12.4 Positron Source White Paper

Tom Himel, Karou Yokoya, Nick Walker

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Executive Summary Summary

The keep-alive source should have at least 10% of the nominal positron intensity. The undulator should go at about the 150 GeV point in the linac

Executive Summary

We were charged to make two recommendations: the requirements for the keep-alive source and the proper location of the undulator.

The primary requirement for the keep-alive source which came out of the availability studies is that it be strong enough that diagnostics (primarily BPMs) work as well with the keep-alive source as they do with full intensity beams. There must be no gain, offset, or resolution changes that prevent machine development and beam based alignment results from being as useful as those done with the undulator source. We asked a few diagnostics people what intensity this would take and they thought they could do it with 1% of design intensity but admitted they were uncertain as systematic errors are the problem and there is no design yet. We recommend a minimum intensity requirement of 10% of nominal intensity to reduce the chance of such systematic errors making the keep-alive source nearly useless, and because there are inexpensive ideas on how to make a ≥10% source. This source would have all bunches filled to 10% of nominal intensity. Note that for many purposes higher single-bunch intensity is better even at the expense of populating a smaller fraction of the bunch train.

After considering a large number of pros and cons between placing the undulator at the end (END) or at the 150 GeV (MID) point of the linac, we concluded that all were minor compared to their differing yields as a function of energy. They are both currently designed to have a yield of 1.5 at a beam-energy of 150 GeV. Note that the desired actual yield is 1.0 and the design value of 1.5 was chosen to ensure that 1.0 can be easily reached without a lot of tuning and to provide some insurance in case the real accelerator doesn't perform to the design. The MID design has a yield that is a constant 1.5 over the full energy range. The END yield varies with beam energy. It has dropped by a factor of 4 by 100 GeV, by a factor of 300 at the Z (meaning the 10% strength keep-alive source would be used at the Z for detector calibration) and has increased a factor of 2.5 by 250 GeV.

The decision basically came down to the advantage of END being that it ameliorates the risk of a low e+ yield at energies above 150 GeV. Its disadvantage is a guaranteed lower yield (and hence luminosity) at beam energies below 150 GeV. With this as the major factor and without additional clarification on the physics requirements (luminosity) at lower centre-of-mass energies, we recommend the MID location for the undulator.

Required Intensity of the keep-alive source

Considerations (what we gain as intensity goes up)

Consider 3 possible levels for the keep-alive positron intensity

- LOW: defined to be enough for diagnostics to work, but not enough to do serious MD and beam based alignment work
- MEDIUM: defined to be enough for diagnostics to work well enough to do serious MD and beam based alignment work, but not enough to work on collective effects or thermal problems in the DRs.
- HIGH: defined to be enough to work on collective effects and thermal problems in the DRs

Availability simulations showed that the gain from LOW was minimal while MEDIUM allowed the ILC with an undulator source to be up almost as much as one with a conventional source. While HIGH didn't increase the availability much more, that certainly depends on assumptions as to how much trouble will be caused by collective effects and heating in the DR. If they are more troublesome than assumed for the simulation, then HIGH intensity could be more important.

Note that ability to go to a higher intensity is always better, so a decision on the requirement must also include information on how hard it is to achieve the requirement.

Description of possible sources

We considered two possible forms of the keep-alive source that have been worked out by the sources group.

1. The first is a 10% intensity source which uses a ~500 MeV linac to direct a beam at the same target used for the undulator source. Details can be found at

   http://www.eurotev.org/e158/e1365/e1378/e1520/EUROTEV-Report-2005-019-1.pdf

2. The second time-shares the 5 GeV positron booster linac to produce roughly full intensity bunches at half the nominal bunch rate. It requires a 250 MeV linac, a high power positron target and capture section, and some transport lines. A drawing can be found at https://ilcsupport.desy.de/cdsagenda/askArchive.php?base=agenda&categ=a0533&id=a053
   3s1t9/moreinfo.

The second source is clearly more difficult and expensive than the first although significantly more powerful.

Recommendation

The availability studies and source costs make it clear that MEDIUM is the preferred option. Next it is necessary to determine what intensity that implies. The primary requirement for the MEDIUM keep-alive source which came out of the availability studies is that it be strong enough that diagnostics (primarily BPMs) work as well with the keep-alive source as they do with full intensity beams. There must be no gain or offset or resolution changes that prevent machine development and beam based alignment results from being as useful as those done with full beam intensity. We asked a few diagnostics people what intensity this would take and they thought they could do it with 1% of design intensity but admitted they were uncertain as systematic errors are the problem and there is no design yet. We recommend a minimum intensity requirement of 10% of nominal intensity to reduce the chance of such systematic errors making the keep-alive source nearly useless and because there are inexpensive ideas on how to make a 10% source. This source would have all bunches filled to 10% of nominal intensity. Note that higher single-bunch intensity is better even at the expense of populating a smaller fraction of the bunch train.

Location of the Undulator

Description of the two locations considered

Two locations have been considered for the location of the undulator.

1.1. At the end of the linac. This would be just downstream of the MPS collimators, energy measurement chicane and fast extraction system. Downstream of it are BDS corrections, diagnostics and the big bends to split the beams to go to two IRs. This will be referred to as END in the remainder of this document.

2.2. At roughly the 150 GeV point of the linac. This energy is chosen so that one can run from the Z energy up to 250 GeV without changing the electron beam energy that goes through the undulator. The electron beam is decelerated in the rest of the linac after the undulator when the beam energy for collision is below 150 GeV. This will be referred to as MID in the remainder of this document.

Temporary design choices for the undulator sources

For both END and MID there are further design choices that need to be made. For clarity of arguments in the paper, we have made these decisions in a way that we think makes each option as good as possible. Once the location is decided, these smaller decisions should certainly be considered more carefully and final decisions made. In some of the pros and cons below we will mention the effect it would have if one of these decisions was taken differently.

Provisions for low energy running

END has a luminosity a factor of four less than MID at 100 GeV as will be discussed below. This could be mitigated to only a factor of two with the addition of a bypass line from the 100 GeV point to the end of the linac, or by increasing the length of the undulator, should the physics case require it. For the purposes of this comparison, we assume this is not done to keep the cost down.

Other design choices

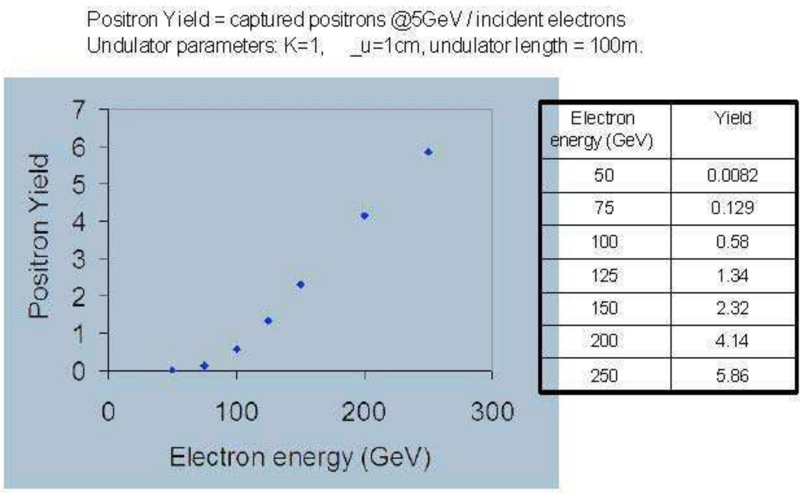
Other design choices such as the allowed emittance growth in the bends, shape of the beam line to separate the gammas from the electrons, and separation distance of the positron target from the electron beam line mainly effect cost. As the cost difference turned out to be smaller than the errors in the cost it isn't necessary to enumerate the design choices here

Pros and cons

Positron yield for beam energies between 100 and 150 GeV and at the Z: favors MID. In this energy range

the beam energy in the END undulator varies between 150 and 100 GeV. $1/\sqrt{s}$ This decreases the e+ production rate and makes the luminosity roughly drop (in addition to the scaling from adiabatic damping) so that at 100 GeV it is one fourth that of the MID solution. See Figure 1 for the simulation results of Wei Gai which are consistent with those of Klaus Floettmann. Note that the physics requirements are not met in the 100 to 150 GeV beam energy range for END. This is mitigated somewhat by energy run plans (http://www.slac.stanford.edu/econf/C010630/papers/E3006.PDF) that have only 10% of the integrated luminosity in the effected energy range. Having the runs at those energies occur at half the luminosity hence makes the average design luminosity of END 10% less than that of MID. Note that the design yield of 1.5 at 150 GeV is considered to be a necessary margin to make sure a yield of 1.0 is actually achievable without constant tuning. It is wrong to use the factor of 1.5 to say the yields at lower energies are adequate.

The END yield at 50 GeV (for Z calibration) is very small. The keep-alive source would be used instead of the undulator for this running. As the keep-alive source is specified to be 10% of the nominal intensity, the Z calibrations for END will take 10 times longer than those for MID. There are widely varying numbers in circulation for the amount of Z luminosity needed for the calibration so we are not able to determine the overall impact of this factor of 10 luminosity difference.



Electron energy (GeV)	Yield
50	0.0082
75	0.129
100	0.58
125	1.34
150	2.32
200	4.14
250	5.86

Figure 1: Positron yield as a function of energy as calculated by Wei Gai at ANL.

Positron yield at high energies: favors END. At high energies, the e+ yield for the END option will be >> 1 making e+ intensity tuning trivial. This is really a risk mitigation effect. If the design yield of 1.5 is achieved, it is large enough and the extra yield doesn't help. However, if we miscalculate the yield or the DR acceptance is significantly smaller than planned, then the extra yield at high energies will be very welcome. A numerical example is that if the DR acceptance is 0.04 instead of the design of 0.09, then the calculated yield at 150 GeV drops from 1.5 to 1.13. For MID it would be 1.13 at all beam energies. For END it would increase to 2.8 at 250 GeV.

The above 2 pros and cons regarding yield are considered by far to be the most important. Cost would be important except that the total cost of the e+ system is fairly small and the cost differences we have evaluated have fairly large uncertainties that depend on engineering which has not been done.

Cost: favors neither. We did a crude cost estimate of the two options. They came out equal within errors. Different assumptions could change the relative cost by around 20% which is not a large enough difference to have a significant impact on the decision. For example adding a bypass line to improve the END low energy luminosity had this effect. Things we took into account in the cost estimate were that END made use of the existing BDS protection collimators and fast extraction dump and required slightly longer arcs to limit emittance growth. There are no designs of either option with enough detail to evaluate differences in terms of number of access shafts or costs to avoid interference of the gamma line with the electron line.

The remaining pros and cons are all much lesser weight and are listed primarily to let people know they were considered and to help guide future reviews and reexaminations of the decision. They are listed in essentially random order.

Energy jitter for beam energies less than 150 GeV: favors END. At low energies when the undulator is at the 150 GeV point, the beam must be decelerated after the undulator. Both the acceleration and deceleration add to the energy jitter resulting in a higher energy jitter for this case than when the undulator is placed at the end. The worst case is when each section of the linac has an energy jitter (probably due to phase jitter) that is) independent of the other sections and the desired beam energy is very low (say 50 GeV to run on the Z^0. For this case, the MID undulator must accelerate the beam to 150 GeV and decelerate it by 100 GeV for a total of 250 GeV of acceleration. $\sqrt{5}$ The end undulator only needs 50 GeV of acceleration for the luminosity beam. Its energy jitter will thus be = 2.2 less than for MID undulator. The WWS requirements state that the energy jitter should be less than 0.1%. A rough calculation based on numbers from the TDR (and the ILC design is different than that) indicate the MID energy jitter would be about 1.4 times this WWS requirement. This would have to be accepted, or mitigated by reducing the random energy jitter of each RF station.

Note that no extra emittance degradation is expected for low energy running with MID. If anything, there will be less emittance growth than for END as the beam reaches a high energy sooner and hence wakefields have a smaller effect.

Need for e+ tuning when energy is changed: favors MID. With the undulator at 150 GeV, the beam energy only varies downstream of the undulator as energy at the IP is varied. For the end undulator, the beam energy will change in the undulator and some tuning of the e+ production is likely. Note that increasing the energy should be easy as the yield increases, but decreasing the energy to near 150 GeV is more likely to require more tuning.

Flexibility of linac operation: favors END. The MID solution requires the first section of the linac to always run at full gradient while END allows the flexibility to run that way or to run everything at lower gradient when the maximum beam energy is not required. Running below 150 GeV in MID requires part of the linac to run back-phased (to decelerate the beam). While possible in principle, actual experience in a SC linac is lacking. (It is commonly done at SLAC.)

BDS upgrade flexibility: favors MID. This flexibility could be important to allow for some improvements, such as additional collimation stages, or lengthening the diagnostics section, or addition of a second interaction region. If the BDS is attached to the end of a straight linac, (the case for MID), one can simply remove cryomodules and extend the BDS into the linac tunnel. If the undulator is placed at the end of the linac, the bends and the undulator would have to be moved upstream in this upgrade scenario.

Difficulty of Main Linac Energy Upgrade.

- If full length tunnels are built and the upgrade is done by adding RF to the downstream end: **favors MID**. For this energy upgrade, MID needs no modifications. END may need to have its undulators replaced with ones better matched to the higher beam energy and perhaps have its bends made more gently to reduce emittance growth. (An option to put the undulator at the end of the phase 1 linac at the 250 GeV point, allowing the phase 2 linac to be constructed downstream was not considered in this paper.)
- If short tunnel is built and upgrade is done by digging more tunnel in the upstream end: **favors neither**. The changes needed for END are the same as above. For MID, one has the choice of leaving it in its original location and making changes similar to END, or moving it upstream to the new 150 GeV point.

Recommendation

After considering a large number of pros and cons between placing the undulator at the end (END) or at the 150 GeV (MID) point of the linac, we concluded that all were minor compared to their differing yields as a function of energy. They are both currently designed to have a yield of 1.5 at a beam-energy of 150 GeV. Note that the desired actual yield is 1.0 and the design value of 1.5 was chosen to ensure that 1.0 can be easily reached without a lot of tuning and to provide some insurance in case the real accelerator doesn't perform to the design. The MID design has a yield that is a constant 1.5 over the full energy range. The END yield varies with beam energy. It has dropped by a factor of 4 by 100 GeV, by a factor of 300 at the Z (meaning the 10% strength keep-alive source would be used at the Z) and has increased a factor of 2.5 by 250 GeV.

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