CLIC Power & Energy

Bernard Jeanneret & Philippe Lebrun

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Main contributors

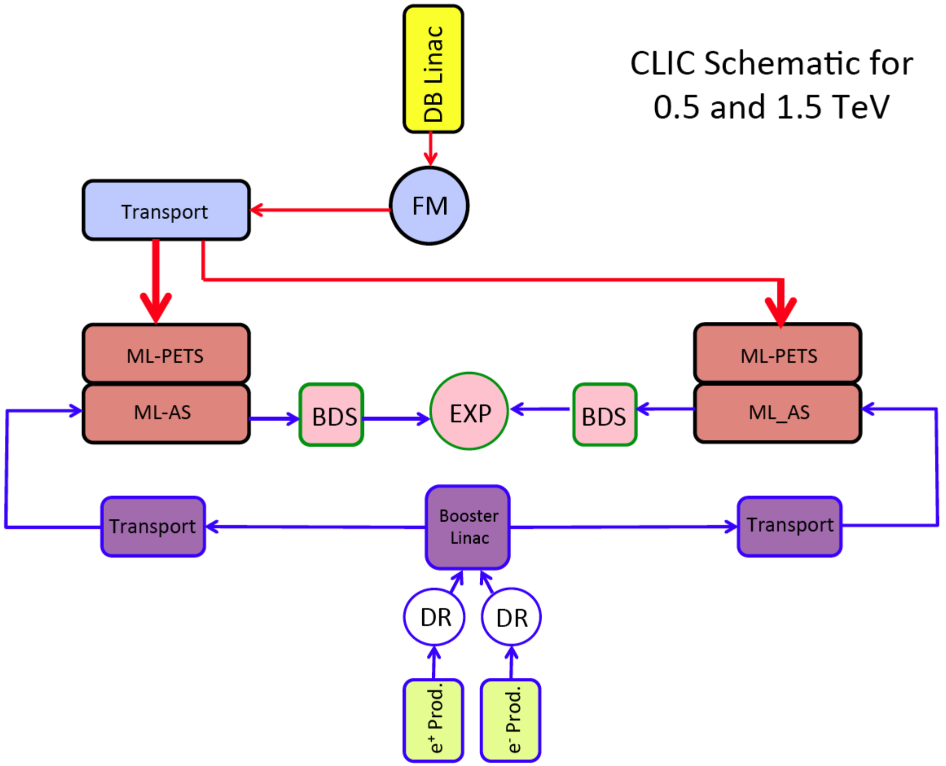
- DB Linac : D. Aguglia, E. Jensen, G. McMonagle, D. Nisbet, R. Wegner
- Magnets and powering : M. Modena, S. Pittet, D. Siemaszko, A. Vorozhtsov
- Main Linac RF : A. Grudiev, G. Ridonne, I. Syratchev
- Cool & Vent : M. Nonis
- Electrical network : C. Jach
- Damping ring : Y. Papaphilippou
- Main beam production : S. Doebert, L. Rinolfi
- BDS and Experimental area : L. Gatignon

OUTLINE

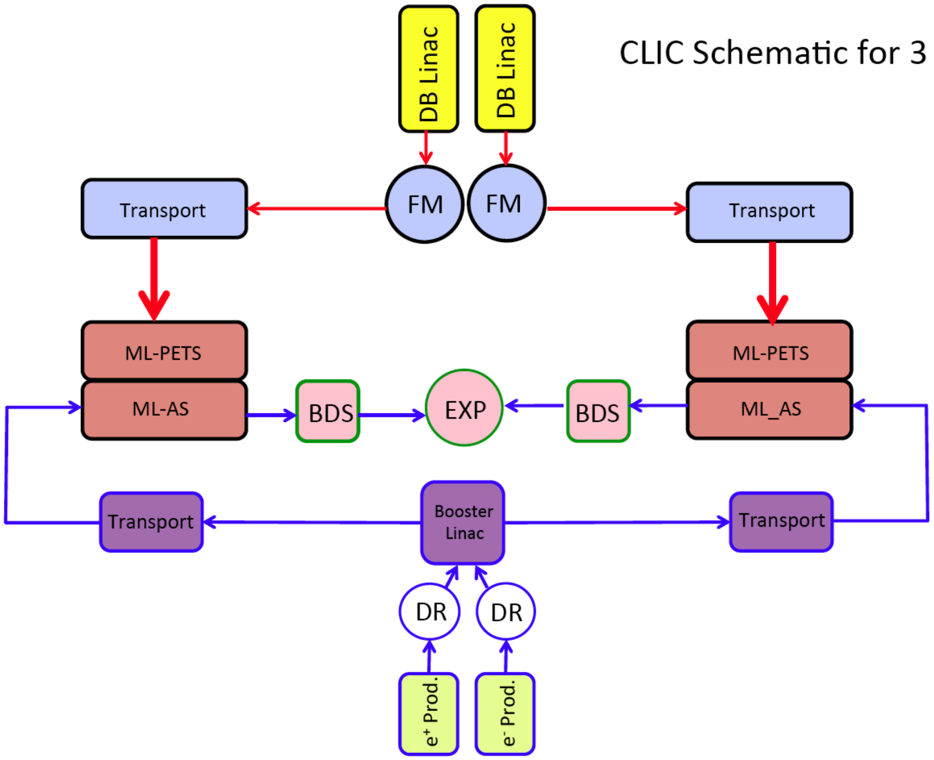
- CLIC power in CDR Vol. I
- Changes appearing in Vol. III
- Power optimization - I
- Power optimization - II , further studies

CLIC power in CDR Vol. I

CLIC functional schematics



CLIC Schematic for 0.5 and 1.5 TeV

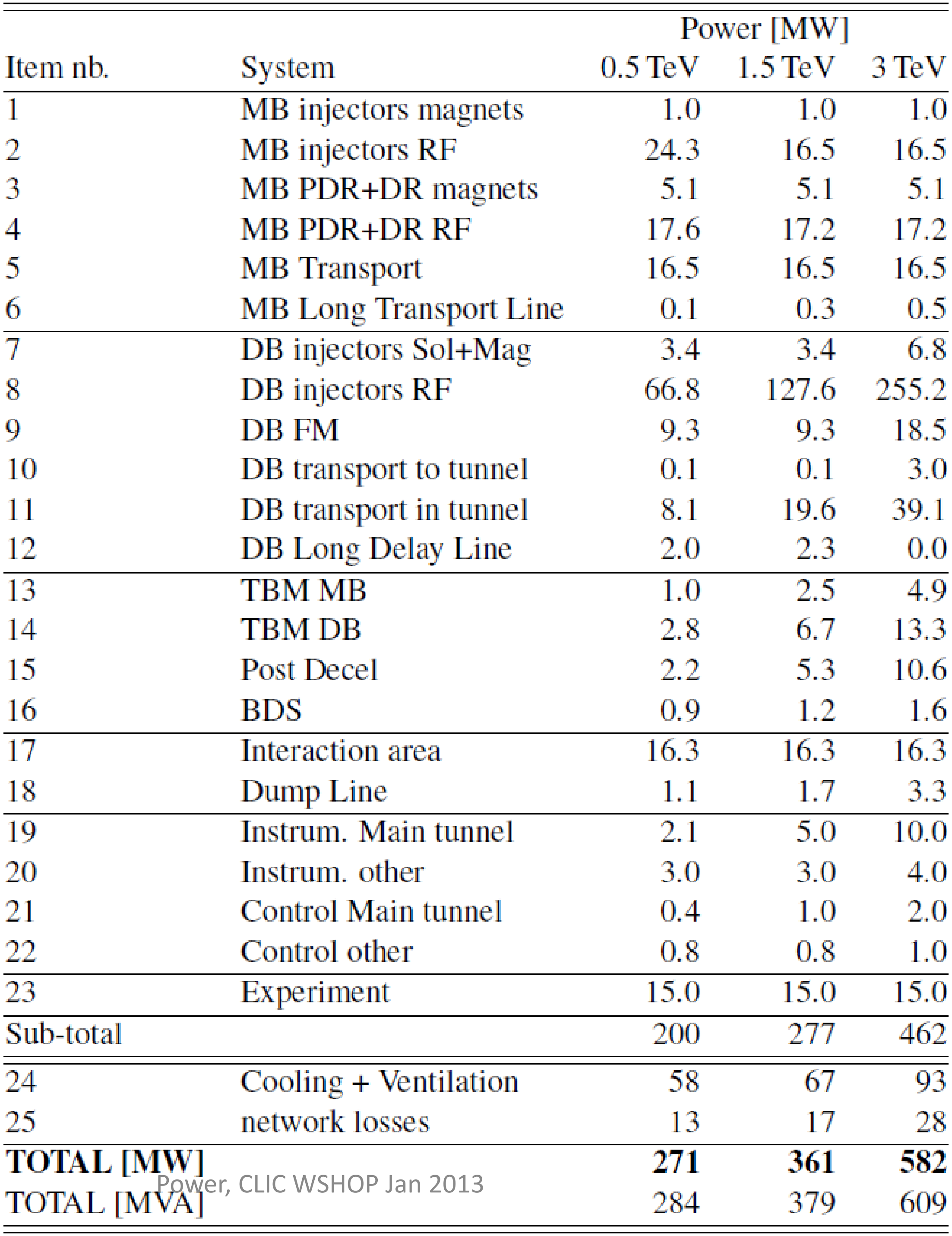


CLIC Schematic for 3 TeV

Pov

CLIC Power map

CDR Vol. I
(or Scenario ‘A’
at 0.5 TeV, see below)



		Power [MW]		
Item nb.	System	0.5 TeV	1.5 TeV	3 TeV
1	MB injectors magnets	1.0	1.0	1.0
2	MB injectors RF	24.3	16.5	16.5
3	MB PDR+DR magnets	5.1	5.1	5.1
4	MB PDR+DR RF	17.6	17.2	17.2
5	MB Transport	16.5	16.5	16.5
6	MB Long Transport Line	0.1	0.3	0.5
7	DB injectors Sol+Mag	3.4	3.4	6.8
8	DB injectors RF	66.8	127.6	255.2
9	DB FM	9.3	9.3	18.5
10	DB transport to tunnel	0.1	0.1	3.0
11	DB transport in tunnel	8.1	19.6	39.1
12	DB Long Delay Line	2.0	2.3	0.0
13	TBM MB	1.0	2.5	4.9
14	TBM DB	2.8	6.7	13.3
15	Post Decel	2.2	5.3	10.6
16	BDS	0.9	1.2	1.6
17	Interaction area	16.3	16.3	16.3
18	Dump Line	1.1	1.7	3.3
19	Instrum. Main tunnel	2.1	5.0	10.0
20	Instrum. other	3.0	3.0	4.0
21	Control Main tunnel	0.4	1.0	2.0
22	Control other	0.8	0.8	1.0
23	Experiment	15.0	15.0	15.0
Sub-total		200	277	462
24	Cooling + Ventilation	58	67	93
25	network losses	13	17	28
TOTAL [MW]		**271**	**361**	**582**
TOTAL [MVA]		284	379	609

Changes appearing in Vol. III

Changes proposed in CDR Vol. III

- Two alternative staging scenarios
  - Each with three stages: 500 GeV, ~1.5 TeV and 3 TeV
  - Scenario A: « optimized for luminosity in the first stage »
  - Scenario B: « optimized for lower entry cost »
  - First and last stages of scenario A are identical to CDR Volume 1
  - Reuse of 80 MV/m structures in scenario A limits the energy of the second stage to 1.4 TeV
- Scenario B has nominal bunch charge at all stages, resulting in
  - Use of final (100 MV/m) gradient structures already at 500 GeV
  - Shorter main linacs (2 x 4 sectors at 500 GeV)
  - Lower installed RF power in the MB and DB production complexes
  - One species of ML accelerating structures
  - Substantial cost reduction w.r.t. A , ~ 1GSF

Main Linac parameters , A vs. B

from CDR Vol III, tables 3.3 p.27 & 3.4 p.29

Scenario A

ECM	TeV	0.5	1.4	3
N_{bunch}		354	312	312
Q_{bunch}	10^9	6.8	3.7	3.7
G	MV/m	80	80/100	100
Lum	10^{34} cm^{-2} s^{-1}	2.3	3.2	5.9
Lum 1%		1.4	1.3	2
L tunnel	km	13.2	27.2	48.3
Total Power	MW	272	364	589

Scenario B

ECM	TeV	0.5	**1.5**	3
N_{bunch}		**312**	312	312
Q_{bunch}	10^9	**3.7**	3.7	3.7
G	MV/m	**100**	**100**	100
Lum	10^{34} cm^{-2} s^{-1}	**1.3**	**3.7**	5.9
Lum 1%		**0.7**	**1.4**	2
L tunnel	km	**11.4**	27.2	48.3
Total Power	MW	**235**	364	589

	A	A	B	B
	LUM_opt		**Low_entry**	
E_CM [TeV]	**0.5**	**1.4**	**0.5**	**1.5**
POWER [MW]				
MB injectors magnets	1	1	1	1
MB injectors RF	**24.3**	16.5	**16.5**	16.5
MB PDR+DR magnets	5.1	5.1	5.1	5.1
MB PDR+DR RF	17.6	17.2	17.2	17.2
MB Transport	16.5	16.5	16.5	16.5
MB Long Transport Line	0.1	0.3	0.1	0.3
DB injectors Sol+Mag	3.4	3.4	3.4	3.4
DB injectors RF	**66.8**	127.6	**49.0**	127.6
DB FM	9.3	9.3	9.3	9.3
DB transport to tunnel	0.1	0.1	0.1	0.1
DB transport in tunnel	8.1	19.6	6.5	19.6
DB Long Delay Line	2.0	2.3	2.0	2.3
TBM MB	2.0	4.9	1.6	4.9
TBM DB	2.8	6.7	2.2	6.7
Post Decel	2.2	5.3	2.0	5.3
BDS	0.9	1.2	0.9	1.2
Interaction area	16.3	16.3	16.3	16.3
Dump Line	1.1	1.7	1.1	1.7
Experiment	15.0	15.0	15.0	15.0
Instrum. Main tunnel	2.1	5.0	2.0	5.0
Instrum. other	3.0	3.0	3.0	3.0
Control Main tunnel	0.4	1.0	0.4	1.0
Control other	0.8	0.8	0.8	0.8
Cooling & Ventilation	58.0	67.0	52.2	67.0
Network Losses	13.0	17.0	11.3	17.0
TOTAL POWER [MW]	**272**	**364**	**235**	**364**

Twice fewer e^+

26% gain :
16% on beam
10% on klystrons at optimum yield

Proportional reduction with the above

Gain : 37 MW
At 500 GeV

Integrated luminosity request

- See CRD vol. III , Chapter 6

(0.3 &) 0.5 TeV	500 fb^{-1}
1.4 / 1.5 TeV	1500 fb^{-1}
3 TeV	2000 fb^{-1}

From power to energy

	Shut down & fault stops	Beam time	Split as		Fractional downtime
1st year	188 days	177 days	59	Commissioning Injectors & sectors 1 by 1	50 %
			59	Commissioning Main Linac 1 by 1	50 %
			59	Luminosity operation	50%
2nd year	188 days	177 days	88	1 linac at a time	30%
			88	Luminosity operation	0%
3rd, 4th …	188 days	177 days	177	Luminosity operation, nominal	0%

Staging Scenario	E_{CM} [TeV]	P_{nominal} [MW]	$P_{\text{waiting for beam}}$ [MW]	P_{shutdown} [MW]
A	0.5	272	168	37
	1.4	364	190	42
	3.0	589	268	58
B	0.5	235	167	35
	1.5	364	190	42
	3.0	589	268	58

See CDR
Vol. III

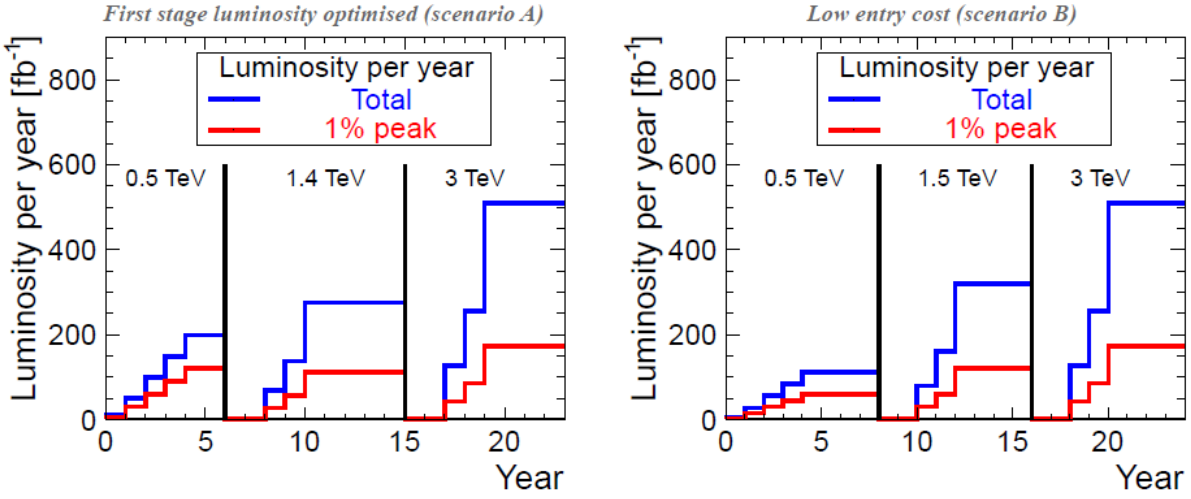
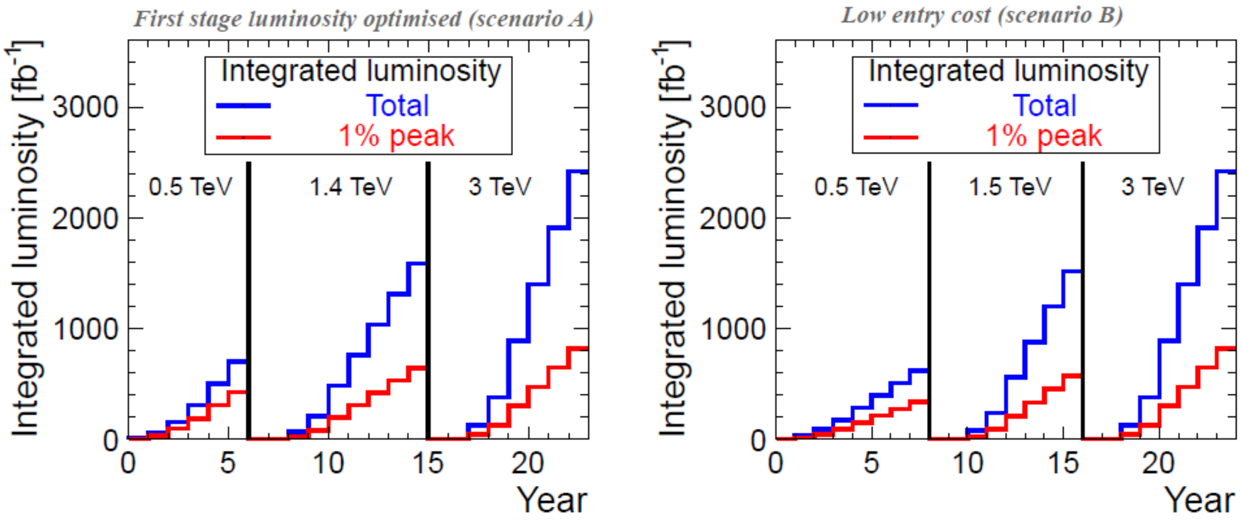


Fig. 5.1: Luminosity per year in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right).



Overall :
23 yrs with A
24 yrs with B
for same
integrated
luminosity

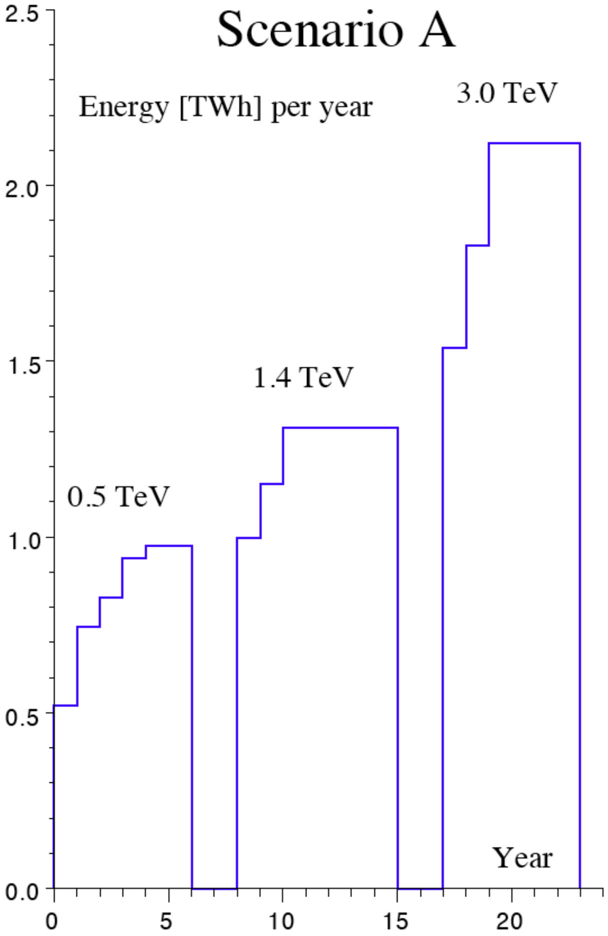
Fig. 5.2: Integrated luminosity in the scenarios optimised for luminosity in the first energy stage (left) and optimised for entry costs (right). Years are counted from the start of beam commissioning. These figures include luminosity ramp-up of four years (5%, 25%, 50%, 75%) in the first stage and two years (25%, 50%) in subsequent stages.

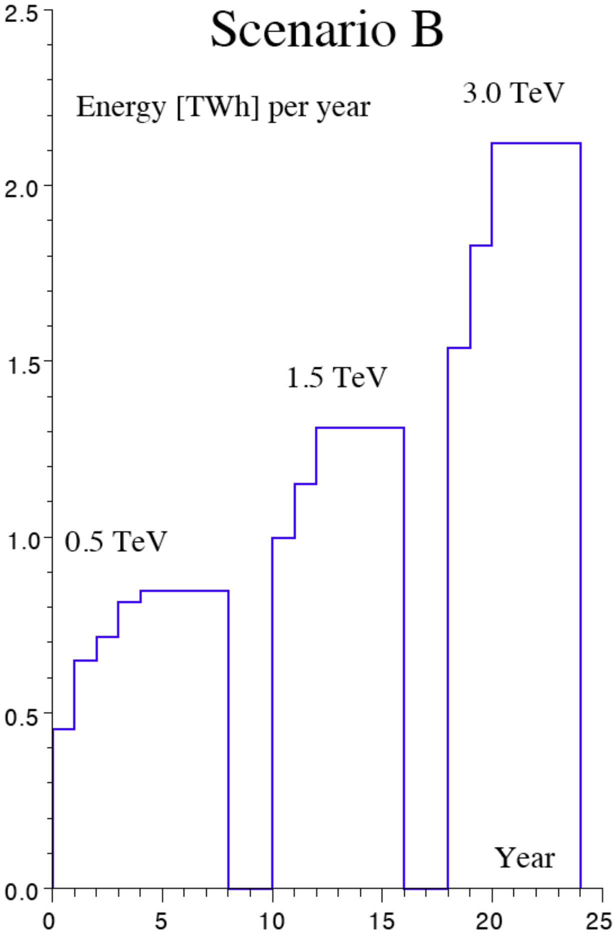
Yearly and total energy consumption

Integral over the whole programme

- Scenario A : 25.6 TWh
- Scenario B : 25.3 TWh

} Nearly identical





Summary for A vs. B

- ‘A’ requires 6 yrs , and ‘B’ 8 yrs for the same integrated Luminosity as 0.5 TeV
- But ‘B’ requires one year less at 1.5 TeV (higher energy → more luminosity)
- Total Program 0.5 -3 TeV, A : 23 yrs, B : 24 yrs
- Same total energy spent
- Cost_A - Cost_B ~ 1 GSF
- Simpler and more homogeneous systems with B

Power optimization - I

DB Linac , Klystron and modulator yields - I

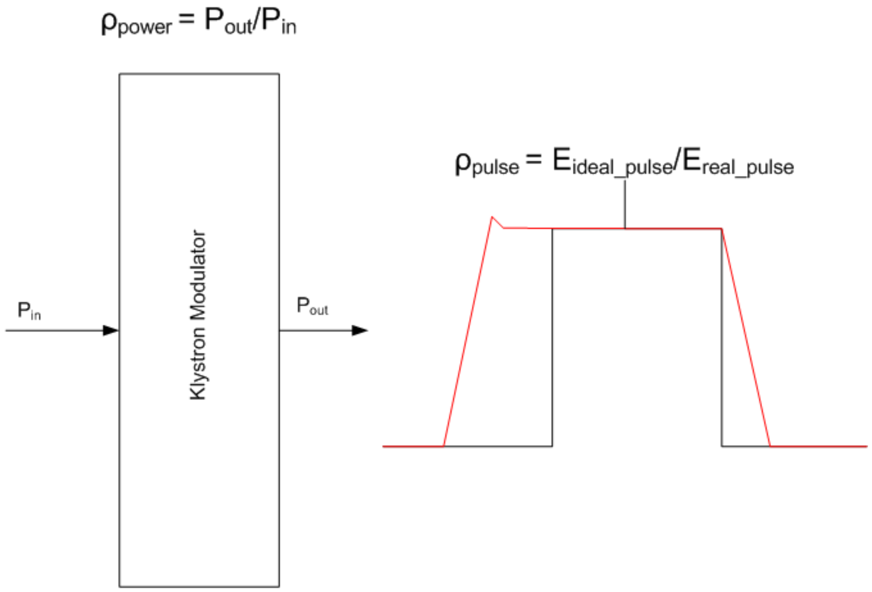
- For being the biggest power position at 3 TeV, the designers of the modulators and klystrons of the DB linac were put under strong pressure for high yields

- For CDR power calculation
  - A target klystron yield η_K=0.7 was chosen
    - This was strongly questioned in Granada_2011
    - Best achieved as of today η_K=0.68 (SLAC) , unstable beyond

  - The rise and set-up times of modulators were fixed ambitiously down to τ = 5µs
    - This while the jitter on output voltage need to be $\delta V/V \approx 10^{-5}$, with best achieved today 10^{-3} (D. Nisbet, D. Aguglia and S.Pittet)

- This shall be put in perspective with the overall picture and with more emphasis on the 500 GeV case

Development of high-efficiency modulators

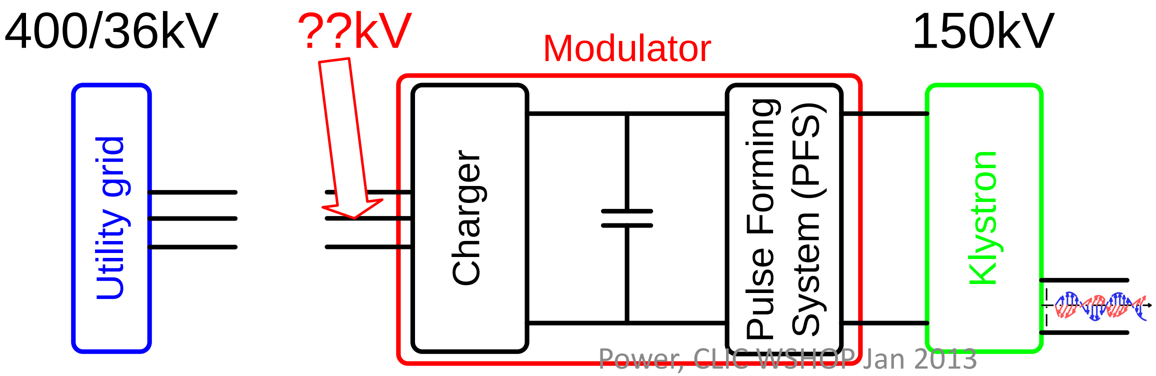


$$\rho_{power} = P_{out}/P_{in}$$

$$\rho_{pulse} = E_{ideal\_pulse}/E_{real\_pulse}$$

Useful flat-top Energy	22MW*140µs = 3.08kJ
Rise/fall time energy	22MW*5µs*2/3= 0.07kJ
Set-up time energy	22MW*5µs = 0.09kJ
Pulse efficiency	**0.95**
Pulse forming system efficiency	0.98
Charger efficiency	0.96
Power efficiency	**0.94**
Overall Modulator efficiency	**89%**

$$\rho_{modulator} = \rho_{power} * \rho_{pulse}$$



D. Nisbet, D. Aguglia
E. Sklavonou & S. Pittet
Granada 2011

DB linac : Klystron & Modulator yields - II

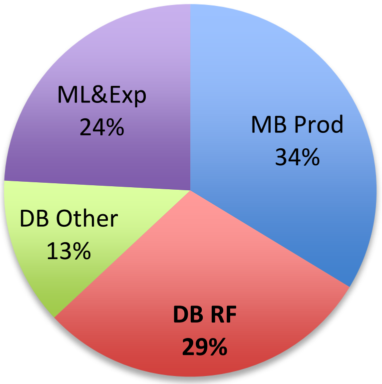
ΔP_1 : Change $\tau = \tau_{rise} = \tau_{\tau set\text{-}up} = 5\mu s$ to $\tau = 10\mu s$

ΔP_2 : Change $\eta_K = 0.7$ to $\eta_K = 0.68$

[MW]	$P_{DB\text{-}RF}$ CDR	ΔP_1	ΔP_2	$P'_{DB\text{-}RF}$	P_{tot} CDR	P'_{tot} CDR
500 B	69	+2.3	+10	81.3	235	247
3 TeV	305	+8	+14	327	589	611

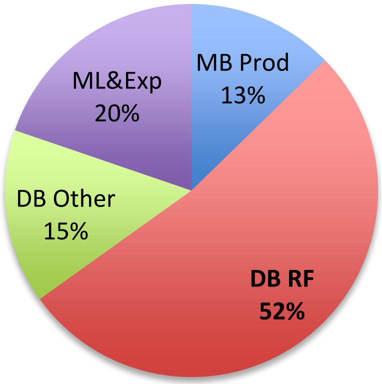
Including all overheads

Fraction $P_{DB\text{-}RF}/P_{tot}$	*CDR*	*relaxed*
500 B	*29%*	*33%*
3 teV	*52%*	*54%*



500 GeV – B, total 235 MW

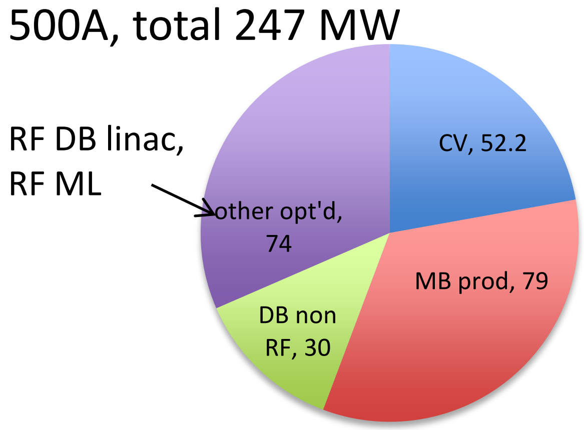
CDR data



3 TeV, total 589 MW

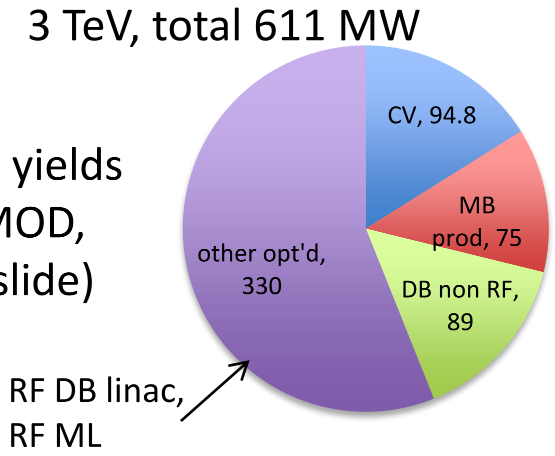
Towards future work

- In the future the focus for optimization may go on for other systems, in particular
  - CV , presently evaluated for low cost with the usual approach
  - MB production deserves a closer look
- It shall be more easy and less challenging to economize 12.3 and 22 MW respectively with these two domains


500A, total 247 MW

RF DB linac, RF ML

With relaxed yields
For DB K & MOD,
(see former slide)


3 TeV, total 611 MW

RF DB linac, RF ML

Power optimization – II further studies

Further power savings - Sobriety

P.Lebrun
Arlington 2012

- Reduced current density in normal-conducting magnets
  - For given magnet size and field, power scales with current density
  - Compromise between capital & real estate costs on one hand, and operation costs on the other hand
- Reduction of HVAC duty
  - Most heat loads already taken by water cooling
  - Possible further reduction in main tunnel by thermal shielding of cables
  - Possible reduction in surface buildings by improved thermal insulation, natural ventilation, relaxation of temperature limits

Further power savings - Efficiency

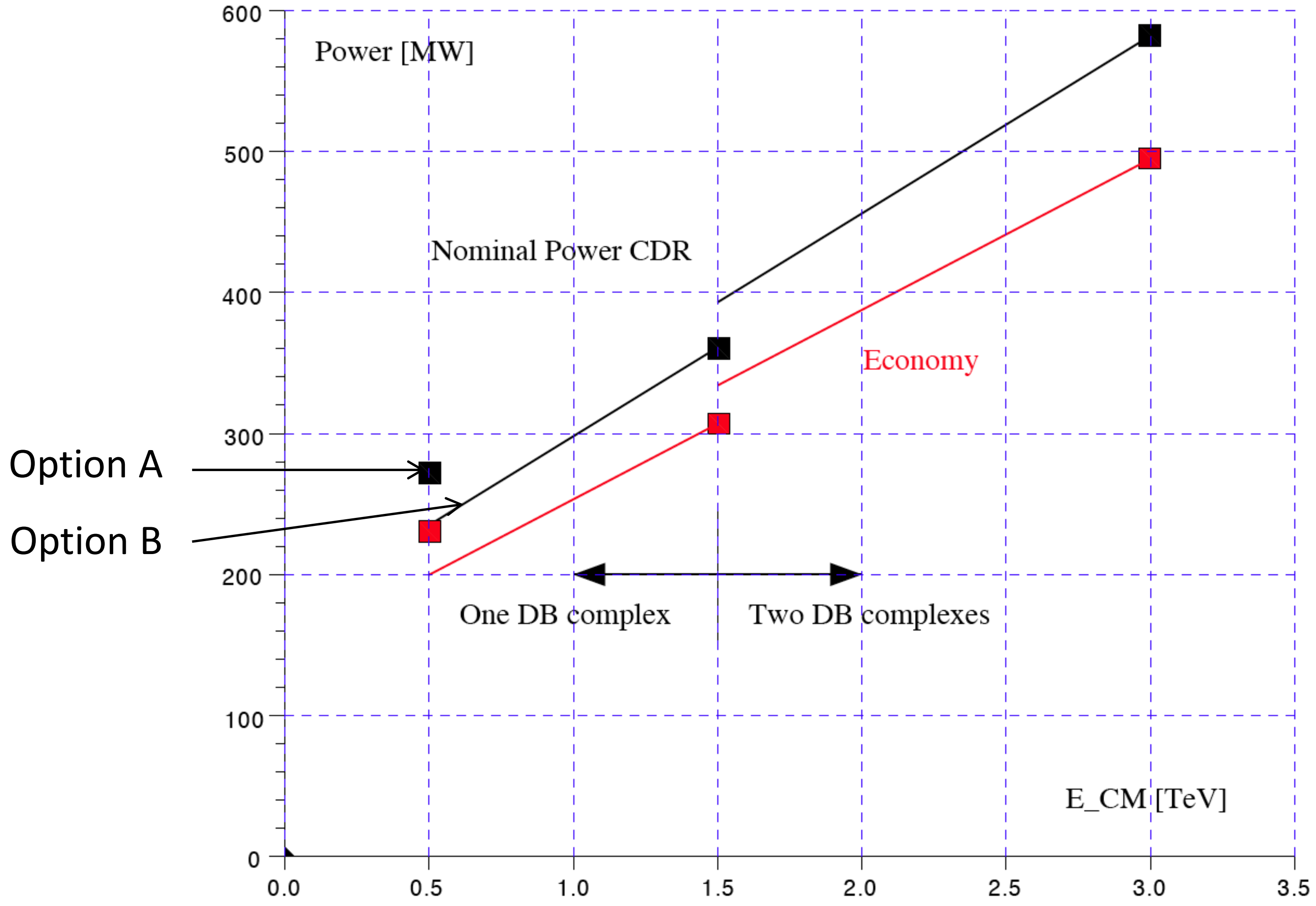
P.Lebrun
Arlington 2012

- Grid-to-RF power conversion
  - R&D on klystrons and modulators (DB and MB production)
  - Powering from the grid at HV
- RF-to-beam power conversion
  - Re-optimization of accelerating structures and gradient with different objective function (present value 0.25)
  - DB Linac structure (on-going, A. Grudiev) →
- Permanent or super-ferric superconducting magnets
  - Permanent magnets
    - distributed uses, e.g. main linac DB quads
    - fixed-field/gradient or mechanical tuning
  - Super-ferric superconducting magnets
    - « grouped » and DC uses, e.g. combiner rings, Damping rings(?), DB and MB return loops in main linacs

higher gradient :
→ Shorter building,
→ Less CV power

⇒ Potential for power savings at 3 TeV
- magnets ~ 86 MW
- cooling & ventilation ~24 MW

Power consumption versus E_{CM}



Option A

Option B

Summary

- Still somebody to prefer Scenario A ?
- Further optimization may decrease substantially the power needs
  - Need studies on all systems, not only on RF
  - Power efficiency must be full part of the design criteria