Eucard-2 Workshop on
Special Compact and Low Consumption Magnet Design
for Future Linear and Circular Colliders

Summary of Sessions 1 & 2

Akira Yamamoto

2014/11/28

Reports Given

	Title	Speaker
Session 1: Future Development Scenarios		
	Forecast for electricity consumption in western countries: consumption curves, costs, estimations etc …	M. Wittenstein
	Why are particle accelerators so inefficient?	P. Lebrun
Session 2: Opportunities of Energy Saving in Accelerators		
	CERN planns towards enerby efficiency	S. Claudet
	Magnet Energy Recovery: a way towards more compact and efficient systems	K. Papastergiou
	Saving opportunities in accelerator magnets	D. Tommasini
	Power Converters design optimization: need for an integrated approach with the magnet design	D. Agulia
	Iron-dominated cycled SC magnets for energy efficiency	L. Bottura
	In-vacuum magnet design and challenges	J. Clarke

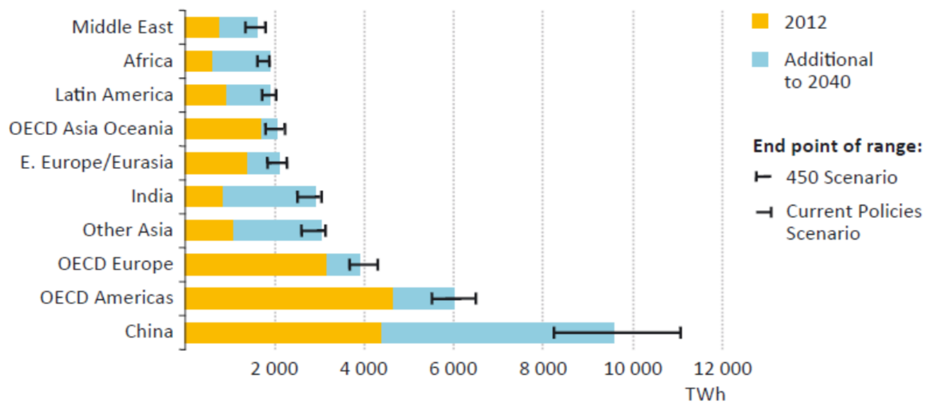
The outlook for electricity in Western Europe

Matthew Wittenstein
IEA Gas, Coal & Power Markets Division
26 November 2014

Demand growth to 2040

- *Globally,* expected to be 2.1 % p.a.
  - But slower in OECD economies

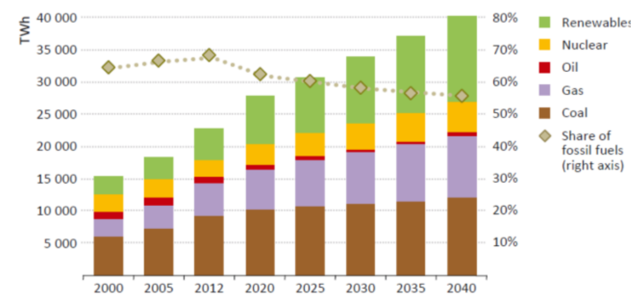
Figure 6.1 ▹ Electricity demand by region in the New Policies Scenario



Source: IEA, World Energy Outlook 2014, New Policies Scenario

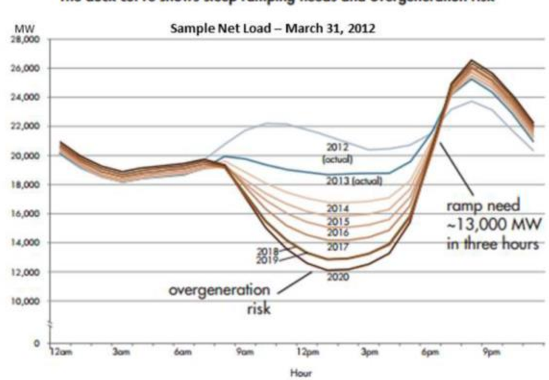
The rise of renewables

Figure 6.8 ▹ World electricity generation by source in the New Policies Scenario



The changing shape of demand: the duck curve

The duck curve shows steep ramping needs and overgeneration risk



(from the California Independent System Operator)

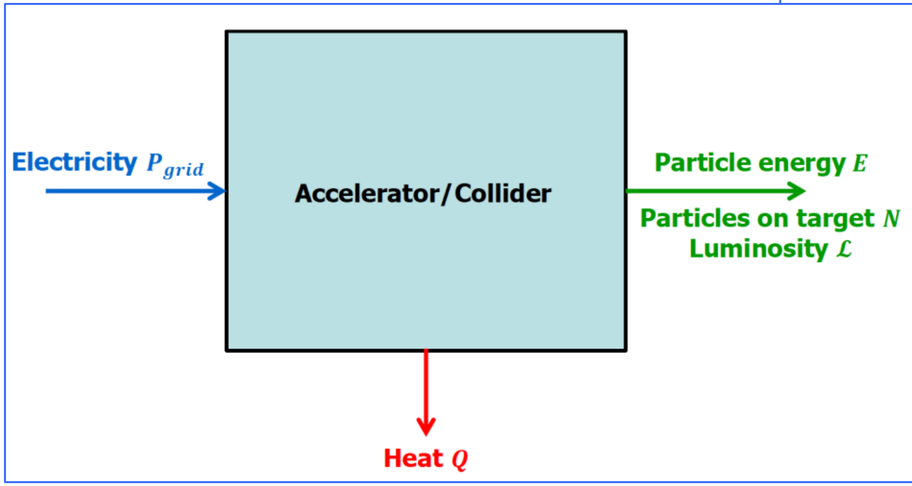
Source: Regulatory Assistance Project

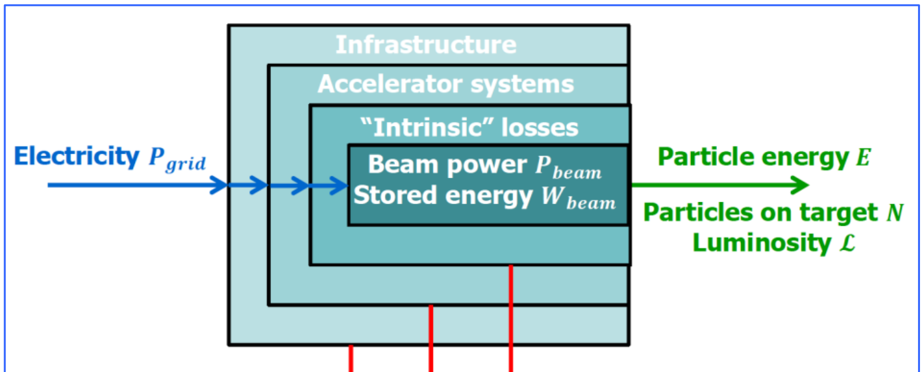
Prices: going up

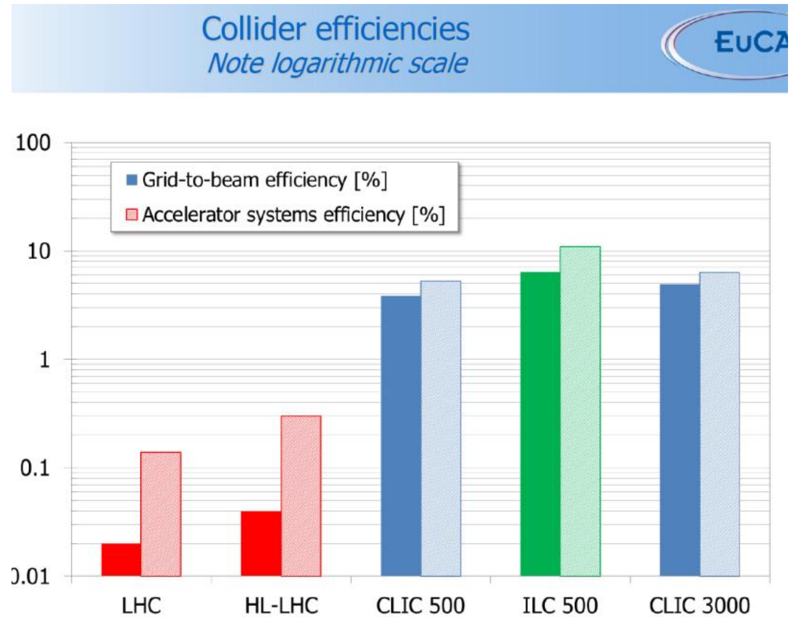
- Wholesale prices in EU are projected to increase by 50%, on average, by 2040
  - Current prices average around 70 USD/MWh
    - Not high enough to recover fixed costs
  - To recover the cost of needed investment, prices will need to rise to around 100 USD/MWh by 2030, and 110 USD/MWh by 2040
    - Prices in EU will be higher, on average, than in other OECD countries, because of the relatively high investment needs
- This is highly dependent on the future of EU renewable policies and wholesale market reforms

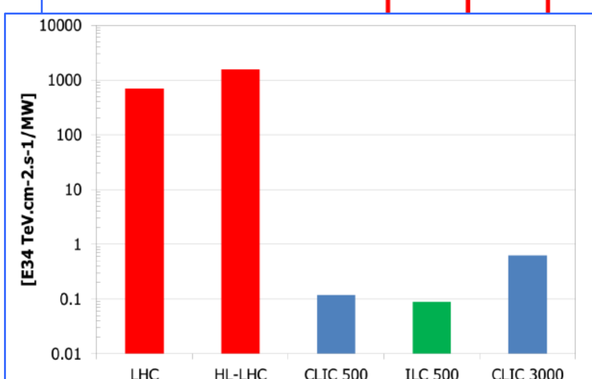
Why are particle accelerators so inefficient?

Philippe Lebrun
CERN, Geneva, Switzerland









- Accelerator systems and infrastructure represent the bulk of electrical power consumption
- Comparing total power consumption and average beam power yields very low values for overall "grid-to-beam" efficiency
- Linear colliders show higher overall "grid-to beam" efficiencies than circular colliders. This partly compensates for their much lower COP/beam power ratio

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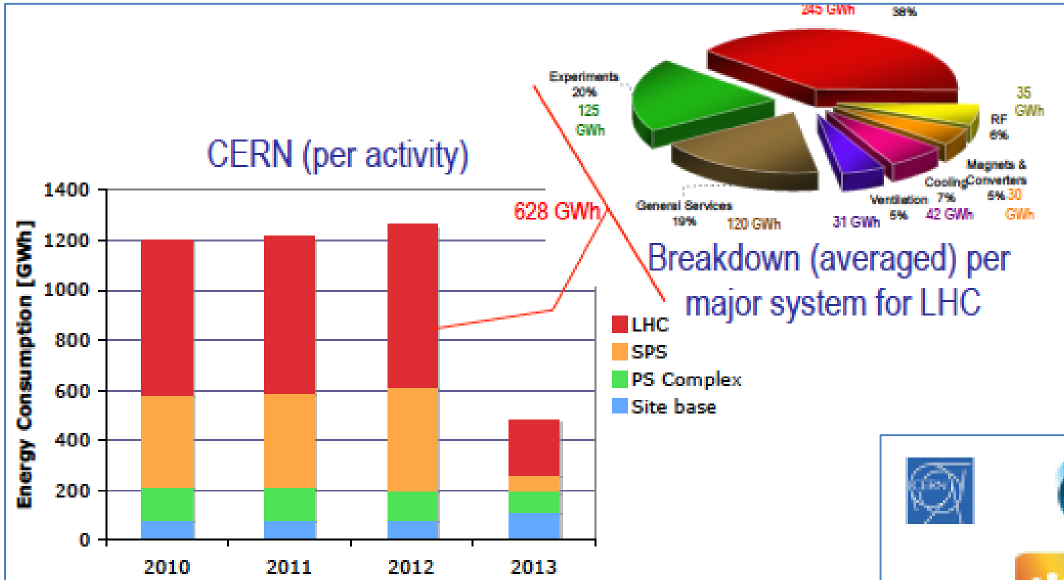
CERN plans towards energy efficiency

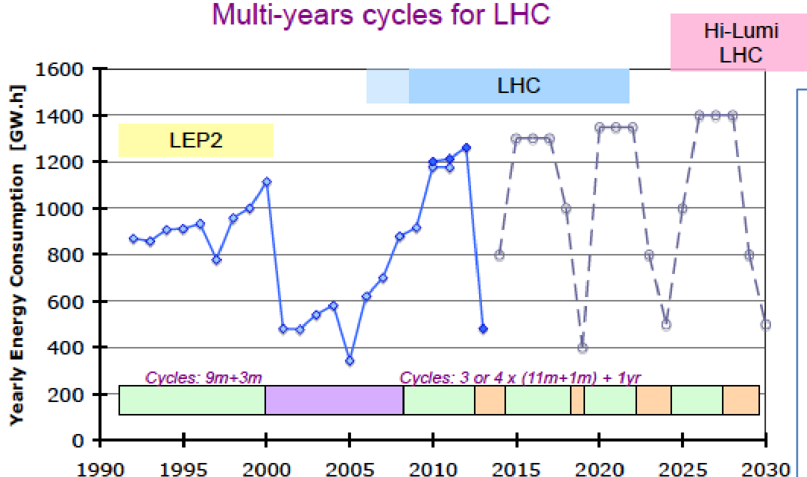
Serge CLAUDET

CERN (per activity)



Typical cycle of 3-4 years up, then 1 year down

Multi-years cycles for LHC



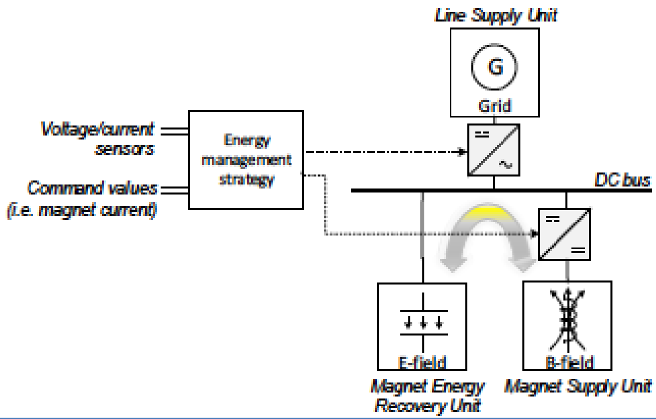
- Energy efficiency should be considered as an engineering parameter, not only as a concept-wish-dream
  - Safety, Quality assurance are part of our goals and priorities, why not Energy awareness ?
  - Evaluation, measurements, specific metrix and trends are essentials
  - Specific actions are being prepared to help for this
- No future accelerator projects without energy efficiency (more generally sustainability?) as part of the objectives
  - One should minimise primary energy consumption and (then) heat rejection
  - Specific selected programs on existing infrastructures is a clever way to get the energy awarness culture as well as proven references. It is visible from outside (communication) and useful for the future !

Magnet Energy Recovery

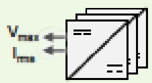
towards more compact and efficient systems

Konstantinos Papastergiou
CERN Technology Department | Electrical Power Converters

- **Magnet Energy Recovery is a specific variant of power cycling in which energy is stored locally in the power converter instead of returning it to the grid**



...ator Designer	Magnet Designer	Converter Designer
...l proton beam by α ...meter within ...in vacuum ...ber dimensions	▪ Calculate beam rigidity, estimate integrated field/magnet length. At this point the energy *E* in the magnet is known.	▪ Magnet energy known. Use current rise time to calculate peak and RMS power needed. E.g. P_{pk}=*E/0.3sec and Prms is typically* $P_{rms}=0.6\times P_{pk}$
...netic cycle duration ...1.2sec), minimum time extraction-to-extraction (e.g.0.9sec so rise and fall time could be 0.3sec each)	▪ Final windings design (number of turns, wire type/cross-section)	▪ Propose a family of power converters
		▪ Finalise system design



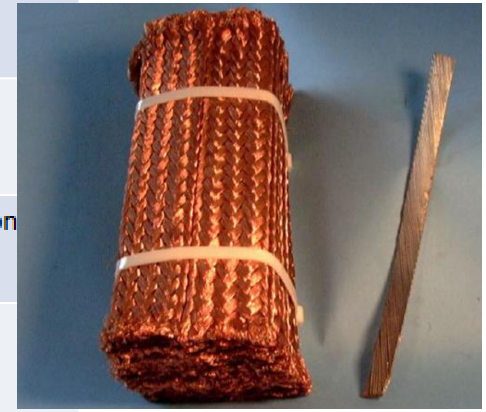
- **We anticipate system level improvements in cost and size**
  - By implementing magnet **current cycling** where possible.
    - ⇨ Economic gains in energy costs can often finance the upgrade of dc magnets
  - By implementing **magnet energy recovery** inside power converter
    - ⇨ Reduction of grid interconnection costs
    - ⇨ Better power quality at the PCC of the power converter
    - ⇨ Longer lifetime of upstream transformers and
    - ⇨ major saving in reactive power compensation capacity

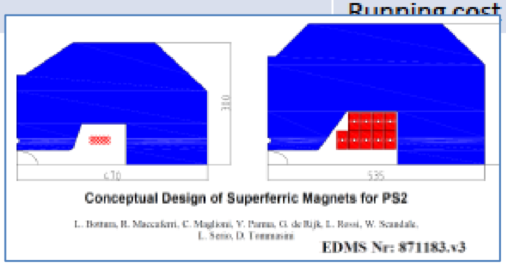
Saving opportunities in accelerator magnets

Davide Tommasini

Saving opportunities

Description	Pro	Cons
Permanent Magnets	No powering Compactness Reliability	Fixed field (unless trimmeable) Large magnets limited in field
Lower current density	Power consumption Easier cooling Reliability especially if air cooled	Size Investment cost
Pulsed operation	Power consumption	Complexity (power converter + operation Not always possible
Superconducting	Absence of Joule losses Enables higher field intensities	Complexity (everything) Investment cost Maintenance (whole system) Dynamic behaviour
Smaller magnet bore	Power consumptio Magnet cost & size	
Combined magnet	Compactness Infrastructure cost	
Use of high saturation materials	Compactness Weight Running cost	





Here, the job can be done by Sc or by Normal magnets

- A superconducting magnet is *often* more complicated
- If the magnet is cycled, dynamic losses increase complication

Indicative threshold for considering superconducting magnets

Single units, DC operated	: 100 KW
Single units, AC operated	: 1 MW
Synchrotrons	: 5-10 MW

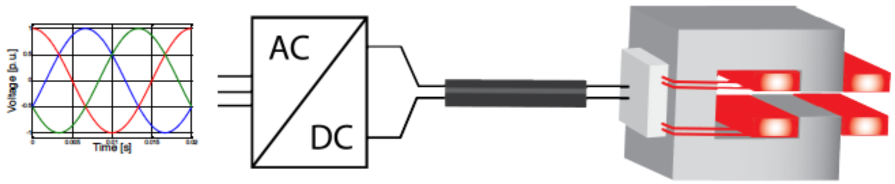
If we had to redo the CERN synchrotrons today we would:

- **certainly** do the PSB NC
- **probably** do the PS NC
- **certainly** do the SPS Sc (probably at higher energy)

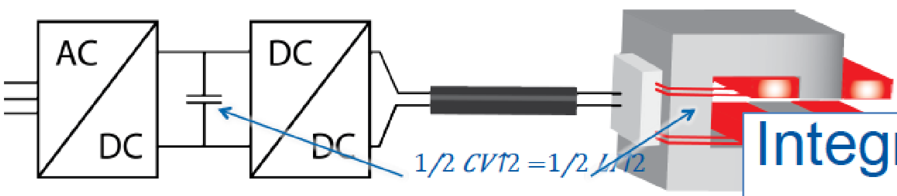
Power Converters design optimization: need for an integrated approach with the magnet design

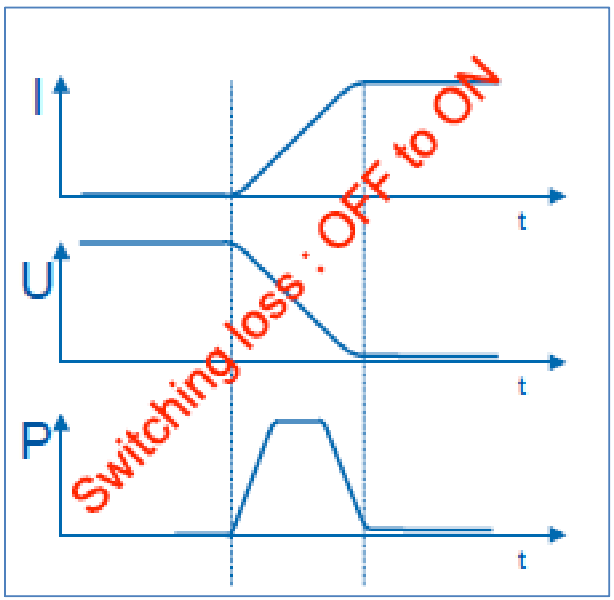
Davide Aguglia

- Direct (often old) AC/DC conversion



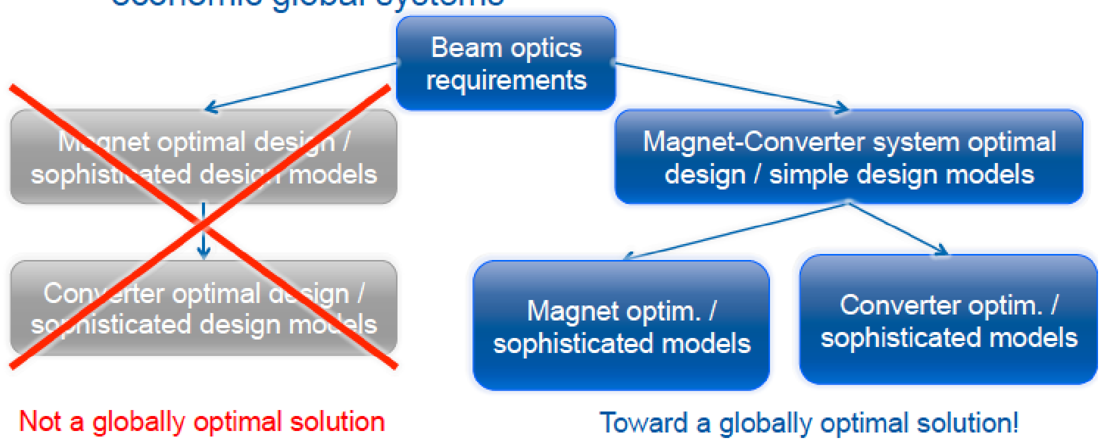
Indirect AC/DC conversion – relatively new!





Integrated design

- Optimal magnet design combined with optimal converter design does not give optimal solution!
- Integrated optimisation, even with simplified modelling gives much better solutions toward efficient, compact, and economic global systems

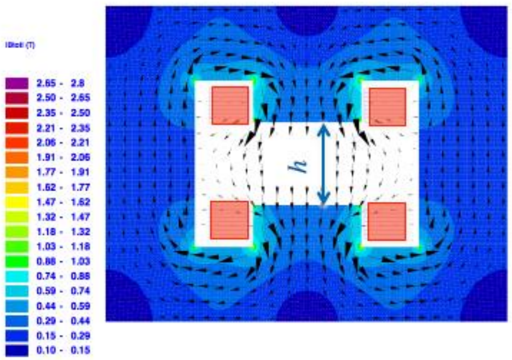


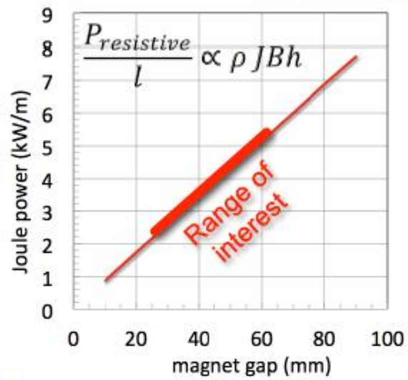
Iron-Dominated Cycled SC Magnets for Energy Efficiency

Luca.Bottura@cern.ch

Trade-off with resistive magnets

J=5 A/mm^2
B=2 T
ρ=1.6 10^{-8} Ω/m
rms factor=0.3

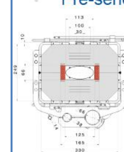




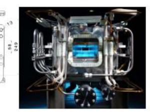
A superconducting magnet will be competitive if we achieve a wall-plug power per unit magnet length *much below* 2…4 kW/m

FAIR at GSI – SIS 100

- Synchrotron for the acceleration of intense $^{238}U^{28+}$ beams up to 2.7 GeV/u and p$^+$ beams up to 29 GeV
- Fast pulsed dipoles, 2 T, 4 T/s (i.e. 1 Hz repetition rate) based on an improved Nuclotron concept
- Several prototypes tested
- Pre-series started, construction end of summer 2015

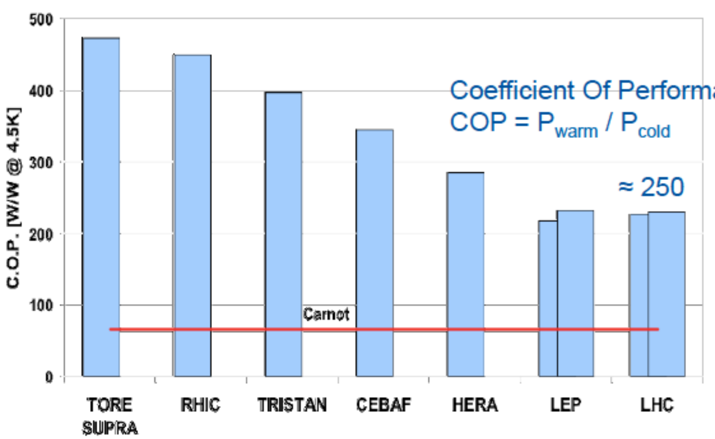


Cross section of first industrial prototype



Pre-series full-scale dipole

By courtesy of E. Fischer (GSI) and BNG

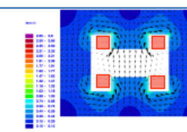


Coefficient Of Performance
COP = P_{warm} / P_{cold}

≈ 250

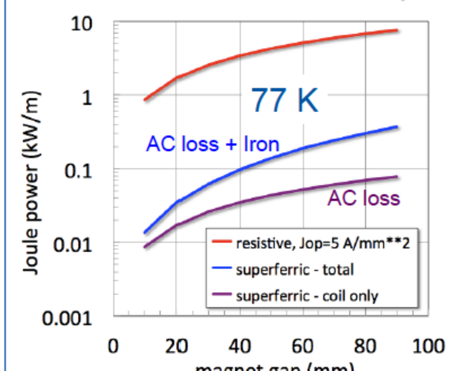
By courtesy of Ph. Lebrun, CERN

The edge of HTS



Resistive magnet $\frac{P_{resistive}}{l} \propto \rho JBh$

SC fast cycled magnet $\frac{P_{SC}}{l} \propto Bh\left(\alpha + \frac{\beta}{J}\frac{dB}{dt}\right)\frac{dB}{dt} + \gamma(Bh)^n\frac{dB}{dt}$



Operation at 77 K
COP = 15

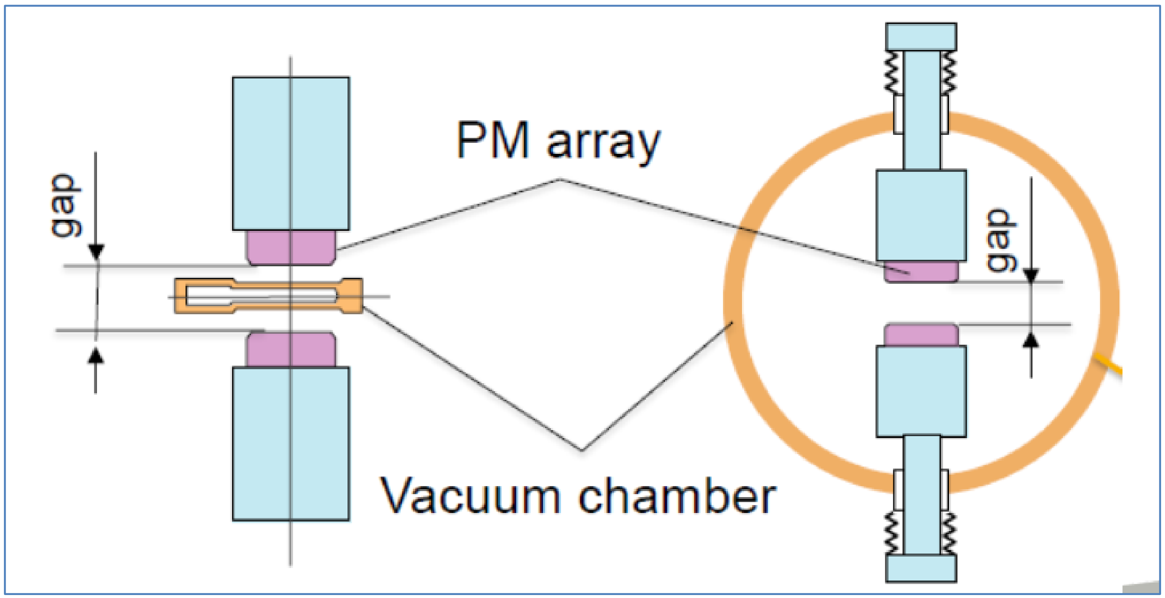
A superferric magnet with loss comparable to a LTS (5 W/m) would be highly

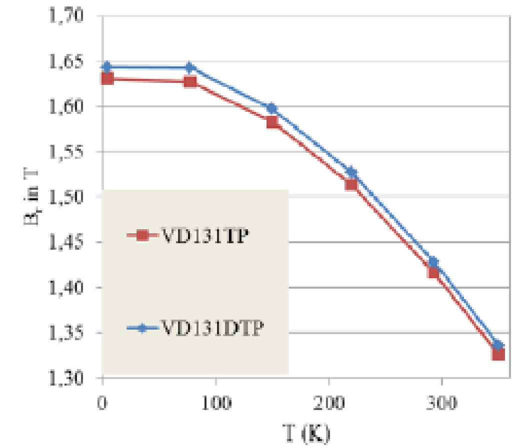
Competitive !

In-Vacuum Magnet Design and Challenges

Jim Clarke

- In a typical permanent magnet undulator we have: $B_0 \propto e^{-\pi g/\lambda_u}$ so to keep K (relatively) high whilst reducing the period we have to reduce the gap, g [Remember $K \propto B_0 \lambda_u$]
- So, the ***magnet gap is a crucial parameter*** in every undulator and, in a sense, it defines the potential output of every light source





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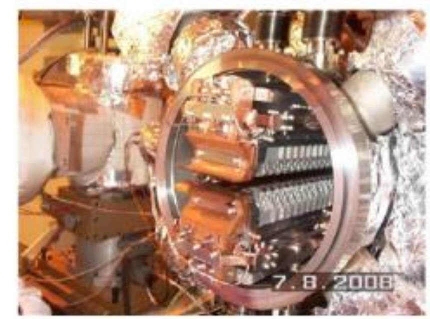
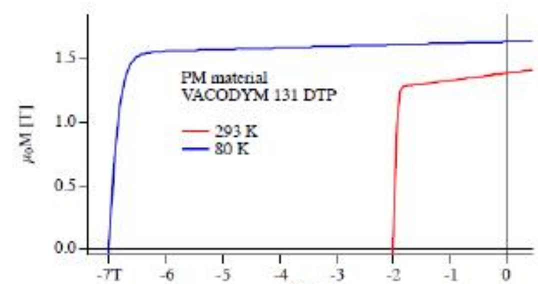
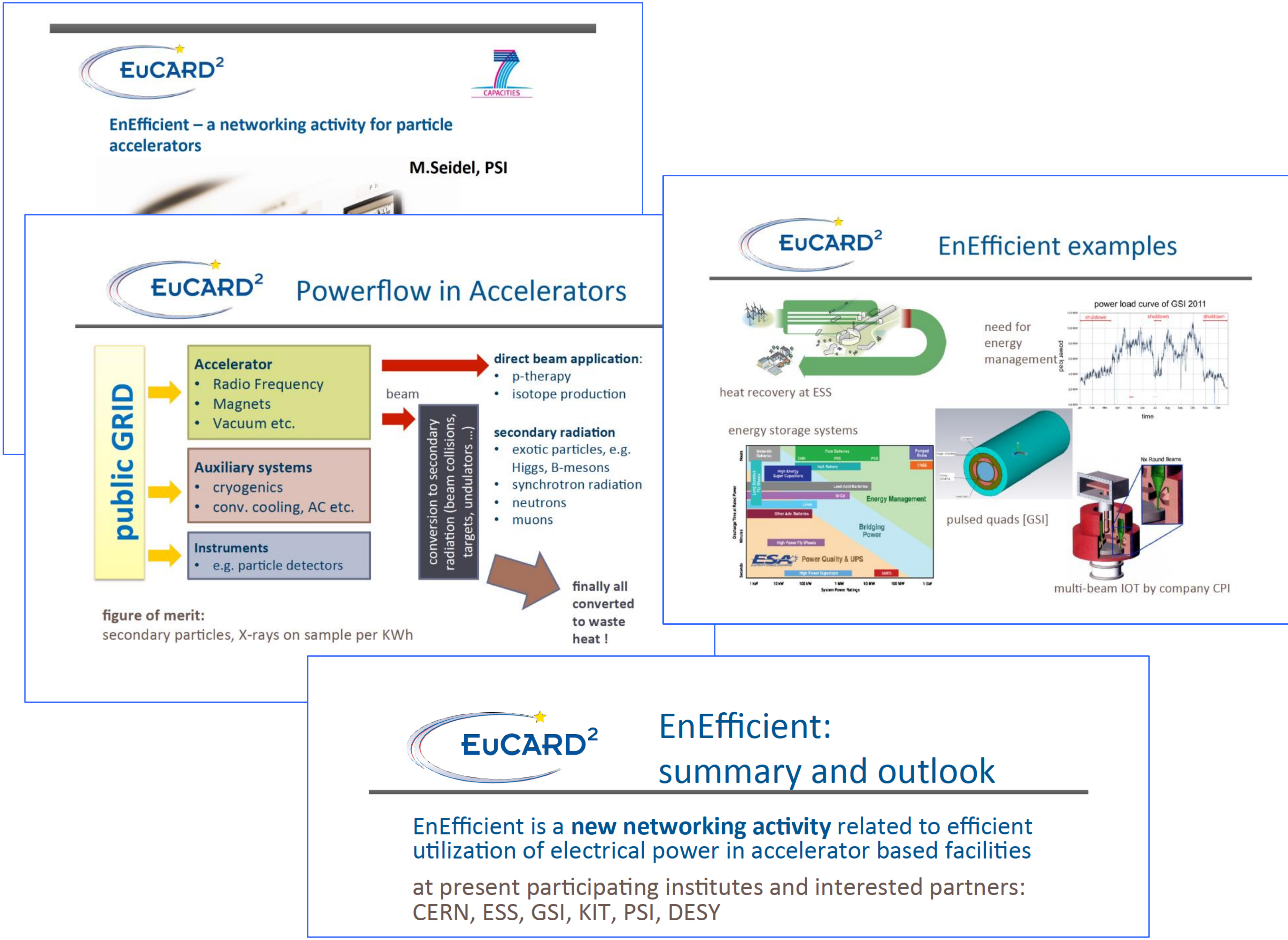


- The most significant enhancement has taken advantage of the in-vacuum technology to cool down the PM blocks to increase the magnetisation of the material and so enhance the magnetic fields – so-called cryogenic PM undulators (CPMUs)



Backup


EuCARD²
CAPACITIES
EnEfficient – a networking activity for particle accelerators
M.Seidel, PSI
EuCARD²
Powerflow in Accelerators
public GRID
Accelerator
• Radio Frequency
• Magnets
• Vacuum etc.
Auxiliary systems
• cryogenics
• conv. cooling, AC etc.
Instruments
• e.g. particle detectors
beam
conversion to secondary radiation (beam collisions, targets, undulators ...)
direct beam application:
• p-therapy
• isotope production
secondary radiation
• exotic particles, e.g. Higgs, B-mesons
• synchrotron radiation
• neutrons
• muons
finally all converted to waste heat !
figure of merit:
secondary particles, X-rays on sample per KWh
EuCARD²
EnEfficient examples
heat recovery at ESS
need for energy management
power load curve of GSI 2011
shutdown
power load
time
energy storage systems
Energy Management
Bridging Power
Power Quality & UPS
pulsed quads [GSI]
Nx Round Beams
multi-beam IOT by company CPI
EuCARD²
EnEfficient:
summary and outlook
EnEfficient is a new networking activity related to efficient utilization of electrical power in accelerator based facilities
at present participating institutes and interested partners:
CERN, ESS, GSI, KIT, PSI, DESY