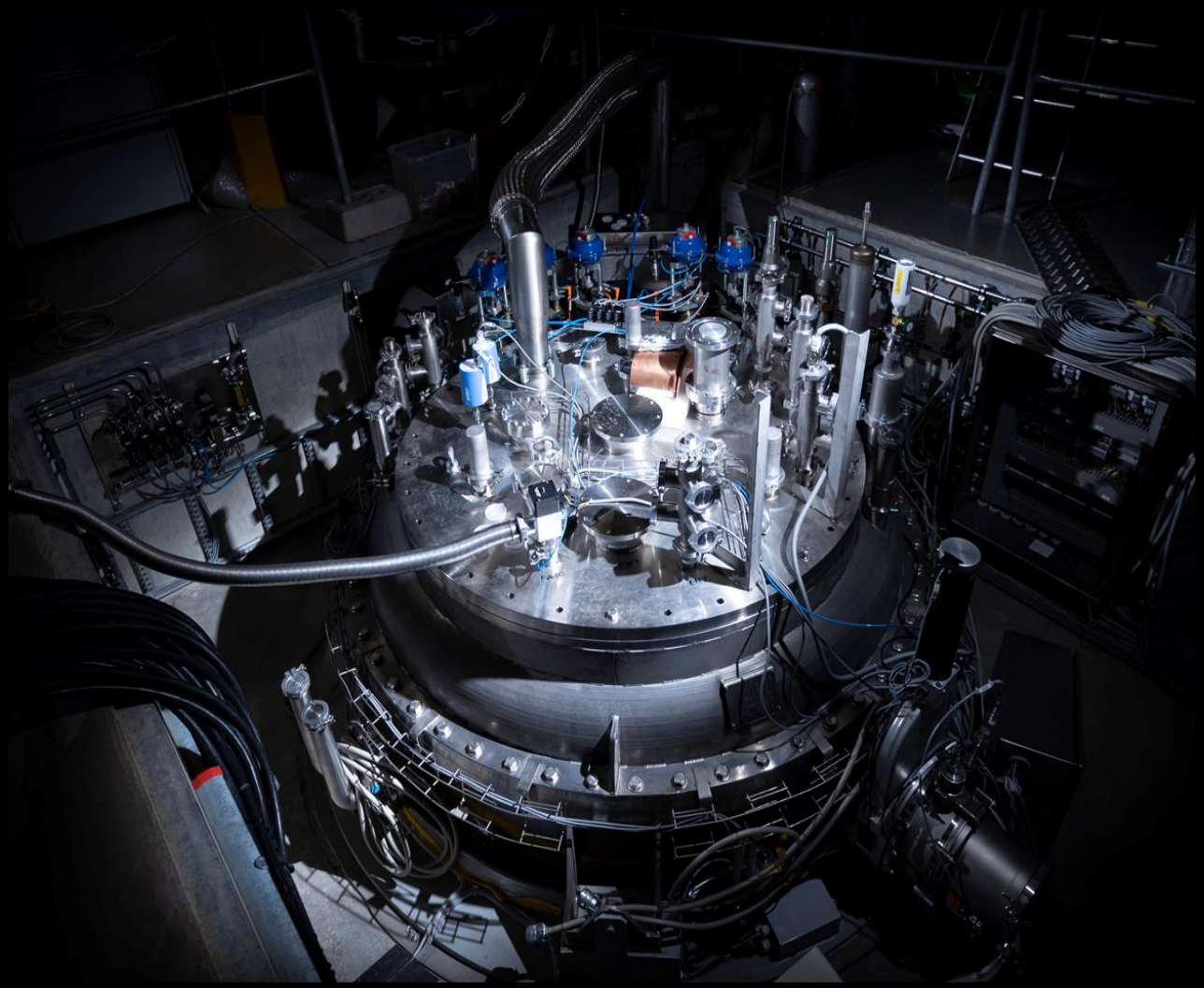


Accelerator development in Sweden

Maja Olvegård

Head of the FREIA division
Uppsala University

RECFA visit to Sweden, May 16, 2024, Lund

ESS – The European Spallation Source

Photo: Perry Nordeng, ESS

MAX IV

The first 4th generation synchrotron light source

In operation since 2016

Photo: Perry Nordeng, MAX IV

- **MAX 4U**
  - Upgrade to stay competitive
  - Beam emittance $\lesssim$ 100 pmrad
  - Simultaneous beamline upgrade
  - Conceptual Design Report by 2025
  - In operation by 2030
- **SXL - A soft X-ray Free Electron Laser (FEL)**
  - Conceptual Design Report complete
  - Waiting for funding

Courtesy: Aymeric Robert, Francesca Curbis & Sverker Werin

ESS – The European Spallation Source

- European Research Infrastructure Consortium
- The most powerful proton driver in the world!

- **2 GeV** linear proton accelerator
- Rotating tungsten wheel target
- High beam power: **5 MW** average, 125 MW peak
- Long pulses 3 ms
- Moderate rep. Rate: 14 Hz
- 15 neutron instruments planned, 22 at a later stage
- 5 instruments ready for first beam on target in 2025

ESS in-kind

Reception of the first spoke cryomodule at the FREIA laboratory in Uppsala for acceptance testing.

Photo: Mikael Wallerstedt

His Majesty the King of Sweden and His Excellency the President of the Republic of France Emmanuel Macron “installing” a spoke cryomodule.

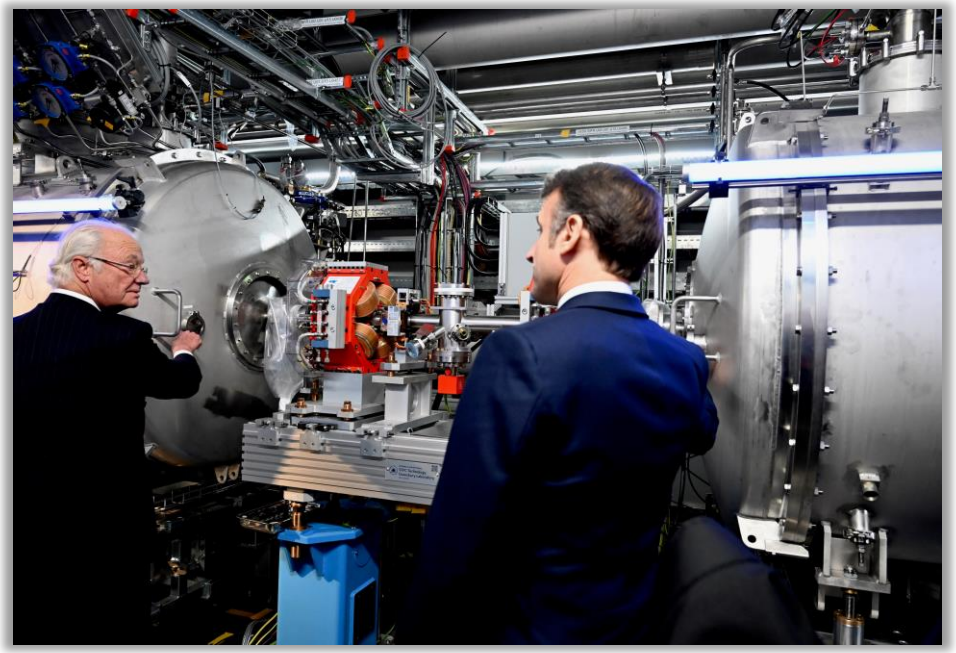


Photo: Ulrika Hammarlund/ESS

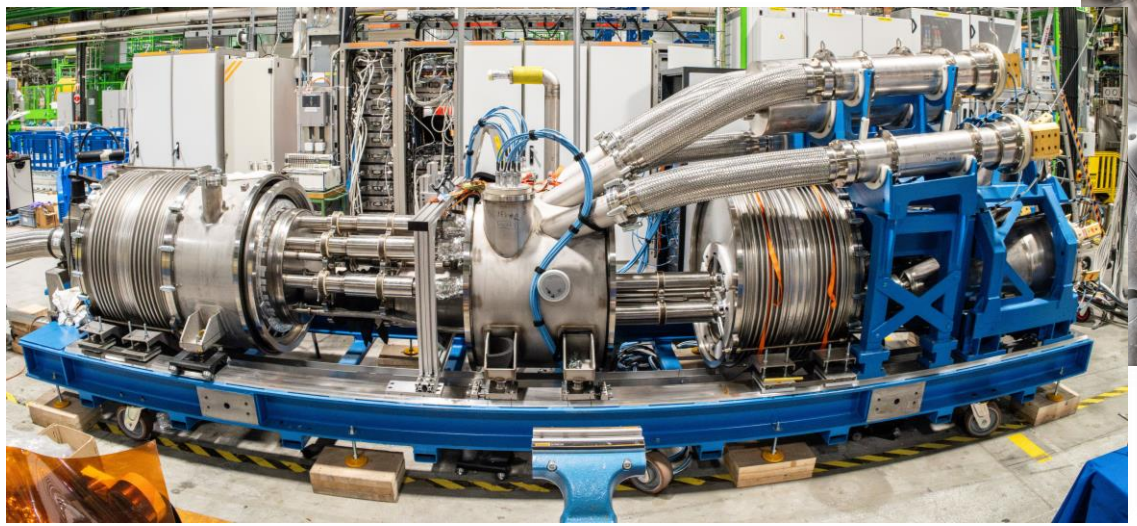
FREIA Facility for Research Instrumentation and Accelerators

- Testing of superconducting accelerator equipment
  - Cavities and cryomodules
  - Magnets
- Development of accelerator equipment and instrumentation
- Design and development of new accelerators
- Basic research in accelerator physics and technology

We act at the intersection between academica, big science research facilities and industry.

HL-LHC

- Delivery of nine **cryostats** for cold powering of magnets near the interaction points
  - Collaboration with Swedish industry
- Testing of superconducting **magnets** and **crab cavities** at the FREIA laboratory



RFR SOLUTIONS
Stainless Steel Excellence

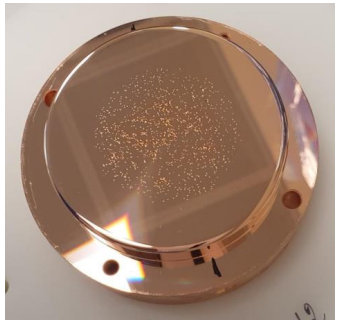
Swedish Research Council, CERN, Uppsala University

Courtesy: Rocio Santiago Kern, Tord Ekelöf

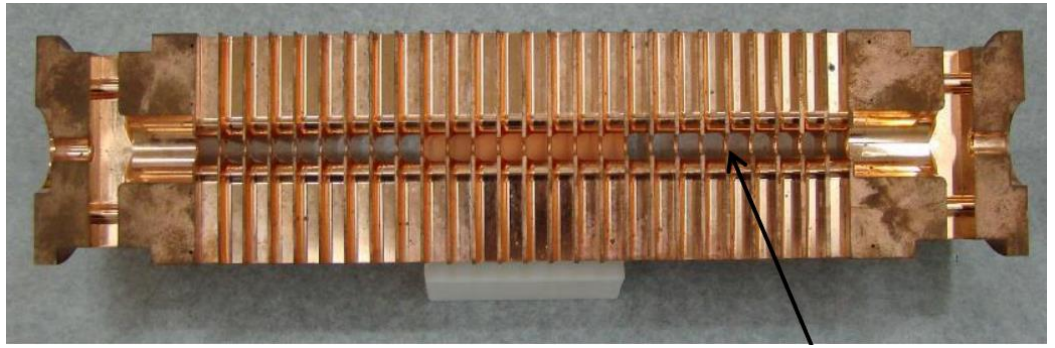
CLIC – The Compact Linear Collider

- Uppsala contributed to the Two-Beam Test Stand demonstrator at CERN.
- We have a test-stand in FREIA where we perform studies of fundamental processes behind electric breakdown in accelerating cavities.
- We work on optimizing the drive beam complex and develop a simulation code with unique features
  - Also essential for the Muon Collider study and the LHeC (energy recovery linacs)

Courtesy: Marek Jacewicz

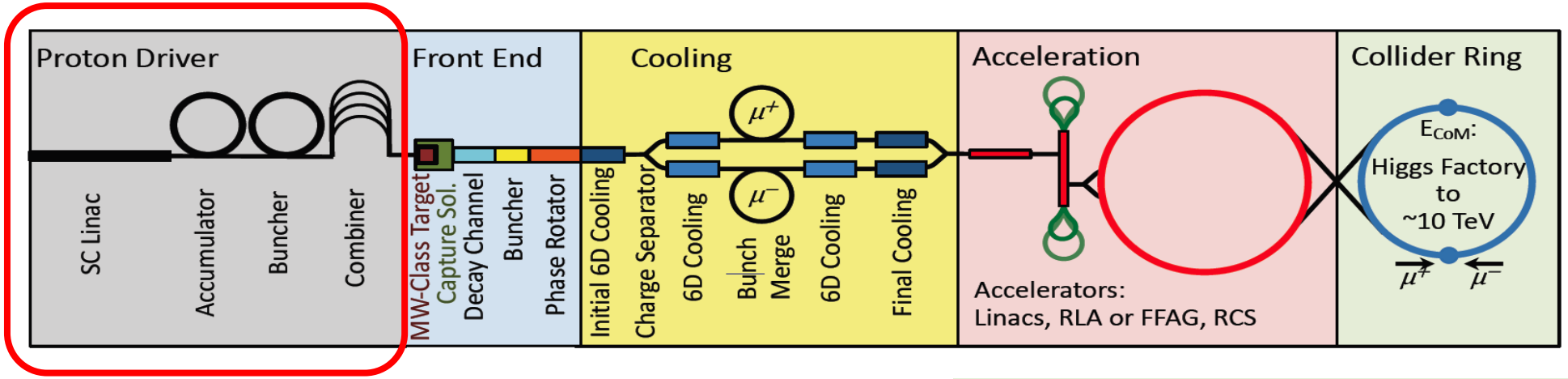


From https://indico.cern.ch/event/388632/ (Walter Wuensch, CERN)



The Muon Collider

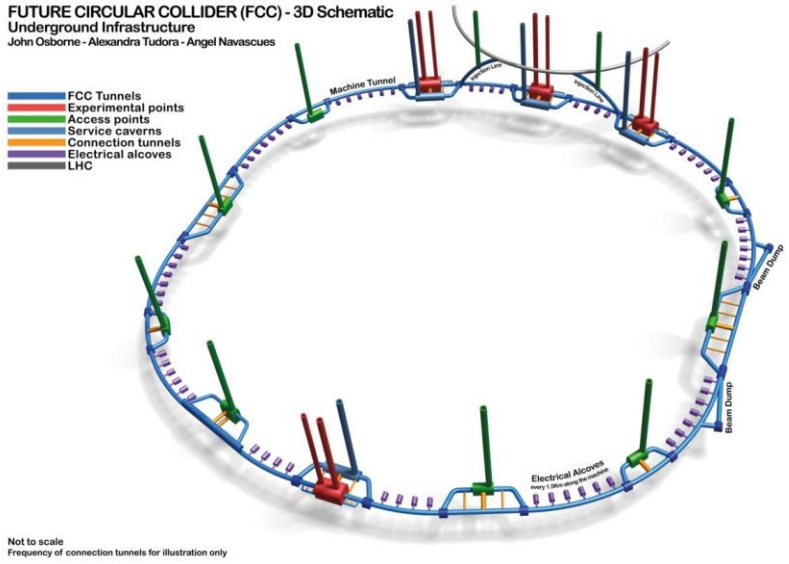
- ESS and Uppsala University are members of the European Consortium MuCol.
- ESS (Natalia Milas) is work package leader for the proton driver.
- Goal: Design a 2 MW H^-/proton accumulator and compressor
  - High-charge beam to produce very short bunches of muons



Horizon Europe Infra-dev, Uppsala University, ESS

Courtesy: Natalia Milas

FCC

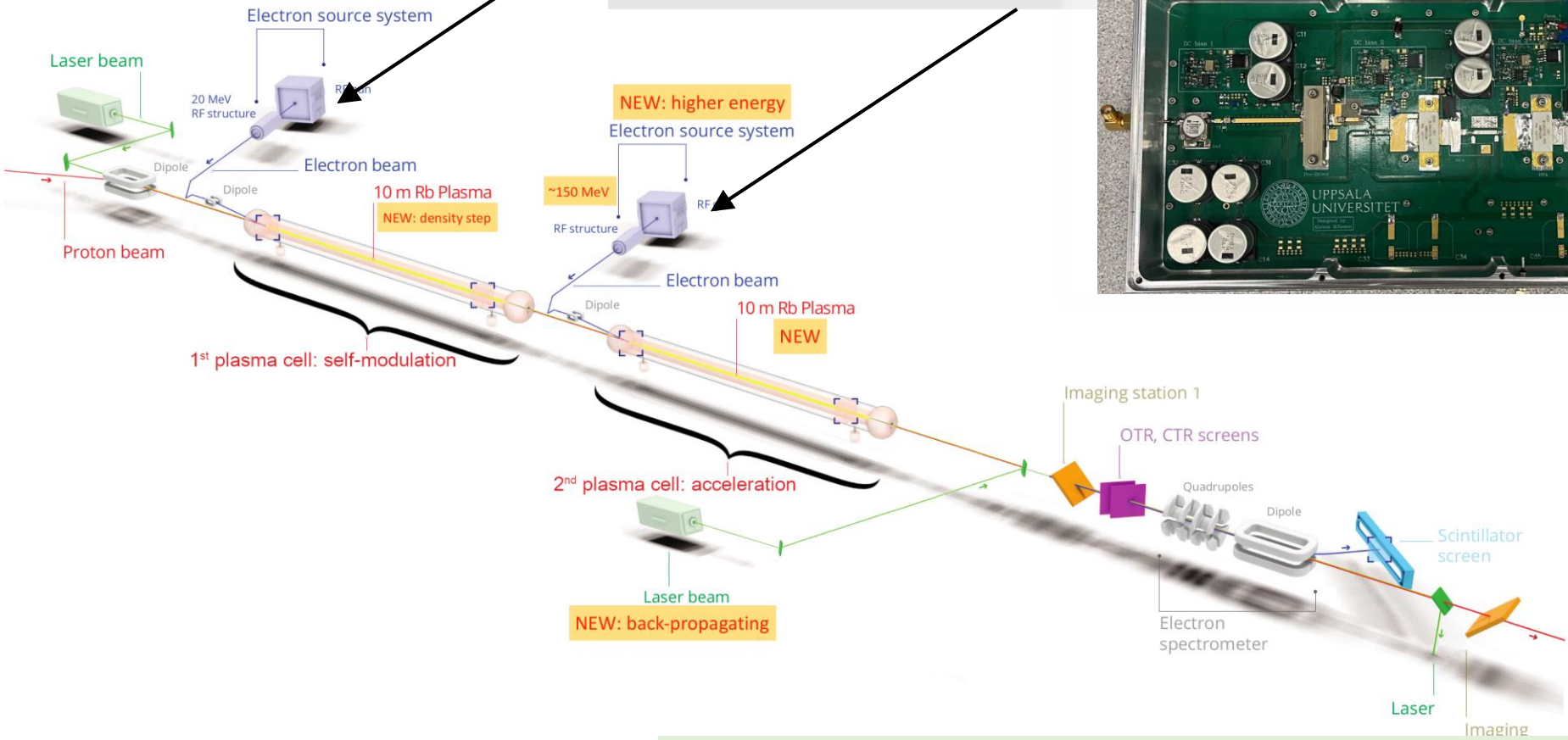


OPEN-PHO-ACCEL-2019-001-34

We are eager to join the work on the Future Circular Collider and hope that FREIA can serve a purpose in the process.

AWAKE

Uppsala develops and delivers RF systems for the two electron injectors for the AWAKE project (run 2).



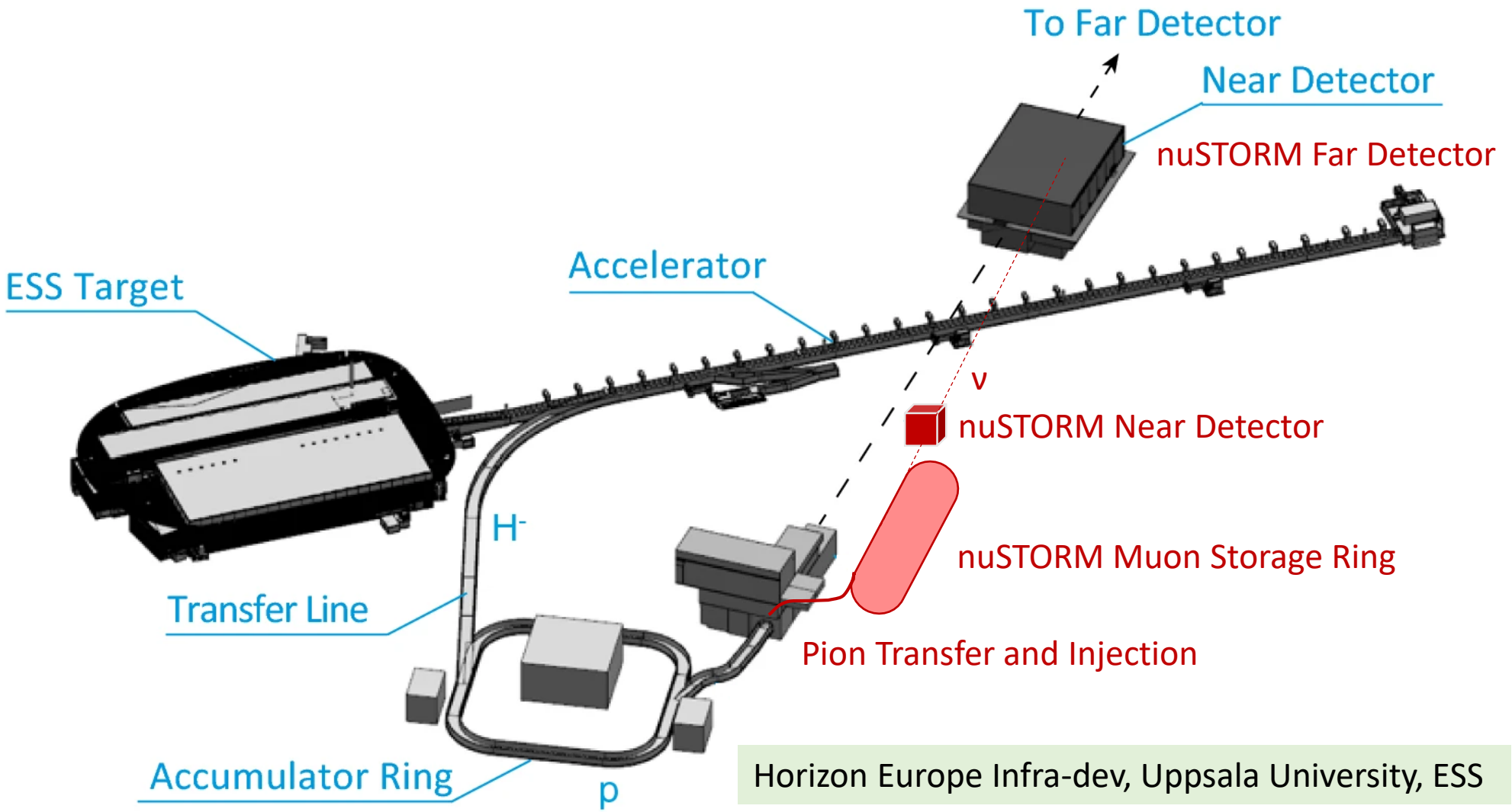
3GHz solid-state amplifier

Courtesy: Kevin Pepitone

Swedish Research Council, grant for accessibility to infrastructure

ESSnuSB

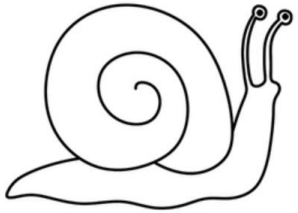
nuSTORM – neutrinos from Stored Muons



Horizon Europe Infra-dev, Uppsala University, ESS

Co-funded by the European Union

RECFA in Sweden 2016



”The Committee was impressed by the accelerator physics activities associated with the new facilities, MAX IV and ESS, and at the FREIA laboratory at Uppsala University. These centres offer excellent opportunities for developing accelerator science in Sweden and for training future accelerator physicists, who are in high demand. The Committee considers that these activities could be better coordinated through a coherent national initiative involving both the universities and the accelerator facilities.”

Prof. H. Abramowicz, 2016 RECFA visit to Sweden 21 July 2016, ECFA/Secr./16/1730

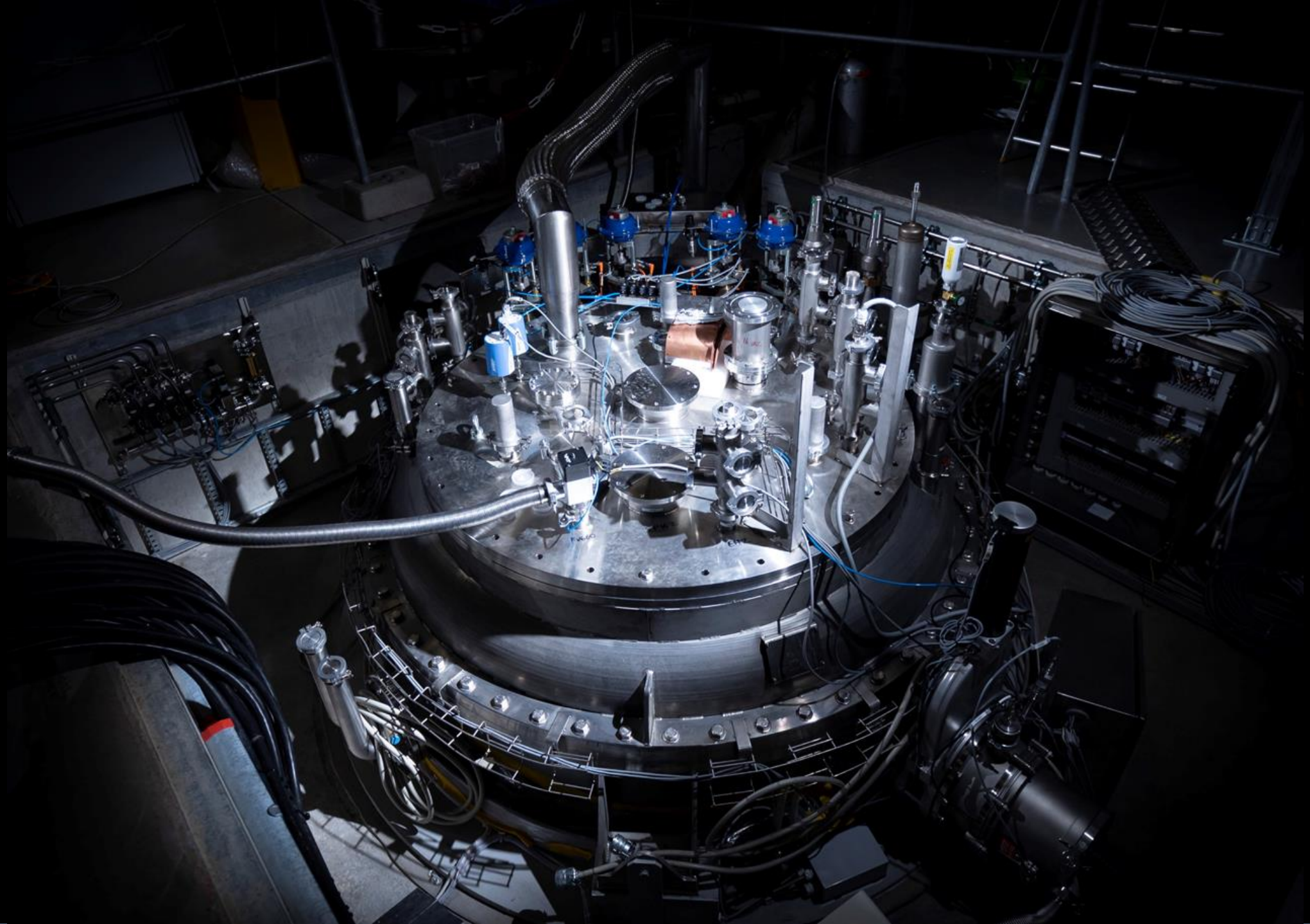
We have proposed the

Swedish National Accelerator and Instrumentation Laboratory

See talk of Richard Brenner

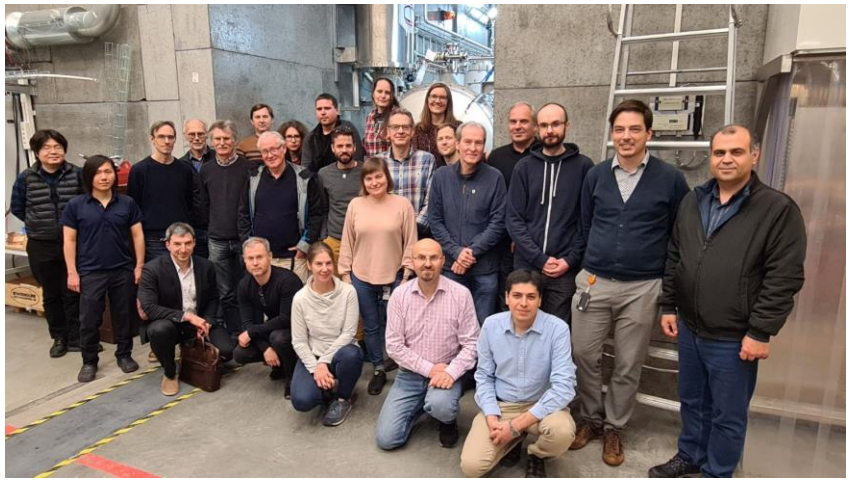
Final remarks

- Home of two magnificent machines: ESS and MAX IV
- MAX IV and Lund University have an ambitious synchrotron/FEL program, aided by Stockholm and Uppsala universities.
- ESS offers a huge potential for a rich particle physics program.
- Uppsala University through the FREIA laboratory contributes to a variety of accelerator facilities and projects, in particular for particle physics.
- Sweden has a strong tradition in accelerator physics, working hard to maintain it.
- The community stands united behind a Swedish national accelerator and instrumentation laboratory (SNAIL).



Extra slides

10 years of FREIA

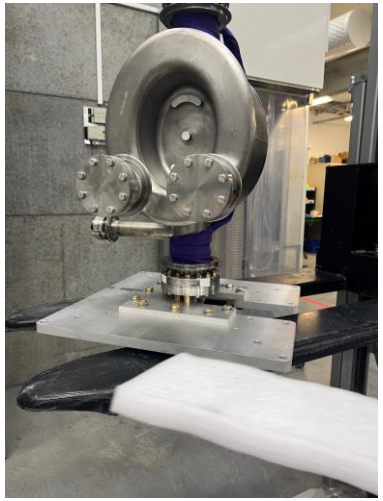


- Superconducting cavity testing for ESS and CERN
- Superconducting accelerating module testing for ESS
- R&D on superconducting magnets for CERN and others
- Testing of superconducting magnets for CERN and the Wigner institute for Physics (Hungary)
- R&D on radiofrequency amplifikation, combination and transfer for ESS, CERN, medical industry, and other
- Design and test of neutron instrumentation for ESS/STFC (UK)
- Design of X-ray beam line for MAX IV
- Vacuum breakdown characterization for future high-gradient accelerators
- Design of new accelerator facilities like the Ångström laser, a Swedish Free-Eelectron Laser, the Muon Collider project, CLIC and the ESS neutrino Super Beam.
- …
- Testing of superconducting accelerator equipment for the MINERVA accelerator (SCK CEN)

European consortia

UPPSALA UNIVERSITET

- HITRI+ and IFAST:
  - Testing of superconducting magnets for medical industry
  - Developing powering systems for medical accelerators.
- EURO-LABS
  - Network of 33 partners in 18 countries
  - To foster and share knowledge and competence
  - ”open lab” principle, transnational access to testing facilities

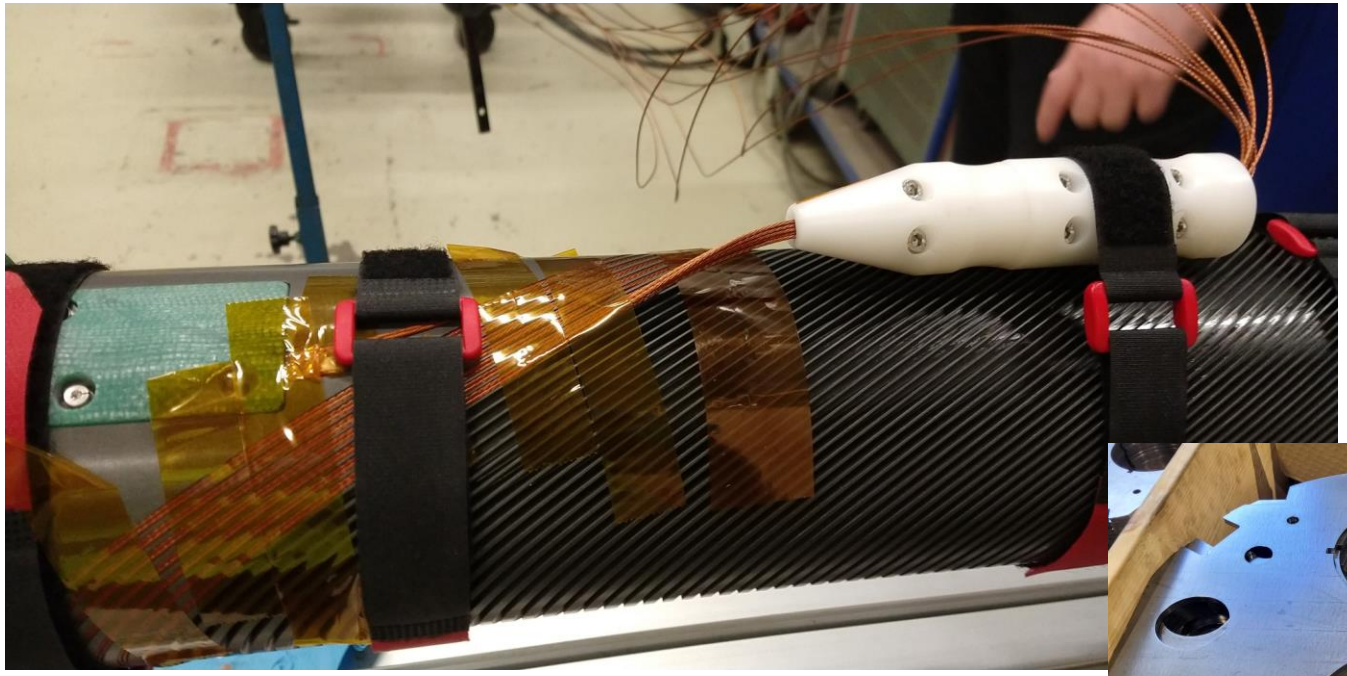


Crab cavity prototype for HL-LHC

➢Uppsala/FREIA has tested a prototype magnet that could serve for injection/extraction in the FCC.

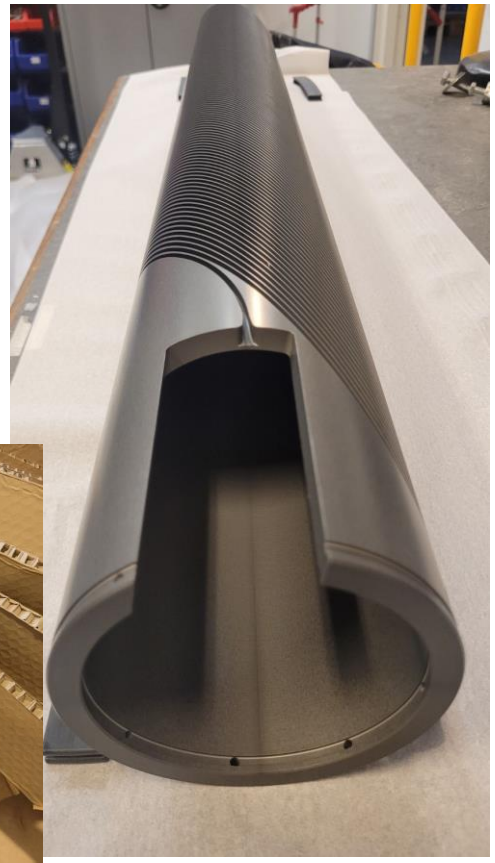
➢Uppsala/FREIA has tested a prototype crab cavity for HL-LHC

Developing superconducting magnets



SCANDITRONIX

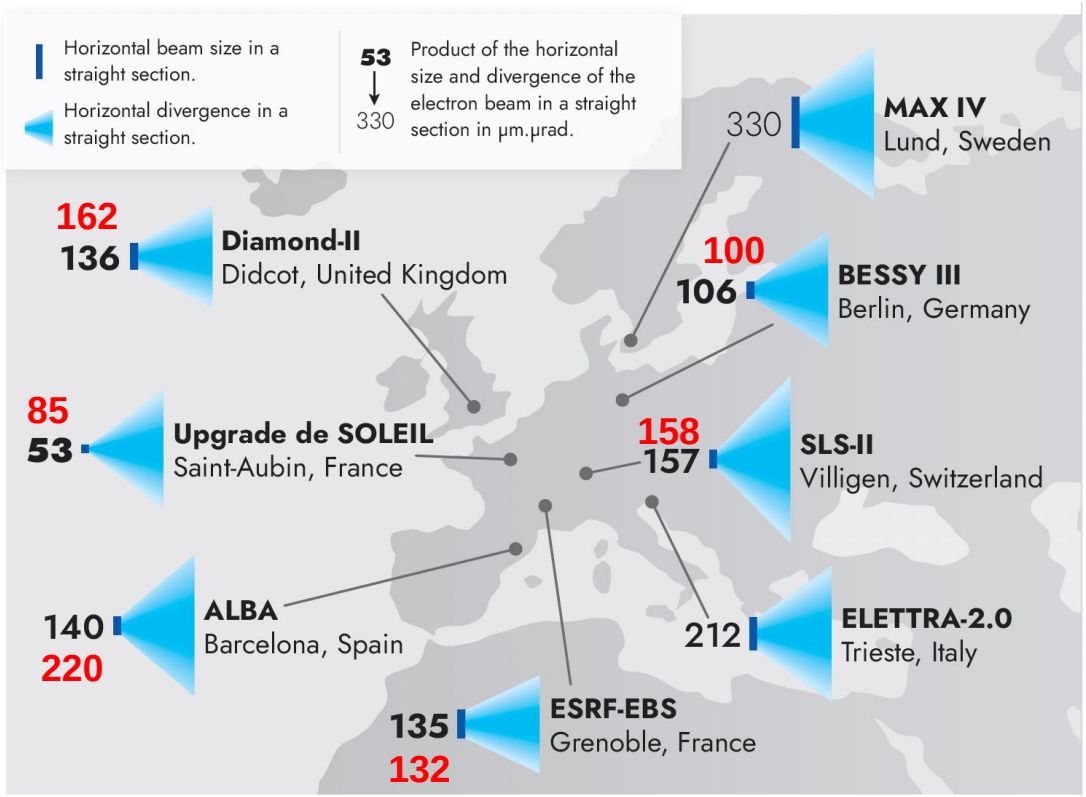
wst.se VATTENSKÄRNING



RYDVERKEN

Swedish Agency for Regional and Economic Growth, Region Kronoberg, Uppsala University

MAX 4U



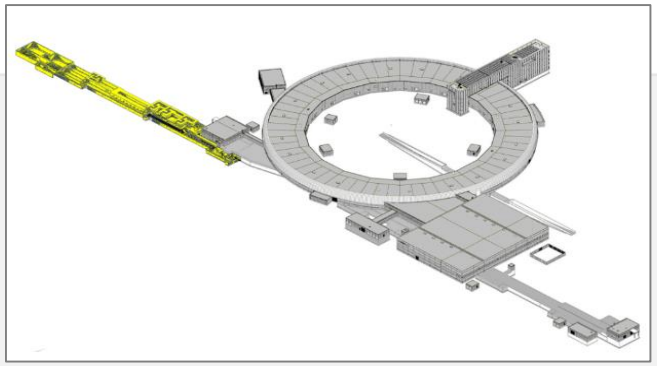
Adapted from the brochure : "A new soleil for the science of tomorrow"

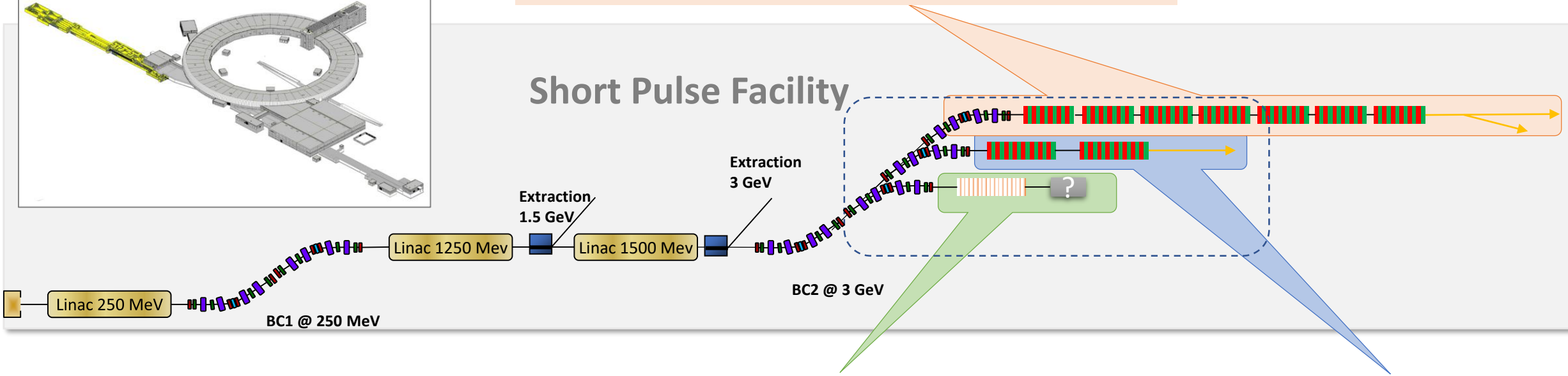
- MAX IV 3.0 GeV Ring – **the first 4th generation** light source worldwide, but the one with the **largest emittance** in Europe by the beginning of next decade.
- Goal
  - identify solutions to ensure the competitiveness of the beamlines
  - upgrade to an emittance $\lesssim$ 100 pmrad
- Upgrade packaged together with the beamlines that directly benefit from such performance boost.
- Cost on the "low side",
- A relatively short "dark" period (~ 1 year)
- CDR by end 2025, realizable by 2030.

Courtesy: Aymeric Robert

MAX IV Short Pulse Facility
R&D towards an FEL

The SXL – Soft X-ray Free Electron Laser (FEL)
3 GeV, 1-5 nm
Conceptual Design Report complete





Longitudinal phase space diagnostics
Port with option for PWFA

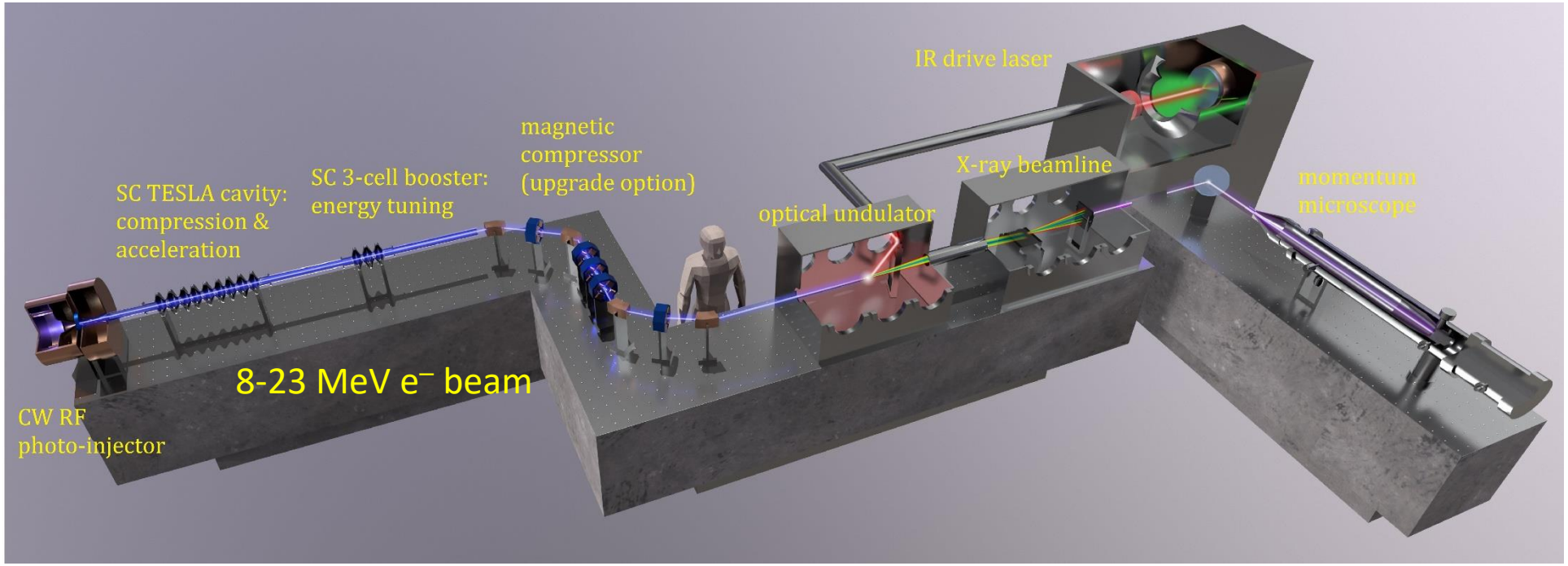
FemtoMAX, FEL test
1.7 GeV, 1-5 nm

Courtesy: Francesca Curbis & Sverker Werin

The Ångström Laser

UPPSALA UNIVERSITET

A medium-scale X-ray source based on a superconducting electron linac.
Stageable from inverse Compton source to small FEL concept.



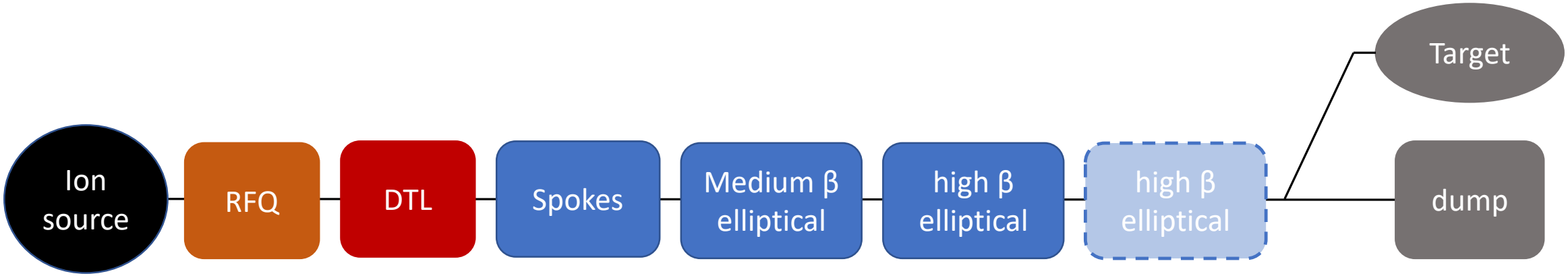
Conceptual Design Report published 2023: https://indico.uu.se/event/1405/

Courtesy: Vitaliy Goryashko

FEL development

- Attosecond pulse generation (UU, LU, DESY, **EuXFEL**) (V. Goryashko)
- Virtual diagnostics: Predicting longitudinal phase space using a Transverse deflecting cavity (J. Lundquist)
- Single-shot transverse coherence in seeded and unseeded free-electron lasers (LU, **Fermi@Elettra**)
- Beam loss and radiation monitoring (Stockholm university, **EuXFEL**)
- …

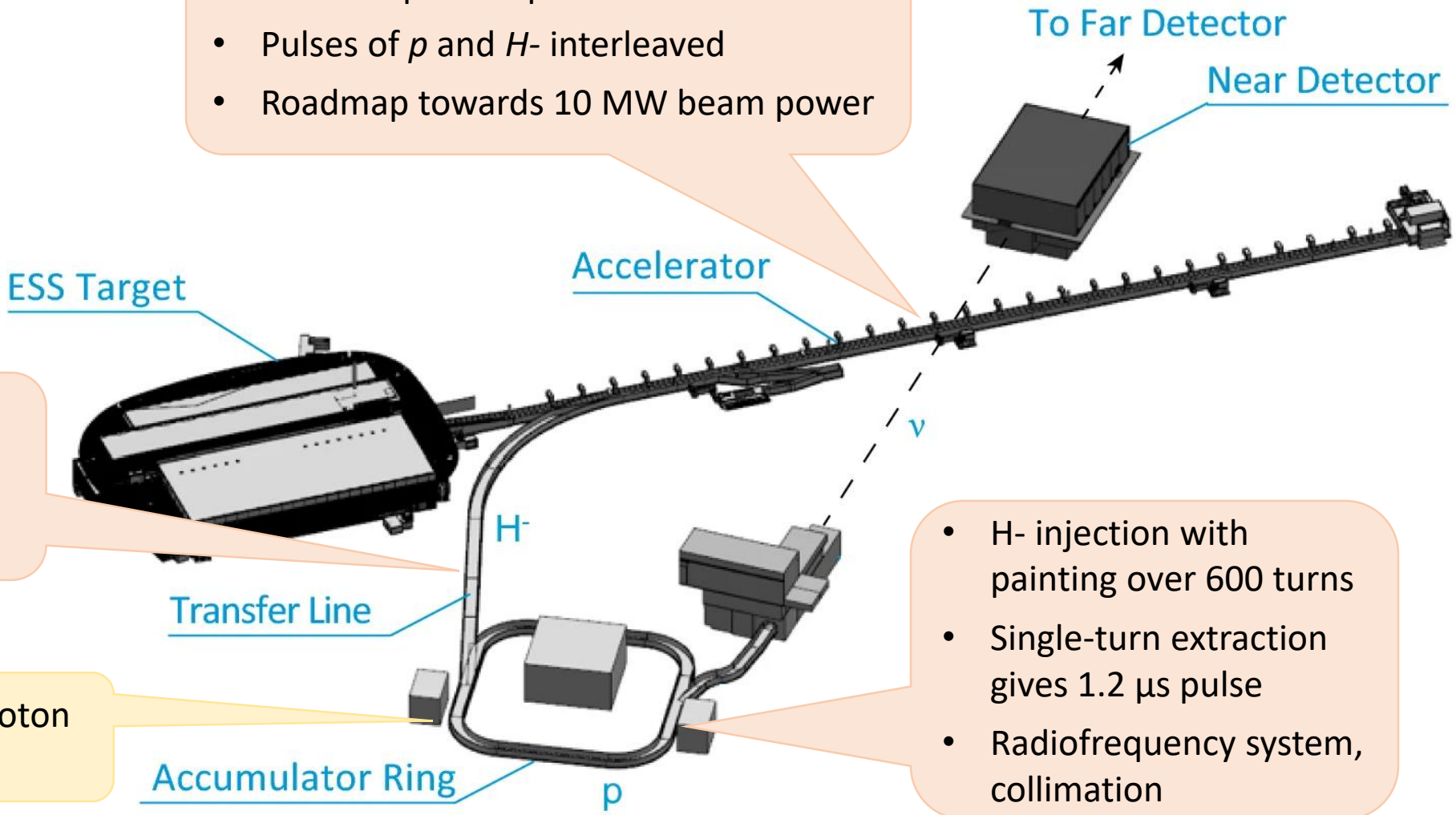
The ESS linac



ESSnuSB

UPPSALA UNIVERSITET

- Doubled pulse repetition rate
- Pulses of *p* and *H-* interleaved
- Roadmap towards 10 MW beam power



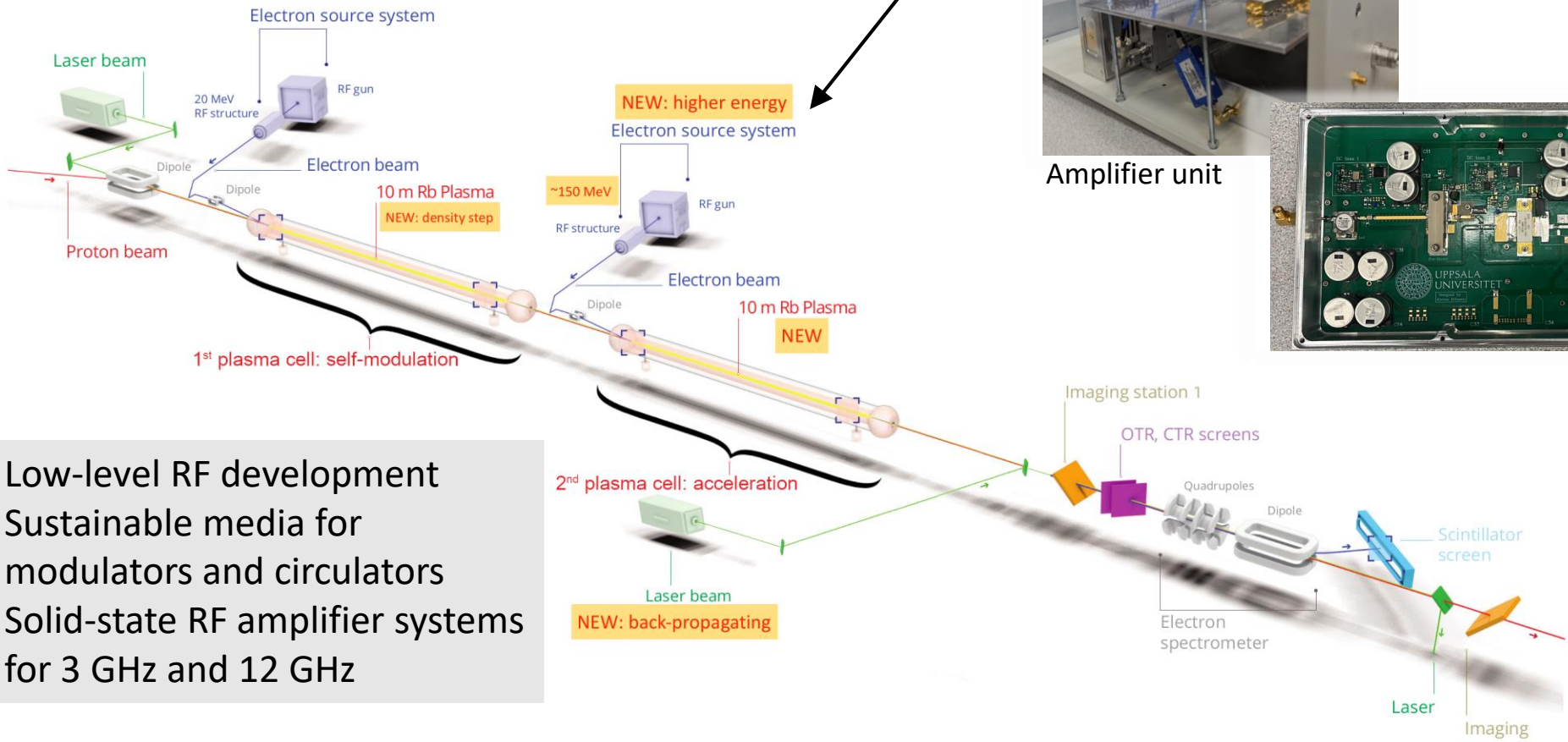
- Low-loss H- transfer
- H- stripping mechanisms studied thoroughly

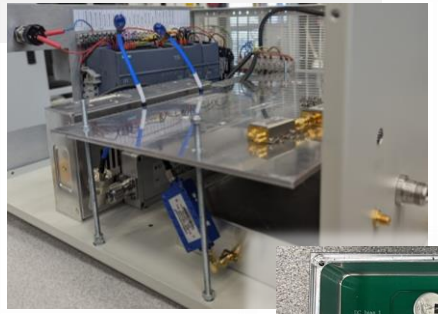
- H- injection with painting over 600 turns
- Single-turn extraction gives 1.2 µs pulse
- Radiofrequency system, collimation

- Medium-duration proton pulse for neutrons?

AWAKE

Uppsala develops and delivers RF systems for the two electron injectors for the AWAKE project (run 2).





Amplifier unit

3GHz solid-state amplifier

- Low-level RF development
- Sustainable media for modulators and circulators
- Solid-state RF amplifier systems for 3 GHz and 12 GHz

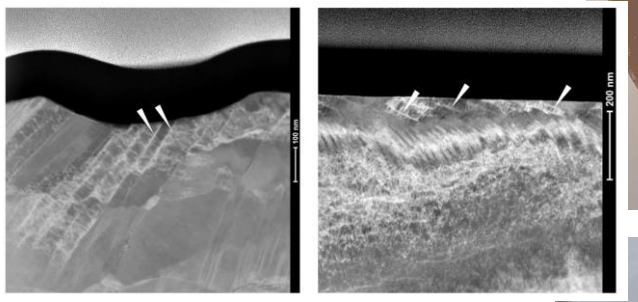
Courtesy: Kevin Pepitone

Swedish Research Council, grant for accessibility to infrastructure

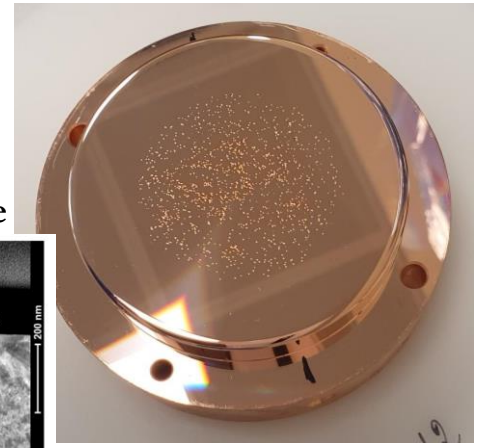
High gradient acceleration

- Cryogenic test-stand in Uppsala to study fundamental processes of high fields – materials dynamics
  - Vacuum breakdown effects in accelerating cavities
  - Field emission
  - Pulsed surface heating

- Applications:
  - CLIC - The Compact Linear Collider
  - CompactLight - compact free elctron laser
  - EuPRAXIA@SPARC - R&D on plasma acceleration
  - FLASH therapy - radiotherapy



Different plastic response in surfaces exposed to high electric fields at cold



Courtesy: Marek Jacewicz