Hardware of Beam Injection and Extraction of the 50 GeV Ring in the KEK/JAERI Project

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and
50GeV Injection/Extraction Collaborators

(ICFA-HB2002 workshop at Fermilab, April 9, 2002,)

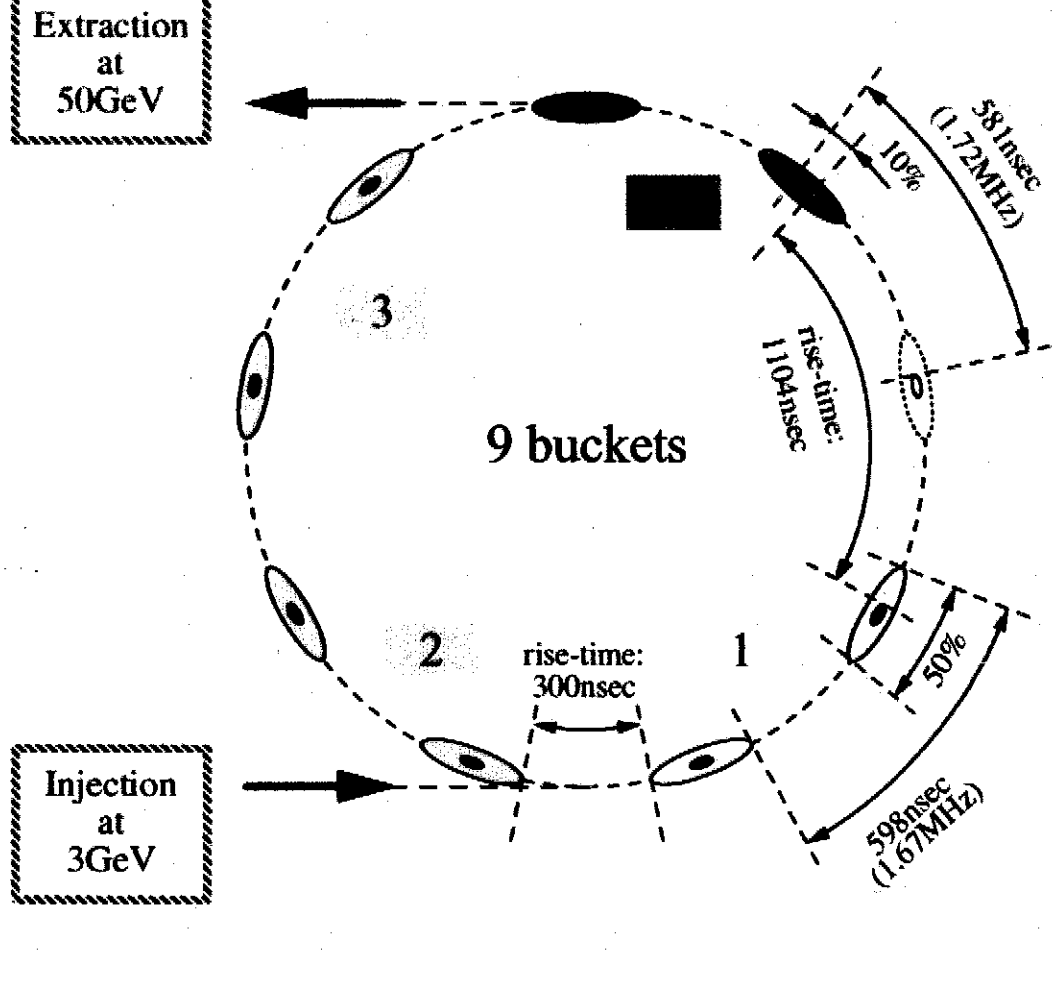
Overview of the layout of injection/extraction beam lines.

Basic injection/extraction parameters.

Some of more detailed description of individual lines.

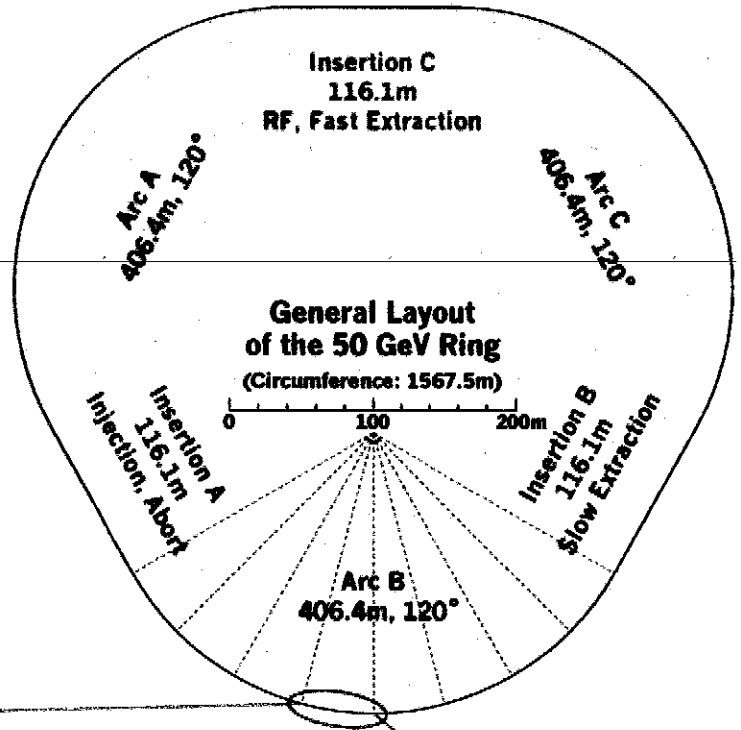
Possibility of the Fast Reverse of the fast extraction beam.

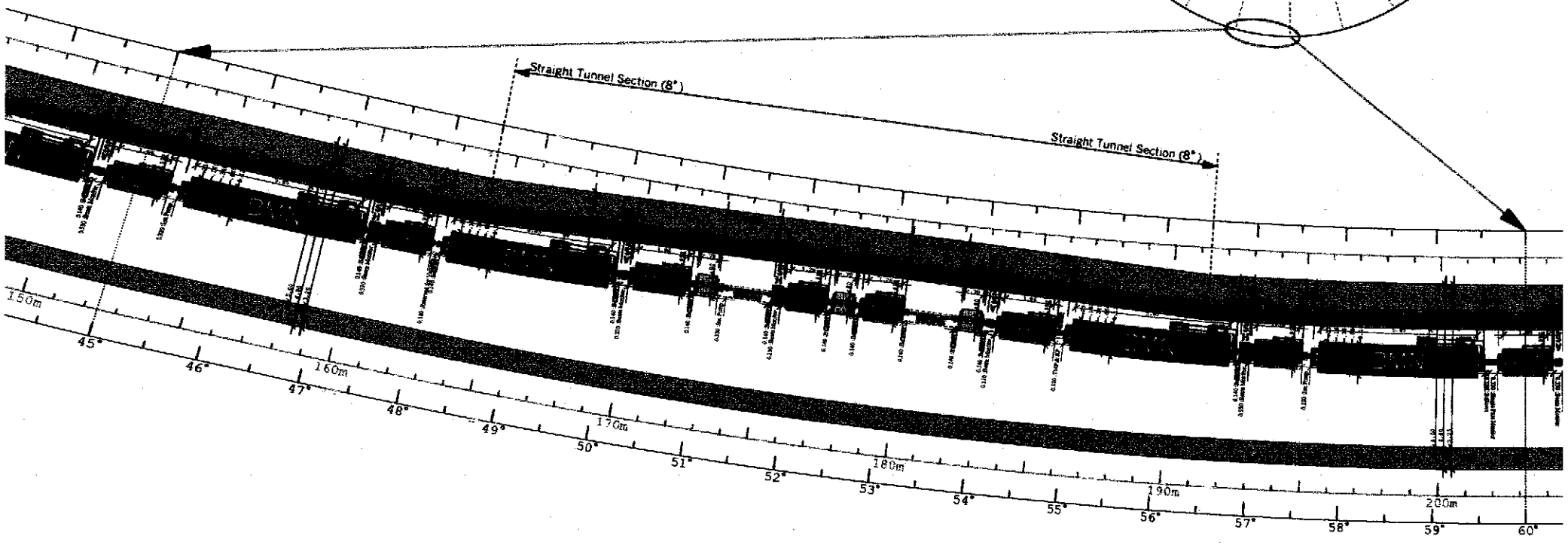
Injection/Extraction Scheme for the 50 GeV Ring



50 GeV Ring

--- 1 Module (15°) of the Arc ---





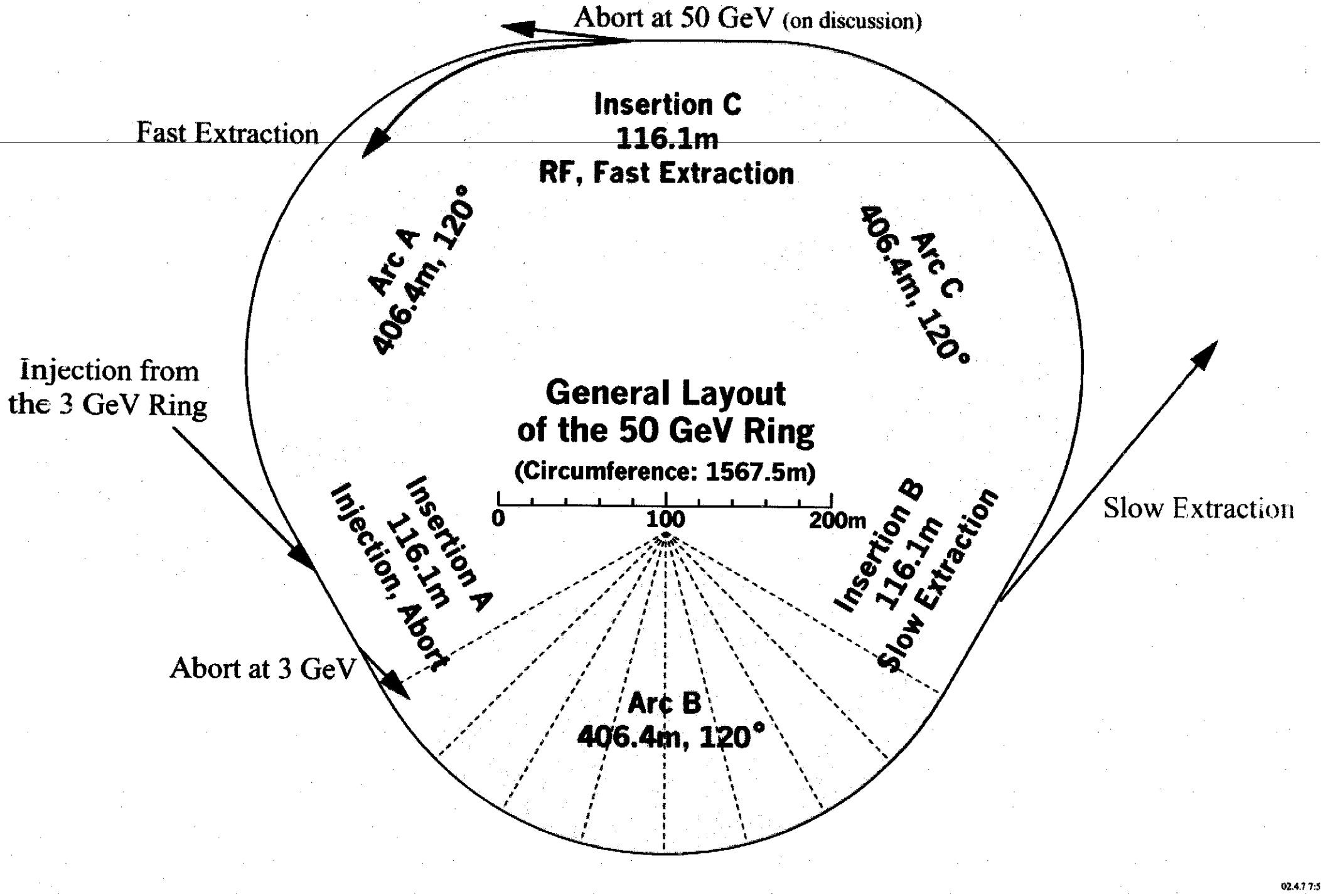
Basic Injection & Extraction Parameters of the 50 GeV Ring

Light Velocity	c [m/s]	2.99792458E+08
Proton Rest Mass Energy	E_0 [GeV]	0.93827234

Ring Circumference	l_{Ring} [m]	1567.5

			3 GeV	50 GeV	(30 GeV)
Kinetic Energy	K [GeV]		3.00000000	50.00000000	30.00000000
Total Energy	E [GeV]	$= E_0 + K$	3.93827234	50.93827234	30.93827234
Momentum	cp [GeV]	$= K*SQRT(1+2E_0/K)$	3.82487046	50.92963022	30.92404146
β	β	$= SQRT(1-E_0^2/E^2)$	0.9712051708	0.9998303413	0.9995400235
Velocity	v [m/s]	$= \beta*c$	2.91159985E+08	2.99741596E+08	2.9965456 1E+0
Magnetic Rigidity	Bρ [Tm]	$= p/q = (cp/q)/c$	12.758394545	169.88296022	103.15149911
Revolution Period	τ_{rev} [nsec]	$= l_{Ring}/v$	5383.6381330	5229.5044234	5231.0233398
Revolution Frequency	f_{rev} [kHz]	$= 1/\tau_{rev}$	185.74799704	191.22270851	191.16718375
RF Period	τ_{RF} [nsec]	$= \tau_{rev}/9$	598.18201477	581.05604704	581.22481554
RF Frequency	f_{RF} [MHz]	$= 1/\tau_{RF}$	1.6717319734	1.7210043766	1.7205046537

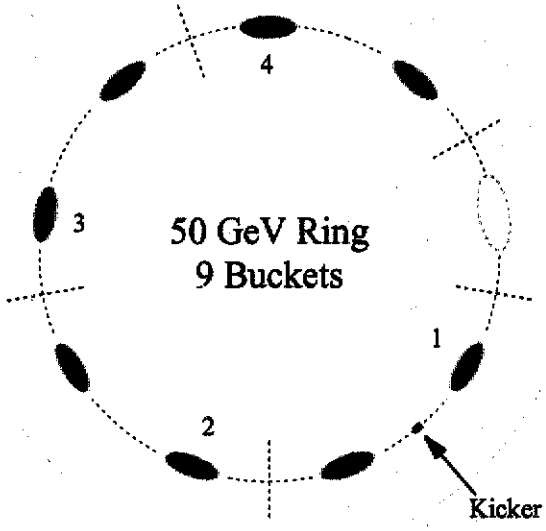
Injection & Extraction Lines of the 50 GeV Ring

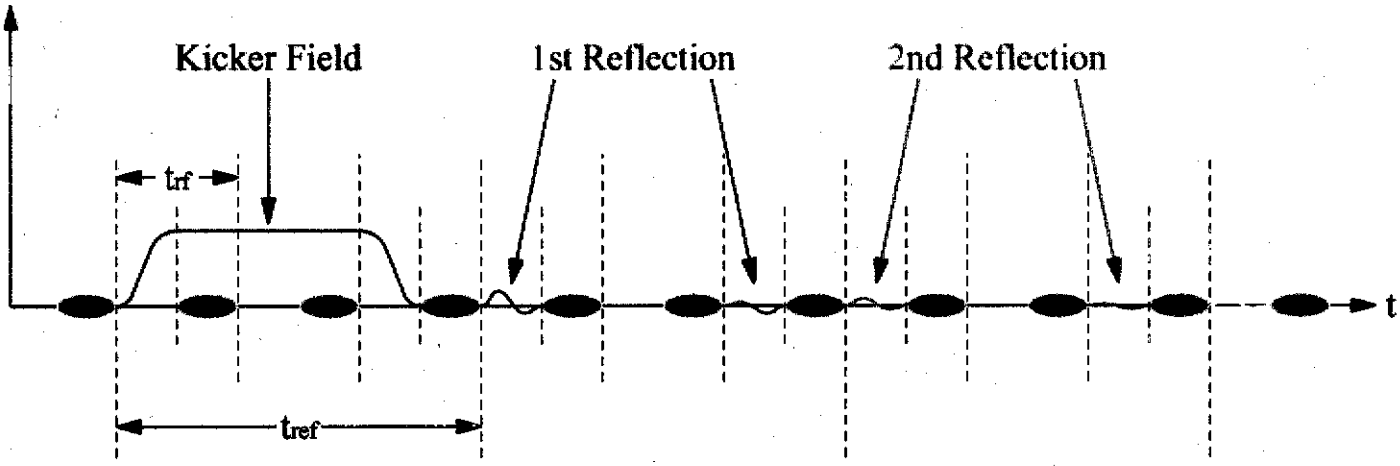


Rise-time, Flat-top, Fall-time of the 50 GeV Ring Kickers

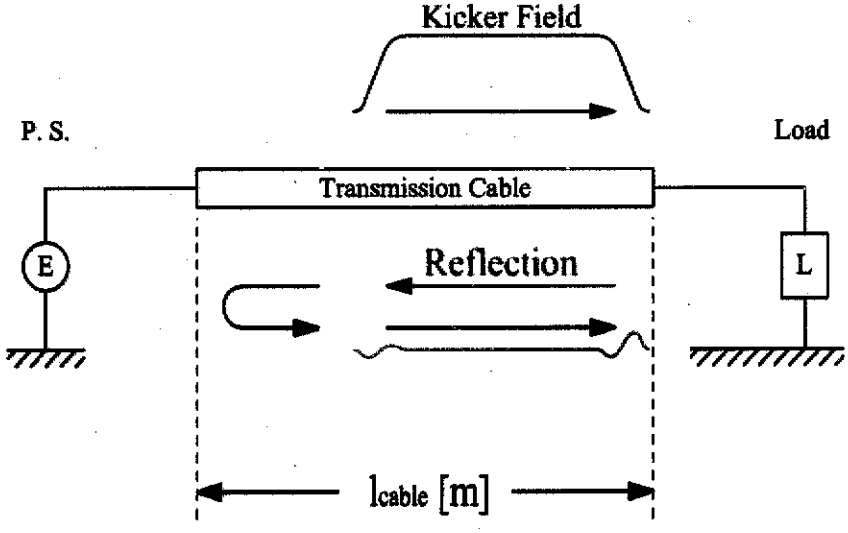
Item	Symbol	Injection (3 GeV)		Abort (3 GeV)		Fast Extraction (50 GeV)	
RF Period	τ_{RF}		600 [nsec]	<=			581 [nsec]
Bunch Length	τ_{bunch}	$= 0.5 \cdot \tau_{RF}$	300 [nsec]	<=		$= 0.1 \cdot \tau_{RF}$	58 [nsec]
Bunch Interval	τ_{int}	$= \tau_{RF} - \tau_{bunch}$	300 [nsec]	<=		$= \tau_{RF} - \tau_{bunch}$	523 [nsec]
Rise-time	τ_{rise}	$= \tau_{int}$	300 [nsec]	$= \tau_{int}$	~~300~~ 900 [nsec]	$= \tau_{int} + \tau_{RF}$	1104 [nsec]
Flat-top	τ_{ft}	$= \tau_{bunch} + \tau_{RF}$	900 [nsec]	$= \tau_{bunch} + 7 \cdot \tau_{RF}$	4500 [nsec]	$= \tau_{bunch} + 7 \cdot \tau_{RF}$	4125 [nsec]
Fall-time	τ_{fall}	$= \tau_{int}$	300 [nsec]	----------		----------	
PFN Pulse Length	τ_{PFN}	$= 2 \cdot \tau_{RF}$	1200 [nsec]	$= 9 \cdot \tau_{RF}$	5400 [nsec]	$= 9 \cdot \tau_{RF}$	5229 [nsec]
PFN Cable Length	l_{PFN}	$= \tau_{PFN} / 10$	120 [m]	$= \tau_{PFN} / 10$	540 [m]	$= \tau_{PFN} / 10$	523 [m]

Reflection Trapping





$t_{ref} = n * t_{rf}$



transmission time ~ 5 nsec/m

t_{ref} ~ 51 * 2 [nsec]

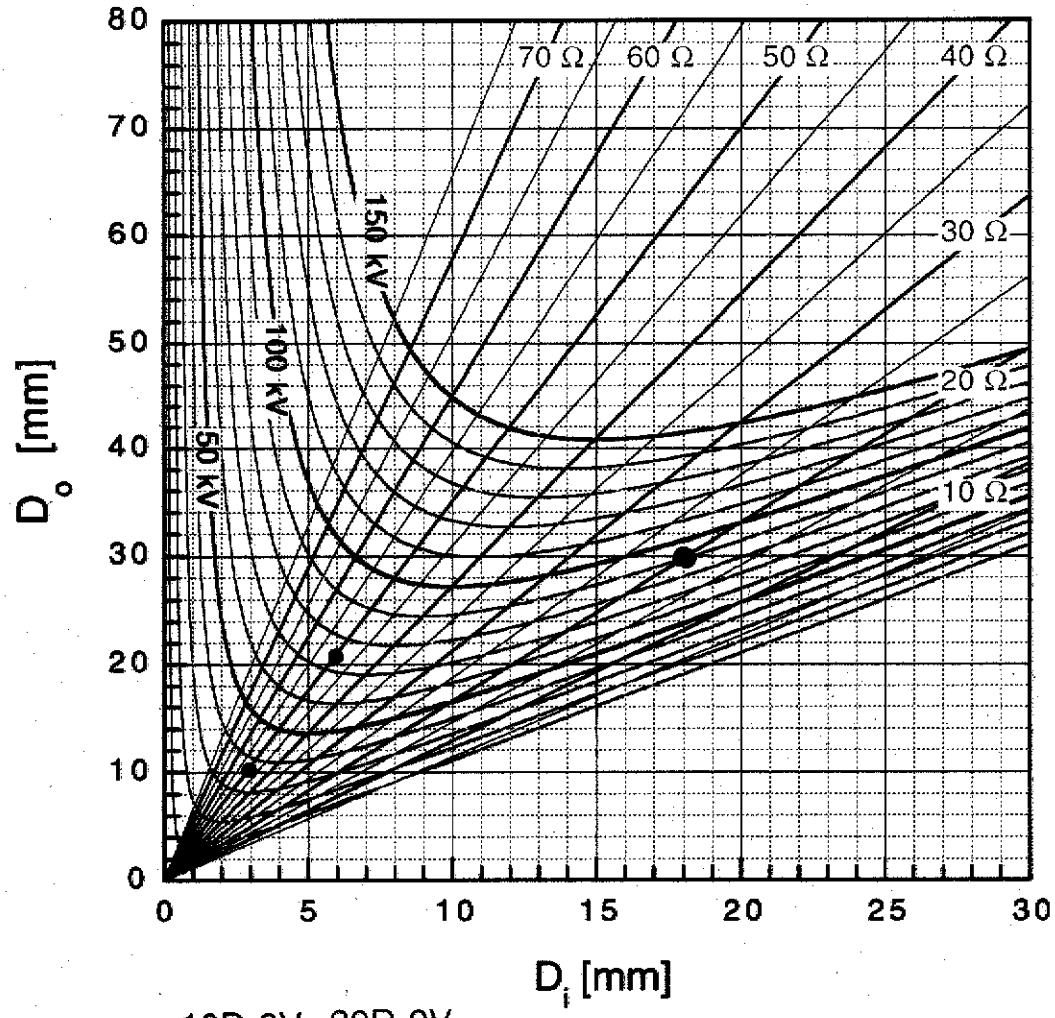
l_{cable} [m] ~ t_{ref} [nsec] / 10

t_{rf} ~ 600 [nsec]
$\Longrightarrow$ t_{ref} ~ 1800 [nsec] (n=3)
$\Longrightarrow$ l_{cable} ~ 180 [m]

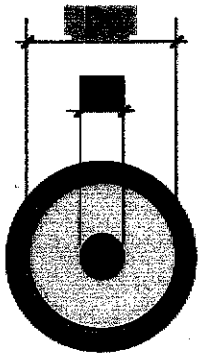
Co-axial Cable

Impedance Z_0 [Ω]

Maximum Voltage V_{max} [kV]



10D-2V 20D-2V

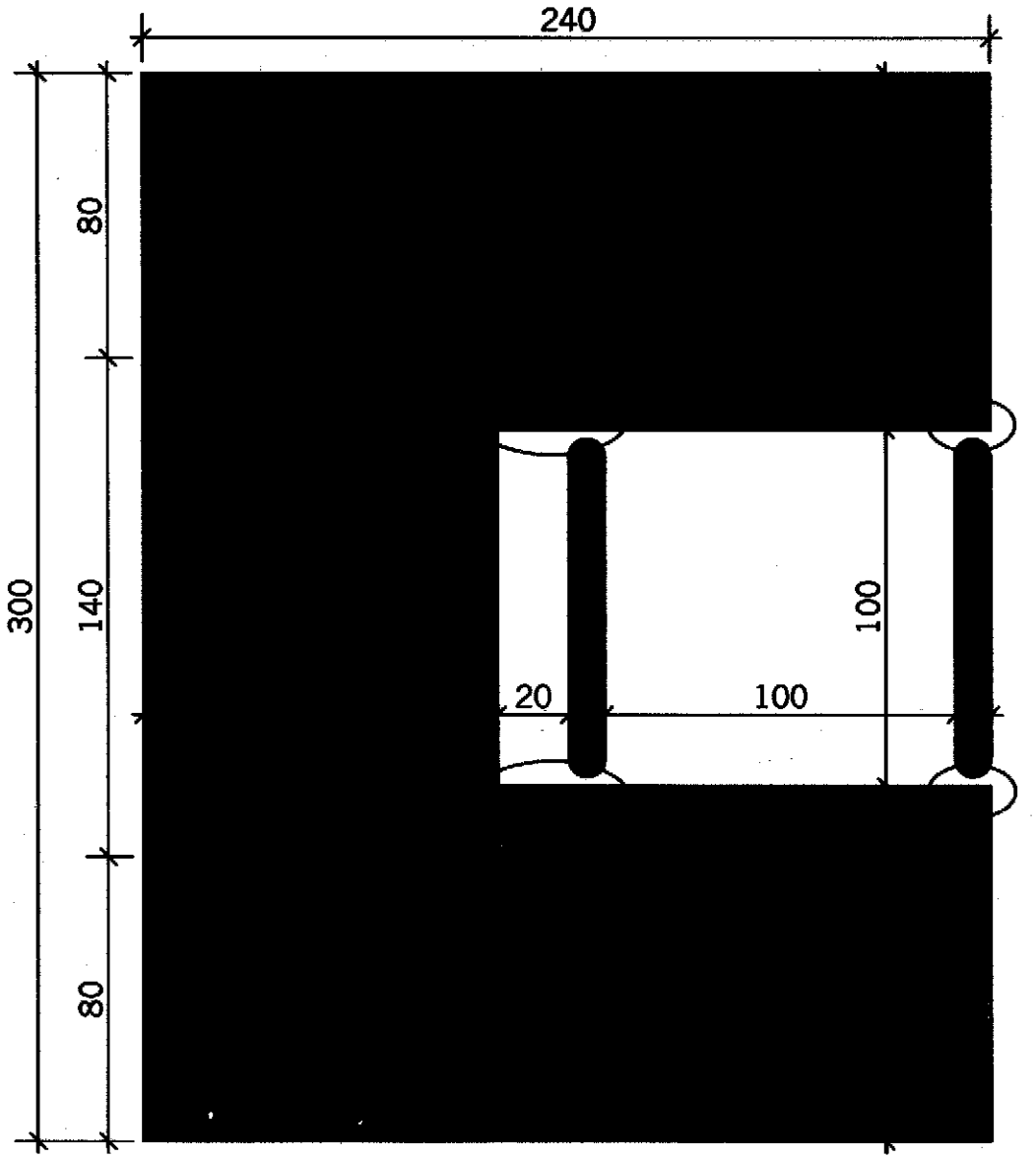


$$Z_0 = \frac{60}{\sqrt{\varepsilon'}} \ln \frac{D_o}{D_i}$$

$$V_{max} = \frac{1}{2} E_{max} D_i \ln \frac{D_o}{D_i}$$

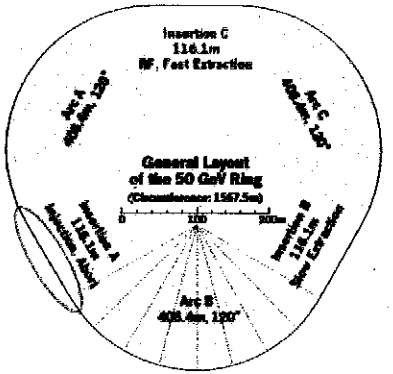
$\varepsilon' = 2.26$, $E_{max} = 20$ kV/mm
for polyethylene

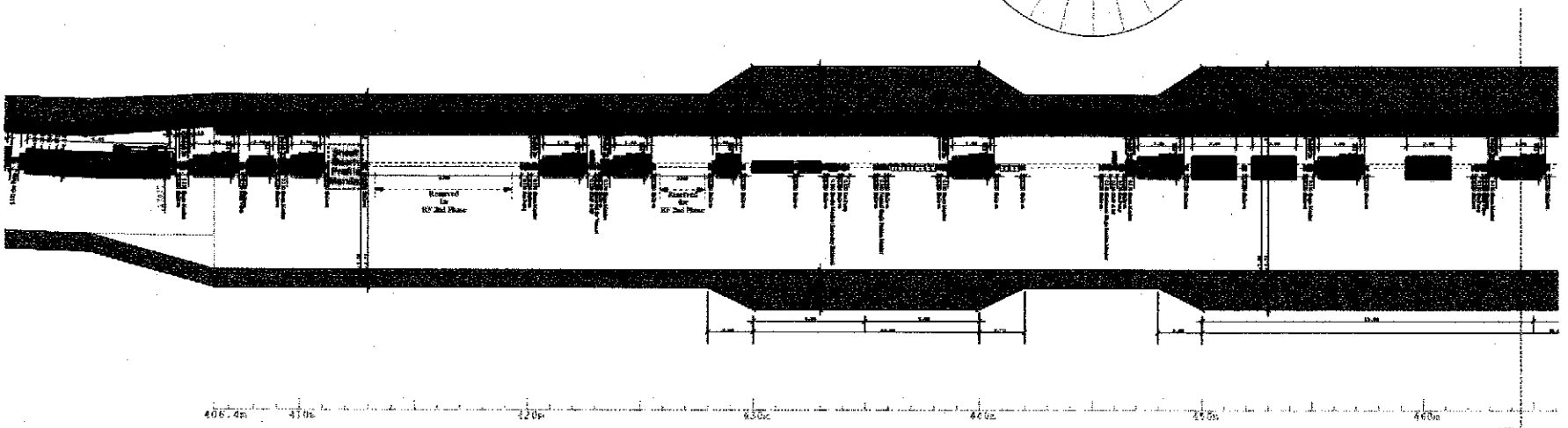
キッカー試作機用フェライトコア形状 (Ver.3)

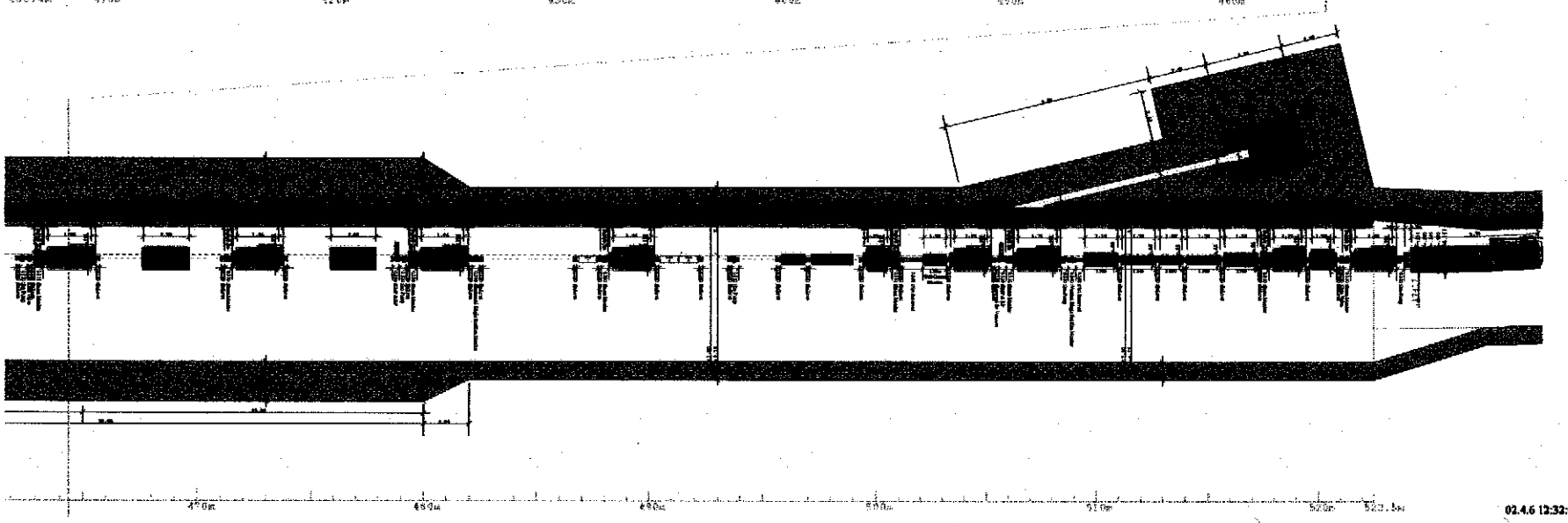


：フェライト切り落し部分。詳細形状は追って指定

50 GeV Ring
--- Insertion A / Injection & Abort ---







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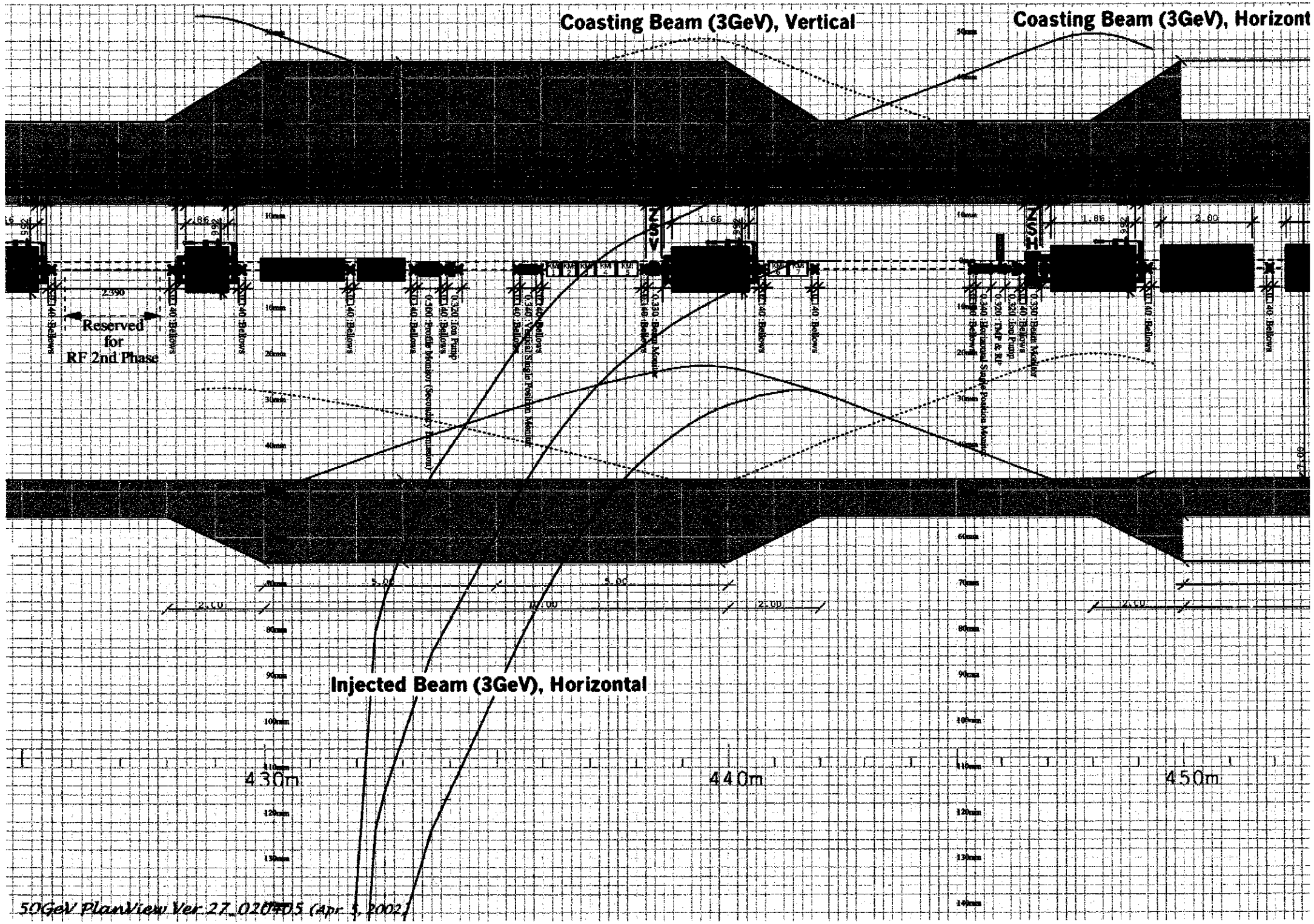
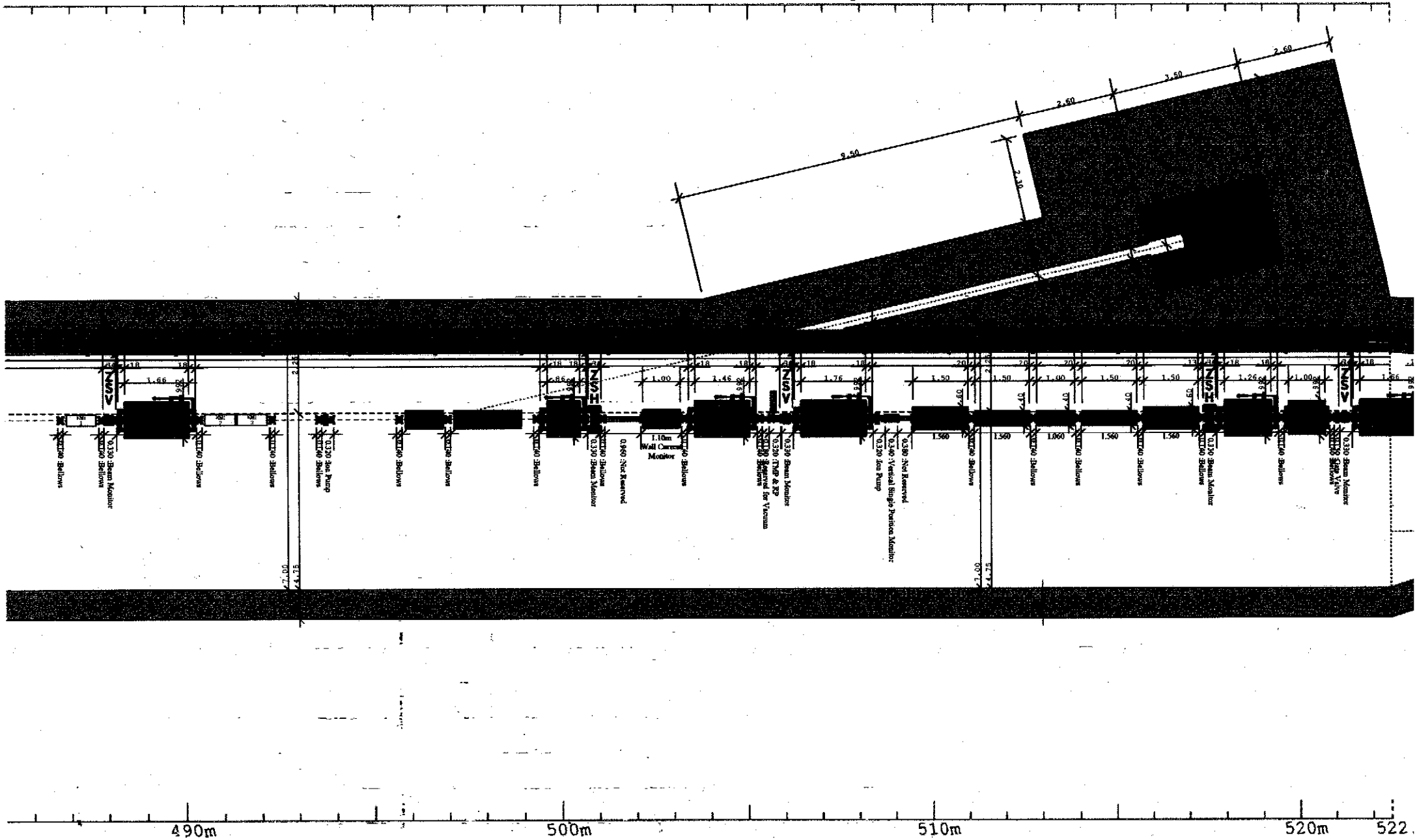

Coasting Beam (3GeV), Vertical
Coasting Beam (3GeV), Horizont
Reserved
for
RF 2nd Phase
Injected Beam (3GeV), Horizontal
430m
440m
450m
50GeV PlanView Ver 27_020405 (Apr 5, 2002)

Injection, Abort



50GeV PlanView Ver.27_020405 (Apr. 5, 2002)

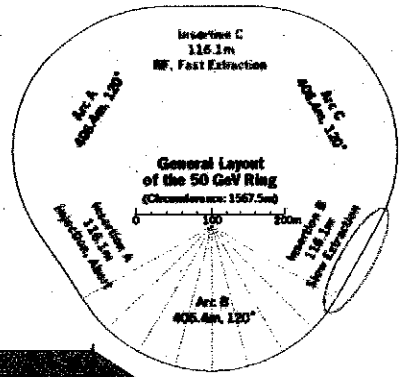
Injection Kicker Parameters of the 50 GeV Ring

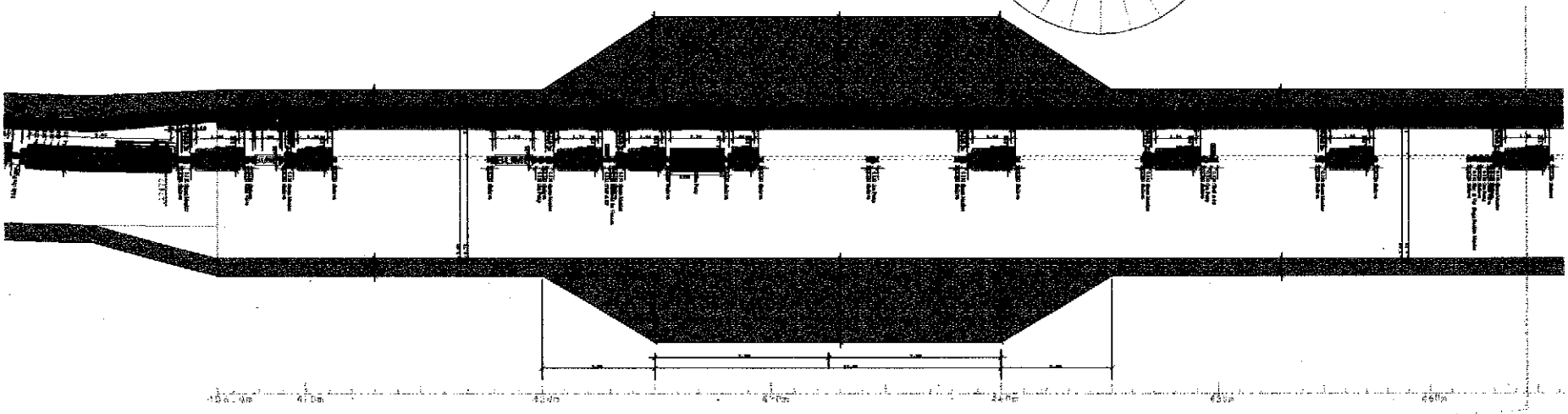
Item	Symbol	Derived from:	Unit	KMI1	KMI2	KMI3	KMI4	KMI5	KMI6	KMI7
Aperture Height	h		[mm]	83	85	88	91	94	94	94
Aperture Width	w		[mm]	105	100	90	82	76	56	56
Aperture Length	l		[mm]	280	300	360	400	440	400	400
PFN Operating Voltage	V_{PFN}		[kV]	60.00	60.00	60.00	60.00	60.00	60.00	60.00
(Maximum Cable Voltage)	V_{max}		[kV]	80.00	80.00	80.00	80.00	80.00	80.00	80.00
(Cable Impedance)	R_{Cable}		[Ω]	20.00	20.00	20.00	20.00	20.00	20.00	20.00
(Parallel # of Cables)	n			2	2	2	2	2	3	3
PFN Impedance	R_0	$= R_{Cable} / n$	[Ω]	10.00	10.00	10.00	10.00	10.00	6.67	6.67
Flat-top Kicker Current	I	$= V_{PFN} / R_0$	[kA]	6.00	6.00	6.00	6.00	6.00	9.00	9.00
Kicker Field	B	$= \mu_0 \cdot I / h$	[T]	0.0908	0.0887	0.0857	0.0829	0.0802	0.1203	0.1203
B·l Product	B·l	$= B \cdot l$	[T·m]	0.0254	0.0266	0.0308	0.0331	0.0353	0.0481	0.0481
Kick Angle	θ	$= B \cdot l / (B\rho)_{3GeV}$	[mrad]	1.9936	2.0858	2.4176	2.5977	2.7662	3.7721	3.7721
Inductance	L	$= \mu_0 \cdot w \cdot l / h$	[μH]	0.4451	0.4435	0.4627	0.4529	0.4470	0.2995	0.2995
Time Constant	τ_0	$= L / R_0$	[nsec]	44.51	44.35	46.27	45.29	44.70	44.92	44.92
0-99% Rise-time	$\tau_{0\text{-}99\%}$	$= 4.6 \cdot \tau_0$	[nsec]	204.76	204.02	212.83	208.35	205.64	206.62	206.62
Switch Turn-on Time	τ_{SW}	(supposed value)	[nsec]	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Total Rise-time	τ_{Total}	$= \tau_{0\text{-}99\%} + \tau_{SW}$	[nsec]	274.76	274.02	282.83	278.35	275.64	276.62	276.62
Nominal Field Strength			[Gauss]	900	880	850	825	800	1200	1200
Maximum Beam Height	(simulated result)		[mm]	80.08	82.16	84.64	87.39	90.44	90.47	86.94
Maximum Beam Width	(simulated result)		[mm]	102.11	94.48	87.13	79.50	72.33	49.62	50.55

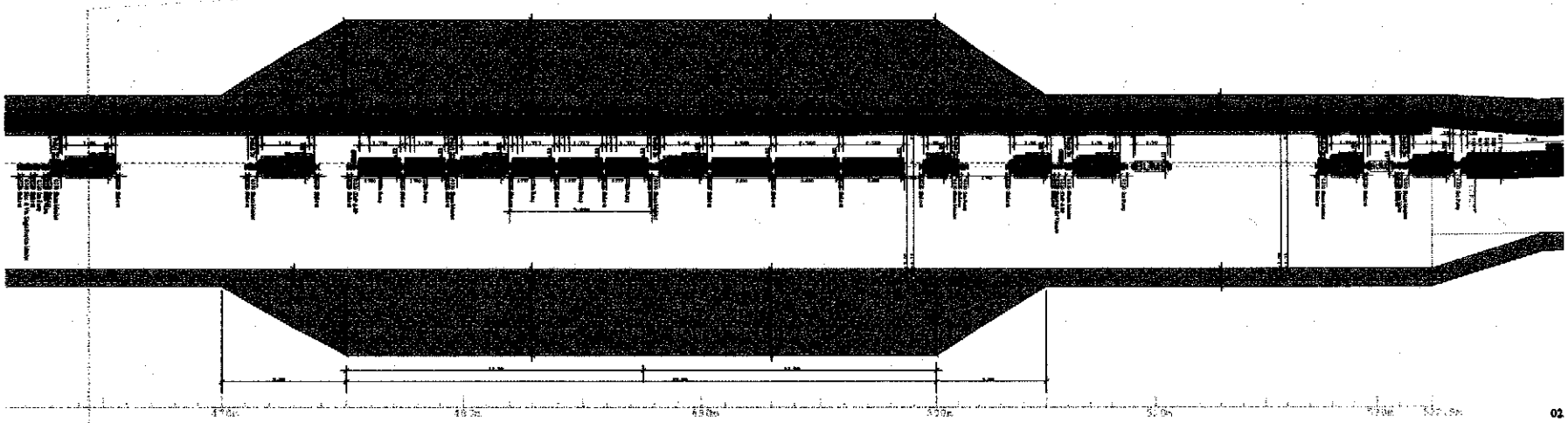
Abort Kicker Parameters of the 50 GeV Ring

Item	Symbol	Derived from:	Unit	KMA1-3
Aperture Height	h		[mm]	100
Aperture Width	w		[mm]	100
Aperture Length	l		[mm]	800
PFN Operating Voltage	V_{PFN}		[kV]	60.00
(Maximum Cable Voltage)	V_{max}		[kV]	80.00
(Cable Impedance)	R_{Cable}		[Ω]	20.00
(Parallel # of Cables)	n			3
PFN Impedance	R_0	$= R_{Cable} / n$	[Ω]	6.67
Flat-top Kicker Current	I	$= V_{PFN} / R_0$	[kA]	9.00
Kicker Field	B	$= \mu_0 \cdot I / h$	[T]	0.1131
B·l Product	B·l	$= B \cdot l$	[T·m]	0.0905
Kick Angle	θ	$= B \cdot l / (B\rho)_{3GeV}$	[mrad]	7.0916
Inductance	L	$= \mu_0 \cdot w \cdot l / h$	[μH]	1.0053
Time Constant	τ_0	$= L / R_0$	[nsec]	150.80
0-99% Rise-time	$\tau_{0\text{-}99\%}$	$= 4.6 \cdot \tau_0$	[nsec]	693.66
Switch Turn-on Time	τ_{SW}	(supposed value)	[nsec]	150.00
Total Rise-time	τ_{Total}	$= \tau_{0\text{-}99\%} + \tau_{SW}$	[nsec]	843.66

50 GeV Ring
--- Insertion B / Slow Extraction ---

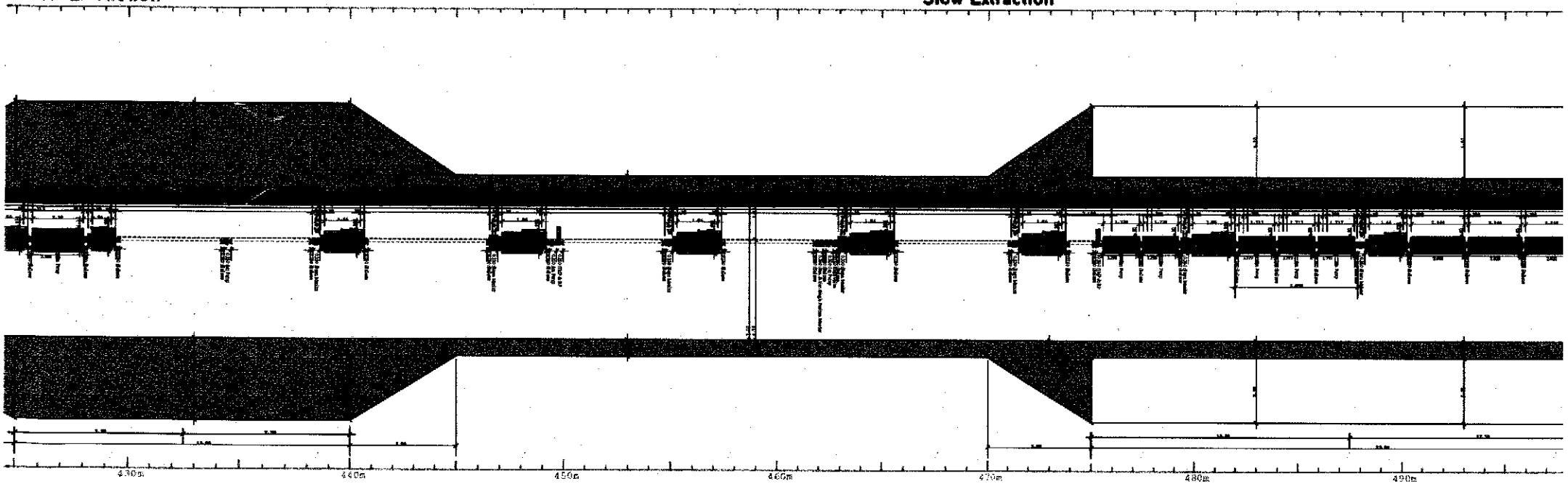




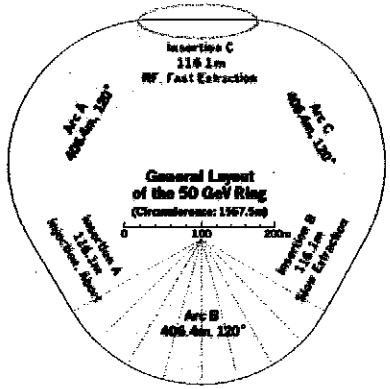


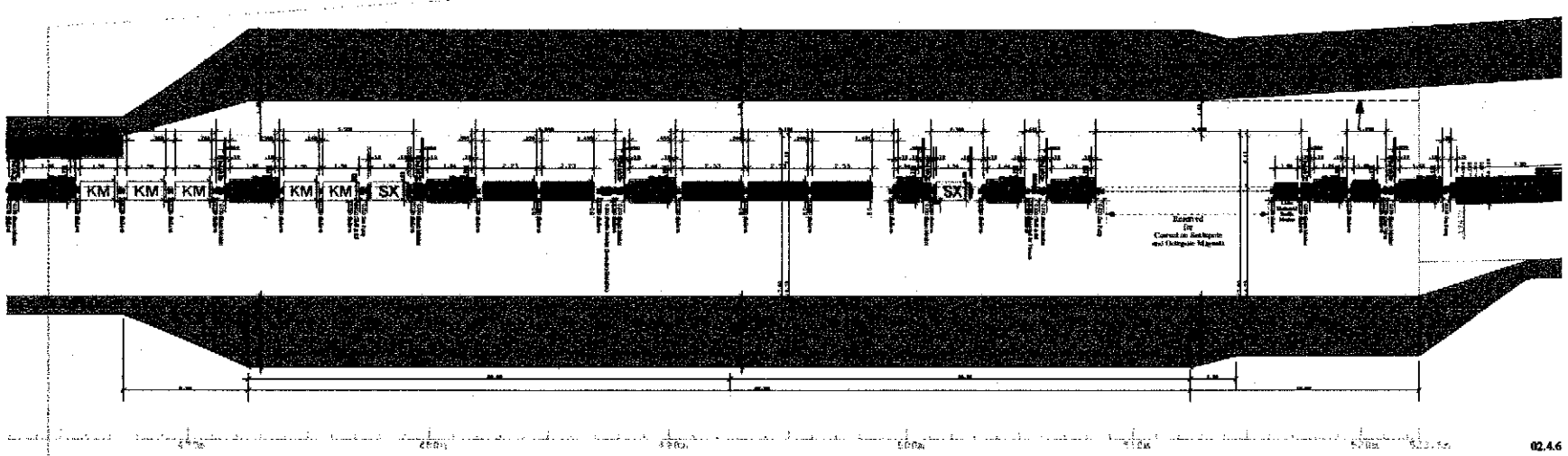
Insertion B
116.1m
Slow Extraction

Insertion B
116.1m
Slow Extraction

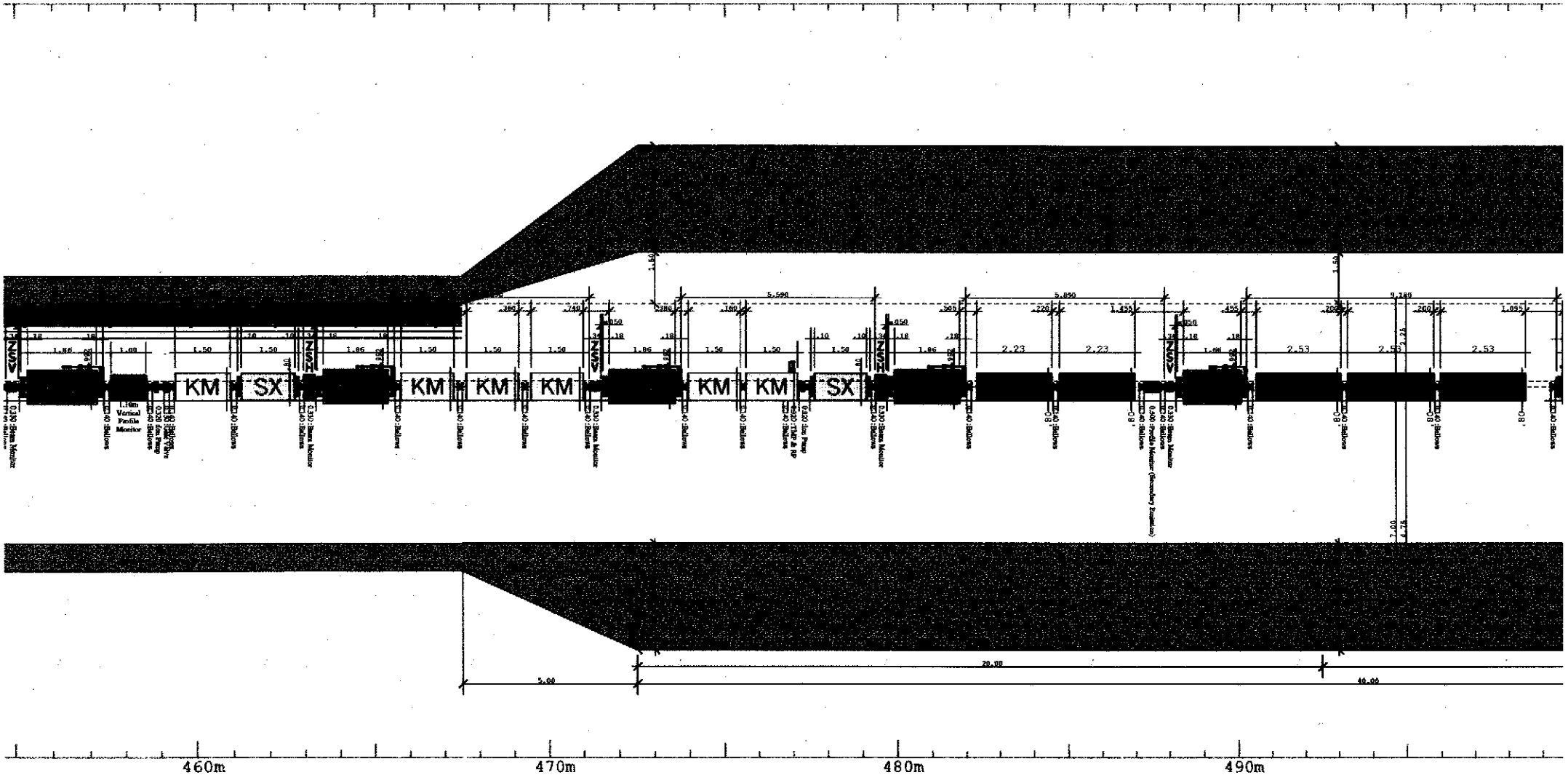


50 GeV Ring
--- Insertion C / RF & Fast Extraction ---





Insertion C
116.1m
RF, Fast Extraction



50GeV PlanView Ver.27_020405 (Apr. 5, 2002)

Fast Extraction Kicker of the 50 GeV Ring

Basic assumption:

--- Lumped kicker.

--- Kicker end grounded. (Kicker field strength doubled by PFN pulse reflection.)

--- 1 turn coil and ferrite return yoke inside vacuum.

--- IGBT switching element.

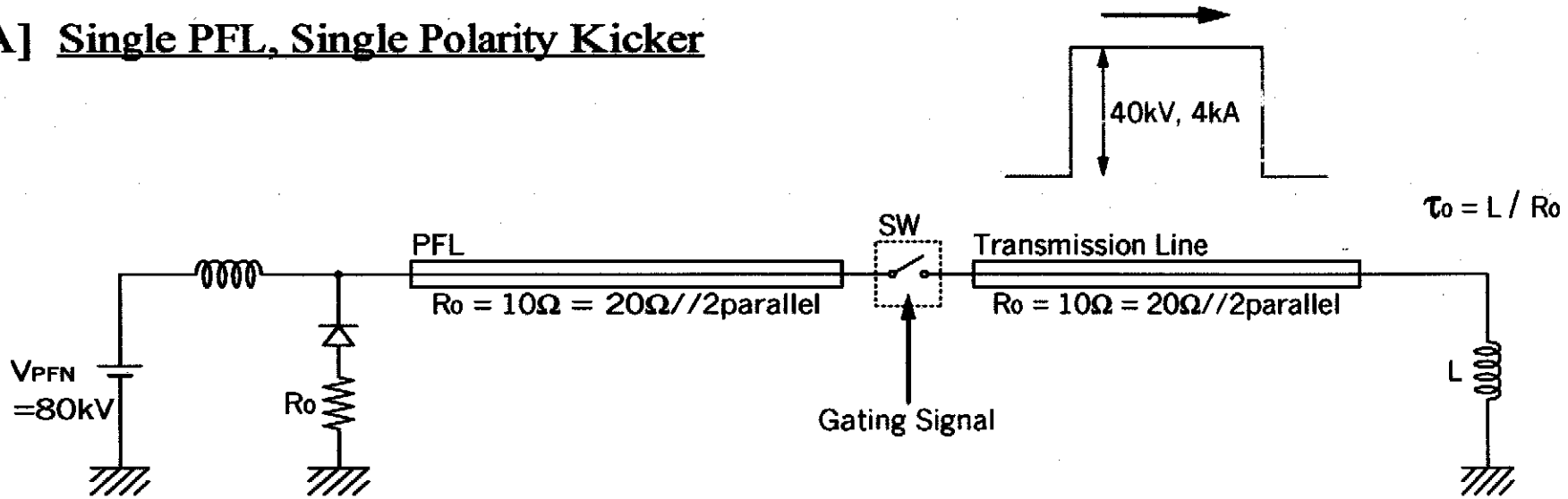
--- Pulse Forming Line with 10Ω impedance. (assuming 20Ω//2 parallel co-axial cables

--- Fast reversal of kick direction required.

PFN charging voltage:	V_{PFN} = 80 [kV]	
		(+40 kV & -40 kV bipolar power supply)
PFN cable impedance:	R_0	= 10 [Ω]
Flat-top kicker current:	I_L	= 8 [kA]

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[A] Single PFL, Single Polarity Kicker



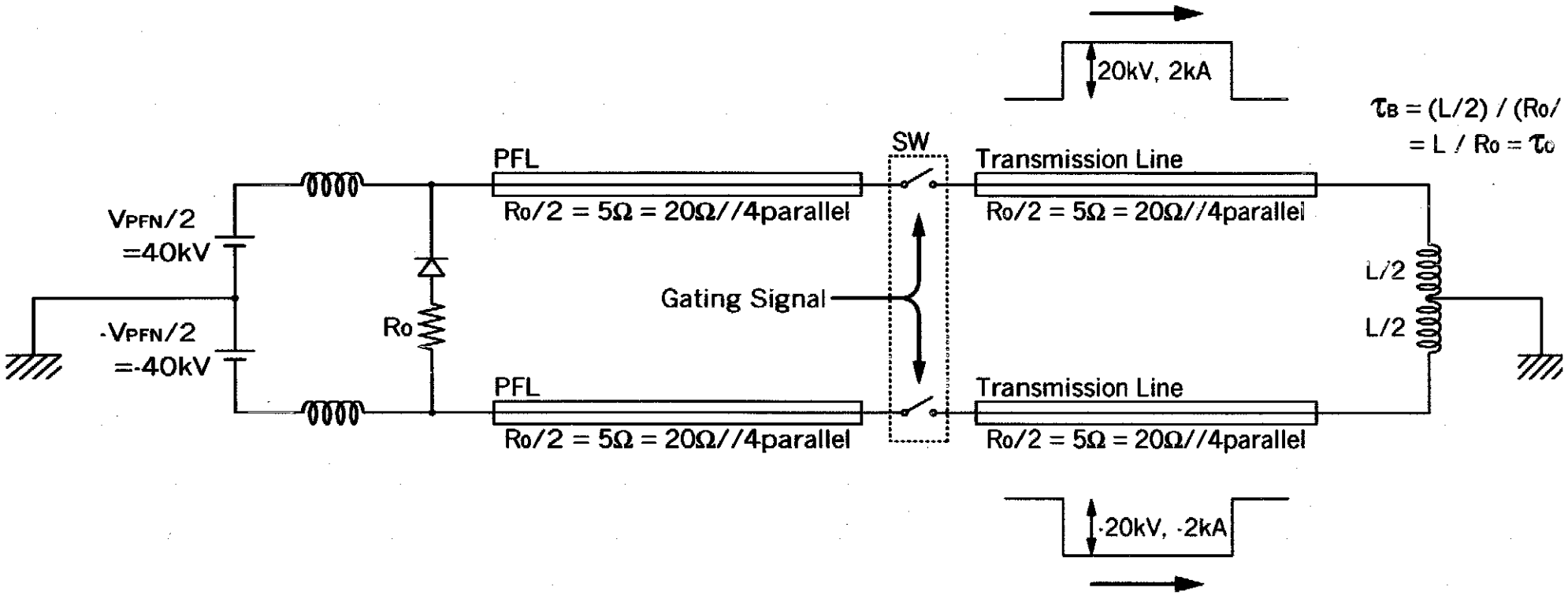
==> Simple and proved configuration.

==> 80 kV high-voltage endurance required. (==> [B])

==> Fast reverse of kick direction not supported. (==> [C])

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[B] Double PFL, Single Polarity Kicker



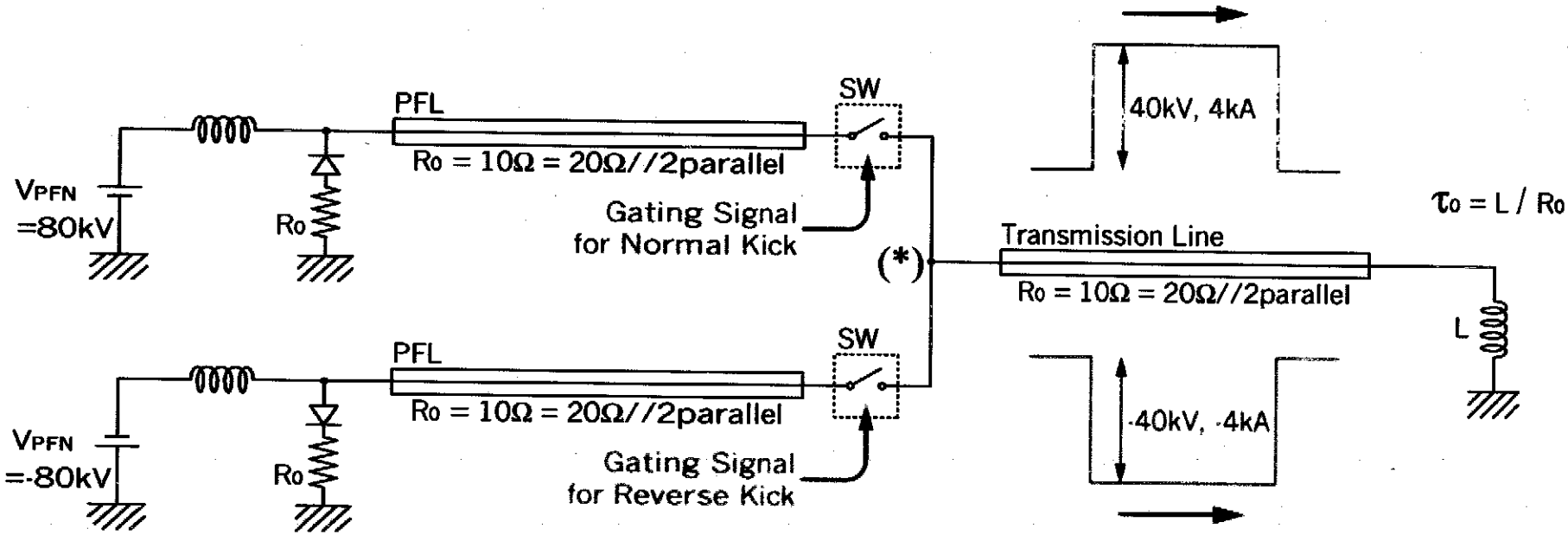
==> Maximum high-voltage reduced to 40 kV.

==> Number of cables (PFL and TL) becomes 16 for each kicker unit.

==> Fast reverse of kick direction not supported. (==> [C])

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[C] Single PFL, Reversible Polarity Kicker



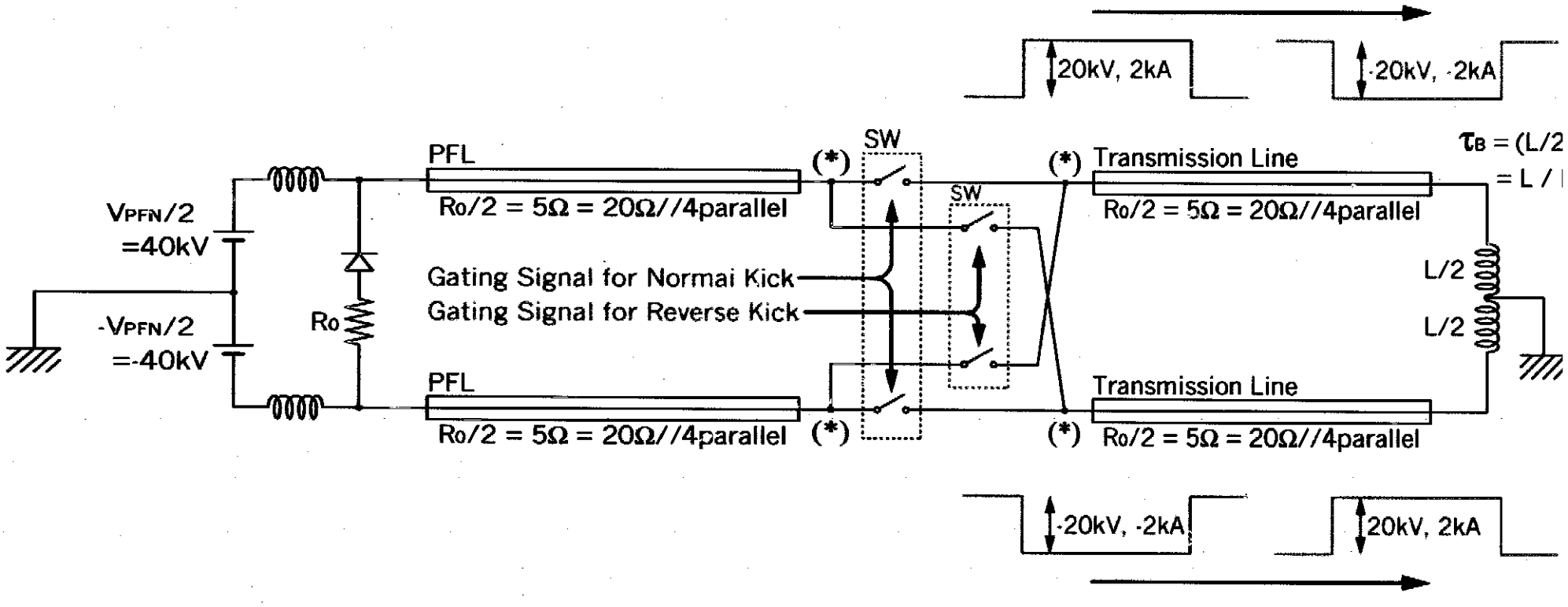
==> Fast reverse of kick direction is supported (in principle).

==> Branching of pulse propagation occurs at the intersection of the Transmisson Lines. (*)

==> 80 kV high-voltage endurance required. (==> [D])

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[D] Double PFL, Reversible Polarity Kicker



==> Maximum high-voltage reduced to 40 kV.

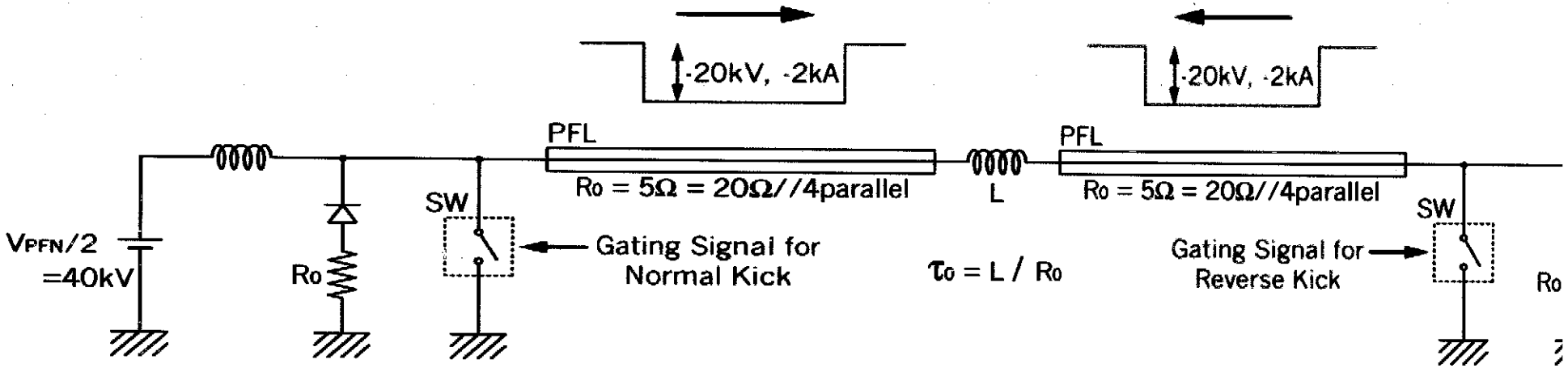
==> Number of cables (PFL and TL) becomes 16 for each kicker unit. (==> [E])

==> Fast reverse of kick direction is supported (in principle).

==> Branching of pulse propagation occurs at the intersections of the PFLs and the TLs.(*) (=

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[E] Blumlein PFL, Reversible Polarity Kicker



==> Simple and proved configuration (at least, with only a Normal Kick switch).

==> Maximum high-voltage reduced to 40 kV.

==> Number of PFL cables becomes 8 for each kicker unit.

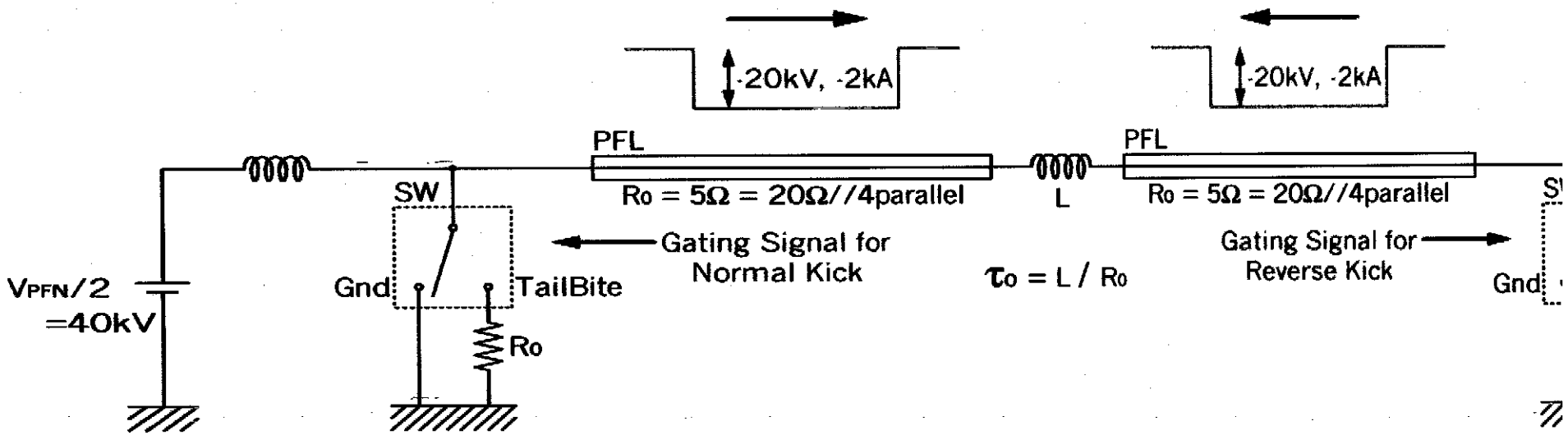
==> Fast reverse of kick direction is supported.

==> No branching problem will occur.

==> Kicker Current follows a two-step fall. (==> [F])

PFN Scheme for the 50GeV-Ring Fast Extraction Kickers

[F] Blumlein PFL, Reversible Polarity Kicker, Gnd/TailBite Alternate Switch



==> Simple and proved configuration (at least, with only a Normal Kick switch).

==> Maximum high-voltage reduced to 40 kV.

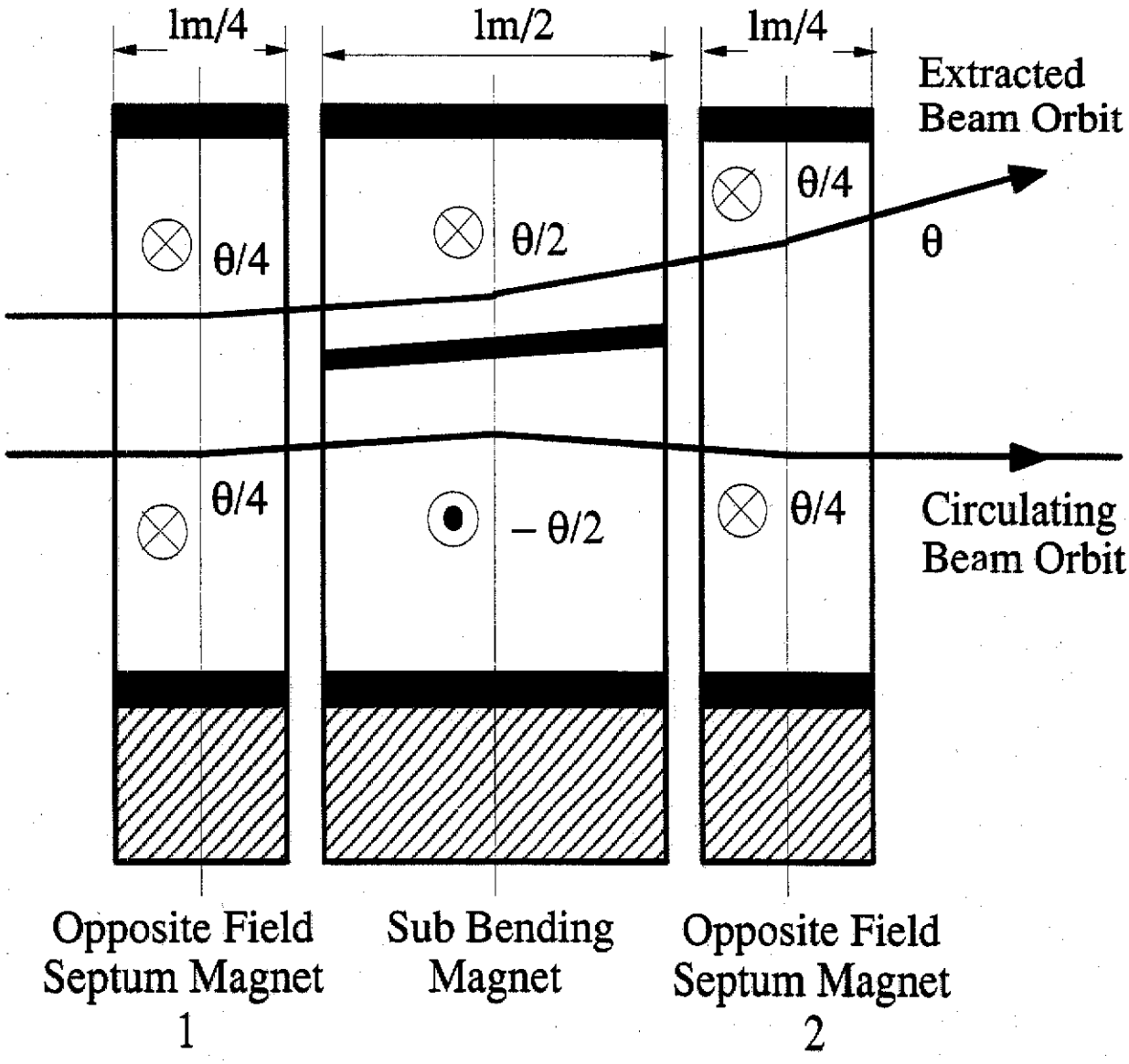
==> Number of PFL cables becomes 8 for each kicker unit.

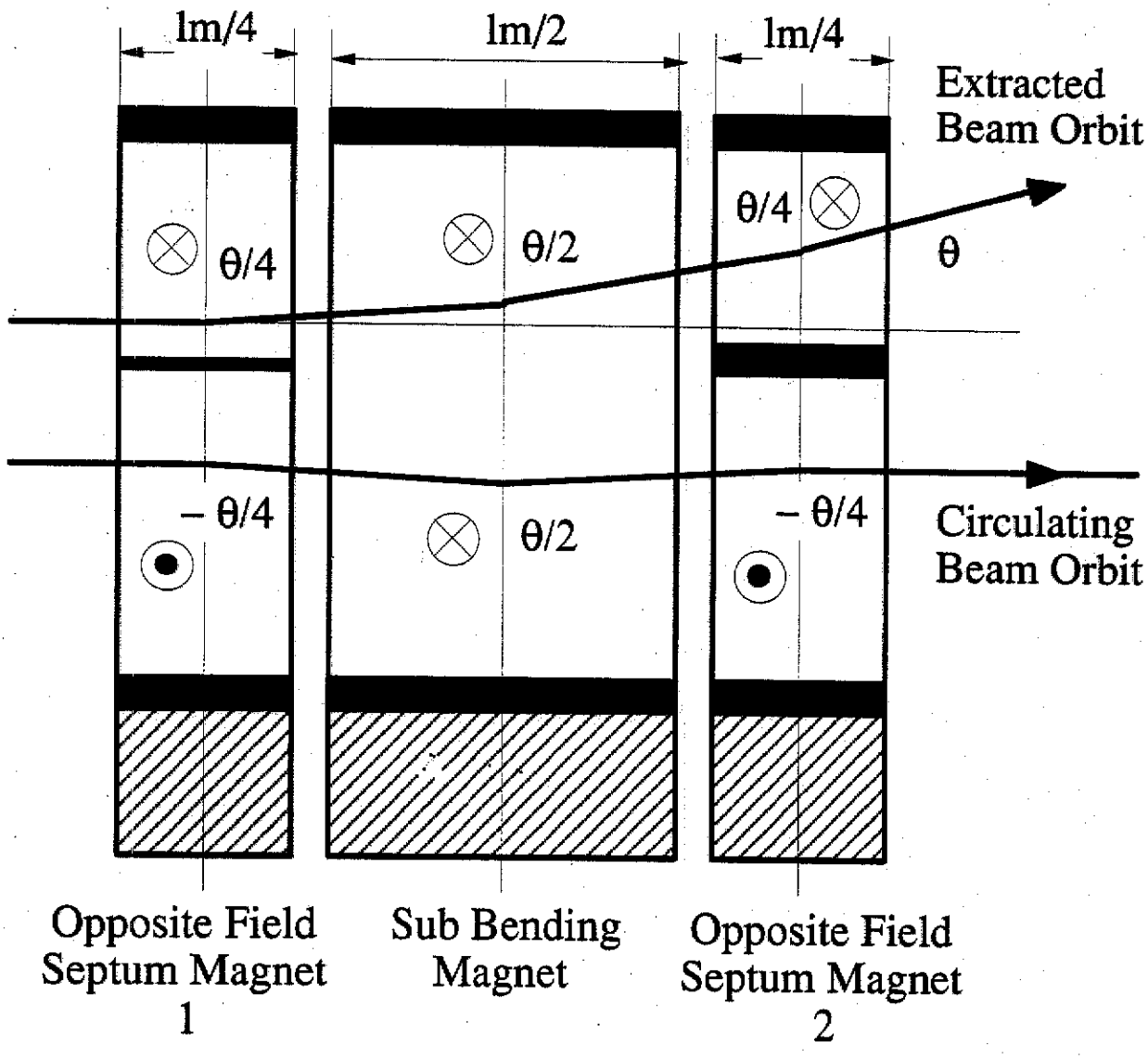
==> Fast reverse of kick direction is supported.

==> No branching problem will occur.

==> Gnd/TailBite Alternate Switch is required.

==> Kicker current will have a clean tail and a variable length flat-top.


lm/4
lm/2
lm/4
Extracted
Beam Orbit
θ/4
θ/2
θ/4
θ
θ/4
– θ/2
θ/4
Circulating
Beam Orbit
Opposite Field
Septum Magnet
1
Sub Bending
Magnet
Opposite Field
Septum Magnet
2


lm/4
lm/2
lm/4
Extracted
Beam Orbit
θ/4
θ/2
θ/4
θ
– θ/4
θ/2
– θ/4
Circulating
Beam Orbit
Opposite Field
Septum Magnet
1
Sub Bending
Magnet
Opposite Field
Septum Magnet
2