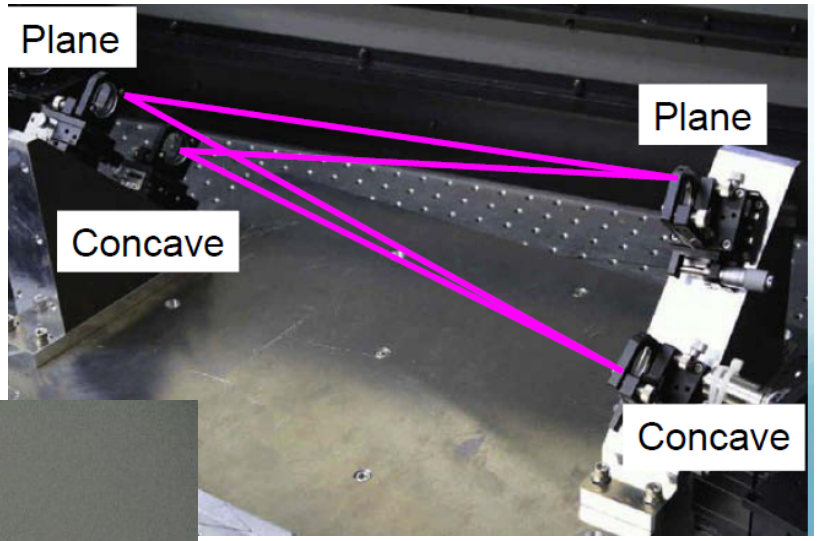
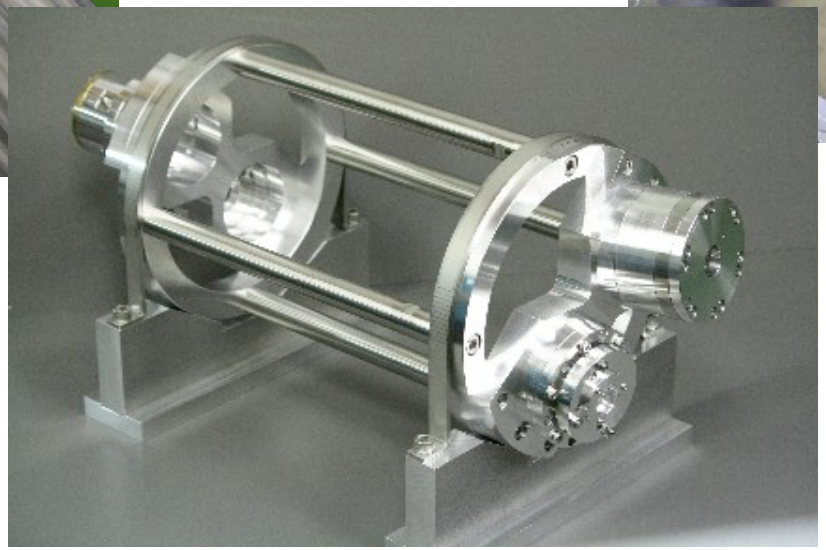
Japanese cavities: results, status, and future





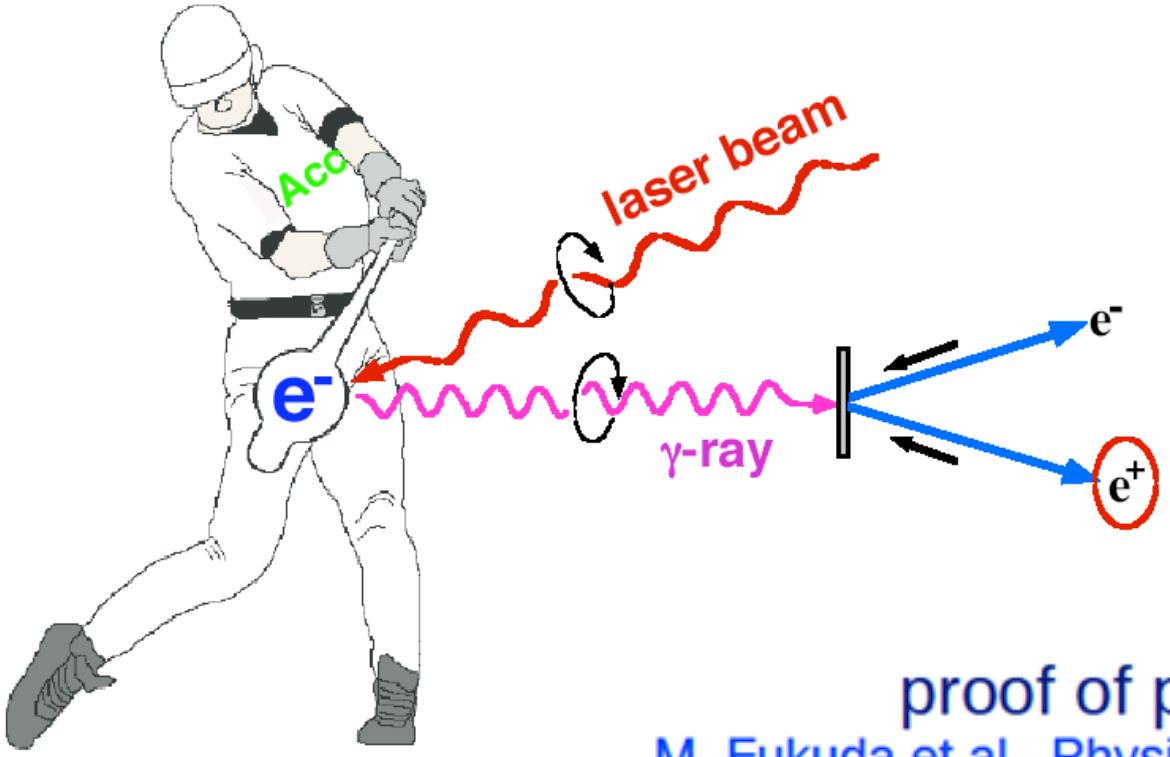
T. Omori (KEK)

20-Oct-2010

IWLC2010 (ILC-CLIC WS) at Genéve

Introduction

- Polarized e+ by laser Compton Scheme



Ee~1GeV for 10MeV gammas

easy to control polarization

proof of principle experiment

M. Fukuda et al., Physical Review Letters 91, 164801 (2003)

T.Omori *et* al., Physical Review Letters 96, 114801(2006)

Toward the positron sources

-> increase intensity of gamma rays

Staking Laser Pulses in Optical Cavity

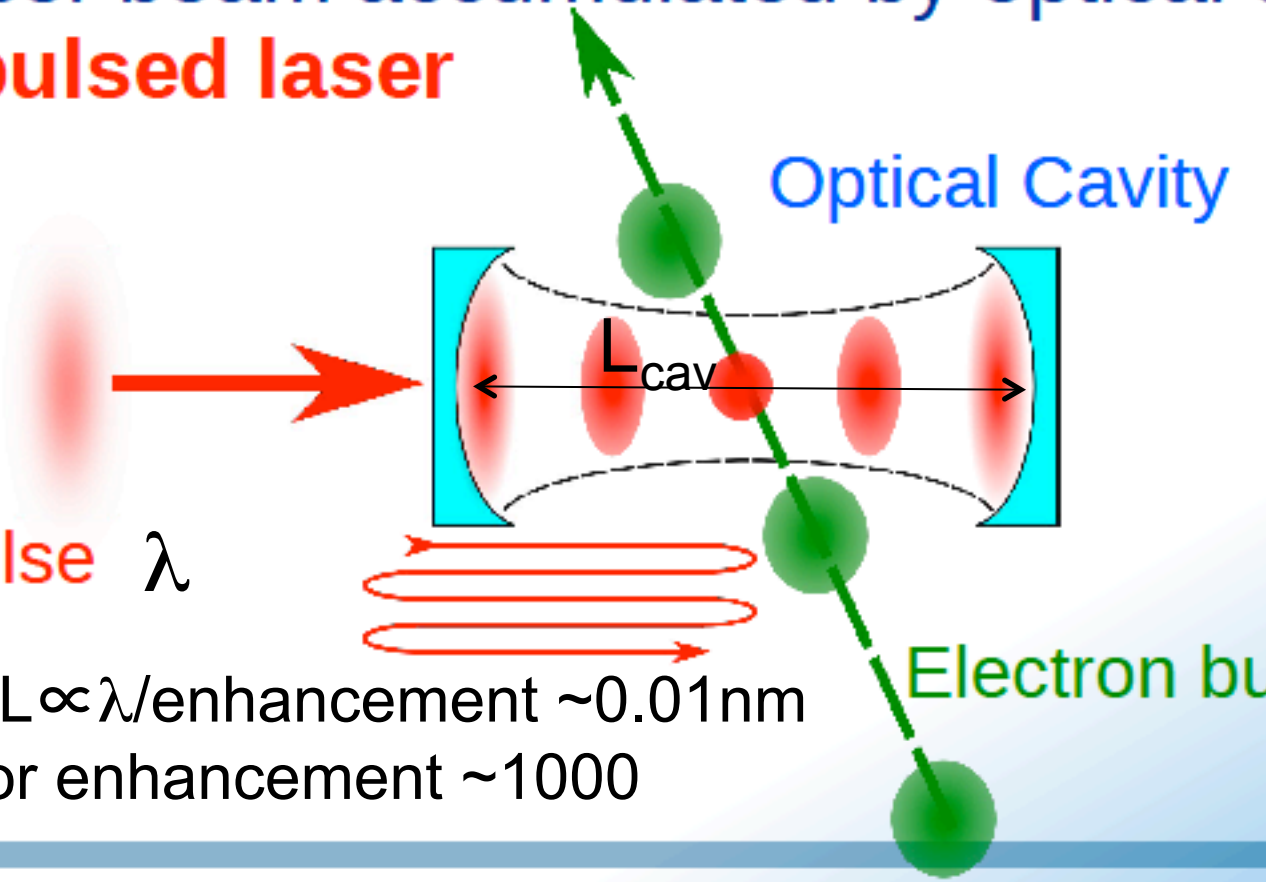
Miyoshi PosiPol2010

Increase power of laser beam at interaction point for increasing gamma yield.

➡ **enhancement with optical cavity**

Laser beam accumulated by optical cavity

➡ **use pulsed laser**



$$L_{cav} = m\frac{\lambda}{2}$$

dL∝λ/enhancement ~0.01nm
for enhancement ~1000

Two Prototype Cavities

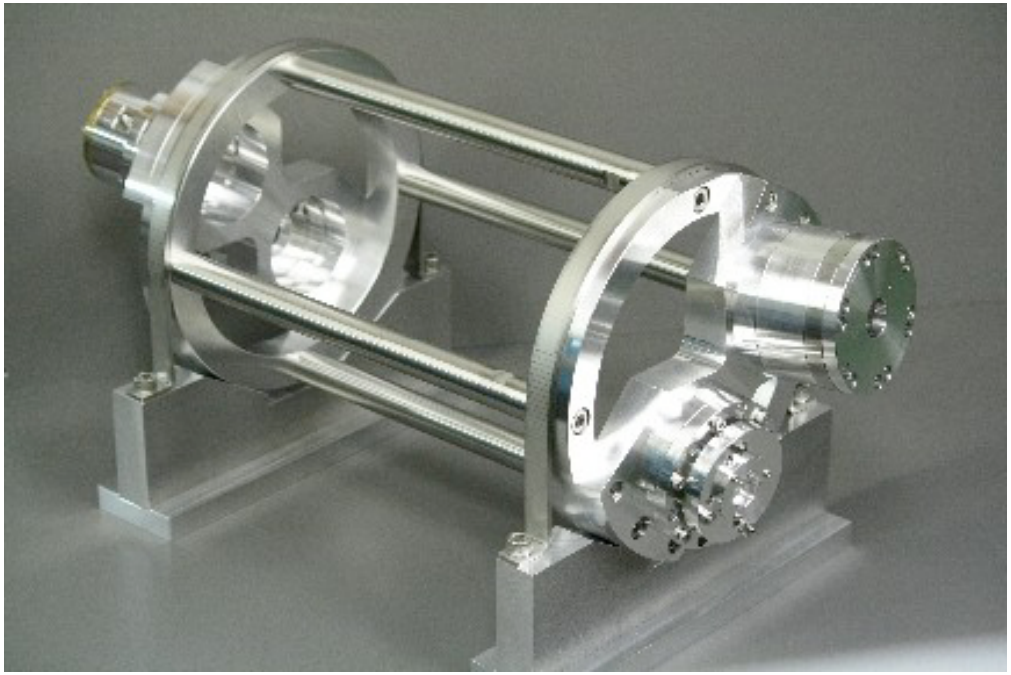
2-mirror cavity

(Hiroshima / Weseda / Kyoto / IHEP / KEK)

moderate enhancement
moderate spot size
simple control

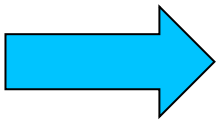
4-mirror cavity

(Inspired by French Activity)



high enhancement
small spot size
complicated control

demonstration of γ ray gen.
accum. exp. w/ cavity and acc.



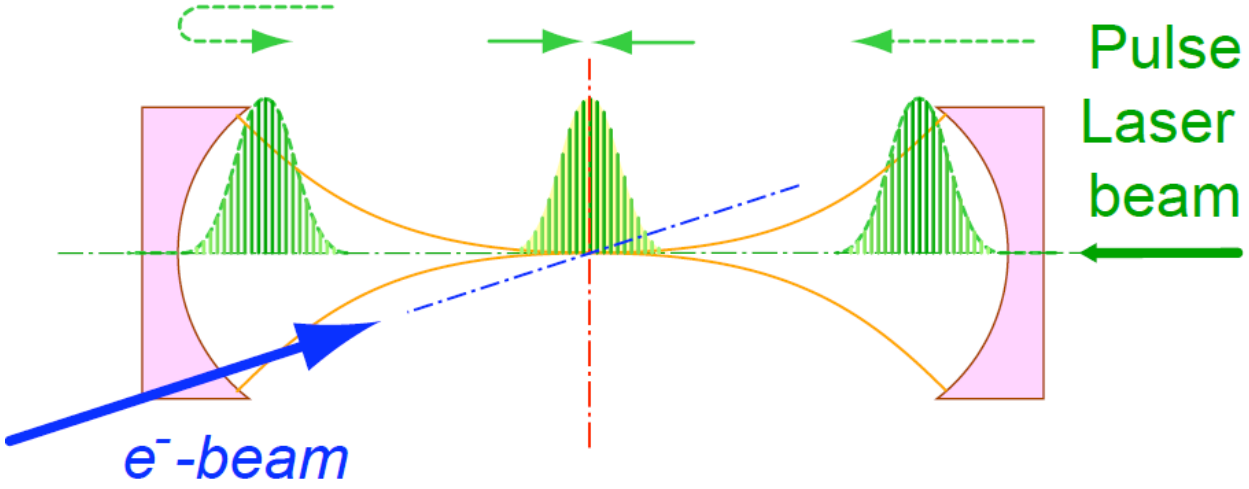
intense γ ray generation

STATUS OF THE 2 MIRROR CAVITY

Experimental Apparatus: Two Mirror Cavity

Experimental R/D in ATF

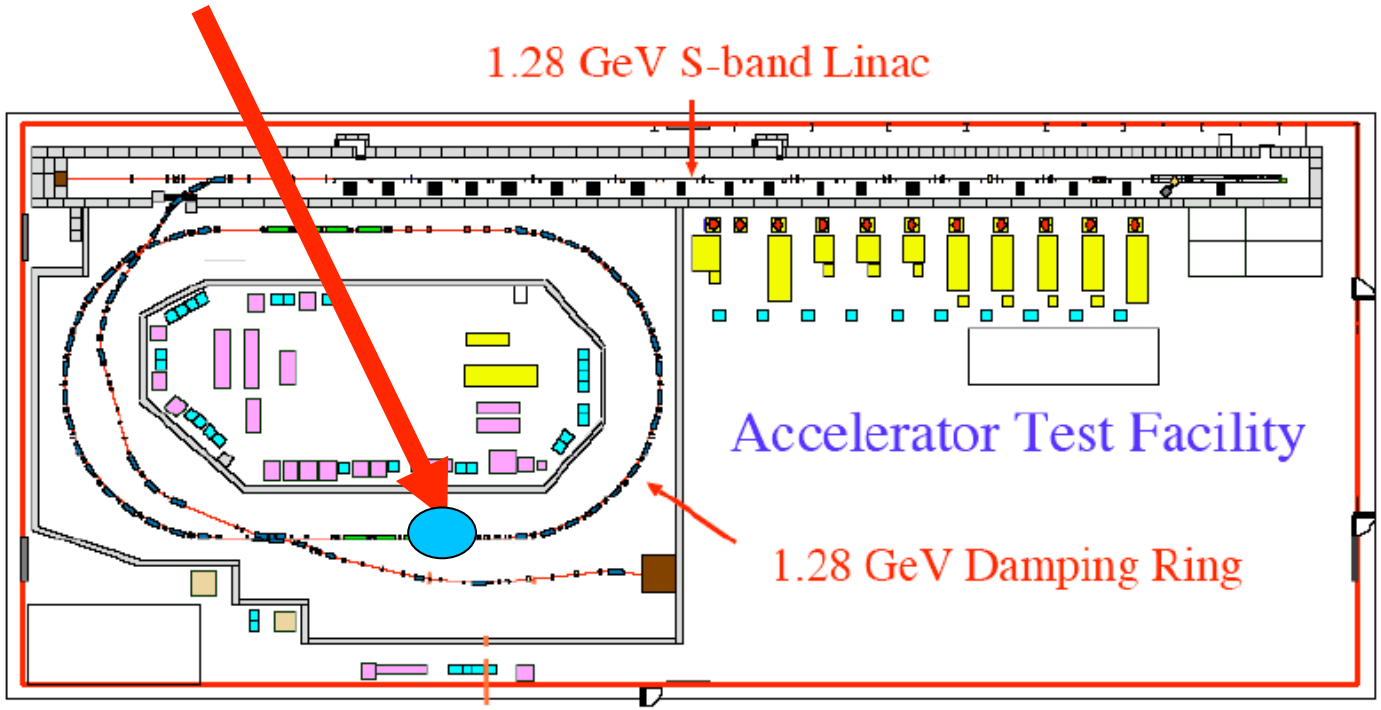
Hiroshima-Waseda-Kyoto-IHEP-KEK



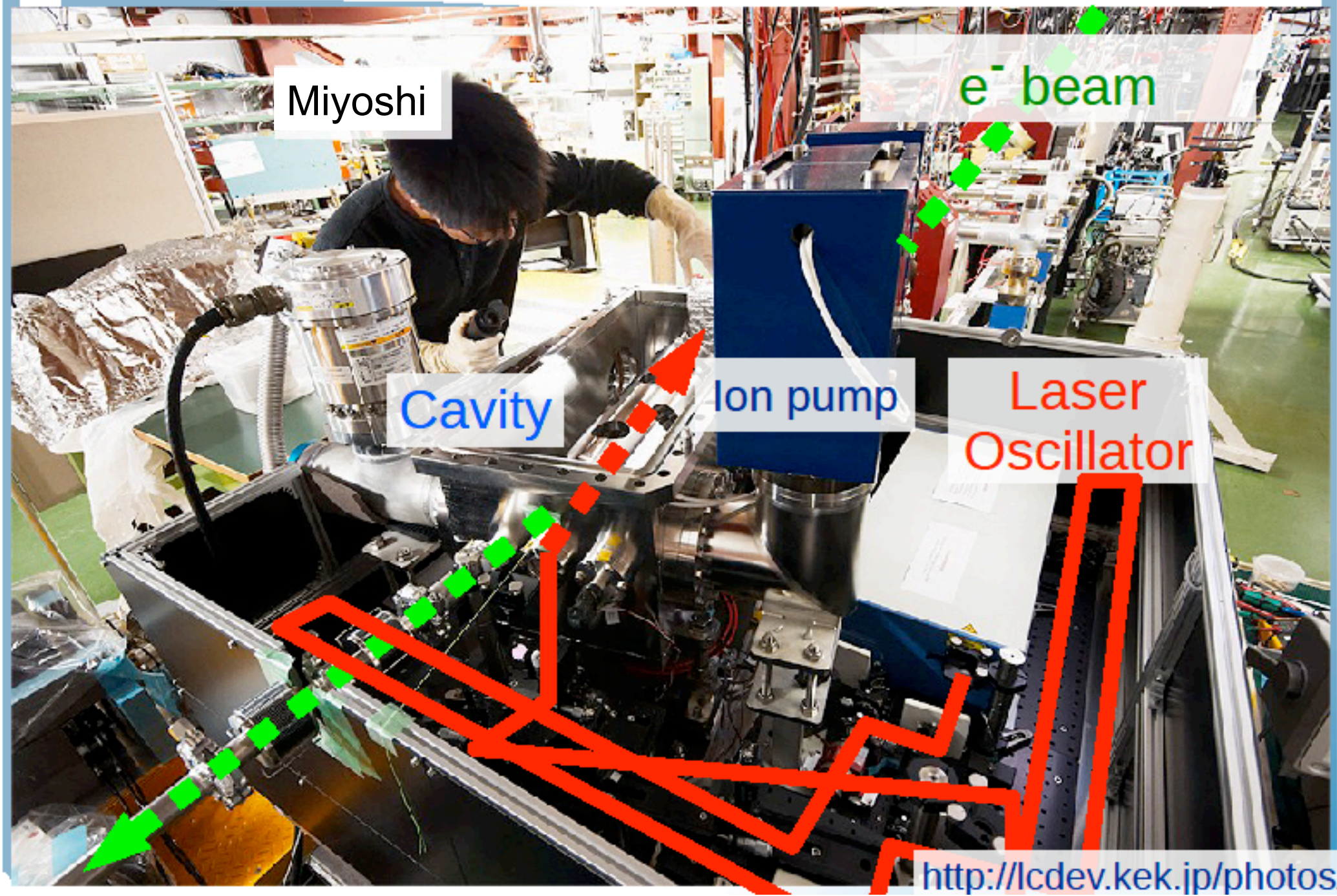
prototype
2-mirror cavity

L_{cav} = 420 mm

Put it in ATF ring



Experimental Apparatus



Progress of the Exp. w 2M Cavity

- **2007/2008 Install Cavity (Enhance x250)**

  Spot size 30 micron (σ), not locked on resonance

  γ-ray generation

  H.Shimizu et al., JPSJ, 78 (2009) 074501

  ⇩ **improve feedback system**

- **2008/2009 Enhance x250, success locked on resonance**

  500 W in cavity, γ-ray generation

  Shuhei Miyoshi et al., NIM, A623 (2010) pp.576-578

  ⇩ **Higher Reflectivity Mirror**
  improve feedback system

- **2008/2009 Enhance x760, success locked on resonance**

  1.5 kW in cavity, γ-ray generation

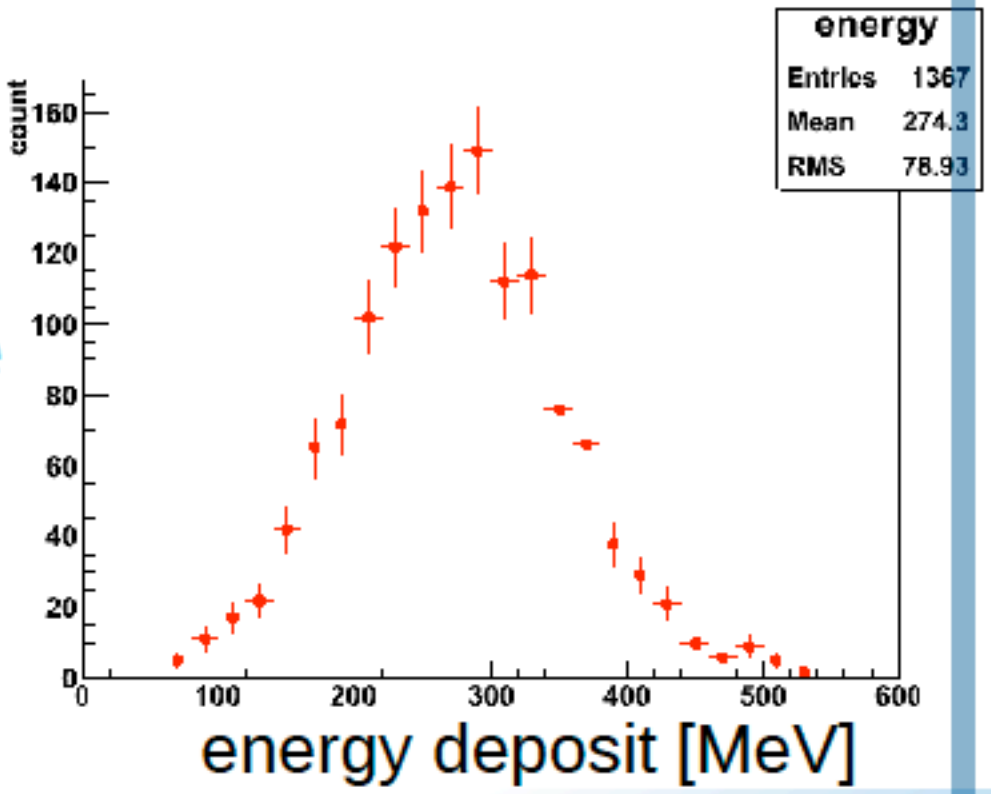
  ⇩ **We are here.**

Result of the Experiment in 2010

Miyoshi PosiPol2010

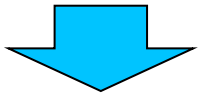
Enhancement factor tripled (250 -> 760),
accumulated power increased from 500W to 1.48kW.

10.9 gamma-rays / train are detected
with single bunch operation
(I~2.2mA).



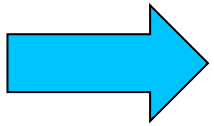
Progress of the Exp. w 2M Cavity

- 2008/2009 Enhance x760, success locked on resonance
  1.5 kW in cavity, γ-ray generation



We are here.

Next step

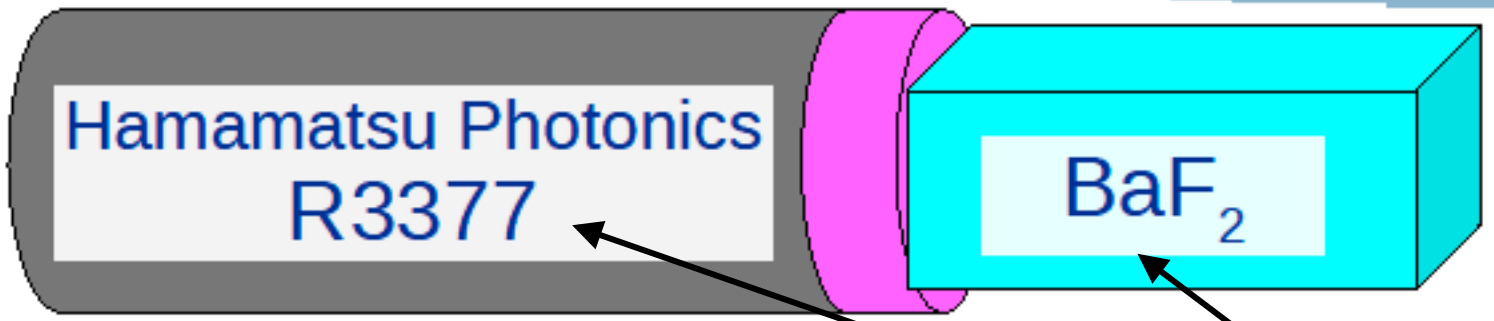


more power enhancement <--- Done

bunch by bunch observation <--- Next

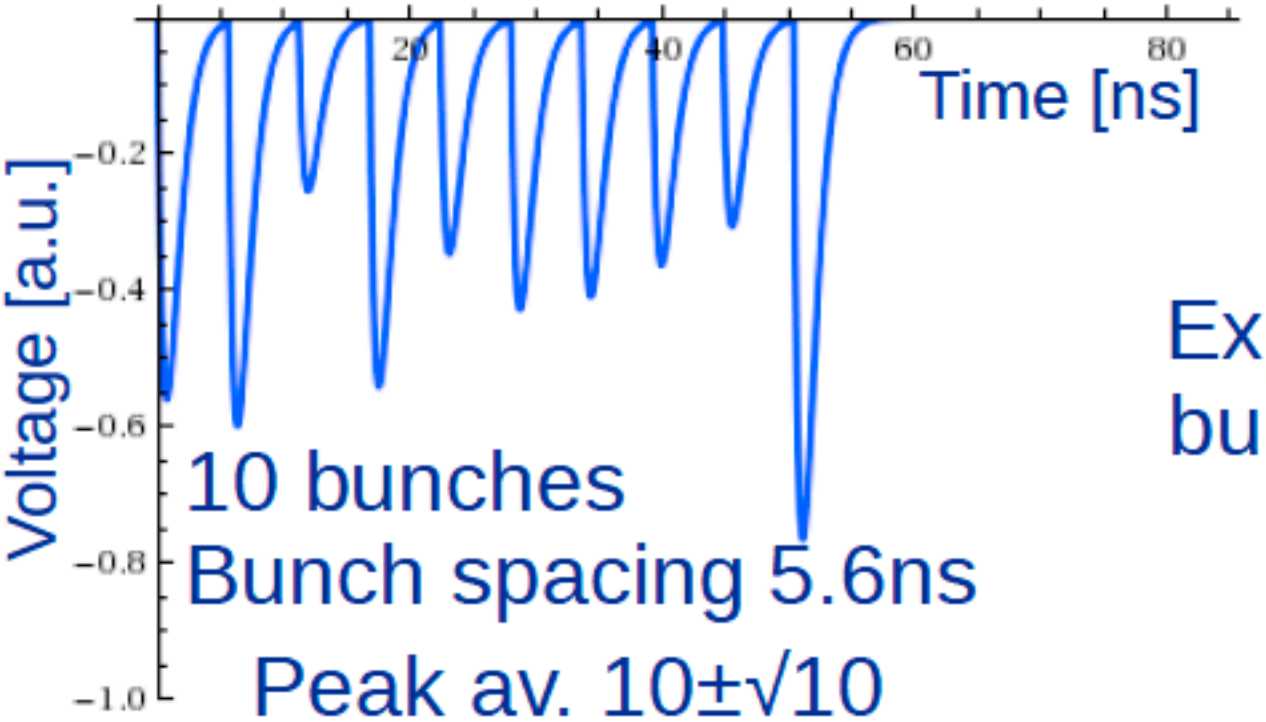
New Gamma-ray Detector

Miyoshi PosiPol2010



- **Fast Crystal**
- **Fast PMT**

Result of simulation



10 bunches
Bunch spacing 5.6ns
Peak av. 10±√10

Expected to obtain bunch information.

New Gamma-ray Detector

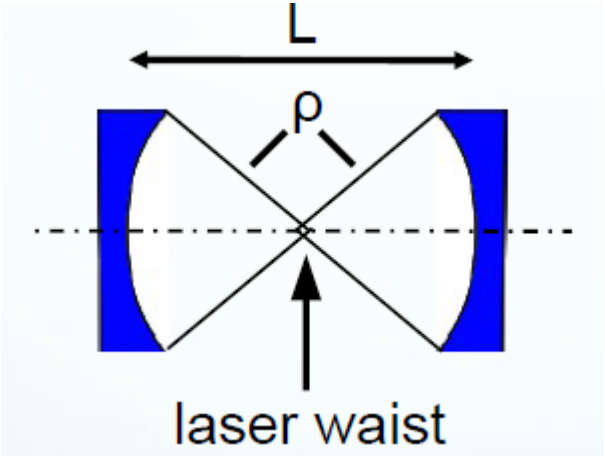
- **Bunch-by-bunch data taking is planed in Oct-Dec/2010.**
  We will use a Oscilloscope for data taking.

- **New fast DAQ is planned by LAL team.**

STATUS OF THE 4 MIRROR CAVITY

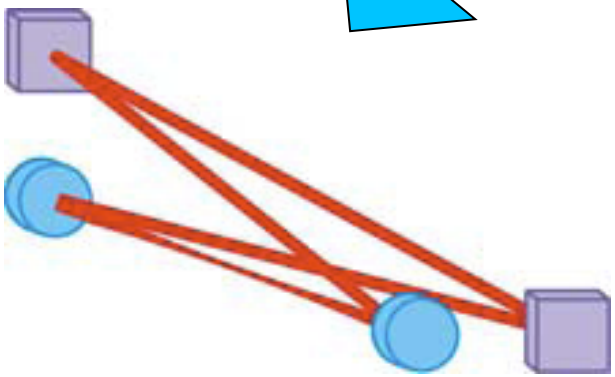
Inspired by French Activities.
Many knowledges were/are transferred from French team.

We should go to 3D 4 mirror ring cavity to get small sport size



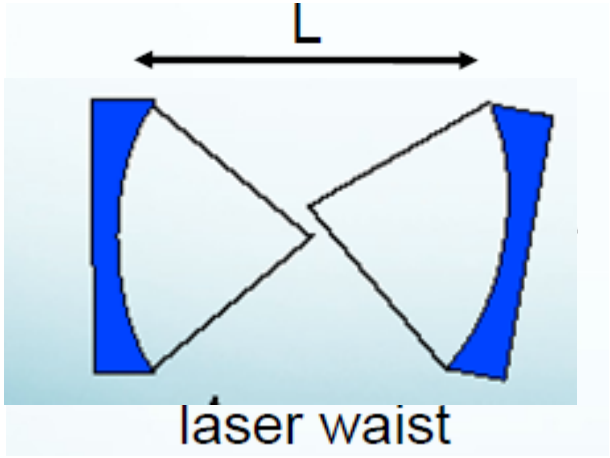
2 mirror cavity is not stable for small spot size

2d 4M has astigmatism



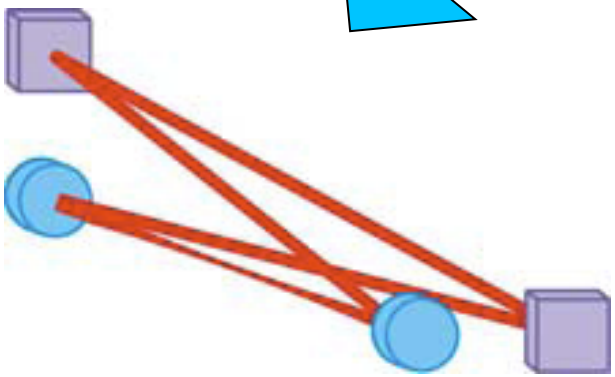
3D (or twisted) 4M ring cavity

We should go to 3D 4 mirror ring cavity to get small sport size



2 mirror cavity is not stable for small spot size

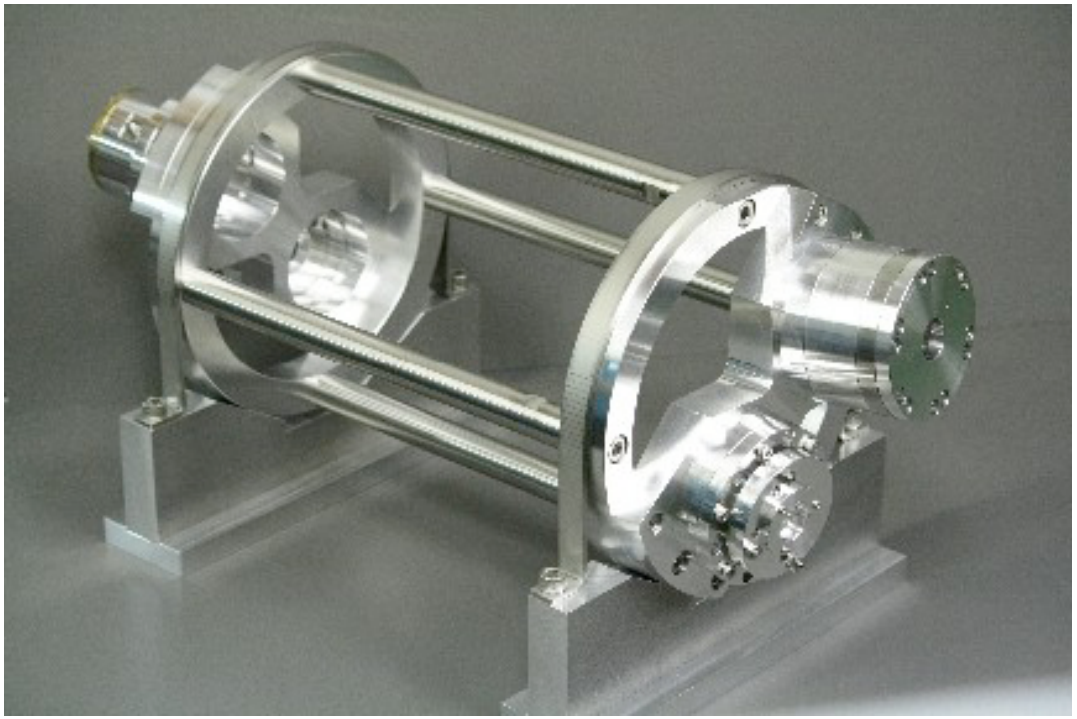
2d 4M has astigmatism



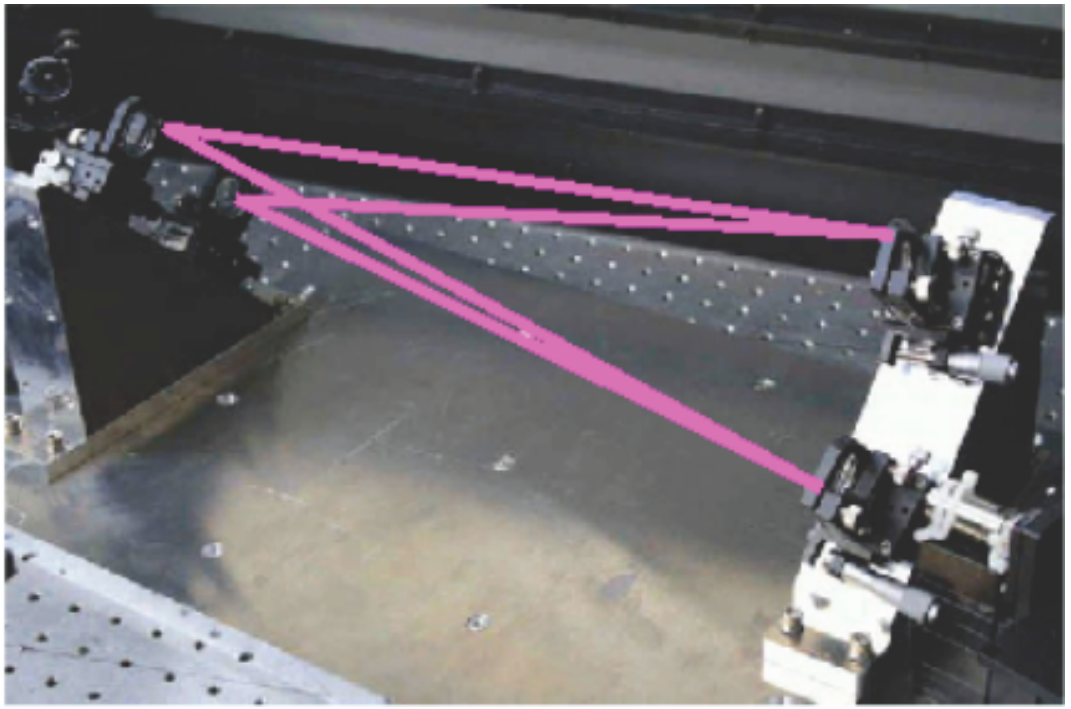
3D (or twisted) 4M ring cavity

4 MIRROR CAVITY

Prototype Cavity

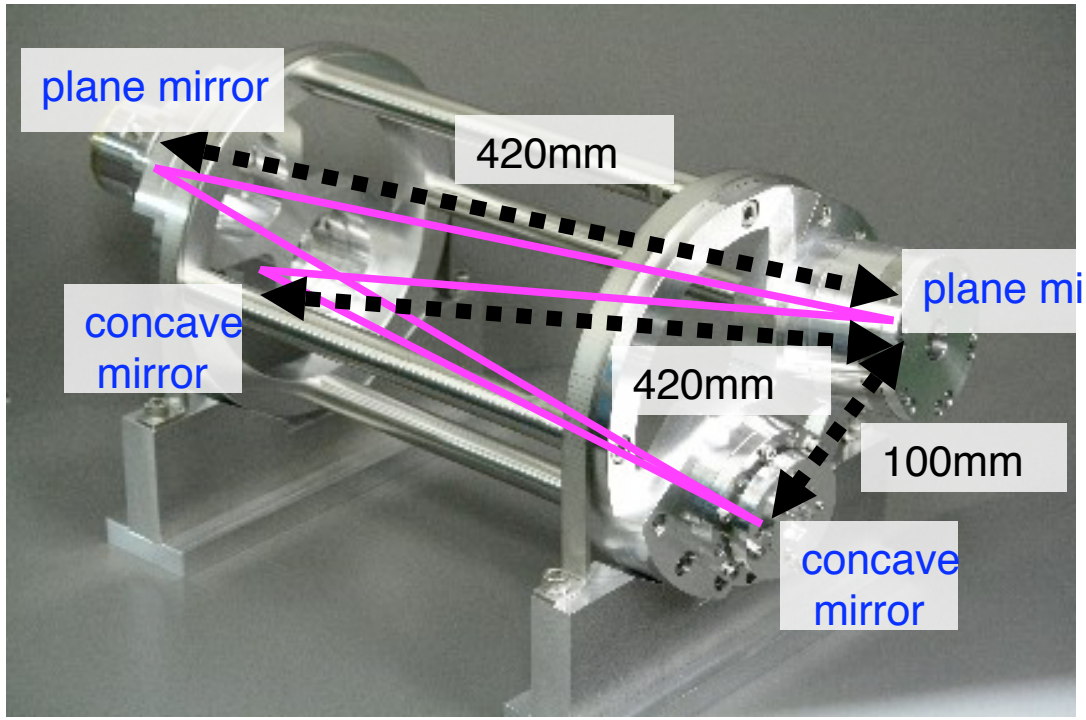


Test Bench Cavity

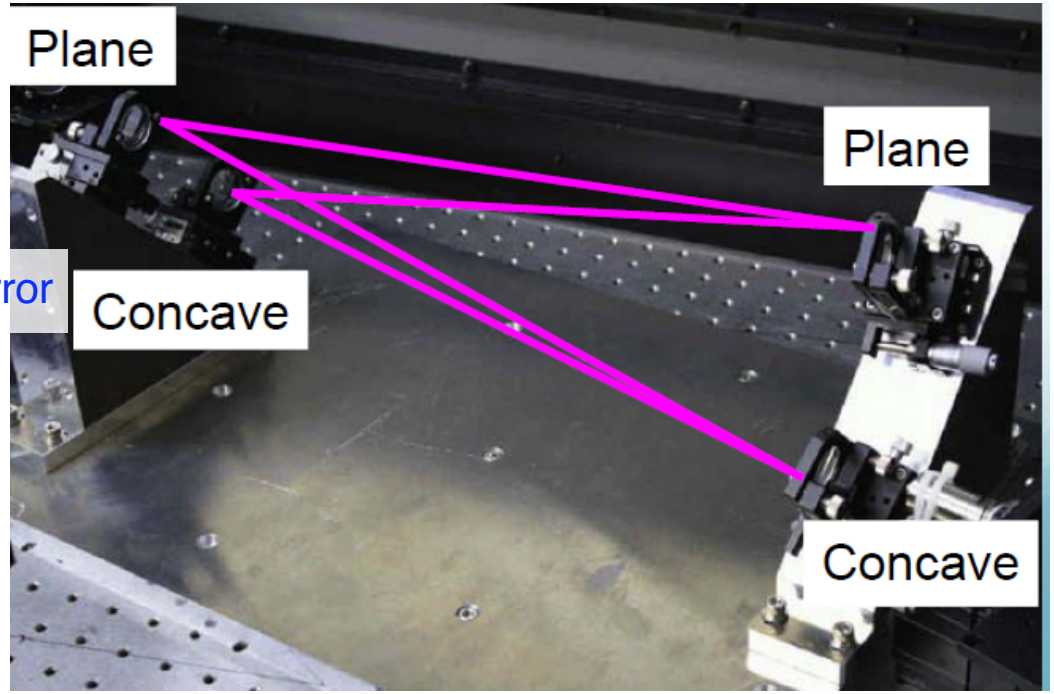


4 MIRROR CAVITY

Prototype Cavity

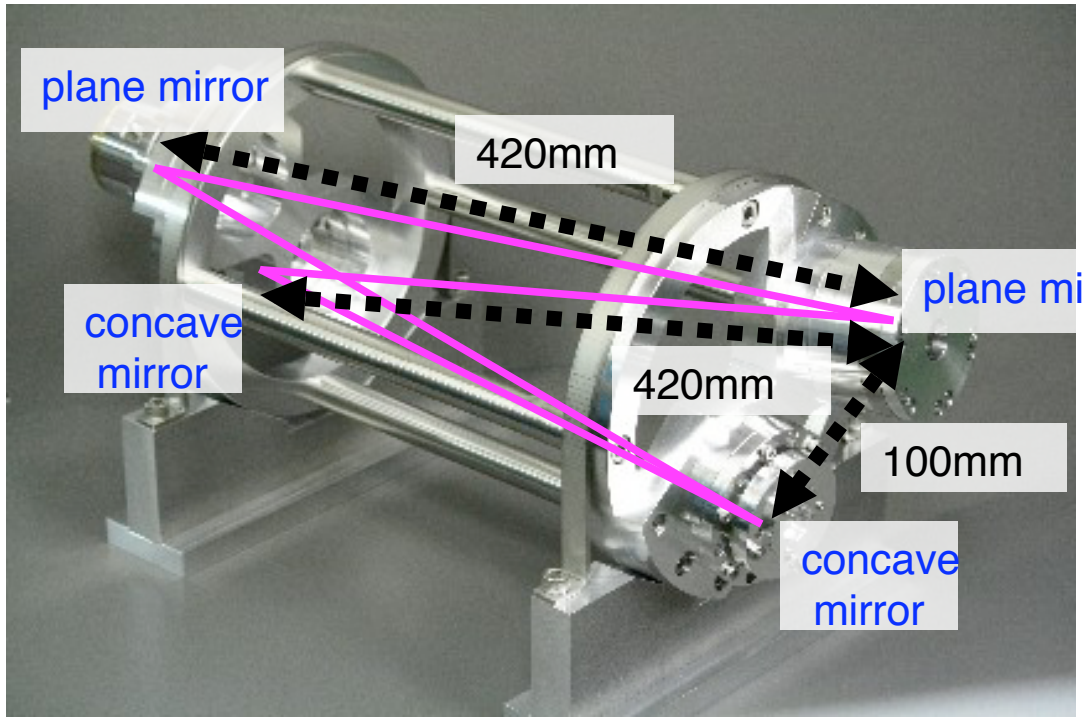


Test Bench Cavity



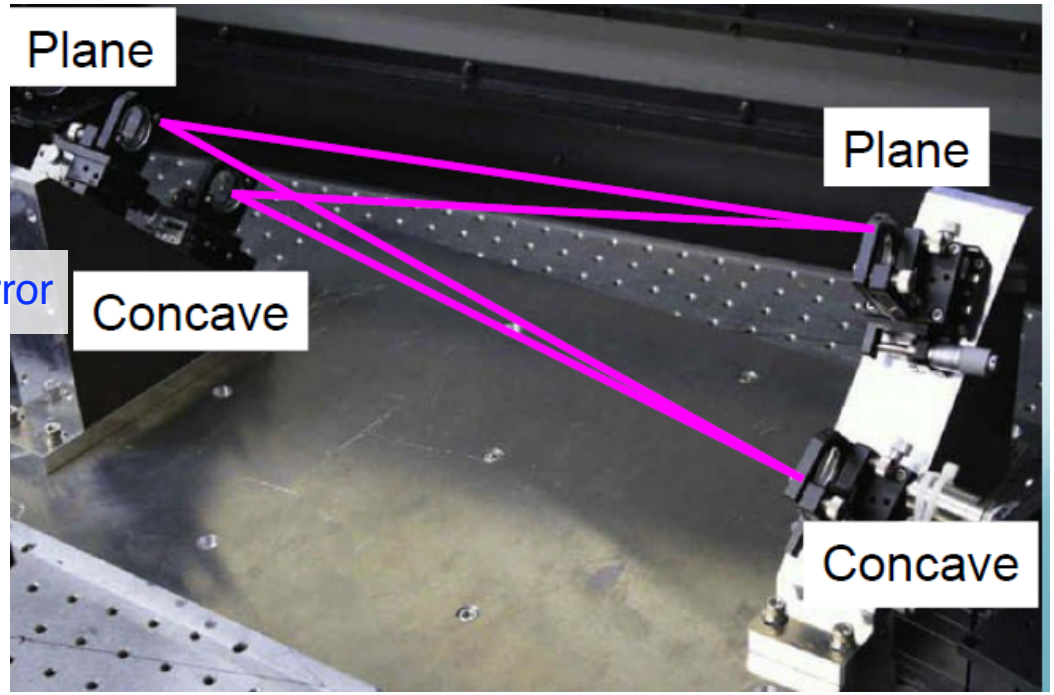
4 MIRROR CAVITY

Prototype Cavity



- All parts are specially designed.
- Less adjustable. Aimed to be much simpler than French Cavity.
- Get experiences to design a vacuum compatible cavity.

Test Bench Cavity



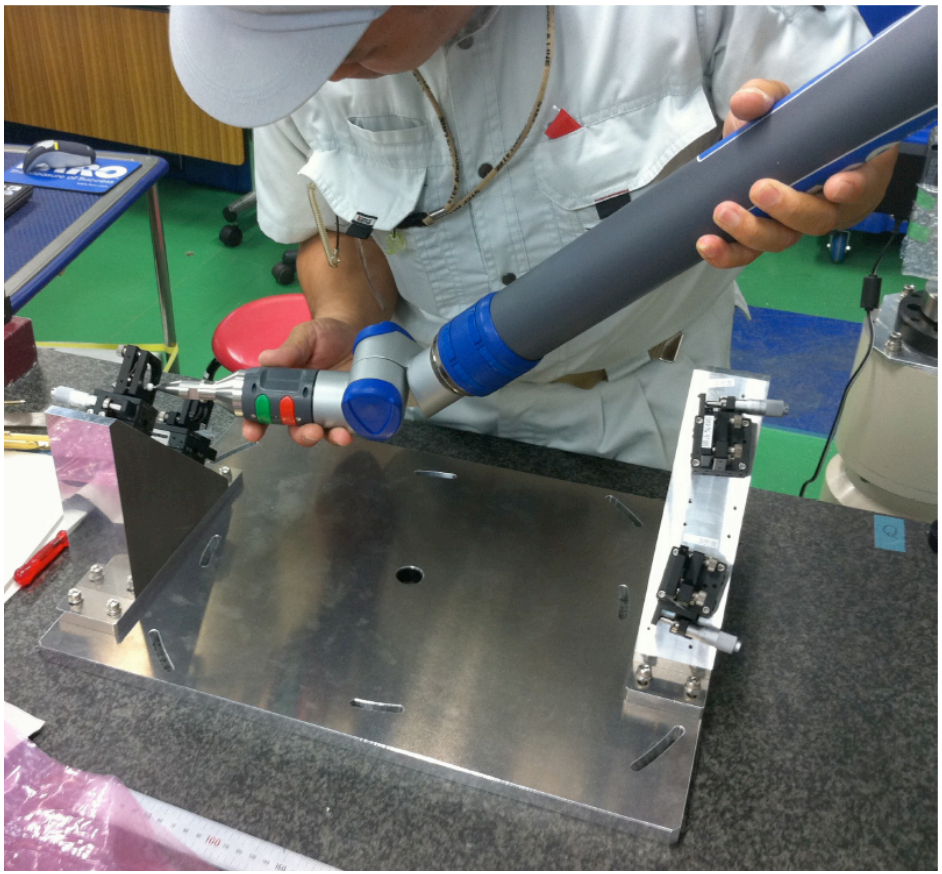
- Assembled by commercially available parts (mostly).
- More adjustable.
- More open structure. We can measure position of mirrors by 3D measuring machine.
- Test the theoretical model.

3D Measuring Machine

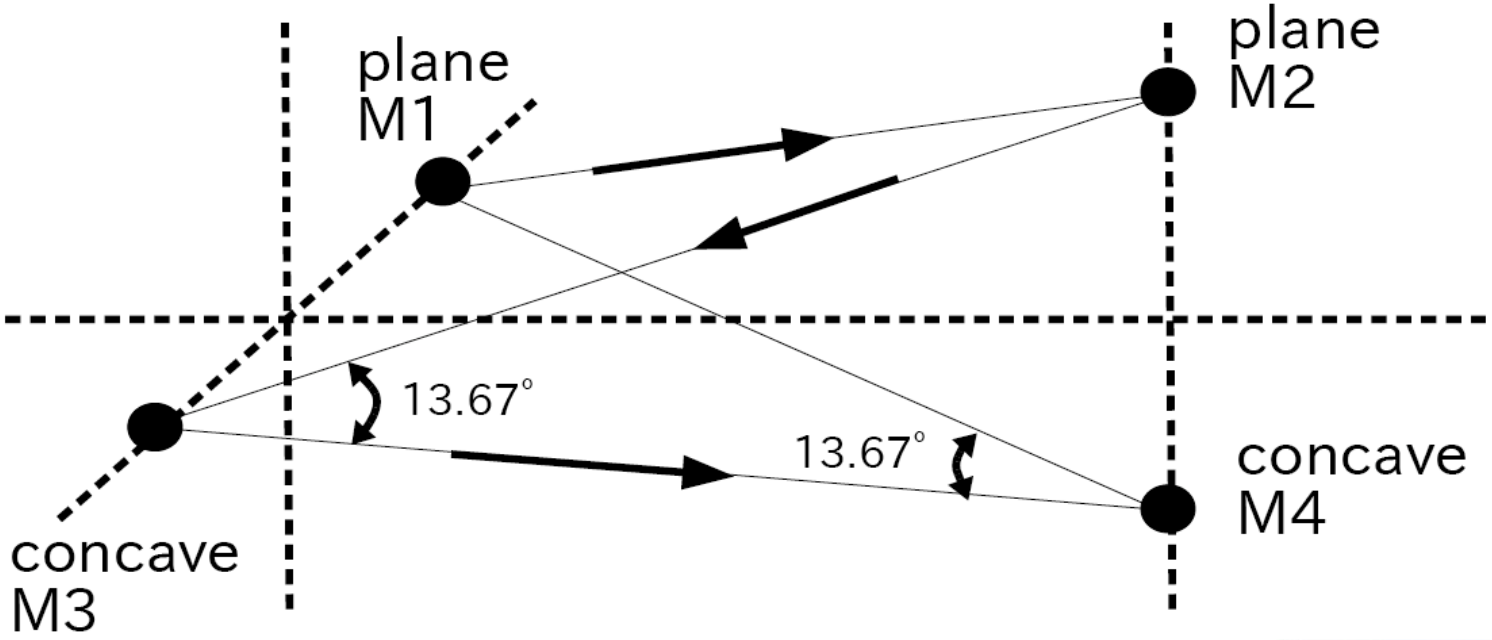
FaroArm

Measure 3D position in 100 micron accuracy.

In order to make comparison with the theoretical model calculations, to reduce ambiguity in geometry is important.

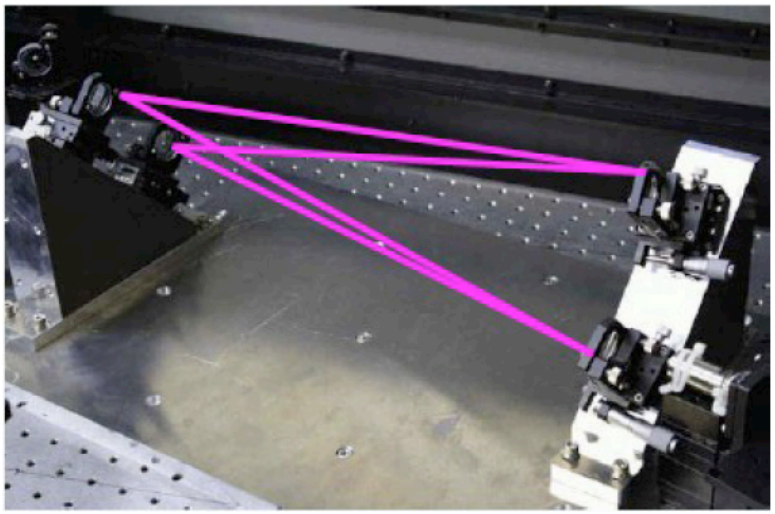


Geometry of the Test Bench Cavity



L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

M2-M4=100mm
M1-M3=100mm



We made theoretical model

Transfer matrix of a single roundtrip

$$M = D(L3/2)\cdot R(\alpha 3)\cdot F(f_t, f_s)\cdot D(L2)\cdot R(\alpha 2)\cdot D(L1)\cdot R(\alpha 1)$$
$$\cdot D(L4)\cdot R(\alpha 4)\cdot F(f_t, f_s)\cdot D(L3/2)$$

Drift space

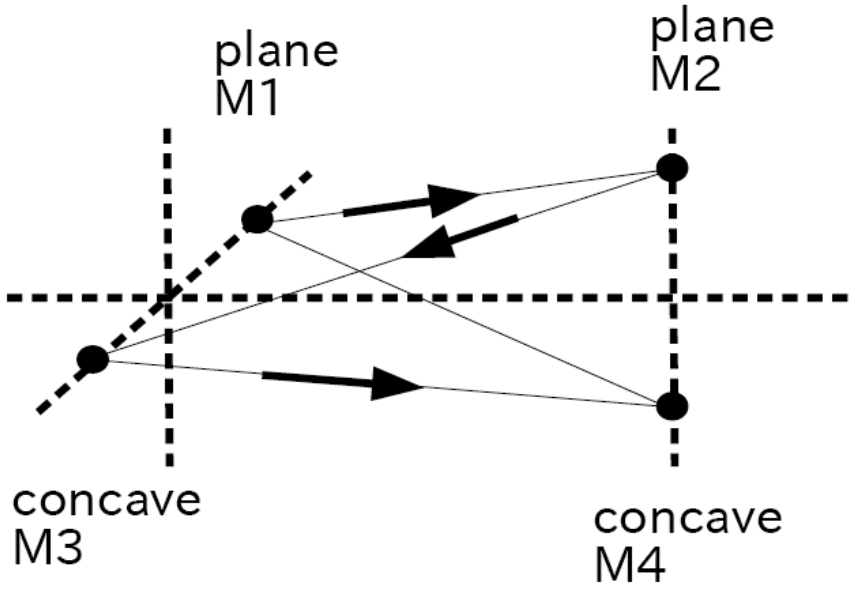
$$D(L)=\begin{pmatrix} 1 & 0 & L & 0 \\ 0 & 1 & 0 & L \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Concave mirror

$$F(f_1, f_2)=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -1/f_1 & 0 & 1 & 0 \\ 0 & -1/f_2 & 0 & 1 \end{pmatrix}$$

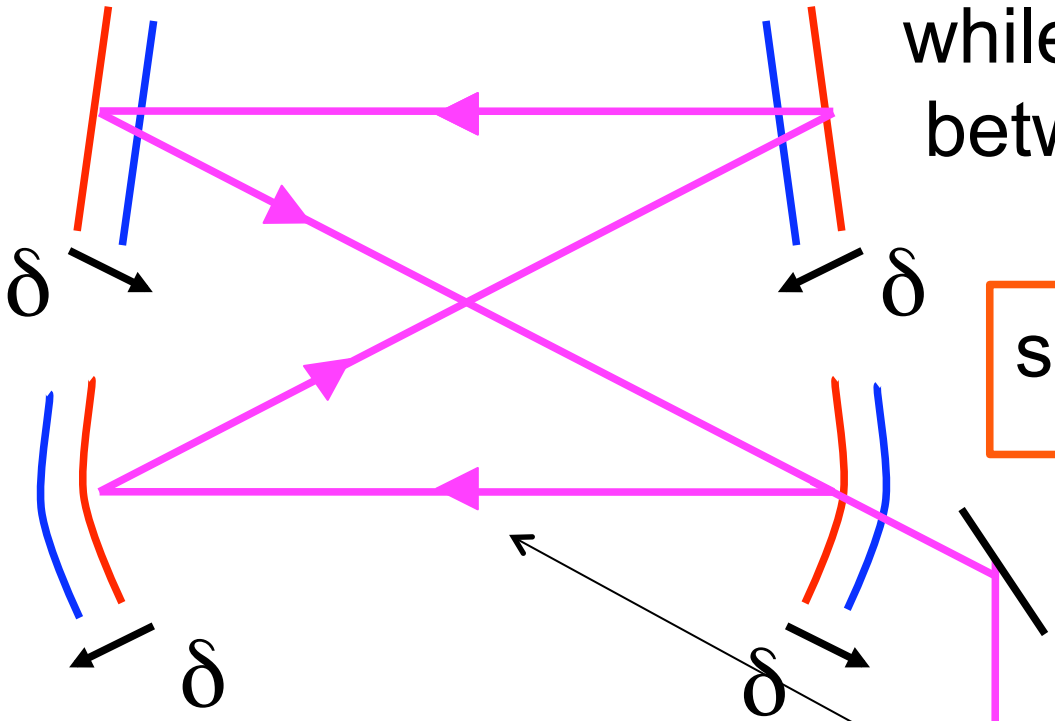
Rotation

$$R(\alpha)=\begin{pmatrix} \cos\alpha & \sin\alpha & 0 & 0 \\ -\sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & \cos\alpha & \sin\alpha \\ 0 & 0 & -\sin\alpha & \cos\alpha \end{pmatrix}$$

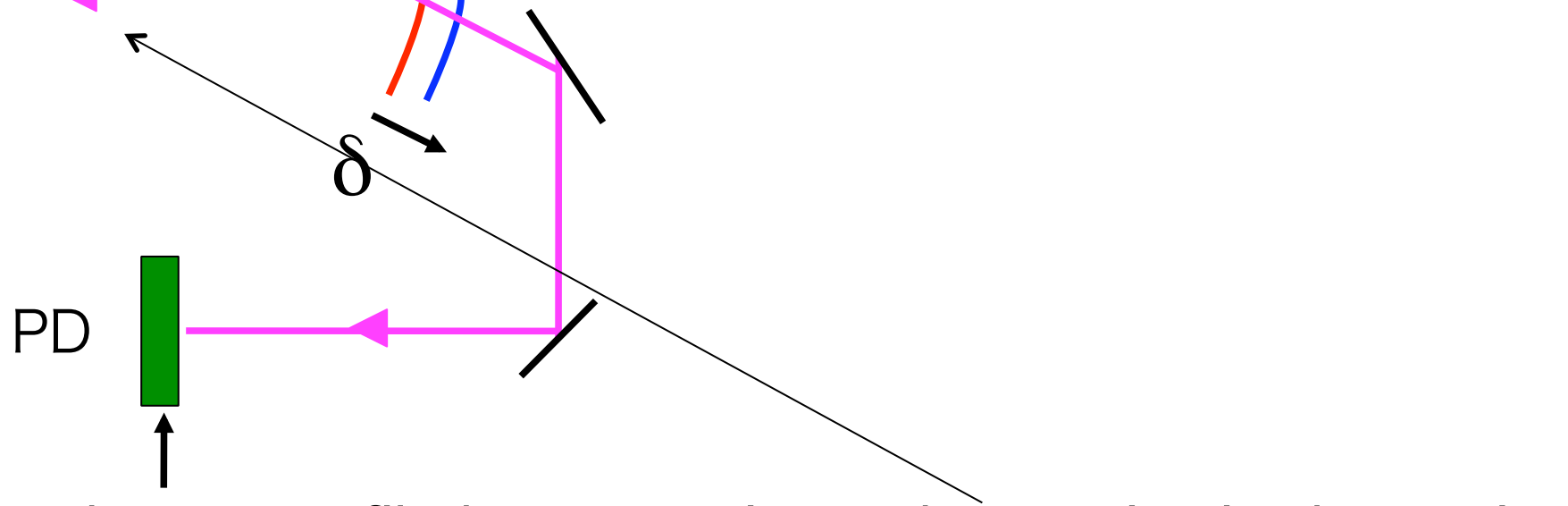


Property of 4M Cavity

δ: keeping circumference constant while changing distance between mirrors



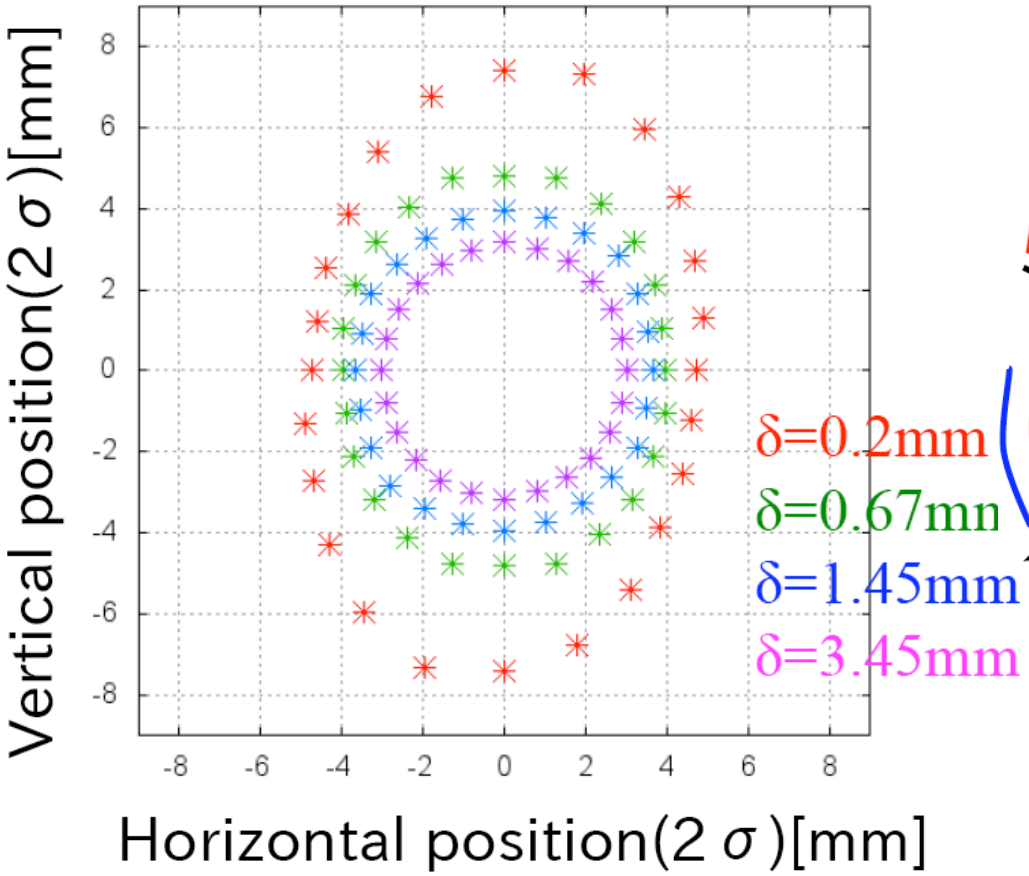
smaller δ : smaller beam waist



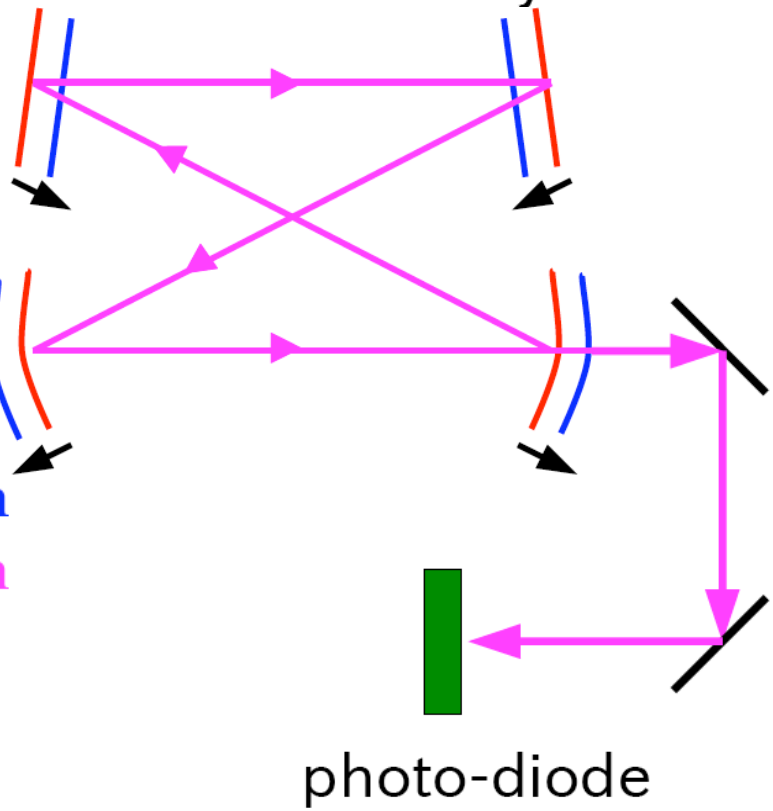
measure beam profile here-->estimate beam size in the cavity

Measurement at outside

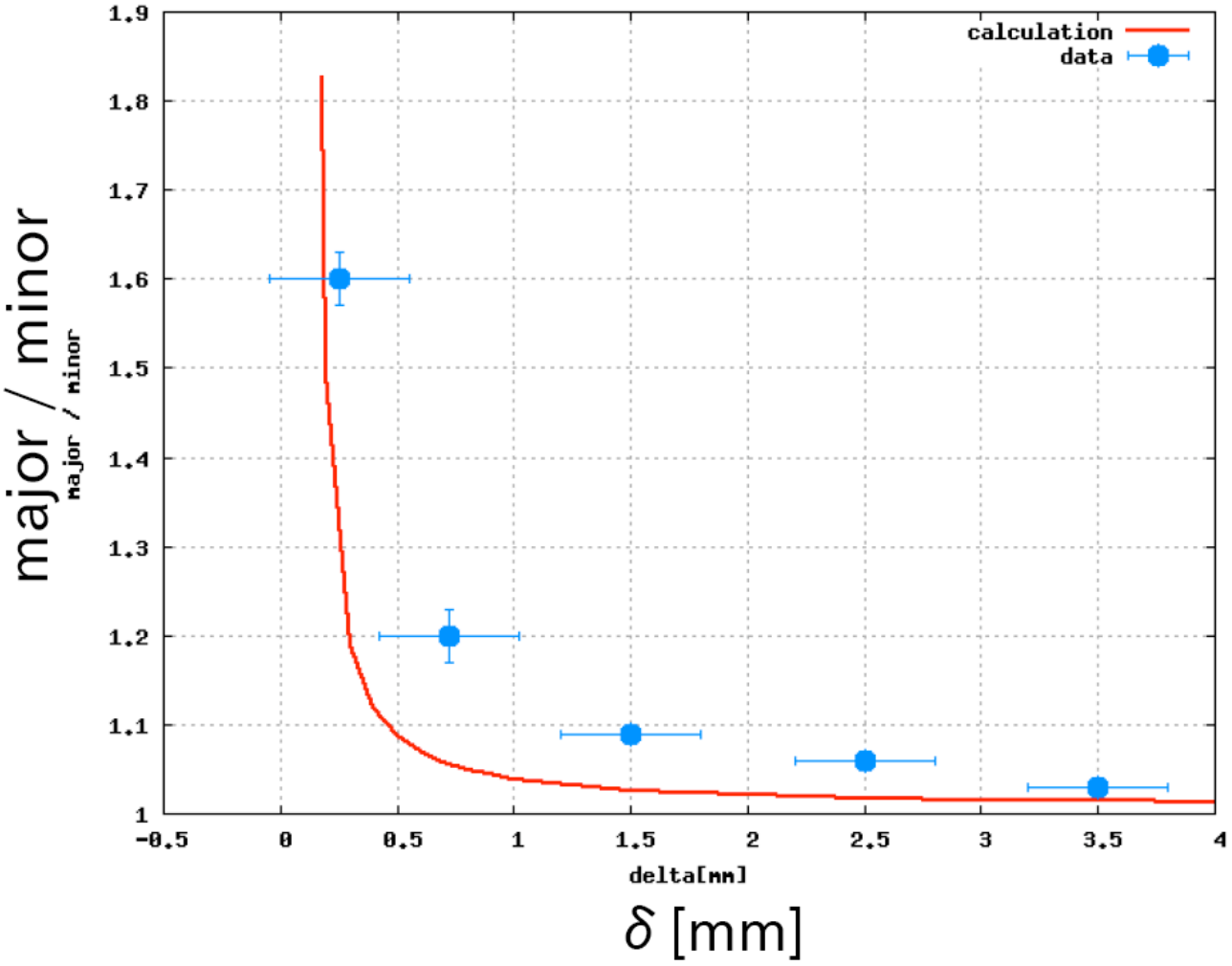
Profile of the transmitted light



We measured the transmitted power at outside 0.4m from cavity.



Comparison: Measurement & Model Calculations



$\delta = (L3-R)/2$

L3 is distance between concave mirrors.

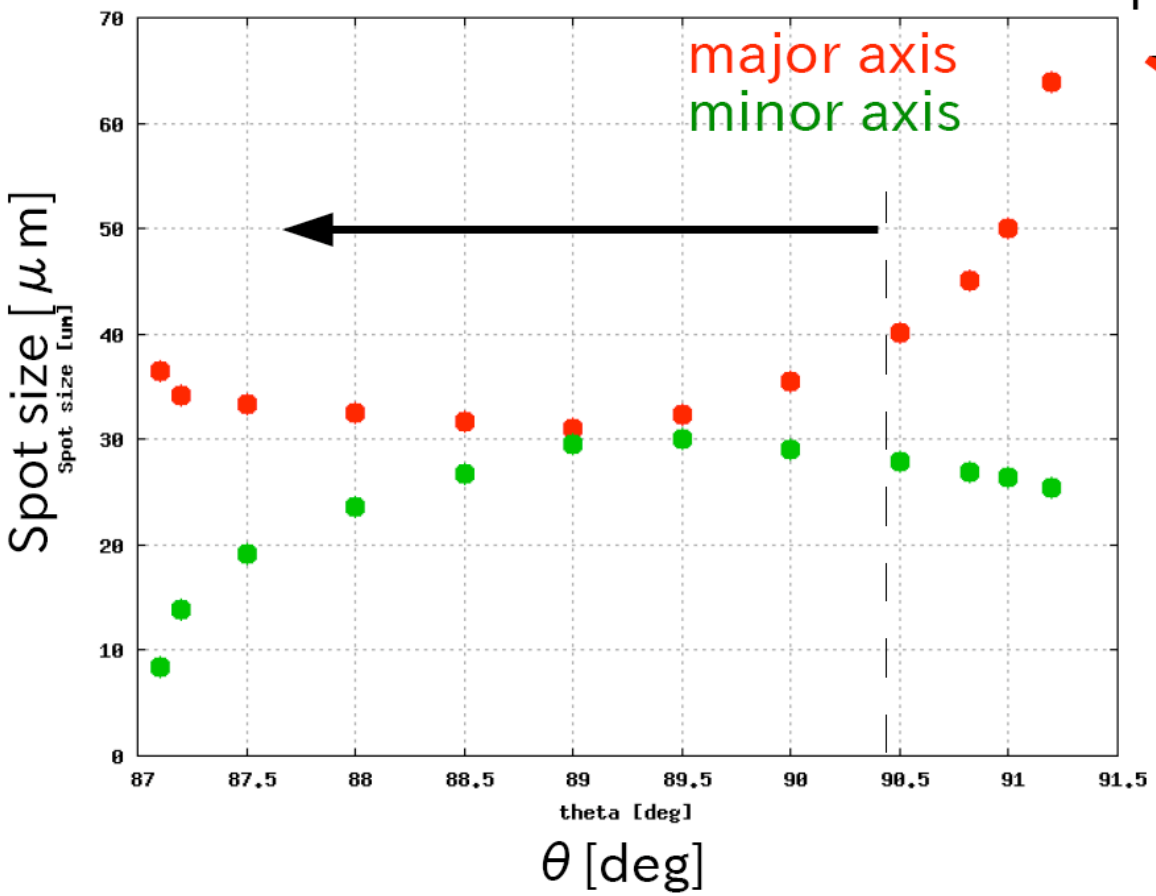
R is the curvature.
R = 422.8 ± 0.3mm

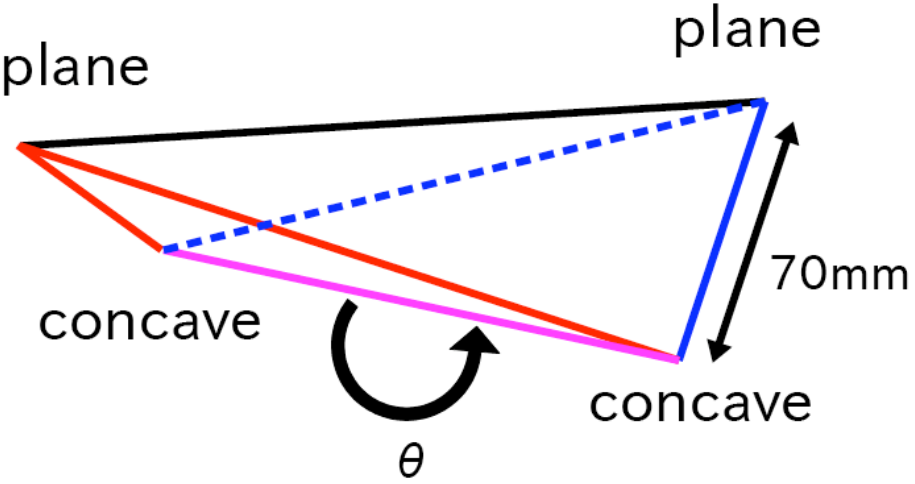
We got good agreement.

Optimization by using the theoretical model

An example: Choice of twist angle

at the center of concave mirrors

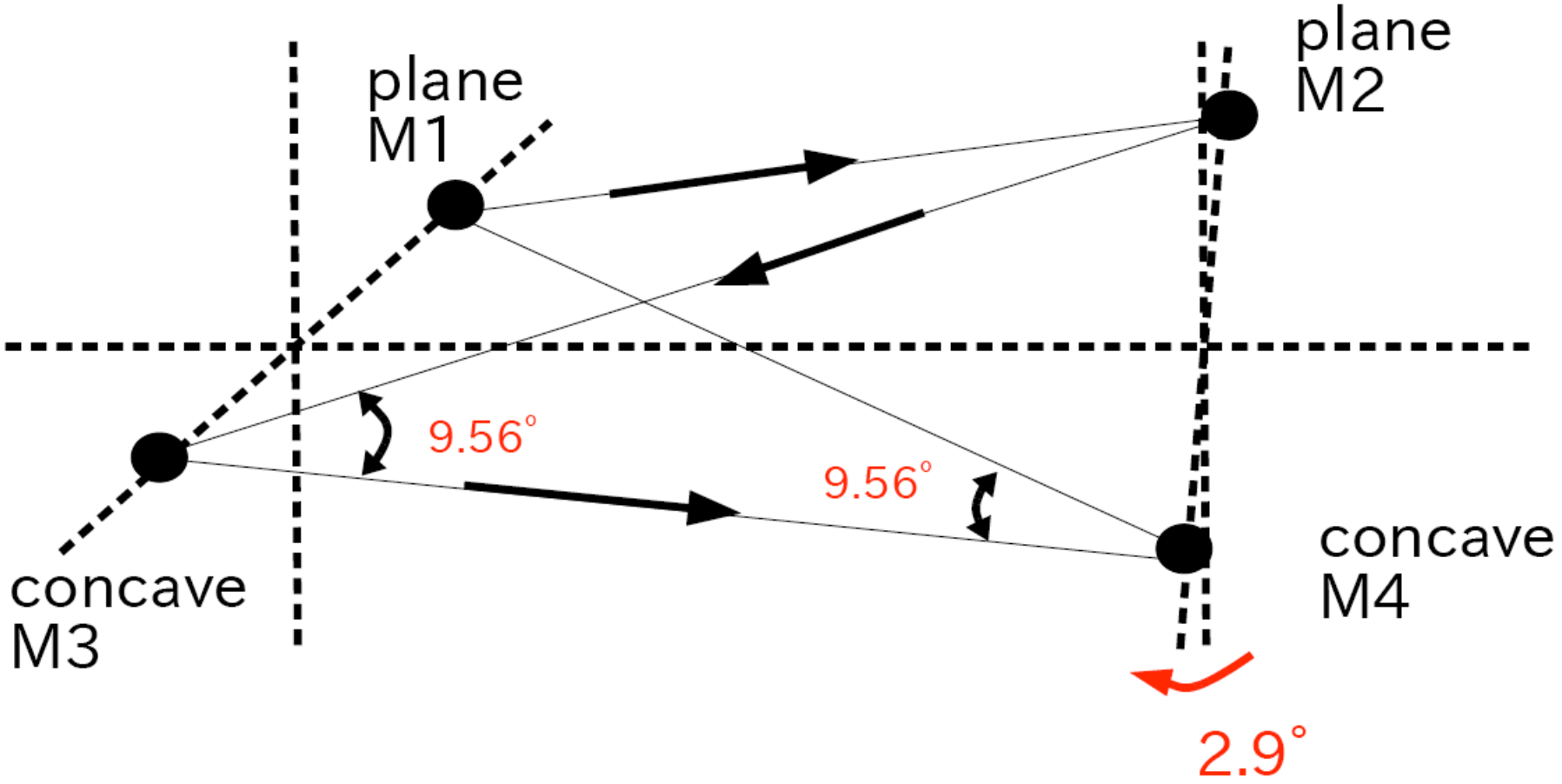




L 3(concave – concave)
=420.10mm

d=70mm

New Design

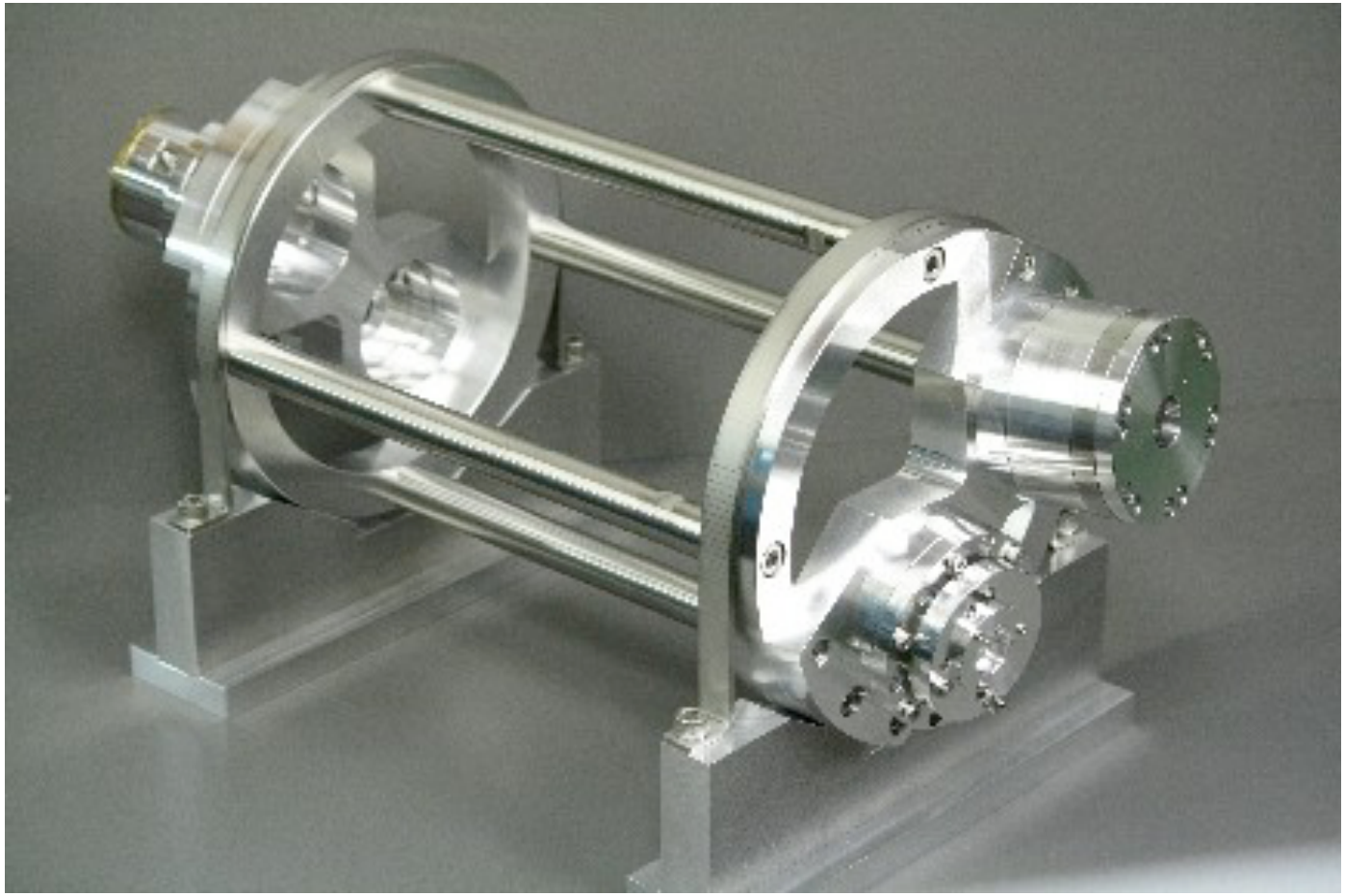


L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

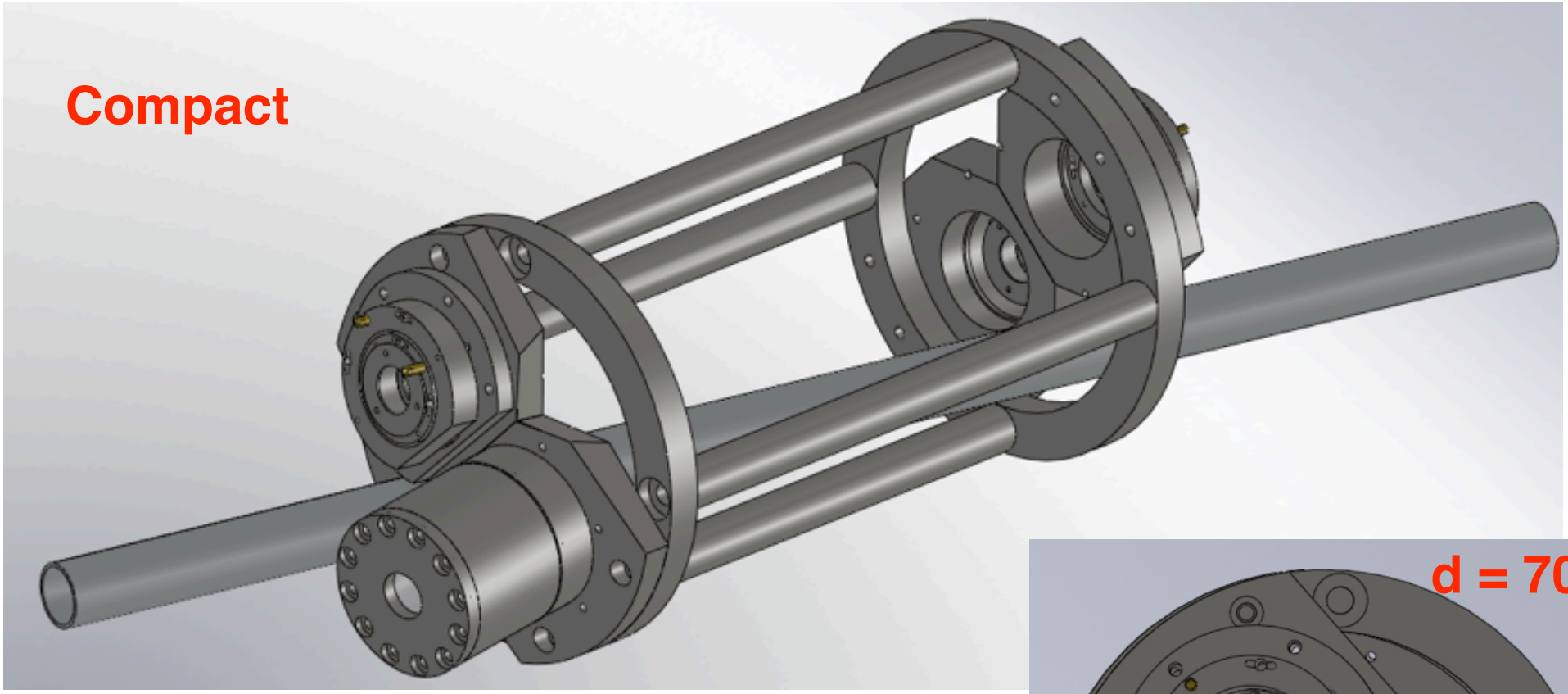
M2-M4=70mm
M1-M3=70mm

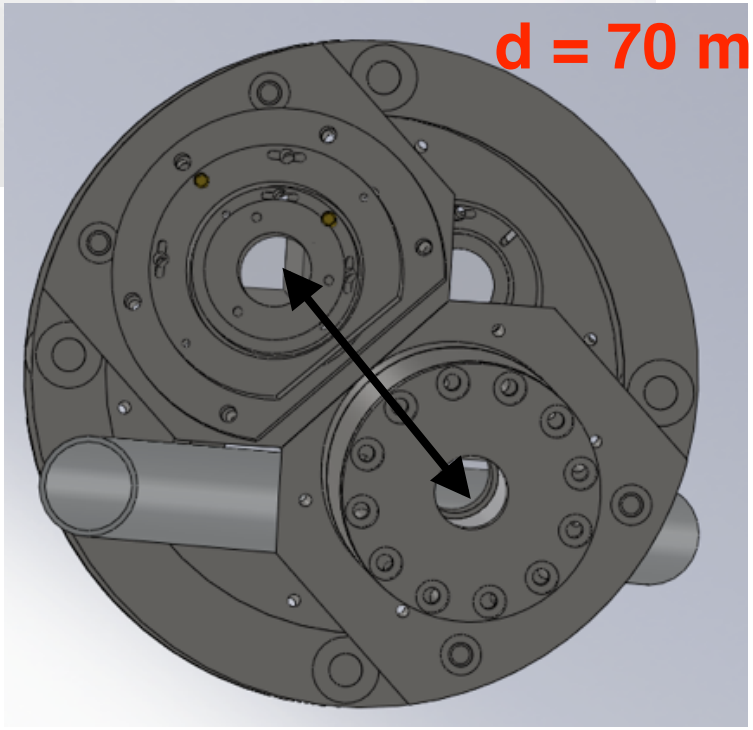
Experience from the Prototype Cavity

- **Gimbal mount is preferable.**
  (The prototype employed kinematic mount.)
- **Easy to see the mirror surface is preferable.**



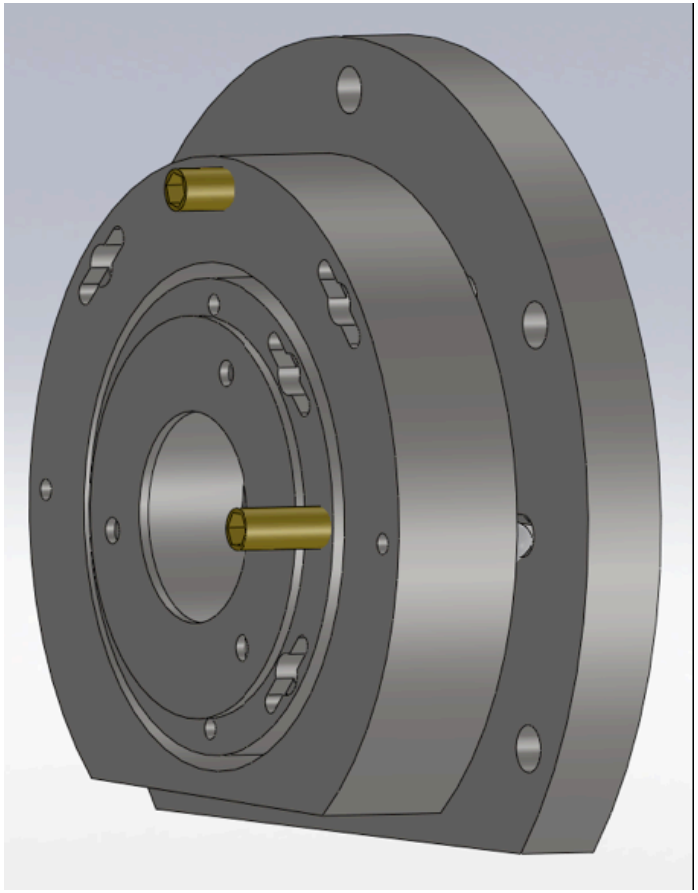
Designing the real Cavity

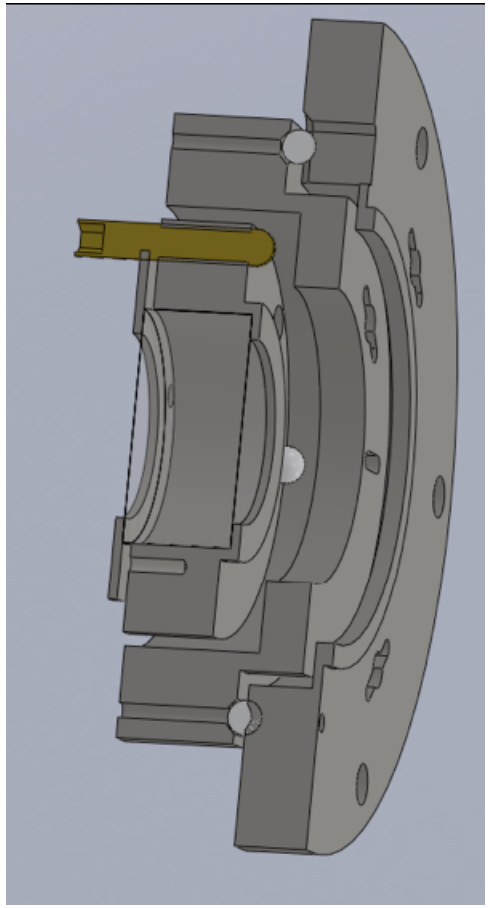


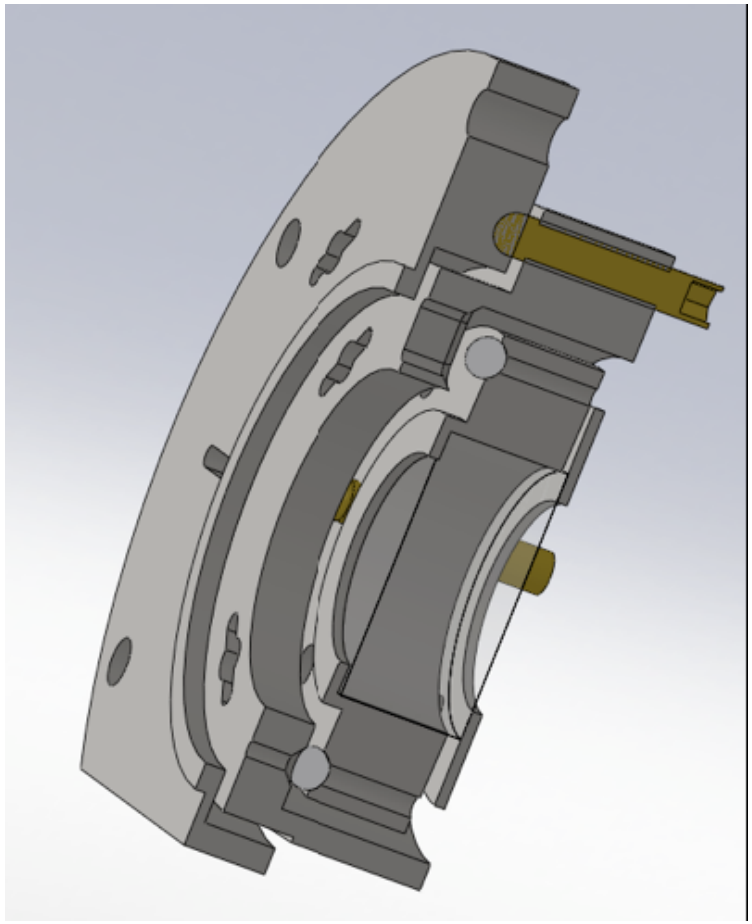


Designing the real Cavity

Gimbal mount

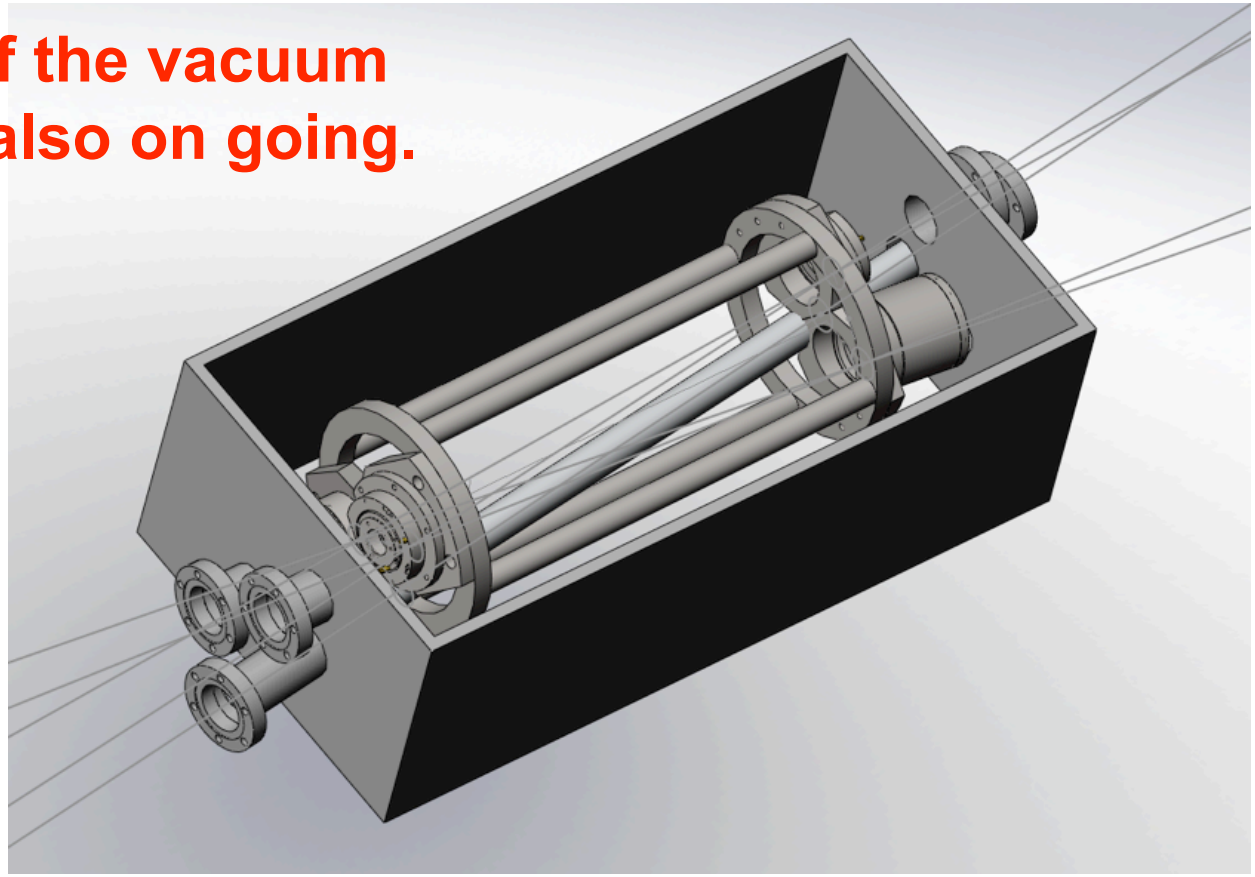


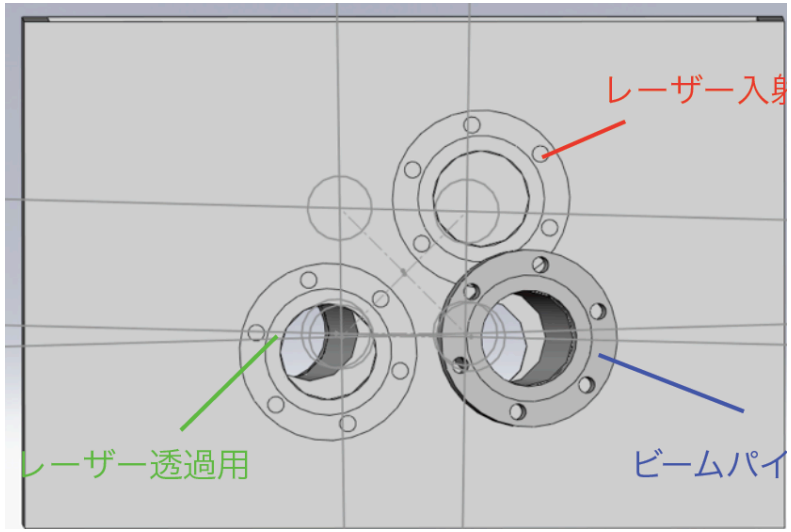


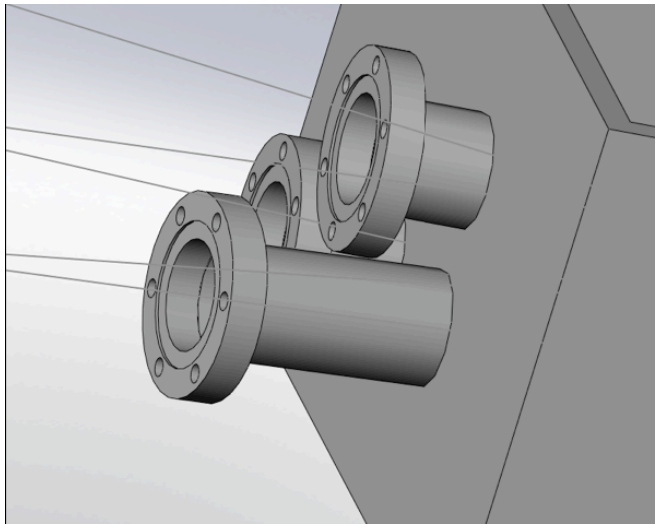


Designing the real Cavity

Designing of the vacuum chamber is also on going.







Schedule of 4M cavity

- Designing is on going.
- Fabrication will be finished by the end of March 2010.
- Designing of the vacuum chamber is also on going.
- We will install the "Japanese" 4M cavity in ATF at summer 2011. The "Japanese" 4M cavity and the "French" 4M cavity will play complementary roll in our entire study plan.

SUMMARY

Summary

- Two Activities
  - 2-mirror cavity
  - 4-mirror cavity

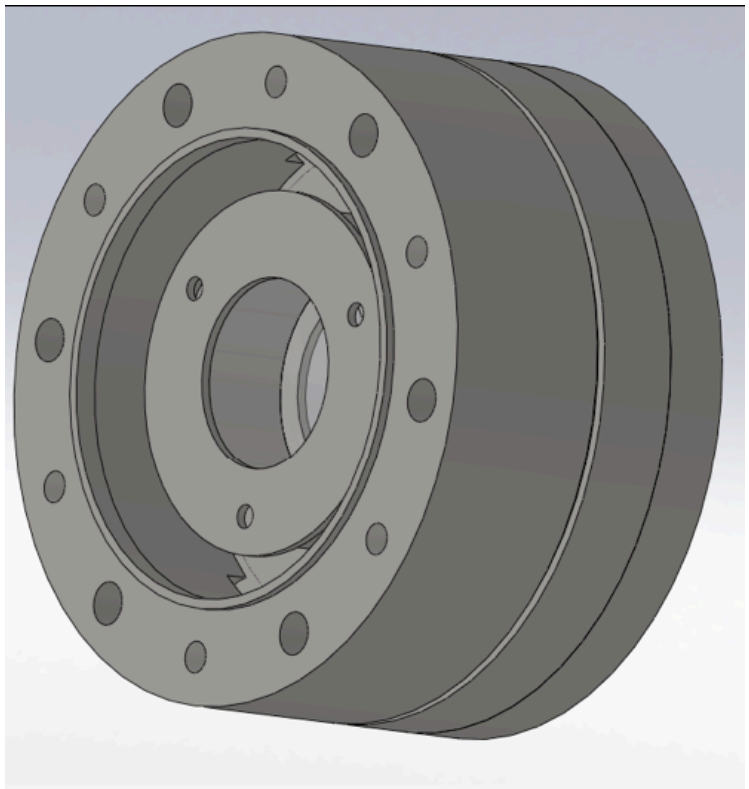
    Inspired by French Activities.

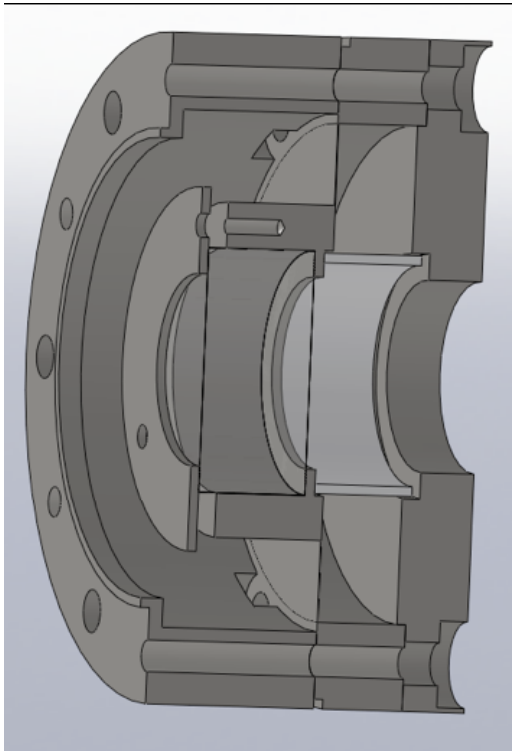
    Many knowledges were/are transferred from French team.

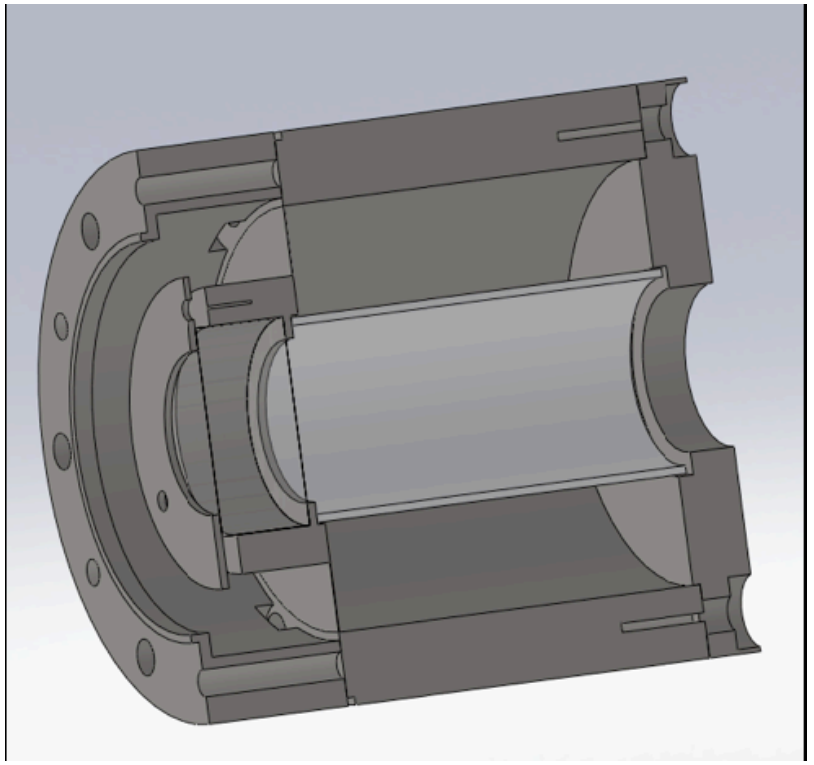
- 2-mirror cavity
  - Enhancement upgrade: x250 --> x760

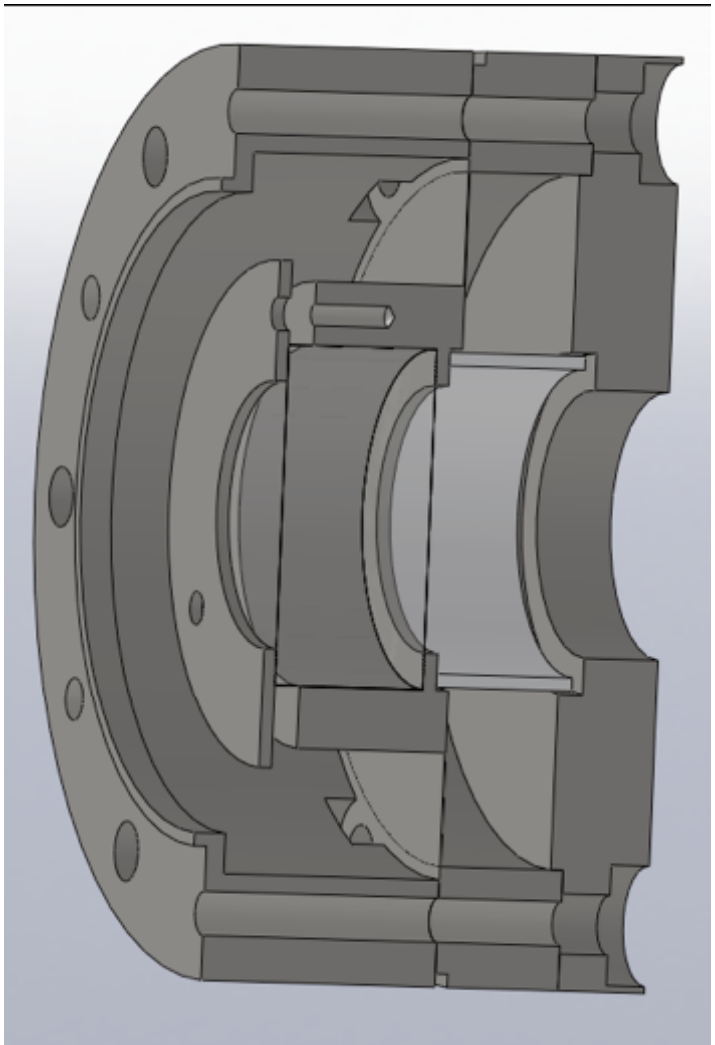
    Stored Power in Cavity: 500 W --> 1.48 kW
  - Almost Ready to take Bunch-by-Bunch Data
- 4-mirror cavity
  - Test bench cavity and comparison with theory.
  - Prototype cavity experience.
  - Real cavity design is on going with vacuum chamber.
  - We will install the cavity into ATF summer 2011.

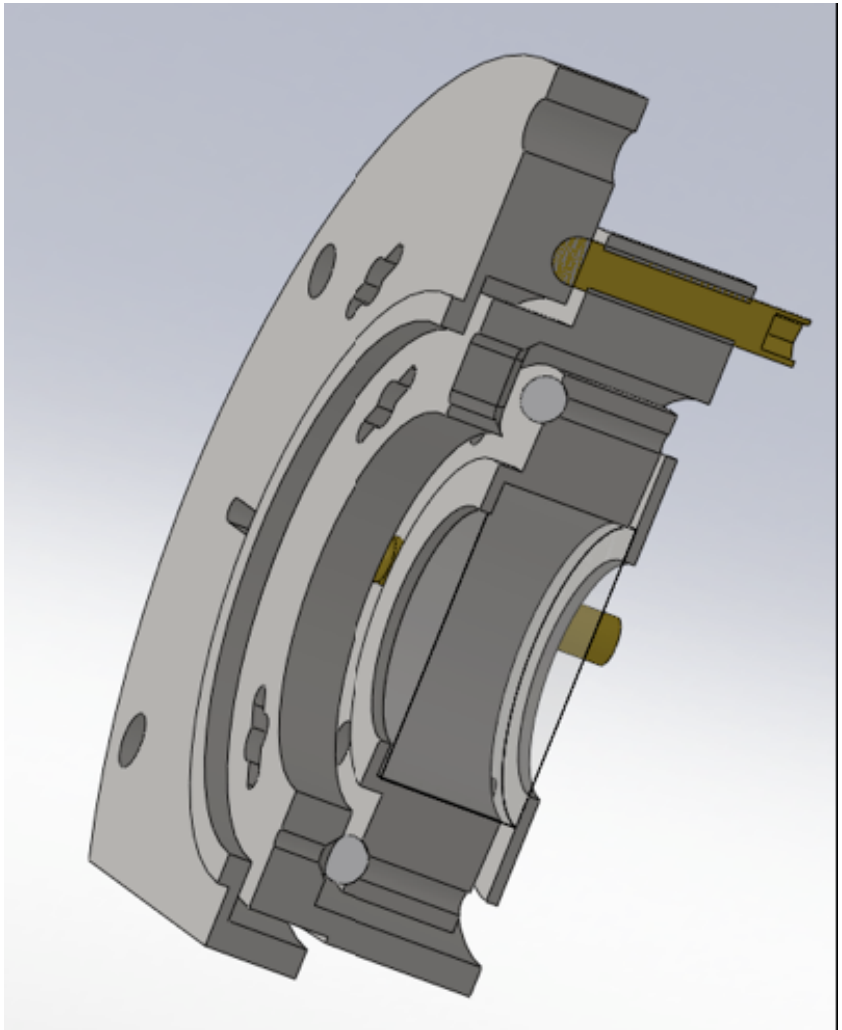
Backups

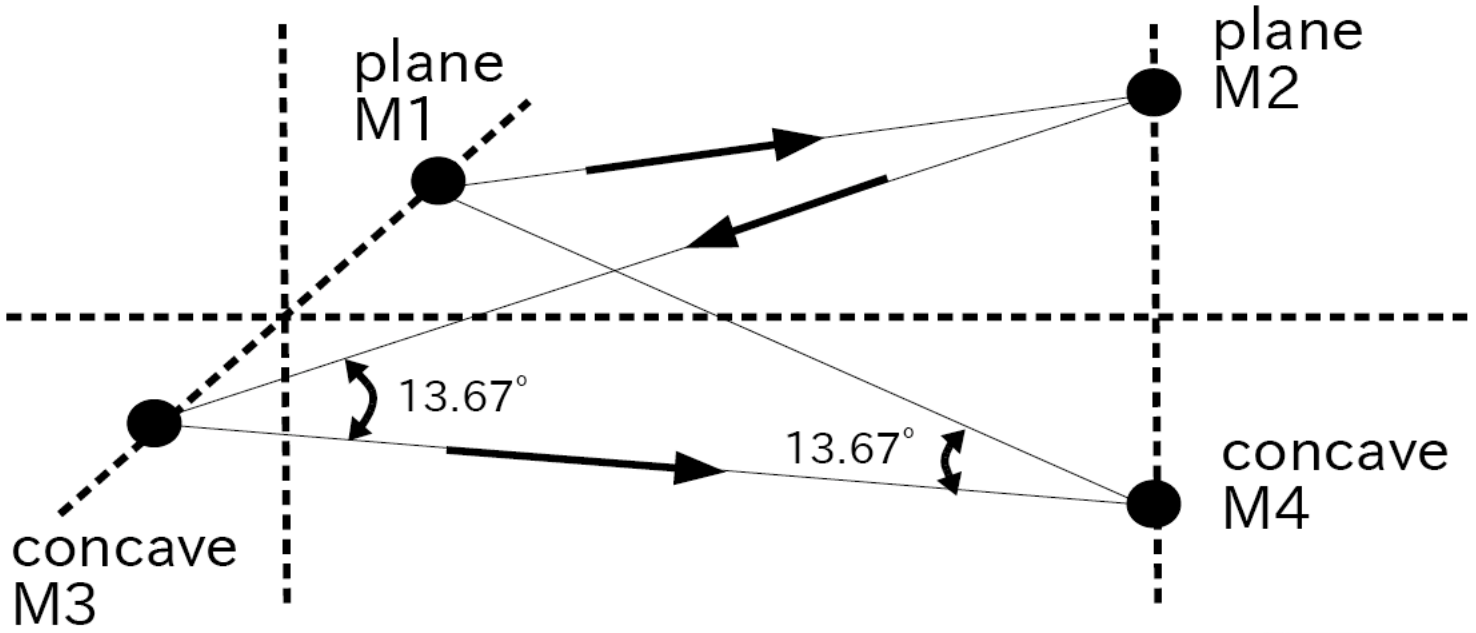






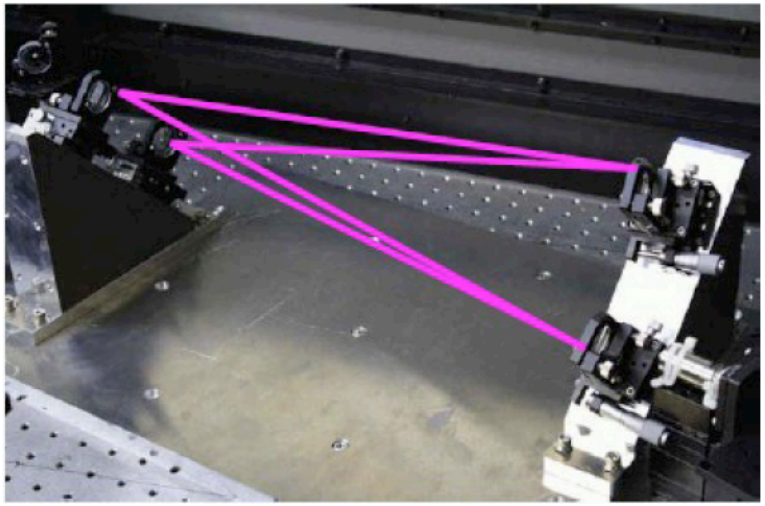






L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

M2-M4=100mm
M1-M3=100mm



Transfer matrix of a single roundtrip

$$M = D(L3/2)\cdot R(\alpha 3)\cdot F(f_t, f_s)\cdot D(L2)\cdot R(\alpha 2)\cdot D(L1)\cdot R(\alpha 1)$$
$$\cdot D(L4)\cdot R(\alpha 4)\cdot F(f_t, f_s)\cdot D(L3/2)$$

Drift space

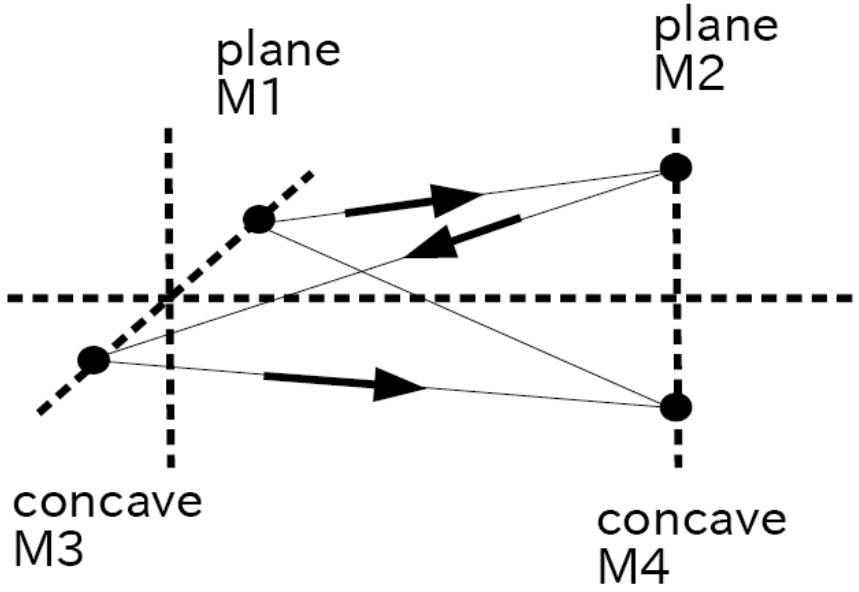
$$D(L)=\begin{pmatrix} 1 & 0 & L & 0 \\ 0 & 1 & 0 & L \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Concave mirror

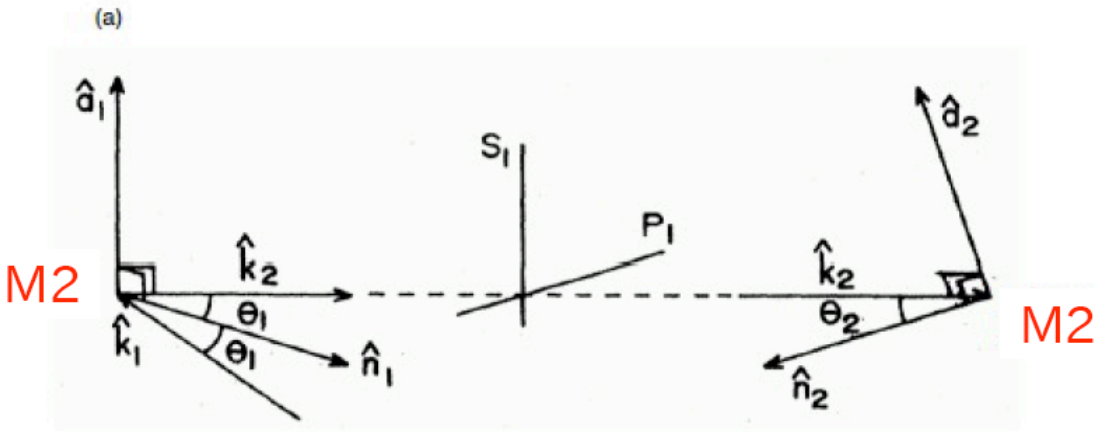
$$F(f_1, f_2)=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -1/f_1 & 0 & 1 & 0 \\ 0 & -1/f_2 & 0 & 1 \end{pmatrix}$$

Rotation

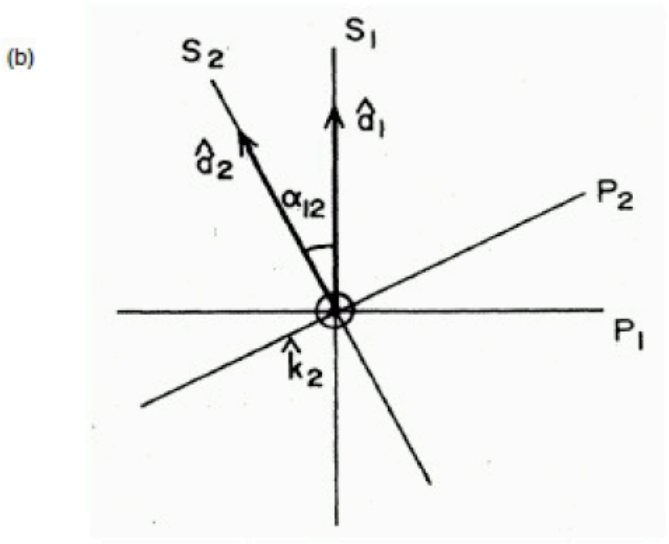
$$R(\alpha)=\begin{pmatrix} \cos\alpha & \sin\alpha & 0 & 0 \\ -\sin\alpha & \cos\alpha & 0 & 0 \\ 0 & 0 & \cos\alpha & \sin\alpha \\ 0 & 0 & -\sin\alpha & \cos\alpha \end{pmatrix}$$



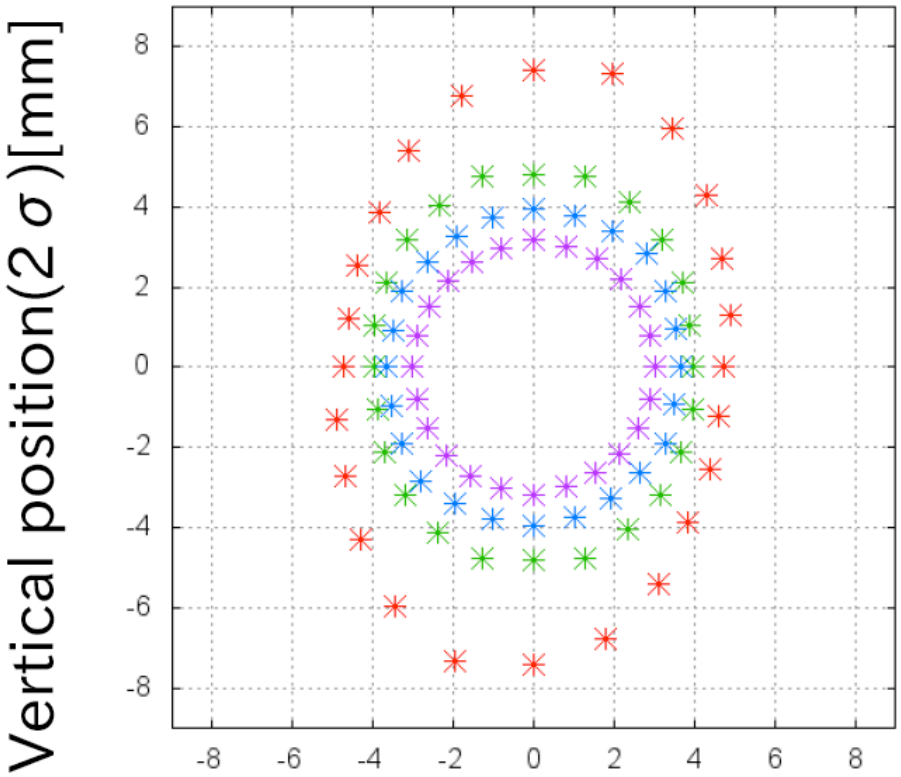
$$\cos\alpha_{12} = \hat{a}_1 \cdot \hat{a}_2$$



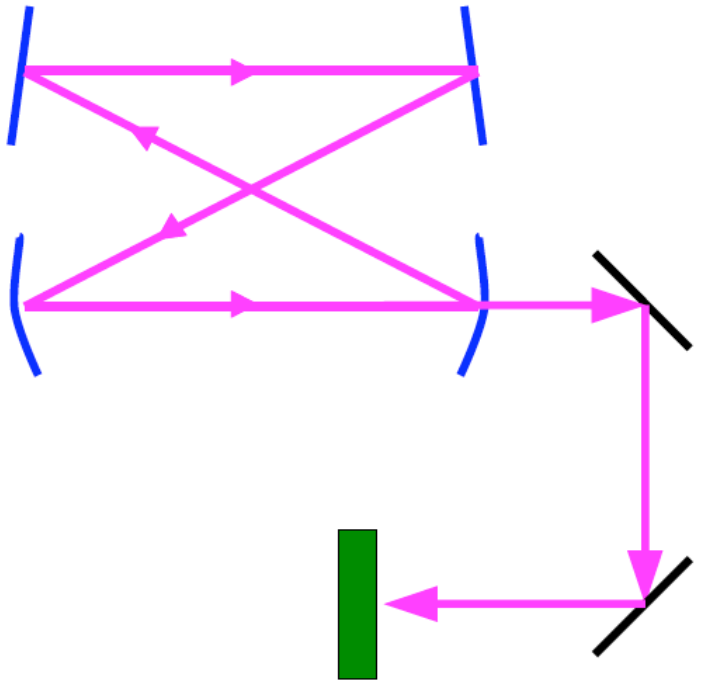
$\alpha 12$ is the image rotation.
$\alpha 12$ = 1.58517 rad
by testbench configuration.

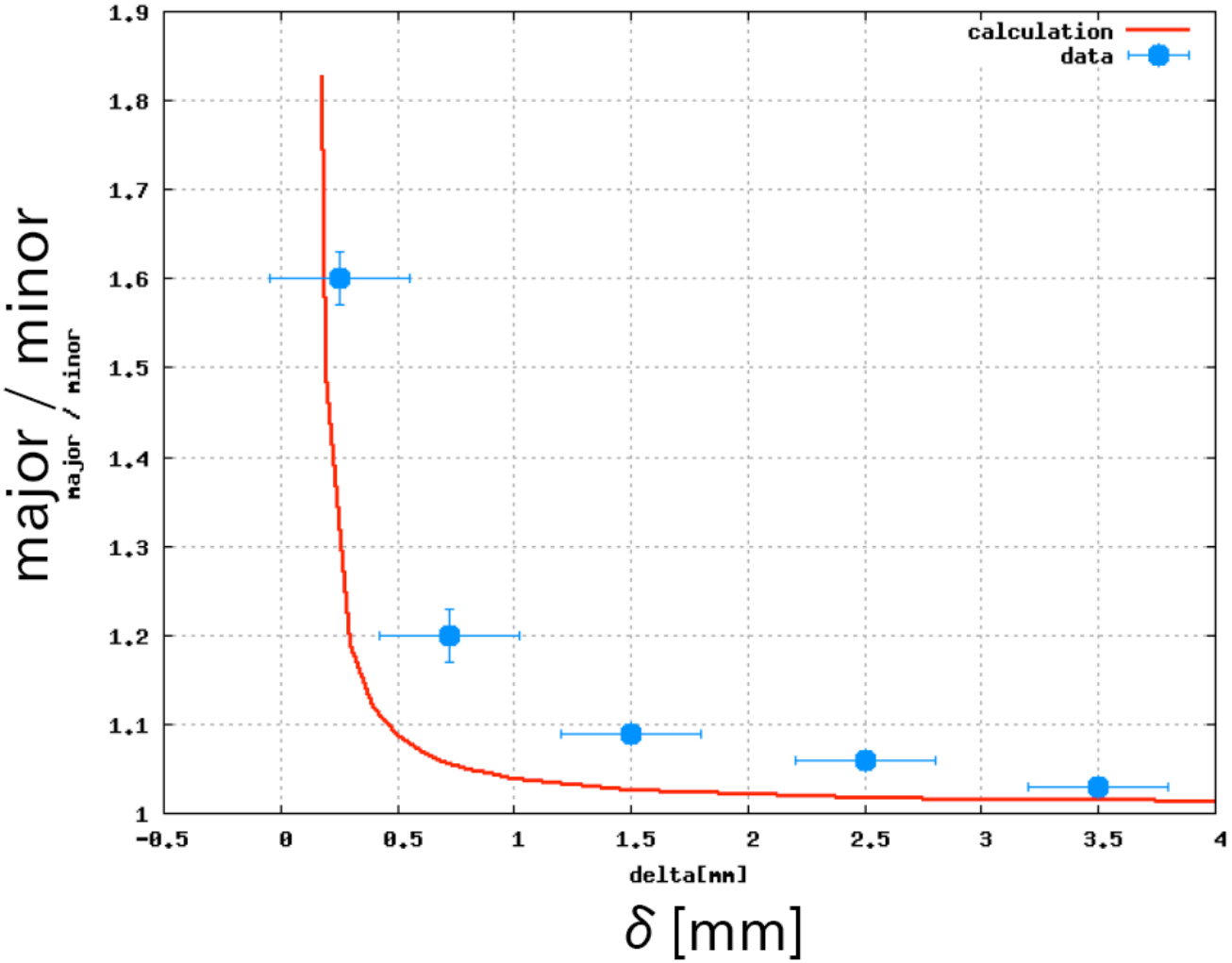


Profile of the transmitted light



We measured the transmitted power at outside 0.4m from cavity.



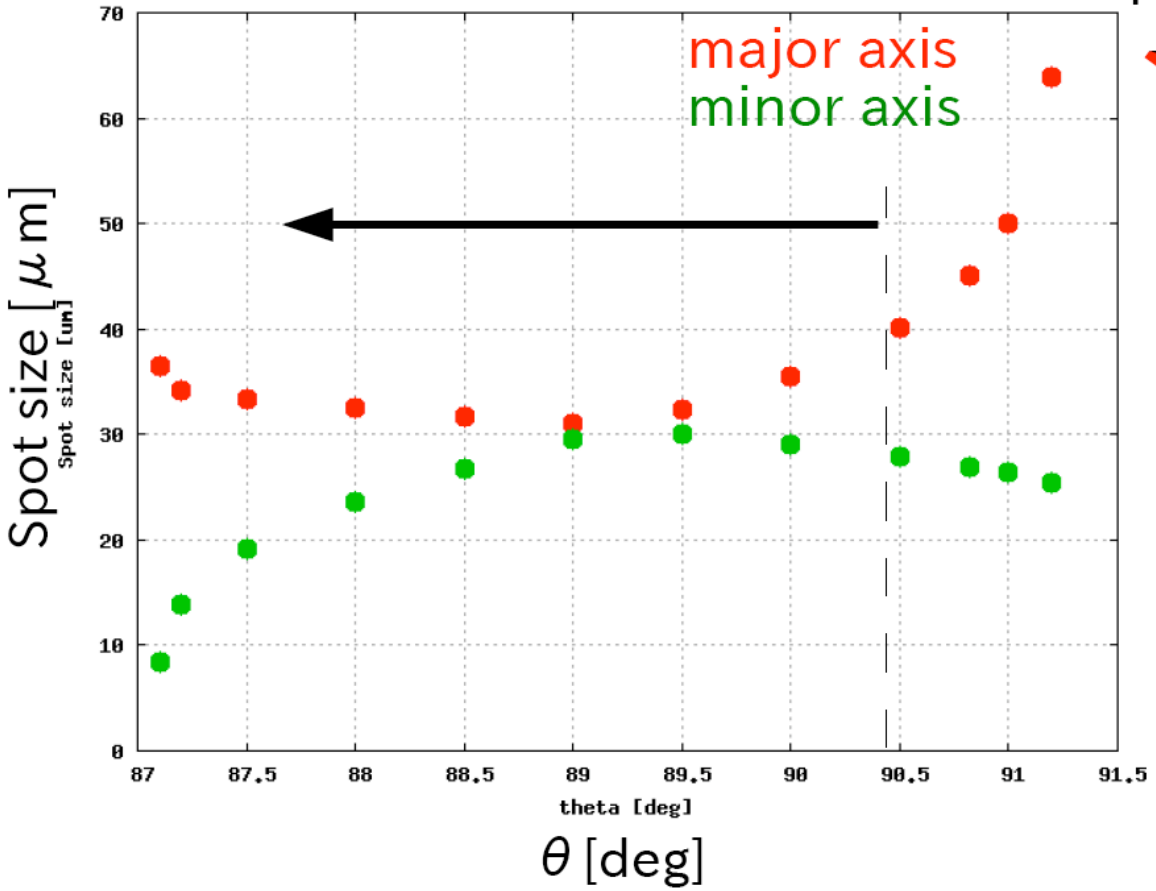


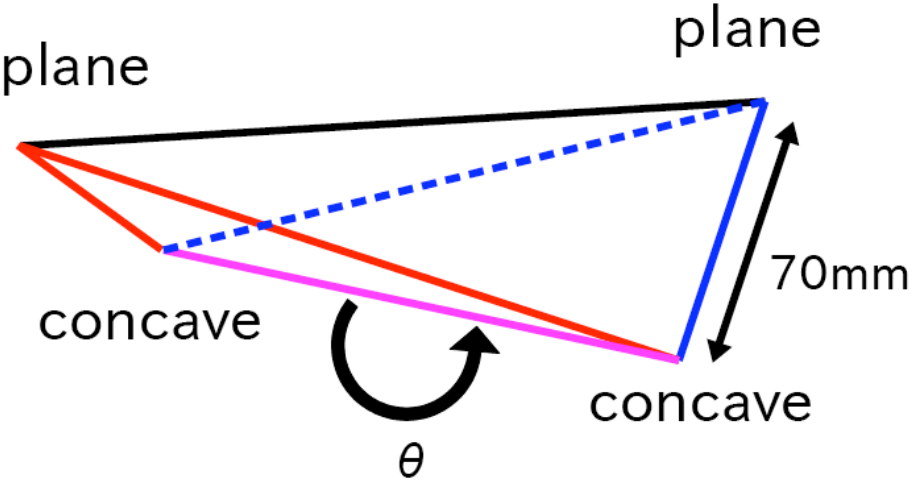
$\delta = (L3-R)/2$

L3 is distance between concave mirrors.

R is the curvature.
R = 422.8 ± 0.3mm

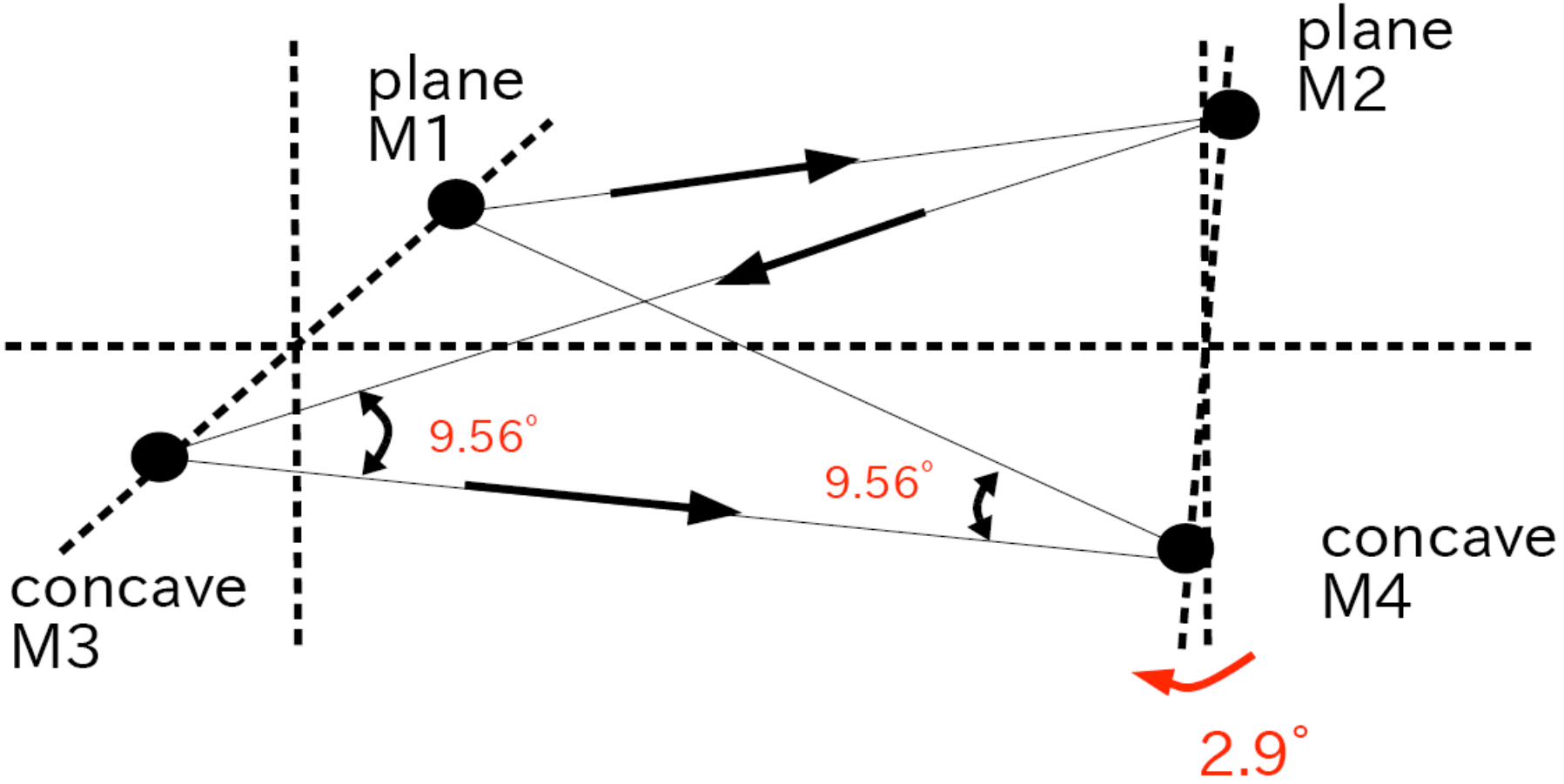
at the center of concave mirrors





L 3(concave – concave)
=420.10mm

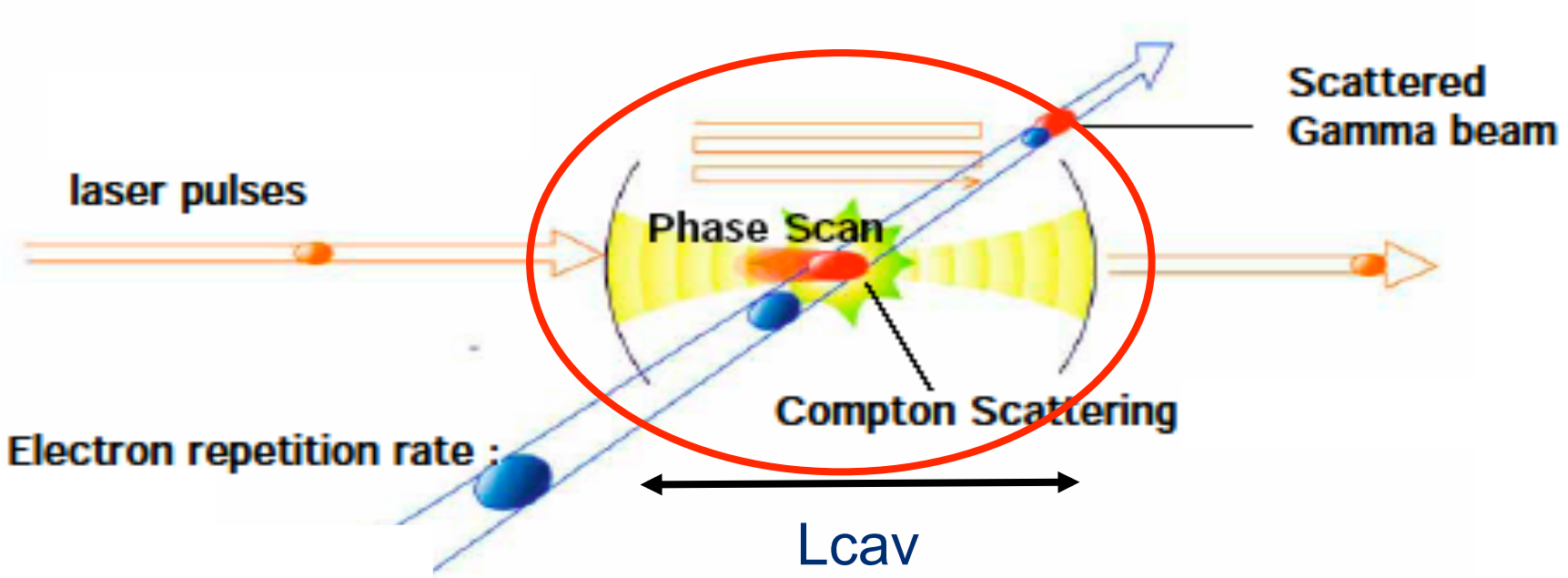
d=70mm



L1=M1-M2=420mm
L2=M2-M3=420mm
L3=M3-M4=420mm
L4=M4-M1=420mm

M2-M4=70mm
M1-M3=70mm

Optical Cavity for Laser-Compton



Higher laser power

L_{cav} = n $\lambda/2$, ΔL<nm laser for pulse stacking

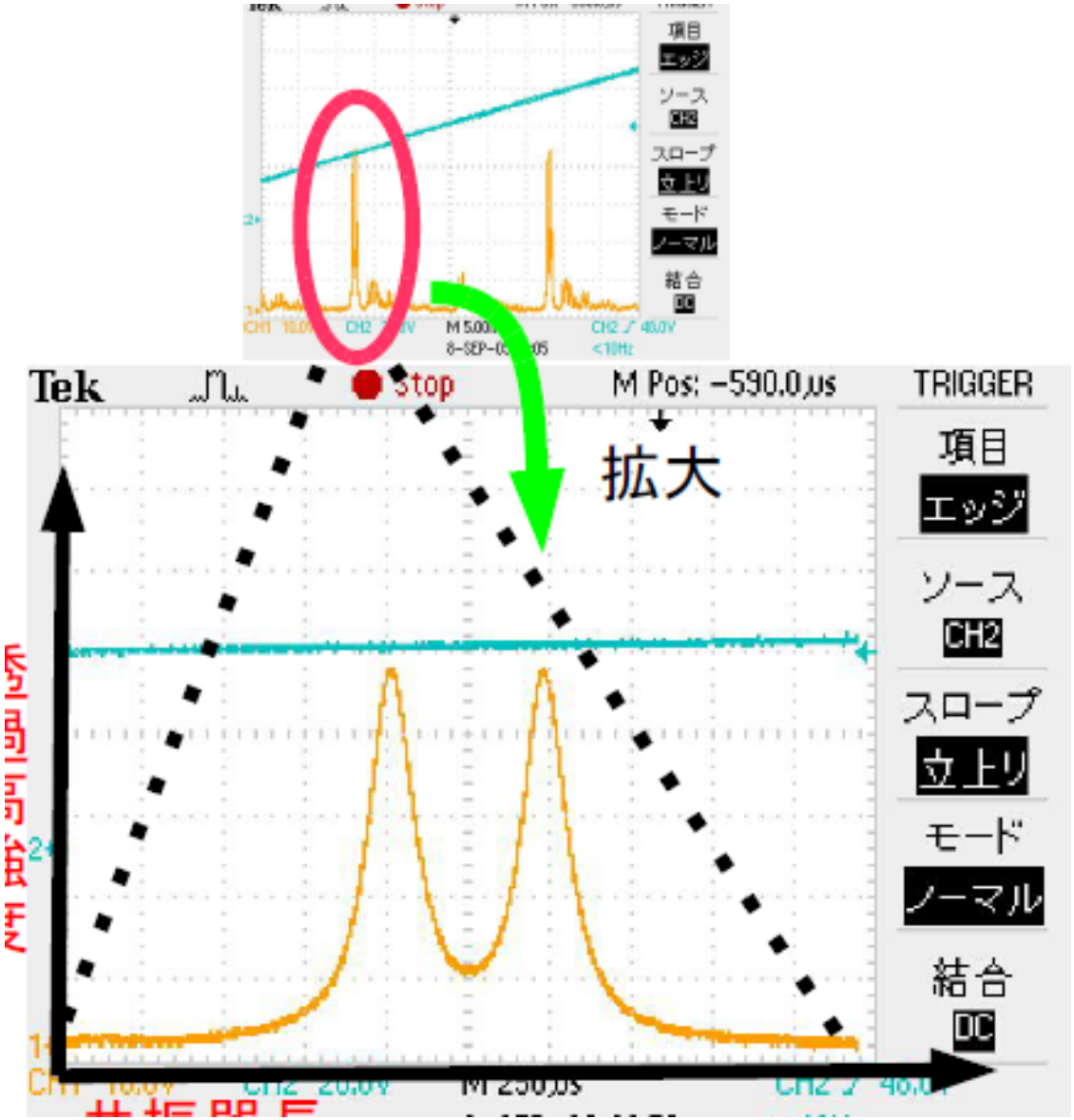
->more enhancement the more precision

ΔT < ps

Laser should be focused for high power density

Accommodate laser cavity in the accelerator

at ALCPG09

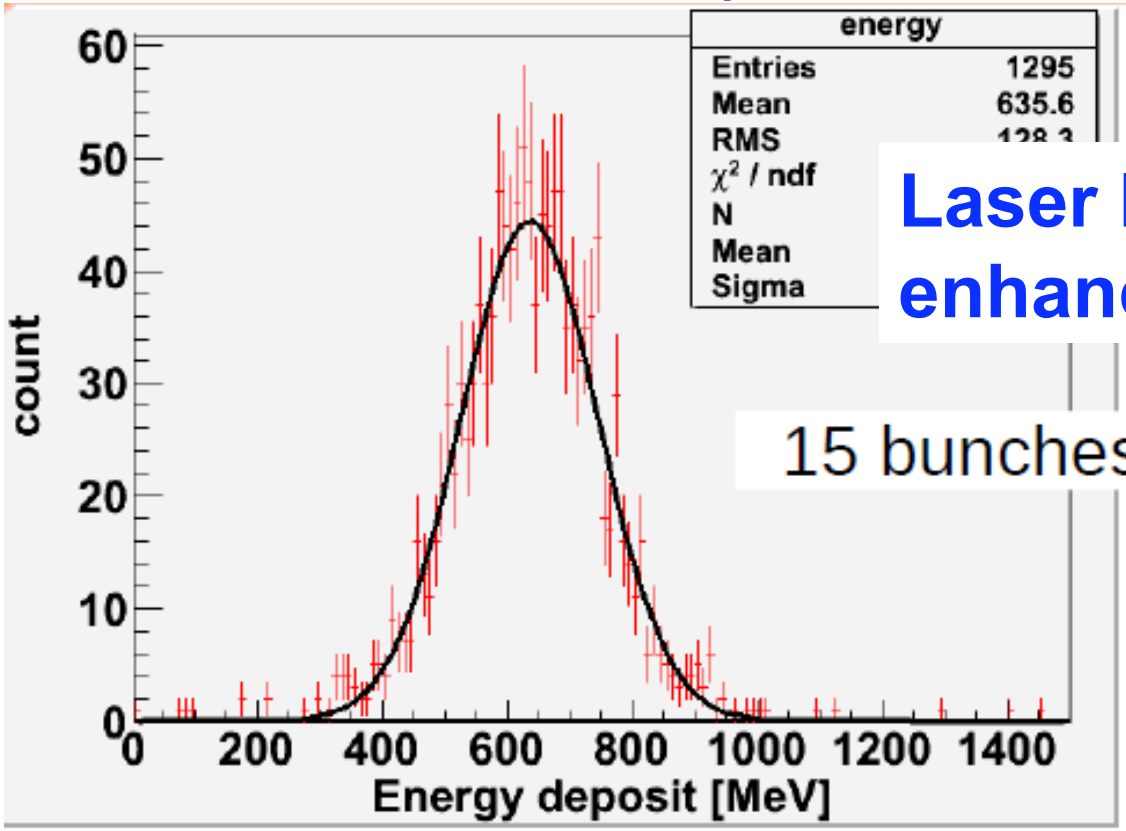


3D 4M cavity resonates with left and right circular polarizaton separately

This is due to geometric phase since light travels twisted path

but situation was more complicated

Result as of 2008 (Reported TILC09)



Laser Power ~500W
enhancement 250

15 bunches / train

27 gamma ray / crossing

Next step

more power enhancement

bunch by bunch observation

AFTER TILC09

- One of the Mirror was replaced with the higher reflectivity one
  - 99.6% -> 99.9%
  - power enhancement
    - 250 -> ~750
  - more precise controll required (~0.1nm)

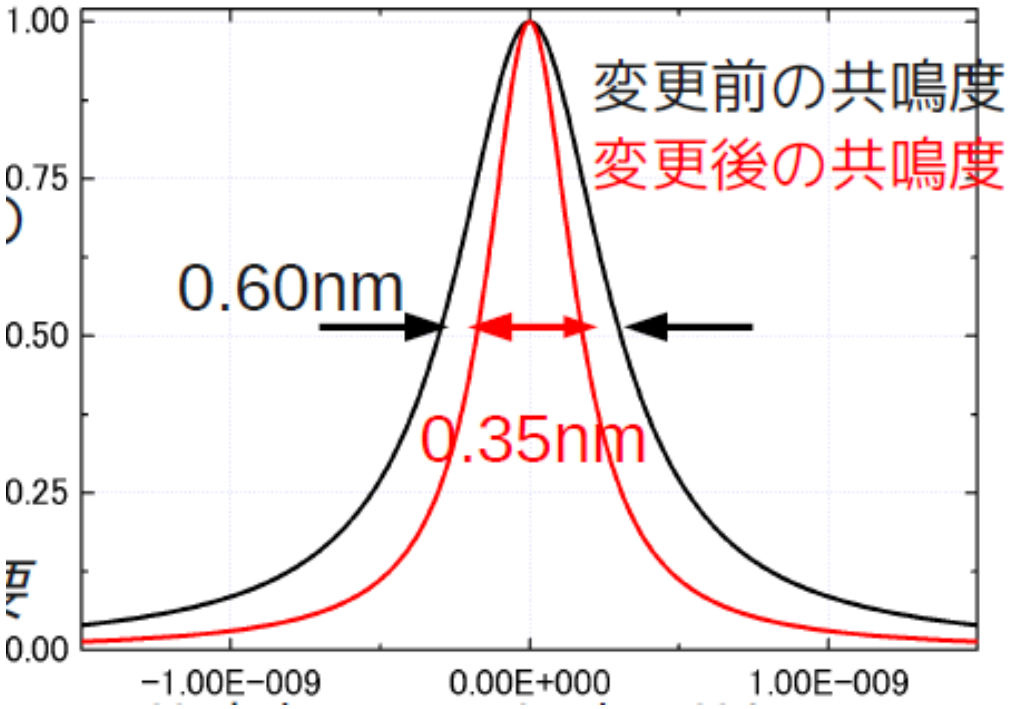
- Status of the cavity w/ new mirror
  - now in ATF DR
  - got 3 times more photons

More enhancement
More precise control

- (99.64%, 99.64%) to (99.64%, 99.94%)
- enhancement: 250 to 760

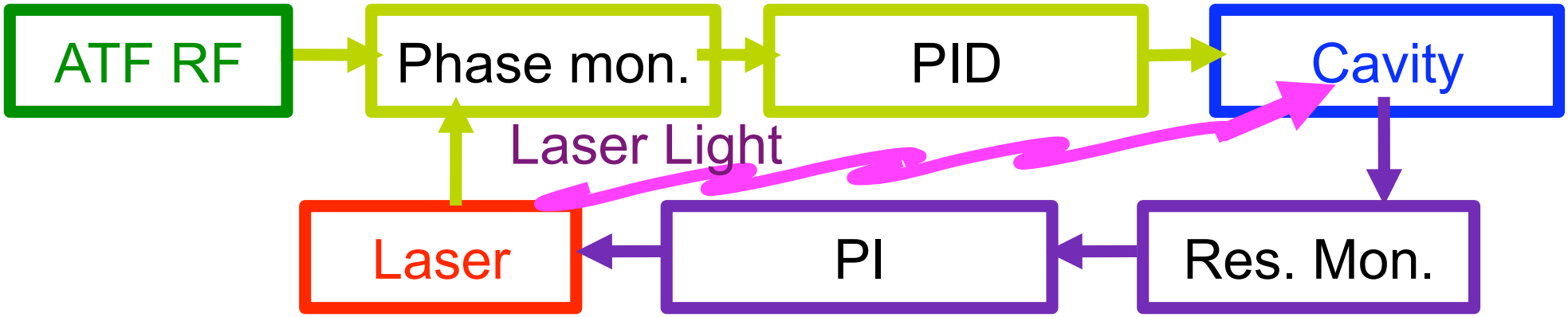
Witdh of resonant peak got down to 0.35nm from 0.60nm

More precise(~faster) control of cavity



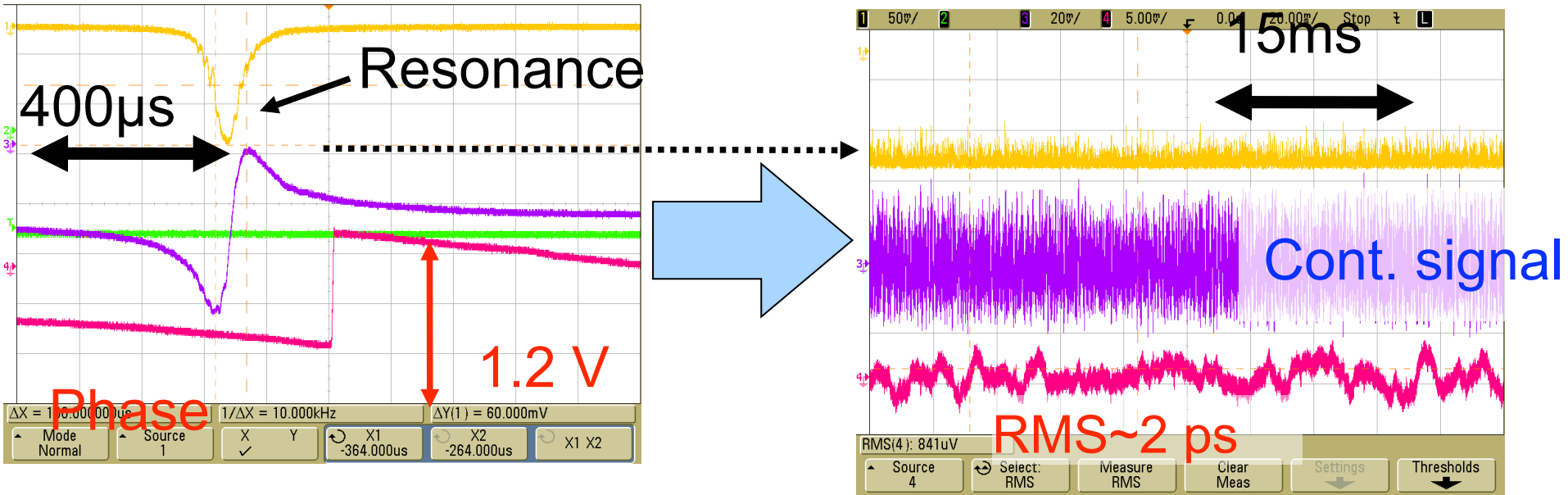
cavity length [nm]

Feed back system in 2008

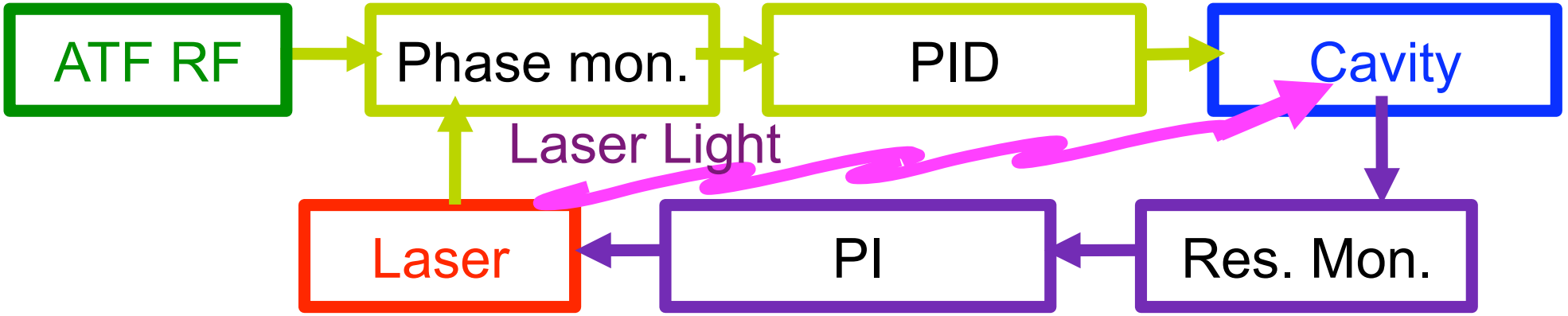


Control:
Laser to keep resonance
Cavity for timing synchronization

Keeping resonance at
250 enhacement
with timing jitter ~2ps



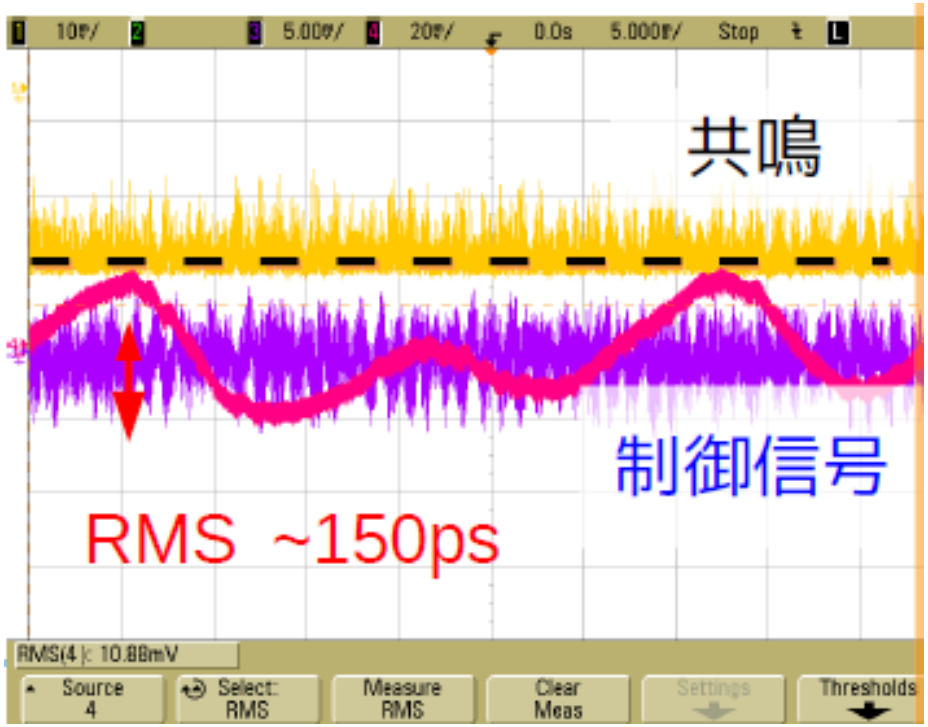
Initial performance with 760 enhancement



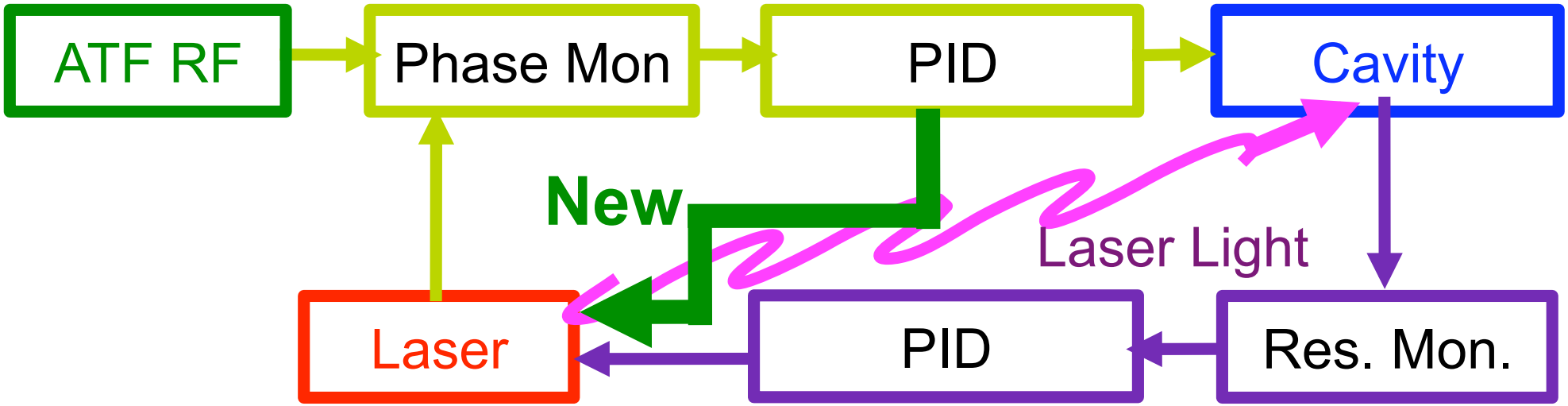
Faster feed back to laser to keep resonance

Larger fluctuation of laser timing

timing control could not follow

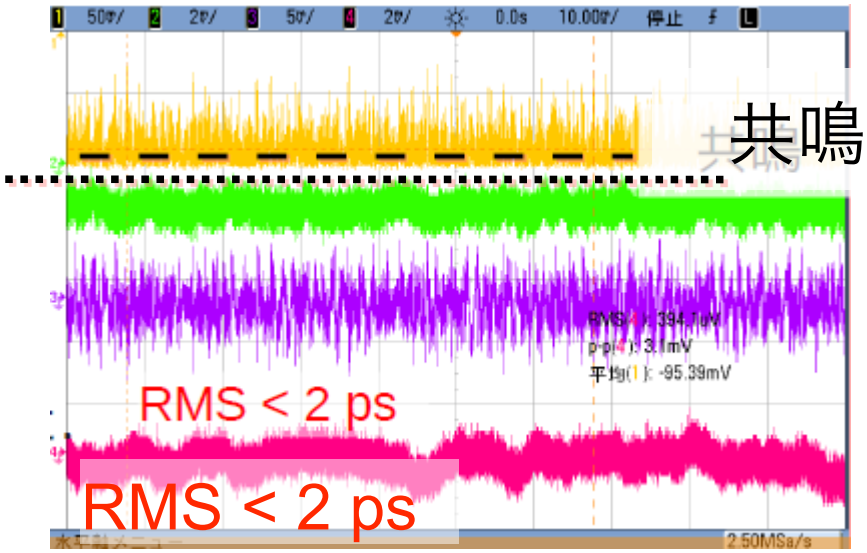


New feedback system



New feedback control
+ improve emviromnet

Timing jitter is now < 2ps



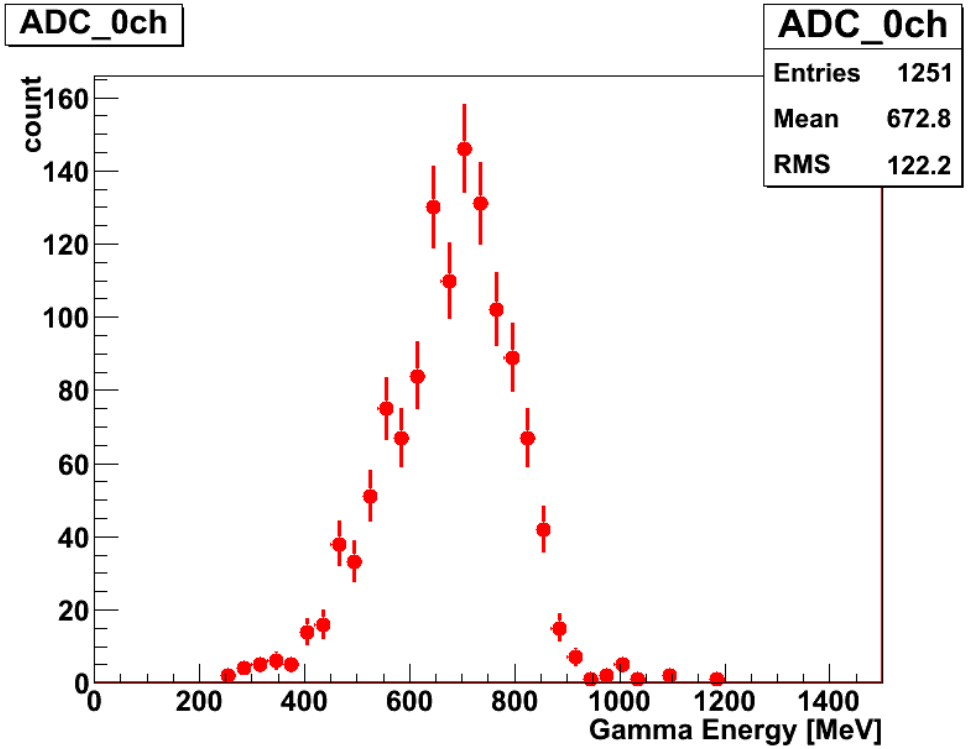
W/ Larger enhansment cavity in 2009

After, extensive studies;

Power enhancement of the cavity ~ factor 3

Laser power 500W to 1.48kW

- 10.8γ/train at 1 bunch (2.2mA)
- 26.8γ/train10cunches(6.7mA)



The electron beam was
not tuned enough in 2009

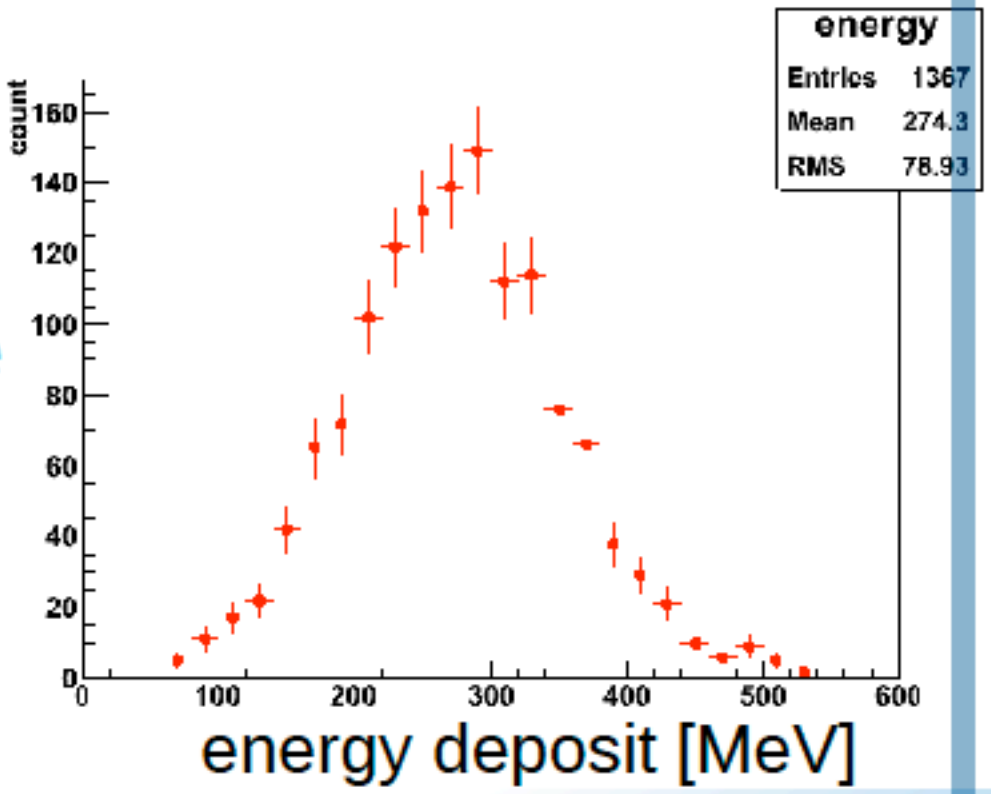
demonstration of 3 times more g by beam tuning
bunch by bunch observation soon

Result of the Experiment in 2010

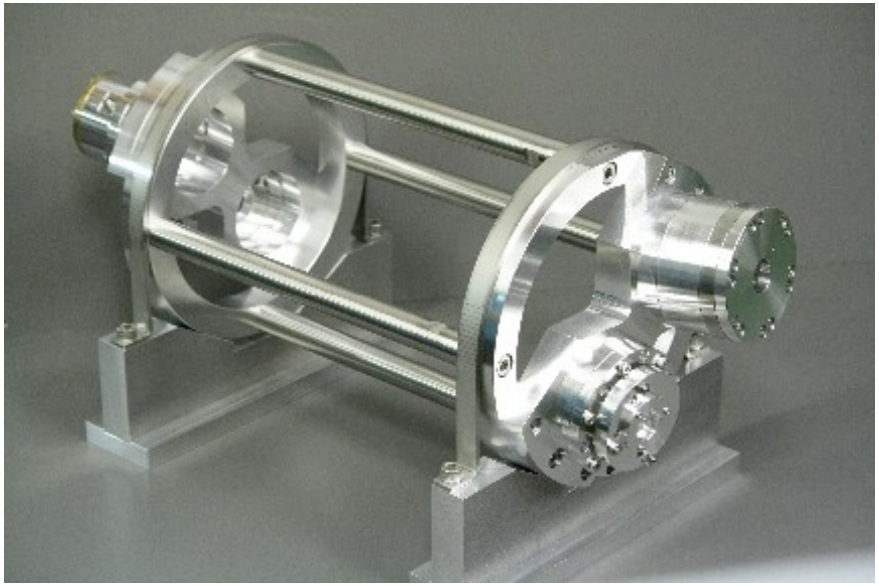
Miyoshi PosiPol2010

Enhancement factor tripled (250 -> 760),
accumulated power increased from 500W to 1.48kW.

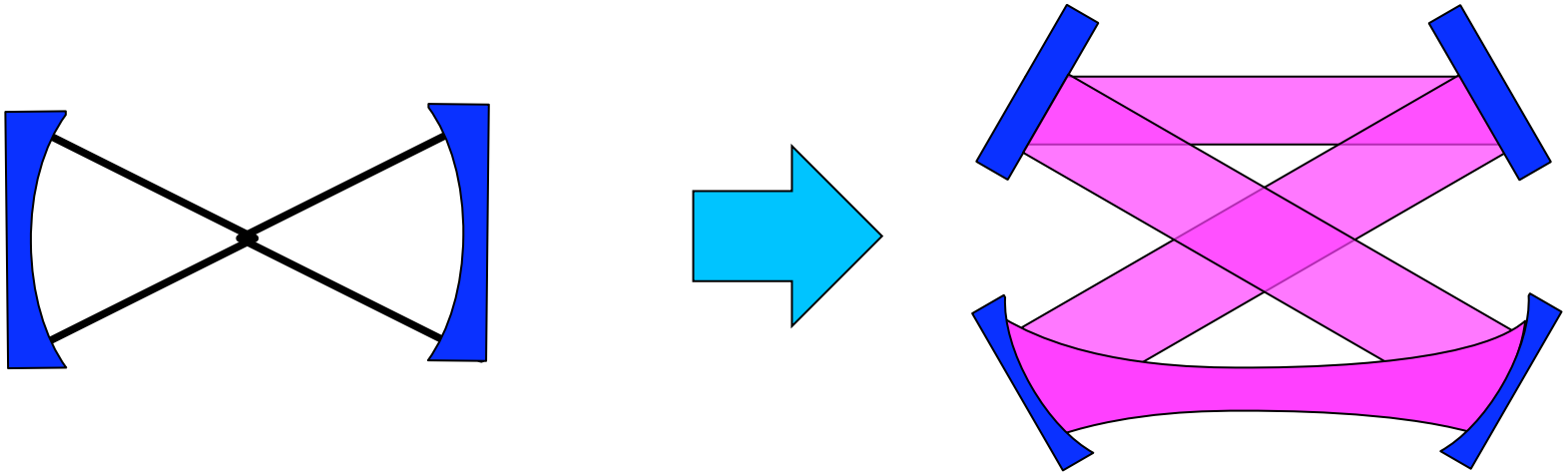
10.9 gamma-rays / train are detected
with single bunch operation
(I~2.2mA).



4 MIRROR CAVITY



to get higher enhancement and smaller beam waist



A prototype 3D4M cavity