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Design of DTL for Acceleration of Ions with charge-to-mass Ratio of 1/2 with a Potential Production of Radioisotopes

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Contents

Introduction

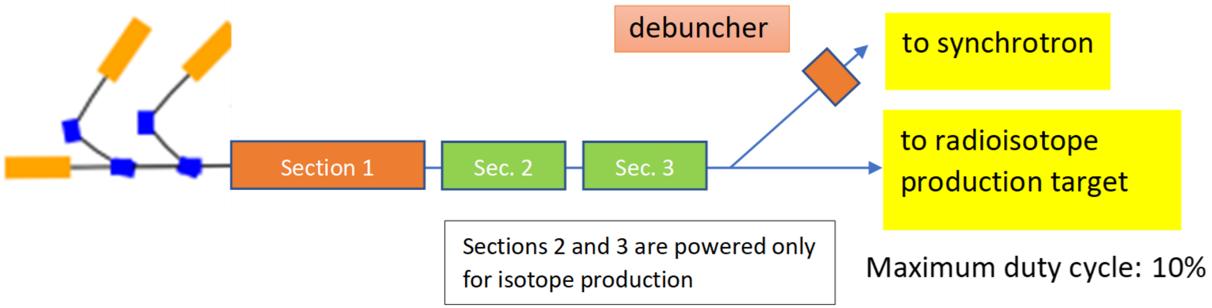
- WP 7.4 of Heavy Ion Therapy Research and Integration (**HITRIplus**) project - Linac injector design (Advanced conceptual design of an optimised linac injector for multiple ions at **10** $\mathbf{MeV/u}$)[1];

- Design of the Drifting Tube Linac (**DTL**) accelerating structure for acceleration of multiple type of ions, using Electromagnetic (**EM**) simulation software;

- Multiple cases were considered in order to achieve the best solution;

1. https://www.hitriplus.eu/;

WP7.4 Requirements of HITRIplus



3 ion sources

$^{12}C^{4+}$, 600 μA, 0.25 π mm mrad, 45 kV

$^{4}He^{2+}$, *0.5 mA*, 0.3 π mm mrad

p or H_2^+, 5 mA, 0.2-0.3 π mm mrad

Linac section1

q/m=1/3

W_{in}=15 keV/u

W_{out}= 5 MeV/u

Linac section2

q/m=1/2

W_{in}= 5 MeV/u

W_{out}= 7.1 MeV/u

Linac section3

q/m=1/2 or 1

W_{in}= 7.1 MeV/u

W_{out}= 10 MeV/u

baseline : 217 MHz

alternative : 352 MHz

1. Courtesy: **M.Vretenar**

DTL Design Requirements

- HITRIplus project requirements for DTL design are as follow:
  - Overall LINAC length shall **not exceed 10** $\mathbf{m}$ – implies total DTL length in range of **5.5** $\mathbf{m}$;
  - Output energy of DTL structure shall be **10** $\mathbf{MeV/u}$;
  - DTL structure shall have two tanks – preferably one for acceleration of ions with $\mathbf{q/m = 1/2}$ and another for ions with $\mathbf{q/m = 1}$;
  - Preferable energy between two tanks is **7** $\mathbf{MeV/u}$ – production of ^{211}**At** (Astatine), which is one of the most promising alpha-emitters for targeted cancer therapy;

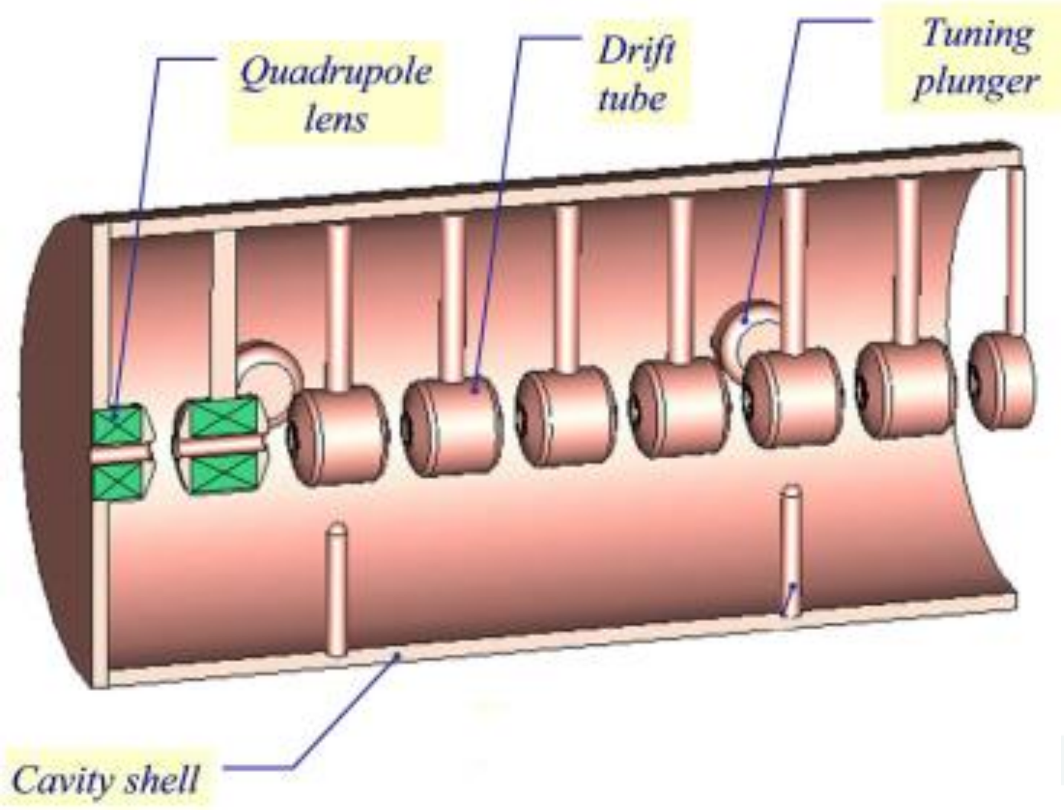
DTL Acceleration Structure

- Necessary accelerator structure for acceleration of heavy ions is **DTL**;

- 3 most popular DTL structures are:
  - Widerøe DTL;
  - Alvarez DTL;
  - H-mode DTL;

DTL Acceleration Structure

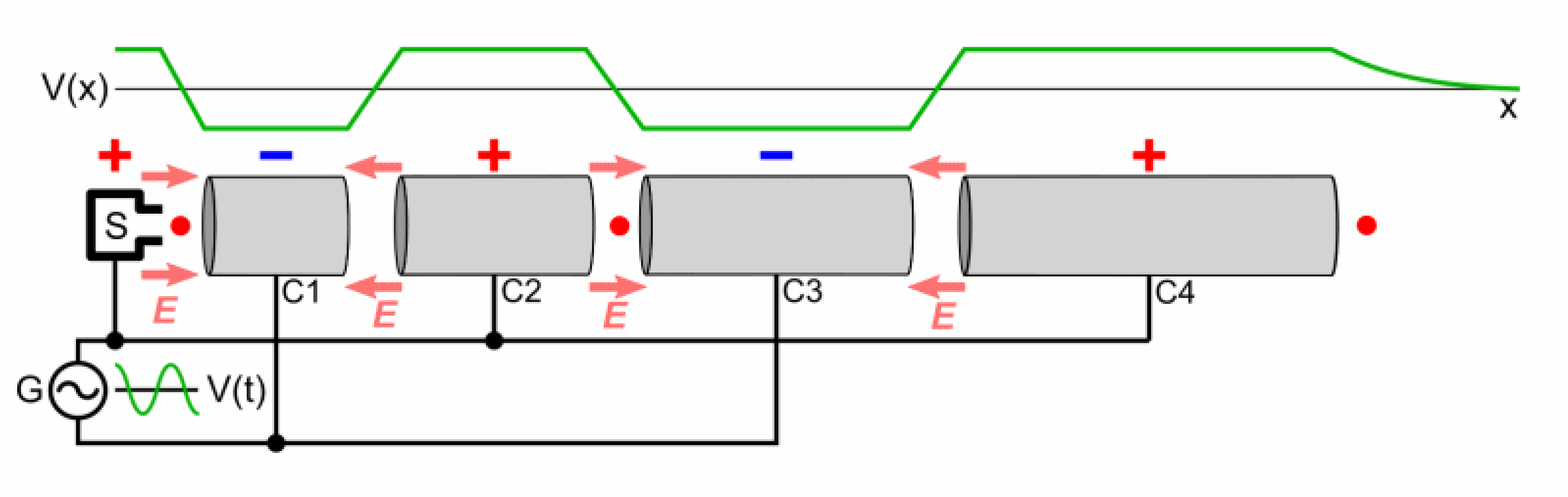
- Longitudinal cross-section of DTL accelerating structure[1];



1. M. Vretenar: “Linear Accelerators”

DTL Acceleration Structure

- Working principle of the **Widerøe DTL** accelerating structure[1];



1. https://en.wikipedia.org/wiki/Linear_particle_accelerator;

Methodology

- EM field distributions and accelerator's figures of merit are obtained with Poisson Superfish Codes;

- The simulation methodology has been benchmarked with the existing **LINAC4**;

- Next to given HITRIplus requirements for DTL design, the following input data are taken as fixed parameters:
  - Frequency: **352.2** $\mathbf{MHz}$
  - Input energy: **2** $\mathbf{MeV/u}$

Considered Cases - INPUTS

- Four cases have been taken into consideration for a design of DTL accelerating structure:

Case	Tank 1		Tank 2	
	q/m	T_{out}	q/m	T_{out}
1	½	7 MeV/u	1	10 MeV
2	½	7 MeV/u	½	10 MeV/u
3	½	5 MeV/u	1	10 MeV
4	½	5 MeV/u	½	10 MeV/u

Considered Cases - OUTPUTS

- Comparison of four considered cases regarding HITRIplus project requirements:

Case	DTL length	T_{out}	Accelerated ions		T_{out}^{TANK1}
			Tank 1	Tank 2	
1	5.35 m	9.91 MeV/u	$^4He^{2+}$, H^+	H^+	7.04 MeV/u

The WINNER is ***1st case***!

Results of 1st Case

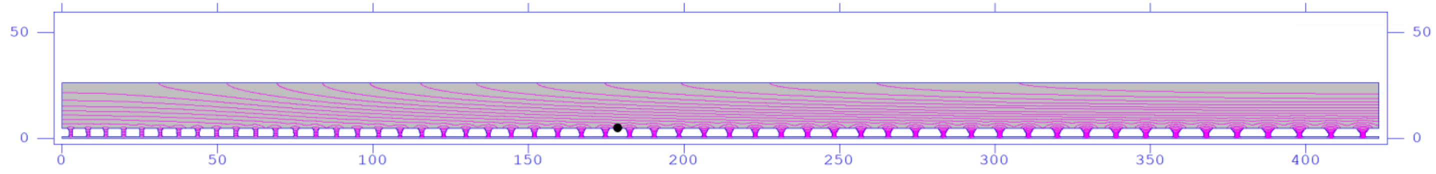


Figure 1: Tank 1 of DTL structure for 1st case

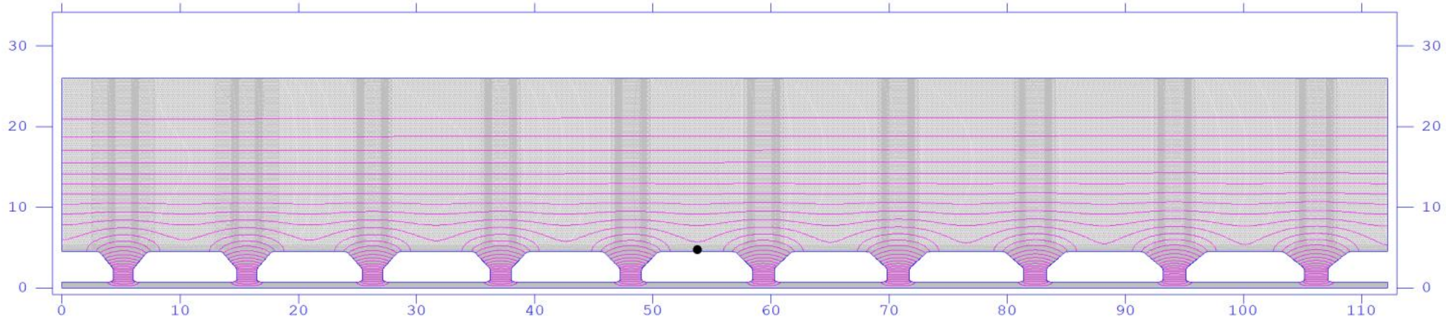


Figure 2: Tank 2 of DTL structure for 1st case

	DTL structure	Units
Input energy	2	MeV/u
RF frequency	352.2	MHz
Beam current during pulse	5	mA
Total RF power	$^{4}He^{2+}$: 613.64 H^{+}: 326.96	kW
Aperture/DT diameter	15/90	mm

	Tank 1	Tank 2	Units
Output energy	7.04	9.91	MeV/u
Length	4.23	1.12	m
Cells per tank	54	10	-
Effective shunt impedance ZT^2	51.63	60.05	MΩ/m
Q-value Q_0	49358.08	49760.08	-
Nominal tank voltage V_0T	$^{4}He^{2+}$: 11.1 H^{+}: 5.55	$^{4}He^{2+}$: - H^{+}: 3.14	MV
Beam power	$^{4}He^{2+}$: 50.4 H^{+}: 25.2	$^{4}He^{2+}$: - H^{+}: 14.35	kW

Conclusions

- Successful design of the DTL accelerating structure for acceleration of multiple type of ions, using EM simulation software Poisson Superfish Codes;

- Four design cases were considered, and the most favourable one was chosen for further studies;

- The most favourable design case has fulfilled all requirement from WP7.4 of HITRIplus project;

Future Perspectives

- 1st case DTL structure will be designed in 3D EM simulation software (e.g., CST Studio Suite);

- Design of DTL tank which will be able to accelerate ions with charge-to-mass ratio of 1/3 both in Poisson Superfish and CST Studio Suite;

- Implementation of DTL structure for acceleration of ions with q/m=1/3 with 1st case DTL structure previously presented;

Thank you for your attention!

EXTRAS

Results of 2nd Case

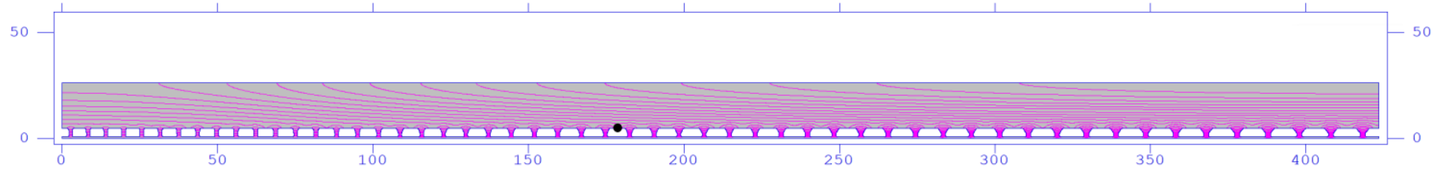


Figure 3: Tank 1 of DTL structure for 2nd case

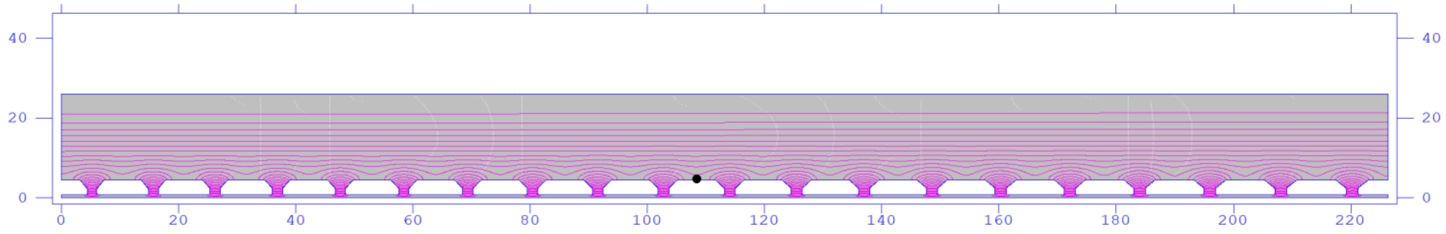


Figure 4: Tank 2 of DTL structure for 2nd case

	DTL structure	Units
Input energy	2	MeV/u
RF frequency	352.2	MHz
Beam current during pulse	5	mA
Total RF power	$^4He^{2+}$: 914.39 H^+: 248.45	kW
Aperture/DT diameter	15/90	mm

	Tank 1	Tank 2	Units
Output energy	7.04	9.94	MeV/u
Length	4.23	2.26	m
Cells per tank	54	20	-
Effective shunt impedance ZT^2	51.63	65.44	MΩ/m
Q-value Q_0	49358.08	54153.9	-
Nominal tank voltage V_0T	$^4He^{2+}$: 11.1 H^+: 5.55	$^4He^{2+}$: 6.34 H^+: 3.17	MV
Beam power	$^4He^{2+}$: 50.4 H^+: 25.2	$^4He^{2+}$: 29 H^+: 14.5	kW

Results of 3rd Case

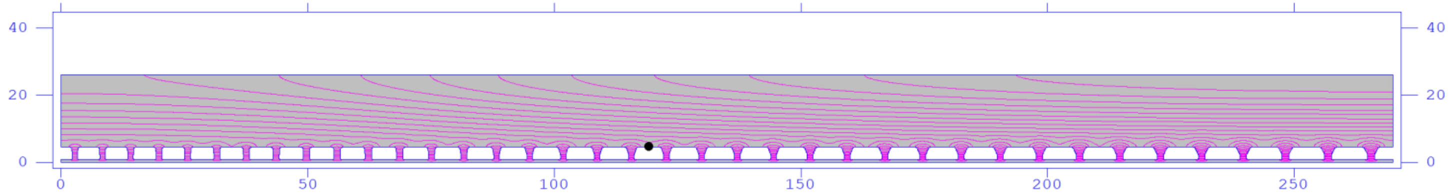


Figure 5: Tank 1 of DTL structure for 3rd case

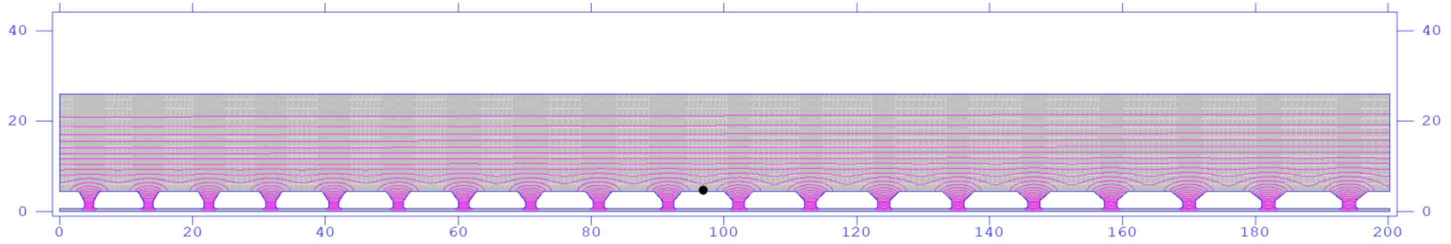


Figure 6: Tank 2 of DTL structure for 3rd case

	DTL structure	Units
Input energy	2	MeV/u
RF frequency	352.2	MHz
Beam current during pulse	5	mA
Total RF power	$^4He^{2+}$: 396.46 H^+: 378.14	kW
Aperture/DT diameter	15/90	mm

	Tank 1	Tank 2	Units
Output energy	5.11	10.2	MeV/u
Length	2.7	2	m
Cells per tank	38	19	-
Effective shunt impedance ZT^2	48.62	62.93	MΩ/m
Q-value Q_0	48681.67	53068.03	-
Nominal tank voltage V_0T	$^4He^{2+}$: 6.93 H^+: 3.46	$^4He^{2+}$: - H^+: 5.56	MV
Beam power	$^4He^{2+}$: 31.1 H^+: 15.55	$^4He^{2+}$: - H^+: 25.45	kW

Results of 4^{th} Case

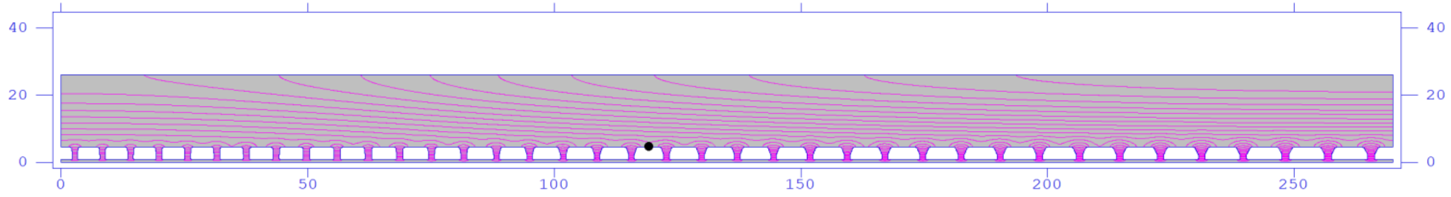


Figure 7: Tank 1 of DTL structure for 4^{th} case

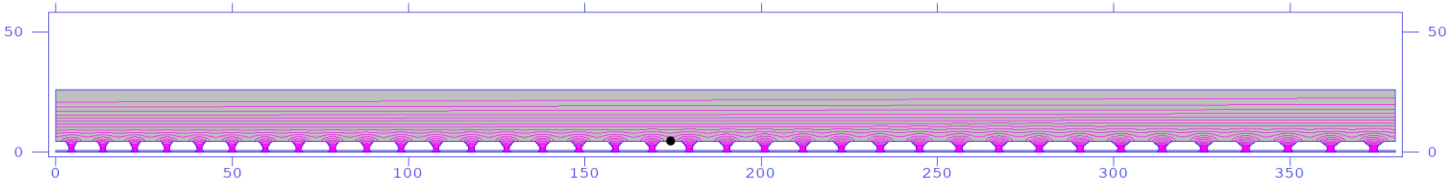


Figure 8: Tank 2 of DTL structure for 4^{th} case

	DTL structure	Units
Input energy	2	MeV/u
RF frequency	352.2	MHz
Beam current during pulse	5	mA
Total RF power	$^4He^{2+}$: 890.13 H^+: 242.38	kW
Aperture/DT diameter	15/90	mm

	Tank 1	Tank 2	Units
Output energy	5.11	9.94	MeV/u
Length	2.7	3.79	M
Cells per tank	38	36	-
Effective shunt impedance ZT^2	48.62	65.93	MΩ/m
Q-value Q_0	48681.67	55548.27	-
Nominal tank voltage V_0T	$^4He^{2+}$: 6.93 H^+: 3.46	$^4He^{2+}$: 10.56 H^+: 5.28	MV
Beam power	$^4He^{2+}$: 31.1 H^+: 15.55	$^4He^{2+}$: 48.3 H^+: 24.15	kW