PROJECT PROMETHEUS:
DESIGN AND CONSTRUCTION OF A RADIO FREQUENCY QUADRUPOLE AT TAEK

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Abstract

The PROMETHEUS Project is ongoing for the design and development of a 4-vane radio frequency quadrupole (RFQ) together with its H^+ ion source, a low energy beam transport (LEBT) line and diagnostics section. The main goal of the project is to achieve the acceleration of the low energy ions up to 1.5 MeV by an RFQ (352 MHz) shorter than 2 meter. A plasma ion source is being developed to produce a 20 keV, 1 mA H^+ beam. Simulation results for ion source, transmission and beam dynamics are presented together with analytical studies performed with newly developed RFQ design code DEMIRCI. Simulation results shows that a beam transmission 99% could be achieved at 1.7 m downstream reaching an energy of 1.5 MeV. As the first phase an Aluminum RFQ prototype, the so-called cold model, will be built for low power RF characterization. In this contribution the status of the project, design considerations, simulation results, the various diagnostics techniques and RFQ manufacturing issues are discussed.

INTRODUCTION

The PROMETHEUS project, at the Turkish Atomic Energy Authority's (TAEK) Saraykoy Nuclear Research and Training Center (SANAEM), aims to gain the necessary knowledge and experience to construct such a proton beam. A Proof of Principle (PoP) accelerator with modest requirements of achieving at least 1.5 MeV proton energy, with an average beam current of at least 1 mA. PoP project also have the challenging goal of having the design and construction of the entire machine in Turkey, from its ion source up to last diagnostic station, including its RF power supply and to complete it in three years.

BEAMLINE DESIGN

The beamline design originates from previous setups and past experience of SANAEM. It consists of an ion source, a low energy beam transport (LEBT), a radio frequency quadrupole (RFQ) and a beam dump with diagnostic stations inserted at the appropriate places. A schematic view of the beamline can be seen in Fig. 1.

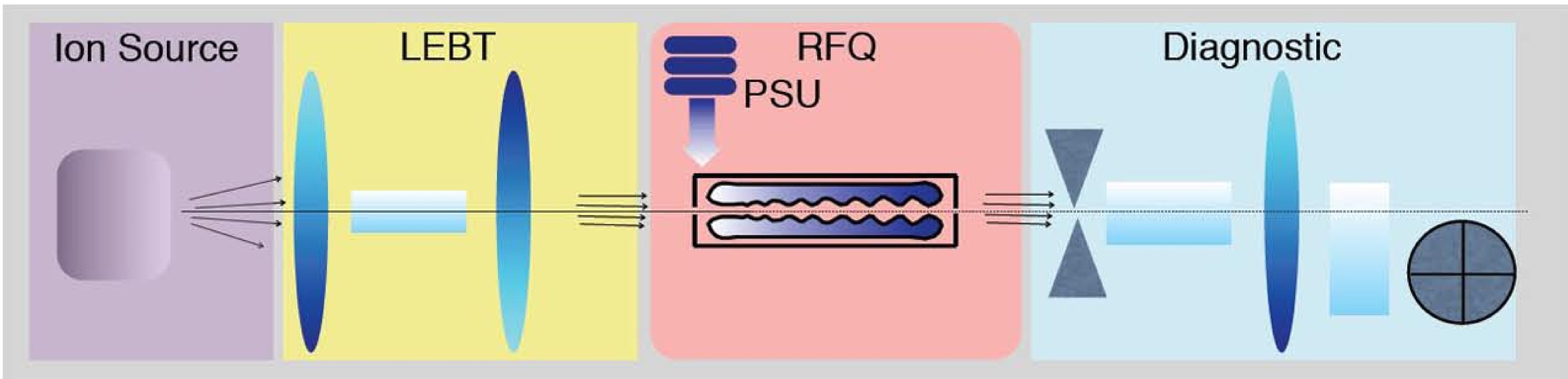

Figure 1: Layout of the SANAEM Beamline.

Ion Source

The H+ ion source, consisting of two parts is being redesigned to match the required input parameters of the main accelerator structure, i.e. the RFQ. The main parameters of the ion source are: 20 keV output energy, at least 1mA of average beam current and a total normalized transverse emittance smaller than 1.5 π.mm.mrad. The actual design is realized with IBSimu[1] and SimIon[2] software packages.

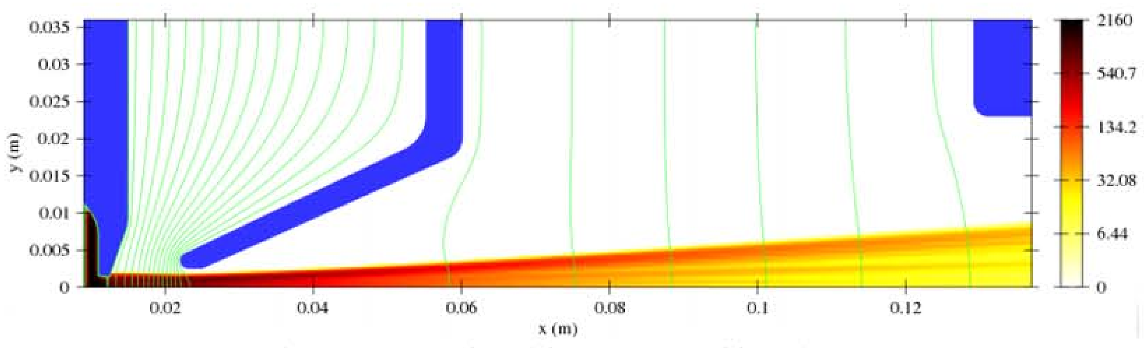

Figure 2: 2D Drawing of the Ion Source with IBSimu.

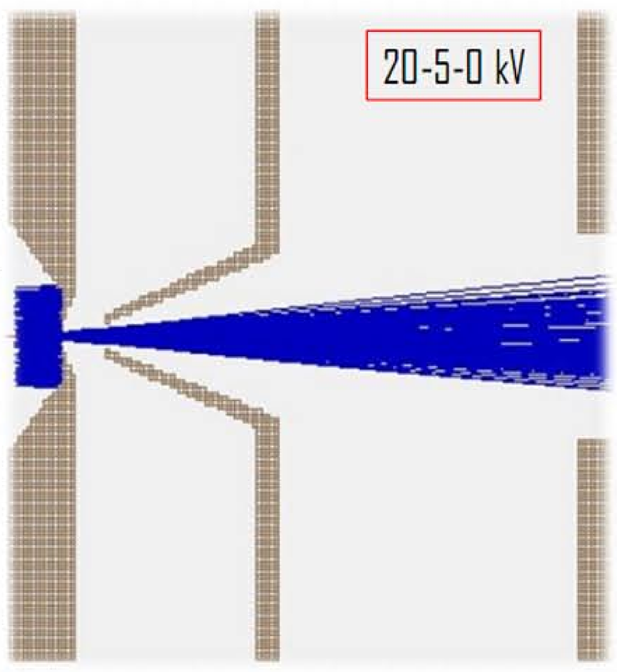

Figure 3: 2D Drawing of the Ion Source with SimIon.

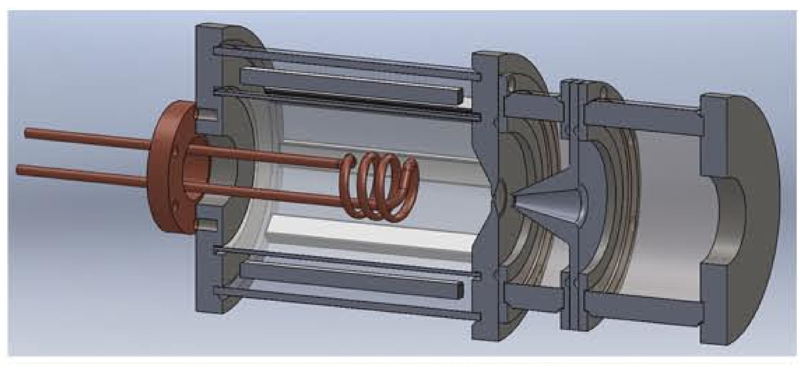

Figure 4: 3D Drawing of the Ion Source.

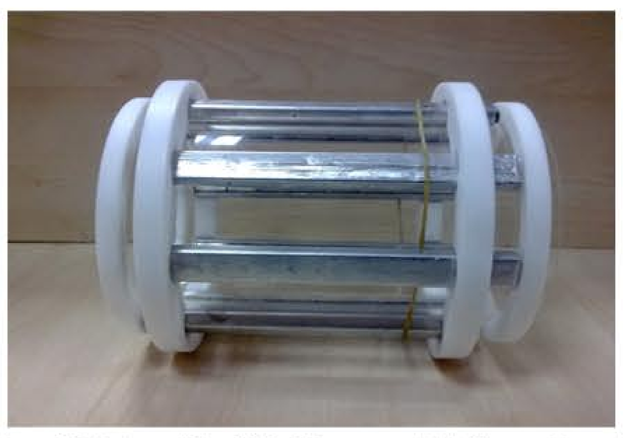

Figure 5: Picture of the 8 Rod Permanent Multicusp Magnets.

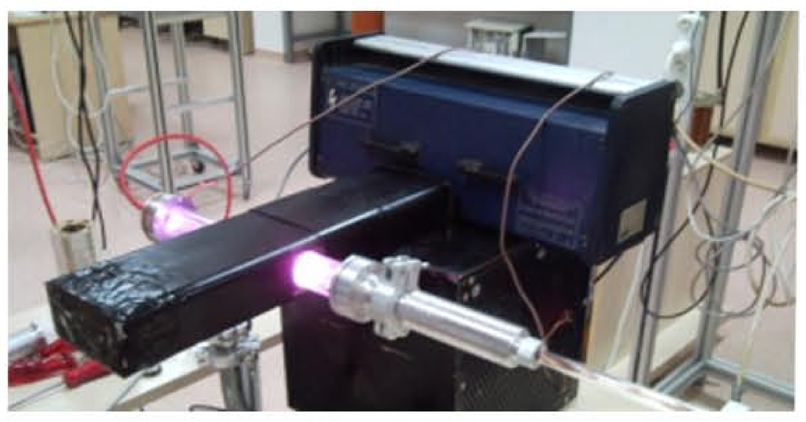

Figure 6: Picture of the Current Ion Source at SANAEM.

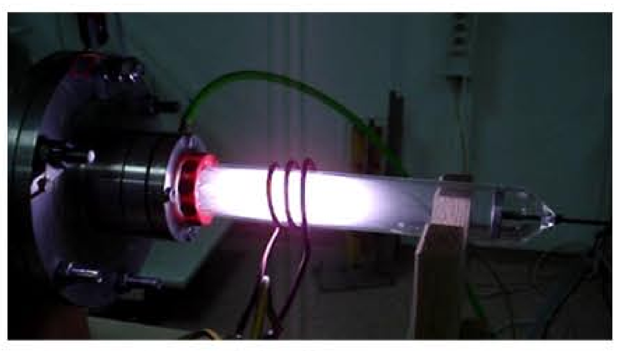

Figure 7: Picture of the Old Ion Source at SANAEM.

LEBT

The LEBT design is obtained with TRAVEL [3] software library and the solenoids themselves by the use of SUPERFISH [4]. The magnetic fields of the two solenoids have been calculated as 2830 Gauss at z = 7.5 cm and 2480 Gauss at z = 72.5 cm.

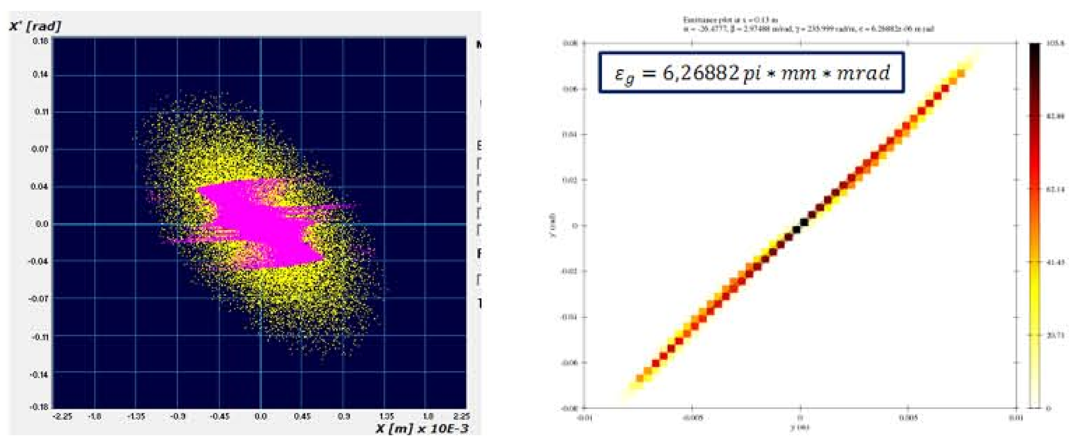

Figure 8: Phase space plots of the LEBT output beams (right) and RFQ acceptance (left).

RFQ

The PoP RFQ has been designed using LIDOS [5], one of the two commercially available computer programs. The main design parameters can be found in Table 1.

Table 1: RFQ Main Design Parameters.

Parameter	Value	Unit
Ein	20	keV
Eout	1.5	MeV
RF	352.21	MHz
I	1	mA
ϵ	1	π.mm.mrad
Vo	60	kV
KP	1.5	-
R_0	2.799	mm
ρ	2.5	mm

The locally developed computer code, DEMIRCI, uses the classical RFQ formulas based on two term potential. It incorporates ROOT [6] library for user interaction and plotting facilities. It interfaces other available software like LIDOS, TOUTATIS[7] and SUPERFISH. It has also a command line interface, designed to be used in batch mode, where GNUPLOT is used for plotting.

Table 2: DEMIRCI-TOUTATIS-LIDOS comparisons.

Parameter	DEMIRCI	LIDOS	TOUTATIS
Length (m)	1.5545	1.585	1.54914
Energy (MeV)	1.536	1.5194	1.49
Time (ns)	249.858	265.81	243.8
Transmission(%)	n/a	99	97

RFQ BEAM DYNAMICS

After the static design, the real vane shapes and actual beam dynamics were primarily calculated by "LIDOS. RFQ.Designer" simulation code. In addition, a similar computer program, TOUTATIS, was used for beam dynamics design to validate the preliminary design by comparing it's results with LIDOS.

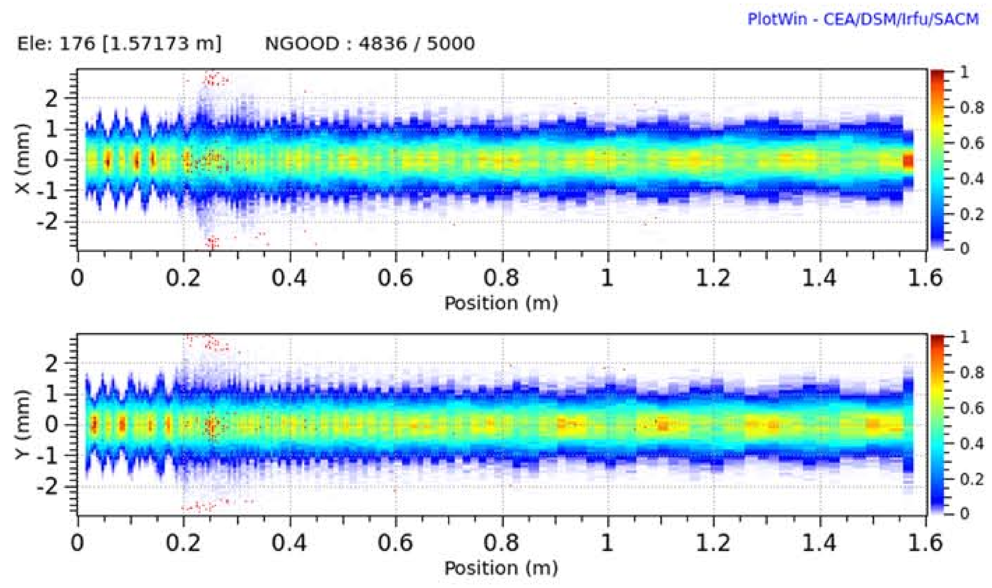

Figure 9: Beam Profiles Along the RFQ.

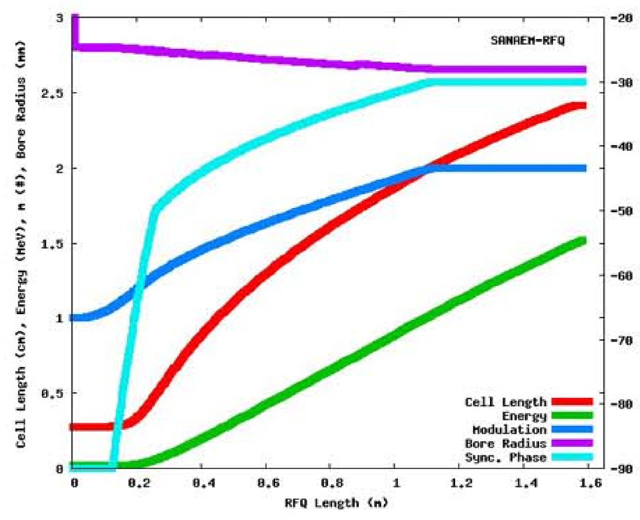

Figure 10: Beam Dynamics Parameters Along the RFQ.

RFQ ELECTROMAGNETIC CONSIDERATIONS

SANAEM RFQ electromagnetic studies were performed by using Superfish, RFQfish and CST MWS[8] simulation programs to fine tune the cavity physical parameters.

Table 3: RFQ Cavity Physical Parameters after 3D design

Parameters	Superfish	CST MWS
Frequency (MHz)	352.200	352.199
Quality Factor	10341.6	10216.4
Power Dissipation (W/cm)	123.5637	125.0779
Kilpatrick Factor	1.52	1.53

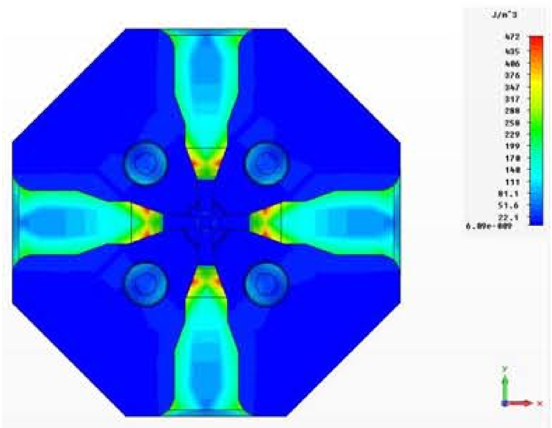

Figure 11: Electrical Energy Density of the SANAEM RFQ in 3D Cross-section.

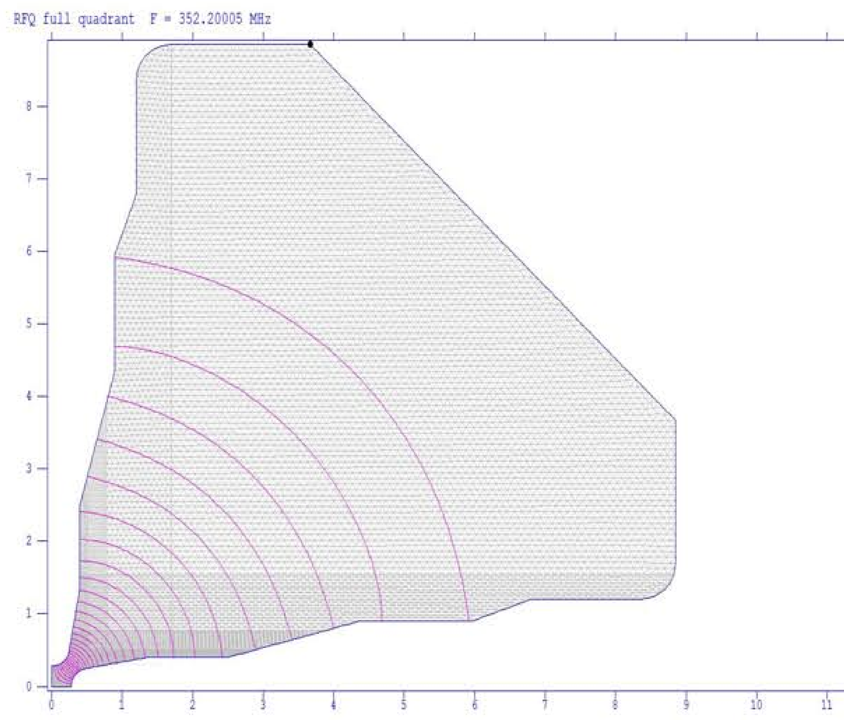

Figure 12: 2D Electromagnetic Design of the SANAEM RFQ.

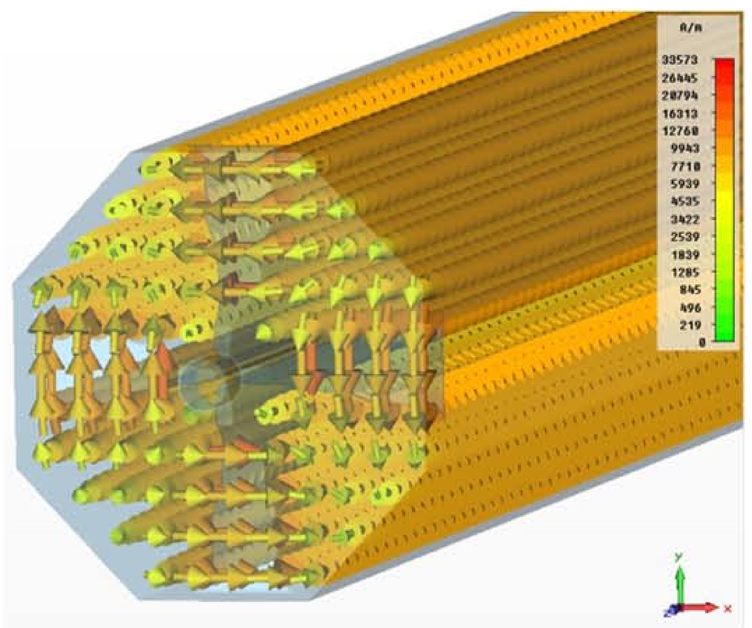

Figure 13: 3D Magnetic Field Distribution of the SANAEM RFQ.

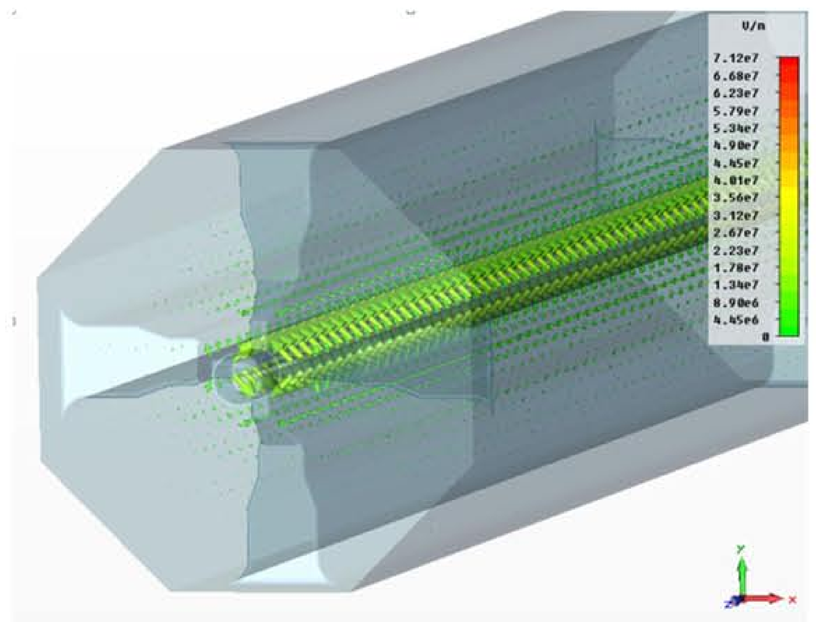

Figure 14: 3D Electric Field Distribution of the SANAEM RFQ.

MECHANICAL CONSTRUCTION

The choice of material, cross-sectional type and the assembly method were driven by local manufacturing constraints and row material accessibility.

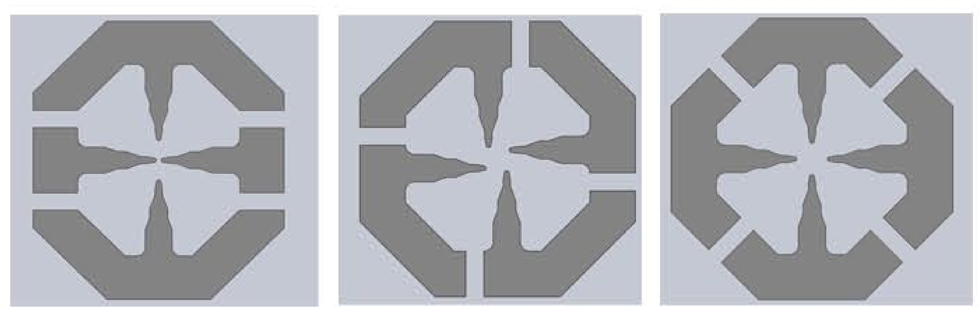

Figure 15: Different Options for Vane and Body Assembly.

CURRENT STATUS AND CONCLUSIONS

As of September 2013, the last pieces of the ion source are being manufactured so that it can be assembled and tested before the end of the month. The LEBT solenoids and diagnostic stations are also being produced with the goal of doing the basic measurements before the end of the year. As the production of the RFQ is somewhat more difficult, a number of engineering models to test various assembly procedures and a so called cold model to understand the machining capabilities and to further test other properties such as vacuum and low power RF. The first accelerated protons are expected to be available by the end of 2015.

Figure 16: The Picture of Test Vane from Aluminum.

ACKNOWLEDGMENT

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