



EUROPEAN  
SPALLATION  
SOURCE

# AN OVERVIEW OF THE STATUS OF ENERGY SUSTAINABILITY AT THE ESS

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6th ESSRI workshop, ESRF

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### Senaste veckan

## Energikrisen slår mot Max IV – kan behöva stänga

”Klart att det finns en oro”.



Forskningsanläggning Max IV gör av med mycket el, någonstans mellan 25 och 30 gigawatttimmar per år, enligt styrelseordförande Peter Honeth.

– Det är väldigt mycket. Ett normalår ligger elkostnaderna på trettio miljoner kronor. Nu är risken att det framöver blir ännu högre belopp, säger han.

**Skyhöga elpriser** och extrema prisökningar kan därför få svåra konsekvenser för Max IV. Men eftersom Max IV har både fasta och rörliga elavtal kommer eventuella prisökningar inte att slå igenom omedelbart, enligt Honeth.

– Vi har ett antal fasta avtal som löper, så de ökade elkostnader som sannolikt kommer i vinter slår inte igenom fullt ut för vår del förrän längre fram, säger han.

### SVENSKA INNOVATIONSKLIMATET

## Energikrisen kan stänga forskningsanläggning

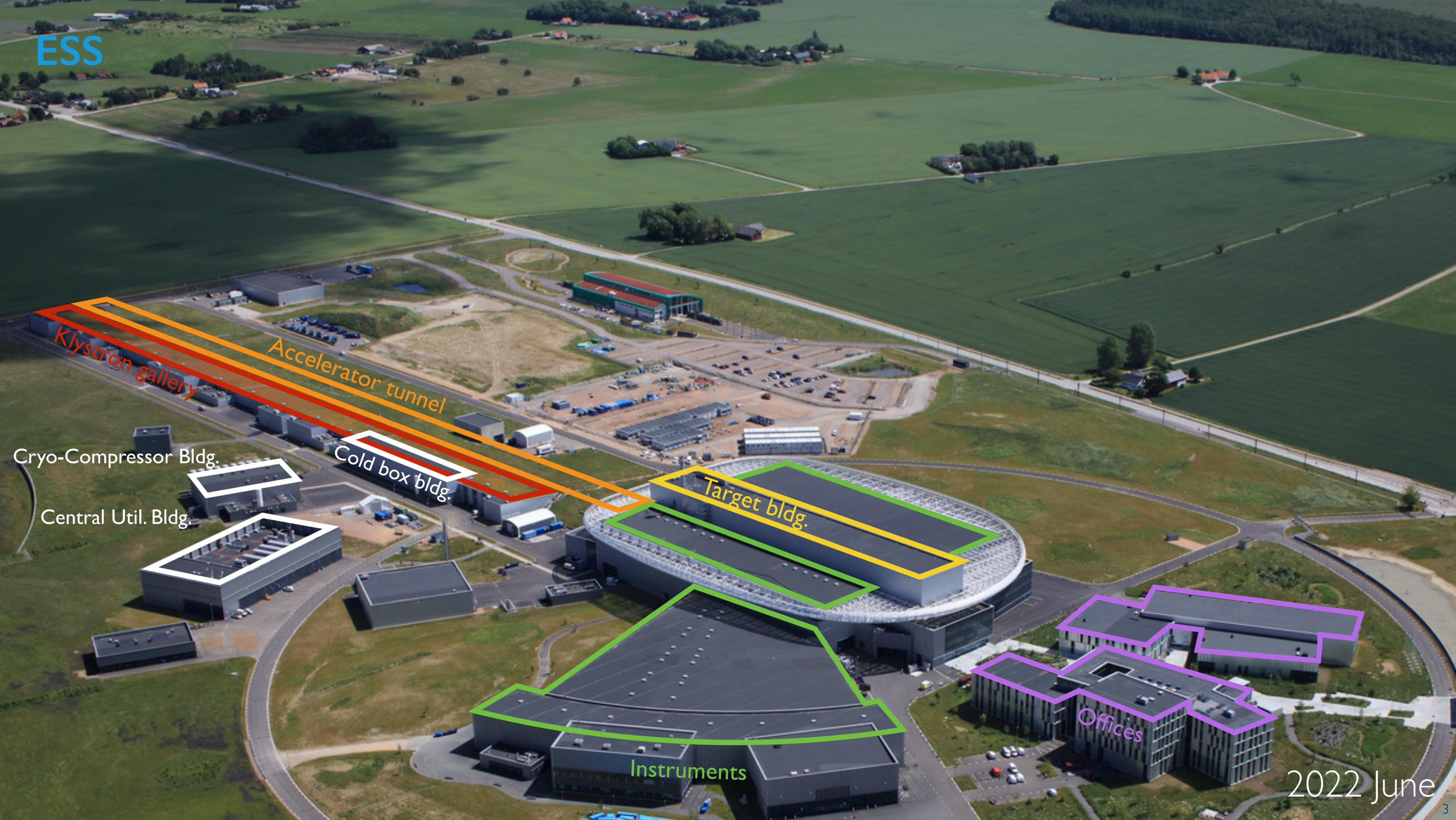


Bild: Björn Lindgren/TT

**Stigande elpriser och prisökningar riskerar leda till att forskningsanläggningen Max IV i Lund kan stängas tillfälligt, skriver Sydsvenskan.**

Tidningen Näringslivet, Sydsvenskan

ESS



Klystron gallery

Accelerator tunnel

Cryo-Compressor Bldg.

Cold box bldg.

Central Util. Bldg.

Target bldg.

Instruments

Offices

2022 June

# ENERGY CONSUMPTION PER DISCIPLINE

(226 GWh)  
65 GWh

307 GWh

88 GWh

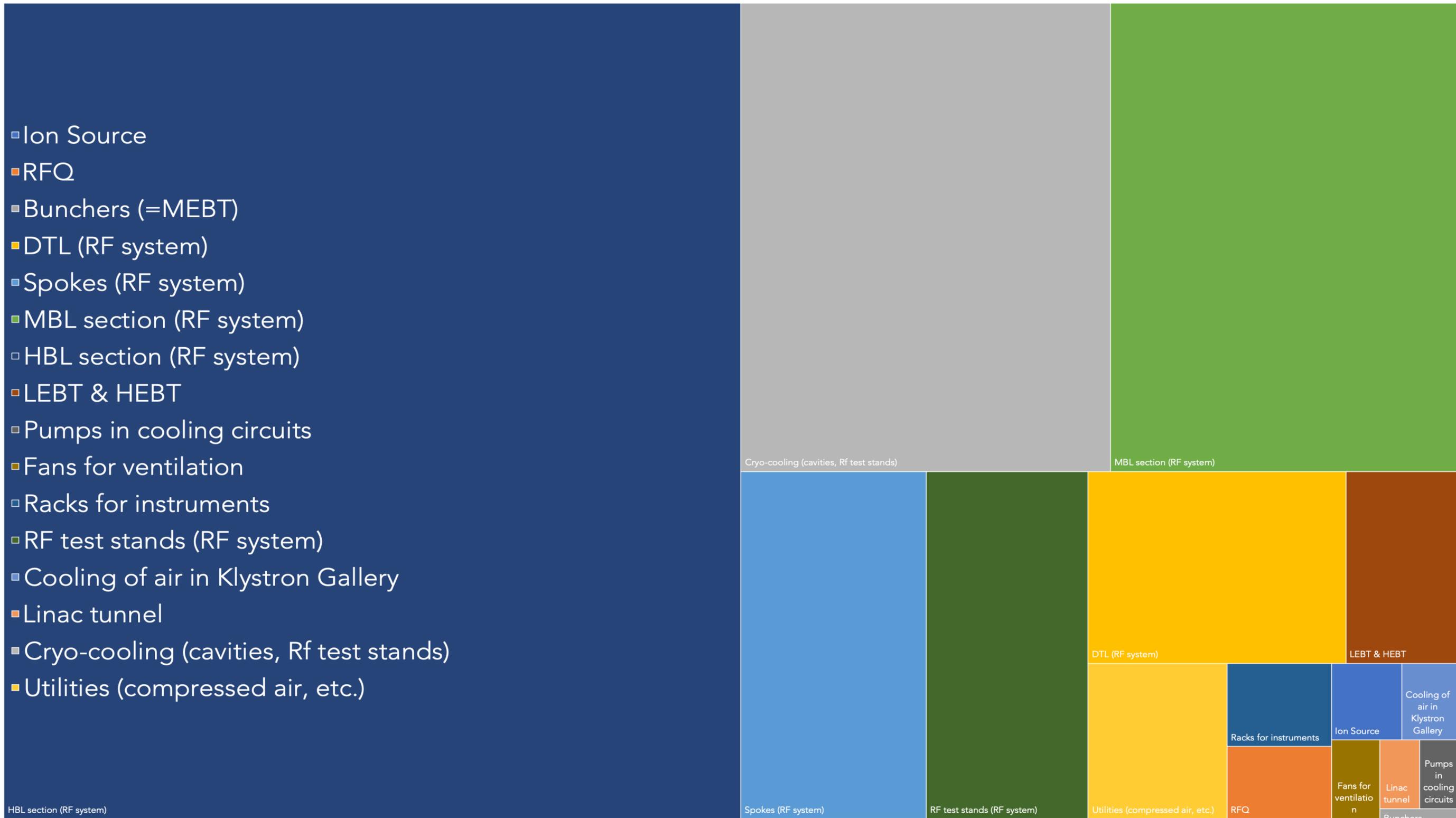
-232 GWh  
44 GWh heat pumps

2 GWh

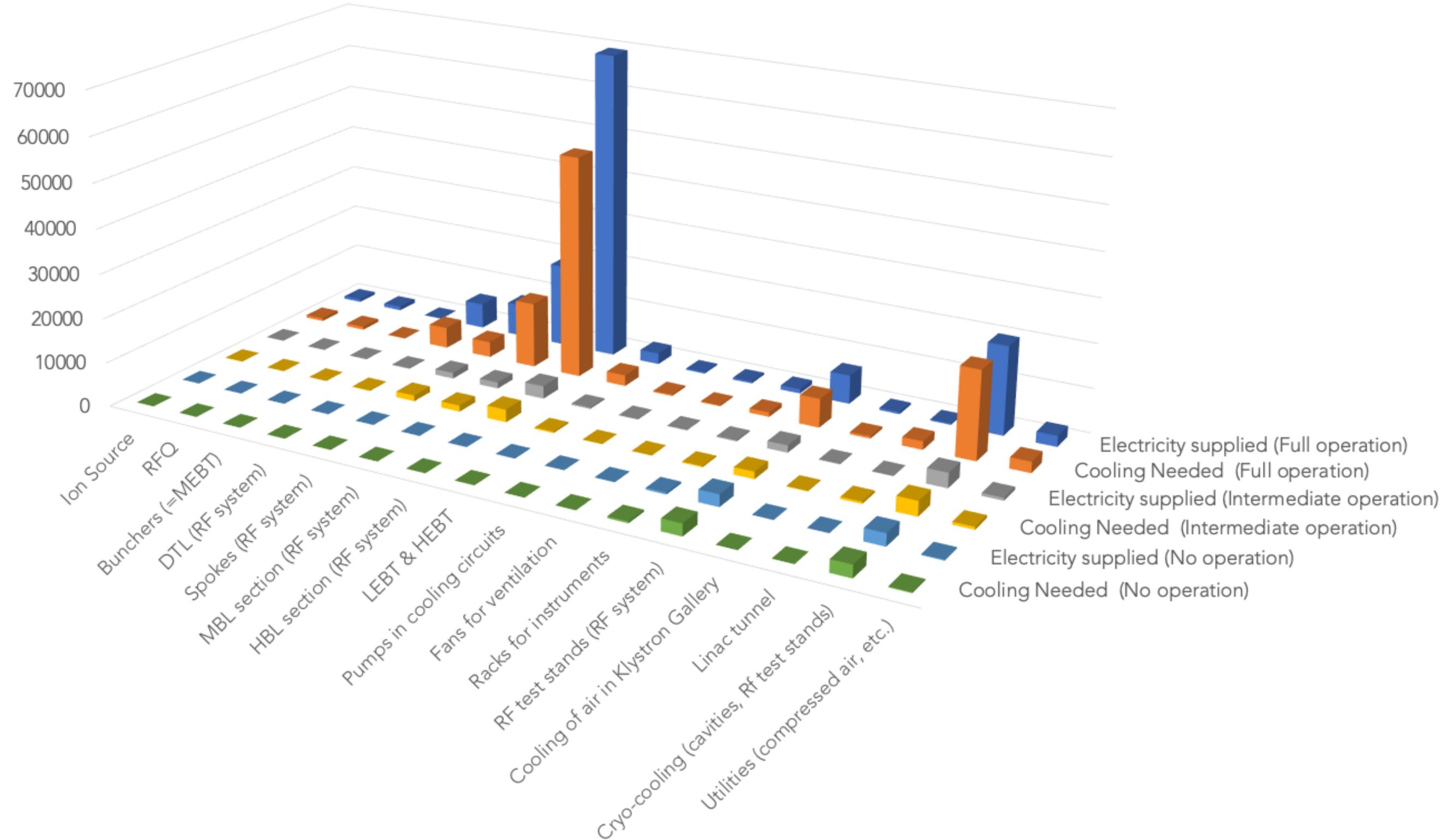


## ACCELERATOR ENERGY CONSUMPTION DETAILS

- ▣ Ion Source
- ▣ RFQ
- ▣ Bunchers (=MEBT)
- ▣ DTL (RF system)
- ▣ Spokes (RF system)
- ▣ MBL section (RF system)
- ▣ HBL section (RF system)
- ▣ LEBT & HEBT
- ▣ Pumps in cooling circuits
- ▣ Fans for ventilation
- ▣ Racks for instruments
- ▣ RF test stands (RF system)
- ▣ Cooling of air in Klystron Gallery
- ▣ Linac tunnel
- ▣ Cryo-cooling (cavities, Rf test stands)
- ▣ Utilities (compressed air, etc.)



## ACCELERATOR ENERGY CONSUMPTION DETAILS



## TARGET ENERGY CONSUMPTION DETAILS

- Target wheel cooling circuit (He+N2)
- Moderator cooling circuit (LH2+He+N2)
- Thermal moderators system
- Inner reflectors system
- Monolith shielding system: Reflectors
- Monolith shielding system
- Tuning beam dumps system
- Monolith Flush+Atmosphere system
- PBW system
- Offgas system
- Helium purification systems
- Low temperature adsorber system
- Active cells, utility rooms, etc. HVAC/RGEC
- Water purification and handling system
- Pump energy intermediate water system

Moderator cooling circuit (LH2+He+N2)

Target wheel cooling circuit (He+N2)

Active cells, utility rooms, etc. HVAC/RGEC

PBW system

Monolith shielding system: Reflectors

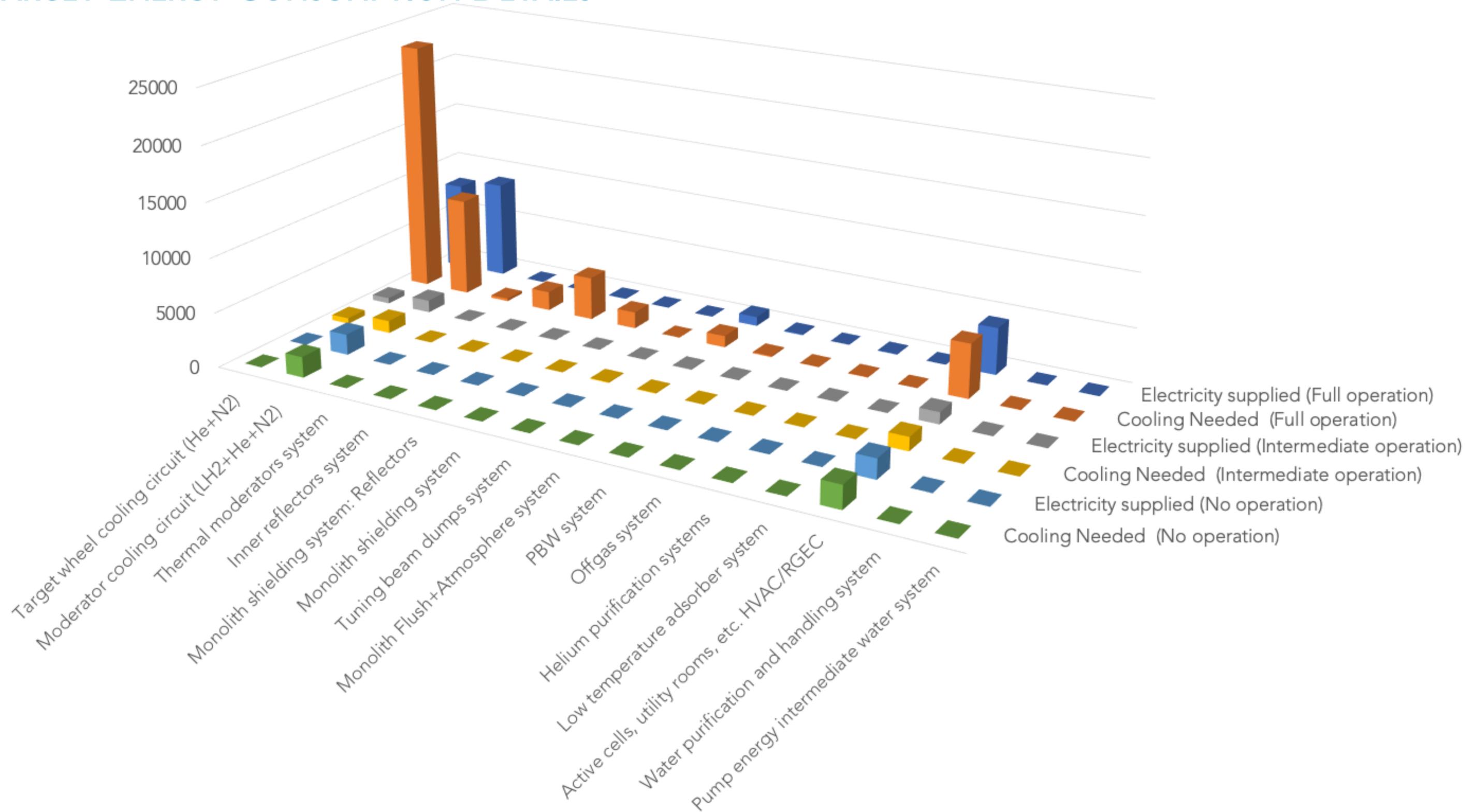
Monolith

Helium purification systems

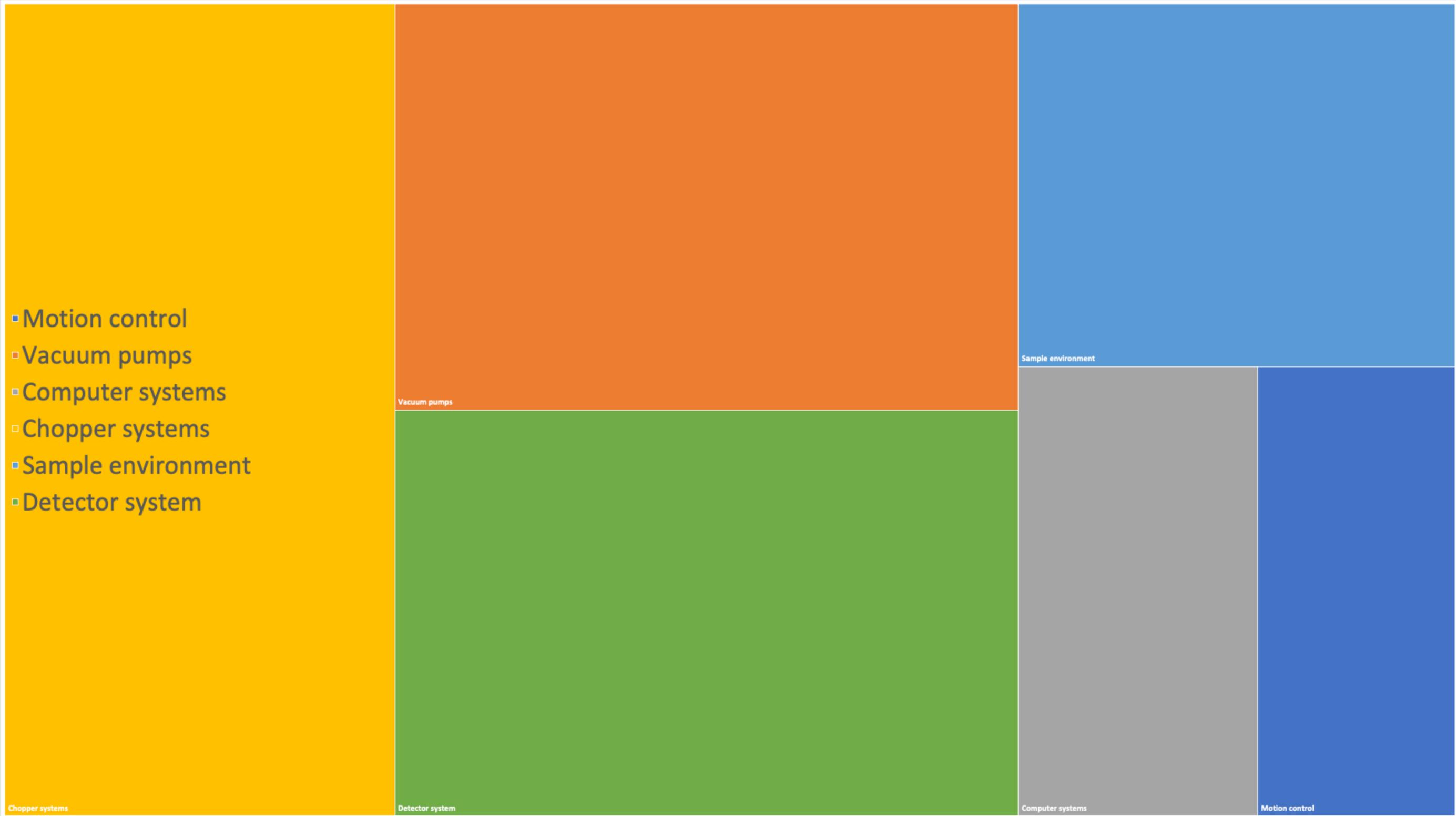
Pump

Monolith Flush+Atmosphere system

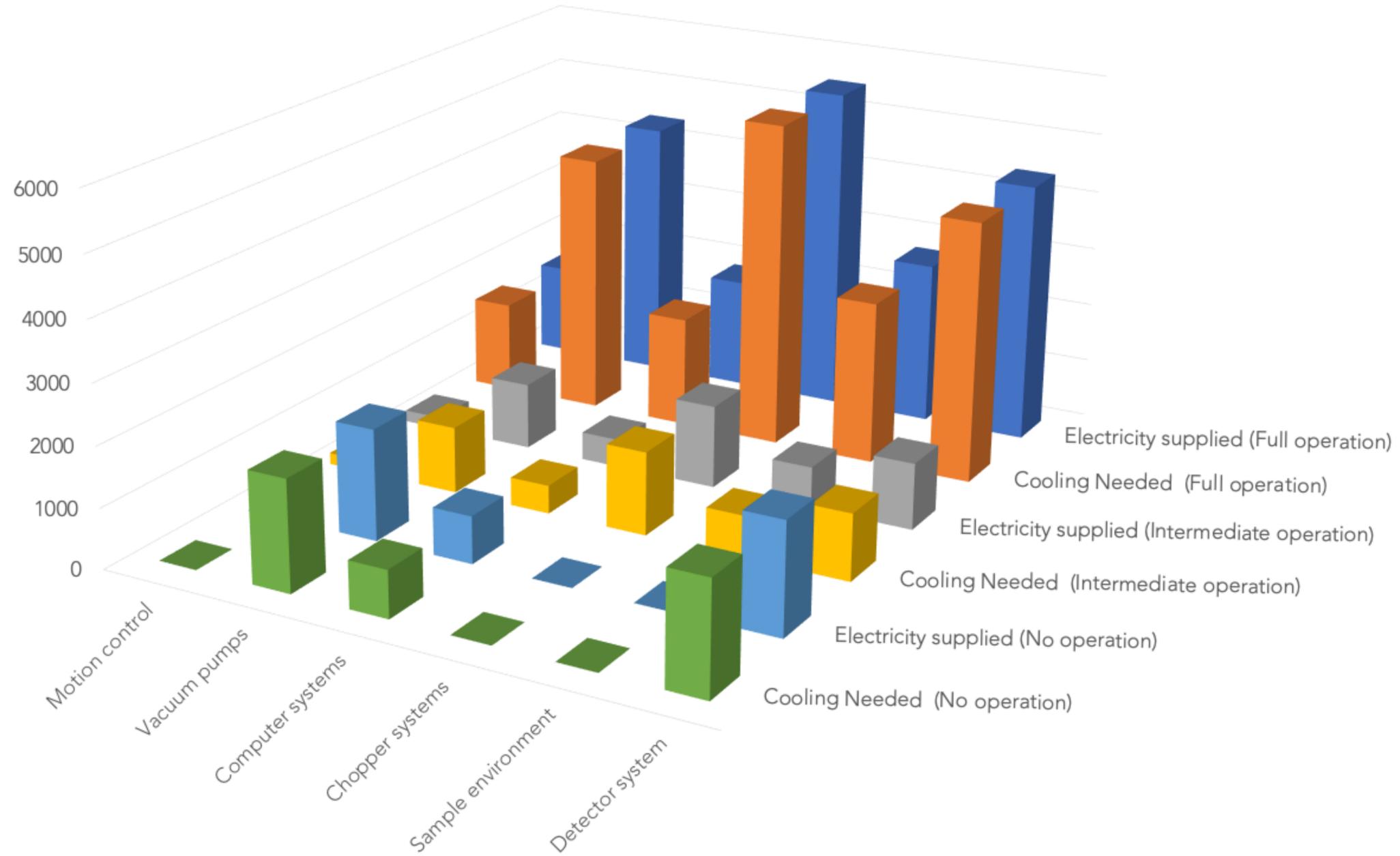
## TARGET ENERGY CONSUMPTION DETAILS



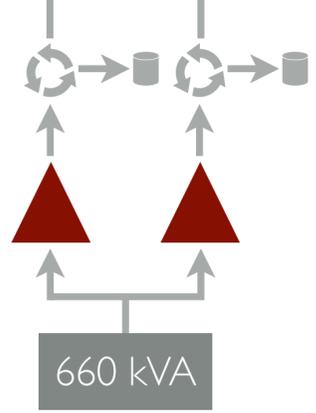
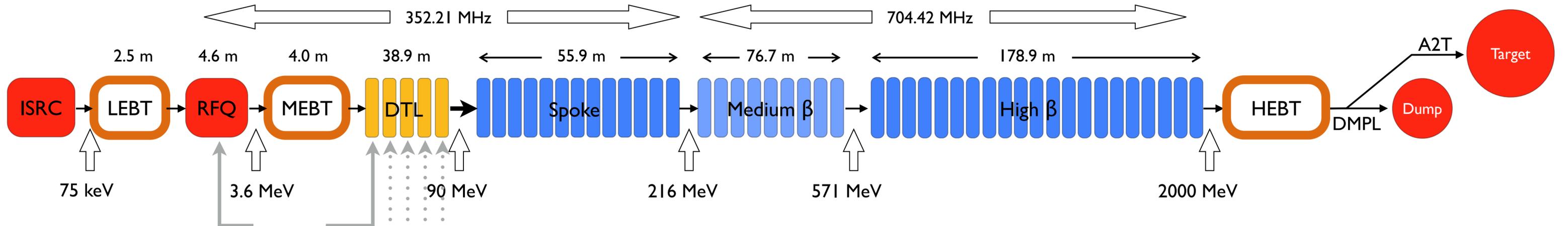
## NSS ENERGY CONSUMPTION DETAILS



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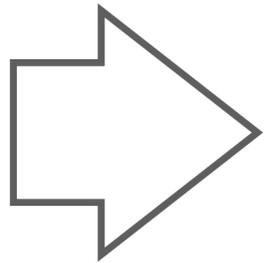


## THE ACCELERATOR



### Design Drivers:

- High average beam power 5 MW
- High peak beam power 125 MW
- High availability >95 %



### Key Linac parameters:

Energy	2.0 GeV
Current	62.5 mA
Repetition rate	14 Hz
Pulse length	2.86 ms
Losses	<1W/m
Ions	p

- Flexible/Upgradable design
- Minimize energy consumption

# ENERGY SAVING MEASURES

## CRYOGENICS

- Heat recovery from compressors
  - Adiabatic compression of return helium:

$$\frac{T_{dis}}{T_{suc}} = \left( \frac{p_{dis}}{p_{suc}} \right)^{\frac{\kappa-1}{\kappa}}$$

- Heat capacity ratio ( $\kappa = 1.66$ )  $\Rightarrow$

- $T_{suc} \sim 40 \text{ °C} \Rightarrow T_{dis} > 300 \text{ °C}$  at the high pressure discharge

- Heat recovery from compressors

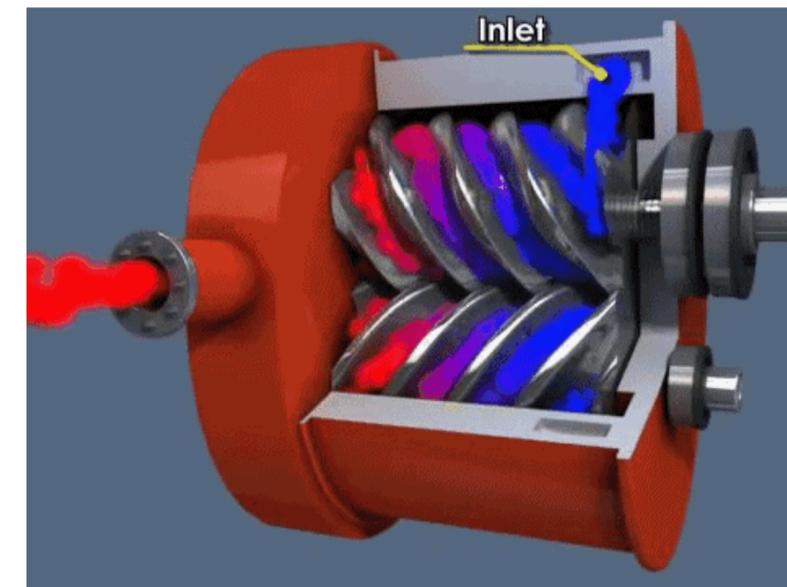
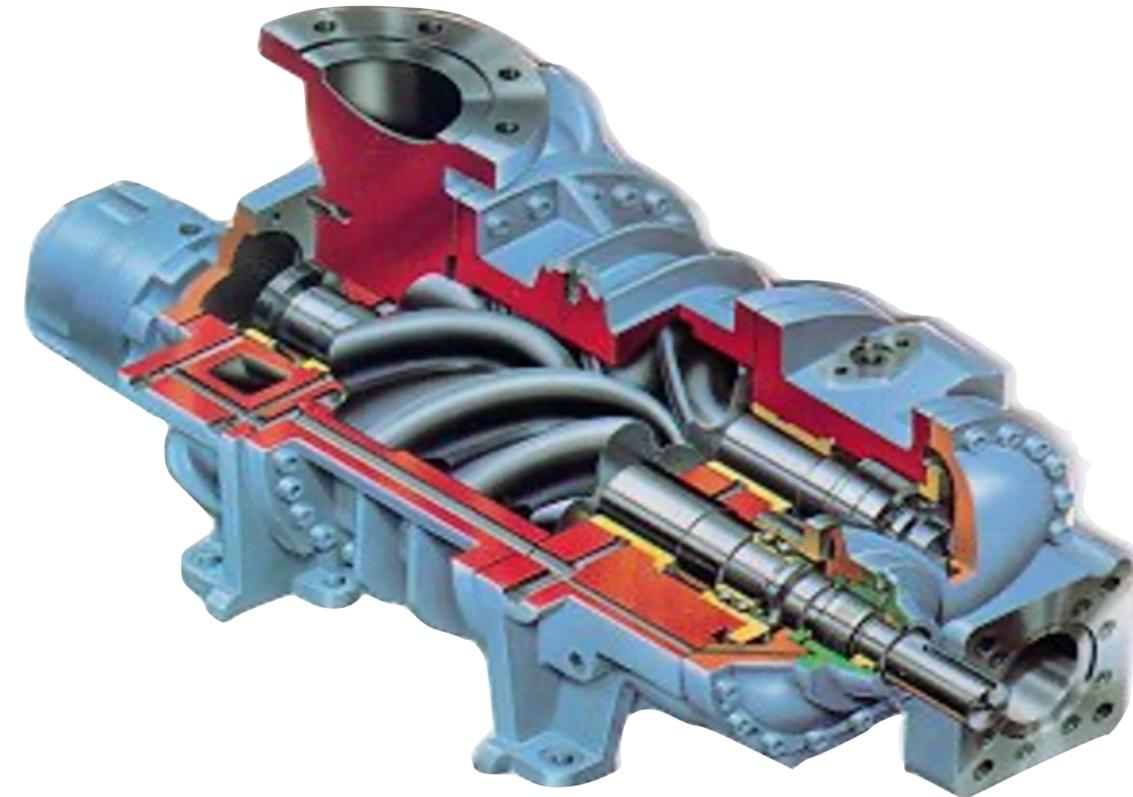
- Quasi-isothermal compression by oil injection

- $T_{suc} \sim 40 \text{ °C} \Rightarrow T_{dis} \sim 80 \text{ °C}$  at the high pressure discharge

$$P_{el} = \frac{1}{\eta_{el}} \frac{1}{\eta_{it}} \dot{m} \frac{\mathcal{R}}{M} T \ln \left( \frac{p_{dis}}{p_{suc}} \right)$$

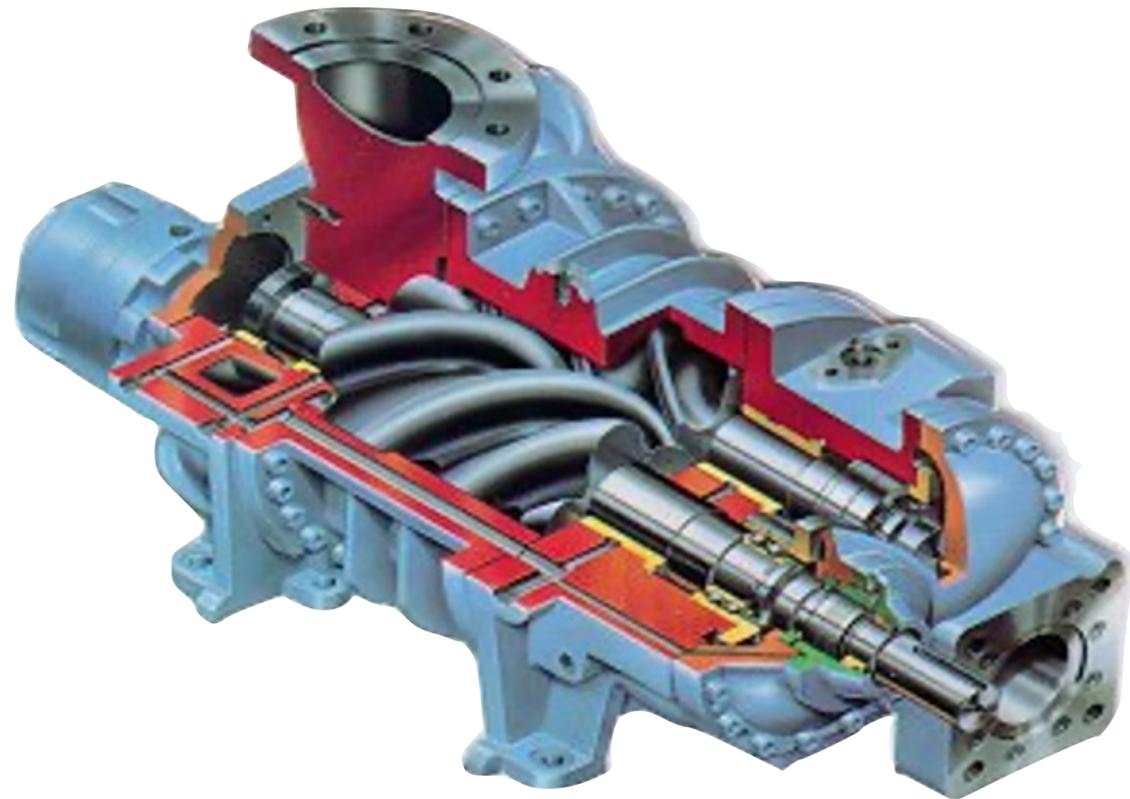
- This requires a large mass flow of oil

Oil flooded screw compressor



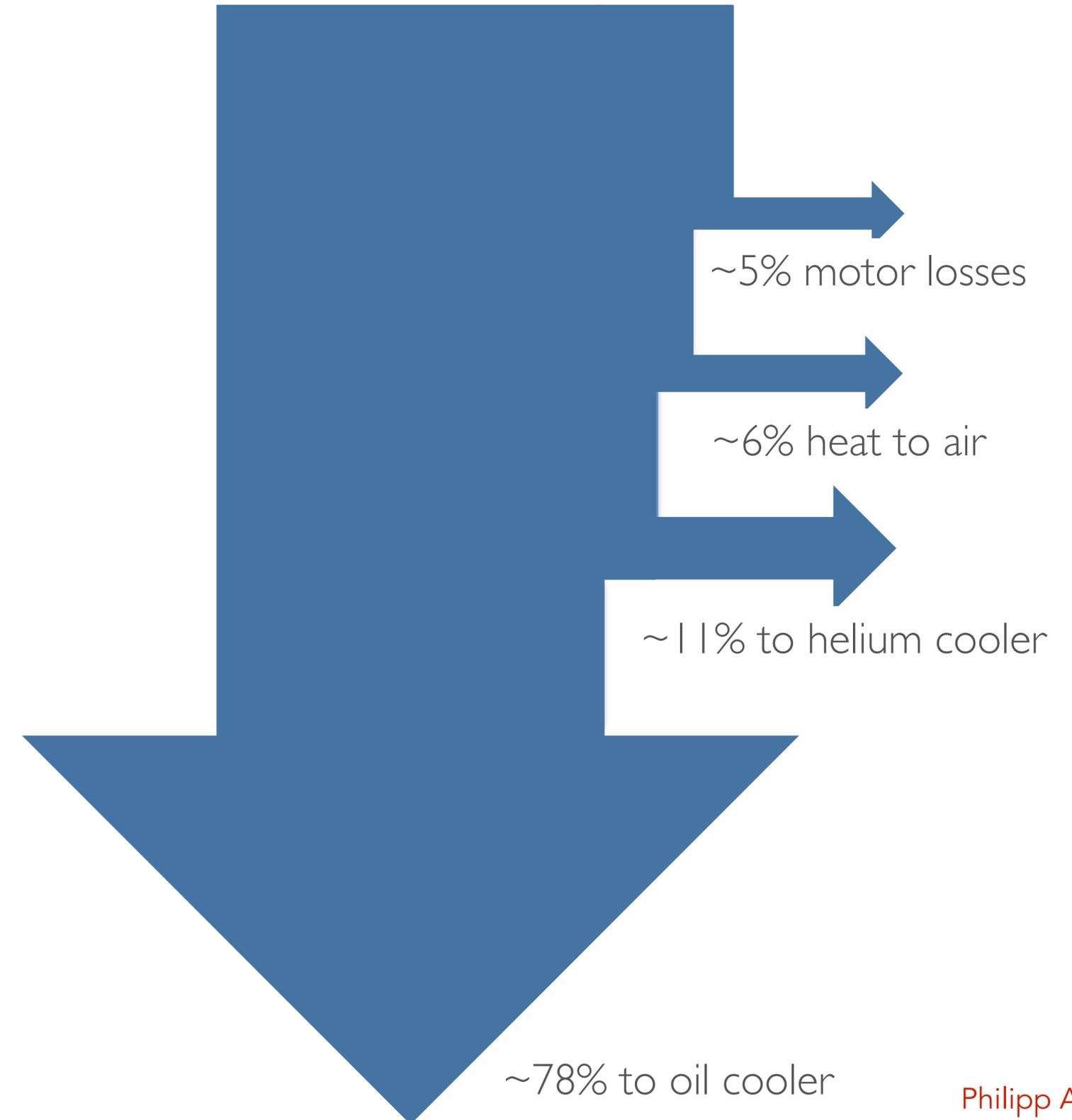
Animated gif from: [compressedair-intel.blogspot.com](http://compressedair-intel.blogspot.com)

### Oil flooded screw compressors



- High pressure state:
  - He flow: 0.735 kg/s
  - Oil flow: 19.285 kg/s
- Power consumption: 1.45 MW
- Heat into oil cooler: 1.13 MW

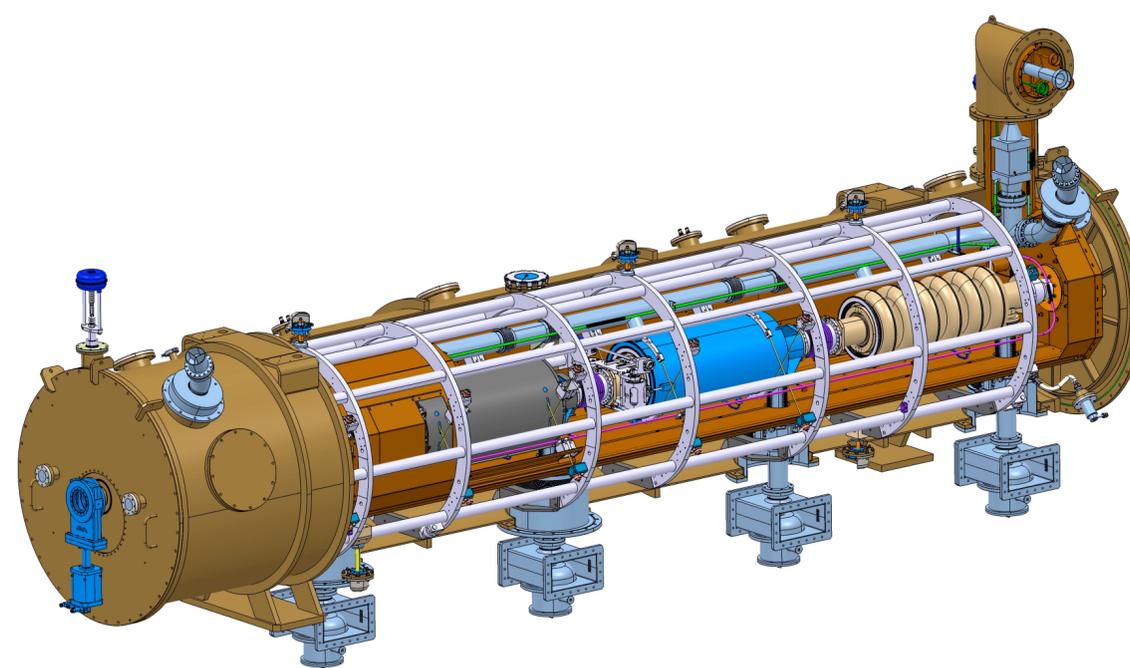
100% Electrical input power



# ENERGY SAVING MEASURES

## CRYO-DISTRIBUTION SYSTEM

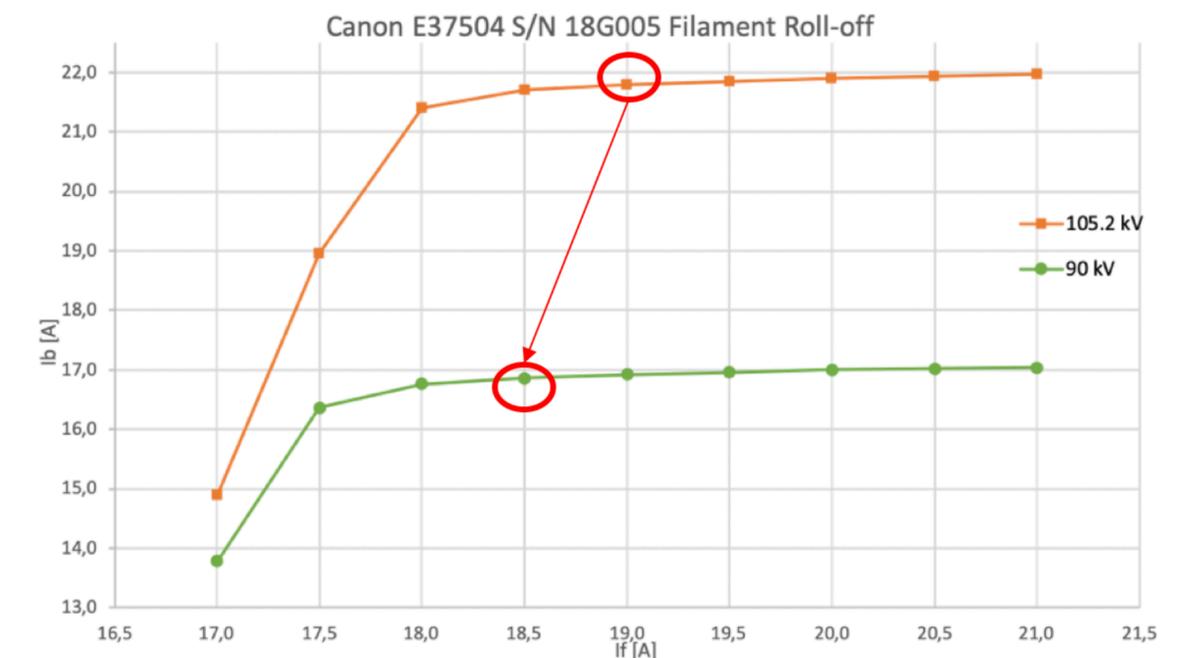
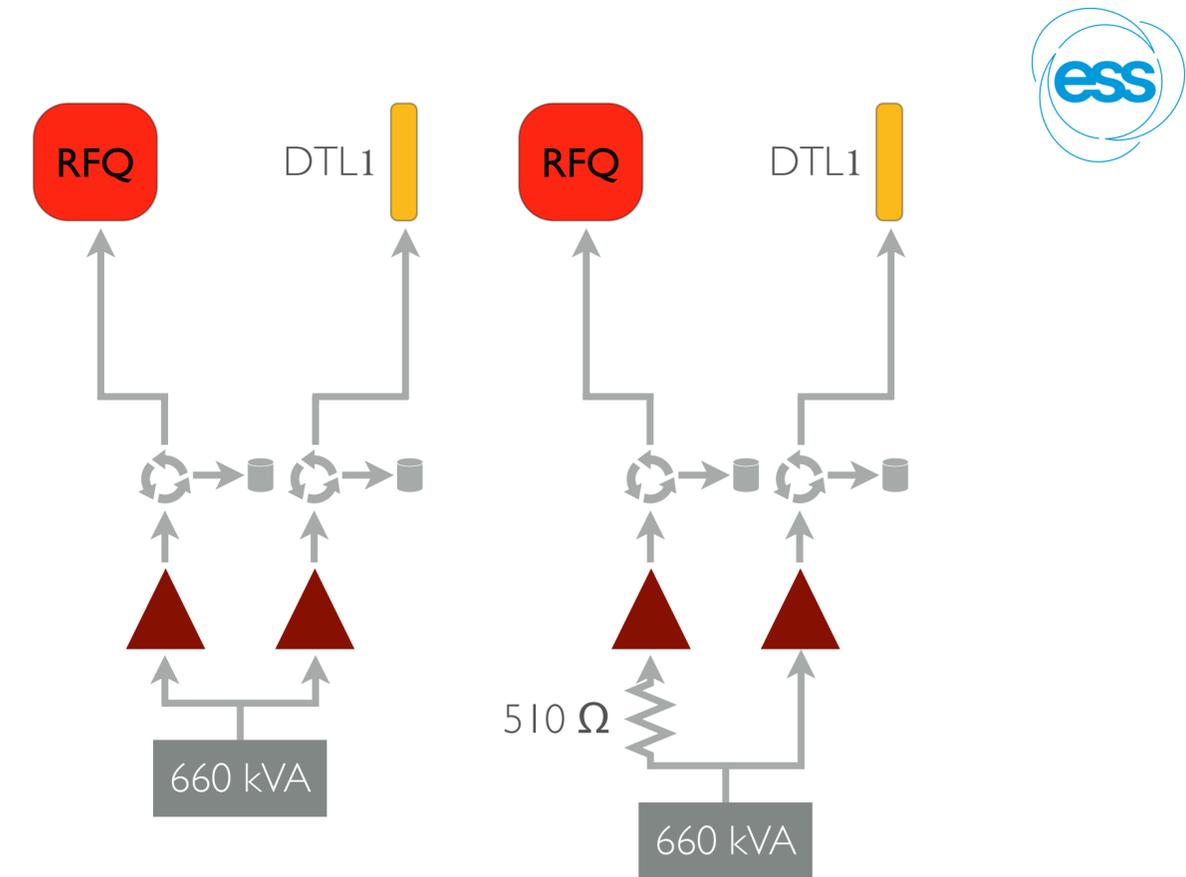
- Helium is transported at 4 K
  - Helium temperature lowered to 2 K only at the jumper connection of Spoke modules
  - Helium temperature lowered to 2 K only inside the elliptical cryomodule
  - Significant saving on static heat-load of +300 m long CDS
- Temperature of CMs thermal shield optimised for the available temperatures from the cryoplant turbines



# ENERGY SAVING MEASURES

## ACCELERATOR - NCL RF

- The worst klystron in terms of operational efficiency is the RFQ klystron.
  - RFQ and DTL are sharing the same modulator.
  - The required saturated power from the klystrons (including LLRF overhead) is:
    - 2.9 MW for DTL1 (109 kV)
    - 1.3 MW for RFQ klystron (90 kV)
  - Right now, the RFQ klystron is also running at 109 kV, with an efficiency at operation of only 19%.
- Solution: dropping the HV just for RFQ klystron.
  - The easiest way (even if not the most efficient) is to drop the voltage by using a series of high power resistors.
  - Some power about 35 kW average will be dissipated on the resistors, but the klystron will draw 25% less current.
  - Annual saving: 363 MWh (~~~33 k€~~)
  - The resistors can be placed in oil in a small oil tank next to the klystron
- Savings on klystron lifetime, as filament current and therefore the filament temperature is reduced at lower beam voltage (and beam current).
  - Applicable not only to NCL klystrons.



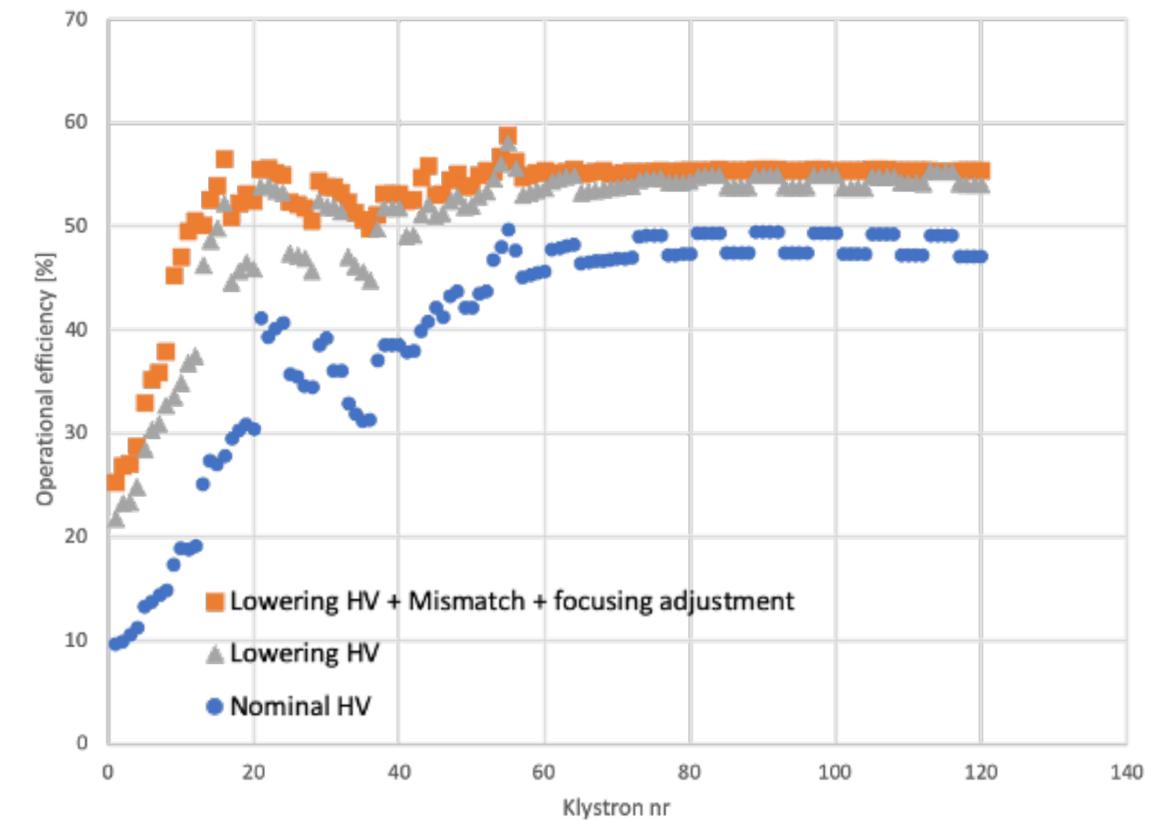
# ENERGY SAVING MEASURES



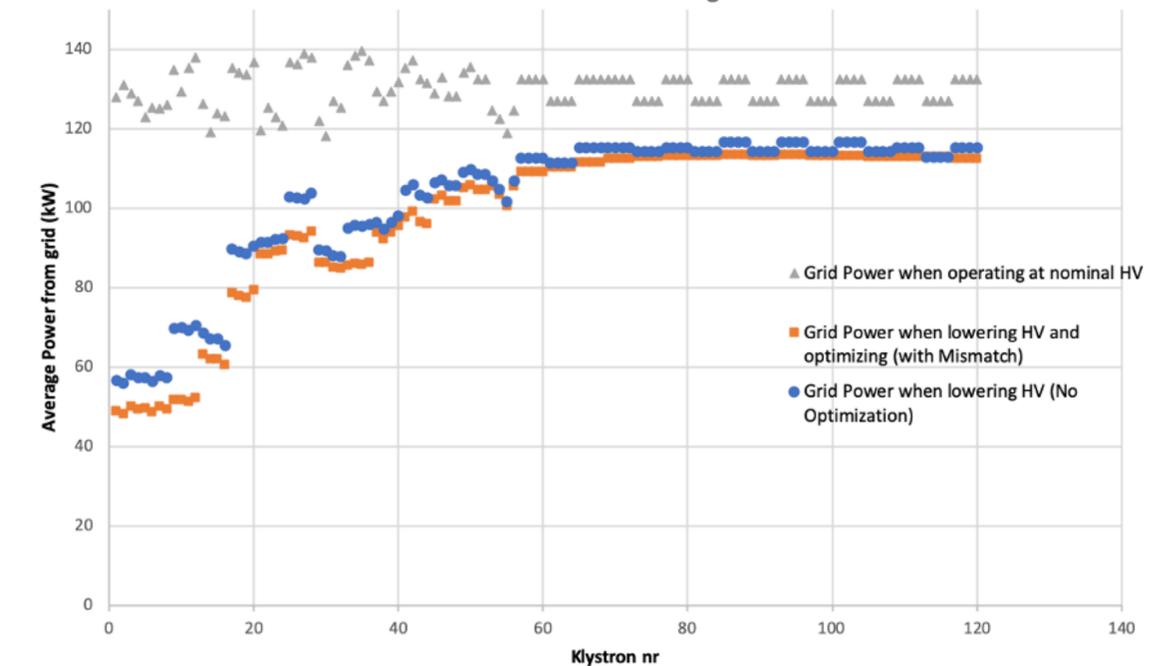
## ACCELERATOR - SCL RF

- Efficiency optimization at operating point
  - Use of mismatch at klystron output (to optimize external Q of klystron output cavity) AND focusing solenoid adjustment to improve efficiency at lower beam voltages
- Assuming we are able to keep the same efficiency at low voltages as at nominal
  - demonstrated on all Canon klystrons, not yet on the klystrons from other manufacturers
- Savings using mismatch in all cells
  - Assumptions:
    - Modulator efficiency: 90%
    - Price of electricity: 0.09 €/kWh
    - Klystrons operating 5500 h/year
  - Annual savings lowering HV: 18.1 GWh (~~1627 k€~~)
  - Annual savings lowering HV + Optimization with mismatch: ~20.9 GWh (~~1881 k€~~)
  - Annual savings only due to Optimization with mismatch: 2.8 GWh (~~253 k€~~)
- High efficiency klystron upgrade would increase the savings even further
  - An additional +28 GWh annually compared to current klystron optimized for low power
    - Requires a much higher investment upfront

Klystron operational efficiency



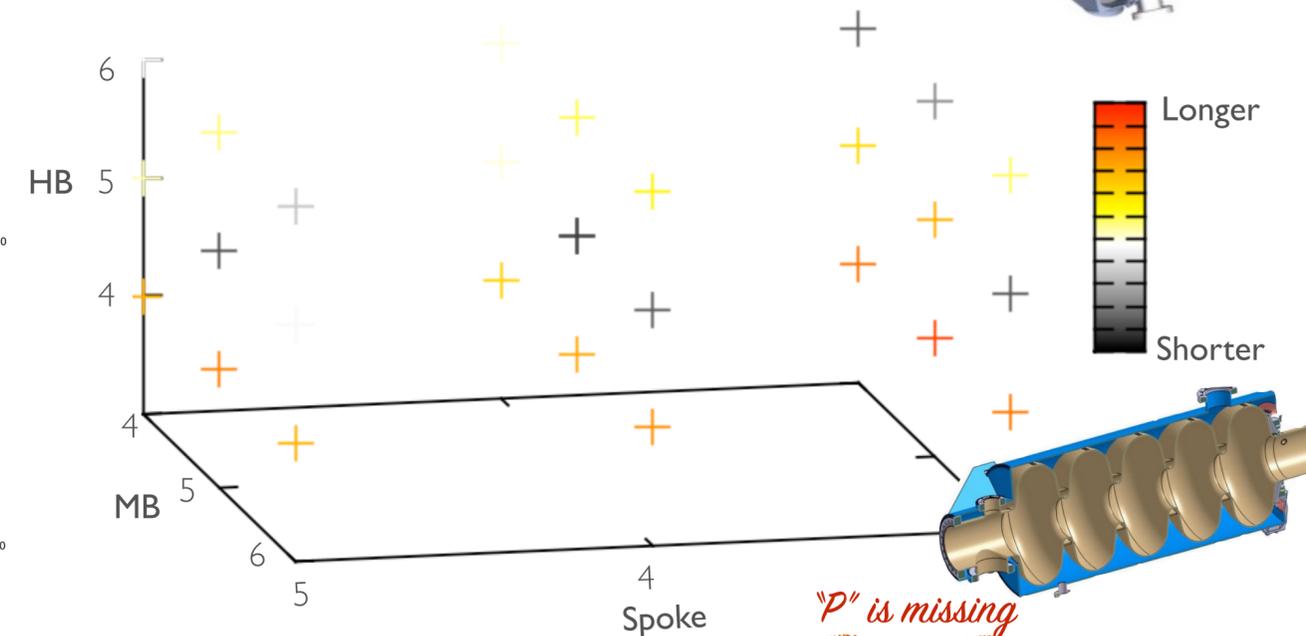
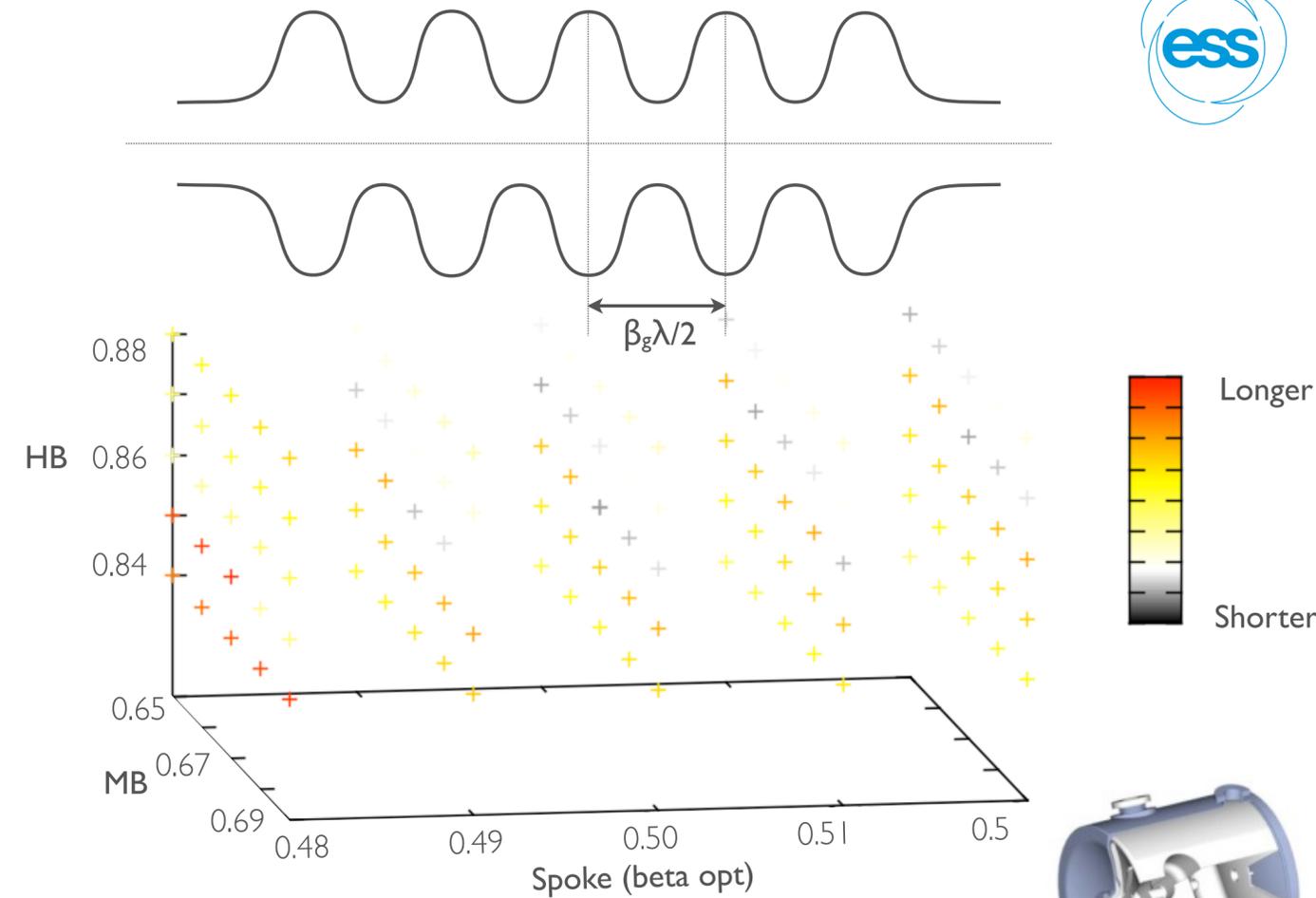
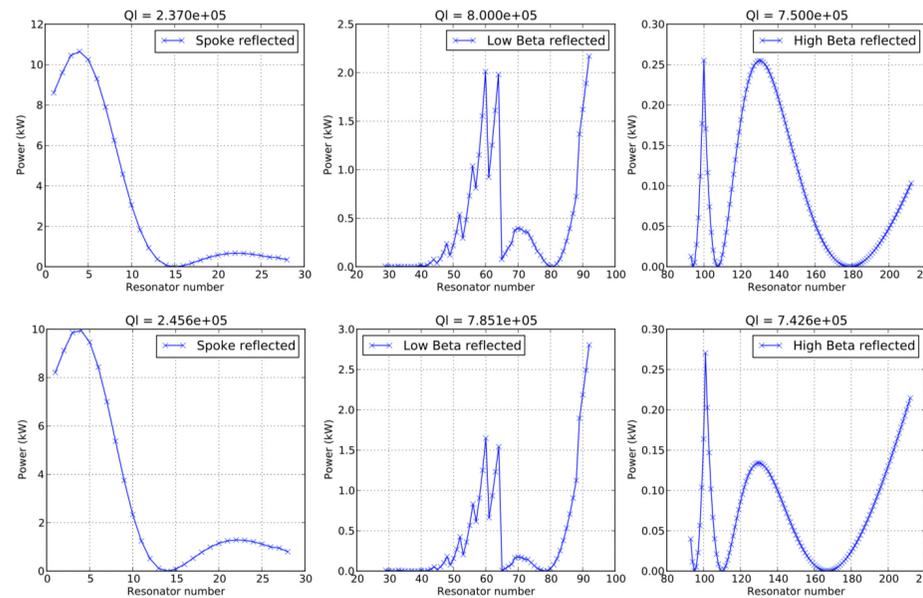
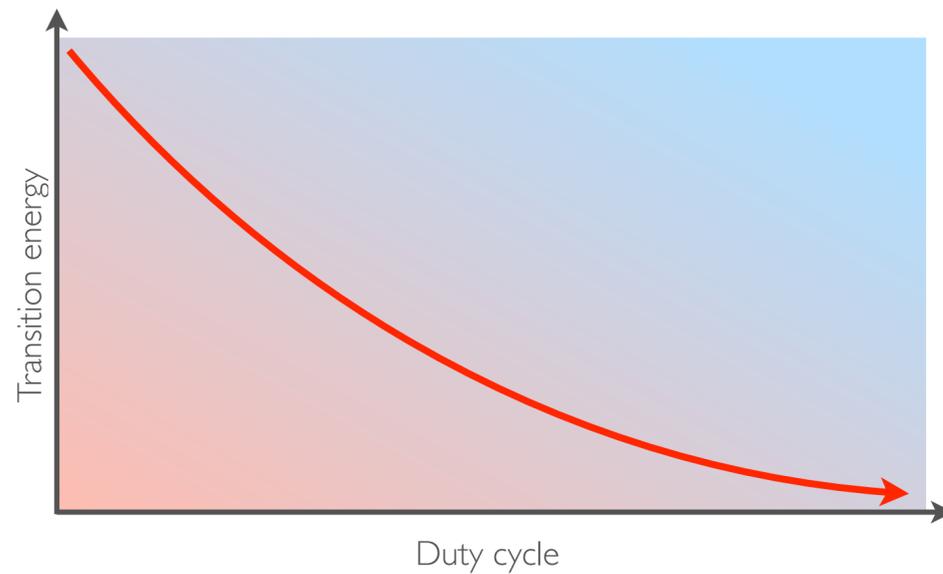
Grid Power with for Medium and High Beta Linac



# ENERGY SAVING MEASURES

## LINAC DESIGN, REDUCED ENERGY CONSUMPTION

- Optimizing the transition energies between sections
- Optimizing the transition energy from NCL to SCL
- Optimizing the geometric betas per cavity type
- Optimizing the number of cells per cavity type
- Minimizing the reflected power from SCL couplers



For more info please look at my talk at the 5th ESSRI: [https://indico.psi.ch/event/6754/contributions/18014/attachments/15682/21836/Energy\\_consumption\\_ESS\\_linac.pdf](https://indico.psi.ch/event/6754/contributions/18014/attachments/15682/21836/Energy_consumption_ESS_linac.pdf)



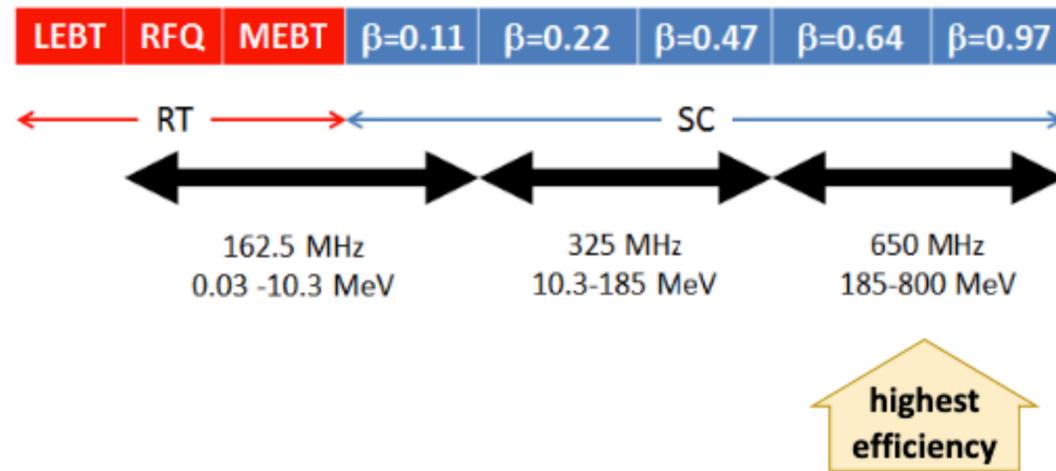
# BUY MORE, SAVE MORE?!

## HOW DOES IT WORK IN ACCELERATORS



### Superconducting Linac : High Efficiency Potential

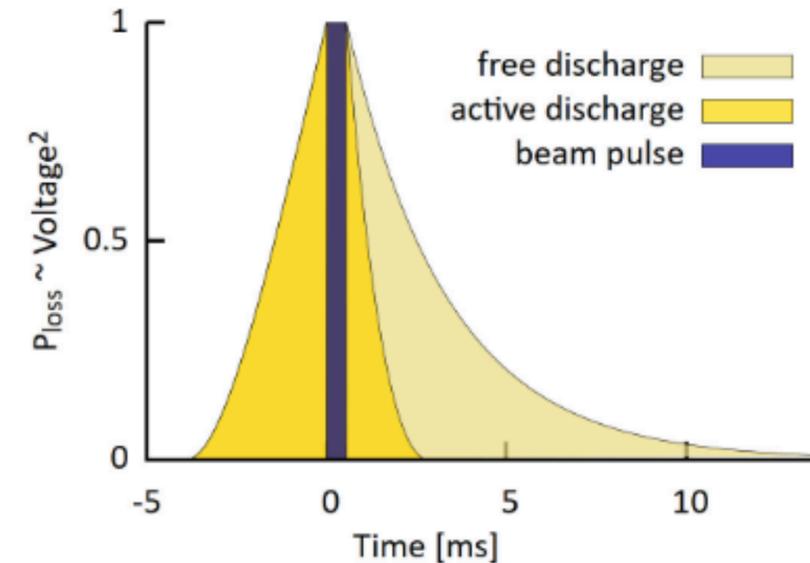
example: PIP-II design of Fermilab



#### PIP-II base parameters:

- $H^-$ , 800MeV, 2.0mA, part of Fermilab complex
- aim: neutrino production (1MW @ 60..120GeV)
- CW operation as upgrade path

#### not efficient in pulsed operation:



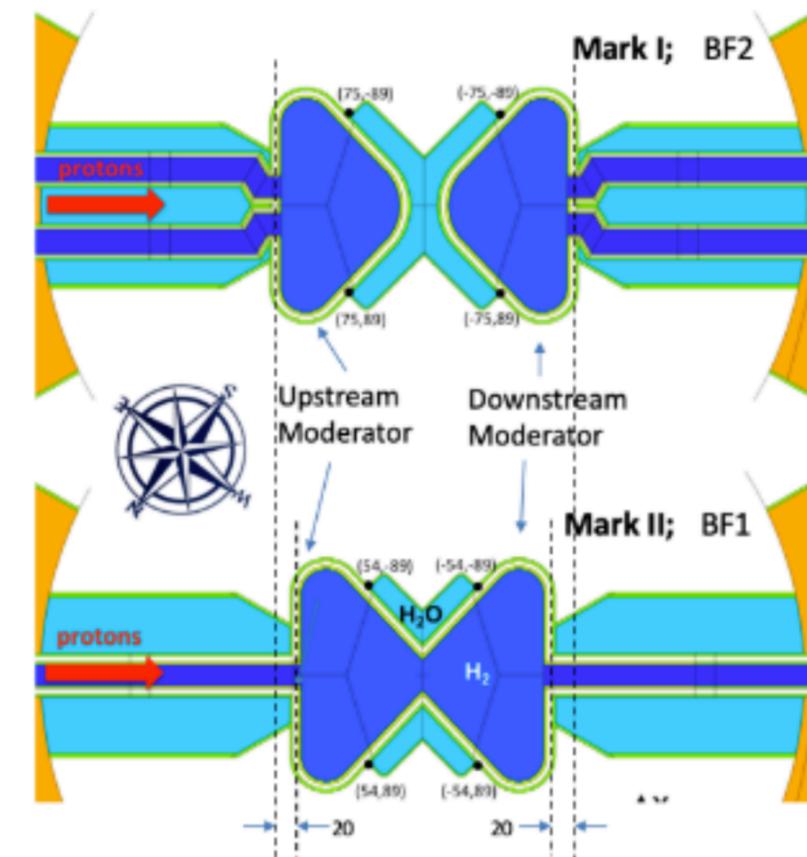
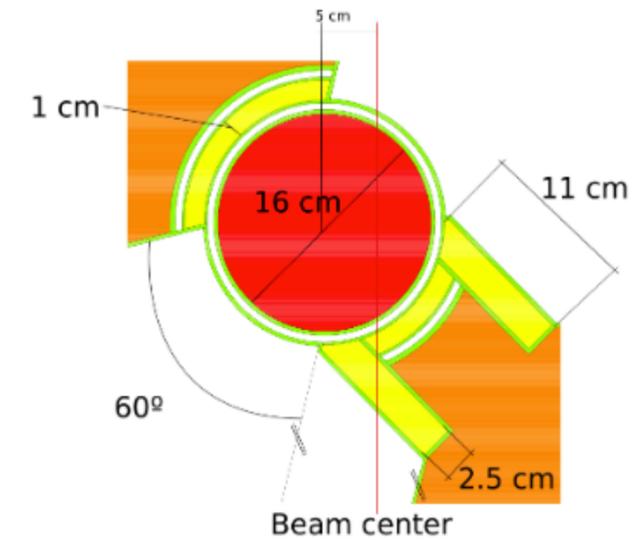
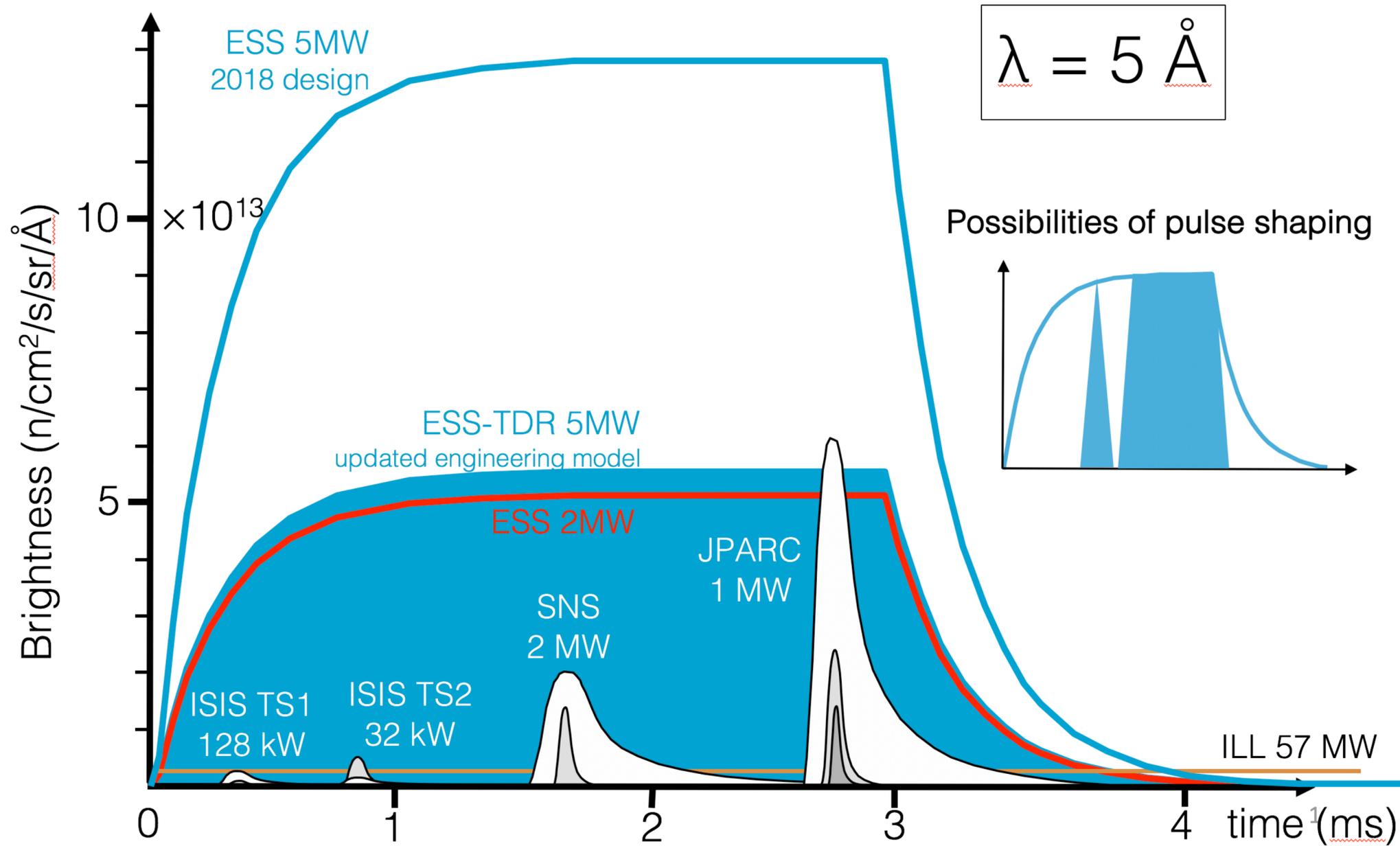
operating regime	avg. RF power	cryogenic power	avg. beam power	grid-to-beam Efficiency
PIP-II pulsed operation	1.44MW	1.19MW	17.6kW	0.7%
PIP-II CW operation	9.10MW	1.83MW	1.60MW	15%

[from presentation B.Chase, Y.Yakovlev, 2018]



# ENERGY SAVING MEASURES

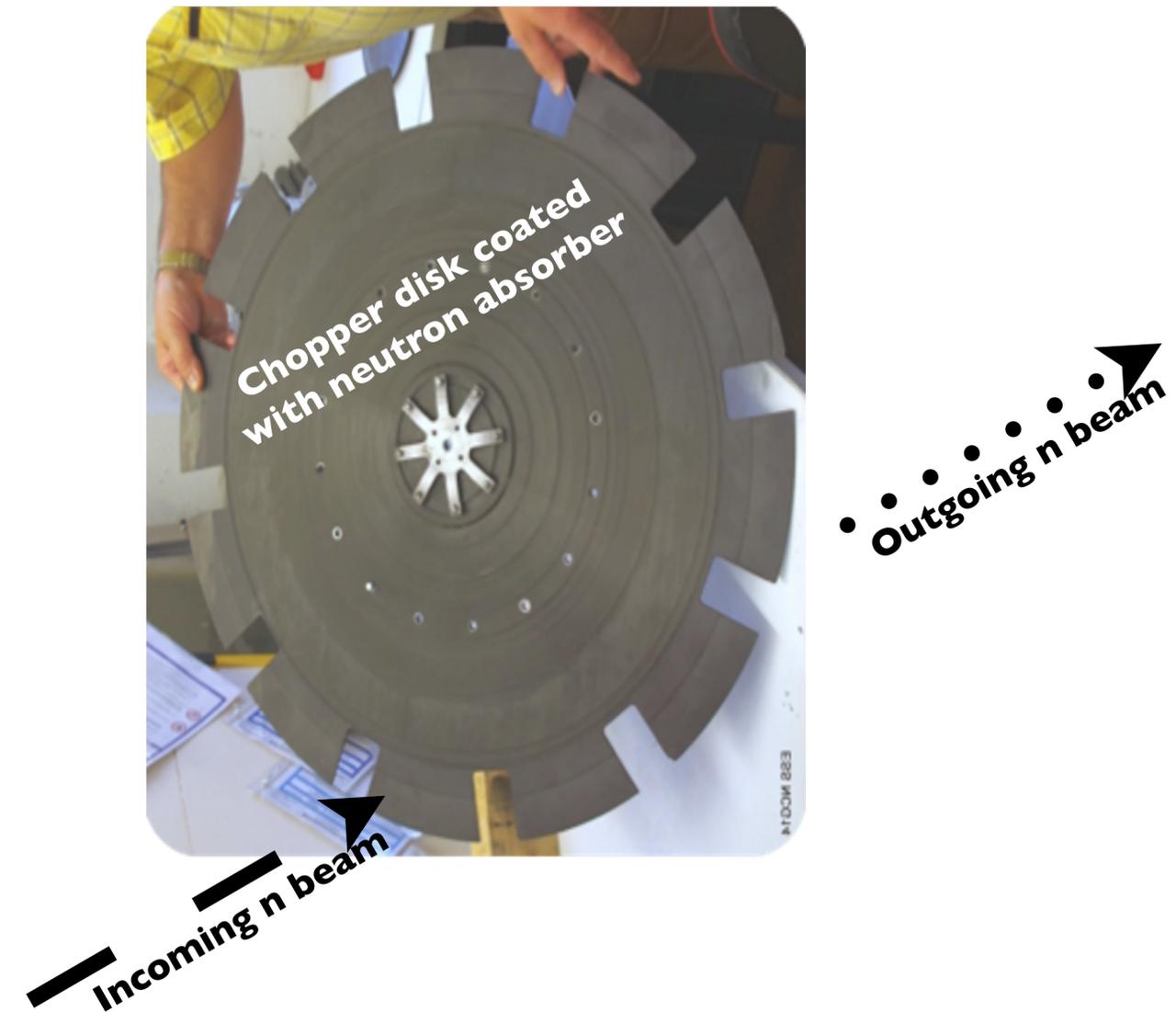
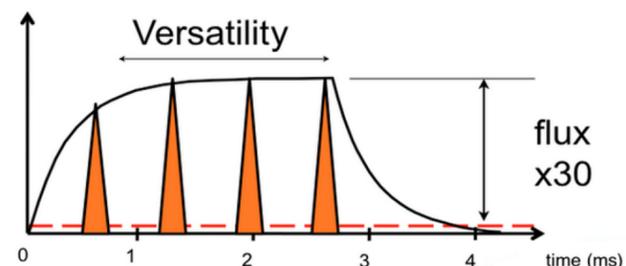
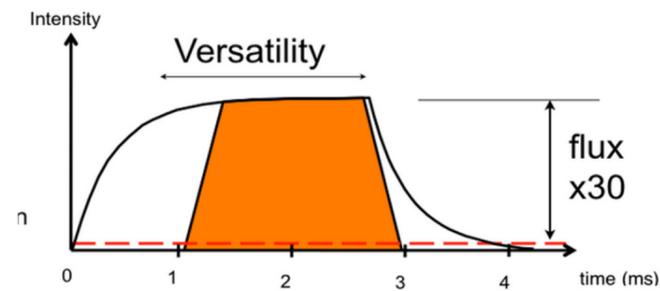
## TARGET



# ENERGY SAVING MEASURES

## NEUTRON CHOPPER SYSTEMS

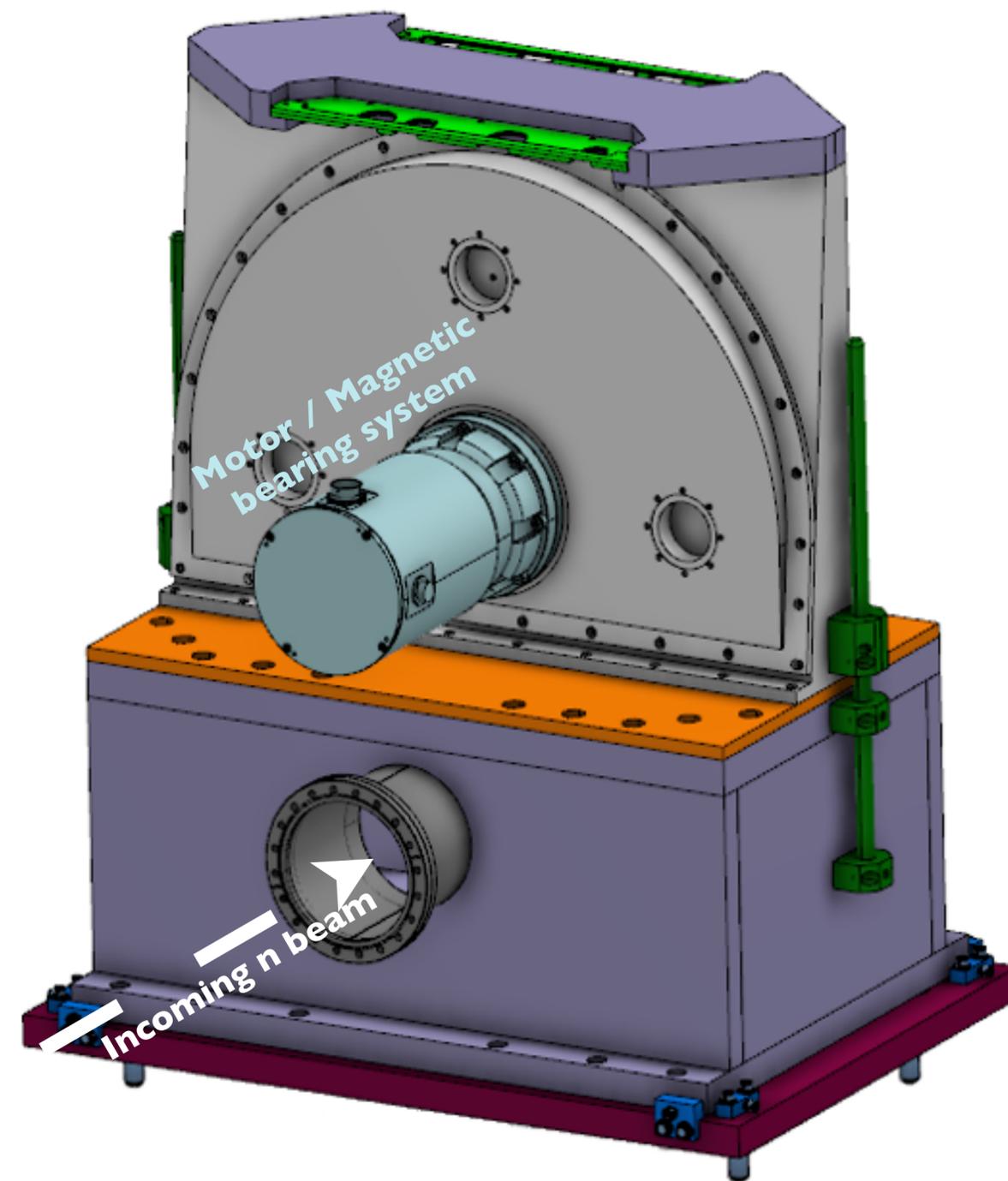
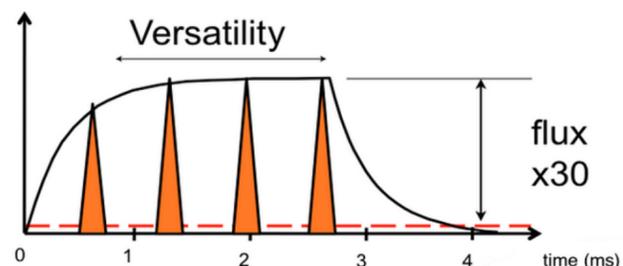
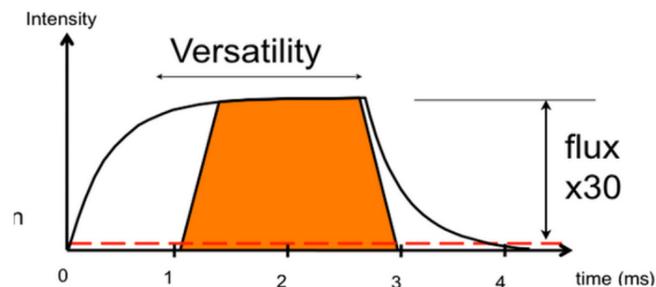
- Magnetic bearing and motor
  - Average power
    - 60-120 W
  - Peak power
    - 700 W
- The main reason to use magnetic bearing systems, is to increase the lifetime and reduce maintenance
  - The side product is a reduced energy consumption
    - ~10-20% lower energy consumption versus conventional bearing systems



# ENERGY SAVING MEASURES

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## BUILDING RESEARCH ESTABLISHMENT ENVIRONMENTAL ASSESSMENT METHOD

- In 2016 It was decided to certify the Office building according to BREEAM
- The turn key contract was signed 2018 with *Skanska* and sustainability requirements were highlighted in the collaboration contract.
- Skanska brought their sustainability requirements to the project.
- In the collaboration between ESS and *Skanska* we set up common goals. One goal was to:
  - The office building is certified according to BREEAM with the goal of **“outstanding”**
- The certificate was important for Campus’ owner *Skandrenting* and for the banks

### BREEAM- WORLD’S FIRST BUILDING ASSESMENT SYSTEM

#### First launched in 1990

- Inspires developers and creators to excel, innovate and make effective use of resources.
- Focus on sustainable value and efficiency
- BREEAM certified developments attract property investments and generates sustainable environments that enhance the well-being of the people who live and work in them

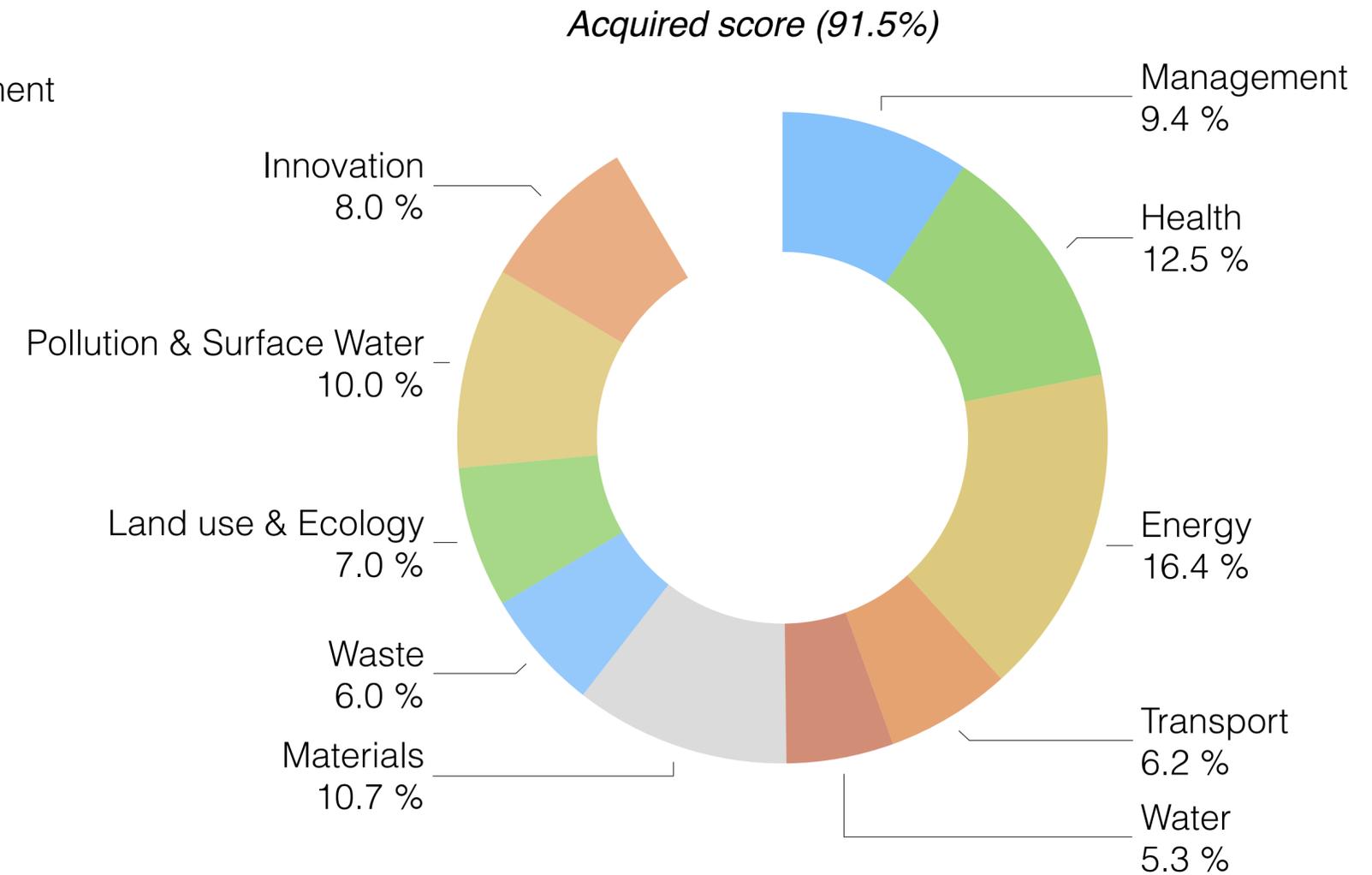
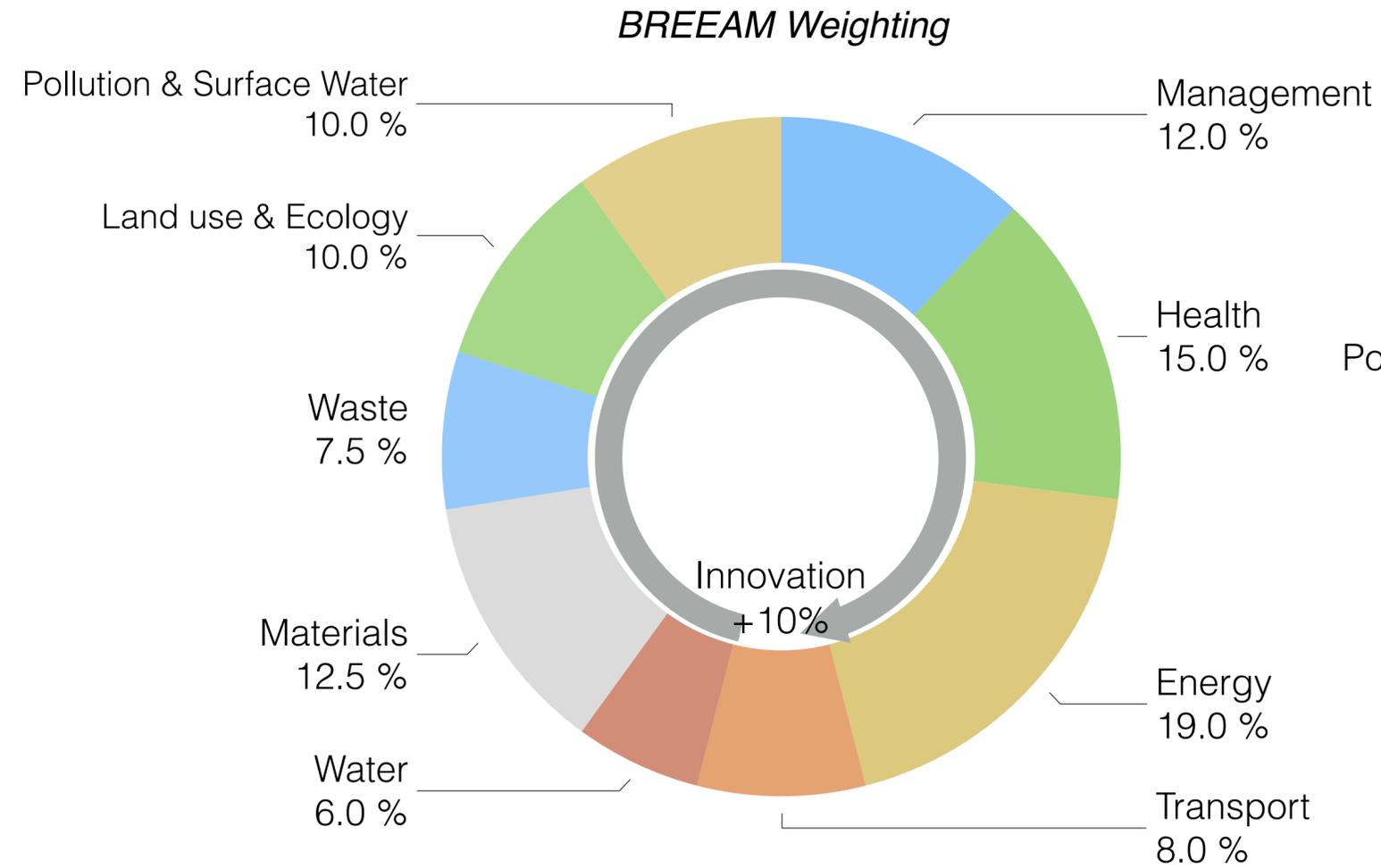
#### BREEAM in numbers worldwide

552,968 Certificates  
2,254,176 Registered Buildings  
77 Countries



#### WORKING CRITERIA

Karin Svedin



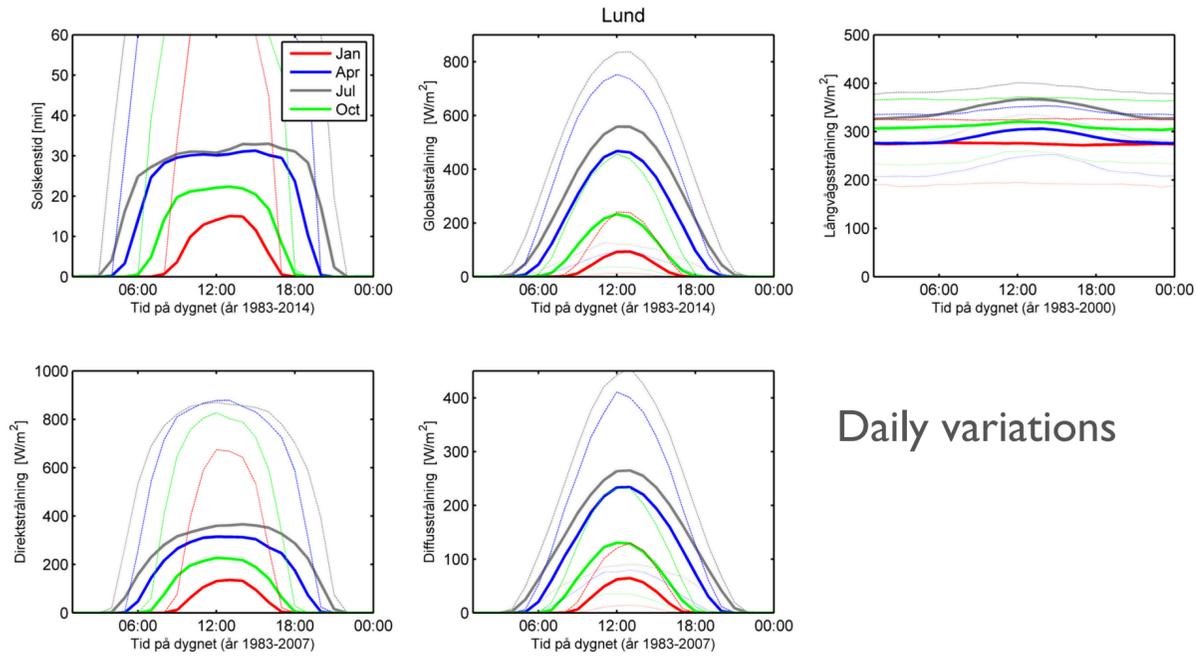
- **Level:** Outstanding is the highest level of BREEAM
- **Score:** 91.5%, this is
  - The highest rate in Sweden looking into all types of projects. 74 projects have been certified in BREEAM International 2013 New Construction.
  - Worldwide this puts ESS on the top 20 buildings of the Office type.

# SOLAR NEUTRONS

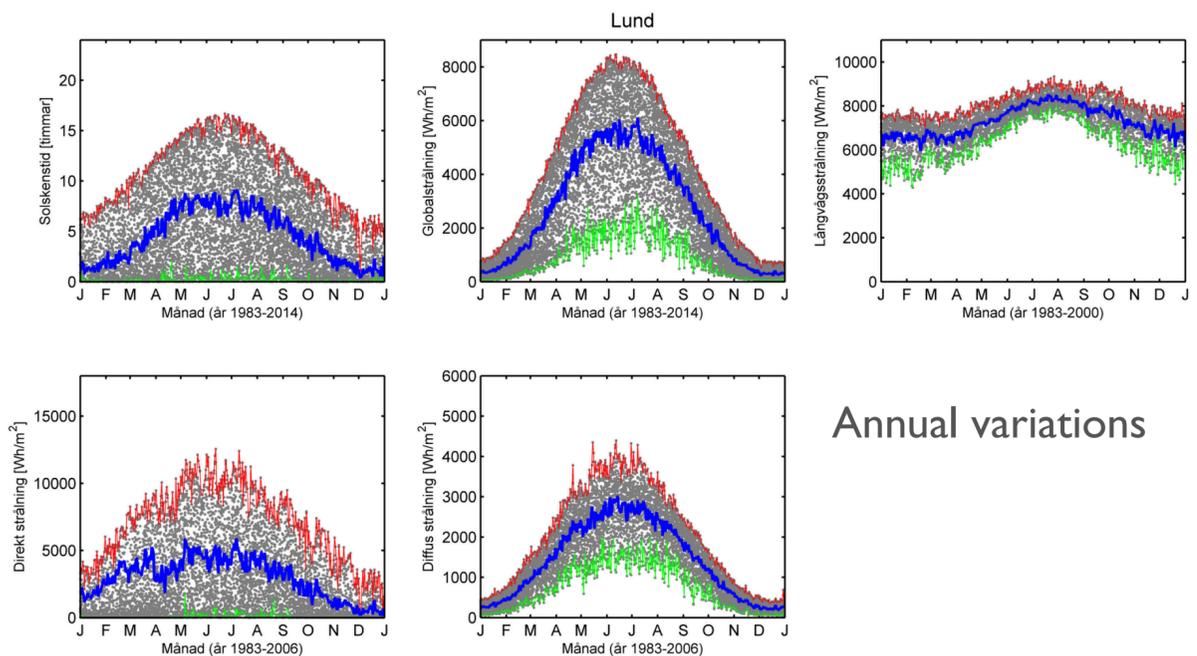


## SOLAR CELLS POWERING THE NEUTRON SOURCE

- Panels are 1.1 x 1.75 m, each rated at 405 W
- With ~19000 panels the installed capacity is ~7.6 MW



Daily variations



Annual variations



<ul style="list-style-type: none"> <li>Solcellspaket Essential</li> <li>18820 solceller</li> <li>Taklutning: Platt tak</li> </ul>	<ul style="list-style-type: none"> <li>Batteri: Ej vald</li> <li>Laddbox: Ej vald</li> </ul>	<ul style="list-style-type: none"> <li>Solcellspaket Essential</li> <li>18820 solceller</li> <li>Taklutning: Platt tak</li> </ul>	<ul style="list-style-type: none"> <li>Batteri: Ej vald</li> <li>Laddbox: Ej vald</li> </ul>
<p>Välj betalningsmetod ⓘ</p> <p><b>Direktbetalning Leasing</b></p>		<p>Välj betalningsmetod ⓘ</p> <p><b>Direktbetalning Leasing</b></p>	
<p>Investering 85 496 387,09 kr</p> <p>Månadsavgift 0 kr</p> <p>Avdrag för grön teknik -12 824 458,06 kr</p> <p><b>Din investering 72 671 929,02 kr</b></p>	<p>Investering 0 kr</p> <p>Månadsavgift 641 222,9 kr</p> <p>ROT -160 305,73 kr</p> <p><b>Din månadskostnad 480 917,18 kr</b></p>		
<p>Uppskattad årsbesparing 9 847 753,2 kr</p> <p>Återbetalningstid 7,7 år</p>	<p>Uppskattad månadsbesparing 820 646,1 kr</p>		

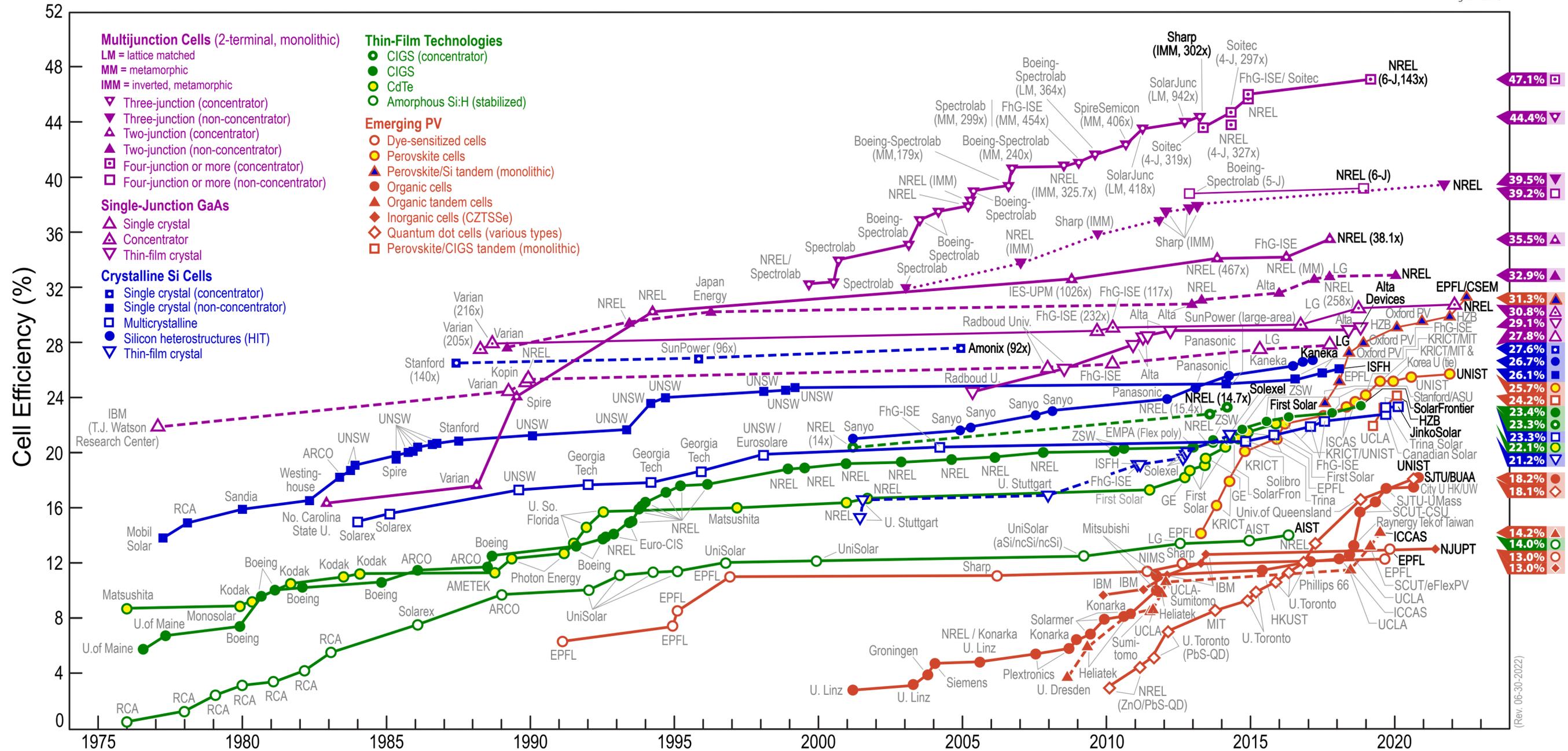
<https://www.smhi.se/kunskapsbanken/meteorologi/stralning/solstralning-i-sverige-1.89984>

# QUANTUM EFFICIENCY

## EVOLUTION OVER TIME



### Best Research-Cell Efficiencies



<https://www.nrel.gov/pv/cell-efficiency.html>

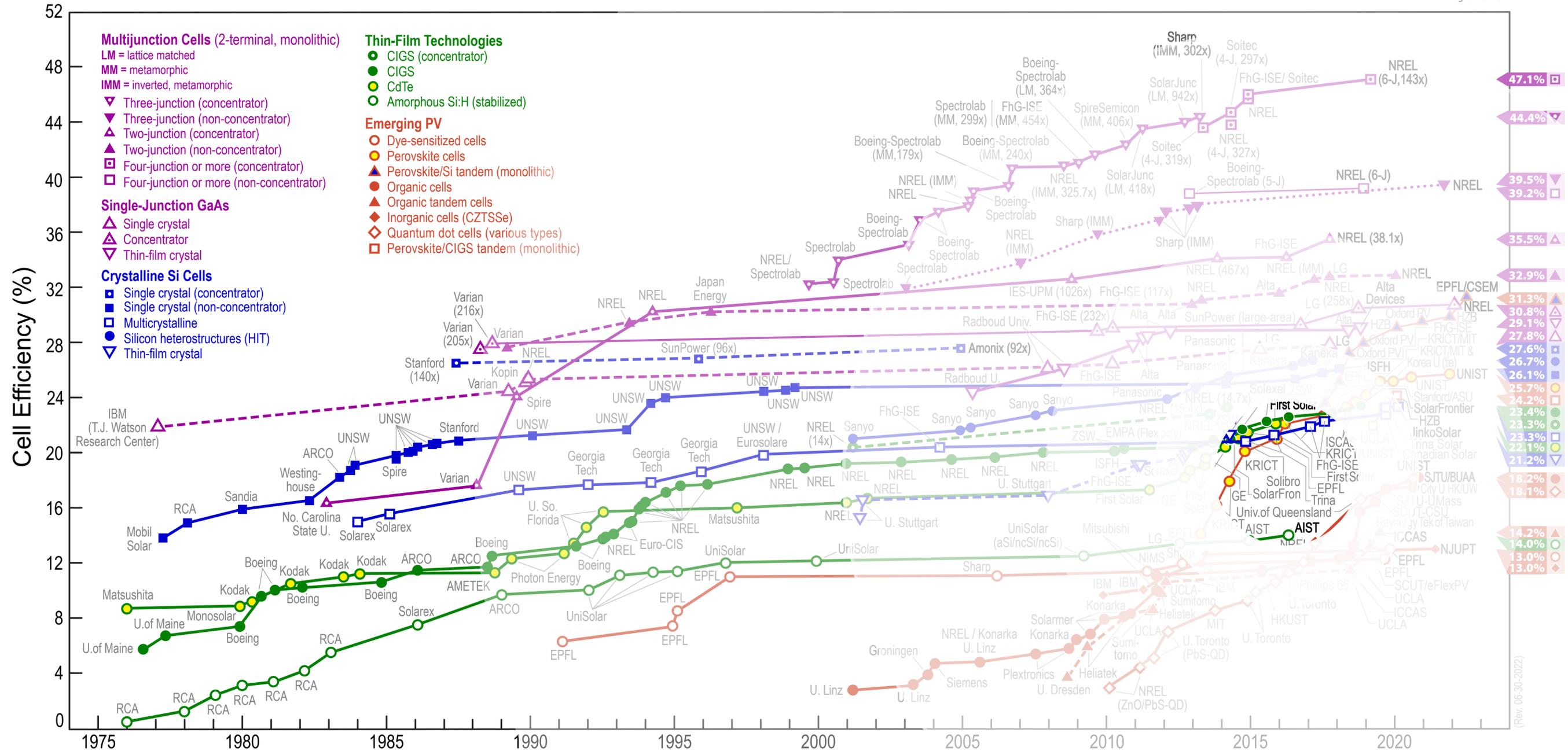
This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO.

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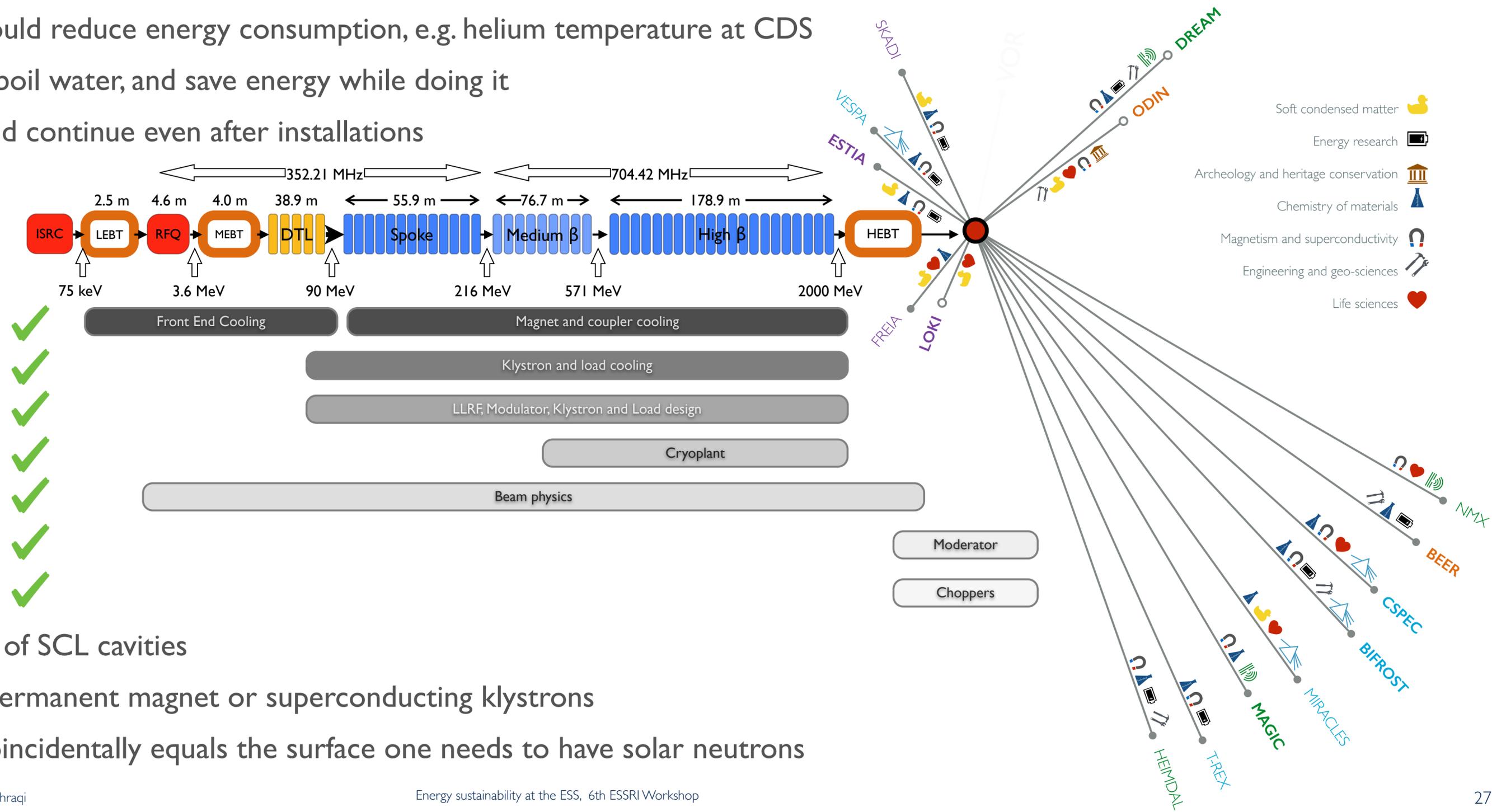
<https://www.nrel.gov/pv/cell-efficiency.html>,

This plot is courtesy of the National Renewable Energy Laboratory, Golden, CO.

# SUMMARY

## WHAT IS DONE AND WHAT COULD BE DONE

- Sometimes the energy saving comes as a side product, e.g the magnetic levitated neutron choppers
- Sometimes a higher performance is achieved at the same energy cost, e.g. the butterfly moderator
- Communication could reduce energy consumption, e.g. helium temperature at CDS
- It could pay off to boil water, and save energy while doing it
- Optimizations could continue even after installations



- Active de-charging of SCL cavities
- Higher efficiency, permanent magnet or superconducting klystrons
- The ESS surface coincidentally equals the surface one needs to have solar neutrons



**THANK YOU FOR YOUR  
ATTENTION**