UPPSALA UNIVERSITET

FREIA Laboratory

Facility for Research Instrumentation and Accelerator Development

Accelerator Development in Uppsala

Roger Ruber

J-PARC, 6 June 2019

UPPSALA UNIVERSITET

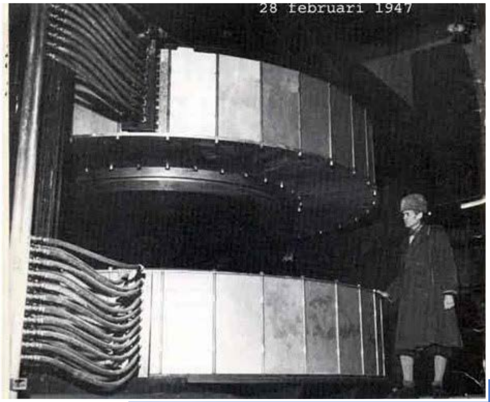
Uppsala Accelerator History

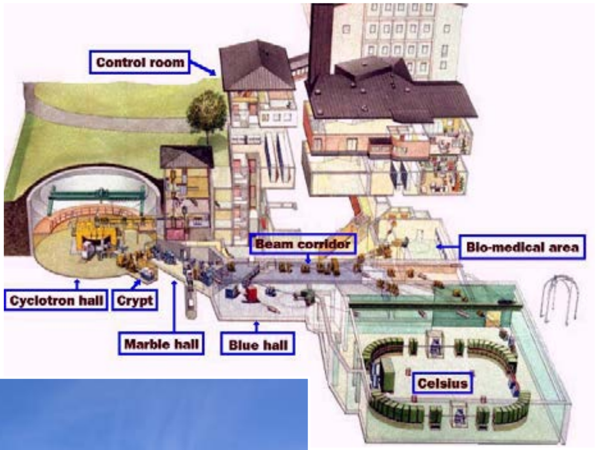
1477: Uppsala University, oldest in Scandinavia

- 25'000 students, 7'000 staff
- historical profiles: Linné, Rudbeck, Celsius, Ångström, Svedberg

1940's: The(odore) Svedberg builds a cyclotron

- Gustaf Werner synchro-cyclotron (1947 - 2016)
  - – nuclear physics & oncology
- CELSIUS ring (1984 - 2005)
  - – nuclear & particle physics





2000's: External projects

- CTF3/CLIC (since 2005)
- FLASH/XFEL (since 2006)
- ESS (since 2009)

2010's: New ventures

- FREIA laboratory (est. 2011)
- Skandion clinic (est. 2015)

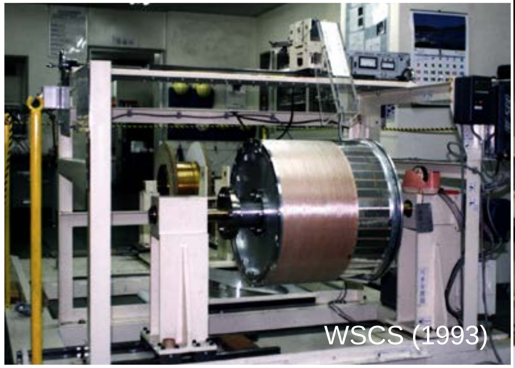
KEK & WASA Superconducting Solenoid

1991-2006 WASA Solenoid

- study rare π^0 and η decays at CELSIUS
  - using internal pellet target
- KEK contributes ultra-thin solenoid
  - 1992-1996 construction & test at KEK

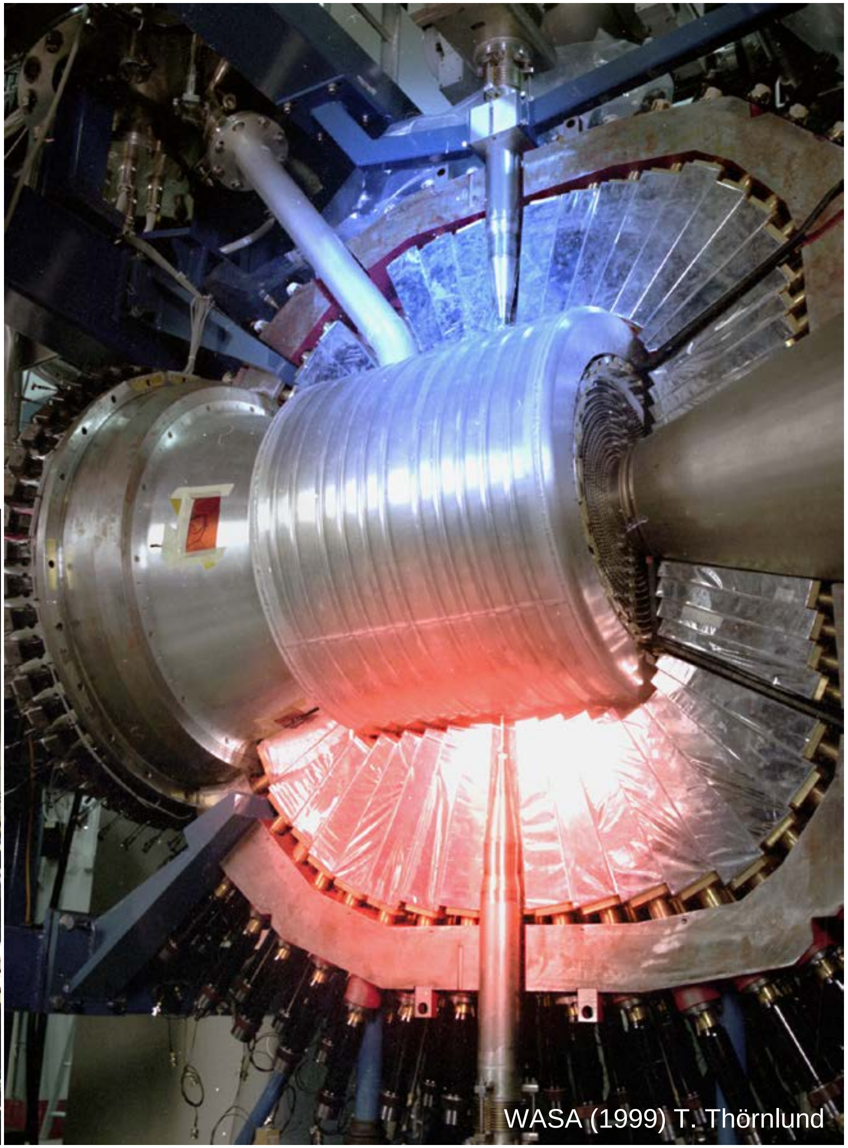
2006 move to Jülich (Germany)

2019 move to GSI/FAIR (Germany)



WSCS (1993)

WSCS (1994)



WASA (1999) T. Thörnlund

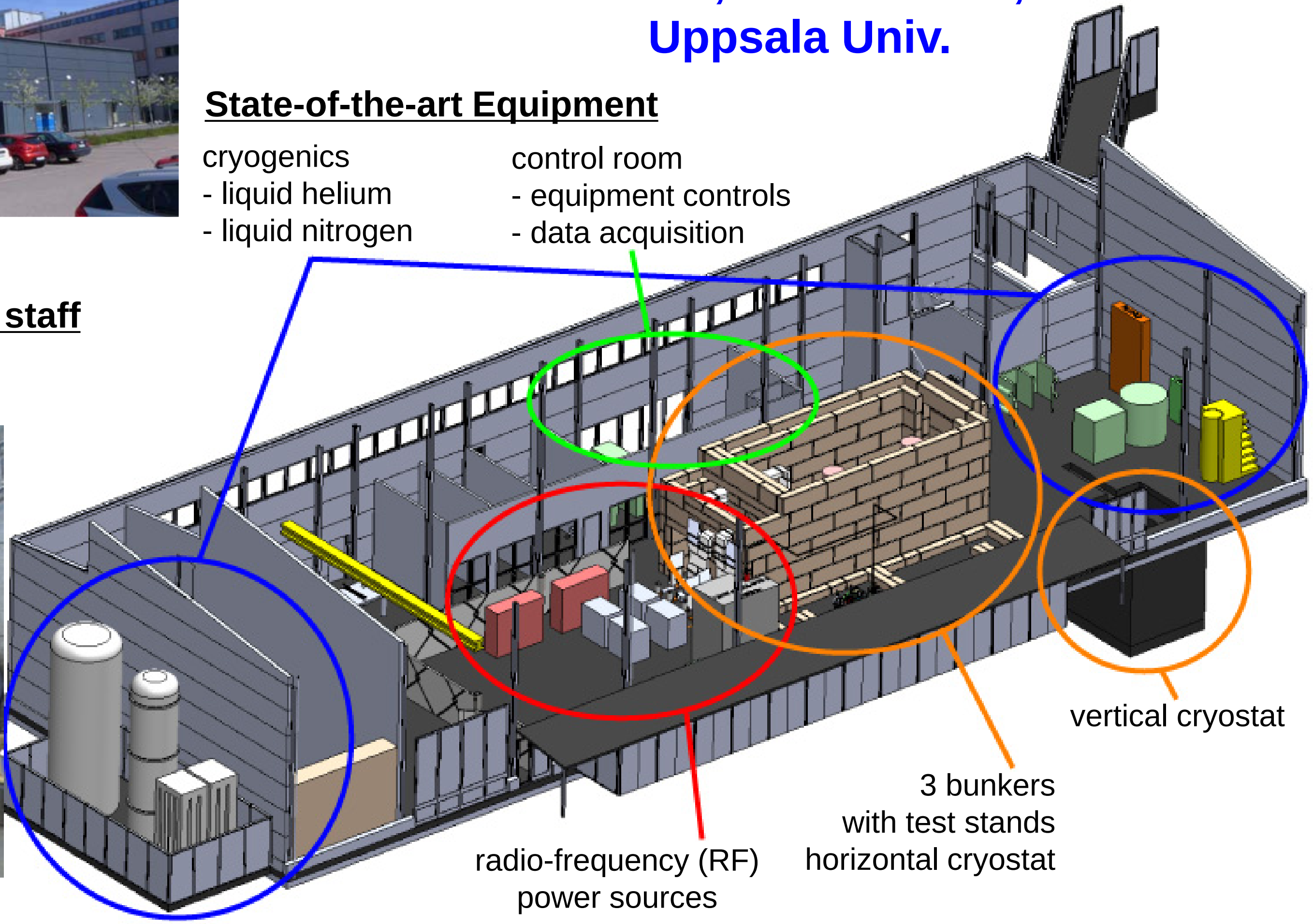
Facility for Research Instrumentation and Accelerator Development

Funded by
KAWS, Government,
Uppsala Univ.

State-of-the-art Equipment

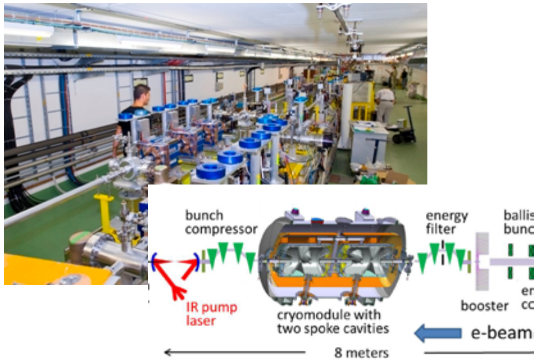
Competent and motivated staff

collaboration of physics (IFA)
and engineering (Teknikum).



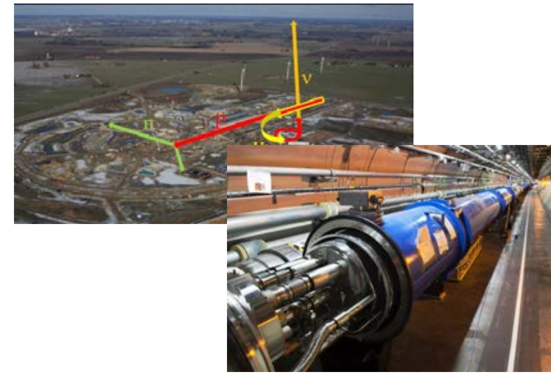
Accelerator Research & Development

Ultra Bright Electron Beams



Accelerator Physics

High Intensity Proton Beams



Cryogenics & Test Stands

SC Cavities & Magnets

RF Generation & Control

Accelerator Technology

Overview of Cryogenic Test Stands

CRYOGENIC TEST STANDS

“HNOSS” Horizontal Cryostat

HNOSS = Horizontal Nugget for Operation of Superconducting Systems

- Test of superconducting cavities/devices
  - 3240 x ø1200mm inner volume
  - up to two cavities simultaneously,
  - each equipped with helium tank,
- Low or High power RF testing
  - fundamental power coupler (top, bottom, side)
  - (cold) tuning system
- Operation in the range 1.8 to 4.5K.

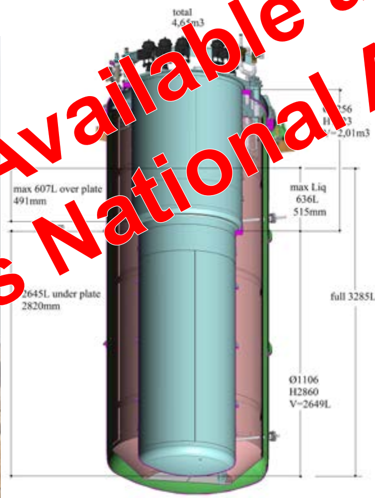
Available as ARIES Trans National Access Facility

"Gersemi" Vertical Cryostat

Under commissioning

- Test of SC cavities & magnets (<350kJ)
  - 3.2m x ø1.1m total volume
  - 2.65m x ø1.1m below lambda plate
    - design includes joint for lambda plate
- Three operation modes
  - vacuum; liquid bath; pressurized (bath with 2K heat exchanger)
- Operation in the range 1.8 to 4.5K

Available as ARIES Trans National Access Facility

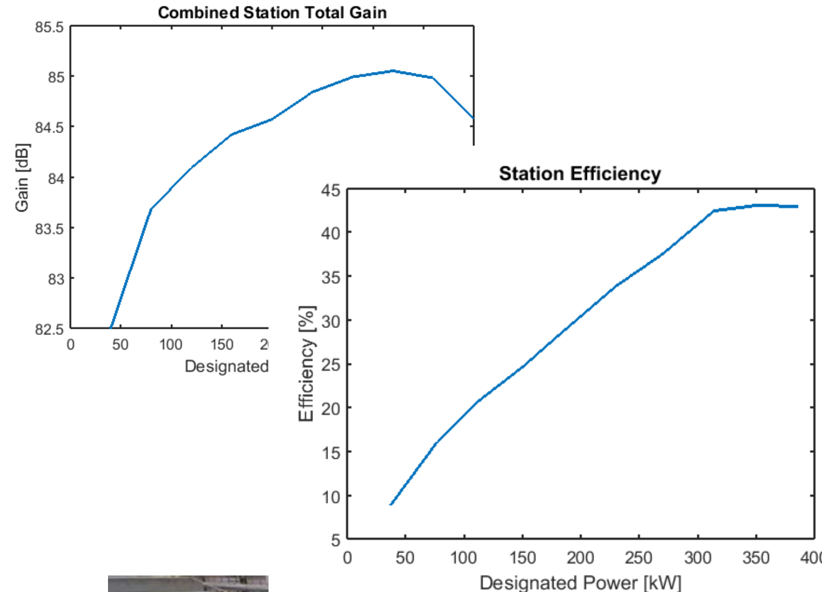


Development of High Power RF Technology

RF GENERATION & CONTROL

High Power RF Amplifiers



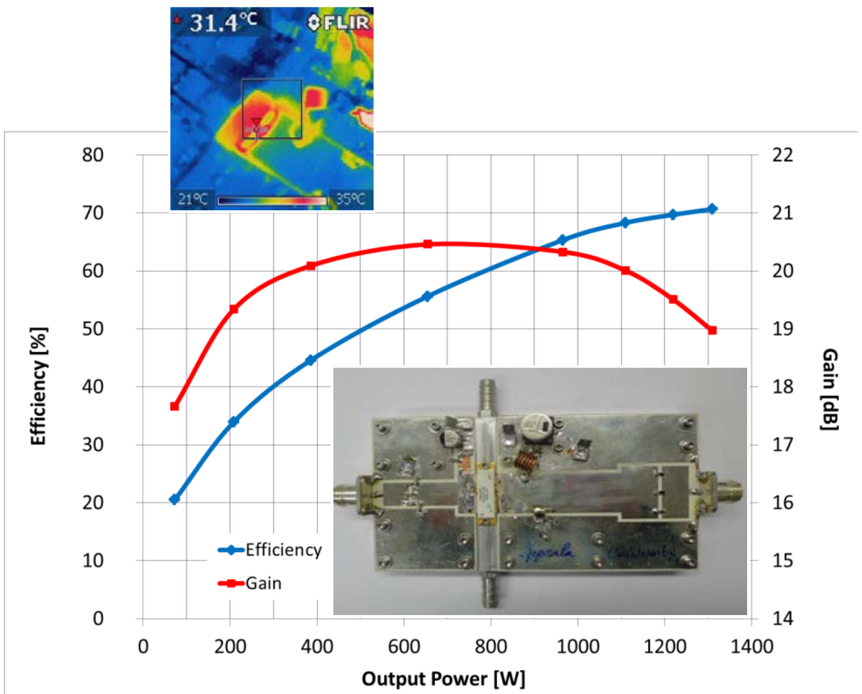



- **400 kW pulsed (352 MHz)**
  - 2 stations, each 2 tetrodes TH595(A)
  - 3.5 ms, 14-28 Hz
  - ESS prototype development
- **50 kW CW (352/400 MHz)**
  - single tetrode TH571b
- **1.2 MW pulsed (704 MHz)**
  - HV modulator & klystron test for ESS

Solid State RF Amplifier

Transistor Amplifier Module

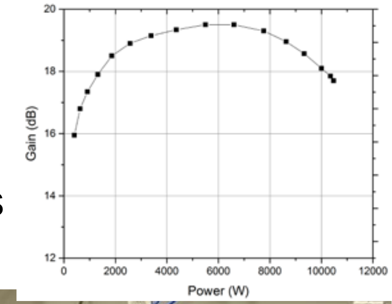
- single ended RF power amplifier
- based on BLF188XR
- 1250 W and 70% efficiency

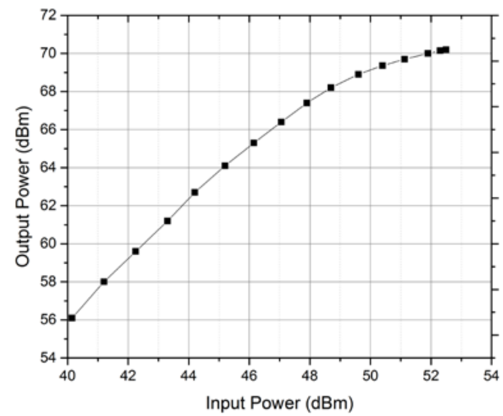


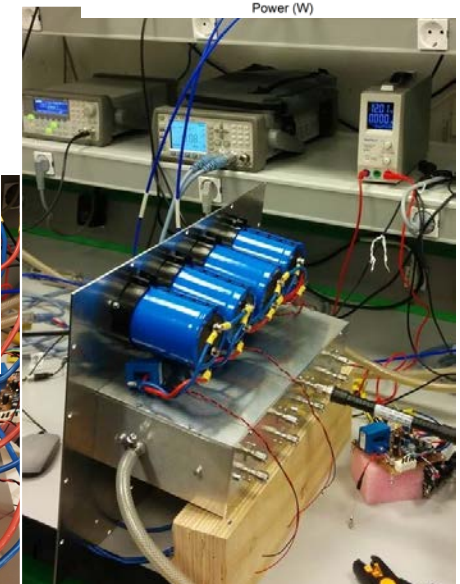
L. Haapala et al. Electronics Letters, vol. 52, (2016) p.1552.

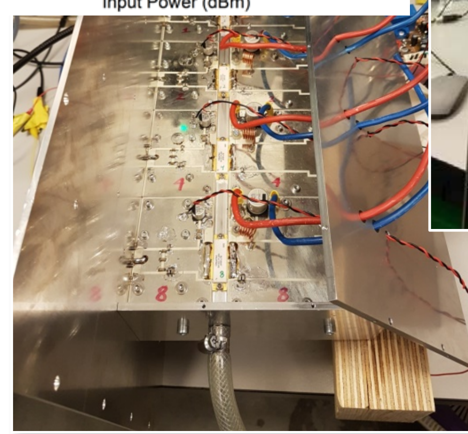
Amplifier Demonstrator

- 8 modules, 10.5 kW
- 69% efficiency
  - pulsed 14 Hz, 3.5 ms









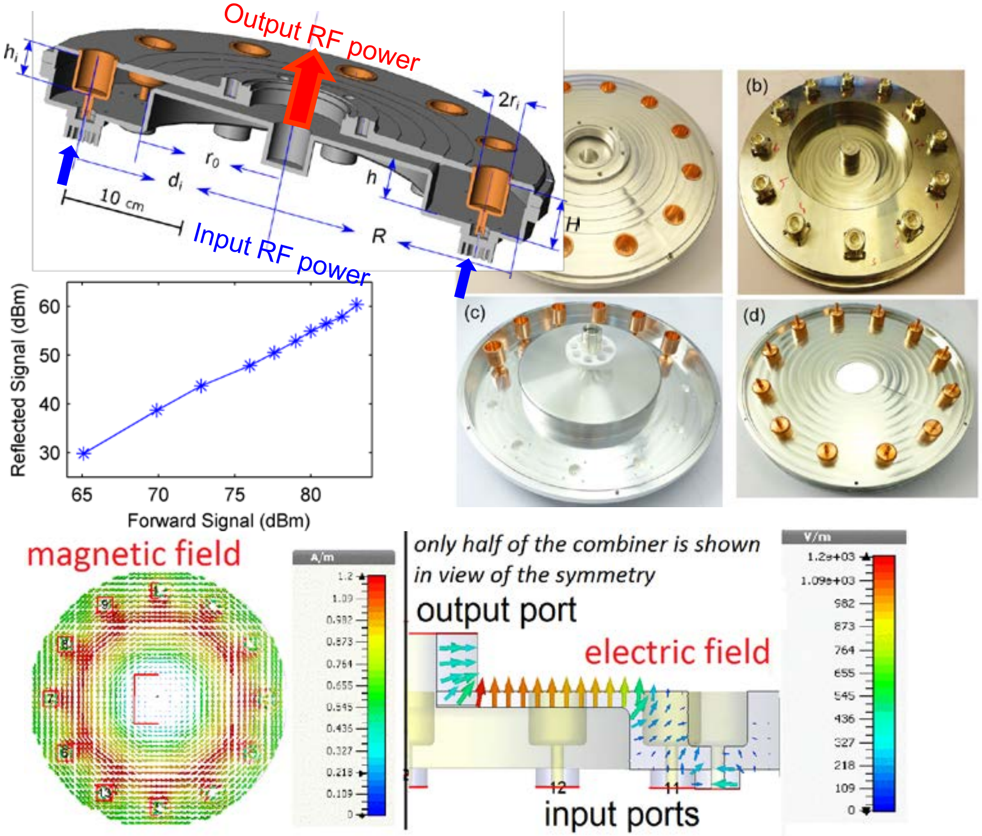
D. Dancila et al.
IOP Conf. Series,
J. Physics Conf. Series
vol. 874, 2017 (012093).

Low-loss Compact Combiners

Compact Cavity Combiner

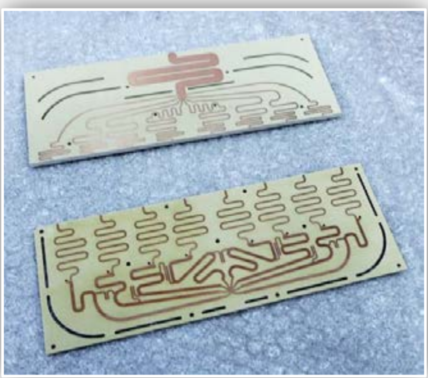
- 352 MHz 200 kW
  - 12 input ports
  - 0.2% insertion loss

V. A. Goryashko et al.
IEEE Microwave and wireless components Letts, vol. 28, 2018.



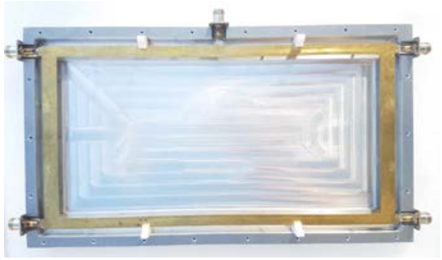
Compact Planar Combiner

- 352 MHz 10 kW
  - 8 input ports
  - Gysel type
  - line coupling compensates parasitic coupling



M. Jobs et al. IEEE Trans. Components, Packaging Manufacturing Tech., vol. 8, 2018.

- 352 MHz 20 kW
  - 2 to 1
    - 2 ext. loads
  - combiner/splitter
  - insert.loss 0.1 dB

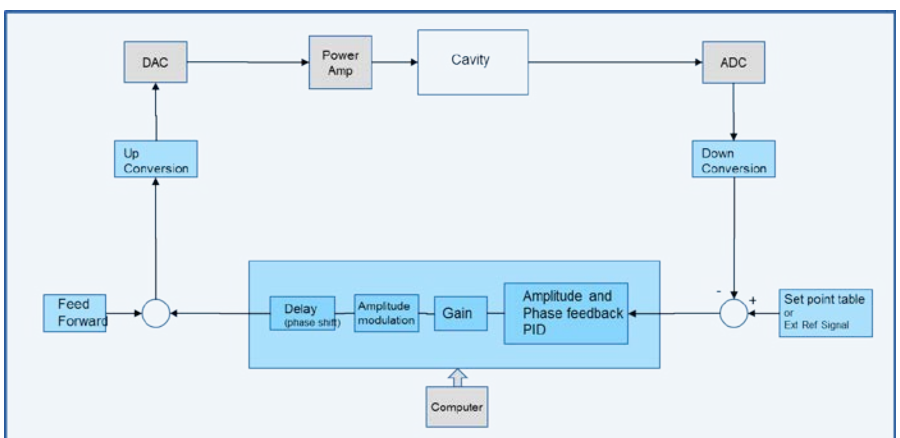


L. Hoang Duc et al. J. of Engineering, 2017.

FPGA Based Digital LLRF

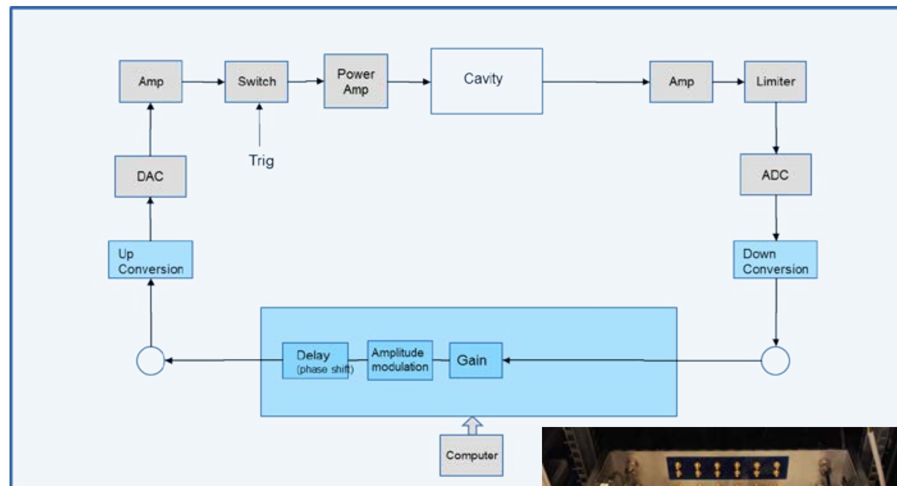
Signal Driven

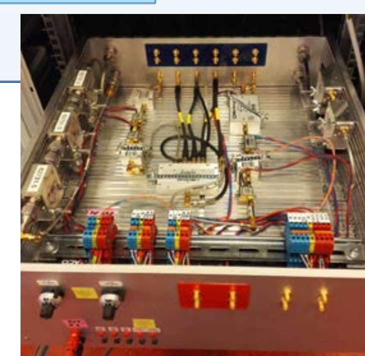
- 2 ADC inputs at 250 Msps
  - (*) analogue bandwidth of 750 MHz
- 2 DAC outputs at 500 Msps
- Digital downconversion to baseband 0 Hz, no analog mixers
  - downconverted signal at 10 Msps or 1 Msps, selectable
- undersampling to operate at any frequency from 10 to 750 MHz*



Self-excited Loop

- CW or
- pulsed mode
  - switch closes the loop for a duration of 2.86 ms, repetition rate of 14 Hz.





Code in the FPGA

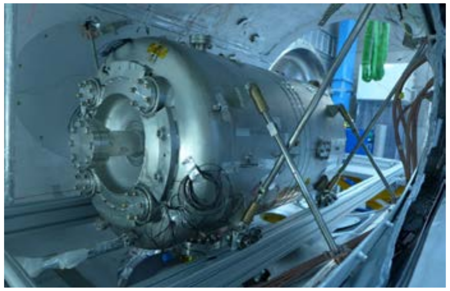
Development of SRF cavities for ESS

SUPERCONDUCTING CAVITIES

ESS Cavities & Cryomodules

Double Spoke Cavity, 352 MHz

- Prototype cavity
  - without and with FPC
  - RF conditioning
  - Q_0, gradient, fill time,
  - Lorentz force detuning, microphonics
  - test LLRF, SEL,
  - tuner operation
  - nominal gradient



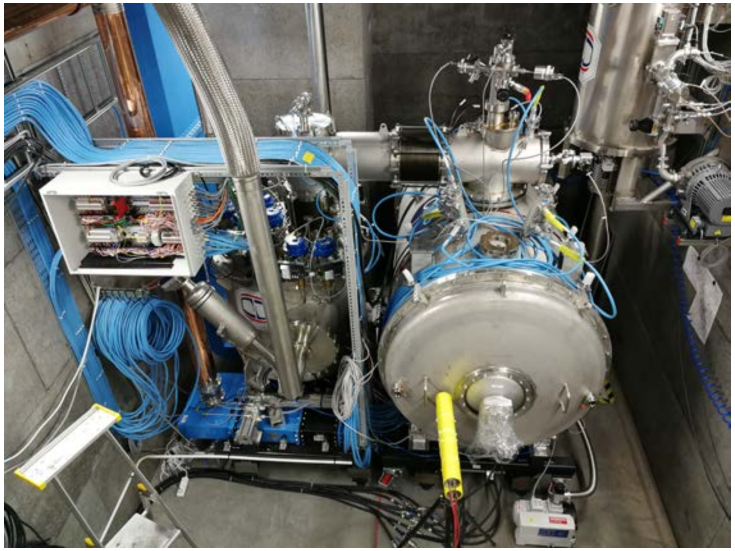
- Cryomodules
  - prototype valve box & cryomodule
  - 13 series cryomodules
    - Oct. 2019 – end 2020 (~6 weeks/CM)

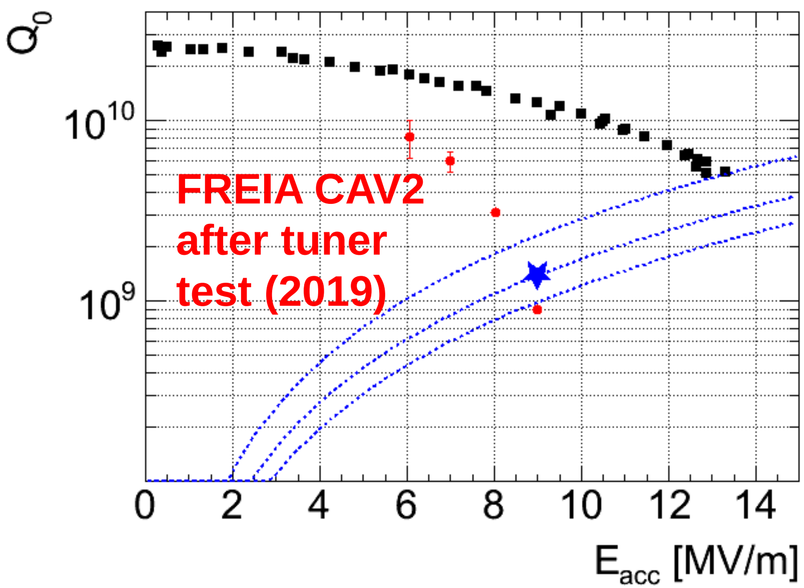
Elliptical Cavity, 704 MHz

- RF stations
  - acceptance test of HV modulator for ESS local test stand
  - test RF distribution (circulator, load)
- Prototype high beta elliptical
  - with power coupler and tuner
  - RF conditioning
  - Q_0, gradient, fill time, heat load
  - Lorentz force detuning, microphonics
  - test LLRF, SEL, tuner operation

Spoke Cryomodule Prototype (2019)

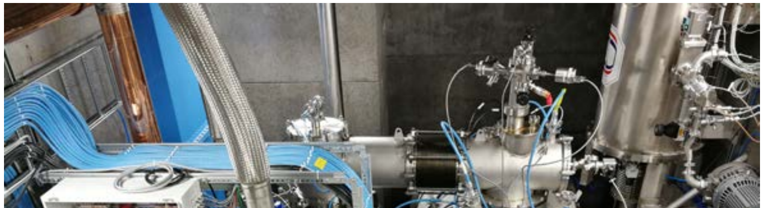
- Warm RF conditioning
  - ~3 days/cavity
  - MP bands were consistent with HNOSS test
    - strength depends on pulse length,
    - 1st/2nd conditioning…
- Cold RF conditioning
  - no coupler activity
  - Quench during cavity conditioning at 4 K
    - burst disc rupture → thermal cycling
- Cavity #2 performance
  - multipacting regions similar as prototype
    - 2-3; 4-5; 7-8 MV/m
  - field emission sensitive to tuner motion or position (under investigation)

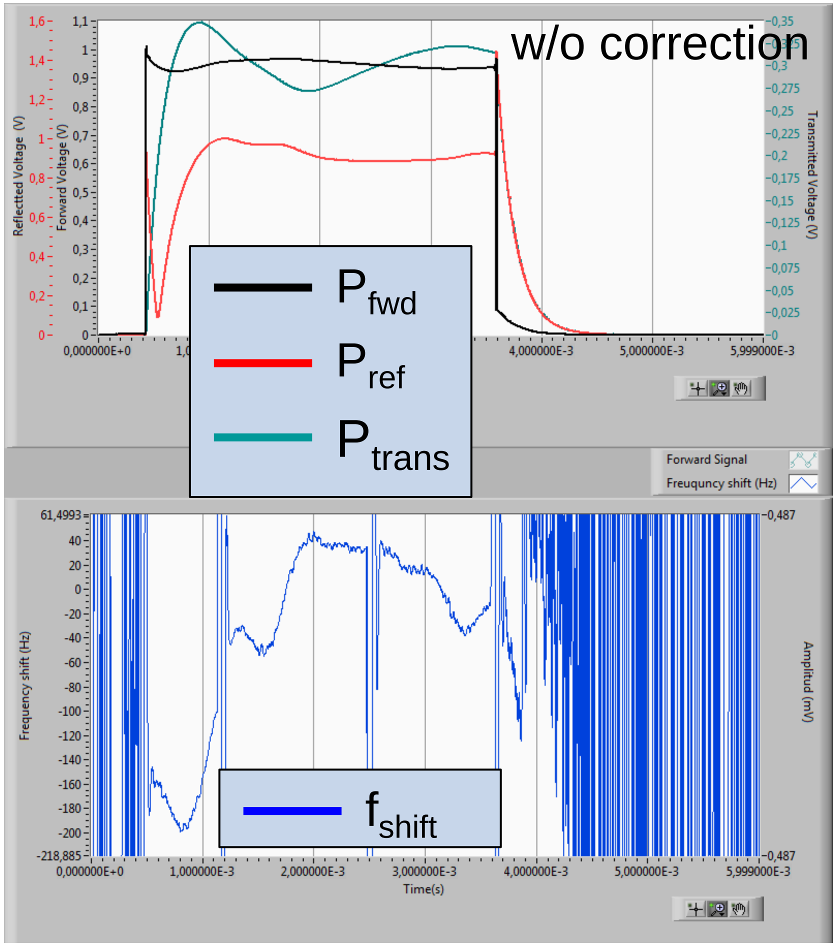


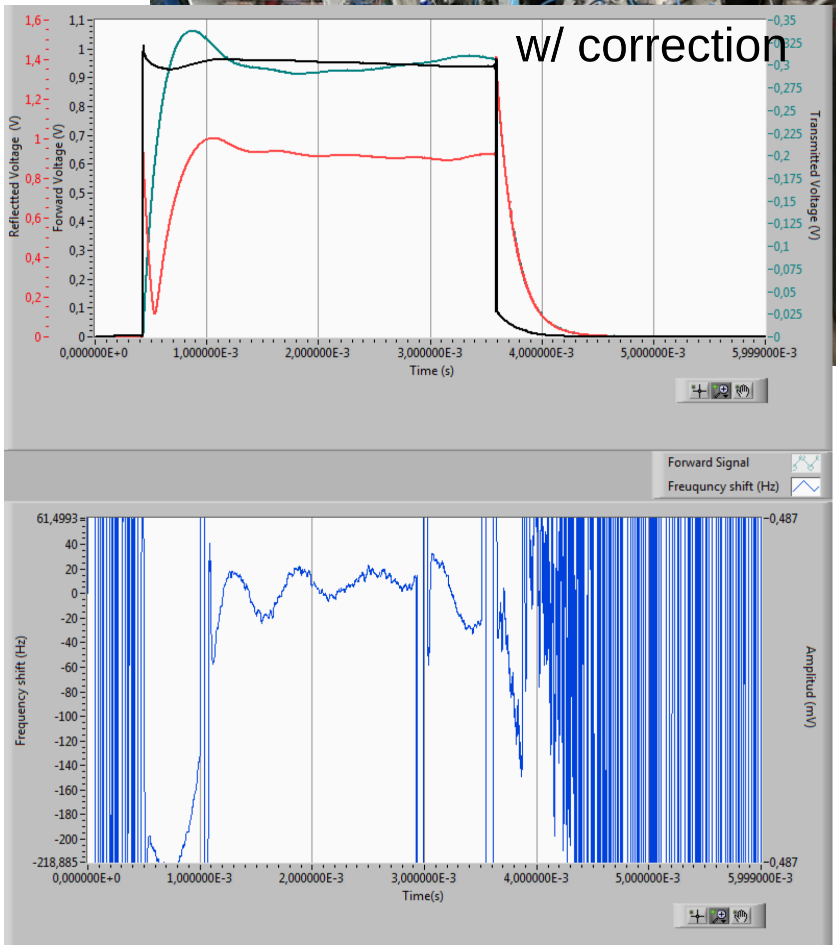


Spoke Cryomodule Prototype (2019)

- Fast tuner performance
  - Lorenz force detuning compensation (piezo)







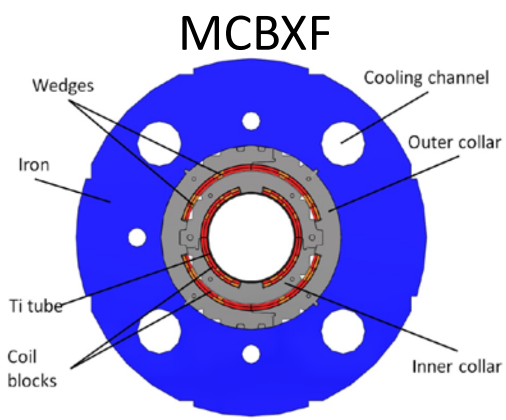
Test and Development of SC Magnets for CERN

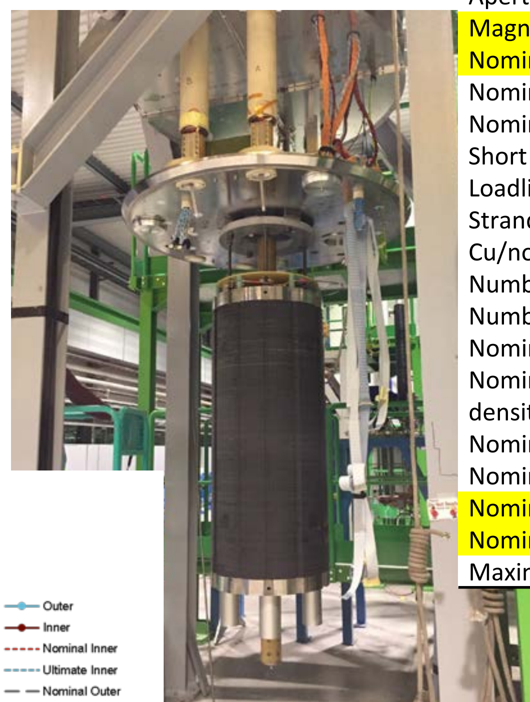
SUPERCONDUCTING MAGNETS

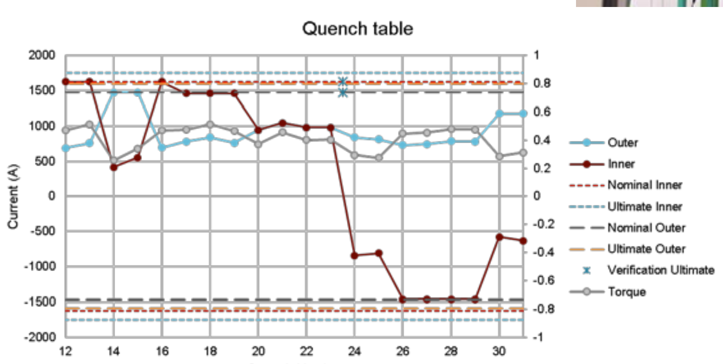
Orbit Correctors for HL-LHC

- Test of nested dipole orbit corrector magnets for the High Luminosity upgrade of LHC
  - magnet design and construction by CIEMAT (Spain)
  - test at FREIA (20 magnets)

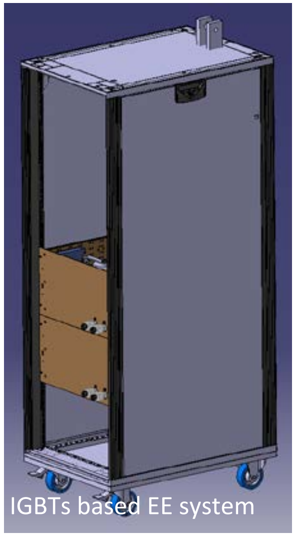
Parameter	Unit	Value
Aperture	mm	150
Magnetic length	m	1.2
Nominal integrated field	T m	2.5
Nominal current inner	A	1625
Nominal current outer	A	1474
Short sample current at 1.9 K	A	
Loadline fraction at 1.9 K		
Strand diameter	mm	0.480
Cu/no_Cu		1.75
Number of turns per layer inner		140
Number of turns per layer outer		191
Nominal strand current density	A/mm²	
Nominal superconductor current density	A/mm²	
Nominal differential inductance inner	mH	58.4
Nominal differential inductance outer	mH	118.8
Nominal stored energy inner	kJ	87
Nominal stored energy outer	kJ	150
Maximum hotspot temp	K	270

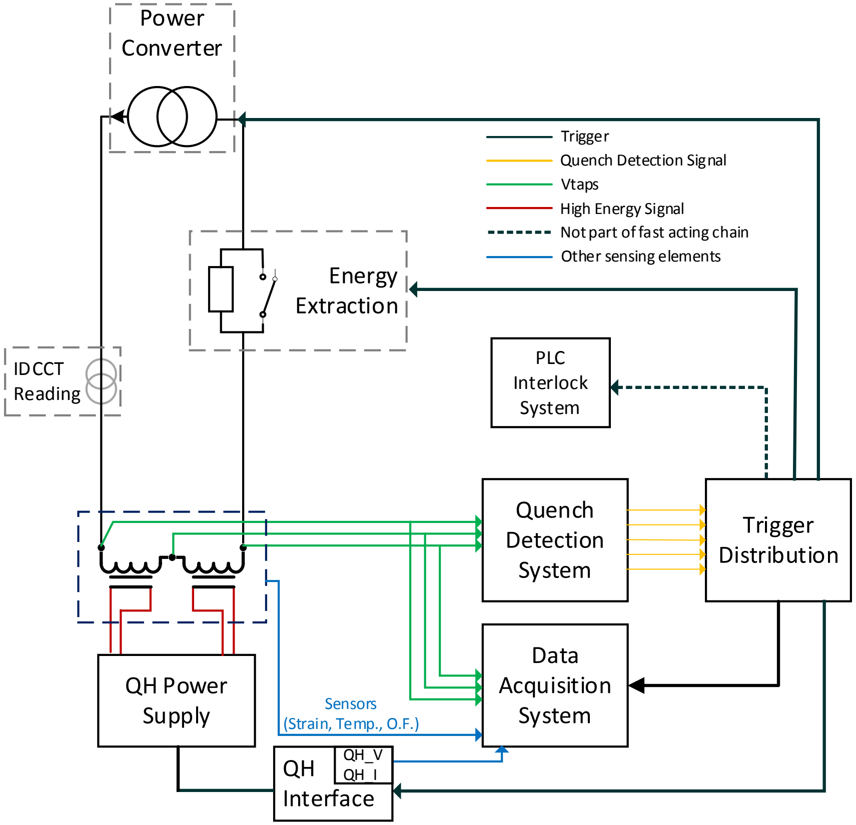


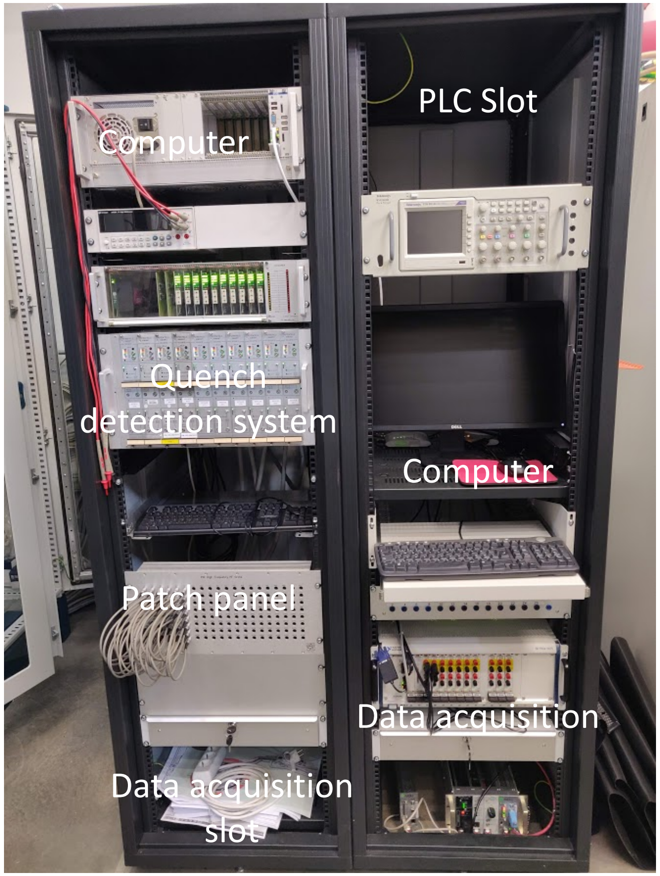




Magnet Powering & Quench Monitoring

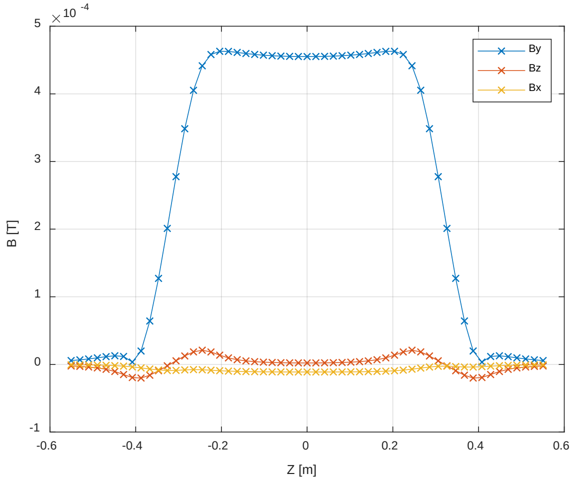


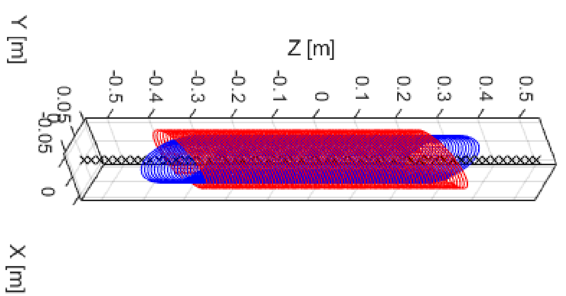


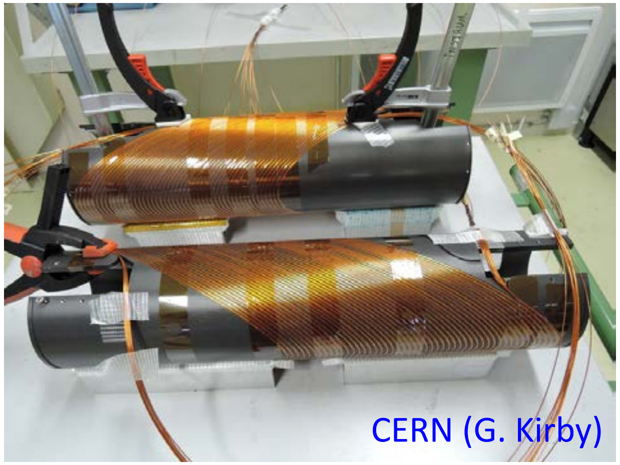


CCT Magnet Development

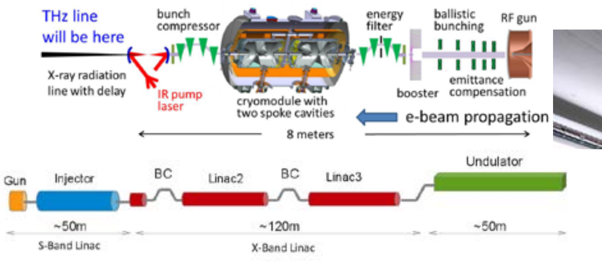
- Canted-Cosine-Theta magnet is a dipole based on the superposition of two oppositely skewed solenoids with respect to the bore axis.
  - produces a perfect cosθ field,
  - is cost effective compared to a conventional SC dipole
    - but not the same field strength possibilities





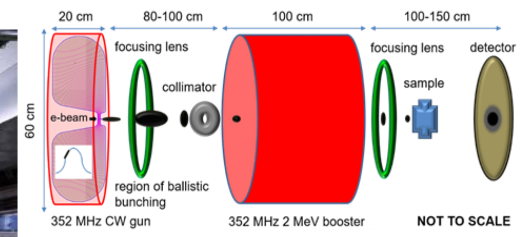


FELs



CLIC

Ultrafast Electron Diffraction

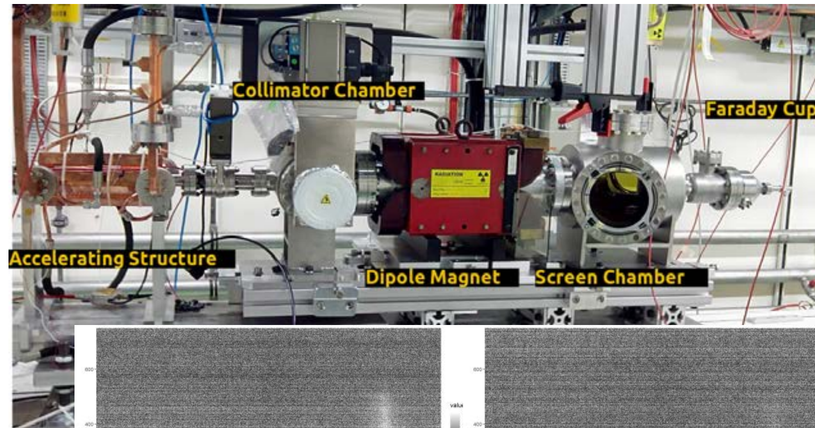


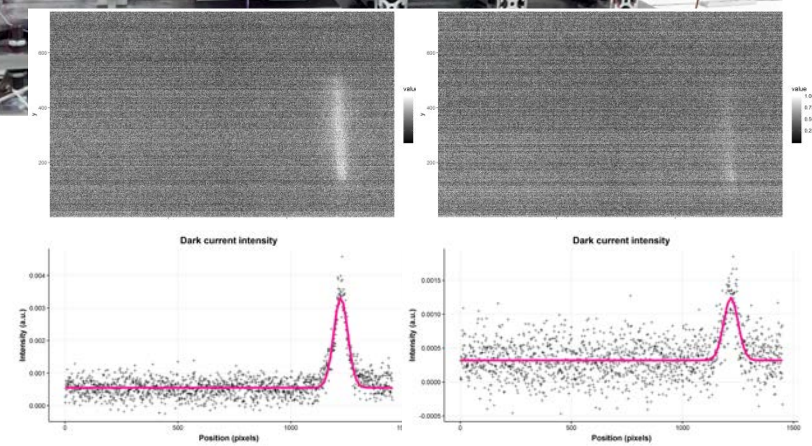
CLIC, Free Electron Lasers, Ultra-fast Electron Diffraction

HIGH BRILLIANCE ELECTRON BEAMS

RF Breakdown Studies

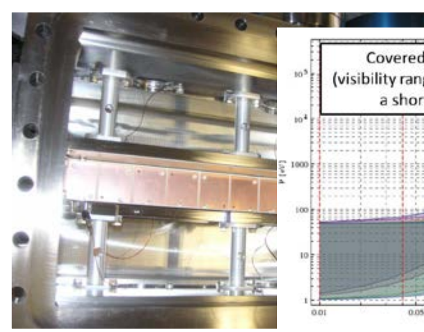
- Models for RF conditioning process
  - why the achievable gradient increases?
  - why an ultimate limit in conditioning?
  - strong dependence on temperature
    - not many data available
  - agree within range of available data
    - but diverge significantly outside that range
  - include temperature-dependent terms,
    - can be distinguished by dedicated experiments
- **Dark currents**
  - No indication of single emitting spot inside cavity
  - Broad energy spectrum
- **Breakdown events**
  - Good correlation with BD position (from RF)
  - Electrons with well defined energies
  - Discovered H2+ in "Flashbox" at TBTS

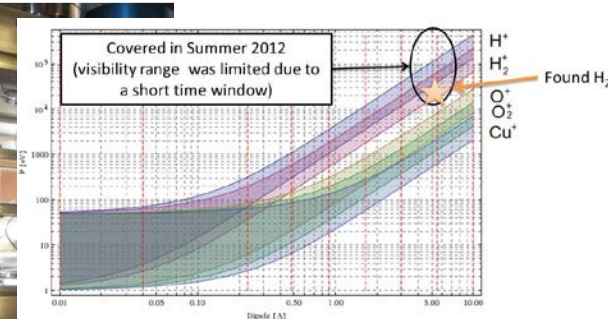




42 MW @ 50ns

34 MW @ 50ns

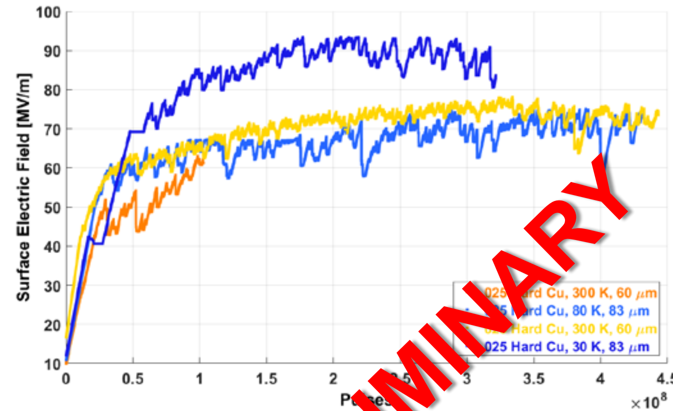


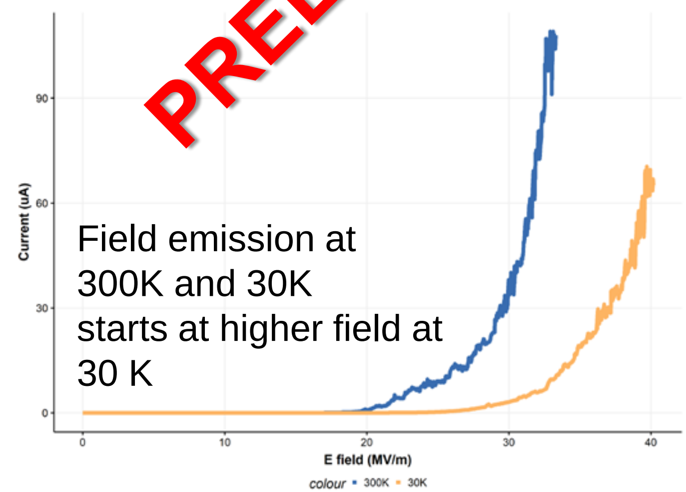


Cryogenic DC Spark System

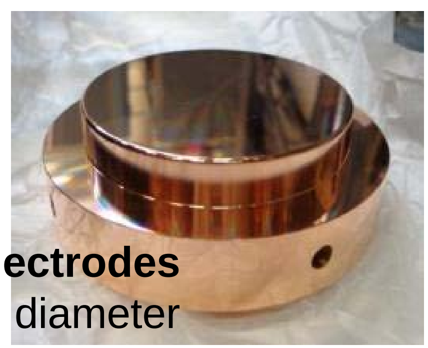
- Field emission and BDR as a function of temperature
- Complement to RF tests
  - very high repetition rate, pulsed DC
  - simple geometry (large planar electrodes)
  - similar high-field behavior in RF and pulsed DC
  - allows in depth studies of the fundamental physics of high-fields (e.g. material and surface science)
  - possibility to find new and potentially important connections between the high-gradient NC and SC fields.

Electrodes at 30K reached almost 20% higher field gradient than at 300 K.





Field emission at 300K and 30K starts at higher field at 30 K

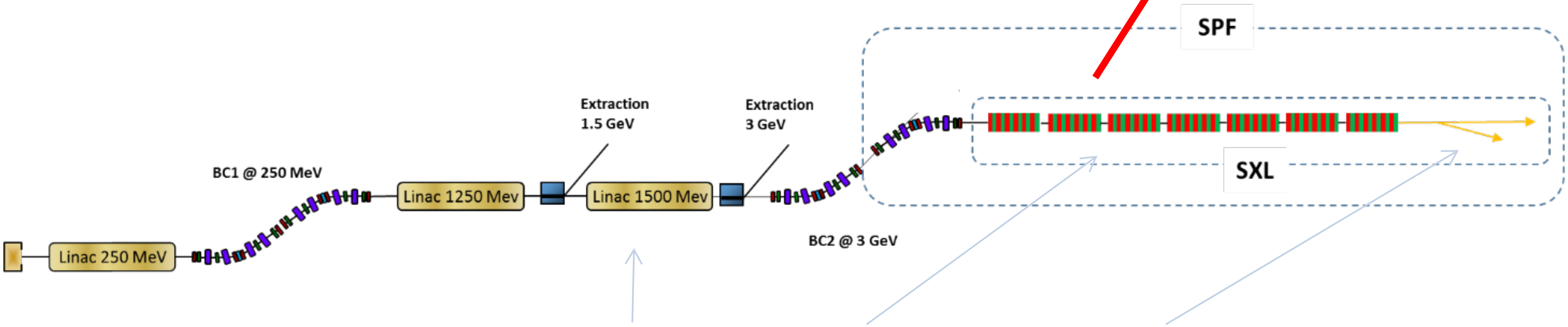


OFE-Cu electrodes
50 mm diameter
60 µm gap

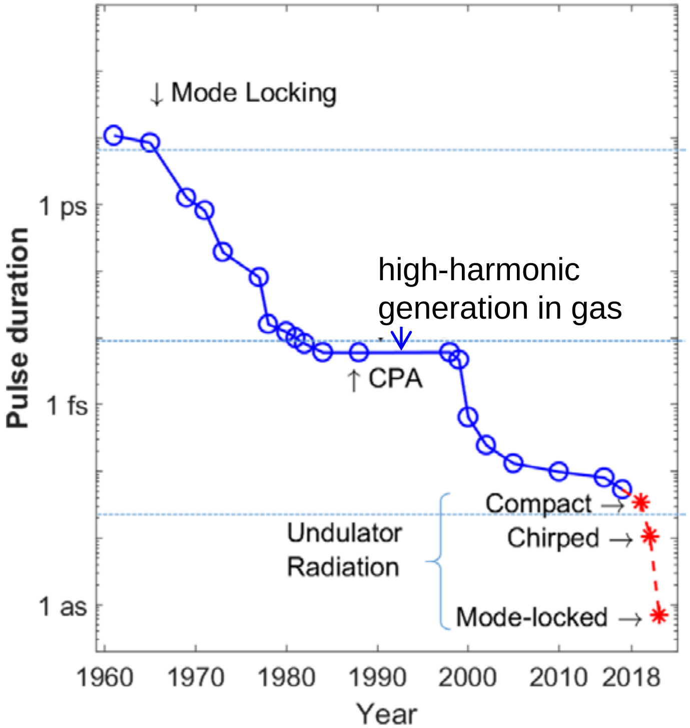
Soft X-ray Laser (SXL) at MAX IV

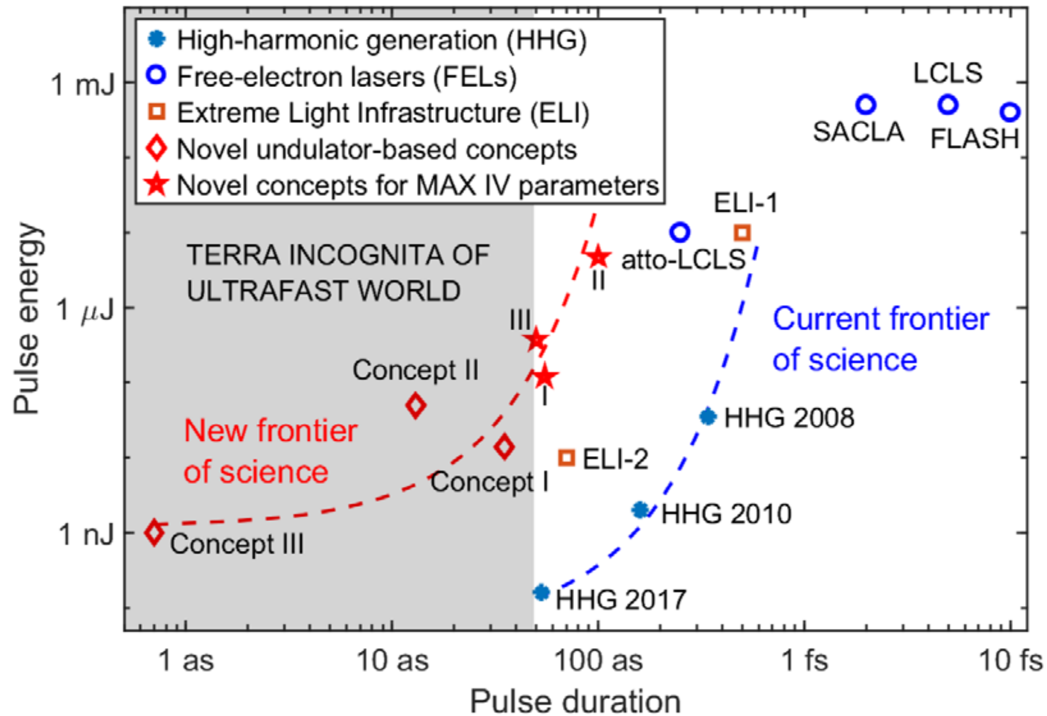
- Collaboration: Uppsala, Stockholm, Lund University, KTH & MAX IV
  - funding from Wallenberg foundation and universities
- Uppsala is involved in
  - accelerator (microbunching instability),
  - FEL (short-pulse generation),
  - optical beamline design.

A. Mak et al "Compact FEL at MAX IV"
J. Synchrotron Rad. (2019) 26.



Attosecond Pulse Generation





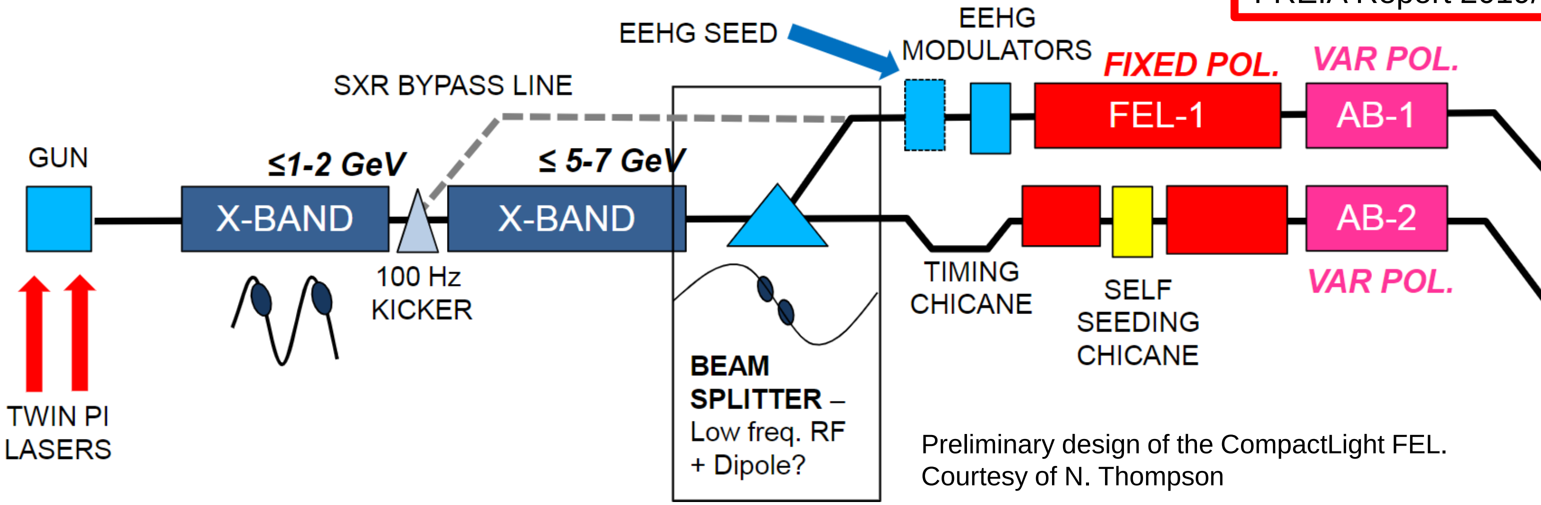
- High-Harmonic Generation (HHG) sources are facing saturation
- Undulator light source is a promising way to the attosecond region
- Application submitted to the EU/H2020 program
  - 12 partners from Germany, Hungary, Italy, UK. Ukraine, Sweden and Japan
- Read more in: A. Mak et al 2019 Rep. Prog. Phys. 82 025901

CompactLight

EU funded project to design the next generation compact FEL

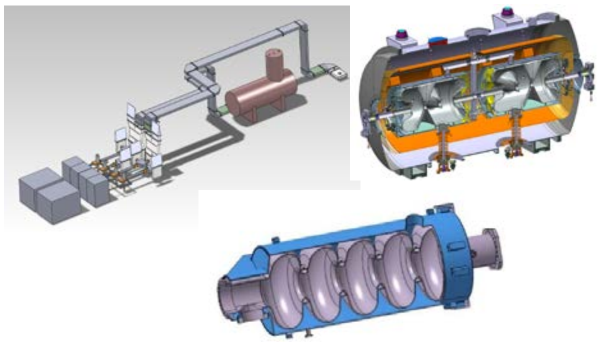
- Consideration of costs and space: reduce linac length
  - opening the way to affordable “Regional Facilities”
- Uppsala:
  - communication with users, specify science requirements
  - definition of FEL system & accelerator/undulator requirements
  - design of the soft X-ray FEL and potentially the beamline
  - breakdown studies in accelerating structures

A. Mak et al “Science Requirements and Performance Specification for the CompactLight”, FREIA Report 2019/01.

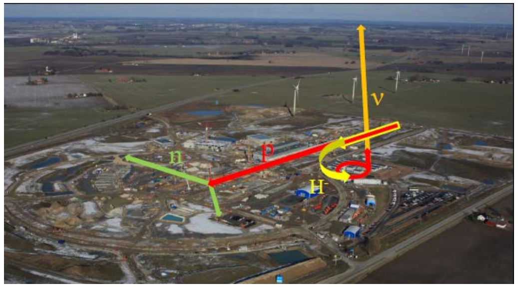


Preliminary design of the CompactLight FEL.
Courtesy of N. Thompson

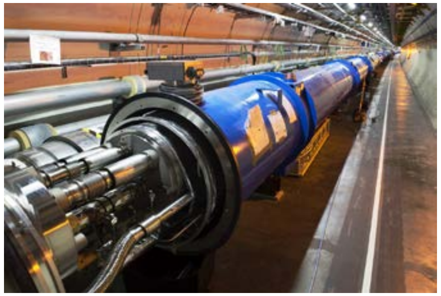
ESS Superconducting Linac



ESS Neutrino Super Beam



HiLumi LHC

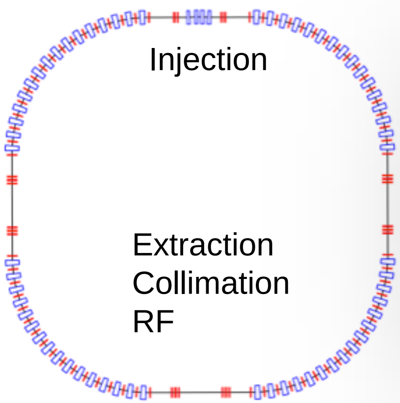


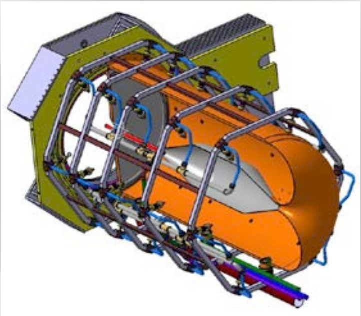
European Spallation Source (ESS) and
High Luminosity LHC (CERN)

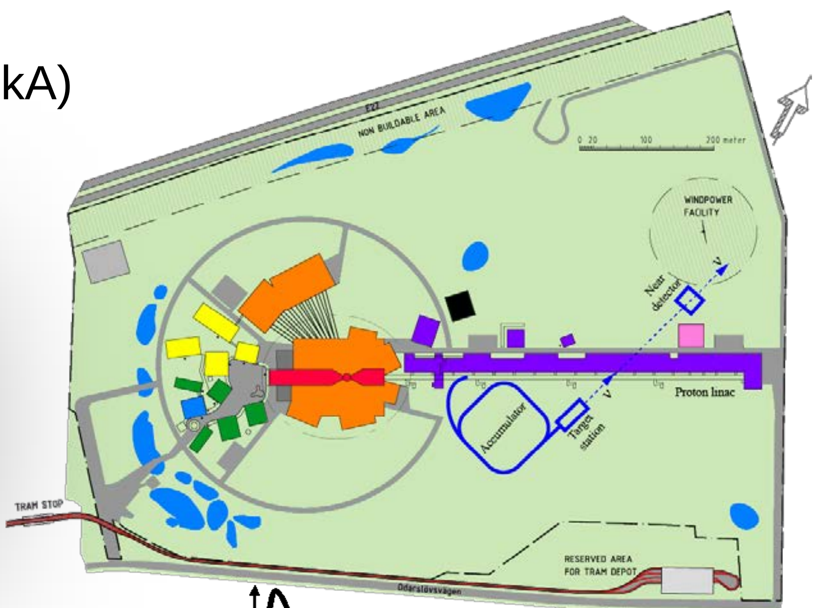
HIGH BRILLIANCE PROTON BEAMS

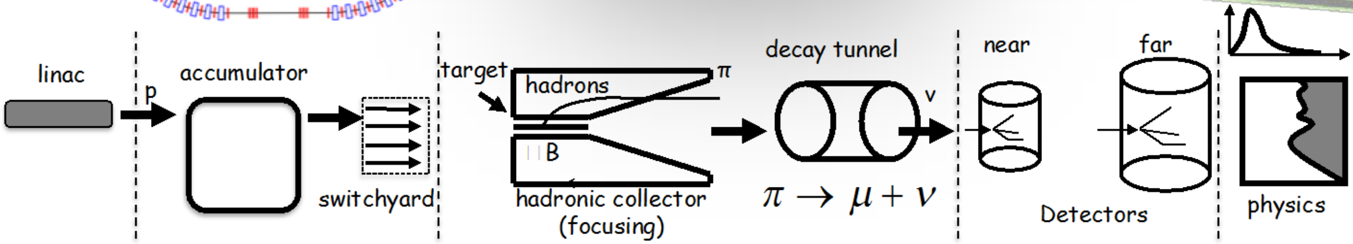
ESS Neutrino Super Beam (ESSnuSB)

- Doubling the ESS beam power for a second target
  - linac duty cycle doubling to 8 % (RF sources, cooling)
    - using new H^- source
  - accumulator ring (~400 m circ.) compress 2.86 ms beam pulse to few µs
    - multi-turn injection, stripping $H^- \rightarrow H^+$
  - 2nd target station with magnetic horn (350 kA)
    - to deliver ~300 MeV neutrinos





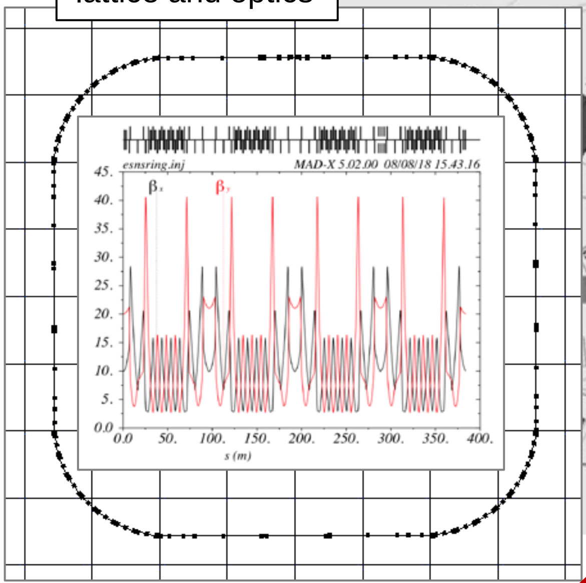


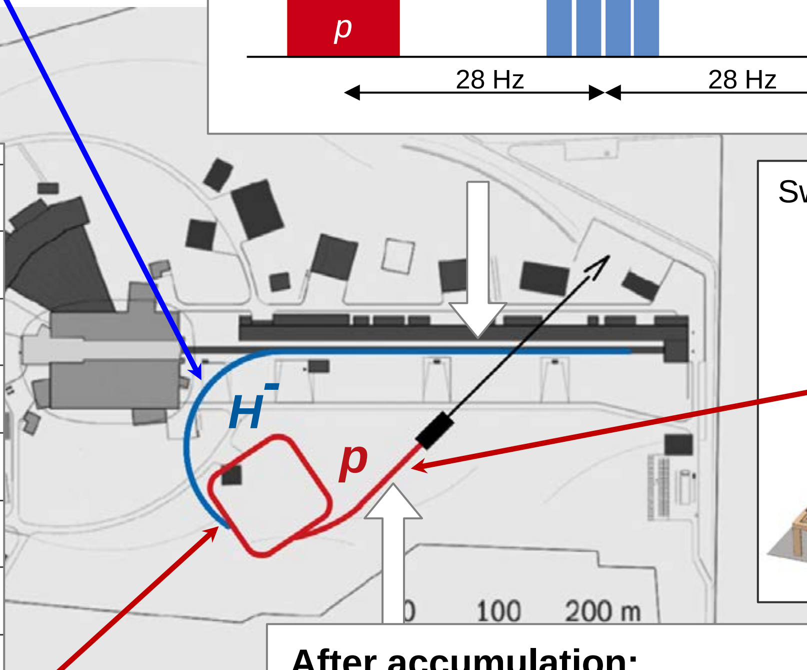


ESSnuSB Accumulator Ring

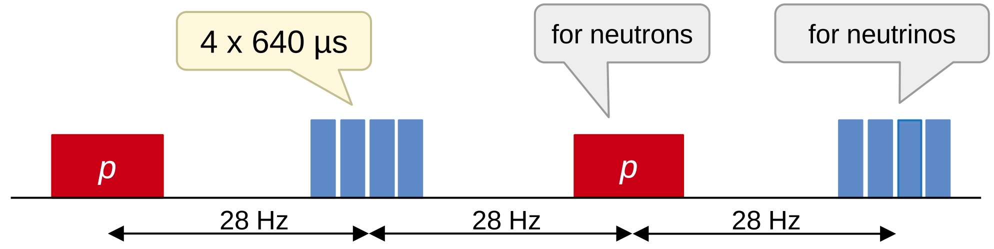
Losses due to Lorentz stripping < 0.1 W/m ⇒
Maximum magnetic field in transfer line 0.15 T

Accumulator ring
lattice and optics

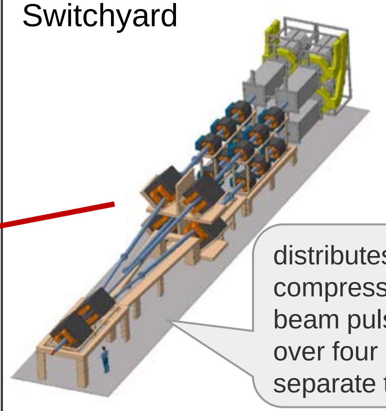




Incoming beam from the linac:

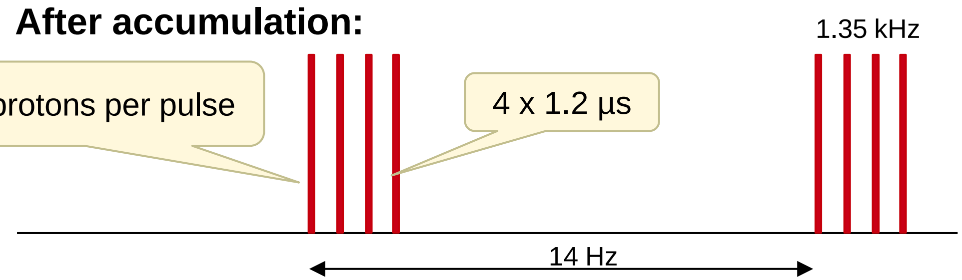


Switchyard



distributes the compressed beam pulses over four separate targets

After accumulation:



384 m circumference
481 injected turns
H^- stripping at injection

UPPSALA UNIVERSITET

Summary

Uppsala University & FREIA Laboratory actively developing accelerator and instrumentation technology

Technology Development

- NC and SC RF cavities
- SC magnets
- RF power generation
- LLRF and controls

Physics Research

- high brilliance beams
- superconducting RF
- RF breakdown

Academic Teaching