CONVENTIONAL DETECTORS FOR A PHOTON-PHOTON COLLIDER

François RICHARD

Talk given at the Gamma-Gamma Collider Workshop at Berkeley, March 28-31, 1994

U.E.R. de l'Université Paris-Sud

Institut National de Physique Nucléaire et de Physique des Particules

Bâtiment 200 - 91405 ORSAY Cedex
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F. RICHARD

Laboratoire de l'Accélérateur Linéaire,
IN2P3-CNRS et Université de Paris-Sud, F-91405 Orsay Cedex, France

Detectors for a photon-photon collider are envisaged using as guide-lines the physics goals and the interaction point environment. Production of SUSY Higgs scalar and pseudo-scalar is emphasized. Some aspects of the interaction point environment are discussed.

Introduction

The possibility of a photon linear collider [1, 2] (PLC) has triggered interest in the community of physicists involved in $e^+e^-$ linear colliders. While feasibility of a PLC is still debated, the practical aspects for what concerns the interaction point IP and the compatibility with $e^+e^-$ detectors have not yet received sufficient attention. The purpose of this note is to serve as an input for the physicists and machine experts participating to this workshop.

The physics goals, which determine the luminosity requirements and the need for polarization, will be reviewed. The emphasis is on Higgs boson production in the standard model and SUSY framework.

Some features of the interaction region are reviewed: Laser + mirrors, separating coils, dead region.

Conventional detector schemes are proposed. By conventional detectors, I mean detectors operating at LEP/SLC or proposed at LHC/SSC.
1. Physics at a PLC

1.1. Basic processes

The relevant cross-sections are shown below.

<table>
<thead>
<tr>
<th>Cross-section</th>
<th>S.M.</th>
<th>Monitoring</th>
<th>SUSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 nb</td>
<td>$\sigma_{TOT}$</td>
<td>[\gamma\gamma \rightarrow W^+W^-]</td>
<td>$\gamma\gamma \rightarrow e^+e^-$</td>
</tr>
<tr>
<td>[\ldots]</td>
<td>[\gamma e \rightarrow \nu W]</td>
<td>$\gamma e \rightarrow \gamma e$</td>
<td></td>
</tr>
<tr>
<td>10 pb</td>
<td>$\gamma e \rightarrow eZ$</td>
<td>$\gamma\gamma \rightarrow \chi^+\chi^-$</td>
<td></td>
</tr>
<tr>
<td>1 pb</td>
<td>SM Higgs</td>
<td>$\gamma\gamma \rightarrow bb$</td>
<td></td>
</tr>
<tr>
<td>100 fb</td>
<td>$\gamma\gamma \rightarrow Z_T^Z_T$</td>
<td>$\gamma e \rightarrow \tilde{e}\tilde{Z}$</td>
<td></td>
</tr>
<tr>
<td>10 fb</td>
<td>$\gamma\gamma \rightarrow \gamma\gamma$</td>
<td>$\gamma\gamma \rightarrow H, A$</td>
<td></td>
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</tbody>
</table>

In the standard sector, there are almost eight orders of magnitude between the elastic photon-photon process and the total cross-section. The total cross-section sets a limit on the maximal luminosity per beam crossing at the level of $10^{31} \text{cm}^2\text{s}^{-1}$ and, therefore, the maximal integrated luminosity will depend strongly on the machine duty cycle. W pair production has a very large cross-section, constant with energy, which can be used for precision test of the standard model. The monitoring process $\gamma\gamma \rightarrow e^+e^-$ has a similar cross-section.

To reach the potentially interesting SUSY Higgs physics [3], one will have to obtain integrated luminosities of at least 100 fb$^{-1}$.

Chargino pair production is also potentially very large, if the lightest chargino has a mass of about 100 GeV as currently expected [4].

1.2. Standard Model Higgs

Higgs production in a PLC is a well explored scenario [5, 6, 7, 8]. I recall here the main conclusions which have been reached with some emphasis on the delicate issues.

A light Higgs boson, with a mass below 130 GeV (as expected in a SUSY scenario), decays primarily into beauty quarks. B-tagging is therefore an important issue bearing in mind that charm is 16 times more coupled in $\gamma\gamma \rightarrow qq$. Longitudinal polarization drastically decreases this process with a narrow band beam tuning [9]. The latter choice is possible assuming that the Higgs boson has been discovered in an $e^+e^-$ collider and/or at LHC. This tuning eliminates almost completely the process $g\gamma \rightarrow qq$ which would increase
by an order of magnitude [10] the background in a wide band beam exploratory search (figure 1a). As shown in figure 1b, with polarization and a conversion point at a finite distance from the interaction point, it is possible to achieve a narrow band beam with a mass resolution of about 5%. The photon-gluon contribution only populates masses well below the maximum (tuned at the Higgs boson mass) and, therefore, becomes negligible.

The energy resolution of the detector has not much impact in reducing the background for a light Higgs search with a narrow band beam PLC. The natural resolution provided by the beam spread is already better than the mass resolution which can be achieved from the hadronic final state. This point will be more quantitatively discussed in section 3.3. For higher masses, the situation changes and a significant gain can be obtained with an optimized hadronic energy reconstruction.

For a heavy Higgs boson, up to 300 GeV, the signal can be observed in a PLC using the ZZ decay mode. The $W^+W^-$ background can be eliminated by requesting $b\bar{b}$ or leptonic Z decays [7]. Above 300 GeV the loop contribution [11] to $\gamma\gamma \rightarrow ZZ$ overwhelms the Higgs signal.

How precisely should one measure $\Gamma(H \rightarrow \gamma\gamma)$?

A generation of new heavy fermions would give large effects easily observable [7]. Large deviations are also possible in a general two Higgs doublet scheme [8].

In the SUSY scenario, the constraints on the doublet parameters are such that only small effects are possible at the 10-20% level. This result was obtained including loops due to charginos and charged Higgs [12] and using a reasonable set of SUSY parameters, i.e. compatible with the experimental constraints.

With the present accuracy given by the various electro-weak measurements, one cannot exclude very large effects due to anomalous couplings [13] which could dramatically, by several orders of magnitude, enhance the coupling of the Higgs bosons to two photons. This type of scenario will be considerably restricted with the results of LEP II on pair production of W bosons.

1.3. SUSY Higgs

In this scheme, two Higgs doublets are present with two CP-even Higgs bosons $h$ and $H$ and one CP-odd Higgs boson $A$. Both couple to photon pairs but the coupling to $H$ (the heaviest Higgs) and $A$ may be substantially reduced with respect to the SM case as shown in figure 2 [14]. The masses of $A$ and $H$ could be above 250 GeV, as suggested by the predictions shown in figure 3. $H$ can be observed in an $e^+e^-$ collider through the bremsstrahlung process $HZ$ or through the fusion mechanism, $W_LW_L \rightarrow H$, but generally one expects very reduced couplings with respect to $h$. The associated production $HA$, the only possibility for $A$ which is not coupled to vector bosons, would request an $e^+e^-$
machine operating at energies above 500 GeV and, therefore, a PLC offers an unique opportunity to produce these particles with a low energy collider.

Decay modes of H and A [15] depend largely on the parameters of the model as shown in figure 4. A heavy H could decay predominantly into a hh, a mode which can be clearly identified since it provides 4 beauty particles in the final state. A heavy A could also give Zh, which again provides easy identification. With enough luminosity, at least 100 fb^{-1}, one would then be able to make a wide band beam search to look for A and H. It would also be possible to distinguish between A and H. A detailed work is clearly needed to work out this scenario.

When tanβ becomes large, A and H will couple preferentially to b\bar{b}. The narrow band beam search, previously described in the case of the standard model Higgs, applies if one assumes that the mass of H and A are known a priori (e.g. found in the HA mode). How can one distinguish between A and H, when they both decay into the same b\bar{b} mode? Ideally, transversely polarized beams would allow some discrimination between the two parities. For a CP-even state, the production amplitude goes like \bar{c}_1\bar{c}_2, where \bar{c}_1 and \bar{c}_2 are the polarization vectors of the incident photons. For a CP-odd state, the production amplitude goes like \bar{c}_1\times \vec{k}\cdot \bar{c}_2, where \vec{k} is the incident photons. If the two incident beams are transversely polarized, with orthogonal polarization vectors, the production amplitude of a CP-even Higgs boson vanishes while the CP-odd amplitude has its maximum. In practice, one can produce transversely polarized photons [16] but the signal/background ratio is severely degraded (one looses the rejection given by longitudinally polarized photons against light fermions) and, therefore, the method cannot be used.

For masses above 340 GeV, H and A could decay primarily into t\bar{t}. The background becomes rather severe since top quarks are 16 times more coupled than bottom quarks. In addition the trick of longitudinal polarization operates poorly on heavy quarks. In [17] a favourable signal over background was found but based on a very optimistic mass resolution for the hadronic final state (see section 3.3).

An Example with 100 fb^{-1}

\[ tanβ=5 \quad m_t=170 \text{ GeV} \quad μ=300 \text{ GeV} \quad m_A=320 \text{ GeV} \quad M_2=200 \text{ GeV} \]

Output: \[ m_h=107 \text{ GeV} \quad m_H \sim m_A \sim 320 \text{ GeV} \quad m_{h,±}=170 \text{ GeV} \]

\[ BR(h \rightarrow b\bar{b})=83\% \quad Γ(h \rightarrow γγ)=5.46 \text{ keV} \quad (5.72\text{keV in SM}) \quad 5000 \text{ evts/s/b} \sim 5 \]

\[ BR(A \rightarrow b\bar{b})=43\% \quad Γ(A \rightarrow γγ)=12.4 \text{ keV} \quad 250 \text{ evts/s/b} \sim 2 \]

\[ BR(A \rightarrow χχ)=37\% \]

\[ BR(H \rightarrow b\bar{b})=45\% \quad Γ(H \rightarrow γγ)=12.4 \text{ keV} \quad 100 \text{ evts/s/b} \sim 0.6 \]

\[ BR(H \rightarrow hh)=26\% \quad 30 \text{ evts} \]
This example corresponds to a reasonable scenario [4] for SUSY parameters with H and A heavy. One may notice a few features already mentioned:

- $\Gamma(h \to \gamma\gamma)$ differs only slightly ($\sim 5\%$) from the SM width
- the rates are very low for $\Lambda$ and $H$ and $100$ fb$^{-1}$ are clearly needed
- $A$ and $H$ can be observed into $b\bar{b}$ with a narrow band beam with $b$-tagging but with a poor $s/b$ which forbids a realistic spin-parity analysis with a transversely polarized beam
- the decay of $H$ into $hh$ is sizeable and allows in this case an unambiguous identification of the CP-even mode.

The neutralino/chargino modes can only be identified by requesting missing transverse energy. A detailed study would be needed to assess the separability with $W$ pairs and with the process $\gamma\gamma \to \chi^+\chi^-$ but, at first sight, there is very little hope to reach a proper separation.

To conclude, a PLC offers a unique possibility to measure neutral Higgs production in the standard model or in the two doublet extension. It may even allow to discover a heavy Higgs boson (H or A) not accessible in an 500 GeV $e^+e^-$ machine.

1.4. $\gamma\gamma \to W^+W^-$

This reaction will provide the most precise test of the standard model. From the detailed study of [18], one can extract a few simple conclusions. In figure 5, constraints on the $\kappa$ and $\lambda$ parameters, which characterize possible deviations from SM, are displayed.

For the total cross-section band, an accuracy of $5\%$ was assumed which seems very conservative given the typical precisions on luminosity achieved at LEP. One may however object that the process $\gamma\gamma \to e^+e^-$ is strongly influenced by the state of polarization of the photon beams and, therefore, is not a good monitor. In fact, in the state $J_Z=0$, this process is almost extinct. A possible way out would be to constantly flip the polarization of the laser beam [9]. One would therefore be able to eliminate, on average, the influence of polarization on luminosity monitoring. Another way out, emphasized at this workshop [19], would be to use the large $4\mu$, which provides sufficient rate (several $10$ pb) and is not affected by polarization. As a tentative conclusion, one may assume that a precision of $1\%$ on luminosity monitoring can be achieved and, since one has $\Delta\sigma_T/\sigma_T \sim 2\Delta\kappa/\kappa$, this measurement sets a very tight constraint on $\kappa$.

For the polarization measurement, one can use the ratio of cross-sections with $J_Z=0$ and $J_Z=2$, the so-called $0/2$ ratio. In this case, the issue is to monitor properly the polarizations and an uncertainty of $1\%$, as assumed in [18], seems appropriate.
Figure 5 shows the accuracy given by the $\gamma \gamma \rightarrow W^+W^-$ process compared to what can be achieved in an $e^+e^-$ machine. As previously stated, a better figure can be reached with a 1% luminosity monitoring. One can emphasize the nice complementarity of the two results, since a PLC would allow to choose between two possible solutions for $\kappa$ given by the $e^+e^-$ measurement.

1.5. Implications for machine parameters and detectors

1.5.1. High luminosity

As stated in section 1.3, the integrated luminosity needed is at least 100 fb$^{-1}$. This figure is not excluded for a PLC where beam-beam effects can be considerably reduced using either magnetic separation or, an innovative suggestion brought by this workshop, with plasma lenses which would strongly defocus the electrons after they have interacted with the laser beam. It would therefore seem possible to increase the particle density at the interaction if one can improve on the emittance of the beam. The potential luminosities are given in [20].

Given the large photon-photon cross-section, if one could reach a photon-photon luminosity of about $10^{34}$cm$^2$s$^{-1}$, would the rate per bunch crossing still be acceptable for conventional detectors?

In the case of TESLA, there would be about 0.5 hadronic interaction per beam crossing. These interactions give low transverse momenta and, therefore, the detector only sees soft particles. The effect on mass reconstruction of heavy particles is therefore very small (see [21]). One can eventually use the microvertex spatial resolution to further reduce this background, since two different interactions will be longitudinally separated by about 1 mm.

In the case of NLC, one would get 0.25 interactions per crossing but, bearing in mind the fact that there are 180 bunches separated by 1 ns, a detailed estimate is needed. As pointed out in [22], the precise timing given by the SLD drift chambers ($\sigma \sim 1.4$ ns) can be used to separate interactions from different bunch crossings.

With present laser technology, the PLC scheme is not easy to implement with the high repetition rates planned for $e^+e^-$ colliders. In the VEPP scheme, there are 300 crossing per second and a luminosity of $10^{34}$cm$^2$s$^{-1}$. With more than 10 hadronic interactions per crossing, the tracking problems may look similar to what is expected at LHC with full luminosity. For this reason, I will also consider the tracking devices which have been proposed for this machine.

1.5.2 Detector properties

B-tagging should be optimal at PLC. This means that a microvertex detector with minimum radius has to be implemented to reach the highest rejection against $c\bar{c}$ events.
In the JLC proposal [21], a radius of 2.5 cm is assumed and, as shown in section 3.1.2, this allows a sufficient bb separation.

Mass resolution of the hadronic final state is needed to reconstruct heavy Higgs bosons. In section 3.3, I will indicate that the ideal calorimetric resolution cannot be reached with a conventional detector using tracking chambers and calorimetry due to various systematic effects.

A perfect hermiticity would be needed to reconstruct missing energy which is a signature for SUSY particles with missing LSP (Lightest Susy Particle assumed neutral, weakly interacting and stable if R-parity is conserved). The process $\gamma\gamma \rightarrow W^+W^-$ provides the largest background when a W decays into a lepton and the lepton is lost in a dead region. If the remaining W decays hadronically it can still be identified by mass reconstruction. If one assumes a forward blind zone of 10°, and a 90% efficiency to reconstruct properly the W mass, this background can be kept at a few per mill level. This would be sufficient for a clean selection of the process $\gamma\gamma \rightarrow \chi^+\chi^-$. 

A PLC is an ideal machine to produce narrow mass states decaying into two photons. Various theories predict such states and, given the very low background due to photon-photon elastic scattering (see section 1.1), one would be able to observe them even if $\Gamma(X \rightarrow \gamma\gamma)$ is of the order of a few 10 eV [8]. This search can be done with a wide-band beam configuration and is of course optimal if the detector has an excellent electromagnetic resolution.

Forward coverage of the detector is obviously more important in a PLC than in an $e^+e^-$ machine since $W^+W^-$ and $f\bar{f}$ are peaked. In addition, standard photon-photon physics, with one or both photons "resolved" as a gluon or a quark, will produce forward jets in the detector. The need for a mask seems unavoidable but it is possible to detect particles down to 10° (see section 3.2).

2. Interaction Point

2.1. Basic constraints

A PLC requires a complex combination of devices in the interaction region which have implications in the detector design.

Very powerful laser beams have to be focused near to the IP. A nearby focusing mirror is needed which would ideally be inside the beam pipe to have a zero crossing angle between the laser and the incident beam and give an optimal conversion probability [23]. One may of course worry about the background induced by such a device and also about the lifetime of these mirrors. In this workshop, a thorough discussion went on to examine various scenarii.
Magnetic separation of the non converted electrons is proposed to reach the highest luminosities [9]. One needs fields of about 1 Tesla. So far no realistic estimate of the parameters of these coils was available. These problems are examined in section 2.2.

As recalled in figure 6, the $e^+e^-$ set up requires a mask to avoid electromagnetic background returning from the quadrupoles into the detector. The primary contribution of this background comes from beamstrahlung, that is low energy radiation by electrons due to the intense electromagnetic field of the opposing beam. This radiation is then converted by this same field into $e^+e^-$ pairs which can be scattered and hit the quadrupoles. In a PLC, the beam-beam effect is greatly reduced and one should reevaluate the masking problem. At this workshop [23], it was pointed out that there is no obvious reason to have a soft electron component in an optimized PLC. There is clearly a need for a full proof of this idea.

2.2. Magnetic separation

The standard arrangement is shown in figure 7 with two coils in the Helmholtz configuration (distance=radius). The current needed is $I_{\text{Amp}} = 10^6 B_{\text{Tesla}} a_{\text{meter}}$, where $a$ is the distance between the two coils. With a ~ 5 cm, one finds 50000 Amps/Tesla. This would require supraconductive coils to have a reasonable size of the conductors. The mechanical effort would be of only 25 kg. This coil sitting in a solenoidal field would experience a torque which would also be rather modest.

This geometry is cumbersome since one would like to install a microvertex cylinder around the beam pipe. The merit of the Helmholtz configuration is not obvious for this problem, since it provides uniformity along the axis of the coil while the beam circulates perpendicular to this axis. Another possibility is to use two conductors parallel to the beam as shown in figure 7. These two bars could be inside the vacuum pipe and one would only need the space to bring the current from outside the pipe. One may also envisage to have the cooling just outside the vacuum pipe and use thermal conductivity to cool the short bar inside the pipe. The current needed is $I_{\text{Amp}} = 2.5 \times 10^6 B_{\text{Tesla}} a_{\text{meter}}$, with a ~ 1 cm, which gives 25000 Amps/Tesla and a mechanical effort of about 20 kg. The effective current density in a supraconductor is ~500 A/mm². The cross-section of this conductor is therefore reasonable and gives a dead zone (due to multiple scattering effect) of about 10% as shown in figure 7.

During this workshop, I became aware of the effect due to the finite length of the beams which imposes to have zero field at the conversion point. If the conversion point has a longitudinal extension of a few mm, the bending effect can spread the beam in the horizontal plane and reduce accordingly the luminosity. Assuming, as an example, that 0.3 Teslas are left at the conversion point, one obtains an additional spread of the photon spot at the interaction point of the order of a few 10nm, which cannot be neglected. Further detailed work is therefore needed to implement a design which reduces the field remaining at the conversion point.
2.3. I.P. set up

A sketch of a possible set up around the I.P. is shown in figure 8. This sketch is by no means realistic but was meant to trigger discussions at this workshop. I have assumed that the laser beam enters the vacuum chamber close to the I.P. and that it is focused by a parabolic mirror which is crossed by the electron beam (a small hole allows this to happen). The laser beam enters the vacuum pipe through a window, which may seriously affect (non linear effects) the optical properties and therefore affect the focusing at the conversion point. It would be better if the laser beam also travels in the vacuum.

The channel driving the current is also sketched on the lower side, while a possible layout for the microvertex detector starting at 2.5 cm from the interaction point is indicated. In section 3.1, I will discuss some choices for this detector.

3. Detectors

Let me first indicate a few guide-lines which determine the choices.

To estimate properly multiple scattering errors due to the extrapolation from the microvertex detector to the interaction point, one has to measure the momenta of the individual tracks and, therefore, a magnetic field is needed. A strong magnetic field, at least 2 Teslas, helps also to trap the electromagnetic background.

A tracking device is needed to measure the individual tracks. This tracking device has to allow tracking down to $10^5$ as pointed out in section 1.5.2. The minimum radius of this device depends on the accuracy requested for the momenta. Depending on the precision of the tracking detector, the radius varies typically between 1 to 2 m.

With a very precise tracking detector and a small radius, one may use a thin coil and put the electromagnetic calorimeter outside this coil as proposed by the ATLAS collaboration [21]. Another choice is to use a standard tracking device (drift chambers), a large radius which allows a good separation between tracks and to have the electromagnetic calorimeter inside the solenoid as in the JLC proposal [21]. This choice implies a very costly solenoid.

3.1. Microvertex

3.1.1. Microvertex detectors

One may schematically distinguish between two types of approaches: detectors which reconstruct points without ambiguities using CCD or pixel devices, double-sided strip detectors which give two orthogonal coordinates with ambiguities.
At SLD, there are two layers of CCD detectors which give an excellent pattern recognition very insensitive to machine backgrounds [25]. The read-out of these CCD takes 160 ms which seems incompatible with a multibunch scheme. One could imagine to divert (kicker magnet) the following bunch trains during the read-out time as proposed in [22]. In the JLC proposal the size of the CCD is reduced and the read-out time is 6ms, compatible with the assumed interval for bunch trains.

An alternative to CCD are pixels developed for hadronic machines. This type of detector will be tried in DELPHI [26] with a pixel size of 330×330 μm². If one takes a cylinder of radius 3 cm and 16 cm long, the power consumption is ~10 W.

Double-sided strip detectors are used in the four LEP experiments. They are fast and give a high precision (~5 μm) but need external information from the main tracking detector to eliminate ambiguities. In a PLC, this method could fail, due to high backgrounds and, therefore, it is conceivable to have an hybrid solution with pixels to provide an internal pattern recognition (see figure 8). Detailed simulation is needed, with generation of backgrounds, to check the feasibility of this solution. In particular, it may turn out that one needs pixels with finer granularity.

3.1.2. Tagging performances

The figure of merit of b-tagging performances is the precision on the impact parameter extrapolated at the interaction point. A typical result, obtained at LEP and SLD is:

\[ \delta = \frac{a}{p \sin^{3/2} \theta} \oplus b \]

where \( a \sim 70 \mu, b \sim 20 \mu \) and \( p \) is the momentum in GeV.

In the geometry of figure 8, one would have \( a \sim 30 \mu \) and \( b \sim 10 \mu \).

A practical estimate of bb and c̅c̅ separation was implemented assuming an angular coverage starting at \( \theta = 35^\circ \). The bb events are generated (for the Higgs search this selection is usually applied) with \( |\cos \theta_b| \leq 0.7 \). Secondary tracks are selected demanding a 2.5σ effect on the impact parameter in space. There should be at least four tracks with significant offsets. This selection eliminates light quark flavours. Some of these tracks, which belong to a common secondary vertex, should form a mass above 2 GeV. This selection is needed to eliminate the c̅c̅ component.

Finally one keeps 55% of the bb and 2% of the c̅c̅ events, a sufficient rejection given that the c̅c̅ background is 16 times larger than bb.

3.2. Tracking

As stated in the introduction, I have examined two choices.

The most conventional one uses large drift chambers with a standard resolution of
\( \sim 100 \ \mu \text{m} \). The choice of a TPC (Track Projection Chamber), excellent for pattern recognition since it reconstructs space points, seems inadequate to resolve bunch trains with small time separation as in NLC/JLC. With a drift distance of \( \sim 2 \text{ m} \), one would integrate about 30 bunches inside the normal drift time in the TESLA machine. A drift chamber, with a short drift distance of \( \sim 5 \text{ cm} \), is more adequate but gives a poorer longitudinal information (the \( z \) coordinate is obtained with wires tilted at small stereo angles). With a radius of about 2 m, these chambers, when combined with the microvertex tracker, provide a momentum resolution \( \Delta p/p^2 \sim 5 \times 10^{-4} \) with a 2 Tesla field.

The alternate solution is to use a microstrip device with a precision of \( \sim 30 \ \mu \text{m} \). A silicon device has a prohibitive cost while a set up based on an array of MSGC (Microstrip gas chamber) is envisaged by LHC experiments [27, 24]. These chambers are built in small cells, \( \sim 25 \times 10 \text{ cm}^2 \), a feature which helps in resolving ambiguities (as compared to long wires in a drift chamber). The cost is still a serious problem. One would reach \( \Delta p/p^2 \sim 2 \times 10^{-4} \) with a 2 Tesla field and a radius of \( \sim 1 \text{ m} \).

The two setups so far discussed are given in figure 9 and figure 10. Figure 11 [27] illustrates in more detail the features of a MSGC array. An angular acceptance down to \( 10^6 \) cannot be achieved with a single drift chamber (length of the wires) but requires discrete components in the forward region.

3.3. Energy reconstruction

I assume that we have liquid argon for electromagnetic calorimetry but with excellent granularity. In case we put the calorimeter outside the coil, at a small radius, there should be a preshower device to insure a very precise spatial separation. What energy resolution can we hope to achieve with this detector?

At LEP/SLD, one combines the informations from the tracking and calorimetry detectors to reconstruct the total visible energy. The energy "cocktail" that we have at the \( Z^0 \) peak is: 56% for charged particles, 27% for photons, 15% for neutrons and \( K_L \), 2% for neutrinos. The energy resolution obtained by ALEPH [28] is \( \Delta E/E \sim 60%/\sqrt{E} \), while one would ideally expect \( \sim 30%/\sqrt{E} \). There are various systematic effects which contribute to this degradation. Secondary interactions, pattern recognition effects limit track reconstruction. The most serious effect seems to come from the finite granularity of the hadron calorimeter: it is difficult to identify the presence of a neutron or a \( K_L \) inside a jet. One should also not forget that this analysis benefits from the excellent granularity of the gaseous electromagnetic calorimeter (\( \Delta \phi \times \Delta \theta \sim 15 \times 15 \text{ mrad} \)). One should therefore check that, with a poorer granularity (\( \Delta \phi \times \Delta \theta \sim 40 \times 40 \text{ mrad} \)), but with a preshower device, there is no degradation. In the JLC proposal [21], they get a resolution on the Higgs mass of 4 GeV, for the process \( hZ \) with \( m_h = 100 \text{ GeV} \) and for a center of mass energy of 300 GeV. This seems to agree with an extrapolation of what is obtained at LEP. What can one expect in the case of a more compact detector remains to be investigated in detail.
For a heavy Higgs (H or Λ in SUSY) of ~300 GeV, one would get a mass resolution of ~10 GeV. In reference [17] the assumption was 5 GeV FWHM which is a factor four too optimistic.

4. Summary

The physics potential of a PLC is enhanced, specially for the SUSY Higgs case, if one can achieve an integrated luminosity of order 100 fb⁻¹. This seems possible with an improved emittance of the electron beam and magnetic separation after the conversion point. It could be done with supraconducting bars without too much interference with the tracking detector (a plasma lens solution is also considered).

High luminosity requires an adequate detector which can stand the induced backgrounds. This requirement depends very much on the duty cycle of the machine. The b-tagging performance of this detector plays an essential part for Higgs physics. A local pattern recognition based on measured points could be provided by CCD detectors or, to avoid long read-out problems, a combination of double sided strip detectors and pixel devices.

Two distinct conventional detectors were discussed. They both combine tracking and calorimetry and provide a total energy resolution limited by various systematic effects which depend on the granularity of the calorimeter. The angular coverage is limited by the masking system to 10°. It is not clear that this masking system is adequate for a photon collider.

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Figure 1: a) Total cross-section for the Higgs signal measured in fb (solid line and right-hand scale) and invariant mass distribution (in fb/10 GeV, left-hand scale) of the various backgrounds [10]. The shaded area, corresponding to the resolved photon backgrounds with two parametrizations of the photon structure functions, is well above $\gamma\gamma \rightarrow b\bar{b}$ for masses below the maximum energy (a 500 GeV $e^+e^-$ collider is assumed).

b) Spectral luminosity [9] of $\gamma\gamma$ collisions. Dashed lines correspond to electron and laser beams with opposite longitudinal polarizations, solid line to unpolarized beams. The $\rho$ parameter depends on the distance between the conversion point and the interaction point.
Figure 2: The ratio $\Gamma(A \rightarrow \gamma\gamma)/\Gamma(\Phi \rightarrow \gamma\gamma)$, where $\Gamma(\Phi \rightarrow \gamma\gamma)$ is the standard model width, is plotted as a function of the Higgs boson mass [14]. A top mass of 100 GeV was assumed with $M=200$ GeV. The first figure is for $\tan\beta=1.5$, the second for $\tan\beta=4$. The various curves correspond to five $\mu$ values: $-2M,-M/2,0,M/2,2M$. 
Figure 3: Mass ranges for the various SUSY particles given in [4].

Figure 4: Branching ratios for H and A particles given in [15] for tanβ = 2.5 and tanβ = 20.
Figure 5: The $2\sigma$ regions [18] in the $\kappa$-$\lambda$ plane from various measurements of $\gamma\gamma \rightarrow W^+W^-$. The resulting error ellipse is influenced mainly by the total cross-section and the $0/2$ ($J_Z$ values) ratio. The figure below shows a comparison with the constraints given by $e^+e^- \rightarrow W^+W^-$. 
Figure 6: Layout of the interaction region for an $e^+e^-$ collider given in [21].

Figure 7: Two possible setups proposed to generate the strong transverse magnetic field needed to sweep the used electrons in a PLC. On top, one has two superconducting Helmholtz coils outside the vacuum tube. An alternate scheme uses two superconducting coils parallel to the beam and located inside the vacuum tube. A transverse cross section of this layout is shown below, indicating the size of the bars and the corresponding dead zone for the vertex detector.
Figure 8: A schematic layout of the I.P. in a photon collider.

Figure 9: A conventional detector scheme using drift chambers and with the electromagnetic calorimeter inside the coil.
Figure 10: A compact detector scheme using MSGC chambers and with the electromagnetic calorimeter outside the coil.
Figure 11: Layout of MSGC chambers for the central detector in [27].