SRF CAVITIES FOR CW OPTION OF PROJECT X LINAC

N. Solyak, I. Gonin, T. Khabiboulline, A. Lunin, N. Perunov and V. Yakovlev, Fermilab, IL 60510, U.S.A.

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ABSTRACT

Alternative option of Project X is based on the CW SC 2GeV Linac with the average current 1mA. Possible option of the CW Linac considered in the paper includes low energy part consisted of a few families SC Spoke cavities (from 2.5 MeV to 466 MeV) and high energy part consisted of 2 types of elliptical cavities (v/c=0.81 and v/c=1). Requirements and designed parameters of cavities are considered.

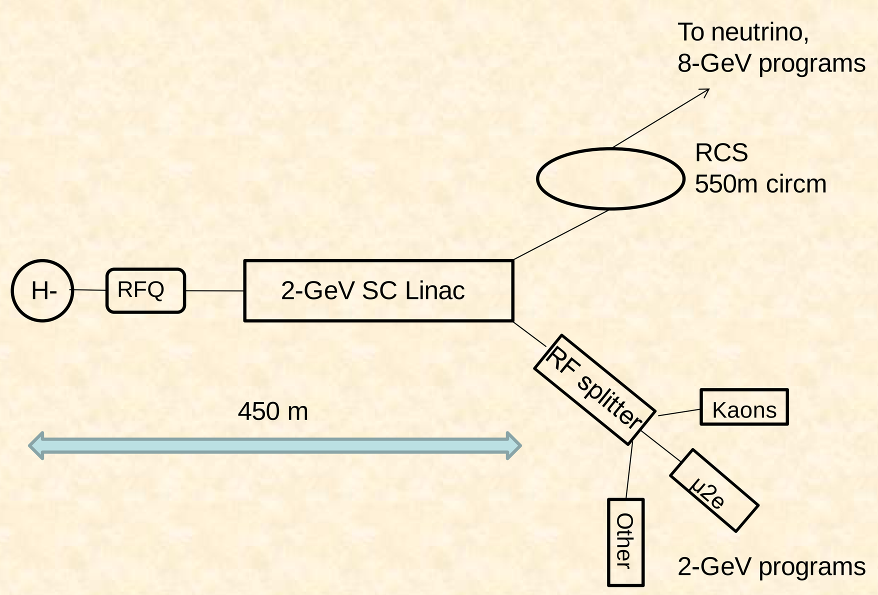


Figure 1: Layout of the 2 GeV proton source.

INTRODUCTION

An alternative scheme [1] of the Project X proton source is based on the 2 GeV CW superconducting linac that accelerates H- beam with the current of 1 mA, see Figure 1The beam originates from a DC H- source. The beam is then bunched and accelerated by a CW normal-conducting RFQ to 2.5 MeV and the bunches are formatted by a chopper following a pre-programmed timeline. From 2.5 MeV to 2 GeV the H- bunches are accelerated by a CW super-conductive linac. A present concept of the linac is based on the 8 GeV pulse linac design [2], including designs of cavities, cryomodules and beam optics (to the extent possible). The CW, 2-GeV linac has an average current (over few microseconds) of 1 mA, with a pulsed current of up to 10 mA. Since the pulsed 8-GeV Project X linac (ICD-1) has a well developed optics operating at this current range, it is possible to use the same structure of the linac and same break points as in the pulsed linac with the necessary modifications to operate in a CW regime.

GENERAL

The CW linac (see Figure 2) consists of a low-energy 325 MHz SCRF section (2.5 - 450 MeV) containing three different families of single-spoke resonators (SSR0, SSR1, SSR2) and one family of a triple-spoke resonator (TSR), and the high energy 1.3-GHz SCRF section (450 MeV – 2 GeV) containing squeezed elliptical βG =0.81cavities (S-ILC), and ILC-type βG=1 cavities.

The break points between sections containing the cavities of different types are shown in Table 1. The bunching cavities together with focusing solenoids are presented. The number of focusing elements and cryomodules are also shown..

Section	Energy range MeV	β	Number of cavities/ lenses/CM	Type of cavities and focusing element	Power/cavity, kW (I_{av}=1 mA)
Bunching SSR0 (β_G=0.11)	2.5	0.073	2/3/2	Single spoke cavity, Solenoid	0.5
SSR0 (β_G=0.11)	2.5-10	0.073-0.146	16/16/2	Single spoke cavity, Solenoid	0.5
SSR1 (β_G=0.22)	10-32	0.146-0.261	18/18/2	Single spoke cavity, Solenoid	1.3
SSR2 (β_G=0.4)	32-117	0.261-0.5	33/17/3	Single spoke cavity, Solenoid	4.1
TSR (β_G=0.6)	117-466	0.5-0.744	48/48/8	Triple spoke cavity, quads	8.5

Table 1: Break points between the sections in the low-energy part of the linac

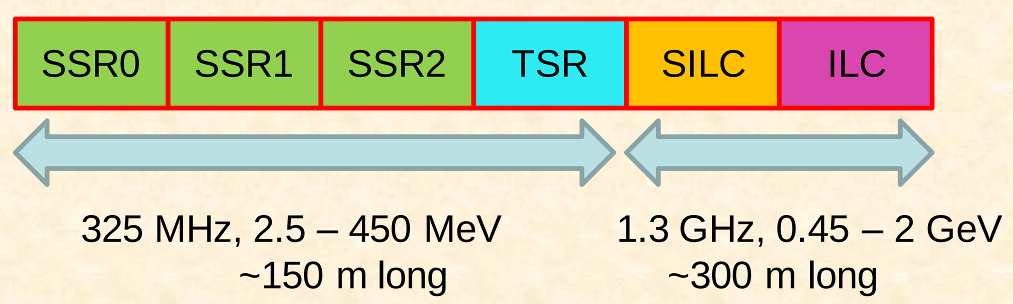


Figure 2: The schematic of the CW linac (2.5 MeV – 2 GeV).

2.5-10 MeV: a single family of CW Spoke (SSR0) SC cavities may be used for acceleration for the beam energy from 2.5 MeV to 10 MeV. The SSR0 cavity for beta =0.073-0.146 was optimized, and the results of optimization are shown in Table 2.

Operating frequency	325	MHz
β_G	0.117	
Cavity diameter	200	mm
R/Q	120	Ω
Average transit time factor (TTF)	0.94	
Electric field enhancement factor, $(E_{max}/E_{acc})/(E_{max}/E_{acc*})$	5.5/5.85	
Magnetic field enhancement factor, $(H_{max}/E_{acc})/(H_{max}/E_{acc*})$	6.5/6.9	[mT/MV/m]
Cavity effective length, D_{eff}=2*βλ/2	108	mm

Table 2: SSR0 cavity parameters.

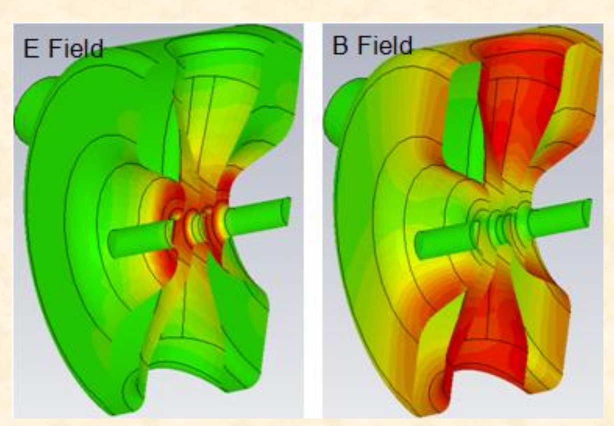


Figure 3: Fields pattern

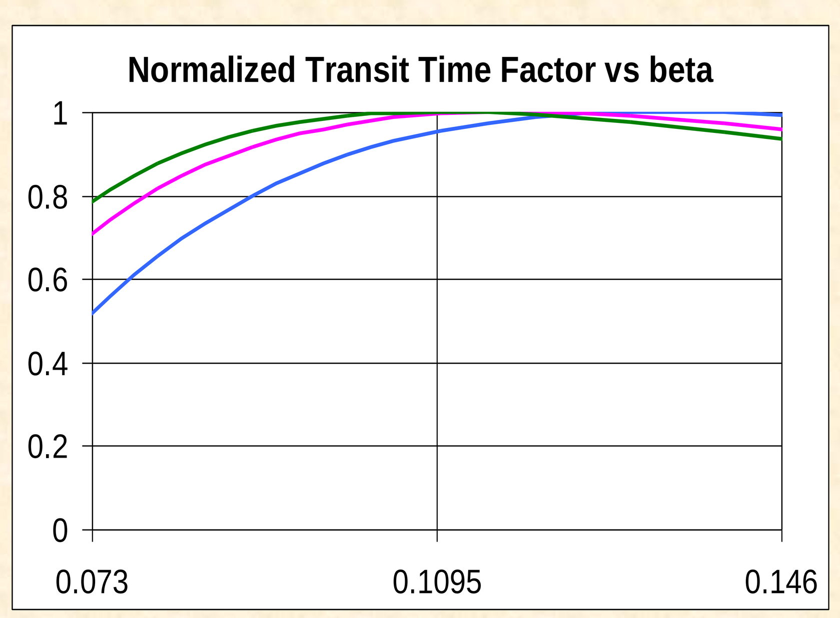


Figure 4: The transit time factor vs. proton beta

2.5-10 MeV Other parts of 325 MHz SC linac are the same (SSR1, SSR2, TSR) as in the ICD-I 8 GeV linac. Parameters of the cavities are shown in Table 3.

cavity type	F [MHz]	E_{acc} [MV/m]	L_{eff}, mm	Ep/E_{acc}	B_p/E_{acc} mT/(MV/m)	R/Q Ω	G Ω	$Q_{0,2K}$ ×10^9	$Q_{0,4K}$ ×10^9	P_{2K} [W]	P_{4K} [W]
SSR0	325	8.7	72	4.1	4.6	120	57	9.5	0.7	0.34	4.67
SSR1	325	10.8	135	2.62	3.87	242	84	14.0	1.0	0.63	8.78
SSR2	325	13.6	246	2.42	3.95	322	112	18.0	1.3	1.93	26.7
TSR	325	9.75	943	3.22	6.85	554	117	19.0	1.4	8.03	109

Table 3: Parameters of the spoke cavities.

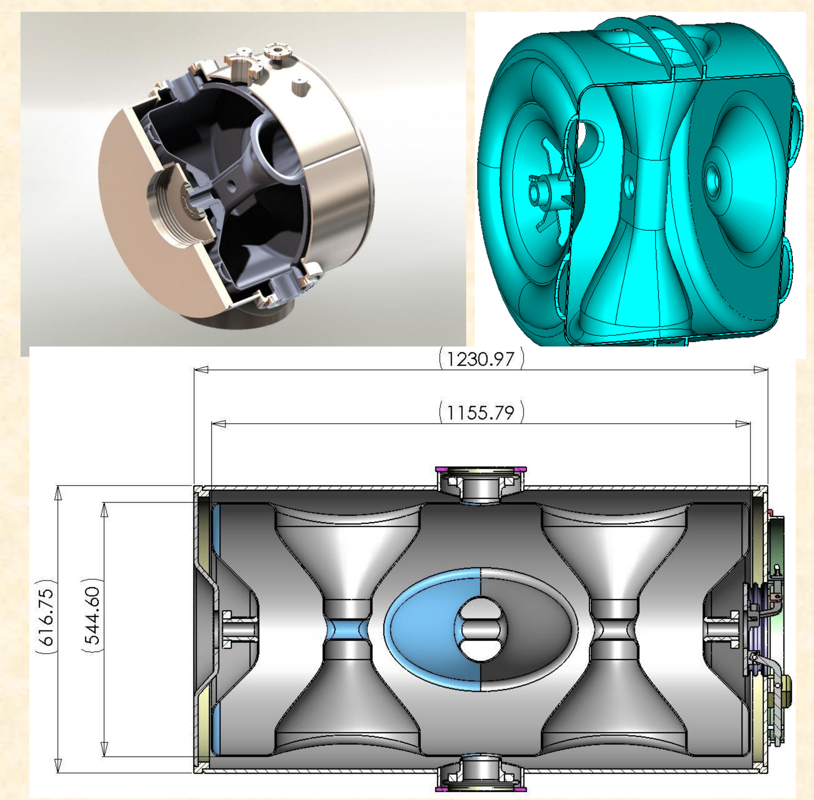


Figure 5: Layouts of SSR1, SSR2 and TSR cavities

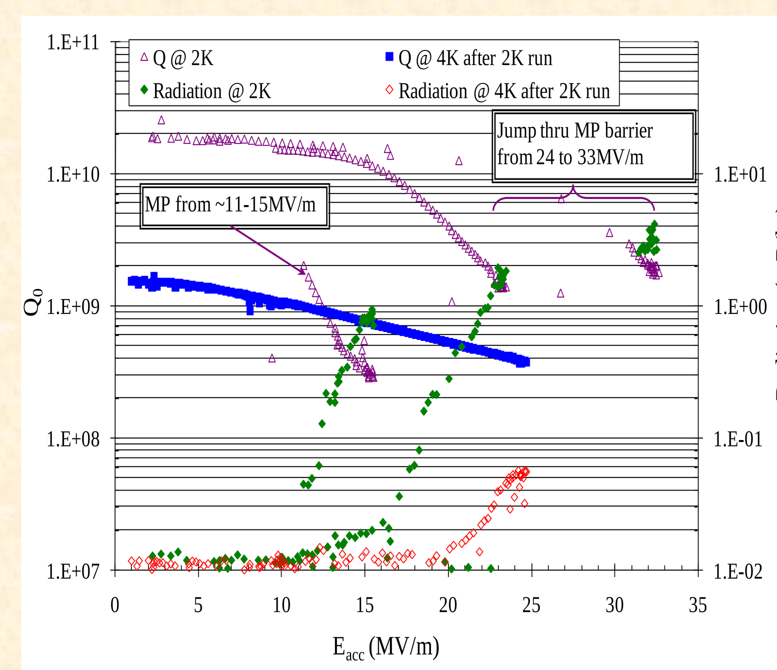


Figure 6: : Q0 vs. acceleration gradient Eacc from the first cold test of SSR1-02 single-spoke cavity (beta = 0.22). In pink the quality factor versus the gradient is shown on different stages of the cavity conditioning at 2 K. In blue the quality vs the gradient is shown at 4 K after 2K run. Maximal Eacc= 25 MeV/m @4K; 33MeV/m@2K.

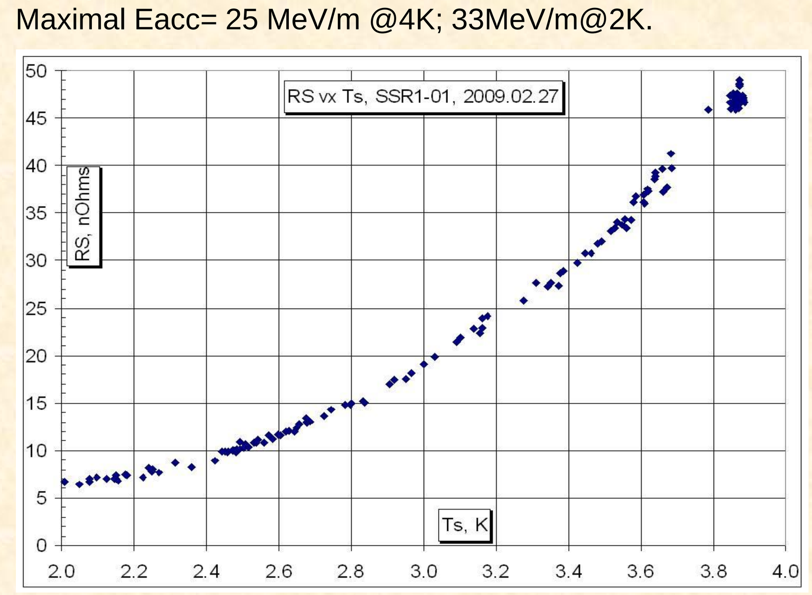
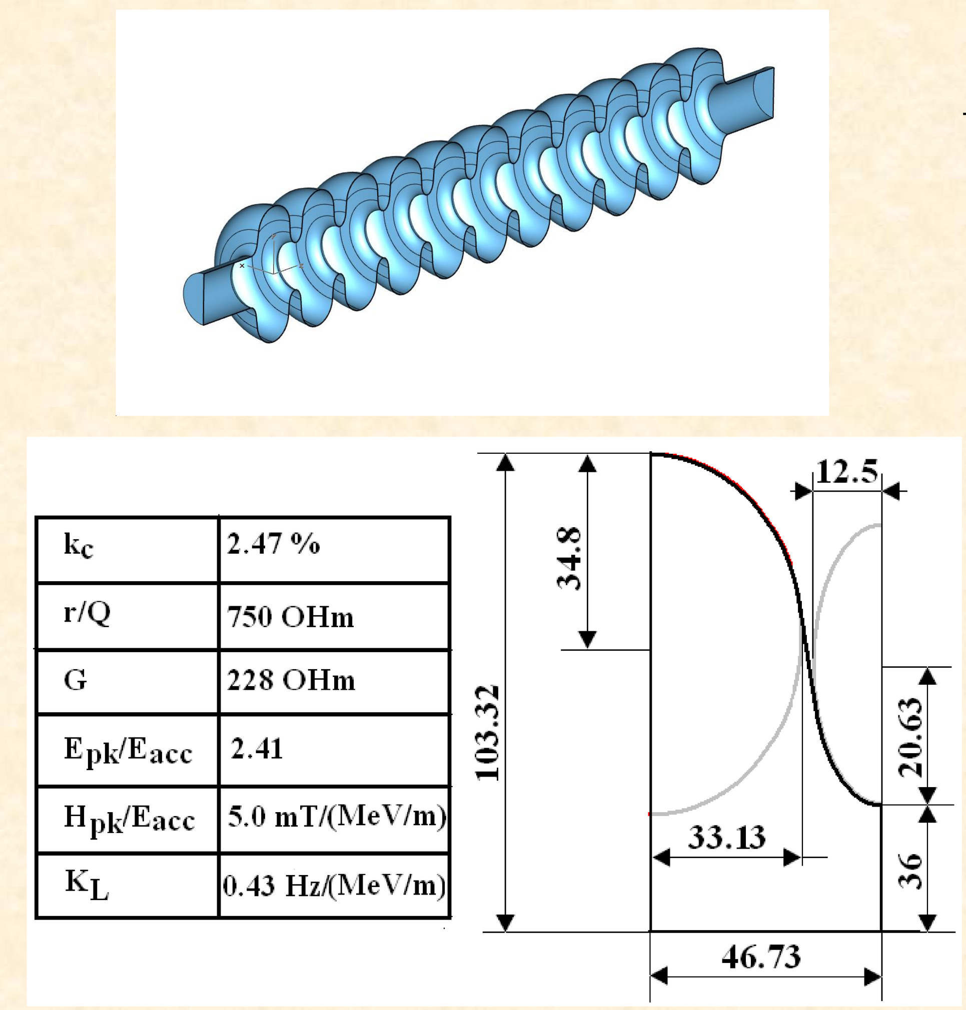


Figure 7: Temperature dependence of the surface resistance for SSR1 cavity.

466-2000 MeV: The acceleration from 466eV to 2 GeV may be provided at 1300 MHz using the same configuration as developed for the ICD-I 8-GeV pulsed linac. This configuration contains two sections, S-ILC and ILC.



k_c	2.47 %
r/Q	750 OHm
G	228 OHm
E_{pk}/E_{acc}	2.41
H_{pk}/E_{acc}	5.0 mT/(MeV/m)
K_L	0.43 Hz/(MeV/m)

Figure 8. 11-cell βG =0.81 cavity layout, parameters, and cell dimensions. Note that the coupling coefficient kc is increased to 2.47% compared 1.87% for the TESLA cavity, in order to provide the same field flatness for large number of cells. It leads to the surface field (electric and magnetic) enhancement factor increase. However, 11-cell cavity provides higher energy gain per cavity than the cavities with smaller number of cells, see [4].

cavity type	F [MHz]	E_{acc} [MV/m]	L_{eff}, mm	Ep/E_{acc}	B_p/E_{acc} mT/(MV/m)	R/Q Ω	G Ω	$Q_{0,2K}$ ×10^9	$Q_{0,4K}$× 10^9	P_{2K} [W]	P_{4K} [W]
11-cell, β=0.81	1300	16.4	1028	2.41	5	750	228	12.7	n/a	29.92	n/a
9-cell, ILC	1300	18	1038	2	4.26	1036	270	15.0	n/a	22.46	n/a

Table 4: Parameters for the cavities of the high-energy sections, SILC and ILC.

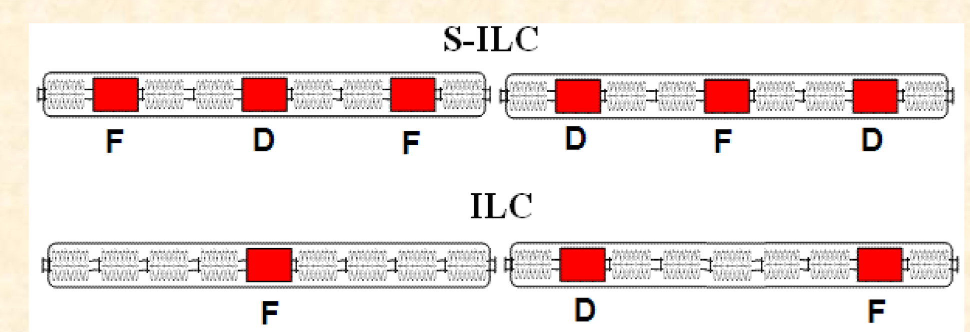


Figure 9: Modified Type-4 ILC cryomodule schematics. The cryomodule in S-ILC section contains three quads in the positions of 2nd, 5th, and 8th cavities, and six 11-cell cavities. The ILC cryomodule has the two different quad locations: in 5th position, and in 2nd and 8th positions.

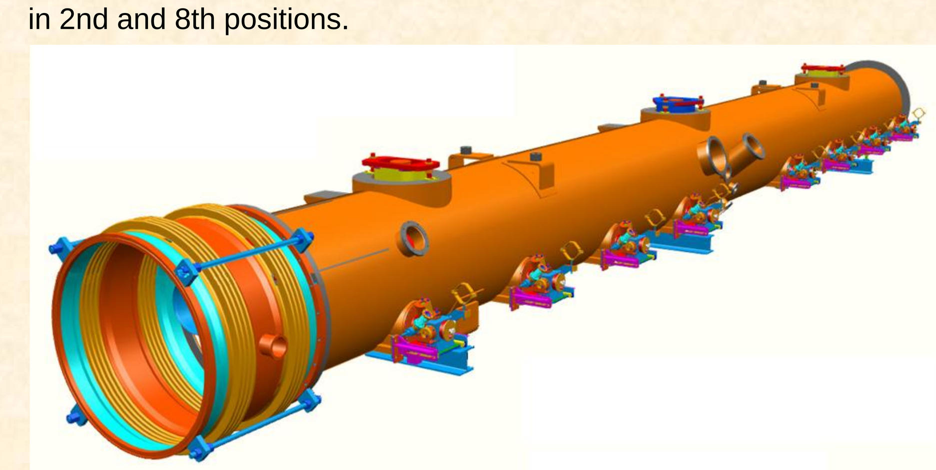


Figure 10: Type-4 ILC cryomodule.

Section	Energy range MeV	β	Number of cavities/ quads/CMs	Type	Max Power/cavity (on crest), kW (I_{av}=1 mA)
S-ILC(β_G=0.81)	466-1200	0.744 -0.9	66 / 42/ 11	Squeezed elliptical	13
ILC (β_G=1)	1200-2000	0.9-0.95	68 / 13 / 9	9-cell ILC	15

Table 5: Break point between the sections in the high-energy part of the linac.

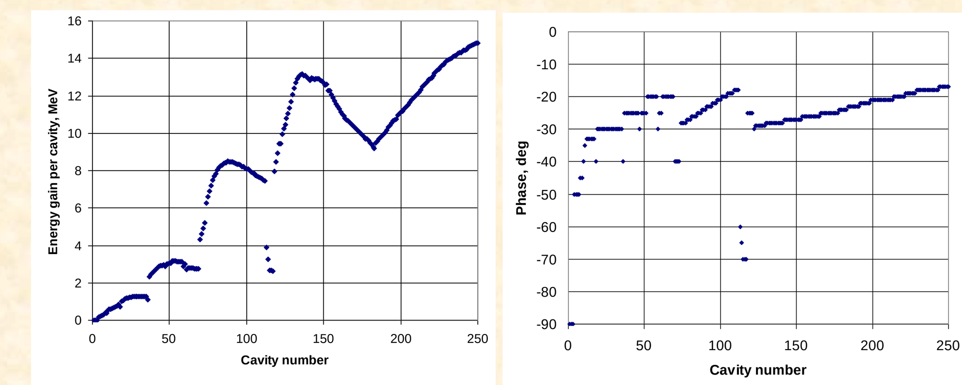
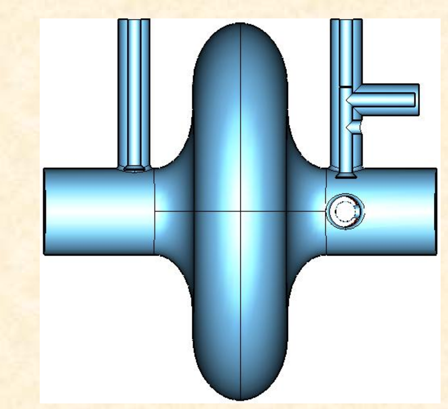


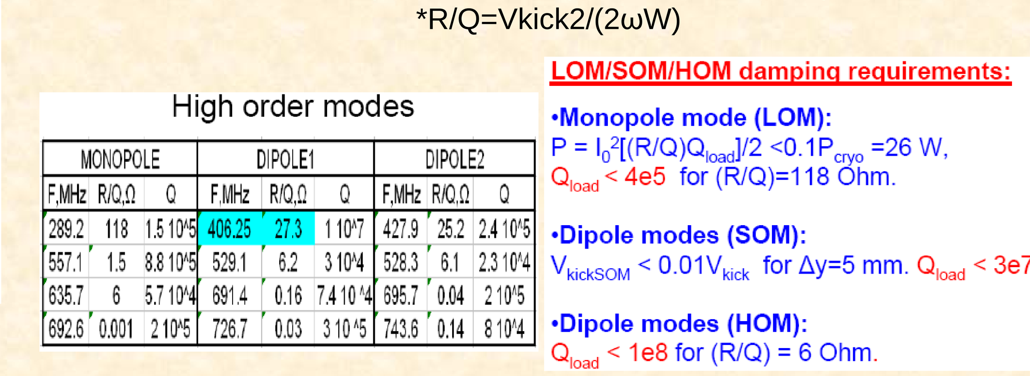
Figure 11: The energy gain per cavity (left) and equilibrium phases (right). Cavities 1-117 are 325 MHz, 118-251 are 1.3 GHz. One can see that the last five cavities (112-117) in the 325 MHz section have very big (60-70°) equilibrium phase and, thus, small energy gain (<4 MeV/cavity), in order to match the beam longitudinal dynamics to the 1.3 GHz section.

RF splitter. RF splitter directs (i) two quarters of the beam to one user (Mu2e), (ii) one quarter to another user (Kaon), and (iii) one quarter to the third (unidentified) user (see Figure 1). The natural way is to use a SC structure with the deflecting TM110 mode operating at the frequency $f0(m\pm1/4)$,where $f0$ is the bunch sequence frequency ($f0$=325 MHz). Operating the structure in CW regime at 406.25 MHz (m=1) with a deflection $\Delta p_\perp c$ of ~15 MeV, it is possible to achieve a required total deflection angle of ±5 mrad.



Parameters	
Esp/Vkick , (MV/m)/MeV	7.8
Bsp /Vkick , mT/MeV	19.2*
R/Q*(Ohm)	27
Longitudinal size (mm)	440
Vertical size (mm)	865
Horizontal size (mm)	962

Figure 12. Layout and main parameters of RF splitter. *R/Q=Vkick2/(2ωW)



High order modes

MONOPOLE			DIPOLE1			DIPOLE2		
F,MHz	R/Q,Ω	Q	F,MHz	R/Q,Ω	Q	F,MHz	R/Q,Ω	Q
289.2	118	1.5 10^5	406.25	27.3	1 10^7	427.9	25.2	2.4 10^5
557.1	1.5	8.8 10^5	529.1	6.2	3 10^4	528.3	6.1	2.3 10^4
635.7	6	5.7 10^4	691.4	0.16	7.4 10 ^4	695.7	0.04	2 10^5
692.6	0.001	2 10^5	726.7	0.03	3 10 ^5	743.6	0.14	8 10^4

Figure 13. Damping of parasitic modes

REFERENCES

[1] V. Lebedev and S. Nagaitsev, “Project X ACD write-Up,” June 2, 2009

[2] S. Holmes, “Fermilab Multi-MW Proton Source: Strategy and Status, “ HEPAP Meeting, November 13, 2008,

[3] P. Ostroumov, “Linac Beam Physics Design,” *Project X* Workshop November 12-13 , 2007.

[4] N. Solyak, et al, “Low-Beta Structure for High Energy Part of Project X,” PAC2009, TU5PFP063.

[5] J. Sekutowicz, Meas. Sci. and Tech., 18(2007), 2285-2292