FFAG RF for 10-20 GeV muon

C. Ohmori, A. Takagi and T. Uesugi
KEK

RF parameters

- Kinetic Energy : 10-20 GeV
- Circumference : ~~1200~~ m ~~120~~ 200 × π
- Longitudinal Emittance : 5 eVs
- RF freqeucney : 24 MHz
- Field Gradient 0.75 MV/m
- Cavity Length ~~1~~ 1.62 m
- Gap Voltage : ~~1.5~~ 2.43 MV
- Beam Pipe : 360 ϕ

Design of High Gradient Cavity

- Length ~~1~~ 1.6~~2~~ m /gap
- Diameter 2m
- Type of Cavity : Air –core
- Driven by a 150 kW class tetrode
- Driving Method: Loop Coupling
- Feeding : Direct or Co-axial line

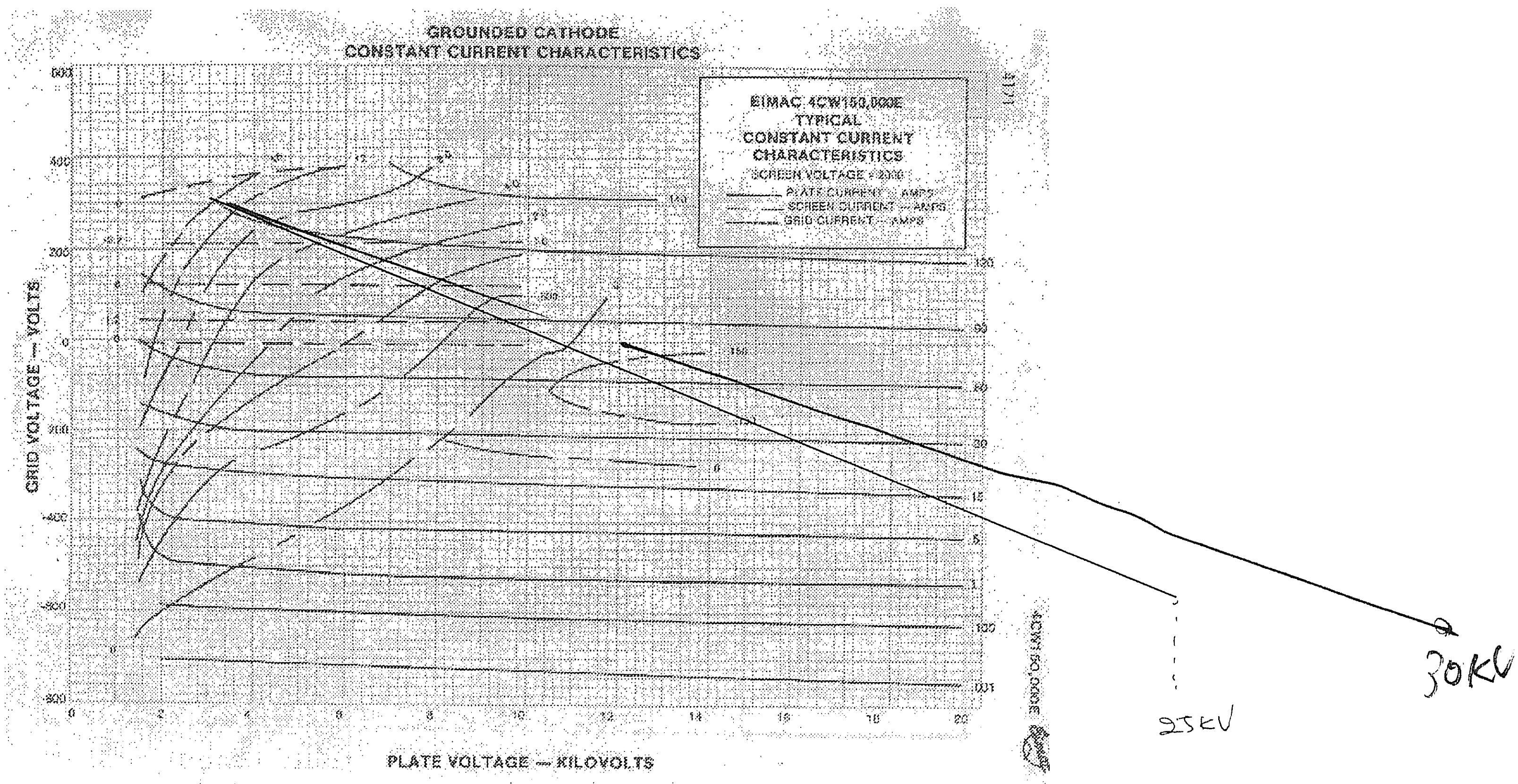
SUPERFISH Calculation(1.6m)

- Frequency : 24.05149 MHz → 24.03 MHz
- Shunt Impedance: 4.28 Mohm → 3.53 MΩ
  (2.678 MOhm/m) → (2.2 MΩ/m)
- Q: 31853.8 → 26400
- Max. E field: 10.126 MV/m, 1.44 Kilp. at 1 MV/m (Z,R = 36,62) → 7.5 MV/m (1.06 Kilp.)
- Max. E field : 15.2 MV/m, 2.16 Kilp.at 1.5 MV/m → 11.95 MV/m (1.7 Kilp)

Design of Amplifier(1.62m Cavity)

- Load : 4.3MOhm → 3.53MΩ
- Vgap:2.43 MV
- 1 AMP per Cavity
- Driven by 150 kW tube, 4CW150kE
- Anode Voltage : 25 kV (Max. 40kV) → 30kV
- Peak Cathode Current: 120A (Max. 140 A) → 120A
- RF Output Power: 0.69 MW (duty < 0.~~16~~%) → 0.84MW
  0.3-4
- Operation : Class B
- Cathode DC Current: 38 A (peak) → 38A

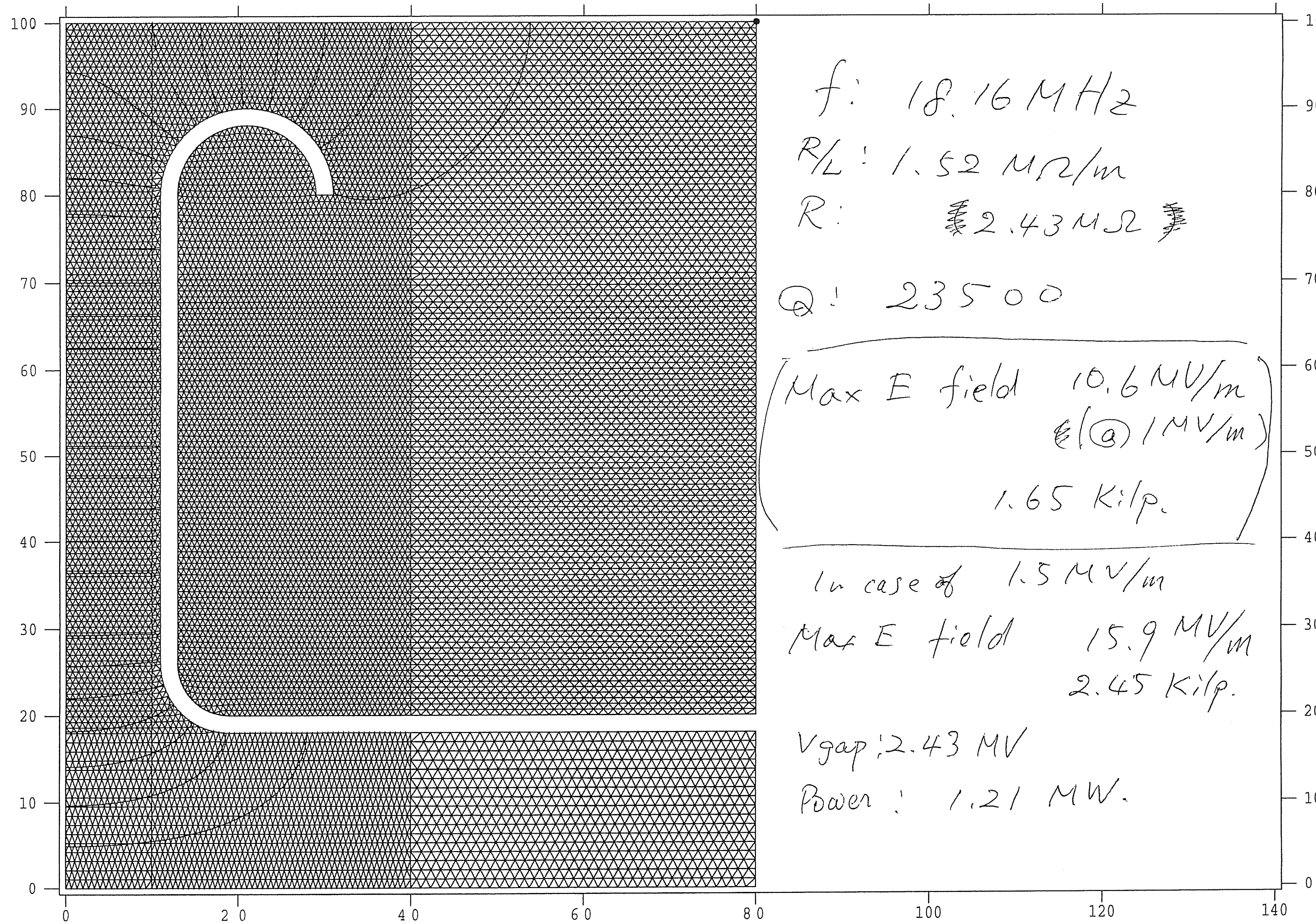
Operation Line of Tube



parameter	inject.	rf	extract.
kin.energy(GeV)	9.8949	14.6147	19.8946
momentum (GeV)	10.0000	14.7200	20.0000
orb.radius(m)	200.0000	200.1153	200.2067
rev freq (MHz)	0.2386	0.2384	0.2383
harmonic no.	---------	100.0000	---------
rf voltage(GV)	---------	0.94248	---------
rf freq (MHz)	---------	23.8424	---------
rate	---------	1.0000	---------
buc-hight(GeV)	---------	7.8347	---------
eta	---------	0.0014	---------

parameter	inject.	rf	extract.
kin.energy(GeV)	9.8949	14.8947	19.8946
momentum (GeV)	10.0000	15.0000	20.0000
orb.radius(m)	120.0000	120.1471	120.2516
rev freq (MHz)	0.3976	0.3971	0.3968
harmonic no.	---------	45.0000	---------
rf voltage(GV)	---------	0.5655	---------
rf freq (MHz)	---------	17.8702	---------
rate	---------	1.0000	---------
buc-hight(GeV)	---------	6.3546	---------
eta	---------	0.0030	---------

nufactory 18MHz Cavity F = 18.16111 MHz



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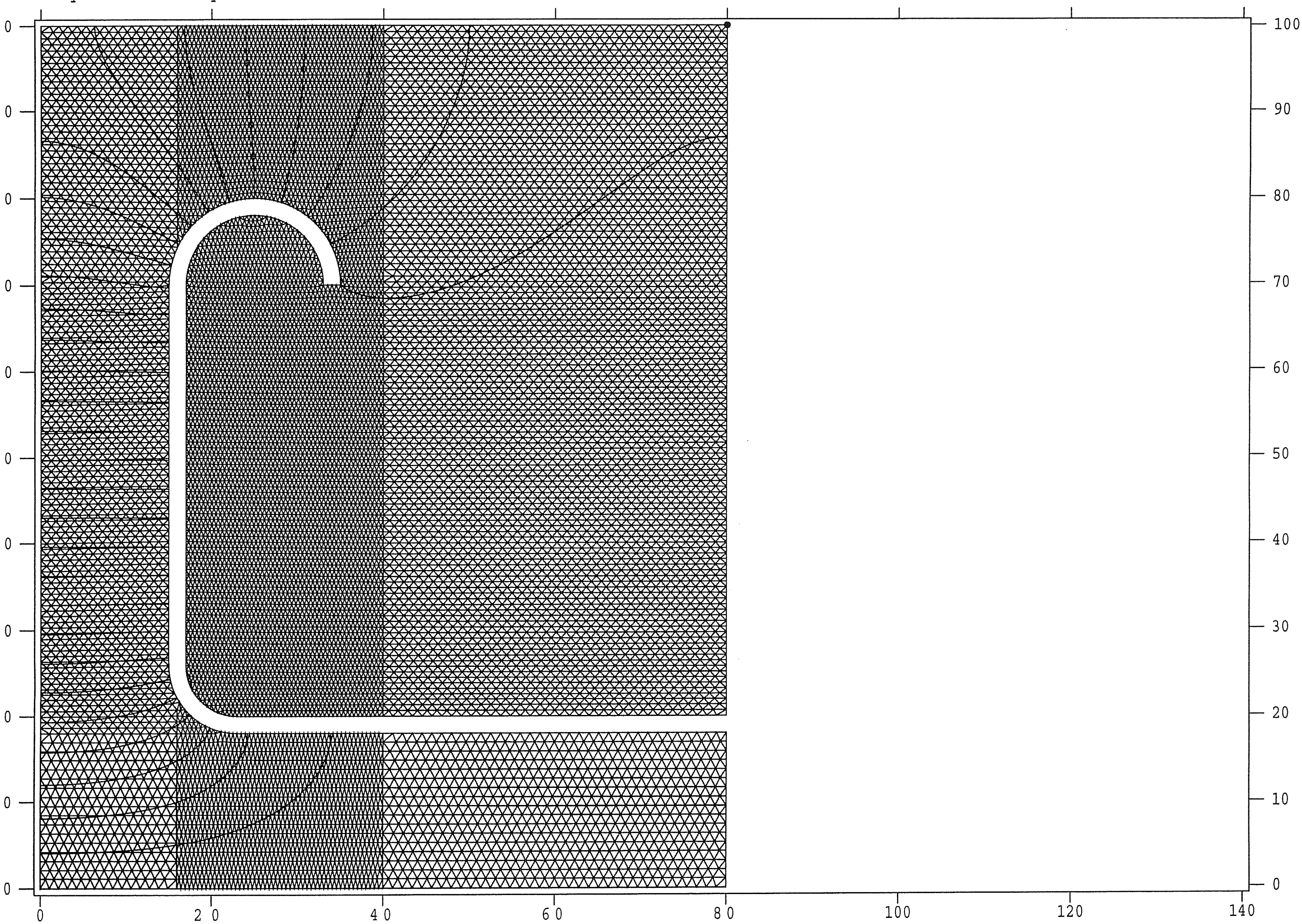
.factory 24MHz Cavity F = 24.029776 MHz



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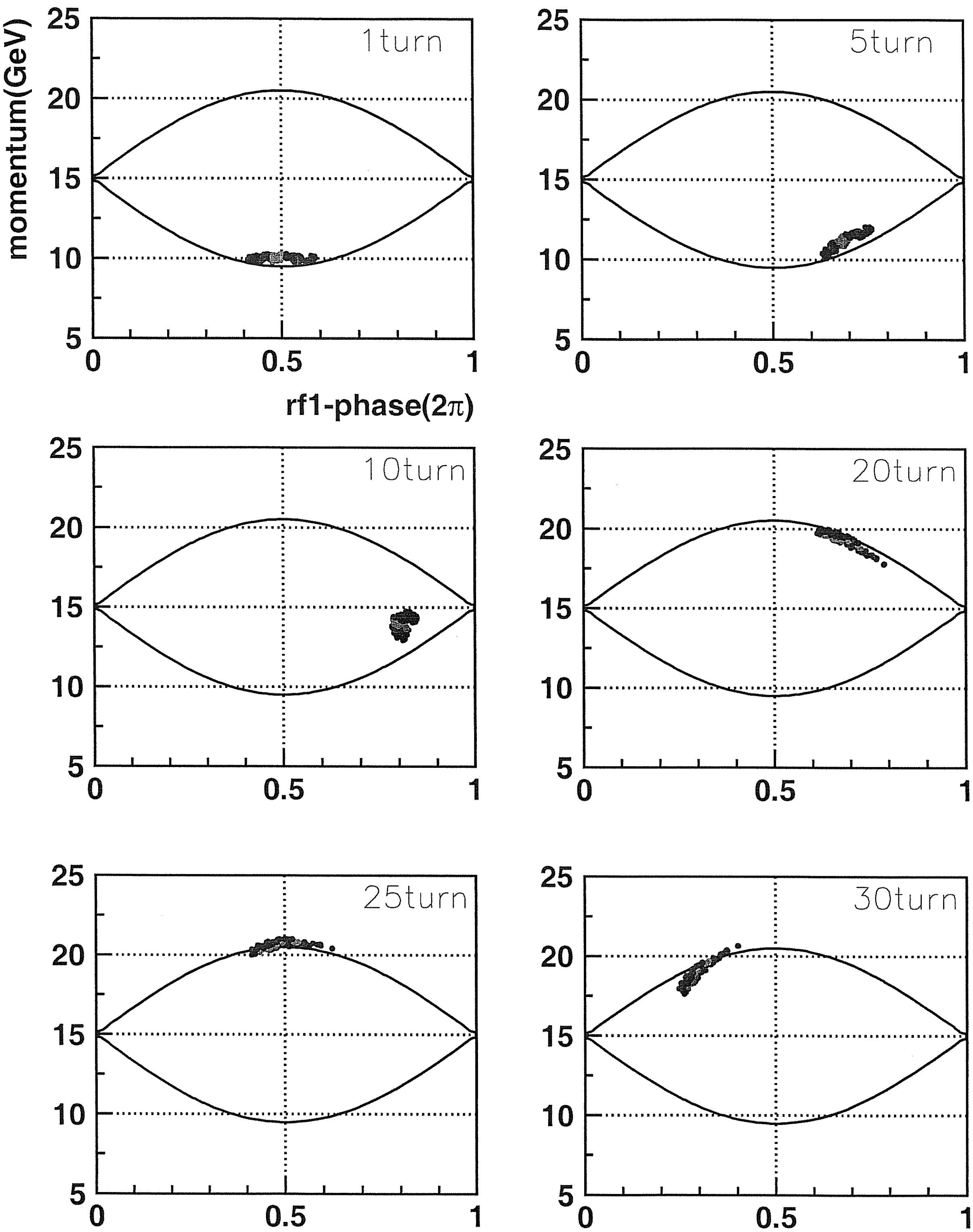
120 m RING

0.75 MV/m
h = 45
17.87 MHz

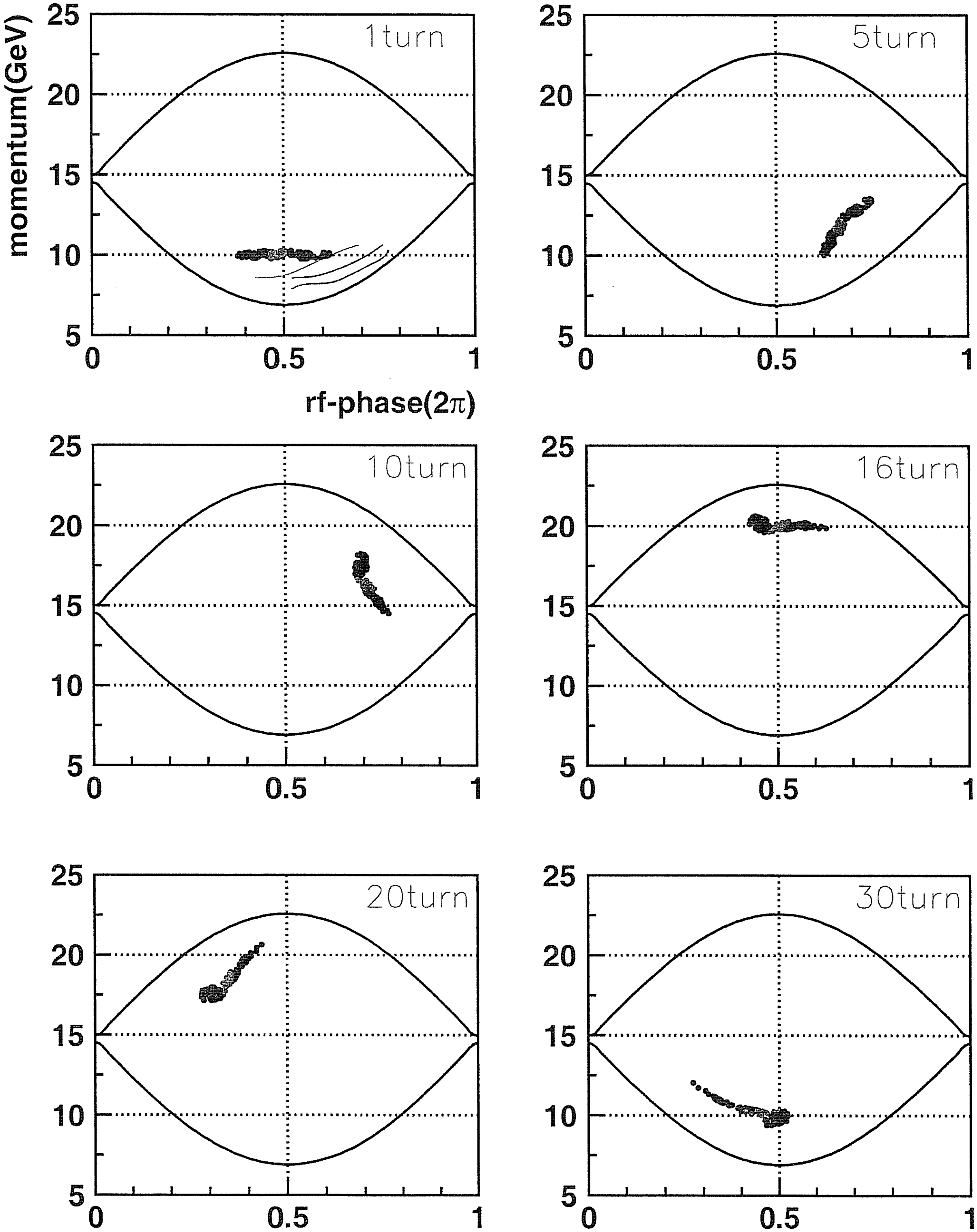
5eVs
dP/P = 3 %.
10 nsec



200m RING

0.75MV/m
h = 100
23.84MHz

5eVs
dP/P = 3%
10nsec



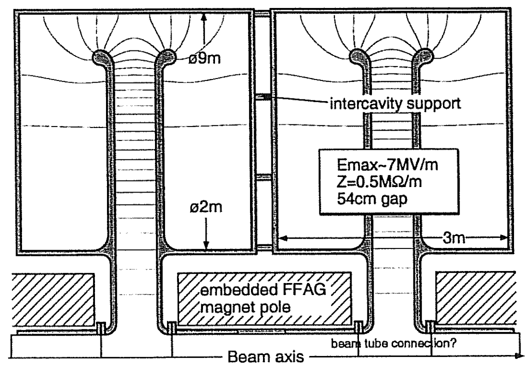


Figure 2.28: ϕ9m cavity with embedded FFAG magnet.

is 7.2MV/m. Because of the higher frequency, higher E_{Kp} and the less requirement for the high field gradient, the design of the 26MHz cavity can be straightforward. Fig.2.29 shows a 26MHz simple reentrant cavity. The asymmetric aperture size makes the capacitive electrode shape oval. Because the shape itself is not so important, just a circular shape electrode with the same capacitance may be sufficient.

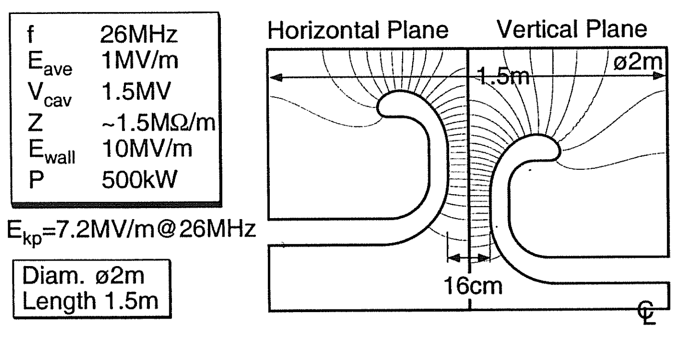


Figure 2.29: 26MHz high gradient cavity

When a higher average gradient and a higher shunt impedance are required, a cavity with large drift tubes can take bending magnets in the drift tubes (see Fig. 2.30). Because of the large diameter of the drift tube, the asymmetry of the aperture does not affect the frequency, and thus the cavity can easily be designed with two dimensional code such as SUPERFISH. This scheme can reduce the spacing factor between the magnets and thus will help to reduce the FFAG ring size.

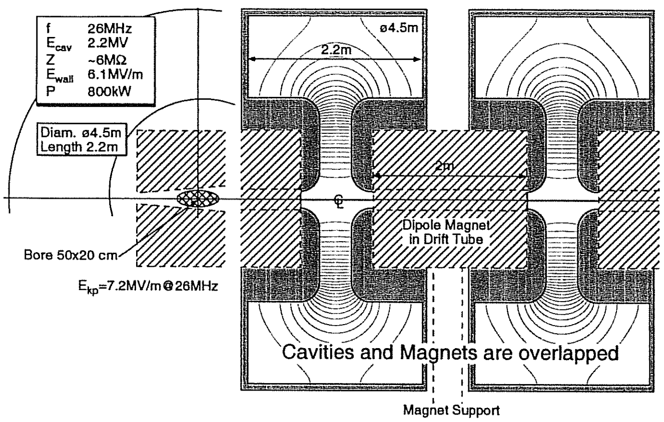


Figure 2.30: 26MHz high gradient cavity with large drift tubes where magnets can be overlapped.

If a magnet density on a ring needs to be increased further, the acceleration gap may be moved into the magnet region. Because the quarter wave length l/4 at 26MHz is about 3m, a bending magnet whose length is 3m or 6m can cover a whole quarter or half wave length cavity(see Fig. 2.31). Because of the orbit excursion, the cavity should be wide in horizontal direction and thus has a flat shape. Although the magnet's gap height has to be large enough, the magnet population on the ring would comes close to 100%. A sparking problem due to the high field gradient between the inner and the outer conductor has to be considered, which may be cured by use of ceramic insulators. Sparking problem in a high magnetic field may cause a problem, while this configuration is usually seen in cyclotrons with lower voltage though.

2.3.2 Magnet

2.3.2.1 Yoke free design of FFAG magnet

One of the problems of the conventional radial sector type of FFAG is that the sector magnets occupy most of the ring circumference. It results in the lack of free space for beam injection and extraction.

Up to now, the FFAG triplet magnet developed in KEK employs the conventional H-type magnet, such that the field flux returns through the side yoke attached to its pole. The triplet magnet used in KEK POP FFAG synchrotron is a complex of three independent H-type sector magnets(see Appendix C).