Report on Injectors and Damping Rings working group

L. Rinolfi

The present slides are derived from the Summary written by Y. Papaphilippou and myself at the end of the CLIC08 workshop but are more focused on e^+ sources

- Brief general overview
- Unpolarized e^+ by channeling
- Compton scheme

http://project-clic08-workshop.web.cern.ch/project-clic08-workshop/

A brief overview of the 2 days:

Number of talks: 26

A common session of 3 talks with “Instrumentation” and “Tests Facilities” working groups

Attendance: ≈ 25 to 30 persons in general for each session

26 speakers coming from 11 laboratories and universities:
ANKA (D), ANL, BINP, CERN, Cockcroft Institute, FNAL,
IPNL (Lyon), KEK, PSI, Lancaster University, LNF (Frascati),

Preliminary overview

The CLIC Main Beams Injector Complex has 3 studies corresponding to 3 configurations:

1) Base Line configuration:

The study is based on 3 TeV (c.m.) with unpolarized e^+ source and with ultra low emittances for the Damping Rings.

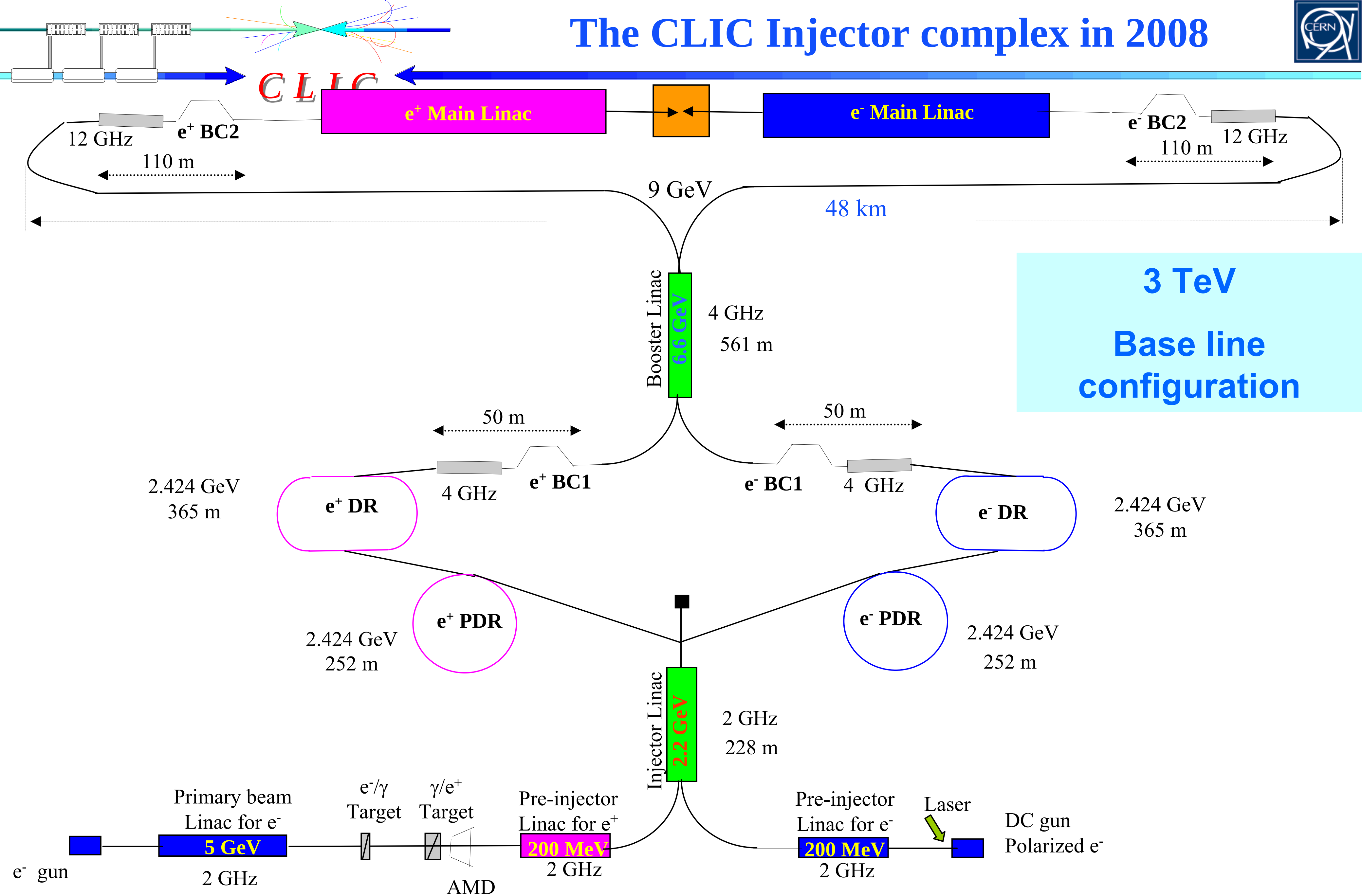
2) Compton configuration:

The study is based on 3 TeV (c.m.) with polarized e^+ source. The undulator option is considered as an alternative.

3) Low energy configuration:

The study is based on 500 GeV (c.m.) with relaxed beam parameters for the Damping Rings but with a double charge per bunch for the lepton sources.

The CLIC Injector complex in 2008



CLIC Main beam parameters

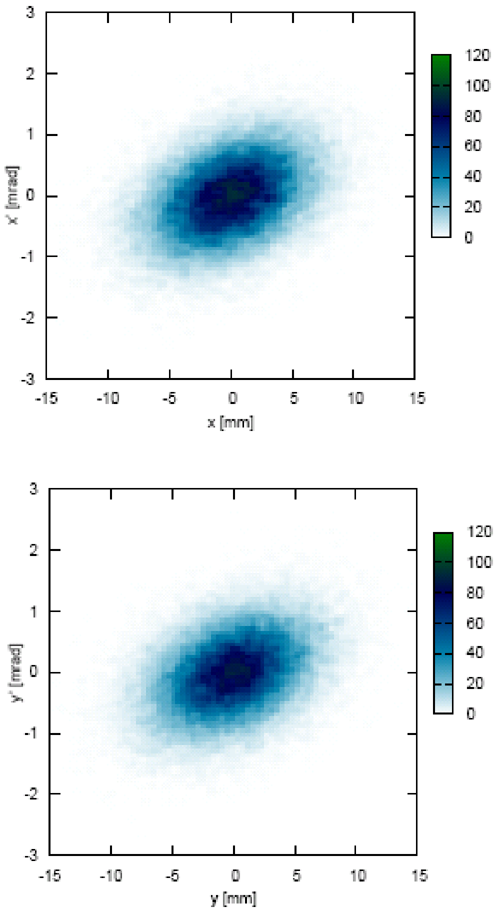
At the entrance of the Main Linac for e^- and e^+

		NLC (1 TeV)	CLIC 2008 (0.5 TeV)	CLIC 2008 (3 TeV)	ILC (0.5 TeV)
E	GeV	8	9	9	15
N	10^9	7.5	7	3.72 - 4	20
n_b	-	190	312	312	2625
Δt_b	ns	1.4	0.5	0.5 (6 RF periods)	369
t_{pulse}	ns	266	156	156	968925
$\varepsilon_{x,y}$	nm, nm	3300, 30	2400, 10	600, 10	8400, 24
σ_z	µm	90-140	72	43 - 45	300
σ_E	%	0.68 (3.2 % FW)	2	1.5 - 2	1.5
f_{rep}	Hz	120	50	50	5
P	kW	219	180	90	630

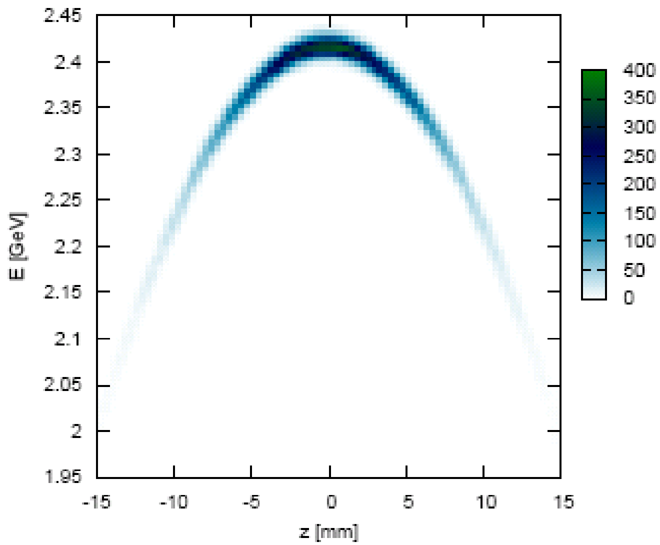
Beam dynamics simulations in Linacs and TL

A. Latina / CERN

Transverse



Longitudinal

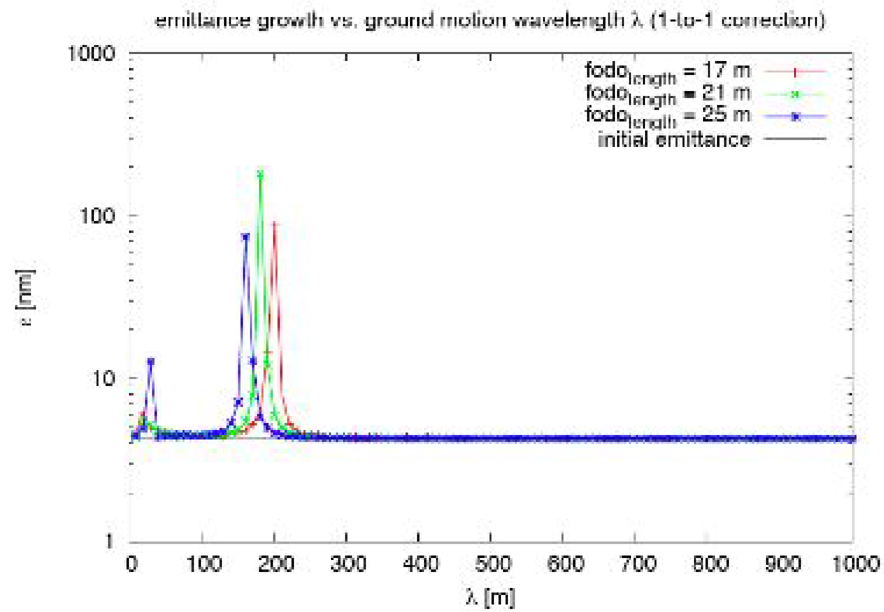


Injector Linac output

Bunch length (rms) = 5 mm

Energy spread (rms) = 65 MeV

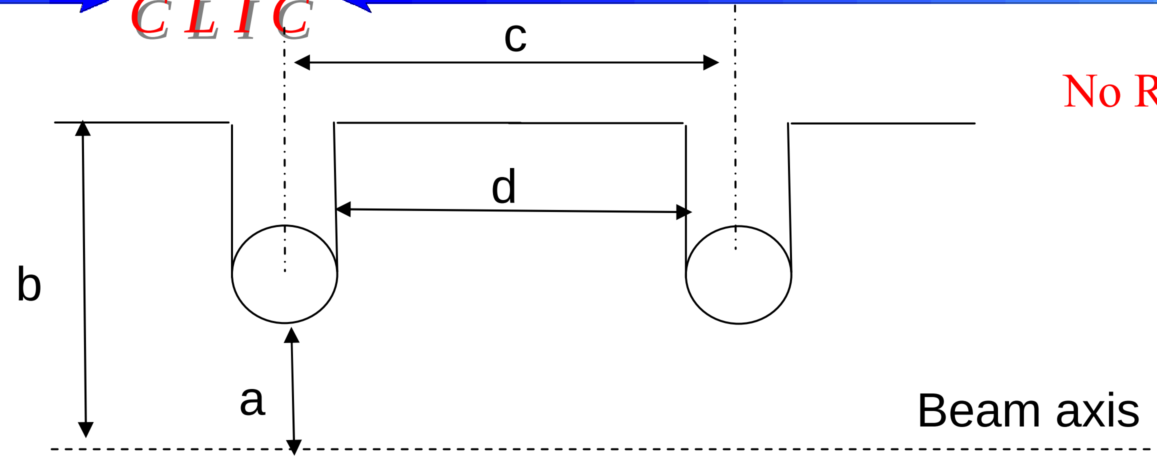
21 km Transfer Line with different FODO optics



Effects of long range wake fields remains to be studied for the Booster Linac

Unusual RF frequencies

No RF power sources available for these frequencies



	Units	2 GHz	2.856 GHz	4 GHz
a	mm	22	15.4	11
b	mm	64.3	45	32
c	mm	50	35	25
d	mm	42.8	30	21
G (unloaded)	MV/m	17	25	36
G (loaded) 1.3 A	MV/m	15	22	30
L	m	4	4	3
		CLIC Injector	NLC structure	CLIC Booster

PDR parameters for CLIC

F. Antoniou / CERN

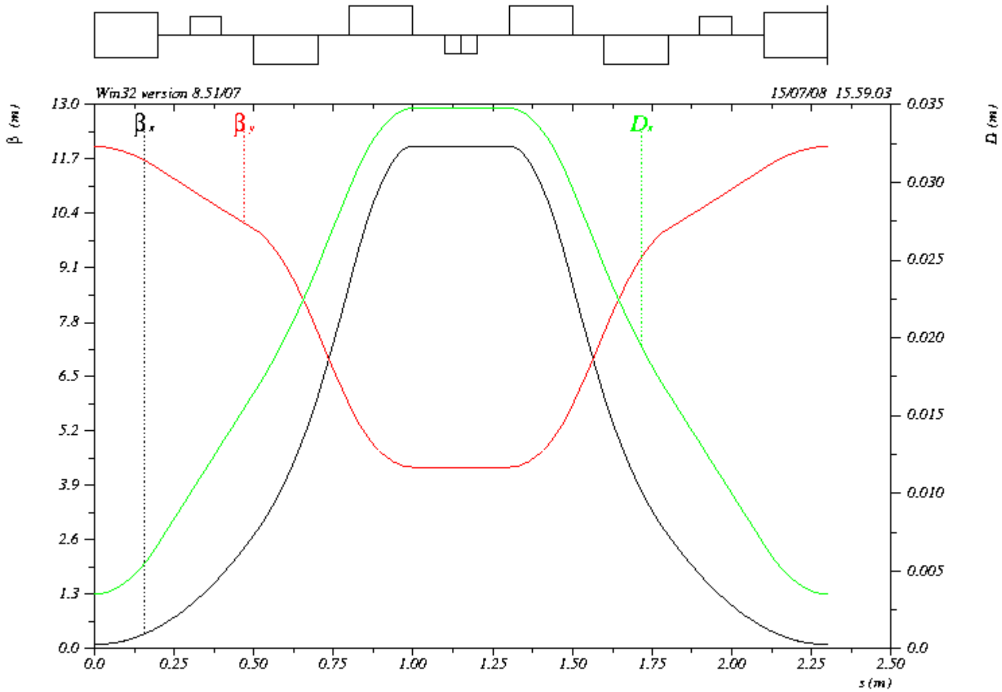
Parameters	CLIC PDR
Energy [GeV]	2.424
Circumference [m]	251.6
Normalized Emittance [μm rad]	18.6
Energy Loss per turn [MeV/turn]	1.6
RF Voltage [MV]	2 (5)
Harmonic Number	1677
Long. Damping time [msec]	1.25
Eq. Momentum spread [%]	0.095
Eq. bunch length [mm]	0.786 (0.952)
Momentum acceptance [%]	2.94 (6.88)
Quad coefficient K1[1/m^2] k1/k2	10.69/-6.32
Mom. Compaction factor, a_c	8.98E-05

CLIC

New arc cells optics for the Damping rings

K. Zolotarev / BINP

P. Raimondi / LNF

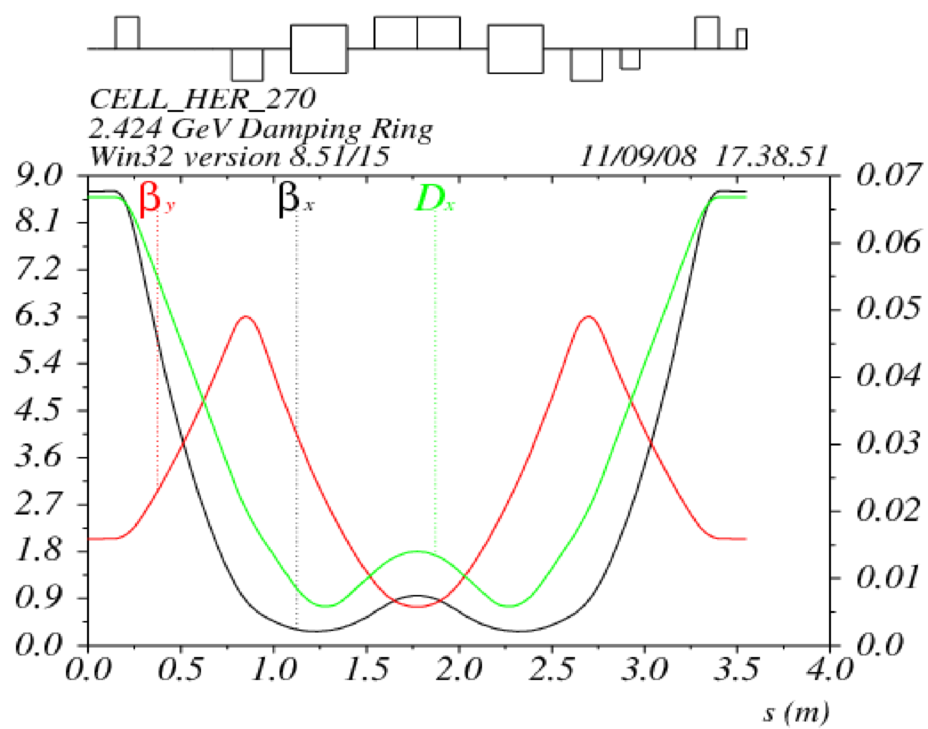


New arc cell design

- Increasing space between magnets, reducing magnet strengths to realistic levels
- Reducing chromaticity, increasing DA
- Even if equilibrium emittance is increased (0current), => IBS dominated emittance stays constant!
- Dipoles have quadrupole gradient (as in ATF!).

Alternative cell based on SUPERB lattice

- Using 2 dipoles per cell with a focusing quadrupole in the middle
- Good optics properties
- To be evaluated for performance when IBS is included



CLIC DR RF system

A. Grudiev / CERN

1) Main issues:

- Frequency: 2 GHz
- Highest peak and average power
- Very strong beam loading transient effects (beam power of ~5 MW during 156 ns, no beam power during the other 1060 ns)
- Small stored energy at 2 GHz
- High energy loss per turn at relatively low voltage results in big sin $\varphi_s = 0.95$ (any examples of operation ?)
- Wake-fields
- Pulsed heating related problem (fatigue, …)

2) Recommendations:

- Reduce energy loss per turn and/or increase RF voltage
- Consider 1GHz frequency (RF system becomes conventional, RF power reduced, but delay loop for recombination is necessary and emittance budget is tight)

CLIC/ILC DR common issues

S. Guiducci / LNF

- Intense interaction between ILC/CLIC in the community working on the DR crucial issues: ultra low emittance and e-cloud mitigation.
- Common WEBX collaboration meetings already organized for CESRTA, ILC and CLIC DR (inscribe yourself in the mailing list)
- It is very important to strengthen the collaboration and include also other beam dynamics and technical aspects.

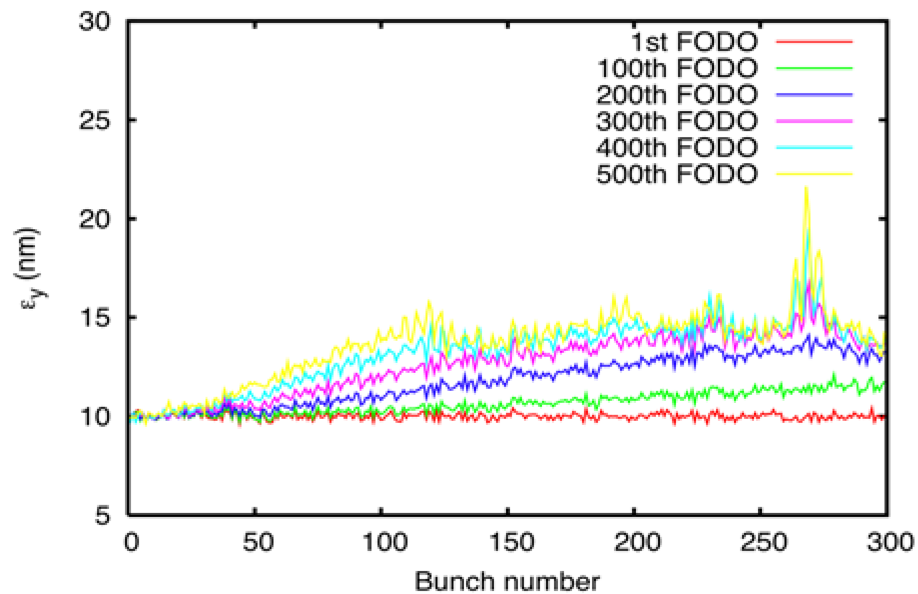
	ILC	CLIC
Energy (GeV)	5	2.4
Circumference (m)	6476	365
Bunch number	2700 - 5400	312
N particles/bunch	2×10^{10}	3.7×10^{9}
Damping time τ_x (ms)	21	1.5
Emittance $\gamma\varepsilon_x$ (nm)	4200	381
Emittance $\gamma\varepsilon_x$ (nm)	20	4.1
Momentum compaction	$(1.3 - 2.8) \times 10^{-4}$	0.80^{-4}
Energy loss/turn (MeV)	8.7	3.9
Energy spread	1.3×10^{-3}	1.4×10^{-3}
Bunch length (mm)	9.0 - 6.0	1.53
RF Voltage (MV)	17 - 32	4.1
RF frequency (MHz)	650	2000

Collective effects in the Injector Complex

G. Rumolo / CERN

- The electron cloud in the e^+ DR impose limits in PEY (99.9% of synchrotron radiation absorbed in the wigglers) and SEY (below 1.3) and can be cured with special **chamber coatings**
- Fast ion instability in :
  - In e^- DR, molecules with A>13 will be trapped (constrains vacuum pressure to around 0.1nTorr
  - Simulation with ***FASTION*** show fast instability in the transfer line (constrains vacuum pressure again to 0.1nTorr)
- Other collective effects in DR
  - Space charge (large vertical tune spread of 0.188 and 10% emittance growth)
  - Single bunch instabilities avoided with smooth impedance design and resistive wall coupled bunch can be controlled with feedback

Chambers	PEY	SEY	ρ [10^{12} e^-/m^3]
Dipole	0.000576	1.3	0.04
		1.8	2
	0.0576	1.3	7
		1.8	40
Wiggler	0.00109	1.3	0.6
	0.109	1.3	45
		1.5	70
		1.8	80



Intrabeam scattering

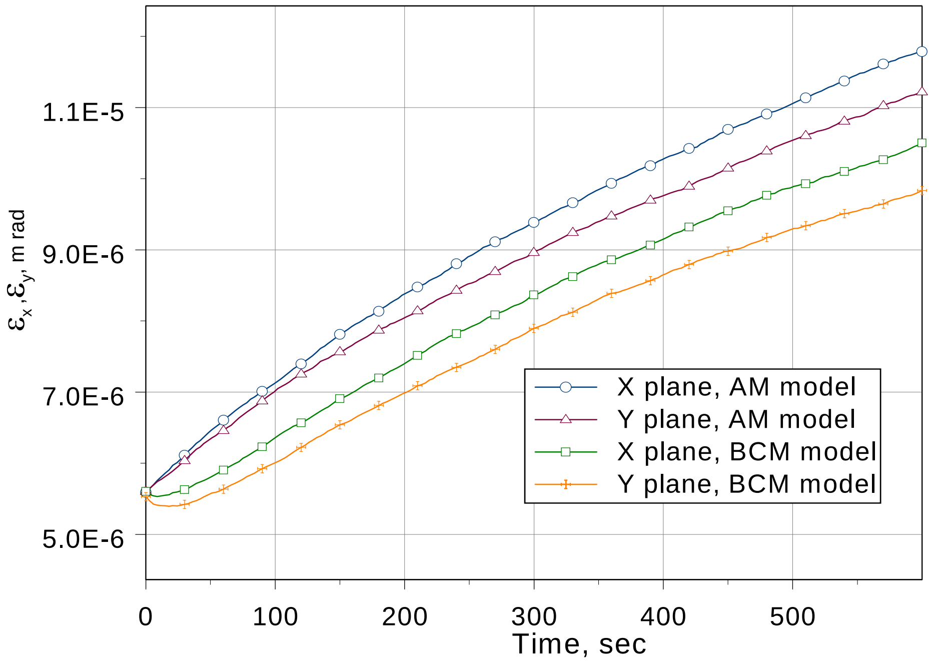
M. Martini / CERN

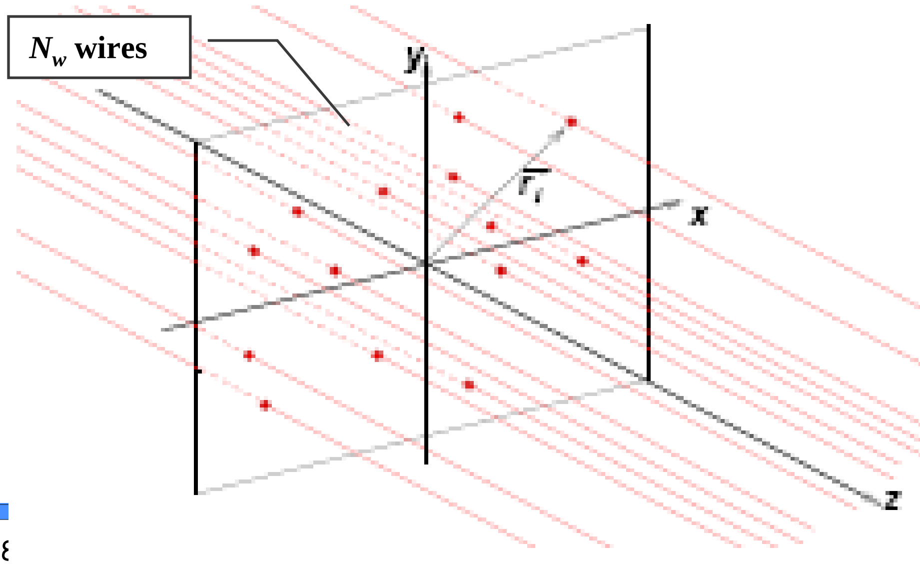
IBS effect evaluated through semi analytical approach (modified Piwinski or Bjorken-Mtingwa formalism)

- Derive analytically the optics parameters for reaching minimum IBS dominated emittance in selected lattices (FODO, TME,…)

Numerical or analytical approach for effect of strong IBS producing non-Gaussian tails including radiation damping is missing

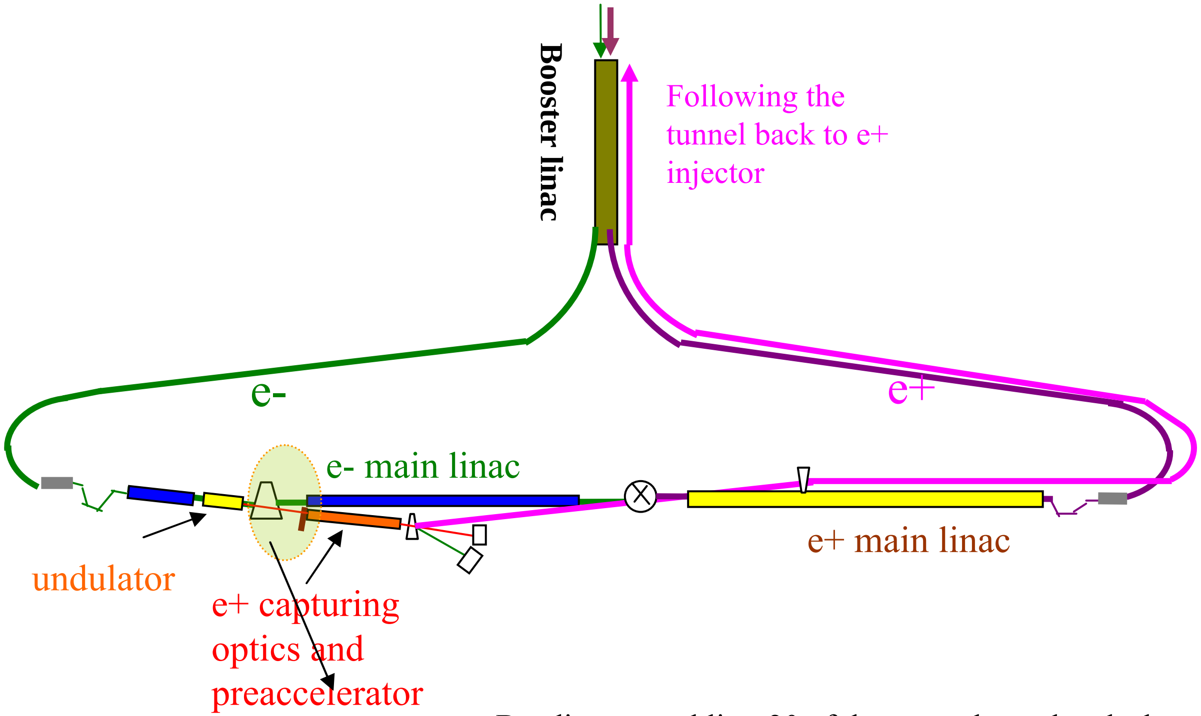
- Codes for non-Gaussian beams exist (e.g. MOCAC) but not all effects included
- Use of stochastic diffusion equation approach may be an alternative (presently used for coasting beams)

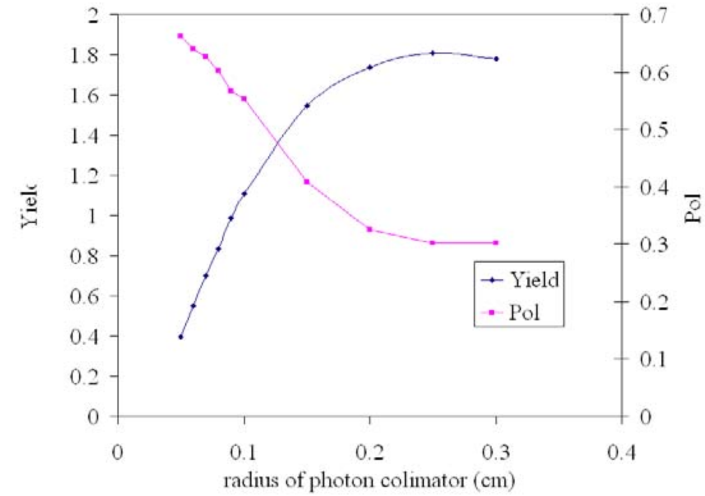




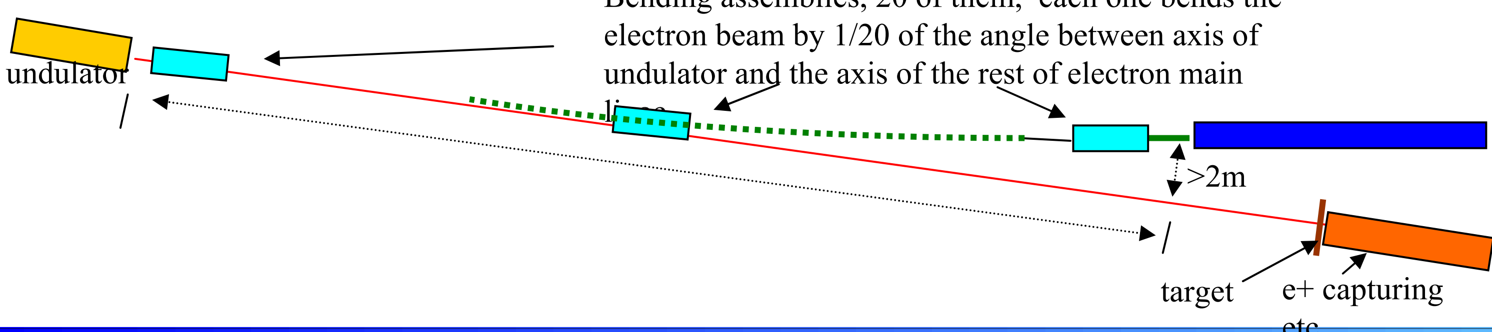
A possible CLIC layout with undulator based e⁺ source

W. Gai / ANL



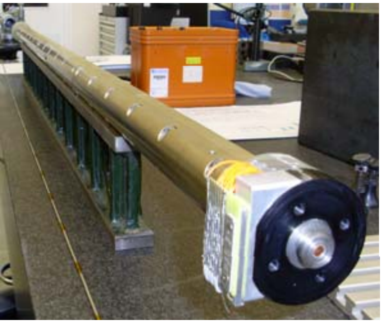


Simulations shows that the undulator will not dilute the emittance of the e- beam.



CLIC undulator option for polarized e^+

I. Bailey / CI

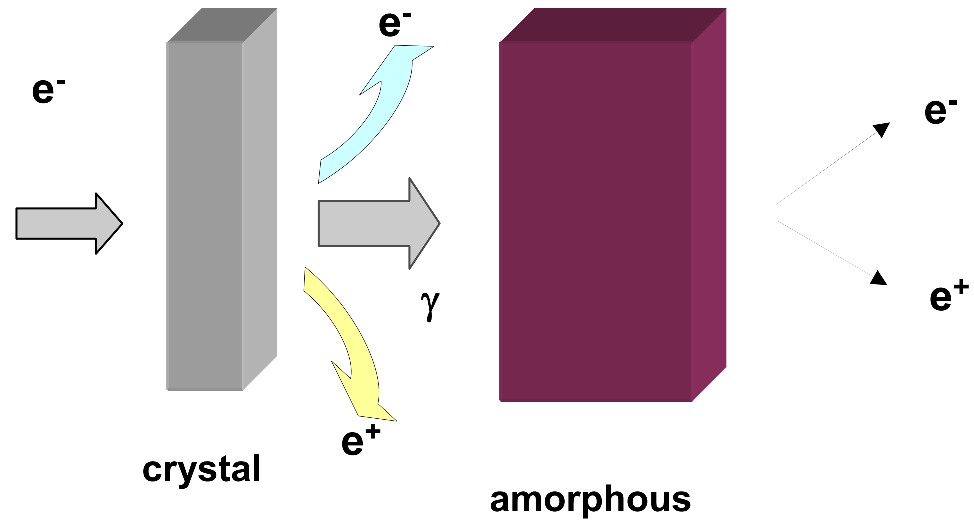


- Positron polarisation is highly desirable
  - Not necessarily only reason to choose undulator
- Polarisation has to be "designed-in" globally.
- Undulator-based positron source technology in mature state.
- Overall impact on machine operation needs to be re-evaluated for CLIC (c.f. ILC)
- Much scope for optimisation studies
  - Coordination required

A formal collaboration between CERN and Cockcroft Institute has been just started with objectives towards the Undulator and Compton schemes.

Unpolarized e^+ source by channelling

A e^- beam impinges on the crystal:
- energy of 5 GeV
- beam size of 2.5 mm



- A crystal e+ source :
  - - a 1.4 mm thick W crystal oriented along <111> axis
  - - a 10 mm thick W amorphous disk

- Charged particles are swept off after the crystal:only γ (> 2MeV) impinge on the amorphous target.

Yield: 0.92 e^+ / e^-

@ 200 MeV

- The distance between the 2 targets is 2 meters.

R. Chehab / IPNL-Lyon, A. Variola, A. Vivoli / LAL, V.M.Strakhovenko / BINP - Novosibirsk

e^+ by channeling from hybrid targets

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
Linac frequency	GHz	2
Beam radius (rms)	mm	2.5
Bunch length (rms)	mm	0.3

Parameter	Unit		
Target		Crystal	Amorph.
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	1.9
Peak energy deposition density (PEDD)	J/g	6.8	15.5

Experimental limit found at SLAC: PEDD = 35 J/g => We have a factor 2 as safety margin

At 500 GeV, if charge is doubled => Double target stations ??

Parameters for e^+ capture section

		R. Chehab (*)	A. Vivoli (**)
AMD[1)] Magnetic Field	T	7 - 0.5	6 - 0.5
AMD Length	m	0.21	0.5
Pre-accelerator Length	m		43
Solenoid Magnetic Field	T	0.5	0.5
Cavities Frequency	GHz	1.5	1.3
Peak Electric Field intensity	MV/m	25	18

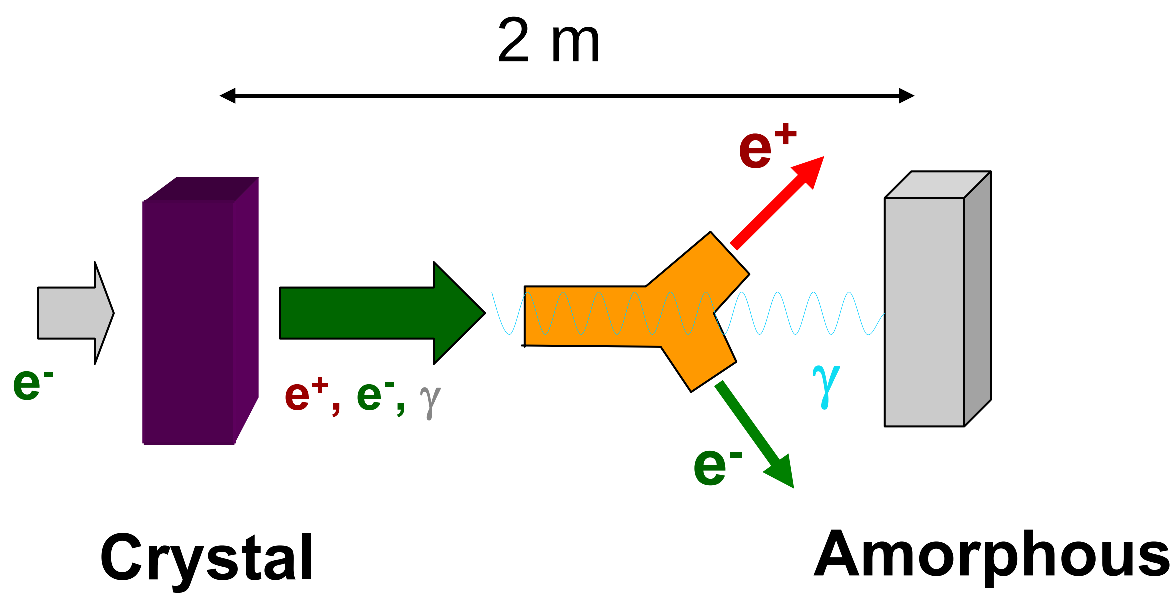
(*) CLIC previous parameters (CLIC Note 465)

(**) New AMD with ILC frequency and gradient. Simulations will be revisited with CLIC frequency (at 2 GHz) and CLIC gradient (15 MV/m).

1) AMD = Adiabatic Matching Device : it is composed of a flux concentrator and long solenoids along the linac accelerating sections

PRELIMINARY CONCLUSIONS for 3 TeV

- The hybrid positron source provides the needed yield for CLIC. A yield >1 e^+/e^- is reachable using only photons coming from the crystal
- The Peak Energy Density Deposition remains under the critical value of 35 J/g (for W) both for the thin crystal and the thick amorphous target.



At 500 GeV, charge is doubled => Study if a double target stations could be avoided ??

POSIPOL Collaboration

J. Urukawa / KEK

- Laser-Compton has a large potential as a future technology.
-
- Many common efforts can be shared in a context of various applications.
  - X-ray/SR sources for industrial and medical applications,
  - Beam diagnostics with Laser,
  - Polarized Positron Generation for ILC, CLIC, SuperB, ..

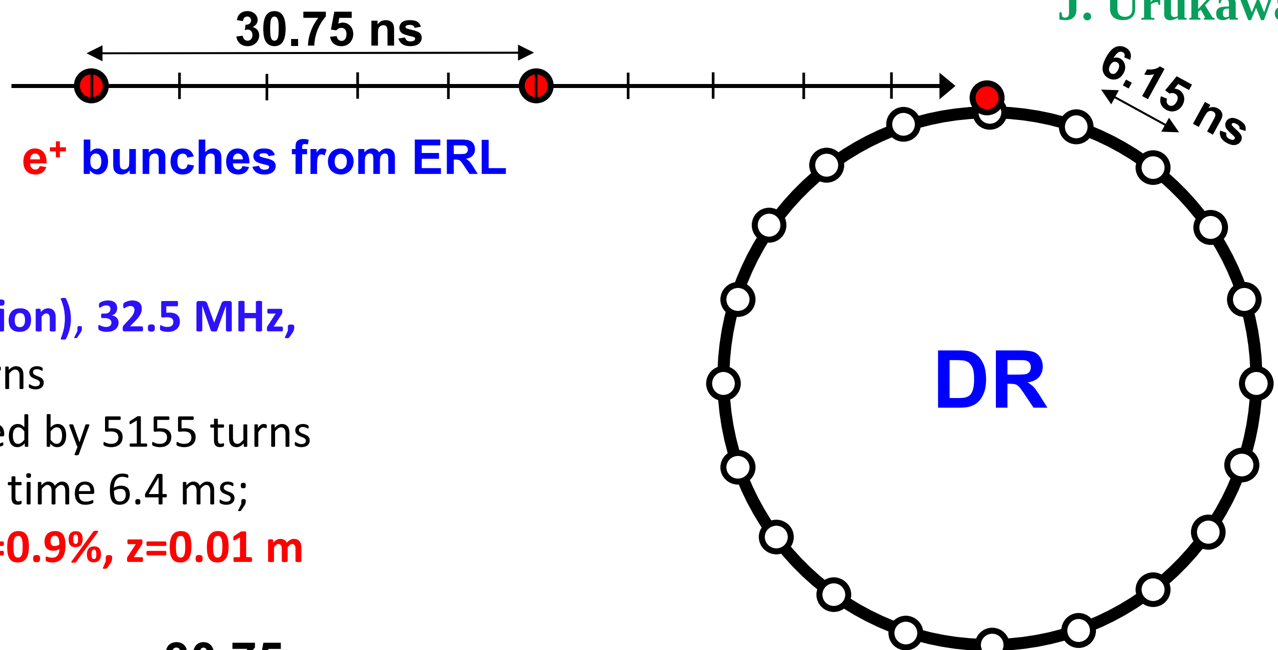
- State-of-the-art technologies are quickly evolved with world-wide synergy.

- PosiPol collaboration has been started in 2006.
- The last annual meeting was held at Hiroshima in July 08. The next meeting will be held at near CERN in 2009.

f_{rep}(ERL) = 32.5 MHz : 1st turn of DR stacking

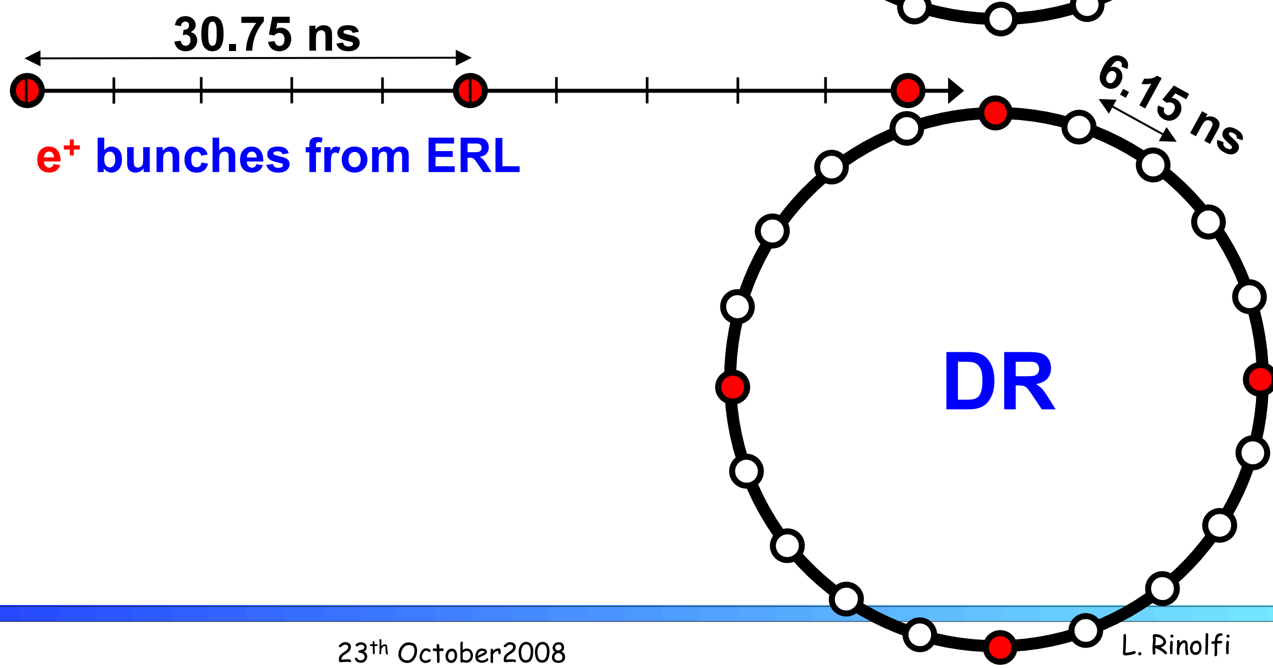
J. Urukawa / KEK

(1) 1st turn begin

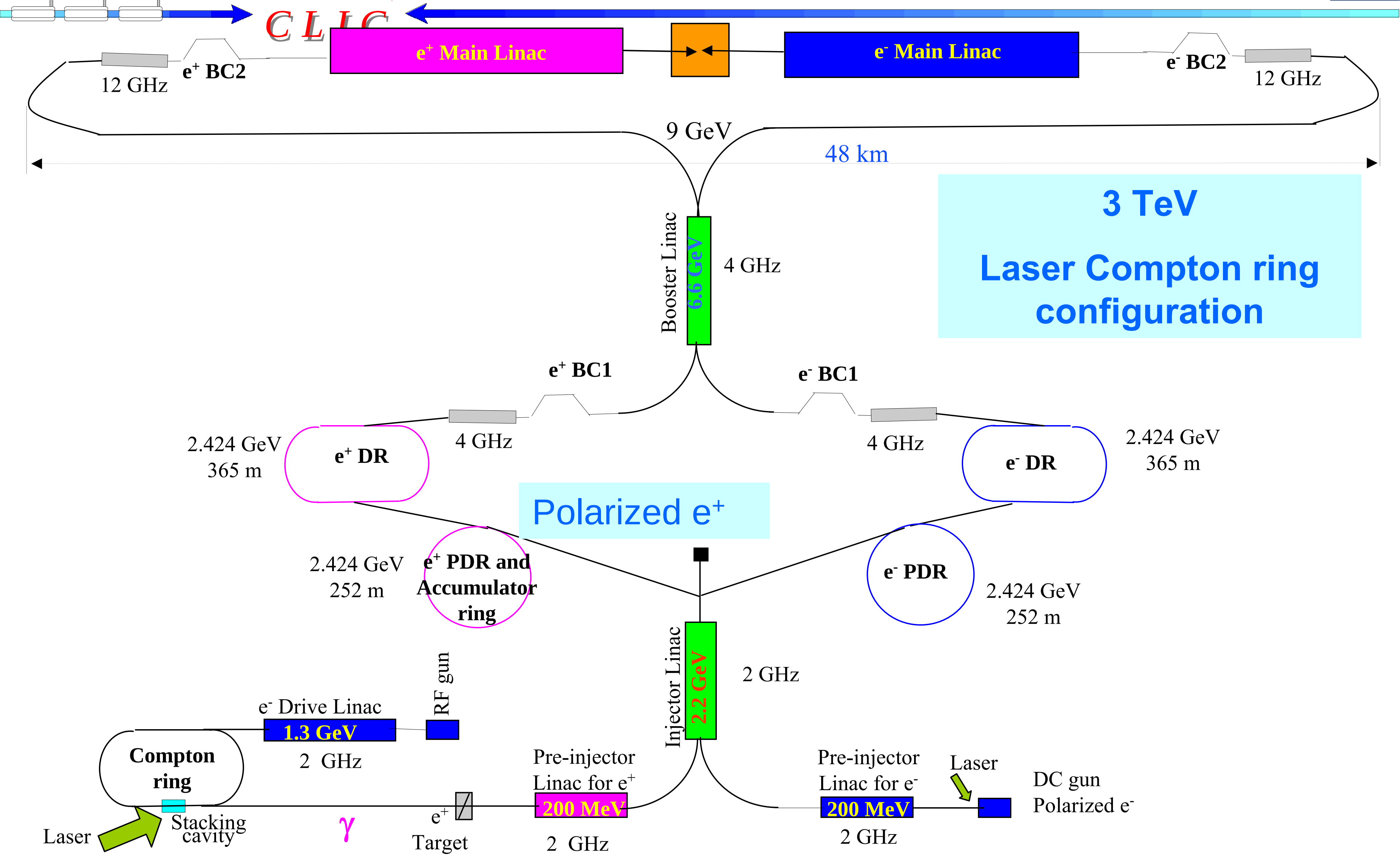


continuous stacking (ERL option), 32.5 MHz, 1020 injections over 5100 turns (inject every 5th turn), followed by 5155 turns (~100 ms) damping; damping time 6.4 ms;
inject with constant offset δ=0.9%, z=0.01 m

(2) 1st turn end



The CLIC Injector complex (Compton ring)



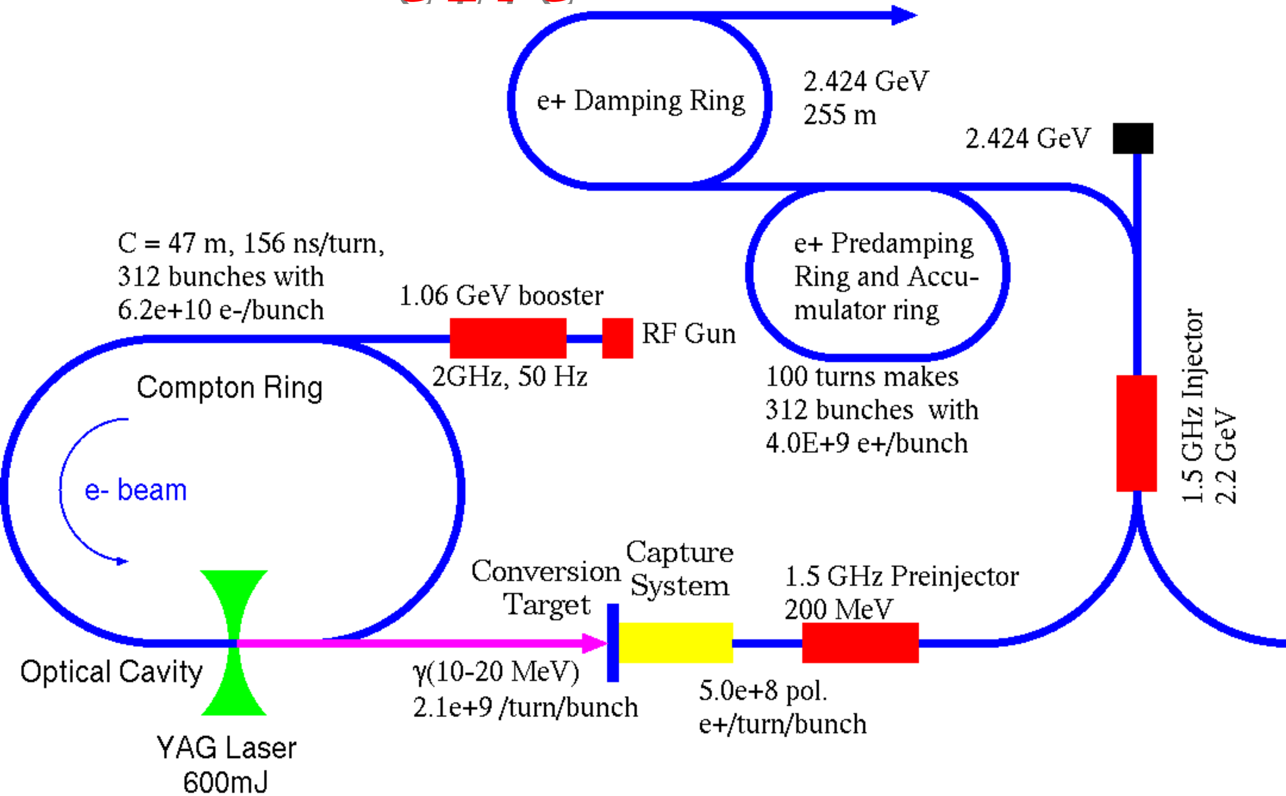
3 TeV

Laser Compton ring configuration

Polarized e^+

CLIC Compton Scheme

J. Urukawa / KEK



<u>ILC/CLIC common issues on Compton:</u>

1) Number of e^- (beam stability)
2) Optical cavity
3) High quality and high power laser
4) Choice of ERL parameters
5) Energy compression before (P)DR
6) Short Damping Time for (P)DR
7) e^+ stacking

Collaboration on Positron Generation strongly supported by CLIC and ILC managements (J.P. Delahaye@PosiPol08)

Polarized e^{+} with Compton scheme

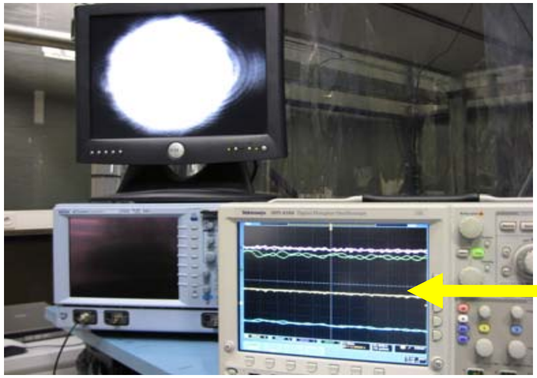
A. Variola / LAL

- -For polarised positron sources we need Compton scattering between nC electron bunches and 0.x J photon pulses.
- -Frep very high (20-160 MHz)
- -Short pulses (high gamma flux cannot cross the high reflectivity mirrors coating. Need a crossing angle). To increase the luminosity the photon pulse must be longitudinally short (few ps) and transversally little (x 10 μm)
- -Need to develop locking system for very high finesse Fabry Perot cavity and stability for little waists
- -In LAL two directions : Locking on a 2 mirror confocal cavity, waist on different type of 4 mirrors cavity

Results at LAL

A. Variola / LAL

1st STEP:



Cavity locked
With gain 1200

Status with our Ti:sa oscilllator@frep=76MHz

- 1rst demonstration of the cavity / comb coupling at very high finesse in ps regime (previous publications were in fs regime)
- We are implementing a 2nd feedback loop to stabilized actively Fce in addition to frep (short time scale ~ 1 month)
- Finesse 30000 !!!!!!!!!!!! (world record@1ps)

Next step (in ~ one month)

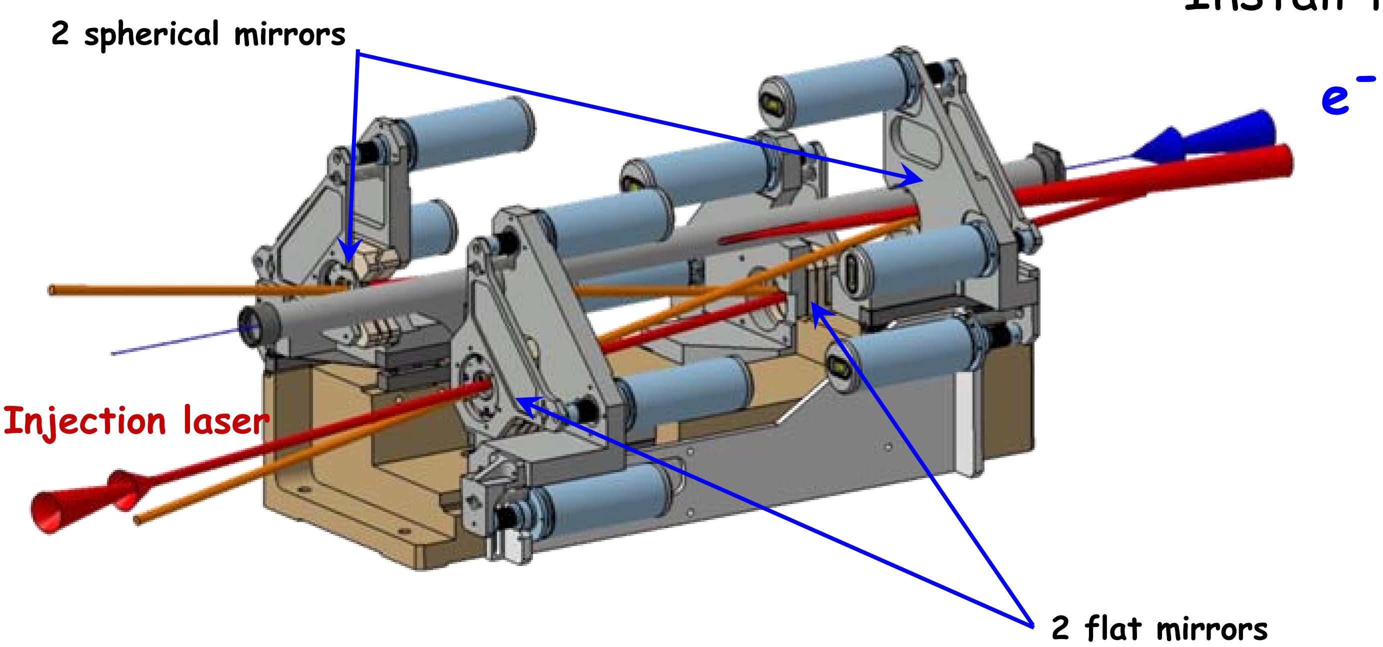
- Try higher finesse (300000 ?) with the Ti:sa oscillator
- Repeat the experiment with an Yb doped oscillator

Optical cavity R&D at LAL

A. Variola / LAL

GOAL => store the maximum power with a very short pulse for Compton
At low power, LAL results: i) finesse = 30000;
ii) waists of the order of few tenths of microns;
iii) studied the best 4 mirrors cavity configurations due to the polarization effects on modes.

Install the system @ ATF KEK



Continuation of the R&D: 2009 => 2011

INSTITUT NATIONAL DE PHYSIQUE NUCLÉAIRE ET DE PHYSIQUE DES PARTICULES

Financé par ANR — Agence Nationale de la Recherche

A. Variola / LAL

- CELIA / Bordeaux (Laser Lab.)
- KEK/ATF
- LAL/Orsay
- LMA/Lyon (Mirror coating Lab.)

- LAL & CERN are collaborating on the positron source design. The results of these activities will be rescaled for the CLIC parameters.

A formal collaboration between CERN and LAL has been just started with objectives towards the unpolarized e^+ sources and Compton schemes.

Compton source basics

F. Zimmermann / CERN

collide 1.3-1.8 GeV e- beam with laser pulse
stored in optical cavity (λ~1 μm);
yield ~ 0.2 γ/e- for single 600 mJ cavity *

convert Compton scattered photons to e+/e-,
and capture e+
yield ~ 0.01 e+/γ *

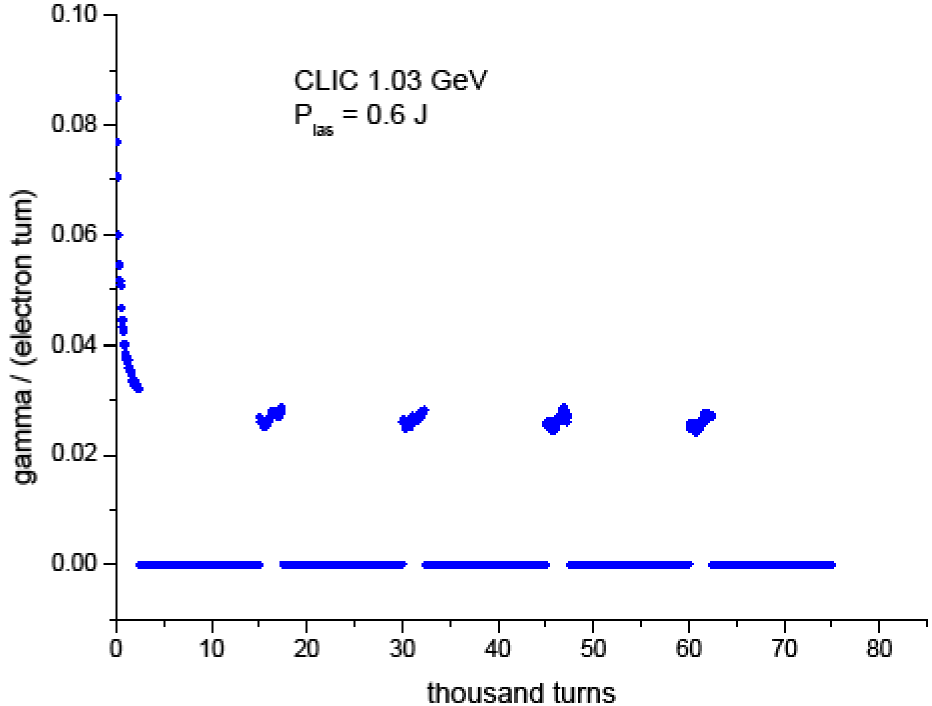
stack in accumulation ring
ex.: $6x10^{10}$ e-/bunch → 10^8 e+ → 40-60 stackings
needed to achieve $4.5x10^9$ e+ / bunch for CLIC;
unless we use several optical cavities like ILC

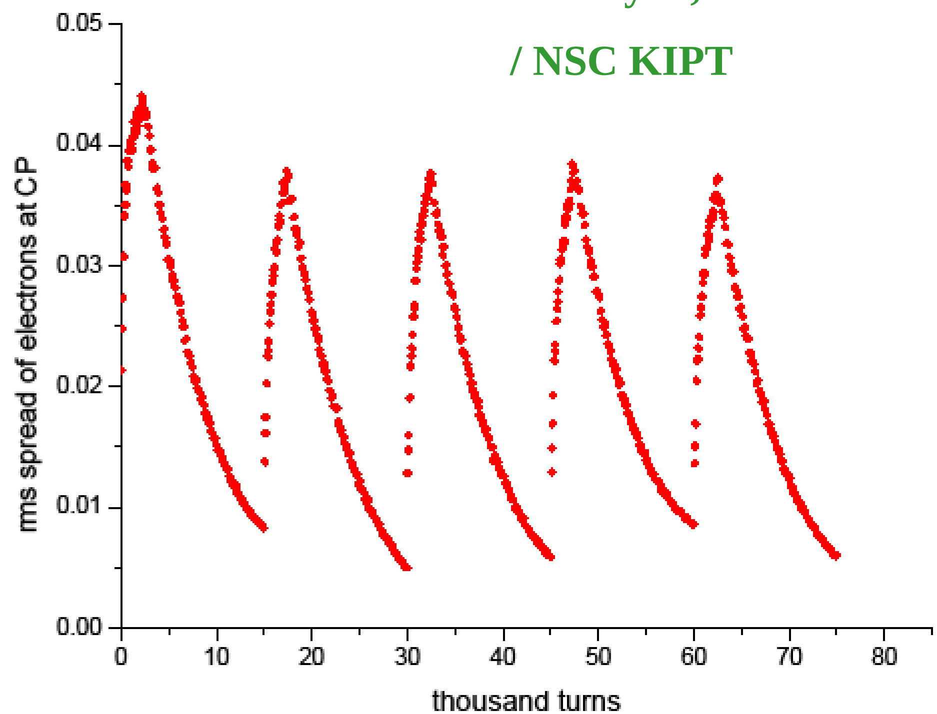
*Tsunehiko Omori, 11 October 2008

Compton ring design

E. Bulyak, P.Gladkikh

/ NSC KIPT





Number of e- = 312 x 6.2 x 10^{10} = 1.93 x10^{13} in the ring

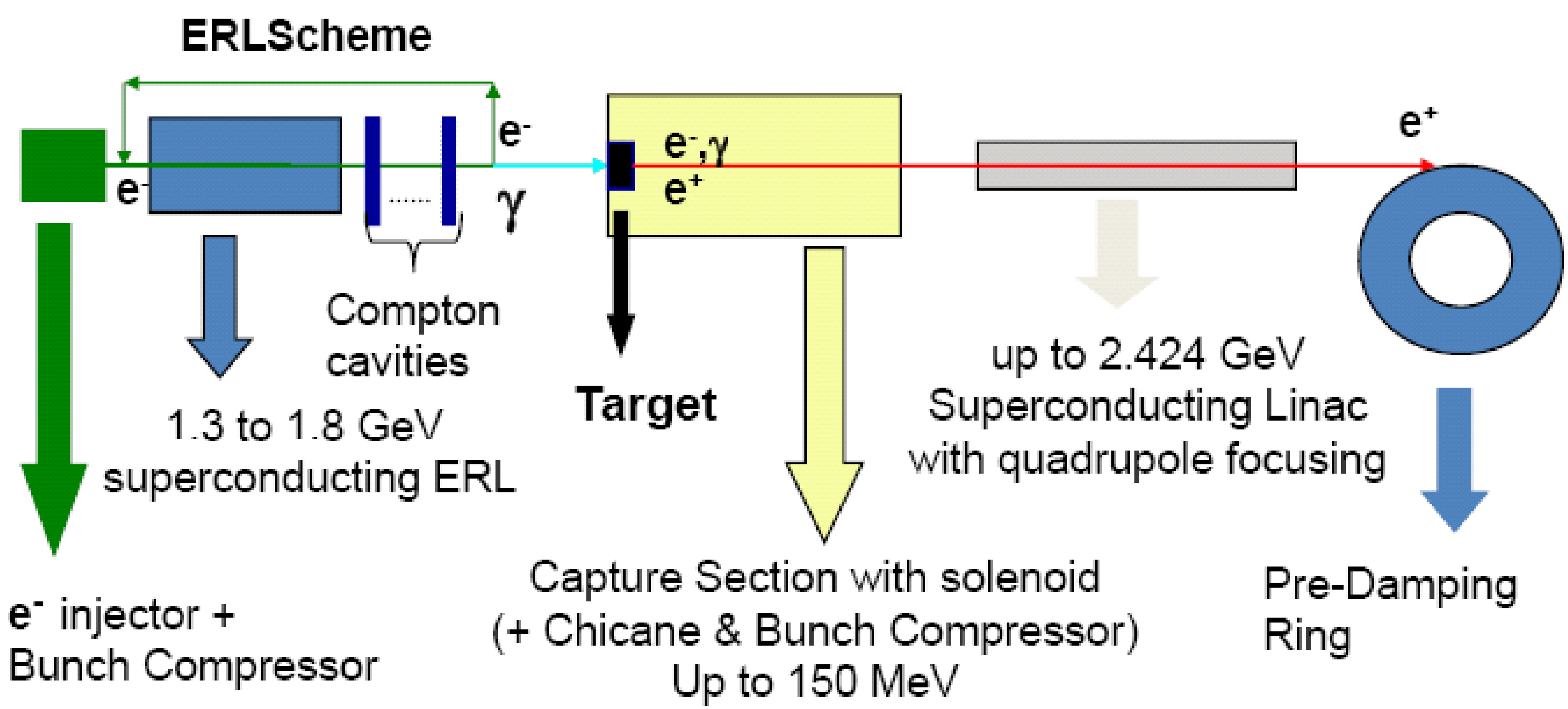
1 cycle = 15 000 turns => T = 156 ns x 15 000 = 2.3 ms

Laser on during 2500 turns

Photon yield = 85 photons / e-

Initial e+ parameters (from Vivoli simulations)

parameter	value
#e+ / pulse	6.65×10^7
longitudinal edge emittance (10 x rms) at ~200 MeV	0.72 meV-s
transverse normalized edge emittance (10 x rms)	0.063 m-rad



Comment on longitudinal emittance

F. Zimmermann / CERN

accelerating the e+ from 200 MeV to 5 GeV in 1.3 GHz linac may increase longitudinal emittance 4 times due to correlated energy spread from rf curvature and non-ideal initial bunch length (Vivoli, Rinolfi)

we do not need to accept this blow up for CLIC!

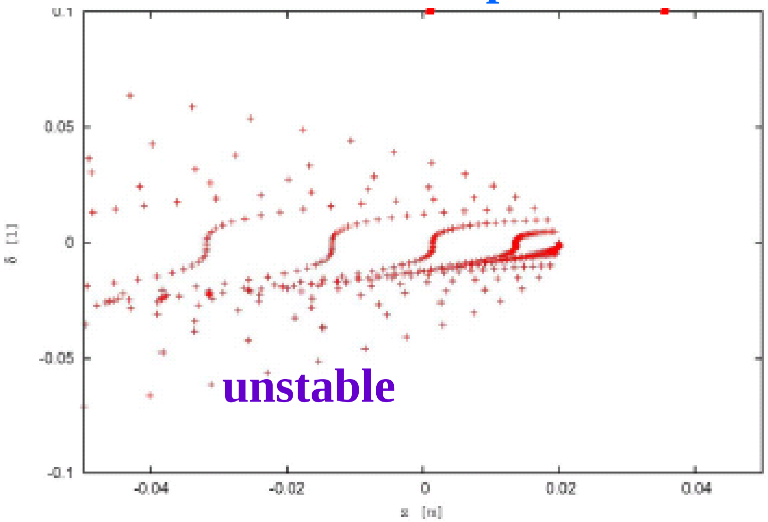
- CLIC DR energy is 2.424 GeV → ½ blow up
- use 700 MHz linac like SPL → ¼ blow up
- + if necessary optional bunch compression, higher harmonic RF, etc.

I assume preservation of normalized emittance

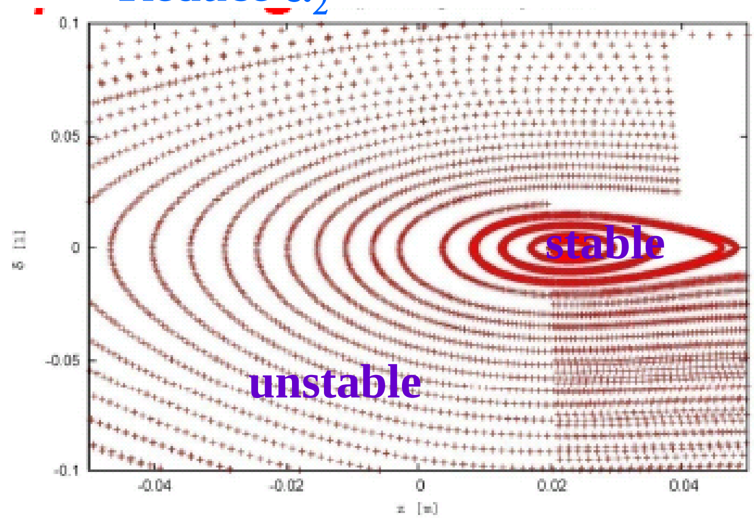
Stacking simulations into the PDR

F. Zimmermann / CERN

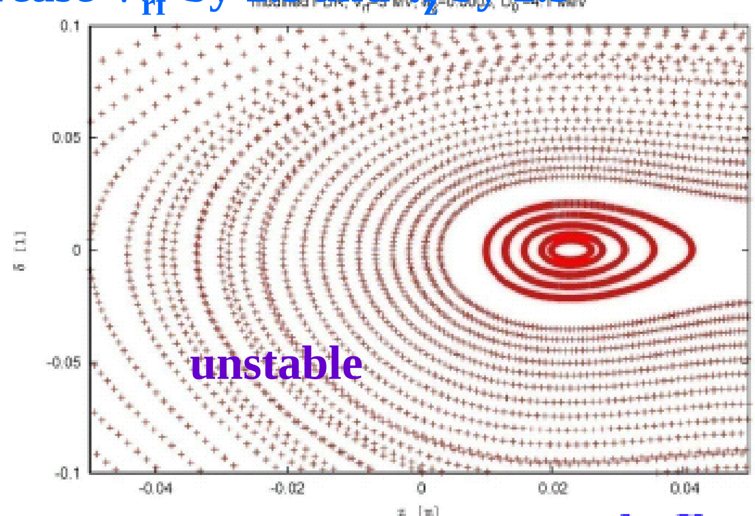
Nominal CLIC PDR parameters



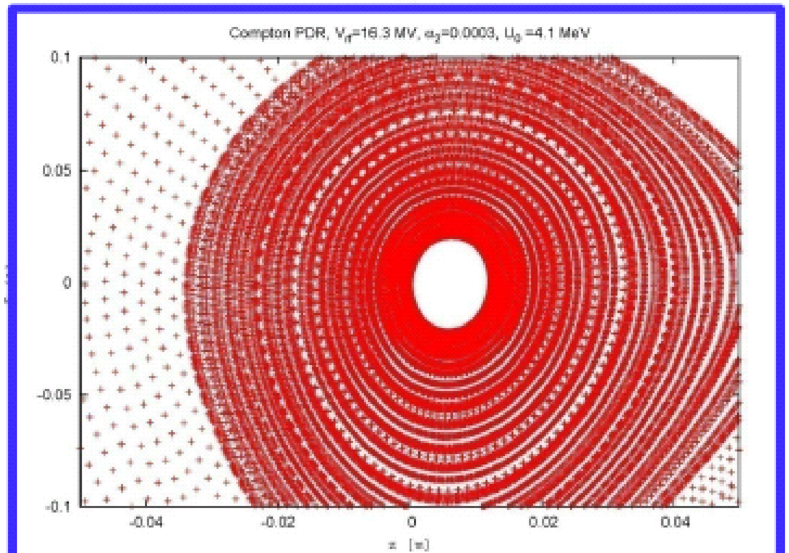
Reduce α_2



Increase V_{rf} by 2.5 and τ_z by 2.5



Increase V_{rf} by 8.1

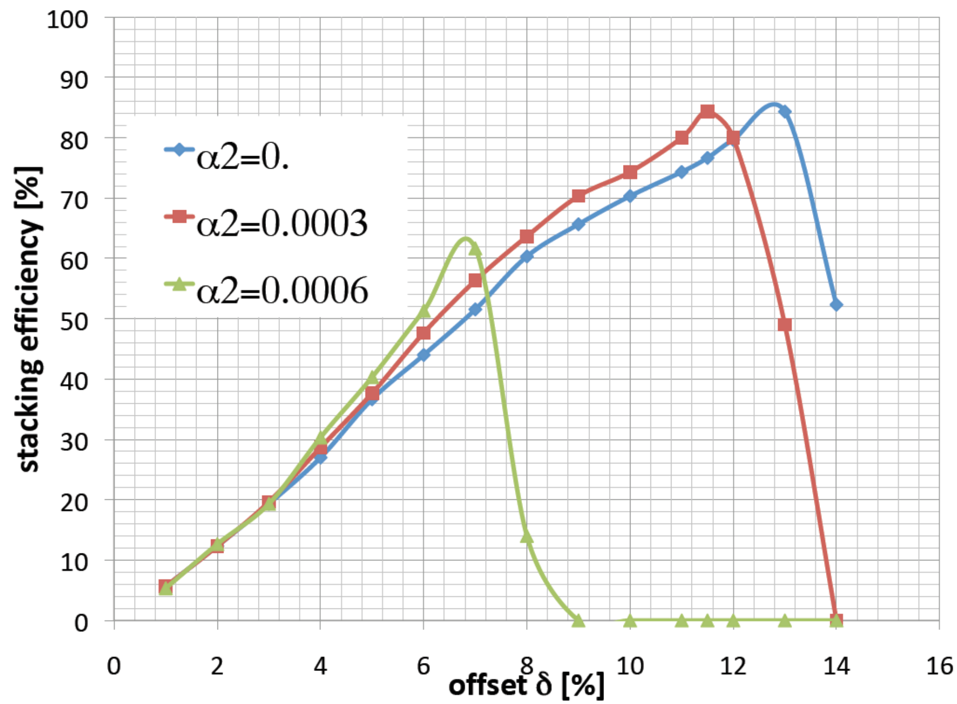


define this as new Compton PDR!

Stacking of polarized e^+ into the PDR

F. Zimmermann / CERN

- CLIC Compton source using ERL or CR
- e+ emittance preservation after capture
- CLIC PDR parameters should have a **low** a_2 ($4x10^{-4}$) and **high** V_{RF} (~16MV)
- 95% efficiency can be achieved with off-momentum off-phase injection
- Needs **10% of momentum acceptance** in PDR (off momentum DA)
- quite some flexibility (# optical cavities vs. e- bunch charge) but a few **challenges** for PDR design



Some conclusions for PDR stacking

F. Zimmermann / CERN

- CLIC Compton source using ERL or CR
- e+ emittance preservation after capture
- CLIC PDR parameters adapted for stability and stacking, $\alpha_2\downarrow\downarrow$ $V_{RF}\uparrow$
- stacking simulation: 95% efficiency with off-momentum off-phase injection
- PDR off-momentum dynamic aperture must be adequate (huge!)
- quite some flexibility (# optical cavities vs. e- bunch charge)
- but a few challenges for PDR design

Conclusion

1) Enormous progress have been made for the CLIC Main Beam Injector Complex since the last CLIC workshop

2) Two new ILC/CLIC working groups are in place for:

i) Damping Rings

ii) e^+ sources

3) The CLIC Main Beam Injector Complex is considered as a classical ensemble based on conventional technology which should provide the requested beam parameters at the entrance of the Main Linacs (easily):

BUT

a) For the Base Line configuration, crucial studies remain to be performed.

b) For polarized e^+, an intense R&D is necessary.

c) For the 500 GeV option, requesting a double charge per bunch, intense studies are necessary to confirm the feasibility (at lower cost).