

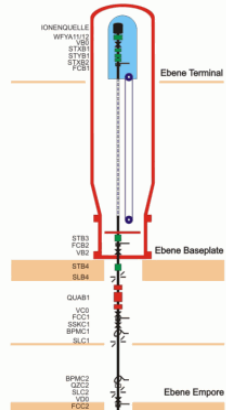
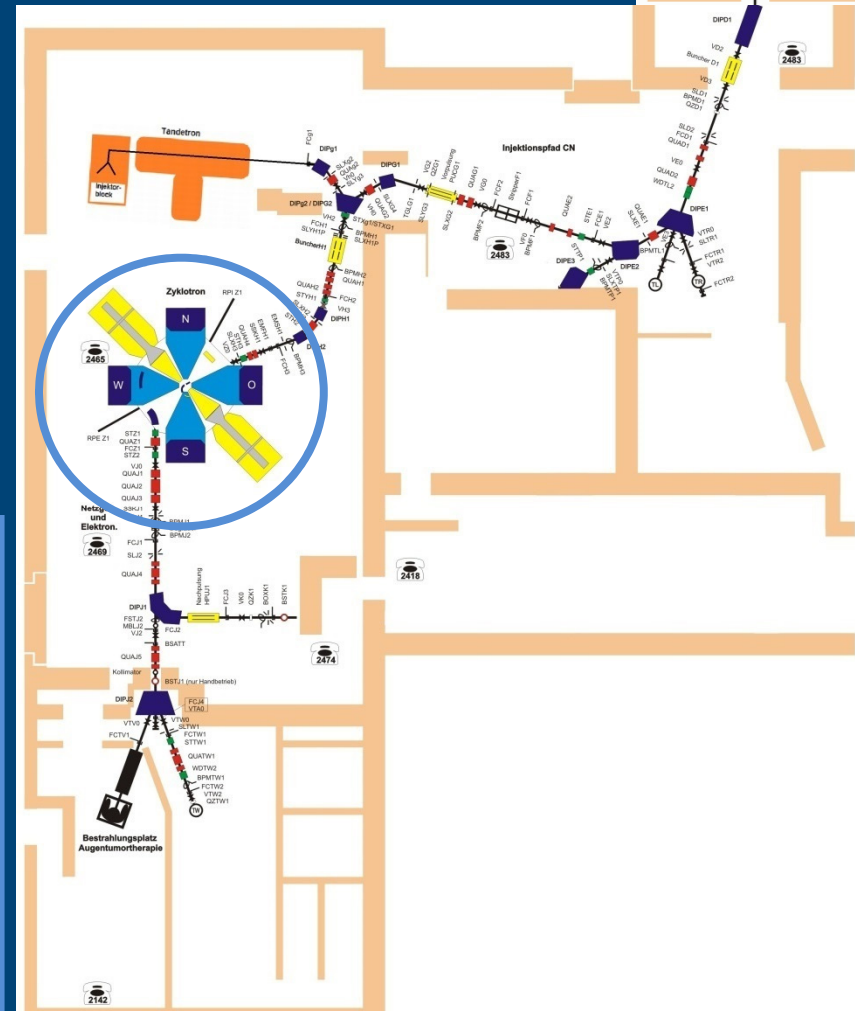
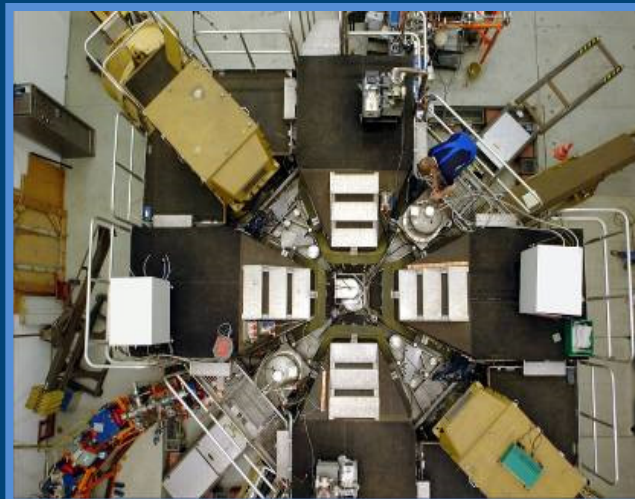
New Time Structures Available at the HZB CYCLOTRON

A. Denker, J. Bundesmann, T. Damerow, T. Faselow,
D. Hildebrand, U. Hiller, C. Rethfeldt, J. Röhrich

Helmholtz-Zentrum Berlin, Protons for Therapy

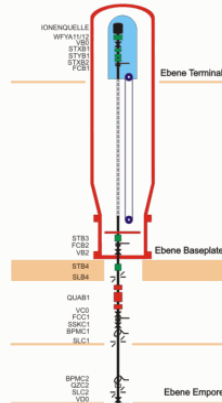
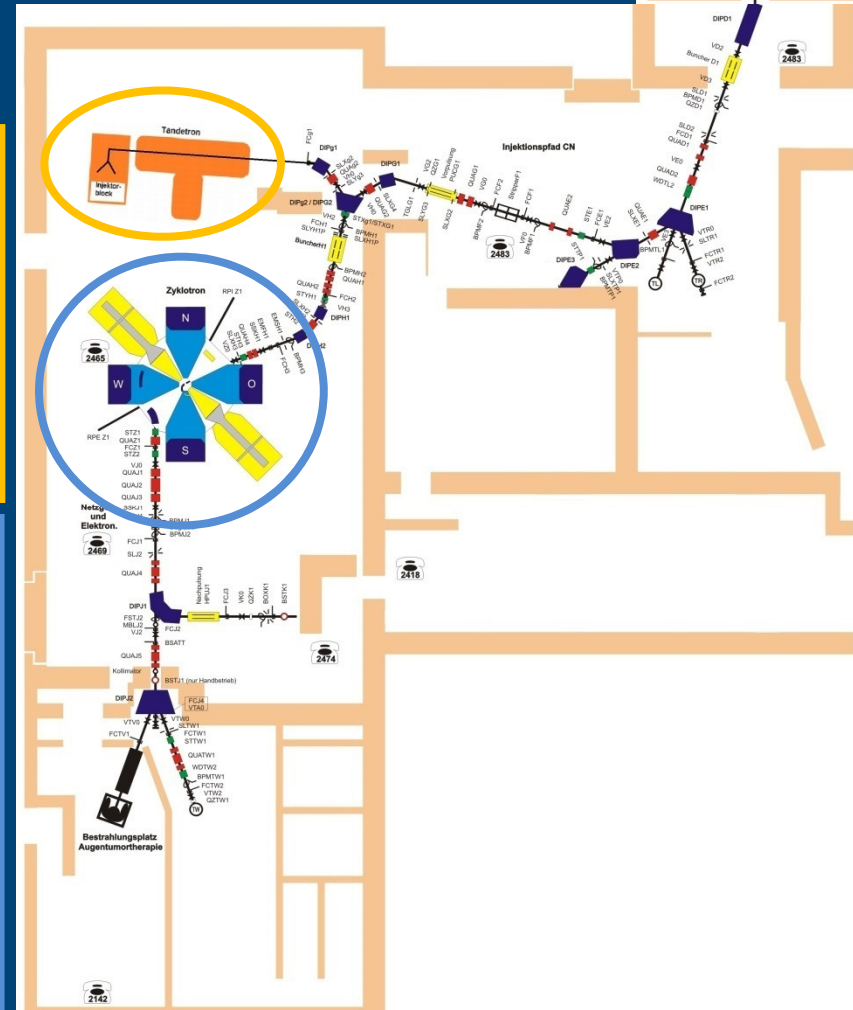
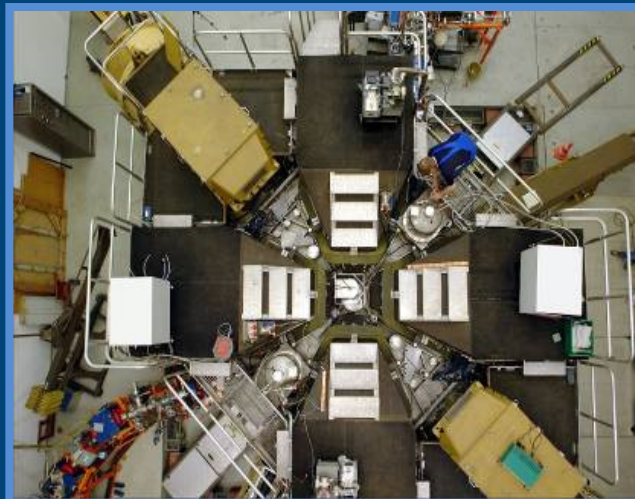
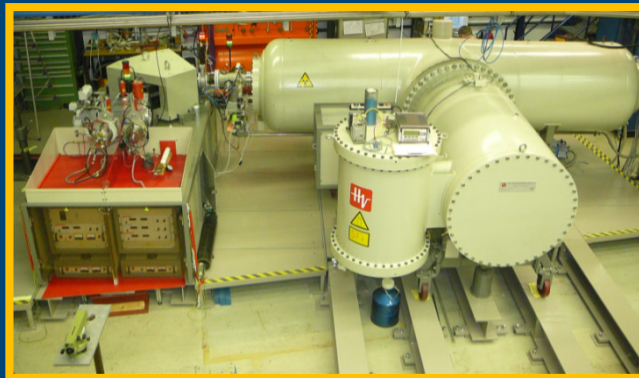
Layout: Accelerators

- $k = 130$ cyclotron (former VICKSI, ISL)
- two injectors:



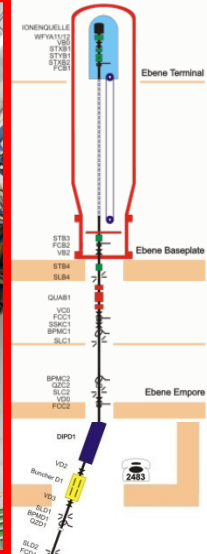
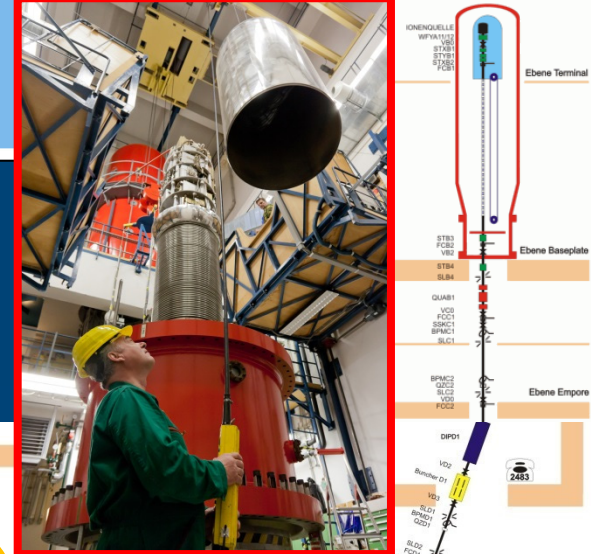
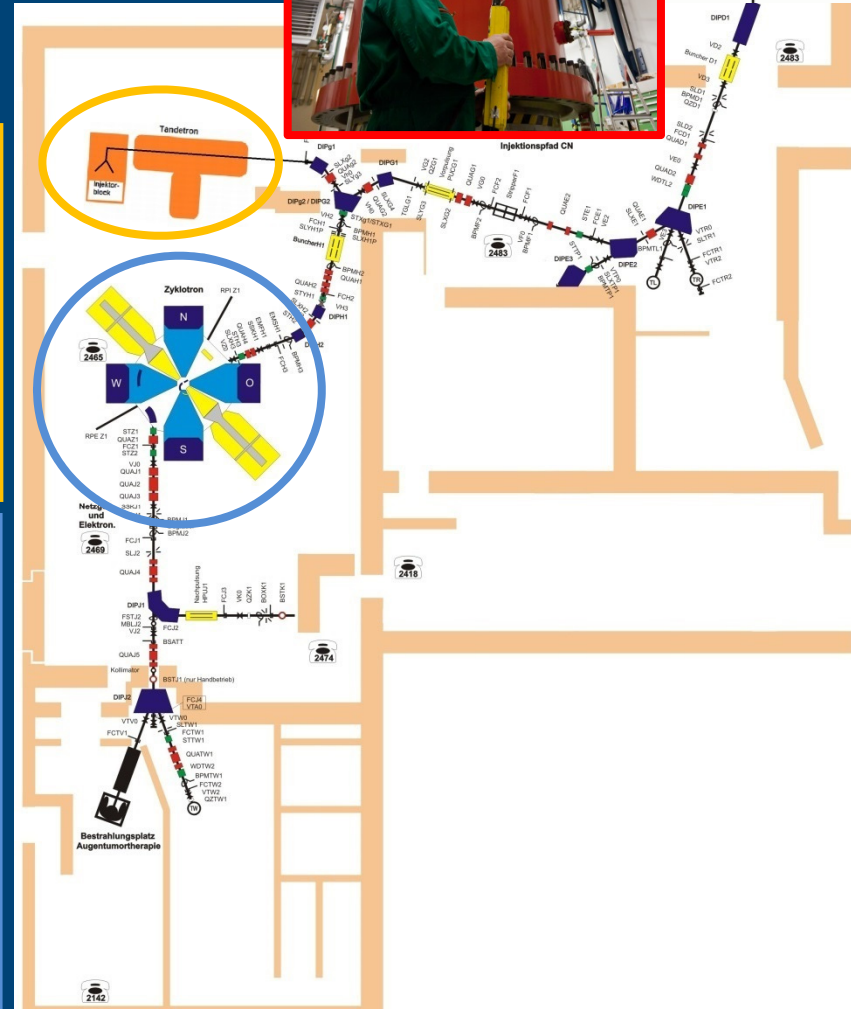
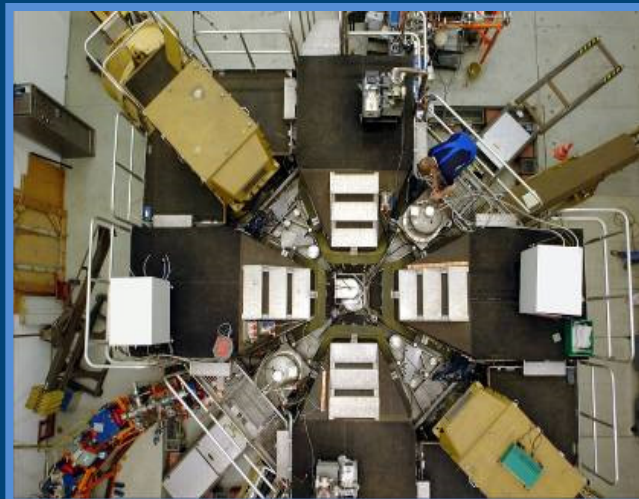
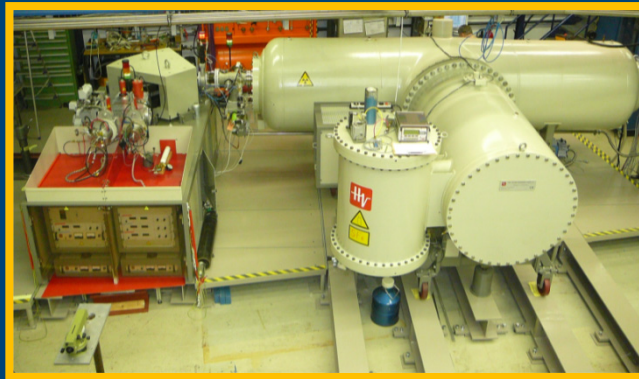
Layout: Accelerators

- $k = 130$ cyclotron (former VICKSI, ISL)
- two injectors:
 - 2 MV Tandatron™, standard for therapy



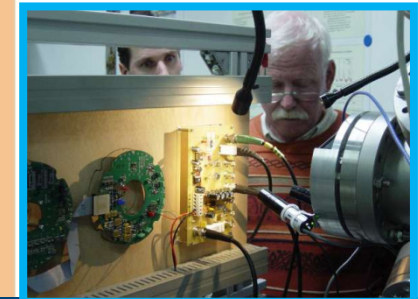
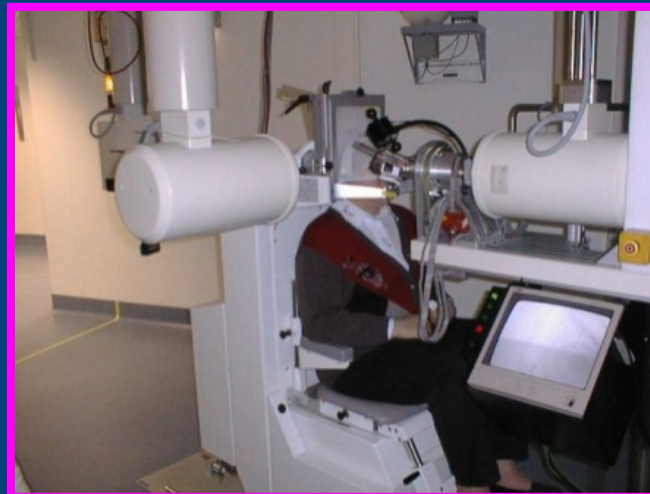
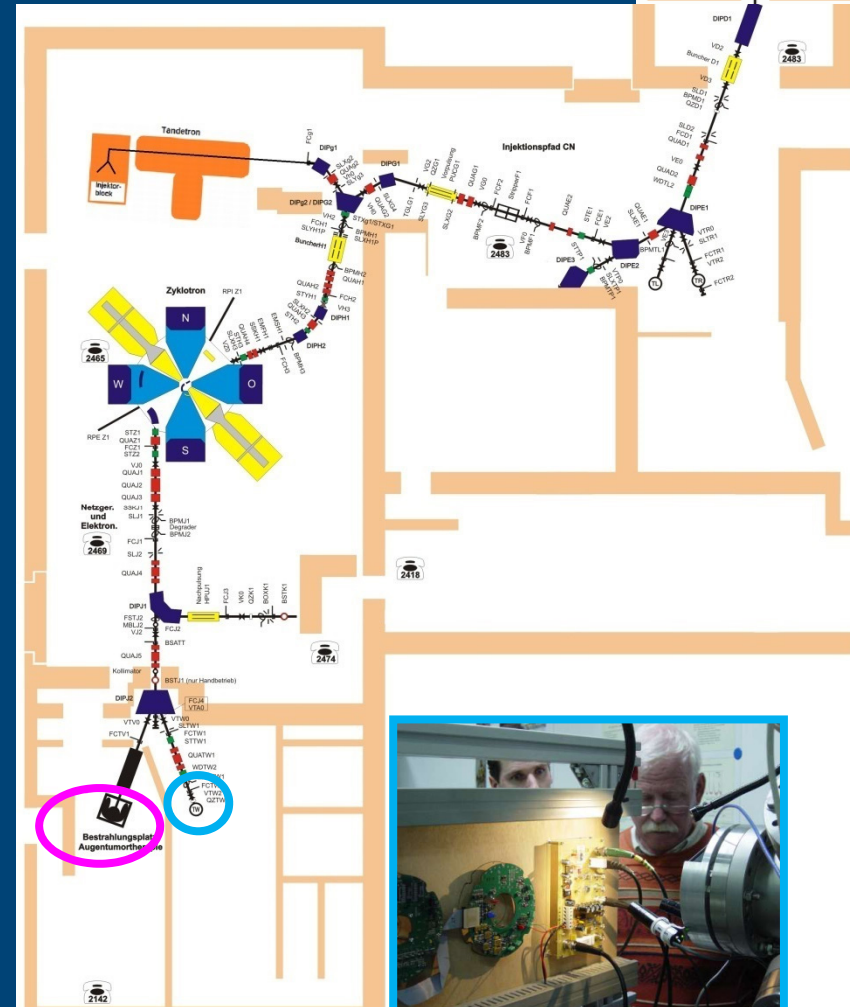
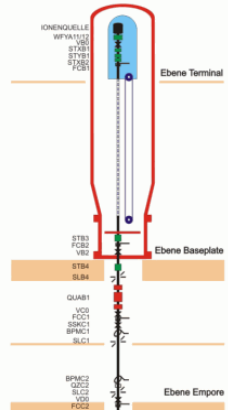
Layout: Accelerators

- $k = 130$ cyclotron (former VICKSI, ISL)
- two injectors:
 - 2 MV Tandetron™, standard for therapy
 - 6 MV Van-de-Graaff, backup, time structures



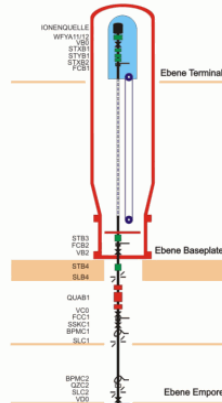
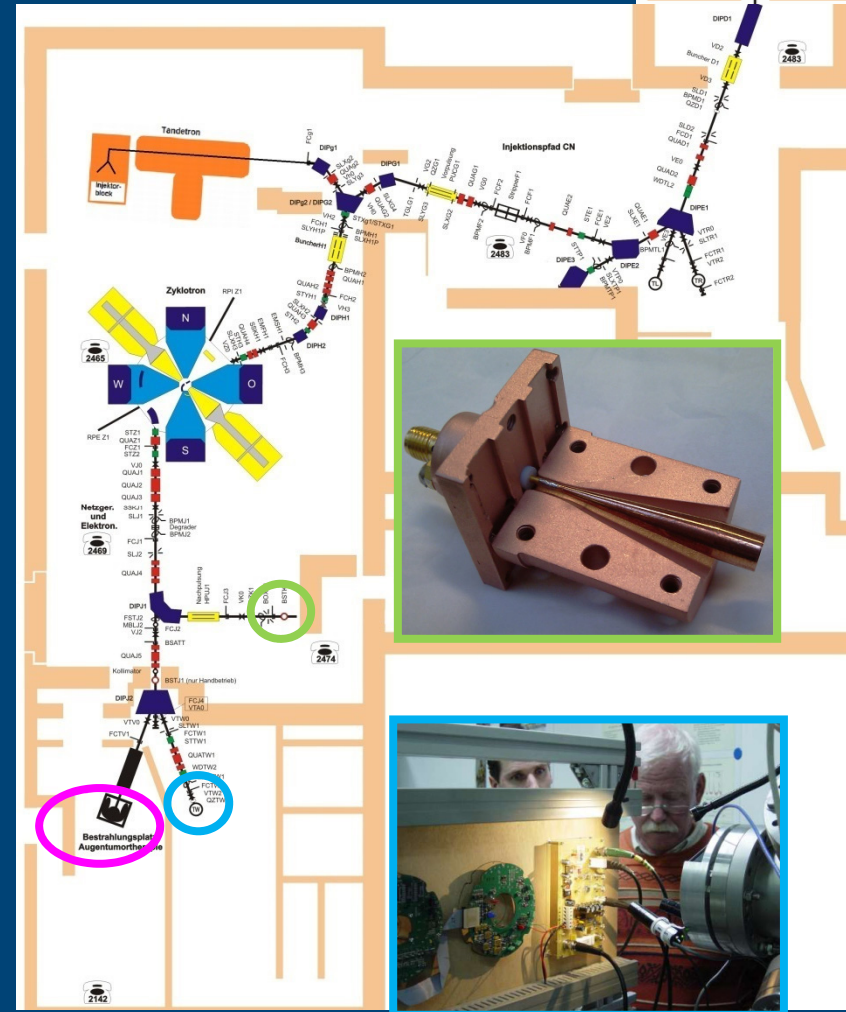
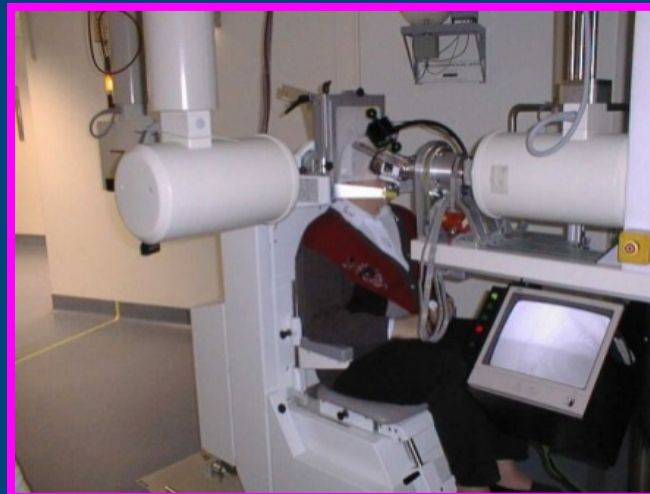
Layout: Target Stations

- k 130 cyclotron (former VICKSI, ISL)
- two injectors:
 - 2 MV Tandetron™, standard for therapy
 - 6 MV Van-de-Graaff, backup, time structures
- three target stations:
 - treatment room
 - experimental station ($I_{\max} = 10 \text{ nA}$)



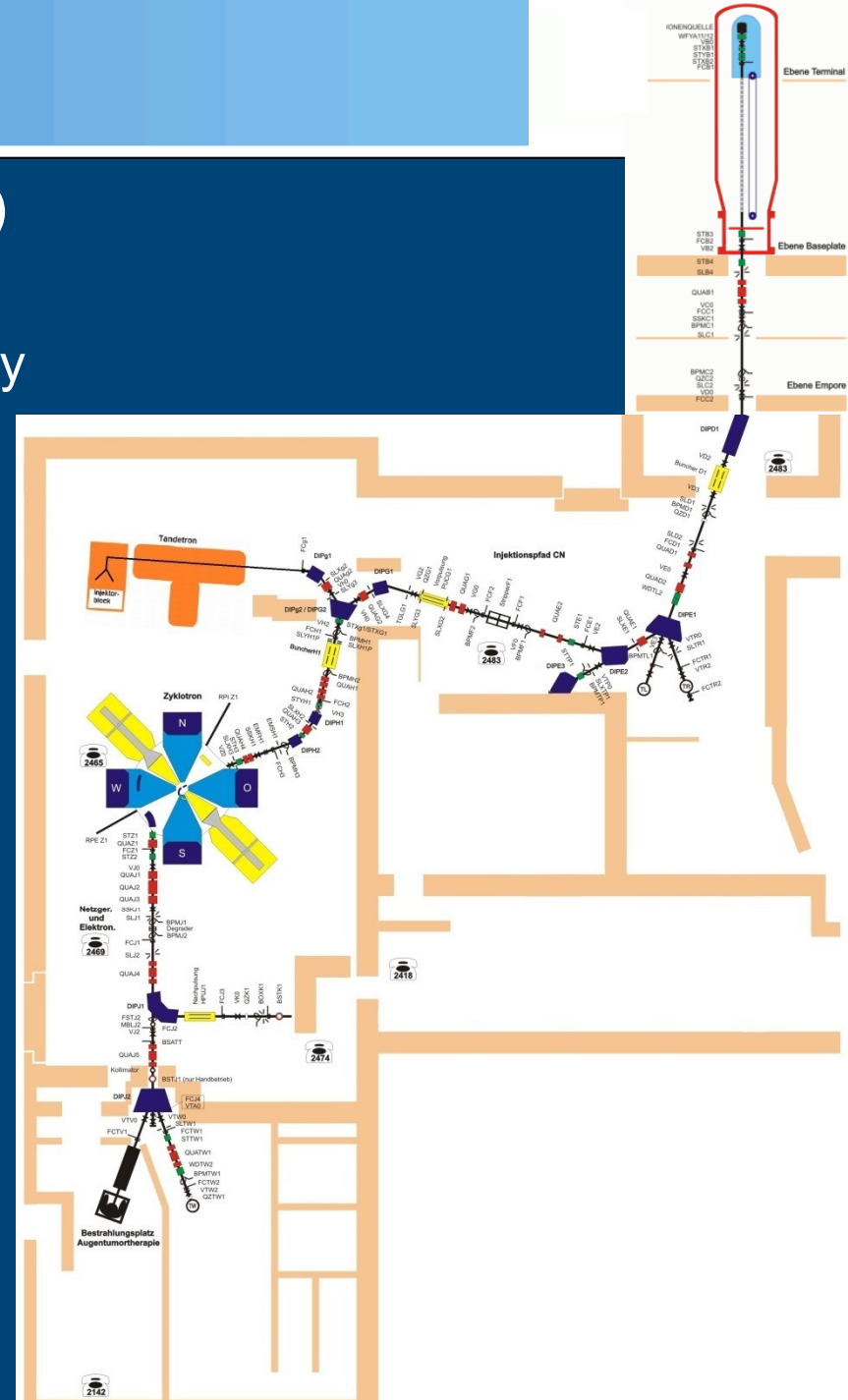
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 - beam line end for tests in cyclotron vault



Layout: Time Structures

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 - beam line end for tests
- time influencing devices
 - cyclotron RF system



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 - cyclotron RF system
 - three bunchers: terminal, injection line



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- time influencing devices
 - cyclotron RF system
 - three bunchers: terminal, injection line
 - two suppressors: injection line, post-suppressor



Layout: Time Structures

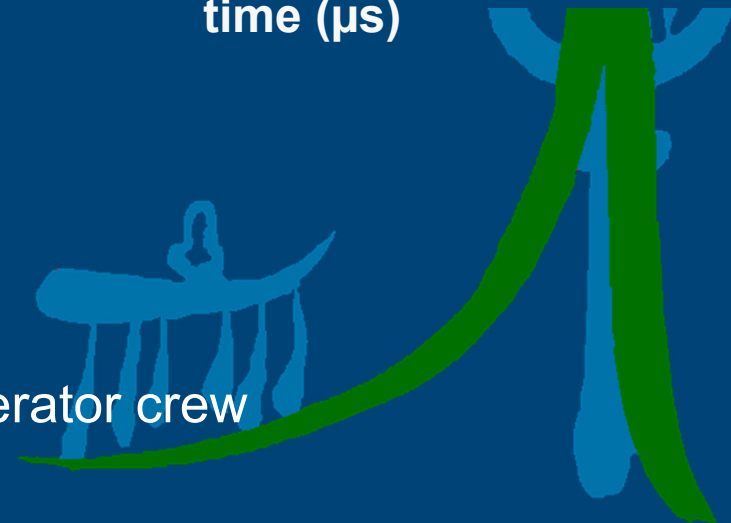
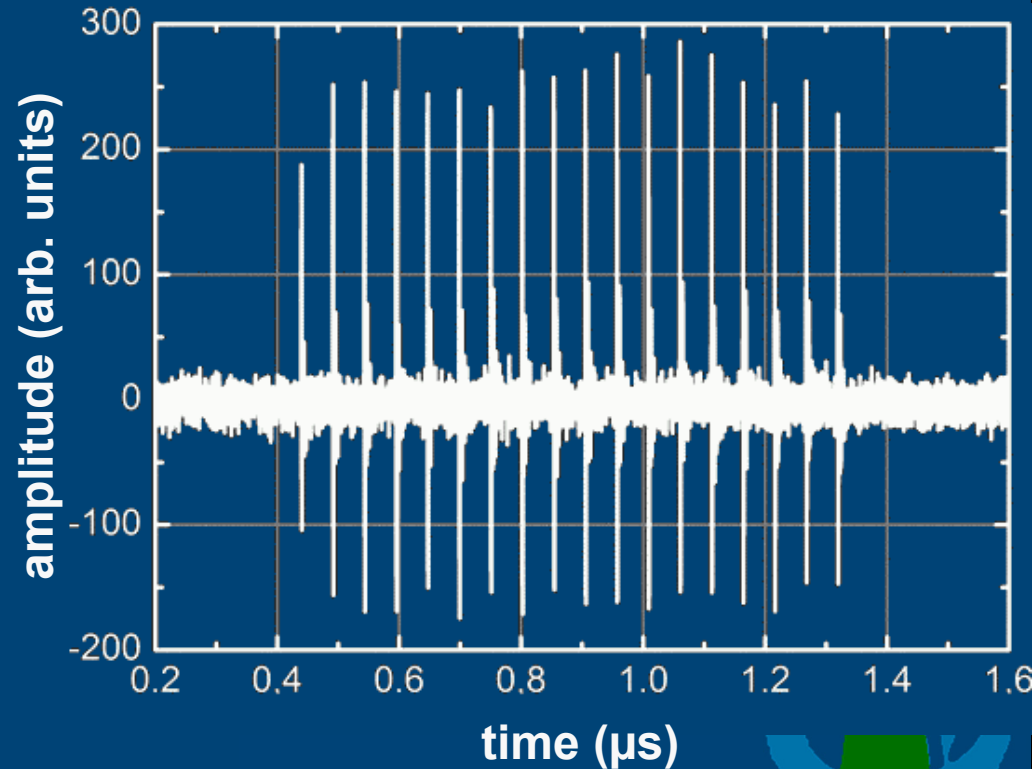
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- time influencing devices
 - cyclotron RF system
 - three bunchers: terminal, injection line
 - two suppressors: injection line, post-suppressor
 - designed for heavy ions!



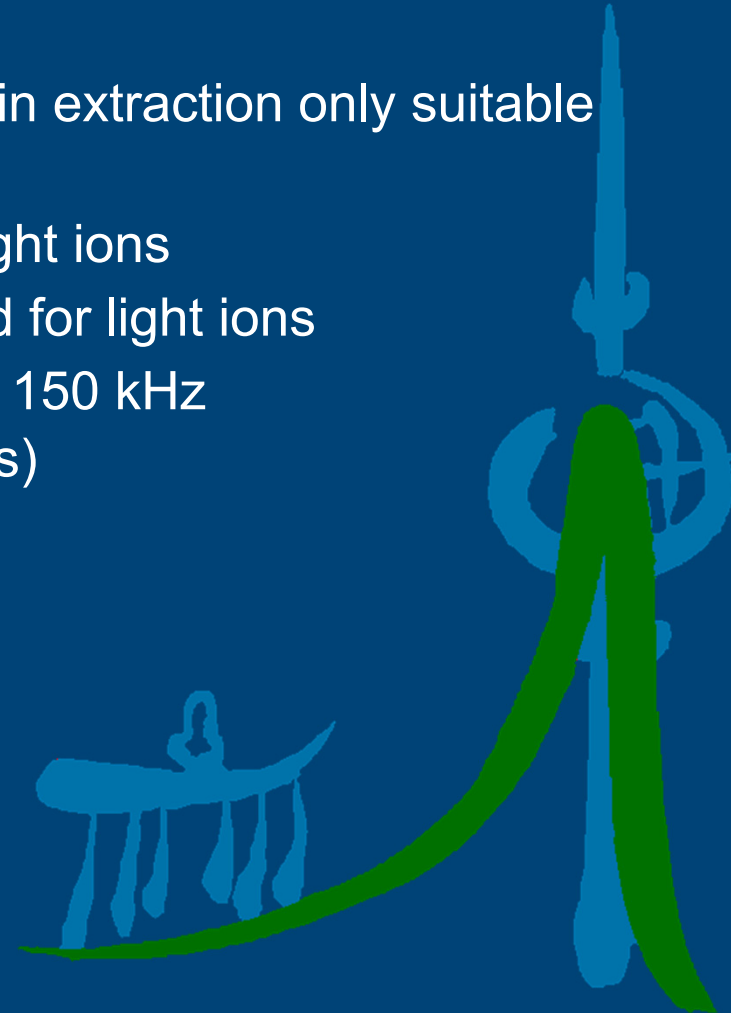
- standard:
 - 68 MeV protons
 - quasi-DC
 - broad beam (\varnothing 50 mm) or focused beam (\varnothing 1 mm) on target,
 - changes in intensity: $0.1 \text{ pA} \leq I_{\text{target}} \leq 10 \text{ nA}$
- deliverable by either Van-de-Graaff or tandetron as injector
- use:
 - medical physics
 - radiation hardness tests
 - PIXE



- pulsed beams with long pulses, e.g.:
 - pulse length: 1 to 10 μs
 - repetition rate: 100 Hz
 - intensity in the pulse: 5 nA to 1 μA on target ($500 \text{ fA} \leq I_{\text{average}} \leq 1 \text{ nA}$)
 - achievable with Van-de-Graaff injector and existing suppressor
- other ions and energies:
 - ^4He 50 MeV
 - ^4He 75 MeV
- challenges:
 - ^4He beams developed before 2004, but with different energies
 - since 2007 change of the guard in the accelerator crew

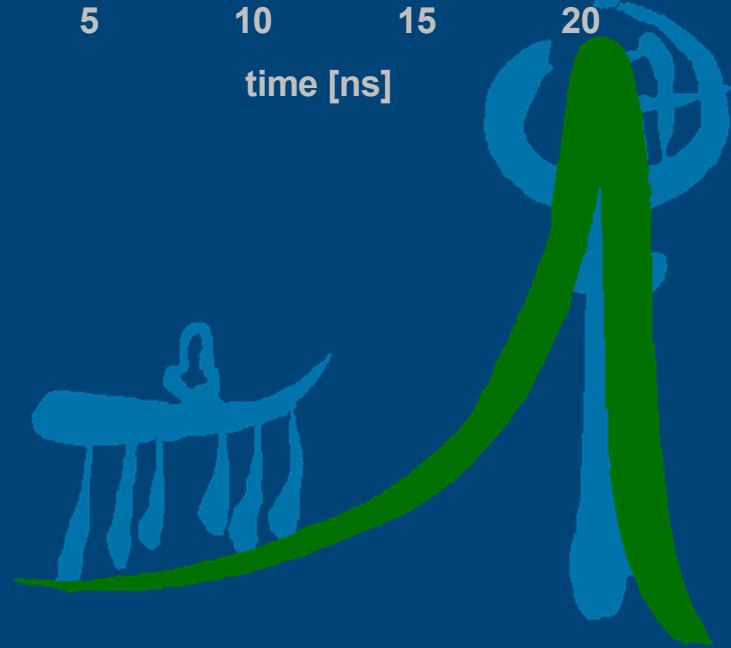
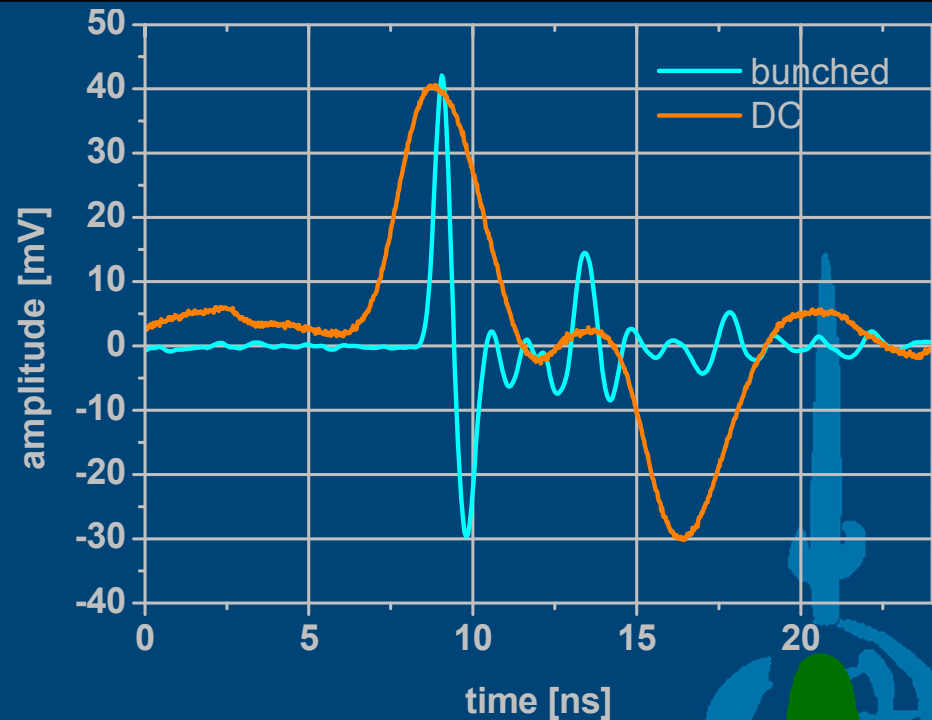


- request for single pulses with a length $\leq 1\text{ ns}$ over a broad range of repetition rates, 1 Hz up to 1 MHz for protons and helium beams
- challenges:
 - length of the proton pulse unknown, pick-up in extraction only suitable for heavy ions
 - buncher in front of cyclotron not usable for light ions
 - single turn extraction needed – never verified for light ions
 - repetition rate of existing pulse suppressor $\leq 150\text{ kHz}$ (75 kHz for high voltages required for protons)



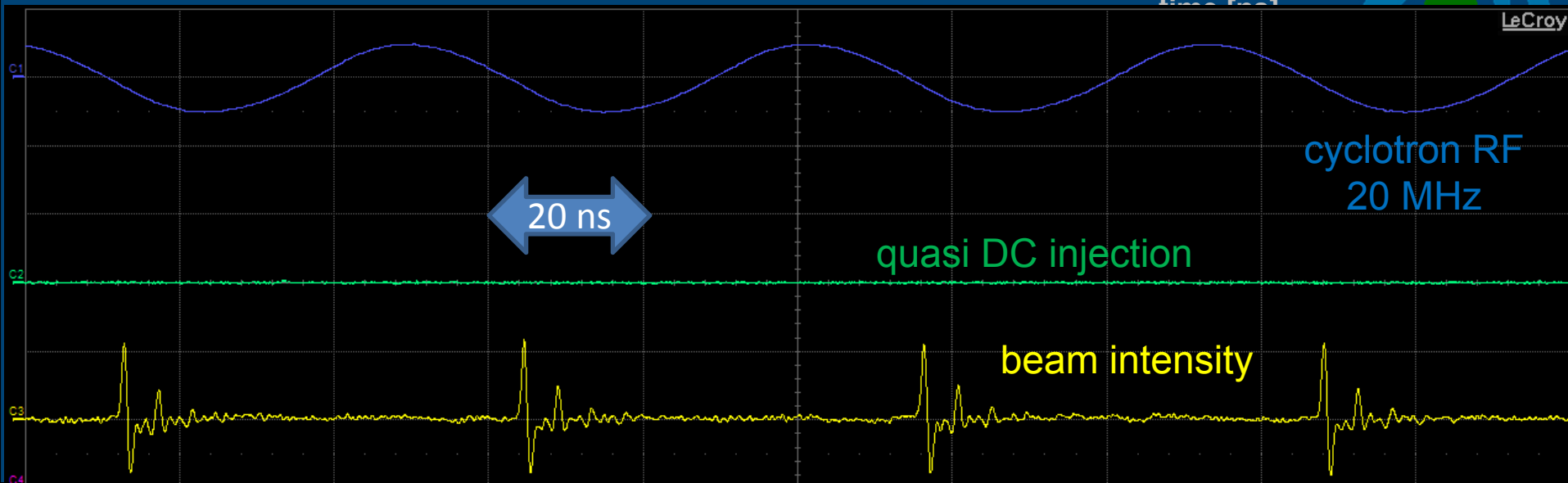
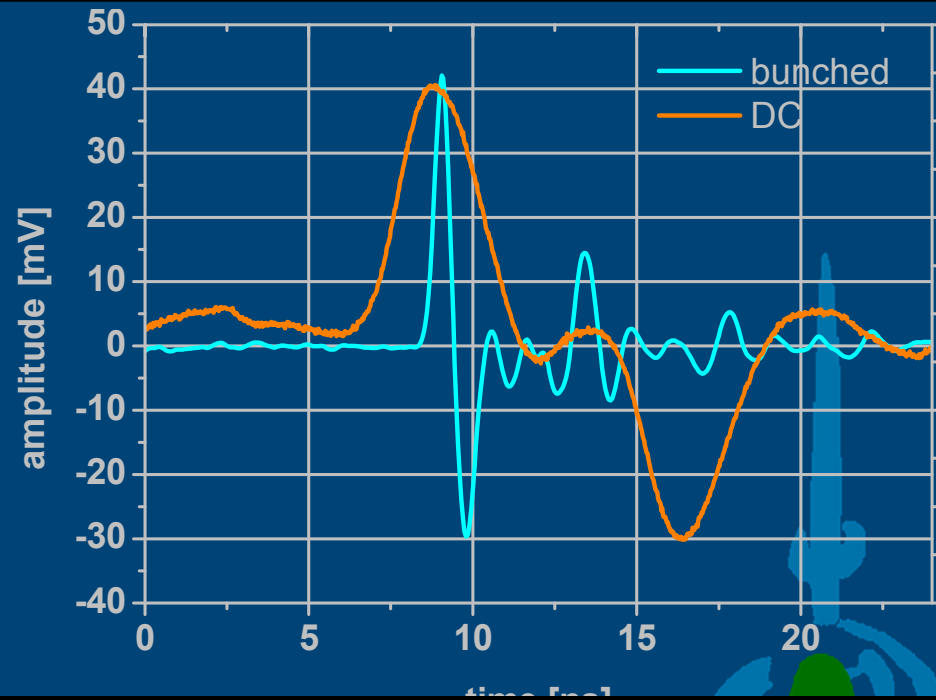
Short Pulses: 1 ns Wanted

- heavy ions: pulse length ≤ 0.5 ns (time of flight measurements)
- protons:
 - new pick-up behind cyclotron for better diagnosis
 - DC injection: width < 5 ns
 - bunched injection: width < 1 ns

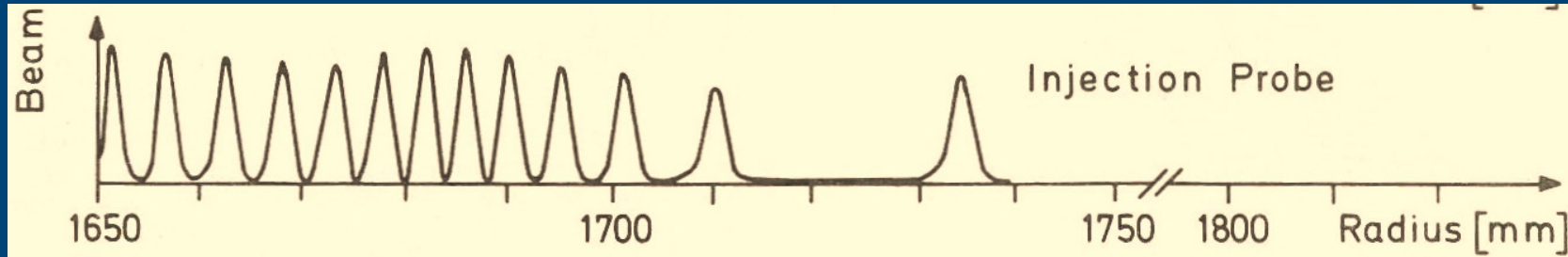


Short Pulses: 1 ns Wanted

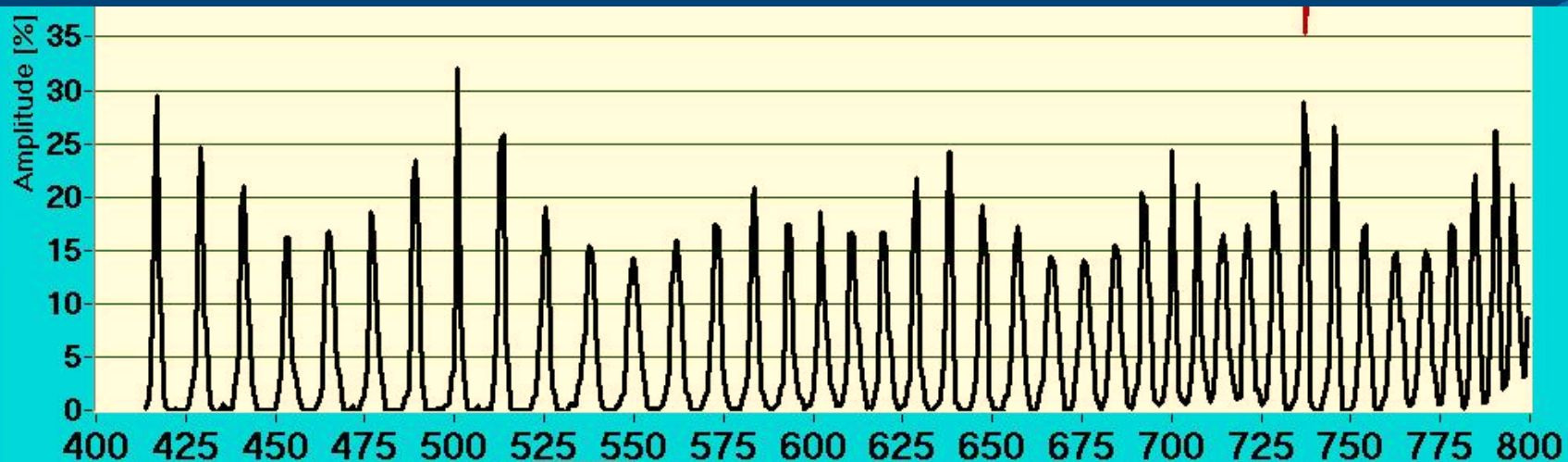
- heavy ions: pulse length ≤ 0.5 ns (time of flight measurements)
- protons:
 - new pick-up behind cyclotron for better diagnosis
 - DC injection: width < 5 ns
 - bunched injection: width < 1 ns
- first part of request fulfilled



- turn pattern of heavy ions, e.g. $^{20}\text{Ne}^{6+}$ 220 MeV
well separated turns in outer part (K. Ziegler, running in of VICKSI)



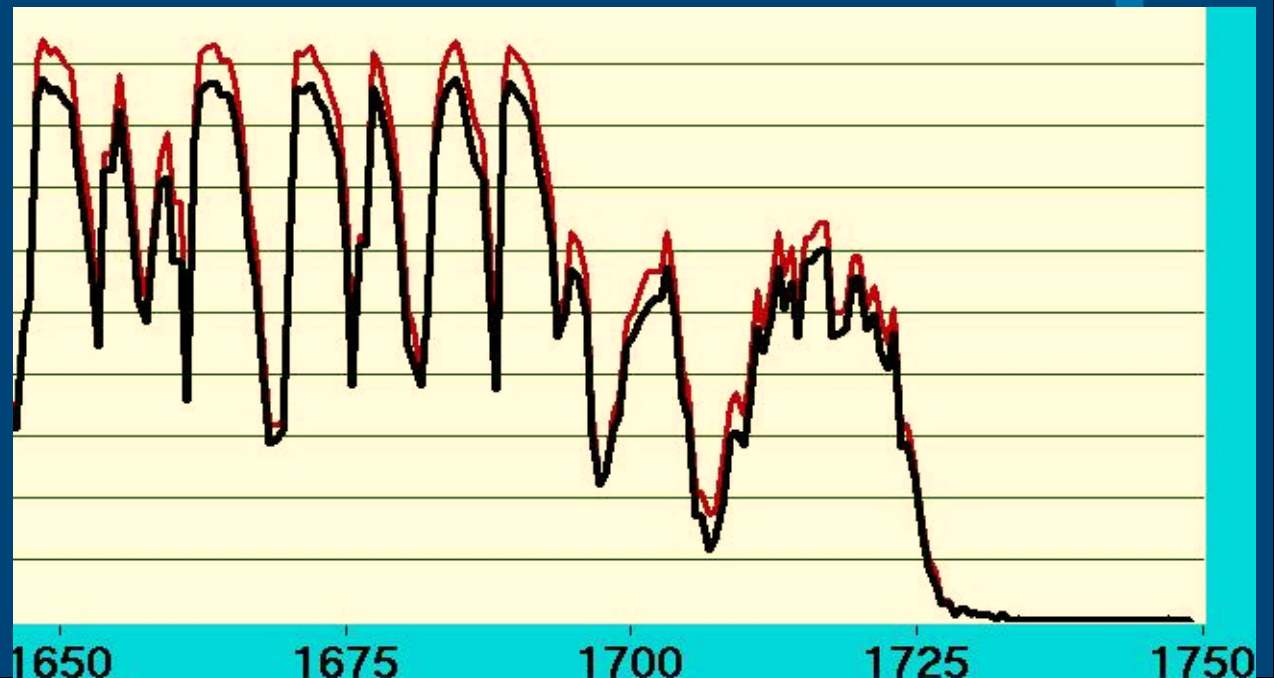
- turn pattern of protons, inner part:
 - turn separation < 19 mm



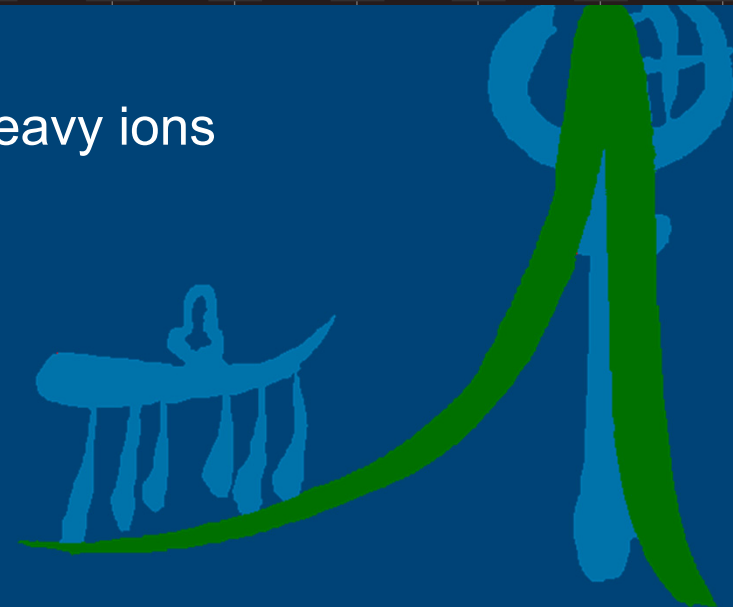
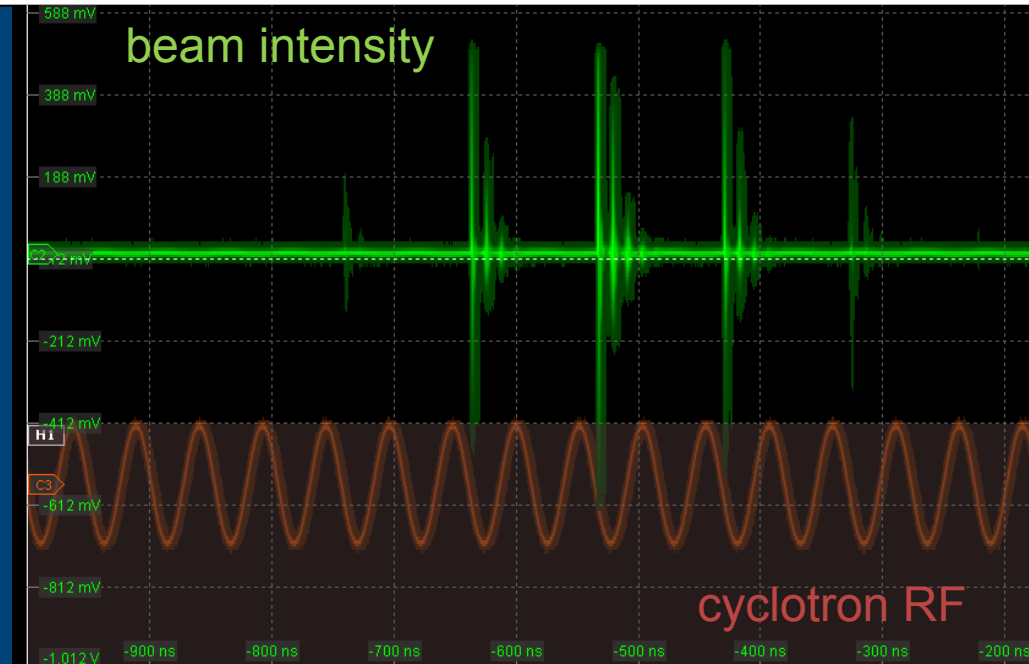
- turn pattern of heavy ions, e.g. $^{20}\text{Ne}^{6+}$ 220 MeV
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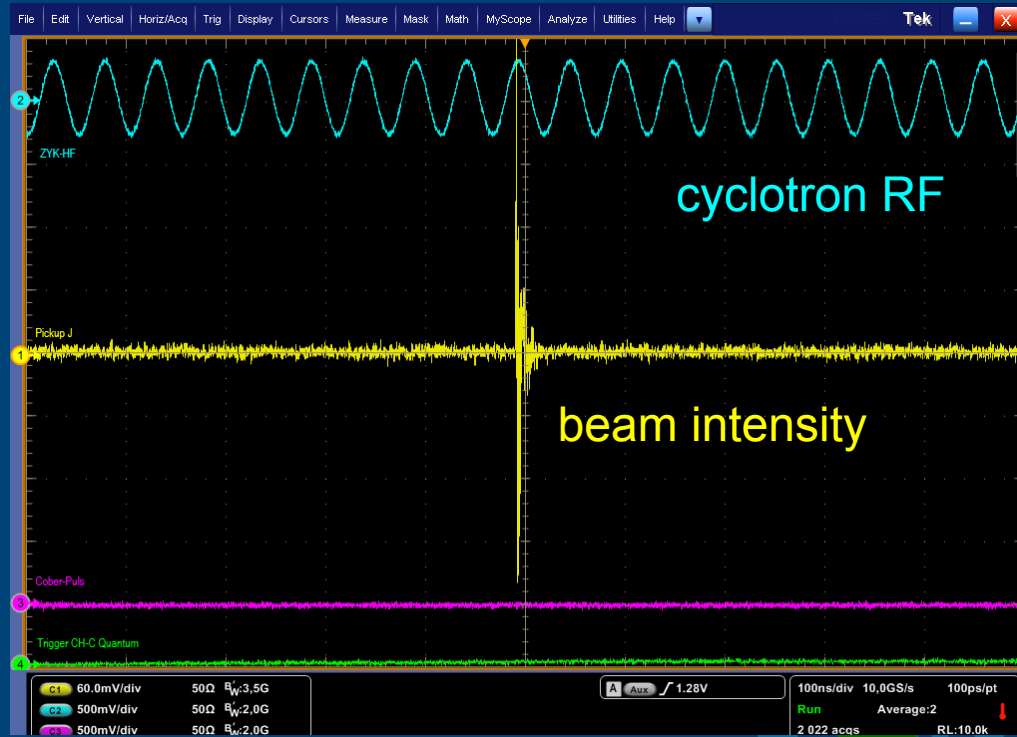
- turn pattern of protons, outer part
 - probe transparent
 - more than one turn in extraction channel
- non-relevant for therapy



- protons, 68 MeV:
 - length of injected pulse:
 ≤ 50 ns
- pick-up signal in extraction before fine tuning:
 - 5 pulses with an interspace of 100 ns (2nd harmonic)
→ multi-turn extraction
- problem:
 - distance of turns very narrow for light ions
 - phase probes in cyclotron only suitable for heavy ions
- only information: the pick-up
→ tuning ambiguous

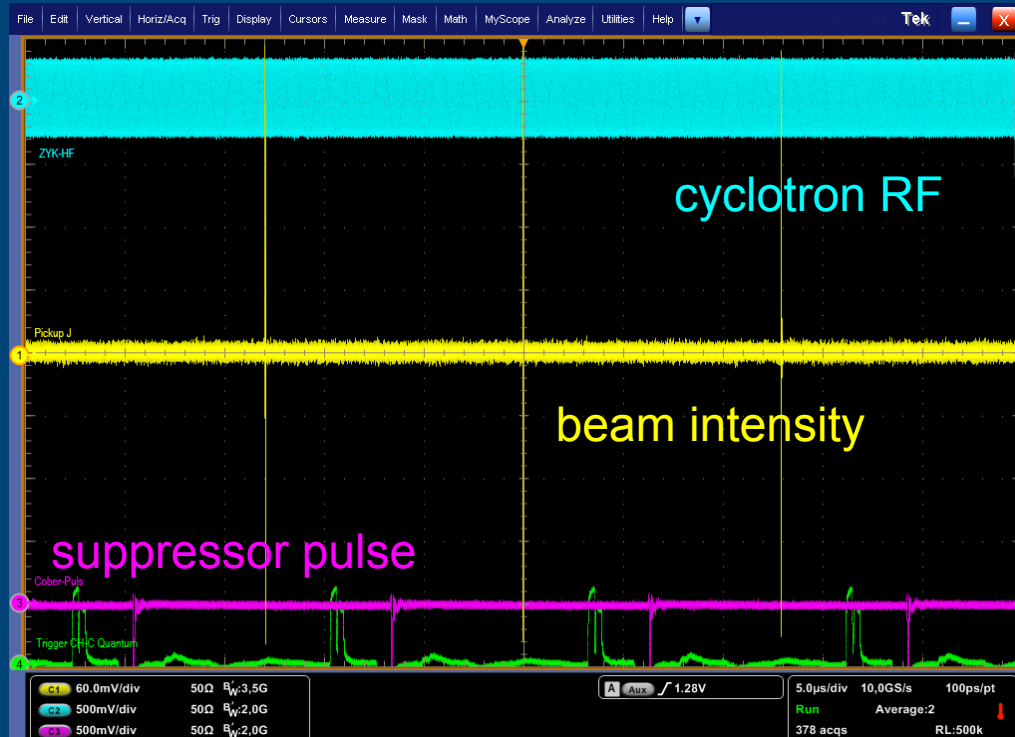
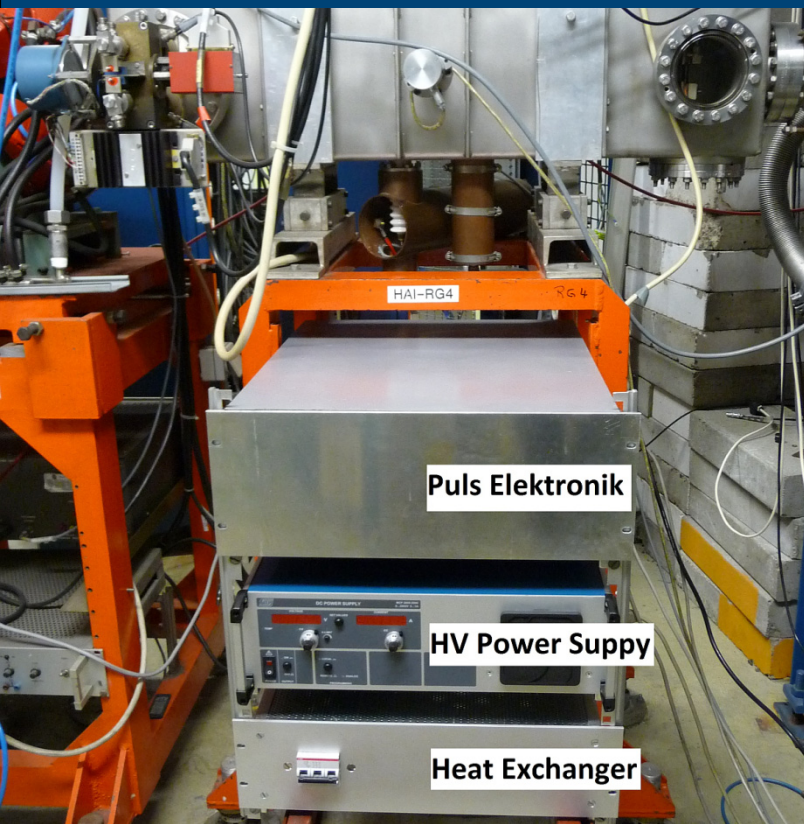


- protons, 68 MeV:
 - length of injected pulse:
 ≤ 50 ns
- pick-up signal in extraction after fine tuning of:
 - phases of bunchers, suppressor and RF
 - magnetic field
- single-turn extraction
- single pulses
- → second part of request fulfilled



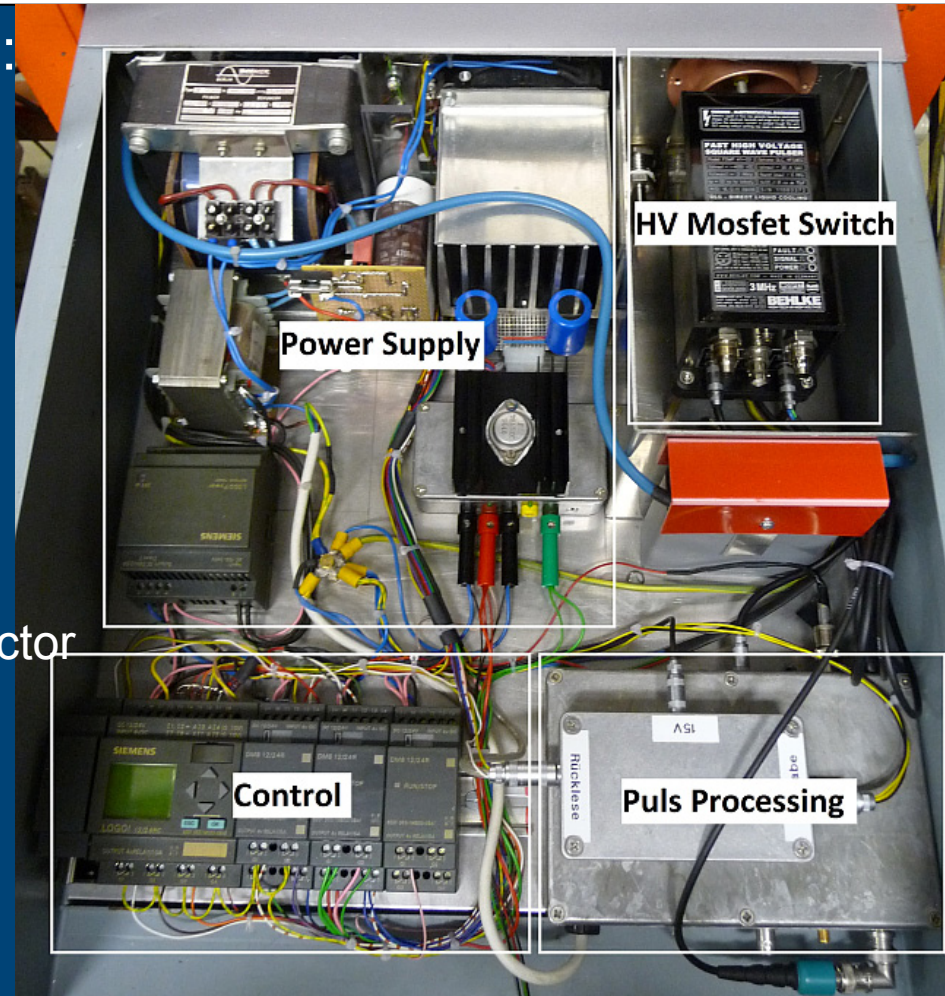
Repetition Rate: 1 MHz Wanted

- suppressor
 - repetition rate max 150 kHz for protons: 75 kHz due to high voltages
- development of new electronic for pulse suppressor



Repetition Rate: new Suppressor

- HV MOS-FET Switch from Behlke:
 - 2.4 MHz selected to ensure operation at 1 MHz
- challenges:
 - cooling (1500 W dissipation loss)
 - fast opto-couplers with sufficient power



	old	new
	tubes	semi-conductor

max. repetition rate	150 kHz	2.4 MHz
max. amplitude	1.2 kV	2 kV
I_{\max}	12.5 A	30 A
min. rise time	20 ns	11 ns
min. fall time	35 ns	11 ns

- old divider, in-house development,
 - wire wrap cards in 5U high 19" racks
 - two 2U high 19" racks for phase shifting and measuring
 - division: 2^n , n integer
- new divider: pulse generator from Quantum
 - any integer
 - LabVIEW controlled

Q9528_value.vi rev. 54

File Edit View Project Operate Tools Window Help

Run Stop

Preset Pulser Delays Cyc-Freq STOP

select

Puls Length td Pulser
Delay 1 (Cyc >>Pulser)
Delay 2 (Pulser >> LeCROY)
Delay 3 (Pulser >> EXP)
Delay 4 (free)

delta T

1 ns
10 ns
100 ns
1 μs

td

50 [ns]

delay 1

194 [ns]

delay 2

90200 [ns]

delay 3

20000 [ns]

delay 4

0 [ns]

Decrement Increment

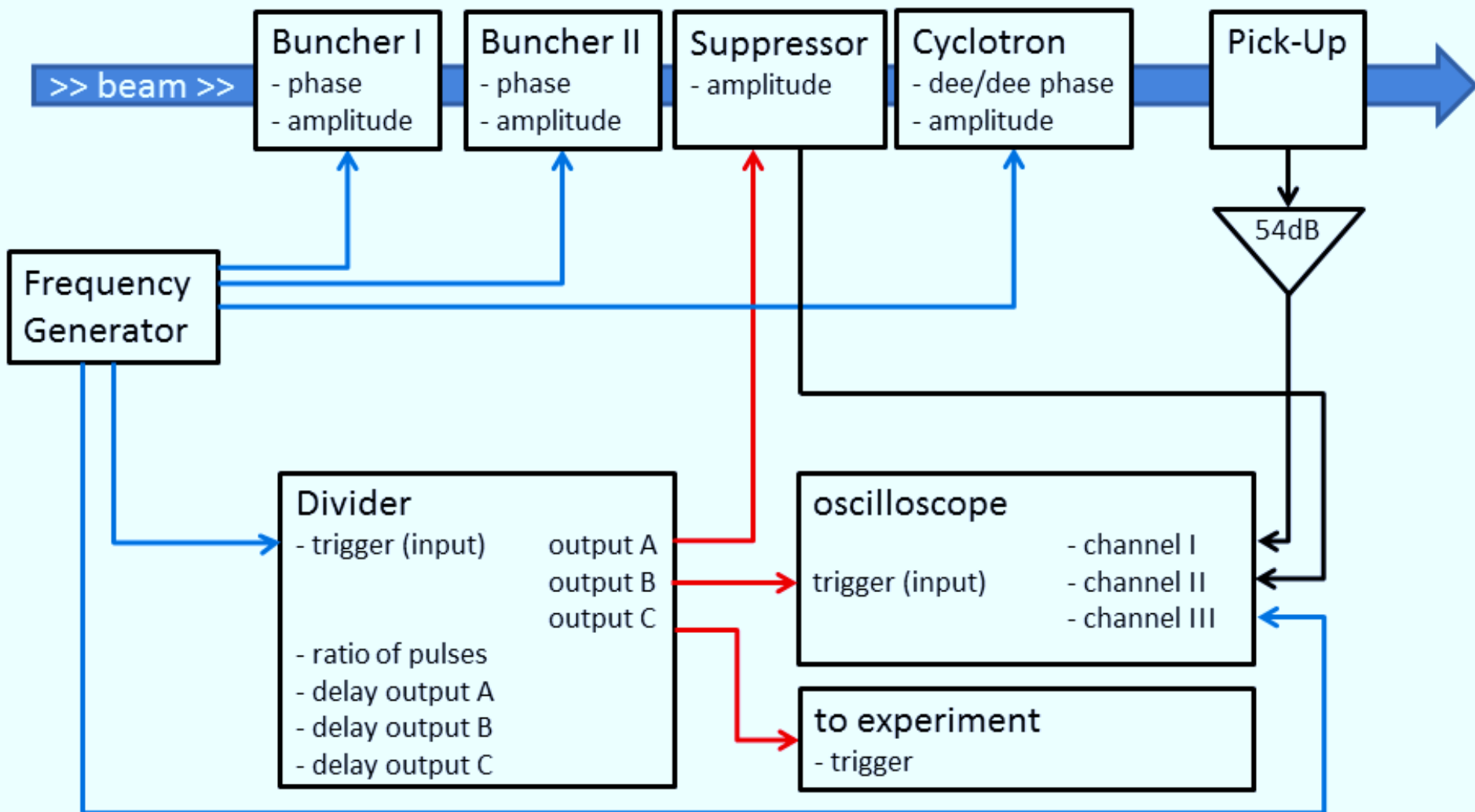
command

:PULS3:DELAY 0.000019317570

Tab Control

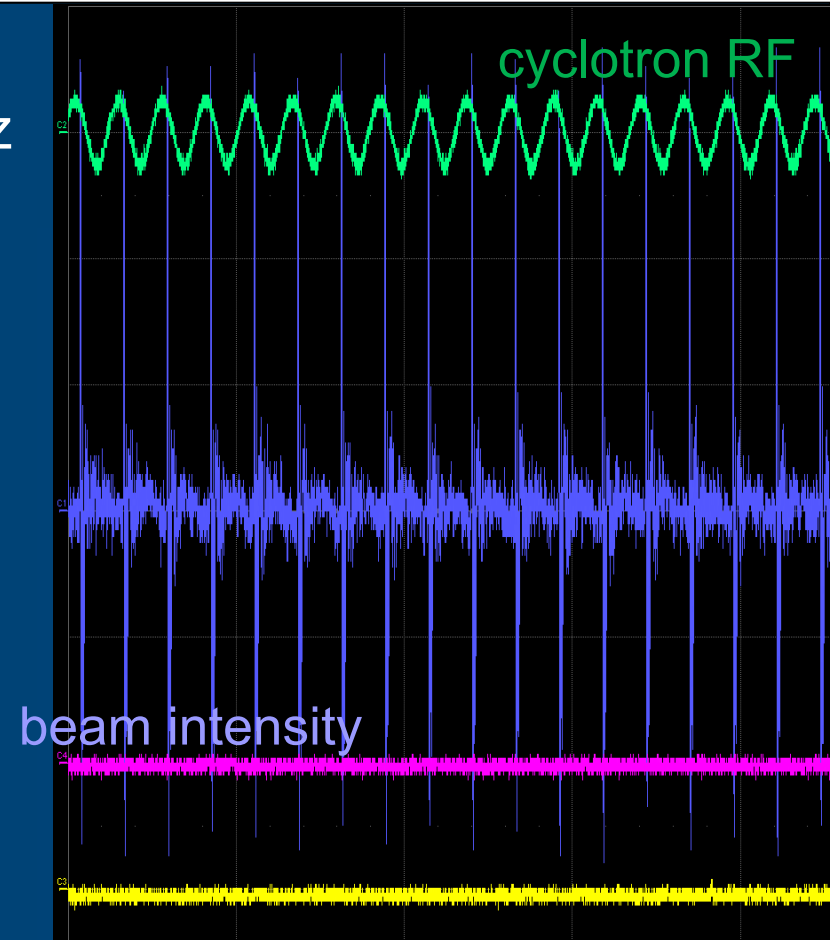
act: CYC_FREQUENZ [MHz]	act: Divider	act: Pulser [KHz]	qt
19.317570	10	1931.757	0.966

- signal plan of RF elements



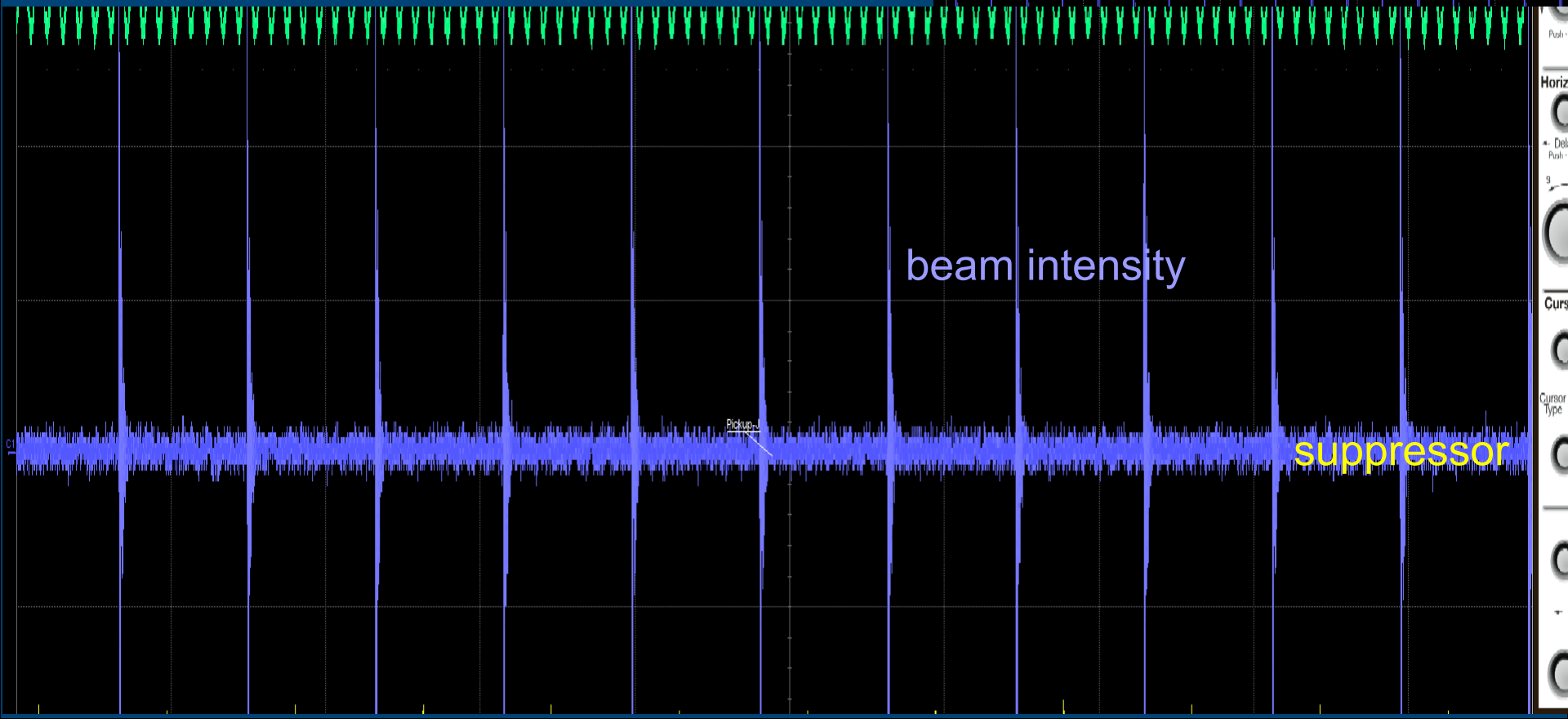
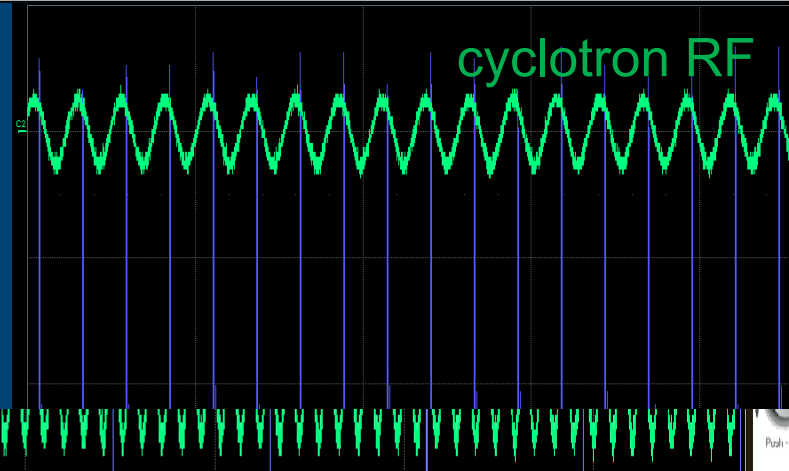
Repetition Rate: 1 MHz wanted

- right: suppressor off
- expected: stable operation up to 1 MHz



Repetition Rate: 1 MHz wanted

- right: suppressor off
- expected: stable operation up to 1 MHz
- obtained: stable operation with 2.4 MHz for more than 10 hours
- third part of request fulfilled

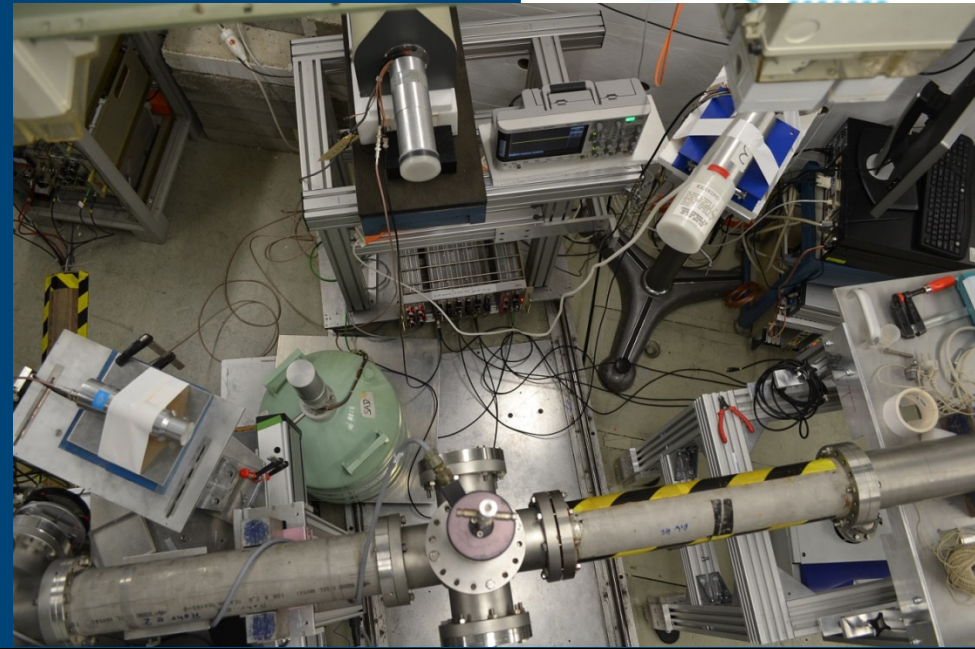
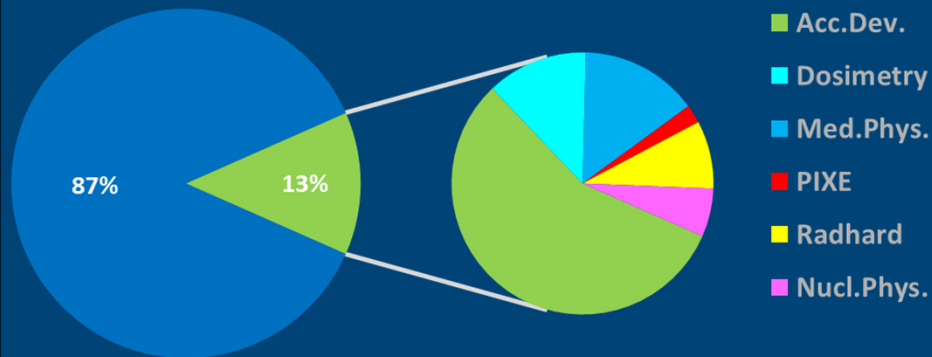


EURADOS

CHARITÉ

CSNSM

- pulsed beams deliverable only by Van-de-Graaff
- simulation of time structures of synchrotrons and synchro-cyclotrons:
 - dosimetry with pulsed neutron fields
 - survey the influence of time structures in the beam for medical dosimetry
e.g.: $7\mu\text{s}$, 1 kHz versus quasi-DC
- nuclear physics:
 - cross section measurements with time-of-flight separation of target γ -rays and neutrons

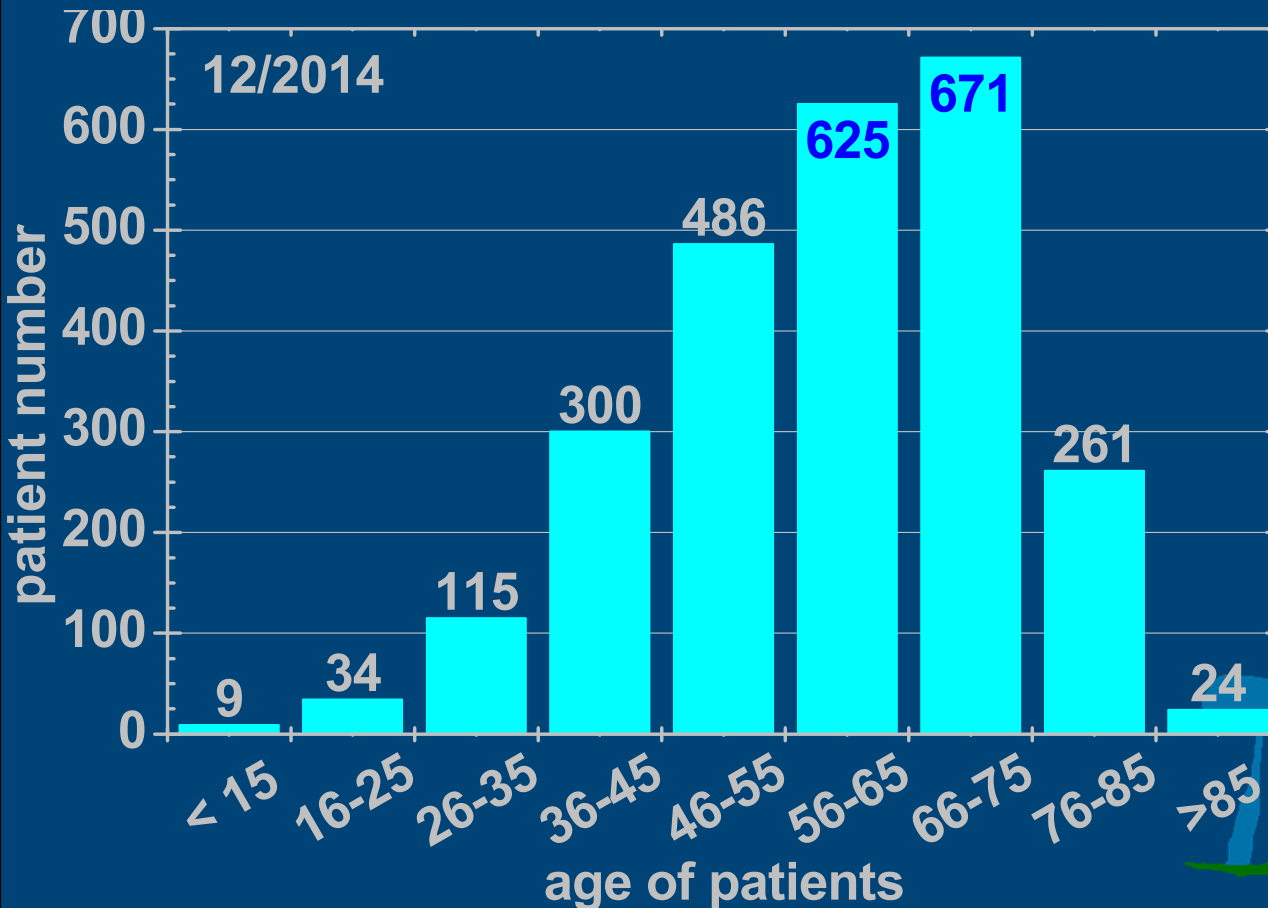


- new pulse suppressor provides freely selectable time structures:
 - pulse length 50 ns to quasi-DC
 - repetition rate from 1 Hz (or even lower) to 2.4 MHz
 - stable operation
- new ion species and energies: ^4He with 50 MeV and 75 MeV with single pulses
- reliable accelerator operation, past years: uptime at least 95 %

Thank you for your attention!



- 20% of patients younger than 45
 - special patients with special radiation protection issues:
 - pregnant women
 - breastfeeding mother



- start in 1998: more than 15 years of therapy
- local tumour control: 96%
- last years ~ 210 patients/year
- 2500th patient in November 2014

