ATF-DR LASERWIRE

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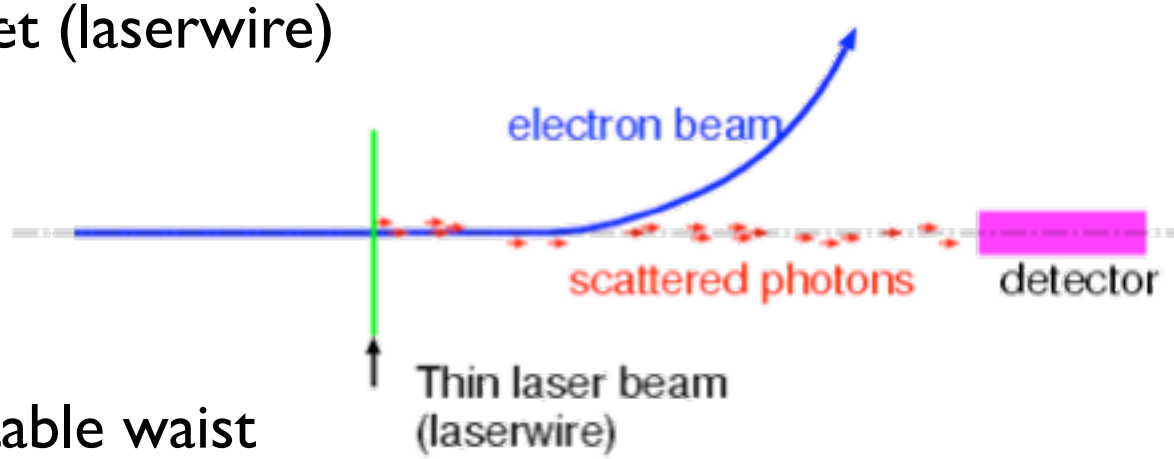
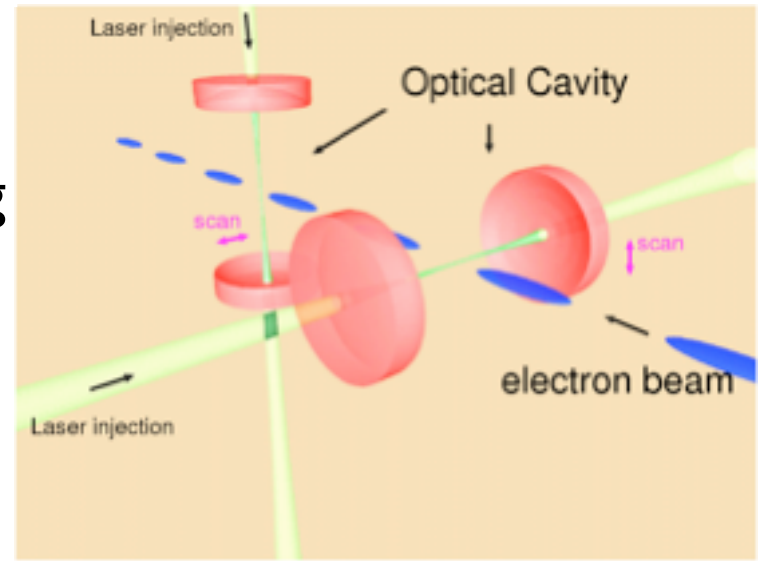
- Optical cavity
- ATF Laserwire
- Higher-Mode Laserwire
- Multi-bunch/damping time
- Pulse-Stacked Laserwire

Laserwire with an external optical cavity

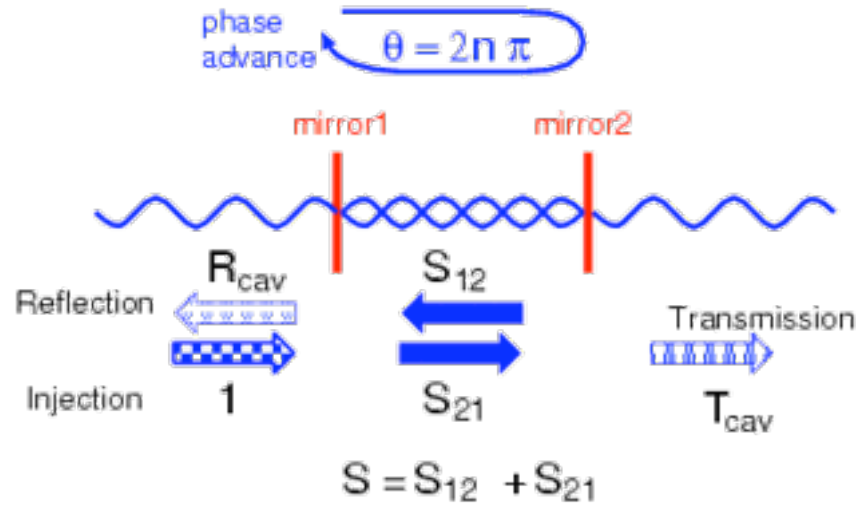
- Requirements for laser target (laserwire)
  - Intensity
  - small width (w0)
- Optical cavity
  - Power build-up
  - Accurately measurable/stable waist
  -
- CW cavity
  - no need to find the right timing
  - bunch separation by signal detection timing
- Pulse cavity
  - efficient collision
  - bunch length

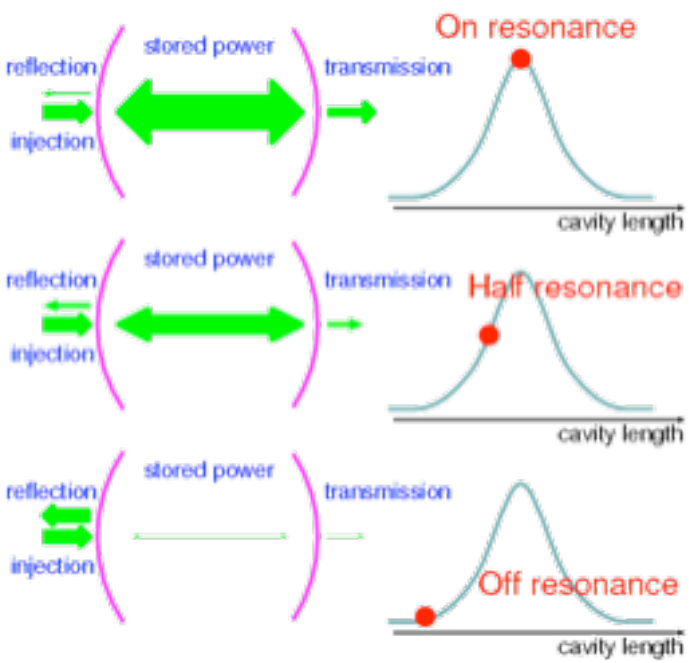


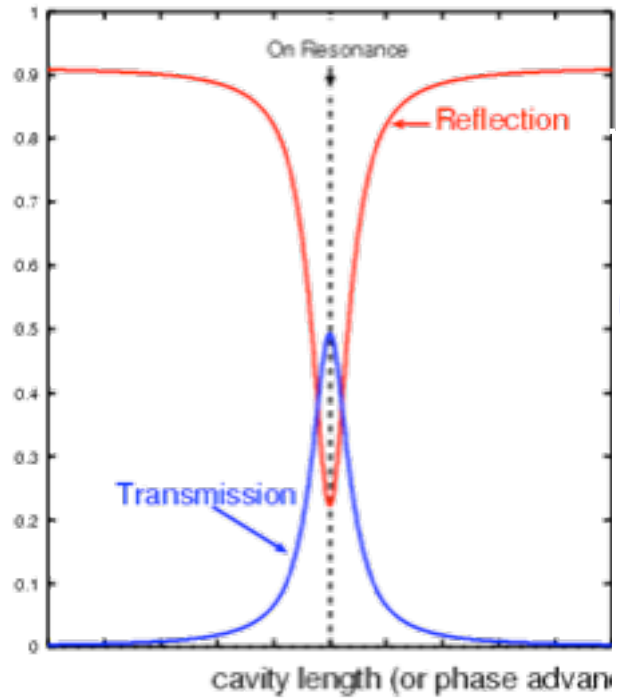


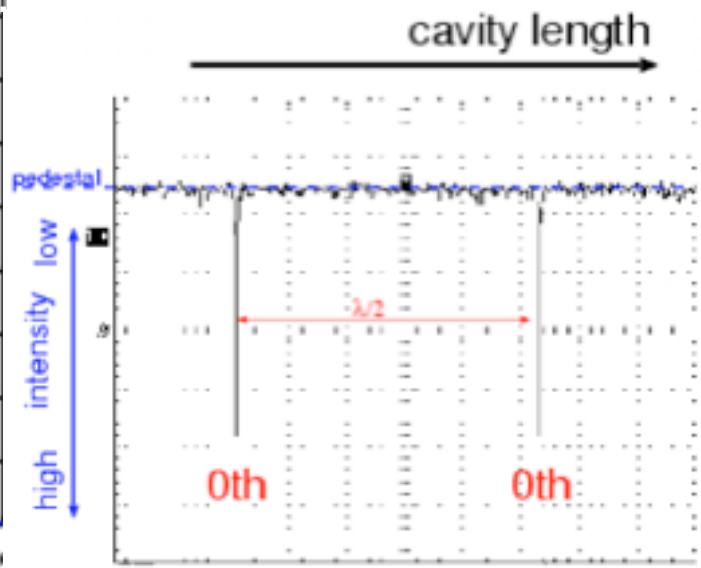
Principles of an optical cavity (power build-up)

- Laser power builds-up if the resonance conditions are satisfied.
- Higher gain, higher reflectance, narrower resonance width.







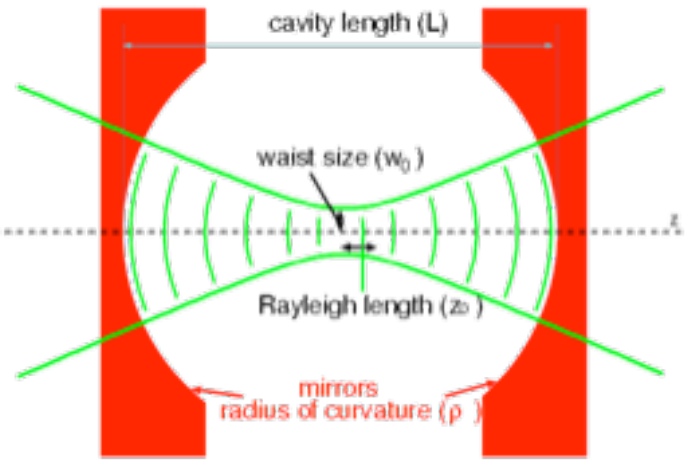


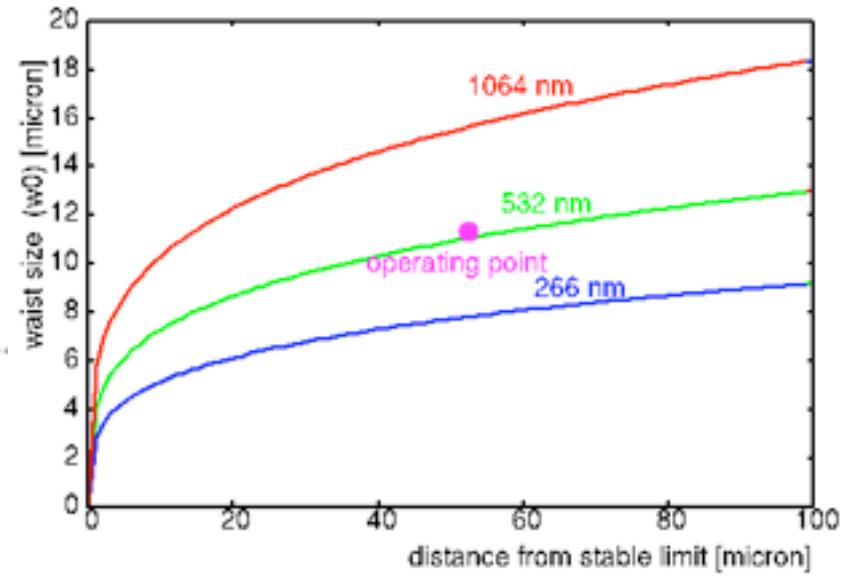
Principles of an optical cavity (waist size)

- Shape of the leaser beam is defined by the cavity, boundary condition given by the mirror. It is stable and accurately measurable.

$$w_0 = 2\sigma$$

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





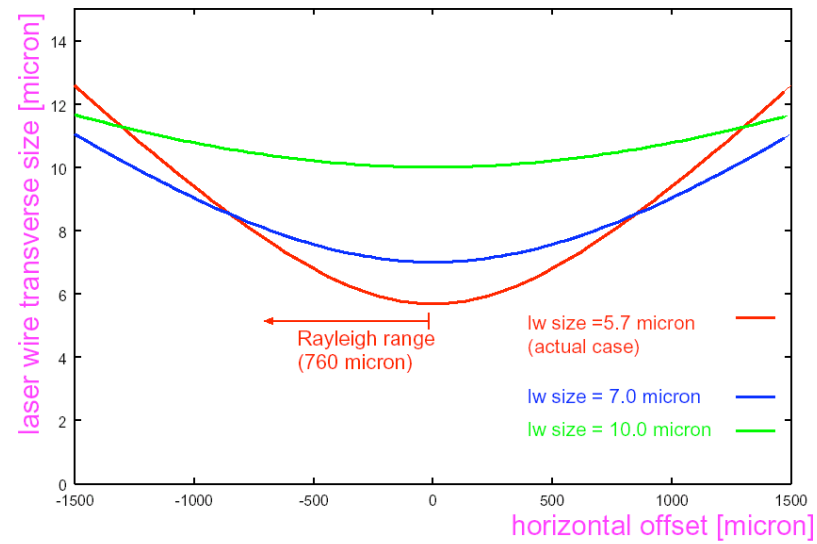
$$E_{mn} = A\frac{w_0}{w(z)}\exp\left(-\frac{x^2+y^2}{w^2(z)}\right)H_m\left(-\frac{\sqrt{2}\,x}{w_0}\right)H_n\left(-\frac{\sqrt{2}\,y}{w_0}\right) \times \exp\left(-ik\frac{x^2+y^2}{2R(z)}\right)\exp(-i\Phi(z))\exp(i\omega t - ikz)$$

$$w(z) = w_0\sqrt{1+(z/z_0)^2}$$

$$R(z) = z\left(1+(z_0/z)^2\right)$$

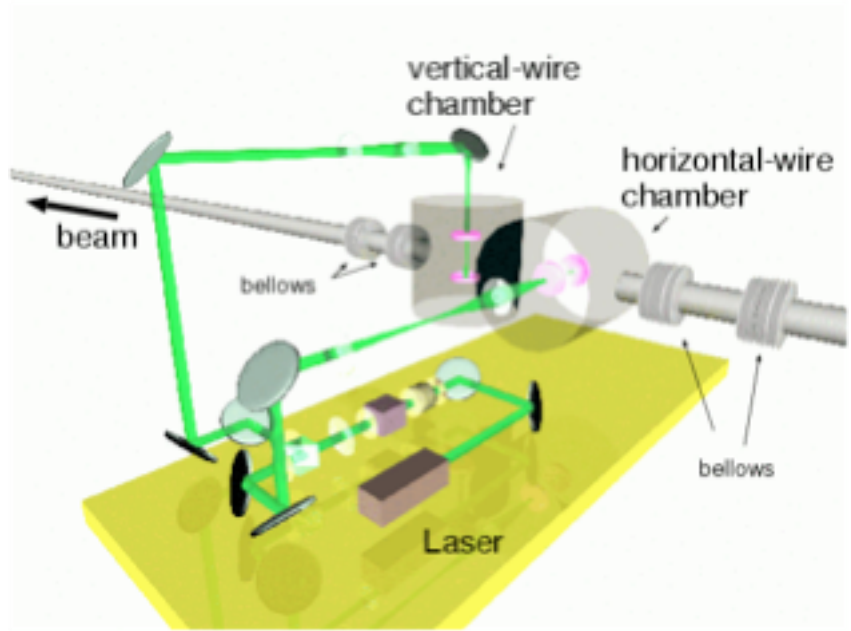
$$\Phi(z) = (m+n+1)\arctan(z/z_0)$$

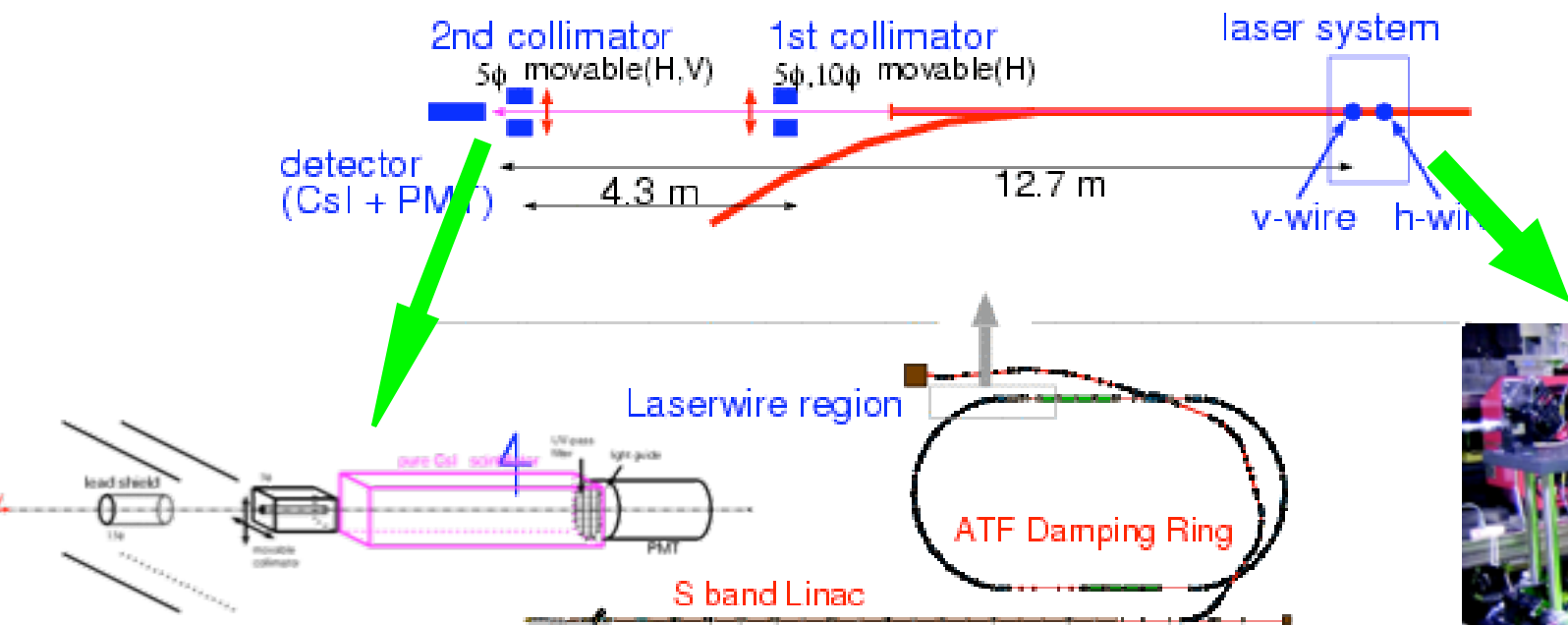
$$z_0 = \pi w_0/\lambda$$



Setup

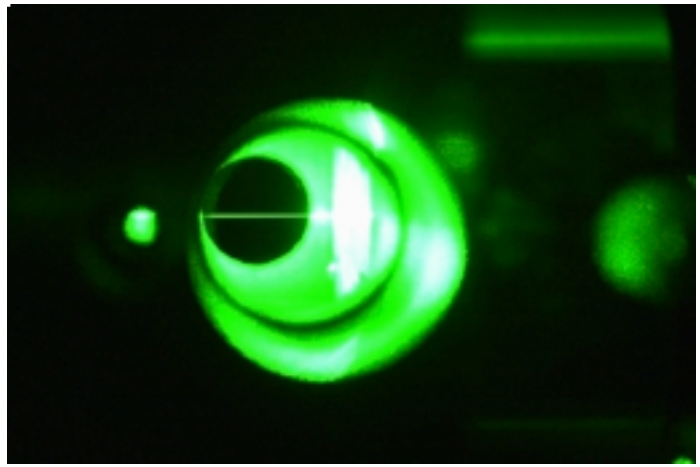
- ATF Damping ring
  - 5 micron (Y),100 micron (X), typical beam size.
  - horizontal and vertical cavity
  - scan by mover table.
- detection
  - CsI scintillator, counting.
  - Compton edge is 28 MeV.



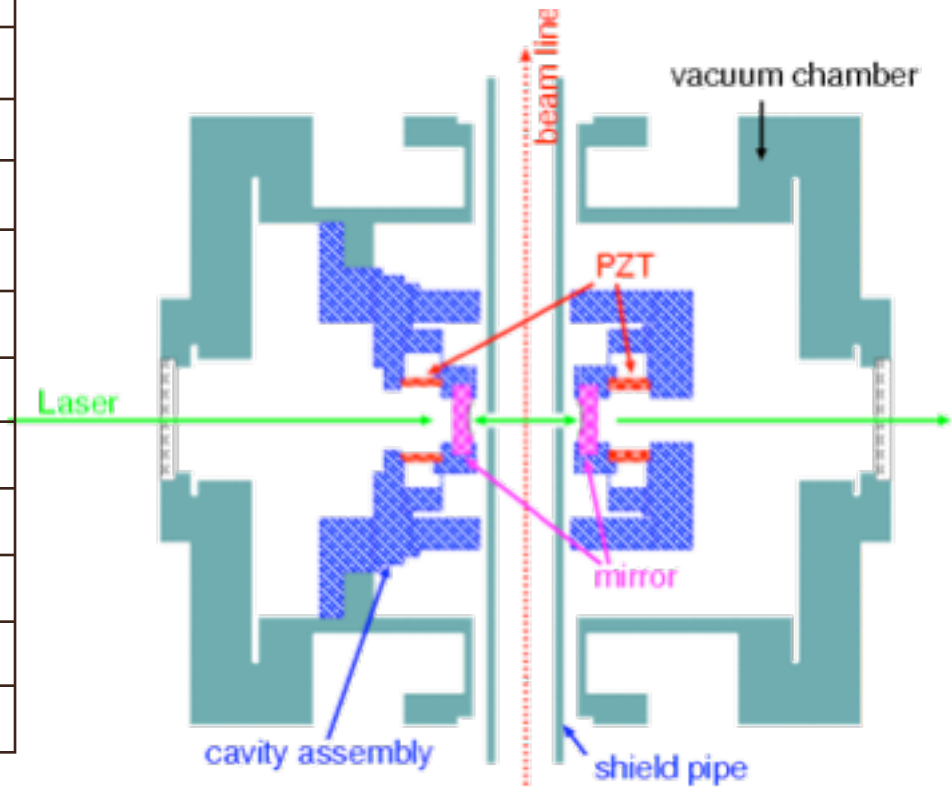


Cavity and the chamber

- Cavity is in the vacuum.
- Position of the cavity mirrors are finely controlled by PZTs.

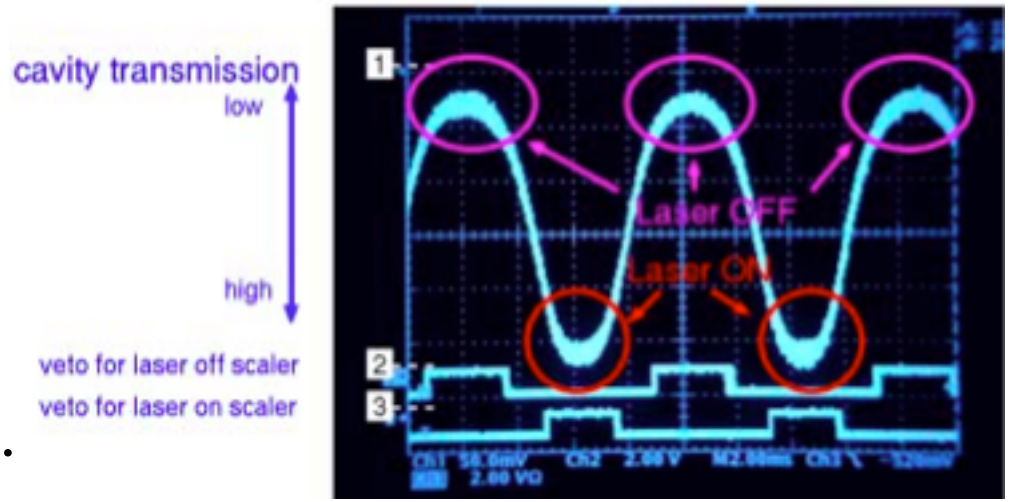


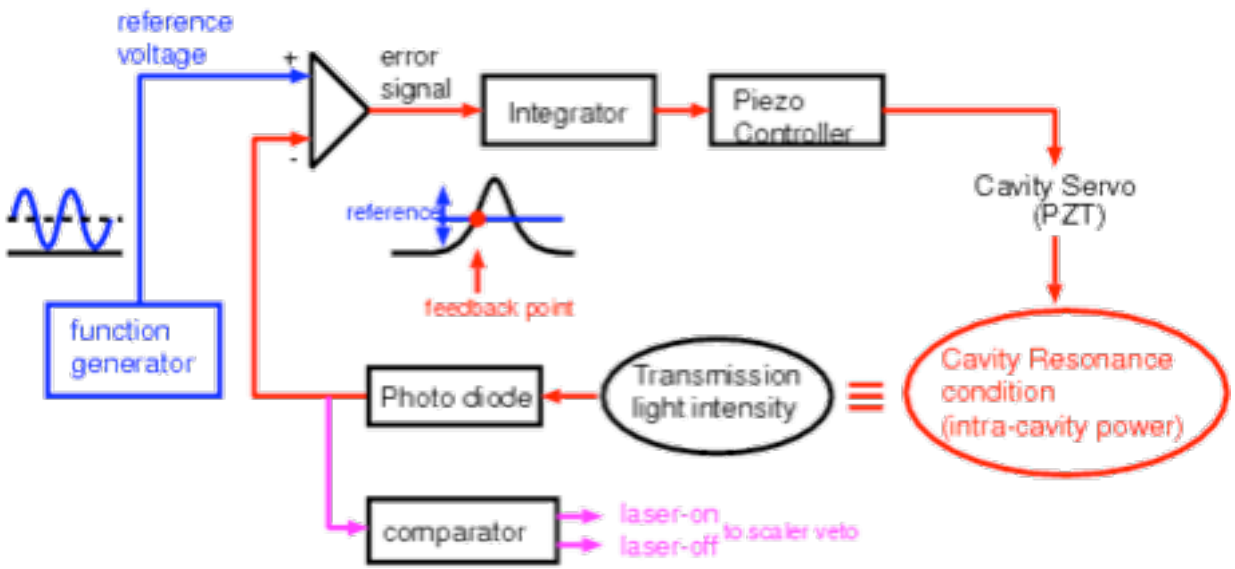
	horizontal-wire	vertical-wire
reflectance (front)	99.1 %	99.8 %
reflectance (rear)	99.9 %	99.9 %
curvature	20 mm	20 mm
finesse	620	1700
enhancement	660	1300
effective power	79 W	156 W
w0	11.3 ±0.16 μm	29.4 ±0.5 μm
Rayleigh length	760 μm	5100 μm
wave length	532 nm	
laser line width	10 kHz (single line)	
laser power	300 mW (cw)	

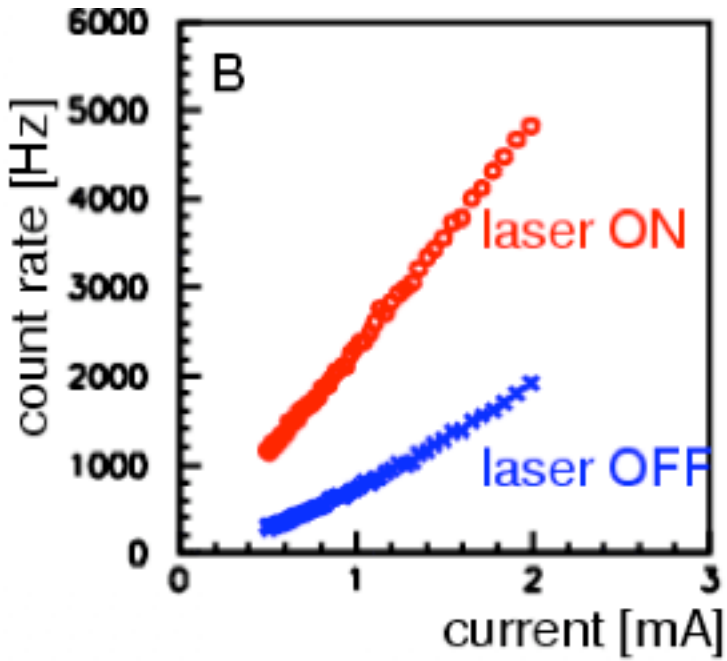


Cavity control

- Sub-nm control is necessary to keep the resonance condition.
- Closed loop system: monitor the cavity transmission, drive the PZT.
- Laser on/off measurement is needed to subtract the background.
  - modulate on the resonance slope.

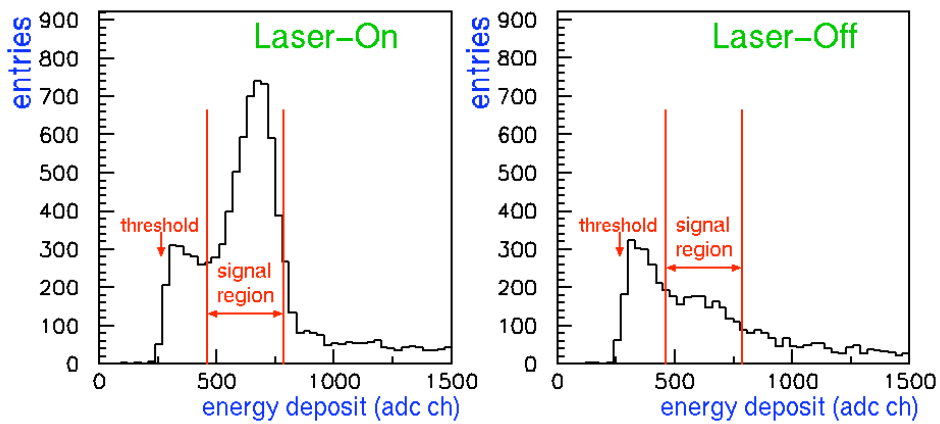


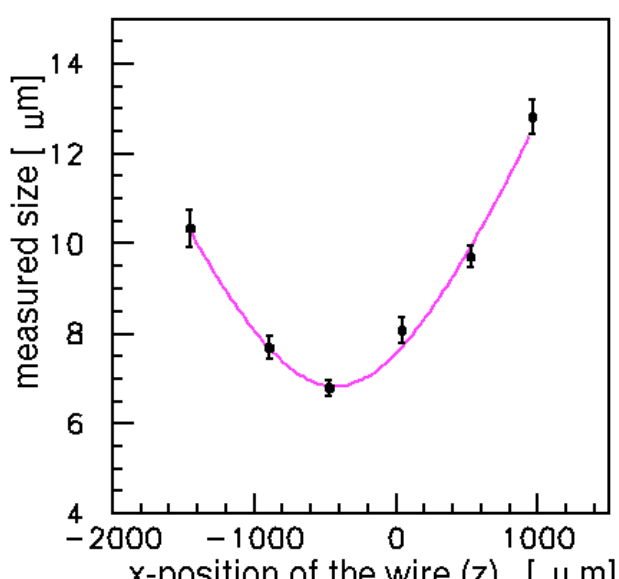


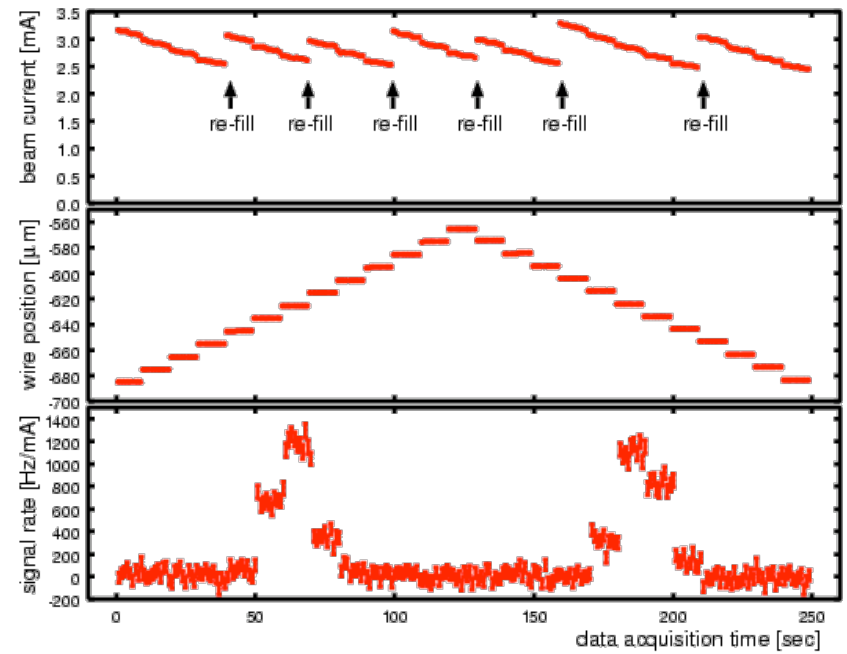


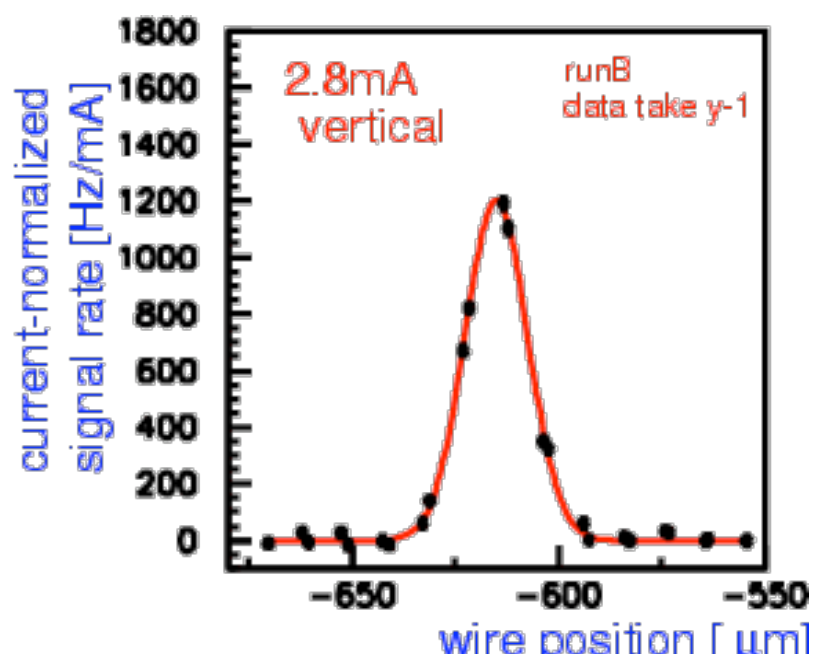
Example of the measurement

- It takes 6 min. to scan.
- Subtracting the contribution of laser's size from the measured size (in quadrature), the beam size is obtained.
  - 7.0 um (measured) - 5.6 um (laser) = 4.2 um



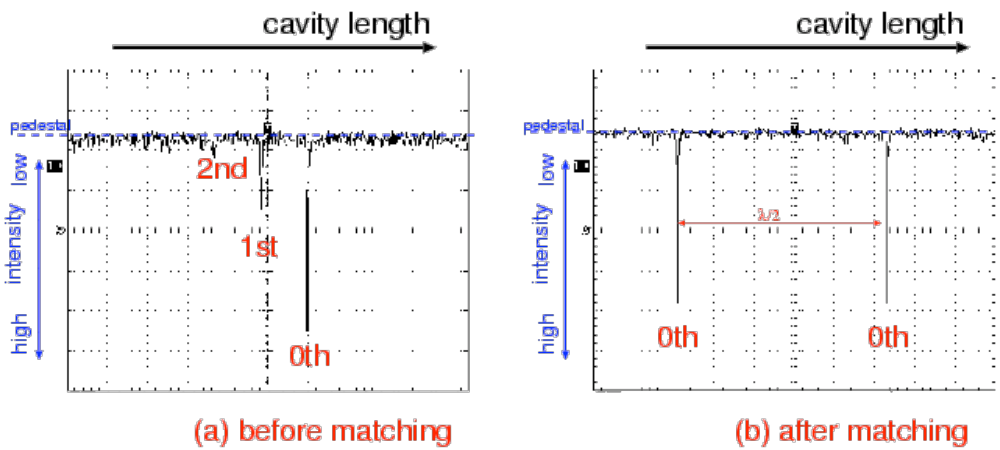


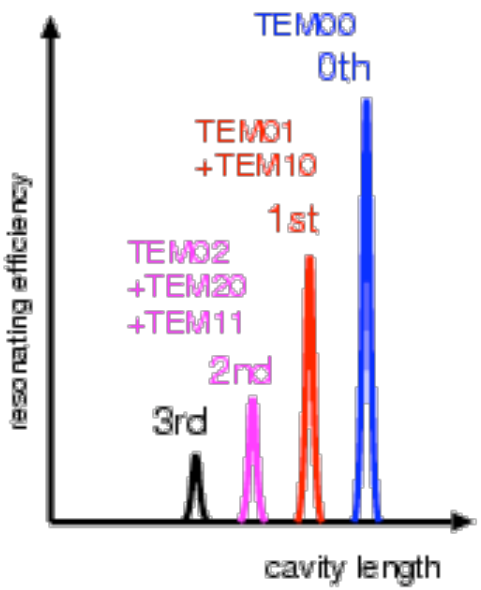


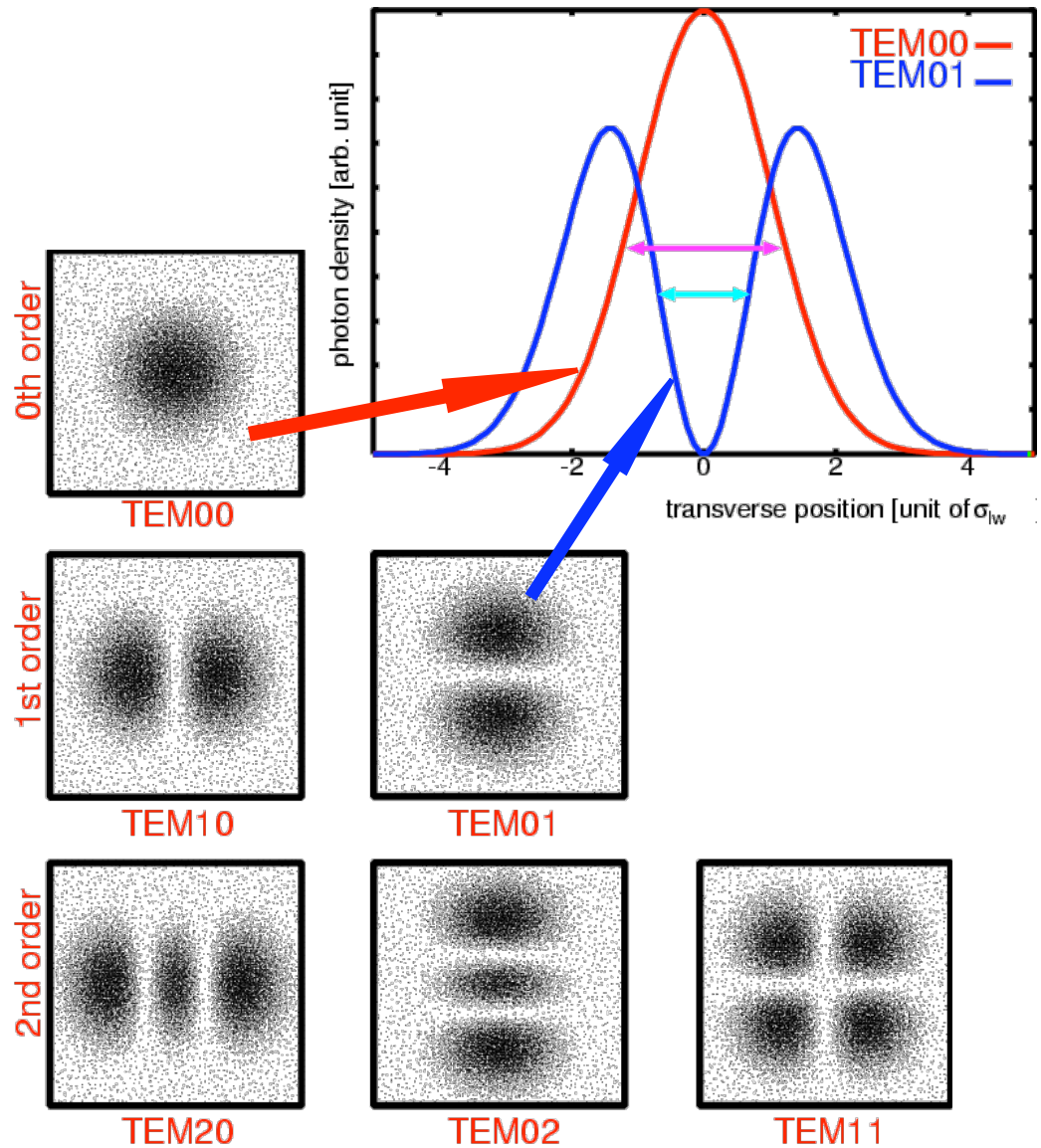


Higher-order modes

- Higher-order transverse mode has smaller structure in the profile.
- How to selectively excite TEM01?

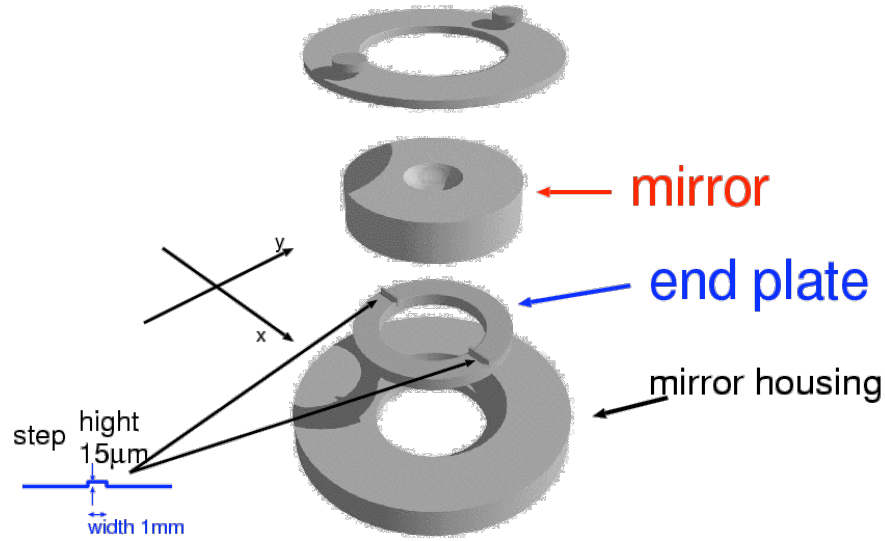


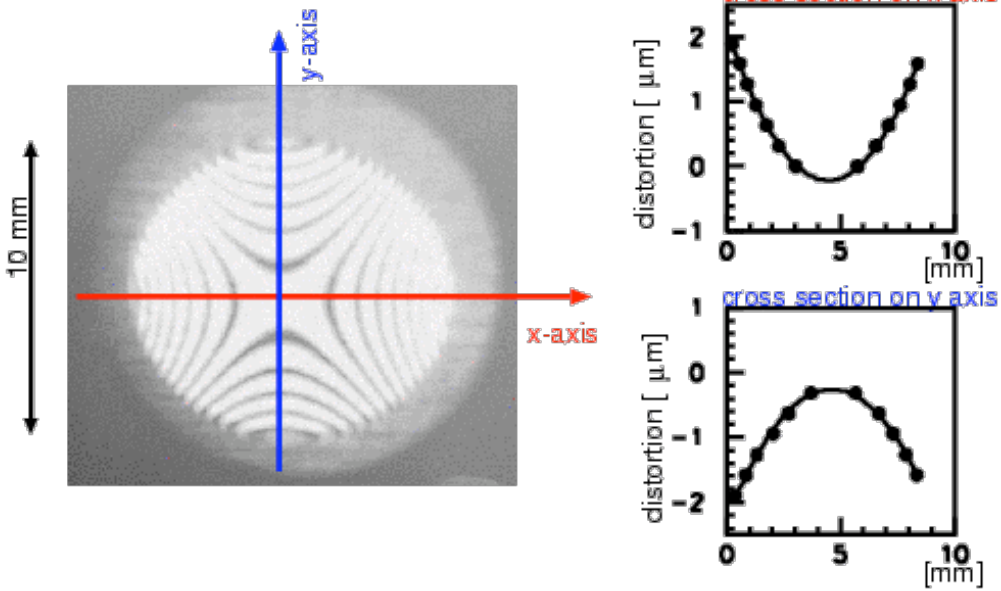


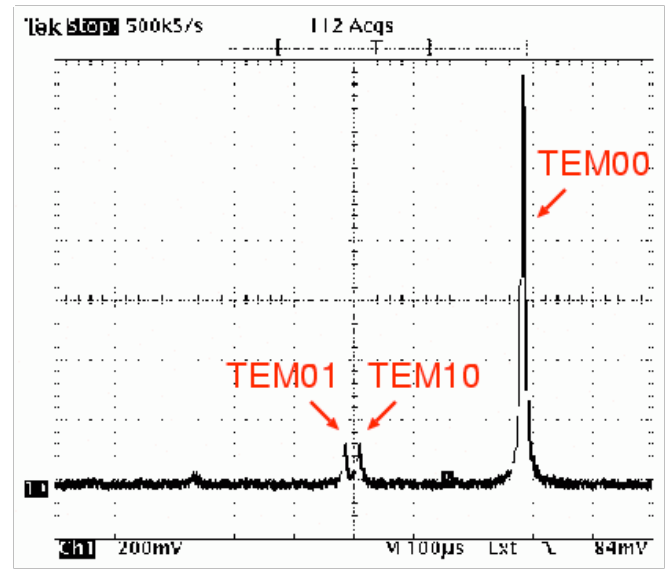


Split the degeneration

- Modification in the mirror holder.
  - steps on the end-plate.
  - mirror is bent like a saddle-shape.
- Succeeding in splitting TEM01 and TEM10.

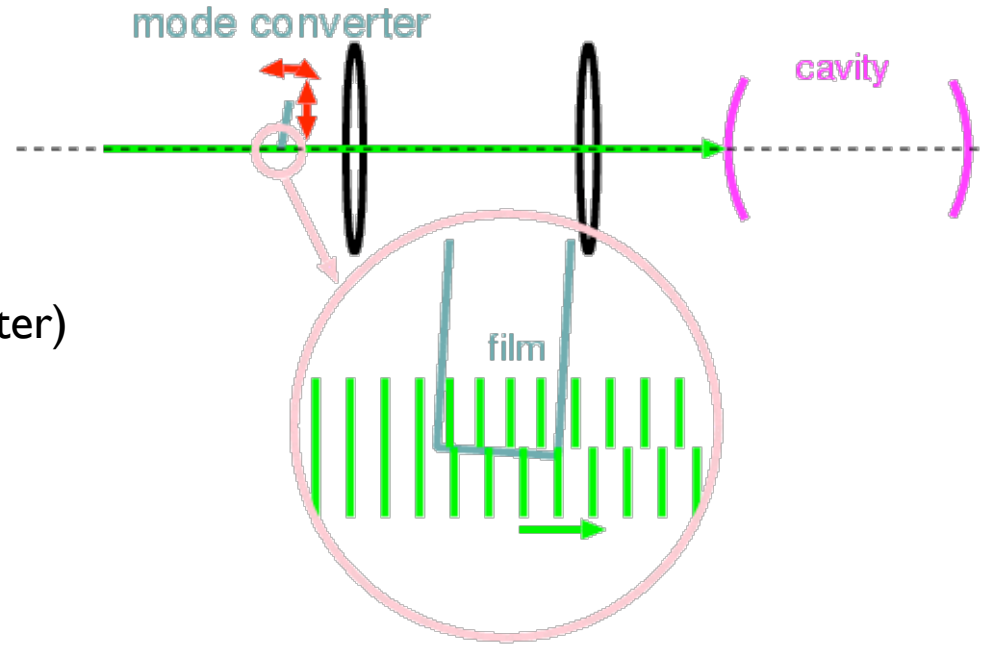




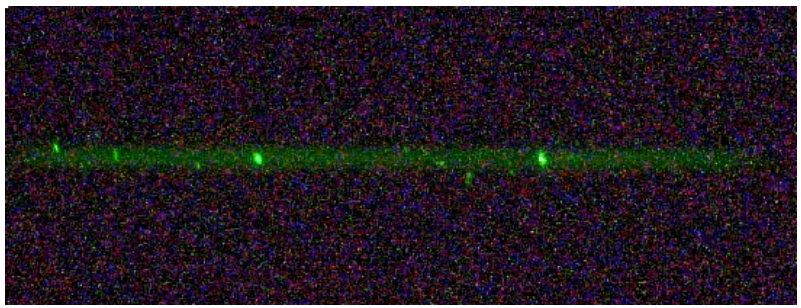


Mode converter

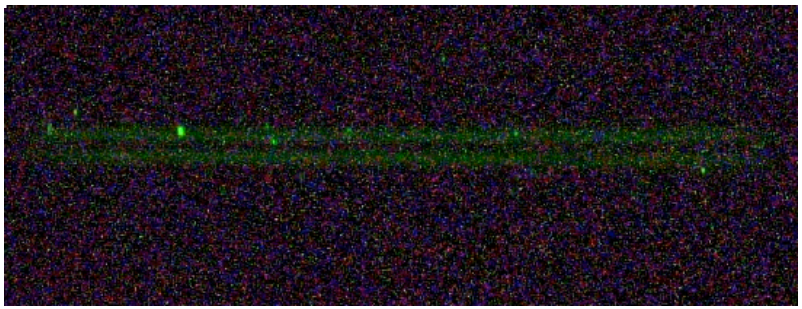
- Laser from the source is TEM00 mode.
- How to couple into TEM01 mode efficiently.
- Thin film inserted half-way in the laser shifts the phase 180 degree.
- Coupling efficiency is 60%, (40% without converter)

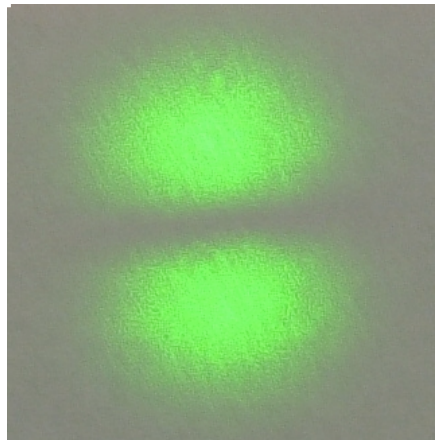


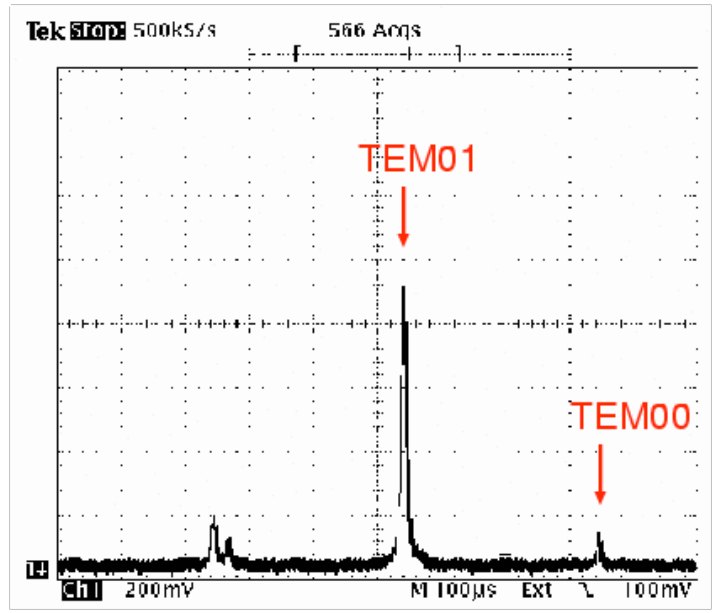
TEM00



TEM01

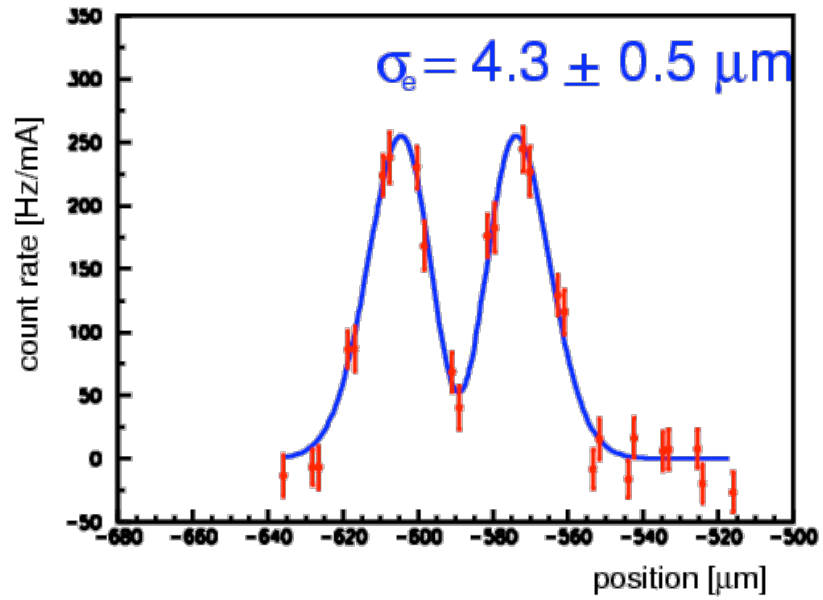


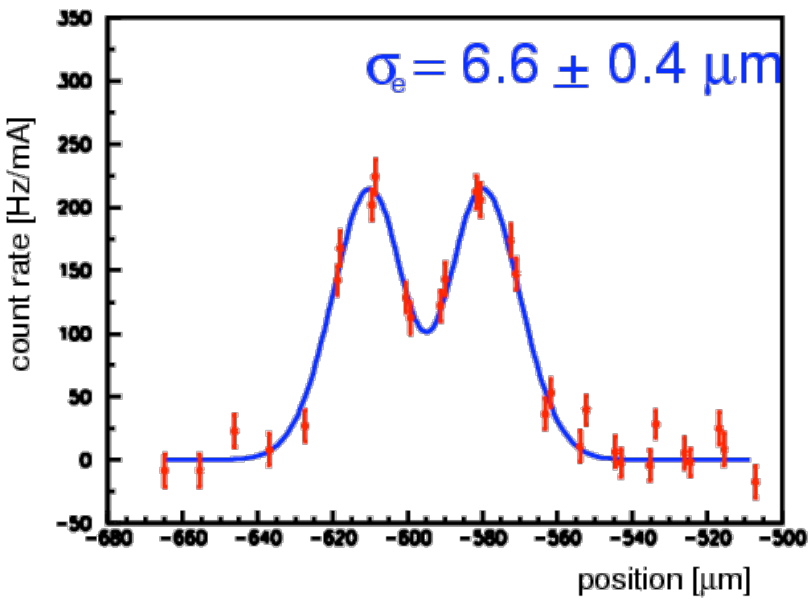


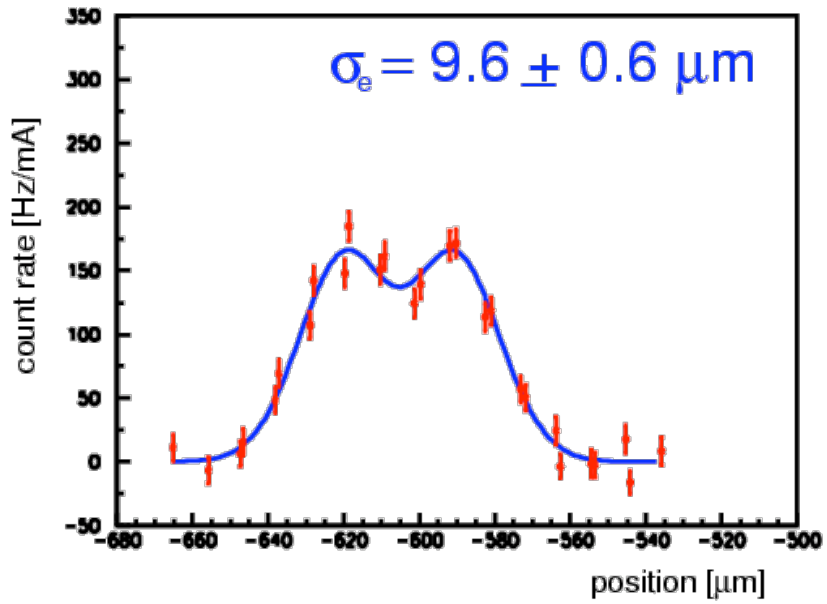


Measurement with a higher-order laserwire

- Test to demonstrate higher-mode measurement.
  - laser size was increased on purpose to be optimized to the typical beam size at ATF.
- Fitting free parameter: laser size, beam size, height, center.
- Laser size is 9.6 um (rms) , cavity was replaced.
- TEM00 mode only
  - 4.2 um was measured with 5.6 um laser.
- TEM01 mode
  - 4.3 um was measured with 9.6 um laser.

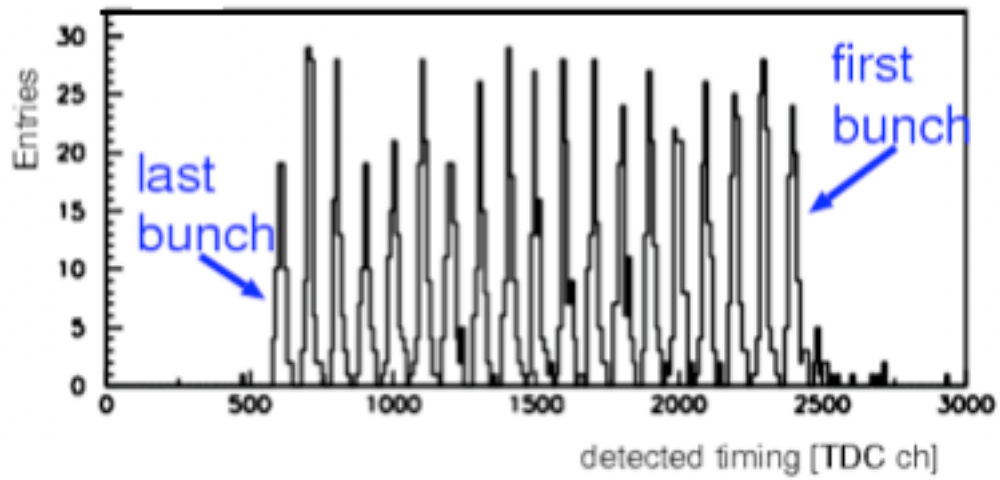




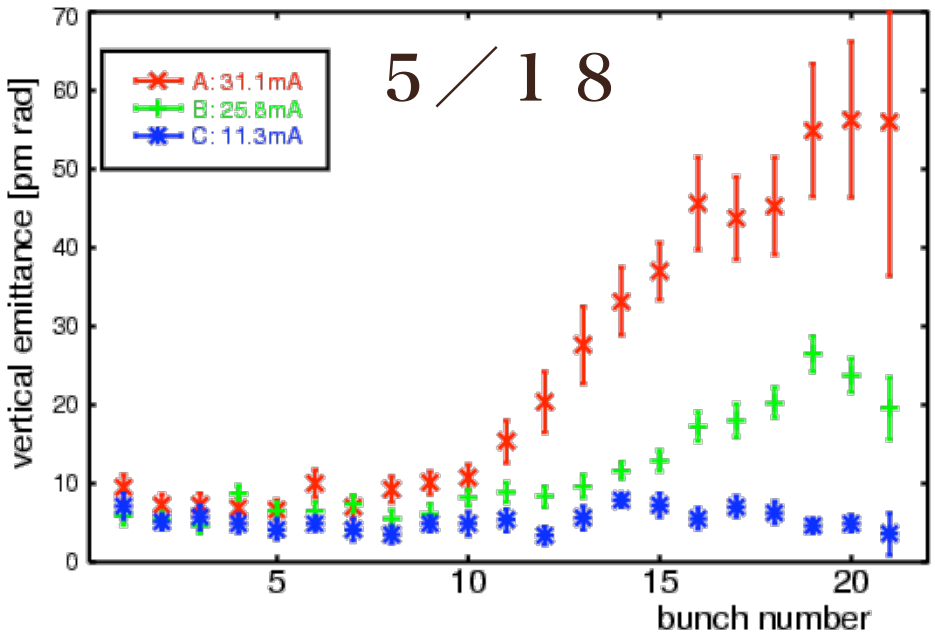


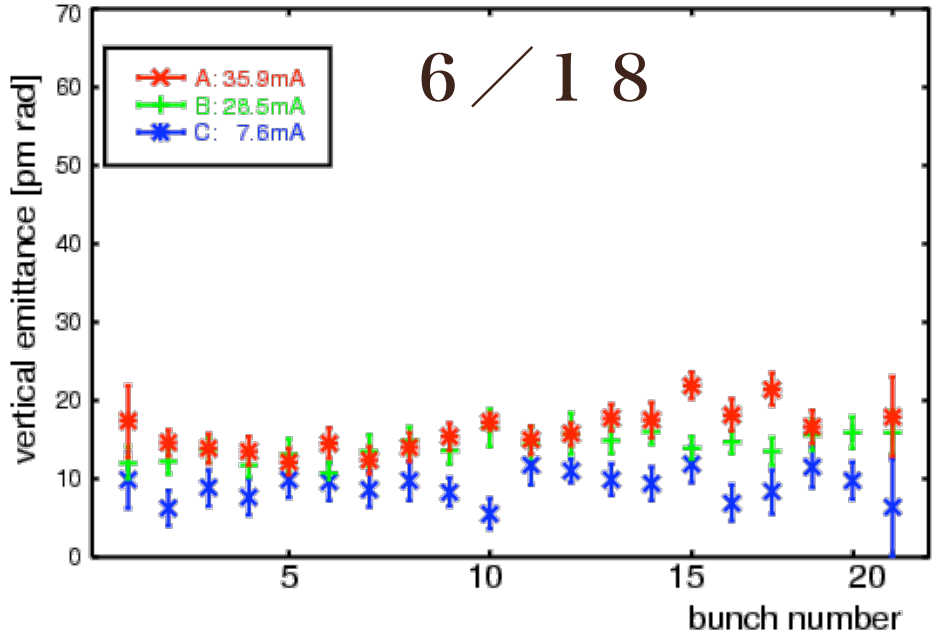
Measurement of a multi-bunch beam

- Detector's time resolution is good enough to identify the bunch number.
- Useful to study beam blow-up in the train.



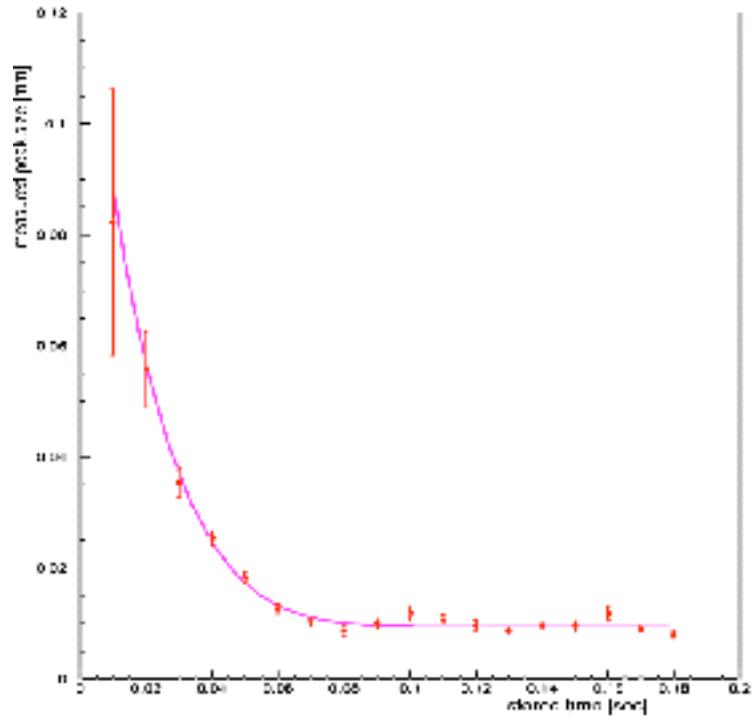
Measurement in 2004

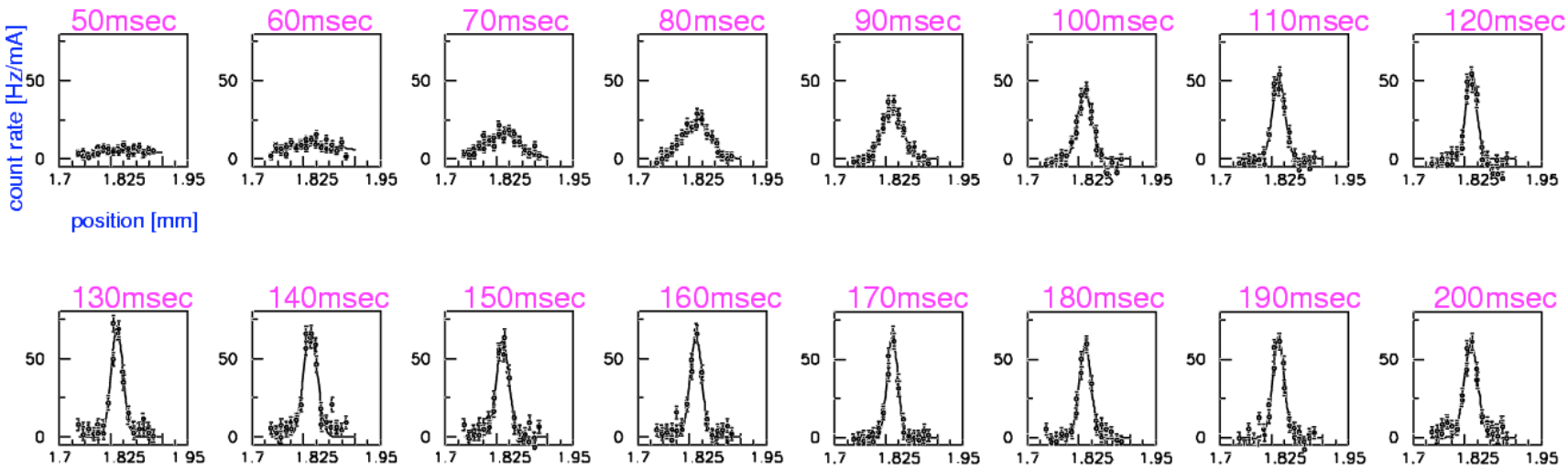




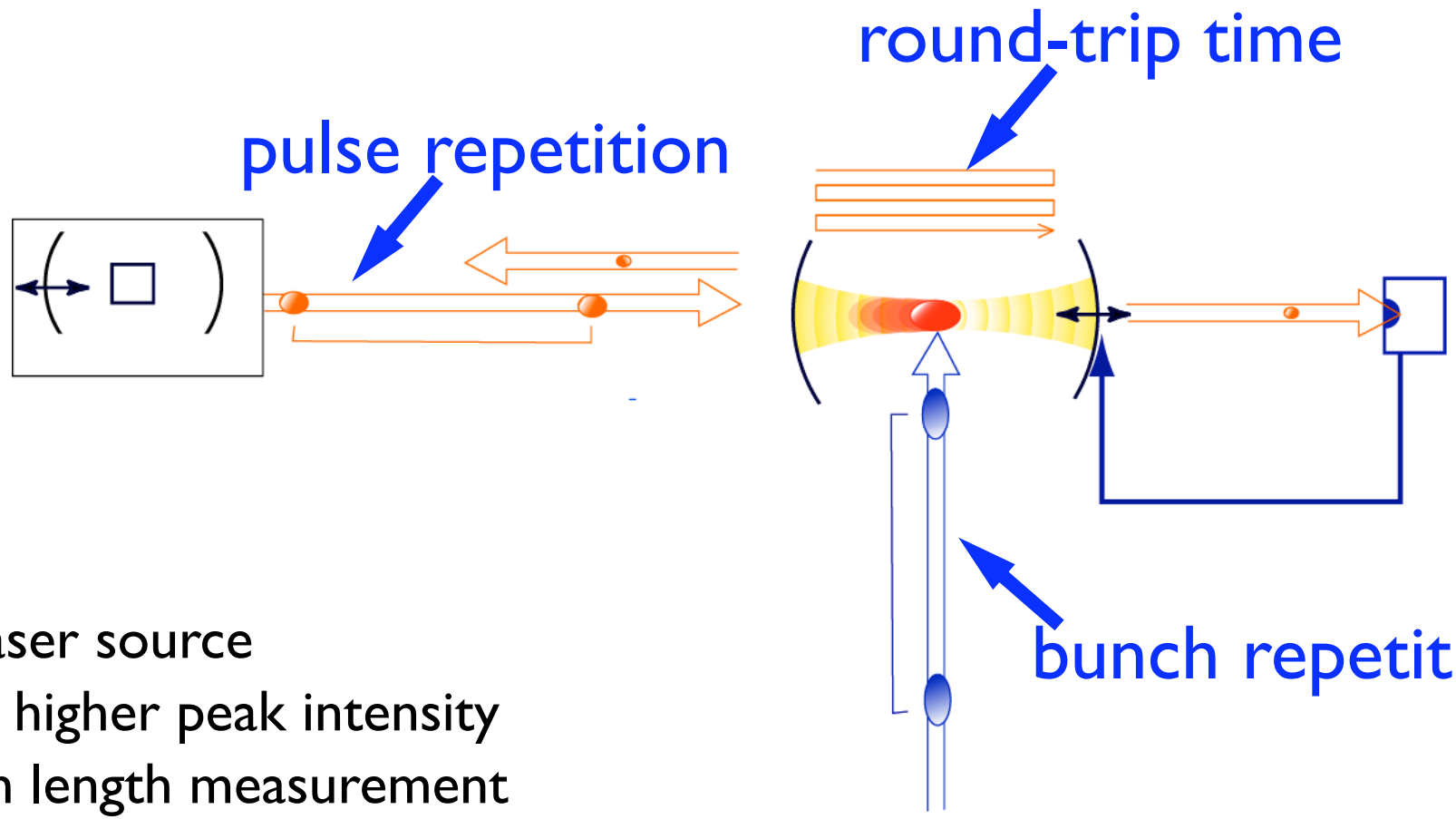
Measurement of the emittance damping

- Repeat beam injection to the DR.
- Separately count up the signal according to the time after the injection.

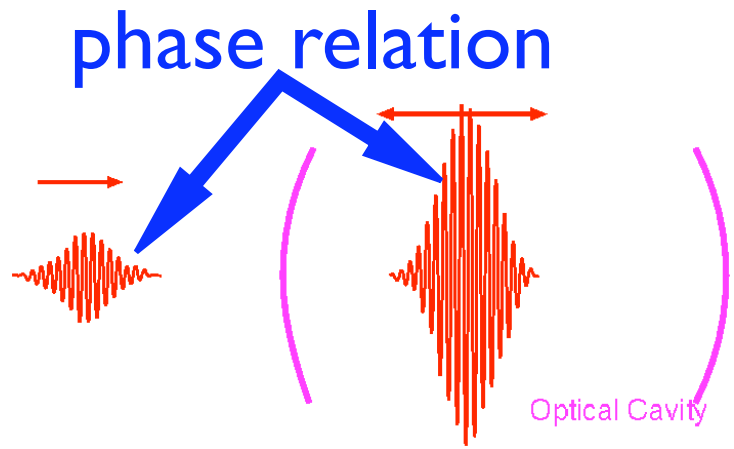




Pulse-stacked laserwire

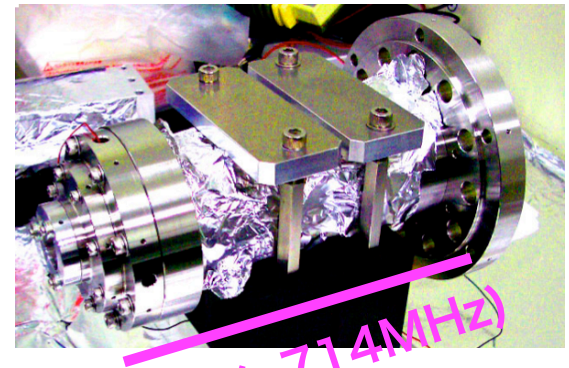


- Pulsed laser source
  - Much higher peak intensity
  - Bunch length measurement
- More complicated control
  - phase relation (keep the resonance)
  - cavity round-trip time
  - pulse repetition
  - synchronization to the beam
  -

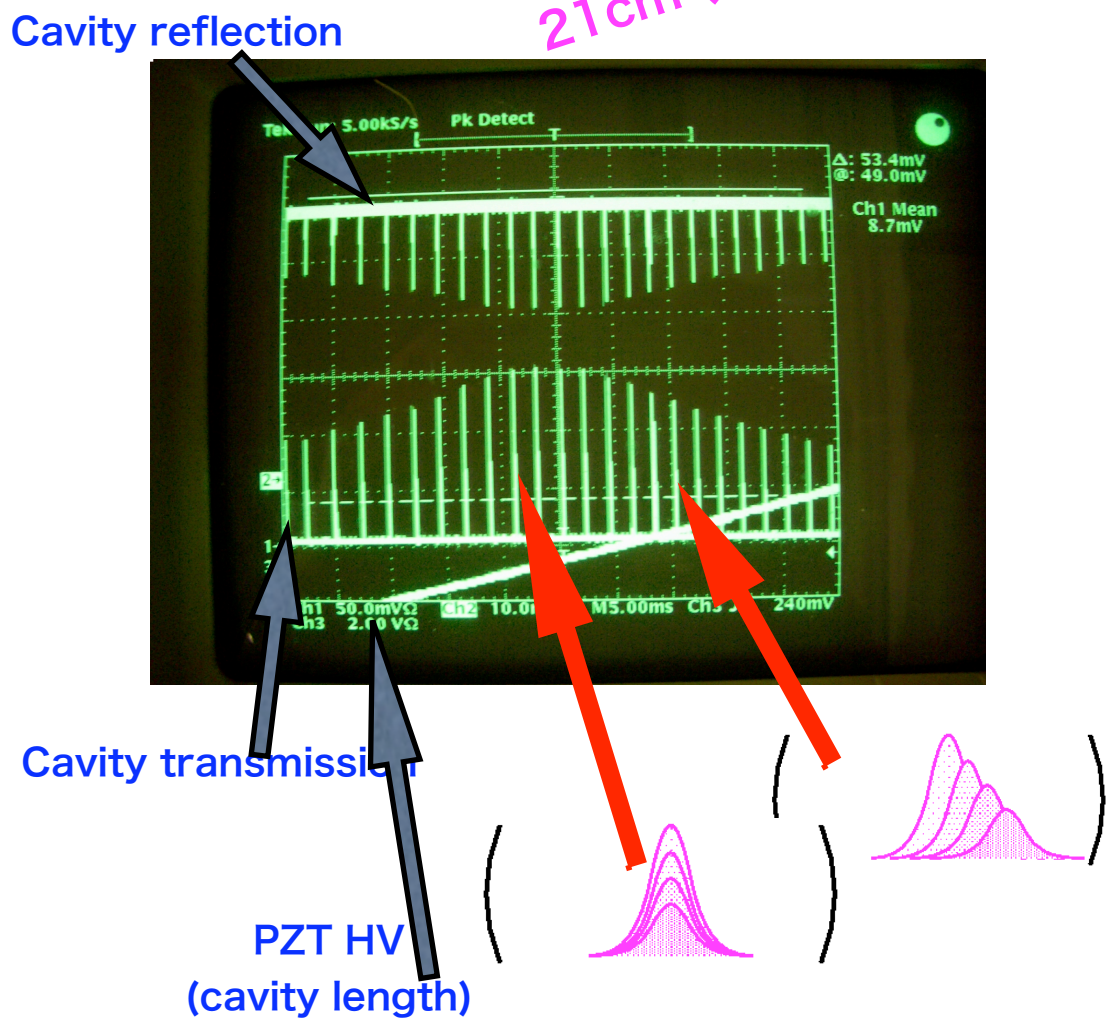


Performance of the optical cavity

- Similar mechanical design as the cw laserwire.
- Two-fold cavity for 357 MHz input
- The cavity length (round-trip time) was finely adjusted.
- Resonance measurement (same way as the cw case)
  - each peak: resonance, overall shape: pulse superposition

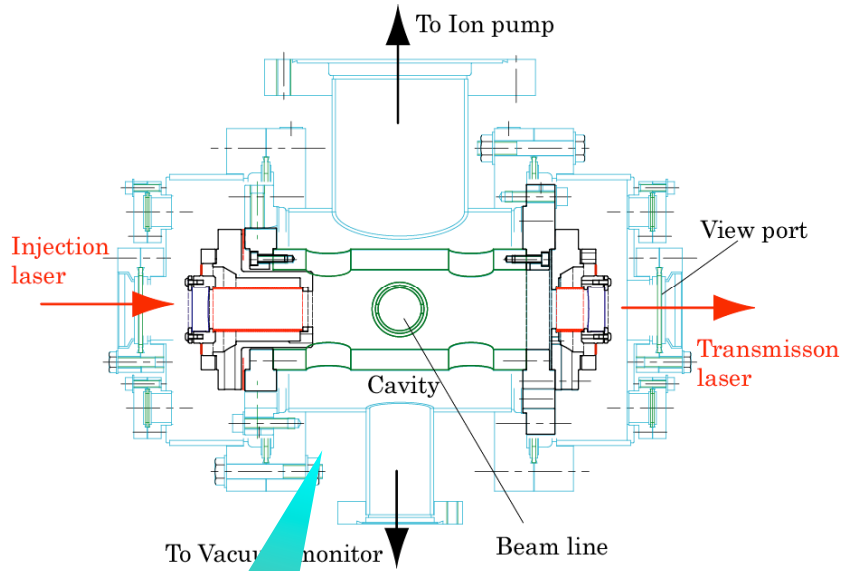


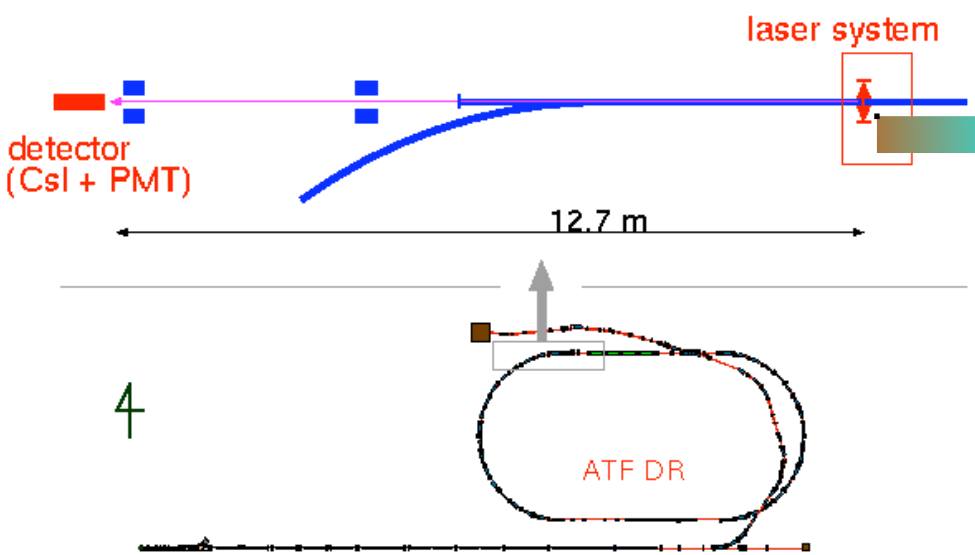
Beam	
repetition	357 MHz (2.8 ns)
bunch length	25 ps (rms)
Laser	
pulse repetition	357 MHz
pulse length	7.3 ps (FWHM)
power	500 mW
wave length	1064 nm
Cavity	
mirror reflectance	99.7 %
mirror curvature	250 mm
cavity length	21 cm
round-trip time	714 MHz
finesse	497
power enhancement	166
w0	250 micron

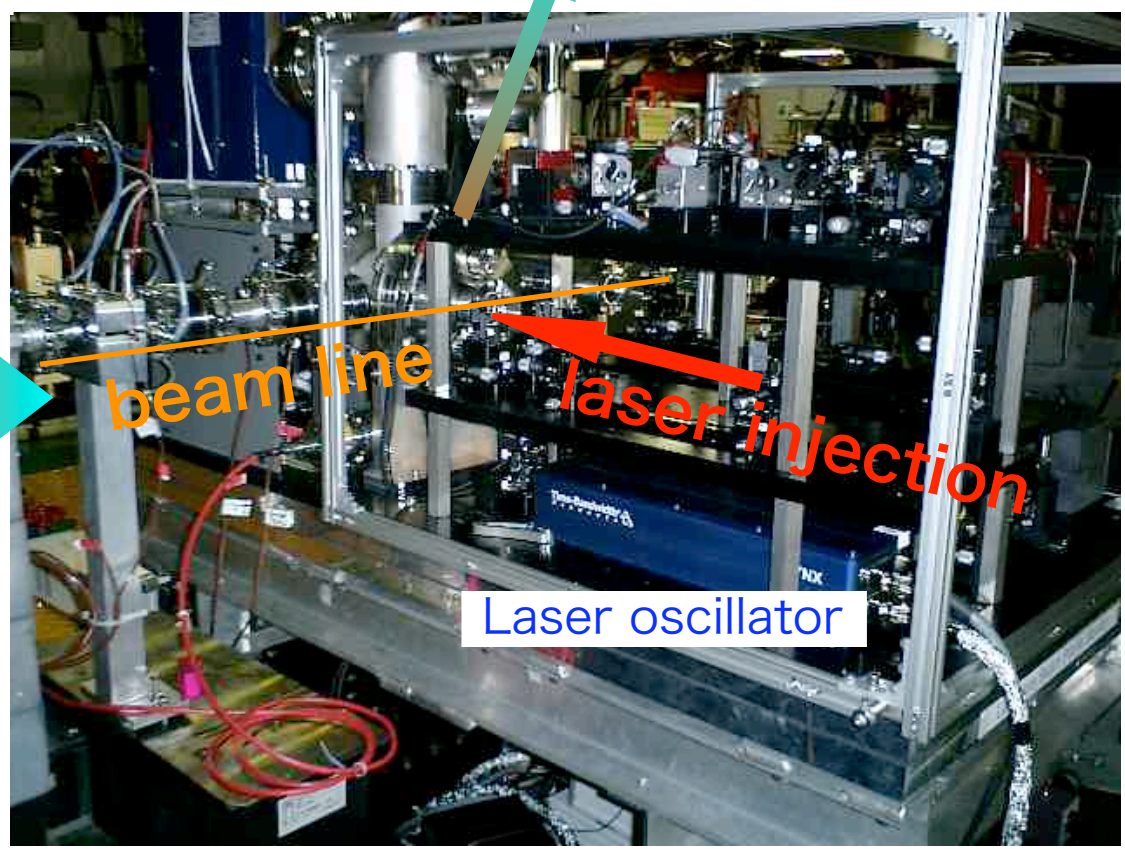


Setup

- One of the Laserwire cavity was replaced with this system.
- Same compton detector.
  - Signal energy is 14 MeV (max.)

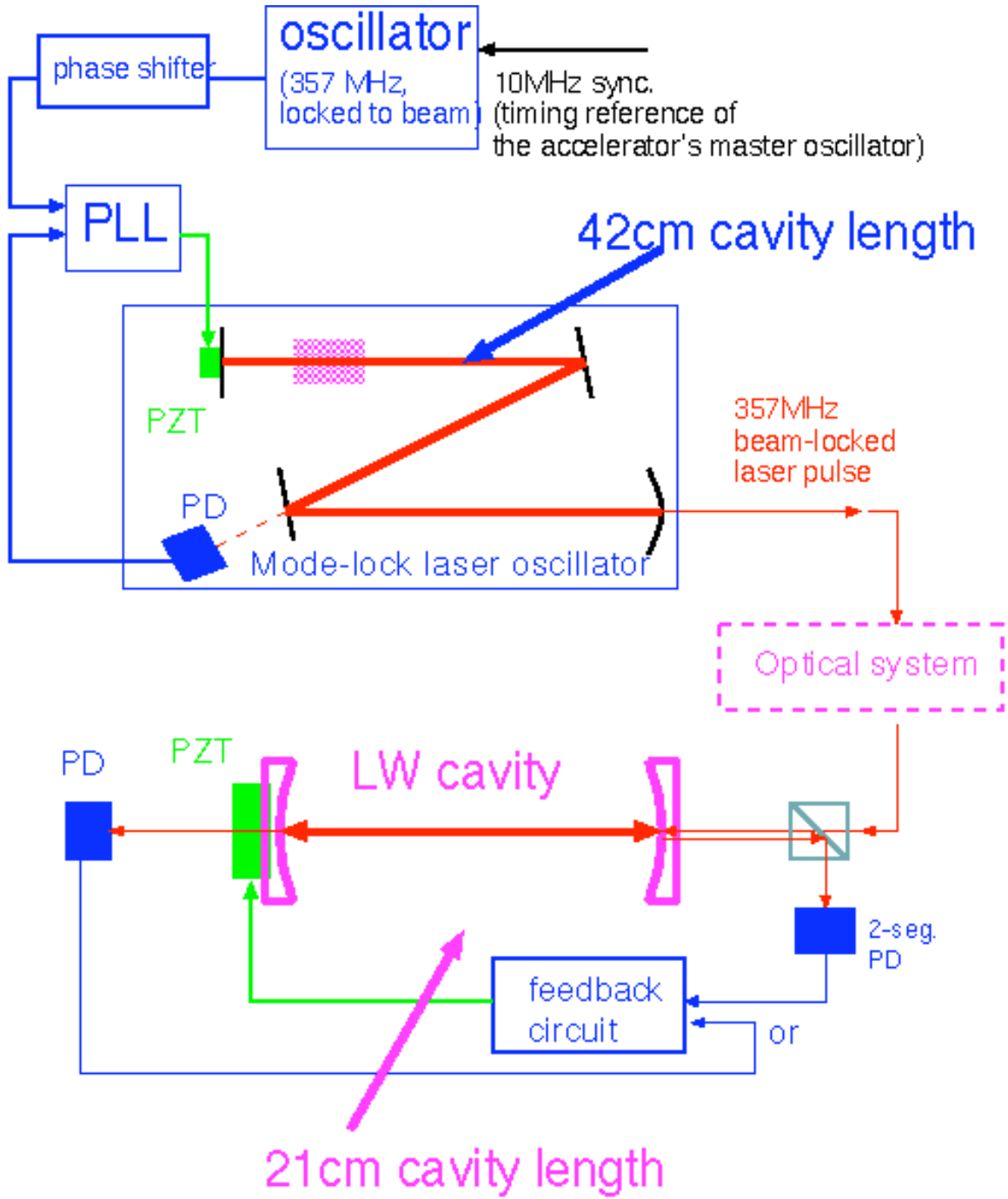






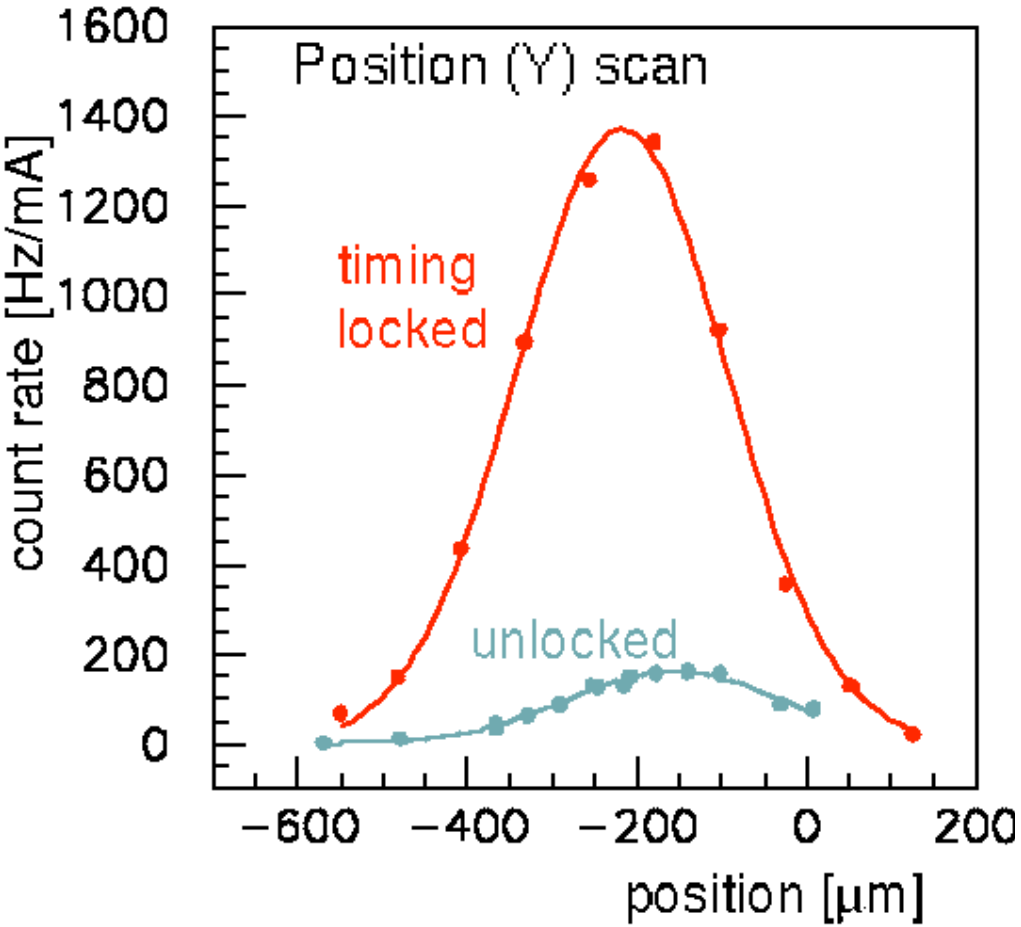
Timing system

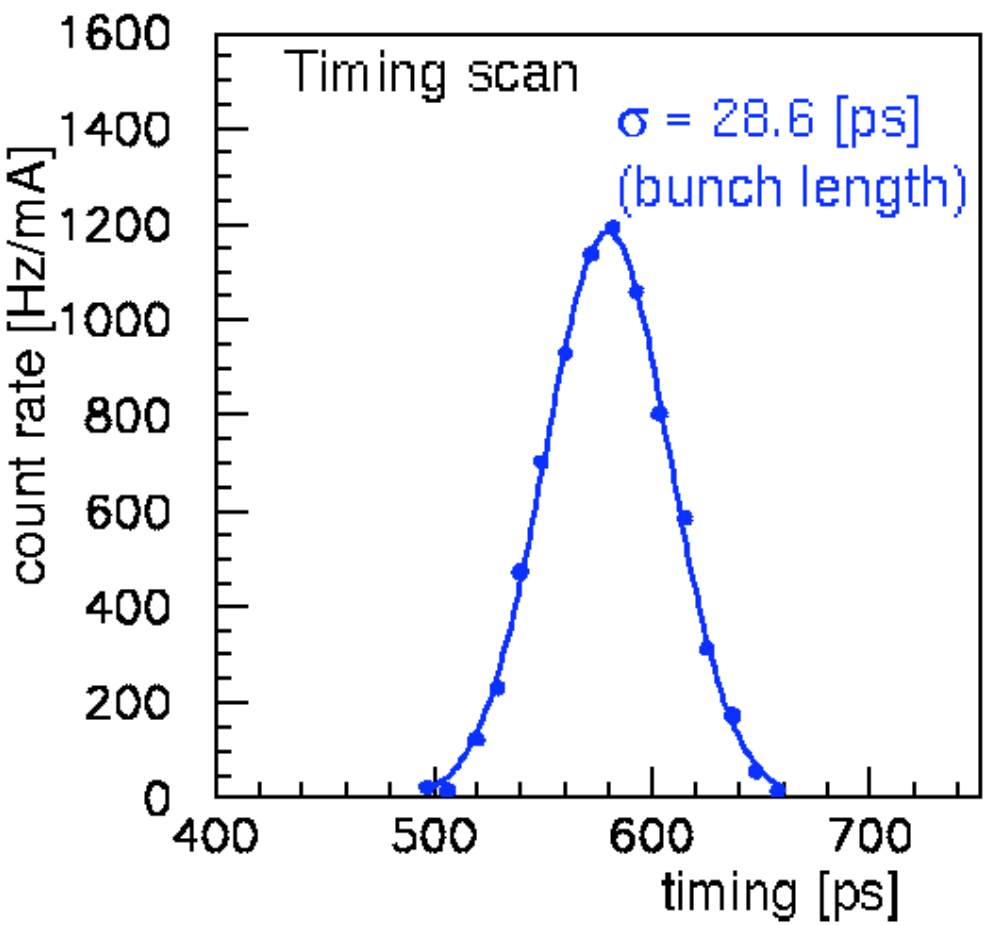
- Laser timing (repetition) is locked to ATF beam.
- LW cavity is controlled to keep the resonance, then the laser pulse inside the cavity is automatically synchronized to the beam.



Preliminary result

- Position scan
  - unlocked to the beam (random timing), and then locked.
  - beam size of laser is 120 um, which dominates the measured profile.
- Timing (phase) scan
  - pulse length of laser is 7 ps. It is useful to measure bunch length.





Summary

- Laserwire monitor
  - has been used to measure small beam size in the ATF damping ring.
  - can measure smaller beam size using the higher mode.
  - has been used to study multi-bunch beam dynamics.
- Pulsed cavity
  - has been tested.
  - can measure bunch length.
  - has a possibility to produce higher flux.