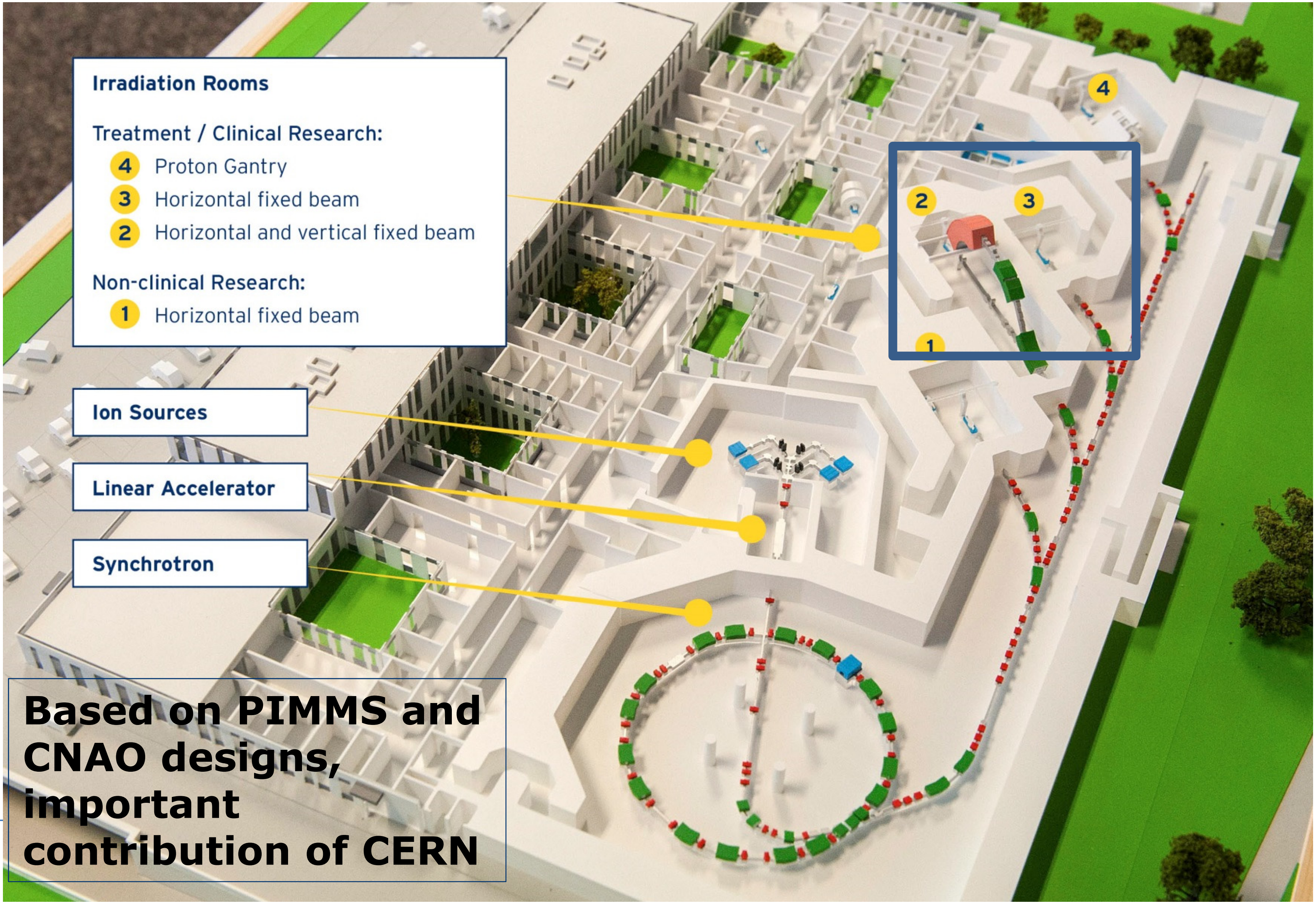
Status of Proton Beam Commissioning at MedAustron Ion Beam Therapy Center

A. Garonna, A. Wastl, C. Kurfuerst, T. Kulenkampff, C. Schmitzer, L. Penescu, M. Pivi, M. Kronberger, F. Osmic, P. Urschuetz

On behalf of the whole MedAustron Therapy Accelerator Division

Adriano.garonna@medaustron.at
http://www.medaustron.at

MedAustron Layout



Based on PIMMS and CNAO designs, important contribution of CERN

Proton Clinical Parameters

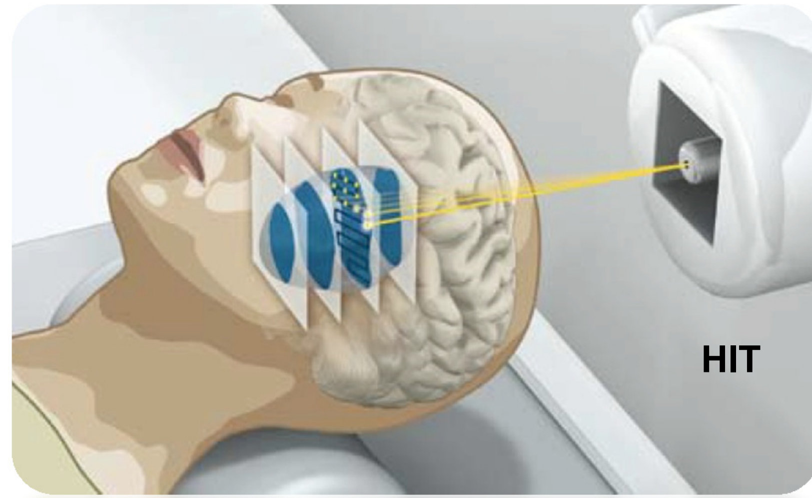
- **Energy**
  - 60-250 MeV
  [3-37 cm penetration depth in water]

- **Intensity**
  - Per pulse: 10^{10} (H^+)
    [1 min for 2 Gy in 1 L tumor]

- **Size**
  - 4-10 mm FWHM transverse
  [as in vacuum]

➢ >65‘000 combinations per IR

➢ Large amount of commissioning work

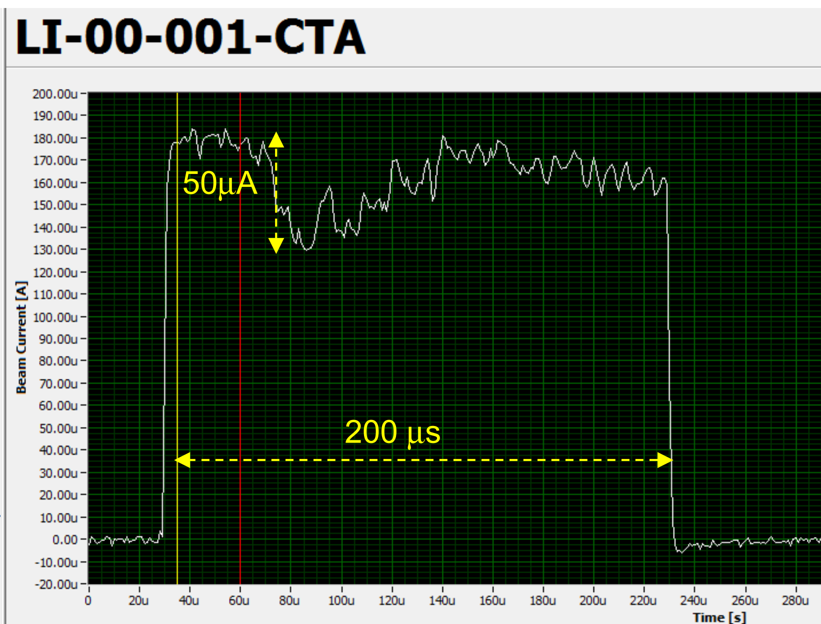


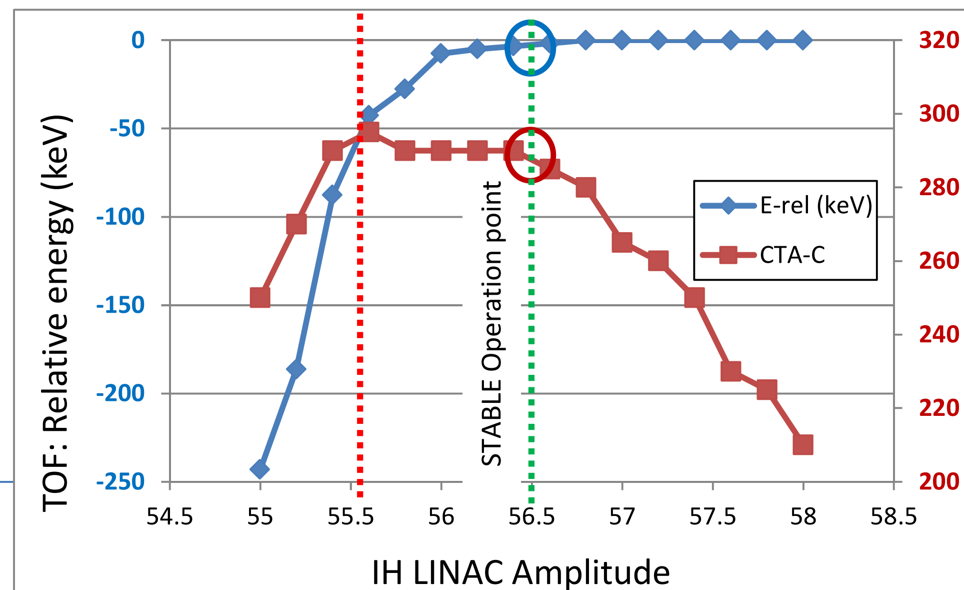
Injector and MEBT Commissioning

MedAustron

S1 current	650 µA
Linac exit current (H_3^+)	290 µA ± 3 %
Transmission through RFQ+Linac	45 %
MEBT exit current (H^+)	805 µA ± 2%
Transmission through MEBT	93 %
Energy Stability	± 0.1 %

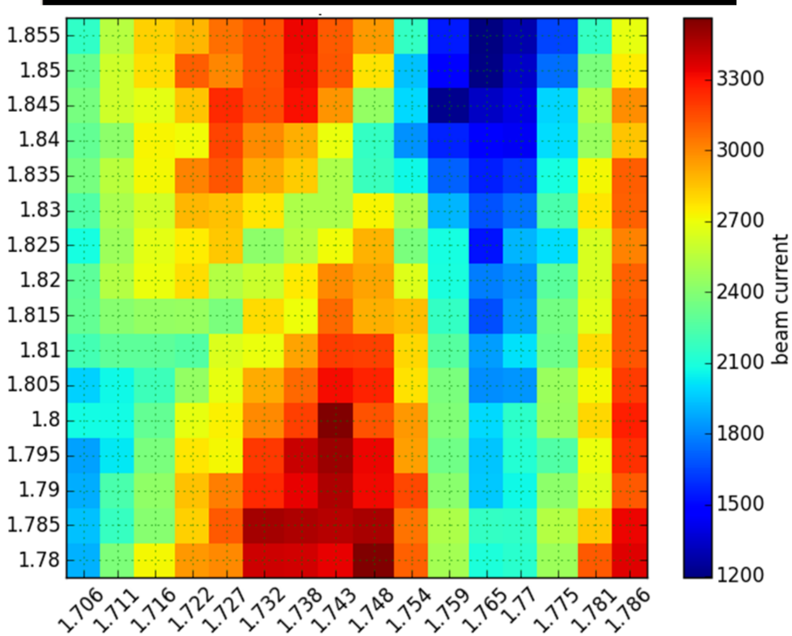
- Completed at end of 2014 with great success in terms of <u>intensity</u> and <u>stability</u>
- source operation point changed to reduce the <u>orbit fluctuations</u> in LEBT : 1 mm trajectory error = 10% transmission drop after linac
- IH operation point fine-tuned to reduce the large intensity <u>variations at end of MEBT</u> (factor 4)





Multi-turn Injection

MedAustron

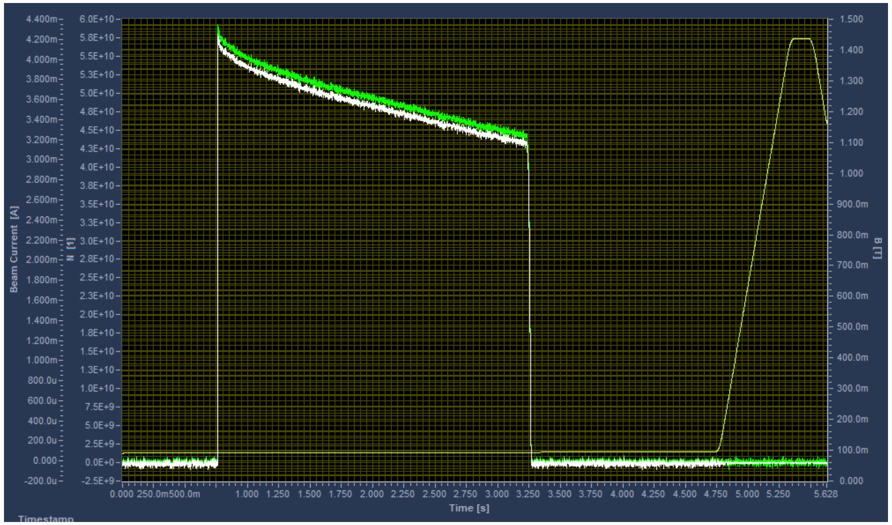


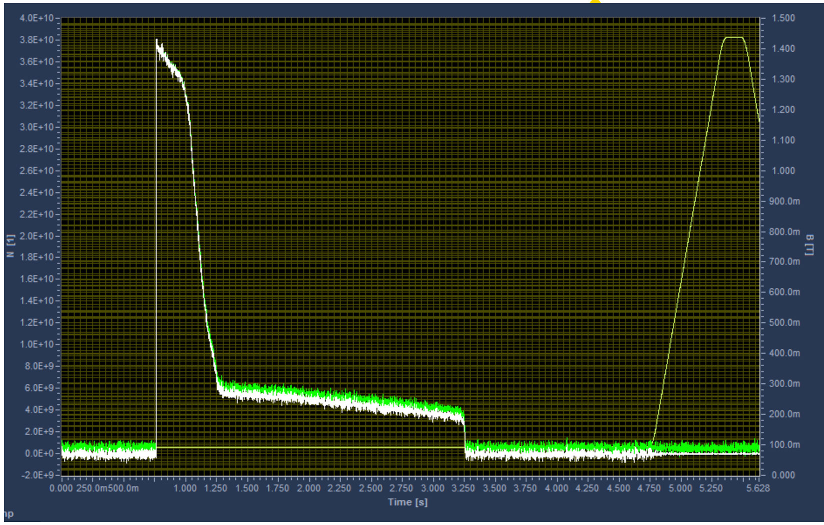
- π orbit bump with linear 80 μs fall time, in order to paint the horizontal phase-space
- up to 6 effective injection turns (max $6 \cdot 10^{10}$ protons) without any orbit correction
- control system tools extensively used to scan machine parameters and optimize beam intensity

[A. Wastl et al., Poster on Operational Applications]

Intensity-related effects

MedAustron





- average space-charge detuning estimated around -0.02 (per 10^{10} p)

  [M. Pivi et al., Poster on Space-Charge effect estimation]

- <u>instability:</u> 90% intensity drop in 100-200 ms, pseudo-random appearance in time

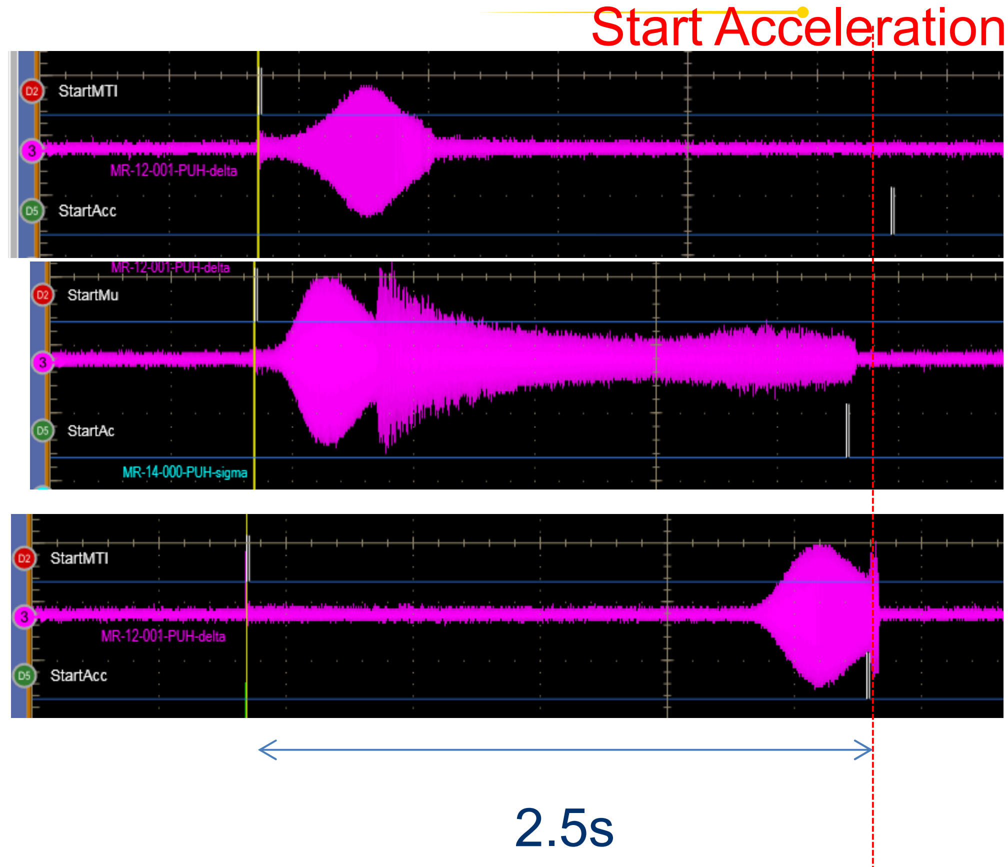
- Investigations did not identify a hardware problem

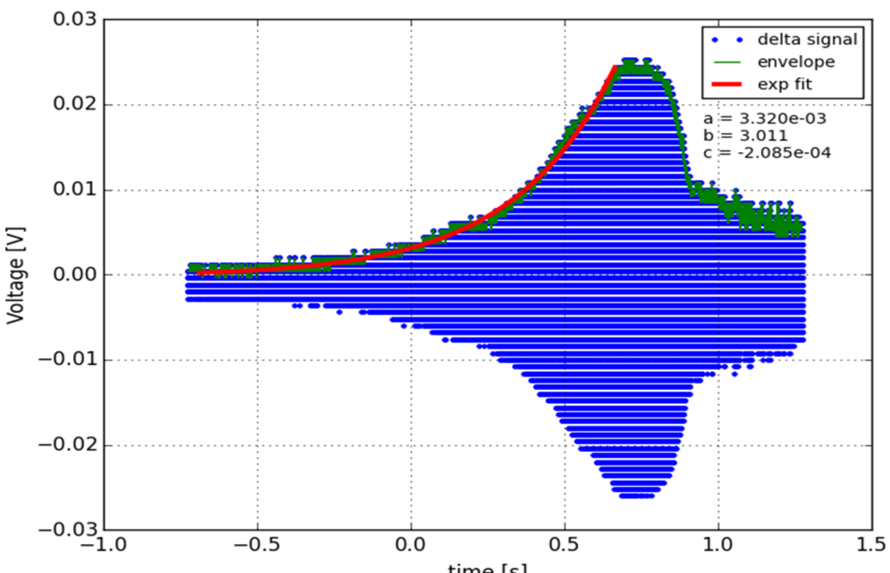
- <u>intensity threshold ~1·10 protons</u>

- observed for unbunched and bunched beams

Beam instability

- <u>PUV signal of ~800 mV</u> (typical max 200 mV)
- Only the delta signals for unbunched beam : <u>coherent beam position oscillations</u>





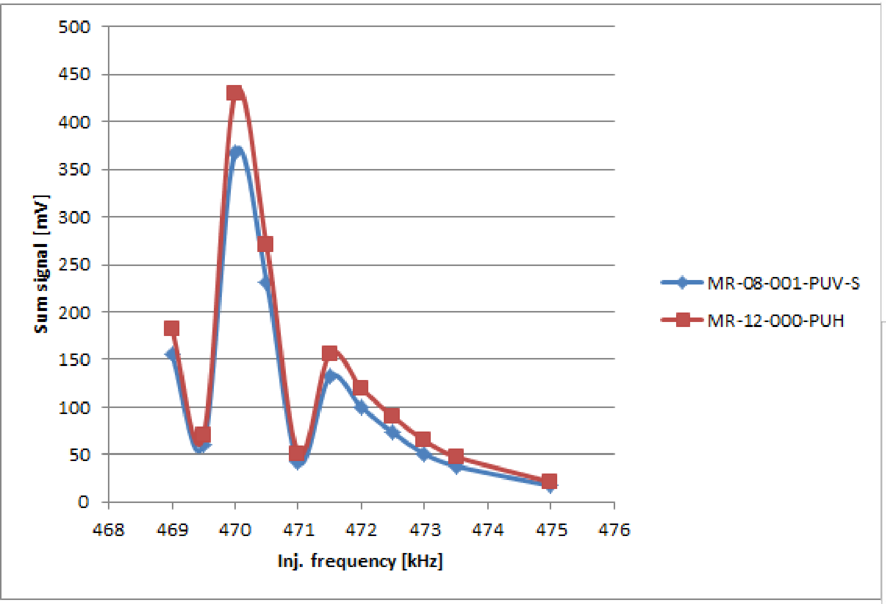
- <u>~140 kHz oscillations</u> (Frev=470 kHz, Qh/v ≈ 1.7 / 1.8)
- <u>Exponential rise constant of 0.1-0.3 s</u>

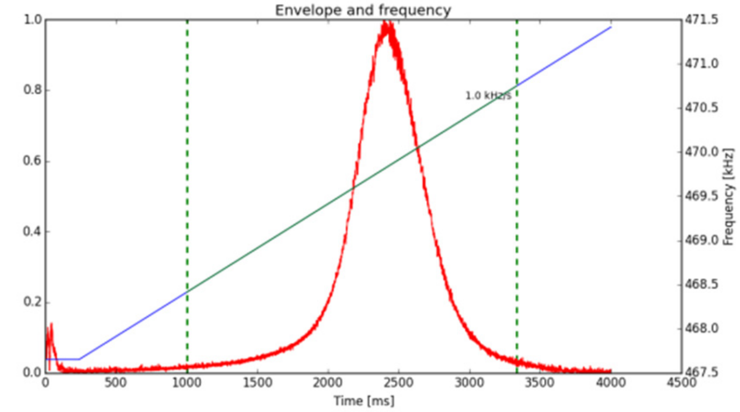
RF Capture

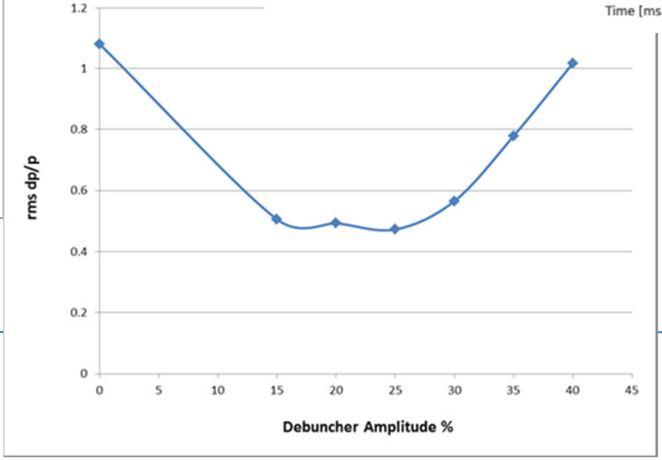
- Voltage adiabatically ramped to 170 V in 100 ms

- Capture frequency determined by sigma PU signals and local CTS maximum

- Debuncher adjustment: zero-crossing phase determined via ToF, amplitude determined by empty bucket measurements and debunching time







Acceleration

- Extensive work on main ring power supply

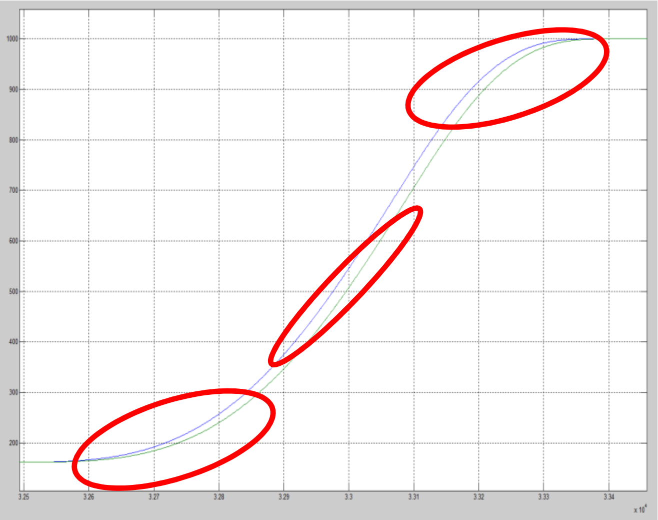
<u>Regulation</u> (2 kHz in I):

$\Delta I/I < 0.1$ % for up to 3 T/s ramps

- Power supply <u>response delay</u>

(independent of ramp rate):

9 ms for Dipoles, 4.5 ms for other families



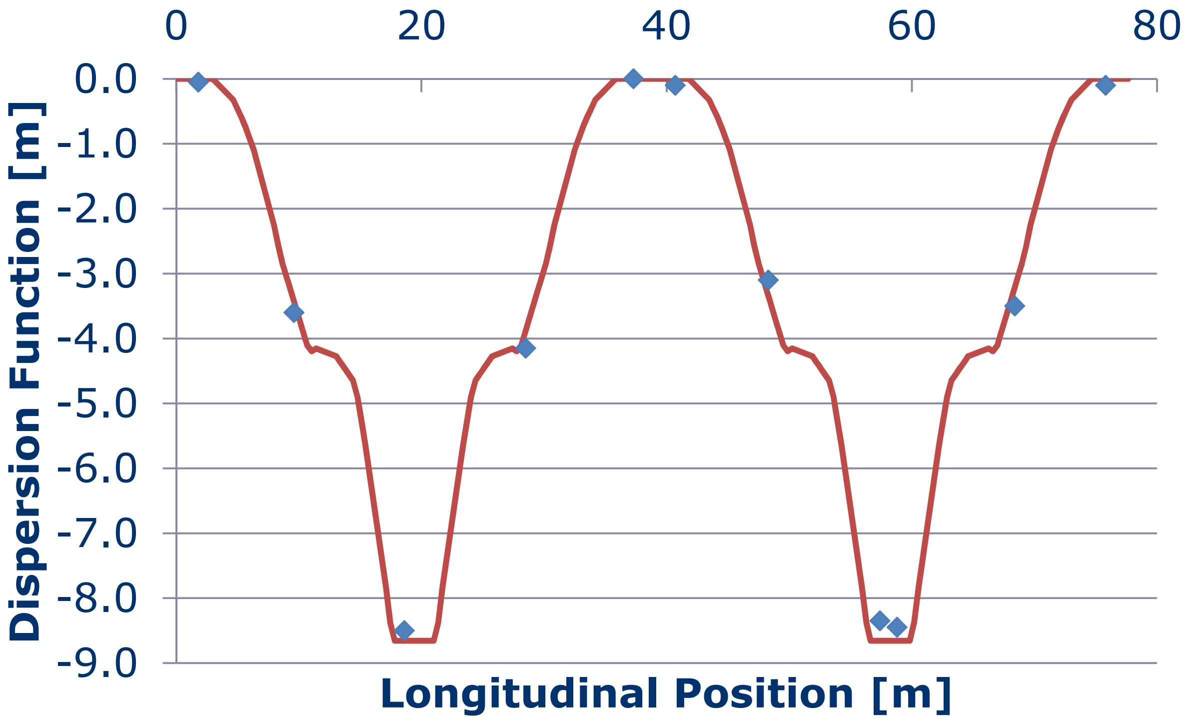
- Linear correction to the frequency program allowed open-loop acceleration

- successful acceleration of protons up to 800 MeV (full frequency swing)

- Use of <u>slow</u> (0.125 T/s) linear ramps with constant 170 V, first trials achieved 0.5 T/s

Dispersion and Orbit

- dispersion measured at 250 MeV using radial loop (confirmed qualitatively by previous measurements without SRF at flat-bottom)



- Closed-orbit error correction: ± 7 / 2 mm in h/v corrected to <± 1 mm with 0.4 mrad max kick

Rematching in SYNC

MedAustron

- Chromaticity:

	H	V
average Q'	-5.2 ± 0.2	**-1.1 ± 0.1**
MADX	-4.0	**-1.1**

- Horizontal tune: constant offset ~ +0.004 compared to MADX, desired tune reached to ± $5\cdot10^{-4}$

- Vertical tune: large constant offset ~ -0.06

Qv	Before rematching	After rematching
average measured	1.724 ± 0.001	**1.785 ± 0.001**
Design tune	**1.789**	

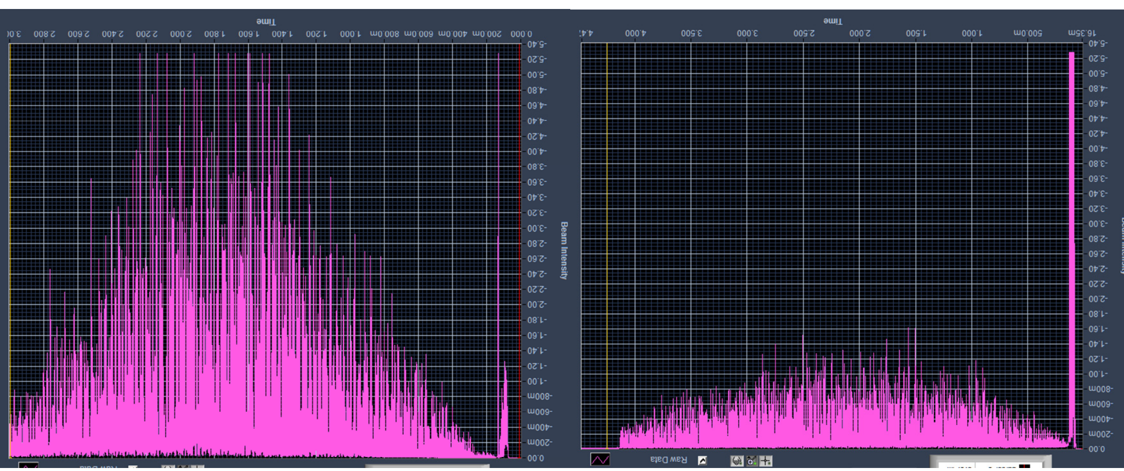
Extraction

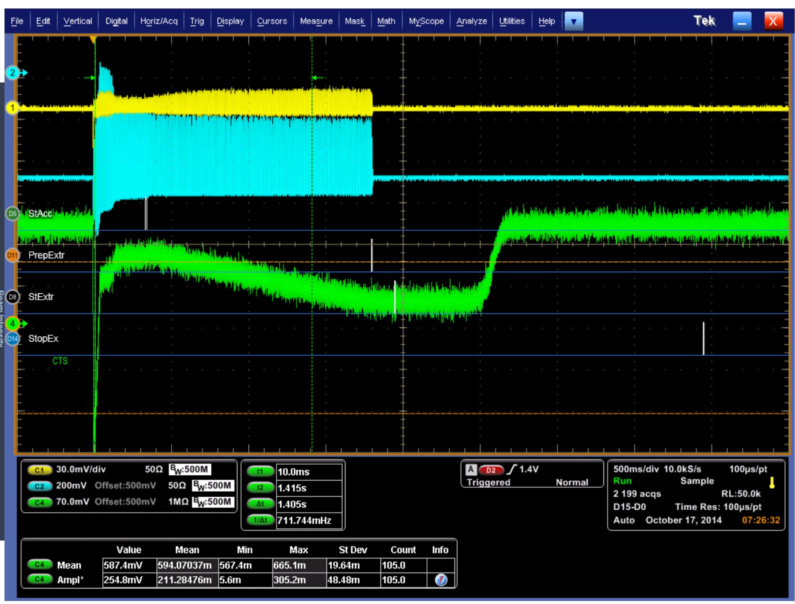
- debunched beam driven longitudinally through the resonance by the betatron core

- before debunching, RF phase jumps to the unstable point at the edge of the bucket :

$$\Delta p/p\text{, tot} = 0.9\cdot10^{-3} \Rightarrow 2.6\cdot10^{-3} \text{ (empty-bucket)}$$

Extracted beam intensity becomes more constant (uniform)





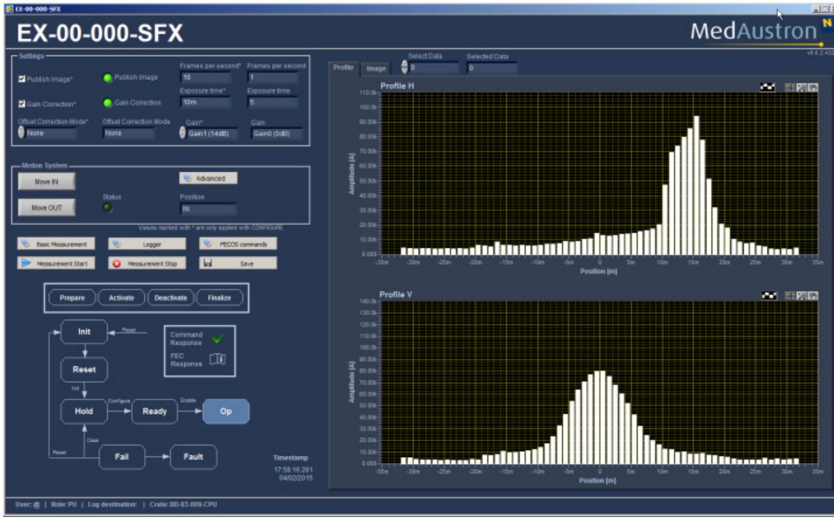
HEBT

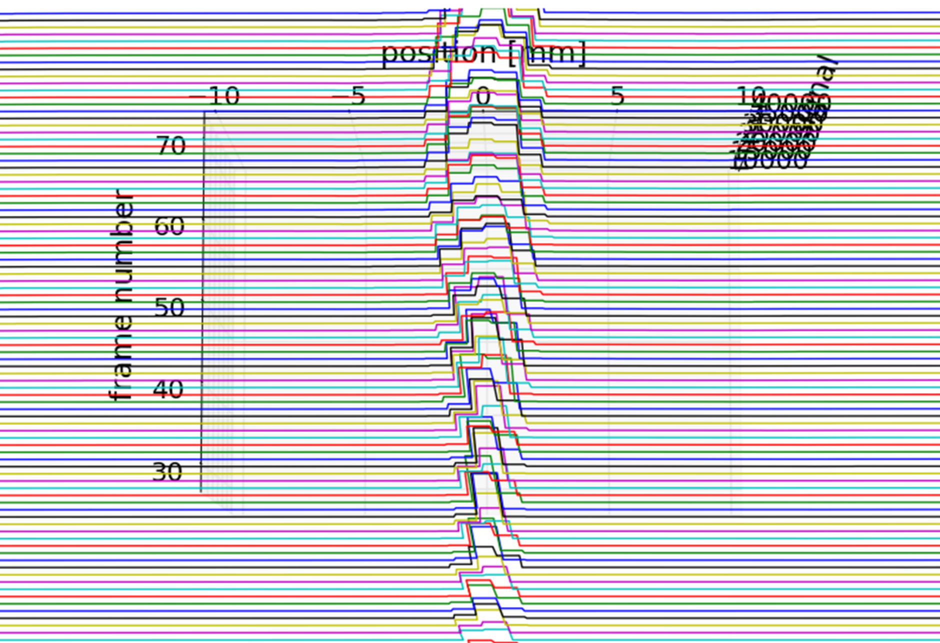
MedAustron

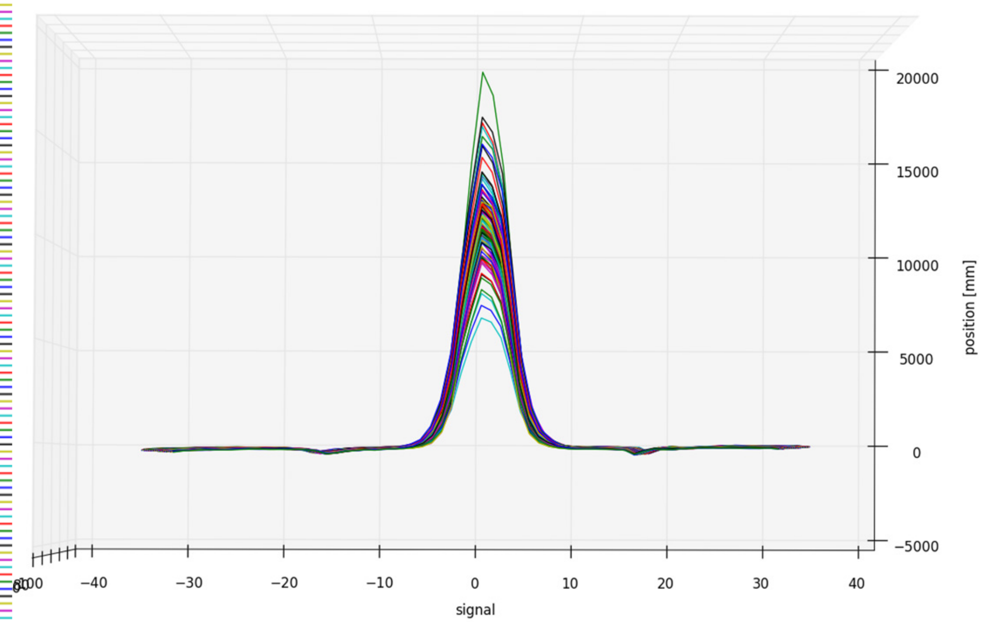
- <u>characteristic phase space distribution</u> from resonant slow extraction

- quadrupoles set for 180º phase advance rotation in ‘phase stepper’:
  V-plane: same beam width
  <u>H-plane: modified beam widths</u>

[A. Wastl et al., Poster on <u>tomography</u> of Horizontal Phase Space Distribution]







Status of intensity optimization – 250 MeV

MedAustron

[design values]	Protons (10^{10})	Transmission (%)
Source to MEBT exit	**15 [6]**	**42 [57]**
After injection in SYNC	**4 [1.5]**	**26 [26]**
After RF capture and acceleration	*1 [1.3]*	*25 [86]*
After extraction, in IR	*0.5 [1]*	*60 [78]*

Towards the first proton treatments

MedAustron

end Q2 2015

- **Accelerator Tuning**
  - Focus on 250 MeV, optimization of intensity, cycle time, beam parameters
  - Setup of 20 clinical energies based on feedback from Medical team (range, size) for IR2-h and IR3

End Q3 2015

- **System 'Freeze'**
  - 255 clinical cycles created by interpolation
  - 'Freeze' of machine parameters
  - Finalization of all technical documentation

End Q2 2015

- **Medical Device**
  - Medical commissioning
  - CE label : Risk Management, Standards, Functional Safety [T. Stadlbauer et al., Poster on Beam Chopper Safety System]

Commissioning is a technical, scientific and human endeavour

MedAustron

Thanks to M. Pullia, C. Viviani, C. Priano, L. Falbo (**CNAO**) and **CERN** for the crucial support

Thank you for your interest

MedAustron

- 'Operational Applications - a Software Framework Used for the Commissioning of the MedAustron Accelerator' (Monday Poster HA002, A. Wastl et al.)
- 'The Beam Chopper Power Converter for MedAustron: Safety by Design and Development' (Wednesday Poster MA002, T. Stadlbauer et al.)
- 'Space Charge Effect Estimation for Synchrotrons with Third-order Resonant Extraction' (Thursday Poster F002 , M. Pivi et al.)
- 'Tomography of Horizontal Phase Space Distribution of a Slow Extracted Proton Beam in the MedAustron High Energy Beam Transfer Line' (Thursday Poster F001, A. Wastl et al.)
- Two open positions :

C/C++ Software Engineer

Electronics Engineer