RF & RF power

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- ***Situation of 88 MHz test cavity***
- ***Availability of amplifiers***
- ***Some comments by F. Tazzioli on closed and open cavities***

Situation of 88 MHz test cavity

Power efficiency optimization

using $P_{mean} = P_{wall} \cdot 3\tau \cdot f_{rep}$ and

$$P_{wall} = \frac{V_0^2}{r_S}, \tau = \frac{Q}{\pi f_{cav.}}$$

$$r = r_S \cdot T^2 = \frac{V_0^2}{P_{wall}} \cdot T^2$$

$$P_{mean} = 3\frac{V_0^2 T^2}{\pi} \cdot \left(\frac{f_{rep}}{f_{cav}}\right) \cdot \left(\frac{Q}{r}\right)$$

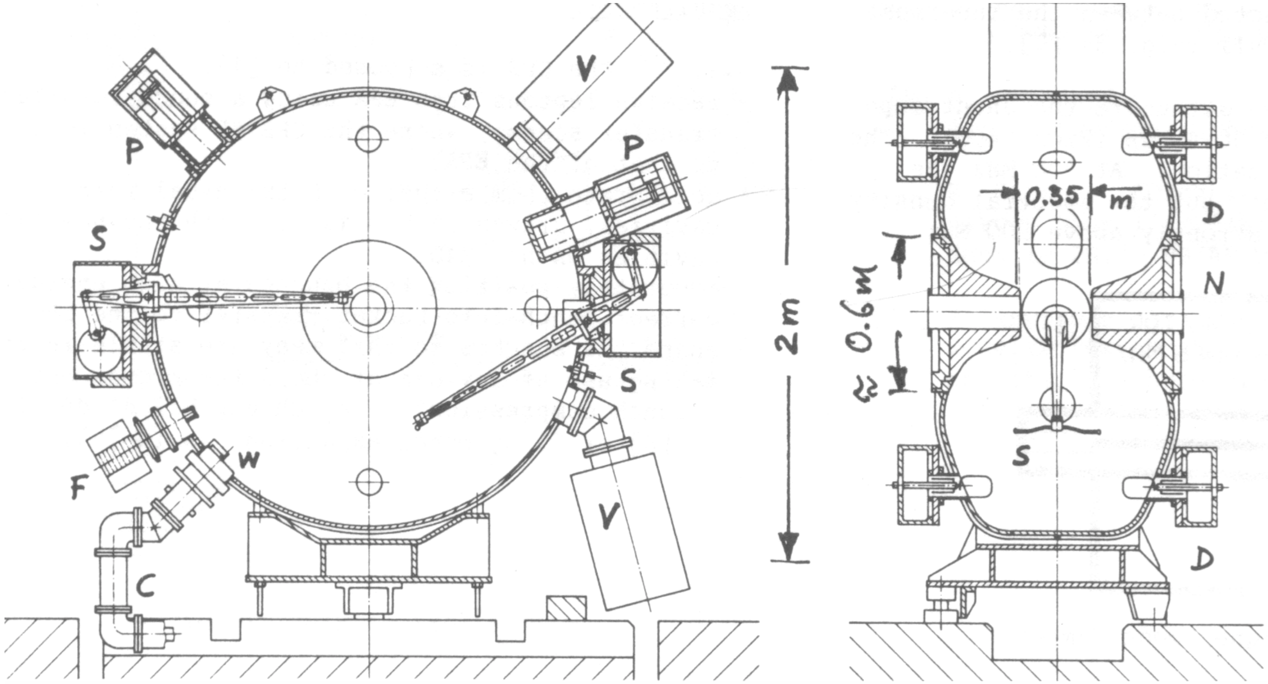
$$\left(\frac{r}{Q}\right) = \sqrt{\frac{L}{C}} \uparrow \Rightarrow L \uparrow, C \downarrow \Rightarrow \text{large gap, large volume}$$

Challenges:

- High gradient at low frequency
  (Kilpatrick: 2.3) ⇒ sparking: tests
- (high) magnetic field lines penetrating the cavities ⇒ multipactor: computations & tests
- large cavity dimensions ⇒ mechanical stability: computations
- field emission induced by lost particles
  ⇒ cavity test with beam.

2. Status of the high gradient test set-up

Original system: PS 114 MHz RF cavity for leptons



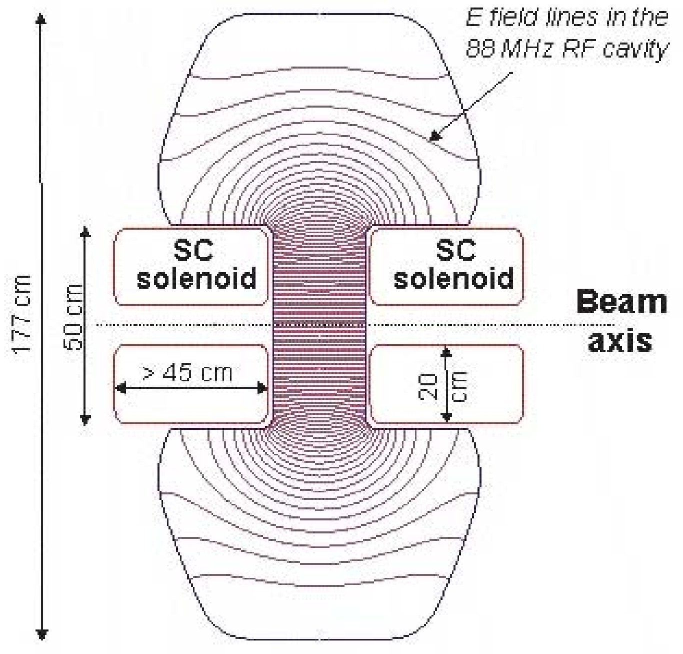
N = nose cone
D = damper
W = RF window
C = cable to amp.
F = ferrite tuner
S = short
P = piston tuner
V = vacuum pump

f = 114.511 MHz
Q= 56000
R/Q = 180 Ohms
V = 500 kV
P (500 kV) = 12.5 kW

114 MHz CAVITY
(e+/e- acceleration in the PS)

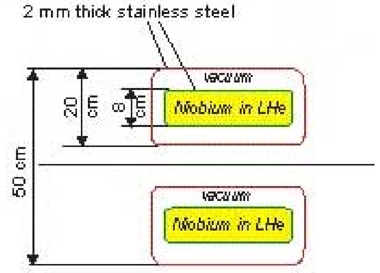
CERN 07/2000

88 MHz test cavity



88 MHZ TESTCAVITY

SUPERCONDUCTING SOLENOID ASSEMBLY



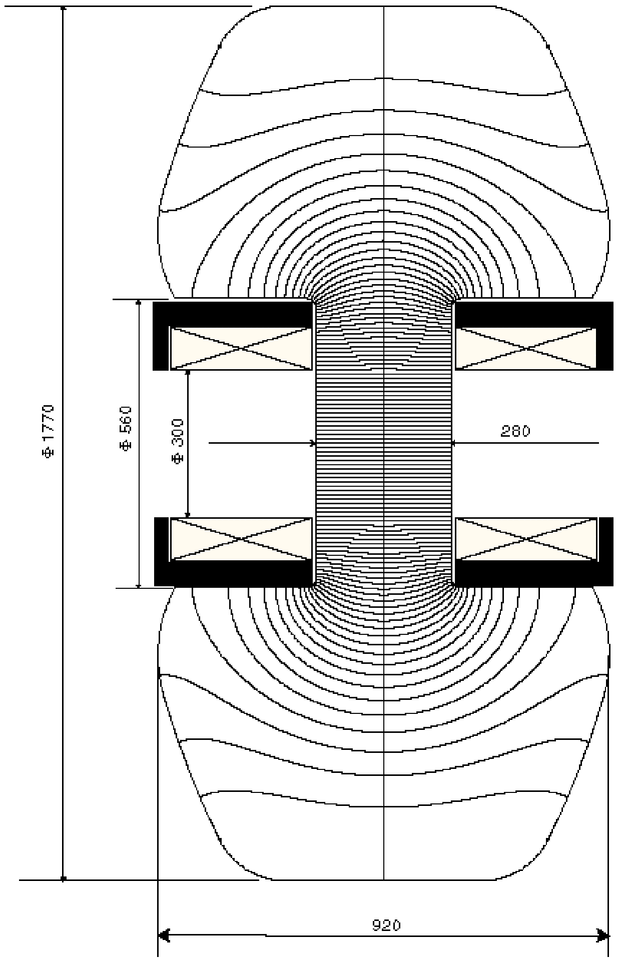
88 MHz test cavity
(made from an 114 MHz structure)

Closed gap case

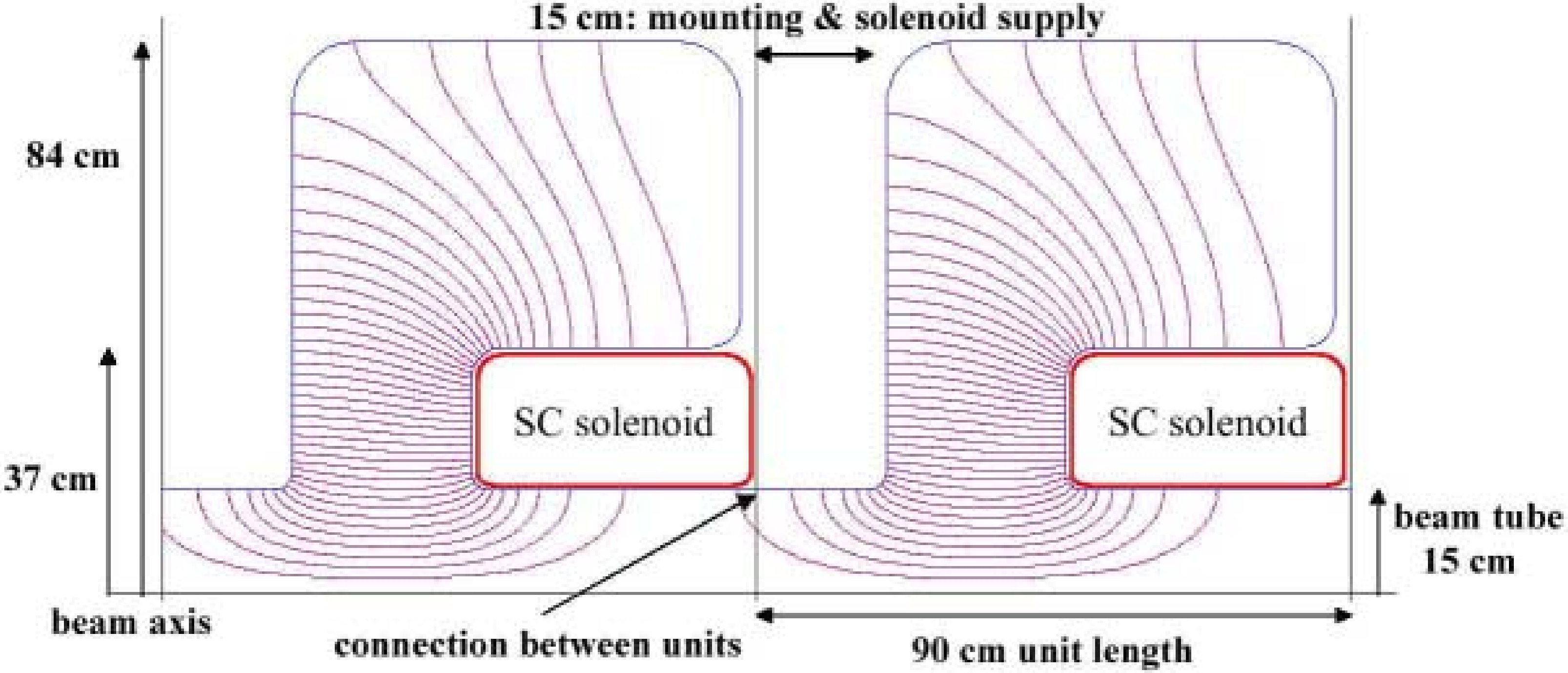
E_0	= 4 MV/m
f_{rep}	= 1 Hz
r/Q	= 113 Ω
τ	= 180 μs
t_{pulse}, f_{rep}	= 1 ms, 1 Hz
P_{peak}	= 1.4 MW
P_{mean}	= 1.4 kW
Kilp.	= 2.3
gap	= 280 mm
length	= 1 m
diameter	= 1.77 m

Open gap case

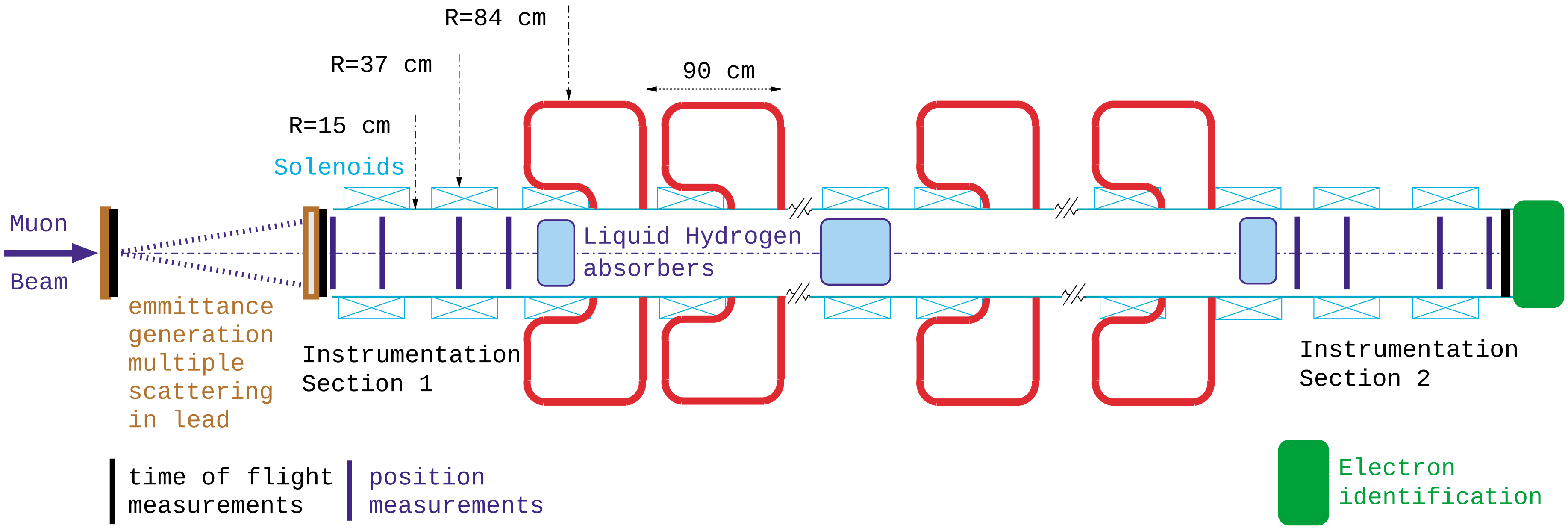
E_0	= 4 MV/m
f_{rep}	= 1 Hz
r/Q	= 107 Ω
τ	= 180 μs
t_{pulse}, f_{rep}	= 1 ms, 1 Hz
P_{peak}	= 1.5 MW
P_{mean}	= 1.5 kW
Kilp.	= 2.3
gap	= 260 mm
length	= 1 m
diameter	= 1.77 m



Asymmetric 88 MHz cavities



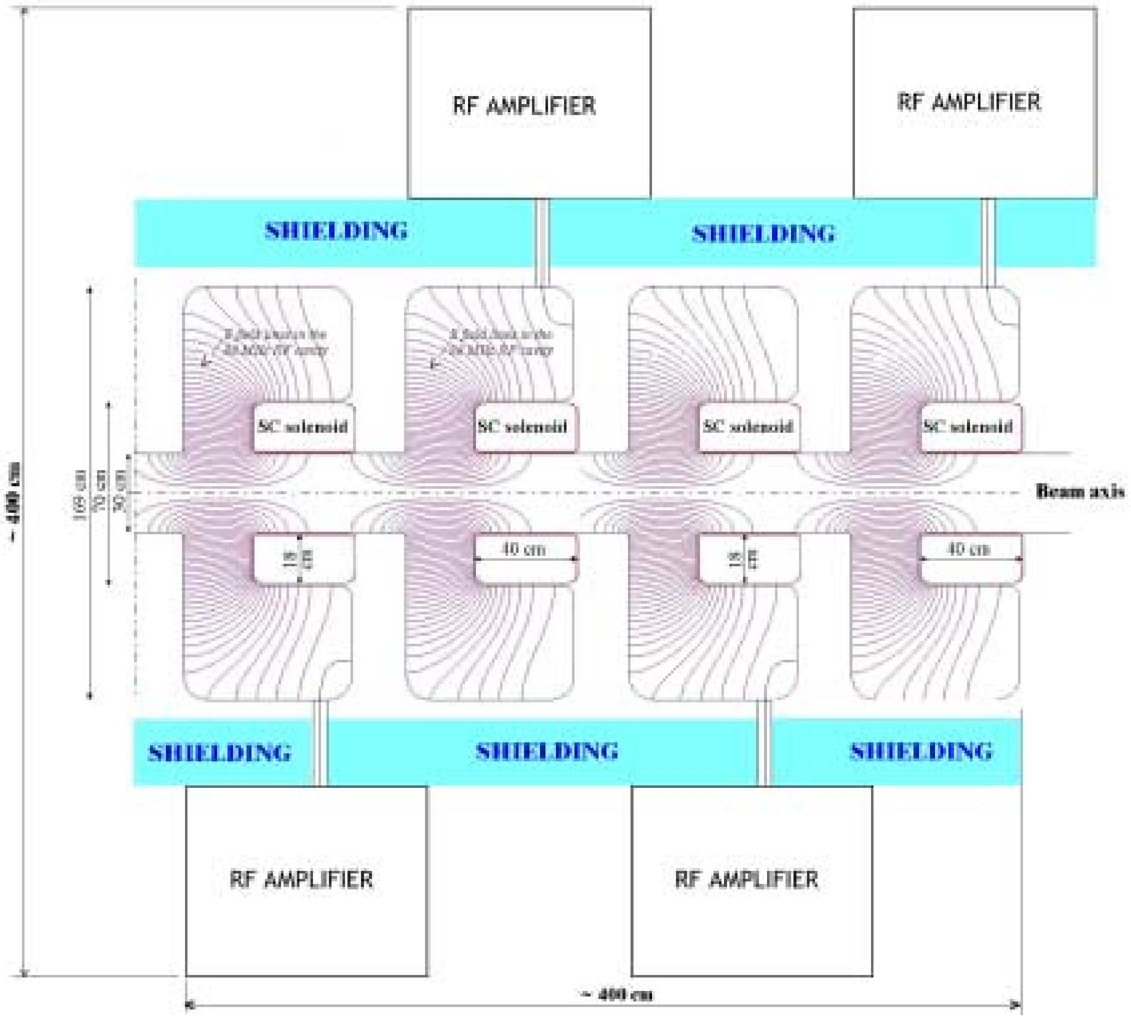
E_0T	= 4 MV/m	τ	= 156 μs	solenoid: 40 x 20 cm
Z_{TT}	= 5 MΩ/m	P_{PEAK}	= 2.19 MW/cavity	Kilpatrick: 2.3
R/Q	= 137 Ω	P_{MEAN}	= 85 kW/m for 75 Hz repetition rate	



R=84 cm
R=37 cm
90 cm
R=15 cm
Solenoids
Muon
Beam
Liquid Hydrogen
absorbers
emmittance
generation
multiple
scattering
in lead
Instrumentation
Section 1
Instrumentation
Section 2
time of flight
measurements
position
measurements
Electron
identification

Preliminary parameters of an 88 MHz option for ICE

Sketch of a 4 cavities module



Electrical power and cooling needs for the 88 MHz option in ICE

Repetition rate	Nb. of cavities	Peak RF gradient	Peak RF power	Pulse duration (RF/beam)	Mean RF power	Power from mains (= cooling needs)
50 Hz	4	14.4 MV	8.2 MW	0.6/0.1 ms	250 kW	**0.5 MW**
	2 x 4	28.8 MV	16.4 MW	0.6/0.1 ms	500 kW	**1 MW**
10 Hz	4	14.4 MV	8.2 MW	1/0.5 ms	82 kW	**0.17 MW**
	2 x 4	28.8 MV	16.4 MW	1/0.5 ms	164 kW	**0.35 MW**

=> Advantage of the 10 Hz option

Overall needs in infrastructure: H. Ullrich

- An 88 MHz test cavity for high gradient is being prepared (2 MW amplifier driving a modified 114 MHz PS cavity)
  - High RF gradient without solenoid: end 2001
  - RF test with solenoid: mid-2002

Cavity with closed gap:

E_0	= 4 MV/m
f_{rep}	= 1 Hz
r/Q	= 113 Ω
τ	= 180 µs
t_{pulse}	= 10.5 ms
P_{peak}	= 1.4 MW
P_{mean}	= 15 kW
Kilp.	= 2.3
gap	= 280 mm
length	= 1 m
diameter	= 1.77 m

88 MHz test cavity
(made from an 114 MHz structure)

The RF chain up to 20 kW is assembled and will soon be turned-on. Next step will be to set-up the 200 kW driver stage which is already assembled

The mechanics of the 2 MW final stage is still in preparation. Most pieces are or will soon be available, kapton capacitor, anode resonator, coupling loops, coaxial lines,...] but assembly is still pending.

As far as I know, nothing has yet been done to prepare diagnostics (no one available).

This work has now a low priority, but we are keen to get results. We estimate that real tests of the full set-up will begin before this summer.

(Roland dixit)

88 MHz test system status and planning

SUMMARY

First turn-on of the complete amplifier chain:	**12/2001**	**(not yet)**
Setting-up on dummy load:	**03/2002**	
High gradient in the cavity:	**05/2002**	
Increase of RF power:	**10/2002 ?**	**(push or 200k)**
Test with solenoid:	**12/2002 ??**	**(financing)**

1. Economically relevant parameters

- Amplifier cost / unit ≡ Peak & mean RF power
  - Peak RF power ≡ *Gradient* & *RF frequency*
  - Mean RF power ≡ Peak RF power & *Duty factor*
- Cavity cost / unit ≡ Gradient & RF frequency
- Number of amplifiers & Number of cavities
- **SUMMARY OF KEY PARAMETERS**

  - Gradient in the cavities (Voltage per cavity)
  - RF frequency
  - Duty factor (repetition rate)

2. Preliminary analysis

Effect of the duty factor

Case 1: **5 ms useful beam time per second (100 μs bursts at 50 Hz or 500 μs bursts at 10 Hz)**

RF freq. [MHz]	Nb. of cavities	Rep. Rate [Hz]	Peak RF gradient [MV]	Peak RF power [MW]	Pulse duration [ms]	Mean RF power [kW]	Power from mains (= cooling needs) [kW]
200	4	50	27.9	16.7	0.25	200	400
		10	27.9	16.7	0.65	110	220
		1	27.9	16.7	5.15	86	172
88	4	50	14.4	8.2	0.6	250	500
		10	14.4	8.2	1	82	170
		1	14.4	8.2	5.5	45	90
	2 x 4	50	28.8	16.4	0.6	500	1000
		10	28.8	16.4	1	164	350
		1	28.8	16.4	5.5	90	180

Case 2: **"refurbished" CERN 200 MHz - 4 MW amplifier (Duty factor = 0.001)**

Repetition rate [Hz]	Filling time [μs]	Flat top duration [μs]
1	150	850
2	2 x 150=300	2 x 350=700
5	5 x 150=750	5 x 50=250

Effect of the voltage per cavity

General considerations

$$N_{cav} = \frac{V_{Total}}{\Delta V_{cav}} \qquad P_{cav} \propto \Delta V_{cav}^2 \qquad \Rightarrow P_{Total} \propto V_{Total} \times \Delta V_{cav}$$

N_{cav} : Number of cavities
V_{total}: Total cavities voltage
ΔV_{cav}: RF voltage / cavity
P_{cav}: RF power / cavity
P_{total}: Total RF power

Case of a limited number of 200 MHz - 4 MW amplifiers

Nb. of amplifiers	Nb. of cavities	Voltage per cavity MV]	Total voltage [MV]
1	1	6.8	6.8
	2	4.8	9.6
	4	3.4	13.6
2	2 x 1	6.8	13.6
	2 x 2	4.8	19.2
	2 x 4	3.4	27.2

Economical optimum: number of cavities & number of amplifiers

Assumption : V_{total} **is imposed**

$$V_{Total} \propto P_{Total} / \Delta V_{cav} \Rightarrow V_{Total} \propto k\sqrt{n} \Rightarrow n = \frac{\alpha}{k^2}$$

$$C_{RF} = k\left(C_{amp} + nC_{cav}\right) \Rightarrow C_{RF} = kC_{amp} + \frac{\alpha}{k} C_{cav}$$

N_{cav} :	Number of cavities	n:	Number of cavities per amplifier
V_{total}:	Total cavities voltage	k:	Number of amplifiers
ΔV_{cav}:	RF voltage / cavity	C_{cav}:	Cavity cost
P_{cav}:	RF power / cavity	C_{amp}:	Amplifier cost
P_{total}:	Total RF power	C_{RF}:	Total RF cost

Tentative application: get 28 MV with 4 MW amplifiers

$C_{amp} = C_{cav}$	$k_{optimum}$ ~4, corresponding to 1 cavity per amplifier
$C_{amp} = 2\ C_{cav}$	$k_{optimum}$ ~3, corresponding to 1 cavity per amplifier
$C_{amp} = 4\ C_{cav}$	$k_{optimum}$ ~2, corresponding to 4 cavities per amplifier

RF–Power Amplifiers available at CERN

200 MHz:

1 amplifier (spare for Linac2) 2 MW, (could be upgraded to 4 MW)
1 amplifier (from Linac1, needs refurbishing for 200 kCHF) 4 MW
(FTH triode tube, ex-TH 516, water-cooled version)

The first one should be used as driver for the second one
⇒Total available power now 4 MW

This could go up to a total of 8 MW, provided we find another driver amplifier of several hundred kW

RF–Power Amplifiers available at CERN

88 MHz:

1 amplifier available 2 MW
(FTH triode tube)
driver (LHC type, modified) available

If amplifier is modified 4 MW achievable, but driver must be pushed

1 amplifier (from Linac1, needs refurbishing for 200 kCHF) 4 MW
(pushed) driver needs to be found or the amplifier above must be used.

Comment by Roland: A second 88 MHz cavity could be made available (i.e. another ex-PS 114 MHz cavity needs to be modified)

➢*Some comments by F. Tazzioli on closed and open 200 MHz cavities for MICE*

Cavities with Beryllium windows or grids versus open iris ones

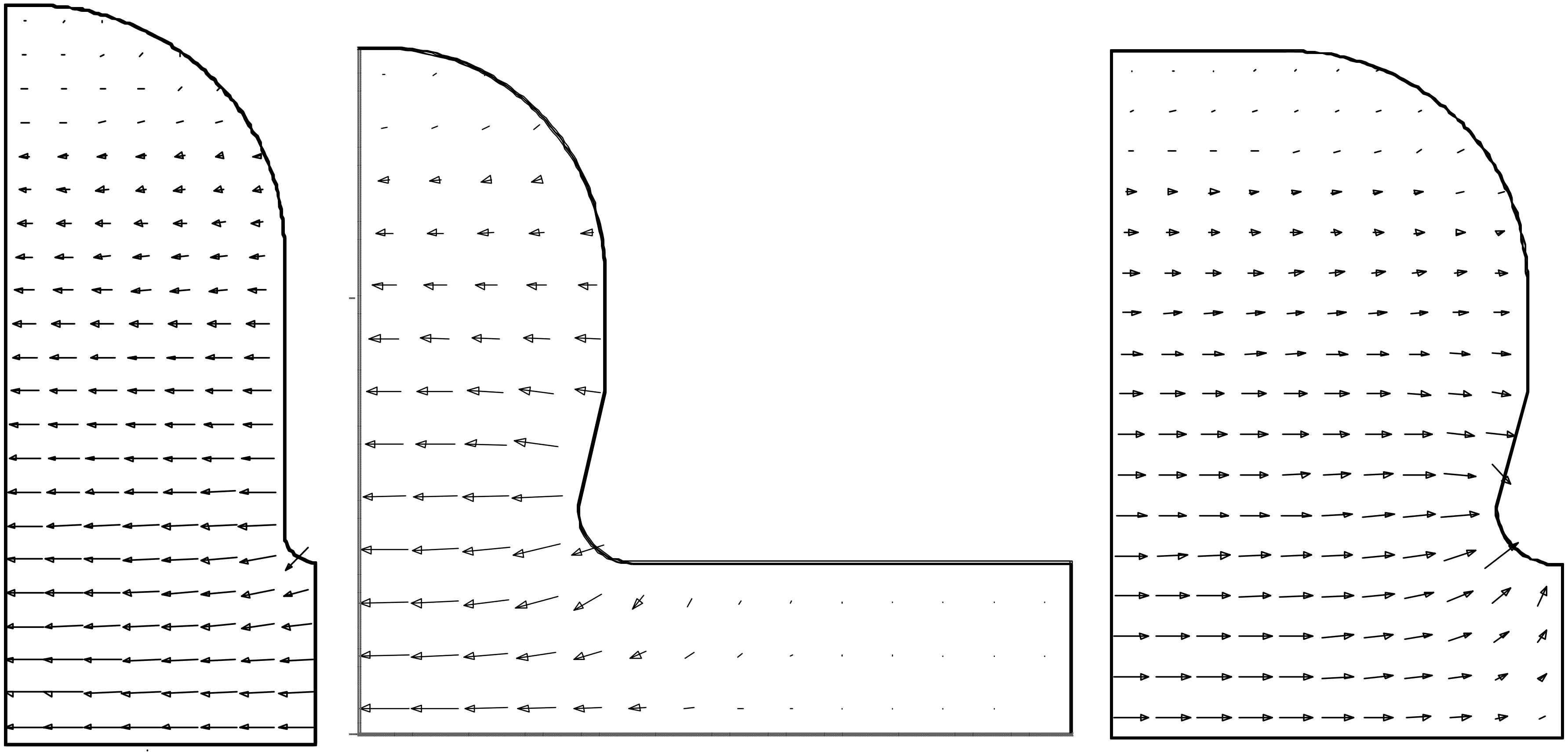
Cavities with closed iris are independent from one another and can be stacked at a distance lower than half a wavelength in order to reduce space occupation. As the ratio of peak to effective fields is low (close to unity) one can reach high accelerating fields without breakdown.

The disadvantages are technical complication and Beryllium brittleness. Overheating of iris windows could be an issue at high duty cycle. Multipactor discharges on the Beryllium windows could also be a problem. The assumed cell length is 45 cm.

Open iris cells are technically simpler and their shunt impedance can be made comparable to that of the closed ones by suitable nose cones. The ratio of peak to effective fields is however higher. Moreover they cannot be stacked arbitrarily close to one another because they couple electrically through the beam tube. They could however be placed at half a wavelength pitch, which is 75 cm. In this case a series of cells would resonate in Pi mode (fields in adjacent cavities are in opposite phase) and a couple of cells could be driven by a single input RF coupler.

Obviously in this case the accelerating field is limited by the maximum power which can be delivered through the input coupler. The peak power required by a single cell of length l=75 cm, for a field of E=10 MV/m is P= (E*l)^2/2*R= 5 MW

Cavity Layouts



Be window   Open cell π mode

	closed	pi mode	open iris
FULL CELL LENGTH [CM]	45		
FREQUENCY[MHZ]	202.36	199.97	201.06
FREQUENCY/CUT OFF FREQU.	0.26	0.26	0.26
SHUNT IMPEDANCE(AT r=0) [MOHM]	5.69	5.92	4.66
R/Q (AT r=0) [OHM]	99.02	82.91	84.24
Q WITHOUT END PLATES	57,440.00	71,419.00	55,284.00
PEAK SURFACE E FIELD AT r=xx [m]	0.17	0.19	0.19
AND z=xx [m]	0.22	0.31	0.19
RATIO PEAK/EFFECTIVE	1.41	2.29	4.55

Conclusions

(Franco Tazzioli)

The Q values given by URMEL are too high for a real cavity, so we multiply them by an empirical reduction factor of 0.8. One can assume that the R/Q values are correct and compare the reduced shunt impedance values per unit length. For the closed iris case one obtains **R= 10 MΩ/m** and $E_{peak}/E_{effective}$ =1.4
against **R=6.4 MΩ/m** and Epeak/Eeffective= 2.3 for the open one (Pi mode). Not considering technical difficulties and other side effects, the comparison is obviously in favor of the closed iris cavities.