A Possible Future Ideal Facility Design

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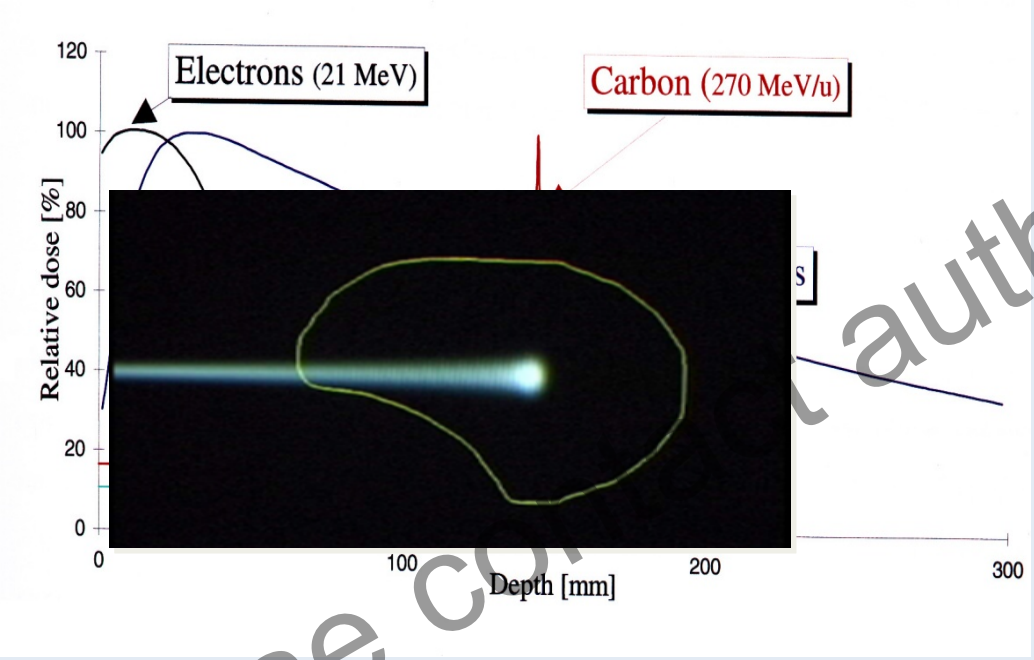
What Everyone Knows

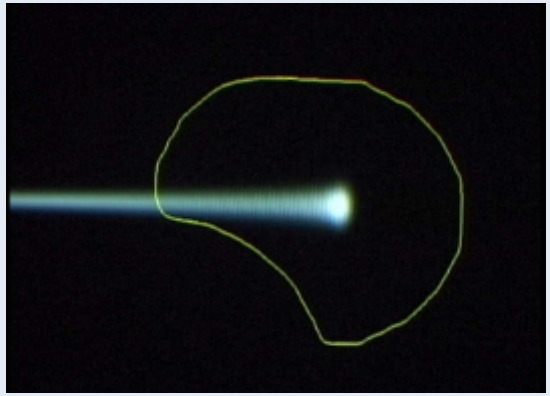
Hadrontherapy vs. radiotherapy



The BRAGG Peak

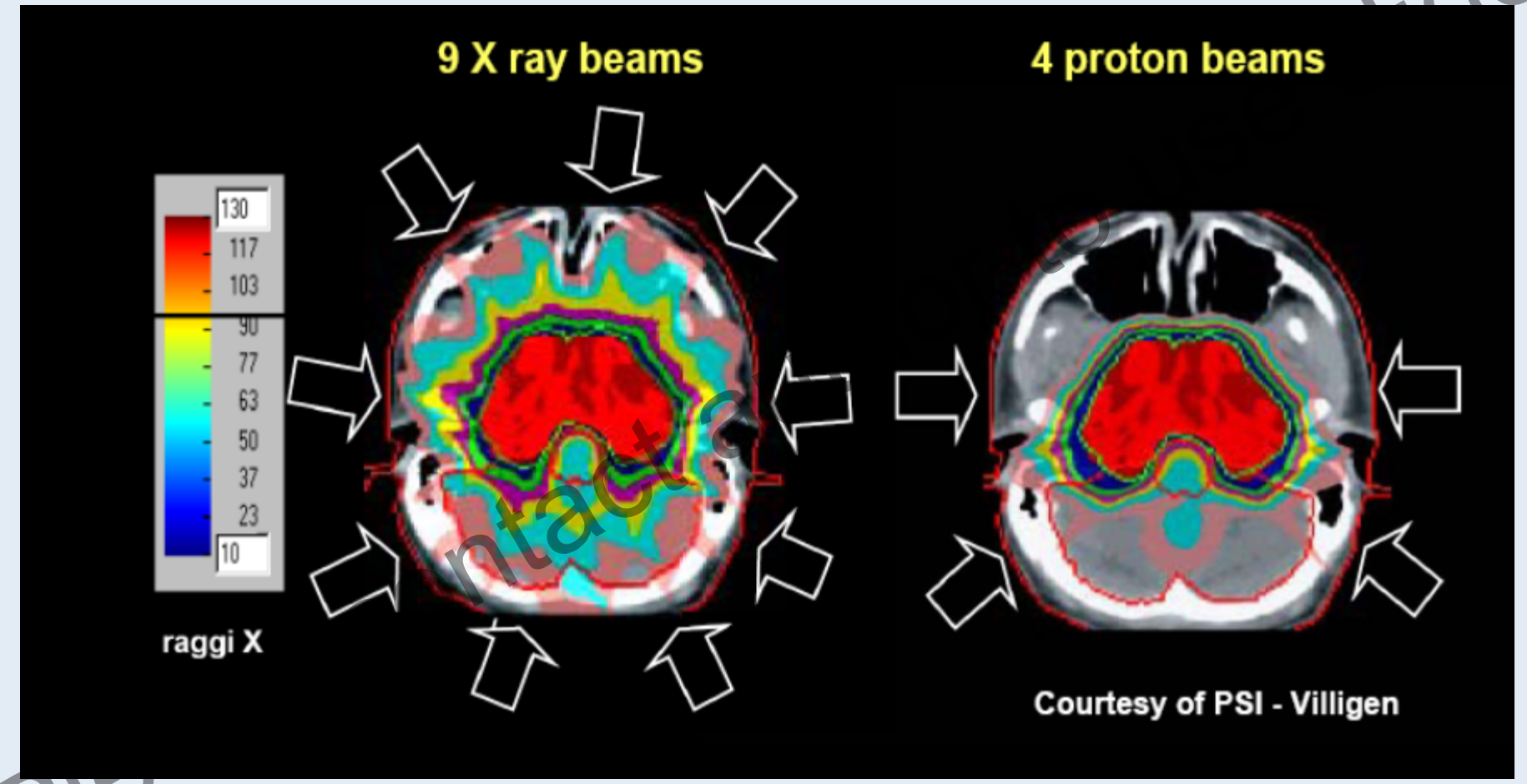
- Tumours close to critical organs
- **Tumours in children**
- Radio-resistant tumours

The physics properties of light ions (Bragg) may make them much more efficient in treating some kinds of tumours



Energy deposition

Comparison of Collateral Damage



History and Reminders

Accelerator reminder PIMMS

"In 1996, CERN initiated the Proton Ion Medical Machine Study (PIMMS), which aimed at designing a synchrotron optimized for the treatment of moving organs with carbon ions (and protons). The participants were TERA (Italy), MedAustron (Austria) and Oncology 2000 (Czech Republic). The design was summarized in two reports issued in 2000.

The study was adapted by TERA and implemented in the CNAO centre in Pavis. The MedAustron facility utilises the same synchrotron design, and is nearing completion in Wiener Neustadt (Austria)."

What is the situation now: Worldwide?

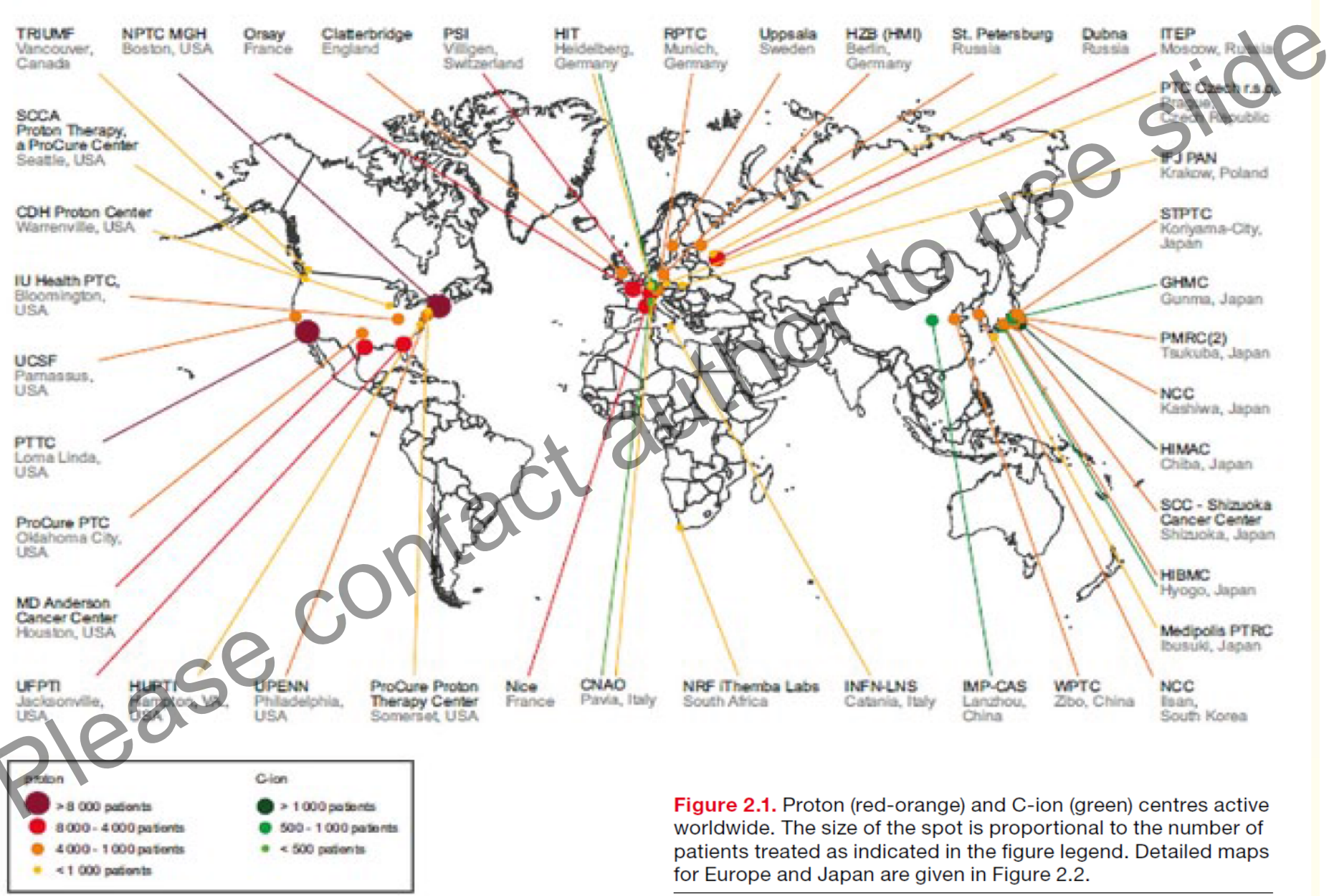


Figure 2.1. Proton (red-orange) and C-ion (green) centres active worldwide. The size of the spot is proportional to the number of patients treated as indicated in the figure legend. Detailed maps for Europe and Japan are given in Figure 2.2.

Europe/Japan

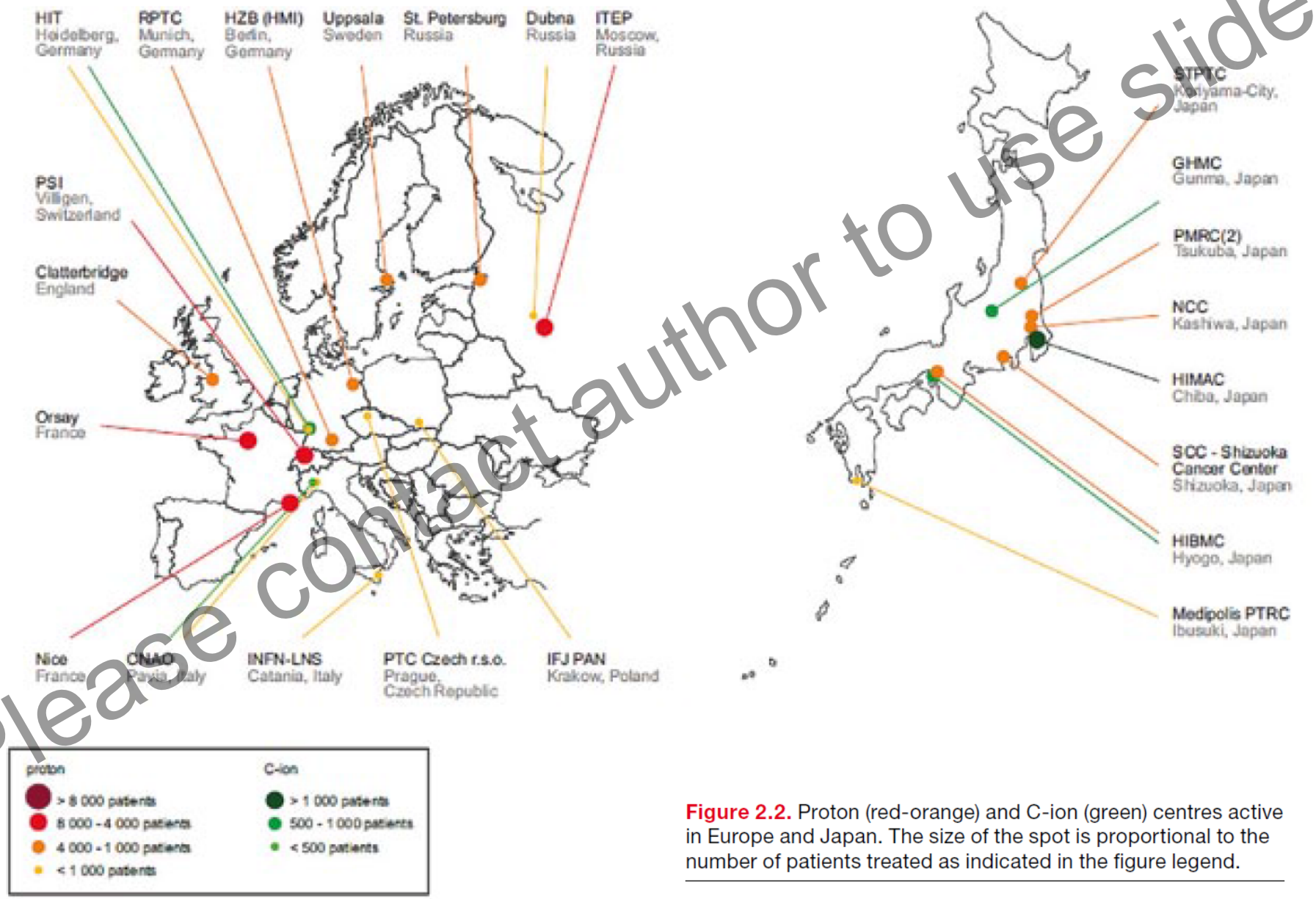
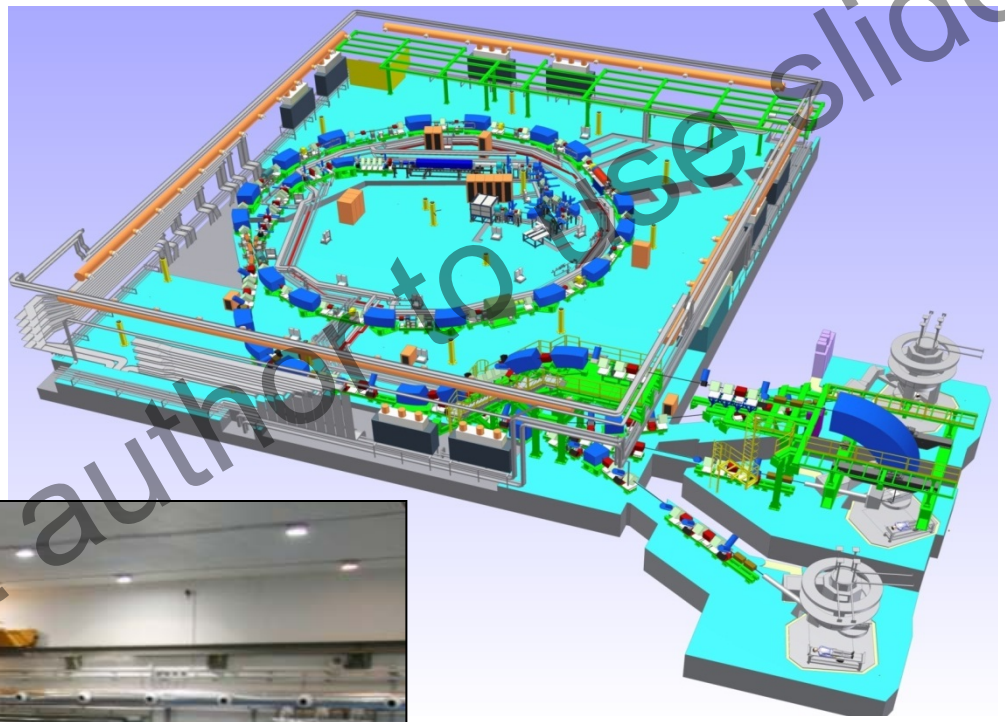


Figure 2.2. Proton (red-orange) and C-ion (green) centres active in Europe and Japan. The size of the spot is proportional to the number of patients treated as indicated in the figure legend.

CNAO in Pavia

CNAO (Pavia) is treating patients



MedAustron is building a centre in Wiener Neustadt

MedAustron Status – Wiener Neustadt

PIMMS1 design has been a big service to the community

- **2 source branches installed**
- **Beam commissioning**
- **Synchrotron hall installation**

What is new on the technology side?

- LHC accelerator technology development
  - Operation of 8T magnets
  - Testing of 11T magnets for Luminosity upgrade
  - Development of 18-20T magnets for energy upgrade
- LHC Detectors developments
  - Crystal scintillators improvements
  - Medipix proliferation and enhancements
  - Developments of new vertex detectors for LHC luminosity upgrade
  - Development of TOF resolution for Luminosity Upgrade (40ps aim)
- CLIC
  - Accelerating structure frequency reduced from 30GHz to 12GHz
  - Development of room temperature structures for 100MV/m gradient
  - Proposals for structures of 3 and 5.7 GHz with 30 and 50 MV/m for medical applications
- LHC Grid
  - Demonstration of the efficiency and reliability
  - Rapid adoption to new domains
- Developments of medical simulations with FLUKA

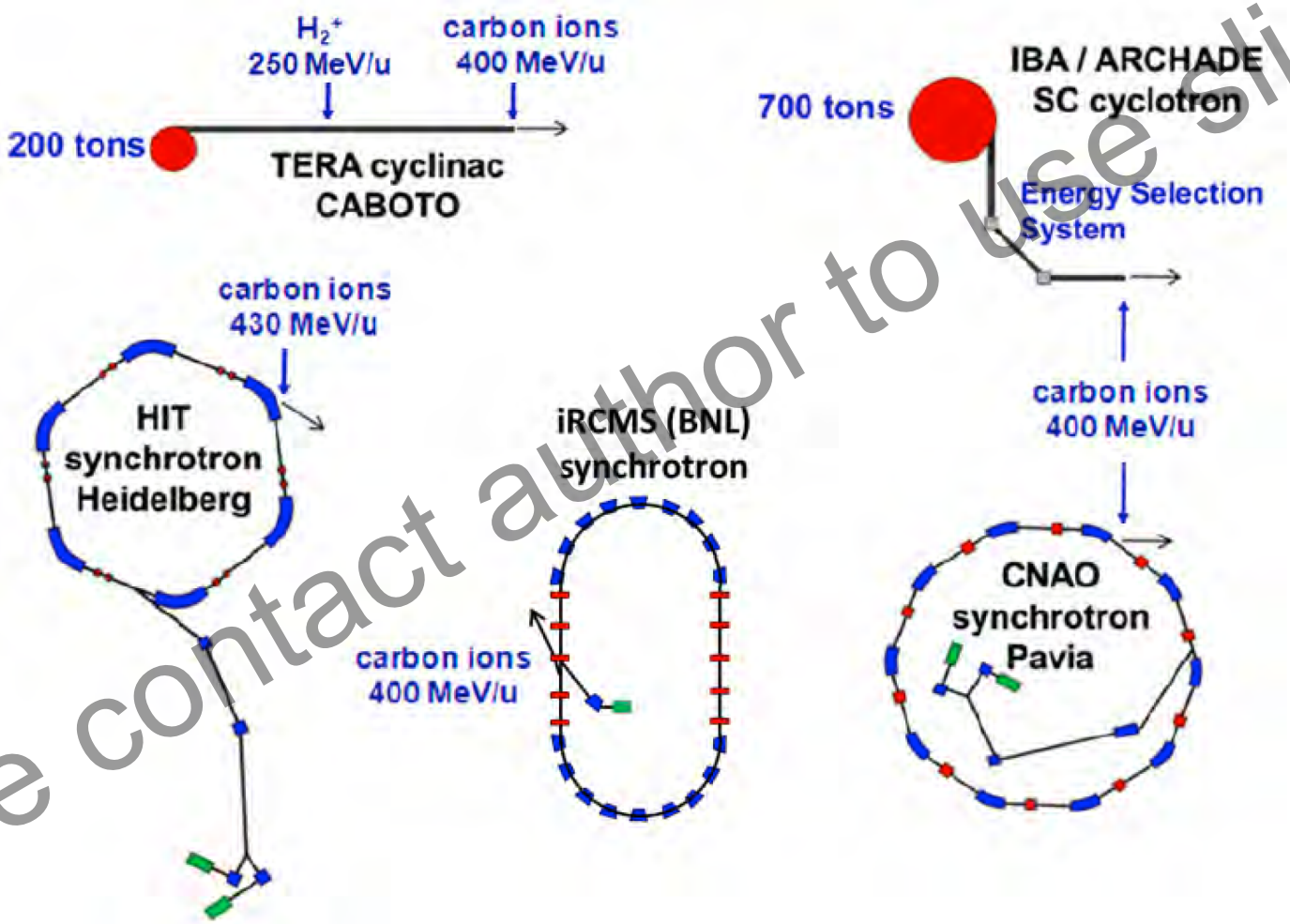
How can we improve the previous design using the new technologies?

Title of Talk: A Possible Future Ideal Facility Design

What should an ideal facility do?

- Treat the tumour and only the tumour
  - ⇒ control and monitor the ideal dose to the tumour
  - ⇒ Minimal collateral radiation "outside" the tumour
  - ⇒Minimal radiation to nearby critical organs
  - ➢ Even if the tumour is moving
- ❑ Be affordable
  - ✓ Capital cost ?
  - ✓Operating costs ?
  - ✓Increased number of treated patients per year ?
- ❑ Compact: Fit into a Teaching Hospital ?

Dimensional comparison for carbon ion accelerators



Courtesy U. Amaldi/A.Degiovanni

Cost Questions (user Specs)

- ***Compactness***
  - Specification of "maximum" dimensions…MA
  - Balance of importance of compactness vs cost..MA
- ***Cost Effectiveness .. The Over-riding Parameter***
  - What is a reasonable cost parameter (e.g. relative cost per patient compared with conventional therapy? Survival parameter?)..MA
  - Reduction of capital cost… Acc + MA
    - Number of treatment rooms + number and specs of gantries
  - Reduction of running and operational costs (experts…)..Acc + MA
    - Number of treatment rooms + gantries
  - number of patients treated per year…MA +Acc

Technical/Medical Questions (user Specs)

- ***Beam Specs*** *(needs R&D)*
  - Type of Light Ion (protons to Carbon or multiple ion capability)…M
  - Central beam energy and energy range (?multiple energies for different functions)….M
  - Beam size (h+v) (emittance)…..M
  - Energy spread of beam….M
- ***Beam Distribution (gantry)***
  - Required angular coverage…..M
  - Allowed rate of change of beam energy…Acc + M
  - Degree of allowed movement of patient…..M
- ***Diagnostics and Imaging*** *(needs Test bed and simulations)*
  - Dose: requirements and precision deposition….M
  - Beam control devices…..Acc
  - Requirements for imaging (update rate, precision, resolution)… M

Technical/Medical Questions (user Specs)

❑ *Spot Scanning (Needs R&D)*

- Comparison of specs for spot scanning (fast with low dose per shot or large dose per shot)…M
- Optimum spot scanning parameters, rate, dose, etc..M
- Control of dose per deposition….M

❑ *Type of Accelerator …Acc*

- Synchrotron (normal or rapid cycling)
- Linac
- Cyclotron
- Or a combination of the above (SC, Cyclo-Linac, etc)

The agreed specs will influence decision on type of accelerators and design of gantries

Source and pre-Accelerator

Accelerator

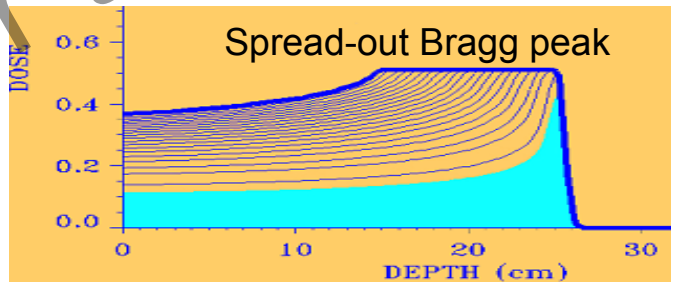
Gantry

Beam Delivery to Patient

Transverse
Passive Beam
Scanning

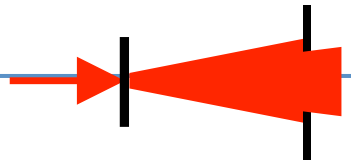
Simplest and most common system

Plus Spreading of Bragg Peak (Energy variation)

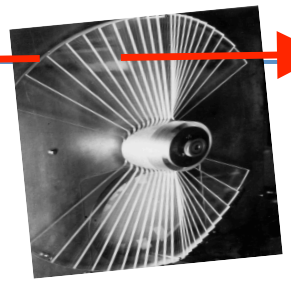


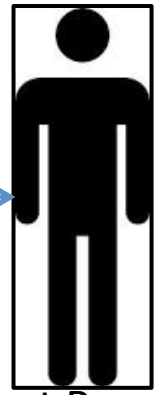
NOT IDEAL

Rotating wheel, modulates proton range



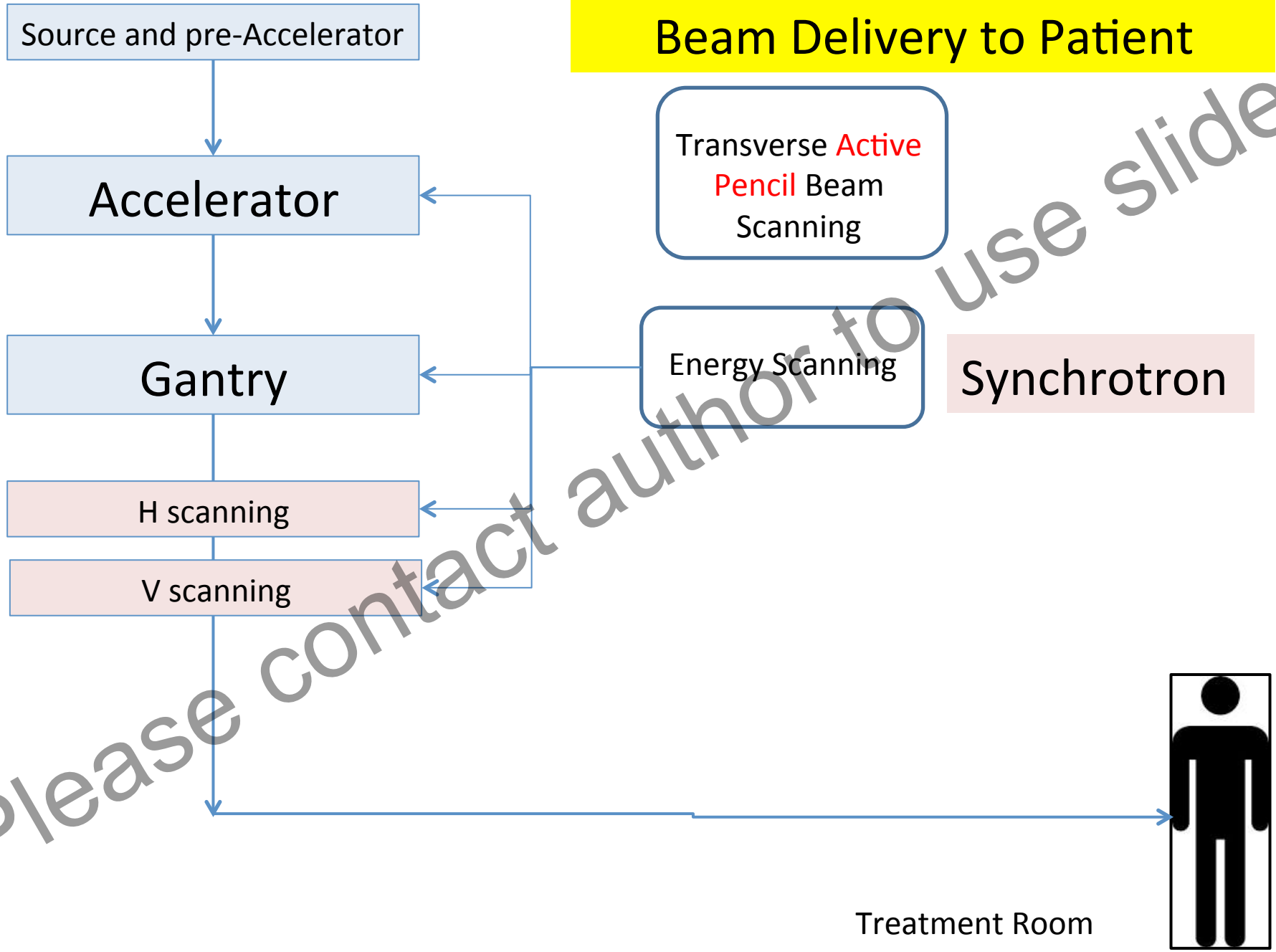
Scatter + collimator





Treatment Room

Beam Delivery to Patient



Beam Delivery to Patient

Source and pre-Accelerator

Accelerator

Gantry

H scanning

V scanning

Range Shift Plates

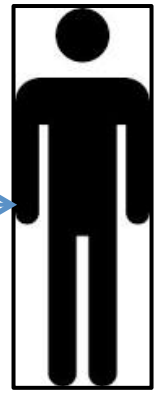
Transverse Active Pencil Beam Scanning

Energy Scanning

Cyclotron

Discrete spot scanning
Continuous spot scanning

Sensitivity to organ movement



Treatment Room

Dealing with Organ Movement

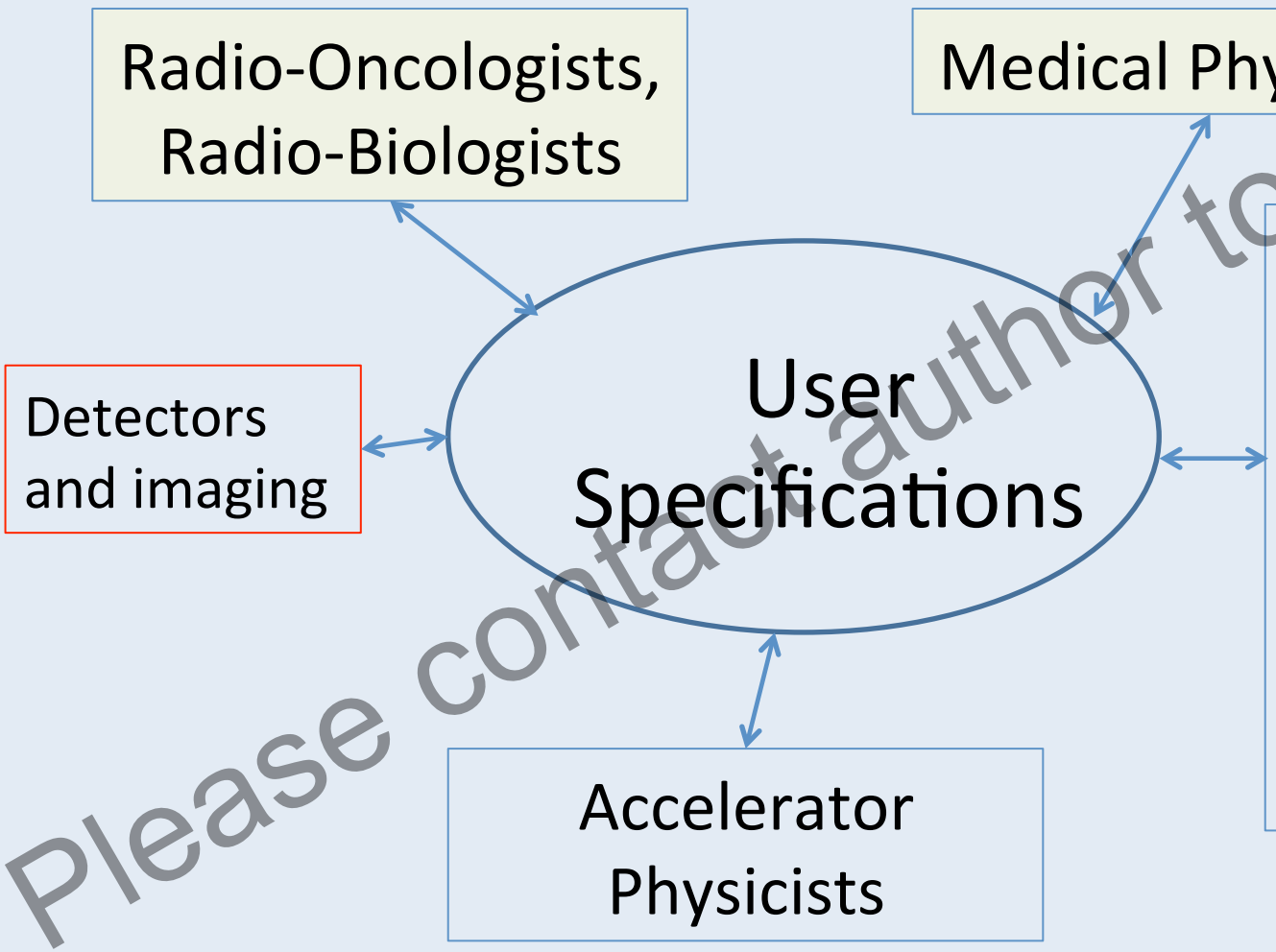
- Time gating: apply dose when the organ is in the correct position. E.g. respiration cycle
- Fast rescanning: very rapid multiple painting. Statistically distribute the dose
- **Tumour tracking: diagnostics and imaging**

All methods need high scanning speeds

The New CERN Initiatives

1. Medical Accelerator Design
   - coordinate an international collaboration to design a [illegible] mpact, cost-effective accelerator facility, using the most adva[illegible]nologies
2. Biomedical Facility
   - creation of a facility at CERN that provid[illegible]e beams of different types and energies to external users for radi[illegible]y and detector development
   - Iterative experimental verificatio[illegible]ation results
3. Detectors for beam co[illegible]and medical imaging
4. Diagnostics and Do[illegible]y for control of radiation
5. Radio-Isotopes [illegible]g and possibly treatment)
6. Large Scale [illegible]uting (simulations, treatment planning telemedi[illegible]tc)
7. Appli[illegible]s other than cancer therapy

User Specs for Hadron Therapy



1. Beam parameters:
   - Particle type(s),
   - Measured position,
   - Energy range
   - Required dose,
   - Real time feedback from detectors
2. Distributing the beam
   - rep rate,
   - spot scanning,
   - gantry
3. Accelerator type,
4. Cost-effectiveness and compactness parameters

- Many of these questions can only be answered with
  - experimental verifications
  - significant simulations
  - Development of diagnostics (imaging, dosimetry)
- $\Rightarrow$ We need a dedicated test facility

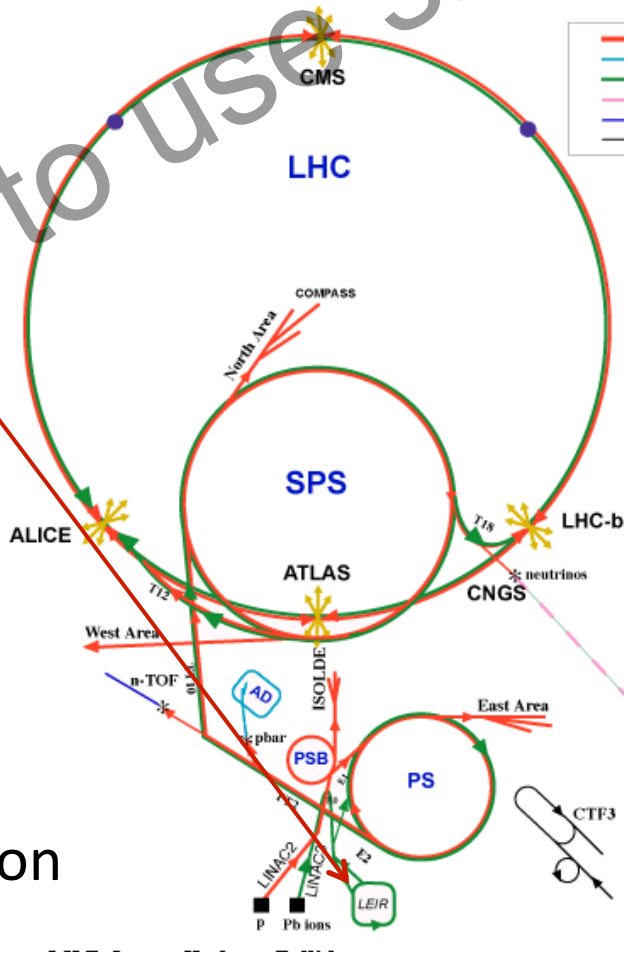
We have many accelerators at CERN

And one is perfect, LEIR

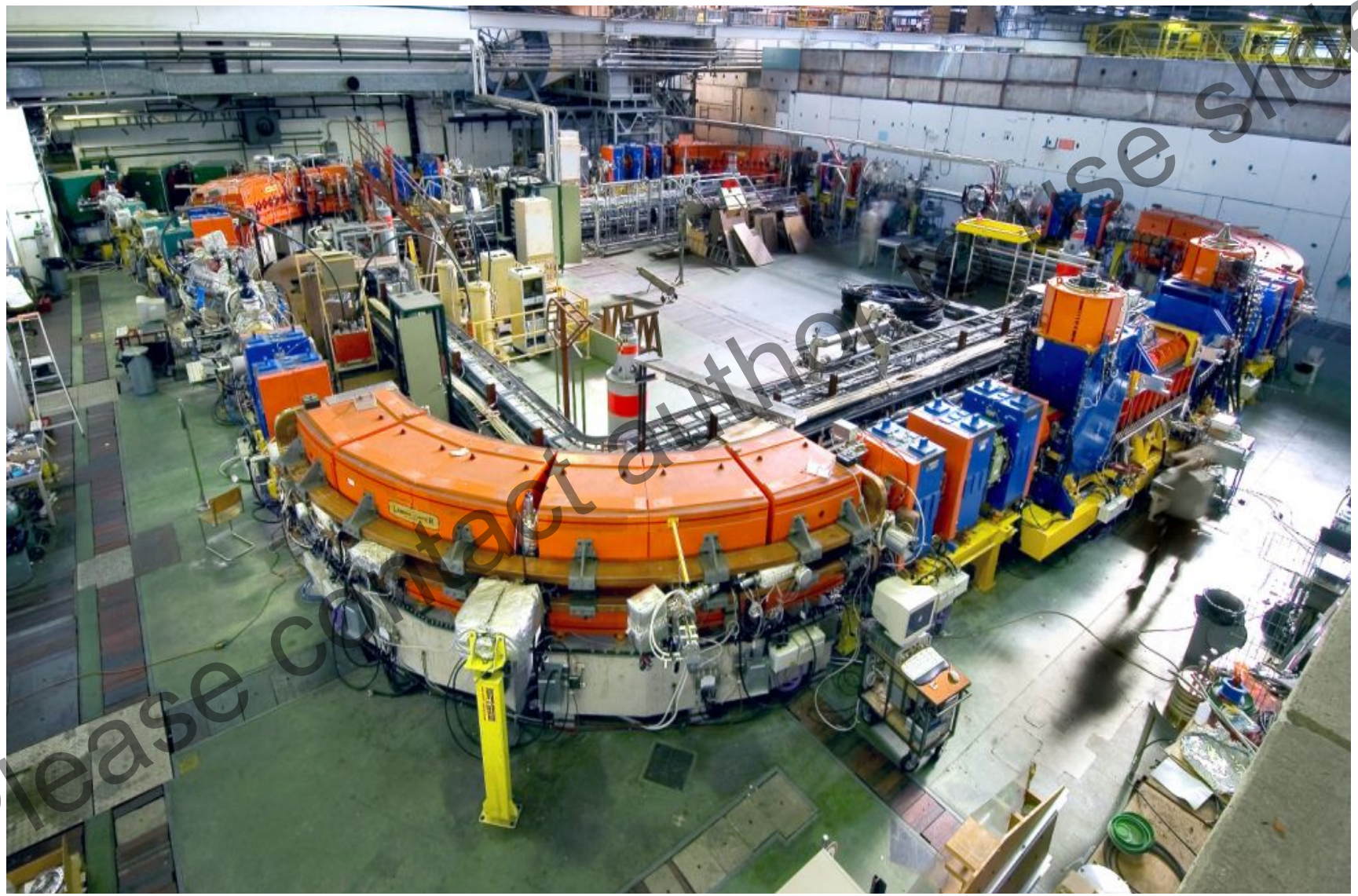
LEIR (Low Energy Ion Ring)

- part of LHC injection chain
- accumulator for LHC ion programme (lead ions)
  - only used for several weeks / year

- Plan to **establish facility** for
  - Test-bed for medical instrumentation
  - Diagnostics and dosimetry
  - **radiobiology**
  - basic physics studies such as fragmentation of ion beams

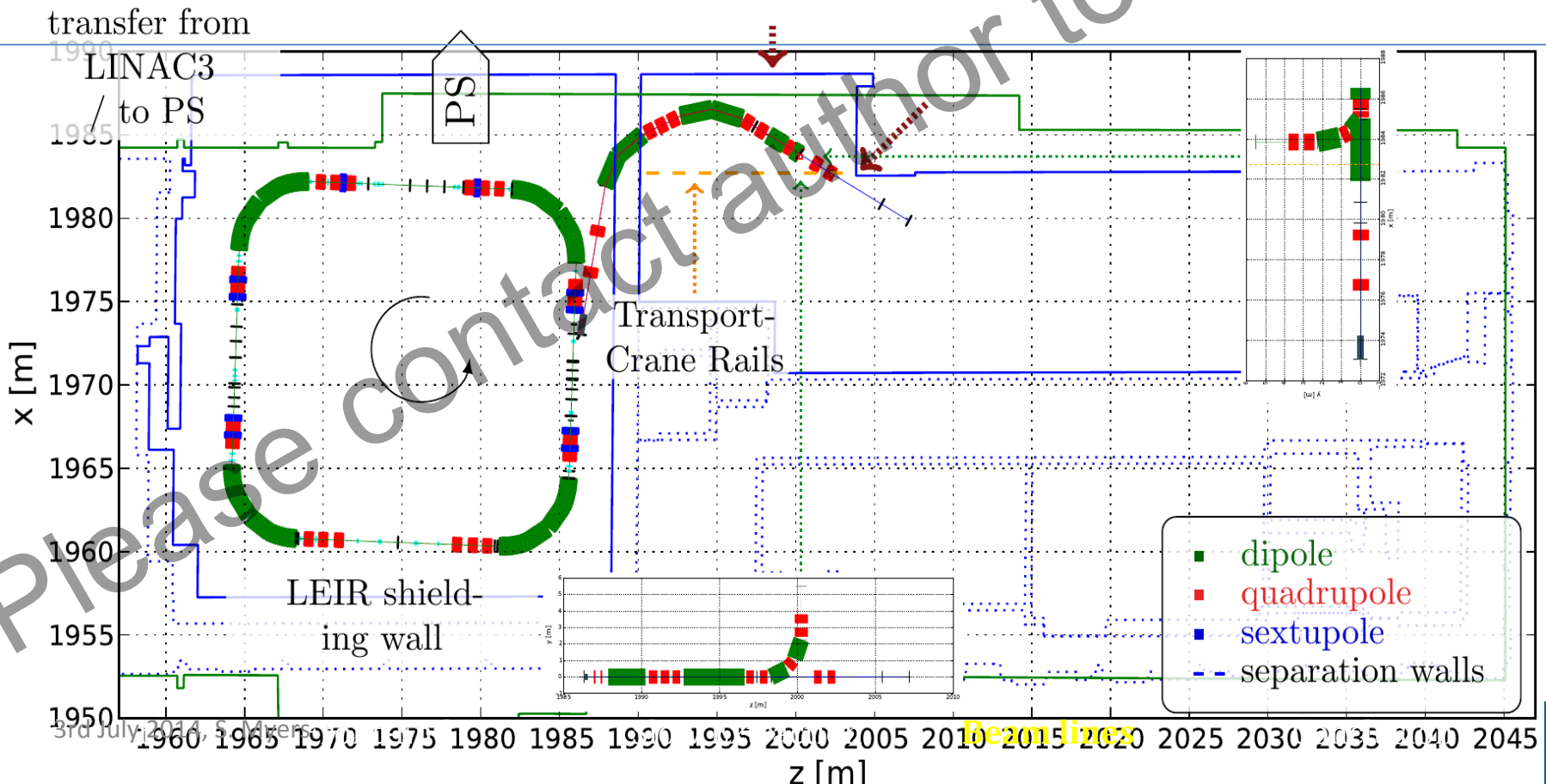


OPENMED: Biomedical Research Facility at CERN



Two experimental beamlines are foreseen

- Horizontal beamline up to maximum energy
- and Vertical beamline up to 2.6 Tm (75 MeV/u C)
- Pencil beam 5-10 mm FWHM and broad beam 5x5 cm^2 considered
- 4 bending magnets (max 1.6 T, ± 40 mm gap) and 12 quadrupoles (max 23 T/m, max 40 mm radius) in total



Radiobiological Facility @ CERN

A unique test bed for medical instrumentation and radio-biological studies

Ions	Priority Rating /5	Why
Protons	5	Clinical
(molecular ion) H_2	2	Correlated particle experiments Experiments -Spatial distribution Variation in response
Helium $_2^3$	5	Possibly clinical
Helium $_2^4$	4	Stable and possibly clinically relevant
D	4 (if clean), 0 (if not)	Radiobiologically interesting, not clinically useful
Li $^6_3$	4	RBE greater than P Fragmentation tail shorter, less dose deposited past the distal edge
B $_5^{10}$	2	Potentially clinical Fragmentations more than Li, better than C
C $_6^{12}$	5	Clinical
N $_7^{14}$	3	Radiobiological Studies
O $_8^{16}$	4	Possibly clinically relevant Radiobiological Studies
Ne $_{10}^{20}$	3-4	Comparison to present radiobiological studies
Ne-Fe	1	To analyse radiobiological trends across the ions
Ca $_{20}^{40}$	1	Intermediate Biologically important trace element
Fe $_{26}^{56}$	3	Radiobiological interpolation

Collection of requirements for Radiobiology Facility

Experiments are of interest?

What are the desired beam properties?

- ion species & energies
- beam intensities & duration
- beam size (micro vs. broad beam)
- beam homogeneity

OPENMED Facility Summary

- With a new Front End (Source)
  - LEIR can provide ions of interest for biomedical studies up to <430 MeV for fully stripped ^{12}C or ^{16}O ions
  - Facility can also be used to test detectors and diagnostics as well as test the results of medical simulations
  - Study well under way:
    - (Re-)implemention of slow ejection with longitudinal and/or transverse excitation
    - New extraction channel (septa) and transfer line to experiment

- All we need is Funding for Implementation

3) Detectors

- Continuous development on particle physics detectors at CERN
- Scintillating crystals
- Medipix
- Diamond detectors

Radio-Isotopes

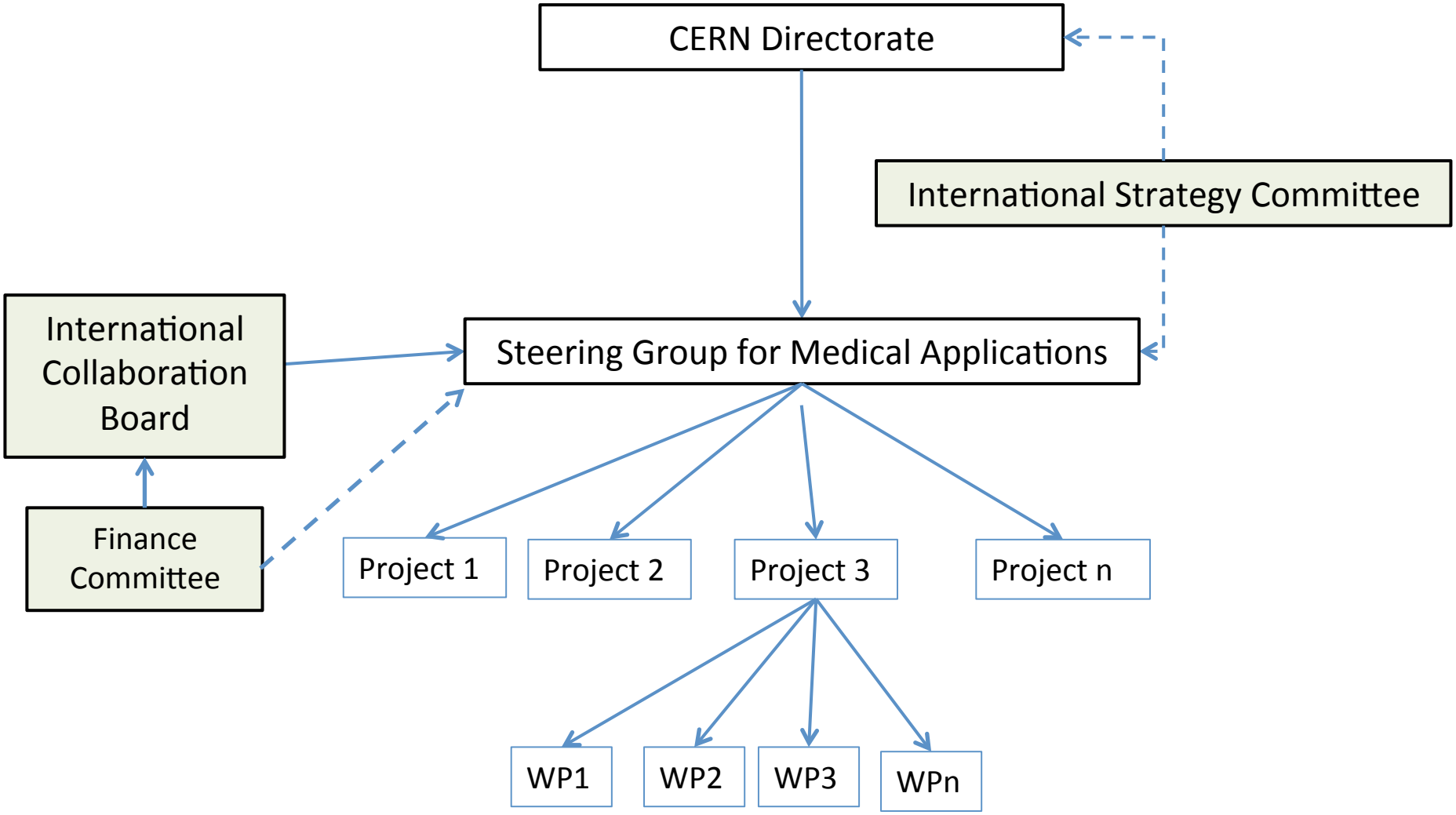
Key Points : Radio-Isotopes

- Securing an adequate supply of radioisotopes is a big challenge, (not only for $^{99}Mo/^{99m}Tc$) but even more for promising "new" radioisotopes such as alpha emitters for radio-immunotherapy.
- A European user facility to be created to supply innovative radioisotopes (produced at ISOLDE-CERN, ILL, PSI, Arronax,...) for R&D in life sciences (preclinical and clinical studies).
- Medicis on ISOLDE

Civil Engineering has started

September 4th 2013

DRAFT Structure (to be discussed)



Fast Moving Targets: Enemy Aircrafts

Heat tracking anti-aircraft missiles

Controlled particle beams to track and eliminate tumours

Fast Moving Organs

Our long term ideal dream: Effectively treat hyperactive pediatric cancer patients

Thank you for your attention