UPPSALA UNIVERSITET

FREIA

FREIA Laboratory

Facility for Research Instrumentation and Accelerator Development

Accelerator Development in Uppsala

Roger Ruber

Uppsala, 11 June 2019

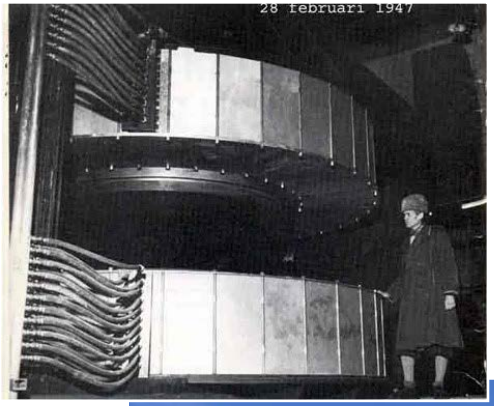
Uppsala Accelerator History

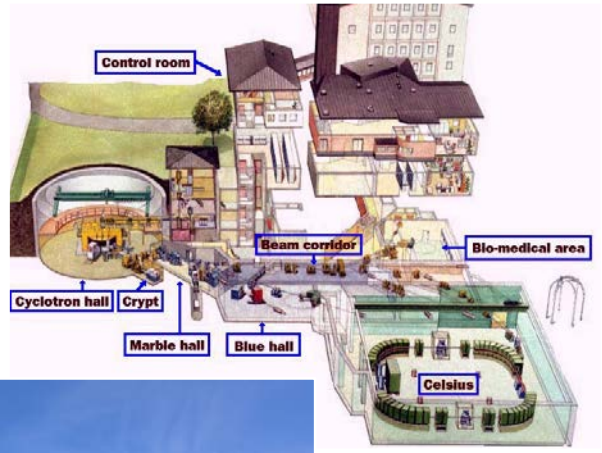
1477: Uppsala University, oldest in Scandinavia

- 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)

FREIA Laboratory

Facility for Research Instrumentation and Accelerator Development

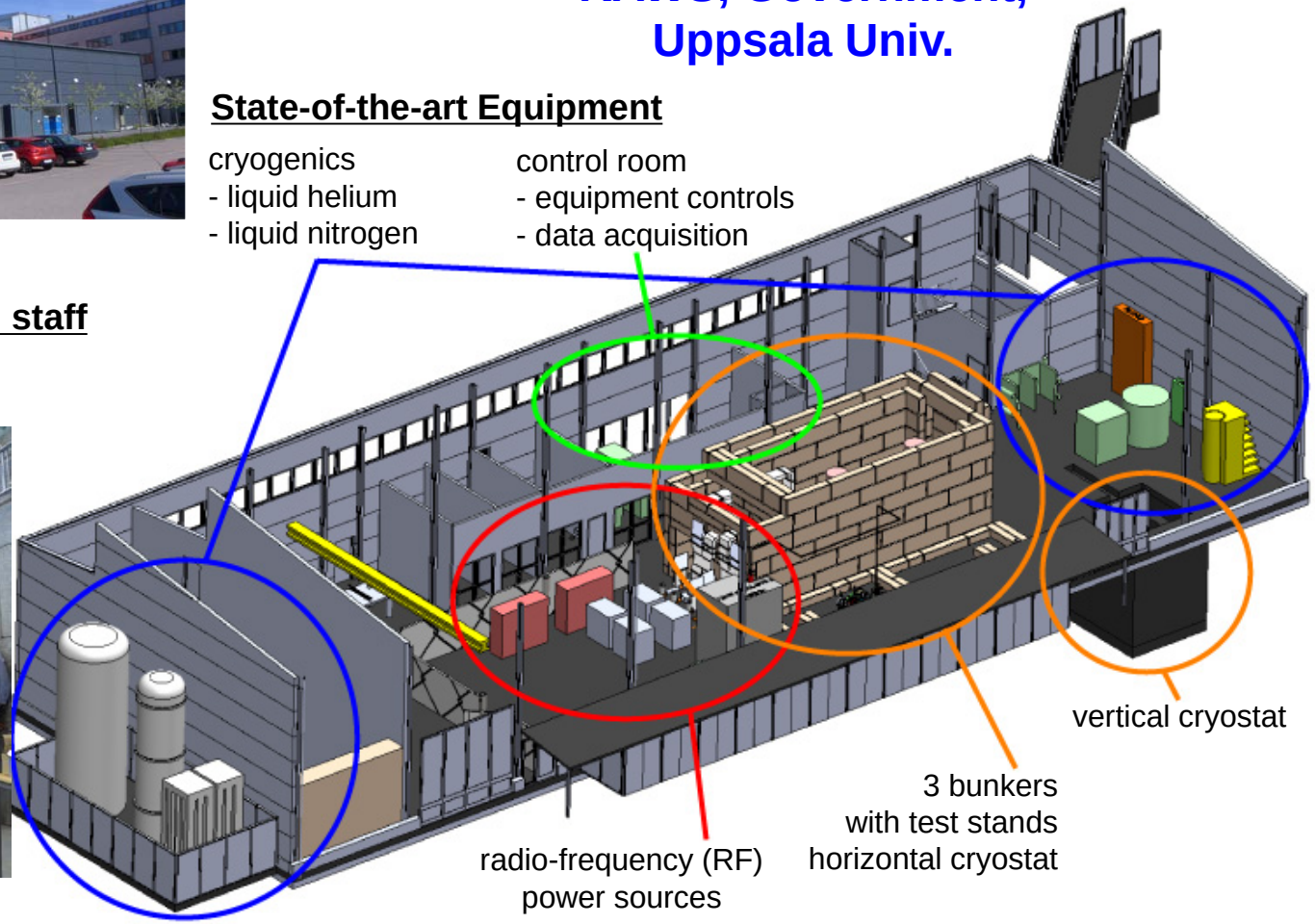
Funded by
KAWS, Government,
Uppsala Univ.

State-of-the-art Equipment

cryogenics
- liquid helium
- liquid nitrogen

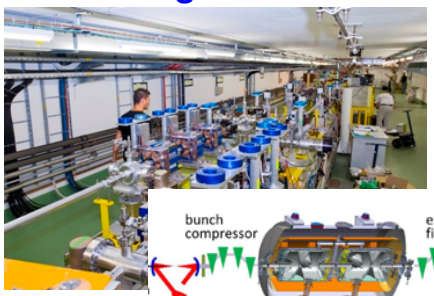
control room
- equipment controls
- data acquisition

Competent and motivated staff
collaboration of physics (IFA)
and engineering (Teknikum).



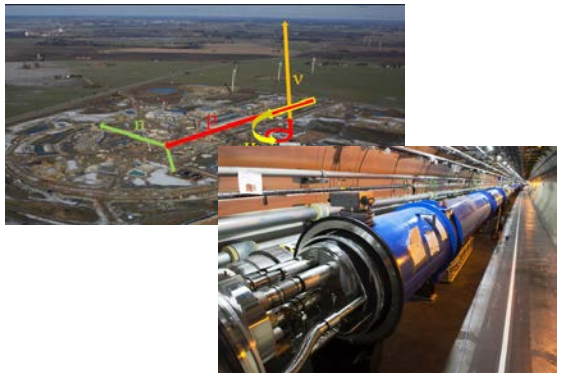
Accelerator Research & Development

Ultra Bright Electron Beams



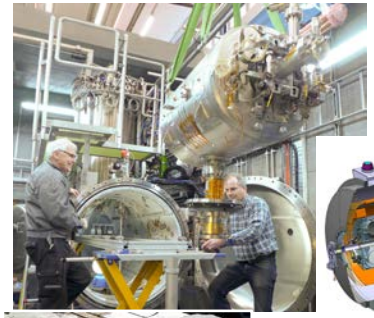
Accelerator Physics

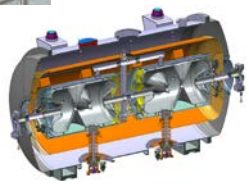
High Intensity Proton Beams

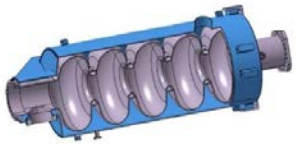


Cryogenics & Test Stands

SC Cavities & Magnets

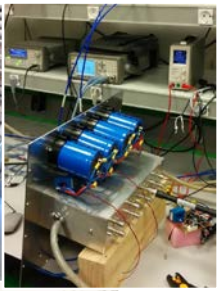


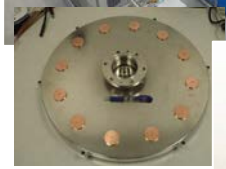


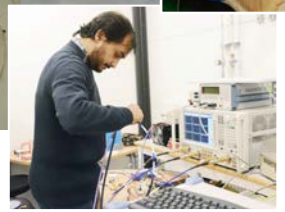


Accelerator Technology

RF Generation & Control







Overview of Cryogenic Test Stands

CRYOGENIC TEST STANDS

Cryogenics

- **Helium liquefaction**
  - 150 l/h at 4.5K (LN2 pre-cooling)
  - 2000 l LHe dewar/buffer, 3+1 outlets
  - cryostats connected in closed loop
- **Gas recovery**
  - 100 m^3 gasbag
  - 3x 25 m^3/h compressor
  - 10 m^3 200 bar storage
- **2K Pumping**
  - ~3.2 g/s at 10 mbar
  - ~4.3 g/s at 15 mbar
  - 110(90)W at 2.0(1.8)K
- **Liquid nitrogen**
  - 20 m^3 LN2 tank

“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

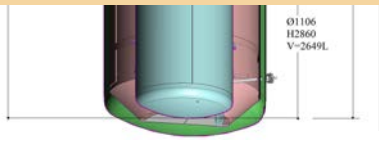
Under commissioning

- Test of SC cavities & magnets (<350kJ)
  - 3.2
  - 2.6
    - d
- Three operation modes
  - vacuum; liquid bath; pressurized (bath with 2K heat exchanger)
- Operation in the range 1.8 to 4.5K

Presentation by K. Pepitone
"News from the FREIA test facility"

Available as ARIES Transnational Access Facility

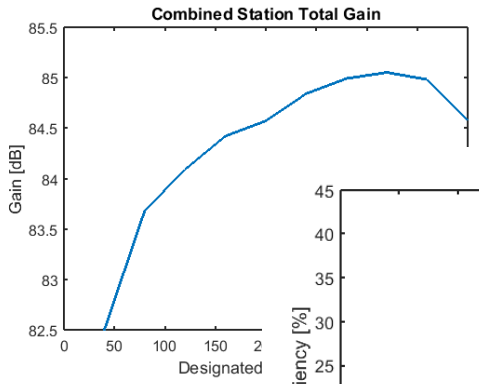
Presentation by R. Santiago Kern
"Challenges of a 1.9 K vertical cryostat design"

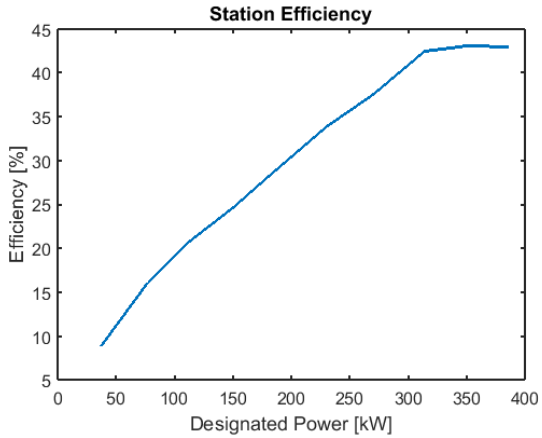


Development of High Power RF Technology

RF GENERATION & CONTROL

High Power RF Amplifiers



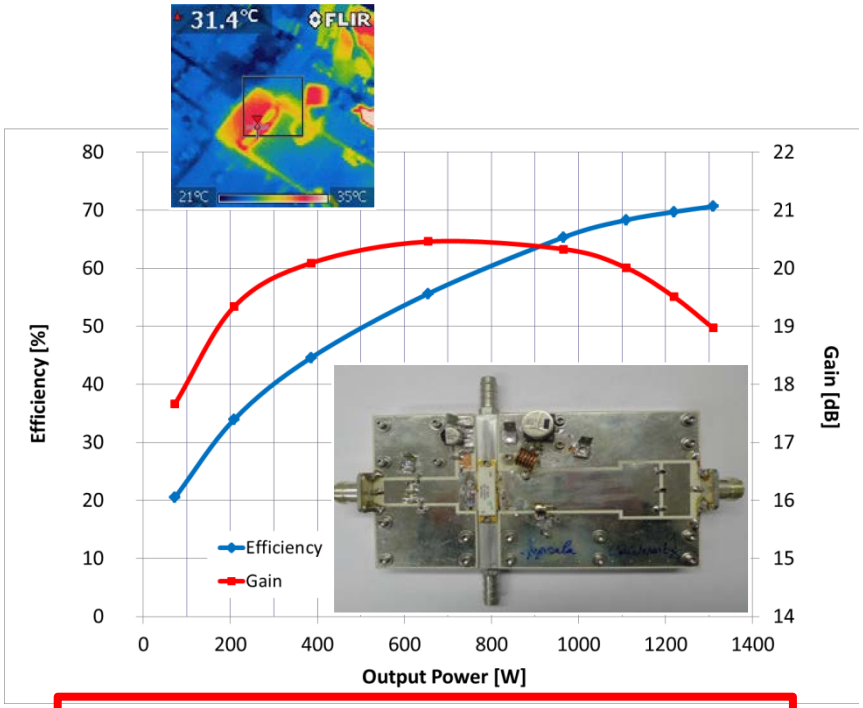


- **400 kW pulsed (352 MHz)**
  - 2 stations, each 2 tetrodes TH595(A)
  - 3.5 ms, 14-28 Hz
  - ESS prototype development
- **50 kW CW (352/400 MHz)**
  - single tetrode TH571b
- **1.2 MW pulsed (704 MHz)**
  - HV modulator & klystron test for ESS

Solid State RF Amplifier

Transistor Amplifier Module

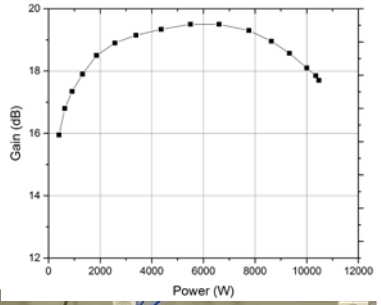
- single ended RF power amplifier
- based on BLF188XR
- 1250 W and 70% efficiency

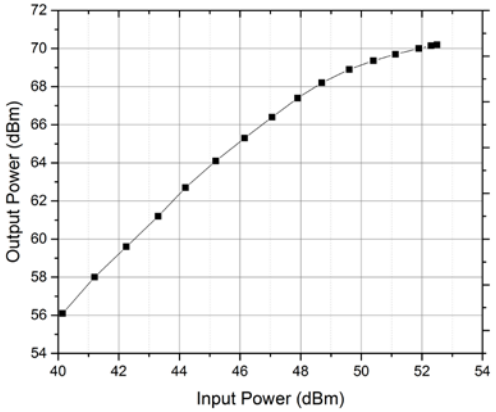


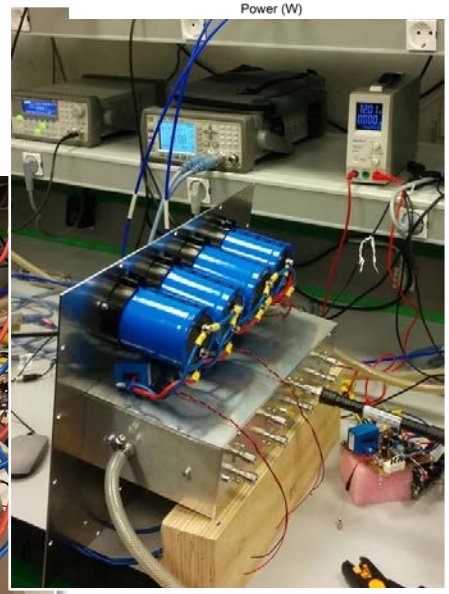
L. Haapala et al. Electronics Letters, vol. 52, (2016) p.1552.

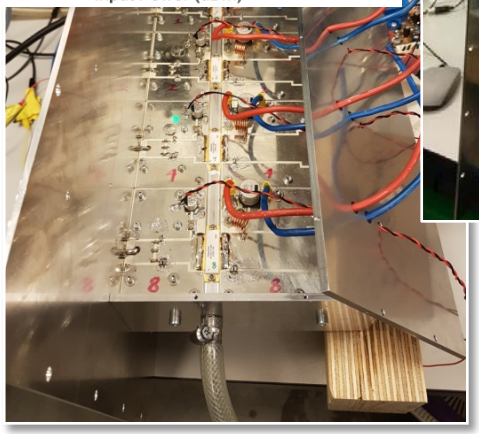
Amplifier Demonstrator

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









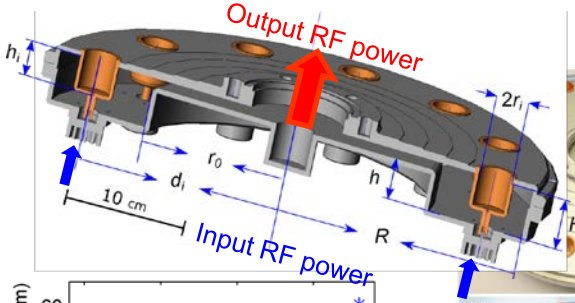
D. Dancila et al.
IOP Conf. Series,
J. Physics Conf. Series
vol. 874, 2017 (012093).

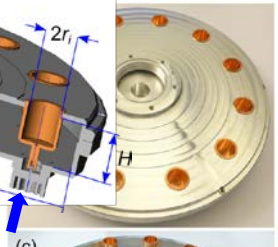
Low-loss Compact Combiners

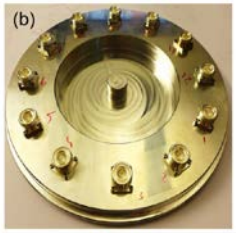
Compact Cavity Combiner

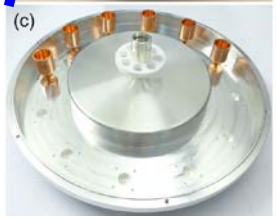
- 352 MHz 200 kW
  - 12 input ports
  - 0.2% insertion loss

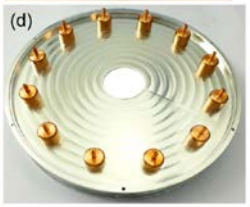
V. A. Goryashko et al.
IEEE Microwave and wireless components Letts, vol. 28, 2018.

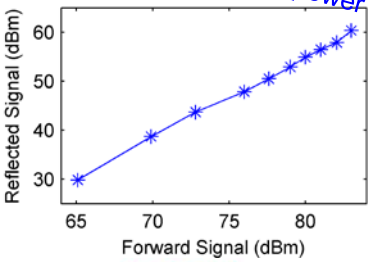


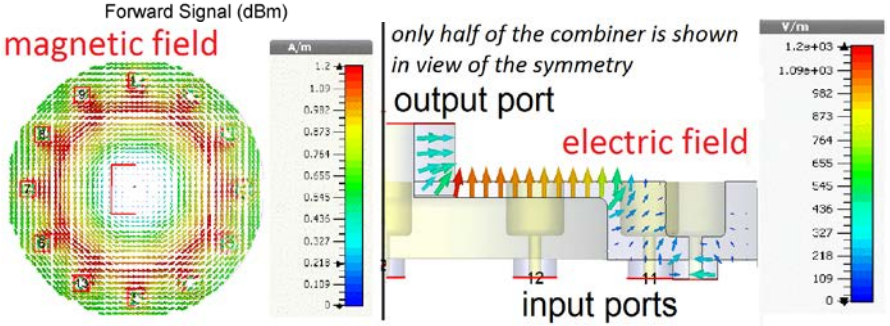






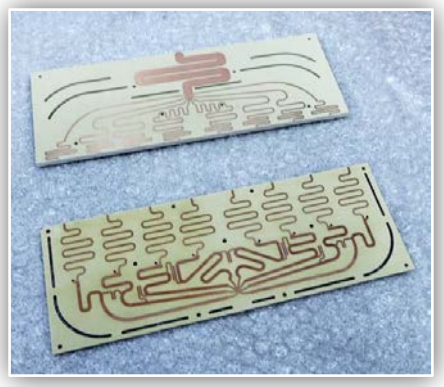






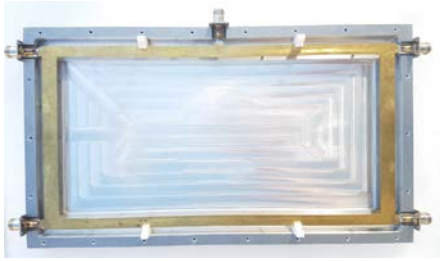
Compact Planar Combiner

- 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

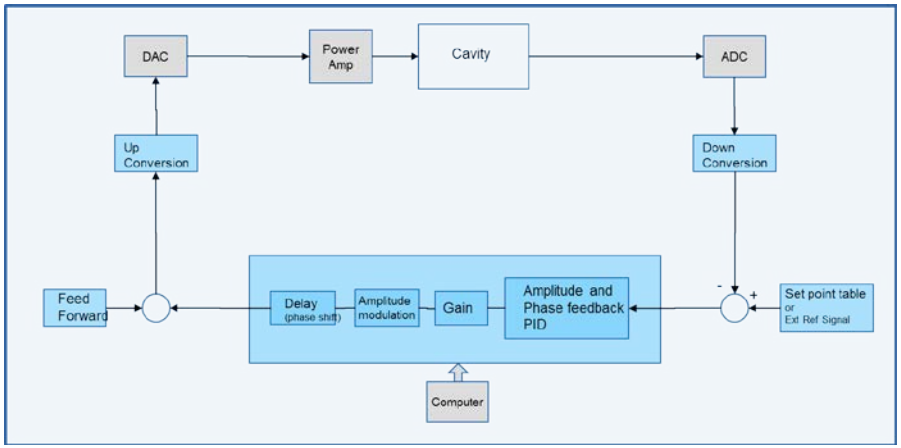


L. Hoang Duc et al. J. of Engineering, 2017.

FPGA Based Digital LLRF

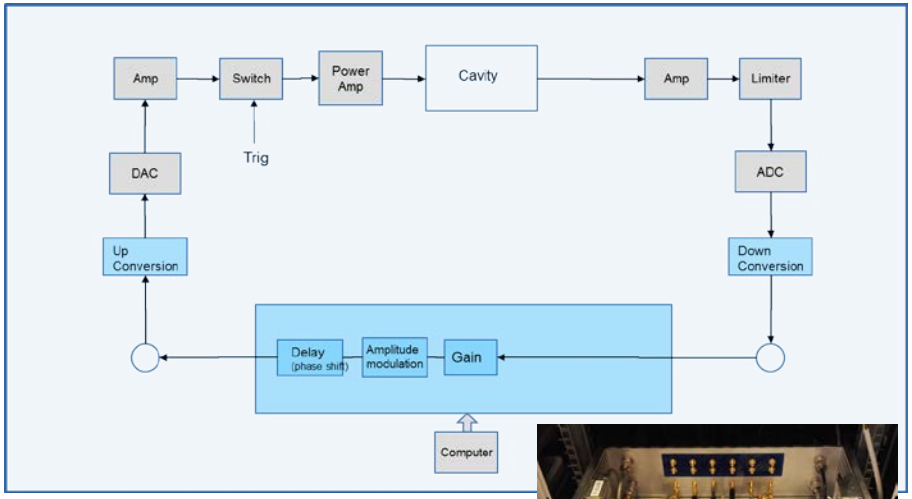
Signal Driven

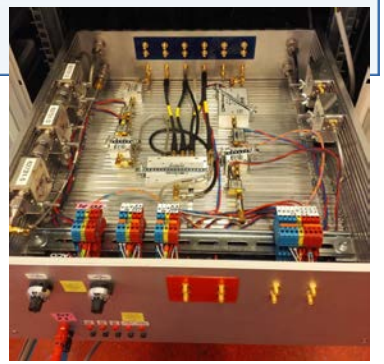
- 2 ADC inputs at 250 Msps
  - (*) analogue bandwidth of 750 MHz
- 2 DAC outputs at 500 Msps
- Digital downconversion to baseband 0 Hz, no analog mixers
  - downconverted signal at 10 Msps or 1 Msps, selectable
- undersampling to operate at any frequency from 10 to 750 MHz*



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

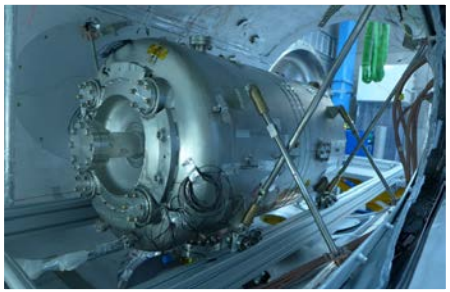
Development of SRF cavities for ESS

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)

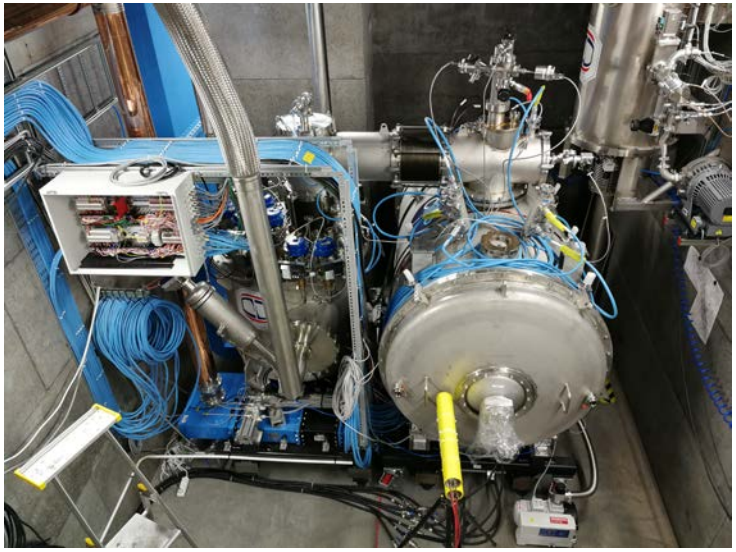
Elliptical Cavity, 704 MHz

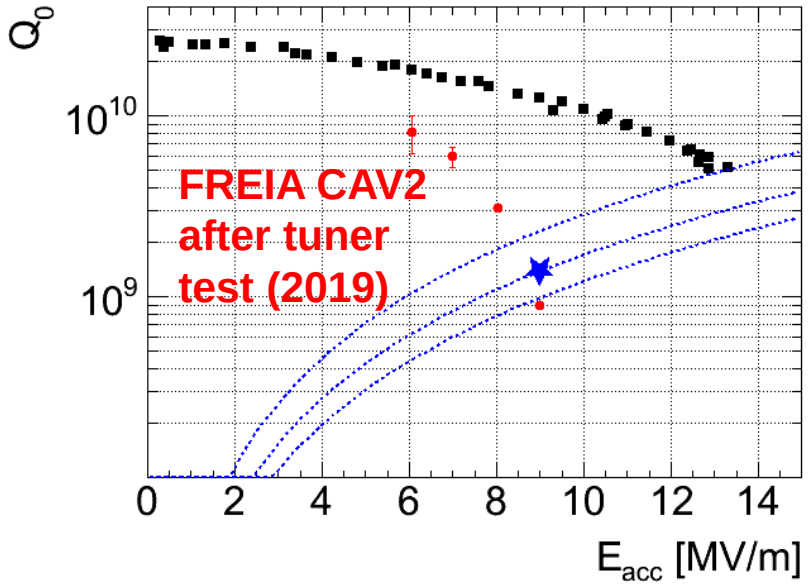
- RF stations
  - acceptance test of HV modulator for ESS local test stand
  - test RF distribution (circulator, load)

- 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)

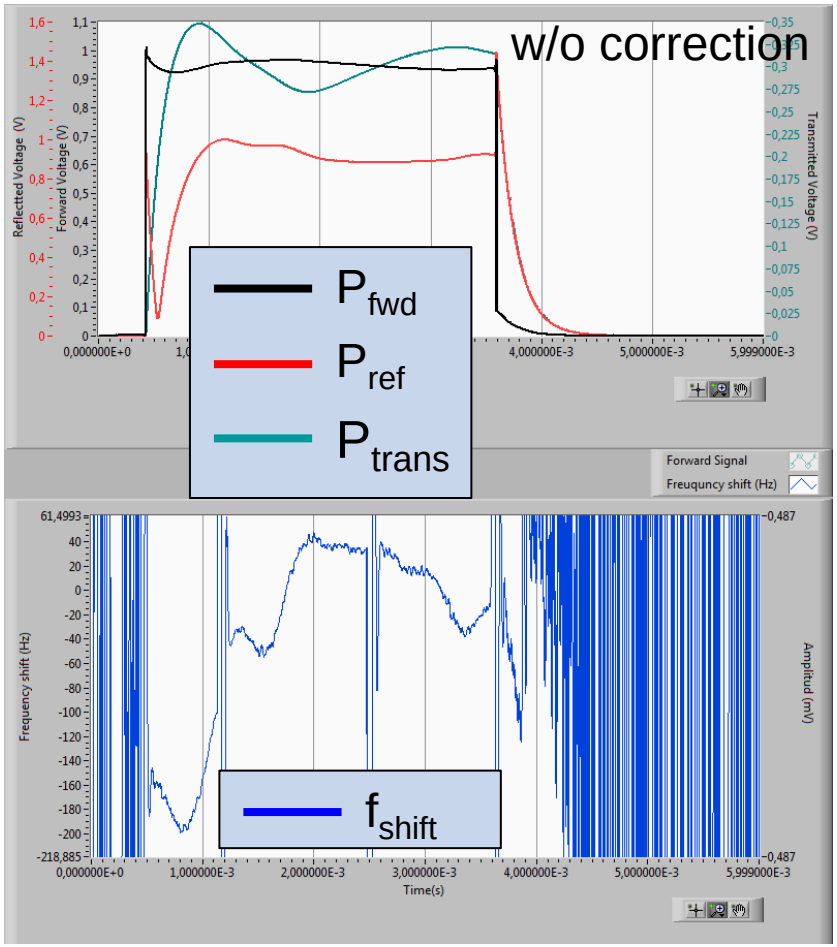
- Warm RF conditioning
  - ~3 days/cavity
  - MP bands were consistent with HNOSS test
    - strength depends on pulse length,
    - 1st/2nd conditioning…
- Cold RF conditioning
  - no coupler activity
  - Quench during cavity conditioning at 4 K
    - burst disc rupture → thermal cycling
- Cavity #2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

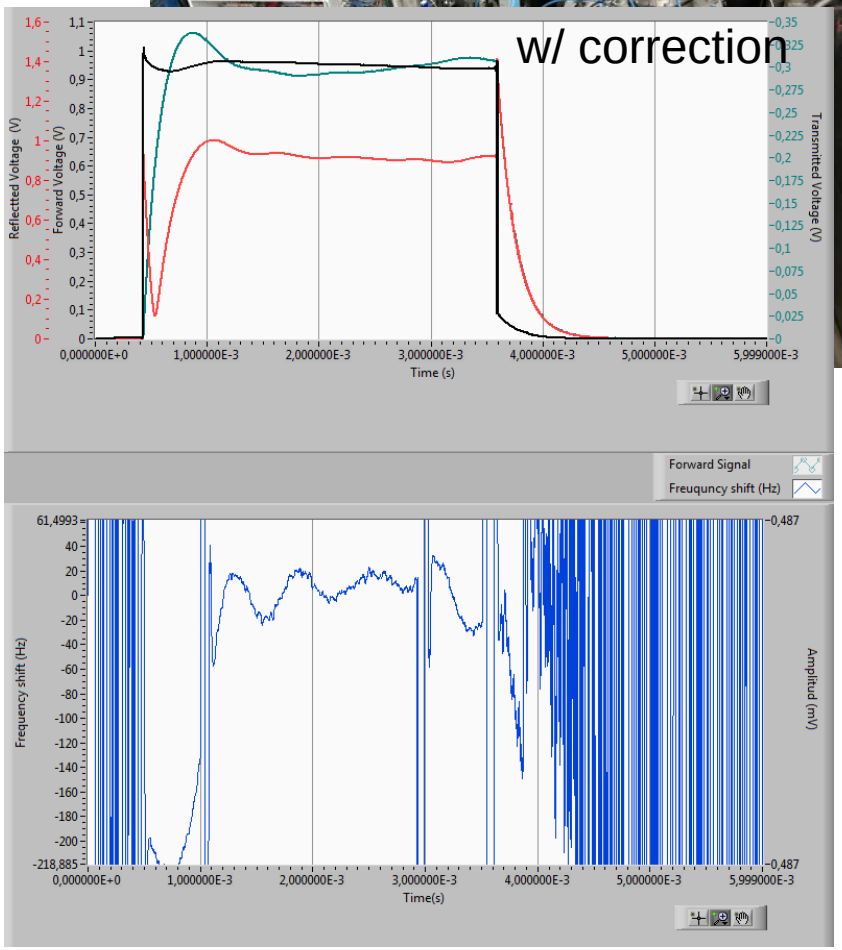




Spoke Cryomodule Prototype (2019)

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



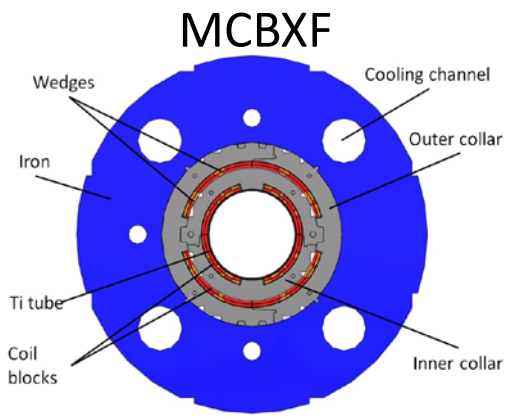


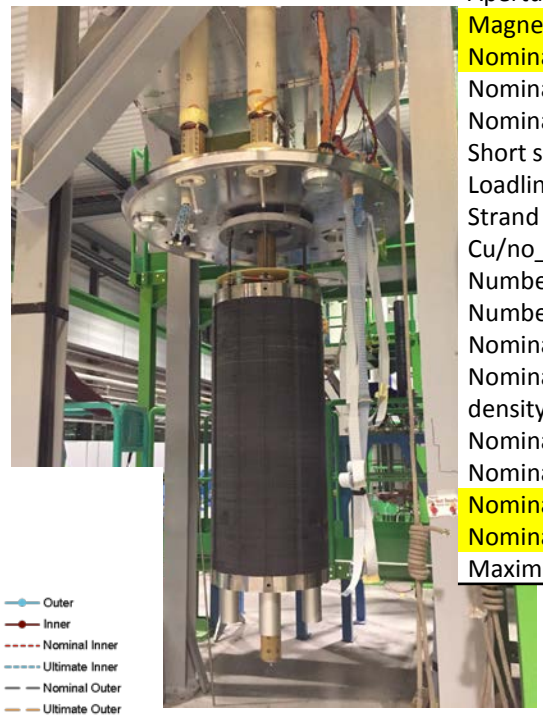
Test and Development of SC Magnets for CERN

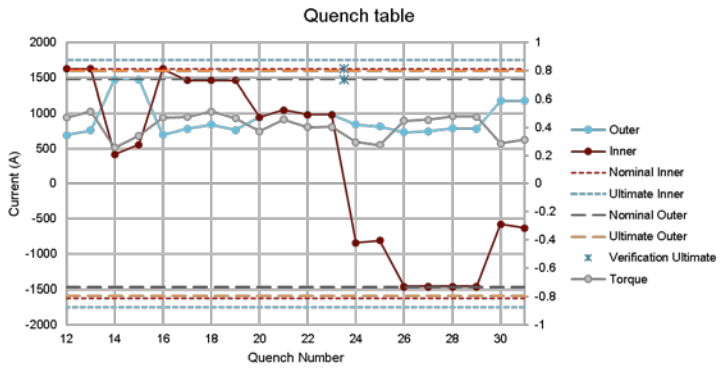
SUPERCONDUCTING MAGNETS

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)

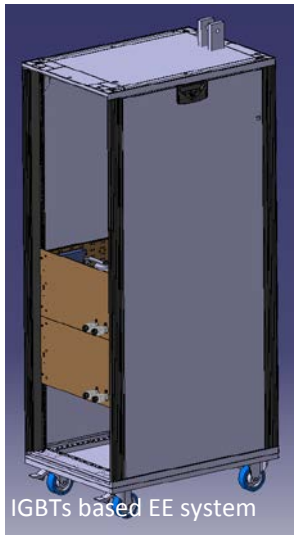


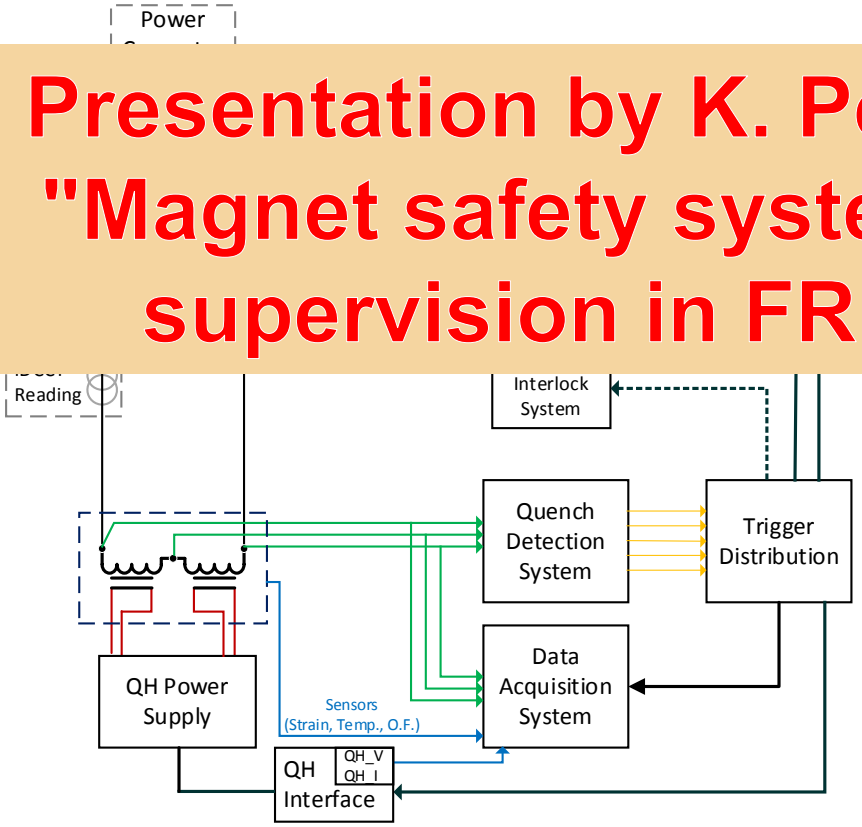




Parameter	Unit	Value
Aperture	mm	150
Magnetic length	m	1.2
Nominal integrated field	T m	2.5
Nominal current inner	A	1625
Nominal current outer	A	1474
Short sample current at 1.9 K	A	
Loadline fraction at 1.9 K		
Strand diameter	mm	0.480
Cu/no_Cu		1.75
Number of turns per layer inner		140
Number of turns per layer outer		191
Nominal strand current density	A/mm^2	
Nominal superconductor current density	A/mm^2	
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

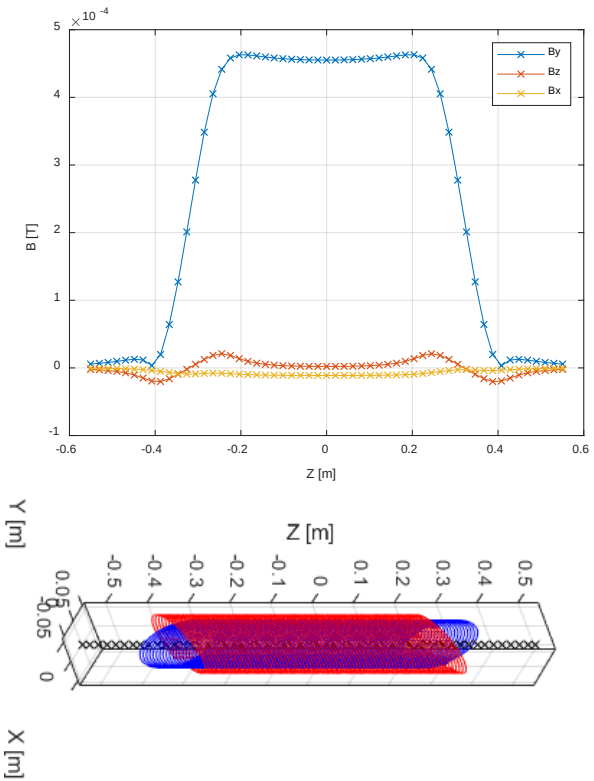


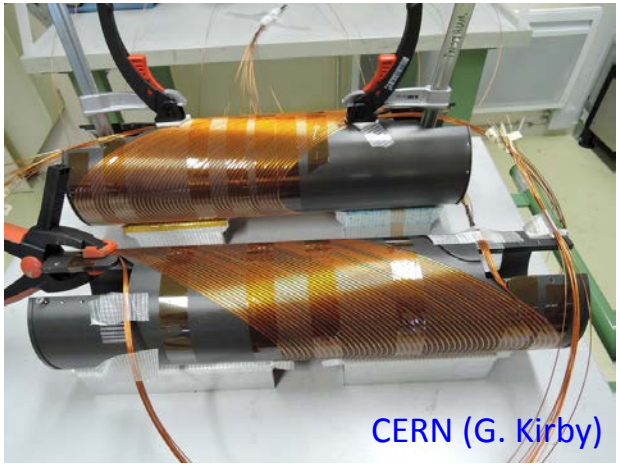


Presentation by K. Pepitone "Magnet safety system and supervision in FREIA"

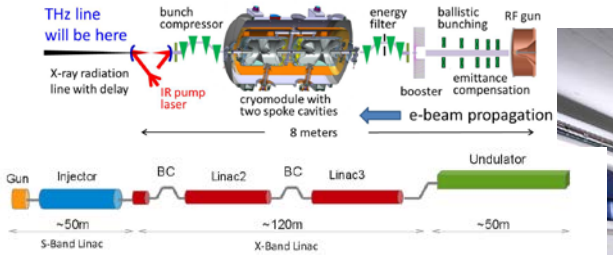
CCT Magnet Development

- 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



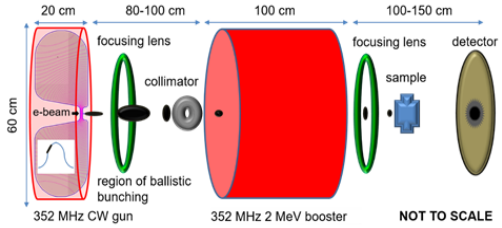


FELs



CLIC

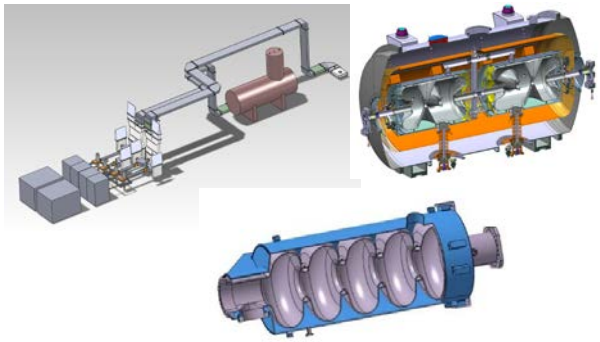
Ultrafast Electron Diffraction



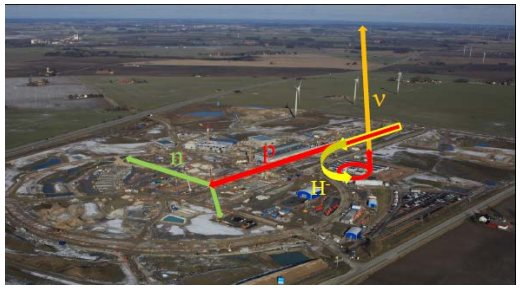
CLIC, Free Electron Lasers, Ultra-fast Electron Diffraction

HIGH BRILLIANCE ELECTRON BEAMS

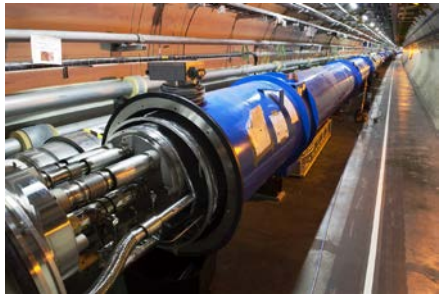
ESS Superconducting Linac



ESS Neutrino Super Beam



HiLumi LHC



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

HIGH BRILLIANCE PROTON BEAMS

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