The ILC Positron Source

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- Overview LC
- Positron source
- Target stress
- Planned experiments
- Conclusions
Overview

- ILC (International Linear Collider), worldwide project, electron-positron collider, energy ~1 TeV

- Unprecedented precision at the TeV scale!
- Detailed TDR finished
- Very advanced engineering studies ongoing
The LC physics offer and challenges

• Staged energy approach:
  – $\sqrt{s} \approx 240$ GeV, `Higgs frontier`
  – $\sqrt{s} \approx 350$ GeV, `Top threshold`
  – $\sqrt{s} \approx 500$ GeV, `Top Yukawa`
  – ($\sqrt{s} = 91$ GeV, `EW Precision frontier`)
  – $\sqrt{s} \approx 1000$ GeV, `Higgs potential`

• Polarized beams and threshold scans:
  – impact on quality and quantity
  – Something ‘new’ comp. to LHC analyses

• Highest precision: high luminosity+polarization required
ILC Machine Overview

- **Damping Rings**
- **Polarised electron source**
- **Ring to Main Linac (RTML)** (inc. bunch compressors)
- **Beam Delivery System (BDS)** & physics detectors
- **e^- Main Linac**
- **e^+ Main Linac**
- **Beam dump**

### Key Parameters:
- **Beams:** $\sigma_x / \sigma_y$ - 474 nm / 6 nm
- **Intensity:** $2 \times 10^{10}$/bunch, 1312 bunch/pulse
- **Repeatition Rate:** 5 Hz
- **Luminosity:** $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- **Polarisation (e^-/e^+):** 80% / 30(60)%

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**ILC e⁺ Source**

- Wide range of drive e⁻ energy: 150 GeV ÷ 250 GeV (design), 500 GeV (upgrade)
- **e⁺ yield**: $1.5 \text{ e⁺/e⁻}$ (50% safety margin)
- DR acceptance:
  - Transverse emittance: $\epsilon_{nx} + \epsilon_{ny} \leq 70 \text{ mm rad}$
  - Max. energy spread: $\pm 37.5 \text{ MeV}$
  - Longitudinal bunch size: $\leq 34 \text{ mm}$
- **e⁺ polarization**: $\sim 30\%$ (up to 60\%, upgrade)
Schematic layout of $e^+$ source

- Choice: $e^+$ via radiation from a helical undulator (because of higher yield, less rad. level, better DR accept., less target stress)

- SC Helical Undulator: 231 m length, 11.5 mm period, $K \leq 0.92$ ($B \leq 0.86$ T)
- (Optional) Photon Collimator: exist principal design (to improve polarization)
- Target: $0.4X_0$ thickness, Ti6Al4V rim rotated with 100 m/s tangential speed
- Flux Concentrator: 12 cm length, $B_{\text{max}} = 3.2$ T, $B_{\text{end}} = 0.5$ T
- NC Capture RF: 1.3 GHz, $\approx 10$ m length, 14.5 MeV/m and 8.5 MeV/m
Pol(e\(^+\)) : Technical facts (yield \(\geq 1.5\))

- \(\sqrt{s}=240\ \text{GeV}\): 120 GeV e- drive beam
  - Undulator with 231 m (\(K=0.92, \lambda=11.5\ \text{mm}\)), collimator \(r=3.5\ \text{mm}\)
  - \(P(e^+)=40\%\)

- \(\sqrt{s}=350\ \text{GeV}\): 175 GeV e- drive beam
  - Collimator with \(r=1.2\ \text{mm}\)
  - \(P(e^+)=56\%\)

- \(\sqrt{s}=500\ \text{GeV}\): 250 GeV e- drive beam
  - Undulator with 144 m, collimator \(r=0.7\ \text{mm}\)
  - \(P(e^+)=59\%\)

- \(\sqrt{s}=1\ \text{TeV}\): 500 GeV e- drive beam
  - Undulator with 176 m (\(K=2.5\)), collimator \(r=0.9\ \text{mm}\)
  - \(P(e^+)=54\%\)
Yield, pol. vs e- energy (231 m undulator)

**Dependence on e\textsuperscript{-} Energy**

<table>
<thead>
<tr>
<th>Yield [e\textsuperscript{+}e\textsuperscript{-}]</th>
<th>Polarization [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>34</td>
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<tr>
<td>8</td>
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<td>6</td>
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<td>2</td>
<td>20</td>
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<td>1</td>
<td>18</td>
</tr>
</tbody>
</table>

Geant4 simulations for

- 231 m undulator, \( B = 0.86 \) T, \( K = 0.92 \)
- 0.4 \( X_0 \) Ti6Al4V target
- FC: 3.2 T to 0.5 T in 12 cm and \( R_{ini} = 6 \) mm
- \( \approx 10 \) m 1.3 GHz RF structure

**e\textsuperscript{+}** Polarization at 250 GeV e\textsuperscript{-}:

\[ \Rightarrow \] To increase polarization up to 30\% a reduction of magnetic field of undulator is needed \( (B = 0.42 \) T, \( K = 0.45 \))

\[ \Rightarrow \] High energy of e\textsuperscript{-} and low field of undulator result in small photon spot size on the target and high peak energy deposited in the target
### Positron Source Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>$e^-$ Energy [GeV]</td>
<td>250</td>
</tr>
<tr>
<td>Number $e^-$ per Bunch</td>
<td>$2 \cdot 10^{10}$</td>
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<tr>
<td>Number of Bunches per Pulse</td>
<td>1312</td>
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<tr>
<td>Bunch Spacing [ns]</td>
<td>554</td>
</tr>
<tr>
<td>Pulse Repetition Rate [Hz]</td>
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</tr>
<tr>
<td>Undulator Field [T]</td>
<td>0.42</td>
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<tr>
<td>Photon Energy (1st harmonic) [MeV]</td>
<td>42.9</td>
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<tr>
<td>Required Undulator Length [m]</td>
<td>147</td>
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<tr>
<td>Average Photon Power [kW]</td>
<td>43</td>
</tr>
<tr>
<td>Relative Energy Deposition in Target [%]</td>
<td>5.3</td>
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<tr>
<td>Photon rms spot size on target [mm]</td>
<td>0.8</td>
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<tr>
<td>Peak Energy Deposition Density in Target [J/g]</td>
<td>?</td>
</tr>
<tr>
<td>Max. Thermal Stress in Target [MPa]</td>
<td>?</td>
</tr>
</tbody>
</table>
**ILC baseline target wheel**

- **Photon Beam**
- **Positrons**
- **Capture Magnet**
- **Ferrofluidic Rotating vacuum seal**
- **Support bearings**
- **Drive motor**
- **Water Union**
  - Cooling water passes through shaft
  - Up spokes to rim
- **Target wheel**
  - 2000 rpm – 100m/s at rim
  - 1ms beam pulse = 10cm
**Target stress**

- **Energy deposition in e+ target (FLUKA)**

Distribution of Energy Density Deposited by Bunch [GeV/(ph cm³)]
Peak energy deposition by bunch
Temperature rise and distribution (ANSYS)

Temperature Rise Induced by First Two Bunches

Distribution of Temperature in Target

Max. Temperature (°C)

Time (s)

26
25
24
23
22
0    100n  200n  300n  400n  500n

26.734 Max
26.396
26.058
25.72
25.381
25.043
24.705
24.367
24.029
23.69
23.352
23.014
22.676
22.337
21.999 Min

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Time evolution of ‘static’ and transient deformation
Time evolution of ‘static’ and transient normal stresses ($s_1+s_2+s_3$)
Static and transient normal stress after 2\textsuperscript{nd} bunch (s1+s2+s3)

Static Structural (ANSYS)

Transient Structural (ANSYS)
Temperature distribution in rotated target (100 m/s)

\[ t_{\text{pulse}} = 0.727 \text{ ms}; \quad \text{Pulse Length} = 7.27 \text{ cm} \]
Absorbed Energy = 456 J; \quad \text{Average during Pulse Power} = 627 \text{ kW}
Peak Power Density = 276 kW/cm\(^3\)

\[ \Delta T_{\text{max pulse}}/\Delta T_{\text{max bunch}} = 37.8; \quad \text{PEDD}_{\text{pulse}} = 45.3 \text{ J/g} \]
s_1 + s_2 + s_3 and the equivalent von Mises stress

- Fatigue limit: Ti ~ 340 MPa: dynamical stress at acceptable level
Planned experiment

- Experimental test of material fatigue limit:
  - Use e-beams with high intensity, high currents, reduce beam size and thickness until \( \frac{dE}{dV} \) similar to target conditions at the ILC
  - mimic the stress via long (~20μs) electron pulses
  - test different materials and geometries
  - approved at Mainz (Germany) at MAMI and MESA

- MAMI c.w. injector, kW, 1mA at 3.5 MeV
  - with a typical beam spot target-thickness scale is 1/10mm (can be reduced to 10μm)
  - due to c.w. capability -> high rep. rate -> ‘artificial aging
  - first beam time: this year

- MESA: preacc. runs with 5-8MW, 10mA at 5-14 MeV
  - Starts 2017
Conclusions

• Baseline LC Positron source well designed, mature level
  – high polarization and luminosity at all different energy stages

• Still target issues (relevant for all LC designs)
  – Bunch-by-bunch simulations of thermal stress induced by photon beam in Ti-alloy target
  – Simulations (still under work) shows that fatigue limit will not be reached
  – Real target geometry and sound wave reflections have to be included
  – Not shown here in detail: backup with analytical calculation done!

• Target tests at MAMI / MESA approved
  – Test fatigue limit of different target materials
  – Starts 2015
# ILC Parameters

<table>
<thead>
<tr>
<th>Centre-of-mass energy</th>
<th>$E_{CM}$ (GeV)</th>
<th>200</th>
<th>230</th>
<th>250</th>
<th>350</th>
<th>500</th>
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<td>Luminosity pulse repetition rate</td>
<td>Hz</td>
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<td>Positron production mode</td>
<td>$P_{AC}$ (MW)</td>
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<td>119</td>
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<td>Estimation AC power</td>
<td>$N \times 10^{10}$</td>
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<td>Bunch population</td>
<td>$n_b$</td>
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<td>Linac bunch interval</td>
<td>$\Delta t_b$ (ns)</td>
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<td>RMS bunch length</td>
<td>$\sigma_z$ (μm)</td>
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<td>Normalized horizontal emittance at IP</td>
<td>$\gamma e_x$ (μm)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Normalized vertical emittance at IP</td>
<td>$\gamma e_y$ (nm)</td>
<td>35</td>
<td>35</td>
<td>35</td>
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<td>Horizontal beta function at IP</td>
<td>$\beta_x^*$ (mm)</td>
<td>16</td>
<td>14</td>
<td>13</td>
<td>16</td>
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<td>Vertical beta function at IP</td>
<td>$\beta_y^*$ (mm)</td>
<td>0.34</td>
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<td>RMS horizontal beam size at IP</td>
<td>$\sigma_x^*$ (nm)</td>
<td>904</td>
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<td>RMS vertical beam size at IP</td>
<td>$\sigma_y^*$ (nm)</td>
<td>7.8</td>
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<td>Vertical disruption parameter</td>
<td>$D_y$</td>
<td>24.3</td>
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<td>24.5</td>
<td>24.3</td>
<td>24.6</td>
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<tr>
<td>Fractional RMS energy loss to beamstrahlung</td>
<td>$\delta_{BS}$ (%)</td>
<td>0.65</td>
<td>0.83</td>
<td>0.97</td>
<td>1.9</td>
<td>4.5</td>
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<tr>
<td>Luminosity</td>
<td>$L \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$</td>
<td>0.56</td>
<td>0.67</td>
<td>0.75</td>
<td>1.0</td>
<td>1.8</td>
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<td>Fraction of $L$ in top 1% $E_{CM}$</td>
<td>$L_{0.01}$ (%)</td>
<td>91</td>
<td>89</td>
<td>87</td>
<td>77</td>
<td>58</td>
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<td>Electron polarisation</td>
<td>$P_-$ (%)</td>
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<td>Positron polarisation</td>
<td>$P_+$ (%)</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Electron relative energy spread at IP</td>
<td>$\Delta p/p$ (%)</td>
<td>0.20</td>
<td>0.19</td>
<td>0.19</td>
<td>0.16</td>
<td>0.13</td>
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<tr>
<td>Positron relative energy spread at IP</td>
<td>$\Delta p/p$ (%)</td>
<td>0.19</td>
<td>0.17</td>
<td>0.15</td>
<td>0.10</td>
<td>0.07</td>
</tr>
</tbody>
</table>
Longitudinal $\sigma_z$ and transversal $\sigma_x$ stress components

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Longitudinal and transversal stress components (static)
Equilibrium (background) temperature in radiative cooled target

Static (equilibrium) simulation was done for 120 GeV $e^-$ beam and for initial target design proposed by Peter Sievers. Currently, Felix is optimizing the design to reduce the peak temperature in Ti part.

All Parts of Target System

Ti Target

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Radiative Cooling, cont.

Bottom surface of coolers have fixed temperature (22 °C) in that way water cooling has been emulated.