Optimization of CLIC main linac accelerating structure for 150 MV/m loaded accelerating gradient

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Outline

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- Luminosity per power optimization results
  - optimum phase advance and frequency
  - sensitivity to the rf constrains
- Power source cost optimization results
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  - increased luminosity
- Summary

Introduction

Optimization at f=30 GHz, $\delta\varphi$=110° and E_{acc}=150 MV/m

a= 1.5-:-2.3 mm ; d= 0.5-:-1 mm ; da= dd= 0.02mm

1081600 structures

The best structure **HDS84** has $L_{bx}\eta/N$ = 12.6 a.u. ; η= 26.7 % ;

<a>= 1.91mm ; a= 2.14-:-1.68mm ; d= 0.88-:-0.76mm

a= 1.5-:-2.3 mm ; d= 0.5-:-1 mm ; da= dd= 0.05mm

30976 structures

Reduced statistics lead to lower $L_{bx}\eta/N$ = 12.3 a.u. ; η= 25.6 % ;

<a>= 1.95mm ; a= 2.2-:-1.7mm ; d= 1.0-:-0.8mm

BUT

require less computations

Introduction

Accelerating structure parameters:

fixed: E_{acc}= 150MV/m,

varied: f= 18-:-30GHz, $\delta\varphi$= 50-:-130°,

a/λ= 0.1-:-0.25, d/λ= 0.05-:-0.1 => 217800 structures

if dd/λ=da/λ=0.005

N_b, N_{cells}, N_{cycles}

Beam dynamics constrains:

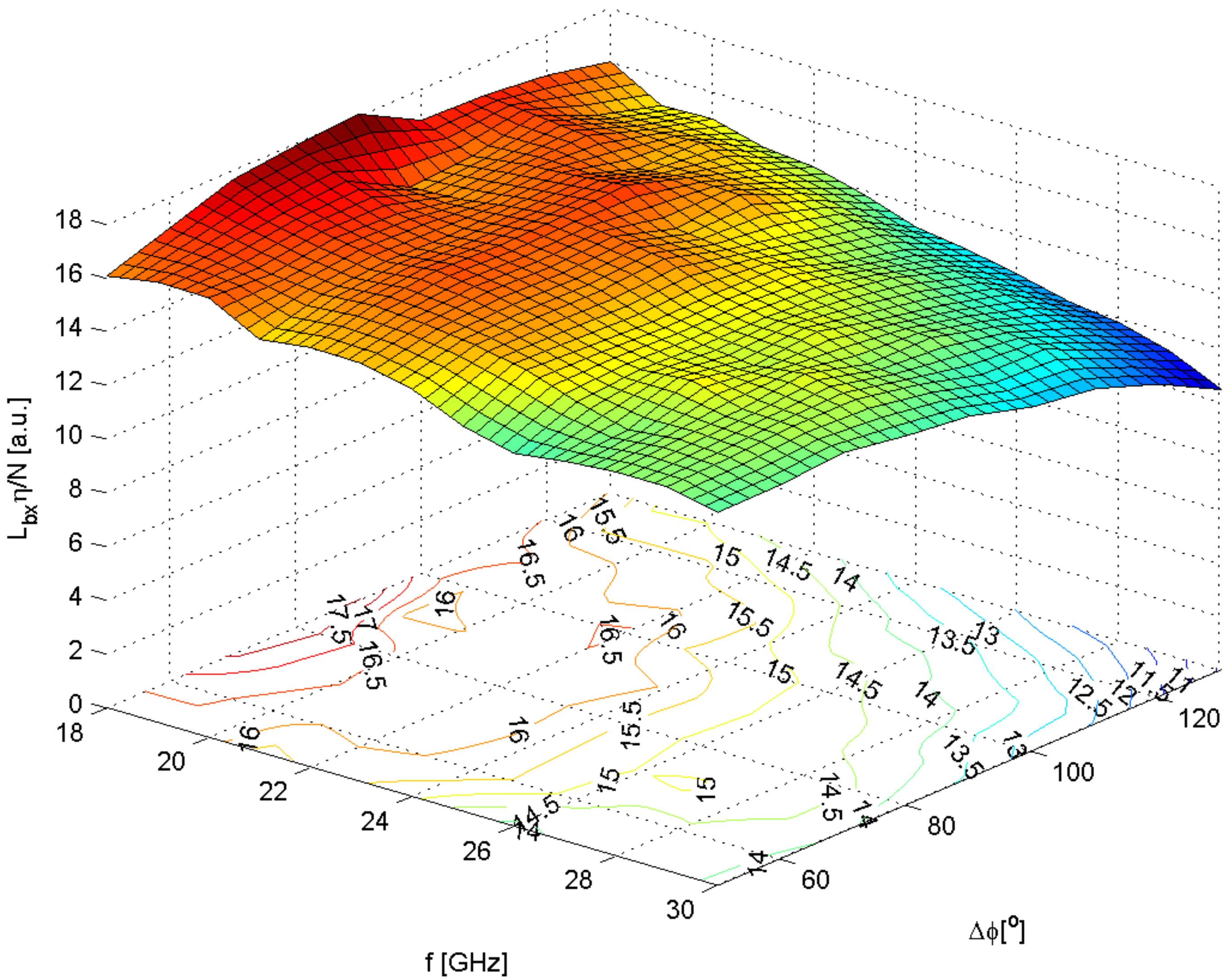
σ_x= 60nm, σ_y= 0.7nm , $W_{t,2}$ = 20V/pC/mm/m for N=4x10^9

σ_z, N, L_{bx} depend on f and a/λ

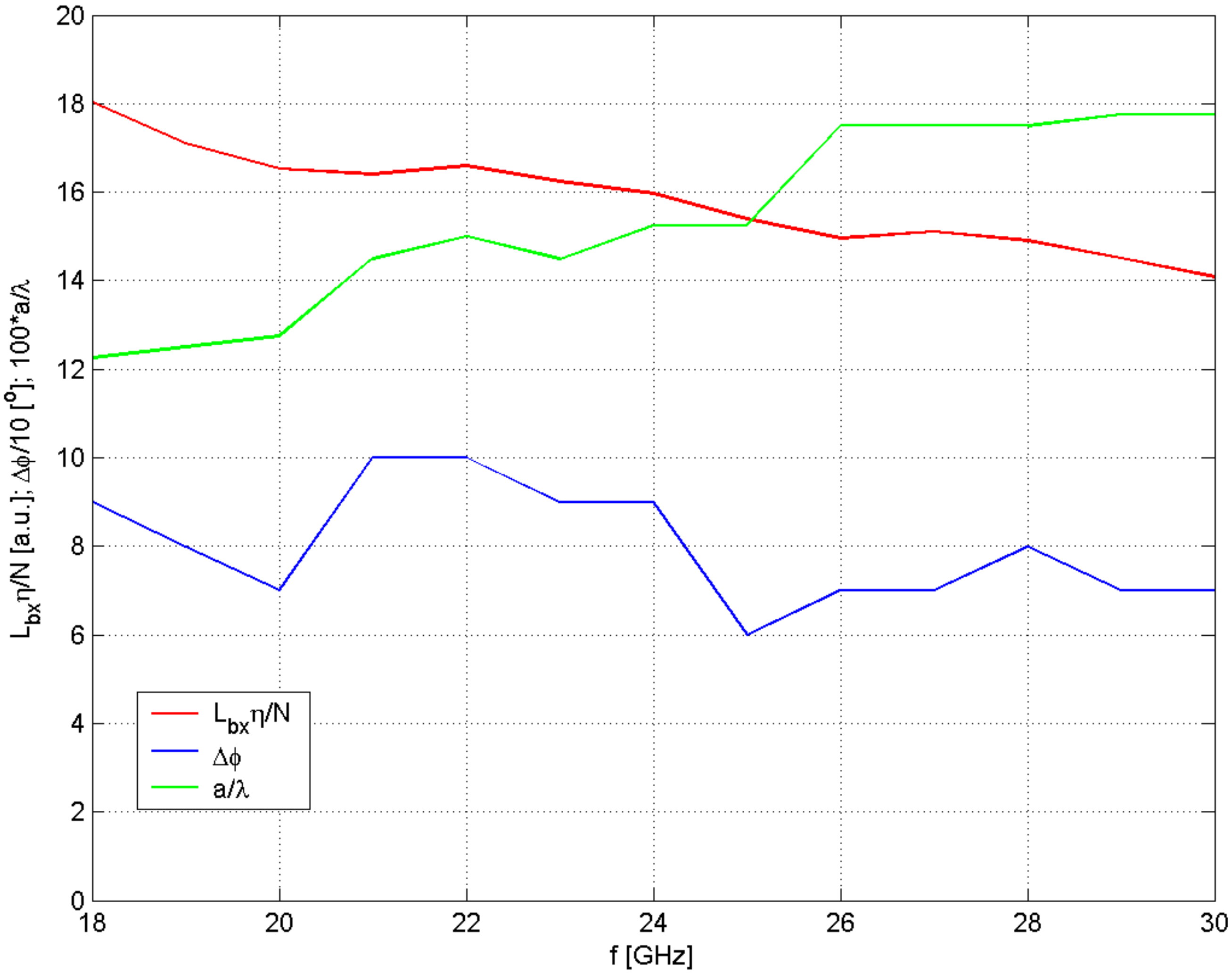
rf breakdown and pulsed surface heating (rf) constrains:

E_{surf} < 378 MV/m, ΔT < 56K, $P_{in}t_p^{1/2}$ < 1225MWns$^{1/2}$

Luminosity per power optimization



Luminosity per power optimization



Parameters of the best structure at different frequencies

f [GHz]	18	24	30	
$\Delta\varphi$ [°]	90	90	70	(110)
$\langle a/\lambda \rangle$	0.1225	0.1525	0.1775	(0.191)
$L_{bx}\eta/N$ [a.u.]	18	16	14	(12.6)
η [%]	38.5	34.6	34.2	(26.7)
$L_{bx}[10^{34}/m^2]$	1.77	1.39	1.07	(1.45)
N $[10^9]$	3.78	3.01	2.6	(3.08)
a_1, a_2 [mm]	2.42, 1.67	2.25, 1.56	2.1, 1.45	
d_1, d_2 [mm]	1.42, 0.667	1.00, 0.625	0.55, 0.35	
N_{cells}, l [mm]	39, 162	73, 228	125, 243	
P_{in}[MW]	112	146	157	
t_p[ns]	120.4	70.9	61.3	
N_b	353	218	217	
N_{cycles}, Δt_b [ns]	5, 0.278	6, 0.25	7, 0.233	

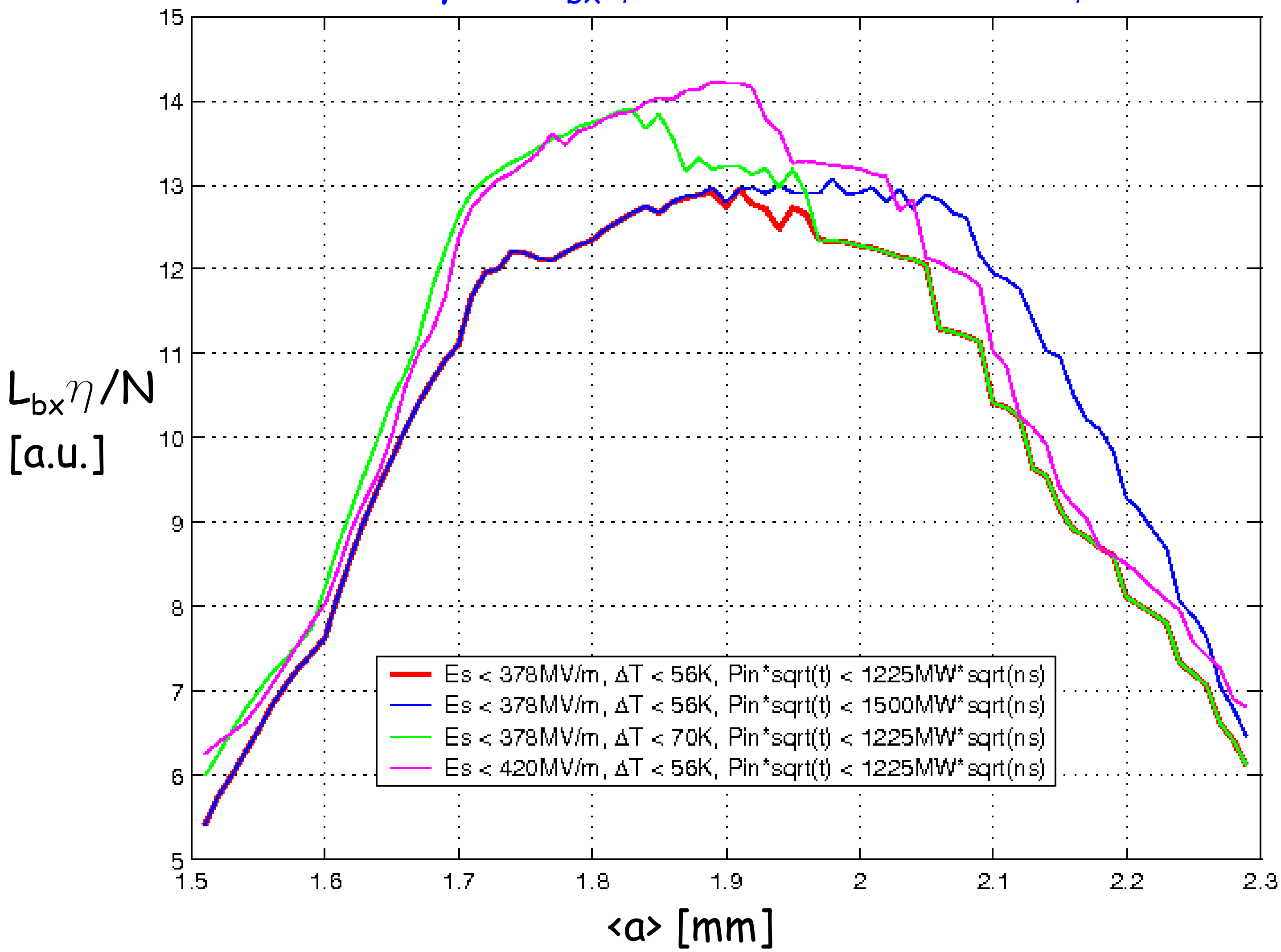
Luminosity per power optimization

Overall parameters based on these 3 structures and present

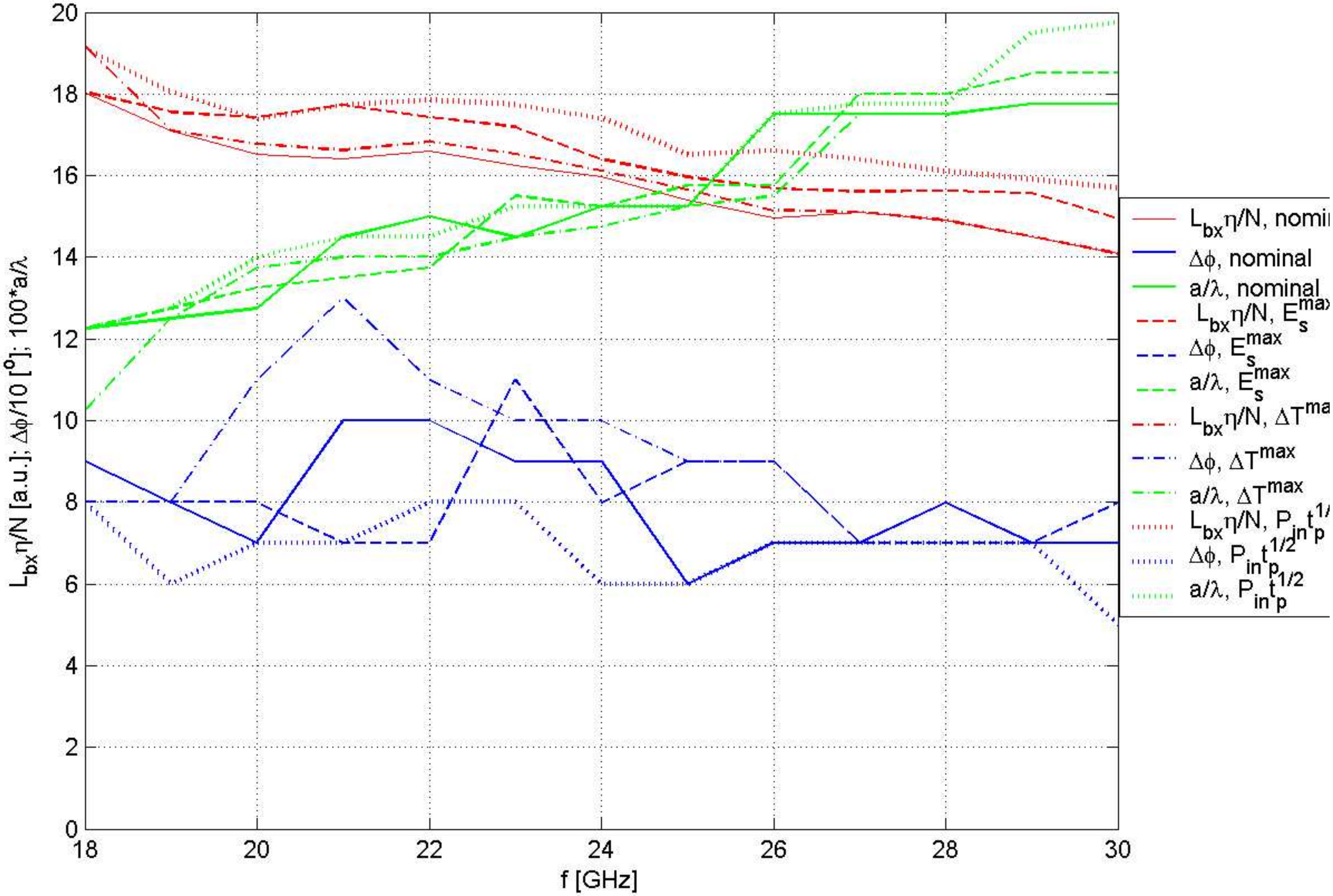
f [GHz]	18	24	30	30
L_1 [10^{34} $cm^{-2}s^{-1}$]	3.3	3.3	3.3	3.3
L_{tot} [10^{34} $cm^{-2}s^{-1}$]	7.2	6.7	6.2	8
σ_z [μm]	45	36	31	35
f_{rep} [Hz]	53	109	142	100
P_b [MW]	16.9	17.2	19.2	14.8
P_{AC} [MW]	220	248	281	319
η_{tot} [%]	15.4	13.8	13.7	9.3

Sensitivity to rf constrains

Sensitivity of $L_{bx}\eta/N$ at f= 30 GHz, $\delta\varphi$= 110°



Sensitivity to rf constrains



Power source cost optimization

H.-H. Braun and D. Schulte, CLIC note 563

$L_1 = 3.3 \times 10^{34}\ cm^{-2}s^{-1}$

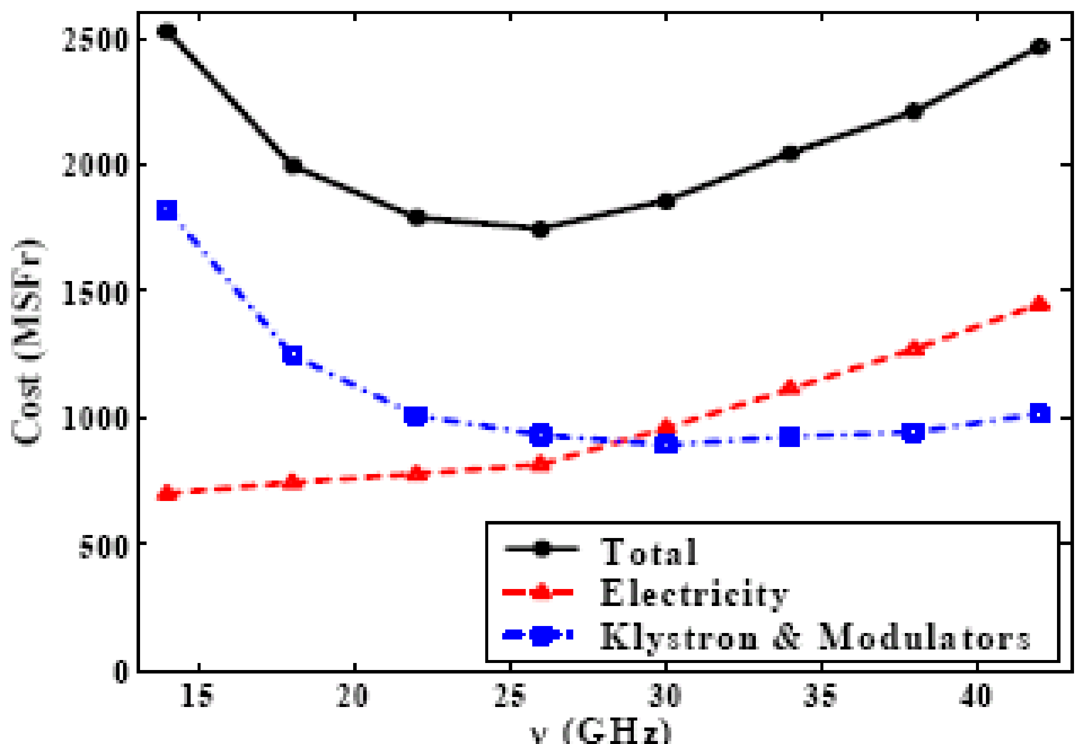


Fig. 4 Costs of power source with $\sigma_x^* \geq 60$nm.

Power source cost optimization

According to Daniel and Hans, total power source cost for fixed L_1:

$$C = C_E + C_I$$

where

$C_E = P_b / (\eta_{AC\text{-}rf} \times \eta_{rf\text{-}beam}) \times 5000h \times 10y \times 0.06SFr/kWh$ -- electricity

$C_I = C_U \times E \times Q_b \times N_b / (\eta_{dbrf\text{-}rf} \times \eta_{rf\text{-}beam}) / 4\ kJ$ ---------- investment

$C_U = 1.725MSFr + 0.012MSFr \times f_{rep}[Hz]$ ----- 4 kJ power source unit

$\eta_{AC\text{-}rf} = 0.4$, $\eta_{dbrf\text{-}rf} = 0.68$

In terms of our parameters:

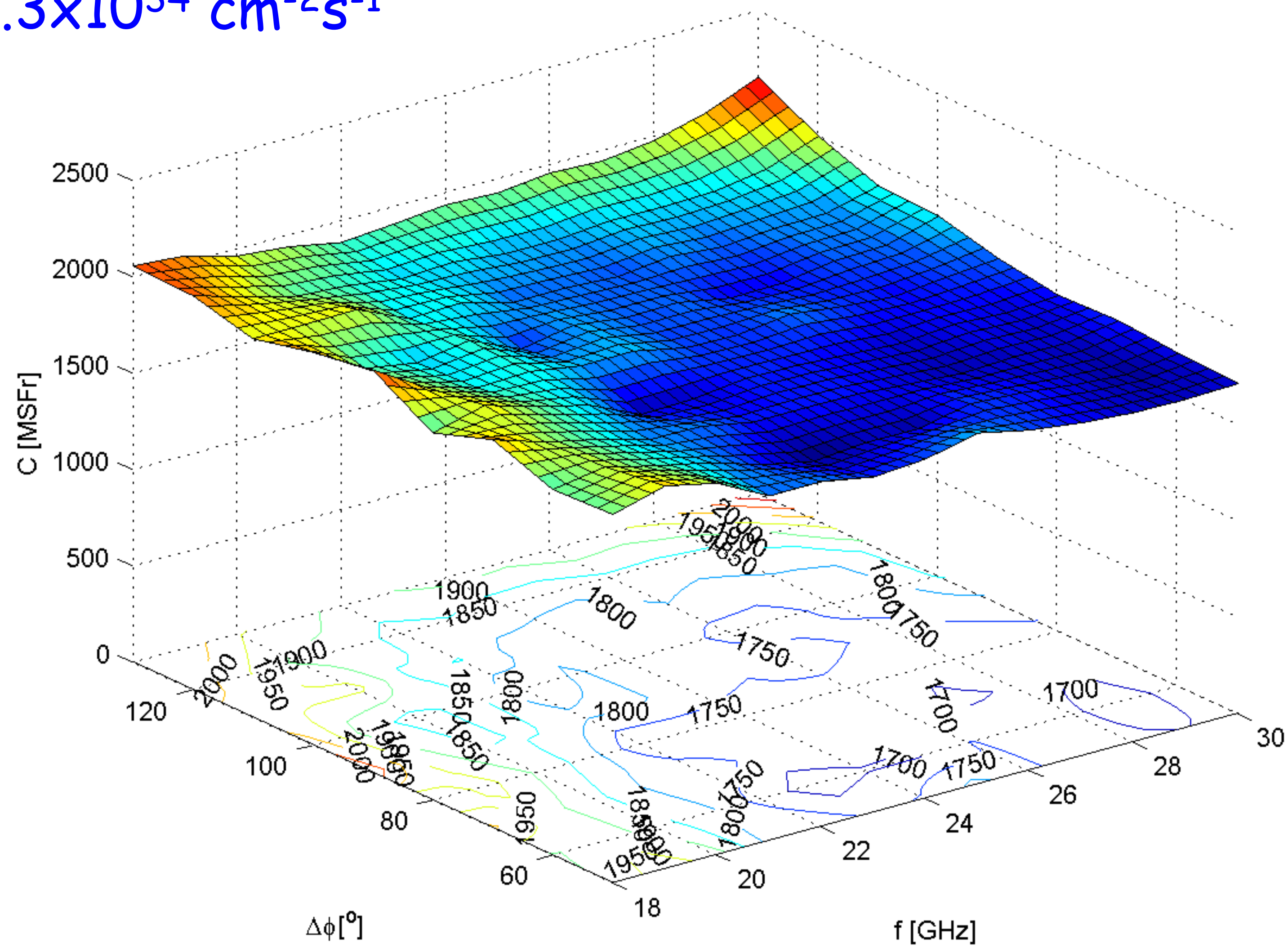
$$C_E \sim (L_{bx}\eta/N)^{-1}$$

$$C_I \sim N_b N/\eta + o\{(L_{bx}\eta/N)^{-1}\}$$

where $\eta = \eta_{rf\text{-}beam}$

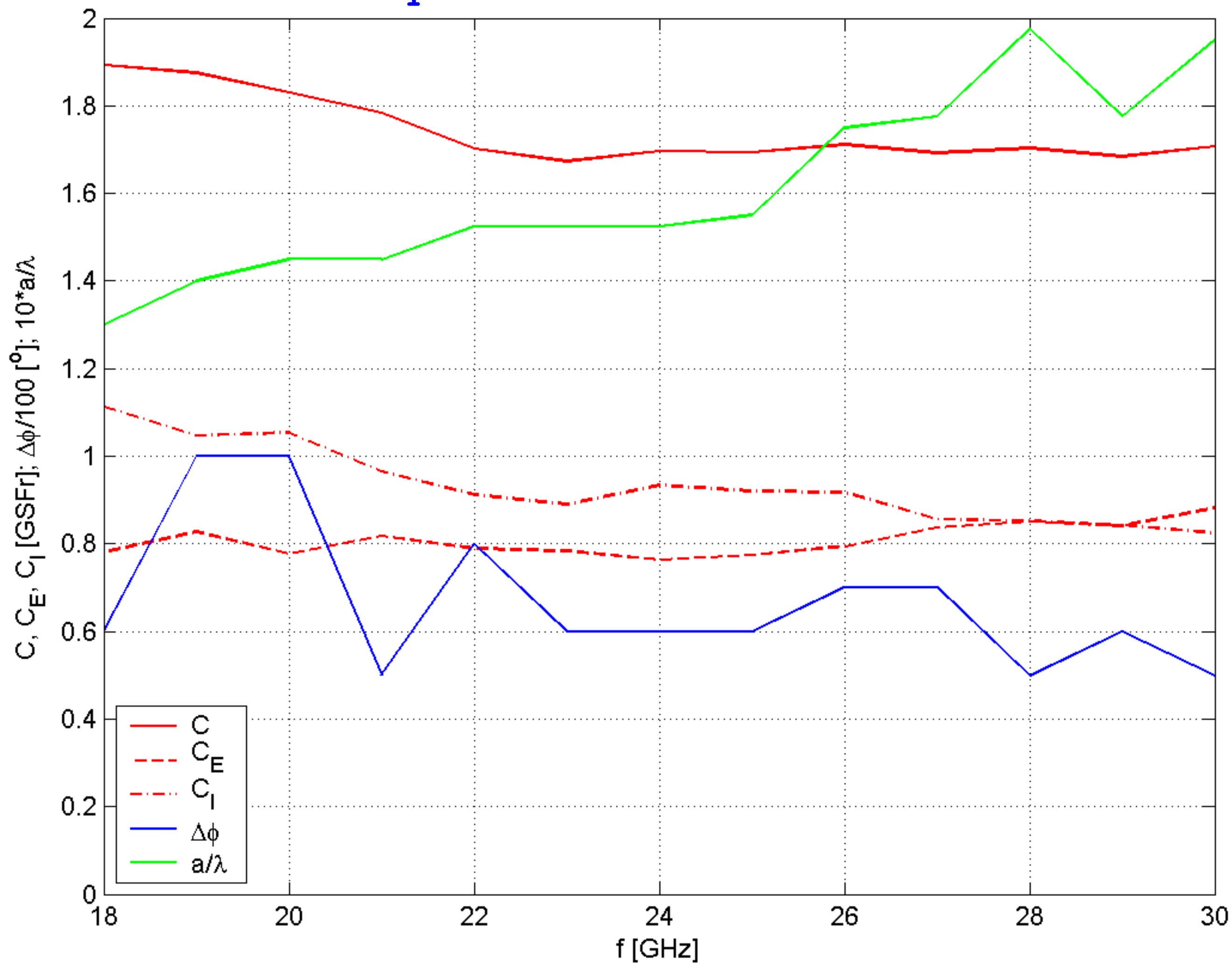
Power source cost optimization

$L_1 = 3.3 \times 10^{34}\ cm^{-2} s^{-1}$



Power source cost optimization

$L_1 = 3.3 \times 10^{34}\ cm^{-2}s^{-1}$



Power source cost optimization

Parameters of the best structure, L_1 = 3.3x10^{34} cm^{-2}s^{-1}

f [GHz]	18	24	30
$\Delta\varphi$ [°]	60	60	50
$\langle a/\lambda \rangle$	0.13	0.1525	0.195
$L_{bx}\eta/N$ [a.u.]	15.2	15.6	13.5
η [%]	33.5	34.2	28.5
L_{bx}[10^{34}/m^2]	1.99	1.39	1.57
N [10^9]	4.38	3.04	3.33
a_1, a_2 [mm]	2.67, 1.67	2.31, 1.5	2.3, 1.6
d_1, d_2 [mm]	0.83, 0.5	0.5, 0.31	0.25, 0.25
N_{cells}, l [mm]	70, 194	120, 250	211, 293
P_{in}[MW]	151	158	214
t_p[ns]	66.0	60.5	32.7
N_b	164	179	86
N_{cycles}, Δt_b [ns]	5, 0.278	6, 0.25	8, 0.267

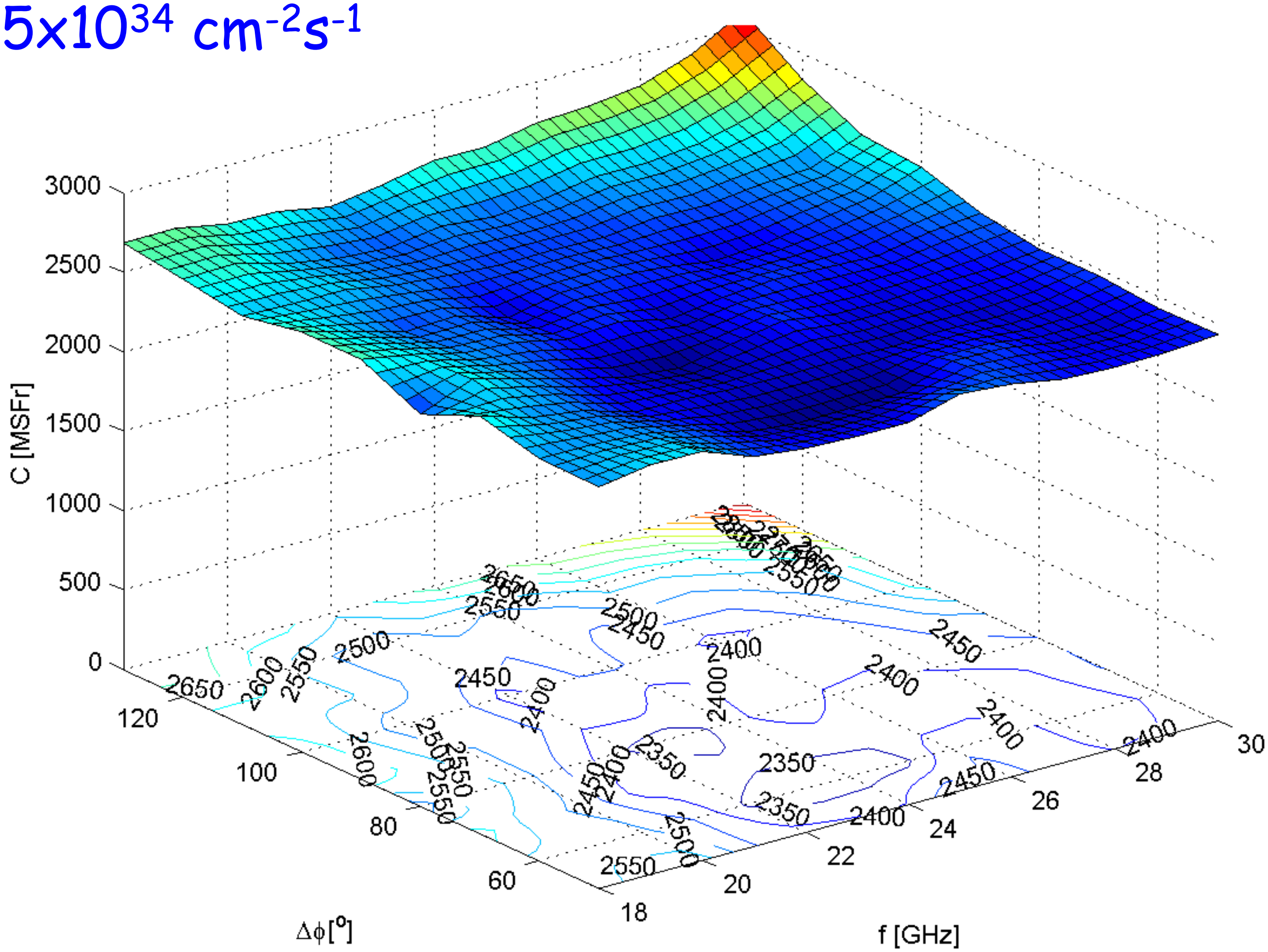
Power source cost optimization

Overall parameters based on these 3 structures and present

f [GHz]	18	24	30	30
L_1 [10^{34} $cm^{-2}s^{-1}$]	3.3	3.3	3.3	3.3
L_{tot} [10^{34} $cm^{-2}s^{-1}$]	7.6	6.7	6.8	8
σ_z [μm]	48	36	35	35
f_{rep} [Hz]	101	133	244	100
P_b [MW]	17.4	17.4	16.8	14.8
P_{AC} [MW]	260	254	294	319
η_{tot} [%]	13.4	13.7	11.4	9.3

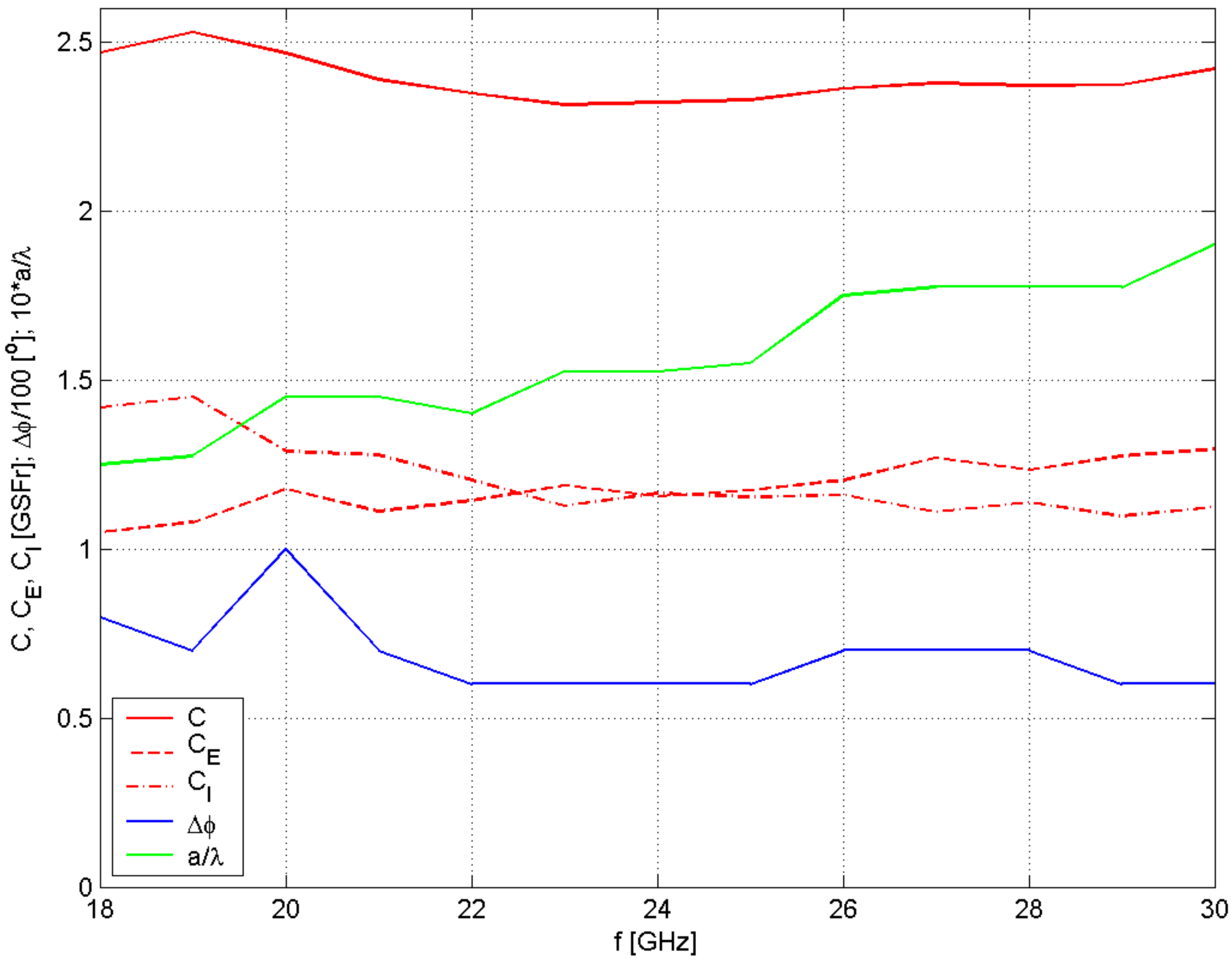
Power source cost optimization

$L_1 = 5 \times 10^{34}\ cm^{-2}s^{-1}$



Power source cost optimization

$L_1 = 5\times10^{34}\ cm^{-2}s^{-1}$



Power source cost optimization

Parameters of the best structure, $L_1 = 5x10^{34}$ Hz/cm^2

f [GHz]	18	24	30
$\Delta\varphi$ [°]	80	60	60
$\langle a/\lambda \rangle$	0.125	0.1525	0.19
$L_{bx}\eta/N$ [a.u.]	17.2	15.6	13.9
η [%]	36.9	34.2	30.4
L_{bx}[10^{34}/m^2]	1.84	1.39	1.42
N [10^9]	3.96	3.04	3.11
a_1, a_2 [mm]	2.5, 1.67	2.31, 1.5	2.25, 1.55
d_1, d_2 [mm]	1.17, 0.58	0.5, 0.31	0.25, 0.35
N_{cells}, l [mm]	50, 185	120, 250	165, 275
P_{in}[MW]	129	158	193
t_p[ns]	90.1	60.5	40.5
N_b	245	179	116
N_{cycles}, Δt_b [ns]	5, 0.278	6, 0.25	8, 0.267

CLIC

Power source cost optimization

Overall parameters based on these 3 structures and present

f [GHz]	18	24	30	30
L_1 [10^{34} cm^{-2}s^{-1}]	5	5	5	3.3
L_{tot} [10^{34} cm^{-2}s^{-1}]	11.1	10.1	10.1	8
σ_z [μm]	48	36	34	35
f_{rep} [Hz]	111	201	303	100
P_b [MW]	25.8	26.3	26.3	14.8
P_{AC} [MW]	350	385	432	319
η_{tot} [%]	14.8	13.7	12.2	9.3

What is the best frequency ?

18 GHz	- Highest luminosity per power - Highest efficiency - Lowest pick power
30 GHz	- Lowest energy per pulse - Biggest a/λ - Smallest iris thickness
24 GHz	- Compromise above items - Lowest cost for L_1=5x10^{34} cm^{-2}s^{-1} - Less dependent on optimization criteria

24 GHz

Summary

- The best 30 GHz structure parameters has been found based on luminosity per power criterion

- The best frequency has been found to be 24 GHz based on luminosity per power and energy per pulse criteria in the form of power source cost estimation

- Parameters of the 24 GHz structure and corresponding linac has been found and compared for L_1 = 3.3 and 5 times 10^{34} $cm^{-2}s^{-1}$