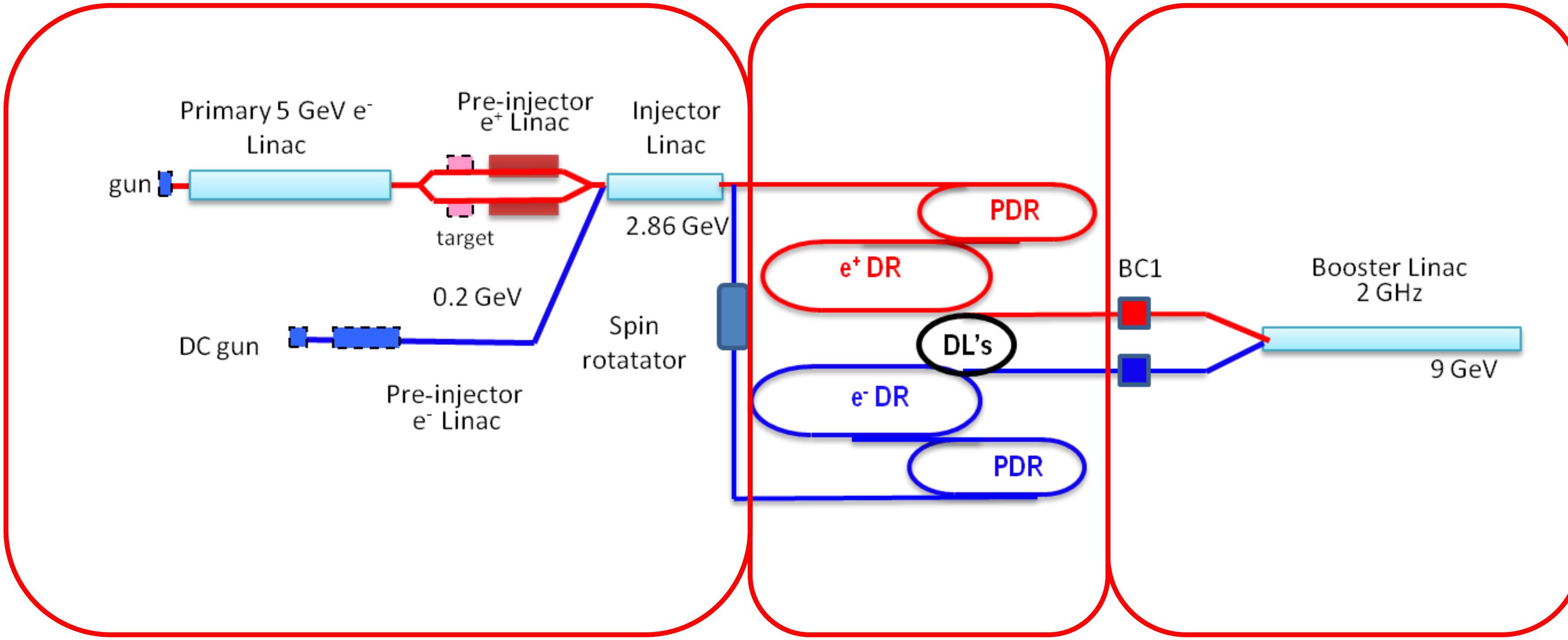
Main Beam Injectors



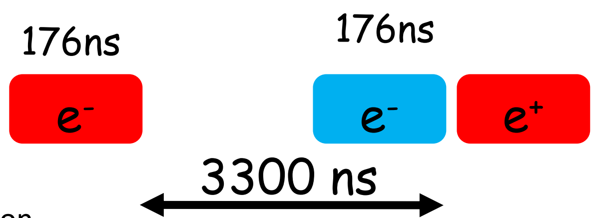
Changes for the New Baseline parameters at 380 GeV

Main assumptions

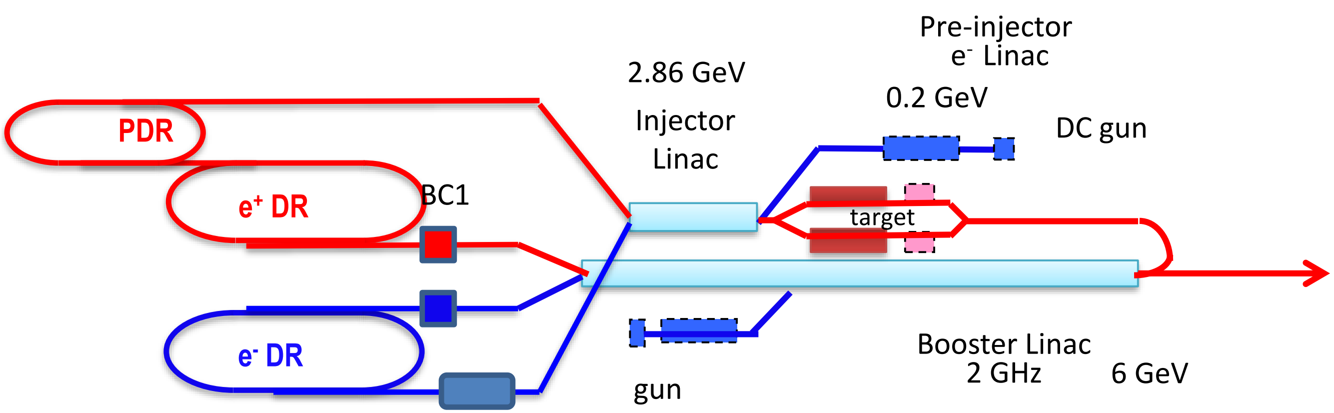
- New Parameters: E= 380 GeV, N= 5.2 10^9 (at IP?), N_b= 352
- PDR for electrons not needed
- Use 2 GHz bunch spacing through out the complex, shorter rf pulses in linac's and no need for delay loop
- No lower energy running. One rf pulse length and charge only
  upgrade scenarios ?
- Optimise timing of the beams to gain efficiency (PC optimisation)
  Consequence will be ~ 4 us offset between electrons and positrons
- Investigate to use booster linac as positron driver (saves positron driver)
  Not investigated yet
- Factor of 2 improvement in positron capture and transport

Alternative layout

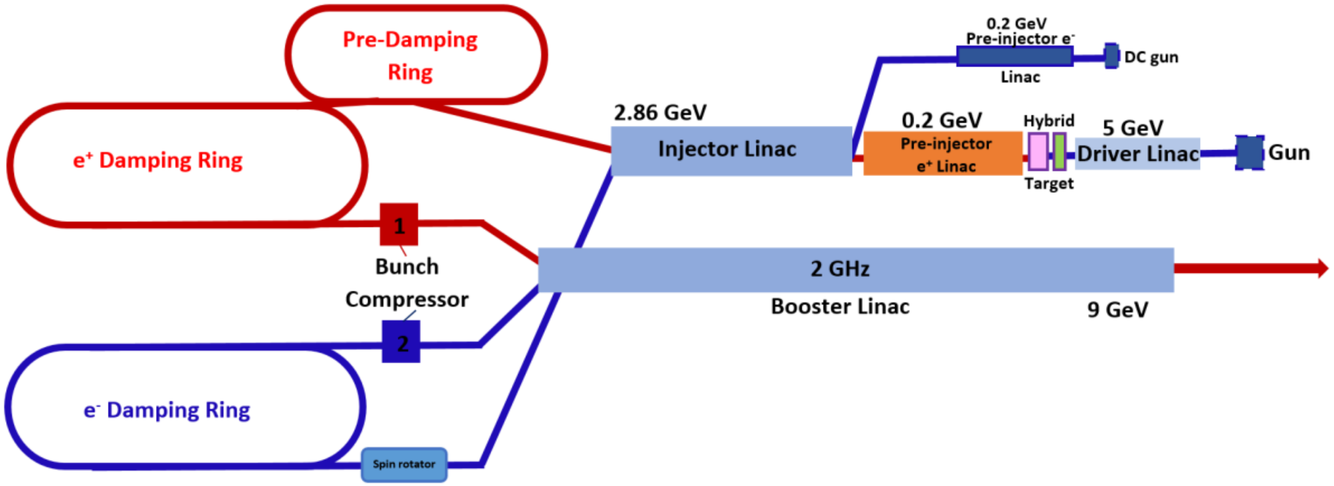
Without positron driver linac



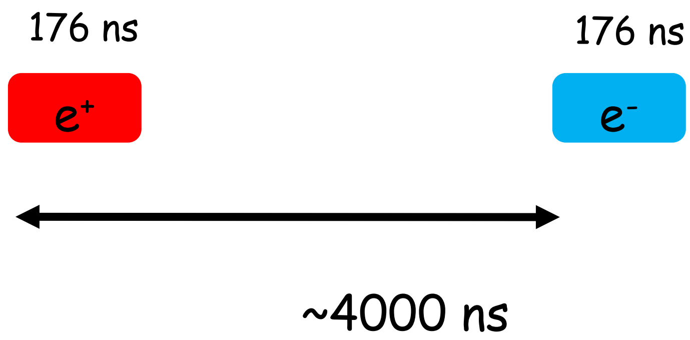
Positron
production
pulse



New schematic layout



Injector timing



Injector linac
and booster linac ?

Decided to go with 4 us difference out of the booster linac but does it work with the damping rings ?

Igor's PC study

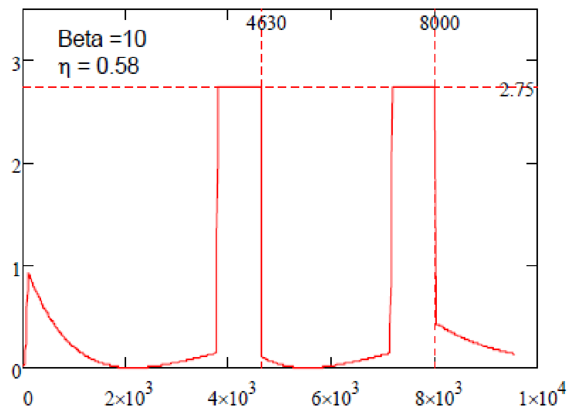
Input:

- Klystron pulse length 8000 ns
- SLED cavity $Q_0 = 2x10^5$, F=2 GHz
- Compression: 2 klystrons RF phase-to-amplitude modulation

Long (540 ns) pulses

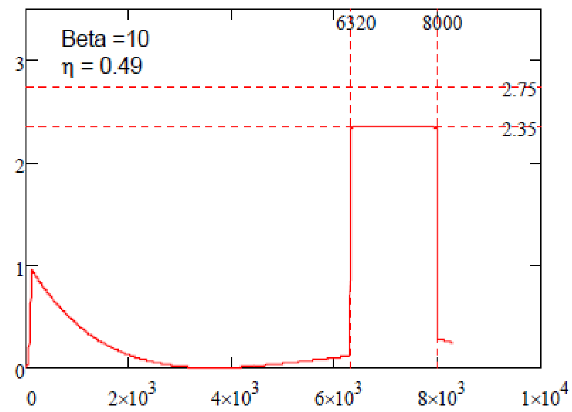
Doubled pulse

pulses: 2 x (540 ns +300 ns)



Single pulse

pulse: 2x540 ns +2x300 ns



The doubled pulse scheme is 17% more efficient and provides more flexibility. This scheme should be recommended.

Have to be optimized for new pulse length, see following

Injector parameters 380 GeV version at PDR

Parameter	Unit	CLIC polarized electrons	CLIC positrons
E	GeV	2.86	2.86
N	10^9	6	6
n_b	-	352	352
Dt_b	ns	0.5	0.5
t_{pulse}	ns	176	176
$e_{x,y}$	mm.mrad	< 20 ?	7071, 7577
s_z	mm	< 4	3.3
s_E	%	< 1	1.63
Charge stability shot-to-shot	%	1	1
Charge stability flatness on flat top	%	1	1
f_{rep}	Hz	50	50
P	kW	45	45

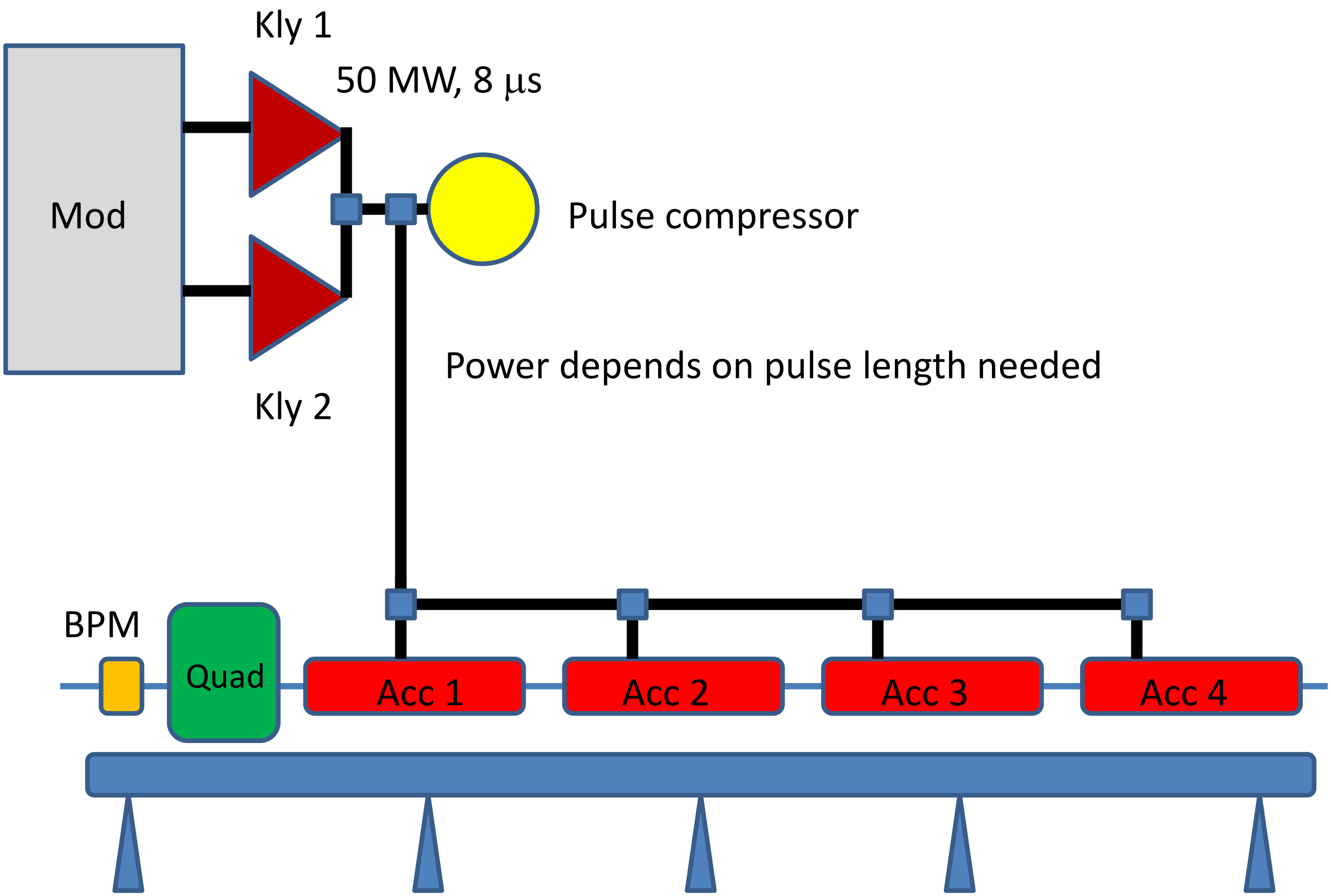
2 GHz accelerating structure

Parameter	Value
Frequency	1998 MHz
Structure length (30 cells)	1.5 m
Shunt impedance	54.3 – 43.3 MΩ/m
Average group velocity	0.0145 c
Filling time	389 ns
Average aperture a	17 mm
Taper $a_{max} - a_{min}$	20 – 14 mm
Cell size b	64.3-62.9 mm
Group velocity vg/c	2.54 – 0.7 %
Cell Length and iris thickness	50 mm, 8 mm

$2\pi/3$ traveling wave, should be damped eventually

Rf-module cost model

Typical 2 GHz rf module including accelerators and beam line



Rf-module cost model

Cost estimate per module
inspired by KEK linac and checked with CTF3 prices

Item	kCHF	No. per module	Mod 4 struct	No. per module	Mod 2 struct	No. per module	Mod 2 struct no PC
Klystron 50 MW, 8 us, focusing coil	300	2	600	2	600	2	600
Modulator for two klystrons+tank	800	1	800	1	800	1	800
accelerating sections, 1.5 m long	100	4	400	2	200	2	200
Pulse compressor	200	1	200	1	200	0	0
wave guides, straight, bend, coupler, divider, loads	400	1	400	0.5	200	0.5	200
girder, support for quads and structures	100	1	100	0.5	50	0.5	50
Vacuum system, beam line and rf network	200	1	200	0.5	100	0.5	100
Beam diagnostic, BPM	35	1	35	0.5	17.5	0.5	17.5
Quad (FODO assumed)	30	1	30	0.5	15	0.5	15
LLRF system	150	1	150	1	150	1	150
Total for one module			2915		2332.5		2132.5

Comparison with other references ?

KEKB-linac:	similar approach	1998	2062	kCHF/module
		2011	2400	kCHF/module
Spring8-linac:	Kly,Mdk, 2 struct, PC, Vacuum		2950	kCHF/module

CLIC injectors: 2915 -2165 kCHF/module

<u>Compare 500 GeV version (difficult)</u>

CLIC main injectors total 9 GeV +booster (262 MCHF for driver linac): 746 MCHF

ILC injectors total e^+ and e^- source components 5 GeV: 402 MCHF (2011)

Value estimate 500 GeV

			Procurement	Grand Total
1. Main Beam Production	1.1. Injectors	1.1.1. Thermoionic gun unpolarized e-	1000000	1000000
1. Main Beam Production	1.1. Injectors	1.1.2. Primary e- Beam Linac for e+	261240000	261240000
1. Main Beam Production	1.1. Injectors	1.1.3. e-/e+ Target (x2)	14000000	14000000
1. Main Beam Production	1.1. Injectors	1.1.4. Pre-injector Linac for e+ (x2)	23325000	23325000
1. Main Beam Production	1.1. Injectors	1.1.5. DC gun Polarised e-	3000000	3000000
1. Main Beam Production	1.1. Injectors	1.1.6. Pre-injector Linac for e-	7920000	7920000
1. Main Beam Production	1.1. Injectors	1.1.7. Injector Linac	136480000	136480000
1. Main Beam Production	1.1. Injectors	1.1.8. Bunching System e- for e+	500000	500000
1. Main Beam Production	1.1. Injectors	1.1.9. Transfer Lines e- to Double Targets Station	100000	100000
1. Main Beam Production	1.1. Injectors	1.1.10. Transfer Lines e+ to Injector Linac	100000	100000
1. Main Beam Production	1.1. Injectors	1.1.11. Bunching System e- for e-	300000	300000
1. Main Beam Production	1.1. Injectors	1.1.12. Pre-injector to Injector Linac Transfer Line	100000	100000
1. Main Beam Production	1.1. Injectors	1.1.14. Spin Rotator e- before PDR	500000	500000
1. Main Beam Production	**1.1. Injectors**	**1.1. Injectors Total**	**448565000**	**448565000**
1. Main Beam Production	**1.1. Injectors**	**1. Main Beam Production Total**	**448565000**	**448565000**
1. Main Beam Production	**1.1. Injectors**	**Grand Total**	**448565000**	**448565000**

Grand Total: 448 MCHF
Uncertainty ~20%

Will be around 260 MCHF for the 380 GeV

Cost per linac
500 GeV

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	Cost
e- pre-injector	200	7.8	1300-1700	64	18	3	3	2.3-2.5	8.0	30	81	7920
e+ pre-injector	200	20	1300-1700	82	15	2	5	2.3-2.5	9.0	40	45	11663
injector linac	2660	11	3600-4000	50	14	2	64	1	127.0	300	42	136480
positron drive linac	5000	20	1300-1700	82	15	2	112	2.3-2.5	223.0	400	45	261240
booster linac	6140	7.3	1700-2000	72	16	2	128	2-2.3	256.0	473	48	298560

Total 716 MCHF

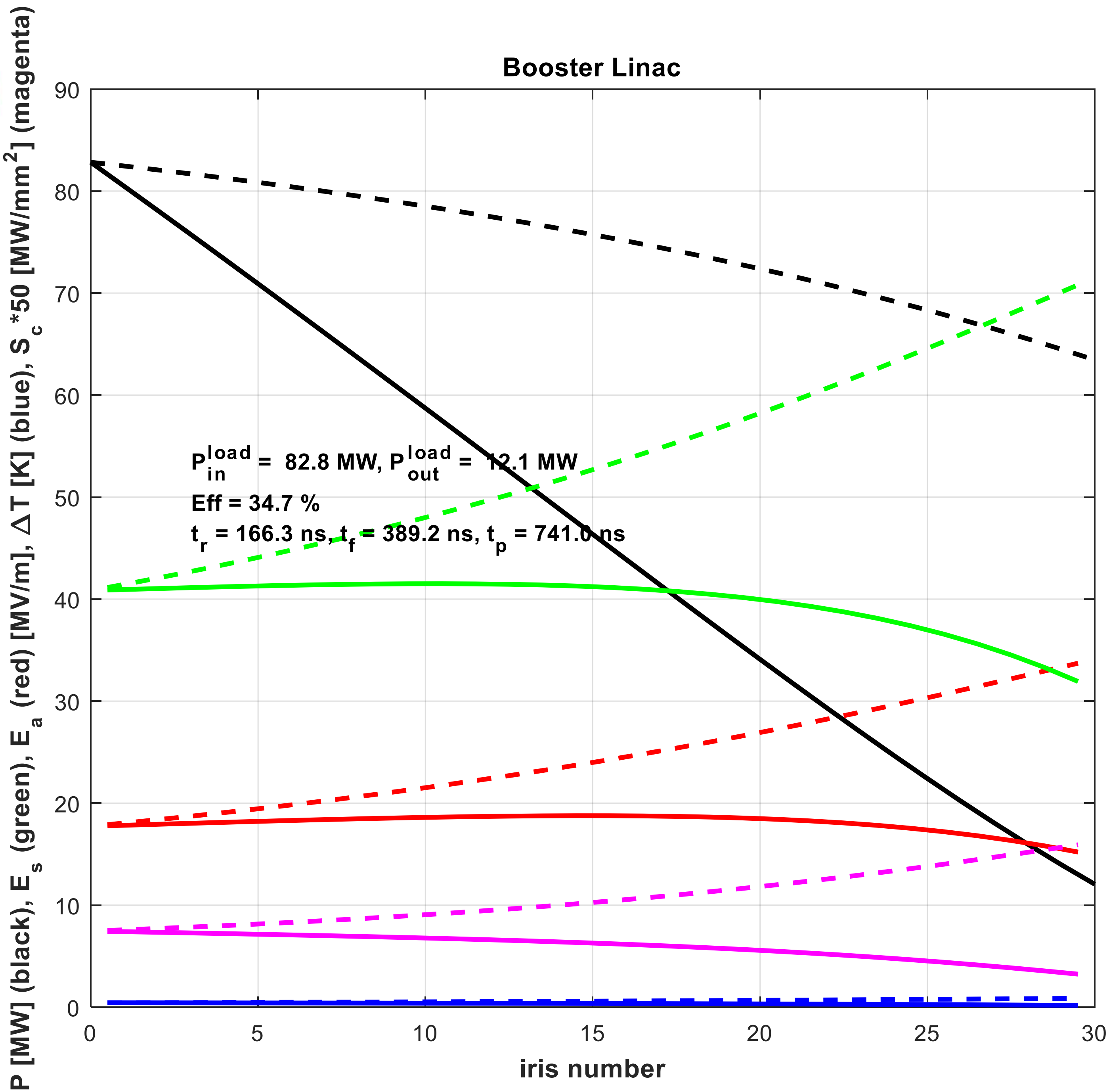
Keep gradient constant, reconfigure structure plumbing and add klystrons
→Almost factor 2 more rf power
Not optimized for the 500 GeV machine; positron yield 0.39

Cost per linac 380 GeV

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	Cost
e- pre-injector	200	6	600	90	20	4	2	4.4	7	14	120	5830
e+ pre-injector	200	20-40	600	102	15	4	4	4.4	14	19	60	11660
injector linac	2660	7	2x600	83	18	3	33	2.7	99	194	81	87120
positron drive linac	5000	7	600	90	20	4	42	4.4	167	326	120	122430
booster linac	6140	5.6	2x600	75	18	3	76	2.7	228	445	81	200640

428 MCHF

Positron capture linac 1 m structure
~ 300 klystrons
Positron yield 1


Booster Linac
P [MW] (black), E_s (green), E_a (red) [MV/m], ΔT [K] (blue), S_c *50 [MW/mm^2] (magenta)
iris number
P_in^load = 82.8 MW, P_out^load = 12.1 MW
Eff = 34.7 %
t_r = 166.3 ns, t_f = 389.2 ns, t_p = 741.0 ns
0
5
10
15
20
25
30
0
10
20
30
40
50
60
70
80
90

Cost per linac

380 GeV parameters													
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	Cost	Efficiency (%)
e- pre-injector	200	6	600	90	20	4	2	4.4	7.0	13.65	120	5830	4.22
e+ pre-injector 1m structure	200	20	600	102	15	4	4	4.4	14.0	18.2	60	11660	7.04
injector linac	2660	7	2x600	83	18	3	33	2.7	99.0	193.05	81	87120	7.94
positron drive linac	5000	6	600	90	20	4	42	4.4	167.0	325.65	120	122430	5.03
booster linac	6140	5.6	2x600	75	18	3	76	2.7	228.0	444.6	81	200640	6.37
												427680	
							157						

Total 428 MCHF

3 GeV vs 5 GeV positron driver

Problem is the beam loading, probably needs more study anyway

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	Cost	Efficiency (%)
e- pre-injector	200	6	600	90	20	4	2	4.4	7.0	13.65	120	5830	4.22
e+ pre-injector 1m structure	200	20	600	102	15	4	4	4.4	14.0	18.2	60	11660	7.04
injector linac	2660	7	2x600	83	18	3	33	2.7	99.0	193.05	81	87120	7.94
positron drive linac	5000	6	600	90	20	4	42	4.4	167.0	325.65	120	122430	5.03
booster linac	6140	5.6	2x600	75	18	3	76	2.7	228.0	444.6	81	200640	6.37
												427680	
							157						
positron drive linac 3 GeV	3000	20	600	102	15	4	50	4.4	200	390	90	145750	8.448

Positron driver needs to use 1 m long structure, fully loaded

Yield 0.4

Probably need to go back to two targets: ~ 30 MCHF +

Tunnel length: ~ 10 MCHF/100m (my guess)

Conclusions

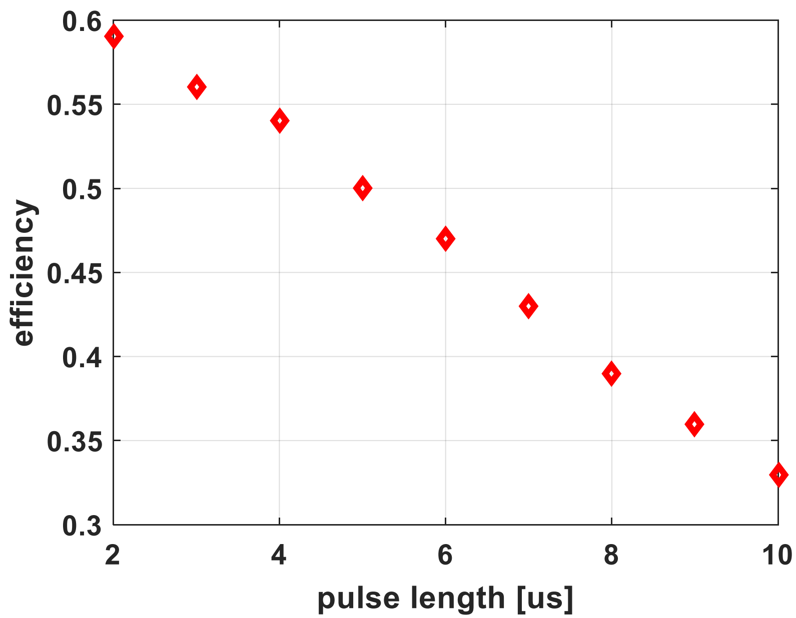
- Injector linac savings: 288 MCHF
- 314 instead of 624 klystrons → 12-15 MW power savings
- Could consider only one positron target and pre-injector linac: ~ 30 MCHF
- Electron PDR + delay loop: ~ 150 MCHF ?

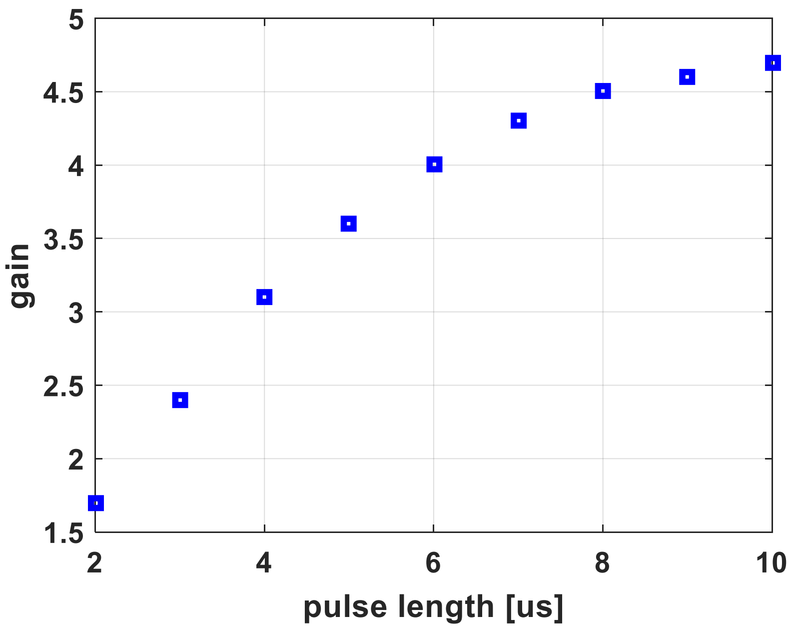
  Consequence: need excellent emittance from polarised electron source

  likely possible but would need some R&D

Additional materiel

Pulse compressor





Example: 2 GHz klystron, 700 ns target pules length with flat top, beta= 10, Q= 200000

Parametric linac cost model

Beam power, efficiency

Linac cost model: $C_{total} = C_{linac} + C_{tunnel}$

$C_{tunnel} = N_s * L_s / fillfactor * C_{civil}$

$C_{linac} = N_s * L_s * C_{struct} + M_s * C_{quad} + N_M * (C_{mod} + C_{WG} + C_{klyst} + C_{module})$

$N_s = E_{total} / grad / L_s$

$M_s = N_s * L_s / fillfactor / 13.5$

$N_M = N_S / config$

$P_B = I_B * E_{total} * t_p * f_R$

$P_{kt} = P_k * N_k * t_{krf} * f_R$

Efficiency= $P_B / P_{kt} = \eta_{acc} + \eta_{PC} + \eta_{Dist}$

$\eta_{max} = 0.4*0.5*0.9 = 0.18$?

N_s= number of structure

L_s=structure length

C_{civil}= tunnel cost/m ?

C_{struct}=cost/m

M_s=Number of quads/13.5 m FODO lattice

N_M= number of modules

C_{mod}=modulator cost

C_{klyst}=klystron cost

C_{WG}= waveguide cost

C_{module}= girder cost

E_{total} = linac energy gain

grad= gradient MV/m

config= NS per module (Mod-Klystron)

(Structure input power)

How do we connect beam parameters to optimized rf system configuration ?

Presently got decent structure efficiency (driver 32%,injector 31%,booster 27%)

But very bad over all efficiency due to rf pulse length constraints, low energy runs

Simplified relative cost model for parameter optimization

Simplified linac cost model: $C_{total} = C_{const} + C_{energy} * E_0 + C_{power} * P_B$

Using something like a constant optimized efficiency