Jerome: "As our brain was already irradiated by accordion music, I propose **ACCORDION** as the acronym, which obviously means ACCeleratOR for Delivering IONs"
We choose a country ... ... of considerable size (e.g. Spain ca. 50 million inhabitants)

- currently 2% inhabitants treated with X-rays
- 12% of those would be better treated with protons
- 3% of those would be better with Carbon-ions

→ $50000000 \times 0.02 \times 0.15 = 15000$ potential HT patients

capacity/treatment room:
- 345 patients/y with protons,
- 690 patients/y with Carbon-ions

→ more than enough patients for whom HT is the better option!

If proton therapy would cost the same as X-ray therapy, 90% of patients would be treated with protons

Context & Business Case

We choose a country …

- … part of the industrialised countries:

  → Money, even for a big facility, is in principle available.
In these circumstances, we want to be ambitious!

→ Go for a combined “heavy” ion facility …

- … which delivers both \( p \) and \( C^{6+} \) beams

  This brings the to-date cutting edge technique to our country.

- … has got multiple irradiation rooms

  optimise efficiency of operation, more treatments per year
Context & Business Case

Clinical goal is most important → use established technologies

Several C/p facilities in operation (HIMAC, HIT, CNAO, Shanghai, ... ) or in commissioning (MedAustron, MIT)
Context & Business Case

Cost estimate

→ 1 patient treated with HT costs ~ 20-25 k€ (~40 M€ for 1810 patient/y*)

→ 1 patient treated with X-rays costs ~ 15 k€: short-term & very long-term side effects (2ndary cancers, irreversible organ failure)

→ facility of 200 M€ investment & yearly operation cost of ~35M€ (2M€ power, 20M€ salaries, maintenance cost 10M€, misc 10%)

Be ready to finance the construction and operation of the facility from public funds.

Time estimate

→ 5 years from approval until first clinical operations

→ operation for at least 20 years

*Capability based on Amaldi et al, (2010), assuming 1 p patient every 3 C-ion patients
Additional benefits

- As our country does not have (any) hadrontherapy centre yet, a hadrontherapy facility is an opportunity for capacity building for future high-tech industry.

- **There are also no other p or ion accelerators** (reaching hundreds of MeV/u) dedicated to other fields of research.

- Co-operation with **other academic fields** outside of medicine creates synergy effects, and comes “almost for free” for a high rigidity accelerator complex.

  *University research opportunities in Biology, Physics, Dosimetry*
  *Training of accelerator physicists and engineers...*
Technical Description

clinical requirements:

- 250 MeV/u $p$  $(B\rho = 2.4 \text{Tm}) \ 10^{10} / \text{s}$
- 400 MeV/u $C^{6+}$ $(B\rho = 6.4 \text{Tm}) \ 10^8-10^9 / \text{s}$

possibly even higher energy for research purposes?

$\rightarrow$ Even stronger magnets and/or larger facility

Higher energetic protons come „for free“ ...
Technical Description

Sync

Linac

IS

Extract. + Delivery

Treatment / Experiment

20 m

20 m
Ion Source: Supernanogan

Choice for established source:

Electron Cyclotron Resonance (ECR) Ion Source

Has been proven in a number of installations:
  • MedAustron ($H_3^{1+}, C^{4+}$)
  • HIMAC
  • CNAO
  • HIT

![Image of ion source](image)

| Beam intensity (within emittance): | $C^{4+}$ | 200 μA | 500 μA |
| Emittance (95%)                  |          | 180 π mm mrad |
| IS-HT, energy spread            |          | 30 kV, < 1% |
| 24h Beam Stability (peak to peak) |          | < 4% |
| Intensity and Emittance          |          | < 4% |
| Reproducibility of all beam parameters after restart before tuning | 5% |
| Maintenance interval Duration (1 ion source) | > 12 month | < 2 weeks |
| Synchrotron injection            |          | < 100 μs |

- permanent magnet
- Frequency 14.25-14.75 GHz
- Operation mode: continuous wave
- Extraction voltage: 24 kV@C^{4+}

[Source: Ion Sources for MedAustron, CERN-BE-Note-2010-001]
Accelerator

Linear accelerator
(8 keV/u \rightarrow 7 \text{ MeV/u})

RFQ (8 keV/u \rightarrow 0.4 \text{ MeV/u})
takes cw-beam from source
bunches and accelerates simultaneously

IH Structure (0.4 \text{ MeV/u} \rightarrow 7 \text{ MeV/u})
Needs pre-bunched beam
Accelerating field between drift tubes
Rigidity $B\rho = p/q$

- min: 0.38 Tm (p at injection)
- max: 6.4 Tm (for C at 400 MeV/u)

Normal conducting magnets: $B \sim 1 - 1.5$ T

- $\rho > 6$ m
- + space for quads, rf, injection, extraction ...
- $\rightarrow$ diameter of ring $\sim 20$ m
Synchrotron cycle

- Inject every few seconds

Accelerator

Beam direction

Circulating beam

Injection beamline

B-field

Septum magnet

Extracted beam
Treatment Rooms

3 treatment rooms

- horizontal + vertical beamline, horizontal beamline, 1 proton gantry (established technology)
- optimize patient workflow: 3 set-up rooms

1 NCR general purpose room w/ v+h beamline (60MeV from below)

Radiobiology, dosimetry R&D, radiation hardness studies, nuclear research
other ions be provided with ion source upgrade (e.g. Li)
Treatment Rooms

Robotic positioning coach

7 DoF (incl pitch & roll & longitudinal)

Interlock system (dose control, beam off)
Quality Assurance water phantom

Imaging/Control in same room
CT scanner around couch (alignment!)
... The cherry on the cake

Use the in-between-injection time for isotope production or other NCR activities?
Investing in this p/C facility will bring our Country to the forefront of contemporary HealthCare

And build the capacity for further high-tech in Spain!

Thank you!
Possible Upgrade: Helium gantry

Just some estimations:

- At fixed energy per nucleon, alpha particles and protons have the same range
- At a given energy per nucleon, \( \text{Brho}(\text{He}) \sim 2\text{Brho}(p) \)
- The max \( \text{Brho} \) of a gantry for protons is \( \sim 2.5\text{Tm} \).
  Assuming a conventional 90° magnet with \( \text{Bmax}=1.5 \text{T} \) will have a length \( \sim 2.81 \text{ m} \)
- \( \text{He}4 \) with a \( \text{Brho} \) of 2.5\( \text{Tm} \) will stop, approx., after 4 cm in water (unuseful)
- \( \text{He}4 \) with a range of \( \sim 10(8) \text{ cm} \) in water has a \( \text{Brho} \) of \( \sim 3.25(3.02) \text{Tm} \). PEADIATRIC APPLICATIONS?
  This would imply that a conventional 90° magnet with \( \text{Bmax}=1.5 \text{T} \) will have a length = 3.66(3.0) m, i.e. 30(20)% longer than 2.81 for 250 MeV protons
- Increasing the magnetic field a little bit* (superferric magnet?) or considering a bit longer-larger-heavier magnets, we could treat pediatric tumours with a helium gantry. Could it be an idea?

With a field of 1.8 T, the same dipole would be 3.05(2.54) m
Matching section: Dispersion is closed by bending dipoles

Phase shifter and stepper

Phase shifter and stepper is a set of quads. Playing with k's it adjusts vertical beta function and orizes phase at whatever (orientation of the bar of charge) to have the desired FWHM

Matching section: Closd dispersion bump

Rotator: Match fixed and rotating part.
2 NCR: 1 H + 1 V (for radiobiology)
1) Is a 15 MeV/u linac possible as injector? Would this energy enough for a radiopharmacy? We should have made some calculus...

2) Use conventional 7 MeV/u linac as injector in another linac for radiopharmacy in the range of few tens of MeV

3) Other?

Medium/high energy room

Move a bit back to include a deflector to send the medium energy beam into another room
Possible Daily Schedule

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Approx. 2000 hours/y dedicated to R&D

4th June 2015

CERN School for Medical Accelerators