Beam Instrumentation requirements in the CLIC Main Beam Injector

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R&D program for the CDR

The CLIC Main Beams generation is focused on 3 studies to produce the bunch charge at the entrance of the Pre-Damping Ring (PDR) :

1) Base Line configuration:

3 TeV (c.m.) - polarized electrons (4.4×10^9 e^-/bunch) and unpolarized positrons (6.7×10^9 e^+/bunch).

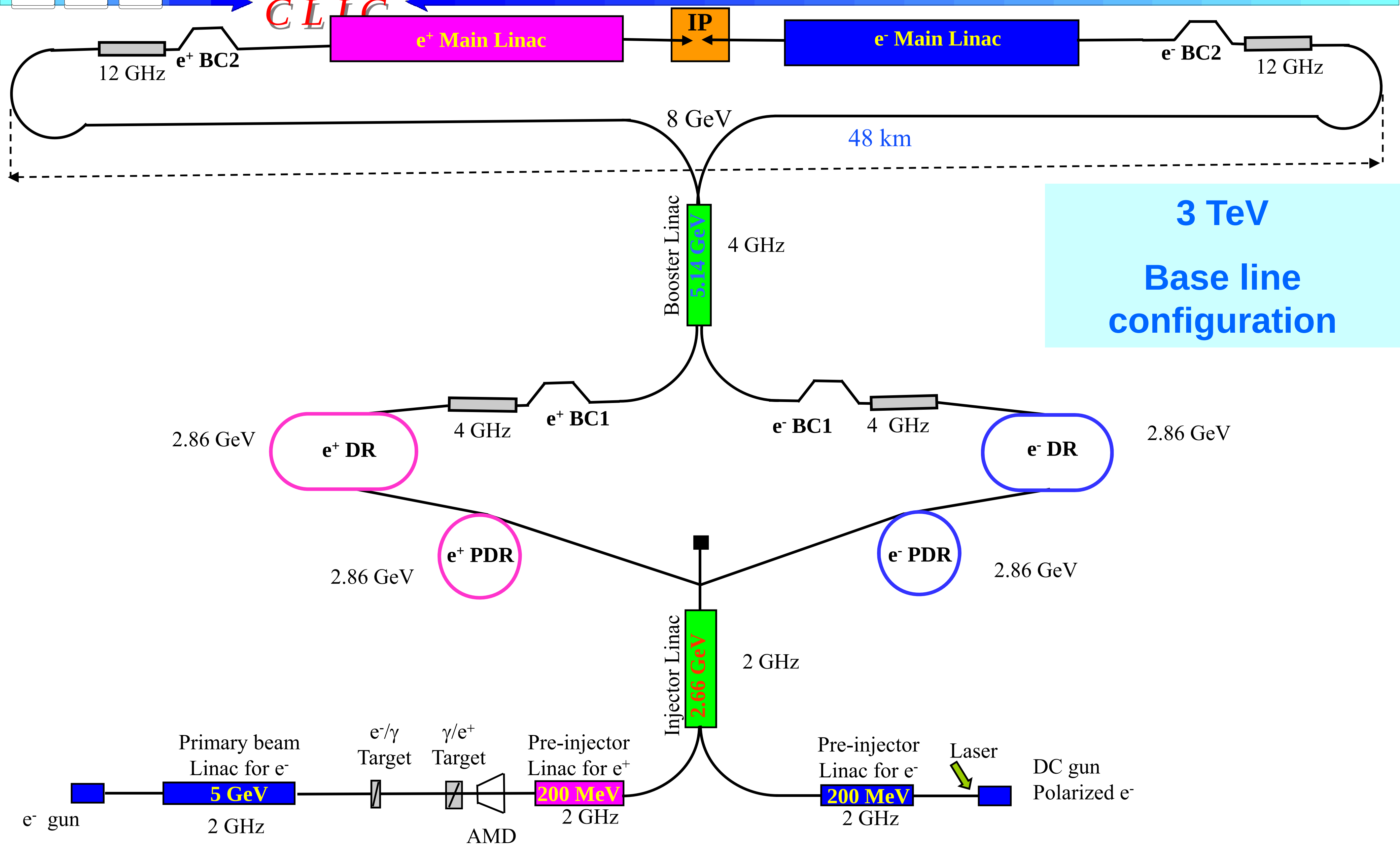
2) Polarized positron configuration:

3 TeV (c.m.) - polarized e^- and e^+ with same charge as above

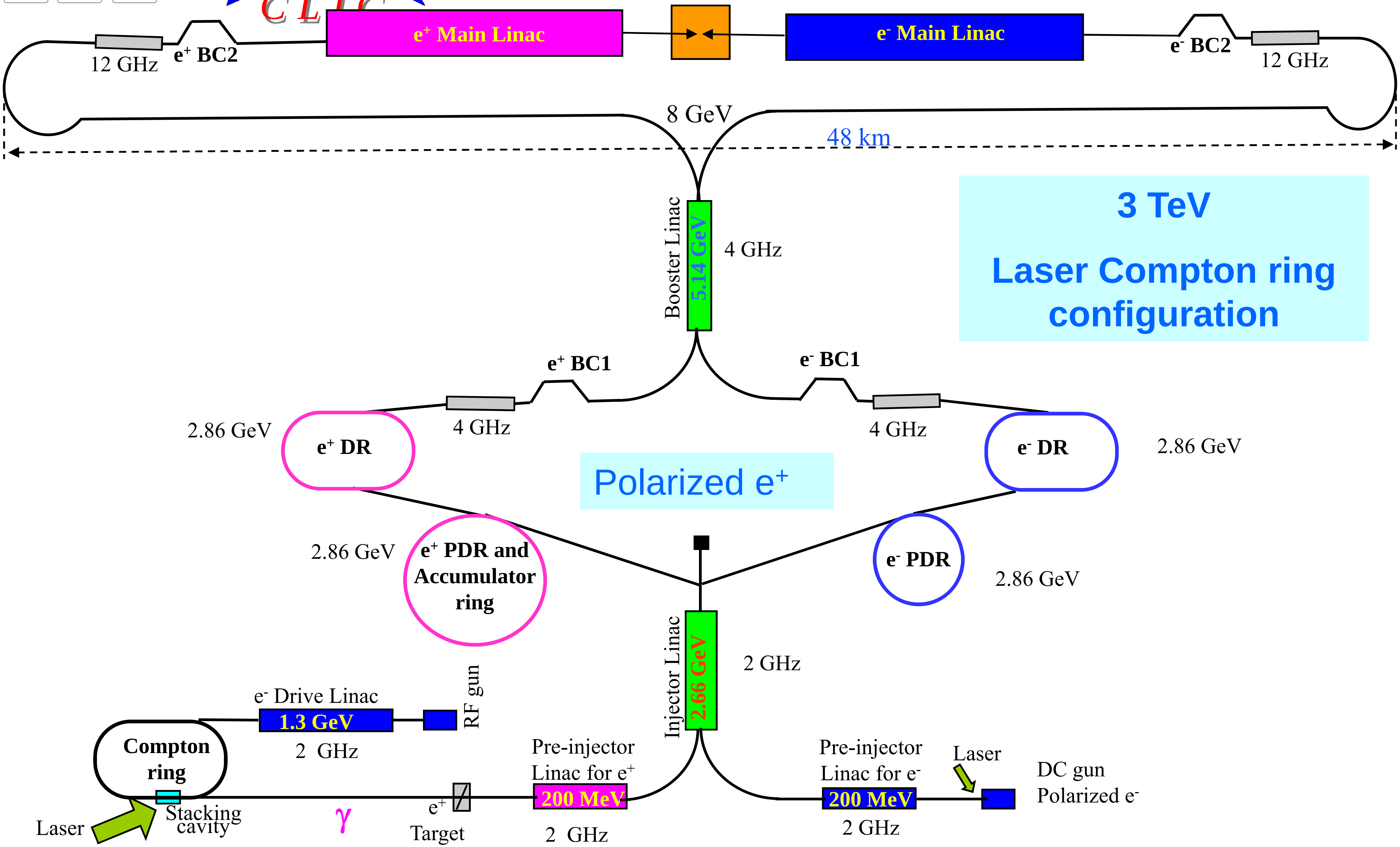
3) Double charge configuration:

500 GeV (c.m.) - polarized electrons (8×10^9 e^-/bunch) and unpolarized positrons (13×10^9 e^+/bunch).

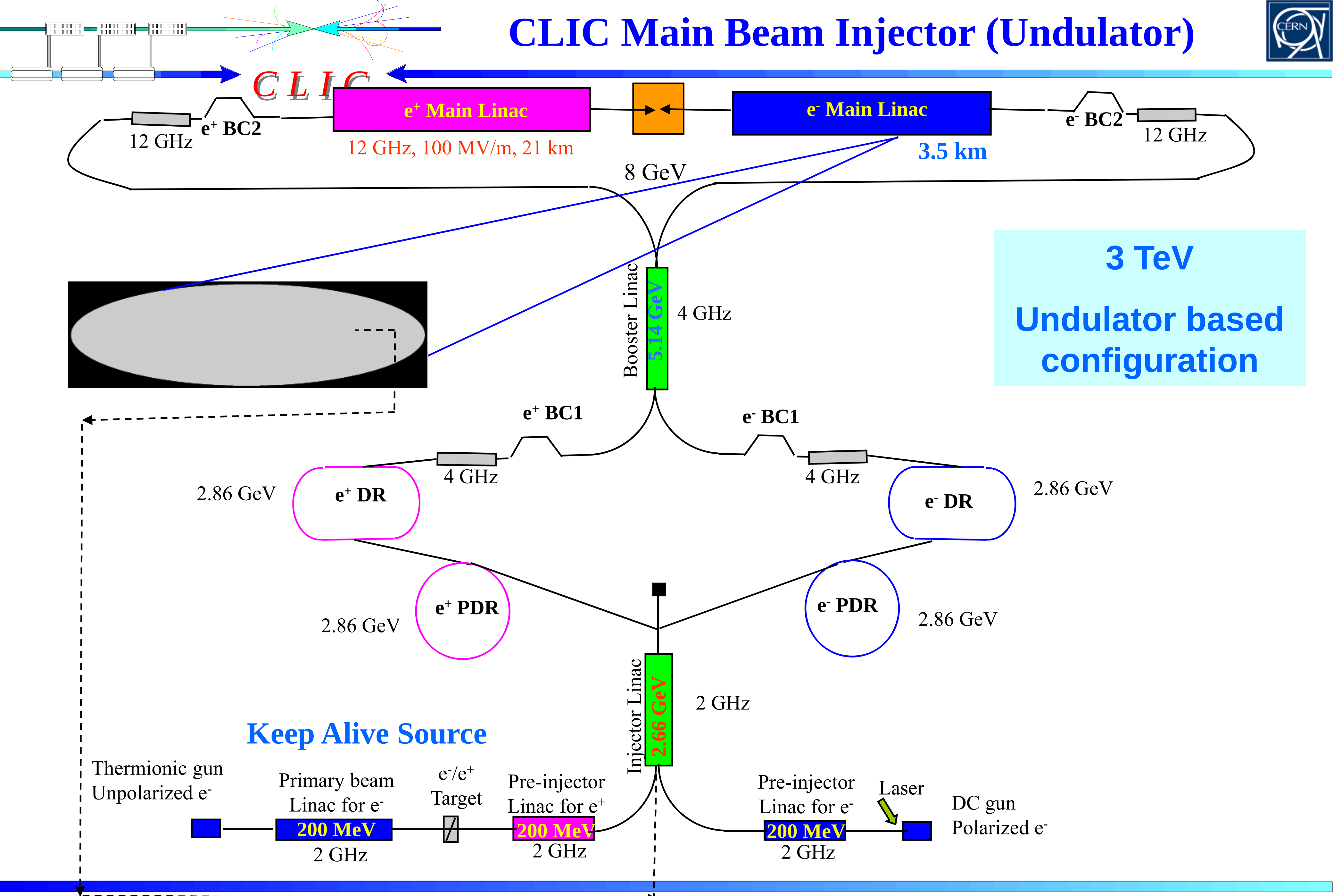
CLIC Main Beam Injector Complex in 2009



CLIC Main Beam Injector complex (Compton)



CLIC Main Beam Injector (Undulator)



CLIC Main Beam nominal parameters

At the entrance of the Main Linac for e^- and e^+

		NLC (1 TeV)	CLIC 2008 (3 TeV)	CLIC 2008 (0.5 TeV)	ILC (0.5 TeV)
E	GeV	8	8	8	15
N	10^9	7.5	4	7	20
n_b	-	190	312	354	2625
Δt_b	ns	1.4	0.5 (6 RF periods)	0.5	369
t_{pulse}	ns	266	156	177	968925
$\varepsilon_{x,y}$	nm, nm	3300, 30	600, 10	2300, 10	8400, 24
σ_z	µm	90-140	43 - 45	72	300
σ_E	%	0.68 (3.2 % FW)	1.5 - 2	2	1.5
f_{rep}	Hz	120	50	50	5
P	kW	219	90	180	630

Generation of polarized electron

Specific issues for polarized e^- source

Parameter	Symbol	0.5 TeV	3 TeV
Number Electrons per microbunch	N_e	**10×10^9**	**6×10^9**
Number of microbunches	n_b	354	312
Width of microbunch	t_b	~ 100 ps	~ 100 ps
Time between microbunches	Δt_b	0.5002 ns	0.5002 ns
Microbunch rep rate	f_b	1999 MHz	1999 MHz
Width of macropulse	T_B	177 ns	56 ns
Macropulse repetition rate	F_B	50 Hz	50 Hz
Charge per micropulse (e x N_e)	C_b	1.6 nC	0.96 nC
Charge per macropulse (C_b x n_b)	C_B	566 nC	300 nC
Average current from gun (C_B x F_B)	I_{ave}	28 μA	15 μA
Average current in macropulse (C_B / T_B)	I_B	3.2 A	1.9 A
Duty Factor w/in macropulse ($t_b/\Delta t_b$)	DF	0.2	0.2
Peak current of micropulse (I_B / DF)	I_{peak}	16 A	9.6 A
Current density (I_{peak} / σ) [spot size radius 1 cm]	D	5 A/cm^2	3 A/cm^2

laser & gun

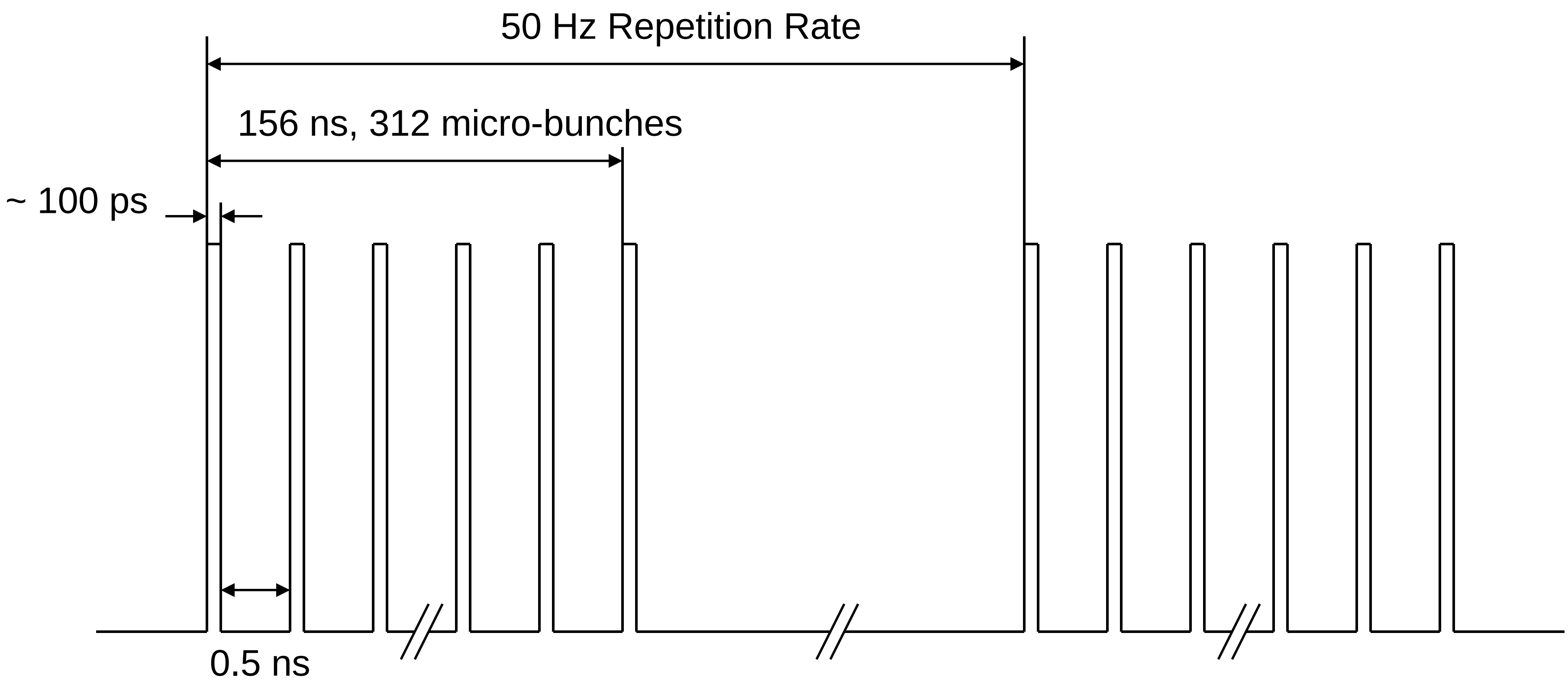
photo cathode

One of the critical issues is the Surface charge limit => needs demonstration => depends on laser system

ILC and CLIC e^- sources

Parameters	ILC	CLIC 0.5 TeV	CLIC 3 TeV
Electrons/microbunch	~3E10	10E9	6E9
Number of microbunches	2625	354	312
Width of Microbunch	1 ns	~100 ps	~100 ps
Time between microbunches	~360 ns	500.2 ps	500.2 ps
Width of Macropulse	1 ms	177 ns	156 ns
Macropulse repetition rate	5 Hz	50 Hz	50 Hz
Charge per macropulse	~12600 nC	566 nC	300 nC
Average current from gun	63 μA	28 μA	15 μA
Peak current of microbunch	4.8 A	16 A	9.6 A
Current density (1 cm radius)	1.5 A/cm^2	5 A/cm^2	3 A/cm^2
Polarization	>80%	>80%	>80%

CLIC e^- beam time structure



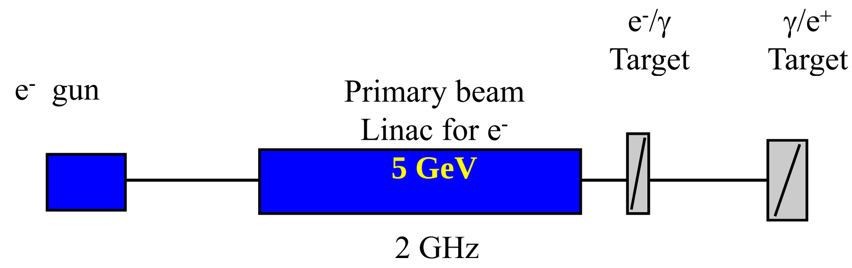
1.999 GHz

$(\Delta I/I)_{\text{bunch to bunch}} \leq 1\%$

$(\Delta I/I)_{\text{pulse to pulse}} \leq 0.2\ \%$

Generation of unpolarized positron

Primary electron beam



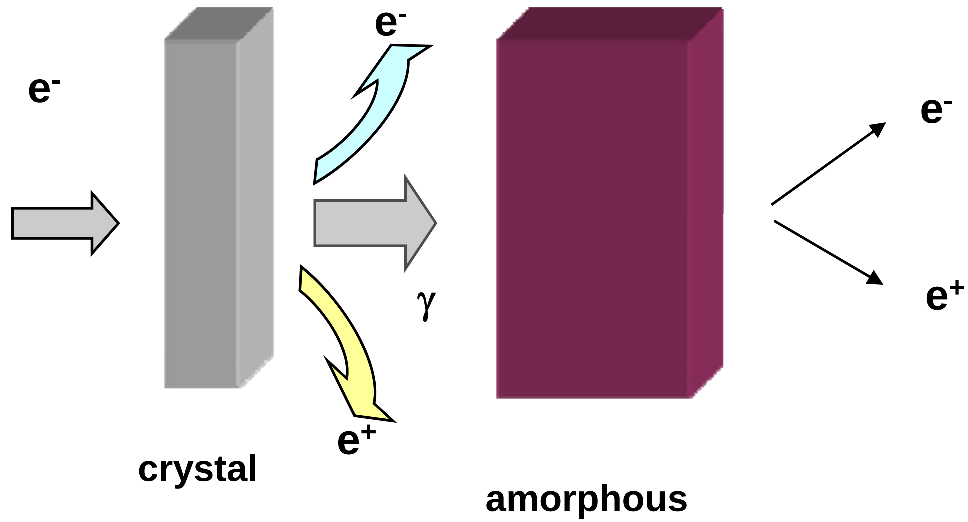
Parameter	Unit	
Primary e- Beam		
Energy	GeV	5
N e- /bunch	10^9	7.5
N bunches / pulse	-	312
N e- / pulse	10^{12}	2.34
Pulse length	ns	156
Repetition frequency	Hz	50
Beam power	kW	94
Beam radius (rms)	mm	2.5
Bunch length (rms)	mm	0.3

Unpolarized e^+ based on hybrid targets

After several simulations, an optimized configuration is given below:

Electron beam on the crystal:
- **energy = 5 GeV**
- **beam spot size = 2.5 mm**

Beam diagnostic required



No space =>

No beam diagnostic

First target is a crystal: 1.4 mm thick W oriented along <111> axis where channeling process occurs

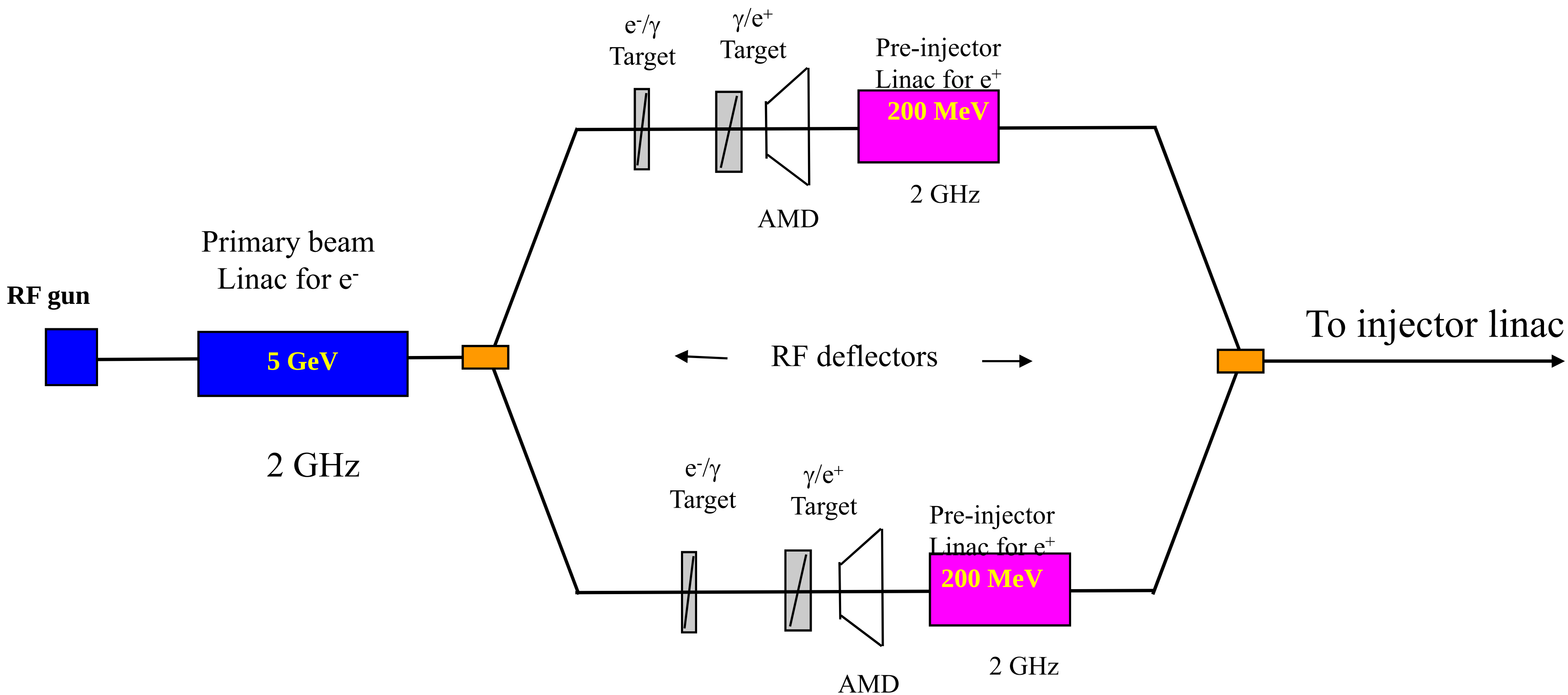
Second target is amorphous: 10 mm thick W

e^+ source for CLIC 500 GeV

Double charge / bunch => Double Peak Energy Deposition Density inside the target

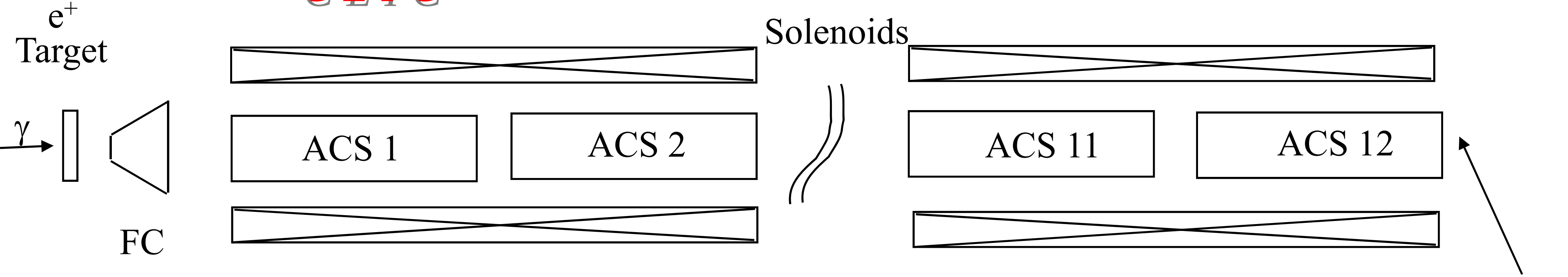
=> very close to the breakdown limit

=> Double target station



=> Double beam diagnostics required

Pre-Injector Linac for e^+



Accelerating Structures (ACS):

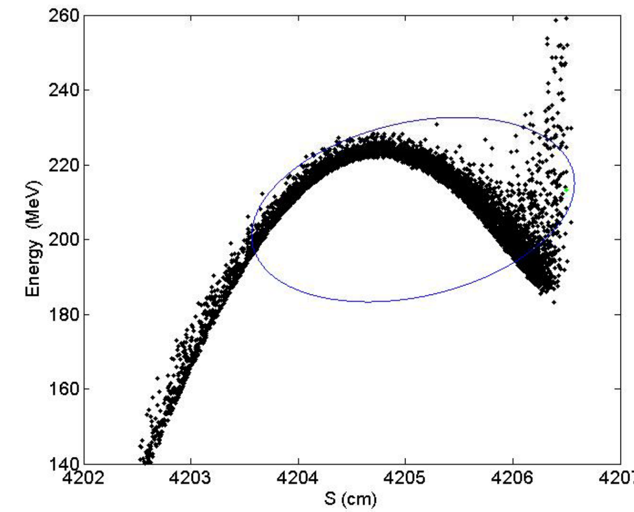
G ≅ 10 MV/m L = 1.8 m Radius = 0.018 m f = 2 GHz

Magnetic Field of Flux Concentrator (FC)	T	6
FC Length	m	0.5
Solenoid Magnetic Field	T	0.5
Length of Pre-Injector Linac	m	42

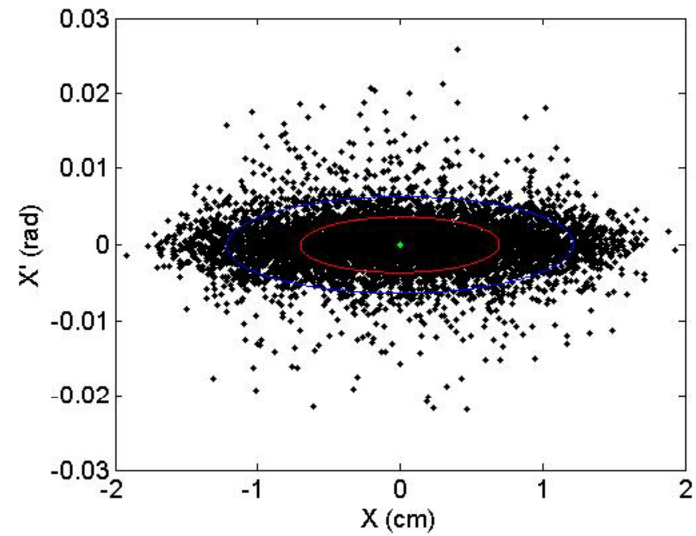
Pre-Injector Linac

Parameter	Unit	CLIC 2009
		EGS4 + ASTRA
Energy (E)	GeV	0.2
No. of particles/bunch (N)	10^9	6.7
Bunch length (rms) (σ_z)	mm	10
Energy Spread (rms) (σ_E)	%	8
Longitudinal emittance	eV.s	0.5×10^{-3}
H and V emittances ($\gamma\varepsilon_x$)	mm. mrad	6700

Longitudinal

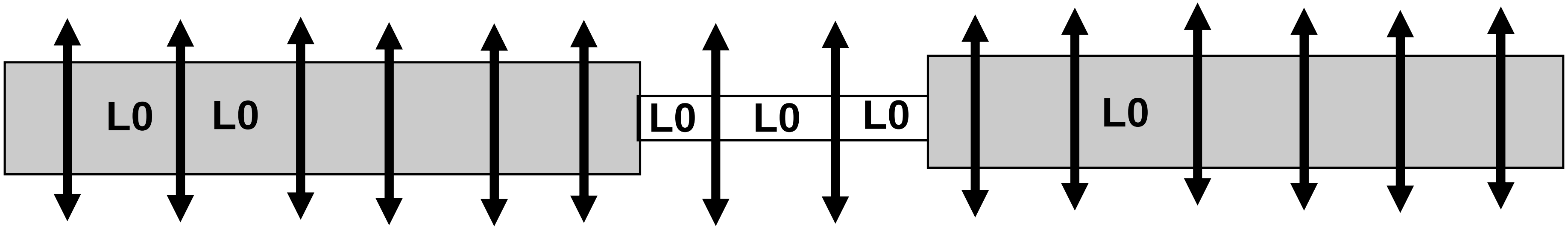


Transversal

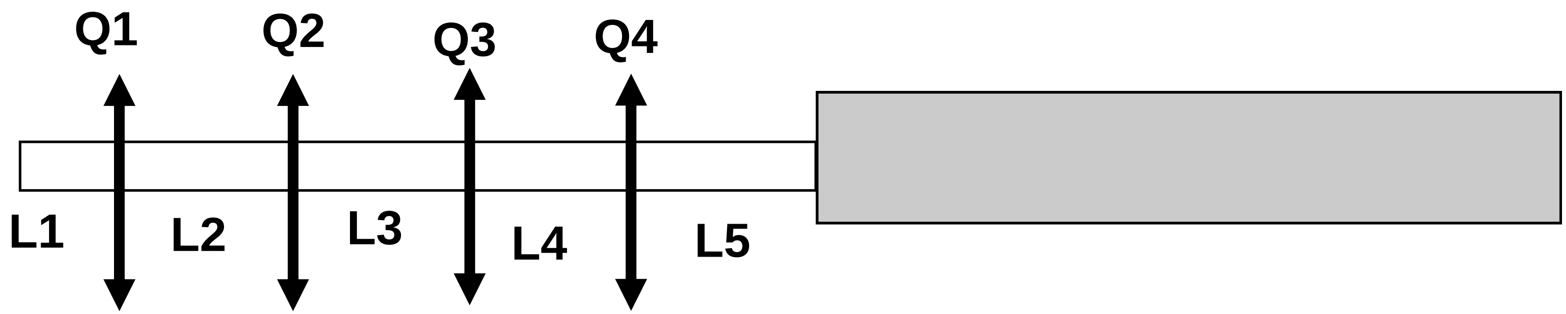


Injector Linac

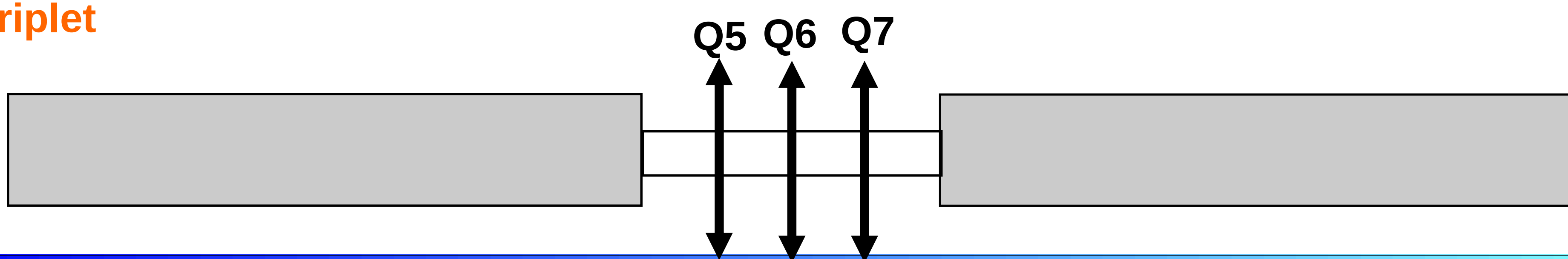
F0DO



Matching from FODO to Triplet



Triplet



CLIC Injector Linac optics parameters

FODO	
Number of Accelerating sections (L= 4 m)	4 x 3 = 12
Number of quadrupoles on accelerating sections (L = 42 cm)	6 x 4 x 3 = 72
Number of quadrupoles between accelerating sections (L = 42 cm)	11 x 2 = 22
Matching section	
Number of quadrupoles (L = 42 cm)	4 x 1 = 4
Triplet	
Number of Accelerating sections (L= 4 m)	21
Number of quadrupoles between accelerating sections (Quad length = 42 cm)	20 x 3 = 60

"ILC/CLIC e^+ generation" working group

J. Clarke (Daresbury), L. Rinolfi (CERN)

The Cockcroft Institute
of Accelerator Science and Technology

Officially set-up at ILC08 workshop
Chicago: 15th - 20th November 2008

Several tests facilities (CERN, CesrTA, CI, JLAB, KEKB, LAL, SLAC, …) are considered where the beam diagnostics are crucial tools.

Purpose of the diagnostics system

1) Aid in tuning the injector complex

2) Measure the beam parameters

3) Implement the machine protection system

Diagnostics system composed of:

1) Charge monitors:	BPE, WCM, ICT,…
2) Beam position monitors:	BPM, BPI, BPS,…
3) Beam profile monitors:	MTV, WBS, Streak camera,…
4) Bunch length monitors:	BPR, PHM,…
5) Emittance measurement:	Pepper pot, quads scan,…
6) Energy spread measurement:	MTV, SDU, …
7) Beam loss monitors:	BLM, ….
8) Polarization monitor:	Mott polarimeter,…

In red, acronyms of devices already used into CTF3

DC gun exit

Length	1	m
Energy	**200**	**keV**
Number of bunches	312	
No. of particles / bunch	6	10^9
Bunch length	50	mm
Energy spread	**3.5**	**%**
Transverse horizontal emittance	**100**	**mm rad**
Transverse vertical emittance	**100**	**mm rad**

	Accuracy	*Resolution*	*Bandwidth*	*Beam tube aperture*	*Non-intercepting device?*	*How many?*
Intensity	1x10^8	2x10^7	1 GHz	Φ 40 mm	yes	1
Position	100 µm	50 µm	1 GHz	Φ 40 mm	yes	2
Beam Size	0.5 mm	0.1 mm			no	1
Energy	1%	0.50%	1 GHz		no	1
Energy Spread	1%	0.50%	1 GHz		no	1
Bunch Length	3 ps	1 ps			yes/no	1
Beam Polarization	5%	1%			no	1

Exit of the pre-injector linac for e^+

Length	60	m
Energy	**200**	**MeV**
Number of bunches	312	
No. of particles / bunch	**6.7**	**10^9 p**
Bunch length	**10**	**mm**
Energy spread	**8**	**%**
Longitudinal emittance	**150 000**	**eV.m**
Transverse horizontal emittance	**6700**	**mm.mrad**
Transverse vertical emittance	**6700**	**mm.mrad**

	Accuracy	*Resolution*	*Bandwidth*	*Beam tube aperture*	*Non-intercepting device?*	*How many?*
Intensity	1x10^8	2x10^7	1 GHz	40 mm	yes	10
Position	100 um	50 um	1 GHz		yes	10
Beam Size	0.5 mm	0.1 mm			no	2
Energy	1%	0.50%	1 GHz		no	1
Energy Spread	1%	0.50%	1 GHz		no	1
Bunch Length	3 ps	1 ps			yes/no	1

Detailed information for all beam diagnostic requirements are under EDMS pages

Summary

1) For the Base Line configuration at 3 TeV, polarized e^- and unpolarized e^+ would be generated close to the requested performance but extensive simulations for both sources, remain to be done to confirm the present studies.

2) Double charge configuration (0.5 TeV): for the polarized electrons, the space charge limit is a real challenge to provide the requested charge pattern

3) For polarized positrons, extensive studies are carried on, in collaboration with several institutes. For the 3 TeV, several major issues remain to be investigated and demonstrated by simulations.

4) The beam intensity stability of both sources could be a performance issue.

The beam instrumentation requirements are still under investigation.