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

Presenter: Lazar Nikitovic

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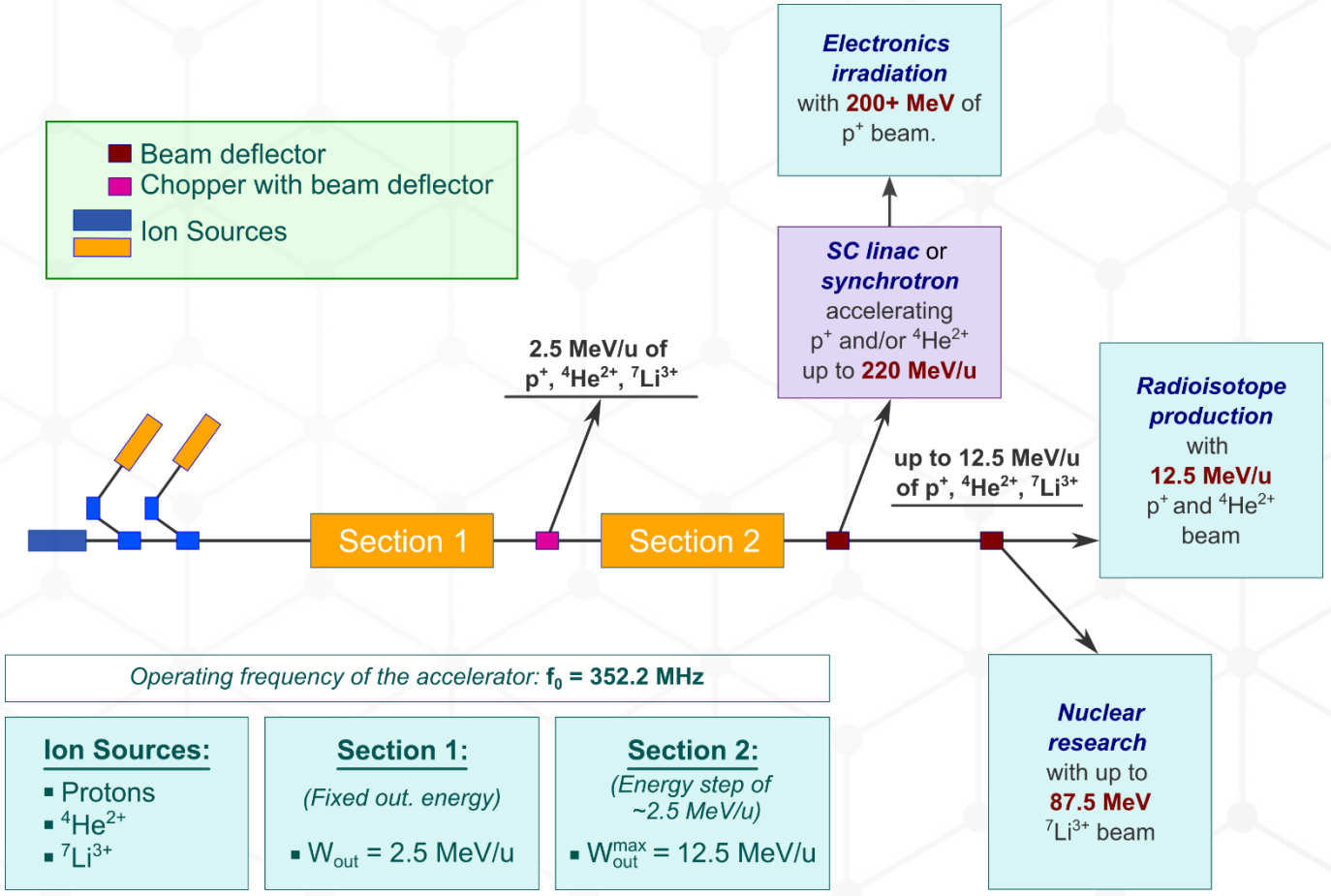
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LINAC LAYOUT

Part 1

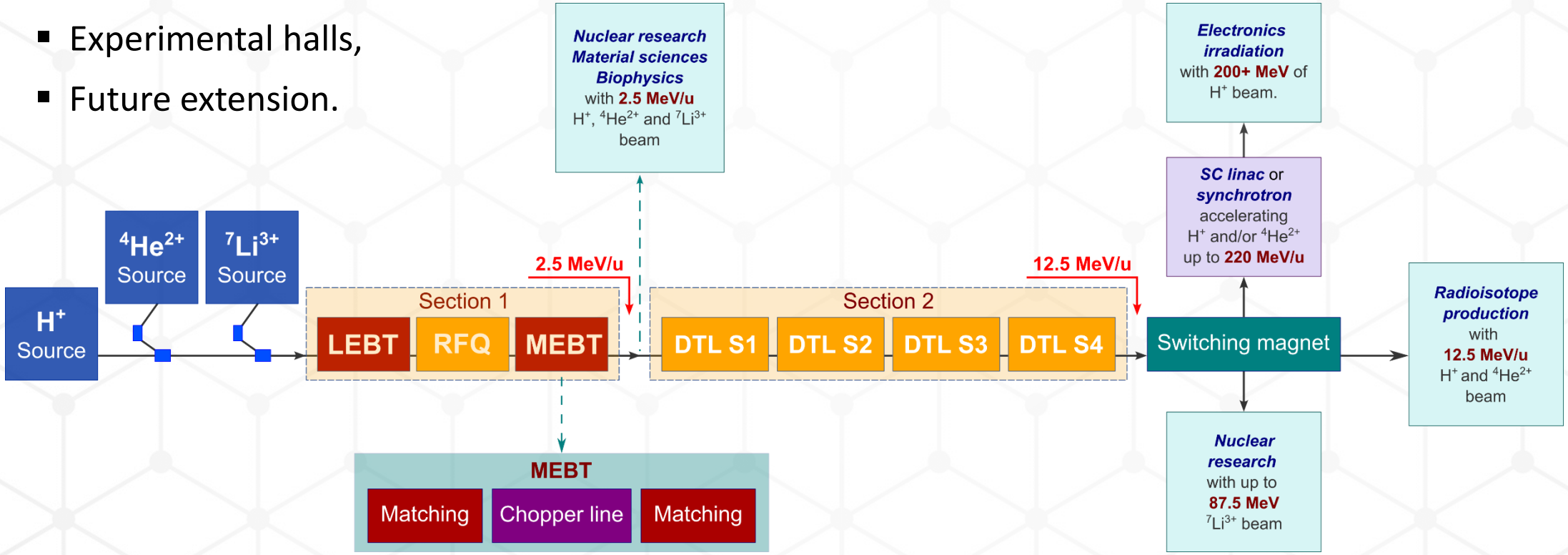
PROPOSED LINAC LAYOUT

- Three ion sources:
  - Protons (H^+),
  - Helium ions ($^4He^{2+}$),
  - Lithium ions ($^7Li^{3+}$).
- Two sections:
  - Bunching and pre-acceleration,
  - Main acceleration.
- Experimental halls:
  - Radioisotope research,
  - Nuclear research.
- Future expansion.



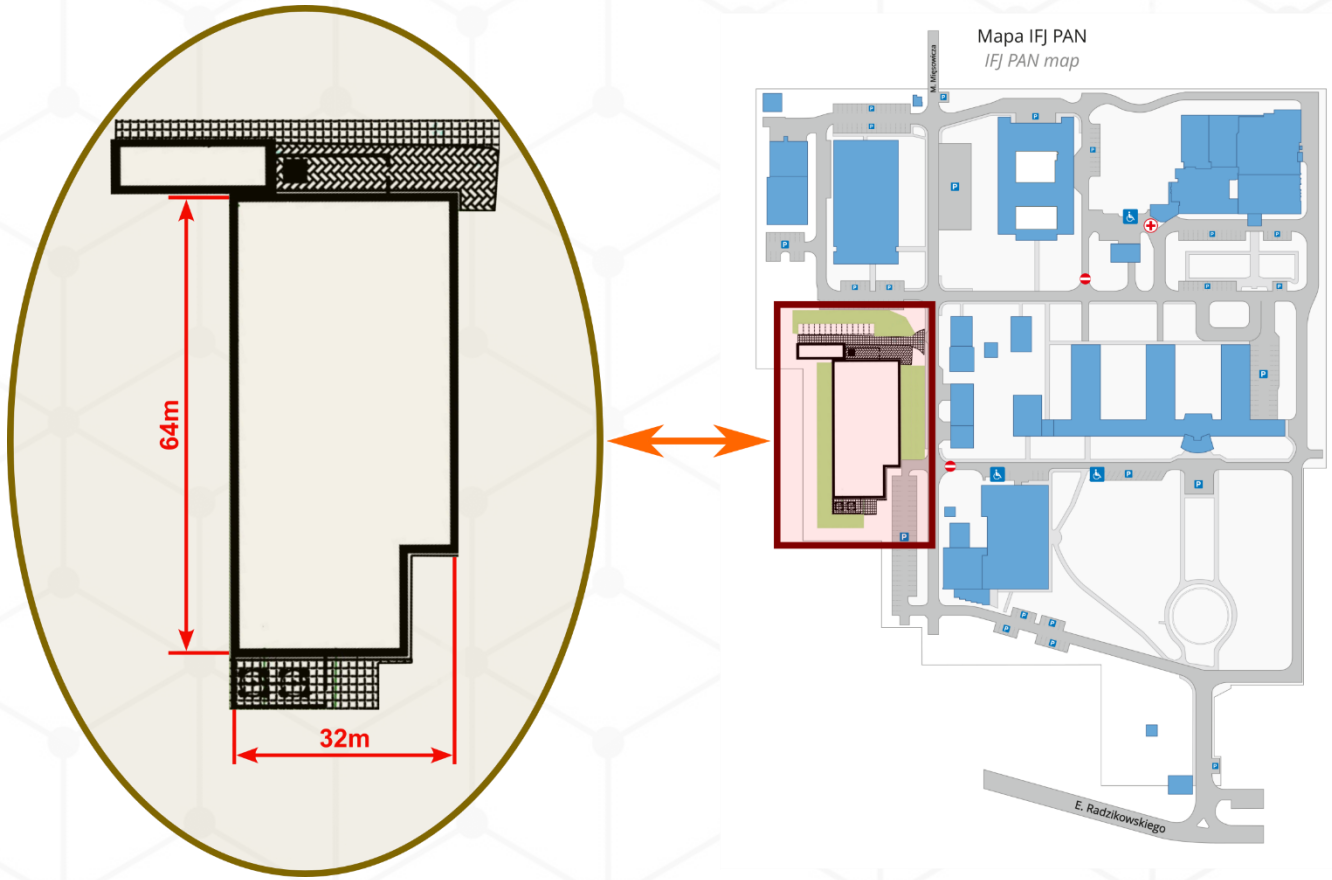
PROPOSED LINAC LAYOUT

- Three ion sources,
- Bunching and pre-acceleration (Section 1),
- Main acceleration (Section 2),
- Experimental halls,
- Future extension.



AVAILABLE SPACE FOR THE LINAC AT IFJ PAN

- The total length of the linac is estimated to be less than 30 m;
- A site of approximately **2000 m²** is available at IFJ PAN as a potential location for the facility.

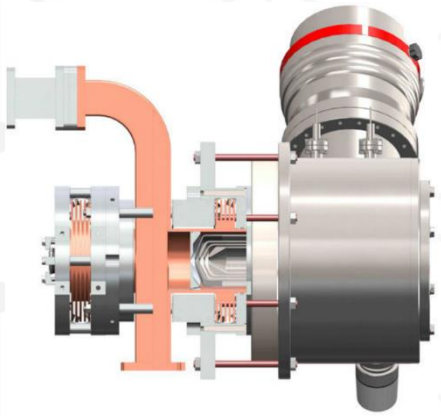


LINAC COMPONENTS

Part 2

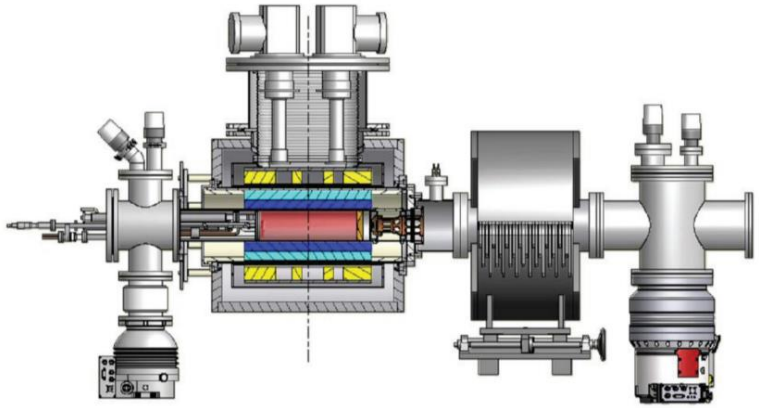
ION SOURCES

Monogan M-1000



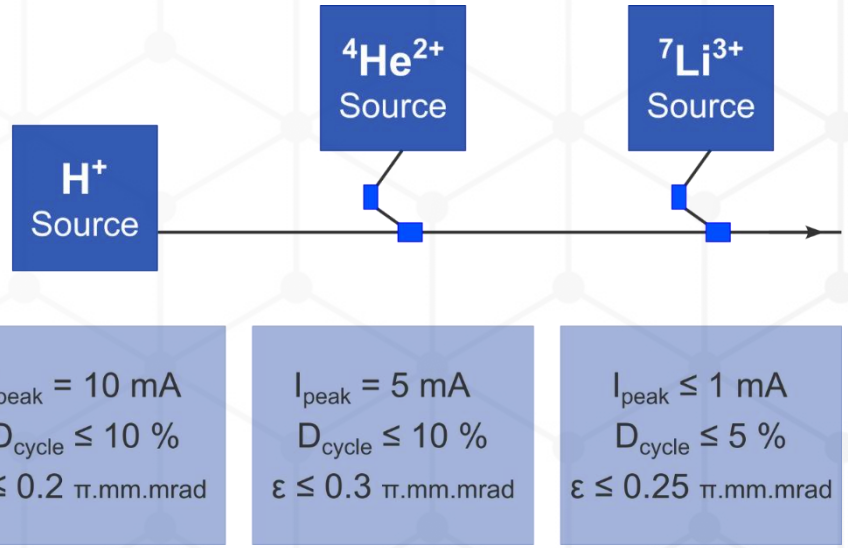
* Geebee International, *Monogan M-1000 – ECR ion source specifications,*

AISHa



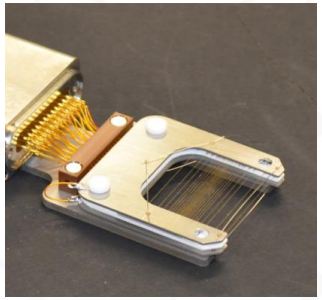
* L. Celona *et al.*, Design of the A*ISHa Ion Source for Hadron Therapy Facilities* (ECRIS2012, Sydney, Australia). Sep. 2012.

- Three ion sources:
  - Protons (H^+),
  - Helium ions ($^4He^{2+}$),
  - Lithium ions ($^7Li^{3+}$).

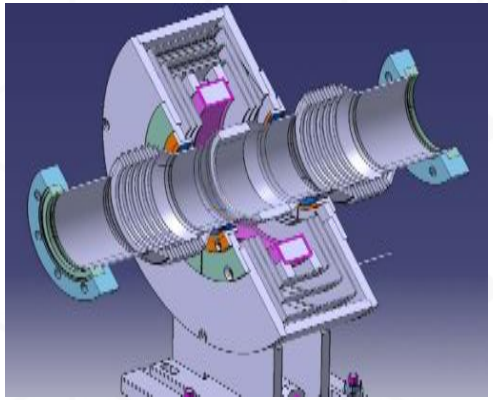


BEAM INSTRUMENTATION*

- Low-Energy Beam Transport (LEBT):
  - Faraday cup,
  - Emittance scanner,
- Radio-Frequency Quadrupole (RFQ):
  - RF pickups.
- Medium-Energy Beam Transport (MEBT):
  - Beam current transformer,
  - Beam position monitor,
  - Emittance scanner.
- Drift Tube Linac (DTL):
  - RF pickups,
  - Beam current transformer,
  - Beam position monitor,
  - Emittance scanner.



(*Wire grid, used for transverse profile measurements*)



(*Beam current transformer*)

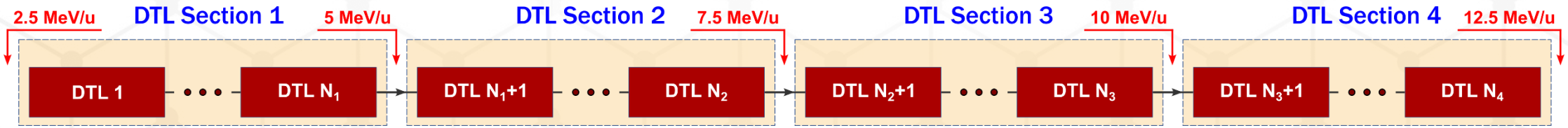


(*Beam position monitor*)

** Curtesy of M. Sapinski, Paul Scherrer Institute (PSI), Switzerland.*

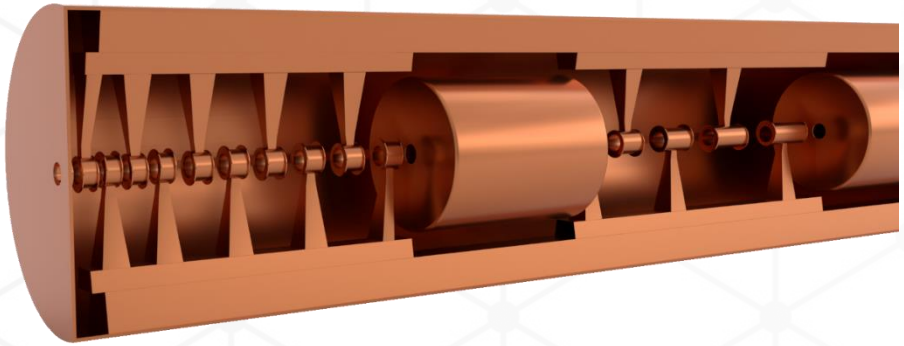
DRIFT TUBE LINAC (DTL)

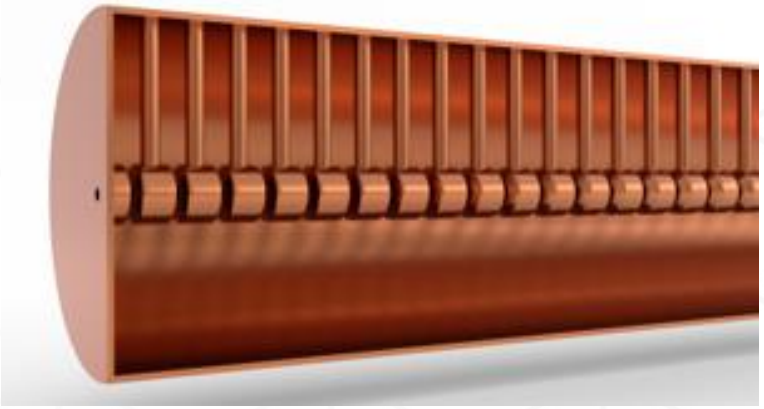
- The DTL consists of four independently switchable sections, allowing the beam output energy to be varied.
- Proposed beam energies at the DTL exit:
  - **2.5 MeV/u** - All four DTL Sections are off,
  - **5.0 MeV/u** - DTL Section 1 is on, the remaining three DTL Sections are off,
  - **7.5 MeV/u** - DTL Sections 1-2 are on, the remaining two DTL Sections are off,
  - **10.0 MeV/u** - DTL Sections 1-3 are on, the last DTL Section is off,
  - **12.5 MeV/u** - All four DTL Sections are on.

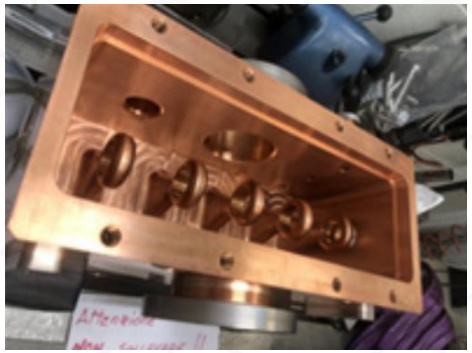


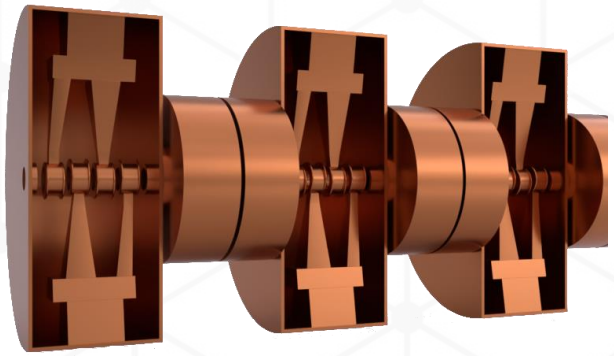
DRIFT TUBE LINAC (DTL)

- Two cavity types are under consideration: H-mode cavities and Alvarez-type cavities.









RESEARCH PROGRAMS

Part 3

RESEARCH PROPOSALS AND THEIR FEASIBILITY

19 project proposals from 15 principal investigators at IFJ PAN, covering fundamental nuclear physics, medical applications, materials science and biophysics, electronics irradiation, and radiochemistry.

- The proposals span major research areas, confirming the need for a versatile light-ion facility.
- **14 of 19 proposals (approximately 74%)** are fully or partially feasible with the proposed linac, uing H^+, $^4He^{2+}$, $^7Li^{3+}$ at energies between 2.5 and 12.5 MeV/u.
- **Five projects require capabilities beyond the baseline design**, including higher energies (approximately 100-300 MeV), continuously variable beam energy, or additional ion species (e.g., $^{12}C^{6+}$ or $^2H^+$) → proposed future upgrade.

No.	Project name	Principal Investigator	Application Category	Primary Particle	Acceleration Stage	Possibility with currently proposed linac
1	Investigation of Nuclear Two-Photon (2γ) Decay in Even-Even Nuclei via Proton Excitation of O_2^+ State	Michał Ciemała	Fundamental Nuclear Physics	H^+	**Variable** 2.5 - 12.5 MeV (*non-negotiable req.*)	YES
2	Study of fission processes induced by protons, alpha particles, and heavy ions	Michał Ciemała	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 $^7Li^{3+}$	YES
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	YES
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^+, $^4He^{2+}$, $^{12}C^{6+}$	250 MeV/u, 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	YES
14	Influence of irradiation on the magnetic properties of coordination polymers	Piotr Konieczny	Material Science / Biophysics	H^+, $^2H^+$, $^4He^{2+}$, $^7Li^{3+}$	2.5 MeV/u, 12.5 MeV/u	YES
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	Blazej 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

APPLICATION EXAMPLES

Fast-neutron production using linac:
p(^{7}Li,n)^{7}Be

$^{7}Li^{3+}$

Requirement 1:

Var. energy: **17 - 50 MeV**
Rep. rate: **2.5 MHz (400 ns)**
Pulse len.: **few ns**
Beam on tar.: **~10 uA**

Requirement 2:

Var. energy: **45 - 87.5 MeV**
Rep. rate: **NaN**
Pulse len.: **NO pulsation**
Beam on tar.: **≤ 1 mA**

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

[1] *Cyclotron ProducedRadionuclides: PhysicalCharacteristics andProduction 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 66/68Ga 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 InIsotopes 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 186gRe 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*

FUTURE DEVELOPMENTS

Part 4

FUTURE DEVELOPMENTS AND OPPORTUNITIES

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

CONCLUSIONS

- A **multi-purpose light-ion linac** delivering H^{+}, $^{4}He^{2+}$ and $^{7}Li^{3+}$ at energies up to 12.5 MeV/u could be realised at IFJ PAN.
- The concept is **demand-driven** → address more then two-thirds of the collected research proposals, spanning nuclear, medical, and applied research.
- A **clear upgrade path** (including a deuteron source and a superconducting linac or synchrotron capable of reaching several hundred MeV) allows the realisation of remaining research projects that are not feasible with the proposed baseline linac.

THANK YOU FOR YOUR ATTENTION!