ICFA Sustainability Panel Meeting

Thomas Roser
Sr. Scientist Emeritus
BNL

March 22, 2023

Agenda

- Welcome
- Panel membership and attendance
- Report from the Chair
- Report from Panel members on sustainability efforts at their labs
- Discussion on possible ICFA sponsoring of an Accelerator Sustainability Workshop series (possibly co-sponsoring the European ESSRI WS series and expand it internationally)
- Any other business
- Adjourn

Panel Members

- https://icfa.hep.net/icfa-panel-on-sustainable-accelerators-and-colliders/

  - **Europe:** Mike Seidel (PSI, Switzerland), Andreas Hoppe (DESY, Germany), Jerome Schwindling (CEA/IRFU, France), Ruggero Ricci (LNF, Italy), Peter McIntosh (STFC, UK), Roberto Losito (CERN, Switzerland)

  - **Asia:** Takayuki Saeki (KEK, Japan), Yuhui Li (IHEP, China), Hiroki Okuno (Riken, Japan), Gwo-Huei Luo (NSRRC, Taiwan), Eugene Levichev (BINP, Russia)

  - **America:** John Byrd (ANL, USA), Soren Prestemon (LBNL, USA), Thomas Roser (BNL, USA), Andrew Hutton (JLAB, USA), Robert Laxdal (TRIUMF, Canada), Vladimir Shiltsev (FNAL, USA), Emilio Nanni (SLAC, USA)

Summary of Activities

- Submission of contribution to Snowmass Community Summer Study (2022) on "Sustainability Considerations for Accelerator and Collider Facilities" (arXiv:2203.07423)
- Panel members were on the IOC of the 6th WS on Energy for Sustainable Science at Research Infrastructures (ESSRI), ESRF, Grenoble, Sep. 29 – 30, 2022
- Panel chair led the Snowmass Accelerator Frontier Implementation Task Force (ITF) in a two-year study to compare and evaluate all future collider proposals. The report evaluated R&D needs, technically limited schedule, cost and environmental impact, mainly power consumption. The final report can be found at arXiv:2208.06030. The next two slides have information from the report relevant to sustainability.
- A continuation of the study is being discussed comparing and evaluating luminosities and carbon footprint of future colliders with possible participation of the ICFA beam dynamics panel and the ICFA sustainability panel.
- Our Panel needs to focus on energy efficiency and not on carbon-neutral energy sources. The only exception is when accelerators can contribute to carbon-neutral energy sources.

Summary of Activities (cont'd)

- Mike Sidel: Here is the link to the workshop on critical materials and life cycle management: https://indico.desy.de/event/35655/timetable/#all.detailed

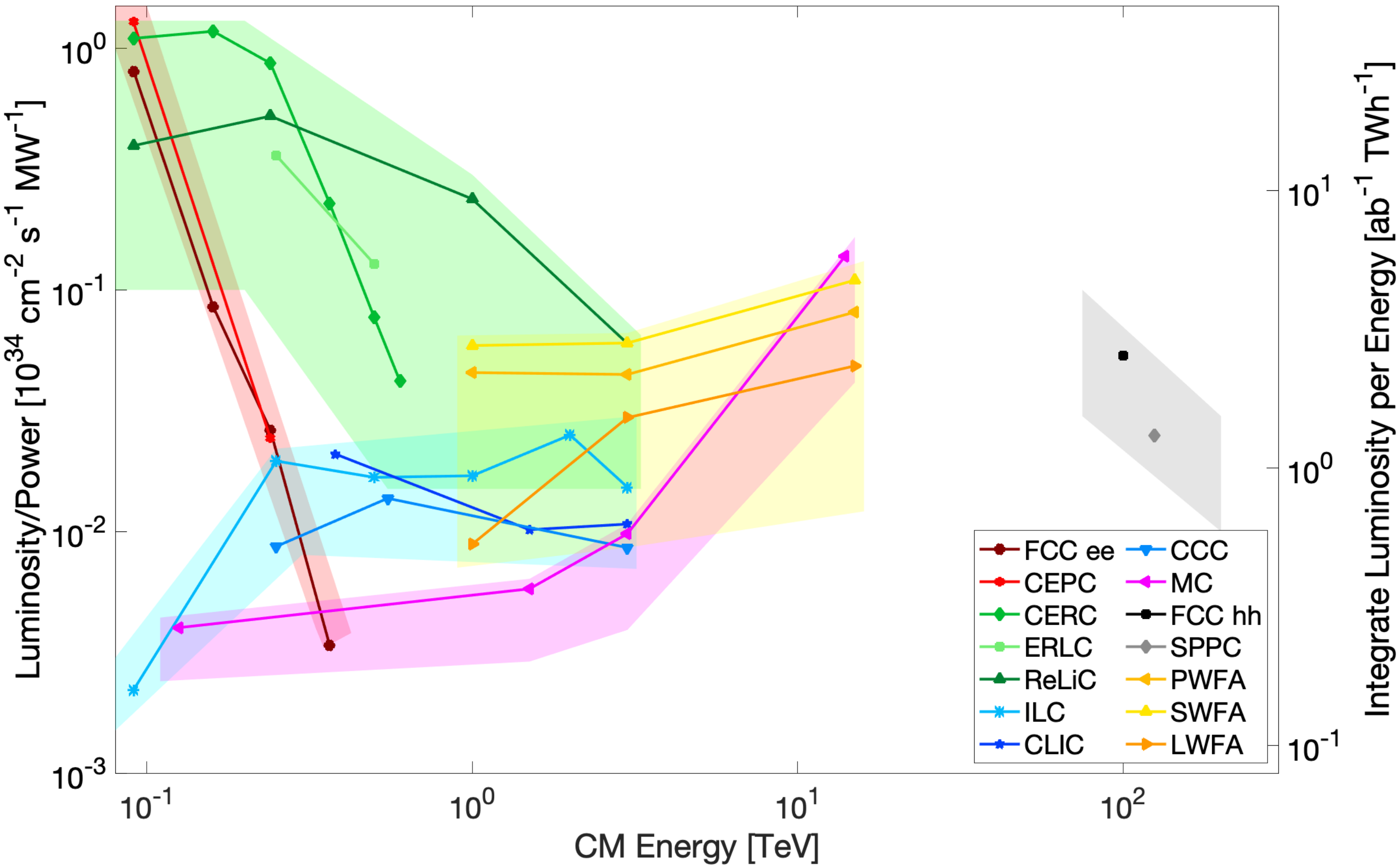
Power, complexity, environmental impact

- Summary table of categories of electric power consumption, size, complexity and required radiation mitigation.
- Darker blue means more impact.
- The WFA at 15 TeV use round beam collisions and have lower power consumption than at 3 TeV with flat beam collisions.

Proposal Name	Power Consumption	Size	Complexity	Radiation Mitigation
FCC-ee (0.24 TeV)	290	91 km	I	I
CEPC (0.24 TeV)	340	100 km	I	I
ILC (0.25 TeV)	140	20.5 km	I	I
CLIC (0.38 TeV)	110	11.4 km	II	I
CCC (0.25 TeV)	150	3.7 km	I	I
CERC (0.24 TeV)	90	91 km	II	I
ReLiC (0.24 TeV)	315	20 km	II	I
ERLC (0.24 TeV)	250	30 km	II	I
XCC (0.125 TeV)	90	1.4 km	II	I
MC (0.13 TeV)	200	0.3 km	I	II
ILC (3 TeV)	~400	59 km	II	II
CLIC (3 TeV)	~550	50.2 km	III	II
CCC (3 TeV)	~700	26.8 km	II	II
ReLiC (3 TeV)	~780	360 km	III	I
MC (3 TeV)	~230	10-20 km	II	III
LWFA (3 TeV)	~340	1.3 km (linac)	II	I
PWFA (3 TeV)	~230	14 km	II	II
SWFA (3 TeV)	~170	18 km	II	II
MC (14 TeV)	~300	27 km	III	III
LWFA (15 TeV)	~1030	6.6 km	III	I
PWFA (15 TeV)	~620	14 km	III	II
SWFA (15 TeV)	~450	90 km	III	II
FCC-hh (100 TeV)	~560	91 km	II	III
SPPC (125 TeV)	~400	100 km	II	III

Luminosity per power consumption

- Figure-of-merit Peak Luminosity (per IP) per Input Power and Integrated Luminosity per TWh.
- Integrated luminosity assumes 10^7 seconds per year.
- The luminosity is per IP.
- Data points are provided to the ITF by proponents of the respective machines.
- The bands around the data points reflect approximate power consumption uncertainty for the different collider concepts.

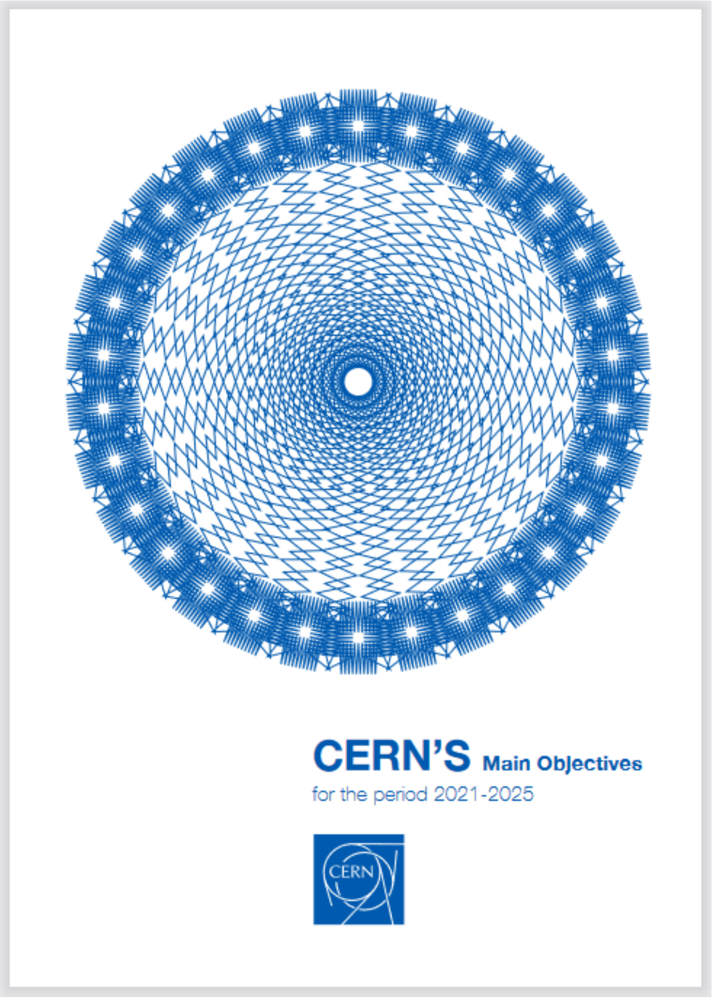


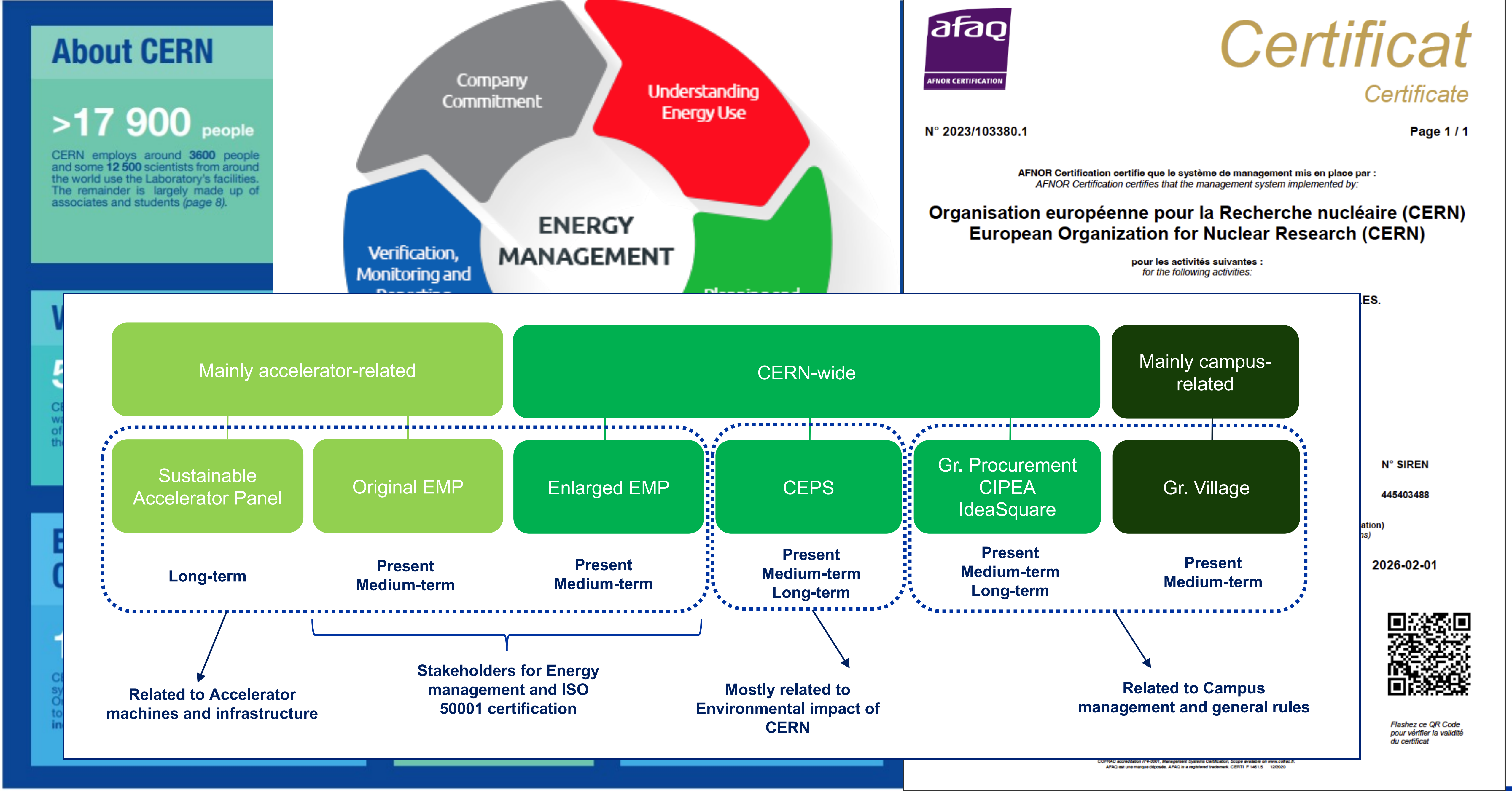
Sustainability : an integral part of CERN Objectives for 2021-2025

One of the **main objectives** of the CERN Directorate for the years 2021-2025.

CERN aims to establish itself as a model for a transparent and ***environmentally responsible research organisation***
-> strong and proactive commitment to environmental protection, along 3 lines:

- ***Minimise the Laboratory's impact*** *on the environment*
- *Pursue actions and technologies aiming at* ***energy saving and reuse***
- ***Identify and develop CERN technologies*** *that may contribute to mitigate the impact of society on the environment.*




About CERN
>17 900 people
CERN employs around 3600 people and some 12 500 scientists from around the world use the Laboratory's facilities. The remainder is largely made up of associates and students (page 8).
Company Commitment
Understanding Energy Use
ENERGY MANAGEMENT
Verification, Monitoring and
afaq
AFNOR CERTIFICATION
Certificat
Certificate
N° 2023/103380.1
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AFNOR Certification certifie que le système de management mis en place par :
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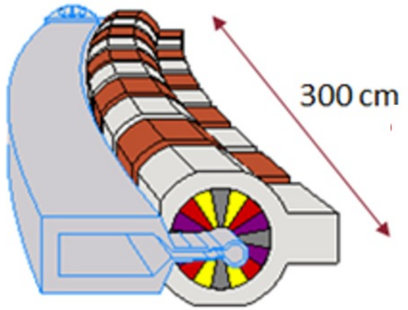
Mainly accelerator-related
CERN-wide
Mainly campus-related
Sustainable Accelerator Panel
Original EMP
Enlarged EMP
CEPS
Gr. Procurement CIPEA IdeaSquare
Gr. Village
Long-term
Present Medium-term
Present Medium-term
Present Medium-term Long-term
Present Medium-term Long-term
Present Medium-term
Related to Accelerator machines and infrastructure
Stakeholders for Energy management and ISO 50001 certification
Mostly related to Environmental impact of CERN
Related to Campus management and general rules

Energy efficiency efforts and plans at BNL

- NSLS II: upgrade plans include replacing large parts of the ring with "complex bends" using permanent Halbach magnets.

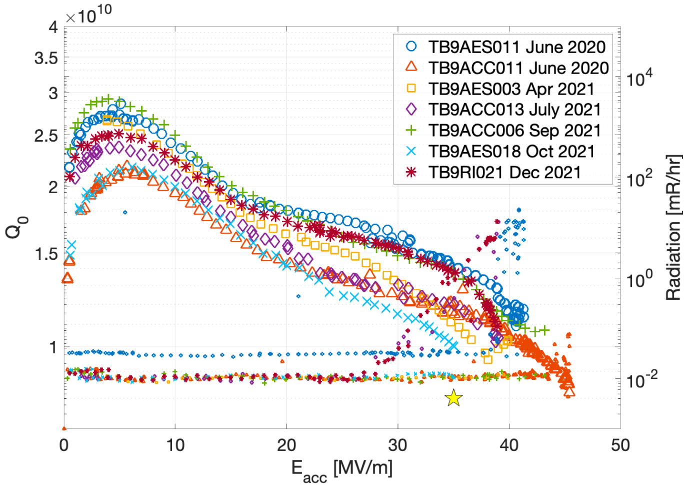


- RHIC (mature facility): many upgrades to improve efficiency (variable speed cooling systems, etc., also careful maintenance to increase equipment lifetime); efficiency upgrade of helium refrigerator

- EIC: RHIC/EIC Helium refrigerator efficiency upgrade; use of Energy Recovery Linac for high intensity electron beam for proton beam electron cooling; efficient reuse of process heat using heat pumps

Sustainable Accelerators R&D at Fermilab

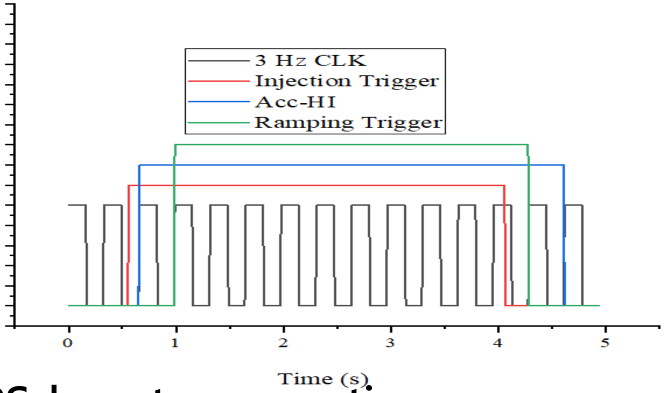
- **High Q_0 SRF cavities:**
  - > 1e10 for current projects (ILC, LCLS-II, etc)
  - > 3e10 for future projects (FCCee, Muon Collider, etc)
  - And high gradient > 45 GV/m
- **HTS high field magnets:**
  - High field solenoids >30 T, inserts (with NHMFL)
  - Economical 0.1T HTS dipoles for FCCee
  - Up to 50 T solenoids for muon colliders (in plan)
- **HTS fast cycling magnets:**
  - For RCS and muon colliders
  - ReBCO ~1m magnet 300 T/s (record)
  - Plans for 1000-3000 T/s prototypes



V.Shiltsev and S.Posen

Power savings NSRRC (Taiwan)

國家同步輻射研究中心
National Synchrotron Radiation Research Center



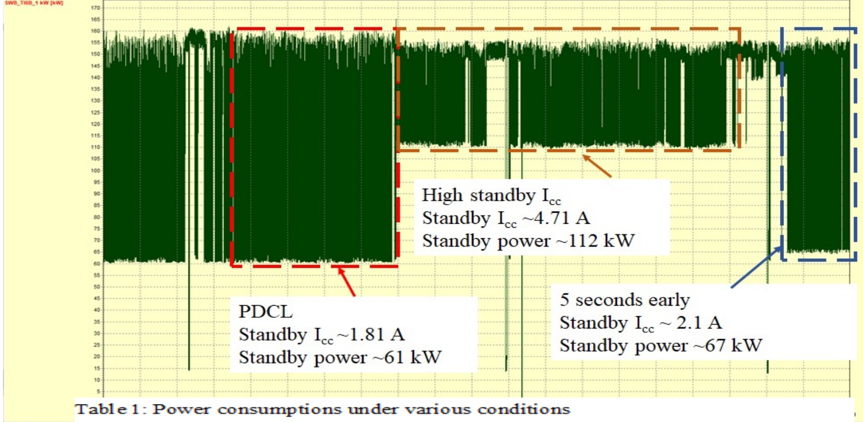


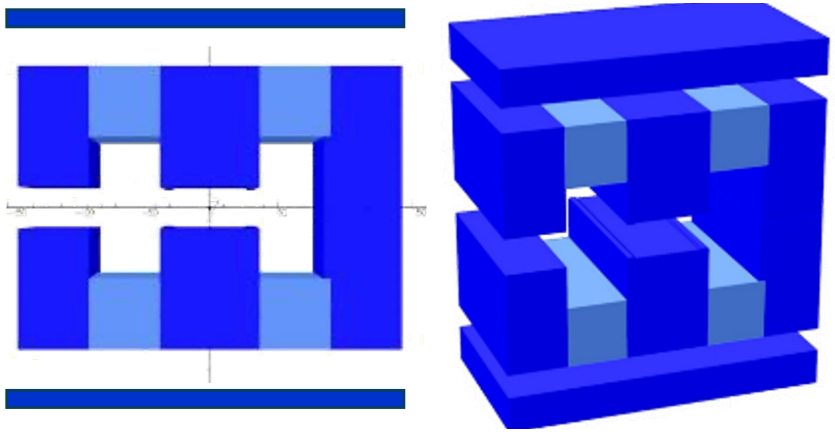
Table 1: Power consumptions under various conditions

	PDCL	High standby I_{cc}	5 s early	Energy saving off
Standby I_{cc} /A	1.81	4.71	2.10	4.90
Injection time /s	2	2	2+5	2
Stand by time /s	240	240	235	240
cycle /s	242	242	242	242
Standby power /kW	61	112	67	--
Injection power /kW	155	155	155	155
Power/cycle /kW s	14950	27190	16830	37510
Power/year /kW h an^{-1}	527821	959964	566834	1324320
PSR /%	60.1	27.5	57.2	0.0

- Intermittence operation of TLS/TPS booster operation for RF system and magnets during top-up injection
- Power saving scheme of klystron operation

- Installation of 1.2 MWp solar panels on the roof of Blds.
- Accumulated solar power: ~8.16 M kW hr.
- Carbon reduction: 4.3 k Tons

(as of Mar. 2023)

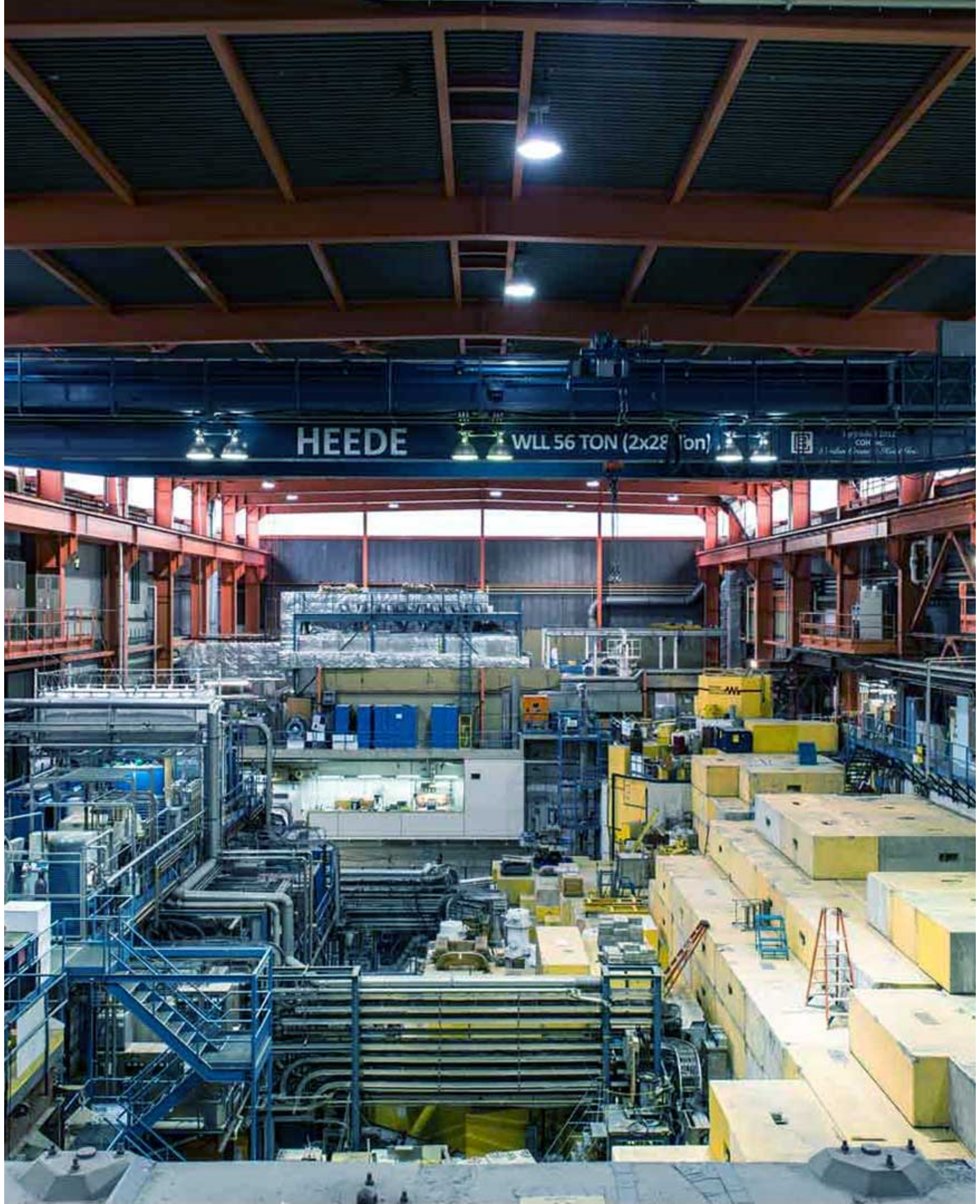


TPS upgrade: using multi-bend lattice to reduce the emittance with lower radiation power loss and using permanent magnets combined with mechanical tuning saving power of dipole magnets.

TRIUMF

Energy efficiency efforts and plans at TRIUMF

- The 500MeV cyclotron is now 50 years old and ISAC is 25 years old - refurbishing efforts are being done on both systems to improve electrical efficiency with partial financial incentive from the local power utility – they help fund a portion of a portion of an FTE to think energy efficiency
  - New higher efficiency power supplies for magnets
  - All new purchases for upgrades are reviewed for power efficiency
- TRIUMF site – exploring the use of heat pumps for future operation together with the local university community
- Sustainability is a new platform of TRIUMF focus for our next FYP starting in 2025
  - Lead institute to discuss ADS for Canada



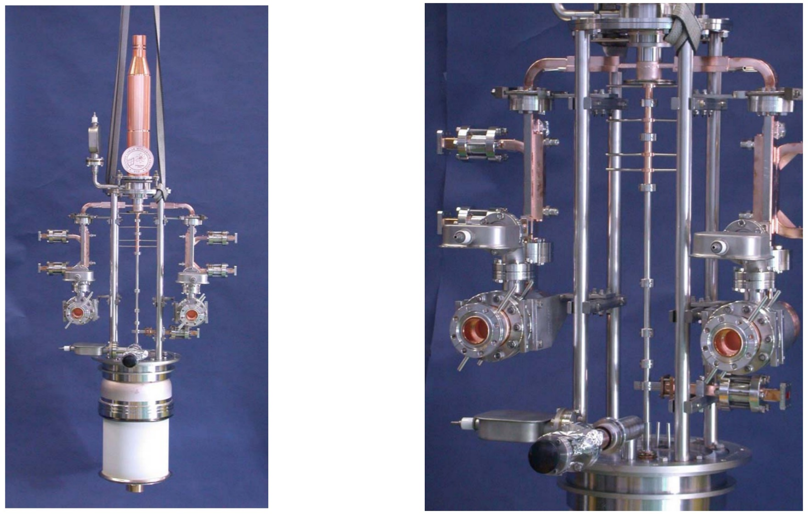
Discovery, accelerated

RF Source Efficiency is a Limiting Factor for Sustainability of Facilities

- For pulsed systems solenoid often uses the most average power
    - Restarting production of PPM 75 MW klystrons
- Incorporating higher efficiency bunching mechanisms in new designs (BAC/COM) developed under HEIKA
- Energy recovery for rf sources – Green RF
- Goal to reach 65-80% electrical efficiency

PPM High Power Klystron

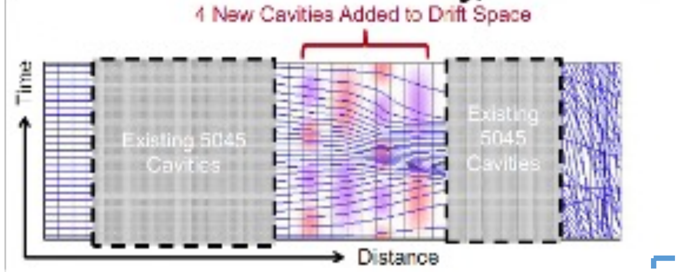
75XP-3



https://indico.cern.ch/event/39372/contributions/1829827/attachments/787979/1080133/AVlieks-X-Band_Klystron_Development_at_SLAC-final.pdf

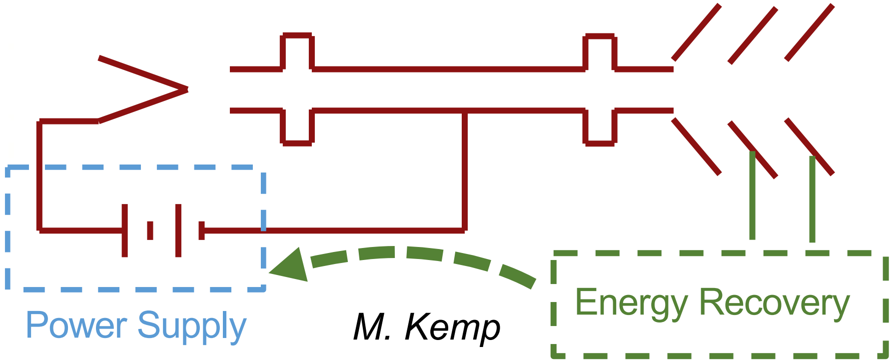
SLAC BAC Prototype

S-band Retrofit +10% efficiency, 73 MW



J. Neilson

Energy Recovery



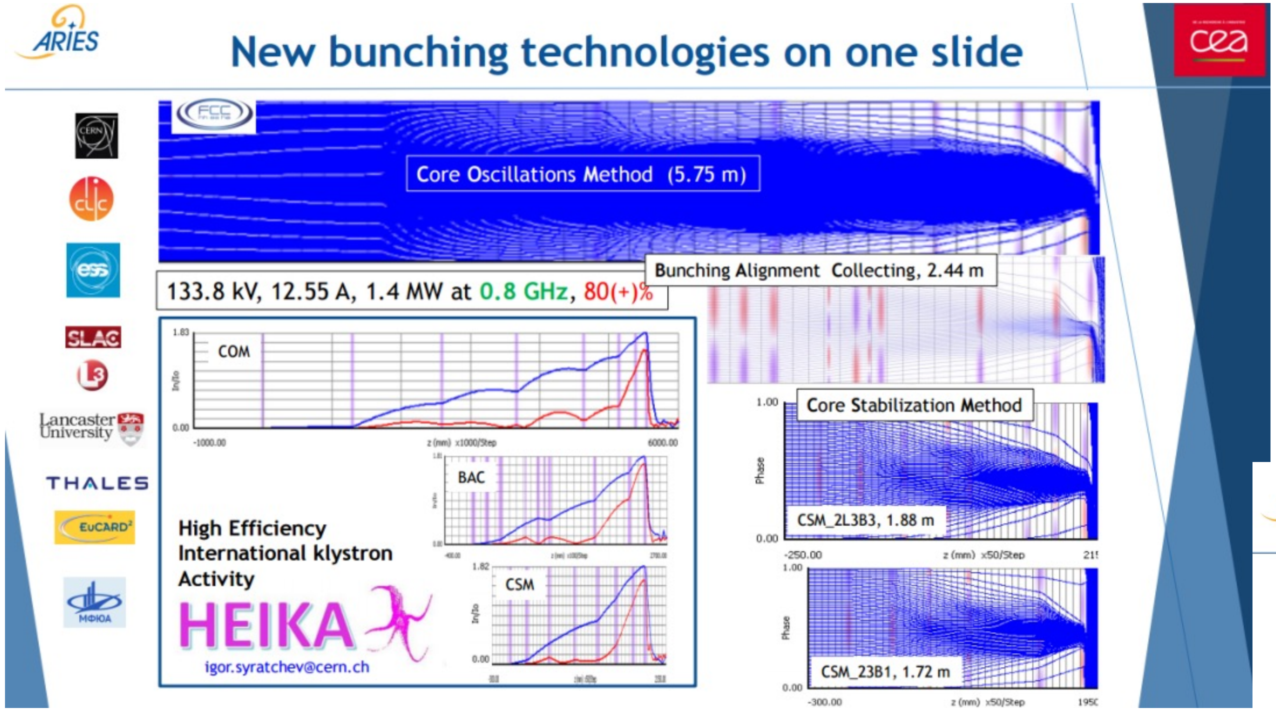
M. Kemp

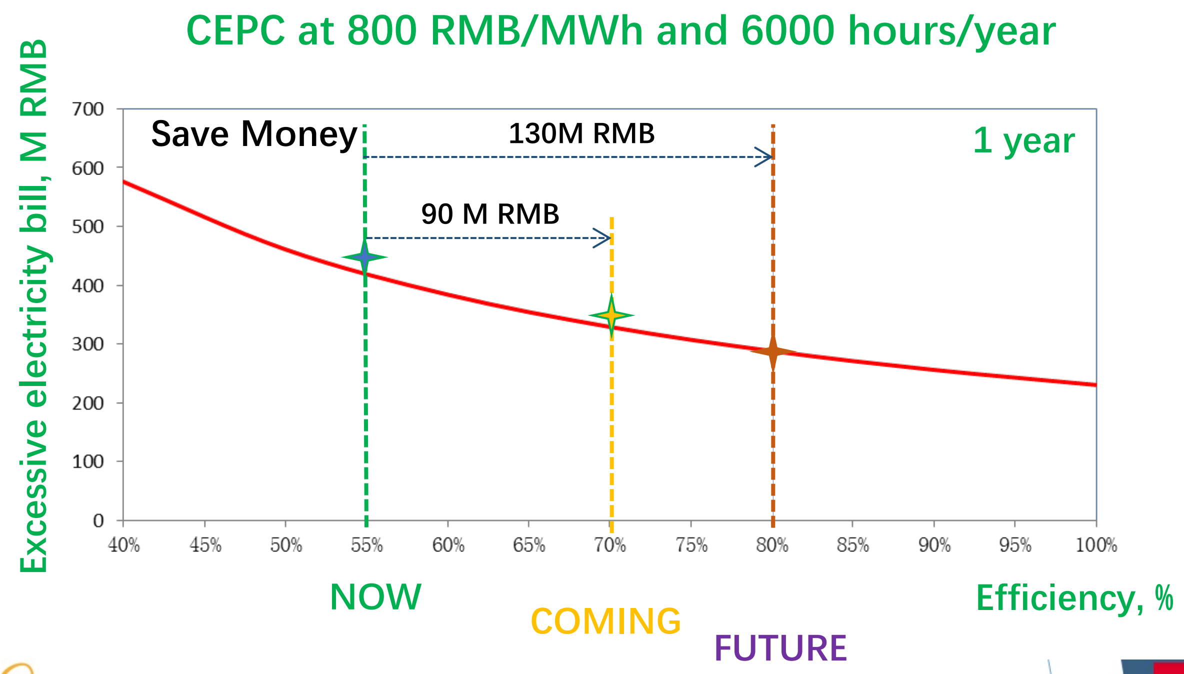
Depressed Collector on VKS-8262

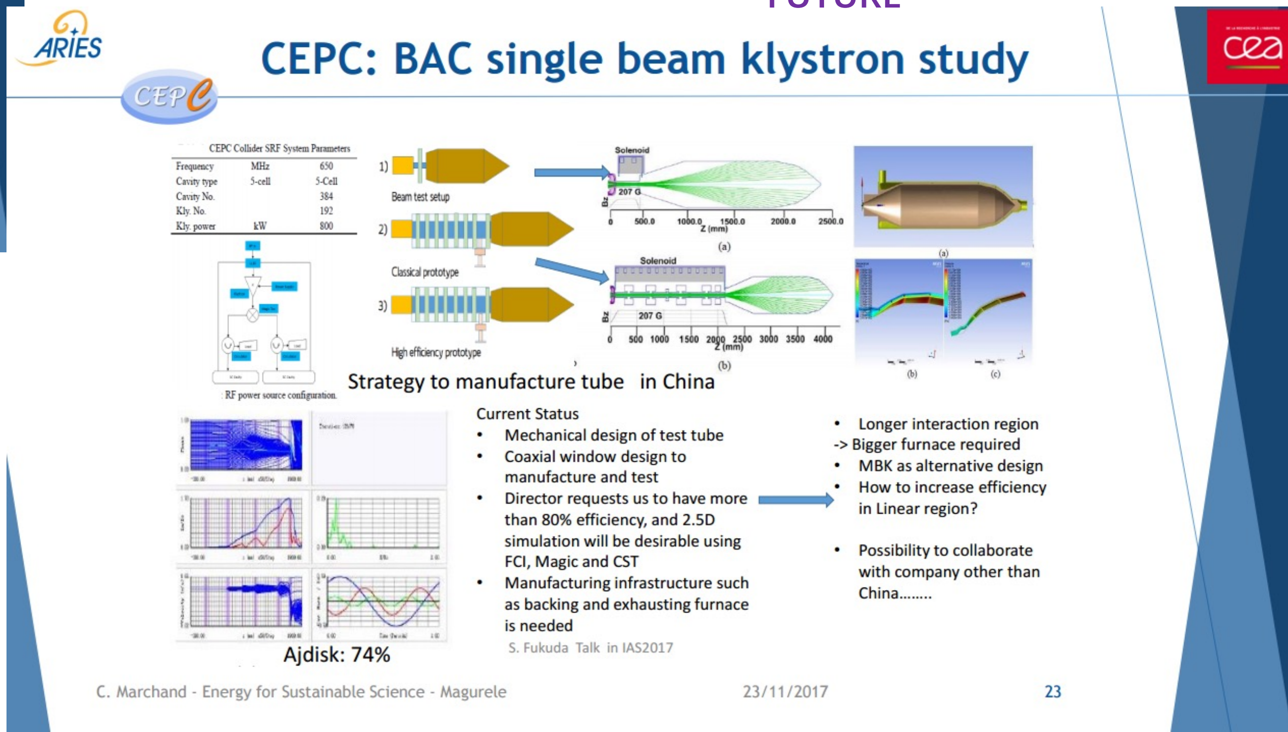
“Inverse” Marx power recovery module

High efficiency klystron for CEPC

- 70% already reached, 80% still need to develop

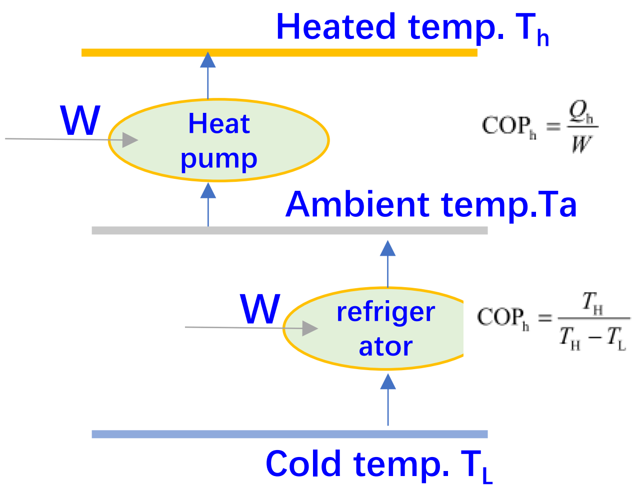


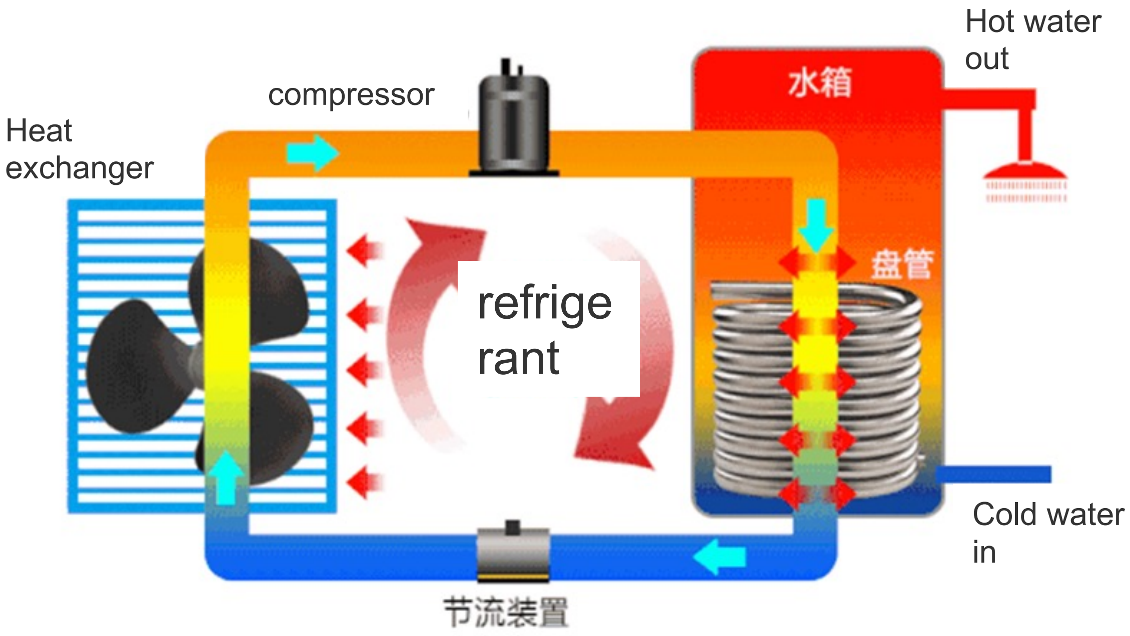




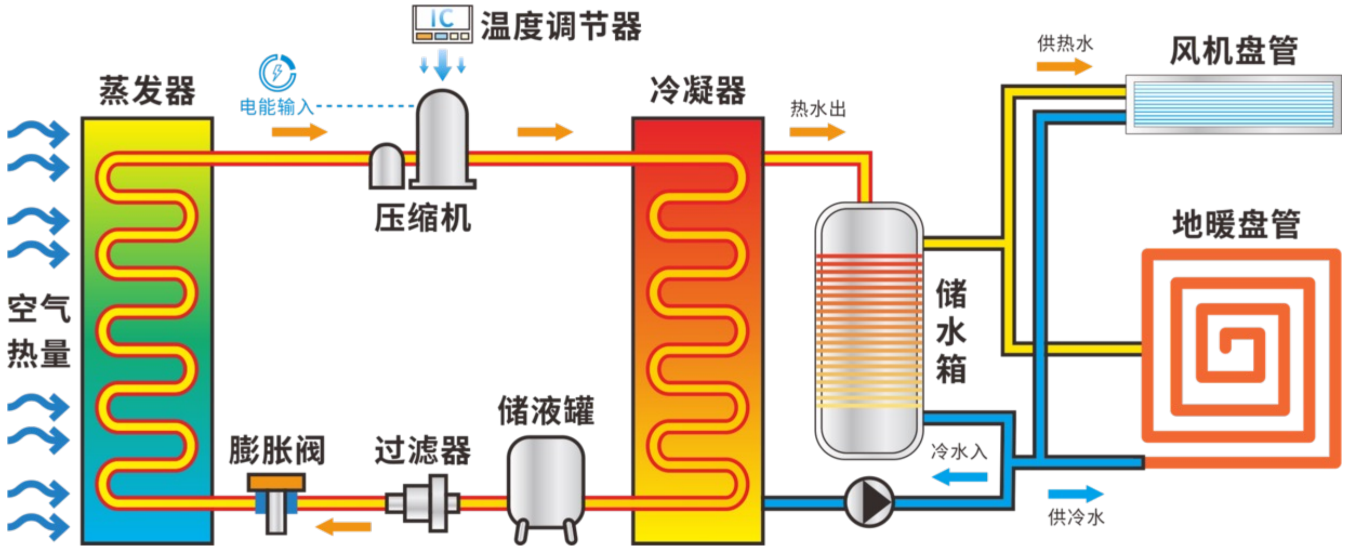
Waste energy reuse plan @ CEPC

- We plan to use heat pump to reuse the waste energy.
- Heat naturally flows from high temperature to low temperature, but not in the opposite direction. A heat pump can reverse the flow of heat from lower temperatures to higher temperatures with minimal added energy.





Heat pump schematic diagram



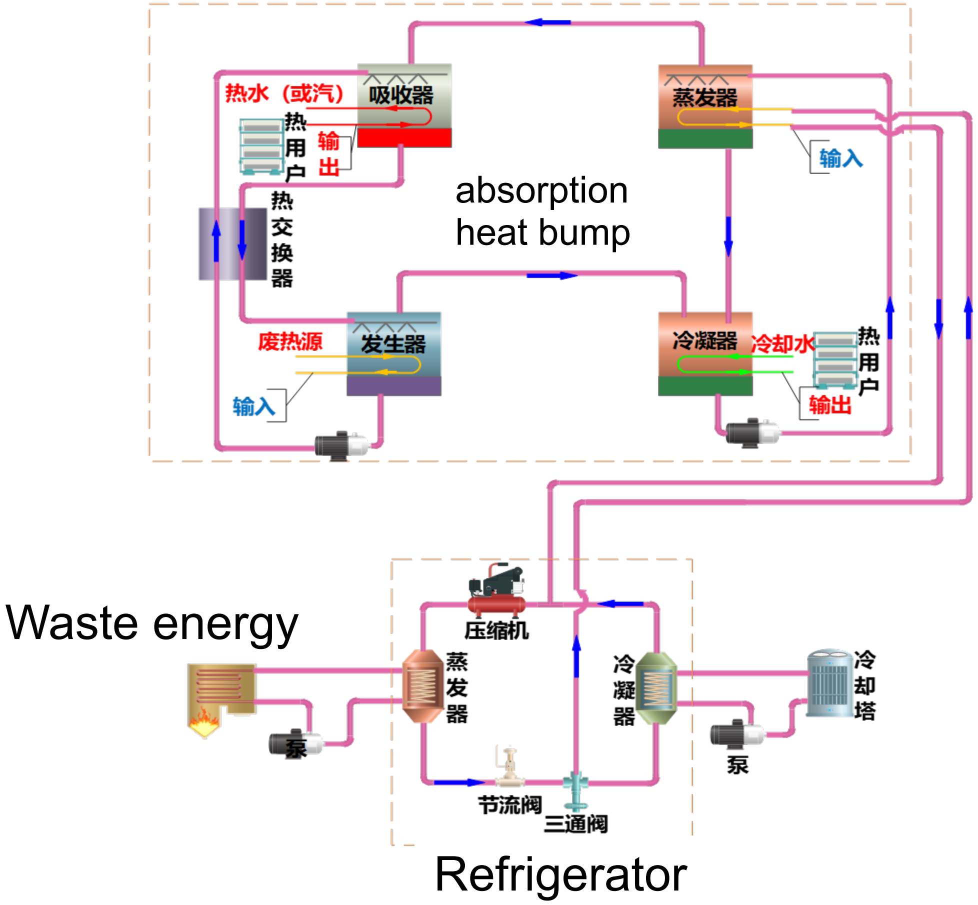
Working principle of air energy heat pump

Waste energy reuse plan @ CEPC

cold-warm switchable heat bump

Refrigerator + absorption heat bump

- We plan to reuse the waste energy by "cold-warm switchable heat bump"
- In winter, it generates hot water at 80 C° for civil heating purposes. In summer, it is switched to generate cold water at 10 C° for air conditioning.



- It is possible to reuse waste energy of 282 MW, which corresponds to 2.92million-GJ per year (assuming an annual heating period of 2,880 hours).

Energy Efficient Efforts at Daresbury Laboratory

- **SRF Thin Films:**
  - Extensive R&D programme underway with Horizon Europe IFAST programme.
  - Aim to demonstrate high-Tc SRF cavity performance (E_{acc} and Q_o) capability.
  - Technology solutions to be developed for future UK-XFEL and ISIS-II facilities.

- **ZEPTO Permanent Magnets:**
  - Tuneable quadrupole and dipole prototypes developed for CLIC.
  - Quadrupole prototype developed and installed on Diamond synchrotron.
  - Technology solutions to be developed for CLARA and future UK-XFEL.

- **High Efficiency Klystrons:**
  - Strong collaboration with CERN to optimise designs for higher efficiency.
  - First prototype demonstrated by Canon – 8 MW, X-Band at 53.5% efficiency, compared to ~40% typical.
  - Technology solutions being developed for HL-LHC and FCC

- **Fast Reactive Tuners:**
  - Strong collaboration also with CERN, to develop viable technology to more optimally match RF power to SRF cavity.
  - Factor of >10x RF power reduction potentially feasible.
  - Recent Horizon Europe innovative Sustainable Accelerator Systems (iSAS) proposal submitted, is a mechanism for integrated capability demonstration.

Science and Technology Facilities Council

Back-up slides

EUROPEAN STRATEGY FOR PARTICLE PHYSICS
Accelerator R&D Roadmap

- 8. Sustainability considerations
  - Scarcity of resources, along with climate change originating from the excessive exploitation of fossil energy are ever growing concerns for humankind. Particularly, the total electric power consumption of scientific facility operations will become more important as the reliance on fossil fuels is being reduced, carbon-neutral energy sources are still being developed and a larger part of the energy consumption is converted from fossil fuel to electric power.
  - In our accelerator community we need to give high priority to the realization of sustainable concepts, particularly when the next generation of large accelerator-based facilities is considered. Indeed, the much-increased performance – higher beam energy and intensity – of proposed new facilities comes together with anticipated increased electric power consumption. In the following we classify the most important development areas for sustainability of accelerator driven research infrastructures in three categories – technologies, concepts and general aspects. We suggest investing R&D efforts in these areas and to assess energy efficiency with an equal level of relevance as the classical performance parameters of the facilities under discussion.

EUROPEAN STRATEGY FOR PARTICLE PHYSICS
Accelerator R&D Roadmap

- Conclusion Recommendation 6
  - Environmental sustainability should be treated as a primary consideration for future facilities, including those in the near-to-medium future, and the R&D programme should be prioritised accordingly. Objective metrics should be set down to allow appraisal of the impact of future facilities over their entire life cycle, including civil-engineering aspects, and of the resources needed to ensure sustainability.

ICFA Panel on Sustainable Accelerators and Colliders

- **Panel mandate** (expanded to include sustainable energy production):
  - Assess and promote developments on energy efficient and sustainable accelerator concepts, technologies and strategies for operation, and assess and promote the use of accelerators for the development of Carbon-neutral energy sources.
  - The panel will formulate recommendations on R&D and support ICFA with networking across the laboratories and communications. The membership will ensure a broad regional participation and coverage of accelerator technologies and concepts, relevant in the context of energy consumption and production.
- **Topics:**
  - **Accelerator concepts for sustainability**: Accelerators based on superconducting or permanent magnets, Energy Recovery Accelerators and Colliders, Muon Colliders, Accelerator Driven Subcritical Reactors
  - **Energy efficient technologies**: low-loss superconducting resonators, efficient RF sources, accelerator-quality permanent magnets, efficient cryogenic systems, superconducting electrical links, heat recovery in aquifers, short-term energy storage
  - **General sustainability aspects**: carbon footprint analysis, water consumption, environment friendly materials, lifecycle management, helium as a scarce resource