Optical Cavity R&D for Photon Colliders

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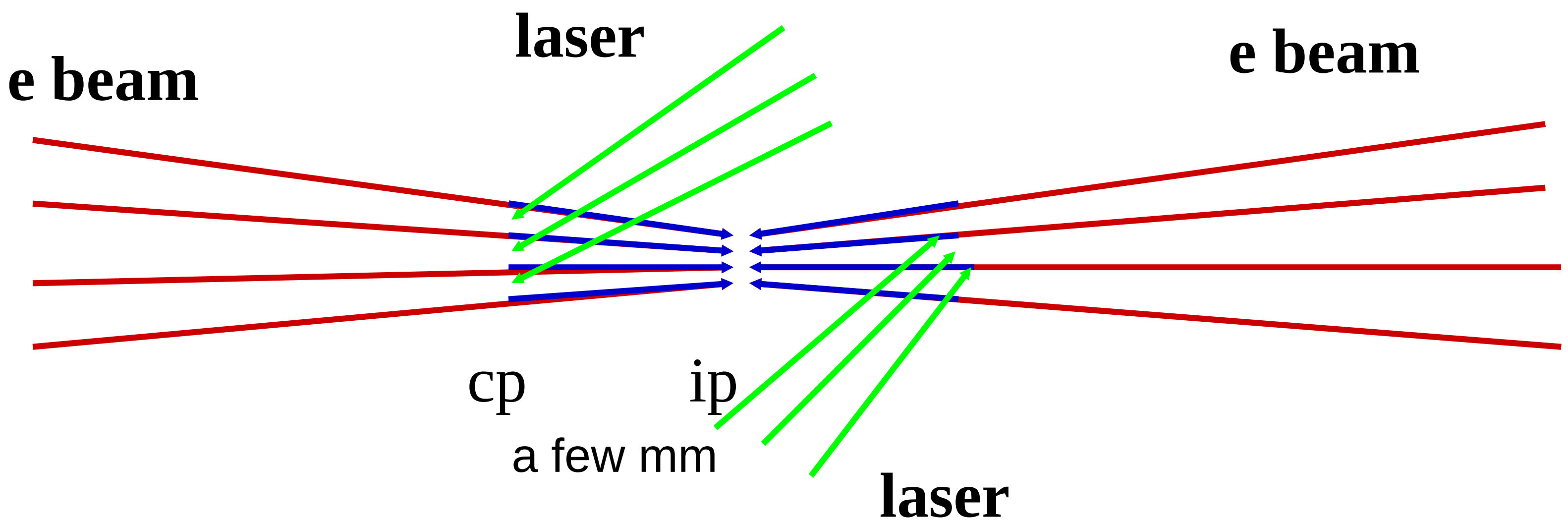
Contents

- Brief Introduction
  - **laser and cavity for the PLC**
- A design of the cavity for the PLC
  - **Design study of an optical cavity for a futurephoton-collider at ILC**
    - G. Klemz [a,b,], K. Meonig [a], I. Will [b],
- Cavity for the PLC and Related Activities
- Possible R&D?

Recent activity document PLC technology being prepared
J. Gronberg, T. Omori, A. Seryi, T. Takahashi, V. Telnov, J. Urakawa, A. Variola, M. Woods

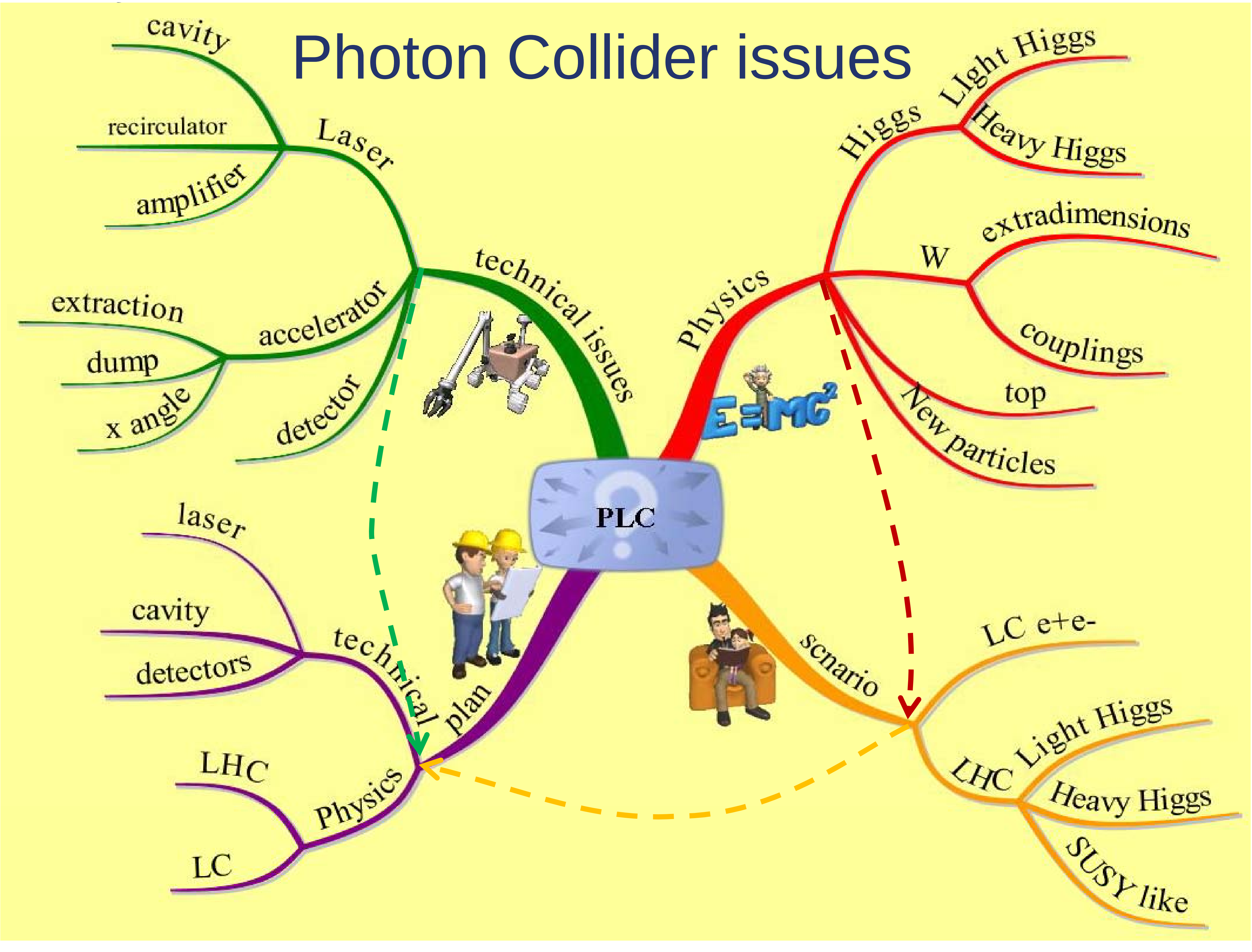
Principle of the Photon Collider



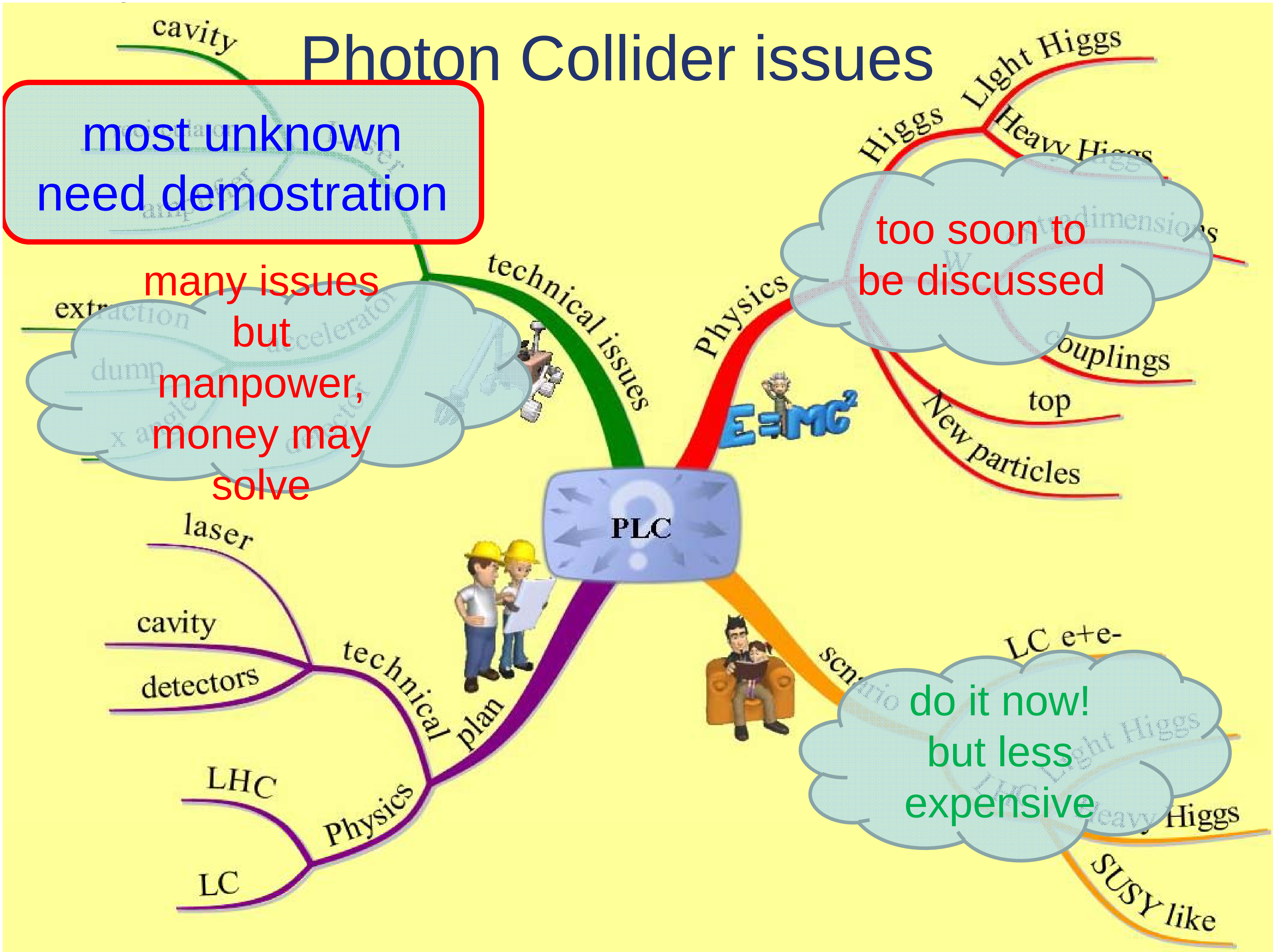
Convert almost all electrons to high energy photons by Compton scattering
specification of the electron beam: fixed (tuned to the PLC)

⇨ Requirement for the lasers

Photon Collider issues



Photon Collider issues



most unknown
need demostration

many issues
but
manpower,
money may
solve

too soon to
be discussed

do it now!
but less
expensive

Lasers for Photon Colliders

- have to meet requirement of;
  - **~5J/pulse, 1-3ps pulse duration**
    - ~2TW pleak power
  - **~300ns separation 3000bunches/train**

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

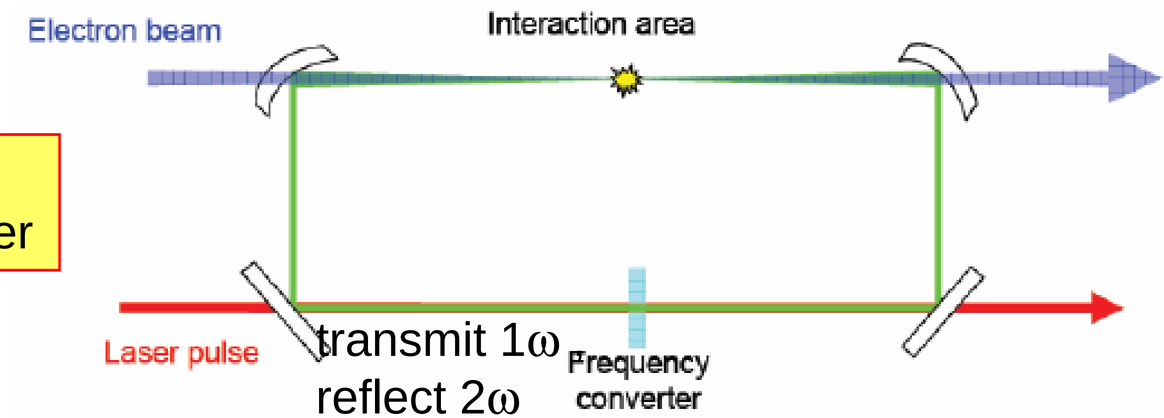
  - **5Hz**
    - ~70kW average power

⇒ Too big to be built by single laser system

  - **O(10μm) focusing**
  - **timing ~1ps**
  - **polarization**

Ideas to reduce laser power

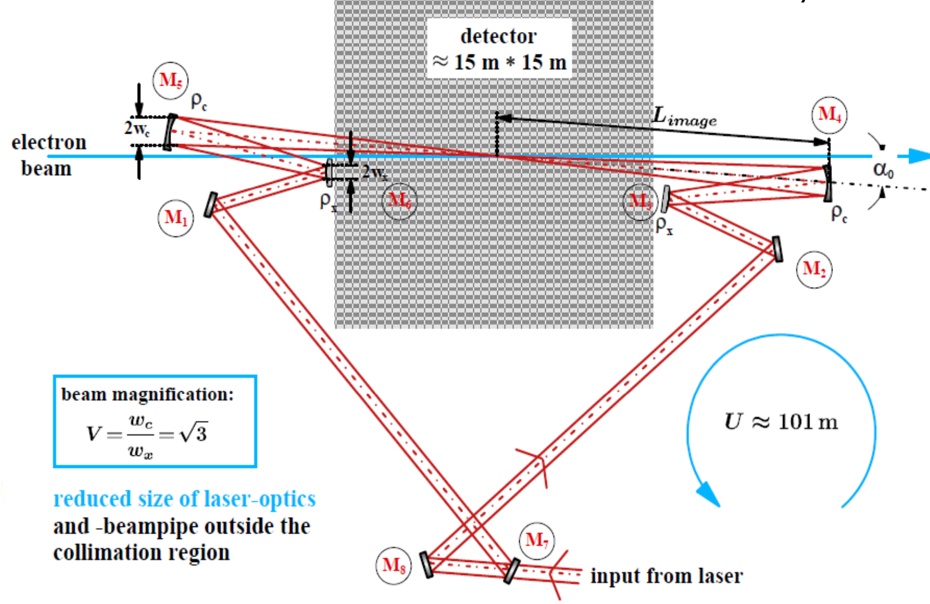
- RING (Recirculation Injection by Nonlinear Gating) Cavity (Gronberg LEI2007)



Recirculation of a laser pulse
to reduce average laser power

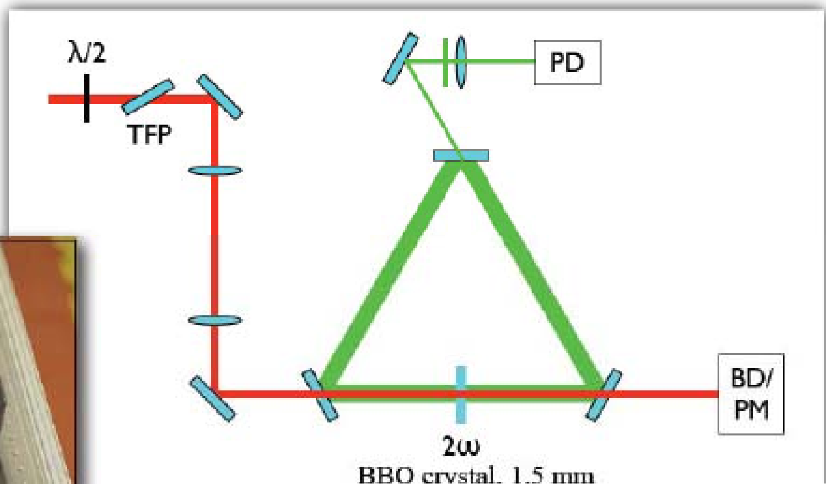
- Pulse Stacking Cavity

Klemiz, Monig

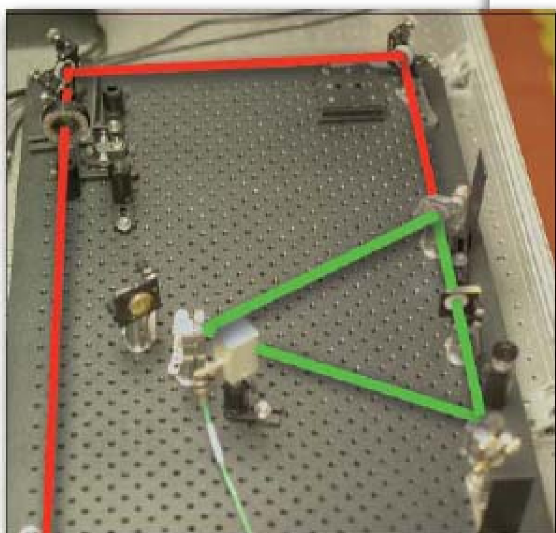


Stack laser pulses on phase
to reduce peak as well as average
power

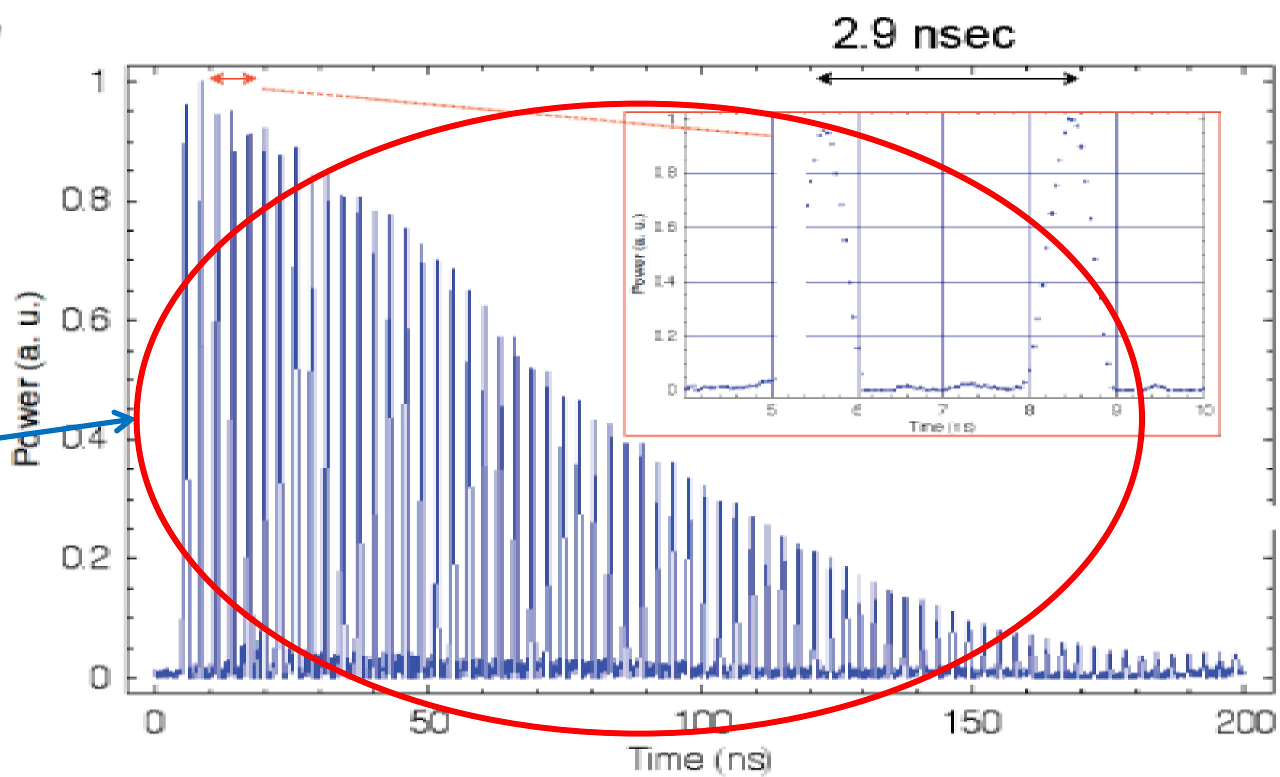
RING cavity at LLNL



I. Jovanovic,et.al



I. Jovanovic, LLNL



Integrated energy is 28.5 times that of a single pulse

The RING system has been demonstrated and published, joule-scale demo next year

Gronberg LEI2007

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

High-power laser pulse recirculation for inverse Compton scattering-produced γ-rays

I. Jovanovic*, M. Shverdin, D. Gibson, C. Brown

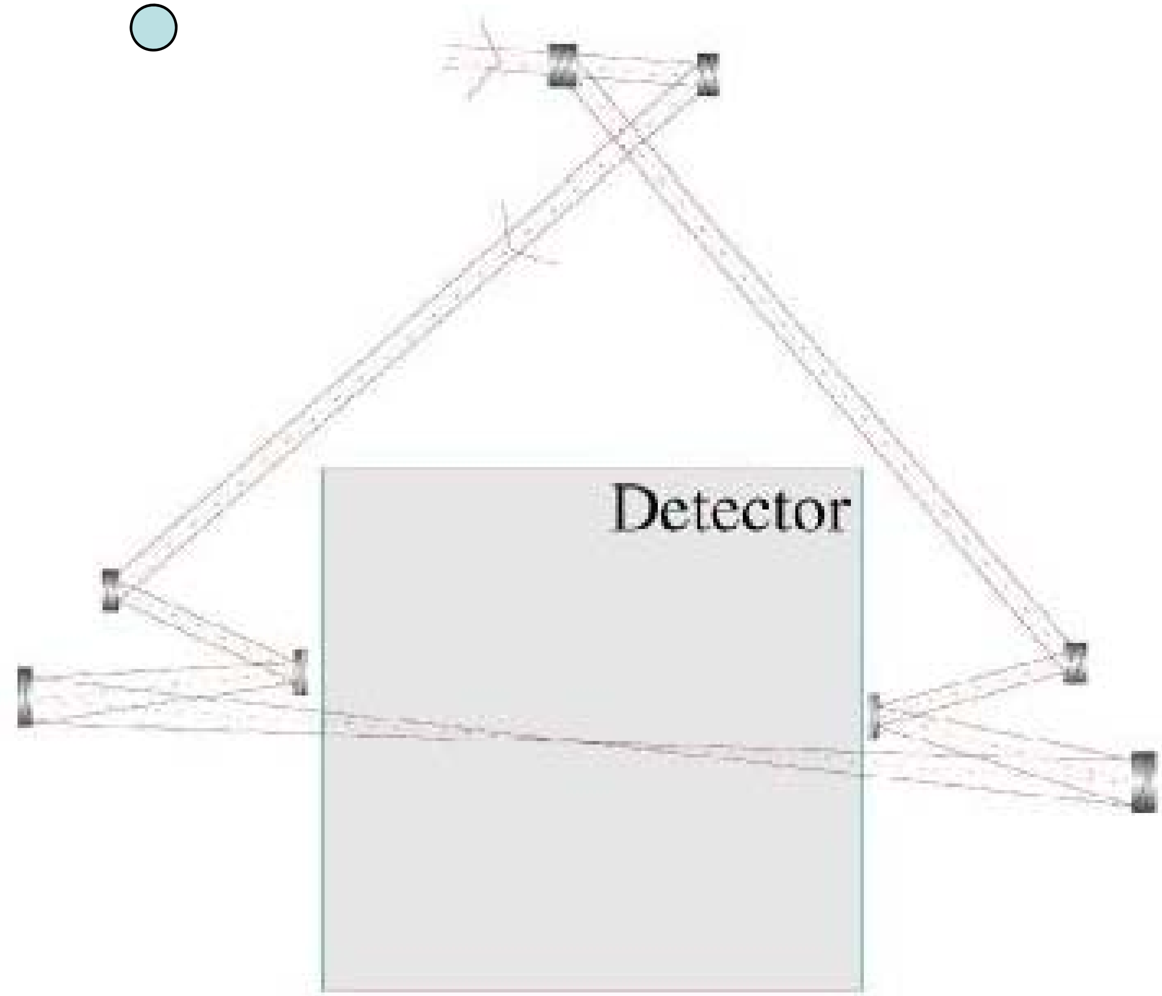
Lawrence Livermore National Laboratory, Mail Code L-270, 7000 East Avenue, Livermore, CA 94550, USA

Received 24 April 2007; accepted 24 April 2007

- RING cavity can increase the effective average power of the laser system by up to 100x
- RING cavity architecture is compatible with recirculation of high energy short laser pulses
- Compared to other "photon trapping" designs, RING cavity has 10x lower B-integral accumulation
- Compared to resonant enhancement schemes, RING cavity does not require interferometric stabilization
- Experimental work is underway to demonstrate recirculation of joule-scale pulses

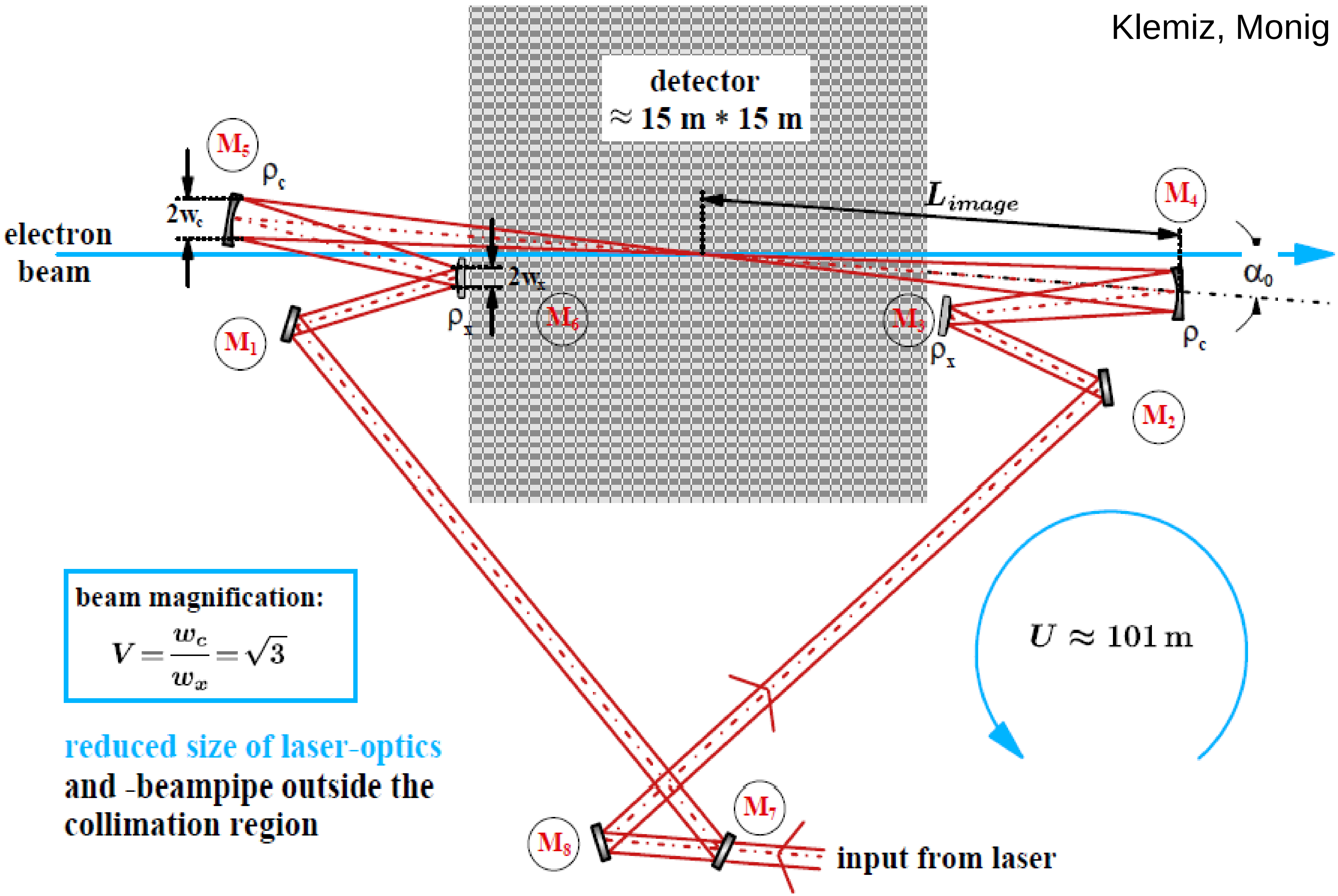
Pulse Stacking Cavity

- total length ~100m
- all mirrors outside
  the detector
- Enhancement
  O(100)



Proposed telescopic, passive, resonant external cavity

Klemiz, Monig

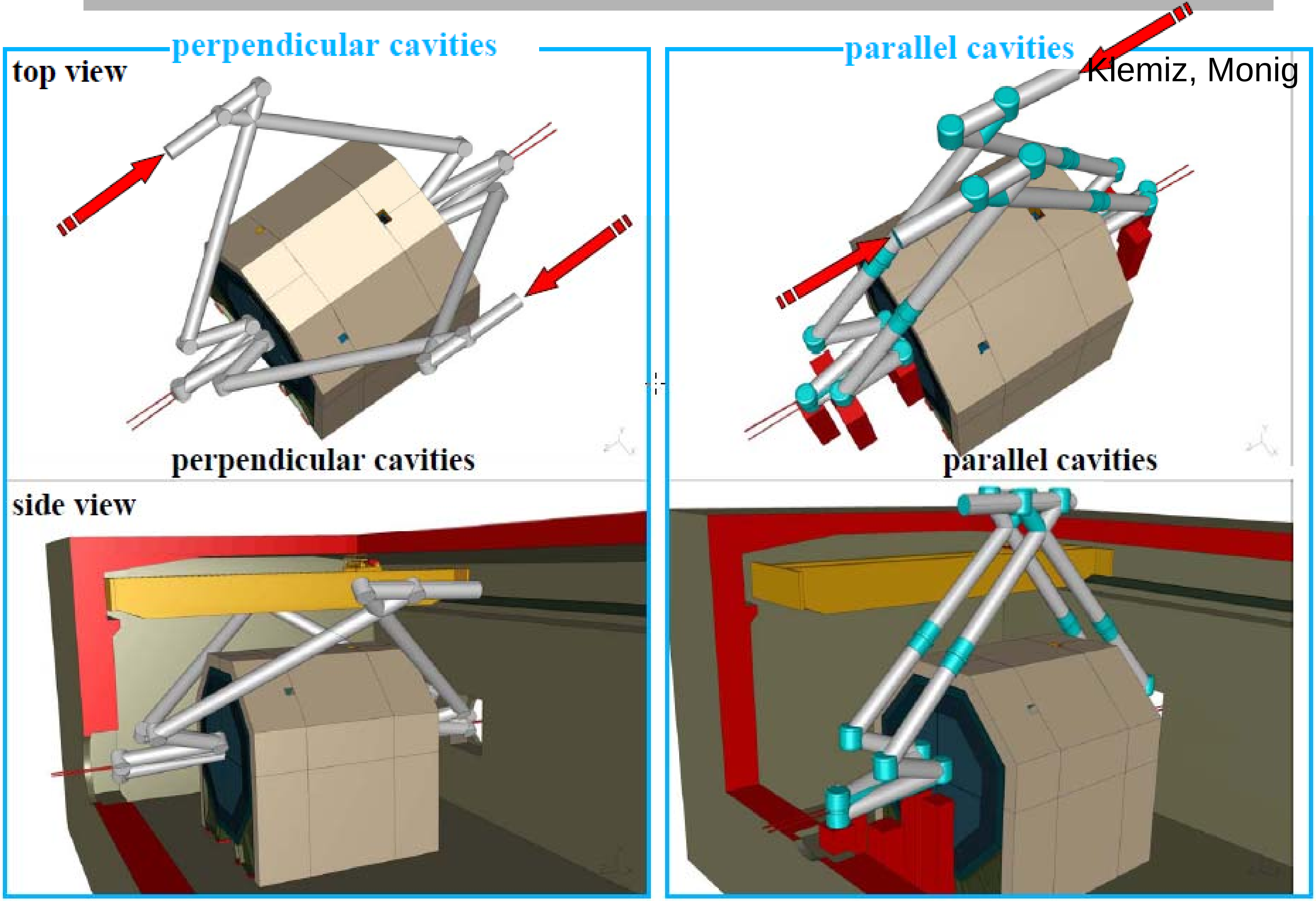


beam magnification:

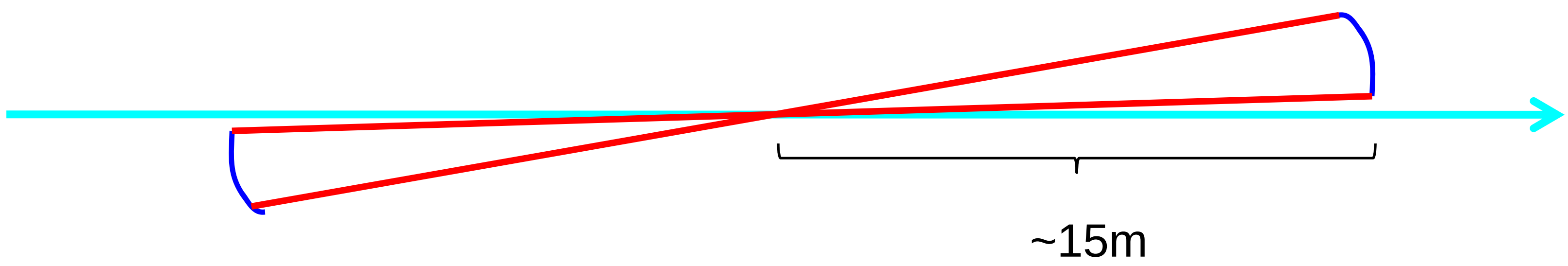
$$V = \frac{w_c}{w_x} = \sqrt{3}$$

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

Possible arrangements of the external cavities



some points of design



Size of mirror -> as small as possible to reduce cost, weight

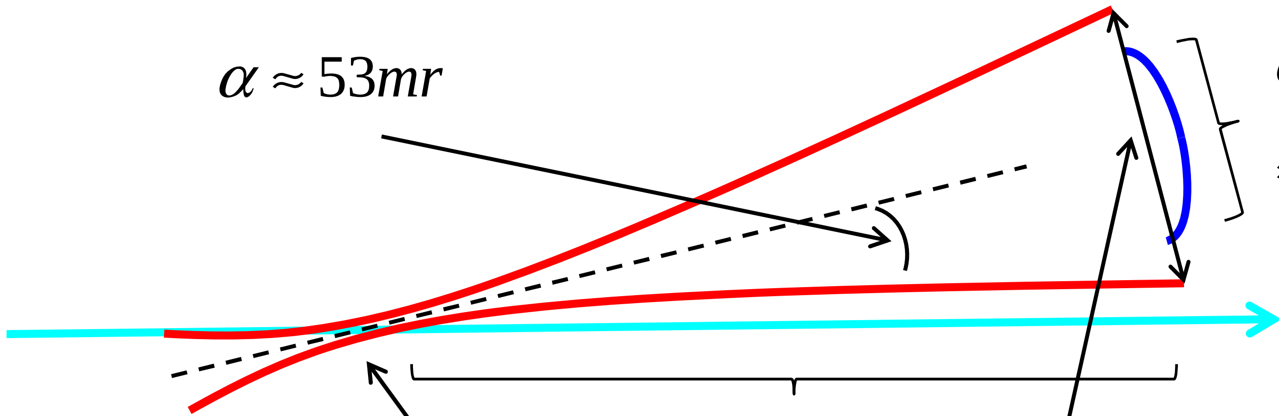
smller spot size → high laser photon density -> high Compton eff.
larger divergence -> larger mirror
larger crossing angle
->lower total photon yield

⇨ to be optimized for luminosity

an optimization

Klemiz, Monig

$\alpha \approx 53mr$



~15m

$\phi = 0.75 \times 2\omega_{gauss}$

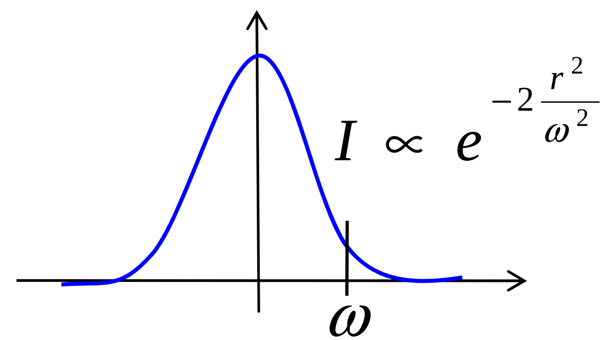
$\approx 120cm$

$\omega_{CP} = 6.5\mu m \Rightarrow 14.3\mu m$

$2\omega_{gauss} \approx 160cm \quad for \quad \omega_{CP} = 6.5\mu m$

$9J / pulse, \; 1.5ps(\sigma)$

$L_{\gamma\gamma} = 1.5 \times 10^{34} cm^{-2} s^{-1}$



miss alignment of mirrors

- waist size at CP

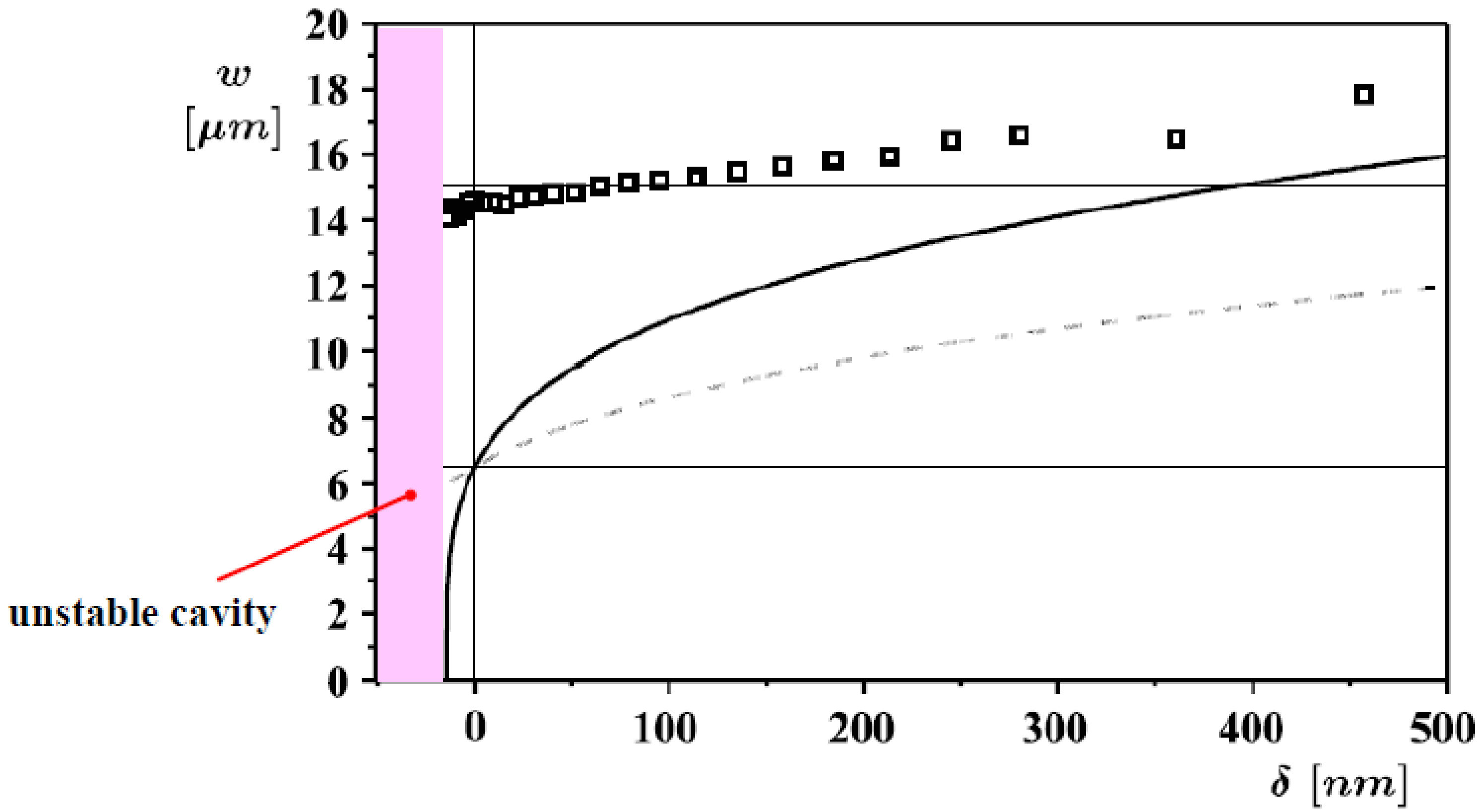
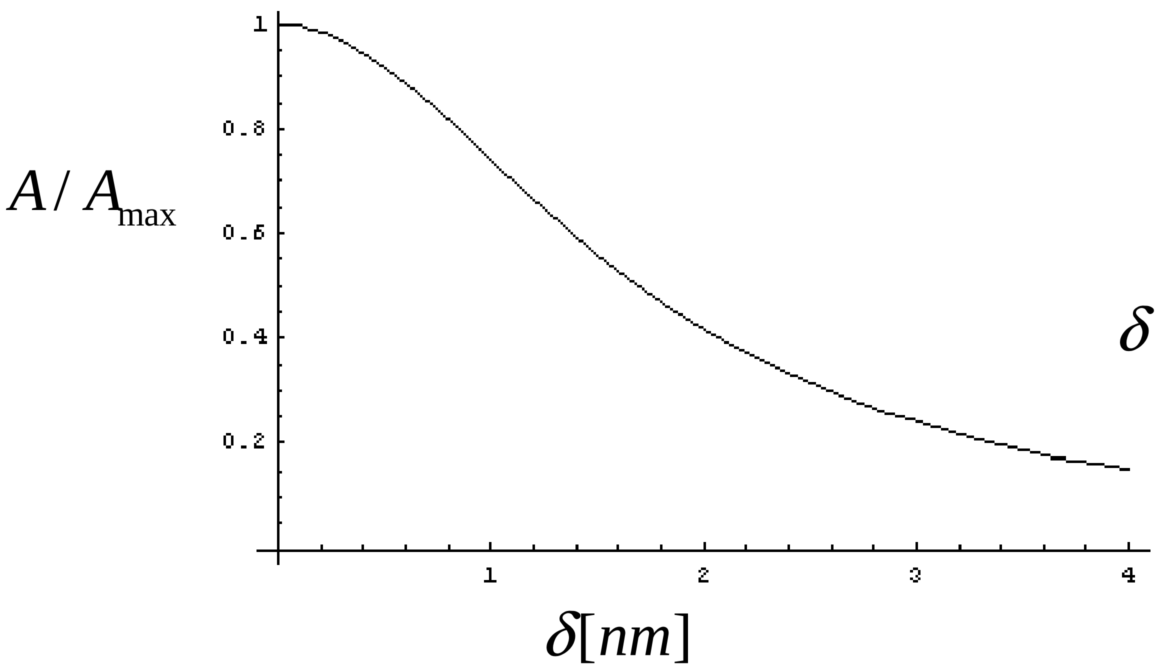


Fig. 10. Sensitivity of the waist within a cavity for nominal 6.5 μm $(1/e^2)$ Gaussian waist against axial displacement δ of either one concave (dashed) or convex mirror (solid line), as well as the corresponding waist for a mirror size scaled according $a_{cc}/w_{cc,\,Gaussian} = 0.75$ (squares). For $\delta = 0$ the beam radius increases to the required $\approx 15\,\mu$m $(1/e^2)$.

control of circumference

$$A(\delta) = A_{max}\frac{1}{1+\left[\frac{2F}{\pi}\sin\left(\pi\frac{\delta}{\lambda}\right)\right]} \approx A_{max}\frac{1}{1+\left[2A_{max}\sin\left(\pi\frac{\delta}{\lambda}\right)\right]}$$



for Amax = 100

$$\delta = \begin{cases} 0.6nm \quad for \quad A/A_{max} = 0.9 \\ 1.7nm \quad for \quad A/A_{max} = 0.5 \end{cases}$$

Requirements for the PLC cavity

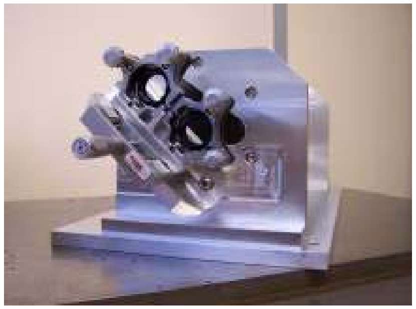
- pulse stacking
  - **enhancement ~ 100**
- focusing laser spot ~ (10μm)
- keeping circularly polarized laser
- synchronized with electron bunch (<ps)
- high vacuum at around the IP
  - **not allowed to affect e beam ~ O(10^{-7} P)**
- large scale
  - **-circumference ~ 100m±(<nm)**
- high power
  -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

~PosiPol
O(m)

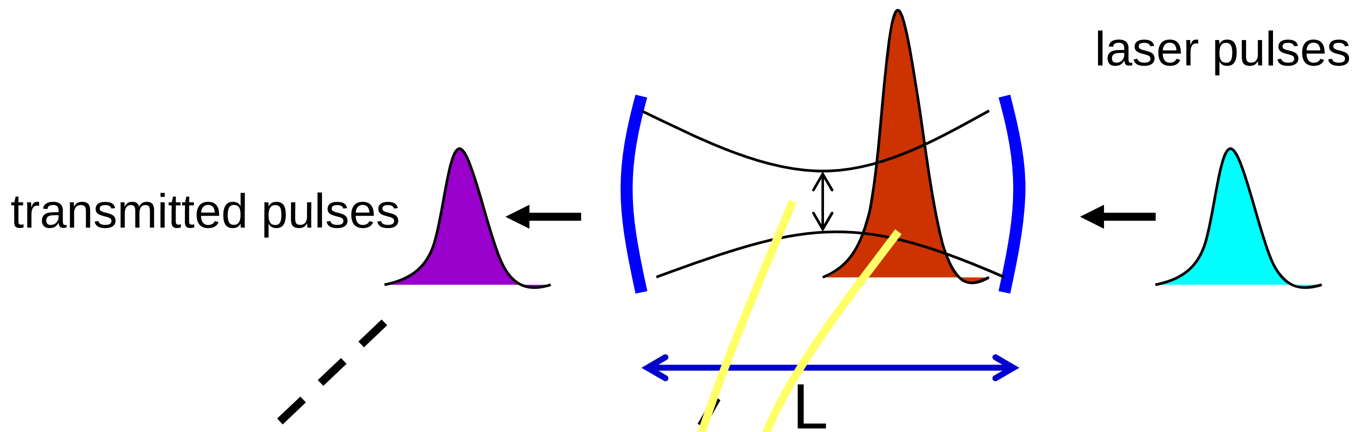
~g wave
CW

unprecedented

PosiPol R&D

	KEK	LAL
		
type	2 mirrors FP	4 mirrors ring
enhancement	1000	10000
Laser spot size	30μm	15μm
Feed back	Analog PID	digital
e-	at ATF, to get experiences with e-beam	stand alone (new w/ e- beam being designed. to be at ATF)

initial performance of the cavity in ATF ring



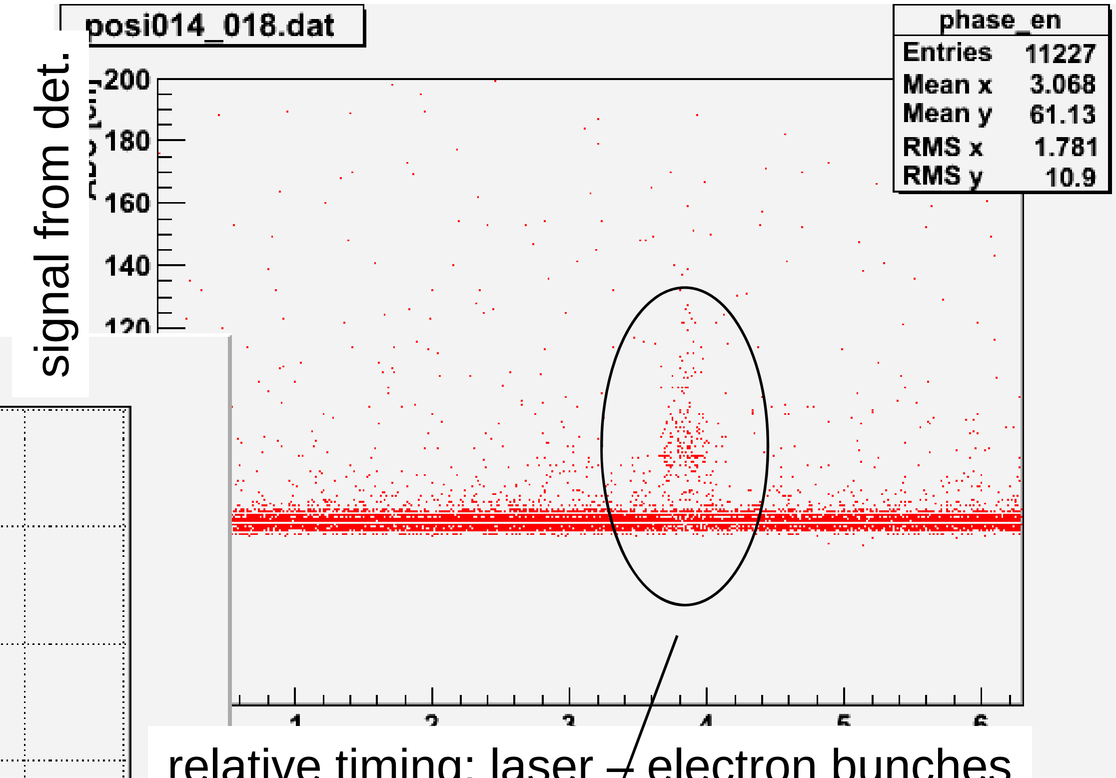
power enhancement ~200

laser focused to 30µm

performances consistent
w/ parameters
in ATF environment

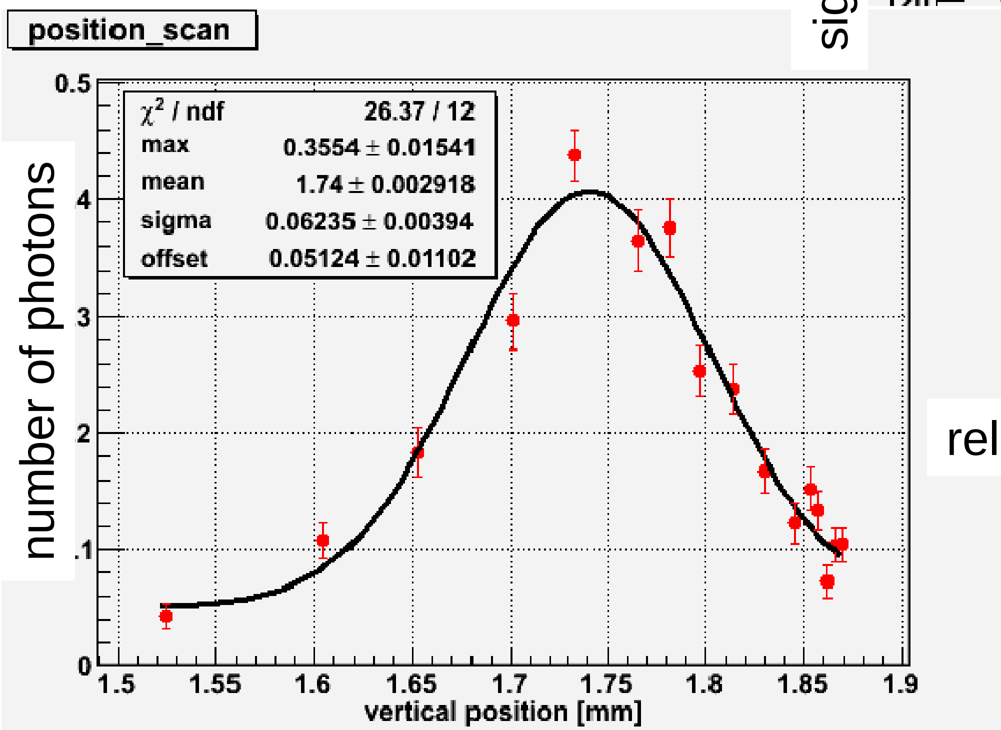
photon generation

trail of
laser-electron collision



relative timing: laser – electron bunches

γ ray from laser-electron collision



relative position: laser – electron bunches

Cavity for the PLC is,,,

Cavity for the PLC = Posipol, Laser wires,X-ray

+ large (like gravitational wave detector)

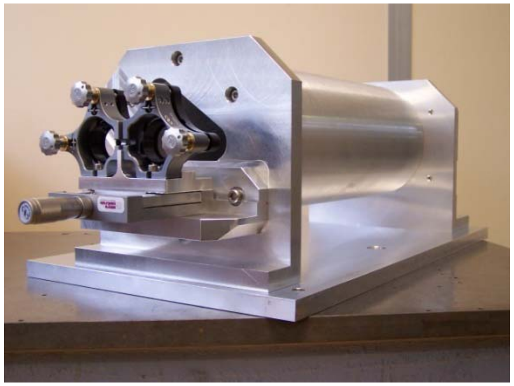
+ high power in cavity (unique for the PLC)

⇨ learn/collaborate from/with ILC related acitivities

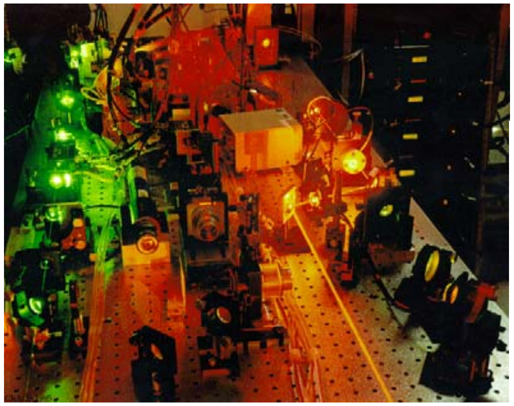
⇨ what about PLC dedicated R&D

Issues for large cavity

- A small one
  - **posipol cavity is one piece**

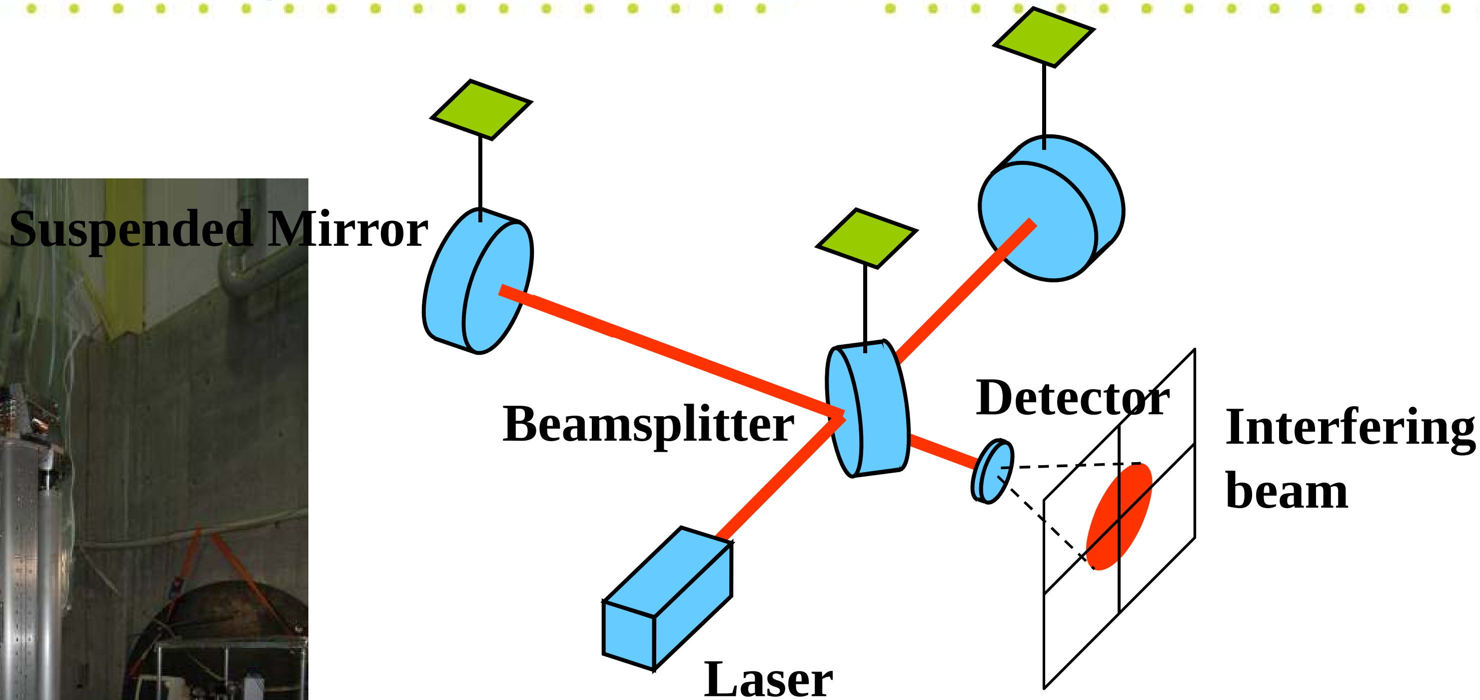


- other cavities such as in mode locked laser
  - **on the table**



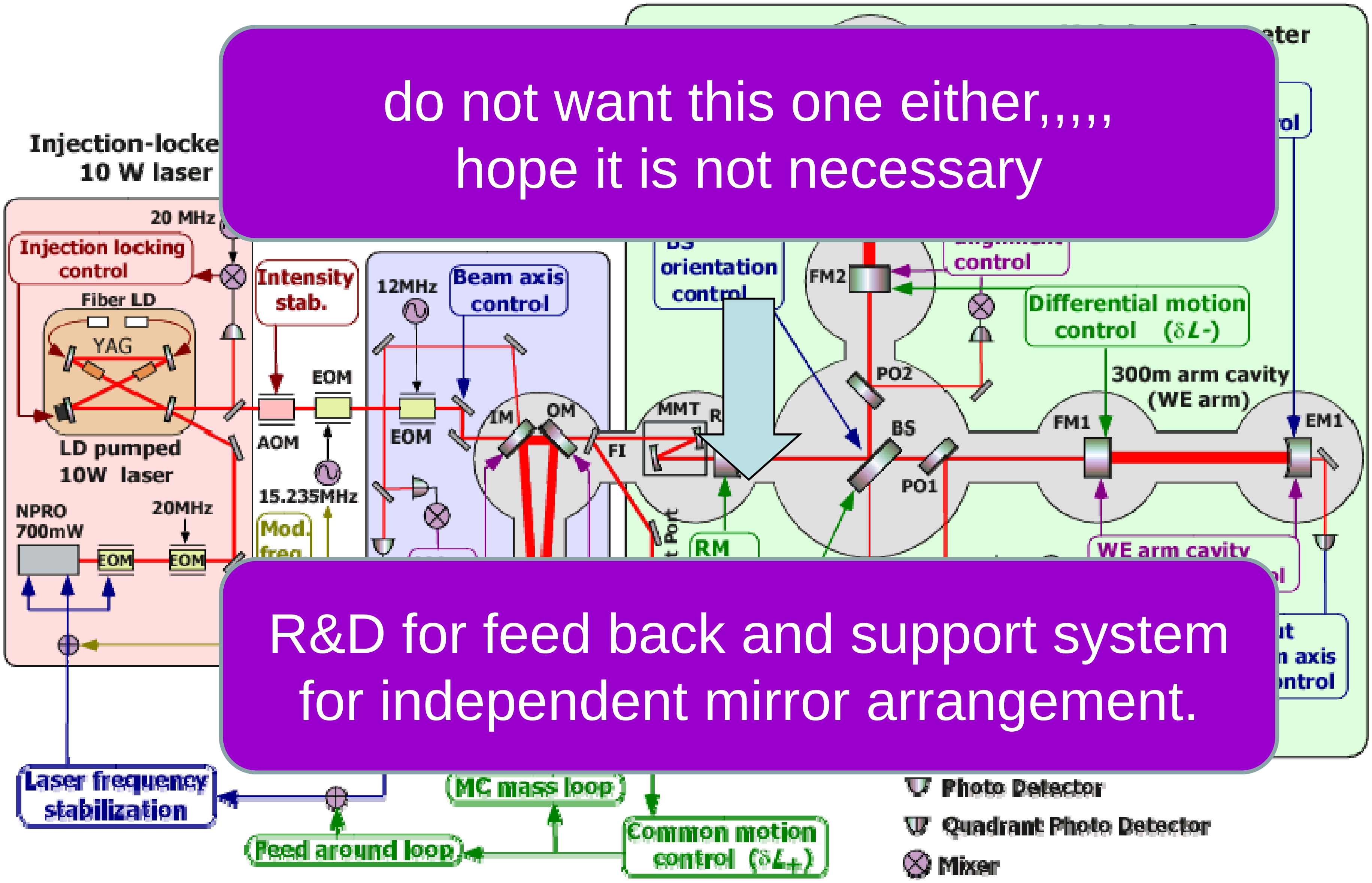
- 100 m long cavity
  - **need to align totally independent mirrors**
    - similar to gravitational wave exp. TAMA, LIGO etc.

g- wave look like



dose not fit to the detector,,,,

Optical system of TAMA300



do not want this one either,,,,
hope it is not necessary

R&D for feed back and support system
for independent mirror arrangement.

Step by step plan?

1. Cavities for Compton based pol. e+ projects
   - **Fabry-Perot type spherical mirror**
   - **Fabry-Perot type off-axis parabolic mirror**
2. Going to large scale
   - **CW laser**
   - **independent mirror control**
3. 1-2m scale (with ATF bunch)
   - **pulse laser (low energy)**
   - **independent mirror control**
4. Cavity w/ high power laser at ATF2-IP
   - **not possible at ATF-DR as high power laser is destructive target**

42cm

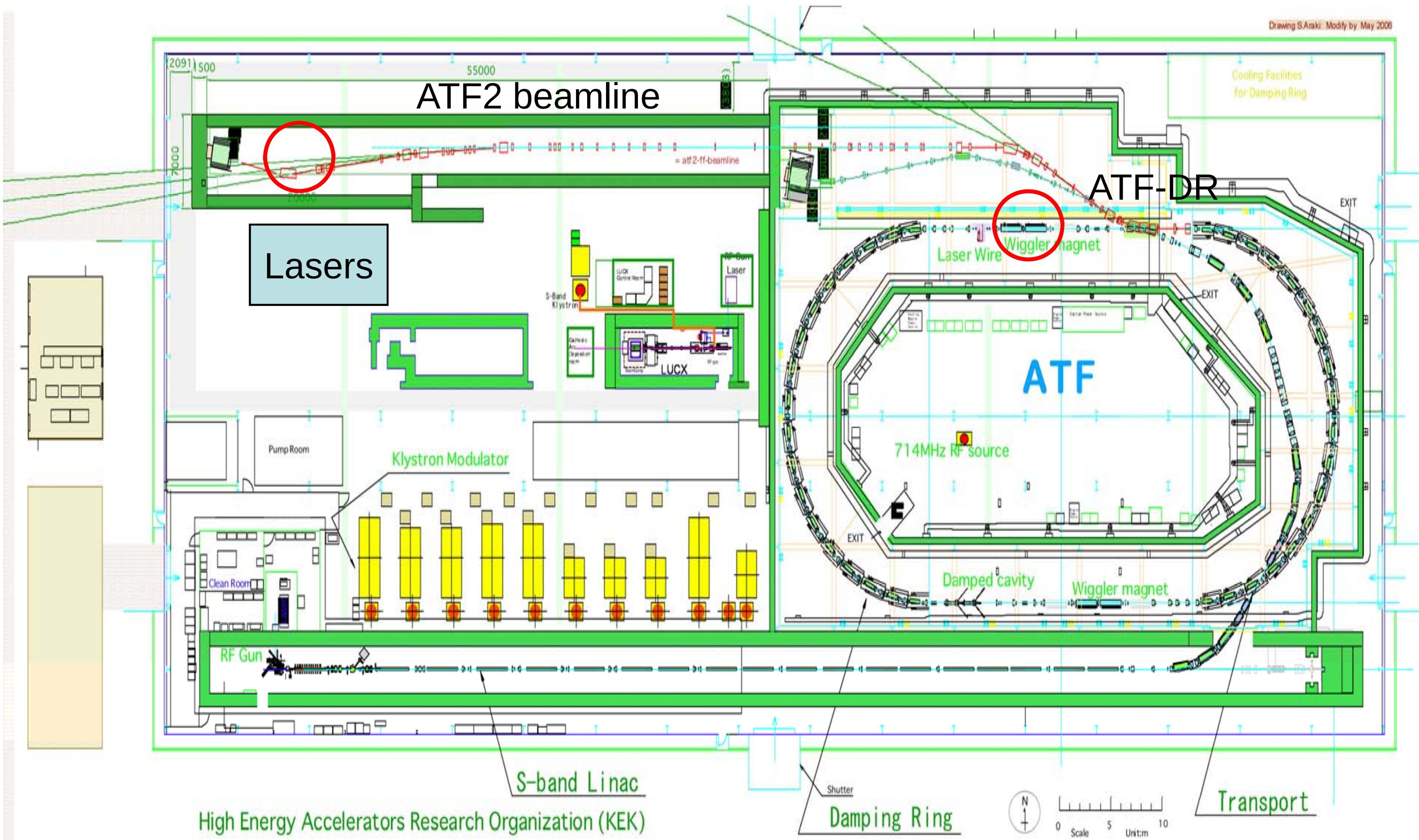
1~2m

ATF-DR

Lab
->ATF-DR
if possible

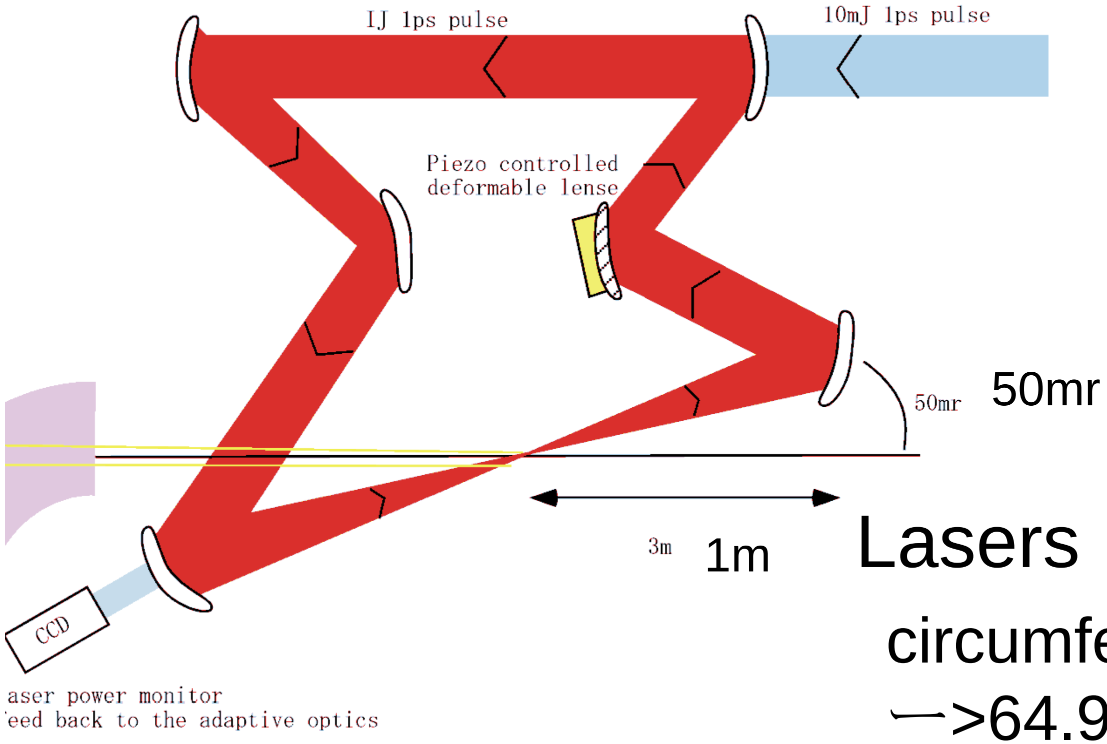
ATF2

ATF-Layout



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

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

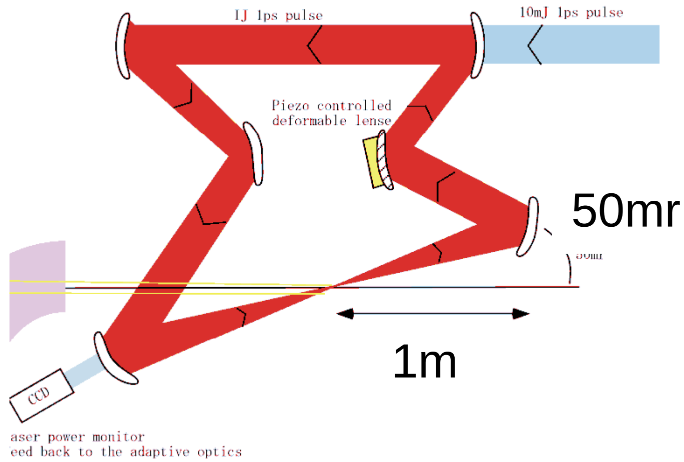
very similar to PosiPol experiment

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

2400γ/xing

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?

What we can do at ESA?

	ESA	ATF/ATF2
e beam	12 GeV	1.3 GeV
	up to 12Hz single bunch	A few Hz 154 ns x 30 bunches
		very stable sub ps
γ s	2 GeV	10MeV
falicity	large enough for 100 sale cavity?	No enoun space for large cavity regulation for the radiation safe
comment		10MeV γ facility for pol e+ etc? physics w/ intense field

Summary

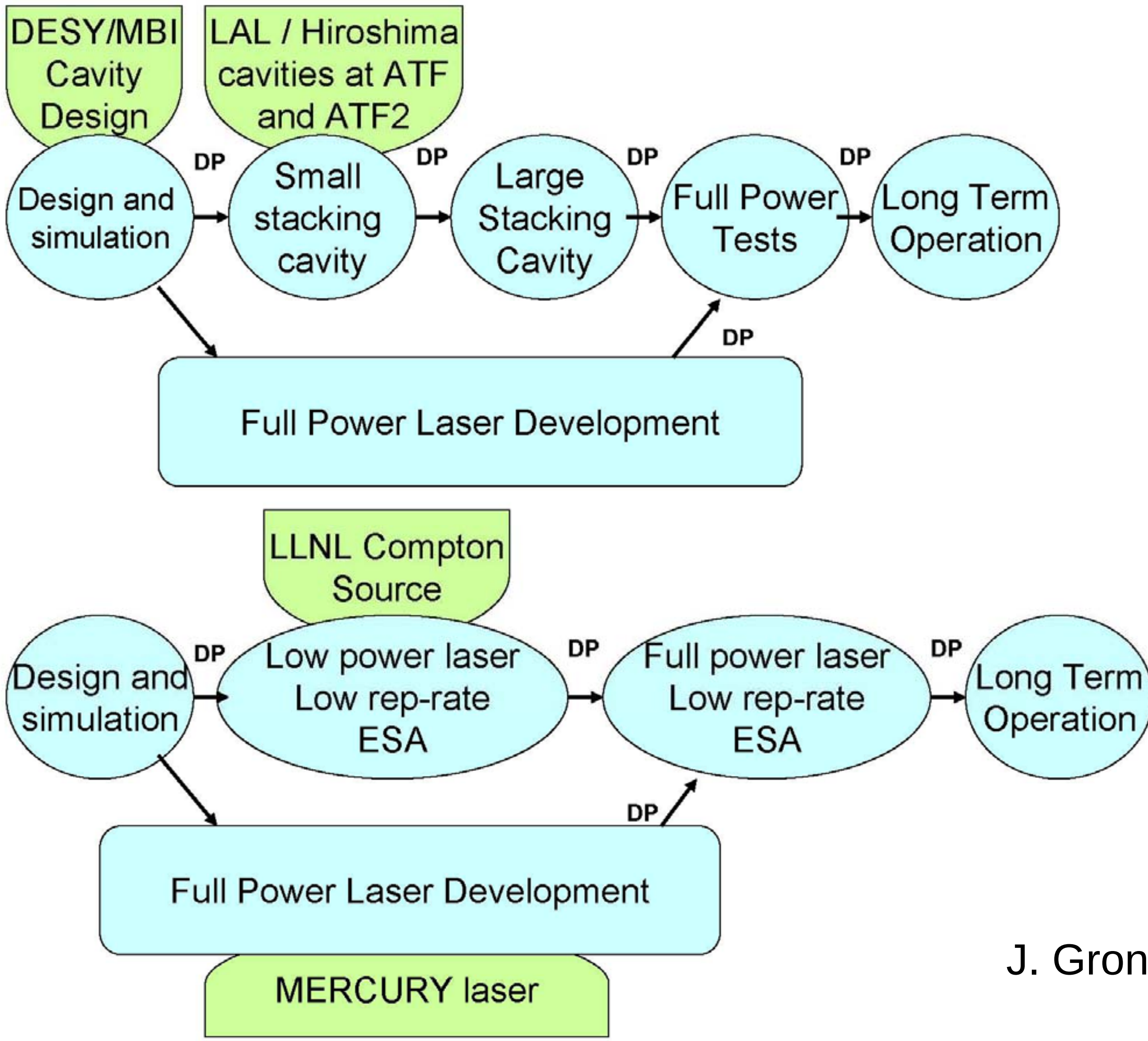
- Role of the PLC is yet to be studied
  - wait for the LHC, initial run of the ILC e+e-
- tehcenical issues should be studied
  - get it ready when needed
  - interest in high flux g ray generation
    - a part of laser-electron int. community
- designs of the cavity exits
  - should see technical feasibility
- much can be learned from on going project
  - Posipol, Lawer Wires, X ray sources g wave detectors
- PLC dedicated study to be considered
  - a lot of issue to do with small scale program

R&D feasible?

- A plan to construct high power laser system at the ATF2
  - **proposal submitted**
- A budget request for quantum beam technology
  - **see Urakawa san for detail**

some projects around laser science are being started

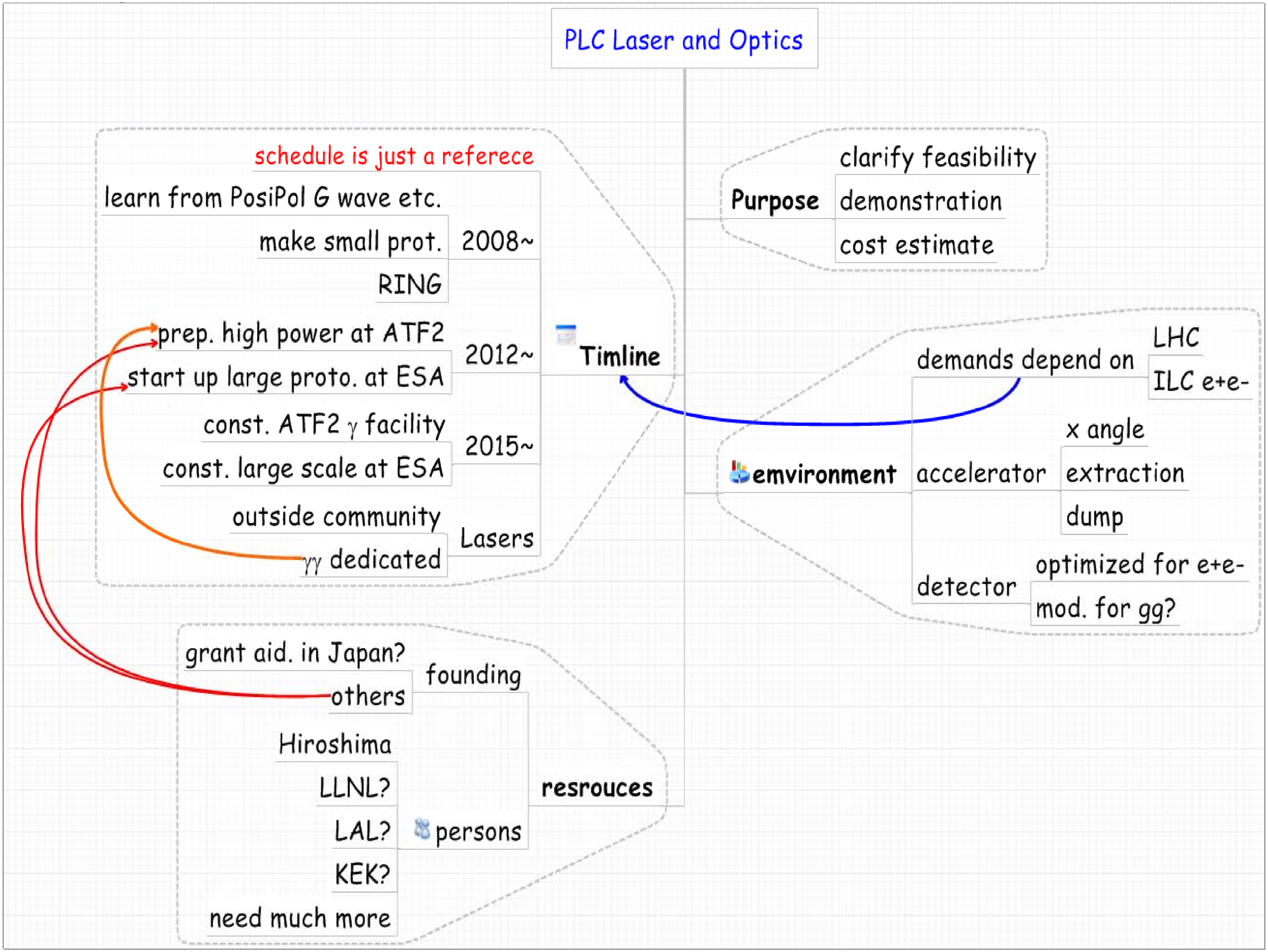
R&D



J. Gronberg et. al

Summary

- Role of the PLC is yet to be studied
  - **wait for the LHC**
  - **initial run of the ILC e+e-**
- get it ready when needed
  - **cavities are one of the most unknow part**
- much can be learned from on goring project
  - **Posipol, Lawer Wires, X ray sources**
  - **gravitational wave detectors**
- need to start PLC dedicated study by,,,,
    - collaboration with other acvityies
  - **dedicated study for feed back system, mirror alignment can be started as relatively low cost project**


PLC Laser and Optics
schedule is just a referece
learn from PosiPol G wave etc.
make small prot.
2008~
RING
prep. high power at ATF2
start up large proto. at ESA
2012~
Timline
const. ATF2 γ facility
const. large scale at ESA
2015~
outside community
γγ dedicated
Lasers
Purpose
clarify feasibility
demonstration
cost estimate
demands depend on
LHC
ILC e+e-
emvironment
accelerator
x angle
extraction
dump
detector
optimized for e+e-
mod. for gg?
grant aid. in Japan?
others
founding
Hiroshima
LLNL?
LAL?
KEK?
need much more
persons
resrouces

Summary

- **Two Ideas of cavities to reduce laser power**
  - **RING**
    - technically easier but moderate power reduction
    - R&D at LLNL for x ray sources
  - **Pulse Stacking**
    - reduce both peak and average power ~(100) but very challenging
    - R&D for PosiPol at KEK-ATF
- **Laser technology continues to improve without our involvement but need an effort to meet design for cavities**
    - *still high power*
    - *mode locked laser for stacking cavity?*
- **γ ray faclity at ATF2 and/or ESA possible?**

•Still much to learn from other field but 100m long cavity is completely different world
•need to setup dedicated R&D toward the large scale cavity and γ ray generation