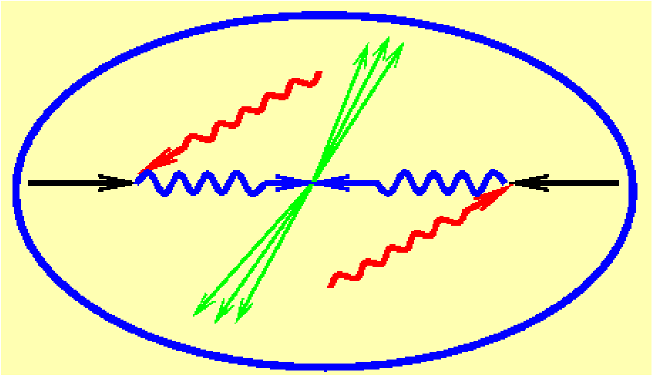

Photon collider: summary

Valery Telnov
Budker INP, Novosibirsk

TILC09, Tsukuba
April 21, 2009

List of talks and discussions on the photon collider (PLC) at TILC09

- April 18, Gamma-Gamma: Joint with MDI, BDS
  1. Valery Telnov, Calibration of the energy at the photon collider
  2. Jeff Gronberg, Status of Laser Technology
  3. Tohru Takahashi, Status of Optical Cavity R&D
  4. Andrei Seryi, BDS Issues (related to PLC as a Precursor to the ILC)
  5. Discussion: Toward the step forward
- April 18 (plenary) Tim Barklow, Gamma-gamma: physics report or (PLC Higgs factory as a Precursor to the ILC)
- April 19, Gamma-Gamma: Joint with Physics
  1. Rui Santos, Neutral Higgs boson pair production in photon-photon annihilation ($\gamma\gamma \to$ hh) in the Two Higgs Doublet Model
  2. Nozomi Maeda, Study on $\gamma\gamma \to$ hh
  3. Valery Telnov, Introduction to the discussion on Physics case of the PLC as the first stage of ILC
  4. Discussion: physics case of the PLC as the first stage of ILC

Rumors that PLC Higgs factory is considered seriously as a Precursor to the ILC and the plenary talk at TILC09 by Tim Barklow on this subject caused a big disturbance in ILC community because it means about 6 years delay of e+e- experiments.

Many people asked me to comment and make clear statements on this subject in the summary talk.

Let me calm you, it was just an suggestion to the ILCSC, initiated by Hirotaka Sugawara, how to decrease the ILC initial cost and thus to get its approval and start construction earlier. The ILC energy needed for the Higgs(120) production in $\gamma\gamma \to h$ is lower than that in $e^+e^- \to Zh$, therefore such collider could be cheaper.

This suggestion was considered by ILCSC but not accepted.

Some details of considerations:

1) On Sept. 20, 2008 H.Sugawara applied to ILCSC with such suggestion and sent transparences of his possible presentation at ILCSC meeting on Oct. 31.

2) This proposal was forwarded to me (V.T) by ILCSC for review.
My opinion was the following (shortly):

a) the cost of such PLC will be not much cheaper because it needs damping ring with small emittance and polarized electrons (there are no polarized electrons guns with small emittance);

b) the laser system is not simple and its development have not started yet;

c) the H(120) can be be studied much better in $e+e- \to ZH$ at $2E=230$ GeV;

d) the PLC give an unique possibility to study new physics at the LC in two additional modes ($\gamma\gamma$,γe) at small incremental cost, give access to higher masses, but it would be better to plan the PLC as the second stage of the ILC.

e) in order to reduce the initial ILC cost it worth to consider e+e-(230) as the first stage.

Some details of considerations (continue):

3) After the ILCSC meeting S.Yamada asked the LOI physics panel (M. Peskin and T. Barklow agreed) to review the physics case for such an approach and B.Barish asked A.Seryi and J.Gronberg to develop machine designs for this kind of staged approach to ILC construction and operation. They attracted for consultations and discussions PLC experts (K.Monig, T.Takahashi, V.Telnov).

4) The draft of the review written by BGPS was discussed at expanded Physics panel with invited experts but did not find support.

5) This BGPS report was considered at ILCSC meeting on Feb.12, 2009 and its conclusion was the following:

Summary of the ILCSC Meeting, 12 February 2009, KEK

Gamma-Gamma ILC Precursor

At its 31 October 2008 meeting, ILCSC received a proposal for a gamma-gamma Higgs factory as a precursor to the ILC; ILCSC asked the GDE and Research Directors to form a group to study this suggestion, and a report of the study was presented to this meeting. A 180 GeV gamma-gamma precursor would cost about half that of the 500 GeV ILC, but would produce much less physics. A better alternative for early Higgs studies would be a ~ 230 GeV e+e- collider for studying the Higgs through ZH production; this would be ~ 30% more costly than the gamma-gamma collider. ILCSC decided not to pursue the gamma-gamma collider further at this time.

Physics case of the PLC as the first stage of ILC was also discussed on April 19 at Gamma-Gamma: Joint with Physics session and all have agreed that PLC is necessary, but it would be better to start with e+e-(230) due to better physics case (if the Higgs(~120) exists).

As soon as e+e- (230) is needed in any case, there is no cost reduction, only the increase.

That is all about PLC as a Precursor to the ILC
(closed)

April 18, Gamma-Gamma: Joint with MDI, BDS

1. Valery Telnov, Calibration of the energy at the photon collider
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V. Telnov, Calibration of the energy at the photon collider

The maximum photon energy

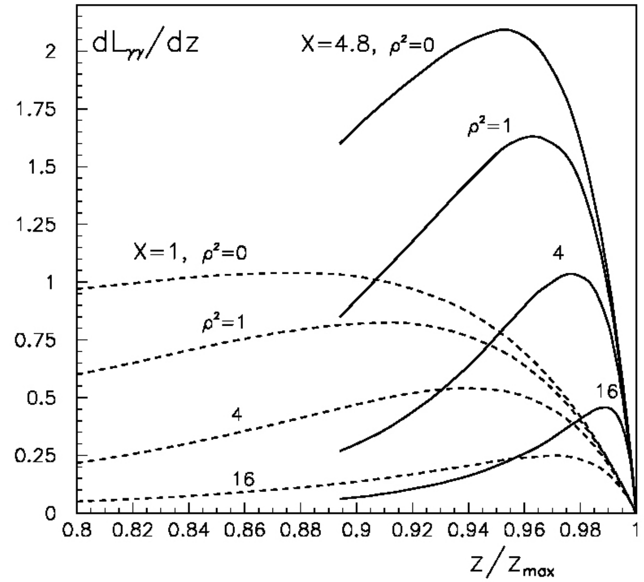
$$\omega_m = E_0 \frac{x}{x+1}, \qquad x = \frac{4E_0\omega_0}{m_e^2 c^4} \qquad (x\sim 2\text{-}5)$$

Due to nonlinear QED effects in a strong field in the laser focus $m_e \to m_e(1+\xi^2)$, where ξ^2 is proportional to the laser photon density.

The required laser flash energy is smaller when ξ^2 is larger, however large ξ^2 leads to the decrease of the maximum photon energy and appearance of higher harmonics in the photon energy spectrum:

$$\omega_m = E_0 \frac{x}{x+1+\xi^2}, \qquad \frac{\Delta\omega_m}{\omega_m} = -\frac{\xi^2}{x+1}$$

$L_{\gamma\gamma}$ high energy edge, $\rho=(b/\gamma)/\sigma_y$

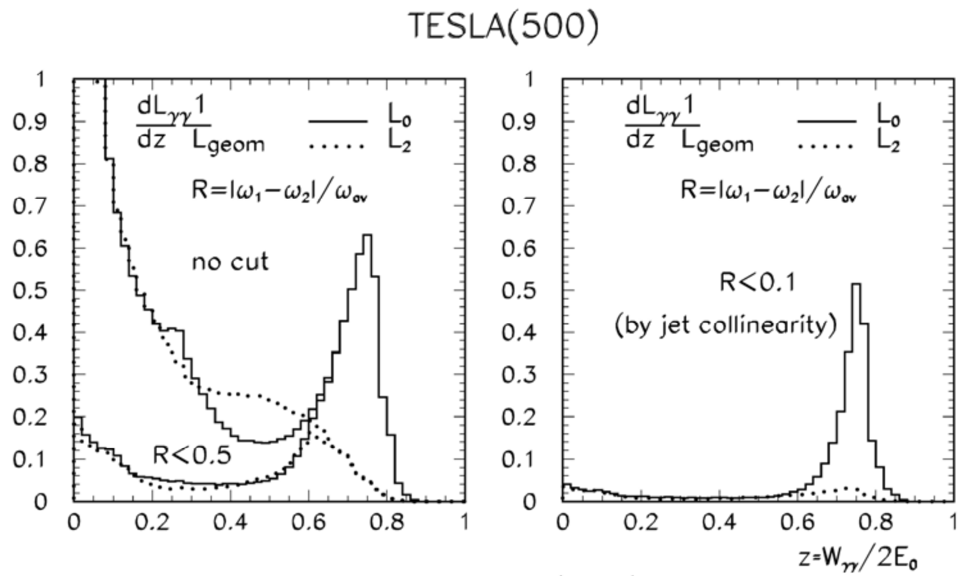


the "width" of the edge of the $\gamma\gamma$ luminosity spectrum is about 2-3% (without nonlinear effects)

The 5% shift corresponds to $\xi^2 \sim 0.3$ at x=4.5.

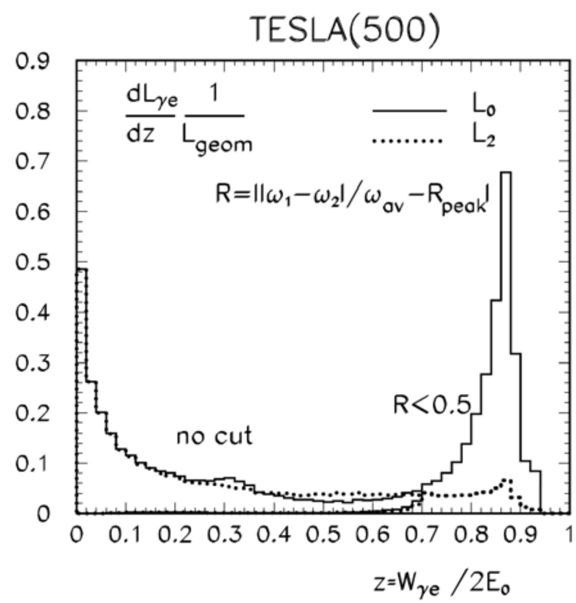
Beside, the density in the laser focus varies that gives the spread $\sigma_{\xi 2} \sim 0.4 \langle\xi^2\rangle$, where $\langle\xi^2\rangle \sim 0.7\xi^2(0)$. If the average shift is 4%, then the additional r.m.s. energy spread is 1.5% So the high energy edge of $\gamma\gamma$ luminosity spectrum is not sharp (width~3-4%) and the maximum energy is unstable due possible variation of the laser focus geometry (displacement, change of the spot size).

Realistic luminosity spectra at the PLC



$\gamma\gamma$

b =2 mm



γe

b =1 cm

(one beam is converted e$\to\gamma$)

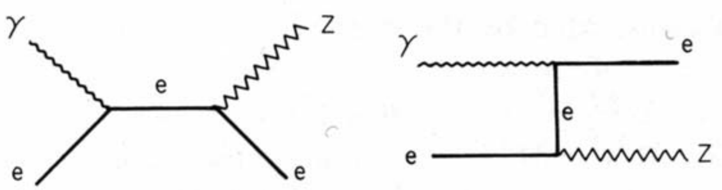
Calibration of the detector

$\gamma e \to \gamma e$

In order to measure energy one needs some value with a dimension of a mass.
On first sight, one can use γe collisions (the energy scale is given by the electron mass m). The scattering angles in collisions of the electrons with an energy E_0 and a photons with edge energy ω_m allow to determine $x=4E_0\omega_0/(m^2c^4)$ and thus to find E_0. However this measurement gives $x/(1+\xi^2)$ and due to large uncertainty in ξ^2 the accuracy of the beam energy measurement will be very pure:

$$\frac{\sigma_{E_0}}{E_0} \sim \frac{\sigma_{\xi^2}}{1+\xi^2} \sim O(1\%)$$

$\gamma e \to eZ$ (the energy scale is given by M_z).



Diagrams for $\gamma e \to Ze$

The second diagram dominates, Z-boson travels predominantly in the direction of the initial electron, the final electron escapes the detector. In most cases only Z decay products are detected.

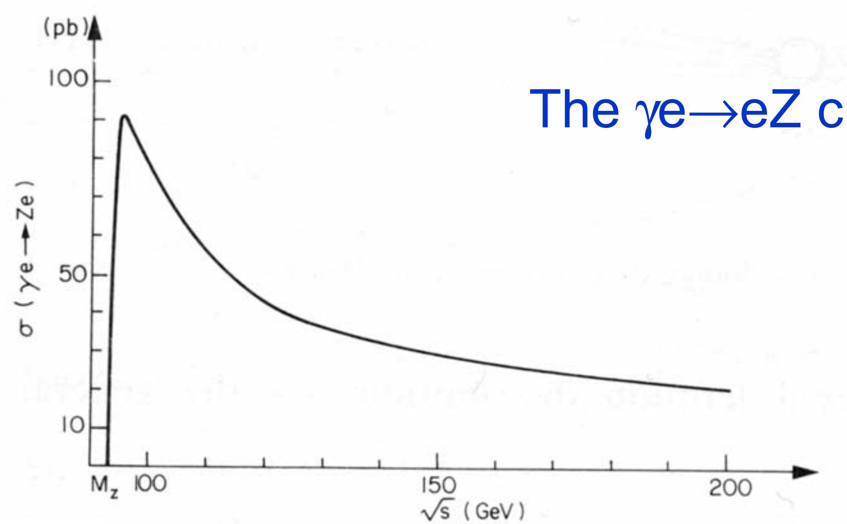
a) If the initial electron has the energy $E_{0,}$, then using angles on final leptons in Z decay one can find the ratio

$$\sqrt{\frac{s'}{s}} = x = \sqrt{\frac{\sin(\theta_{\mu^+}) + \sin(\theta_{\mu^-}) - |\sin(\theta_{\mu^+}+\theta_{\mu^-})|}{\sin(\theta_{\mu^+}) + \sin(\theta_{\mu^-}) + |\sin(\theta_{\mu^+}+\theta_{\mu^-})|}},$$

The peak in the distribution gives the ratio M_Z and E_0. The similar method was used successfully at LEP-2: $e^+e^- \to Z\gamma$ (practically the same diagram)

b) If the initial electron has $E \neq E_0$ (there are a lot of such electrons in mixed $\gamma\gamma, \gamma e$ collisions) and Z-boson is detected, then one can use leptons from Z for calibration of the tracking system, by to introducing corrections which shift the Z-peak to the right M_Z mass.

c) if all three final leptons are detected, then using only angles one can find energies of these particles and thus to calibrate the momenta up to almost maximum energies. The cross section for such topology is smaller than the total by about one order of magnitude.



Integrated cross-section $\sigma(\gamma e \rightarrow Z e)$

The $\gamma e \rightarrow eZ$ cross section is large

Conclusion (V. Telnov, Calibration of the energy at the photon collider)

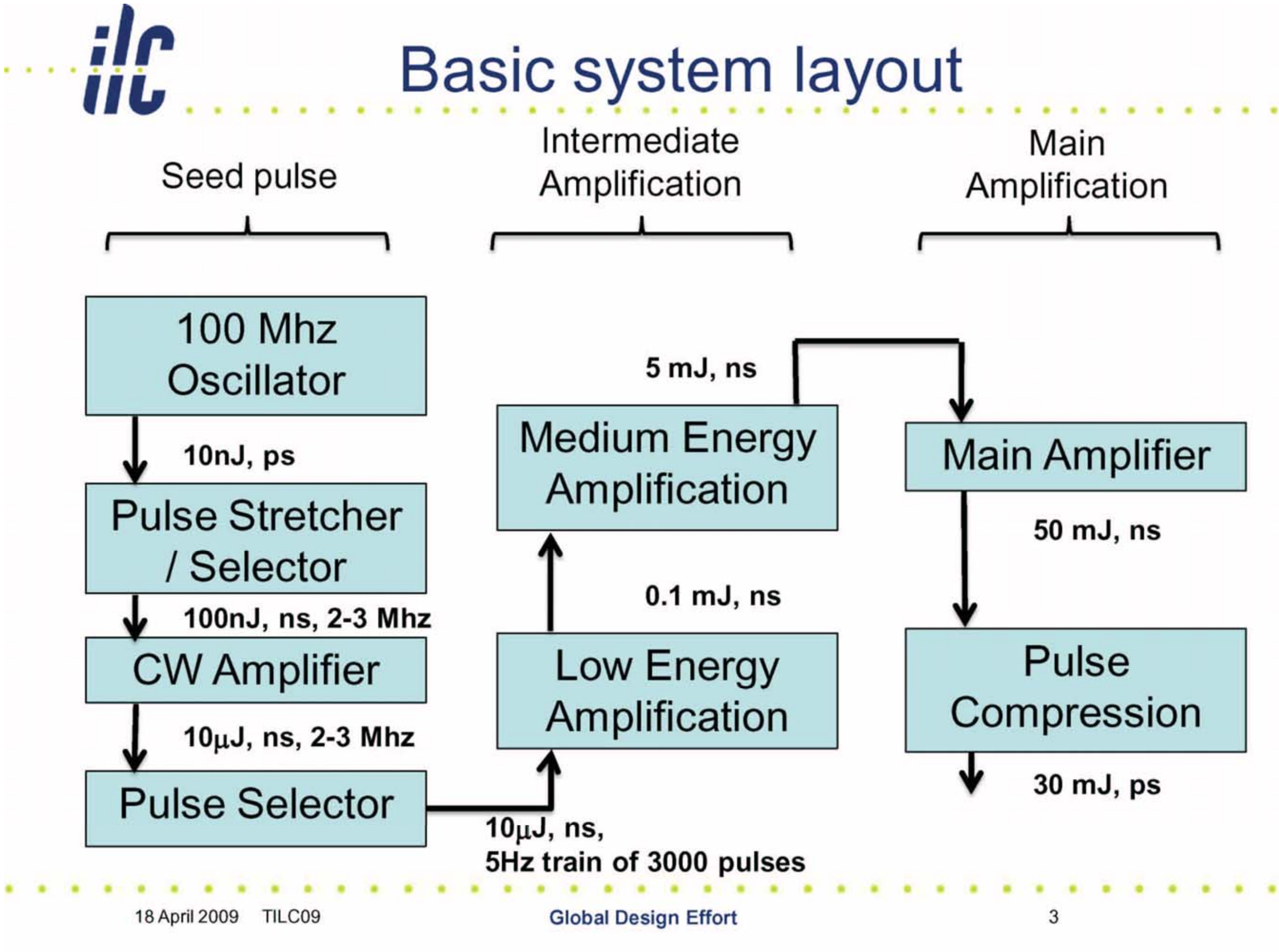
- At the photon collider the edge energy of the photon spectra and the electron beam energy E_0 are not strictly connected due to nonlinear effects in the Compton scattering (dependence on the laser intensity).
- The absolute energy calibration of the detector can be done using the process $\gamma e \to eZ$ (during normal runs in γe mode or mixed $\gamma\gamma$ and γe mode).
- Some energy spectrometer upstream the IP will be useful for monitoring the stability of the energy and its controllable variations (during the energy scan) and, of course, for tuning of the LC.
- The absolute energy calibration by the spectrometer would be useful as a cross check of the detector calibration.

Jeff Gronberg (and Brent Stuart),

Photon collider laser work at LLNL.

Laser requirements:

- Pulse train matched to the ILC bunch structure + ~300 extra pulses per train to initially fill the cavity
- 30mJ / pulse around 1kW average power
- Beam quality able to drive the cavity:
  - **Pointing stability**
  - **Phase matching**
  - **Wavefront quality**


Basic system layout
Seed pulse
Intermediate Amplification
Main Amplification
100 Mhz Oscillator
10nJ, ps
Pulse Stretcher / Selector
100nJ, ns, 2-3 Mhz
CW Amplifier
10μJ, ns, 2-3 Mhz
Pulse Selector
10μJ, ns,
5Hz train of 3000 pulses
Low Energy Amplification
0.1 mJ, ns
Medium Energy Amplification
5 mJ, ns
Main Amplifier
50 mJ, ns
Pulse Compression
30 mJ, ps
18 April 2009 TILC09
Global Design Effort
3

Pulse injection

100 Mhz Oscillator

↓ **10nJ, ps**

Pulse Stretcher / Selector

↓ **100nJ, ns, 2-3 Mhz**

CW Amplifier

↓ **10μJ, ns, 2-3 Mhz**

Pulse Selector

KM Labs pulse stretcher/compressor

Lasermetrics Pockels cell and driver

- Off-the-shelf technology
- Similar to lasers for ILC photogun
- Special photon collider requirements:
  - **Higher pointing stability**
  - **Higher bandwidth for narrower pulses**
  - **Tighter wavefront quality**

Intermediate Amplification

5 mJ, ns

Medium Energy Amplification

0.1 mJ, ns

Low Energy Amplification

10μJ, ns,
5Hz train of 3000 pulses

Cutting Edge Optronics' slab pumphead, the Whisper MiniSlab™

Cutting Edge Optronics RBA PowerPULSE

- Off-the-shelf technology exists to reach this power level
- At this level non-linear and thermal effects begin to be important

Main Amplifier

5 mJ, ns

↓

Main Amplifier

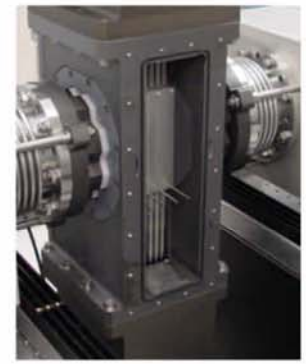
↓

50 mJ, ns

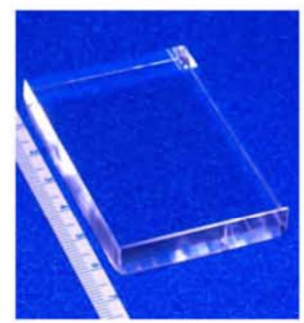
- Not commercially available
- Basic enabling technologies exist:
  - **Diode pumping**
  - **Thermal management**
  - **Long upper state lifetime materials**

Diode pumped
Higher efficiency and reliability

Forced cooling
Allows 10-Hz operation



Yb:crystals
Increased energy storage and efficiency (Yb:S-FAP)



18 April 2009 TILC09 **Global Design Effort** 6

MERCURY laser is an existence proof

- MERCURY:
  - **10 Hz**
  - **60 J/pulse**
  - **Good wavefront quality**
- But there are differences going from single pulse to a pulse train
  - **Non-linear effects are lower**
  - **Thermal distortions will change over the trains**

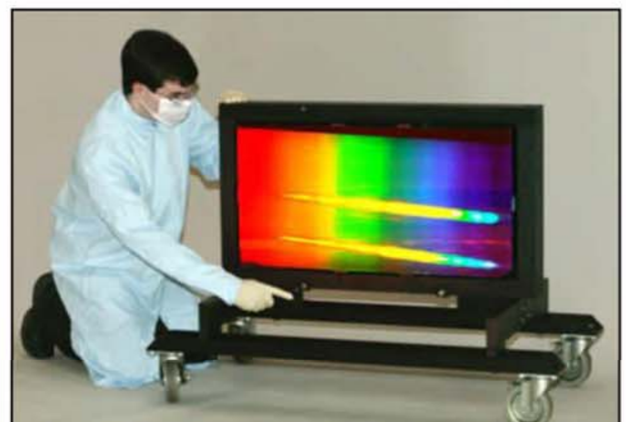
Pulse Compression

50 mJ, ns → **Pulse Compression** → 30 mJ, ps

- System will be in vacuum after compression
- Large gratings are needed to keep power levels low

Vacuum compressor (Titan – LLNL)

World's largest dielectric gratings (LLNL)



Prototyping: Stage 0 (Now)

- Pre-conceptual design and simulation of the system. Is there a solution?
  - **Create a pulse train and get it to 30mJ/pulse**
  - ? **Couple pulses to cavity**
- Simulate full cavity behavior so that required tolerances can be specified for:
  - **Pointing tolerance**
  - **Phase accuracy**
  - **Feedback and control systems**
  - **Wavefront quality**
- Simulate the full laser system to determine if tolerances can be achieved
- Convene full outside review of the design
  - **Next year**

Prototyping: Stage 1

100 Mhz Oscillator
↓ **10nJ, ps**
Pulse Stretcher / Selector
↓ **100nJ, ns, 100 Mhz**
CW Amplifier
↓ **10μJ, ns, 100 Mhz**
Pulse Selector
↓
Pulse Compression →

- Build CEP stabilized oscillator and two mirror cavity
  - **Demonstrate coherent addition and locking of oscillator to cavity**
- Add CW laser and demonstrate higher power operation
- Design next stage

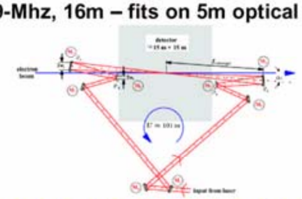
Two mirror cavity at 100Mhz

Prototyping: Stage 2

100 Mhz Oscillator
↓ **10nJ, ps**
Pulse Stretcher / Selector
↓ **100nJ, ns, 19 Mhz**
CW Amplifier
↓ **10μJ, ns, 19 Mhz**
Pulse Selector
↓
Pulse Compression →

- Replace two mirror cavity with small-scale version of photon collider cavity
- Investigate and downselect materials for next amplifier stages
- Design next stage

Scaled version of gamma-gamma cavity
19-Mhz, 16m – fits on 5m optical table

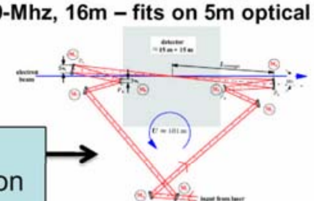


Prototyping: Stage 3

100 Mhz Oscillator
↓ **10nJ, ps**
Pulse Stretcher / Selector
↓ **100nJ, ns, 19 Mhz**
CW Amplifier
↓ **10μJ, ns, 19 Mhz**
Pulse Selector
↓ **10μJ, ns, 5Hz train of 3000 pulses**
Low Energy Amplification → **0.1 mJ ns** → Pulse Compression →

- Build and commission low-energy amplifier
  - **Demonstrate ILC pulse train with uniform gain**
  - **Demonstrate scaled cavity operation**
- Design next stage

Scaled version of gamma-gamma cavity
19-Mhz, 16m – fits on 5m optical table



Prototyping: Stage 4

100 Mhz Oscillator

10nJ, ps

Pulse Stretcher / Selector

100nJ, ns, 19 Mhz

CW Amplifier

10μJ, ns, 19 Mhz

Pulse Selector

10μJ, ns, 5Hz train of 3000 pulses

Low Energy Amplification

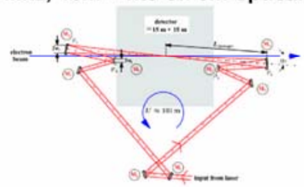
0.1 mJ ns

Medium Energy Amplification

5 mJ, ns

Pulse Compression

Scaled version of gamma-gamma cavity 19-Mhz, 16m – fits on 5m optical table



- Decide on gain medium for nex stages
- Build and demonstrate me energy pulse tra and cavity opera
- Add deformable mirror for wavef correction
- Compton backs demo? (SLAC c ATF2)
- Design next sta

Prototyping: Stage 5

100 Mhz Oscillator

10nJ, ps

Pulse Stretcher / Selector

100nJ, ns, 19 Mhz

CW Amplifier

10μJ, ns, 19 Mhz

Pulse Selector

10μJ, ns, 5Hz train of 3000 pulses

Low Energy Amplification

0.1 mJ ns

Medium Energy Amplification

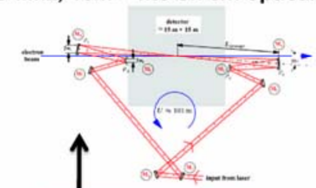
5 mJ, ns

Main Amplifier

50 mJ, ns

Pulse Compression

Scaled version of gamma-gamma cavity 19-Mhz, 16m – fits on 5m optical table



- Build main amplifier
- Demonstrate full power operation at 19Mhz

Prototyping: Stage 6

100 Mhz Oscillator

10nJ, ps

Pulse Stretcher / Selector

100nJ, ns, 19 Mhz

CW Amplifier

10μJ, ns, 19 Mhz

Pulse Selector

10μJ, ns, 5Hz train of 3000 pulses

Low Energy Amplification

0.1 mJ ns

Medium Energy Amplification

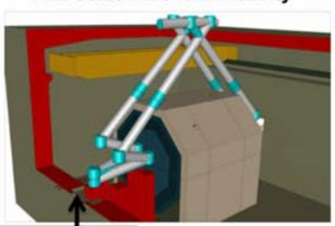
5 mJ, ns

Main Amplifier

50 mJ, ns

Pulse Compression

Full scale DESY/MBI cavity



- Build full scale cavity
- Demonstrate operation

Summary

- Creating a laser system that can create a train of pulses with the correct energy seems workable
- Still to be determined: the required tolerances on laser beam quality to allow it to drive the cavity
- Rough estimate of cost for a laser system is $20M once it is a known technology
- Prototyping program to build the first one is probably about double that.

Tohru Takahashi, Status of Optical Cavity R&D

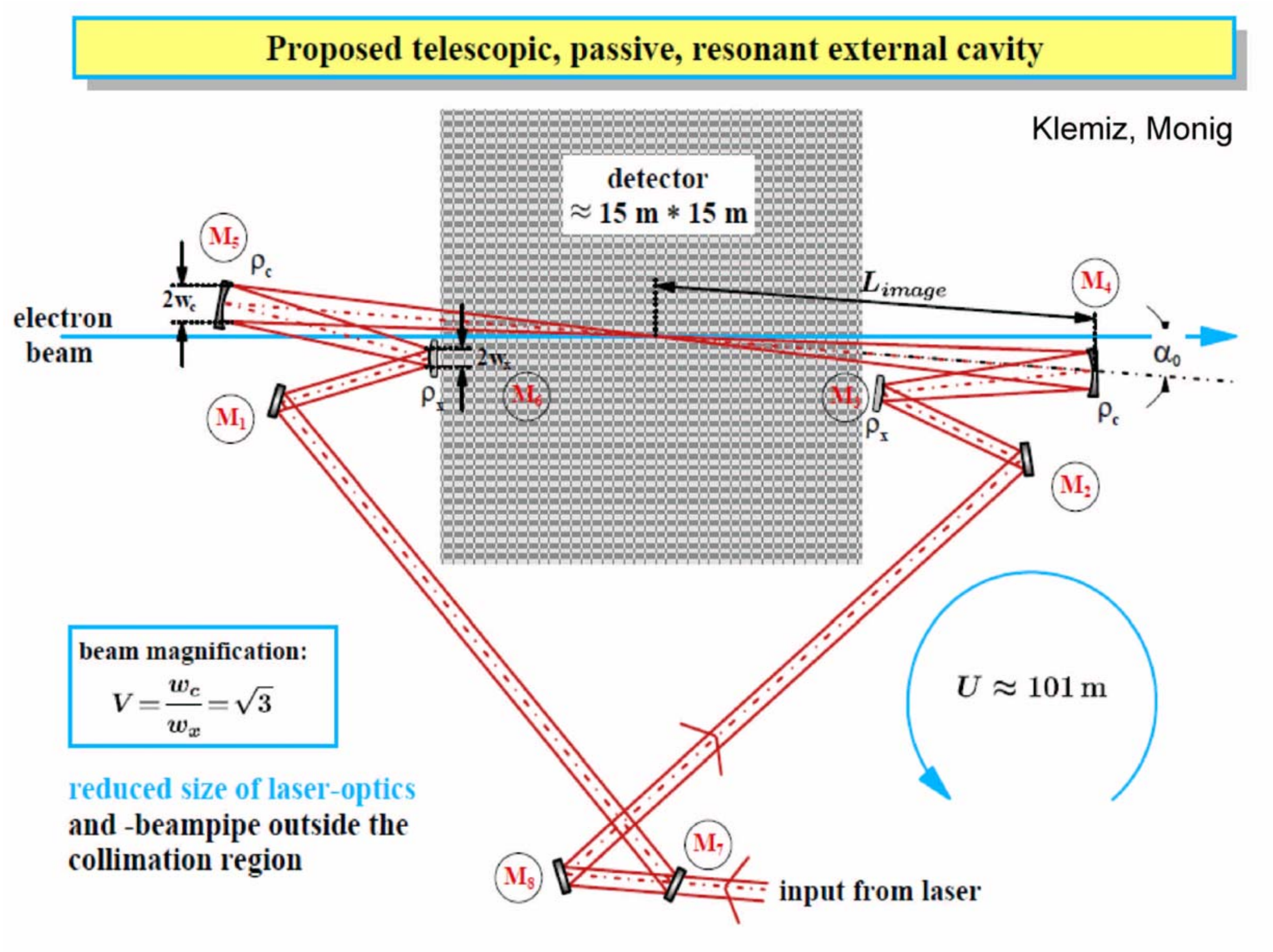
Optical Cavity R&D around KEK-ATF

T.Takahashi
Hiroshima Univ.

Nov. 2008
LCWS08
at Chicago

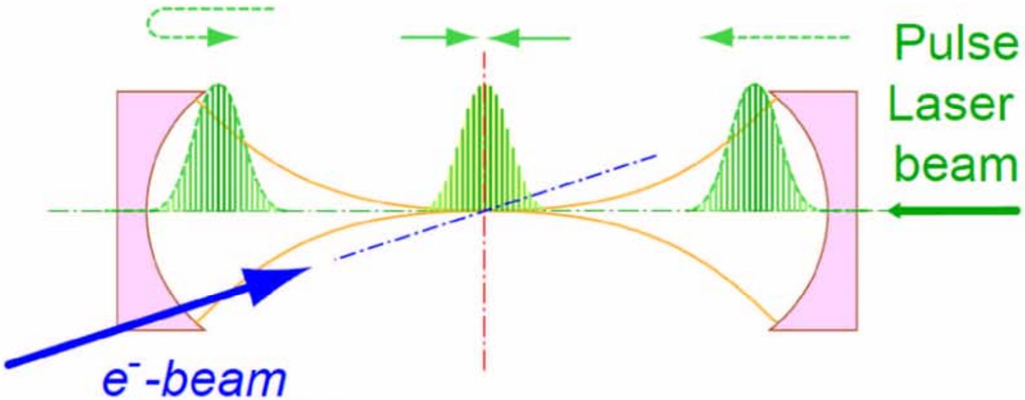
T.Takahashi Hiroshima

That is what is needed for PLC



Experimental R/D in ATF

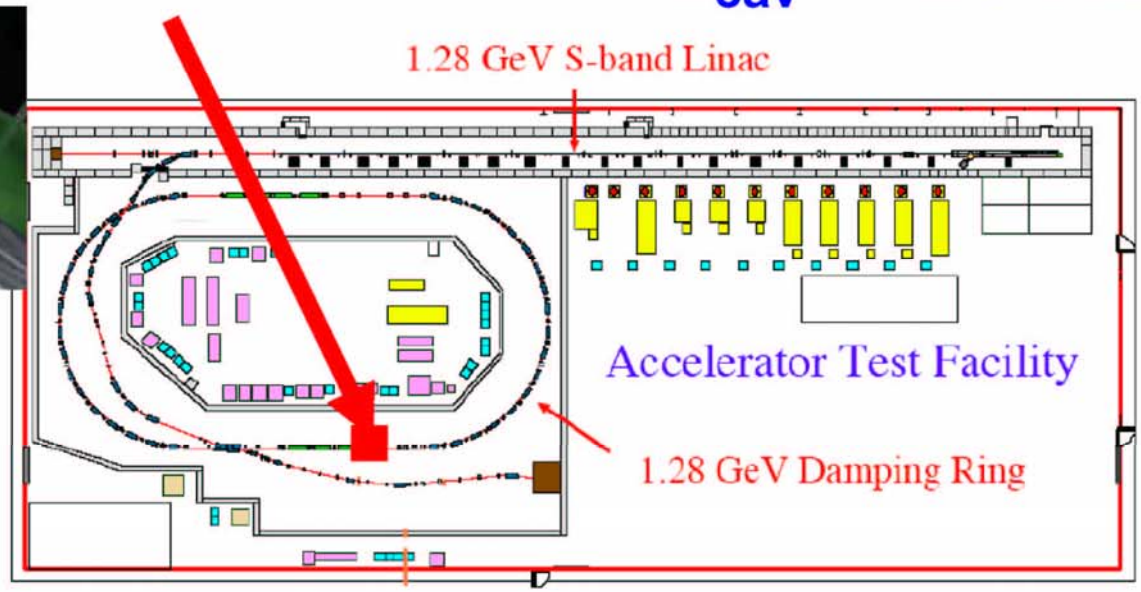
Hiroshima-Waseda-Kyoto-IHEP-KEK



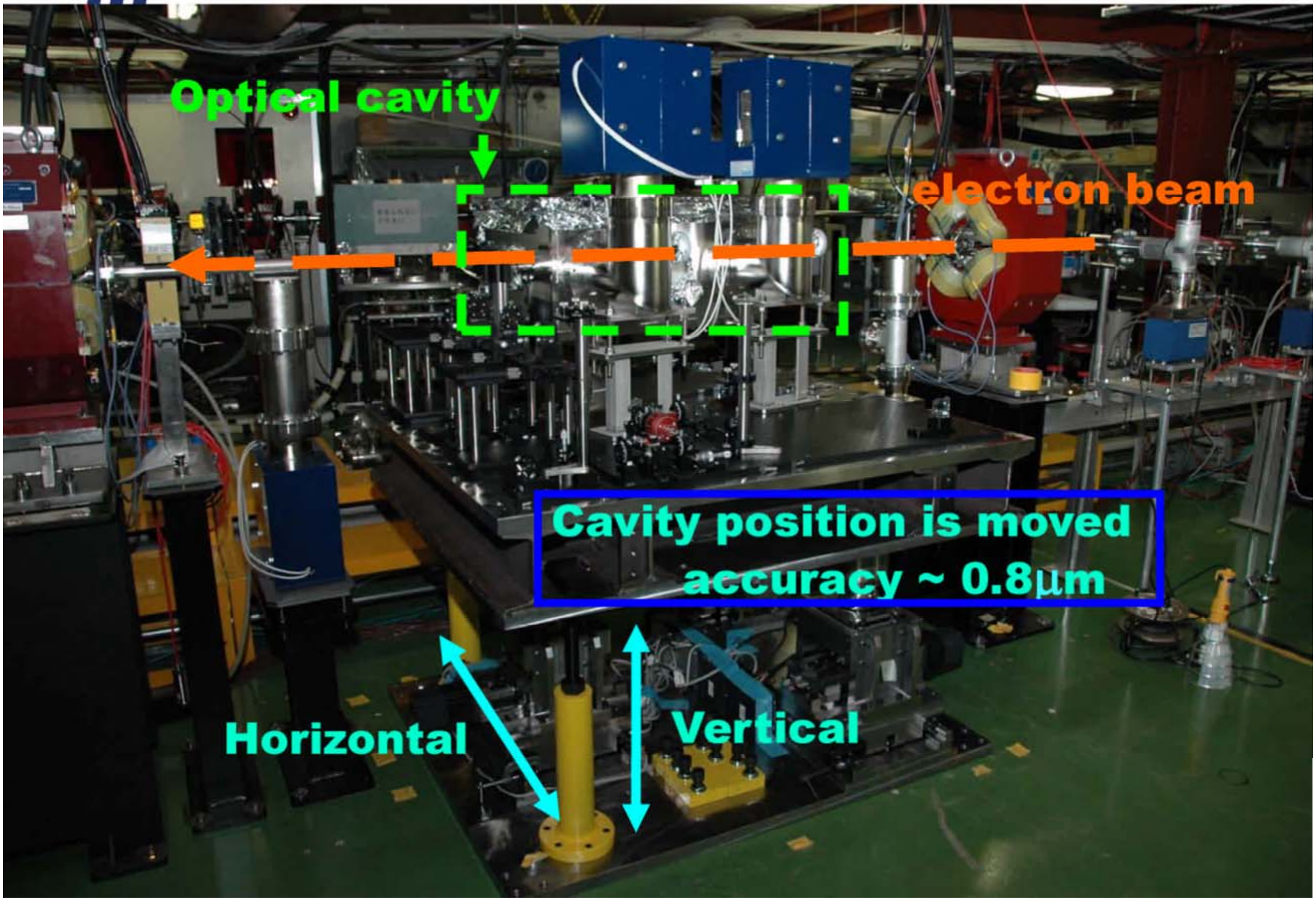
Make a fist prototype 2-mirror cavity

L_{cav} = 420 mm

Put it in ATF ring

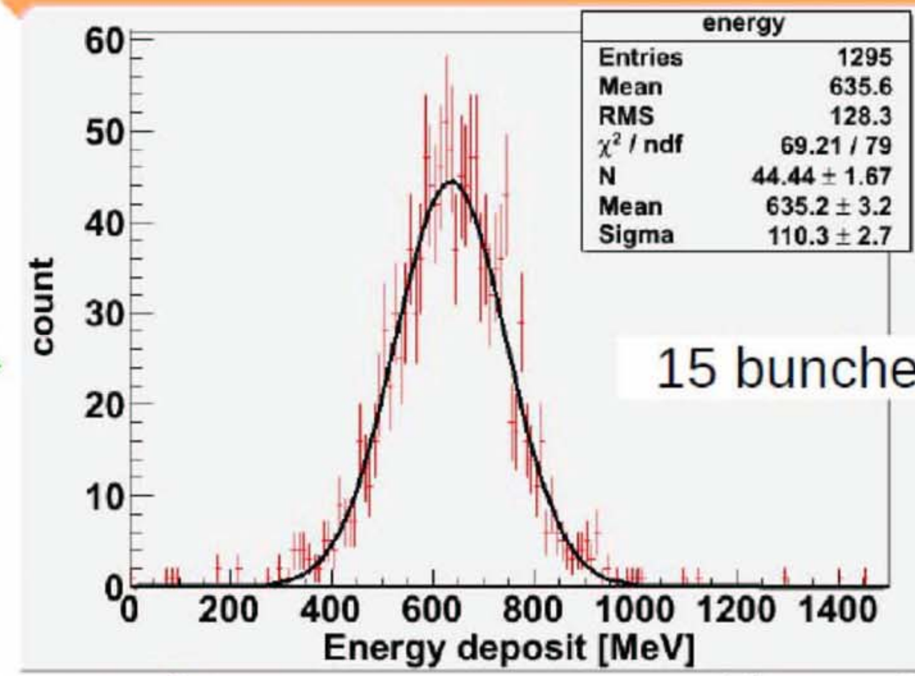


Set up at KEK-ATF



2-mirror cavity works

Result



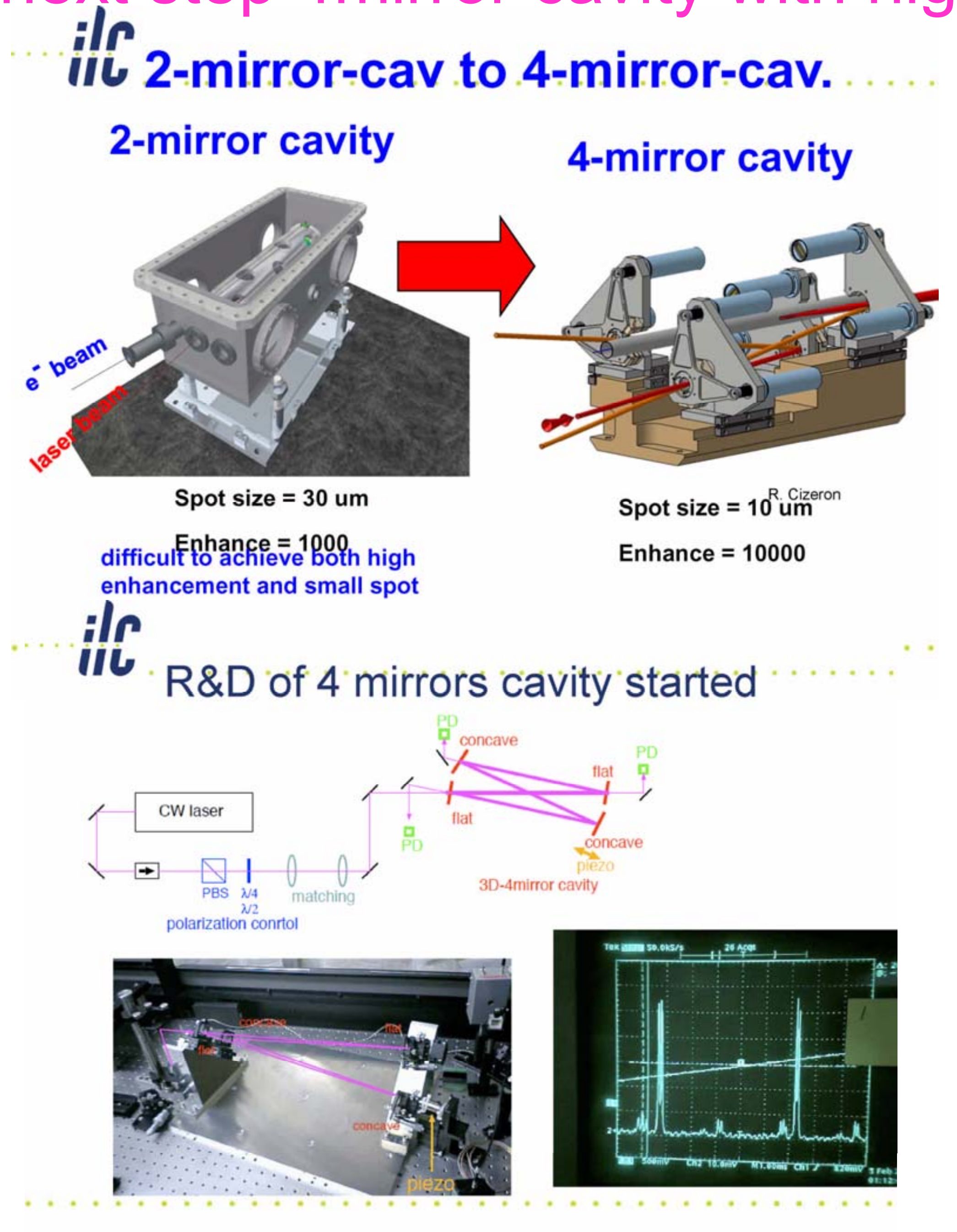
15 bunches / train

We detected 27 gamma-rays / bunch train.
generation 60 gamma-rays / train to all angle.

→ 60×2.16MHz ~ 1.2×10^8 [gamma / second]

Revolution

The next step 4mirror cavity with high Q



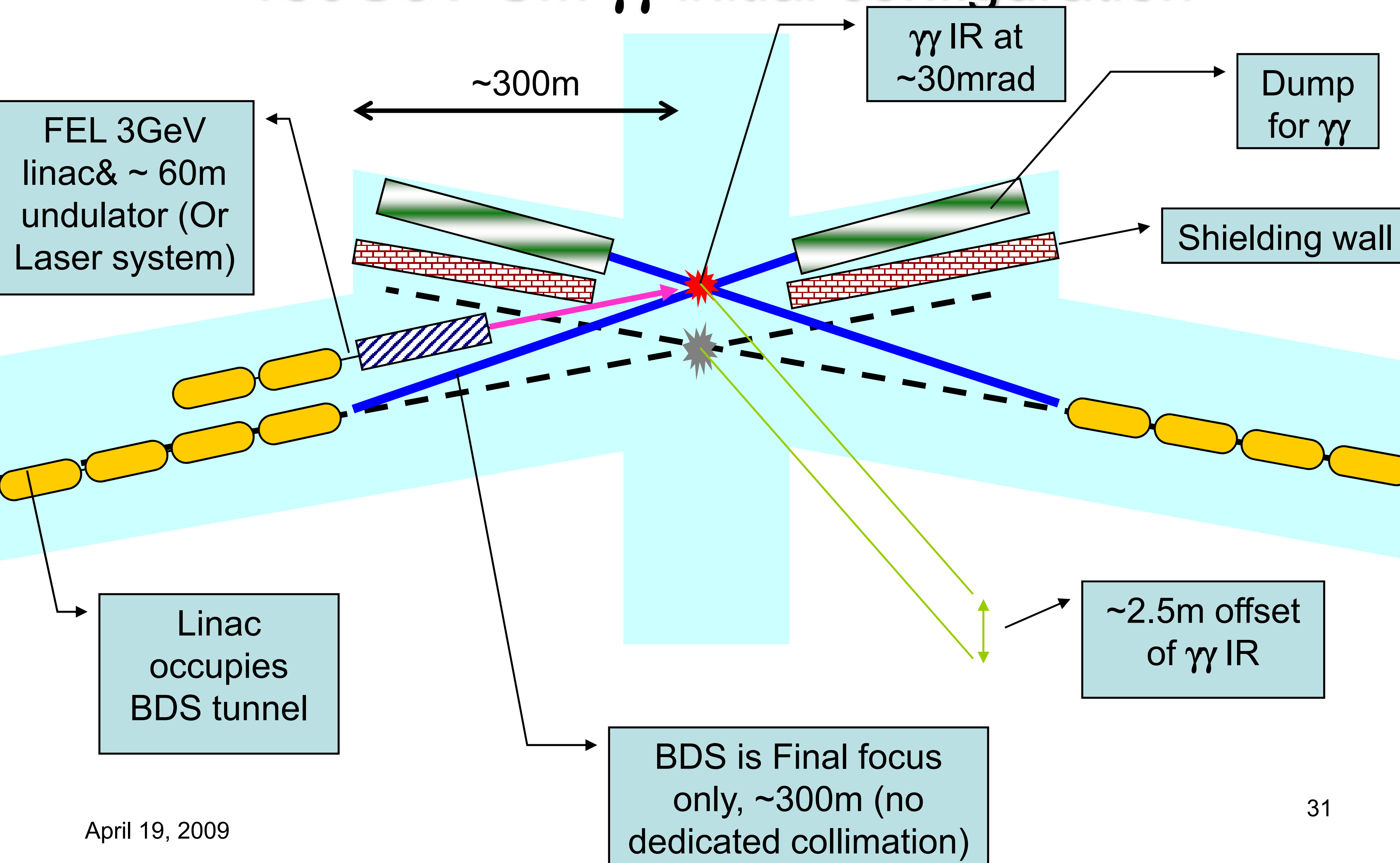
Summary and prospects

- **photon generation by Laser pulse stacking cavity / accelerator has been demonstrated both for**
  - **Polarized electron source (PosiPol)**
  - **hard x ray generation (LUCX)**
- **A project for x ray source has started**
- **All projects going to 4 mirror ring cavity**
  - **Technique with Ring cavity and e-beam will be accumulated in next 3-4year**
- Specific study is for 100 m long cavity is necessary
  - **supporting 1m scale mirrors**
  - **adaptive optics to maintain phase front**
  - **Feed back experiment to cavity design**
    - 3 Dimensional cavity
    - polarization

T.Takahashi Hiroshima

Andrei Seryi, BDS Issues (related to PLC as a Precursor to the ILC)
(schemes, parameters and schedule, see his and T.Barklow'a talks)

180GeV CM γγ initial configuration



Discussion: PLC: Toward the step forward

Practically all technologies required for the photon collider laser system already exist (have been developed in frames of other big projects).

As the next step we would like to develop (on a paper) a detailed scheme we need for the photon collider, to optimize it, to analyze tolerances , methods of stabilization, to figure out what already exists and known and what should be experimental checks.

The main problem: this study needs some money. Where we can get these resources:

- From the ILC budjet?
- Some grants? At present there are no documents which clearly states that the PLC is the part of the ILC and that its development is supported by the ILC management.
- From budget of some laboratories?
- Donations from rich people? But we can not promise results soon.

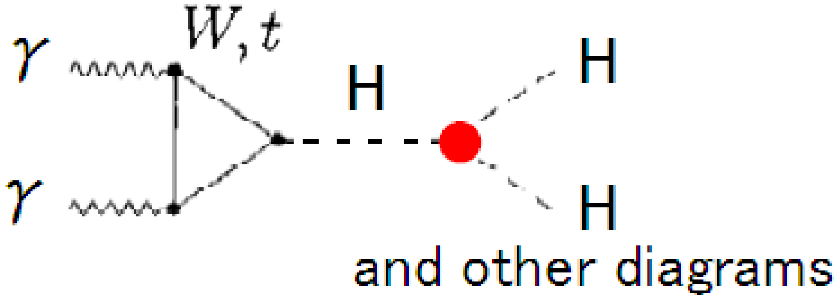
Not clear.

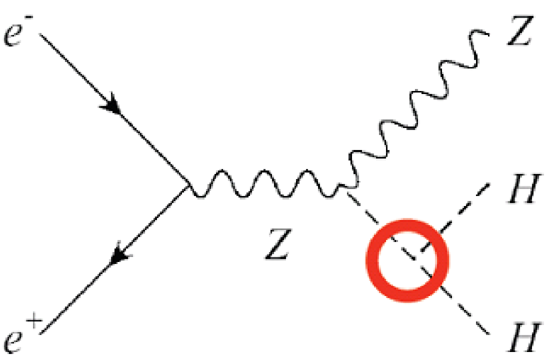
Nozomi Maeda (Hiroshima),

Feasibility study of Higgs pair creation in $\gamma\gamma$ collider

$\gamma\gamma$->HH

Measurement of Higgs self-coupling constant $\lambda=\lambda^{SM}(1+\delta\kappa)$ by $\gamma\gamma$->HH





1. This process occurs at low energy(than e^+e^-).
2. λ contribution to cross section is different.

$\rightarrow$Can PLC measure Higgs self-coupling constant λ?

Energy optimization

$$sensitivity = \frac{|N(\delta\kappa) - N_{SM}|}{\sqrt{N_{obs}}} = \frac{L|\eta\sigma(\delta\kappa) - \eta\sigma_{SM}|}{\sqrt{L(\eta\sigma(\delta\kappa) + \eta_B\sigma_B)}}$$

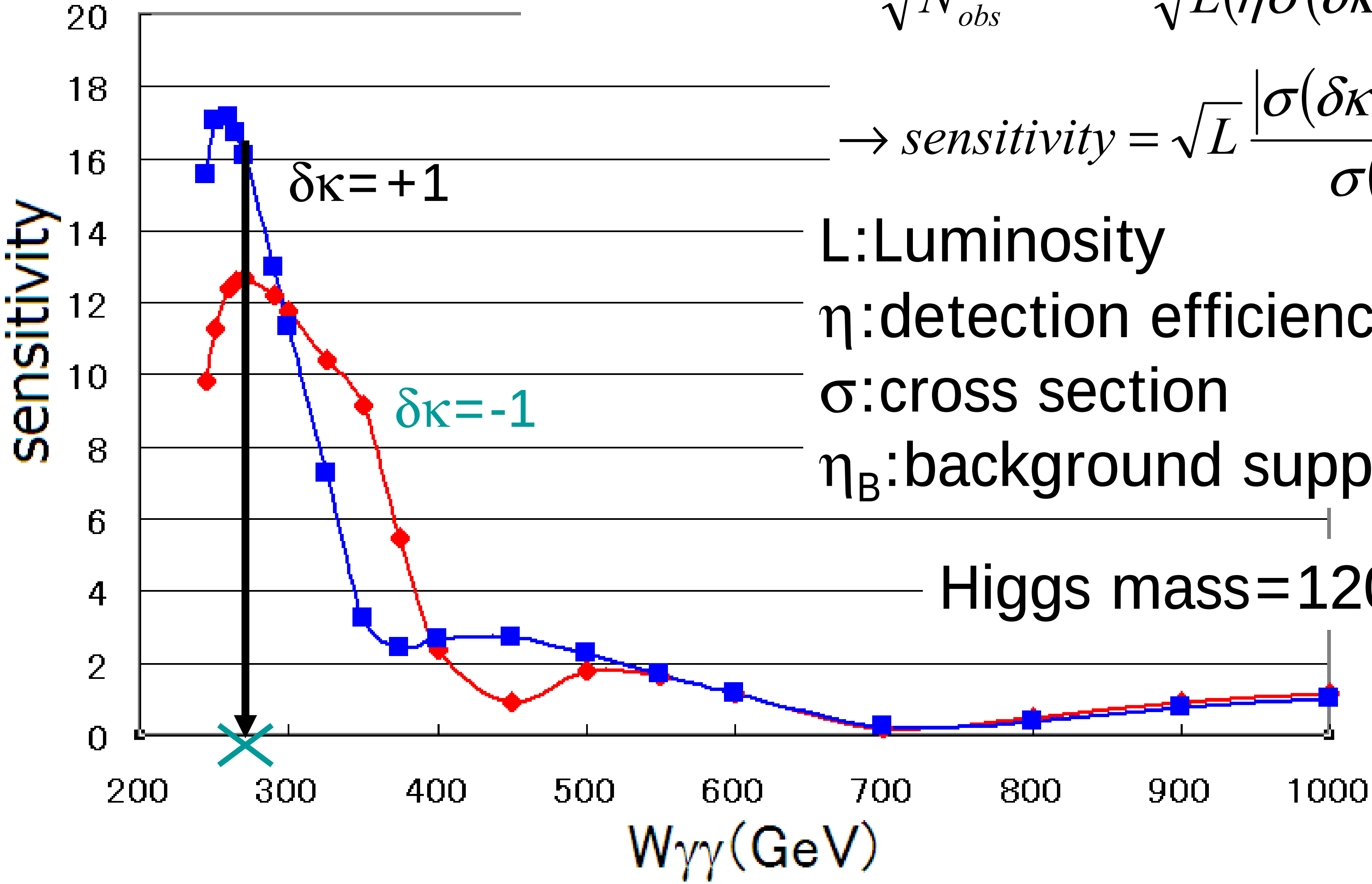
$$\rightarrow sensitivity = \sqrt{L}\,\frac{|\sigma(\delta\kappa) - \sigma_{SM}|}{\sigma(\delta\kappa)}$$

L:Luminosity

η:detection efficiency

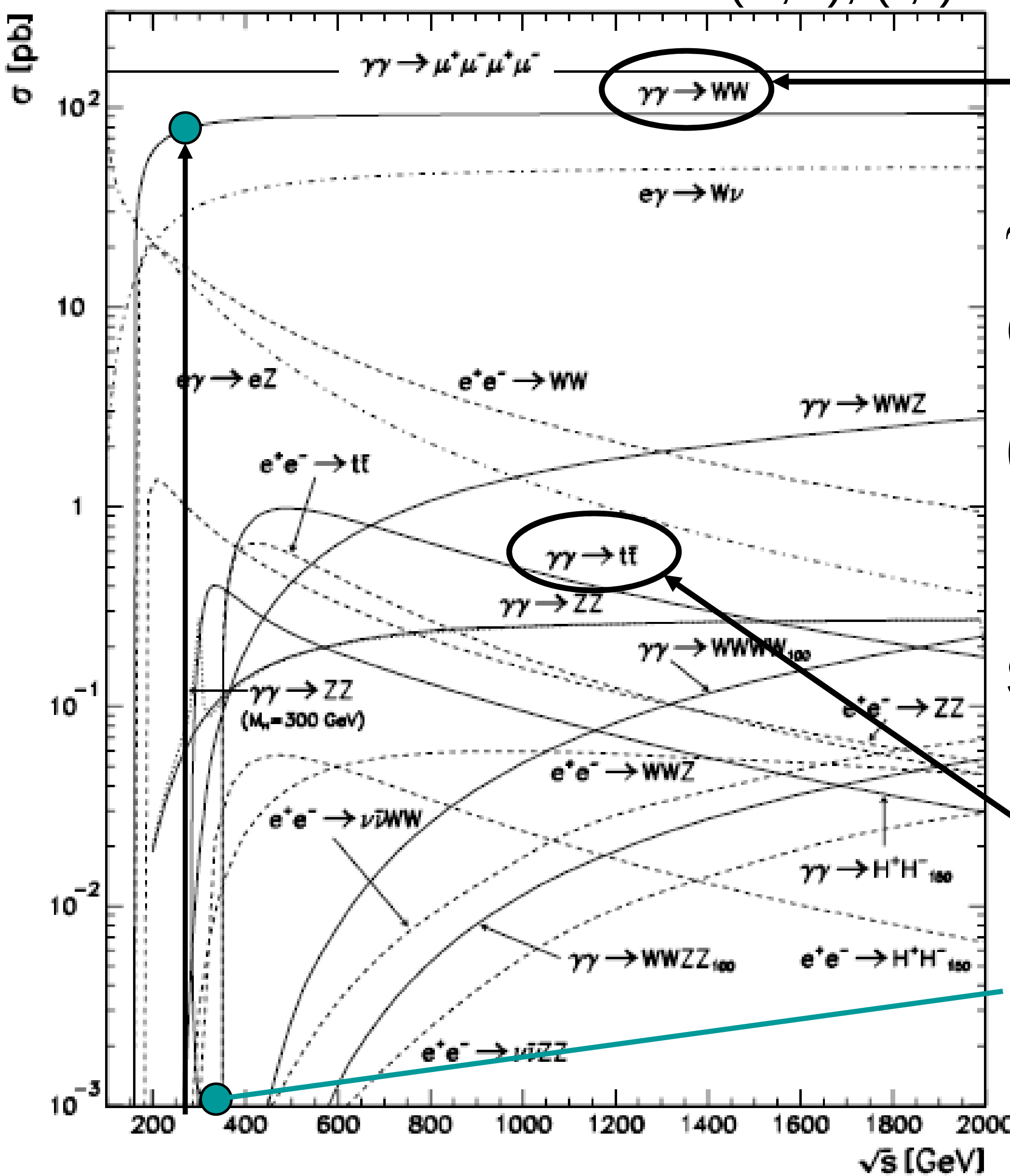
σ:cross section

η_B:background suppression



Background

(+,+), (-,-)



main background is $\gamma\gamma$->WW (σ_B ~ 90pb)

cf.) Signal:σ = 0.044fb

0.044fb/90pb = 4.9×10^{-7}

10^{-7} background supression is necessary.

$\gamma\gamma$->tt does not occur.

Optimum energy is below tt threshold.

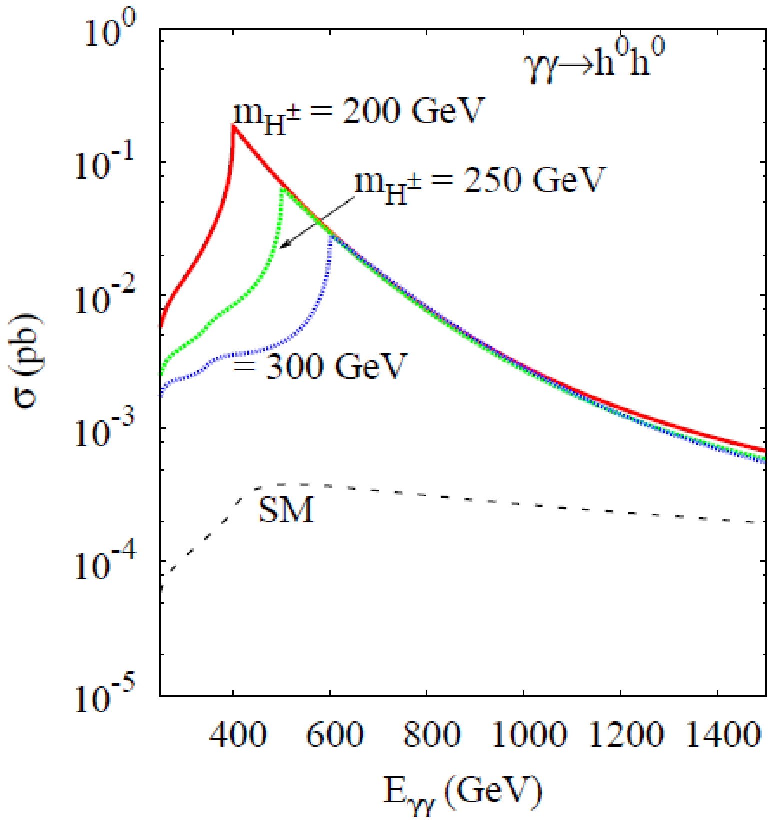
In analysis 4 jets were required, with b-tagging, realistic luminosity spectrum.

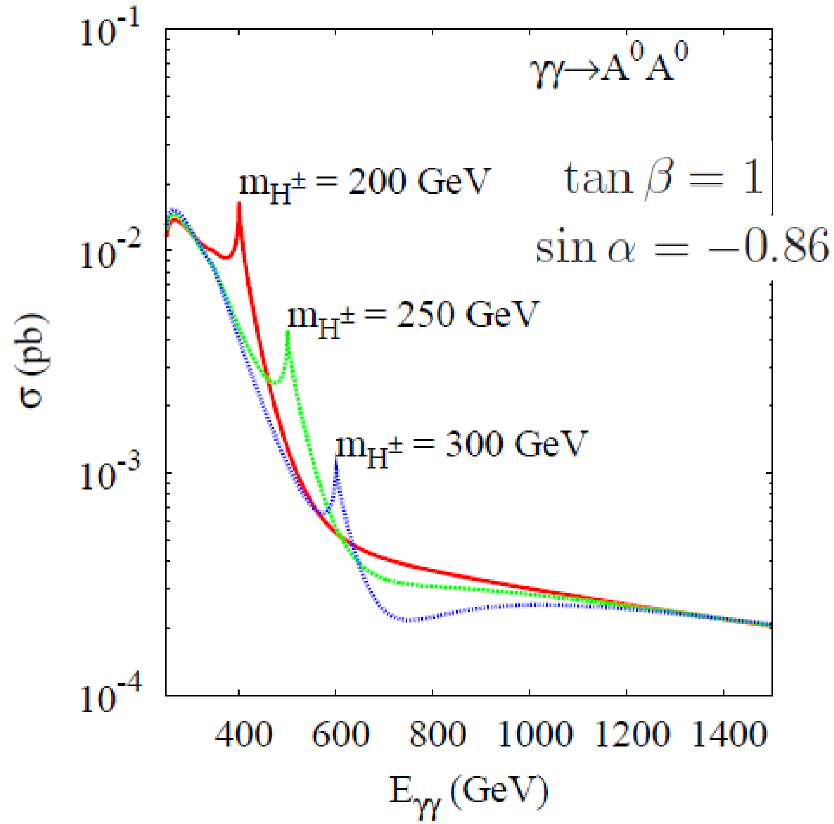
The result:

after 10 year operation with “optimistic” luminosity (as in TESLA TDR on the PLC) one can obtain 21 events of effect and 0 background (I am not sure that the number of simulated background events was sufficient to make such statement).

Next plan, consider HH->bbWW*(B.R.=0.18)

Rui Santos, $\gamma\gamma \rightarrow$hh (AA) in 2HDM

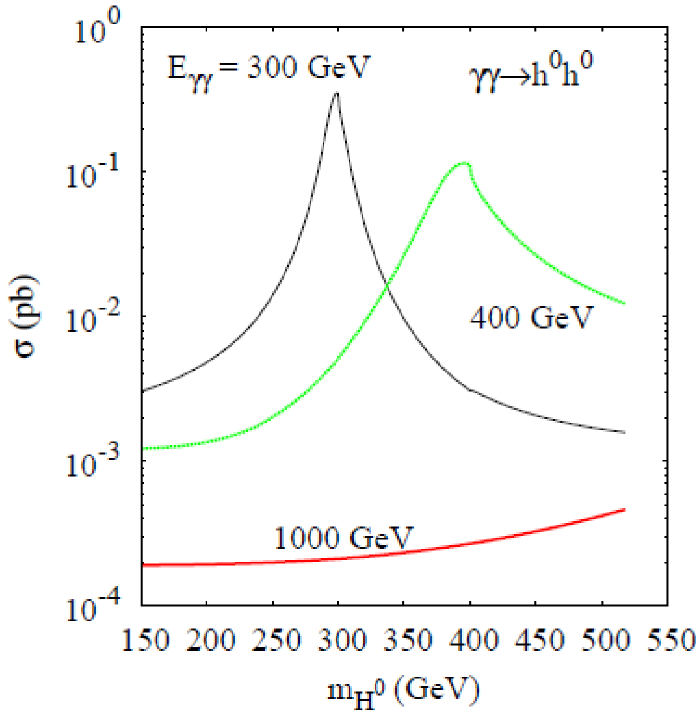


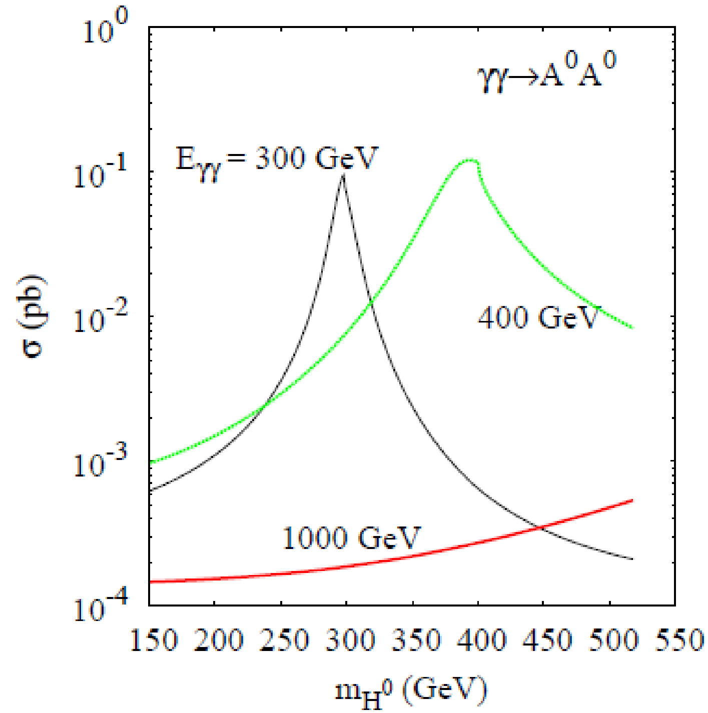


$$m_{h^0}, m_{H^0}, m_{A^0}, m_{12} = 120, 200, 120, 300 \text{ GeV}$$

Cross section as a function of the center of mass energy for different values of the charged Higgs mass. It is clear that the cross section can be several orders of magnitude above the corresponding SM cross section.

Total cross sections





$m_{h^0}, m_{H^\pm}, m_{A^0}, m_{12} = 120,\ 250,\ 150,\ 200\ GeV$ $\sin\alpha = 0.9$ and $\tan\beta = 1.5$

Cross section as a function of the heavy Higgs mass. Here we see the resonant behaviour $\gamma\gamma \to H \to hh$ of the cross section.

Conclusion

- Appreciating Sugawara's suggestion to start the ILC operation as soon as possible at minimum energy required for the Higgs(~120), that is the PLC with 2E~180 GeV, we believe that e+e $\rightarrow$ ZH at 2E~230 GeV is a better alternative.
  The photon collider should be considered as the second stage.

- The next step on PLC is development of a realistic laser scheme (still on a paper).

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