CLIC Main Beam Injector Complex review

Louis Rinolfi

for the CLIC Collaboration

Acknowledgements

F. Antoniou, X. Artru, I. Bailey, A. Brachmann, E. Bulyak, R. Chehab, M. Chevallier, J. Clarke, O. Dadoun, S. Doebert, E. Eroglu, A. Ferrari, W. Gai, P. Gladkikh, T. Kamitani, M. Kuriki, A. Latina, W. Liu, T. Maruyama, T. Omori, Y. Papaphilippou, M. Poelker, F. Poirier, I. Pogorelski, D. Schulte, J. Sheppard, V. Strakhovenko, F. Stulle, T. Takahashi, F. Tecker, J. Urakawa, A. Variola, A. Vivoli, V. Yakimenko, L. Zang, F. Zhou, F. Zimmermann

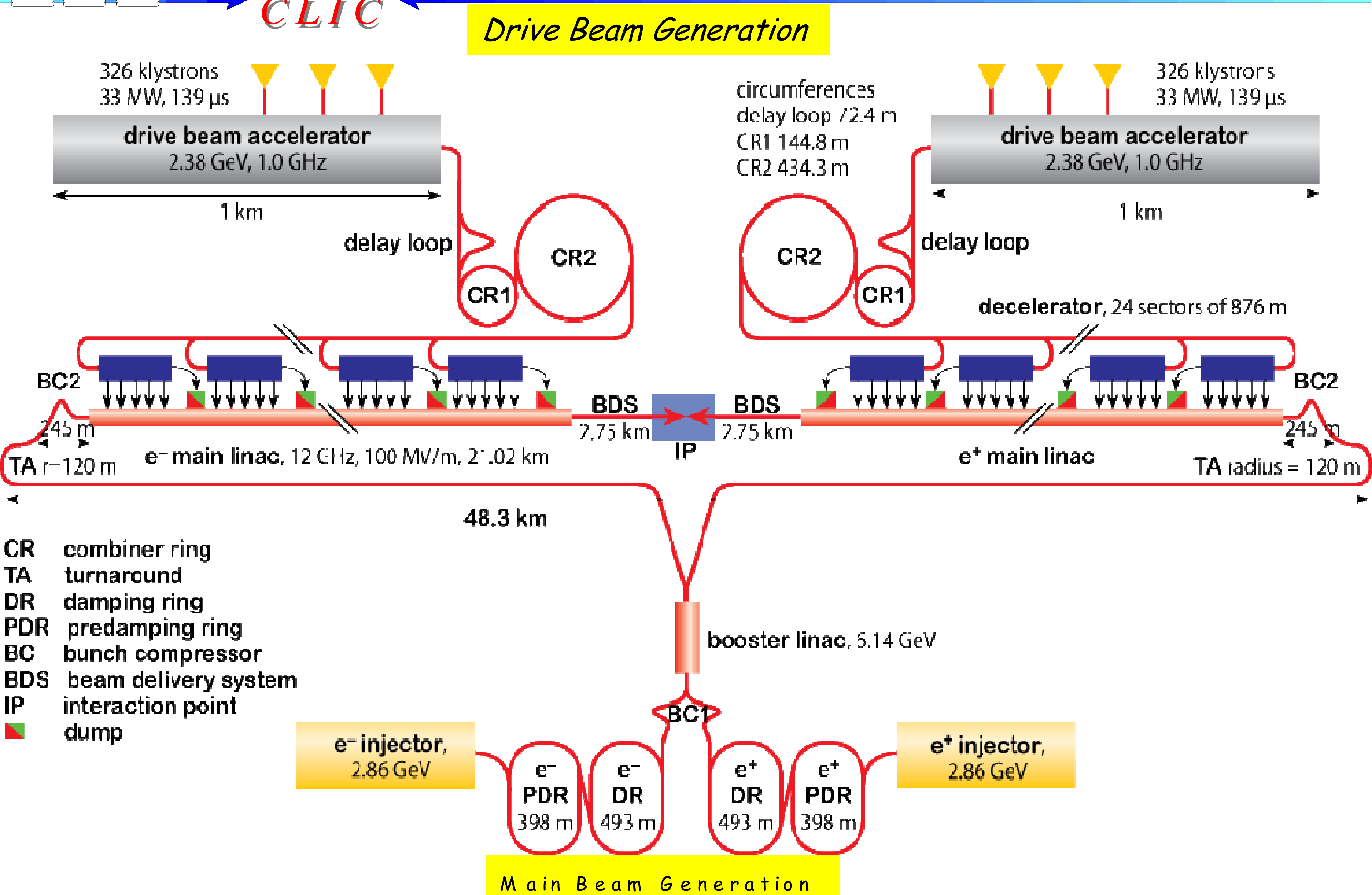
Collaborations

for the CLIC Main Beam Generation studies

Alphabetic order for countries

Countries	Institutes	Collaborators	Subject
France	LAL	I. Chaikovska, O. Dadoun, F. Poirier, A. Variola	e^+ studies
France	IPNL	X. Artru, R. Chehab, M. Chevallier, V. Stakhovenko	Channeling studies
Germany	FZR Rossendorf	J. Teichert	Compton sources
Japan	Hiroshima Uni.	M. Kuriki, T. Takahashi	Experiments at KEKB
Japan	KEK	T. Kamitani, T. Omori, J. Urakawa	e^+ studies
Turkey	Uludag University	E. Eroglu, A. Kenan Çiftçi, E. Pilicer, I.Tapan	FLUKA simulations
Ukraine	Kharkov Institute	E. Bulyak, P. Gladkikh	Compton Rings
United Kingdom	Cockcroft Institute	I. Bailey, J. Clarke, L. Zang	Undulator e^+ studies
USA	ANL	W. Gai, W. Liu	Undulator e^+ studies
USA	BNL	I. Pogorelski, V. Yakimenko	Compton Linac
USA	JLAB	M.Poelker	DC gun for polarized e-
USA	SLAC	A. Brachmann, T. Maryama, J. Sheppard, F. Zhou	Polarized e- sources

General CLIC layout for 3 TeV



CLIC Main Beam generation

CLIC Main Beams generation: 4 studies are ongoing to produce e^+/e^- with the requested parameters at the entrance of the Pre-Damping Ring (PDR):

1) Baseline configuration:

3 TeV (c.m.) - polarized electrons (*5×10^9* e^-/bunch) and unpolarized positrons (*7.6×10^9* e^+/bunch). Pulse of 156 ns long with 312 bunches

2) Double charge configuration:

500 GeV (c.m.) - polarized electrons (*10×10^9* e^-/bunch) and unpolarized positrons (*15.2×10^9* e^+/bunch) with same pulse length as above

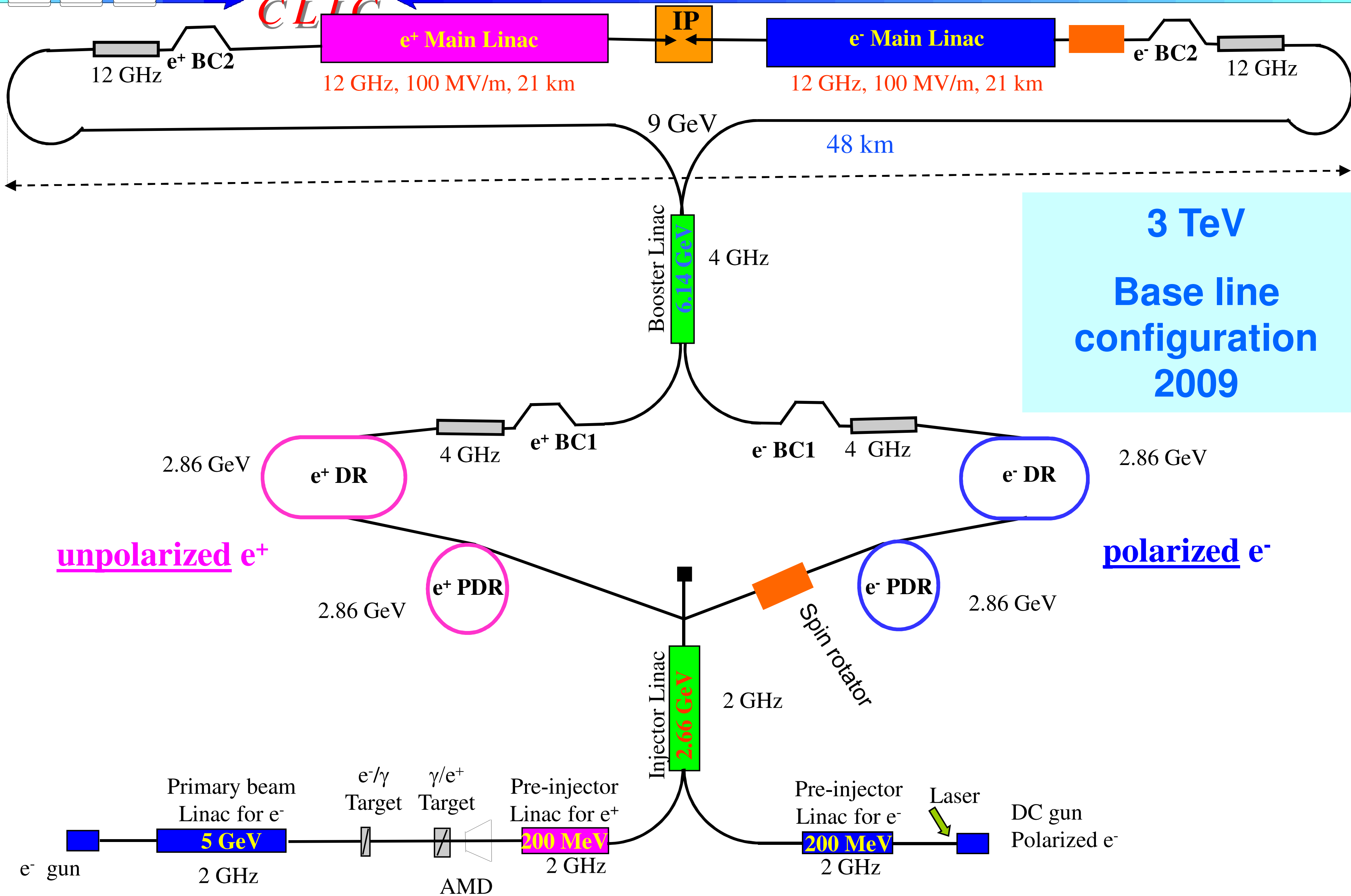
3) Polarized positron configuration:

3 TeV (c.m.) - polarized e^- and e^+ with same parameters as for the baseline

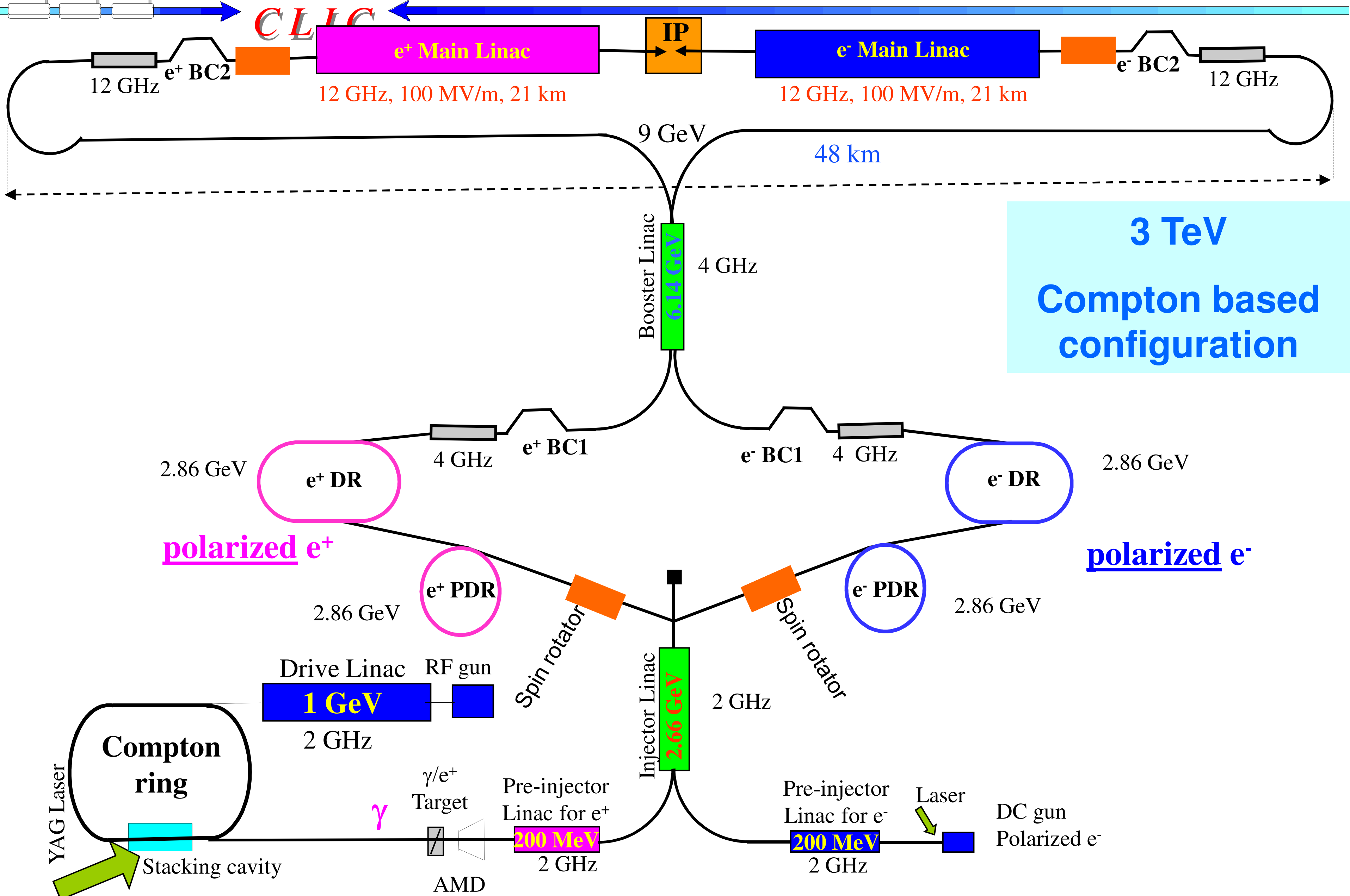
4) Low energy configuration (< 3 TeV):

4.1) Polarized e^- and unpolarized e^+ (as the base line) but with the highest repetition frequency
4.2) Polarized e^- and unpolarized e^+ with half the baseline charge but 800 bunches

CLIC Main Beam Injector Complex



CLIC Main Beam Injector Complex



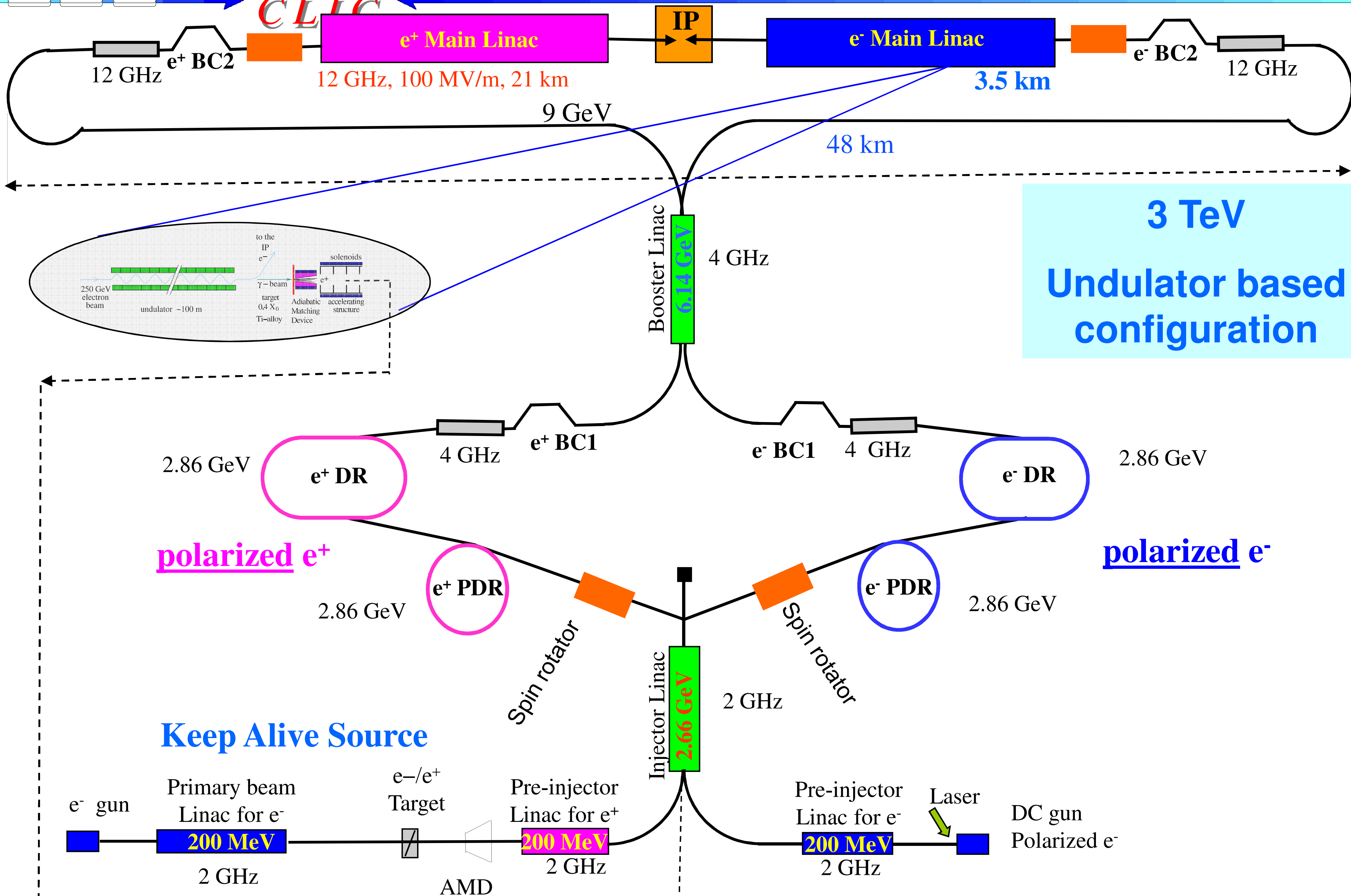
3 TeV

Compton based configuration

CLIC Main Beam Injector Complex

3 TeV

Undulator based configuration



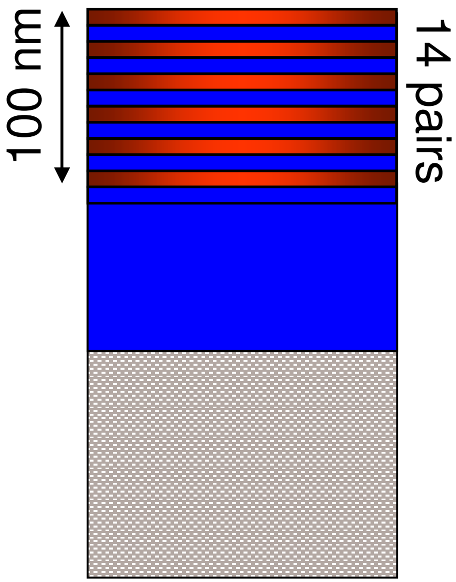
Polarized electrons

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
Total charge per pulse	79×10^{12}	3.5×10^{12}	1.9×10^{12}
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
Average current in macropulse	0.013	3.2	1.9
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%

Photocathodes for ILC and CLIC

Superlattice GaAs:
Layers of GaAs on GaAsP



No strain relaxation
QE ~ 1%
Pol ~ 85%
@ 780 nm

First successful superlattice by KEK/Nagoya group.

T. Omori et al, Phys Rev Lett 67 (1991) pp3294-3297.

Large band-gap photocathode gave a high current. First GaAs-GaAsP photocathode with superlattice structure, strain, modulation doping by KEK/Nagoya group.

T. Nakanishi at al, NIM, A455, pp.109-112 (2000)

Developments at SLAC.

"Systematic study of polarized electron emission from strained GaAs/GaAs superlattice photocathodes" T. Maruyama et al., Applied Physics Letter, Vol 85, N 13, 2004

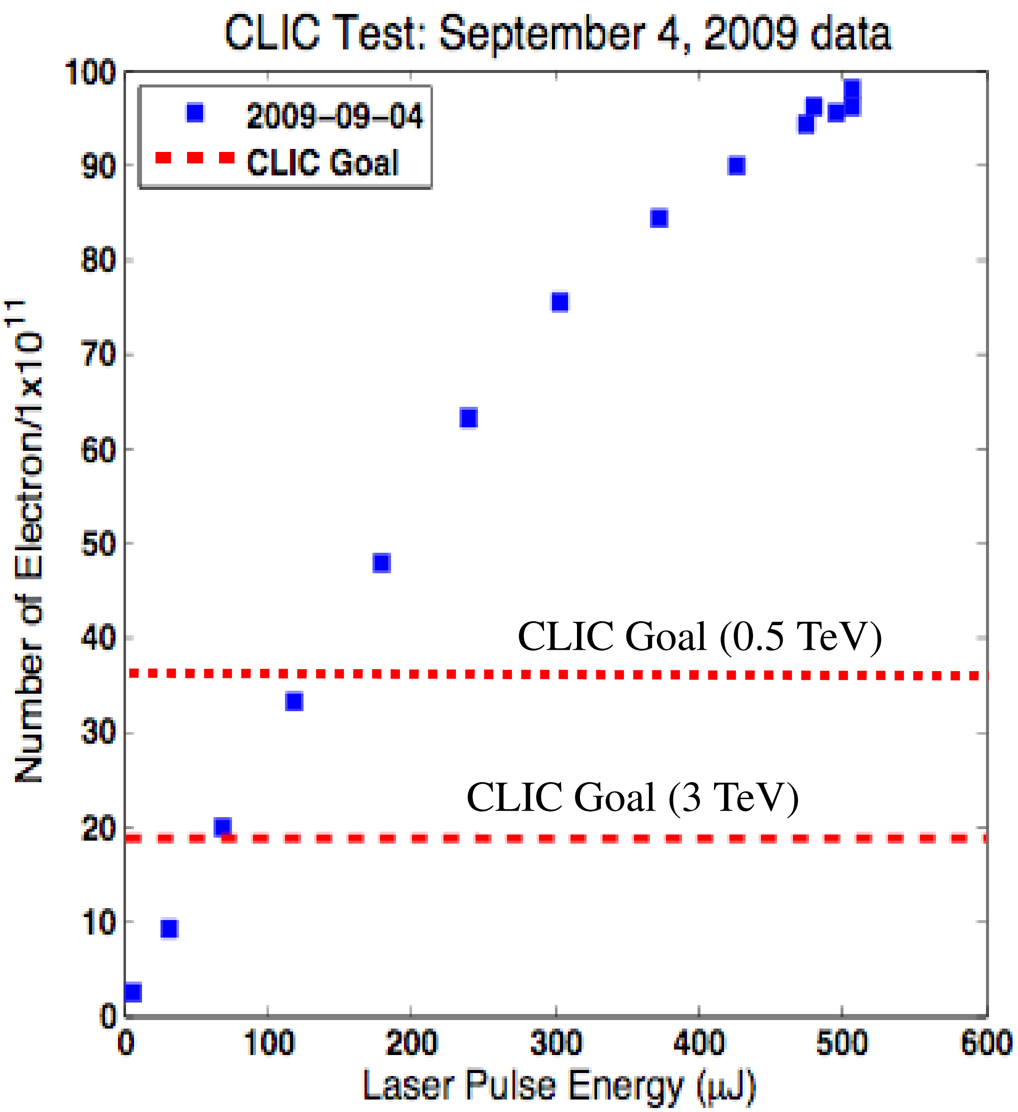
Developments at JLAB.

"Lifetime Measurements of High Polarization Strained Superlattice Gallium Arsenide at Beam Current > 1 mA Using a New 100 kV Load Lock Photogun", J. Grames et al., Particle Accelerator Conference, Albuquerque, NM, June 25-29, 2007

See J. Sheppard talk and M. Poelker talk

Polarized e⁻ produced at SLAC

See J. Sheppard talk



The total charge produced is a:

factor 3 above the CLIC requirement for 0.5 TeV and

factor 5 above the CLIC requirements for 3 TeV

QE ~ 0.5 - 0.7 %

The measured polarization is ~ 82 %

CLIC polarized e⁻ source challenges

CLIC

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% => Measurements and accuracy

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

Long life time

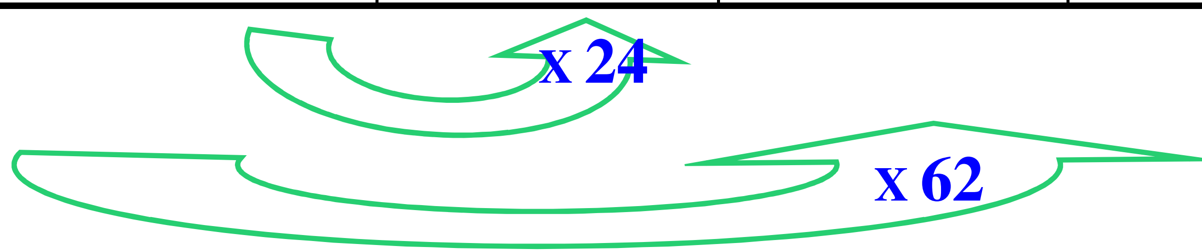
Laser:

Laser frequency:	2 GHz or cw
Pulse length:	0.1 to 800 ns
Pulse energy:	> 1 mJ

Unpolarized positrons

Flux of e^+

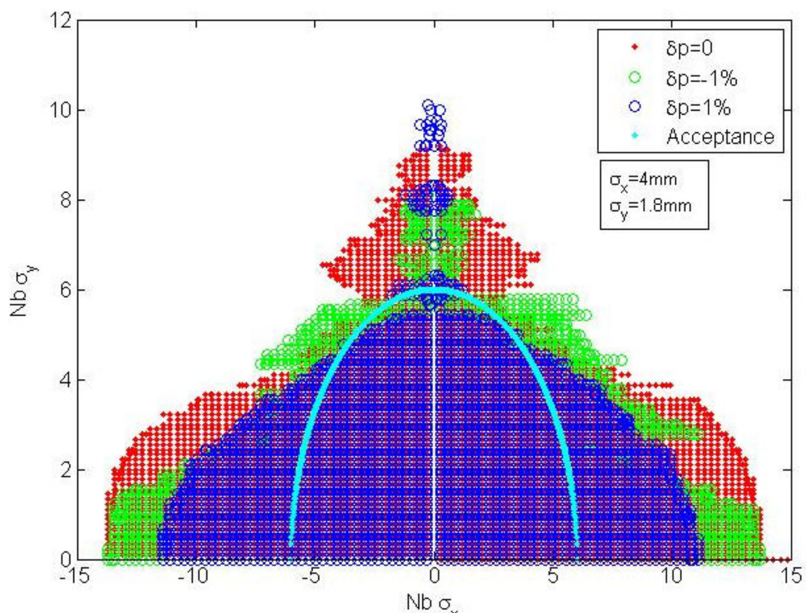
	SLC	CLIC	ILC	LHeC
e^+/ bunch	3.5×10^{10}	0.67×10^{10}	2×10^{10}	1.5×10^{10}
Bunches / macropulse	1	312	2625	20833
Macropulse Rep. Rate.	120	50	5	10
e^+ / second	0.042×10^{14}	1×10^{14}	2.6×10^{14}	31×10^{14}



CLIC Pre-Damping Ring acceptance

See F. Antoniou talk

	e+ to the PDR	
	Simulations CLIC Notes 465 and 737	Vivoli simulations 2008
Energy	200 MeV, 1.98 GeV and 2.4 GeV	200 MeV
Number of particles	6.8×10^9	6.4×10^9
Bunch length (rms)	5 mm	9 mm
Energy spread (rms)	2.7 %	1 %
Normalized rms emittances	9300 mm.mrad	7000 mm.mrad



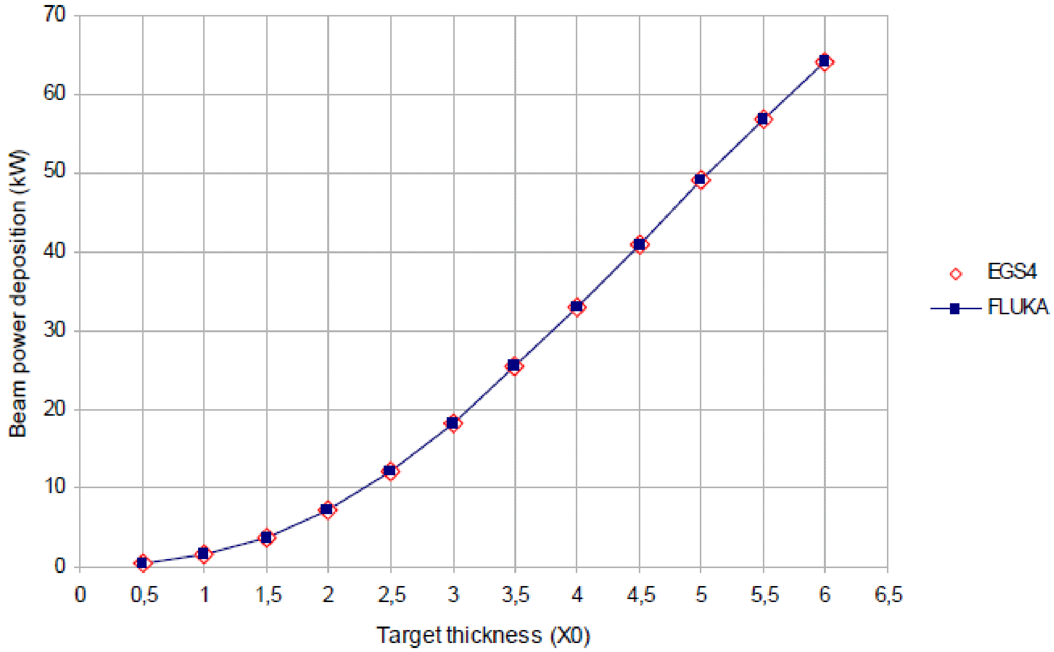
Pre-Damping Ring design is based on these values

PDR geometrical acceptance:

$H = V = 6\ \sigma$

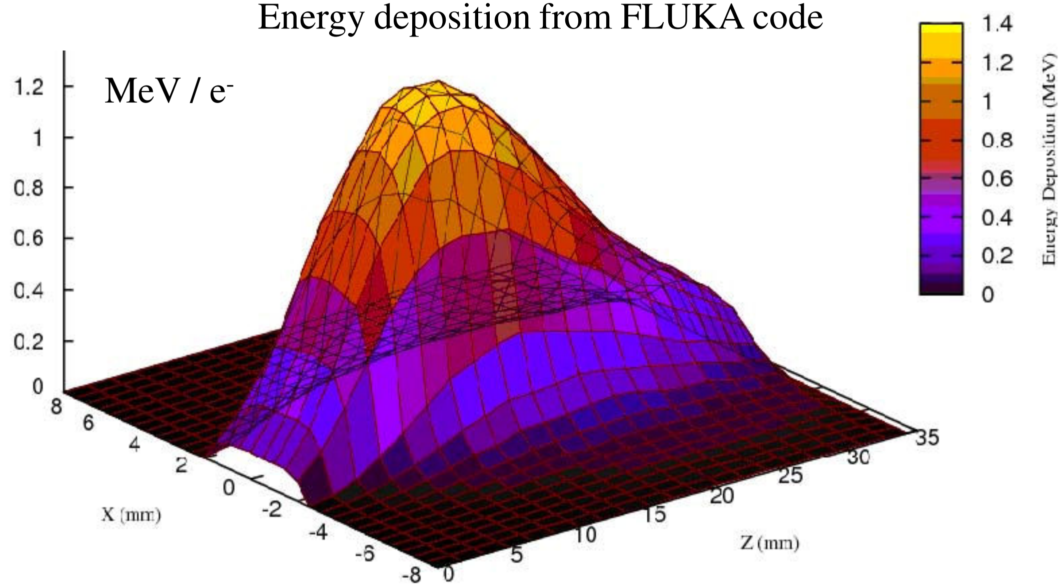
FLUKA simulations for a W target

E. Eroglu / Uludag University



Excellent agreement between EGS4 and FLUKA

Energy deposition from FLUKA code



<u>Amorphous W target (CLIC Note 465):</u>

Electron beam energy: 2 GeV

Charge: $2x10^{12}$ e^-/pulse

Repetition frequency: 200 Hz

CLIC

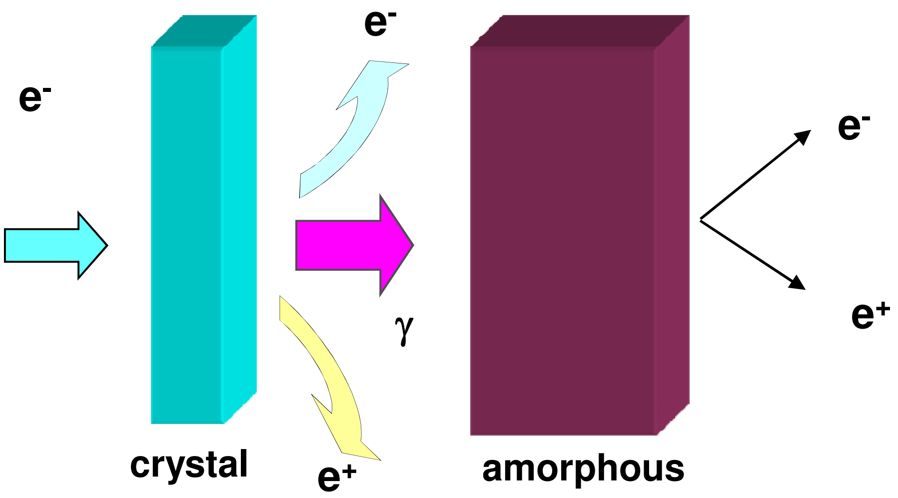
Unpolarized e^+ based on hybrid targets

See O. Dadoun talk and T. Takahashi talk

R. Chehab and A. Variola (LAL) have proposed the concept of hybrid targets

<u>Current values:</u>

Primary e^- energy: 5 GeV
Spot size radius (e^-): 2.5 mm
Crystal thickness: 1.4 mm
Distance (crystal-amorph): 3 m
Amorphous thickness: 10 mm



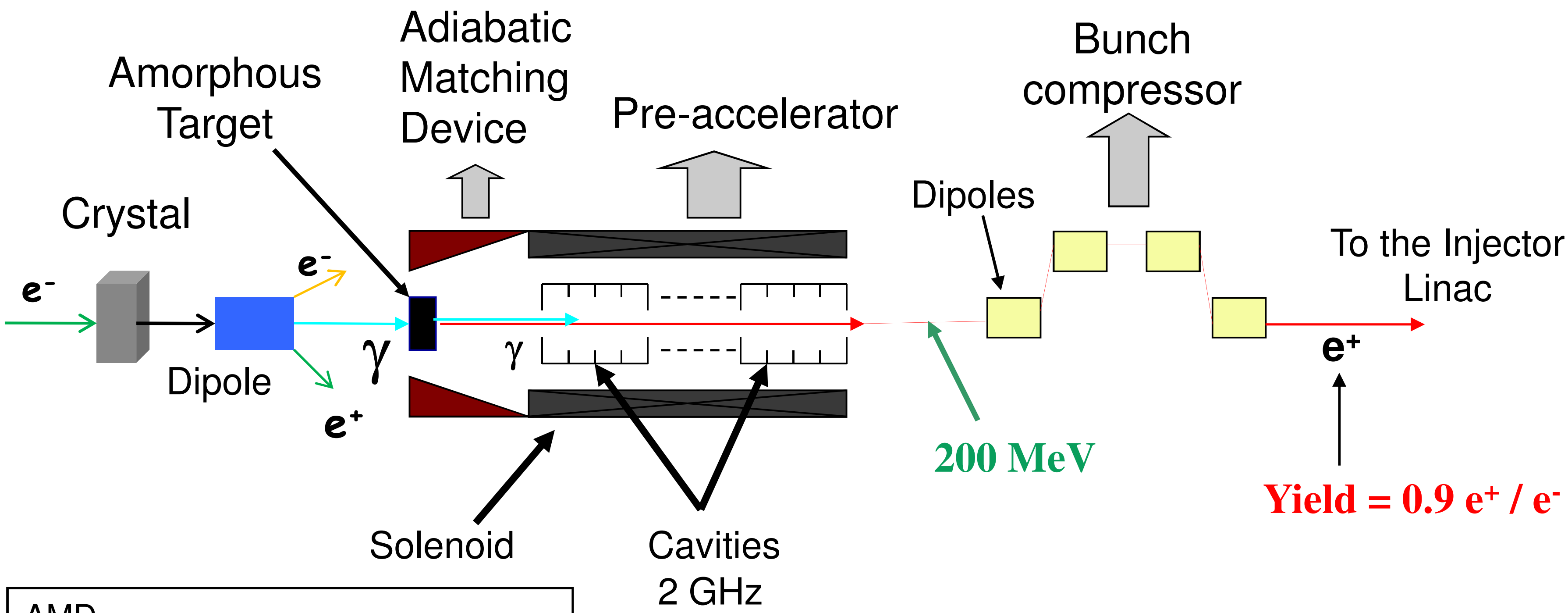
- First target is a W crystal oriented along <111> axis where channeling process occurs.
- Second target is W amorphous, a few meters downstream, receiving only photons

CLIC Note : « Study of a hybrid e^+ source using channeling for CLIC »

First tests with beam have been already performed at KEKB

CLIC Pre-Injector Linac for e^+

See A. Vivoli talk and F. Poirier talk



AMD

• Length :	L = 20 cm
• Magnetic Filed:	B = 6 - 0.5 T
• Final Aperture:	r = 2 cm

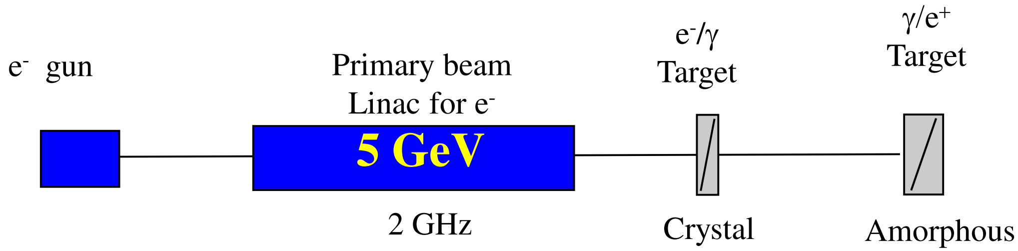
SOLENOID

• Length :	L = 41 m
• Magnetic Filed:	B = 0.5 T
• Drift Tube Aperture:	r = 2 cm

Accelerating cavities:

• Number of cavities:	N = 63
• Length:	L = 60 cm
• Max Energy Gain:	ΔE = 5.95 MeV
• Maximum Gradient:	E_z (r=0) = 25 MV/m
• Frequency:	f = 2 GHz

Primary electron beam



Parameter	Unit	CLIC
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

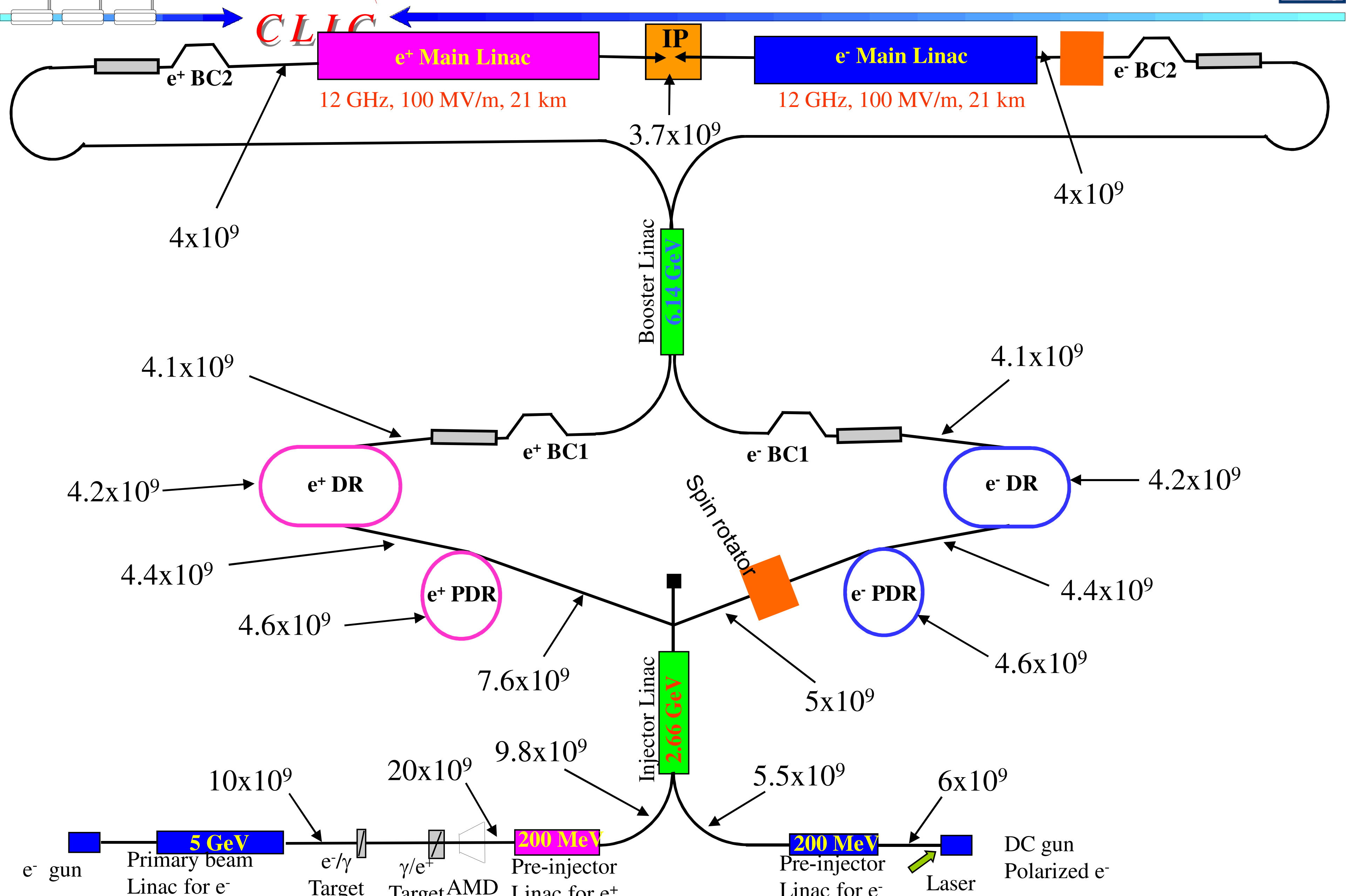
Electron beam parameters on the crystal target

With a yield of 0.9 e^+/e^- at 200 MeV and 6.7×10^9 e^+/bunch needed at 200 MeV, the requested charge is 7.5×10^9 e^-/bunch on the target

LAL simulations for the Yield and the Peak Energy Deposition Density in the amorphous target are based on these values

See O. Dadoun talk

Charges along the Injector Complex



Target issues for CLIC lower energies

CLIC

Upper limit for the Peak Energy Deposition Density (PEDD) = 35 J / g

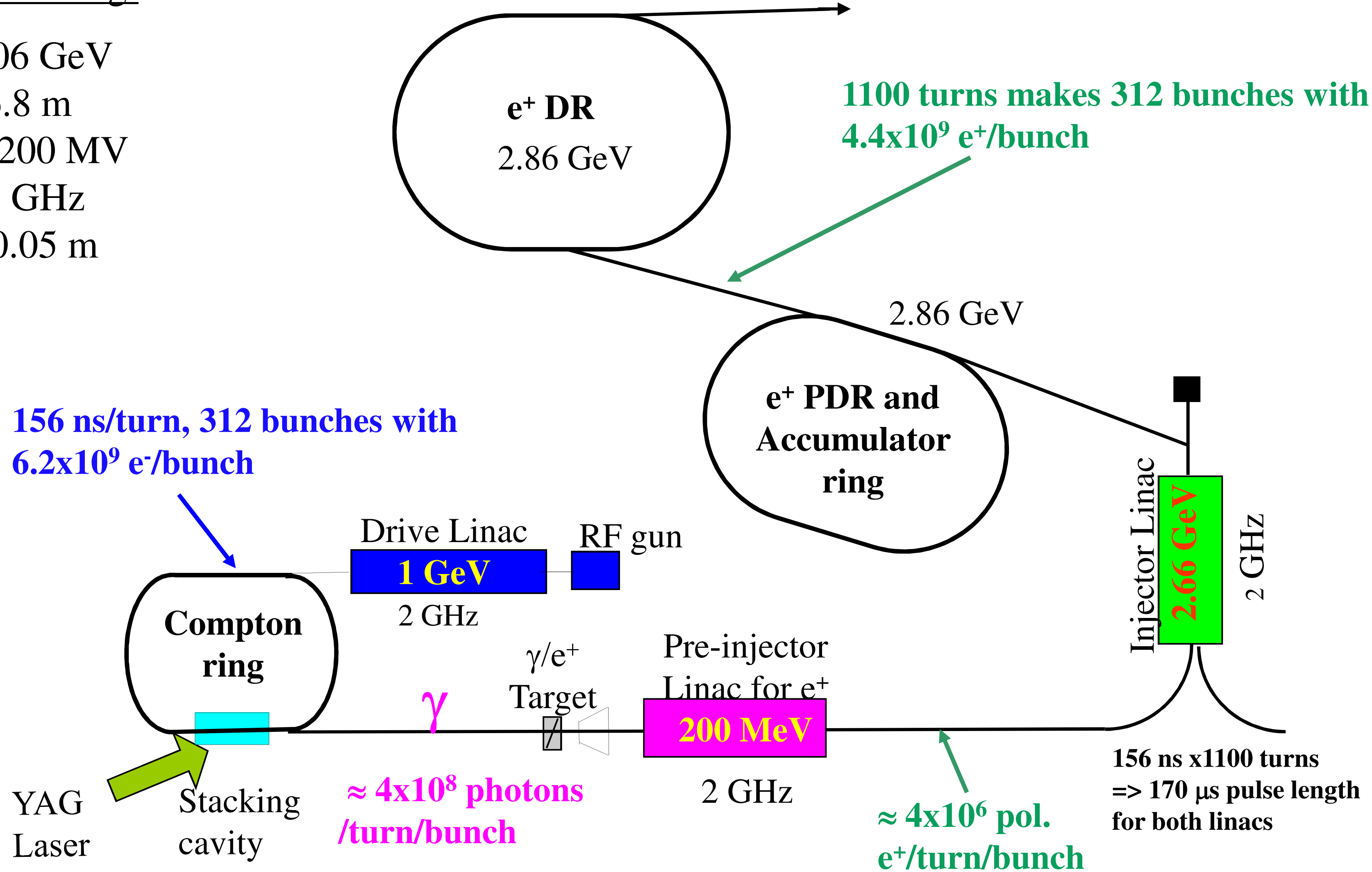
CLIC machine at 3 TeV but working at lower energies (0.5 < E < 3 TeV)	Yield (e^+/e^-) after the AMD	E_{tot} (J/train)	P (kW)	PEDD (J/g)
Base line for e^+ 312 bunches 7.5×10^9 e-/bunch 50 Hz	2	196	9.8	22
Change repetition frequency for e^+ 312 bunches 7.5×10^9 e-/bunch 68 Hz	2	267	13.3	30
Change the number of bunches for e^+ 800 bunches 3.75×10^9 e-/bunch 50 Hz	2	250	12.5	28

Polarized positrons

CLIC based Compton Ring

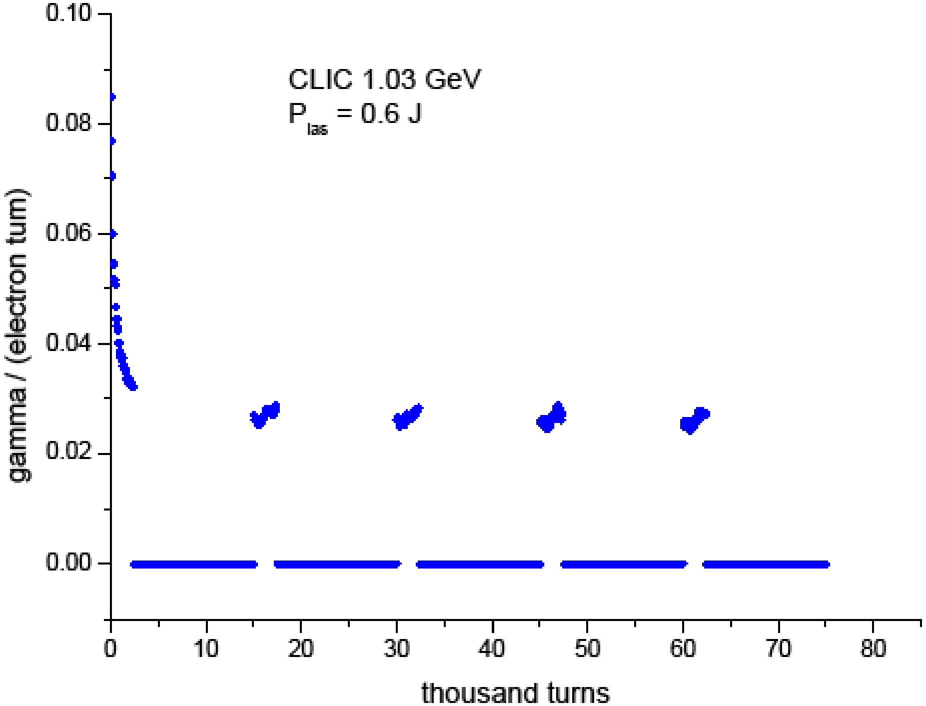
<u>Compton Ring:</u>

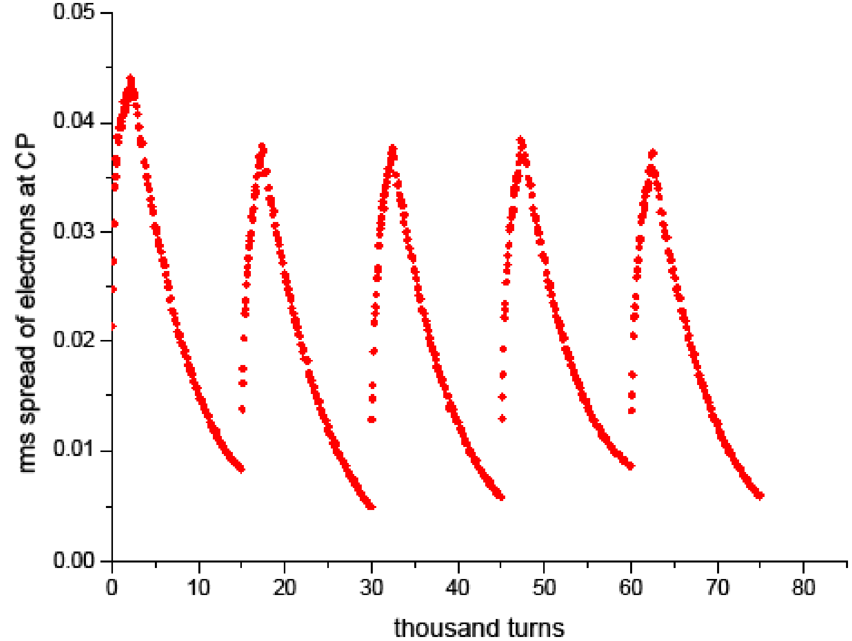
$E = 1.06$ GeV
$C = 46.8$ m
$V_{RF} = 200$ MV
$f_{RF} = 2$ GHz
$\beta_{CP} = 0.05$ m



Compton Ring performance

E. Bulyak / NSC KIPT





Number of e- = 312 x 6.2 x 10^9 = 1.93 x10^{12} in the ring

1 cycle = 15 000 turns = > T = 156 ns x 15 000 = 2.3 ms

Laser on during 2500 turns

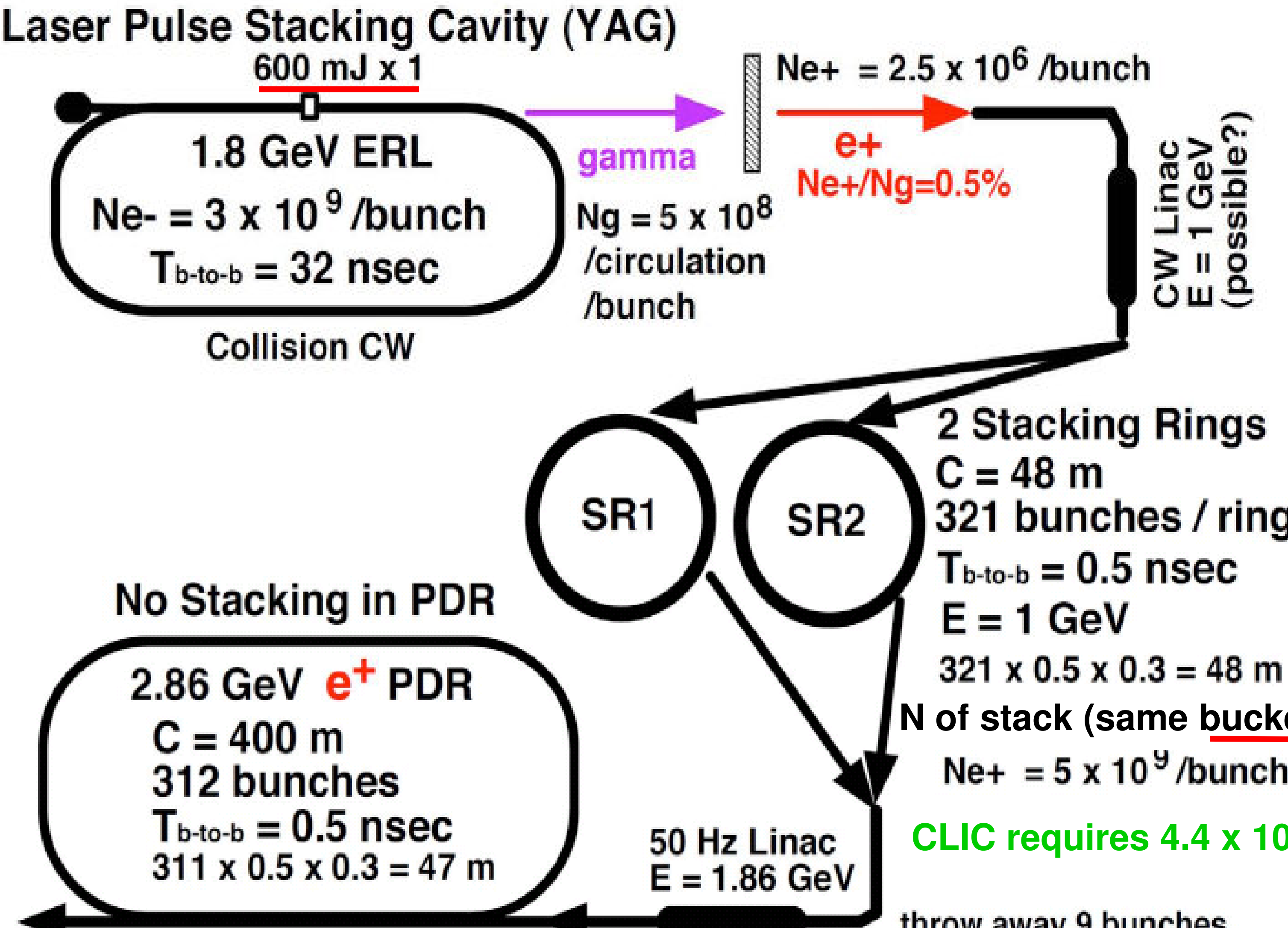
Photon yield = 0.063 photons / e- / turn (simulation)

Photon flux: 1.33x10^{16} photons / s

Laser pulse:
E = 1.164 eV
r = 0.005 mm
l = 0.9 mm

CLIC Compton ERL

See T. Omori talk

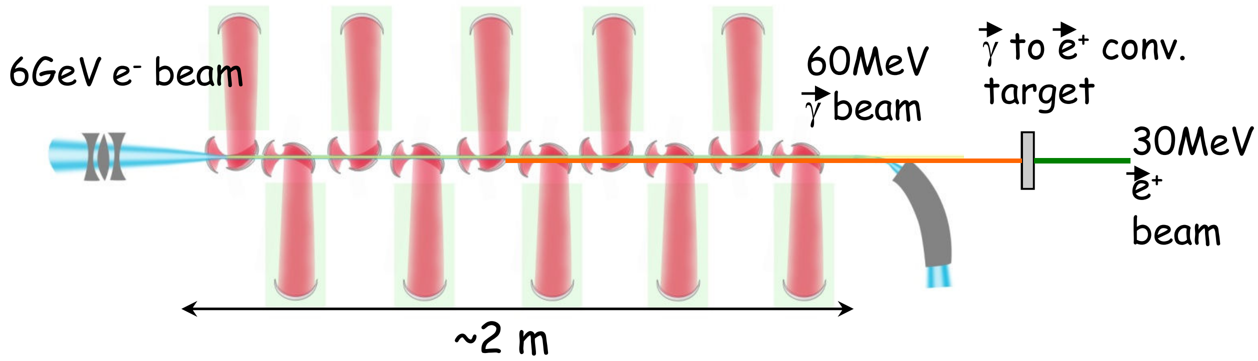


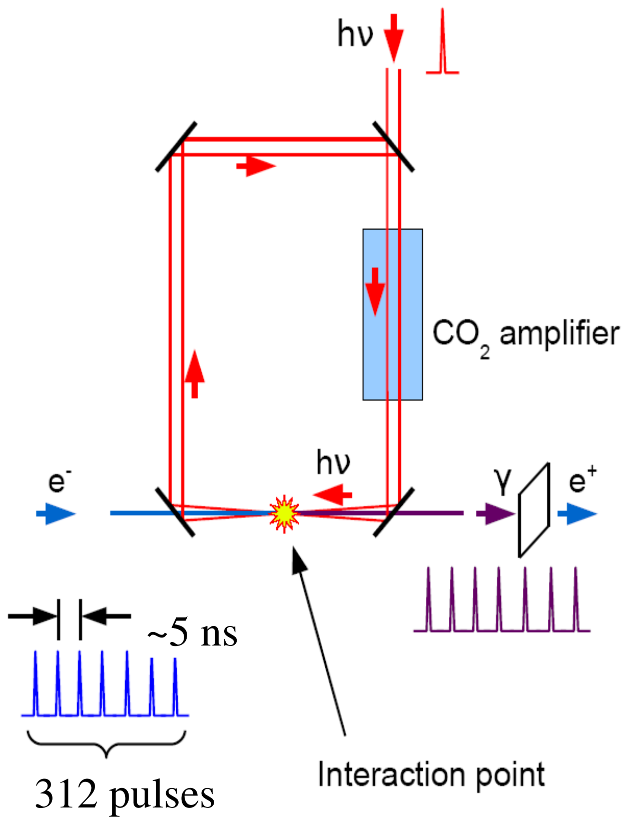
CLIC requires 4.4 x 10^9 e^+/ bunch

4.2x10^9 e^+/bunch

CLIC Compton Linac

See V. Yakimenko talk





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

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

i.e. ≈ 50 gammas to generate 1 e^+

<u>Data for CLIC:</u>

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

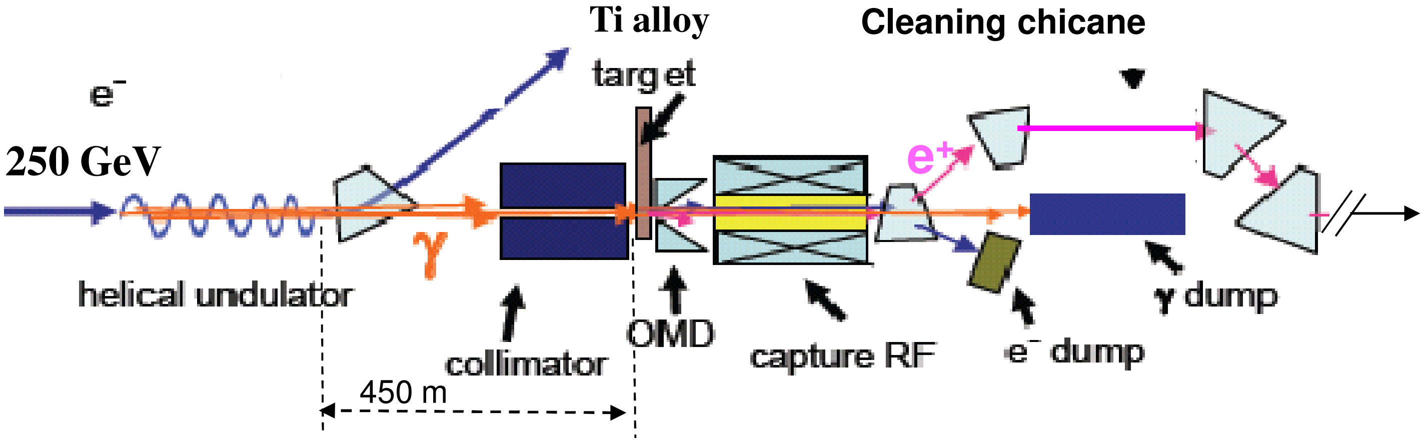
$N_{e-} = 0.32 \times 10^{12}$ / bunch ~ 50 nC

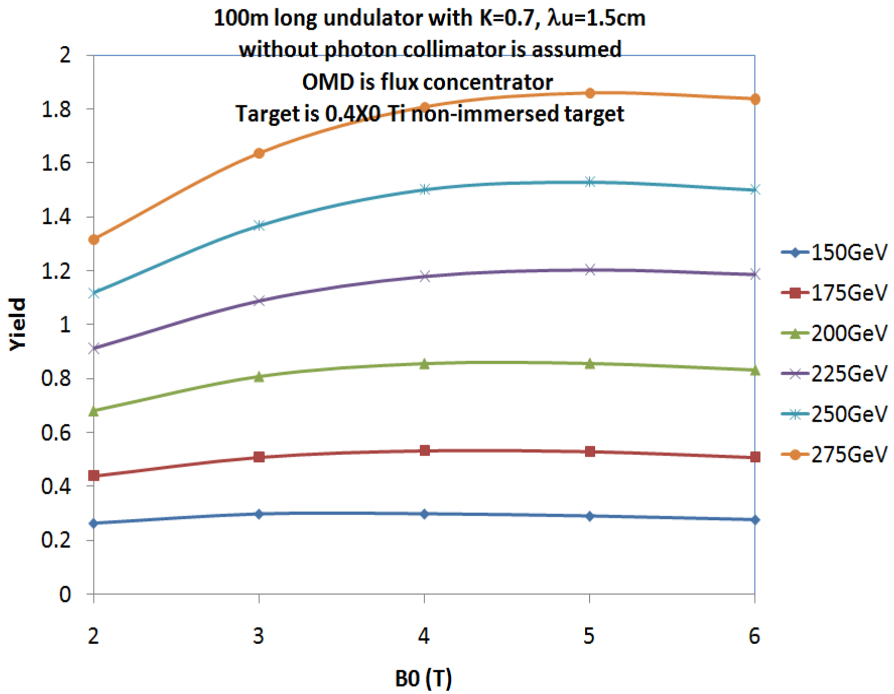
With 5 nC / e^- bunch and 10 Compton IP's

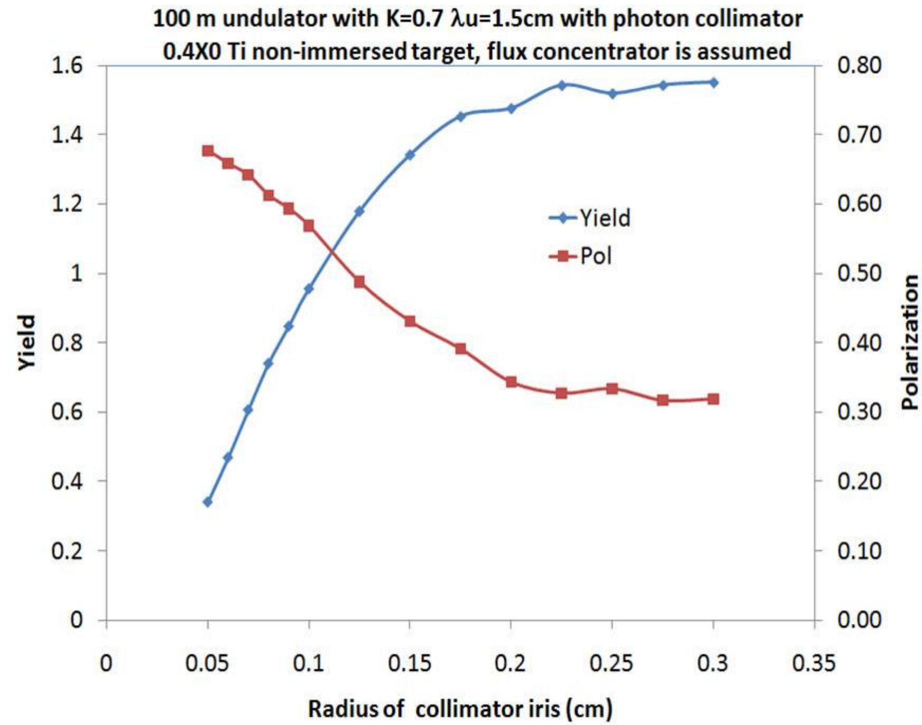
=> 1 nC / e^+ bunch

CLIC Undulator scheme

See W. Gai talk

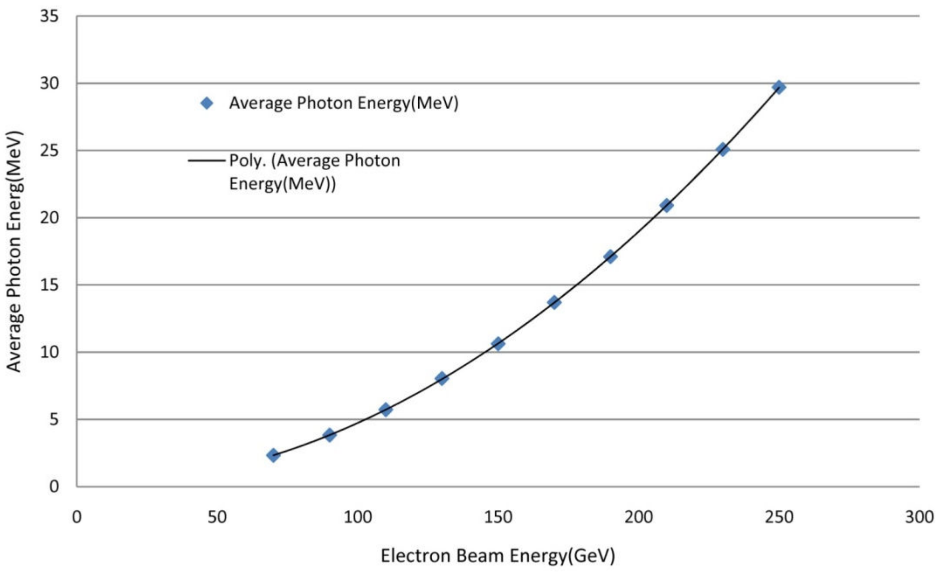






CLIC Undulator scheme

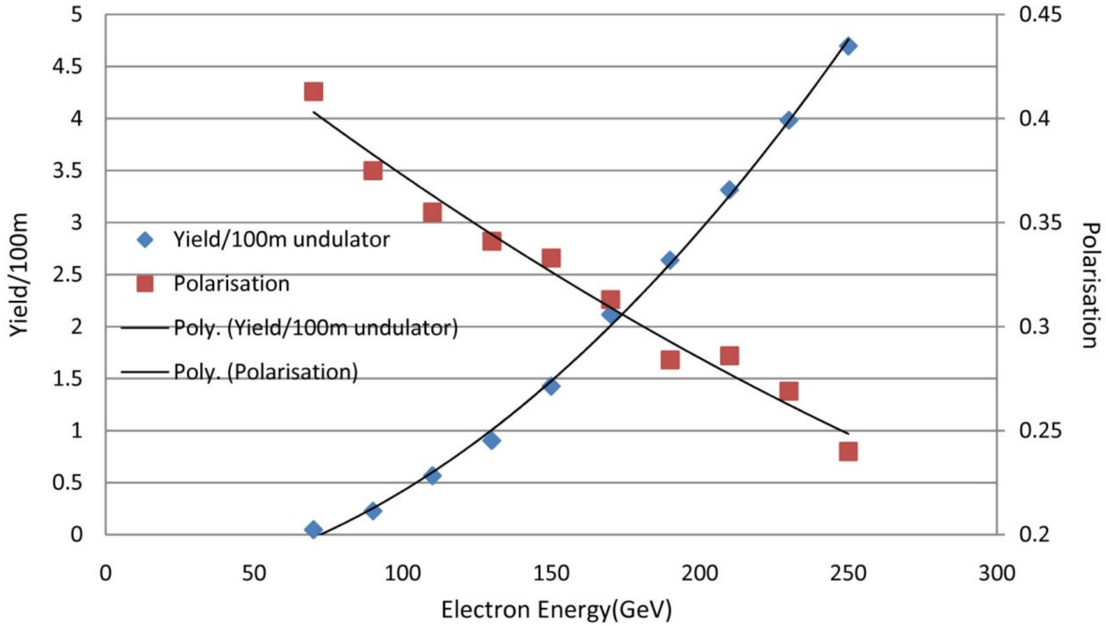
L. Zang / CI



Undulator 100 m long with:

K = 0.92

λ_u = 12 mm



Upgrade from 500 GeV to 3 TeV under discussion

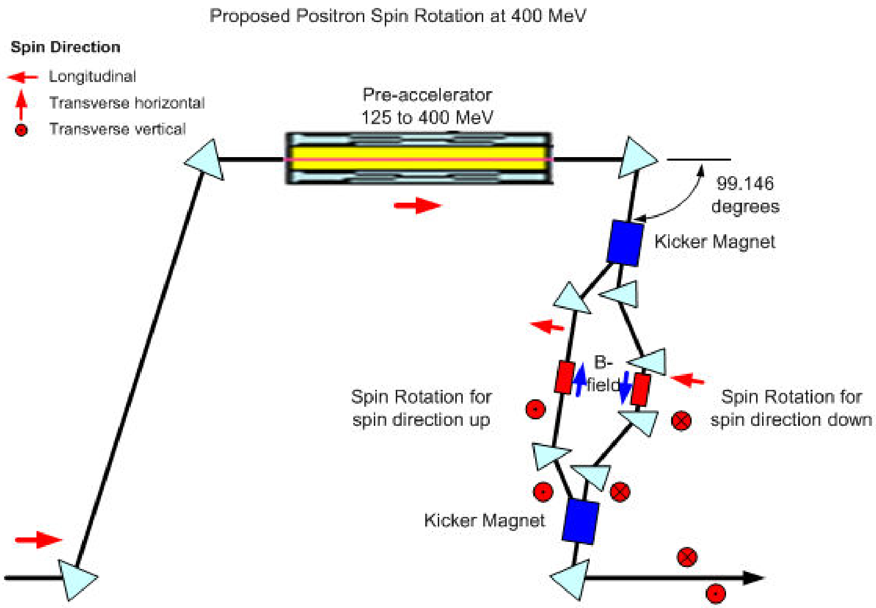
Injector Linac & Spin Rotators

For the CLIC Injector Linac, a design exits based on 2007 parameters.

"Design study of the CLIC Injector and Booster linacs with the 2007 beam parameters" by A. Ferrari, A. Latina, L. Rinolfi, CLIC Note 737, May 2008

For the CLIC Spin rotators, nothing has been done yet.

Only study for ILC spin rotators exits. Initially foreseen at 5 GeV and now a new proposal has been made to implement these devices at 400 MeV.



K. Moffeit / SLAC

At "2009 Linear Collider workshop" Albuquerque, September 2009

See S. Riemann talk about polarimetry

Some challenges for the e^+ source

1) A single hybrid targets station or several stations to cover all the CLIC needs
2) Devices for Undulator scheme (Helical undulator, collimators, dumps,…)
3) Devices for Compton schemes (Optical cavities at IP, powerful laser systems,…)
4) Targets issues (Heat load dynamics, beam energy deposition, shock waves, breakdown limits, activation, ….)
5) Adiabatic Matching Device (AMD)
6) Capture sections (Transport and collimation of large emittances, high beam loading)
7) Trade off between yield, polarization and emittances
8) Design and implementation of the spin rotators
9) Polarization issues (Analyze systematic errors of polarization measurements)
10) Efficient use of existing codes (EGS4, FLUKA, Geant4, PPS-Sim, Parmela, …)
11) Integration issues for the target station (remote handling in radioactive area)
12) Radioactivity issues
13) ……..

See J. Clarke talk for ILC/CLIC common issues

Summary

➢ For polarized e$^-$, the requested performance for a DC gun have been obtained. Complete simulations up to the PDR remain to be done. R&D for the laser system (stability,…) to be investigated.

➢ For unpolarized e$^+$ and for the baseline (3 TeV), the hybrid target configuration, the capture section and the transport up to the PDR provide a solution with a single target station. The double charge (0.5 TeV) requires more studies and investigations.

➢ For polarized positrons, several big challenges remain to be investigated for all process (Compton ring or linac, ERL, Undulator).

➢ For the spin rotators, studies remain to be done.

A big THANK YOU to all collaborators contributing to these CLIC studies