# Design, Parameters and Beamdynamics

CLIC Project Meeting

Wednesday December 11th, 2024

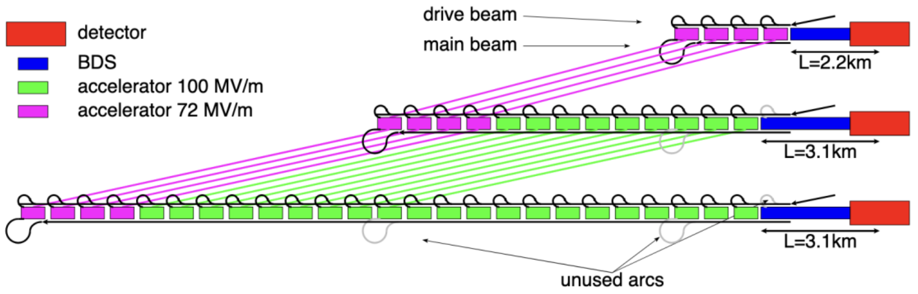
Daniel Schulte, Vera Cilento, Andrea Latina et al.

# Previous Parameters

| Parameter | Unit | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|---|
| Centre-of-mass energy | GeV | 380 | 1500 | 3000 |
| Repetition frequency | Hz | 50 | 50 | 50 |
| Nb. of bunches per train | | 352 | 312 | 312 |
| Bunch separation | ns | 0.5 | 0.5 | 0.5 |
| Pulse length | ns | 244 | 244 | 244 |
| Accelerating gradient | MV/m | 72 | 72/100 | 72/100 |
| Total luminosity | $10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ | 2.3 | 3.7 | 5.9 |
| Lum. above 99 % of $\sqrt{s}$ | $10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ | 1.3 | 1.4 | 2 |
| Total int. lum. per year | $\text{fb}^{-1}$ | 276 | 444 | 708 |
| Main linac tunnel length | km | 11.4 | 29.0 | 50.1 |
| Nb. of particles per bunch | $10^9$ | 5.2 | 3.7 | 3.7 |
| Bunch length | µm | 70 | 44 | 44 |
| IP beam size | nm | 149/2.0 | ~60/1.5 | ~40/1 |
| Final RMS energy spread | % | 0.35 | 0.35 | 0.35 |
| Crossing angle (at IP) | mrad | 16.5 | 20 | 20 |

CLIC study
Snowmass submission

⇒ Chapter 2, with adjustment



# New Energy Stages

380 GeV remains baseline

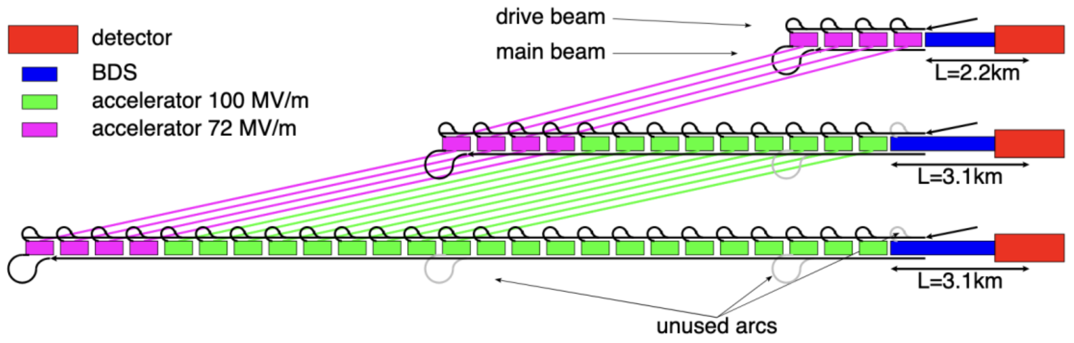
250 GeV initial option

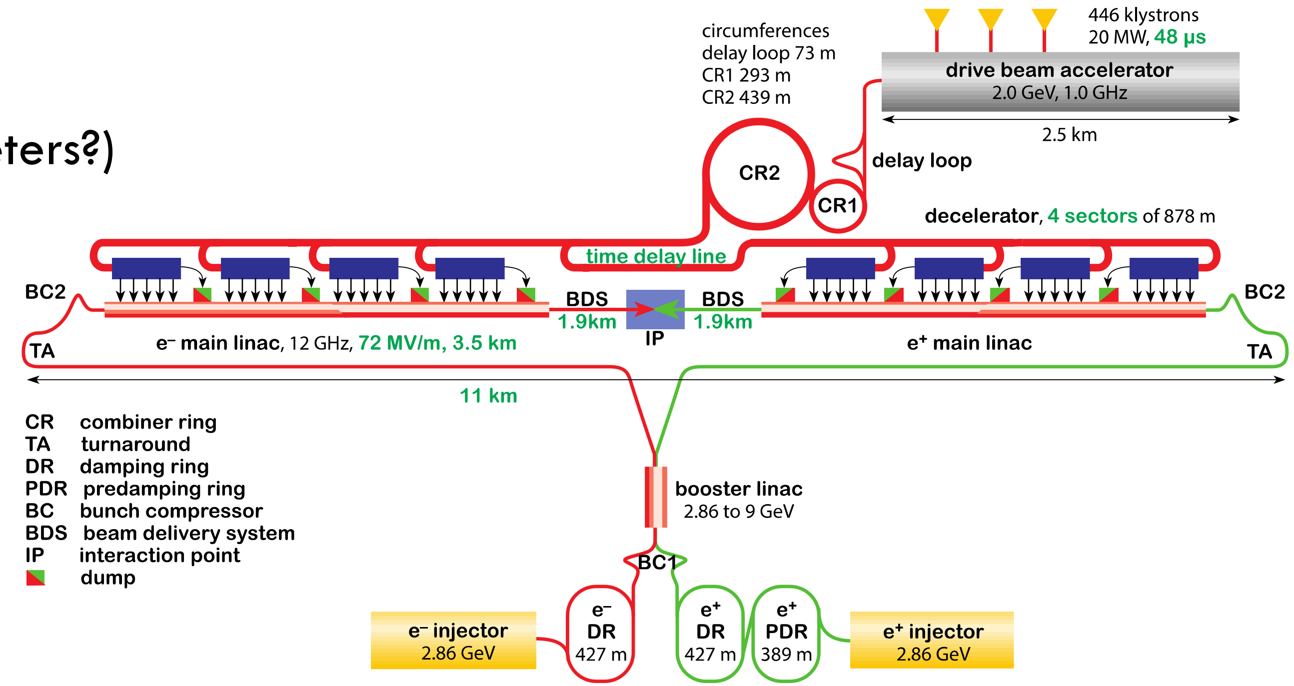
- Build 380 GeV tunnel but only install about 2/3* of the accelerating structures in each drive beam sector

*More precisely (250-9)/(380-9)

1.5 TeV potential upgrade

- Could go to 2 TeV with single drive beam (parameters?)
- Upgrade path remains similar to previous designs



# Luminosities

Luminosity at lower energy can be better

- Same margins at all energies but need less in main linac and BDS
- Required 90% likelyhood to meet static performance in each system not overall

Could increase luminosity at 380 by 50%

Can double repetition rate to 100 Hz

- Needs to address two different feedback states

Alexei Grudiev et al.

Can feed two detectors

Need to check switching frequency (stored energy in dipoles?)

As consequence L=2.25x10$^{34}$ cm$^{-2}$s$^{-1}$ and L=4.5x10$^{34}$ cm$^{-2}$s$^{-1}$ is possible at 380 GeV

At 1.5 TeV remain at L=3.7x10$^{34}$ cm$^{-2}$s$^{-1}$

At 250 GeV scale with energy L=1.5(1.48)x10$^{34}$ cm$^{-2}$s$^{-1}$ and L=3(2.96)x10$^{34}$ cm$^{-2}$s$^{-1}$

# Reminder: Improved Luminosity

Could increase luminosity at 380 by 50%

Old target: L=1.5x10$^{34}$ cm$^{-2}$s$^{-1}$
Achieved in perfect machine: L=4.3x10$^{34}$ cm$^{-2}$s$^{-1}$

Average with static imperfections: L=3x10$^{34}$ cm$^{-2}$s$^{-1}$
90% are better than L=2.35x10$^{34}$ cm$^{-2}$s$^{-1}$

Average also with ground motion: L=2.8x10$^{34}$ cm$^{-2}$s$^{-1}$
90% achieve L>2.3x10$^{34}$ cm$^{-2}$s$^{-1}$

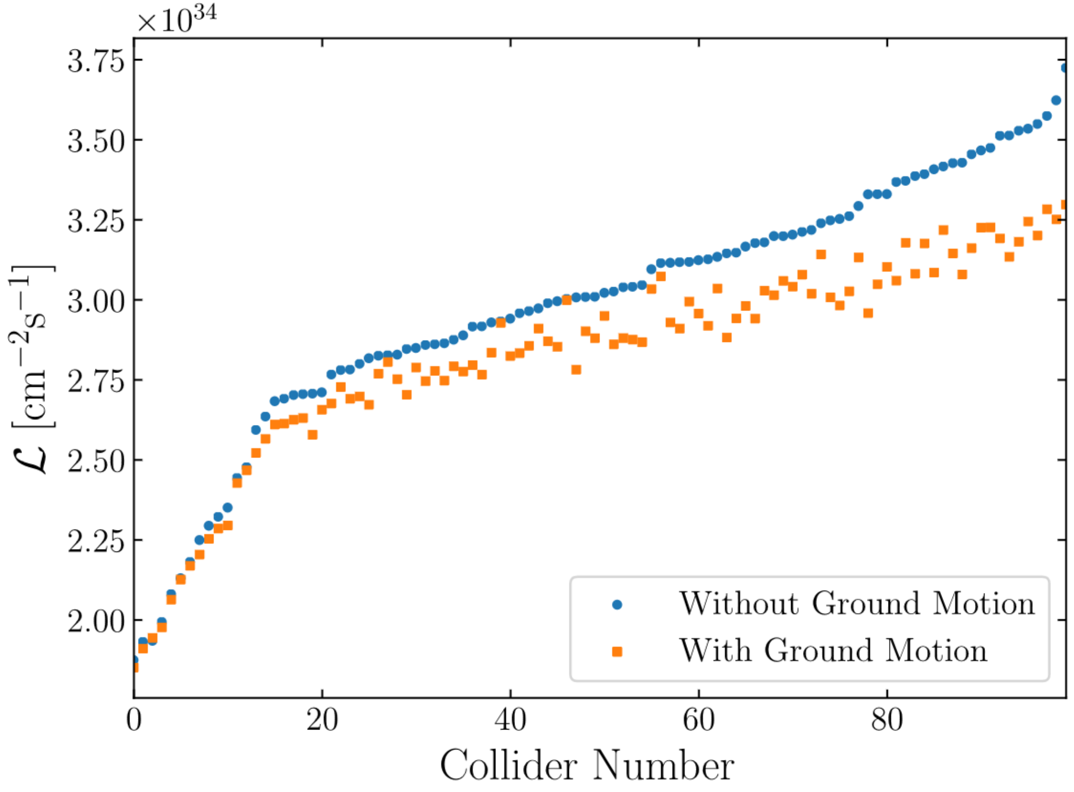
Adjust horizontal beam size for each case (differs from Chet's presentation, but in published paper)

Very small impact of other imperfections

In addition, reduced emittance growth in RTML and ML
L=2.25x10$^{34}$ cm$^{-2}$s$^{-1}$ is realistic

Documented for Snowmass, Explained in chapter 2

C. Gohil, P.N. Burrows, N. Blaskovic, A. Latina, J. Ogren, D. Schulte



# Main Linac Emittance Growth

A. Pastushenko, D. Schulte
⇒ Chapter 3

Use of tuning knobs in main linac reduces emittance growth

Note: full integration unfortunately not yet done

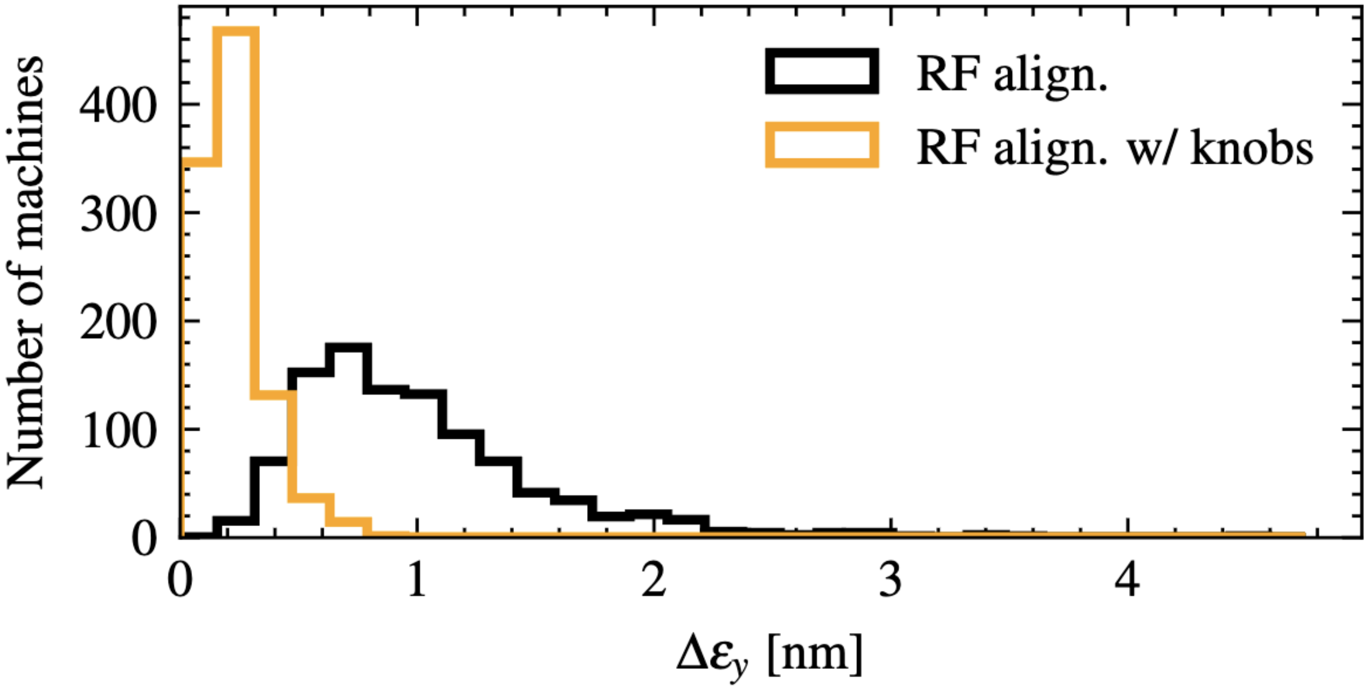


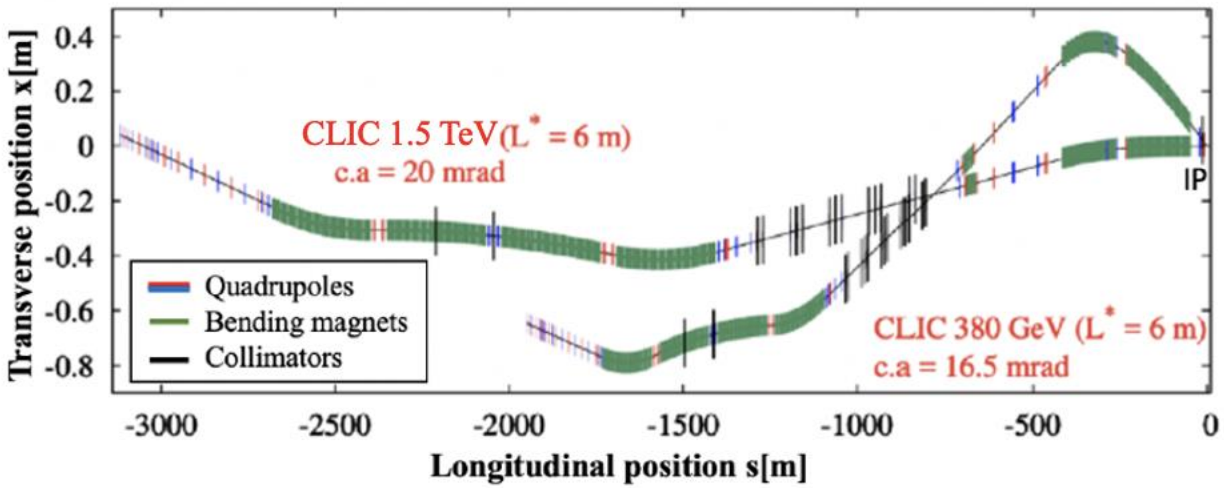

Table 2: RMS Element Misalignments after the Prealig
ment

| Imperfection | With respect to | Value |
|---|---|---|
| Girder end point | Wire reference | 12 µm |
| Girder end point | Articulation point | 5 µm |
| Cavity offset | Girder axis | 14 µm |
| Cavity tilt | Girder axis | 141 µrad |
| Quadrupole offset | Girder axis | 14 µm |
| Quadrupole roll | Longitudinal axis | 100 µrad |
| BPM offset | Wire reference | 14 µm |

# BDS Status: One IR

F. Plassard

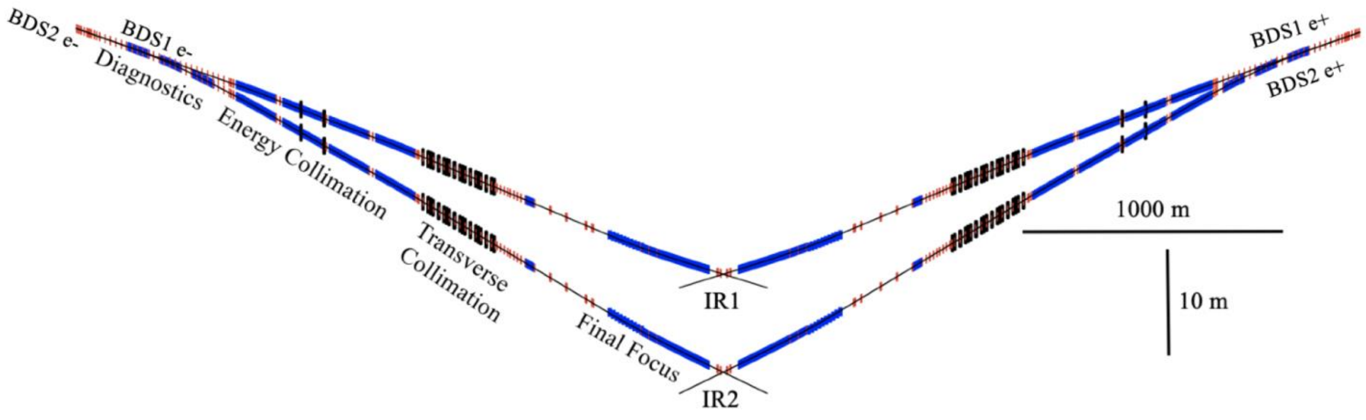
| CLIC Parameters Overview | | |
|---|---|---|
| **Energy [GeV]** | 380 | 1500 |
| **Final drift** $L^*$ $[m]$ | 6 | 6 |
| **FFS length** $[m]$ | 770 | 770 |
| **BDS length** $[m]$ | 1948 | 3117 |
| **Norm. emittance (IP)** $\epsilon_{n,x}/\epsilon_{n,y}$ $[nm]$ | 920/15 | 660/20 |
| **Beta function (IP)** $\beta_x^*/\beta_y^*$ $[mm]$ | 8/0.1 | 8/0.11 |
| **Beam size (IP)** $\sigma_x^*/\sigma_y^*$ $[nm]$ | 140/2.1 | 60/1.5 |
| **Bunch length** $\sigma_z$ $[\mu m]$ | 70 | 44 |
| **Energy spread** $\delta_p$ $[\%]$ | 0.3 | 0.3 |
| **Bunch population** $N$ $[\times 10^9]$ | 5.2 | 3.72 |
| **Number of bunches** $N_b$ | 352 | 312 |
| **Repetition rate** $f$ $[Hz]$ | 50 | 50 |
| **Total luminosity** $\mathcal{L}_{tot}$ $[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ | 2.5 | 4.1 |



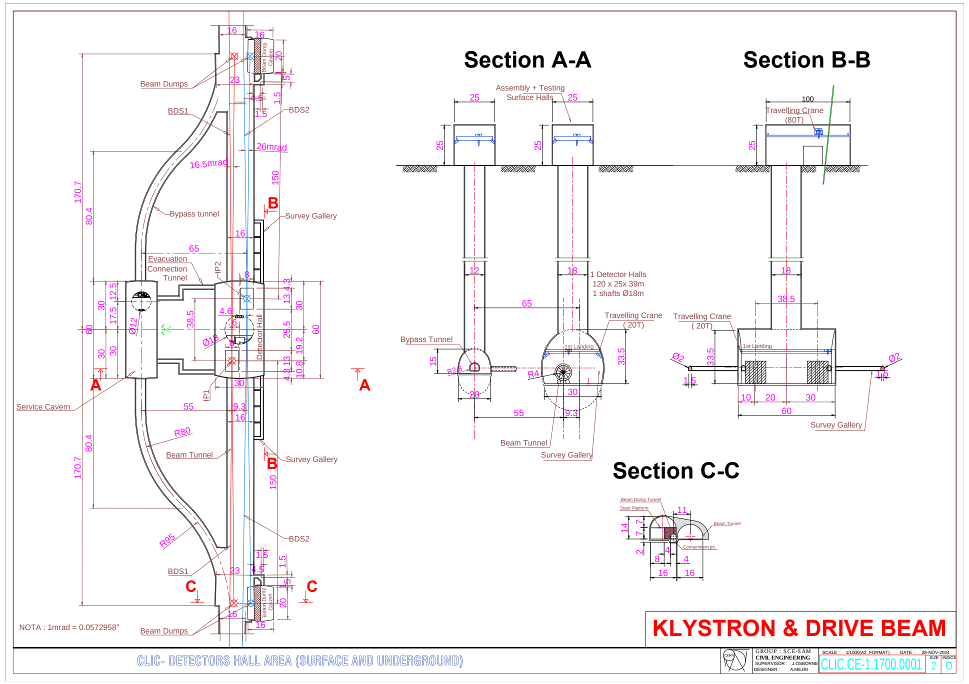

- Optimization of the 1.5 TeV design is ongoing (L. Kenendy), with a potential reduction in length of 500 to 800 meters.
- Using the option with the reduced $\beta^*$ optics (A. Pastushenko) could improve the performace by 2%.
- Further optimization of the 380 GeV design length may still be possible in the future.

# Two IR Design

Vera Cilento




| CLIC Dual BDS at 380 GeV | | |
|---|---|---|
| | IR1 | IR2 |
| **Final drift** $L^*$ $[m]$ | 6 | 6 |
| **FFS length** $[m]$ | 770 | 770 |
| **BDS length** $[m]$ | 2294 | 2256 |
| **Norm. emittance (IP)** $\epsilon_{n,x}/\epsilon_{n,y}$ $[nm]$ | 920/15 | 920/15 |
| **Beta function (IP)** $\beta^*_x/\beta^*_y$ $[mm]$ | 8/0.1 | 8/0.1 |
| **Beam size (IP)** $\sigma^*_x/\sigma^*_y$ $[nm]$ | 140/2.3 | 140/2.29 |
| **Bunch length** $\sigma_z$ $[\mu m]$ | 70 | 70 |
| **Energy spread** $\delta_p$ $[\%]$ | 0.3 | 0.3 |
| **Bunch population** $N$ $[\times 10^9]$ | 5.2 | 5.2 |
| **Number of bunches** $N_b$ | 352 | 352 |
| **Repetition rate** $f$ $[Hz]$ | 50 | 50 |
| **Crossing angle [mrad]** | 16.5 | 26 |
| **Total luminosity** $\mathcal{L}_{tot}$ $[10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}]$ | 2.4 | 2.36 |




- There should be enough space between the beam dump and the beam line.
- Possible solutions for insufficient space include adding shielding or incorporating a vertical bending magnet in BDS2. This option still requires further optimization but appears feasible, with a luminosity loss of 7% for a 0.4 m vertical offset.
- Using the option with the reduced $\beta^*$ optics (A. Pastushenko) could improve the performace by 2%.

# Main Beam Injectors

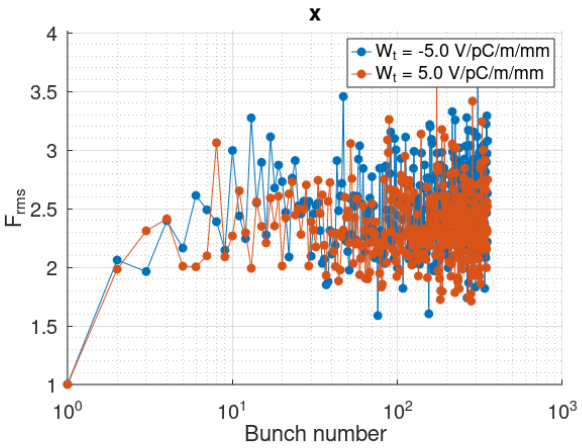
Y. Zhao, A. Kurtulus, A. Latina, A. Grudiev, S. Doebert

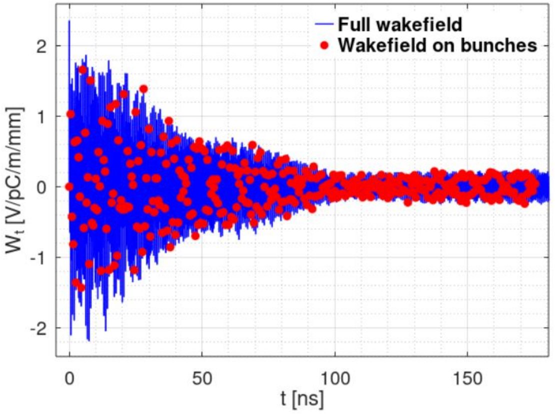
**Positron source:**

- **Start-to-end optimisation of the positron source**
- Electron **driver energy reduced** from **5 GeV** to **2.3 GeV**
- ✓ **Final positron yield: ~1.8 (380 GeV) – 2.4 (3 TeV)**

**Rings to Main Linac:**

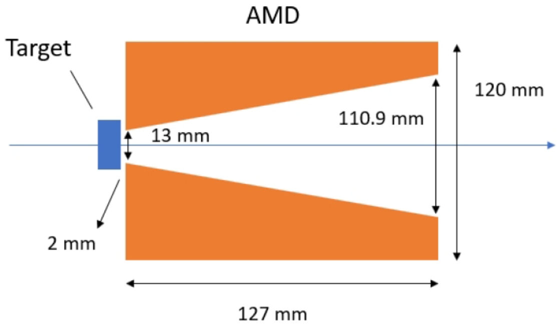
- **Bunch Compressor 2:** X-band RF power consumption **reduced by 50%**
- **Booster:** **new RF design** of the L-band structure optimised for multi-bunch operation
- **Beam-Based Alignment** performance: **improved for robustness**
  - Allows for tighter emittance budgets



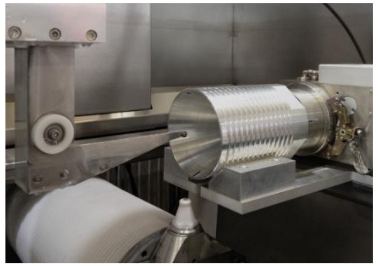




Robust multi-bunch beam dynamics studies in collaboration with RF experts

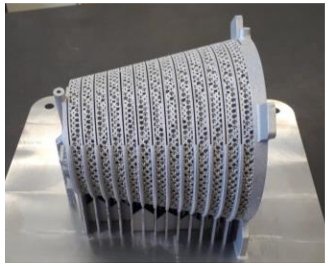
**Positron target region** and **optimised capture device** (prototyped)



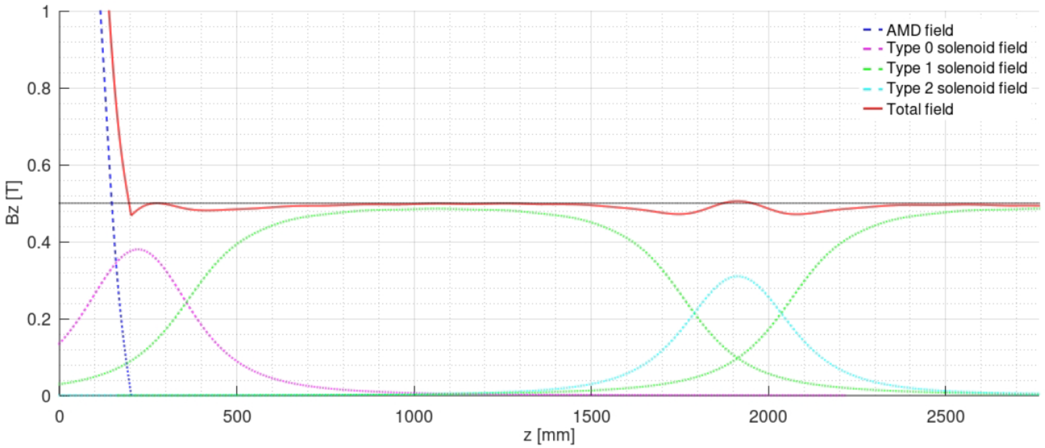

**Schematic layout**



**EDM**



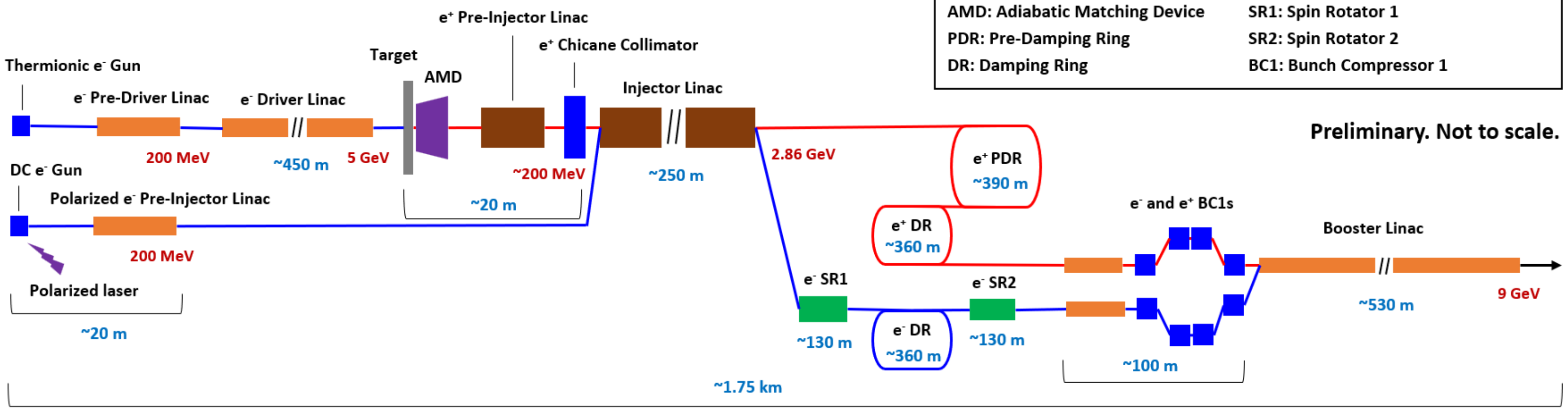
**3D printed**




**Realistic simulation fields of different components**

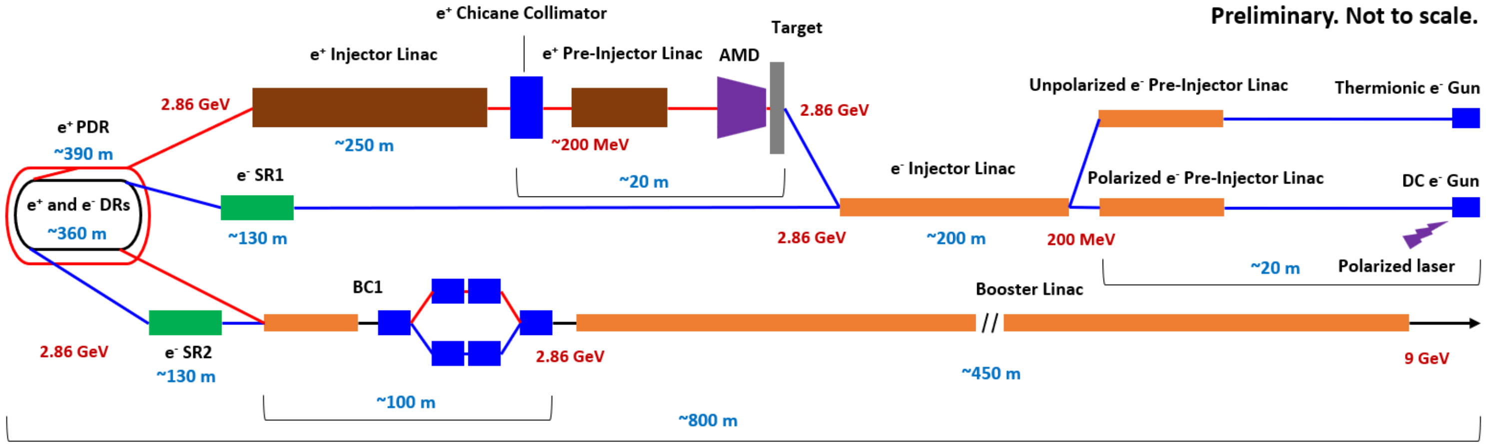
# Proposal for a new Optimised Layout

- **Old (baseline)**




| | |
|---|---|
| AMD: Adiabatic Matching Device | SR1: Spin Rotator 1 |
| PDR: Pre-Damping Ring | SR2: Spin Rotator 2 |
| DR: Damping Ring | BC1: Bunch Compressor 1 |

- **New (alternative)**




| | |
|---|---|
| AMD: Adiabatic Matching Device | SR1: Spin Rotator 1 |
| PDR: Pre-Damping Ring | SR2: Spin Rotator 2 |
| DR: Damping Ring | BC1: Bunch Compressor 1 |

Y. Zhao, A. Kurtulus, A. Latina, A. Grudiev, S. Doebert

# Operational Scenarios

Operate 10 years at each energy

Ramp-up as before

- First stage first three years with 10%, 30%, 60%
- Following stages ramp-up as 25% 75%

As before $1.2 \times 10^{7}$ s luminosity per year

This yields:

- 380 GeV at $2.25 \times 10^{34}$ $cm^{-2}s^{-1}$ yields 2.2 $ab^{-1}$
- 380 GeV at $4.5 \times 10^{34}$ $cm^{-2}s^{-1}$ yields 4.3 $ab^{-1}$

- 250 GeV at $1.5 \times 10^{34}$ $cm^{-2}s^{-1}$ yields 1.4 $ab^{-1}$
- 250 GeV at $3.0 \times 10^{34}$ $cm^{-2}s^{-1}$ yields 2.8 $ab^{-1}$

- 1.5 TeV at $3.7 \times 10^{34}$ $cm^{-2}s^{-1}$ yields 4 $ab^{-1}$

Ph. Lebrun, L. Linssen, D. Schulte, S. Stapnes, E: Adli et al.

$\Rightarrow$ Chapter 2

Distribution of beam on both experiments to be defined