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

M.Seidel, PSI

network related to:

efficient and cost effective utilization of electrical power in accelerator based research facilities

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

- What is Eucard-2?
- Powerflow in Accelerators
- EnEfficient and it’s Tasks

What is Eucard-2 ?

[**European Coordination for Accelerator Research**]

- Integrating Activity Project for coordinated Research and Development on Particle Accelerators, co-funded by the European Commission under the FP7 Capacities Programme.
- running from 5/13 to 5/17

Who is involved?

- 40 partners from 15 European countries, including Russia.
- 10 accelerator laboratories, 23 technology institutes/universities, 5 scientific research institutes and 2 industrial partners.

What benefits does EuCARD-2 offer?

- 6 **networking activities**, including close collaboration with Industry.
- The goal of the Networking activities is to break the barriers between traditional communities and foster a coherent and multi-disciplinary approach to the complex and multiform issues of upgrading highly sophisticated infrastructures.

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)

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 !

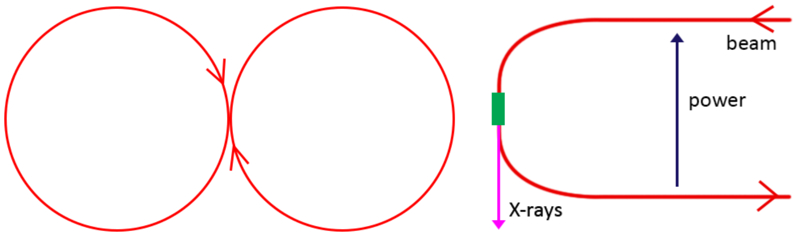
figure of merit:
secondary particles, X-rays on sample, destroyed cancer cells ... per KWh

conversion efficiency to secondary radiation

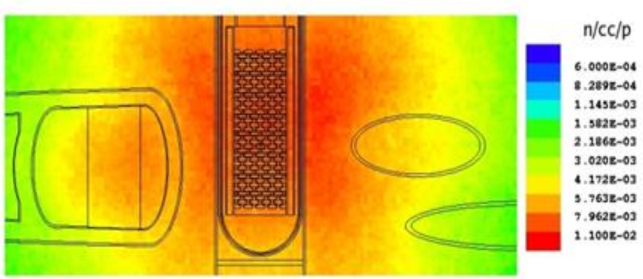
In most accelerator applications a conversion to secondary beams/particles is necessary; typically this conversion process has great potential for the overall efficiency

- **Synchrotron Radiation**
  optimized undulators; FEL: coherent radiation; energy recovery linac
- **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



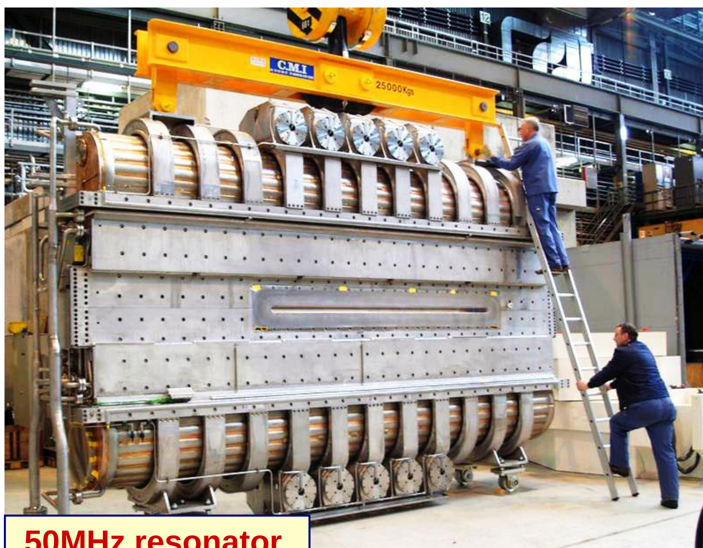
EuCARD²

Example: PSI Facility, 10MW

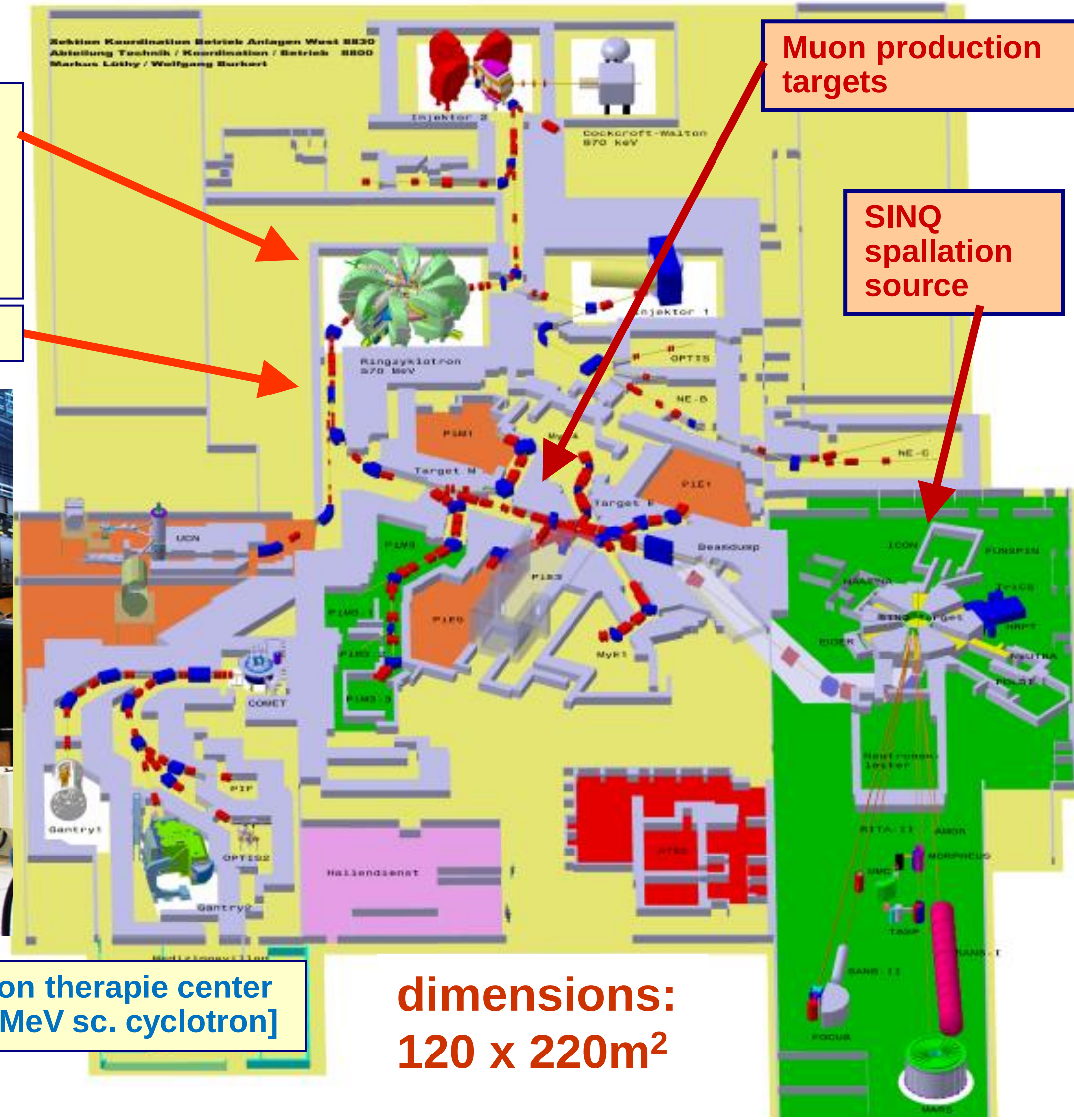
Ring Cyclotron 590 MeV
loss ≈ 10^{-4}

Power transfer through
4 amplifier chains
4 resonators 50MHz

2.2 mA /1.3 MW



50MHz resonator



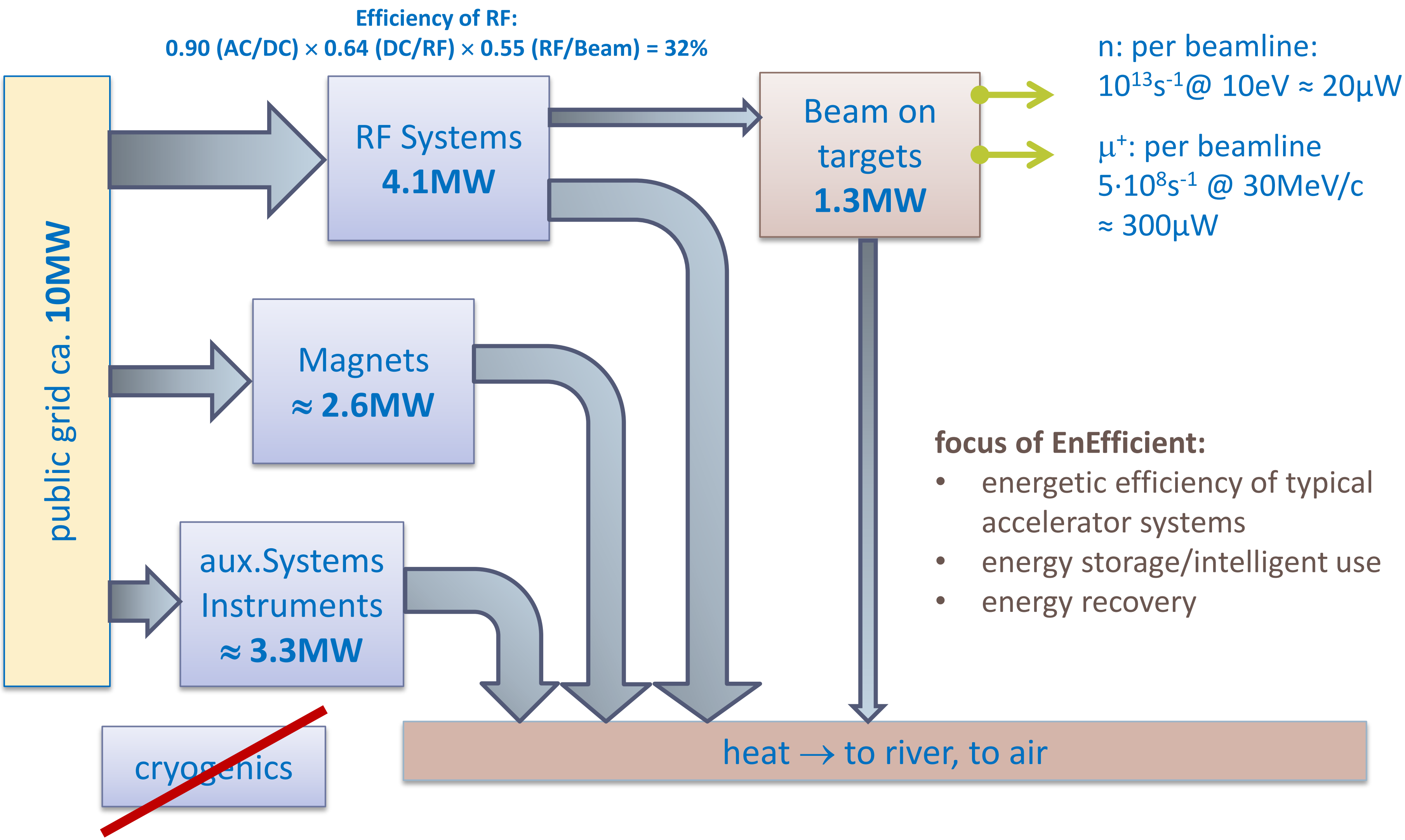
Muon production targets

SINQ spallation source

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

task 1: energy recovery from cooling circuits

- led by Thomas Parker, Erica Lindström (ESS)
- in any large facility most power is converted finally to heat; this power should be utilized as best as possible
- for best recovery the temperature level of cooling circuits must be high

→ evaluate the potential/inventory of different facilities, temperature levels and best recovery technologies

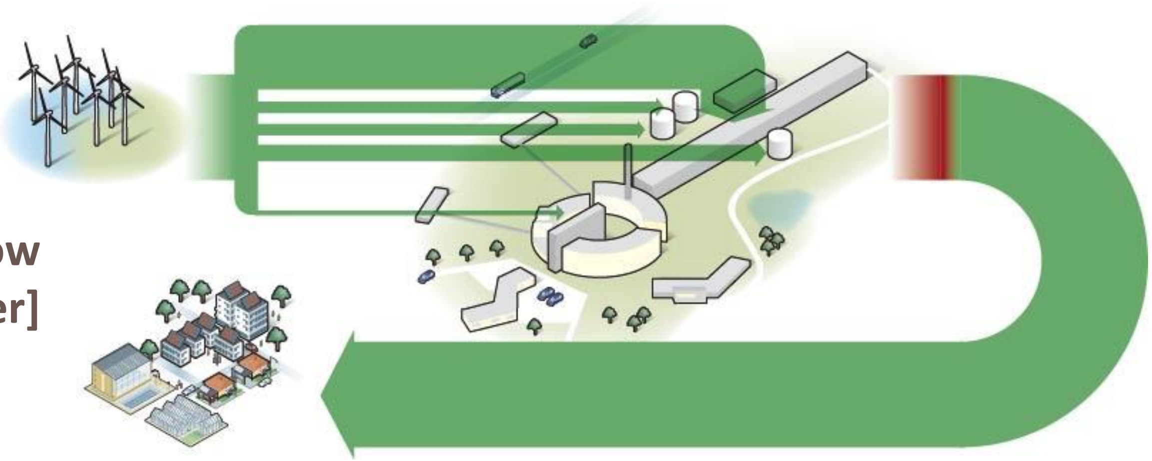
→ concerning temperature level – which compromises are acceptable?

→ presently data from large facilities collected; workshop in fall 2014

task 1: energy recovery from cooling circuits

the European Spallation Source (ESS) in Lund is based on a high power accelerator (5MW)

→ heat recovery methods are planned in from the beginning



ESS power flow [Th.Parker]

task 2: higher electronic efficiency RF power generation

- led by Erk Jensen (CERN)
- for accelerators with high beam power the conversion efficiency from grid to beam is of utmost importance, e.g. ESS, ILC, CLIC, LHeC …

→ study efficiency of conventional power sources: klystron, sheet- and multi-beam; also power distribution schemes

→ new devices and concepts, e.g.: multi-beam IOT's with solid state driver; magnetrons with better stability; RF aspects of energy recovery linac for LHeC with 400MW beam power

→ direct recovery of electrical energy from spent RF

→ first workshop early 2014 in preparation

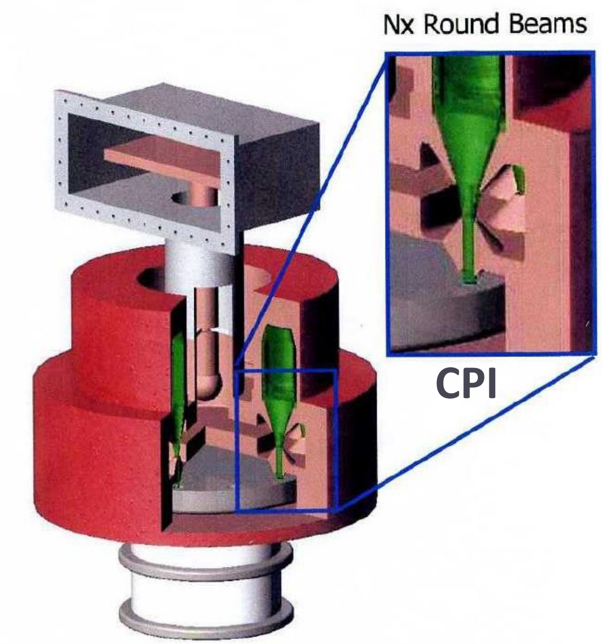
task 2: higher electronic efficiency RF power generation

- IOT's can reach higher efficiency (theoretical 78%) than klystrons and have advantages with regulation behavior
- however, today the max. power is insufficient

→ multi-beam IOT's could provide sufficient power while keeping the advantages

example: study of multi-beam IOT by company CPI

RF Power: 1 MW
frequency range: 650-750 MHz



task 3: short term energy storage systems

- led by Michael Sander (KIT)
- short interruptions of the grid may lead to significant downtimes of large accelerator facilities
- many accelerators operate in cycles / pulsed mode, i.e. their power draw from the grid varies

→ energy storage systems for varying duration and capacity are needed to bridge interruptions and to smooth the power draw from the grid

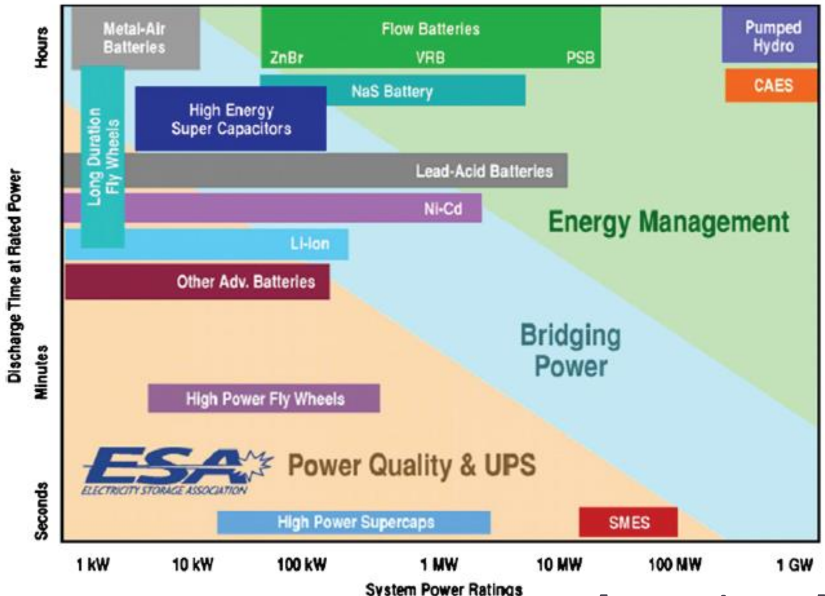
→ goal is to investigate the spectrum of technical solutions for energy storage and to assess their applicability for accelerators; synergies with renewable energies

task 3: short term energy storage systems

comparison of different state-of-the-art energy storage systems (courtesy: ESA)

storage systems include:

- Super- or Ultra-Capacitors
- Superconducting Magnetic Energy Storage (SMES)
- Rechargeable Batteries (e.g. Lead or Lithium Ion Batteries)
- Flywheel Energy Storage



[M.Sander,KIT]

LIQHYSMES is a combination of a superconducting energy storage coil for quick power release, then overtaken by a gas turbine or fuel cells operating with liquid H_2 storage

task 4: virtual power plant

- led by J.Stadlmann (GSI)
- flexibility of the power consumer can save cost and becomes more relevant with increasing contribution of renewable power sources to the grid

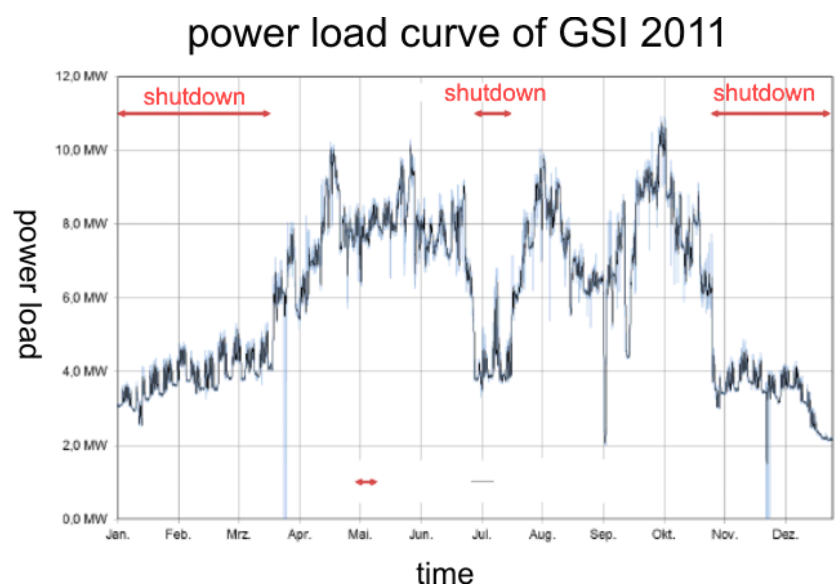
→ explore options to temporarily reduce power consumption in accelerator facilities, for example not refilling a storage ring, depending on supply situation

→ operation modes, automated information exchange with supplier, intelligent control system, potential cost savings per kWh

task 4: virtual power plant

power load example of GSI in 2011, demonstrating the strongly varying load, depending on accelerator status

detailed analysis and coordination of the different consumers in a complex accelerator facility could provide a more even power load and better adaptation to the situation in the grid



[J.Stadlmann, GSI]

task 5: beam transfer channels with low power consumption

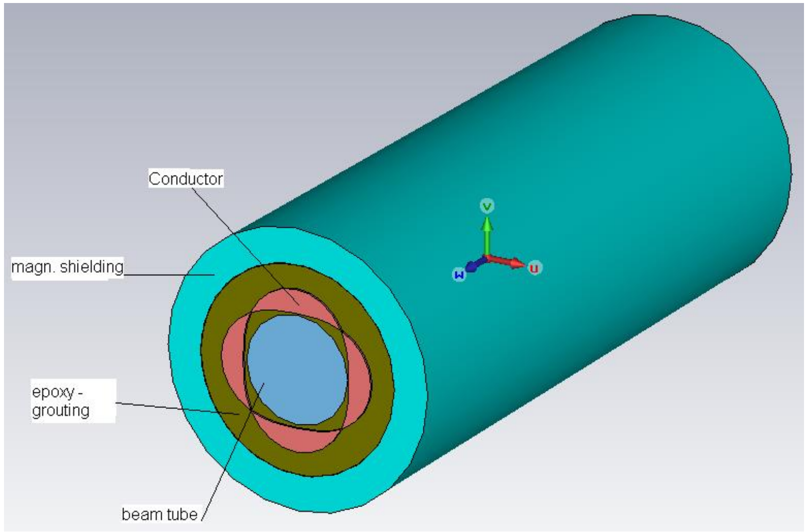
- led by P.Spiller (GSI)
- beam transfer channels using conventional dipole/quadrupole magnets have significant power consumption

→ perform comparative study of alternative schemes using pulsed magnets, permanent magnets or s.c. magnets

→ aspects: power consumption, cost, energy reach, stability/reproducibility

task 5: beam transfer channels with low power consumption

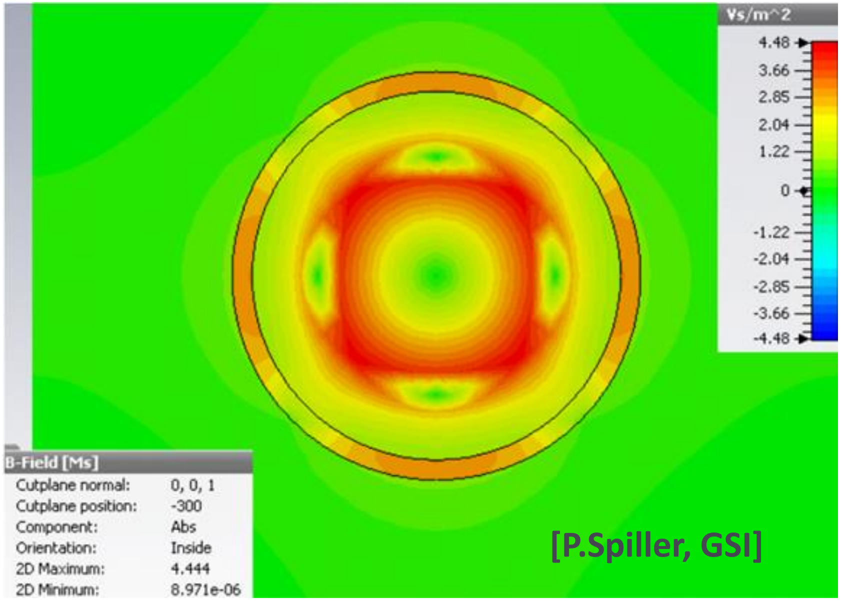
- **pulsed magnets**: for pulsed beams fields are needed only during passage of a beam, i.e. a small fraction of time



previous work at GSI:

four conductors arrangements leading the high current pulse; epoxy resin for mechanical stability; laminated shielding of electromagnetic pulse

magnetic field simulation in CST* at a current peak of 400 kA (on the right)



EnEfficient: summary and outlook

EnEfficient is a **new networking activity** related to efficient utilization of electrical power in accelerator based facilities

the aim is to hold workshops, evaluate present technology, identify areas with promising potential and to initiate development projects; findings and results will be documented

a selection of themes is organized in 5 tasks and will be discussed in a series of workshops; tomorrow first meeting!

at present participating institutes and interested partners: CERN, ESS, GSI, KIT, PSI, possibly CNRS Grenoble, DESY

interested colleagues are very welcome to participate in this network

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