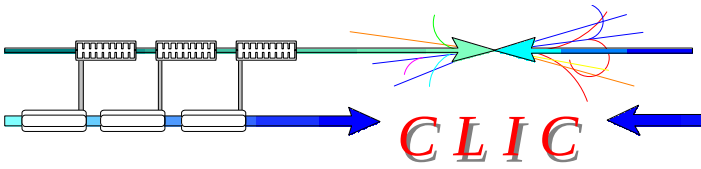
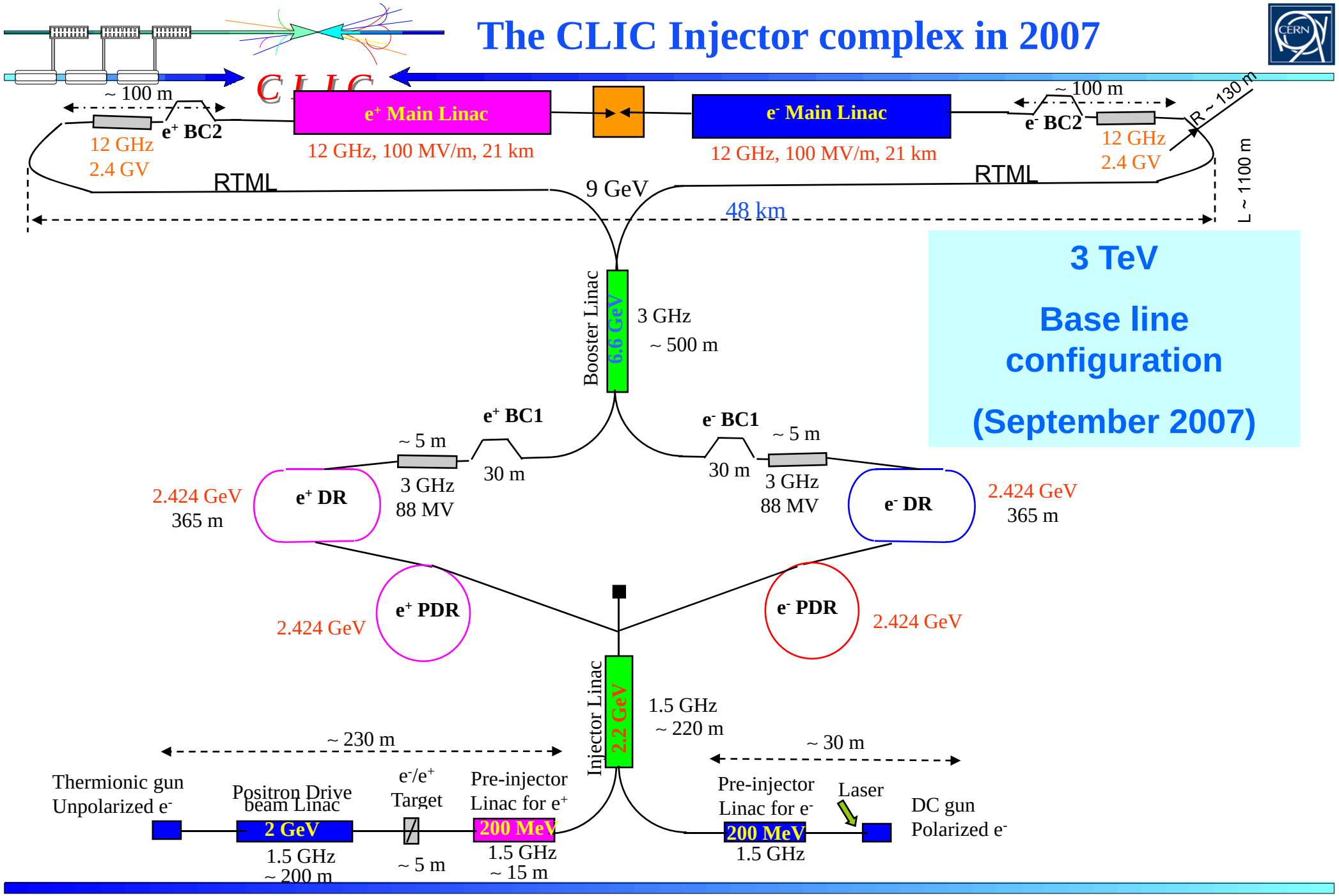



# CLIC Main Beam Injector Complex

## Review and status

L. Rinolfi

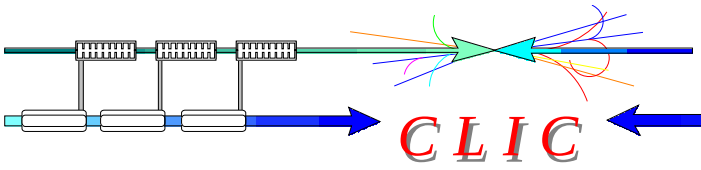
# The CLIC Injector complex in 2007




**3 TeV**

**Base line configuration**

**(September 2007)**




# CLIC Main beam parameters

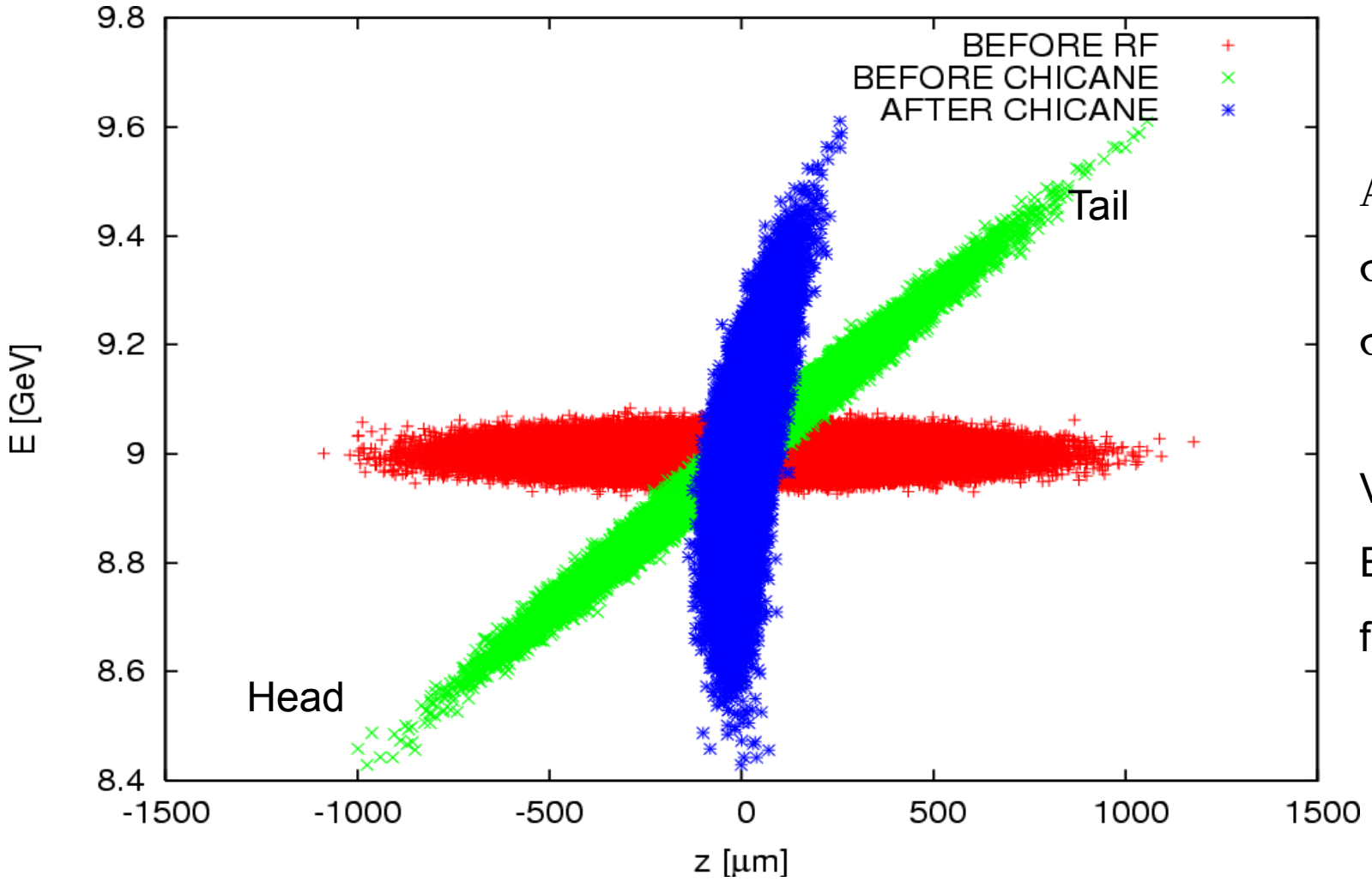
## At the entrance of the Main Linac for $e^-$ and $e^+$

| | | NLC (1 TeV) | CLIC Note 465 Simulations | CLIC 2007 (September) | CLIC 2007 (October) |
|---|---|---|---|---|---|
| $E$ | GeV | 8 | 9 | 9 | 9 |
| $N$ | $10^9$ | 7.5 | 4.2 | 4 - 4.1 | 3.72 - 4 |
| $n_b$ | - | 190 | 154 | 311 | 312 |
| $\Delta t_b$ | ns | 1.4 | 0.667 | 0.667 (8 RF periods) | 0.5 (6 RF periods) |
| $t_{pulse}$ | ns | 266 | 102 | 207 | 156 |
| $\varepsilon_{x,y}$ | nm, nm | 3300, 30 | 615, 8.6 | 600, 10 | 600, 10 |
| $\sigma_z$ | μm | 90-140 | 50 | 43 - 45 | 43 - 45 |
| $\sigma_E$ | % | 0.68 (3.2 % FW) | < 1 | 1.5 - 2 | 1.5 - 2 |
| $f_{rep}$ | Hz | 120 | 100 | 50 | 50 |
| $P$ | kW | 219 | 93 | 91 | 90 |

# The two stages of Bunch Compressor

| Parameter | DR | BC1 | | BC2 | |
|---|---|---|---|---|---|
| | Out | In | Out | In | Out |
| Energy (GeV) | 2.424 | 2.424 | 2.424 | 9 | 9 |
| No. of $e^+$ /bunch ($10^9$) | 4.4 | 4.4 | 4.3 | 4.2 | 4.1 |
| Bunch length (rms) (mm) | 1.5 | 1.5 | 0.175 | 0.175 | 0.044 |
| Energy Spread (rms) (%) | 0.137 | 0.137 | 1.2 | 0.32 | 1.3 |
| Longitud. emitt. (eV.m) | 4980 | 4980 | 4980 | 4980 | 4980 |
| BC factor | - | 8.6 | | 4 | |
| RF frequency | - | 3 GHz | | 12 GHz | |
| Gradient (Loaded) | - | 22 MV/m | | 40 MV/m | |
| Structure length | | 4 m | | 1 m | |
| Rf voltage | - | 88 MV | | 2400 MV | |
| Length of linac | - | 5 m | | 65 m | |
| Length of chicane | - | 30 m | | 40 m | |
| Total length | - | ~ 35 m | | ~ 105 m | |

# Second stage Bunch Compressor




After chicane BC2:

$\sigma_E$ = 1.3 %

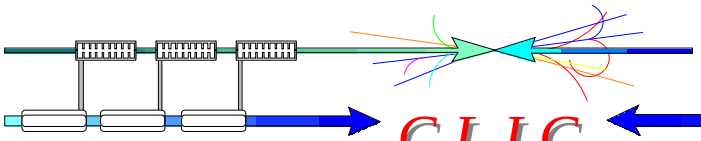
$\sigma_z$ = 0.044 mm

$V_{RF}$ = 2.4 GV

E = 40 MV/m

$f_{RF}$ = 12 GHz

A. Latina (CERN) & F. Stulle (PSI)





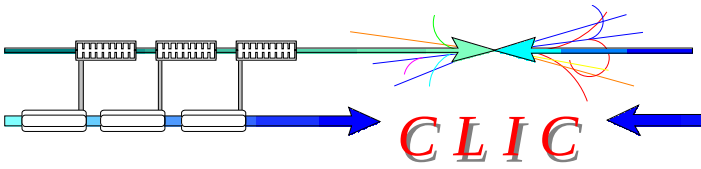
# Damping rings

Y. Papaphilippou

## Impact of coupling on new parameters

- When coupling set to 0 hor. and ver. emittance of 312nm and 3.6nm
- When vertical dispersion set to 0 hor. and ver. emittance of 322nm and 3.4nm
- When both are zero hor. and ver. emittance of 328nm and 3.1nm
- Future work should be focused on re-evaluating the alignment tolerances and coupling correction schemes in order to restore nominal emittance

| PARAMETER | 2006 | 2006 revised | NEW |
|---|---|---|---|
| energy [GeV] | 2.424 | | |
| circumference [m] | 365.2 | | |
| bunch population [E+09] | 2.56 | | 5.20 |
| bunch spacing [ns] | 0.533 | | 0.667 |
| number of bunches/train | 110 | | 311 |
| number of trains | 4 | | 1 |
| store time/train [ms] | 13.3 | | 20 |
| rms bunch length [mm] | 1.51 | 1.50 | 1.50 |
| rms momentum spread [%] | 0.136 | 0.129 | 0.137 |
| hor. normalised emittance [nm] | 380 | 308 | 432 |
| ver. normalised emittance [nm] | 2.4 | 3.9 | 4.3 |
| lon. normalised emittance [eV m] | 5000 | 4724 | 4993 |
| coupling [%] | 0.6 | 0.13 | 0.13 |
| ver. dispersion invariant [μm] | 0 | 0.248 | 0.248 |
| wiggler field [T] | 2.5 | | |
| wiggler period [cm] | 5 | | |
| energy loss/turn [MeV] | 3.903 | | |
| hor./ver./lon./ damping times [ms] | 1.5/1.5/0.75 | | |
| RF Voltage [MV] | 4.25 | | 4.345 |
| number of RF cycles | 2 | | 1 |
| repetition rate [Hz] | 150 | | 50 |
| RF frequency [GHz] | 1.875 | | 1.499 |




# Damping rings

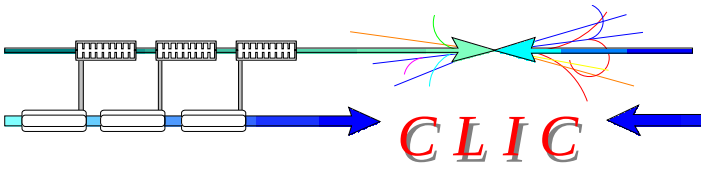
| Parameter | Unit | CLIC 2006 Note 627 | CLIC 2007 (September) | CLIC 2007 (October) |
|---|---|---|---|---|
| Energy (E) | GeV | 2.424 | 2.424 | 2.424 |
| No. of particles/bunch (N) | $10^9$ | 2.6 | 4.4 | 4.1 |
| Bunch length (rms) ($\sigma_z$) | mm | 1.55 | 1.5 | 1.53 |
| Energy Spread (rms) ($\sigma_E$) | % | 0.13 | 0.137 | 0.134 |
| Longitudinal emittance ($\varepsilon_l$) | eV.m | 4980 | 4980 | 4996 |
| Horizontal emittance ($\gamma\varepsilon_x$) | nm. rad | 550 **(450) (*)** | 432 | 381 **(540) (*)** |
| Vertical emittance ($\gamma\varepsilon_y$) | nm. rad | 3.3 **(3)(*)** | 4.3 | 4.1 **(5)(*)** |

**(*) Goal**

BINP studies => E. Levitchev (BINP)

Superconducting wiggler => R. Rossmanith (ANKA)

IBS => M. Martini, F. Zimmermann (CERN)




# Pre-Damping rings exit

Design values for $e^+$.

(should be better for $e^-$)

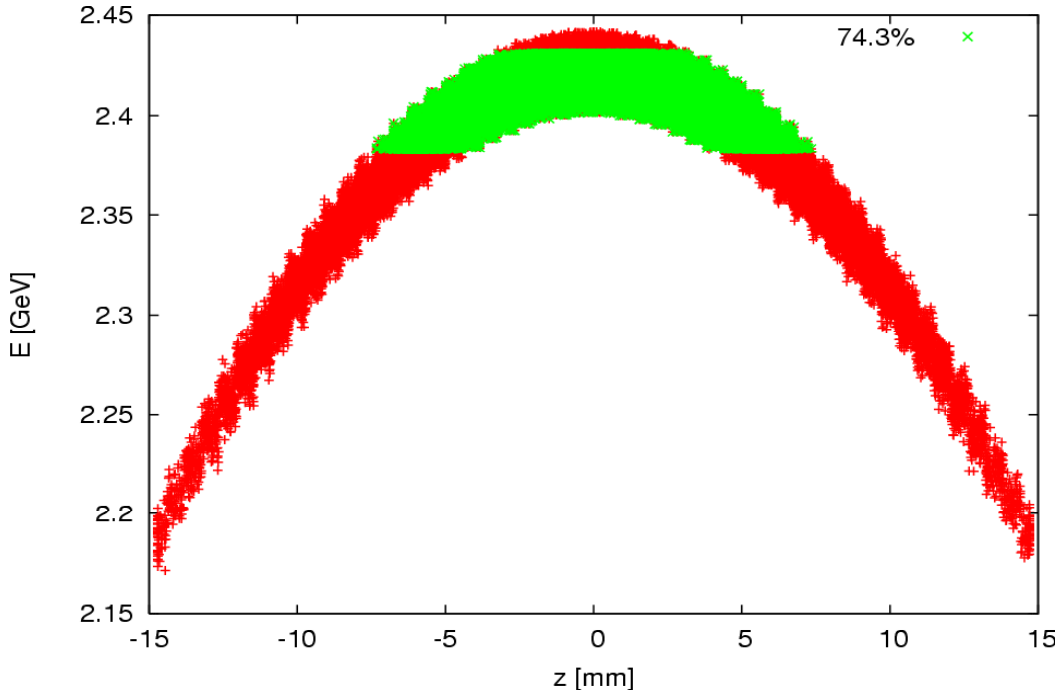
| Parameter | Unit | CLIC 2007 (*) | NLC PDR(**) |
|---|---|---|---|
| Energy (E) | GeV | 2.424 | 1.98 |
| No. of particles/bunch (N) | $10^9$ | 4.5 | 7.5 |
| Bunch length (rms) ($\sigma_z$) | mm | 10 | 5.1 |
| Energy Spread (rms) ($\sigma_E$) | % | 0.5 | 0.09 |
| Longitudinal emittance ($\varepsilon_l$) | eV.m | 121000 | 9000 |
| Horizontal emittance ($\gamma\varepsilon_x$) | nm. rad | 63000 | 46000 |
| Vertical emittance ($\gamma\varepsilon_y$) | nm. rad | 1500 | 4600 |

(*) M. Korostelev CLIC meeting 28 July 2006

(**) I. Reichel, A. Wolsky EPAC 2004

# Simulations for the Injector Linac ($e^+$)

PLACET simulation => A. Latina




Longitudinal distribution

$E_{mean}$ = 2.4 GeV

$N_{e+}$ = 6.4 x $10^9$ / bunch

$\Delta E$ = 17 MV/m

Total distribution:

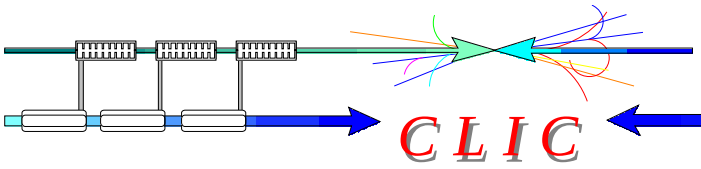
$\sigma_E$ = 1.5 %

rms bunch length 5 mm

For acceptance $\Delta E/E$ = 2 % FW

Capture = 74 % of $e^+$

rms bunch length 3.2 mm




# Injector Linac

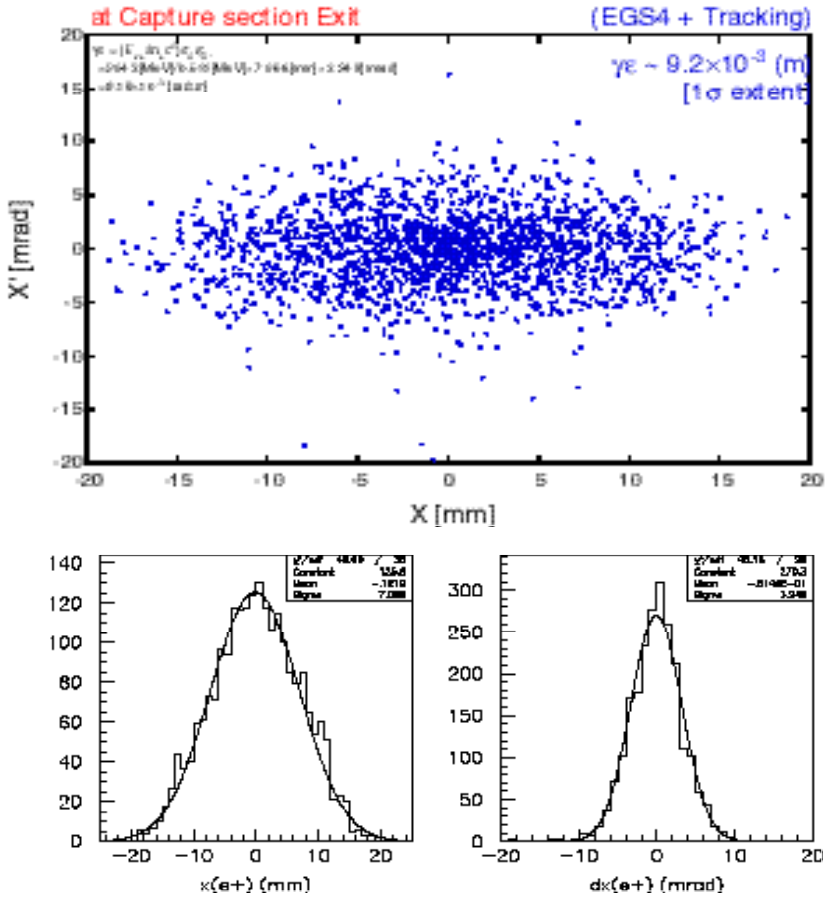
MAD simulations => A. Ferrari  PLACET simulations => A. Latina

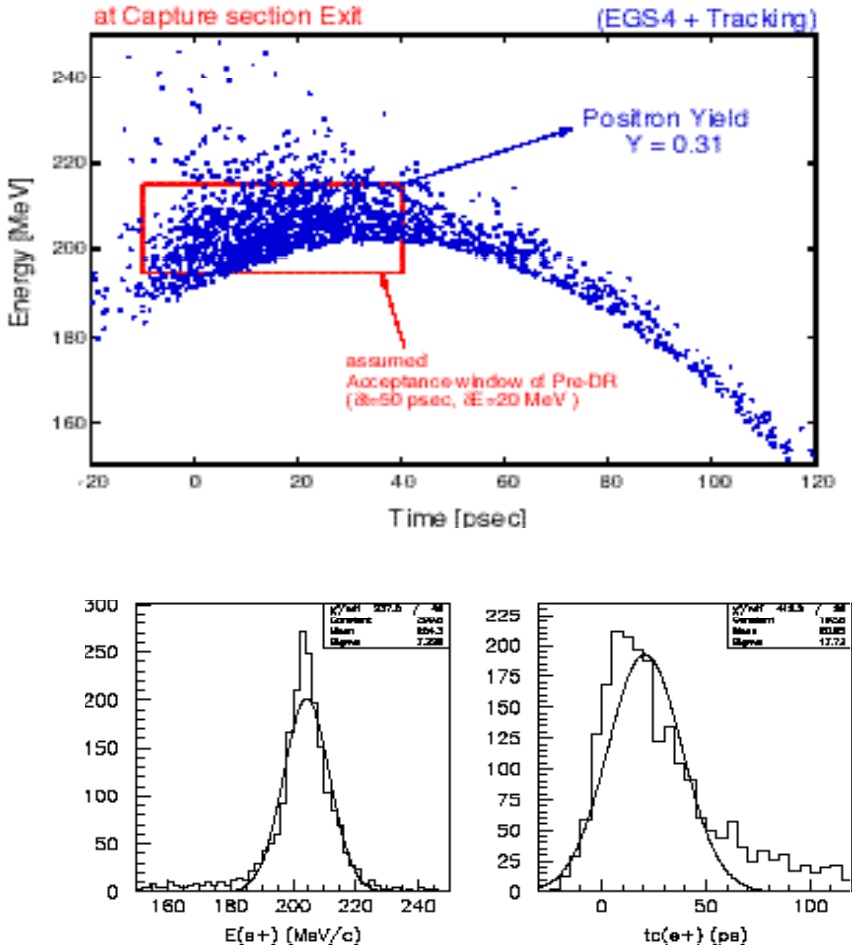
| Parameter | Unit | $e^-$ | $e^+$ |
|---|---|---|---|
| Energy (E) | GeV | 2.424 | 2.424 |
| No. of particles/bunch (N) | $10^9$ | 4.7 | 6.4 |
| Bunch length (rms) ($\sigma_z$) | mm | 1 | 5 |
| Energy Spread (rms) ($\sigma_E$) | % | 0.07 | 1.5 |
| Longitudinal emittance ($\varepsilon_l$) | eV.m | 1700 | 240000 |
| Horizontal emittance ($\gamma\varepsilon_x$) | nm. rad | $100 \times 10^3$ | $9.7 \times 10^6$ |
| Vertical emittance ($\gamma\varepsilon_y$) | nm. rad | $100 \times 10^3$ | $9.7 \times 10^6$ |

New parameters => Studies of new accelerating structures ( 2 GHz) => S. Doebert

# Simulations for the Pre-Injector Linac ($e^+$)

## For positrons at 200 MeV

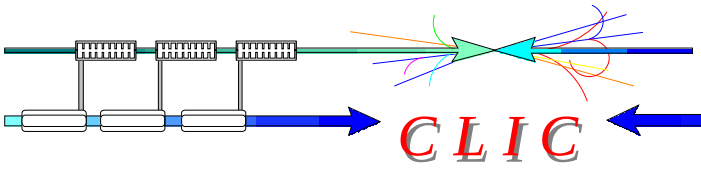



The normalised transverse emittances are:

$\gamma\varepsilon_{x,y} = 9.2\ 10^{-3}$ rad.m $\approx$ 0.01 rad.m [at 1 $\sigma$]

$\sigma_E = 7$ MeV and $\sigma_t = 17$ ps.




# Pre-Injector Linac

## For positrons after capture section

| Parameter | Unit | CLIC 2007 (*) |
|---|---|---|
| Energy (E) | GeV | 0.2 |
| No. of particles/bunch (N) | $10^9$ | 6.7 |
| Bunch length (rms) ($\sigma_z$) | mm | 5 |
| Energy Spread (rms) ($\sigma_E$) | % | 3.5 |
| Longitudinal emittance ($\varepsilon_l$) | eV.m | 35000 |
| Horizontal emittance ($\gamma\varepsilon_x$) | nm. rad | $9.2 \times 10^6$ |
| Vertical emittance ($\gamma\varepsilon_y$) | nm. rad | $9.2 \times 10^6$ |

Assuming 95 % of transmission efficiency in the Injector Linac and 70% of capture efficiency in the PDR

=> N ($e^+$) = $6.7 \times 10^9$

Simulations have shown

**Yield = 0.31 $e^+$/ $e^-$ GeV**

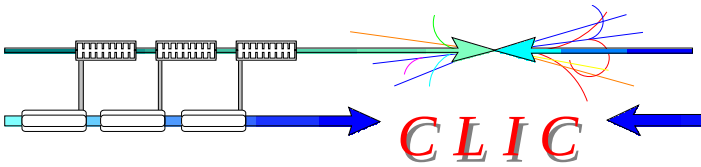
=> N ($e^-$) = $11 \times 10^9$

at 2 GeV

If decelerating phase used

**=> Yield = 0.39 $e^+$/$e^-$ GeV**

(*) T. Kamitani, L. Rinolfi CLIC Note 465



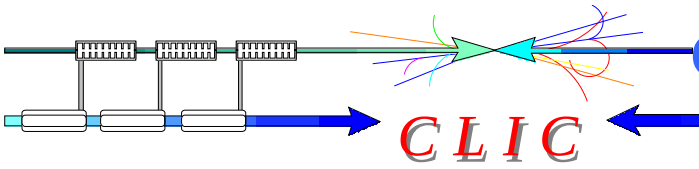

# CLIC Conventional $e^+$ source (*)

| Parameter | Unit | CLIC |
|---|---|---|
| **Primary Beam** | | |
| Energy (E) | GeV | 2 |
| N $e^-$ /bunch (N) | $10^9$ | 13.5 |
| N bunches / pulse | - | 154 |
| Pulse length | ns | 102 |
| Repetition frequency | Hz | 100 |
| Beam power | kW | 66.5 |
| Linac frequency | GHz | 1.5 |
| Beam radius (rms) ($\sigma_{x,y}$) | mm | 2 |
| Bunch length (rms) ($\sigma_z$) | mm | 3 |

(*) T. Kamitani, L. Rinolfi CLIC Note 465

| Parameter | Unit | |
|---|---|---|
| **Target** | | |
| Material | | $W_{75}Re_{25}$ |
| Length (4 $\chi_0$) | mm | 14 |
| Beam power deposited | kW | 16.5 |
| Deposited P / Beam Power | % | 25 |
| Pulse energy density per area | $10^{12}$ GeV/mm$^2$ | 0.33 |
| Energy lost per volume | $10^{10}$ GeV/mm$^3$ | 0.64 |
| Peak energy deposition density | J/g | 53 |

**Limit from SLAC target: 35 J/g => a double target**




# CLIC Conventional $e^+$ source (October 2007)

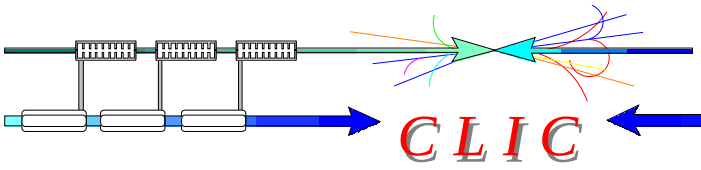
| Parameter | Unit | CLIC |
|---|---|---|
| **Primary Beam** | | |
| Energy (E) | GeV | 2 |
| N $e^-$ /bunch (N) | $10^9$ | 11 |
| N bunches / pulse | - | 312 |
| Pulse length | ns | 156 |
| Repetition frequency | Hz | 50 |
| Beam power | kW | 55 |
| Linac frequency | GHz | 2 |
| Beam radius (rms) ($\sigma_{x,y}$) | mm | 2 |
| Bunch length (rms) ($\sigma_z$) | mm | 3 |

| Parameter | Unit | |
|---|---|---|
| **Target** | | |
| Material | | $W_{75}Re_{25}$ |
| Length (4 $\chi_0$) | mm | 14 |
| Beam power deposited | kW | 13.6 |
| Deposited P / Beam Power | % | 25 |
| Pulse energy density per area | $10^{12}$ GeV/mm$^2$ | 0.54 |
| Energy lost per volume | $10^{10}$ GeV/mm$^3$ | 1.0 |
| Peak energy deposition density | J/g | 87.5 |

**Limit from SLAC target: 35 J/g => a triple target**

Collaboration with:

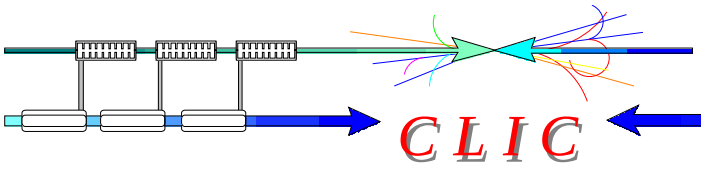
R. Chehab IPN L




# Evolution for e⁻

**All rms values are given at the exit of each system**

| | Energy | N/bunch | $\sigma_z$ | $\Delta E/E$ | $\gamma\varepsilon_x/\gamma\varepsilon_y$ |
|---|---|---|---|---|---|
| | GeV | $10^9$ | mm | % | rad.nm |
| DC gun | 0.120 | 6 | a few | < 1 | $3.5\ 10^3$ |
| Pre-injector | 0.2 | 5 | 1 | 1 | $100\ 10^3$ |
| Injector Linac | 2.424 | 4.7 | 1 | 0.07 | $100\ 10^3$ |
| Pre-Damping | 2.424 | 4.5 | to | be | evaluated |
| Damping ring | 2.424 | 4.4 | 1.5 | 0.137 | 381/4.1 |
| BC1 | 2.424 | 4.3 | 0.175 | 1.2 | under evaluation |
| Booster Linac | 9 | 4.2 | 0.175 | 0.32 | under evaluation |
| BC2 | 9 | 4.1 | 0.044 | 1.3 | 600/10 |
| Main Linac | 1500 | 4 | 0.044 | 0.3 | 660/20 |




# Evolution summary for $e^+$

**All rms values are given at the exit of each system**

| | Energy | N/bunch | $\sigma_z$ | $\Delta E/E$ | $\gamma\varepsilon_x/\gamma\varepsilon_y$ |
|---|---|---|---|---|---|
| | GeV | $10^9$ | mm | % | rad.nm |
| Pre-injector | 0.2 | 6.7 | 5 | 3.5 | $9.2\ 10^6$ |
| Injector Linac | 2.424 | 6.4 | 5 | 1.5 | $9.7\ 10^6$ |
| Pre-Damping | 2.424 | 4.5 | 10 | 0.5 | $6310^3/1.510^3$ |
| Damping ring | 2.424 | 4.4 | 1.5 | 0.137 | 381/4.1 |
| BC1 | 2.424 | 4.3 | 0.175 | 1.2 | under evaluation |
| Booster Linac | 9 | 4.2 | 0.175 | 0.32 | under evaluation |
| BC2 | 9 | 4.1 | 0.044 | 1.3 | 600/10 |
| Main Linac | 1500 | 4 | 0.044 | 0.3 | 660/20 |

# Polarization

## @ POSIPOL 2007

**Gudrid Moortgat-Pick (Duhram) :**

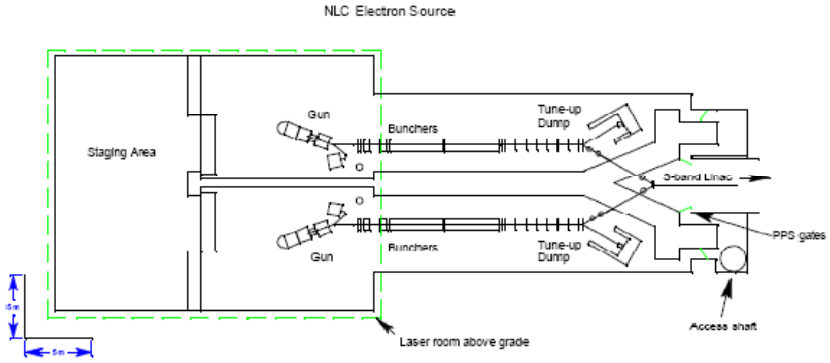
- Discovery via high precision measurements
  - test of the Standard Model (SM) with unprecedented precision
  - even smallest hints of NP could be observed
- Beam polarization (e- and e+) important
  - important for analyzing the coupling structure
  - important for enhancing the precision

**Sabine Riemann (DESY) :**

**With $e^+$ polarization :**
**• processes can be enhanced or suppressed;**
**• clean initial states with known helicities**

# Conventional polarized e⁻ source

| Parameter | Unit | NLC |
|---|---|---|
| Photocathode | | GaAs |
| Energy | MeV | 0.120 |
| N e⁻ /bunch | $10^9$ | 18 |
| Bunch length | ps | 700 (FWHM) |
| Energy spread | % | < 1 |
| Emittance | mm.mrad | 5 (edge) |

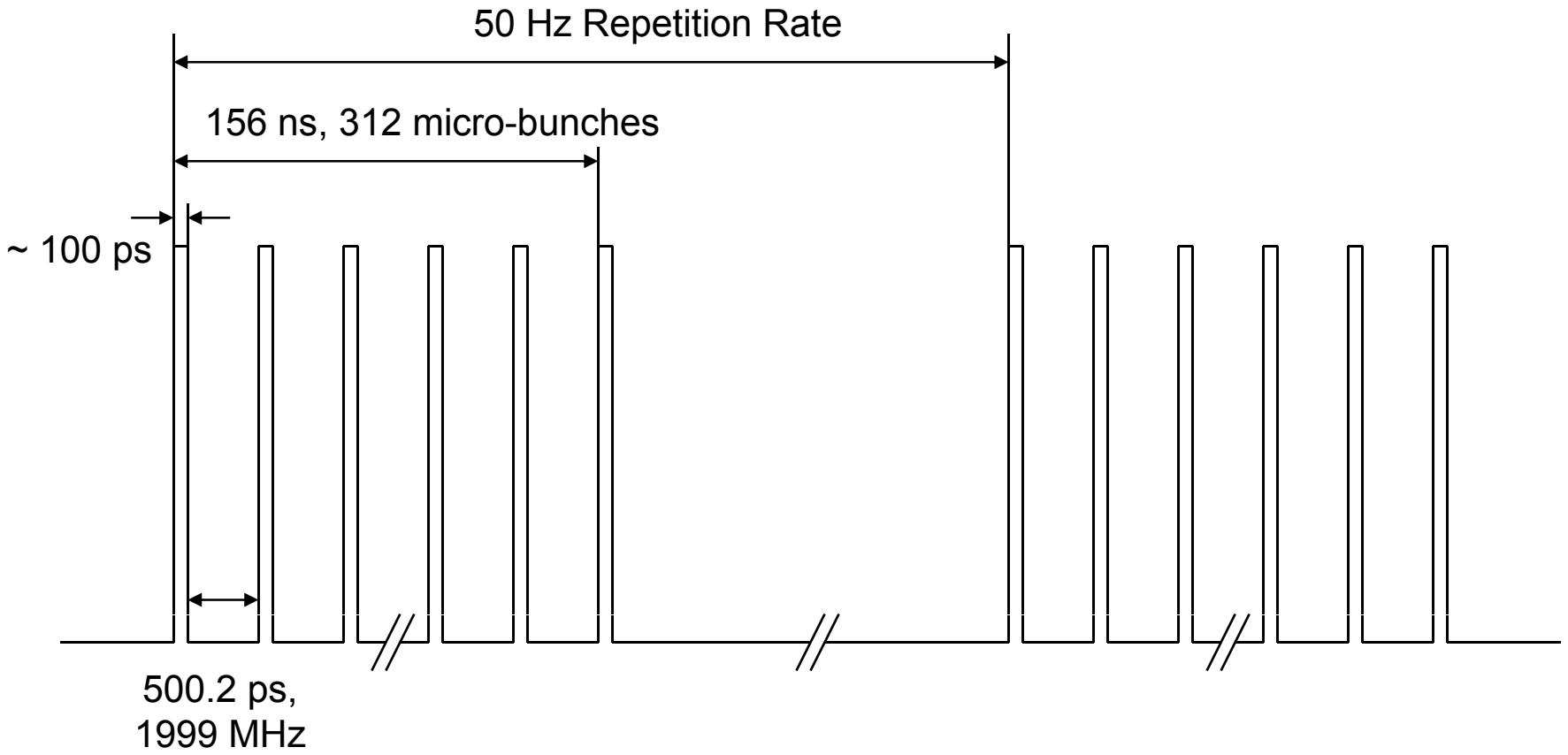


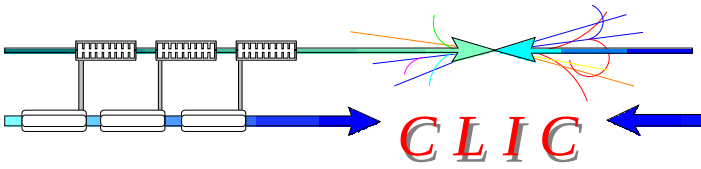
# CLIC e- Beam Time Structure

**(October 2007)**

Collaboration with:

M. Poelker JLAB



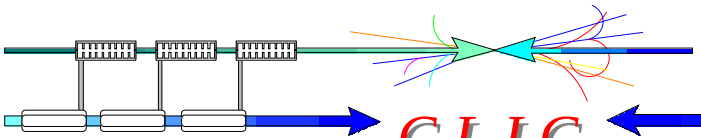



# CLIC $e^-$ Beam Source Parameters

## (October 2007)

| Parameter | Symbol | Value |
|---|---|---|
| Number Electrons per microbunch | $N_e$ | $6 \times 10^9$ |
| Number of microbunches | $n_b$ | 312 |
| Width of microbunch | $t_b$ | ~ 100 ps |
| Time between microbunches | $\Delta t_b$ | 500.2 ps |
| Microbunch rep rate | $f_b$ | 1999 MHz |
| Width of macropulse | $T_B$ | 156 ns |
| Macropulse repetition rate | $f_{rep}$ | 50 Hz |
| Charge per micropulse | $C_b$ | 0.96 nC |
| Charge per macropulse | $C_B$ | 300 nC |
| Average current from gun ($C_B$ x $F_B$) | $I_{ave}$ | 15 uA |
| Average current macropulse ($C_B$ / $T_B$) | $I_B$ | 1.9 A |
| Duty Factor w/in macropulse (100ps/500ps) | DF | 0.2 |
| Peak current of micropulse ($I_B$ / DF) | $I_{peak}$ | 9.6 A |

# The CLIC Injector complex




e⁺ Main Linac

12 GHz, 100 MV/m, 21 km

e⁻ Main Linac

3.5 km

12 GHz

e⁺ BC2

e⁻ BC2

12 GHz

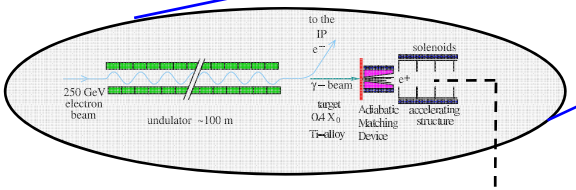
9 GeV

## Undulator configuration

Collaboration with:

J. Sheppard SLAC

W. Gei / L. Wanming ANL




Booster Linac 6.6 GeV

3 GHz

e⁺ BC1

e⁻ BC1

3 GHz

3 GHz

2.424 GeV

e⁺ DR

e⁻ DR

2.424 GeV

e⁺ PDR

e⁻ PDR

2.424 GeV

2.424 GeV

Injector Linac 2.2 GeV

1.5 GHz

## Keep Alive Source

Thermionic gun
Unpolarized e⁻

Primary beam
Linac for e⁻
200 MeV
1.5 GHz

e⁻/e⁺
Target

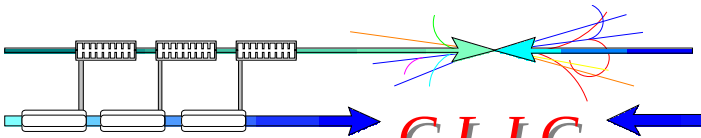
Pre-injector
Linac for e⁺
200 MeV
1.5 GHz

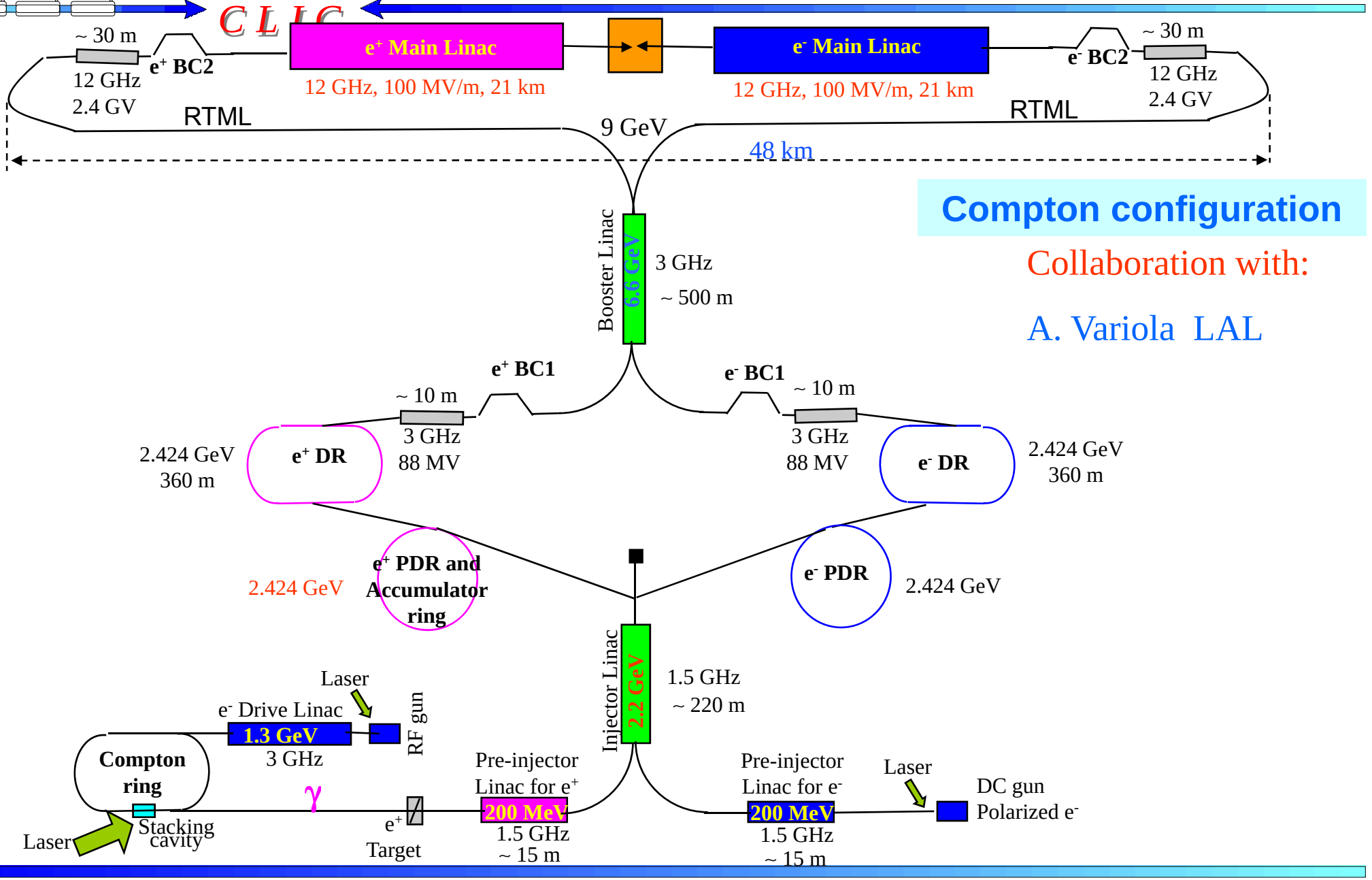
Pre-injector
Linac for e⁻
200 MeV
1.5 GHz

Laser

DC gun
Polarized e⁻

# The CLIC Injector complex (Compton)





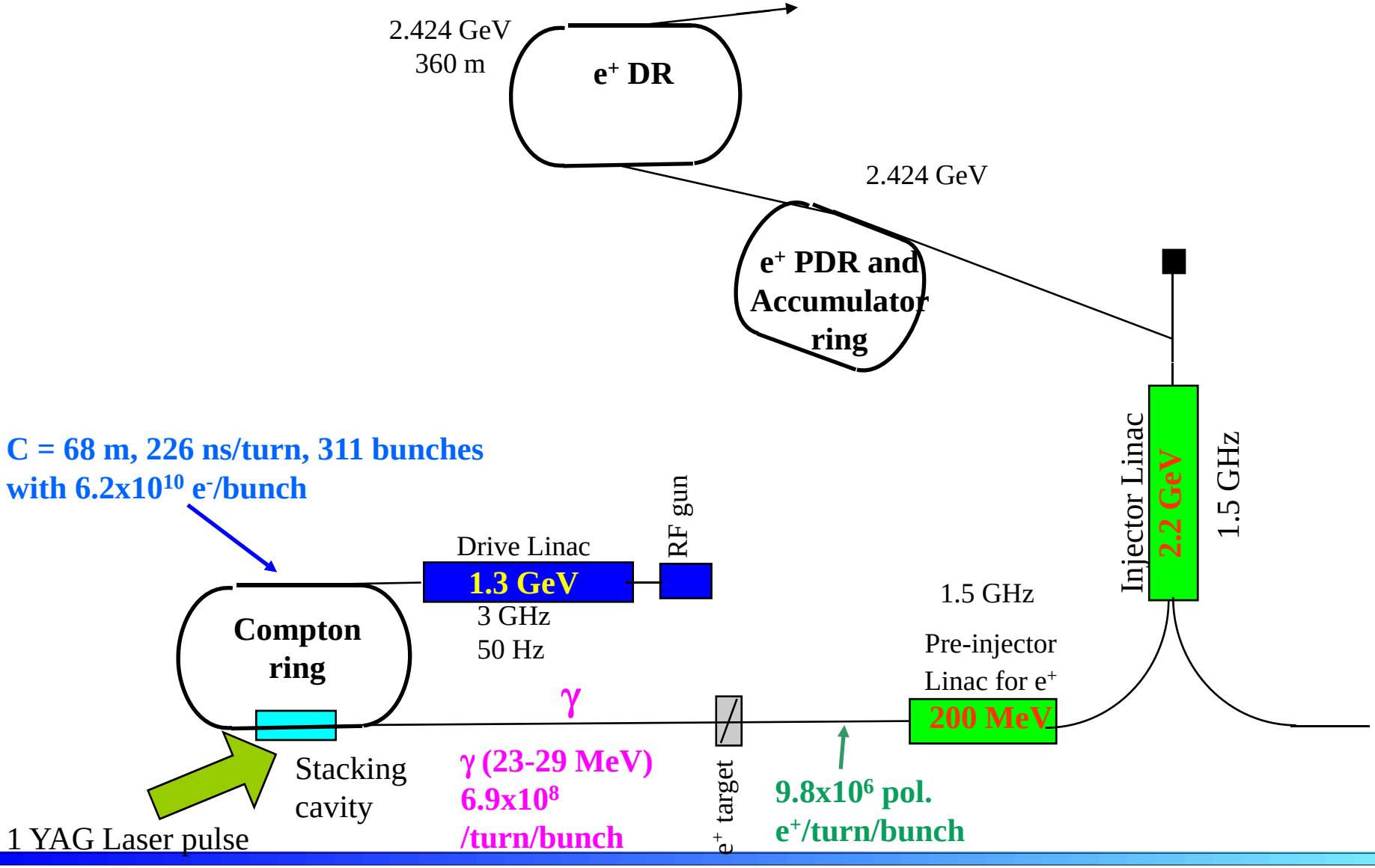

## Compton configuration

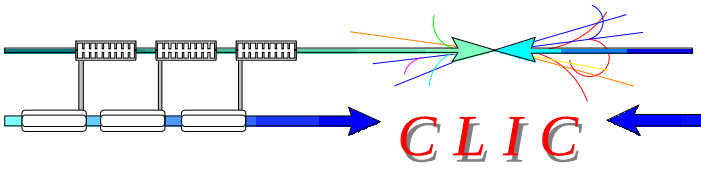
Collaboration with:

A. Variola LAL

# CLIC scheme with polarized $e^+$

## Compton configuration






# Summary

1) No major work has been done with the new (October 2007) parameters
=> A complete review of the Injector complex is necessary.

2) A design of the Pre-dampings is needed (for $e^+$ and $e^-$ ) and many issues for the Damping rings (emittances, IBS,…) remain to be studied.

4) The options (Compton, Undulator) for polarized $e^+$ should be studied with the new CLIC parameters.

**The talks in this "Injectors & Damping rings" working group would discuss the above topics.**