Linear and Circular Colliders:
A few topics

Luminosity
Gamma-gamma
Beam polarization

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Luminosity Comparison

Tim Barklow, FCC-ee Workshop Sep. 2015
Low Energy Region (not in TDR)

\[ \sqrt{s} = 90, \ 160 \text{ GeV} \]

![Graph showing luminosity vs. \( \sqrt{s} \) for different experiments: ILC Baseline, CLIC, CEPC (2 IPs), ILC LumUp.](image)

Tim Barklow, CEPC Workshop Aug. 2015

2016/1/20 IAS, Yokoya
Scaling of LC Luminosity to Lower Energies

- One of the advantages of circular collider is the high luminosity at low energy region
- ILC is not suited for $E_{\text{CM}}<250\text{GeV}$
- TDR gives serious study results only down to $E_{\text{CM}}=250\text{GeV}$
  - No serious study to Z-pole and W-pair
- Often asked to give luminosity values at such energies
- Simplest scaling low
  - Same beta $\rightarrow$ L proportional to E
- This is a bit optimistic
  - Increased beam divergence angle due to larger geometric emittance would cause background
  - Require deeper beam collimation
  - Final quad should be shorter
  - Linac beam dynamics with lower beam energy
Efforts for Low Energy Operation of ILC

- Another problem: positron production
- Use electron for collision:
  - i.e., $E_e = E_{CM}/2$
- Undulator pitch 11.5mm
  - $K = 0.92$ (0.86T)
  - Helical, NbTi
- Poor production rate below $E_e = 125\text{GeV}$
- Study being done for shorter pitch, e.g., using Nb$_3$Sn, but not ready.
  - Z-pole is anyway impossible
10Hz Operation

• Use every other electron pulse for positron production $E_e=150\text{GeV}$ and collision experiment $E_e=E_{CM}/2$
  • → every other pulse with different energies

• Operate the electron linac at doubled rate (10Hz)

• This is mentioned in TDR

• Some components already included in TDR
  • Doubled rep rate of Damping Ring (stronger wiggler, more RF)
  • But details are left out

• There are also other possibilities,

• But no resources now

• If both ILC & CEPS be built, ... we do not need this mode
Gamma-gamma Collider

• Advantage of LC
  • Not impossible with circular colliders, but the luminosity would be much lower
    • $\gamma\gamma$ luminosity is $\sim 1/3$ of e+e- luminosity
  • Nonetheless, ILC has not been optimized for $\gamma\gamma$
    • $\gamma\gamma$ community is not strong enough

• Crossing angle
  • $\gamma\gamma$ requires larger crossing angle (25mrad thought to be the optimum) for avoiding low energy electrons from multiple Compton scattering
    • ILC TDR: 14mrad
  • It is hard to change the crossing angle after construction
    • Do not want to move the beam dump
750 GeV Diphoton Resonance?

• If this be true, can be a good target of ILC $\gamma\gamma$
  • $E_\gamma \sim 0.8E_e$
  • $E_{\gamma\gamma} = 700$-800GeV is best suited with ILC after extension to $E_{CM} = 1$TeV

• Expected luminosity $> 10^{34}$

• Laser technology would be mature by that time
  • Strong motivation would accelerate laser development
  • $\lambda_L = 2\mu$m optimum

• If this possibility to be considered seriously, it can be taken into account now
Beam Polarization

• One of the advantages of the ILC is the collision of polarized beams
  • Electron: 80% in TDR
  • Positron: 30% TDR baseline, can be raised to =60%
Positron Polarization

• ~30% comes at free
• Should use lower field (<0.86T) at $E_e > 150\text{GeV}$

![Graph showing captured positron beam yield and captured positron beam polarization against drive electron beam energy.](image)
Helicity vs $E_\gamma$

Helicity vs $\theta_\gamma$

\textbf{Photon Helicity vs. Energy}

\textbf{Photon Helicity vs. Angle}

points inside 22600
points outside 200

points inside 22099
points outside 211
Photon Collimator

• Higher photon polarization, hence higher positron polarization, can be obtained by collimating the photons from undulator.
2 reasons of depolarization
- Below 1% level at ILC
- But can be significant at CLIC 3TeV

Precession in B-B field
- B-B magnetic field causes depolarization
- For the ring parameters, depolarization per collision is
  \[ <\Delta P> = 0.3 \times 10^{-4} \text{ to } 1 \times 10^{-4} \text{ for FCC-Z to FCC-t} \]
  \[ 3 \times 10^{-4} \text{ for CEPC-H} \]
- But the effect does not accumulate over multiple turns.

Spin-flip radiation
- \[ <\Delta P> = \left(\frac{7}{12}\right) \Upsilon^2 n_\gamma \] per collision
  \[ n_\gamma \text{ = number of photons / electron/collision} \]
  \[ \Upsilon \text{ = Upsilon parameter} \]
- negligible at ILC 500GeV (but not at CLIC 1TeV)
- For the ring,
  \[ <\Delta P> = 0.33 \times 10^{-8} \text{ (FCC-H)}, \ 1.25 \times 10^{-8} \text{ (FCC-t)}, \ 2.6 \times 10^{-8} \text{ (CEPC-H)} \]
  Depolarization time ~100min for CEPC-H
Beam Polarization in Circular Colliders

• Use of beam polarization
  • Energy calibration
    • Z mass = 91.1876 ± 0.0021 GeV measured at LEP
      2.3 × 10^(-5)
    • ~5% polarization enough for this purpose
  • Polarized colliding beam experiments (longitudinal polarization) like at HERA
    • Need spin rotator
    • 30-40 % polarization at least

• How to get polarized beam
  • Spontaneous radiative polarization (Sokolov-Ternov effect)
  • Injection and acceleration of polarized beam
Depolarization due to Energy Spread

\[ \delta y_G = \delta v_{spin} = 1 \]

\[ \sigma = 1\% \text{ of 120 GeV} \]

- This explanation is too simplistic
- Lots of sophisticated theories since late 1970’s

Polarization at LEP
Comparison of theory and observation

Energy scale for TLEP is \(3^{1/4}=1.3\) times higher

U. Wienands, MIT WS, 2013
Radiative Polarization Time

- No energy spread problem at FCC-Z and CEPC-Z
- But spontaneous polarization too slow

<table>
<thead>
<tr>
<th></th>
<th>FCCee (4IP)</th>
<th>CEPC</th>
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<tbody>
<tr>
<td></td>
<td>Z</td>
<td>W</td>
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<tr>
<td>Circumference km</td>
<td>100</td>
<td>100</td>
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<tr>
<td>E beam GeV</td>
<td>45.6</td>
<td>80.4</td>
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<tr>
<td>$\sigma_E$ (SR) MeV</td>
<td>24</td>
<td>74</td>
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<tr>
<td>$\sigma_E$ (with BS) MeV</td>
<td>28</td>
<td>84</td>
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<tr>
<td>$U_0$ GeV</td>
<td>0.037</td>
<td>0.355</td>
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<tr>
<td>Pol $\tau$ hours</td>
<td>240</td>
<td>14.1</td>
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<tr>
<td>Beam life</td>
<td>6.7</td>
<td>1.4</td>
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For Faster Polarization

• LEP type asymmetric wiggler can increase $\alpha+$, hence reduce the polarization time.

• But the energy spread and SR loss also increase.

\[ \sigma_E \propto \sqrt{\frac{I_3}{I_2}} \quad U_0 \propto I_2 \quad I_3 = \int ds / |\rho|^3, \quad I_2 = \int ds / \rho^2 \]

• Hence,
  \[ A_P = A_E^2 \times A_U \]
  \[ A_P = \text{improvement factor of } \tau_p \]
  \[ A_E = \text{increase of } \sigma_E, \quad A_U = \text{increase of } U_0 \]

• Polarized beam experiment at FCC-Z, at least $A_P \sim 100$ needed
  • $A_E$ only up to 1.5-2 allowed (energy spread depol.)
  • Hence $A_U \sim 40$, → beam current must lowered by 1/40
  • Local SR too large at asymmetric wigglers
  • Moreover, spin rotator needed for longitudinal polarization

• Pilot bunch can be used for energy calibration
  • Long beam life (no beam beam)
  • 2-3 hours are enough for CEPC to reach the polarization level needed for calibration (Most realistic foe CEPC)
Injection and Acceleration of Polarized Beam

• Injection/acceleration of polarized beams seems feasible

• What’s needed?
  • Polarized beam source
  • For positron,
    • CBAF?
    • Compton seems feasible
    • Undulator like ILC?
    • Required intensity much lower than in ILC
  • Resonance crossing in the booster ring (and maybe pre-booster ring) \rightarrow double Siberian snake
  • Spin rotator in the collider ring (for longitudinal polarization)
    • Local synchrotron radiation is an issue

• Note the depolarization due to the energy spread still exists
My Conclusion on Beam Polarization

• Sokolov-Ternov can still be used for energy calibration at CEPC-Z (54km) and (perhaps) at FCC-W
  • A bit slow but may be possible at FCC-Z
  • If the energy calibration is the only purpose at these energies, pre-polarized beam not needed
• Issue to be studied is the expected accuracy of the calibration
  • Can we reach $1e^{-6}$ (0.1% of $\sigma_E$)
  • How large is the energy difference between the pilot bunches and the colliding bunches?

• Collision of longitudinally polarized beam is very hard even with pre-polarized beam