The Design of the Positron Source for the International Linear Collider

Jim Clarke, ASTeC, Daresbury Laboratory

EPAC 2008, Genoa
23rd to 27th June, 2008
What is the ILC?

- The ILC is a proposed **electron-positron collider**
- Both beams have maximum energy **250 GeV**
- Total length of facility **~35 km**
- Peak Luminosity **$2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$**
• The ILC positron source is much more demanding than any other positron source yet built

• Requires \( \sim 1000 \) times more positrons per macropulse than the SLC

• Each bunch must contain \( 2 \times 10^{10} \) positrons (3.2 nC)

• 2625 bunches per macropulse @ 5Hz

• Additionally, must have upgrade path to provide polarized positrons with polarization \( \sim 60\% \)
Three possible solutions have been proposed:

- **Electrons** into a target (‘conventional’)
- **High energy photons** into a target
  - Gammas generated by an **Undulator**
  - Gammas generated by **Compton Scattering**
- All three options have been studied and the advantages and disadvantages compared

When the baseline was established for the ILC in 2005 the **Undulator-based source** was selected as it was judged to be the **lowest risk option**
- **10MeV+ photon beam** generated in helical undulator by **150 GeV electrons**
- Photon beam travels ~400 m beyond undulator and then generates e⁺e⁻ pairs in **titanium alloy target**
- Positrons captured and accelerated to 125 MeV
- Any electrons and remaining photons are then separated and dumped
- Positrons further accelerated to **400 MeV and transported for ~5km**
- Accelerated to 5 GeV and **injected into Damping Ring**
• Experiment at SLAC (E166 in 2005) to demonstrate feasibility of this technique

• Successfully generated (polarized) positrons in good agreement with simulations

\[ \text{46.6 GeV electrons} \]
\[ \text{1m long undulator, 0.9mm aperture, } \lambda_u = 2.54\text{mm} \]
\[ \text{Tungsten target} \]

The Undulator

- To generate the photons with a high enough energy (>10MeV) need to use **short period, high field**, undulator
- For sufficient positrons undulator must be ~200m
- Short period, high field, only possible with **narrow aperture**:
  - Resistive wall effects
  - Vessel surface roughness effects
  - Synchrotron radiation power problems
  - Generating a vacuum with difficult aspect ratio
  - Mechanical tolerances
  - Manufacturing issues

- **Superconducting** technology solution chosen after ‘competition’ with permanent magnet

Undulator Details

- Several **short prototypes** have been tested
- Focus now on design, manufacture and testing of a **full cryomodule**
- Daresbury & Rutherford Appleton Laboratories are jointly building a full scale **4m undulator** module
- Cornell have had a similar program of building short prototypes and intended to build a full cryomodule

<table>
<thead>
<tr>
<th>Undulator Parameters</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undulator period</td>
<td>( \lambda )</td>
<td>1.15</td>
<td>cm</td>
</tr>
<tr>
<td>Undulator strength</td>
<td>( K )</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Undulator type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Active undulator length</td>
<td>( L_u )</td>
<td>147</td>
<td>m</td>
</tr>
<tr>
<td>Field on axis</td>
<td>( B )</td>
<td>0.86</td>
<td>T</td>
</tr>
<tr>
<td>Beam aperture</td>
<td></td>
<td>5.85</td>
<td>mm</td>
</tr>
<tr>
<td>Photon energy (1\textsuperscript{st} harmonic cutoff)</td>
<td>( E_{c10} )</td>
<td>10.06</td>
<td>MeV</td>
</tr>
<tr>
<td>Photon beam power</td>
<td>( P_\gamma )</td>
<td>131</td>
<td>kW</td>
</tr>
</tbody>
</table>
Similar schemes developed by both groups

Diameter of cryostat ~10 cm (4”)

- Completed design;
- System for magnetic measurement designed;
- Undulator includes correctors and BPMs;

Å Mikhailichenko, Cornell

S Carr, RAL

Current input one/few modules (ten)

Will be extended to 2 m long ~4 m total
1.75m Undulator Fabrication

- Winding
- Potted and in one half of steel yoke
- Complete magnet
4m Cryomodule Fabrication

Heat Shield

Vacuum Vessel

U Beam

He Vessel
Both long undulators have exceeded the design current (216 A) by ~40%.

The two nominally identical magnets have quite different behaviours – the reason is not understood.
Several materials have been considered for the conversion target. 

Titanium alloy selected as has greatest safety margin.

Need to rotate target to reduce local radiation damage and thermal effects (1m diameter selected).

Positron capture enhanced by magnetic field but eddy current effects limit field level.

Rim & spokes not solid disk to help mitigate these eddy current effects.

<table>
<thead>
<tr>
<th>Target Parameters</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target material</td>
<td></td>
<td>Ti-6%Al-4%V</td>
<td></td>
</tr>
<tr>
<td>Target thickness</td>
<td>$L_t$</td>
<td>0.4 / 1.4</td>
<td>r.l. / cm</td>
</tr>
<tr>
<td>Target power adsorption</td>
<td></td>
<td>8</td>
<td>%</td>
</tr>
<tr>
<td>Incident spot size on target</td>
<td>$\sigma_i$</td>
<td>&gt; 1.7</td>
<td>mm, rms</td>
</tr>
</tbody>
</table>
Experiment initiated at Cockcroft Institute/Daresbury Laboratory to monitor *eddy current* effects and *mechanical stability* of full size wheel at design velocity.

- Rotary torque transducer
- Dipole magnet
- 15kW drive motor
- Target Wheel

I Bailey et al, MOPP069
Experiment will start when personnel guards are in place

Should be completed by end of 2008
Target Activation

- Equivalent dose rate calculated after **5000 hours** of operation at **1m** from the source
- **Remote handling** required so can exchange target modules rapidly
- No intention to make in-situ repairs of the target

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Undulator Based</th>
</tr>
</thead>
<tbody>
<tr>
<td>after Source Switch-Off</td>
<td>700</td>
<td>280</td>
</tr>
<tr>
<td>after 1 hour</td>
<td>628</td>
<td>248</td>
</tr>
<tr>
<td>after 1 day</td>
<td>574</td>
<td>111</td>
</tr>
<tr>
<td>after 1 week</td>
<td>469</td>
<td>86</td>
</tr>
</tbody>
</table>

A. Ushakov, MOPP077
Capturing the Positrons

- If a linac is placed directly after the target then \(\sim 10\%\) of the positrons are captured.
- Using an appropriate magnetic field can enhance the capture significantly.
  - Simple solenoid (QWT, no field on target) \(\sim 15\%\)
  - Flux concentrator \(\sim 21\%\)
  - Lithium lens \(\sim 40\%\)

- Flux concentrator is an established technique.
- Needs to be scaled up from \(\mu\text{s to ms}\) pulse lengths.
- Further study needed to prove feasibility.
- Would need a prototype.
- Presently assumed solution.
- Current flows co-linearly with positrons
- Induced magnetic field gives **focussing**
- Lithium will be liquid with flow of ~1m/s
- Capture up to **~40%** of positrons
- Would also need **prototype**
- **Modest** investment needed now for significant savings overall

A Mikhailichenko, WEPP157

- Concerns mainly about **survivability** of windows
- Radiation damage
- Thermal shock & cycling
- Cavitation of the lithium
Extensive modelling of the source has been carried out by several groups

- Used for global optimisation of undulator, target, and capture section parameters
- Yield simulations include undulator, collimation, target, capture magnet, and linacs
- Modelling of polarisation of positrons also included
Undulator is **cold bore** (4K) and will **quench itself** unless (low power) **collimators** are included in the cryomodule string.

Full ~200m undulator made up of many ~2m sections, each treated separately.

**Power per metre** without collimators >10W/m. Limit of cryosystem is ~1 W/m.

Inclusion of 5mm diameter **photon collimators** (shown in red) in room temperature sections reduces power level to ~0.05 W/m.

D J Scott
**Energy spread increase** of electron beam for 200m long undulator at room and cryogenic temperatures for alternative vessel materials due to **resistive wall impedance**

![Graph showing energy spread increase for different materials](image)

**Surface roughness** necessary to produce an energy spread of 0.005% (nominal for ILC is 0.05%) for different vessel radii and form factors.

![Graph showing surface roughness vs. vessel radius](image)

**Energy spread increase** of electron beam at room (solid) and cryogenic (dashed) temperatures for copper vessel due to **resistive wall impedance**

![Graph showing energy spread for different models](image)

Mean **emittance increase** due to **geometric wakes** of misaligned taper sections and photon collimators in undulator section.

![Graph showing emittance increase vs. rms displacement](image)
Positron Polarization

- Helical undulator generates *circularly polarised light*
- This then produces longitudinally *polarized positrons*
- Selecting *photons near axis* maximises polarisation rate
- **Baseline** source generates ~30% polarization (already very useful!)
- Upgrade by *collimating photon beam* to select the appropriate photons and by *lengthening undulator* to make up for subsequent loss in intensity
- Can readily achieve ~60% polarisation
The ILC positron source requires \textbf{\sout{1000 times more positrons}} per macropulse than ever before achieved.

The positrons are generated by \textbf{>10MeV photons} which are produced by a \textbf{150GeV electron beam} in a long superconducting undulator.

The upgrade to a \textbf{polarized positron source} is simple and straightforward.

A \textbf{full scale undulator module} has been successfully fabricated.

A \textbf{conversion target eddy current experiment} is in progress.

Other critical subsystems will need \textbf{prototyping} in the future – eg Lithium lens & Flux concentrator \textbf{(some investment needed!)}. 

All simulations show the source to be \textbf{feasible} and any potential detrimental effects to be \textbf{small}.

Detailed \textbf{engineering and integration} of the full source has now been initiated.
<table>
<thead>
<tr>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.R. Bailey</td>
</tr>
<tr>
<td>D.P. Barber</td>
</tr>
<tr>
<td>E. Baynham</td>
</tr>
<tr>
<td>V. Bharadwaj</td>
</tr>
<tr>
<td>T.W. Bradshaw</td>
</tr>
<tr>
<td>A. Brummitt</td>
</tr>
<tr>
<td>A. Bungau</td>
</tr>
<tr>
<td>F.S. Carr</td>
</tr>
<tr>
<td>N.A. Collomb</td>
</tr>
<tr>
<td>J. Dainton</td>
</tr>
<tr>
<td>R. Dollan</td>
</tr>
<tr>
<td>W. Gai</td>
</tr>
<tr>
<td>J. Gronberg</td>
</tr>
<tr>
<td>A.F. Hartin</td>
</tr>
<tr>
<td>S. Hesselbach</td>
</tr>
<tr>
<td>K.M. Hock</td>
</tr>
<tr>
<td>Y. Ivanyushenko</td>
</tr>
<tr>
<td>L.J. Jenner</td>
</tr>
<tr>
<td>K. Laihem</td>
</tr>
<tr>
<td>A. Lintern</td>
</tr>
<tr>
<td>W. Liu</td>
</tr>
<tr>
<td>T. Lohse</td>
</tr>
<tr>
<td>O.B. Malyshev</td>
</tr>
<tr>
<td>L.I. Malysheva</td>
</tr>
<tr>
<td>A.A. Mikhailichenko</td>
</tr>
<tr>
<td>G.A. Moortgat-Pick</td>
</tr>
<tr>
<td>W.T. Piggott</td>
</tr>
<tr>
<td>S. Riemann</td>
</tr>
<tr>
<td>J. Rochford</td>
</tr>
<tr>
<td>N.C. Ryder</td>
</tr>
<tr>
<td>A. Schaelicke</td>
</tr>
<tr>
<td>D.J. Scott</td>
</tr>
<tr>
<td>J.C. Sheppard</td>
</tr>
<tr>
<td>A. Ushakov</td>
</tr>
<tr>
<td>L. Zang</td>
</tr>
</tbody>
</table>

---

Accelerator Science and Technology Centre