3.2.7 Booster Injection and Extraction

3.2.7.1 Overview

The Booster has two magnet systems for injection:

Septum Si
Kicker Ki

The Booster has three magnet systems for extraction:

Kicker Ke, comprising two identical magnets and power supplies
Septum Se

An overview of the equipment placement is shown in Fig.f291_a (Section 2.9, Storage Ring Injection). Figs.f3271_a and f3271_b show the general layout of the pulsed magnets in the machine tunnel. These magnet systems are summarised in Tables t3271_a - t3271_d:

Magnet Technology	Eddy current septum
Magnet Deflection	7.0^{o}
Circulating Beam Aperture	unrestricted
Injected Beam Aperture	25mm (H) x 12mm (V)
Magnet Length	600mm
Septum Thickness	3mm
Magnetic Field	68mT at 100MeV
Magnet Inductance	≈1.7μH
Magnet Current	650A
Magnet Current Waveform	Half-sine, 70μs length
Total Non-Systematic Error	<0.9% horizontal, 880μrad vertical

Table t3271_a: Summary of Booster Septum Si.

Magnet Technology	Window-frame, with conductor and ferrite core in vacuum
Magnet Deflection	13mrad
Magnet Aperture	32mm (H) x 22mm (V)
Magnet Length	500mm
Magnet Field	9mT at100MeV
Magnet Inductance	≈1.3μH
Magnet Current	150A
Magnet Current Waveform	Rectangular, 700ns length
Total Non-Systematic Error	<1.4% horizontal. 28μrad vertical

Table t3271_b: Summary of Booster Kicker Ki

Magnet Technology	Window-frame, with conductor and ferrite core in vacuum
Magnet Deflection	twice 2.45mrad = 4.9mrad
Magnet Aperture	32mm (H) x 22mm (V)
Magnet Length	twice 500mm = 1000mm
Magnet Field	39mT at 2.4GeV
Magnet Inductance	≈1.3µH each
Magnet Current	690A
Magnet Current Waveform	Rectangular, 700ns length
Total Non-Systematic Error	<1.4% horizontal. 28µrad vertical

Table t3271_c: Summary of Booster Kicker Ke
(two magnets and supplies identical to Ki*)*.

Magnet Technology	Eddy current, with electron beam ante-chamber and magnetic screen
Magnet Deflection	6.46^{o}
Circulating Beam Aperture	unrestricted
Extracted Beam Aperture	25mm (H) x 6mm (V)
Magnet Length	1040mm
Septum Thickness	3mm
Magnetic Field	0.87T at 2.4GeV
Magnet Inductance	≈5.7µH
Magnet Current	4.2kA
Magnet Current Waveform	Half-sine, 70µs length
Total Non-Systematic Error	<0.4% horizontal, 470µrad vertical

Table t3271_d: Summary of Booster Septum Se
(magnet construction and power supply identical to Septum Si).

The Booster kickers are identical simple lumped inductance designs, mounted inside the vacuum, with the pulsed power supplies mounted as close as possible to the magnet terminations.

The Booster septum magnets are an improved eddy current design. The design details and References are given in Section 2.9

The error estimates given in the above Tables are worst-case values for these magnet systems; typical operational values should be much less. The detailed error calculations are in Ref. 3-5, Section 2.9.

3.2.7.2 Booster Kicker Magnet Systems

In normal use, the rise time of the Booster kickers can be a conservative value without restricting the Injector operation. A rise/fall time of 50nsec is about the technological limit for kickers, and so the choice is made for a conservative value of 200nsec. This should permit modest voltages for the kicker supplies, hence reliable operation. The precision filling of the Storage Ring buckets requires that there is some control over the length of the bunch train that leaves the Booster. This will be controlled by the Linac cannon, leaving the gap of 200nsec in which the Booster kickers can operate without difficult constraints on jitter or timing drift.

The Injection Kicker Ki is for a relatively low energy and low deflection. An electrostatic deflection could be used, but to reduce the cost of spare parts, the choice was made to copy the design of the Extraction Kickers. The two Extraction Kickers Ke1 and Ke2 are combined in a single vacuum tank, and placed symmetrically after a BD and before a BF magnet. Other positions of Ke1 and Ke2 were tried, but the requirement for placement of sextupoles are steerers limited the options.

These kickers will be housed in similar vacuum chambers to the septum magnets, but without the non-circulating electron beam port. Figs. f294_a and f294_b show a typical tank. The ribs inside the tank are machined flat after welding to give the required horizontal mechanical tolerances. Precision locating holes are drilled into these ribs, and also on the top surface of the tank to give on-axis alignment points. The easy top access to the rectangular tank is an important feature to avoid assembly difficulties with a cylindrical tank. The pulsed power supplies are mounted beside the tank, and feature a thermostatically-controlled cooling fan to maintain the capacitors at a constant temperature. Each tank is fitted with a flashing warning light and interlock switches over the access hatches, for personnel safety.

The magnet cross-section and basic parameters are shown in Fig.f3272_a and f3272_b. The choice was made to avoid a transmission line design, since this is not beneficial once the pulsed power supplies are mounted very close to the magnet. Thus the pulser load would be a lumped inductance. The magnet conductors are two solid copper bars. These bars are held in place with precision machined ceramic spacers, but are free to expand longitudinally. The ceramic spacers slot into recesses in a copper "box" shape. The outer bar will be heated by synchrotron radiation; this is unavoidable because of the proximity of the Booster bending magnet. Provisionally, the conductors are cooled by radiation only.

Fig f3272_c shows the simulation circuit for these kickers. An SCR switch is shown, but this could also be a thyratron. The rectangular waveform length is fixed by the length of the PFN coax cables. The results in Fig f3272_d show a current waveform that is remarkably "clean", largely due to the saturating inductor L13.

3.2.7.3 Booster Septum Magnet Systems

The septum magnet design is very similar to that used for the Storage Ring. The design is detailed in Section 2.9.

The septum pulsed power supplies are identical to that used for the Storage Ring. The design is detailed in Section 2.9.

The Booster Injection Septum Si has a low current because of the low energy from the Linac. However the beam emittance is higher than for the rest of the machine; the Linac is specified to have a 2σ emittance of 100π µm. rad at 100MeV, or $\varepsilon_x = \varepsilon_y = 510$nm.rad The x and z Beta-functions are 9m and 8m respectively at the septum, giving around +/-2mm beam size. The vertical clearance of 12mm gives negligible loss to this beam. The septum exit is placed so that the septum is as far away from the circulating beam as possible, while keeping a standard vacuum chamber cross section in the following quadrupole. The down-stream vacuum pipe is of enlarged cross section to accomodate the injected beam. The concrete wall of the machine tunnel should permit access to the magnet terminals on the inner side of the Booster ring. Since the septum is so far away from the circulating beam, no provision is made for manual adjustment of the septum tank in the transverse direction.

The Booster Extraction Septum Se requires a relatively large deflection to clear the yoke of the following booster BF magnet. The beam sizes are of the order of σ_x= 250µm and σ_y=90µm, and are not considered for the septa dimensions. The vertical clearance required is estimated solely from gross beam steering errors during commissioning at 6mm. The Booster will only work with single-turn extraction, so any delayed leakage field from an eddy current septum is not a concern. There are several possibilities for placement of the kickers and septum in the booster magnet lattice, with rather similar results; the placement in Fig.3.5.3 of Se is found by maximising the septum length while still clearing the rear of the following Focusing Dipole.

The deflection errors in Se are most likely to cause beam loss at the septum S12. The global figures must be split between alignment error, magnet error and field non-homogeneity.

The septum edge is placed at so that the extracted beam is at +16mm at the entrance; this gives reasonable deflection values for the two kickers without the septum projecting too far into the circulating beam chamber. Provision is made for manual adjustment of the septum tank in the transverse direction of +/-2mm.

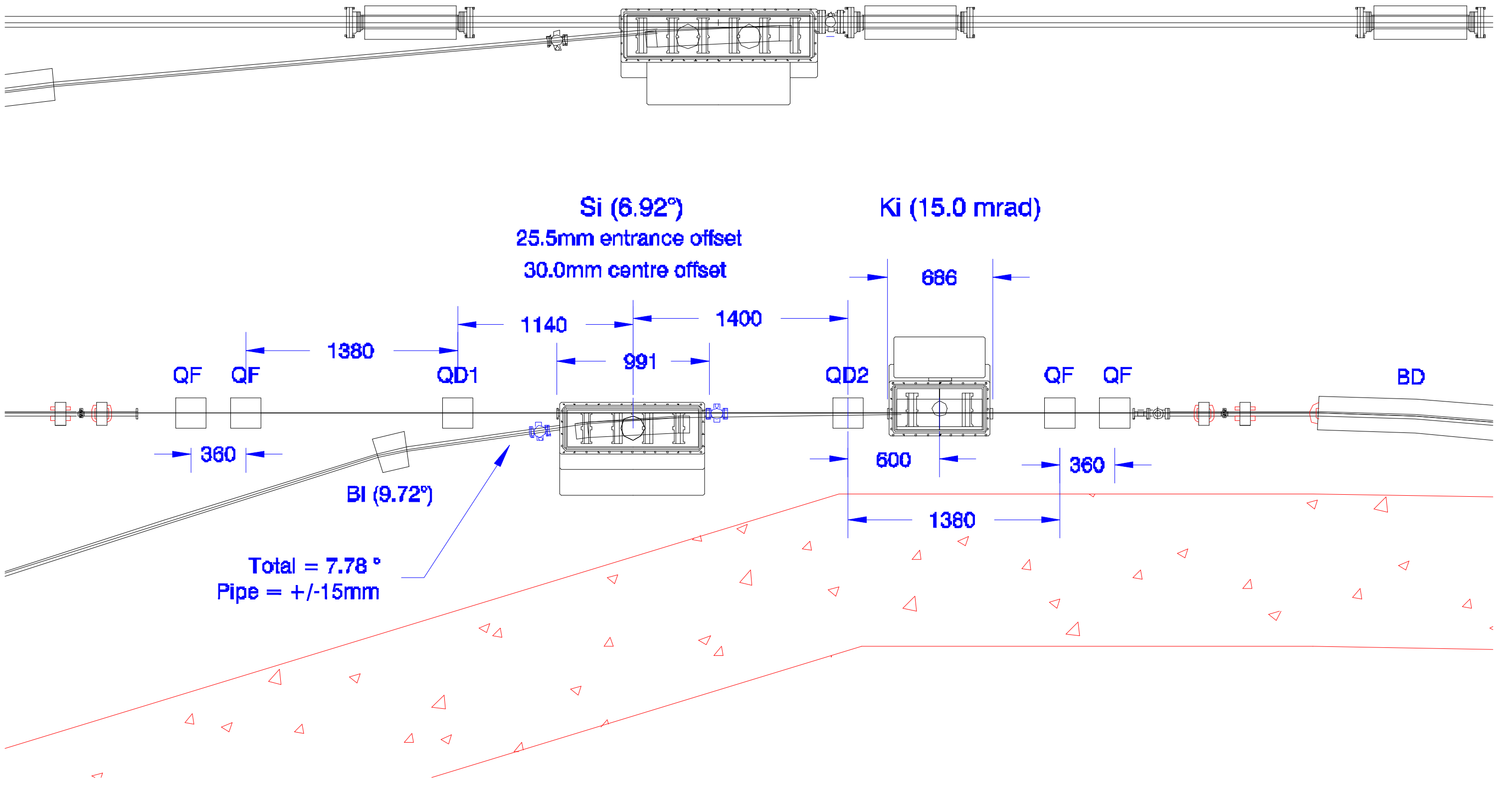


Fig.f3271_a: Booster injection configuration (approximate)

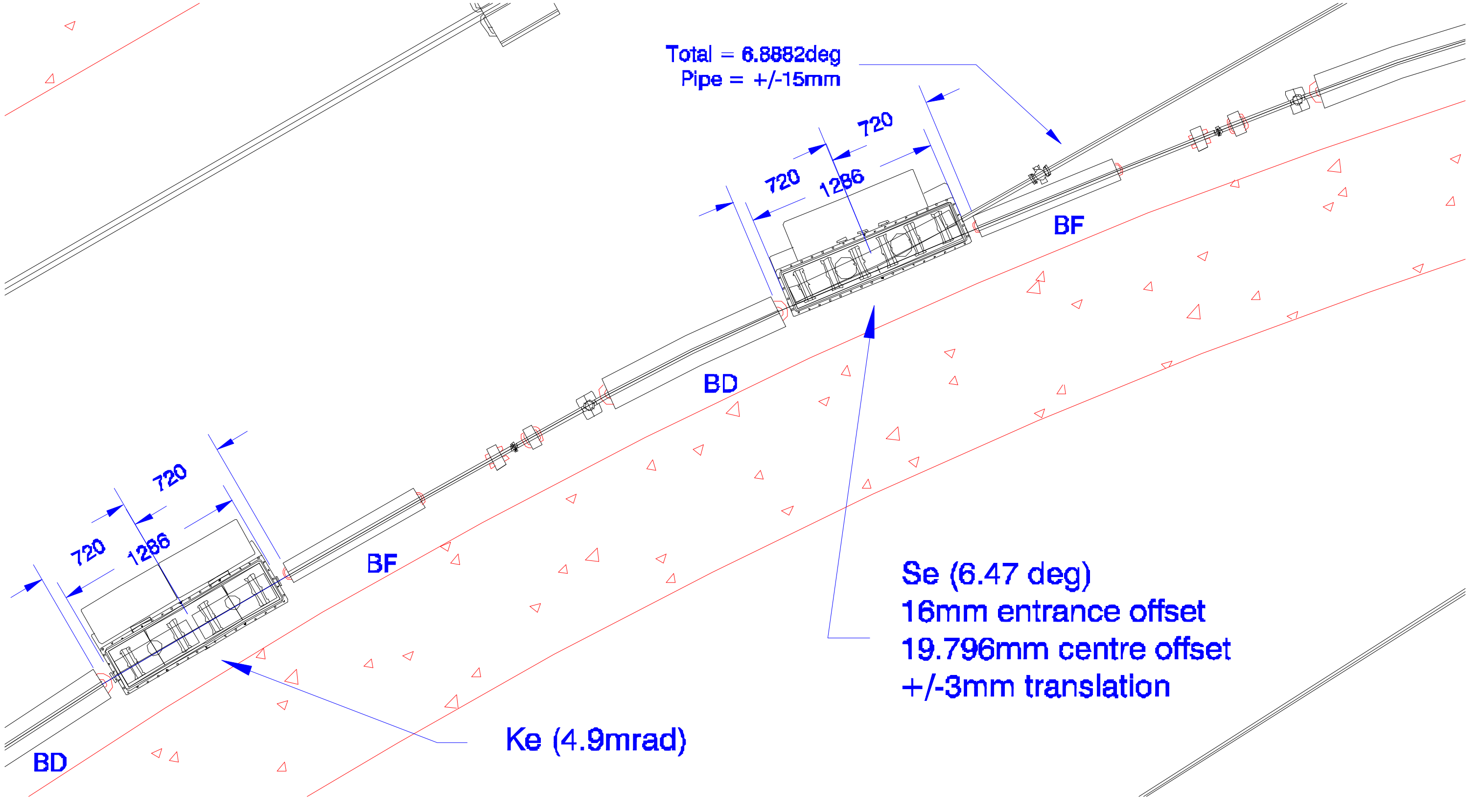
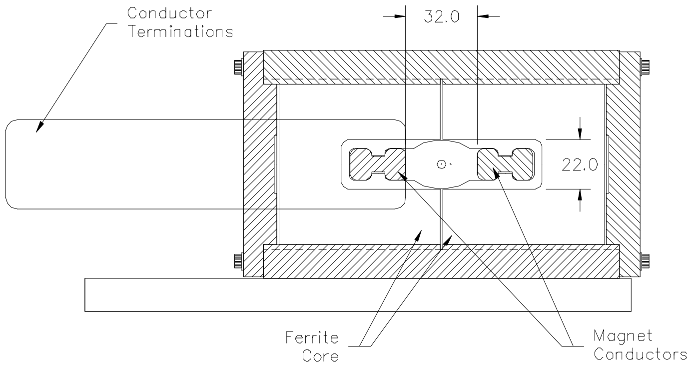


Fig.f3271 b: Booster extraction configuration.

Kicker Ki and Ke (twin unit)



PARAMETER	GIVEN VALUE	DERIVED VALUE
Maximum Particle Energy E (GeV)	2.4 GeV	
Magnet Gap Length l (mm)	500 mm	
Angle (mrad)	2.45 mrad	
Bending Radius		204.08 m
Field Intensity		0.039 T
Magnet Gap Width w (mm)	32 mm	
Magnet Gap Height g (mm)	22 mm	
Number of turns on magnet	1 turns	
Magnet Inductance		0.91 uH
Peak Current		687 A
Energy in Magnet		215.5 mJ
Flat-top tolerance (+/-)	.01	
Particle Beam Duration (usec)	.7 usec	
Go conductor X-section perimeter	80 mm	
Return conductor X-section perimeter	80 mm	
Resistive Loss per Cycle		0.9 mJ
Pulse Repetition Rate (Hz)	3 Hz	
Power Loss		2.7 mW
Cable Velocity Factor (eg 0.67)	.67	
PFN Length		70.25 m
Transmission Cable Length (m)	0 m	
Cable Loss at 1GHz (dB/100m)(eg 20)	3 dB/100m	
Pulse within tolerance band for		0.699 us
Cable Impedance (50/25/16.67/12.5 ohm)	16.7 Ohm	
PFN Voltage		22937 V

Fig f3272_a: Basic parameters for the Booster Extraction Kicker. Clamping details of the magnet ferrites are not shown.

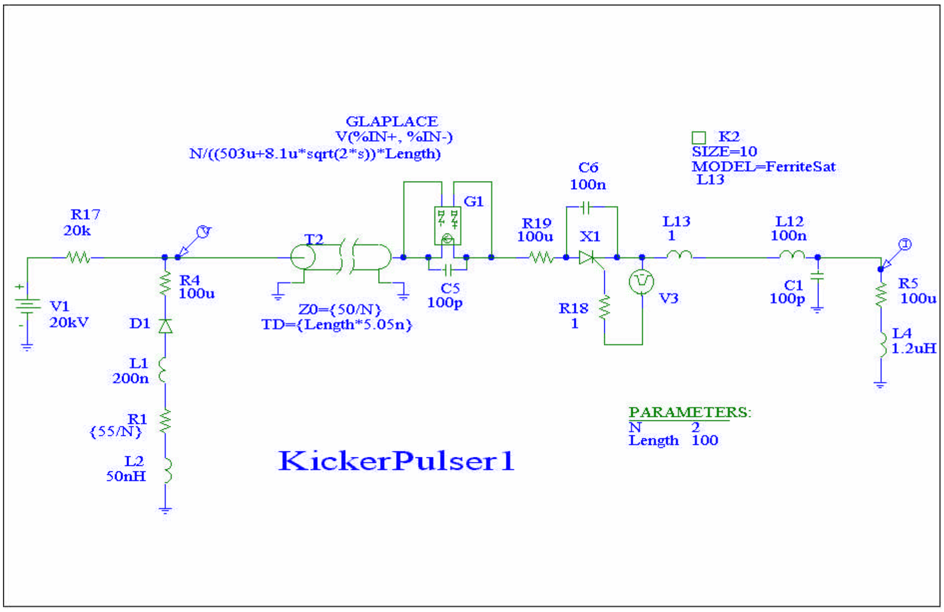


Fig f3272_b: Pulser simulation circuit for Booster kickers.
The component values are indicative only.

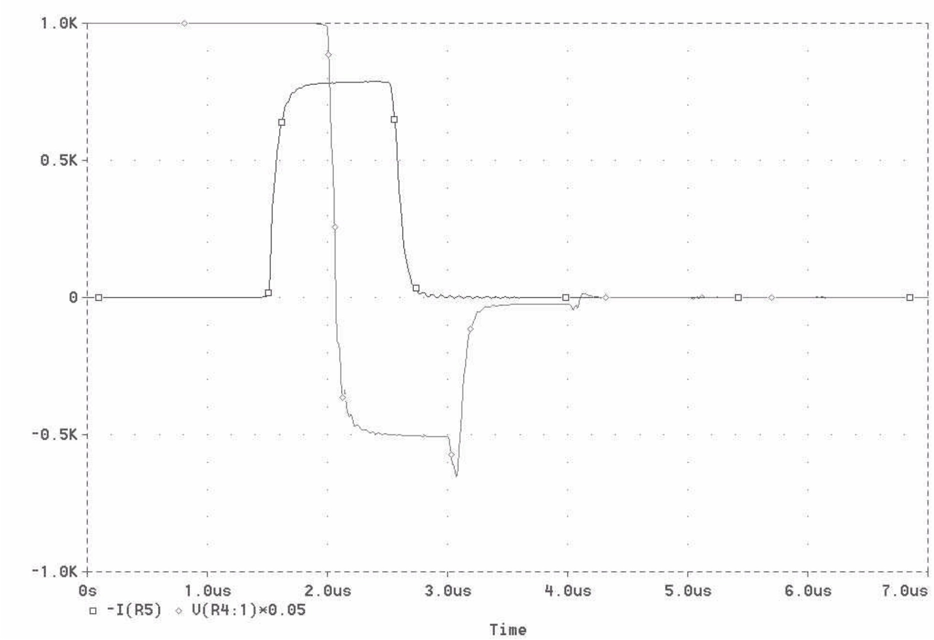
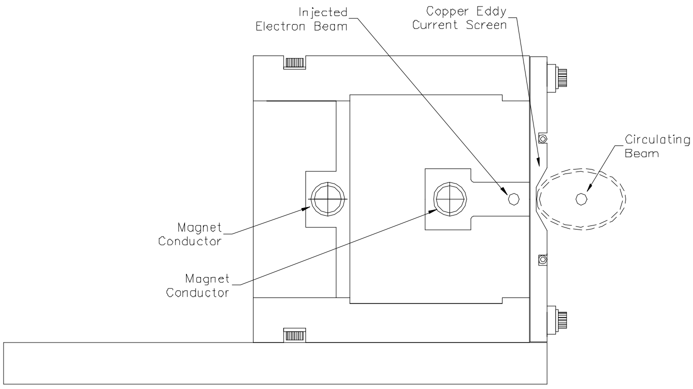


Fig f3272_c: Simulation results for Fig f3272_b.

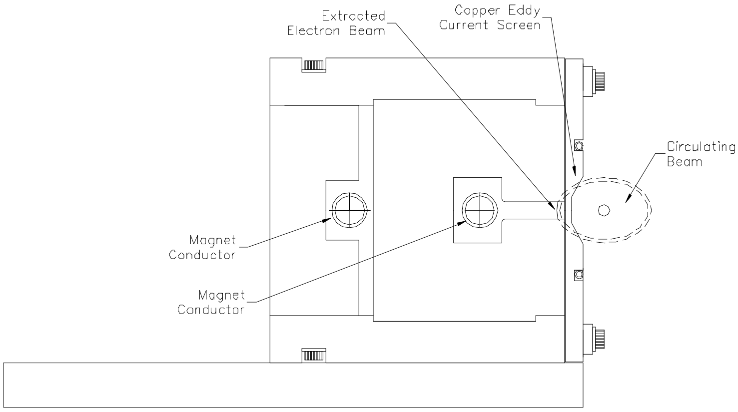
Septum Si



PARAMETER	GIVEN VALUE	DERIVED VALUE
Maximum Particle Energy E (GeV)	.1 GeV	
Magnet Gap Length l (mm)	600 mm	
Angle (mrad)	122 mrad	
Bending Radius		4.92 m
Field Intensity		0.068 T
Magnet Gap Width w (mm)	25 mm	
Magnet Gap Height g (mm)	12 mm	
Number of turns on magnet	1 turns	
Magnet Inductance		1.57 uH
Peak Current		648 A
Energy in Magnet		329.5 mJ
Flat-top tolerance (+/-)	.001	
Particle Beam Duration (usec)	.7 usec	
Recommended Resonating Capacitor		165.2 uF
Recommended Capacitor Tolerance		2.8%
Recommended Half-Sine Pulse		50.6 usec
Go conductor X-section perimeter	31 mm	
Return conductor X-section perimeter	31 mm	
Resistive Loss per Cycle		10.6 mJ
Core Loss per Cycle		40.4 mJ
Pulse Repetition Rate (Hz)	3 Hz	
Power Loss		153.0 mW
Capacitor Voltage		66 V

Fig.f3272_d: View at EXIT of Si, with magnet parameters

Septum Se



PARAMETER	GIVEN VALUE	DERIVED VALUE
Maximum Particle Energy E (GeV)	2.4 GeV	
Magnet Gap Length l (mm)	1040 mm	
Angle (mrad)	113 mrad	
Bending Radius		9.20 m
Field Intensity		0.870 T
Magnet Gap Width w (mm)	25 mm	
Magnet Gap Height g (mm)	6 mm	
Number of turns on magnet	1 turns	
Magnet Inductance		5.45 uH
Peak Current		4153 A
Energy in Magnet		47.0 J
Flat-top tolerance (+/-)	.001	
Particle Beam Duration (usec)	.7 usec	
Recommended Resonating Capacitor		47.7 uF
Recommended Capacitor Tolerance		2.8%
Recommended Half-Sine Pulse		50.6 usec
Go conductor X-section perimeter	31 mm	
Return conductor X-section perimeter	31 mm	
Resistive Loss per Cycle		758.5 mJ
Core Loss per Cycle		6.6 J
Pulse Repetition Rate (Hz)	3 Hz	
Power Loss		22.2 W
Capacitor Voltage		1458 V

Fig.f3272_e: View at ENTRANCE of Se, with magnet parameters.