GG6 summary

Valery Telnov

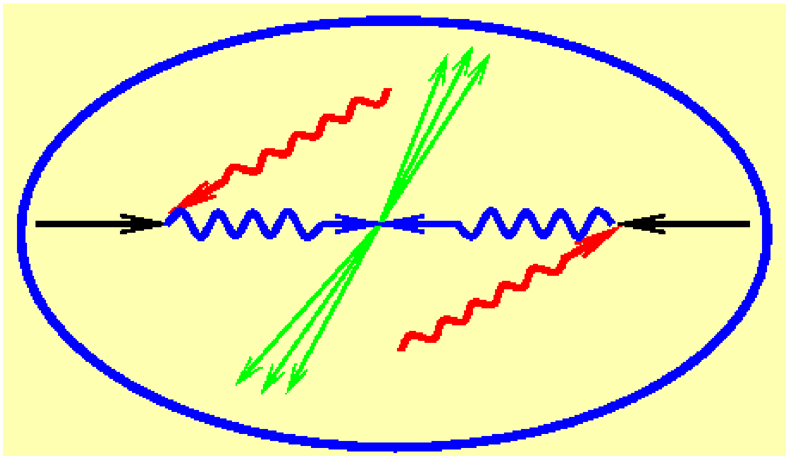
Snowmass, Aug.19, 2005,

Goal of the Global Group GG6

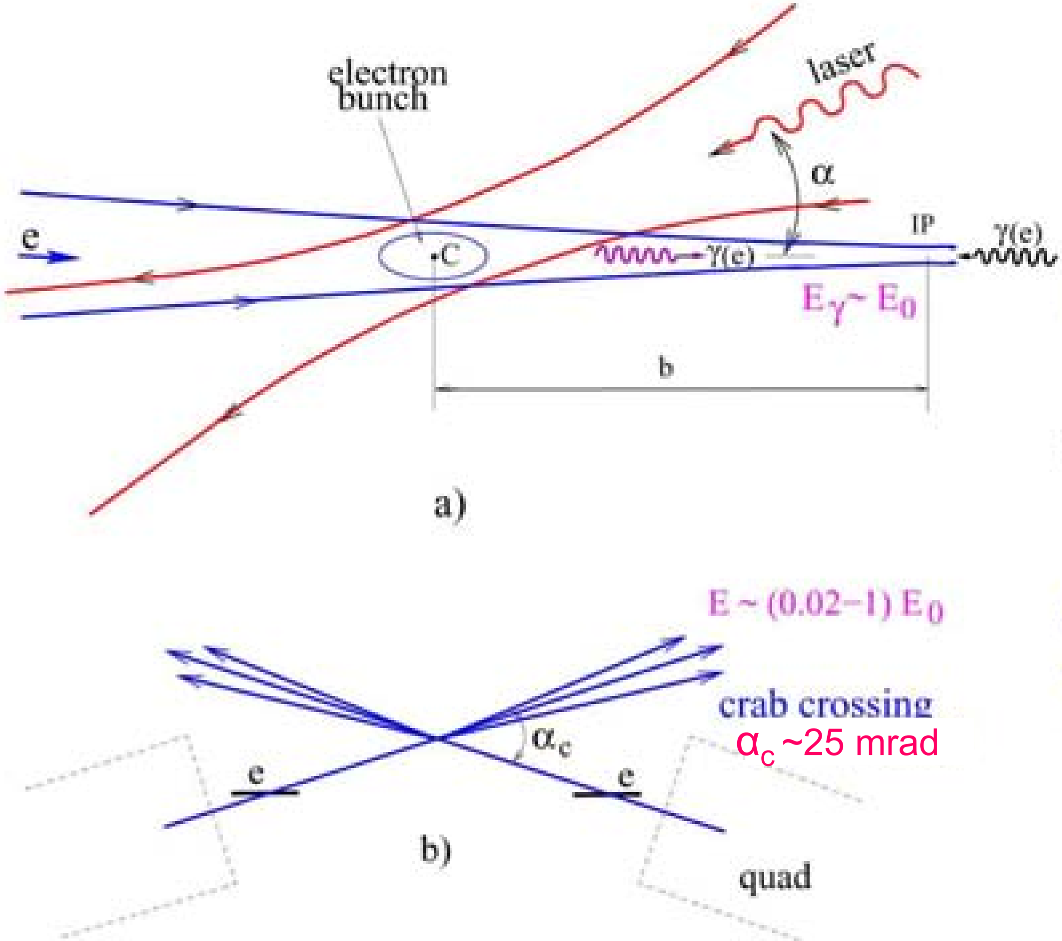
GG6, Options:

Understand requirements and configurational issues related to possible alternatives to e+e- collisions, including $\gamma\gamma$, γe, e-e-, GigaZ and fixed target; identify potential performance parameters.

Photon Collider at ILC



Scheme of $\gamma\gamma$, γe collider



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

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

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

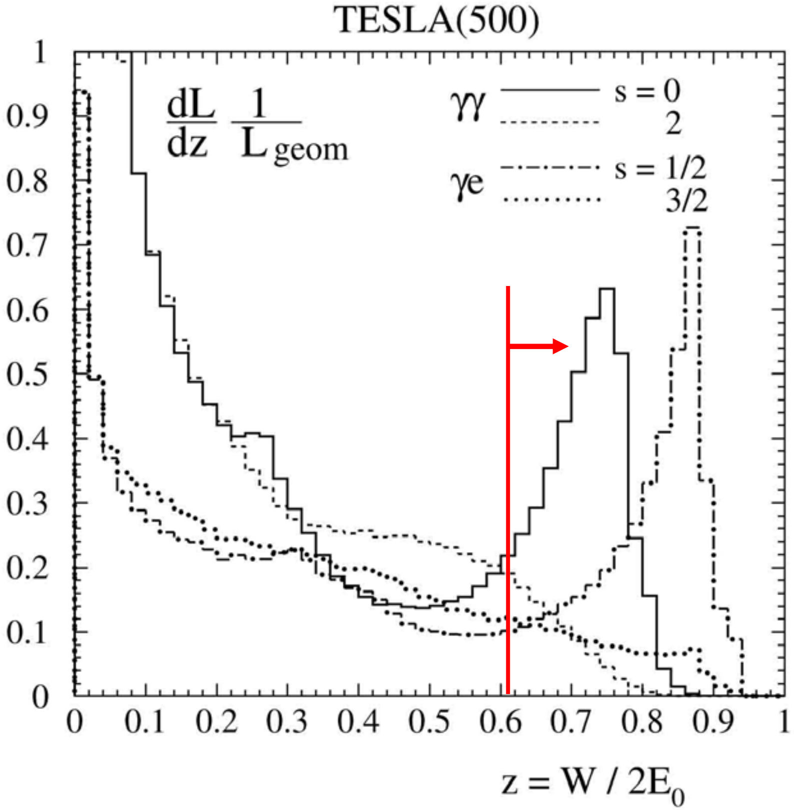
$x = 4.8$ is the threshold for
$\gamma\gamma_L \to e^+e^-$ at conv. reg.

ω_{max}~0.8 E_0

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

Luminosity spectra

(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 ILC conditions

$L_{\gamma\gamma}(z>z_m)$ ~(0.17-0.55) L_{e+e-}(nom)

(but cross sections in γγ are larger by one order!)

First number - nominal beam emittances

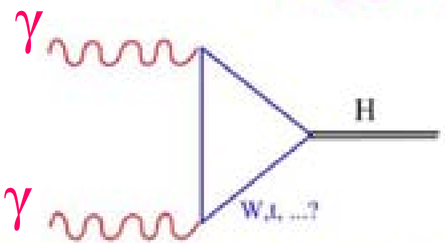
Second - optimistic emittances

(possible, needs optimization of DR for γγ)

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

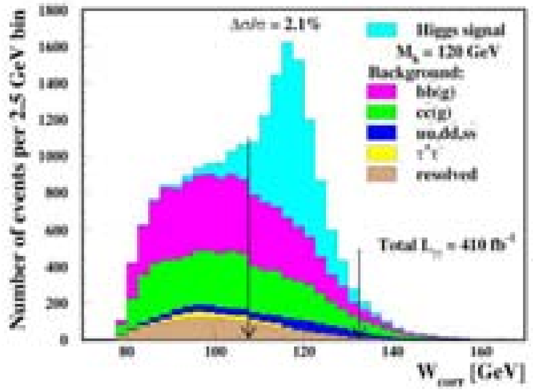
Some examples of physics

Higgs boson

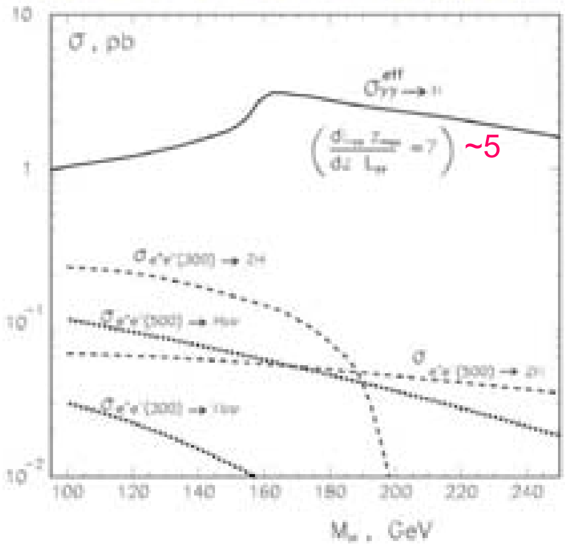


Very sensitive to heavy charge particles in the loop.

realistic simulation P.Niezurawski



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



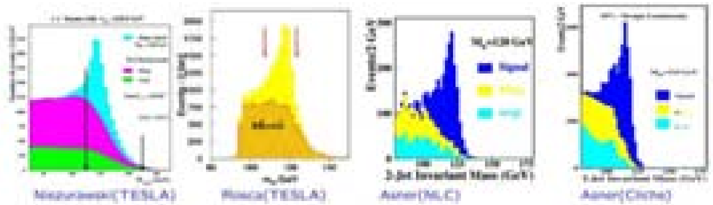
$$\dot{N}_{\gamma\gamma\to H} = L_{\gamma\gamma} \times \frac{dL_{\gamma\gamma} M_H}{dW_{\gamma\gamma} L_{\gamma\gamma}} \frac{4\pi^2 \Gamma_{\gamma\gamma}(1+\lambda_1\lambda_2)}{M_H^3}$$

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)

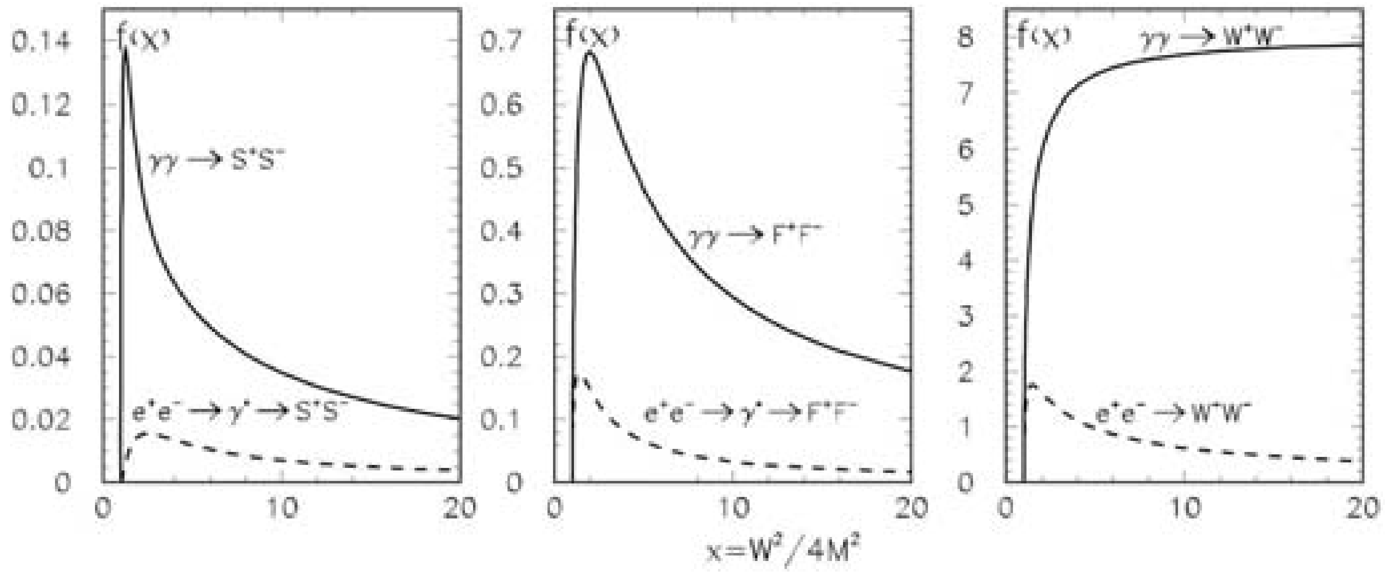


Some examples of Physics

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

With polarized photon beams the difference is even larger.

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

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.

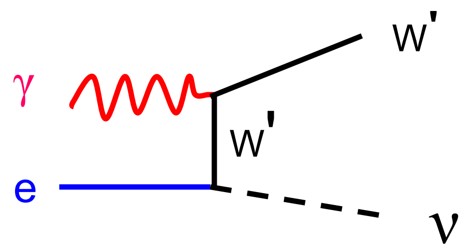
$M_H \approx M_A$, in e$^+$e$^-$ collisions H and A are produced in pairs (for certain param. region), while in $\gamma\gamma$ as the single resonances, therefore:

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

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^-

- the energy is smaller only by 10-20%
- the number of events is similar or even larger
- access to higher particle masses
- higher precision for some phenomena
- different type of reactions

Special requirements for the photon collider

1. For removal of the disrupted beams the crossing angle at one of the interaction regions should be about 25 mrad (the exact number depends on the final quad design); the quad's fringe field should not scatter the outgoing low energy beam; WG4

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); WG3b

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); WG4

4. Very wide disrupted beam should be transported to the beam dump with acceptable losses; WG4
   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); Detec.

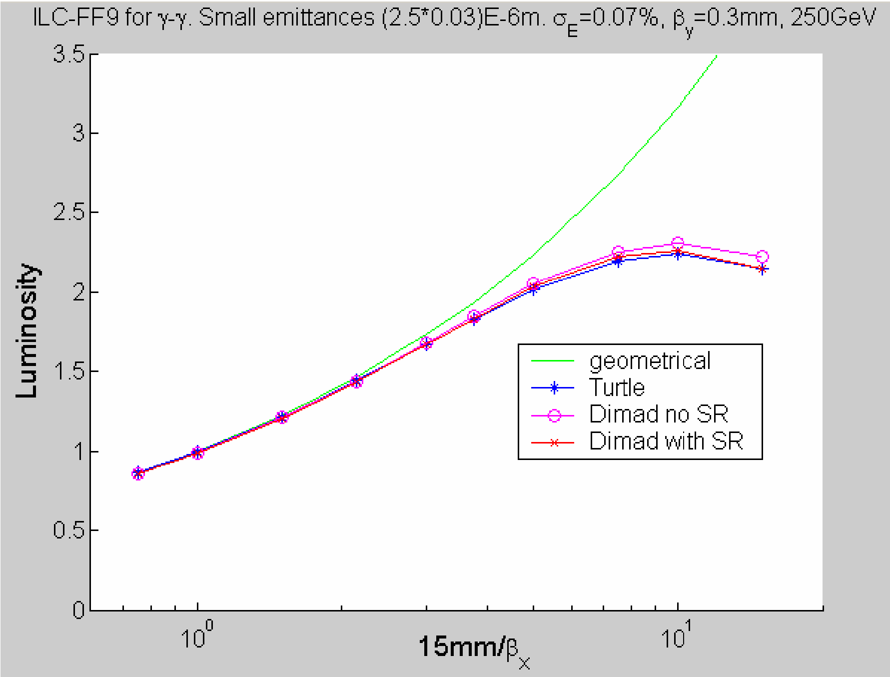
6. A space for laser beam lines and housing is needed.

β-functions

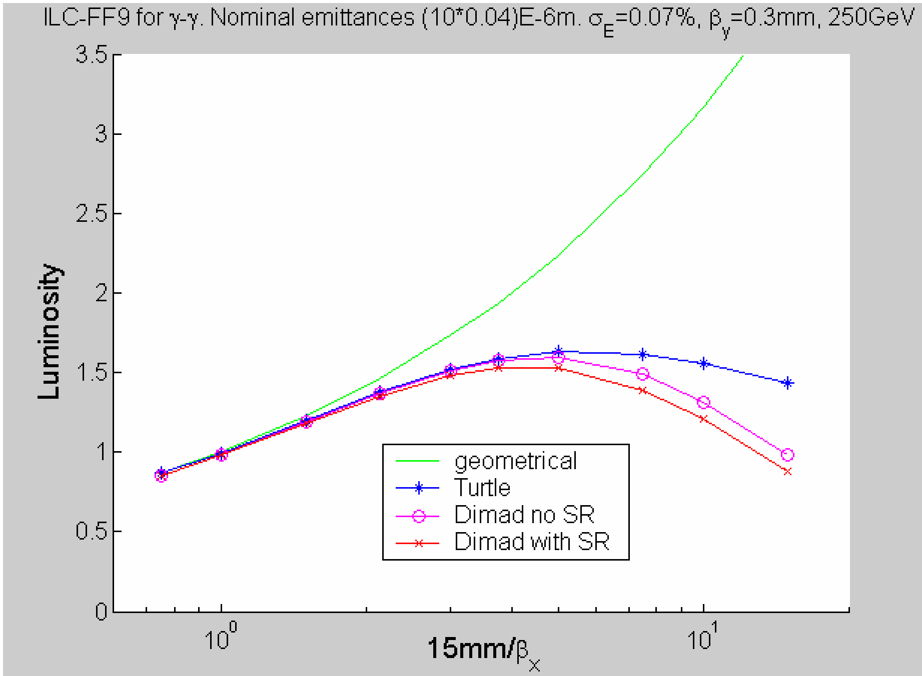
There is no problems to make $\beta_y = \sigma_z$ or even several times smaller, but there is a problem with reducing β_x due to chromo-geometric abberations.

Minimum value of β_x depends on the emittances (A.Seryi).

$\varepsilon_{nx} = 0.25 \cdot 10^{-6}$ m $\Rightarrow \beta_x^{eff} \sim 2.2$ mm



$\varepsilon_{nx} = 1 \cdot 10^{-6}$ m $\Rightarrow \beta_x^{eff} \sim 5$ mm
nominal



Emittances

Nominal ILC emittances (T.Raubemheimer table)

$\varepsilon_{nx}=10^{-5}$ m·rad, $\varepsilon_{ny}=4\ x10^{-8}$ m·rad. Smaller emittances are not needed for *e+e-* due to beam-beam collision effects (beamstrahlung and instability).

For such emittances the minimum effective $\beta_x \sim 5$ mm (A.Seryi)

With TESLA damping ring optimized for $\gamma\gamma$ (W.Decking) we had at the IP $\varepsilon_{nx}=0.25x10^{-5}$ m·rad, $\varepsilon_{ny}=3x10^{-8}$ m·rad and min. effective $\beta_x \sim 2.2$ mm. Similar emittances reported S.Mishra at LCWS04. With such emittances the geometric e^-e^- luminosity is larger than with the nominal ILC parameters by a factor of 3.5!

This is a large factor. It is desirable to decrease emittances, especially ε_{nx} , as much as it is possible

According to A. Wolski, such reduction of emittances in damping rings is possible by adding more wigglers (smaller damping time suppresses intra-beam scattering), but this possibility needs more detailed consideration.

Comparison of $L_{\gamma\gamma}$ and L_{e+e-}

At the nominal ILC parameters $L_{e+e-}=2\cdot10^{34}$ cm^{-2}c^{-1}. For same parameters, CP-IP distance b=1 mm and $t/\lambda_c=1$ $L_{\gamma\gamma}(z>0.8z_m)=3.4\cdot10^{33}$ or

$$L_{\gamma\gamma} / L_{e+e-} = 0.17$$

If one reduces somewhat emittances:

$\varepsilon_{nx}=10^{-5} \rightarrow 0.5\cdot10^{-5}$; $\varepsilon_{ny}=4\ 10^{-8} \rightarrow 3\cdot10^{-8}$ and $\beta_x=5 \rightarrow 3.7$ mm

then $L_{\gamma\gamma} / L_{e+e-} = 0.32$ (0.3 in TESLA TDR).

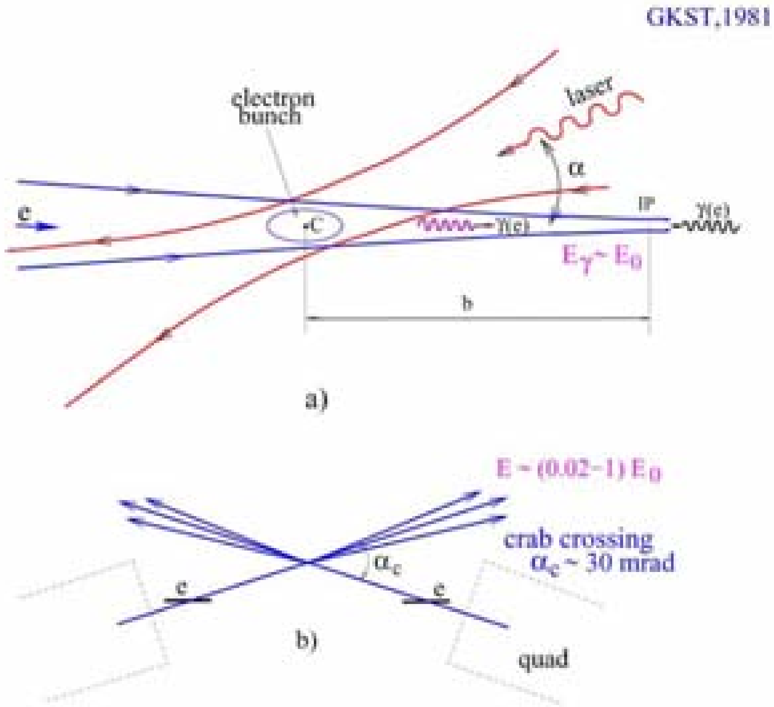
Optimistically, $\varepsilon_{nx}=10^{-5} \rightarrow 0.25\cdot10^{-5}$ ($\beta_x=5 \rightarrow 2.2$ mm)

then $L_{\gamma\gamma} / L_{e+e-} = 0.59$

Note, cross section in $\gamma\gamma$ are larger then in e+e- by a factor of 10.

So, even in the worst (nominal) case the number of events in $\gamma\gamma$ collisions is larger than that in e+e-, but it seems possible to increase the $\gamma\gamma$ luminosity by the additional factor 2 - 3.5.

Collision angle, crab-crossing scheme



After the collision the beams have a large energy spread: $E \sim (0.02-1)E_0$ and disruption angles $\theta_d \sim$ 10-12 mrad (the background from particles with larger angle is less than from unavoidable backgrounds).

The removal of disrupted beams need large crab-crossing angle:

$\alpha_c \sim R_{quad}/L^* + \theta_d$

$\sim 6/400 + 0.01 \sim 25$ mrad.

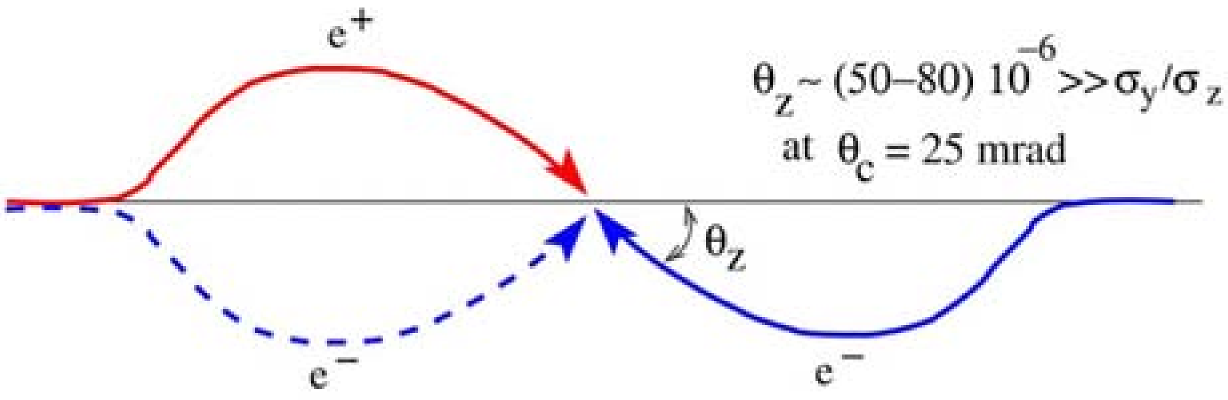
(For e^+e^- $\alpha_c = 20$ mrad is one of possible options.)

It is very desirable to have the crossing compatible with both collision modes, i.e. ≥ 25 mrads.

There are several problem due to crossing angle:

- Due to the detector field e^-e^- beam collide at a non-zero (unacceptably large) vertical collision angle;
- The increase of the vertical beam size due to radiation in the detector field;
- The “big bend” length depends strongly on the bending angle;
- The additional vertical deflection for low energy particles

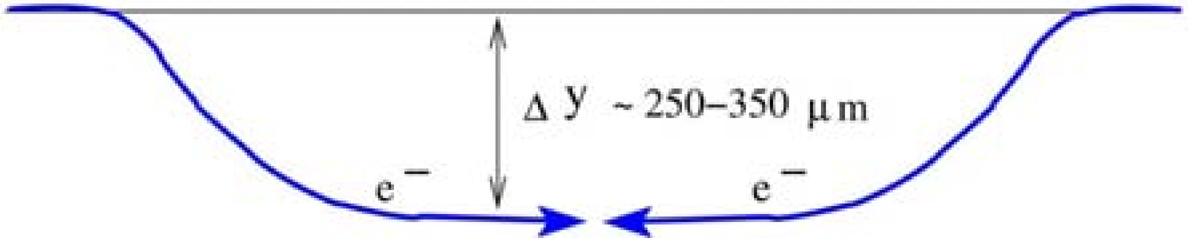
Trajectories in the detector field at $\alpha_c \neq 0$



OK for e+e−, but not OK for e−e−(gamma−gamma)

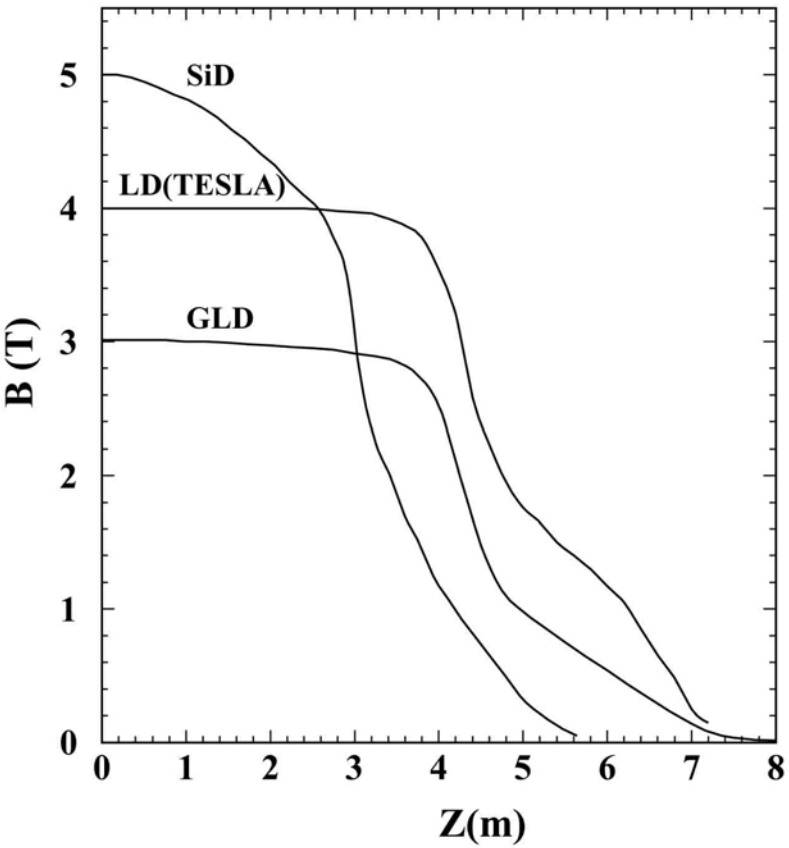
Vertical shifts of final qurds helps
for e−e−(γγ)

(or using correcting dipole coils)



Increase of σ_y due to SR

Detector field at the axis



Deflecting force which causes SR

$$F_y = e\frac{v}{c}(-B_z\,\theta_0 + B_r) = -e\frac{v}{c}\,\theta_0\left(B_z + \frac{\partial B_z}{\partial z}\,\frac{z}{2}\right).$$

where $\theta_0=\alpha_c/2$

Influence of SR on luminosity was found by full simulation

(V.Telnov, physics/0507134)

Results on $L(\alpha_c)/L(0)$

e^+e^- collisions

α_c(mrad)	0	20	25	30	35	40
LD	1.	0.98	0.95	0.88	0.83	0.76
SID	1.	0.995	0.985	0.98	0.95	0.91
GLD	1.	0.995	0.98	0.97	0.94	0.925

$\gamma\gamma$ collisions

α_c(mrad)	0	20	25	30	35	40
LD	1	0.99	0.96	0.925	0.86	0.79
SID	1	0.99	0.975	0.955	0.91	0.86
GLD	1	0.995	0.985	0.98	0.97	0.93

Statistical accuracy about $\pm 0.5\%$.

Conclusion: $\alpha_c = 25$ mrad is OK for all detectors.

For $\alpha_c = 30$ mrad the luminosity loss for LD is somewhat large, but possible can be optimized by proper shaping of the magnetic field (tails).

Configurations of tunnels

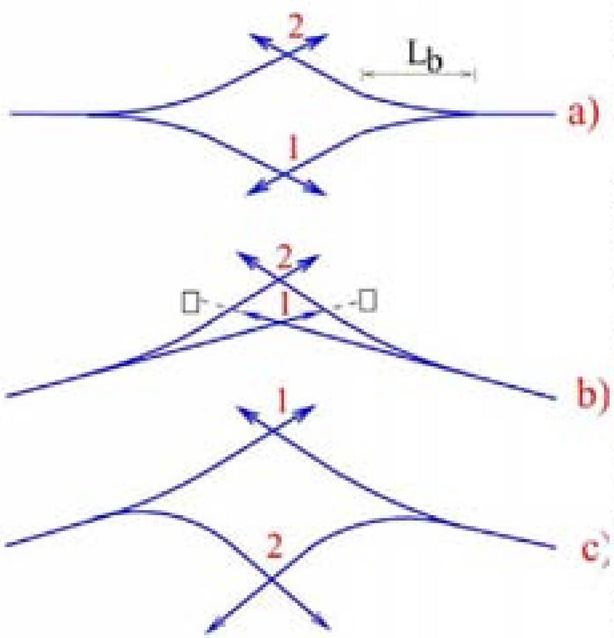


Figure 2: Possible configurations of tunnels at the ILC. The crab-crossing angle for e^+e^- (IP1) is about $\alpha_{c,1}$ = 0–20 mrad, smaller than that for $\gamma\gamma$ (IP2) which is $\alpha_{c,2} \sim$ 25 mrad.

Scheme a) the angle between tunnels is zero, it is the simplest configuration. The only problem: for maximum beam energies the bending length L_b required for a small emittance dilution may be too long.

Scheme b) there is non-zero angle between tunnels, bending angles are minimum, but may be problems with the space for detectors and for dumping of beams at the IP1.

Scheme c) the angle between tunnels is non-zero, as in the scheme a) the beams are bent in opposing directions, there is no problem with the space, but due to different bending angles the maximum energy for IP1 and IP2 are different. This scheme has sense only when tunnels will be used in future for other multi-TeV linear collider.

$$\Delta\epsilon_{nx} \propto \frac{E^6\alpha_b^5}{L_b^4}.$$

Taking the coefficient from the NLC ZDR one gets

$$\Delta\epsilon_{nx} = 1.8\times10^{-10}\left(\frac{2E_0}{\text{TeV}}\right)^6\left(\frac{\text{km}}{L_b}\right)^4\left(\frac{\alpha_b}{10\,\text{mrad}}\right)^5\ \text{m}$$

For $\epsilon_{nx} = 2\times10^{-6}$ m, $\alpha_b = 10$ mrad,
$\Delta\epsilon_{nx}/\epsilon_{nx} = 0.05$ at

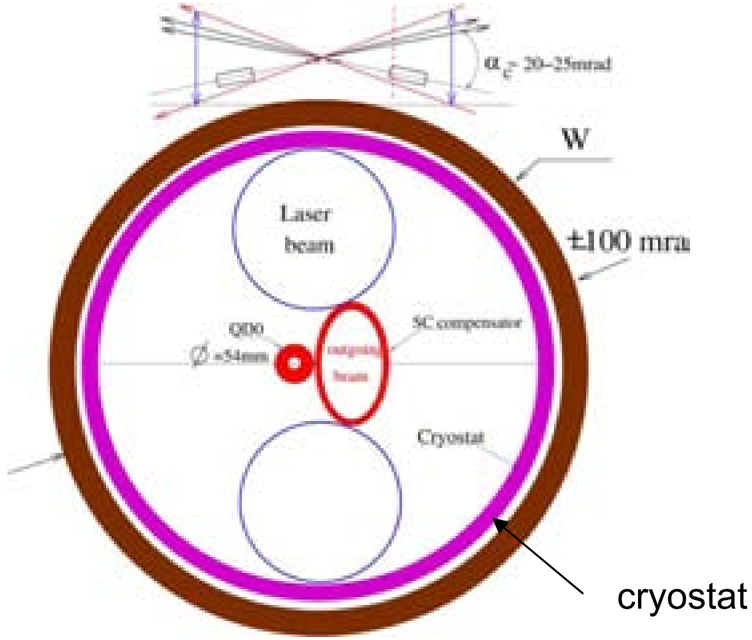
$2E_0$ TeV	1	2	3	5
L_b km	0.2	0.57	1.04	2.25

Optimum configuration depends on $E_{0,max}$

Final quads

The size of quads and the disruption angle determine the crossing angle.
Additional requirements:

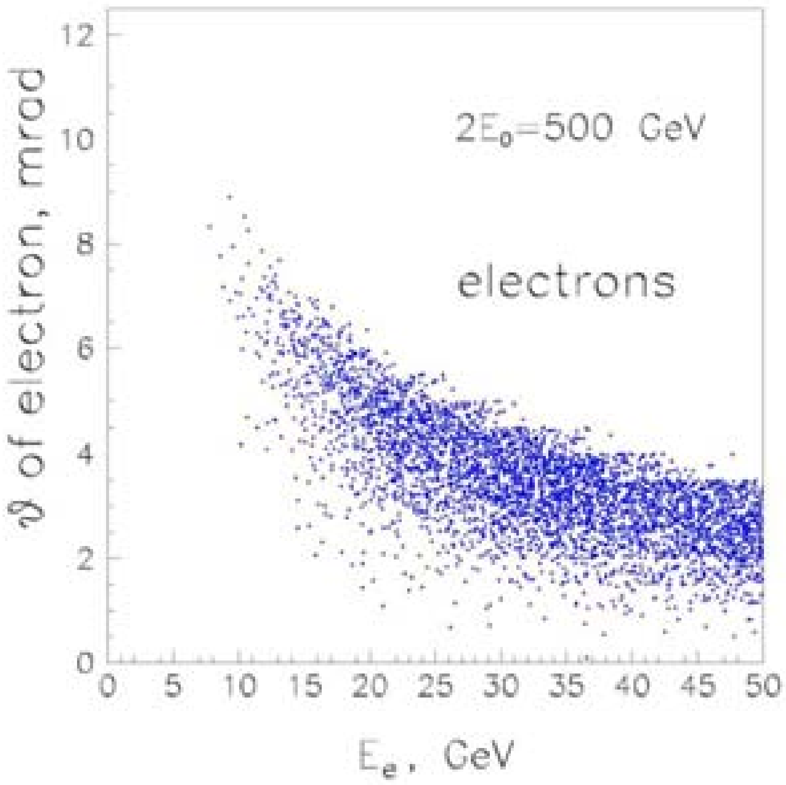
- quad's field should be small in the region of low energy disrupted beams;
- quads should not stay on the way of laser beams



Details in B.Parker's talk.

There are other ideas on quad designs. A compact quad without the field compensators and with a small diameter cryostat is not excluded. The work is just in the beginning.

Properties of the beams after CP,IP



Electrons:

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

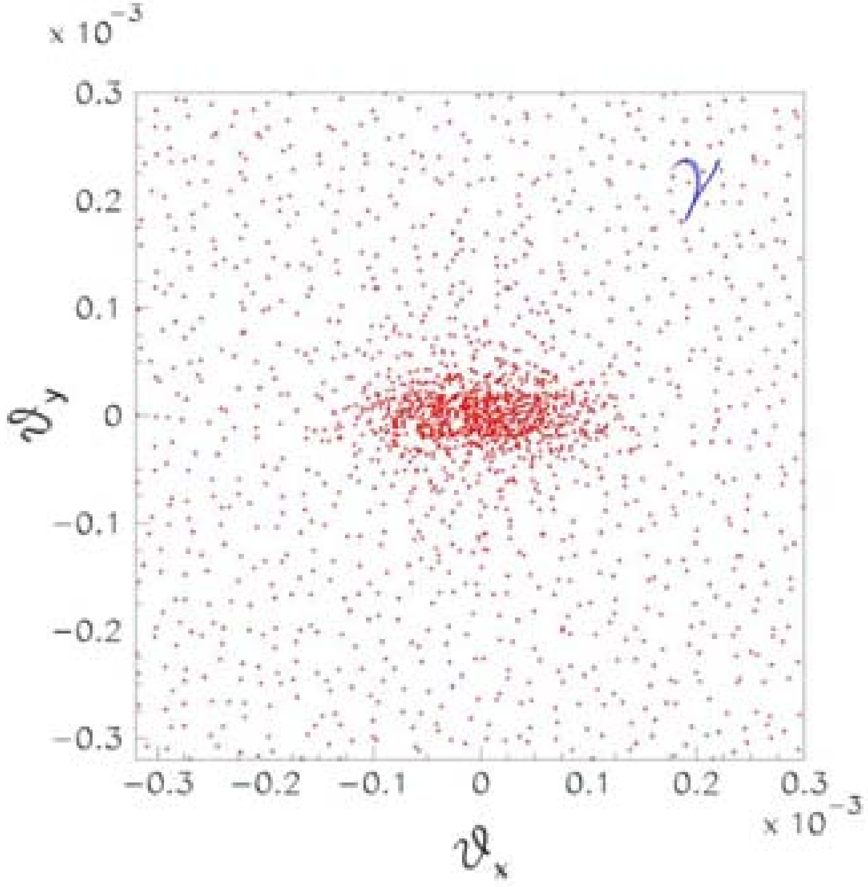
practically same for
E_0=100 and 250 GeV

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

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

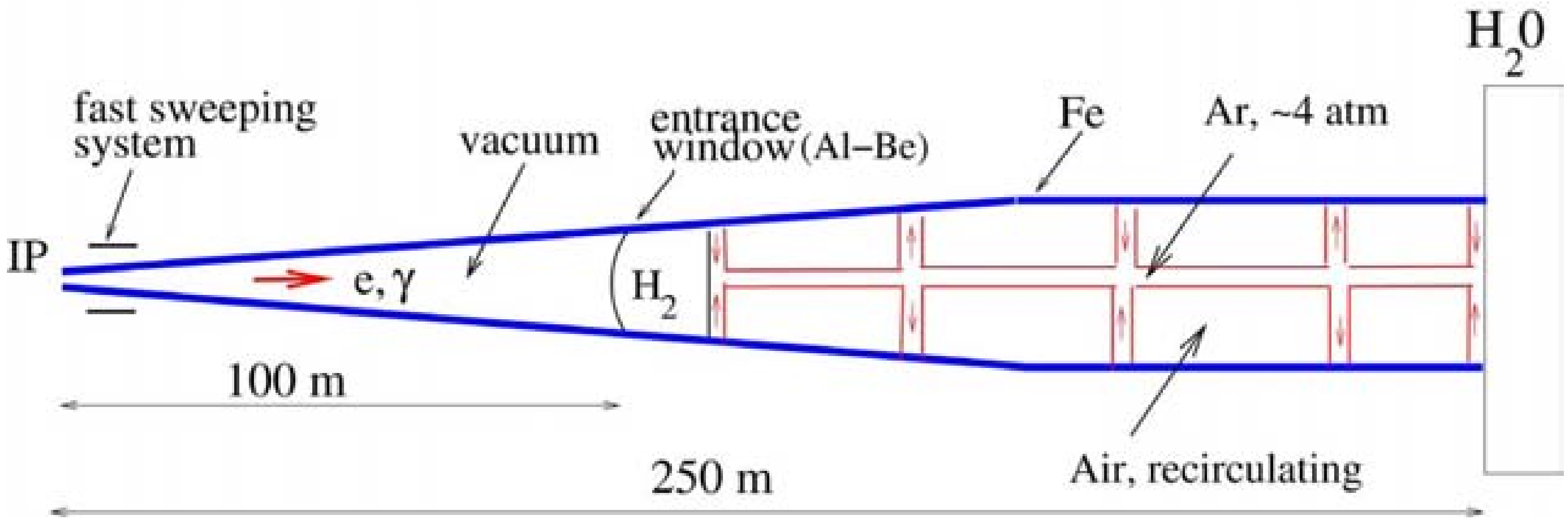
An additional vertical deflection, about ±4 mrad, adds the detector field

On the contrary, the angular distribution of photons after Compton scattering is very narrow, equal to the angular divergence of electron beams at the IP: $\sigma_{\theta x} \sim 4 \cdot 10^{-5}$ rad, $\sigma_{\theta x} \sim 1.5 \cdot 10^{-5}$ rad, that is 1 x 0.35 cm^2 and beam power about 10 MW at the beam dump. No one material can withstand with such average power and energy of one ILC train.



Possible scheme of the beam dump for the photon collider

V.Telnov



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. The volume with H_2 in front of the gas converter serves for reducing the flux of backward neutrons.

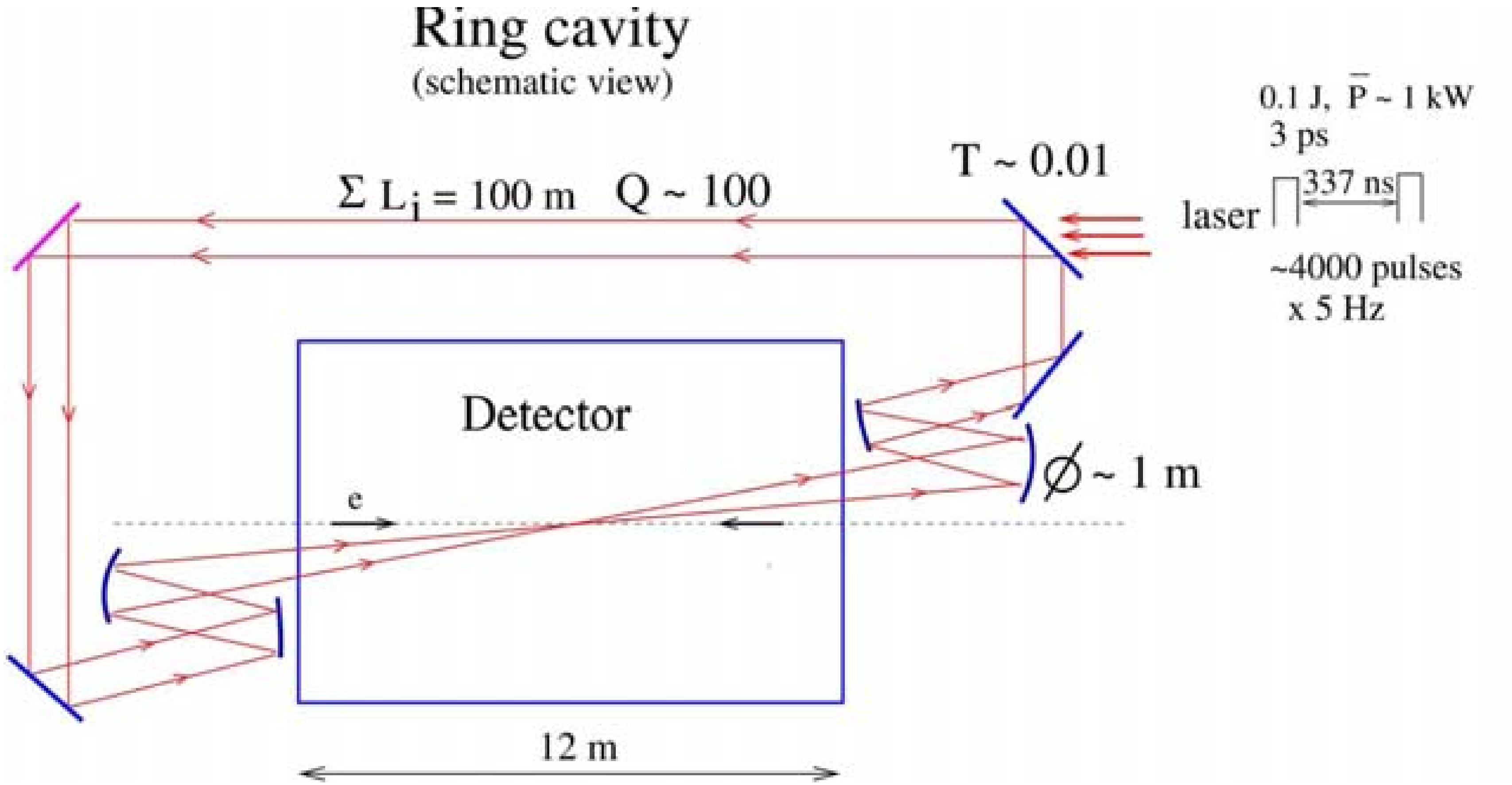
Needs detailed consideration

Requirements for laser

- Wavelength ~1 μm (good for 2E<0.8 TeV)
- Time structure Δct~100 m, 3000 bunch/train
- Flash energy ~9 J
- Pulse length ~1-2 ps

The best scheme is storage and recirculation of very powerful laser bunch is an external optical cavity.

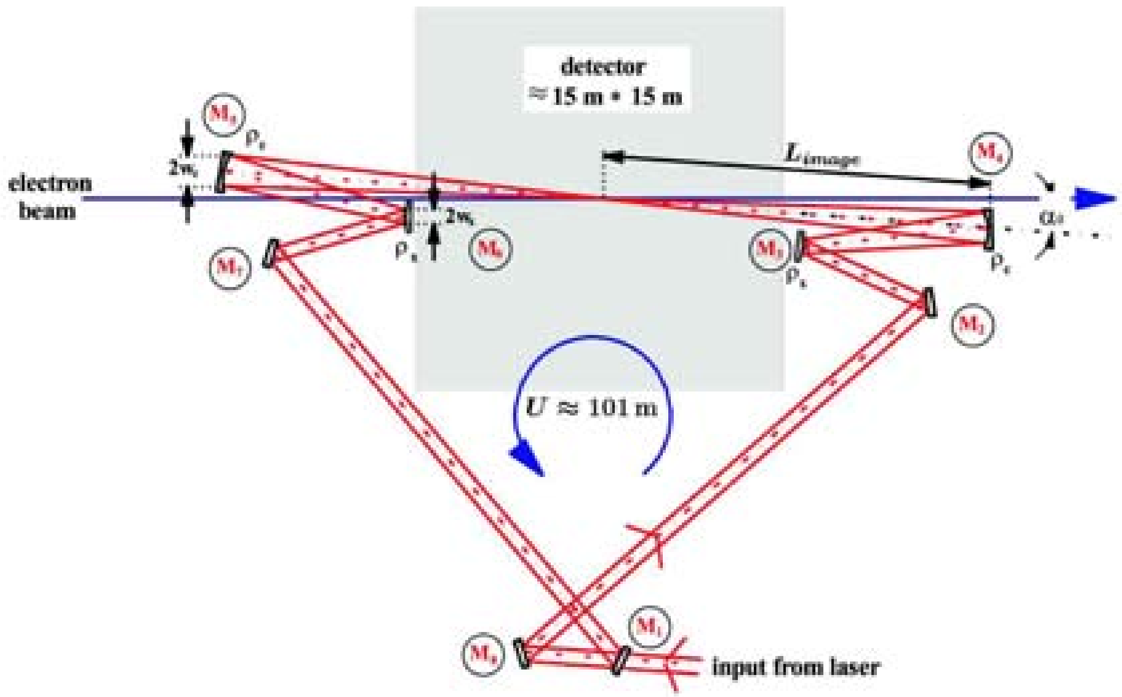
Laser system



Optimum f#=F/2R~17 for flat-top laser beam

Flash energy A~9 J

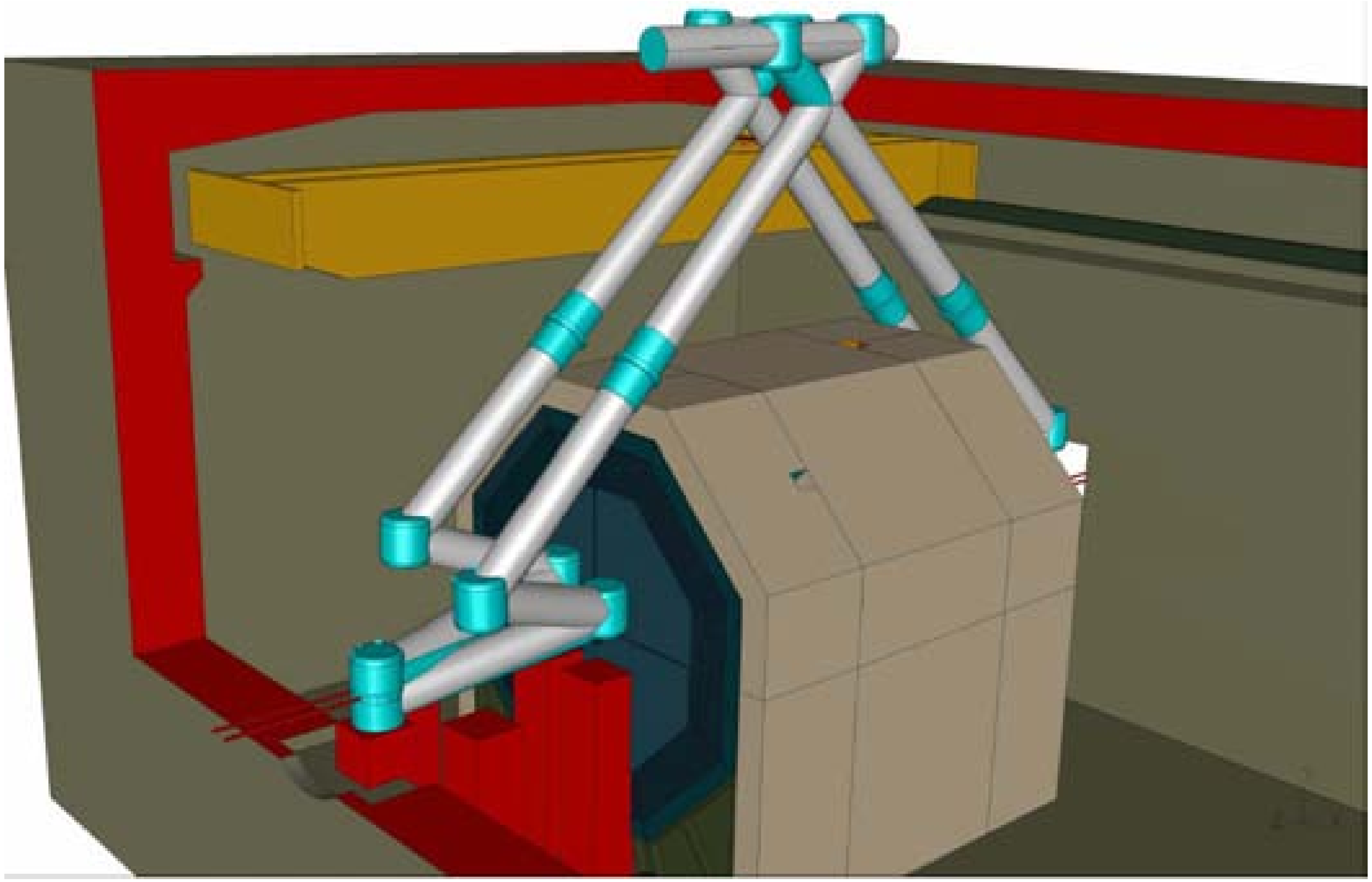
At DESY-Zeuthen optimization was done at the wave level. The cavity was pumped by a truncated Gaussian beam with account of diffraction losses (which are negligibly small).



The next step is a detailed technical consideration of the optical cavity together with laser cavity experts. Desirable to finish a first round by the end of this year.

View of the detector with the laser system

(the pumping laser is in the building at the surface)



For easier manipulation with bridge crane and smaller vibrations it may be better to hide laser tubes under the detector

Cost of drive laser (J.Gronberg,LLNL)

- Laser seems within range of current parameters, but
  - Real design from real laser physicists is necessary
  - Timing and wavefront quality must be specified
- A system of 2 lasers + 1-2 spares is necessary for operations
  - Lasers should be Order(10M) each
- Space in the cavern for a clean room (10mx30m?)
- Operations consoles upstairs

Summary on the photon collider

- In order to increase $L_{\gamma\gamma}$ it is desirable to decrease emittances in the DRs.
- The crab crossing angle α_c~25 mrad is fully compatible with e^+e^-, decrease of L_{e+e-} is small. In order to fix the angle, detailed designs of the quad, compensator and simulation of beam losses are required.
- The non-zero vertical collision angle can be compensated by the shift of quads (or dipole coils).
- There are ideas on the beam dump for the photon collider, detailed consideration is necessary.
- There are some considerations of the laser optical cavity for the photon collider, next steps needs participation of laser experts (needs money).
- At the photon collider, the angle ±100 mrad is occupied by laser beams; it should be taken into account in a design of one of detectors.

e^-e^- collisions

Electron-electron collider presents very unique possibility for study of many phenomena at ILC in very clean conditions (without background from annihilation processes). Physics in e-e- collisions was discussed at many e-e- workshops (C.Heusch) and published in IJMPh A.

Such type of collisions needs minimum modification of ILC, mainly in the final focus system, but, nevertheless, needs attention of accelerator people. Due to beam repulsion the attainable luminosity is by a factor of 5 lower than in e+e- collisions.

At present workshop P.Bambade discussed a possibility of e-e- in the scheme with 2 mrad collision angle (where quads deflect outgoing beams). It was shown that the e+e- final focus system can be readjusted to e-e- in the case of more rounder than optimal beams, with additional loss in the luminosity by a factor of 2 and larger beamstrahlung.

In summary: this option is important, and though seems simple technically (change of + to -), but in reality its realization needs careful consideration of all accelerator pats and solutions are not always simple.

GigaZ

K.Moenig

What is GigaZ?

Running on the Z with high luminosity for 10^9 recorded Z decays

- Reachable luminosity: $\mathcal{L} = 5 \cdot 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$
  ➡ $\sim 50 - 100$ days for 10^9 Zs
- Beamstrahlung loss (outgoing beam): $\delta_b = 0.1\%$
- Depolarisation: $\Delta\mathcal{P} = 0.1\%$
  ➡ placement of polarimeters not really an issue
- Z-rate: 100-200 Hz
- Additional requirements (motivation in this talk)
  - polarised electron and positron beam
  - very high precision on polarisation and beam energy
  - very low beam energy spread

Physics motivation of GigaZ

- $\sin^2\theta^l_{eff}$: Want to measure $\sin^2\theta^l_{eff}$ from left-right asymmetry to $\mathcal{O}(10^{-5})$
- Z-lineshape: Improve Z-width by a factor two, cross section ratios by a factor three
  ($\Rightarrow$ factor two on $\Delta\rho$, factor three on α_s)
- $\mathrm{Zb\bar{b}}$ couplings: improve factor 5-10 wrt. LEP
- m_{W}: measure m_{W} to 6 MeV

+ calibration of detectors

Conclusions

- There exists a huge potential of GigaZ, especially in $\sin^2\theta^l_{eff}$ and m_W
- However there are substantial requirements left:
  - positron polarisation
  - precision polarimetry
  - measurement of the beam energy
  - understanding of beamstrahlung and beamspread
  - understanding of > 1 Z multiplicities in a bunch train
  - understanding of theory and experimental input parameters ($\alpha(m_Z)$!!)
- ILC should be prepared to run in GigaZ mode not to miss a great opportunity

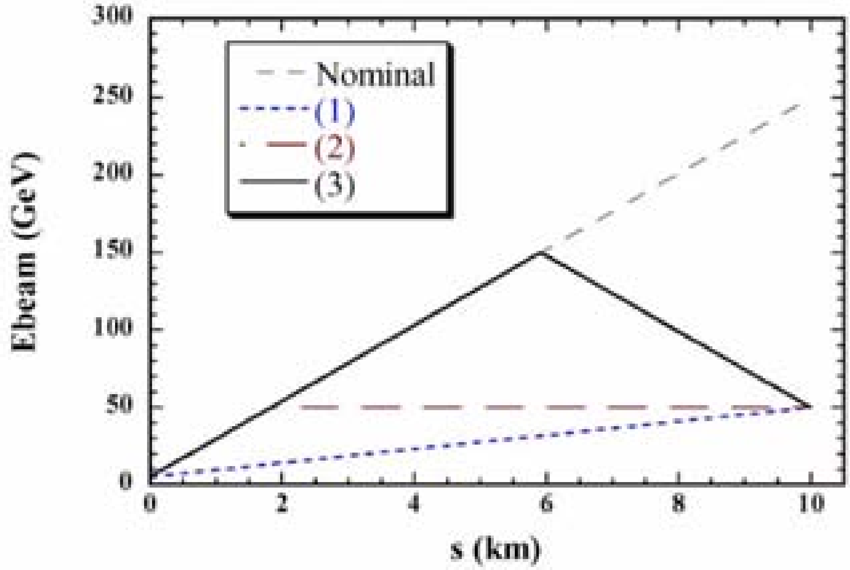
Obtaining of low energies for GigaZ

K.Kubo

Three cases

(Final Beam energy 50 GeV where Nominal is 250 GeV)

1. Constant gradient
2. Accelerate first, then, no acceleration
3. Accelerate to 150 GeV, then, deccelerate to 50 GeV



Emittance increase ratio compared with nominal operation

		Constant beta	Beta ~ sqrt(E)
(1)	Constant gradient from 5 to 50 GeV	3.20	1.94
(2)	Accelerate with nominal gradient, then, no acceleration	1.61	1.40
(3)	Accelerate to 150 GeV, then, decelerate to 50 GeV	1.15	1.12

3- best but needs more power

2- is most economic solution

Conclusion: if polarized positrons are produced by the laser scheme, bypasses are not needed.

The case of undulator positron source

Duncan Scott

ASTeC Accelerator Science and Technology Centre

Requirements

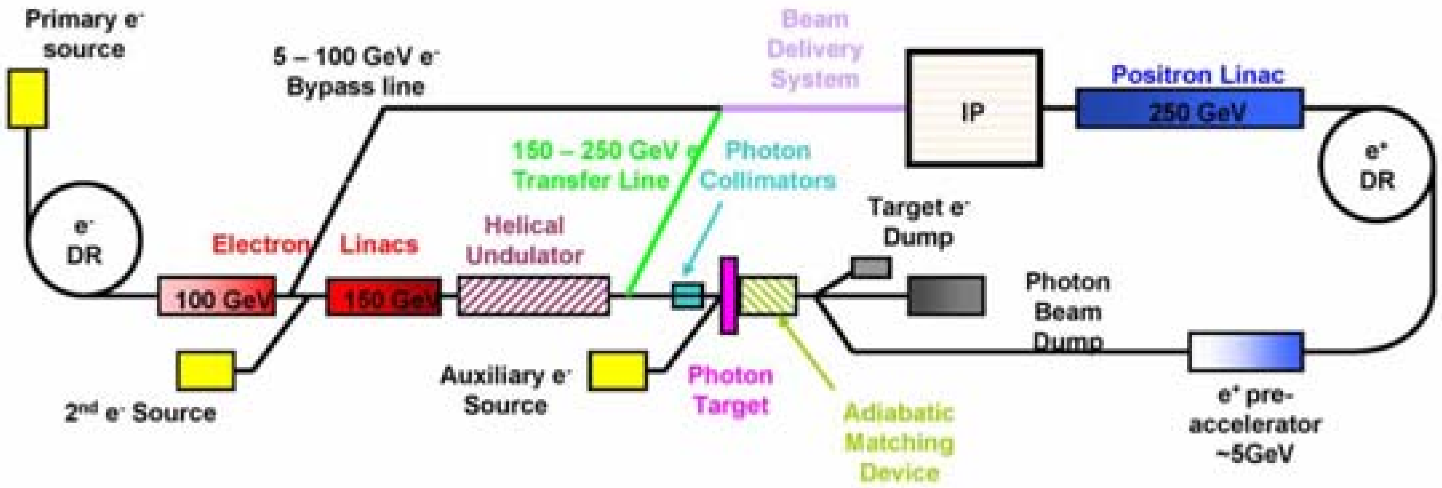
- Need ~50GeV electron beam at IP
- Need 150GeV (minimum) electron beam for the undulator to work
- Two options
  - Split the electron linac in two
  - Decelerate the electrons
- Going to show a few schematics of layouts
- (They are from the positron source sessions, so biased towards positron source components!)

17/08/05 Duncan Scott: Undulator Source Overview 2

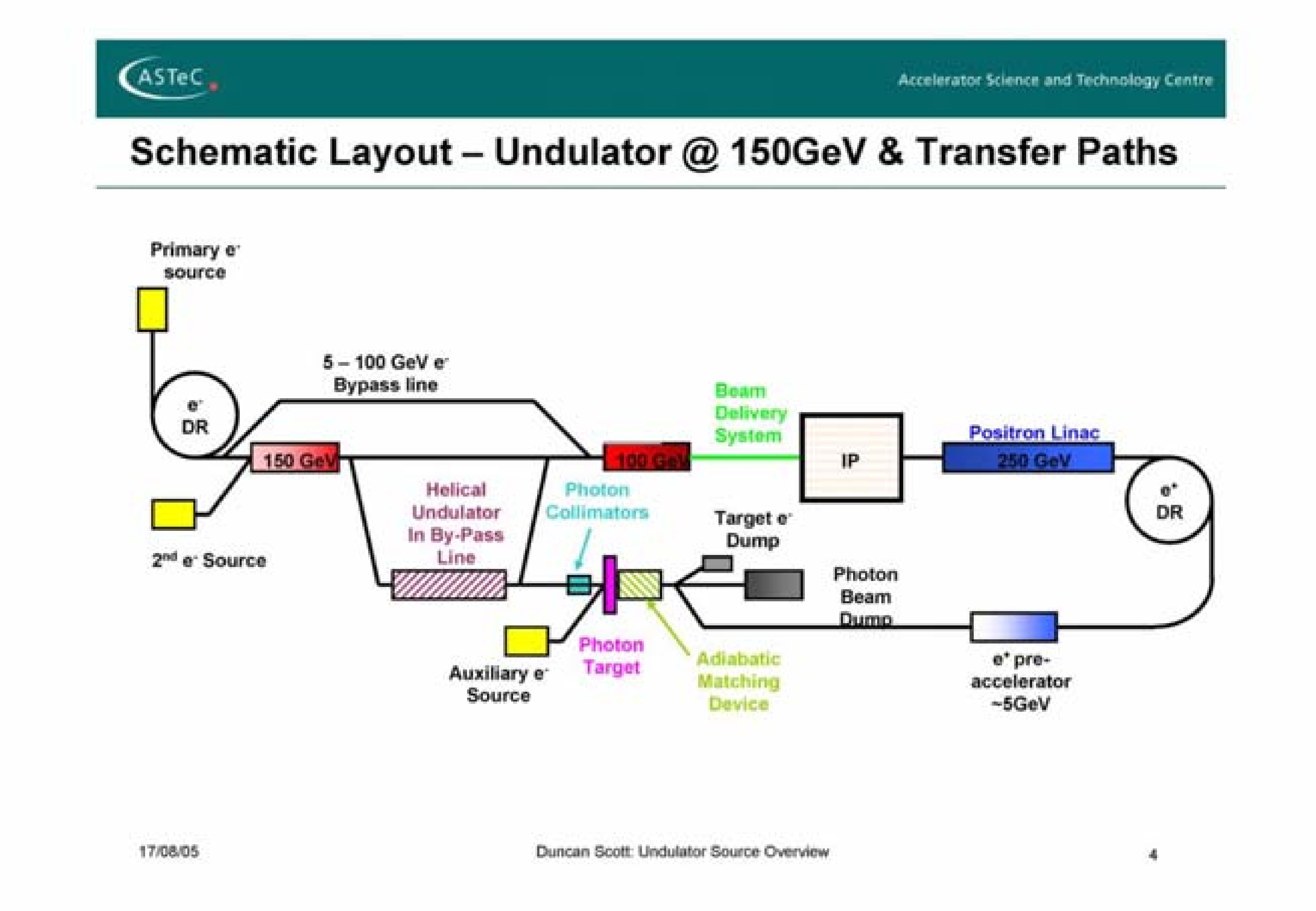
ASTeC Accelerator Science and Technology Centre

Schematic Layout – Undulator @ 250GeV & Transfer Paths

NB bypass line can go anywhere between 50GeV and 100GeV



17/08/05 Duncan Scott: Undulator Source Overview 3



ASTeC
Accelerator Science and Technology Centre
Schematic Layout – Undulator @ 150GeV & Transfer Paths
Primary e- source
e- DR
5 – 100 GeV e- Bypass line
150 GeV
100 GeV
Beam Delivery System
IP
Positron Linac
250 GeV
e+ DR
2nd e- Source
Helical Undulator In By-Pass Line
Photon Collimators
Target e- Dump
Photon Beam Dump
Photon Target
Auxiliary e- Source
Adiabatic Matching Device
e+ pre-accelerator ~5GeV
17/08/05
Duncan Scott: Undulator Source Overview
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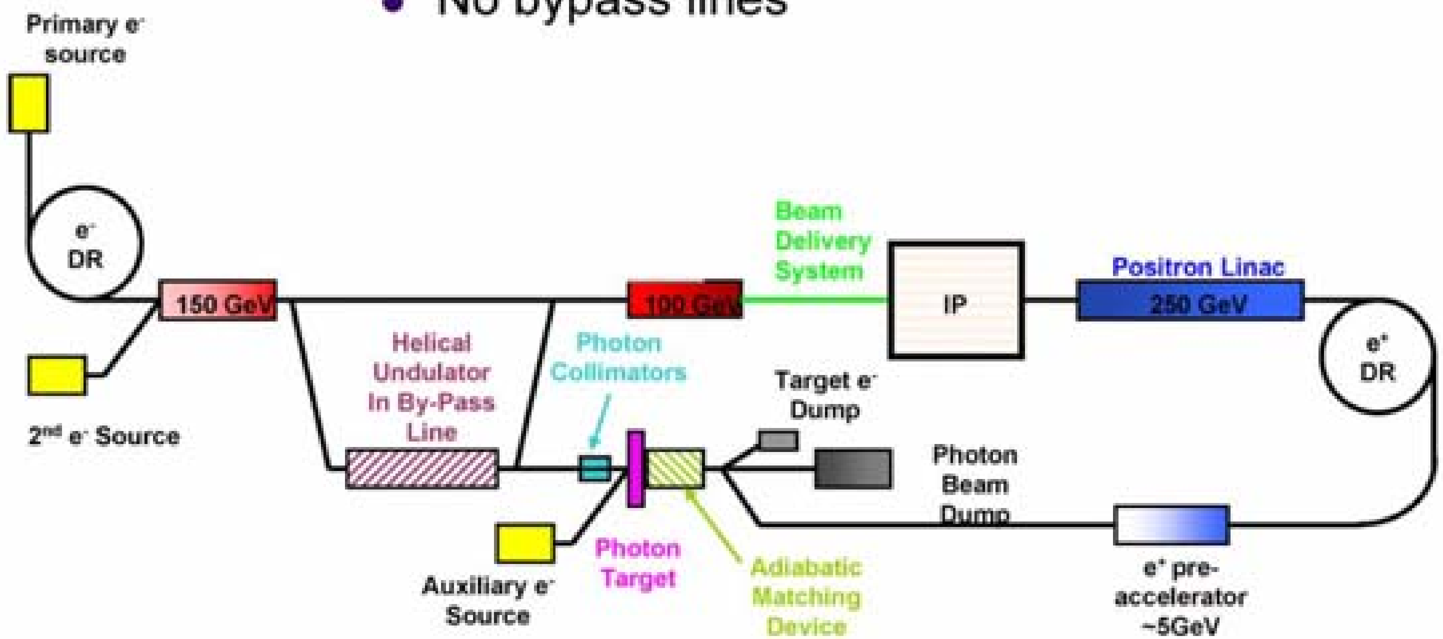
Schematic Layout – Undulator @ 150GeV & Deceleration

- No bypass lines



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Requirements

- All schemes will work – but make operation/design more complicated
- Deceleration seems more complicated
  - Bunch to bunch energy jitter is proportional to the number of klystrons so gets better
  - Relative energy spread in a bunch is proportional to the linac length so increases
  - Fixes undulator at 150GeV
  - Operation more complicated
- Transfer paths seem like a better option
  - Cost a bit more money

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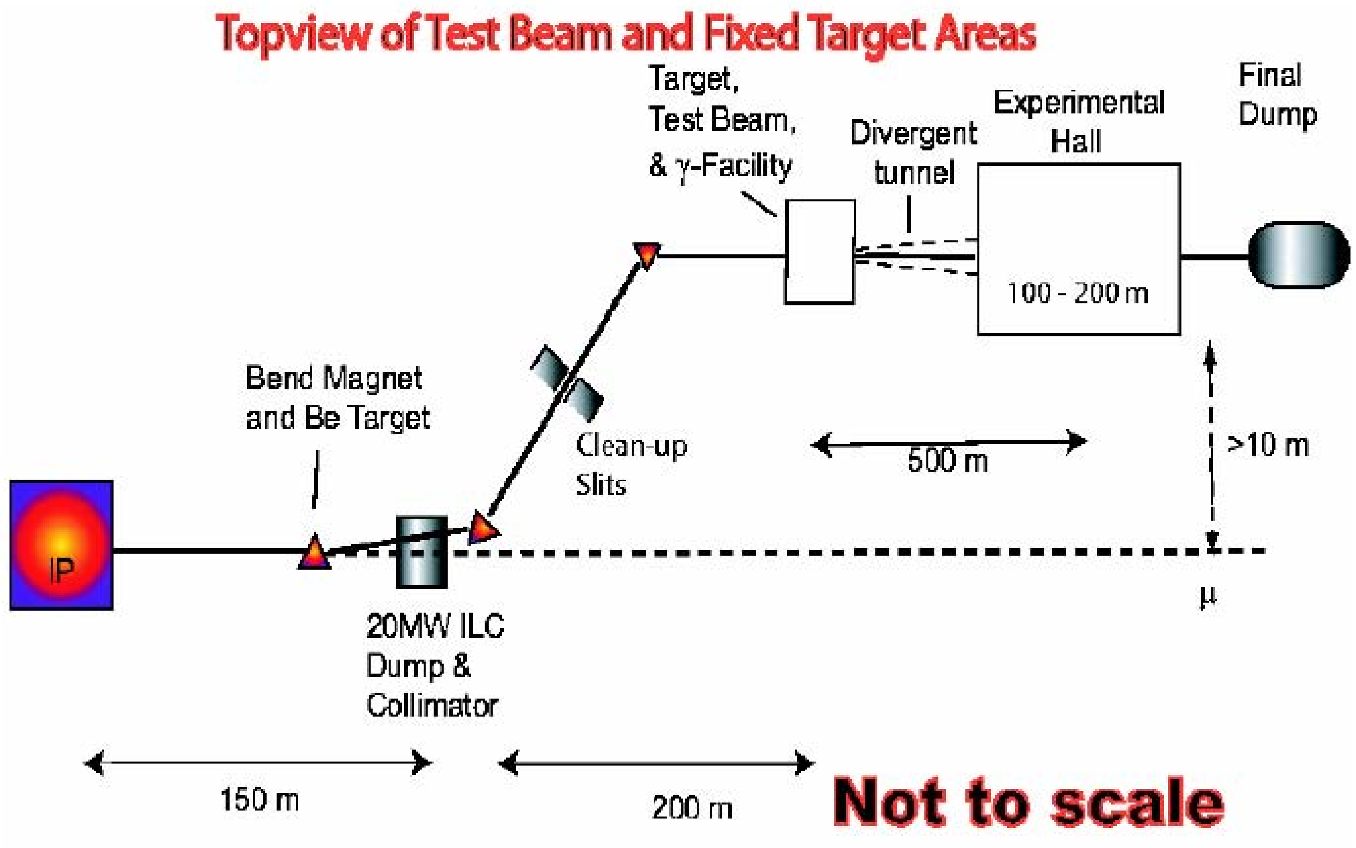
Fixed target

S.Mtingwa,Y.Kolomensky
S.Kanemura et al.

SLAC Style

SLAC-PUB-8570; arXiv:physics/0101070



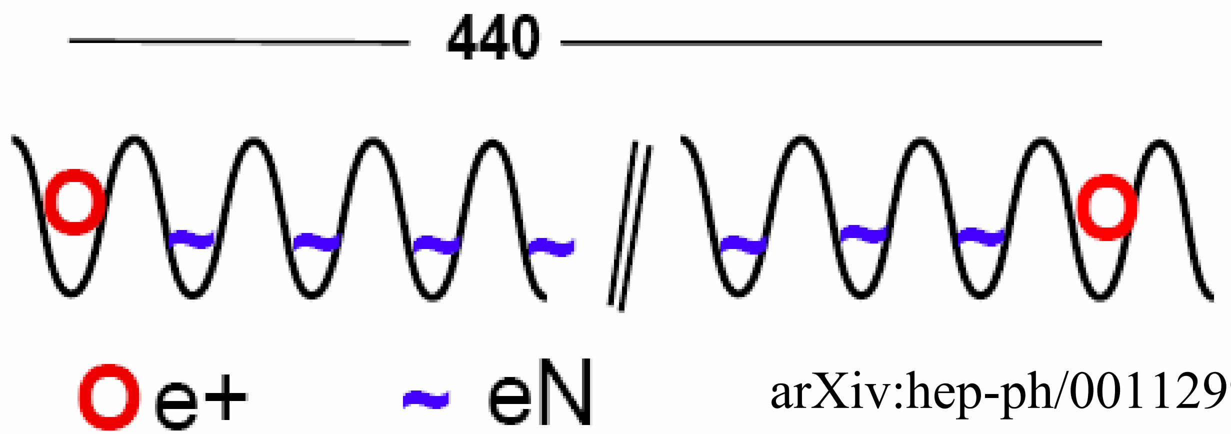
17 Machine-Detector Interface @ ILC, SLAC, Jan 6-8, 2005 *Rainer Pitthan*

Different Approach: TESLA-N

Some experiments look for coincidences, and require high duty cycle

Idea: use the positron arm to create low charge ~0.5% duty factor beam for HERMES-style experiments at higher momentum transfer (transversely, semi-exclusive measurements, g_1).

- ✓ Fill empty 440 buckets between 2820 e^+ buckets with low-charge ($2*10^4$) electron bunches
- ✓ Additional beam loading small (0.04%)



arXiv:hep-ph/0011299

Fixed target experiments is traditional method of particle physics and should be not ignored at ILC.

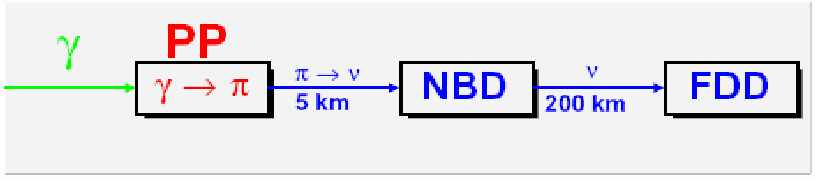
More fantasies

I. Initiation of an accelerator–driven sub–critical reactor

The idea to work with sub–critical nuclear reactor, initiated by proton or electron beam, for foolproof production of energy and (or) cleaning of nuclear pollution is well known (Rubbia). Here proton or electron beam with particle energy of about 1 GeV is suggested to produce neutrons in the cascades within body of reactor. The problem here is in obtaining necessary beam power of about 5 MW or larger.
For definiteness, in TESLA project we expect mean used beam power about 11 MW with electrons or (and) photons having energies of about hundreds GeV. In the suitable target this particle energy can be transmitted to low energy particles to initiate fission process in reactor.

no comments

II. Neutrino factory



A. Pion producer (PP) – water cylinder of length about 20 cm (*radiation length*). Here electrons produce photons via bremsstrahlung, and than these photons (or direct photons) produce pions via $\gamma N \to \pi\pi\pi ... N$
B. Neutrino transformer (NT) – low vacuum pipe of length 1–5 km and radius about 2m for $\pi \to \mu\nu$ decay with $0.6 \cdot 10^{11}$ ν/s and angular spread $2 \div 0.4$ mrad. $1 \div 2$ events $\nu_\mu N \to \mu X$
C. Nearby detector (NBD) at 1.1-10km after NT – for estimates: water of length 100m with radius 2-10 m. – $1 \div 100$ events $\nu_\mu \to \mu X$/sec
D. Far distance detector (FDD) at the distance $L = 100 \div 200$ km: water of length 1 km with radius about 40 m with $\sim 100 \div 1000$ events $\nu_\tau N \to \tau X$/year from $\nu_\mu \to \nu_\tau$ oscillations (twice larger than background).

Advantages in comparison with proton produced neutrinos are not clear

Thank you!