Design of a PET-isotope-based hadron therapy facility

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Solid ground for Science

Abstract Landscapes

Summary

- ^{12}C treatment specifications
- Existing Carbon facilities
- Challenges for ^{11}C treatment
- Workshop methodology
- Fun

^{12}C treatment specifications

SPILLS:
0.1 to 10 seconds

ENERGIES:
C^{6+}: 120 to 400 MeV/u

- *Energies corresponding to 3-37 cm penetration depth in human tissue*
- *~1 minute to deliver 2 Gray in 1 L tumor volume*

INTENSITIES:
C^{6+}: $\leq 4 \cdot 10^8$ particles/spill
(4 intensity steps for each beam species)

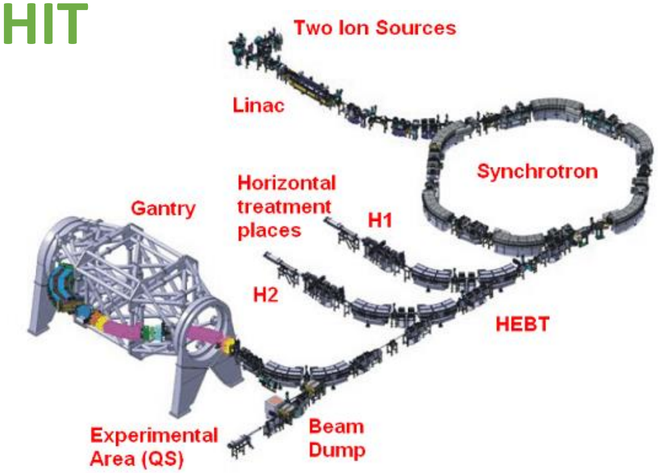
BEAM SIZES:
4 to 10mm
(4 intensity steps)

QA VERIFICATION (at irradiation room)	TOLERANCE LEVEL
Position	± 0.5mm
Size (FWHM)	MAX {±1.0mm; ±10%}
Intensity	±30 %

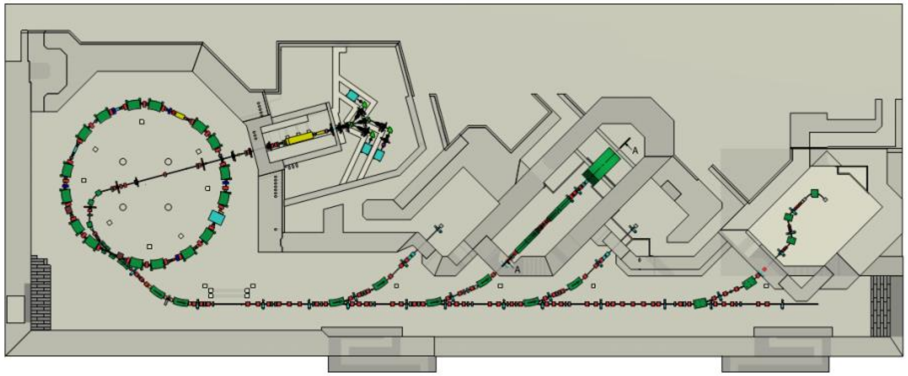
- ✓ **Spill formation**: defined in the synchrotron
  - Duration.
  - Intensity uniformity.
  - Position uniformity.
- ✓ **Spot formation**: defined in the HEBT line
  - Spot size
  - Position at isocenter
- ✓ Restrictions on injector: not critical
  - Most of the injected beam limitations can be corrected in the synchrotron

Existing Carbon facilities

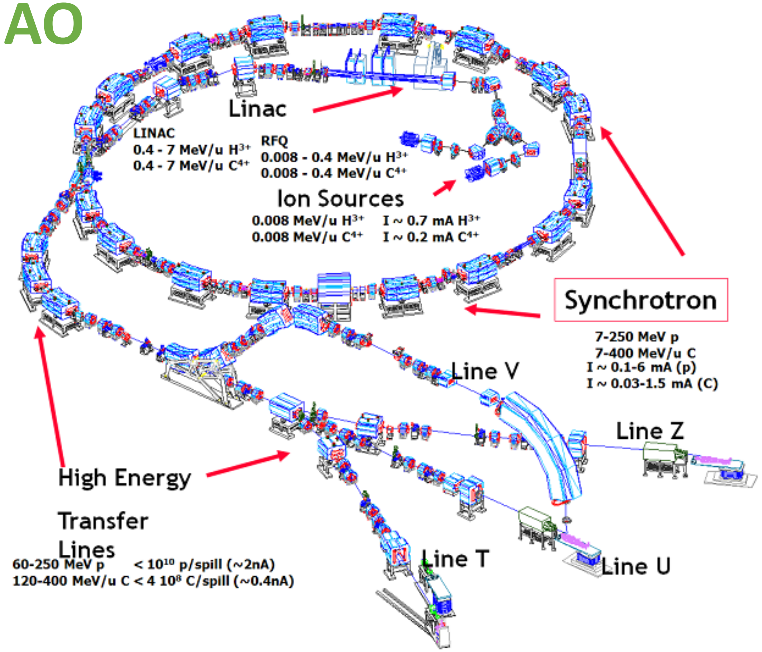
HIT



MedAustron



CNAO



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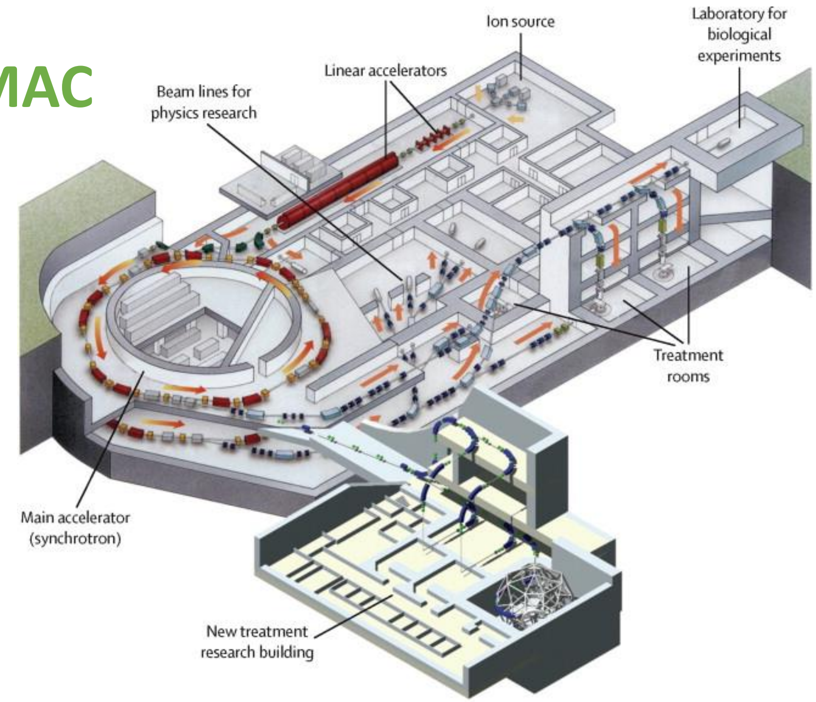
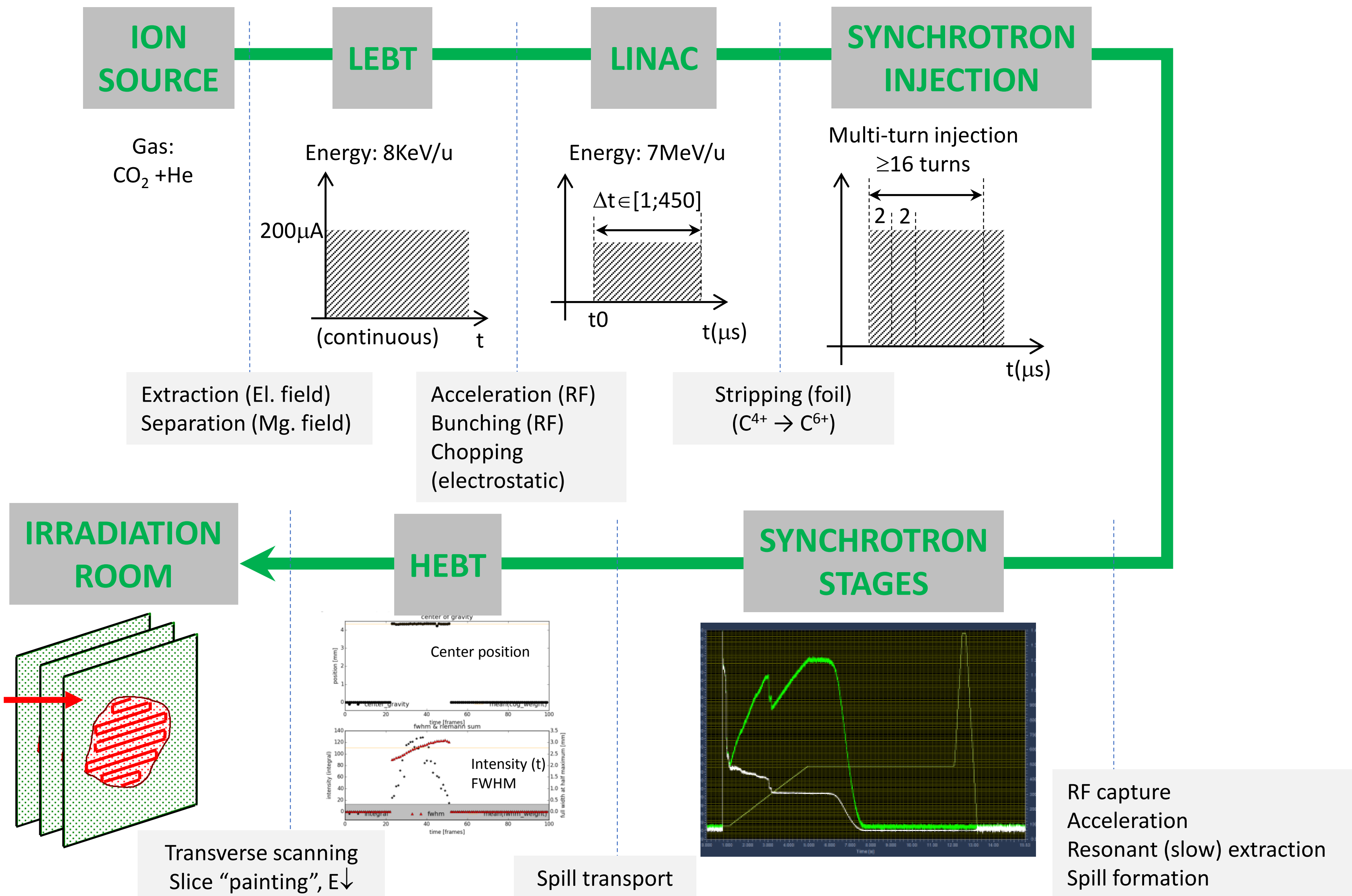


Operation scheme - MedAustron



Challenges for ^{11}C treatment

Design recipe:

- ✓ Production
- ✓ Accumulation
- ✓ Acceleration
- ✓ Delivery

Challenges for ^{11}C

- ➢ PRODUCTION
- ➢ ACCUMULATION

Options for PRODUCTION

- ➢ Batch releases ^{11}C molecule to ion source
- ➢ ISOL production
- ➢ In-flight production
  - Fragmentation (e.g. ^{12}C beam on ^{7}Be target)
  - Fusion-evaporation (low beam energy)

Options for ACCUMULATION

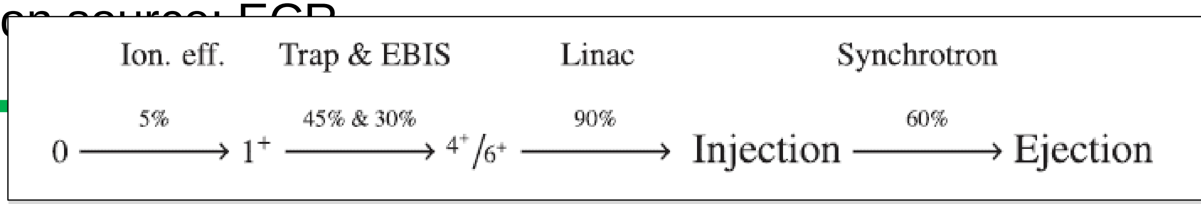
- ➢ Batch containing supply atoms
- ➢ 1+ ions accumulated in a trap
- ➢ 6+ ions accumulated in a ring

Design baseline

A

- Use of compact PET cyclotron
- 10–20 MeV protons
- 30 GBq batches can be produced every 30 min
- Reaction: $^{14}N(p,\alpha)^{11}C$ in high pressure N_2 targets
- Ion source: ECR

$3 \cdot 10^{10}$ $^{11}CO_2/s$



$1 \cdot 10^{8}$ $^{11}CO_2/s$

Validation location: existing ^{12}C therapy facility

B

- Use of ISOL production scheme
- Spallation reactions $^{19}F(p,X)^{11}C$ and $^{23}Na(p,X)^{11}C$
- Use commercial cyclotron: 70 MeV, 1.2 mA beam
- Target: molten fluoride, made of a NaF:LiF eutectic
- Ion s

$4 \cdot 10^{11}$ $^{11}CO_2/s$

5% ionization efficiency,
45% for transport and trapping,
16.2% for injection into the synchrotron

$1.5 \cdot 10^{8}$ $^{11}CO_2/s$

Validation location: existing ISOL facility

R.S. Augusto et al. / Nuclear Instruments and Methods in Physics Research B 376 (2016) 374–378

Information structure

"DOMINO model" for all components

Acceptance	Performance	Output
Min/max values • Charge state • Intensity • Time • Energy	Efficiency Time structure Operation steps (Operation modes) Limitations Risks	• Charge state • Intensity • Time • Energy

SPARK: We have experts among us!
GAS: The "stupid questions" are welcome!

First line of experts

Simon → Production and mass separation of $^{11}CO^+$
Annie → Molecular breakup in RFQ cooler
Johanna → Charge breeding scheme
KyungDon → Treatment planning for ^{11}C

Method	Cyclotron		Target	Reaction	In target production	Trap charging time	Injector	Injector repetition rate
	E [MeV]	I[μA]			[pps]	(ms)	[p/injection cycle]	[Hz]
PET production (production batch)	22	150	N_2 ($\leqslant$1 atm)	$^{14}N(p,\alpha)^{11}C$	3×10^{10}	741	1.5×10^8	1.3
REX-ISOLDE (ISOL)	70	1200	NaF:LiF eutectic	$^{19}F(p,2\alpha n)^{11}C$	4×10^{11}	56	1.5×10^8	18

Advanced considerations

Quality assurance of the design:

- Reliability of the used numbers;
- Constraints related to safety, vacuum, performance stability, measurement precision, operation
- Resource redundancy

Quality assurance of the performance:

- Important points to monitor

Stability and reproducibility

The accelerator is able to generate:

- ✓ Number of different energies: **255**
- ✓ Number of beam sizes: **4**
- ✓ Number of intensities: **4**
- ✓ Number of extraction times: **8**
- Beam combinations per beam line: **32640**

Are we happy with the ^{11}C?...

And with the baseline?