L. Keller
Aug. 2005

Zero Degree Extraction using an Electrostatic Separator

Take another look at using an electrostatic separator and a weak dipole to allow a zero degree crossing angle a la the TESLA TDR. See also: O. Napoli, et.al, Interaction Region Layout, Feedback and Background Issues for TESLA.

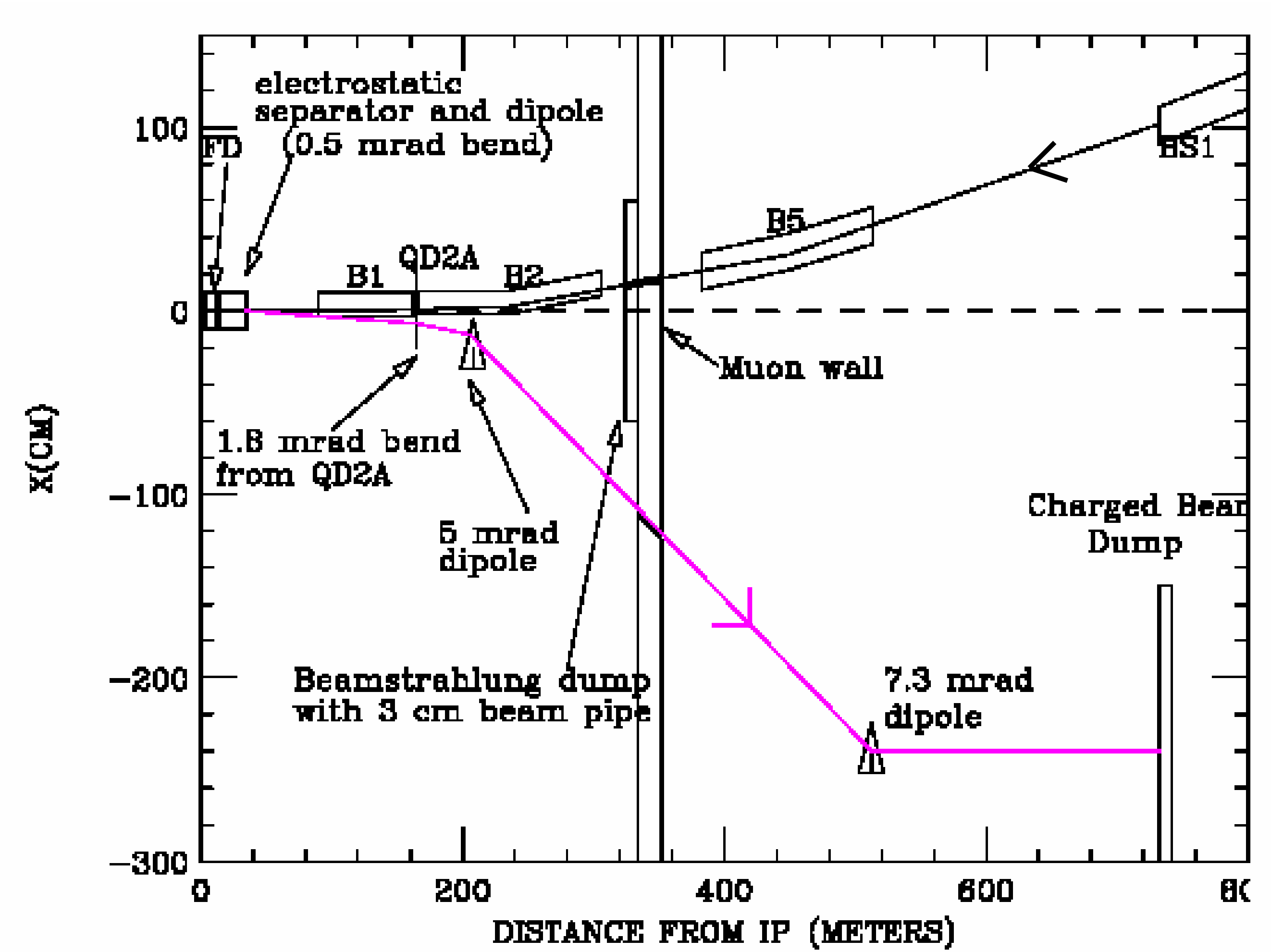
Problems with the TDR:

1. **Dipole, thin copper septum absorbed several kW of beamstrahlung radiation under some steering conditions.**
   Proposed solution: Extract in the horizontal plane to get the dipole septum completely outside the beamstrahlung cone.

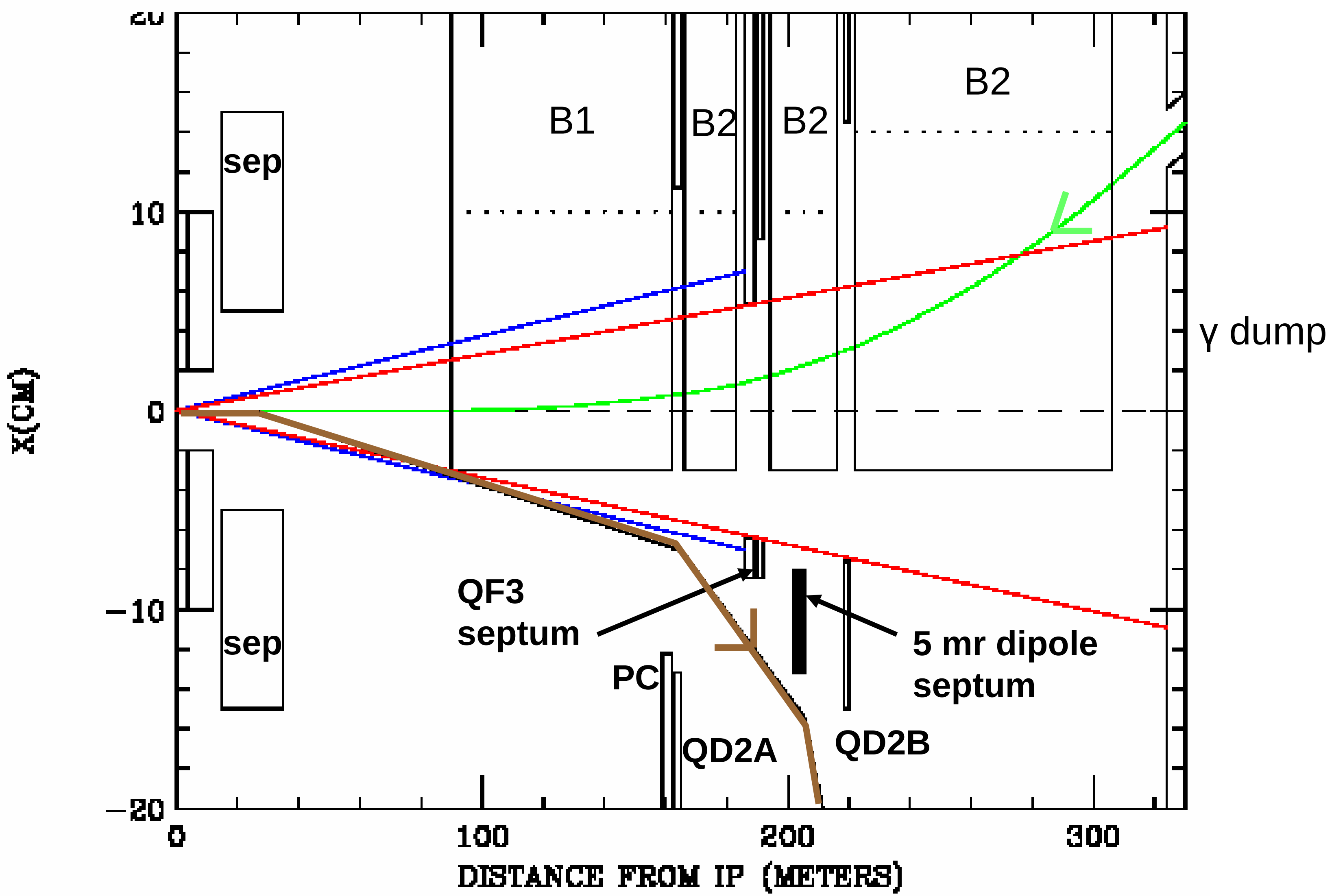
2. **Too much beam loss on a synchrotron radiation mask between the separators.**
   Proposed solution: Move the mask closer to the IP and the separator further from the IP, add another mask inboard from the separator for the outgoing synchrotron radiation.

3. **Large electric field (≈100 kV/cm) needed for 1 TeV CM probably not realistic.**
   Proposed solution: Reduce the maximum electric field to 50 kV/cm at 1 TeV CM (31 kV/cm @ 500 GeV CM).

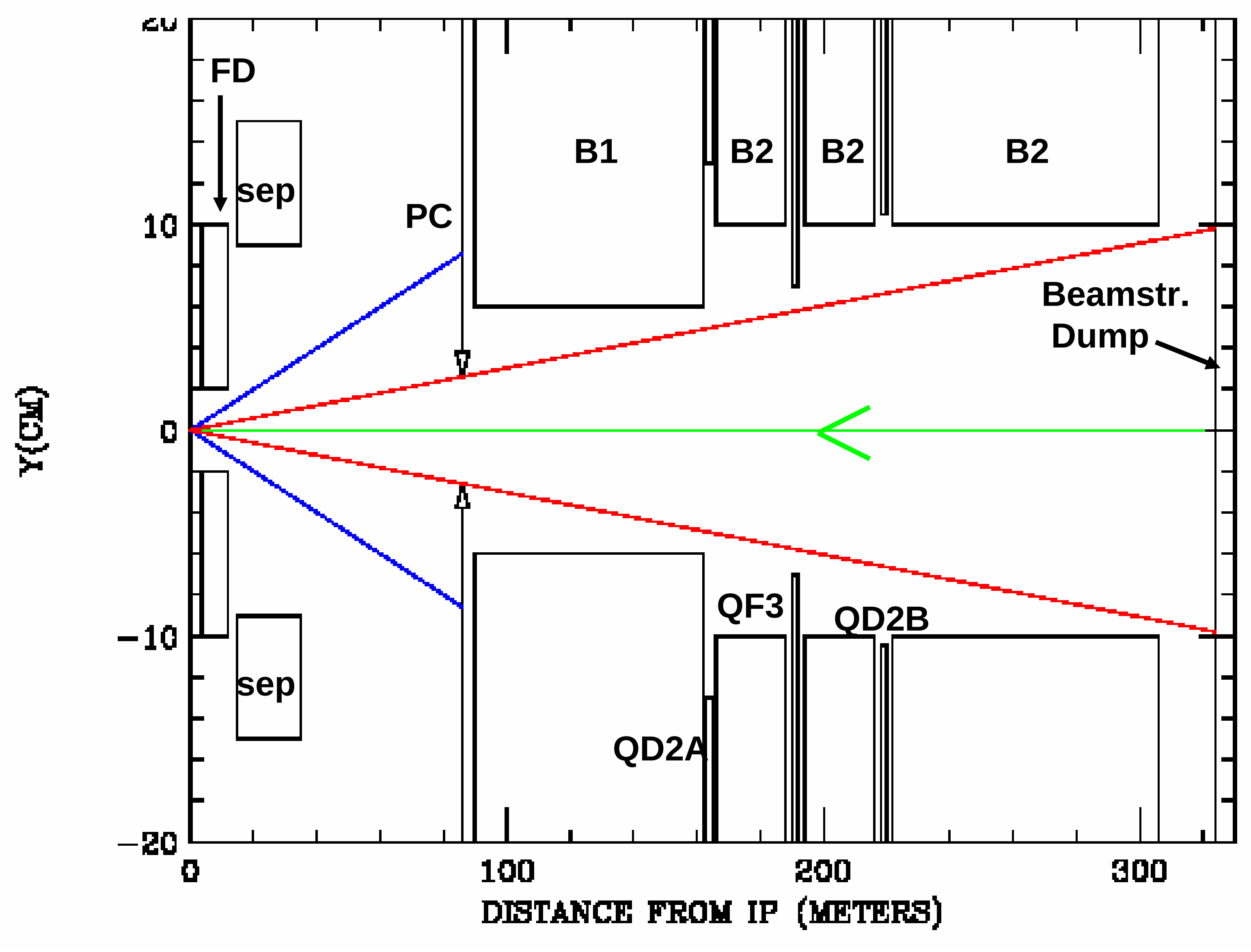
Plan View of Zero Degree Extraction from IP to Charged Beam Dump



Plan View of Zero Degree Extraction Showing Beamstrahlung Collimation

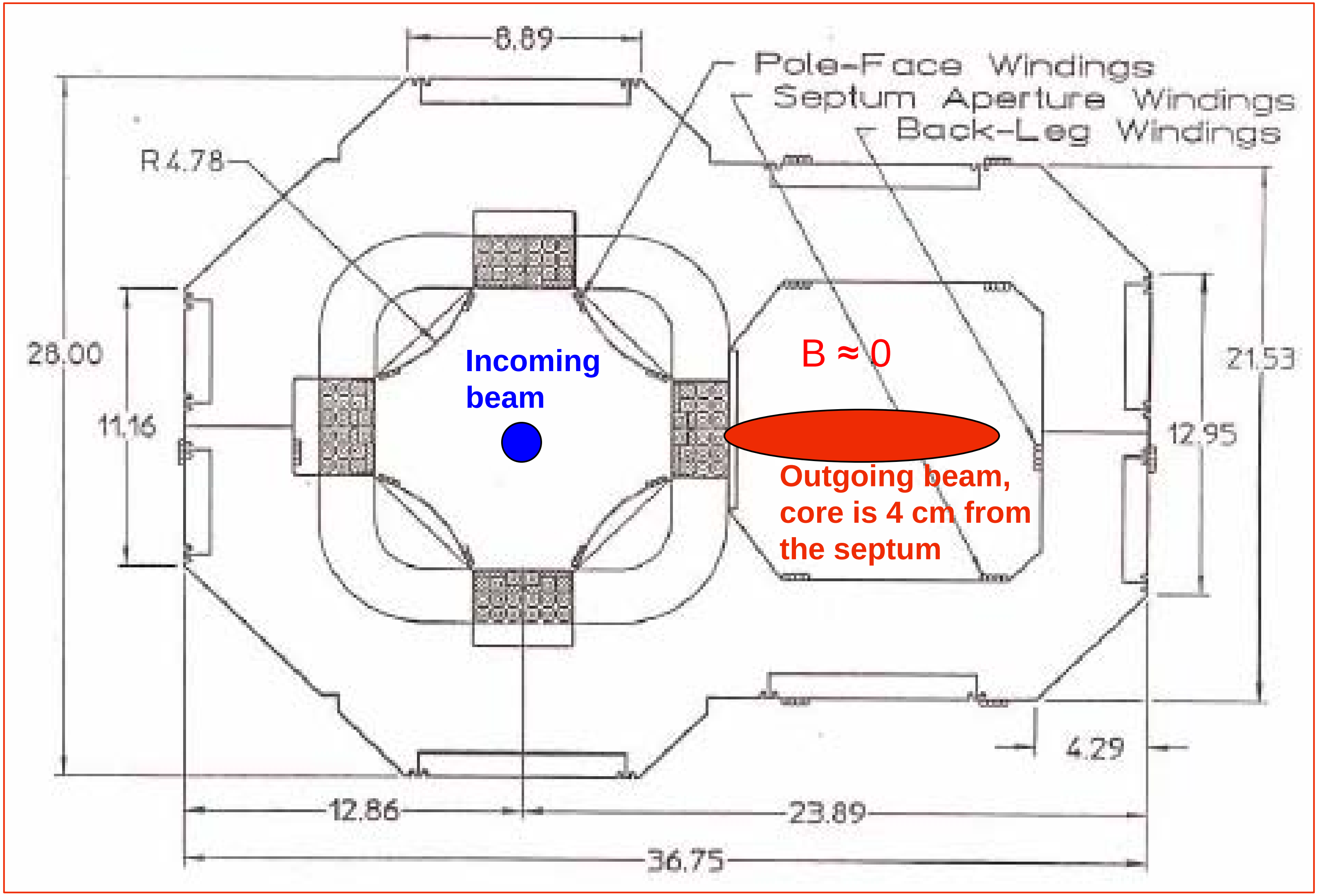


Elevation View of Zero Degree Extraction Showing Beamstrahlung Collimation



Cross Section of the PEPII/BaBar IR Septum Quad

QF3 modeled after this design



(units cm)

LEP and SPS Electrostatic Separator Experience*

1. At an operating field of 30 kV/cm the breakdown rate was <0.01/hr for 3 ma, 100 GeV beams. With no beam, the breakdown rate at 50 kV/cm was ~0.2/hr. In SPS, the breakdown rate was 10/hr at 110 kV/cm.

2. The separators operated successfully in a "high" flux of synchrotron radiation which drew several hundred μamp from the high voltage power supply. Estimated 10^{17}/sec unmasked synchrotron photons w/ critical energy 70 KeV hit the plates.

3. LEP operated for many years with 40, four meter long separator modules.

4. The required pressure is less than 10^{-9} mbar, LEP had 10^{-10} mbar or better.

5. CERN has experience supporting the separator plates in the orientation required for bending in the horizontal plane.

* CERN SL-Note-2000-002 MS and private communication with Brennan Goddard, CERN

Separator Issues

a) Need a 10 cm gap between plates to keep dispersed beam from hitting the plates on the low energy side. Offset the separator toward the low energy side.

b) Need pressure ≈ 1 nT in the separator, ideally ≈ 0.1 nT.

c) Does scattered synchrotron radiation from the upbeam mask cause breakdown?

d) Do radiative bhabha's hitting the plates cause breakdown?

e) At 1 TEV CM, to keep the electric field and maximum voltage within the bounds of CERN experience, the total separator length must increase from 20 to 25 m; and a collimator must be inserted approximately halfway through the separator module chain to keep low energy disrupted beam tail from hitting the plates directly. What is the effect of this collimator?

End View of a LEP 4 m Electrostatic Separator Tank

Fig 1. Separator tank with electrodes.

Analysis Steps

Given: existing 20 mrad FF optics, look at possible modifications later.

Charged Beam:

1. **Use GUINEA-PIG disrupted beam rays for head-on and worst-case vertical offset for two CM energies and two parameter sets including radiative bhabha's.**

2. **Input the rays to TURTLE and track the beam to the charged dump.**

3. **Record hits on collimators.**

Beamstrahlung:

Use the GUINEA-PIG photon trajectories for the same conditions as above and track each photon until it hits an aperture in the system or reaches the beamstrahlung dump.

Collimators in the Zero Degree Extraction Line

Collimator Name	Location (from IP)	Function
MASK 1	13 m	Shield IP beam pipe from incoming soft bend synch. rad. Shield elect. sep. plates from extracted beam synch. rad.
PC−B1	86	Vertical beamstrahlung, $\lvert \theta\gamma \text{ (vert)} \rvert \geq 0.38$ mrad
PC−QD2A	163	Disrupted beam low energy tail, $\Delta E/E < -25\%$
PC−QF3	185	Horizizontal beamstrahlung, $\lvert \theta\gamma \text{ (horiz)} \rvert \geq 0.38$ mrad Disrupted beam horizontal tails

Magnets – 500 GeV CM

Name	Distance from IP (m)	Length (m)	Radius/ 1/2 gap (cm)	Poletip field (T)	Notes
QD0	3.51	2.2	2.0	2.83	
SD0	5.86	0.6	2.0	1.32	
QF1	7.81	2.0	2.0	1.60	
SF1	9.96	0.3	2.0	1.24	
B1	90.1	73.5	6.0	0.0025	C-magnet
QD2A	163.9	2.0	13.0	1.22	
B2	166.2	139.6	10.0	0.0070	C-magnet
QF3	190.8	2.0	7.0	0.75	Septum (BaBar Q2)
B_EXT1	203	5.0	6.0	0.84	"Thick" septum
QD2B	217.7	2.0	10.5	0.18	
B_EXT2	509	6.0	6.0	1.00	

(yellow) = incoming and outgoing beams

(red) = incoming beam only

(green) = outgoing beam only

Power Lost on Beam Line Elements in Zero Degree Extraction Line*

(Units Kilowatts)

500 GeV CM, "Nominal" Parameter Set*

Loss Point	Head On		Worst Case Vertical Offset		Radiative Bhabha's
	Charged	Beam-strahlung	Charged	Beam-strahlung	Charged
QD0/SD0	0	0	0	0	0.000022
QF1/SF1	0	0	0	0	0.000024
Synch. Mask	0	0	0	0	0.00045
Separator Plates	0	0	0	0	0.0001
PC−86 (B1)	0.0013	0	13	3.3	0.00007
PC−163 (QD2A)	16	0	9	0	0.0064
PC−185 (QF3)	1.7	0.4	0.06	11	0.0006
Beamstrahlung dump	—	264	—	361	—
Charged dump	11,280	—	11,280	—	—

*Twenty meter long separator chain begins 15 m from the IP

Changes for 1 TeV CM

1. Longer final doublet – separator moves 2 m further from the IP.

2. Longer separator to keep the same gap (10 cm) and stay within reasonable maximum voltage (250 kV) – leads to an intermediate collimator halfway along the separator chain.

Power Lost on Beam Line Elements in Zero Degree Extraction Line

(Units Kilowatts)

1 TeV CM, "Nominal" Parameter Set*

Loss Point	Head On		Worst Case Vertical Offset		Radiative Bhabha's
	Charged	Beam-strahlung	Charged	Beam-strahlung	Charged
QD0/SD0	0.00023	0	0	0	0.00013
QF1/SF1	0.1	0	0.1	0	0.0002
Synch. Mask	0	0	0	0	0.00045
Separator Collimator	0.2	0	0.16	0	0.0013
Separator Plates	0	0	0.02	0	0.0002
PC−86 (B1)	0.03	0	92	0.002	0.00066
PC−163 (QD2A)	110	0	95	0	0.021
PC−185 (QF3)	2.5	0	0.3	0.7	0.00024
Beamstrahlung dump	—	1,087	—	1,696	—
Charged dump	18,000	—	17,900	—	—

*Twenty-five meter long separator chain begins 17 m from the IP

Machine Protection, Fault Examples

Separator breakdown during the bunch train:
(dipole remains on)

Outgoing bunches: **0.5 mrad bend becomes 0.25 mrad bend. Bunches hit QF3 low-Z septum collimator.**

Incoming bunches: **0 mrad bend becomes 0.25 mrad bend. Bunches pass cleanly through the IP region and hit AB7, 450 m from the IP.**

The low-Z protection collimators which intercept these errant bunches have to survive ≈ 30 bunches before the machine protection system takes the beam to the linac dump.

Next Steps if this is to Become a Viable Alternative to the 2 mrad Baseline Configuration

Need more collaborators to:

1. **Design higher order optics to limit beam losses beyond the 5 mrad dipole.**
2. **Design optics for the energy spectrometer and Compton polarimeter (can the spot be made small enough at the laser IP)?**
3. **Modify the FF optics to create space within the dipole string for protection collimators at QD2A and QF3 at 500 GeV and 1TeV CM.**
4. **Look at the optimum position of QD2A to minimize the separator bend angle (brief look by Andrei showed the bend can be reduced by more than 20%, i.e. 50 kV/cm @ 1 TeV CM => 40 kV/cm).**
5. **Design the septum quadrupole QF3 and the 5 mrad septum dipole.**
6. **Simulate radiative bhabha's hitting the separator plates. Preliminary indications are that these contribute less than one microamp of separator current at 500 GeV CM.**
7. **Simulate the scattered synchrotron radiation from the mask which protects the separator and estimate the photon flux hitting the separator plates.**
8. **Continue beam loss simulations with all parameter sets.**

Conclusions:

To show that head-on collisions are a viable option, a level of effort comparable to that expended on the 2 mrad crossing angle must be started soon if this option could be considered as part of the baseline configuration by the end of 2005.

At 500 GeV CM, "nominal" parameter set:

The separator requirements are well within the LEP experience.

The charged beam and beamstrahlung losses appear tolerable, pending design of the full extraction line

Required pressure less than 10^{-9} mbar, LEP had 10^{-10} mbar or better.

Simulations of scattered synchrotron radiation and radiative bhabha's hitting the separator plates need to be finished.

It has yet to be shown that energy and polarization measurements in the extraction line are possible.

Parasitic bunch crossing at 50 m => separation is 1.25 cm => Is this enough? (Deepa, et.al.)

Conclusions (cont.) :

At 500 GeV CM, "high lum" parameter set: (show stopper)?

Have to open the separator gap to 20 cm to avoid intolerable losses on the plates. In principle this is OK, but there are also several hundred kW of disrupted beam lost on the energy slit at QD2A.

At 1 TeV CM, "nominal" parameter set:

The charged beam and beamstrahlung losses appear tolerable, pending design of the full extraction line.

The LEP group has tested separators at the required field of 50 kV/cm, but has little experience with long term operation in the accelerator environment.

The separator needs to be lengthened from 20 to 25 m, and a new collimator introduced. The effect of this collimator on the breakdown rate must be understood.

Is 150 ns bunch spacing required? (Parasitic bunch crossing at 25 m is only 650   separation).

Backup

RF Kicker Machine Protection, Fault Examples

1) **Reduced kick of out-going bunch, => undisrupted bunches (380 x 32) hit protection collimator, => 50 ˚C/bunch temp. rise in solid aluminum. May be OK in an aluminum plate/water collimator.**

2) **No kick, undisrupted bunches go backward through incoming line. If this happened in SLC, the incoming arc had an energy taper, so the backward bunch was lost in the arc and may have caused an ion chamber trip.**

3) **Kicker at wrong phase so the incoming bunch gets a kick (A. Seryi) => severe damage potential - see next slide.**

4) **Incoming dark current bunches see non-zero kicker field and hit elements in the IR (A. Seryi) => MPS trips and/or large backgrounds in the detector.**

Kicker out-of-phase for incoming main bunches or dark current bunches