A Dedicated β-beam Linac concept

presented by

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Involved key persons:

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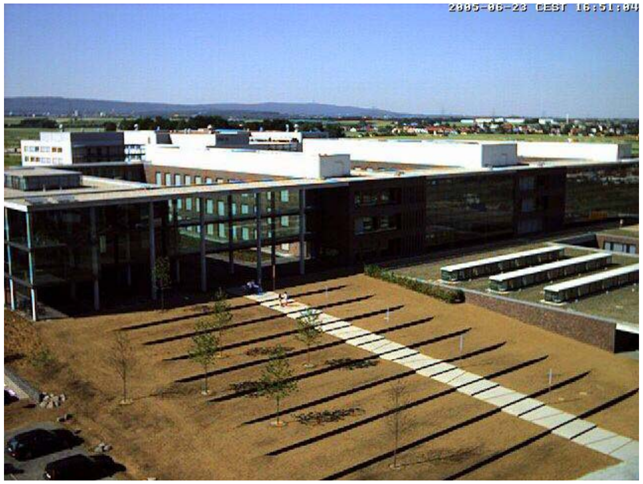
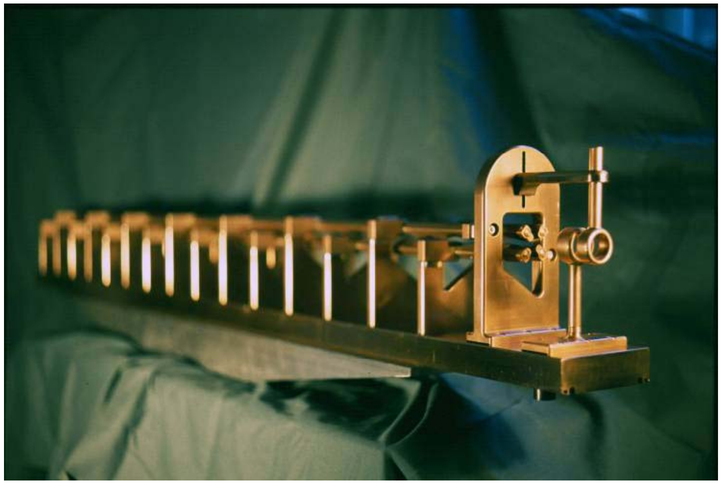
Outline

- Introduction (current activities at the IAP)
- A n.c. RFQ injector for EURISOLs post accelerator (task 6)
- Existing light ion linac concepts (SNS, CERN, GSI)
- Advantages of H-mode Cavities
- Our 1st order β-beam linac concept
- RFQ for β-beams (first beam dynamics)
- Conclusion

Introduction



New building



Medicine RFQ

SARAF CW RFQ

Medicine IH

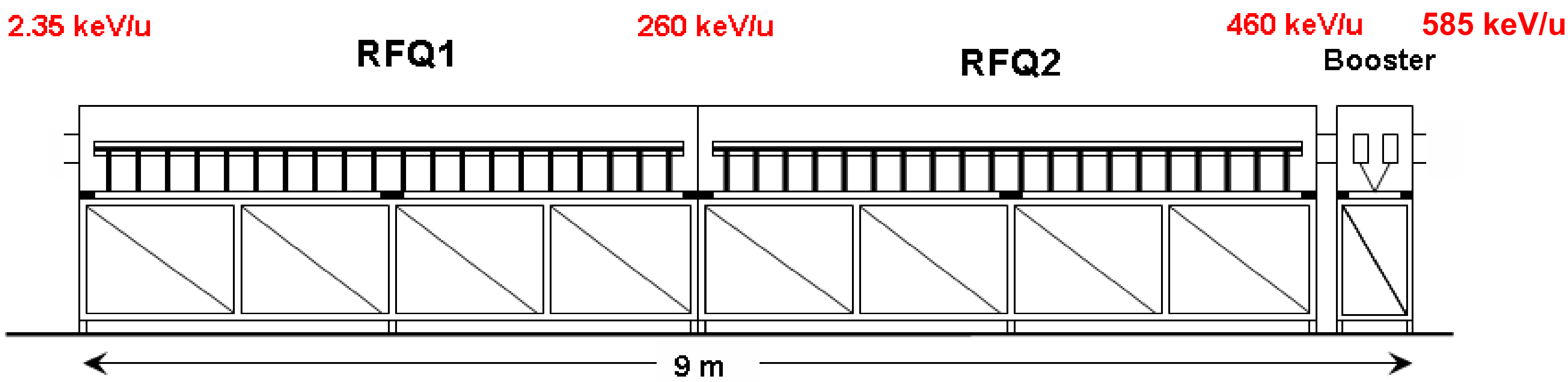
MAFF IH-RFQ

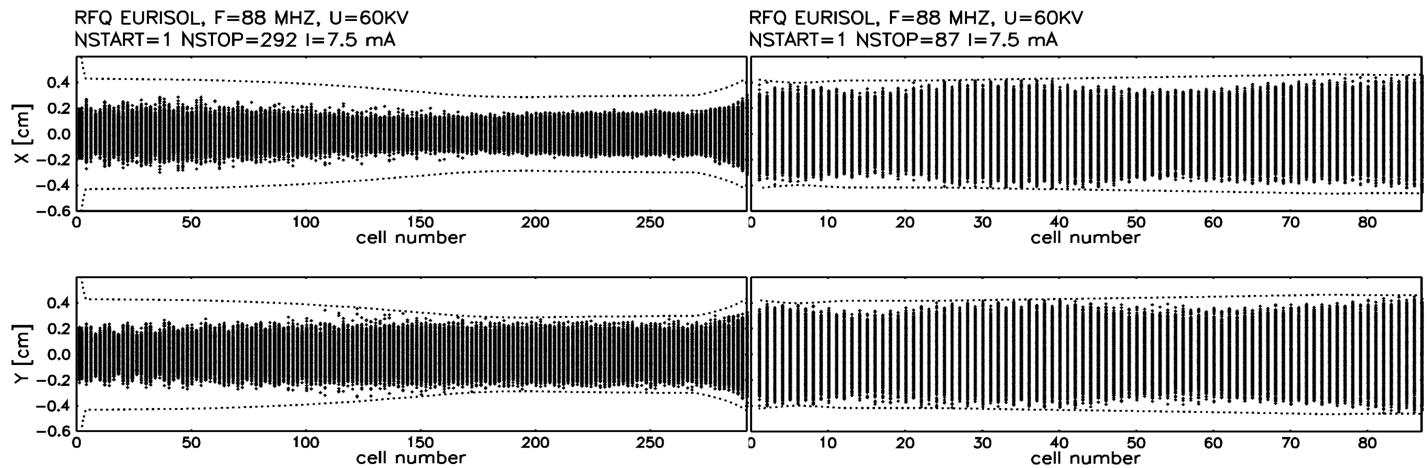
CH - SC

Investigations on the MAFF RFQ with special respect to EURISOL requirements

	NC-RFQ1		NC-RFQ2	
l	387 cm		395 cm	
f_0	88 MHz		88 MHz	
m/q	≤9.52		≤9.52	
W_{in}	2.35 keV/u → 5keV/u		260 keV/u	
W_{out}	260 keV/u		460 keV/u	
a	0.43 cm		0.43 cm	
V_{el}	60 kV		60 kV	
P_{RF}	131 kW		131 kW	
duty cycle	100%		100%	
$\varepsilon_{rms,n}$ input	0.1 mm mrad		0.104 mm mrad	
T (0 mA/~~7.5 mA~~)	100%	~~97.9%~~	99.8%	~~94.4%~~
$\Delta\varepsilon_t$ (0 mA/~~7.5 mA~~)	4%	~~9%~~	0%	~~1.5%~~
ΔW (0 mA/~~7.5 mA~~)	1.2%	~~2.5%~~	1%	~~2%~~
Δφ (0 mA/~~7.5 mA~~)	±17°	~~±23°~~	±15°	~~±18°~~

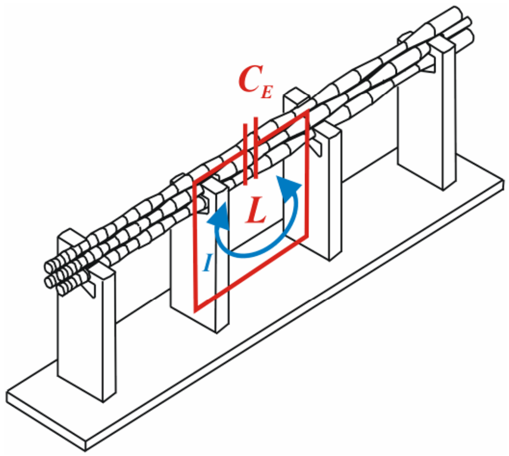
A normal conducting RFQ tandem as an injector for EURISOLs superconducting QWRs





Comparison of the 4-rod and the IH RFQ structures

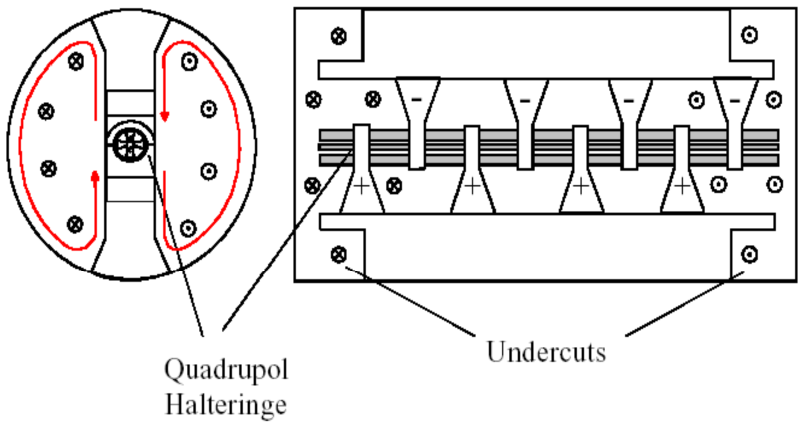
Scheme of the 4-rod RFQ



Advantages:

easy mechanical accessibility - cheap production of parts - lots of RF tuning opportunities (Flatness), thermal expansion in only one direction.

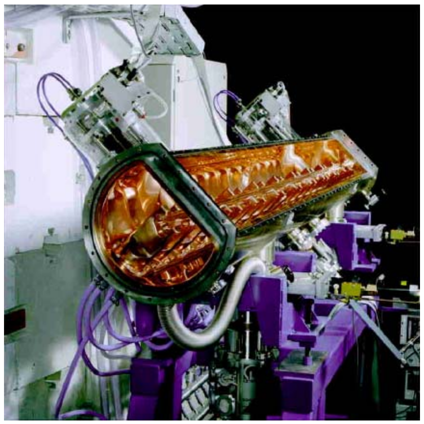
Scheme of the IH RFQ



Advantages:

less power consumption - advantageous power dissipation on electrodes (10% inst. 30%) - less dipole - easy adjustment.

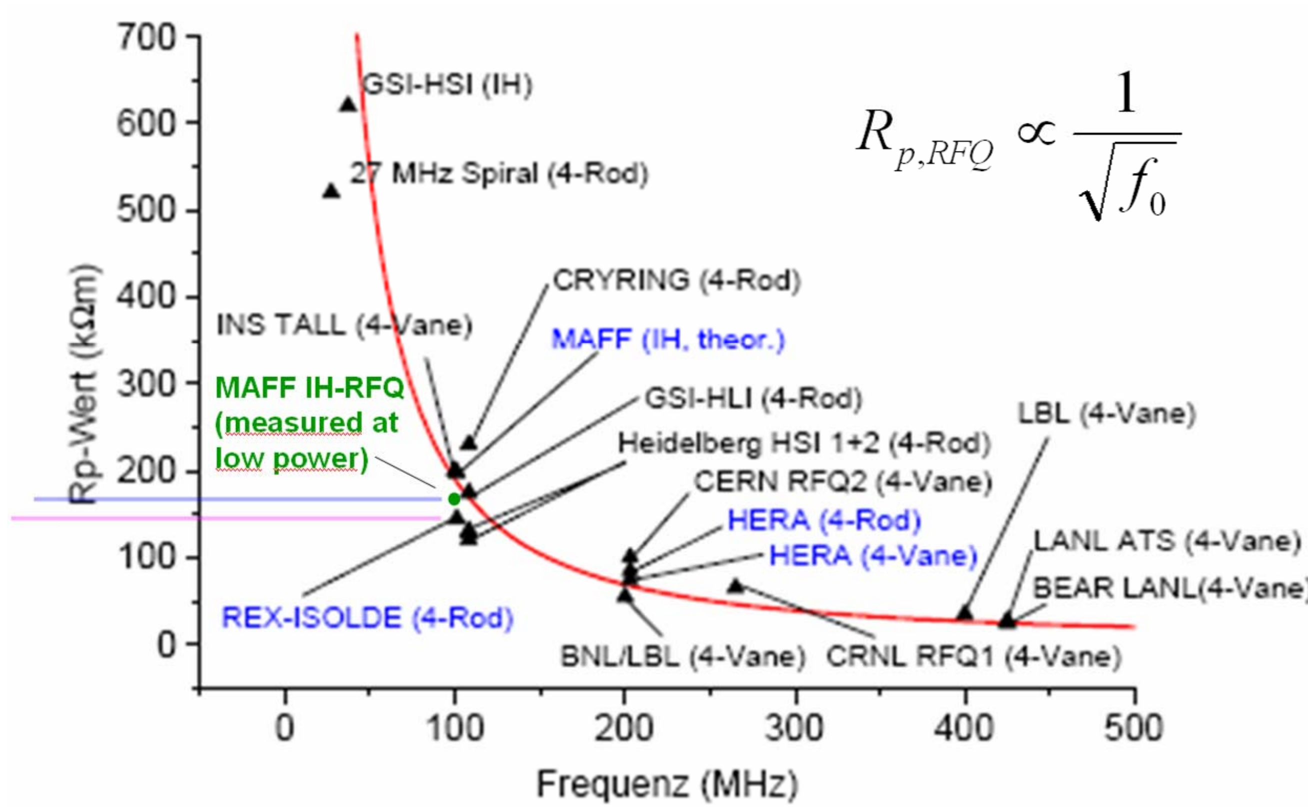
Comparison of the 4-rod and the IH RFQ structures



REX ISOLDE 4-rod-RFQ

MAFF IH-RFQ

RFQ Shunt Impedsance as a function of frequency



starting point

input energy	8 keV/u
Final energy	100 MeV/u
mass to charge ratio	≤ 3
duty cycle	0.05 %
beam current	50 mA
Input emittance (rms, normalized)	0.2 π mm mrad (?)

First conclusions from that:

beam loading quite high (approximately 200 kW/cavity pulsed) → normal conductivity. So one would need big Klystrons anyhow.

Operating costs are cheap at r.t. due to low duty cycle (very small thermal loads).

EURISOL Design Study

Example I: The SNS Linac

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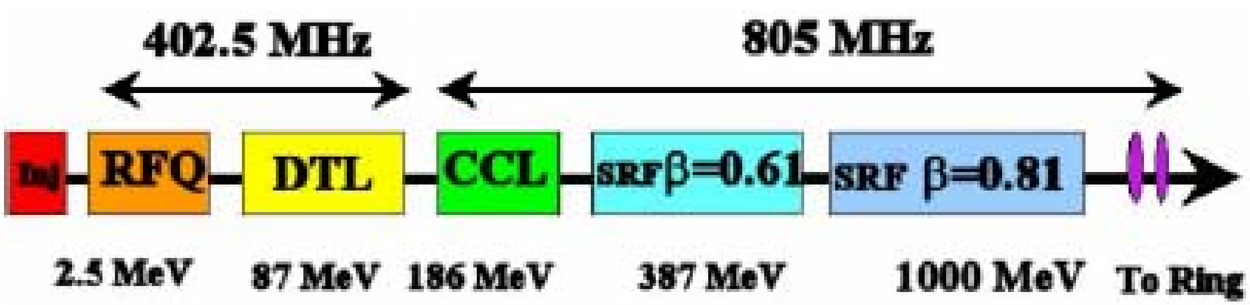
Proton beam energy on target	1.0	GeV
Proton beam current on target	1.4	mA
Proton beam power on target	1.4	MW
Pulse repetition rate	60	Hz
Beam macropulse duty factor	6	%
H- peak current from front end	>38	mA
Aver. current per macropulse	26	mA
Chopper beam-on duty factor	68	%
Linac length, incl. front end	335	m
Ring circumference	248	m
Ring fill time	1	ms
Ring extraction gap	250	ns
Protons per pulse on target	1.5×10^{14}	
Liquid mercury target	18 tons	1 m^3
Number of moderators	4	
Minimum initial instruments	8	



real estate gradient = 2.99 MV/m

EURISOL Design Study

Example II: linac 4 at CERNas an 65 mA injector for the PS booster (PSB)

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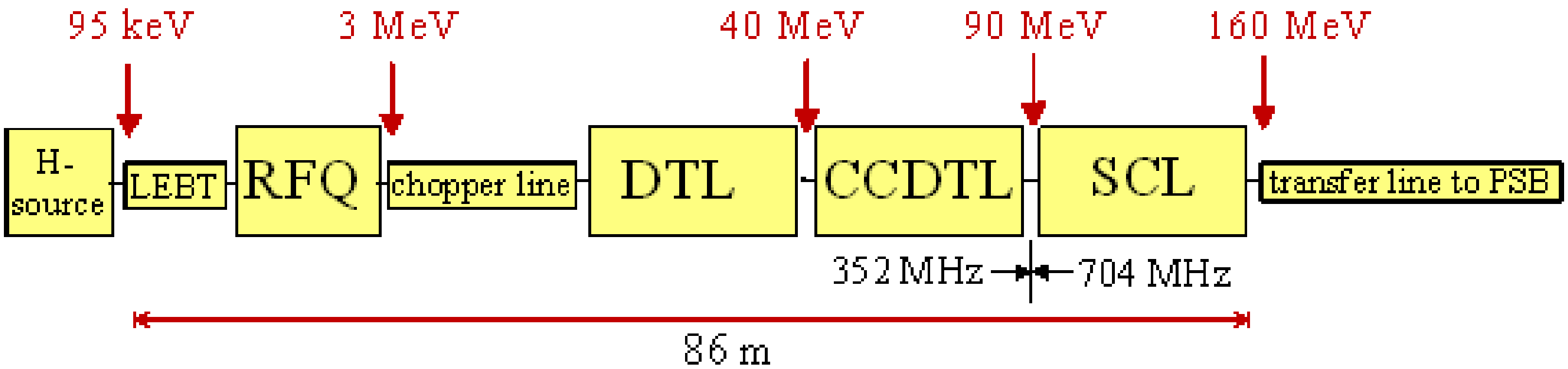
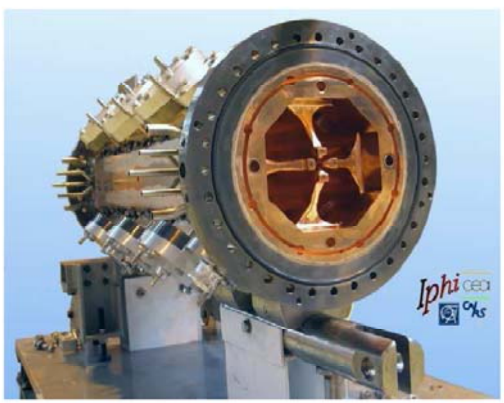
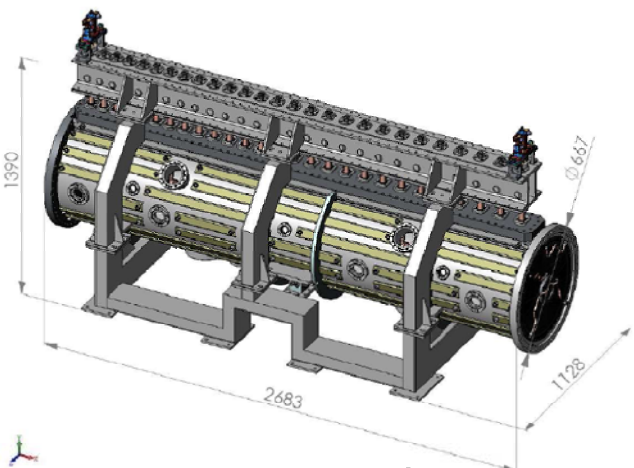


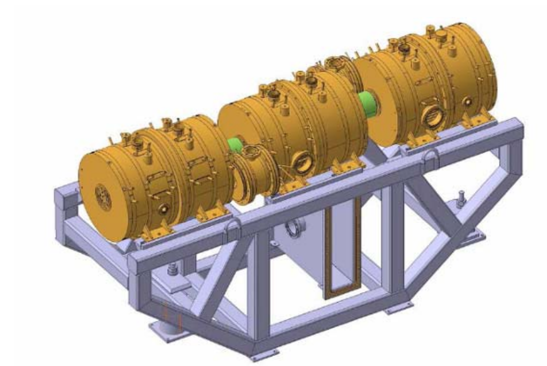


4-vane RFQ



Alvarez 3.5 MV/m

CCDTL 3-4 MV/m



real estate gradient = 1.86 MV/m

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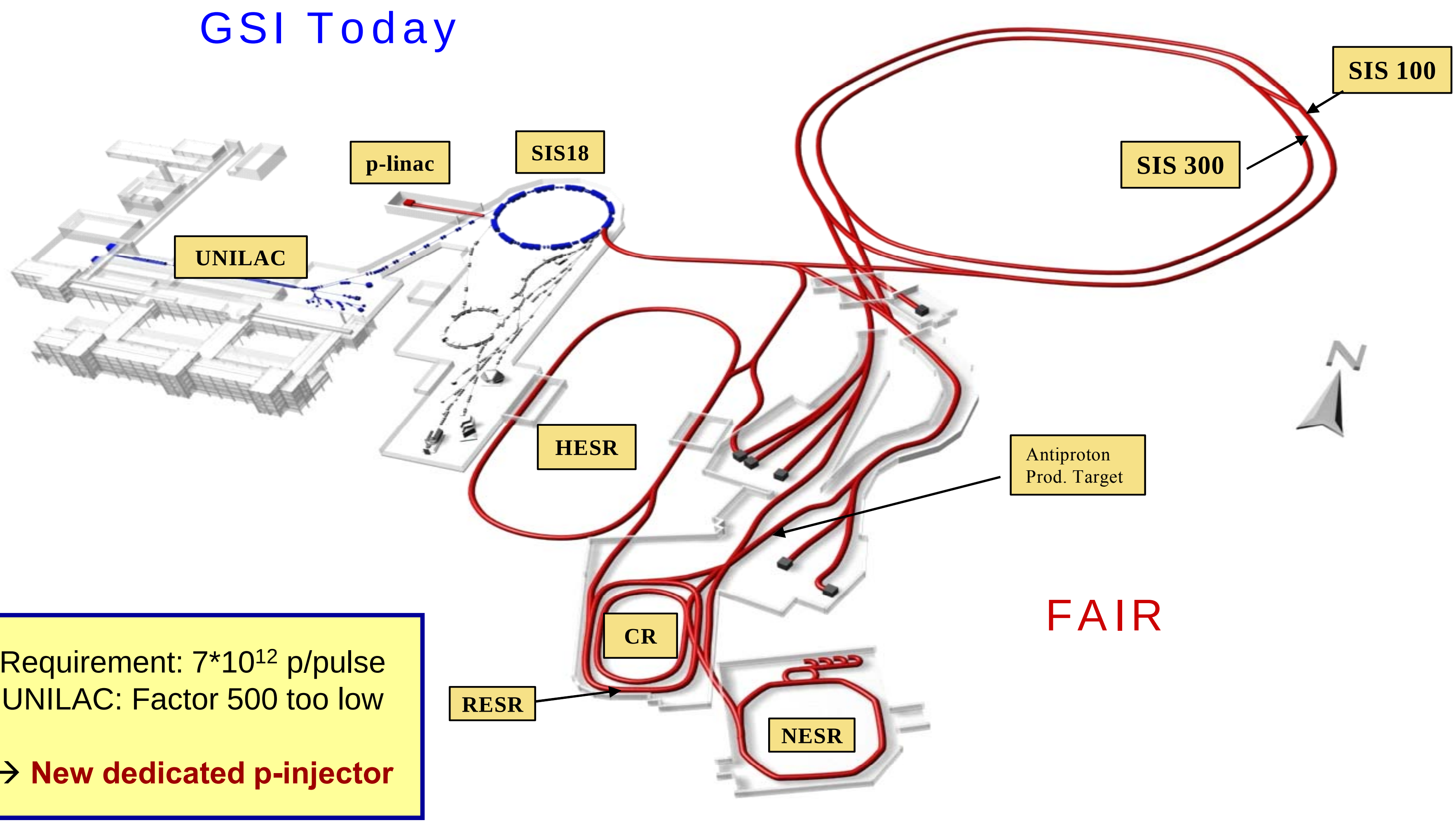
Example III: FAIR - Facility for Antiproton and Ion Research



Requirement: $7 \cdot 10^{12}$ p/pulse
UNILAC: Factor 500 too low

→ **New dedicated p-injector**

Example III: FAIR - Facility for Antiproton and Ion Research

Particles	Protons	RF drivers (6x)	2.5 MW Klystrons
Current (mA)	70	Puls 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. CH	Linac length (m)	25

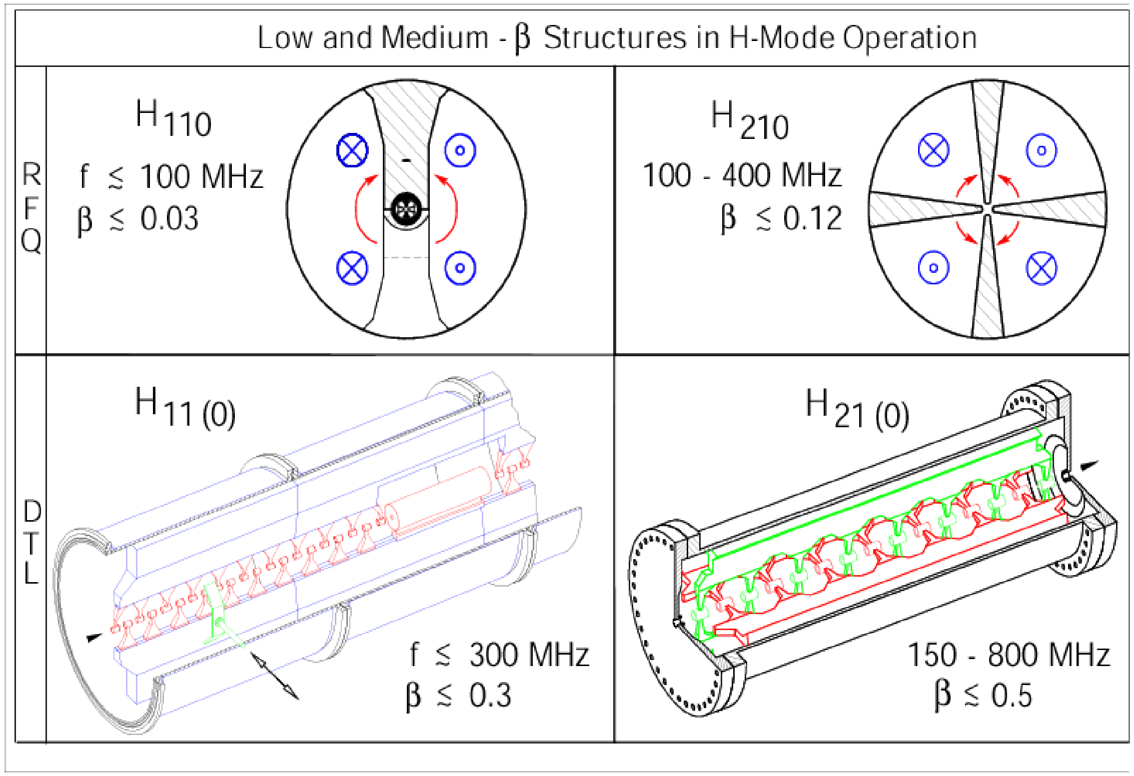
High gradients (3-7 MV/m), low duty cycle → r.t. CH-structures

real estate gradient = 2.8 MV/m

The Family of H-mode cavities

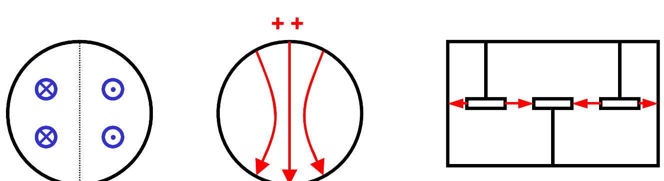
IH-RFQ

4-Vane RFQ

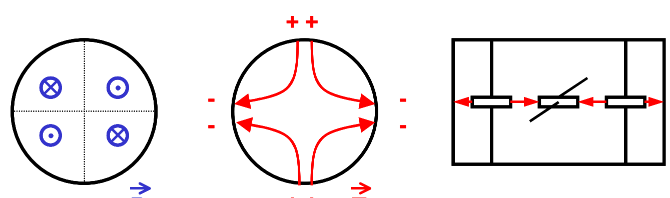


IH-Structure

CH-Structure

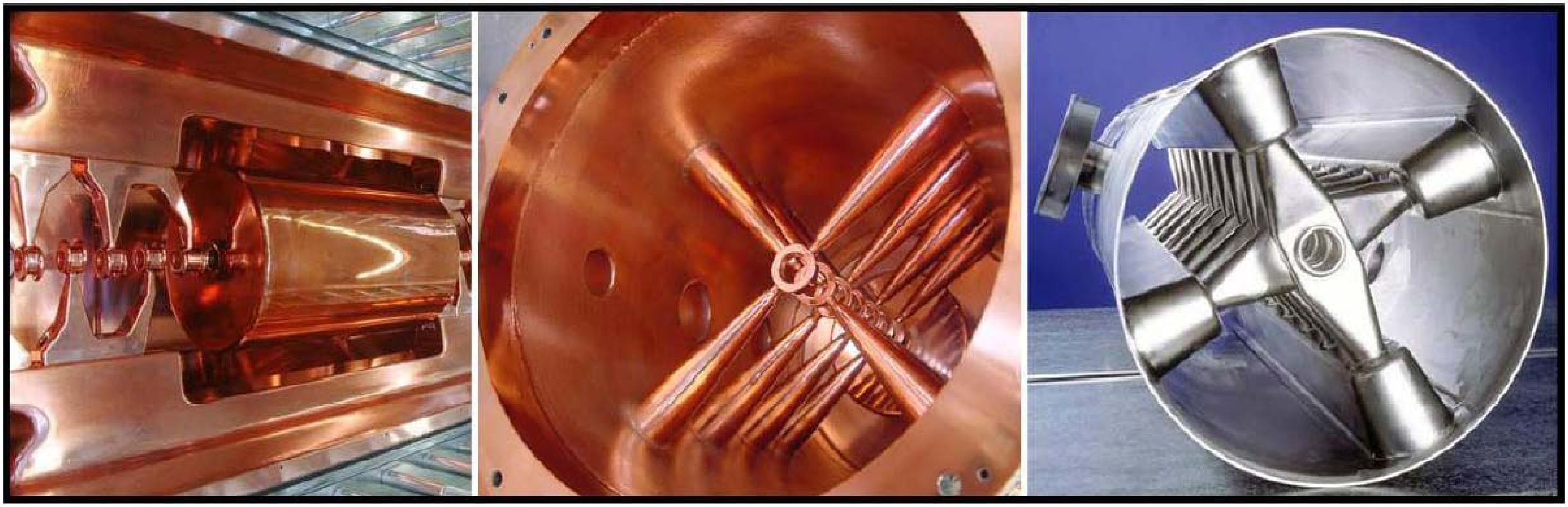


Interdigital H-Mode (IH)



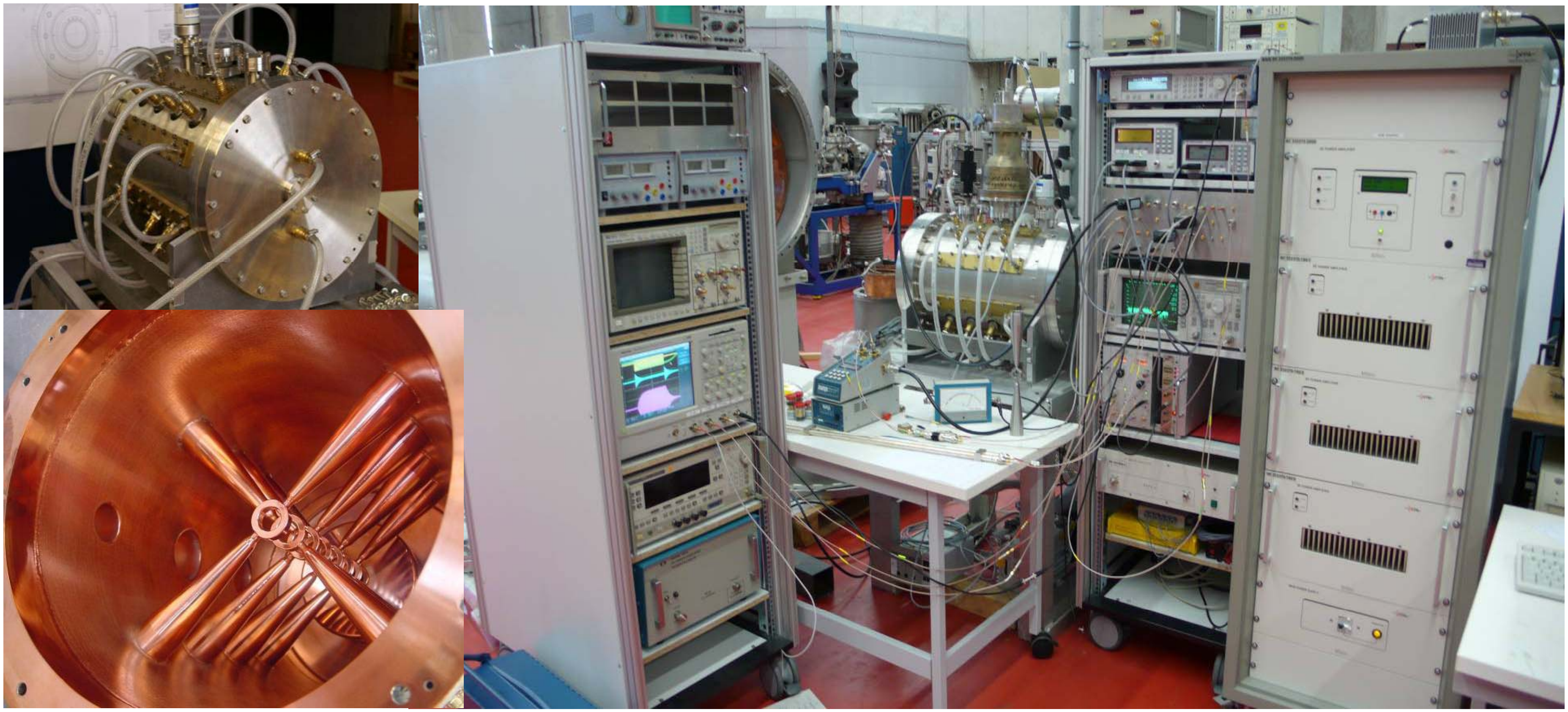
Crossbar H-Mode (CH)

H-mode DTL- cavities



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

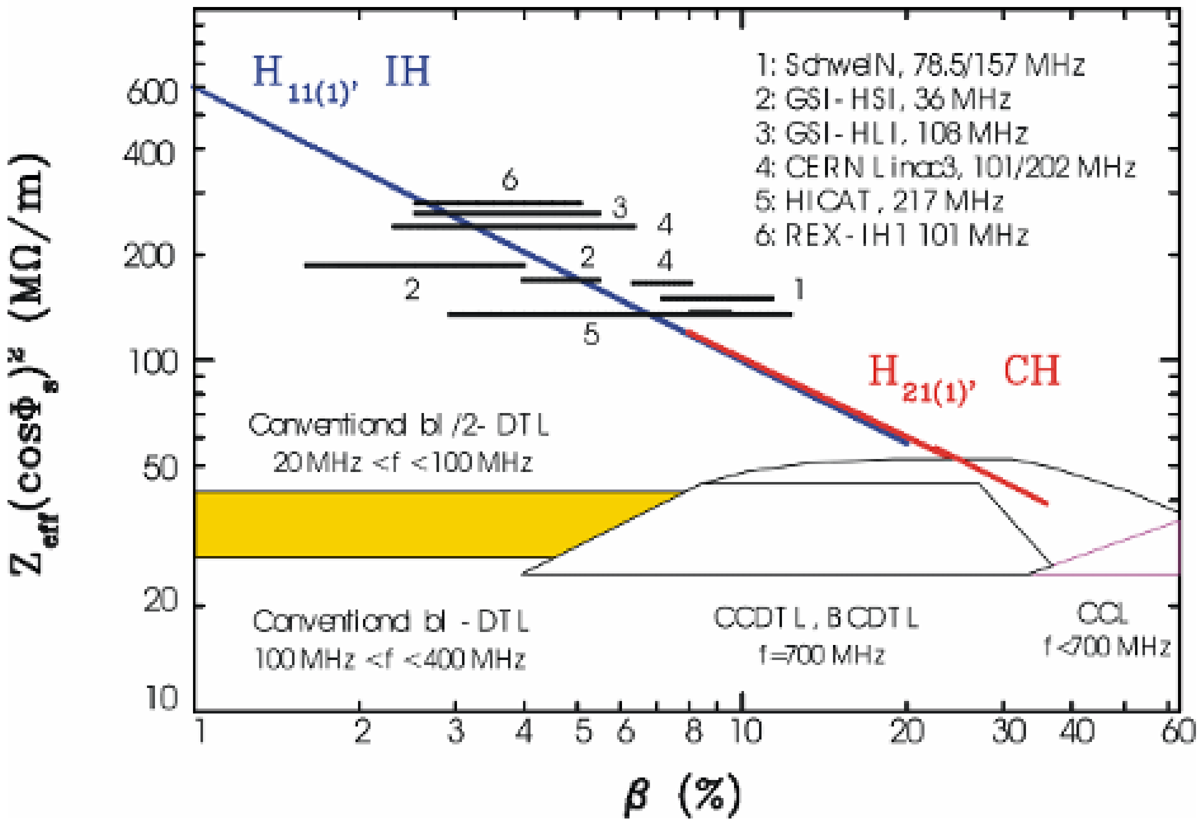
r.t. CH-prototype for FAIR



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

Measured Q_0: 13000 (95 % Ideal MWS Value)

Effective shunt impedance vs. beta (including the synchronous phase)

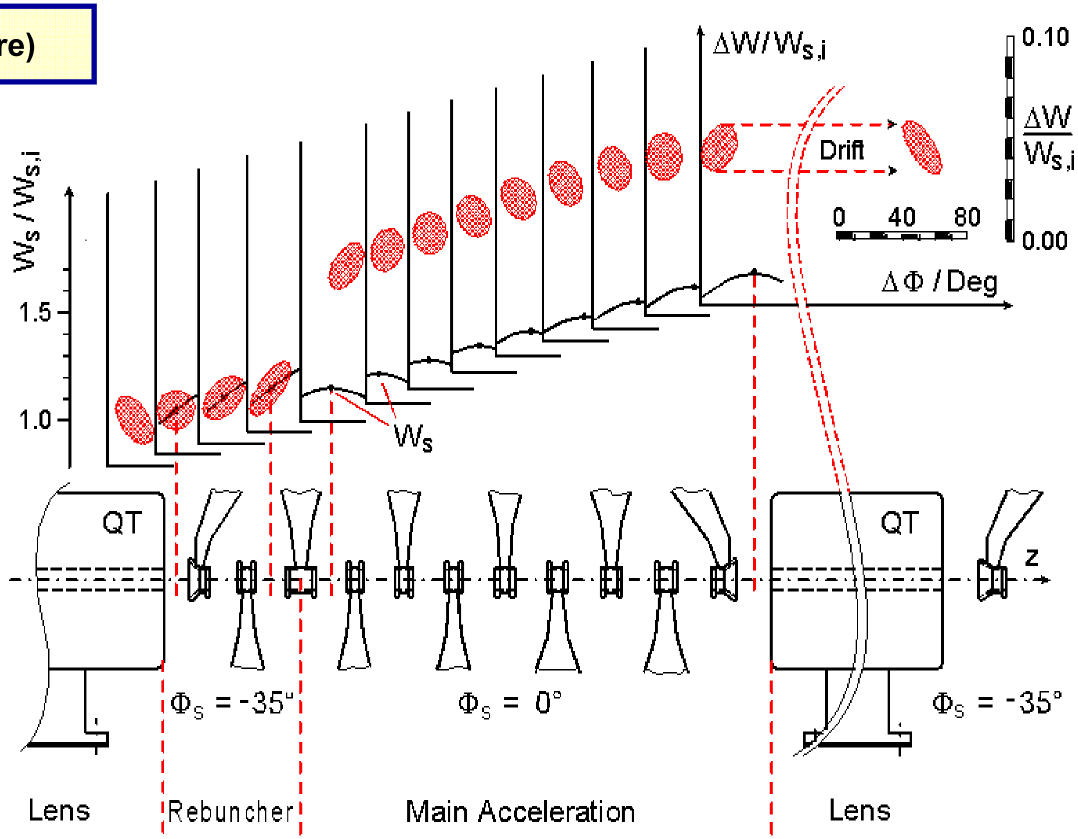


Beam dynamics (KONUS) code: LORASR

KONUS (Combined Zero Degree Structure)

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

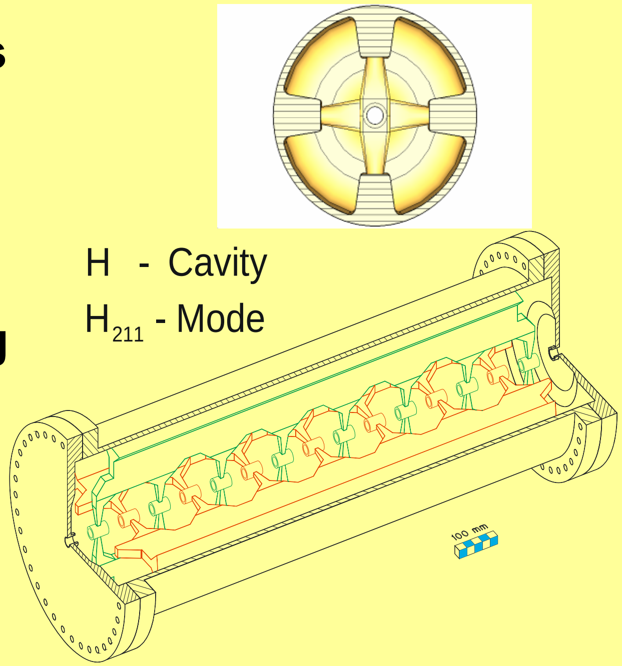
→ Strong triplet-channel



Beam dynamics divided into three sections

Properties of CH-structures

- High efficiency (Z) for low and medium energies ($0.1 \leq \beta \leq 0.5$)
- 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



EURISOL Design Study

A dedicated normal conducting β-beta beam linac concept (paper at EPAC06)

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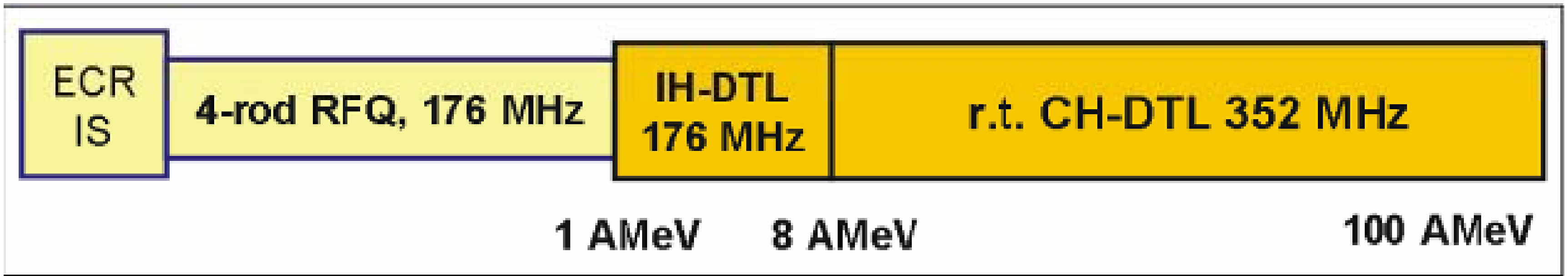
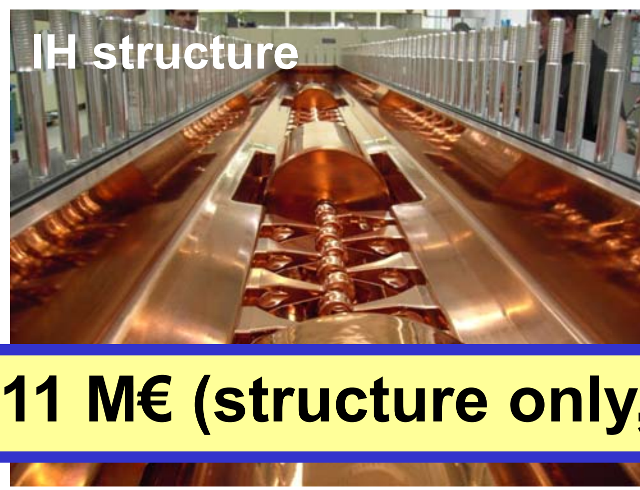
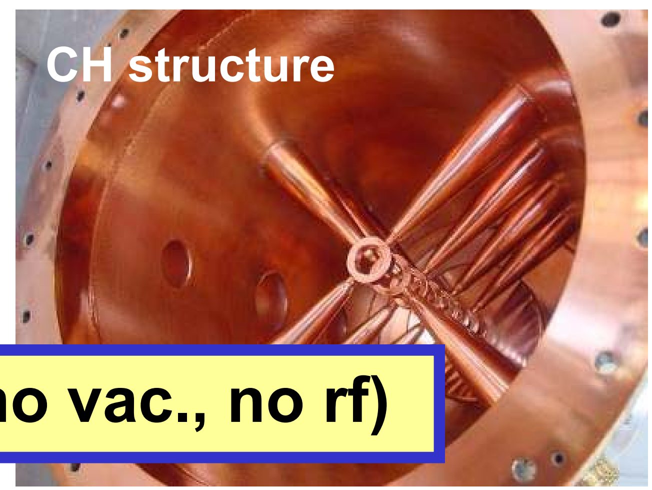


about 110 m.

real estate gradient = 2.73 MV/m

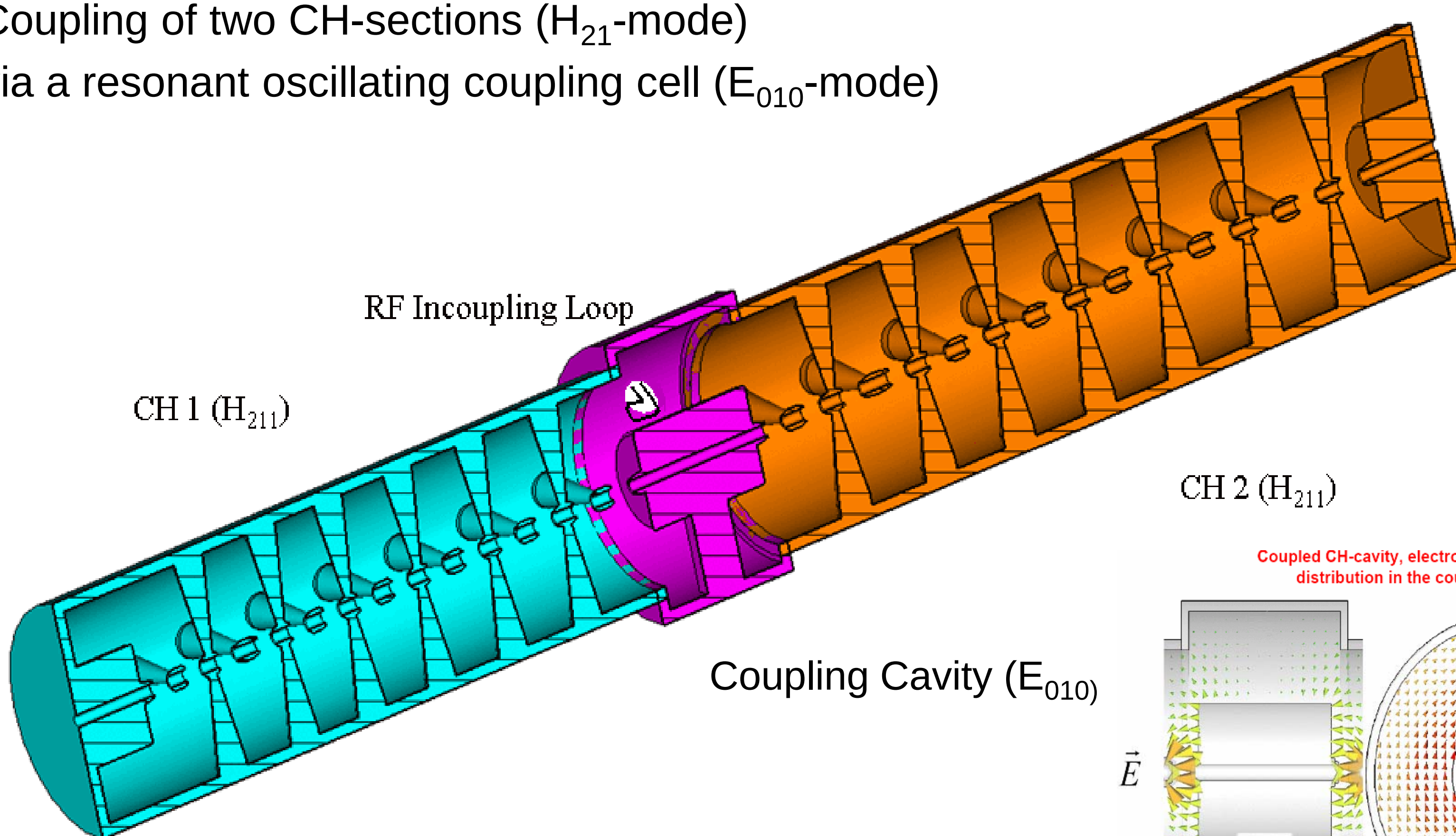


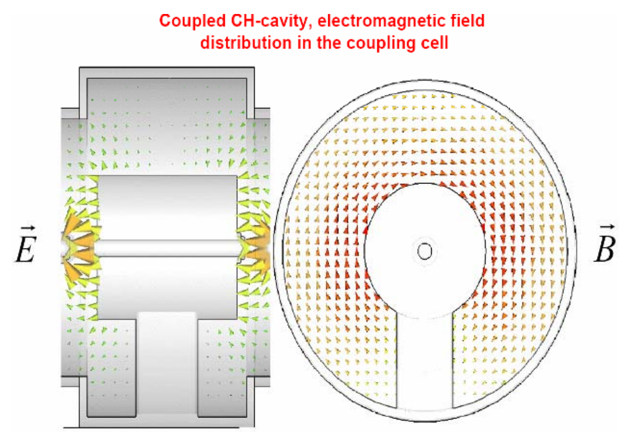


Costs: 11 M€ (structure only, no vac., no rf)

The Coupled CH (CCH)

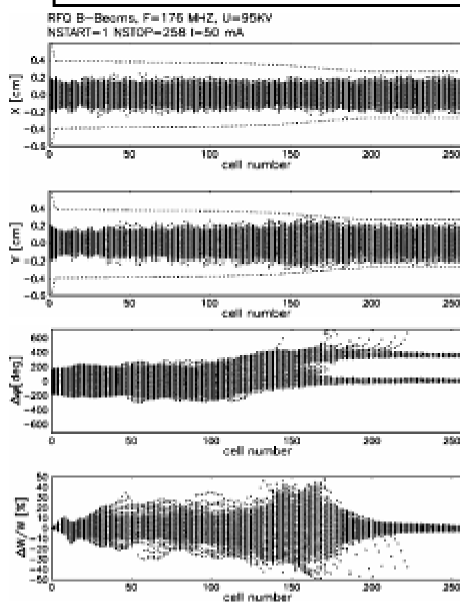
Coupling of two CH-sections (H_{21}-mode)
via a resonant oscillating coupling cell (E_{010}-mode)

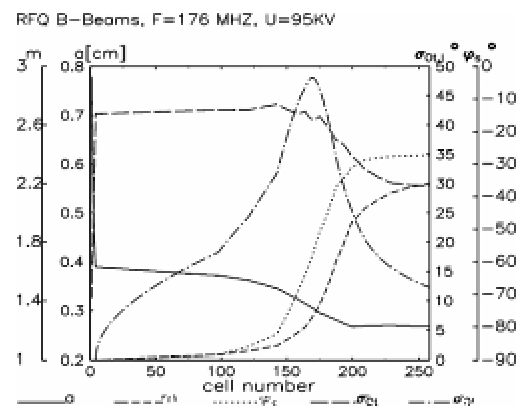




A DEDICATED β-BEAM RFQ CONCEPT

DEDICATED β-BEAM RFQ PARAMETERS	
length l	275 cm
frequency f_0	**176 MHz**
mass to charge ratio m/q	≤3
input energy W_{in}	8 keV/u
output energy W_{out}	1 MeV/u
electrode voltage V_{el}	95 kV
input emittance total	50 mm mrad
transmission T (50 mA)	97%





Conclusions

- H-mode cavities are very attractive for β-beam application
- A frequency of 352 MHz is reasonable with respect to the costs for power supplies (Klystrons)
- There is a reasonable 1st order concept for a dedicated high efficient β-beam linac
- There are some concrete suggestions for β-beam RFQ design

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Next possible steps

- We now would need some more detailed investigations on cavity designs as well as on beam dynamics

- Approximately 6 man month would be required to do so. (Ph. D. Thesis??)

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