Accelerator Research at Uppsala University

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14 July 2015 at ODU

UPPSALA UNIVERSITET

Uppsala University

Oldest university in Scandinavia (1477)

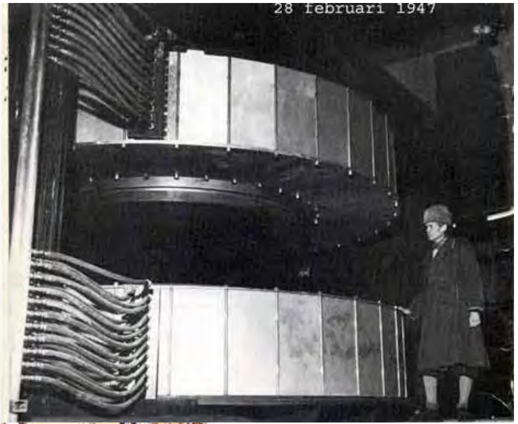
- Sweden
  - 9.7 million (pop.), 450'000 km^2, 430 GEur (BNP)
- Uppsala
  - 25'000 students, 9'000 staff, 630 MEur annual budget
  - faculties of theology, law, medicin, pharmacy, arts, social sciences, languages, educational sciences, science and technology
  - university library and hospital

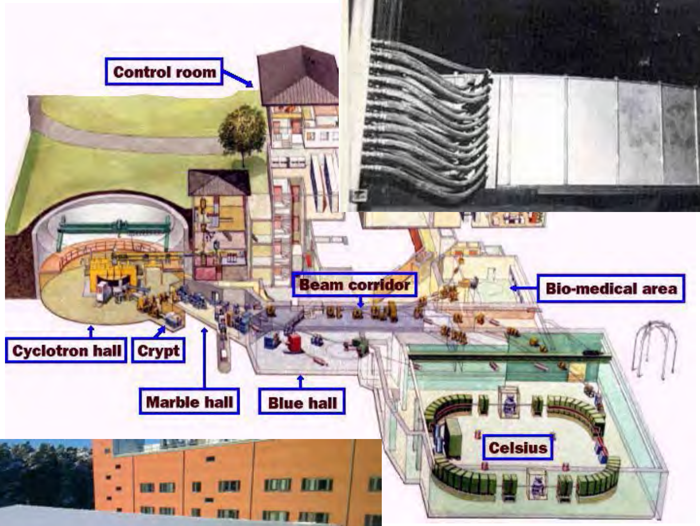
- Science and technology
  - 10'000 students, 1'800 staff
  - historical profiles: Linnaeus, Rudbeck, Celsius, Ångström, Siegbahn, Svedberg
  - R&D areas
    - physics, chemistry, biology, earth sciences, engineering, mathematics, IT

Uppsala Accelerator History

1940's: The(odore) Svedberg proposes to build a cyclotron

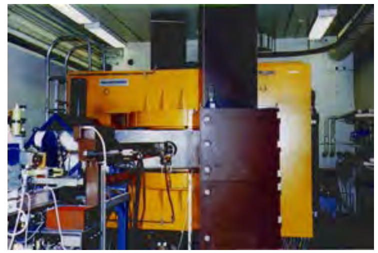
- Gustaf Werner synchro-cyclotron (1947 - 2015)
  - nuclear physics & cancer treatment
- CELSIUS ring (1984 - 2005)
  - nuclear physics
- CTF3/CLIC (since 2005)
- FLASH/XFEL (since 2008)
- ESS (since 2009)
- FREIA laboratory (since 2011)
- Skandion clinic (2015)
  - cancer treatment





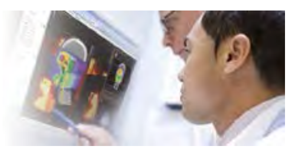
Offshoots from Uppsala Accelerator R&D

- Scanditronix
  - major supplier
    - cyclotrons 1970-80's
    - PETs 1980's



- GE Medical Systems PET and cyclotrons
  - former Scanditronix

- IBA Dosimetry
  - former Scanditronix Wellhöfer



- Scanditronix Magnets
  - magnets

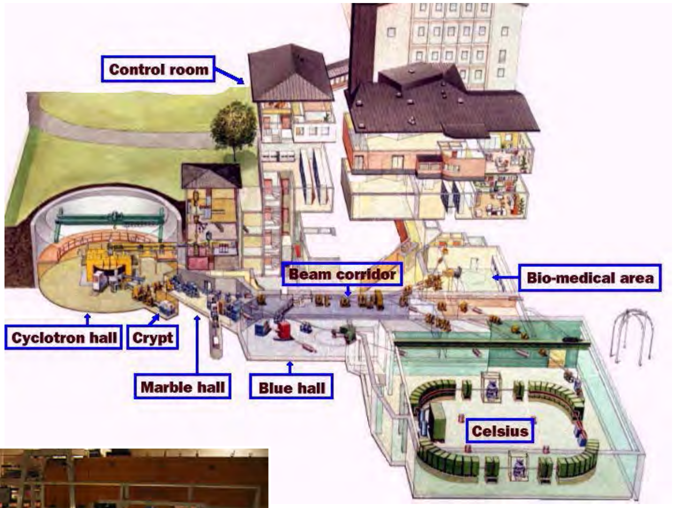
- ScandiNova
  - high voltage pulse modulators

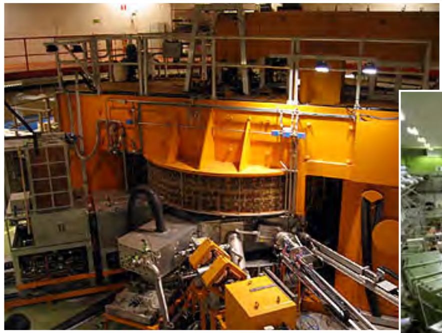
- Gammadata
  - physics tools education, research, industry

- Skandionkliniken
  - proton therapy centre

Nuclear Physics and Cancer Treatment

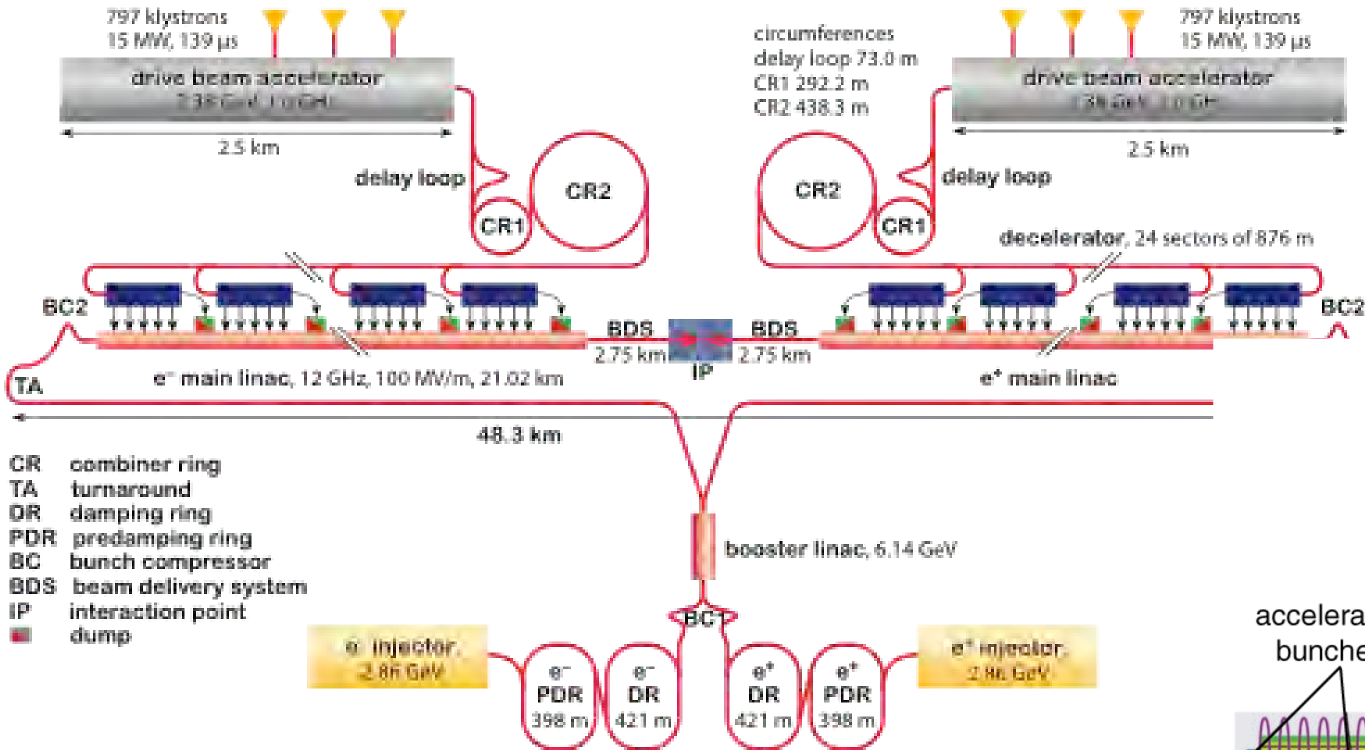
- Gustaf Werner synchro-cyclotron (1947 - 2015†)
  - protons (180 MeV) and heavy ions
  - proton therapy (first patient treated 1957)
  - radio-isotope production
- CELSIUS storage and accelerator ring (1984 - 2006†)
  - protons (1360 MeV) and heavy ions
  - electron cooler (300 keV)
  - gas-jet and pellet target

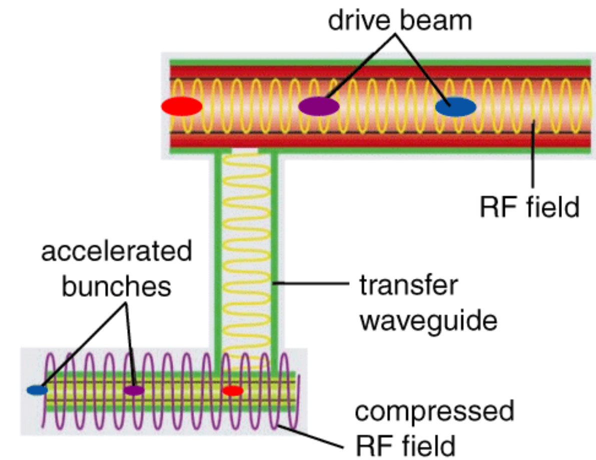




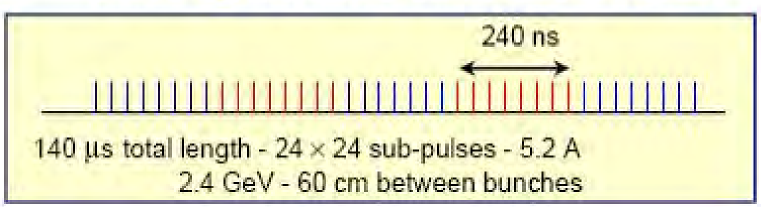
- Skandion clinic (from August 2015)
  - proton therapy
  - commercial operator

CLIC Compact Linear Collider Study

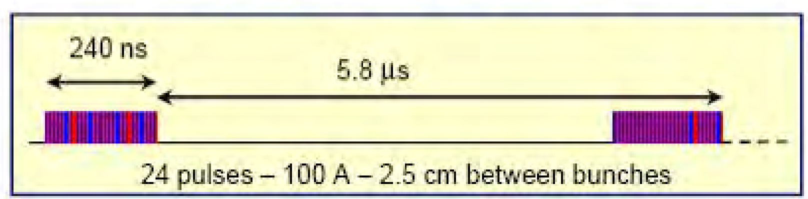




Drive beam time structure - initial

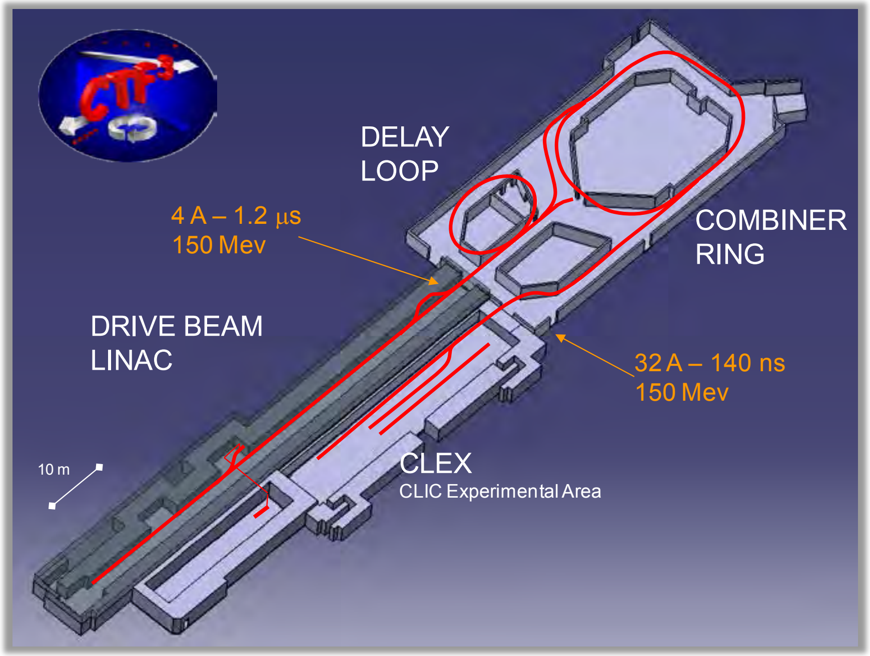


Drive beam time structure - final



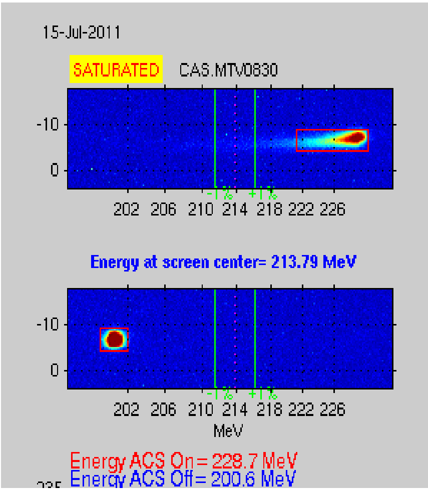
High Gradient X-band Technology

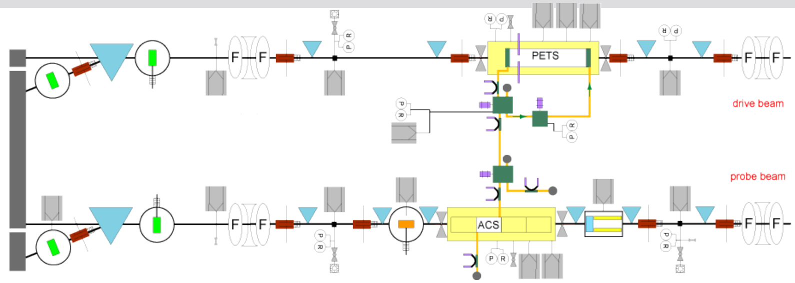
- Two-beam Test Stand at CTF3
  - proof-of-principle CLIC two-beam acceleration scheme
  - conditioning and test of PETS and accelerating structures

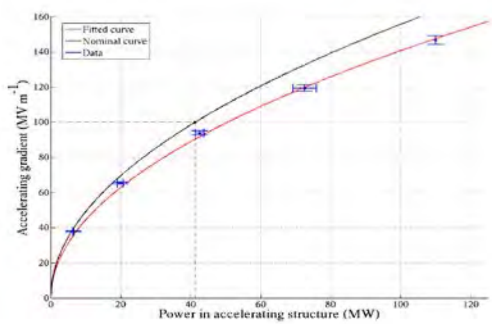


- RF breakdown studies
  - possible beam kick (in TBTS)
  - ejected electrons and ions (in TBTS & Xbox 12GHz klystron test stand)
  - in-situ SEM DC-spark study

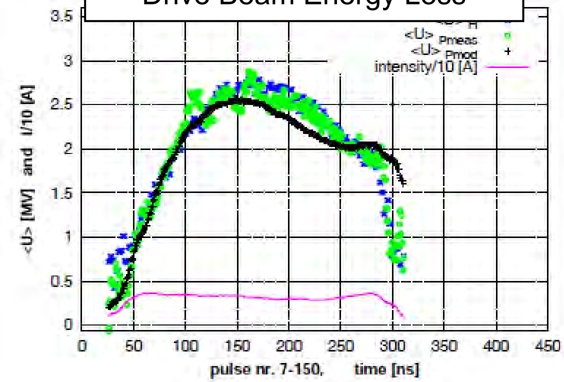
Two-beam Test Stand



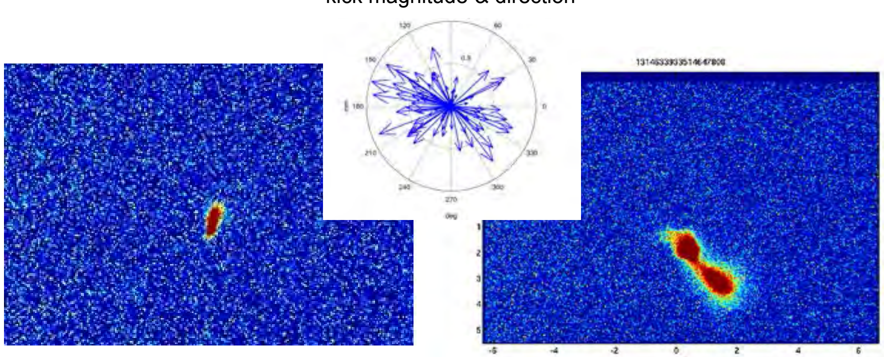




Drive Beam Energy Loss



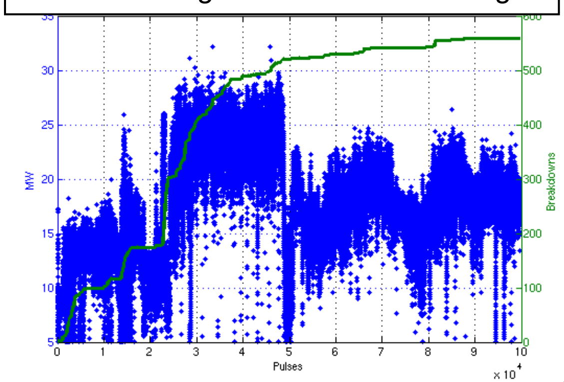
kick magnitude & direction



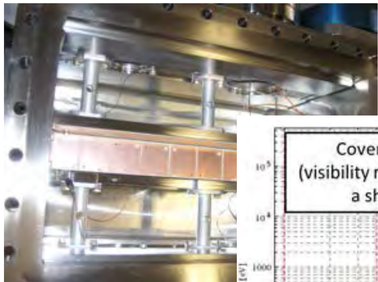
Beam without BD

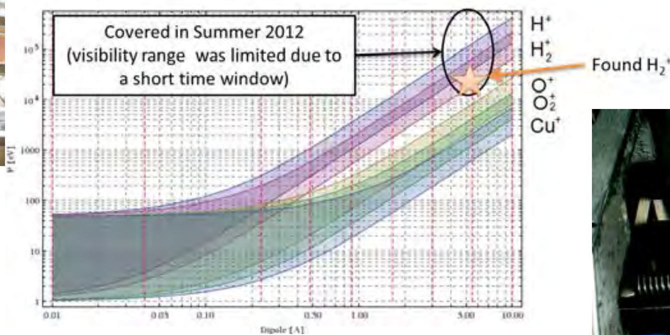
Beam with BD
Kick : 0.4 mrad

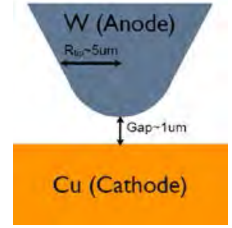
Accelerating Structure Conditioning



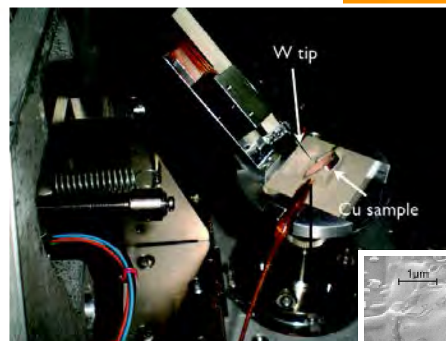
RF Breakdown Studies

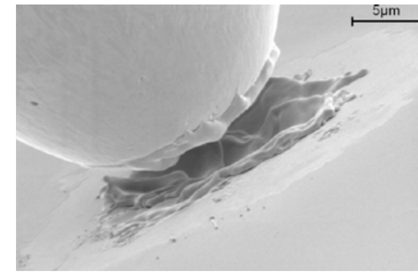


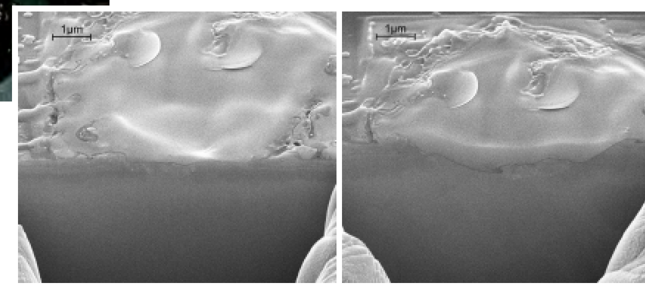


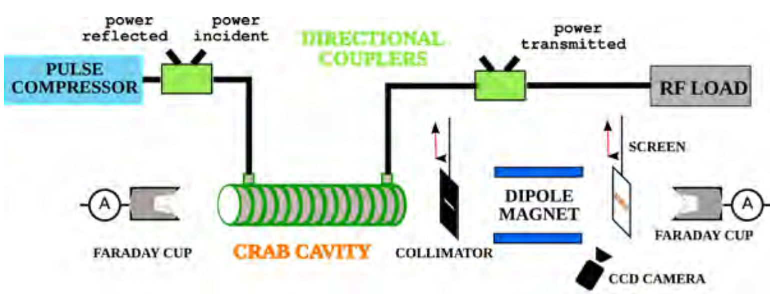


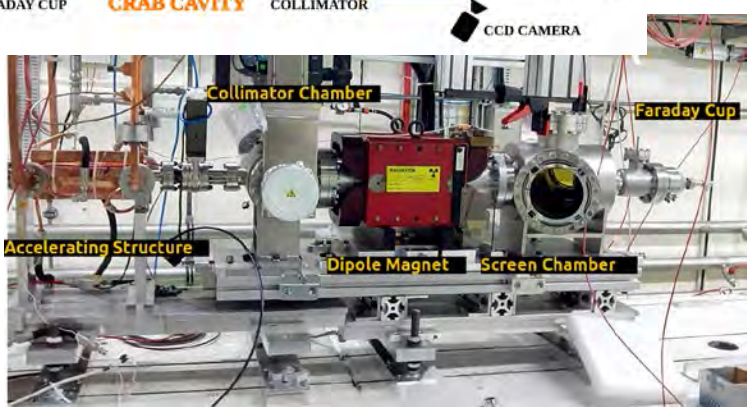
1kV/micron=1GV/m

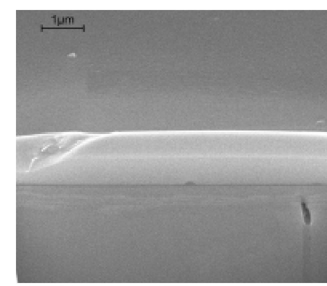


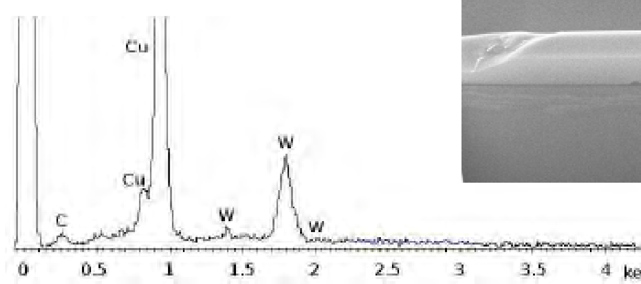












Free Electron Laser Studies

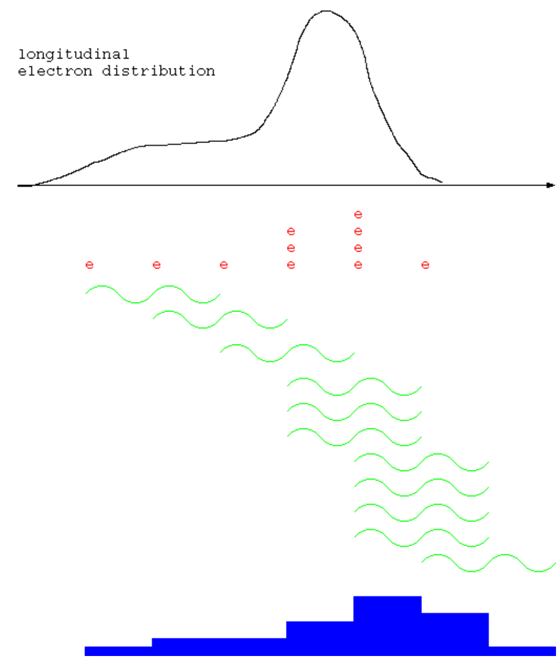
Manipulating bright electron bunches with external laser

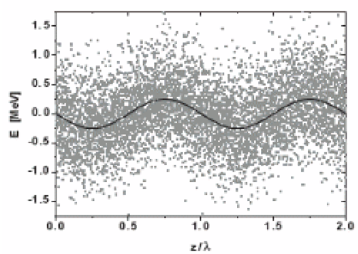
SUFEL STOCKHOLM-UPPSALA CENTRE FOR FREE ELECTRON LASER RESEARCH

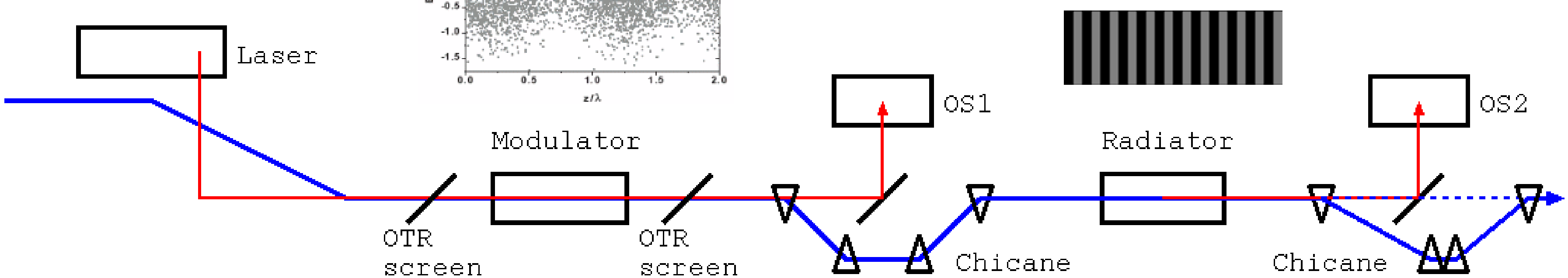
- Stockholm-Uppsala FEL Centre (www.frielektronlaser.se)
  - started after closure of CELSIUS (UU) and CRYRING (SU)
  - participate in the XFEL planning phase
    - for diagnostic purposes
      - Optical Replica Synthesizer (ORS at FLASH)
      - measure ultra-short bunches in the 10's of fs range
      - too fast for electronics (10 GS/s, 100ps),
      - but can be done with optics (so-called FROG)
      - make an optical copy of the electron bunch and analyze that with laser methods
  - leading to XFEL participation
    - for beam stability
      - Laser Heater (at European XFEL)
      - Swedish in-kind
  - and a FEL in the Stockholm-Uppsala region

Optical Replica Synthesizer in FLASH

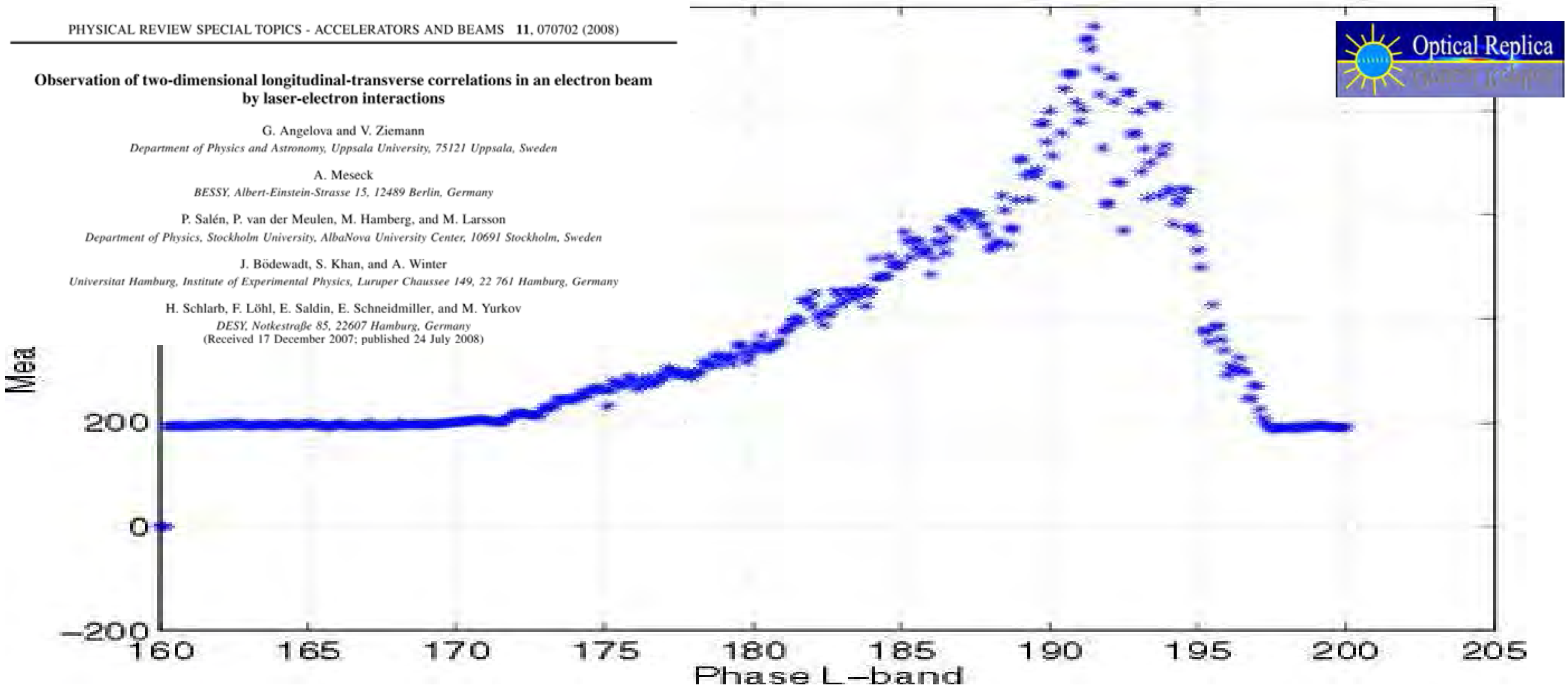
- make an optical copy of the electron bunch and analyze that with laser methods.
  - temporal overlap of sub-ps electron bunch und laser pulse
  - rough adjustment on photo diode on OS1 per synchrotron radiation and laser ~ 100 ps
  - fine-tuning on OS2 by observing coherent OTR of modulated electrons







OTR on OS2-camera while 200 fs laser-pulse passes through electron bunch


PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **11**, 070702 (2008)

Observation of two-dimensional longitudinal-transverse correlations in an electron beam by laser-electron interactions

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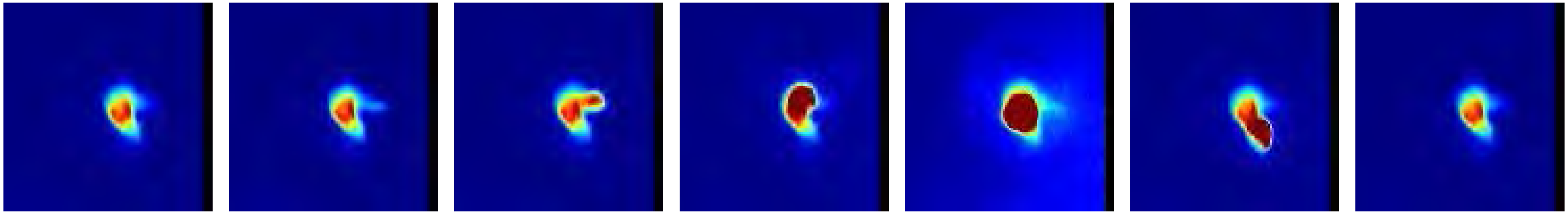
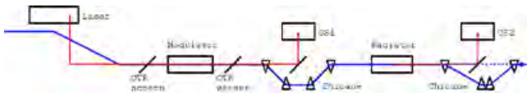
(Received 17 December 2007; published 24 July 2008)



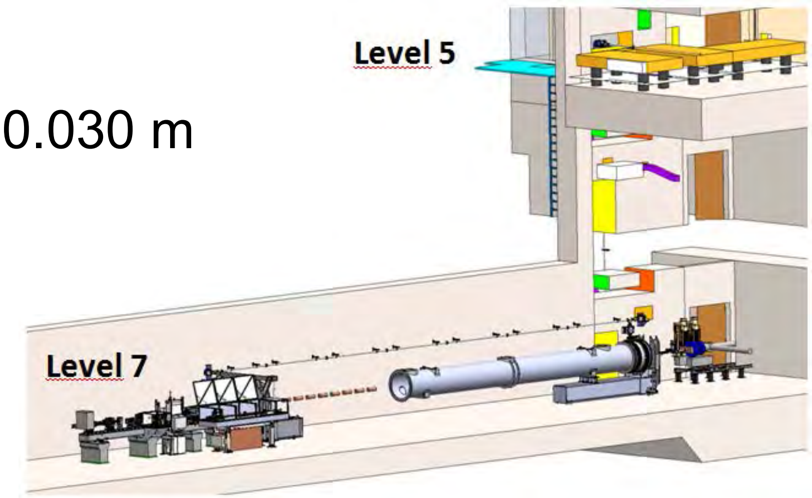


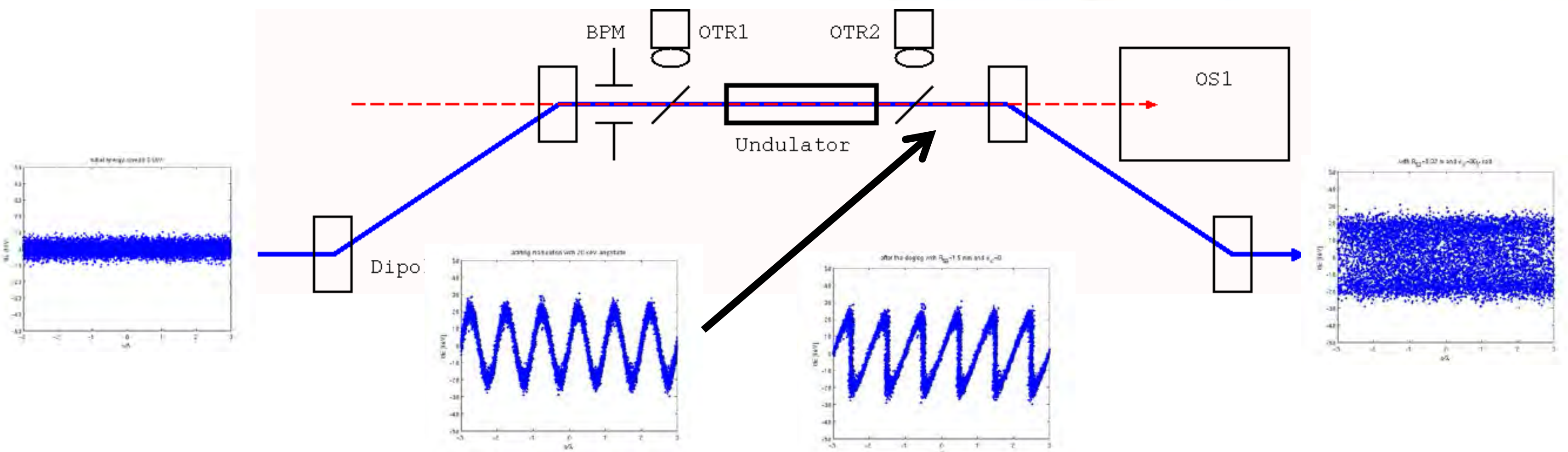
EuXFEL Laser Heater

- Why...
  - Electrons are born in the photo cathode with a very small momentum spread (~3 keV)
    - makes them susceptible to microbunching instability on their travel through the linear accelerator and bunching chicanes
  - Add Landau damping (decoherence) in a well-controlled way to increase momentum spread
    - induce moderate momentum modulation by passing a laser over the electrons in an undulator
    - and smear out by coupling some of the angular spread into the longitudinal plane
- How...
  - Pass IR laser over beam in undulator → modulate dE
  - R52 of 2nd leg of chicane couples 'transverse heat' into the longitudinal plane and smears out the modulation

The Installation

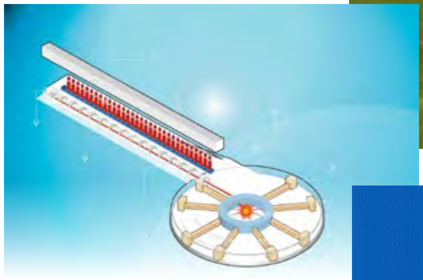
- use 1030 nm photons, operate between 110 and 160 MeV
- permanent undulator with variable gap: 8+2 periods of l=74 mm
- chicane offset 30 mm:
  - second half has R56=0.003/2 m, R52=0.030 m
- pulse energy up to 50 uJ (2.5 MW, 20ps)
- Beta functions 9 and 12 m, σ ~ 0.2 mm

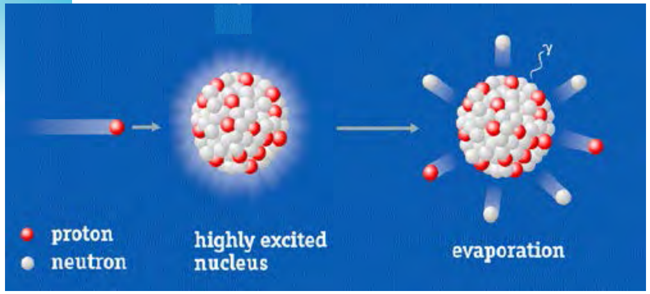




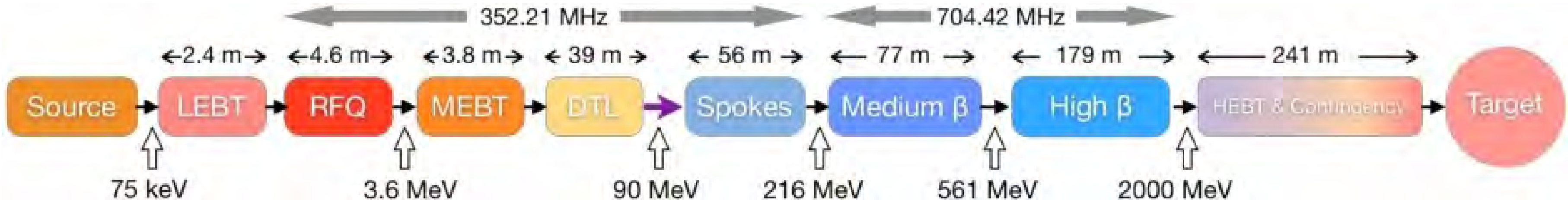
The European Spallation Source (ESS)

- Lund, Sweden, next to MAX-IV
  - to replace aging research reactors
  - 2019 first neutrons
  - 2019 – 2025 consolidation and operation
  - 2025 – 2040 operation
- 5 MW pulsed cold neutron source, long pulse
  - 14 Hz rep. rate, 4% duty factor
  - >95% reliability for user time
  - short pulse requires ring, but user demand satisfied by existing facilities (ISIS, SNS, J-PARC)
- High intensity allows studies of
  - complex materials, weak signals, time dependent phenomena
- Cost estimates (2008 prices)
  - 1,5 G€ / 10 years
  - 50% by Sweden, Denmark, Norway





The ESS Accelerator

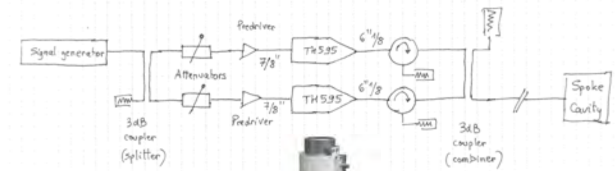


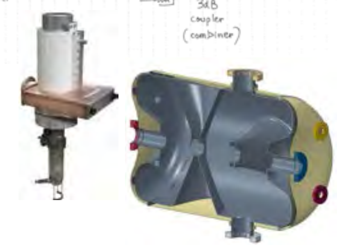
	Length [m]	No. Cavities	No. Magnets	No. Steerers	β	No. Sections	Power [kW]
LEBT	2.38		2 Solenoid	2 x 2		1	
RFQ	4.6	1				1	1600
MEBT	3.83	3	11 Quad	10 x 2		1	15
DTL	38.9	5	PMQs	15 x 2		5	2200
LEDP + Spoke	55.9	26	26 Quad	26	0.50	13	330
Medium Beta	76.7	36	18 Quad	18	0.67	9	870
High Beta	178.9	84	42 Quad	42	0.86	21	1100
HEBP	130.4		32 Quad	32	(0.86)	15	
DogLeg	66.2		12 Q + 2D	14			
A2T	46.4		6 Q + 8 Raster				
	604.21	**155**					

Responsibility for ESS Accelerator

1) Contribution to the technical design & construction effort

- design concept spoke accelerating cavity power source
- design concept radio-frequency (RF) power distribution
- survey test stand infrastructure and requirements
- study of upgrade scenarios RF systems for ESS power upgrade





2) Development spoke cavity high power RF amplifier

- soak test with water cooled load, then accelerating cavity, incl. controls
- collaboration with industry to develop vacuum tube and solid-state based prototypes

3) Spoke cavity system test

- dressed prototype cavity (in horizontal cryostat)
- prototype cryomodule (2 spoke cavities)
- LLRF and high power RF amplifier

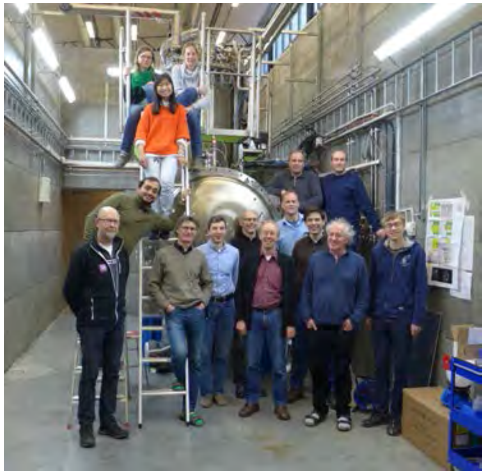
4) Acceptance test cryostat-modules

- for all final modules before installation

Test Stand Matrix		f	P	prototype				series			
				low power		high power		low power		high power	
		[MHz]	[kW]	where	when	where	when	where	when	where	when
P0	Cavities										
	Ion source	--	--	LNS		LNS				on site	
	LEBT buncher	352	10	LNS ?		LNS ?				on site	
	RFQ	352	1000	CEA		CEA				on site	
	MEBT	--	--	ESS-B ?		ESS-B ?				on site	
	DTL	352	2100	LNL		CERN (Linac4)				on site	
	double spoke	352	240	IPNO		**UU**	2014/5	??		--	
	medium beta	704	500	CEA		CEA		DESY ?		--	
	high beta	704	900	CEA		CEA		DESY ?		--	
P1	Couplers										
	double spoke	352	800	IPNO		CEA		??		??	
	medium beta	704	650	CEA ?		CEA		??		??	
	high beta	704	1200	CEA		CEA		??		??	
P2	RF System										
	modulator	--	5600	--	--	ESS		--		ESS	
	NC linac	352	2800	--	--	ESS		--		ESS	
	double spoke	352	300	--	--	**UU**	2014	--		ESS	
	medium beta	704	600	--	--	ESS		--		ESS	
	high beta		1200	--	--	ESS		--		ESS	
P3	Cryomodule										
	double spoke	352	2x 300	IPNO		**UU**	2015/6	IPNO		**UU**	2017/8
	medium beta	704	4x650	CEA	--	CEA	--	CEA/ESS		ESS	
	high beta	704	4x1200	--	--	--	--	CEA/ESS		ESS	

What & Whom?

Facility for Research Instrumentation and Accelerator Development



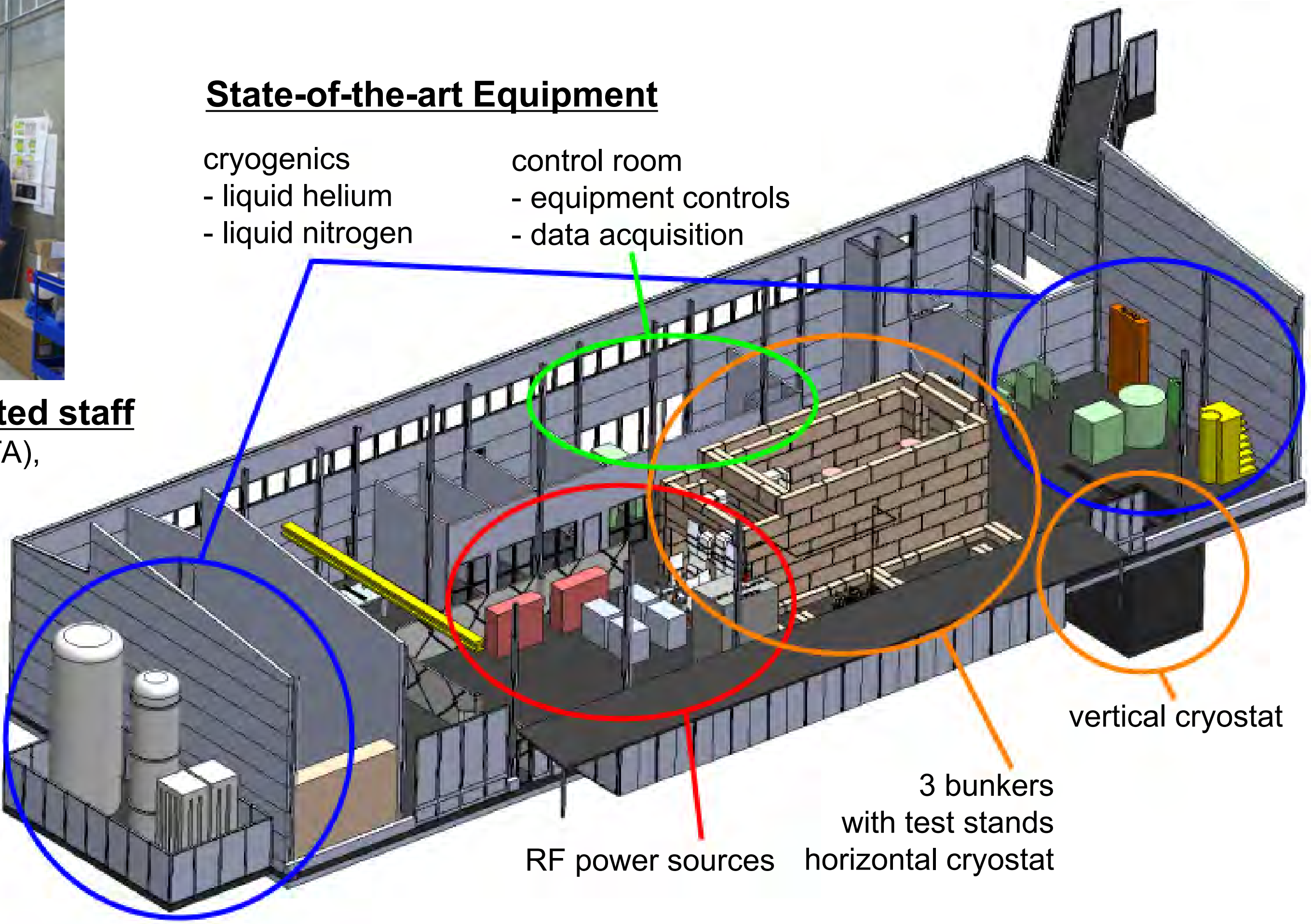
Competent and motivated staff

collaboration with physics (IFA), engineering (Teknikum), TSL and Ångström workshop

State-of-the-art Equipment

cryogenics
- liquid helium
- liquid nitrogen

control room
- equipment controls
- data acquisition



Funded by KAWS, Government, Uppsala Univ.

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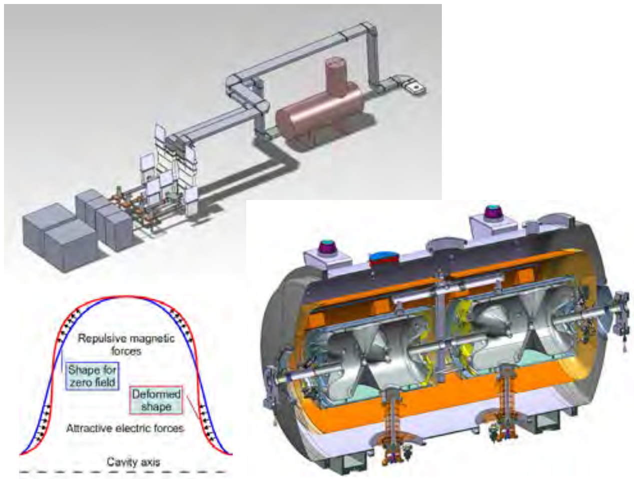
Overview of Activities

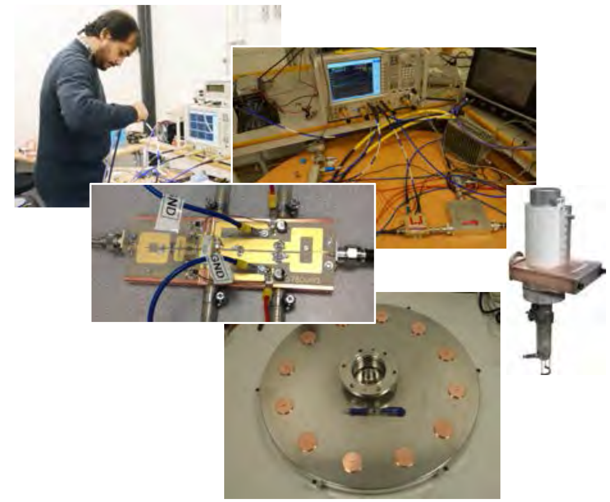
SRF Spoke Cavities & Linac



linearcollider.org/M.Grecki

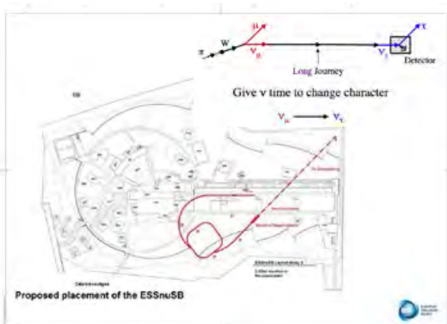
Cryogenics

High Power RF Amplifiers Solid-state & Vacuum Tube

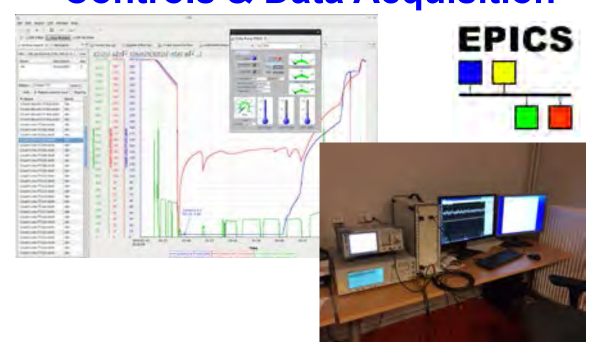


SRF Test Stand

ESS neutrino Super-beam



Controls & Data Acquisition



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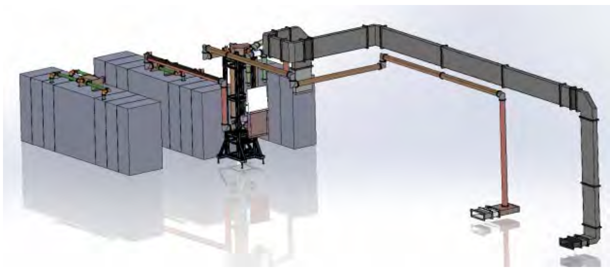
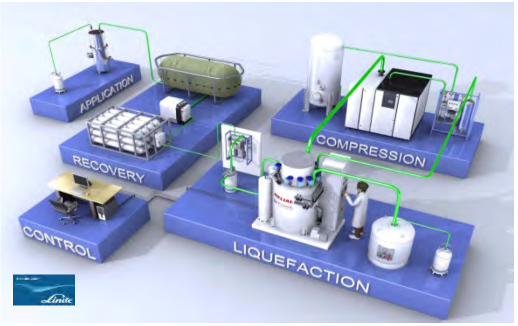
The Test Stand

- Three main subsystems needed



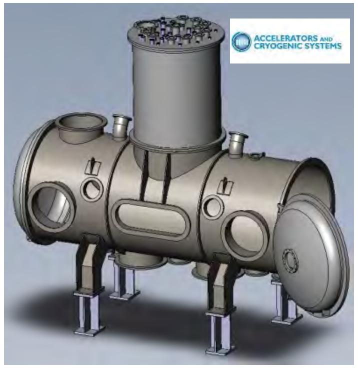
RF Power Source



Cryogenics

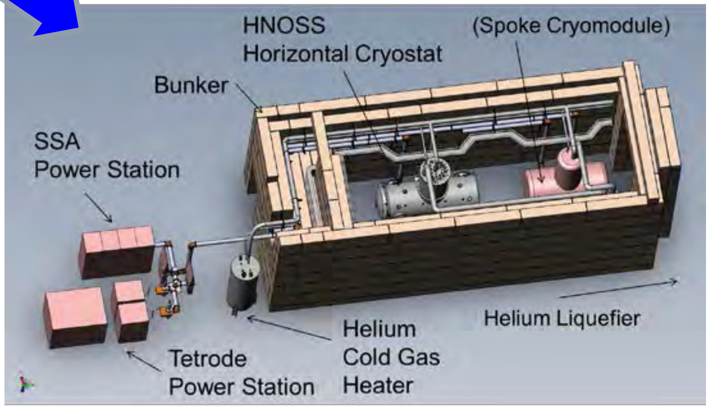
Courtesy of P. Duthil

Spoke Cavity
(superconducting)



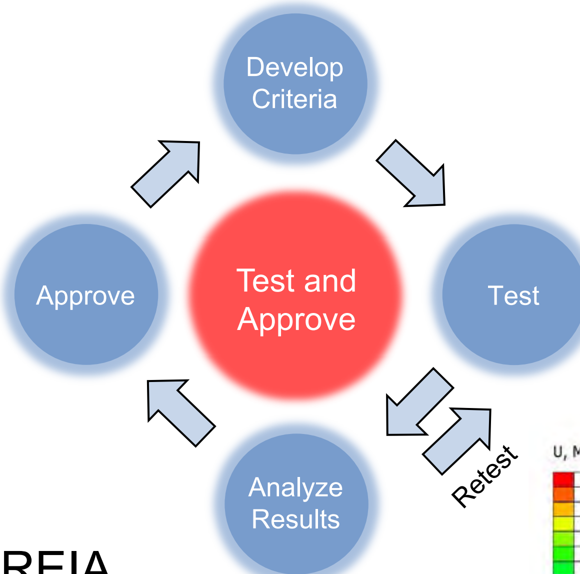
Cryostat

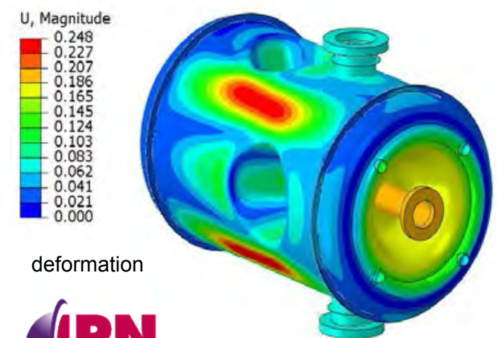
Implementation



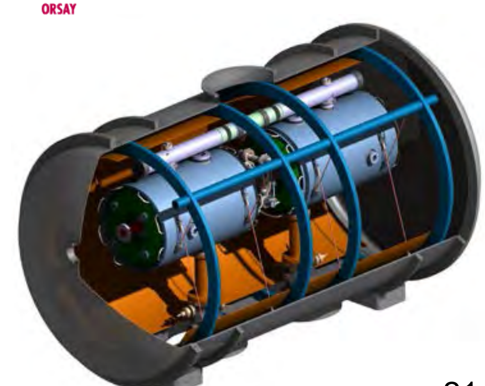
Spoke Cavity & Cryomodule

- IPN Orsay design
  - single spoke
  - f_0 = 352.21 MHz
  - T_{oper} = ~2K
- Phase 1: Bare cavity test
  - with antenna (and helium tank)
  - low power
  - verify Orsay measurement at FREIA
- Phase 2: Dressed cavity test
  - with power coupler, tuners
  - full power
  - verify behaviour before ordering series
- Phase 3: Cryomodule & valve box test
  - full power on both cavities
  - verify behaviour before ordering series





deformation



The FREIA Laboratory

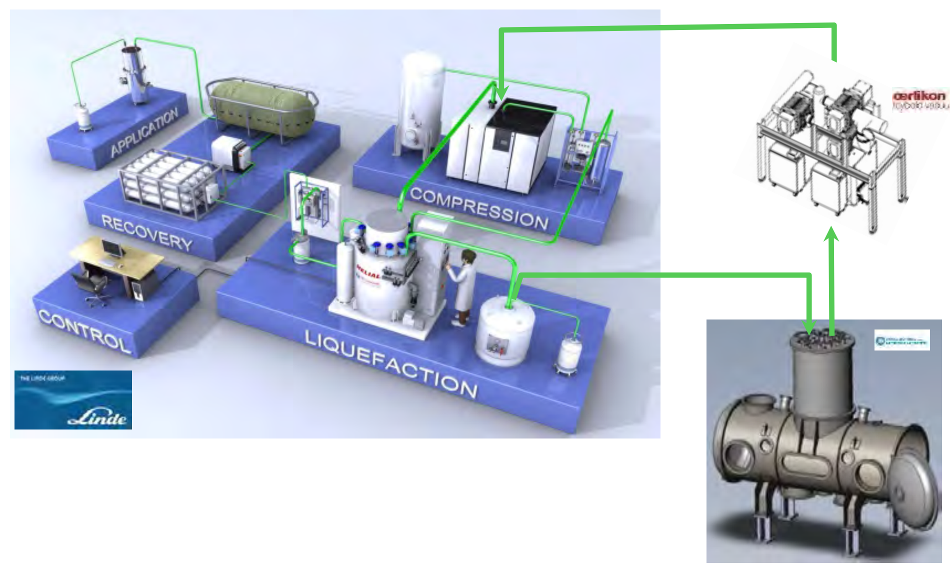
Photos courtesy T. Thörnlund & R. Santiago Kern/UU

Cryogenics

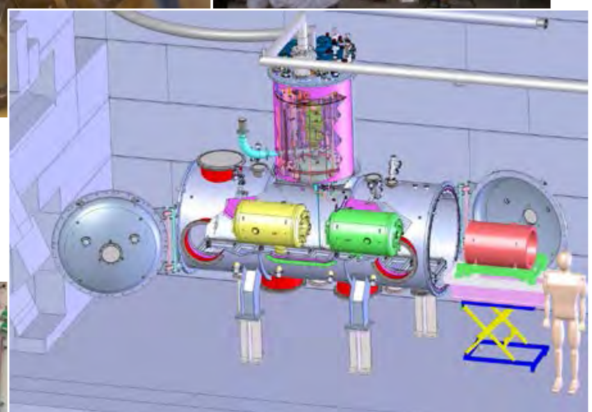
Cryogenic System

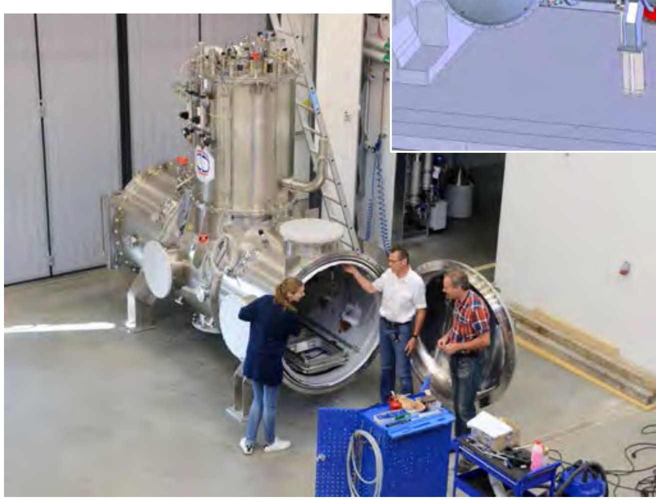
Commercial tender

- Over 150 l/h at 4.5K (LN2 pre-cooling)
- 2000 l LHe dewar/buffer, 3+1 outlets
- 20 m3 LN2 tank
- 100 m3 gasbag + recovery system
- HNOSS connected in closed loop



HNOSS Horizontal Cryostat





HNOSS: Horizontal Nugget for Operation of Superconducting Systems

Commercial tender

- Main Vacuum Vessel
  - 3240 x ø1300mm inner volume
  - “beam” axis at 1600mm
- Valve box (on top of main vessel)
- Interconnection box (ICB)
  - Distributes cryogens to HNOSS and CM
- Cryogenic transfer lines
  - LN2 and LHe
- Gas heater for return GHe
  - from 2K to 300K
- Control system

\+ mock-up cavity for acceptance test

High Power RF Amplifier

Tetrode based

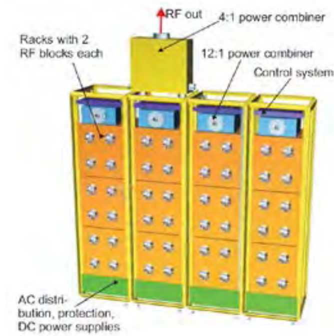
Commercial tender

- based on 2x TH-595, water+air cooled
- SSA pre-amplifier
- crow-bar with fast solid-state switches
- commercial power supplies

Solid-state based

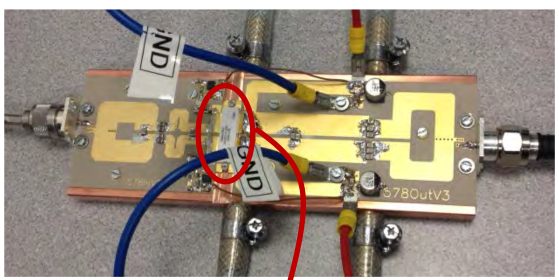
Industry development

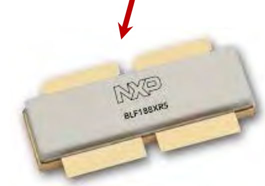
- 4x 100 kW 19” racks
- vendor-specific combiners
  – different per stage



In-house development

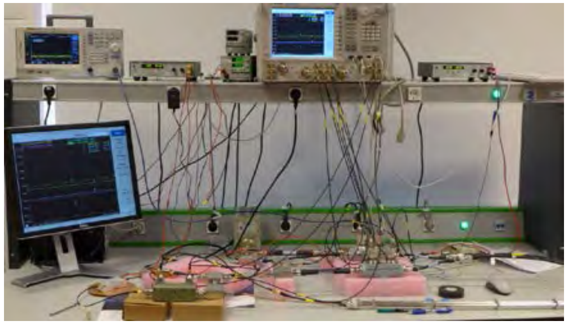
- optimized 1 kW transistor modules
- 100 kW compact combiner
- 10 kW prototype amplifier



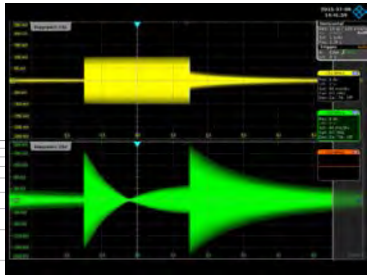


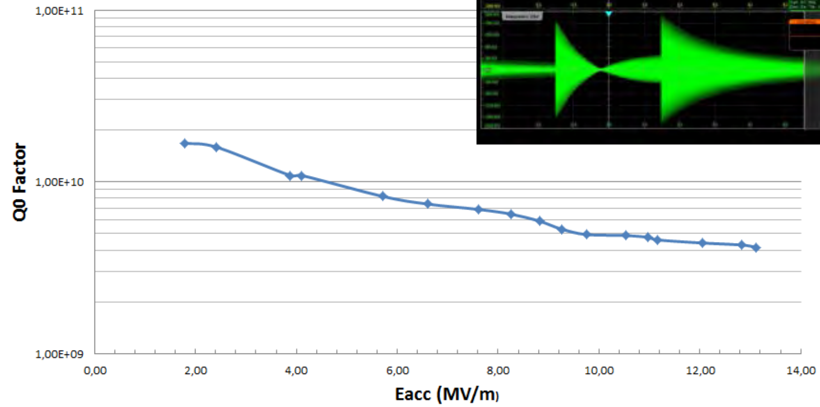
Preliminary Results Germaine Cavity

- Using self-excited loop

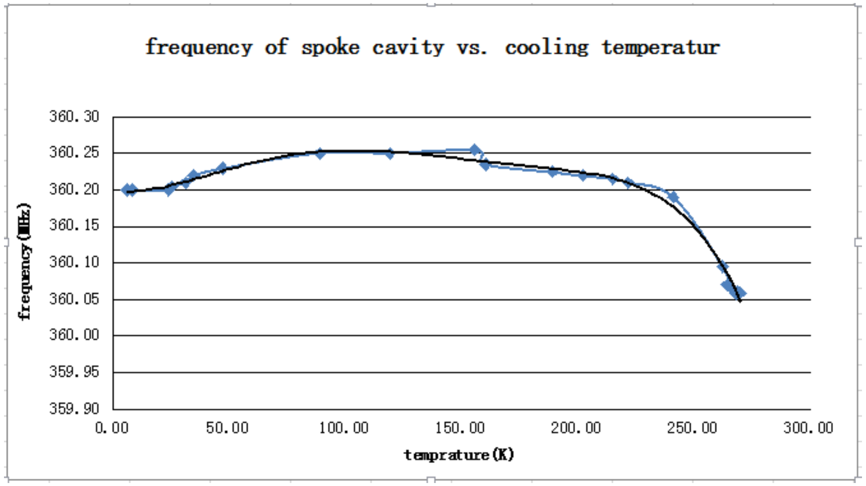


- Q0 vs Eacc

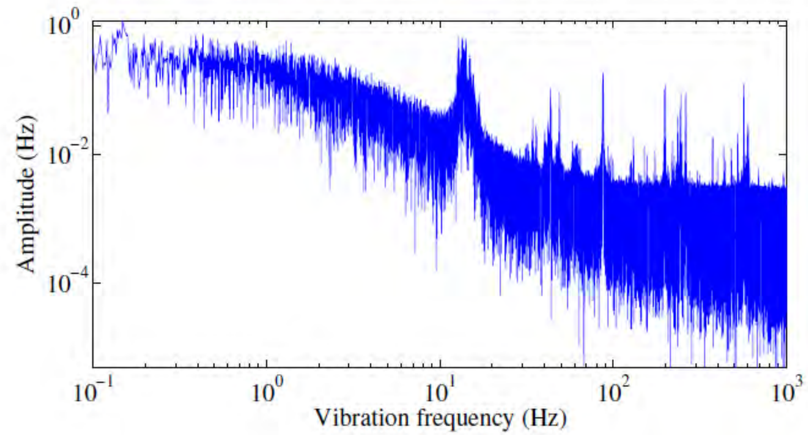




- Resonance frequency
  - 4.2K: 352.033MHz
  - 1.8K: 352,029MHz



- Microphonics
  - 14 Hz resonance ??



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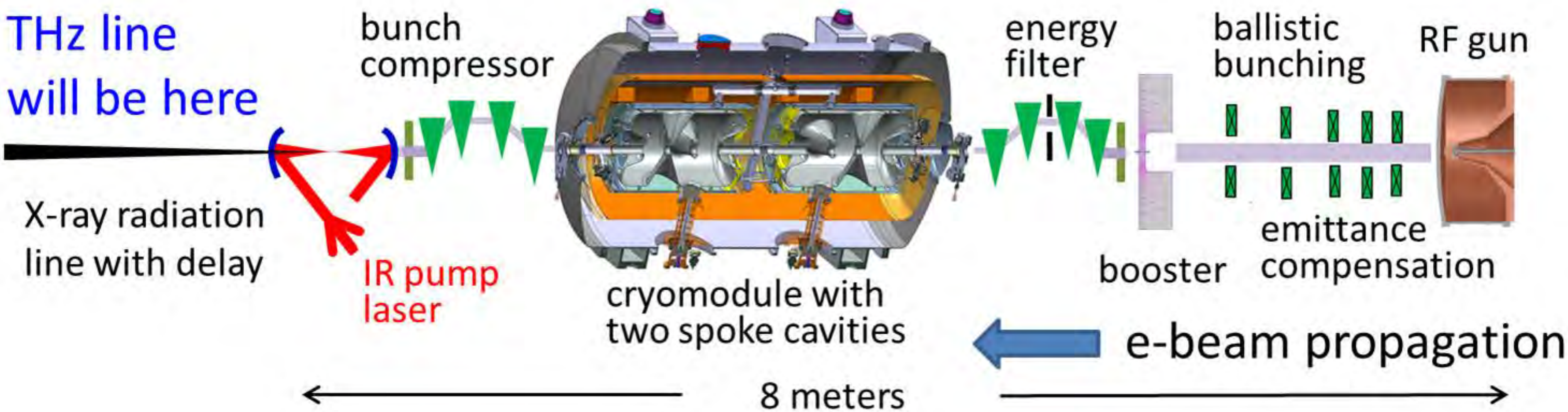
The Bright Future...

- Now we have
  - FREIA Laboratory
  - Stockholm-Uppsala FEL Centre
  - experience from NC-RF and SRF; XFEL participation
- Volker Ziemann and Atoosa Meseck wrote a memo in 2012 suggesting to consider a smaller THz FEL
  - and that has become popular since...
  - length max. 10-20 m; beam energy 10-20 MeV
  - The FEL center with Mats Larsson as director is now working towards a THz facility as part of FREIA
- MAXlab application for FEL extension was rejected recently
- Volker Ziemann is preparing another memo suggesting to consider a small X-band FEL in the basement of the Biomedical Center (BMC)
  - length max. 300 m; beam energy ~2 GeV

Preliminary Design THz/X-ray Source



IR Laser

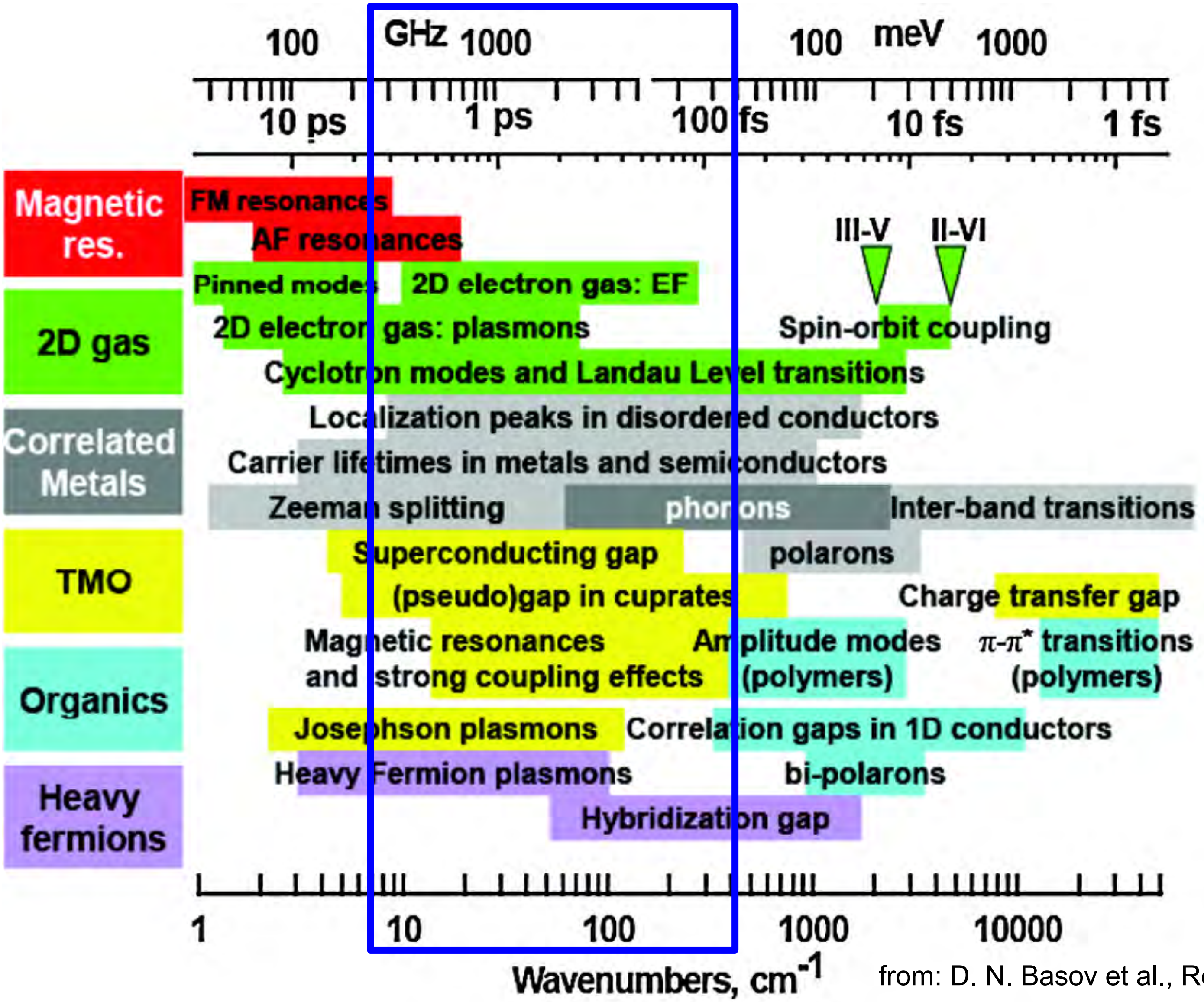
wavelength	um	1.028
duration	ps	0.3
rep. rate	kHz	10
pulse energy	mJ	1
average power	W	10

X-ray yield

photon energy	keV	1.2-4.1
duration	ps	0.3
rep. rate	kHz	10
photons/shot		4400
peak brightness		$2\ 10^{18}$

- Accelerator in CW mode with 10 kHz rep-rate
- Purpose of the Compton source is to complement the THz source for pump-probe experiments though it can also be stand-alone.

Why? Low-energy Excitations

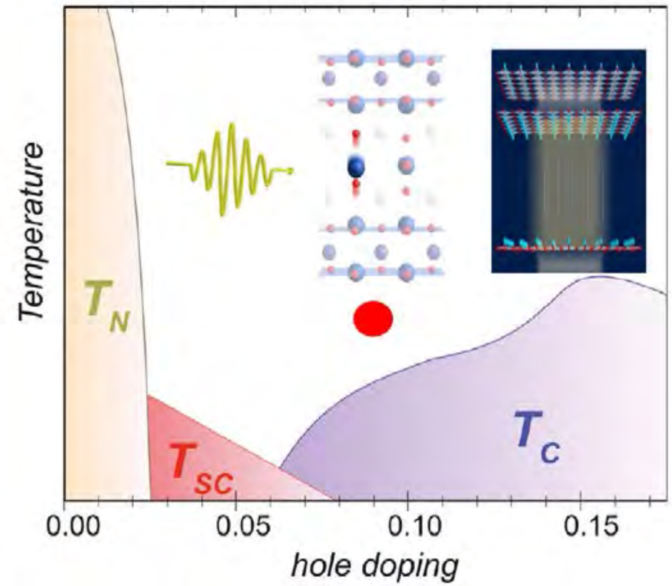


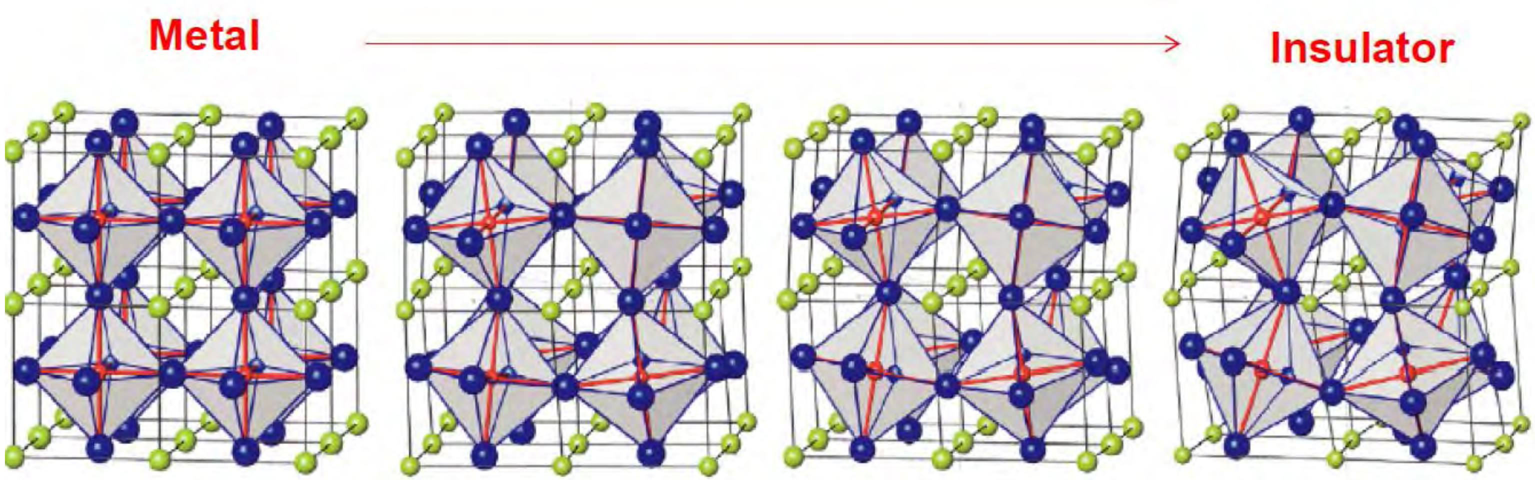
from: D. N. Basov et al., Rev. of Mod. Phys. 2011

New Dynamic Materials

New dynamic materials via control of chemical bonds angles

- Ultra-short THz pulses
  - direct access to low energy excitations
  - no parasitic effects from optical transitions
  - low heat deposit
- Physics
  - THz light induced superconductivity
  - Metal to insulator transitions
  - Giant magnetoresonance





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Wish List Intense THz Radiation

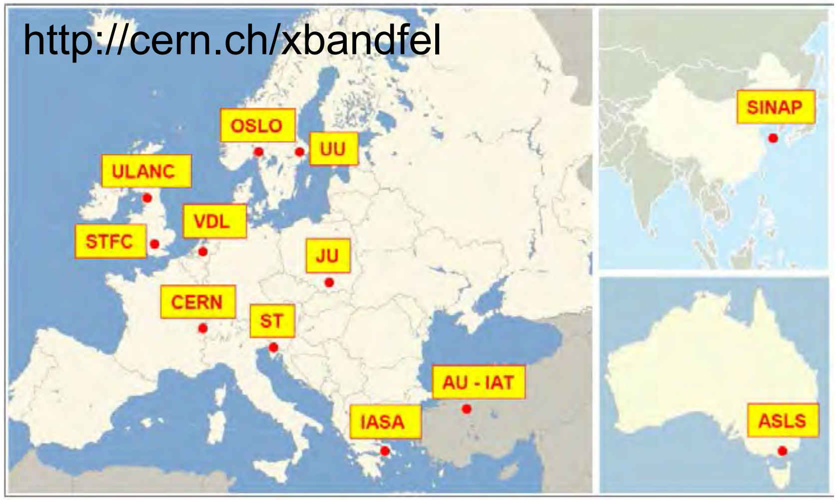
	Half-cycle pulses for time-resolved experiments	Multi-cycle for frequency-resolved experiments
Spectral range [THz]	0.3-30	0.3-30
Pulse duration [ps]	0.1-1	1-10
Energy [uJ]	1000	100
Peak Field [GV/m]	1	0.1
Spectral width [%]	up to 100%	< 10%
Rep. rate [kHz]	1-100	1-100
Polarization control + pulse shape control		
Synchronized optical and X-ray pulses for pump-probe experiments		

The X-band FEL Collaboration

To promote the use of X-band technology for FEL based photon sources

X-band FEL Research & Development

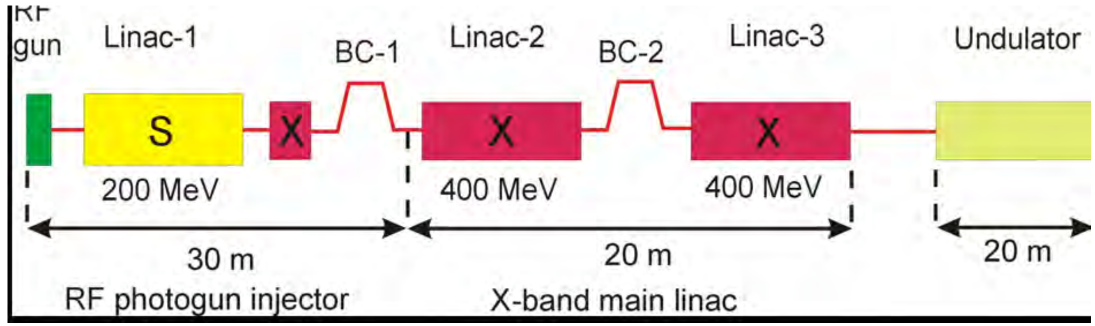
- started with an idea from KVI (NL) to build a small FEL (100m)
  - their proposal was rejected, but the idea is living on
  - demand for new FEL facilities is worldwide continuously increasing, spurring plans for new dedicated machines. This led to a general reconsideration of costs and space issues, particularly for the hard X-ray sources, driven by long and expensive multi-GeV NC linacs.
  - for these machines the use of X-band technology can greatly reduce cost and capital investment, reducing the linac length and the size of buildings, opening the way to the construction of a multitude of affordable "Regional Facilities".



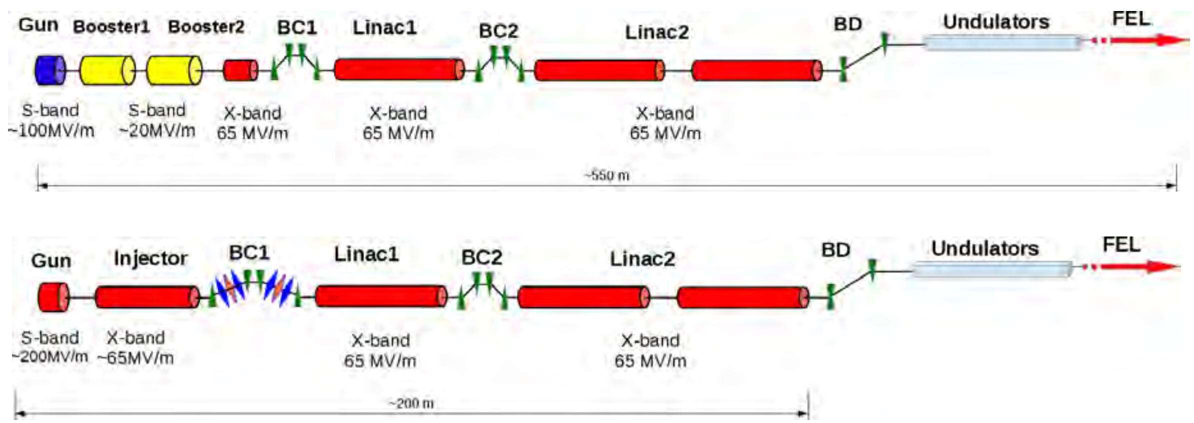
Courtesy of G. D'Auria

XbFEL Layout

- ZFEL proposal (2010)
  - ~100m total length
  - 2.1 GeV beam
  - 0.766 nm wavelength



- XbFEL proposal (2014)
  - 300 MeV injector
    - S-band or X-band for high rep-rate
  - 2 GeV Linac 1
  - 6 GeV Linac 2



- proposing to use CTF3/CALIFES as test bench by converting TBTS to klystron driven line

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Conclusions

Uppsala has a long history and is active in several collaborations

- cyclotron will be shut down soon, but
- several exciting projects ongoing, and
- FREIA has opened new opportunities for unique scientific projects
- dreaming to construct a small FEL
  - but in need of a good science case, a "killer app"

Thanks to my colleagues in the different collaborations, at the Dept. of Physics & Astronomy and the FREIA Laboratory.