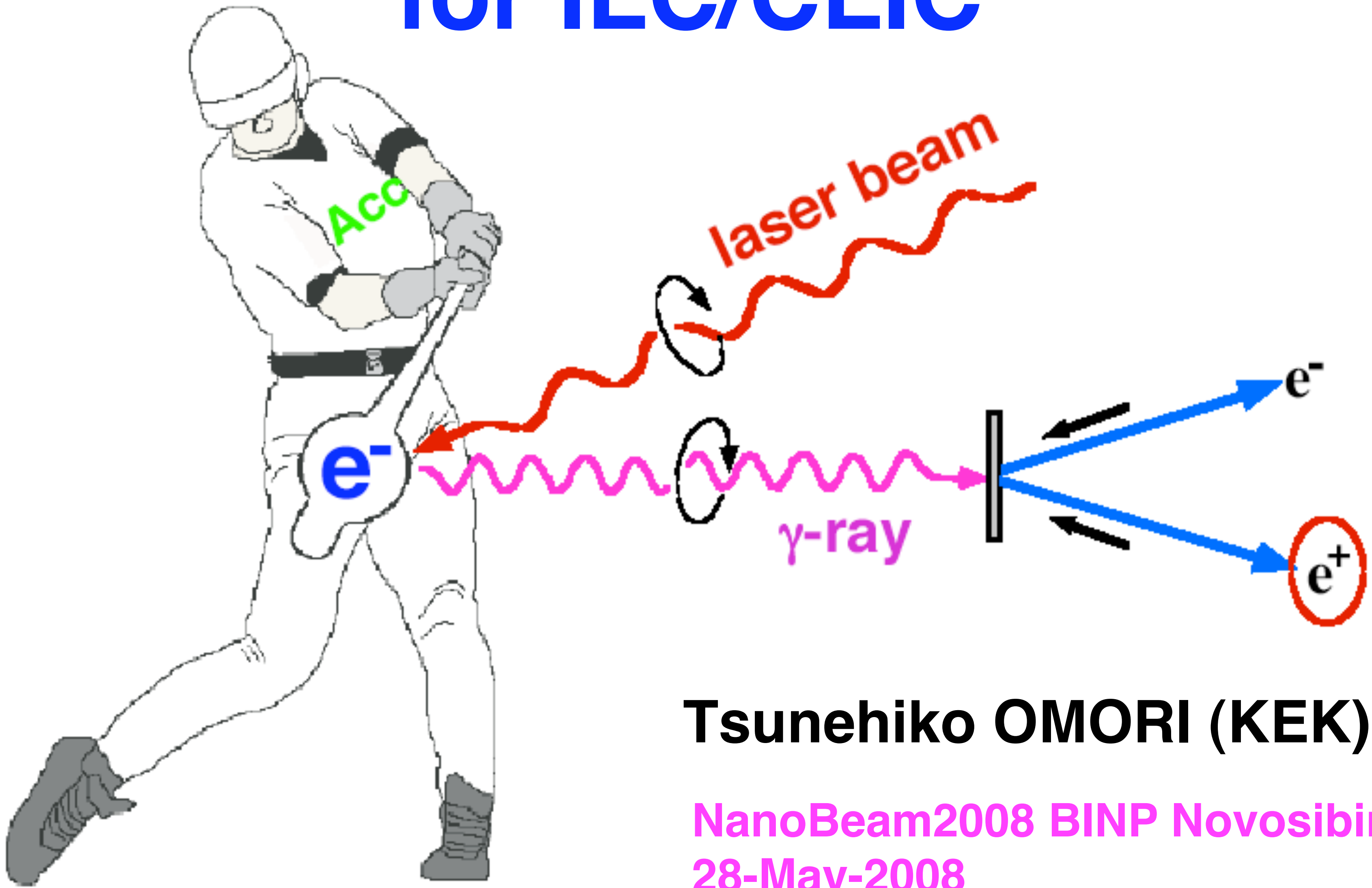
Laser-Compton Based e^+ Source for ILC/CLIC



Tsunehiko OMORI (KEK)

NanoBeam2008 BINP Novosibirsk
28-May-2008

Today's Talk

1. Laser-Compton e^+ source for ILC/CLIC.

2. R/D for Laser-Compton e^+ source
   ---- Laser Stacking Optical Cavity ----

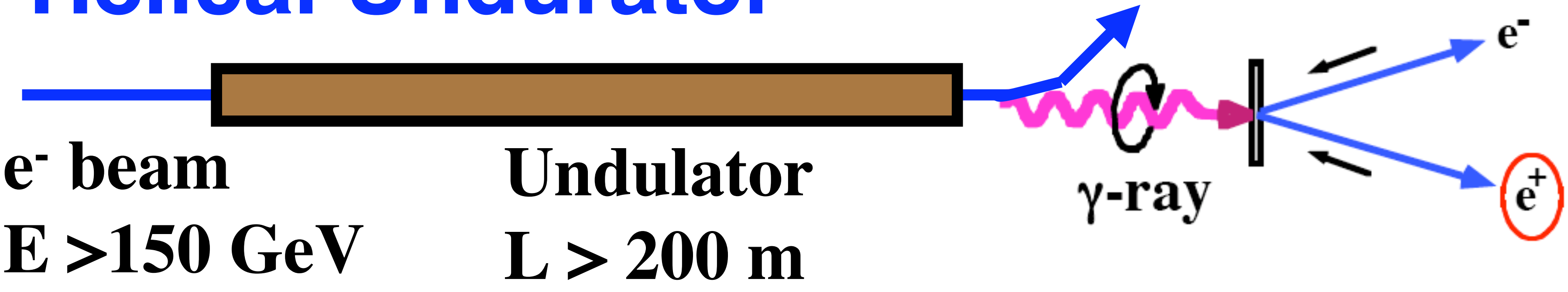
3. PosiPol Collaboration

4. Summary

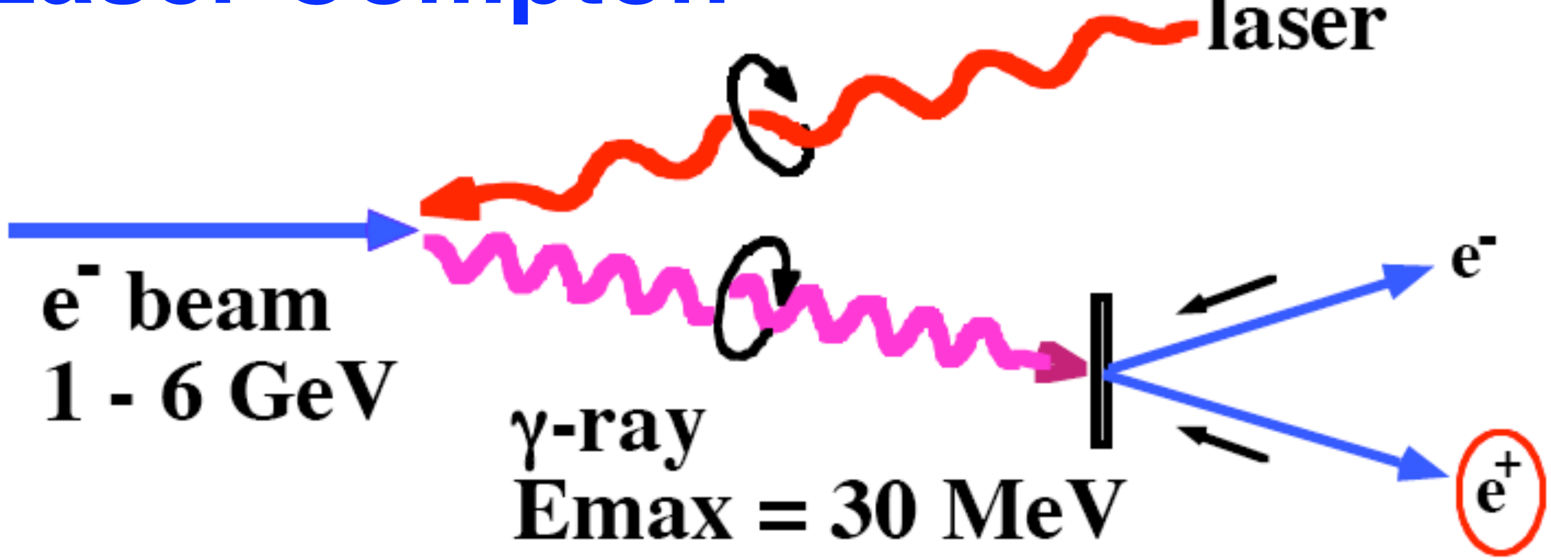
Laser-Compton e^+ source for ILC/CLIC

Two ways to get pol. e+

(1) Helical Undurator



(2) Laser Compton



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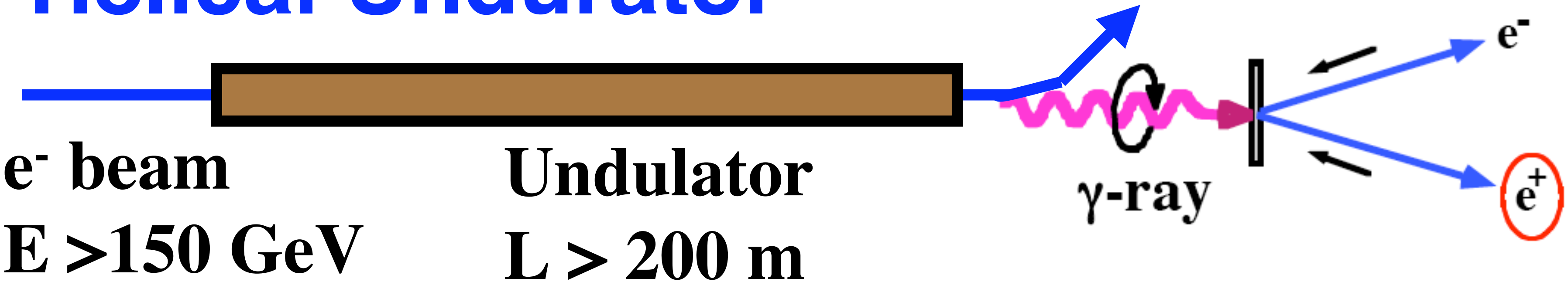
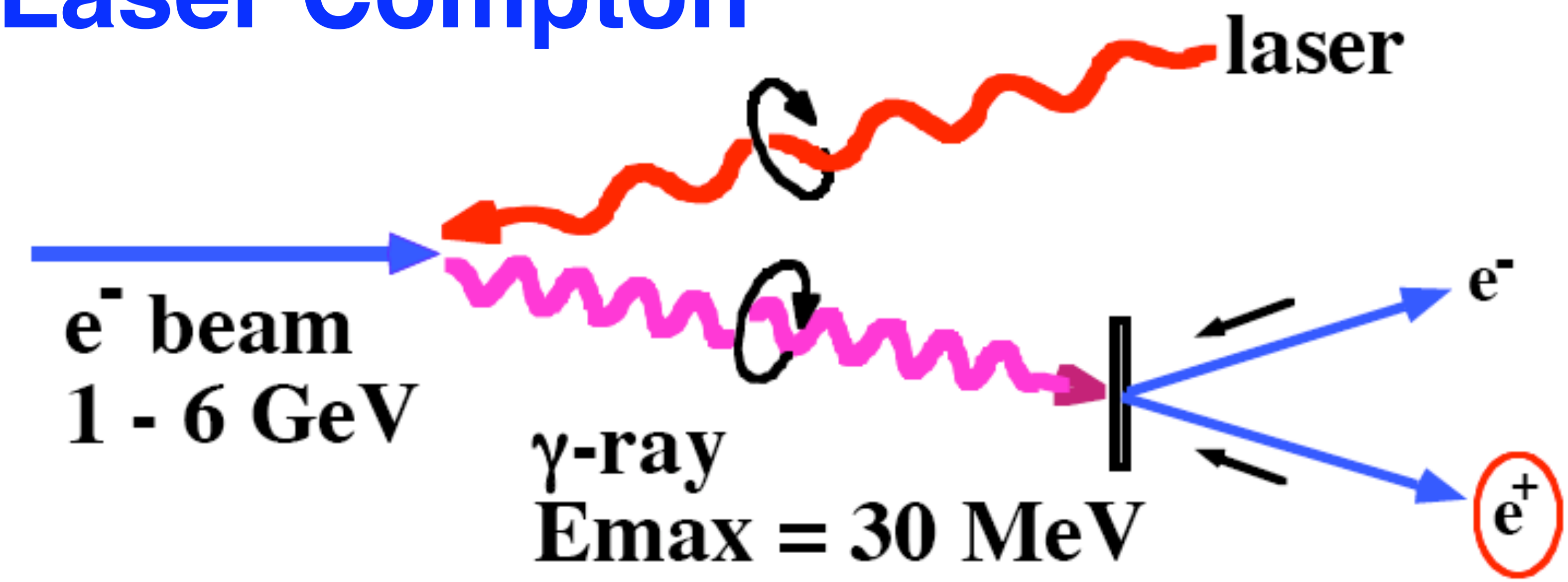


Our Proposal

(2) Laser Compton



Why Laser-Compton ?

i) Positron Polarization.

ii) Independence

Undulator-base e^+ : use e^- main linac

Problem on design, construction, commissioning, maintenance,

Laser-base e^+ : independent

Easier construction, operation, commissioning, maintenance

iii) Polarization flip @ 5Hz (for CLIC @ 50 Hz)

iv) High polarization

v) Low energy operation

Undulator-base e^+ : need deceleration

Laser-base e^+ : no problem

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Laser-base e^+ : no problem

vi) Synergy in wide area of fields/applications

Status of Compton scheme

Proof-of-Principle demonstration was done.

ATF-Compton Collaboration

Polarized γ-ray generation: M. Fukuda et al., PRL 91(2003)164801

Polarized e+ generation: T. Omori et al., PRL 96 (2006) 114801

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Discuss later

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Discuss later

We have 3 schemes.

Choice 1 : How to provide e- beam

Storage Ring, ERL, Linac

Choice 2 : How to provide laser beam

Wave length (λ=1μm or λ=10μm)

staking cavity or non stacking cavity

Choice 3 : e+ stacking in DR or Not

Laser Compton e^+ Source for ILC/CLIC

We have 3 schemes.

1. Ring Base Laser Compton
   Storage Ring + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR
   S. Araki et al., physics/0509016

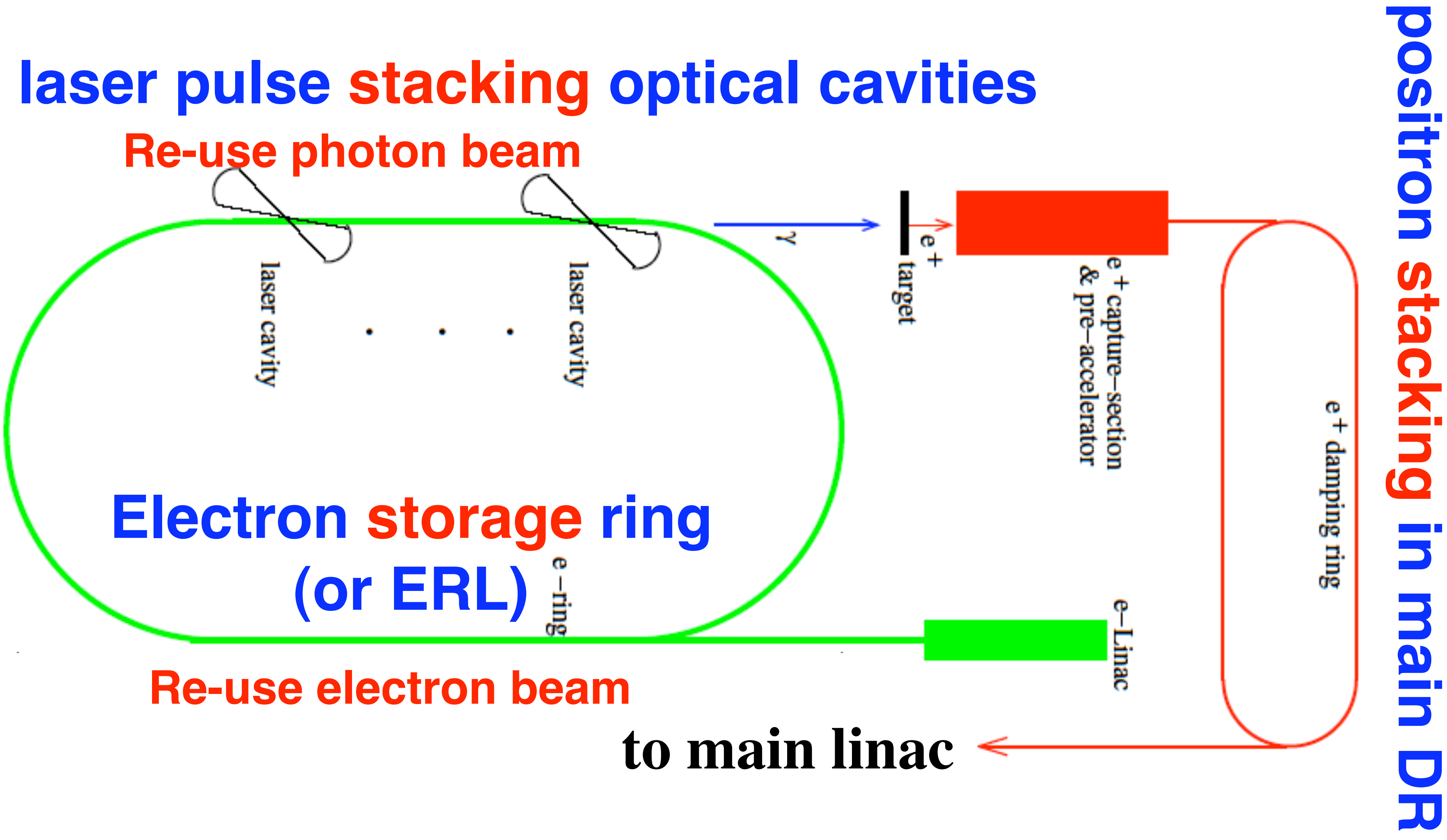
2. ERL Base Laser Compton
   ERL + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR

3. Linac Base Laser Compton
   Linac + non-stacking Laser Cavity (λ=10μm),
   and No stacking in DR
   Proposal V. Yakimenko and I. Pogorersky
   T. Omori et al., Nucl. Instr. and Meth. in Phys. Res., A500 (2003) pp 232-252

Good! But we have to choose!

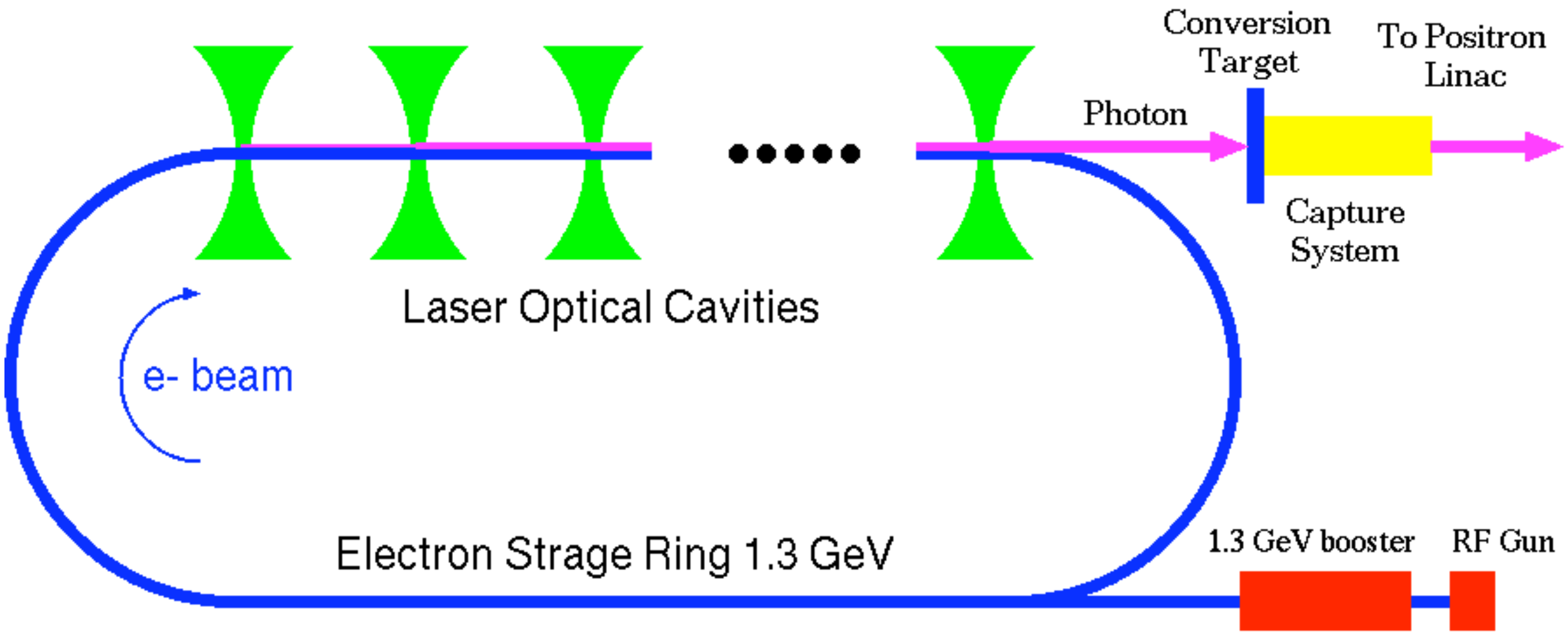
Ring Base Compton (an example)

Re-use Concept



Compton Ring Scheme for ILC

- Compton scattering of e- beam stored in storage ring off laser stored in Optical Cavity.
- 15 nC 1.3 GeV electron bunches x 10 of 600mJ stored laser -> 1.7E+10 γ rays -> 2.4E+8 e+.
- By stacking 100 bunches on a same bucket in DR, 2.4E+10 e+/bunch is obtained.



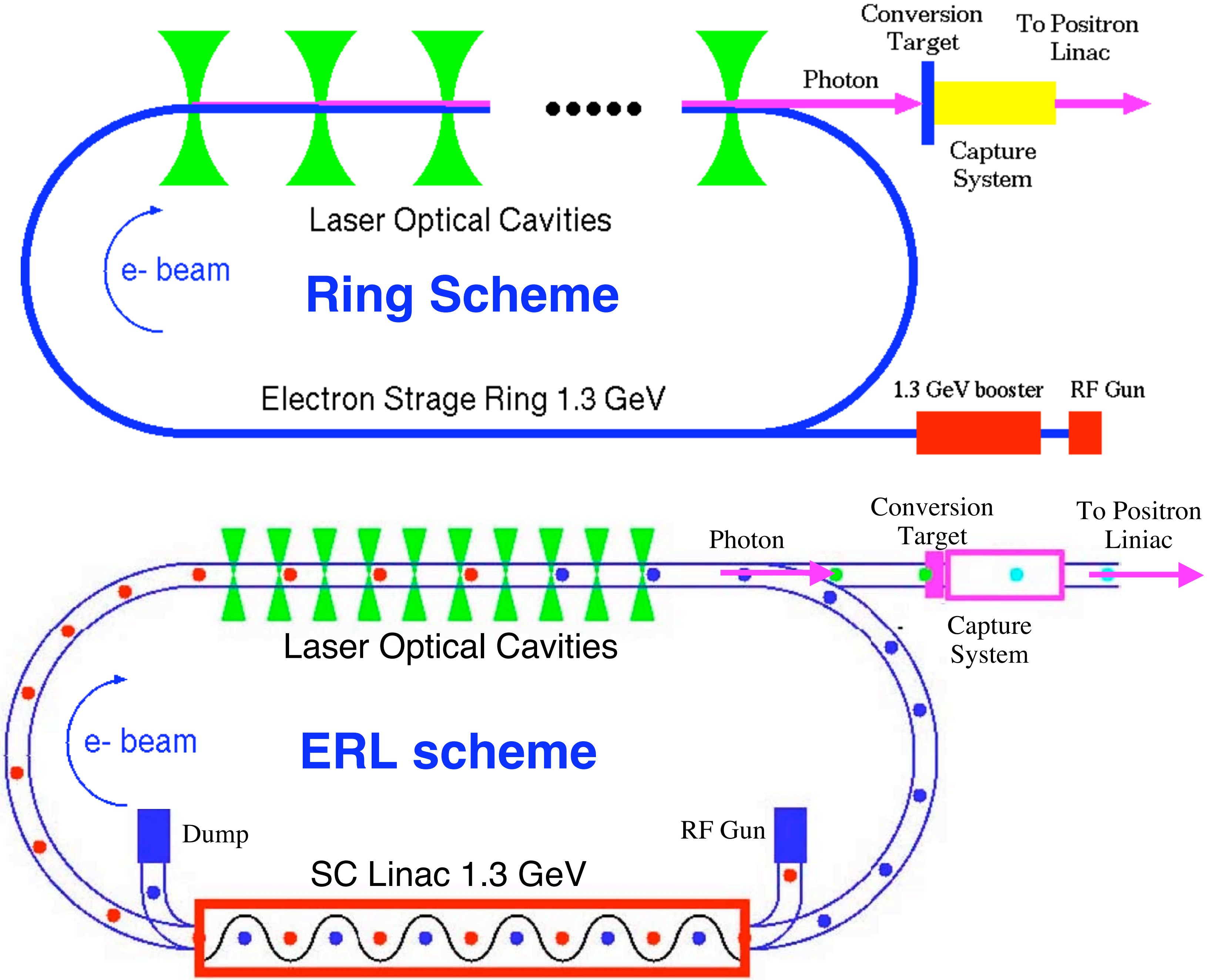
R/D for
Laser-Compton e^+ source

---- Laser Stacking Optical Cavity ---

Why Stacking Cavity R/D?

a) Laser Stacking Optical Cavity is a Key in both Ring & ERL scheme

Laser Stacking Cavity is a Key in both Ring and ERL scheme



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c) The efficiency of whole system highly depends on the optical cavity design.

- laser spot size
- collision angle
- enhancement factor
- compatibility with e-baem

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- laser spot size
- collision angle
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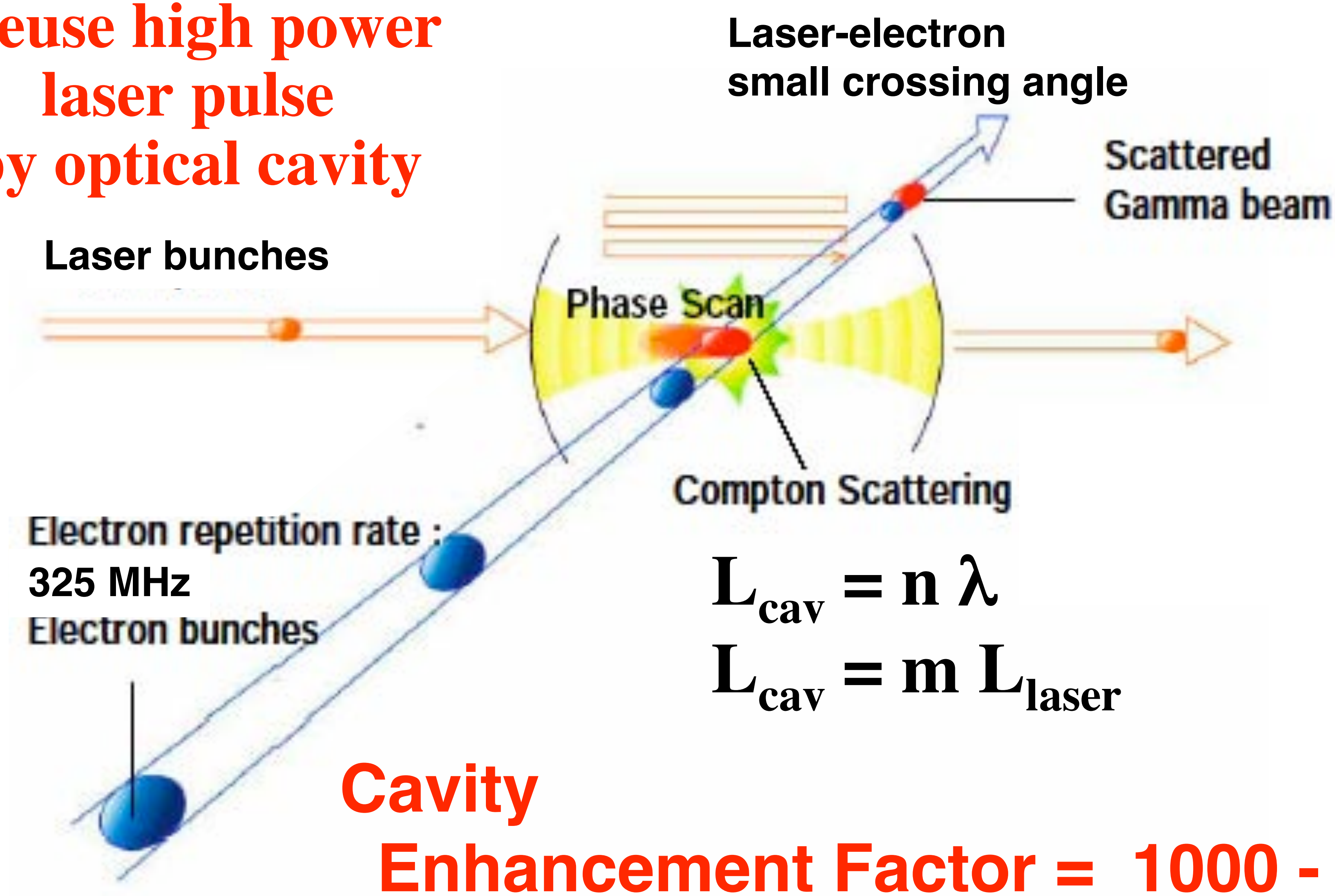
Simulation alone is not effective in desiging cavity.

We need experimental R/D.

Optical Cavity for Pulse Laser Beam Stacking

Reuse high power laser pulse by optical cavity



$$L_{cav} = n\,\lambda$$

$$L_{cav} = m\,L_{laser}$$

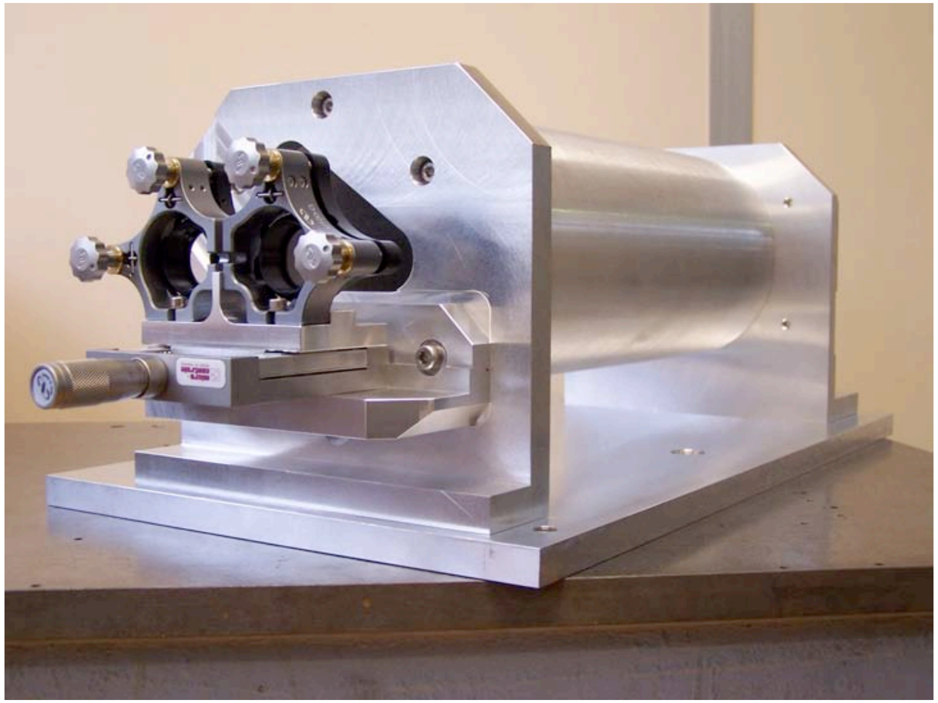
Cavity Enhancement Factor = 1000 - 10^5

Prototype Cavities

2-mirror cavity (Hiroshima / Weseda / Kyoto / IHEP / KEK)

moderate enhancement
moderate spot size
simple control

4-mirror cavity (LAL)



high enhancement
small spot size
complicated control

2-mirror cavity at ATF

R/D in Japan

Moderate Enhancement ~ 1000

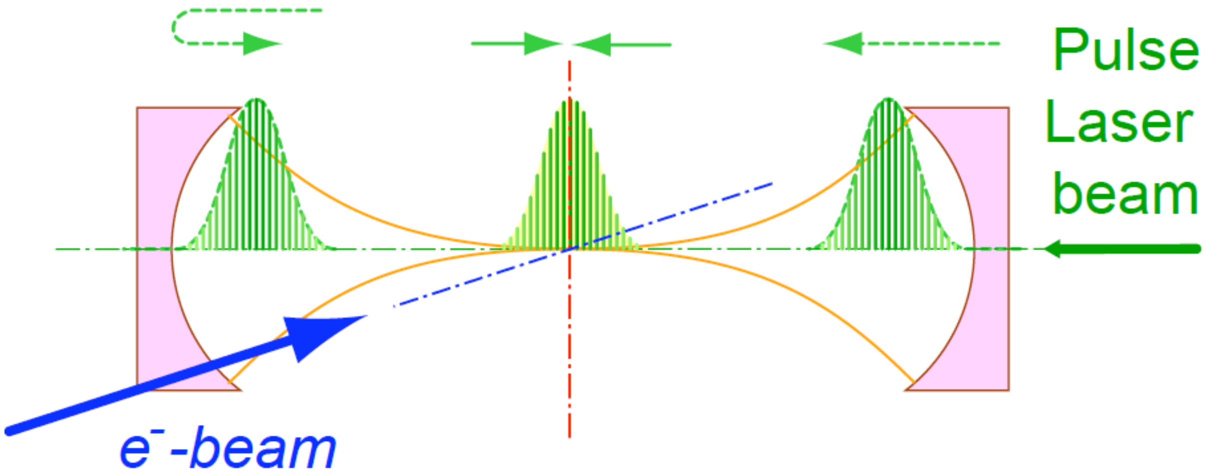
Moderate spot size ~ 30 micron

Simple cavity stucture with two mirrors

Get experinence with e^- beam

Experimental R/D in ATF

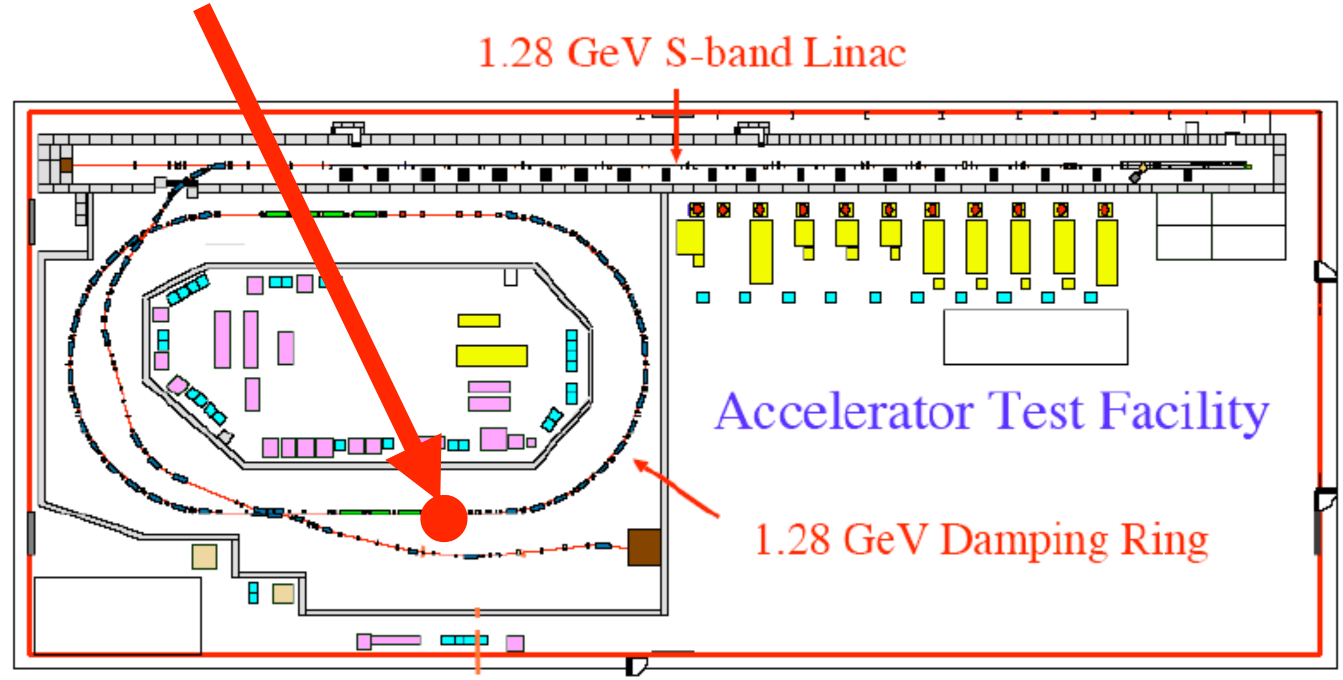
Hiroshima-Waseda-Kyoto-IHEP-KEK



Make a fist prototype 2-mirror cavity

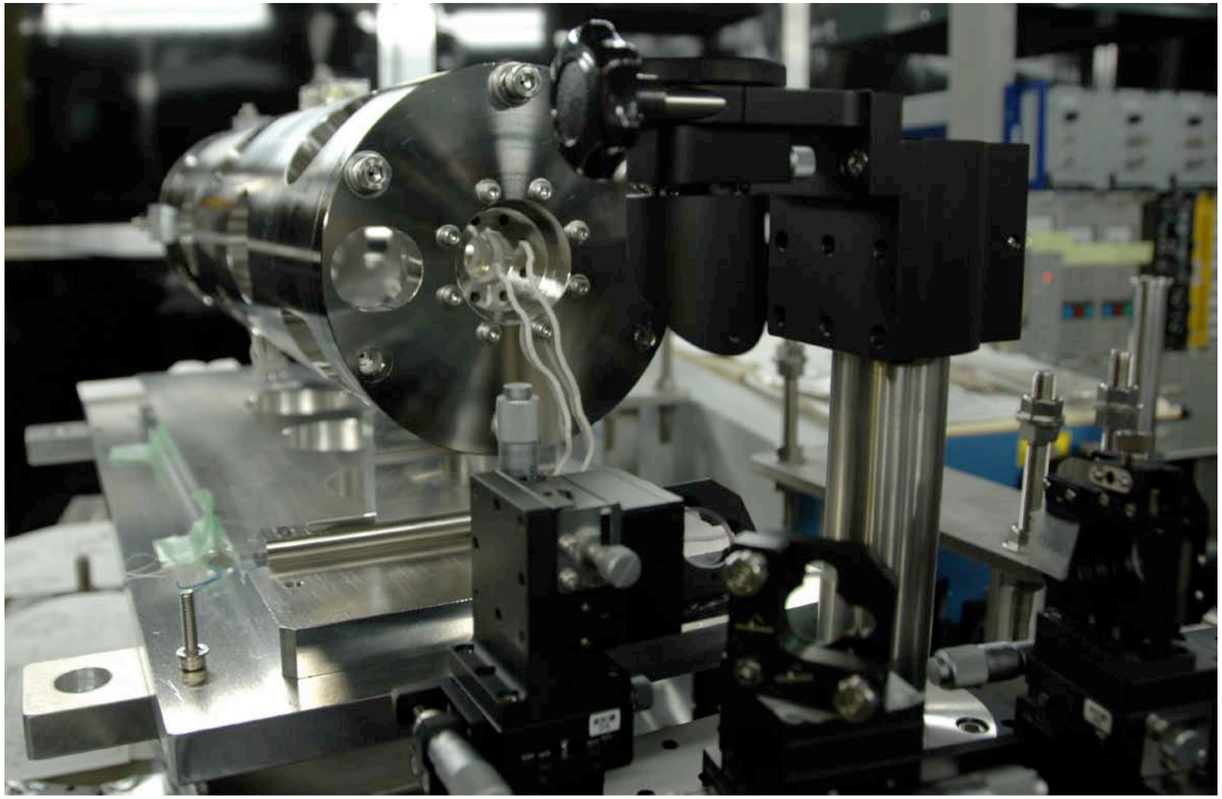
L_{cav} = 420 mm

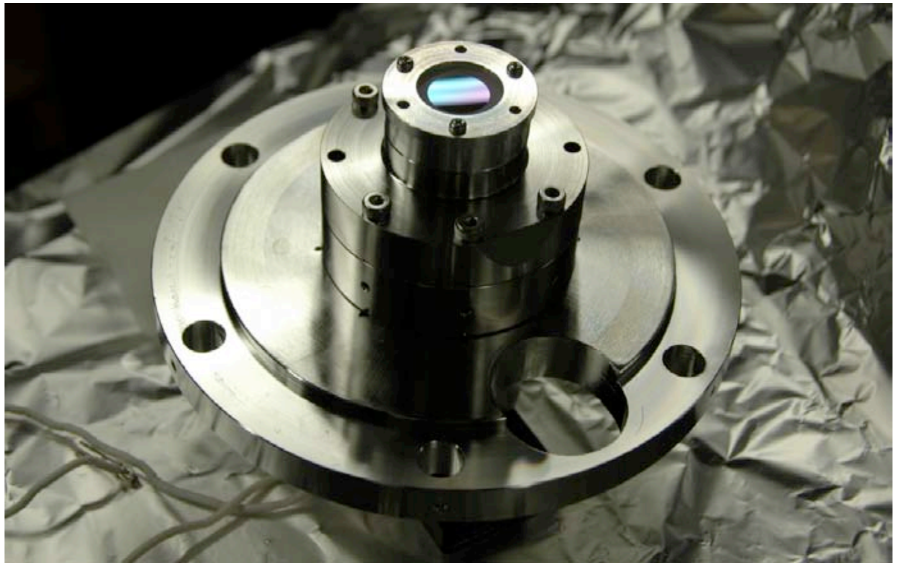
Put it in ATF ring



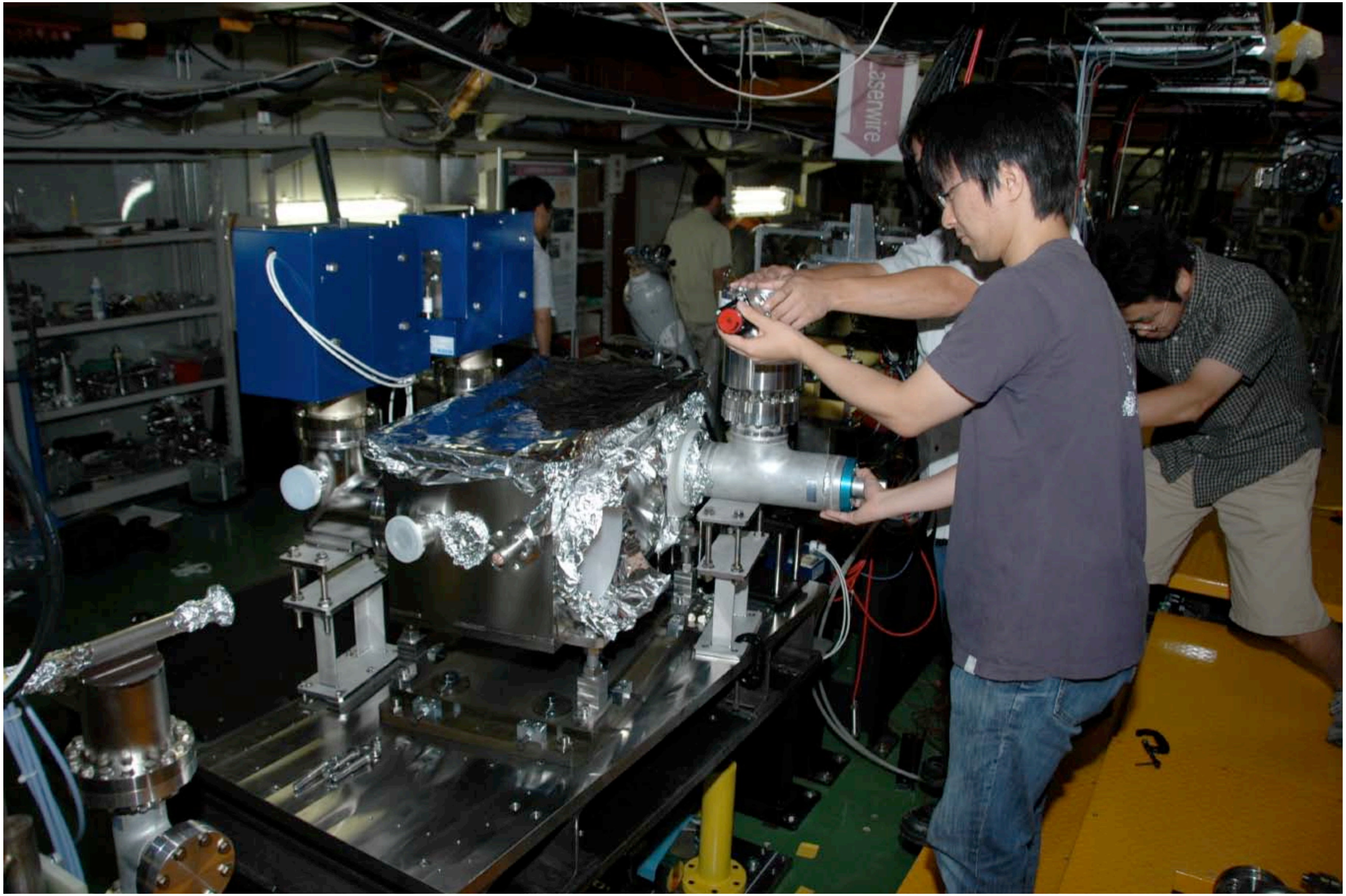
Laser Stacking Optical Cavity in Vacuum Chamber

Summer 2007: Assembling the Optical Cavity



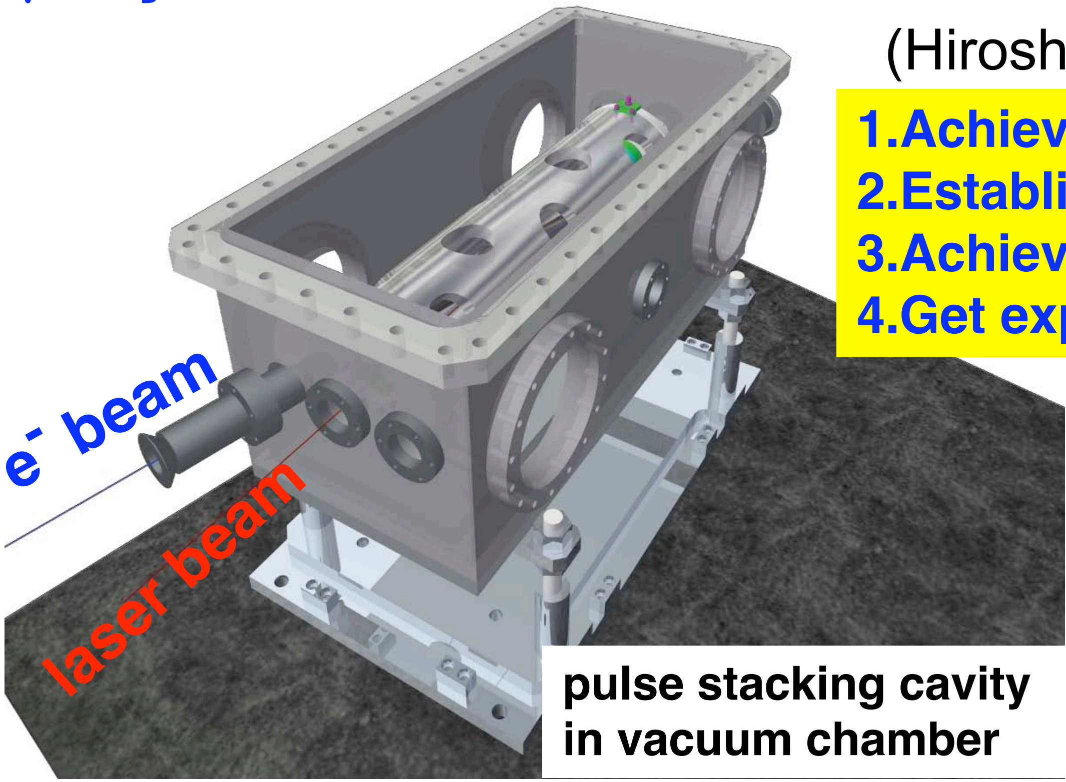


October 2007: Install the 2-mirror cavity into ATF-DR



γ-ray Generation with Laser Pulse Stacking Optical Cavity

(Hiroshima-Waseda-IHEP-KEK)



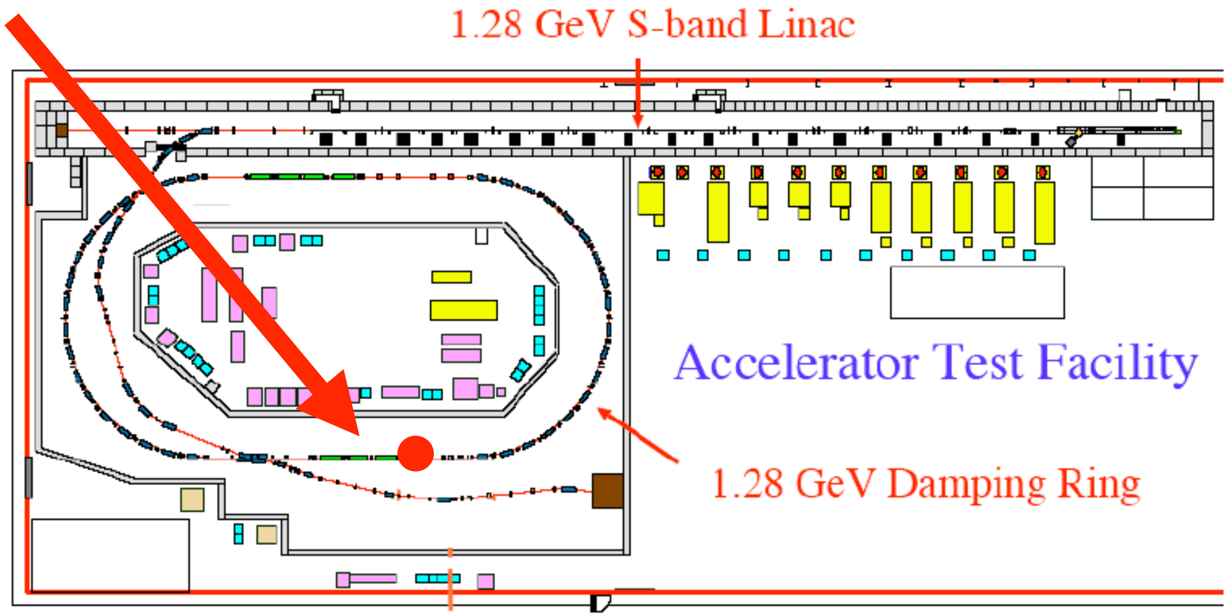
1.Achieve high enhancement & small spot size
2.Establish feedback technology
3.Achieve small crossing angle
4.Get experinence with e^- beam

We will detect 20 γ’s/collision in current configuration.
Test is on going.
(so far achieved 3 γ’s/collision)
Goal: detect 400 γ’s/collision

Stack power estimate

date	Finesse	electron	transmitted power	incident power	reflected power	input power	λ	stack power	
		1/pulse	W	W	W	W		transmi	by i
8/3/14	200	?		6.2	6	0.2	1.1	-	
8/4/10	218	2.9E+10	0.325	5.3	4.5	0.8	2.5	81	
8/4/15	110	1.5E+10	0.119	5.3	5	0.3	2	30	
8/4/22	486	2.2E+10	1.69	5.3	2.5	2.8	3	423	
	486	2.3E+10	1.64	5.3	2.51	2.79	3	410	
	486	2.6E+10	1.55	5.3	2.55	2.75	3.1	388	

by transmitted power ~ 400W



4-mirror cavity at ATF

R/D in France

Very High Enhancement ~ 20000 - 100000

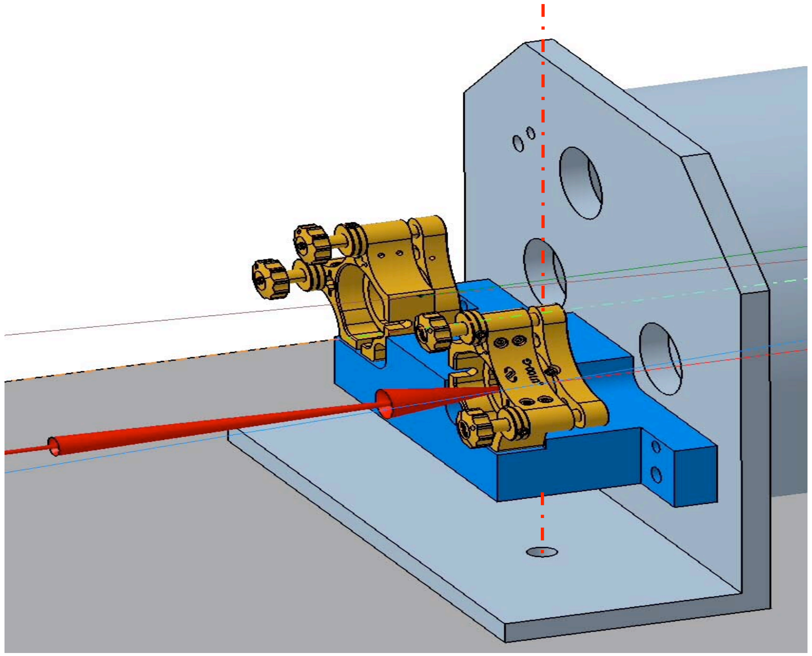
Small Spot size ~ 30 micron in ATF
(~ 10 micron in ILC)

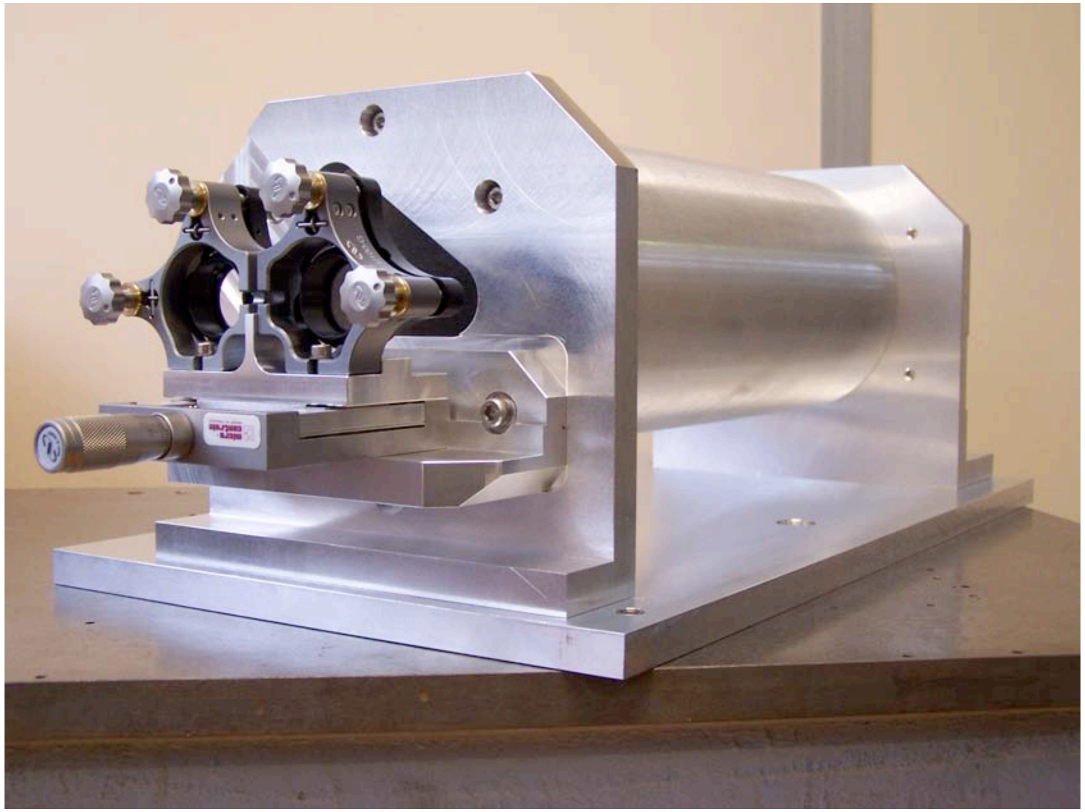
Sofisticated cavity stucture with 4 mirrors

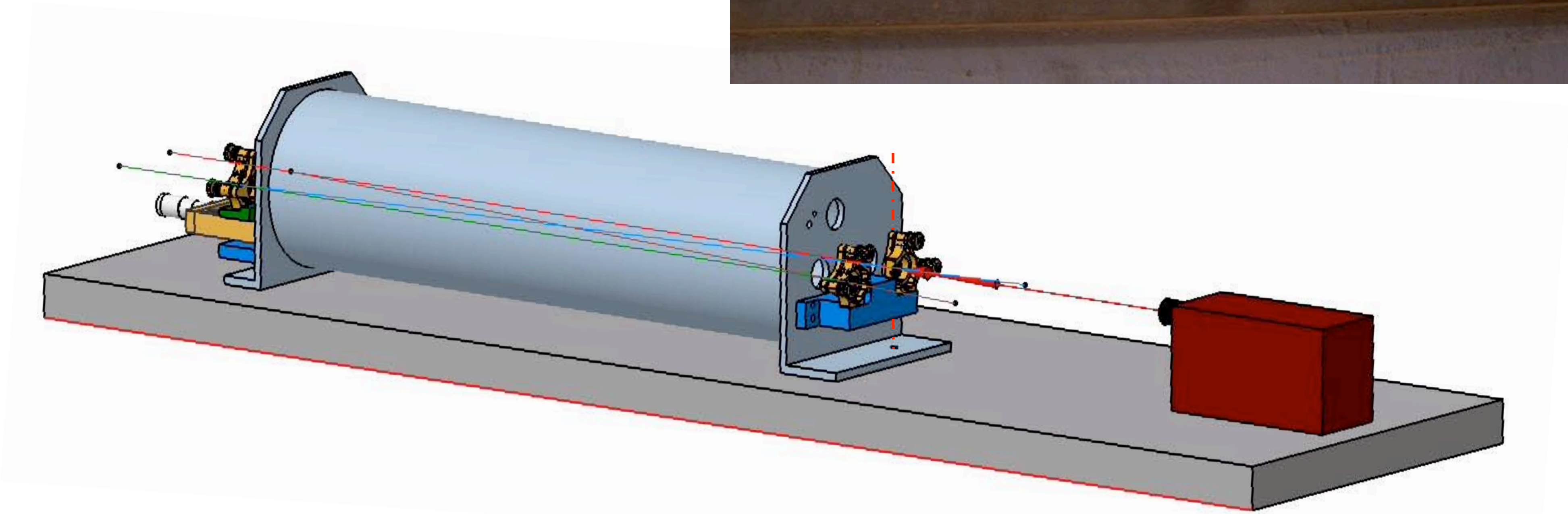
Start with no e^- beam

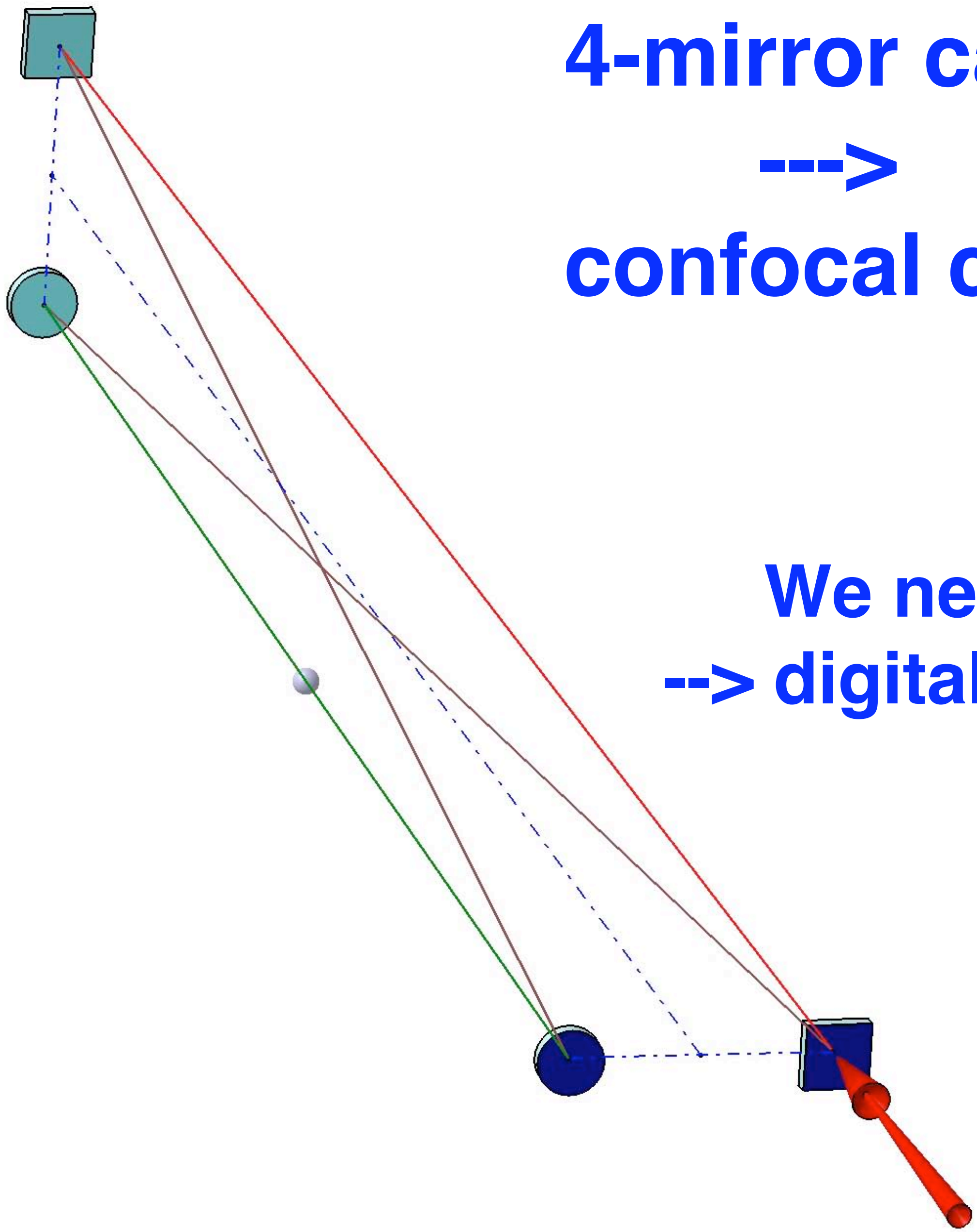
Later we will make e^- beam compatible cavity

Prototype 4-mirror cavity in LAL Orsey









4-mirror cavity

--->

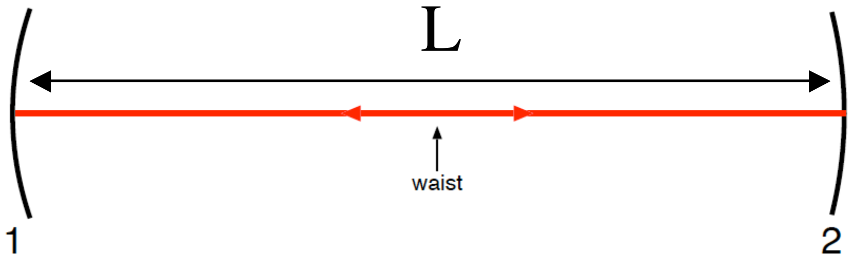
confocal configuration

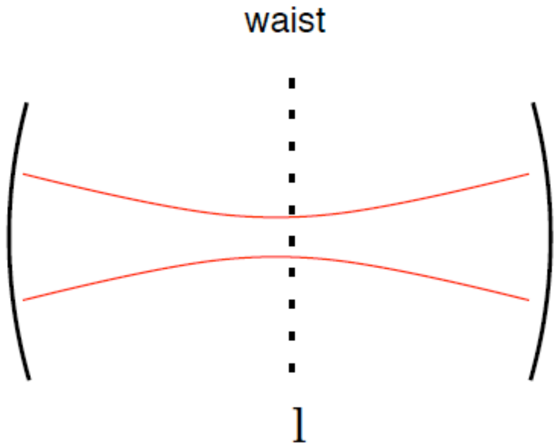
We need complicated control.

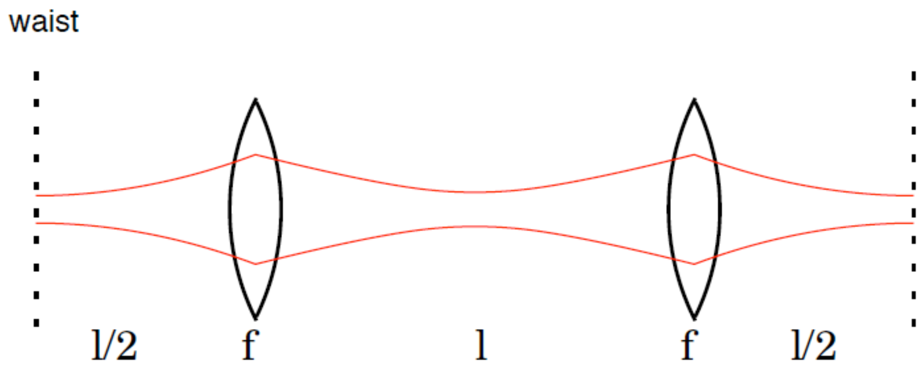
--> digital feedback

2-mirror cavity

R1=R2=L/2



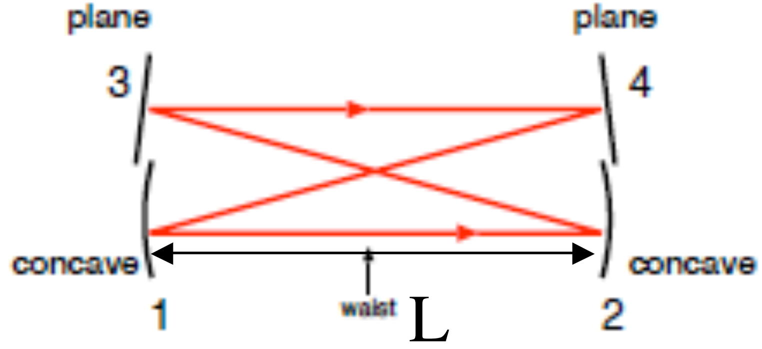


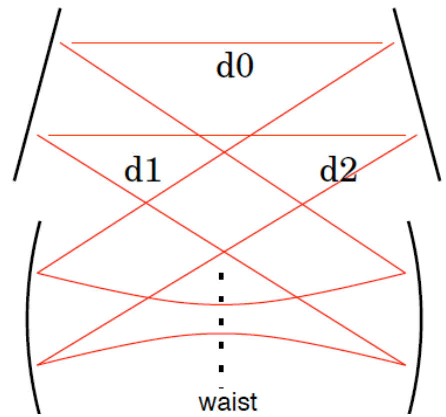


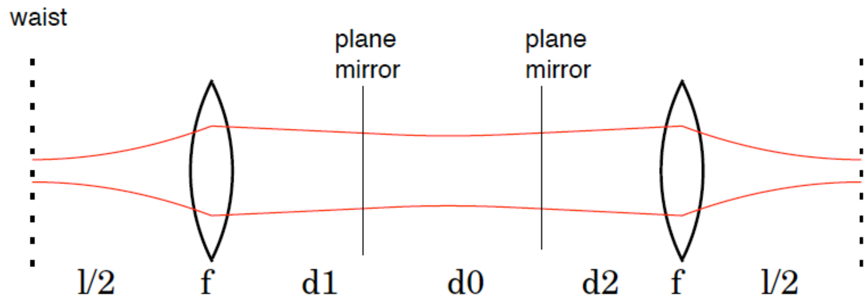
concentric

4-mirror cavity

R1=R2=L



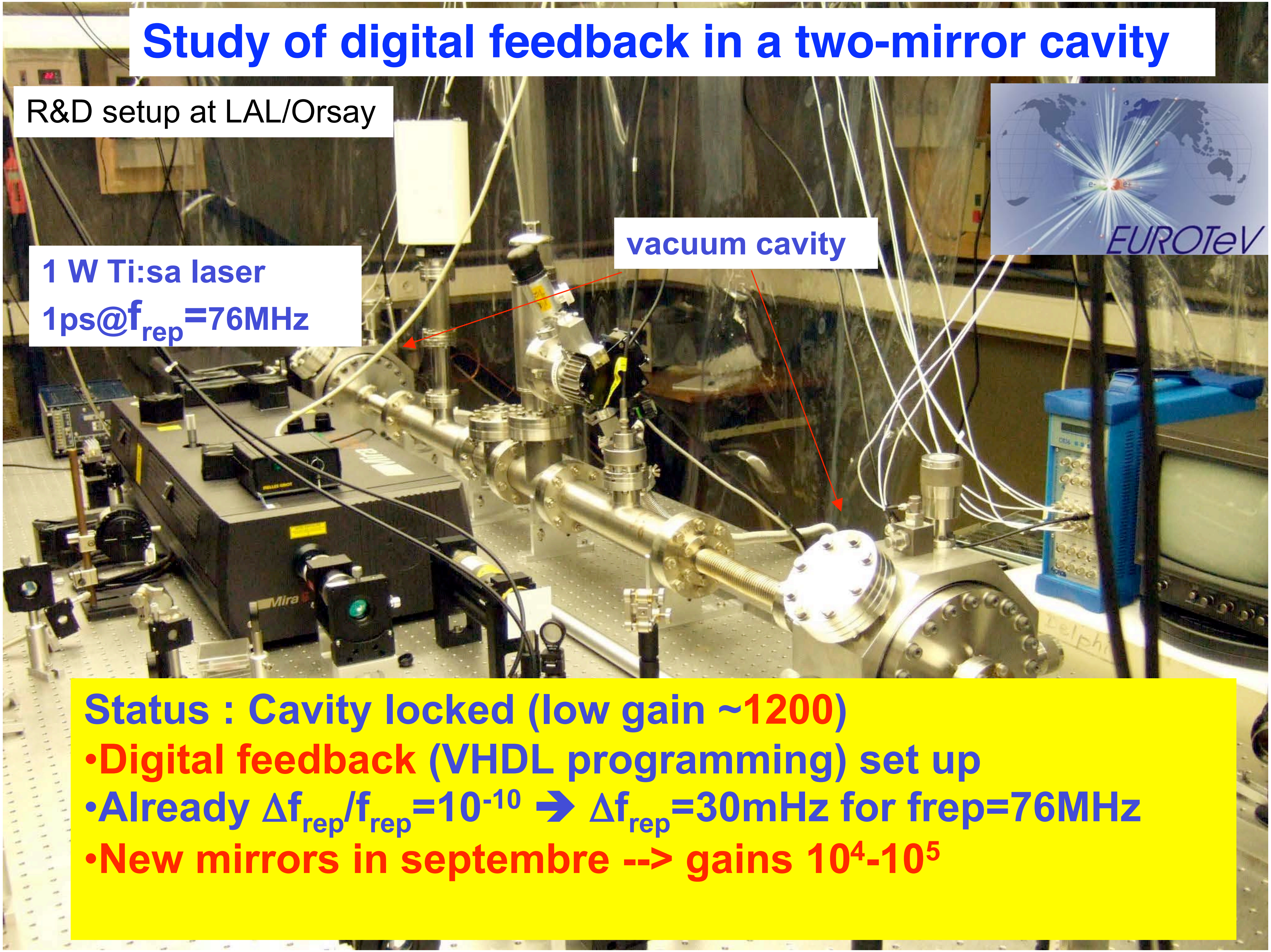




confocal

Study of digital feedback in a two-mirror cavity

R&D setup at LAL/Orsay



EUROTeV

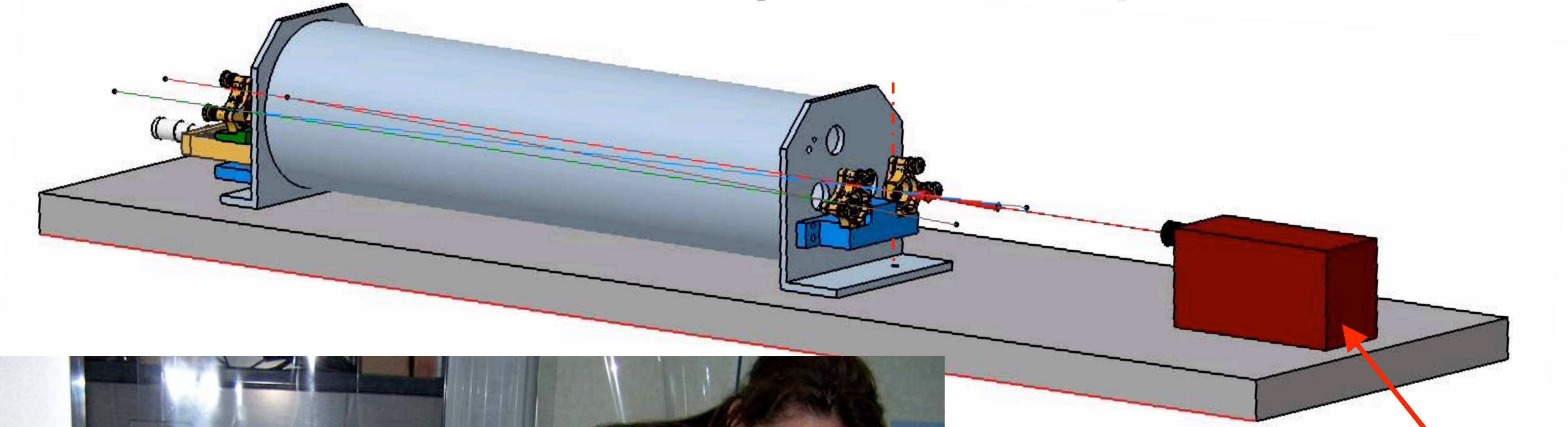
1 W Ti:sa laser
1ps@f_{rep}=76MHz

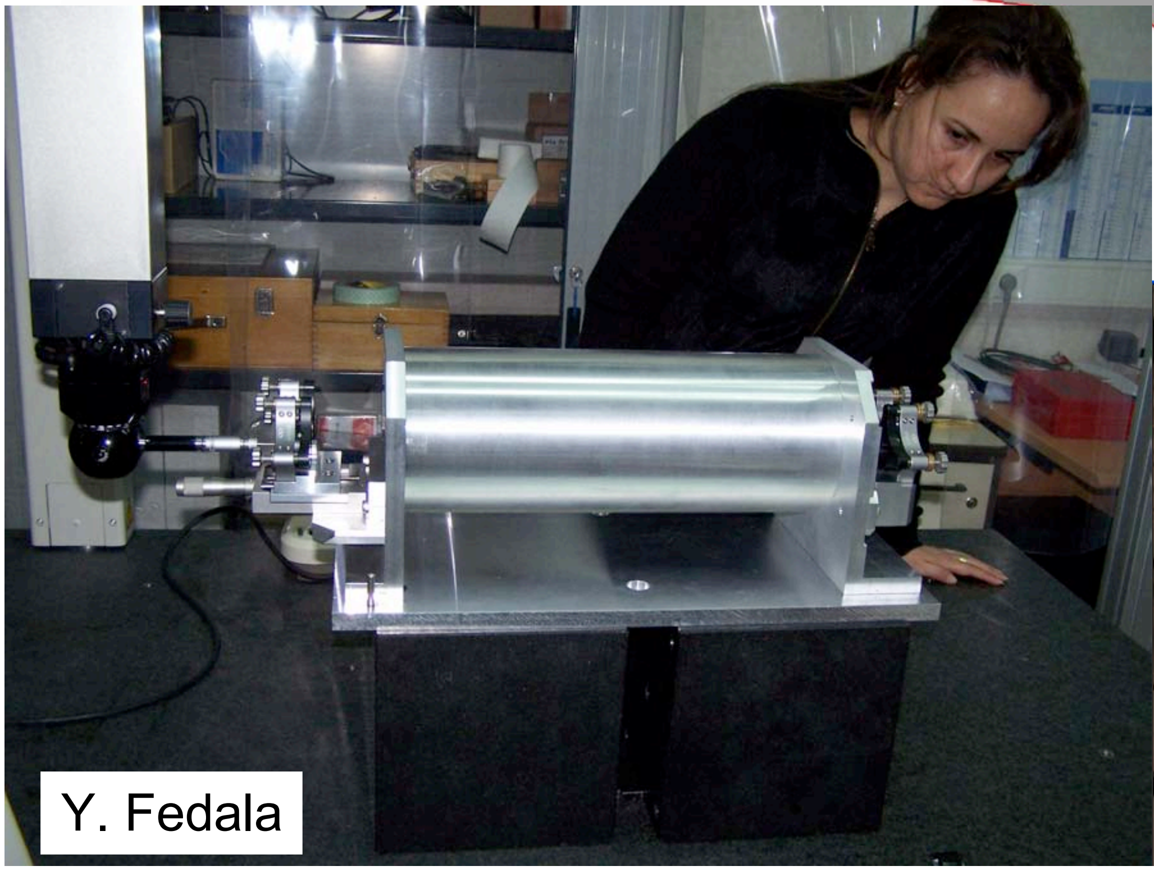
vacuum cavity

Status : Cavity locked (low gain ~1200)
- **Digital feedback (VHDL programming) set up**
- **Already $\Delta f_{rep}/f_{rep}=10^{-10}$ ➔ Δf_{rep}=30mHz for frep=76MHz**
- **New mirrors in septembre --> gains 10^4-10^5**

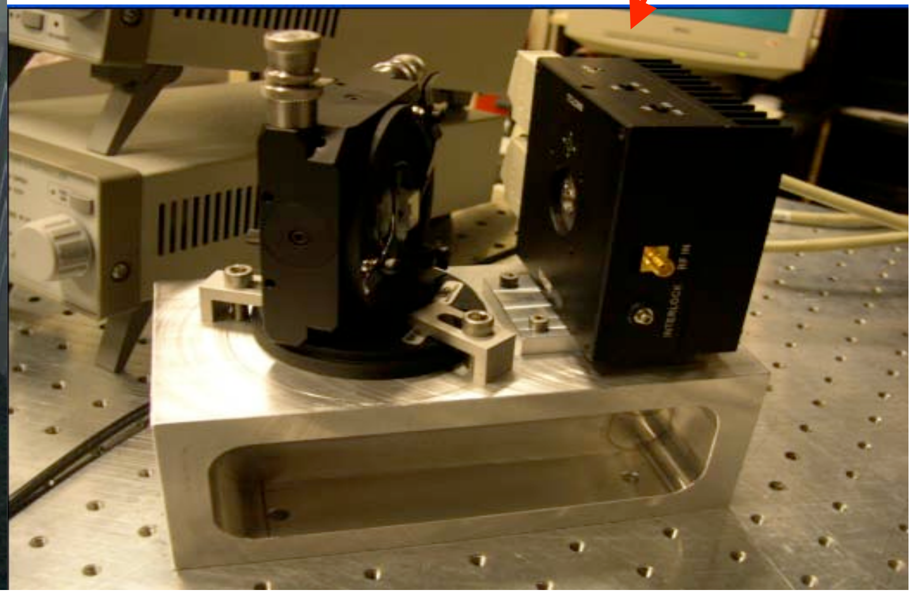
Study of 4-mirror cavity is on going at LAL

this cavity is not conpatible wth e-beam





Cw laser diode in
extended cavity config
(Littrow configuration)



R/D in France and in Japan are Complementary

R/D in France

Very High Enhancement ~ 20000 - 100000

R/D in Japan

Moderate Enhancement ~ 1000

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Get experinence with e^- beam

R/D in France and in Japan are Complementary

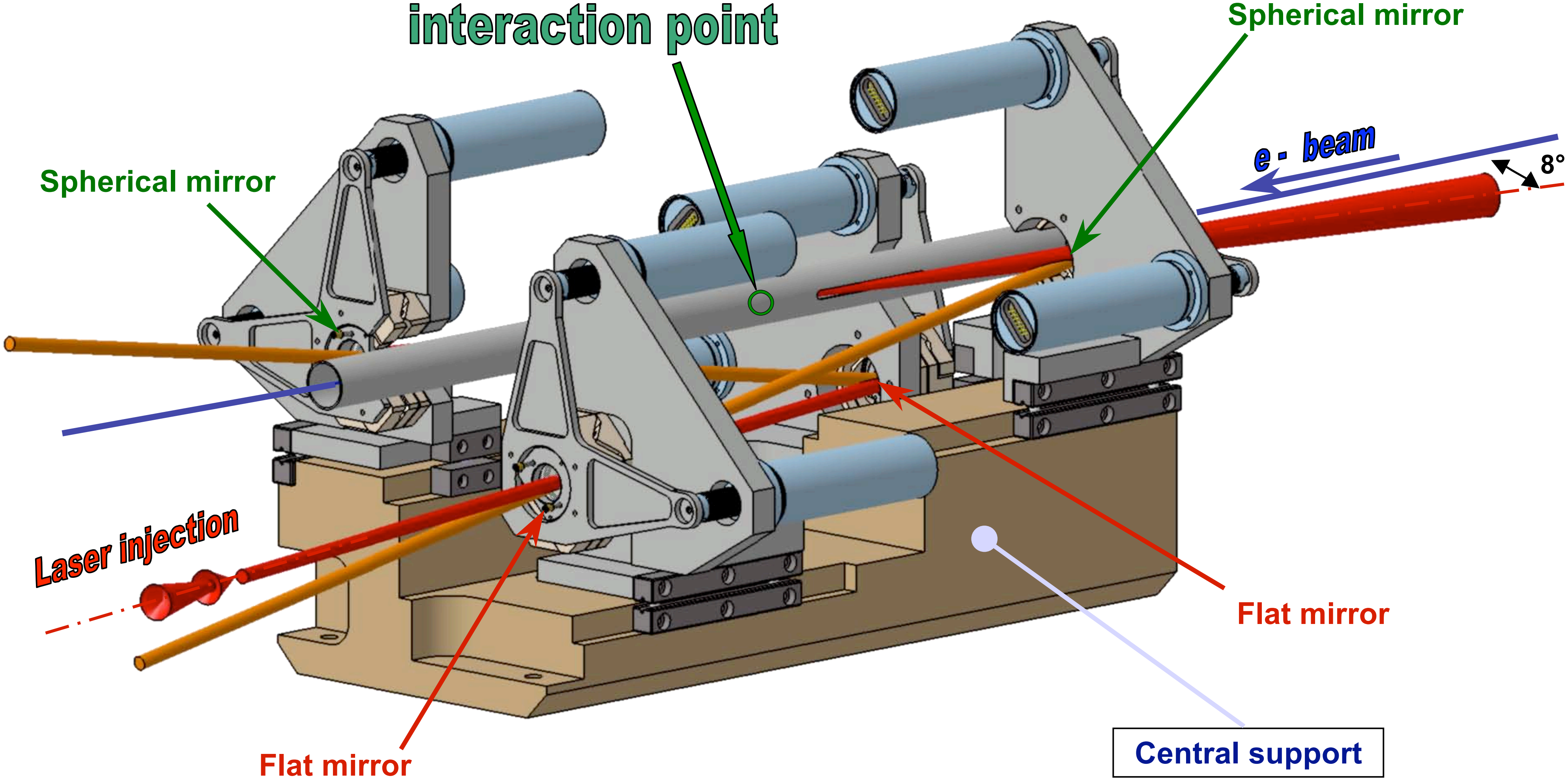
R/D in France

- Very High Enhancement ~ 20000 - 100000
- Small spot size ~ 30 micron (10 micron in ILC)
- Sofisticated cavity stucture with 4 mirrors
- Digital feedback
- Start with no e^- beam
- In late 2009: e^- beam compatible cavity in ATF

R/D in Japan

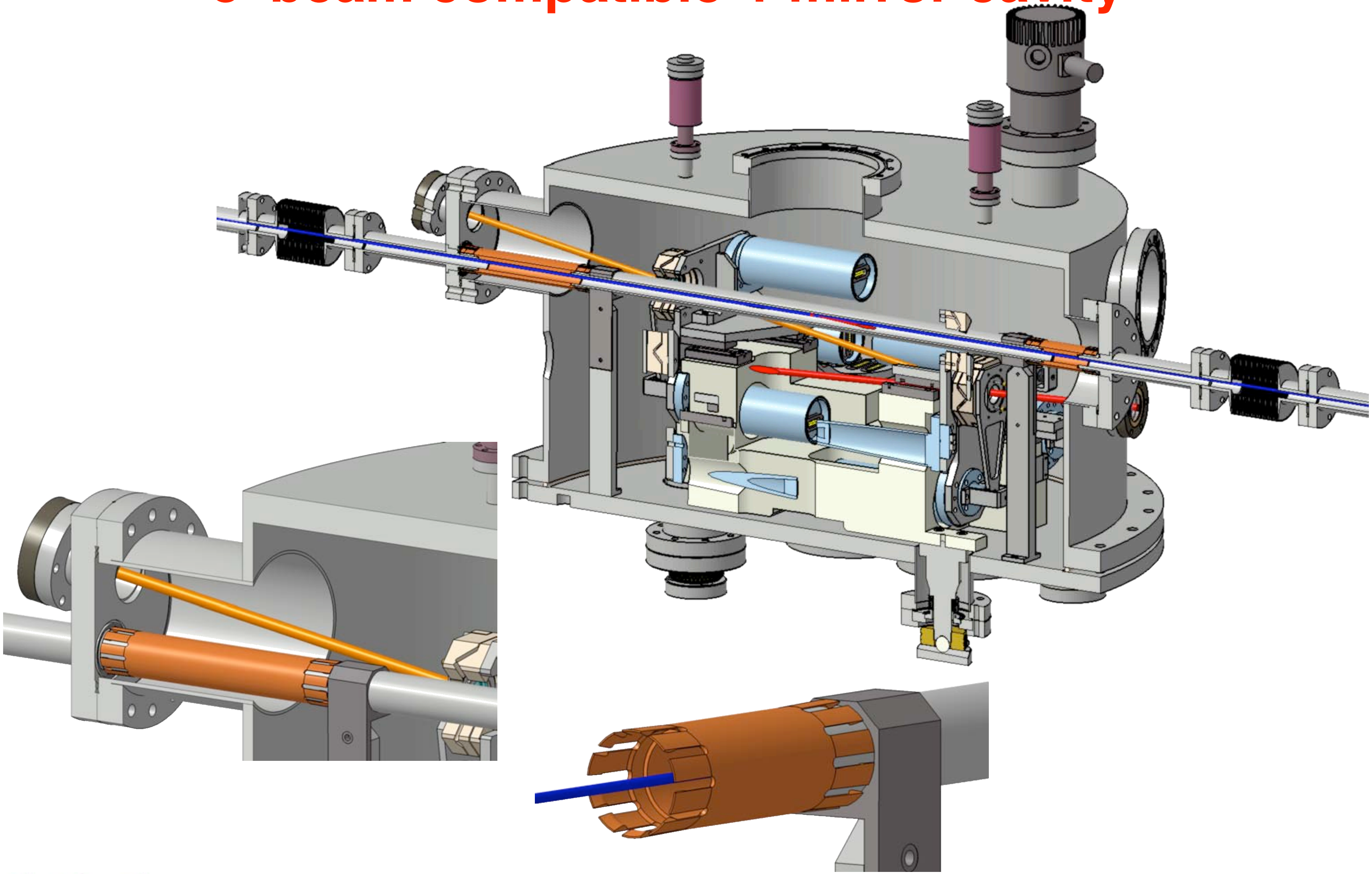
- Moderate Enhancement ~ 1000
- Moderate spot size ~ 30 micron
- Simple cavity stucture with two mirrors
- Analog feedback
- Get experinence with e^- beam

e^- beam compatible 4-mirror cavity



R. Cizeron
LAL 30/01/2008

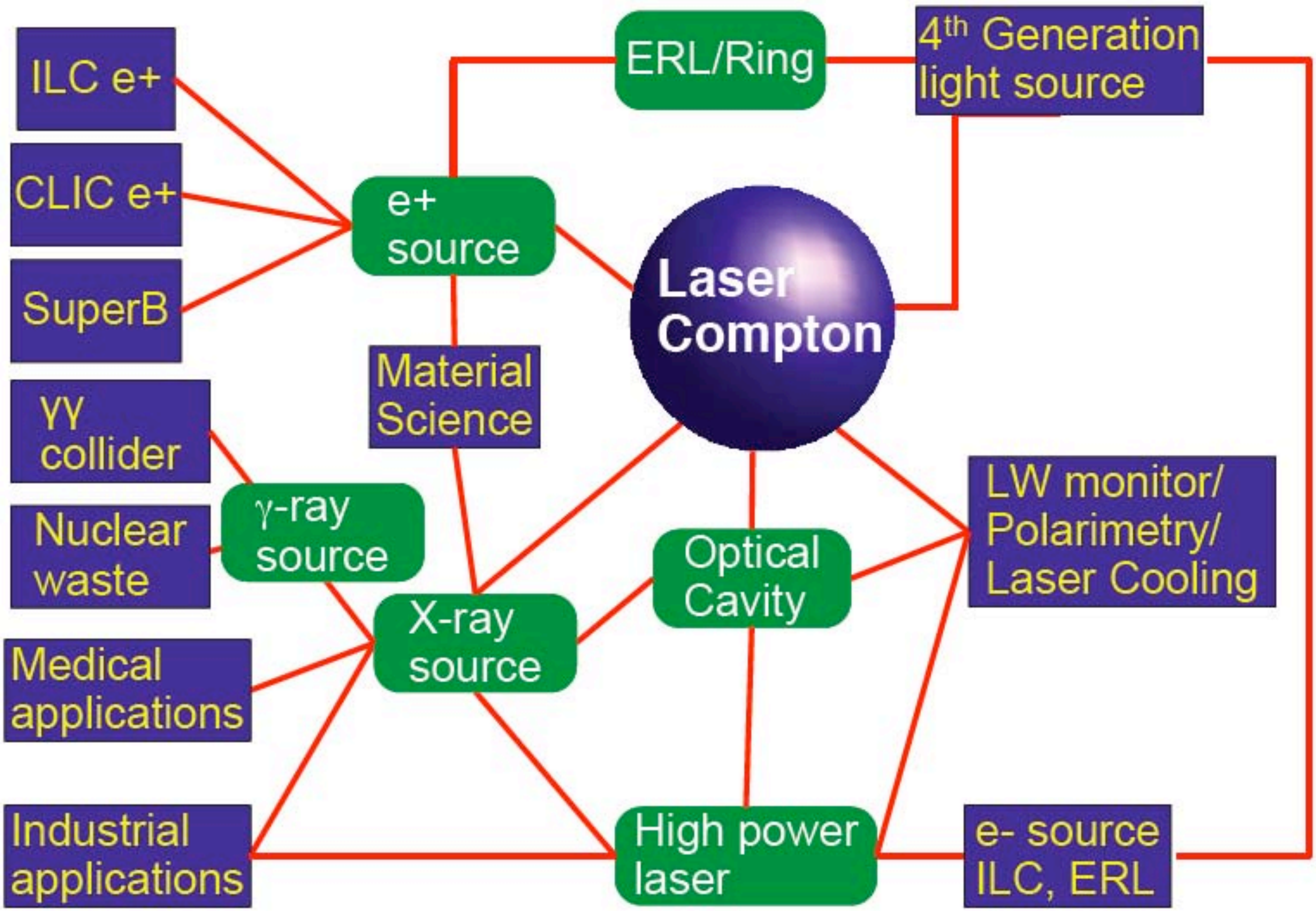
e^- beam compatible 4-mirror cavity



R. Cizeron
LAL 30/01/2008

PosiPol Collaboration

World-Wide-Web of Laser Compton



World-wide PosiPol Collaboration

Collaborating Institutes:

BINP, CERN, DESY, Hiroshima, IHEP, IPN, KEK, Kyoto, LAL, CELIA/Bordeaux, NIRS, NSC-KIPT, SHI, Waseda, BNL, JAEA and ANL

Sakae Araki, Yasuo Higashi, Yousuke Honda, Masao Kuriki, Toshiyuki Okugi, Tsunehiko Omori, Takashi Taniguchi, Nobuhiro Terunuma, Junji Urakawa, Yoshimasa Kurihara, Takuya Kamitani, X. Artru, M. Chevallier, V. Strakhovenko, Eugene Bulyak, Peter Gladkikh, Klaus Meonig, Robert Chehab, Alessandro Variola, Fabian Zomer, Alessandro Vivoli, Richard Cizeron, Viktor Soskov, Didier Jehanno, M. Jacquet, R. Chiche, Yasmina Federa, Eric Cormier, Louis Rinolfi, Frank Zimmermann, Kazuyuki Sakaue, Tachishige Hirose, Masakazu Washio, Noboru Sasao, Hirokazu Yokoyama, Masafumi Fukuda, Koichiro Hirano, Mikio Takano, Tohru Takahashi, Hirotaka Shimizu, Shuhei Miyoshi, Akira Tsunemi, Ryoichi Hajima, Li XaioPing, Pei Guoxi, Jie Gao, V. Yakinenko, Igo Pogorelsky, Wai Gai, and Wanming Liu

POSIPOL 2006
CERN Geneve
26-27 April

http://posipol2006.web.cern.ch/Posipol2006/

POSIPOL 2007
LAL Orsay
23-25 May

http://events.lal.in2p3.fr/conferences/Posipol07/

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POSIPOL 2006
CERN Geneve
26-27 April
http://posipol2006.web.cern.ch/Posipol2006/

POSIPOL 2007
LAL Orsay
23-25 May
http://events.lal.in2p3.fr/conferences/Posipol07/

POSIPOL 2008
Hiroshima
16-18 June
http://home.hiroshima-u.ac.jp/posipol/

PosiPol-Collaboration

1. Laser-Compton has a large potential as a future technology.
2. Many common efforts can be shared in a context of various applications.
   - Compact and high quality X-ray source for industrial and medical applications
   - γ-ray source for disposal of nuclear wastes
   - Beam diagnostics with Laser
   - Laser Cooling
   - Polarized Positron Generation for ILC and CLIC
   - $\gamma\gamma$ collider
3. State-of-the-art technologies are quickly evolved with world-wide synergy.
   - Laser Stacking Optical Cavity,
   - Laser,
   - ERL ....

Summary

Summary 1

1. Laser Compton e+ source is attractive option for ILC/CLIC

   Independent system

   high polarization

   5 Hz polarization flip (for CLIC 50 Hz flip)

   Operability

   wide applications

2. Three schemes are proposed

   Ring Laser Compton

   ERL Laser Compton

   Linac Laser Compton

Summary 2

3. Laser Stacking Optical Cavity is a key
   (a) In Japan, we are generating γ-ray by installing the stacking cavity in ATF-DR.
   (b) In France, we are developing a very advanced cavity with 4 mirrors. In late 2009, a 4-mirror cavity will be installed in ATF-DR for γ-ray generation.

4. We have a world-wide collaboration for Compton.
   Not only for ILC/CLIC e^+ source.
   Also for many other applications.

Backup Slides

R&D items

CR/ERL simulations studies (Kharkov, LAL, JAEA, KEK)
- design studies
- beam dynamics studies

Laser Stacking Cavity (LAL, Hiroshima, IHEP, KEK)
- experimental R/D

e+ capture (LAL, ANL, IHEP, IHEP)
- We will start collaboration with KEKB upgrade study

e+ stacking in DR (CERN)
- Basic beam dynamics studies

Laser
- Fiber laser / Mode-lock laser (cooperation with companies)
- CO_2 laser (BNL)

R&D items

CR/ERL simulations studies (Kharkov, LAL, JAEA, KEK)
- design studies
- beam dynamics studies

Laser Stacking Cavity (LAL, Hiroshima, IHEP, KEK) <- Today
- experimental R/D

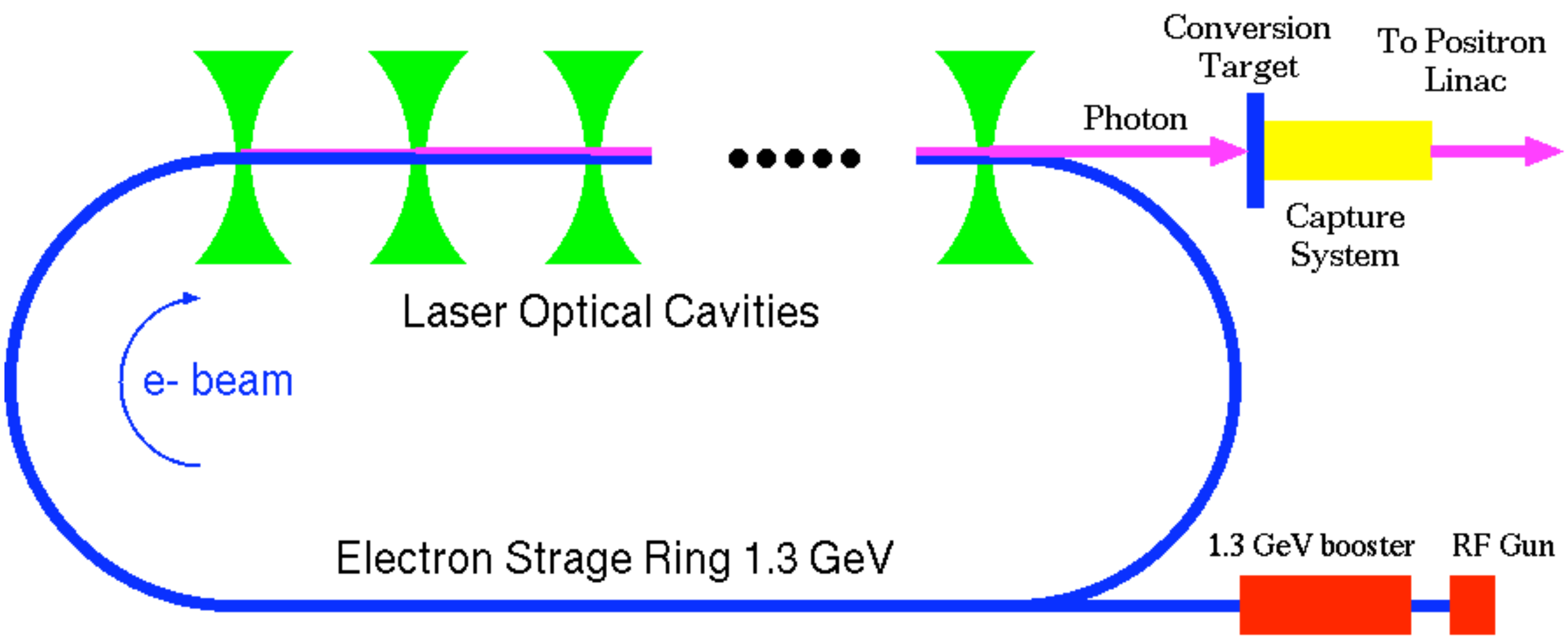
e+ capture (LAL, ANL, IHEP, IHEP)
- We will start collaboration with KEKB upgrade study

e+ stacking in DR (CERN)
- Basic beam dynamics studies

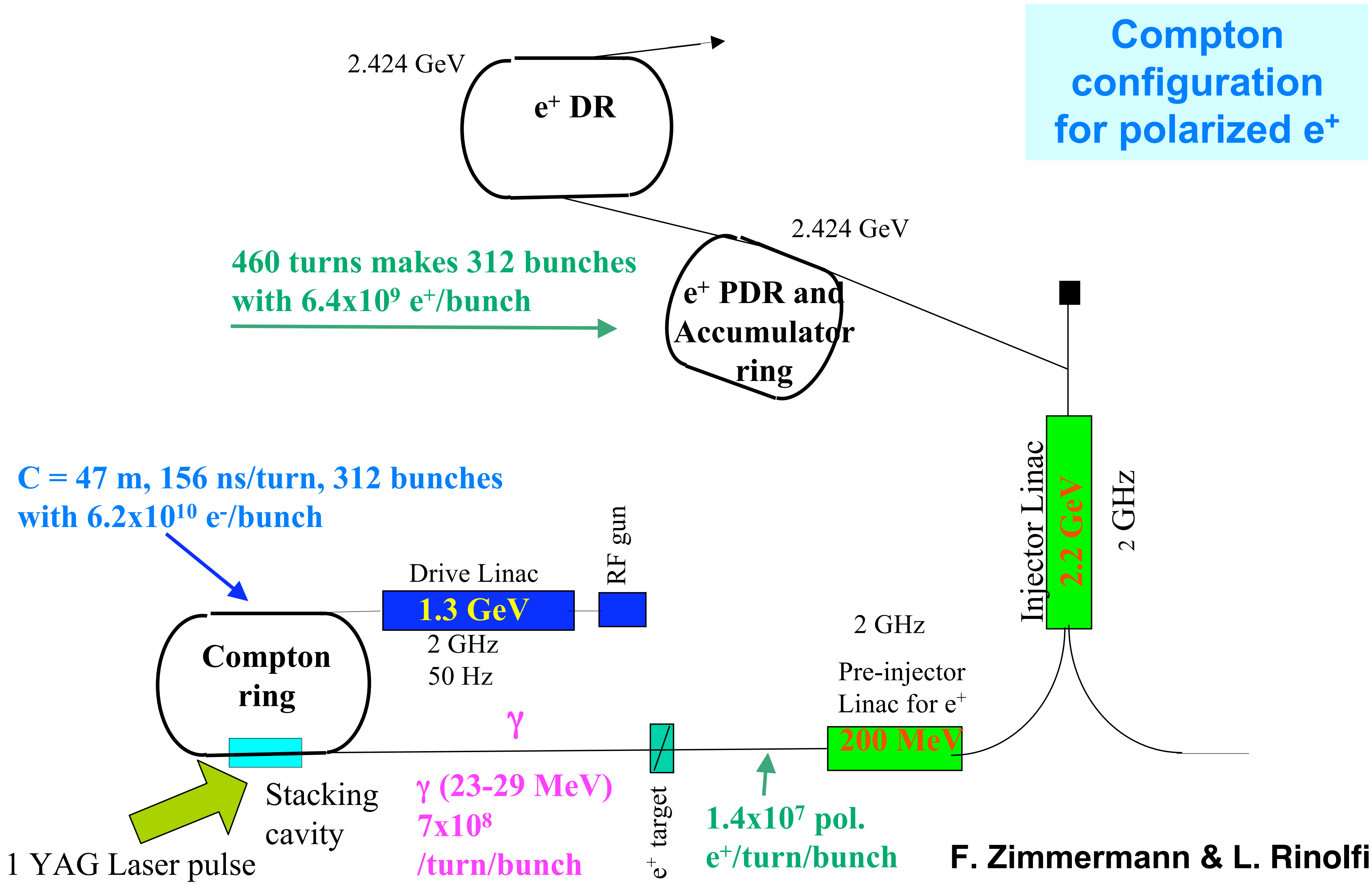
Laser
- Fiber laser / Mode-lock laser (cooperation with companies)
- CO2 laser (BNL)

Compton Ring Scheme for ILC

- Compton scattering of e- beam stored in storage ring off laser stored in Optical Cavity.
- 15 nC 1.3 GeV electron bunches x 10 of 600mJ stored laser -> 1.7E+10 γ rays -> 2.4E+8 e+.
- By stacking 100 bunches on a same bucket in DR, 2.4E+10 e+/bunch is obtained.



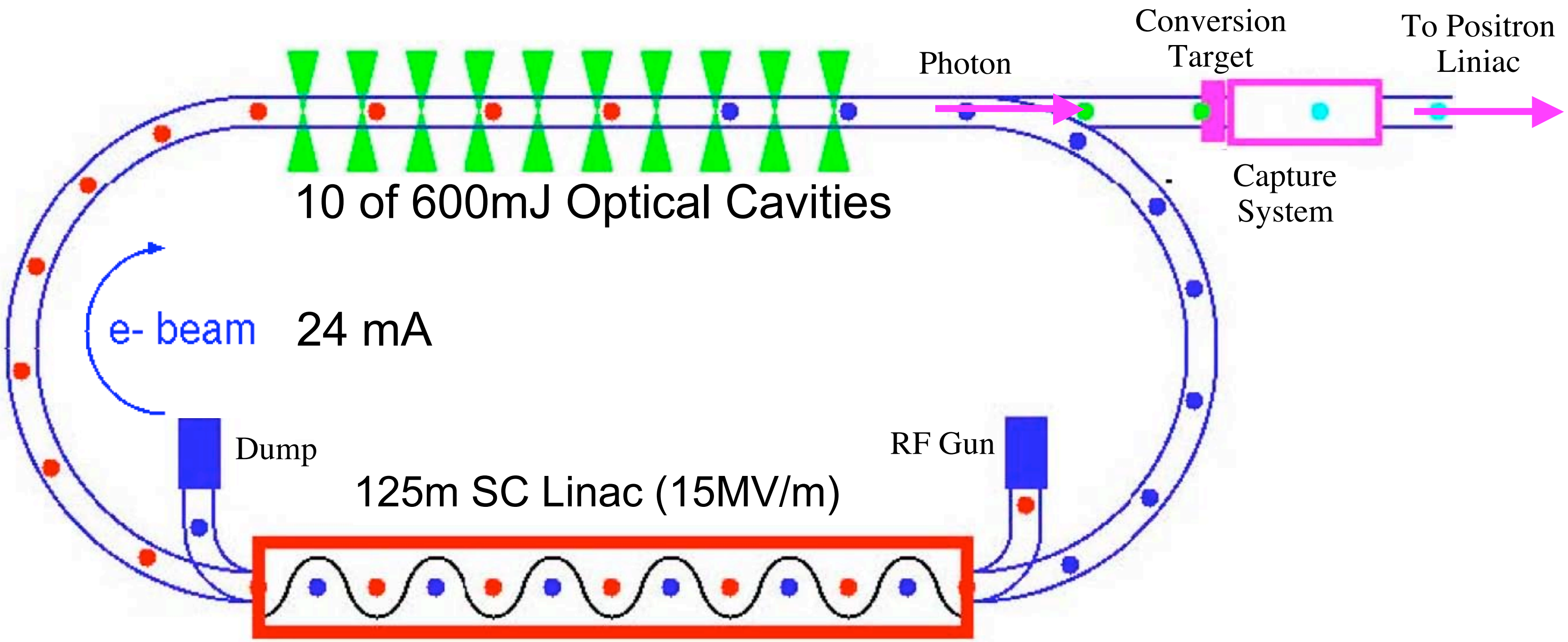
Ring Compton scheme for CLIC in 2008



F. Zimmermann & L. Rinolfi

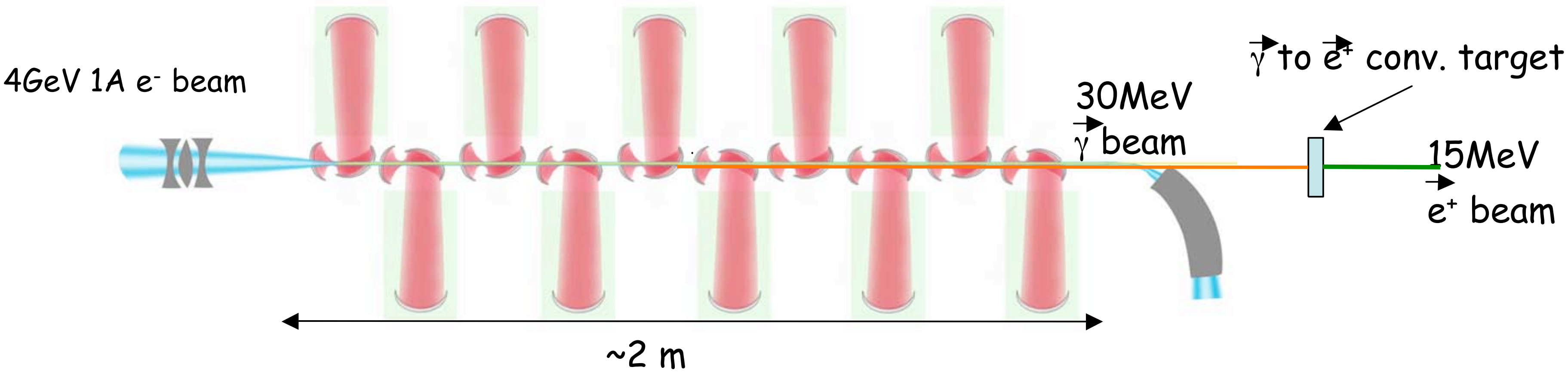
ERL scheme = Linac scheme + Ring scheme (for ILC)

- Both advantages (high yield + high repetition) are compatible in ERL solution.
  - **0.64 nC 1.3 GeV bunches x 10 of 600 mJ laser, repeated by 40.8MHz -> 6.4E+9 γ-rays -> 2E+7 e+.**
  - **Continuous stacking the e+ bunches on a same bucket in DR during 100ms, the final intensity is 2E+10 e+.**



Linac Scheme for ILC

- Polarized γ-ray beam is generated in the Compton back scattering inside optical cavity of CO_2 laser beam and 4 GeV e-beam produced by linac.
  - **4GeV 15nC e- beam with 12 ns spacing.**
  - **10 CPs, which stores 10 J CO_2 laser pulse repeated by 83 Mhz cycle.**
- 5E+11 γ-ray -> 2E+10 e+ (2% conversion)
- 1.2μs pulse, which contains 100 bunches, are repeated by 150 Hz to generated 3000 bunches within 200ms.
- No stacking in DR



By V. Yakimenko and Pogorersky

Points of R/D

Achieve both

high enhancement & small spot
(less stabile) & (less stabile)

Points for high enhancement factor

remove/suppress vibration

establish feed-back technology

Points for small spot

$2\rho - L_{cav}$ --> +0

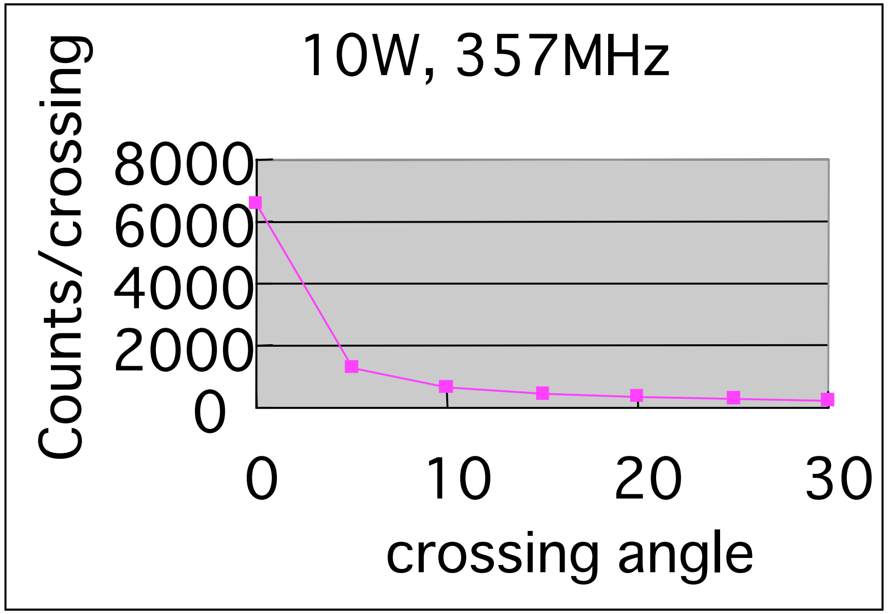
good matching between laser and cavity

all are common in pol. e^+ and laser wire

Points of R/D (continued)

Achieve smaller crossing angle

Number of γ-rays strongly depends on crossing angle



ATF

e^- bunch length = 9 mm (rms)

Ne = 1×10^{10}/bunch

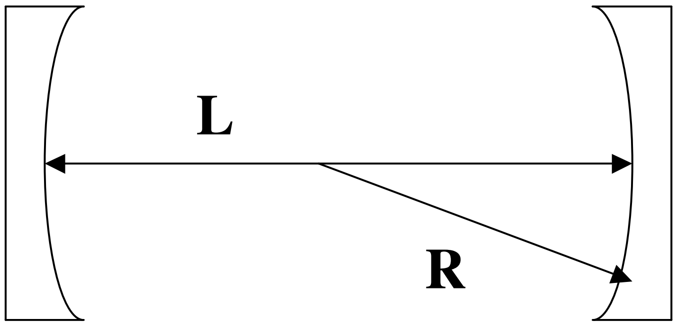
--> Small crossing angle is preferable

--> constraint in chamber design

This in NOT common in pol. e^+ and laser wire

Laser stacking cavity with Two Spherical Mirrors

Choice of R and spot size



L = 420.00 mm

our choice for 1st prototype →

Mirror R (mm)	rms laser spot size (micron)
250	88
211	35
210.5	30
210.1	20
210.01	11
210.001	6

concentric configuration

R + R ~ L

Expected Number of γ-rays

design values with R=99.9 %

Number of γ-rays/bunch

Electron :Ne = 2×10^{10} (single bunch operation)
Laser : 10 W (28 nJ/bunch)
Optical Cavity: Enhancement = 1000

Nγ =1300/bunch X-ing angle = 10 deg
Nγ = 900/bunch X-ing angle = 15 deg

Number of γ-rays/second

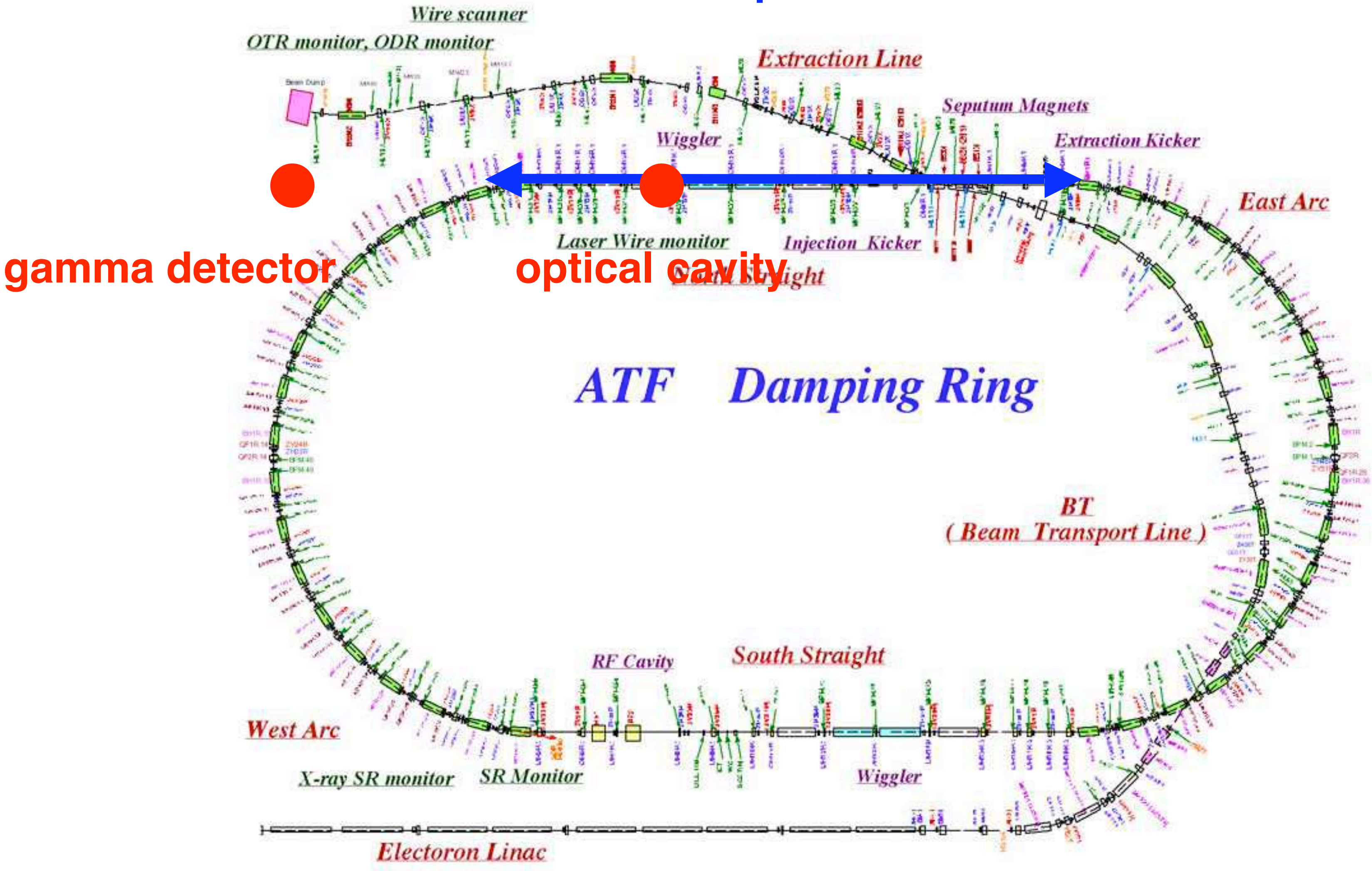
Electron :Ne =1×10^{10} (multi-bunch and multi-train operation)
Electron 20 bunches/train, 3 trains/ring
Laser : 10 W (28 nJ/bunch)
Optical Cavity: Enhancement = 1000

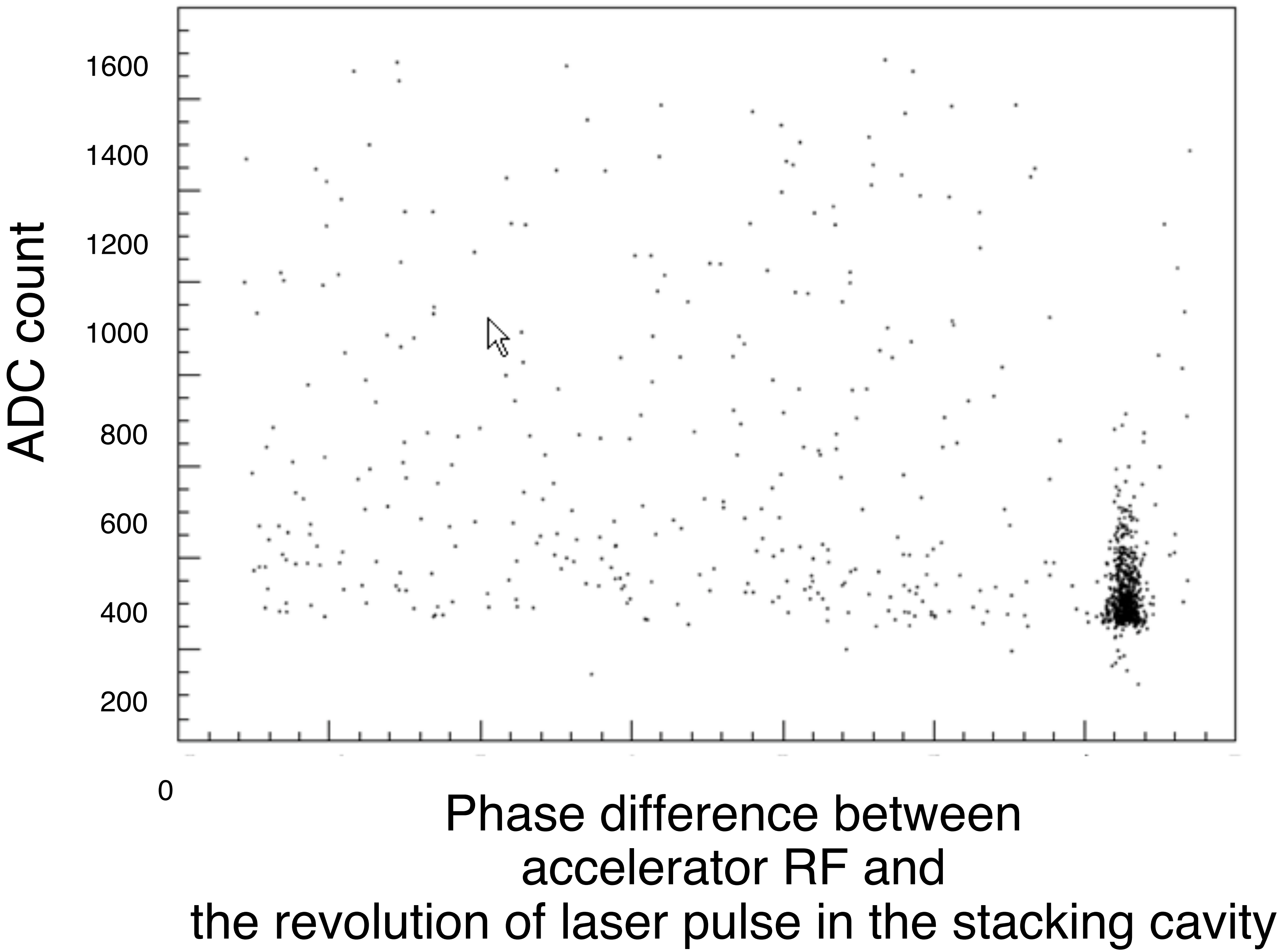
Nγ = 8.5×10^{10}/sec X-ing angle = 10 deg
Nγ = 5.7×10^{10}/sec X-ing angle = 15 deg

Open ADC gate when electron bunch running north straight section and transmission light from optical cavity exceed threshold level.

No timing fixing between optical cavity and storage ring. Both accelerator RF and the revolution of laser pulse in the stacking cavity are about 357 MHz, but they are very slightly different. Difference of their phases are running.

Then observe the correlation between the phase difference vs detector out put.

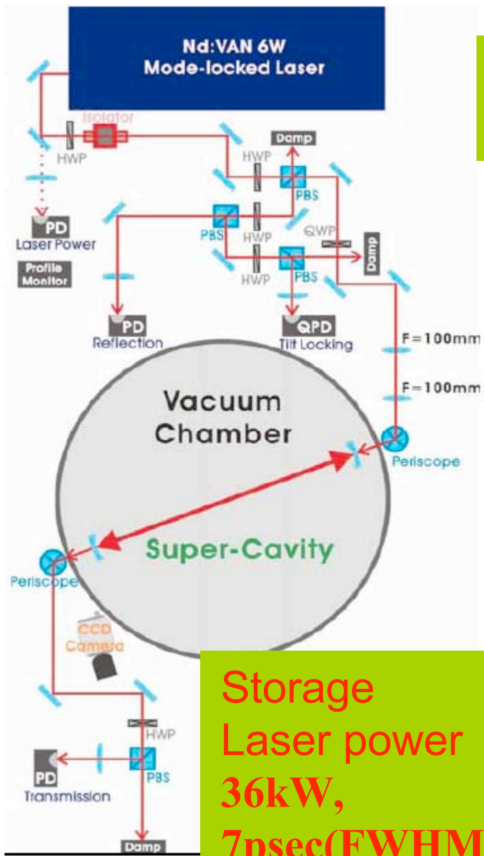




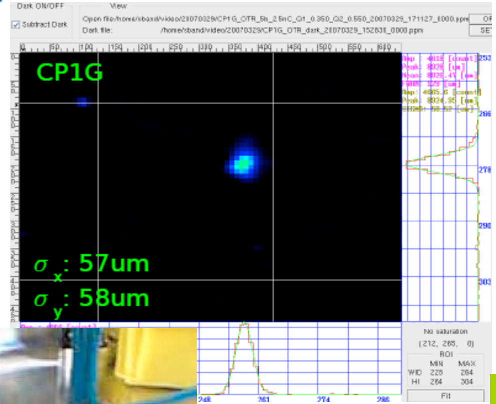
ADC count
1600
1400
1200
1000
800
600
400
200
0
Phase difference between
accelerator RF and
the revolution of laser pulse in the stacking cavity

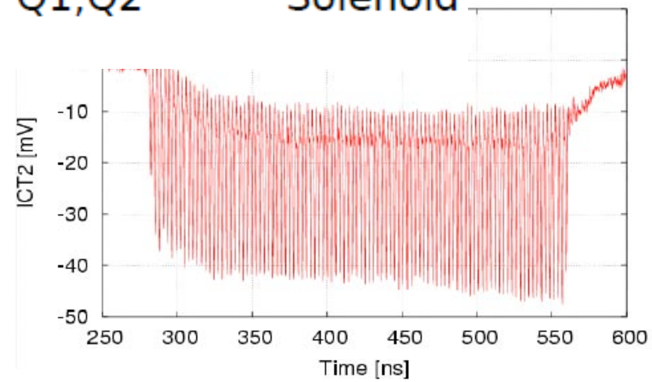
Laser Undulator Compact X-ray (LUCX) Project at KEK-ATF
(Kyoto-Waseda-KEK)

43MeV Multi-bunch beam+ Super-Cavity = 33keV X-ray.



Beam size at CP 60μm in σ





Storage
Laser power
36kW,
7psec(FWHM),
next step :1MW

Multi-bunch e- beam 300nC at gun

At present, laser waist size is **30μm** in σ. We should reduce both beam size at CP down to 30μm.
33keV X-ray generation based on inverse Compton scattering is started from May 2007 with Super-Cavity.

Future R/D

Achieve both

high enhancement(1000) & small spot (30μm)
(less stabile) & (less stabile)

1. Points for high enhancement factor

remove/suppress vibration

establish feed-back technology

(Mirror R = 99.7%-→R=99.9%-→R=99.99%-→R=99.999%?)

Next step : from 1000 to 10000 or 100000

2. Points for small spot

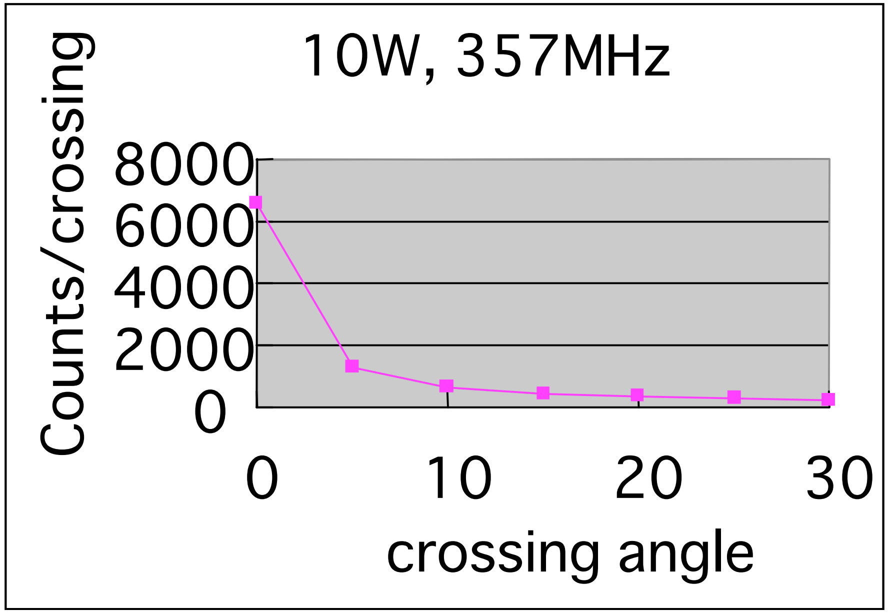
$2\rho - L_{cav}$ --> +0 Next step : from 30μm to 10μm or 6μm

good matching between laser and cavity

3. Points of R/D (continued)

Achieve smaller crossing angle

Number of γ-rays strongly depends on crossing angle



ATF

e^- bunch length = 9 mm (rms)

Ne = 1×10^{10}/bunch

(In the case of 1mm bunch length, this dependence is not strong.)

Short bunch beam is preferable.

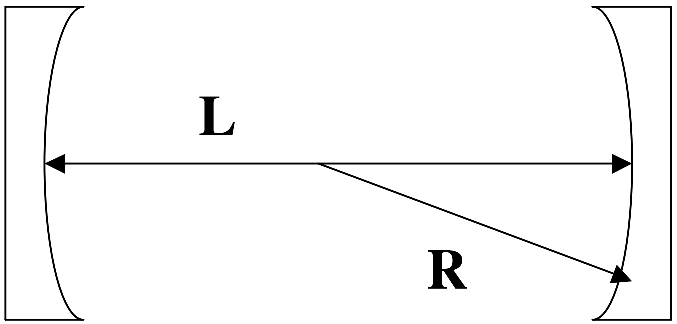
Next step : from 12 degree to 8 degree or 5 degree.

--> Small crossing angle is preferable.

--> constraint in chamber design

Laser stacking cavity with Two Spherical Mirrors

Choice of R and spot size



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R + R ~ L

World-Wide-Web of Laser Compton