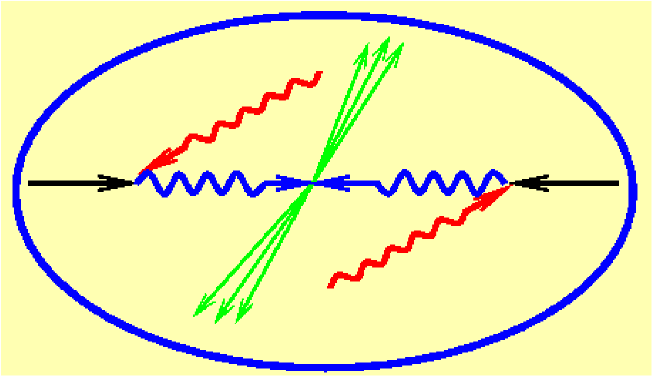


Status of the Photon collider at the ILC

Valery Telnov

Budker INP, Novosibirsk

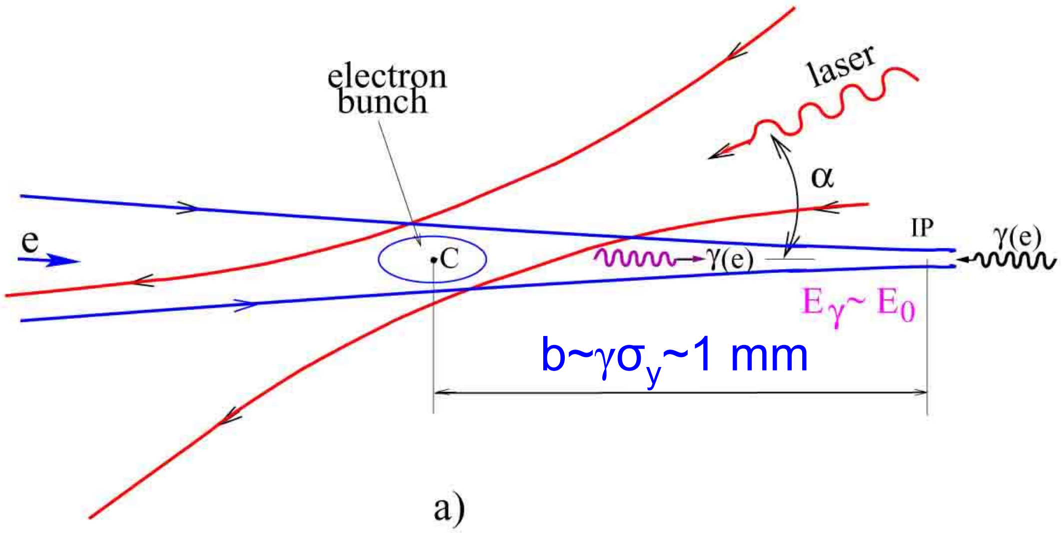
ECFA workshop on linear colliders
Warsaw, June 10, 2008

Contents

- Introduction, physics motivation
- Interaction region issues
- Lasers, optics
- Detector issues
- The photon collider at ILC, current status
- Conclusion

Scheme of $\gamma\gamma$, γe collider

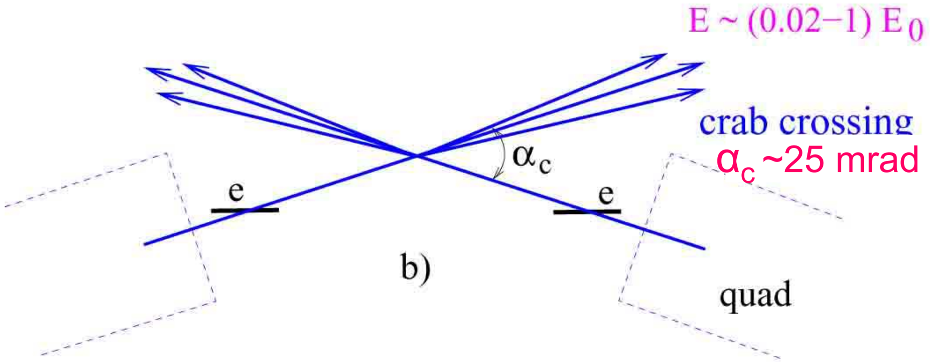
GKST,1981



$$\omega_m = \frac{x}{x+1} E_0$$

$$x \approx \frac{4E_0\omega_0}{m^2c^4} \simeq 15.3 \left[\frac{E_0}{\mathrm{TeV}}\right] \left[\frac{\omega_0}{\mathrm{eV}}\right]$$

$E_0 = 250$ GeV, $\omega_0 = 1.17$ eV
($\lambda = 1.06$ μm) $\Rightarrow$
x=4.5, ω_m=0.82E_0=205 GeV



$x = 4.8$ is the threshold for $\gamma\gamma_L \to e^+e^-$ at conv. reg.

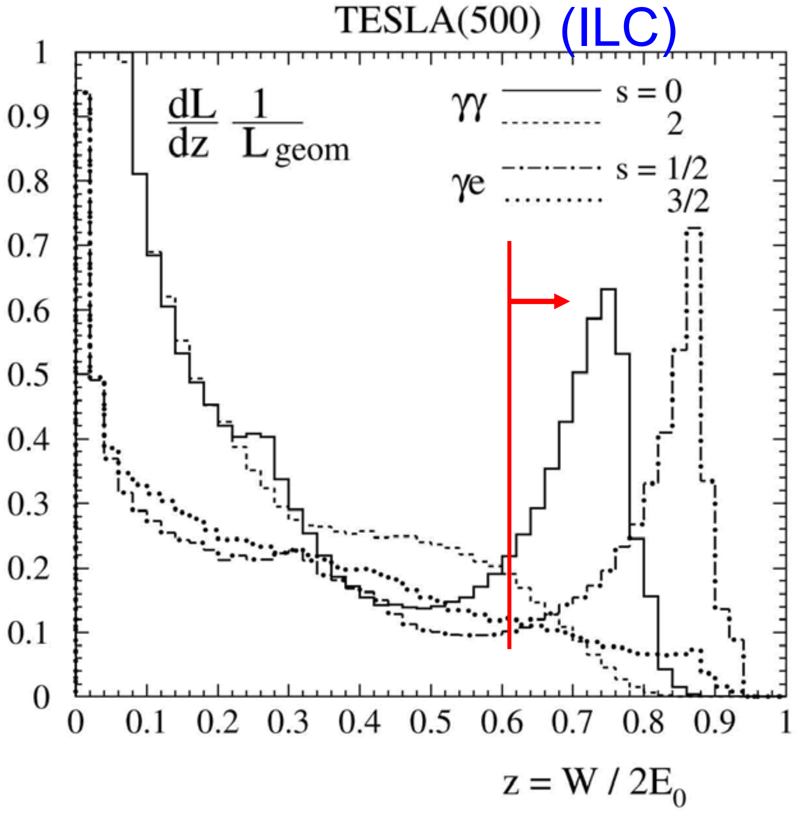
ω_{max}~0.8 E_0

$W_{\gamma\gamma,\,max} \sim 0.8\cdot 2E_0$
$W_{\gamma e,\,max} \sim 0.9\cdot 2E_0$

Realistic luminosity spectra ($\gamma\gamma$ and γe)

(with account multiple Compton scattering, beamstrahlung photons and beam-beam collision effects)

(decomposed in two states of J_z)



Usually a luminosity at the photon collider is defined as the luminosity in the high energy peak, $z>0.8z_m$.

For nominal ILC beams

$L_{\gamma\gamma}(z>0.8z_m) \sim 0.17\ L_{e+e-}(\mathrm{nom})$
$\sim 0.35 \cdot 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

(but cross sections in $\gamma\gamma$ are larger by one order!)

The luminosity could be larger by a factor of 3 with DRs optimized for $\gamma\gamma$)

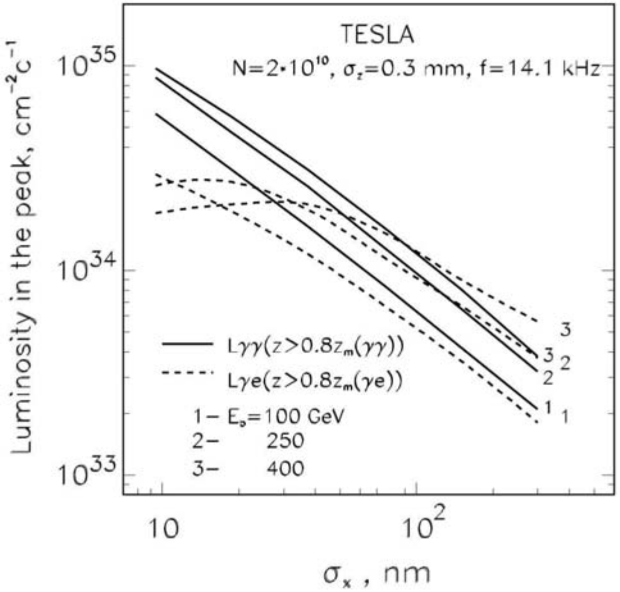
For γe it is better to convert only one electron beam, in this case it will be easier to identify γe reactions, to measure its luminosity (and polarization) and the γe luminosity will be larger.

Factors limiting $\gamma\gamma,\gamma e$ luminosities

Collisions effects:

- Coherent pair creation
- Beamstrahlung
- Beam-beam repulsion

On the right: dependence of $\gamma\gamma$ and γe luminosities in the high energy peak on the horizontal beam size:



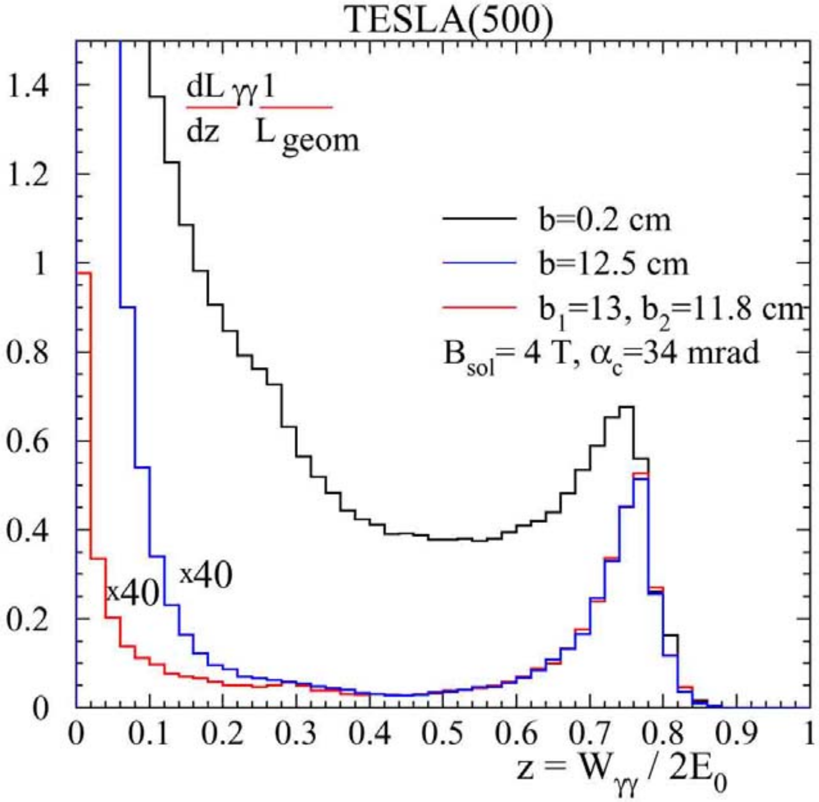
For the ILC electron beams $\sigma_x \sim 250$ nm at $2E_0 = 500$. Having beams with smaller emittances one could have by one order higher $\gamma\gamma$ luminosity.

γe luminosity in the high energy peak is limited due to the beam repulsion and beamstrahlung

At e^+e^- the luminosity is limitted by collision effects (beamstrahlung, instability), while in $\gamma\gamma$ collsions only by available beam sizes or geometric e^-e^- luminosity (for at $2E_0$<1 TeV).

γ γ- luminosity spectrum for QCD study

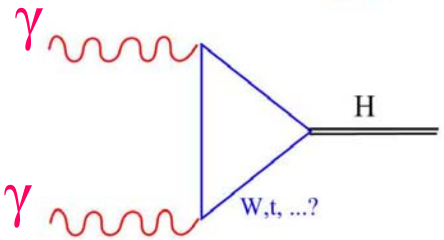
For measurement of the total cross section or QCD study one needs lower luminosity (to decrease overlaping of events (about 1 hadronic event at the nominal luminosity), but more monochromatic. This can be achieved by increasing CP-IP distance.



Owing to the crossing angle and the detector field electron beams are deflected after the conversion point and do not collider, if b1≠b2 (red).

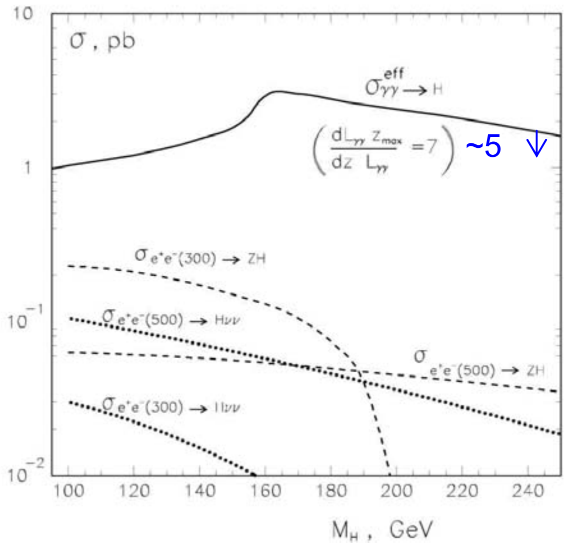
Some examples of physics at PLC

Higgs boson

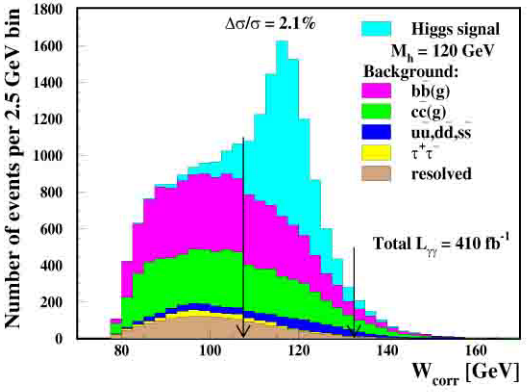


Very sensitive to heavy charge particles in the loop.

Cross sections of the Higgs boson in $\gamma\gamma$ and e^+e^- collisions



realistic simulation P.Niezurawski et al



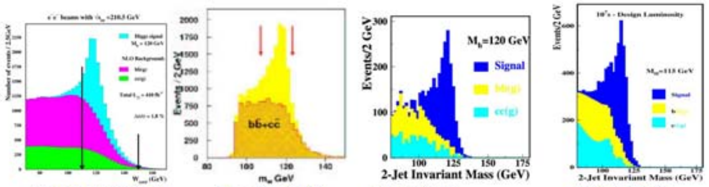
$$\dot{N}_{\gamma\gamma\to H} = L_{\gamma\gamma}\times\frac{dL_{\gamma\gamma}M_H}{dW_{\gamma\gamma}L_{\gamma\gamma}}\frac{4\pi^2\Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_H^3}$$

At ILC

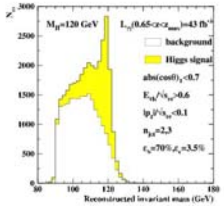
$$\frac{N(\gamma\gamma\to H)}{N(e^+e^-\to H+X)}\sim 1-10$$

For M_H=115-250 GeV

(previous analyses)



Niezurawski(TESLA) Rosca(TESLA) Asner(NLC) Asner(Cliche)



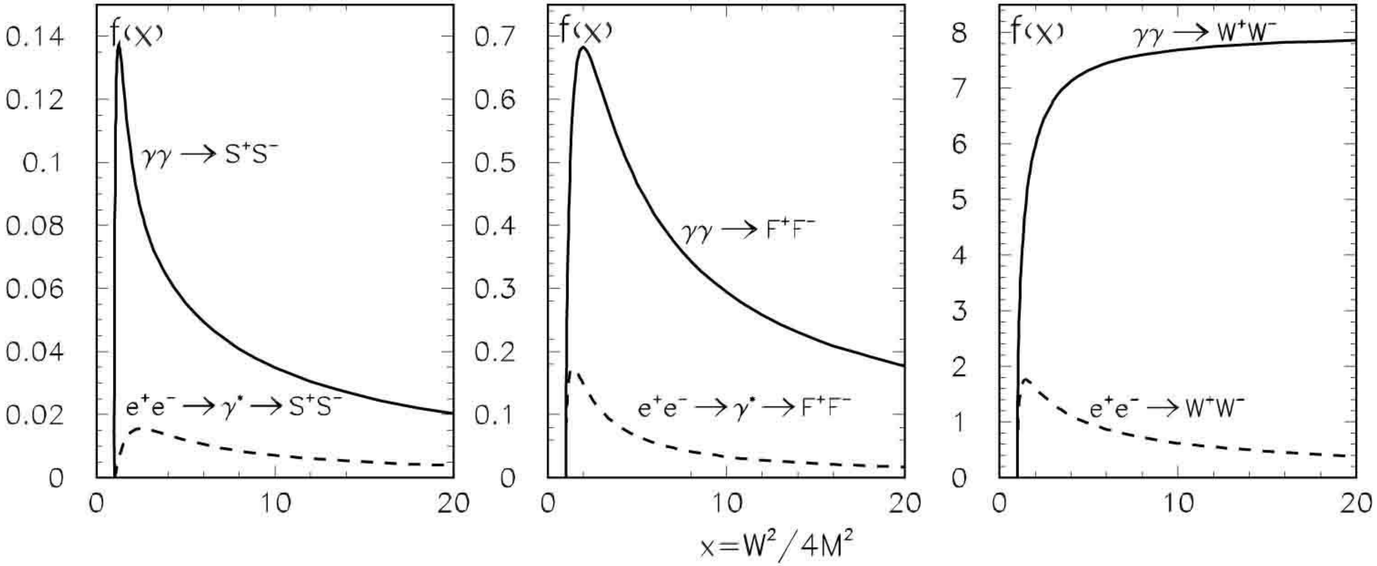
S.Soldner-Rembold

At nominal luminosities the number of Higgs in $\gamma\gamma$ will be similar to that in e+e-, one can measure $\Gamma(h\to\gamma\gamma)$ with 2% accuracy.

Charged pair production in e^+e^- and $\gamma\gamma$ collisions.

(S (scalars), F (fermions), W (W-bosons);

$\sigma = (\pi\alpha^2/M^2)f(x)$, beams unpolarized)



unpolarized
beams

So, typical cross sections for charged pair production in $\gamma\gamma$ collisions is larger than in e^+e^- by one order of magnitude and depend differently on physics parameters

Supersymmetry in $\gamma\gamma$

In supersymmetric model there are 5 Higgs bosons:

h^0 light, with $m_h < 130$ GeV

H^0, A^0 heavy Higgs bosons;

H^+, H^- charged bosons.

$M_H \approx M_A$, in e$^+$e$^-$ collisions H and A are produced in pairs (for certain param. region), while in $\gamma\gamma$ as the single resonances, therefore:

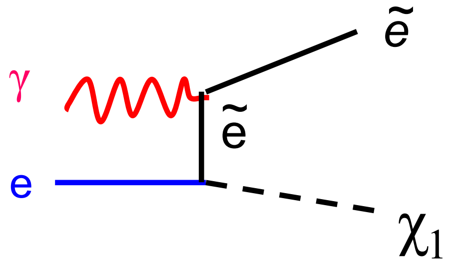
in e$^+$e$^-$ collisions $M_{H,A}^{max} \sim E_0$ (e$^+$e$^-$ $\rightarrow H + A$)
in $\gamma\gamma$ collisions $M_{H,A}^{max} \sim 1.6E_0$ ($\gamma\gamma$ $\rightarrow H(A)$)

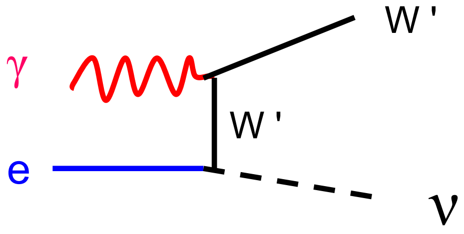
For some SUSY parameters H,A can be seen only in $\gamma\gamma$
(but not in e+e- and LHC)

Supersymmetry in γe

At a γe collider charged particles with masses higher than in e^+e^- collisions at the same collider can be produced (a heavy charged particle plus a light neutral one, such as a new W' boson and neutrino or supersymmetric charged particle plus neutralino):

$$m_{\tilde{e}^-} < 0.9 \times 2E_0 - m_{\tilde{\chi}_1^0}$$





Physics motivation: summary

In $\gamma\gamma$, γe collisions compared to e^+e^-

1. the energy is smaller only by 10-20%
2. the number of events is similar or even higher
3. access to higher particle masses
4. higher precision for some phenomena
5. different type of reactions (different dependence on theoretical parameters)

It is the unique case when the same collider allows to study new physics in several types of collisions at the cost of rather small additional investments

Photon collider at ILC

The PLC is “the option” at ILC (all except e+e-(500) are options). However, it is important to make decisions on the baseline ILC design not prohibitive or unnecessarily difficult for the photon collider, which allow to reach its ultimate performance and rather easy transition between e^+e^- and $\gamma\gamma$, γe modes.

Interaction region issues

1. For removal of the disrupted beams the crossing angle at one of the interaction regions should be about 25 mrad.

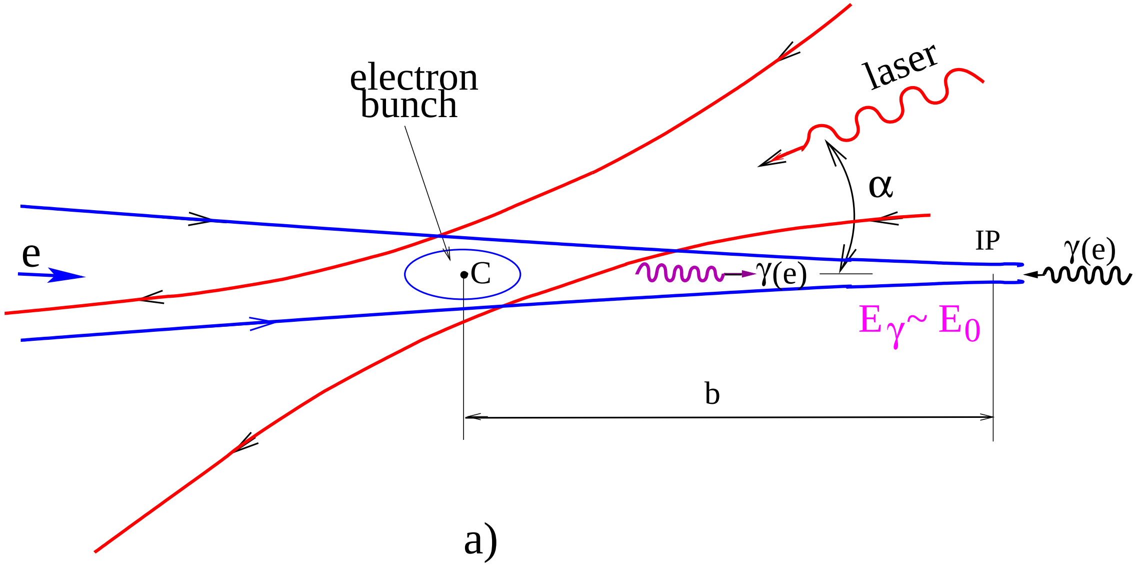
2. The $\gamma\gamma$ luminosity is almost proportional to the geometric e-e- luminosity, therefore the product of horizontal and vertical emittances should be as small as possible (requirements to damping rings and beam transport lines);

3. The final focus system should provide a spot size at the interaction point as small as possible (the horizontal β-functions can be smaller by one order of magnitude than that in the e+e- case);

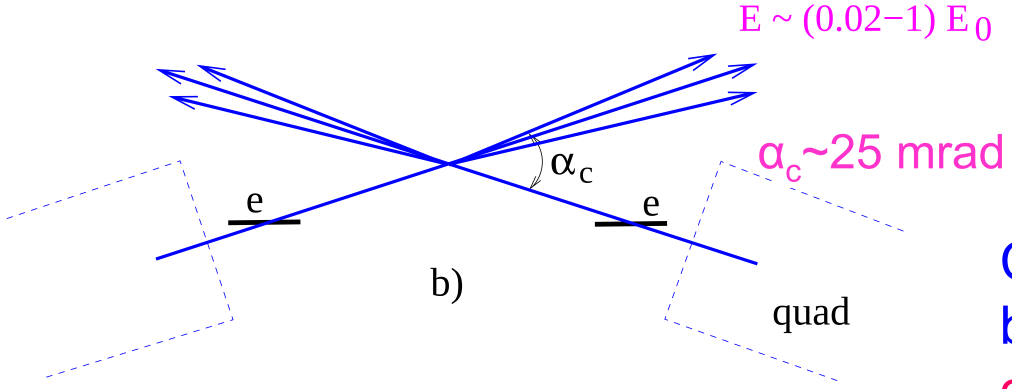
4. Very wide disrupted beam should be transported to the beam dump with acceptable losses; the beam dump should withstand absorption of very narrow photon beam after Compton scattering;

5. The detector design should allow replacement of elements in the forward region (<100 mrad);

Crab-crossing angle



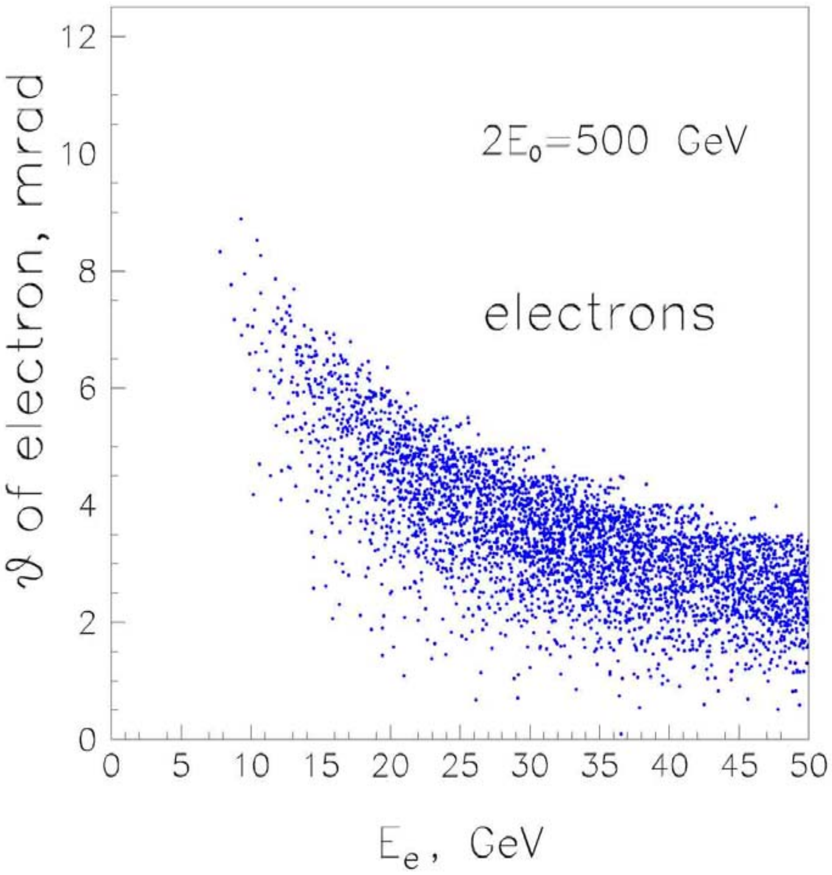
a)



b)

Crossing angle is determined by the angular spread in the disrupted beam and the radius of the first quad

Properties of the beams after CP,IP



Electrons:

E_{min}~6 GeV,
$\theta_{x\ max}$~8 mrad
$\theta_{y\ max}$~10 mrad

practically same for
E_0=100 and 250 GeV

For low energy particles the deflection in the field of opposing beam

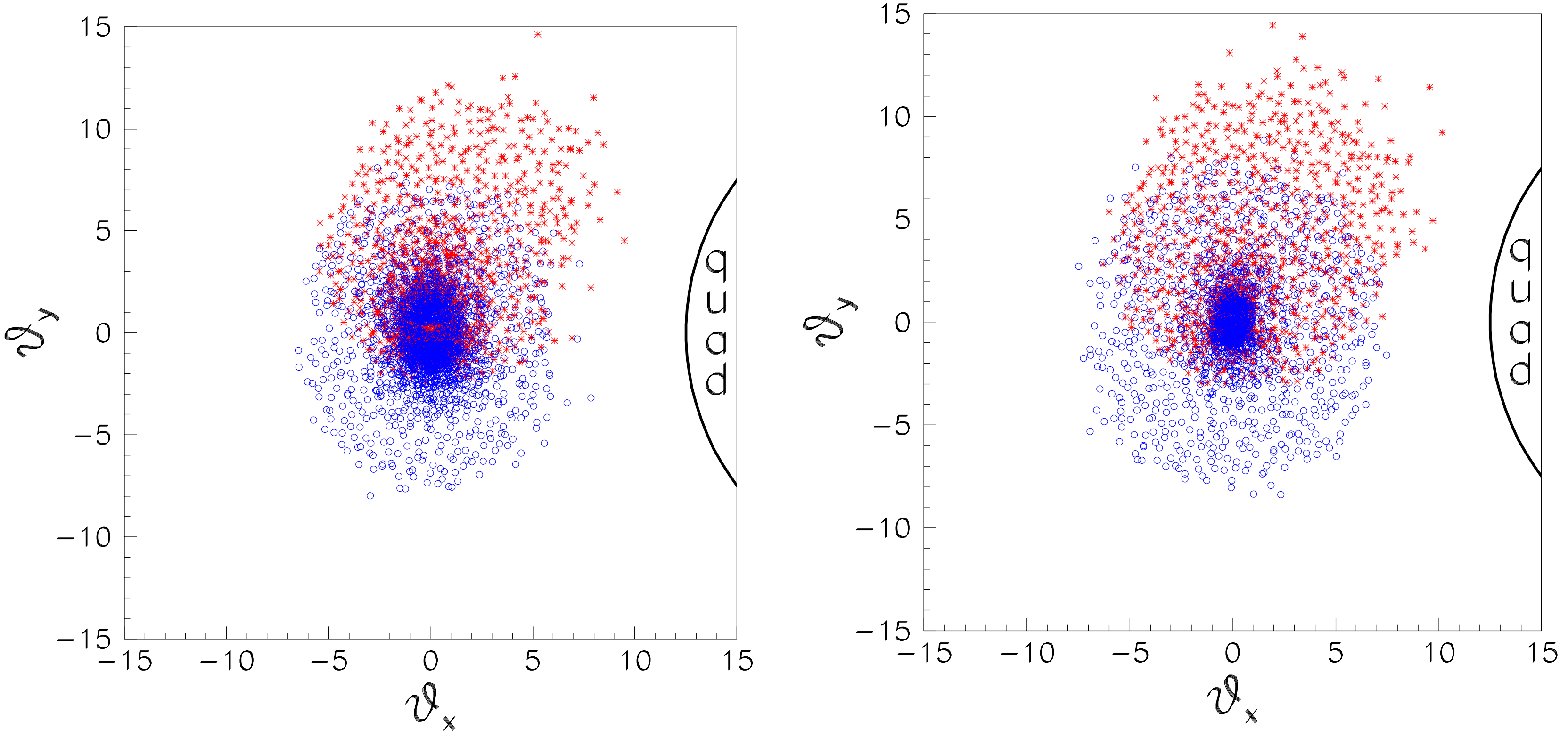
$$\vartheta \propto 1/\sqrt{E\sigma_z}$$

An additional vertical deflection, about ±4 mrad, adds the detector field

$$\alpha_c = (5/400)\ (\text{quad}) + 12.5 \cdot 10^{-3} (\text{beam}) \sim 25\ \text{mrad}$$

Disrupted beam with account of the detector field (at the front of the first quad, L~4 m)

Telnov, Snowmass2005



$2E_0$=200 GeV

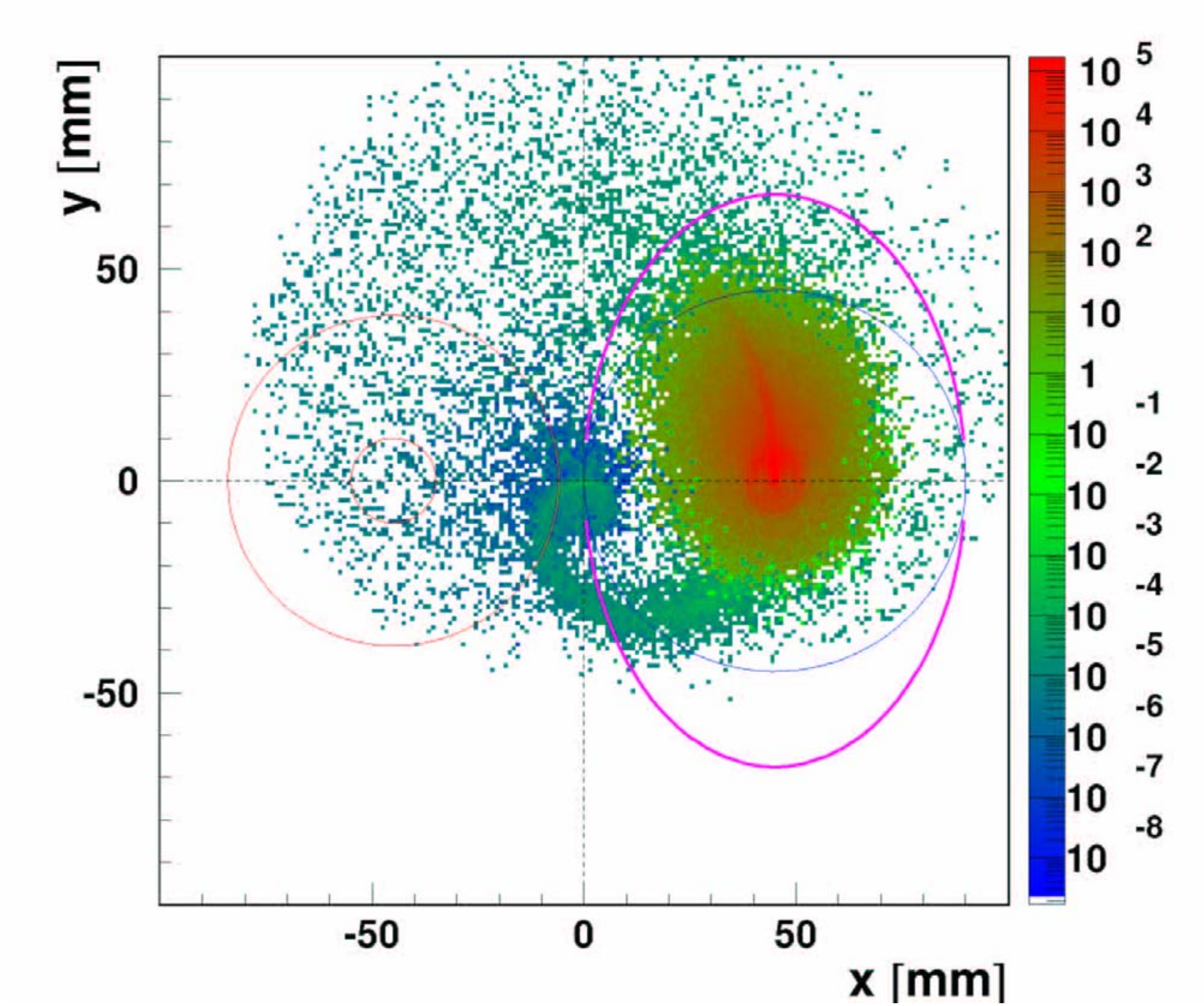
$2E_0$=500 GeV

With account of tails the save beam sizes are larger by about 20 %.

Same with account of secondary e+e- pairs

at L=4.5 m

A.F.Zarnecki, LCWS06



$P_{quad} < 1$ W

Beam dump

V.Telnov, 2005

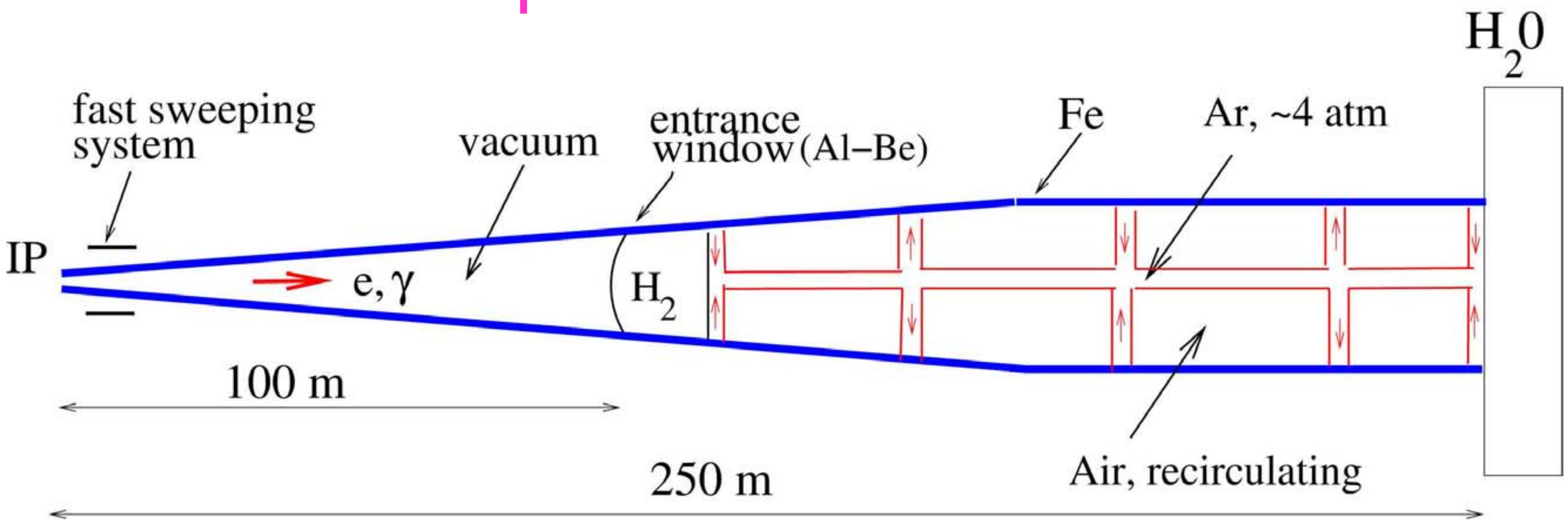
The disrupted beam at the photon collider has

3 components, two are wide and one narrow:

1. e^+,e^- with the angular spread ~10 mrad (need some focusing);
2. beamstrahlung photons with angles up to 3-4 mrad;

   R~1 m at L=250 m from the IP.
3. Compton photons with angles $\sigma_{\theta x}\sim 4\cdot 10^{-5}$ rad, $\sigma_{\theta y}\sim 1.5\cdot 10^{-5}$ rad, that is 1 x 0.35 cm^2 at the distance 250 m. The beam dump should withstand absorption of a very narrow photon beam.

Possible scheme of the beam dump for the photon collider



The photon beam produces a shower in the long gas (Ar) target and its density at the beam dump becomes acceptable.

The electron beam without collisions is also very narrow, its density is reduced by the fast sweeping system. As the result, the thermal load is acceptable everywhere.

The volume with H_2 in front of the gas converter serves for reducing the flux of backward neutrons (simulation gives, at least, factor of 10).

In order to reduce angular spread of disrupted electrons some focusing after the exit from the detector is necessary.

Needs detailed technical consideration!

The photon collider in RDR

Unfortunately, in the RDR (2007) only one IP with 14 mrad crossing angle is assumed with two detectors working in pull-push mode. Driven by a need to reduce the initial ILC cost, the GDE-RDR team considered (in the accelerator book) only e+e- mode (assuming that options can be added later). The layout of IR in RDR is not compatible with the photon collider which needs 25 mrad crossing angle, e.t.c..

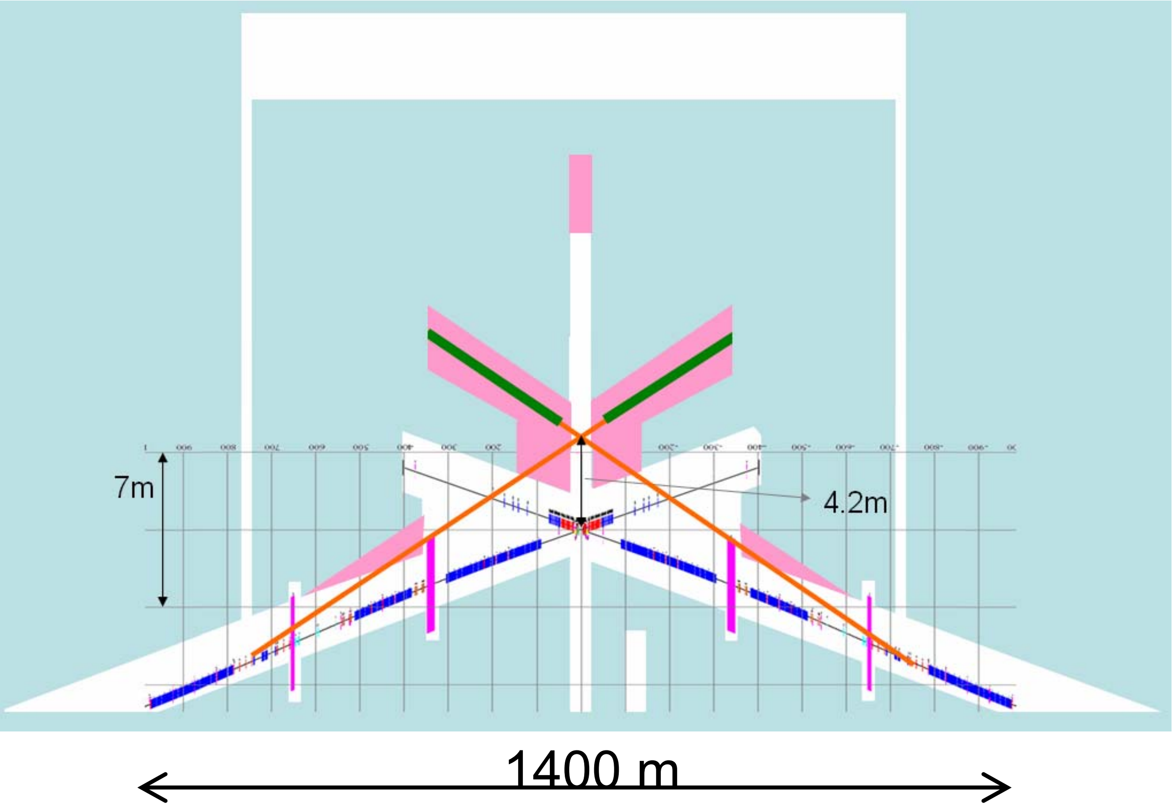
It is obvious that the total cost is minimum when all underground construction works (excavations) are done at once. Moreover, such excavation in the IP region in the middle of the ILC operation will be technologically and politically impossible.

In Sept.2007 at IRENG2007 the GDE has agreed that the ILC Technical Design should include the photon collider. It was decided (promised) to correct the layout of the interaction-region area in order to make it compatible with $\gamma\gamma$ collisions, the underground space will be reserved for an upgrade to the 25 mrad crossing angle.

The scheme of upgrade from 14 to 25 mrad

(just principle, numbers will be changed somewhat)

14mr => 25mr



- additional angle is 5.5mrad and shift of detector by about 3-4 m

Upgrade 14 mr (e^+e^-) to 25 mr ($\gamma\gamma$)

- Tunnel in FF area need to be wider
- For transition from e+e- to $\gamma\gamma$ one should shift the detector by about 0.0055*600=3.3 m as well as to shift 600 m of the upstream beam line or (better) to construct an additional final transformer and doublet. In that case the transition between e+e- and $\gamma\gamma$ modes will be faster.
- Two extra 250 m tunnels for $\gamma\gamma$ beam dump.
- Somewhat wider experimental hall. Different position of shielding walls.

Remark

In principle, one can use the same crossing angle ~25 mrad for e+e- and $\gamma\gamma$, but e+e- people want a special extraction line with beam diagnostic (energy, spectrum, polarization), while $\gamma\gamma$ needs clear way to the beam dump (which is very special). Replacements of beam dumps will be difficult due to the induced radioactivity. So, different crossing angles are even more preferable.

However, it is not clear whether e+e- needs such very instrumented extraction line. There are a lot of diagnostics upstream the IP(energy and polarization) and in the detector (acollinearity angles, e+e- pair), which may be sufficient for reconstruction of beam properties. In addition, one can measure easily beam profiles downstream the IP. Such effects as depolarization during the collision can be accounted by simulation. Replacement of the complicated extraction line by a simpler one will make the ILC will be cheaper, it will be not restriction on the ILC parameters, luminosity can be higher.

This needs further serious study.

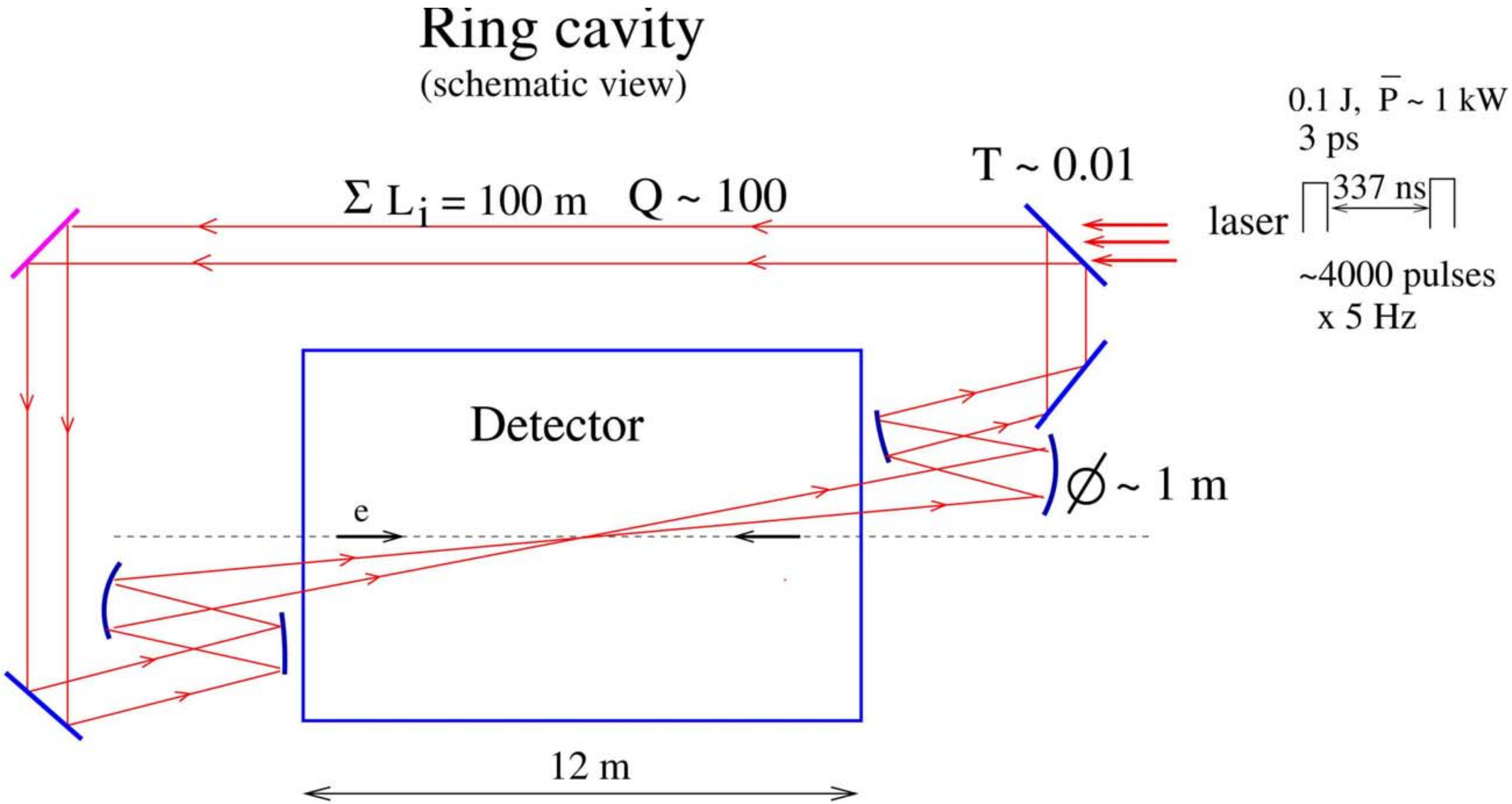
Requirements for laser

Wavelength	~1 μm (good for 2E<0.8 TeV)
Time structure	Δct~100 m, 3000 bunch/train, 5 Hz
Flash energy	~5-10 J
Pulse length	~1-2 ps

If a laser pulse is used only once, the average required power is P~150 kW and the power inside one train is 30 MW! Fortunately, only 10^{-9} part of the laser photons is knocked out in one collision with the electron beam, therefore the laser bunch can be used many times.

The best is the scheme with accumulation of very powerful laser bunch is an external optical cavity. The pulse structure at ILC (3000 bunches in the train with inter-pulse distance ~100 m) is very good for such cavity. It allows to decrease the laser power by a factor of 100-300 (or even more).

Laser system

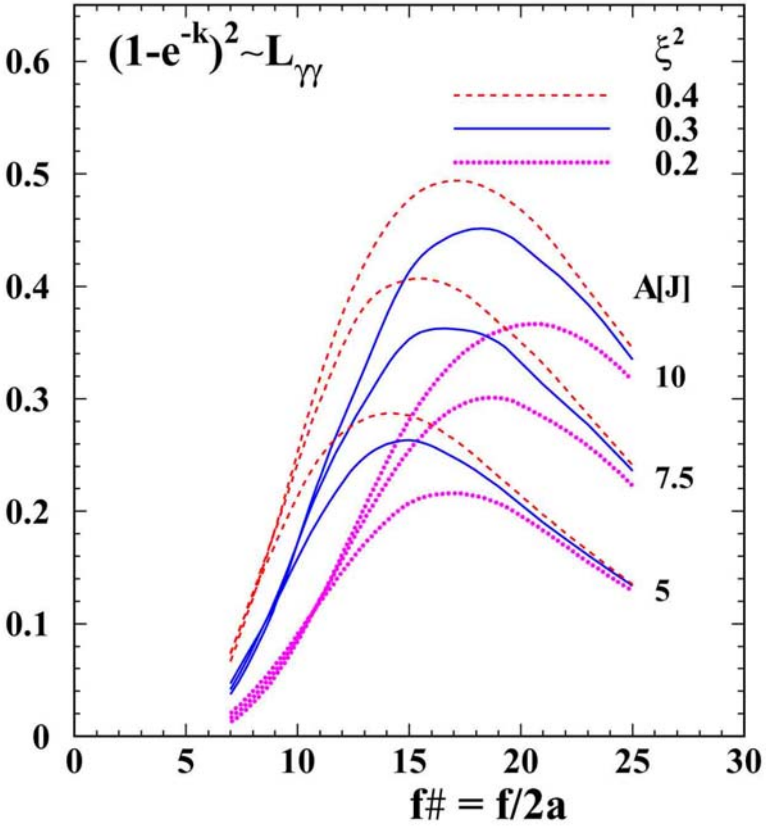


The cavity includes adaptive mirrors and diagnostics. Optimum angular divergence of the laser beam is ±30 mrad, A≈9 J (k=1), $\sigma_t \approx 1.3$ ps, $\sigma_{x,L} \sim 7$ μm

Parameters of the laser system

The figure shows how the conversion efficiency depends on the f# of the laser focusing system for flat top beams in radial and Gaussian in the longitudinal directions

T.V.



f- focal distance
a – mirror radius

The parameter $$\xi^2 = \frac{e^2B^2}{m^2c^2\omega^2} = \frac{2n_\gamma r_e^2\lambda}{\alpha}$$

characterizes the probability of Compton scattering on several laser photons simultaneously, it should be kept below 0.2-0.4, depending on the par. x)

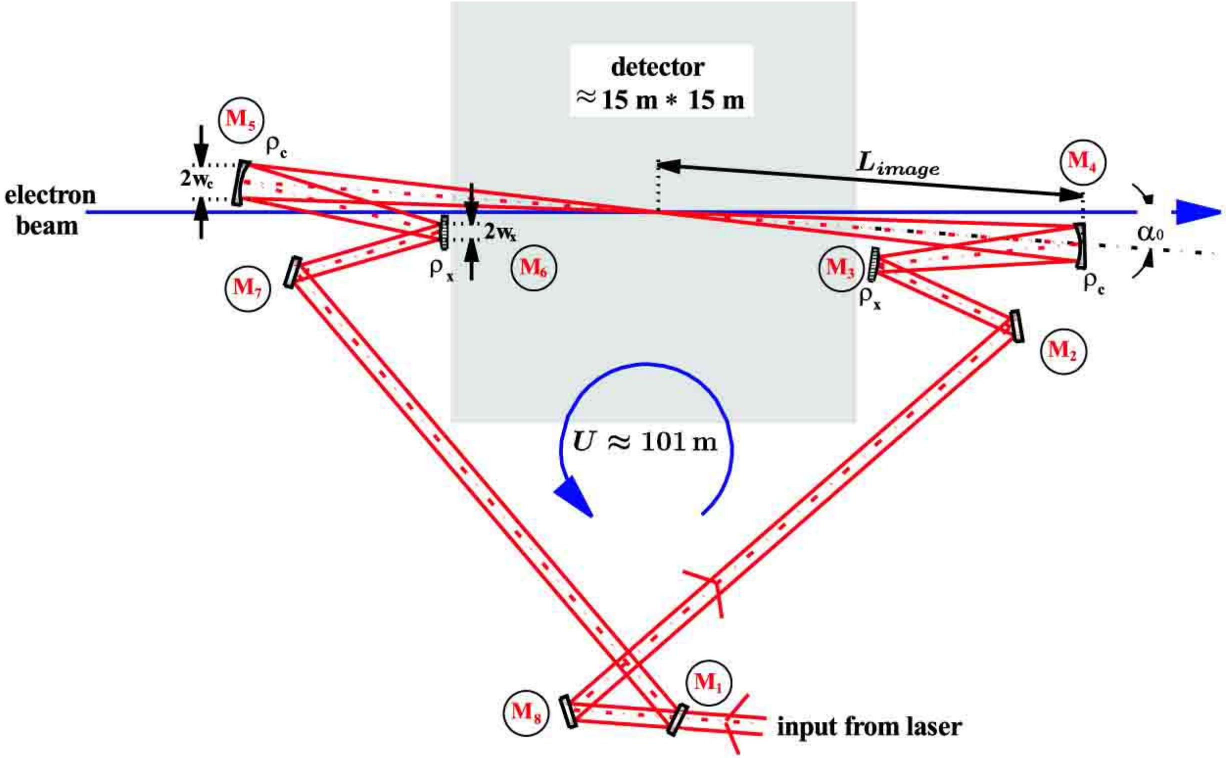
For ILC beams, α_c=25 mrad, and θ_{min}=17 mrad (see fig. with the quad) the optimum $f_\#$ =f/2a ≈ 17, A≈9 J (k=1), σ_t ≈ 1.3 ps, $\sigma_{x,L}$~7 µm.

So, the angle of the laser beam is ±1/2$f_\#$ = ±30 mrad,

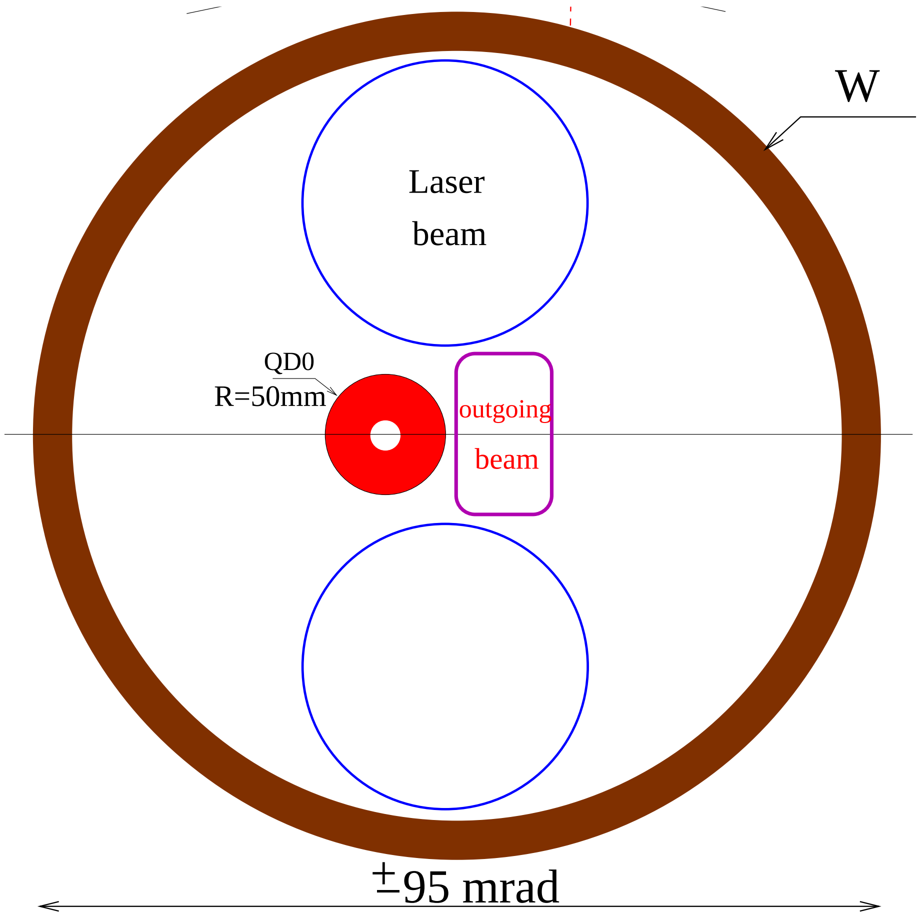
The diameter of the focusing mirror at L=15 m from the IP is about 90 cm.

Simulation of the ring optical cavity in DESY-Zeuthen

Considerations were done at the wave level with account of diffraction losses (which are negligibly small). Obtained numbers are close to that for flat-top beams (shown above).



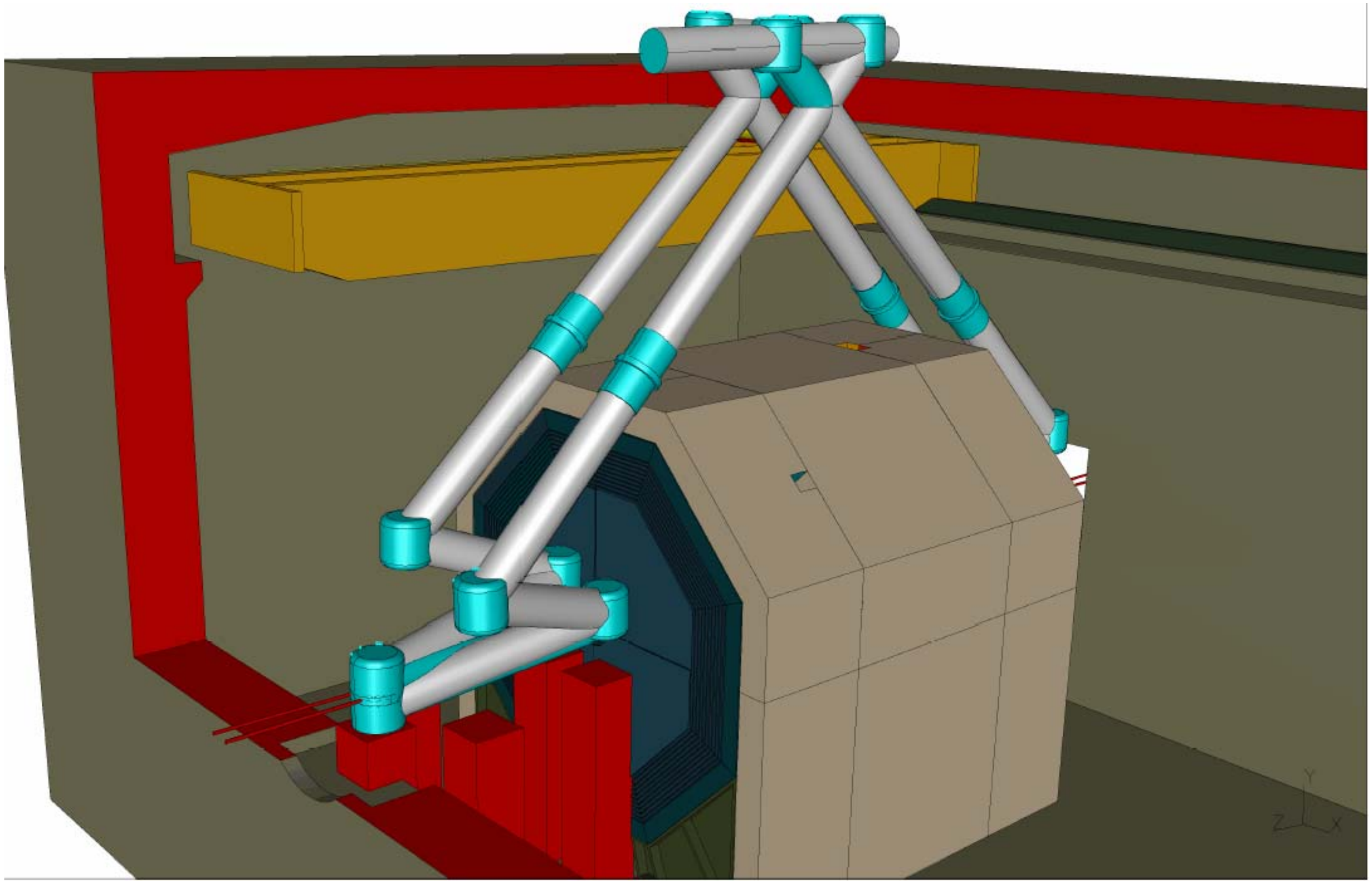
Layout of the quad, electron and laser beams at the distance 4 m from the interaction point (IP)



View of the detector with the laser system

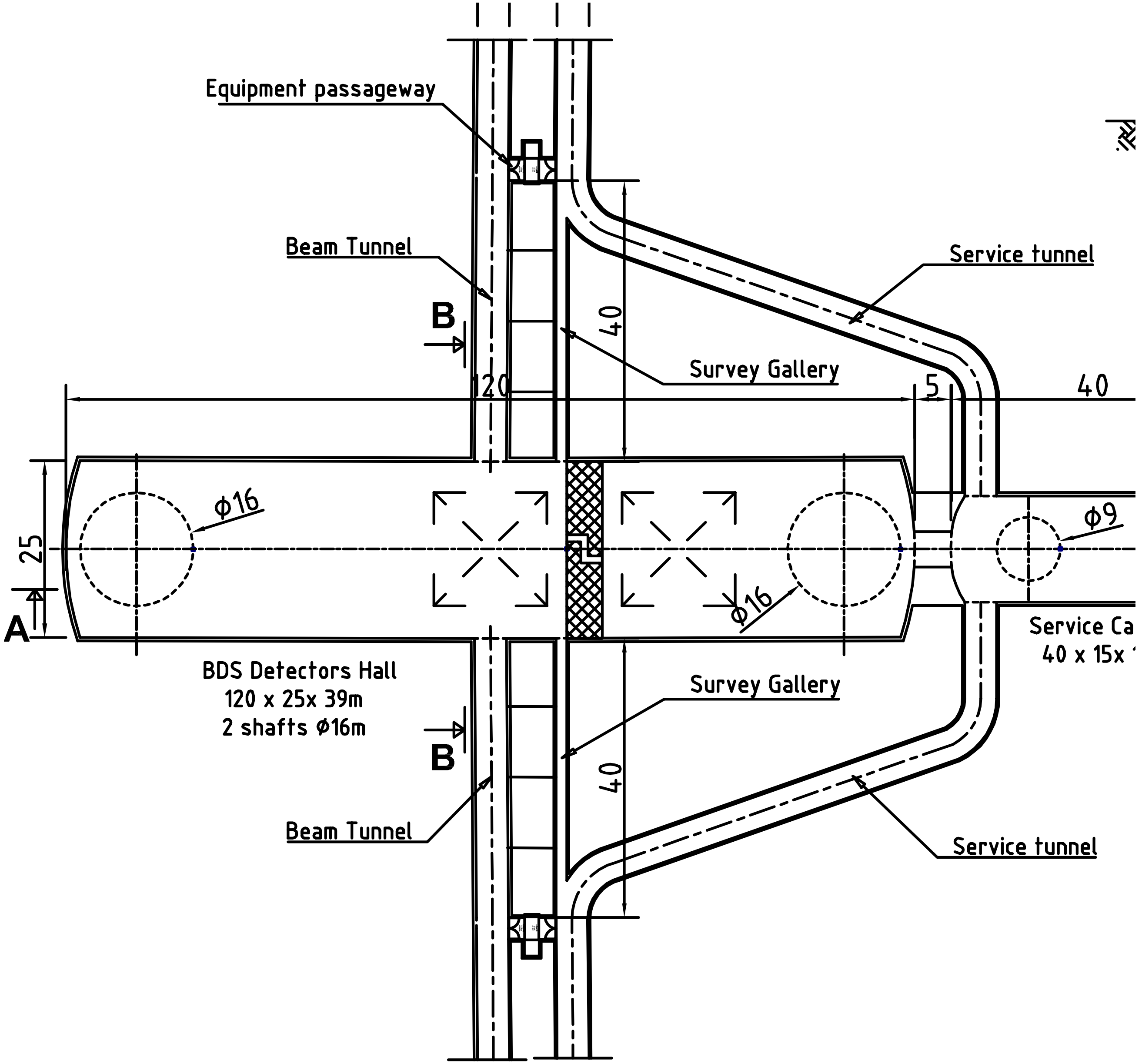
(just the very first approach)

Klemz, Monig…



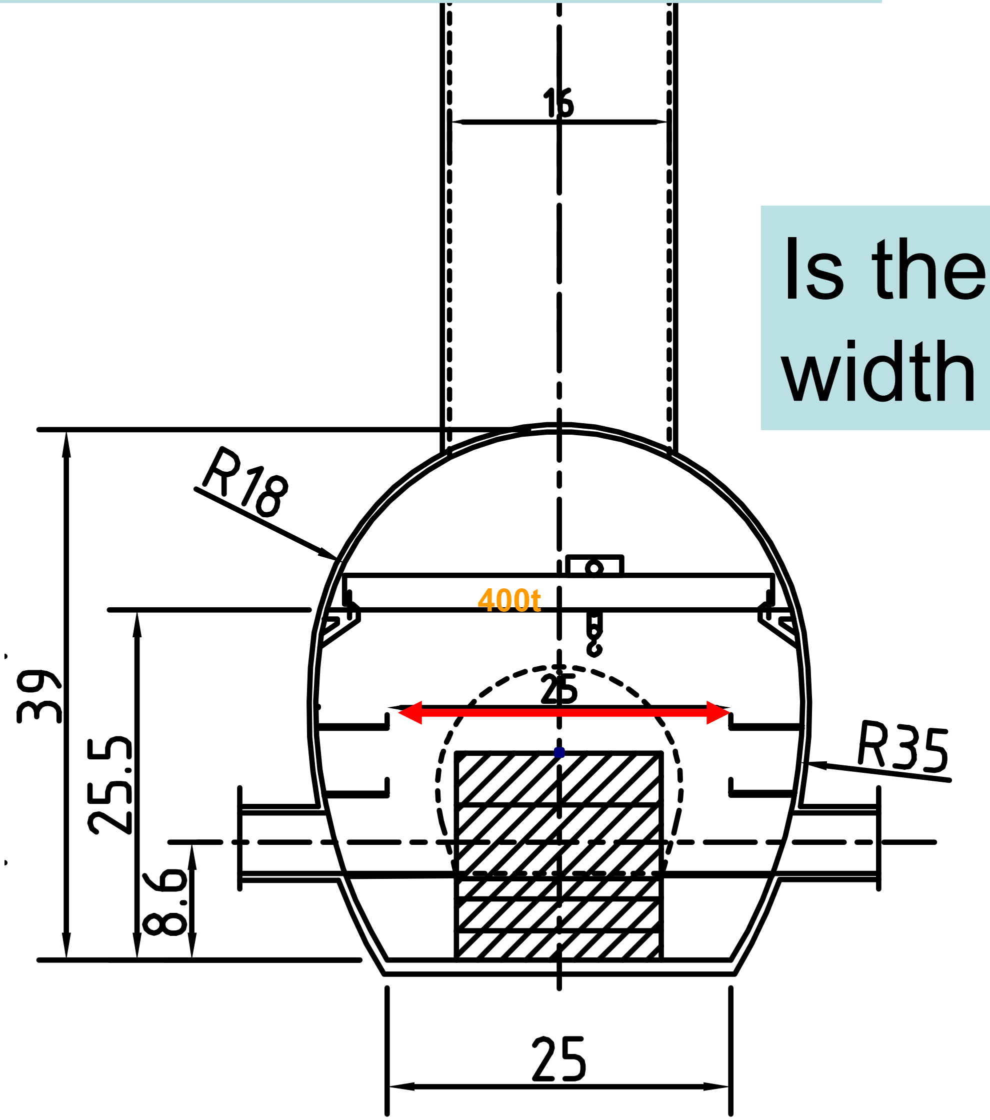
The above scheme does not fit the ILC experimental hall

RDR Baseline Layouts for Interaction Region



RDR Baseline Layouts for Interaction Region

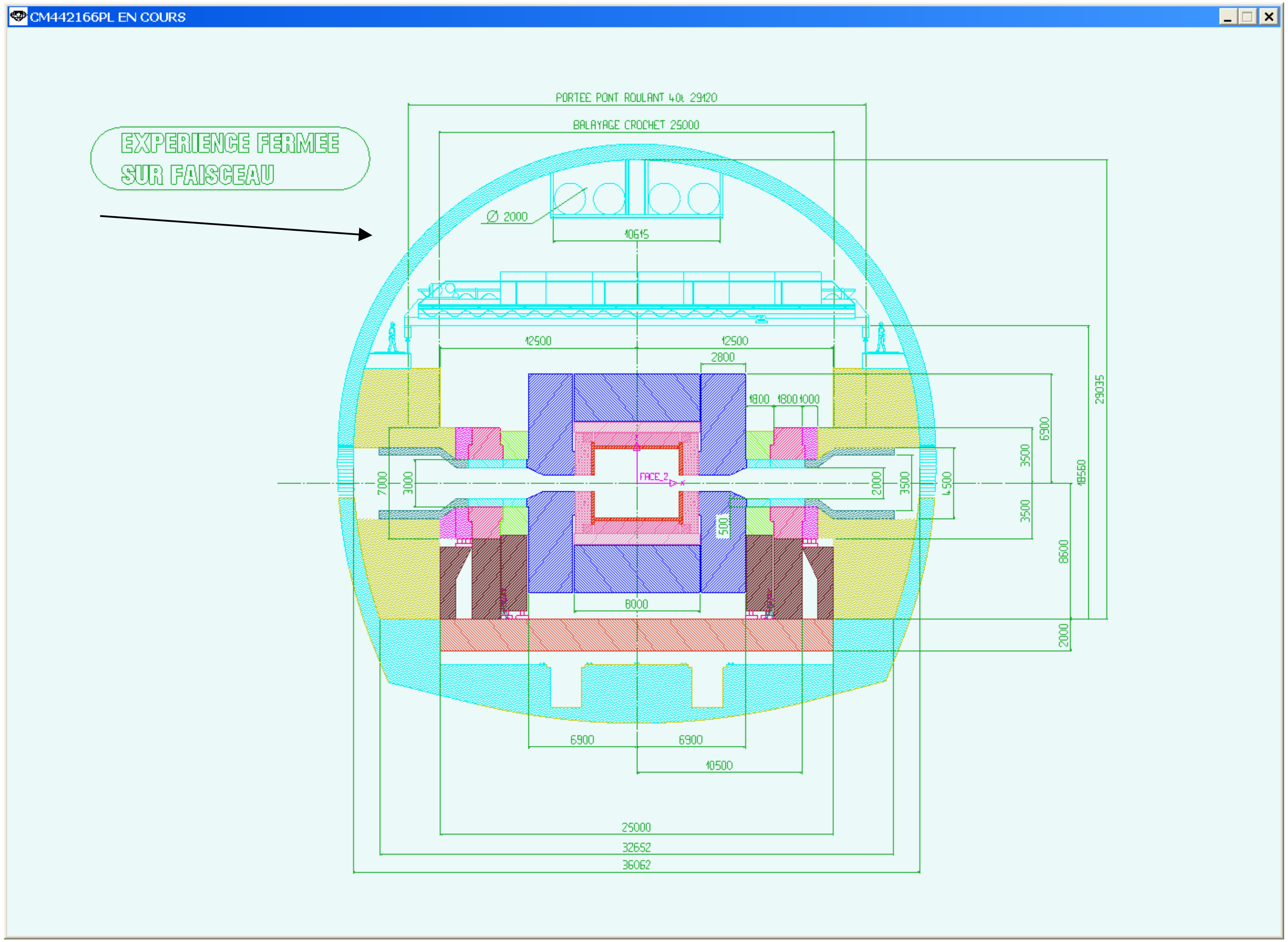
J.Osborne



Is the RDR cavern width enough ?

GLD in beam position

(one of variants)



So, there is not too much space for 100 m optical cavity in the experimental hall. PLC needs also the room near the detector for the laser itself (what size? 10x20 m?)

We need a better understanding of our laser system.
It is a quite urgent task to find a solution for layout of laser optics in the experimental hall and the laser room!

The GDE is waiting for our suggestions.

Laser experts considered requirements to the optical cavity for the photon collider and by now have not revealed any stoppers.

At present there is a very big activity on development of the laser pulse stacking cavities at Orsay, KEK, CERN, BNL, LLNL for

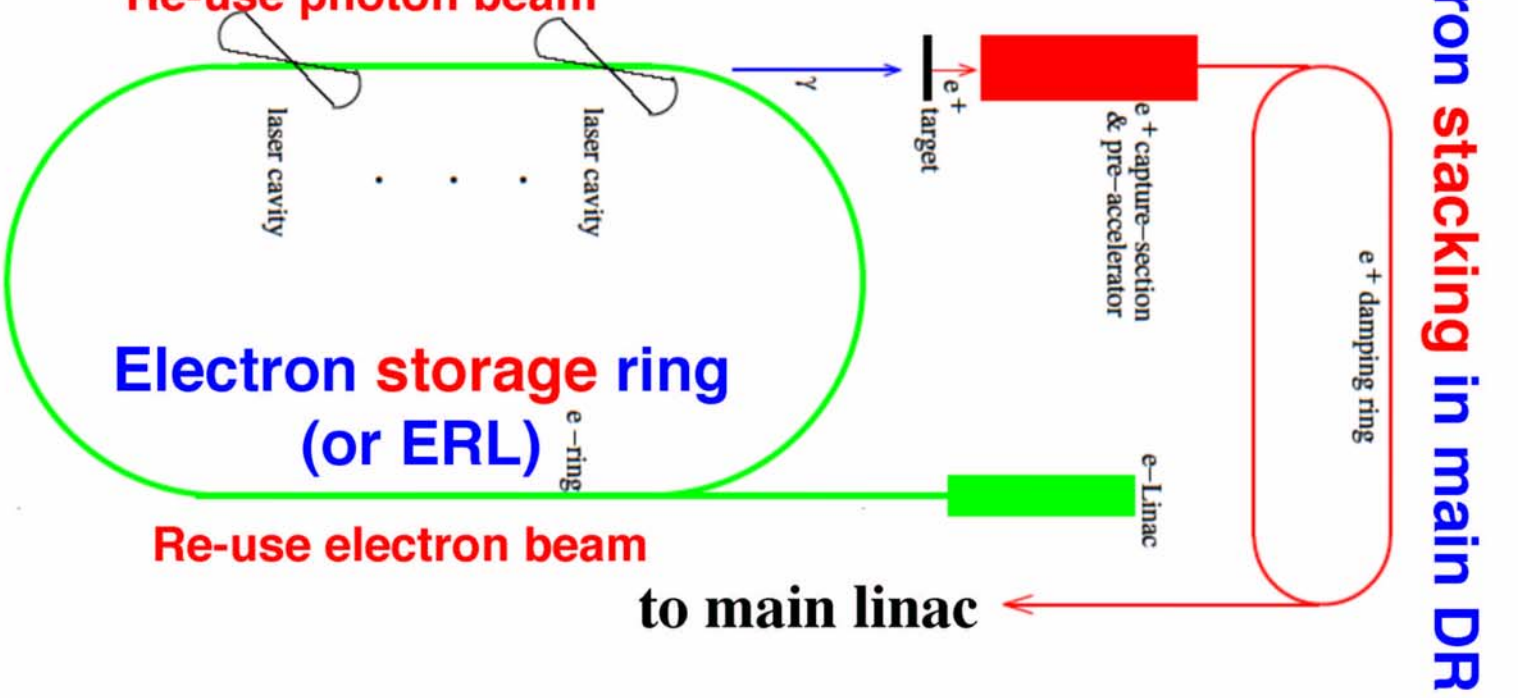
ILC polarimetry
Laser wire
Laser source of polarized positrons(ILC,CLIC,Super-B)
X-ray sources

All these developments are very helpful for the photon collider.

T.Omori

Ring Base Compton (an example)

Re-use Concept



laser pulse stacking optical cavities

Re-use photon beam

Electron storage ring
(or ERL)

Re-use electron beam

to main linac

positron stacking in main DR

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

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

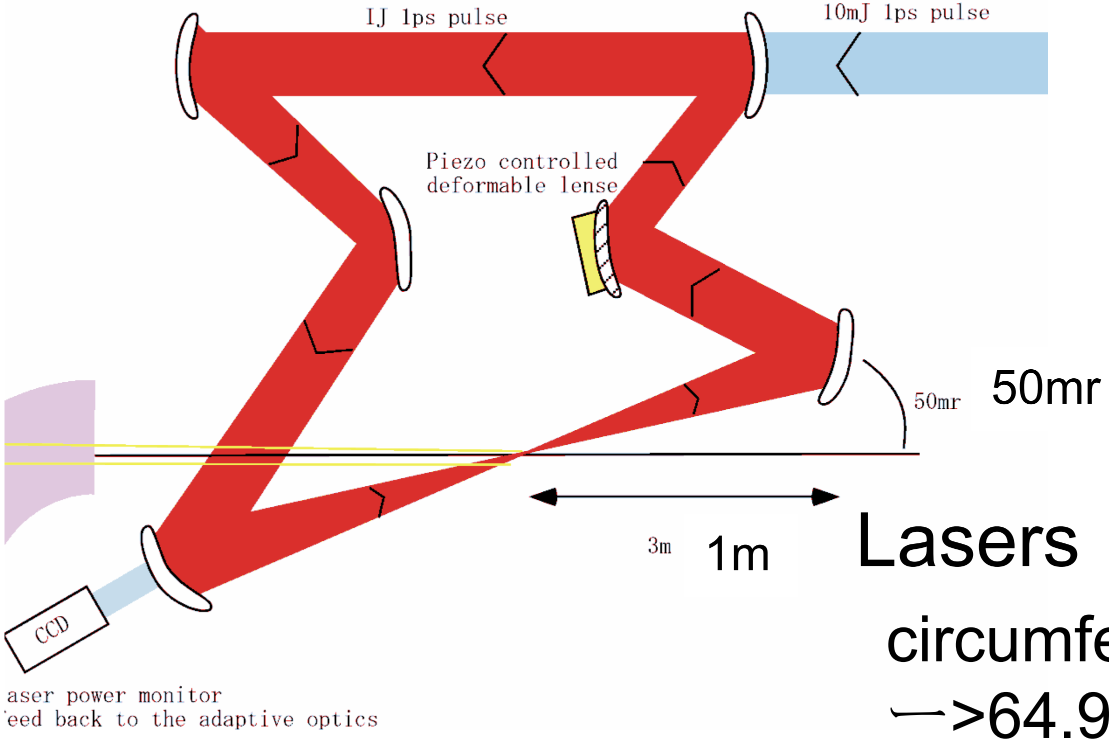
Start with no e^- beam

Later we will make e^- beam compatible cavity

Ring cavity at ATF-DR

-after we learn a lot from PosiPol cavities-

T.Takahashi Hiroshima



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

A laser pulse hits once in 10 turns

Lasers

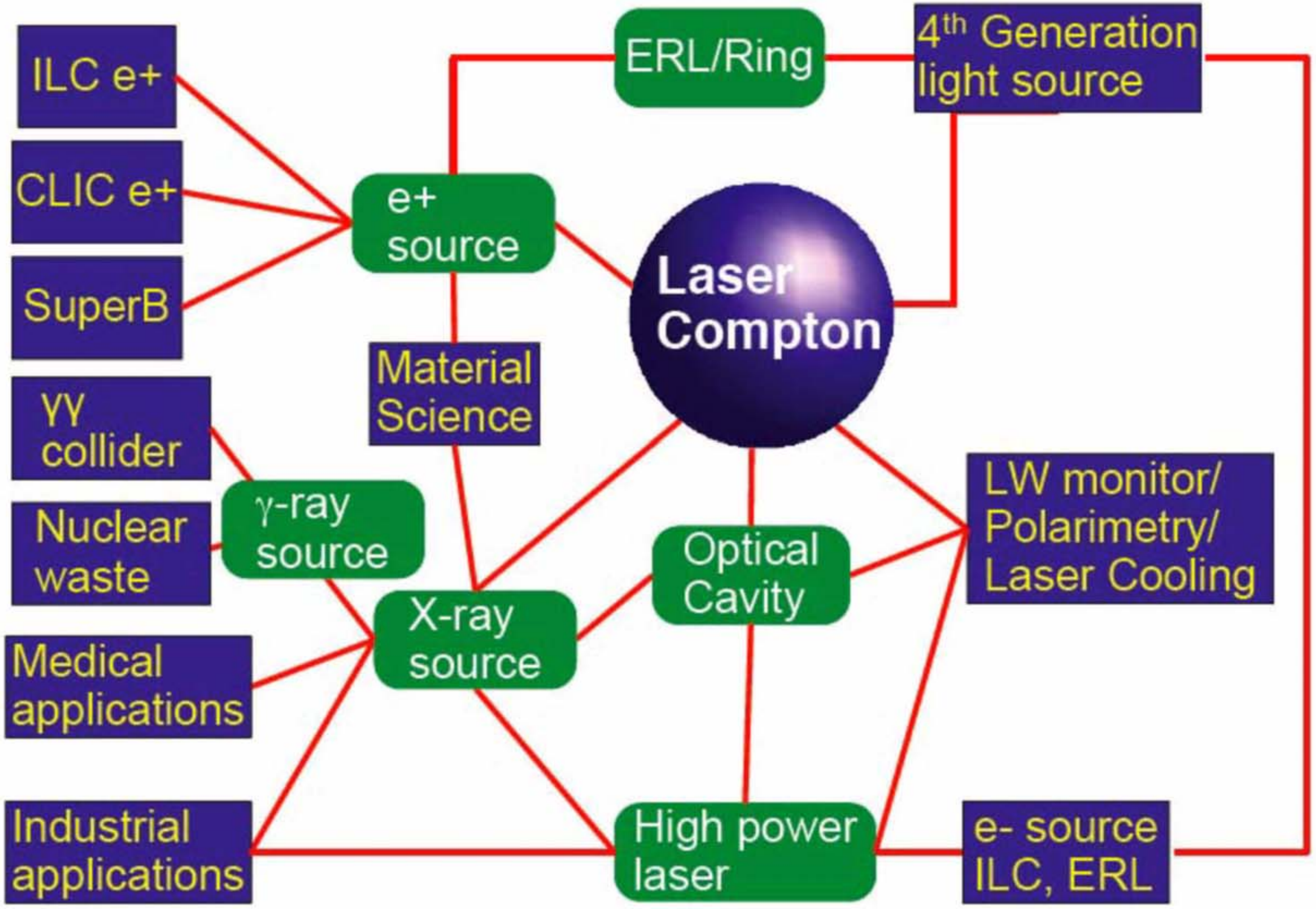
circumference 4.62m (15.4ns)
->64.9MHz

very similar to PosiPol experiment →

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

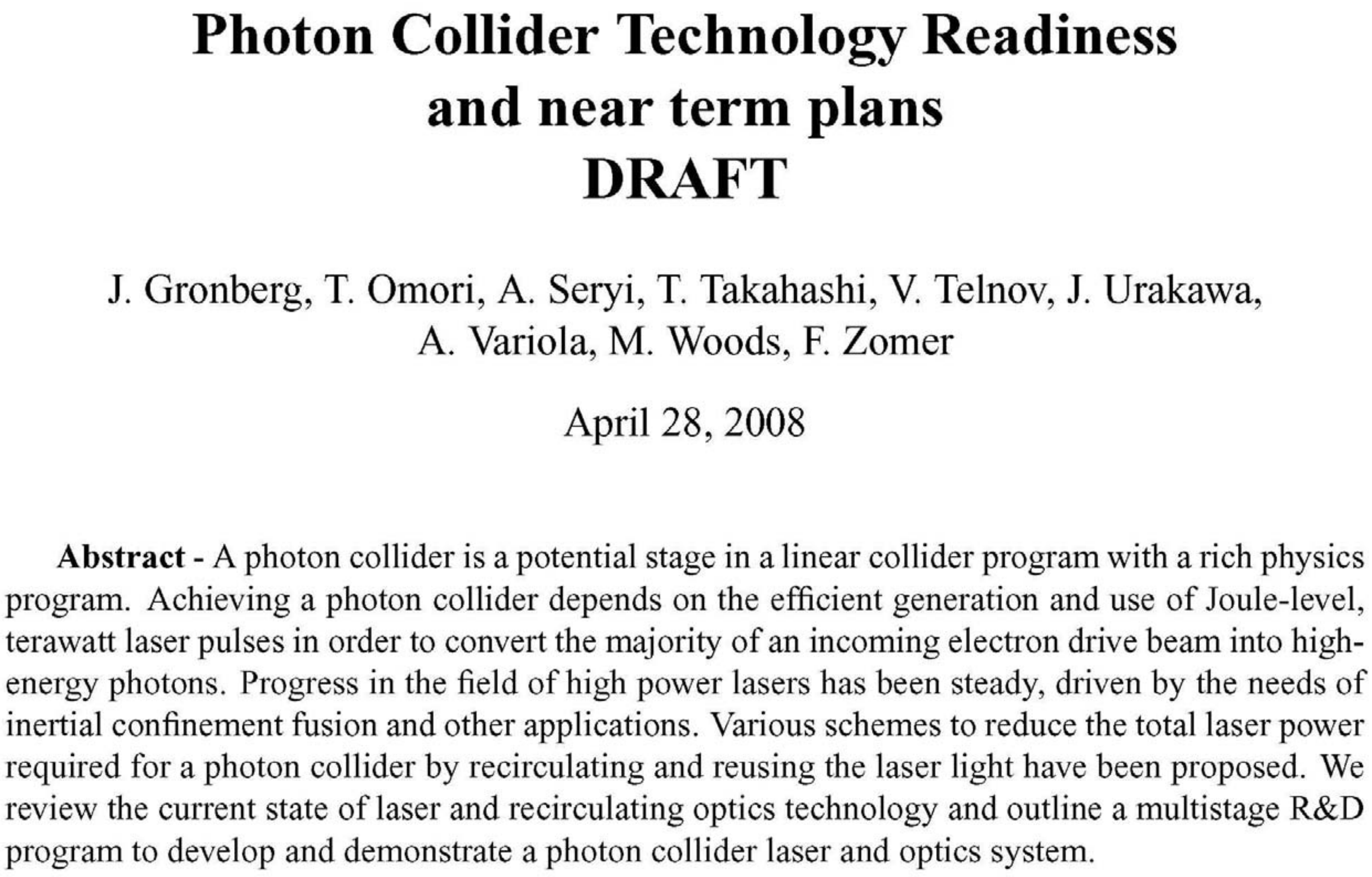
2400γ/xing

World-Wide-Web of Laser Compton



+laser cooling
for PLC factory

Recently we decided to initiate a special R&D of the laser system for the photon collider (and plan to apply for money).



Photon Collider Technology Readiness and near term plans
DRAFT

J. Gronberg, T. Omori, A. Seryi, T. Takahashi, V. Telnov, J. Urakawa,
A. Variola, M. Woods, F. Zomer

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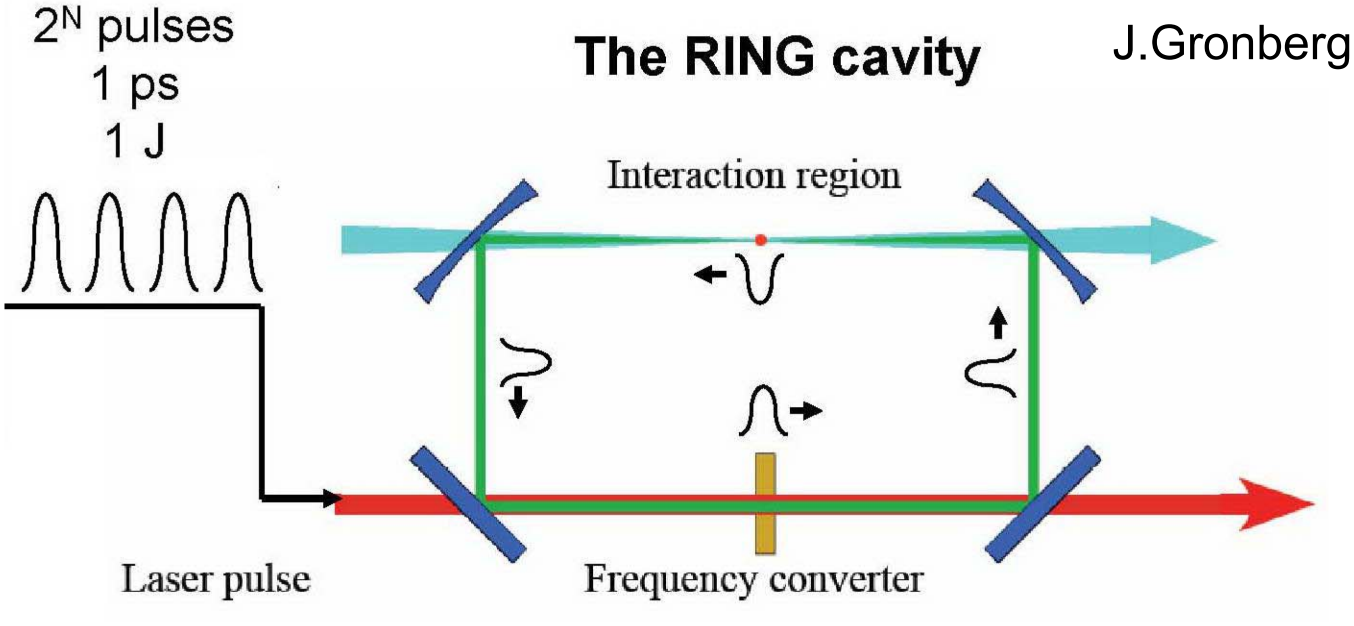
Abstract - A photon collider is a potential stage in a linear collider program with a rich physics program. Achieving a photon collider depends on the efficient generation and use of Joule-level, terawatt laser pulses in order to convert the majority of an incoming electron drive beam into high-energy photons. Progress in the field of high power lasers has been steady, driven by the needs of inertial confinement fusion and other applications. Various schemes to reduce the total laser power required for a photon collider by recirculating and reusing the laser light have been proposed. We review the current state of laser and recirculating optics technology and outline a multistage R&D program to develop and demonstrate a photon collider laser and optics system.

Beside the baseline pulse stacking optical cavity (with a large factor Q>100) also the ring cavity developed at LLNL which just traps the pulse train will be considered (Q~15).

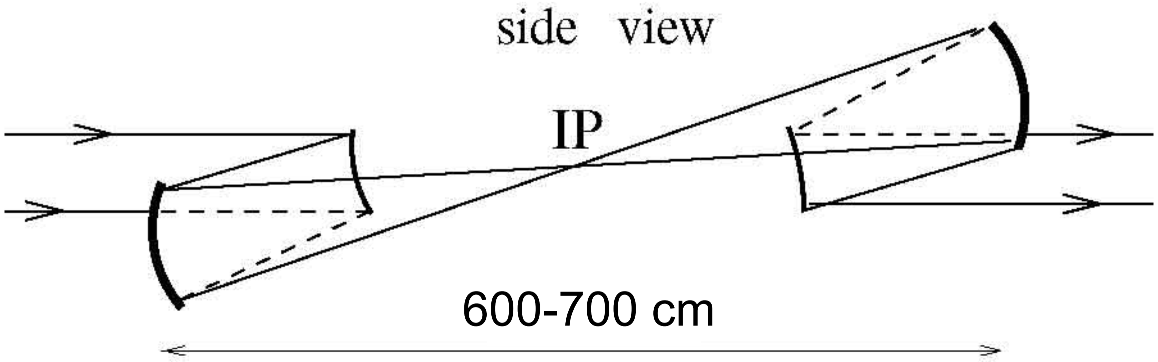


J.Gronberg)

Laser optics and detectors

- If the final mirror is outside the detector at the distance ~15 m from the center, its diameter is about d~90 cm, very large (other mirrors in the loop can be of smaller diameter).
- Laser beams need ±95 mrad hole in the detector, so the detector should have special removable parts in ECAL, HCAL and the yoke.

Another solution: mirrors inside the detector (smaller holes)



There problem is still to be considered.

Next steps on the photon collider

(in the frame of the ILC TDR):

- to make the IR design compatible with the PLC;
- to find an optimum way for transition from 14 to 25 mrad;
- to consider space requirements for the PLC laser system (allocation of the laser optics in and around the detector, space (the room) for the laser);
- to start a preliminary study with detector groups on possible modification of the detector for gamma-gamma (not clear which detector)
- to start the development of the laser system

Conclusion (I)

The physics expected in the 0.1-1 TeV region is very exciting, and the ILC with e+e-, e-e-, $\gamma\gamma$, γe beams would be an unique machine for the study physics in this energy region.

There are no doubts that, if e+e- linear collider is built, the photon collider should be build as well (independently on the physics scenario).

However, at present, there is a tendency to minimize the ILC cost by excluding options or postponing their consideration (and decisions) to far future. This is a mistake. The ILC is the expensive machine, therefore one should fully exploit its potential. Almost doubling the physics program at few % incremental cost is a very good investment which makes the ILC more attractive.

Conclusion (2)

Technical problems of the photon collider and their solutions are well understood at the conceptual level. Further steps need a joint work with the accelerator, MDI and detector groups. However, there are problems:

- the work on the ILC is focused exclusively on the baseline e+e- design;
- the photon collider is not integrated to the ILC organization structure, its status is not well defined;
- there are no PLC representative in the GDE or detector committees;
- there are no financial resources –

all this makes the work on the photon collider very difficult.

The photon collider is developed since 1981 in parallel with e+e-, in the tight international collaboration since 1988. It was always considered as a very natural part of any linear collider. Let us continue together advancement to the our dream !