CLIC Injector Baseline

- Polarized electron source
- Positron source
- Linacs and beam transport
- Conclusion and Outlook

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Introduction

1) Base Line configuration:

3 TeV (c.m.) - unpolarized e^+ source - very small emittance's from DR.

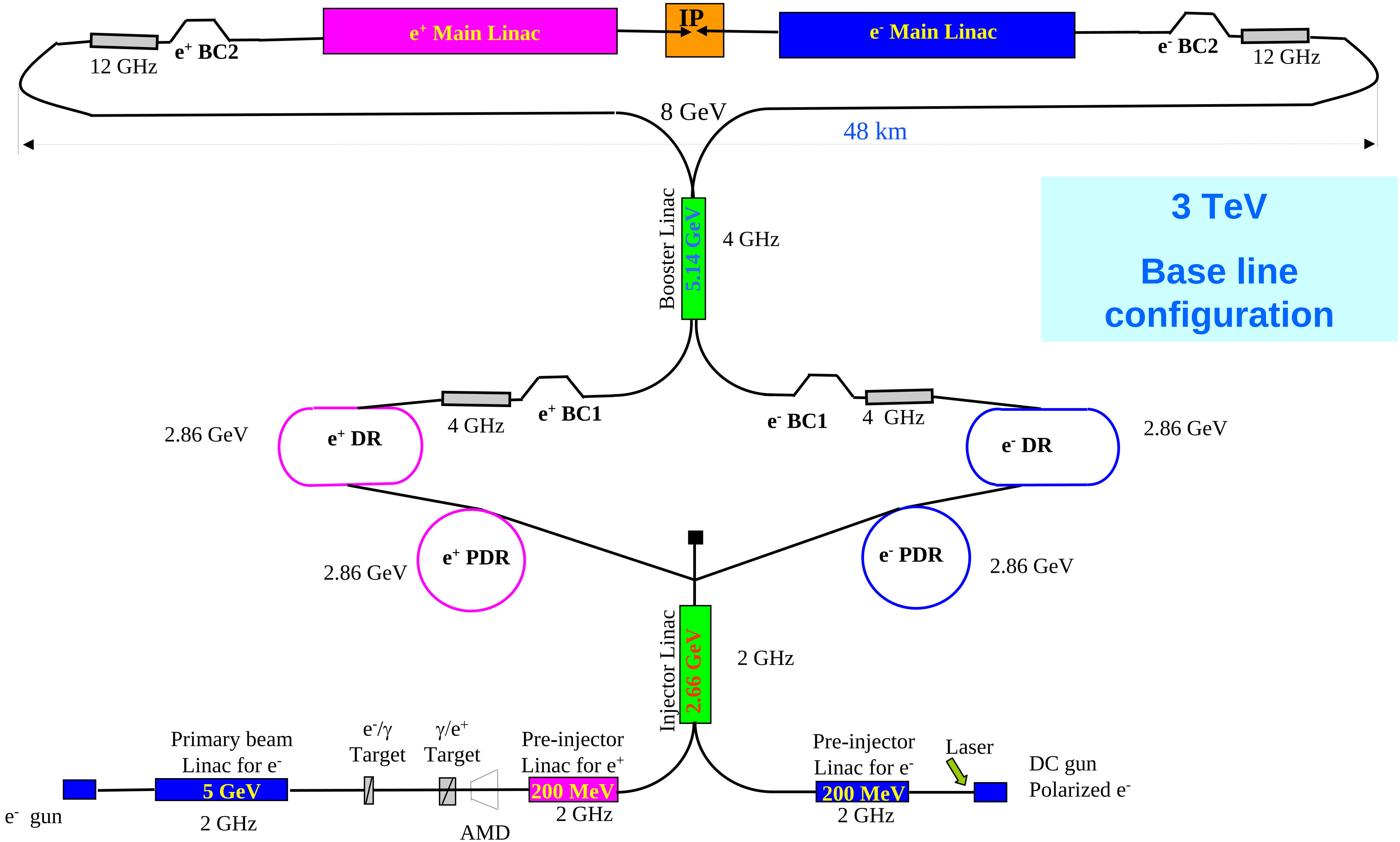
2) Low energy configuration:

500 GeV (c.m.) - double charge per bunch => 'relaxed' emittance's

3) Polarized positron option:

3 TeV (c.m.) - polarized e^+ source – Compton scheme
Undulator alternative option

CLIC Main Beam Injector Complex in 2009



CLIC Main Beam nominal parameters

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

		NLC (1 TeV)	CLIC (3 TeV)	CLIC (0.5 TeV)	ILC (0.5 TeV)
E	GeV	8	8	8	15
N	10^9	7.5	3.72	6.8	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

Concept: single high voltage DC photo injector

No detailed design so far

Try to understand better the limitations of the approach with the help of collaborations (SLAC, Jefferson Lab)

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 ps	500 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%

Alternative schemes: 1 GHz acceleration + delay loop or combination in pre-damping ring

CLIC Electron Beam Demo

Proposal by J. Sheppard/SLAC

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.

Formal CERN/SLAC collaboration under discussion for this topic

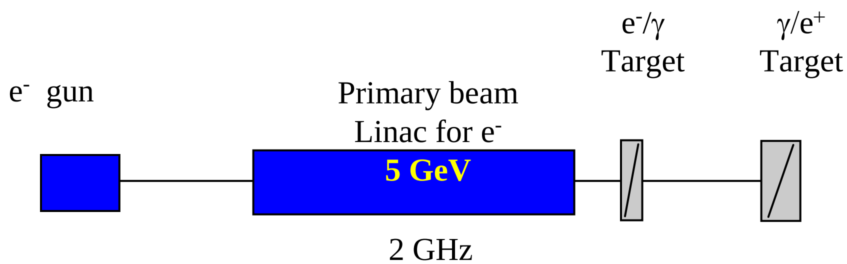
Generation of unpolarized positron

Concept: 5 GeV electrons converted by a hybrid target

Detailed simulations of the positron production and capture

(collaboration with LAL, KEK)

Primary electron beam

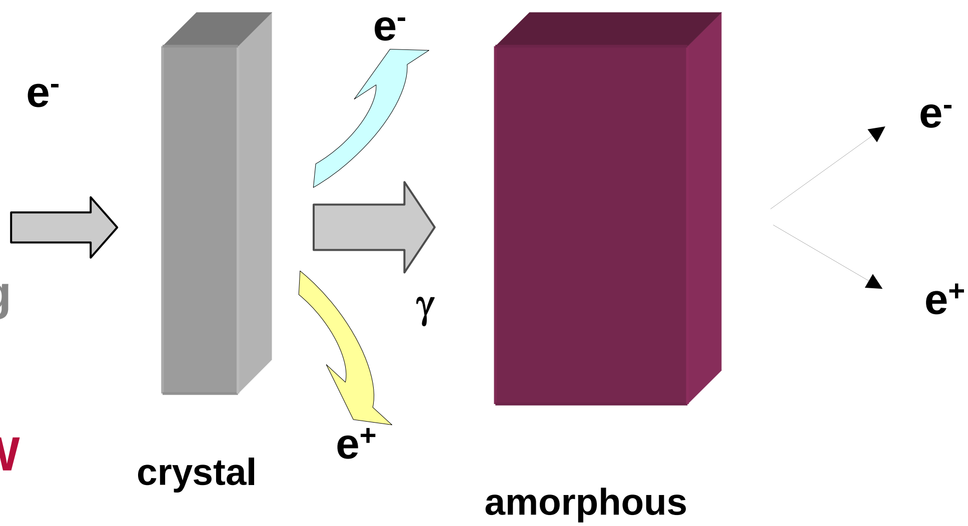


Parameter	Unit	
Primary e^- Beam		
Energy	GeV	5
N e^- /bunch	10^9	7.5
N bunches / pulse	-	312
N e^- / pulse	10^{12}	2.34
Pulse length	ns	156
Repetition frequency	Hz	50
Beam power	kW	94
Beam radius (rms)	mm	2.5
Bunch length (rms)	mm	0.3

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



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

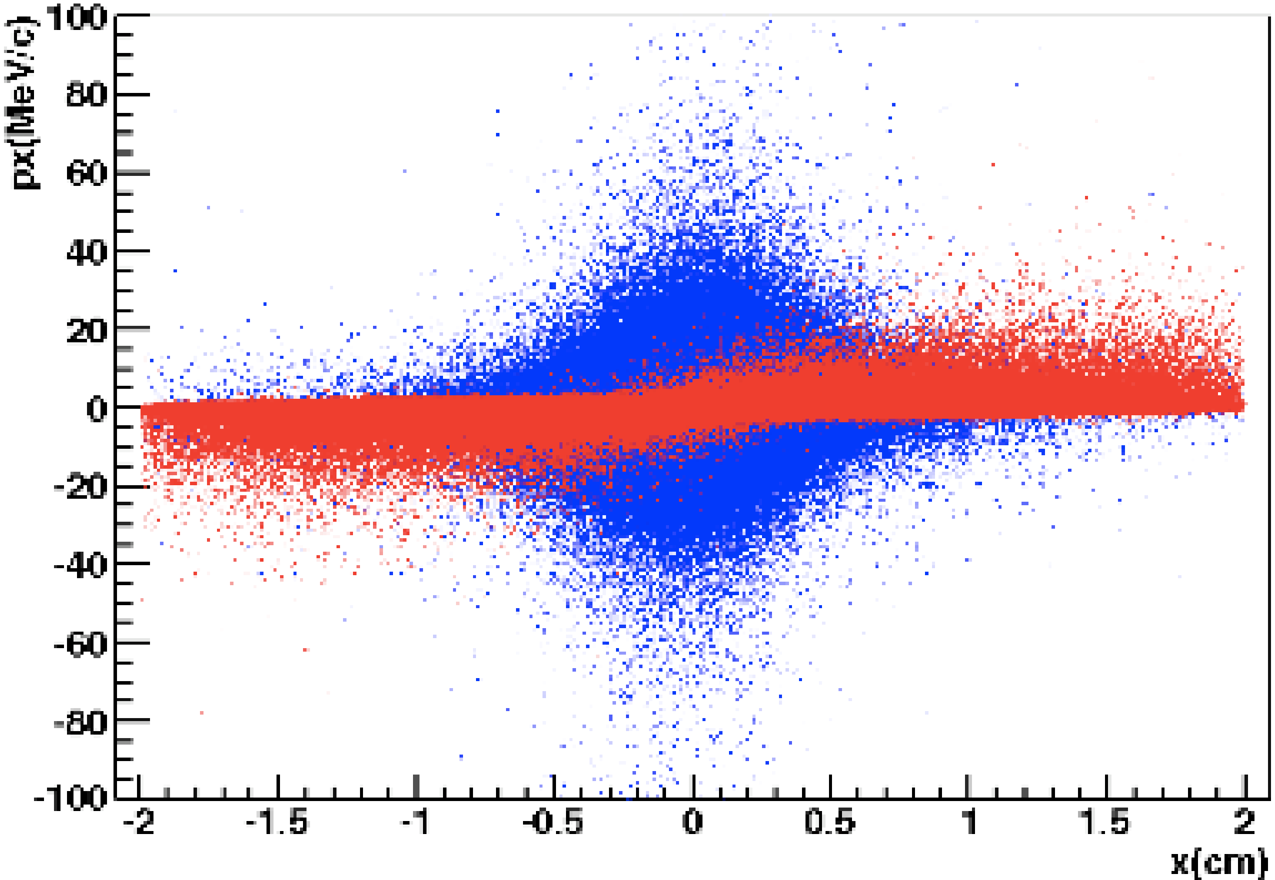
Charged particles are swept off after the crystal: only γ (> 2MeV) impinge on the amorphous target.

The distance between the two targets is 3 meters

Collaboration with LAL

Results just downstream the e^+ target

O. Dadoun / LAL



Blue: after the target

Red: after the AMD (*)

Yield = 2.1 e^+ / e^-

Max energy = 1.9×10^9 GeV / mm^3

Peak Energy Density Deposition

PEDD = 15.5 J/g

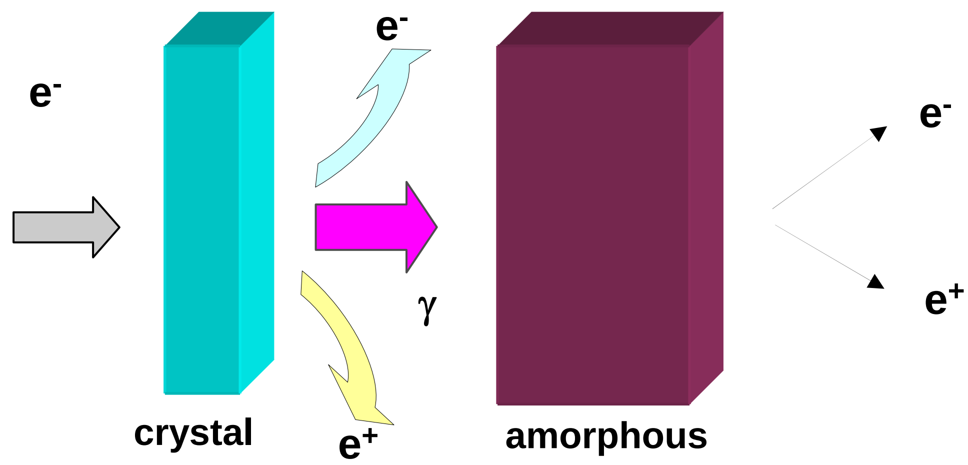
(*) AMD = Adiabatic Matching Device:

B_0 = 6 T, L = 50 cm, α = 22m^{-1}

$$B = \frac{B_0}{1+\alpha z}$$

Experimental limit found at SLAC:
with a PEDD $\geq$ 35 J/g
=> target does not survive

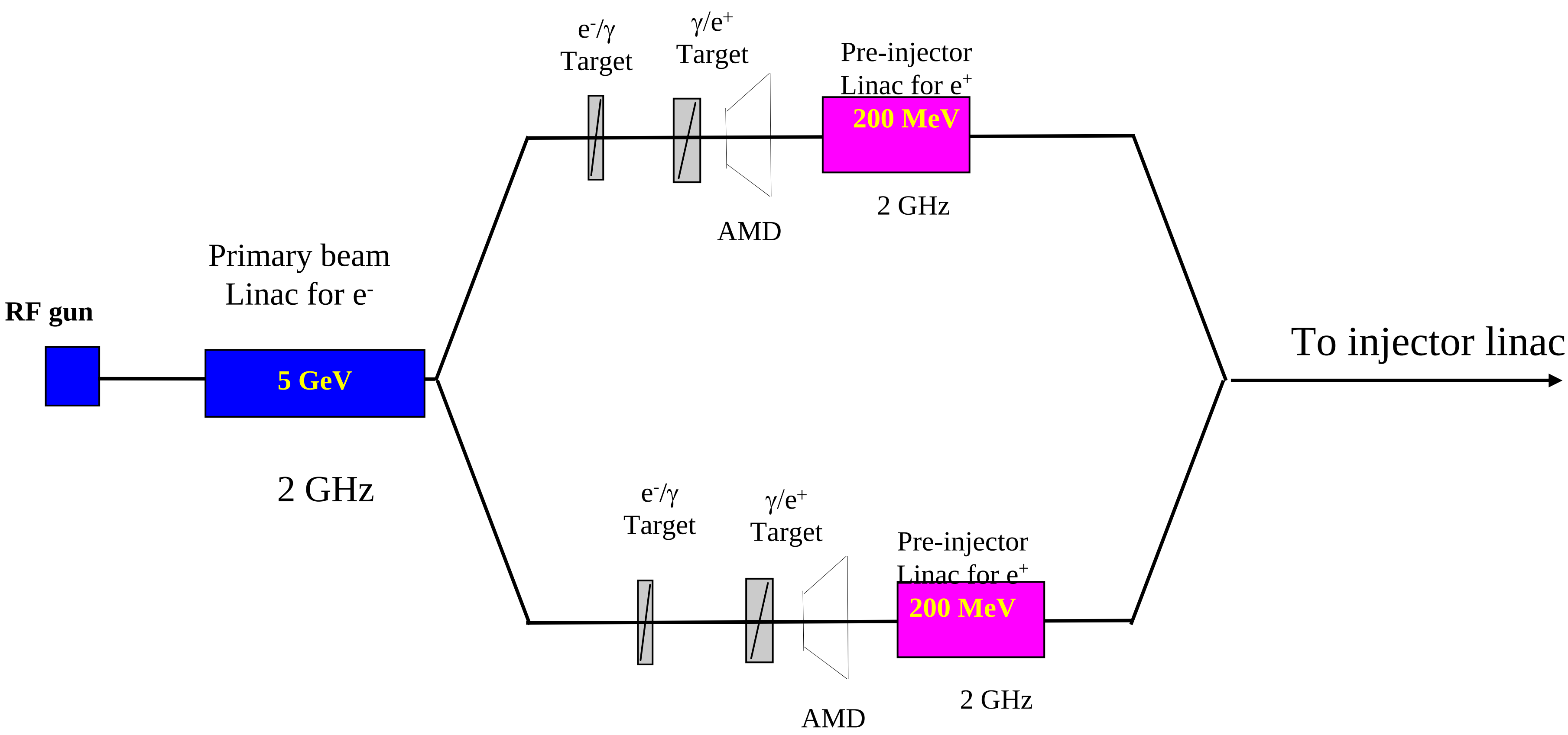
Beam power and PEDD



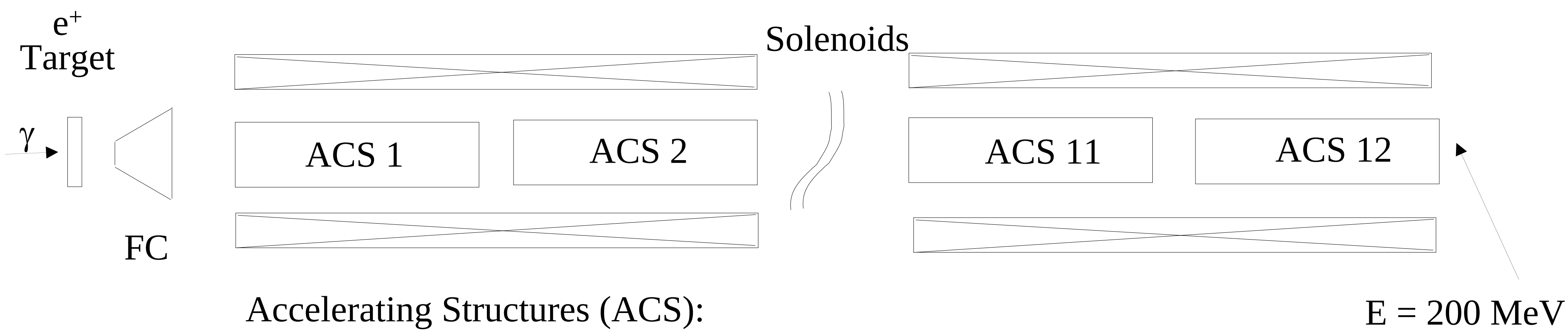
Parameter	Unit		
Target		Crystal	Amorphous
Material		W	W
Length	mm	1.4	10
Beam power deposited	kW	0.2	7.5
Deposited P / Beam Power	%	0.2	8
Energy lost per volume	10^9 GeV/mm^3	0.8	1.9
Peak energy deposition density (PEDD)	J/g	6.8	15.5

e^+ source for CLIC 500 GeV

Double charge / bunch => Double PEDD => ≈ breakdown limit => Double target station



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

Yield: 0.9 e^+ / e^-
@ 200 MeV

Estimation of transport efficiency for e^+ beam

	# of bunches per pulse	# of positrons per bunch	# of positrons per pulse	Total charge (nC)	Current (A)
Exit of BC2 = Entrance of Main Linac (9 GeV)	312	4×10^9	1.24×10^{12}	200	1.3
At exit Pre- Damping ring (2.424 GeV)	312	4.4×10^9	1.37×10^{12}	220	1.4
At exit Injector Linac (2.424 GeV)	312	6.4×10^9	2×10^{12}	319	2
At exit Pre- Injector Linac (200 MeV)	312	6.7×10^9	2.1×10^{12}	334	2.1

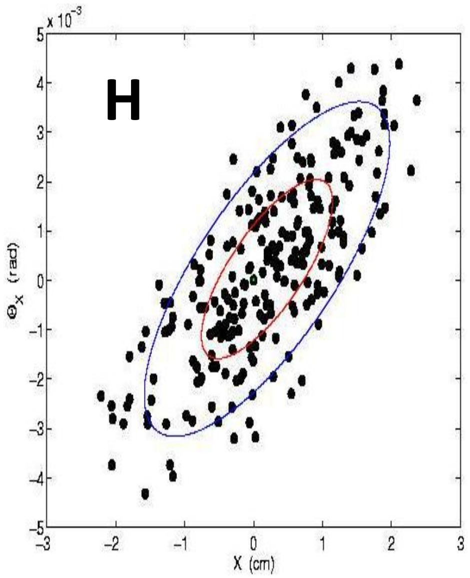
Assuming ~ 90 % efficiency between the PDR and the Main Linac

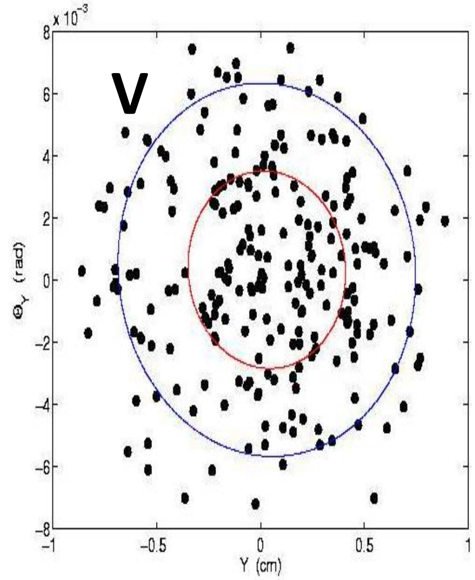
Assuming ~ 70 % capture efficiency in the PDR => **this efficiency would be improved**

Assuming ~ 95 % efficiency between the Pre-Injector and the Injector Linac

Simulations e^+ source based on channeling

- **TRANSVERSE EMITTANCES AT END OF CLIC PRE-INJECTOR ($\sigma^- = 2.5$ mm)**



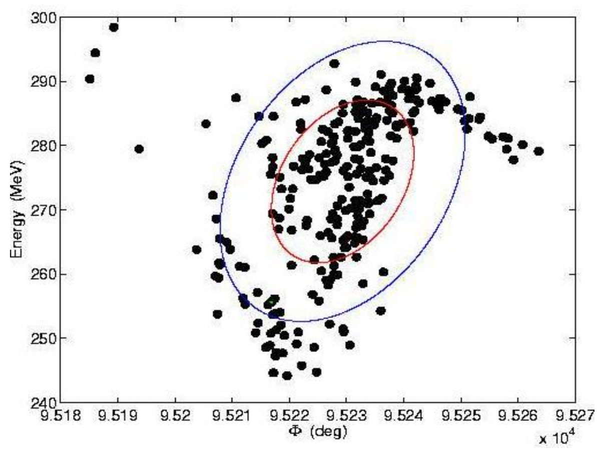


Blue: 80 %
Red: rms

$\varepsilon_x = \varepsilon_y$ = **17π mm.mrad**

$\gamma\varepsilon_x = \gamma\varepsilon_y$ = **6650 π mm.mrad**

- **LONGITUDINAL EMITTANCE AT END OF CLIC PRE-INJECTOR @ 200 MeV**



Blue: 80 %

Red: rms
ε_z =13.6 cm.MeV = 136000 eV.m

Injector Linac output parameters

Pre-Damping ring input

rms values

Parameter	Unit	**e** $^{-}$	**e** $^{+}$
Energy (E)	GeV	2.424	2.424
No. of particles/bunch (N)	10^9	4.4	6.4
Bunch length (rms) (σ_z)	mm	1	5
Energy Spread (rms) (σ_E)	%	0.1	2.7 (*)
Horizontal emittance ($\gamma\varepsilon_x$)	mm. mrad	100	9300
Vertical emittance ($\gamma\varepsilon_y$)	mm. mrad	100	9300

(*) Simulations have been performed with a bunch compressor at the entrance of the Injector Linac which brings the bunch length from 5 mm down to 2mm:

=> The rms energy spread, at 2.4 GeV, is just below 1% (see CLIC Note 737)

CLIC Pre-Damping Ring for the Base line

F. Antoniou / CERN

PARAMETER	PDR
Eenergy [GeV]	2.424
Circumference [m]	252
Number of particles / bunch [10^9]	4.4
Number of trains	1
FWHH momentum spread [%] accepted at injection	3 % (~ 1.3 % rms) (*)
Hor. /ver. / lon./ damping times [ms]	2.5 / 2.5 / 1.2 (**)
Repetition rate [ms]	20
RF frequency [GHz]	2

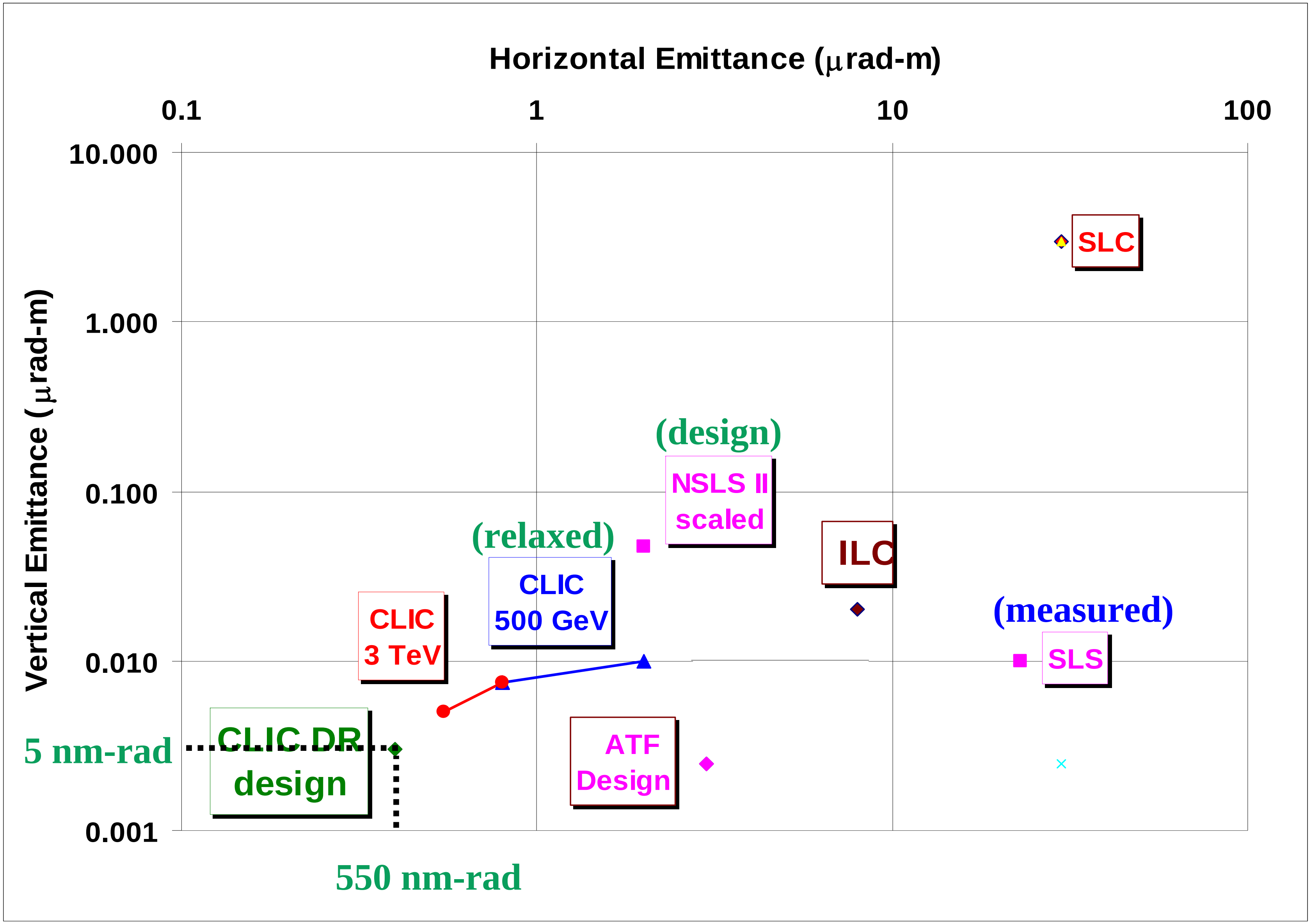
(*) The rms momentum spread at injection could be reduced (~ 1%) by implementing either a bunch compressor at the entrance of the injector Linac (see previous slide) or an harmonic cavity which smooth the longitudinal distribution.

(**) With 6 damping times the injected normalized emittances are reduced from:

$\gamma\varepsilon$ = 9300 mm.mrad down to $\gamma\varepsilon$ = 18 mm.mrad

Beam emittances at Damping Rings

J.P. Delahaye / CERN



CLIC Damping Rings emittances

Y. Papaphilippou / CERN

PARAMETER	**NLC**	**CLIC** requested (obtained by design)
Energy (GeV)	1.98	2.424
Bunch population (10^9)	7.5	4.1
Bunch spacing [ns]	1.4	0.5
Number of bunches / train	192	312
Number of trains	3	1
Repetition rate [Hz]	120	50
Extracted hor. normalized emittance [nm]	2370	<550 (382)
Extracted ver. normalized emittance [nm]	<30	<5 (4)
Extracted long. normalized emittance [eV m]	10890	<5000 (4990)

For 500 GeV option, the nominal requested rms normalized emittances are:

$\gamma\varepsilon_x$ = 2400 nm-rad and $\gamma\varepsilon_y$ = 10 nm-rad

Collective effects issues

1) Pre-Damping Rings and Damping Rings

- Space Charge

  => important emittance growth

- Single bunch instability thresholds
- Resistive wall coupled bunch instabilities
- Electron cloud (Positron rings)

  => constraints on the wigglers

  => special vacuum chamber coating

- Fast Beam Ion Instability (Electron rings)

  => vacuum < 1 nTorr

- Intra Beam Scattering (IBS)

  => crucial effects on emittances

2) Transfer Lines

- Fast Beam Ion Instabilities

  => vacuum 0.1 nTorr

- CSR in Bunch Compressors
- ISR in turn around loop

The two stages of the 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)	4.1	4.1	4.1	3.9	3.9
Bunch length (rms) (mm)	1.5	1.5	0.175	0.175	0.044
Energy Spread (rms) (%)	0.137	0.137	1.17	0.316	1.26
Longitud. emitt. (eV.m)	< 5000	< 5000	< 5000	< 5000	< 5000
BC factor	-	8.6		4	
RF frequency	-	4 GHz		12 GHz	
Gradient (Loaded)	-	14 MV/m		39 MV/m	
Structure length		4 m		1 m	
RF voltage	-	224 MV (4 ACS)		2480 MV (64 ACS)	
Length of linac	-	16 m		64 m	
Length of chicane	-	30 m		40 m	
Total length	-	~ 50 m		~ 110 m	

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, in parallel with an important R&D program, 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; for the positrons, it would require a double target stations under the present conditions.

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

Booster Linac output parameters

Beginning of the long transfer line

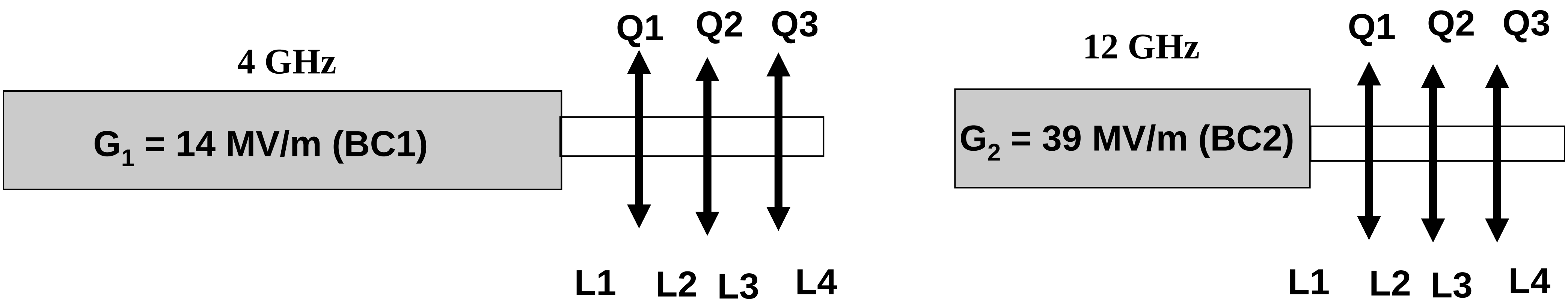
rms values

Parameter	Unit	**e^- / e^+**
Energy (E)	GeV	9
No. of particles/bunch (N)	10^9	4
Bunch length (rms) (σ_z)	mm	0.173
Energy Spread (rms) (σ_E)	%	0.32
Horizontal emittance ($\gamma\varepsilon_x$)	nm. rad	380
Vertical emittance ($\gamma\varepsilon_y$)	nm. rad	4.1

Wakefield effects should be investigated carefully in particular for the 500 GeV parameters

BC1 and BC2 for the energy-time correlation

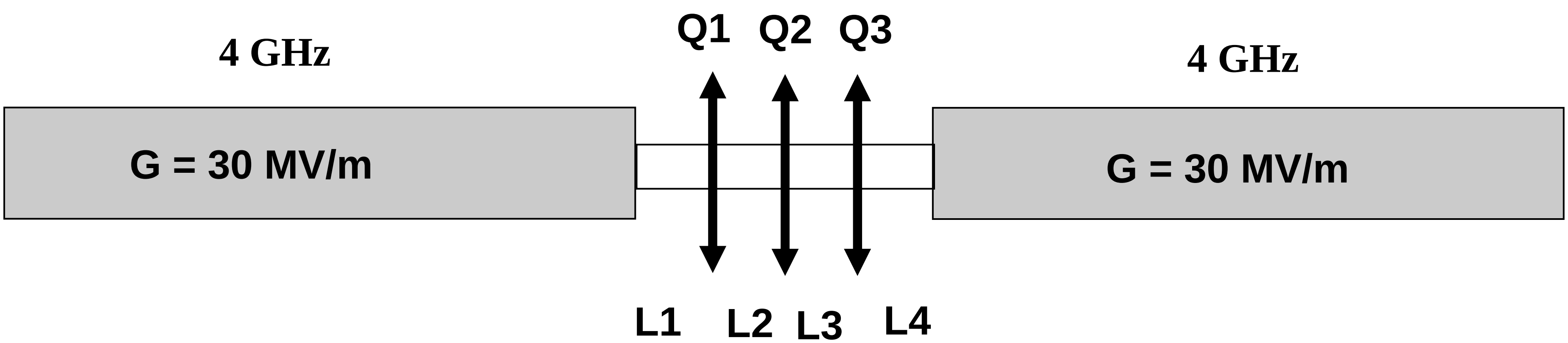
Triplet for BC1	
Number of Accelerating sections (L= 4 m)	4
Number of quadrupoles between accelerating sections (Quad length = 36 cm)	4 x 3 = 12



Triplet for BC2	
Number of Accelerating sections (L= 1 m)	64
Number of quadrupoles between accelerating sections (Quad length = 36 cm)	64 x 4 = 256

CLIC Booster Linac optics parameters

Triplet	
Number of Accelerating sections (L= 3 m)	75
Number of quadrupoless between accelerating sections (Quad length = 36 cm)	75 x 3 = 225



$Q1 = Q3 = 0.19\ m^{-2}$

$Q2 = 0.37\ m^{-2}$

$L1 = L2 = L3 = L4 = 0.60\ m$

Ring To Main Linac (RTML)

Emittances requested @ DR output	Unit	**e^- / e^+**	**Emittance budget $\Delta\varepsilon$ (nm.rad)**
Horiz. emittance ($\gamma\varepsilon_x$)	nm. rad	550	**$\Delta\varepsilon$** = 50 no design solution today
Verti. emittance ($\gamma\varepsilon_y$)	nm. rad	5	**$\Delta\varepsilon$** = 5 under evaluation
Emittances obtained @ DR output			
Horizontal emittance ($\gamma\varepsilon_x$)	nm. rad	382	**$\Delta\varepsilon$** = 218 design solution exists today
Vertical emittance ($\gamma\varepsilon_y$)	nm. rad	4	**$\Delta\varepsilon$** = 6 under evaluation

Collaborations

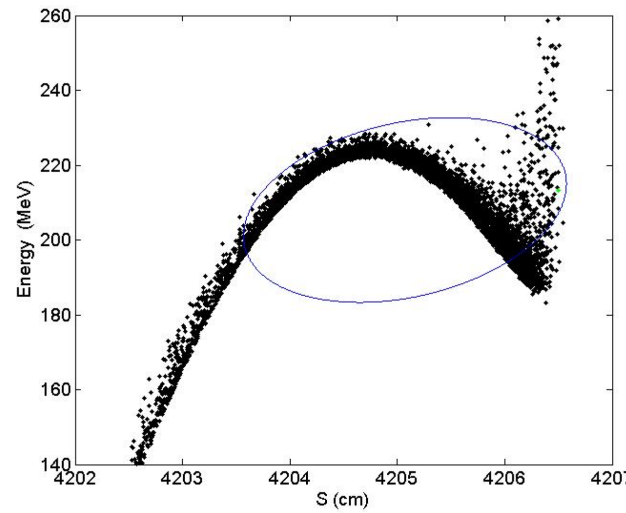
Countries	Institutes	Contact person	Subject	Status	Date
France	LAL	A. Variola	e+ studies	Formal agreement	September 2008
Germany	FZR Rossendorf	J. Teichert	Compton sources	In preparation	November 2008
Japan	KEK	T. Omori	e+ studies	Informal agreement	October 2007
Japan	KEK	J. Urakawa	R&D on targets systems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

Pre-Injector Linac

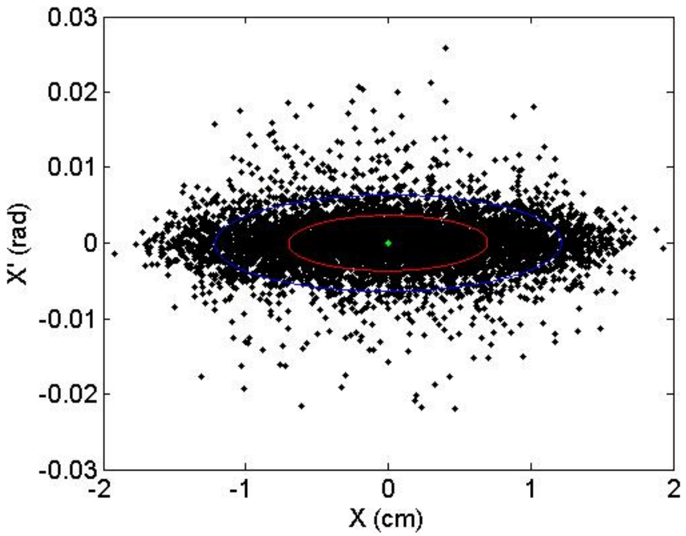
Positron parameters

Parameter	Unit	CLIC 2009 (A. Vivoli)
		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

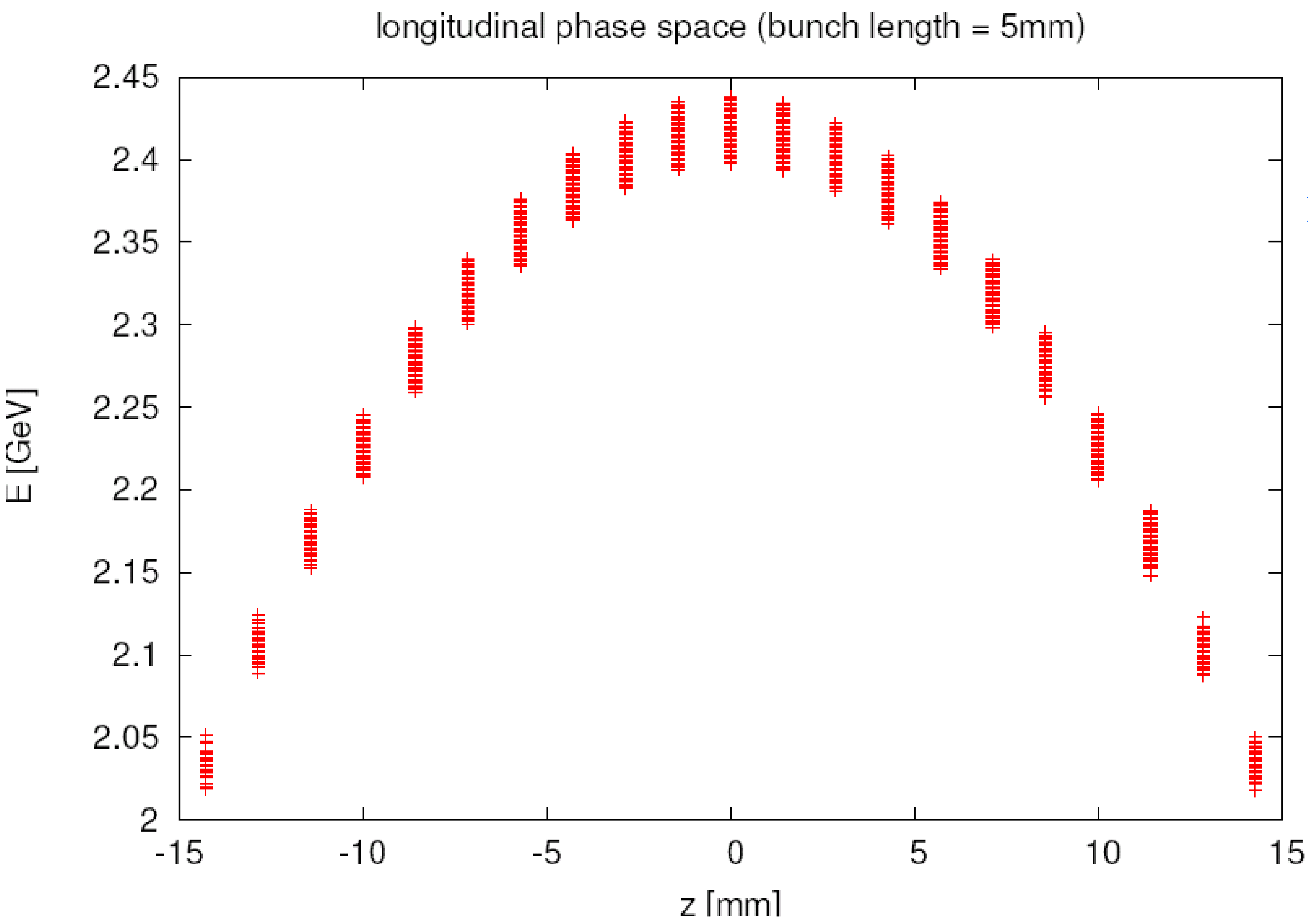
Longitudinal



Transversal



Beam dynamics simulations in Injector Linac

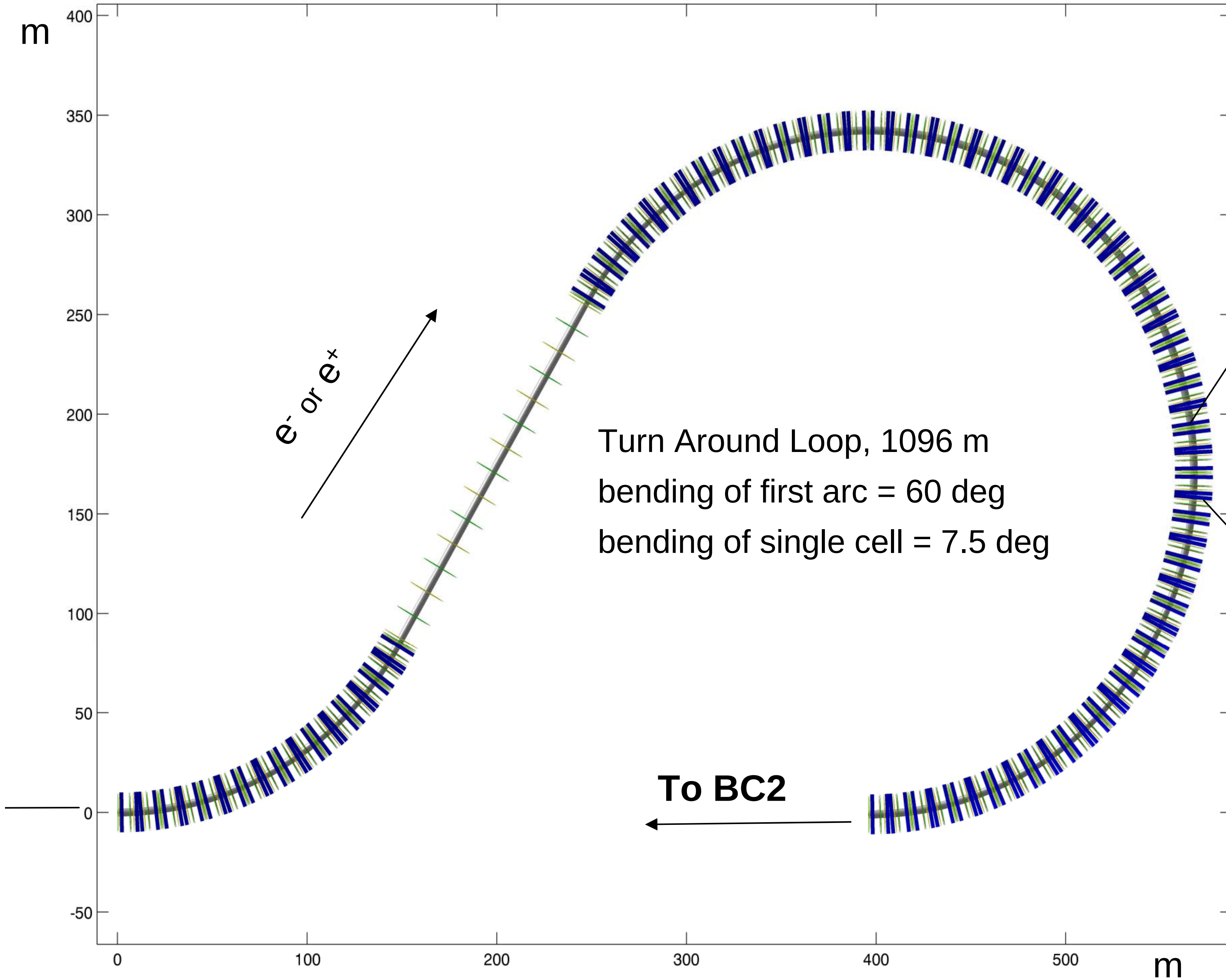


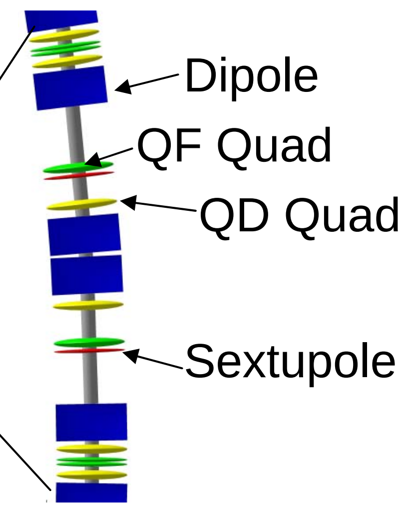
Bunch length (rms) = 5 mm

Energy spread (rms) = 65 MeV

Turn Around Loop

F. Stulle / CERN





Main issues:

- ISR => ε growth
- Polarization