Use of Polarized $\gamma$'s to Produce Polarized Positron at Collider Energies — How to Test it Sensibly With 50 GeV $e^-$ in the FFTB

NLC Collaboration Video Meeting
**γ-Production and Polarization of e⁺**

Proposed in '79 by Amaldi & Pelegrini and Balakin & Mikhailichenko

**Basic Idea:** make polarized γ's, this enables use of thin target

**Problem:** only forward γ's are circular polarized, only highest energy e⁺ have longitudinal high enough polarization

See Mikhailichenko’s talk in: WG1, LC02
Proposal

- Use the SLAC 50 GeV low emittance beam in conjunction with a ≈1-2 mm period undulator to demonstrate undulator based production of polarized positrons from polarized γ’s for linear colliders (at the same time investigate different methods how to make the γ’s in the future)

- Measure the yield, spectrum, and polarization of both the photons and positrons

Do this in the next 18-30 months in the FFTB enclosure:

- Proof of Principle Demonstration
- Validate Codes
- Develop γ Spin Diagnostics
- Develop e+ Spin Diagnostics
Why Make Polarized $e^+$ at all?

- Error in polarization measurements dominate statistics for Giga-Z
- Effective polarization increases with both $e^-$ and $e^+$ being polarized, making the error less important
- Essential for Giga-Z, $P_{e^-} = 0.9$ and $P_{e^+} = 0.7 \rightarrow P_{\text{eff}}>0.98$
- Consequently: Giga-Z can only be a start-up experiment if polarized $e^+$ are available from the beginning.
How to Make Positrons

Proposal goes to the heart of how to make positrons:

Present **NLC baseline** includes the 3-of-4-concept. This needs 4 SLC-type thick (~5 rad lengths) targets

- **Advantages**
  - independent of primary e⁻ production
  - Works, as we know from SLC

- **Disadvantages**
  - messy, as we know from SLC
  - each target close to the mechanical limit
  - cannot be extended to polarized e⁺ production
The TESLA concept needs

• \(\sim 200 \text{ GeV} \) electrons from the TESLA \(e^-\) production beam, and a \(\sim 40 \text{ m} \) 15 mm period undulator, to make 20 MeV \(\gamma\)'s.
  — TESLA base plan does not include polarization

• Later upgrade: 200 m helical\(^1\) undulator to make 20 MeV polarized \(\gamma\)'s to make polarized positrons

• Not clear if 20 MeV is optimum
  — Possibly higher energy \(\gamma\)'s, produced by other means, lead to better selection/collection of positrons with a higher polarization

\(^1\) Crossed planar undulators are also called helical, see later
Using Polarized $\gamma$'s in TESLA's Scheme

- **Advantage:** can use thin (< 0.5 radiation length) Ti target. Less thermal and radiation load on the target.

- **Disadvantage:** it couples $e^+$ production to primary $e^-$ production

- **Disadvantage:** needs 200 GeV beams even if the physics only needs 50 GeV (Giga-Z) or ~125 GeV (Higgs)

- **Need ~ 200 m of undulator** and additional tunnel and transfer lines across IR region

- **Impacts on quality of beam, possibly important for later upgrades**
Even if 20 MeV γ-Energy is the optimal energy for e+ production and collection, 20 MeV γ's do not have to be made from 100’s of GeV electrons with 200 m long cm-type undulators. There are other possibilities:

- Taking electro-mechanical undulators to the limit (~1 mm) requires “only” 50 GeV, but still long undulators
- Using laser undulators (Compton backscatter) requires only ~1-5 GeV
- If plasma undulators (a la E-157), with their Mega Gauss fields, can be made to work, undulators can be very short
The FFTB Test

Goals:

• **demonstrate** the viability of undulator based positron production, both polarized and unpolarized

  Example: crossed planar undulators work even in the SASE case

• **design** (steal, borrow) conversion, collection, and detection systems

• **measure** the yield, spectrum, and polarization of $\gamma$'s and $e^+$'s.
# NLC - The Next Linear Collider Project

## Is a Test Possible at all in FFTB?

### Important qualities of the beam

- **Size** < 50 $\mu$m to thread through a narrow mm-undulator
- **Divergence** < $1/\gamma$

<table>
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<th>Parameter</th>
<th>Units</th>
<th>TESLA</th>
<th>NLC</th>
<th>FFTB</th>
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<td>0.72</td>
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<tr>
<td>$Y_+$</td>
<td>%</td>
<td>1-5</td>
<td>2</td>
<td>2-5</td>
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<tr>
<td>$L_u$</td>
<td>m</td>
<td>150</td>
<td>250</td>
<td>1</td>
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<tr>
<td>$N_s/pulse$</td>
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<td>1.5x10$^{12}$</td>
<td>1-3x10$^{7}$</td>
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<tr>
<td>$N_s/bunch$</td>
<td>-</td>
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<tr>
<td>Polarization</td>
<td>%</td>
<td>40-70</td>
<td>40-70</td>
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### Critical parameters in red

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<th>$\beta_x,\beta_y$</th>
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<td>m-rad</td>
<td>m</td>
<td>$\mu$m</td>
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<td>39</td>
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</tr>
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</table>

3/14/02

Pitthan/Sheppard
Can You Make the Undulator?

The requirements are pushing the state of the art, but are be possible.

If successful, it is not solving a problem which does not need to be solved for Full Linear Colliders, it allows to back off with the energy for e+ production from 100's to 50 GeV.

Compton backscatter tempting candidate for alternative technology, but needs breakthrough in average power of lasers.
Figure shows Yield demands:

Need to cut out ~80 % of the positrons to get high enough average polarization.

So need to start with enough γ's, to wit about 5 times more than for the unpolarized positron case.

EGS simulation from David Schultz' Snowmass Talk:
http://www-project.slac.stanford.edu/lc/local/systems/Injector/PositronSource.htm
Test and Collider are Connected Issues

- Explore how to **test the concept now** (~ a few years) in an expedient manner (cheap) using the 50 GeV beam available at SLAC
  - make polarized $\gamma$'s
  - measure $\gamma$ polarization
  - measure e+ polarization
- Explore **how and if** this translates into NLC positron production
- It is possible that we will do this test, learn about polarimetry and other connected matters, and then decide to use **a different method** to make the $\gamma$'s.
Get Some Feeling for Undulator Numbers

Undulator $K$ parameter:

$$K = 0.934 \lambda_u [\text{cm}] B_0 [\text{T}]$$

Note: $K \ll 1$ by necessity for micro Undulators

For $K \ll 1$, $\gamma$-Energy independent of undulator strength

Radiated energy per electron

$$\Delta E [\text{eV}] = 725 \ E^2 [\text{GeV}] \ K^2 \ L_u [\text{m}] / \lambda_u^2 [\text{cm}]$$

$$E_1 [\text{keV}] = 0.95 \ E^2 [\text{GeV}] / \lambda_u [\text{cm}]$$

For $K \ll 1$, nearly all radiation in fundamental Photon energy scales with square of beam energy

Example: 50 GeV, $\lambda_u = 1\text{mm}$

$$E_1 = 23.7 \text{ MeV}$$
What are the Yields?

SLAC has in the FFTB: $N_e \approx 1 \times 10^{10} \, e^-/bunch$, $E = 50 \, GeV$, and

$\gamma \varepsilon_x = \gamma \varepsilon_y = 1.5 \times 10^{-5} \, m-rad \, (coupled)$. 

For a planar undulator with $\lambda_u = 1 \, mm$ and $B_0 = 0.5 \, T$

$$K_u = 0.047 \rightarrow E_{c10} = 23.7 \, MeV \rightarrow E_{av} = 12 \, MeV$$

$$\Delta E \approx 0.38 \, MeV/m/e^-$$

In this energy region, $h \nu Y_p$, the yield of positrons from $\gamma$'s incident on 0.4 r.l. of Ti, is about 0.05 $e^+$/photon.

For $N_\gamma = 1 \times 10^{10} \, e^-$ per bunch, the expected yield of $e^+$ is then

$$N_{e^+} = N_\gamma \times \Delta E / E_{av} \times Y_{e^+} = 1.5 \times 10^7 \, e^+ / m/bunch$$

(For a helical undulator the yield is double)
Sketch of Hardware
Important: Decision on Undulator

Touchy, because experts have historical vested interests. Cross-over between advantages of permanent magnet vs superconducting technology in the 1 - 2 mm region.

- Collect information on performance and cost of planar helical and solenoidal helical undulators
- Planar undulators in orthogonal planes also produce elliptical photons, that is any planar undulator system can be made to produce circular polarized photons (K.-J. Kim, 1984)
- Explore superconducting vs. non-superconducting technology

Some possibilities follow:
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**Built and Tested (Rossmanith)!**

- Example for planar configuration with a double superconducting solenoid from ANKA (Karlsruhe - Mainz, PAC99).
- Period $\lambda_u = 3.8$ mm
- Design field $B_0$ (solenoid center) = 0.5 Tesla, field in gap can be 3 times higher

**Improved Geometry**

- Experiment at Mainz at 885 MeV: achieved were 1.8 keV X-rays
- Scaled to 52 GeV: 6.2 MeV
- Scaled to 52 GeV @ 1.0 mm: $\approx 25$ MeV

Notice nice shape of spectrum
**Designed:** Superconducting with Iron

- DESY double helix design (Flöttmann, Wipf). Has by necessity twice the undulator length than the ANKA design.
- Designed for $\lambda_u = 12$ mm, but can reach smaller values.

From TESLA Report 1995-05; also in LINAC96, TUP80.
**Designed:** Permanent Magnet Helical Design

- At SSRL: hybrid/PM development

Periodical structure machined into the steel mono block. Can reach mm.
Example of Helical Planar Undulator

A completely different approach is described Tatchyn et al., in Rev.Sci.Instr. 60(1989)1796.

Made out of “cerrated” NdFeB (no N/S alternating poles) in a biased iron yoke.

It reaches $B_0=0.3$ T with 706 $\mu$m undulator period at a gap of 0.25 mm.
Polarimetry

For $\gamma$-polarimetry 2 methods have been proposed (Schopper 1958)
• Interaction with polarized matter (an iron block)
• Helicity Transfer to secondary particles

Three options proposed for e+ from E-158 experts (Chudakov, JLAB, see http://www.slac.stanford.edu/~gen/slac_20mev_polarimetry.html):
• Bhabha scattering (instead of Møller for e-) on polarized e-, as in polarized iron foils.
• 2-photon annihilation on polarized e-, as in polarized iron foils.
• Mott scattering on a heavy nucleus

Mott scattering works best at lower energy and is already difficult at 5 MeV. Single arm Møller measurements have a high back ground, double arm measurements are difficult because of the low SLC duty cycle.

Work in progress, a good topic for a University group.
So What is Required

- A modeled proposal, including beam line and detector hardware requirements, and which simulates results
- Cost and schedule development
- Submittal and acceptance of proposal
- Construction, Installation, Checkout, and Commissioning
- Experiment and comparison with simulations