Challenges of the Beam Delivery System for the future Linear Colliders

Eduardo Marin
eduardo.marin.lacoma@cern.ch

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Particle Physics, Nuclear Physics and Astroparticle Physics

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1. Introduction

2. Linear Collider
   - Linear collider components
   - Beam Delivery System

3. Accelerator Test Facility
   - Lattice Design
   - Tuning feasibility

4. Conclusions
LHC is not enough?

Now...
Energy (CM) = 7 TeV
Luminosity = $1 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$
In 2013...
Energy (CM) = 14 TeV
Luminosity = $1 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$
Upgrade in 2020...
Energy (CM) = 14 TeV
Luminosity = $10 \cdot 10^{34}\text{cm}^{-2}\text{s}^{-1}$

High precision physics

Advantages of a point like structure collisions (leptons, $e^+, e^-$):
- know and tune CM
- fully re-constructable events
- polarised beams

A lepton collider performs higher precision physics research than LHC
At the TeV energy regime the lepton circular collider becomes unaffordable because of synchrotron radiation.

### Linear Collider Projects: CLIC & ILC

<table>
<thead>
<tr>
<th>Project</th>
<th>Accel. Gradient [MV/m]</th>
<th>Footprint [Km]</th>
<th>Energy (CM) [TeV]</th>
<th>Peak Luminosity [cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILC</td>
<td>35</td>
<td>30</td>
<td>1.0</td>
<td>2.0$\cdot$10$^{34}$</td>
</tr>
<tr>
<td>CLIC</td>
<td>100</td>
<td>48</td>
<td>3.0</td>
<td>2.4$\cdot$10$^{34}$</td>
</tr>
</tbody>
</table>
Main components of a linear collider

**Source** + **Damping Ring** + **Main Linac** + **Beam Delivery System**

<table>
<thead>
<tr>
<th>Components</th>
<th>S</th>
<th>DR</th>
<th>ML</th>
<th>BDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>2.86</td>
<td>2.86</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Horizontal beam size [nm]</td>
<td>$3 \cdot 10^9$</td>
<td>$3 \cdot 10^4$</td>
<td>$4 \cdot 10^3$</td>
<td>45</td>
</tr>
<tr>
<td>Vertical beam size [nm]</td>
<td>$4 \cdot 10^5$</td>
<td>$3 \cdot 10^3$</td>
<td>$4 \cdot 10^2$</td>
<td>1</td>
</tr>
<tr>
<td>Luminosity [$10^{34} \text{cm}^{-2}\text{s}^{-1}$]</td>
<td>$\approx 1 \cdot 10^{-9}$</td>
<td>$\approx 1 \cdot 10^{-6}$</td>
<td>$\approx 1 \cdot 10^{-4}$</td>
<td>2.4</td>
</tr>
</tbody>
</table>
The CLIC-Beam Delivery System

CLIC is based in the 2 beam (Drive & Main) accelerating scheme to produce a high gradient of 100 MV/m in the accelerating structures → COMPACT

The goals of the BDS are:
- To collimate the beam in energy and position
- To deliver a stable beam at the IP
- To enhance Luminosity by squeezing the beam size down to the nm regime

⇒ FEASIBLE ?

eduardo.marin.lacoma@cern.ch

BDS Challenges, 6/17
ATF2 Goal: To test the future Linear Colliders FFS based on local chromaticity correction.

ATF2 Nominal lattice: $\beta_y^* = 100\,\mu m$, $\sigma_y^* = 38\,nm$ (related to ILC lattice)

ATF2 Ultra-low $\beta^*$ lattice: $\beta_y^* = 25\,\mu m$, $\sigma_y^* = 20\,nm$ (related to CLIC lattice)
The multipolar components of the FFS magnets increase $\sigma^*_x, \sigma^*_y$.

To minimise its detrimental effect, different cures have been studied:
- Replacing the Final Doublet magnets.
- Skew sextupole insertion.
- Swapping the quadrupoles.
- Modifying the optics.
New Final Doublet magnets

From the comparison between the measured multipolar components and the specified tolerances for the Final Doublet, it is required to replace the FD.

<table>
<thead>
<tr>
<th>Component</th>
<th>Sextupolar $[10^{-4}]$</th>
<th>Octupolar $[10^{-4}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Skew</td>
</tr>
<tr>
<td>@ R=1 cm</td>
<td>Tol.UL  Measured Tol.NL</td>
<td>Tol.UL  Measured Tol.NL</td>
</tr>
<tr>
<td>QF1FF</td>
<td>0.37  2.7  1.2</td>
<td>0.07  0.28  0.3</td>
</tr>
<tr>
<td>QD0FF</td>
<td>0.2  1.84  1.0</td>
<td>0.18  1.76  0.8</td>
</tr>
</tbody>
</table>

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PMQ

- When replacing the present final doublet by the new FD based on permanent material, a noticeable $\sigma_y^*$ reduction is observed, however it is not enough.

CERN is developing a new quadrupole based on permanent magnet material (Sm2Co17) to satisfy the challenging tolerances.

Skew sextupole magnet

- Skew sextupole insertion: A skew sextupole is inserted in the line in order to compensate the skew sextupolar component present in the quadrupoles.
Swapping proposal

Sorting the quadrupoles according to their field quality and placing the best magnets in the more restrictive tolerance locations.

By swapping the quadrupoles according to the skew sextupolar component a significant gain is observed.
Alternative solution

**Optics modification:** Increasing $\beta_x$ at the IP, the impact of the multipolar components along the beamline are significantly reduced.

This lattice design was used during ATF2 operation in May and Dec 2010 run.
By combining all considered solutions, replacing FD, optimising the skew sextupole, sorting the quadrupoles and increasing $\beta_x$ at the IP, the evaluated vertical beam size at the IP is 25 nm.

Before loading this lattice into ATF2, first it has to be demonstrated its tunability.
**Tuning**

- The tuning process consists in bringing the machine performance to its design under realistic machine imperfections.

**Tuning algorithm**

The tuning is based on orthogonal knobs which correct the dominant aberrations at the IP as dispersion, coupling, waist shift...

![Graph showing the relationship between Δβx/σ₀ and βx Knob value []](image-url)
Tuning experiments

- Participated in 3 tuning experiments of 1 week duration each
- Minimum achieved $\sigma_y^* = 300\text{nm}$

![Tuning by knobs. ATF2 $\beta_y^*=$100 um $\beta_x^*=$10.0mm](image)

Experimental validation of the tuning algorithm.
The test facilities as ATF2 are extremely important to demonstrate the feasibility of the future Linear Colliders.

The impact of realistic errors on the ATF2 lattices has been minimised in order to keep their performance as close as possible to the design one.

Simulations demonstrate the tuning feasibility of the ATF2 lattices, while experimental result confirms a similar tendency in the range within $300 \text{ nm} < \sigma_y^* < 1000 \text{ nm}$.

Further tuning attempts should confirm the tuning feasibility of ATF2 down to 38 and 25nm, hence the FFS based on local chromaticy correction would be validated.