LCD - Power Consumption

A look at the LHC Detectors power consumption and a tentative evaluation of LC Detectors needs.

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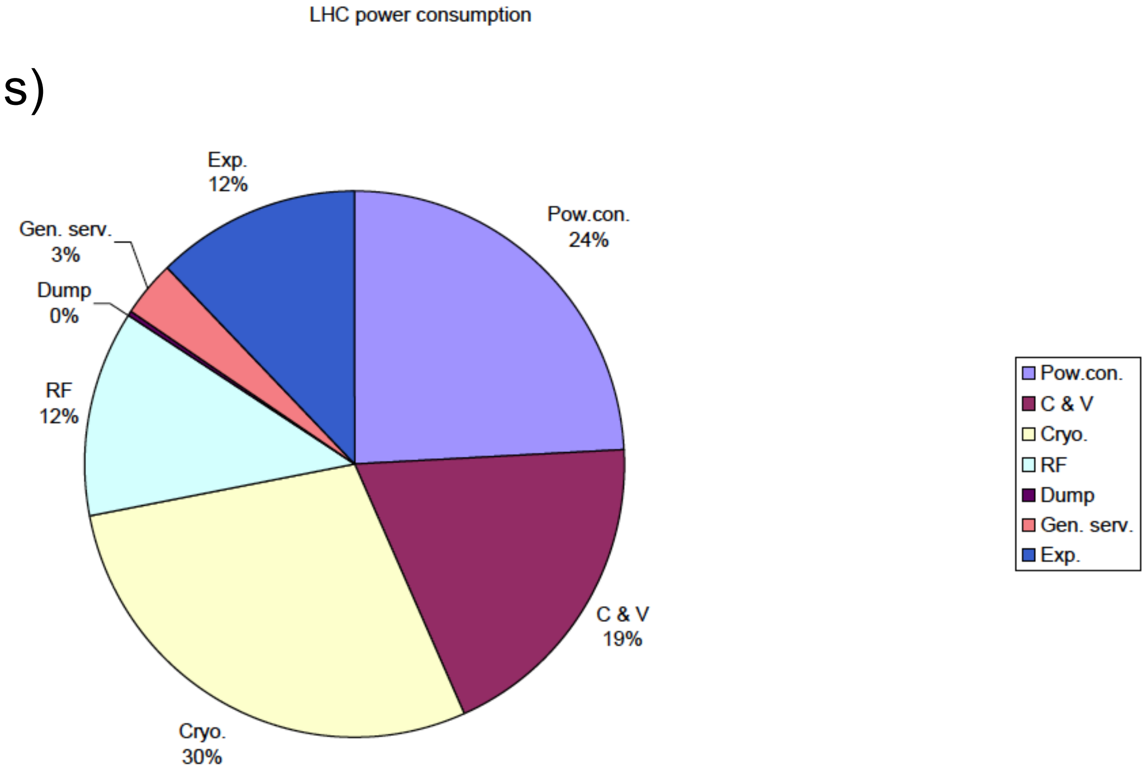
The LHC electrical power.

The electrical steady-state power of LHC is shared by the following main systems:

- Cryogenics
- Power converters
- Cooling & Ventilation (including experimental areas)
- Radiofrequencies
- Experiments (see later for details)



The total power is 132MW corresponding to 157MVA, with an average power factor 0.84

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LHC Detectors power consumption (year 2011).

Atlas	Total	38945	MWh	
	Magnet	2030	MWh	*(superconducting magnet)*
	Cryogenics	26163	MWh	*(Toroids + Solenoid + L-Ar Ecal)*
	Electronics	10752	MWh	
CMS	Total	16117	MWh	
	Magnet	818	MWh	*(superconducting magnet)*
	Cryogenics	6217	MWh	*(Solenoid)*
	Electronics	9082	MWh	
Alice	Total	49903	MWh	
	Magnet	46897	MWh	*(resistive magnet)*
	Electronics	3006	MWh	
LHCb	Total	24607	MWh	
	Magnet	20636	MWh	*(resistive magnet)*
	Electronics	3971	MWh	

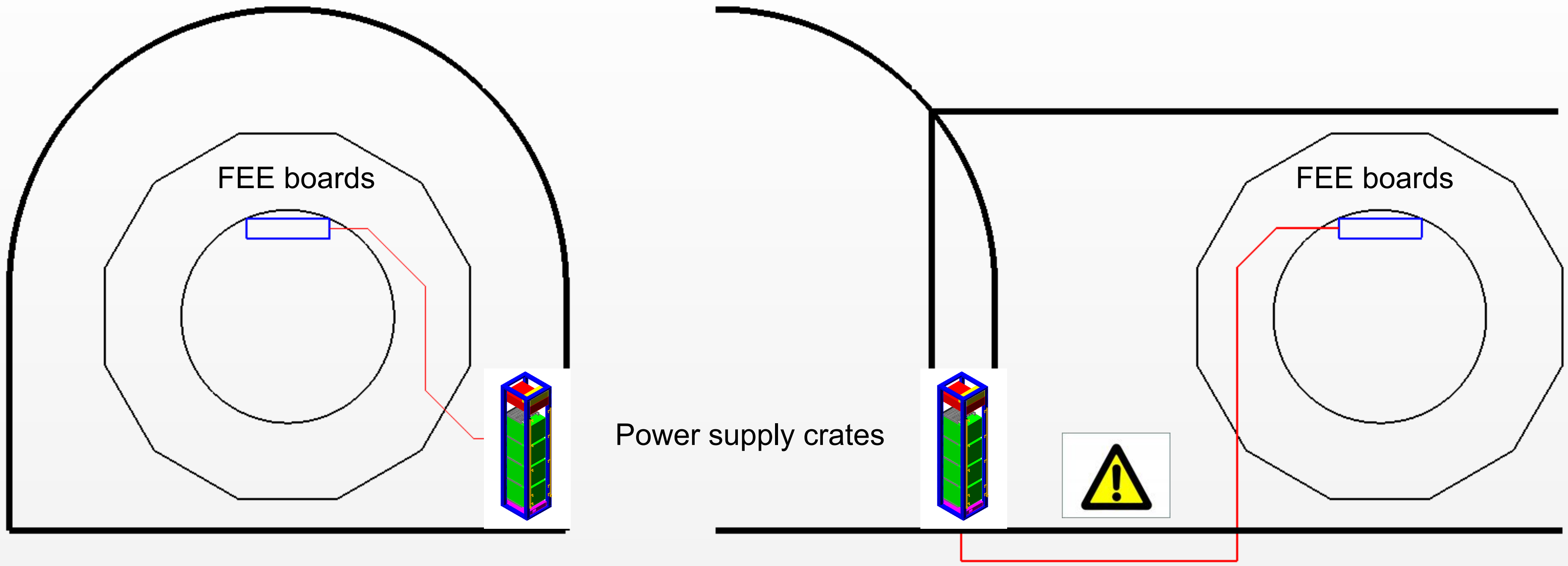
CMS global power consumption and duty cycle.

Detector Magnet (Cryogenics + Powering):	900 kW
Detector Electronics Total:	2000 kW
Front-End Electronics:	600 kW
DAQ Electronics:	700 kW
Offline Electronics:	700 kW *(will be 1MW after LS1)*
Detector Services Total:	1300$^{(winter)}$ – 1400$^{(summer)}$ kW
Cooling:	700$^{(w)}$ – 1000$^{(s)}$ kW
HVAC:	600$^{(w)}$ – 400$^{(s)}$ kW
CMS Detector Total (steady-state):	4.25 MW

Considering 1 week off every 6 weeks + 4 weeks off YETS, there are 40 weeks of run i.e. 280 days, $\frac{16117}{280}$ gives 58 MWh/day as daily average consumption (C) over a year run. The steady-state average power is 2.9 MW (see above), thus the duty cycle results to be in average $f_{duty} = \frac{58}{(2.9x24)} = 0.83$

FEE power efficiency: from the wall-plug to the detector.

At CMS, the average efficiency (η_{TOT}) of the FEE powering chain is about 67%.
1/3 of the power is lost either in the <u>power supply crates</u> (η=0.8), or in the <u>voltage regulators</u> (η=0.9) or in the <u>cables</u> (η=0.5 – 0.95). The spread in the cable efficiency is explained by the fact that the cable cross section is a compromise between the maximum compactness (i.e. no dead-space) and minimum power losses. CMS is a stationary detector, for a LC Detector moving on platform, the length of cables could be significantly higher (and consequently the power losses).



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CMS sub-detectors FEE power consumption.

Sub-detector	Technology	Power/ Channel mW	Nr. Of Channels	Total sub-detector kW
VERTEX	SILICON PIXELS	5.5×10^{-2}	$66 \mathrm{X} 10^{6}$	3.63 x2 for cables losses
TRACKER	SILICON STRIPS	2.3	$9.3 \mathrm{X} 10^{6}$	21.39, at t=0 +60% after 10 years x2 for cables losses
PRE-SHOWER	SILICON STRIPS	36.5	1.37×10^{5}	5 x1.6 for cables losses
ECAL	SCINTILLATING CRYSTALS	2.5×10^{3}	7.58×10^{4}	190 x1.6 for cables losses
HCAL	SCINTILLATING FIBERS			<5
MUON	GAS CHAMBERS			<60

CMS & LC Detectors difference from powering point of view.

The daily total consumption (at the wall-plug), results to be:

$$C_{TOT} = C_1 + C_2 + \ldots + C_n = \sum C_{(i)} = \frac{P_{peak(i)} \times f_{duty(i)}}{\eta_{(i)}}$$

Where: 1,2, …, n are the different detector sub-systems
$P_{peak} = p_{channel}$ x channels
f_{duty} = the fraction of time the sub-system is <on>
η = efficiency of the power chain

It is expected that LC Detectors will have a higher nr. of channel with a much smaller duty factor and a comparable, or slightly lower, efficiency (in the case of push-pull).

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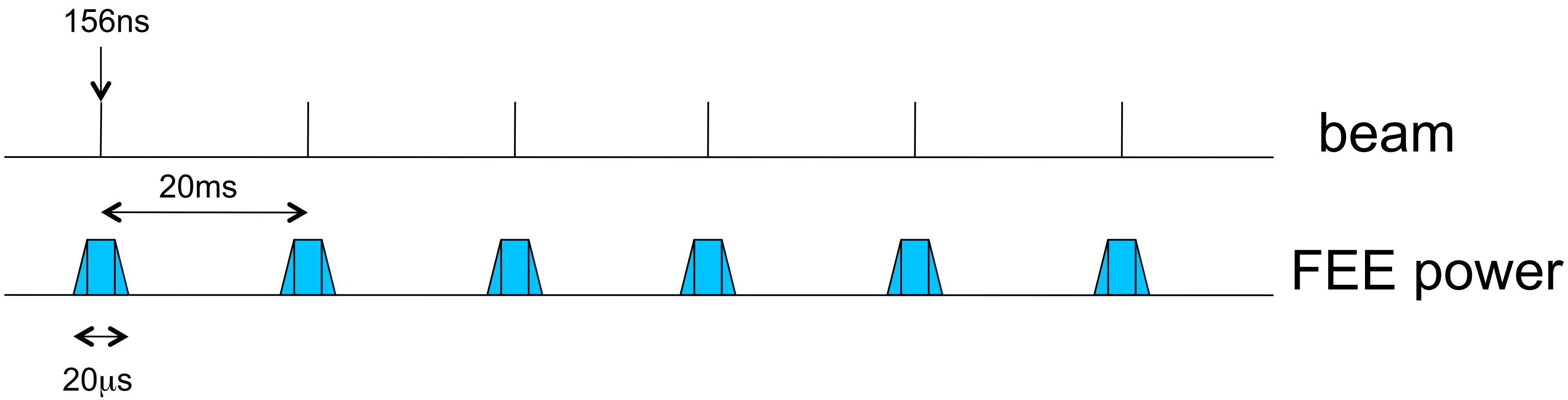
CLIC Detector power-pulsing scheme (e.g. VTX analog power).



The analog part of the FEE is powered for only 20 μs every 20ms and the average power over one second is reduced to a small fraction of the peak power. Similar scheme applies to all the sub-detectors, with the only possible exception of the muon chambers.

The energy for the pulse is stored at the FEE boards → low currents in cables almost constant, peak power transfer only locally.

LC sub-detectors FEE (minimal) power consumption.

The power-pulsing mode proposed for LCD will reduce the power consumption (C) by reducing considerably the duty factor (f_{duty}). By consequence, also the fraction of the cooling power dedicated to the detector FEE will be reduced significantly and air-cooling (although much less effective than water) is a valuable option.

The average power depends on the number of channels of the different sub-detectors and their technology:

Sub-detector	Technology	Power/Channel mW	Nr. Of channels	Total power W
Vertex	Silicon pixels	$2x10^{-4}$	$3.5x10^{9}$	700
Tracker	Silicon strips	0.05	$1.6x10^{7}$	770 – 1760
Ecal	Silicon pads	0.01	$1.12x10^{8}$	1,120
Hcal	Scintillating tiles	0.01	$8.9x10^{6}$	89

Other systems (superconducting magnet, Offline farm) would be likely operated at steady-state, with a duty cycle very similar to a LHC-like detector (0.83).

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Estimated power consumption for LC Detectors.

From the previous considerations, we can estimate that the average power consumption of the FEE & DAQ(1) would be significantly reduced to a few percent (possibly less that 10kW) and the cooling required would be also reduced, although not the same amount as power.

A rough estimate could be the following:

Detector Magnet (Cryogenics + Powering):	900 kW
Detector Electronics Total:	1020 kW
Front-End Electronics:	10 kW
DAQ Electronics:	10 kW
Offline Electronics:	1000 kW
Detector Services Total:	1300(w) – 1400(s) kW
Cooling:	500(w) – 750(s) kW
HVAC:	600(w) – 400(s) kW
Detector Total (including services):	3.05 MW

(1) No trigger electronics and moderate data-rate (e.g. CLIC_ILD 1.6Tbit/sec for all sub-detector) would significantly reduce the DAQ Electronics consumption wrt CMS.

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Comparison with the CLIC accelerator power budget.

CLIC ENERGY	ACCELERATOR POWER	DETECTOR CONTRIBUTION
500 GeV	256 MW	1.2%
1.5 TeV	346 MW	0.9%
3.0 TeV	567 MW	0.5%

Considerations on detector commissioning with cosmics.

The power-pulsing scheme limits the FEE duty cycle with evident benefice effects on the heat dissipation inside the detector. On the other hand, when the detector is off-beam (either because in the garage position or the machine is off), there is little chance to work with cosmics(1).

(1) At LHC, after the dipole interconnection accident in 2008, detectors have collected more than 10^6 cosmics events, allowing an accurate preliminary calibration and check of the DAQ system.

Conclusions.

The power consumption of a LHC Detector (e.g. CMS) results to be the contribution of three main sub-systems (Detector Electronics – HVAC – Magnet/ Cryogenics). For a typical LC Detector, the proposed power-pulsing scheme for the FEE, would significantly reduce the Detector Electronics consumption by a factor 50 or more wrt CMS. The global consumption however, would not be significantly different from what we have at LHC, as the Magnet/Cryogenics, the Offline electronics and the HVAC part are not dependent on the Detector powering scheme.

The comparison with the expected power consumption from the CLIC accelerator, shows that the amount of power required by the experiment would be a tiny fraction of the total budget.

The significant advantage of the power pulsing scheme stays with the possible reduction of material budget in the design of the inner sub-detectors.

References.

1) LHC Power Consumption, Engineering Specification LHC-E-ES-0001-2007.
2) The CERN LHC: Accelerator & Experiments, vol. 2. JINST 3 2008.
3) Recueil des puissances électriques en 03/2011 et estimation des puissances pour l'exploitation du LHC jusqu'à HL-LHC. Note technique ELG-HVNET-EN-0028
4) R. Kieffer, CALICE Calorimeters Power Issues, LC Power Distribution & Pulsing WS, LAL May 2011.
5) G. Blanchot, C. Fuentes Rojas, Introduction to powering schemes for the CLIC detectors. LCD-Note-2011-019.
6) G. Blanchot, C. Fuentes Rojas, Power pulsing schemes for vertex detectors at CLIC. LCD-OPEN-2012-015
7) Physics & Detectors at CLIC – CLIC Conceptual Design Report. CERN-2012-002.
8) B. Jeanneret, Ph. Lebrun, CLIC Power & Energy, CLIC Workshop 2013

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Back-up slides.