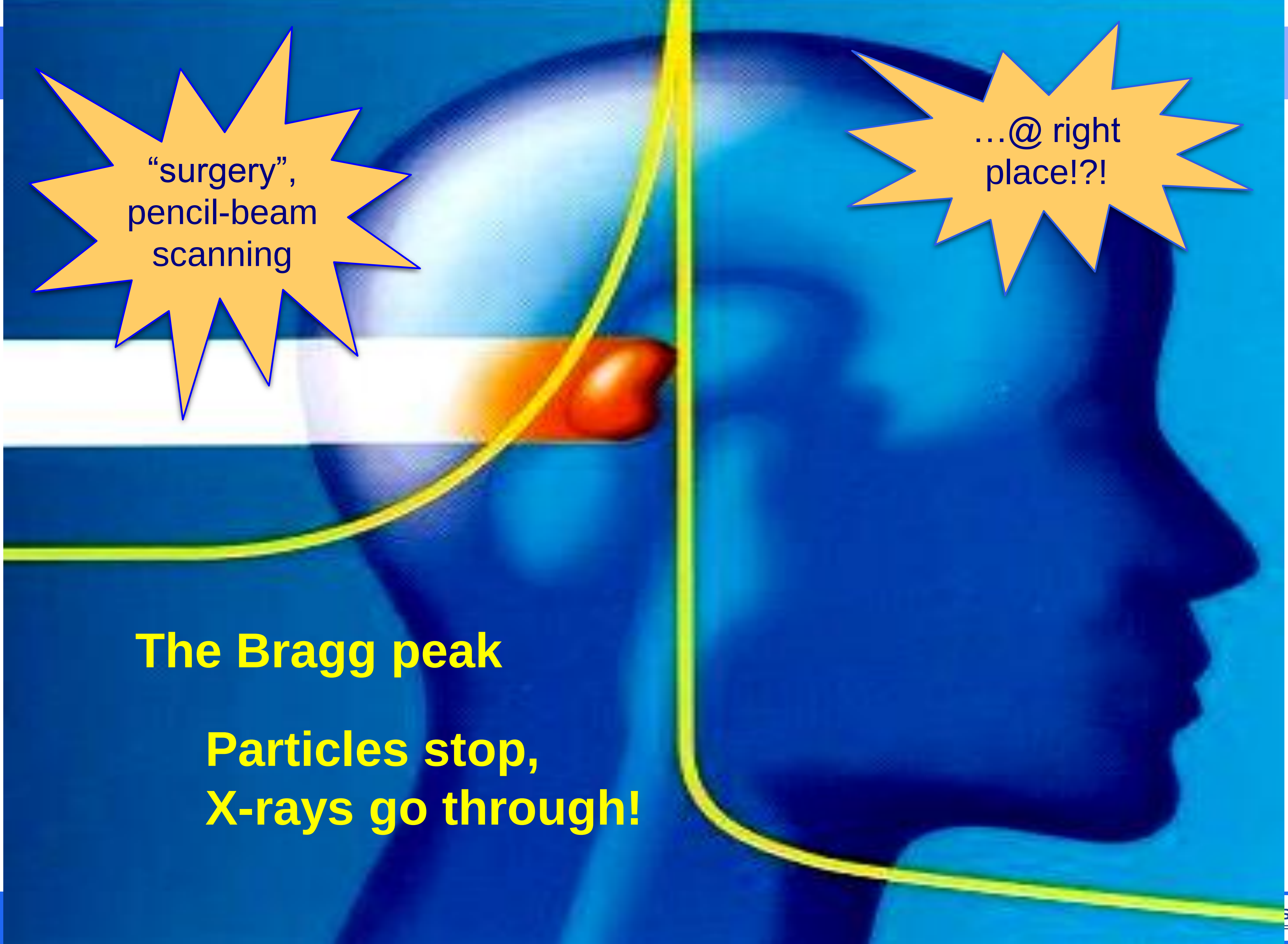
Radiotherapie et accelerateurs de particules

Elena Benedetto, Tera-Care Association

Particle Therapy MasterClass,

15th Mar 2024, CERN


"surgery", pencil-beam scanning
…@ right place!?!
The Bragg peak
Particles stop,
X-rays go through!

Proton (hadron) radiation therapy

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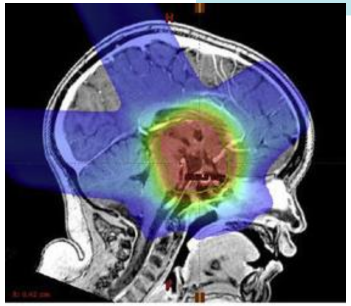
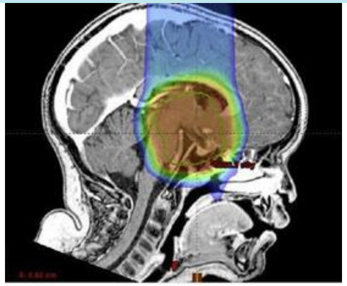
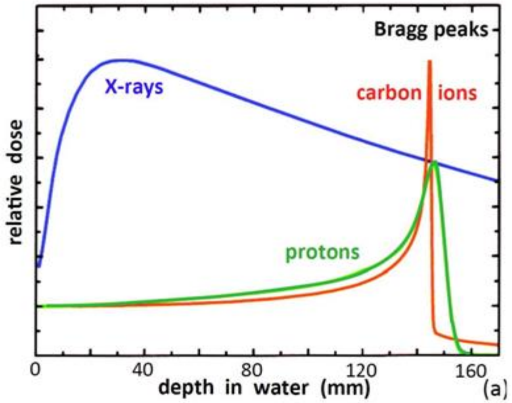


photons IMRT

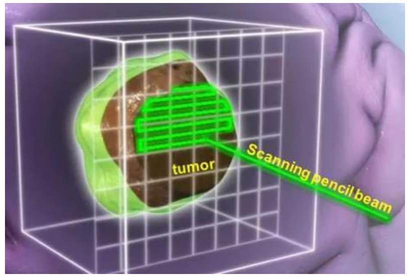


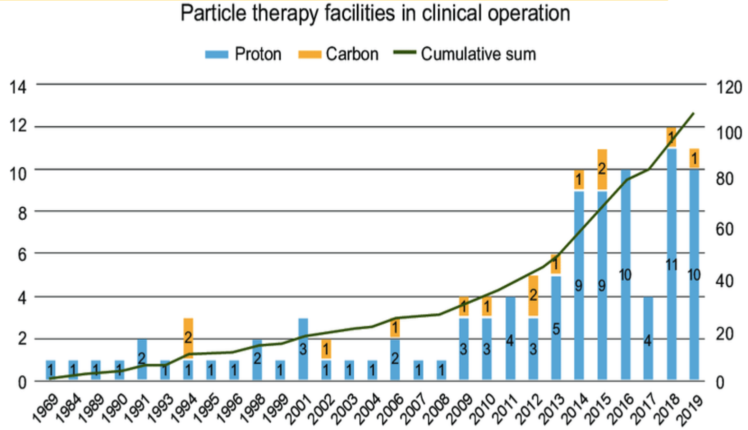
protons

Bragg Peak: hadrons deposit energy @ specific depth, depending on the beam energy



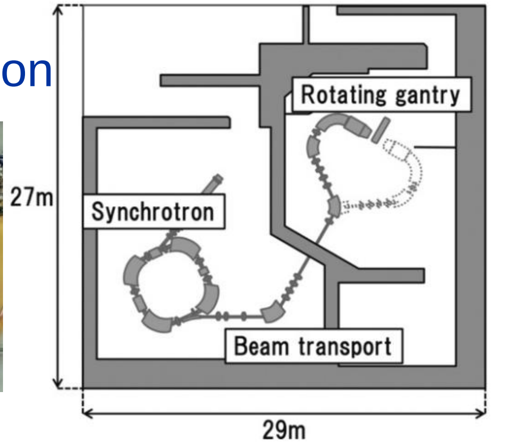
3D beam scanning



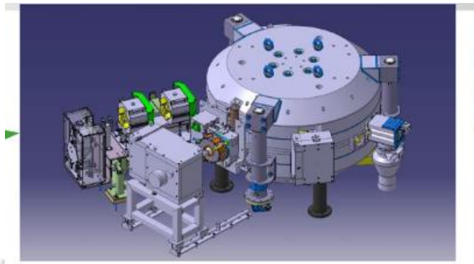


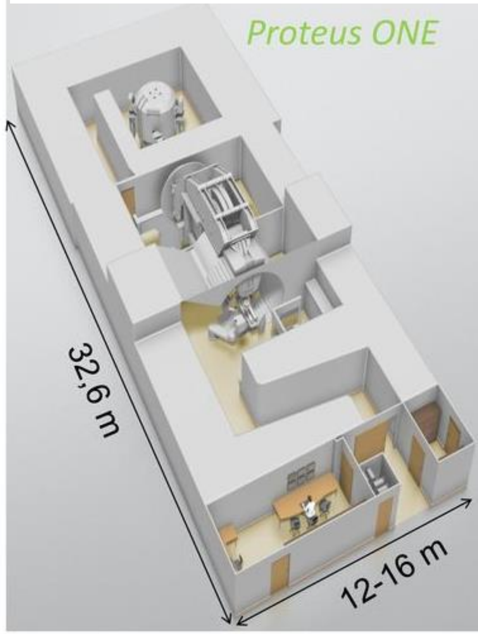
110 particle - proton therapy facilities,
30 in Europe (Vs. 14’000 X-ray facilities)

HITACHI Synchrotron

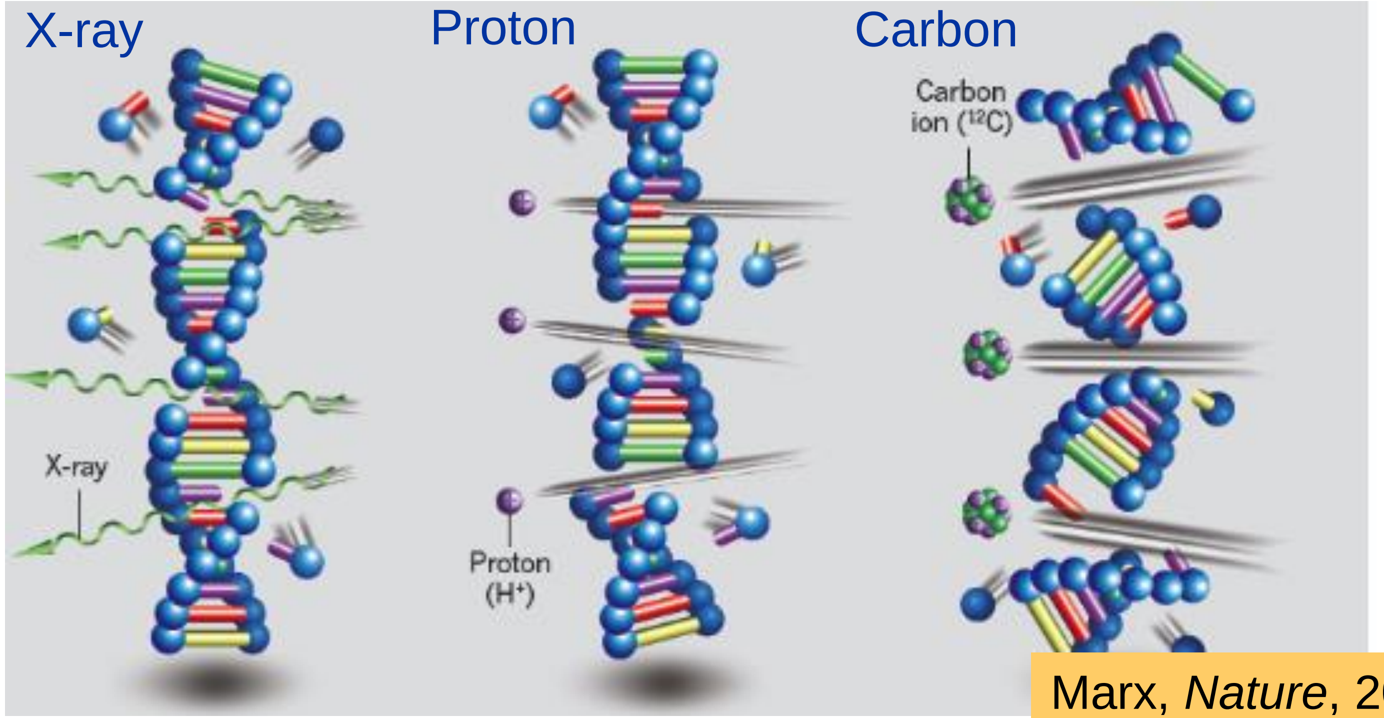


IBA SynchroCyclotron





Why Carbon ions?

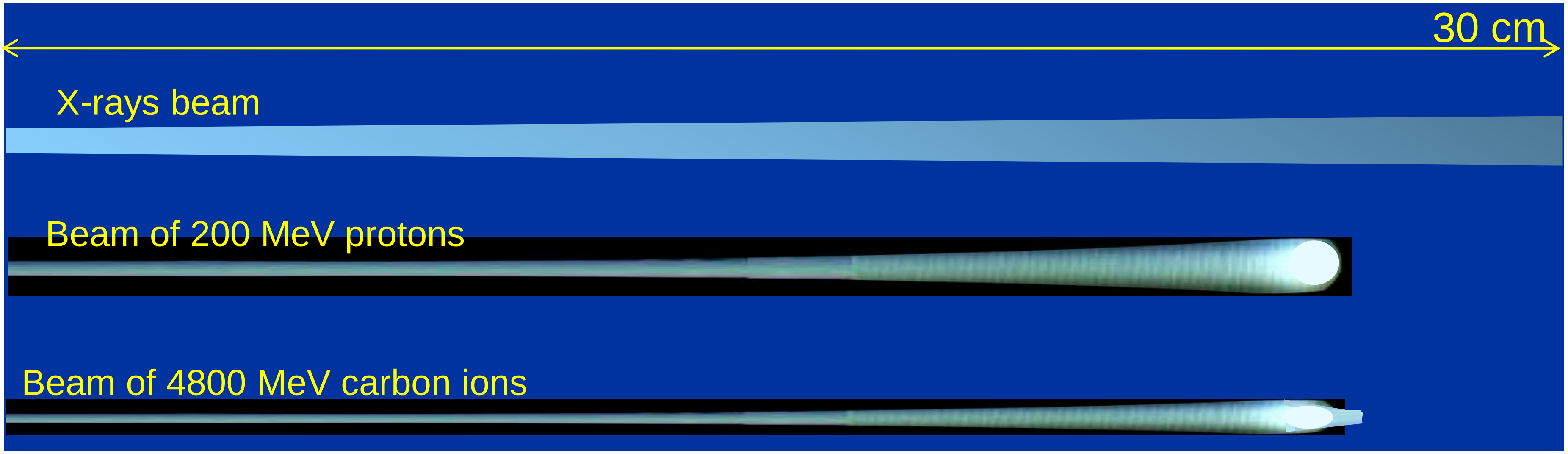


Marx, *Nature*, 2014

Single-strand breaks (easy to repair) vs. double-strand breaks (not reparable)

- ✓ 3x more damage (RBE)
- ✓ also in oxygen-depleted “radioresistant” tumours

Which particle? Which energy?



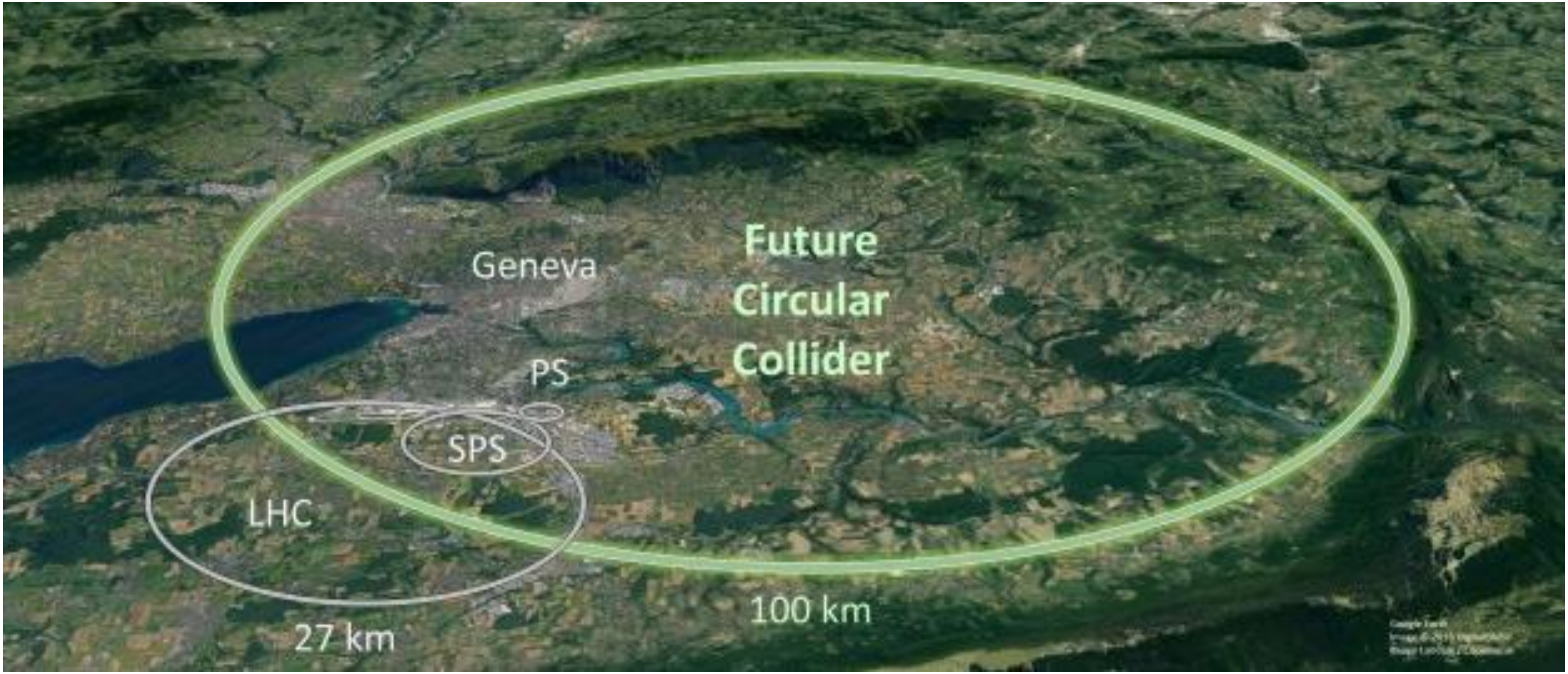
Need range: 3 mm to 300 mm in water-equivalent

Protons: 60 - 250 MeV

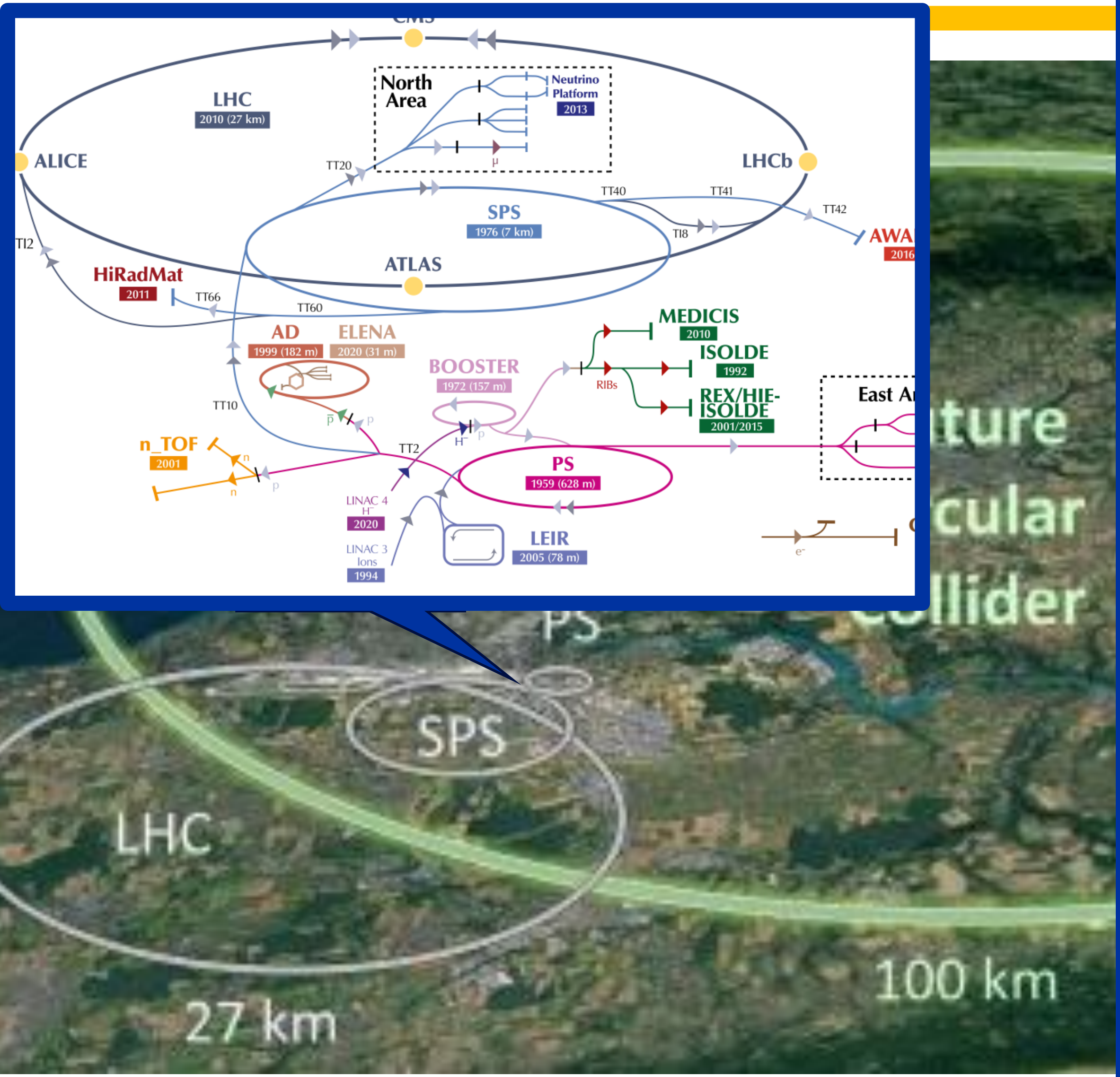
Carbon: 100 – 430 MeV/u

Beam "rigidity" ~2.7x

@ CERN



@ CERN



Next Ion Medical Machine Study (NIMMS)

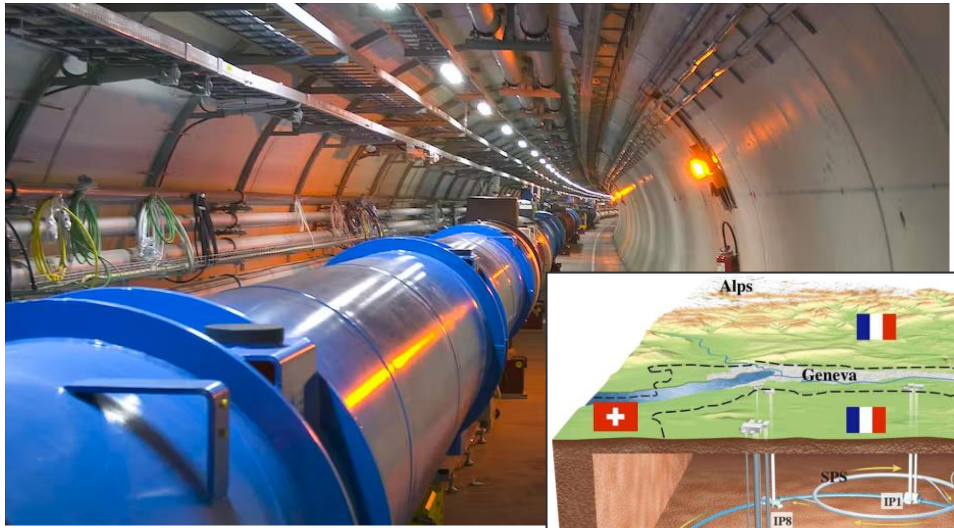
PIMMS: collaboration CERN, TERA, MedAustron, TDR in 2000

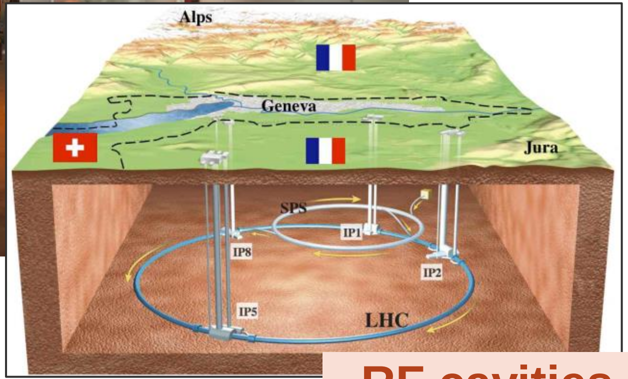
- C-ion ring, 75 m circumference

NIMMS: collaboration CERN, Tera-Care, SEEIIST, Riga U., et al., started 2018

- Higher (x 20) beam intensity stored:
  for flexible extraction (and FLASH)
- Reduce dimensions, weight (and cost)
  ~30 m length

Synchrotrons





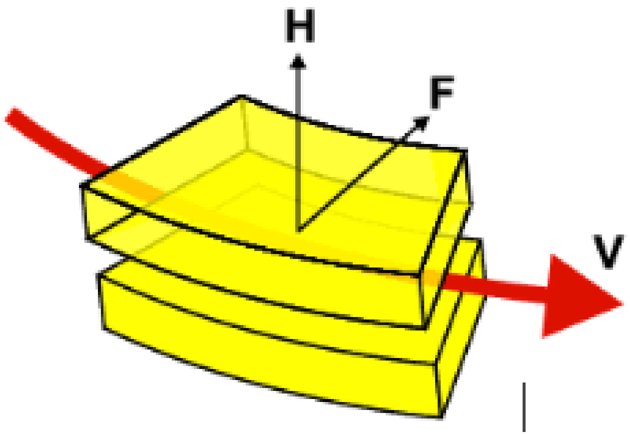
LHC,
circumference 27 km

Hitachi p-therapy , < 27 m

RF cavities to accelerate the beam (~1billion turns)
Dipole magnets to bend
Quadrupole magnets to focus (e.g. lenses)
Special magnets for beam dynamics
Injection/Extraction systems
Beam monitors, power supplies, controls, vacuum…
Safety, reliability, reproducibility,…

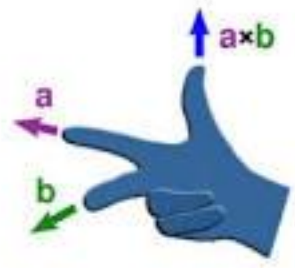
Medical environment
Cheap, robust, easy to operate
No 24/7 experts availability

Dipole Magnets and Beam rigidity



Lorentz Force

$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$

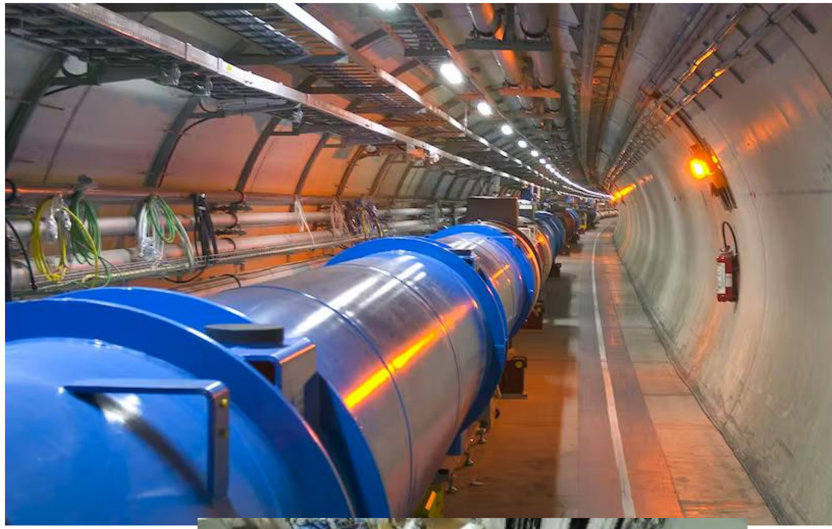


Centrifugal force:

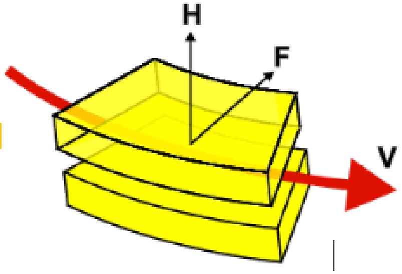
$F = m\,v^2 / r$

Beam "rigidity" $B\rho$

= how difficult it is to bend



Dipole Magnets & Beam rigidity

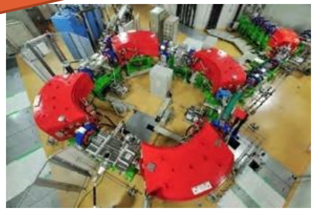


Range: 3mm to 300 mm (Bragg Peak)

- Protons: 60 - 220 MeV (max. $B\rho$ = 2.4 Tm)
- Carbon: 100 - 400 MeV/u (max. $B\rho$ = 6.3 Tm)
- Helium: 60 - 220 MeV (max. $B\rho$ = 4.5 Tm)

$B\rho$ = beam rigidity, how difficult it is to bend

Protons



HITACHI Synchrotron
~6 m size

Carbon ions

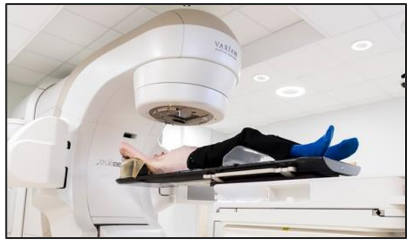
CNAO Synchrotron
25 m diameter

Size (cost!) matters…

HIT carbon
gantry

(600 tons)

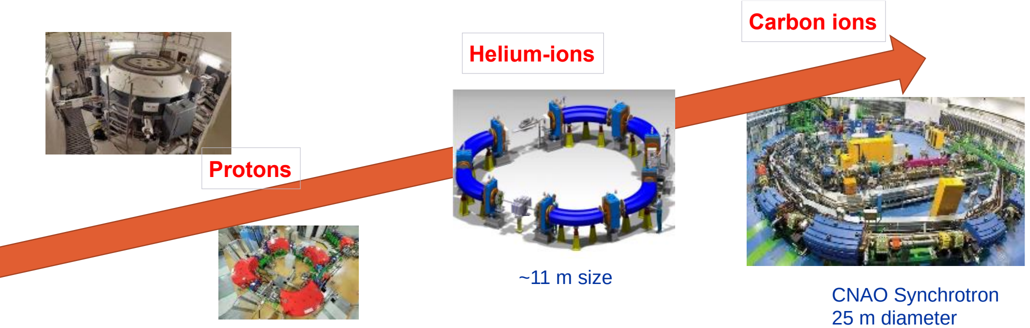
IBA proton gantry



Varian X-ray linac

Reduce size, cost, complexity!

“Light ions”



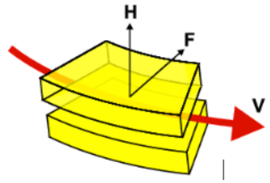
~11 m size

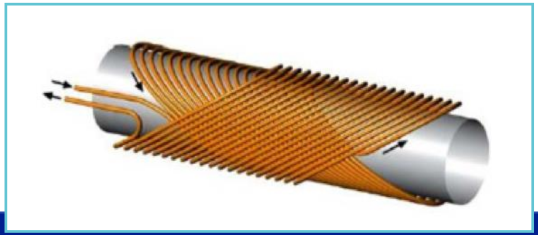
CNAO Synchrotron
25 m diameter

HITACHI Synchrotron
~6 m size

Superconductivity

$B\rho$

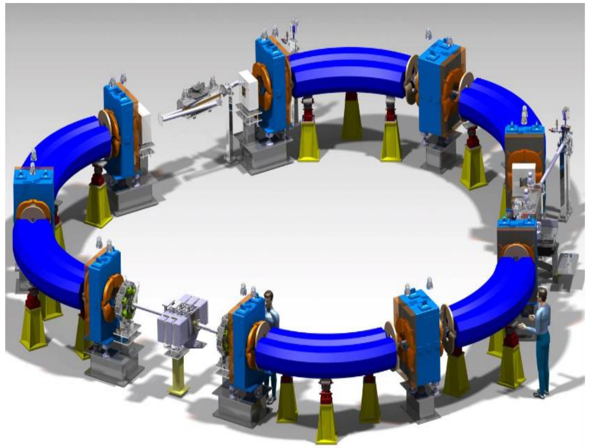


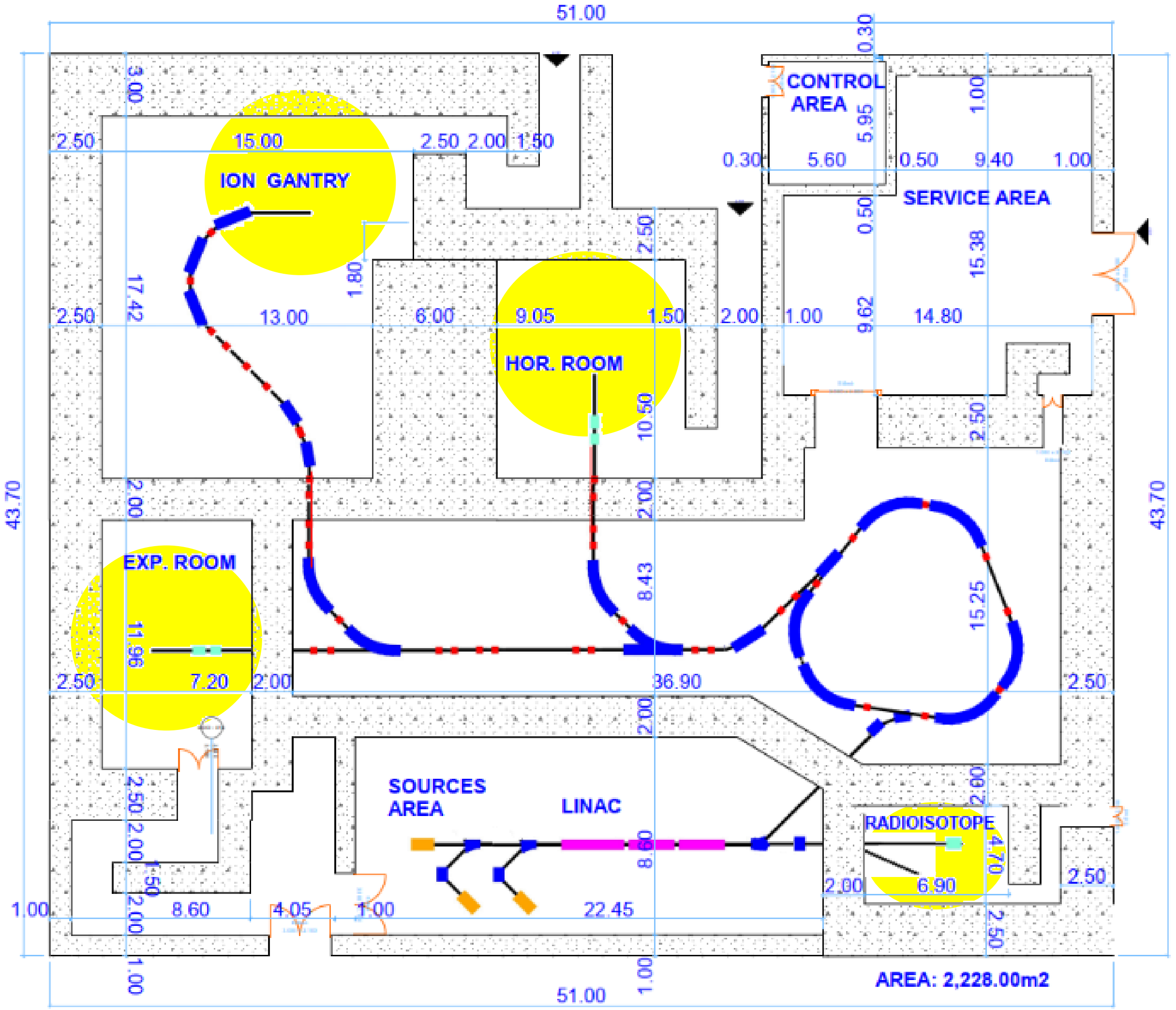


An example: Helium-theraphy synchrotron

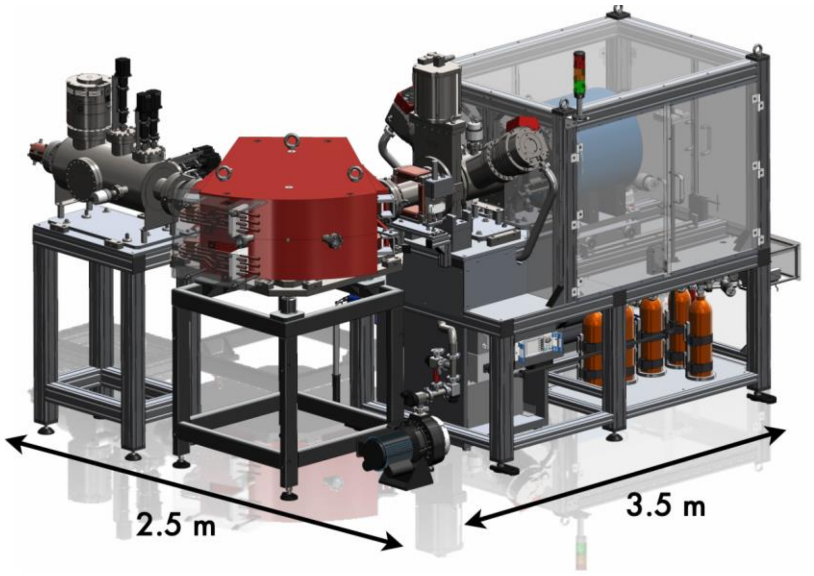
Layout by D.Kaprinis, architect

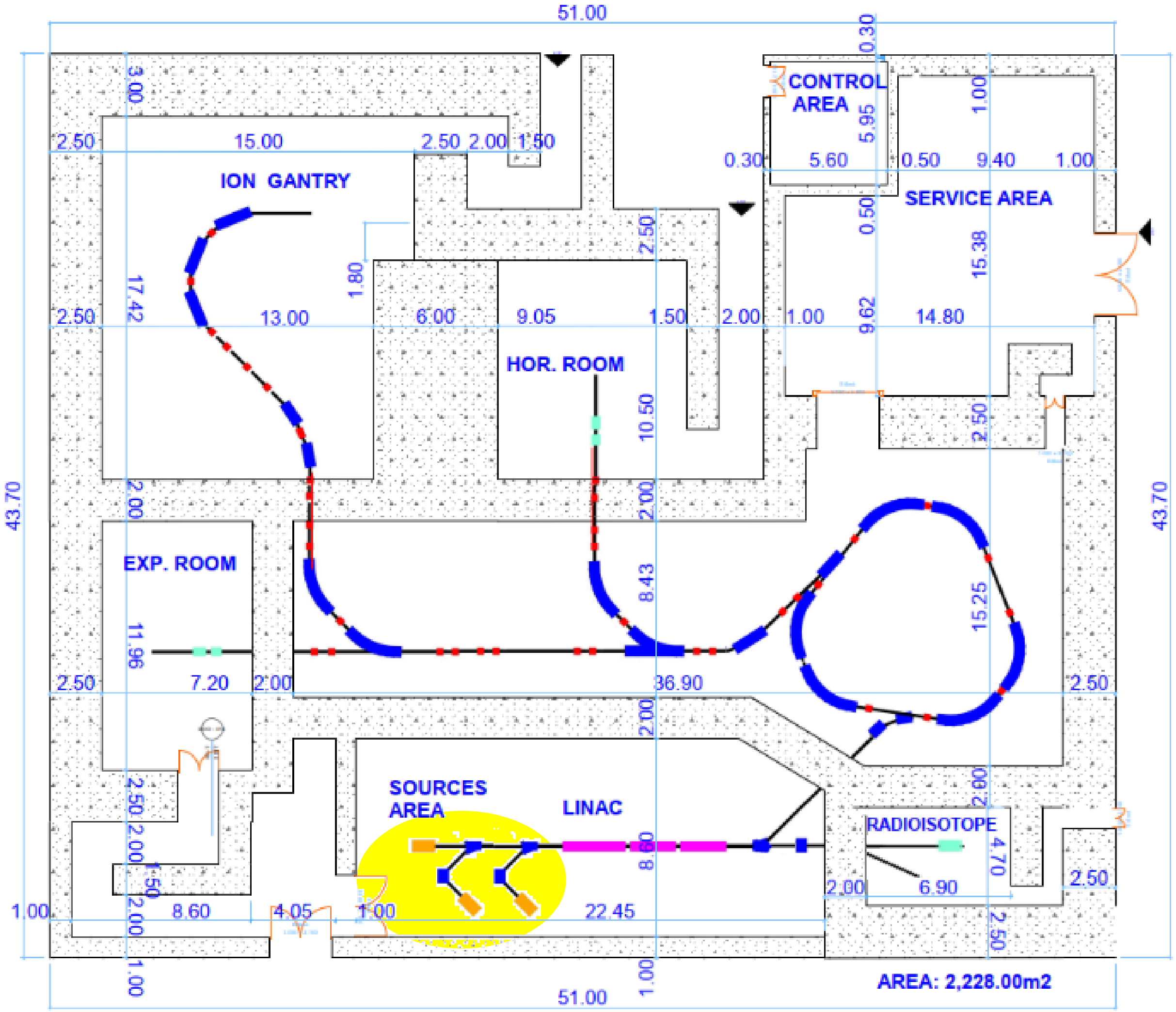
- Two beamlines for treatment, one for research.
- Rotating superconducting gantry (HITRIplus /SIG collaborations).
- Linac for parallel radioisotope production (211At for targeted alpha therapy)
- Surface ~2,200 m2



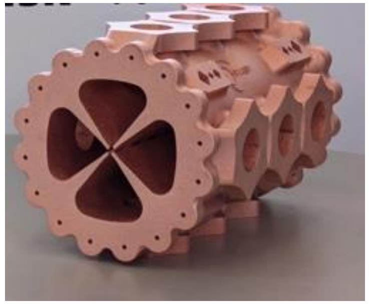


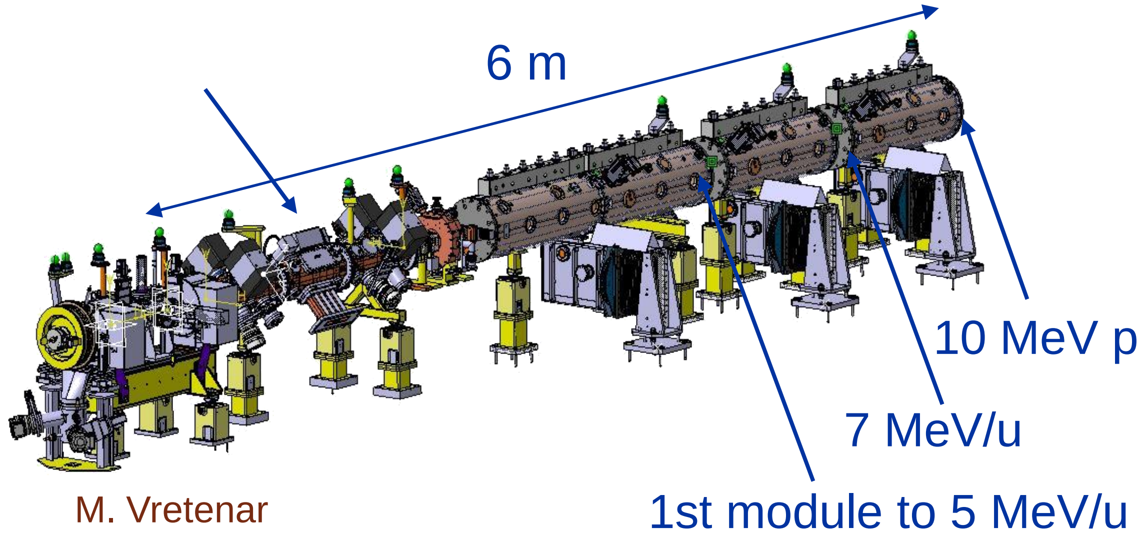
Sources


2.5 m
3.5 m

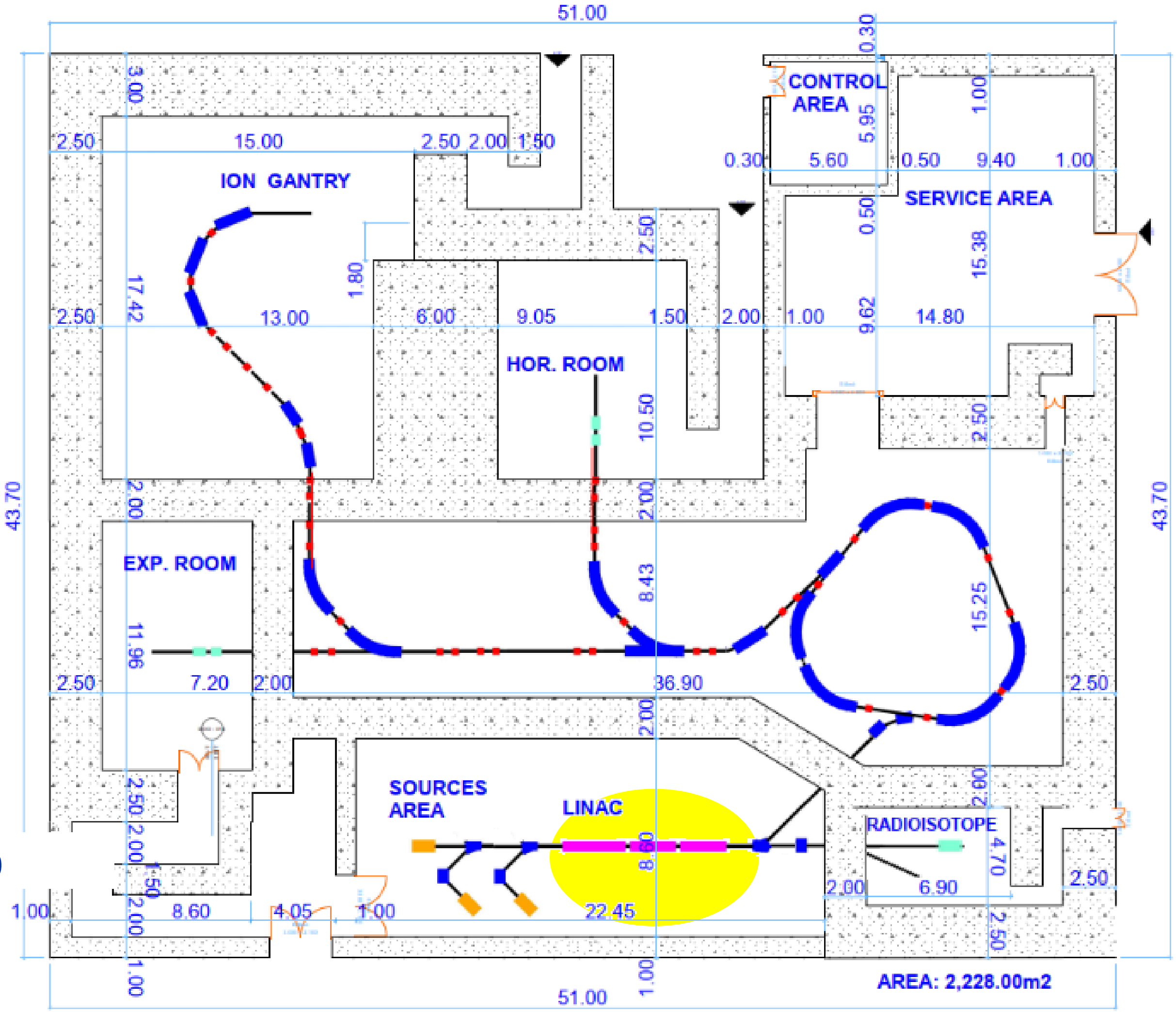

51.00
43.70
CONTROL AREA
ION GANTRY
SERVICE AREA
HOR. ROOM
EXP. ROOM
SOURCES AREA
LINAC
RADIOISOTOPE
AREA: 2,228.00m2

Linac injector

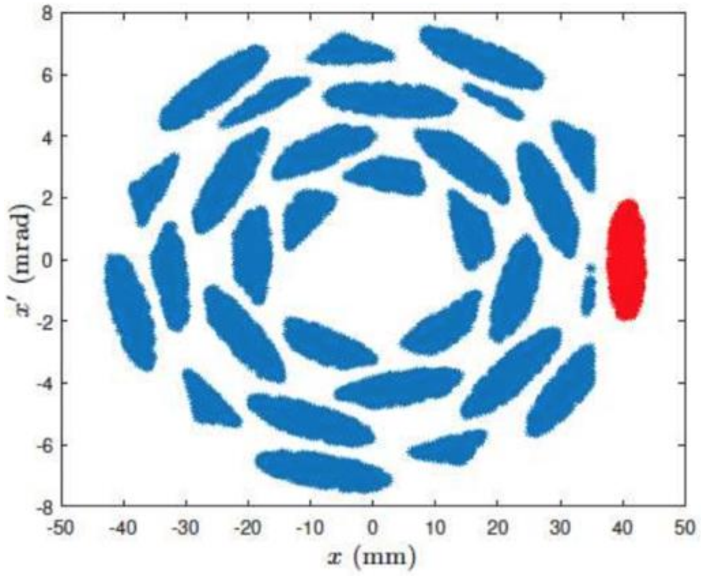


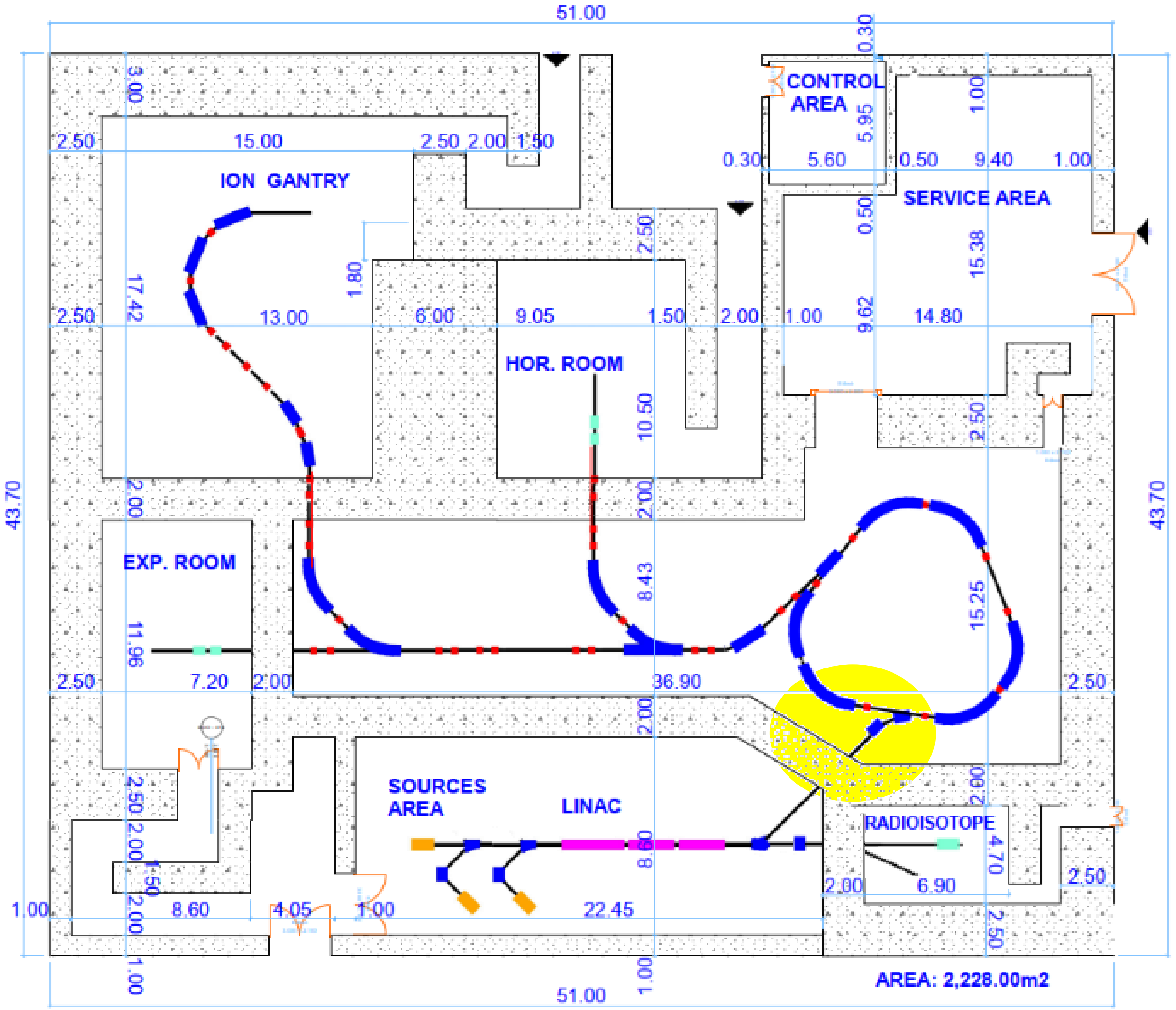


M. Vretenar



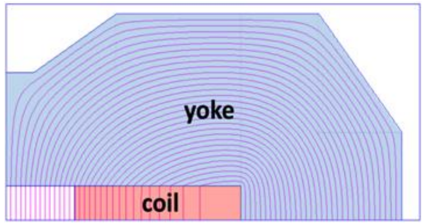
Injection in the synchrotron





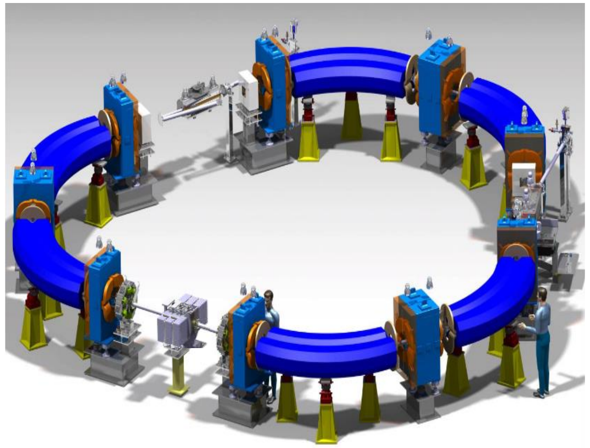
Synchrotron: magnets and optics

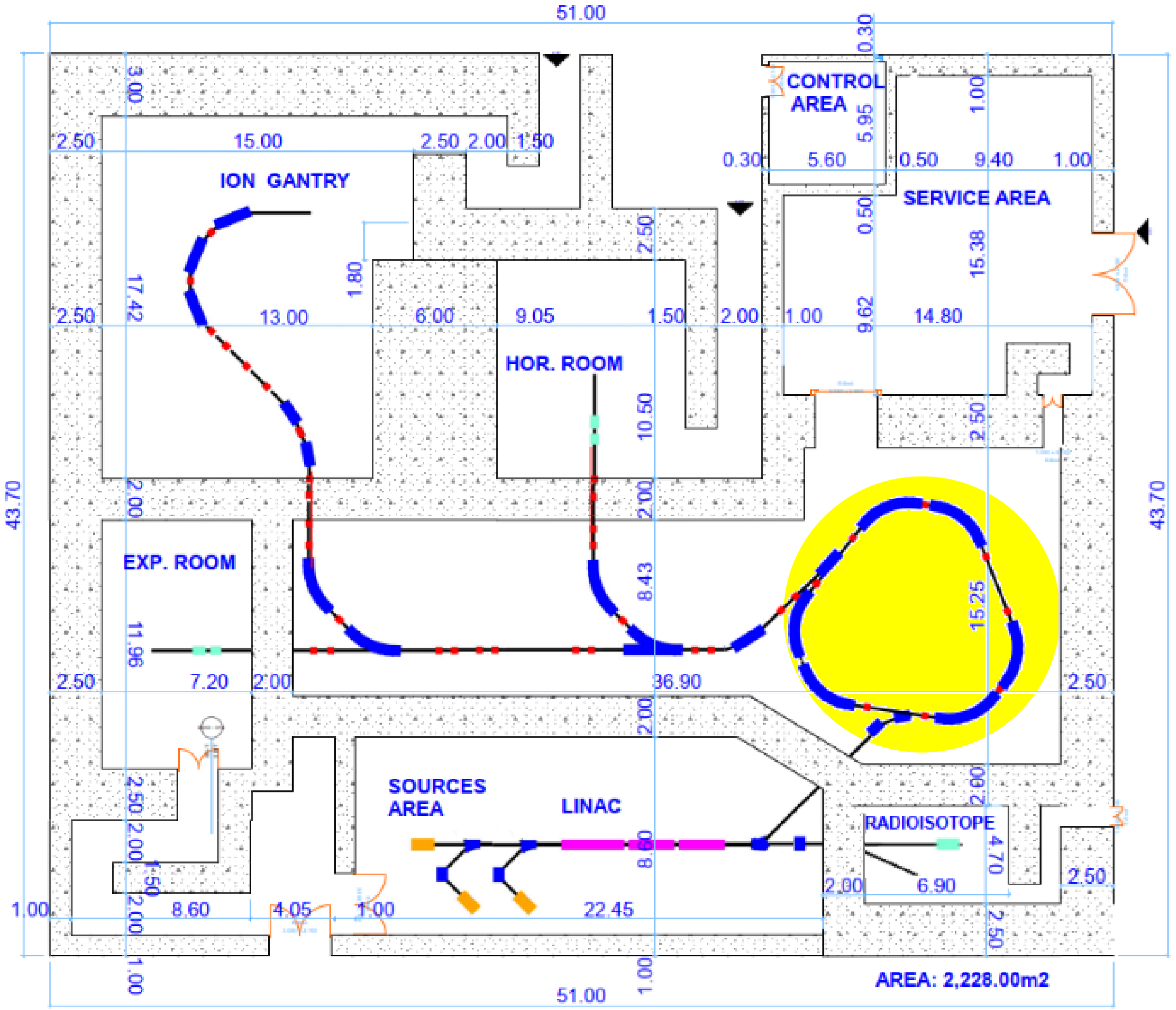
- Dipole field of 1.65 T with window-frame magnets



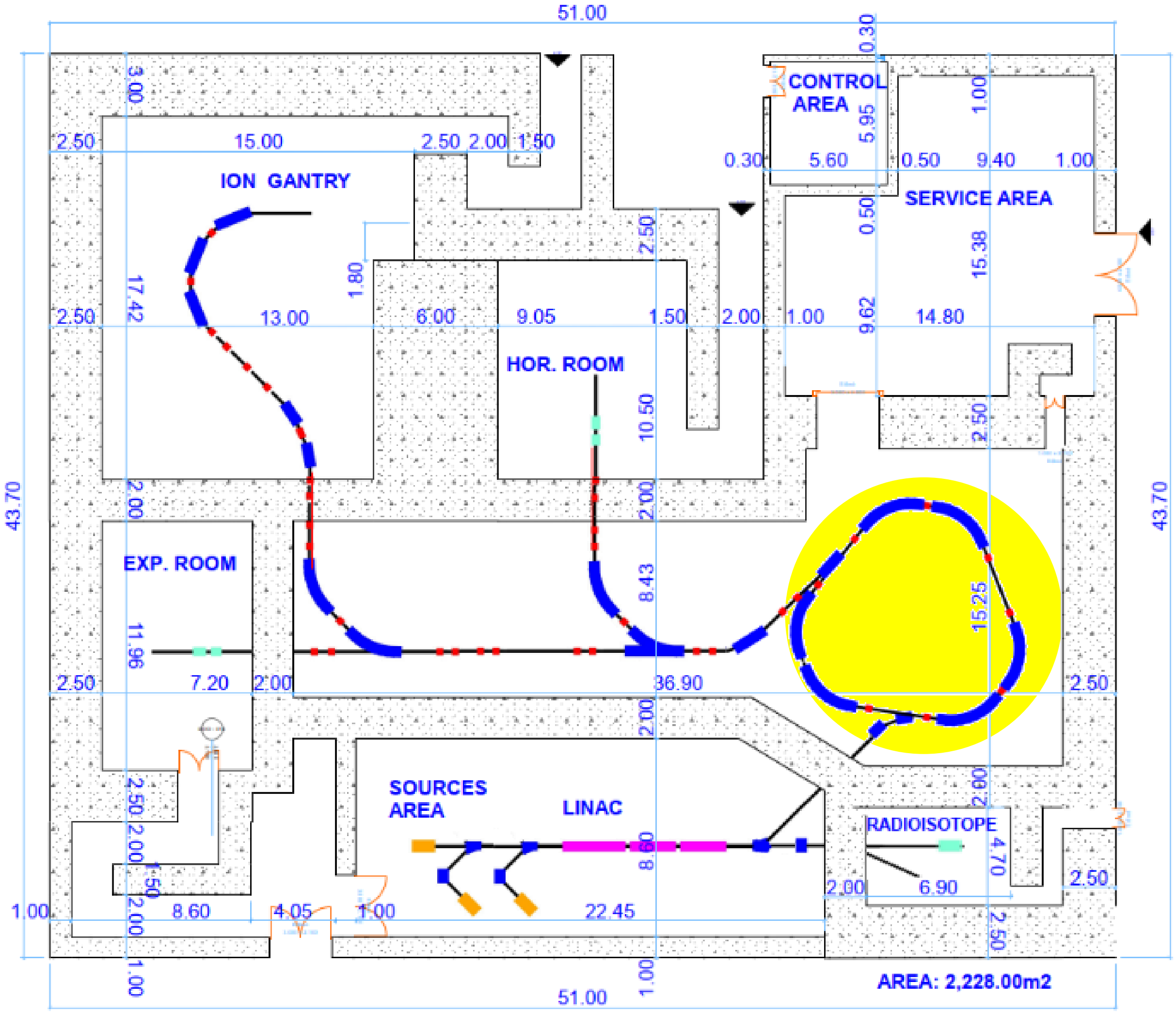
D. Tommasini

- Main challenge is compactness: how to place all the equipment, keeping flexibility in working point and optics functions





Synchrotron: injection/extraction equipment



Beam Delivery