Beam quality and stability improvements for a single-cell photo-cathode RF gun

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Characteristics of Spring-8 RFgun

1. Laser

   THG of Ti:Sa Laser (266 nm, 10Hz, 200 μJ/pulse@nominal)

   Spatial profile ----> Spatial filter & Homogenizer

   Temporal distribution ----> Stretched with a SiO_2 glass rods

   Energy stability ----> 2% with Homogenizer & Pinhole

2 RF cavity

   S-band (2856MHz), Single-cell pill-box type cavity

   Cu cathode

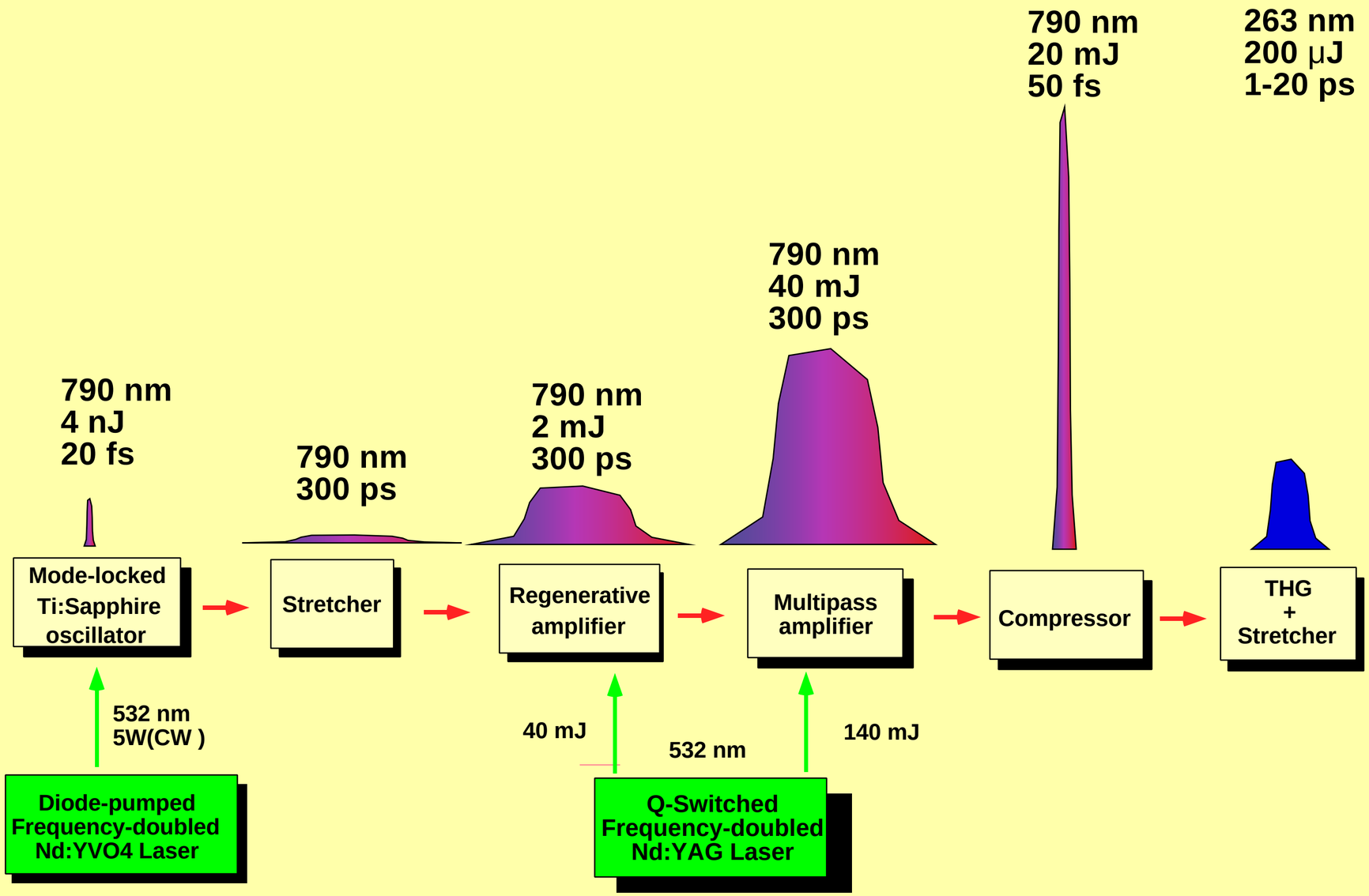
   High electric field ----> 175 MV/m (@4.1 MeV)

3 Synchronization between Laser & RF

   RF generation from laser pulses(89.25 MHz±0.08Hz)

   RMS jitter = 1.7 ps

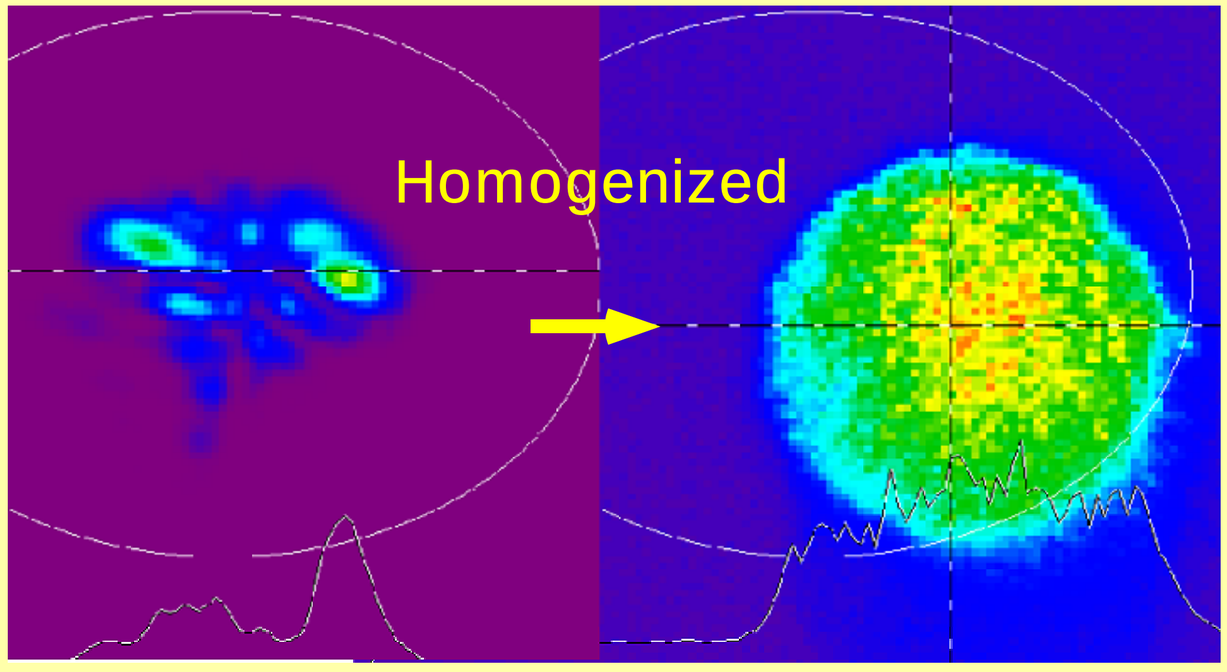
Configuration of Laser System



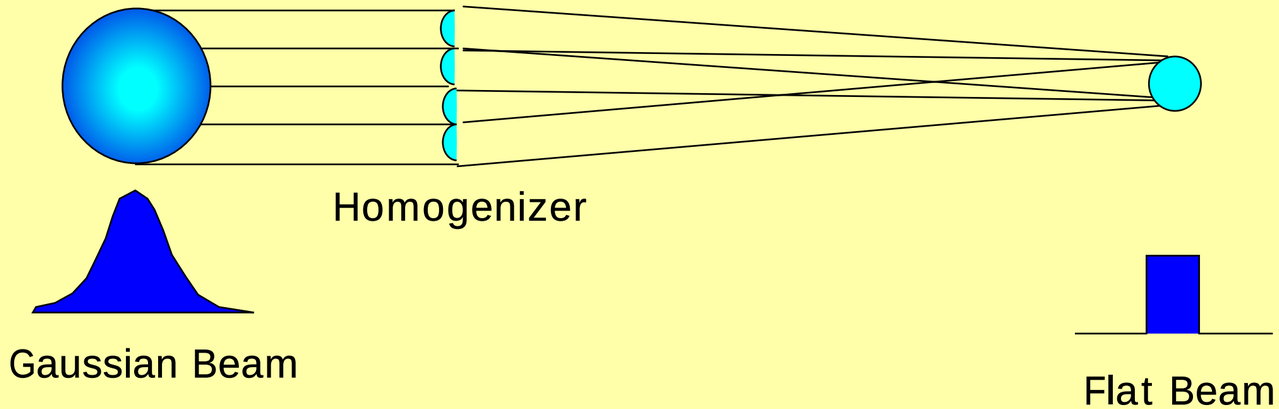
Improvement of Laser System

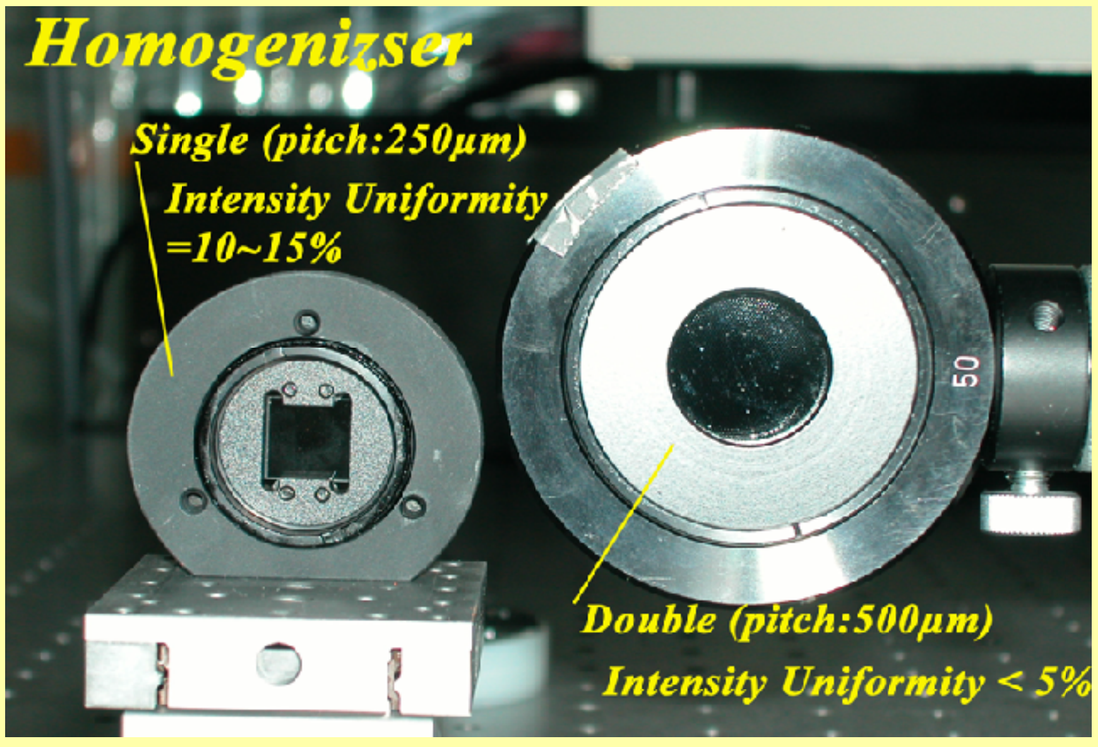
1. Environments
   - Improved cooling system of oscillator--> long-time operation
   - Decreased Air flow ----> Low-energy fluctuation of regen amp

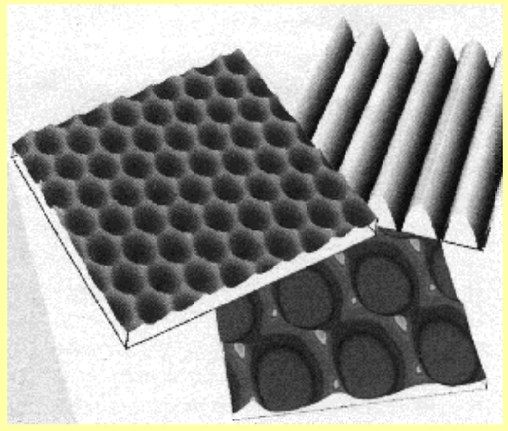
2 Laser Profile Improvements
   - Alignment of multi-path amplifier
   - Apply a microlens arrays as a spatial homogenizer



Homogenizer (microlens array)

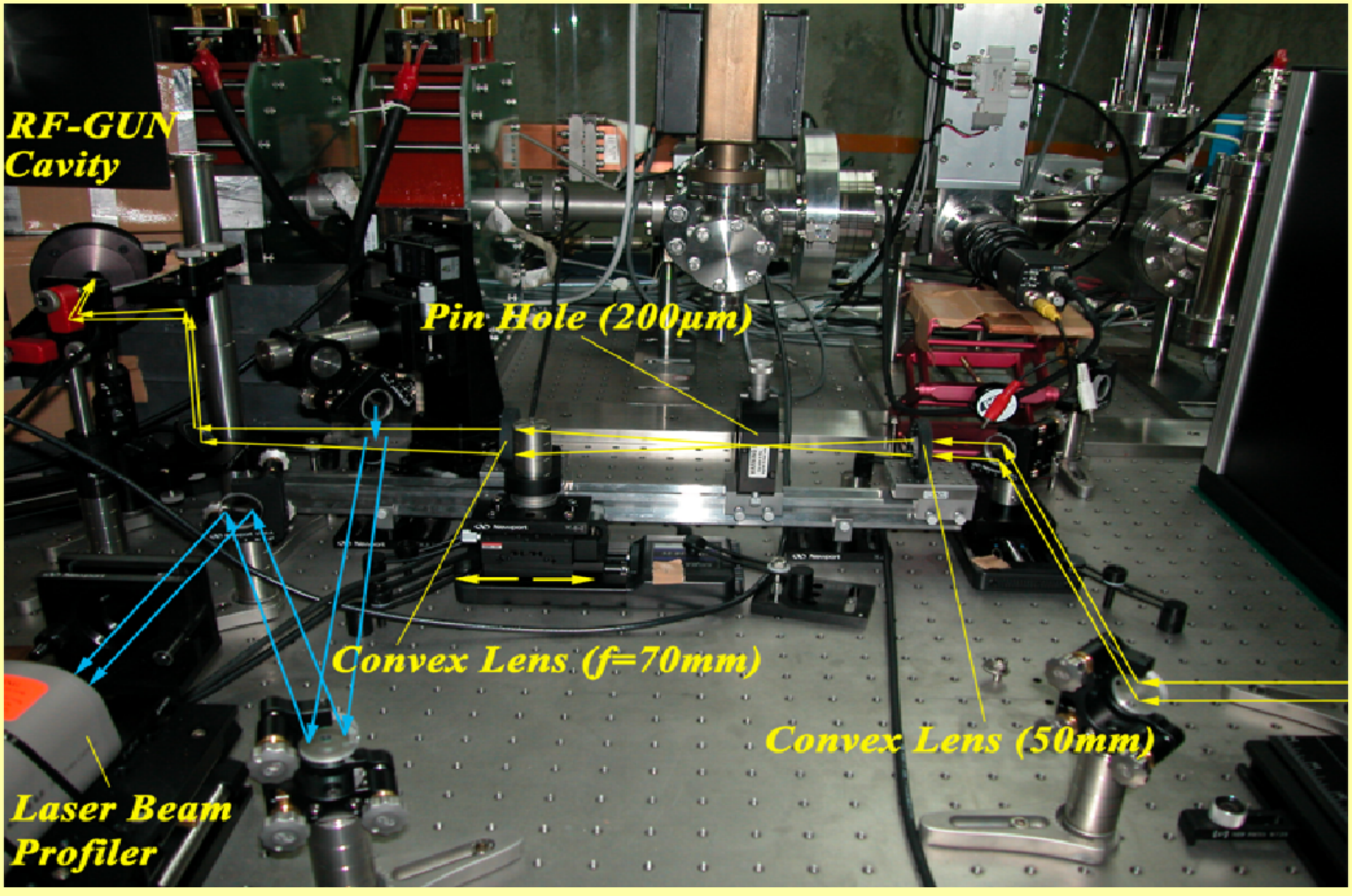






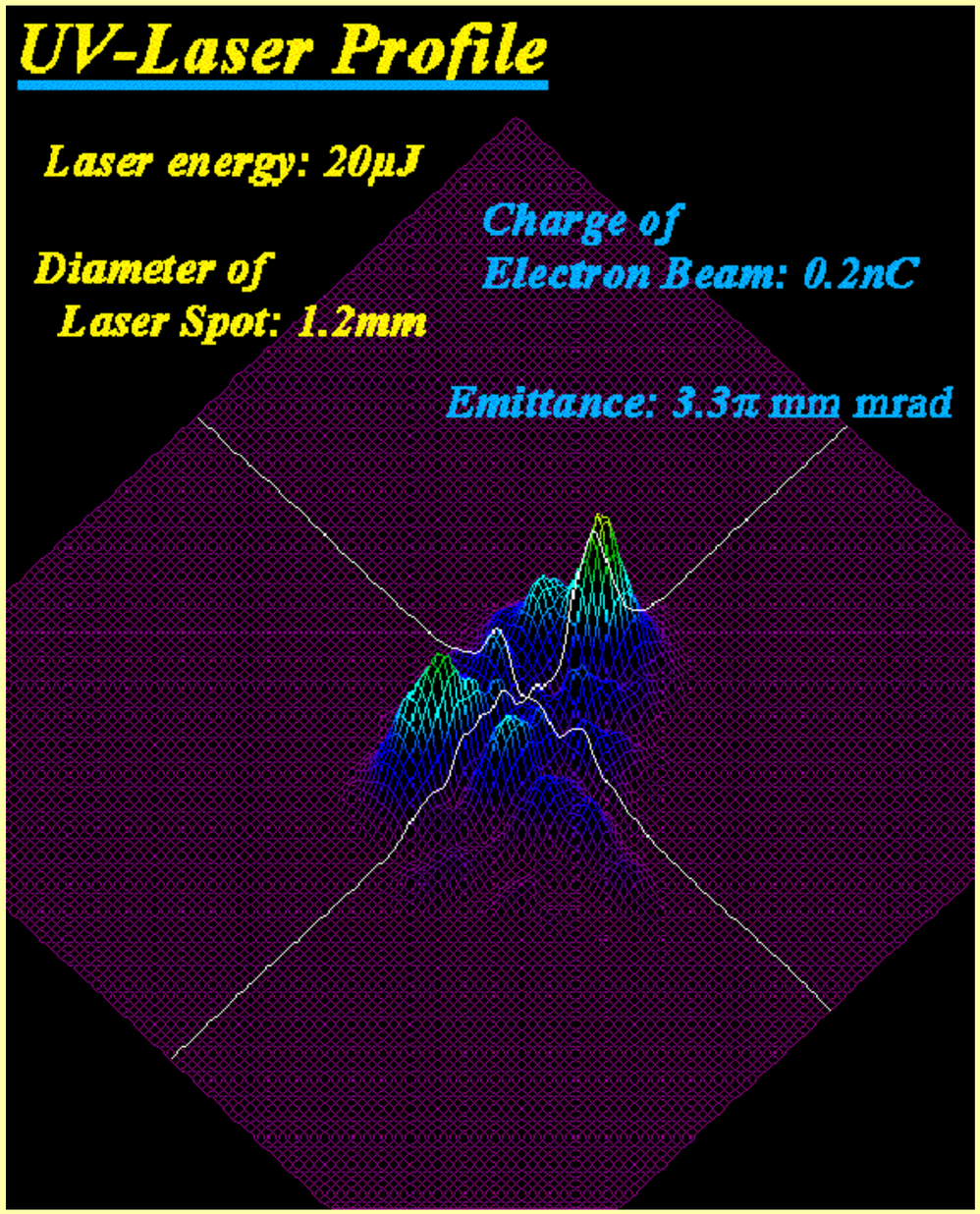
micro structure of Homogenizer

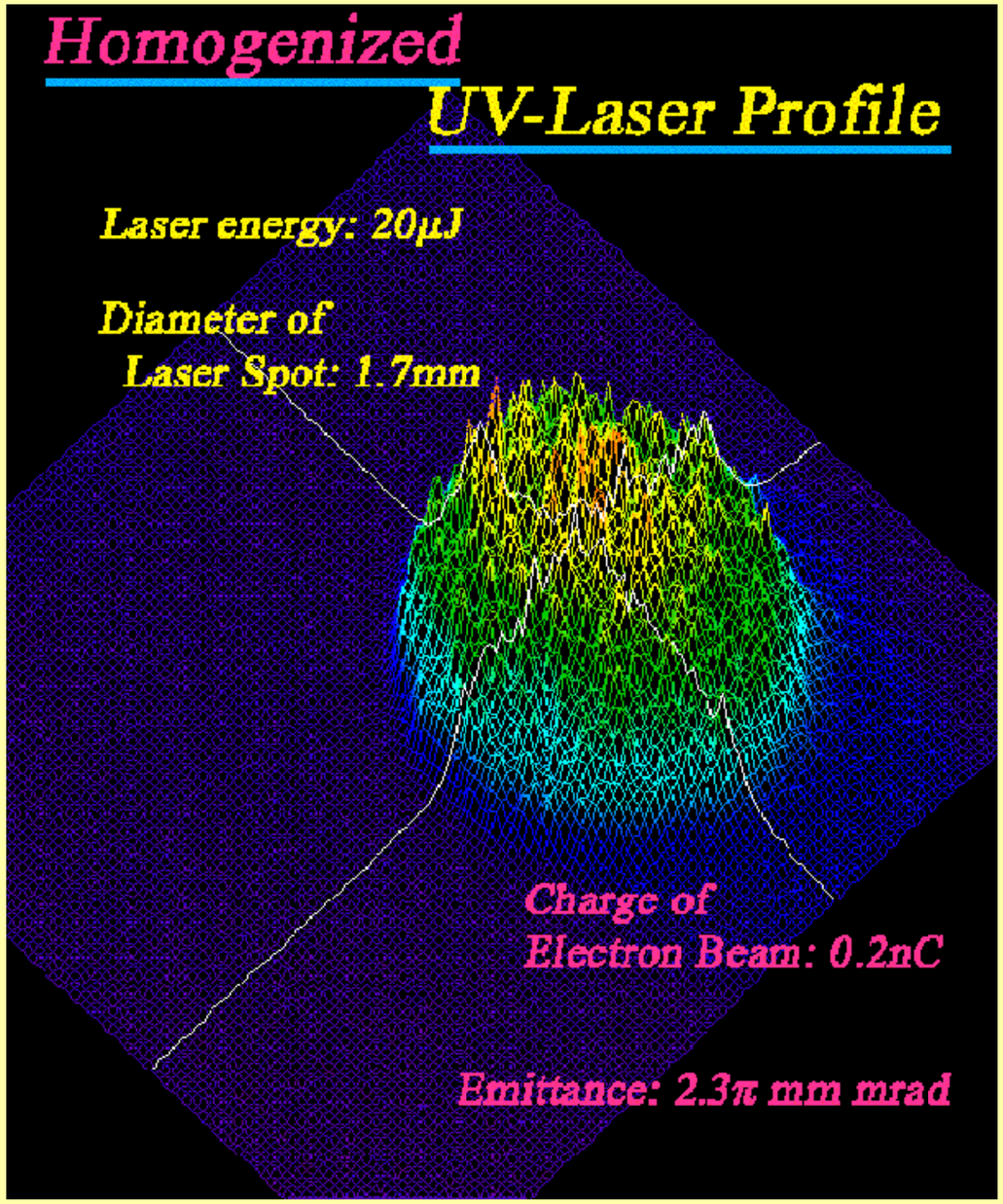
UV Laser Transport and Diagnostics (before Homogenizer installed)



Installation of Homogenizer

Improvements of Laser Profile & Beam Emittance





Synchronization System

Laser Oscillator
89.25 MHz

Laser Pulses

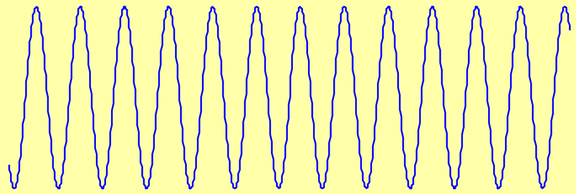
To Amplifier

Slow(~8Hz)
Feedback

fast
photo-diode

Piezo Driver

89.25 MHz
Bandpass filter



RF 89.25MHz

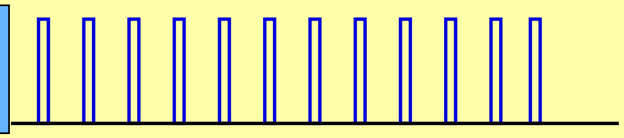
GPIB

PC

GPIB

Frequency Counter

Pulse Generator



89.25 MHz
Pulse width 175ps

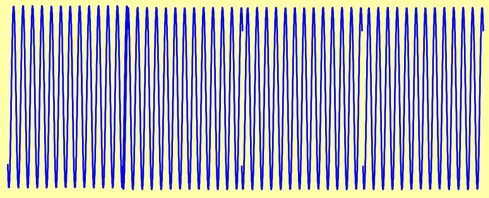
GUN

KLYSTRON

RF
MODULATION
AMP

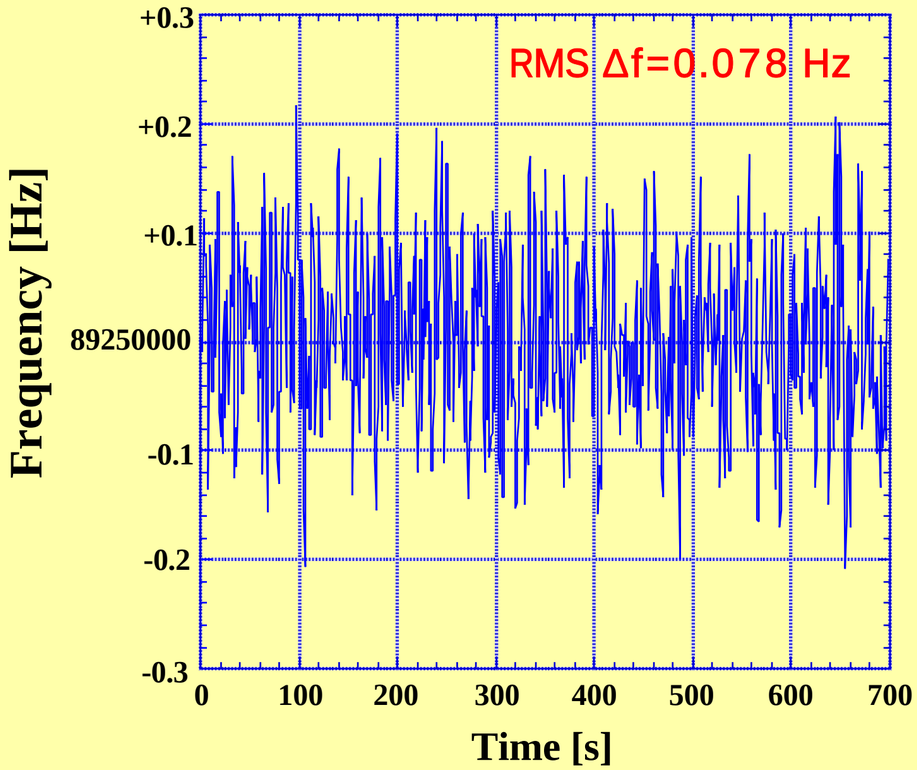
Phase
Shifter

2856 MHz
Bandpass filter

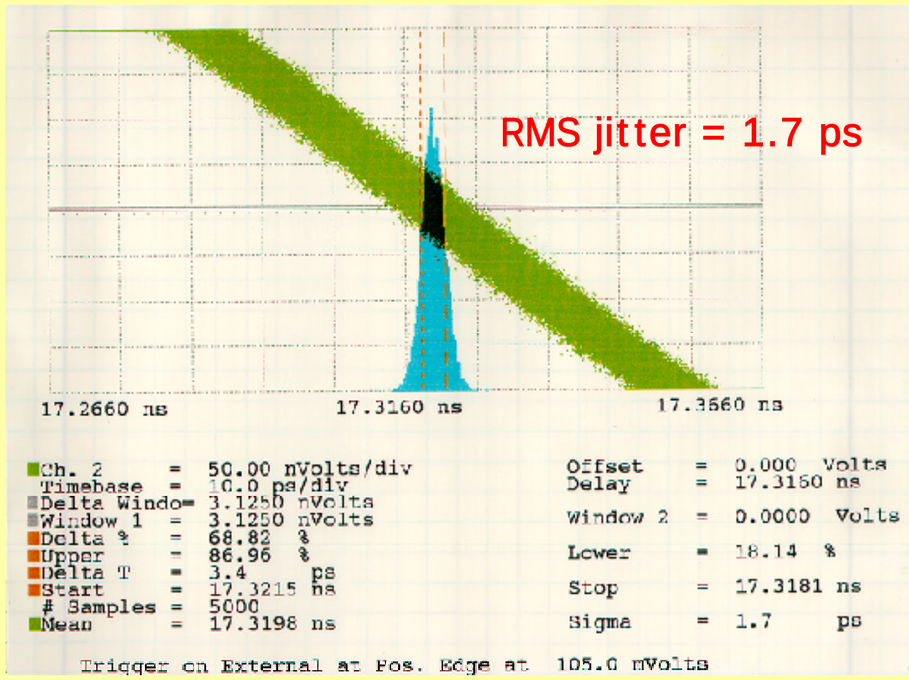


RF 2856MHz

Measurement of Synchronization

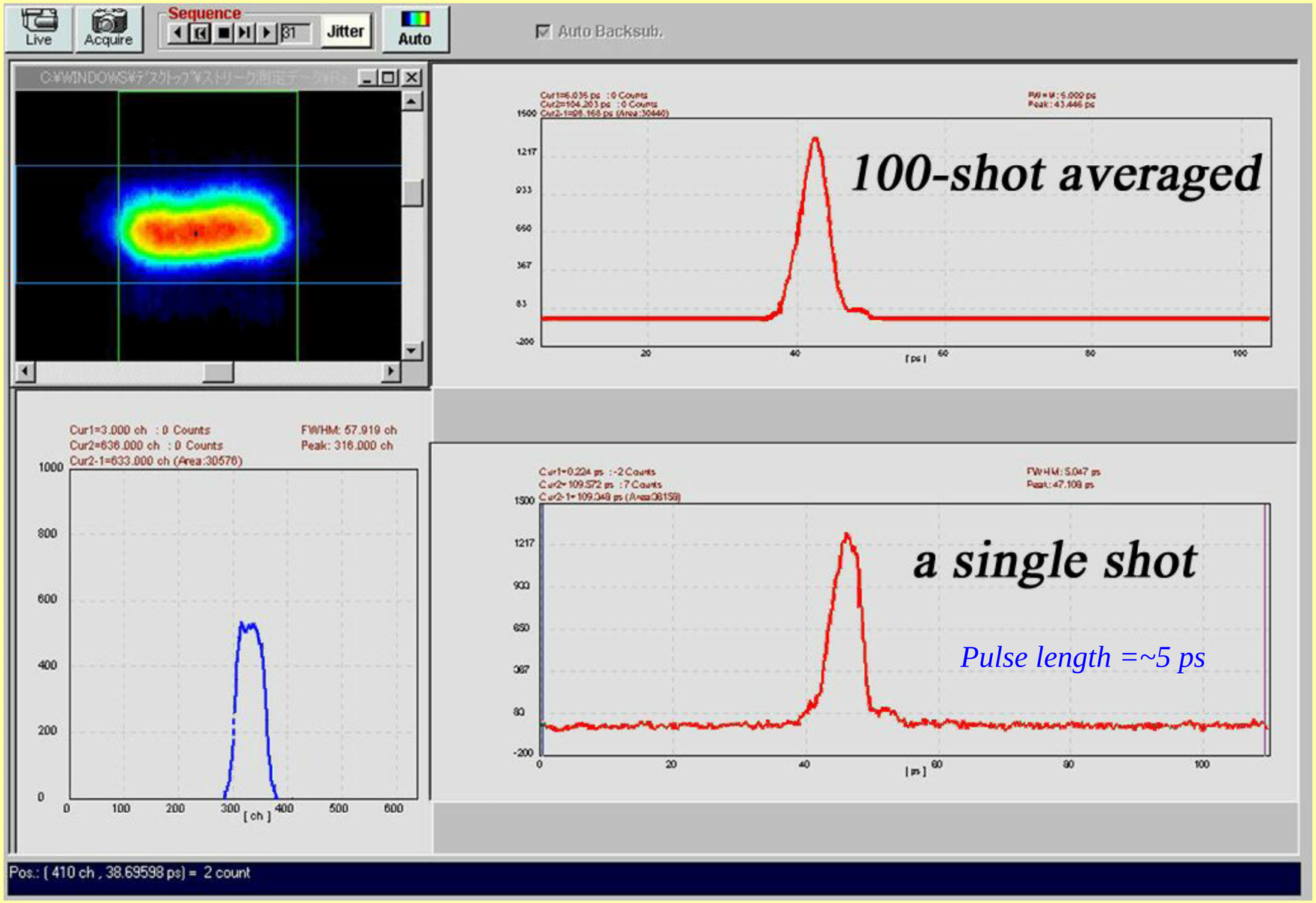


Laser Frequency Stability



Jitter Measurement with Sampling Oscilloscope

Measurement of Laser Pulse Length with Streak Camera



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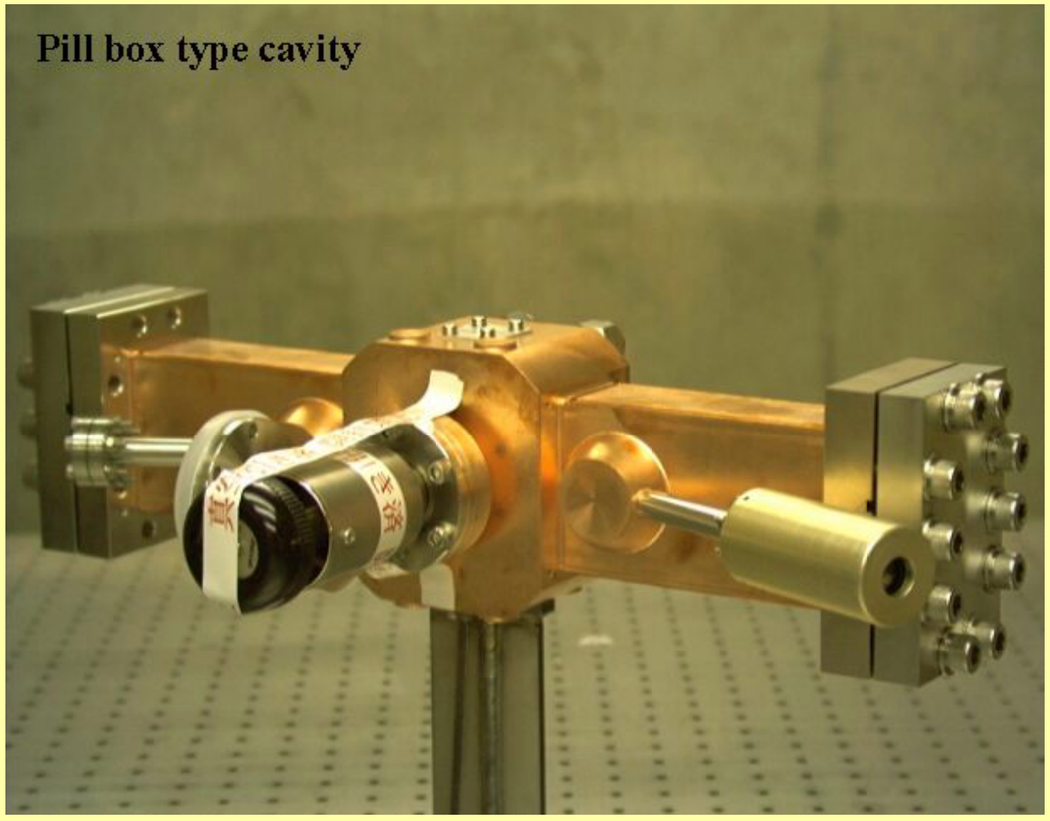
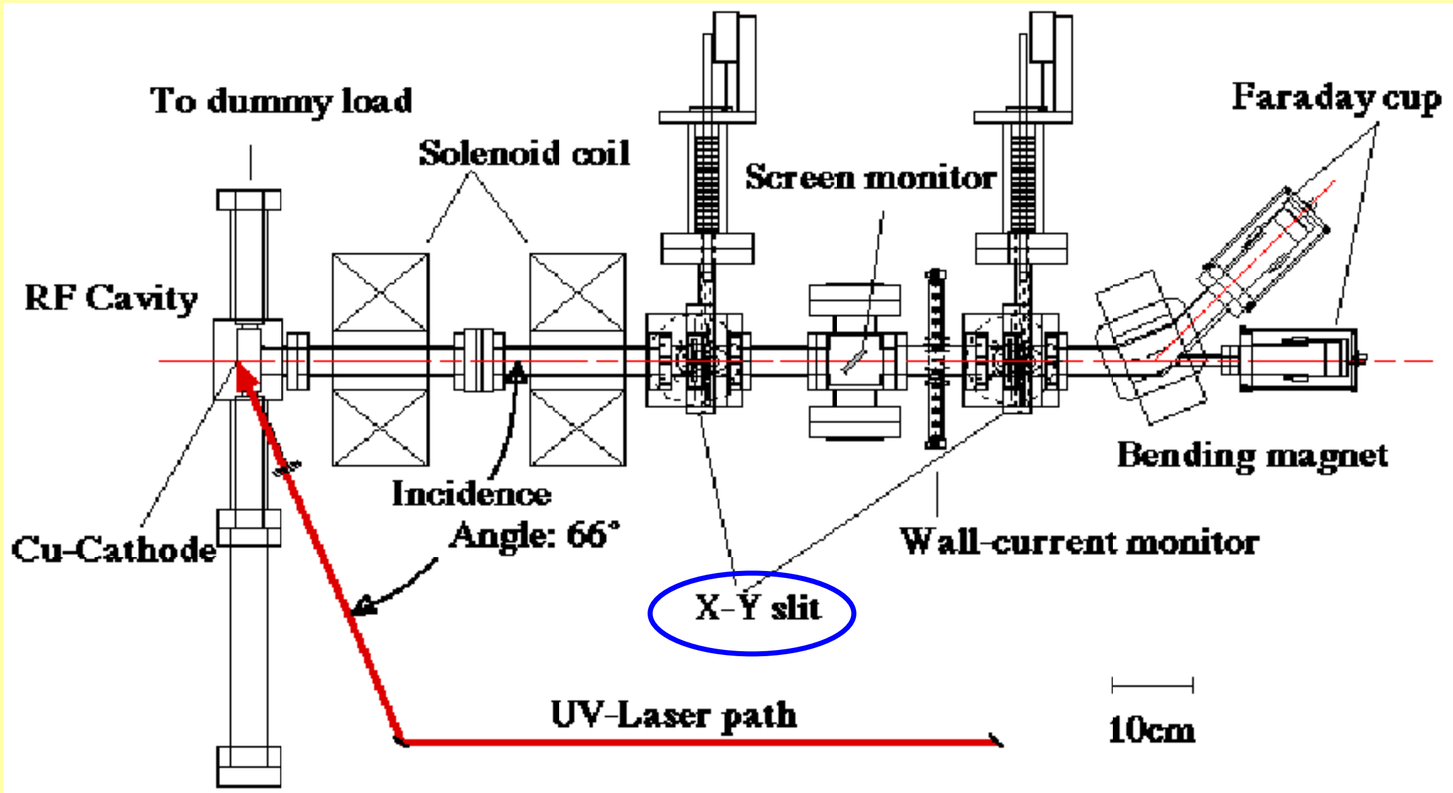
RF System & RF cavity



Klystron	
Type	Toshiba E3712
Maximum Power	80MW
Repetition Rate	10Hz (Max 60Hz)

Cavity		
Type	Single cell (Pill box type)	
RF wave in the cavity	Standing wave	
Maximum Electric Field on cathode	175	MV/m
Acceleration gap Length	28	mm
Maximum Beam Energy	4.1	MeV

Beam Emittance Measurement with double slits

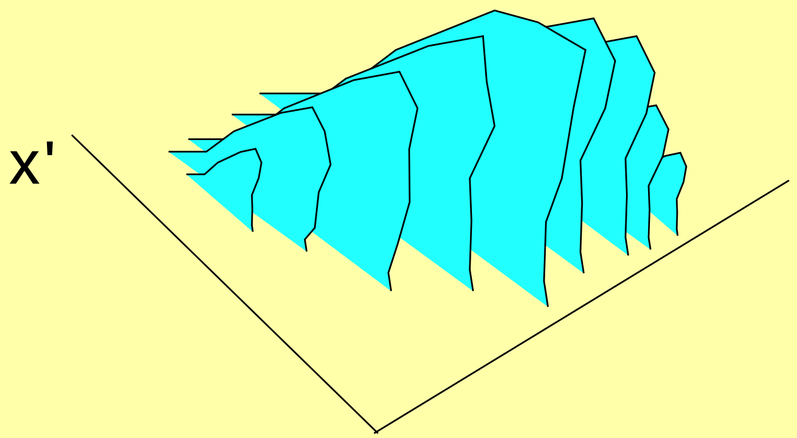


Adjusted or Optimized Parameters

RF phase
Magnetic Field of Solenoids
Laser Profiles
Laser Spot size
Laser position
Laser pulse energy

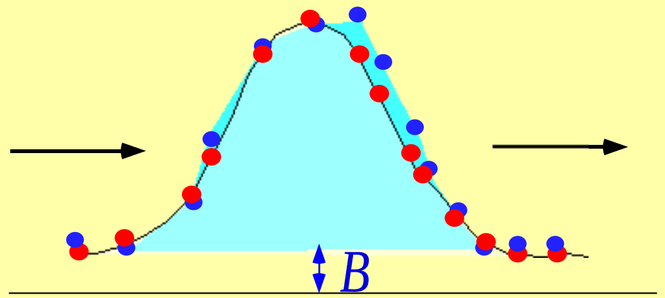
Data Analysis of Beam Emittance Measurement

Analysis 1 Gaussian Fitting



Measured Distribution

$$f(x)=A\exp\left(-\frac{x'^2}{2\sigma^2}\right)+B$$

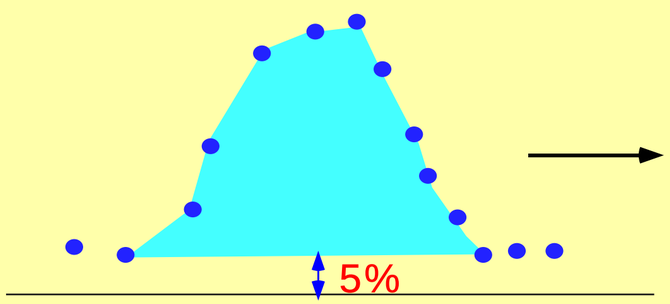


subtract *B* as noise

Gaussian+offset Fitting
-> data replacing

Calculation by
normalized RMS
Emittance Formula

Analysis 2 Direct Evaluation (fast but inaccurate)



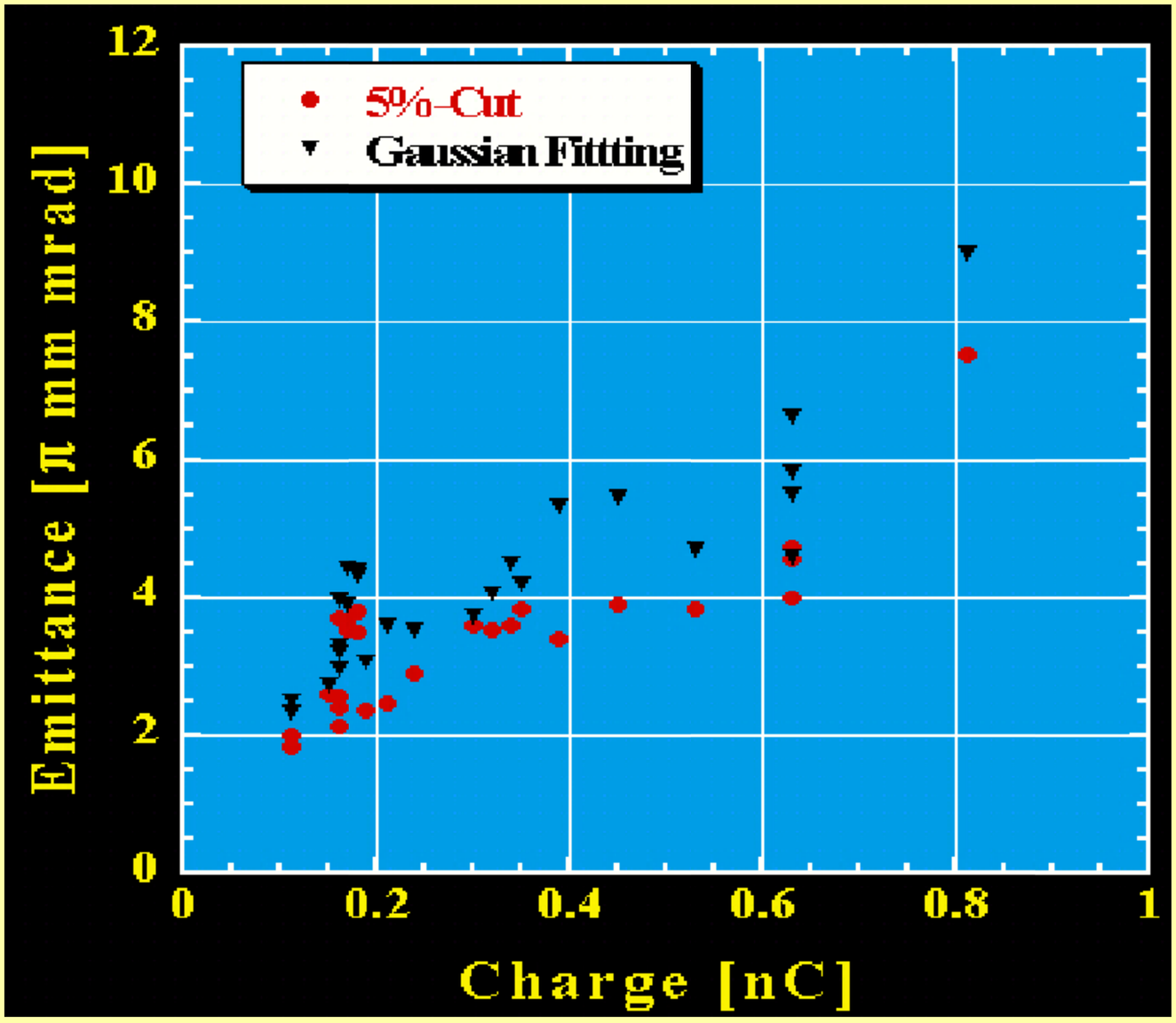
subtract 5% of Maximum as noise

Calculation by
normalized RMS
Emittance Formula

Normalized RMS Emittance

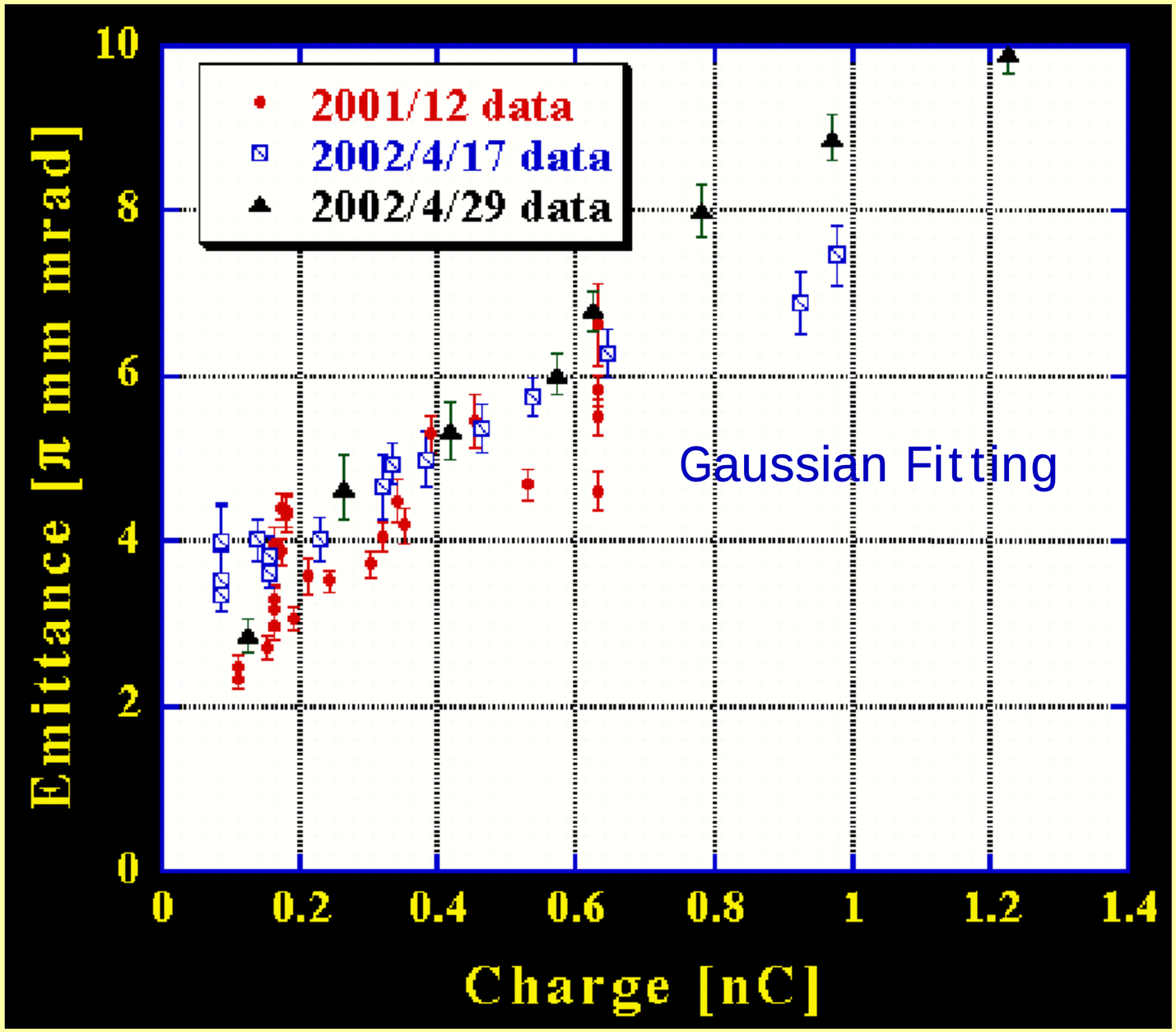
$$\varepsilon = \beta\gamma\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

Comparison between different data analyses of Emittance Measurements

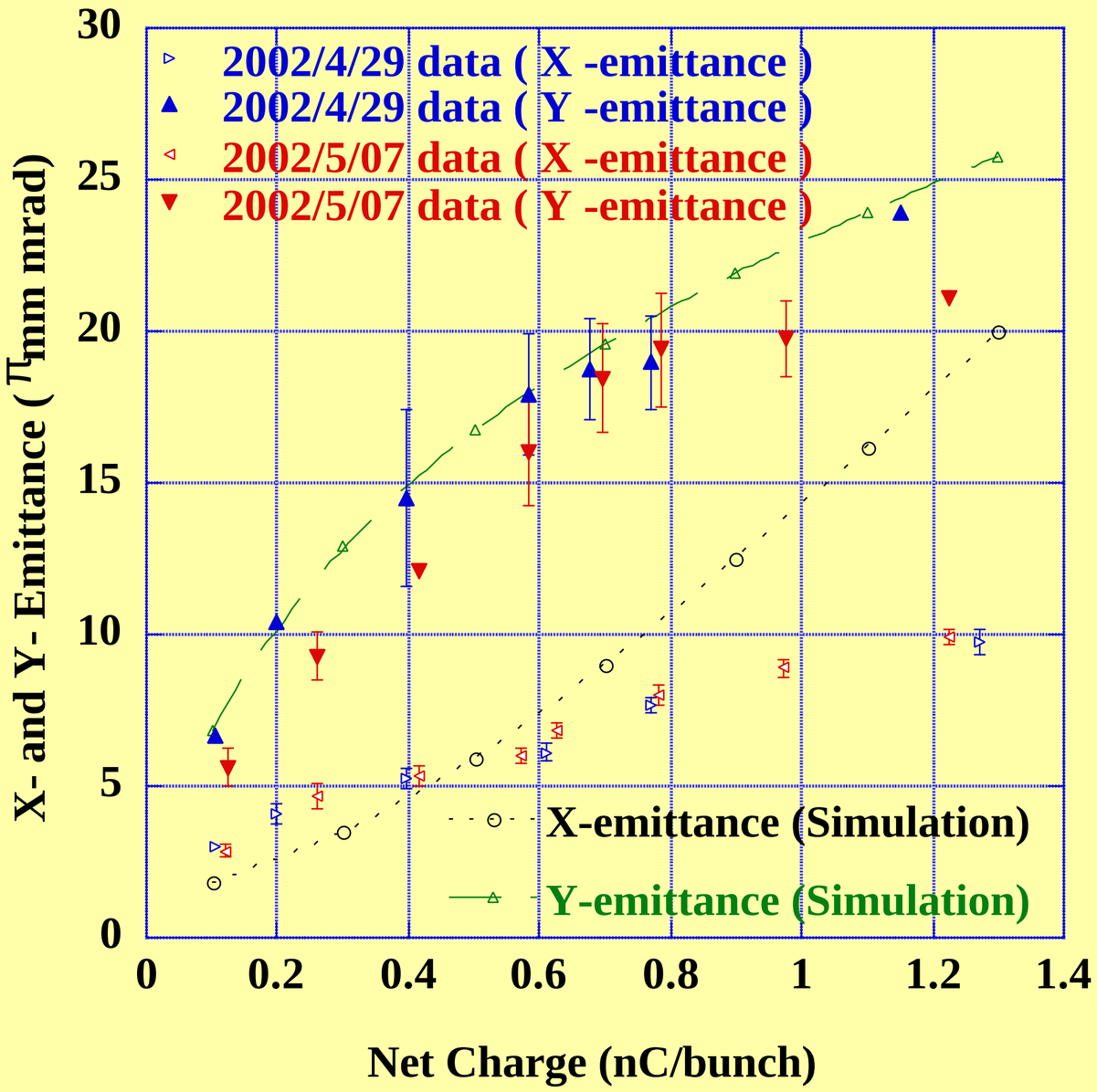


ε(Gaussian Fitting)> ε(Direct, 5% cut)

Charge dependences of Beam Emittance



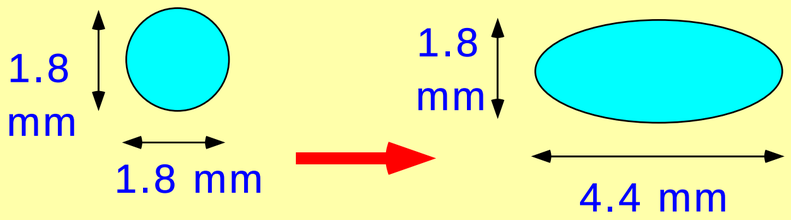
Comparison of horizontal(X) and vertical(Y) beam emittance



εy>εx

Effect of Laser Incident Angle

1 Laser spot size on cathode



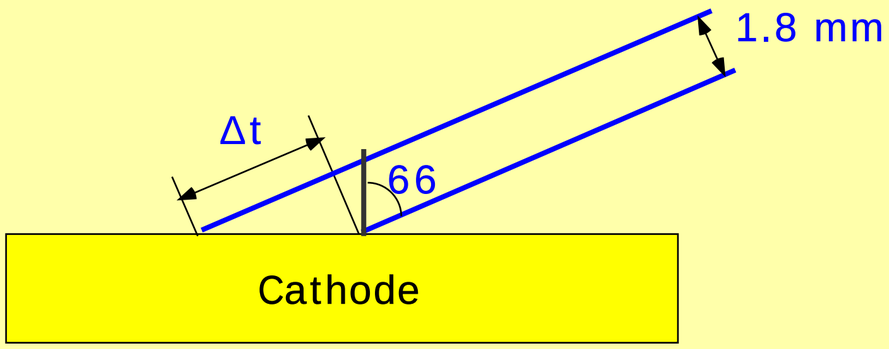
Laser Profile

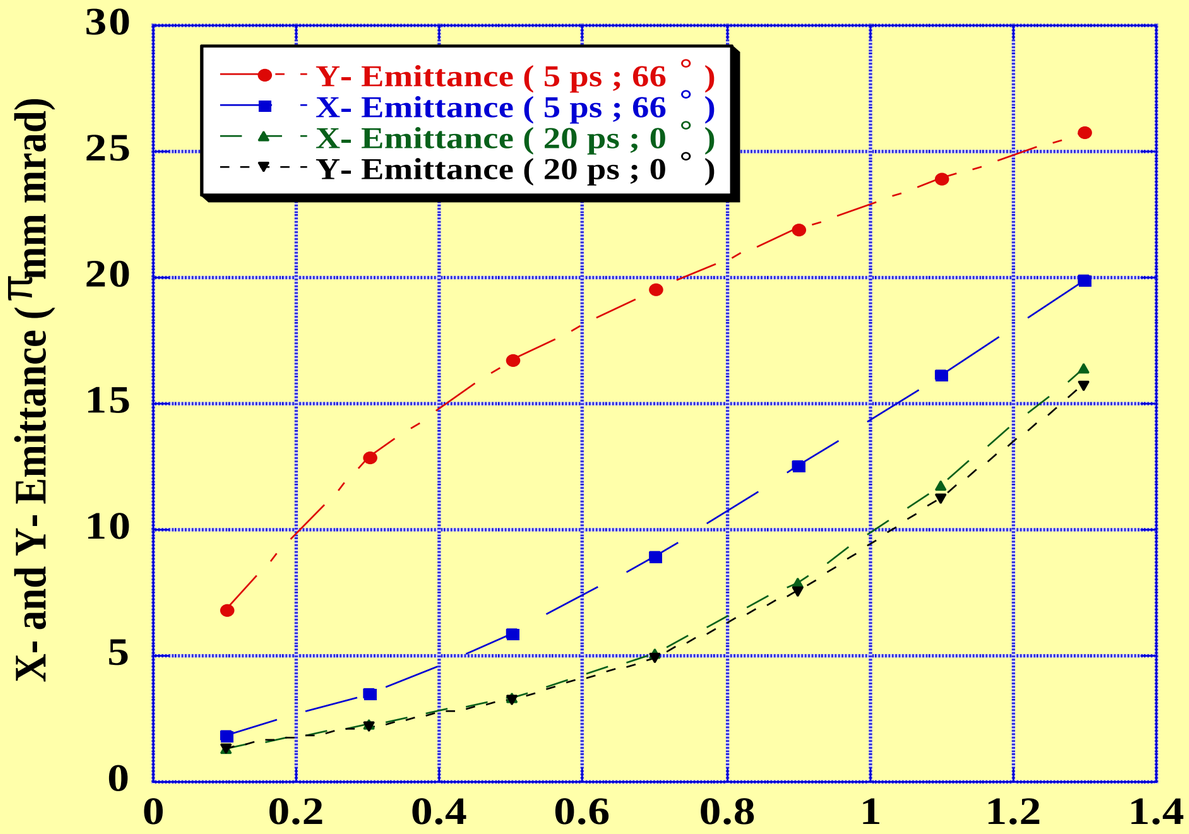
Laser on Cathode @66 deg

2 Time delay on cathode

Δt = 0.0 ps (0 deg)

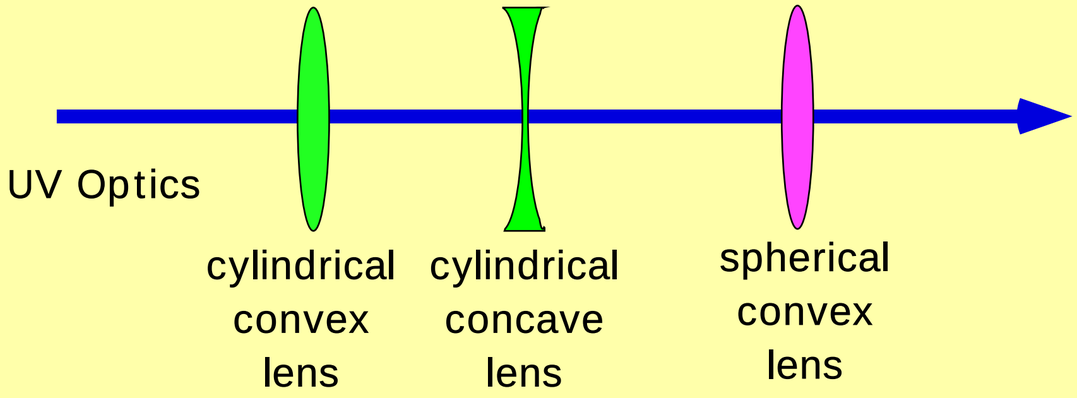
Δt=13.4 ps (66 deg)

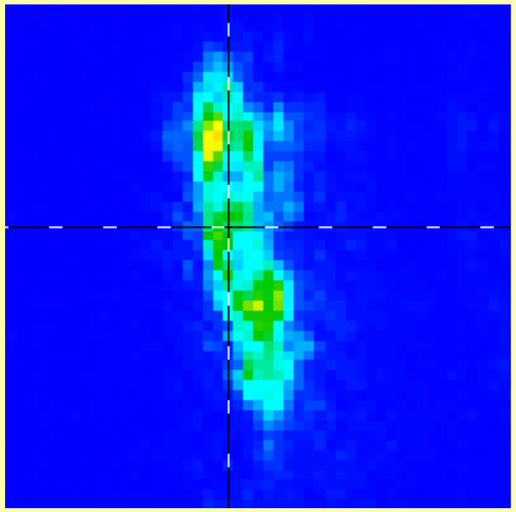




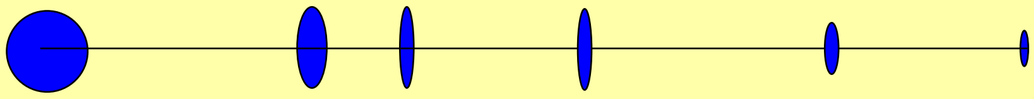
Results of Simulation for the cases of incident angle of 0 and 66 degree.

Laser beam transformation to ellipsoidal shape with cylindrical lens





Δx 0.60 mm
Δy 1.89 mm

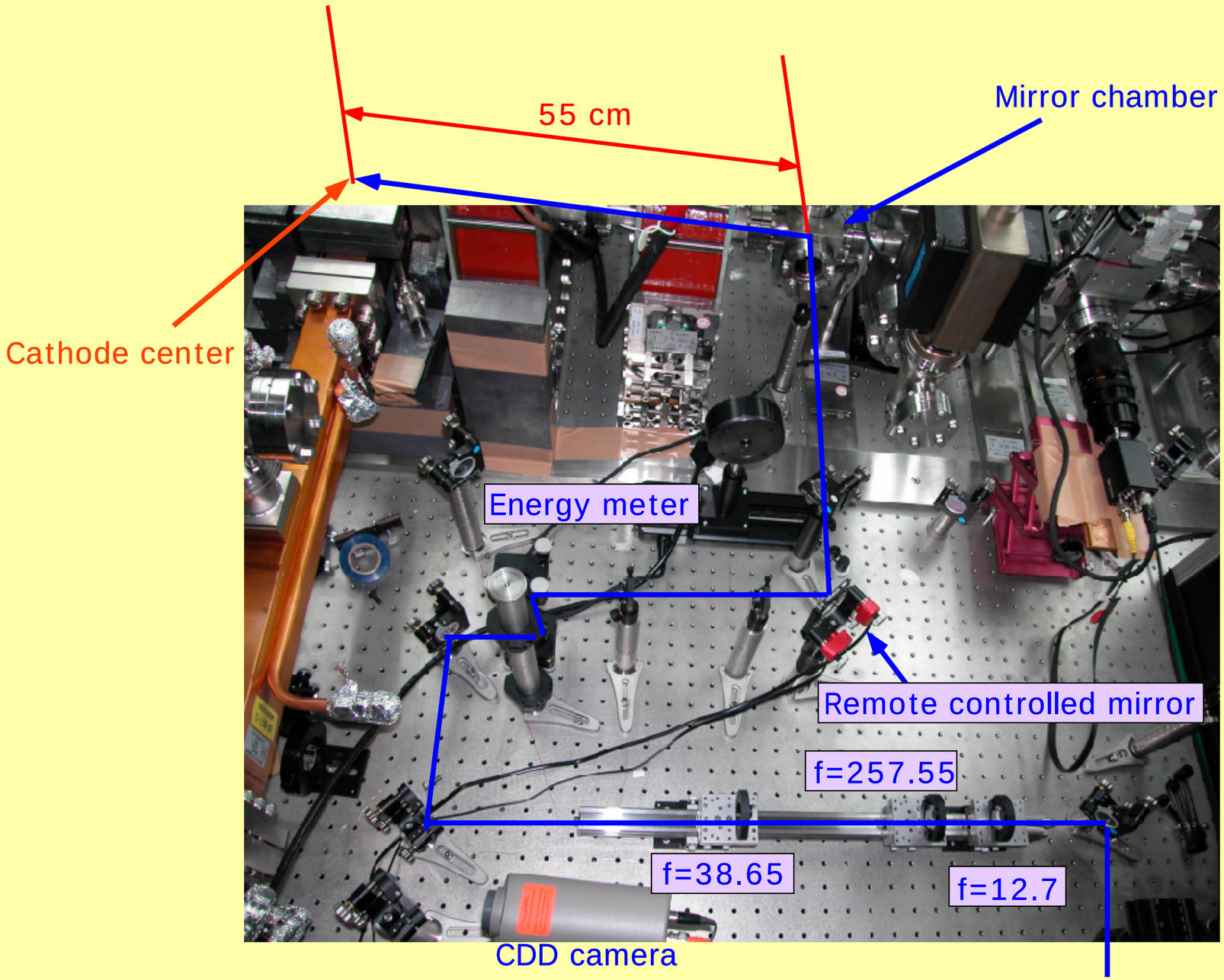


Laser shape

	circle(@0.1nC)	ellipse(@0.2nC)
x emittance	3.0	3.9
y emittance	6.6	5.4

Vertical emittance was improved.
Without homogenizer

Installation of zero-degree injection optics



Plans

1. Emittance measurement for 0º Injection
2. Installation of accelerator tube after RF-gun
3. Comparison between double slits & Q-scan
4. Improve resolution of emittance measurement
5. Beam pulse length measurement
6. RF generation without pulse generator--> low jitter
7. Faster feedback of piezo mirror (PLL)
8. Temporal profile optimization

etc..

Summary

1. Laser Homogenizer succeeded.
   Laser energy fluctuation < 2 %
   2 mmmrad @0.1 nC

2 Good synchronization with generating RF from laser pulse.
   RMS jitter < 1.7 ps.

3. Effect of non-right angle injection was investigated.
   Vertical emittance > Horizontal emittance @66 deg

4. Ellipsoidal laser profile was formed with cylindrical lens.

5. Vertical emittance was improved with ellipsoidal laser profile.