An Overview of Recent RFQ Projects

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Introduction
recent
present
Summary

IAP projects

Linac08, Victoria, Vancouver Island, Canada, Sept. 29, 2008 structure: rf-properties, mechanics, experience

general considerations

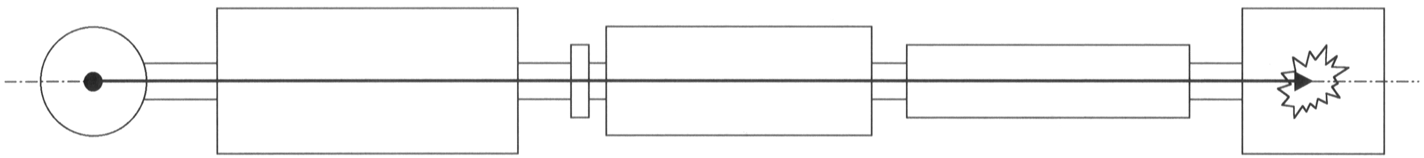
riscs, reliability, costs, time (p. prejustice)

$$B \approx \frac{U_Q}{a^2_{eff}} * \lambda^2$$ **focusing strength**

U_Q /a : limited by sparking, rf - power

a : tolerances (mech. alignment, rf – field distribution)

λ : size: RFQ-length, Ez ~ $1/\beta$ (RFQ)



Ion source RFQ DTL CCL Exp

Institut für Angewandte Physik
J.W. Goethe Universität, Frankfurt, Germany

Accelerator development

Linacs, ion sources, beam transport

Post accelerator structures,

IH-DTL-linacs, nc-sc

RFQs

Design, prototype tests, beam test,,,

GSI,Desy,CERN, Orsay, Saclay, MPI,HMI, MSI,,

BNL, MSU ,,

Protons, heavy ions, clusters, RIB,

applications: implantation, n-source, medical

RFQ design

Electrodes design input:

1.) U_Q, 2.) T_i, T_f, I_{lim}, ε

design a,m,φ as f (n_i, L)

defines beam properties: transmission, rl-emittance

defines structure properties: L, N

rf-structure

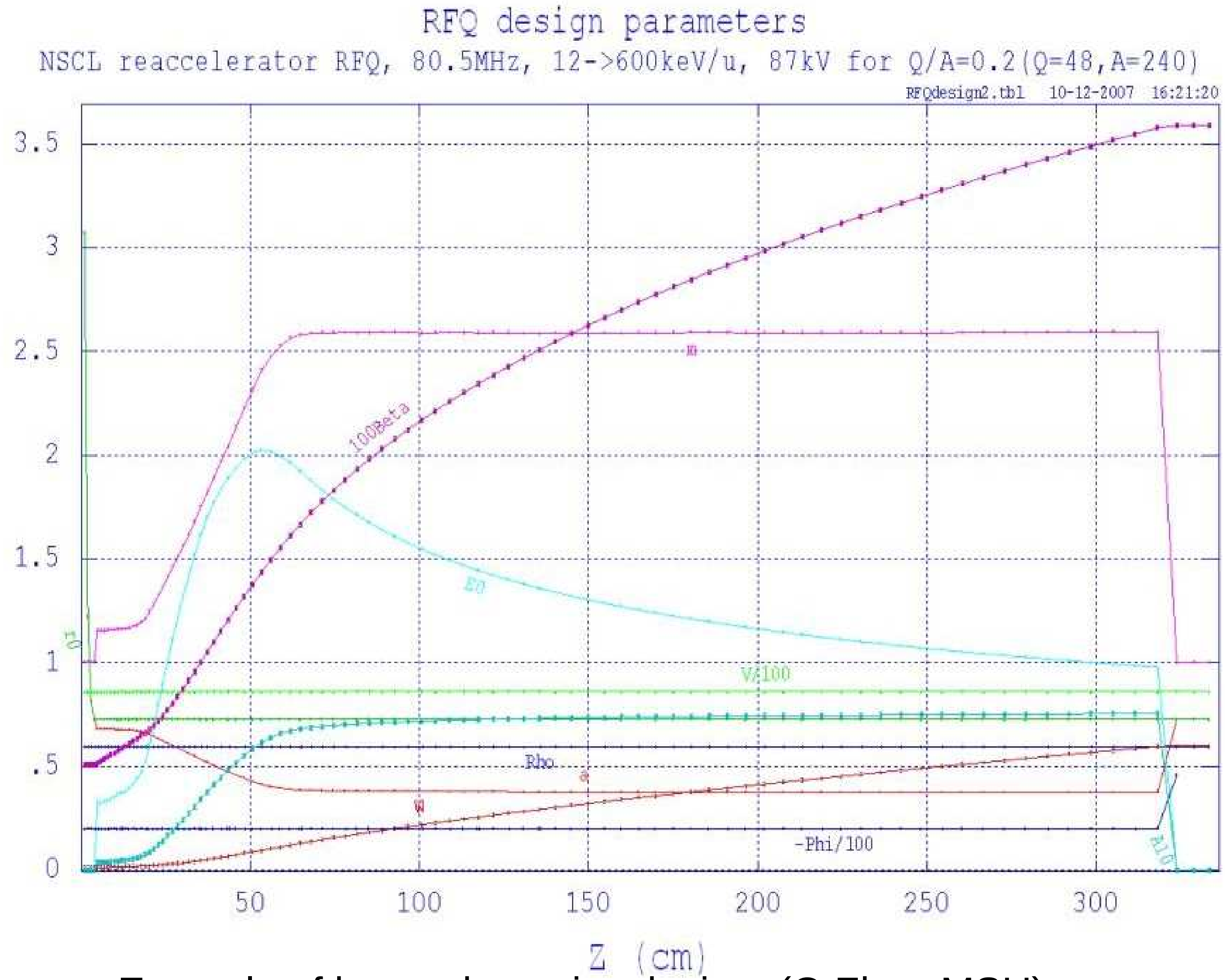
a transformer producing electrode voltage

type, impedance, stability, sparking,,,,

mechanics

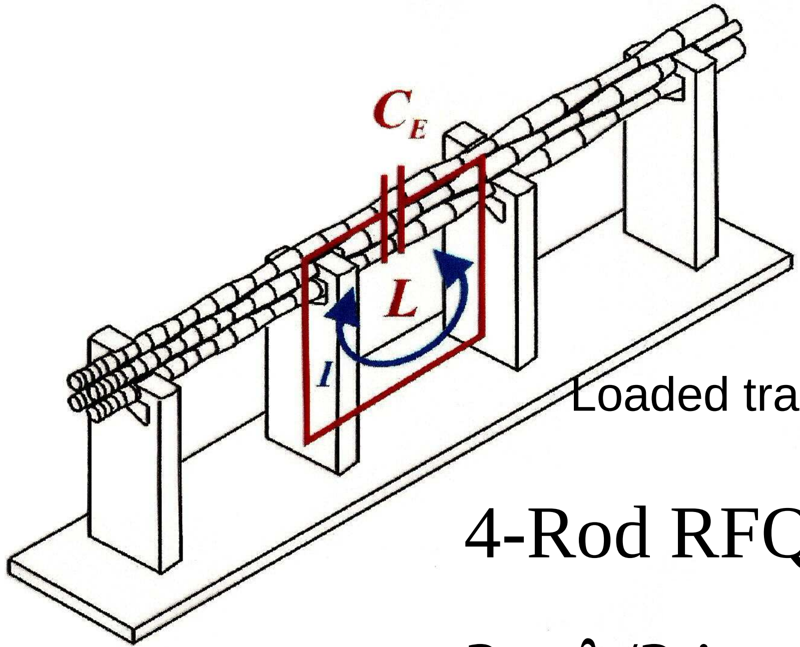
stability, cooling, complexity, cost,,,,:

by AS-IAP-UF



Example of beam dynamics design (Q.Zhao,MSU)

Rf-structure to produce these fields:

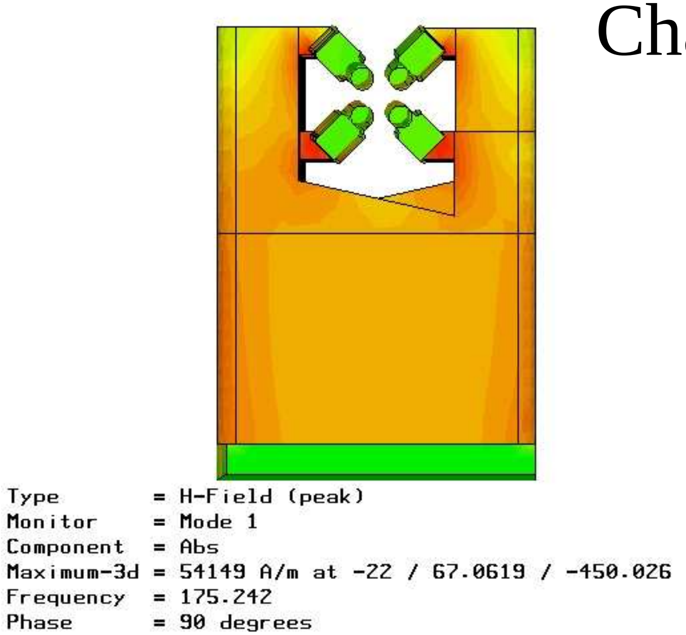


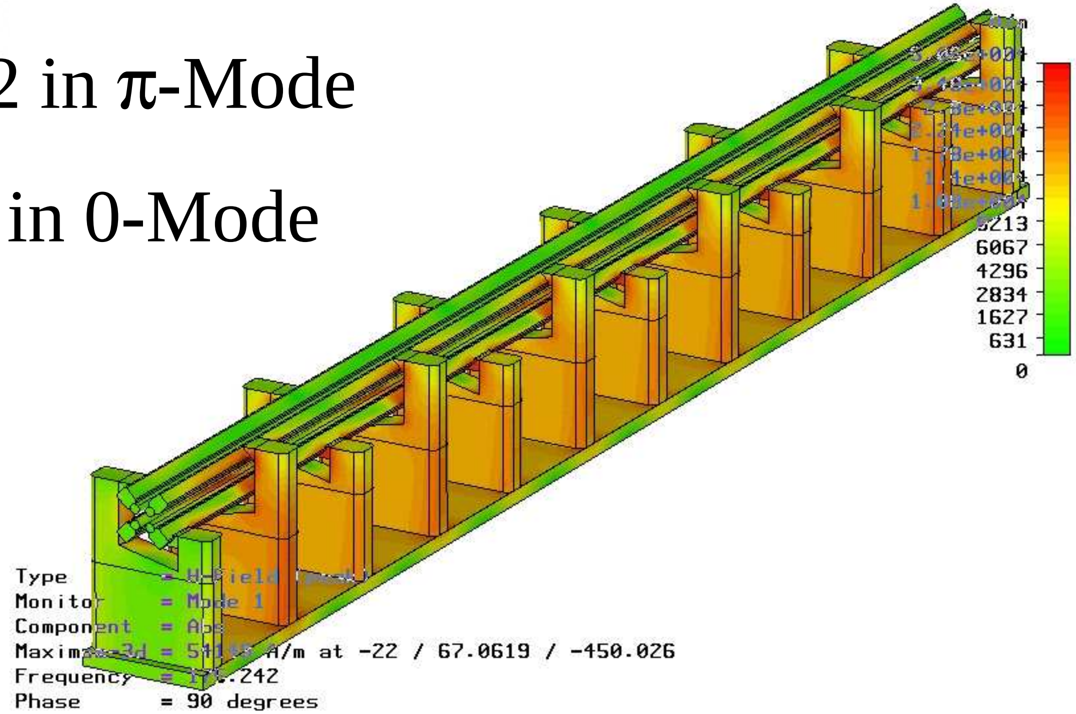
Loaded transmission line

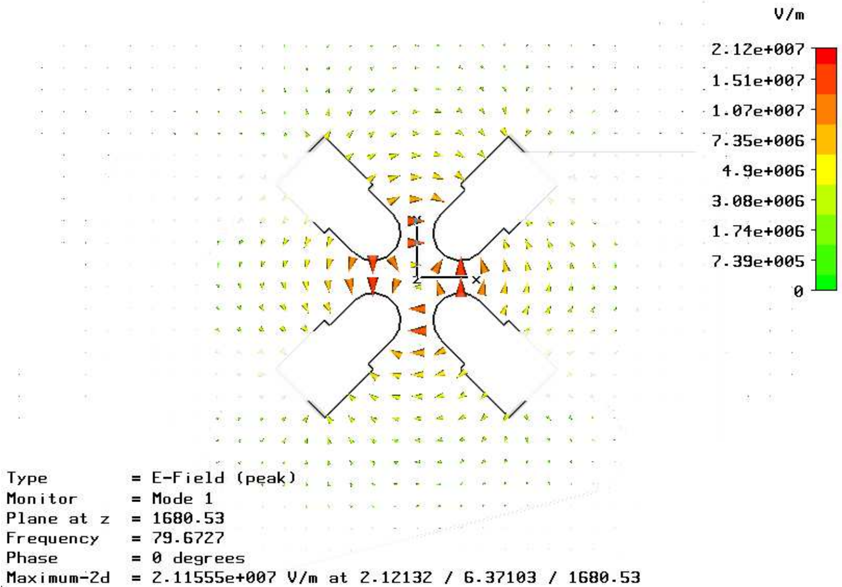
4-Rod RFQ basic cell

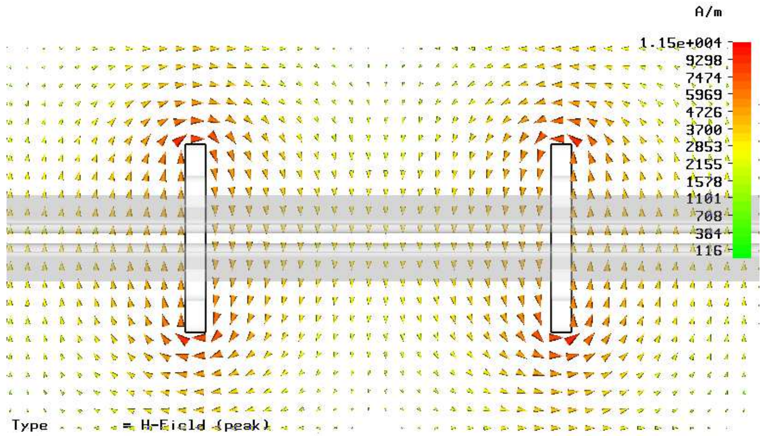
2 x λ/2 in π-Mode

Chain in 0-Mode

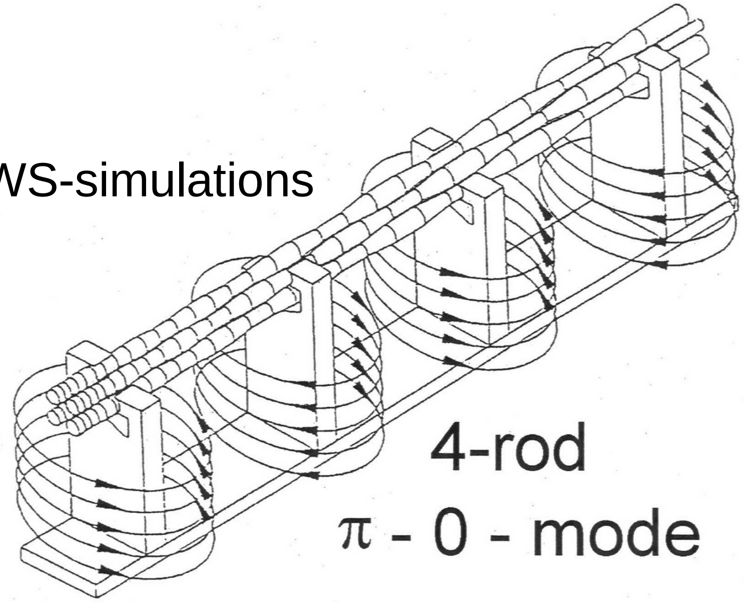








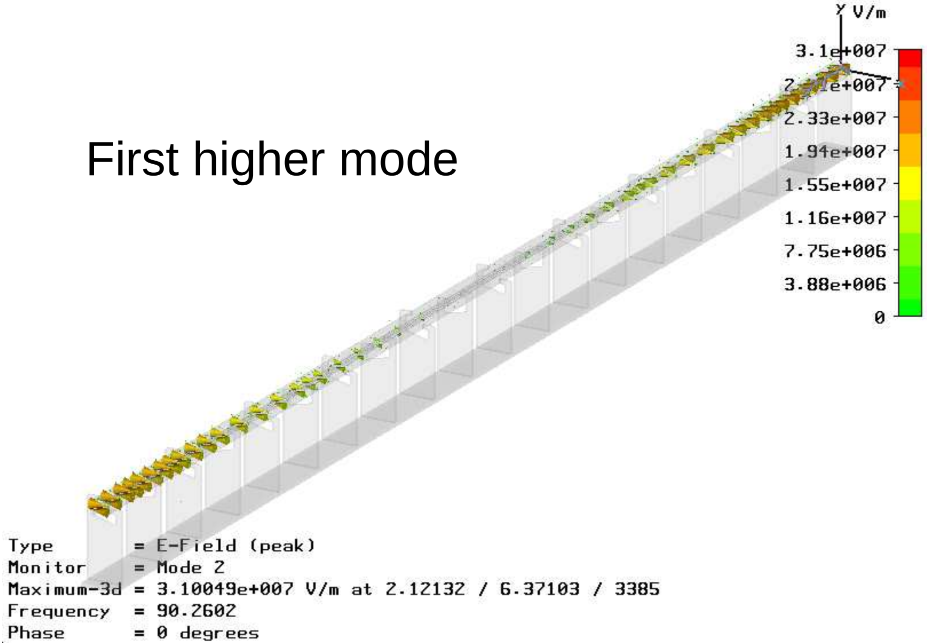
MWS-simulations



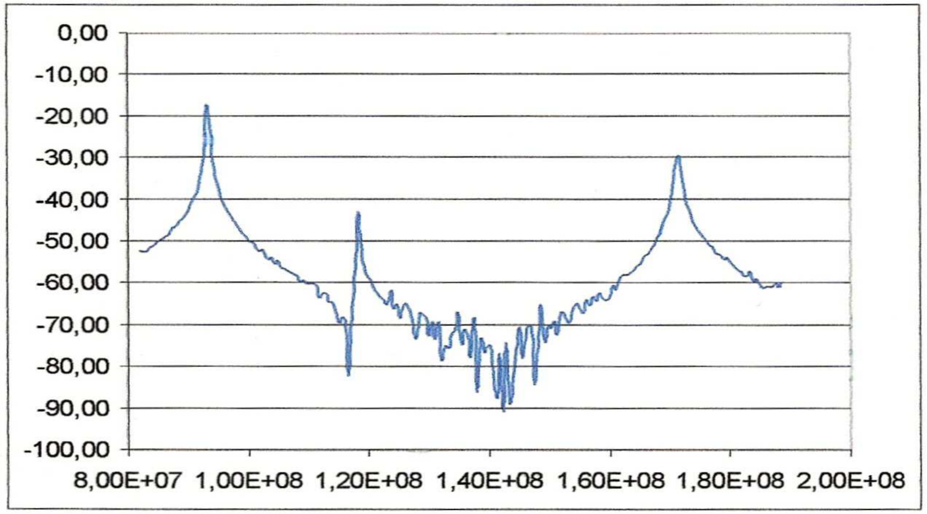
4-rod

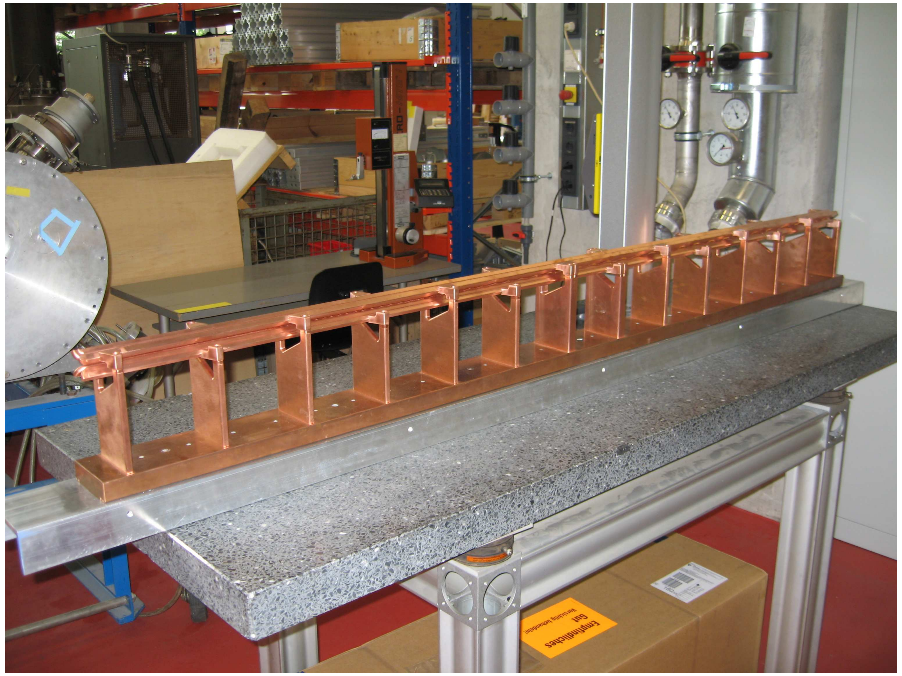
π - 0 - mode

First higher mode

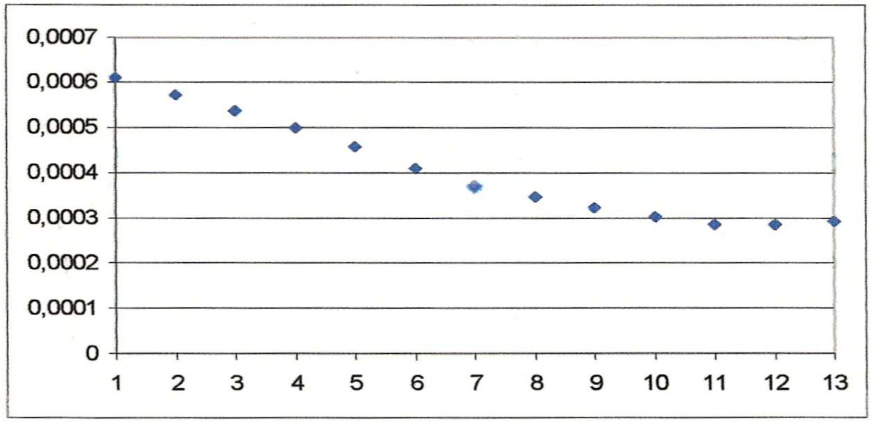


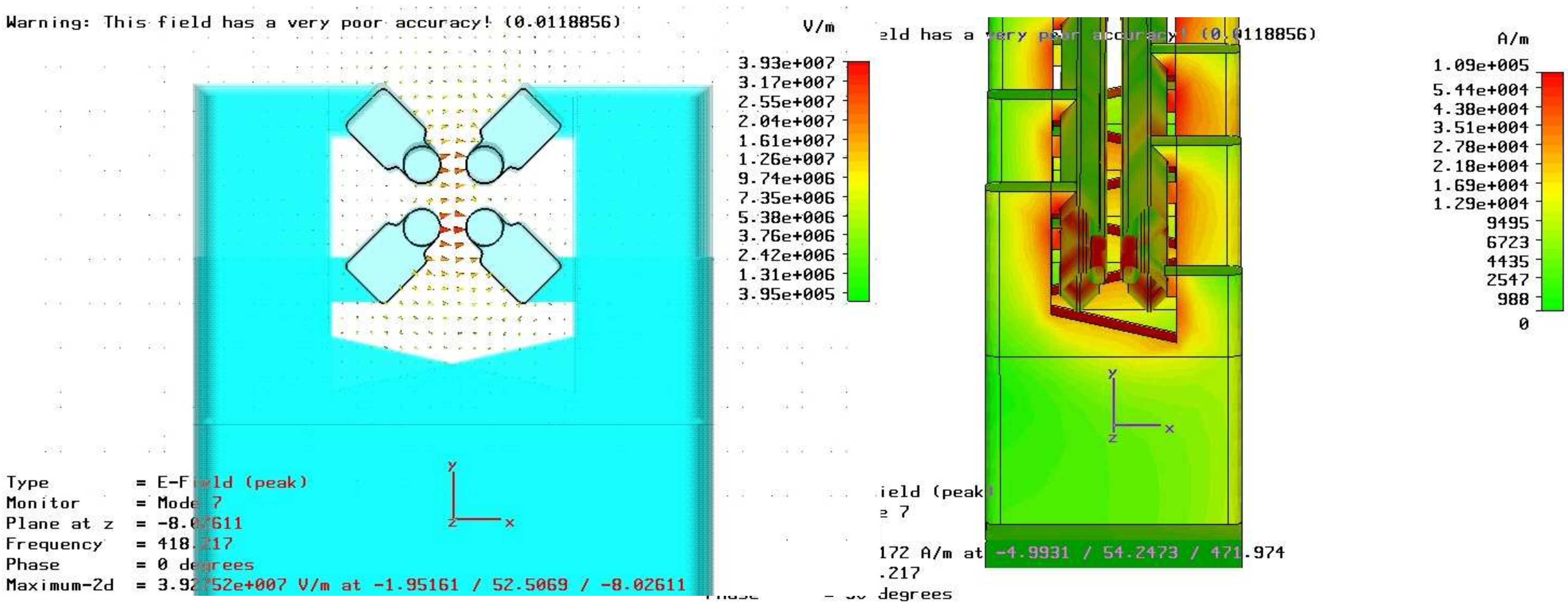
HOM Spektrum





Flatness

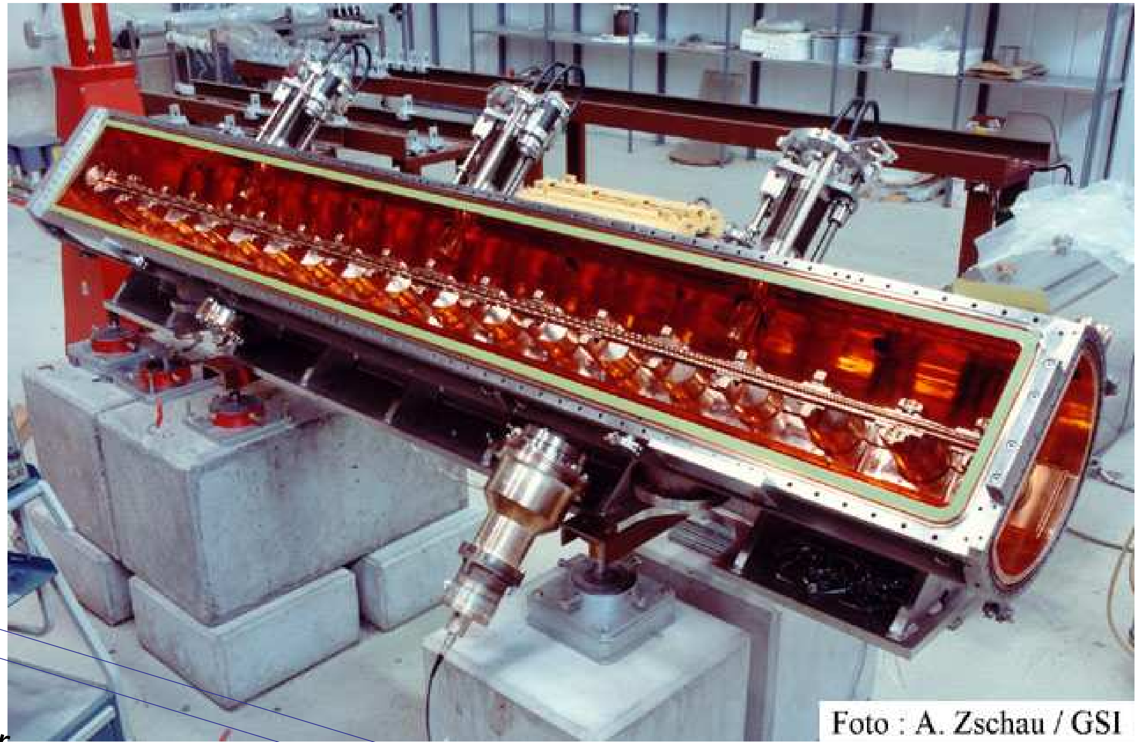


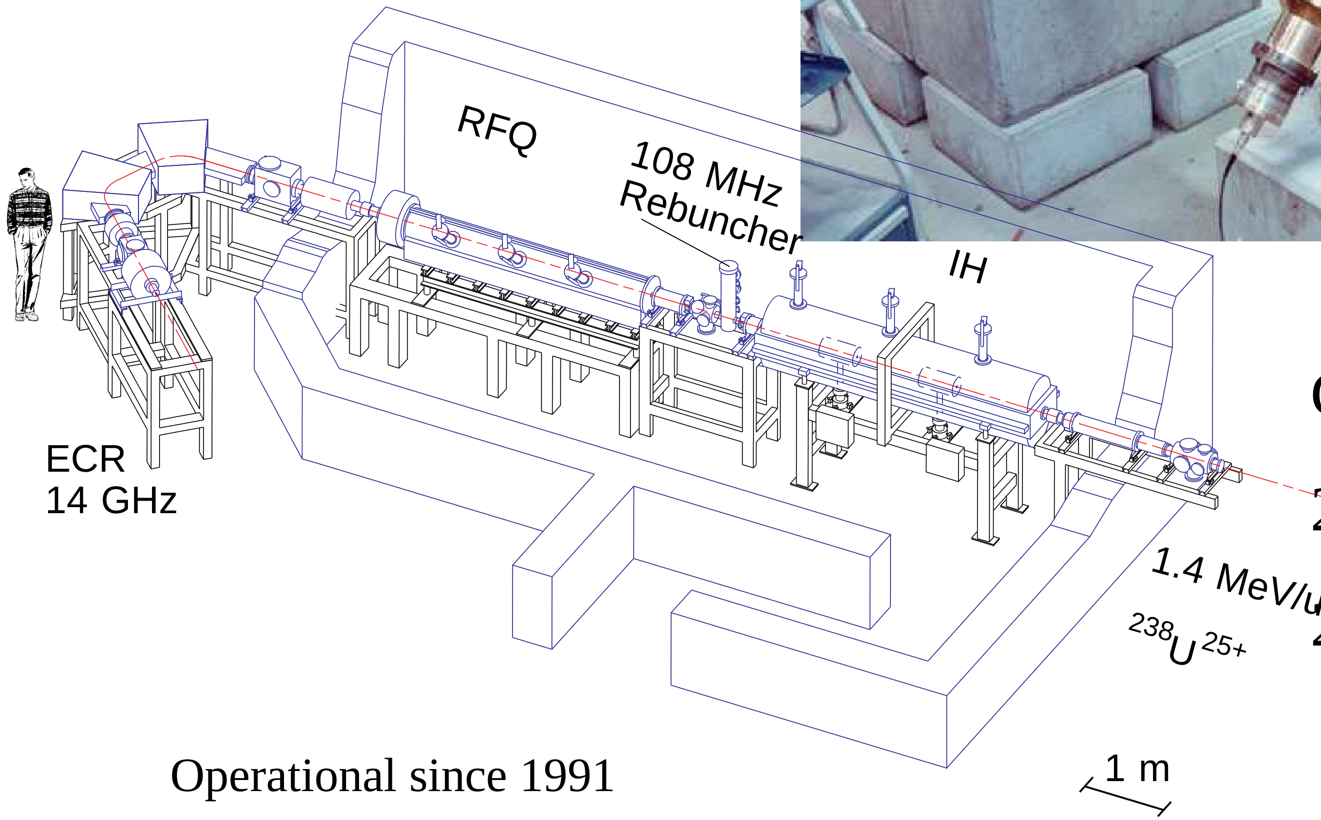


Example for a dipole Mode (f_0=175MHz)

$f_d > 2 * f_0$

First ECR-RFQ-IH-DTL combination





GSI HLI

2.5-300 keV/u, U 28+

25% df

Operational since 1991

Possible upgrade: higher duty factor, matching, (water tube erosion)

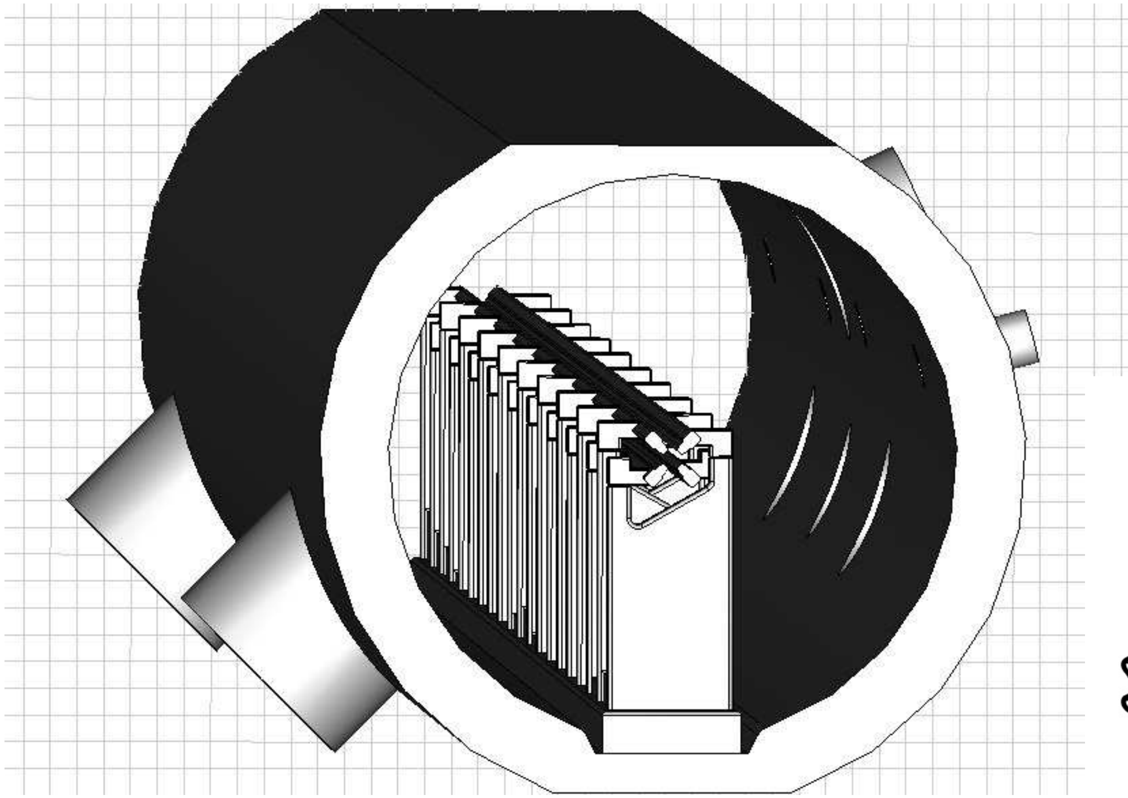
PARAMETER	HLI	HLI-n
Frequency [MHz]	108.48	108.48
A/q	8.5	6
Input Energy [MeV/u]	0.0025	0.004
Output Energy [MeV/u]	0.3	0.3
Inter-ElectrodeVoltage[kV]	85	55
εin norm., rms [π mm mrad]	0.07	0.1
εoutx. n., rms [π mm-mrad]	0.12	0.1009
Electrode Length [cm]	305	199.5
Duty factor [%]	25	100

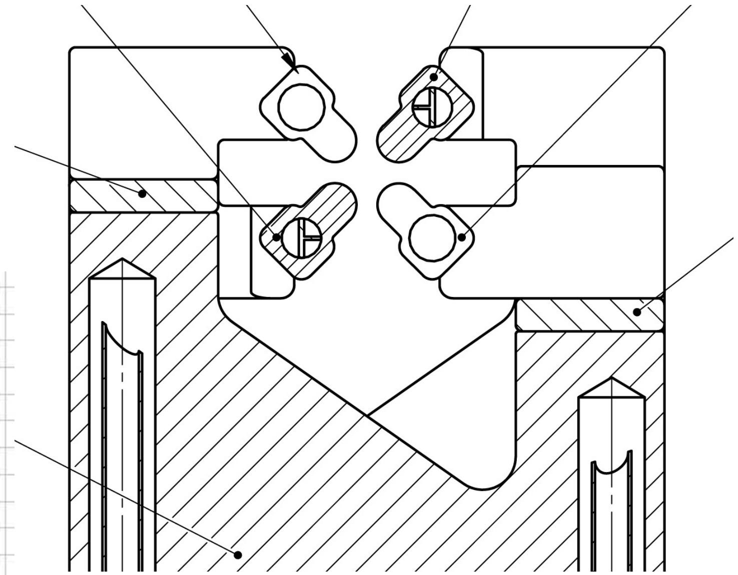
Higher duty cycle

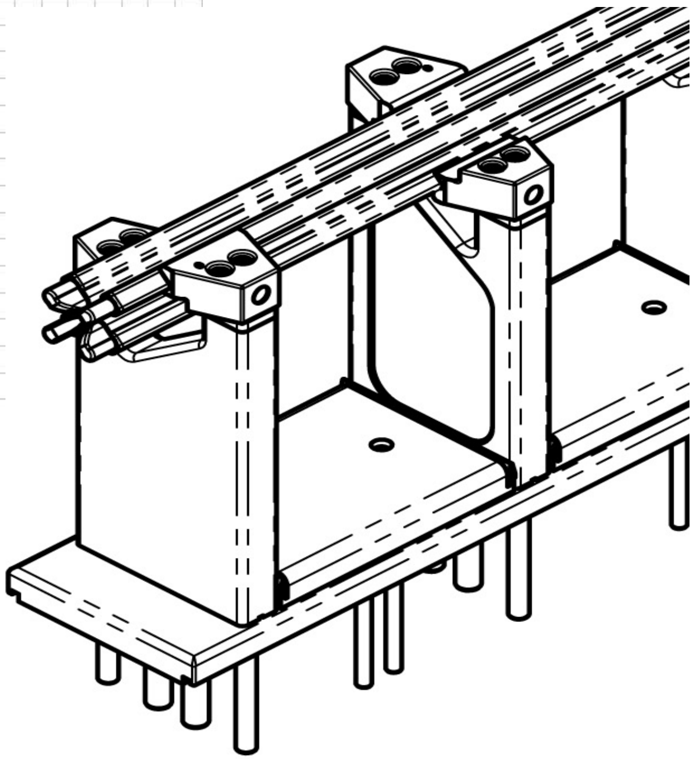
for A/q ≤ 6

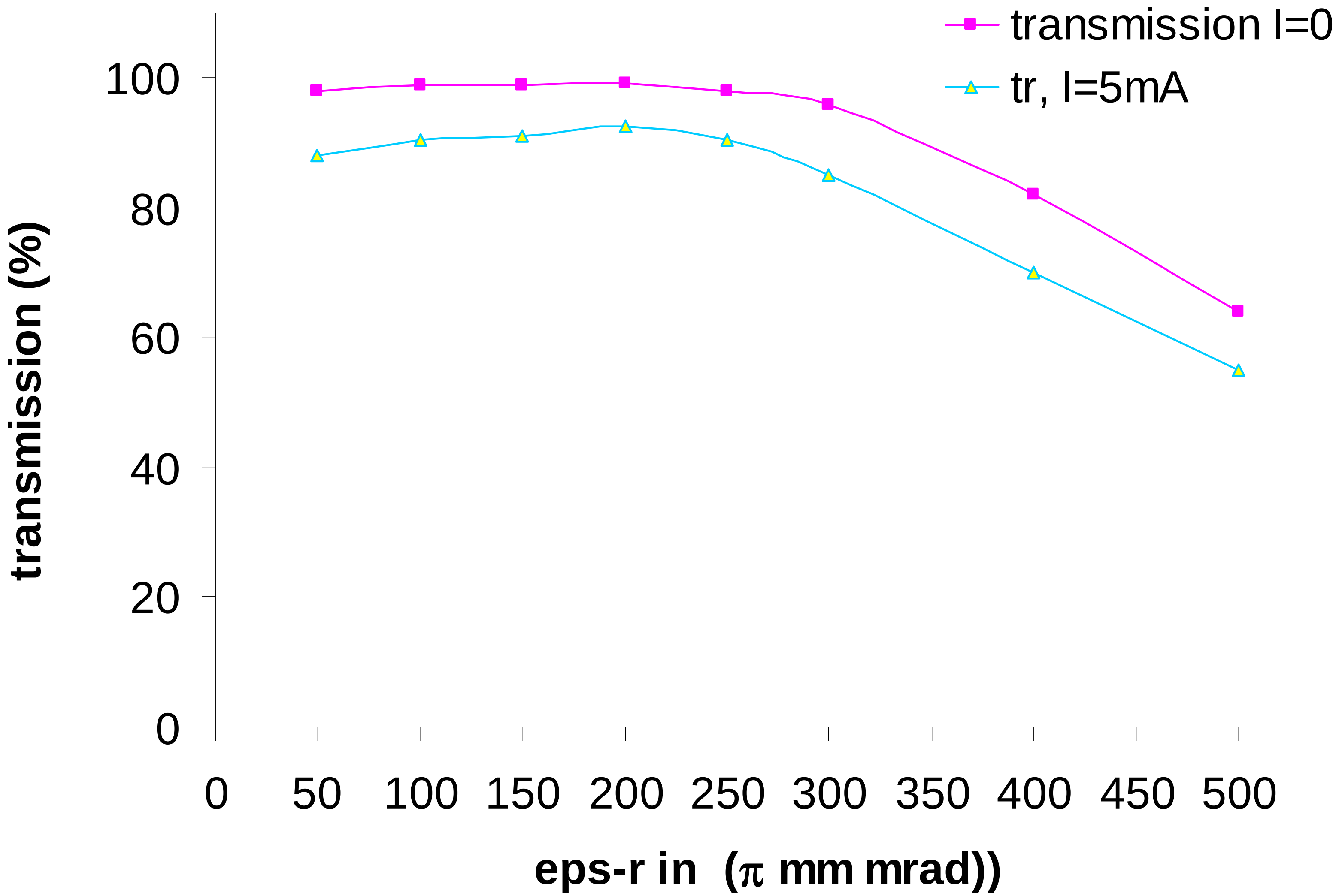
Ti = 4keV/u

eps

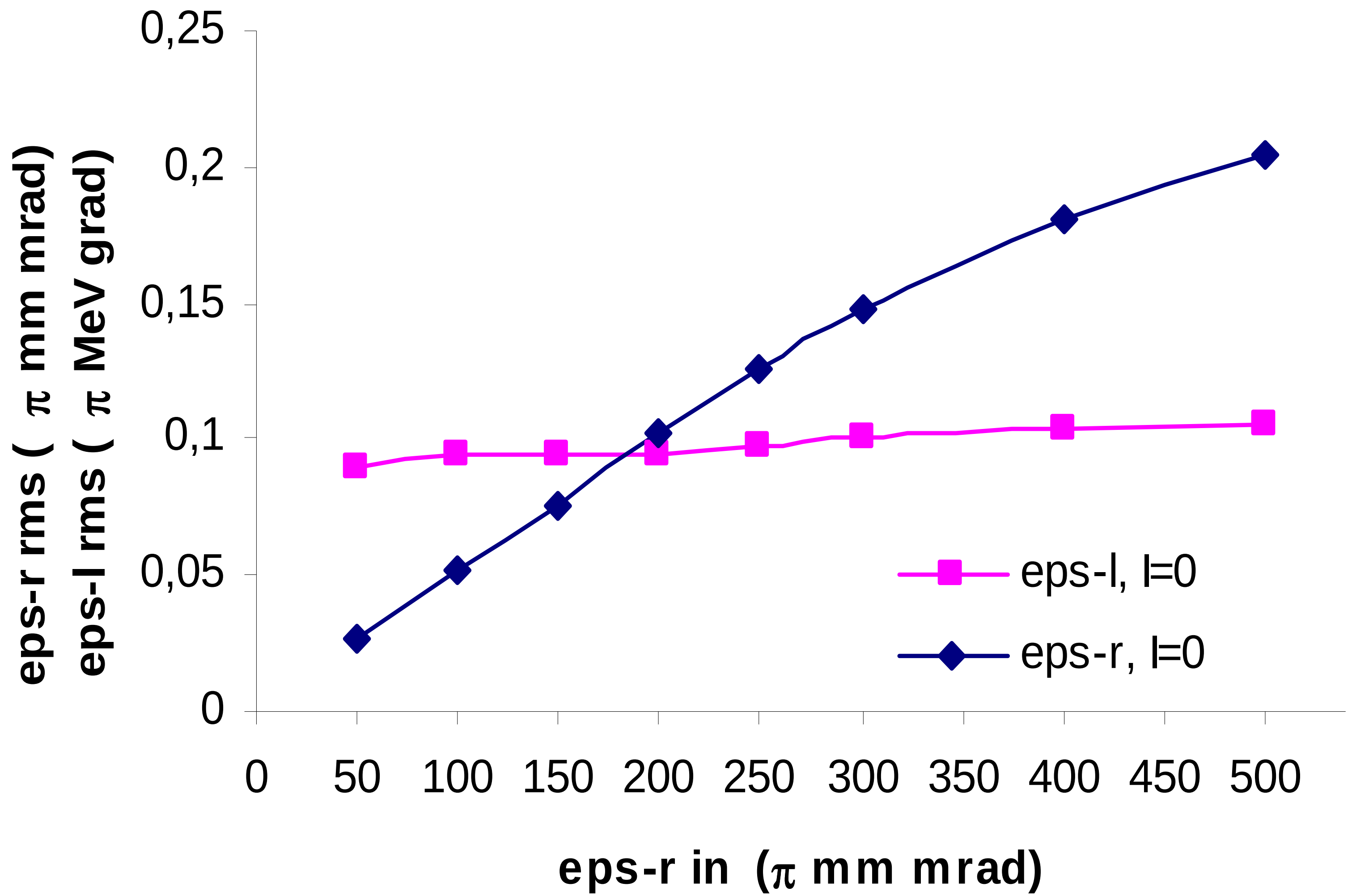






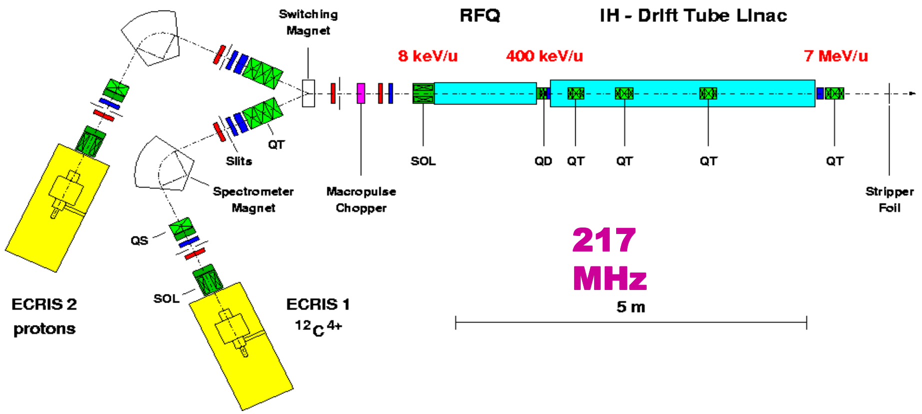


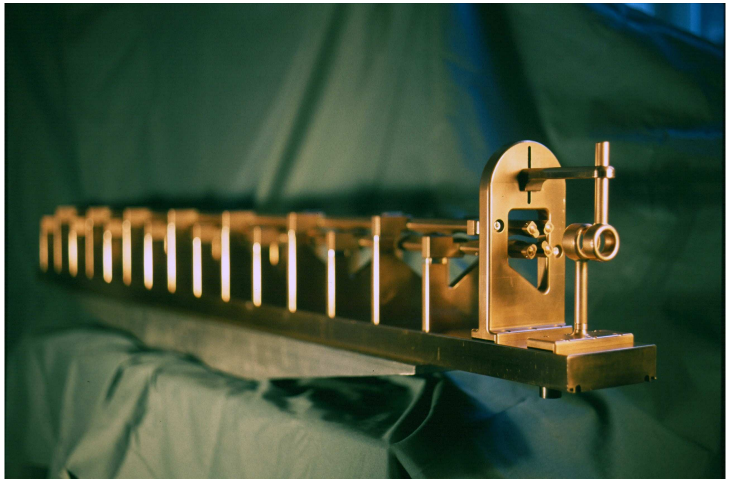
Transmission as function of the input emittance

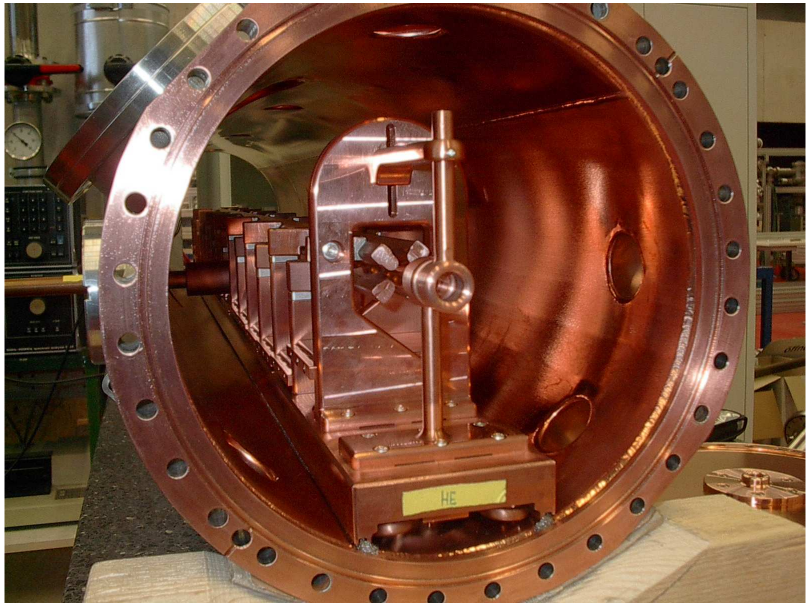


radial and longitudinal output emittance as function of input emittance (I = 0 mA)

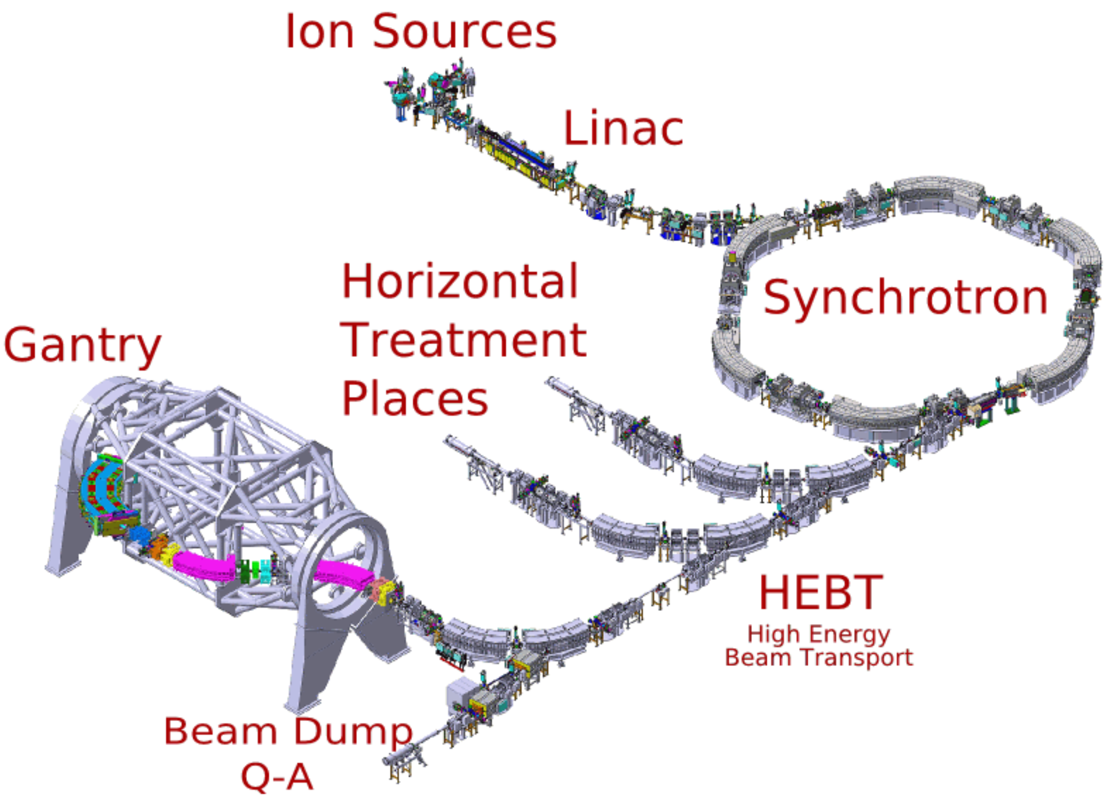
Another ECR-RFQ-IH-DTL combination







Operating frequency	216.816 MHz
Ion species	$^{12}C^{4+}$, protons
Length of tank	1.40 m
# of RFQ cells	219
Input/output energy	8 / 403 keV/u
Input emittance	$\varepsilon_{x,y}$=150 πmm mrad
Electrode voltage	70 kV
Power consumption	165 kW

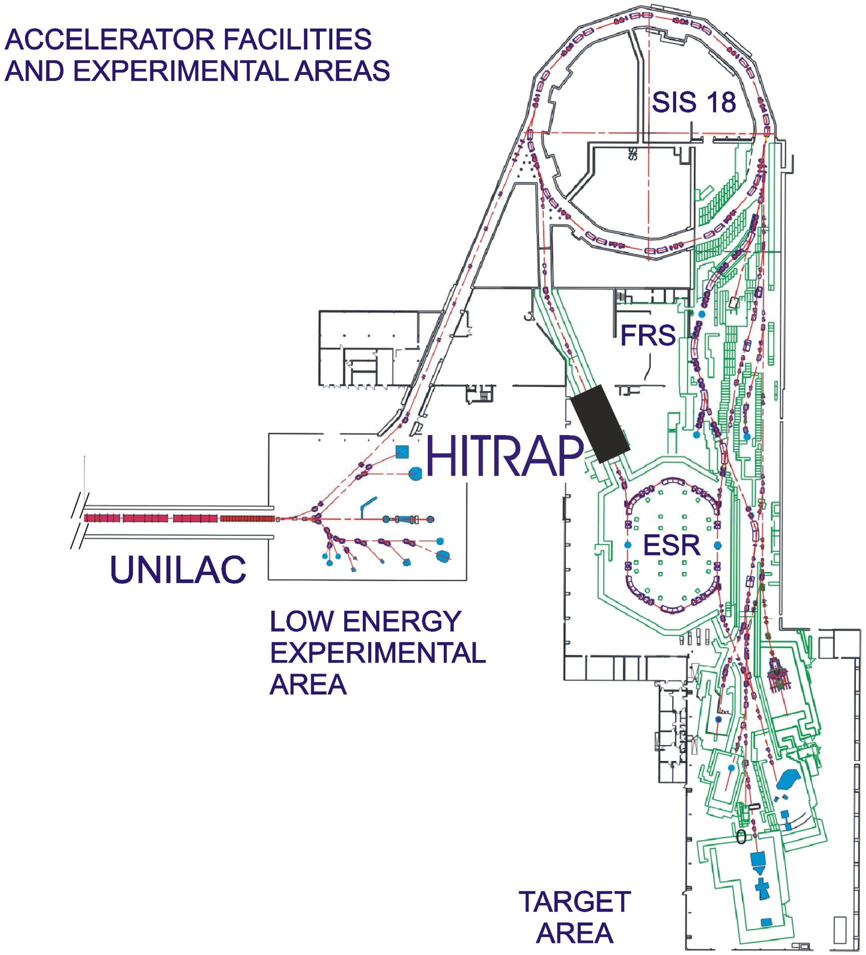


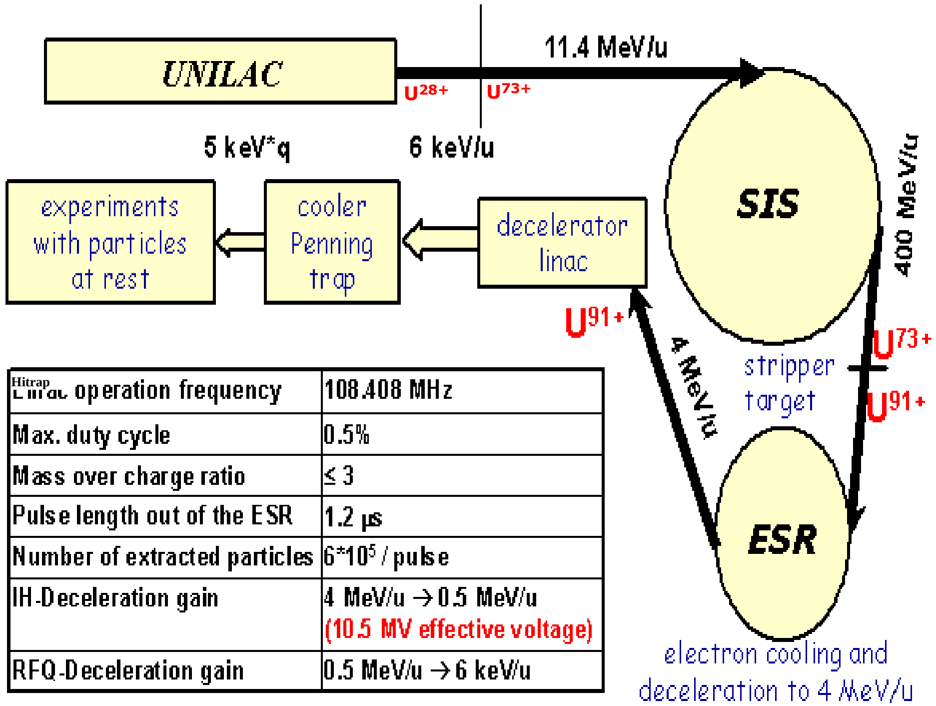
- 2 ECR ion sources (p, C)
  - Circumference 65 m
  - KO extraction (bunched)
  - Extraction time 5 s
  - Spill interruptions
- 3 treatment places
- 7 MeV/u injector linac
  - 2 horizontal fixed beam
- Compact synchrotron
  - 1 isocentric gantry
- 1 research & QA place

Three more RFQs (built) aligned and tuned

M.Maier MOP057

B.Schlitt W205





Hitrap Linac operation frequency	108.408 MHz
Max. duty cycle	0.5%
Mass over charge ratio	≤ 3
Pulse length out of the ESR	1.2 µs
Number of extracted particles	$6*10^5$ / pulse
IH-Deceleration gain	4 MeV/u → 0.5 MeV/u (10.5 MV effective voltage)
RFQ-Deceleration gain	0.5 MeV/u → 6 keV/u

HITRAP at GSI

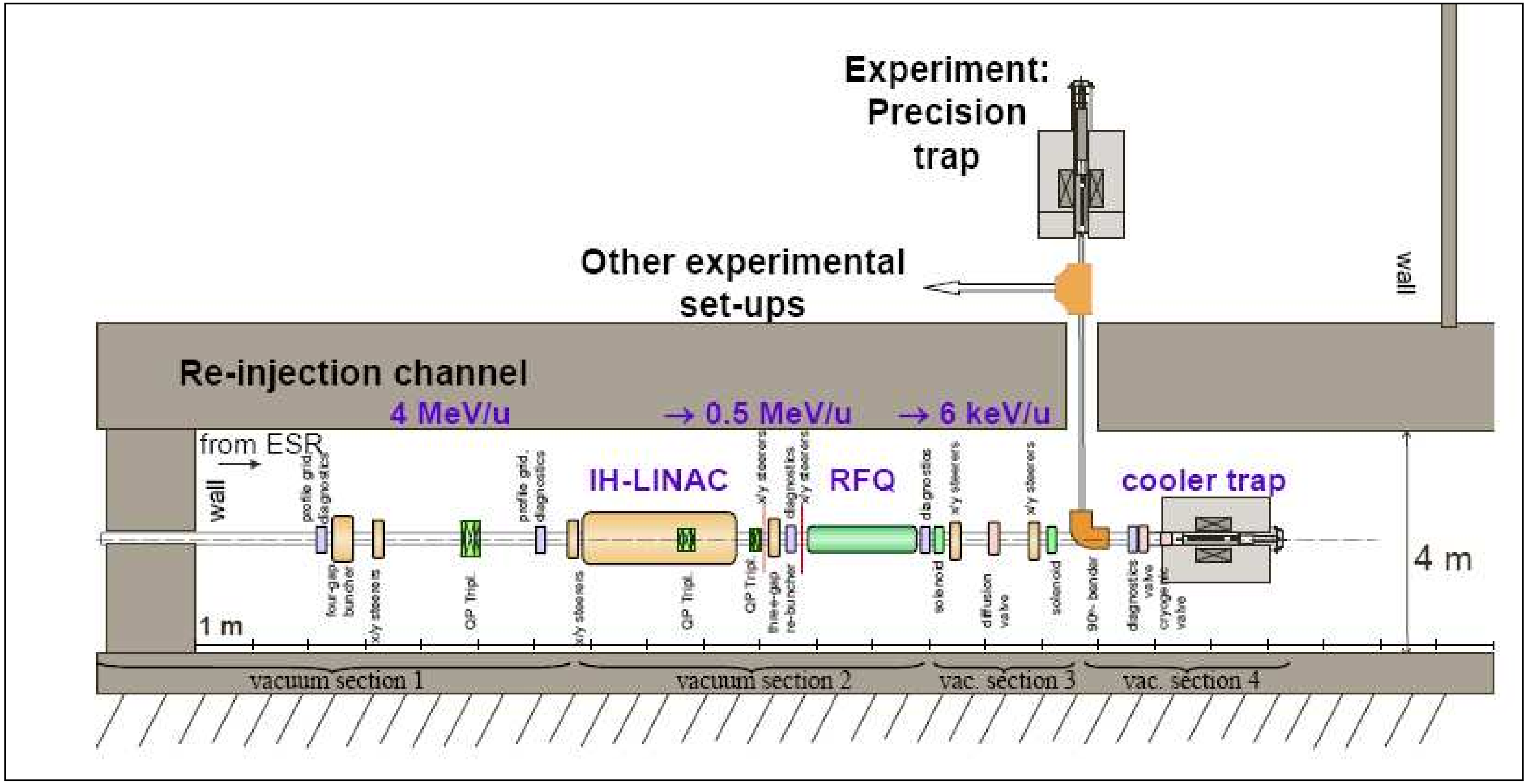
W Barth MO204

L.Dahl MOP019

J. Pfister TUP074

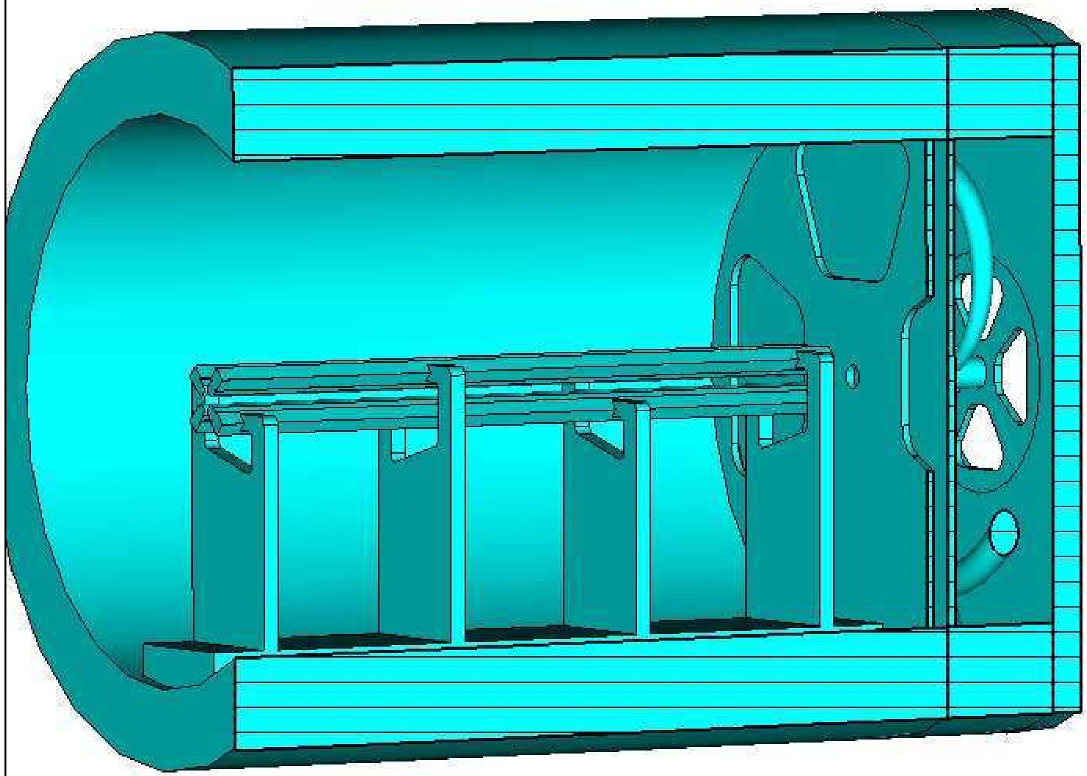
Another ECR-RFQ-IH-DTL combination

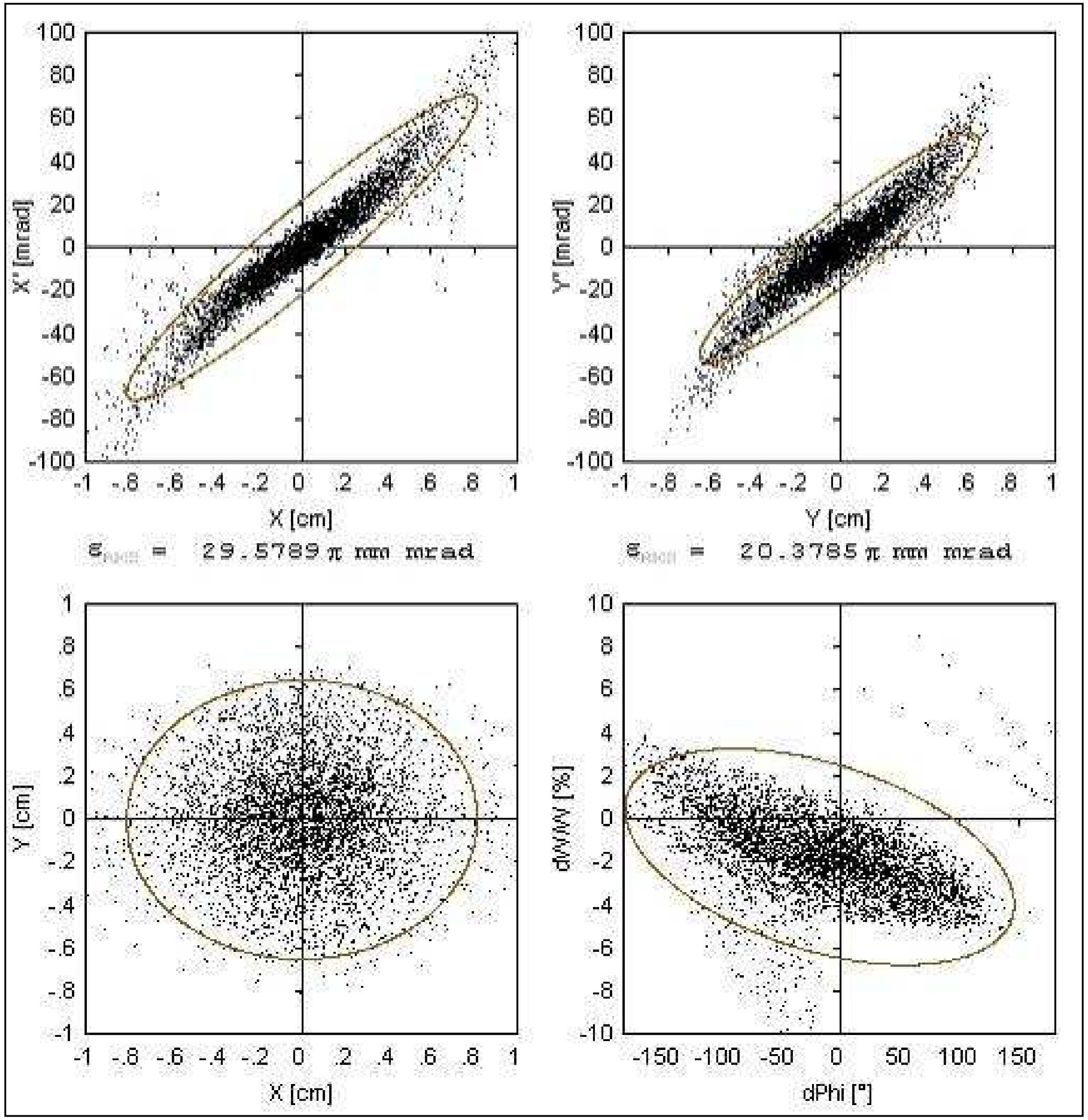
HITRAP at GSI



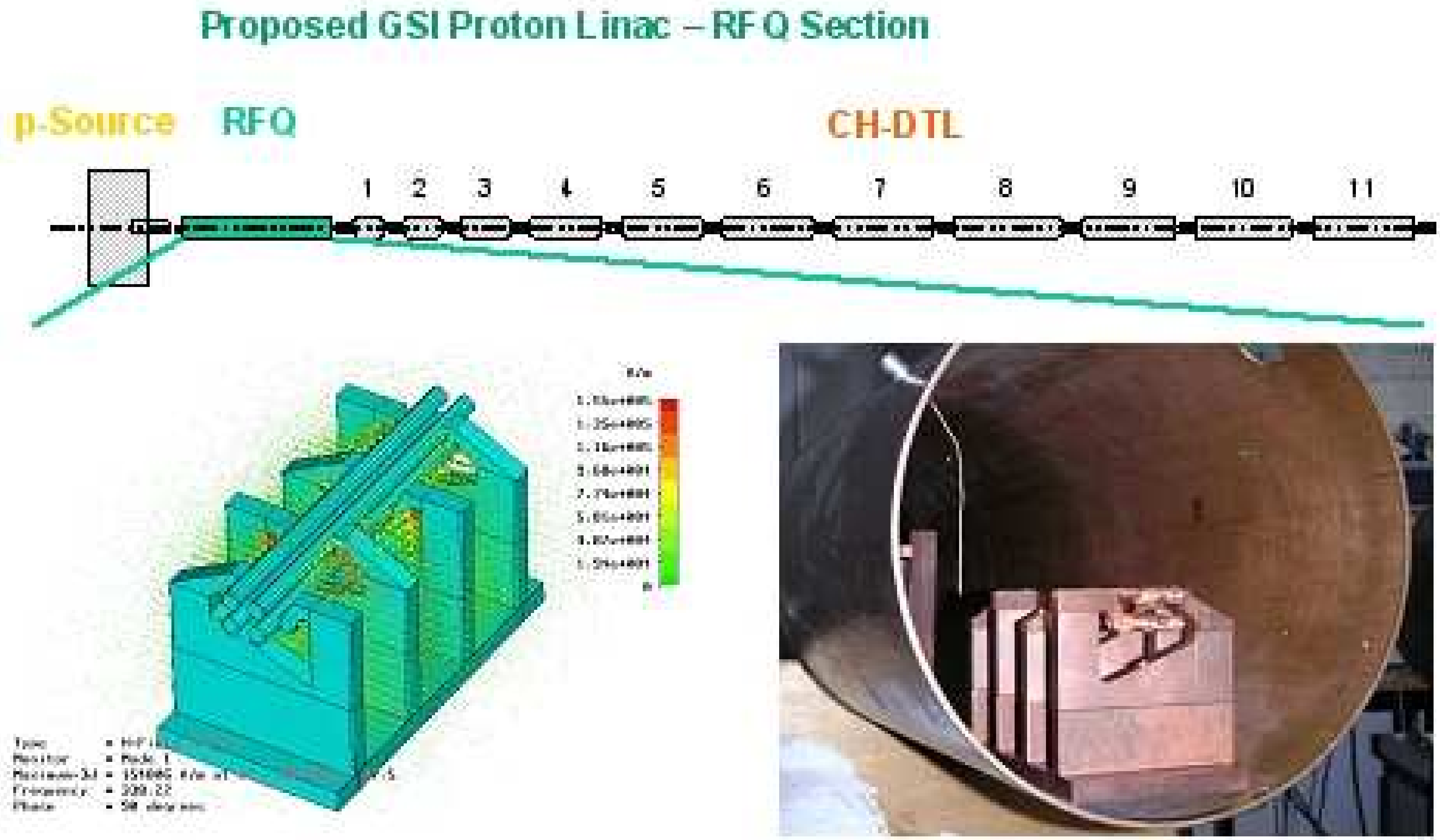
Input energy / output energy	500 keV/u / 6kev/u
Charge-to-mass ratio q/A	> 1/3
Frequency	108.408 MHz
Electrode voltage	77.5 kV
RFQ length	1.9 m
Input emittance (norm.)	0.24 π mm mrad
Radial output emittance (norm.)	0.37 π mm mrad
RF-Power	90 kW

HITRAP-RFQ





HITRAP output beam



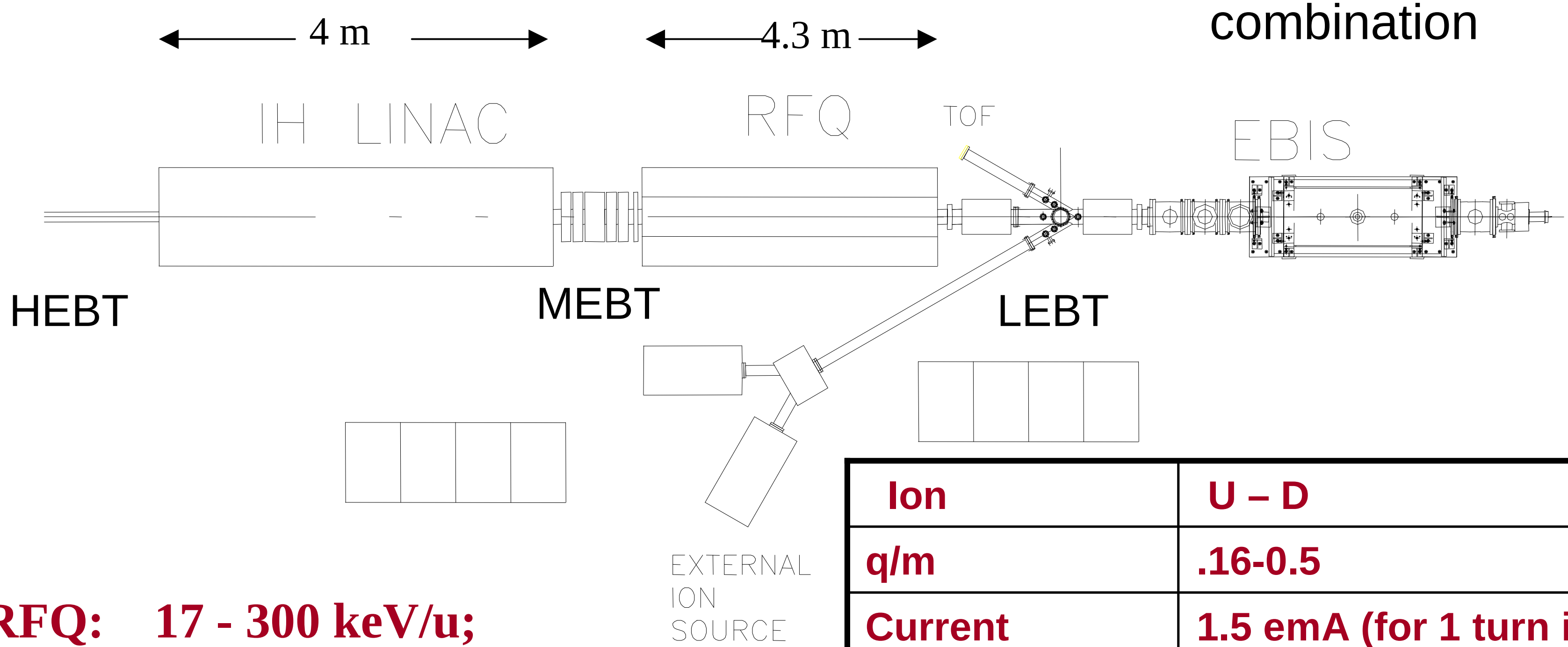
4-Rod RFQ: 352MHz, 75keV-3MeV, I_{max}=100mA

L.Groening (MOP075)


PHOBOS
10:00 o'clock
12:00 o'clock
BRAHMS & PP2PP ($\vec{p}$)
2:00 o'clock
RHIC
4:00 o'clock
PHENIX($\vec{p}$)
8:00 o'clock
STAR ($\vec{p}$)
6:00 o'clock
2 superconducting rings
3.8 km circumference
NSRL
μ g-2
HEP/NP(p)
LINAC
BOOSTER
AGS
TANDEMS

Preinjector Layout

Another
ECR-RFQ-IH-DTL
combination



Ion	U – D
q/m	.16-0.5
Current	1.5 emA (for 1 turn inj)
Pulse Length Rep. Rate Duty Factor	10 μs 5 Hz 0.005 %
Emittance	0.7 π mm rad (nor, 90%)
Energy Spread	1.8 keV/amu

RFQ: 17 - 300 keV/u; 100 MHz

IH Linac: 0.3 - 2.0 MeV/u; 100 MHz

J.Alessi TUP120

M.Vossberg MOP033

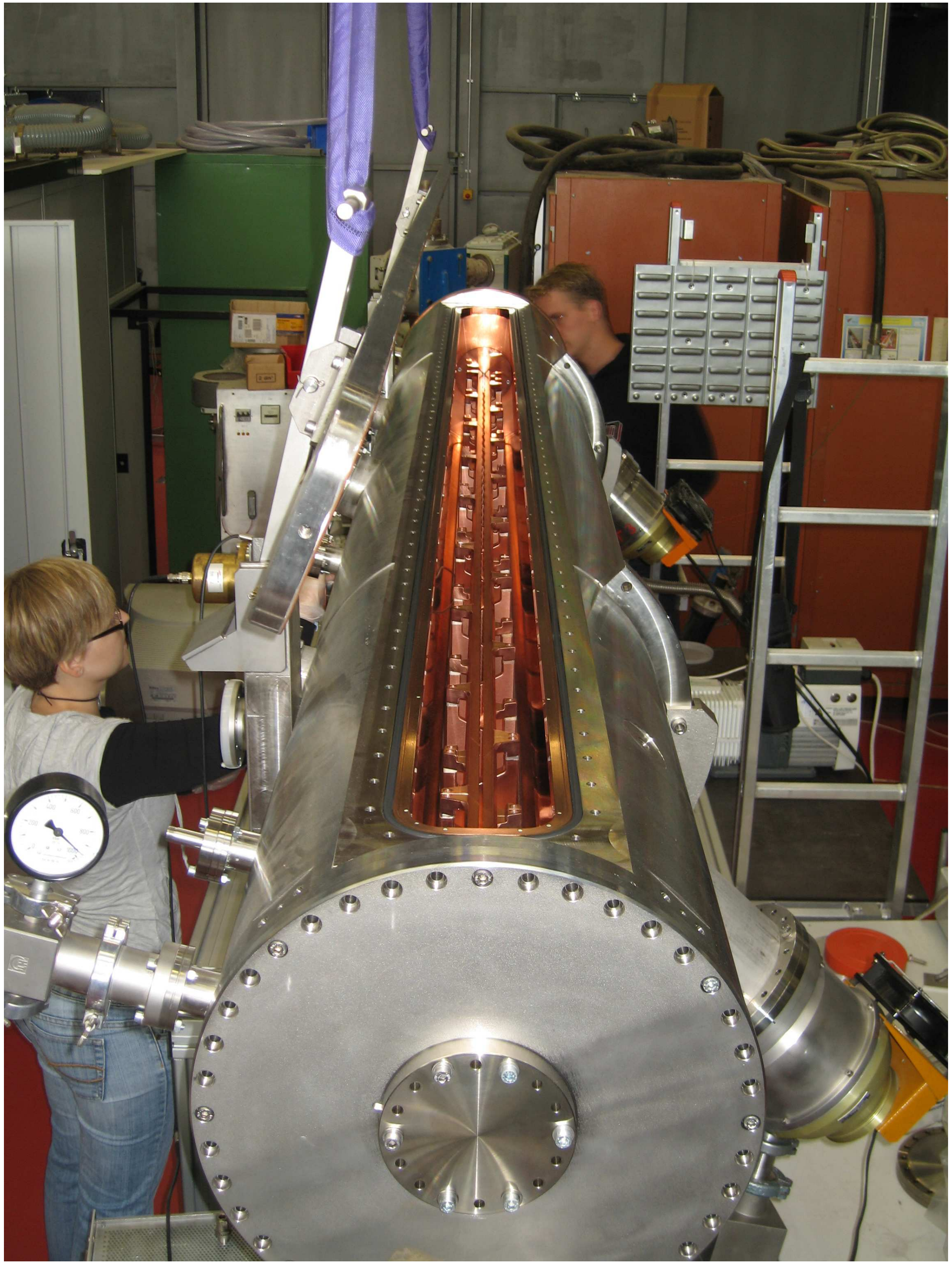
Low emittance

High transmission

Compact

Reduction of the exit angle

RHO_coefficient (R/r_0)	0.85
A/q	6.25 / 1
Designed Input Energy [MeV] (total / per nucleon)	0.10625 / 0.017
Designed Output Energy [MeV] (total / per nucleon)	1.87500 / 0.300
Calculated Output Energy [MeV]	**1.886**
Frequency [MHz]	100.625
Inter-Electrode Voltage [kV]	70
$\varepsilon_{in}^{trans., n., rms}$ / $\varepsilon_{in}^{trans., n., real}$ [π *mm-mrad]*	0.0583 / 0.3498
Peak Beam Current [mA]	10
Minimum (Absolute) Synchronous Phase [°]	-30.21
Minimum Aperture [cm]	0.3172
Maximum Modulation	1.9505
Kilpatrick Factor	1.8290
$\varepsilon_{out}^{x., n., rms}$ [π *cm-mrad]*	0.0082(100%) 0.0060(90%)
$\varepsilon_{out}^{y., n., rms}$ [π *cm-mrad]*	0.0084(100%) 0.0063 (90%)
$\varepsilon_{out}^{z., rms}$ [π *MeV-deg]*	0.1016(100%) 0.0561(90%)
Relative Energy Spread [%] (½ ΔW of 90% Transported Particles/Wout)	1.22
EXITFFL [cm]	5.0
Electrode Length [cm]	311.80
Total Number of Cells	190
Elimit [MeV]	1.1839
Beam Transmission Efficiency [%]	97.75 (4000)



Design

Simulation,,,,,,,,

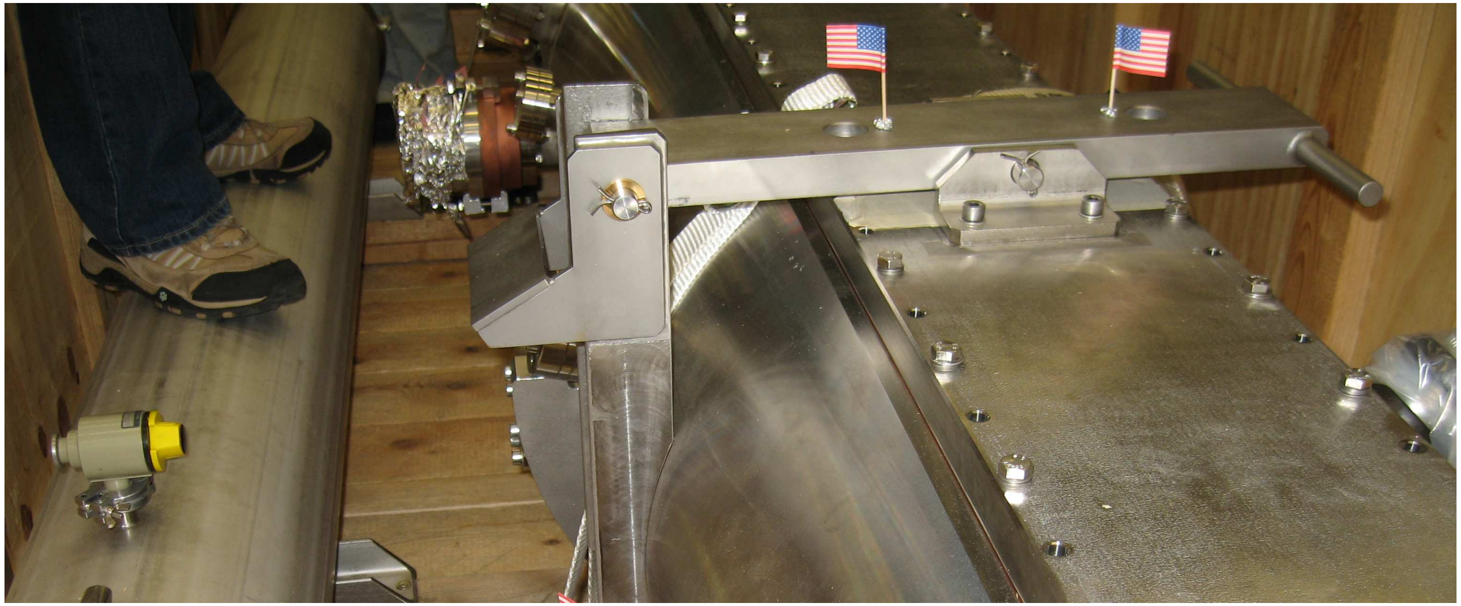
Puplication

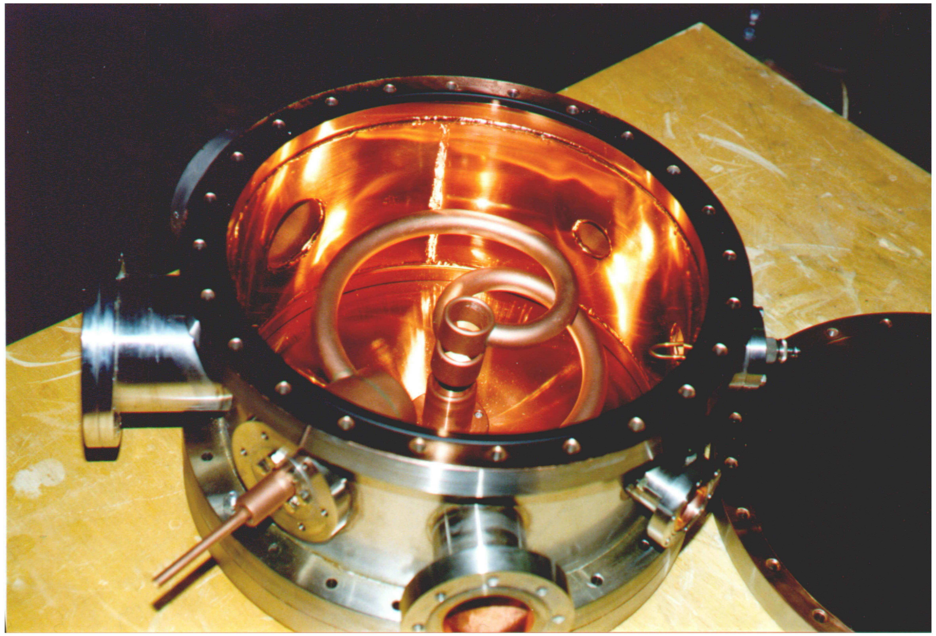
Proposal,,

CDR,TDR,

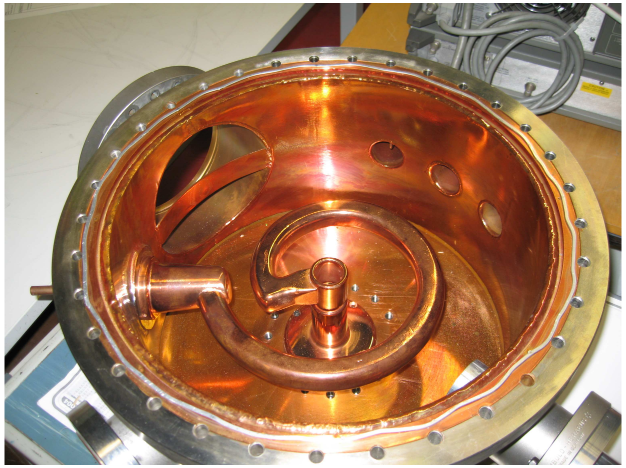
PR

hardware

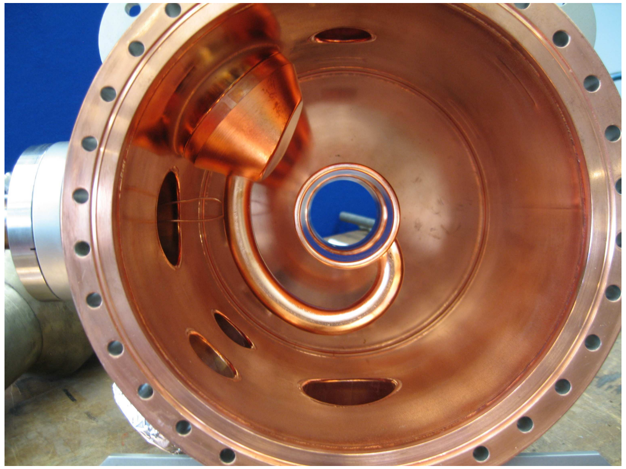




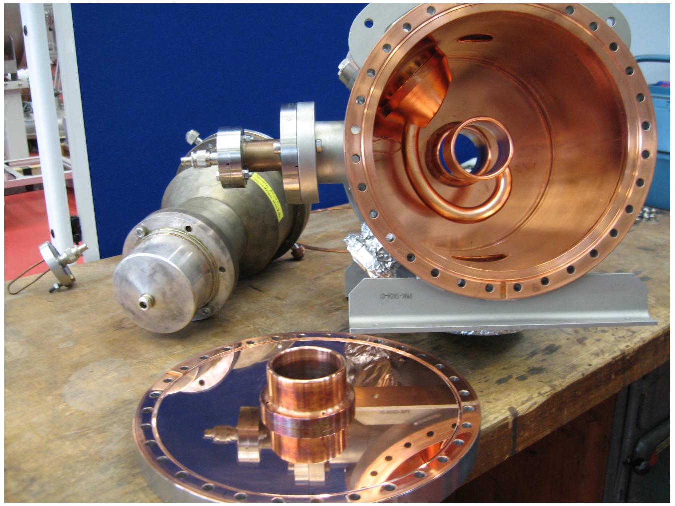
REX-Isolde



GSI-HITRAP



Med-HE



BNL: C1,C2,C3 are being built

The SARAF SC Linear Accelerator

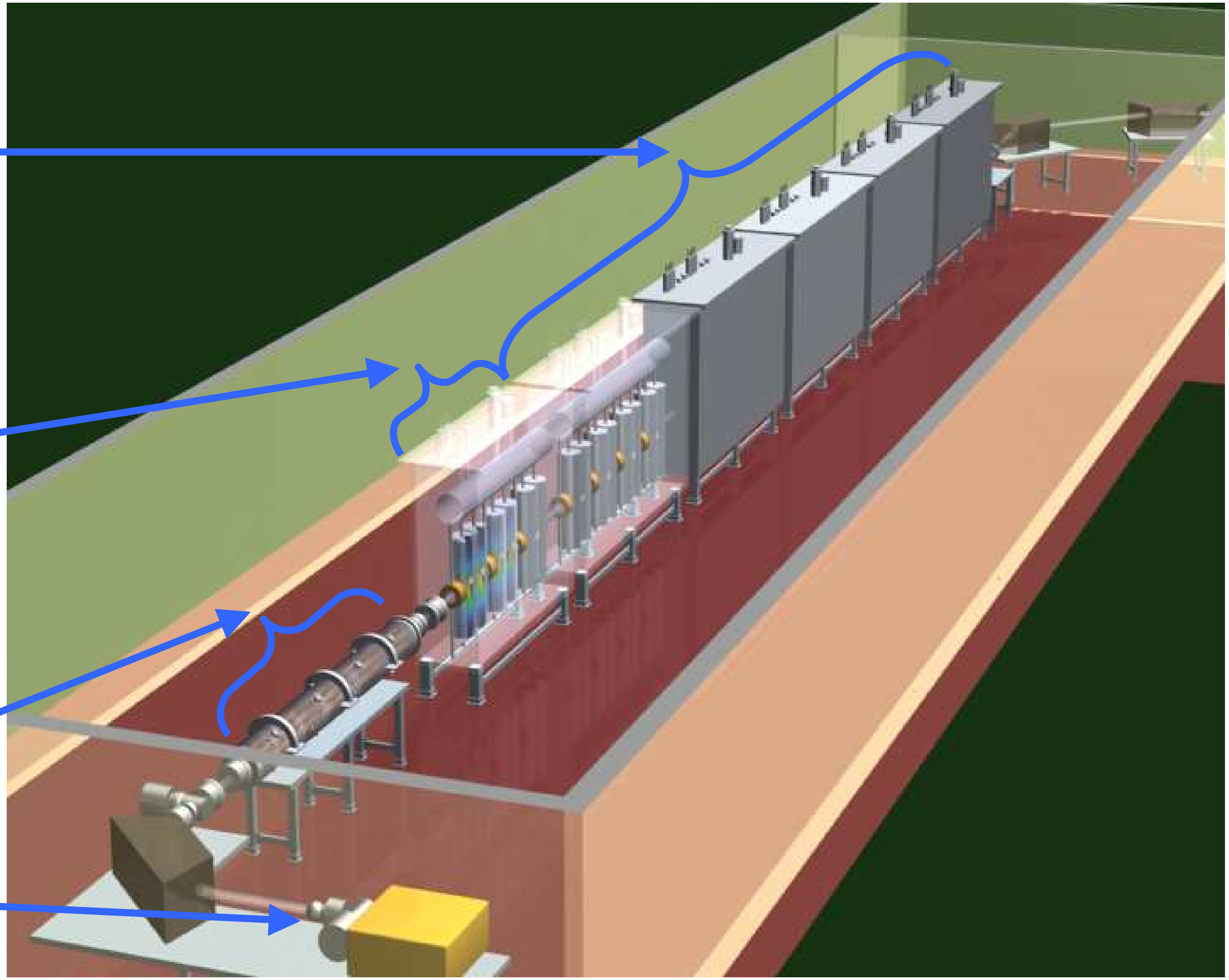
Protons/Deuterons, 5 - 40 MeV, 40 µA - 4 mA, RF SC linac

2^{nd} – 6^{th} cryostats
40 SC HWR
176 MHz β_0=0.15

1^{st} cryostat
6 SC HWR
176 MHz β_0=0.09

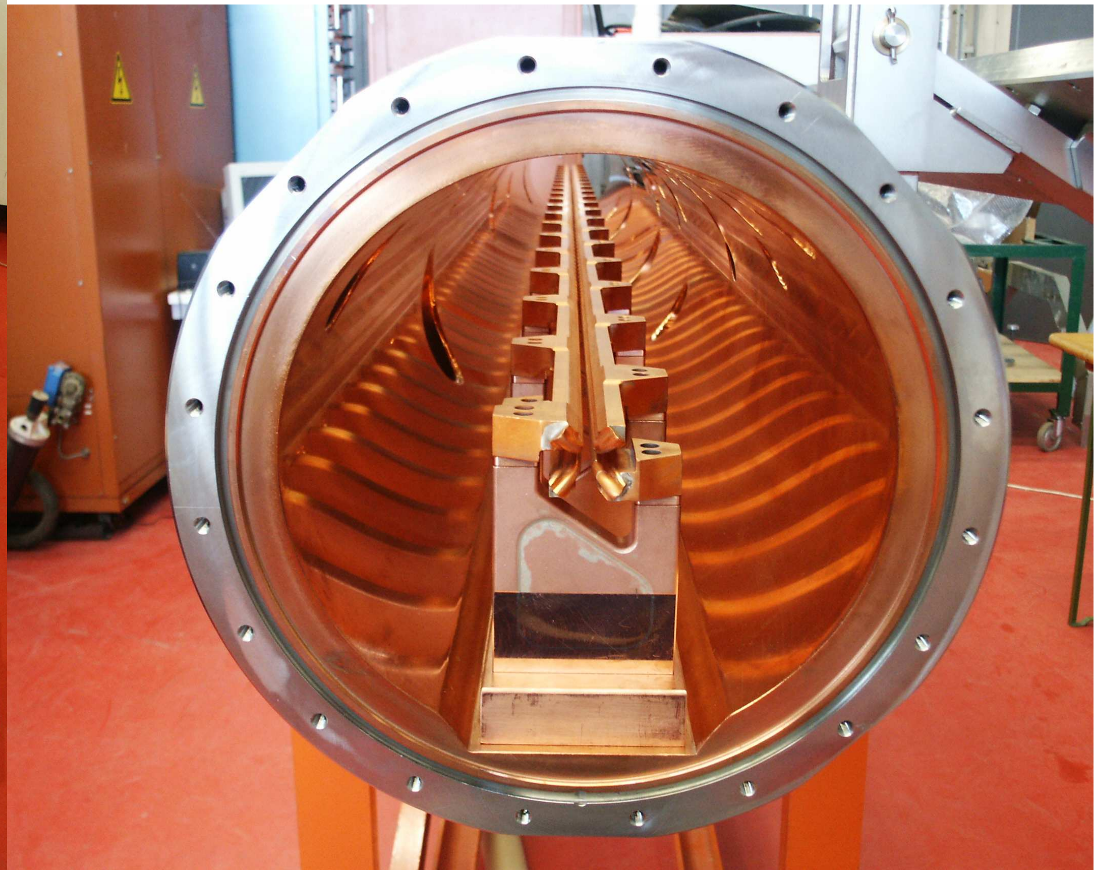
RFQ
176 MHz M/q≤2
1.5 MeV/u

ECR ion source
20 keV/u 5 mA

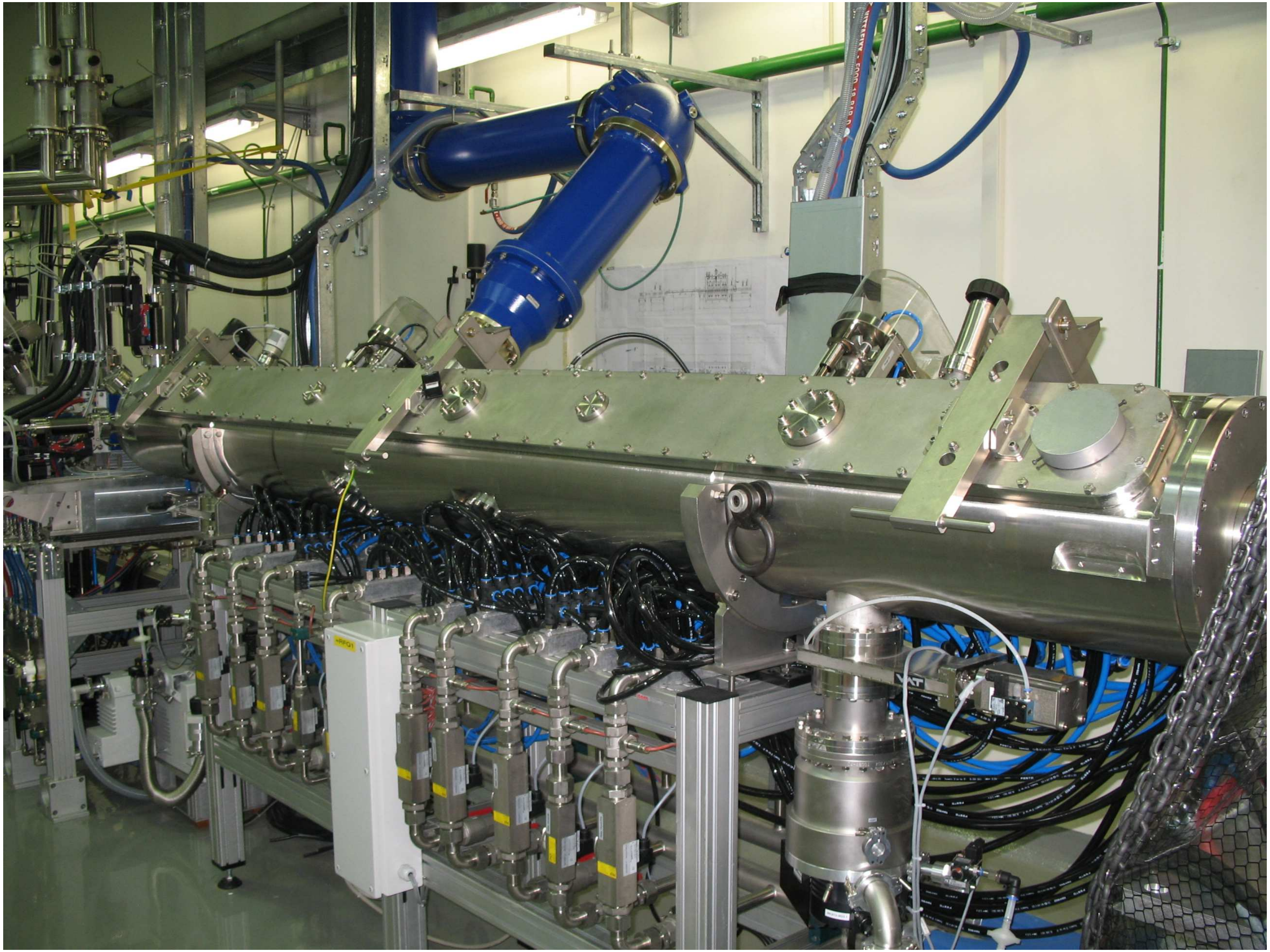


I. Mardor MO203

SARAF – Soreq Applied Research Accelerator Facility



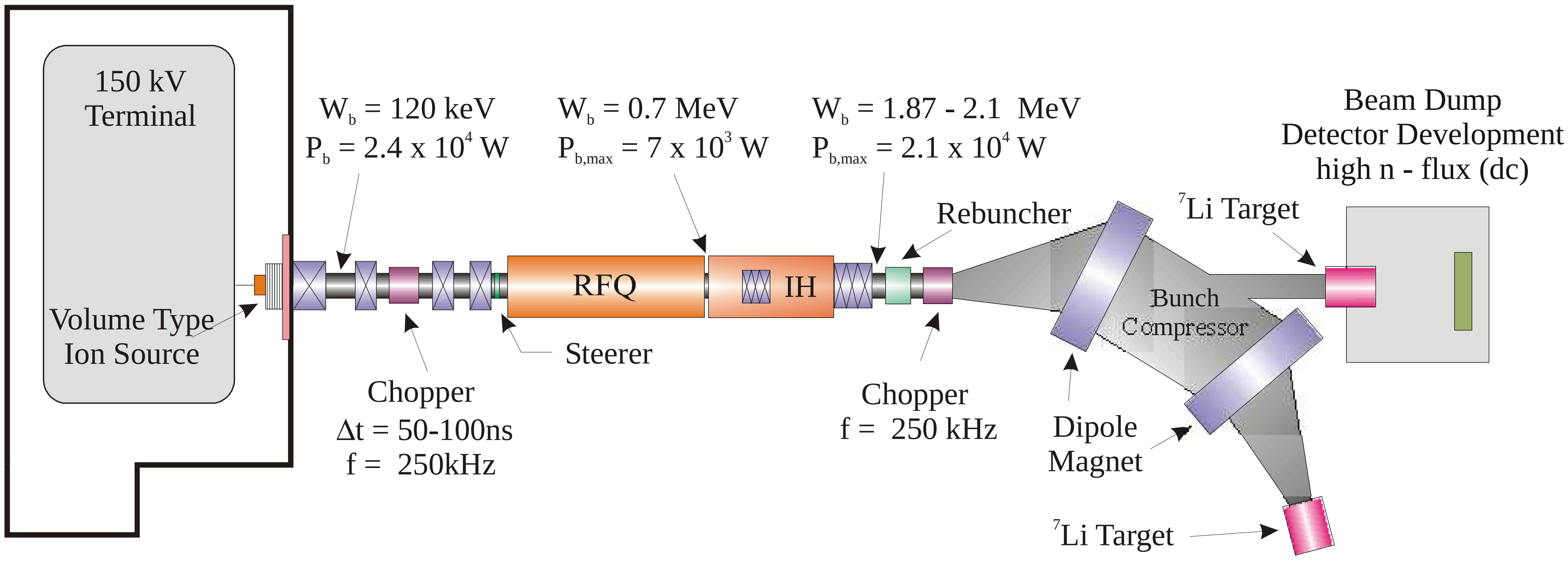
SARAF –RFQ: 3 MeV D+, 175MHz, CW


VAT

Another ECR-RFQ-IH-DTL combination

FRANZ Key Parameters

FRANZ Overview



- Extracted source current : 200 mA dc
- Pulsed beam target : 10^7 n / cm^{2}s at l=0.8 m
- 'Straight' beam target : 10^8 n / cm^{2}s

Frequency	175 MHz
Input energy	120 keV
Output energy	0.7 MeV
Beam current	150/200 mA
output emittance rms norm.	0.1 π mm mrad
Long. Emittance	20keV*30degr.
Electrode voltage	75 kV
RFQ length	1.75 m
cell number	95

FRANZ – RFQ parameters

A.Bechtold MOP001

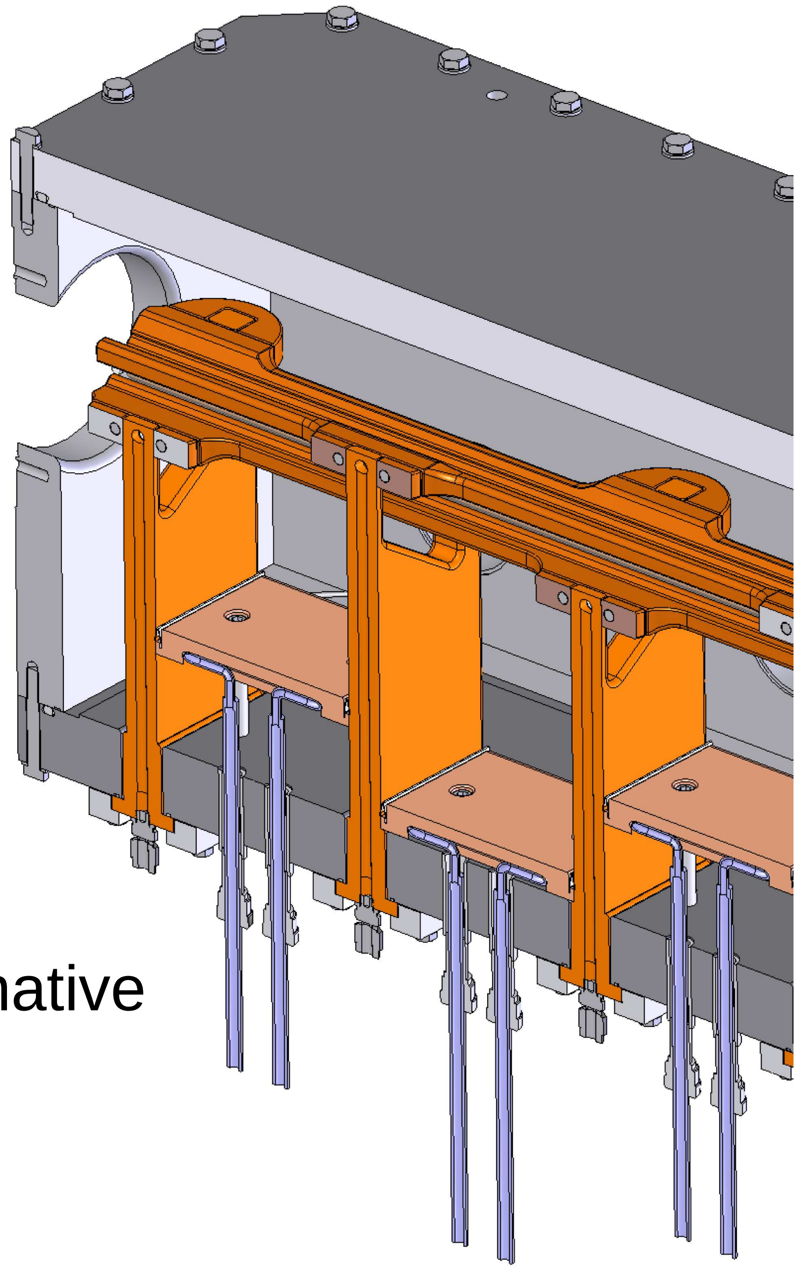
O.Meusel MOP002

Modifications:

Less complex

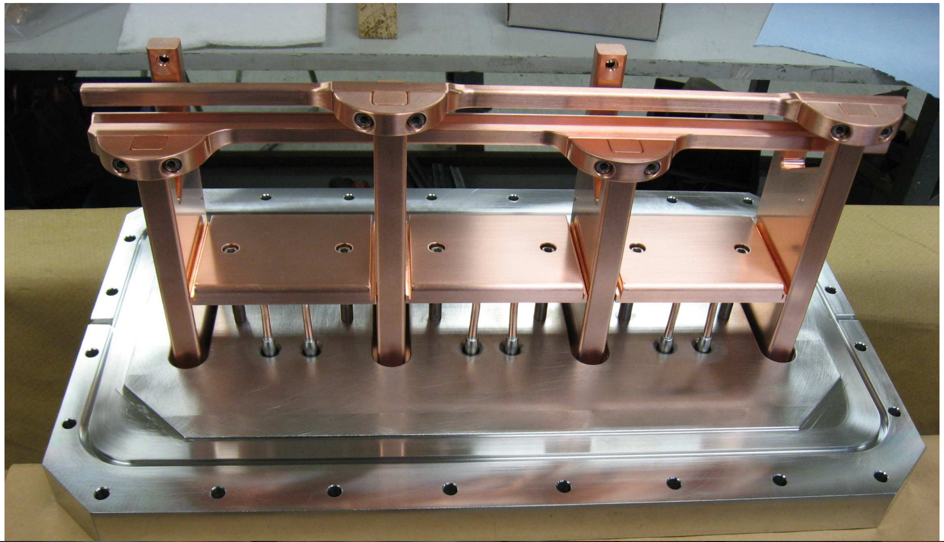
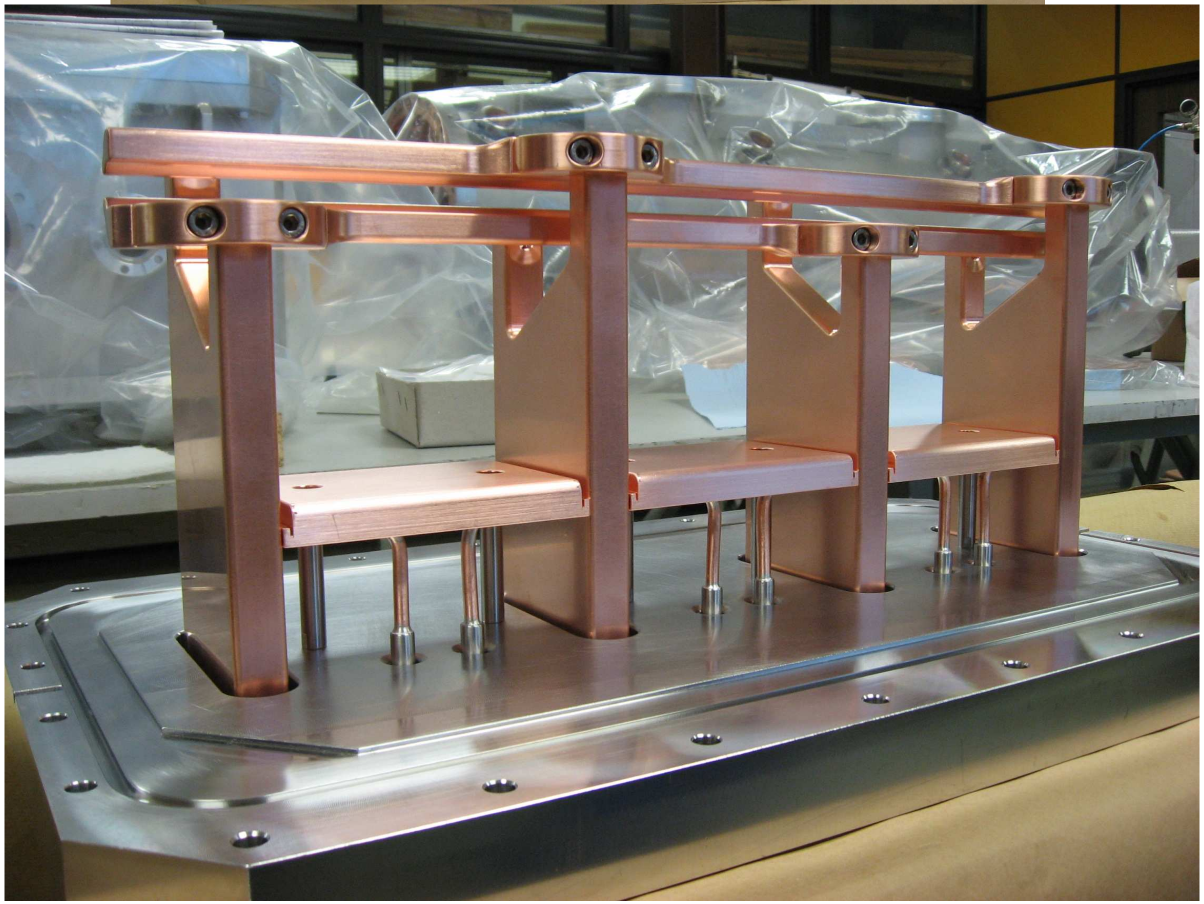
Cooling
simpler

Size problem



Example of alternative
design:

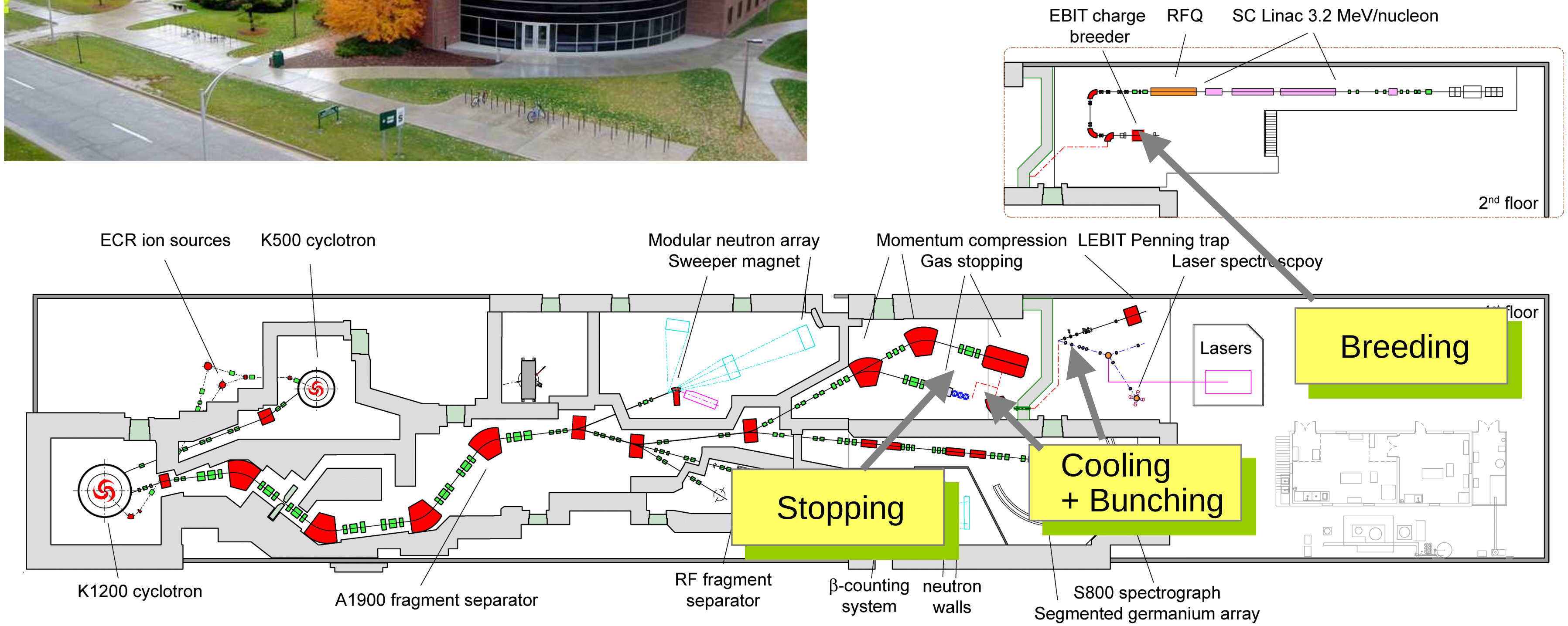
Prototype

National Superconducting Cyclotron Facility

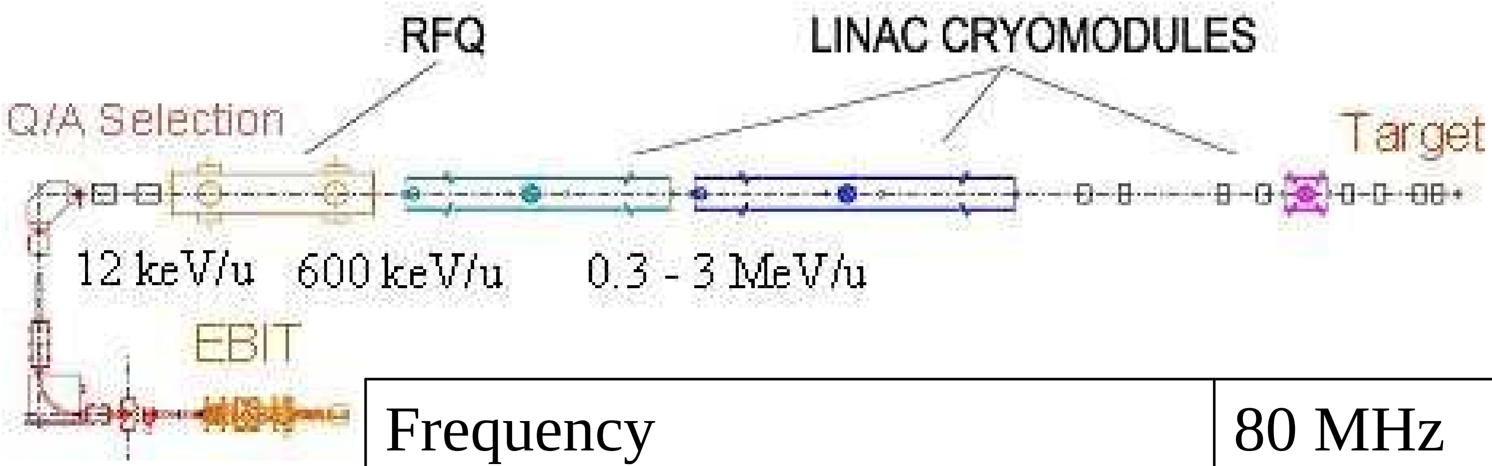
National user facility (700 users, 300 employees, NSF funded)

RIB production with projectile fragmentation and in-flight separation at 100-200 MeV/u



First facility to perform experiments with stopped (manipulated) projectile fragments

- Precision Penning trap mass measurements program with LEBIT since 2005
- Laser spectroscopy and beam polarization under development (2010)
- Re-accelerate stopped beams from projectile fragmentation in 2010

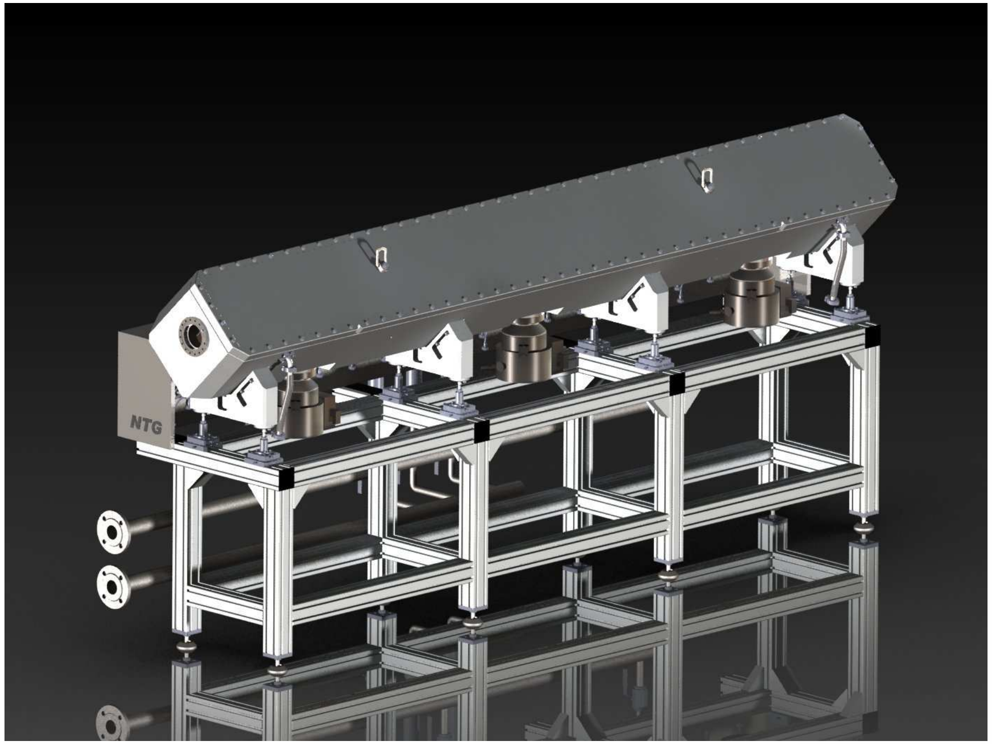


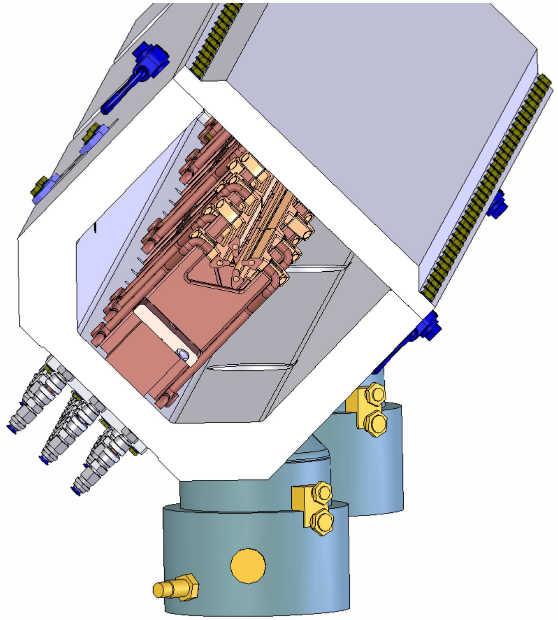
Frequency	80 MHz
Input energy	12 keV/u
Output energy	0.6 MeV/u
Charge to mass ratio	> 0.2
output emittance rms norm.	0.1 π mm mrad
Long. Emittance	30keV/u*degr.
Electrode voltage	87 kV
RFQ length	3.35 m
cell number	93

CW

X. Wu MOP056

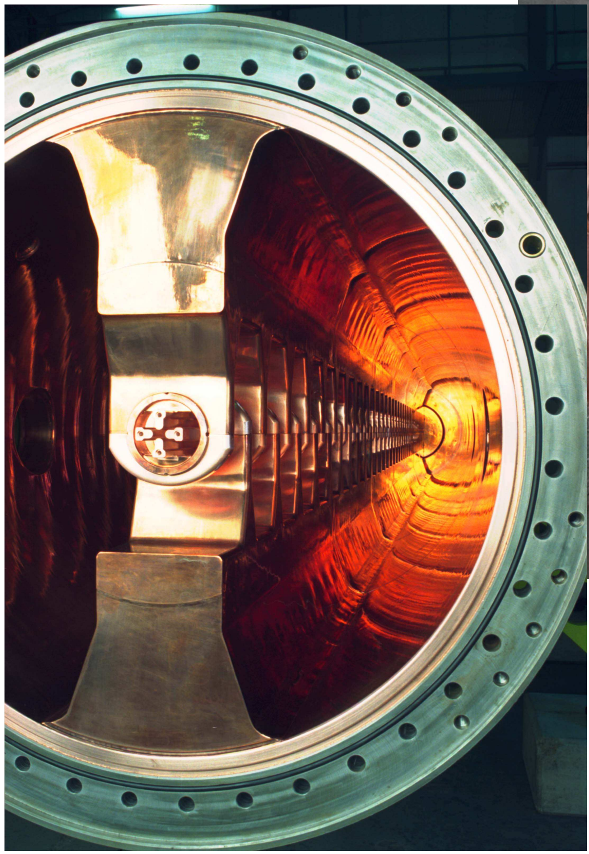
Q.Zhao THP069

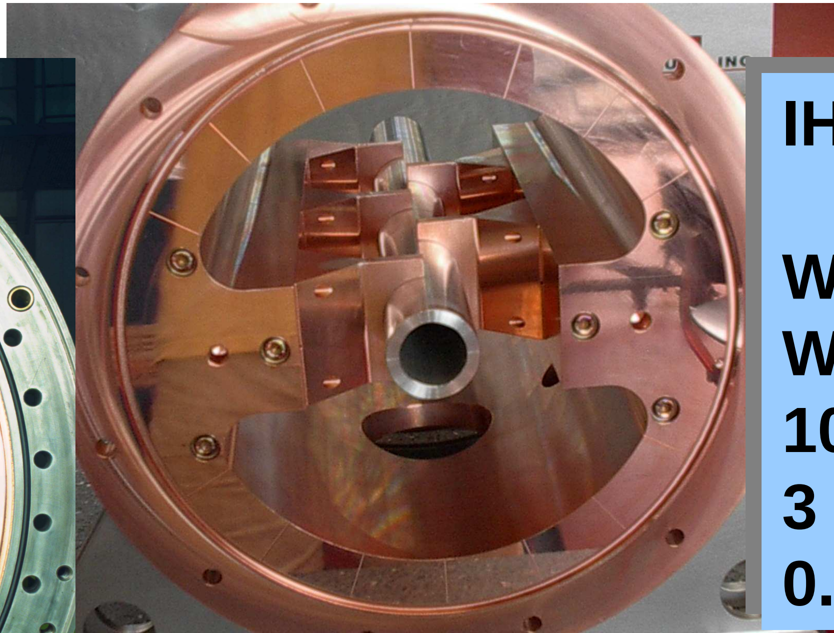




Al-cavity, st.steel flanges, block milling, cooling tubes (el,st),

Check-NTG



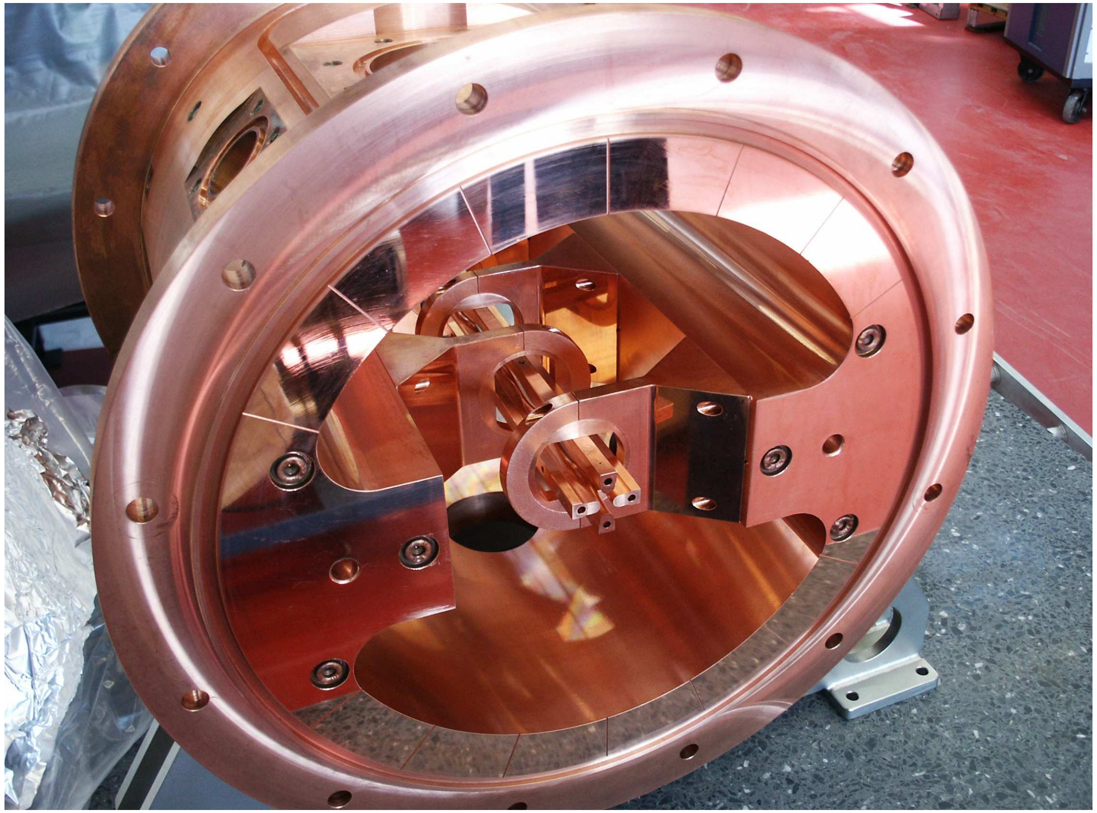


IH-RFQ für MAFF:

W_{in}=2.5 keV/u
W_{out}=300keV/u
101.28 MHz
3 m Length
0.32 m Diameter

IH-RFQ - GSI:

36 MHz
9.4 m
0.76 m Diameter



Riken-RFQ

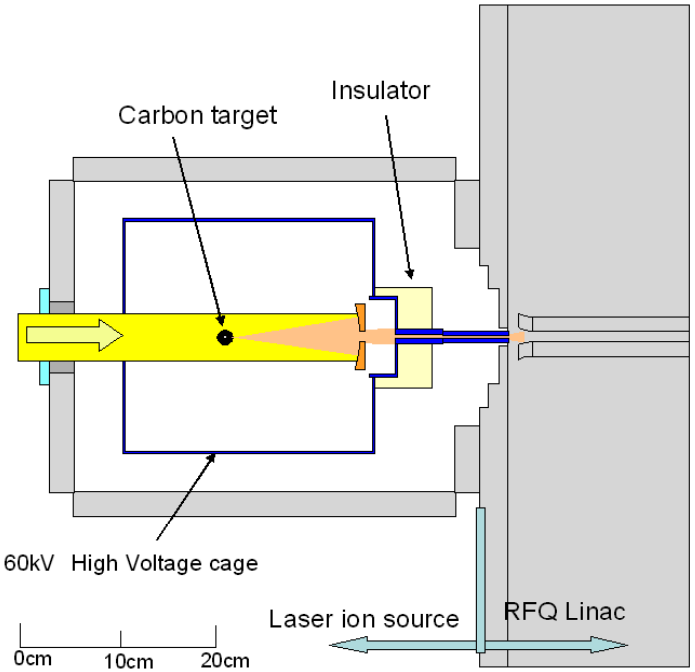
Laser ion-source, direct injection into RFQ

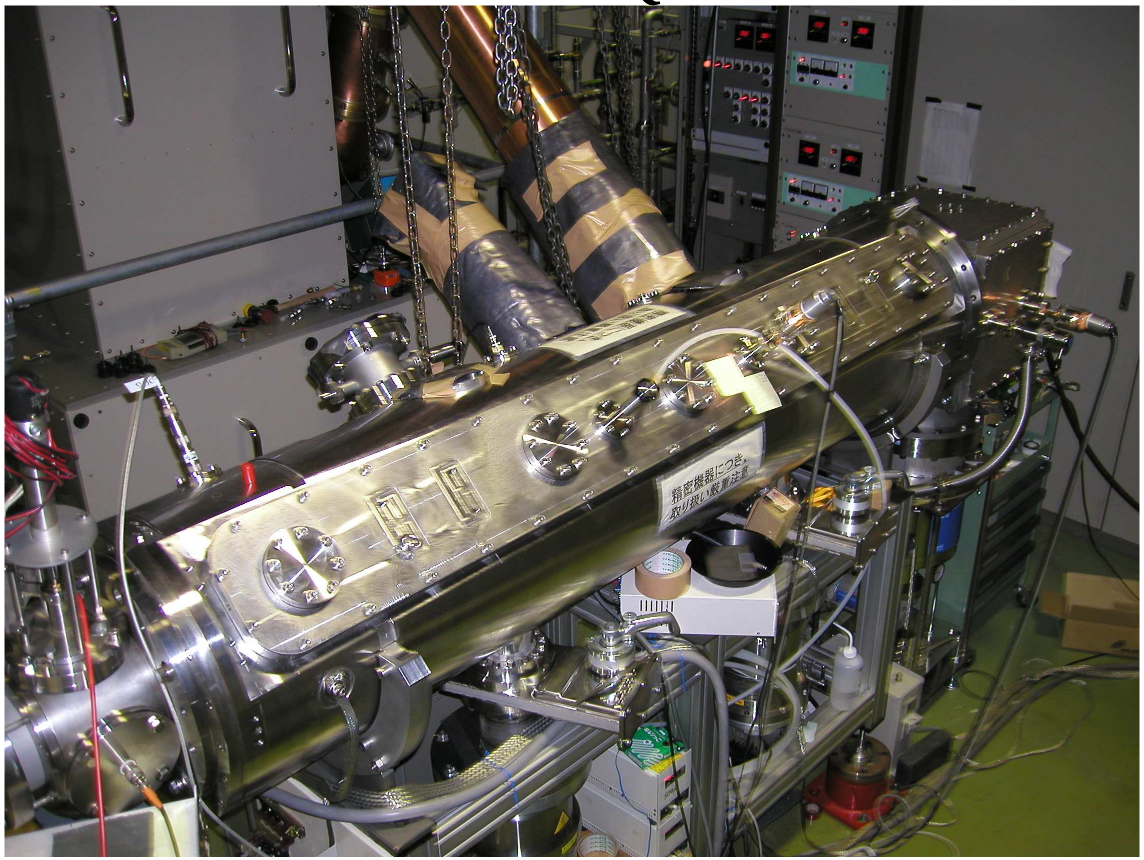
I max = 60 mA C^{4+}

M. Okumura

MOP0044

Second Au^{12+} : new RFQ insert:

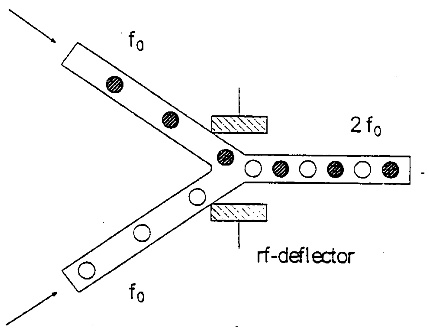




Ion source current/brillance: limited by the ion source / plasma density

emittance is prop. to the beam current $\varepsilon_N \sim I_{Ion}$

"Funneling"



ideal: same emittance, twice the beam current

$\varepsilon_N \sim$ const., higher currents at higher energies

Theory:

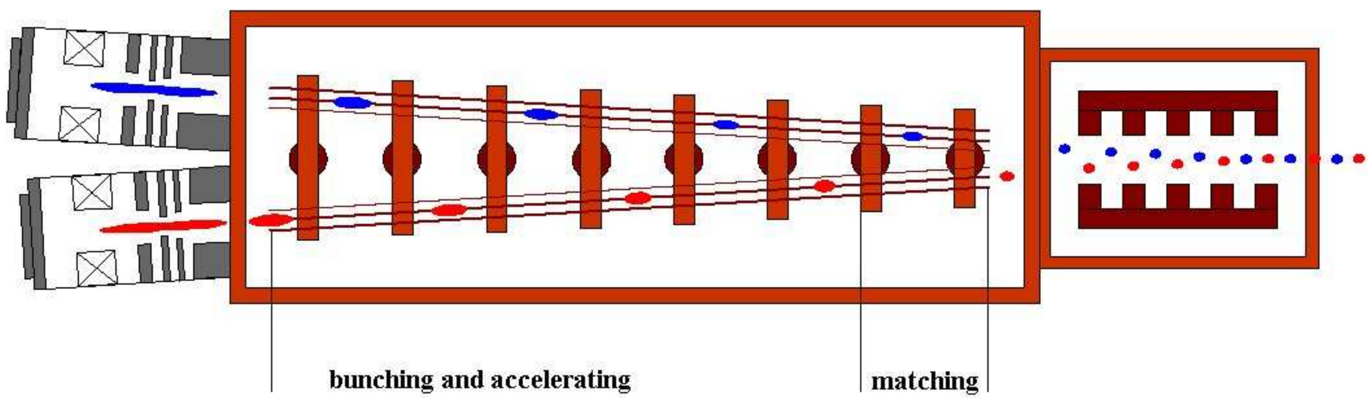
Two/multigap deflector

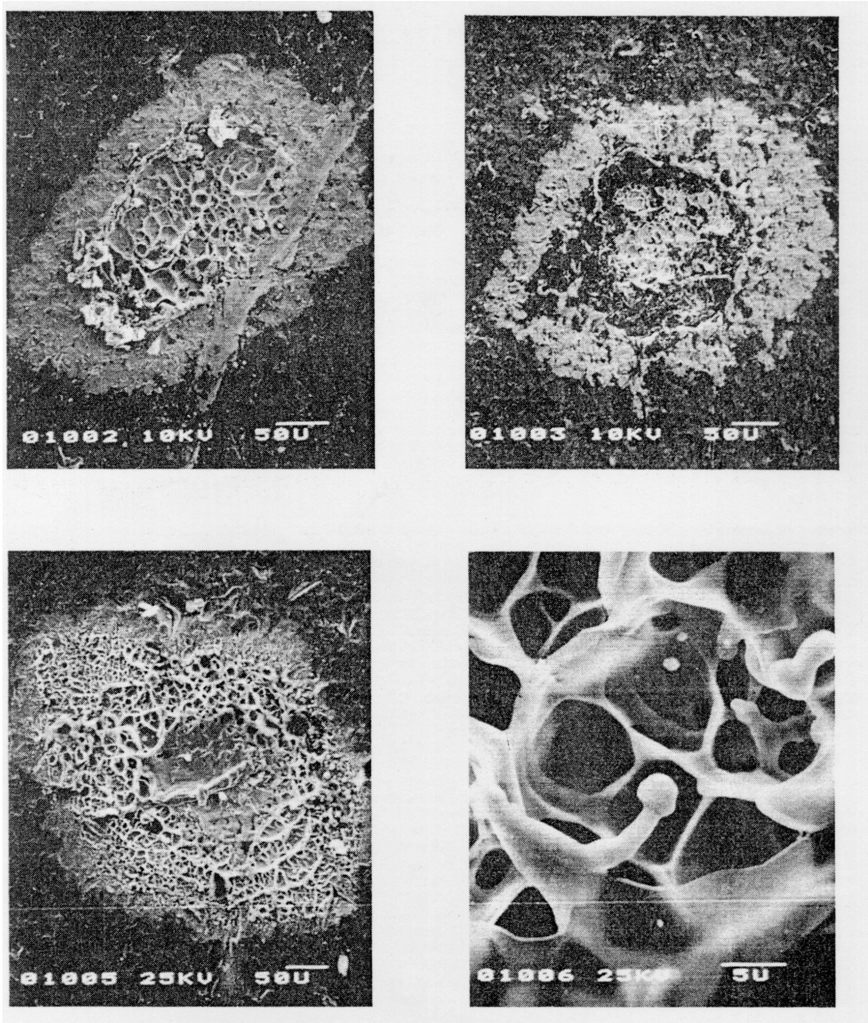
Critical matching

Experiment:

Two beam funneling

$\Delta\varepsilon > 0$, $Tr < 1$





Sparking :

limits the voltage U_g which can be applied to a gap
Improvement by surface preparation and conditioning
and electronic control
discharge started by electrons, dumps rf power
"how many Kilpatrick?"

R+D

Designs of optimized Med-RFQs

Heavy ion linac design

Neutron generators

Radiography

Implanters

R+D Issues

Beam dynamics:

High current, small emittance growth

Matching between stages

Beam losses

Beam formimg,

low voltage design (cw)

$\sum$: fight Liouville, stay linear

Structures:

Duty Faktor

Power density, cooling

Materials

Reliability

integral high duty factor operation

critical:

Power/length,

structure length/ λ

W.I.P.

Real critical points, problems ?

none !

responsible:
recent: B.Hofmann, J.Thibus, P.Fischer,L.Brendel
former: A.Bechtold, H.Zimmermann
presently:
M.Vossberg, N. Müller, J. Maus, P. Kolb, J. Schmidt, U. Bartz
AS

NTG: support in engineering, precise manufacture

there are some minor technical problems to be solved, like
tuning, cooling, copper plating, alignment, coupling, non-metric screws, GPM, psi,,-Units,,,,,,,
time schedules,,,

I want to thank my colleagues and our RFQ-group for help and good teamwork, which is necessary for successful projects and thesises. I have to thank the partners in our collaborations for entrusting us with such work, for patience and understanding which sometimes is necessary, because of the special style of University people, old and young ones, and for the Germanenglish (Denglisch)