Optimization of the CLIC Positron Source

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Thanks the help from C. Bayar & S. Doebert & L. Rinolfi & O. Dadoun

Outline

Introduction

Layout of CLIC at 3 TeV stage

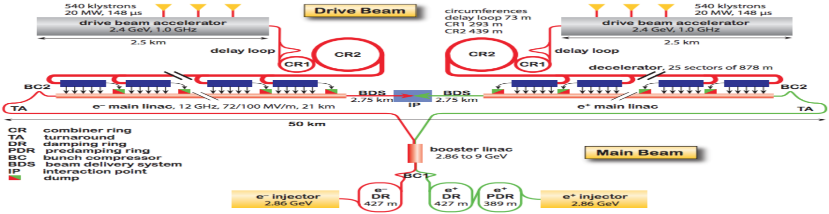


Table: Beam parameters at the entrance of pre-damping ring

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
$f_{\rm rev}$ [Hz]	50

Introduction - The positron source sketch

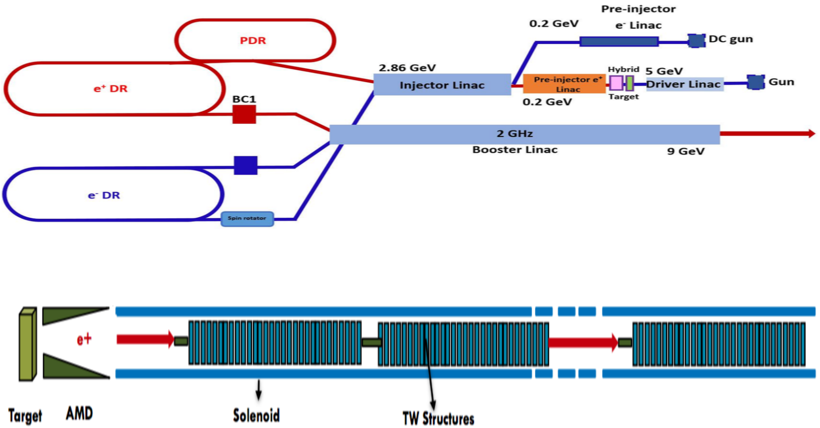


Figure: Schematic layout of the main beam injector complex

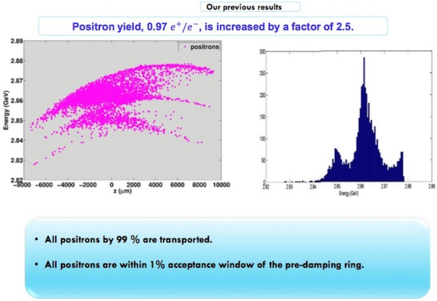
Review 3 TeV - CDR

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 target 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



From BPM report by C. Bayar

Positron yield: 0.97

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)

From CLIC CDR

Motivation

Main Changes:

- The positron yield before the pre-damping ring has been improved from 0.39 to 0.97[1]
- The first energy stage of CLIC is 380 GeV

Rationale: improving performance & 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.

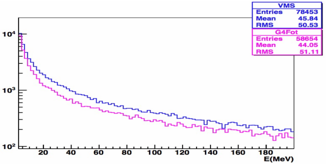
- Start-to-end optimization
  - 5 GeV
  - 3 GeV

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

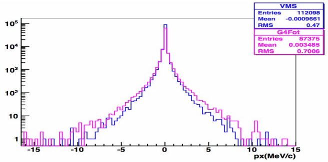
Positron Generation Simulation - Channeling Process

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

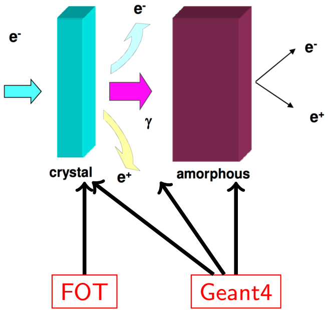
[3] O. Dadoun, Journal of Physics: Conference Series 357 (2012) 012024

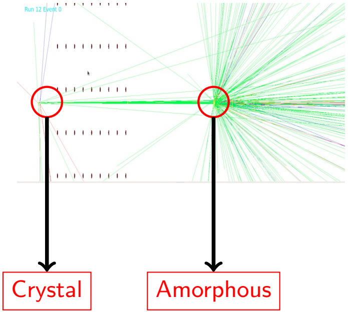
Positron Generation Simulation

Positron yield for CDR case: 7.2

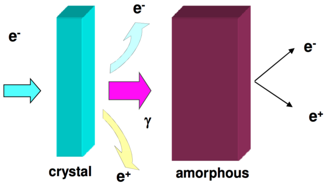
Procedure

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.





Peak Energy Deposition Density (PEDD)



- Due to the channeling process, the PEDD in crystal is tiny.
- The amorphous target is split to cells: $0.5 \times 0.5 \times 0.5$ mm^3
- Standard electromagnetic processes are considered:
  - Pair production
  - Bremsstrahlung
  - Photon Electric effect
  - Coulomb Scatter
  - Annihilation
  - ...
- PEDD $= \frac{E_{\mathrm{max}}}{V_{\mathrm{cell}} \times N_{e^-,\mathrm{sim}}} \times \frac{N_{e^+,\mathrm{train}}}{\mathrm{positron\ \ yield}} < 35J/g$

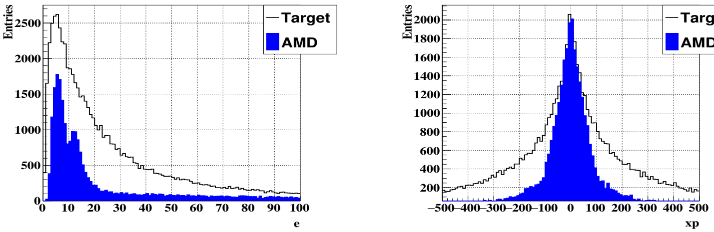
AMD simulation

Ideal magnetic field on axis: $B_z(z,0) = \frac{B_0}{1+\mu z}$[4]

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[5] (very fast)



Energy (MeV) $x'(mrad)$

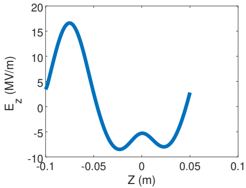
- The parameters can be changed easily.
- It is much easier to do the start-to-end optimization

[4] Off-axis magnetic field is got from CLIC-NOTE-465 by T. Kamitani & L. Rinolfi
[5] A. Latina, MOPRC016, Proceedings of LINAC2016

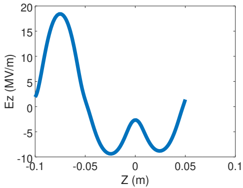
Field Map - Need by RF-Track for tracking simulation

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

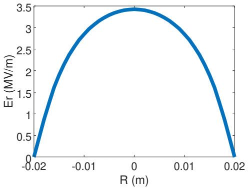
- Wave length $\lambda = 0.15$ m
- Traveling wave structure length: 1.5 m



E_z On axis



E_z off-axis R $= 1.5$ cm

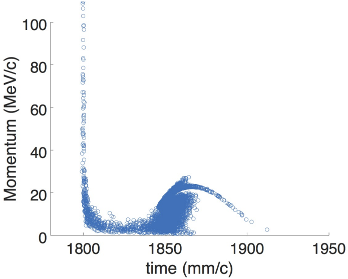


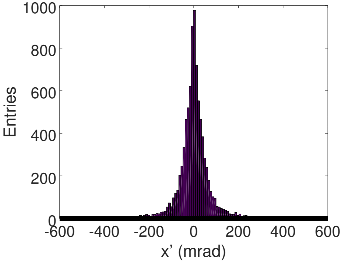
E_r at Z $= 0$

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

Decelerating Parts

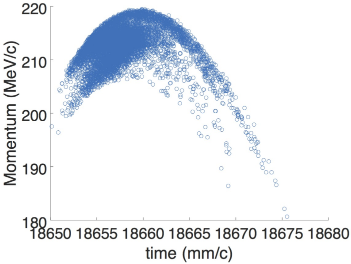
Positron yield is 1.03

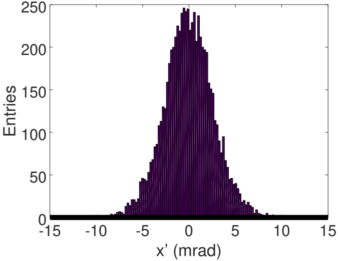




Accelerating Parts - The following 10 TWs

Positron yield is 0.92





The previous simulation with PARMELA [6] gives positron yield 0.97.

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

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

Injector Linac

We assume the transmission efficiency in the injector linac is 100%.

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

Start-To-End optimization

Primary Electron Gun:

- 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.

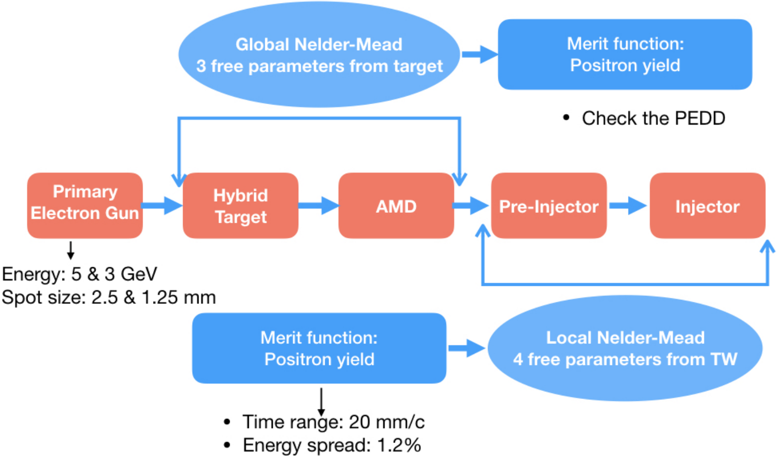
- Phases for the decelerating and accelerating structure
- Gradients for the decelerating and accelerating structure

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 changed to the C++ standard library version
- Geant4 - 4.10.04.b01
- GCC - 7.2.1 (or 6.2.0)
- octave - 4.2.1
- RF-Track (updated to 2018-Jan-15th)
- ROOT - 6.12.04
- (placet)

Start-to-end optimization - Nested Optimization



Start-to-end optimization - Results - 2.5 mm spot size

5 GeV primary electron bunch

- Crystal target thickness: 2.17 mm
- Amorphous target thickness: 16.6 mm
- Distance: 0.67 m
- Phase: -33 & 85 degree
- Gradient: 13.1 & 18.2 MV/m
- Positron yield: 1.30
- PEDD: 17.7 J/g

3 GeV primary electron bunch

- Crystal target thickness: 2.20 mm
- Amorphous target thickness: 12.3 mm
- Distance: 0.65 m
- Phase: -43 & 78 degree
- Gradient: 13.7 & 18.0 MV/m
- Positron yield: 0.76
- PEDD: 17.1 J/g

Start-to-end optimization - Results - 1.25 mm spot size

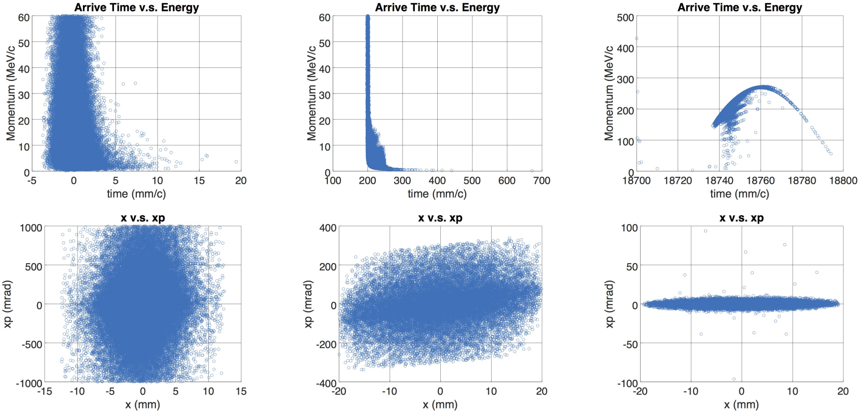
5 GeV primary electron bunch

- Crystal target thickness: 1.68 mm
- Amorphous target thickness: 14.9 mm
- Distance: 0.66 m
- Phase: -30 & 90 degree
- Gradient: 17.2 & 17.5 MV/m
- Positron yield: 1.94
- PEDD: 29.3 J/g

3 GeV primary electron bunch

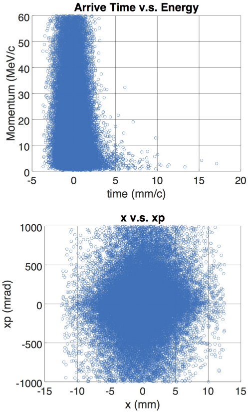
- Crystal target thickness: 1.54 mm
- Amorphous target thickness: 11.5 mm
- Distance: 0.62 m
- Phase: -34 & 88 degree
- Gradient: 15.9 & 17.2 MV/m
- Positron yield: 1.03
- PEDD: 26.7 J/g

Phase space - 5 GeV, 2.5 mm spot size

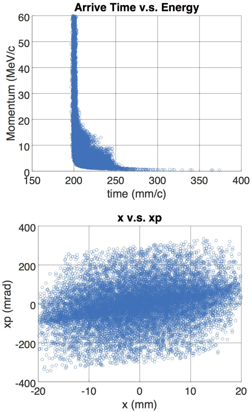


Target AMD TW11

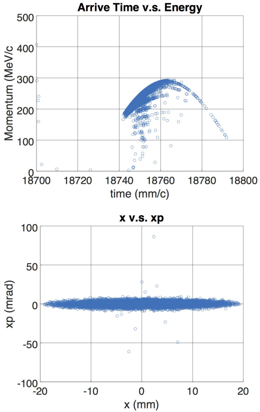
Longitudinal phase space - 5 GeV, 2.5 mm spot size



Target



AMD



TW11

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 is determined as (within the PEDD limit):

Table: Positron yield

Positron yield	5 GeV	3 GeV
2.5 mm spot size	1.30	0.76
1.25 mm spot size	1.94	1.03

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