FRANZ
A Facility for Neutron and Accelerator Physics

Long Phi Chau
chau@iap.uni-frankfurt.de

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Frankfurt Neutron Source at the Stern - Gerlach- Zentrum

Stern-Gerlach Center

Institute for Applied Physics (accelerator and plasma physics)	Institute for Physics (material research)	Institute for Nuclear Physics (atomic and nuclear physics)

Host larger experiments at the Goethe-University

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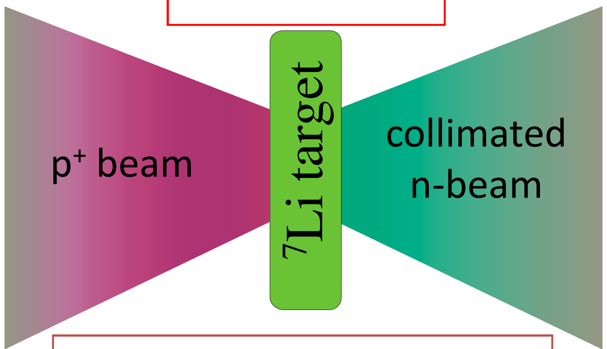
FRANZ

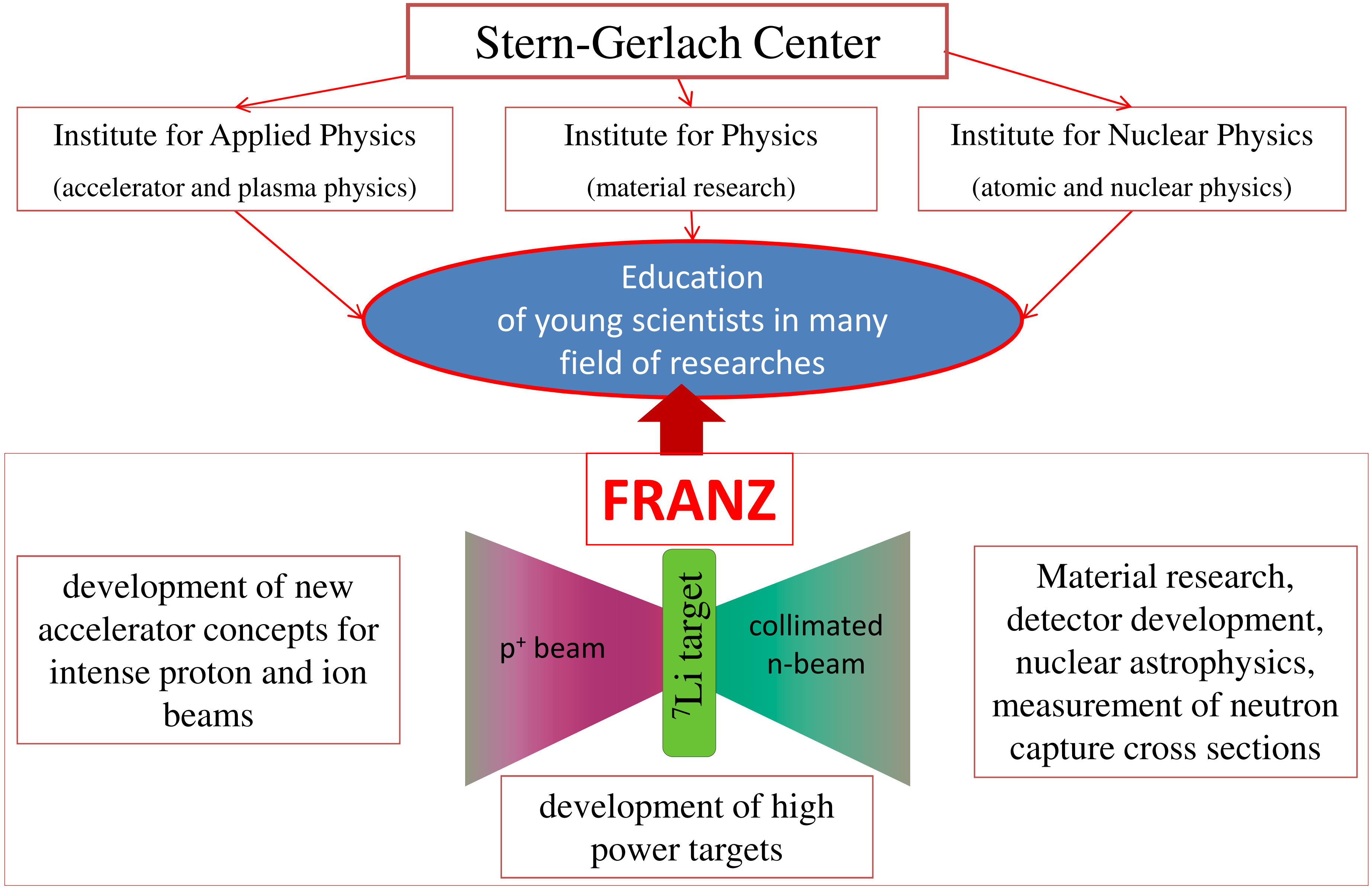
development of new accelerator concepts for intense proton and ion beams

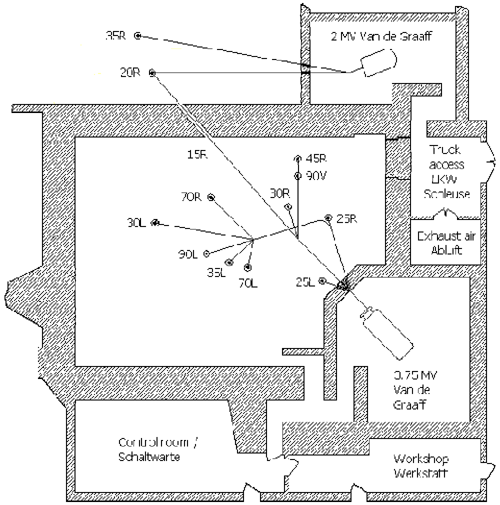


Material research, detector development, nuclear astrophysics, measurement of neutron capture cross sections

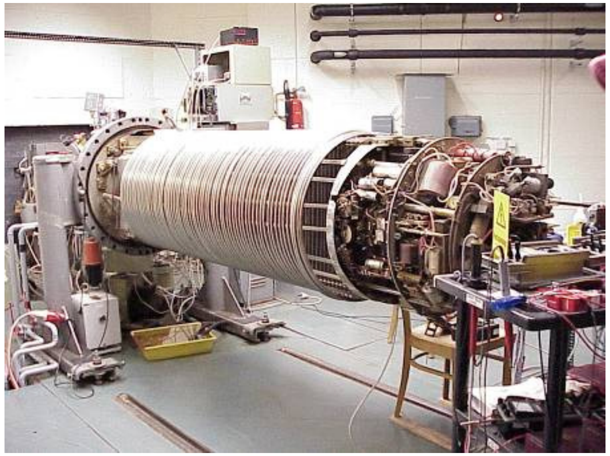
development of high power targets

Frankfurt Neutron Source at the Stern - Gerlach- Zentrum






FRANZ Käppeler



- Franz Käppeler retired since 2008: his research group is dissolved.
- Technology and knowledge transfer to GSI and Goethe-University.
- The FRANZ facility will increase the intensities by about 3 orders of magnitude. Allows investigations on radioactive samples with N about 10^{15}: Sub-milli-gramm sample of short-lived isotopes.
- Continuation and extension of the physics programme started around 1980 at the 3.7 MV Van-de-Graaff Laboratory at FZ Karlsruhe by using the expertise of the Institute for Applied Physics (IAP).

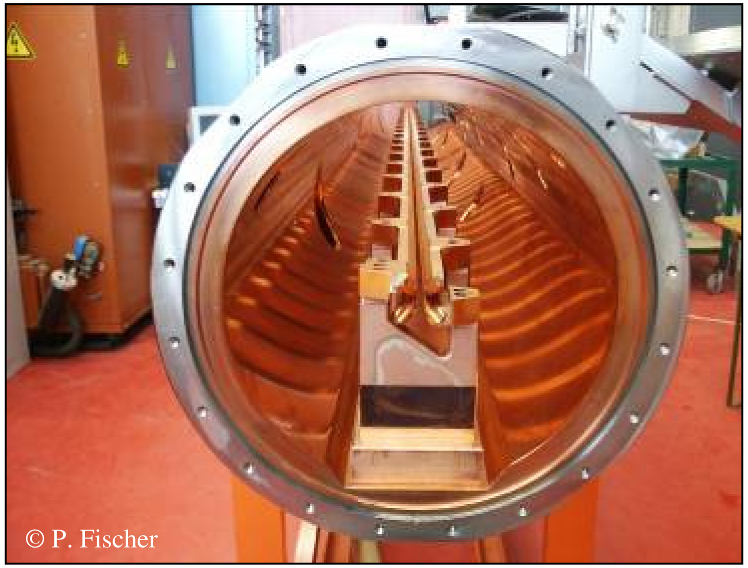
Comparison of the proposed facility with existing intense neutron sources

Facility	Neutron flux at sample position *) [$cm^{-2} s^{-1}$]	Repetition Rate [Hz]	Flight path [m]	Pulse Width [ns]	Neutron energy range [keV]
FZ Karlsruhe	$1 \cdot 10^4$	250000	0.8	0.7	1-200
DANCE, Los Alamos	$5 \cdot 10^5$	20	20	250	th-10^5
n_TOF, CERN	$5 \cdot 10^4$	0,4	185	6	th-10^6
GELINA, Geel	$5 \cdot 10^4$	800	30	1	th-10^5
ORELA, Oak Ridge	$2 \cdot 10^4$	525	40	8	th-10^4
Elbe Dresden	$1 \cdot 10^5$	500000	3.7	0.4	50 - 10^4
FRANZ, Frankfurt	$1 \cdot 10^7$	250000	0.8	1	1-200 (500)

*) **Integrated flux between 1 keV and 100 keV only**

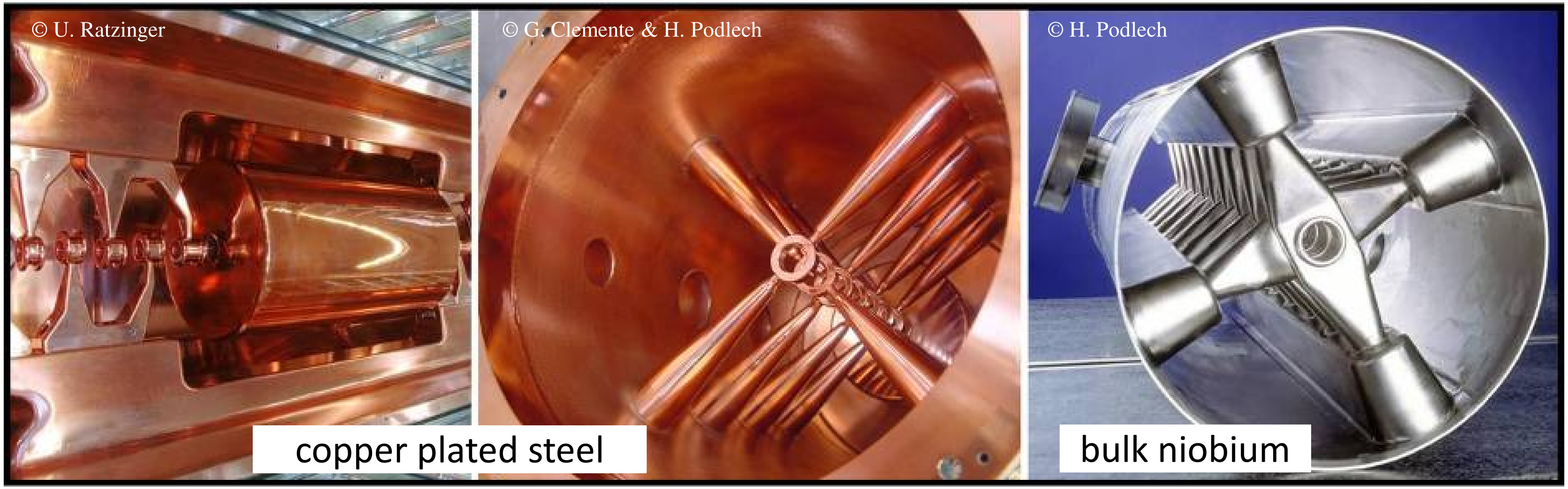
- Expertise of IAP in linac design and construction.

Four-Rod-RFQ, A.Schempp and co-workers



- SARAF – Project Israel; f_0 = 176 MHz, I = 50 mA, P = 64 kW/m, cw – operation.
- About 30 RFQ tanks were delivered to several laboratories.

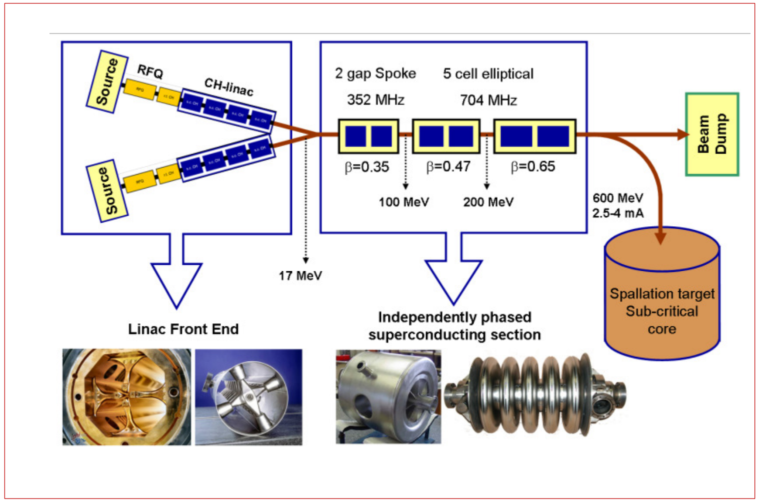
- Expertise of IAP in linac design and construction.

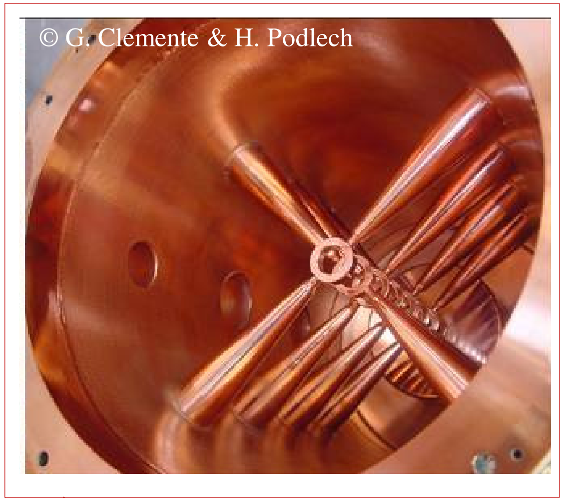


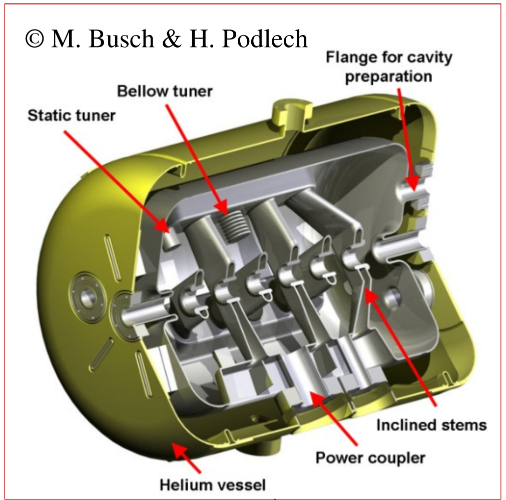
r.t. IH-DTL	r.t. CH-DTL	s.c. CH-DTL
W < 30 MeV	W < 150 MeV	W < 150 MeV
30-250 MHz	150-700 MHz	150-700 MHz

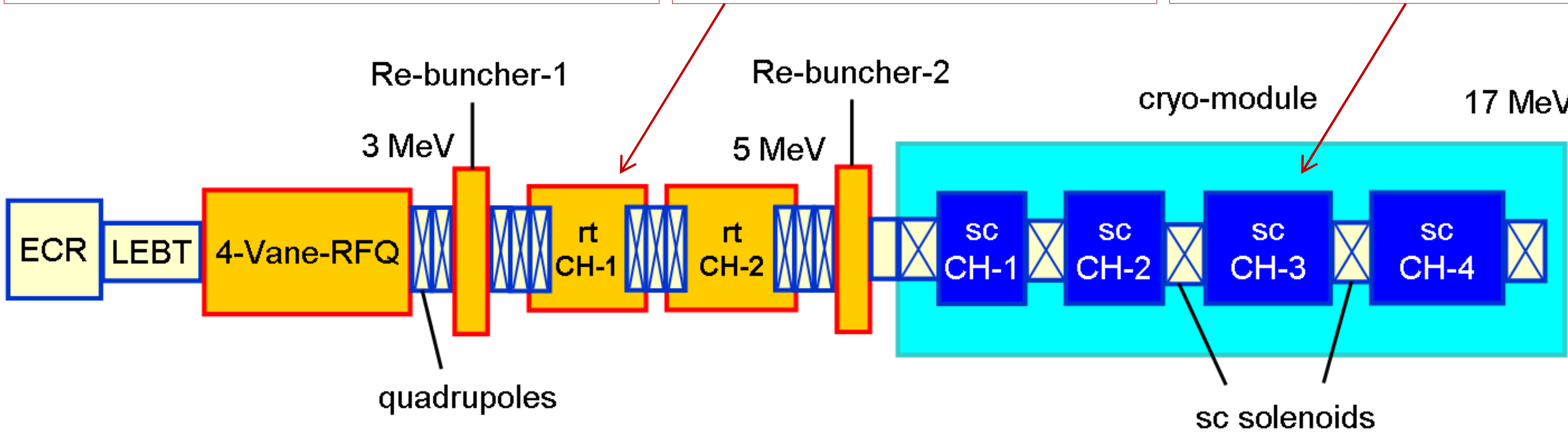
- IAP contributions to: GSI injectors, CERN Linac 3, Medical Injector Linacs.
- Actual involvement in the development of a novel Proton Injector for GSI.

- Expertise of IAP in linac design and construction.

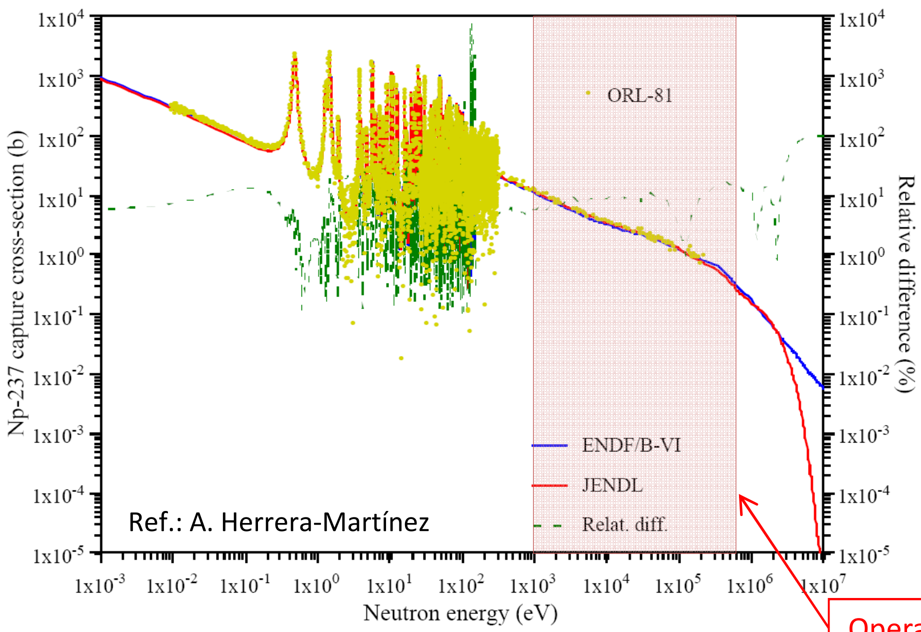


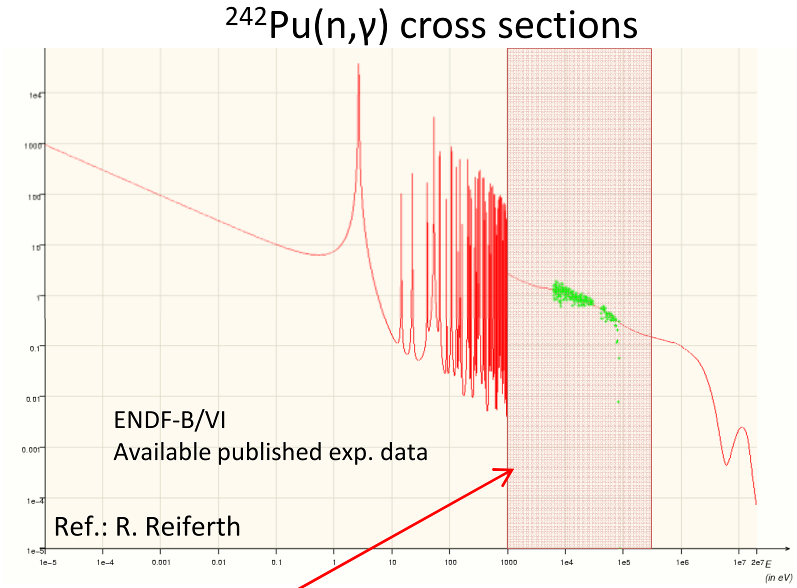






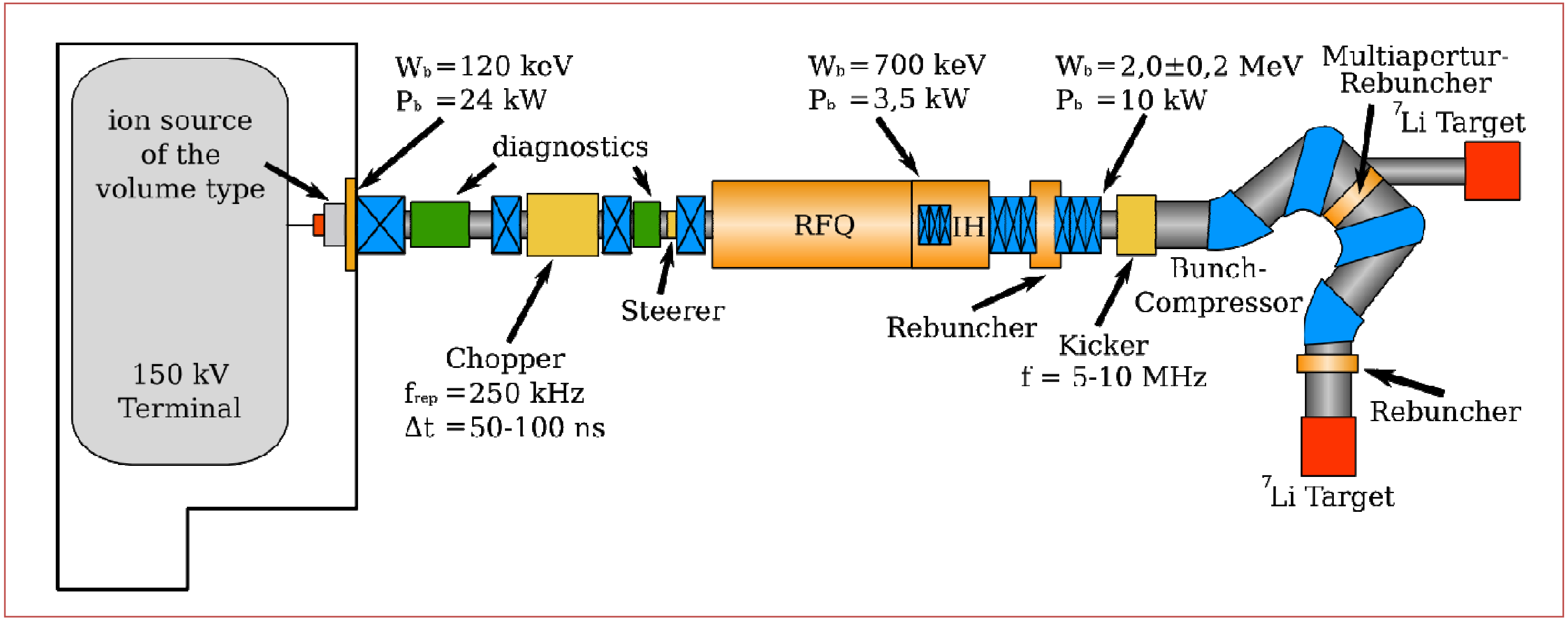
- An other actual involvement: Reference design for EUROTRANS low beta DTL.
- Experience at FRANZ could contribute to the EUROTRANS DTL-design.





Operation range of FRANZ

- Core design: Monte Carlo Simulation prediction of operation conditions.
- Lack of neutron cross-section data in keV-range.
- Reliable design of transmutation device: accurate neutron cross-section data.
- FRANZ could contribute more accurate neutron cross section data in 1keV to 500keV range, because of the high intensities.



dc extraction & transport

cw operation $< I_b >$ ~ 30 - 60 mA => <P> ~ 60 - 120 kW

activation mode

pulsed operation, rep. rate 250 kHz, τ = 1ns

$< I_b >$~ 2 mA => <P> ~ 4 kW

$I_{b,peak}$ ~ 10 A => P_{peak} ~ 20 MW

compressor mode

Compressor mode: Primary beam properties and resulting neutron flux

low energy proton beam

Beam energy: 120 keV

Beam current: 200 mA

Pulse width: 50 - 150 ns

→

Proton beam at the target

Final energy (adjustable): 1.8 - 2.2 MeV

Repetition rate: 100 - 250 kHz

Pulse width : 1 ns

↓

Neutron production

$$^{7}Li(p,n)\rightarrow{}^{7}Be$$

target and detector – with kindly support by FZK and GSI.

→

Neutron beam

Energy: 1 - 500 keV

Production rate:

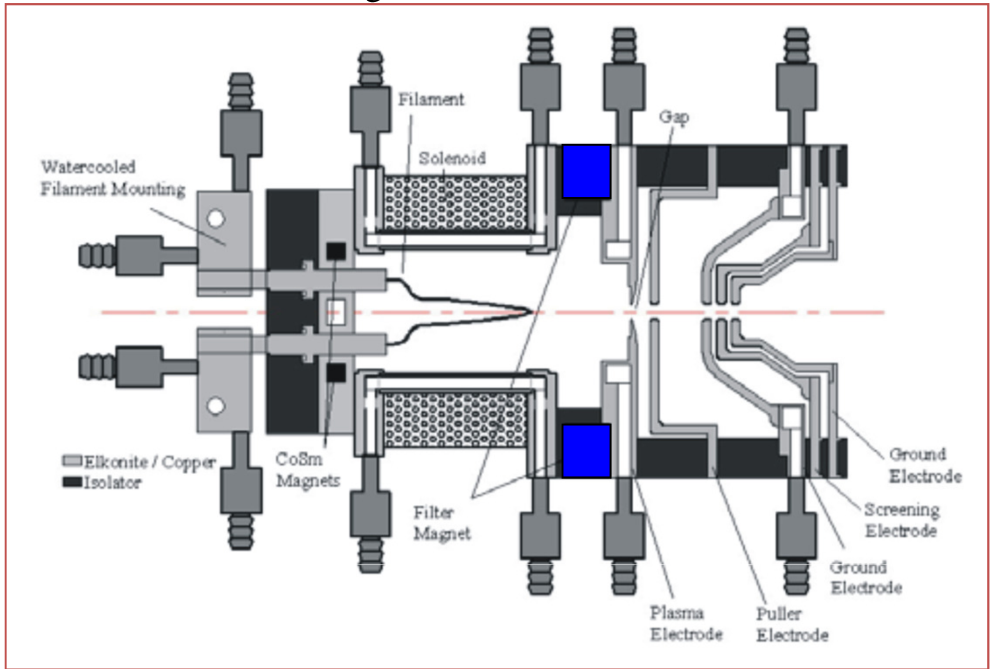
$$\leq 2\cdot 10^{5}\,\mathrm{n/pulse} \rightarrow \leq 5\cdot 10^{10}\,\mathrm{n/s}$$

Neutron flux at the sample:

$$\leq 120\,\mathrm{n/pulse} \rightarrow \leq 3\cdot 10^{7}\,\mathrm{n/s} \rightarrow \leq 1\cdot 10^{7}\,\mathrm{n/cm^{2}s}$$

Volume type ion source with hot filament driven gas discharge

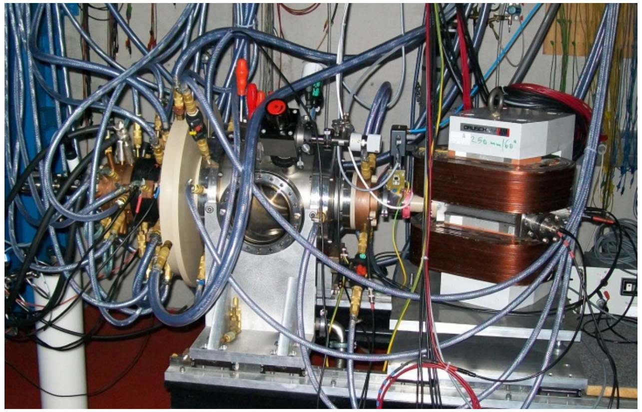
© K. Volk, R. Nörenberg



Cross-sectional view of the ion source

Operation mode	dc
Ion species / fraction	Protons / 90 %
Discharge power	10 – 12 kW
Extraction current	200 mA
Extraction voltage	62 kV
Extraction field strength	5 kV/mm
Beam energy	120 keV
Input emittance (norm. rms)	0.07 π mm mrad
Aspect ratio	0.2

- Filament driven discharge: high brilliance ion beam
- Filter magnet: high proton fraction
- First beam tests are running.



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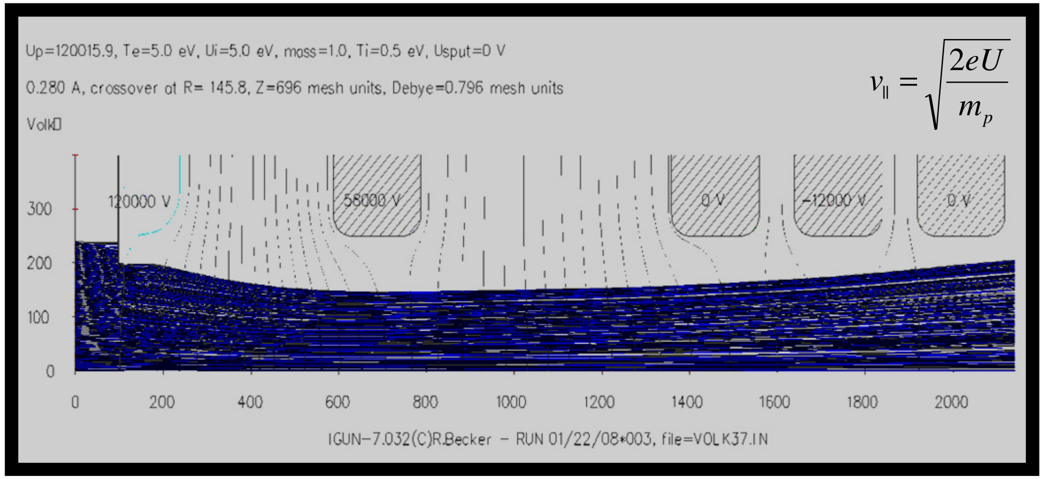
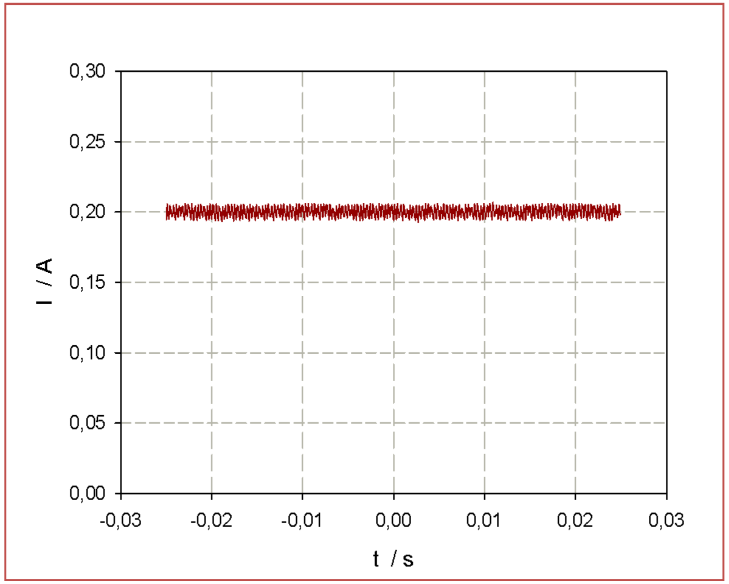
Ion source: extraction



$$v_{\parallel} = \sqrt{\frac{2eU}{m_p}}$$

simulated beam extraction using a pentode system



extracted beam current with 3% noice (simulated)

$$n_p = \frac{I}{2\pi e \cdot v_{\parallel} \cdot r_b}$$

proton density $n_p = 8.2 \cdot 10^{14}\ m^{-3}$

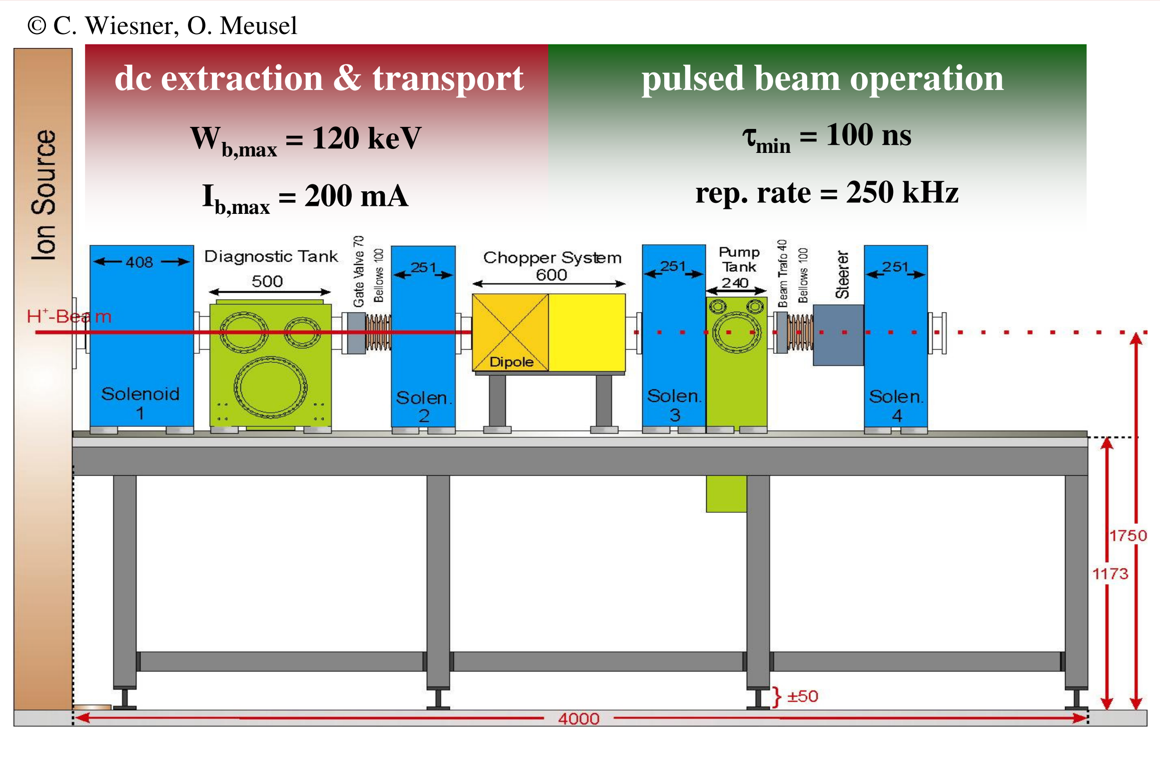
$$K = \frac{1}{4\pi\varepsilon_0}\sqrt{\frac{A}{2q}} \cdot \frac{I}{U^{3/2}}$$

gen. Perveance $K = 3.1 \cdot 10^{-3}$

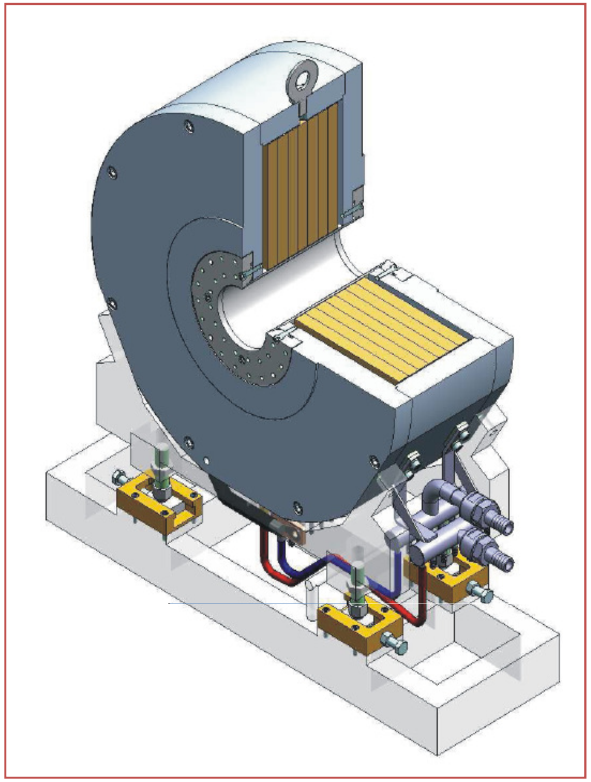
$$\eta = \frac{I_{peak}}{I_0}$$

compression ratio $\eta = 1$

- Pentode extraction system: extraction properties independent to end energy
- Space charge compensation adjustable.



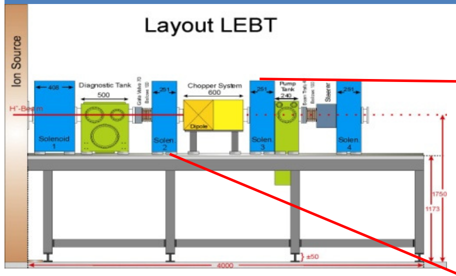
scheme of LEBT section



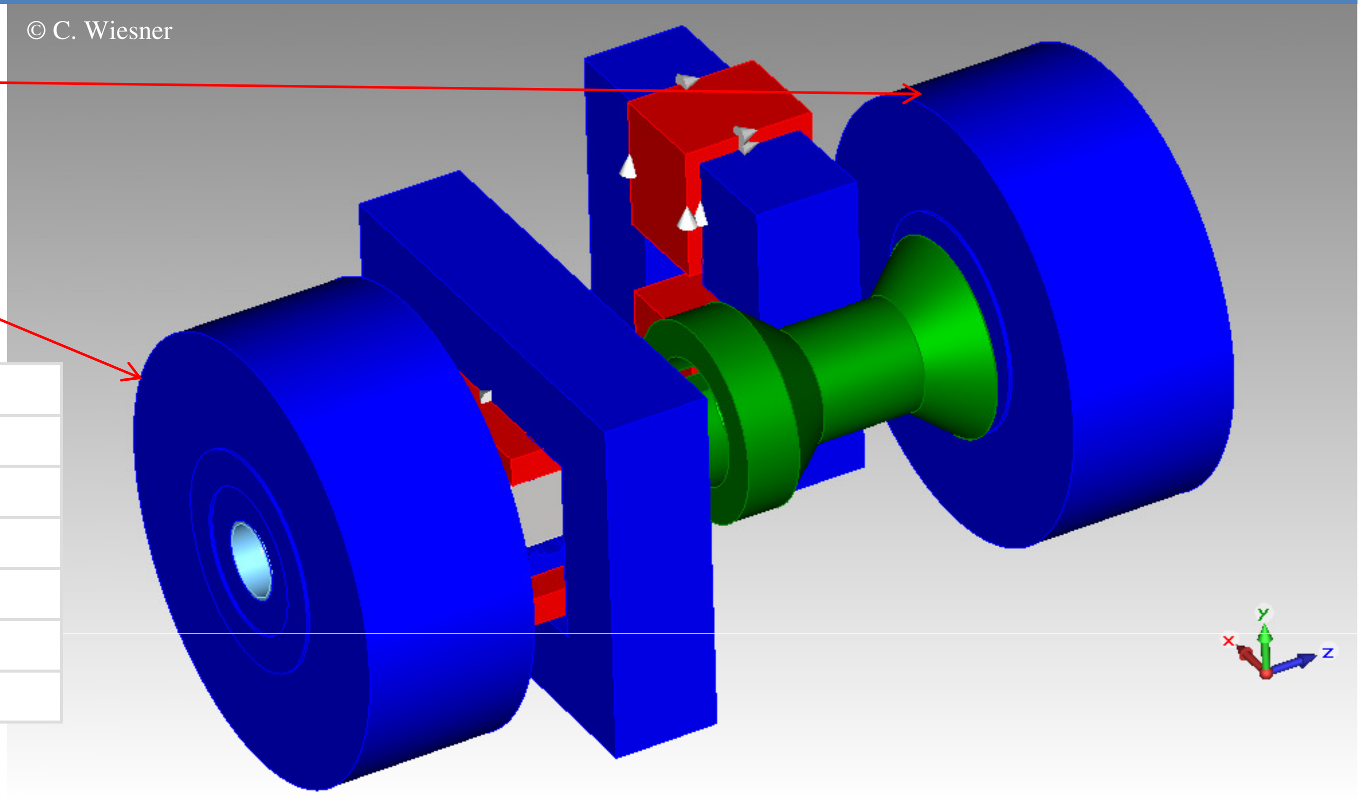
aperture 100 mm, $B_z = 0.6$ T

- Double telescopic system.
- Solenoidal transport section to provide space charge compensation.
- Pulsed Wien-filter: DC-beam => 100ns macro bunches with 250kHz repetition.

Pulsed Wien-Filter: E×B-Kicker



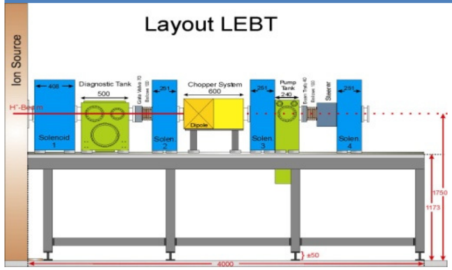
scheme of LEBT section



Kicker Frequency	250 kHz
Solenoid2	422 mT
Solenoid3	537 mT
Dipole	60 mT
C-magnet	300 mT
U_{max}	± 6 kV
Beam Energy	120 keV

- Static magnetic field, temporally compensated by electric field.
- C-magnet : deflection enhancement.
- Fast switch array (MOSFET) + nano-crystaline tape wound core.

Pulsed Wien-Filter: E×B-Kicker



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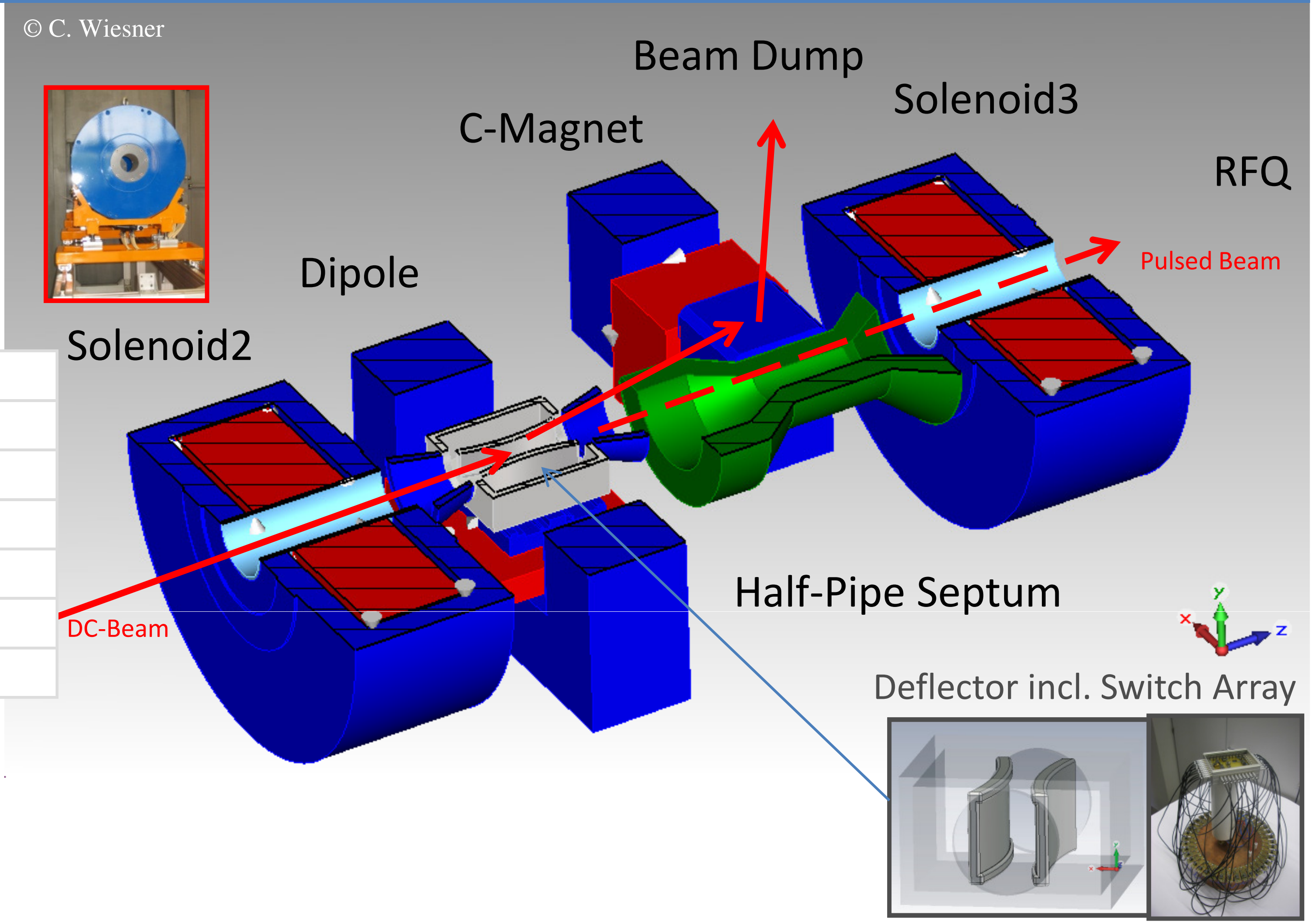
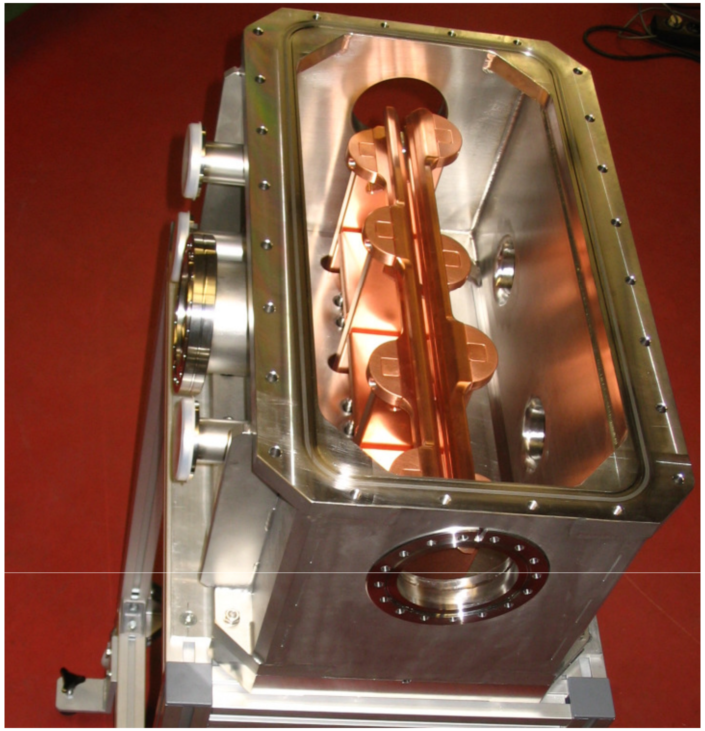


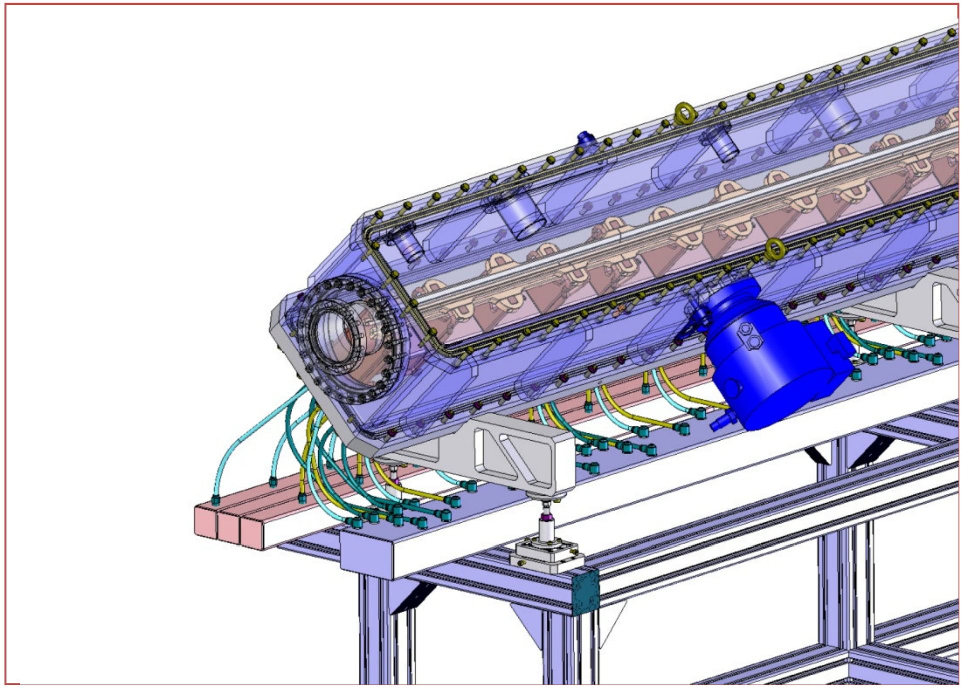
- Static magnetic field, temporally compensated by electric field.
- C-magnet : deflection enhancement.
- Fast switch array (MOSFET) + nano-crystaline tape wound core.

Radio Frequency Quadrupole - RFQ

© A. Schempp / NTG company



RFQ test module

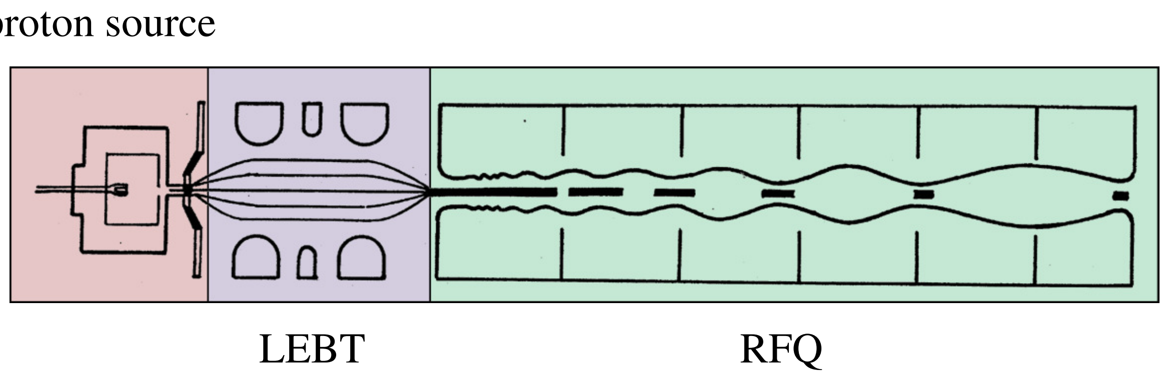


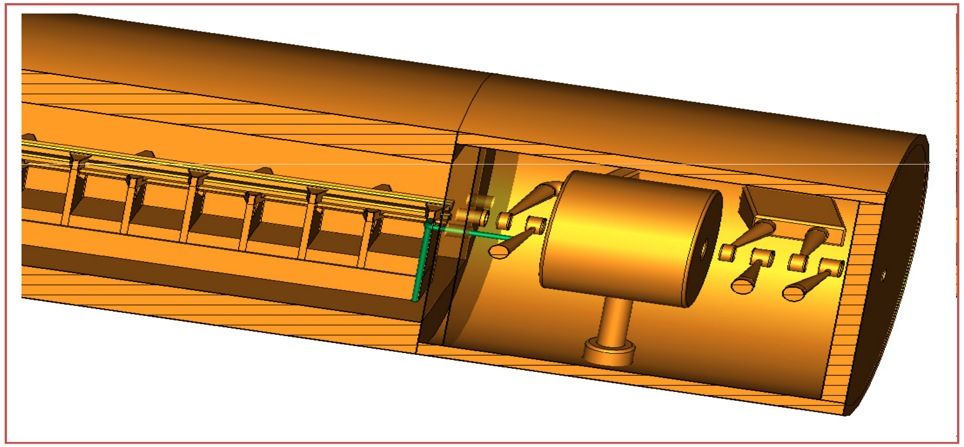
RFQ technical design

- Beam dynamics
- Design studies
- Power test at scaled model

Focusing, Compression and Acceleration

Operating frequency	175 MHz
Ion species	Protons
Length of RFQ	1.7 m
Length of IH-DTL	0.6 m
Tank diameter IH	510 mm
# of RFQ cells	97
# of IH gaps	8
Input energy	120 keV
Input emittance (norm. rms)	0.56 π mm mrad
Electrode voltage (RFQ)	75 kV
Max. gap Voltage IH-DTL	300 kV
Exp. Power consumption RFQ	150 kW
Exp. Power consumption IH	45 kW
Current	max. 200 mA
Output eenergy RFQ	700 keV
Output ebergy IH	2 MeV
Coupling factor	0.03

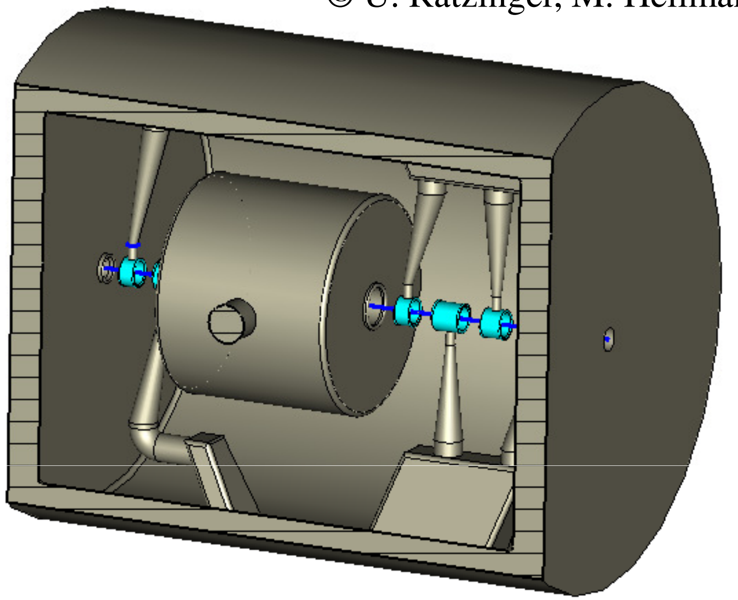




- RFQ: Micro bunching + pre-acceleration.
- RFQ-IH combination (coupled cavities): one power amplifier, shorter drift space.
- IH-cavity: main acceleration, KONUS dynamics.

final energy 2 MeV

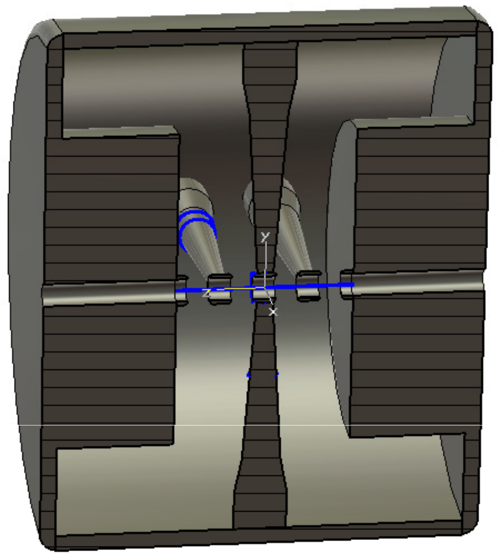
© U. Ratzinger, M. Heilmann



8 gap and internal msq triplet
output beam enrgy 2MeV

energy variation ± 0.2 MeV

© H. Podlech, A. Metz



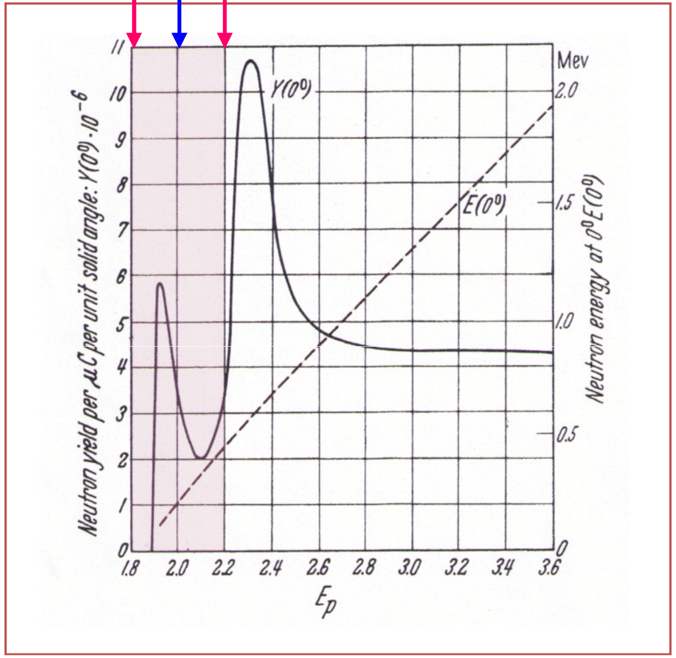
CH type cavity 4gap

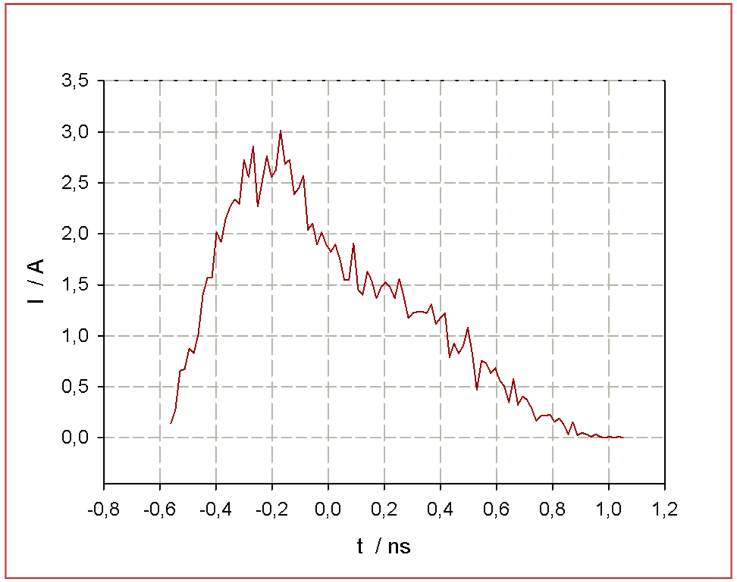
- IH-cavity: main acceleration.
- KONUS (Combined Zero degree structure) dynamics: high efficiency acceleration.
- CH-cavity: rebunching and variation of end energy (activation mode).

Properties of a single micro bunch downstream of the accelerator

RFQ-IH $E_p = 2$ MeV

CH $\Delta E_p = \pm 0.2$ MeV





microbunch current distribution (simulated)

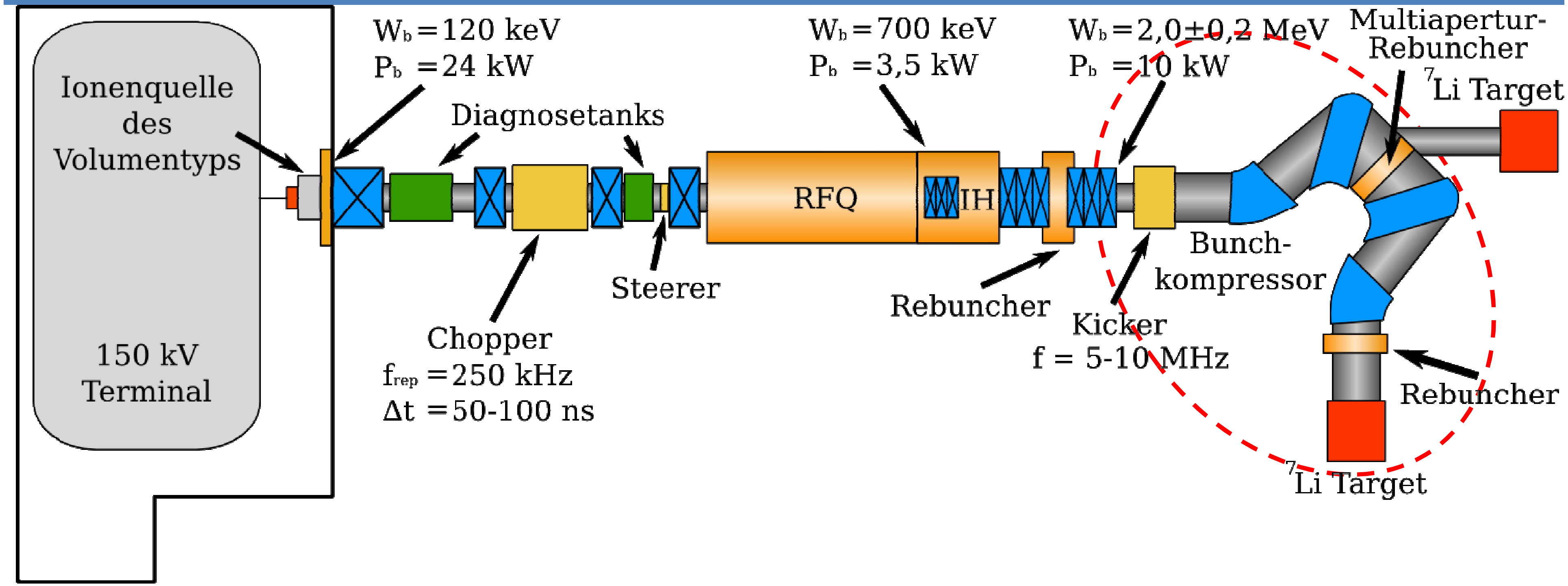
compression ratio $\eta = 6$

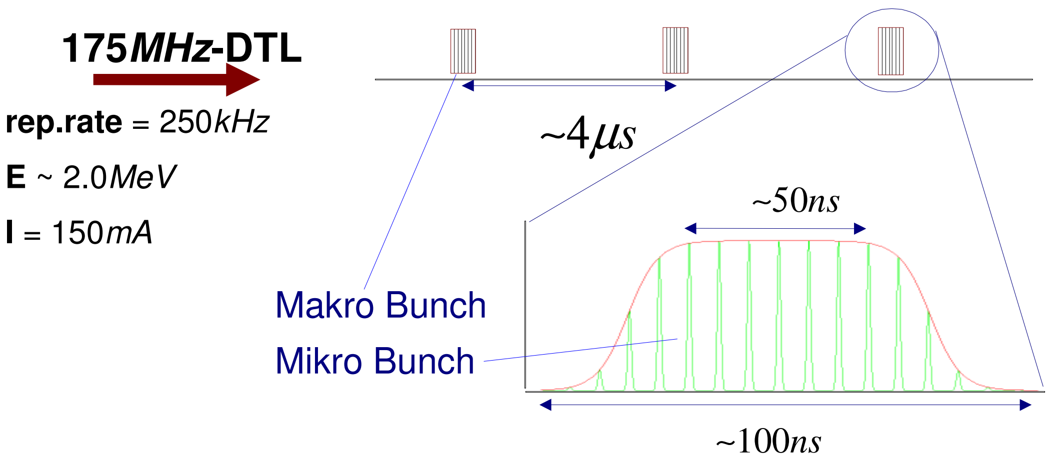
gen. Perveance $K = 2.7 \cdot 10^{-4}$

$n_p = 1.2 \cdot 10^{15}$ m^{-3}

- IH-cavity: main acceleration.
- KONUS (Combined Zero degree structure) dynamics: high efficiency acceleration.
- CH-cavity: rebunching and variation of end energy (activation mode).

Layout based on Mobley-type bunch compressor

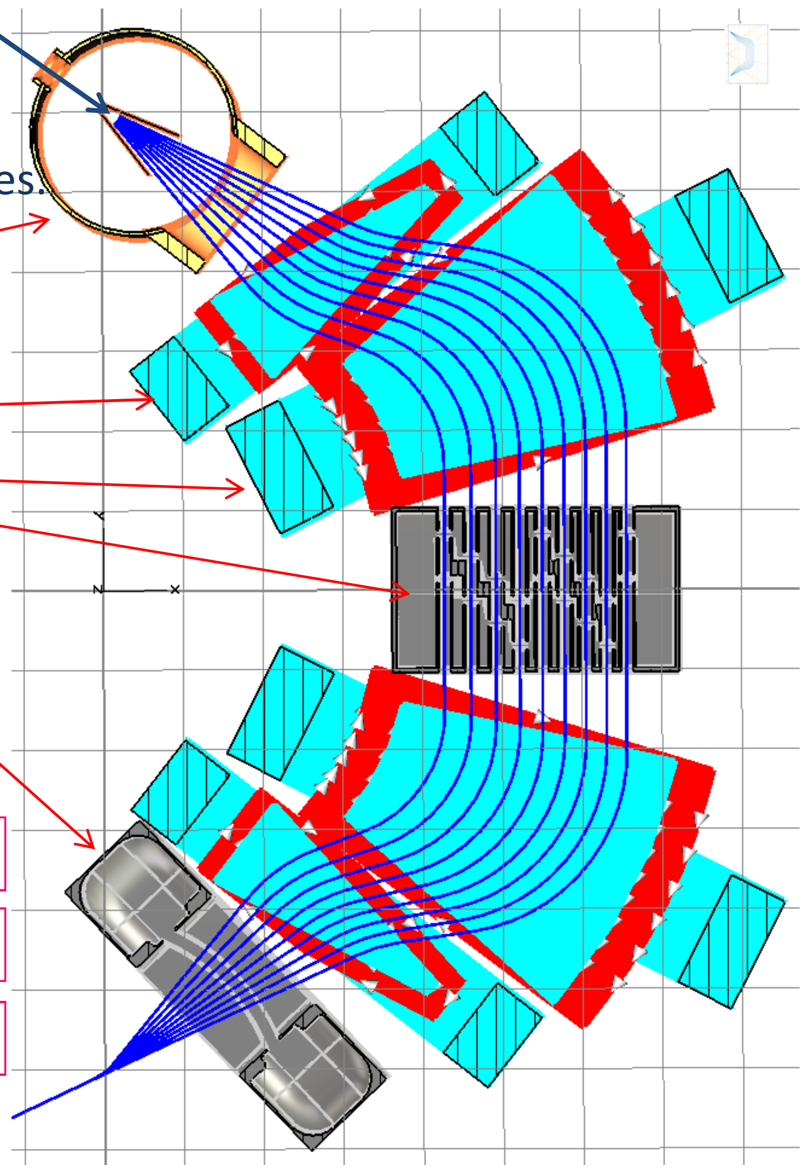




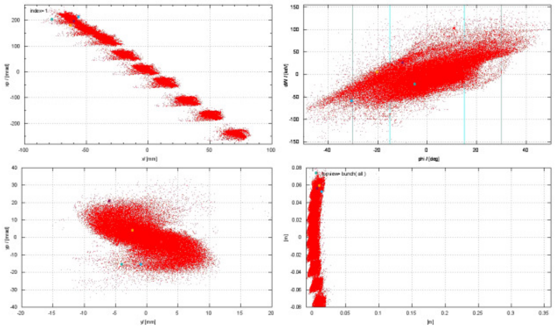
- N_{bunch} = 9
- ΔT = 50-100*ns* => $\Delta T_{rms} \approx 1ns$
- $A_{(beam\ at\ target)}$ < $3x3cm^2$
- $I_{(per\ pulse)}$ ≈ 8*A*
- $(\Delta W/W)_{rms}$ < ± 5%

Working principle:
- periodic deflection onto different trajectories.
- path differences compensate time differences.
- micro-bunch-rebunching due to high space charge forces.

Components:
- Kicker: f = 5*MHz*, U_{max}=250*kV*
- Homogeneous dipoles: B_1 = -515.0*mT*
- Dipoles with gradient: B_2 = 551.9 ± 98.4*mT*
- Multi-Aperture-Rebuncher: U_{eff}= 100-140*kV*, P≈10*kW*
- Broad-Gap-Rebuncher: U_{eff}= 120*kV*, P≈10*kW*



Merging: projections 30cm in front of the focus.



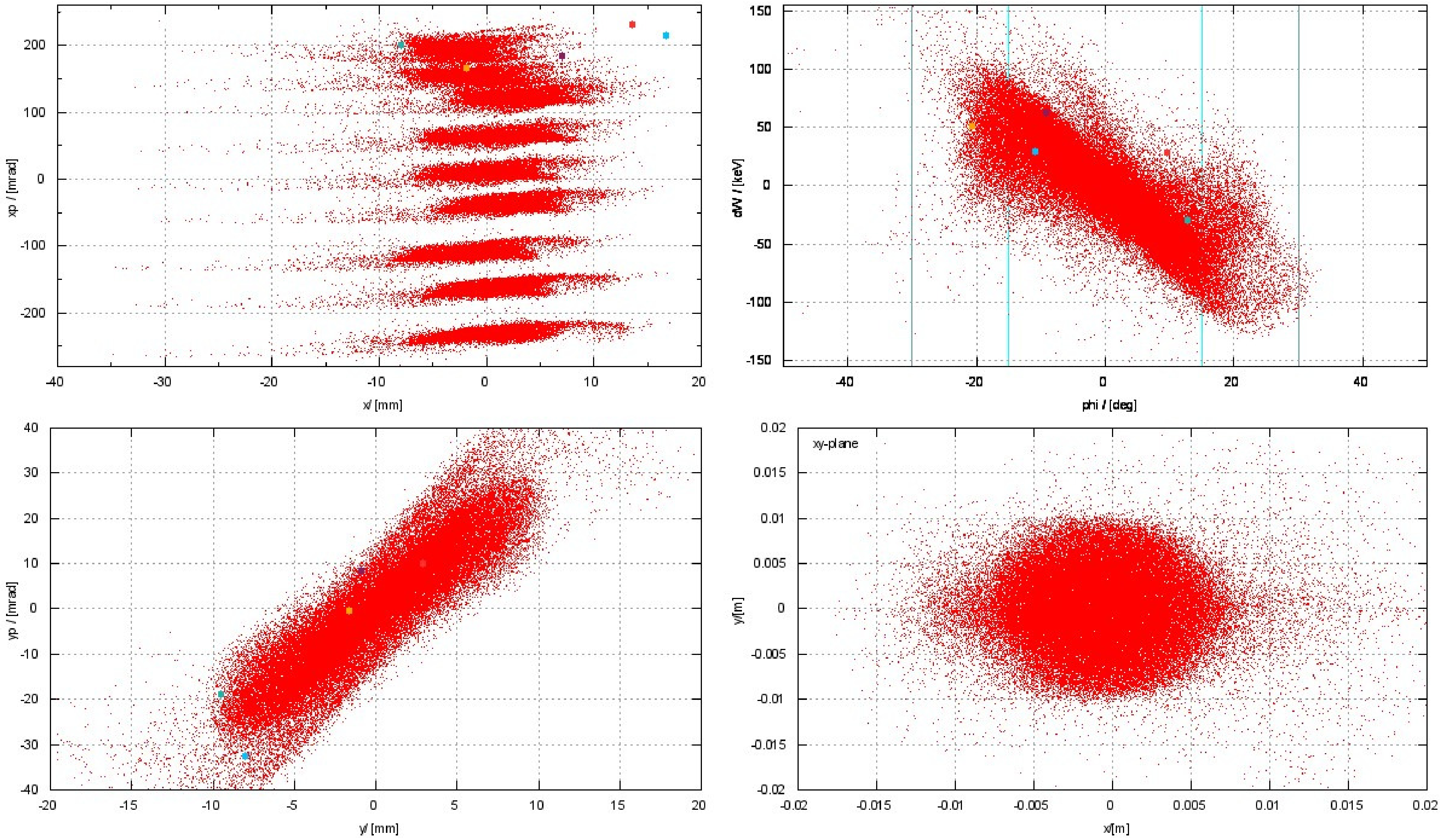
compression ratio $\eta = 48$

gen. Perveance $K = 2.2 \cdot 10^{-3}$

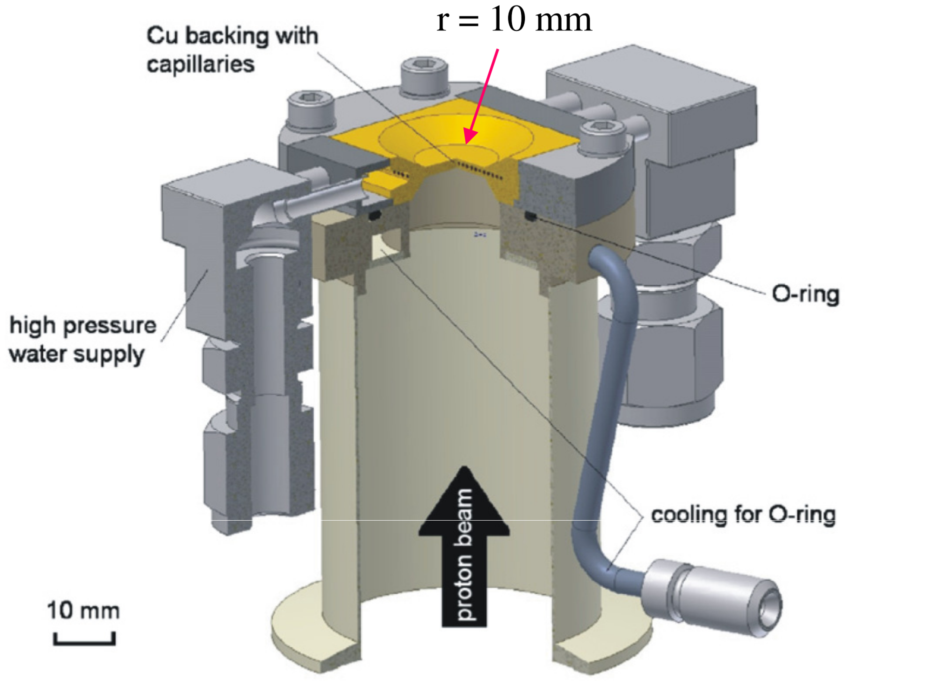
$n_p = 9.75 \cdot 10^{15}\ m^{-3}$

=> Peak current up to 10A

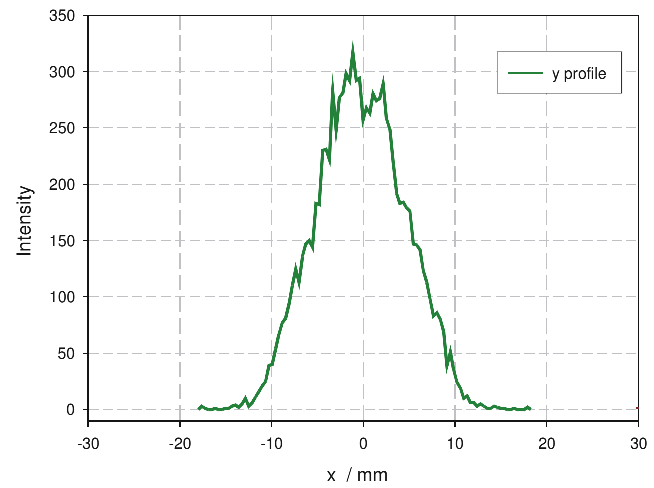
Bunch Compressor: Merging - Projections at the target



- Requirements: $(\Delta W/W)_{rms} < \pm 5\%$ ✓ $\Delta T_{rms} < 1ns$ ✓ $A < 3x3cm^2$ ✓



target prototype for beam power up to 6 kW



transverse beam profile (simulated)

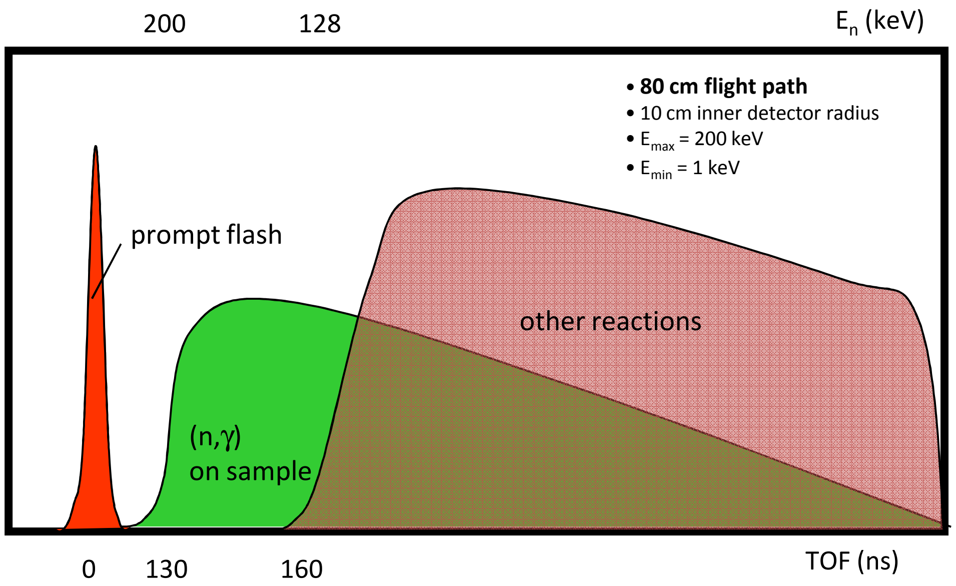
avg. power ~ 4 kW

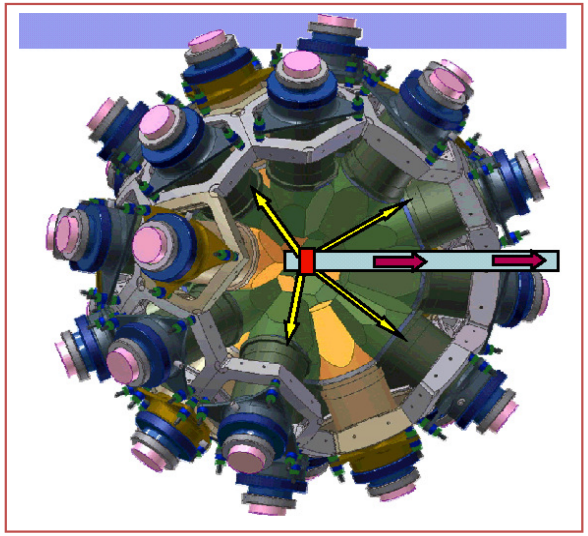
peak power ~ 20 MW

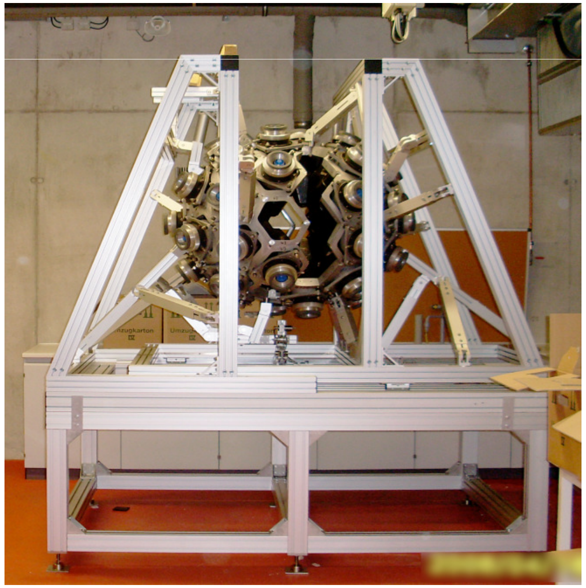
- Scaled prototype was built and tested.
- D. Petrich et al., Nucl. Instr. Methods A **596**, 269-275(2008)

4πBaF$_2$ Detector Array

- 4π colorimetrical measurements: good energy resolution.
- high granularity (#42): signal to noise ratio.
- fast timing (< 1ns) to achieve acceptable TOF resolution.
- suppression of other-reaction-signals.



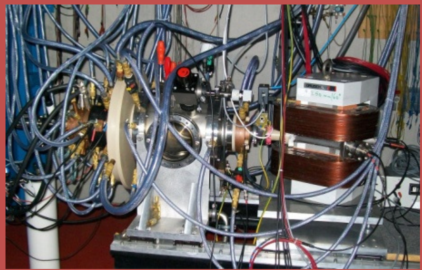




- M. Heil et al., Nucl. Instr. Methods A**459**, 229(2001).
- R. Reiferth et al., Publication of Astrophysical Society of Australia, **26**, 255-258(2009).

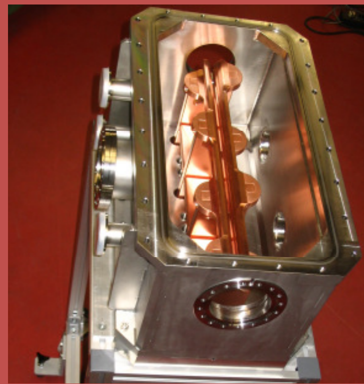
Systems Perspective

source is constructed

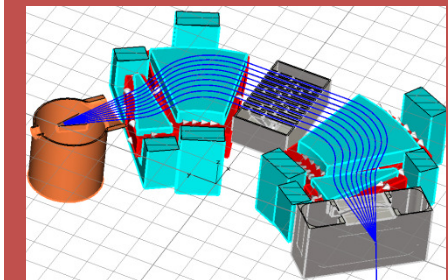


LEBT vacuum tests

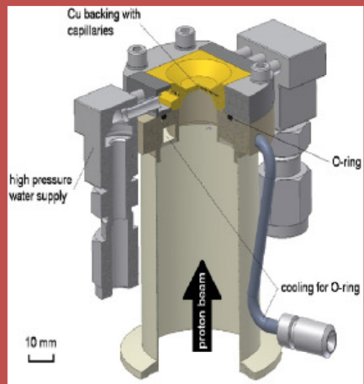
RFQ test module



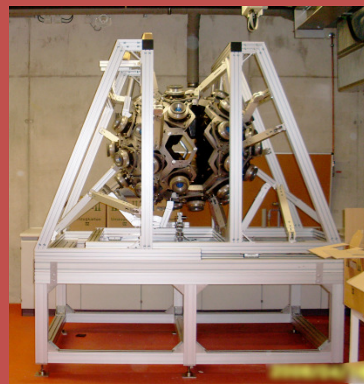
First Beam 2010



compressor design



high power target test



detector reassembled

Thank you for your attention.

on behalf of:

H. Dinter, M. Heilmann, H. Klein, M. Meusel, D. Noll, H. Podlech, U. Ratzinger, A. Schempp, C. Wagner, C. Wiesner, S. Schmidt, W. Schweizer, K. Volk

IAP, Goethe University Frankfurt

M. Heil, R. Plag, R. Reifarth

GSI, Darmstadt

K. Stiebing, J. Stroth

IKF, Goethe University Frankfurt

F. Käppeler, D. Petrich

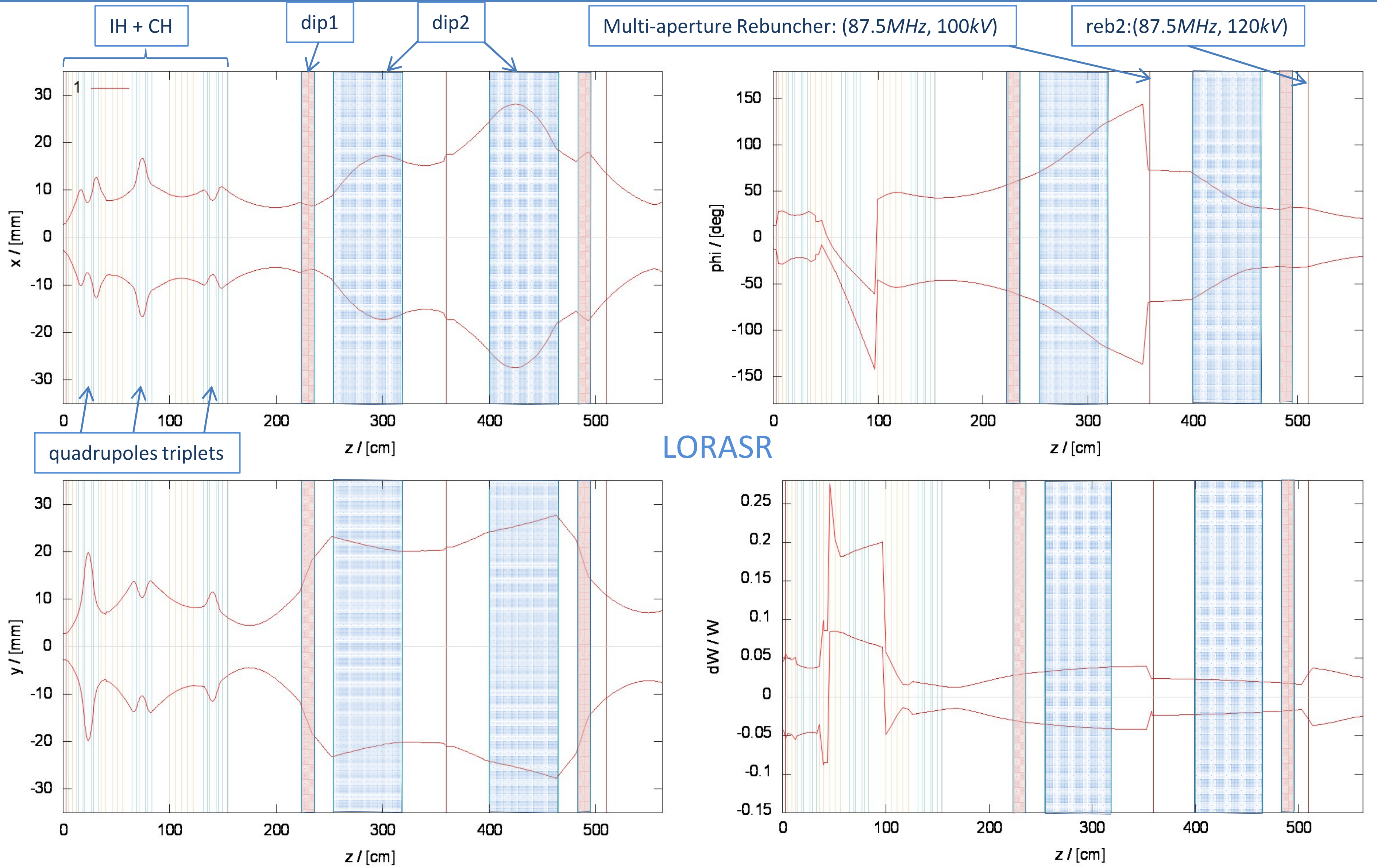
IKF, FZ Karlsruhe

acknowledgment:

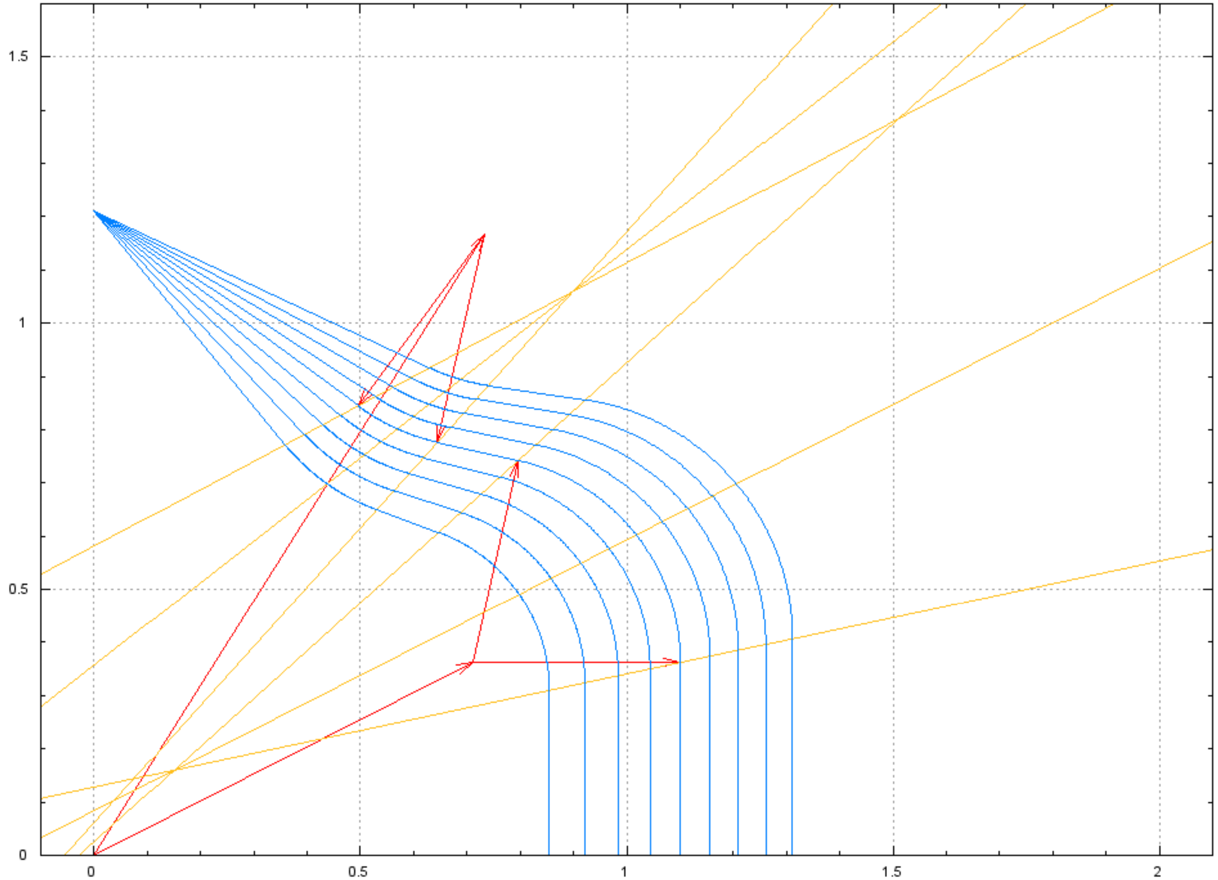
LINAC-AG	http://linac.physik.uni-frankfurt.de/
AG-Schempp	http://iaprfq.physik.uni-frankfurt.de/
NNP-AG	http://nnp.physik.uni-frankfurt.de

FZK / GSI / IAEA

Bunch Compressor: Envelopes(95%) – bunch(1)



Bunch Compressor: geometrical parameters

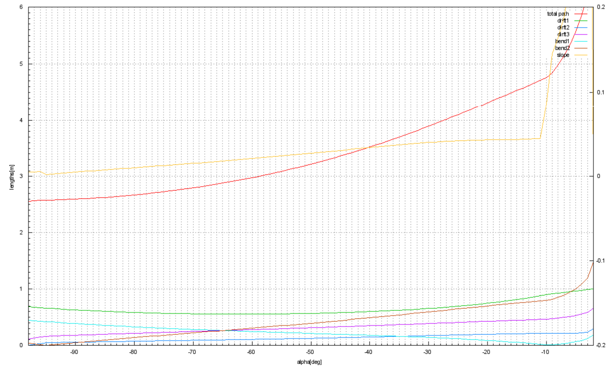


g9_5x

$B_1 \quad = \quad -0.51497[T]$

$\alpha_{max} \quad = \quad 25.69[deg]$

$< \alpha > \quad = \quad 3.21[deg]$



al [deg]	tp [m]	dr1 [m]	dr2 [m]	dr3 [m]	b1 [m]	b2 [m]	bet1 [deg]	bet2 [deg]	R2 [m]	B2 [T]	d_x1 [m]	d_x2 [m]	d_x3 [m]	d_x4 [m]	d_x5 [m]	d_a [deg]	d_x1p [m]	d_tp [m]	psi11 [deg]	psi12 [deg]	psi21 [deg]	psi22 [deg]
-25.000	4.0995	0.6949	0.1845	0.4069	0.1162	0.6472	16.645	-81.645	0.4542	0.4535	0.0397	0.0352	0.0412	0.0515	0.0504	2.702	0.0328	-0.1125	37.0000	33.6455	39.6455	12.0000
-27.702	3.9870	0.6718	0.1777	0.3962	0.1296	0.6182	18.560	-80.857	0.4381	0.4702	0.0382	0.0353	0.0419	0.0529	0.0518	2.781	0.0326	-0.1125	34.2979	32.8575	38.8575	12.0000
-30.483	3.8745	0.6510	0.1707	0.3852	0.1421	0.5884	20.349	-79.866	0.4221	0.4880	0.0374	0.0359	0.0429	0.0545	0.0533	2.887	0.0328	-0.1125	31.5167	31.8661	37.8661	12.0000
-33.370	3.7620	0.6323	0.1633	0.3738	0.1540	0.5576	22.052	-78.682	0.4061	0.5073	0.0370	0.0369	0.0442	0.0563	0.0551	3.023	0.0334	-0.1125	28.6298	30.6819	36.6819	12.0000
-36.393	3.6495	0.6154	0.1558	0.3621	0.1655	0.5259	23.703	-77.310	0.3898	0.5285	0.0371	0.0385	0.0461	0.0584	0.0571	3.194	0.0343	-0.1125	25.6071	29.3105	35.3105	12.0000
-39.587	3.5370	0.6003	0.1480	0.3500	0.1769	0.4932	25.339	-75.753	0.3731	0.5522	0.0377	0.0407	0.0485	0.0610	0.0596	3.409	0.0358	-0.1125	22.4131	27.7526	33.7526	12.0000
-42.995	3.4245	0.5870	0.1401	0.3373	0.1885	0.4593	27.001	-74.005	0.3556	0.5793	0.0390	0.0437	0.0516	0.0641	0.0627	3.677	0.0377	-0.1125	19.0046	26.0054	32.0054	12.0000
-46.672	3.3120	0.5754	0.1320	0.3240	0.2006	0.4239	28.735	-72.063	0.3370	0.6112	0.0411	0.0477	0.0557	0.0681	0.0666	4.017	0.0404	-0.1125	15.3277	24.0631	30.0631	12.0000
-50.689	3.1995	0.5660	0.1237	0.3098	0.2137	0.3866	30.607	-69.918	0.3168	0.6502	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.0000	0.0000	11.3105	21.9176	27.9176	12.0000