Development of Room Temperature and Superconducting CH-Structures for High Power Applications

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Overview

- H-mode cavities – CH-structure
- room temperature (rt) CH-structure (FAIR p-linac)
- superconducting (sc) CH-structure
- Projects (EUROTRANS, IFMIF)

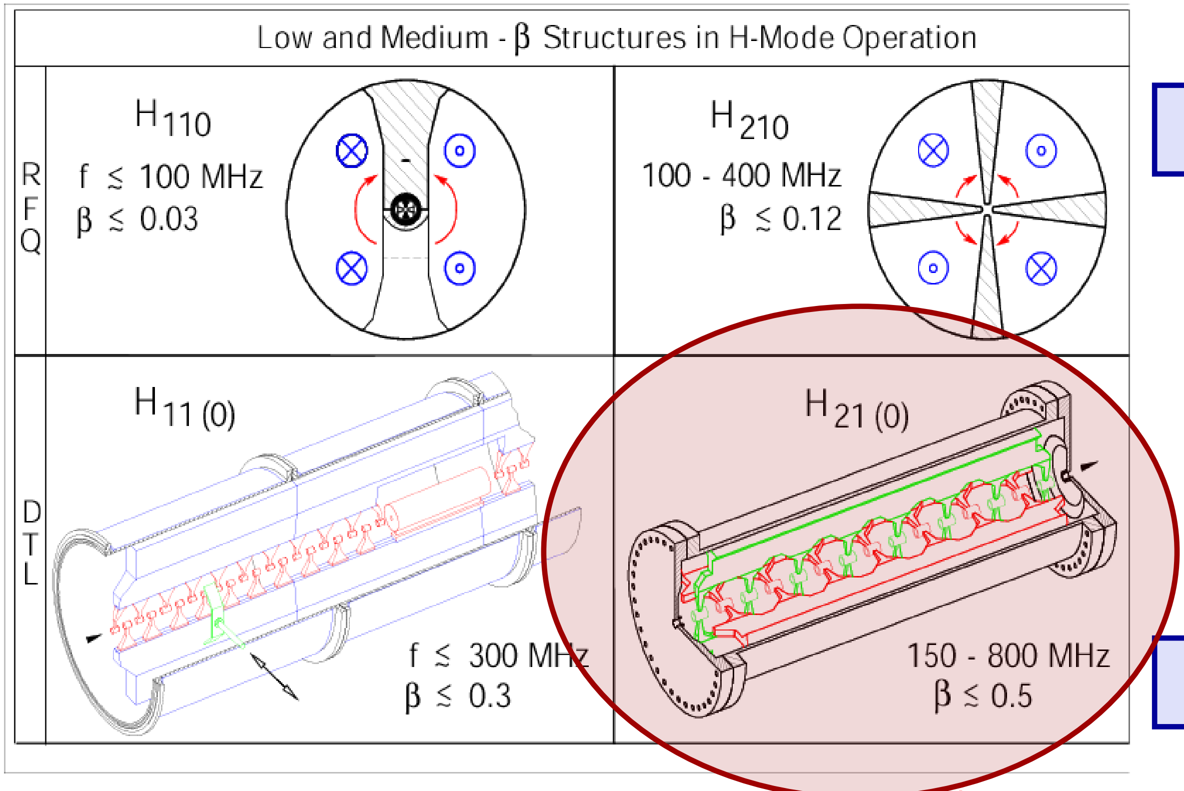
The Family of H-mode cavities (H_{11}, H_{21})

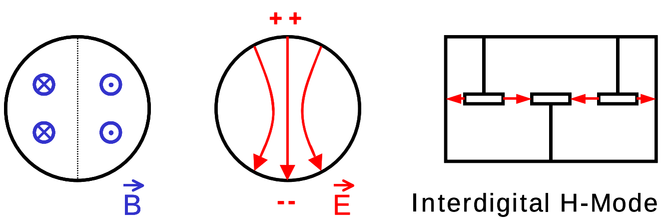
IH-RFQ

4-Vane RFQ

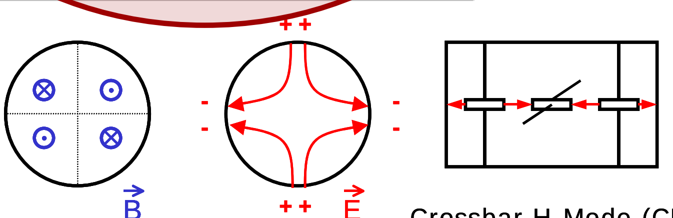
IH-Structure

CH-Structure





Interdigital H-Mode (IH)

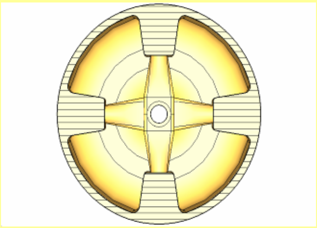


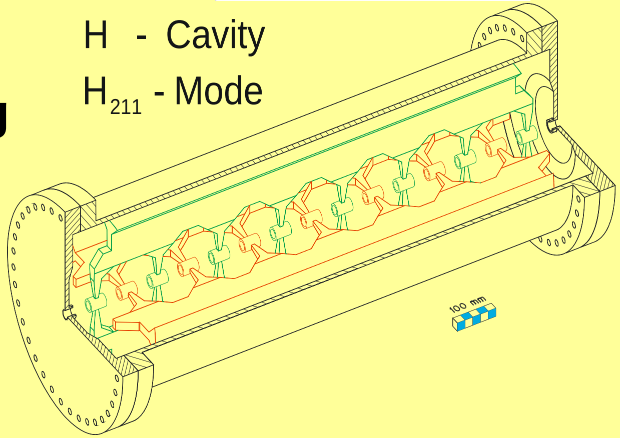
Crossbar H-Mode (CH)

The CH-Structure

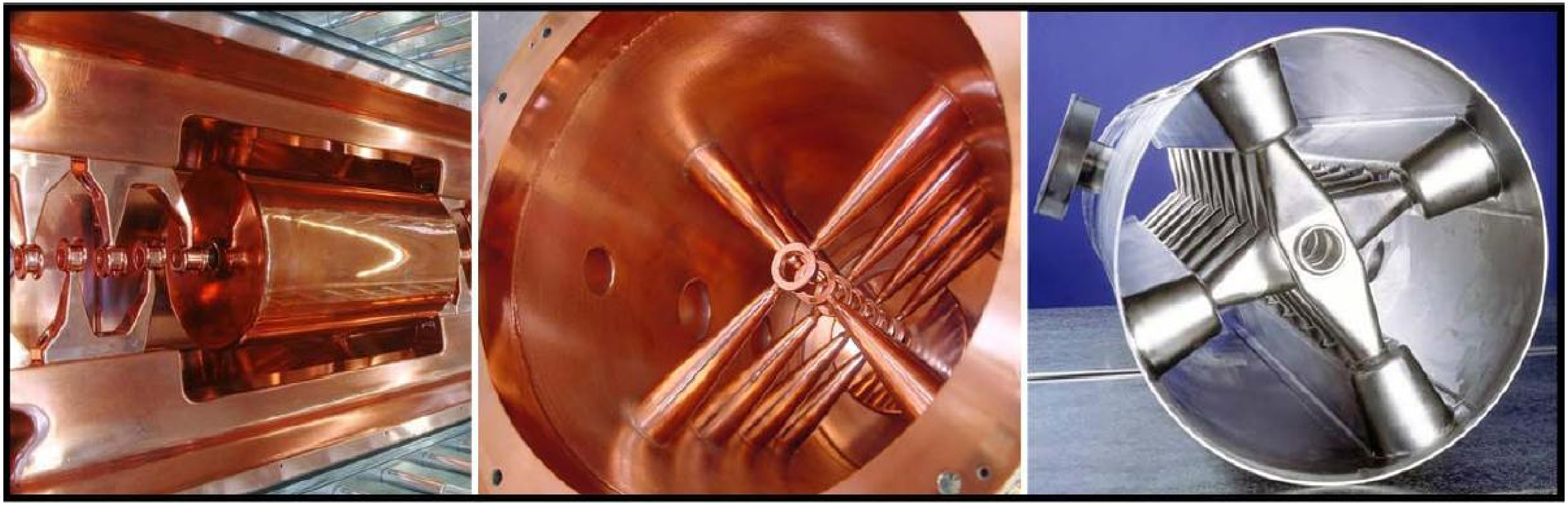
Cross-Bar H-Mode-Structure

- High efficiency (Z) for low and medium energies (3-100 AMeV)
- Homogeneous distribution of losses
  → Good cooling possibilities
- Possible cw operation
- Use of KONUS → Less rf defocusing
  → long lensfree sections
- High real estate gradients
- High mechanical stability
- Room temperature- and superconducting operation



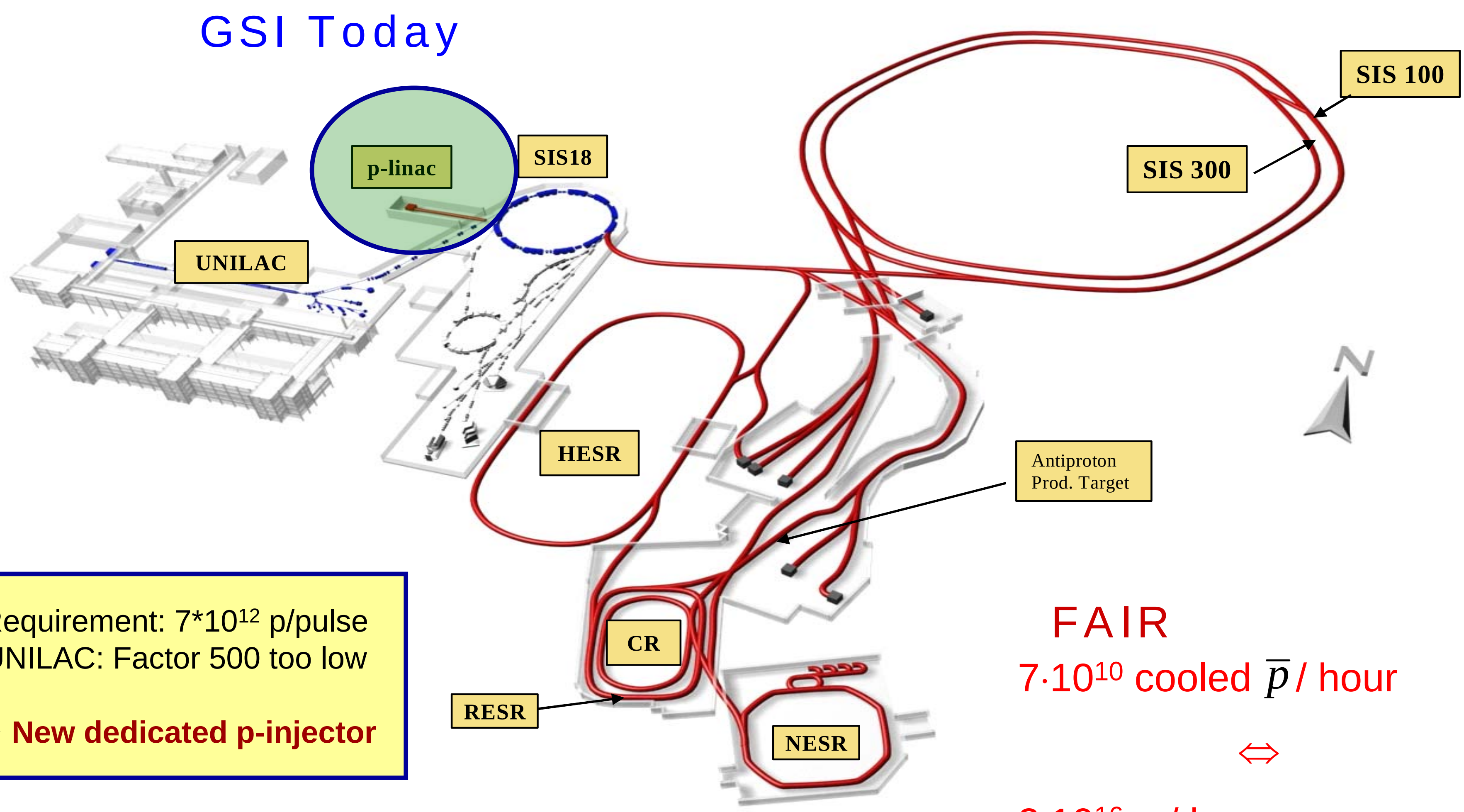


H-mode DTL- cavities



rt IH	rt CH	sc CH
E< 30 AMeV 30<f<250 MHz	E< 100 AMeV 150<f<700 MHz	E< 100 AMeV 150<f<700 MHz

FAIR: Facility for Antiproton and Ion Research



Requirement: 7*10^12 p/pulse
UNILAC: Factor 500 too low

→ **New dedicated p-injector**

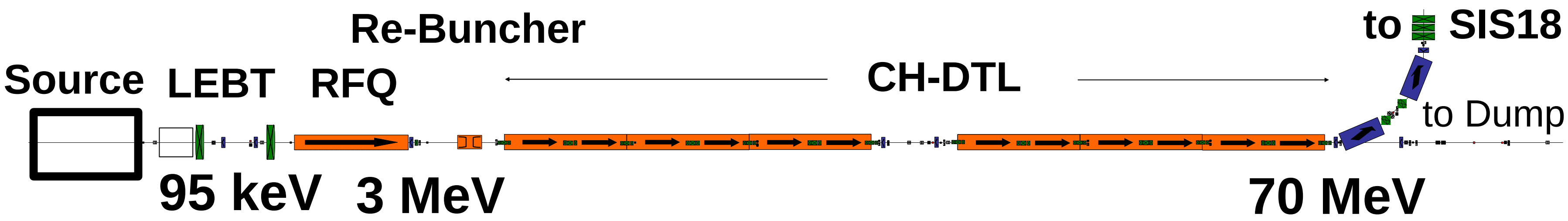
FAIR

$7 \cdot 10^{10}$ cooled $\bar{p}$ / hour

⇔

$2 \cdot 10^{16}$ p / hour

FAIR proton-linac

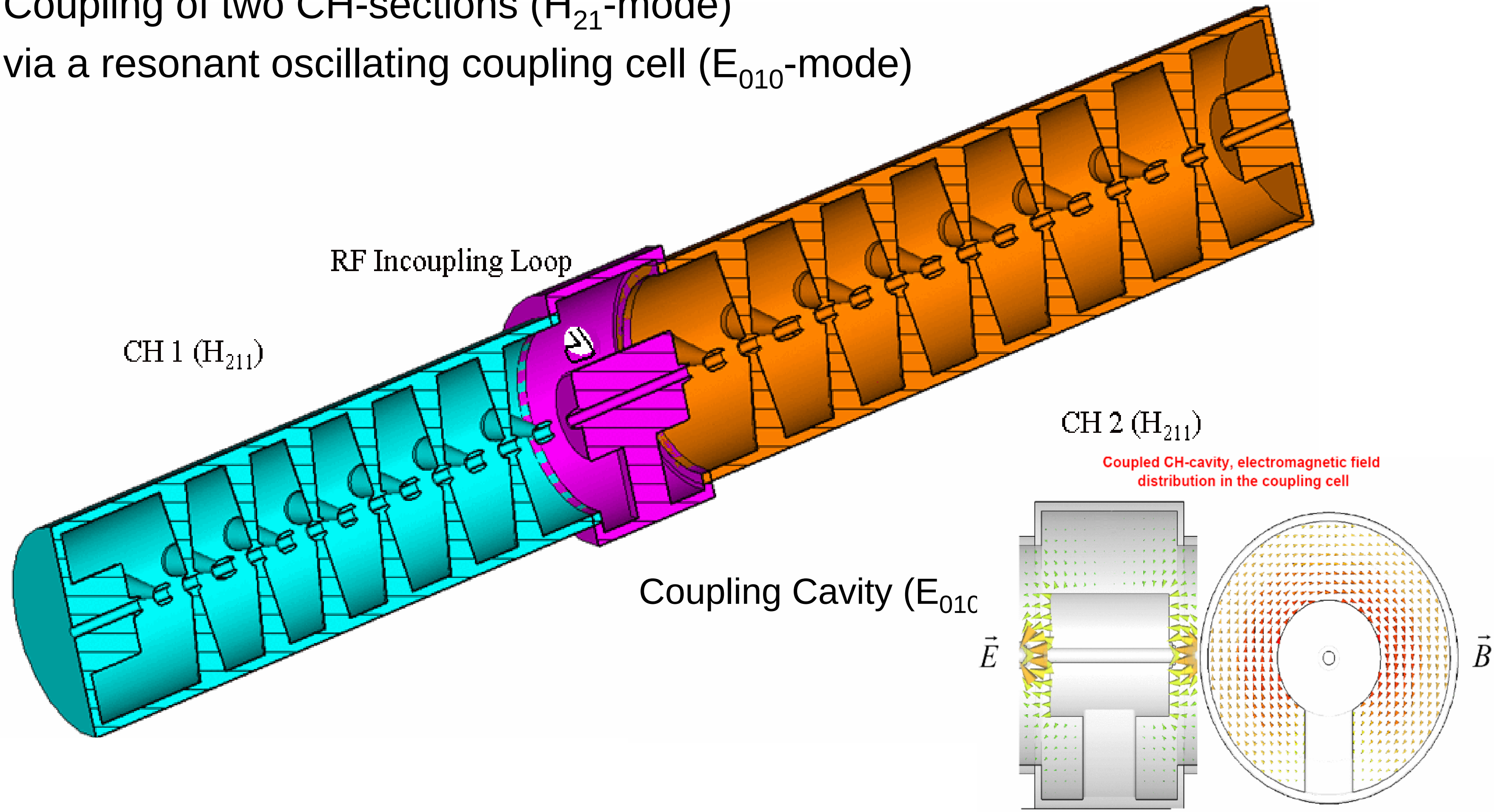


Particles	Protons	RF drivers (6x)	2.5 MW Klystrons
Current (mA)	70	Pulse power (MW)	4.9
Energy (MeV)	70	Beam pulse length (μs)	36
Frequency (MHz)	325.224	Repetition rate (Hz)	4
RF structures (6x)	r.t. CCH	Linac length (m)	25

High gradients (3-7 MV/m), low duty cycle → r.t. CH-structures

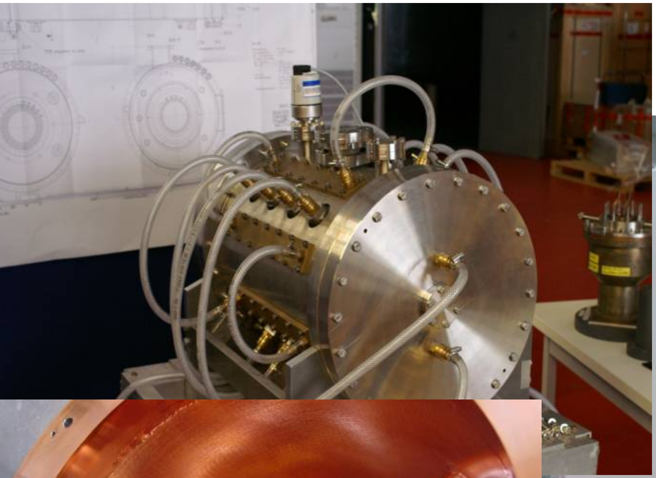
The Coupled CH (CCH)

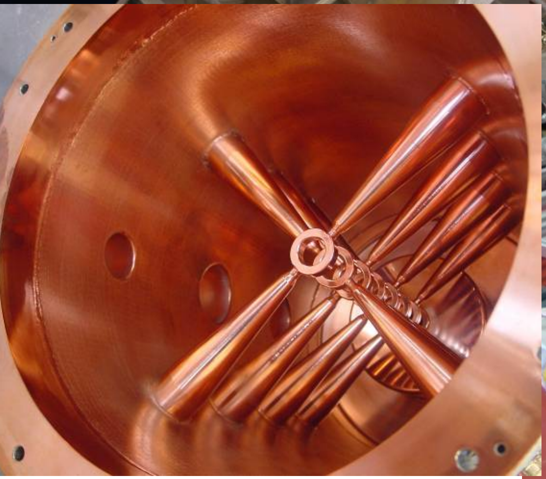
Coupling of two CH-sections (H_{21}-mode)
via a resonant oscillating coupling cell (E_{010}-mode)

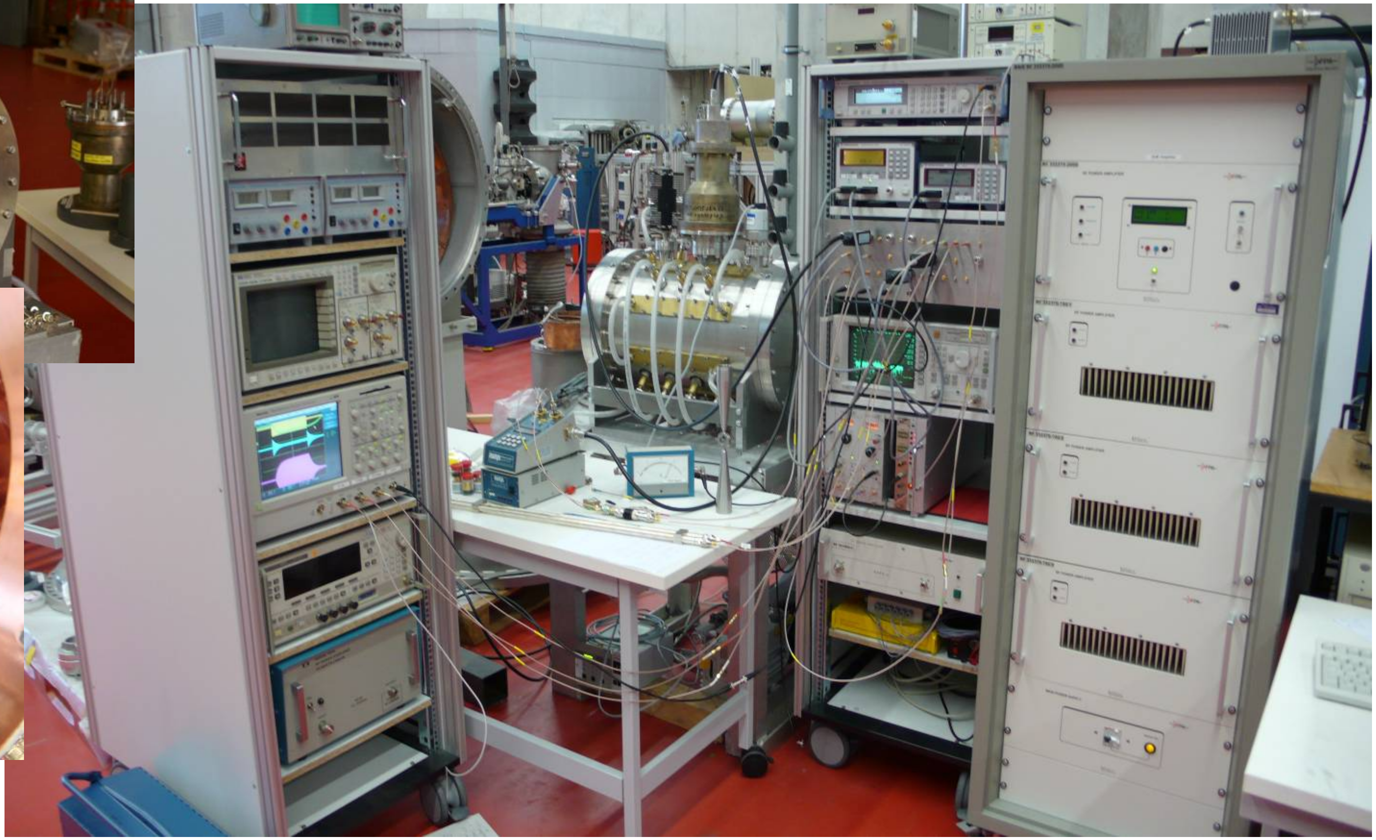


Coupled CH-cavity, electromagnetic field distribution in the coupling cell

r.t. CH-prototype Test Setup







The 2 kW level (4kW/m, ~ 310 kV) has been reached within 20 minutes

Measured Q_0: 13000 (95 % Ideal MWS Value)

Motivation for the Development of the Superconducting CH-Structure

Several fixed velocity accelerators with cw operation are under discussion
(i.e. Spallation neutron sources, IFMIF, Transmuter, isotope production...)

→ Superconducting operation

→ lack of efficient superconducting low β cavities, whereas efficient means large energy gain per cavity

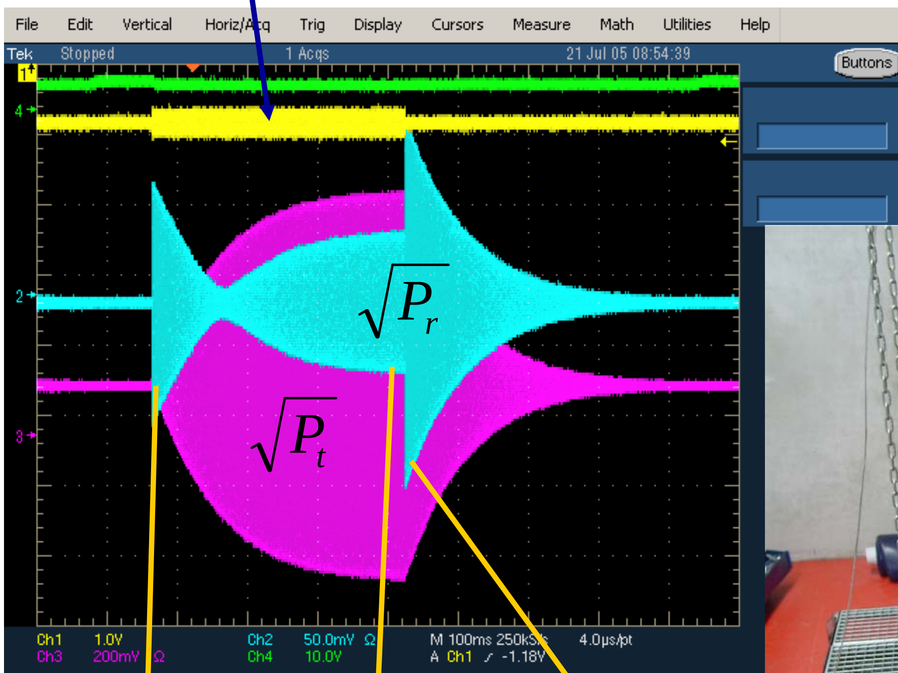
Superconducting CH-Prototype

The first low energy s.c. **multi cell** cavity

Gap number	19
Length (mm)	1048
Frequency (MHz)	350
β	0.1
E_p/E_a ($\beta\lambda$-definition)	5.2
B_p/E_a (mT/(MV/m))	5.7
$G=R_sQ_0$ (Ω)	56
R_a/Q (Ω) (T incl.)	3180
$(R_a/Q)G$ (Ω^2)	178000
Q_0 (BCS, 4.4K, 352 MHz)	1.5×10^9
W (mJ/(MV/m)^2)	155

Cryogenic Test of the sc CH-cavity

$\sqrt{P_f}$



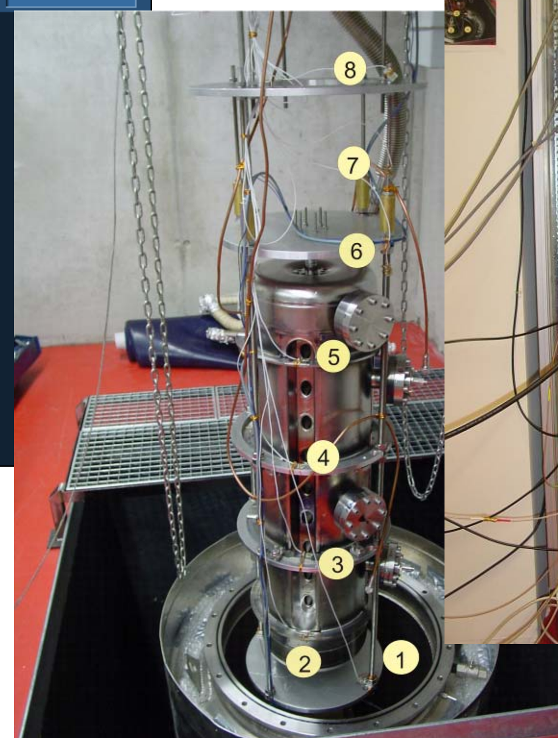
$\sqrt{P_r}$

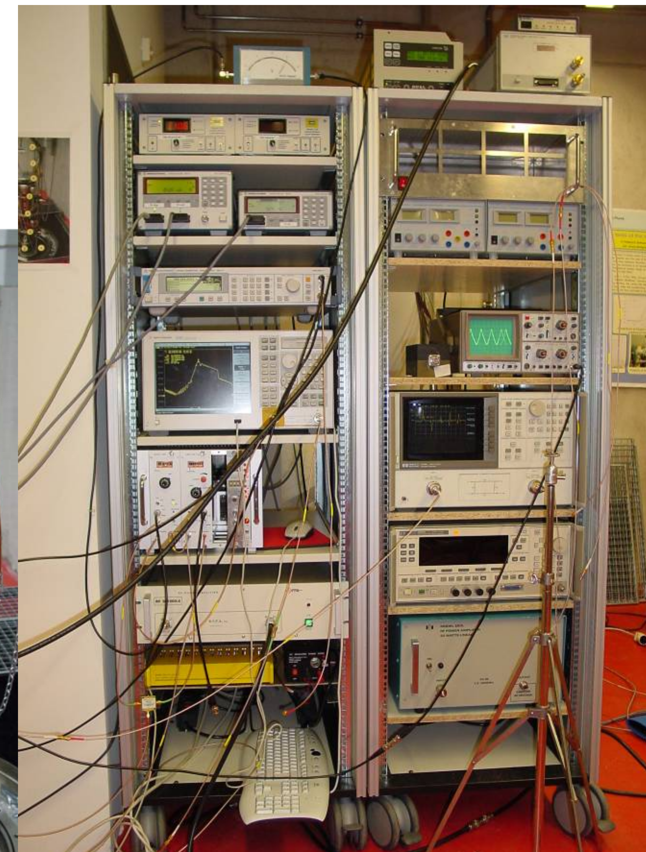
$\sqrt{P_t}$

$$\sqrt{P_{on}} = \sqrt{P_f}$$

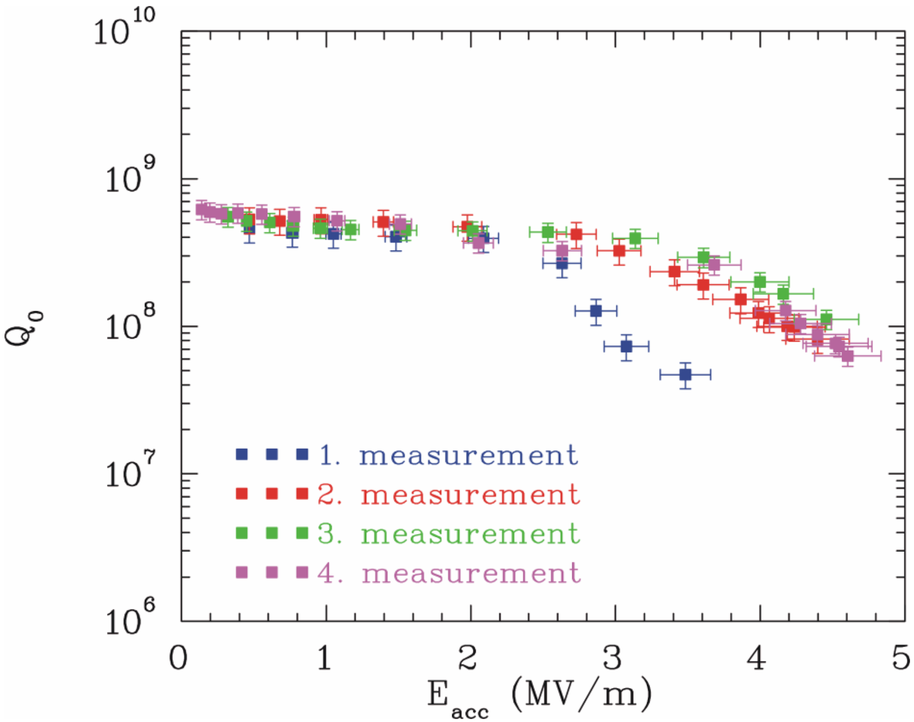
$$\sqrt{P_r}$$

$$\sqrt{P_{off}} = \sqrt{P_e}$$

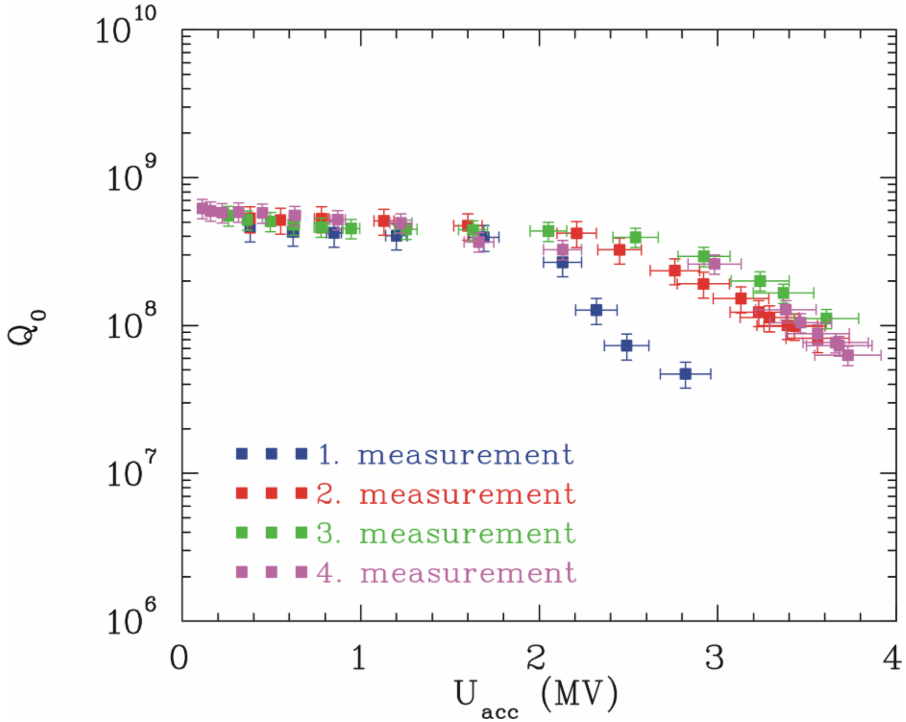




Q_0 versus Gradient and Voltage



Gradient



Voltage

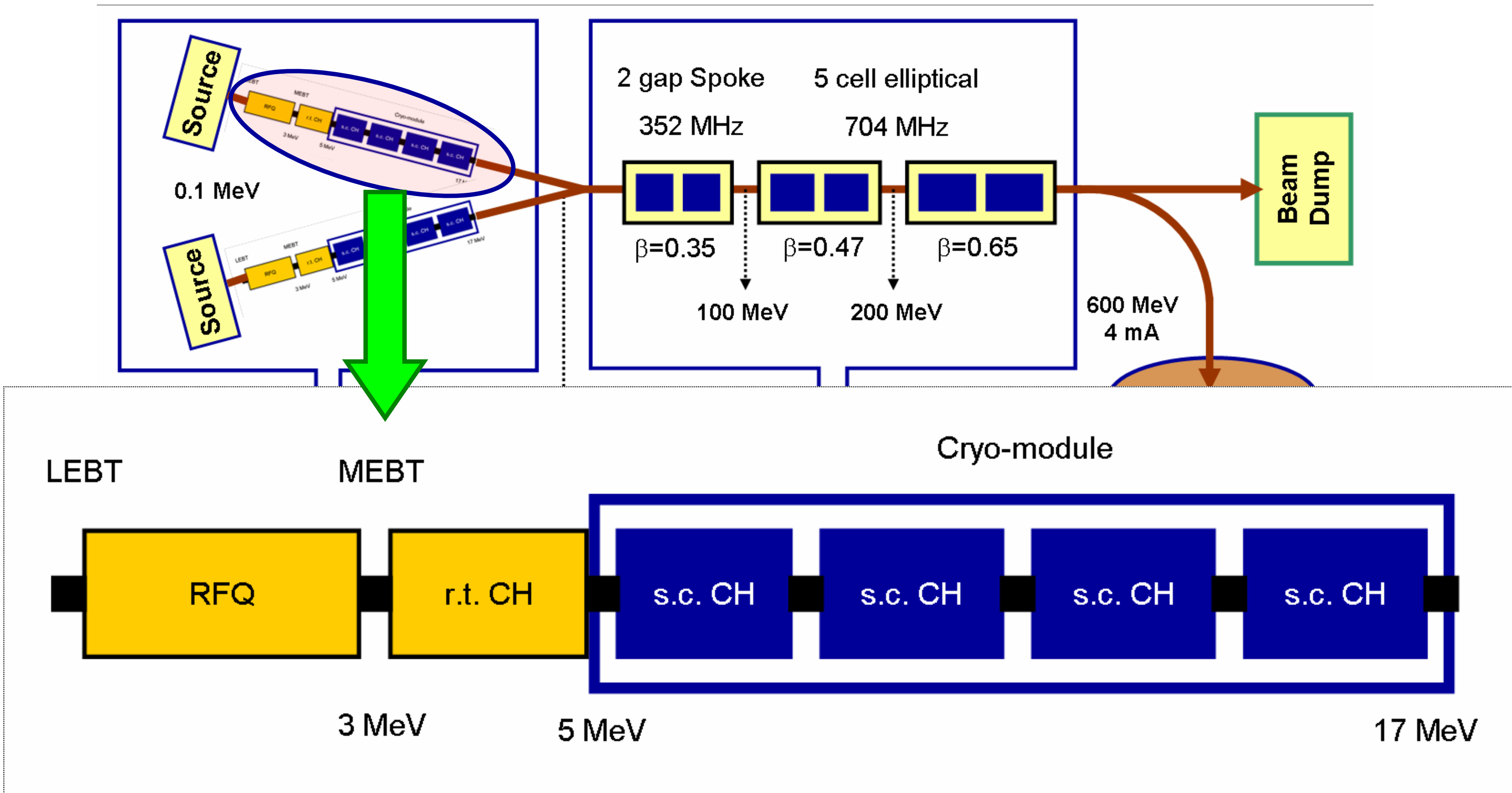
L=n/2βλ=9.5βλ

Projects and possible applications (sc CH)

EUROTRANS (Nuclear waste transmutation)

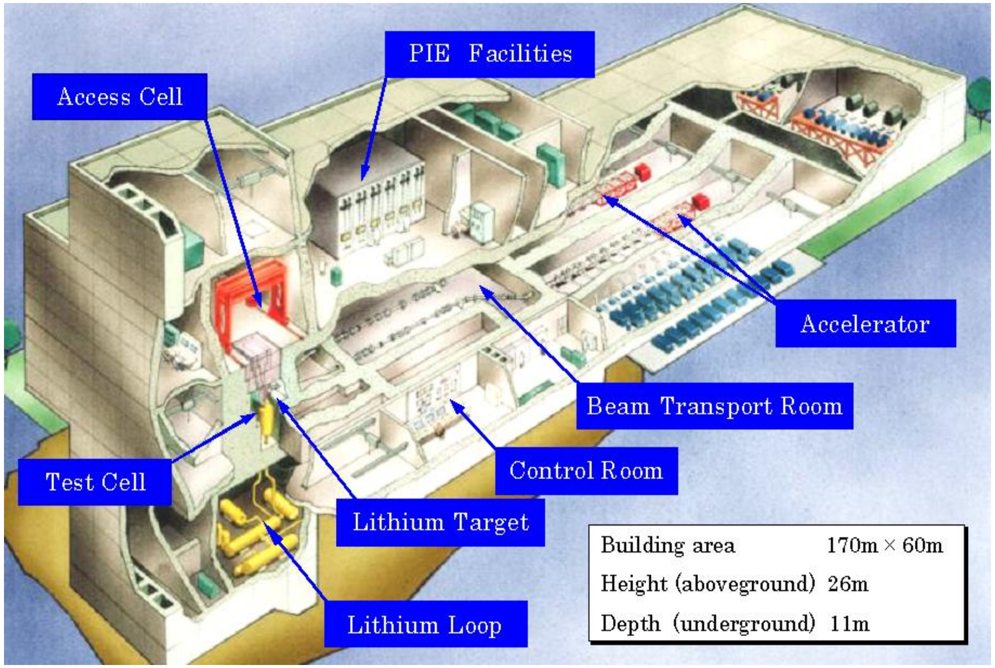
IFMIF (Fusion material research)

A CH-Injector for XADS/EUROTRANS



IFMIF

International Fusion Material Irradiation Facility

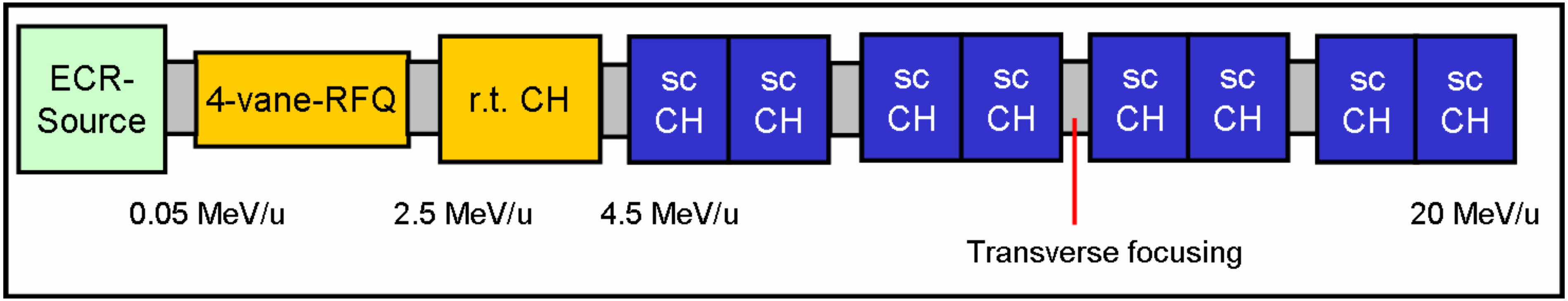


- High flux source of fast neutrons
- Development of new material for fusion reactors
- Up to 100 dpa/fpy
- Liquid Li target

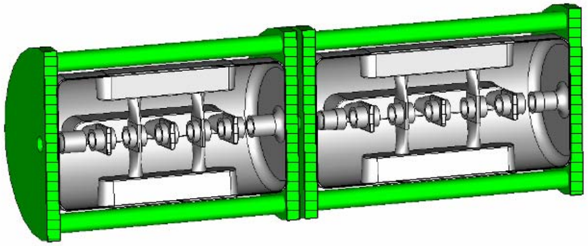
Reference design: Alvarez!

- Beam: 40 MeV Deuterons
- Beam current 2x125 mA
- Beam power: 10 MW
- Duty cycle 100%
- RFQ/CH combination with 175 MHz

r.t./s.c. CH-linac for IFMIF



- One room temperature H-mode cavity (2.5-4.5 AMeV)
- 8 superconducting CH-cavities (per linac)
- Sc cavity RF power: 30 W
- Static losses: 20 W per cavity
  → 800 W@4K →
- 3 Cryo plants (500 W each) for IFMIF, 2 in operation ,1 stand by
- Beam loading per cavity 400-500 kW
- Power couplers: 2 coaxial-couplers per cavity with 250 kW



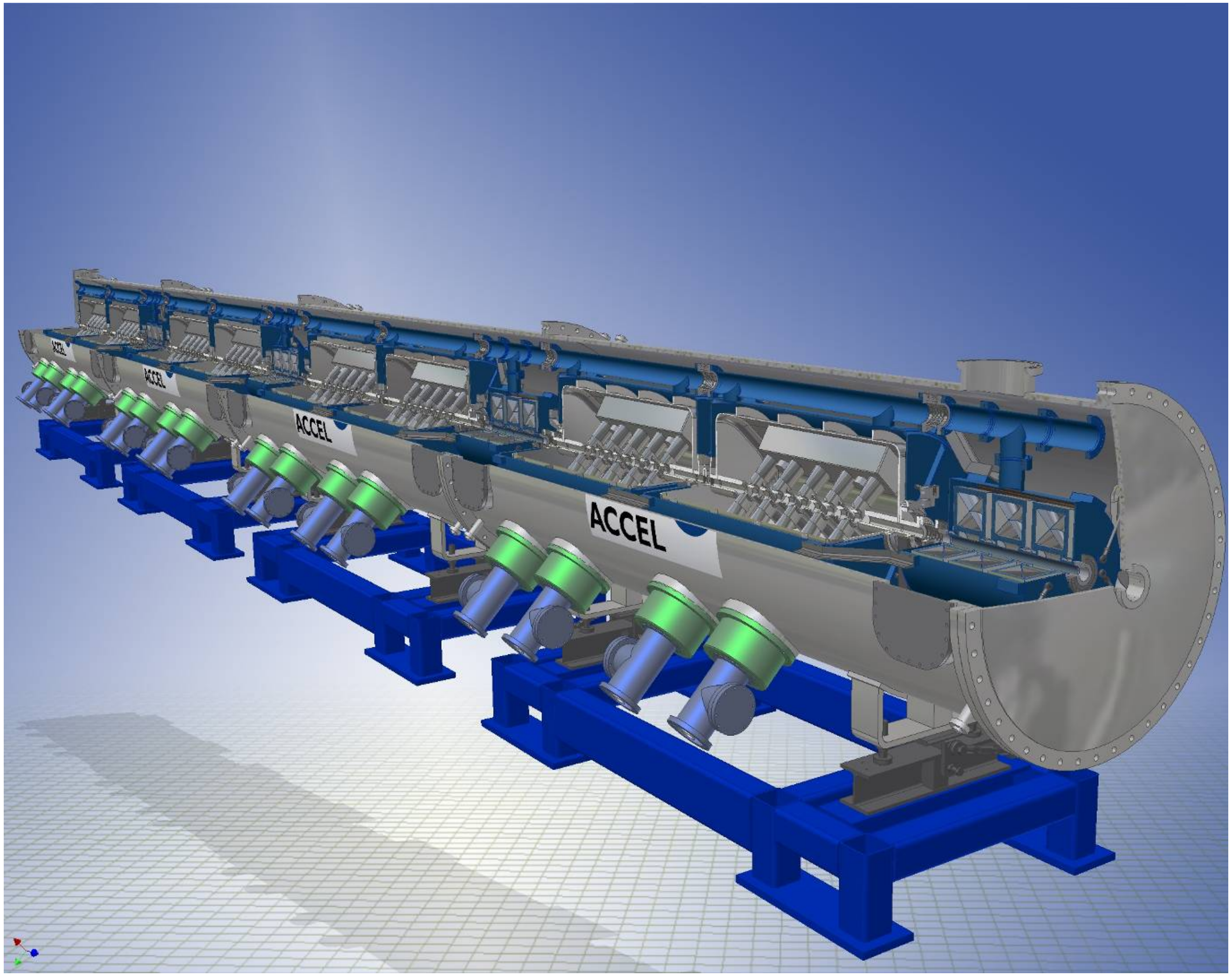
s.c. cavity doublet with tuner

Main advantages

Stable cw operation without thermal problems

Significant operational cost savings: 5 MW → 45 Mio kWh/a

IFMIF IAP Proposal: sc CH-Linac



People

U. Ratzinger	C. Clemente
H. Klein	R. Tiede
H. Podlech	M. Busch
H. Liebermann	F. Dziuba
C. Zhang	D. Bänsch
A. Bechtold	I. Müller

Conclusion

- The CH-structure is a very efficient DTL-Structure

  → larger real estate gradient, smaller number of sub-systems

  → reliability, cost reduction

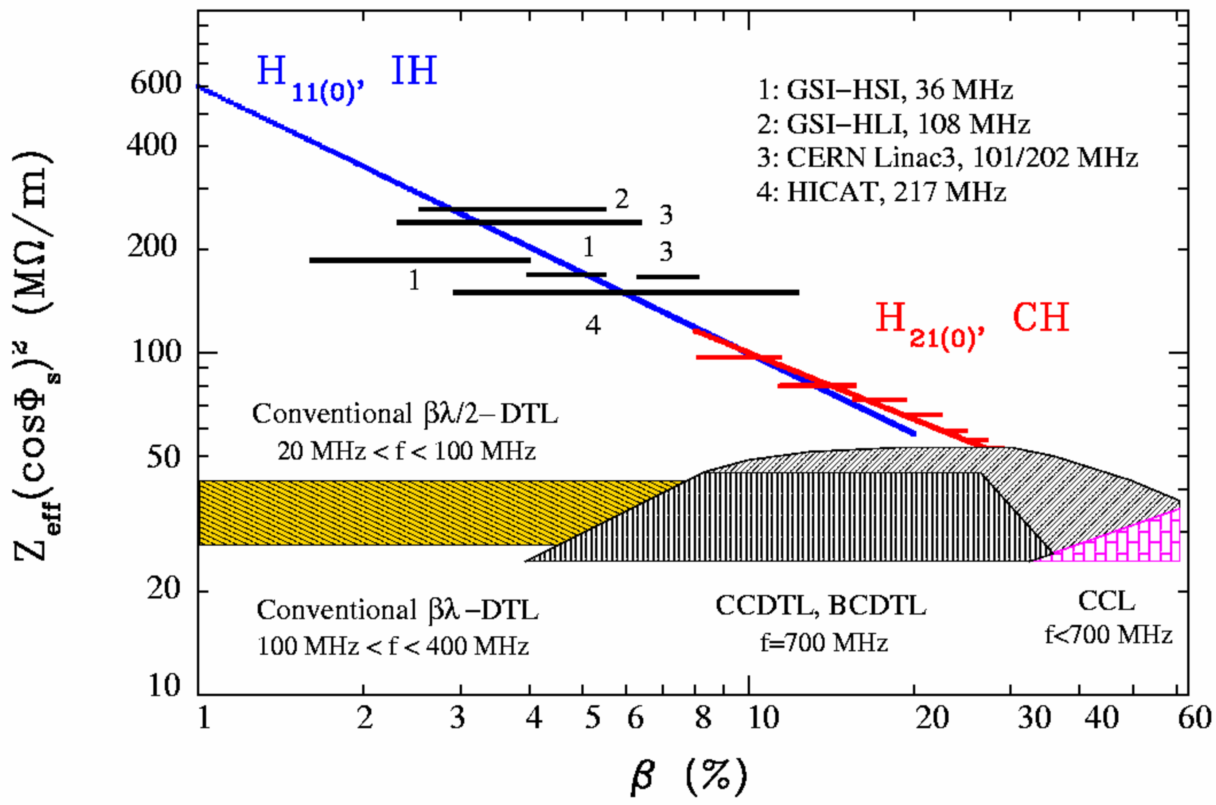
- Suitable for room temperature and superconducting operation

- Prototypes have been developed and tested successfully

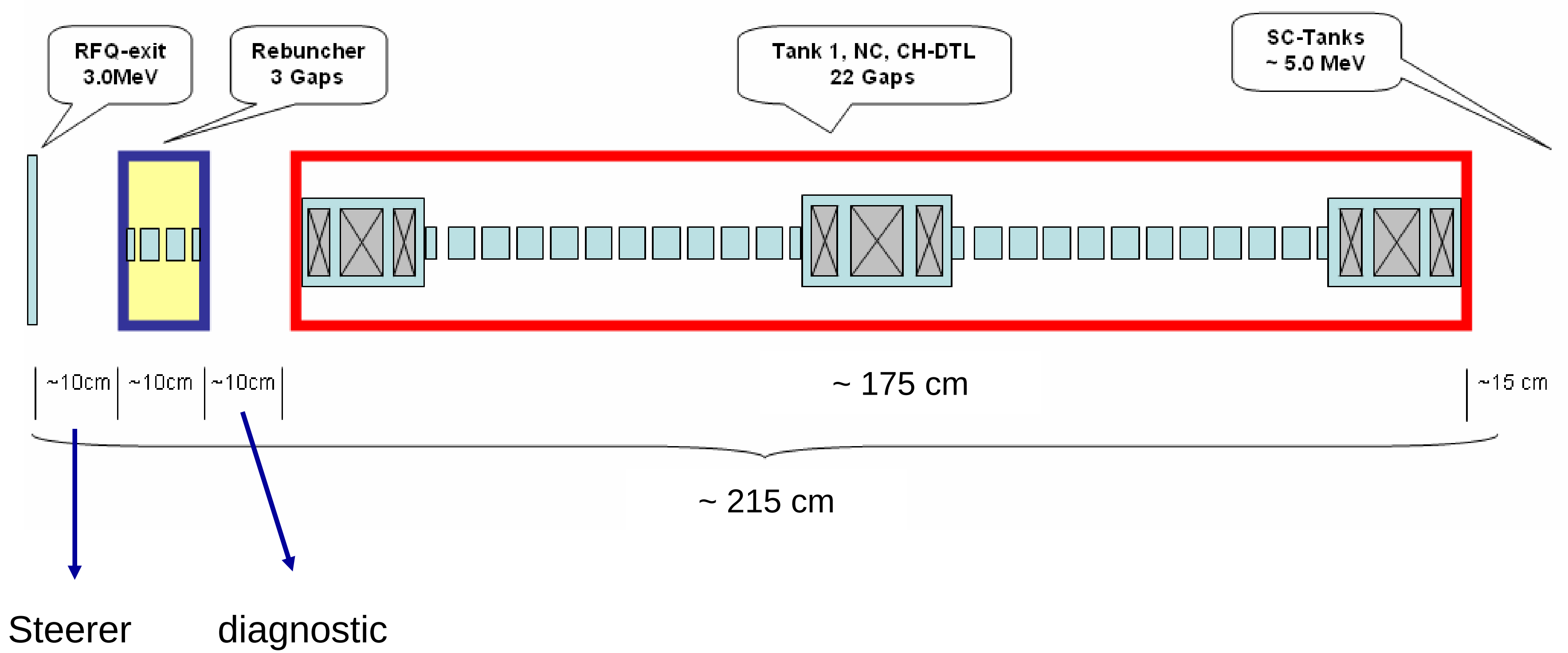
- Projects: FAIR p-linac, EUROTRANS, IFMIF

Thank you for your attention

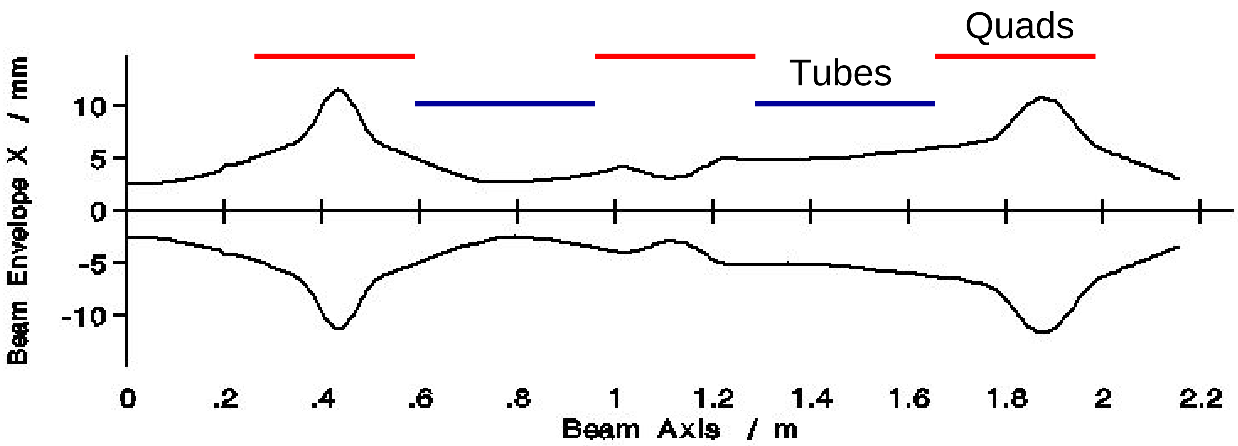
Effective Shunt Impedance of DTL-Cavities

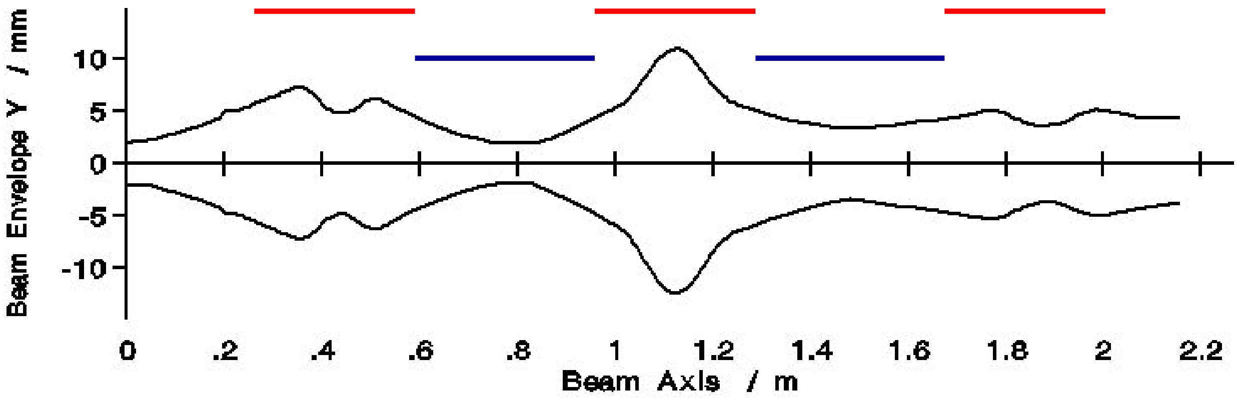


r.t. CH-cavity and MEBT for EUROTRANS



Envelopes r.t. CH-cavity





Beam Dynamics (KONUS)
Code: LORASR

KONUS (Combined Zero Degree Structure)

0-degree-sections reduce rf defocusing
→ Less focusing elements required
→ long lens free sections
→ slim drift tubes →
→ high shunt impedance

→ Strong triplet-channel