WP2:
11Carbon PET-aided hadron therapy

Research objectives

ESR positions

Secondments

L. Penescu, MedAustron
On behalf of WP2

WP2 Scope. Presentation summary.

MedAustron

Scope of WP2: 11Carbon PET-aided hadron therapy

- ✓ **Production** and **mass separation** of $^{11}CO^{+}$. (**ESR11**)
- ✓ Development of **charge breeding** scheme required for acceleration. (**ESR3**)
- ✓ Full **acceleration** and **treatment** - ^{11}C hadron therapy test and planning. (**ESR9**)
- ✓ Further development of bioconjugates suitable for **imaging** and treatment of the ovarian cancer. New bifunctional fluorescent and radioactive bioligand. Tests with 11C as chelate. (**ESR15**)
- ✓ Development of multimodal **imaging** methodologies for the treatment planning. Methodology and preclinical techniques. Biological models. (**ESR12**)

PARTNERS

ESR11:	University of Leuven (Recruiting and Enrolment; 36 mo)		+ CNAO (Secondment; 10 mo)
ESR3:	CERN (Recruiting; 36 mo)	+ Chalmers University of Technology (Enrolment)	+ MedAustron (Secondment; 5 mo)
ESR9:	CNAO (Recruiting; 36 mo)	+ University of Pavia (Enrolment)	+ CERN, HUG (Secondment; 3 + 3 mo)
ESR15:	HUG (Recruiting; 36 mo)	+ EPFL (Enrolment)	+ AAA (Secondment; 3 mo)
ESR12:	HUG (Recruiting; 36 mo)	+ University of Geneva (Enrolment)	+ CNAO (Secondment; 3 mo)

Presentation SUMMARY

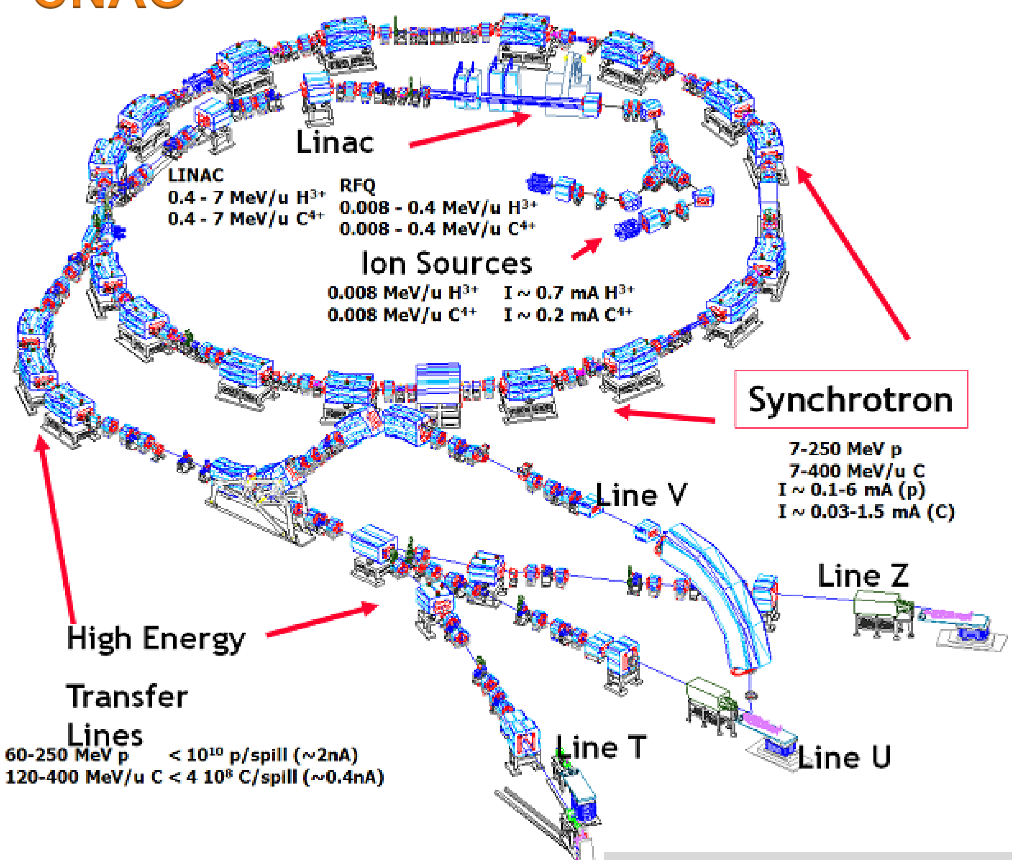
- ➢ Delivering a beam for treatment at an existing facility (MedAustron, CNAO, HIT).
- ➢ Possibilities for mixing/replacing ^{12}C with ^{11}C, for treatment and PET imaging.
- ➢ Open questions (to be addressed by the ESRs).

PIMMS-based accelerators: HIT, CNAO, MedAustron

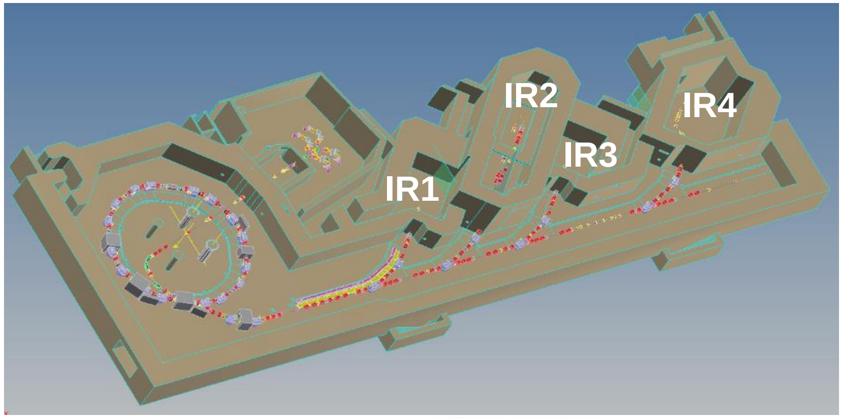
MedAustron

PIMMS: Proton-Ion Medical Machine Study, CERN 2000-006

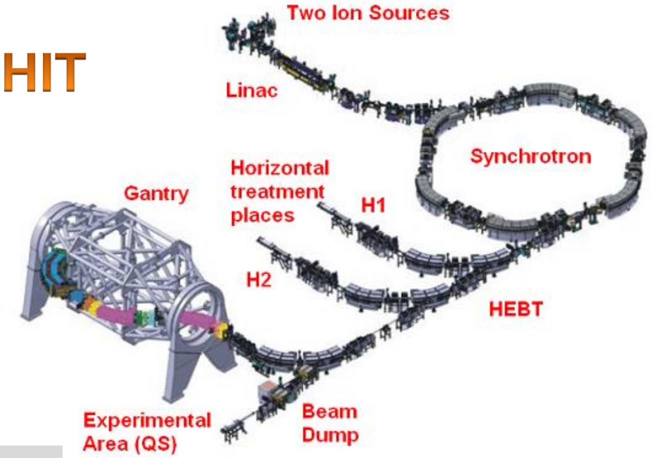
CNAO



MedAustron



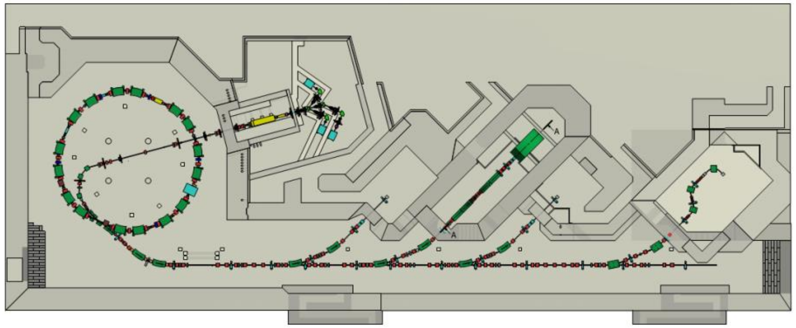
HIT



- ✓ Same main ideas
- ✓ Different implementation choices

The 12C beam path at MedAustron

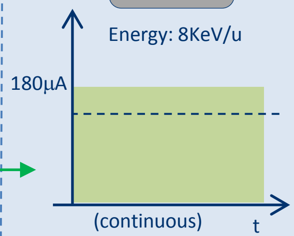
MedAustron

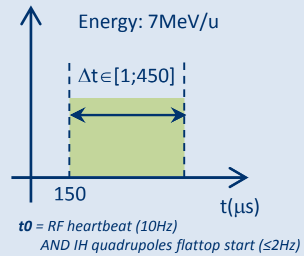


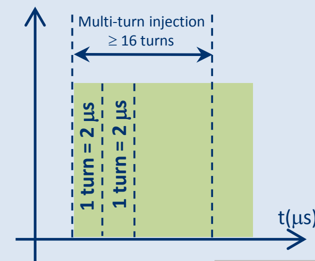
GAS BOTTLES → ION SOURCE → LEBT → IH → SYNC INJECTION → SYNC STAGES

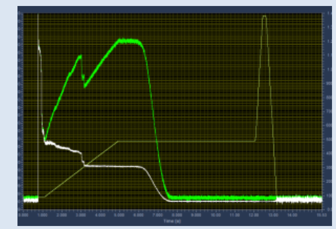
CO_2
He

C^{1+} to C^{6+}
O^{1+} to O^{6+}
He^{+}, He^{2+}
CO^{+}
C^{4+}
He, CO_2, O_2
pumping









Ionization (RF)

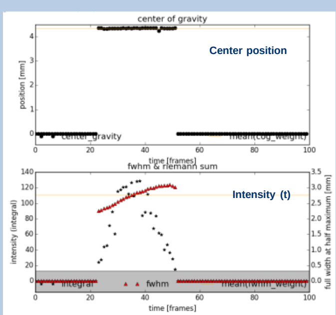
Extraction (El. field)
Separation (Mg. field)

Acceleration (RF)
Bunching (RF)
Chopping (EFE)

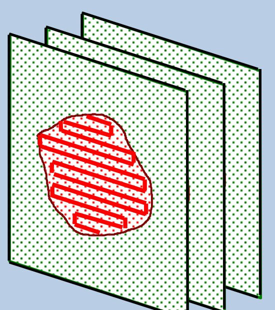
Stripping (C foil)
($C^{4+} \rightarrow C^{6+}$)

RF capture
Acceleration
Resonant (slow) extraction
Spill formation

HEBT → IRRADIATION ROOM



Spill transport



Transverse scanning
Slice "painting", E↓

- Pencil beam: 4 to 10 mm FWHM in vacuum
- Fast magnetic deflection, H and V (20 m/s)
- Scanning field size: 20 x 20 cm^2 (IR 1 to 3)
- Beam position accuracy: ± 0.5 mm

- $\leq 1\cdot10^{10}$ protons/spill; $\leq 4\cdot10^{8}$ C-ions/spill
- Energies corresponding to 3-37 cm penetration depth in human tissue
- ~ 1 minute to deliver 2 Gray in 1 L tumor volume

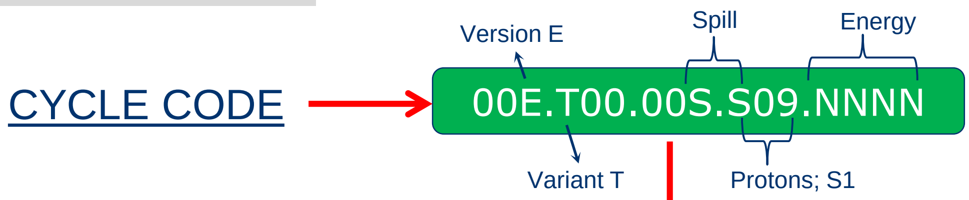
Requesting a beam

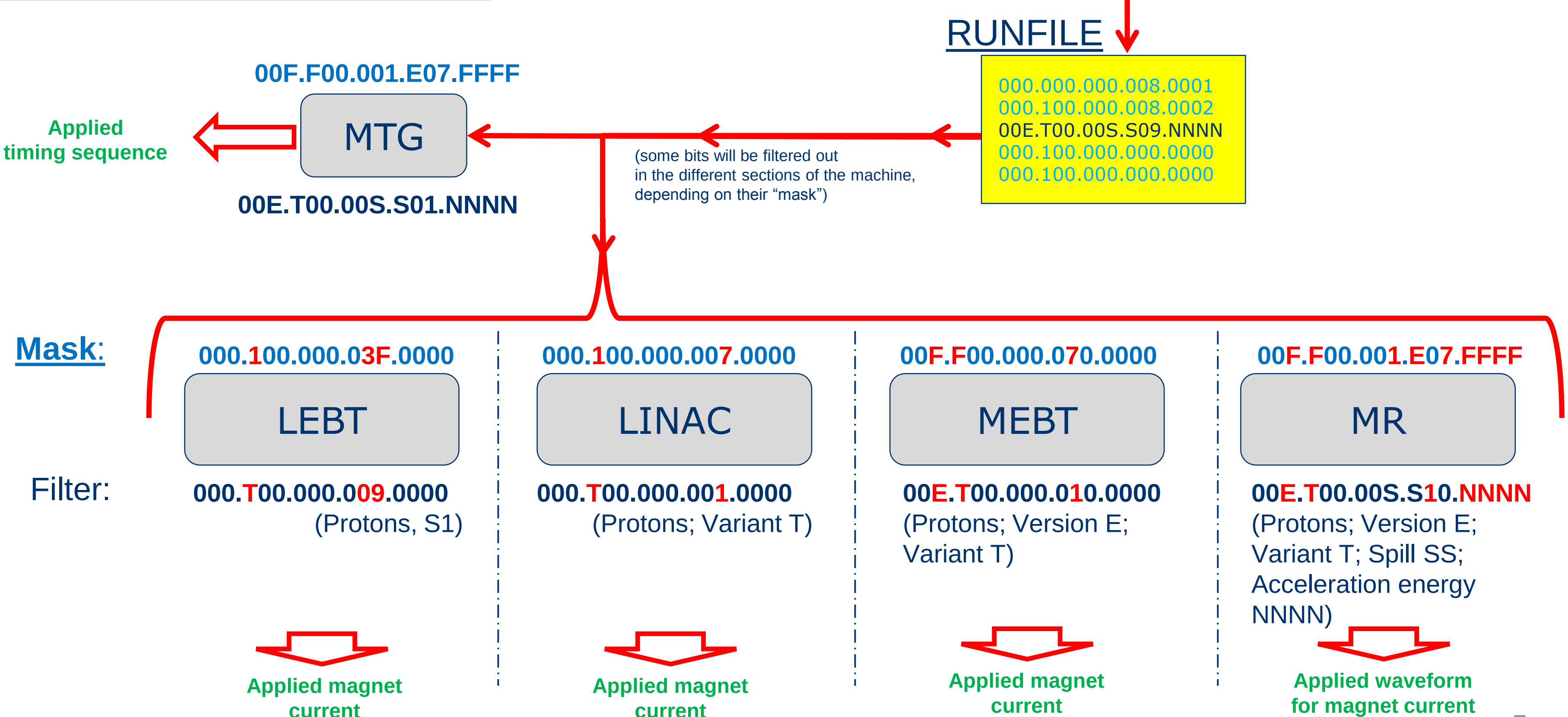
MedAustron

Treatment plan = a sequence of cycle codes

The bits of a cycle code contain information on:

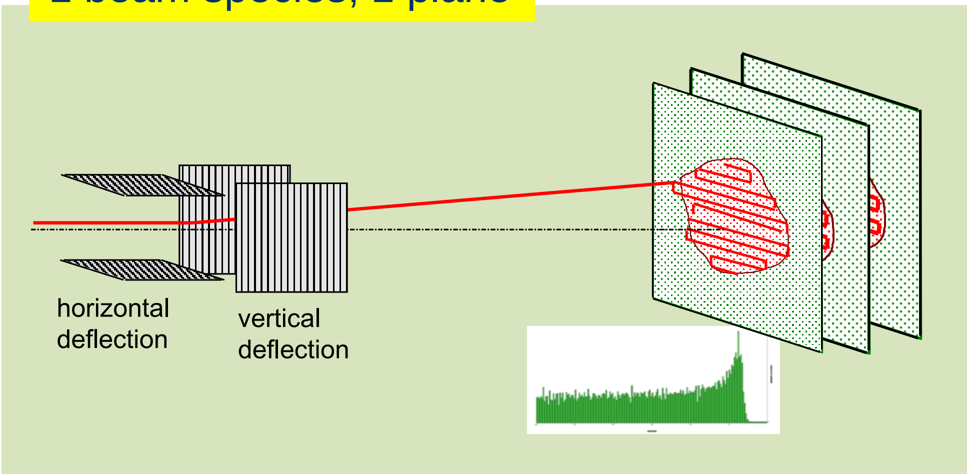
- Extraction Energy
- Spill length
- Beam size
- Irradiation room
- MEBT degrader used
- Particle type.
- Ion Source.
- Variant.
- Version.



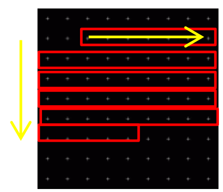


Delivering 2 beam species

1 beam species, 1 plane



- 3D matrix of intensities defined by treatment plan
- Point by point scanning of slices
- A spill can cover a full slice
- From high E to low E



1 beam species, 2 planes (H and V)

- Treatment plan with dose splitting between planes.
- Different penetration depths (=energies) for the 2 planes.
- Full scan in 1 plane, followed by full scan in 2^{nd} plane.
- Scan in 1 plane as above.
- (hysteresis of cw magnets)
- Scan in 2^{nd} plane following same strategy as above.

12C and/or 11C

- ✓ Treatment
- ✓ PET imaging

2 beam species, 1 (or 2) planes

- Treatment plan with dose splitting between species.
- Different penetration depths (=energies) for the 2 species.
- Full scan in 1 plane, followed by full scan in 2^{nd} plane.
- Scan in 1 plane as above.
- (hysteresis of cw magnets)
- Scan in 2^{nd} plane following same strategy as above.

The accelerator side: commissioning a "cycle code"

The accelerator is able to generate:

- ✓ Number of ion species: **2**
- ✓ Number of different energies: **255**
- ✓ Number of beam sizes: **4**
- ✓ Number of intensities: **4**
- ✓ Number of extraction times: **8**

- ➢ Beam combinations per beam line: **65280**
- ➢ Gantry: different angles need to be considered
- ➢ Non-clinical research: extended energy range

PARAMETERS which are NOT part of cycle code, but part of design + commissioning:

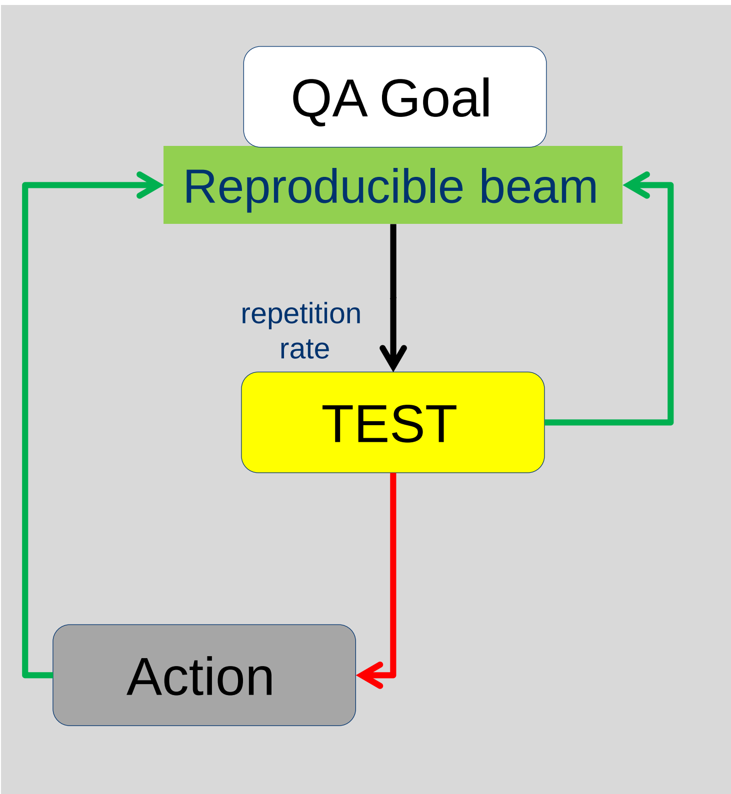
- ➢ Energy spread
- ➢ Spill quality (stability: intensity, position)
- ➢ Choices of beam optics (longitudinal and transversal)

DURATION OF A CYCLE – depends on accelerator performance:

- ➢ Injection time
- ➢ Acceleration time
- ➢ Short hysteresis time
- ➢ Hardware configuration time

Preparation and QA of a medical beam

MedAustron



Reproducible BEAM

(A) Same applied settings

(B) Reproducible machine performance

Understanding of:
- Hardware stability
- Hardware – Hardware interactions
- HW – Beam interactions
- Beam – Beam interactions
- Aging effects
- Maintenance effects
- Failure statistics

✓ **Spill formation**: defined in the synchrotron
  - Duration.
  - Intensity uniformity.
  - Position uniformity.

✓ **Spot formation**: defined in the HEBT line
  - Spot size
  - Position at isocenter

✓ Restrictions on injector: not critical
  - Most of the injected beam limitations can be corrected in the synchrotron

Question marks vs. ESR topics

MedAustron

1) How to produce the 11C with needed intensity, reproducibility and stability?
2) Where to inject the 11C along the beam path? (answer correlated to 1…)
3) PET-related questions…

1) Compact PET cyclotron → N2 target → release of 11CO2 into ion source → beam path joining 12C
2) ISOL production → mass separation and charge breeding (→ post-acceleration?) → beam path joining 12C

- ✓ **Production** and **mass separation** of $^{11}CO^{+}$ (**ESR11**)
- ✓ Development of **charge breeding** scheme required for acceleration (**ESR3**)
- ✓ Full **acceleration** and **treatment** - ^{11}C hadron therapy test and planning (**ESR9**)
- ✓ Further development of bioconjugates suitable for **imaging** and treatment of the ovarian cancer. New bifunctional fluorescent and radioactive bioligand. Tests with 11C as chelate. (**ESR15**)
- ✓ Development of multimodal **imaging** methodologies for the treatment planning. Methodology and preclinical techniques. Biological models. (**ESR12**)

TO HAVE IN MIND: The available intensity per spill is not a veto-condition.

Accelerator efficiency depends on all of the following:

- Intensity per spill
- Cycle time (acceleration time; hysteresis; re/configuration; injection of 11C?)
- Strategy for using effectively all accelerated particles.
- Dealing successfully with machine limitations at higher intensities.