The CLIC Electron and Positron Polarized Sources

THIS IS STILL A DRAFT

L. Rinolfi

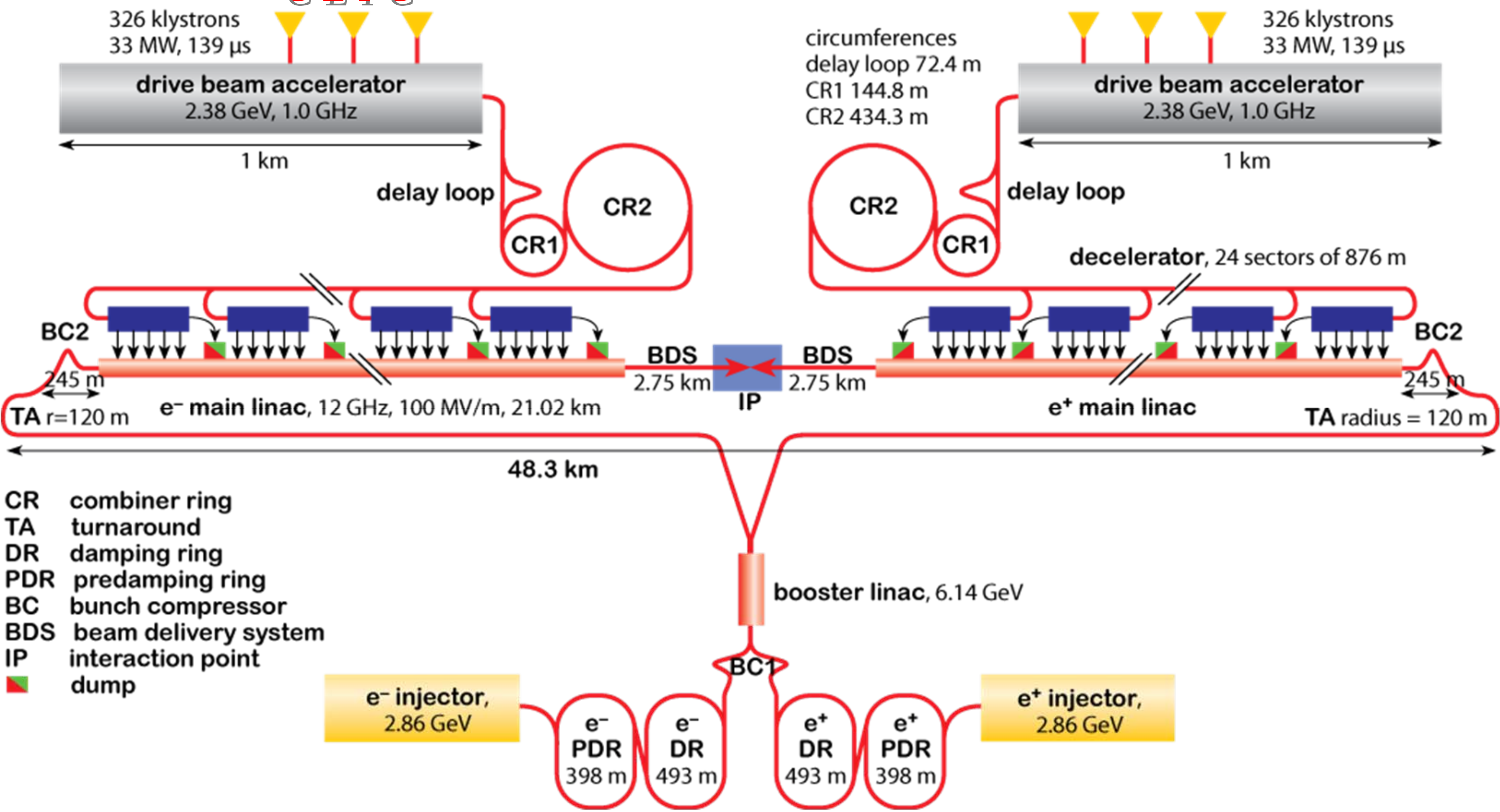
Acknowledgements

Thank you to those you have already provided data

Simulation results, technical information and comments are still welcome

List of co-authors and institutes

General CLIC layout for 3 TeV



CR combiner ring
TA turnaround
DR damping ring
PDR predamping ring
BC bunch compressor
BDS beam delivery system
IP interaction point
dump

CLIC Leptons sources studies

The CLIC Main Beams generation is focused on 3 studies to produce e^+/e^- with the requested parameters 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 (6.4×10^9 e^+/bunch).

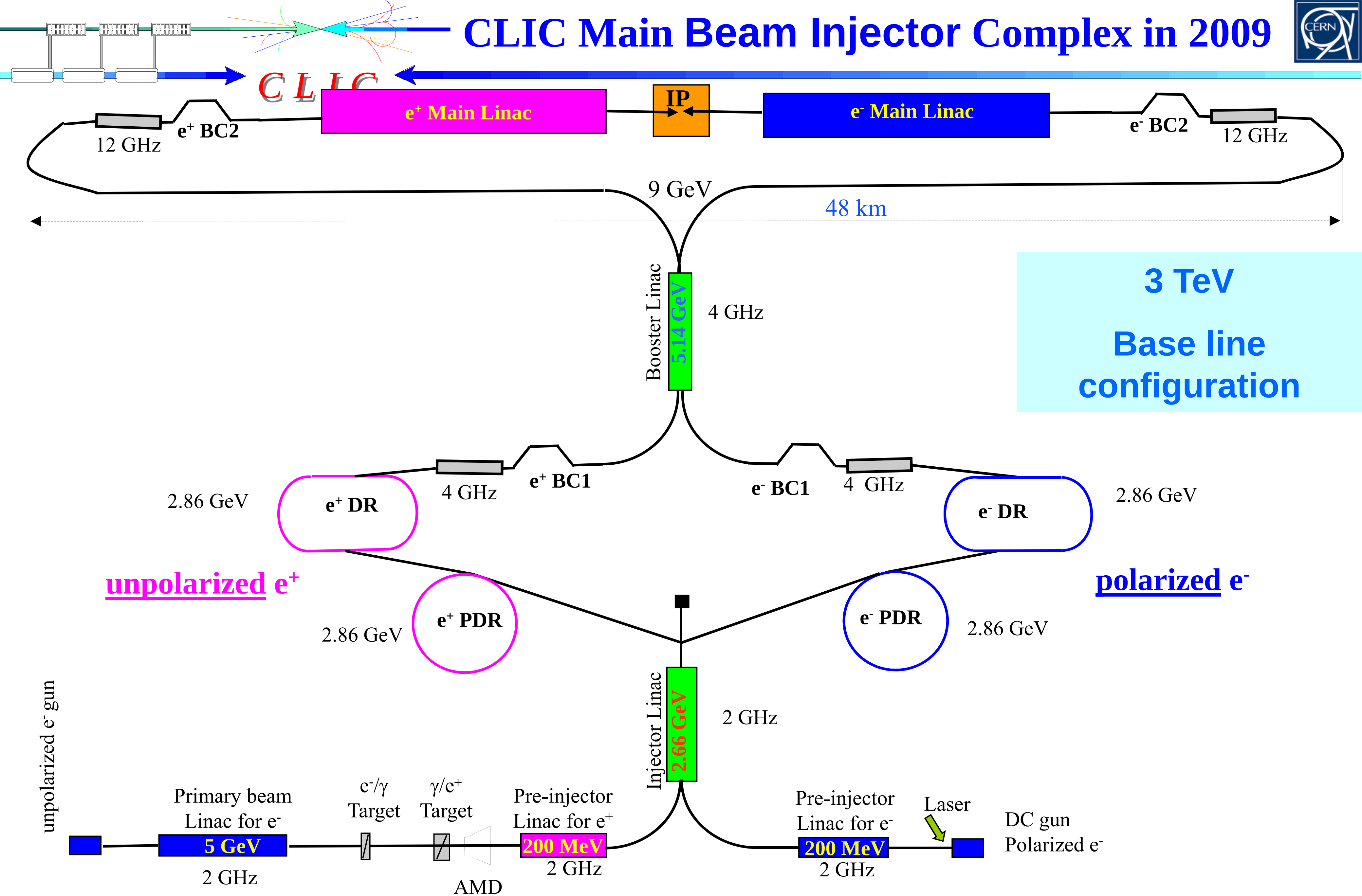
2) Polarized positron configuration:

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 (un)polarized positrons (12×10^9 e^+/bunch).

CLIC Main Beam Injector Complex in 2009



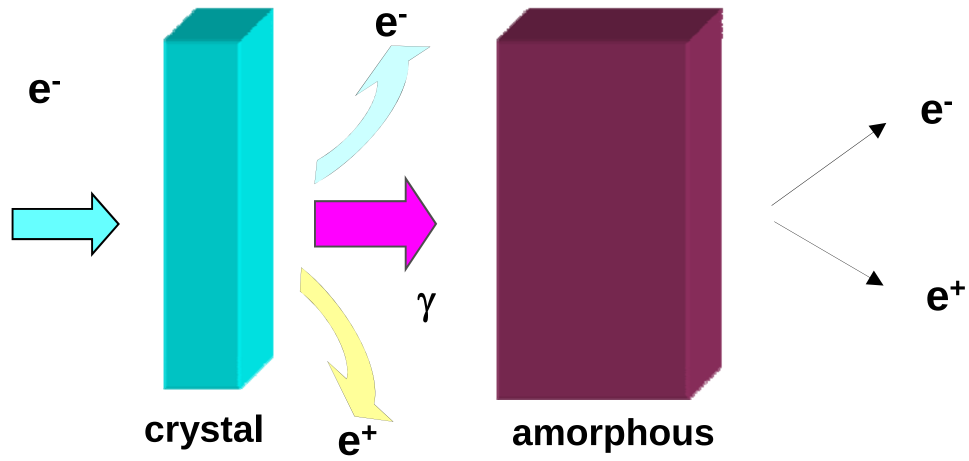
Unpolarized e⁺ based on hybrid targets

Electron beam on the crystal:

- energy = 5 GeV
- beam spot size = 2.5 mm

> First target is a crystal oriented along <111> axis where channeling process occurs

> Second target is amorphous.



Target		Crystal	Amorphous
Material		W	W
Length	mm	1.4	10
Beam power deposited	kW	0.2	7.5
Deposited P / Beam Power	%	0.2	8
Energy lost per volume	10^9 GeV/mm^3	0.8	2
Peak Energy Deposition Density (PEDD)	J/g	6.8	18

R. Chehab, A. Variola; Simulations by O. Dadoun / LAL and V. Strakhovenko / BINP - ***CLIC Note in preparation***

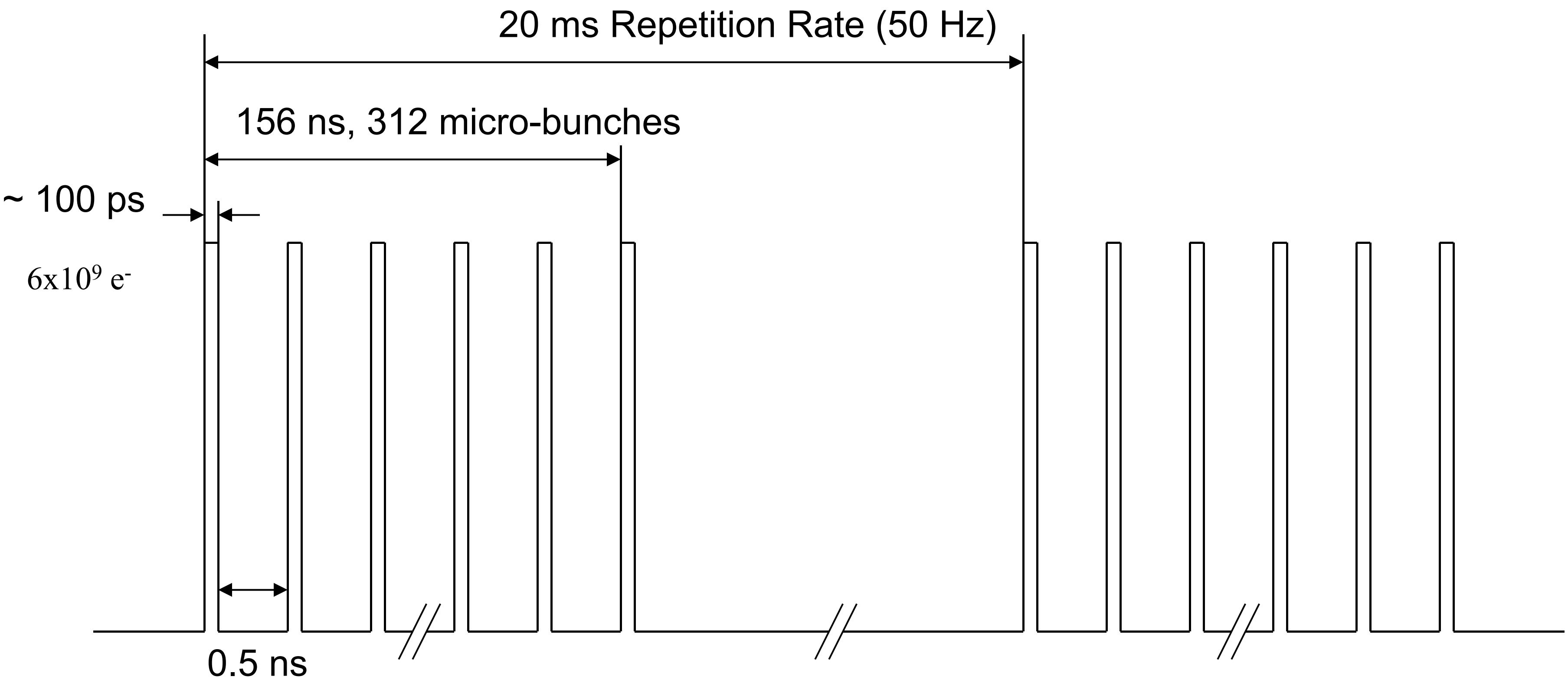
CLIC Main Beam nominal parameters

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

		NLC (1 TeV)	CLIC 2009 (3 TeV)	CLIC 2009 (0.5 TeV)	ILC (0.5 TeV)
E	GeV	8	9	9	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

CLIC e⁻ beam time structure at 3 TeV



1.999 GHz

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

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

Issues for the CLIC 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	156 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	3×10^{10}	1×10^{10}	0.6×10^{10}
Charge / microbunch	4.8 nC	1.6 nC	1 nC
Number of microbunches	2625	354	312
Width of Microbunch	1 ns	~ 0.1 ns	~ 0.1 ns
Time between microbunches	360 ns	0.5002 ns	0.5002 ns
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/cm²	5 A/cm²	3 A/cm²
Polarization	>80%	>80%	>80%

cw laser parameters for e⁻ source

$$E_L = \frac{hc}{q}\frac{Q}{\lambda \times QE}$$

$$E_L(J) = 1.24 \times 10^{-6}\frac{Q(nC)}{\lambda(nm) \times QE}$$

λ ≈ 775 - 780 nm for GaAs photocathodes

QE ≈ 0.2 % (Nagoya, JLAB, SLAC)

η ≈ 70% for the bunching system

Parameters	Units	CLIC 500 GeV	CLIC 3 TeV
Laser energy on photocathode ($E_B = E_L / \eta$)	J	647×10^{-6}	
Peak power ($P_p = E_B / T_B$)	W	3654	
Average power ($P_a = E_B \times F_B$)	W	0.032	
Repetition frequency (F_B)	Hz	50	50

Pulsed laser parameters for e^- source

$\lambda \approx$ 775 - 780 nm for GaAs photocathodes

QE ≈ 0.2 %

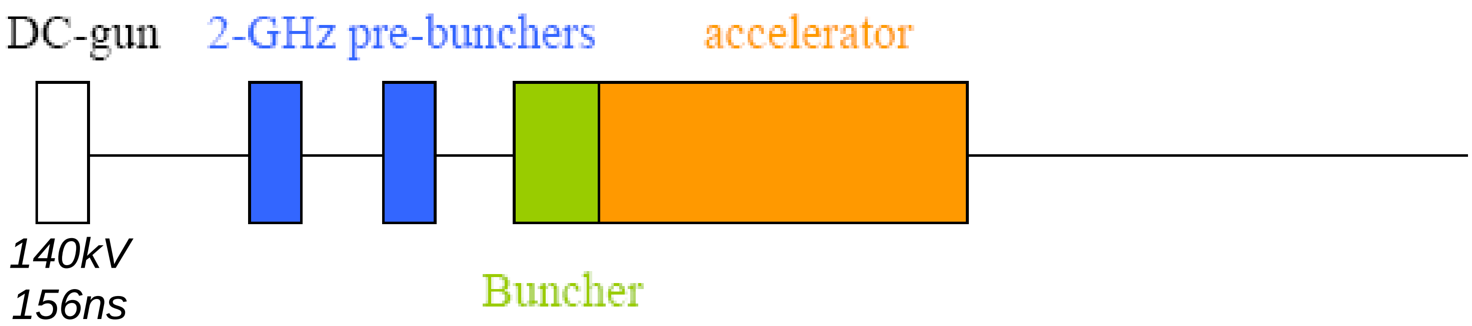
$\eta \approx$ 90%

Parameters	Units	CLIC 500 GeV	CLIC 3 TeV
Micropulse repetition frequency (f_p)	MHz	2000	2000
Micropulse length (t_p)	ns	0.1	0.1
Micropulse laser energy on photocathode ($E_B = E_L / \eta$)	J	1.3×10^{-6}	
Micropulse peak power ($Pp = E_B / t_p$)	W	13	
Macropulse laser energy on photocathode ($E_m = E_B \times n_b$)	J	460×10^{-6}	
Macropulse peak power ($P_m = E_m / T_B$)	W	2600	
Macropulse average power ($P_a = E_m \times F_B$)	W	23	
Repetition frequency (F_B)	Hz	50	50

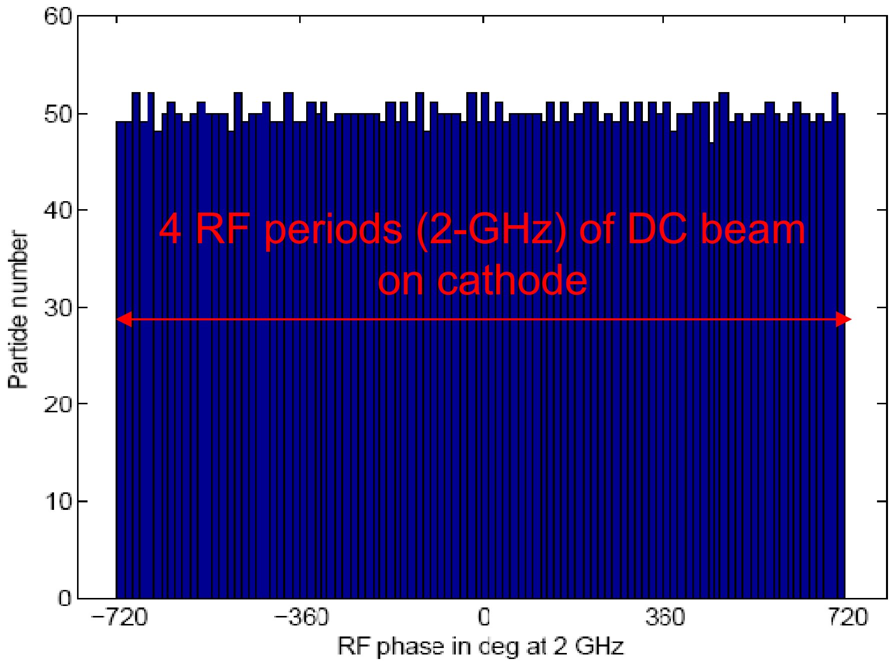
A. Brachmann, J. Sheppard /SLAC

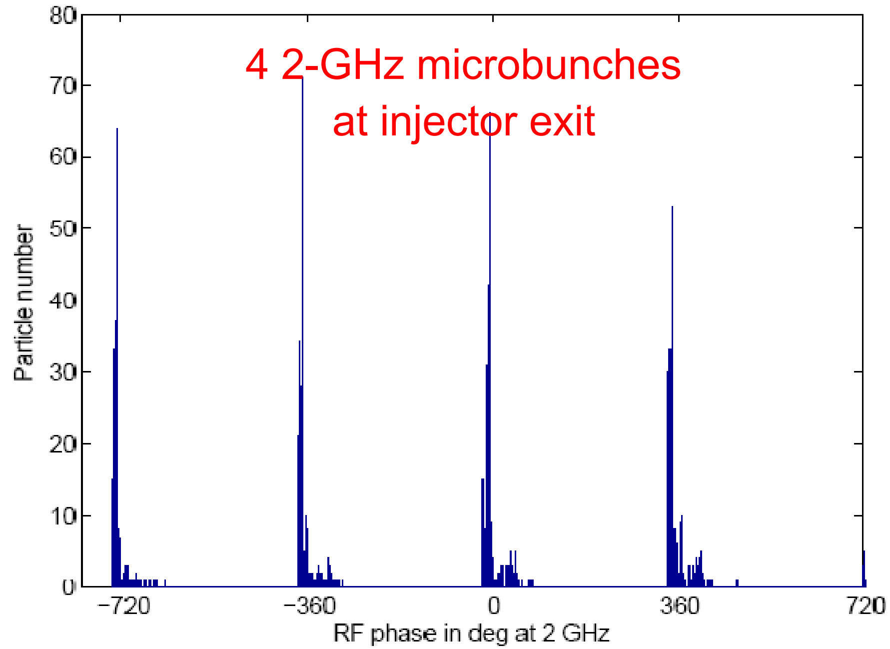
CLIC bunching system

Feng Zhou/SLAC



156ns DC beam (312 2-GHz RF periods)
$\Rightarrow$ 312 2-GHz microbunches





Simulations for the CLIC e^- source

F. Zhou / SLAC

Parameters	Units	CLIC 3 TeV
Gun voltage	kV	140
Injector energy	MeV	20
Initial charge at the gun	nC	1
Capture efficiency	%	88
Initial bunch length at the cathode	ns	156
Final bunch length (FWHM)	ps	14
Energy spread (FWHM)	keV	100
Normalized rms emittance	mm.mrad	22

At GaAs photo-cathode		Pulse	cw
Nb e-/microbunch	10^9	6	6x 312
Nb bunches		312	-
Peak current of microbunch	A	9.6	1.9
Current density	A/cm^2	3	0.6

Ultra-short pulse beam with high charge (< 10 ps, @1 nC/bunch) is not yet successful

Low beam emittance with high charge (< 1 π.mm.mrad, @1 nC/bunch) is not yet realized

R&D is ongoing at SLAC, JLAB, Japan,…

CLIC polarized e⁻ source challenges

Gun:

Reliable load locked gun

High voltage 100 kV - 350 kV => No field emission

Ultra-high vacuum requirments => range of 10^{-11} Torr

Cathode/anode optics => challenge for uniform focusing properties

Photocathode:

Production of the full current with space charge and surface charge limits

High polarization: 80 % - 90%

High Quantum Efficiency: 0.2 – 1 % => Photo-cathodes preparation techniques

Long life time

Laser:

Laser frequency:	2 GHz or cw
Pulse length:	0.1 to 1 ns or 156 ns
Pulse energy:	~ 1 mJ

Goals:

The major goals for photocathode development at SLAC for the ILC and CLIC are:

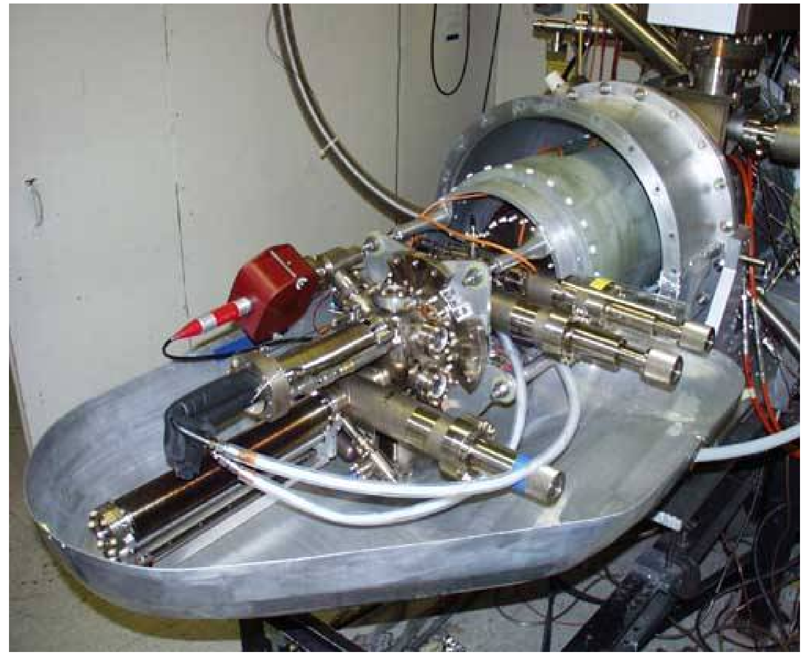
1) demonstration of full charge production without space charge and surface charge limitation;

2) >85% polarization;

3) ~1% QE and long QE lifetime.

DC guns for polarized e⁻ source

JLAB 100 kV electron gun
(courtesy from M. Poelker)

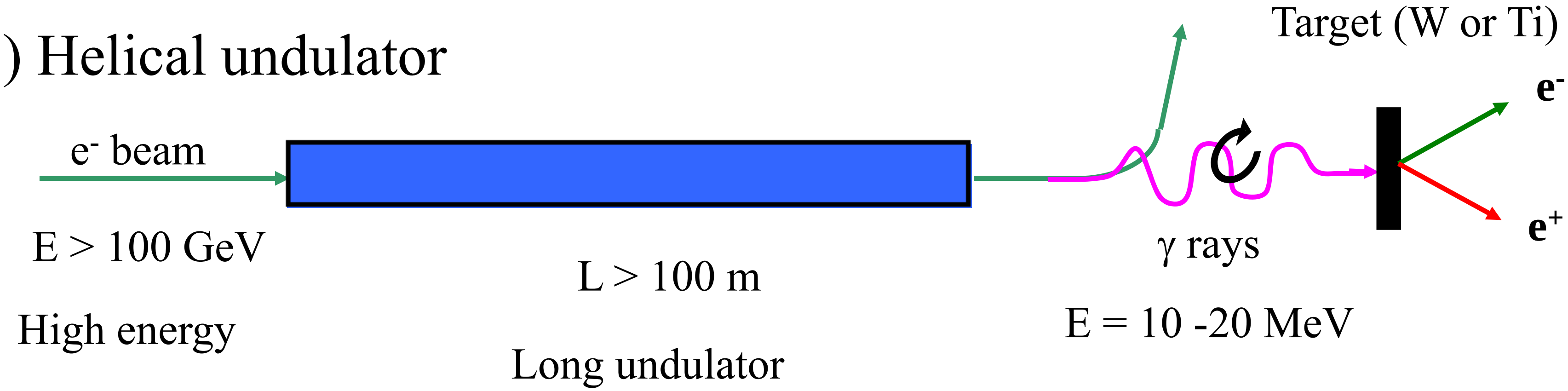


SLAC 120 kV electron gun
(courtesy from J. Sheppard)

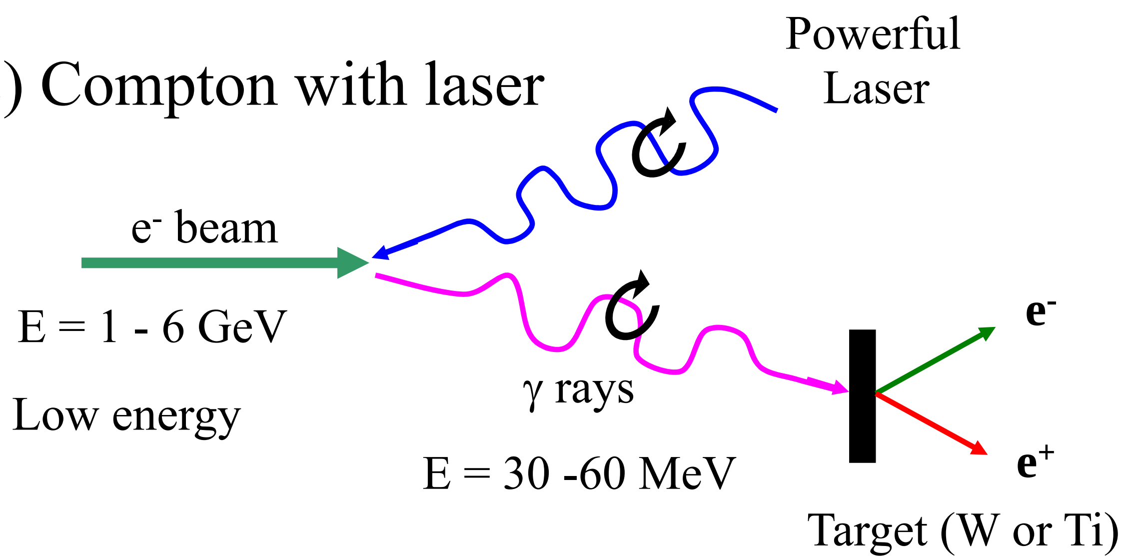
Generation of polarized positron

Two methods to produce polarized e^+

1) Helical undulator

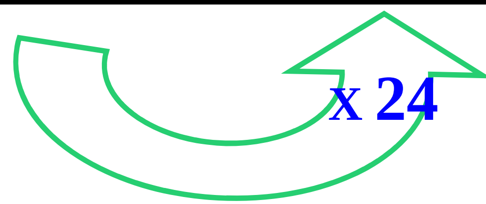


2) Compton with laser

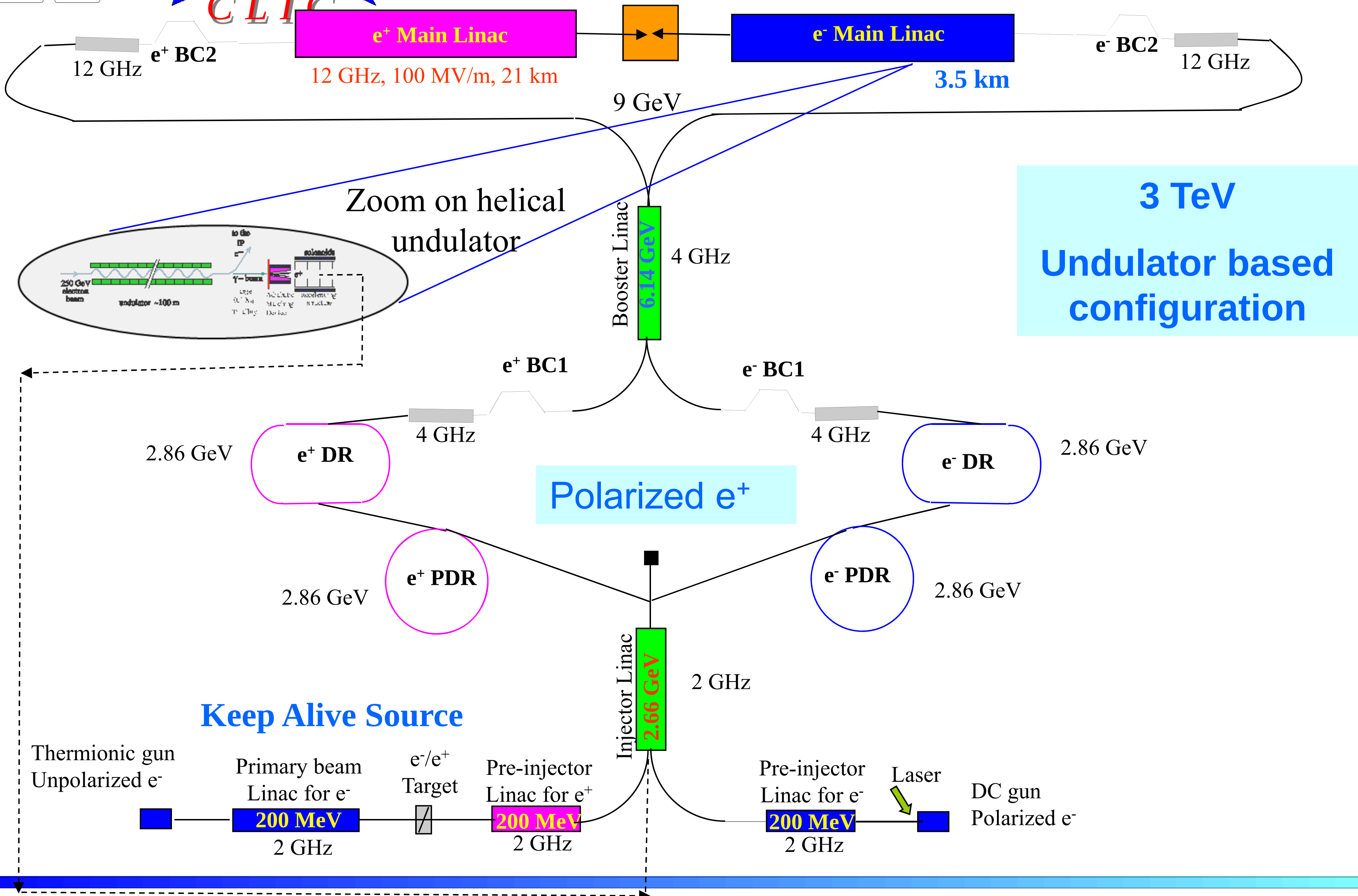


Flux of e^+

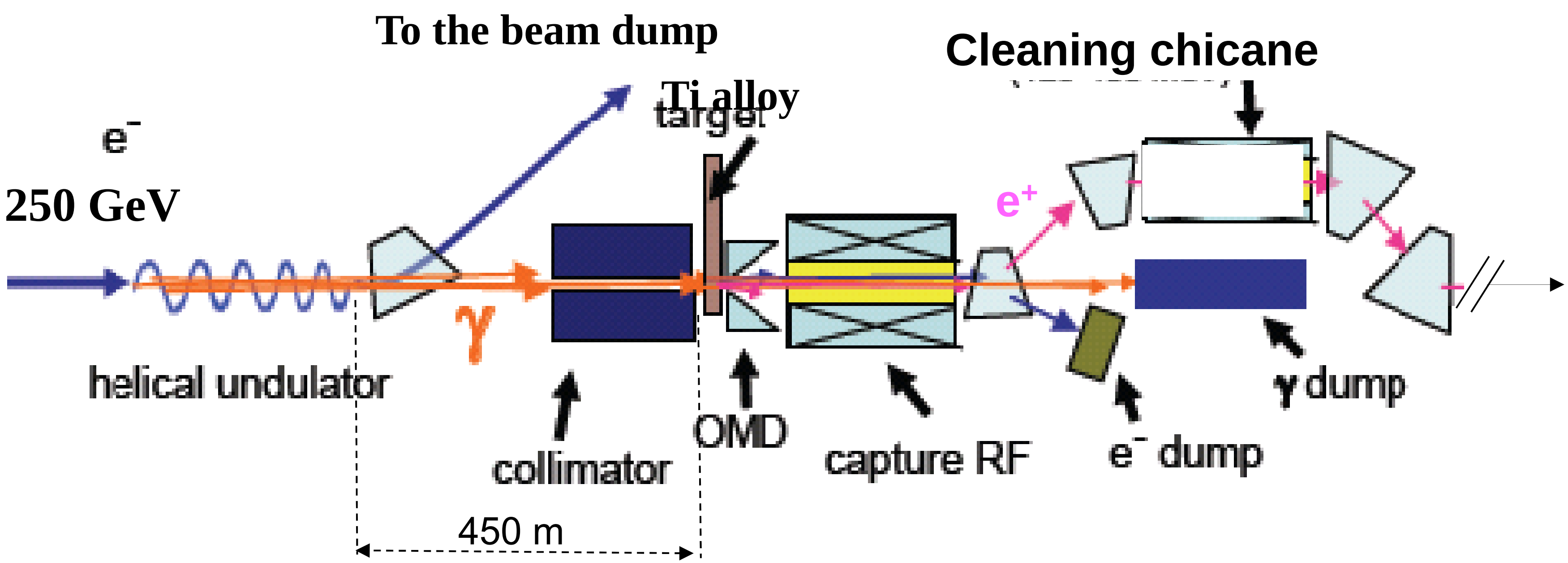
	SLC	CLIC	ILC	LHeC
Positrons / bunch	3.5×10^{10}	0.64×10^{10}	2×10^{10}	1.5×10^{10}
Bunches / macropulse	1	312	2625	20833
Macropulse Rep Rate	120	50	5	10
Positrons / second	0.042×10^{14}	1×10^{14}	2.6×10^{14}	31×10^{14}



CLIC Main Beam Injector (Undulator)



Undulator scheme



Undulator:

K = 0.5 - 0.75

λ_u = 1 - 1.5 cm

L = 100 m

OMD:

B = 7T - 0.5T

L = 20 cm

Pre-Injector Linac:

G = 10 MV/m

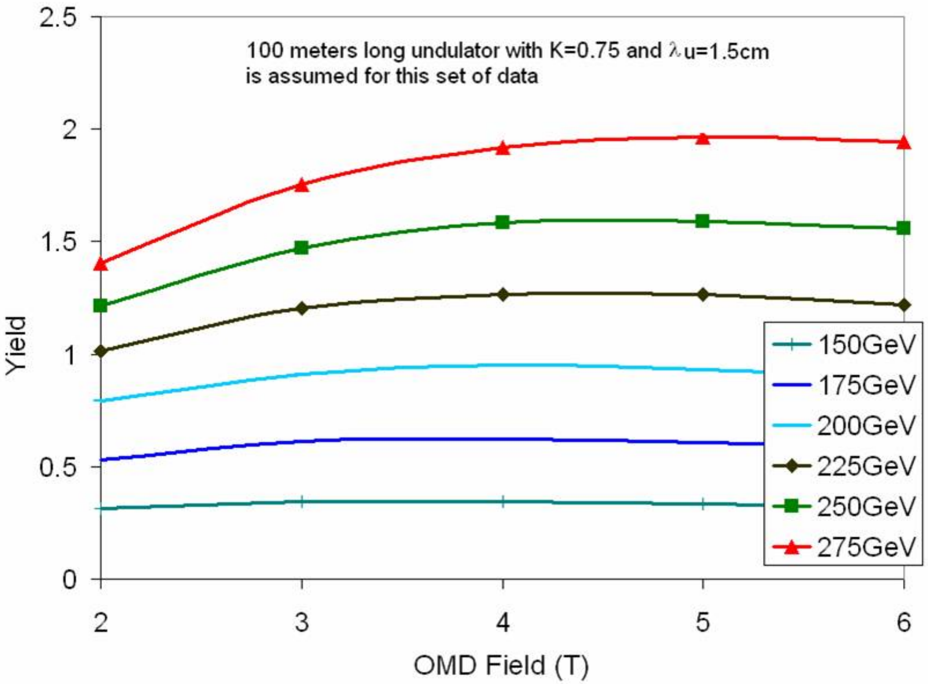
f = 1.3 GHz

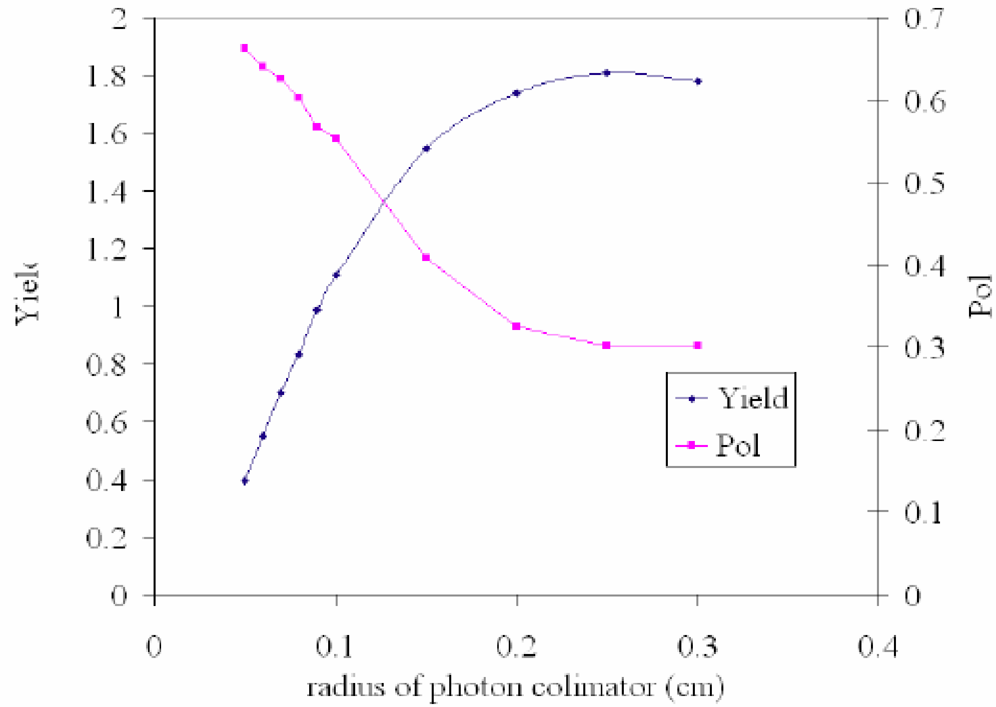
E = 200 MeV

Bo = 0.5 T

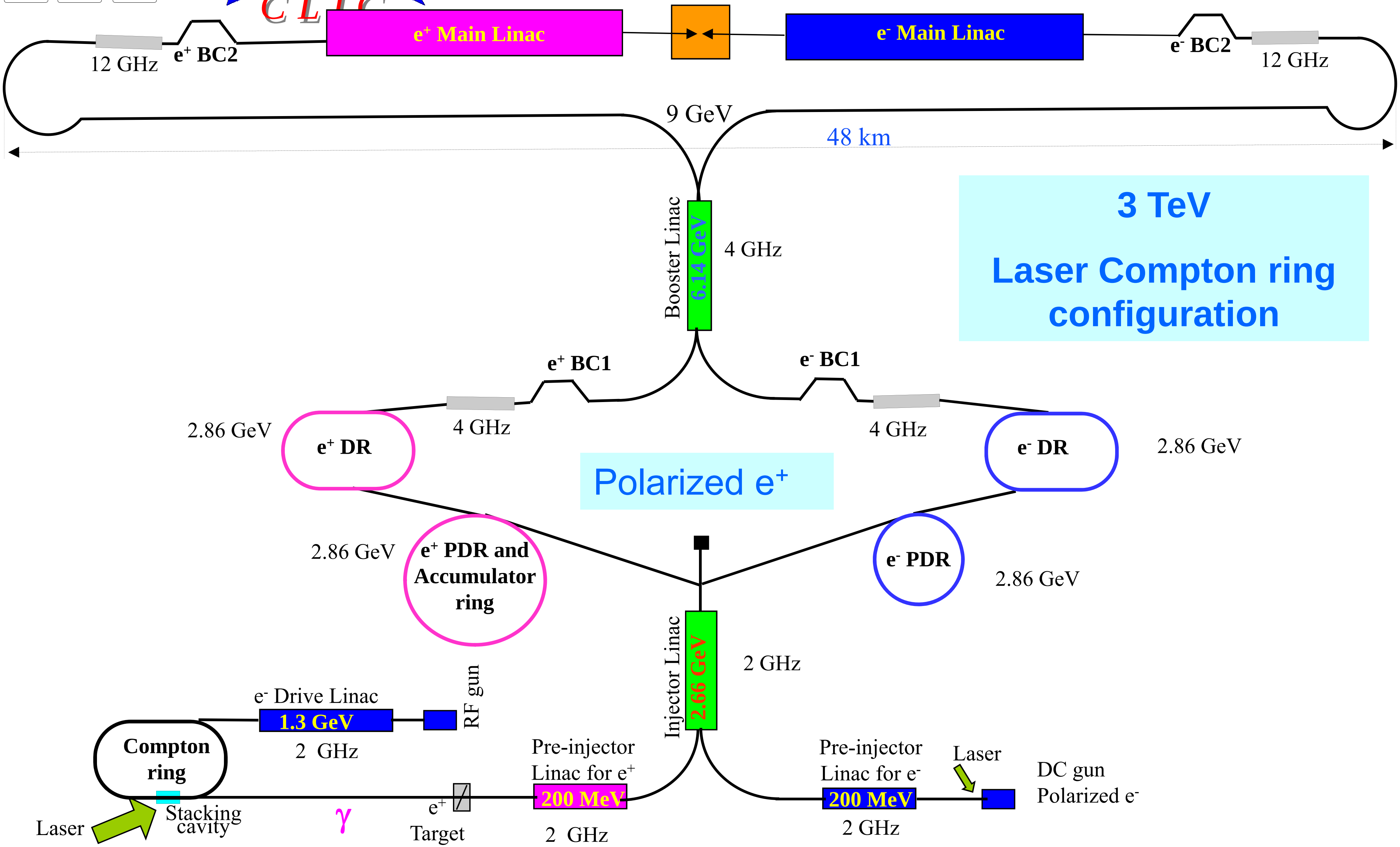
Results of simulations for an undulator

W. Gai, W. Liu / ANL





CLIC Main Beam Injector (Compton Ring)

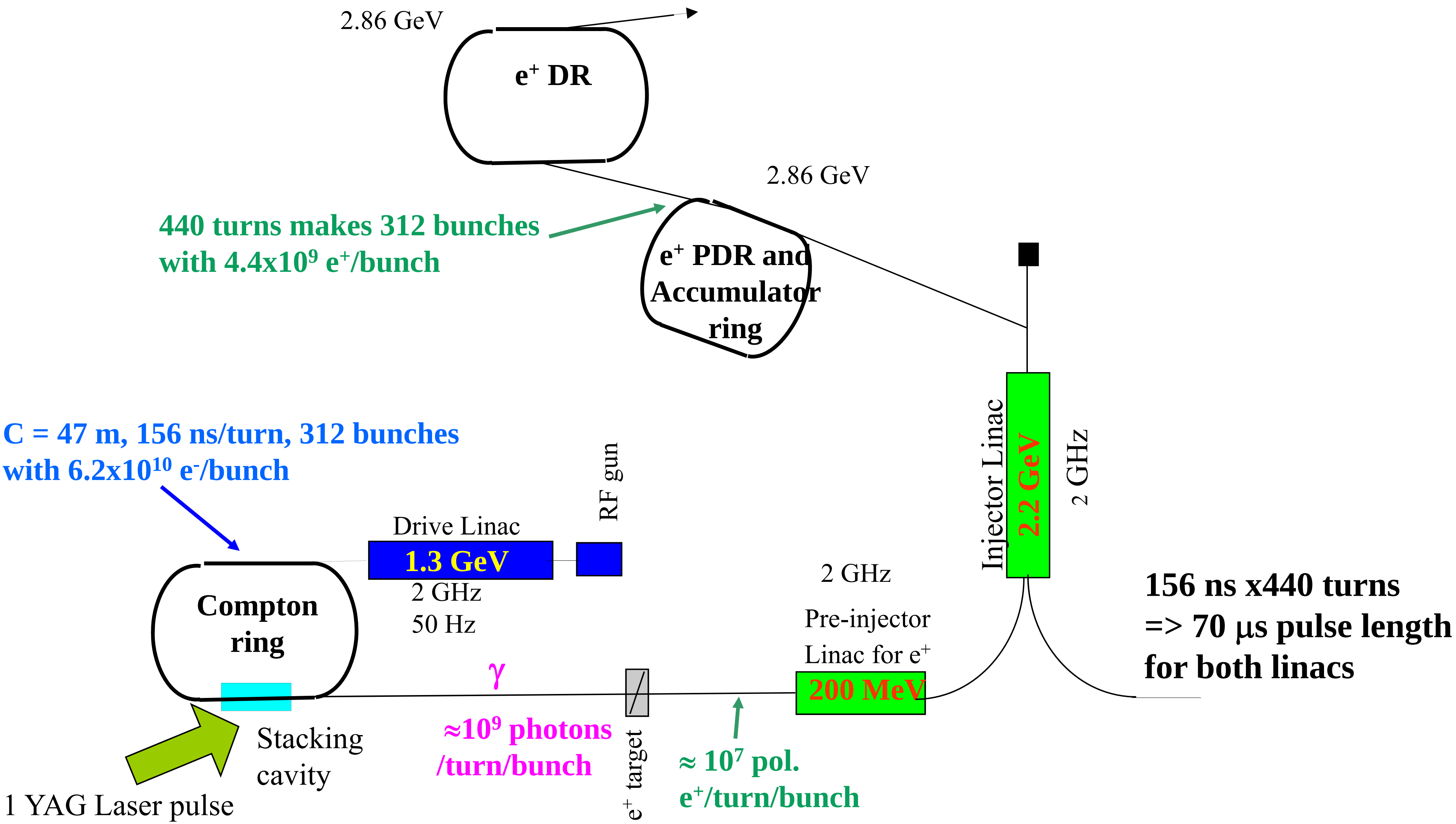


3 TeV

Laser Compton ring configuration

Polarized e+

CLIC Compton scheme

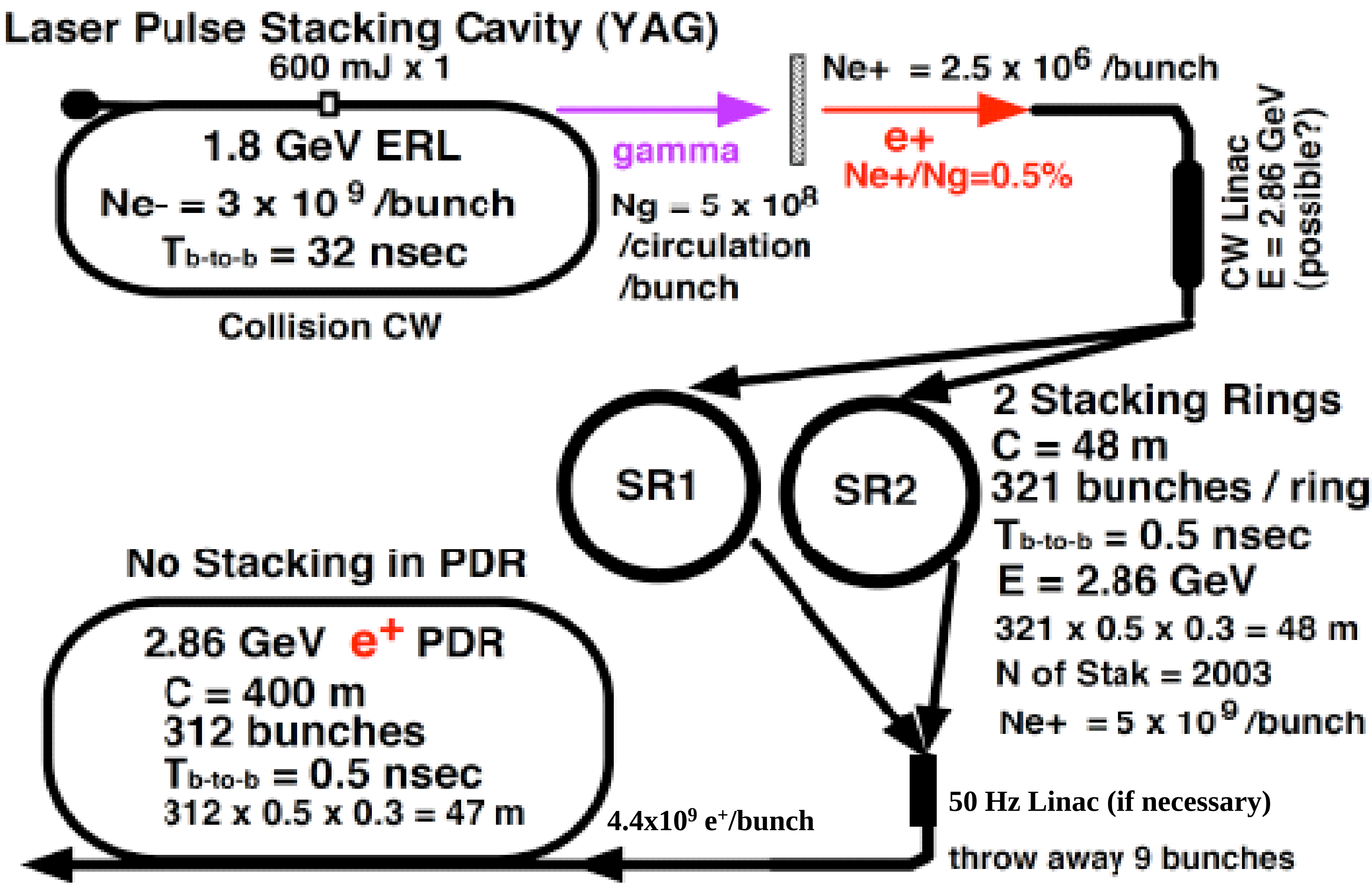


Results of simulations for Compton ring

E. Bulyak, P. Gladkikh / NSC-KIPT-Kharkov

CLIC Injector (Compton ERL)

T. Omori/ KEK, L.R. / CERN



Challenges and performance for the ERL

collision

- e^- beam (ERL)

  3×10^9 e^-/bunch

  E = 1.8 GeV

- Laser

  600 mJ / cavity

  1 cavity in ERL

- 5×10^8 γ-rays/bunch

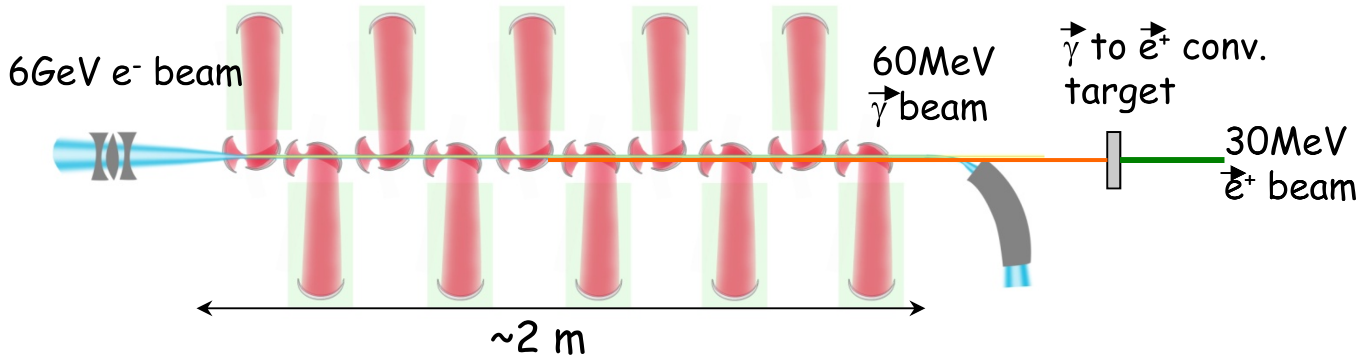
  thin conversion target: yield 0.5 %

- 2.5×10^6 e^+/bunch

  2003 stacking in the same bucket

- 5×10^9 e^+/bunch (CLIC requires 6.4×10^9 when not damped and 4.4×10^9 e^+/ bunch when damped)

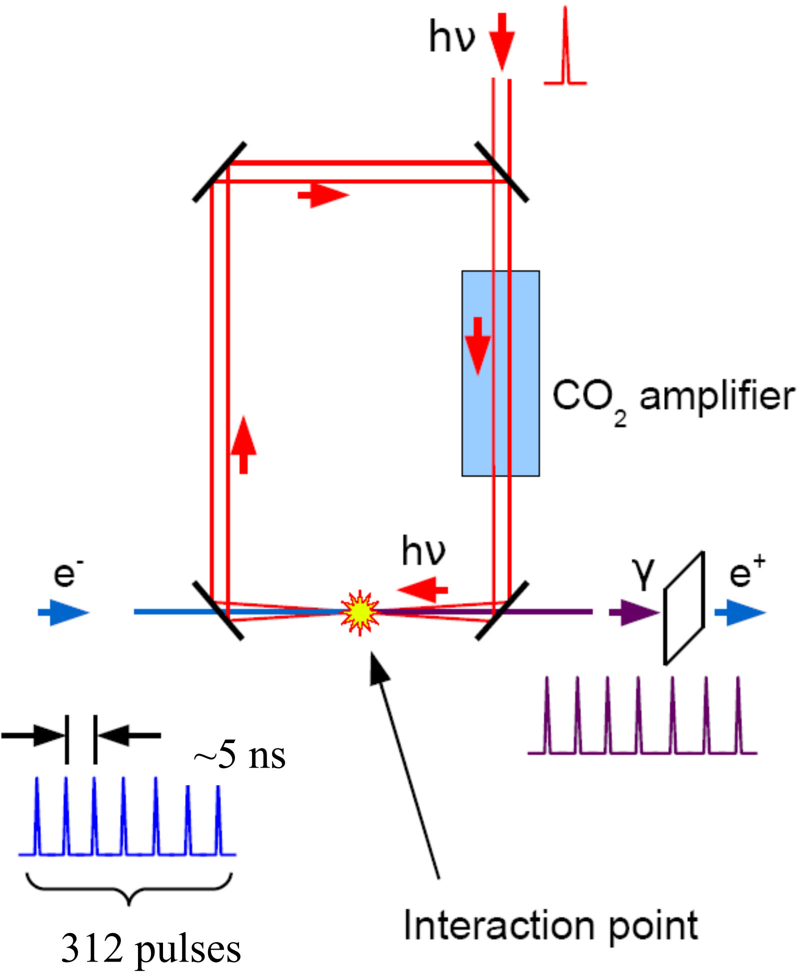
CLIC Injector (Compton Linac)



$N_\gamma / N_{e-} = 1$ (demonstrated at BNL)

$N_{e+} / N_\gamma = 0.02$ (expected)

i.e. ≈ 50 gammas to generate 1 e^+



Data for CLIC:

$N_{e+} = 6.4 \times 10^9$ / bunch ~ 1 nC

$N_{e-} = 0.32 \times 10^{12}$ / bunch ~ 50 nC

With 5 nC / e^- bunch and 10 Compton IP's

=> 1 nC / e^+ bunch

I. Pogorelski, V. Yakimenko / BNL

CLIC collaborations for e$^+$/e$^-$ sources

CLIC

Alphabetic order for countries

Countries	Institutes	Contact persons	Subject	Status	Date
France	LAL	A. Variola R. Chehab	e+ studies	Formal agreement	September 2008
Germany	FZR Rossendorf	J. Teichert	Compton sources	In preparation	November 2008
Japan	KEK	T. Omori M. Kuriki	e+ studies	Informal agreement	October 2007
Japan	KEK	J. Urakawa T. Kamitani	R&D on targets systems and experiments at KEKB	In preparation	January 2009
Turkey	Ankara University	A.Kenan Çiftçi E. Eroglu	FLUKA simulations	Informal agreement	June 2008
Ukraine	Kharkov Institute	E. Bulyak P. Gladikikh	Compton Rings	Informal agreement	April 2006
United Kingdom	Cockcroft Institute	J. Clarke I. Bailey	e+ studies	Formal agreement	October 2008
USA	Argonne Laboratory	W. Gai W. Liu	e+ studies	Formal agreement	January 2009
USA	Jefferson Laboratory	M. Poelker	Polarized e-	Formal agreement	September 2007
USA	SLAC	J. Sheppard A. Brachmann F. Zhou	Polarized e-	Informal agreement	August 2008

Summary

➢ 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, in parallel with an important R&D program, remain to be done to confirm the present studies.

➢ For polarized positrons, several challenges remain to be investigated and demonstrated by simulations. Fortunately extensive studies are carried on, in collaboration with several institutes.