

PROPOSAL FOR A MULTI-PURPOSE
LIGHT-ION LINEAR ACCELERATOR
FOR NUCLEAR, MEDICAL, AND
APPLIED RESEARCH

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PRE-CONCEPTUAL DESIGN REPORT

Part 1

PRE-CONCEPTUAL DESIGN REPORT

- Preparation of the pre-Conceptual Design Report (pCDR) for a multi-purpose light-ion linear accelerator is underway;
- First draft of the pCDR expected by November 2026.

IFJ PAN Report: Pre-Conceptual Design Report

IFJ-PAN-2026-001

Multi-Purpose Light-Ion Linear Accelerator

Pre-Conceptual Design Report

Editor: D. Bocian

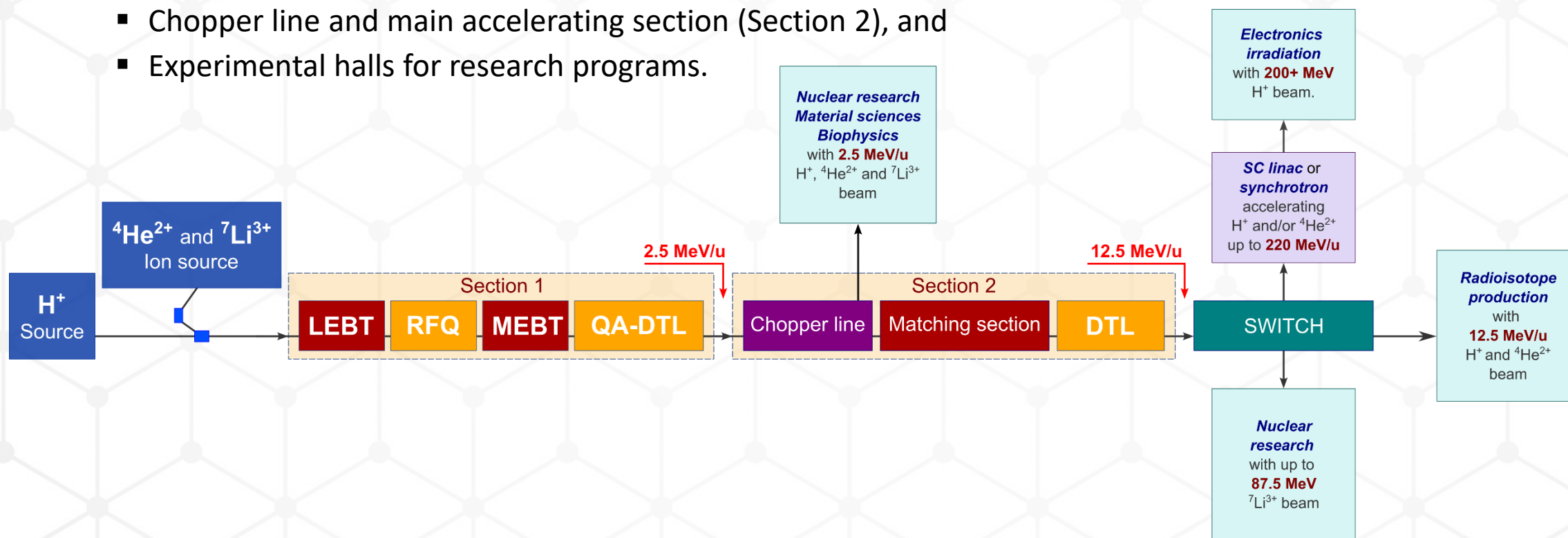
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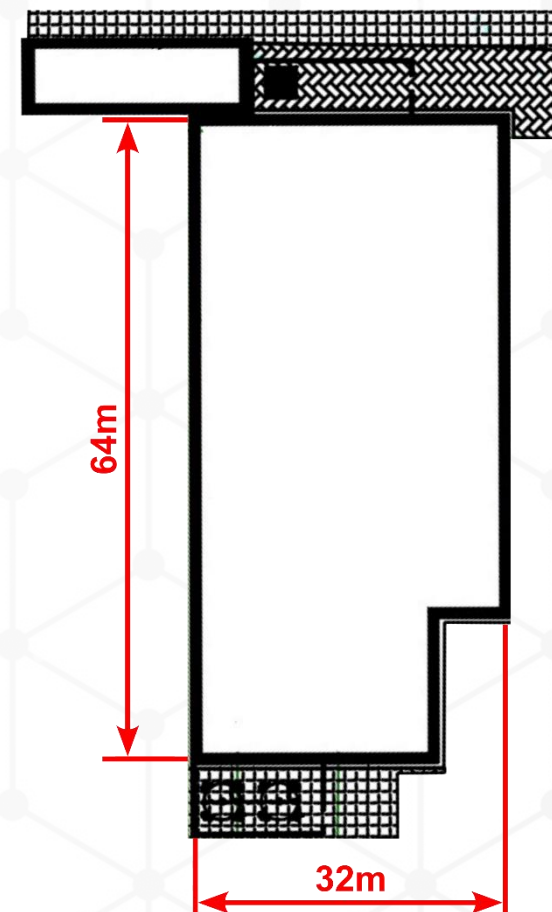
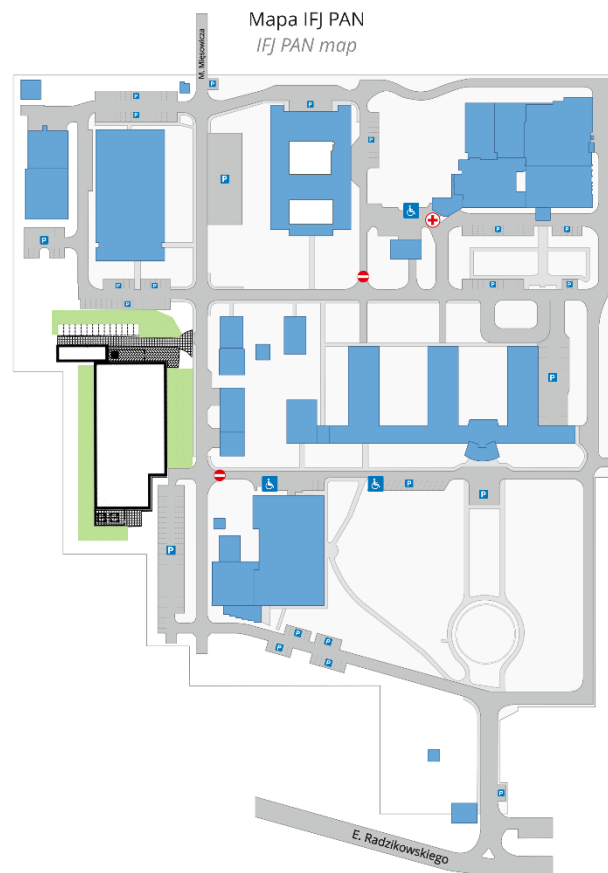
PROPOSED LINAC LAYOUT

- Proposed layout (see Figure):
 - Ion sources,
 - Beam bunching and pre-acceleration section (Section 1),
 - Chopper line and main accelerating section (Section 2), and
 - Experimental halls for research programs.



AVAILABLE SPACE FOR THE LINAC AT IFJ PAN

- The complete linac is estimated to be under 30 m long;
- A **~2000 m²** site at IFJ PAN is available as a potential location for the facility.

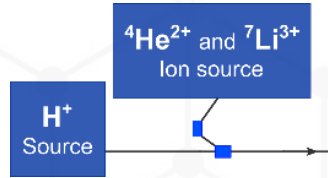




MAIN COMPONENTS OF THE LINEAR ACCELERATOR

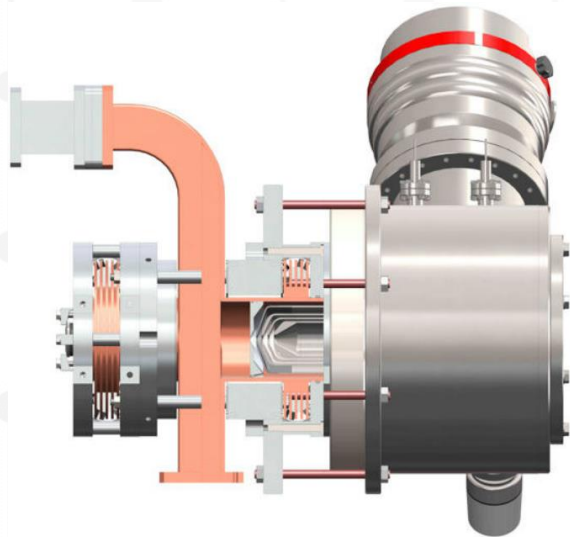
Part 2

ION SOURCES



Monogan M-1000

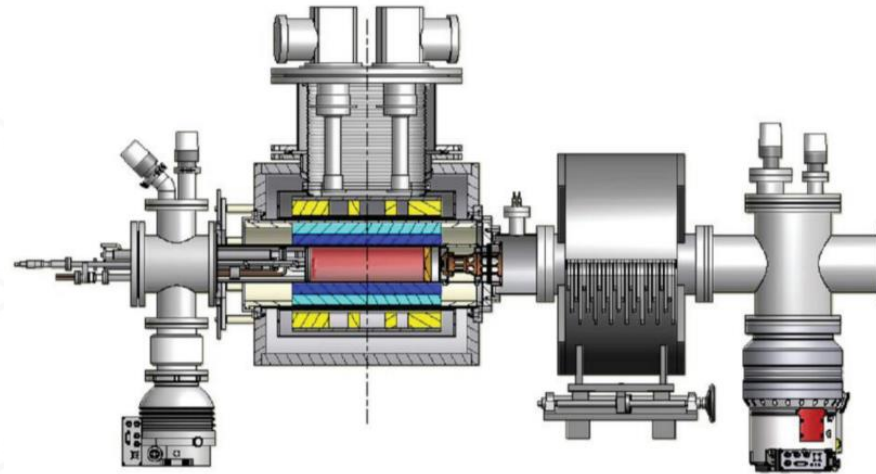
- *Pantechnik, France,*
- 20 mA of protons,
- $0.2 \pi \cdot \text{mm} \cdot \text{mrad}$.



* Geebee International, *Monogan M-1000 – ECR ion source specifications*, <https://www.geebeeinternational.com/products/accelerator-systems/ion-sources/monogan-m-1000-specifications.html>.

AISHa

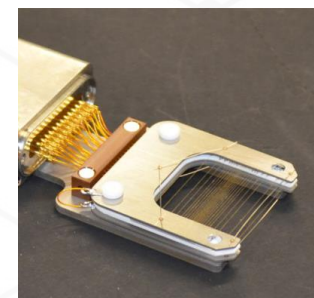
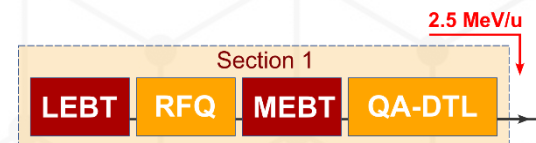
- *INFN-Catania, Italy,*
- 5.4 mA of alphas ($^4\text{He}^{2+}$),
- $0.42 \pi \cdot \text{mm} \cdot \text{mrad}$.
- 0.2 mA of $^7\text{Li}^{3+}$,
- $\sim 0.1-0.2 \pi \cdot \text{mm} \cdot \text{mrad}$.



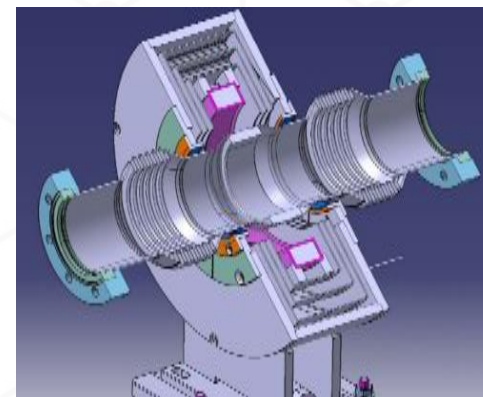
* L. Celona *et al.*, *Design of the AISHa Ion Source for Hadron Therapy Facilities* (ECRIS2012, Sydney, Australia). Sep. 2012.

BEAM TRANSFER LINES - LEBT AND MEBT

- LEBT and MEBT will be equipped with beam diagnostics to monitor key parameters: intensity, position, transverse profile and emittance;
- Purpose:
 - Compare calculated and measured beam parameters during commissioning,
 - Monitor and tune beam parameters during regular operation.
- Considered instrumentation:
 - Faraday cup – total beam current (destructive),
 - Beam current transformer (BCT) – total beam current (non-destructive),
 - Beam position monitor (BPM) – transverse beam position,
 - Wire grid – transverse profile,
 - Pepper-pot – transverse emittance.



(Wire grid, used for transverse profile measurements)

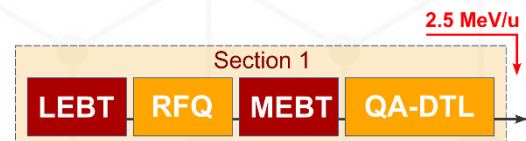


(Beam current transformer)



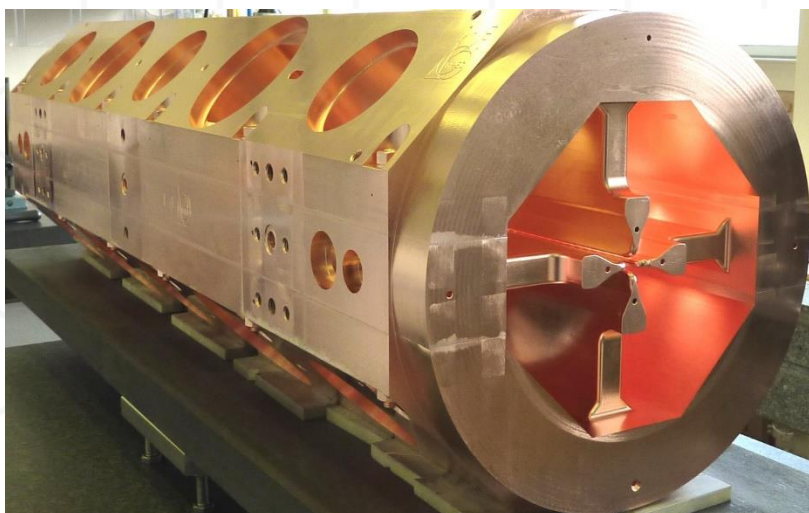
(Beam position monitor)

SECTION 1 - RFQ AND QA-DTL



Radio-Frequency Quadrupole (RFQ)

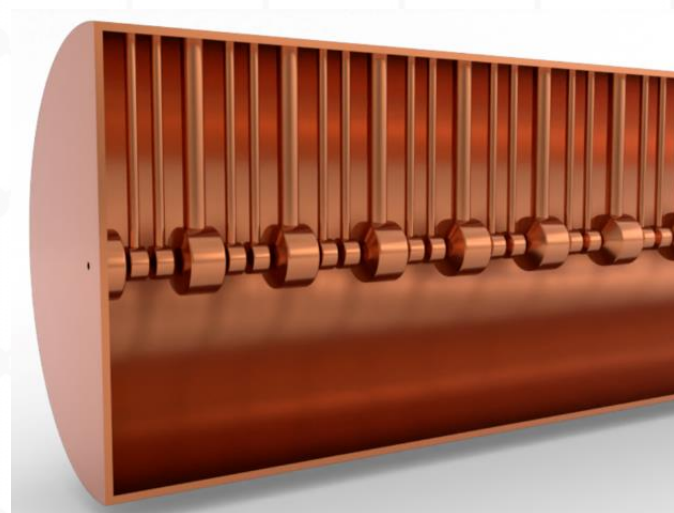
- Beam bunching,
- Initial acceleration.



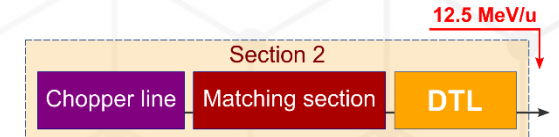
* S. Mathot et al., *Mechanical Design, Brazing and Assembly Procedures of the Linac4 RFQ* (IPAC2010, Kyoto, Japan). May. 2010.

Quasi-Alvarez Drift Tube Linac (QA-DTL)

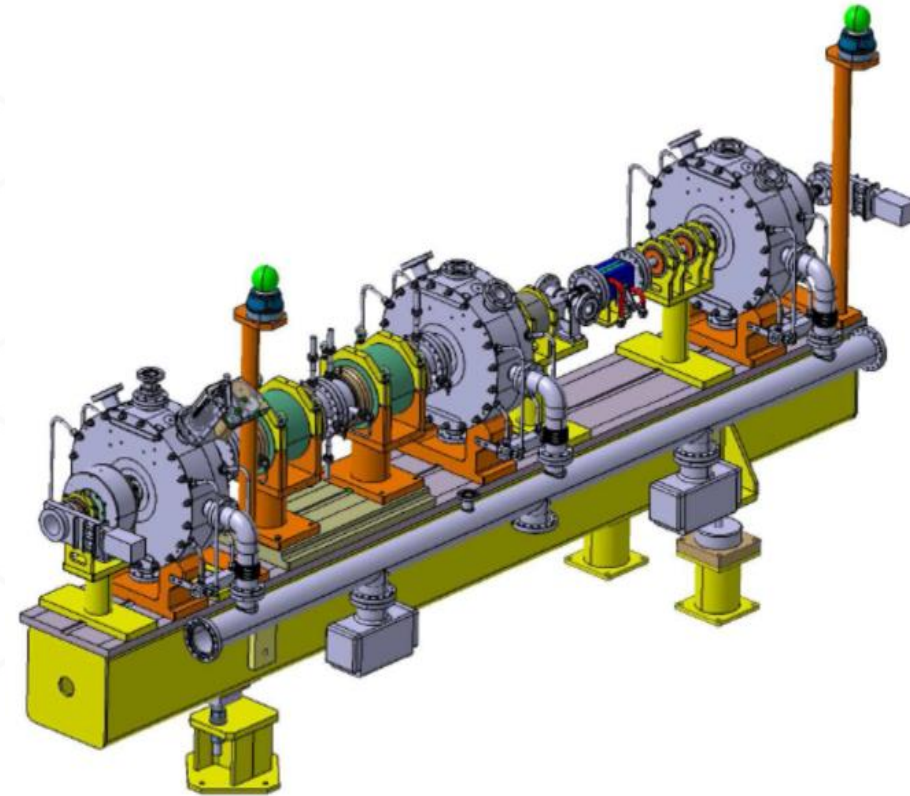
- Acceleration of low-velocity ions,
- Keeps the RFQ short → reduces cost.



SECTION 2 - CHOPPER LINE & MATCHING SECTIONS

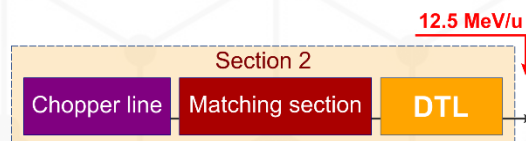


- Foreseen components of the chopper line and matching sections:
 - Upstream matching section (4 quadrupoles & 1 bunching cavity),
 - Beam chopper (2 quadrupoles with chopper plates),
 - Transport line for chopped beam (bunching cavity, quadrupole & beam dump),
 - Downstream matching section (4 quadrupoles & 1 bunching cavity).



* M. Vretenar *et al.*, *Linac4 Design Report* (CERN Yellow Reports: Monographs). Sep. 2020, vol. 6/2020.

SECTION 2 = DTL

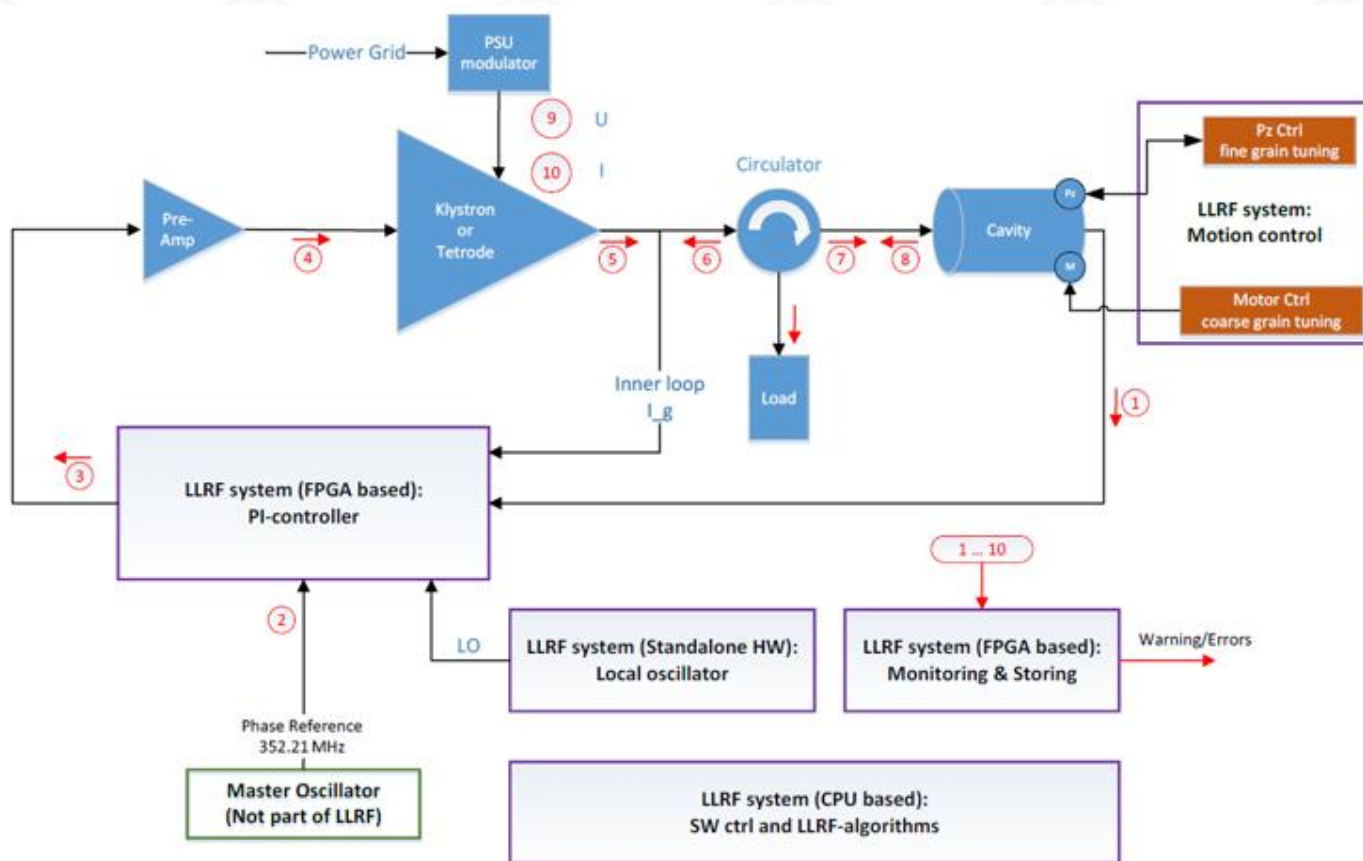


Alvarez Drift Tube Linac (DTL)

- Main accelerating cavity;
- Follows the chopper line;
- Requires a matching section at its entrance;
- Accelerates the desired particles (H^+ , ${}^4He^{2+}$ and ${}^7Li^{3+}$) up to 12.5 MeV/u;
- Electromagnetic over permanent magnet quadrupoles \rightarrow tunable focusing gradients during operation (required when switching between ion species).



RF POWER GENERATION AND LOW-LEVEL RF SYSTEM



* K. Klys et al., *EPICS Based Tool for LLRF Operation Support and Testing* (ICALEPCS2023, Cape Town, South Africa). Oct. 2023.



RESEARCH PROGRAMS

Part 3

RESEARCH PROPOSALS AND THEIR FEASIBILITY

A collection of 19 project proposals from 15 principal investigators at IFJ PAN, spanning fundamental nuclear physics, medical applications, materials science/biophysics, electronics irradiation, and radiochemistry!

- Proposals cover all major research directions, confirming a need for a versatile light-ion facility;
- 13 of 19 proposals (~68%) are fully or partially feasible with the currently proposed linac (H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 2.5 and 12.5 MeV/u);
- Deuterons (${}^2H^+$) recur across several proposals;
- The 6 currently unfeasible projects require higher energies (~100-300 MeV), continuously variable energy, or additional ion species (e.g. ${}^{12}C^{6+}$) → precisely the capabilities of the planned future upgrade.

No.	Project name	Principal Investigator	Application Category	Primary Particle	Acceleration Stage	Possibility with currently proposed linac
1	Investigation of Nuclear Two-Photon (2 γ) Decay in Even-Even Nuclei via Proton Excitation of O_2^+ State	Michał Ciemala	Fundamental Nuclear Physics	H^+	Variable 2.5 - 12.5 MeV (non-negotiable req.)	NO
2	Study of fission processes induced by protons, alpha particles, and heavy ions	Michał Ciemala	Fundamental Nuclear Physics	H^+ , ${}^4He^{2+}$, heavy ions	Variable 20 - 200 MeV, 12.5 MeV, 250 MeV	Partially, H^+ , ${}^4He^{2+}$ at 12.5 MeV/u
3	Measurement of proton or alpha beam excited giant resonances (GDR, GQR) gamma-ray decay	Maria Kmiecik	Fundamental Nuclear Physics	H^+ , ${}^4He^{2+}$	250 MeV, 20 - 80 MeV of ${}^4He^{2+}$, 100 - 250 MeV of H^+	Partially, (maybe) ${}^4He^{2+}$ at 20 - 50 MeV
4	Gamma spectroscopy of the nuclei produced in fast-neutron-induced fission reaction	Łukasz Iskra	Fundamental Nuclear Physics	H^+ , ${}^7Li^{3+}$	2.5 MeV of H^+ , 25 - 50 MeV of ${}^7Li^{3+}$	Partially, H^+ at 2.5 MeV, and (maybe) ${}^7Li^{3+}$ at 35 - 50 MeV
5	Half-life measurements of long-lived isotopes	Łukasz Iskra	Fundamental Nuclear Physics Material Science / Biophysics	${}^7Li^{3+}$	2.5 MeV/u, 12.5 MeV/u, 25 - 50 MeV	Partially, (maybe) ${}^7Li^{3+}$ at 35 - 50 MeV
6	Measurements of stretched resonances decays in light atomic nuclei	Natalia Cieplicka-Oryńczak	Fundamental Nuclear Physics	H^+	Variable 100 - 150 MeV	NO
7	Discrete gamma-ray spectroscopy in light ion beam-induced reactions	Magdalena Matejska-Minda	Fundamental Nuclear Physics	${}^4He^{2+}$, ${}^{16}O^{8+}$	12.5 MeV/u	Partially, ${}^4He^{2+}$ at 12.5 MeV/u
8	Few nucleon system dynamics	Adam Kozela	Fundamental Nuclear Physics	H^+ , ${}^2H^+$, ${}^3He^{2+}$	250 MeV/u	NO
9	Production of radionuclides	Jerzy Mietelski	Medical Applications Analytic Radiochemistry	H^+ , ${}^2H^+$, ${}^4He^{2+}$, ${}^7Li^{3+}$, heavy ions	12.5 MeV/u, 250 MeV/u	Partially, H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 12.5 MeV/u
10	Hadron particle electronic irradiation facility	Jan Swakoń	Electronics Irradiation	H^+ , ${}^4He^{2+}$	250 MeV/u	NO
11	New methods for hadron radiotherapy	Jan Swakoń	Fundamental Nuclear Physics Medical Applications Electronics Irradiation Material Science / Biophysics	H^+ , ${}^4He^{2+}$, ${}^{12}C^{6+}$	60 - 250 MeV of H^+ , 30 - 230 MeV/u of ${}^4He^{2+}$, 400 MeV/u of ${}^{12}C^{6+}$	NO
12	Neutron dosimetry and applications in the energy range from fast to thermal neutrons	Jan Swakoń	Medical Applications	H^+	2.5 MeV, 250 MeV	Partially, H^+ at 2.5 MeV
13	Studies of irradiation-induced defects in materials	Paweł Horodek	Material Science / Biophysics	H^+ , ${}^2H^+$, ${}^4He^{2+}$, ${}^7Li^{3+}$	2.5 MeV/u, 12.5 MeV/u	Partially, H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 2.5 MeV/u, and H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 12.5 MeV/u
14	Influence of irradiation on the magnetic properties of coordination polymers	Piotr Konieczny	Material Science / Biophysics	H^+ , ${}^2H^+$, ${}^4He^{2+}$, ${}^7Li^{3+}$, heavy ions	2.5 MeV/u, 12.5 MeV/u	Partially, H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 2.5 MeV/u, and H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 12.5 MeV/u
15	Radiobiological response to proton irradiation enhanced by metallic nanoparticles	Bartosz Klębowski	Medical Applications	H^+	12.5 MeV, 250 MeV, Variable 5 - 12 MeV	Partially, H^+ at 12.5 MeV/u, and (maybe) H^+ at 5 - 12.5 MeV
16	High Resolution Proton Induced X-Ray Emission (HR-PIXE) for the application in biological and chemical studies	Joanna Czapla	Material Science / Biophysics	H^+	2.5 MeV	YES
17	Implementation of beam energy and energy spread diagnostics	Wiktor Parol	Fundamental Nuclear Physics Medical Applications Electronics Irradiation Material Science / Biophysics	H^+ , ${}^2H^+$	Variable 10 - 300 MeV/u	NO
18	Investigation of Radiation Hardening in Metastable Materials for Cryogenic Applications	Błażej Skoczen	Material Science / Biophysics	H^+ , ${}^2H^+$, ${}^4He^{2+}$, ${}^7Li^{3+}$	2.5 MeV/u, 12.5 MeV, 250 MeV/u	Partially, H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 2.5 MeV/u, and H^+ , ${}^4He^{2+}$, ${}^7Li^{3+}$ at 12.5 MeV/u
19	User-driven research needs for neutron and proton-based studies using the IFJ PAN LINAC	Konrad Szaciłowski	Material Science / Biophysics	H^+	1 - 3 MeV	YES

RADIOISOTOPE PRODUCTION (MEDICAL APPLICATION)

Purpose	Order	Short	Long	Reactions	Energies [MeV]	References
PET	1	⁶⁴ Cu	Copper-64	⁶⁴ Ni(p,n) ⁶⁴ Cu	9 - 12	[1][2]
	2	¹⁸ F	Flourine-18	⁶⁴ Ni(p,n) ⁶⁴ Cu	11	[3]
	3	⁶⁸ Ga	Gallium-68	¹⁶ O(α, np) ¹⁸ F	40	[4]
	4	¹²⁴ I	Iodine-124	⁶⁸ Zn(p, n) ⁶⁸ Ga	12.5	[5][6]
	5	⁸⁹ Zr	Zirconium-89	¹²⁴ Te(p, n) ¹²⁴ I	12.5	[1][7]
SPECT	6	⁶⁷ Ga	Gallium-67	⁸⁹ V(p, n) ⁸⁹ Zr	12.5	[8]
	7	¹¹¹ In	Indium-111	⁶⁵ Cu(α, 2n) ⁶⁷ Ga	28	[9]
	8	²⁰³ Pb	Lead-203	¹⁰⁹ Ag(α, 2n) ¹¹¹ In	27, 30	[10][11]
THERAPEUTICS	9	²¹¹ At	Astatine-211	²⁰³ Tl(p, n) ²⁰³ Pb	12.5	[12]
	10	¹³¹ I	Iodine-131	²⁰⁹ Bi(α, 2n) ²¹¹ At	28	[1]
	11	¹³¹ I	Iodine-131	^{nat} Xe(α, xn) ¹³¹ Ba → ¹³¹ I	50	[13]
	12	¹⁹² Ir	Iridium-192	¹²¹ Sb(α, 2n) ¹²³ I	26	[14]
	13	²¹² Pb	Lead-212	¹⁹² Os(p, n) ¹⁹² Ir	12.5	[15]
	14	¹⁸⁶ Re	Rhenium-186	²²⁸ Th → ²¹² Pb	12.5	[16]
	15	^{117m} Sn	Tin-117m	¹⁸⁶ W(p, n) ¹⁸⁶ Re	12	[17]
			¹⁸⁶ W(α, x) ¹⁸⁶ Re	43	[17]	
			¹¹⁶ Cd(α, 3n) ^{117m} Sn	42	[18]	

- High-intensity H⁺ and ⁴He²⁺ beams cover the radioisotopes listed in the left table;
- Adding a ²H⁺ source in the future would extend production to those marked in red (right table);
- Both ²H⁺ and ⁴He²⁺ have the same q/m → no linac modification needed.

Purpose	Order	Short	Long	Reactions	Energies [MeV]	References
PET	1	⁶⁴ Cu	Copper-64	⁶⁴ Ni(d, x) ⁶⁴ Cu	19	[1]
SPECT	2	⁶⁷ Ga	Gallium-67	^{nat} Zn(d, x) ⁶⁴ Cu	<20	
	3	¹²³ I	Iodine-123	⁶⁴ Zn(d, 2p) ⁶⁴ Cu	20	
THERAPEUTICS	4	²²⁵ Ac	Actinium-225	⁶⁷ Zn(d, 2n) ⁶⁷ Ga	14	[2]
	5	⁶⁷ Cu	Copper-67	¹²² Te(d, n) ¹²³ I	14	[3][4]
	6	¹⁷⁷ Lu	Lutetium-177	²²⁶ Ra(d, 3n) ²²⁵ Ac	19	[5]
	7	¹⁰³ Pd	Palladium-103	⁷⁰ Zn(d, x) ⁶⁷ Cu	25	[6]
	8	¹⁸⁶ Re	Rhenium-186	¹⁷⁶ Yb(d, n) ¹⁷⁷ Lu	21	[7]
	9	⁴⁷ Sc	Scandium-47	¹⁷⁶ Yb(d, x) ¹⁷⁷ Lu	25	[8]
			¹⁸⁶ W(d, 2n) ¹⁸⁶ Re	15	[10]	
			⁵⁰ Ti(d, an) ⁴⁷ Sc	25	[11]	

[1] Cyclotron Produced Radionuclides: Physical Characteristics and Production Methods
 [2] Production and Quality control of Cyclotron produced Copper-64: A Validation study for the use of ⁶⁴CuCl₂ as a radiochemical precursor for radiolabeling of ligands
 [3] Production of copper-64 using a hospital cyclotron: targetry, purification and quality analysis
 [4] Production and Quality Control of Fluorine-18 Labelled Radiopharmaceuticals
 [5] Gallium-68 Cyclotron Production
 [6] Very high specific activity ^{66/68}Ga from zinc targets for PET
 [7] Iodine-124: A Promising Positron Emitter for Organic PET Chemistry
 [8] Evaluation of nuclear reaction cross sections for optimization of production of the important non-standard positron emitting radionuclide ⁸⁹Zr using proton and deuteron induced reactions on ⁸⁹Y target
 [9] Nuclear model analysis and optimization of production data of the medically interesting ^{66,67,68}Ga via alpha induced reactions on ^{63,65}Cu targets
 [10] Interaction between In impurity atoms and impurity atoms of Mn and Co dissolved in silver
 [11] Determination of Excitation Function for Production of Isotopes by natAg (α, xn) Reaction
 [12] Optimized production, purification, and radiolabeling of the ²⁰³Pb/²¹²Pb theranostic pair for nuclear medicine
 [13] Investigation of excitation functions of alpha induced reactions on natXe: Production of the therapeutic radioisotope ¹³¹Cs
 [14] Overview and evaluation of different nuclear level density models for the ¹²³I radionuclide production
 [15] Low energy cyclotron production and cyclometalation chemistry of iridium-192
 [16] Production, purification, and radiolabeling of the ²⁰³Pb/²¹²Pb theranostic pair
 [17] Cyclotron production of no carrier added ¹⁸⁶Re radionuclide for theranostic applications
 [18] Investigations of proton and deuteron induced nuclear reactions on natural and enriched Titanium, Calcium and Vanadium targets, with special reference to the production of ⁴⁷Sc

[1] Copper-64 Radiopharmaceuticals: Production, Quality Control and Clinical Applications
 [2] Production of ⁶⁷Ga by Deuteron Irradiation of Zinc
 [3] Cyclotron Produced Radionuclides: Physical Characteristics and Production Methods
 [4] Excitation functions of deuteron induced nuclear reactions on natural tellurium and enriched ¹²²Te: Production of ¹²³I via the ¹²²Te(d,n)¹²³I-process
 [5] Method for producing actinium-225
 [6] Is ⁷⁰Zn(d,x)⁶⁷Cu the Best Way to Produce ⁶⁷Cu for Medical Applications?
 [7] Optimization of Deuteron Irradiation of ¹⁷⁶Yb for Producing ¹⁷⁷Lu of High Specific Activity Exceeding 3000 GBq/mg
 [8] Estimated Isotopic Compositions of Yb in Enriched ¹⁷⁶Yb for Producing ¹⁷⁷Lu with High Radionuclide Purity by ¹⁷⁶Yb(d,x)¹⁷⁷Lu
 [9] Excitation function and yield for the ¹⁰³Rh(d,2n)¹⁰³Pd nuclear reaction: Optimization of the production of palladium-103
 [10] Cyclotron production of no carrier added ¹⁸⁶Re radionuclide for theranostic applications
 [11] Investigations of proton and deuteron induced nuclear reactions on natural and enriched Titanium, Calcium and Vanadium targets, with special reference to the production of ⁴⁷Sc



FUTURE DEVELOPMENTS AND OPPORTUNITIES

Part 4

FUTURE DEVELOPMENTS AND OPPORTUNITIES

- Deuteron ($^2\text{H}^+$) acceleration \rightarrow additional radioisotopes (same q/m as $^4\text{He}^{2+}$ - no linac changes);
- Facility upgrade via superconducting linac or synchrotron \rightarrow accelerate H^+ , $^4\text{He}^{2+}$ and $^7\text{Li}^{3+}$ ions to higher energies (up to several hundred MeV);
- Higher energies \rightarrow broader research programs;
- Neutron production station (12.5 MeV protons on Be or Li target) \rightarrow Boron Neutron Capture Therapy (BNCT) or neutron-diffraction oriented research.

CONCLUSIONS

- A compact ($< 30\text{ m}$), multi-purpose light-ion linac (delivering H^+ , ${}^4\text{He}^{2+}$ and ${}^7\text{Li}^{3+}$ up to 12.5 MeV/u) can be realized on the available site at IFJ PAN.;
- The concept is *demand-driven* \rightarrow it already addresses approximately two-thirds of the research proposals gathered across the institute, spanning nuclear, medical, and applied research;
- A clear upgrade path (a deuteron source, and a superconducting linac or synchrotron reaching several hundred MeV) extends coverage to the remaining proposals *without redesigning the baseline*;
- *Next step* \rightarrow completion of the pre-Conceptual Design Report, with a first draft expected in November 2026;

THANK YOU FOR YOUR ATTENTION!