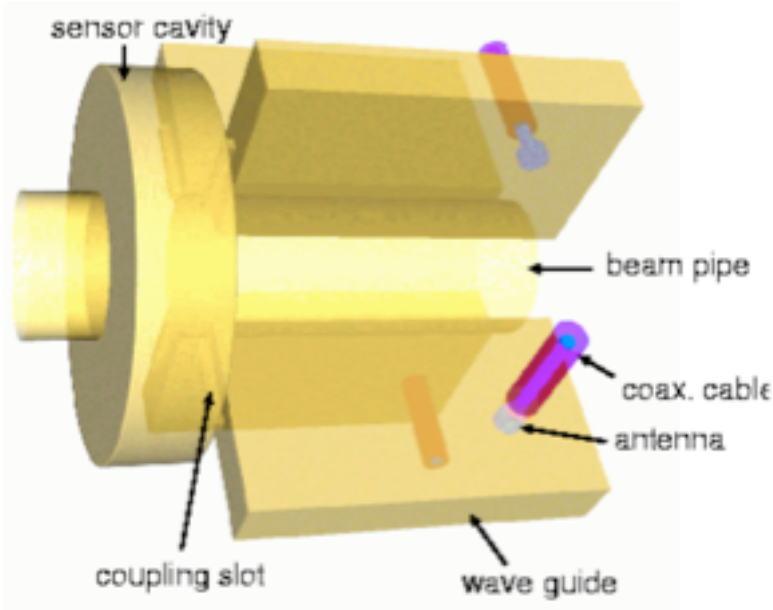
- performance
  - resolution: 3um at 10^10e/bunch
  - intensity dependence: +-150um
- upgrade plan
  - narrow-band system with digital recording
    - 100nm resolution, 500nm accuracy expected

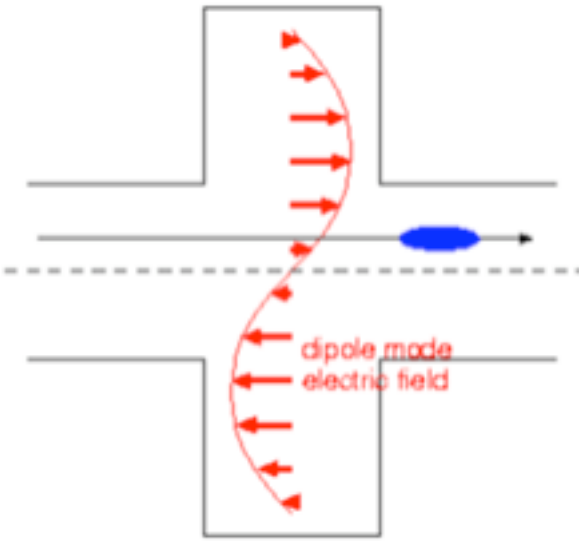


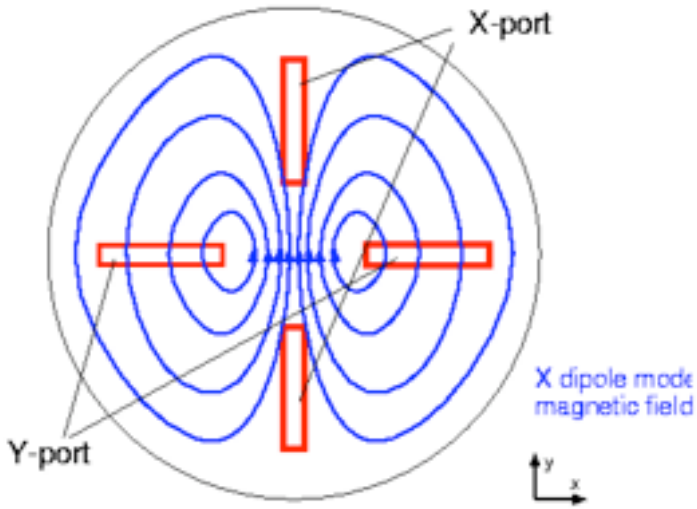


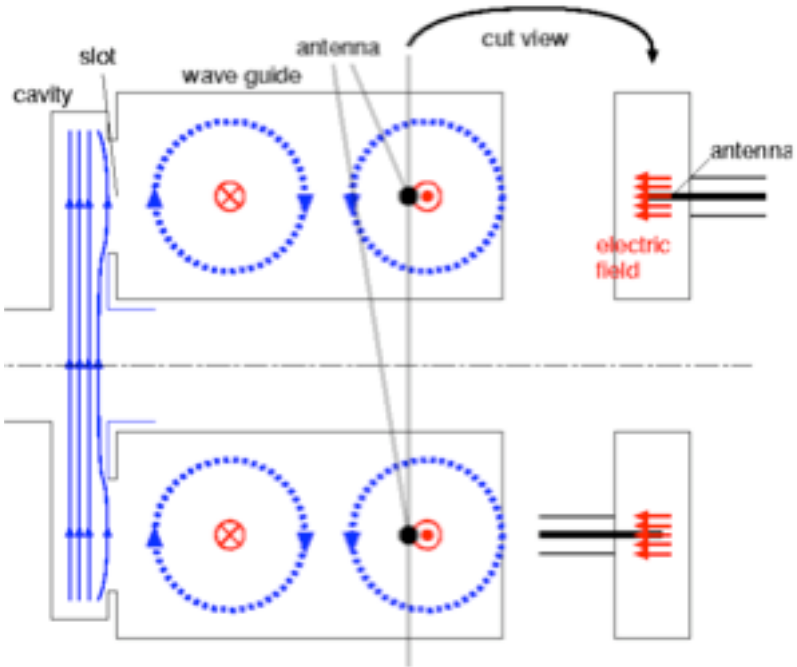
Cavity BPM

- Cavity BPM
  - strong signal, possible to reach nm resolution
  - mechanical rigidity, electrical center stability
- Several types of cavity BPMs are tested in ATF ext.line.
  - basic design is same for all type
  - C-band is optimal for ATF beam (bunch length)



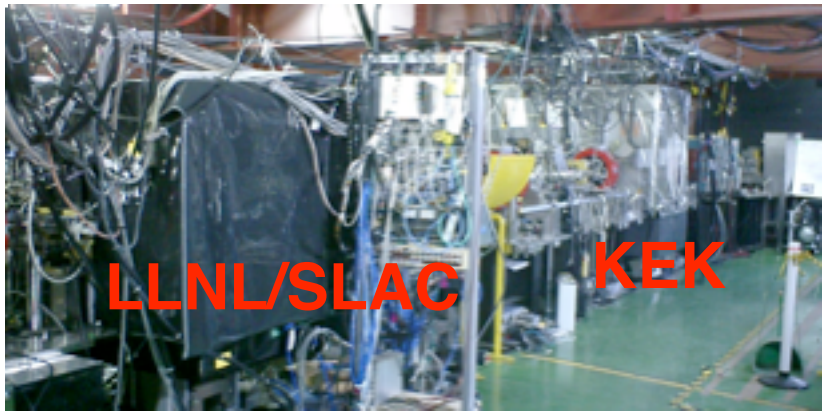


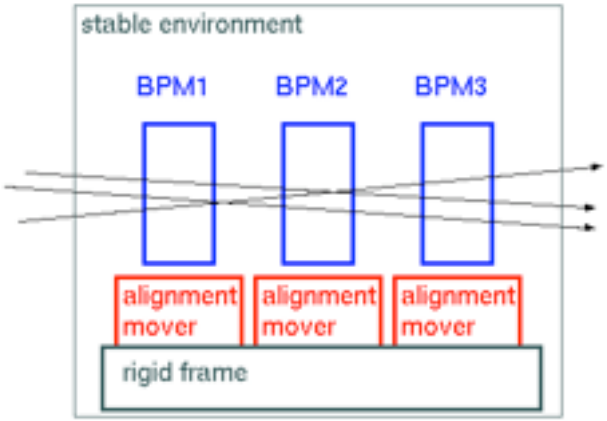


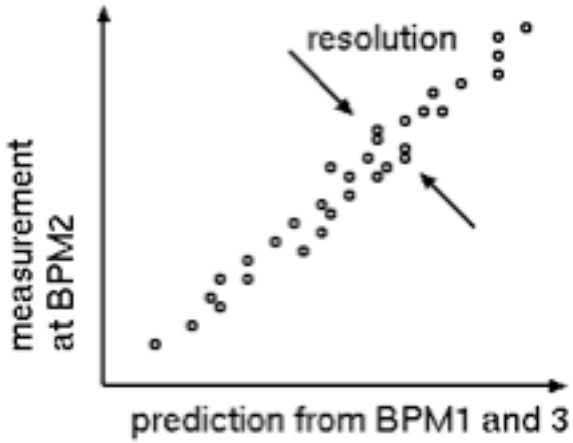


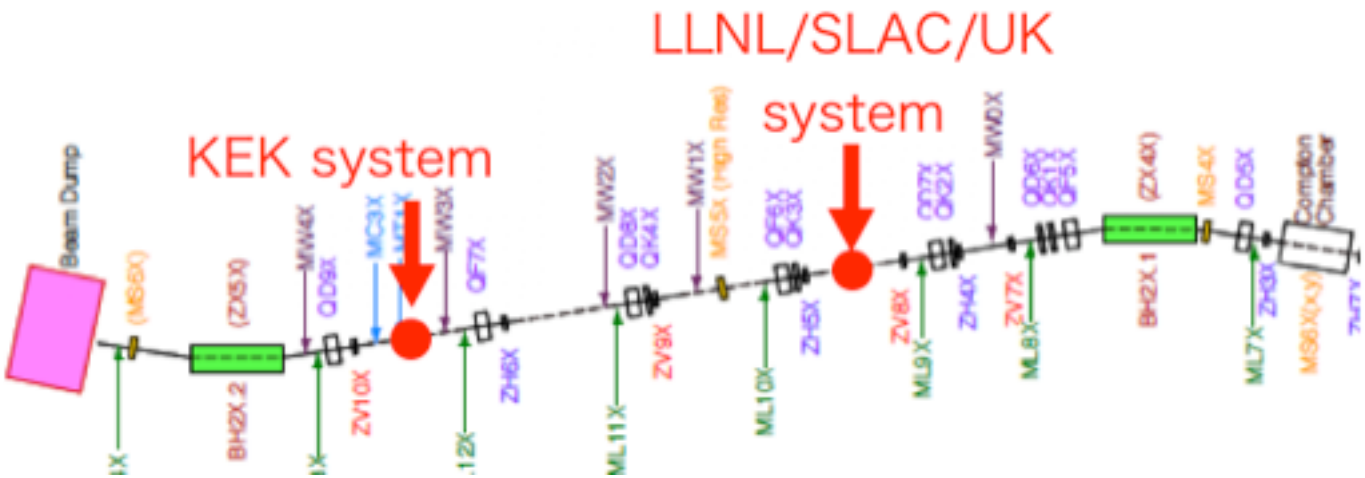
nm-resolution BPM

- Test bed for very high resolution BPM
  - triplet of BPM supported by a rigid frame
  - mover system to align within 10um
- Two sets of system are installed in the ext.line
  - BINP/LLNL/SLAC/UK group (upstream)
  - KEK group (downstream)



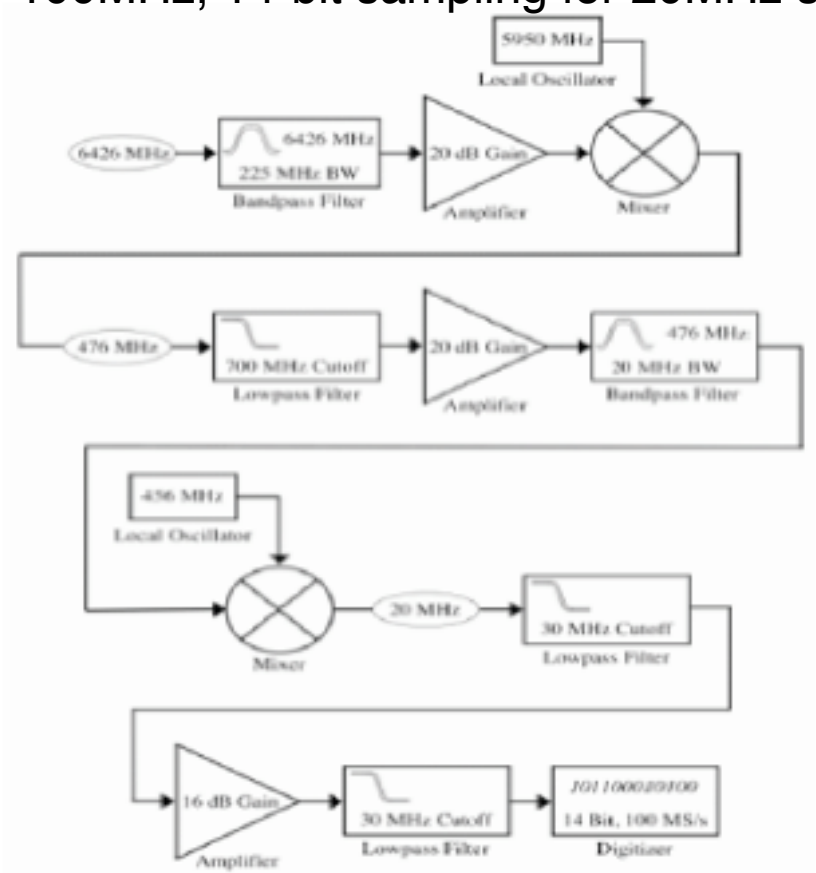


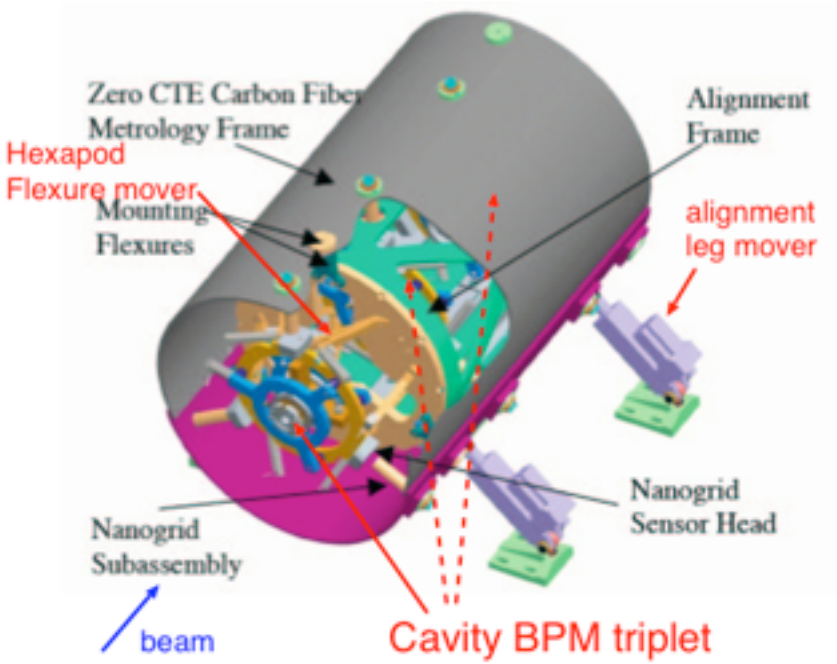


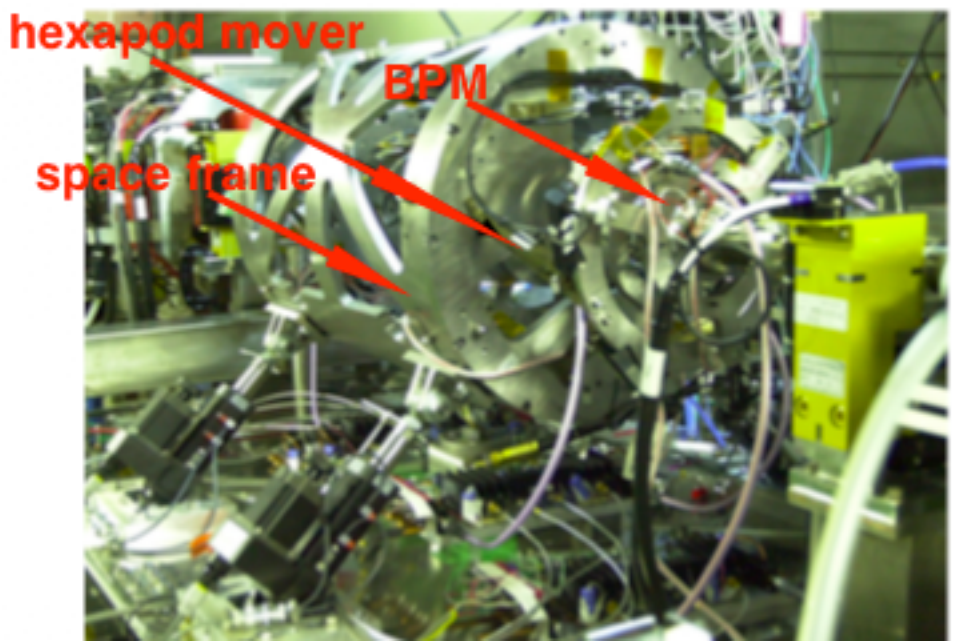


nm-resolution BPM (upstream)

- space frame
  - alignment mover for overall frame
  - 6D hexapod flexure mover for each BPM
- rigid-body monitoring system
  - laser sensor on metrology frame
  - <5nm stability
- digital wf recording
  - 6.43GHz->20MHz, two-stage down-mix
  - 100MHz, 14-bit sampling for 20MHz signal

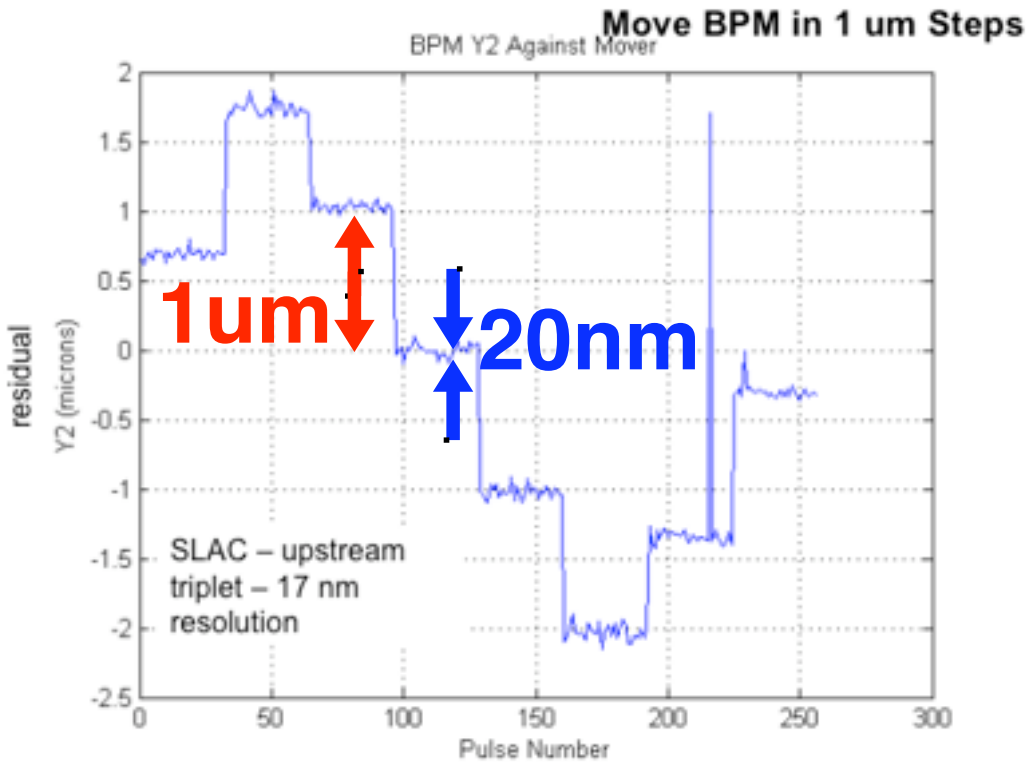


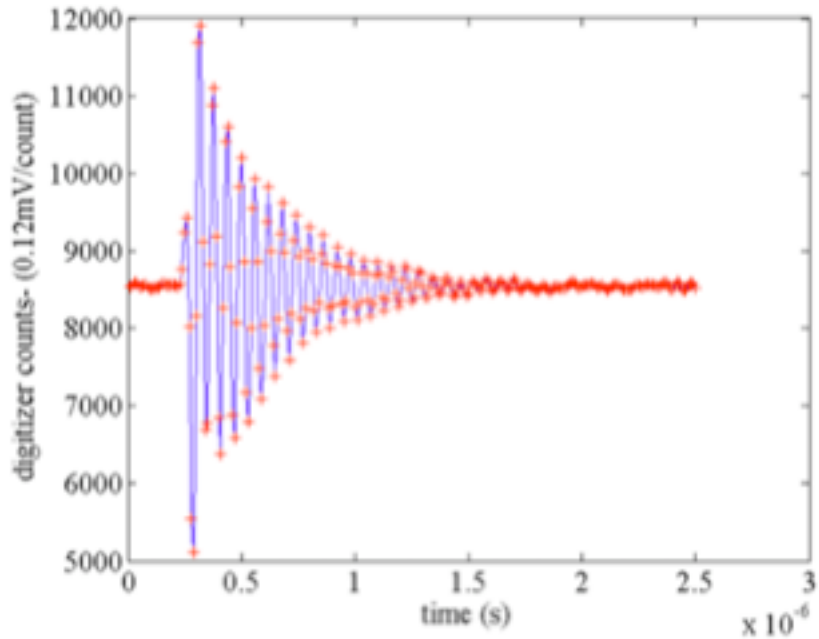




nm-resolution BPM (upstream)

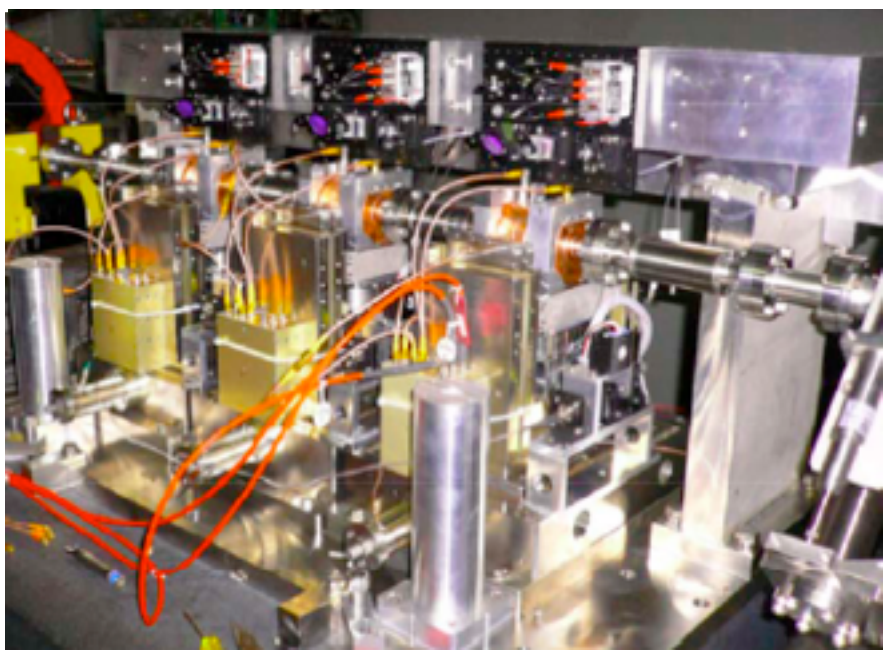
- Analysis of the waveform
  - fitting with decaying sinusoidal
  - digital down conversion (BW 2.5MHz)
- calibration
  - convert I-Q phase to position-angle
  - mover with known step
- 17nm resolution was proved

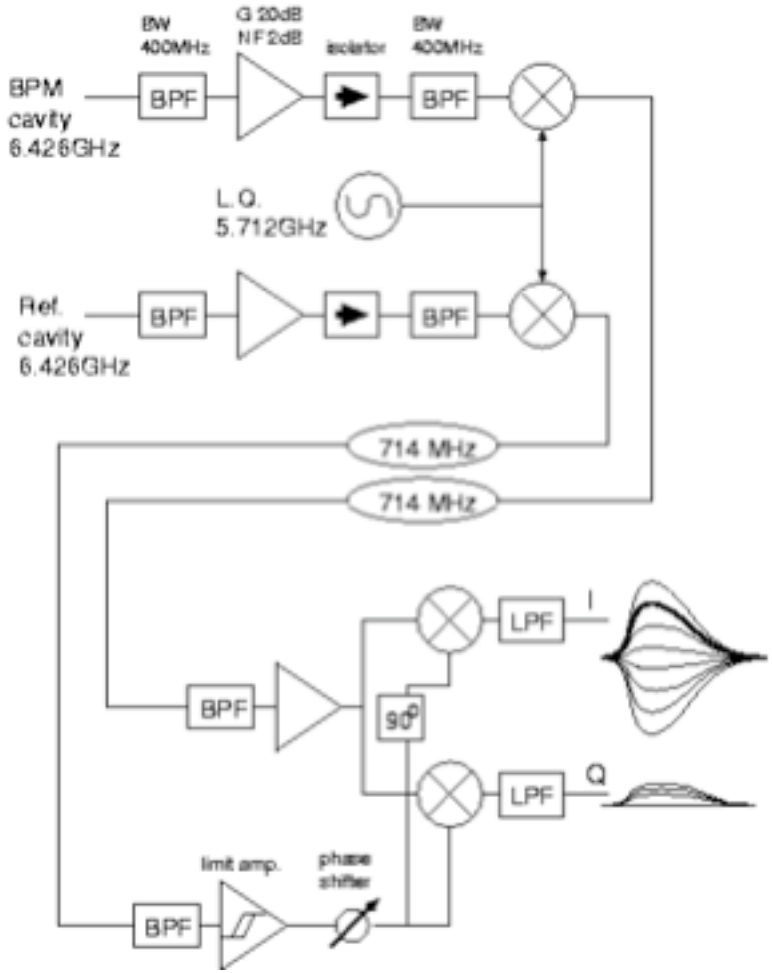


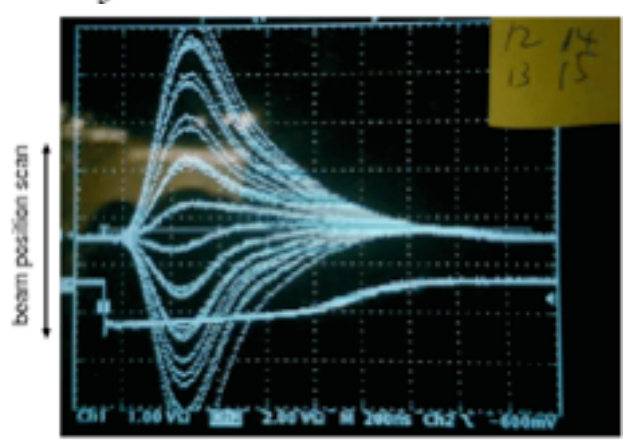


nm-resolution BPM (downstream)

- frame
  - piezo mover with an active stabilization
  - laser interferometer sentor
- electronics
  - analogue processing (BW 1MHz)
  - phase detection with a reference cavity

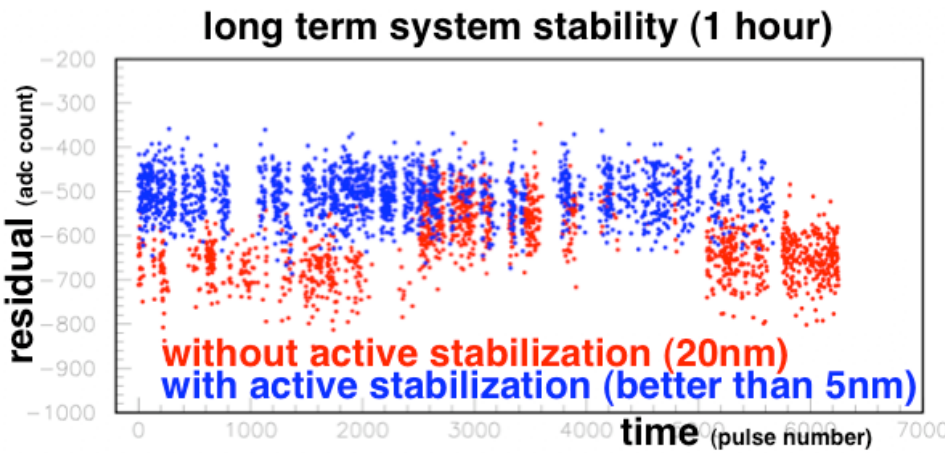


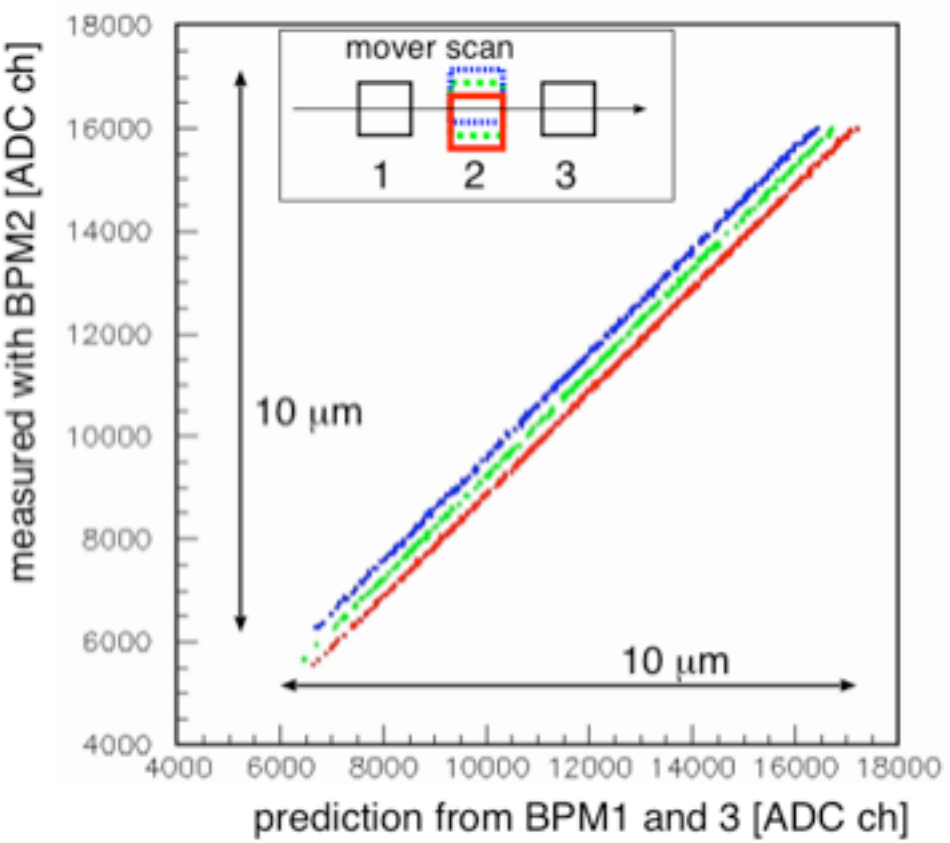


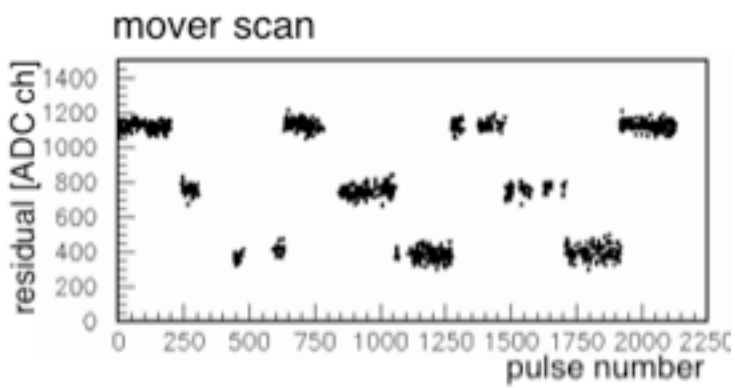


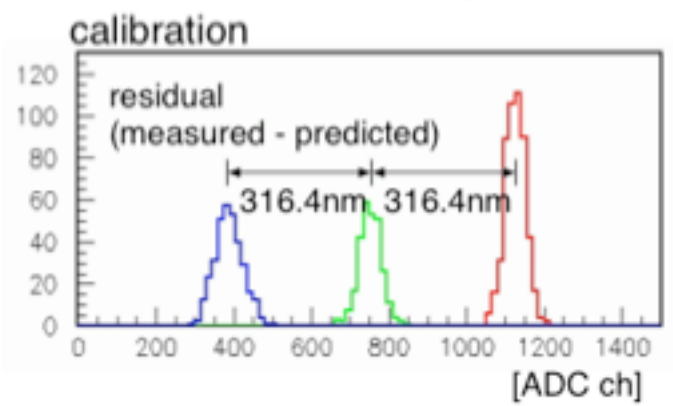
nm-resolution BPM (downstream)

- Resolution estimation
  - calibration
    - move one of the BPM with known amount
  - residual (prediction-measurement)
    - RMS 21.2nm (17.3nm resolution)
    - 0.4nC beam charge
    - consistent with the calculation
- System stability
  - shows improvement with the active stabilization



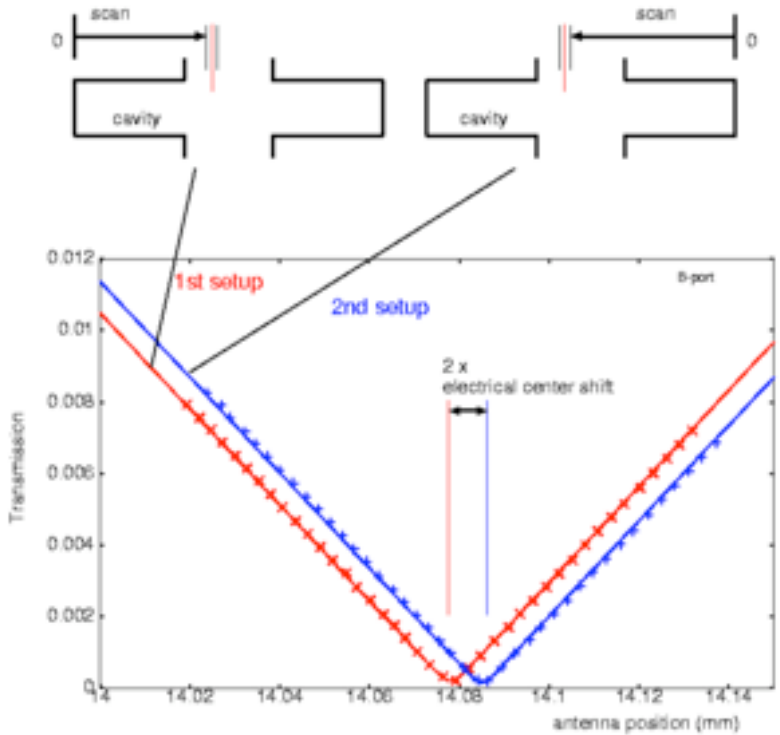


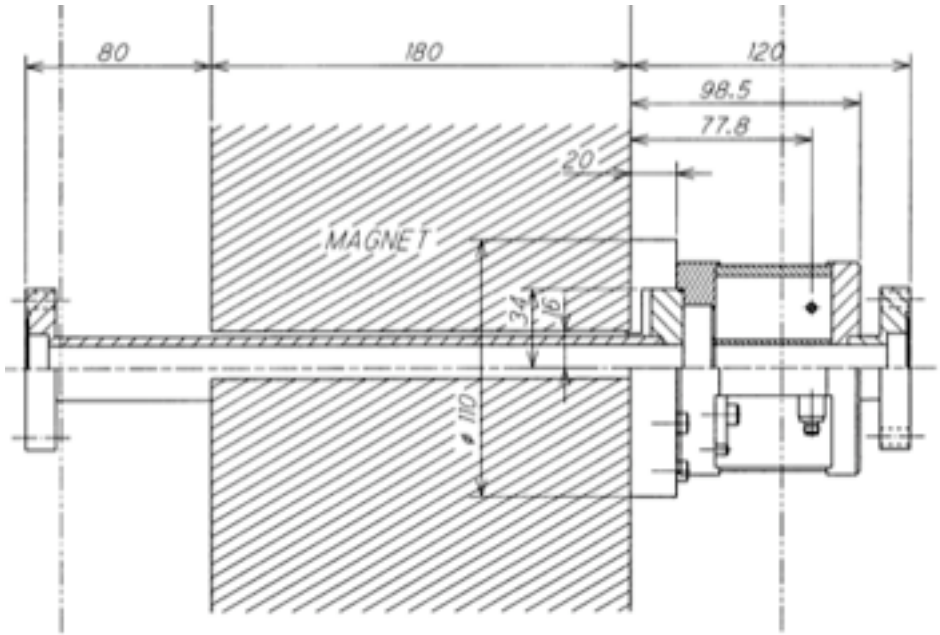




ATF2 cavity BPM

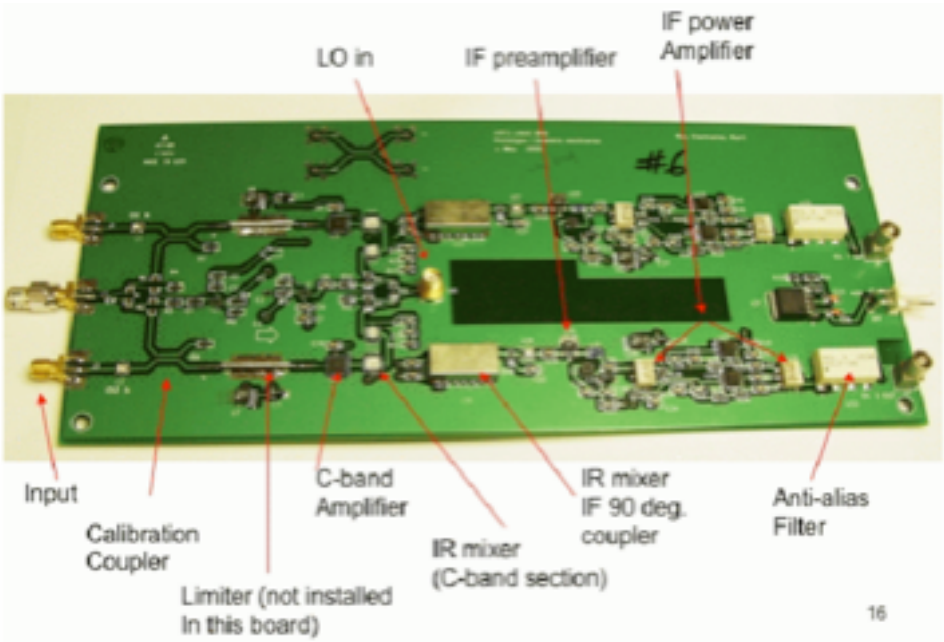
- main monitor for ATF2 beam line
  - 100nm resolution, 2um stability
  - attached on every quadrupole
- fabrication in PAL (talk by JY-Huang)
- performance tests at bench
  - electrical center accuracy < 5um
  - isolation of x and y modes < -40dB
    - post-fabrication tuning

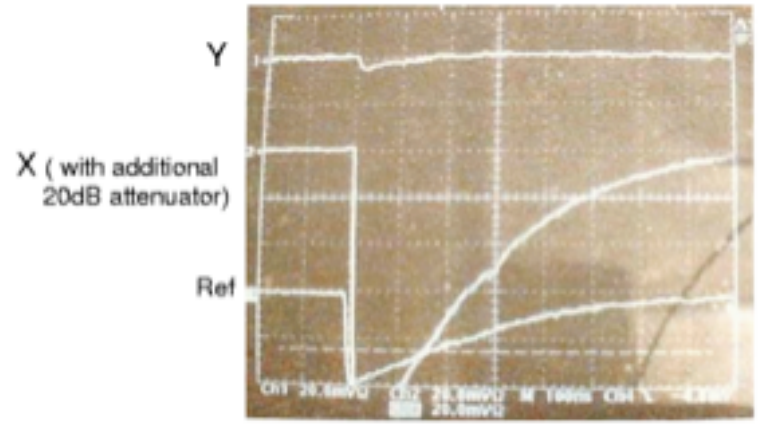




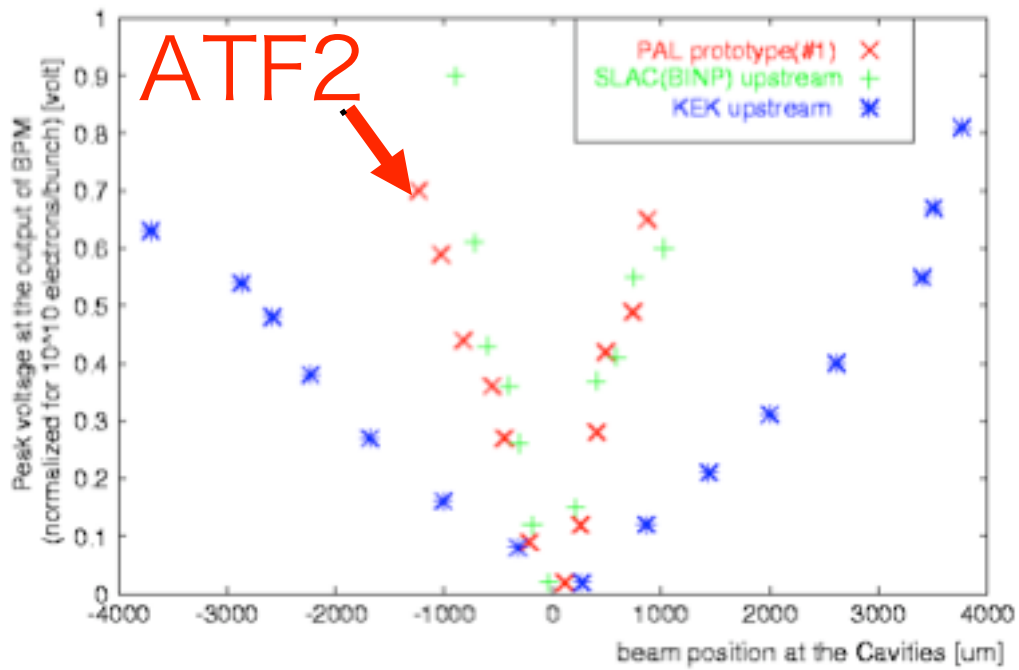
ATF2 cavity BPM

- Beam tests
  - signal strength was confirmed
  - x-y isolation was confirmed
- electronics
  - PCB version of down converter
  - various monitors are implemented
    - temperature, gain calibration etc.
-



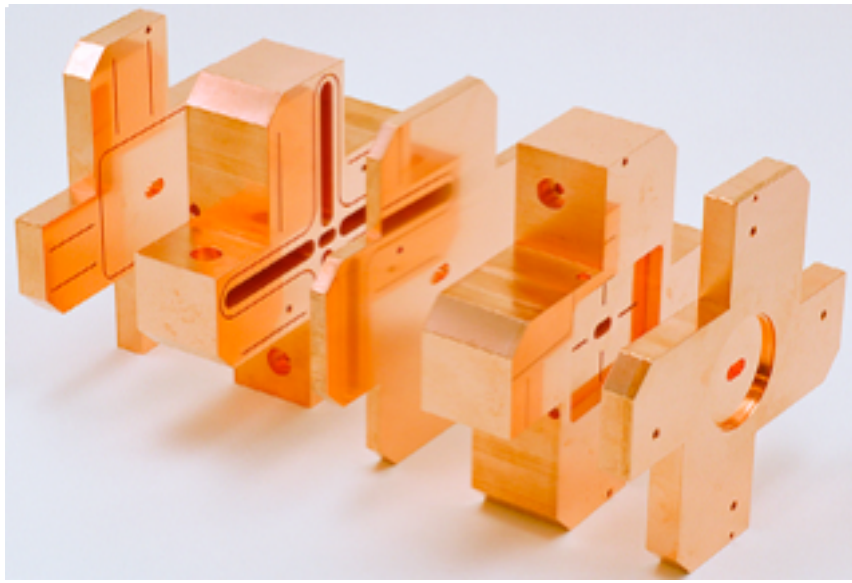


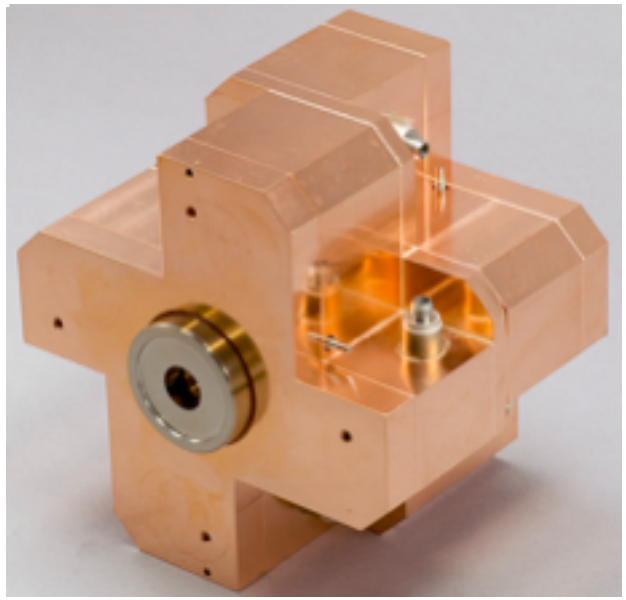
offset in x 5mm, signal in Y-port < 50 µm
< -40dB x-y isolation

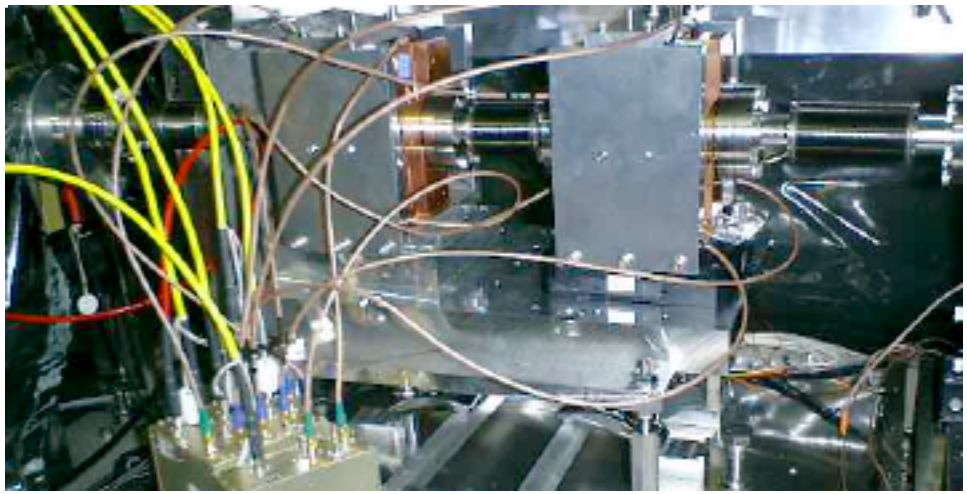


ATF2 IP-BPM

- purpose
  - beam stability measurement at ATF2 virtual IP
  - required resolution is 2nm
- IP optics (strongly focused)
  - angular jitter
  - x jitter is larger than y jitter
- special design
  - thin gap cavity to reduce angle signal
  - rectangular cavity to separate x and y modes
  - high coupling for stronger signal
- beam tests started Nov.2006
  - position sensitivity was confirmed
  - angular sensitivity was confirmed





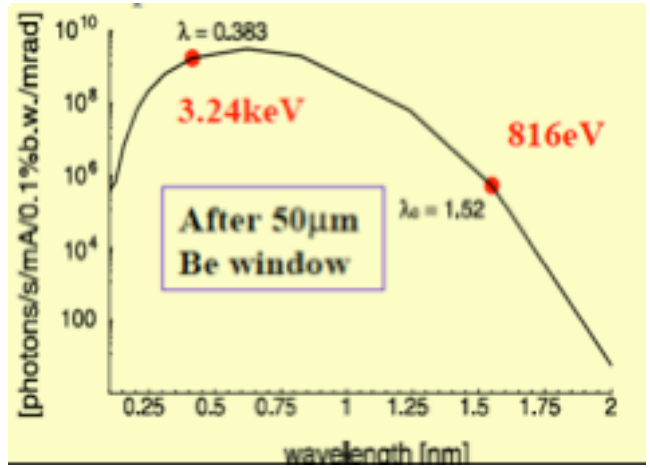


Beam Size Monitors

- Imaging type
- Scanning type

X-Ray SR Imaging Monitor

- direct 2D imagning of beam spot
  - real-time monitor
- SR Imaging
  - diffraction limit
    - visible light: ~10um
    - X-ray (3.24keV): improves to 0.25um
      - 3.24keV is the highest flux in the case of ATF ring inclulding attenuation at the window
  - optical component: FZP
    - spatial resolution is determined by the most outer ring
    - two lens optics to make the system compact
    - designed system resolution: 1.7um

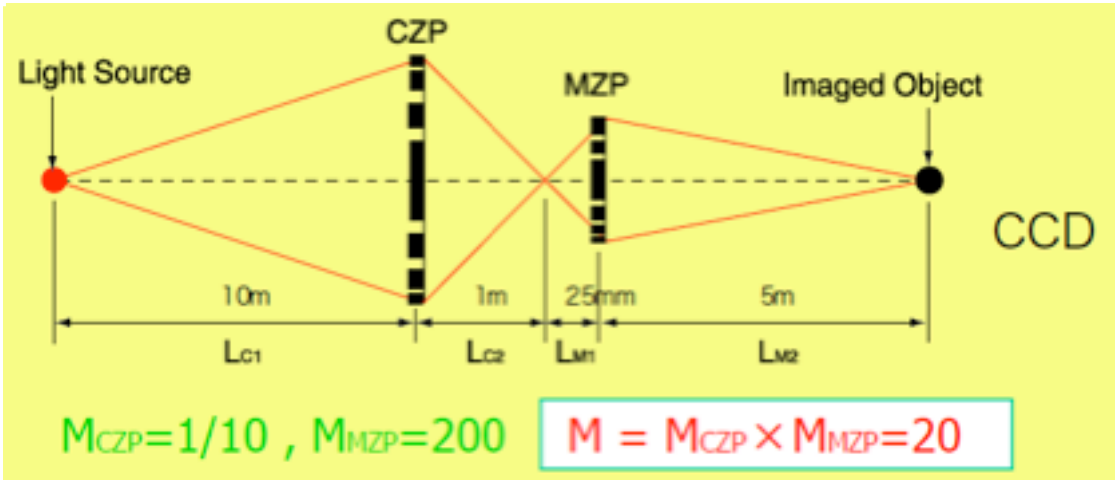


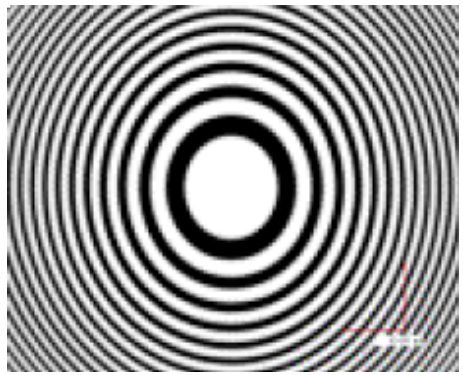
$$r_n = \sqrt{nf\lambda}$$

λ: wave length, f: focal kength

$$\delta = 1.22 \times \Delta r_n$$

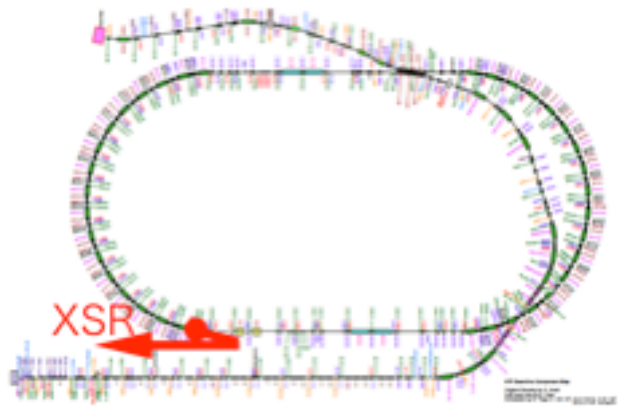
Δr_n: width of the most outer zone

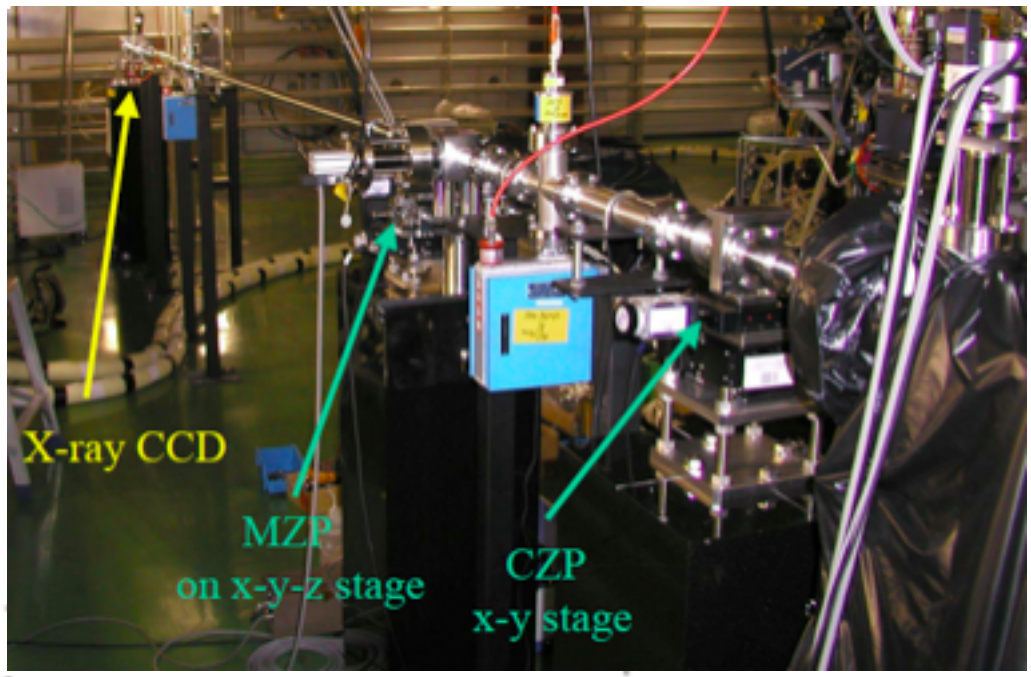


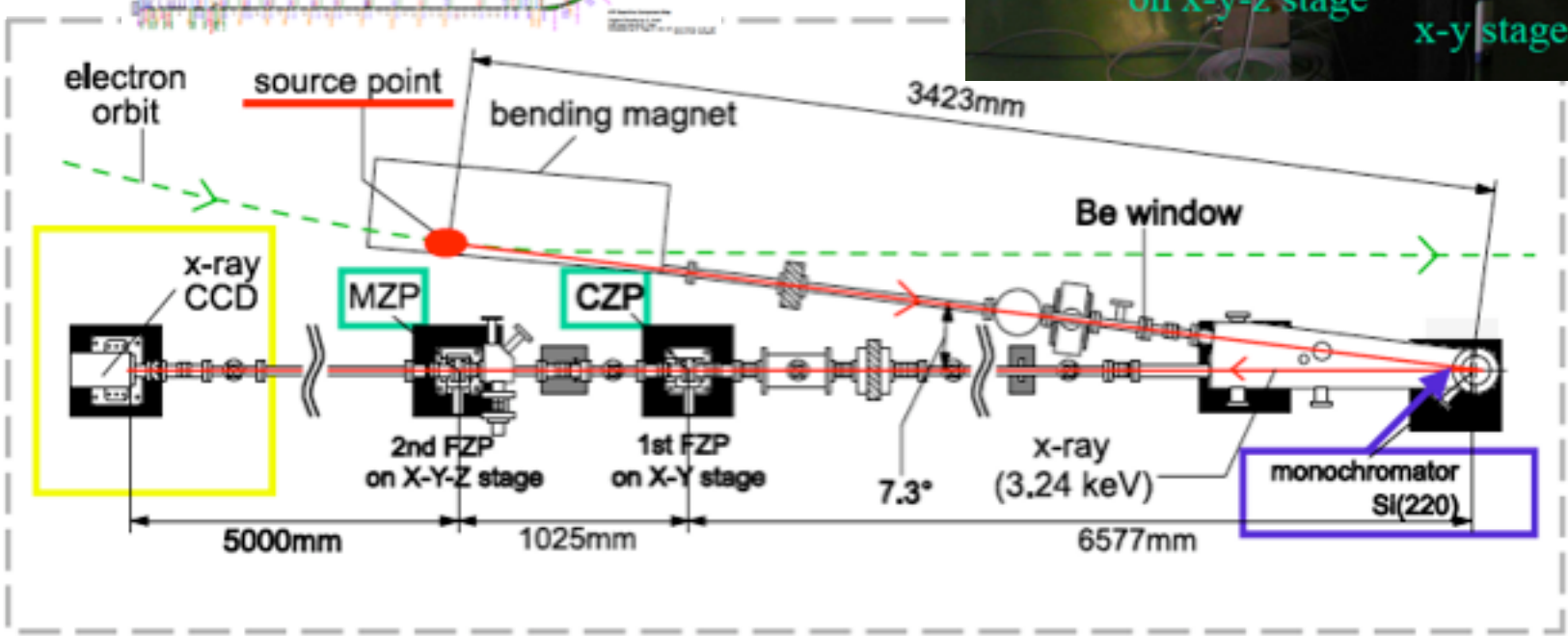


X-Ray SR system

- Source point: final bend in the arc section of the ring
- window -> monochrometor -> CZP -> MZP -> CCD , all in vacuum
- X-ray line length: 3.4m + 12.6m
- alignment movers for FZPs
  - search the best focus
- 1msec time shutter

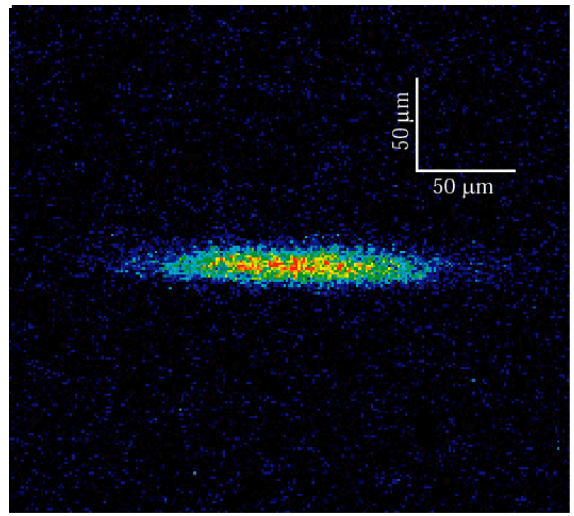


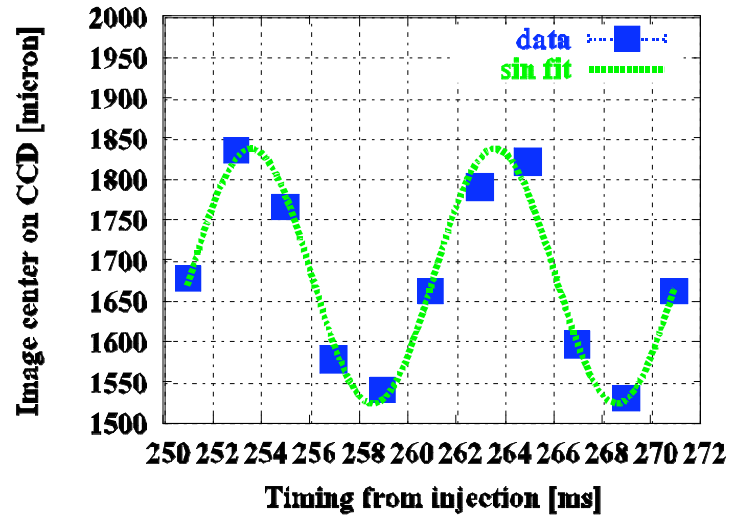


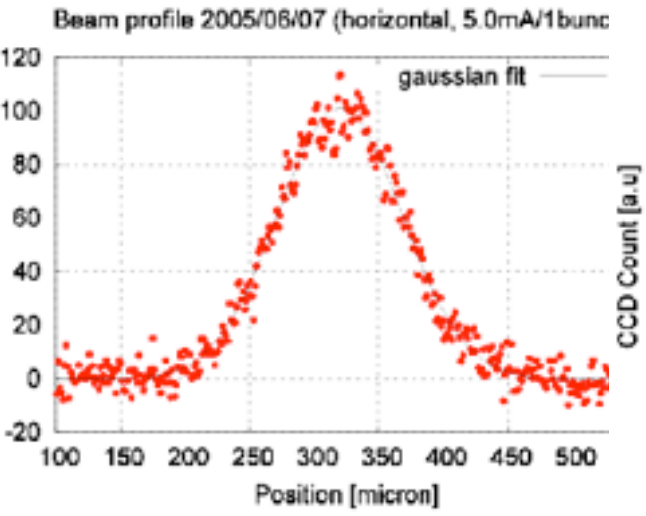


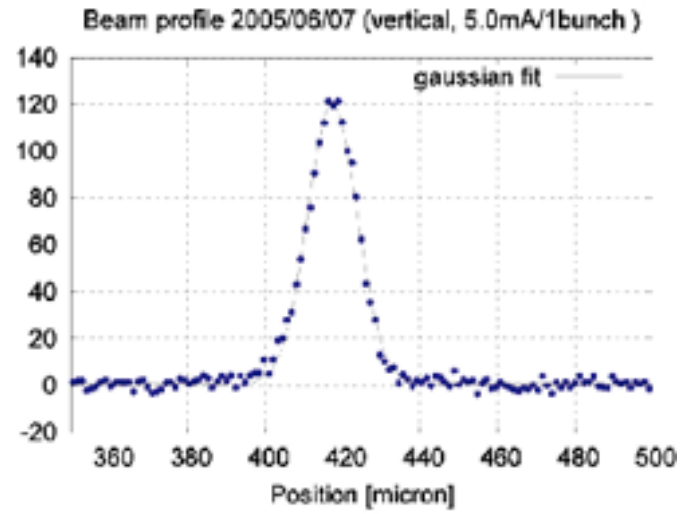
X-Ray SR Imaging Monitor

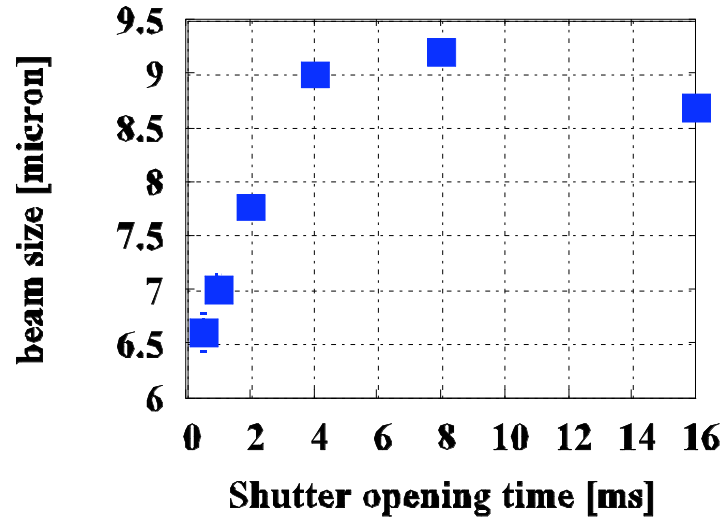
- position jitter of the image was suppressed with the fast time shutter (1msec)
- measured beam size
  - x size: 48.2um
  - y size: 6.4um





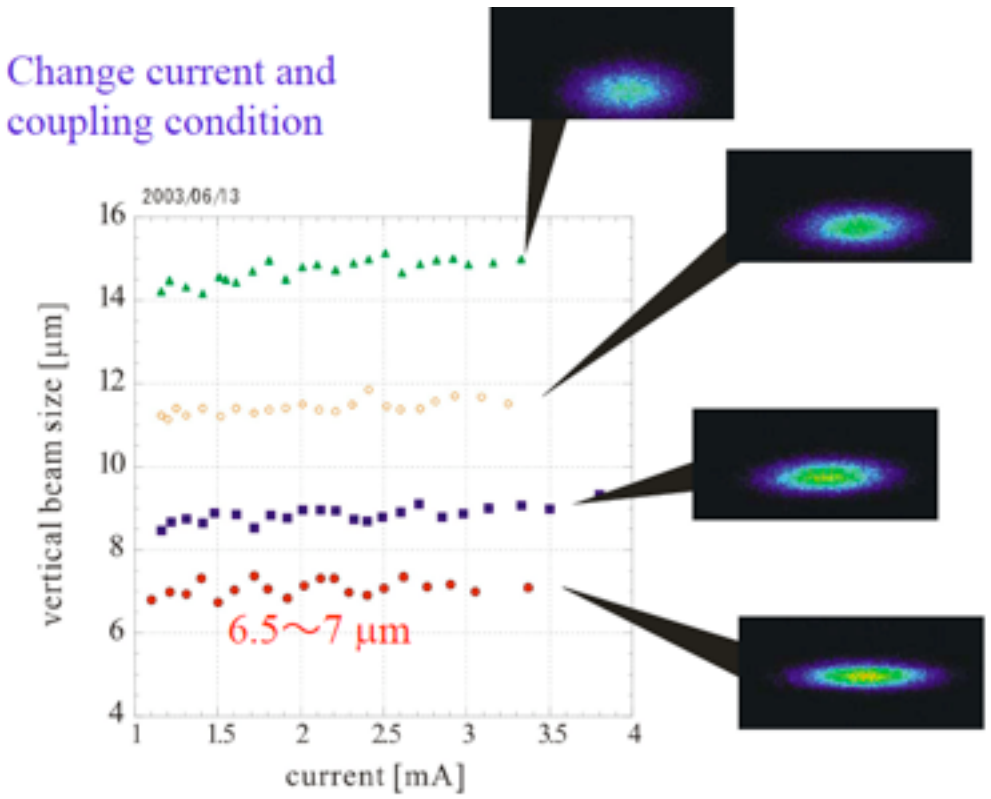


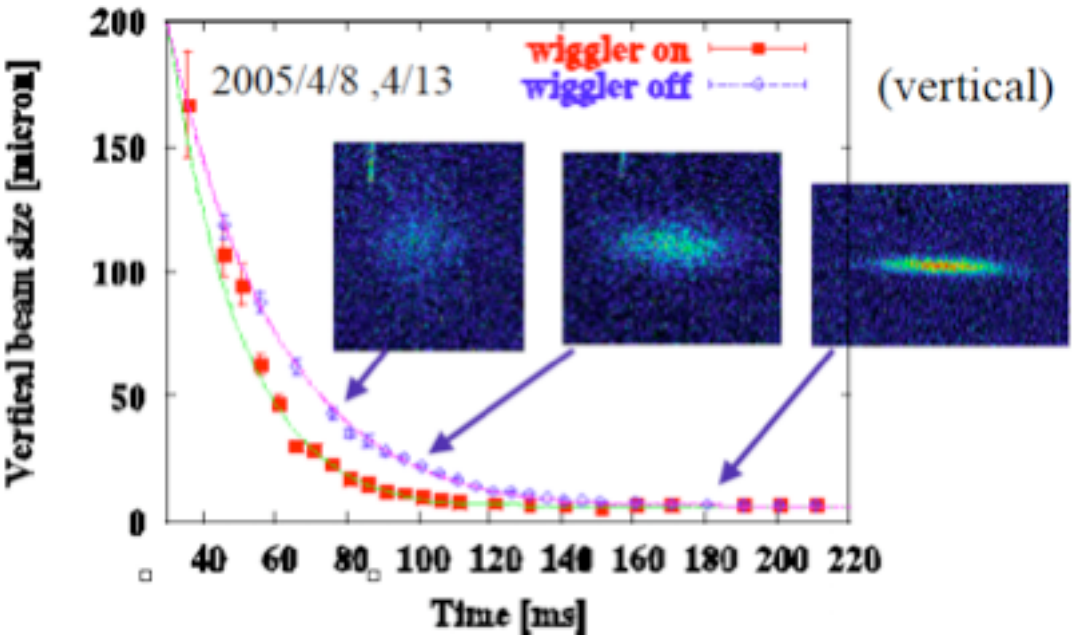




X-Ray SR Imaging Monitor

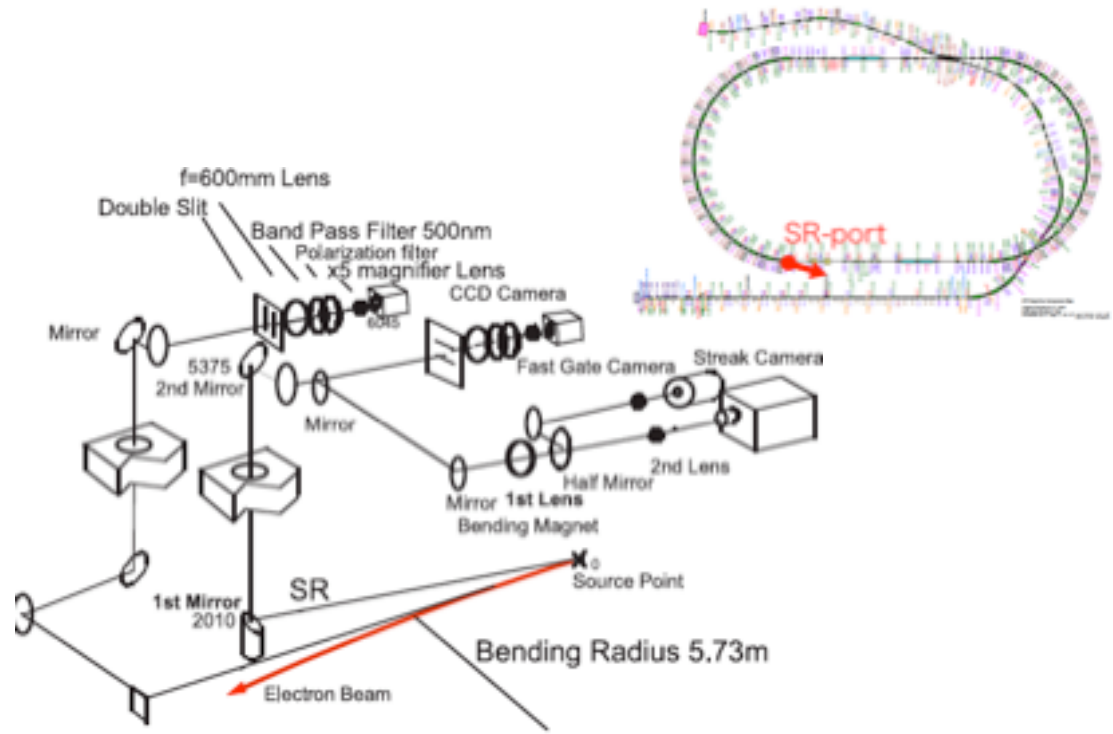
- Check emittance tuning of the DR
- Time resolution is faster than damping time
  - observation of transverse damping

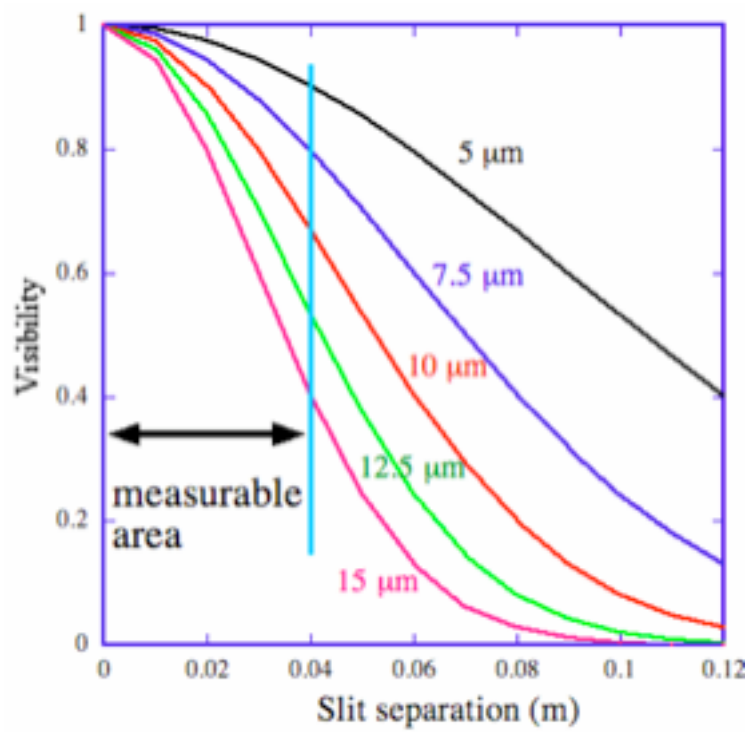


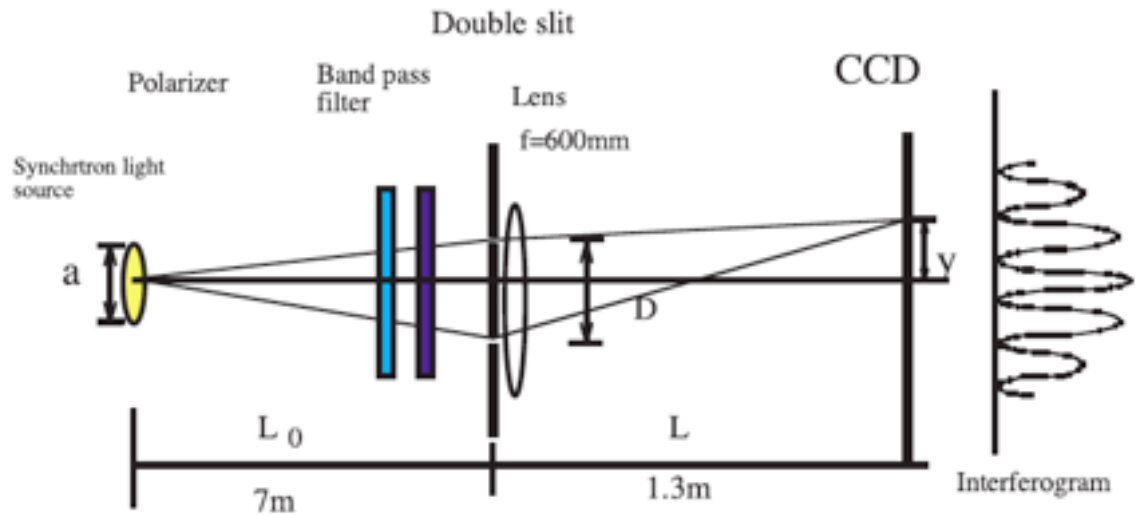


SR Interferometer

- measure the spot size of the SR source from spatial coherence of SR
  - double-slit interferometer
  - < diffraction limit of imaging
- shot-by-shot measurement
- limit
  - slit separation
  - light intensity (filter band width)
  - mechanical vibration
  - setup alignment

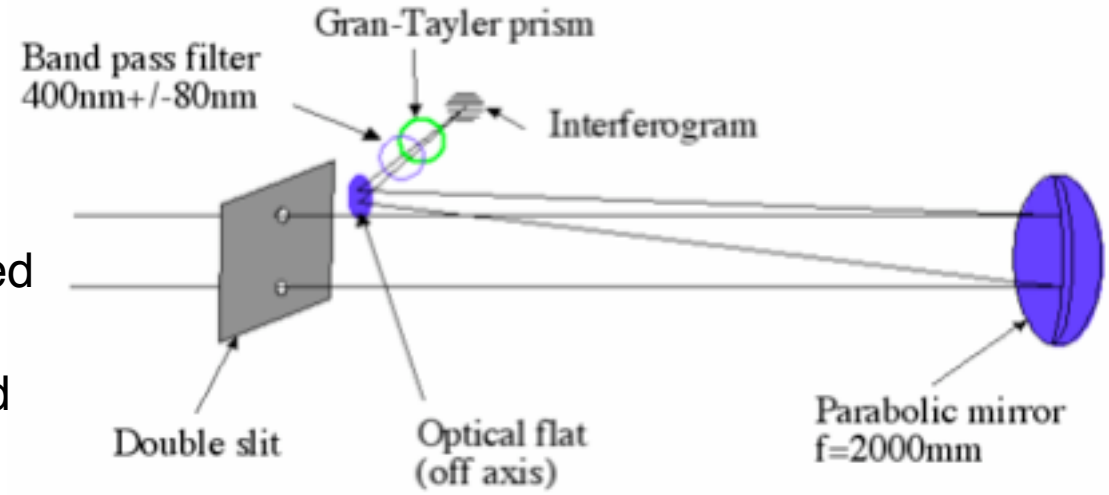


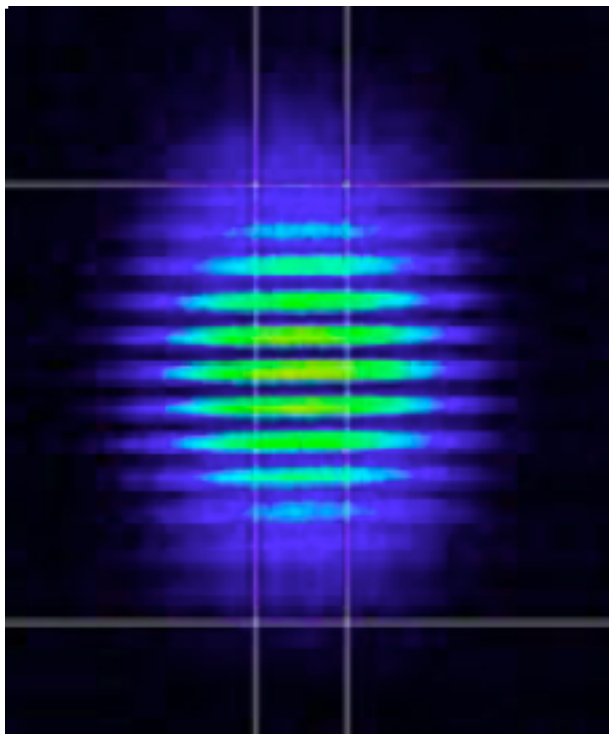


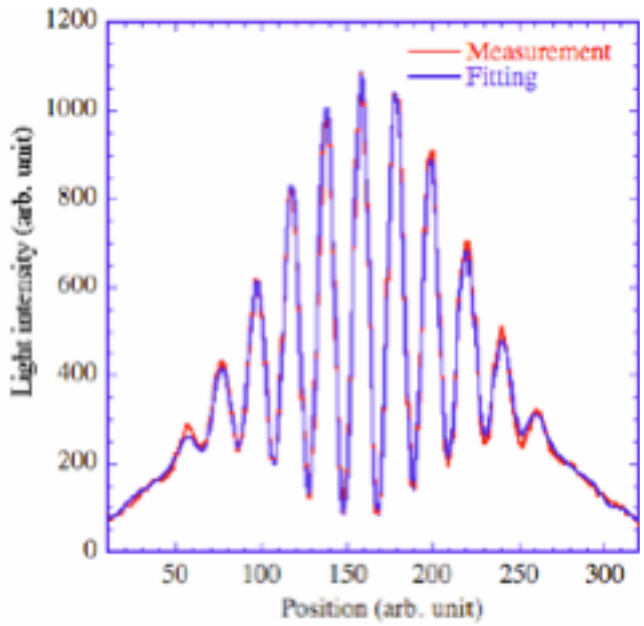


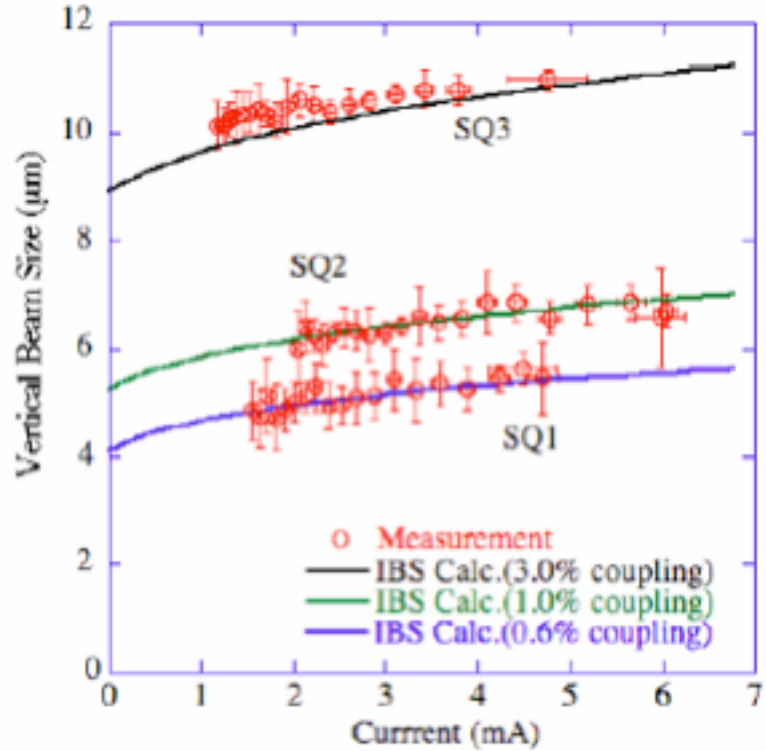
SR Interferometer

- interferometer system improvement
  - utilize reflective optics not to be affected by dispersion effects.
  - fitting analysis of the image
  - fast shutter speed not to be affected by vibration
- 5um vertical beam size was measured



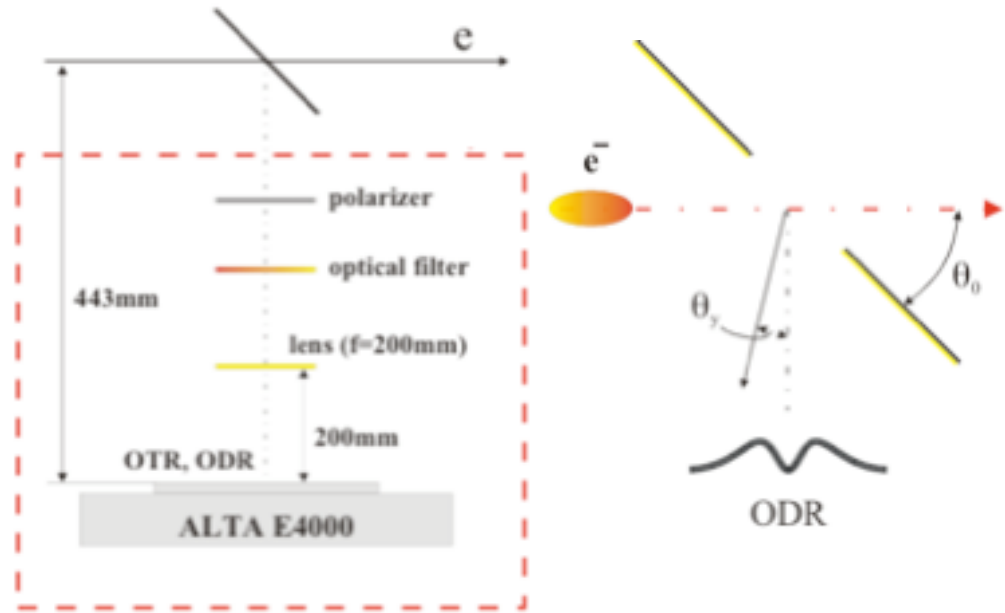


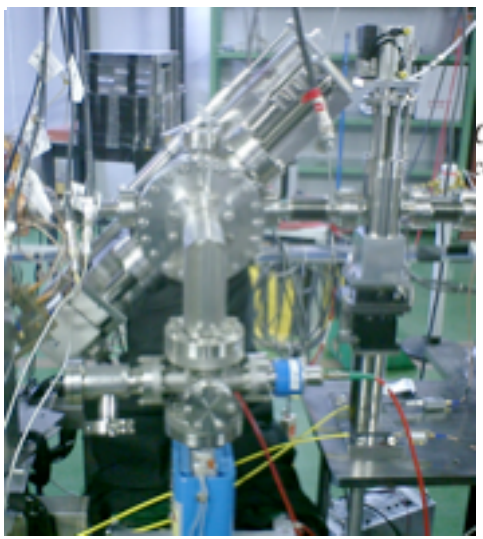


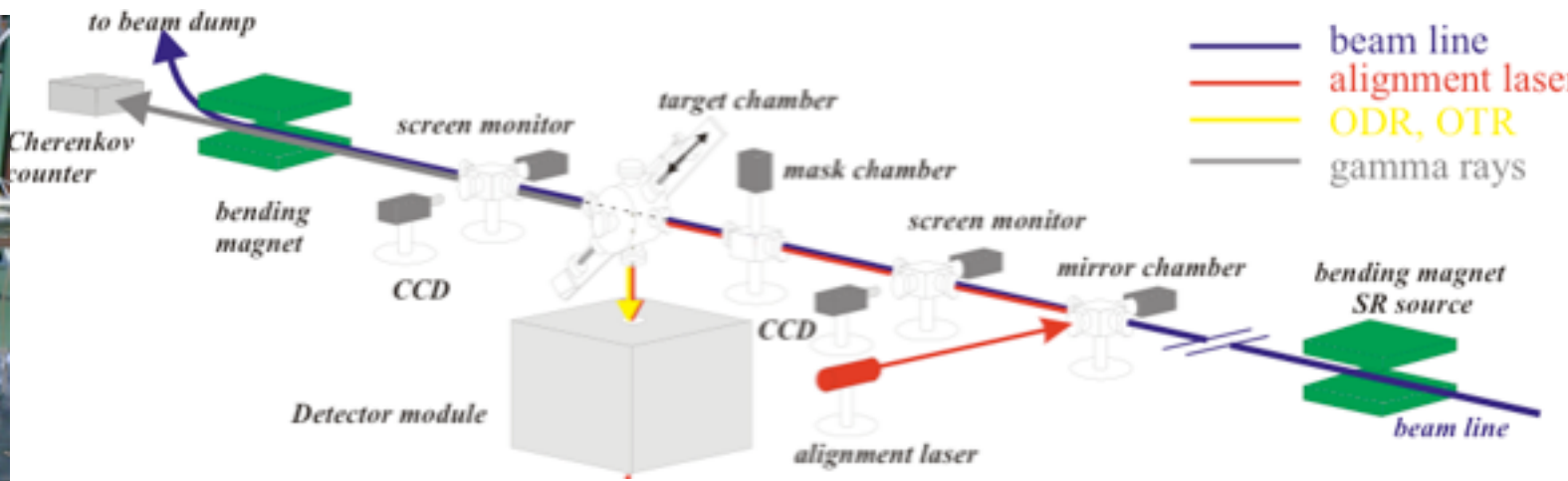


ODR beam size monitor

- Single-shot beam size measurement in the extraction line
- Optical Diffraction Radiation
  - visible radiation from a conductive object near the beam orbit
  - 45deg. plate radiates toward parpendicular direction of the beam
- beam size measurement
  - slit target (230um aperture)
  - interference of ODR from two edges of the target
  - two-peak pattern on a cooled CCD

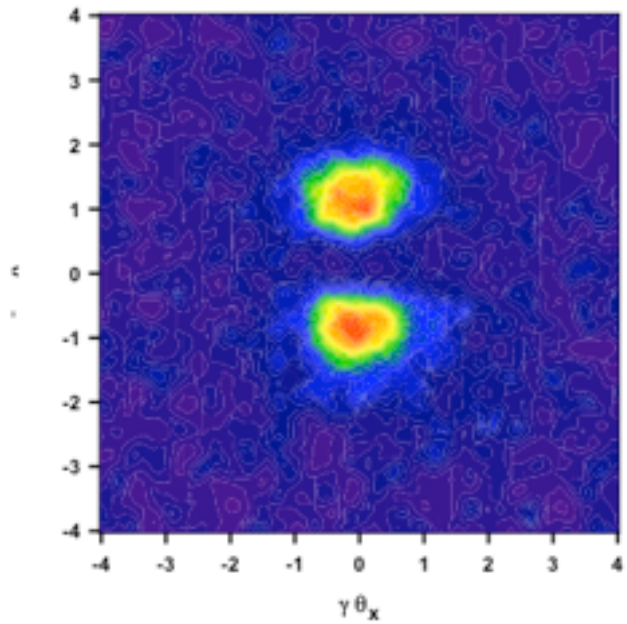


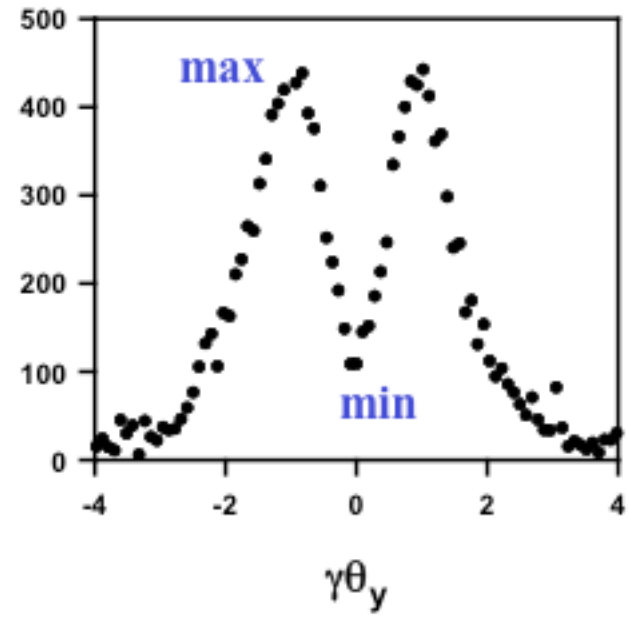


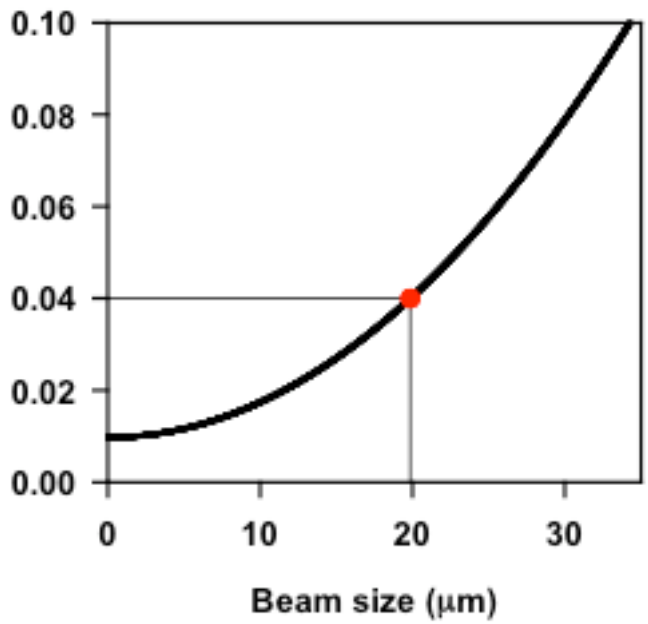


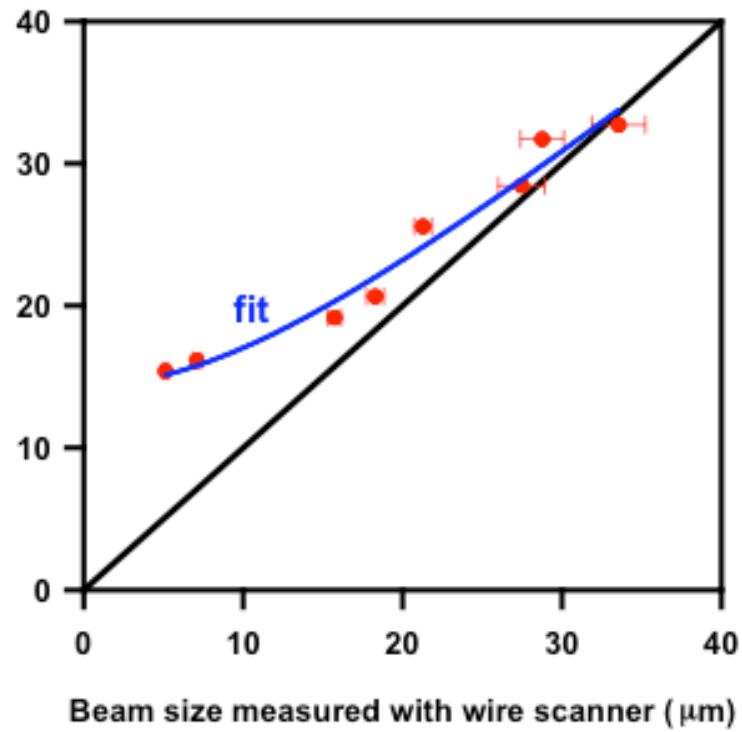
ODR beam size monitor

- min/max is a good measure to tell the beam size
- performance test
  - comparison with wire-scanner
  - measurable as small as 15um
- setting up
  - align the beam position to the slit center
  - reduce SR background
  - quality of the target is important



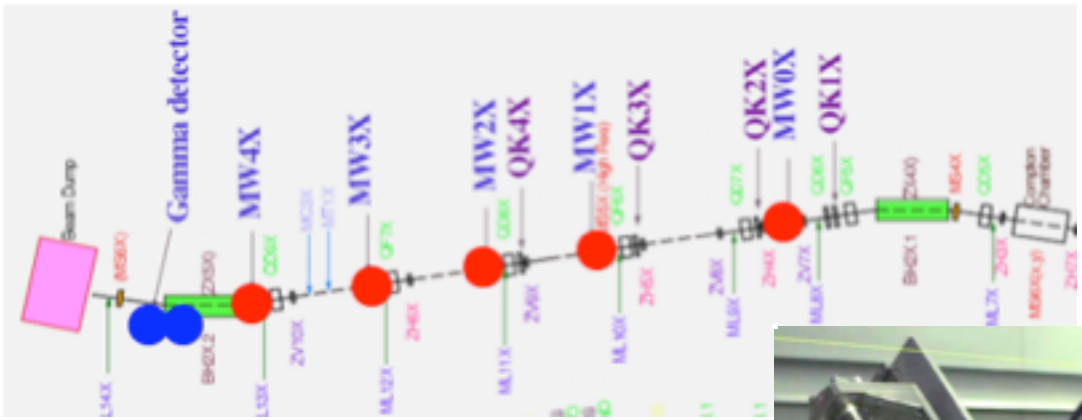


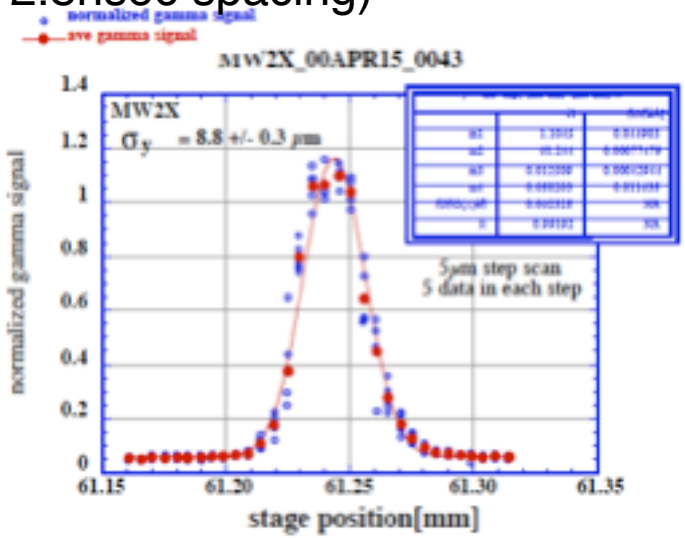


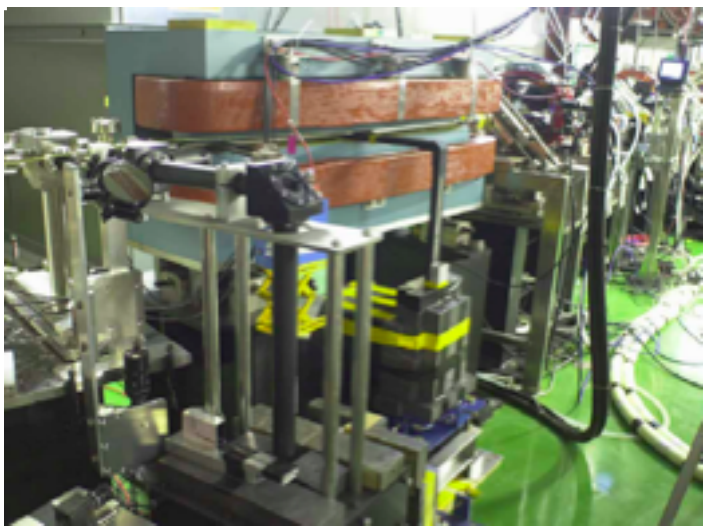


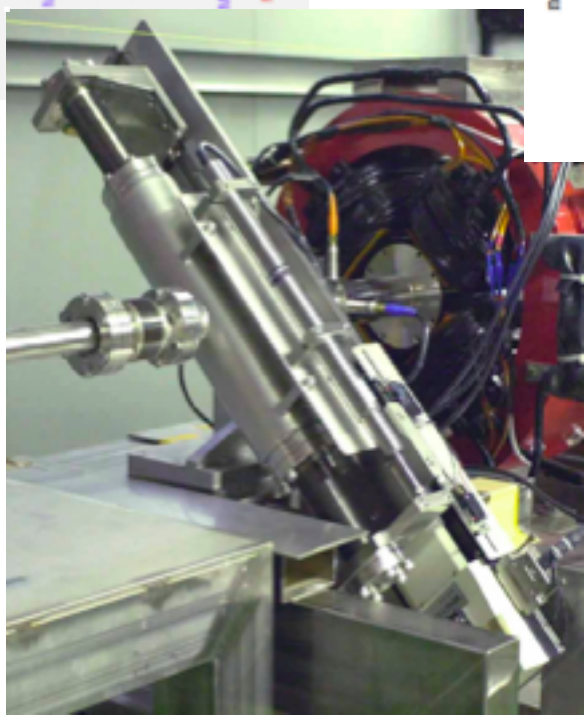
Wire scanner system

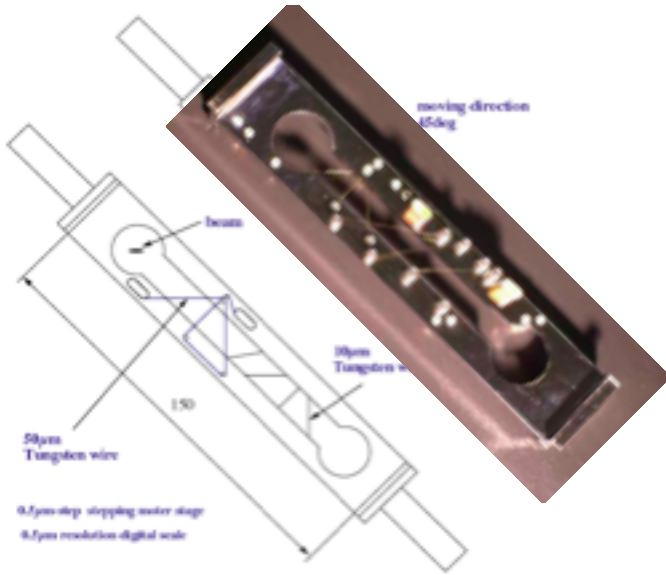
- 5wire scanners are located in the straight section (dispersion less) of the ext.line
  - tungsten wire of 10um diameter
  - x,y,45deg., 10deg. direction wires are mounted in a scanning stage
- air cherenkov detector
  - two types of sensor: PMT, and APD (multi-bunch with 2.8nsec spacing)





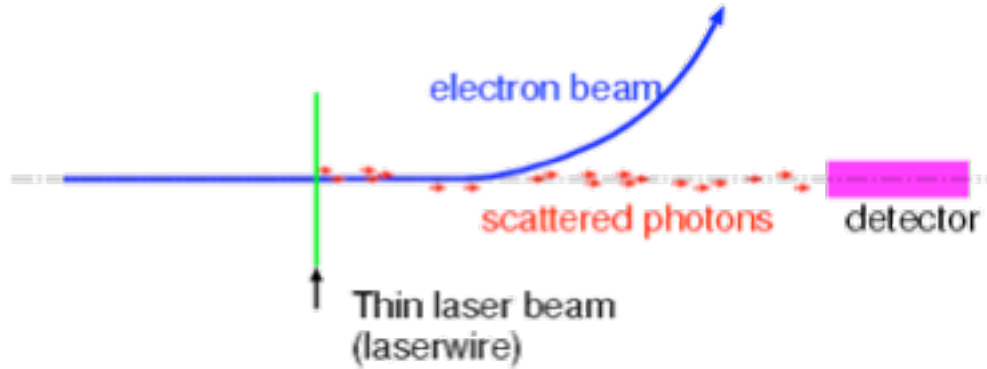


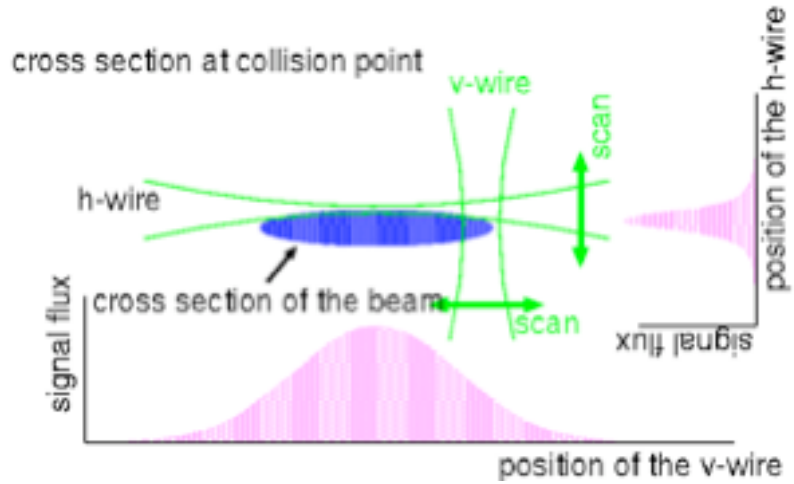


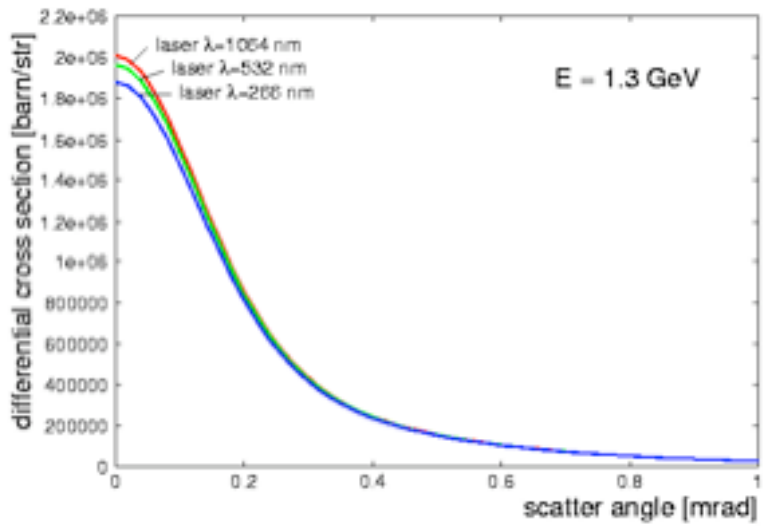


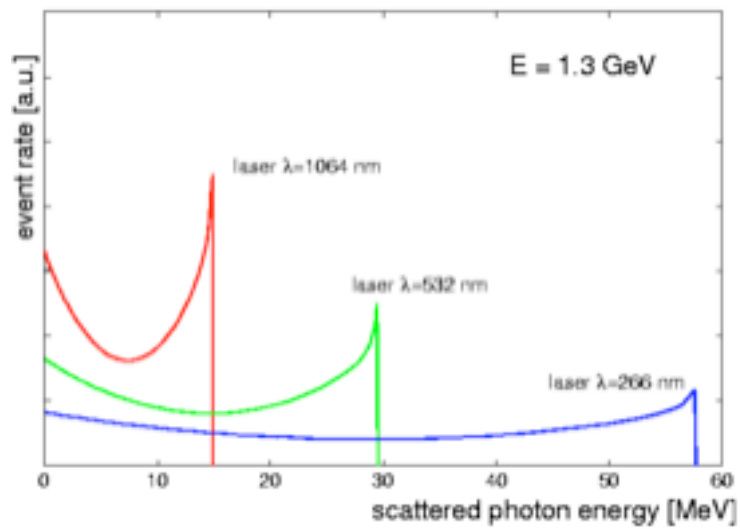
Laserwire monitor

- Replace target of wire-scanner with a focused laser beam
  - non-invasive measurement
  - not damaged by beam
- interaction
  - Compton scattering
  - 28MeV scattered photon (ATF case)
- laser
  - high power and focused
- two different systems
  - cw laser with a build-up cavity (ring)
  - pulsed laser with a strong focus (ext.line)



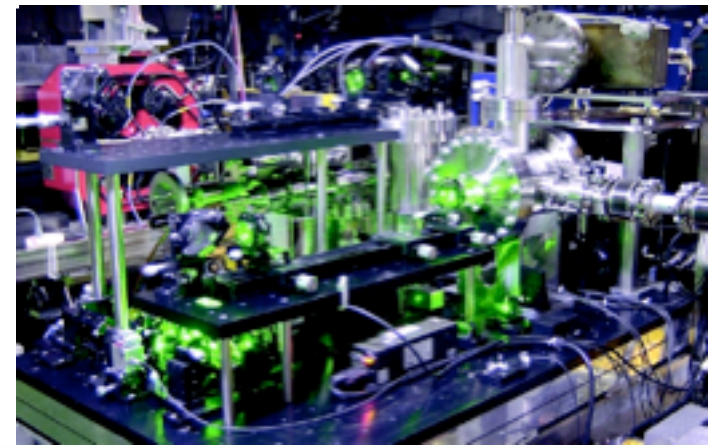


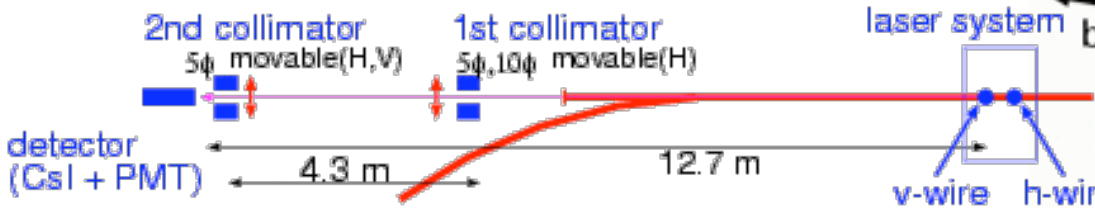


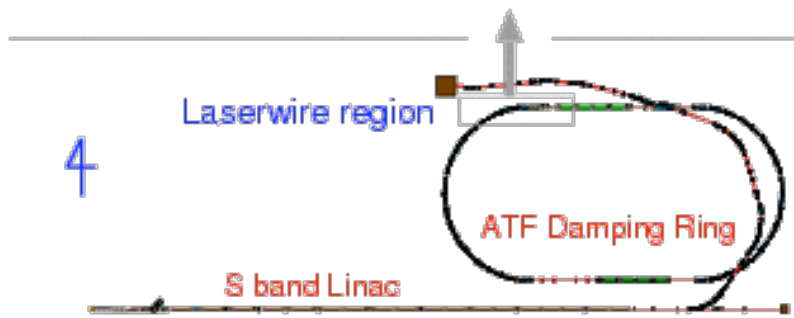


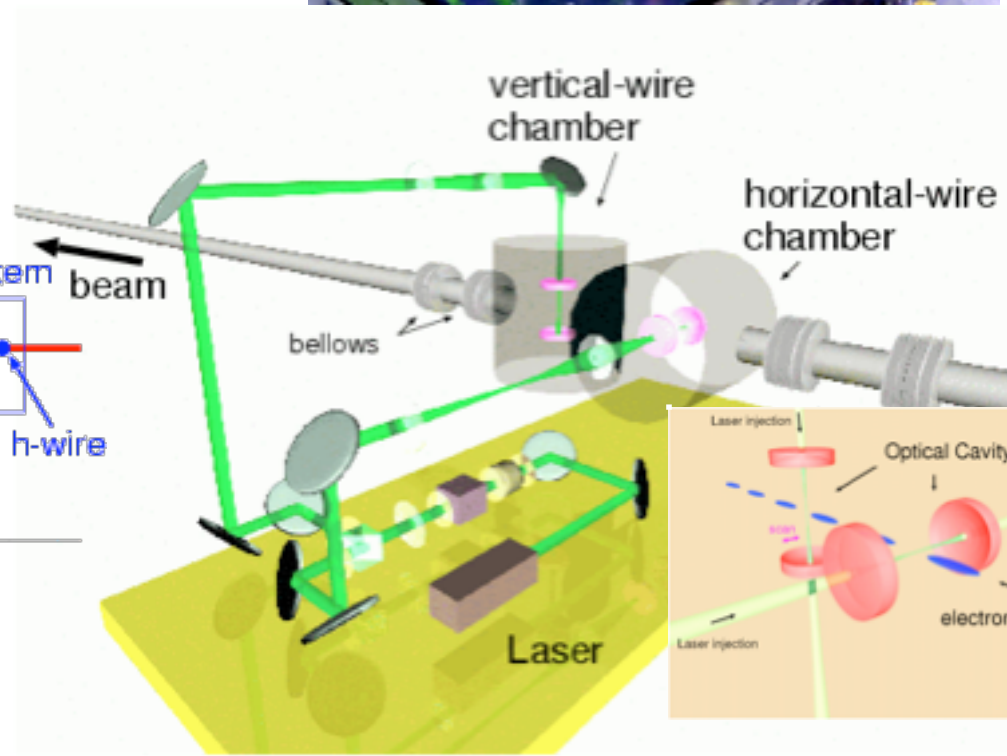
Laserwire monitor (DR)

- Laser system
  - cw laser, optical components
  - build-up optical cavity
- scanning mover
  - whole laser system is on the mover table
- detector
  - CsI counter, fast enough to separate bunches



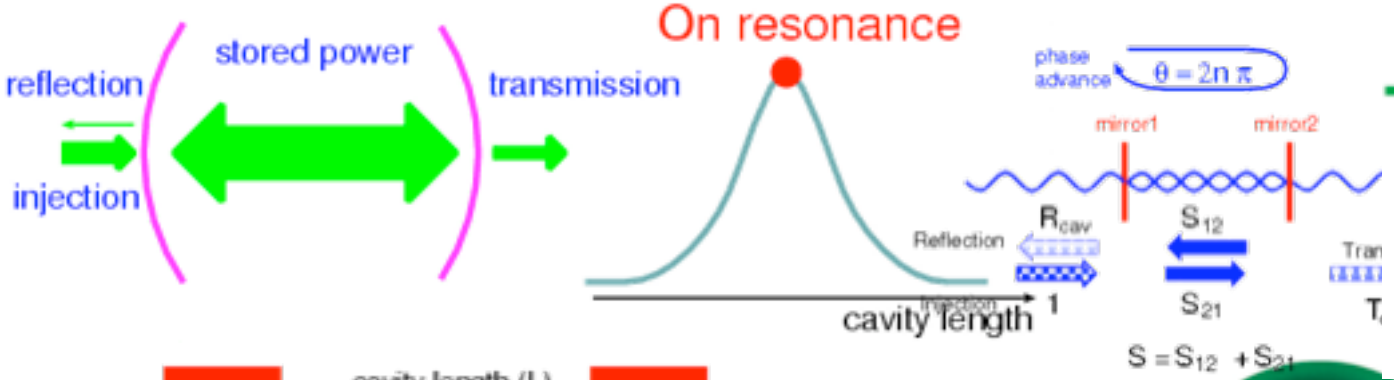


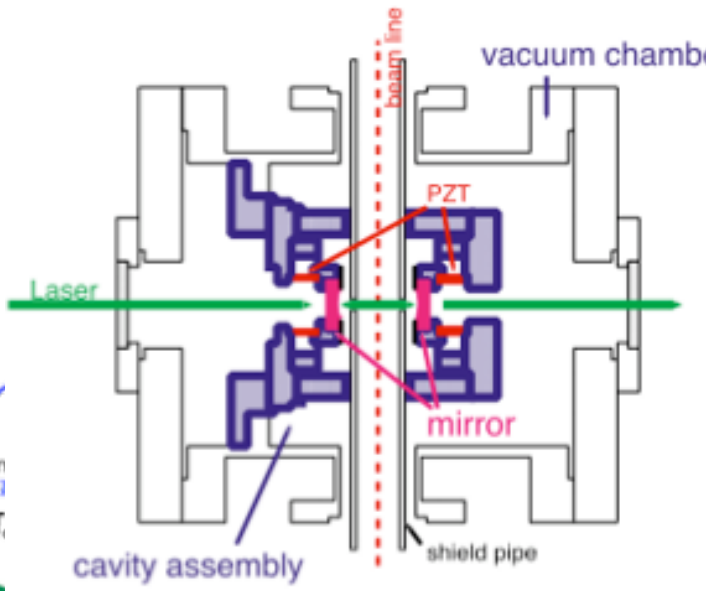


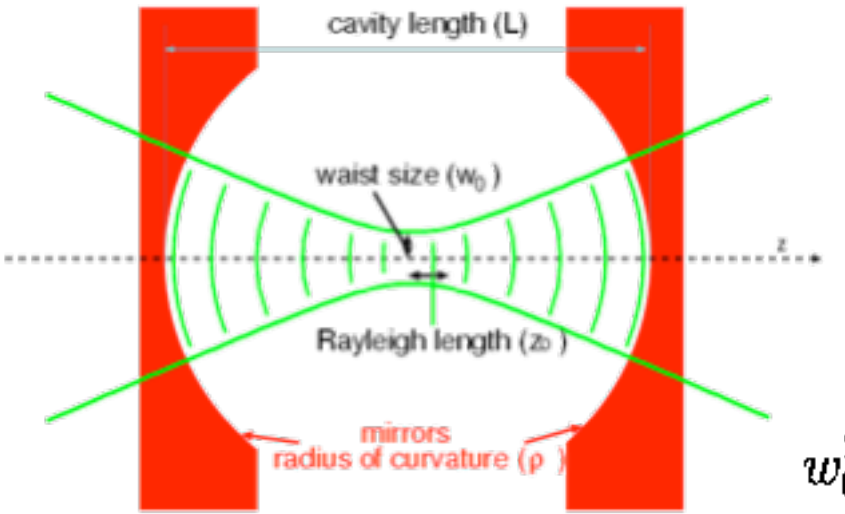


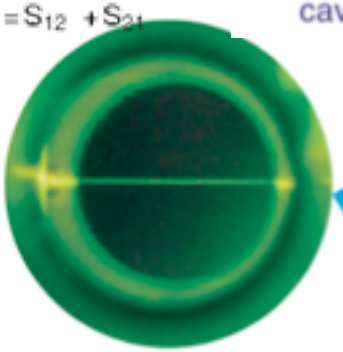
Laserwire monitor (DR)

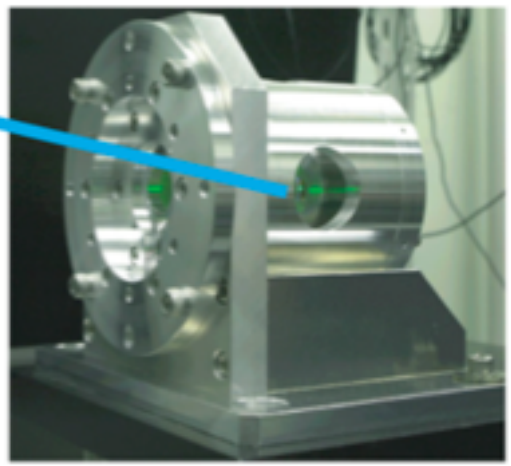
- Optical cavity
  - high effective power
    - high finesse build-up cavity, x1000 power enhancement
    - feedback control to keep resonance
  - small spot size
    - nearly concentric configuration, 5.6um size
    - stable realization of fixed spot size









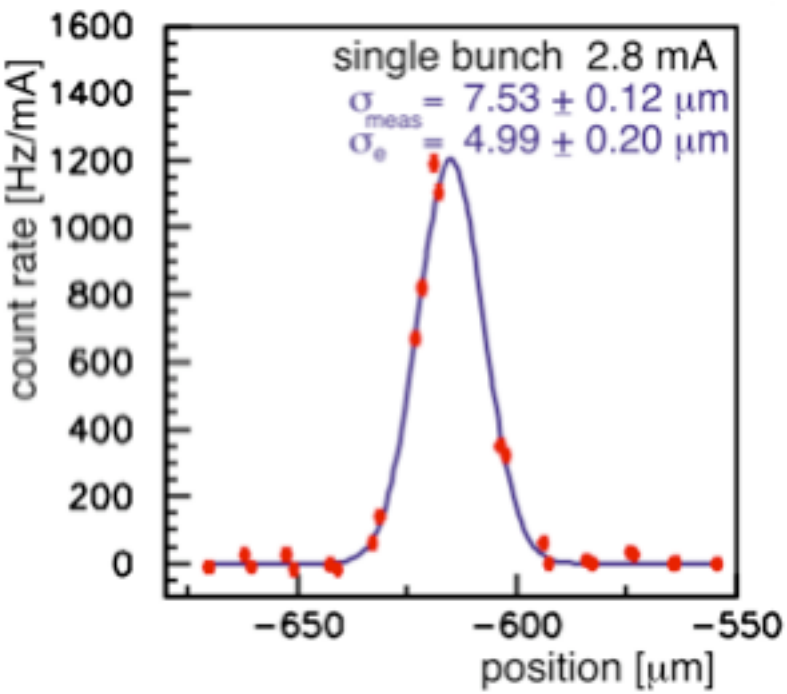


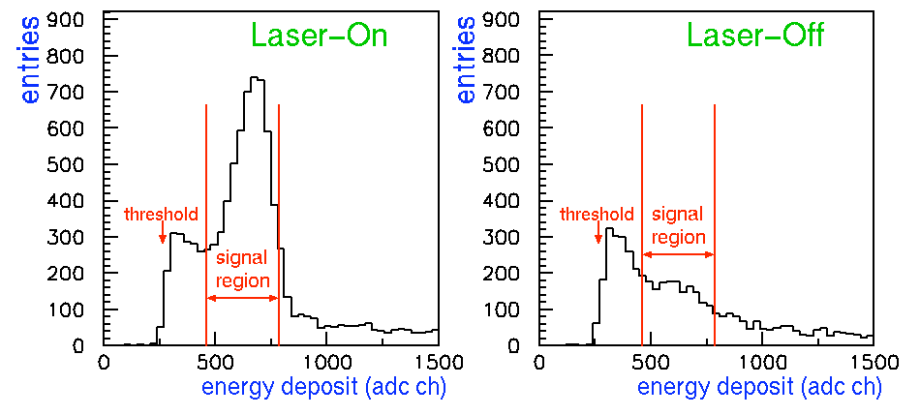
$$w_0^2 = \frac{\lambda}{\pi}\frac{\sqrt{L(2\rho - L)}}{2}$$

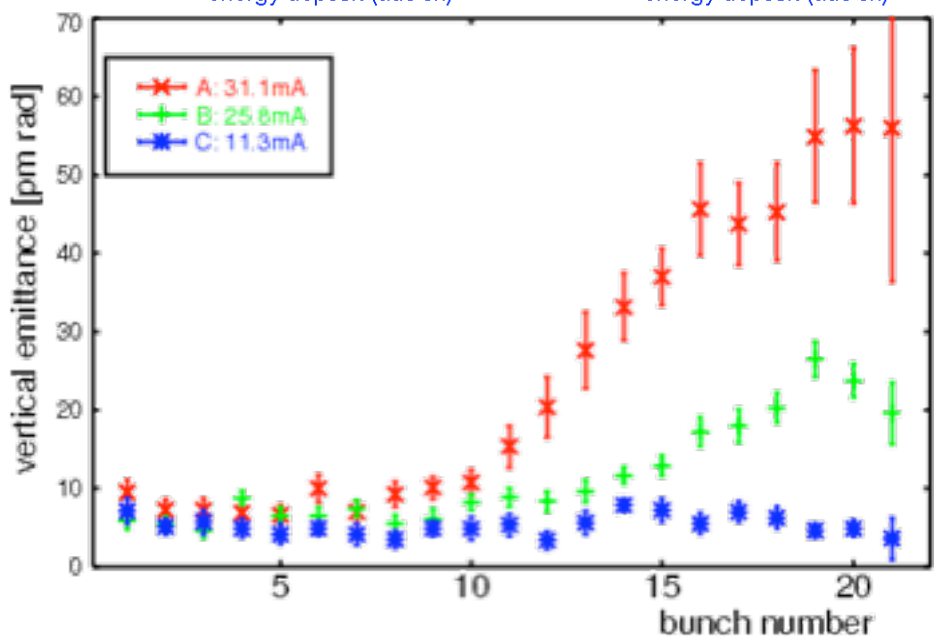
Laserwire monitor (DR)

- counting detection
  - measure laser-on and off simultaneously
- subtract contribution of the laser size from the measured width
- multi-bunch measurement
  - time resolution of the detector is fast enough to identify 2.8nsec spacing bunches

$$\sigma_e = \sqrt{\sigma_{meas}^2 - \sigma_{lw}^2}$$

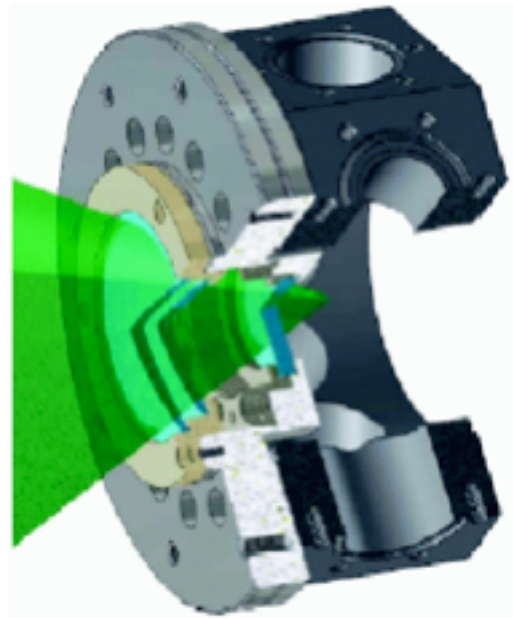


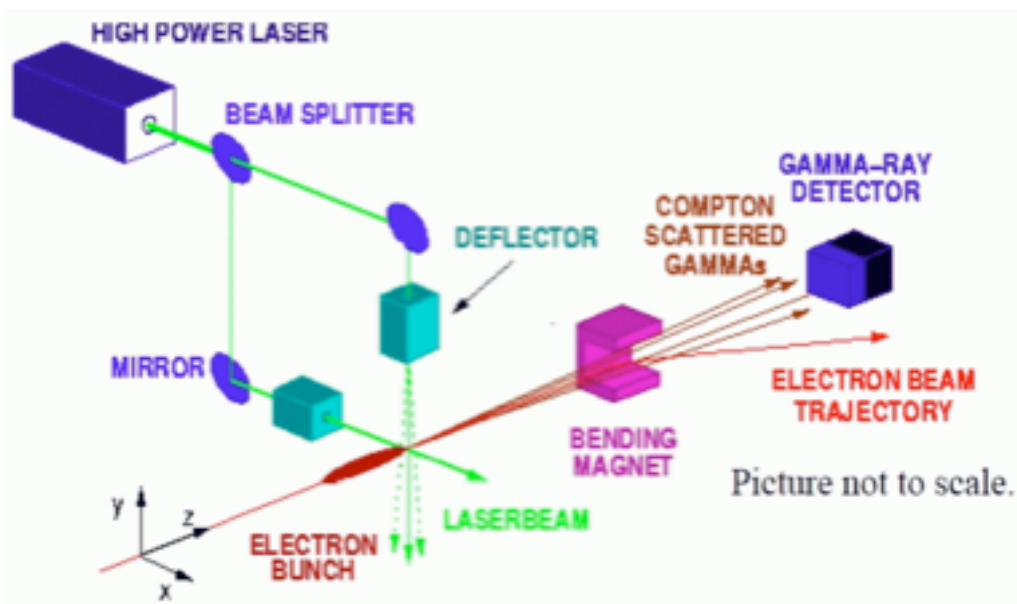


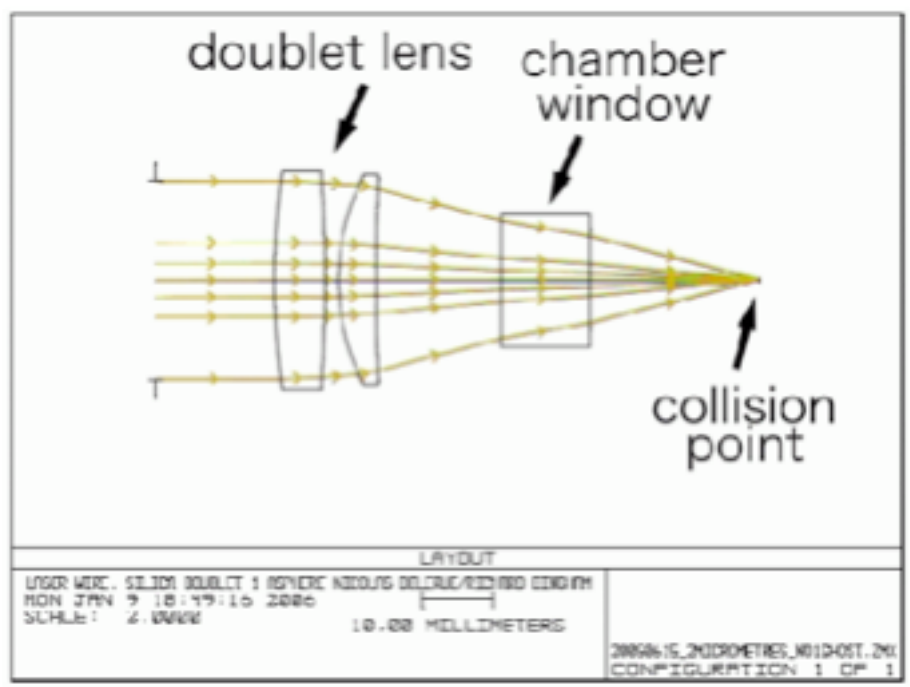


Laser wire monitor (ext.line)

- single path beam line
  - higher laser power is necessary
  - high power pulsed laser (100psec)
- special focusing lens
  - F#2 lens (1um spot) in preparation
  - test with F#10 lens at present

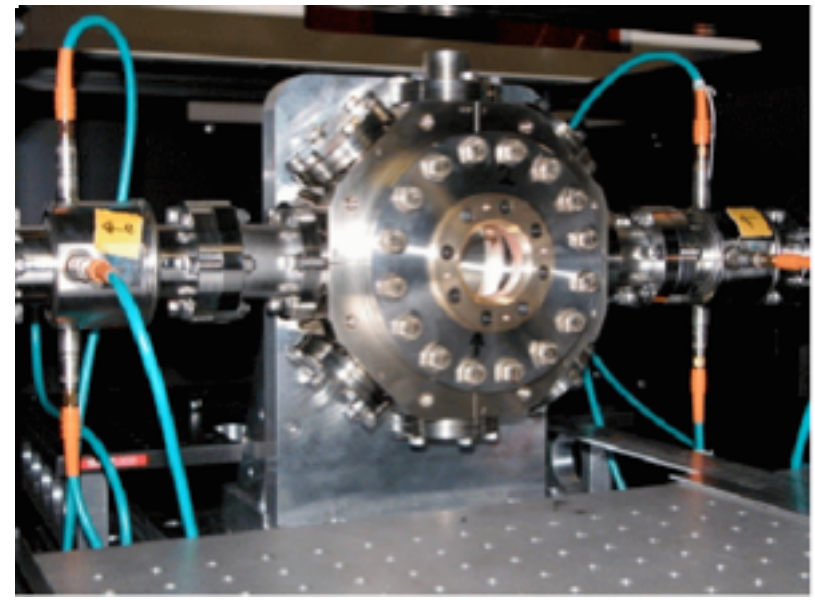


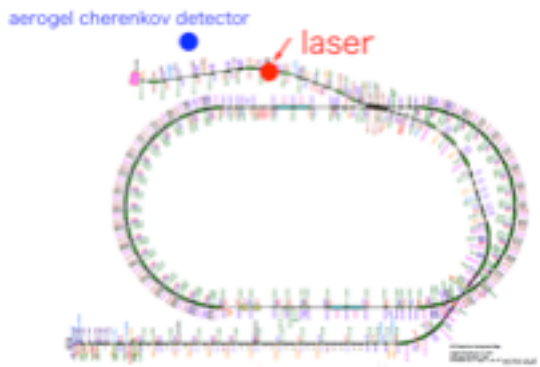




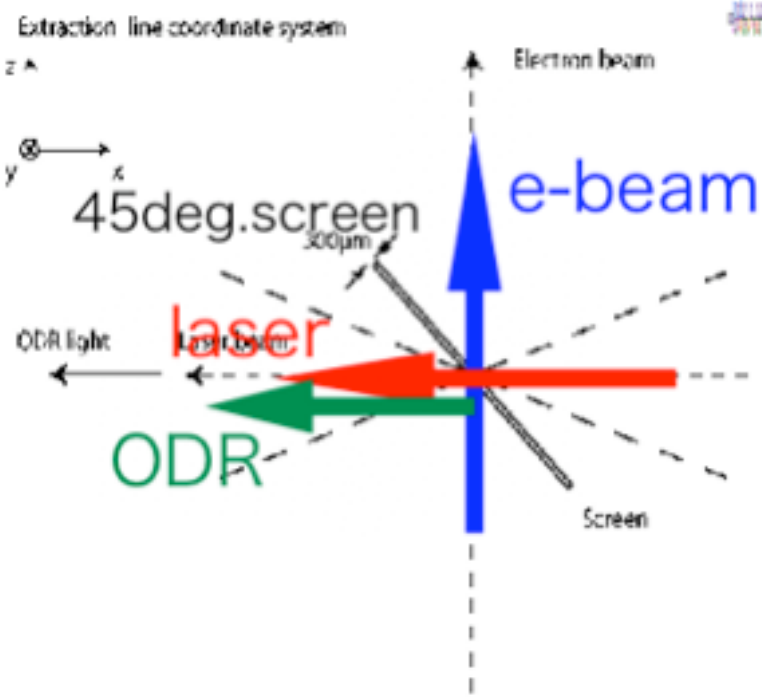
Laser wire monitor (ext.line)

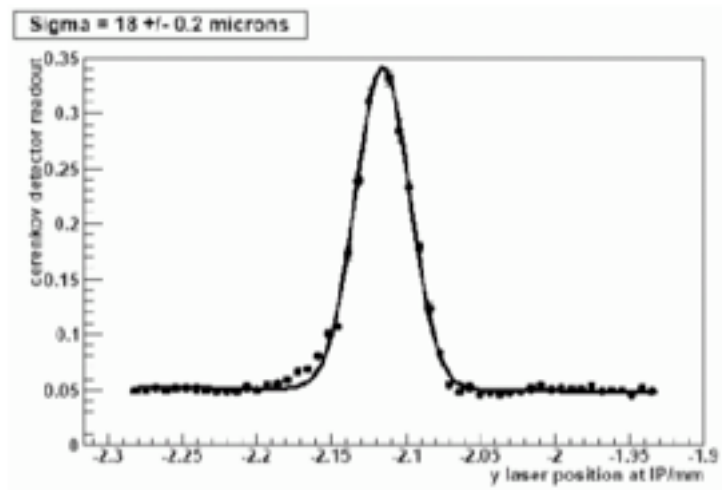
- detector
  - aerogel cherenkov counter
- test at the ext.line
  - establish laser-beam collision
    - timing adjustment
  - laser focusing quality

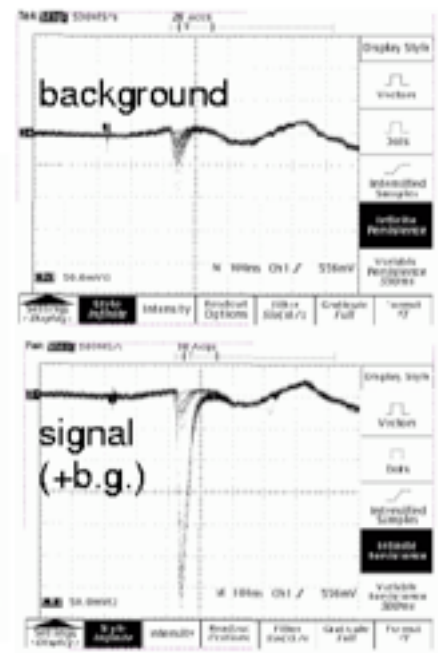




Overlap screen





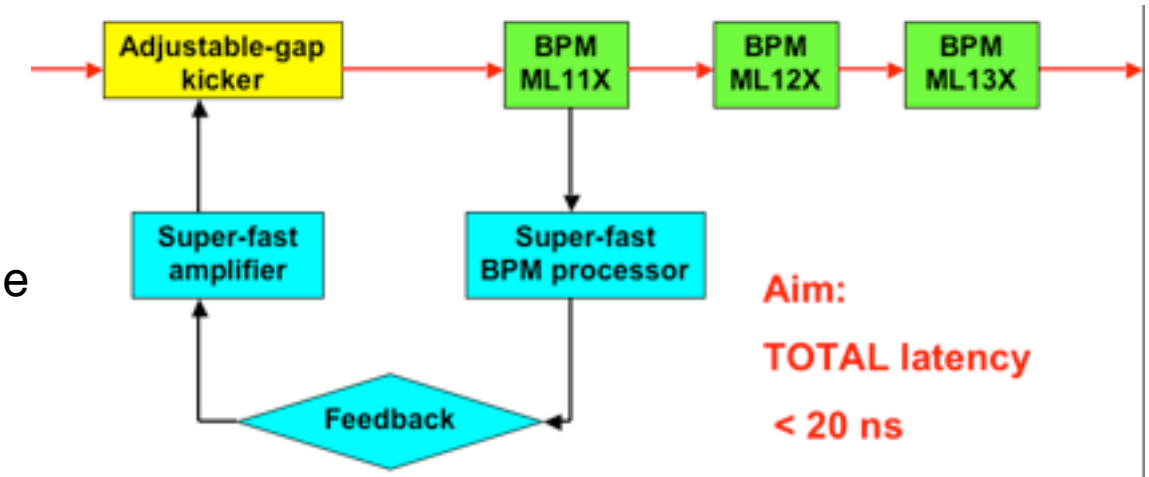


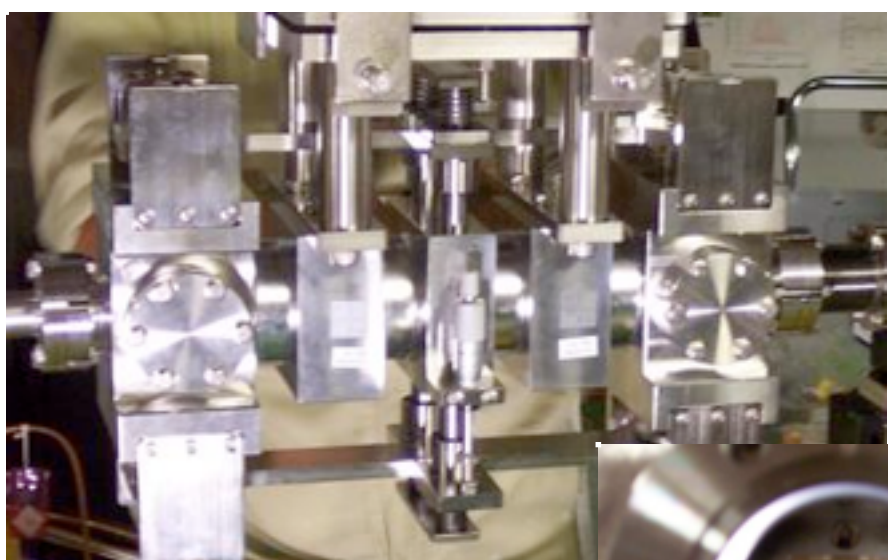
Beam Control

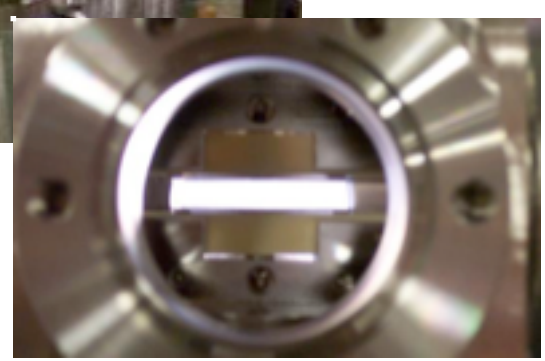
- beam position feedback stabilization for multi-bunch

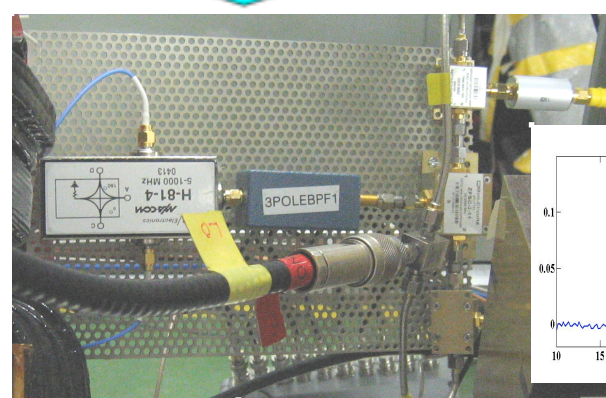
FONT3

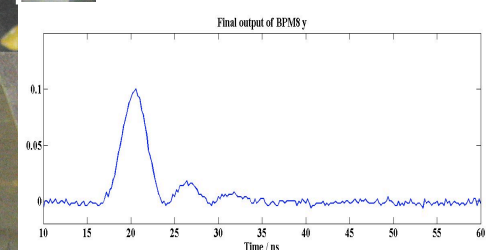
- beam position stabilization
  - feedback within a train
  - multi-bunch 2.8nsec x20
- system
  - adjustable-gap strip-line kicker
  - strip-line bpm with a fast analogue processor (5um resolution)

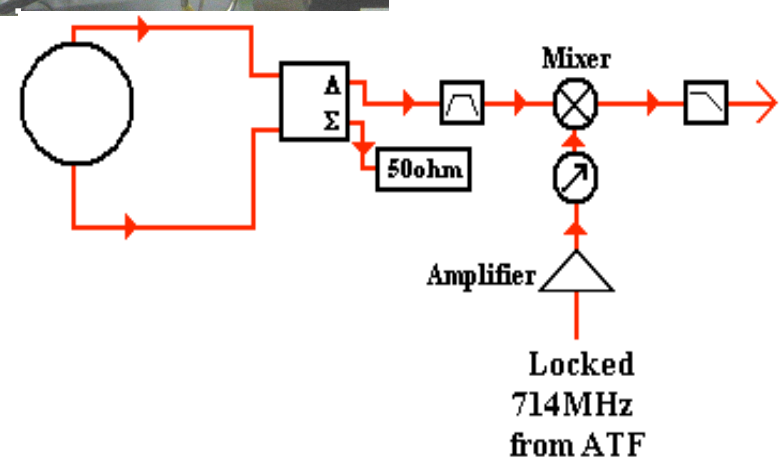








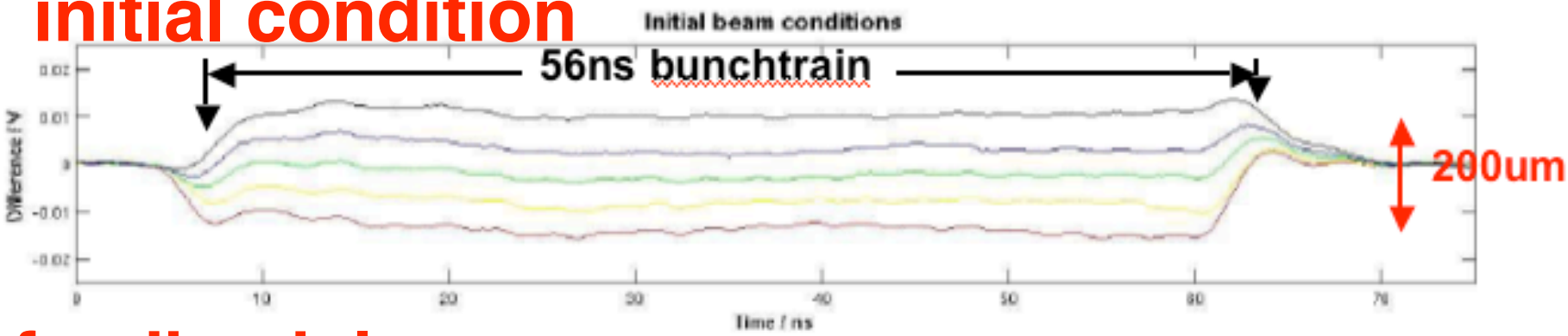




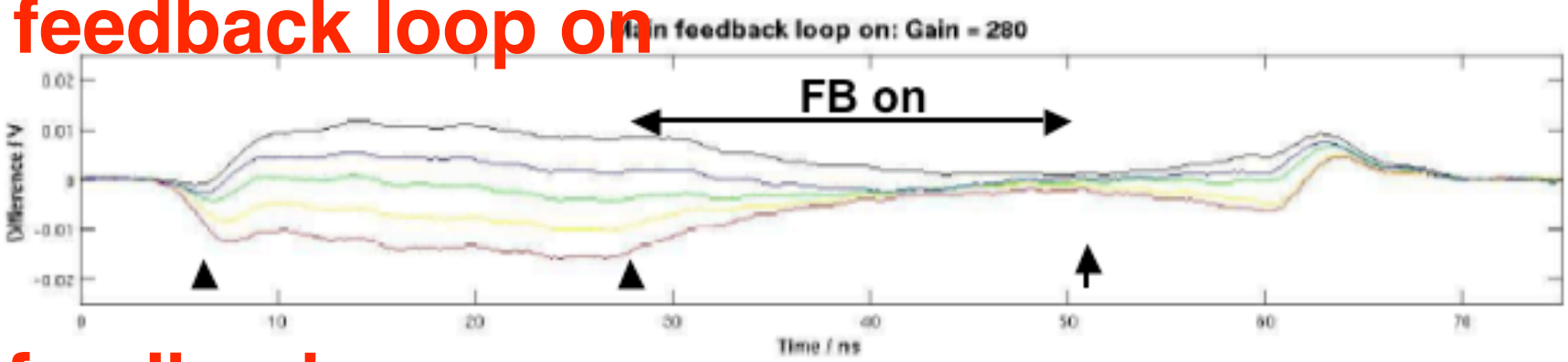
FONT3

- proved fast feedback

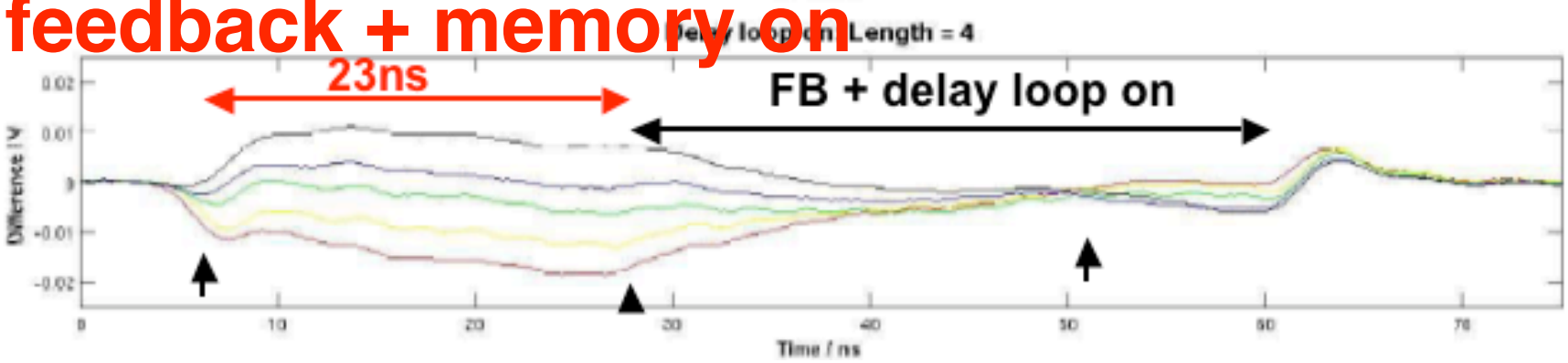
initial condition



feedback loop on

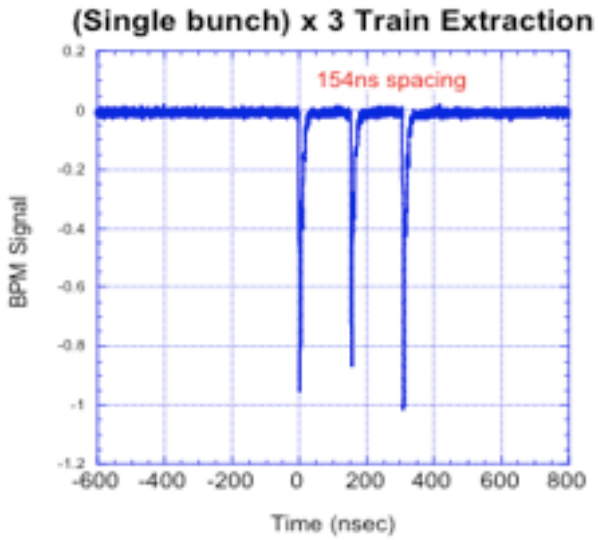


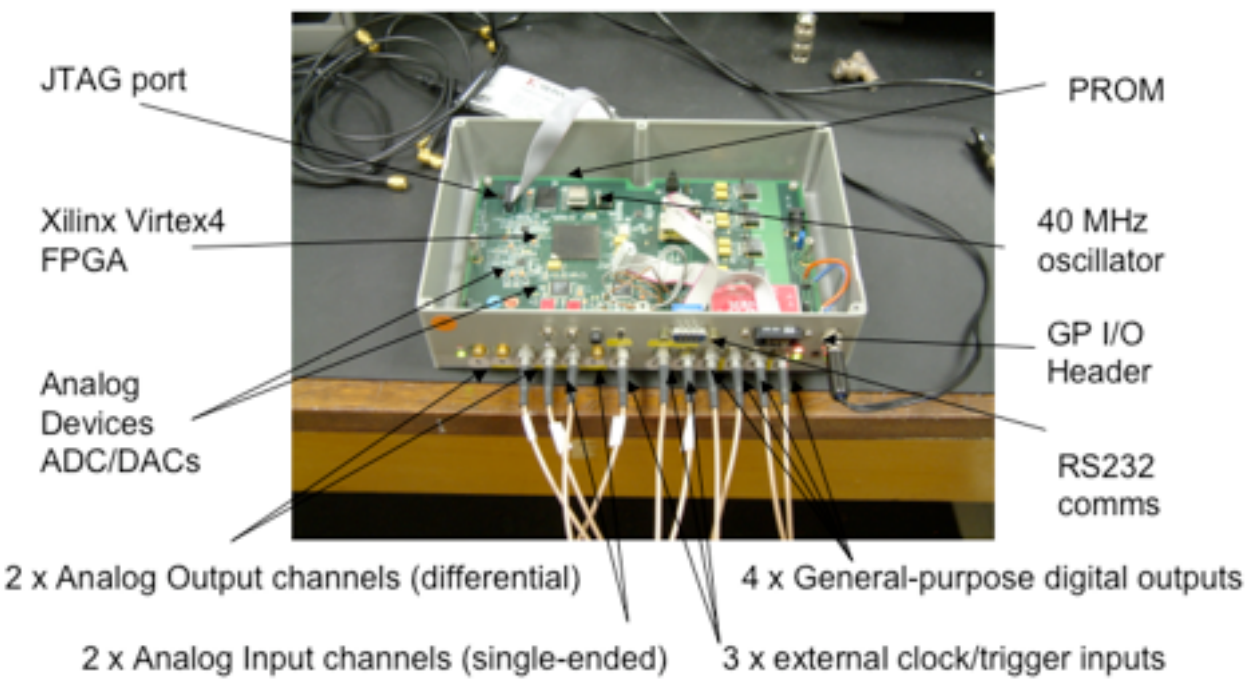
feedback + memory on

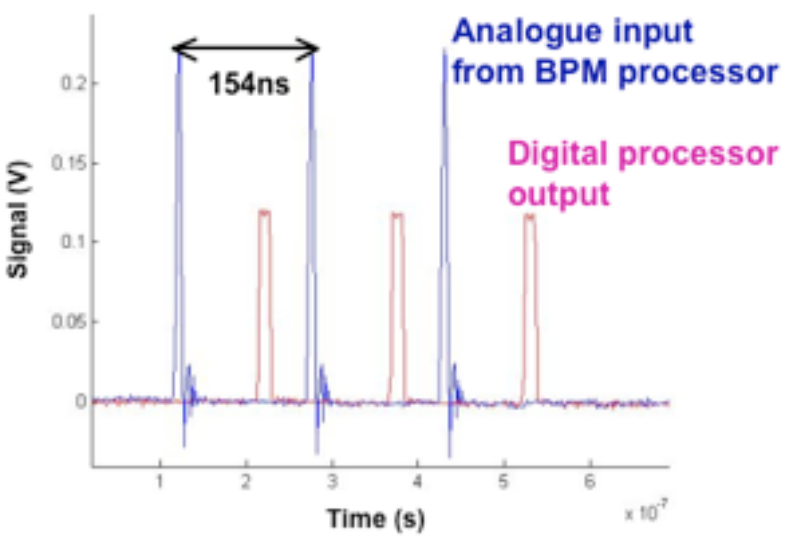


FONT4

- ILC bunch spacing is ~300nsec
  - enough time to process with a digital board
- ATF can produce a three bunch train with 150nsec spacing
- development of a digital board
  - produce a feedback signal to the kicker from analogue processed signal of the BPM







summary

- There are many beam monitor R&D activities in ATF