THE NEW AXIAL BUNCHER AT INFN-LNS

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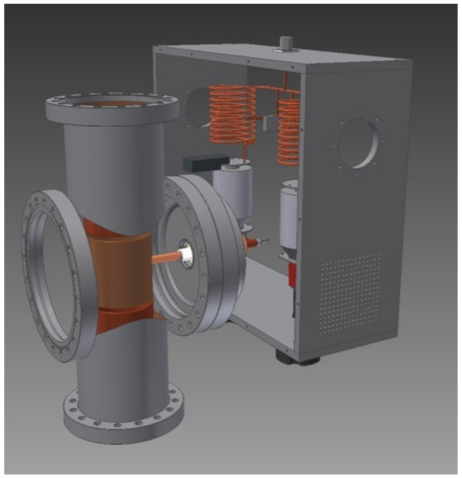
INFN-LNS



INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

CYC13 VANCOUVER

Talking points

- **Main reasons for a new axial buncher**
- **Buncher study**
- **Design: mechanical, electrical, numerical simulations**
- **LLRF system of the buncher**
- **Test and measurements**
- **Conclusions**
- **References**
- **Discussion**

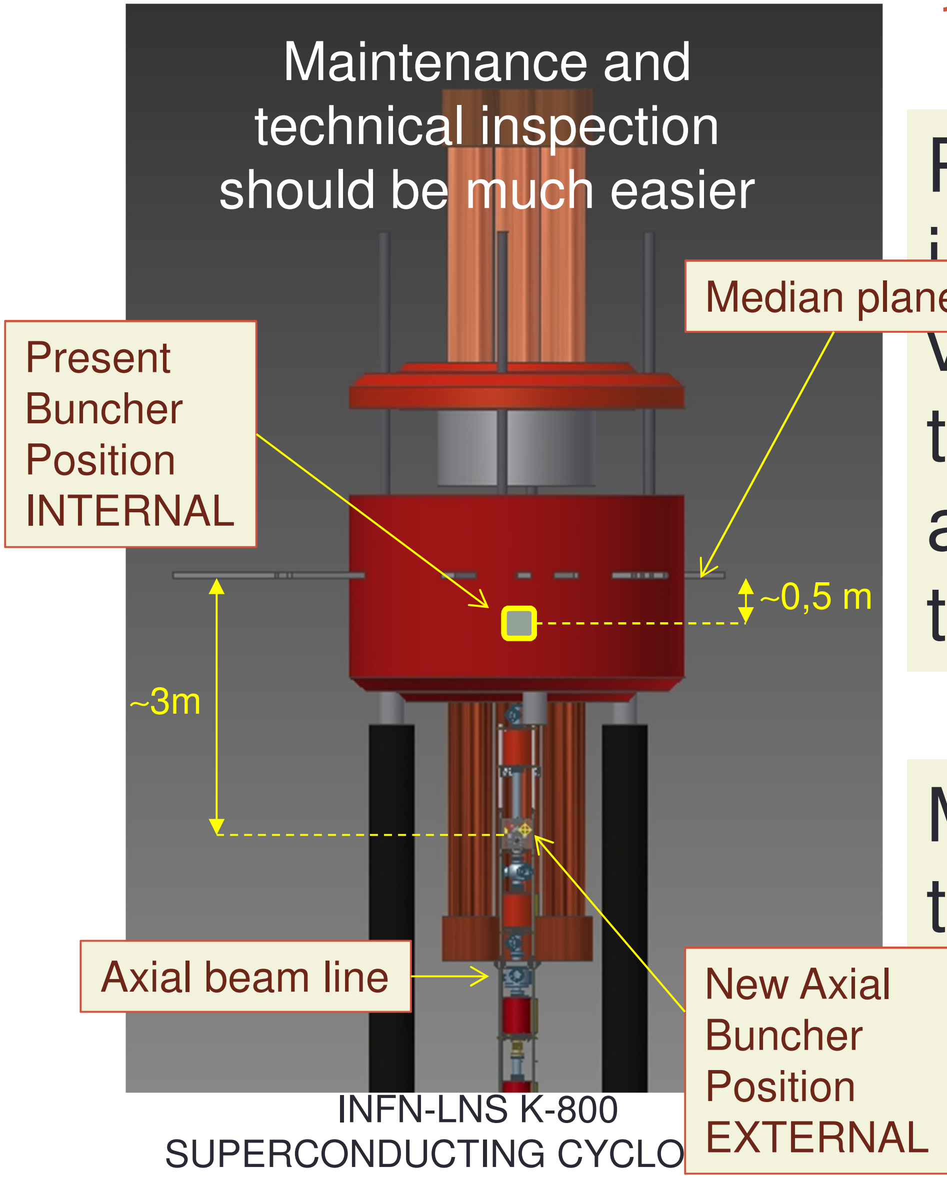
New axial buncher, main reasons.

INFN-LNS K-800
SUPERCONDUCTING CYCLOTRON

Present axial buncher is installed along the vertical beam line inside the yoke of the cyclotron at about half meter from the median plane.

Maintenance and technical inspection are very difficult to carry out in this situation.

New axial buncher, main reasons.

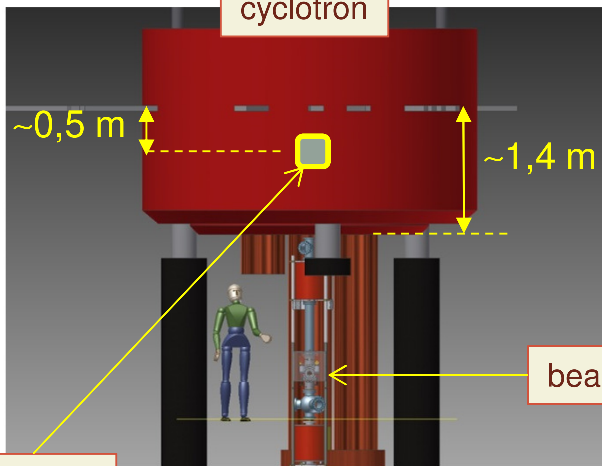


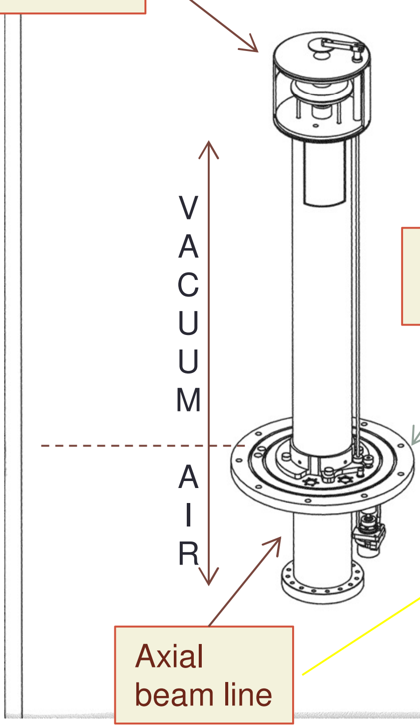
INFN-LNS K-800 SUPERCONDUCTING CYCLO

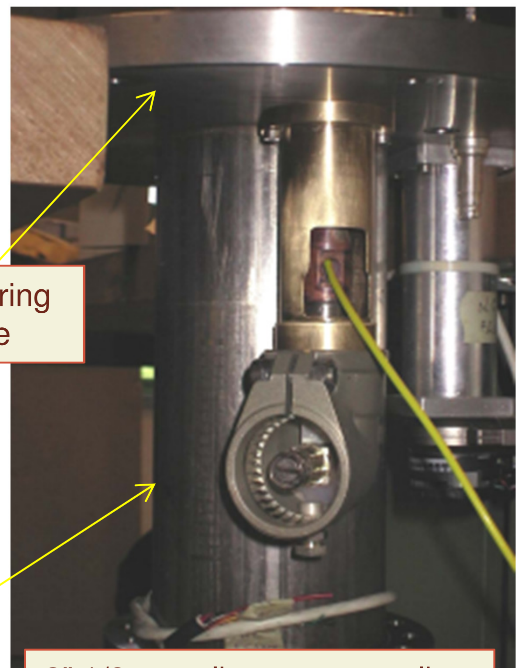
Present axial buncher is installed along the vertical beam line inside the yoke of the cyclotron at about half meter from the median plane.

Maintenance and technical inspection are very difficult to carry out in this situation.

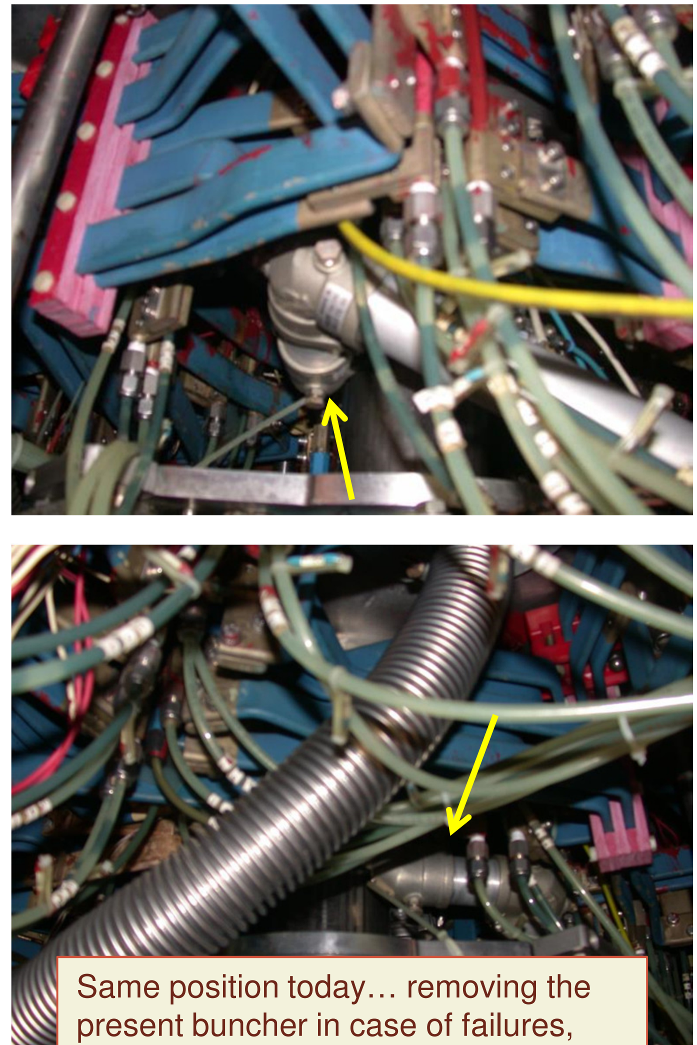
Just to give an idea of the complexity involved in maintenance work of the present buncher



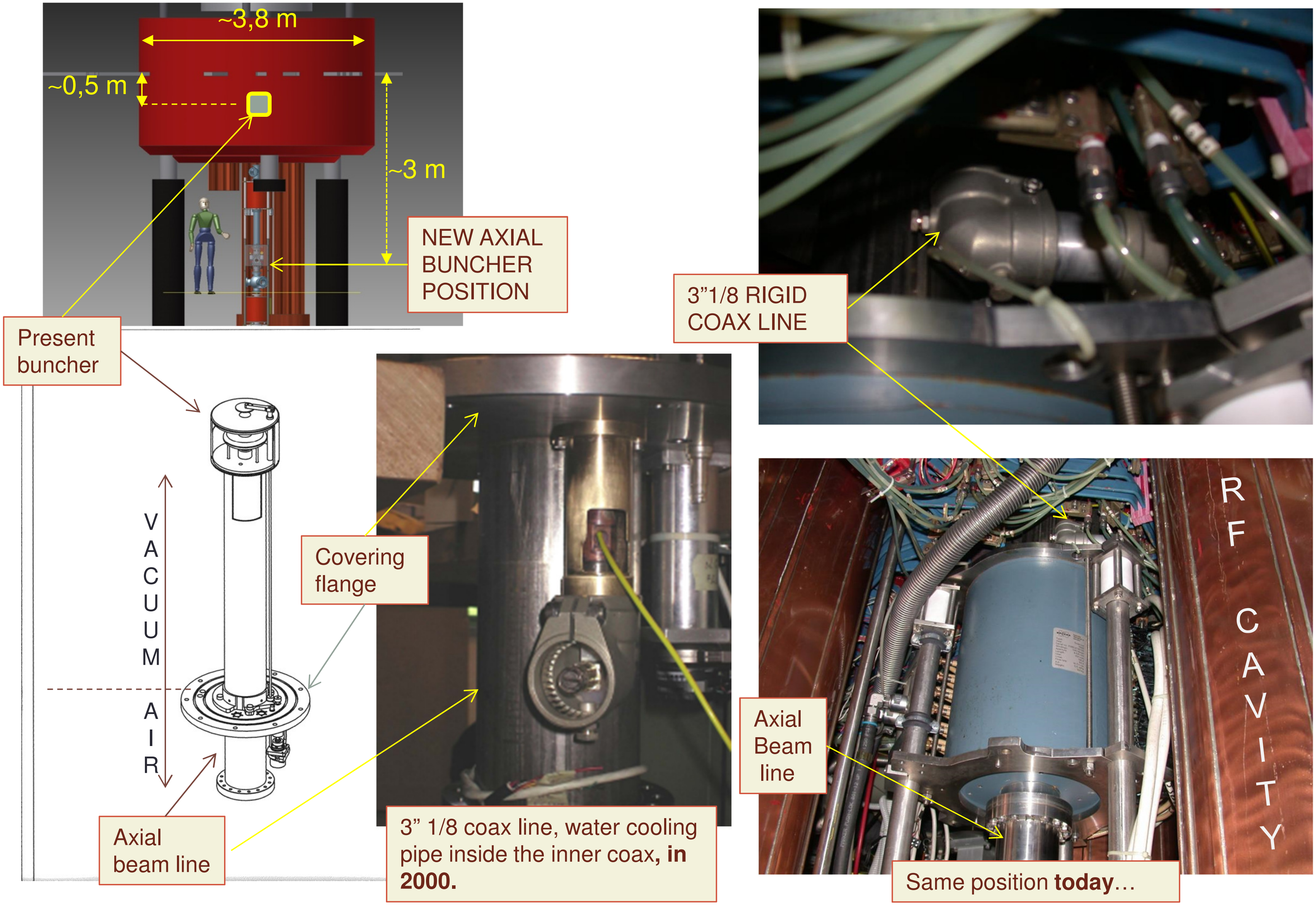




3” 1/8 coax line, water cooling pipe inside the inner coax, **dated 2000**.



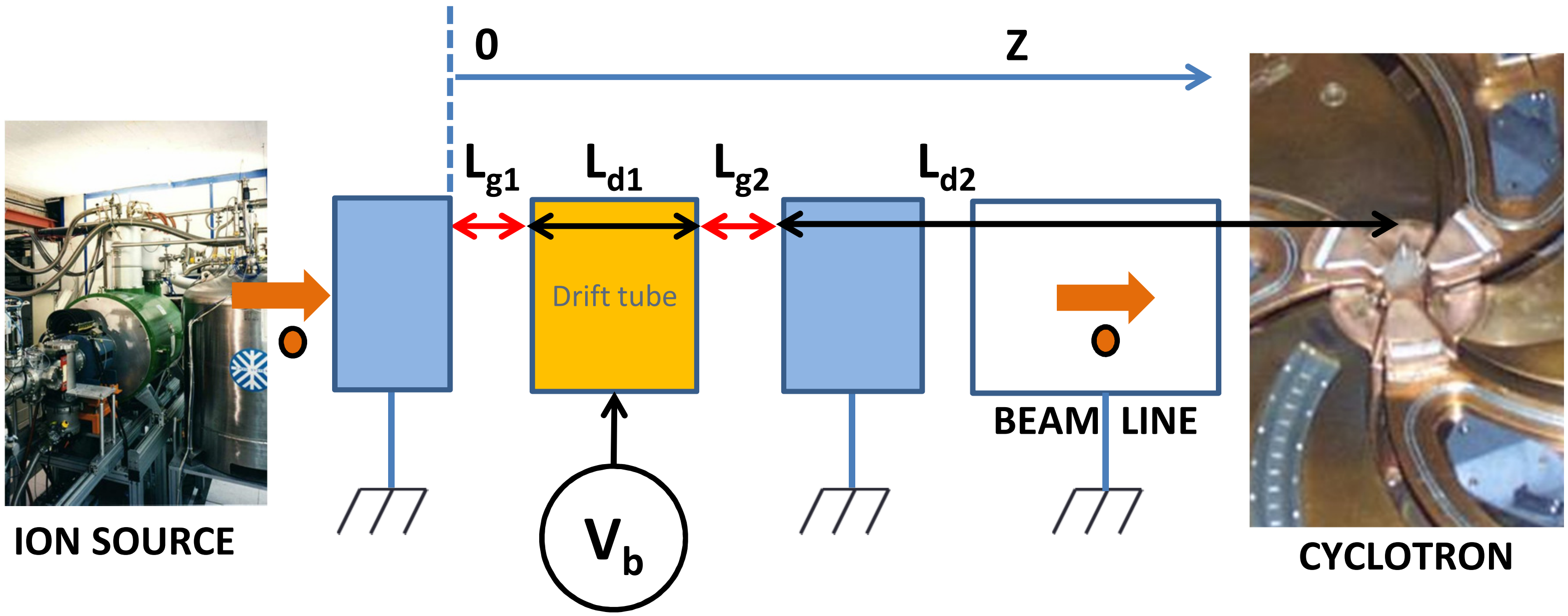
Same position today… removing the present buncher in case of failures, maintenance can be problematic


~3,8 m
~0,5 m
~3 m
NEW AXIAL BUNCHER POSITION
Present buncher
VACUUM
AIR
Covering flange
Axial beam line
3” 1/8 coax line, water cooling pipe inside the inner coax, **in 2000.**
3”1/8 RIGID COAX LINE
Axial Beam line
Same position **today**…
RF CAVITY

THE AXIAL BUNCHER STUDY

the buncher consists of a drift tube driven by a sinusoidal RF signal in the range of 15-50 MHz, a matching box, an amplifier, and an electronic control system.

Basic two gap buncher structure



$$V_B = V_{MB}\,\mathbf{sin}(\omega t + \varphi_0)$$

It is a **drift tube**, fed by a sinusoidal voltage and placed between two grounded tube electrodes.

L_{g1} **and** L_{g2} are the two gaps of 5 mm length

The distance between the Buncher and the inflector at the cyclotron central region (time focus) is 3011 mm, and it is imposed by mechanical constraints

Ion source beam table

0	1	2	3	4
"Ion"	"MeV/n"	"Vo(kV)"	Fh2(MHz)"	"Vb(Volt)"
"4 He 1+"	25	17	25.576	80.369
"4 He 2+"	62	20.22	39.312	86.762
"4 He 2+"	80	24.72	43.617	105.709
"9 Be 3+"	45	22.21	33.742	95.018
"12 C 3+"	23	15.47	24.41	66.123
"13 C 4+	[illegible]	[illegible]	42	102.74
"27Al 9+	[illegible]	[illegible]	71	84.484
"40Ar9+	[illegible]	[illegible]	.9	64.61
"48Ca9+	[illegible]	[illegible]	35	39.529
'48Ca15+	[illegible]	[illegible]	42	100.966
'58Ni 21+"	50	22.52	35.457	96.22
'84Kr 17+"	20	16.81	22.9	71.831
12Sn 31+"	43	25.65	33.08	109.611
16Sn 21+"	17	16.03	21.15	68.5
29Xe 31+"	35	24.03	29.835	102.685
97 Au 31+"	15	16.62	20.071	71.047
197 Au 36"	23	21.17	24.41	90.5

We now illustrate the typical case for α particles

$$v_{z0} = \sqrt{2q_i V_s / m_i}$$ particle velocity $z=0$

charge

Voltage source output electrode

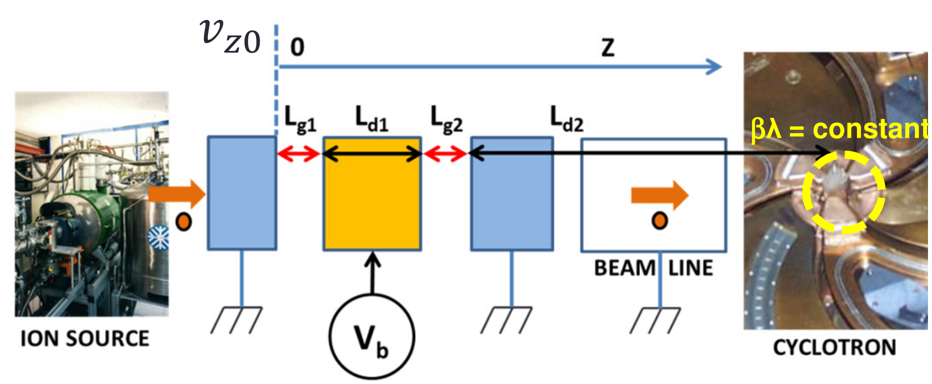
mass

(with f cyclotron frequency) **is the path of the particles in one period** and, because of the **fixed geometry of the cyclotron central region, has to be constant**

$$\boldsymbol{\beta\lambda = v_{z0}/f}$$

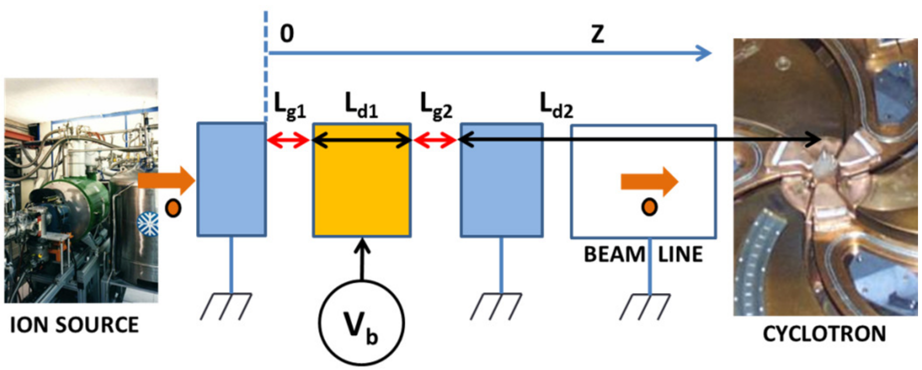
L_{d1} = 83.5 mm drift tube length

This length is chosen so **that $L_{d1}+L_{g1}$ is an odd integer multiple of the $(N+1/2)\beta\lambda/2$** in our case with N=2 and βλ=35,4 mm



α Charged particle case

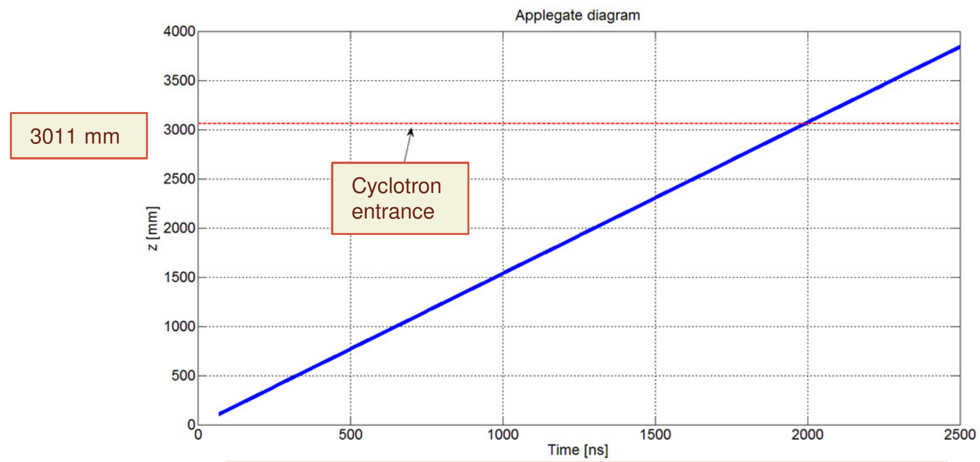
0	1	2	3
"Ion"	"MeV/n"	"Vo(kV)"	"Fh2(MHz)"
"4 He 1+"	25	17	25.576
"4 He 2+"	62	20.22	39.312
"4 He 2+"	80	24.72	43.617



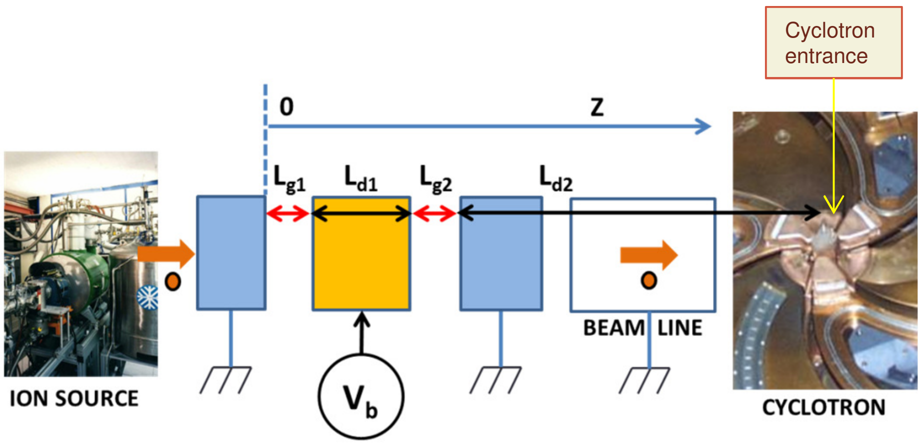
- $L_{g1} = L_{g2} = 5$ mm
- $L_{d1} = 83.5$ mm
- $L_{d2} = 3011$ mm - $L_{g2} - (L_{d1}/2) = 2964.25$ mm
- $v_{z0} = \sqrt{\frac{2\, q_i\, V_s}{m_i}}$ particle velocity when it arrives at the z = 0 position, due to the ion source voltage

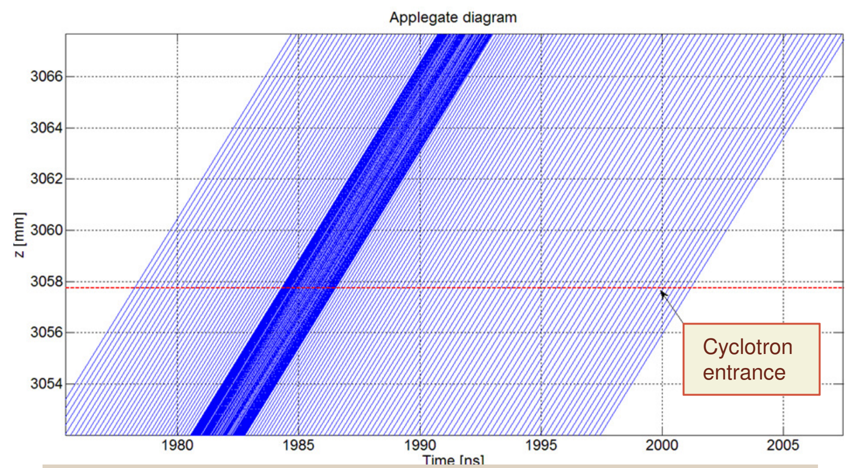
- Ion specie considered = $^4He^{2+}$
- Ion source voltage - $V_s = 24.72$ kV
- $V_B = V_{MB} \sin(\omega t + \varphi_0)$
- $V_{MB} = 70.1174/0.95$ V
- $\omega = 2\pi\, 43.617 \cdot 10^6$ rad/s
- $\beta_0 \lambda_0 = \frac{v_{z0}}{f} = 35.28$ mm
- Cyclotron acceptance interval phase = 35°

In this case the calculated particle trajectories are shown in the Applegate diagrams, referred to one period



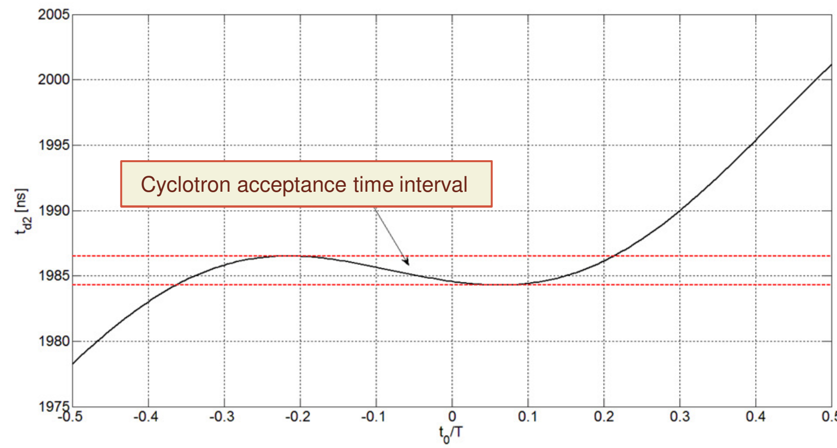
Applegate diagram. There is the indication of the z-position of the Cyclotron entrance.



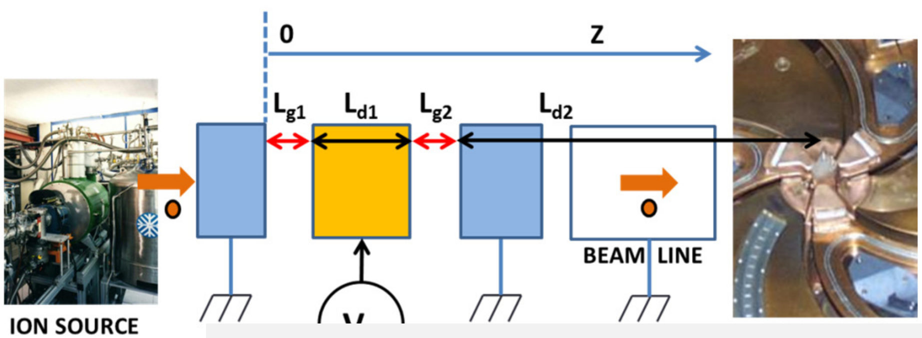


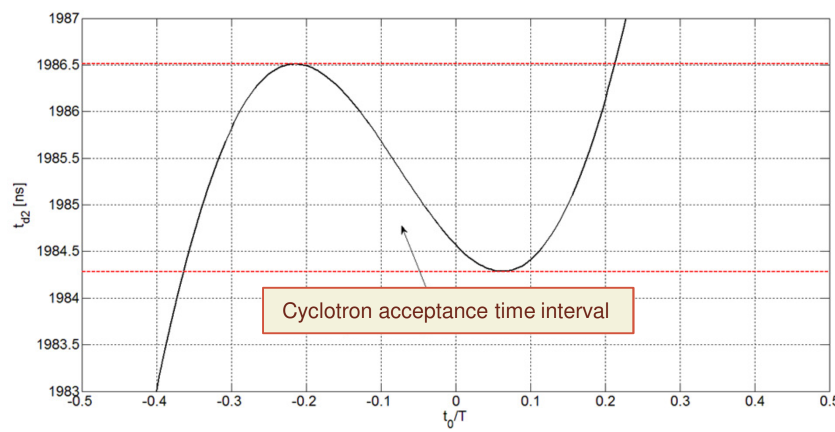
Enlarged view of the Applegate diagram. There is the indication of the z-position of the Cyclotron entrance.

In the graph the plot of t_{d2} versus t_0/T is shown. The V_{MB} voltage has been applied to optimize the particle transmission within the cyclotron acceptance time, referred to the 35° phase. This is clearly shown, where the curve is tangent to the dotted boundaries.



Arrival time of each particle at the Cyclotron entrance, with respect to the t_0 time when each particle arrives at the z = 0 position. T = 1/f.

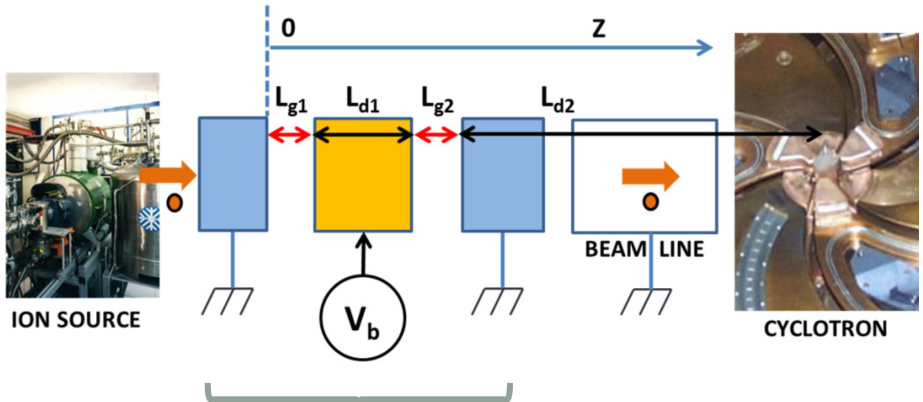


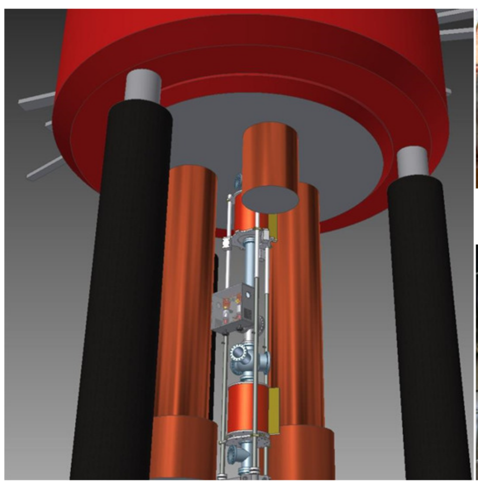


1/f.

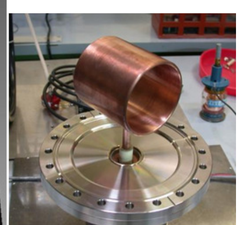
Under these conditions the particle transmission to the cyclotron is $TR = 57.6\%$, and the energy spread is $\Delta E/E = 1.15\%$.

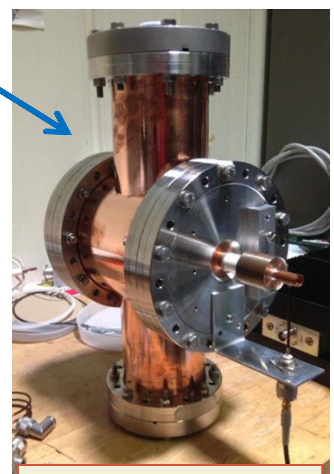
Mechanical design (drift tube mostly)

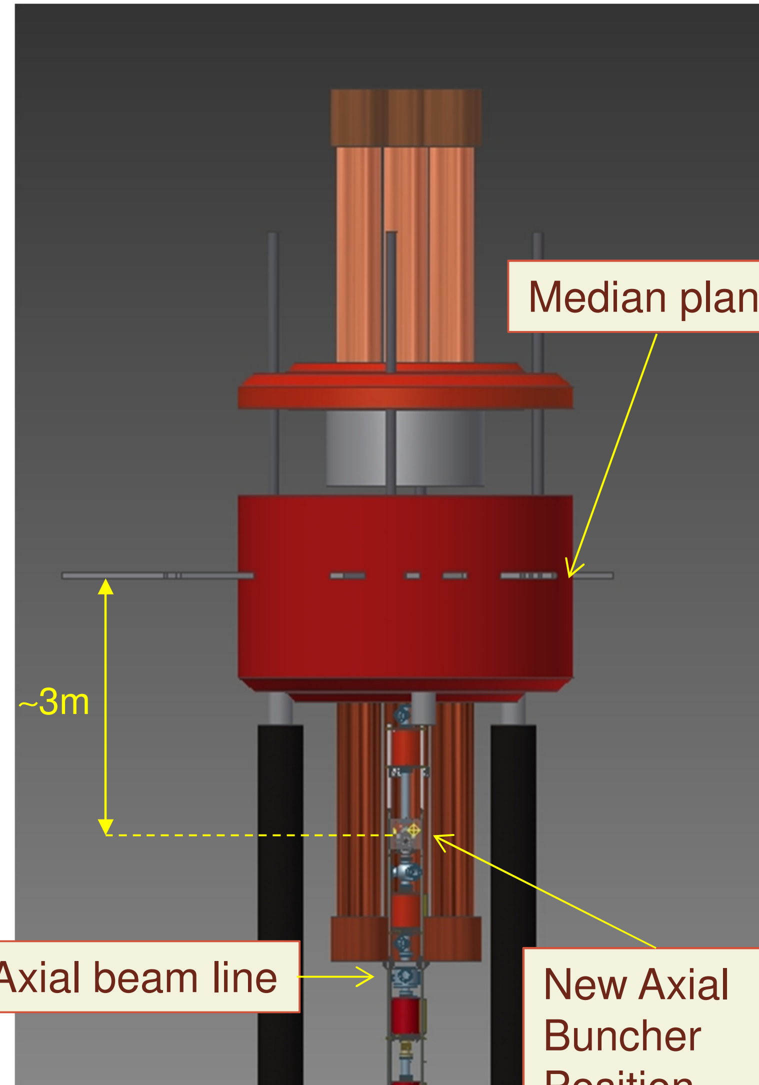




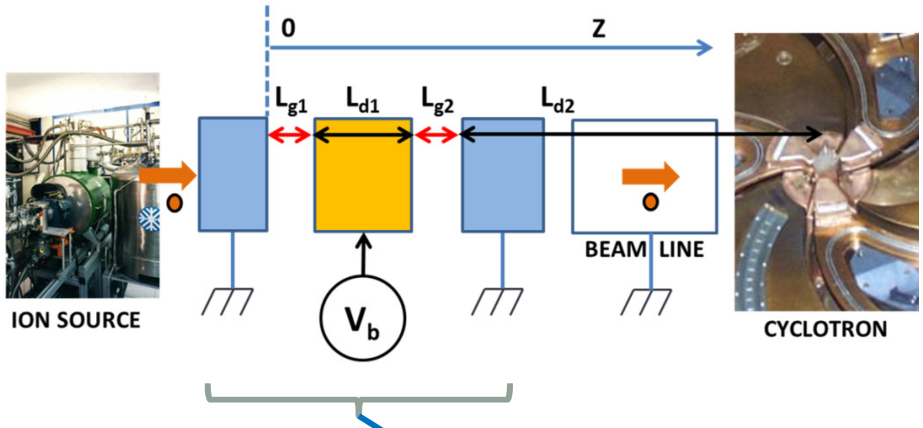

Ground

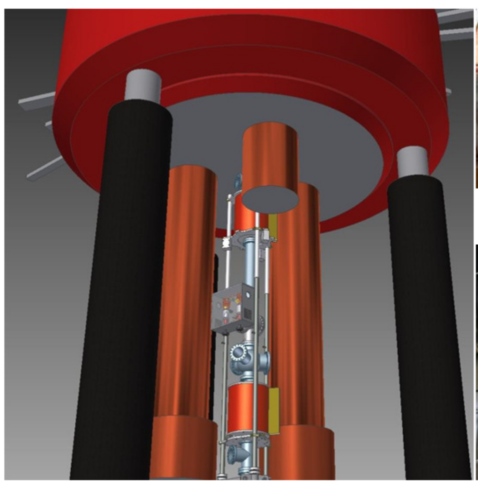

Drift tube


New axial buncher

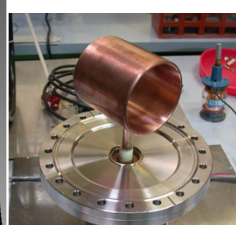


Mechanical design (drift tube mostly)

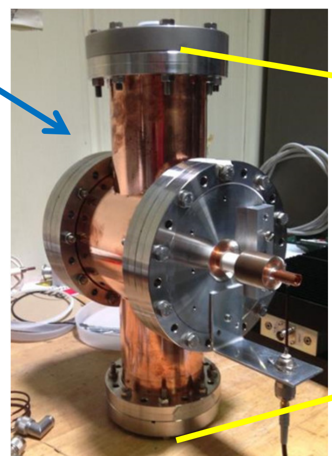




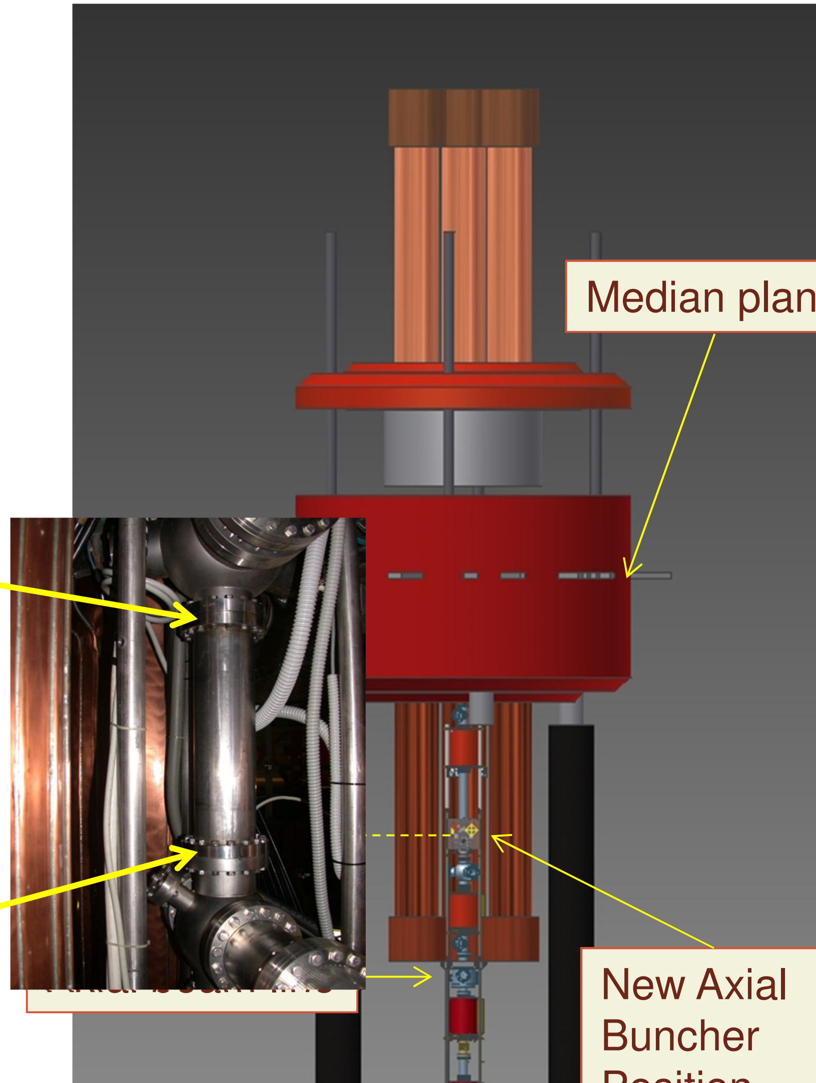
Ground



Drift tube



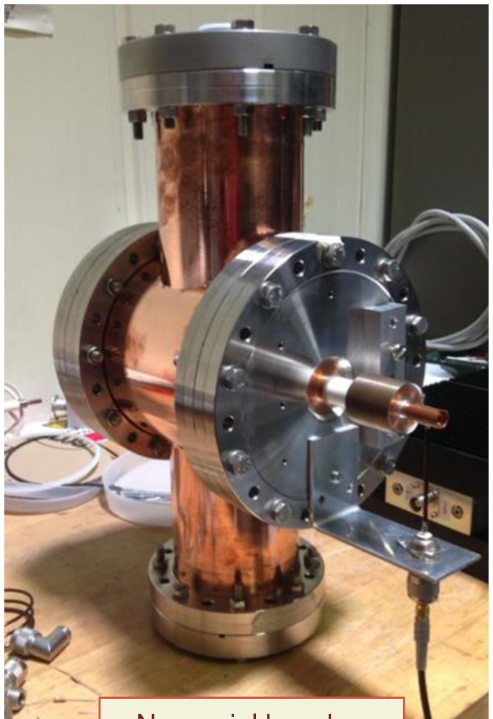
New axial buncher



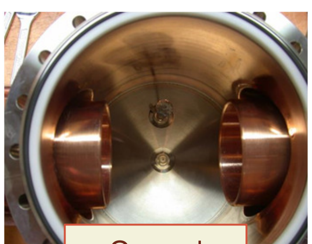
Median plane

New Axial Buncher Position EXTERNAL

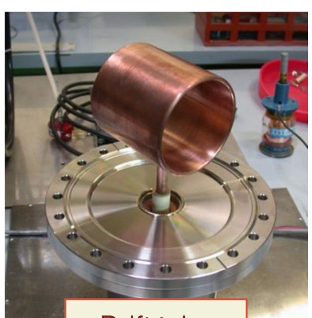
Mechanical details



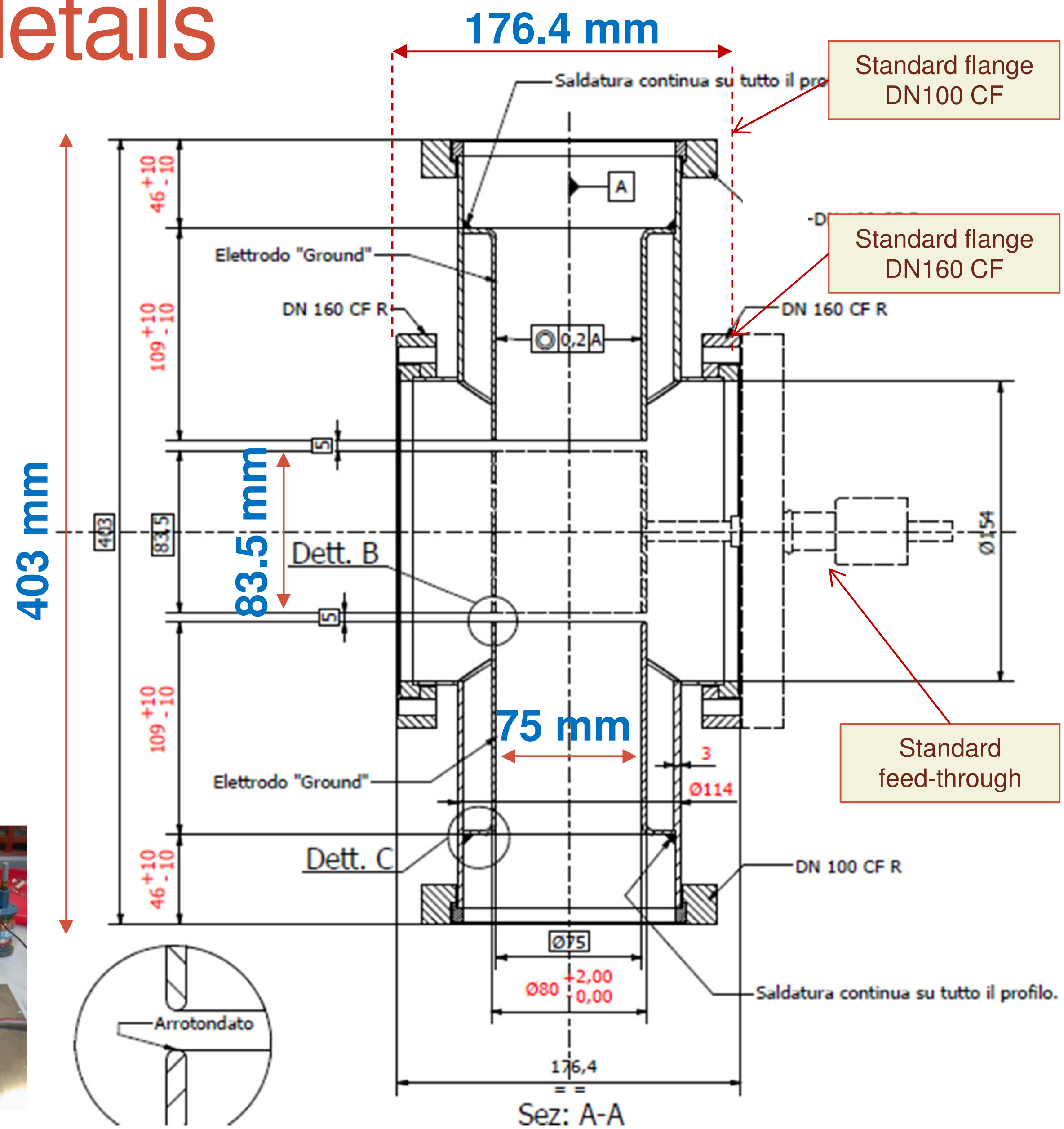
New axial buncher



Ground electrodes



Drift tube

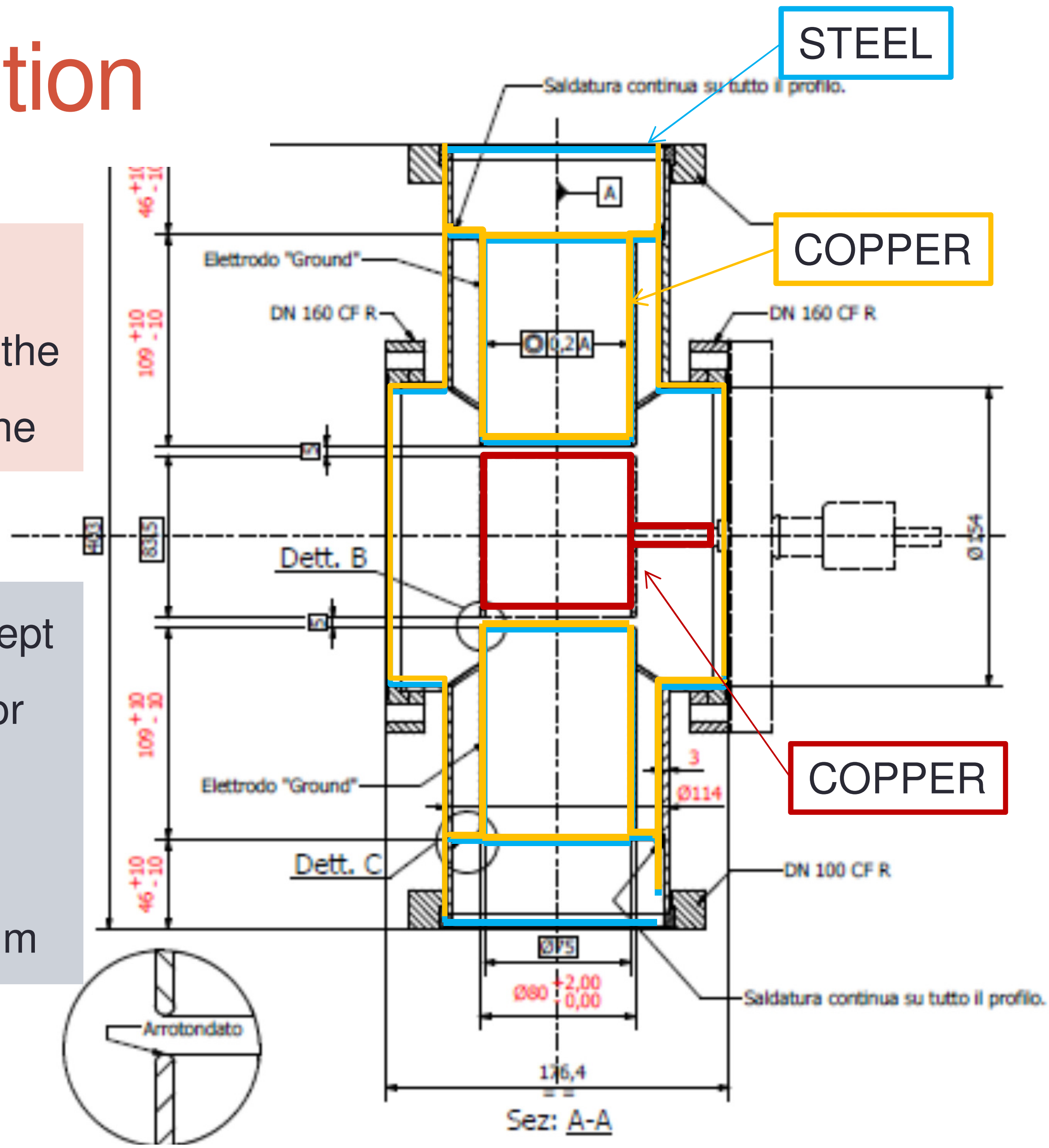


Copper deposition

Drift tube copper made.

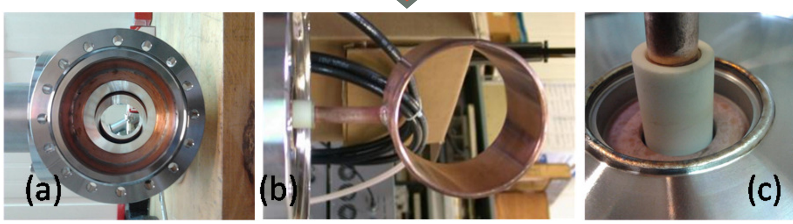
Galvanic copper deposition on the ground electrodes and beam line

All surfaces are in copper (except flanges). Consequently Q-factor increases, prevents/minimizes any copper surfaces facing a steel surface under high vacuum

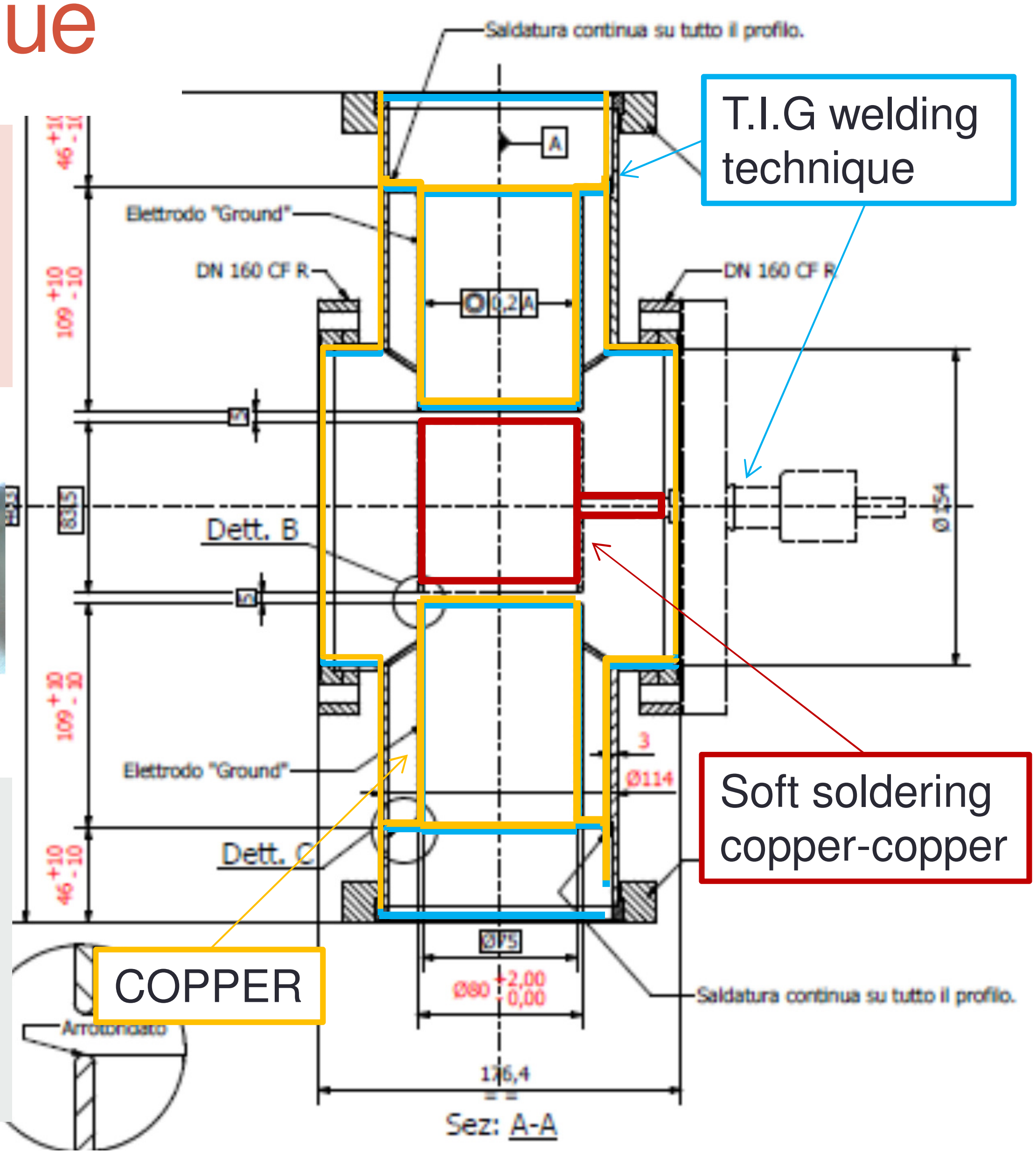


Soldering technique

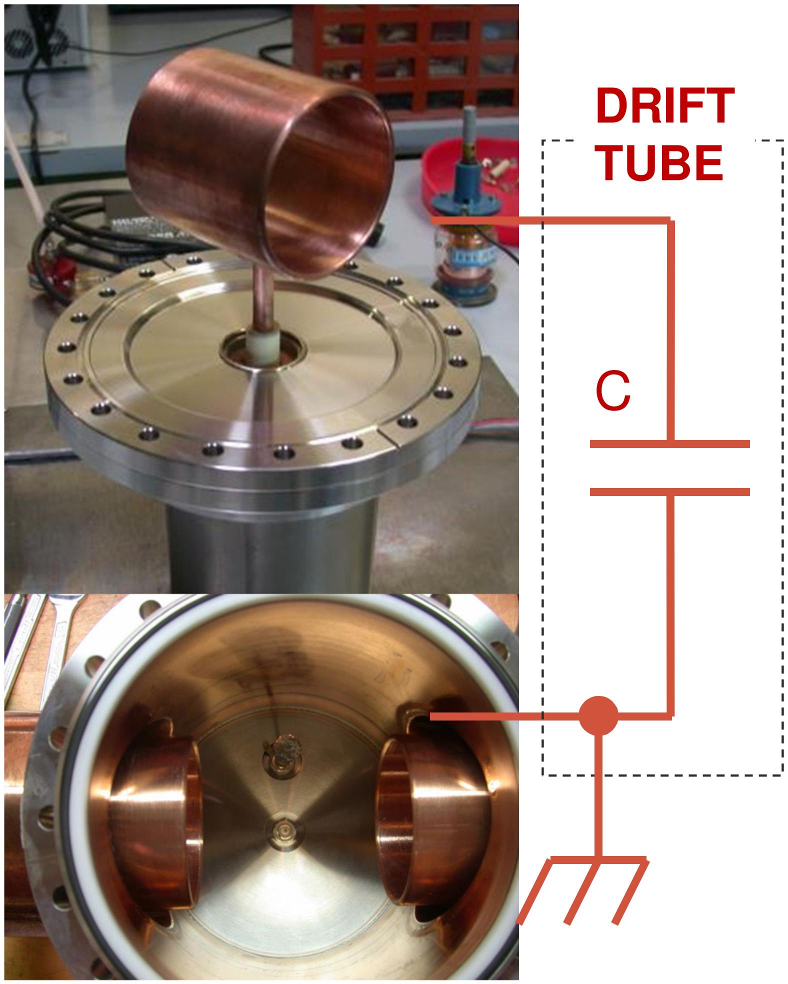
A soft soldering has been adopted to connect the feed-through to the drift tube, copper-copper (b).



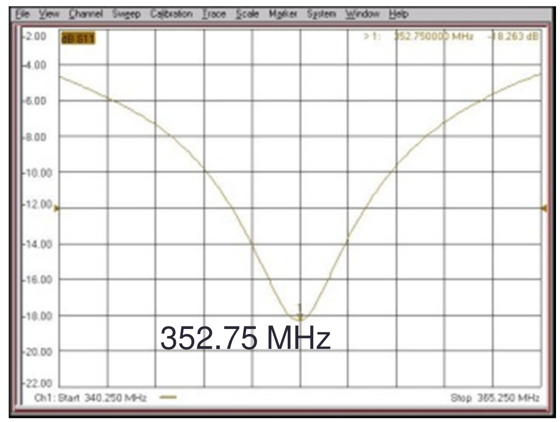
T.I.G. welding has been adopted to weld the flange at ground (steel-steel) and to connect the ground electrodes to the beam line (a, c).

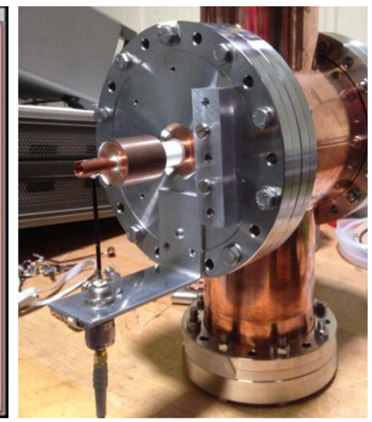


Electrical design

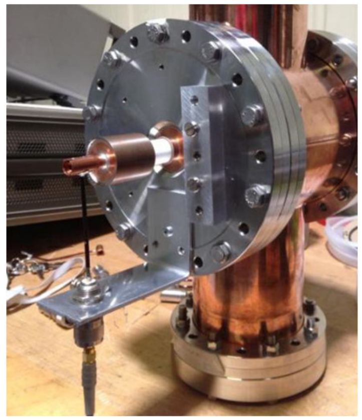


From the electrical point of view the **drift tube** can be seen as a **capacitance**.





An LCR meter confirms the simulated capacitance value **of about 27pF** and, with a vector network analyser, the **self-resonance of 352,75 MHz** has been measured through an **N-adaptor.**



From a fixed frequency system

of 352.75 MHz

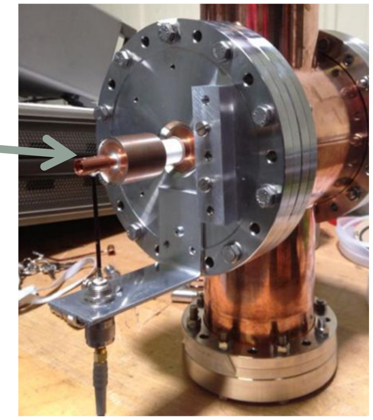
to the cyclotron frequency

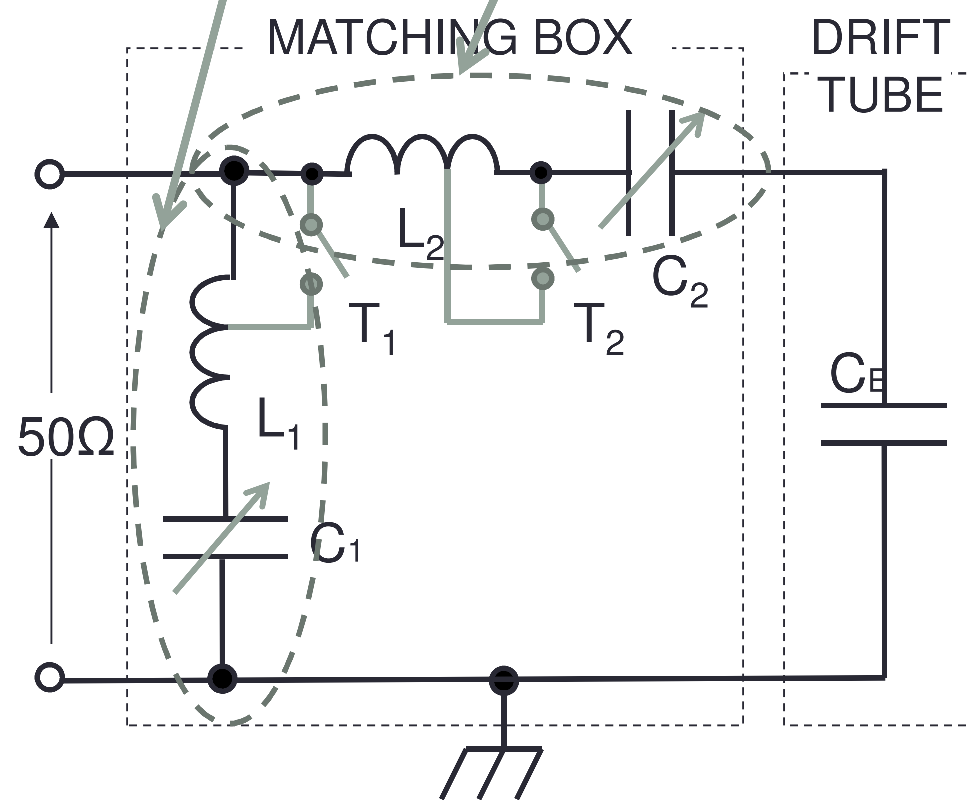
bandwidth of 15-50 MHz

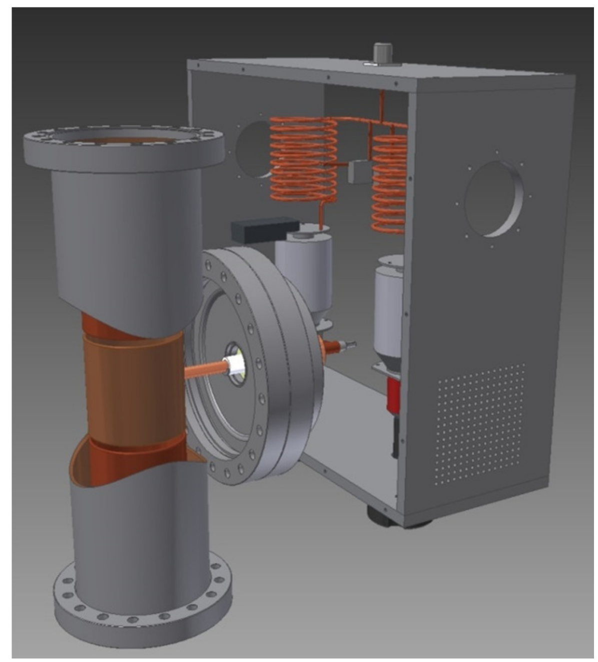
We need a sort of **transformer network** to match this "drift tube capacitance" in terms of impedance (standard 50 Ω) and total bandwidth (15-50 MHz)

Impedance transformer from Z_0 to buncher impedance Z_b

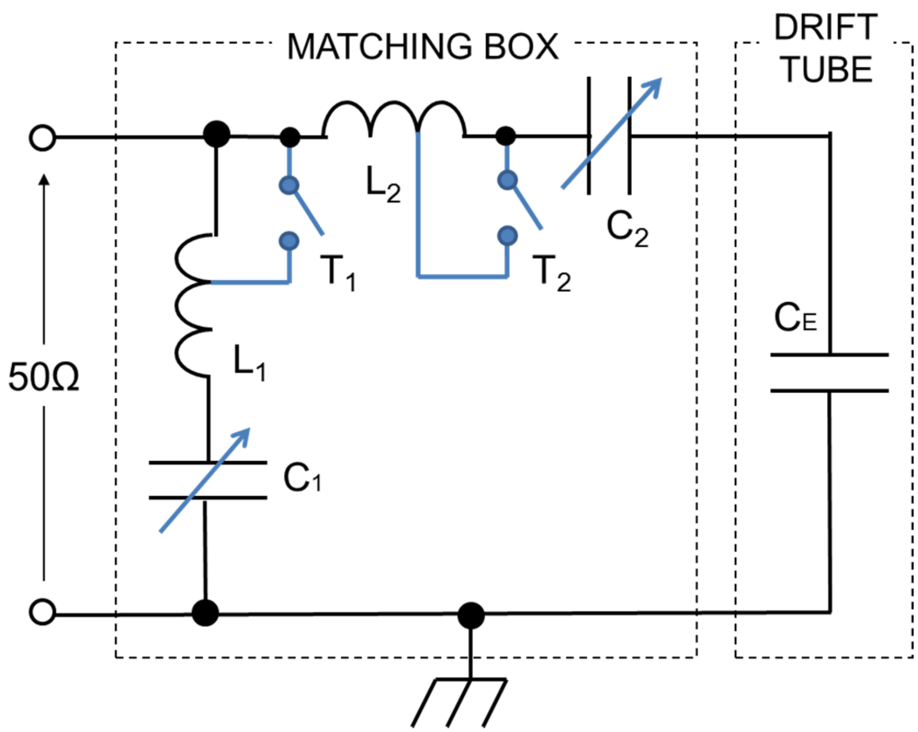
$$Z_{in} = \frac{Z_{shunt} \cdot (Z_{series} + Z_b)}{Z_{shunt} + (Z_{series} + Z_b)}$$

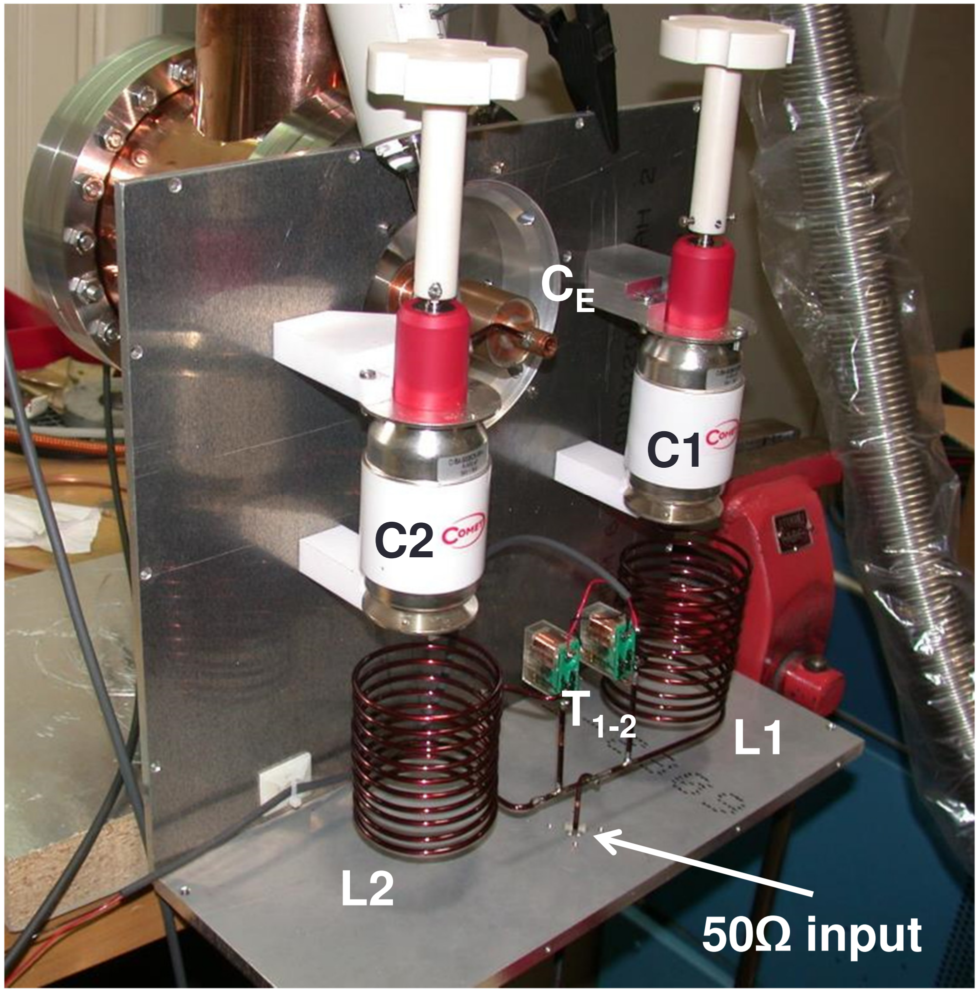






2 bandwidths to cover all the frequency range between 15 – 50 MHz



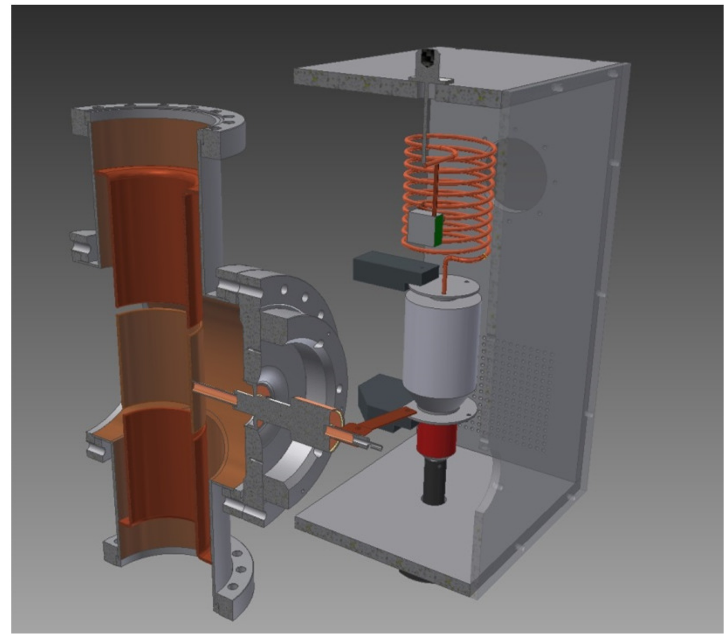


Lower Bandwidth: 13.3-25 MHz $L_1 = L_2 = 4.2\ \mu H$ (T_1-T_2 open)

Higher Bandwidth: 25-51 MHz $L_1 = L_2 = 1.3\ \mu H$ (T_1-T_2 closed)

$C_1 = C_2$ variable capacitors between 5 – 500 pF

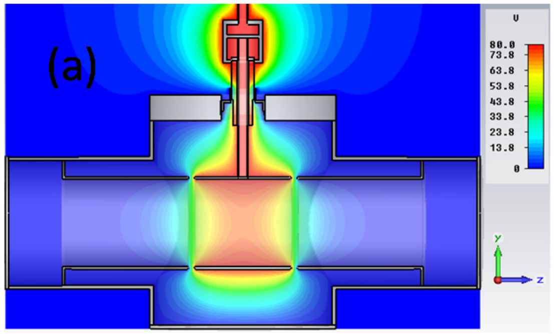
direct connection between drift-tube and matching box.

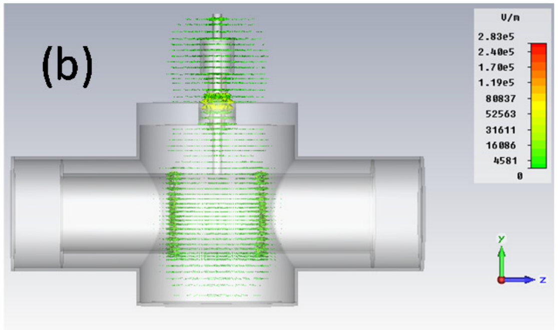


This particular design prevents any connection through coaxial transmission line. It reduces the entire geometry, the connection losses, the total RF power and the maintenance.

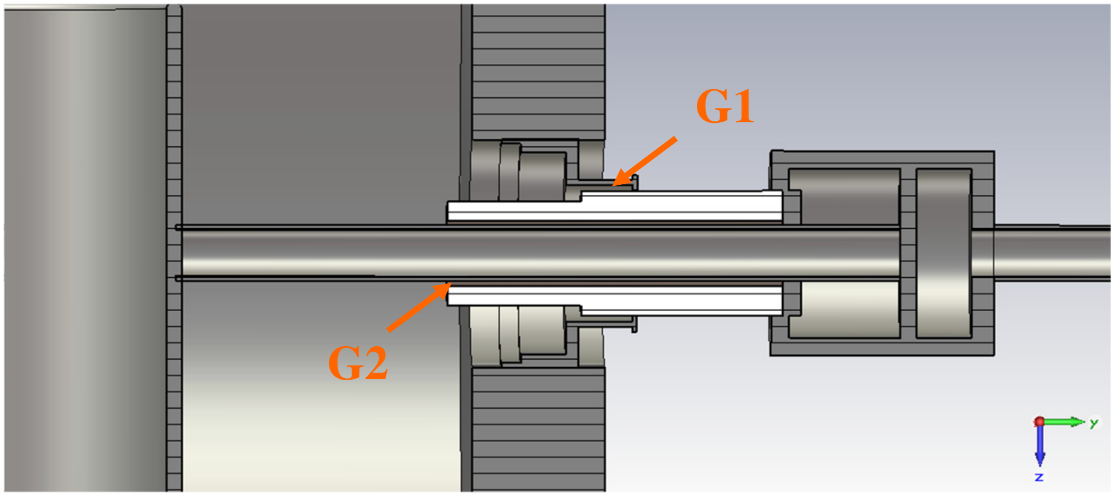
Numerical simulations

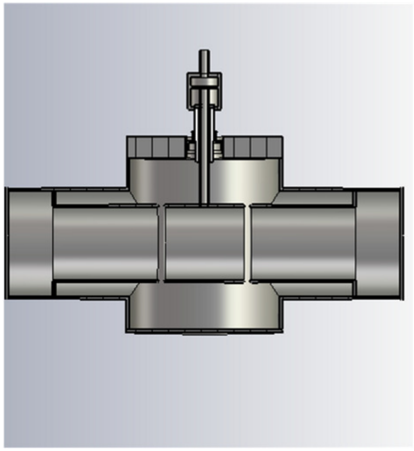
potential (a). 3D electric field distribution (b).





G1	G2	Mutual Capacitance	Mode 1		Mode 2		Mode 3		Mode 4	
			F	A	F	A	F	A	F	A
0.27	0.35	30.562 pF	319.3	3.034e-8	633.9	2.233e-8	869.4	3.170e-8	958.2	9.336e-8
1	0.35	29.205 pF	335.9	4.724e-8	634.8	2.348e-8	869.5	3.079e-8	958.4	1.105e-8
1	0.5	28.348 pF	352.5	5.317e-8	636.0	2.416e-8	869.5	3.031e-8	958.5	1.028e-8
1	0.8	27.778 pF	400.5	8.240e-8	640.5	4.418e-8	869.5	3.268e-8	958.9	8.600e-8
1	1.03	26.990 pF	409.0	8.407e-8	641.5	3.904e-8	869.5	2.729e-8	959.0	8.333e-8

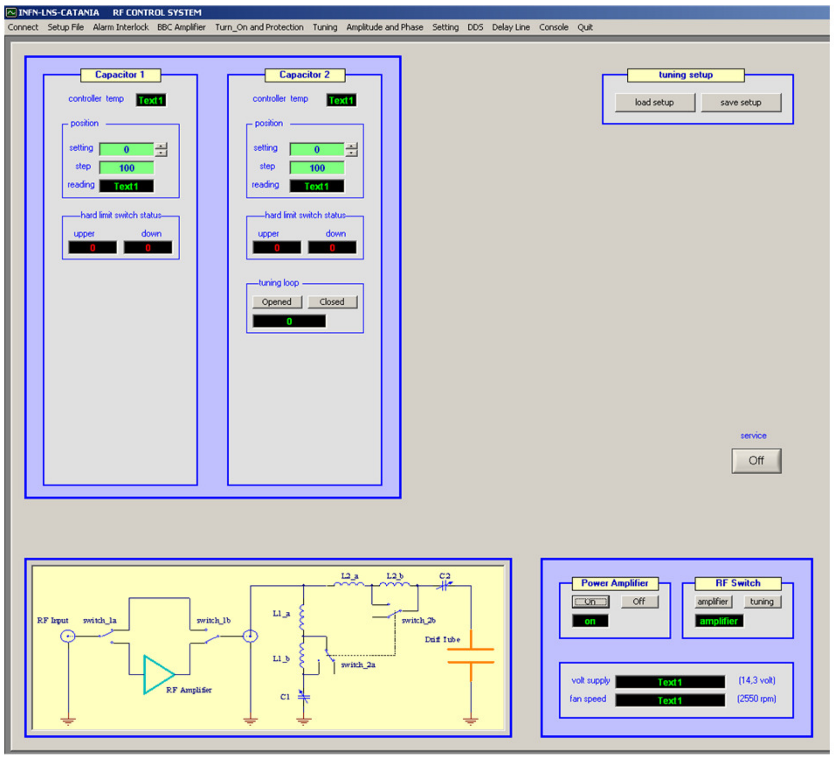


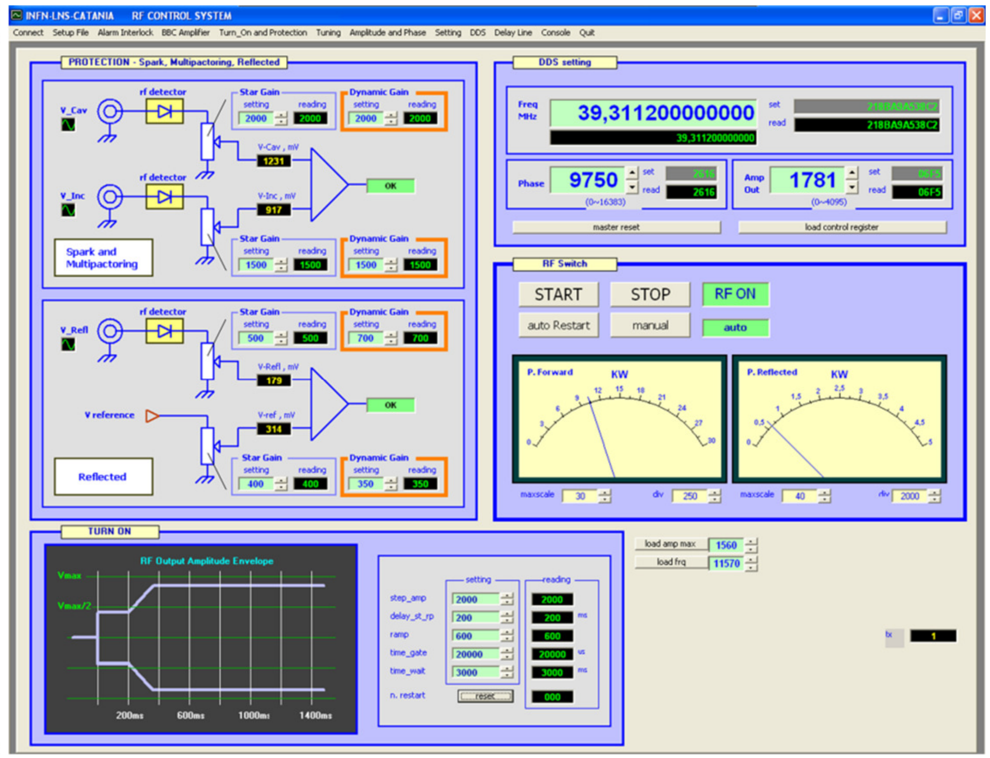


LOW LEVEL RF

MATCHING BOX CONTROL PANEL

LLRF CONTROL PANEL SET FREQUENCY, AMPLITUDE, PHASE BY THE DDS TECHNIQUE

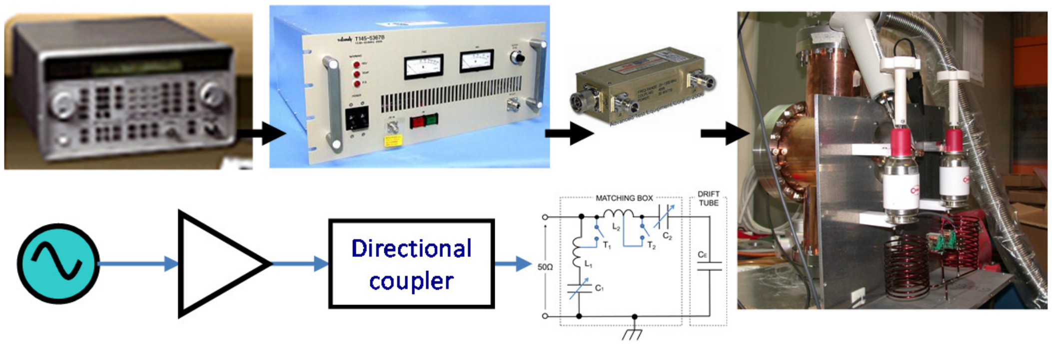




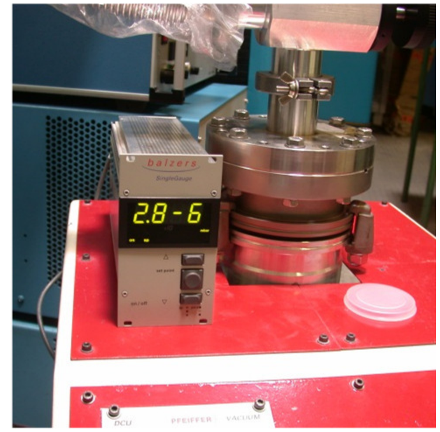
PROTECT THE SYSTEM (MULTIPACT, REFLECTED WAVE)

TURN ON/OFF THE SYSTEM (AUTO-MANUAL MODE)

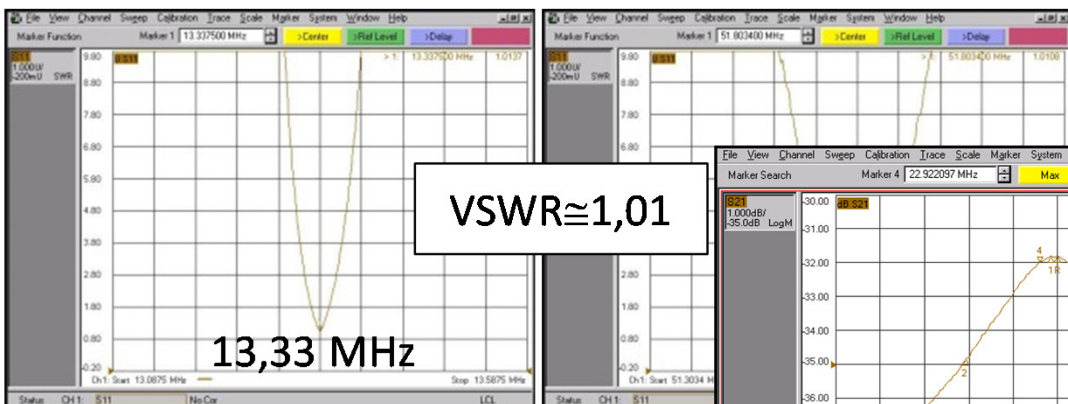
Test and measurements



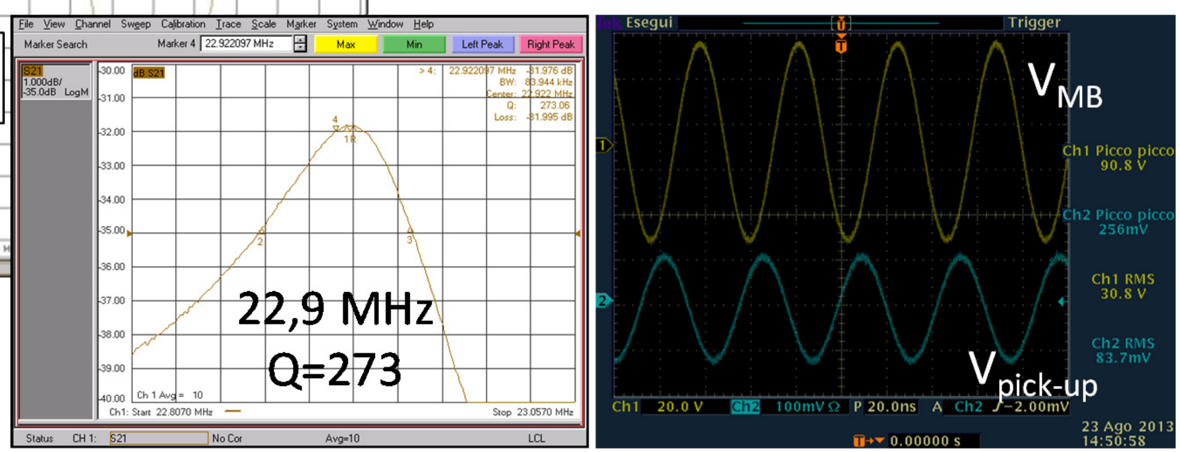
BLOCK DIAGRAM



VACUUM LEVEL

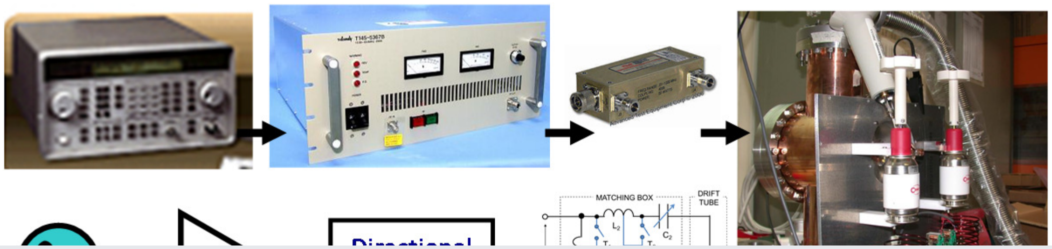


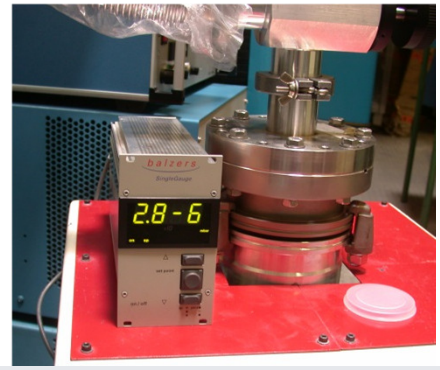
BANDWIDTH



Q-FACTOR AND VOLTAGES

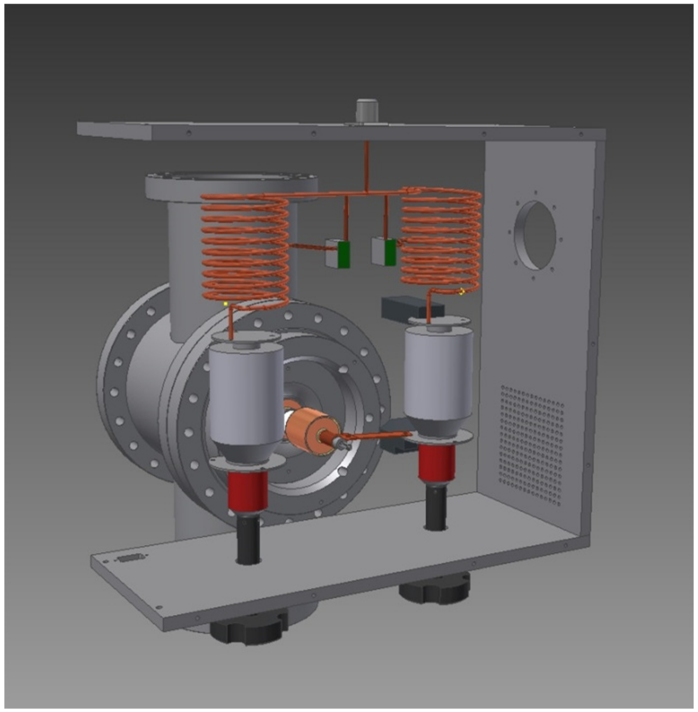
Test and measurements





Useful mechanical/electrical tool design to measure the drift tube voltage from outside the matching box

Conclusion



Axial buncher in brief

- Frequency range 15 -50 MHz
- Voltage on the drift tube 64 -110 V
- Gain calculated about 6
- Energy spread 1,15%
- Particles transmission to the cyclotron is 57.6 %

All RF tests and measurement have been achieved at full power on the test bench. The cyclotron long maintenance programme has delayed the final test on the axial beam line of the new buncher. We believe we can produce a first test on the beam at the beginning of 2014.

Thank you for your kindly attention

References:

- D. Rifuggiato et al., "Variety of beam production at the INFN LNS Superconducting Cyclotron", M0PPT011, these proceedings.
- L. Calabretta et al, The Radiofrequency Pulsing System at INFN-LNS, USA,CYCLOTRONS 2001, p. 297.
- C. Goldstein and A. Laisne, NIM 61, 221, 1968.
- [W.J.G.M. Kleeven et al, NIM B 64, 367, 1992.
- S. Gammino et al, Review of scientific instruments volume 70, nr. 9 September 1999.
- A. Caruso et al, MOPCP057 Proceedings of CYCLOTRONS 2010, Lanzhou, China, p. 159.

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