Workshop Energy for Sustainable Science

Energy Management for Large-Scale Research Infrastructures

Report on Session 4

Energy supply: challenges in future technical solutions

Philippe Lebrun

CERN, Geneva, Switzerland

Session 4 program

- F. Caspers (CERN), *Radiofrequency energy recovery studies at CERN*
- O. Henderson (TRIUMF & U. of British Columbia), *Turning TRIUMF accelerators into green machines*
- S. Claudet (CERN), *Cryogenics design and operation at the LHC: optimization and reduction of power consumption*
- J.P. Burnet (CERN), *A 60 MW power system with intermediate energy storage for a large pulsed load*

Radiofrequency Energy Recovery Studies at CERN

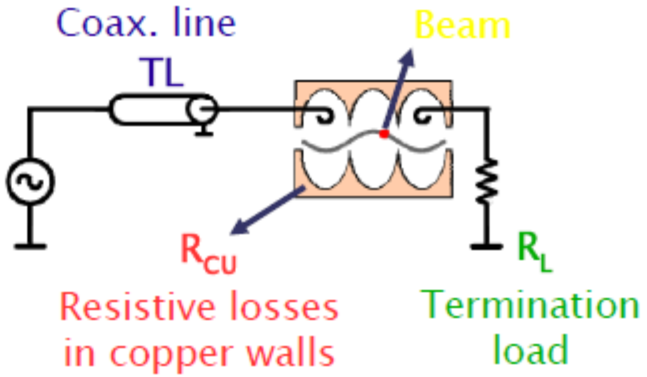
M. Betz, **F. Caspers**, S. Federmann
CERN

The problem

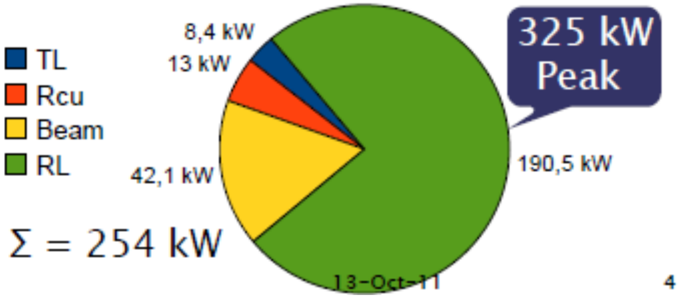
Power dissipation in termination loads

- Average power dissipation in R_L: 4 x 190.5 kW
- Water-cooled termination loads in the tunnel
- Heat is not utilized and dissipated to the environment by heat exchangers (cooling towers) on the surface

- Annual:
  - 6.7 million kWh
  - ~ 450 000 €



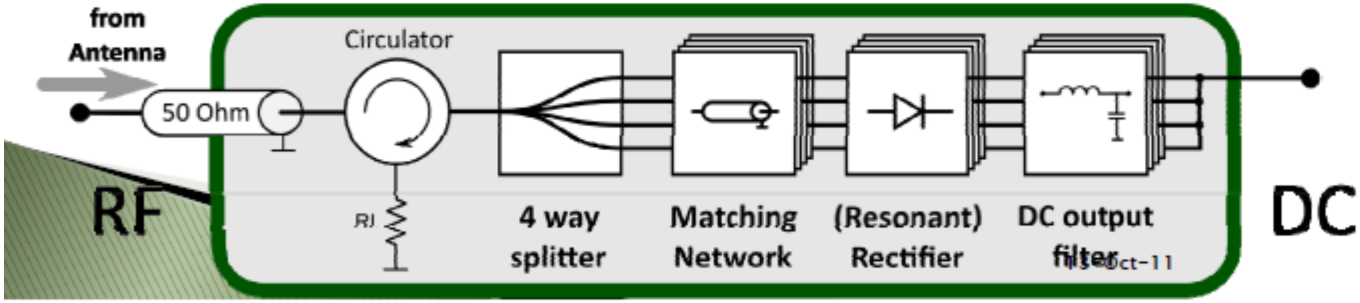
Distribution of the average (24 h) Power dissipation per Cavity (there are 4):

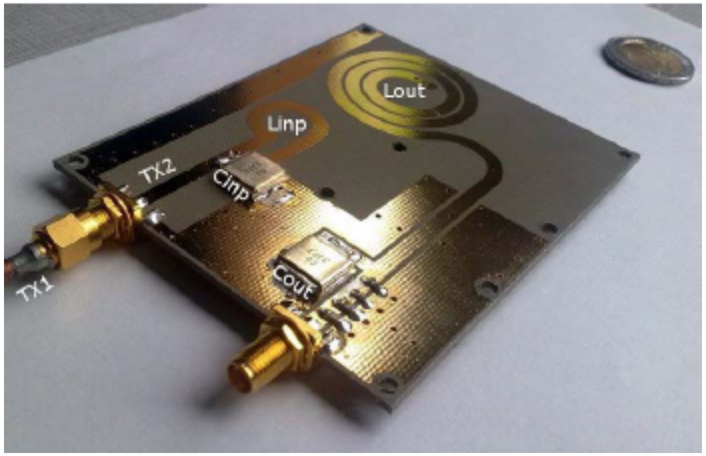


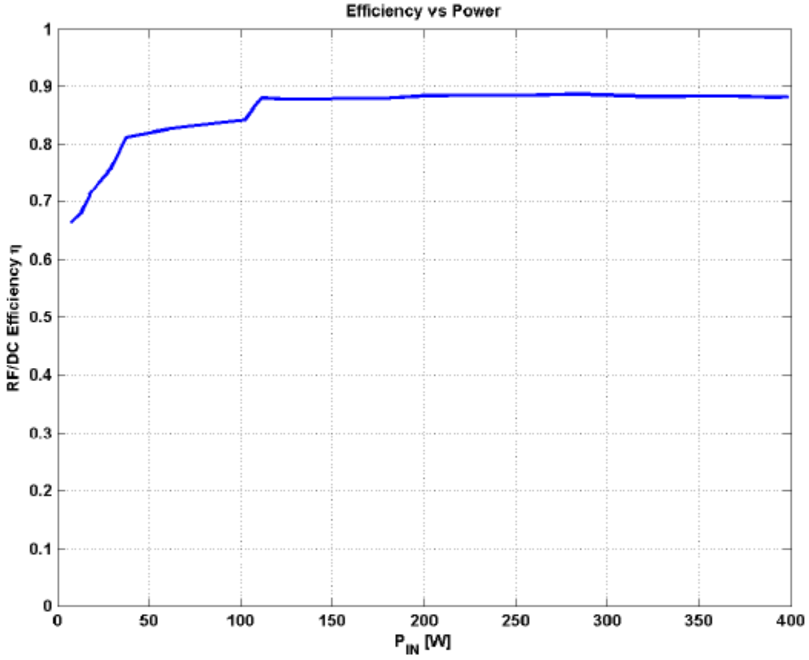
$\Sigma = 254$ kW

We assume: 0.067 € / kWh.
Which is the average energy cost for CERN in Nov. 2009

Part 1: RF energy recovery using rectifiers







- Maximum efficiency at:
  - 284 W
  - 88.7 %
- For reduced power we still see a fair efficiency

Part 2: RF energy recovery using high temperature loads

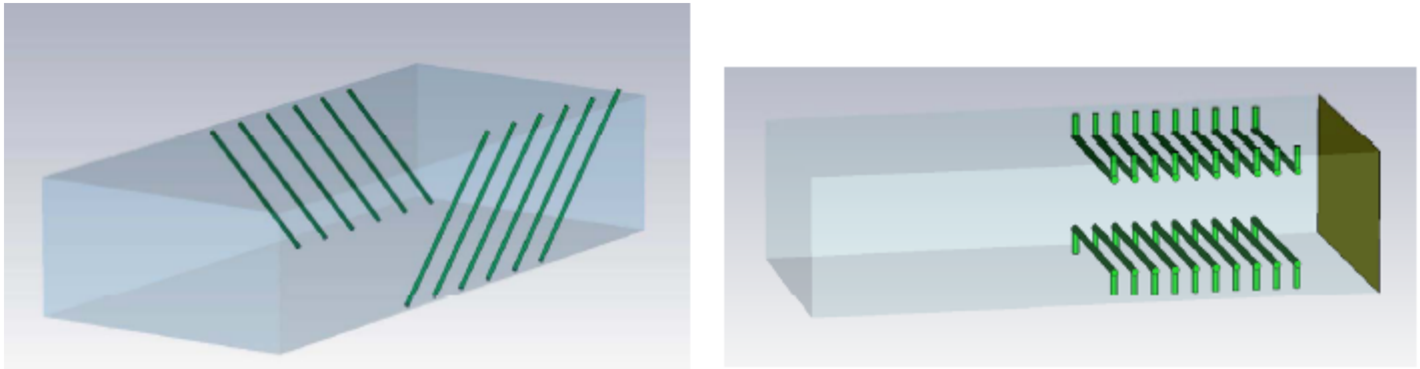
Motivation

- Conventional RF power loads produce cooling water at **low pressure** and **moderate temperature**
  - This kind of energy is **barely usable**

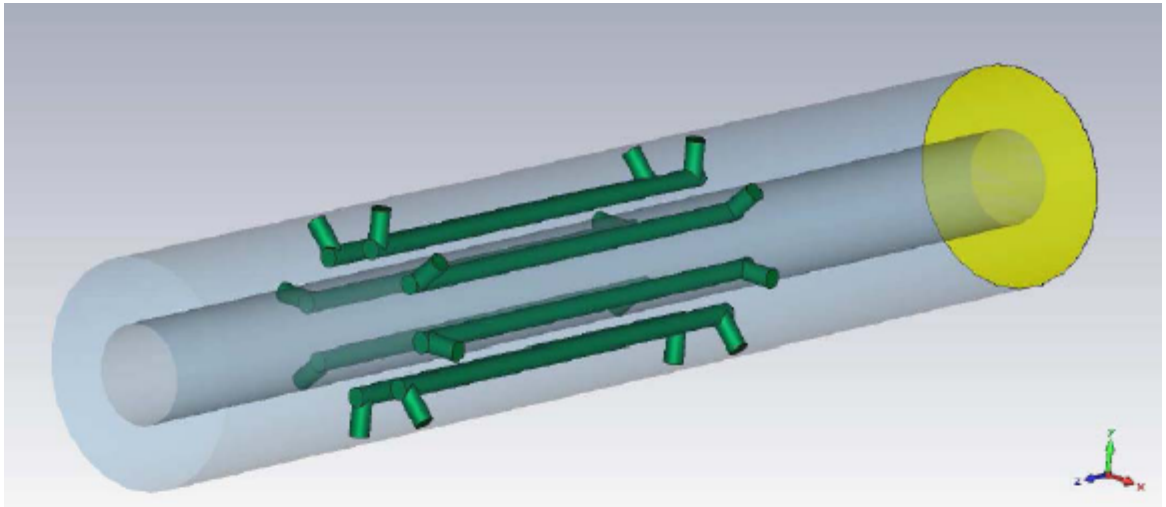
- We propose RF loads producing cooling water above **150 °C** at up to **100 bar** pressure which is **technically usable**
  (Domestic heating, steam turbines, Stirling engines, etc.)

- 2 concepts will be discussed:
  - Narrowband waveguide absorbers
  - X-Band travelling wave structures

Waveguide absorber



Coaxial absorber



Conclusions

- Direct conversion from RF to DC is the most efficient way of RF energy recovery. However, also the most complex one. We have done a a small step in this direction.

- High temperature loads could be closer to practical realization, their cost should be smaller. However their efficiency is fundamentally limited by Carnot's theorem.

campus + community planning
campus sustainability

Turning TRIUMF Accelerators into Green Machines

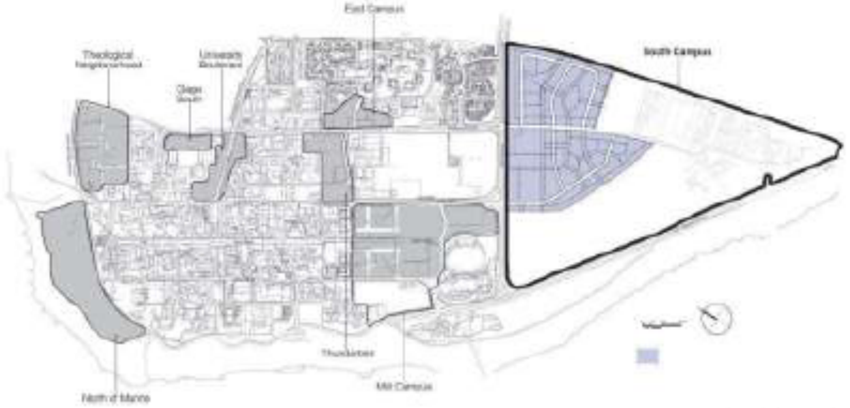
October 13, 2011

Orion Henderson

Director, Operational Sustainability,
University of British Columbia, Canada

DE System Pre-Feasibility Study

Stage 1 (Energy Demand): Future buildings at Wesbrook Place



	Units	BAU Scenario (at full build out)
Total Future Floor Space	m^2	392,000
Total energy requirements at build out	(MWh / yr)	33,000
Heating Electricity Consumption	MWh / year	9,060
Natural Gas Consumption	GJ / year	116,000
Peak Energy Demand	MW	13
GHG emissions	tonnes of CO_2e / year	5,640

DE System Pre-Feasibility Study

Stage 2 (Options Analysis): Low Carbon Energy Sources

- **Ground Source Geothermal Energy**
- **Biomass Combustion (Cogeneration?)**
- **Sewer Heat Recovery**
- **Industrial Heat Recovery (TRIUMF)**

DE System Pre-Feasibility Study

Stage 5: Study Results

	BAU	TRIUMF	Savings
Cost of energy	$71/MWh	$105/MWh	+30%
Natural gas (GJ/yr)	116,000	57,600	-50%
Electricity (MWh/yr)	9,000	6,700	-25%
GHG Emissions (tonne CO2e/yr	5,640	2800	-50%

How do we make DE supplied energy cost more competitive with the traditional mix of energy sources (i.e. direct natural gas and electricity)?

CERN

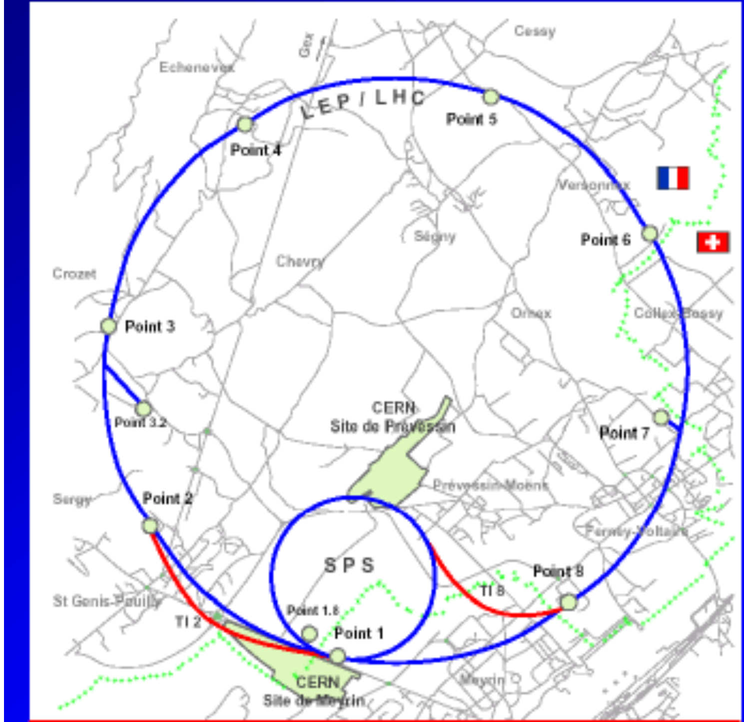
LHC Cryo-OP

LHC Cryogenics design and operation: optimization and reduction of the energy consumption

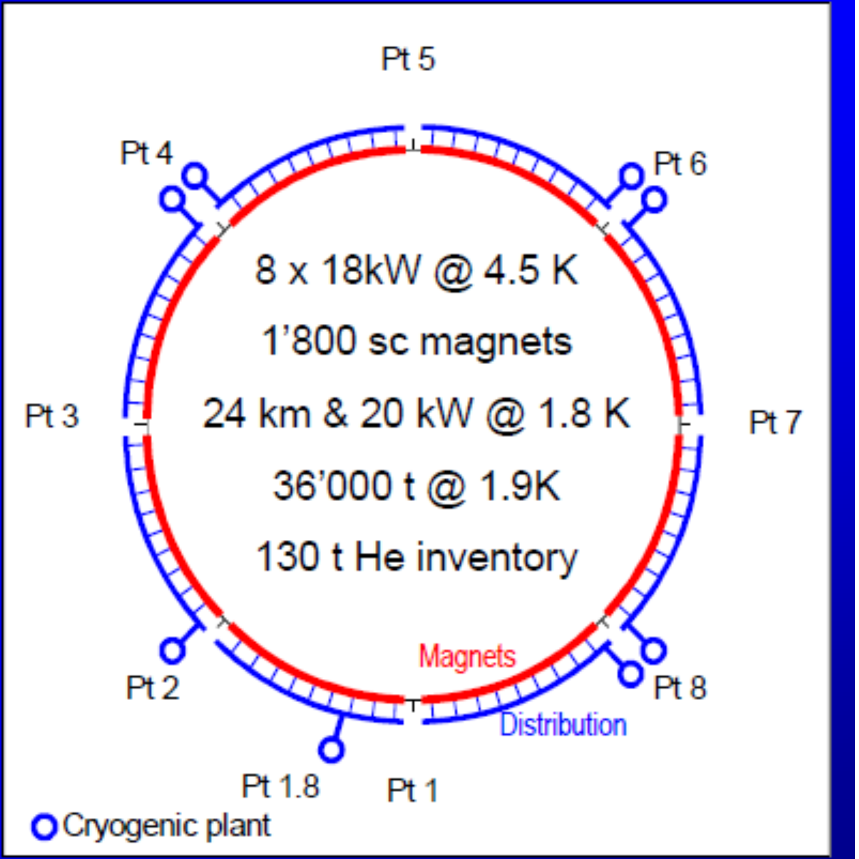
S. Claudet (CERN, Geneva)

LHC Cryogenics OPeration team leader

Layout of LHC cryogenics



LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide



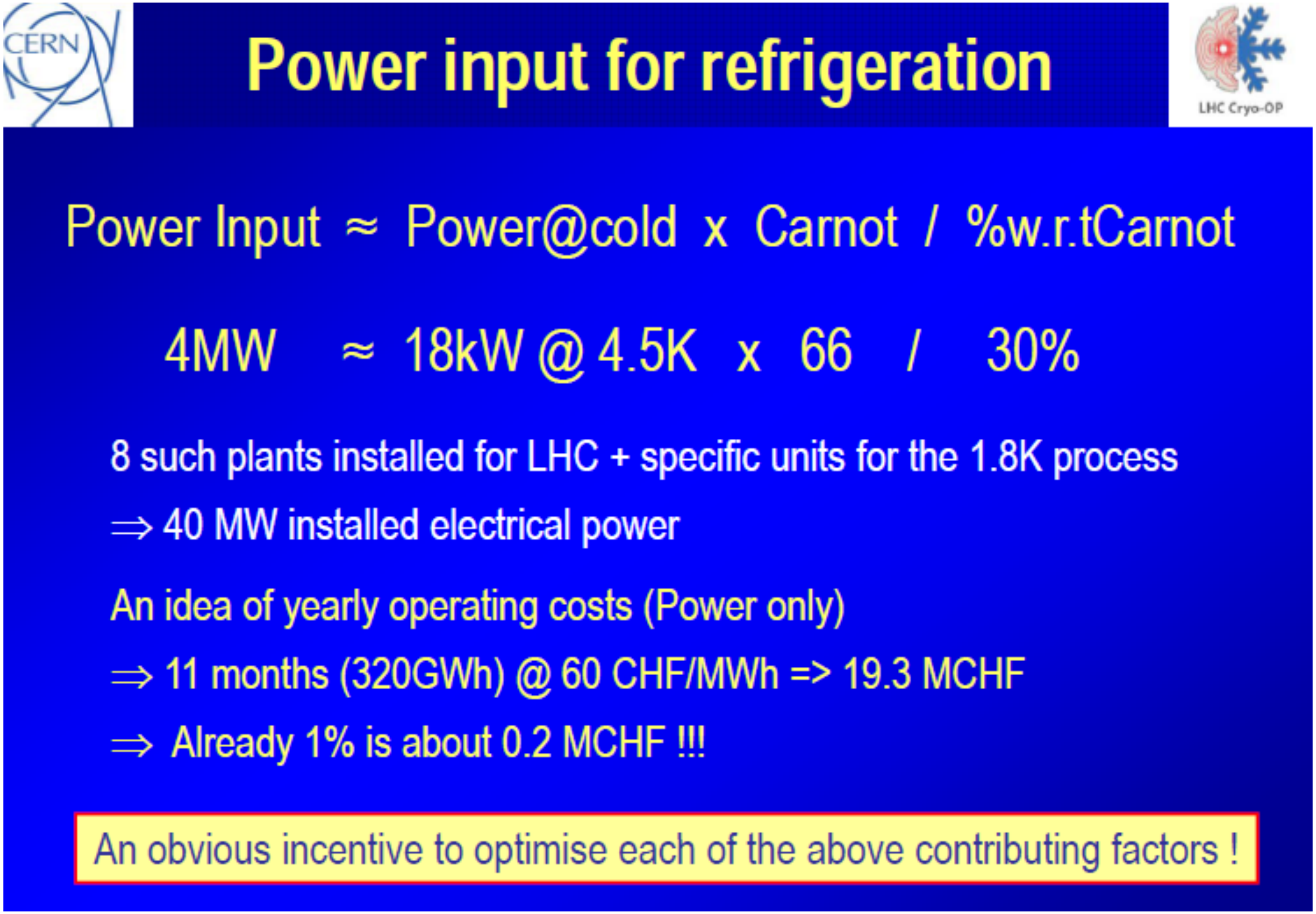
8 x 18kW @ 4.5 K

1'800 sc magnets

24 km & 20 kW @ 1.8 K

36'000 t @ 1.9K

130 t He inventory



Power input for refrigeration

Power Input ≈ Power@cold x Carnot / %w.r.tCarnot

4MW ≈ 18kW @ 4.5K x 66 / 30%

8 such plants installed for LHC + specific units for the 1.8K process

⇒ 40 MW installed electrical power

An idea of yearly operating costs (Power only)

⇒ 11 months (320GWh) @ 60 CHF/MWh => 19.3 MCHF

⇒ Already 1% is about 0.2 MCHF !!!

An obvious incentive to optimise each of the above contributing factors !

Contracting refrigerators

Similar amounts !

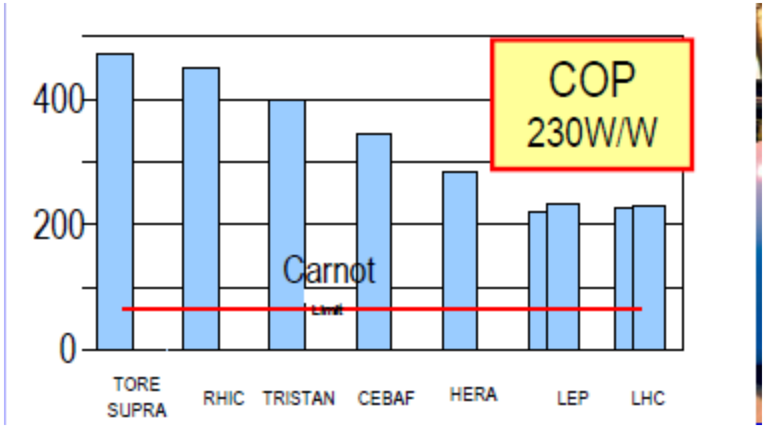
Adjudication : LOWEST — CAPITAL Cost + OPERATING cost over 10 years

Values provided in quotations by bidders

1/3 Low load — 2/3 Max load — *(6600 hr/yr)*

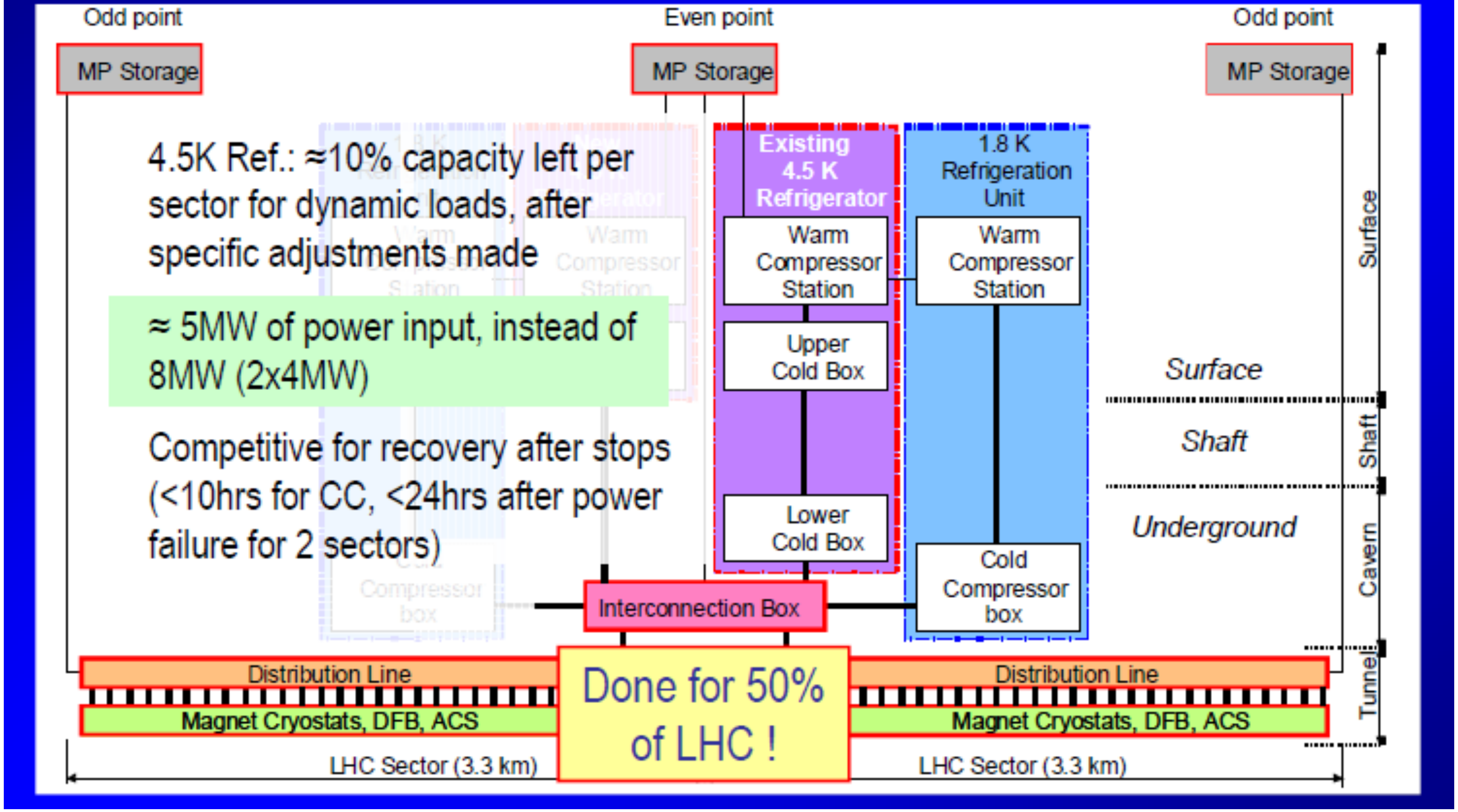
Operating cost: Garanteed power consumption x hours x 60 CHF/MWh

Real performance measured for acceptance, with bonus/malus correction



Efficient operation at low load

Typical LHC even point

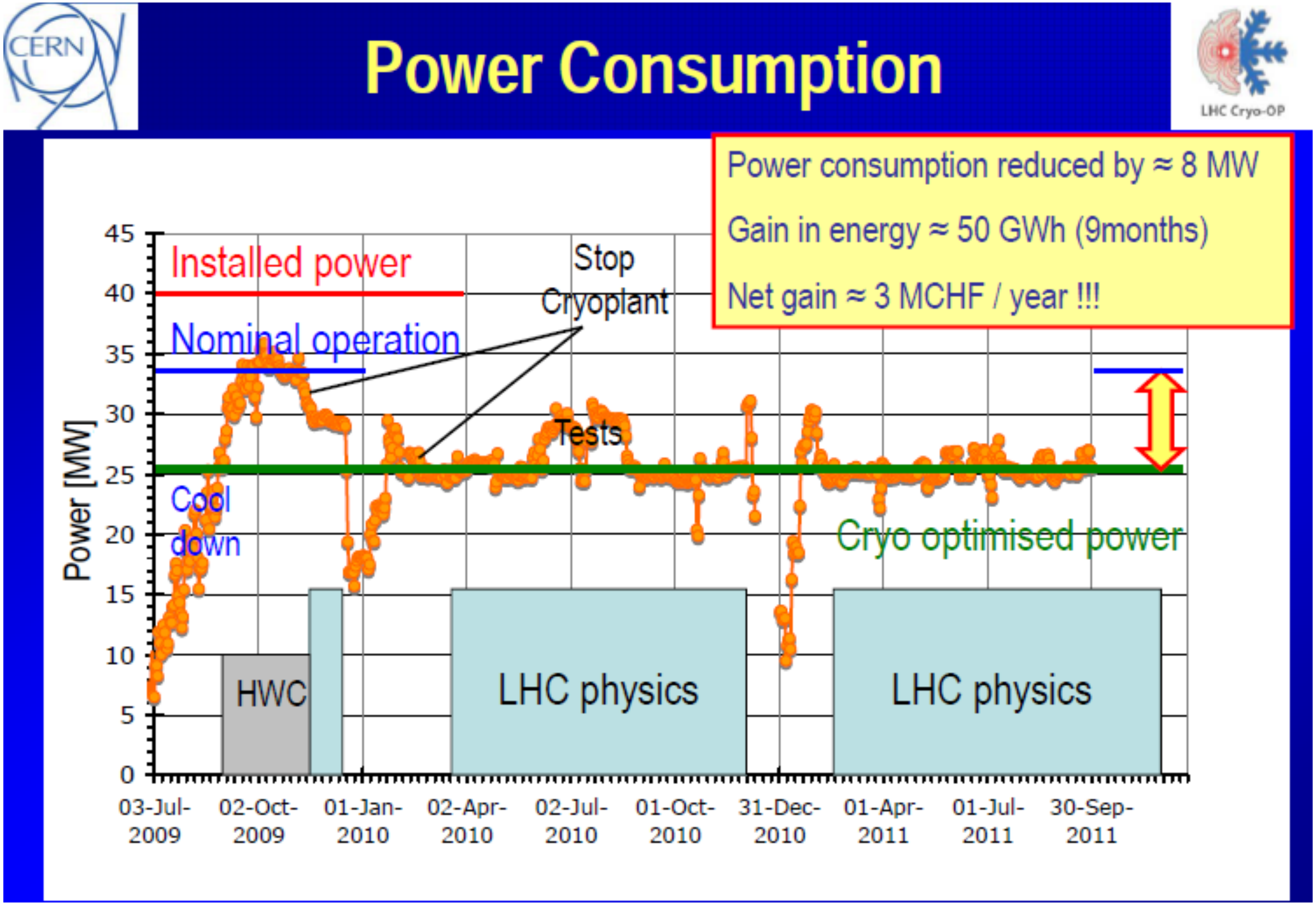


4.5K Ref.: ≈10% capacity left per sector for dynamic loads, after specific adjustments made

≈ 5MW of power input, instead of 8MW (2x4MW)

Competitive for recovery after stops (<10hrs for CC, <24hrs after power failure for 2 sectors)

Done for 50% of LHC !

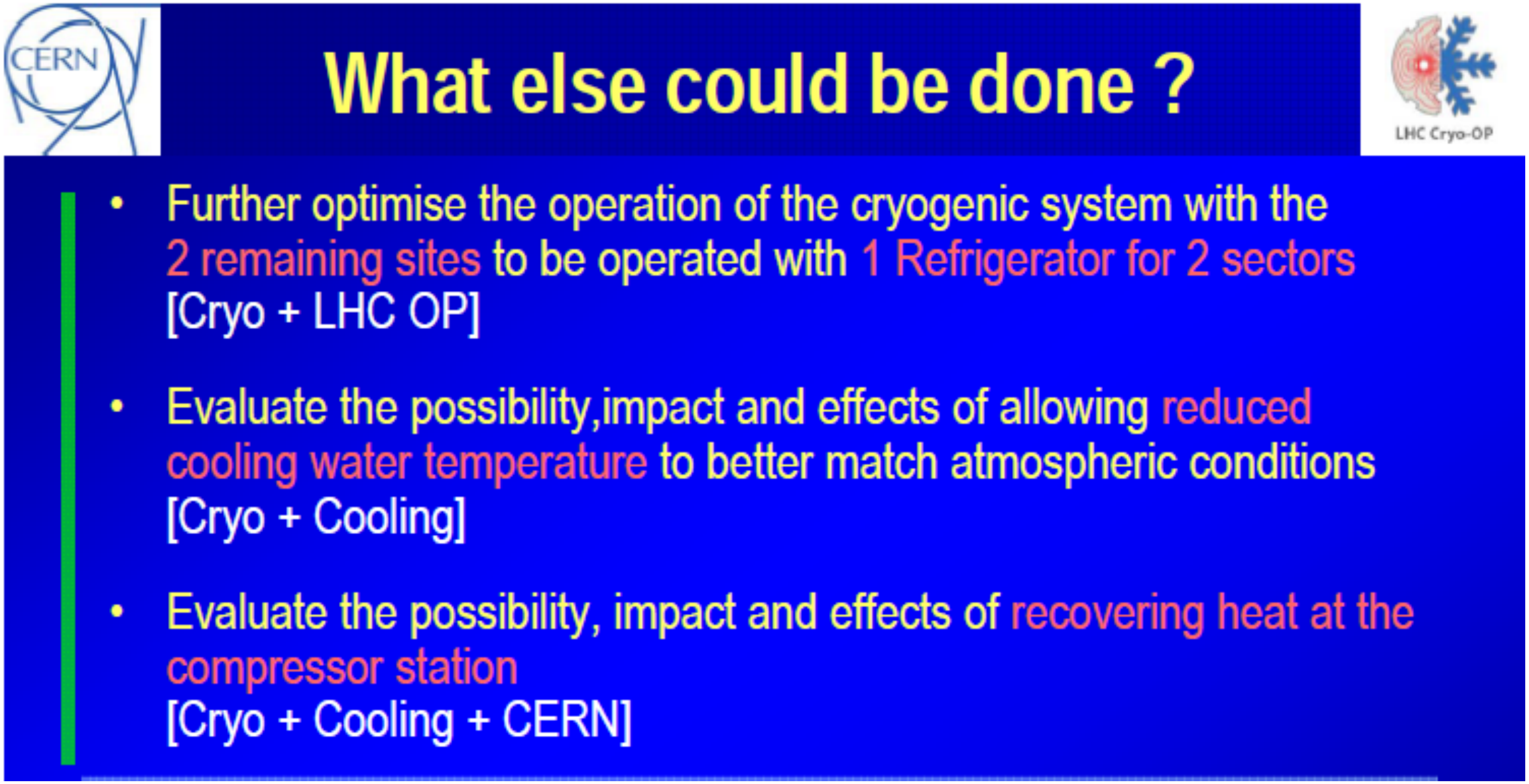


Power Consumption

Power consumption reduced by ≈ 8 MW

Gain in energy ≈ 50 GWh (9months)

Net gain ≈ 3 MCHF / year !!!

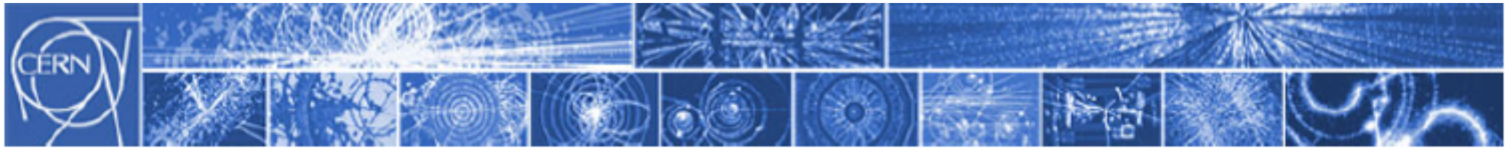


What else could be done ?

- Further optimise the operation of the cryogenic system with the 2 remaining sites to be operated with 1 Refrigerator for 2 sectors [Cryo + LHC OP]
- Evaluate the possibility,impact and effects of allowing reduced cooling water temperature to better match atmospheric conditions [Cryo + Cooling]
- Evaluate the possibility, impact and effects of recovering heat at the compressor station [Cryo + Cooling + CERN]

Workshop
Energy for
Sustainable
Science

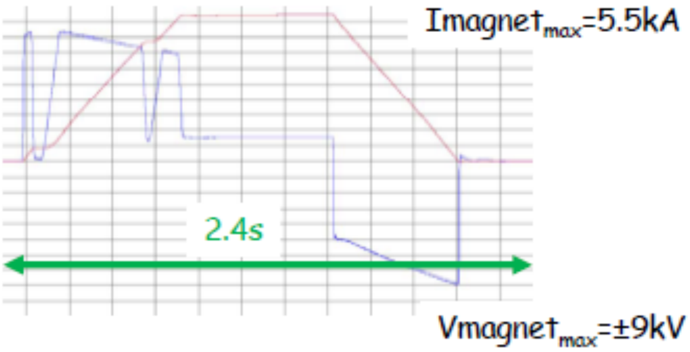
Energy Management for Large-Scale Research Infrastructures



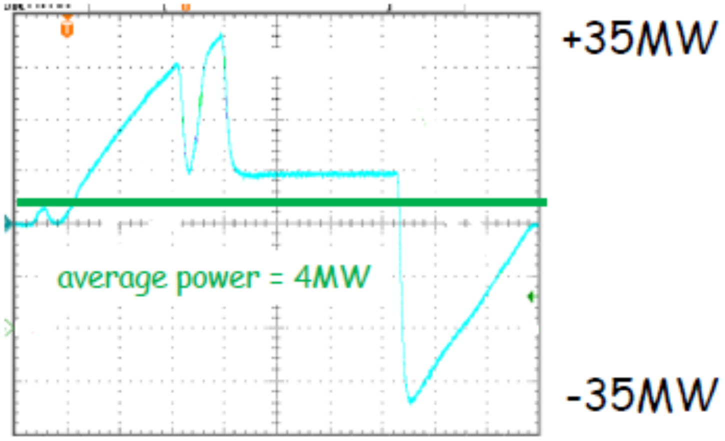
A novel 60 MW Pulsed Power System based on Capacitive Energy Storage

Jean-Paul Burnet / CERN

PS cycles



Blue: Umagnet 1 kV / div
Red: Imagnet 500A / div



Light blue: Power_to_magnet 10 MW / div

Power(t) = I_magnet(t) x V_magnet(t)

The peak power needed for the main magnets is ±40MW with a dynamic of 1MW per ms
The average power is only 4MW !!!

The challenge:
Power a machine which needs a peak power 10 times the average power
with a very high dynamic !!!

Local energy storage system

The idea is to reproduce the same principle as with the present rotating system.

- Need energy storage devices
  - Batteries
  - Capacitors
  - Supercapacitors
  - SMES (see next slide)

	Batteries	**Capacitors**	**Supercaps**
Energy Density	100-700kJ/kg	300J/kg	100-500kJ/kg
Charge Discharge cycles	Limited < 10000	Unlimited	Limited < 100000

Only power capacitors can do millions of charge discharge cycles !!!!

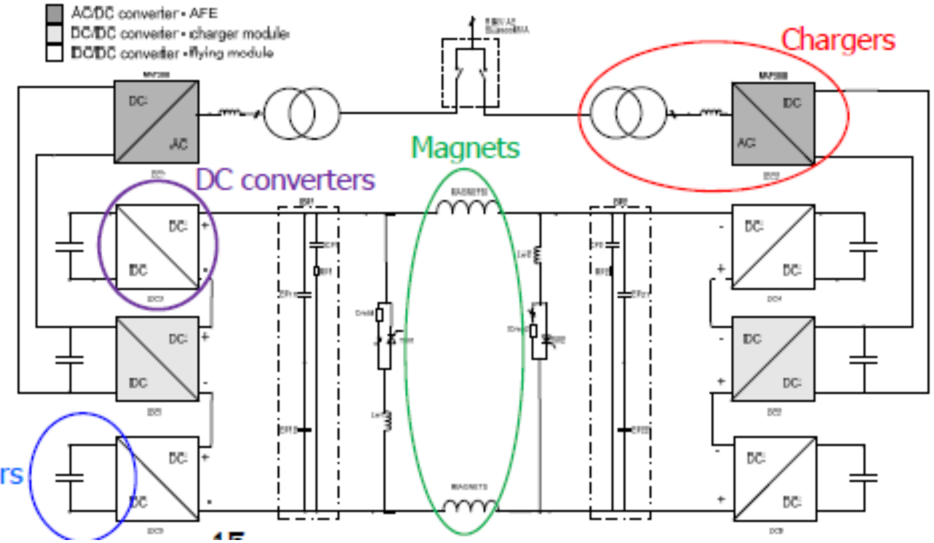
- Need the associated power electronics
  - Design a topology which can integrate the energy storage inside the power converter

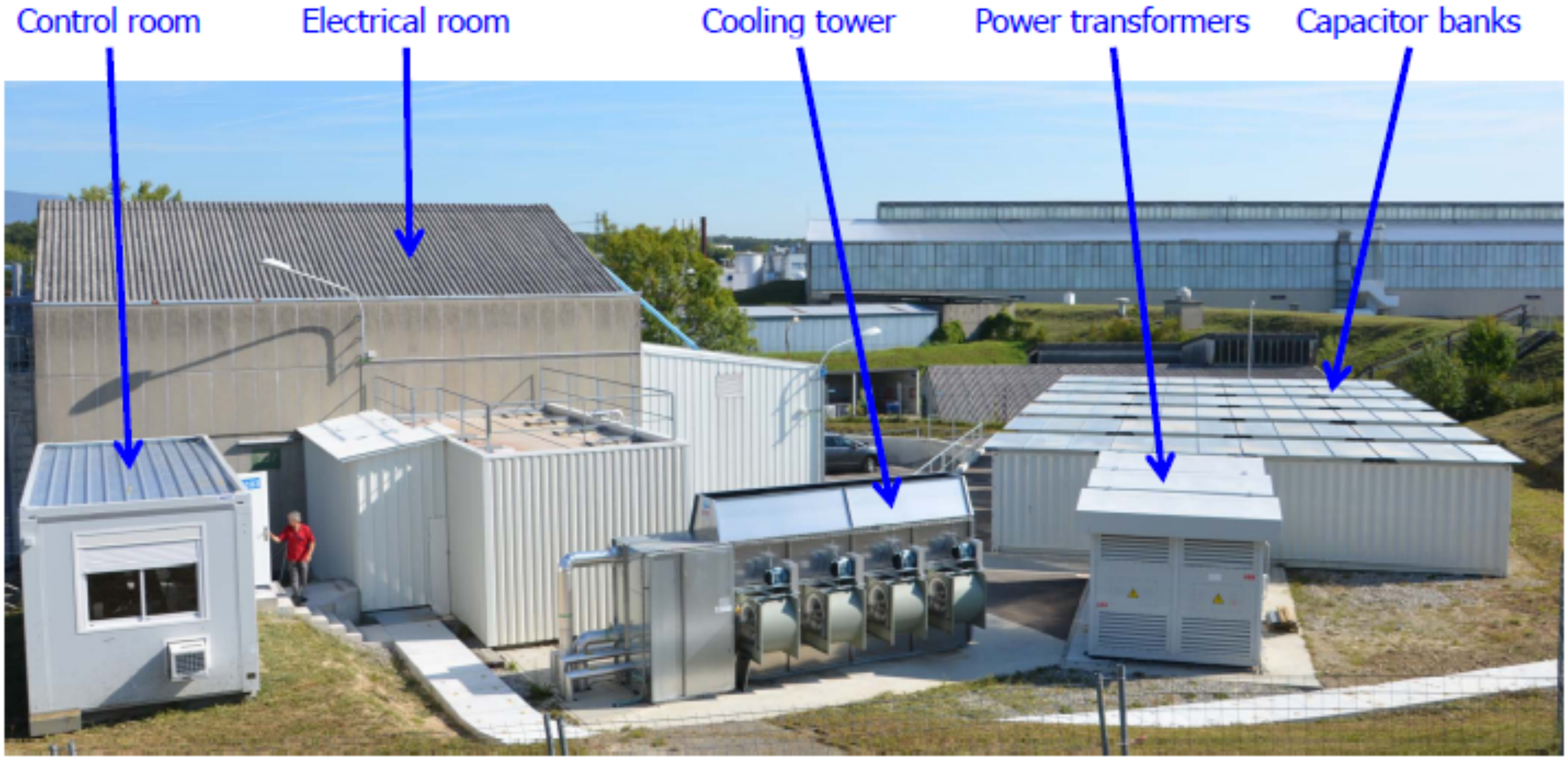
New power system designed by CERN

The energy to be transferred to the magnets is stored in capacitors
The capacitor banks are integrated in the power converter

- DC/DC converters transfer the power from the storage capacitors to the magnets.
- Four flying capacitors banks are not connected directly to the mains. They are charged via the magnets
- Only two AC/DC converters (called chargers) are connected to the mains and supply the losses of the system and of the magnets.

Patent
The global system with dedicated control has been filed as a patent application. European Patent Office, Appl. Nr: 06012385.8 (CERN & EPFL)




Control room
Electrical room
Cooling tower
Power transformers
Capacitor banks

Conclusions

Advanced power electronics associated with storage devices allow a better energy management between the load and the network.

With POPS, CERN demonstrated that it is possible to design a power system which takes the strict minimum required energy from the electrical network, avoiding large power fluctuation on the mains, and minimizing the total losses.

Electrical storage devices are key elements, Will SMES can play a major role in a near future?.

Power quality is a critical issue for particles accelerators, a local energy storage helps to solve this problem.

5 rules are proposed to build new facilities.

Smart power management is possible for particles accelerators. !

Be smart, choose the most advanced technology!

Concluding remarks

- Large research facilities such as high-energy particle accelerators have been confronted for many years with the issue of energy efficiency, in view of its impact on their high investment and operating costs
- Their design, construction and operation has therefore already integrated a number of features towards this goal, e.g.
  - First- and second-law efficiency of cryogenic systems
  - Development of RF power sources and accelerating structures for high grid-to RF and RF-to-beam efficiencies
  - Optimized operation modes matching energy availability and price constraints
- Still, a lot remains to be done as the facilities become larger and the boundary conditions, including their social acceptance, more demanding, along three main lines of development
  - Reduction of primary electricity consumption
  - Electrical energy recovery
  - Waste heat recovery and valorization
- On par with outreach or knowledge & technology transfer, energy efficiency in large research infrastructures is truly “science for the citizen”