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A Comparison of different Program Options at a Linear Collider

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Summary of parallel session I presented at LCWS2002, August 2002, Jeju Island , Korea

SUMMARY OF SESSION I: PROGRAM OPTIONS

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1 Introduction

All next generation linear collider designs [1, 2, 3] define as their basic running mode $\mathrm{e^+e^-}$ beams with polarized electrons and a center of mass energy $\sqrt{s} \approx 350 - 500\,\mathrm{GeV}$. However there are several options which allow to enhance the physics output of the projects significantly with moderate investment. In the "Program options" session at LCWS2002 the following options have been discussed:

- adding a second interaction region [4, 5];
- positron and transverse polarization, including polarimetry [6, 7, 8];
- running with high statistics on the Z-pole and at the W-pair threshold (GigaZ) [9, 10];
- running in a $\gamma\gamma\,(e\gamma,\, e^-e^-)$ mode [11, 12, 13, 14];
- energy upgrade of the collider [15].

In addition there have been presentations about a possible running strategy for a physics scenario with many new particles within the reach of the linear collider [16] and detector differences for the different collider designs [17].

2 Detector differences for TESLA/NLC/JLC

There are several differences between the machine designs that require changes in the detector [17]. Some of these differences are optional and can be changed if there are physics requirements for it and some are intrinsic in the choice of the warm (JLC/NLC) or superconducting (TESLA) cavities.

The most important difference is the time structure of the pulses. TESLA has bunch trains of about 3000 bunches per train with a bunch spacing of 300 ns and a repetition rate of 5 Hz while the other designs have trains of about 200 bunches with 2 ns bunch spacing and 100 Hz repetition rate.

Time stamping for individual tracks is clearly easier in the TESLA case. Bunch tagging is important at the high design luminosities in order not to sum $\gamma\gamma$ background from several bunch crossings. Slow detectors like CCDs integrate over a train in the warm design while the number of bunches that are integrated in TESLA depends on the readout speed so that it depends on the details of the detector in which machine design less bunches are summed up. For example for the microvertex detector, CCD sensors with present day technology would integrate over too many bunches to be used at TESLA. However R&D is under way to make them fast enough to be read out in about 100 TESLA bunch crossings [18].

Power can be saved and thus cooling be reduced if the detectors are switched off between trains. It was under discussion if the smaller duty fraction of the warm machine or the longer breaks between trains in TESLA is more effective.

The warm machines need to have a crossing angle between the beams, while TESLA can have head on collisions, if required. A crossing angle results in a somewhat reduced forward coverage, where studies are needed what this really means for physics. On the other hand polarimetry behind the interaction point might not be possible without a crossing angle. If it is possible with a crossing angle and if it is needed also needs to be studied.

Both designs can use permanent magnets to save costs. Those magnets reduce the energy flexibility of the machine and it needs to be evaluated how often a detector calibration on the Z-peak is required.

3 Run scenarios

In most of the physics studies done up to now a single channel has been analyzed typically assuming the luminosity for one year of running. Especially in a physics scenario with many new particles and corresponding thresholds to scan there might be conflicting requirements in beam energy and polarization from the different channels. It is thus a valid question to ask in how far a linear collider can fulfill its promises as a whole and not only for selected channels. To study this question an MSSM scenario with light superpartners, the Snowmass point SPS1 [19], had been chosen as a physics rich scenario and a detailed run plan has been worked out [16]. This run plan assumed for the first phase of the LC seven years, simulating a realistic startup procedure. Also some time for calibration on the Z-peak and an e^-e^- run to measure the selectron mass are included.

In summary the results of the individual analyzes hold for the global scenario and most masses of the new particles can be measured with permille precision. This also means that the present design luminosities are sufficient for the proposed physics analyzes.

4 One or two interaction regions

All machine designs contain the possibility to have two interaction regions that can run at center of mass energies up to 1 TeV. A few open points need to be clarified, but there should be no principle problem to run the two interaction points in parallel [5]. However, two interaction regions don't create additional luminosity at a linear collider.

The arguments in favor of two interaction regions are [4], the possibility to cross check results obtained with one experiment, the possibility to optimize one IP for e^+e^- and the other for $\gamma\gamma$ and to have less physicists per detector. However two interaction regions are more expensive by about 10% and the accelerator is somewhat more complex.

There was a general consensus that it would be desirable to have two interaction regions, one optimized for e^+e^- and the other compatible with $\gamma\gamma$. However also the possibility that this is too expensive was discussed. A push pull solution with two detectors in one interaction region seems not to be wanted. Further studies are needed to understand what is lost in the e^+e^- mode if the only interaction region is compatible with $\gamma\gamma$ and if the same detector can be used for both running modes, possibly changing the region inside the mask.

5 Positron, transverse polarization and polarimetry

In general there are three types of arguments to have polarized electrons and positrons [6].

In most Standard Model processes like processes with s-channel vector particle exchange or W-pair production it is in principle sufficient to have one beam polarized. However polarizing both beams enhances the effective polarization and allows to use the Blondel scheme to measure the polarizations. As two examples positron polarization doubles the sensitivity to anomalous triple gauge boson couplings and reduces the error for the weak mixing angle in the GigaZ mode by about a factor four, even if the beam polarization can be measured to 0.25%.

Some t-channel processes like $e^+e^- \rightarrow We\nu$ can only be switched off if both beams are polarized.

In some processes positron polarization gives additional information. As an example in Supersymmetry the partners of the left and right handed fermions are different particles and for selectron production in the t-channel there exists a unique relation between the chirality of the beam and the chiral quantum number of the produced SUSY partner.

The physics case for transverse polarization is under study but it can for example be used to project out longitudinal W production. However any process can only be sensitive to the product of the transverse polarizations of the two beams so that positron polarization is a prerequisite for transverse polarization.

There exist two schemes to produce polarized positrons [7]. For TESLA it is proposed to send the high energy electron beam through a helical undulator to produce polarized photons which are then converted to positrons in a thin target. In the scheme developed for JLC the polarized photons are produced by Compton scattering of a 6 GeV electron beam with a CO_2 laser. Both system are challenging but seem feasible with 60% positron polarization within reach.

For all machine projects polarimeters are being designed [8]. All aim to measure longitudinal polarization with 0.25% precision. The JLC design also aims to measure transverse polarization. It is currently under discussion if polarimetry behind the interaction point is possible and needed.

6 GigaZ

Another option for a Linear Collider is to run with high luminosity close to the Z-peak and the W-pair threshold. This allows to improve the accuracy of the weak mixing angle and the Zbb couplings by about an order of magnitude and the other electroweak observables like the W-mass or the Z-width by a factor two to three. The luminosity at low energies is proportional to the collision energy at best. But even this proportionality cannot be reached in both types of machine without modifications, the normal conduction designs have beam loading problems while TESLA cannot produce enough positrons [10]. Both problems can be solved using bypass lines. These lines are already included in the JLC/NLC design.

However stringent requirements on the control of the detector and the beam parameters are needed not to be dominated by uncertainties from these sources [9]. To control the polarization in a way sufficient for the $\sin^2\theta^l_{eff}$ measurement, positron polarization is important. Excellent polarimetry is needed in addition for relative measurements. The difference in the absolute values of the positive and negative helicity states needs to be known to 10^{-4} and time dependences have to be tracked to correct for correlations. For the beam energy a precision of 10^{-5} relative to the Z-mass in a region of about 1 GeV around $m_{\rm Z}$ and of $5 \cdot 10^{-5}$ between $m_{\rm Z}$ and the W-pair threshold is required. In addition the beam-energy spread and the beamstrahlung need to be known to a few percent.

7 $\gamma\gamma$, $e\gamma$ and $\mathrm{e^-e^-}$

$\gamma\gamma$ and $e\gamma$ are probably the most discussed options and the physics case has been treated in a special session [20]. From the machine point of view there seem to be no big problems [11]. The accelerator would run in $\mathrm{e^-e^-}$ mode to achieve higher beam polarization resulting in more peaked photon spectra. In addition this mode reduces the background from beamstrahlung. Since beamstrahlung is a less severe problem in $\gamma\gamma$ the beam parameters can be optimized to increase the geometric luminosity. With these parameters the luminosity in the high energy part of the $\gamma\gamma$ spectrum can be about 30% of the e^+e^- luminosity. The same parameters also allow for e^-e^- running with a third of the e^+e^- luminosity.

The more challenging part of a $\gamma\gamma$ collider is the laser needed for the conversion [12]. Pulses with few Joule pulse energy, a diffraction limited spot of a few 100μm Rayleigh length and the time structure of the machine are needed to achieve a good conversion efficiency. For the NLC a design has been worked out that is based on the Mercury laser from the Livermore fusion program. The laser starts to work and a full system test is planned at the SLC. For TESLA a ring resonator is planned to reduce the required laser power by a factor 10 to 100. The total length of the resonator is about 100m and a 1/9 prototype should be build soon. It has to be studied if the Mercury laser can be used as drive laser for the resonator at TESLA.

The $\gamma\gamma$ detector should be as close as possible to the e^+e^- one [13]. Especially if a laser-resonator like the one proposed for TESLA is used the region inside the mask has to be redesigned. In addition the disrupted beam is much larger than in e^+e^- due to the beam laser interaction. This results in many particles hitting the detector in the beampipe region. The background in the TPC is a factor 20 larger than in e^+e^-. In the vertex detector the background from incoherent pair creation is similar to e^+e^-, the one from backscattering from the main beam still needs to be evaluated. Since photons cannot be deflected easily there has to be a direct line of sight from the interaction point to the beam dump. This leads to a large flux of neutrons in the microvertex detector.

Another challenge in $\gamma\gamma$ is the measurement of the luminosity [14]. For a $\gamma\gamma$ angular momentum of $J_z = 2$ a good gauge process, $\gamma\gamma \to \ell^+\ell^-$ exists, allowing a statistical precision of 0.2% to 0.4% per year. Unfortunately the cross section for this process is almost zero for $J_z = 0$ which is the configuration needed for the Higgs studies. As a possible way out it is proposed to flip the electron and photon helicity in one beam and measure the luminosity in a special run. Possible systematic uncertainties of this configuration have to be studied.

In $e\gamma$ in principle the cross section of the process $e\gamma \to e\gamma$ is finite for both signs of the helicity product $\lambda_e\lambda_\gamma$ with different angular dependencies. However for the parasitic $e\gamma$ luminosity during $\gamma\gamma$ running, where the direction of the photon and of the electron is not known, the $\lambda_e\lambda_\gamma = -1$ component is always much below the $\lambda_e\lambda_\gamma = 1$ one. Using $e\gamma \to e\ell^+\ell^-$ in addition should allow to measure the two components separately. If also the different λ_γ and λ_e have to be distinguished, a process involving a weak coupling like $e\gamma \to eZ$ has to be used.

8 Energy upgrade

The physics case for an energy upgrade has been discussed [15]. There are at least three reasons to go beyond the initial $\sqrt{s} = 500\,\mathrm{GeV}$. Since some cross sections, like $\mathrm{e^+e^-} \to \nu\nu\mathrm{H}$ rise logarithmically with energy, there can be a statistical advantage to run at higher energies. This advantage could be compensated, however, with running at lower energies with improved luminosities. For some observables, like gauge bosons couplings, the sensitivity rises with energy. This rise is often very steep and a compensation is possible only to a very limited amount. The third reason for higher energies are new production thresholds. In this case there is no way to compensate higher energy with more luminosity.

In any physics scenario there are strong reasons to run at a center of mass energy around 1 TeV. Within the Standard Model with a light Higgs the threshold for $\mathrm{e^+e^-} \to \mathrm{t\bar{t}H}$ opens and the rate for $\mathrm{H} \to \mu^+\mu^-$ gets large enough to be measured. Within Supersymmetry the probability is very high that there are new thresholds between 0.5 and 1 TeV and to study strong electroweak symmetry breaking one needs a high sensitivity to anomalous gauge boson interactions. The exact value of the center of mass energy can only be specified when all the physics, and thus all the threshold energies, are known.

On the long term one certainly wants to go also beyond 2 TeV, but it is premature to discuss this topic in detail, before results from LHC and the next generation linear collider are available.

It should however also be noted that experimentation gets more difficult at higher energy, since for example beamstrahlung, track density and $\gamma\gamma$ background increase.

9 Conclusions

There exist several options to go beyond the baseline design of a next generation linear collider. All these options have a well defined physics case and seem technically feasible. Some options, like the energy upgrade, have to be forseen from the beginning. Others like GigaZ can probably be implemented while the LC is already running. However financial constraints might require to drop or downgrade some of the options. The community has thus to find a procedure to set priorities soon.

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References

[1] K. Yokoya, *JLC*, these proceedings.

[2] D. Burke, *NLC*, these proceedings.

[3] Y. Cho, *TESLA*, these proceedings.

[4] P. Burrows, *1 or 2 IPs?*, these proceedings.

[5] T. Markiewicz, *Constraints on working with two IRs*, these proceedings.

[6] K. Desch, *Physics benefits of positron and transverse polarization*, these proceedings.

[7] T. Omori, *Positron polarisation and production technologies and impact on the machine*, these proceedings.

[8] Y. Kurihara, *Polarimetry at Tesla, at NLC/JLC*, these proceedings.

[9] K. Mönig, *Measurement prerequisites to GigaZ*, these proceedings.

[10] K. Yokoya, *Tesla/NLC/JLC machine capabilities at GigaZ*, these proceedings.

[11] T. Takahashi $\gamma\gamma\,(e^-e^-)$ *technology and machine constraints*, these proceedings.

[12] J. Gronberg, *Laser work at Livermore*, these proceedings.

[13] A. Stahl *How the detector must be changed for $\gamma\gamma\,(e^-e^-)$*, these proceedings.

[14] V. Telnov, *Measurement of $\gamma\gamma$ and γe luminosities*, these proceedings.

[15] T. Barklow, *The case for the high end energy*, these proceedings.

[16] P. Grannis, *Run Strategy*, these proceedings.

[17] J. Brau, *Collider technology implications for experiments*, these proceedings.

[18] M. Winter, *Summary of Workgroup G. Vertexing & Tracking*, these proceedings.

[19] B. C. Allanach *et al.*, Eur. Phys. J. **C25** (2002) 113.

[20] M. Krawczyk, *Summary of Workgroup E. $\gamma-\gamma$ and $e-\gamma$ Physics*, these proceedings.