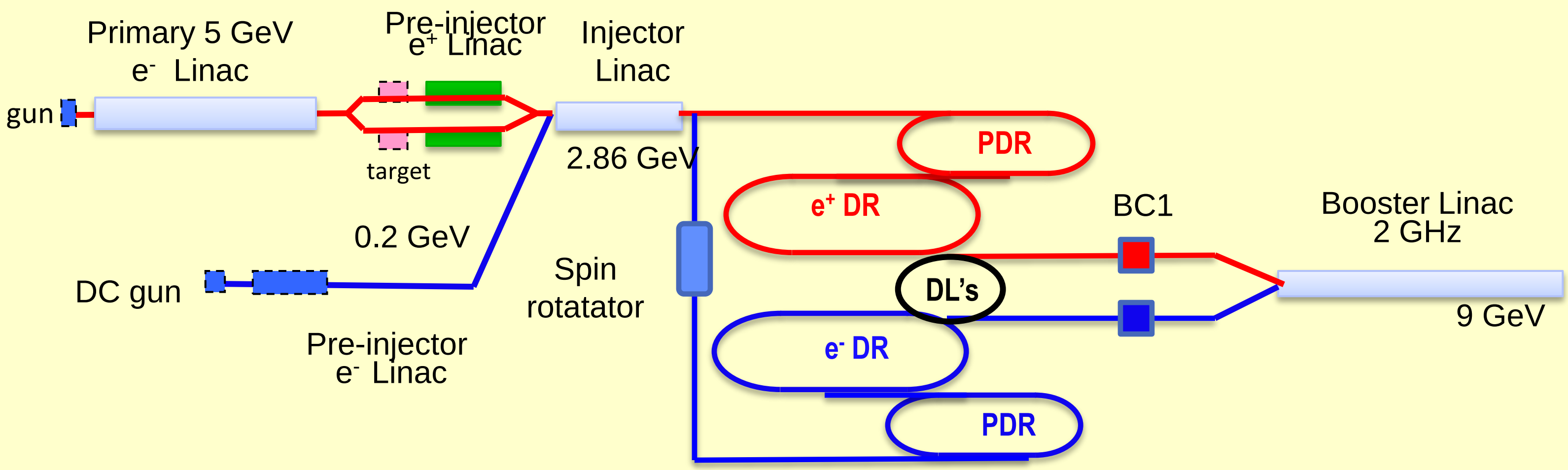
Status of the CLIC main beam injectors

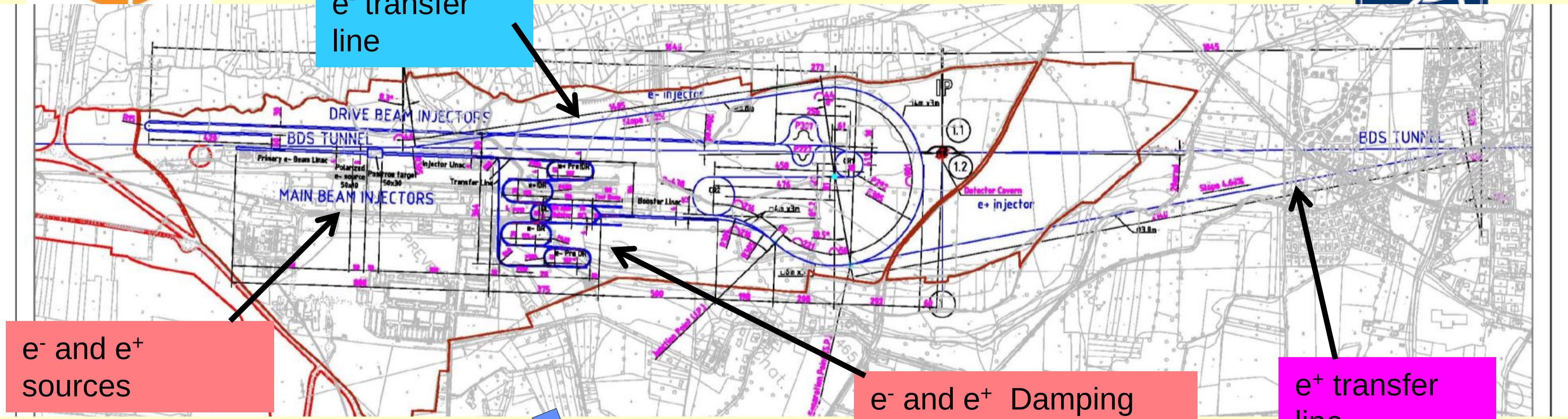
Overview of the CLIC main beam injectors complex as documented in the CDR

Layout

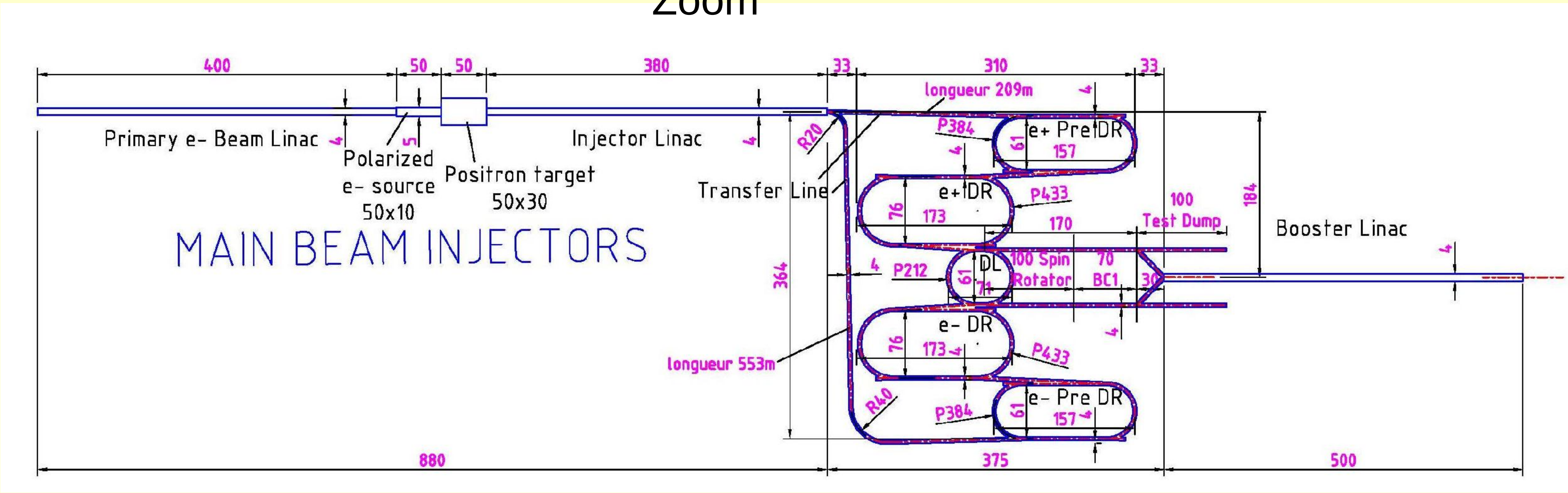


- Two hybrid positron sources (only one needed for 3 TeV)
- Common injector linac
- All linac at 2 GHz , bunch spacing 1 GHz before the damping rings

CLIC Main Beam complex



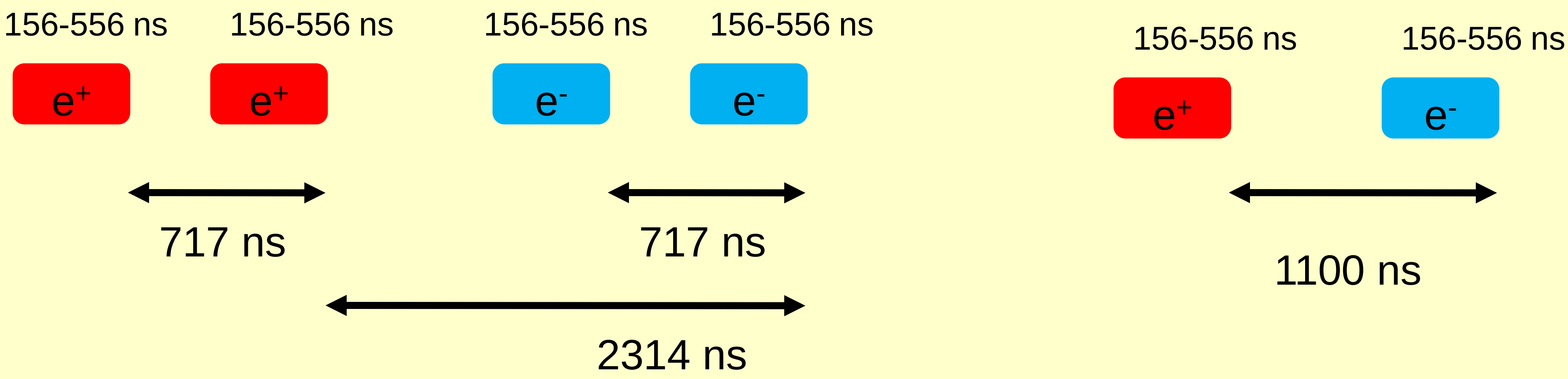
Zoom



Beam timing and operational modes

Before damping ring
(1 GHz bunch spacing)

After damping ring
(2 GHz bunch spacing)



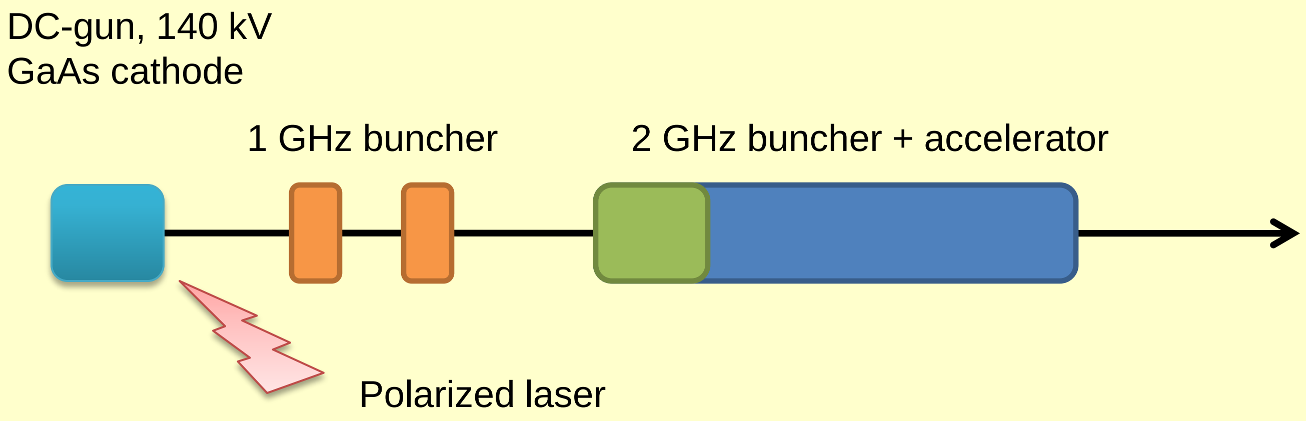
Operational mode	Charge per bunch (nC)	Number of bunches
Nominal	0.6	312
500 GeV	1.2	312
Low energy scans	0.6, 0.45, 0.4, 0.3, 0.23	312, 472, 552, 792, 1112

Beam parameters

Parameter	Unit	CLIC polarized electrons	CLIC positrons	CLIC booster
E	GeV	2.86	2.86	9
N	10^9	4.3	4.3	3.75
n_b	-	312	312	312
Δt_b	ns	1	1	0.5
t_{pulse}	ns	312	312	156
$\varepsilon_{x,y}$	μm	< 100	7071, 7577	$600,10 \cdot 10^{-3}$
σ_z	mm	< 4	3.3	$44 \cdot 10^{-3}$
σ_E	%	< 1	1.63	1.7
Charge stability shot-to-shot	%	0.1	0.1	0.1
Charge stability flatness on flat top	%	0.1	0.1	0.1
f_{rep}	Hz	50	50	50
P	kW	29	29	85

Polarized electron source

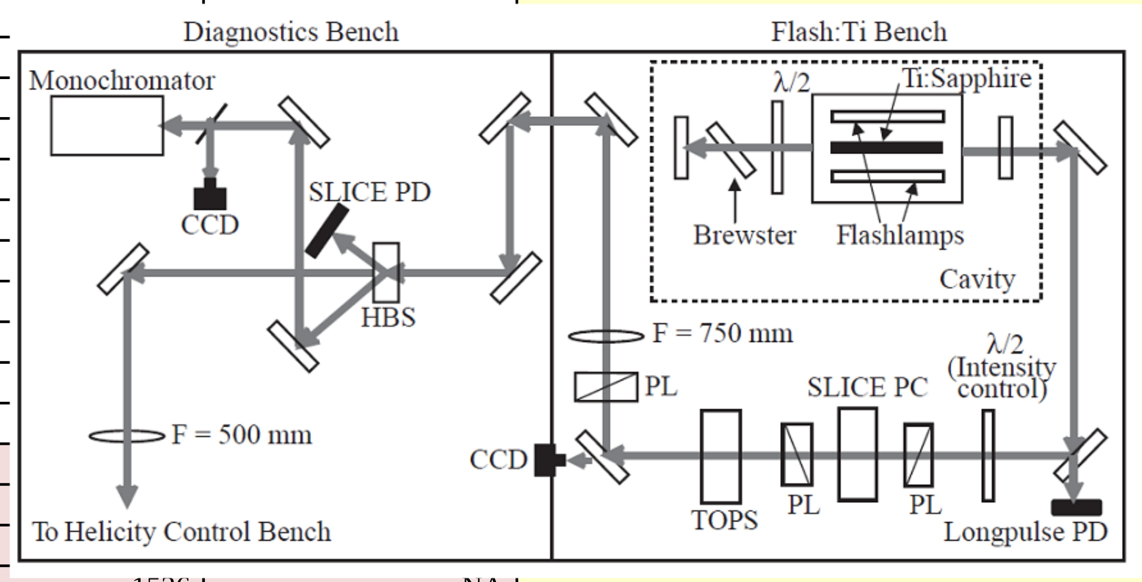
- Classical polarized source wit bunching system
- Charge production demonstrated by SLAC experiment
- Simulations showed 87 % capture efficiency (F. Zou, SLAC)



Polarized electron source parameters

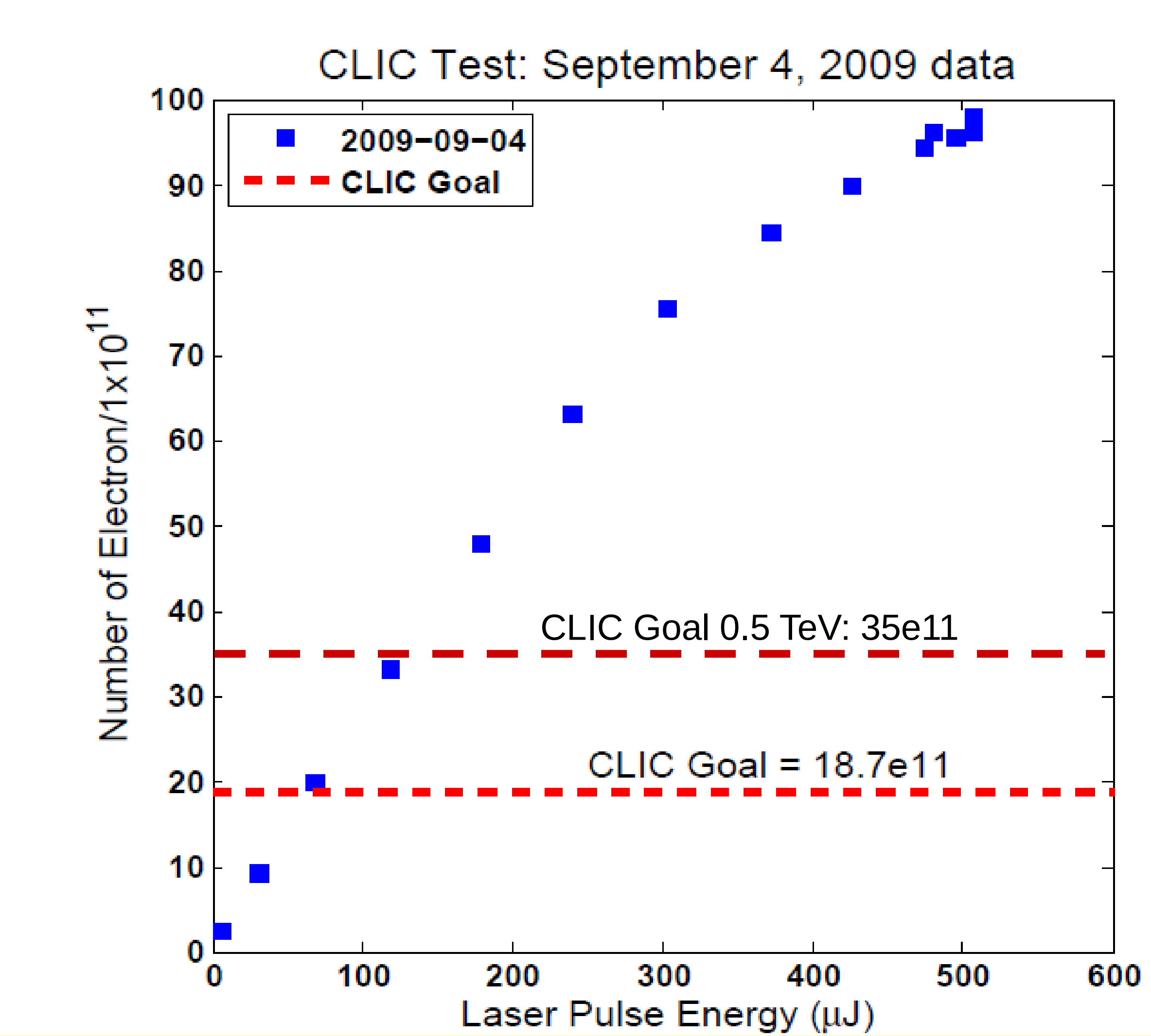
Laser scheme

POLARIZED SOURCE FOR CLIC		CLIC 1 GHz	CLIC DC/ SLAC Demo
Number of electrons per bunch (*10^9)	Electrons		
Charge/single bunch (nC)	Electrons		
Charge/macrobunch (nC)	Electrons		
Bunch spacing(ns)	Electrons		
RF frequeny (GHz)	Electrons		
Bunch length at cathode (ps)	Electrons		
Number of bunches	Electrons		
Repetition rate (Hz)	Electrons		
QE(%)	Electrons		
Polarization	Electrons		
Circular polarization	Electrons		
Laser wavelength (nm)	Laser		
Energy/micropulse on cathode (nJ)	Laser		
Energy/macropulse on cathode (μJ)	Laser		
Energy/micropulse laser room (nJ)	Laser	1526	NA
Energy/macrop. Laser room (μJ)	Laser	476	633
Mean power per pulse (kW)	Laser	1.5	2
Average power at cathode wavelength(mW)	Laser	8	9.5



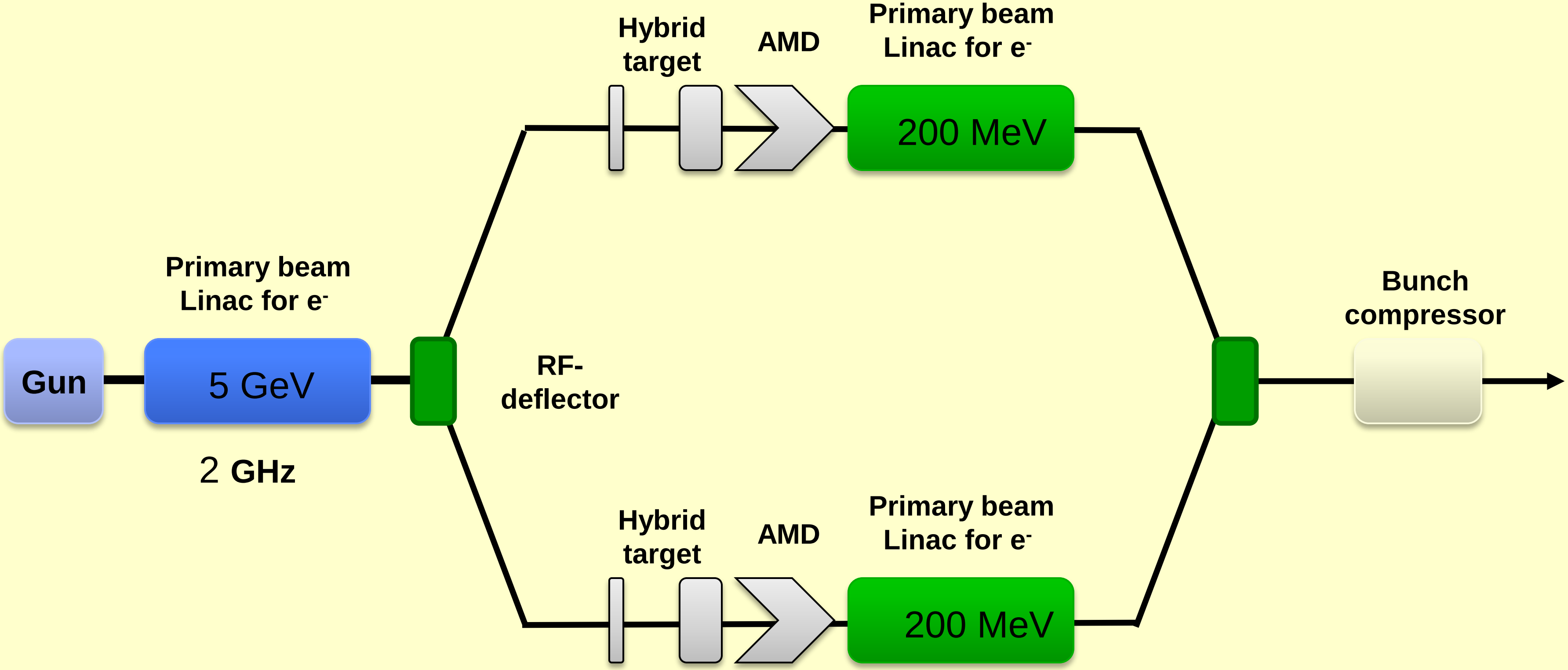
For the 1 GHz approach cathode current densities of 3-6 A/cm^2 would be needed, the dc approach uses < 1 A/cm^2

Polarized electron source



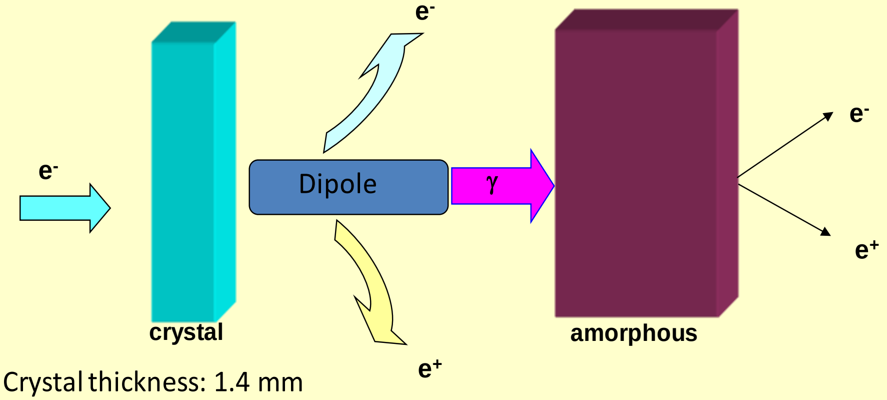
J. Shepard

Positron source conventional ?



AMD: 200 mm long, 20 mm radius, 6T field

Hybrid target



Crystal thickness: 1.4 mm
Oriented along the <111> axis

Distance (crystal-amorphous) d = 2 m

Amorphous thickness e =10 mm

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	χ_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	χ_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

Primary electron beam and linac

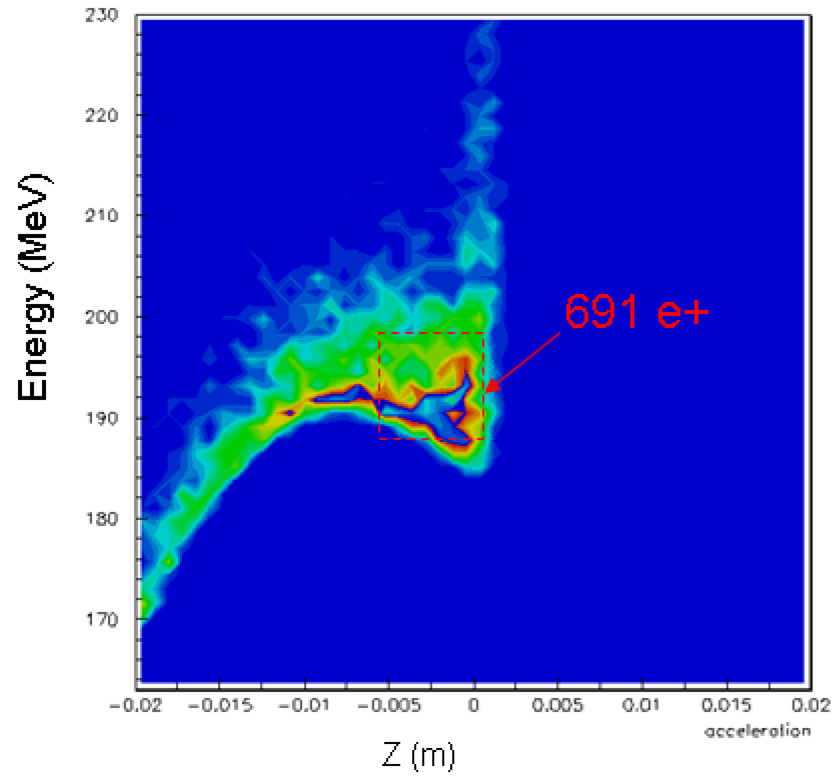
Parameters		
Energy	5	GeV
Number of e^- / bunch	1.1×10^{10}	
Charge / bunch	1.8	nC
Bunches per pulse	312	
Pulse repetition rate	50	Hz
Beam radius (rms)	2.5	mm
Bunch length (rms)	1	ps
Beam power	140	kW

- Can be done with thermionic gun or photo injector (CTF3 and Phin are nice references)
- 2 GHz rf system as used for other injector linac's

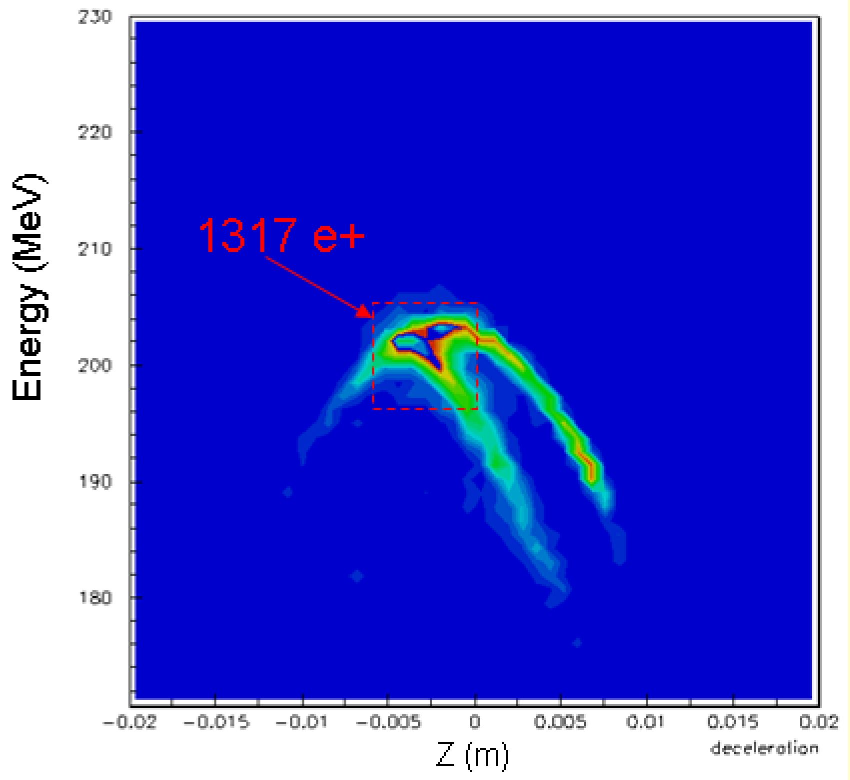
Yield simulations
capture and pre-injector linac

Energy density at 200 MeV

Accelerating mode



decelerating mode



Positron yield: after target: ~8 e^+/e^-
at 200 MeV: 0.9 e^+/e^-
into PDR: 0.39 e^+/e^-

O. Dadoun

Common injector linac

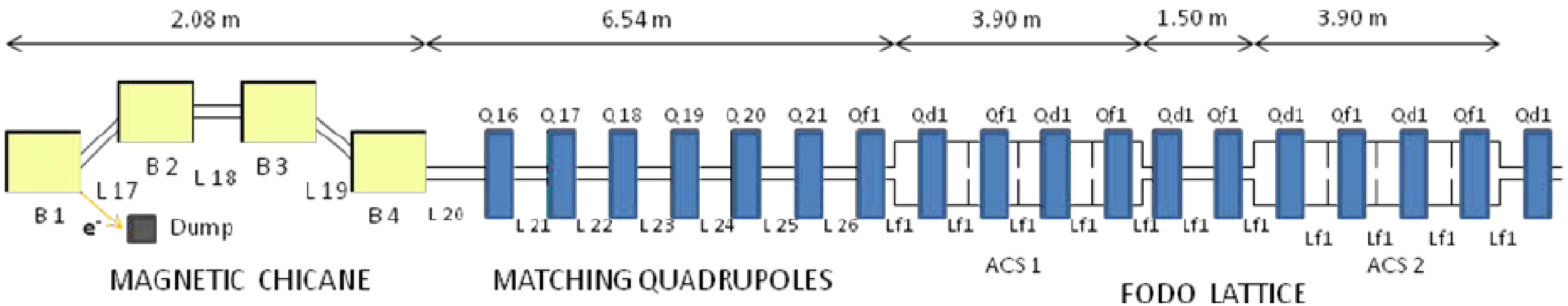
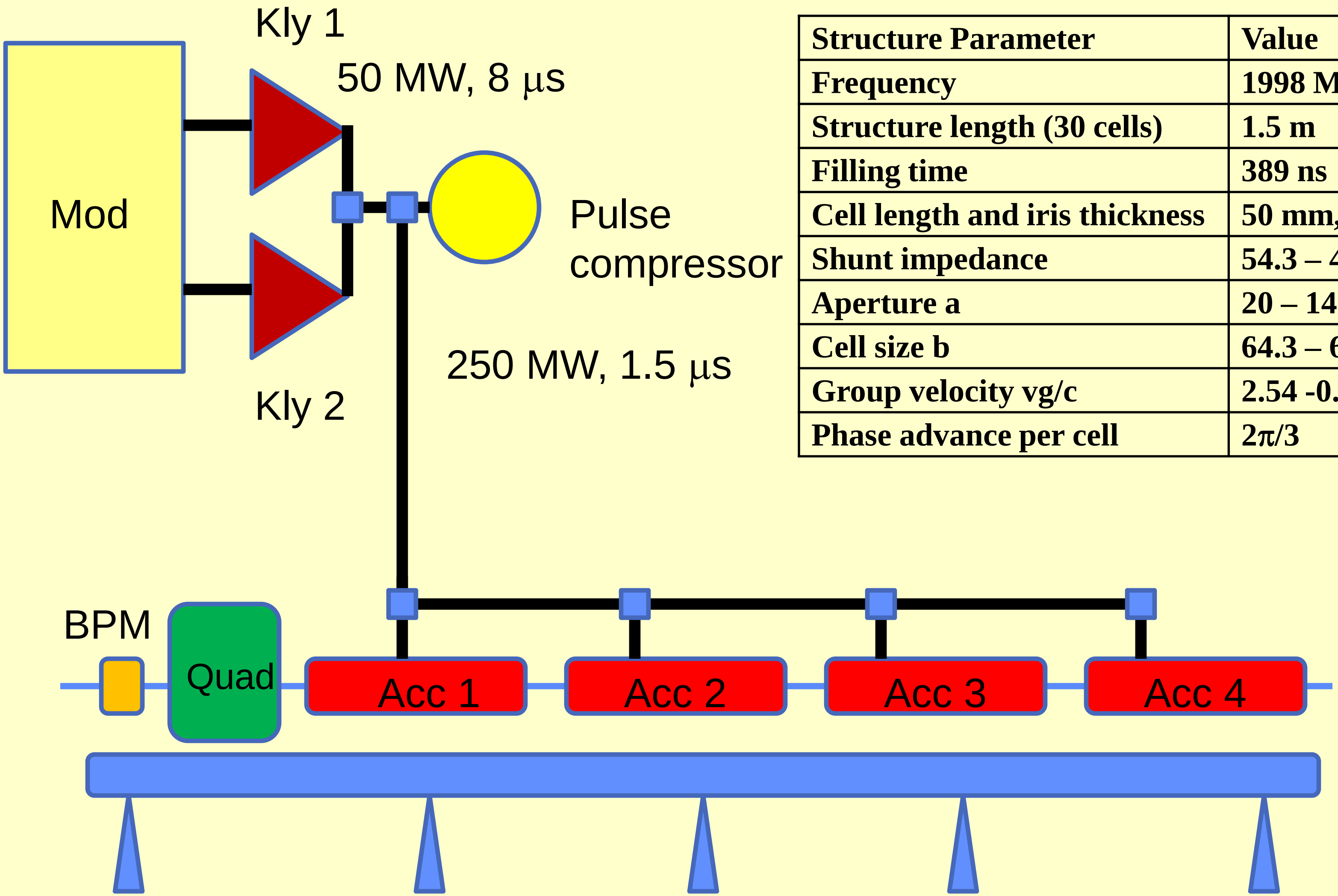


Table 20 – Beam parameters at the end of the Injector Linac.

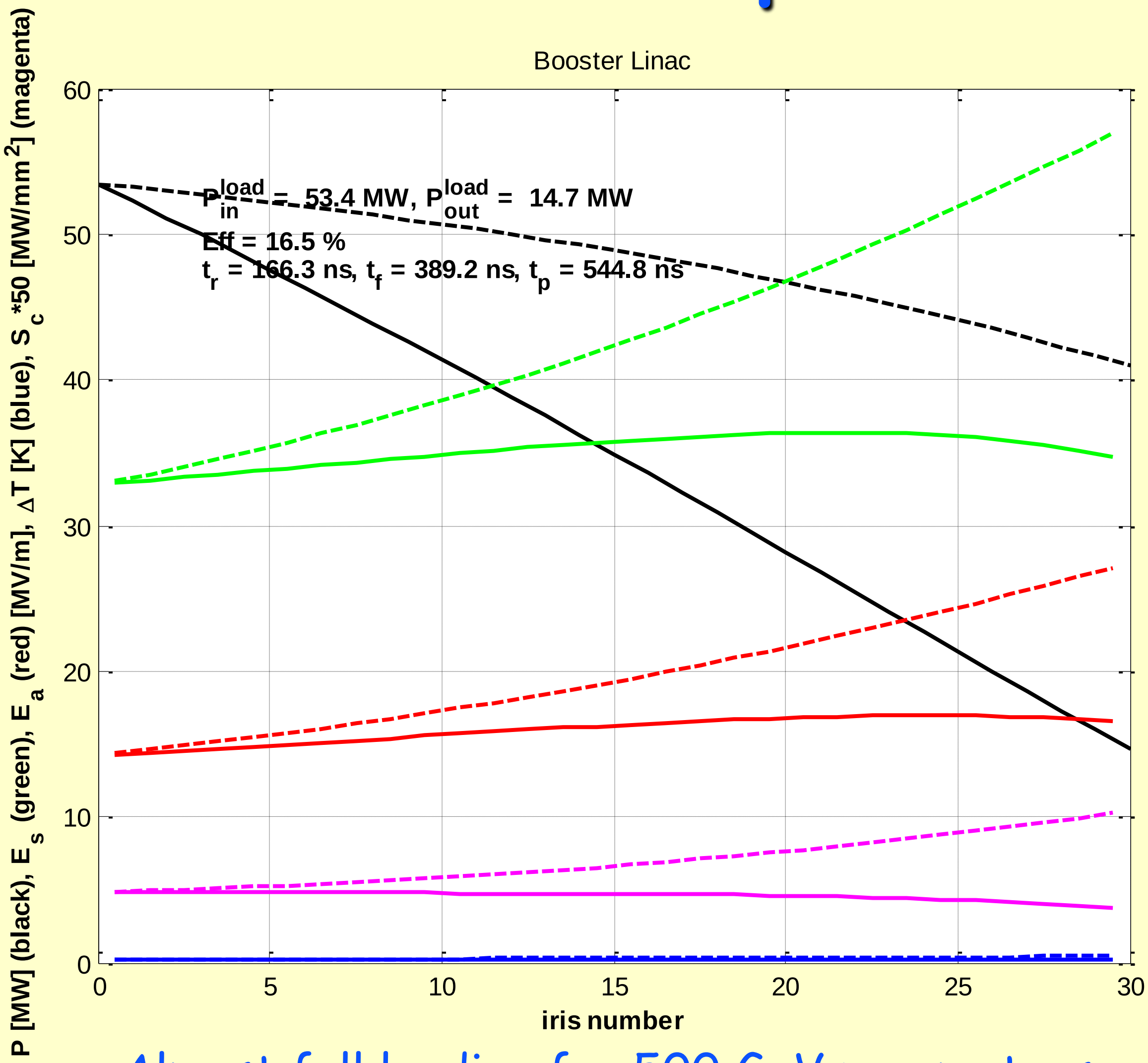
Beam Parameter	Unit	Value
Mean energy	MeV	2825
Yield	e^+/e^-	0.70
Horizontal Normalized Emittance (rms)	mm mrad	7685
Vertical Normalized Emittance (rms)	mm mrad	8105
Energy spread (rms)	%	4.5
Bunch length (rms)	mm	5.4

Injector linac rf system



Structure Parameter	Value
Frequency	1998 MHz
Structure length (30 cells)	1.5 m
Filling time	389 ns
Cell length and iris thickness	50 mm, 8 mm
Shunt impedance	54.3 – 43.3 MΩ/m
Aperture a	20 – 14 mm
Cell size b	64.3 – 62.9
Group velocity vg/c	2.54 -0.7 %
Phase advance per cell	$2\pi/3$

Linac structure beam loading and power flow



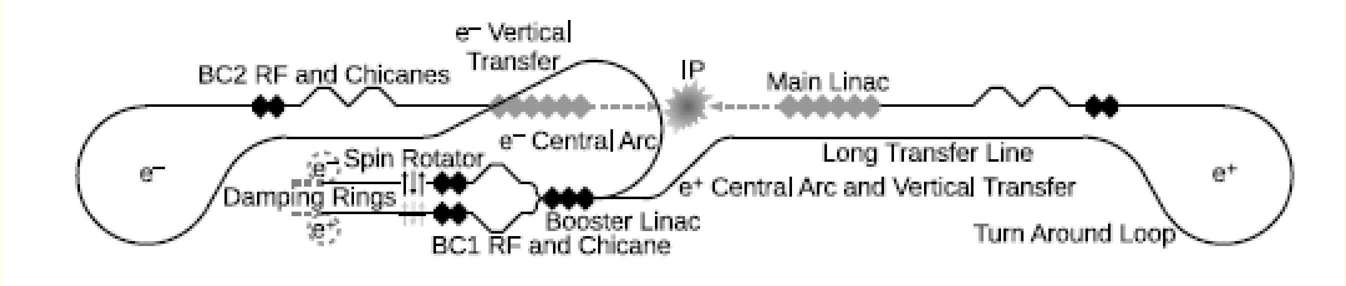
Parameters:
tapered
f= 1998 MHz
L= 1.5 m
Pin= 53.4 MW
Nb= 312
N = 4.0 e9
Eacc = 16 MV/m
Eff = 16.5%

Almost full loading for 500 GeV parameters,
will need amplitude modulation for beam loading compensation

Bunch compressors

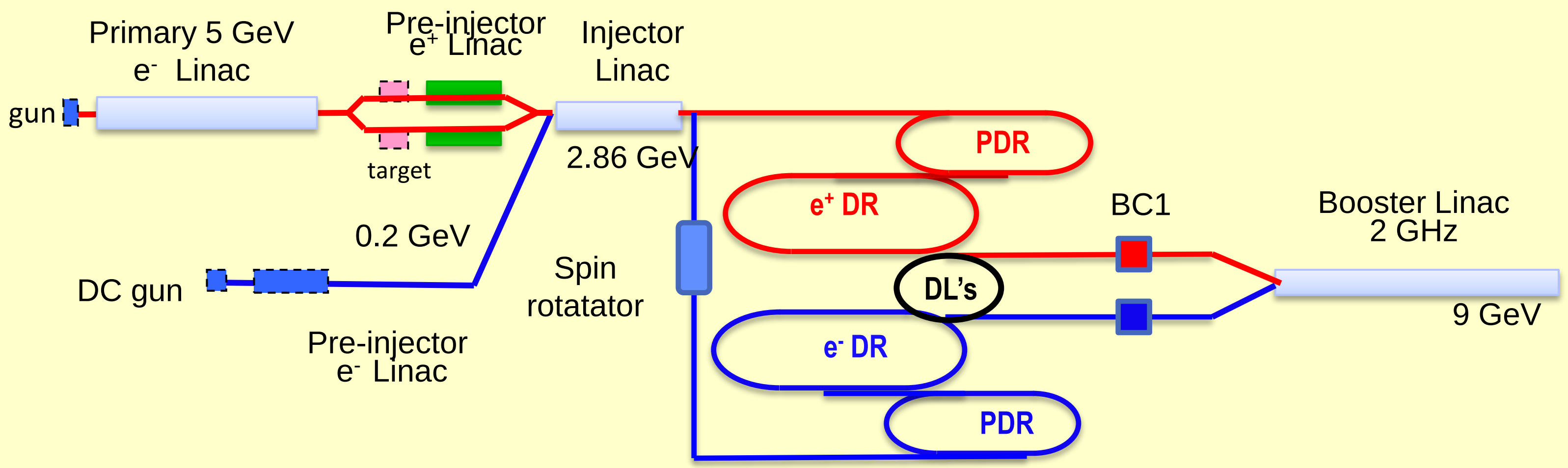
Two stages of bunch compressors, CSR, wake fields and tolerances have been studied

	BC1, 2.86 GeV	BC2, 9 GeV
Rf frequency	2 GHz, 15 MV/m	12 GHz, 74 MV/m
Phase tolerance	0.1 deg	0.1 deg
Bunch length after compression	300 μm factor 5.3	44 μm factor 6.8
Enegy spread after compression	0.25 %	1.7 %
Voltage	447 MV	1776 MV



Linac Parameters

LINAC	Energy Gain (MeV)	Bunch charge (10^9)	rf pulse length (ns)	Power per structure (MW)	Loaded gradient (MV/m)	Configuration (struct/klyst)	No of rf stations	pulse compressor gain	No of structures	Length (m)
e- pre-injector	200	4.3	1300-1700	54	18	2	4	2.3-2.5	7	30
e+ pre-injector	200	11	1300-1700	56	15	2	4	2.3-2.5	9	40
injector linac	2660	6	3600-4000	44	15	1	118	1	118	300
positron drive linac	5000	11	1300-1700	56	15	2	111	2.3-2.5	222	400
booster linac	6140	4	1700-2000	44	16	2	128	2-2.3	256	473



CDR, what's next ?

- Start work on low energy machine
- Cost optimization, Pre-damping ring, positron driver linac
- Follow up some issues from the CDR within the CLIC work package structure
- More focus on polarized positron studies in the future, revisit undulator scheme, study polarization transport

Potential for cost reduction

Cut pre-damping ring for electrons:

Which transverse and longitudinal emittance is needed from 200 MeV linac ?
Emittance possible: 25 - 50 μm, do we need more energy ?

Reduce beam power of positron drive linac:

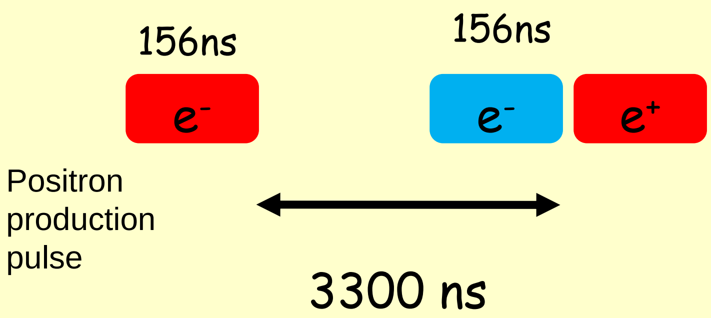
Lower beam current and use multiple injection into PDR, timing ?
Lower beam energy (less yield) and use multiple injection
Saving potential ?

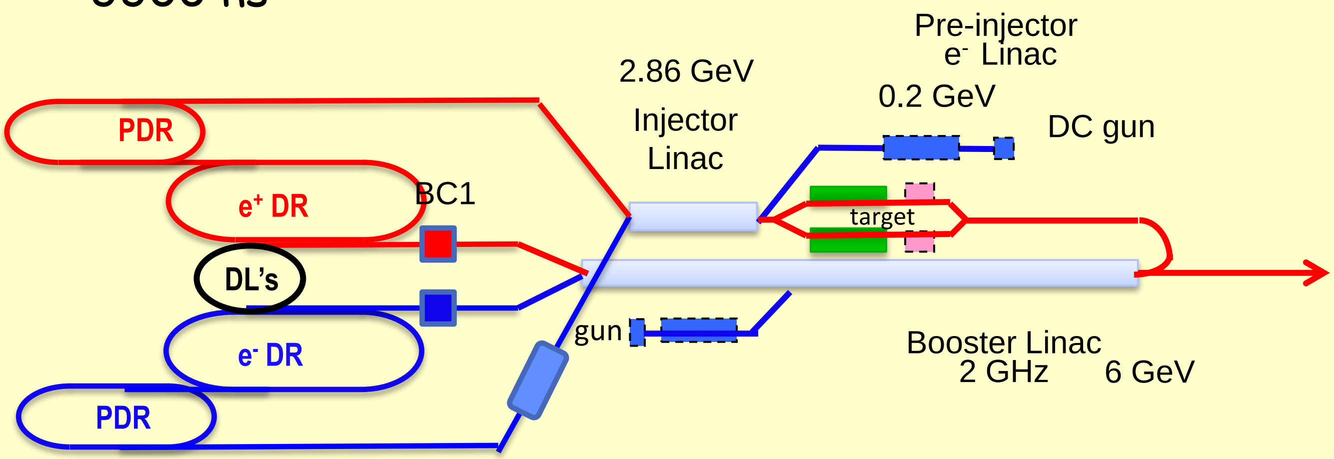
Use booster linac as well as positron drive linac:

Save entire linac +tunnel (>160 MCHF), need more rf power in booster linac,
Put injector linac in same tunnel as booster (see layout)

Alternative layout

Without positron driver linac





Pre-Damping ring acceptance

Table 3.7: List of magnetic parameters for the CLIC PDRs.

Type	Location	Length [m]	Number	Families	Pole tip field [T]	Full aperture H/V [mm]
Dipoles	Arc DS-BM	1.31	34 4	1	1.2	60/30
Quadrupoles	Arc LSS DS-BM	0.28 0.20 0.35	128 36 32	2 2 16	1.0	60/60
Sextupoles	Arc DS-BM	0.30	68 + 34 8	2 2	0.5	60/60
Wigglers	LSS	3.00	36	1	1.9	60/41

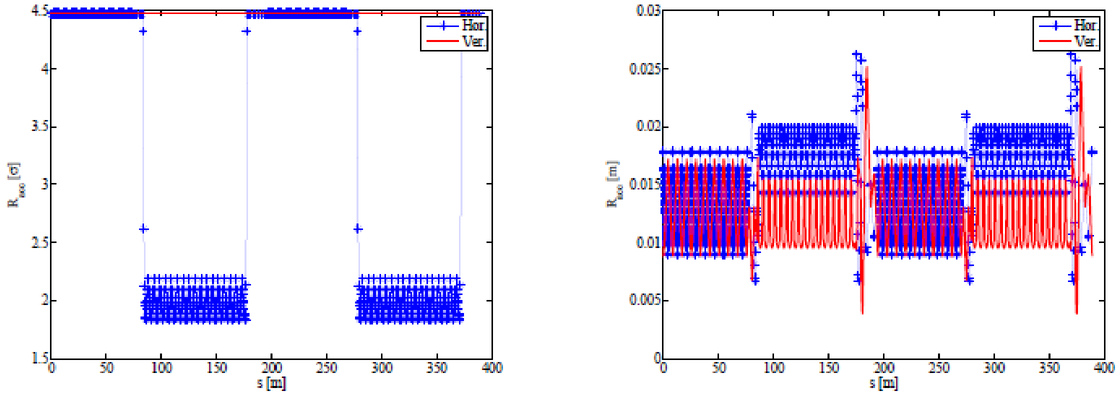
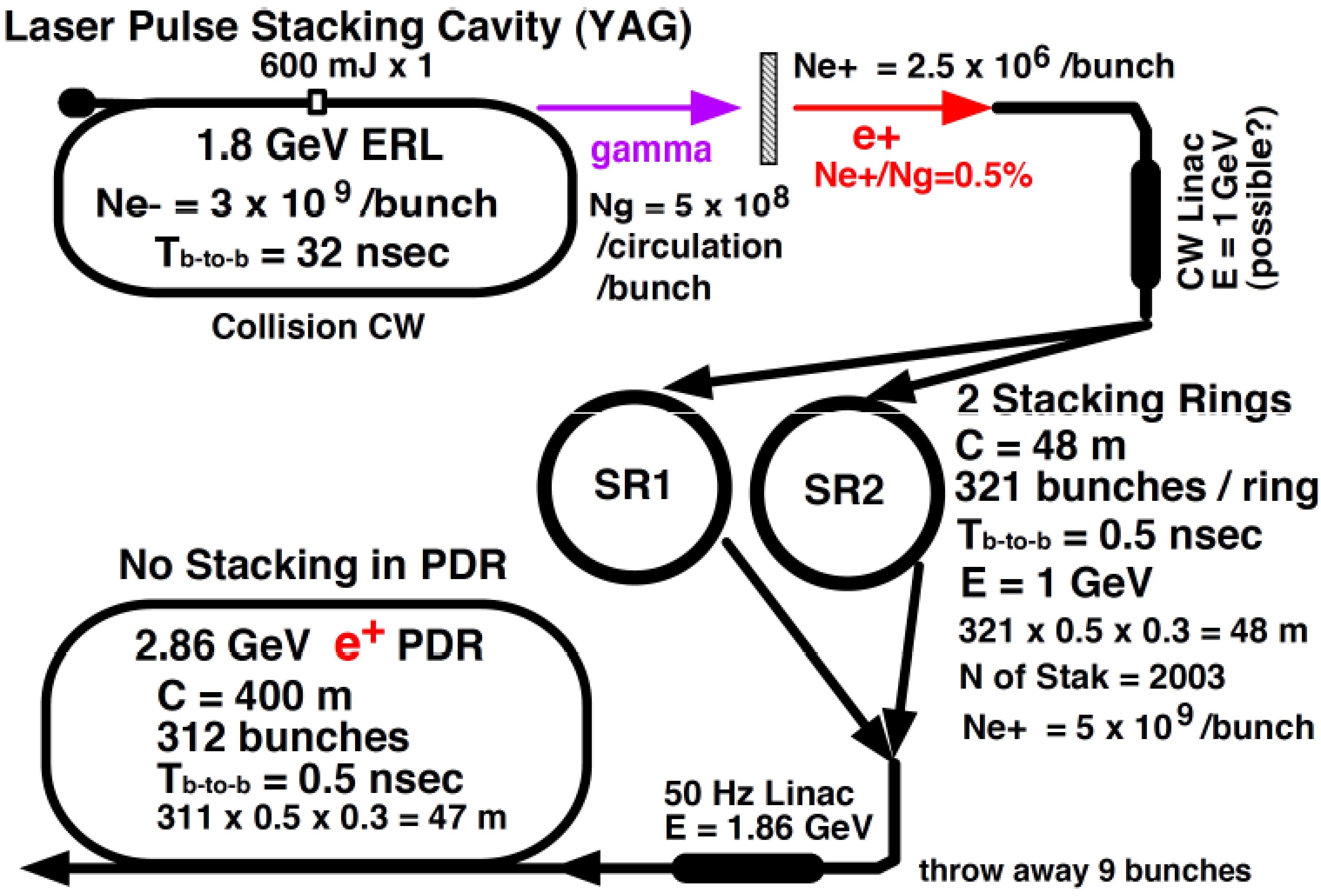


Fig. 3.11: The required acceptance around the PDR in order to fit the positron beam in units of beam sizes (left) and in metres (right).

Omori's ERL scheme for CLIC

Configuration



Omori's ERL scheme for CLIC

Stacking Ring (SR)

SR makes stacking and pre^2 damping

- C = 48.15 m
- 0.156 μs / turn
- 321 bunches in a ring

  321 x 0.5 ns x 0.3 m/ns = 48.15 m

match

- stack in the same bucket every 64th turn

  (injected beam: $T_{b\text{-}to\text{-}b}$ = 32 ns --> explain later)
- N of stacking in the same bucket = 2003

  64 x 2003 = 128 192 turns = 1.2 x 10^5 turns

  0.156 μs x 1.2 x 10^5 = 19.9979 ms ≃ 20 ms
- "Stacking = 20 ms" + "Damping in SR = 20 ms"

  --> total 40 ms /cycle (25 Hz)

Omori's ERL scheme for CLIC

Number of γ-rays/ e⁺s

- e⁻ beam (ERL)
  - 3 x 10^9 e⁻/bunch
  - E = 1.8 GeV
- Laser
  - 600 mJ / cavity
  - 1 cavity in ERL

collision

- 5 x 10^8 γ-rays/bunch

↓ thin conversion target: yield 0.5 %

- 2.5 x 10^6 e⁺/bunch

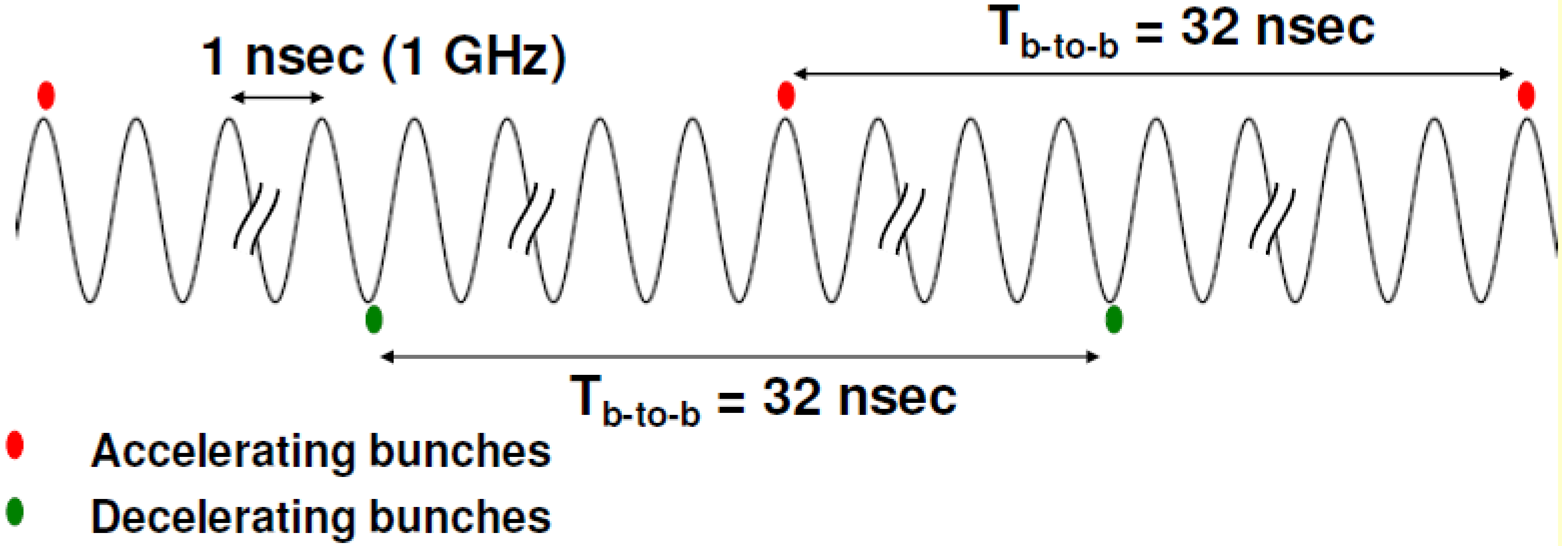
↓ 2003 stacking in the same bucket

- 5 x 10^9 e⁺/bunch (CLIC requires 4.2 x 10^9)

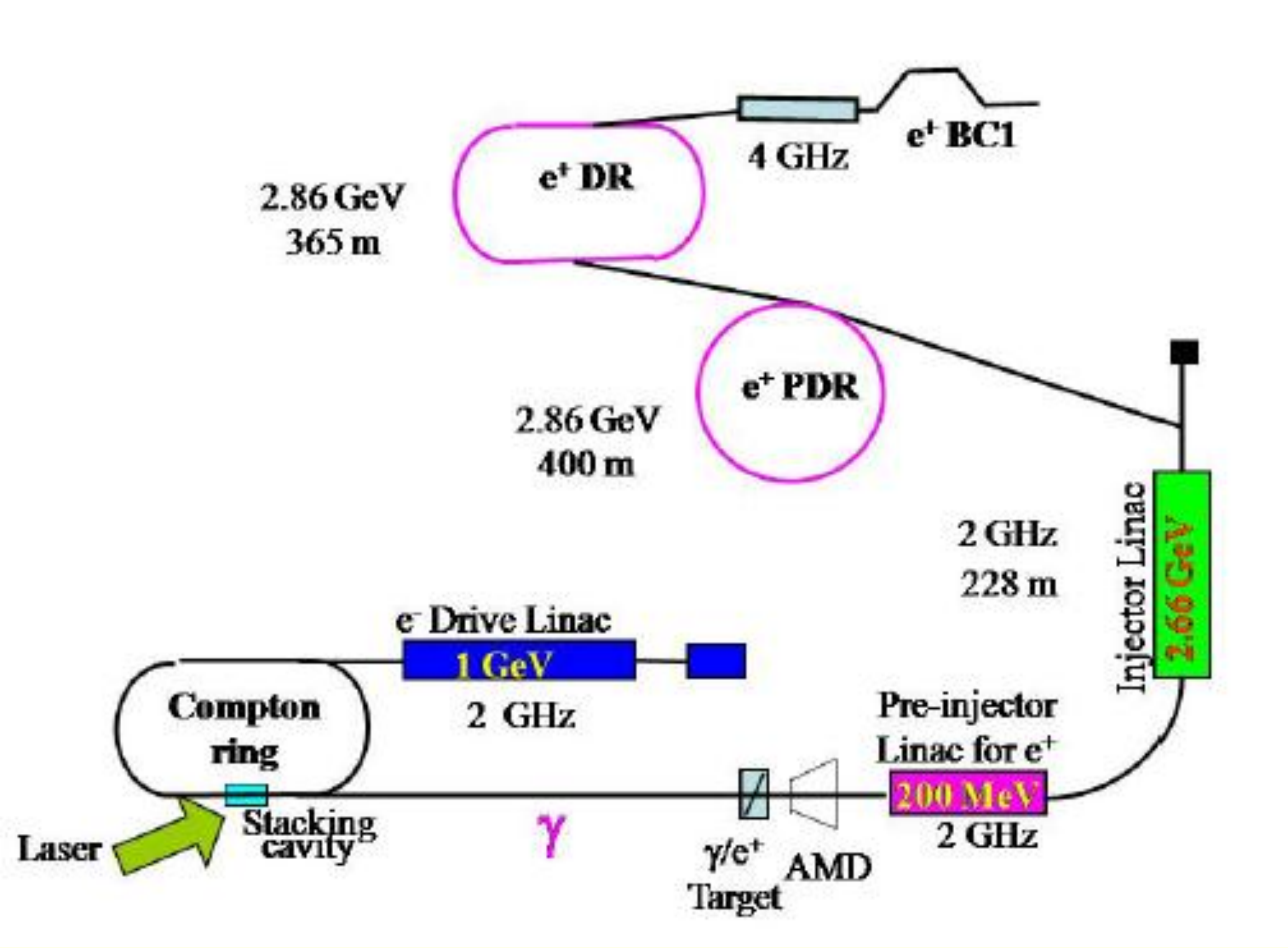
Omori's ERL scheme for CLIC

ERL

- 3×10^9 e^-/bunch
- E = 1.8 GeV
- $T_{b\text{-}to\text{-}b}$ = 32 ns
- F_{ref} = 31.25 MHz
- F_{RF} = 1 GHz (for example)



Compton-ring for CLIC



Compton-ring for CLIC

Table 1: CLIC parameters for e+ beam

Parameters	Units	CLIC 3 TeV
Energy	MeV	200
N e^+ / bunch	10^9	6.7
N bunches/pulse	-	312
Bunch spacing	ns	0.5
Pulse length	ns	156
Emittance (x,y)	mm.mrad	< 10 000
Bunch length	mm	< 10
Energy spread	%	< 8
Repetition rate	Hz	50

Compton-ring for CLIC

Compton Ring Parameters:
E=1 GeV, 2 GHz, 312 bunches, 6.2 10^{10} e^-/bunch,
156 ns Circumference
60% polarization
Laser Energy 590 mJ
Yield: 2.1 10^9 photons/turn/bunch
10^7 e^+.turn/bunch
→ 440 turn stacking in Pre-damping ring to get 4.2 10^9 positrons

Compton Linac option:
10 laser IP's, 4 GeV linac with 5 nC/bunch,
(could we use the drive beam linac)
How realistic are 10 laser IP's ?

CLIC Compton schemes for polarized positron production

- Not much done since 2010, ring scheme by Eugene et al., ERL scheme by Omori-san, Linac scheme studied as well
- Stacking needed either in PDR or dedicated rings
- Compton-ring was considered most promising
- Difficult to judge how realistic the schemes are
  Any comments ?
- How about direct conversion from polarized electrons as done by JLAB ? Any feelings ?
  Conversion yield ~10^{-3}, 1000 x times stacking ?
  What would be optimized parameters

Conclusions

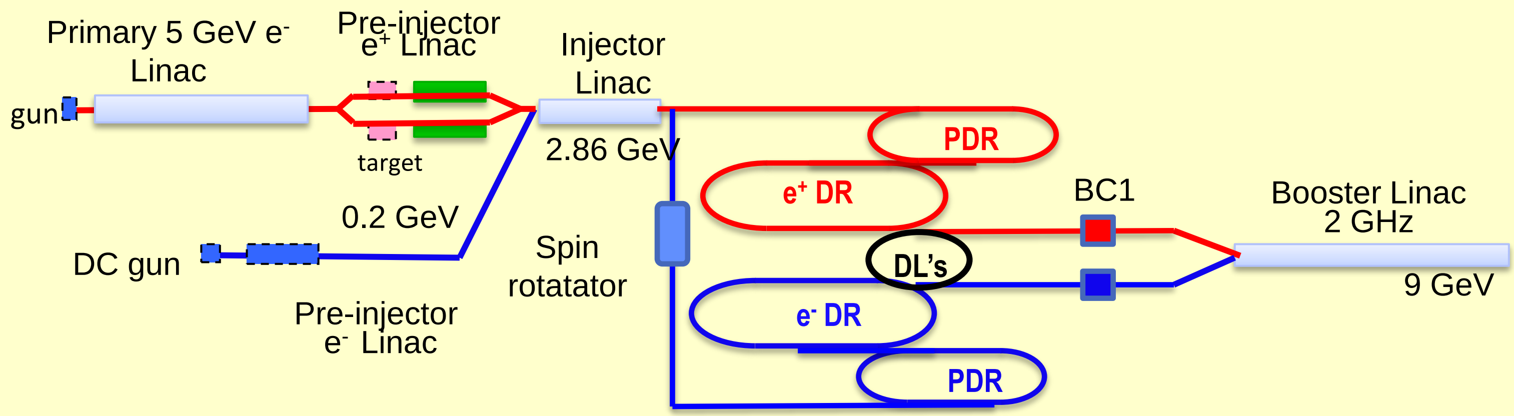
- Big effort to get the conceptual design of the CLIC main beam injectors, rather conceptual in many places but main problems studied and identified
- General believe that the injectors are feasible and relatively conservative approaches are used
- Obviously more work remains to be done

Collaborations

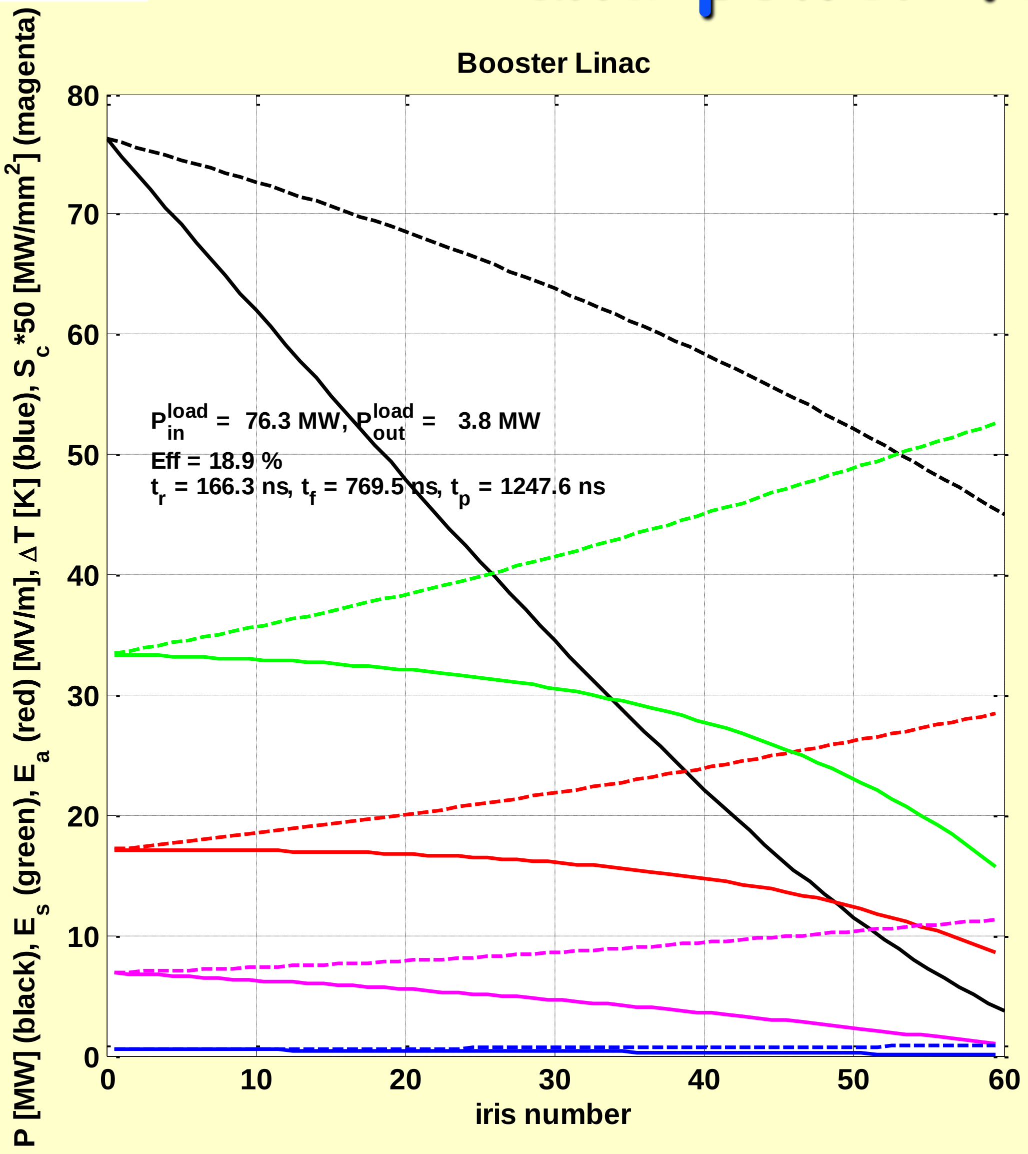
Polarized electron source:	SLAC, TJNAF
Positron source:	KEK, LAL
Polarized positrons:	KEK, LAL, ANL, CI, KIPT, Ankara University

Linac Parameters and cost

LINAC	Energy Gain (MeV)	Bunch charge (10^9)	rf pulse length (ns)	Power per structure (MW)	Loaded gradient (MV/m)	Configuration (structure/2 klystrons)	No of rf modules	pulse compressor gain	No of structures	Length (m)	Energy gain per module (MeV)	Cost
e- pre-injector	200	4.3	1300-1700	54	18	4	2	2.3-2.5	8.0	30	108	5830
e+ pre-injector	200	11	1300-1700	56	15	4	3	2.3-2.5	9.0	40	90	8745
injector linac	2660	6	3600-4000	44	15	2	60	1	119.0	300	45	127950
positron drive linac	5000	11	1300-1700	56	15	4	56	2.3-2.5	223.0	400	90	163240
booster linac	6140	4	1700-2000	53	16	4	64	2-2.3	256.0	473	96	186560



Linac structure beam loading and power flow



Parameters:
tapered
f= 1998 MHz
L= 3 m
Pin= 77 MW
Nb= 624
N = 4.0 e9
Eacc = 15 MV/m