Energy efficiency of particle accelerators – a network in the European program EUCARD-2

M.Seidel, PSI

1st EuCARD-2 Annual Meeting, DESY Hamburg, Mai 19-23, 2014

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Outline

Energy Efficiency in Particle Accelerators

- Motivation and Difficulties for EnEfficient
- Powerflow in Accelerators
- Tasks and Themes
- Workshops and Examples
  - CLIC workshop
  - Heat Recovery
  - Energy Management
- Outlook and Conclusions

Workpackages in Eucard

Management and Communication

- WP1: Management and Communication (MANCOM)

Networking Activities

- WP2: Catalysing Innovation (INNovation)
- WP3: Energy Efficiency (EnEfficient)
- WP4: Accelerator Applications (AccApplic)
- WP5: Extreme Beams (XBEAM)
- WP6: Low Emittance Rings (LOW-e-RING)
- WP7: Novel Accelerators (EuroNNAc2)

Transnational Access

- WP8: ICTF@STFC
- WP9: HiRadMat@SPS and MagNet@CERN

Joint Research Activities

- WP10: Future Magnets (MAG)
- WP11: Collimator Materials for fast High Density Energy Deposition (COMA-HDED)
- WP12: Innovative Radio Frequency Technologies (RF)
- WP13: Novel Acceleration Techniques (ANAC2)

Motivation for EnEfficient

- worldwide scarcity of resources and climate change also impacts research facilities and is of great political importance

  [e.g. Swiss “Energiestrategie 2050”:

  public institutions asked to improve efficiency by 20% till 2020 …]

- next generation accelerator facilities provide a new quality of research opportunities, but often connected with a new quality of energy consumption as well

  [EuroXFEL, FAIR, ESS, LHeC, FCC, ILC, CLIC, Project-X …]

→ wee need to intensify our efforts to optimize the energy efficiency of accelerator systems

Energy Efficiency – why is it often low priority?

- first priority of a typical accelerator based project are aspects like: **Luminosity, Beam Power, X-Ray Brightness, Emittance** and so forth
- second priority is technical reliability and **overall availability**
- only then other aspects are operating cost and **energy efficiency**

compromises:

- high energy efficiency often causes **higher investments** which amortize slowly
- efficiency friendly choices **often contradict technical reliability and flexible operating conditions** (e.g. high operating temperature of klystrons, or interdependence of public heating and operation of a facility)

→ despite of such difficulties it is obvious that political and public acceptance for future accelerator projects make it **mandatory to consider Energy Efficiency** for each new project

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

conversion efficiency to secondary radiation

In most accelerator applications a conversion to secondary beams/particles is necessary; typically this conversion process has great potential for the overall efficiency

- **Synchrotron Radiation**

  emittance!; optimized undulators; FEL: coherent radiation; energy recovery

- **Colliders**

  recirculation concept to re-use beam;

  low-beta insertion; crab cavities etc.

- **Neutron Sources**

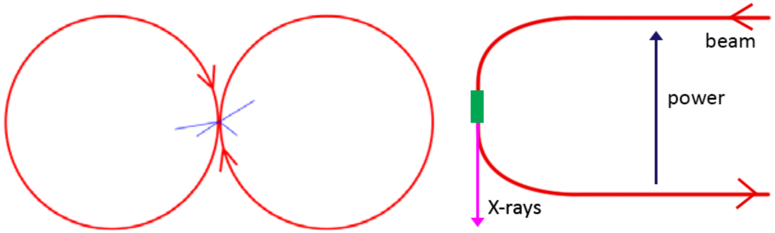
  target layout; choice of beam energy;

  moderators, neutron guides etc.

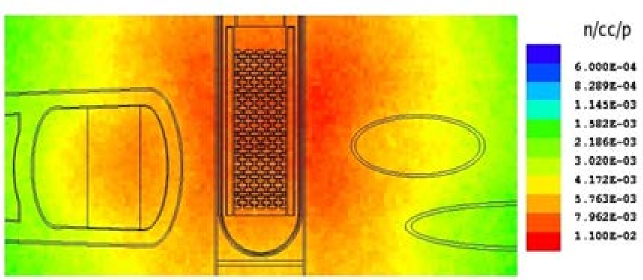
- **Muon Sources**

  target layout; capture optics; µ-cooling

efficient concepts:
collider / energy recovery



neutron source optimization:
spallation target / moderator



Example: PSI Facility, 10MW

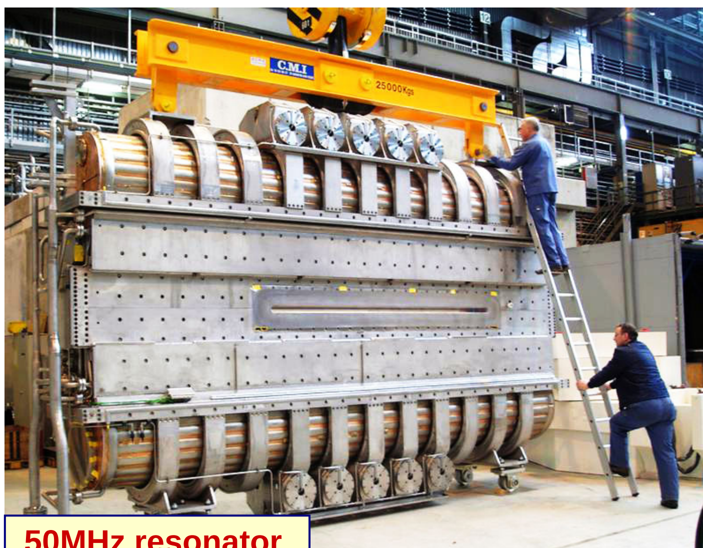
Ring Cyclotron 590 MeV
loss ≈ 10^{-4}

Power transfer through
4 amplifier chains
4 resonators 50MHz

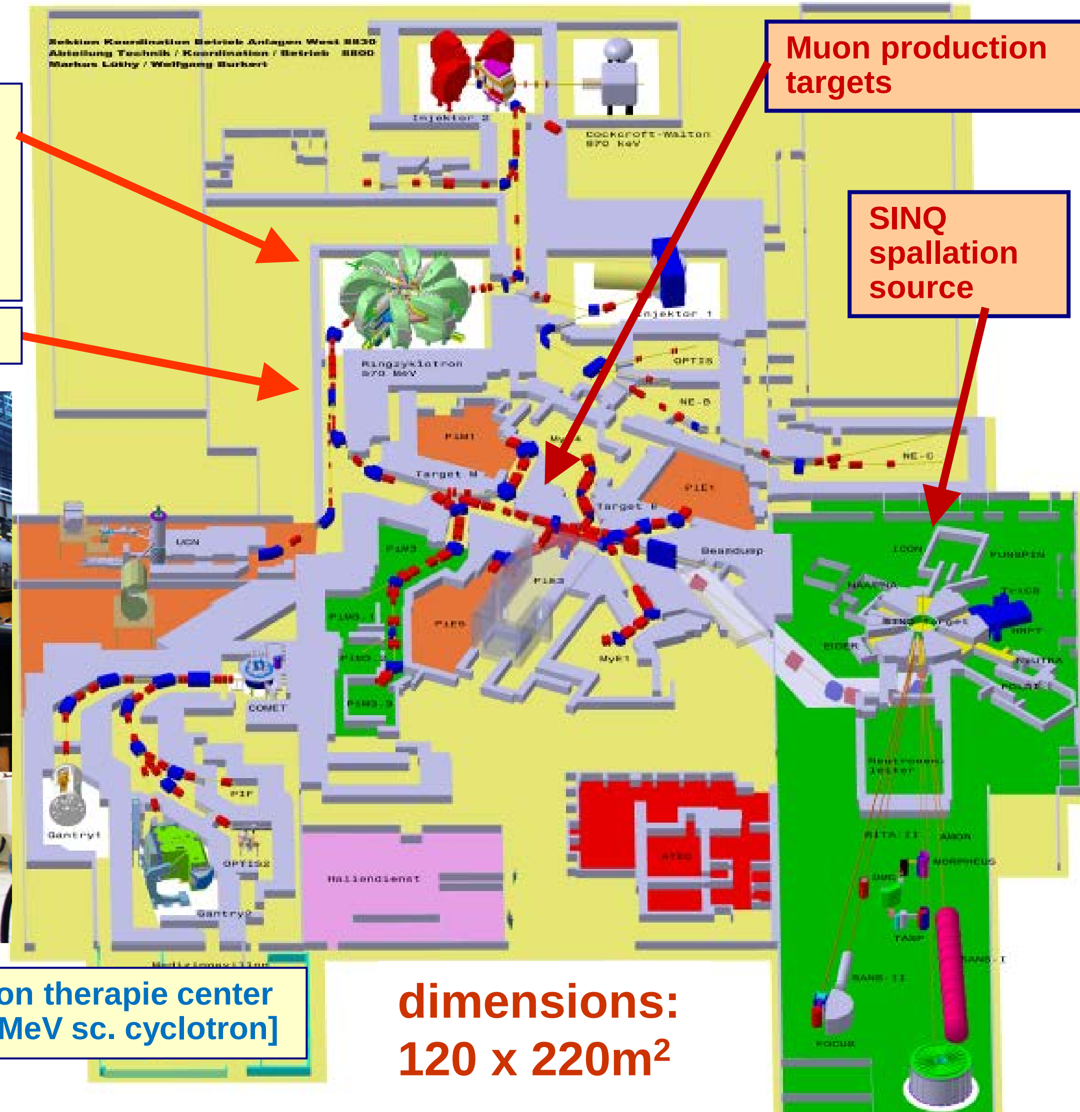
2.2 mA /1.3 MW

Muon production targets

SINQ spallation source



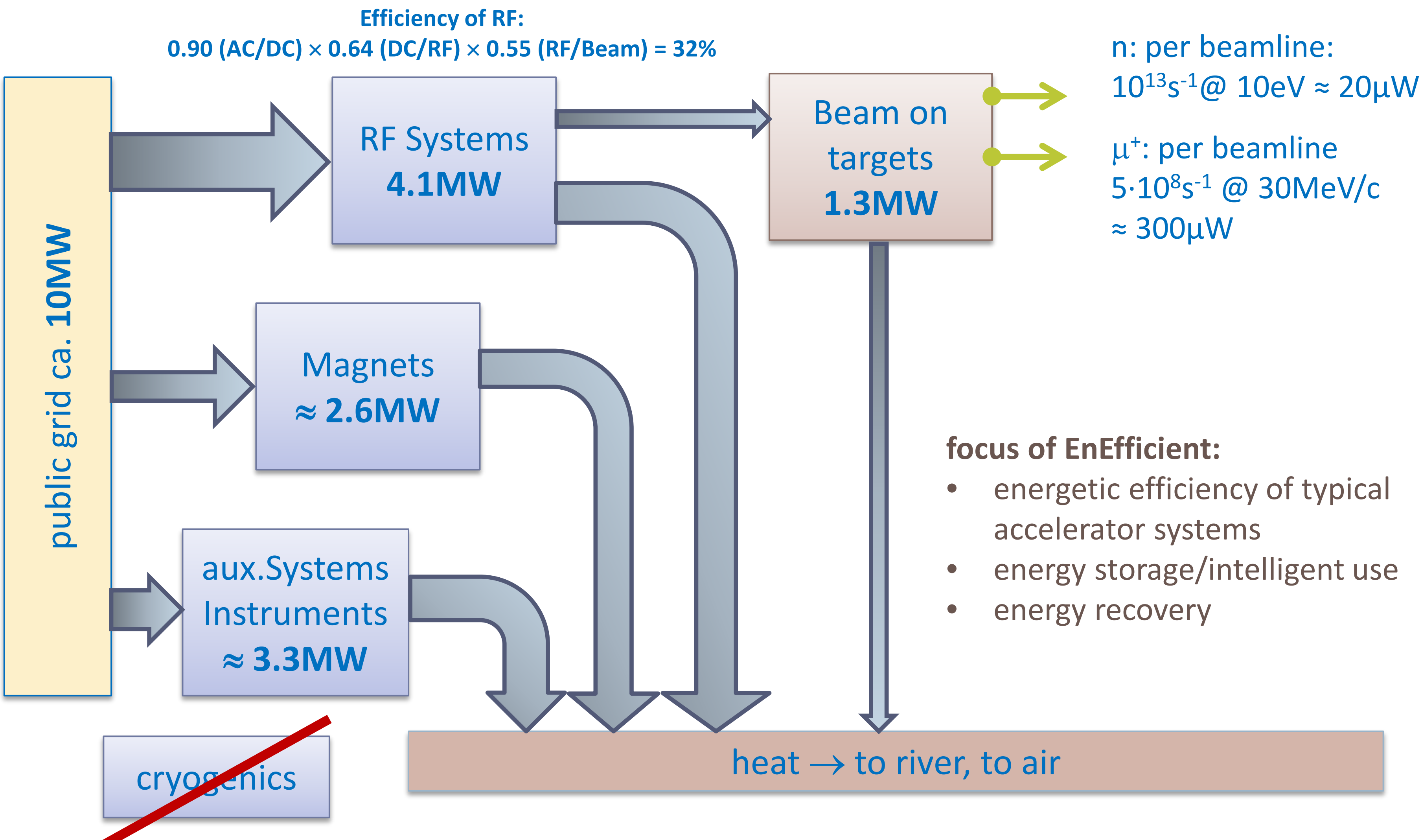
50MHz resonator



proton therapie center
[250MeV sc. cyclotron]

dimensions:
120 x 220m²

Example: PSI-HIPA Powerflow



focus of EnEfficient:

- energetic efficiency of typical accelerator systems
- energy storage/intelligent use
- energy recovery

tasks within EnEfficient

task 1: energy recovery from cooling circuits, Th.Parker, E.Lindström (ESS)

[workshop April 14, survey of European Labs, applications of heat, T-levels etc.]

task 2: higher electronic efficiency RF power generation, E.Jensen (CERN)

[workshop Daresbury in June, e.g. Multi Beam IOT's]

task 3: short term energy storage systems, R.Gehring (KIT)

[non-interruptable power, short term storage, wide spread of time scales …]

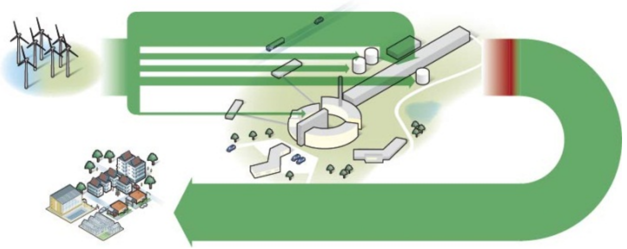
task 4: virtual power plant, J.Stadlmann (GSI)

[adaptation of operation to grid situation – context renewables…, possibly backup power generator …]

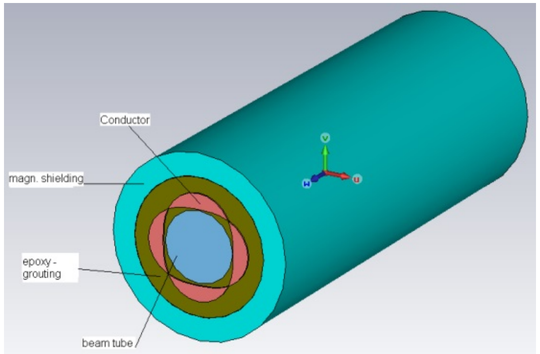
task 5: beam transfer channels with low power consumption, P.Spiller (GSI)

[pulsed magnets, low power conventional magnets, permanent magnets, parameter comparison etc.]

Energy Efficiency Examples

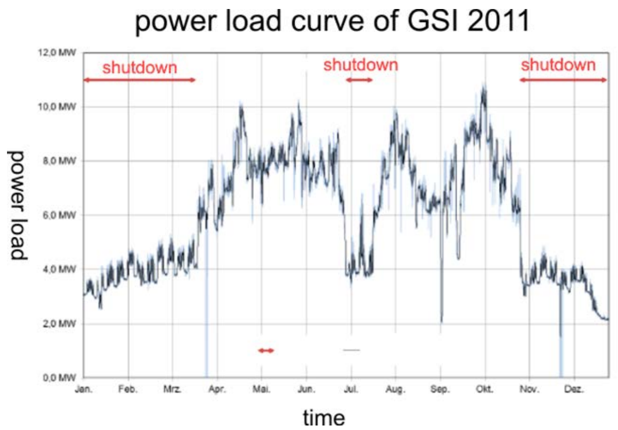


heat recovery at ESS

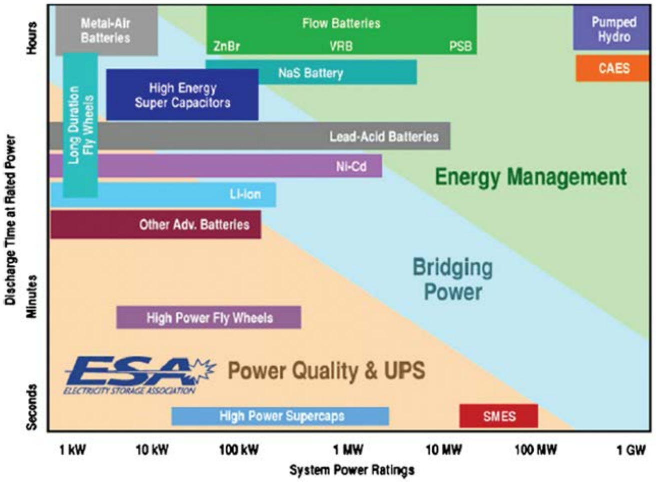


pulsed quads [GSI]

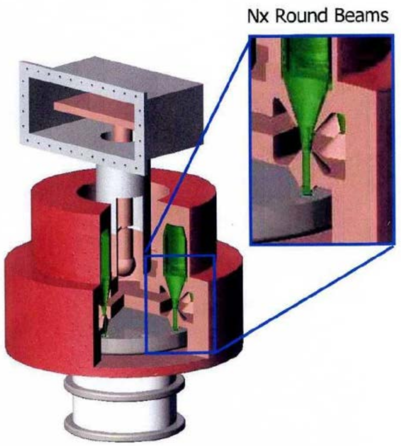
need for energy management



review of energy storage systems



permanent magnet [CLIC]



multi-beam IOT by company CPI

Workshop in Lund on Heat Recovery and General E-Themes

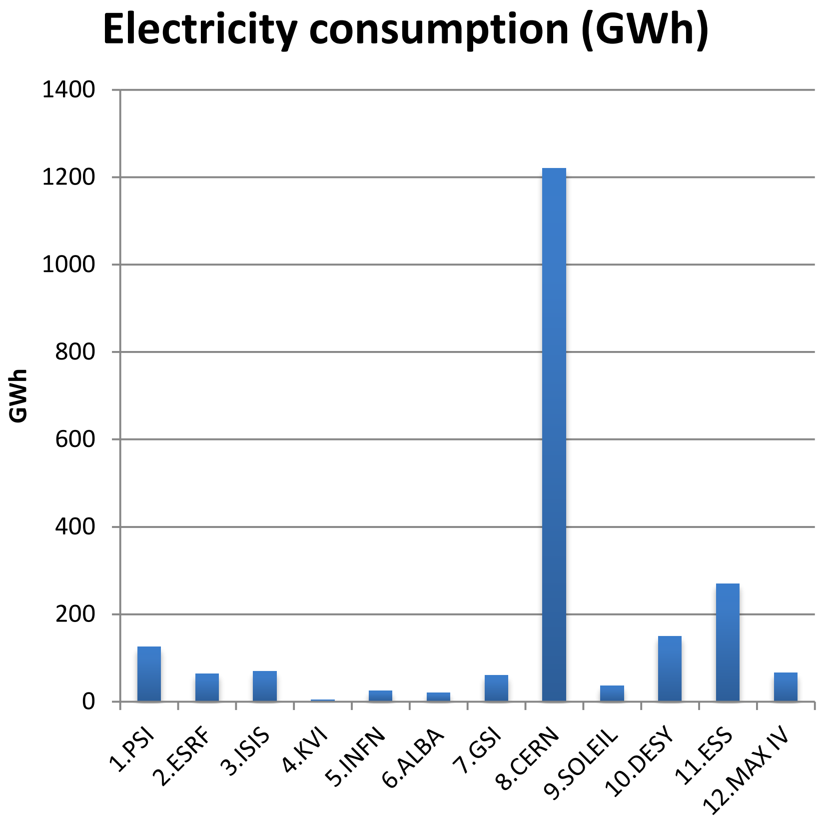
Participants (Experts) from
DESY, ALBA, SOLEIL, ESS, MAX-4, PSI, DAFNE, ISIS (institutes)
E.ON, Kraftringen, Lund municipality (industry, local authorities)

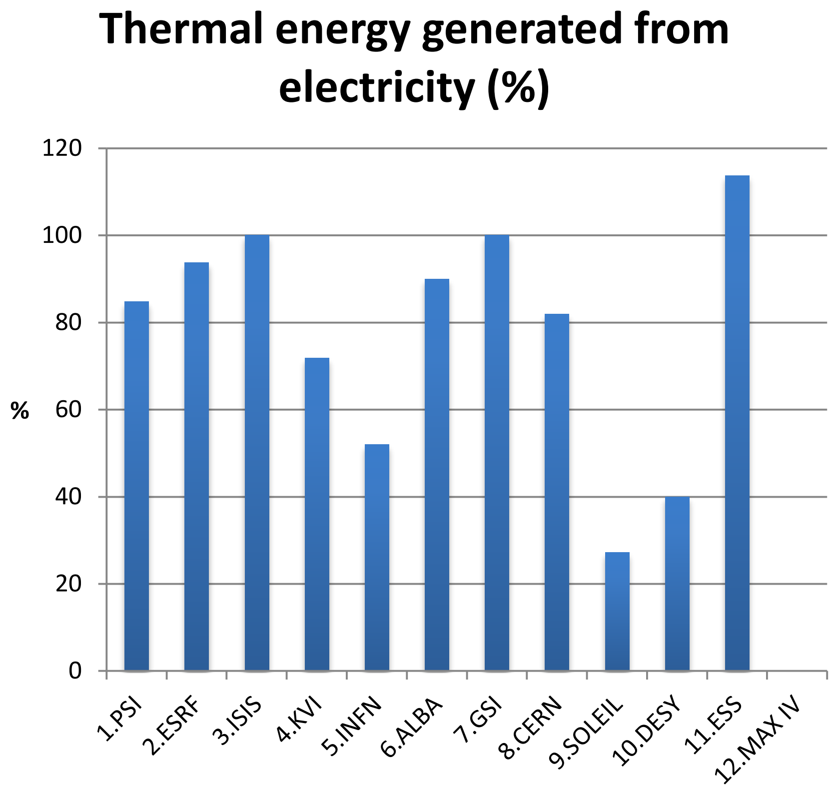
- heat recovery works for many facilities; high temperatures beneficial
- local heat distribution system required
- greenhouses present interesting application (non-linear scaling)
- new facilities MAX-4 and ESS foresee heat recovery on large scale

examples on next slides …

Lab Survey: Energy Consumption & Heat

J.Torberntsson, ESS





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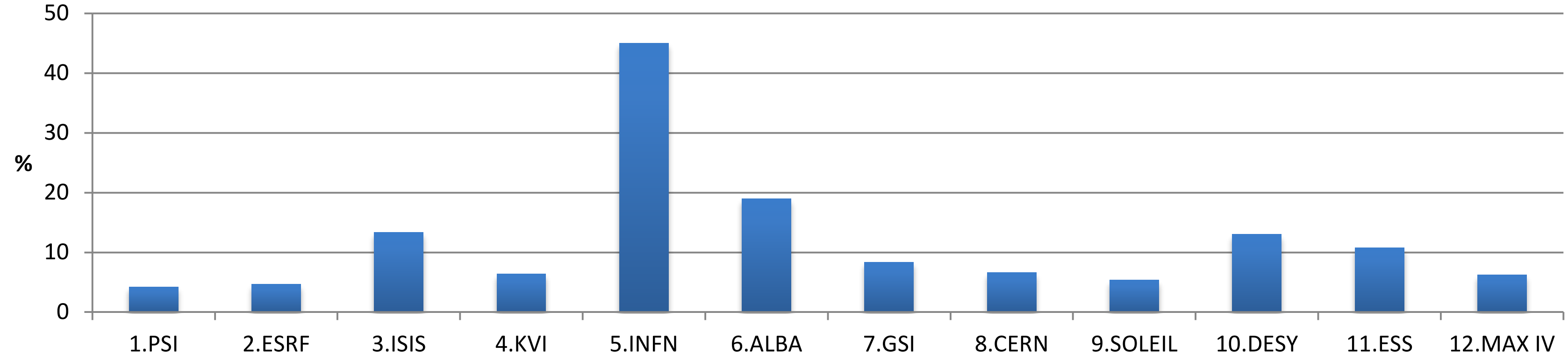
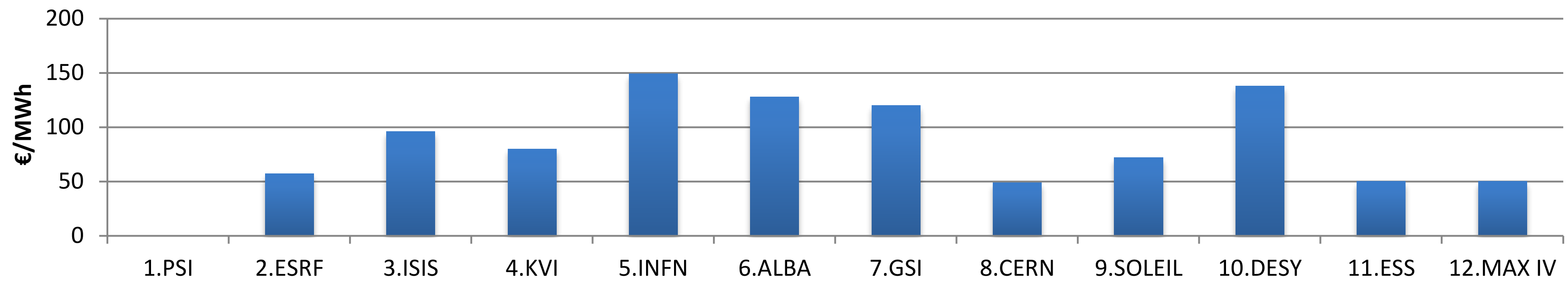
Lab Survey: Energy Cost

J.Torberntsson, ESS

Energy-related part of costs (%)



Electricity price (€/MWh)



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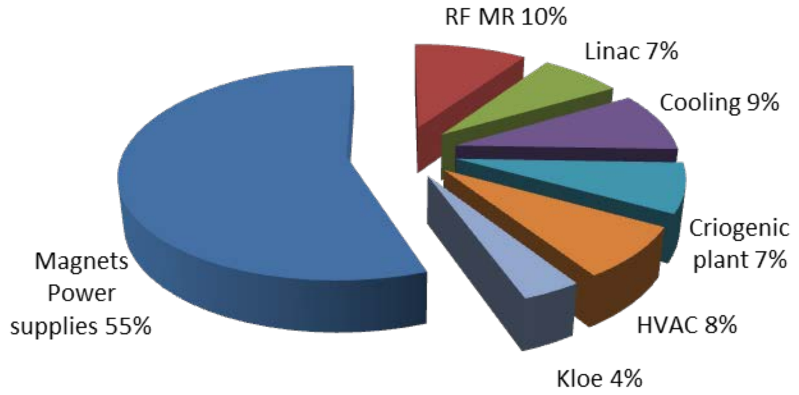
Lund workshop: optimizations at DAFNE

R.Ricci,
U.Rotundo
INFN Frascati

	kW	€cent/kWh	K€/day	1 year bill (200 run days) [M€]	Up-to date 1 year bill [M€]
Run KLOE 2005-2006	5.900	9,8	13,88	2,78	5,12
Run KLOE (Dec 2013)	3.340	18,08	14,49	2,90	2,90
Power demand reduction =	**2.560**		**200 days run saving =**		**2,22**

	dec-2005	NOW
Magnets Power supplies	3.984	1.850
RF MR	524	320
Linac	201	233
Cooling	600	300
Criogenic plant	250	250
HVAC	250	260
Kloe	150	120
tot	5.959	3.333

Wiggler pole shaping and current reduction (730-> 400 A)	1700 kW
n. 4 Septa 34° magnets new coils	250 kW
n. 4 Splitter magnets removal (new interaction zone for the crab-waist)	160 kW
Dafne RF system optimization	170 kW
Dafne cooling system optimization	280 kW
Total power demand reduction	2.560 kW



Use of Waste Heat

- produce work → electrical power?

$$W_{\max} = Q\left(1 - T_0/T\right)$$

example: T=40°C: efficiency 8%
T=95°C: efficiency 20%

- convert heat to higher T level for heating purposes

$$Q_{\mathrm{H}} = W \cdot \mathrm{COP}$$

example: T=40°C, T_{use} =80°C, COP=5: W=10kW, Q_C=40kW, Q_H=50kW (availabe for heating)

- use heat directly at available temperature

example: T_{use}=50°C …80°C : heating
T_{use}=25°C…50°C: green houses, food production

An increase in temperature from 8.6 to 13.7 ^{o}C doubled the growth rate in salmon smolt.

BY B.Fyhn Terjesen, Nofima

A.Kiessling

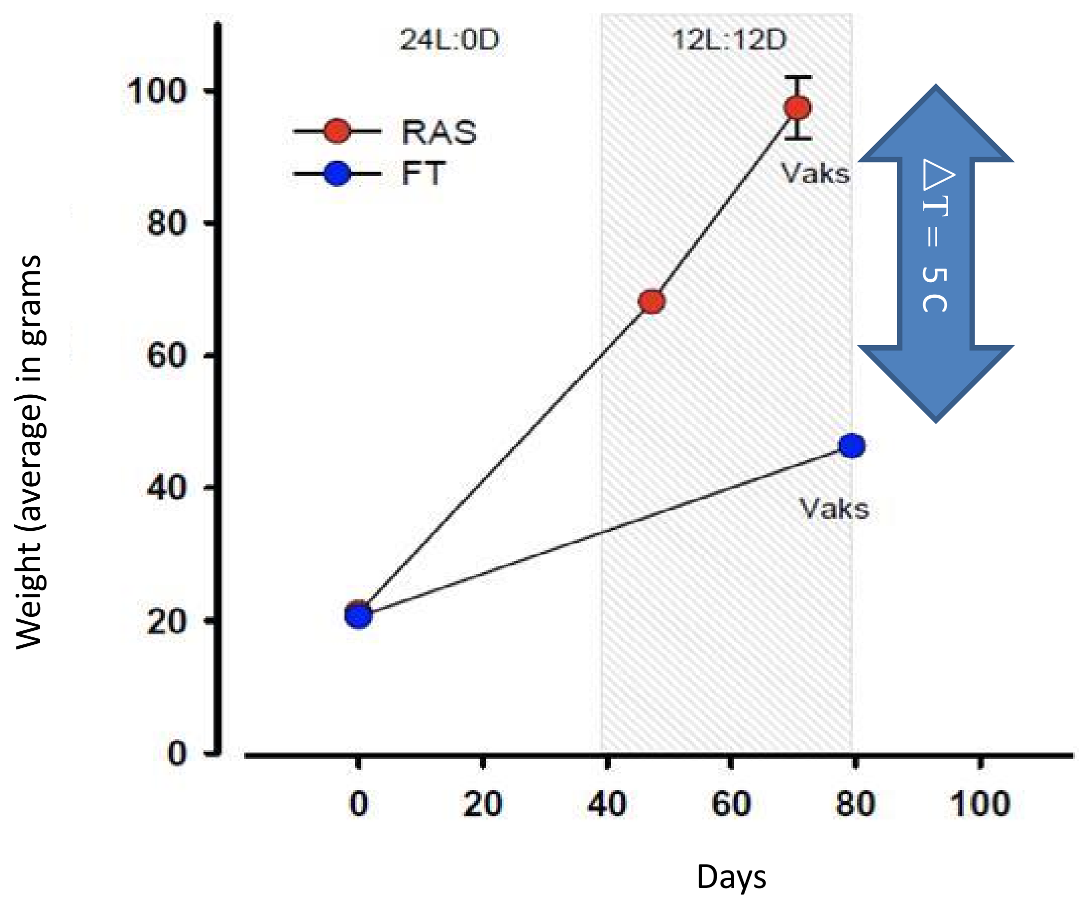
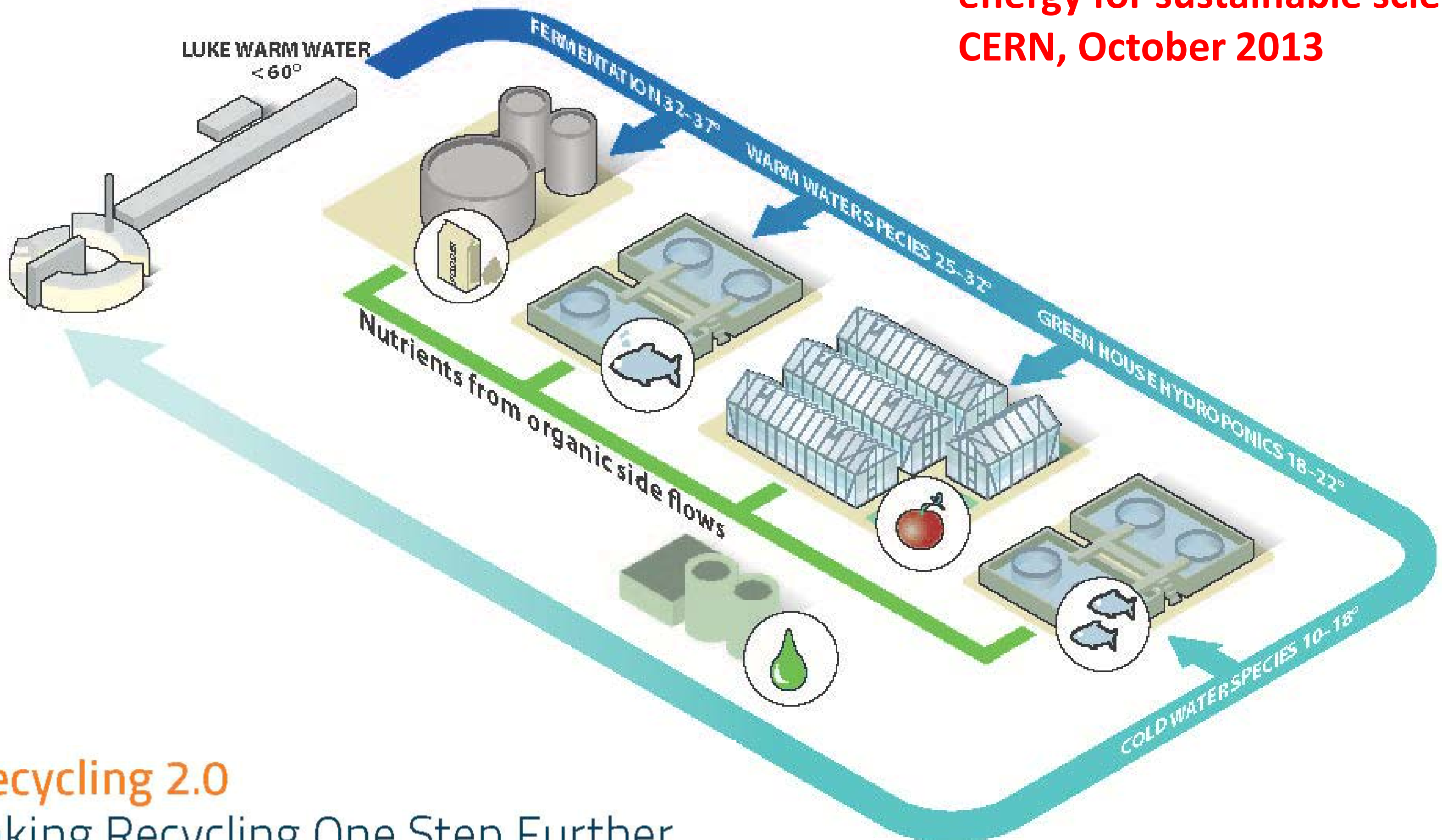


Photo A.Kiessling

Surplus energy and food production.

Anders.kiessling@slu.se

energy for sustainable science, CERN, October 2013



Recycling 2.0

Taking Recycling One Step Further

Illustration Peter Lönnegård & FredrikIndebetou

February 14 Session on CLIC Energy Efficiency

indico.cern.ch/event/275412

Paths to CLIC power and energy efficiency *Room Georges Charpak (Room F), CERN*	*Philippe LEBRUN* 08:30 - 08:50
Foreseen operating modes and transients affecting CLIC power/energy consumption	*Dr. Andrea LATINA*
Development of permanent-magnet based accelerator magnets *Room Georges Charpak (Room F), CERN*	*Ben SHEPERD* 09:10 - 09:30
Power/size trade-offs in classical electromagnets *Room Georges Charpak (Room F), CERN*	*Michele MODENA* 09:30 - 09:50
How to reduce cooling and ventilation duties in CLIC *Room Georges Charpak (Room F), CERN*	*Mauro NONIS* 09:50 - 10:10
Future electricity supply contracts, peak periods and tariffs *Room Georges Charpak (Room F), CERN*	*Francois DUVAL* 10:10 - 10:30
Coffee break *Room Georges Charpak (Room F), CERN*	10:30 - 11:00
Challenges and development of high-performance klystron modulators for the CLIC Drive Beam	*Davide AGUGLIA*
Status on klystron modulator repeatability for the CLIC Drive Beam *Room Georges Charpak (Room F), CERN*	*Anthony DAL GOBBO* 11:20 - 11:40
Development of two-klystron modulator topologies for the CLIC Drive Beam	*Francisco CABALEIRO MAGALLANES et al.*
Active front-end and power system optimization for the CLIC Drive Beam klystron modulators	*Marija JANKOVIC*

adaptation to grid situation, „virtual power plant“

low power beam transport

cooling, heat recovery

higher electronic efficiency RF generation

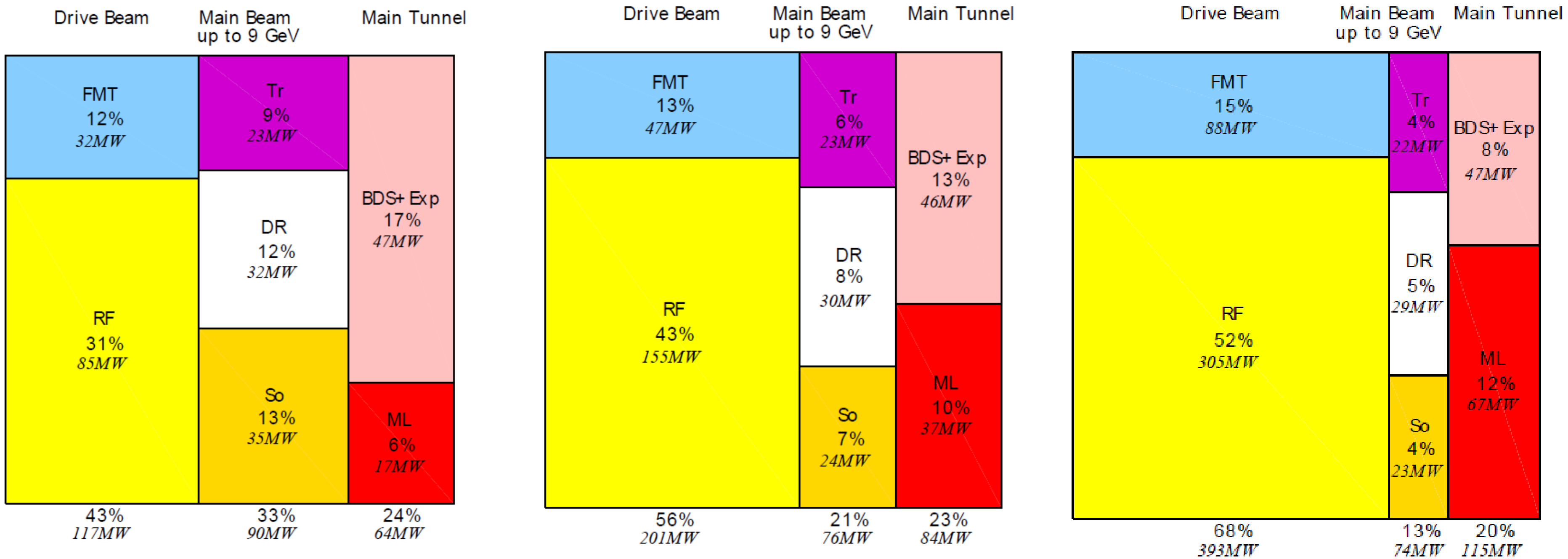
striking example: CLIC CDR power consumption

Power consumption of ancillary systems ventilated pro rata and included in numbers by WBS domain

500 GeV A
Total 272 MW

1.5 TeV
Total 364 MW

3 TeV
Total 589 MW

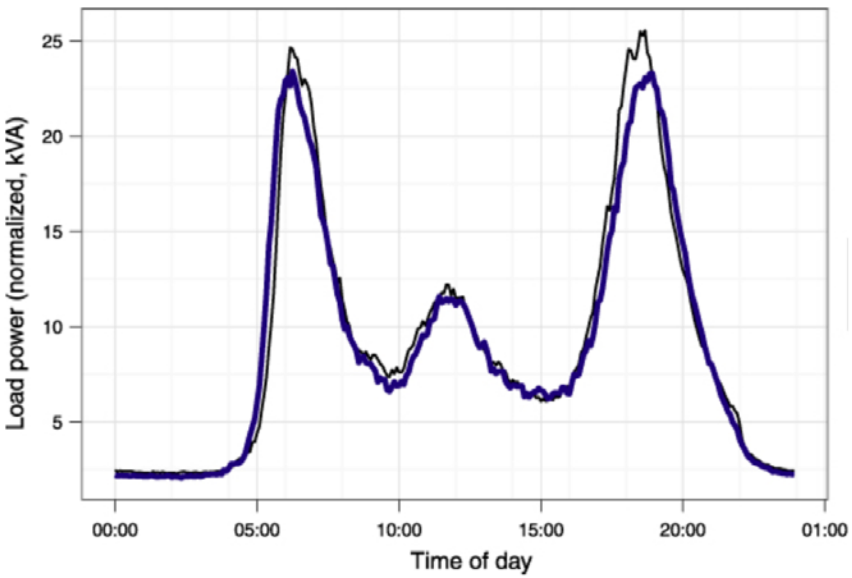


RF: drive beam linac, FMT: frequency multiplication & transport, So: sources & acceleration up to 2.5 GeV, DR: damping rings, Tr: booster linac up to 9 GeV & transport, ML: main linacs, BDS: beam delivery system, main dump & experimental area

Ph. Lebrun

EuCARD² CLIC Study on standby modes

Energy consumption per day



Andrea Latina, CERN

(calculation for 3TeV case)

- 1 day with 2 × standbys:

  $E_{standby}$ = 582 MW × 14 hours + 2 × (4 × 268 MWh + 1 × 425 MWh) = 11.14 GWh

  $L_{standby}t = 2.0\times10^{34}\ cm^{-2}s^{-1} \times (14 + 2 \times ½)$ hours = $1.08\ fb^{-1}$

Energy consumed is reduced by 18% (-2.826 GWh)

Luminosity delivered is reduced by 37% ($-0.648\ fb^{-1}$)

F.Duval, CERN

Example: EDF (French utility)

(comsumption part of one of the industry 400 kV tariff)

Highest price is ~7 times the lowest one

Season	Tariff daily period	Price (c/kWh
Winter (December, January & February)	Peak period: 8:00 to 10:00 and 17:00 to 19:00	13.966
	Valley period: 22:00 à 6:00	4.225
	Full period: 6:00 to 8:00, 10:00 to 17:00 and 19:00 to 22:00	8.664
Middle season (March & November)	Valley period: 1:00 to 7:00	2.977
	Full period: 0:00 to 1:00 and 7:00 to 24:00	4.599
Summer (April, May, June, September and October)	Valley period: 0:00 to 6:00 and 22:00 to 24:00	2.014
	Full period: 6:00 to 22:00	3.919
July & August	Full day	2.918

energy spot market prices

→ energy managment, virtual power plant

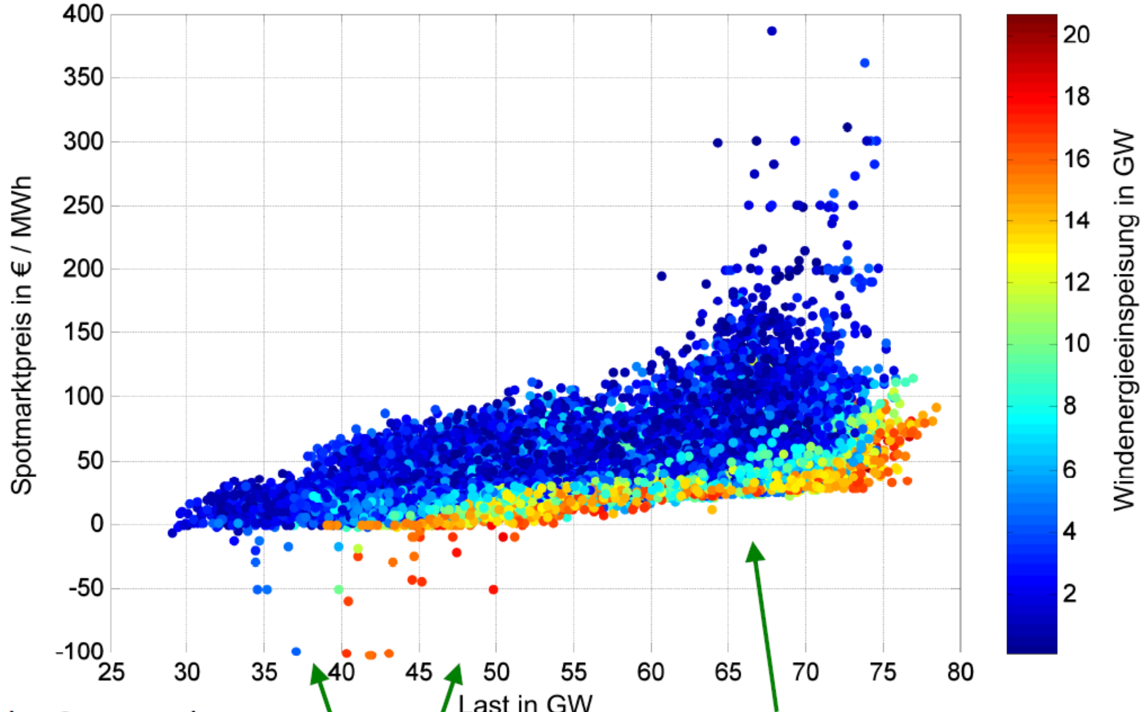
found on the internet

renewables cause strong variations

Impact on accelerators?

Korrelation Wind & Last & EEX – deutliche Zusammenhänge

stündliche aufgelöste Daten für 2007 und 2008



Negative Strompreise zu Schwachlastzeiten bei wenig / viel Wind

Wind senkt den Spotmarktpreis

Quelle: IWES - work in progress, 2010

Energy Management or „virtual power plant“

in the presence of more and more renewable energies flexibility becomes more important

- adapt operation to situation on Grid, e.g. through efficient standby modes
- energy storage on site, e.g. utilizing cryogenic facility?
- cost effective backup power station, gas turbine?

→ workshop planned for 2015 (J.Stadlmann, GSI)

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

next workshops:

June 3-4, 2014 - Workshop on **EnEfficient RF Sources**, organized at Cockroft Institute in Daresbury
More Information: https://indico.cern.ch/conferenceDisplay.py?confId=297025

November 26-28, 2014: Compact and Low Consumption Magnet Design for Future Linear and Circular Colliders, at CERN.

we are seeking more collaborators, interested colleagues are very welcome to participate in this network

information and contact under: www.psi.ch\enefficient