Photon Collider testbed and other possibilities at future ATF2

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Hiroshima Univ.

Dec 21 2007
ATF2 meeting

future but before ILC

Once ATF2 has accomplished its primary goal, it will be an ultra high-quality beam facility

- Photon beam for the PLC option of the ILC
  - **physics scenario is yet to be described**
    - wait for LHC & ILC e+e- run
  - **accelerator and detector issues to be considered**

→ Optical cavity: the most unknown component

- Physics with electron beam and lasers
  - **topics from the workshop on Laser-Electron Interaction toward the ILC (Dec 12-14, Hiroshima)**

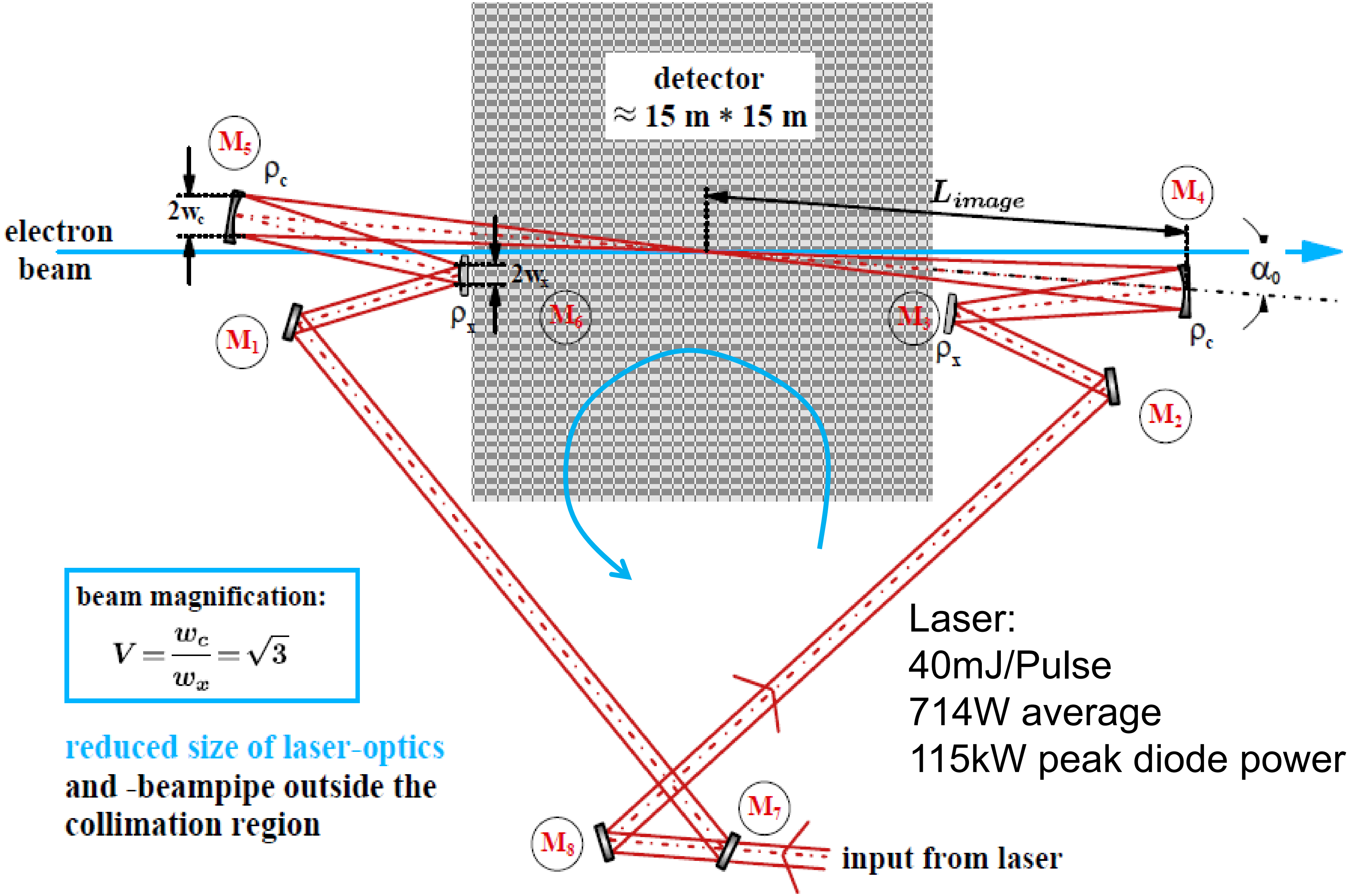
Lasers for Photon Colliders

- have to meet requirement of;
  - **5J/pulse, 1-3ps pulse duration**
    - ~2TW pleak power
  - **337ns separation 3000bunches/train**

$$High \quad pumping \quad power = \frac{5J \times 3000}{1ms \times eff\,(0.3)} = 50MW$$

  - **5Hz**
    - ~70kW average power
  - **O(10μm) focusing**
  - **timing ~1ps**
- too costly to be built by single laser

Proposed telescopic, passive, resonant external cavity



beam magnification:

$$V = \frac{w_c}{w_x} = \sqrt{3}$$

reduced size of laser-optics and -beampipe outside the collimation region

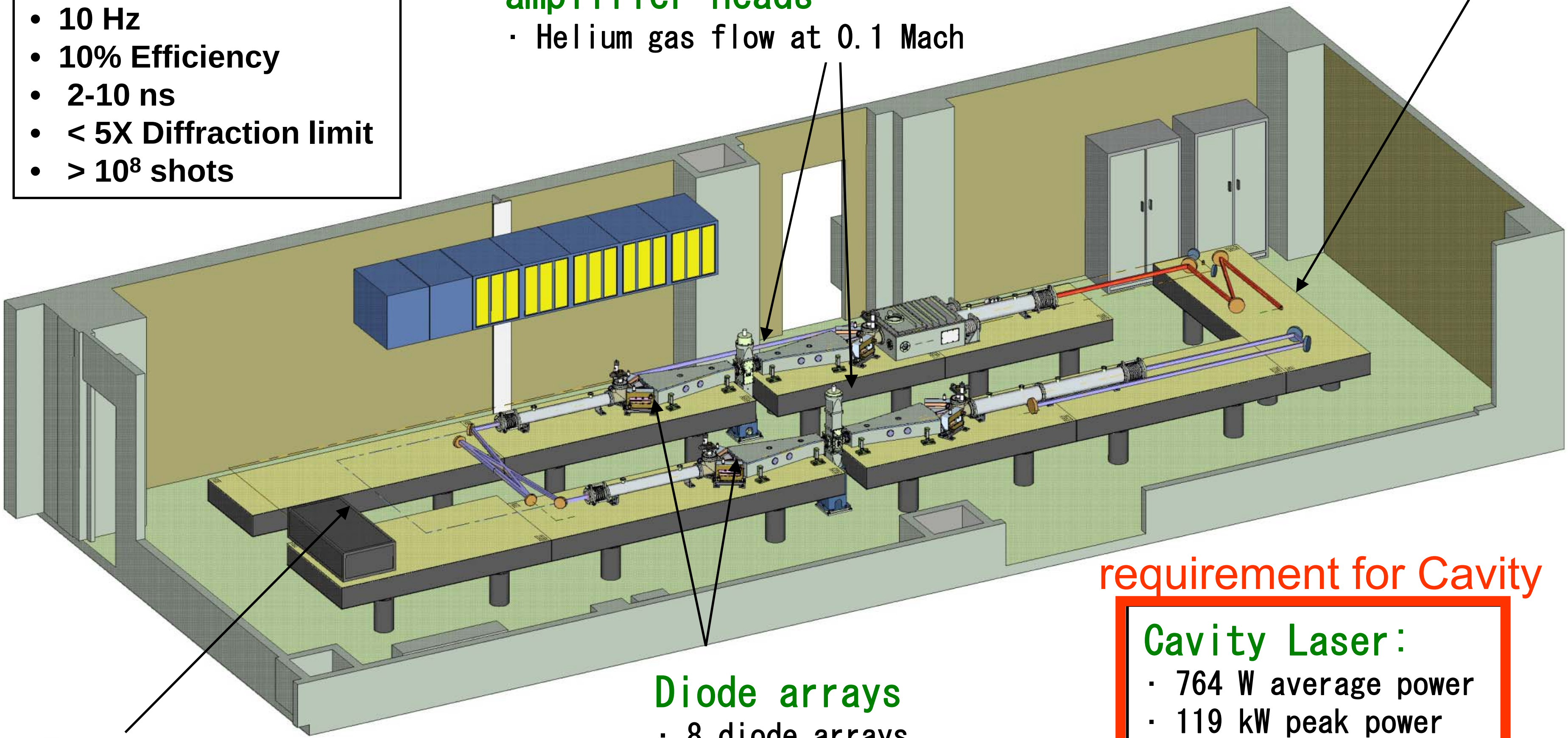
Laser:
40mJ/Pulse
714W average
115kW peak diode power

The MERCURY laser already has more average power than we need

Goal:
- **100 J**
- **10 Hz**
- **10% Efficiency**
- **2-10 ns**
- **< 5X Diffraction limit**
- **> 10^8 shots**

Gas-cooled amplifier heads
- Helium gas flow at 0.1 Mach

Gronberg
Output



requirement for Cavity

Cavity Laser:
- 764 W average power
- 119 kW peak power

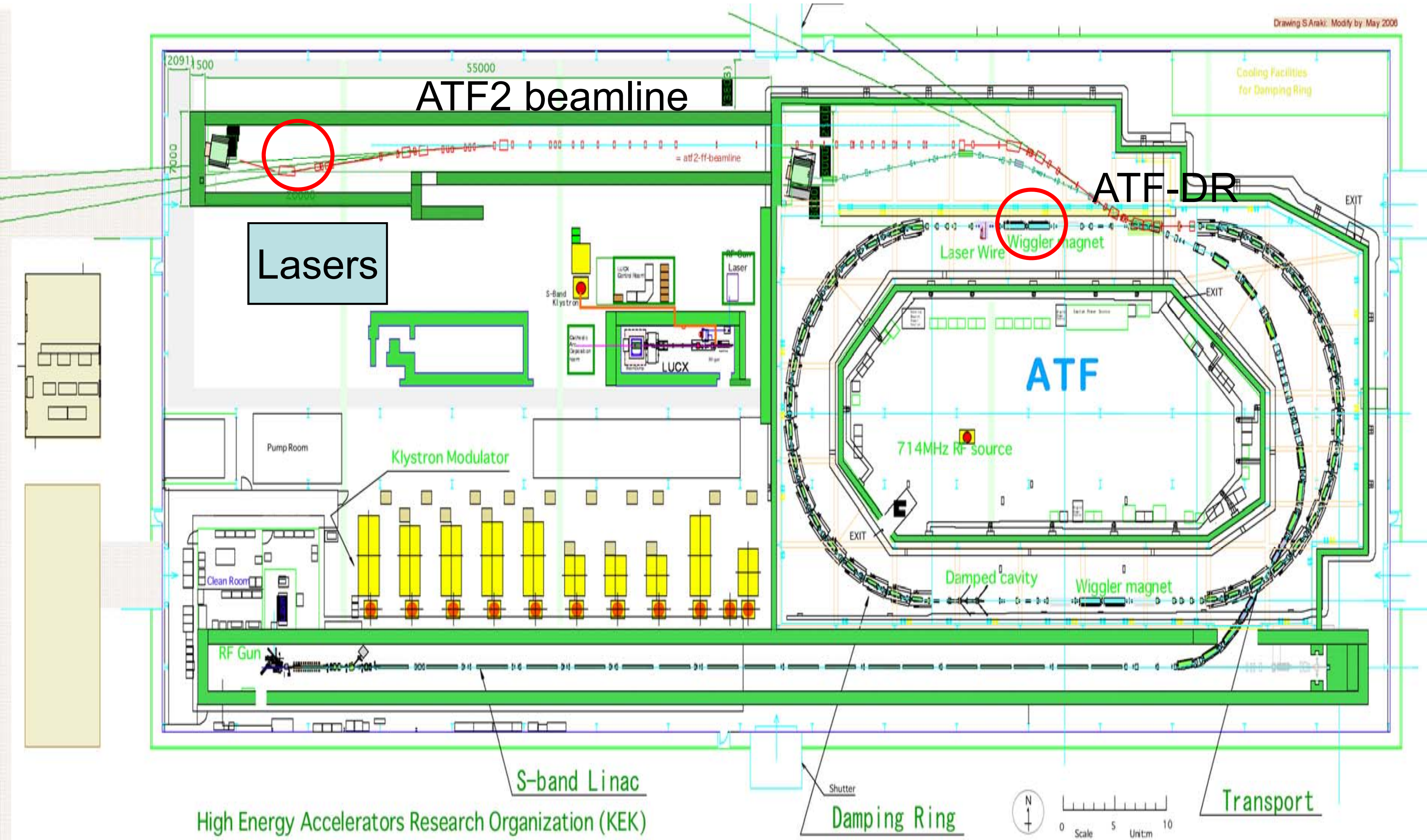
Diode arrays
- 8 diode arrays
- 6624 diodes total
- 730 kW peak power

Front-end
- 300 mJ

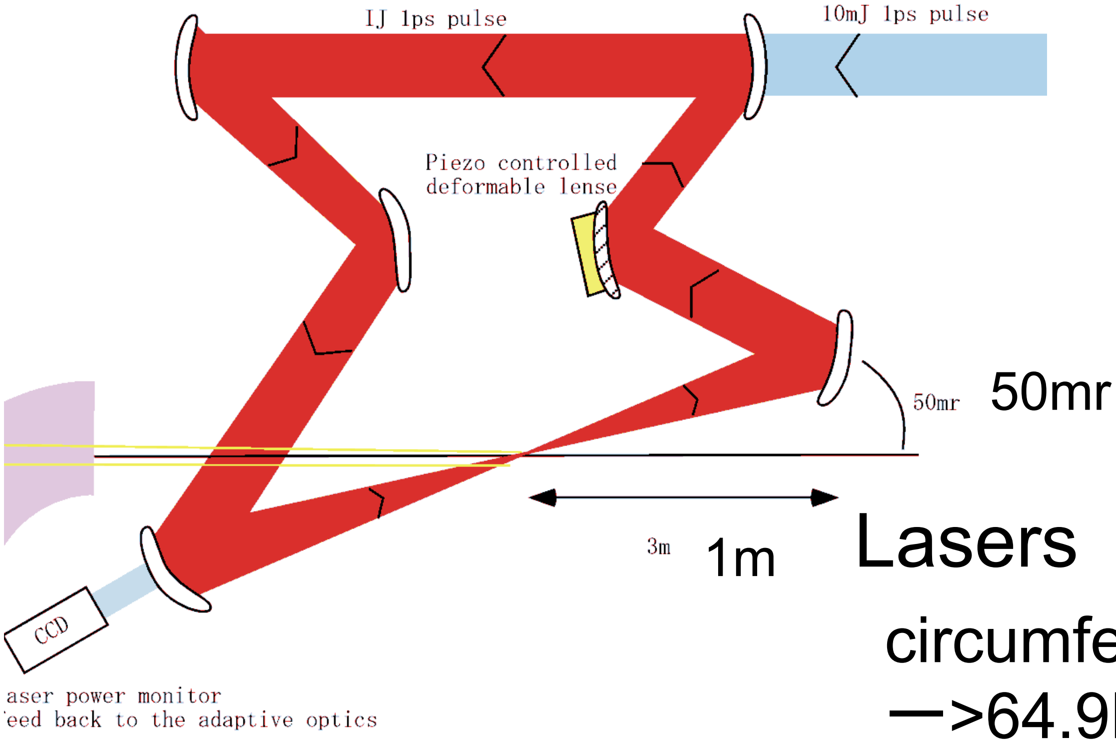
what we need for PLC cavity

- pulse stacking
- enhancement ~ 100
- keeping circularly polarized laser
- high power
  - **O(10J)/pulse, ~2TW, ~70kW**
- focusing laser spot ~ (10μm)
- large scale - circumference ~ 100m±(<nm)
- synchronized with electron bunch (<ps)
- high vacuum
  - **not allowed to affect e beam ~ O(10^{-7} P)**

ATF-Layout


ATF2 beamline
Lasers
ATF-DR
Laser Wire
Wiggler magnet
ATF
714MHz RF source
Damped cavity
Wiggler magnet
Klystron Modulator
Pump Room
Clean Room
RF Gun
LUCX
S-Band Klystron
Laser
EXIT
55000
2091
500
Drawing S.Araki Modify by May 2006
Cooling Facilities for Damping Ring
S-band Linac
Shutter
Damping Ring
Transport
High Energy Accelerators Research Organization (KEK)
Scale
Unit:m
0
5
10
N

Ring cavity at ATF-DR
-after we learn a lot from PosiPol cavities-



For 154ns spacing:
1/10 scale (15.4ns)

A laser pulse hits once in 10 turns

Lasers

circumference 4.62m (15.4ns)
—>64.9MHz

very similar to
PosiPol experiment

10W mode locked,,,154nJ/pulse
->15.4μJ/pulse w/ 100 pulse stacking

2400γ/xing

Step by step plan

1. Cavities for Compton based pol. e+ projects
   – Fabry-Perot type spherical mirror
   – Fabry-Perot type off-axis parabolic mirror

42cm

ATF-DR

2. Going to large scale
   – CW laser
   – independent mirror control
3. 1-2m scale (with ATF bunch)
   – pulse laser (low energy)
   – independent mirror control

1~2m

Lab
->ATF-DR
if possible

4. Cavity w/ high power laser at ATF2-IP
   – not possible at ATF-DR as high power laser is destructive target

ATF2
~2015?

LEI 2007

First Announcement

Committees

Working groups

Scientific Program

Social Program

Important Dates

Registration

Practical Information

Accommodation

Contact

International Workshop
on
Physics and Technologies
of
Laser-Electron Interaction toward the ILC

December 12 – 14, 2007

Hiroshima University, Higashi-Hiroshima, Japan

A Sake Brewery street near Hiroshima University

Explore early universe in the laboratory

by reproducing interaction

Axion, neutrino

ILC

Polarized electrons
Laser wires,,,,,
Photon Colliders

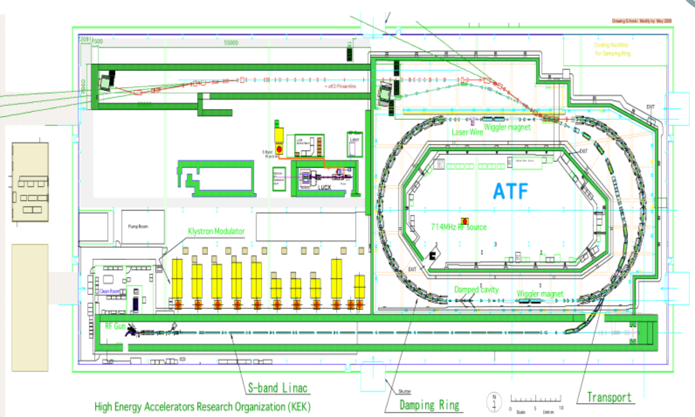
intense field
Unrhu, Swinger field
self-focusing

Lasers
Optical Cavity
High power lasers

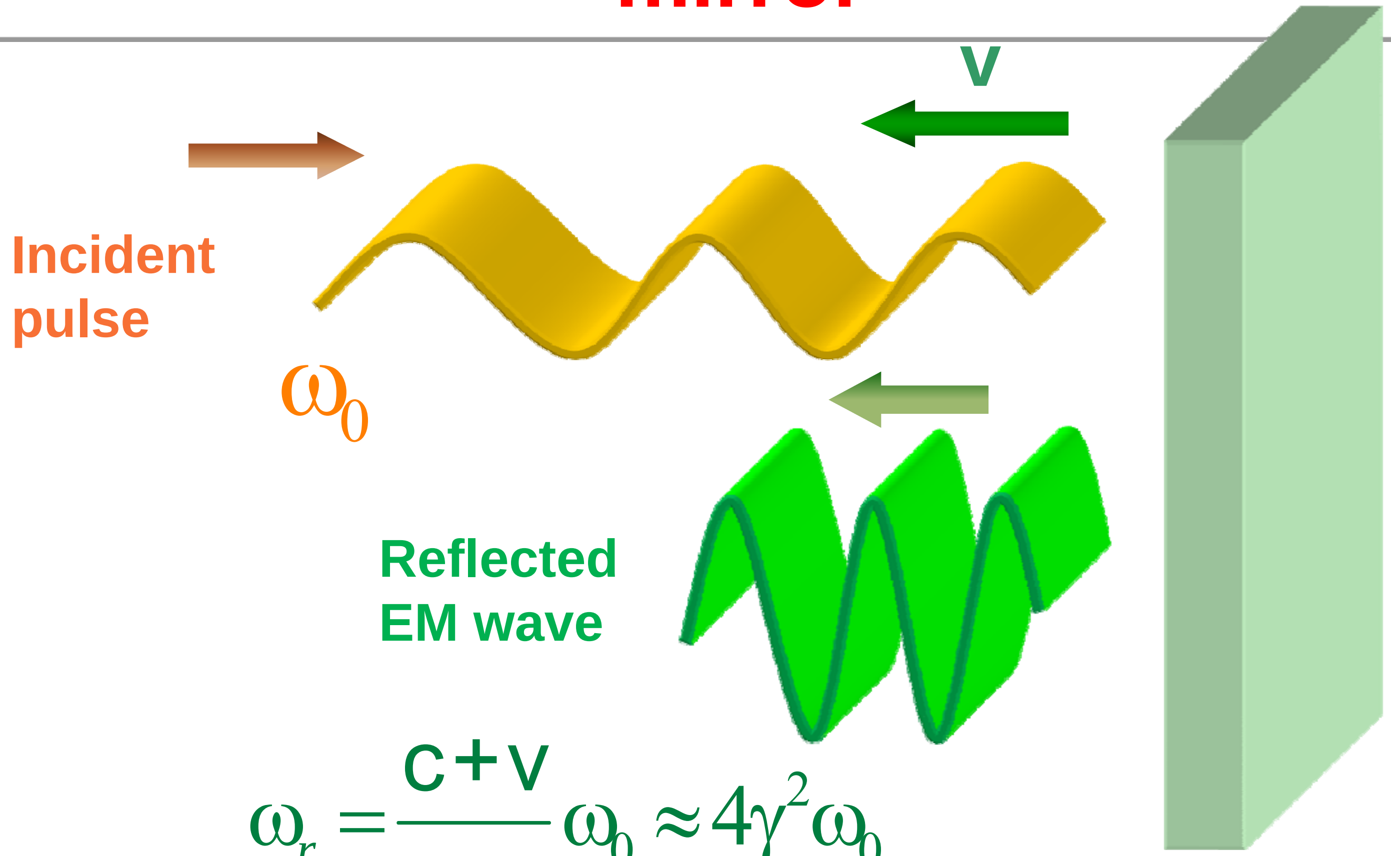
by creating environment

gravitational wave detectors

getting information of space-time structure



Reflection of EM wave at the relativistic mirror

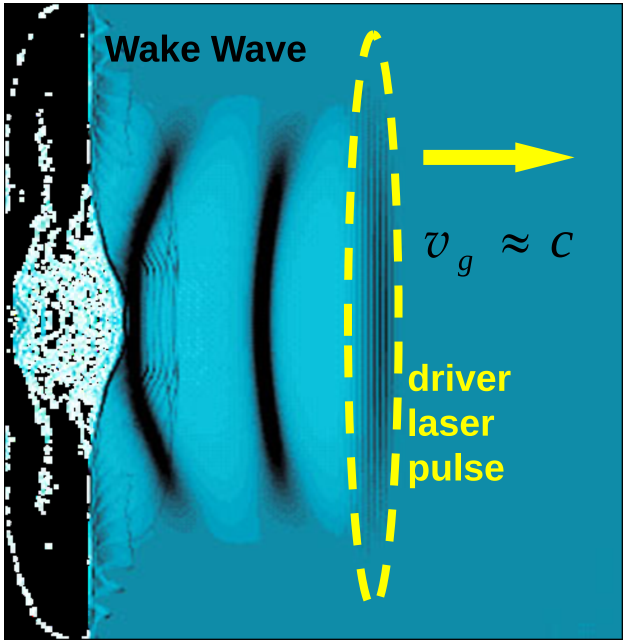


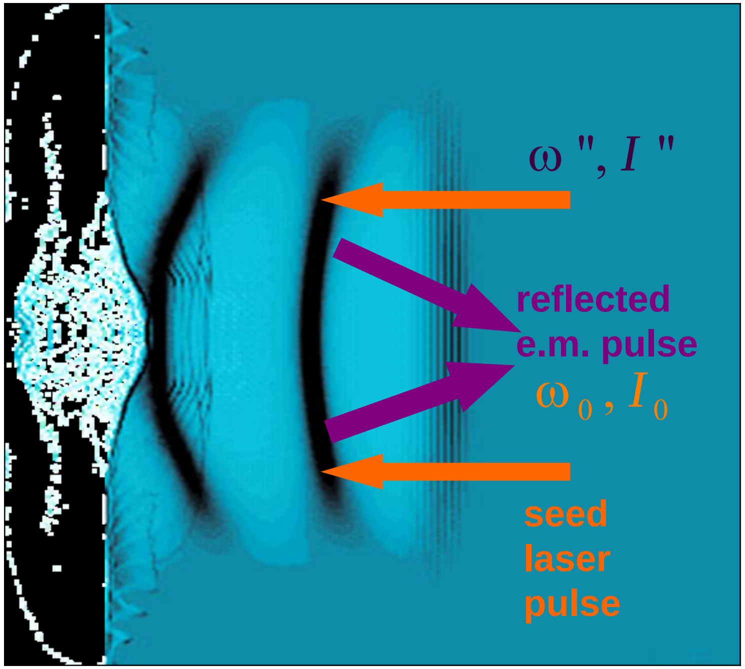
$$\omega_r = \frac{c+v}{c-v}\omega_0 \approx 4\gamma^2\omega_0$$

A. Einstein, Ann. Phys. (Leipzig) 17, 891 (1905)

Bulanov

EM Pulse Intensification and Shortening in Flying Mirror Light Intensification Process





$$\omega'' = \frac{1+v_{ph}/c}{1-v_{ph}/c}\,\omega \approx 4\gamma_{ph}^2\omega_0$$

$$I''_{max} \approx \kappa(\gamma_{ph})\,\gamma_{ph}^6\left(\frac{D}{\lambda}\right)^2 I_0$$

$$\kappa(\gamma_{ph}) \sim \gamma_{ph}^{-3}$$

M. Kando, et.al、
Phys. Rev. Lett. 99, 135001 (2007)

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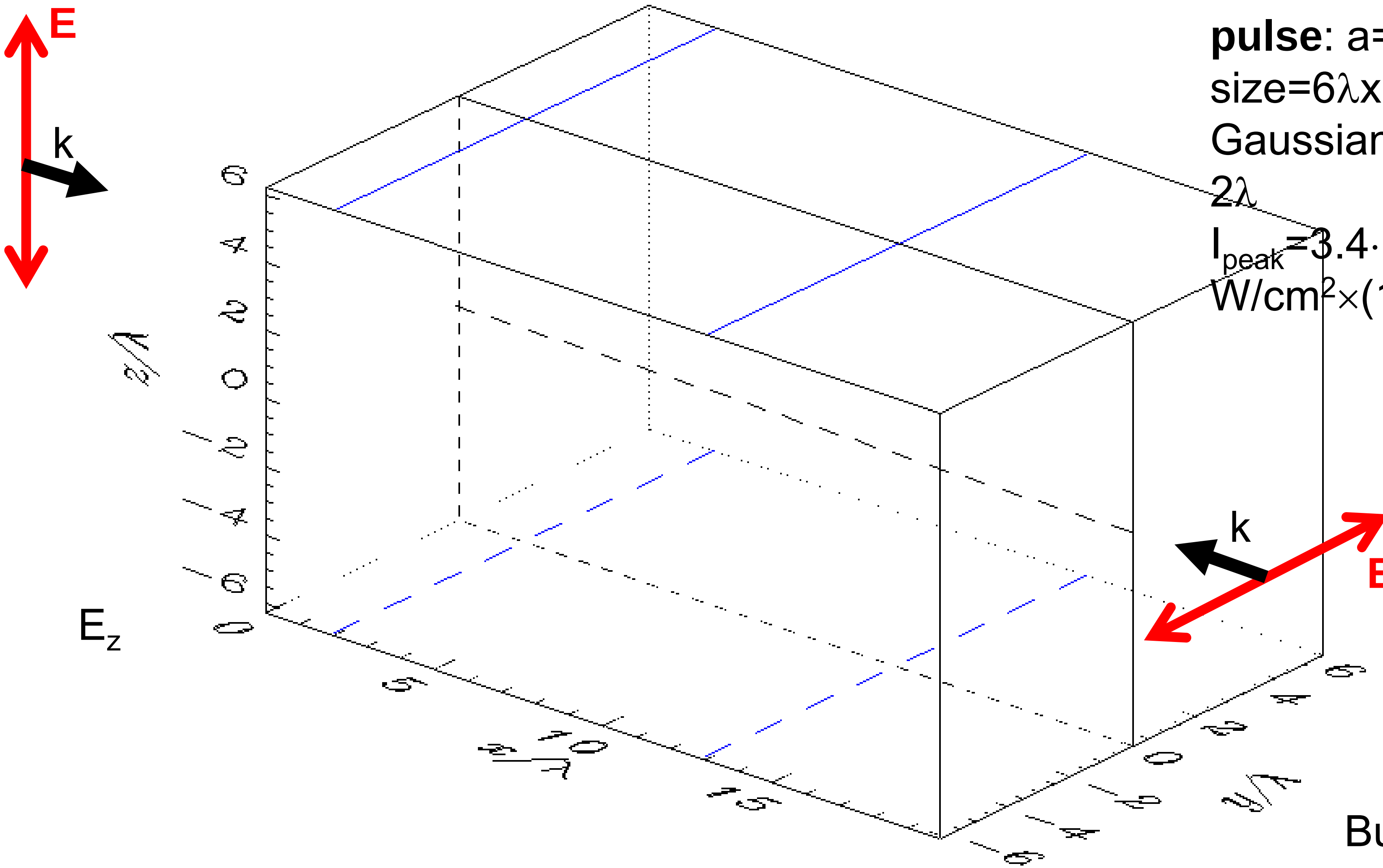
3D Particle-In-Cell simulation (II)

Driver pulse: ***a=1.7***
size=3λx6λx6λ, Gaussian
$I_{peak}=4\cdot10^{18}\ W/cm^2\times(1\mu m/\lambda)^2$

Reflecting pulse: a=0.05
size=6λx6λx6λ, Gaussian, $\lambda_s = 2\lambda$
$I_{peak}=3.4\cdot10^{15}\ W/cm^2\times(1\mu m/\lambda)^2$



E_z

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E_x

XZ,color: E_y XY,contour: E_z XY,color: E_x at z=0

REMP

Laser Energy Required to Achieve the Schwinger Field

The wakefield excited in $10^{18}cm^{-3}$ plasma by the EM wave with $a_0 = 15$ has the Lorentz factor $a_0^{1/2}(\omega_{pe}/\omega) \approx 125$.

The laser pulse intensification of the order of 465 may be realized.

For the counter-propagating $1\mu m$, 2×10^{19} W/cm^2 laser pulse with the reflected beam diameter is $40\mu m$, the final intensity is 5×10^{28} W/cm^2.

The driver pulse intensity should be sufficiently high and its beam diameter should be enough to give such a wide mirror, i.e. to be 4×10^{20} W/cm^2 with the diameter $40\mu m$.

The driver and source must carry 6 kJ and 30 J, respectively.

Reflected intensity can approach the Schwinger limit. In this range of the electromagnetic field intensity it becomes possible to investigate such the fundamental problems of nowadays physics using already available laser, as e.g. the electron-positron pair creation in vacuum and the photon-photon scattering **WITH the ELI and HiPER LASERS PARAMETERS**.

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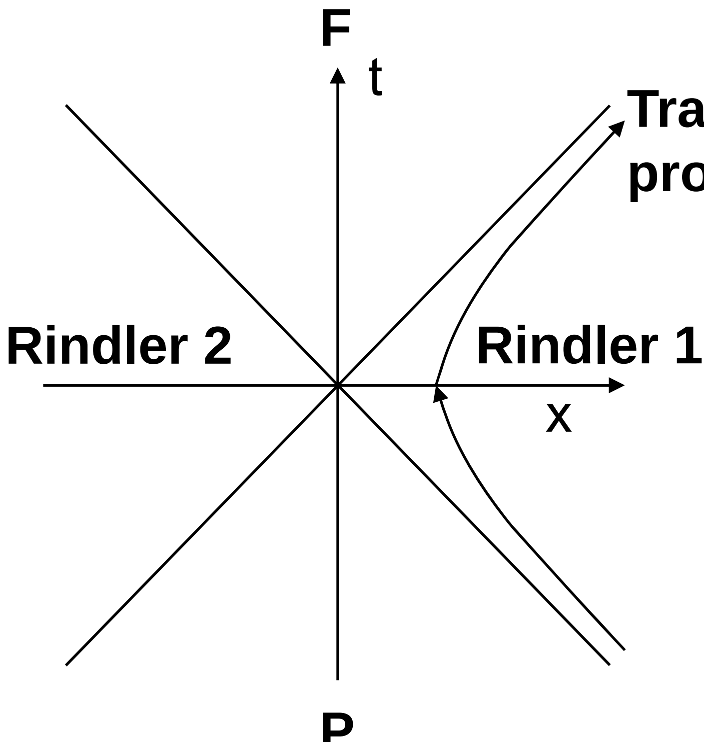
Radiation via event horizon
- access to zero-point energy -

homma



Minkowski spacetime

Trajectory of observer with a constant proper acceleration α (Rindler observer)

Rindler 1 and 2 are causally disconnected (introduction of an event horizon)

$$\phi = \sum_{k=-\infty}^{+\infty} (a_k u_k + a^+{}_k u_k^*)$$

$$\phi = \sum_{k=-\infty}^{+\infty} (b^{(1)}{}_k u_k^{(1)} + b^{(1)^+}{}_k u_k^{(1)*} + b^{(2)}{}_k u_k^{(2)} + b^{(2)^+}{}_k u_k^{(2)*})$$

Minkowski spacetime looks as if thermal ba to a Rindler observer via the Bogoliubov tra

$$\langle 0_M \mid b^{+(1,2)} b^{(1,2)} \mid 0_M \rangle \propto \frac{1}{e^{-2\pi\omega/\alpha} - 1}$$

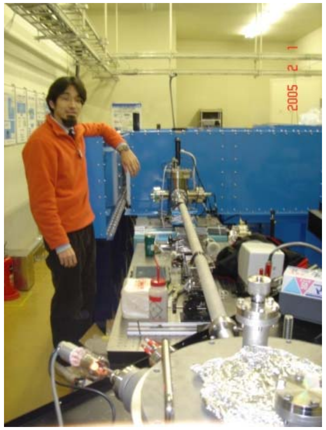
Optical laser as a source of acceleration
Electron as an Rindler particle

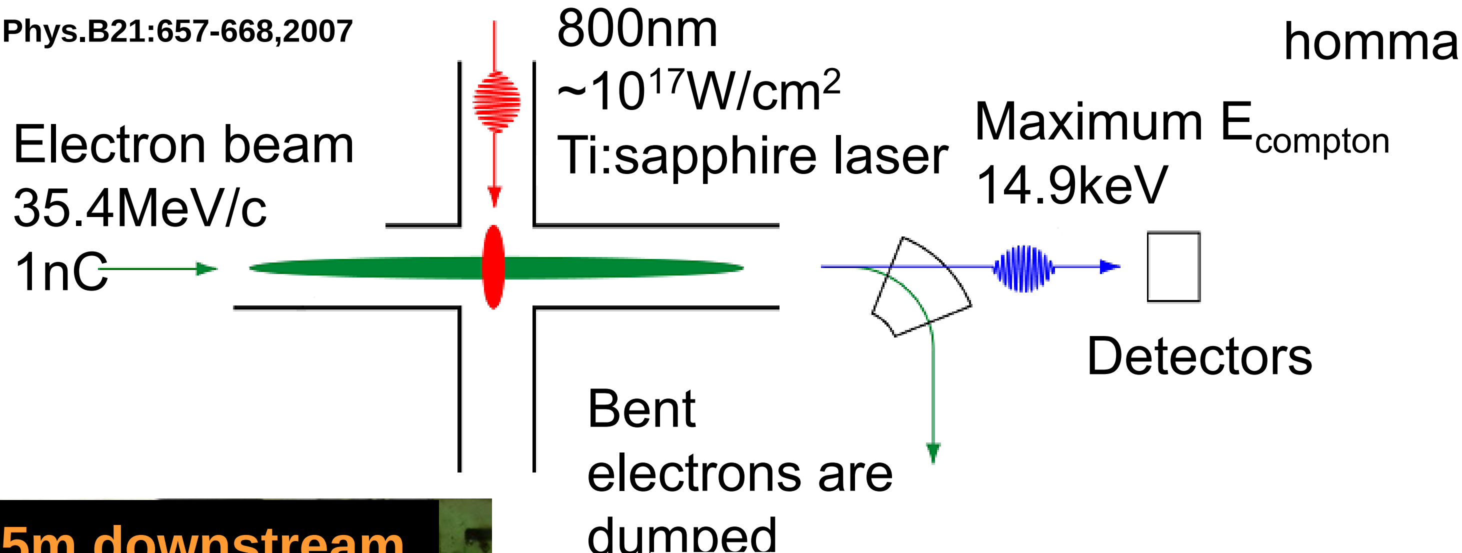
Unruh temp.⇔ Hawking temp.

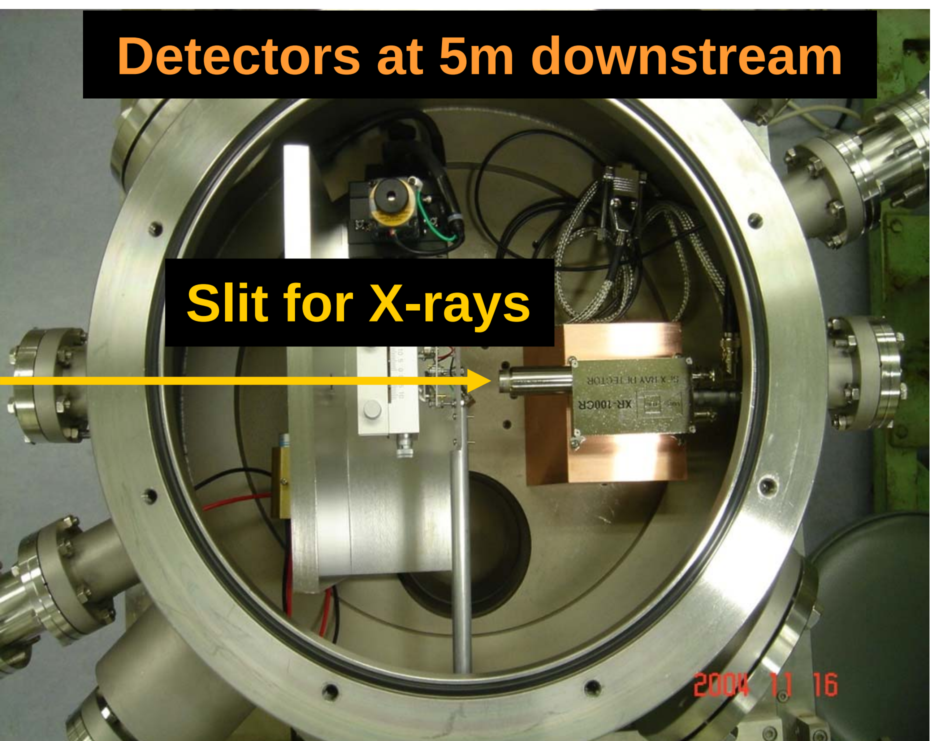
$$k_B T = \frac{\alpha}{2\pi} \Leftrightarrow k_B T = \frac{\kappa}{2\pi}$$

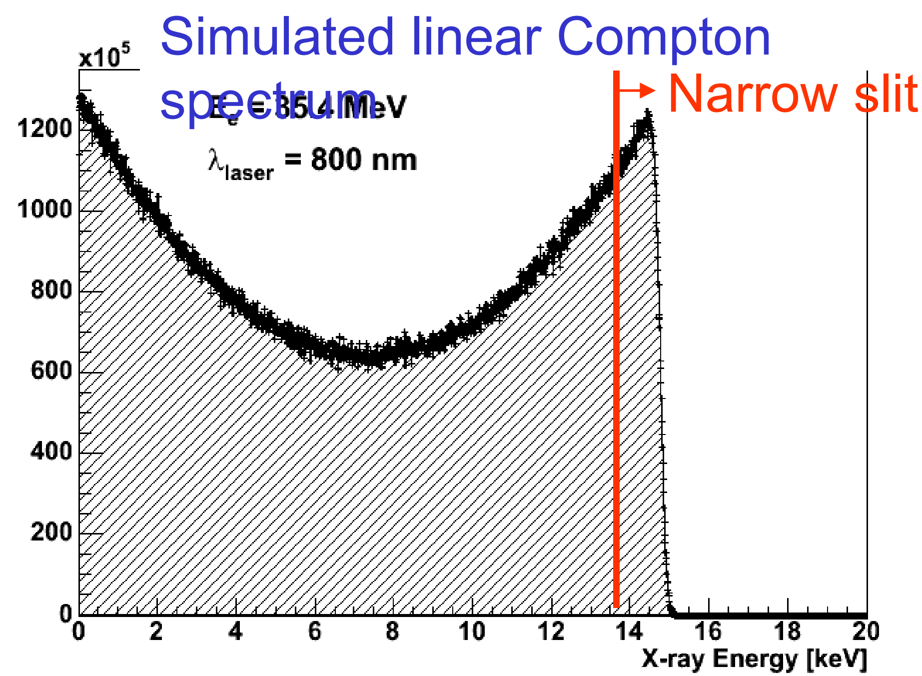
A test at Sumitomo Heavy Industries (now at AIST)

K.Homma Int.J.Mod.Phys.B21:657-668,2007









Arrival time distribution measured by PMT sensitive to 200~700 nm range with Q.E. > 10%

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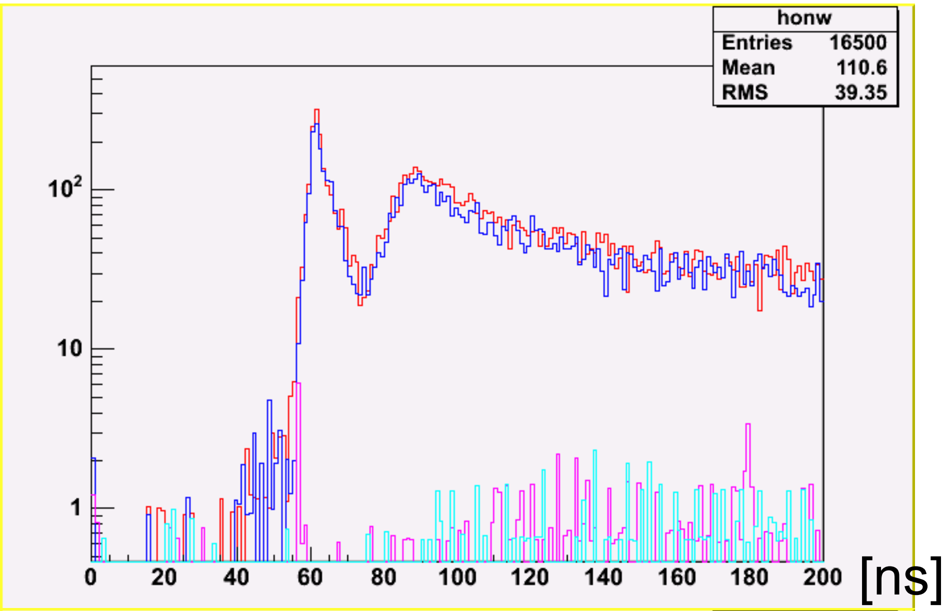
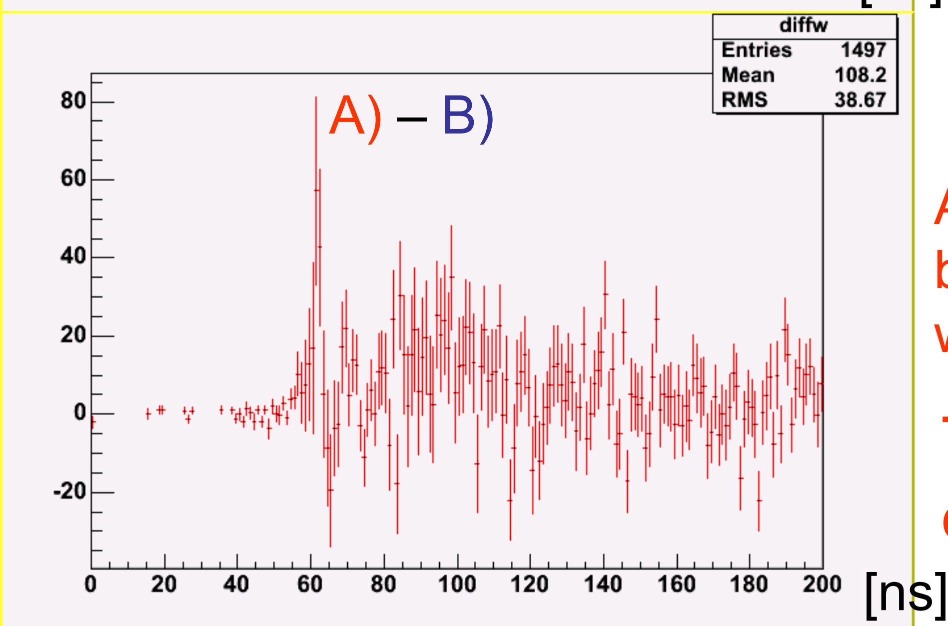


A) e-beam on / laser on (laser leak + sig

B) e-beam off / laser on (laser leak)

C) e-beam on / laser off (Brems.)

D) e-beam off / laser off (noise etc.)



A sharp peak is located at 1ns narrow bin with ~2 sigma deviation from zero, which is different from Brems. position.

There seems to be an enhancement of visible rays.

Summary

- ATF2 can be
  - place for he PLC test bed
    - demonstration of high intense photon beam
- ATF2 beam + intense field
  - possibly place to perform another aspect of particle physics

Intense field

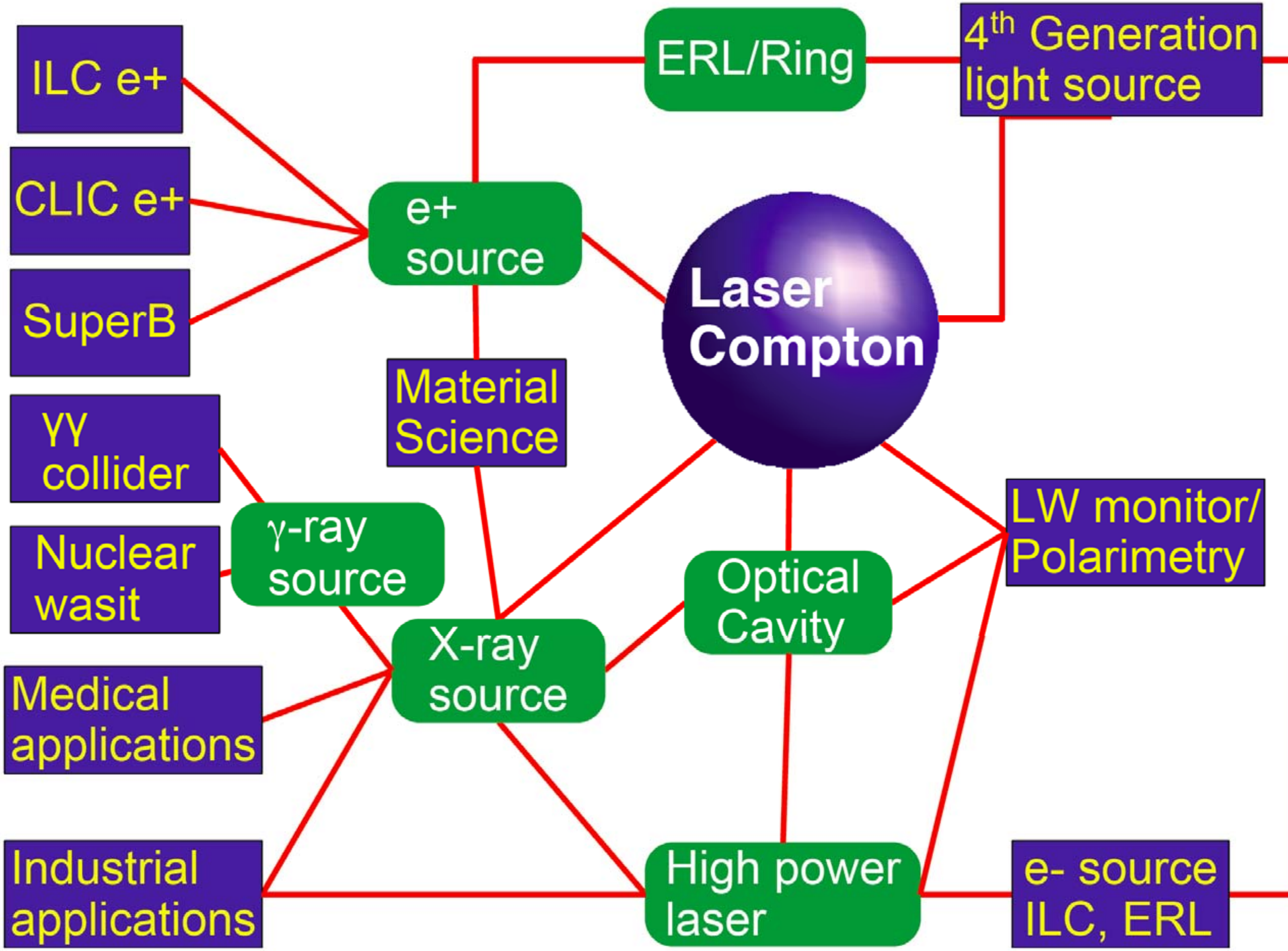
very high but low repetetion

PW lasers, flying mirrors

not very high (~TW or more) but high repetiton

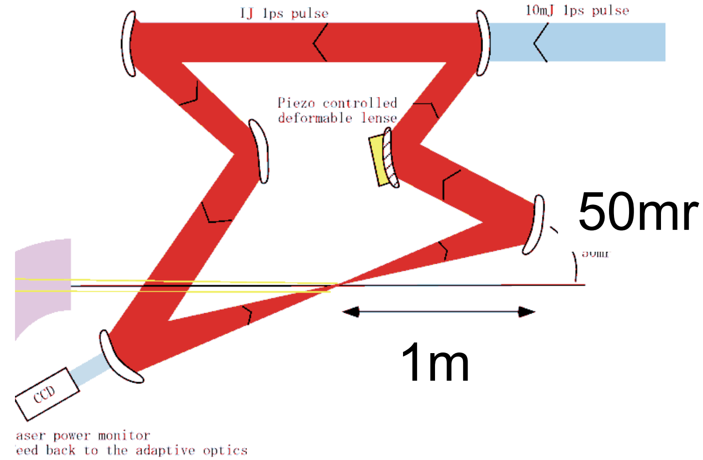
optical cavity + pulse lasers <- ILC technology

World-Wide-We b of Laser Compton



Ring cavity+High power at ATF2-IP

Cavity can be the same as ATF-DR but the laser is not



we want 50mJ/pulse for the laser (5J/pulse in cavity)

⇨ 64.9MHz ×50mJ=3.245kW

Continuous pumping (64.9MHz)of the cavity is not wise:
just for 20 bunches (for a train)

Average power = 50mJ×20×repetition = as low as 1W (or less)

Peak laser pumping power = $\dfrac{50mJ \times 20}{1ms \times eff\,(0.3)} = 3.3kW$

need mini-Mercury amplifier?