Optimization of the CLIC Positron Source

Yanliang Han[1,2], Andrea Latina[2], Daniel Schulte[2], Lianliang Ma[1,2]

[1]Shandong University

[2]CERN

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Thanks the help from C. Bayar & S. Doebert

Outline

Introduction

Layout of CLIC at 3 TeV stage

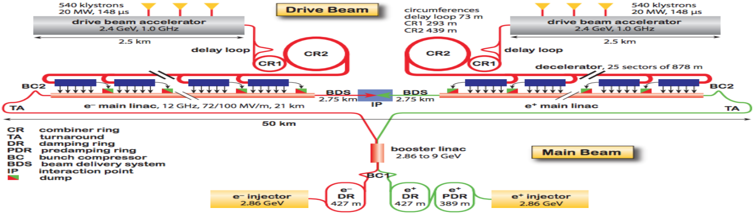


Table: Beam parameters at the entrance of pre-damping ring

Parameters	Value
E [GeV]	2.86
N	6.6×10^9
n_b	312
$\Delta t_b[ns]$	1
$\epsilon_{x,y}[\mu m]$	7000
σ_z [mm]	5.4
σ_E [%]	4.5
f_{rev} [Hz]	50

Introduction - The positron source sketch

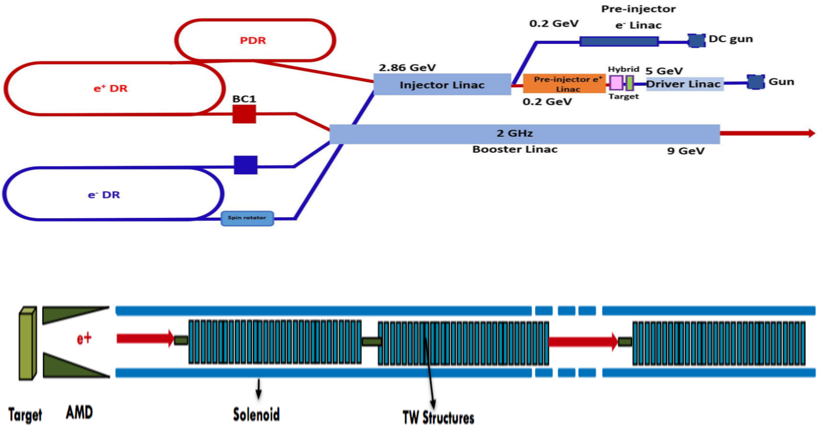


Figure: Schematic layout of the main beam injector complex

Review 3 TeV - CDR

Target parameters:

- Primary electron energy: 5 GeV
- Crystal thickness: 1.4 mm ($0.4\chi_0$)
- Distance: 2 m
- Amorphous thickness: 10 mm ($3\chi_0$)
- The positron yield after AMD is 8.0

AMD - $B(z) = \frac{B_0}{1+\mu z}$

- $B_0 = 6$ T, $\mu = 55\mathrm{m}^{-1}$, L $= 20$ cm
- The positron yield after AMD is 2.1

Pre-injector

- Accelerating the positrons to 200 MeV
- First decelerating and then accelerating
- Inside the 0.5 Tesla solenoid
- The positron yield after pre-injector is 0.9

Injector Linac

- Accelerating the positron to 2.86 GeV
- A bunch compressor is needed before the injector
- The positron yield after injector linac is 0.7 (effective: 0.39)

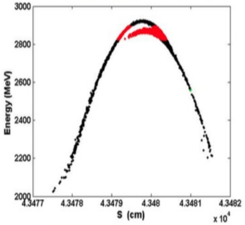
Review - Update on transmission

From AMD to injector linac

OUR PREVIOUS STUDIES: INJECTOR LINAC

*CDR

*Positron yield (CDR): 0.70 e^+/e^-



Energy acceptance → 1%: → yield: 0.39 e^+/e^-

Table 21 – Positron yield for different values of the energy acceptance of the Pre-Damping Ring.

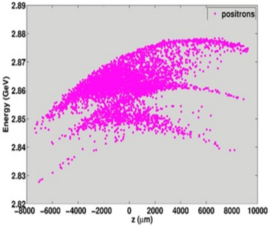
Energy Acceptance %	Yield (e^+/e^-)
1.2	0.453
2	0.561
3	0.619

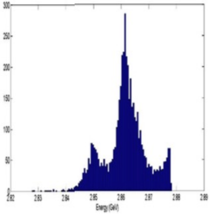
http://cds.cern.ch/record/1277226/files/CERN-OPEN-2010-020.pdf

The yield is defined as the total number of positrons at the exit of the amorphous target compared to the number of electrons impinging onto the crystal target

Our previous results

Positron yield, 0.97 e^+/e^-, is increased by a factor of 2.5.





- All positrons by 99 % are transported.
- All positrons are within 1% acceptance window of the pre-damping ring.

CLIC Beam Physics Meeting 28 September 2017 CERN
Cafer Bayar

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From CLIC BPM report by C. Bayar

Motivation

Main Changes:

- The positron yield before the pre-damping ring has been improved from 0.39 to 0.97[1]

Rationale: saving cost

- Reduce the current of the primary electron bunch
- Reduce the energy of the primary electrons bunch
  - 3 GeV is considered.

How? - First, we need to improve the final positron yield as high as possible.

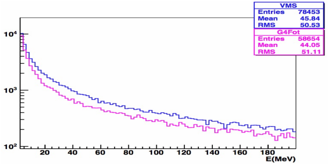
- Start-to-end optimization
  - 5 GeV
  - 3 GeV

[1] C. Bayar, NIMA 869 (2017) 56-62

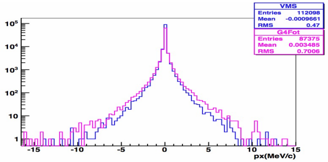
Positron Generation Simulation - Channeling Process

There are two program to simulate the crystal channeling process

- VMS by V. M. Strakhovenko (Budker-INP, Russia)
  - Used for simulation in CLIC CDR
  - Photon distributions with only 4 different electron energies are provided
- FOT by X. Artru [2] (French National Centre for Scientific Research)
  - The primary electron energy and crystal thickness can be scanned



Energy distribution for photons



Px distributions for photons

Discrepancy between two codes: 10% - 20%[3]

Comments from X. Artru:

- The two codes are implemented rather different.
- It is not simple to guess which is better.

[2] X. Artru, NIMB48 (1990) 278-282

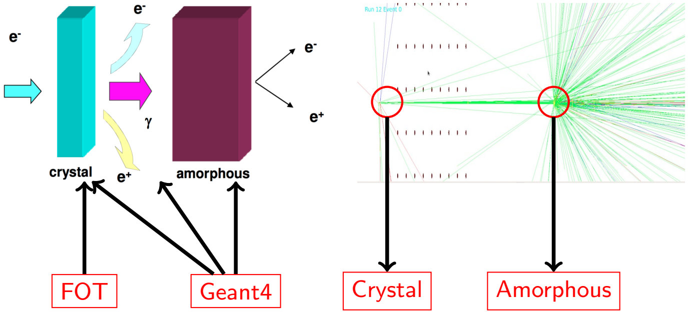
[3] O. Dadoun, Journal of Physics: Conference Series 357 (2012) 012024

Positron Generation Simulation

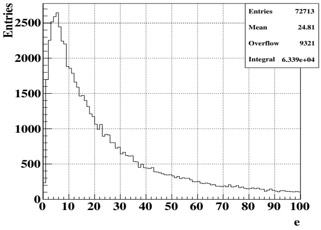
Procedure

Positron yield for CDR case: 7.2

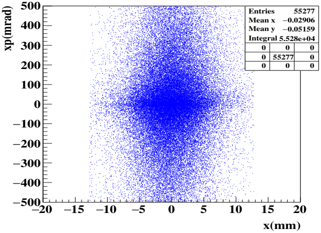
1. FOT is used to generate photons in crystal tungsten (coherent & incoherent bremsstrahlung, channeling)
2. These photons are set as primary particles in Geant4.
3. Standard EM process in Geant4 is simulated in crystal & amorphous tungsten target.



Energy & Phase Space After Target



Energy (MeV)



$x - x'$

Here $x' = \frac{P_x}{P_z}$

Peak Energy Deposition Density

It is found experimentally that PEDD should be limited to 35J/g.

The PEDD for the CDR configuration is 1.14 GeV/cm^3/e^- (30 J/g).

- 5 GeV primary electron
  - Positron yield increase from 0.39 $\rightarrow$ 0.97
  - Only need 40.2% primary electron compared to CDR (380 GeV case, 52.6%)
- 3 GeV primary electron
  - Positron yield temporally is 0.44
  - PEDD is 0.65 GeV/cm^3/e^- - 57% of PEDD in CDR
    - 380 GeV case - 22.3 J/g
    - 3 TeV case - 15.2 J/g

PEDD is not a limitation factor for CLIC positron source.

- Based on electron bunch transverse radius 2.5 mm
- We can consider to reduce the size

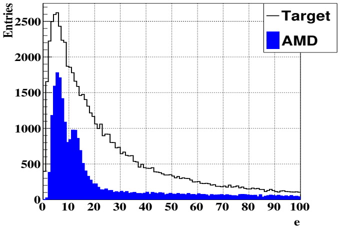
AMD simulation

Ideal magnetic field on axis: $B_z(z,0) = \frac{B_0}{1+\mu z}$

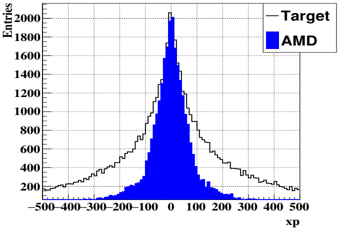
Positron yield after AMD is 2.8

- $B_0 = 6$ T, $\mu = 55$ m^{-1}, Length $= 20$ cm

The simulation is done by RF-Track[4] (very fast)



Energy (MeV)



$x'(mrad)$

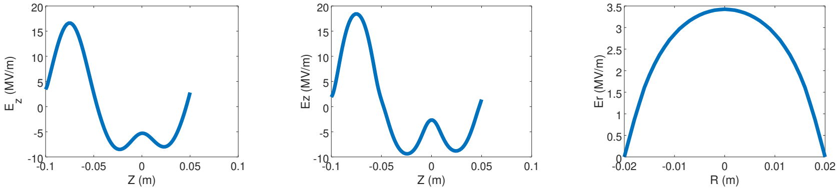
- The parameters can be changed easily.
- It is much easier to do the start-to-end optimization

[4] A. Latina, MOPRC016, Proceedings of LINAC2016

Field Map - Need by RF-Track for tracking simulation

The field map for the $\frac{2\pi}{3}$ traveling wave structure is calculated with CST 2017.

- Wave length $\lambda = 0.15$ m
- Traveling wave structure length: 1.5 m

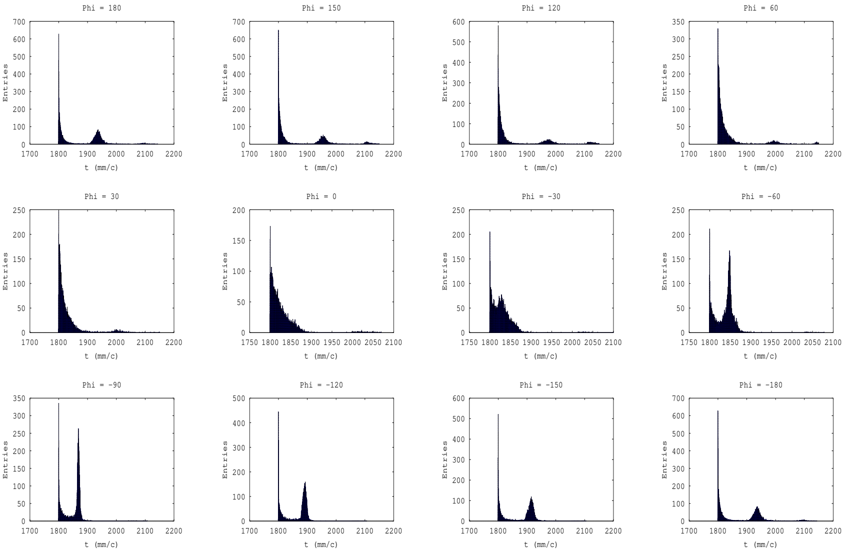


E_z On axis $\quad$ E_z off-axis R = 1.5 cm $\quad$ E_r at Z = 0

The standing wave solution from SUPERFISH is also used to construct the traveling wave solution. These two methods are consistent with each other.

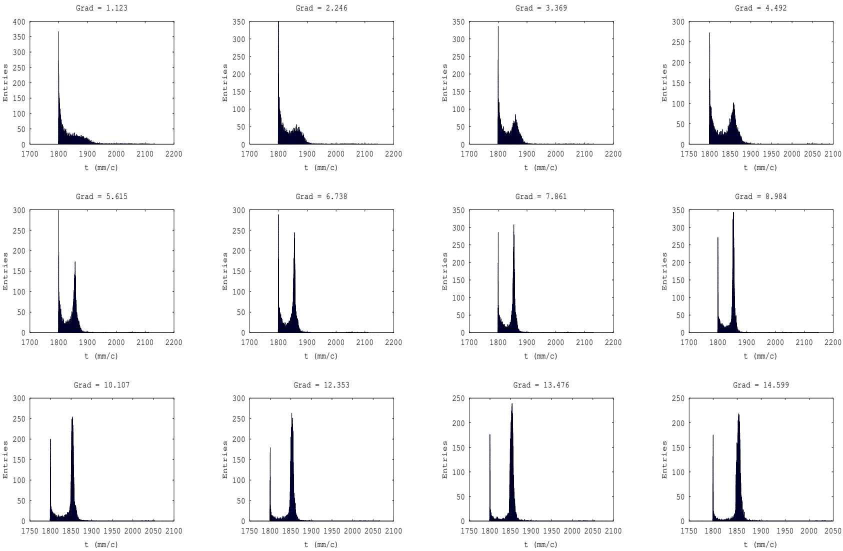
Decelerating Part - The first TW

Scan the phase



Decelerating Part

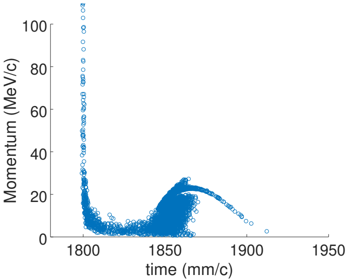
Scan the gradient

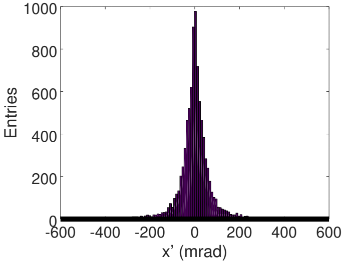


Decelerating Parts

Positron yield is 1.03

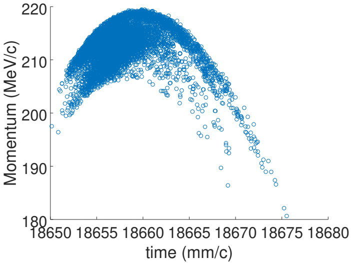
- phase = -70 degree
- gradient = 9.0 MV/m

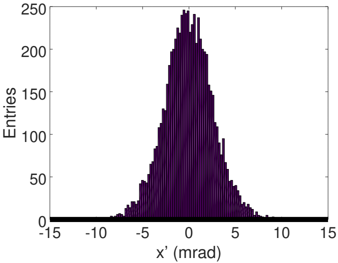




Accelerating Parts - The following 10 TWs

Positron yield is 0.92





The previous simulation with PARMELA [5] gives positron yield 0.97.

- The new result 0.92 are not different a lot from the previous one
- We can begin the start-to-end simulation

[5] C. Bayar, NIMA 869 (2017) 56-62

Start-To-End optimization

Primary Electron Bun:

- E = 5 GeV & 3 GeV, $\Delta E/E = 10^{-3}$
- $\Delta P_x/P = 10^{-5}$
- $\sigma_{x,y} = 2.5$ mm, $\sigma_z = 1$ mm

Target:

- Crystal tungsten thickness: 0.5 $\rightarrow$ 3.0 mm
- Amorphous tungsten thickness: 6 $\rightarrow$ 20 mm
- Distance between two tungstens: 0.5 $\rightarrow$ 3 m

The AMD parameters is not optimised for now.

Traveling wave structure - Optimize for each target configuration.

- Phases for the decelerating and accelerating structure
- Gradients for the decelerating and accelerating structure

Injector Linacs:
$E_f = E_i + \Delta E \cos(2\pi\omega t)$, here t is the arrive time at the end of pre-injector

Start-to-end optimization - Software version

- FOT - The random generators are to the C++ standard library version
- Gean4 - 4.10.04.b01
- GCC - 7.2.1
- octave - 4.2.1
- RF-Track - up-to-date (2018-Jan-15th)
- ROOT - 6.12.04

Problem met when doing the optimization:

The GCC 6.X is unstable for FOT + Geant4.

Start-to-end optimization results - not finised

5 GeV primary electron bunch

- Crystal target thickness: 1.8 mm
- Amorphous target thickness: 15.5 mm
- Distance: 1.08 m
- Phase: -37 & 38 degree
- Gradient: 15.1 & 16.4 MV/m
- Positron yield: 1.00

3 GeV primary electron bunch

- Crystal target thickness: 1.93 mm
- Amorphous target thickness: 16.2 mm
- Distance: 1.07 m
- Phase: -37 & 42 degree
- Gradient: 14.5 & 15.7 MV/m
- Positron yield: 0.48

Work in Progress & Plan

Work in Proress

- The start-to-end optimization is still running - at least 2 weeks is needed.

Plan

- Continue the Optimization of the two options: 3 GeV and 5 GeV
  - Include the AMD parameters
    - Parameters: B_0, μ & Length
    - Consider the tapered aperture along AMD.
  - Consider more freedoms for the traveling wave structure
  - Use PLACET to simulate the injector linac tracking
- Compare for performance and cost

Conclusion

- The positron source start-to-end optimization environment is setup successfully
  - The program FOT is used to simulate the channeling process in crystal tungsten.
  - Geant4 is used to simulation the electromagnetic process in crystal & amorphous tungsten target.
  - AMD & traveling wave structure are simulation by RF-Track with proper field-map.
  - The injector linac is considered by simple calculation.
- The positron yield (NOT BEST) is determined as:
  - 5 GeV - 1.00
  - 3 GeV - 0.48
- More freedoms will be considered in order to get better results

Thank you!

Backup

Difference between FOT & VMS

- coherent bremsstrahlung & channeling
  - FOT: Baier-Katkov formula - include non-uniformity field
  - VMS: uniform field approximation.
- incoherent bremsstrahlung
  - FOT: included in Baier-Katkov formula
  - VMS: calculated separately
- e^+e^- pair production
  - FOT: Not included, should be simulated in Geant4
  - VMS: Coherent effects is considered when pair is produced in VMS