Charge Limit and Its Impacts on LC e-Source Designs

Axel Brachmann, John Sheppard, and Feng Zhou

SLAC

ICFA Mini-workshop on Novel Concepts for Linear Accelerator and Colliders, SLAC, July 8-10, 2009

Major parameters of LC e- sources

Parameters	**ILC** [1]	**CLIC** [2]
Electrons/microbunch (@cathode)	4.8nC	0.96nC
Number of microbunches (@cathode)	2625	312
Width of Microbunch (@cathode)	1.3 ns	100 ps
Time between microbunches (@cathode)	~360 ns	500.2 ps
Width of Macropulse	1 ms	156 ns
Macropulse repetition rate	5 Hz	50 Hz
Charge per macropulse	12600 nC	300 nC
Average current from gun	63 μA	15 μA
Peak current of microbunch	3.8 A	9.6 A
Current intensity (@1 cm radius)	1.2 A/cm^2	3.0 A/cm^2
Polarization	>80%	>80%

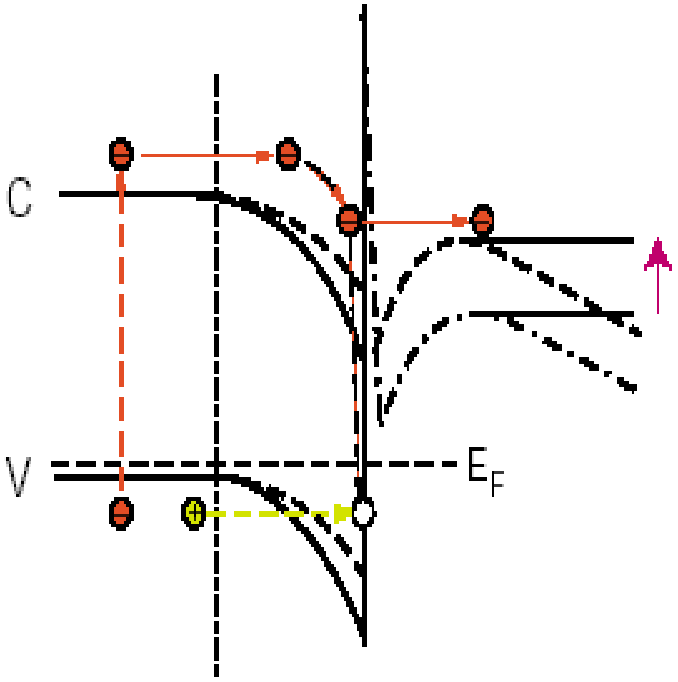
[1] ILC RDR, 2007.
[2] L. Rinolfi, CLIC workshop, CERN, 2007.

Cathode requirements for LC

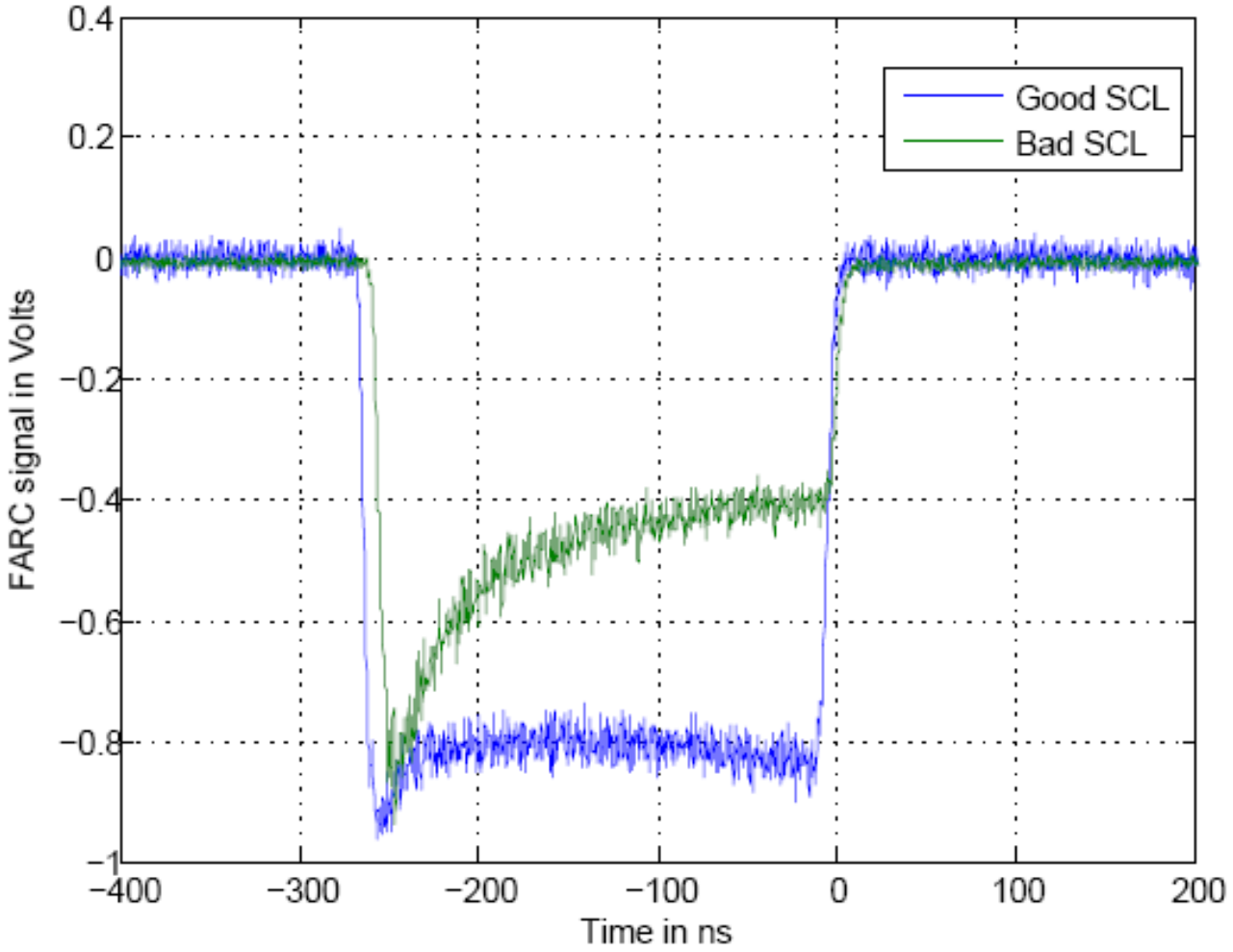
- Less charge limit (surface charge and space charge)
- High polarization
- High QE and QE lifetime

Surface photovoltaic effect: surface charge limit @GaAs/GaAsP

- Photon absorption excites electrons to conduction band
- Electrons can be trapped near the surface
- Electrostatic potential from trapped electrons raised affinity.
- Increased affinity decreases emission probability.



Good vs bad surface charge limit: observed at SLAC's GTF



Feng Zhou/SLAC

Surface charge limit at LC injectors

- ILC: individual 1.3ns microbunch's surface charge limit probably ok but it may be accumulated along 1ms of 2625 microbunches.
  - The 1ms surface charge limit is not concluded until ILC beam is generated and measured at SLAC's GTF (ILC laser under developments at SLAC).

- CLIC injector parameters:
  - Space charge with CLIC original injector parameters (100ps microbunch with 1nC charge) is high and also surface charge limit with the parameters is needed to understand.
  - One better idea (Brachmann, Sheppard, and Zhou, 2009): DC beam (156ns/312nC) instead of 312 microbunches (100ps/1nC) on cathode: surface charge limit is in less problem and laser requirements are also loosed.

Space charge limit

- Space charge limit (Child law):

$$j_0 = \left(2.33\times10^{-6}\right)V_0^{3/2}/d^2$$

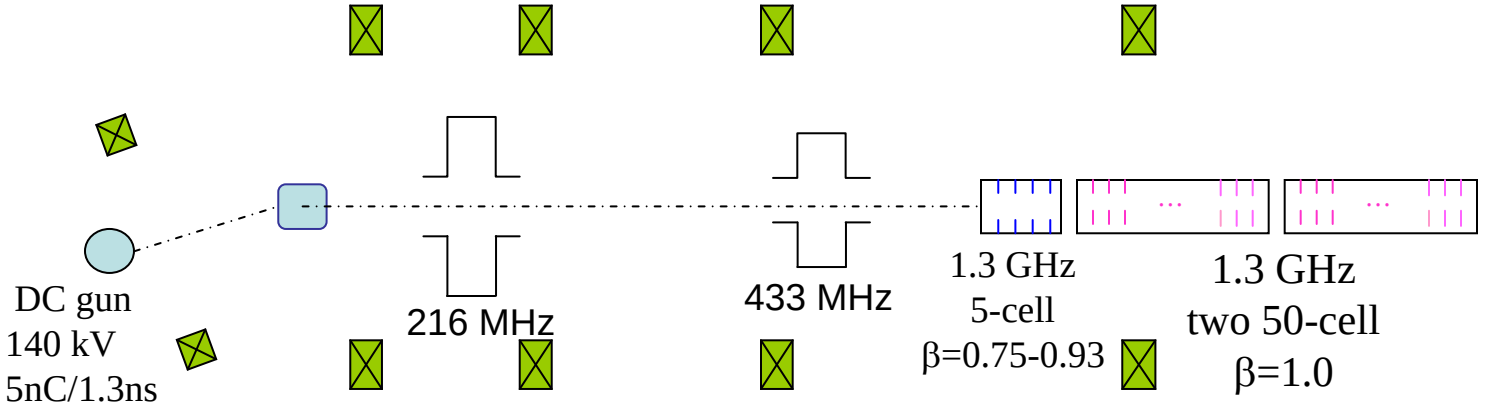
where j_0, V, d, E in A/cm², volts, cm, V/m

- Assume 140 kV and d=3cm, then j_0=14 A/cm².
- Current intensity at ILC and CLIC on cathode:
  - 1.2A/cm² of ILC assuming 4.8nC/1.3ns and 1cm radius
  - 3.0A/cm² of CLIC assuming 1nC/100ps and 1cm radius
  - 0.64A/cm² of CLIC assuming 312nC/156ns (DC beam) and 1cm radius

Parameters for LC injectors

- Given surface charge and space charge, time structures on the cathode:
  - ILC: 1.3 ns 2625 microbunches with 360 ns of micro-bunch separation to be bunched into 20ps 2625 microbunches .
  - CLIC: 156 ns DC beam to be bunched into 312 2-GHz 14ps microbunches at injector exit.
- Parameters on the cathode still need to be demonstrated: being studied at SLAC's GTF.
- Given the chosen parameters, ILC and CLIC injectors are designed and modeled.

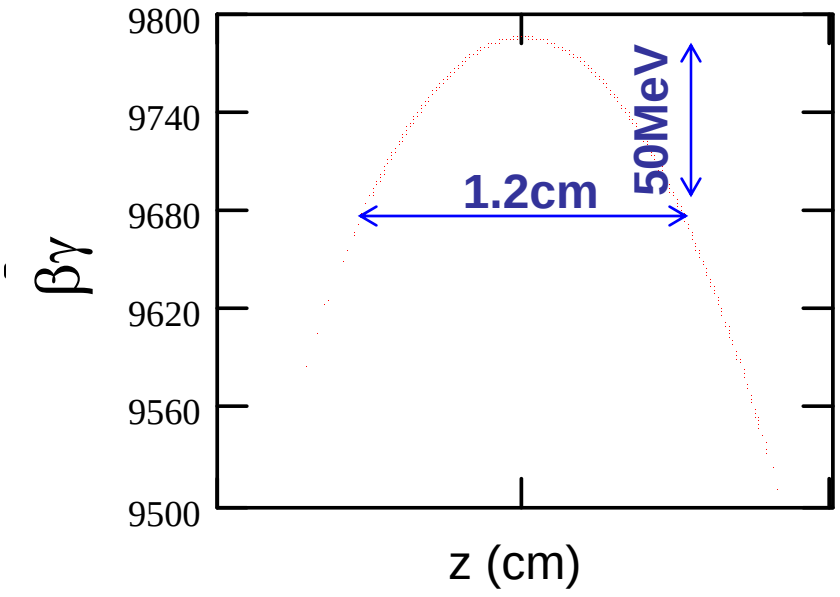
ILC: bunching system



- DC-gun: 140 kV, 1.3 ns
- SHBs with 216.7 and 433 MHz: bunch compressed down to 200 ps FWHM.
- One 5-cell tapered-β TW L-band buncher with 5.5 MV/m: bunch compressed down to 20 ps FWHM.
- Two 50-cell TW structures with 8.5 MV/m of gradient accelerate beam to 76 MeV.

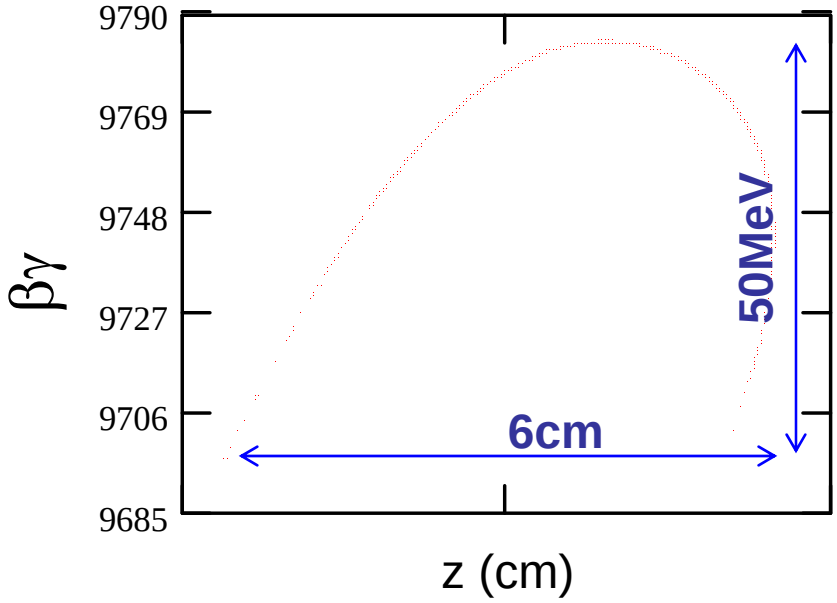
ILC: longitudinal phase spaces @ DR entrance (5 GeV)

w/o energy compression



88% of e- from the gun are captured

with energy compression

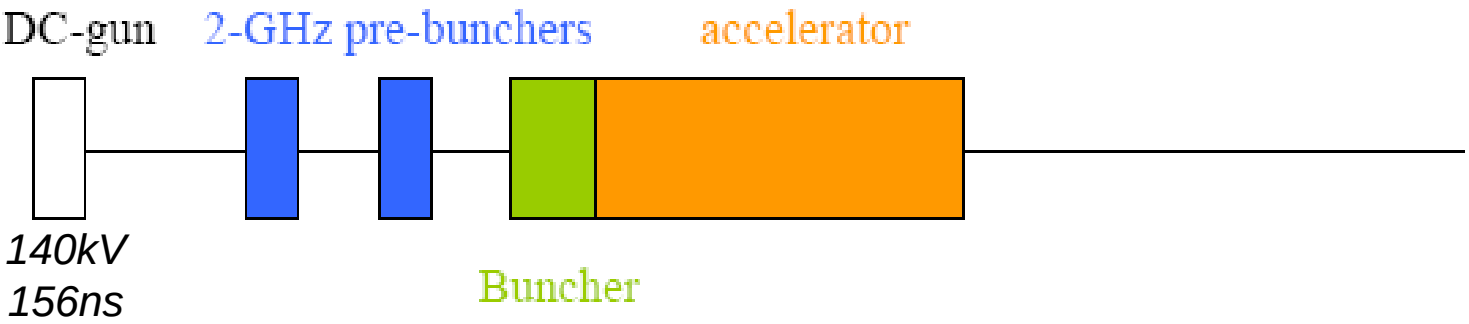


94% of e- from the gun are captured

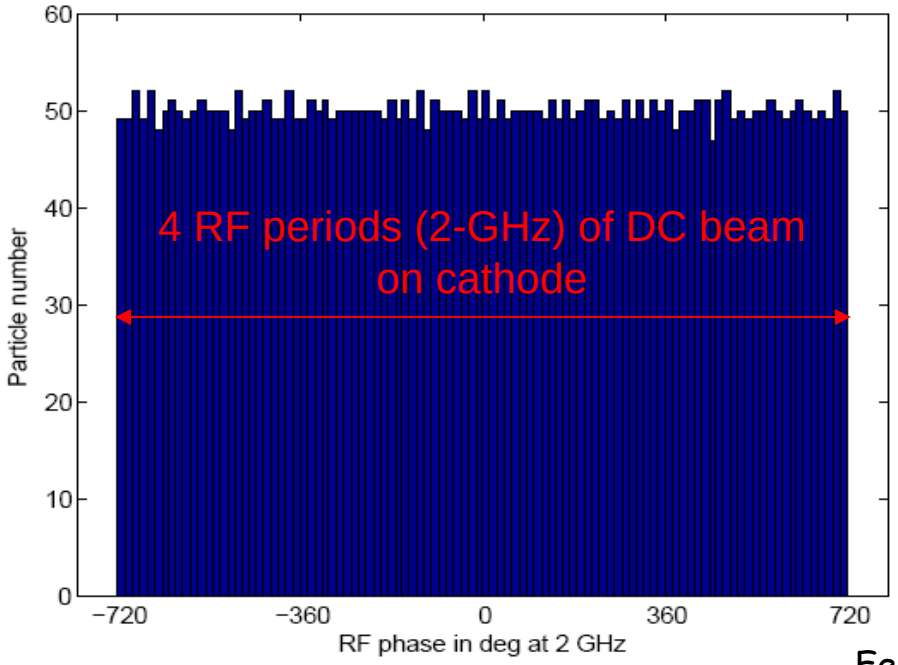
ILC: achieved parameters

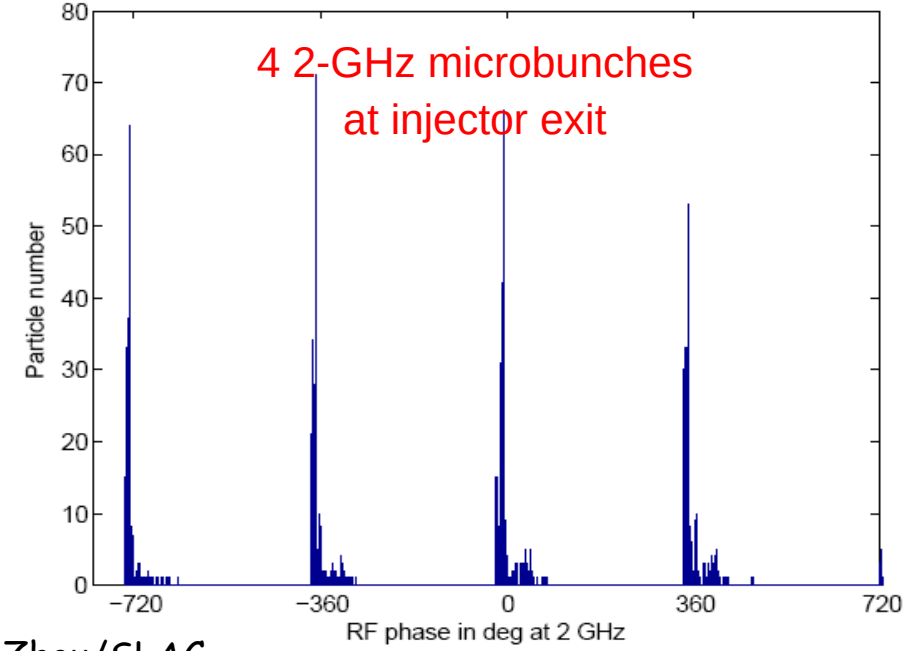
Gun voltage	140kV
Injector energy	76MeV
Initial charge at the gun	5.0nC
Capture efficiency within DR acceptance	
without energy compression	88%
with energy compression	94%
Initial bunch length on cathode	1.3ns
Final Bunch length FWHM (FW)	20ps (45 ps)
Energy spread FWHM (FW)	100keV (1.5MeV)
Norm. rms emittance at 76MeV	40μm

CLIC: bunching system



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





Feng Zhou/SLAC

CLIC: achieved parameters

Gun voltage Injector energy	140kV 19MeV
Charge required/microbunch @inj Efficiency from gun to injector exit Achieved charge/microbunch within a window ($\Delta z \times \Delta E$ = 50ps×0.45MeV)	~1nC 88% 1.32 nC
Initial DC beam length on cathode Final phase extension FWHM (FW) # of generated microbunches at injector exit	156ns 14ps (50ps) 312
Final energy spread FWHM (FW)	100keV (1MeV)
Norm. rms emittance at injector exit	22μm

Summary

- Polarized cathode's charge limit (surface charge and space charge) impacts the choices of LC e- source parameters:
  - ILC charge limit not concluded until it is demonstrated at SLAC's GTF.
  - CLIC charge limit is probably an issue if to adopt 312 100ps microbunches on the cathode
  - CLIC charge limit should be better if to adopt 156ns DC beam on the cathode, which will be tested at SLAC's GTF.
- Given the chosen time structures, both ILC and CLIC injectors are designed. Good 6-D phase spaces are achieved.

E-source parameters	ILC	CLIC (original)	CLIC (SLAC proposed)
Number of microbunches (@cath)	2625	312	1 DC beam
Electrons/(micro)bunch (@cath)	4.8nC	0.96nC	300nC
Capture efficiency (@inj)	~90%	-	88%
Number of microbunches (@inj)	2625	312	312
Width of (micro)bunch (@cath)	1.3 ns	~100 ps	156 ns DC
Width of microbunch (@inj)	20 ps	-	14 ps
Time between microbunches (cath)	360 ns	500.2 ps	-
Time between microbunches (@inj)	360 ns	500.2 ps	~500 ps
Width of Macropulse	1 ms	156 ns	156 ns
Macropulse repetition rate	5 Hz	50 Hz	50 Hz
Charge per macropulse	12600 C	300 nC	300 nC
Average current from gun	63 μA	15 μA	15 μA
Peak current of (micro)bunch@cath	3.8 A	9.6 A	1.9 A
Current intensity (@1cm radius)	1.2 A/cm^2	3.0 A/cm^2	0.64 A/cm^2
Polarization	>80%	>80%	>80%

Feng Zhou/SLAC

Thanks Jym Clendenin and Takashi Maruyama
for very helpful discussions.