Summary Note – WG3

Accelerator technologies for industrial & medical applications

Byung-Hoon OH
with WG3 group members

List of presentation in WG3

Accelerator technologies for industrial & medical applications

	Title	Speaker	Affiliation	
1	Present status of Cryomodule and Cryoplant for LIPAc	K. Sakamoto	ITER, Aomori Fusion Energy Center	√
2	Transmission- and Scanning- Muon Microscopye	Yukinori Nagatani	KEK J-PARC	√
3	Electron linacs for radiotherapy	Chuanxiang Tang/ Hao Zha	Tsinghua University/China	√
4	Development of a superconducting cyclotron based proton herapy sysmte at HUST	Kuanjun Fan/ Deming Li	HUST/Sinap, China	√
5	Carbon Ion Radiotherapy	Guoqing Xiao/ Jiawen Xia	IMP, China	X
6	Towards a Hadron Driver for the Next Generation of Cancer Therapy	Ken Takayama	KEK, Japan	√
7	Full-Body PET Camera based on Liq. Xenon TPC technology	Toshiaki Tauchi	KEK, Japan	√

List of presentation in WG3

Accelerator technologies for industrial & medical applications

	Title	Speaker	Affiliation	
8	Laser driven proton acceleration enhancement by using nanophotonic butterfly wing targets	M.Y. Jung	ETRI, Korea	X
9	Physical design of the proton linac injector for the synchrotron based proton therapy system in China	Shuxin heng/ Qingzi Xing	Tsinghua University, China	√
10	Irradiation electron linacs	Huaibi Chen	Tsinghua University/China	√
11	Electron Accelerator (or neutrons) for radiography	B.C. Lee	KAERI/Korea	X
12	Medical Imaging and Therapy Radioisotope Production Techniques with High Current Cyclotrons	W. Gelbart, K. Butalag, RR Johnson	Advanced System Design Ltd/ TeamBest/ U. of British Columbia	√
13	Start of mutation breeding research using ion beam in Korea	Si-Yong Kang	KAERI/Korea	√

Presenters from (in Alphabet order)

China	; 4 (3)
Japan	; 4 (4)
Korea	; 3 (1)
Canada	; 1 (1)
total	; 12 (9)

Presented topics related on

Hardron accelerator ; 5
Electron accelerator ; 3
PET camera with Liquid Xenon detector ; 1

Accelerators applications for

neutron generator for fusion material test
muon microscopy
radiation therapy
electron irradiation & sterilization
ion beam breeding

WG3-1

Progress of Linear IFMIF Prototype Accelerator (LIPAc) in collaboration with EU

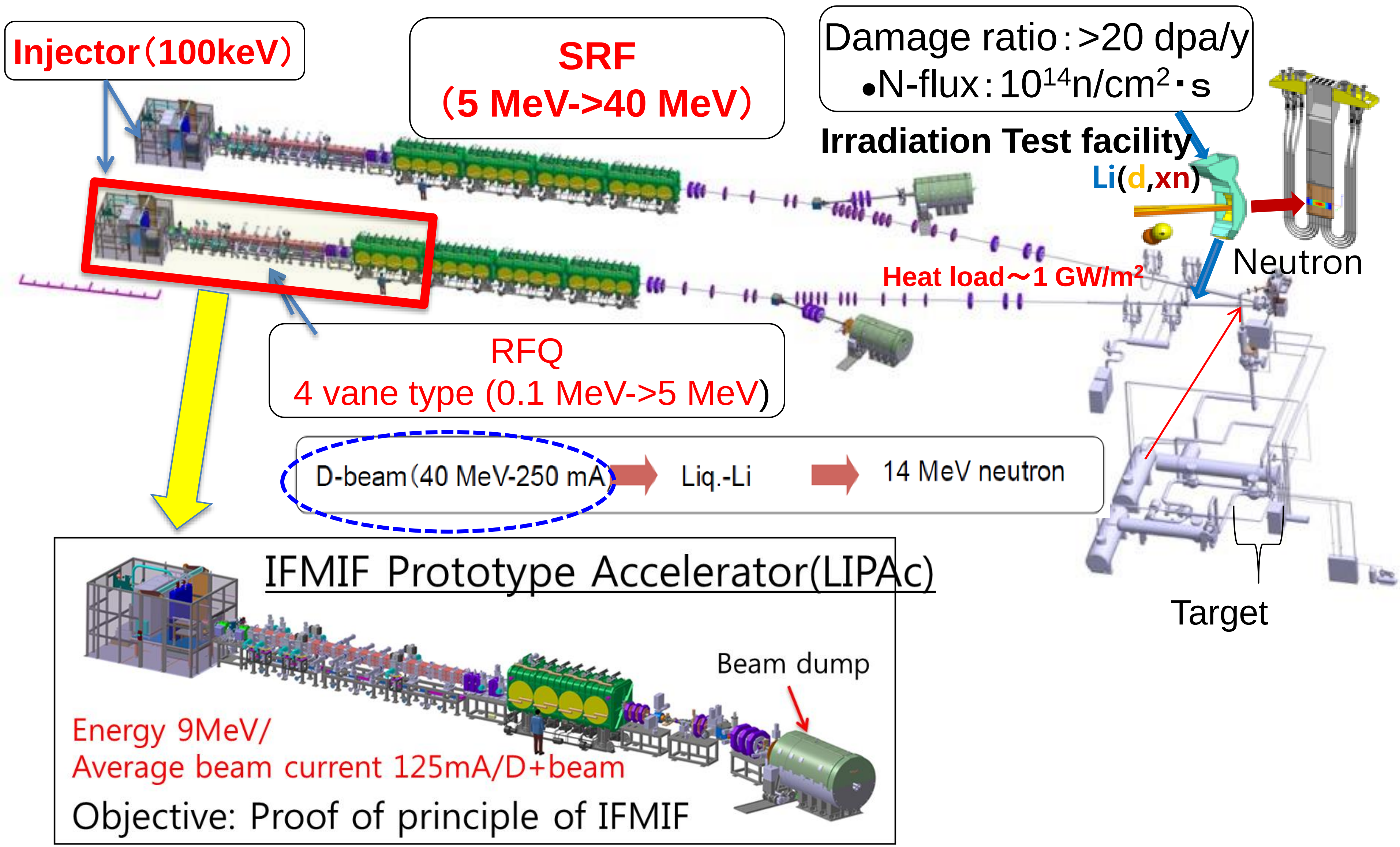
K. Sakamoto

(QST, Rokkasho Fusion Institute)

International Fusion Material Irradiation Facility（IFMIF）

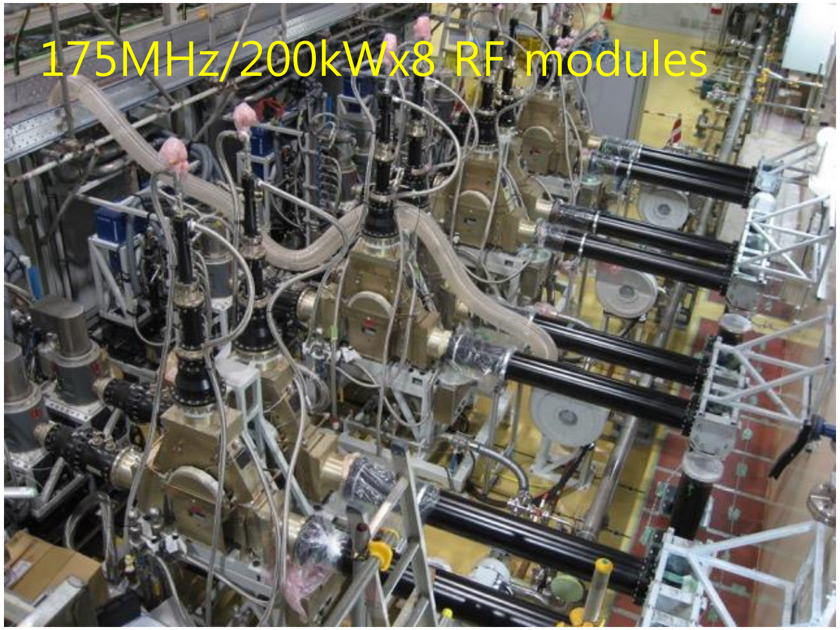
(Sakamoto)

High Intensity neutron source for fusion material irradiation

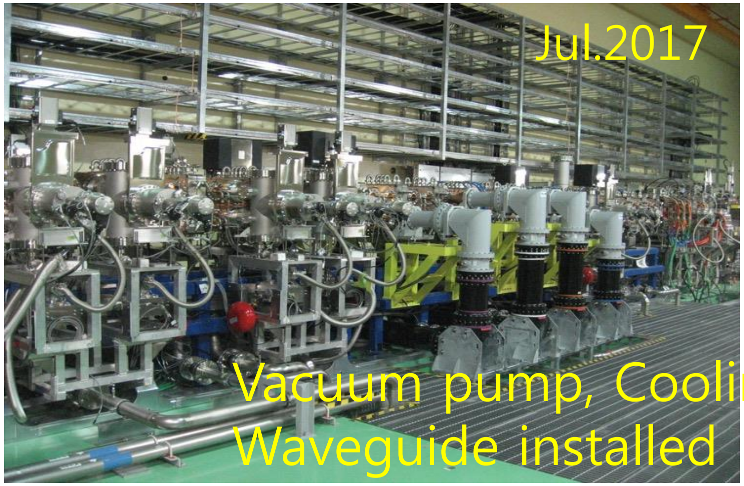


IFMIF Prototype Accelerator (Sakamoto)

RFQ Conditioning is underway with simultaneous RF power injection from 8 RF modules.



Waveguides were connected from RF module to RFQ

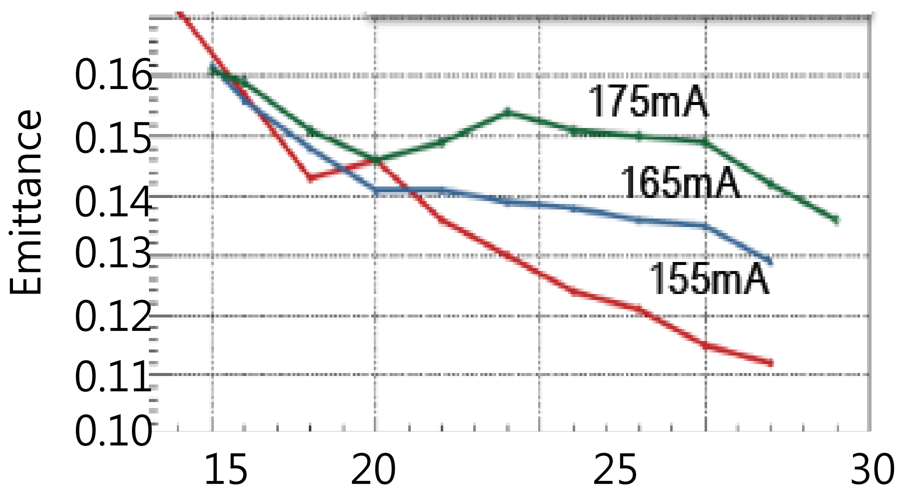


RF conditioning of RFQ (9.8m) is underway.

- RF voltage between the vanes exceeds the required voltage for D+ acceleration.

IFMIF Prototype Accelerator (Sakamoto)

Injector Experiment (Oct.2017-)



Good Emittance of 0.15πmm•mrad
was achieved. (target : <0.3πmm•mrad)
D+ beam／100kV.

Parallel Commissioning is underway for RFQ, MEBT, D-Plate, control system, toward the first RFQ beam acceleration.

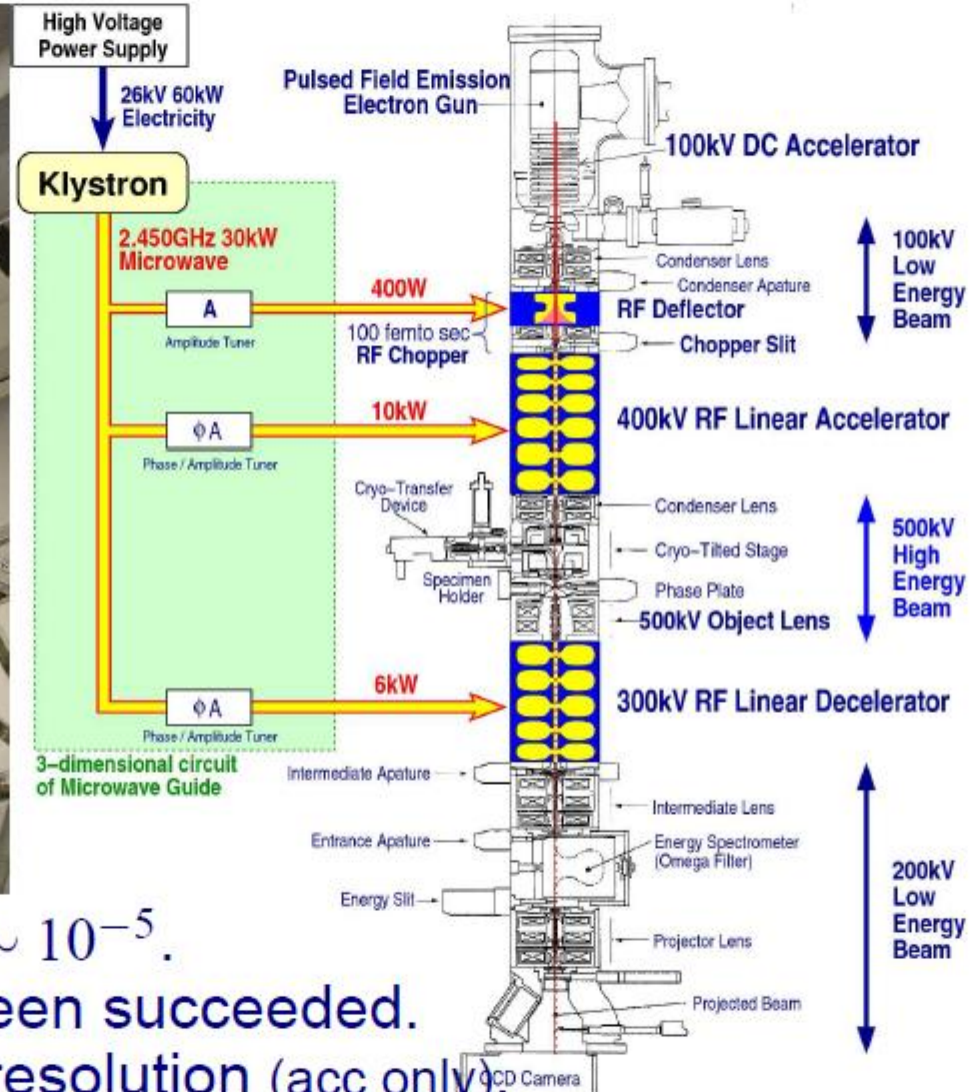
- First beam acceleration will be started from Feb. 2018.
- SRF will be installed in 2019.

WG3-2

Low Energy Muon Microscope

Yukinori Nagatani
(KEK J-PARC)

500kV Linac-TEM at NIPS (Okazaki)

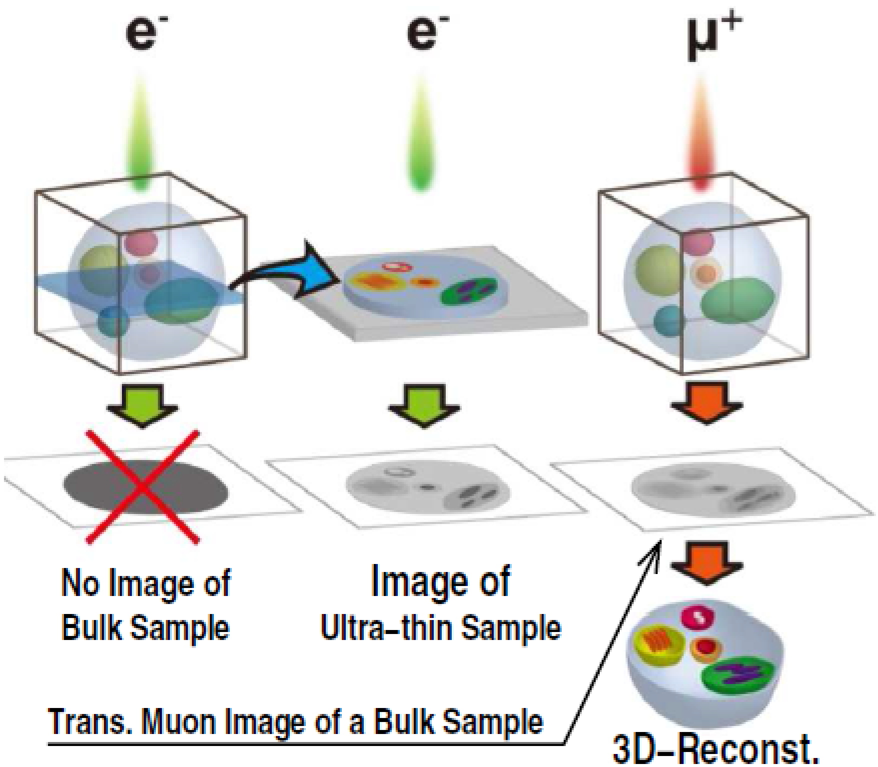


Accelerator with $\Delta E/E \sim 10^{-5}$.

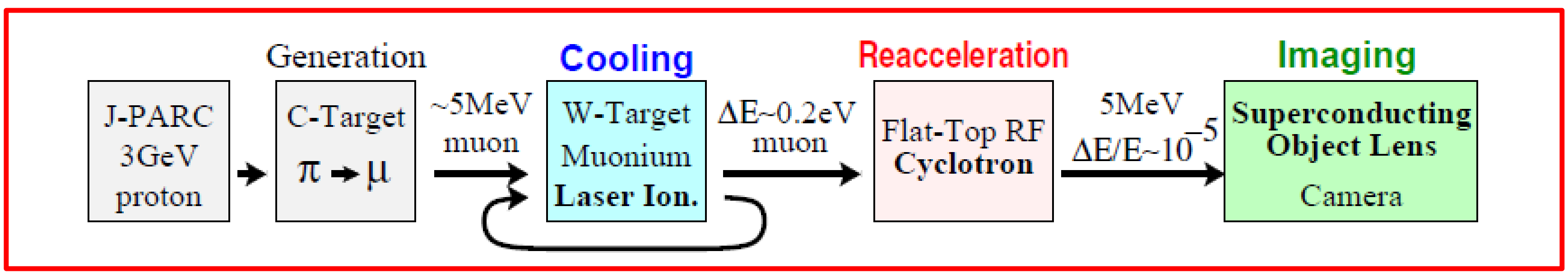
Proof of Concept has been succeeded.

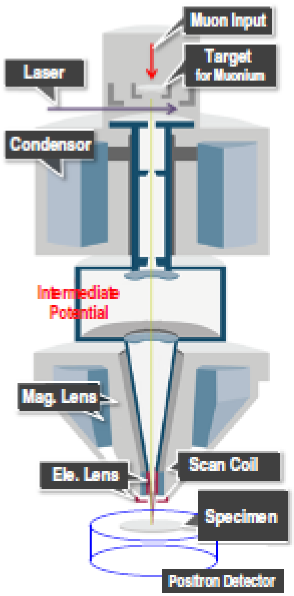
Current status: 0.9 nm resolution (acc only).

Transmission Muon Microscopy



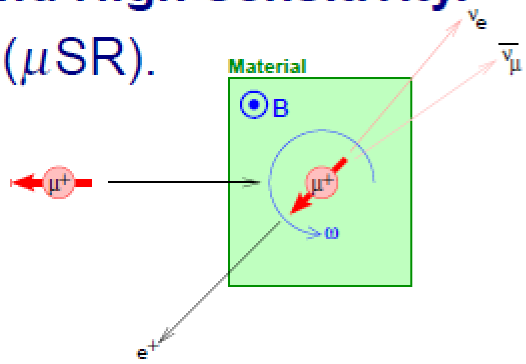
- **Deep penetration-power** of accelerated muon (~ 10MeV) is employed for microscopy.
- A cryo/live neurons ($> 10\mu m$) can be directly obserbed.
- Electric field is visualized.
- Muons are generated by accelerator (J-PARC).
- Cooling down of muons clarifies its **wave-properties**.

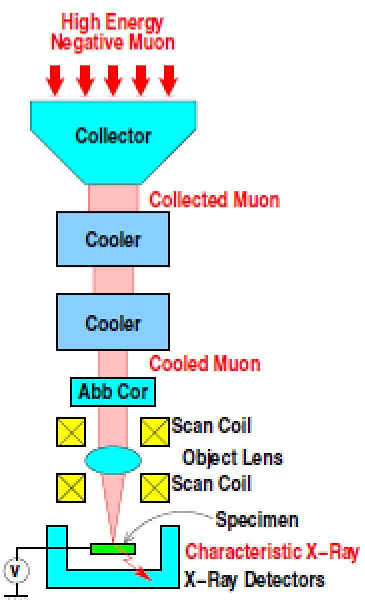




Scanning Positive Muon Microscopy

- **It can visualize 3D magnetic field in material.**
- **Nanometer-resolution and High-sensitivity.**
- ○Using muon spin rotation (μSR).
- ○XY-scan, and
  Z-scan by energy-scan.





Scanning Negative Muon Microscopy

- **It can visualise 3D distribution of elements, isotopes and chemical boundings.**
- Nanometer resolution.
- Any elements (including H, Li) are detectable.
- Much higer sensitivity than EDX/EDM.
- ○Using muon-induced characteristic X-ray, which is 200-times higer than one by electron.

WG3-3

Electron linacs for radiotherapy

Chuanxiang Tang/ Hao Zha

(Tsinghua University/China)

WG3-13

Irradiation electron linacs

Huaibi Chen

(Tsinghua University, China)

WG3-9

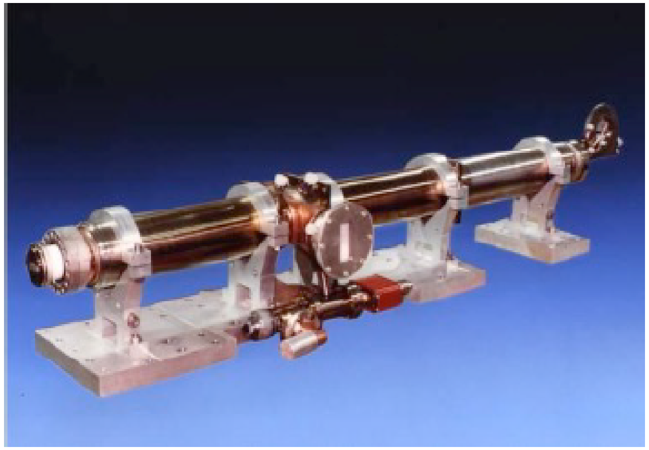
Physical design of the proton linac injector for the synchrotron based proton therapy system in China

Shuxin heng/ Qingzi Xing

(Tsinghua University, China)

History in Tsinghua accelerator lab

1974	✓ Convened a research group of more than 40 institutes to develop the first medical electron linac in China;
1977	✓ BJ-10 travelling wave linac(10 MeV electron)
1987	✓ 4 MeV axis-coupling linac
1993	✓ 14 MeV linac
1998	✓ Multi-energy linac (6~20 MeV)
2003	✓ Dual-beam linac (X-ray/electron)
2006	✓ Dual beam energy linac (kV/MV)
2009	✓ Electron standing wave linac for IMRT
2012	✓ C-band 6 MeV linac (1000 rad/min, 40 cm)
2016	✓ High dose rate 6 MeV linac（1400 rad/min）
2018	✓ X-band 6MeV linac (expected: 800 rad/min)



kV/MV coaxial LINAC

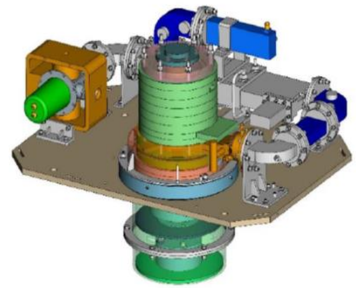
- We fabricated a prototype linac tube in 2007 and successfully demonstrated the energy switching (6 MV to 600 kV) . However, there are still some challenges:
  - Dose rate is not high (about 800 cGy/min @ 1 meter)
  - Linac tube is working not stably at low energy state (600 kV)

kV/MV Linac tube

Full radiotherapy machine prototype (developed by NUCTECH. Inc, China)

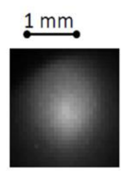
S-band large dose-rate LINAC

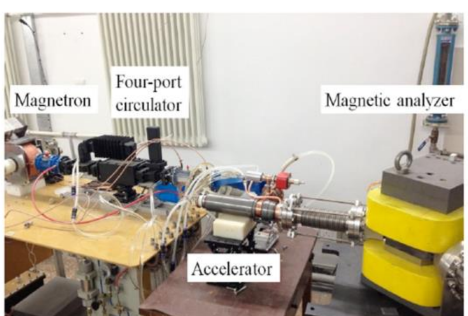
- A full module of X-ray source: magnetron + waveguide + linac tube (with shielding) , weight = 500 kg.
  - Mechanically adapted for many kind of radiotherapy machines;
  - Control it like a step motor: trig→ try to deliver a dose unit (1 MU) → feedback the real dose;
  - Pins are reserved to aligned the linac tube (by twisting them).



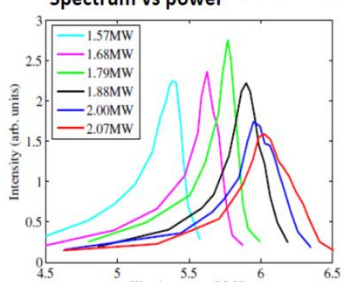
C-band medical LINAC

- The LINAC installed a titanium window at its end. So that we can measure parameters of the output electron beam:
  - Spot size: less than 1.5 mm ☺
  - Spectrum FWHM: 0.4 MeV ☹ (expected 0.1 MeV, may due to jitter in the power source)





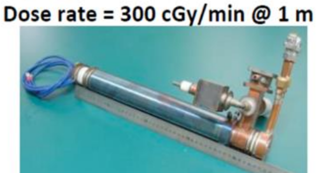
Spectrum vs power

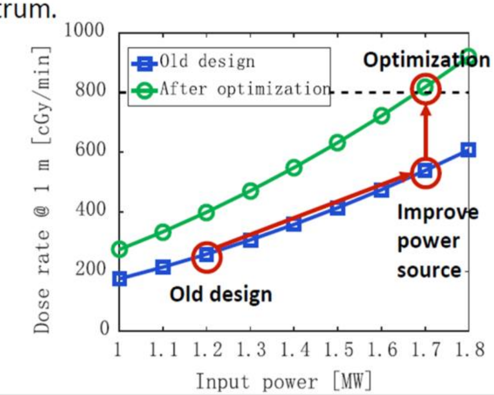


X-band medical LINAC

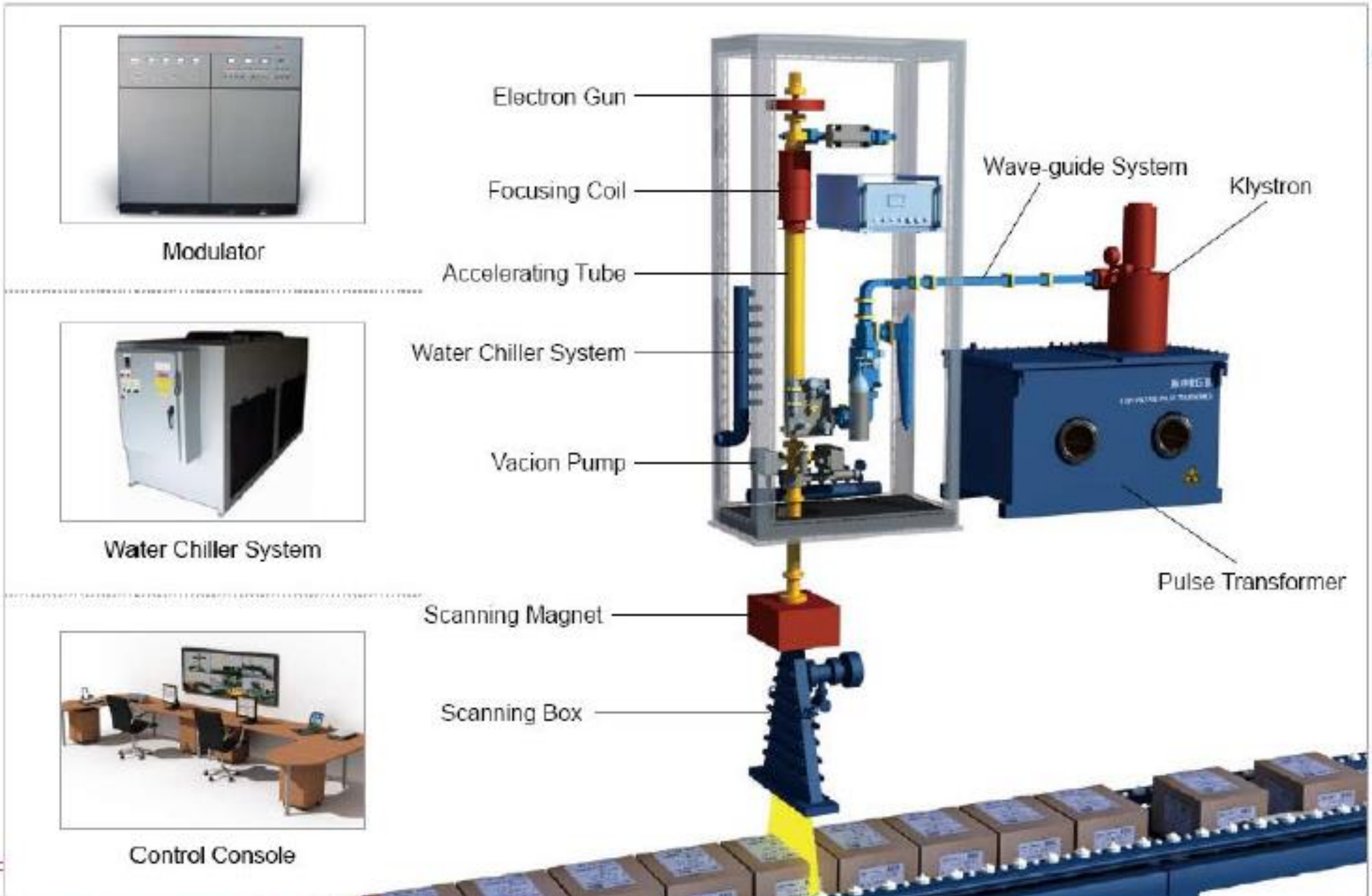
- We developed an X-band tube in the year 2000 (old design). The new X-band tube will improved :
  - More powerful source (expect 1.7 – 1.8 MW)
  - Increase the shunt impedance
  - Increase the capture ratio (less power absorbed by un-captured beam)
  - Optimize the beam spectrum.

Old design:
Input power = 1.2 MW
Dose rate = 300 cGy/min @ 1 m





accelerator technology for irradiation & sterilization

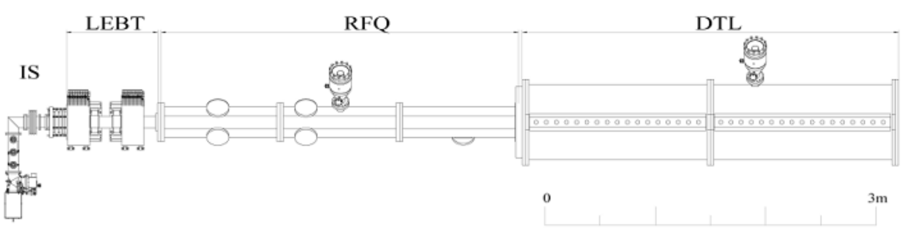


Physical design of the proton linac injector for the synchrotron based proton therapy system in China

- One proton linac injector is being designed by Tsinghua University for one synchrotron-based proton therapy system
  - Ion source: ECR source
  - LEBT: magnetic LEBT; electric optional
  - RFQ: four-vane type, abundant manufacturing experiences
  - DTL: Alvarez-type DTL
  - Adopting domestic mature technologies and cost control

Beam requirement of the linac injector

PARAMETER	VALUE
Ion type	Proton
Output beam energy	7 MeV
Output beam momentum spread	±0.3% (≥8 mA)
Output peak current	≥12 mA
Output normalized transverse emittance (90% particles)	≤1.2π mm•mrad
RF frequency	325 MHz
Repetition rate	0.5 Hz
Output beam pulse width	40~100 μs

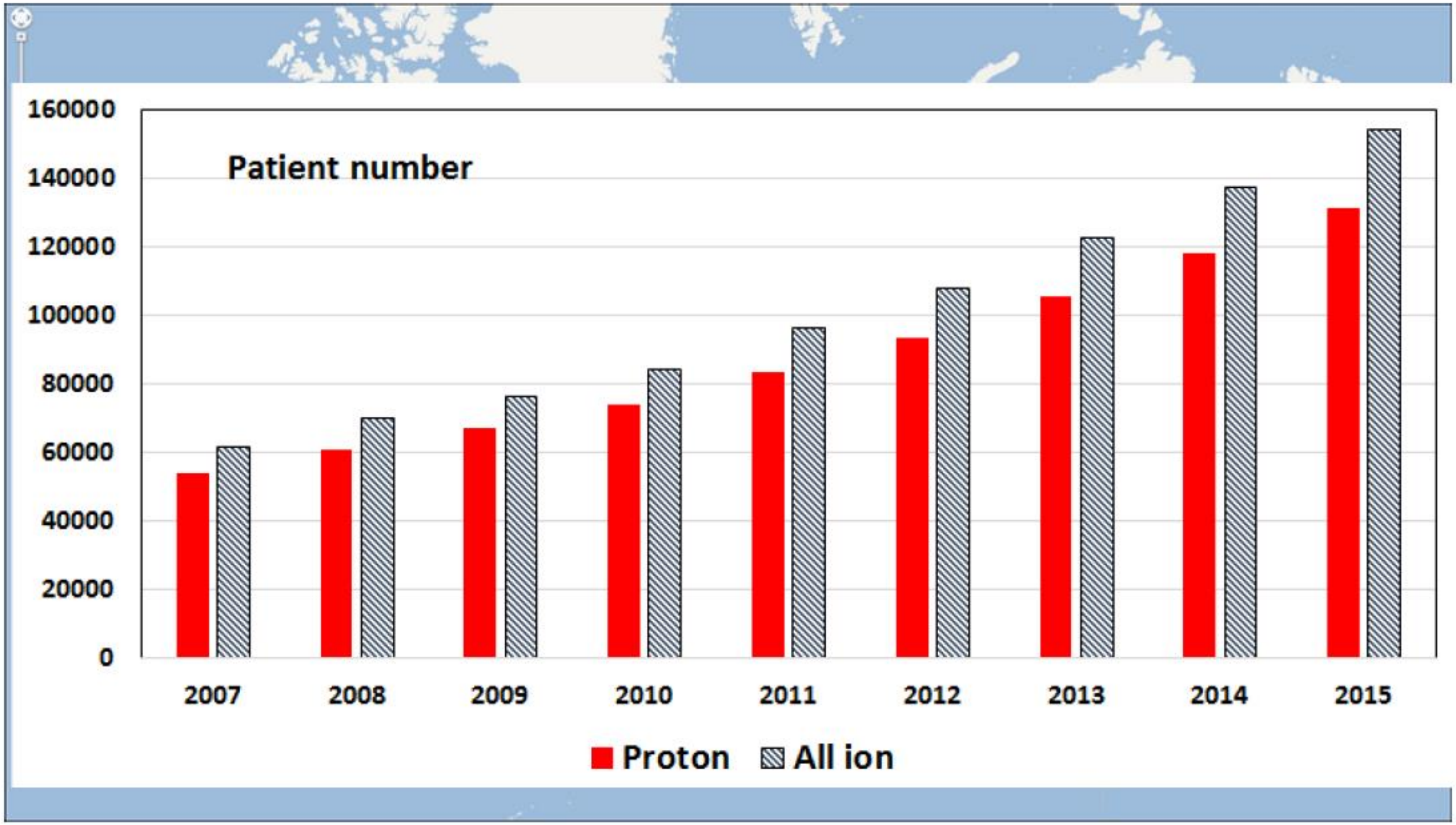


WG3-4

Development of a superconducting cyclotron based Proton therapy system at HUST

Kuanjun Fan
(HUST/Sinap, China)

Proton therapy(PT)



- PTCOG: 67 proton therapy centers are in operation,
- More than 175,000 patients have been treated by ions, and 86% ai treated by proton (150,000).
- About 60 proton therapy centers are under construction or in plan

Wuhan-PTF project

- **HUST organizes a big team to R&D the project**
  - 7 multidisciplinary groups cooperate

華中科技大學
HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

TONGJI XIEHE HGTECH

1. R&D management,
2. General system design; Beam transport line, Gantry, nozzle, control system, safety system, IGPT, TPS...
3. PT center construction
4. Clinical experiment, CFDA certificate...
5. Future industrialization of PT system;

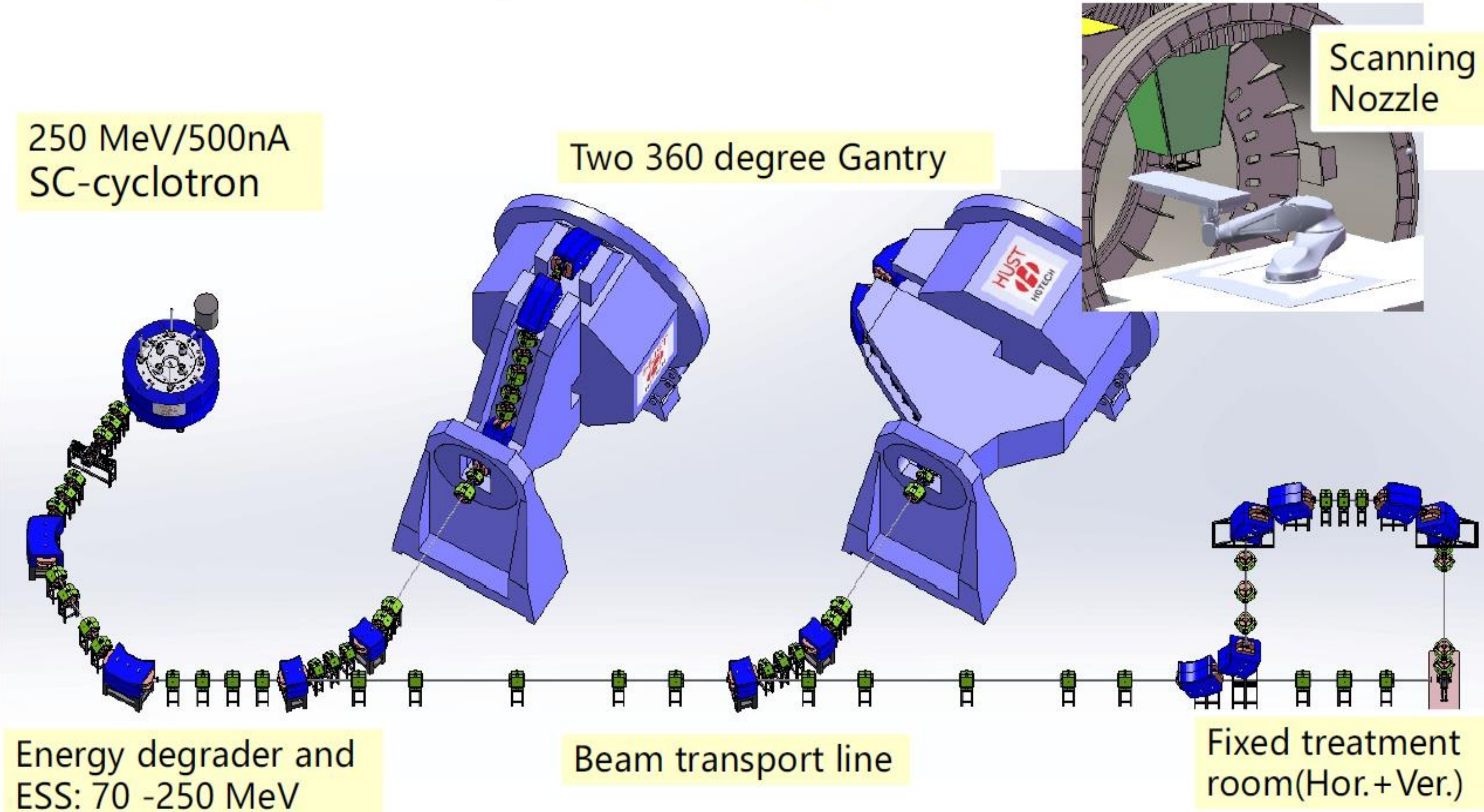
中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

Superconducting cyclotron

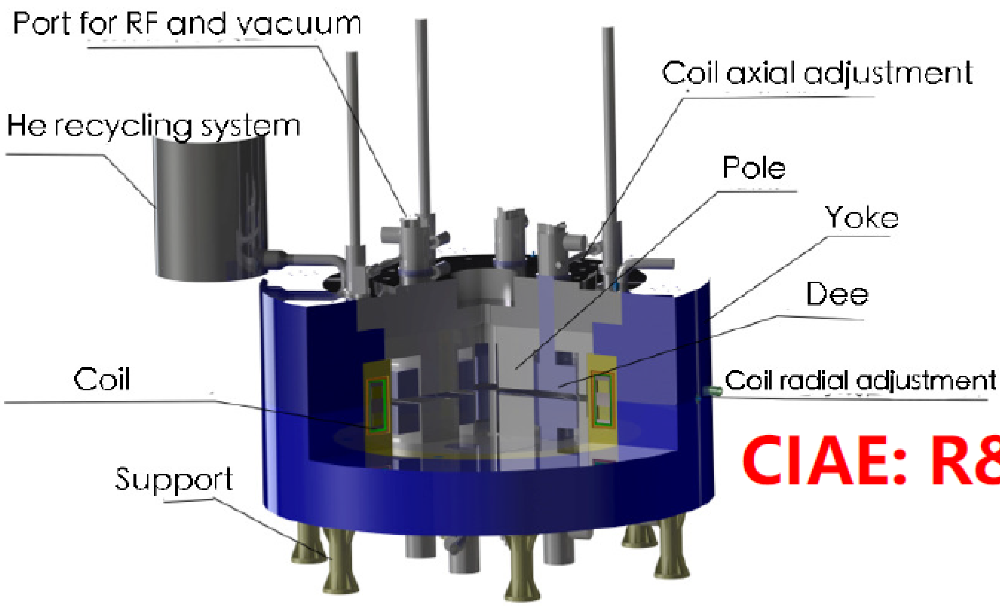
Wuhan-PTF layout

Wuhan-PTF

- **One SC cyclotron, one beam line with ESS system, 2 rotating gantries, one fixed treatment rooms, 2 nozzles with pencil beam scanning;**



SC-cyclotron



CIAE: R&D

□ Parameters:

- Weight: 90 Tons;
- Diameter: 3.5 m
- Max magnetic: 3.2 Tesla;
- RF cavity number: 4
- Beam current: >500 nA;
- Extraction efficiency: >60%

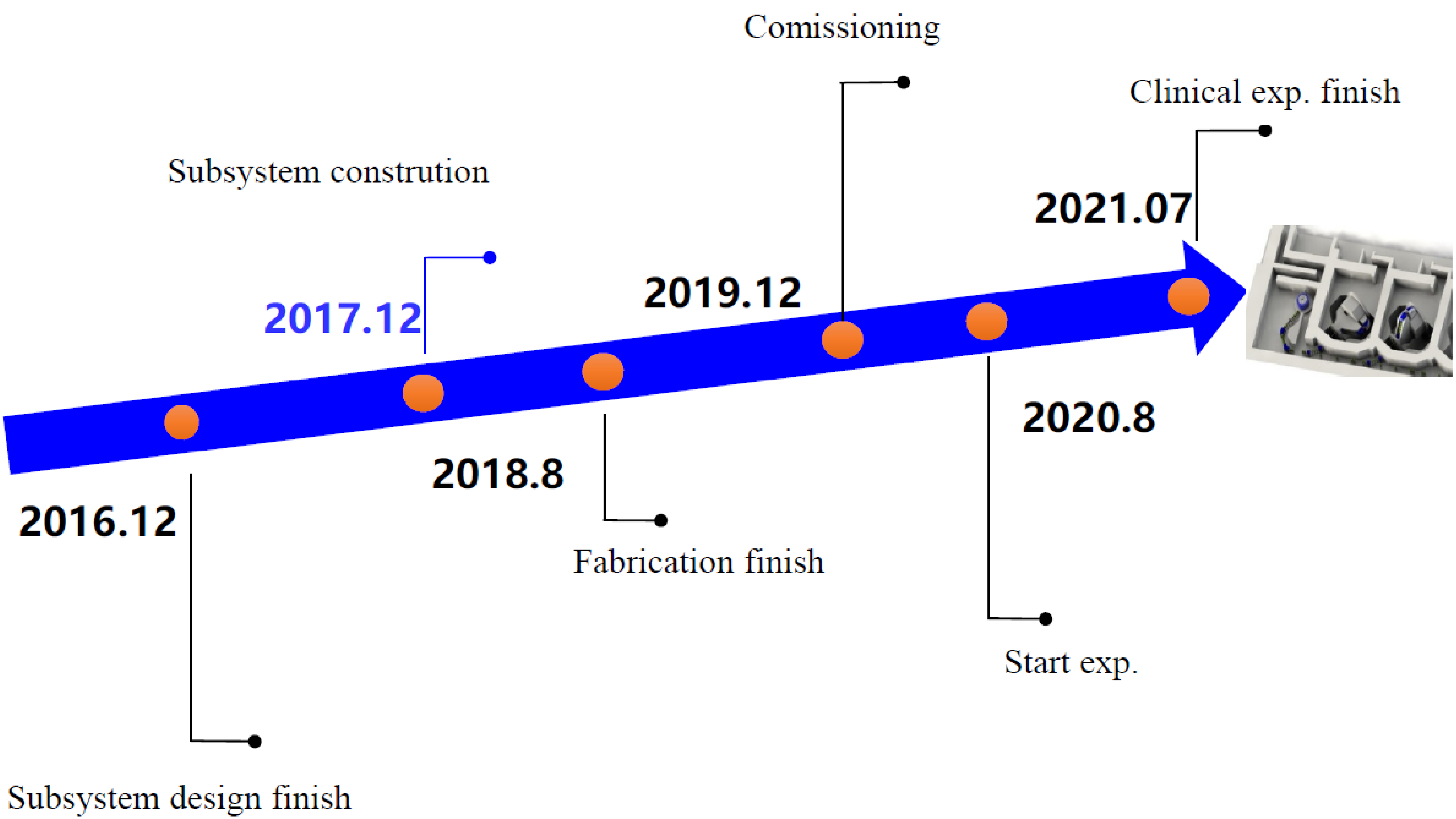
□ SC cyclotron features:

- Compact, energy saving, simplicity, DC-like beam, high stability / reliability,
- Ability to modulate beam intensity rapidly and accurately →IMPT

First trial SC cyclotron R&D in China, challenges are expected.

- Magnet, RF system, cryostat, cold PIG source, compact central region, extraction, quench protection....

Schedule


2016.12
Subsystem design finish
2017.12
Subsystem constrution
2018.8
Fabrication finish
2019.12
Comissioning
2020.8
Start exp.
2021.07
Clinical exp. finish

WG3-6

Towards a Hadron Driver for the Next Generation of Cancer Therapy

Ken Takayama

(KEK/JAPAN)

Takayama: Expected Features in the Future Hadron Therapy

Demand | **Possible solution** | **(detail)** | **Our answer**

(1) Low cost (construction, operation, maintenance)
- Compact and simple driver system → Injector -free
- Gantry-free → Relocation of patient (*)

(2) Higher quality of irradiation
- Net shorter irradiation time → Fast cycling driver
- Precise irradiation → 3D spot scanning on moving target
- Uniformity/concentration on tumor → 3D spot scanning on moving target

(3) Low loss
- Use of Non-destructive device → Energy sweep extraction from a driver

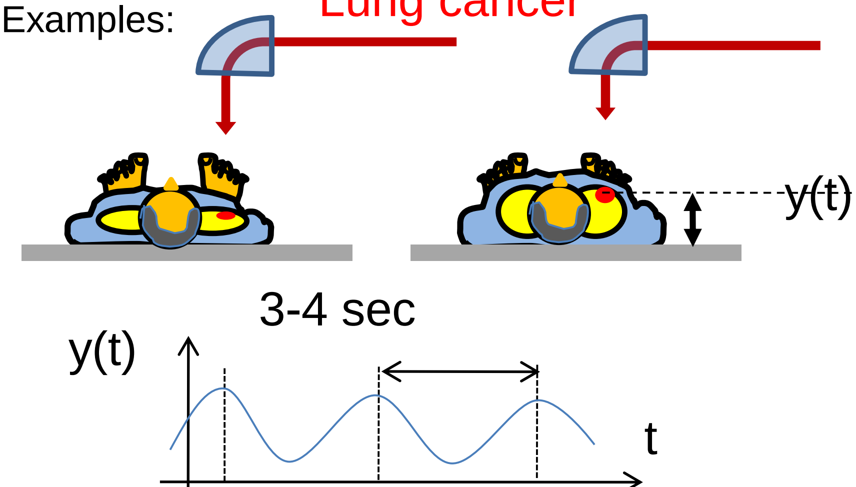
Relocation of patient (*) → Capture of tumor image in a real time

Injector -free, Fast cycling driver, Energy sweep extraction from a driver → **Compact fast cycling induction synchrotron**

Capture of tumor image in a real time → **Real time PET camera**

Examples:

Lung cancer



(*) What happen when a patient body is physically rotated?

Liver cancer

Change in position and deformation due to Gravitation

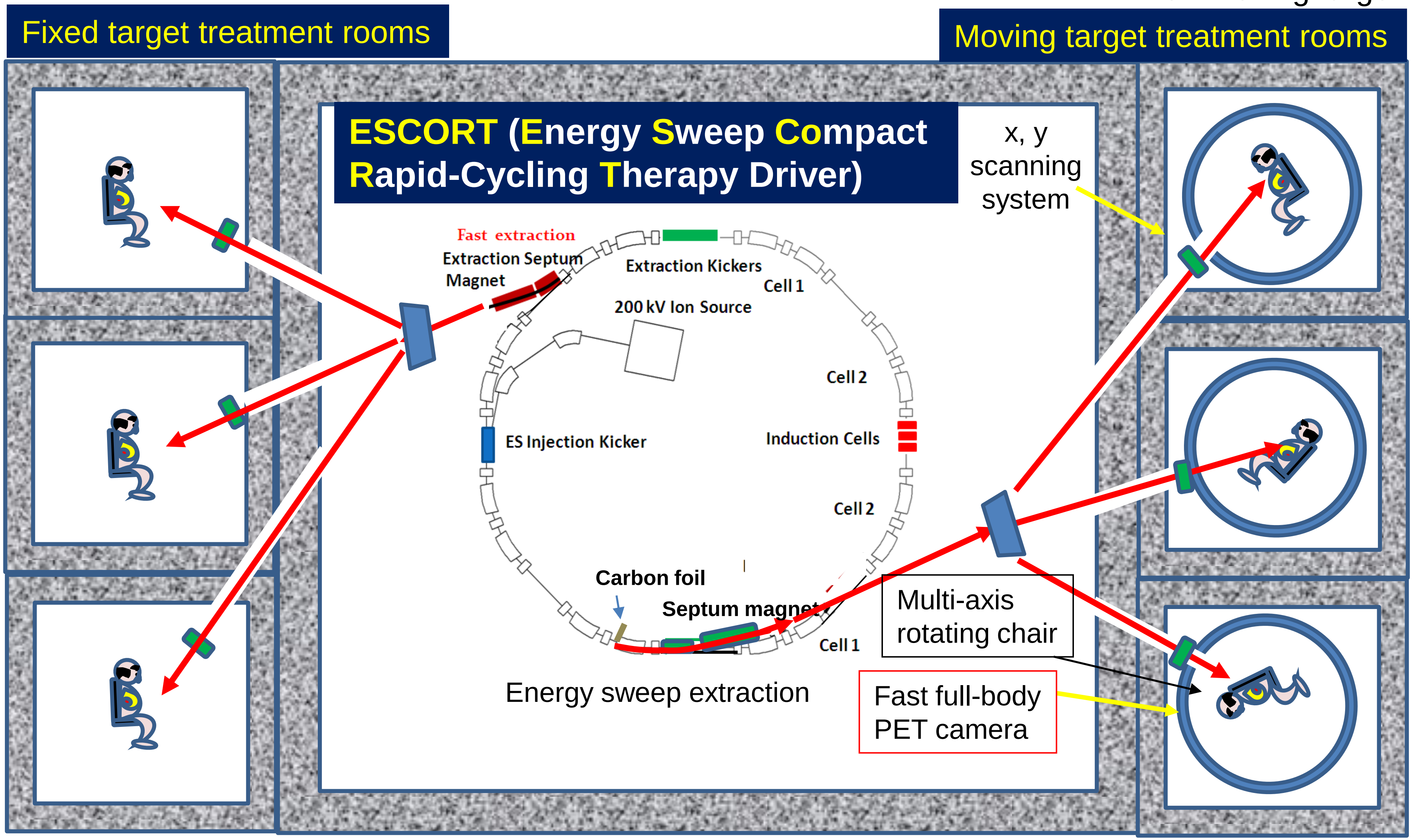
Image of the Next Generation of Hadron Therapy of gantry-free and injector-free, with continuous spot-scanning in the x,y and z directions from 4π angle

Properties:

- Injector-free
- 20 Hz Continuous energy sweep extraction
- Any heavy ions such as p, ^{3}He, C, etc. can be delivered.

➡

- Low cost
- 3D spot scanning on moving target

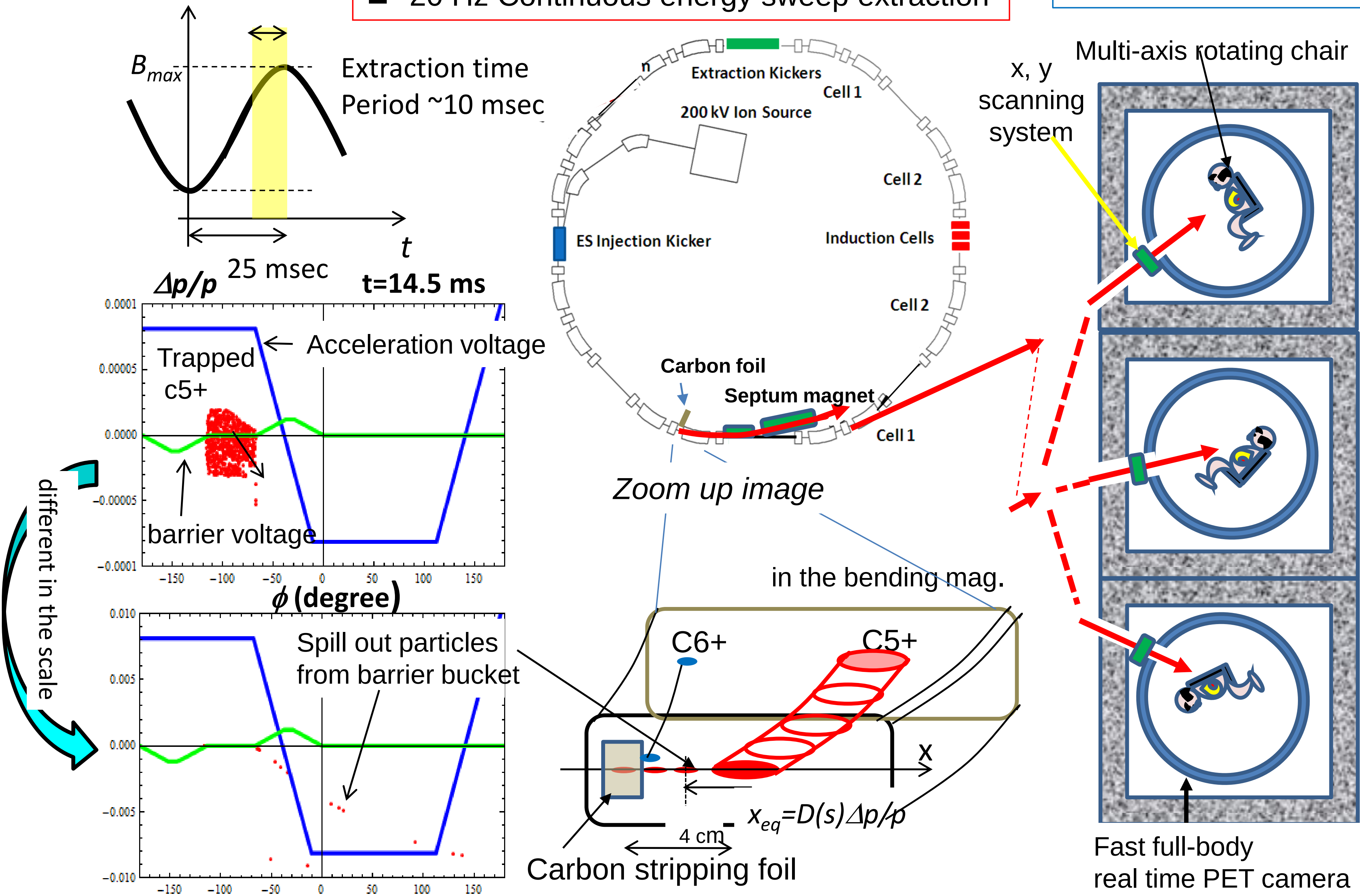


ESCORT (Energy Sweep COmpact Rapid-Cycling Therapy Driver)

Properties

- Injector-free, Induction Synchrotron
- 20 Hz Continuous energy sweep extraction

- Low cost
- 3D spot scanning on moving target



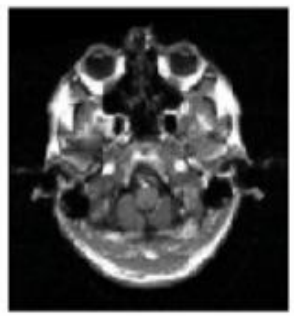
WG3-7

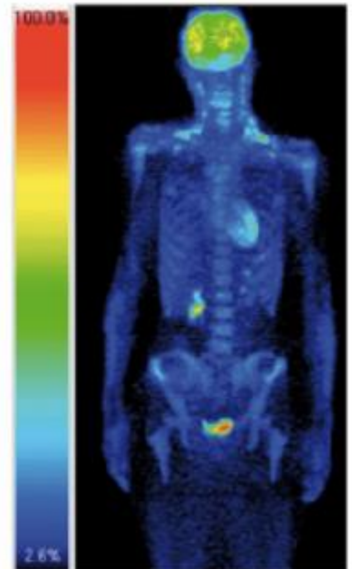
Full-Body PET Camera based on Liq. Xenon TPC technology

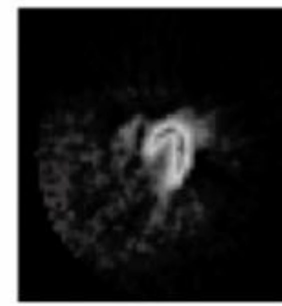
Toshiaki Tauchi
(KEK, Japan)

Various Medical Tomographys

	CT	MRT	PET	SPECT
	Computer-Tomography	Magneto-Resonance-Tomography	Positron Emission Tomography	Single-Photon-Emissions-Computed-Tomography







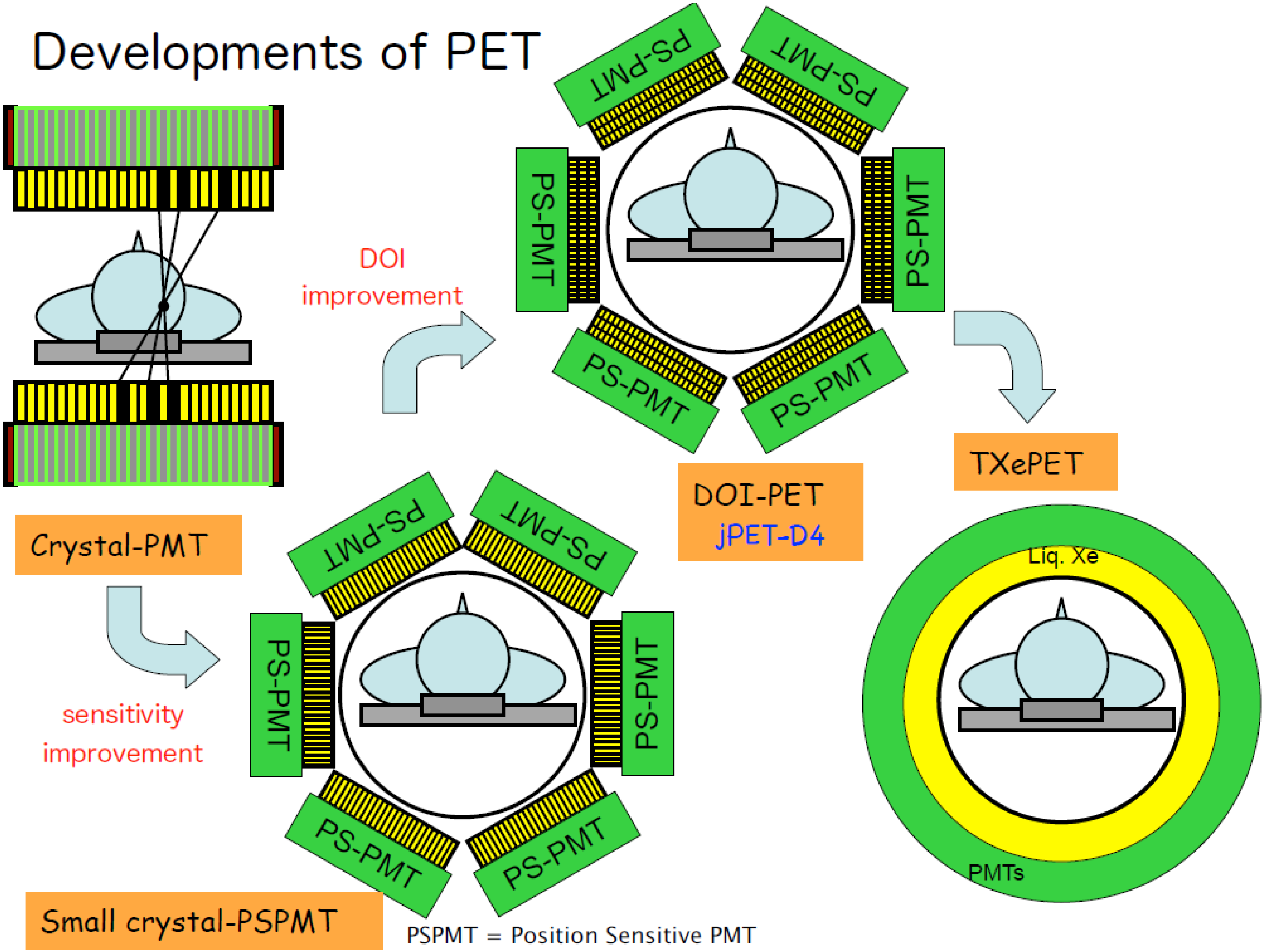
	CT	MRT	FWHM) PET	SPECT
Resolution:	0,5 - 1 mm	1 mm	5 mm	5 mm
Radiation Dose: (flight ~0,05)	~10 mSv	0 mSv	~5 mSv	~3 mSv

(natural annual dose=2.4mSv)

Anatomy
(Anatomical imaging)

Metabolism
(Functional imaging)

Developments of PET



PSPMT = Position Sensitive PMT

TXePET

PET based on TPC in liquid Xenon

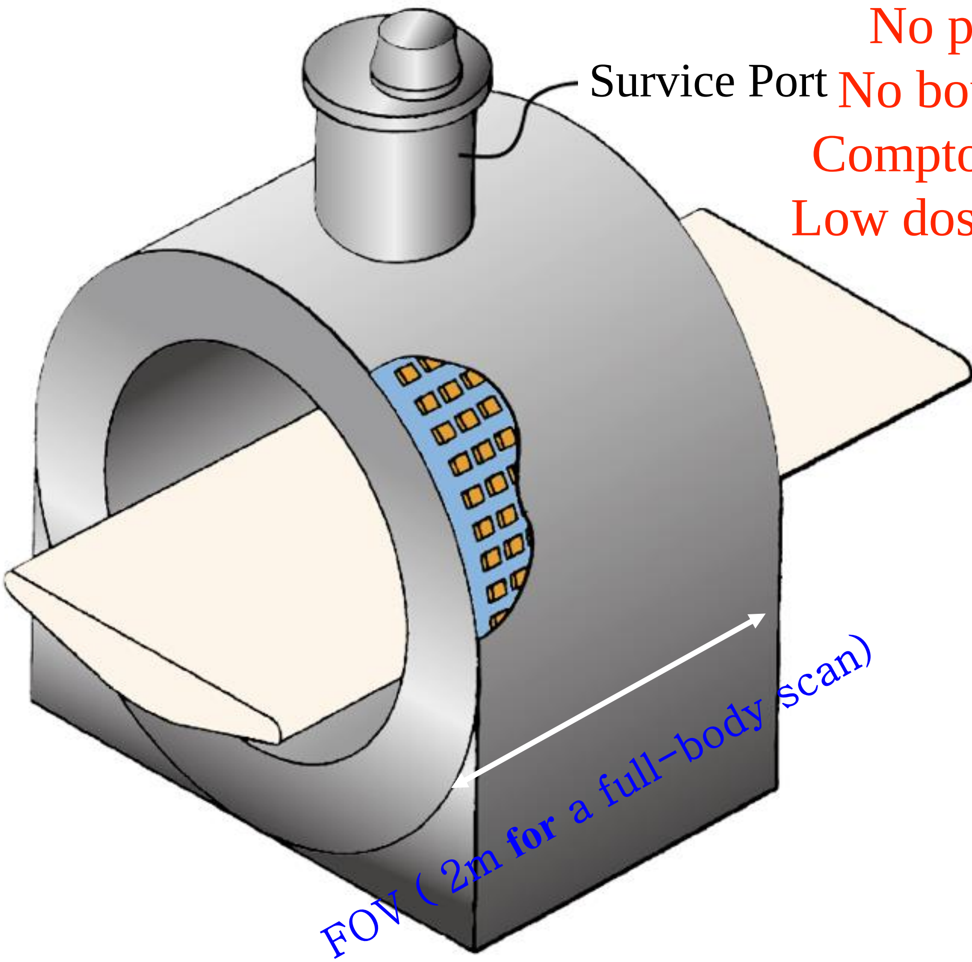
3D position resolution of 1mm^3

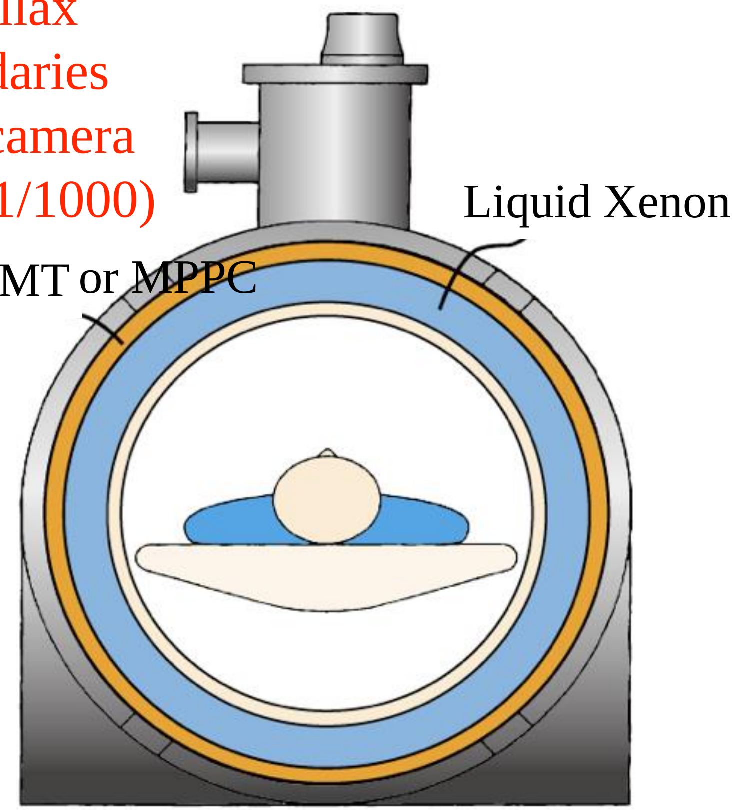
No parallax

No boundaries

Compton camera

Low dose (1/1000)





Prototype of the full-body PET and in-beam imaging

fully implementing the capability of Compton camera

Low activity medical imaging (20kBq injected in a rat) or the imaging time can be <1sec, i.e. realtime imaging ?

Evolution of **XEMIS2 (small animal imaging)**

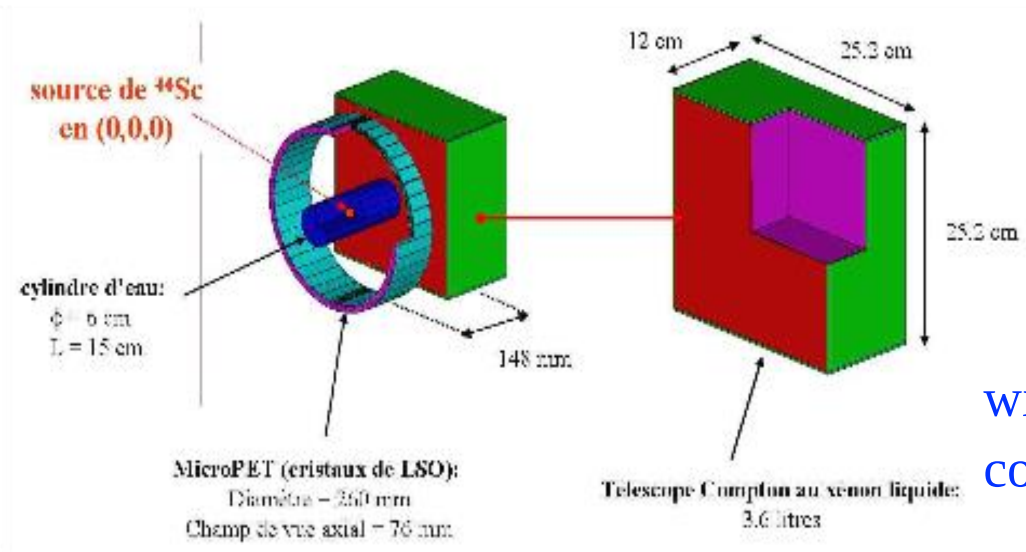
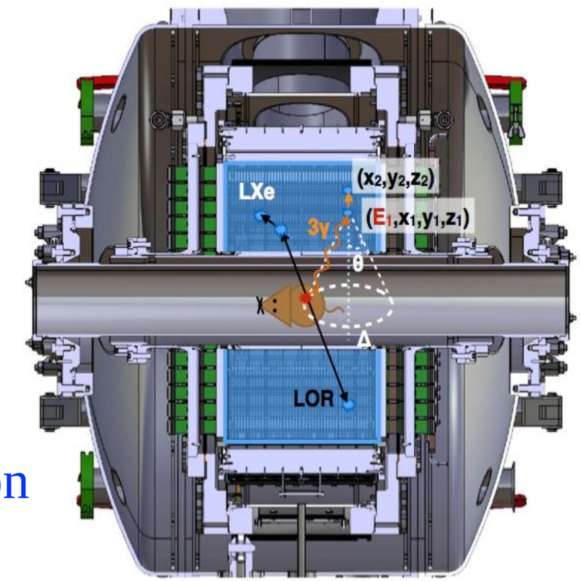


FIG. 6.4 – Représentation du télescope Compton au xénon liquide associé à une micro-TEP au LSO

Subatech group

with KEK collaboration



3γ sensitivity > 7 %

Expected resolution along the LOR = 1cm

Doctor thesis of C.Grignon, Nantes university, 2007, and C.Grignon et al., NIM A571 (2007)142-145

L. Gallego Manzano et al., NIM A787(2015) 89-93

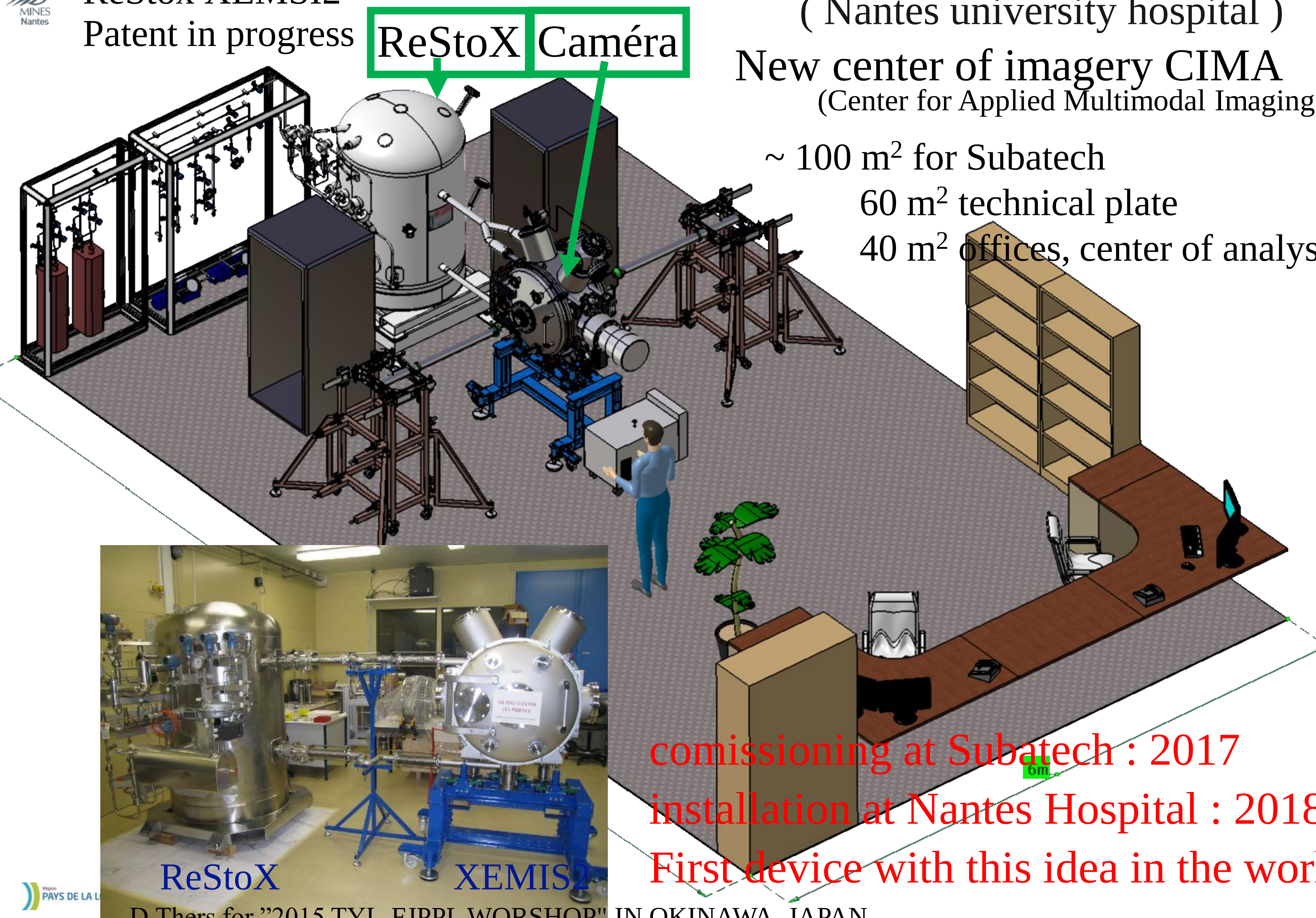
Establishment of XEMIS2 in CHU-Nantes

ReStox XEMSI2
Patent in progress

(Nantes university hospital)

New center of imagery CIMA
(Center for Applied Multimodal Imaging)

~ 100 m² for Subatech
60 m² technical plate
40 m² offices, center of analysis



comissioning at Subatech : 2017
installation at Nantes Hospital : 2018
First device with this idea in the world

WG3-11

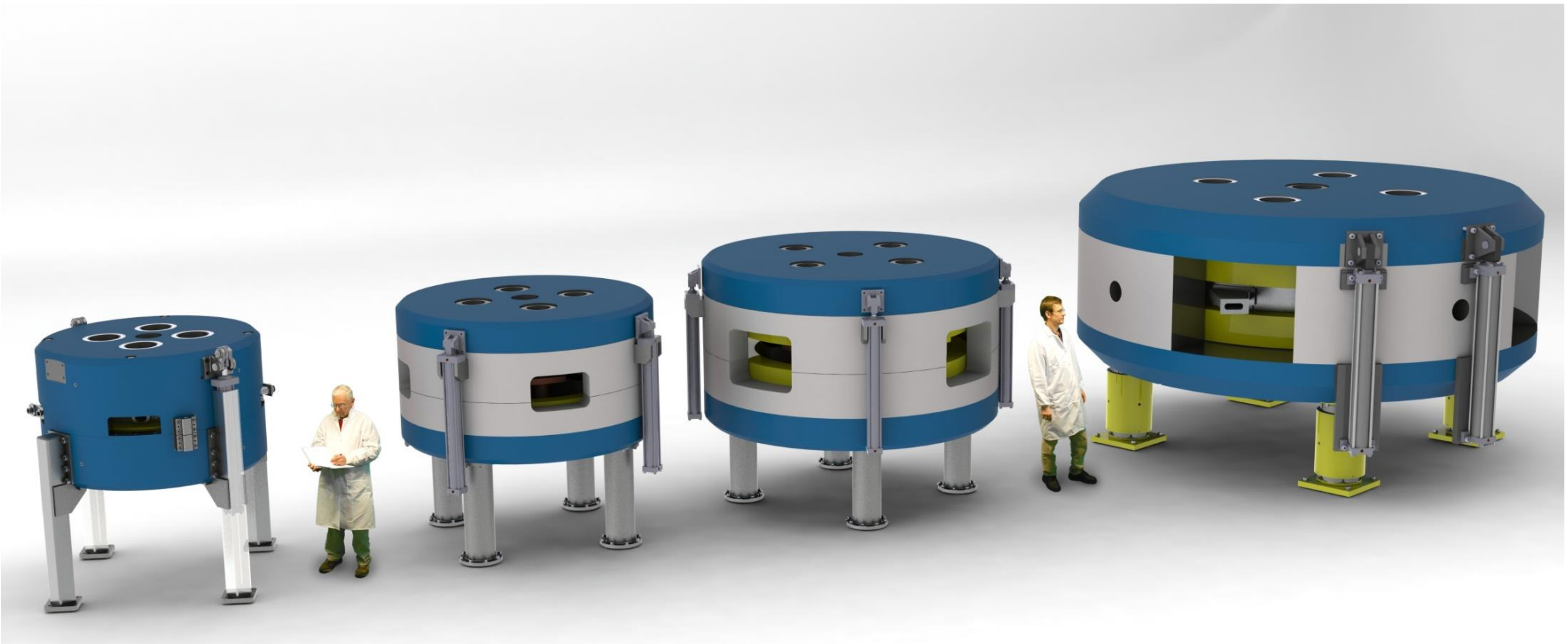
Theranostic Radioisotope production Techniques with High Current Cyclotrons

RR Johnson*

(Univ British Columbia)

Key features for Medical Radioisotope Production with compact cyclotrons

Energy, intensity, targets

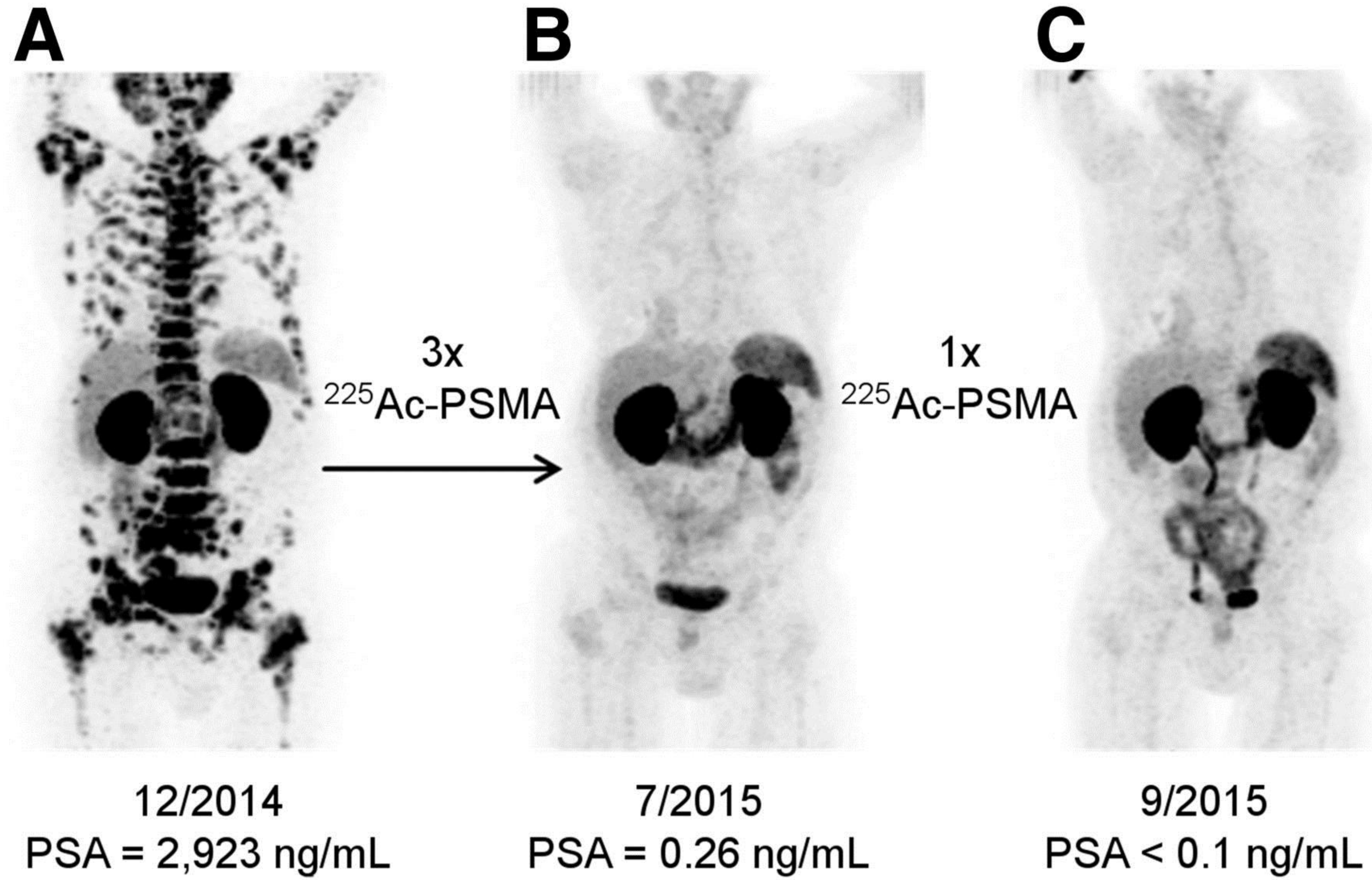


B15 PET
15 MeV
1000 (200} uA +
Targets Radiochem

B25
20-25 MeV
1000 (400)uA +
Targets Radiochem

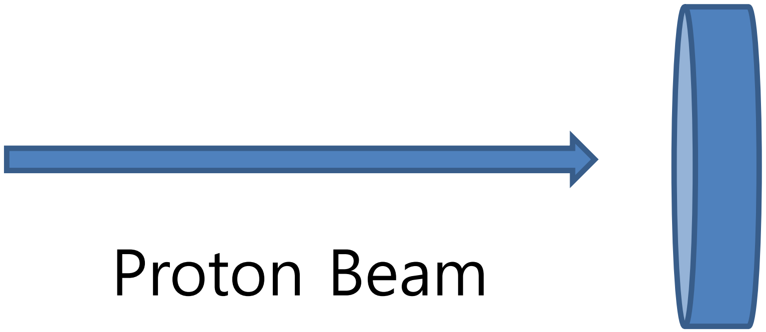
B35 (28)
15-35(28) MeV
1000(400) uA
Targets Radiochem

B70
35-70 MeV
1000 uA
Targets Radiochem



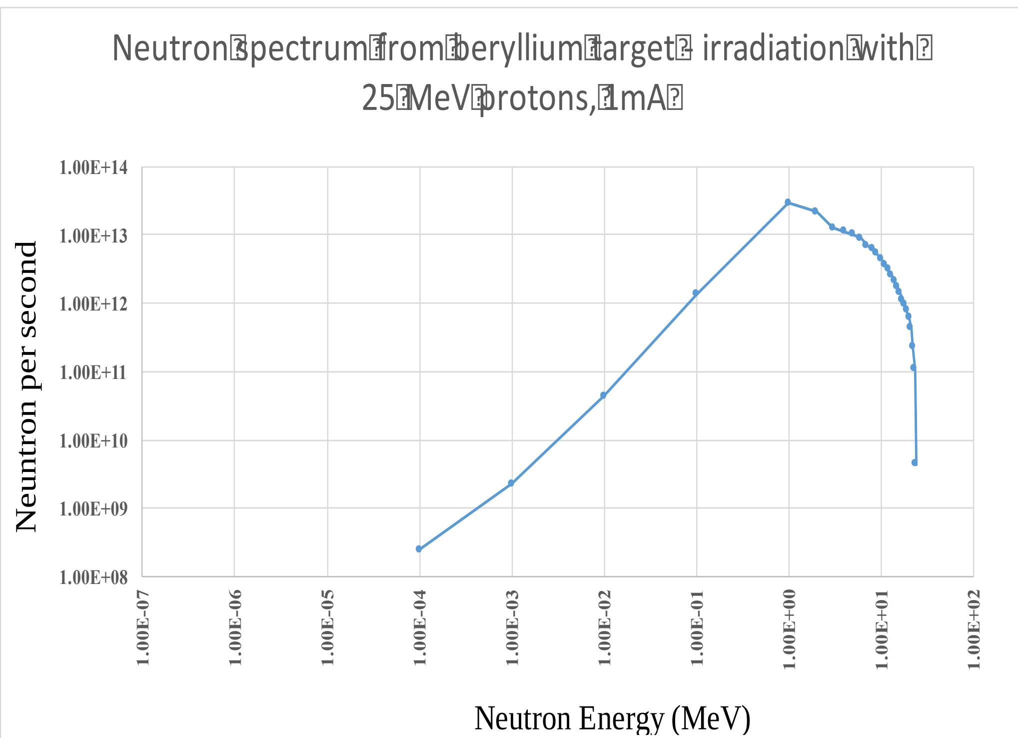
68Ga-PSMA-11 PET/CT scans of patient A. Pretherapeutic tumor spread (A), restaging 2 mo after third cy cle of 225Ac-PSMA-617 (B), and restaging 2 mo after one additional consolidation therapy (C). Clemens K ratochwil et al. J Nucl Med 2016;57:1941-1944

Irradiation at 25 MeV

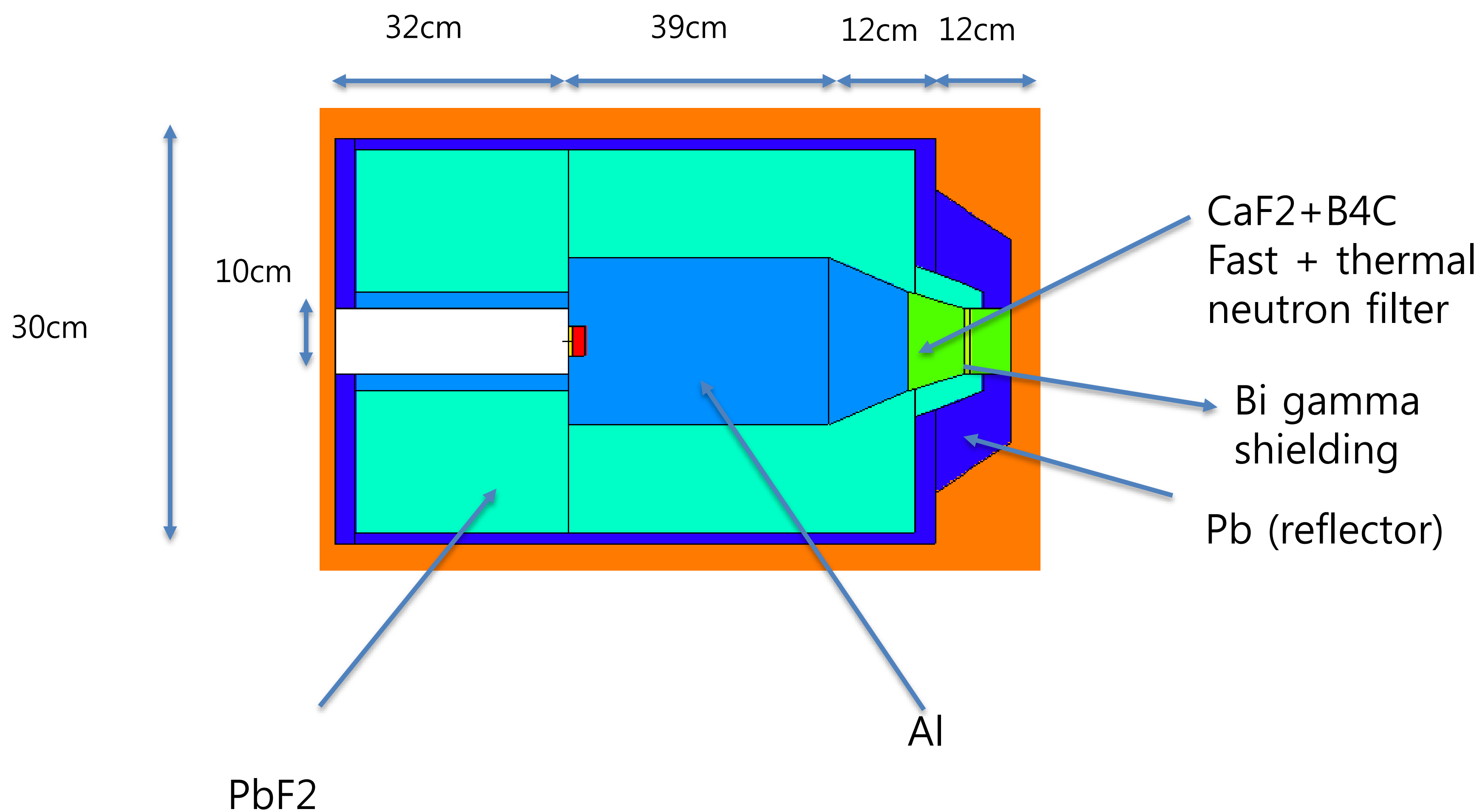


Simulations performed by MCNP6

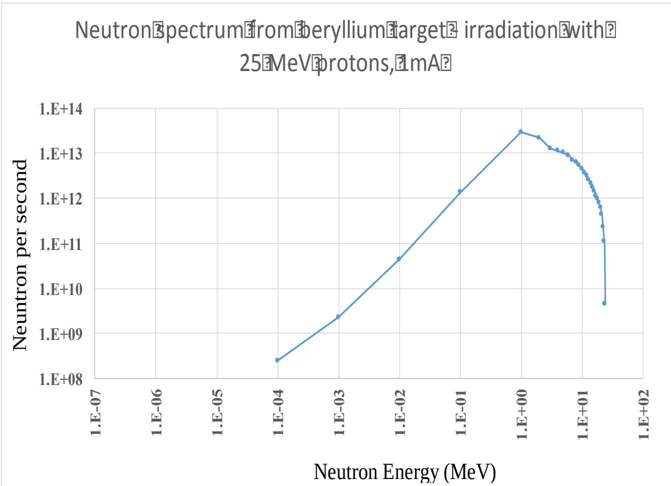
Proton beam energy 25MeV
Target thickness: 3.97mm
Target radius: 2.5cm
Pd Layer: 200 um
Cu cooling bulk: 2cm

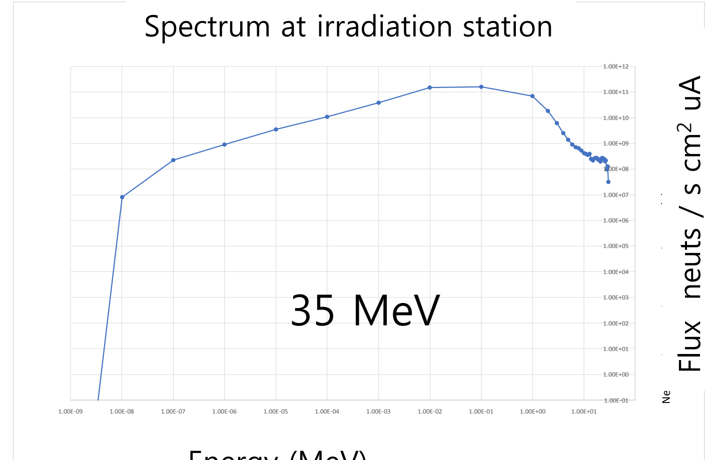


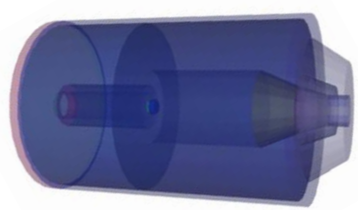
Neutron beam shaper for BNCT



Adjust beam shaper material and geometry to obtain legitimate spectrum



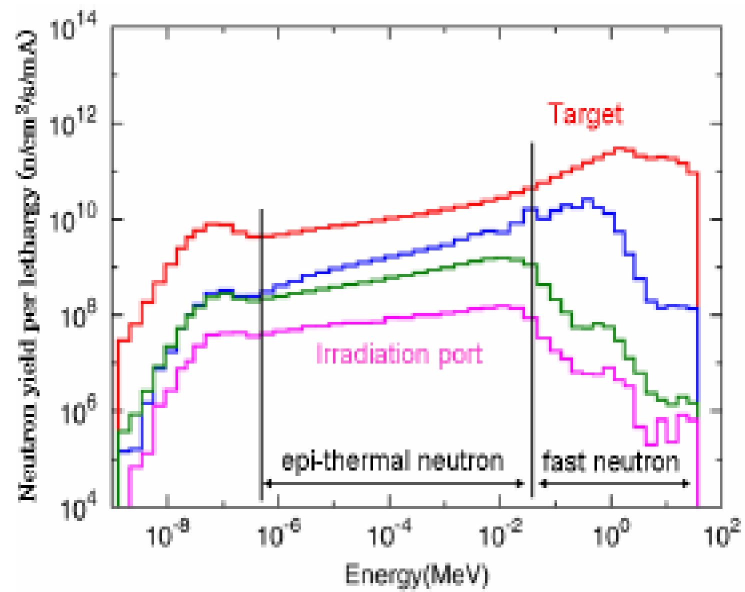




Simulations by MCNP6

A 25 MeV cyclotron may be enough

Still working on it TBA



[T. Mutsimoto et al 2010]

BNCT

WG3-12

Start of Mutation Breeding Research Using Ion Beam in Korea

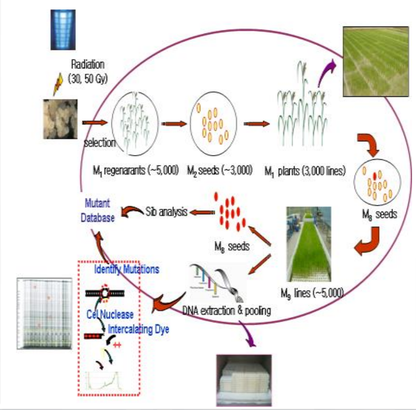
Dr. Si-Yong Kang
(Advanced Radiation Technology, Korea)

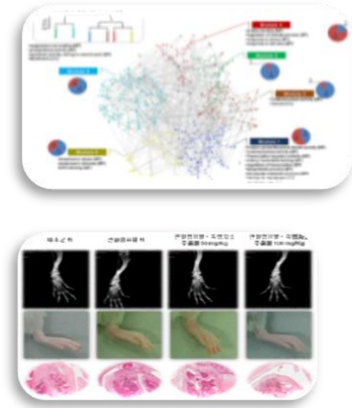
Main Achievements of Mutation Breeding in KAERI with gamma ray and proton

KAERI

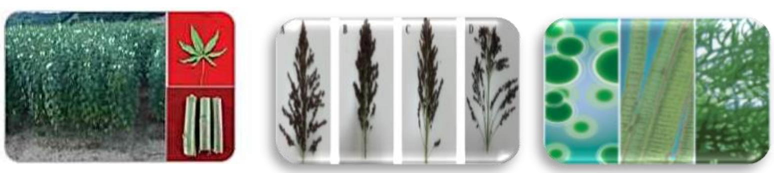
Development of new crop varieties with high function (rice, soybean, perilla, blackberry, etc) and their commercialization

Functional genomics and metabolomics study using various mutant genetic resources





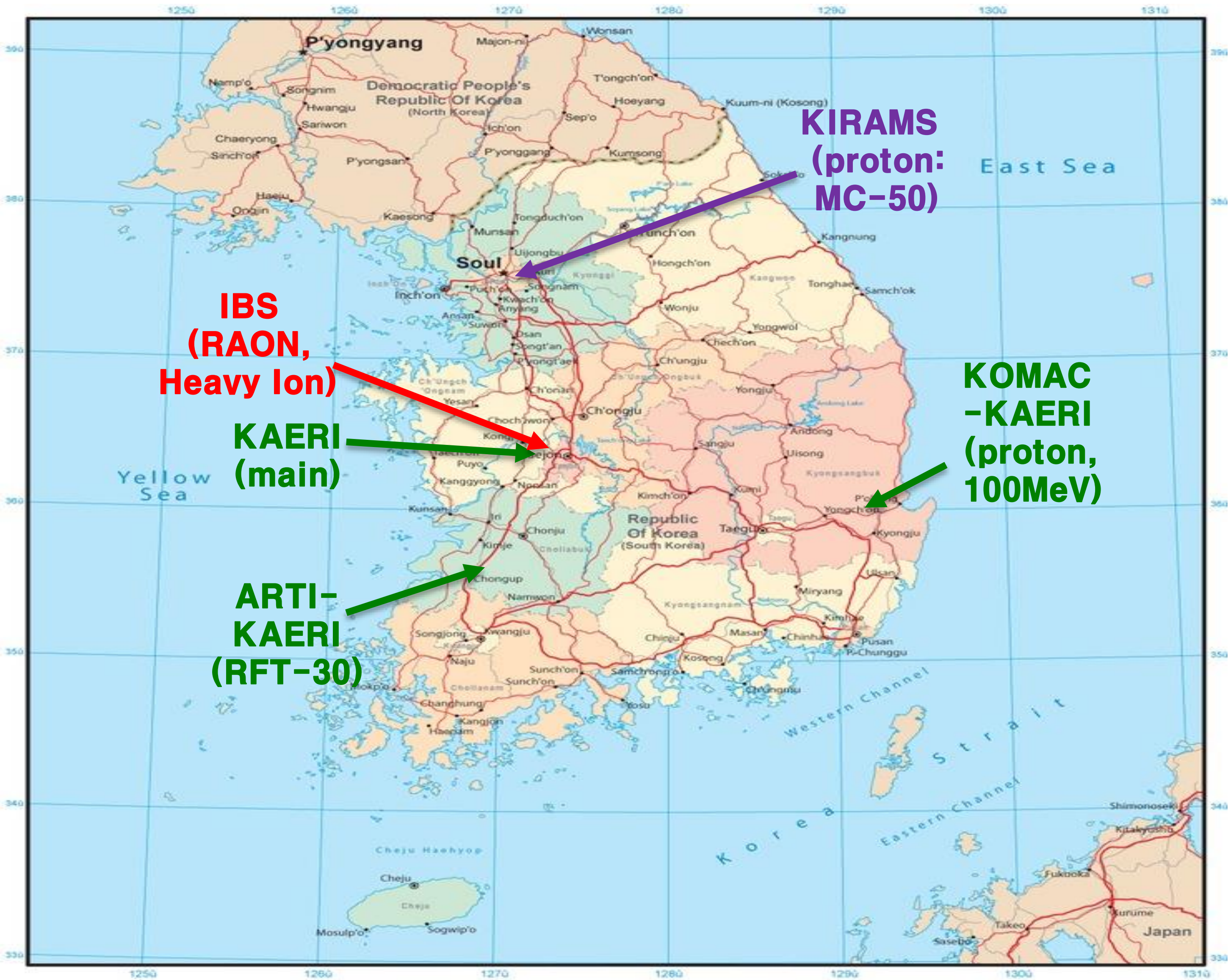
Breeding of bio-energy plants (kenaf, rape, sorghum, algae, etc)



Ornamental plants (orchid, rose, poinsettia, wild flowers, succulent plants, etc) breeding jointed with other research organs

Breeding of chrysanthemum & Korean national flower "hibiscus "

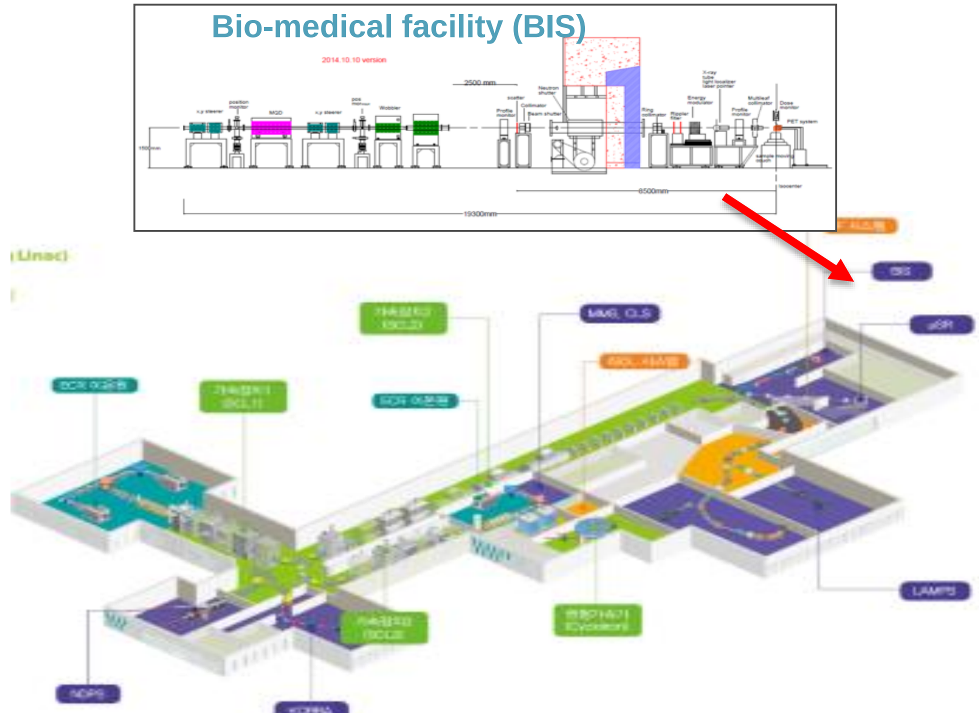
Ion-beam irradiation Facilities in Korea



In future : Heavy Ion Beam Research

- Construction of RAON, heavy ion-beam accelerator project, will be finished in 2021, at Sindong, Daejeon, IBS.
- Suggested to make a beam line for breeding

RAON 조감도



RAON, IBS, Daejeon (2021)

- Comparison of mutation induction rate with other radiations
- Identify of irradiation condition of new heavy ion beam for each plant
- Development of useful new varieties and genetic resources