Design of the Interaction Region for KEKB

MAC Review, KEK
June 8, 1995

Nobu Toge (KEK)

Cast

The Boss		S. Kurokawa
Parameter Committee chair.		K. Satoh
Beam-Beam theory / simulation		K. Hirata K. Ohmi
Superconducting magnets		K. Tsuchiya, +++
Normal-conducting magnets		H. Nakayama
Support, alignment		R. Sugahara
Vacuum system		K. Kanazawa
Near-IP lattice design		H. Koiso K. Oide
Detector facility	The Boss	F. Takasaki
	Structure	H. Yamaoka
	Background	S. Uno
	Vertex detector	T. Matsuda
Others		N. Toge

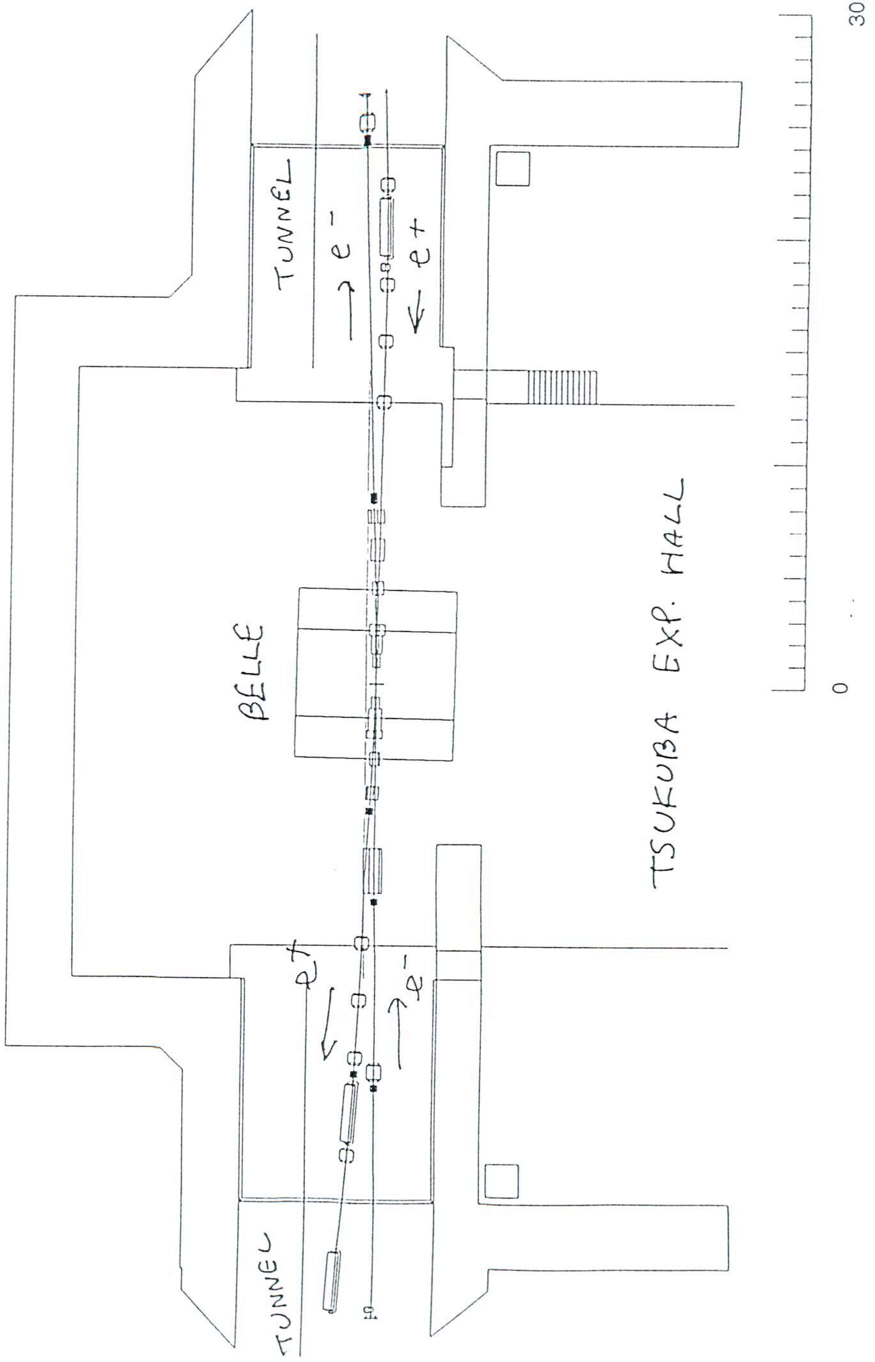
Fundamental Design Assumptions

- Only one IR (Tsukuba area)
- Finite crossing angle (11 mrad x 2)

We have a nearly consistent design of the interaction region (IR):

- Can geometrically fit.
- Can use 40 mmϕ circular vac. ch. at IP.
- Magnetic interference solvable.
- Feasible construction + support scenario.
- Have connected with the rest of the straight section.

Will walk through those items in this report.



Topics

1. Basic Beam Parameters (Brief)
2. Constraints from the Detector Facility
3. Finite Angle Crossing (Brief)
4. Beamline Near the Detector Facility
5. Solenoid Field Compensation
6. Aperture Specifications for S-L/R and QCS-L/R
7. Beamline Outside the Detector Facility
8. Beamline Beyond QC2
9. Support / Alignment of Accelerator Components
10. Task Plans for the Immediate Future.

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1. Basic Beam Parameters

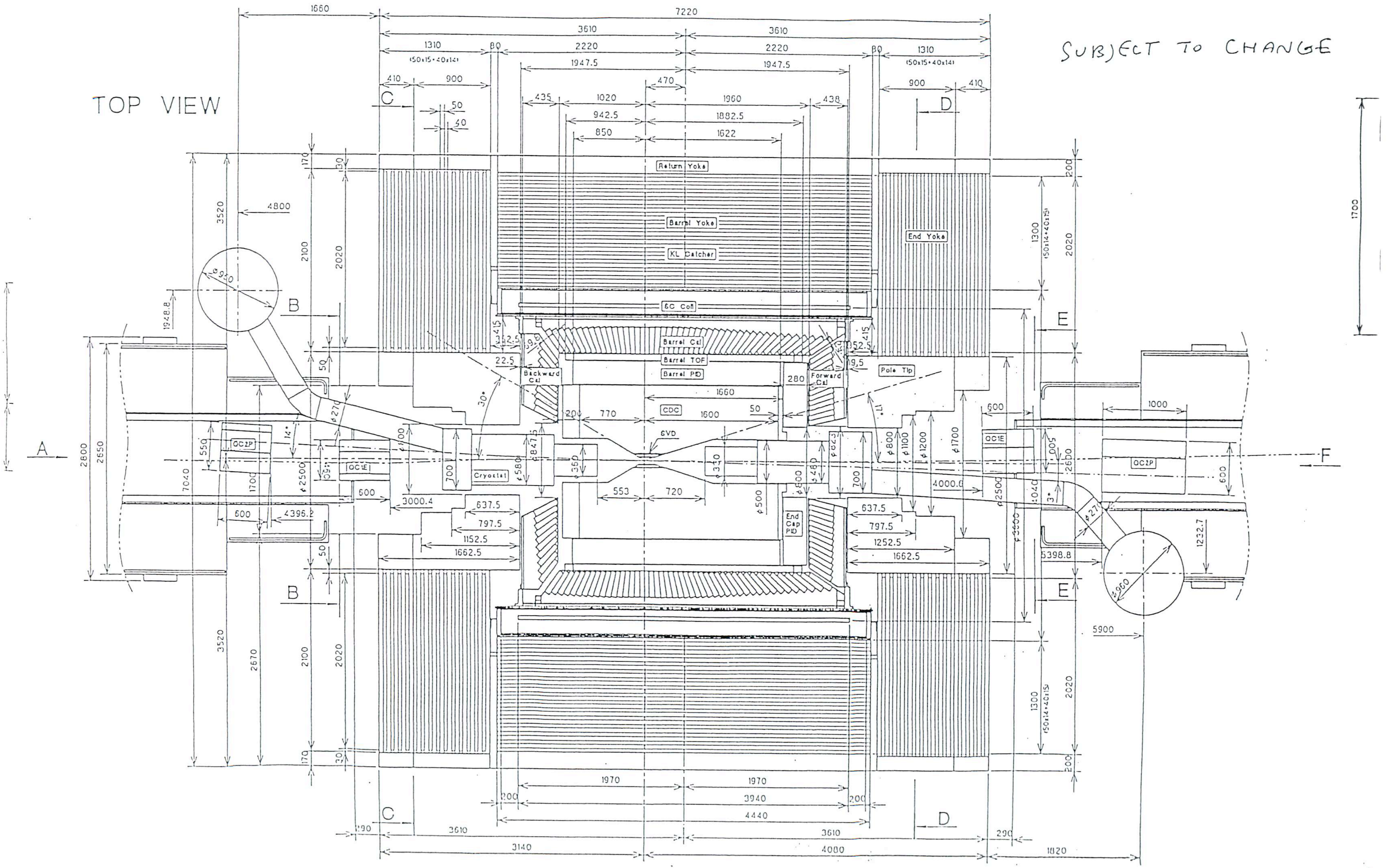
Luminosity goal	1×10^{34}	$cm^{-2}s^{-1}$
Crossing angle	2 x 11	mrad
Bunch spacing	0.59	m

	Positrons	Electrons	
Energy	3.5	8.0	GeV
Bunch inten.	3.3×10^{10}	1.4×10^{10}	/ bunch
Beam current	2.6	1.1	A
Energy spread	7.7×10^{-4}	7.8×10^{-4}	
σ_z	4	4	mm
Synch. tune	0.01 ~ 0.02	0.01 ~ 0.02	

	Horizontal	Vertical	
Betatron tune	45.52	45.08	(HER)
	47.52	43.08	(LER)
Emittance	1.8×10^{-8}	3.6×10^{-10}	m
Beta*	0.33	0.01	m
σ_{IP}	77	1.9	µm
Max. tune shift	0.039	0.052	
σ_{IP} / σ_z	19.2	0.48	mrad
Inj. beam env.	1.2×10^{-5}	1.2×10^{-6}	m

TOP VIEW

SUBJECT TO CHANGE



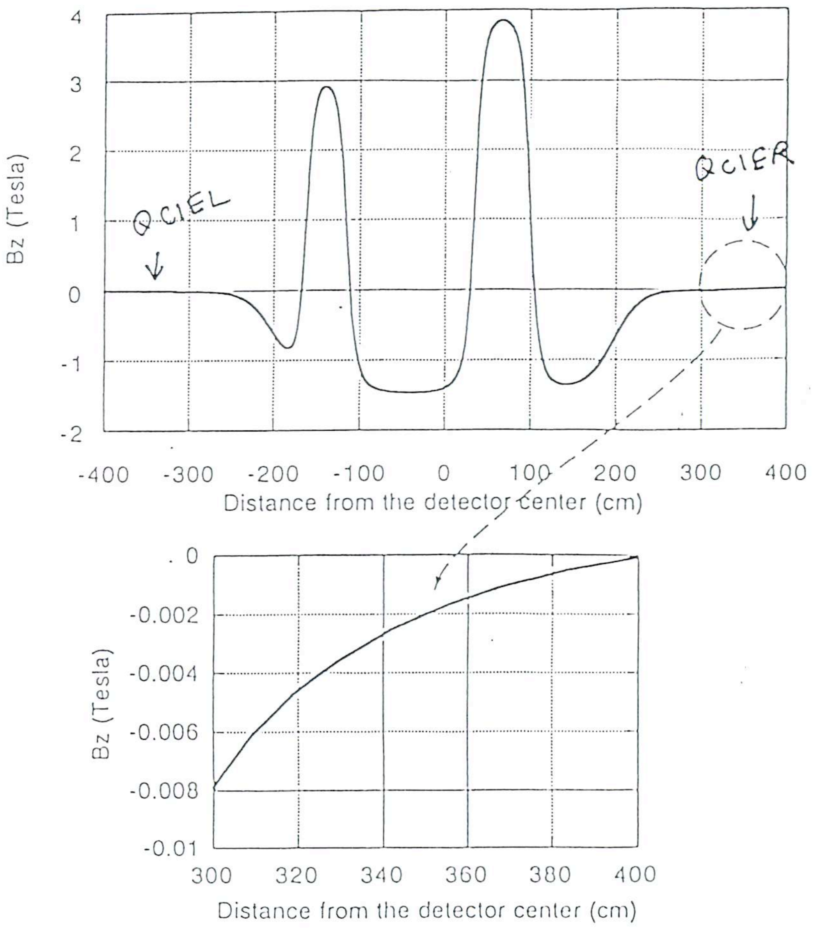
2. Constraints from (or Desires of) the Detector Facility

Component	Desired Polar angle coverage (deg)
Fwd K_LC / μ-det.	25 ~ 45
Bkd K_LC / μ-det.	113 ~ 155
Fwd Calorimeter	11.5 ~ 32.5
Bkd Calorimeter	130 ~ 160
Central Drift Chamber	17 ~ 150
Silicon Vertex Detector	17 ~ 150

Barrel particle ID will be with Silica Aerogel (no DIRC). Endcap particle ID still an open question. Decision in July.

Solenoid field	1.5	T
Iron length	3610 x 2	mm
IP position	–470	mm
CDC Inner Radius	280	mm
Vertex vac. ch. radius	20	mm

Need to allocate room for cabling and gas tubing as well.



3. Finite Angle Crossing

1. Without this, cannot do bunch spacing s_B ~ 0.6 m (minimum), without this.
   (Perhaps > 2 x 5 mrad needed).

2. Allows flexible choices of bunch intensity N vs. bunch spacing s_B .

3. Eliminates the need for separation bend dipoles.
   (if > ~ 2 x 8 mrad is used).

4. Thanks to 3,
   - Relaxed space allocation near the IP.
   - Nice room for compensation solenoid.
   - Reduced SR / particle background.

5. 2 x 11 mrad still allows single superconducting quad for common focusing $e^+ e^-$.
   - Operational flexibility for varying E_{CM}.

6. Large e^-/e^+ beam separation.
   No worries on parasitic crossing.
   > +/– 3mm separation at Z = 0.3 m.
   i.e. >> 20 σ_x separation

The question is whether the beam dynamics in the beam-beam interactions permit this configuration.

⇨ Check the presentation earlier (Hirata).

4. Beamline Near the Detector Facility

- Common (e^- and e^+) final vertical focusing with
  QCS (superconducting).
  $dB / dx = 18.8$ T /m
  L_{EFF} ~ 0.5 m
  I ~ 2200 A

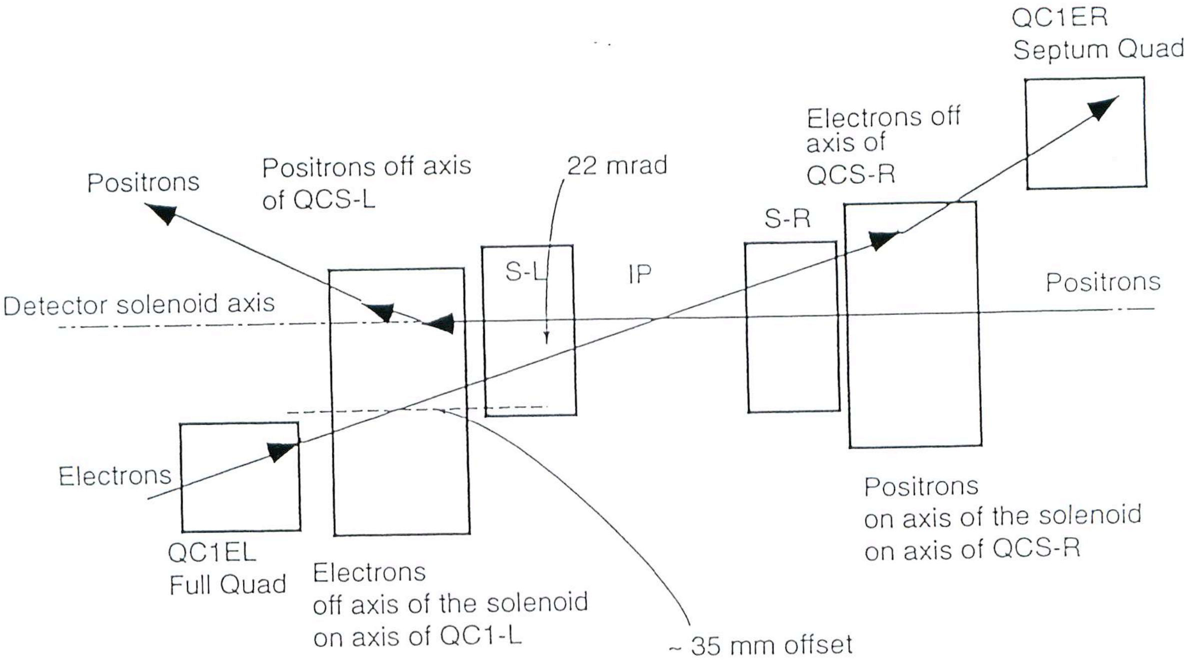
- Remaining e^- final vertical focusing with QC1.
  $dB / dx = 12$ ~ 15 T/m
  $L_{EFF} = 0.6$ m

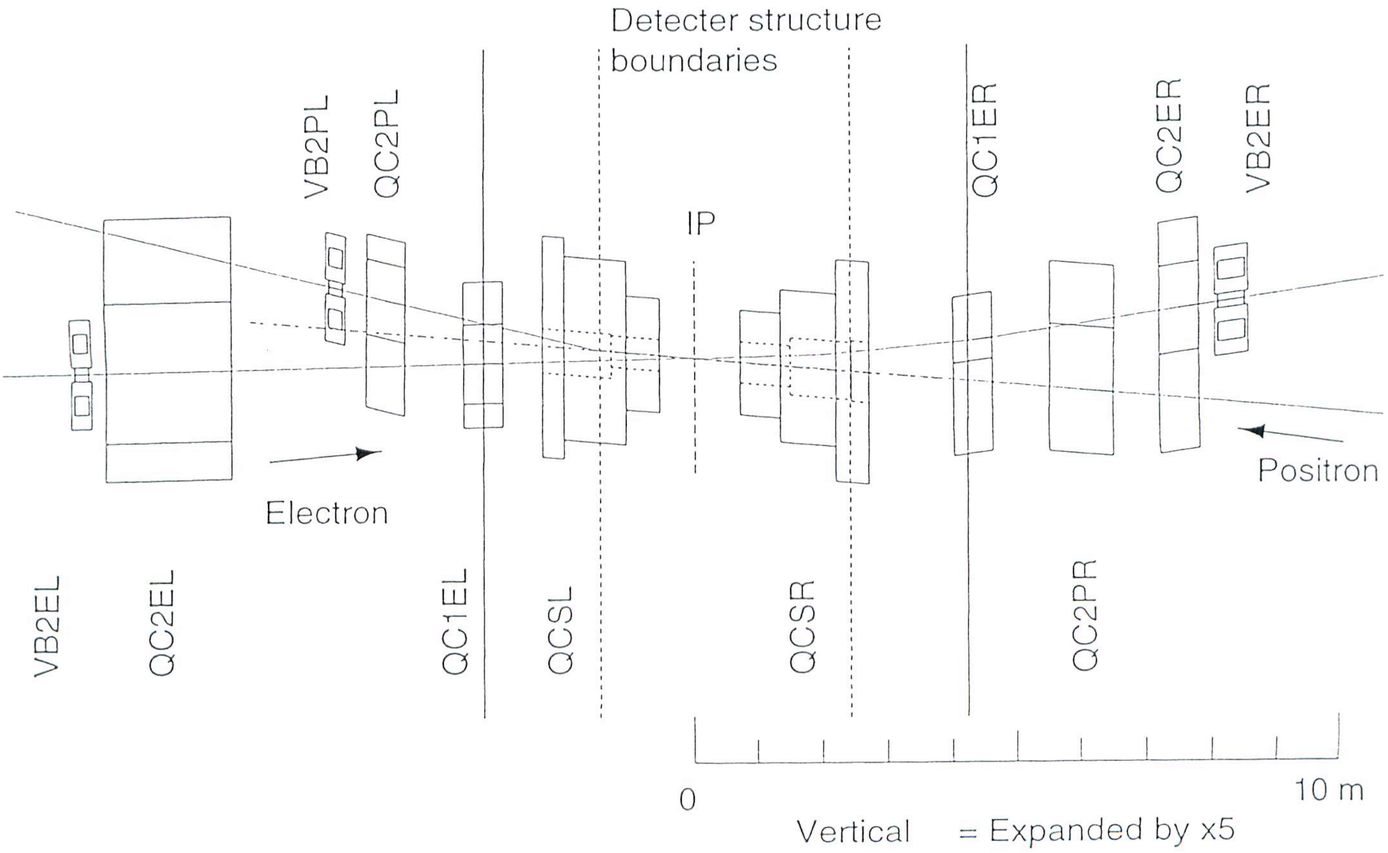
- Solenoid field compensation with S-L and S-R (superconducting).
  $B_Z = 4.4$ ~ 5.4 T
  $L_{EFF} = 0.4$ ~ 0.6 m

- Incoming beams are centered on quadrupole axes for minimizing incoming synchrotron radiation.

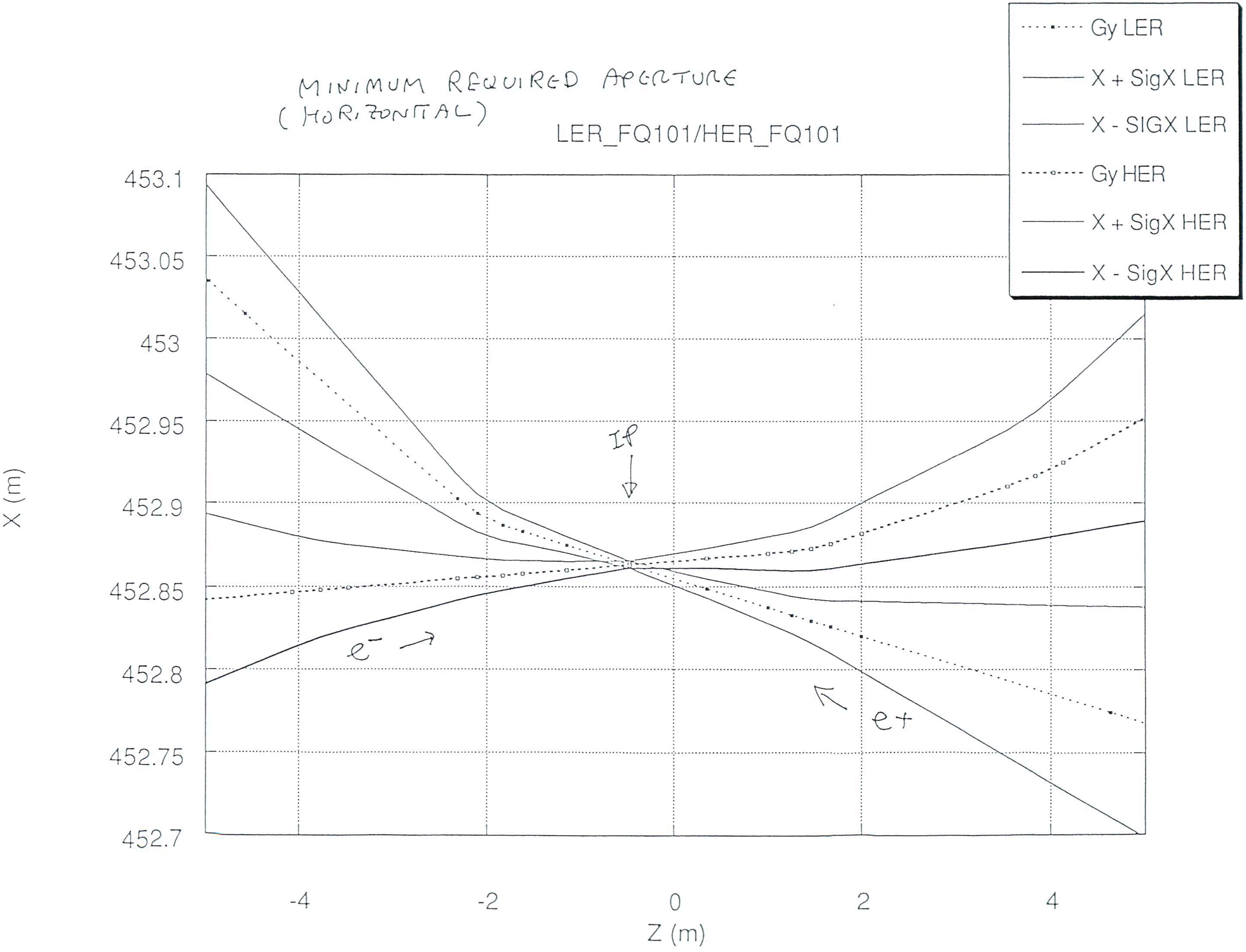
  Non-concentric coil config. is needed for QCS-L.

- S-L and S-R are on the detector field axis.

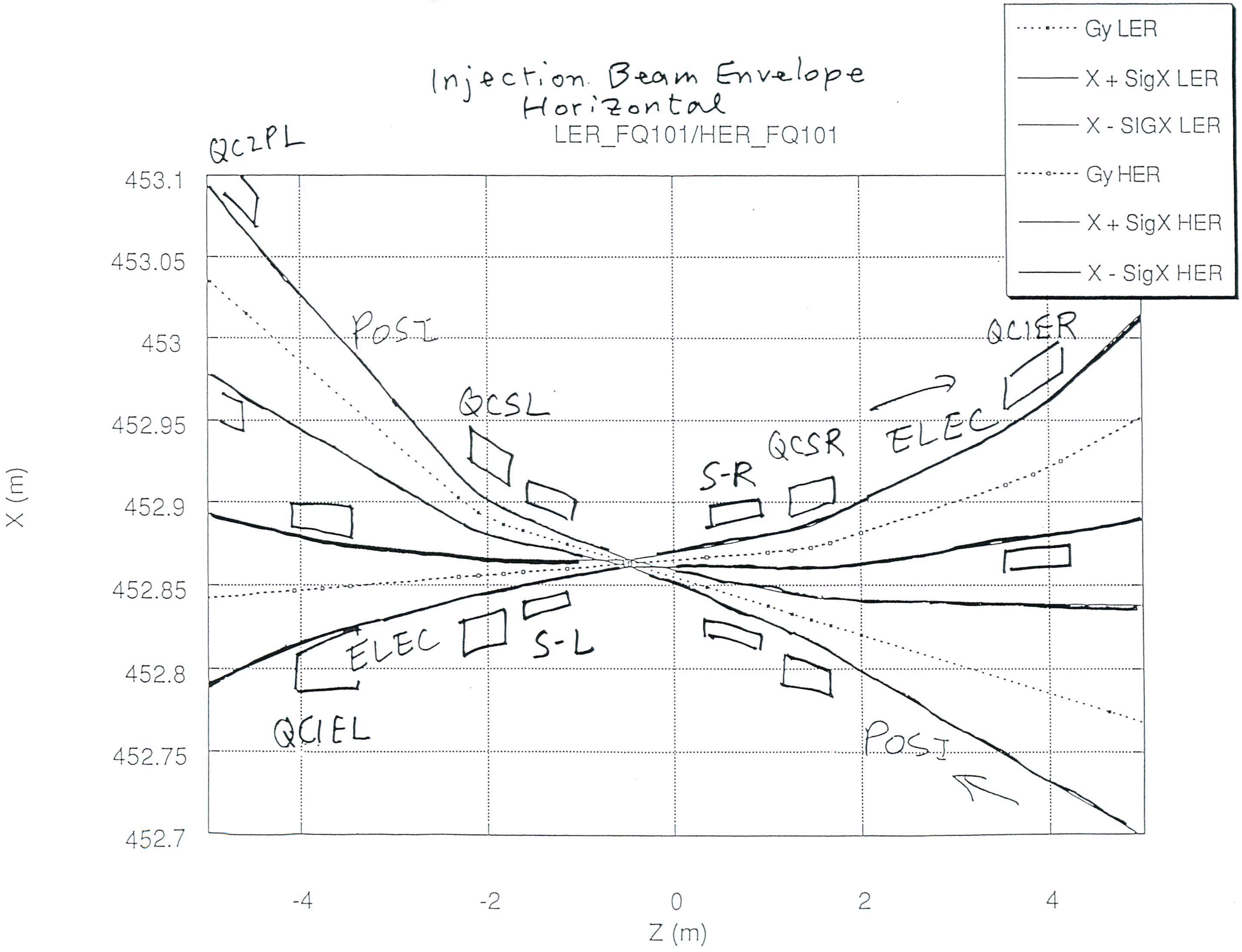

QC1ER
Septum Quad
Electrons off
axis of
QCS-R
Positrons
Positrons off axis
of QCS-L
22 mrad
S-R
S-L
IP
Positrons
Detector solenoid axis
Electrons
QC1EL
Full Quad
Electrons
off axis of the solenoid
on axis of QC1-L
~ 35 mm offset
Positrons
on axis of the solenoid
on axis of QCS-R


Detecter structure
boundaries
VB2PL
QC2PL
QC1ER
QC2ER
VB2ER
IP
Electron
Positron
VB2EL
QC2EL
QC1EL
QCSL
QCSR
QC2PR
0
10 m
Vertical = Expanded by x5

MINIMUM REQUIRED APERTURE
(HORIZONTAL)



Injection Beam Envelope Horizontal



5. Solenoid Field Compensation

⇨ Talk by K.Tsuchiya for details.

- Detector solenoid field = 1.5 T for + / – 3m.
- Ideal field compensation is to bring $B_Z = 0$ everywhere.
- Beam dynamics calculations show that making $\int B_z dz = 0$ is acceptable.
  This will be done.

	S-R	S-L	
Central field	5.4	4.4	T
Coil curr. density	300	258	A/mm2
Coil			
Inner diam.	190	190	nn
Outer diam.	220	220	mm
Length	650	470	mm
Max. field of conductor	5.4	4.5	mm
Stored energy	225	115	kJ
Mag. pressure(radial)*	9.2	6.4	MN/m2
Body force (axial)*	3.3	22	kN

*when placed inside 1.5 T detector field

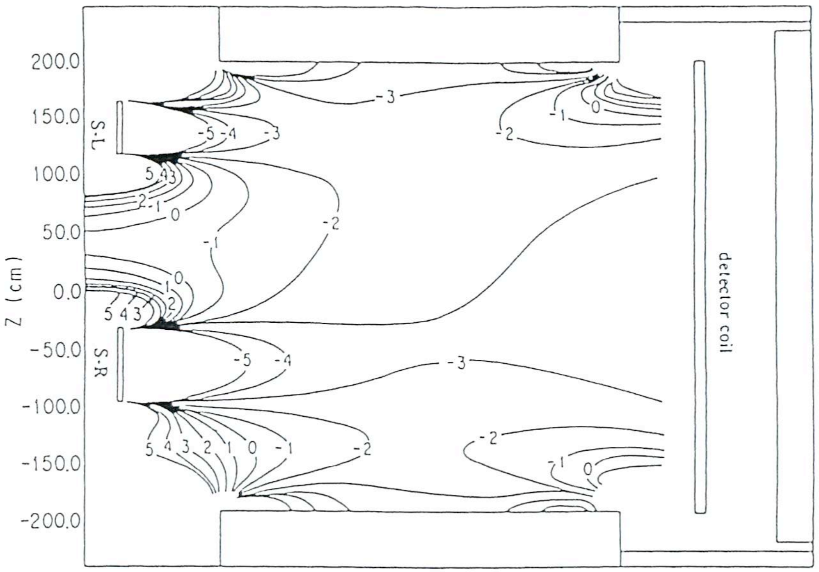


Figure 7.7: The contour lines of field distortions relative to the nominal 1.5 T solenoid field. The number attached to each contour line indicates the field deviation expressed in the unit of percent.

- Up to 5 % field distortion will be created in the detector tracking volume (nominal 1.5 T solenoid field)

  Simulation studies by BELLE folks have shown that its effect can be corrected without degrading the momentum resolution.

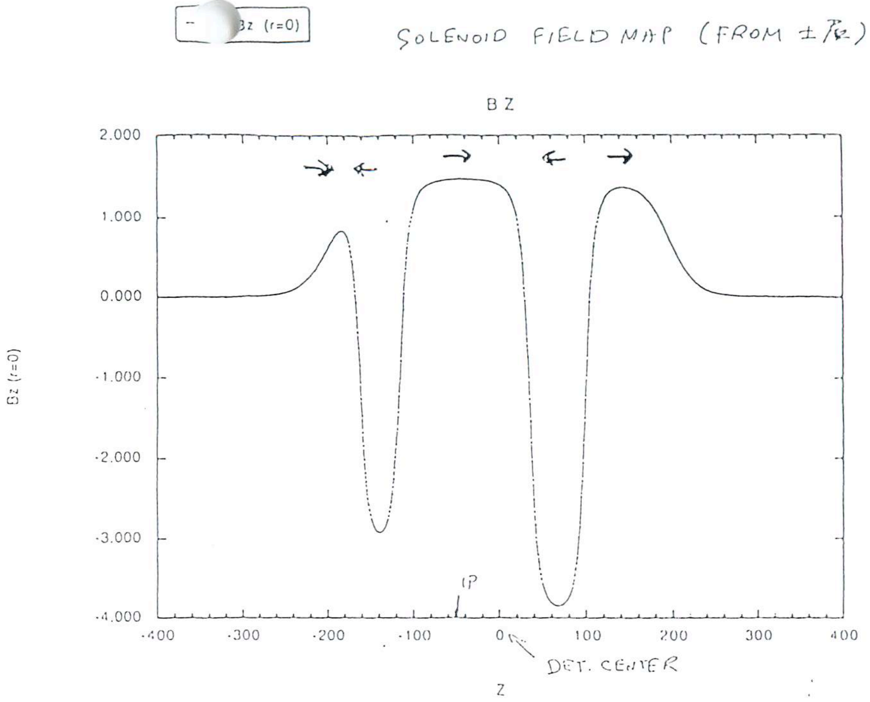
  → No 'extra' solenoid compensation.
  BUT, need to do field mapping!! ~ Sep. '97

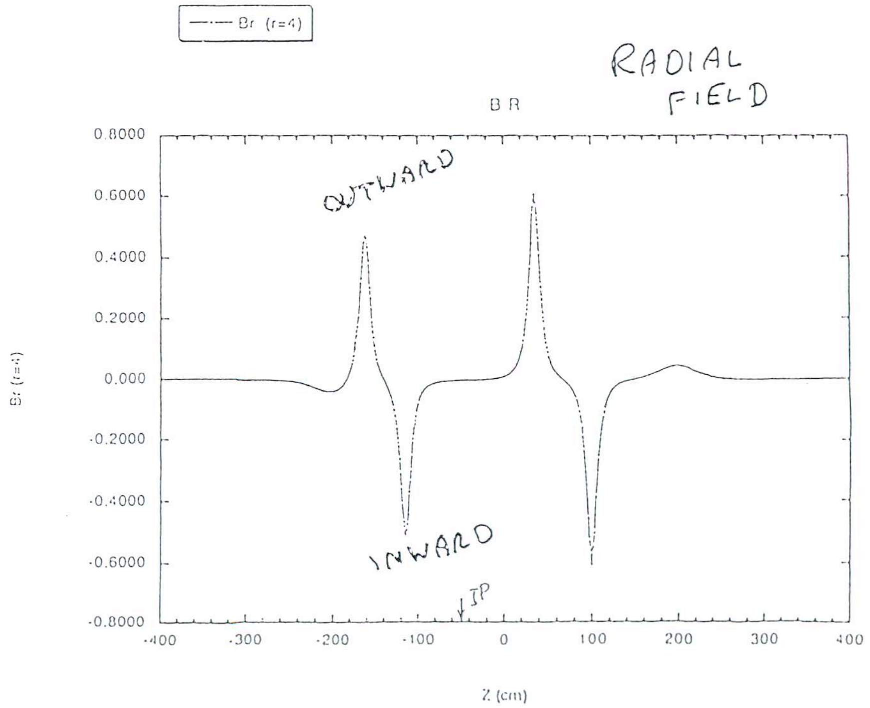
- Effects of multipole fields near QCS on the dynamic aperture have been evaluated.

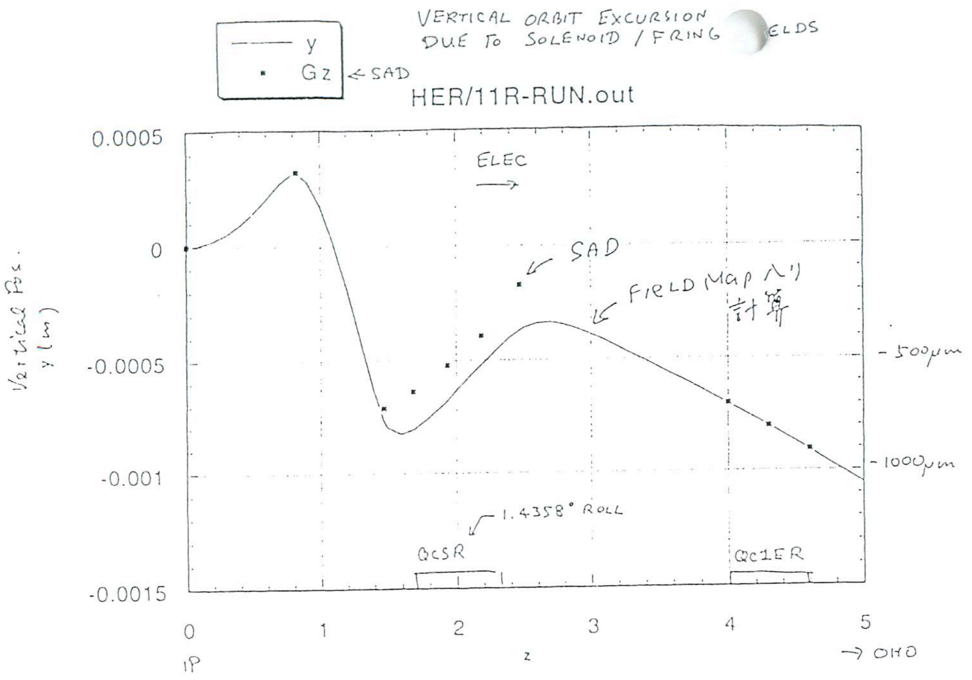
  Coil fringe fields . . . . . OK
  "Coupling" with the detector iron . . . . OK

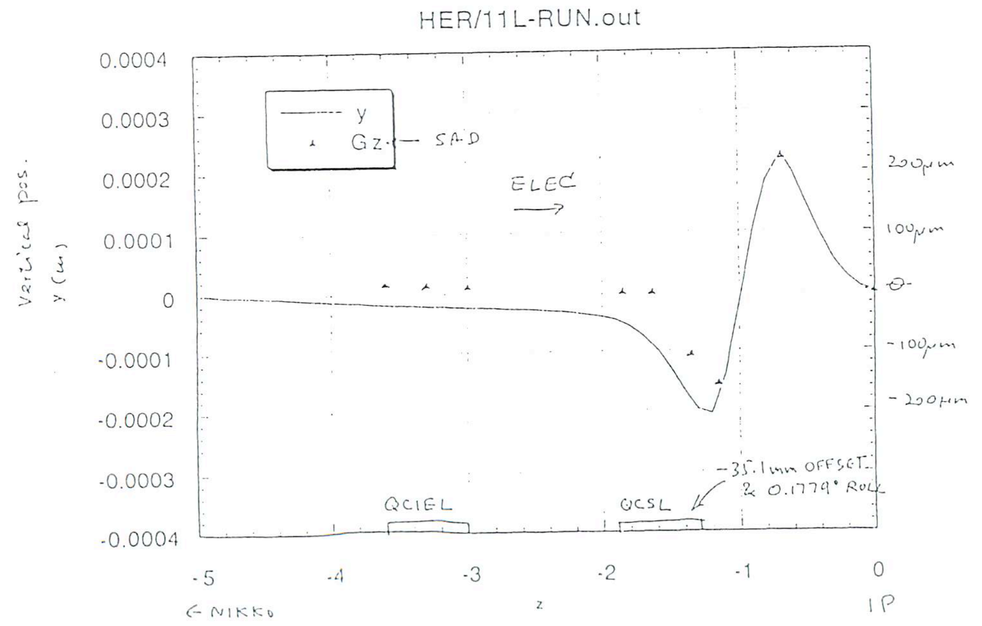
- Leak solenoid field from the detector iron near QC1.
  Optimization work is still in progress.
  Need detailed 3-D calculation. This is in preparation.

SOLENOID FIELD MAP (FROM ± Pz).









6. Aperture Allocation for S-L/R and QCS-L/R

- Injection time beam envelope has effective emittance of

  $\varepsilon_x = 1.2 \times 10^{-5}$ m

  $\varepsilon_y = 1.2 \times 10^{-6}$ m

  As "injection aperture", allocate

  $\varepsilon_x = 2.0 \times 10^{-5}$ m

  $\varepsilon_y = 2.0 \times 10^{-6}$ m

  for S-L/R and QCS-L/R.

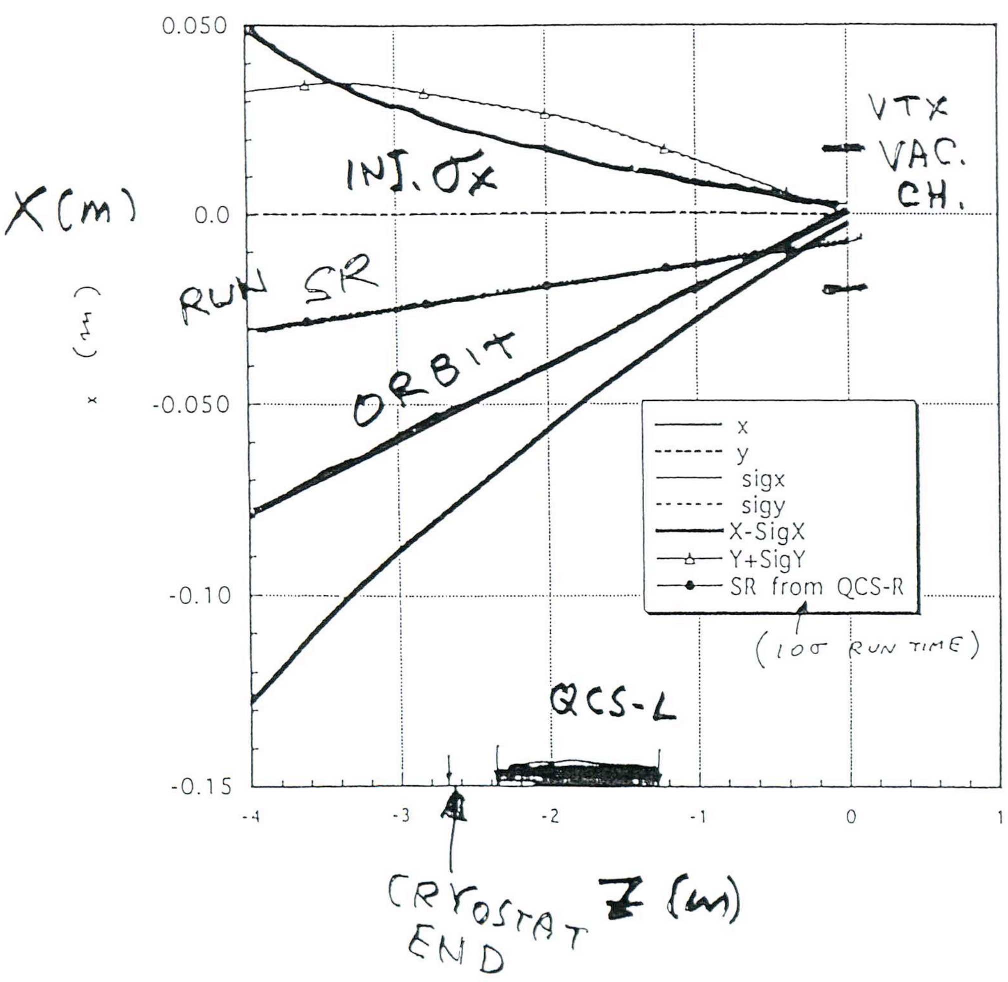
- SR (Synchrotron Radiation) aperture

  Not to intercept SR photons from 10σ particles during the regular run time (i.e. damped beam).

Z	X+σ_X	Y+σ_Y	
-1.283	0.036	0.018	SOL OUTER END
-2.373	0.069	0.030	QCS OUTER END
-2.653	0.078	0.031	CRYO OUTER END.

APERTURE NEEDED FOR ELEC

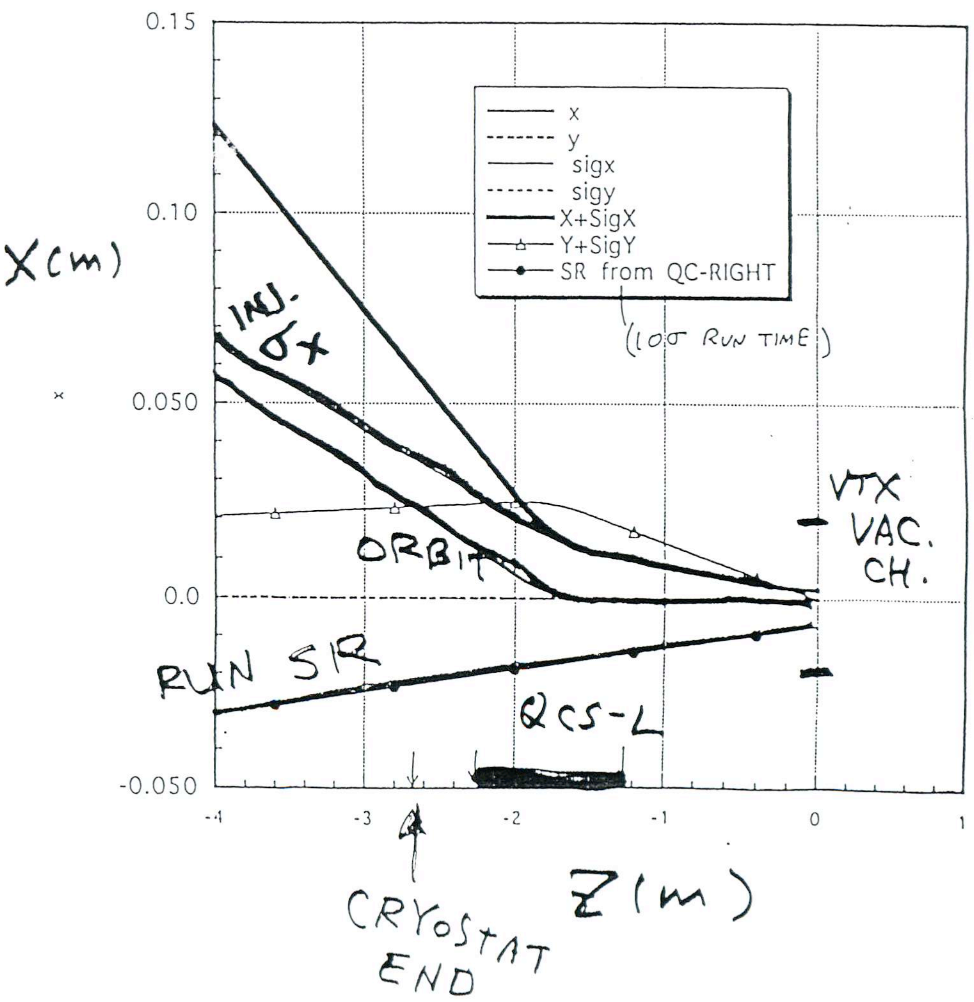
HER-33/10L-INJ.out



Z	X+σ_X	Y+σ_Y	
-1.283	0.010	0.018	SOL OUTER END
-2.373	0.045	0.023	QCS OUTER END
-2.653	0.058	0.023	CRYO OUTER END

APERTURE NEEDED FOR POSI

LER33/10L-INJ.out

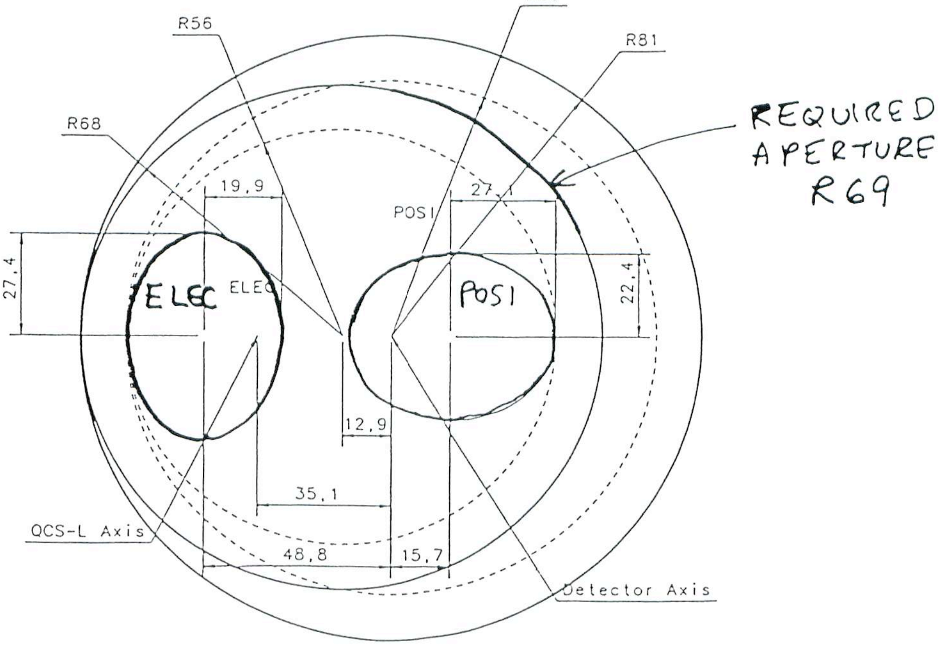


QCS-LEFT

Toge

QCS-L Aperture Evaluation

Case: QCSL moved towardw IP by 15 cm



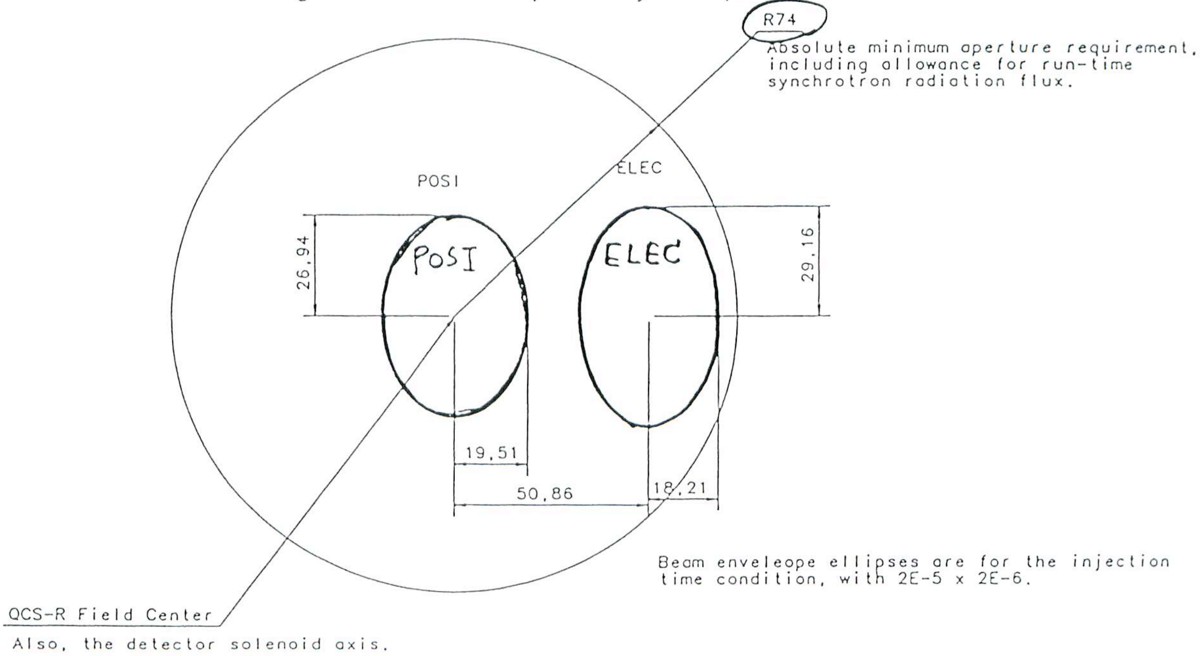
UNIT - mm

FRONT

Toge

QCS-R Aperture Evaluation

Calculation done at Z = 2.185 m
Only for reference purposes when
calculating the field quality requirements.



Absolute minimum aperture requirement, including allowance for run-time synchrotron radiation flux.

Beam enveleope ellipses are for the injection time condition, with 2E-5 x 2E-6.

Also, the detector solenoid axis.

UNIT - mm

QCSR-aperture: 16NOV94 N.Toge

FRONT

Ref. Talk by K. Kanazawa and S. Uno

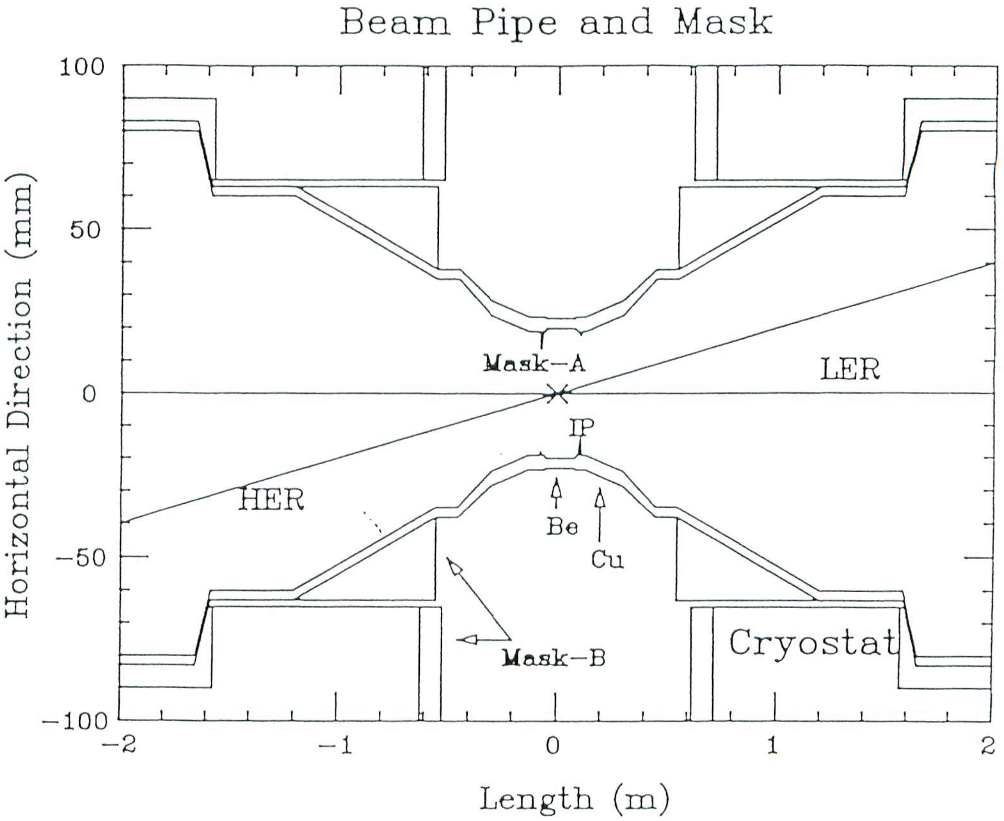


Figure 7.16: The arrangement of the central beam pipe at the IP and horizontal masks

⇒ Have come up with “reasonable” S + QCS sizes, i.e.

- Cryostat outer radius can fit within CDC.
- Same QCS winding can be used for L and R!
- Magnetic forces considered manageable.
- Non-concentric make of QCS-L is considered feasible.
- Multipole field errors have been evaluated.
- Effects of fabrication errors have been evaluated.
- Cryogenic system design in progress
(4.5 K, single phase Liq.He at 0.16 MPa).
- Have agreed on the endcap (EC) opening diameter to be 1000 mm.

Cabling for detector components: PID, SVD, CDC/HV must go through the space between the EC hole and the cryostat connection box.

Need 570 cm^2.

This is considered possible with ~ 30 % contingencies.

7. Beamline Outside the Detector Facility

- QC1 magnets for extra vertical focusing of e–.
- Independent QC2 magnets for horizontal focusing e– and e+.

- Specially-shaped QC1 and QC2 for optimized focusing of e– and e+.

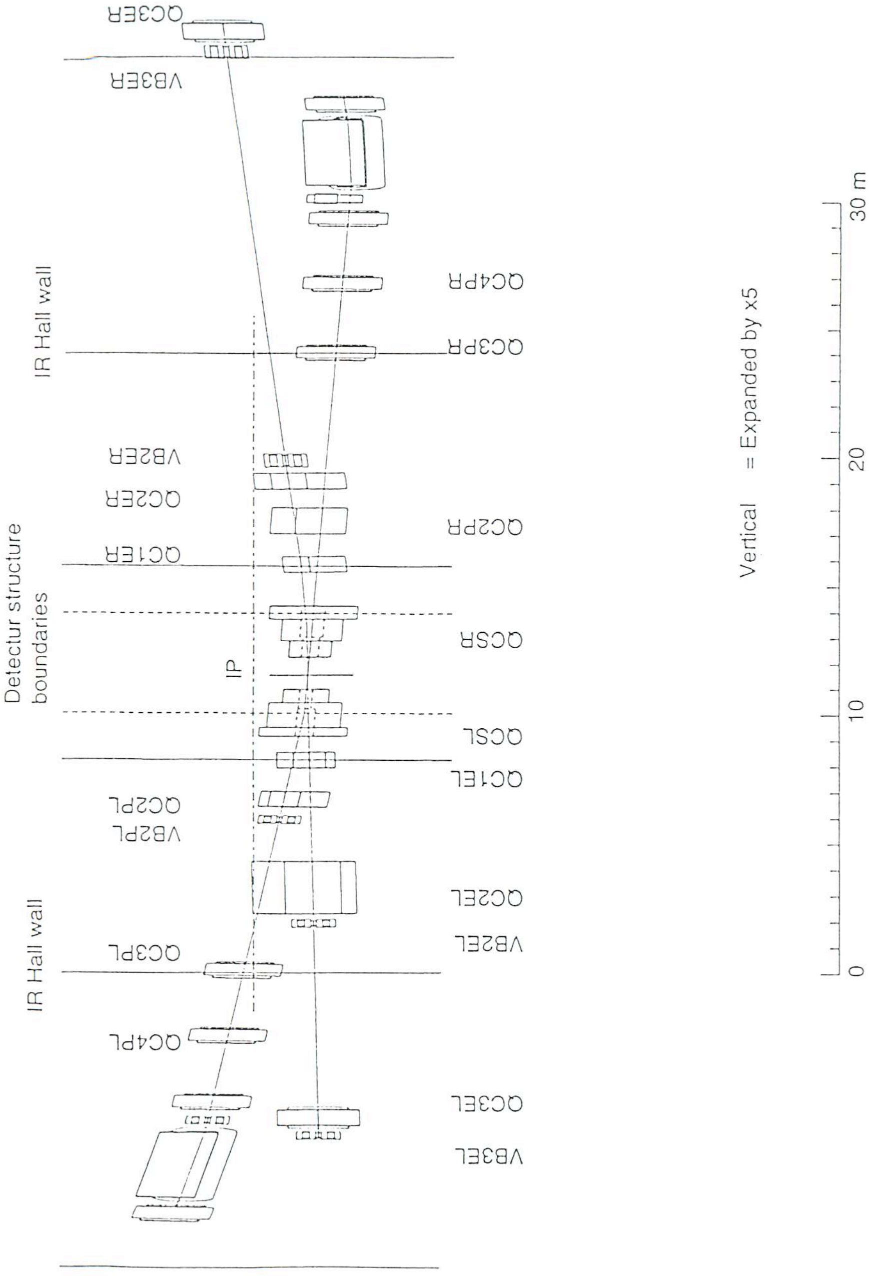
- Aperture allocations based on inj. beam envelope:
$\varepsilon_x = 1.4 \times 10^{-5}$ m (+ 5 mm)
$\varepsilon_y = 1.4 \times 10^{-6}$ m (+ 5 mm)
- 1st version engineering design exists for all QC1/2 magnets.

- High current density is considered manageable.

⇨ For more details, check the talk by H. Nakayama.

- Efforts to minimize the SR crytical energies of particle thru these quads, particularly when they are moving towards the IP.

☛ Need to review requirements on the field quality.



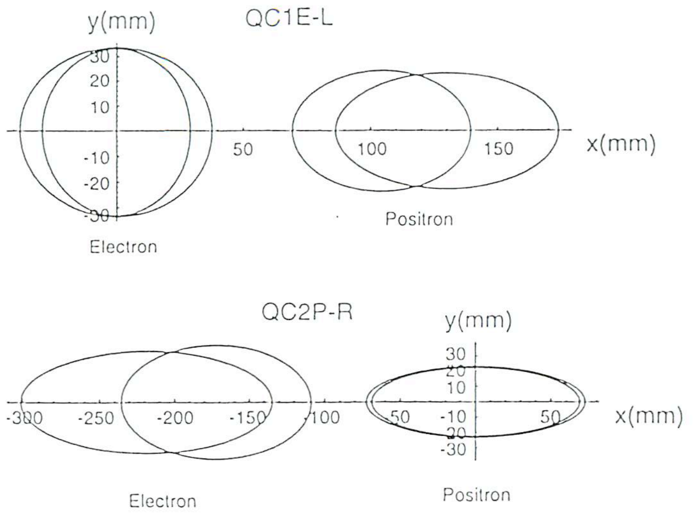


Figure 7.11: Beam positions and beam envelopes during the injection time at the edges of QC1E-L and QC2P-R.

		QC1E-L	QC2E-L	QC1E-R	QC2E-R
Entrance aperture(e^-)	horizontal(mm)	37.66	114.7	38.47	99.5
	vertical(mm)	33.62	18.5	39.85	30.4
Exit aperture(e^-)	horizontal(mm)	29.04	106.7	47.27	105.2
	vertical(mm)	32.99	20.4	40.43	29.8
Entrance aperture(e^+)	horizontal(mm)	43.85	50.9	48.1	61.5
	vertical(mm)	22.8	33.9	24.5	29.2
Exit aperture(e^+)	horizontal(mm)	34.96	53.1	56.95	66.2
	vertical(mm)	23.77	30.8	23.51	26.7
Beam separation	entrance(mm)	130.14	339.0	112.2	254.8
Beam separation	exit(mm)	100.42	302.0	132.2	283.0
Max. field gradient	(T/m)	15.4	6.1	12.6	10.2
Pole length	(m)	0.6	1.0	0.6	0.6

Table 7.11: Specification of IR quads for HER.

8. Beamline beyond QC2

- Important for global review of SR and beam-loss evaluations.

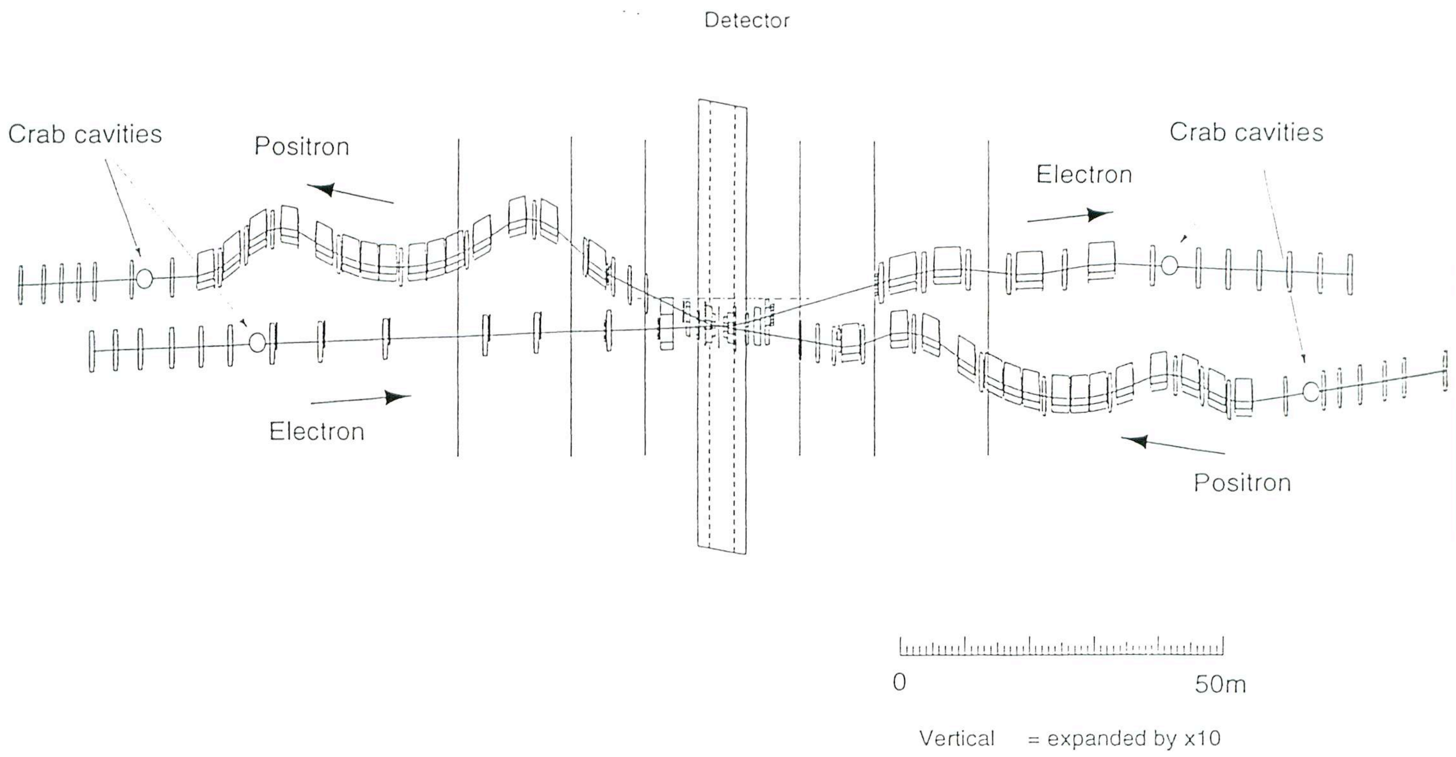
- The lattice configuration:

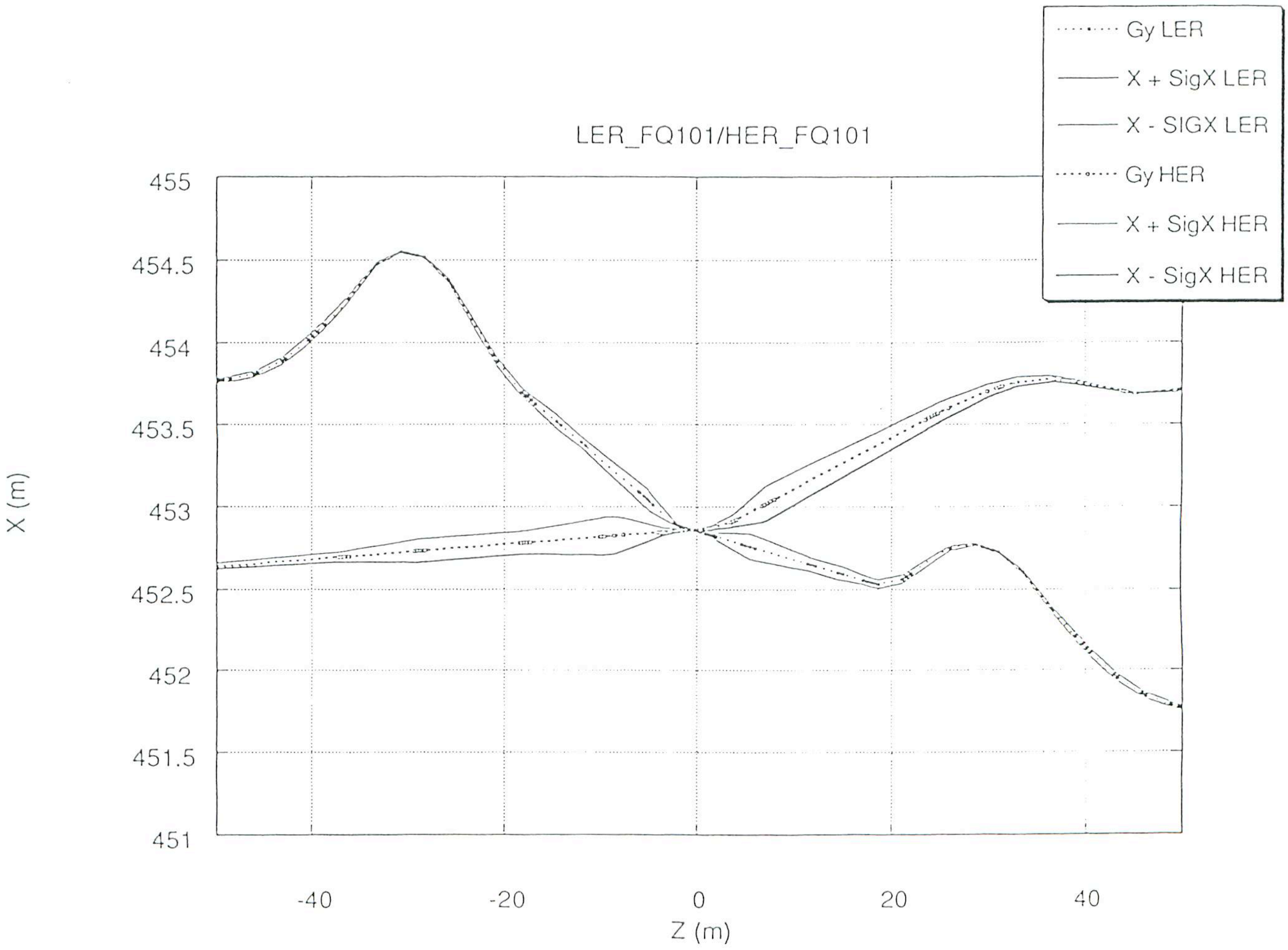
  HER (e–): Non-local chrom. correction.

  LER(e+): Local Y-chrom. correction.

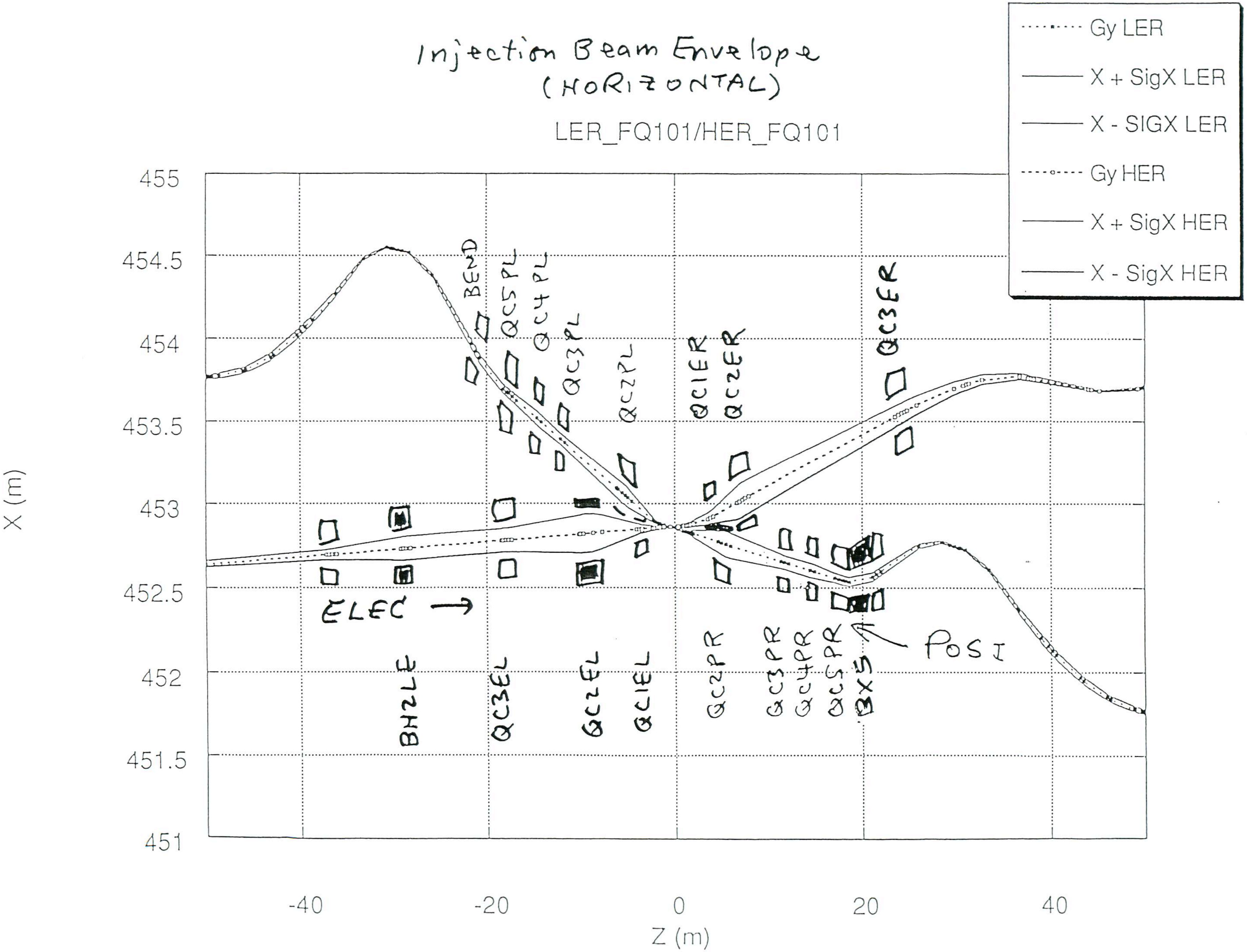
Consider compatibility with Crab cavities.

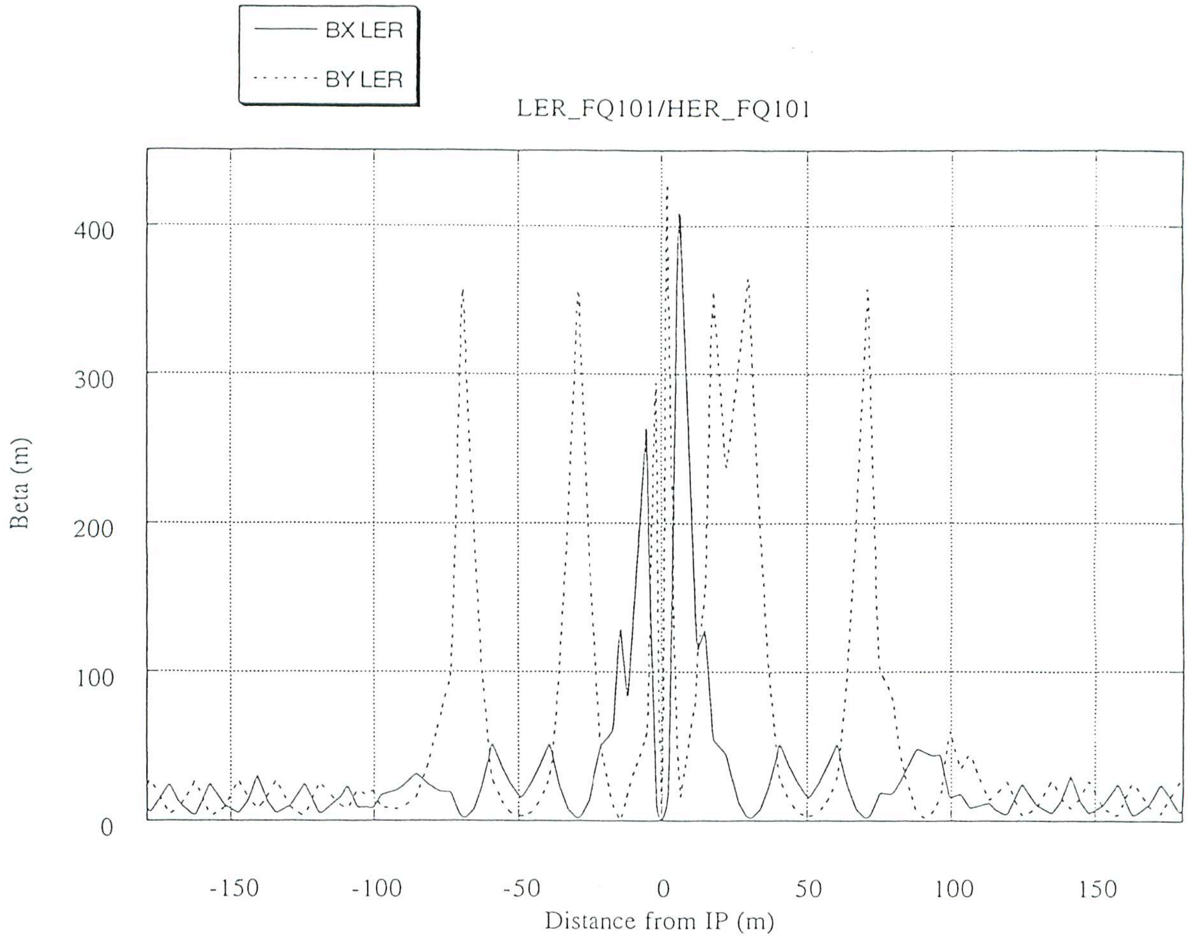
Tsukuba Straight Section
(Distorted View)

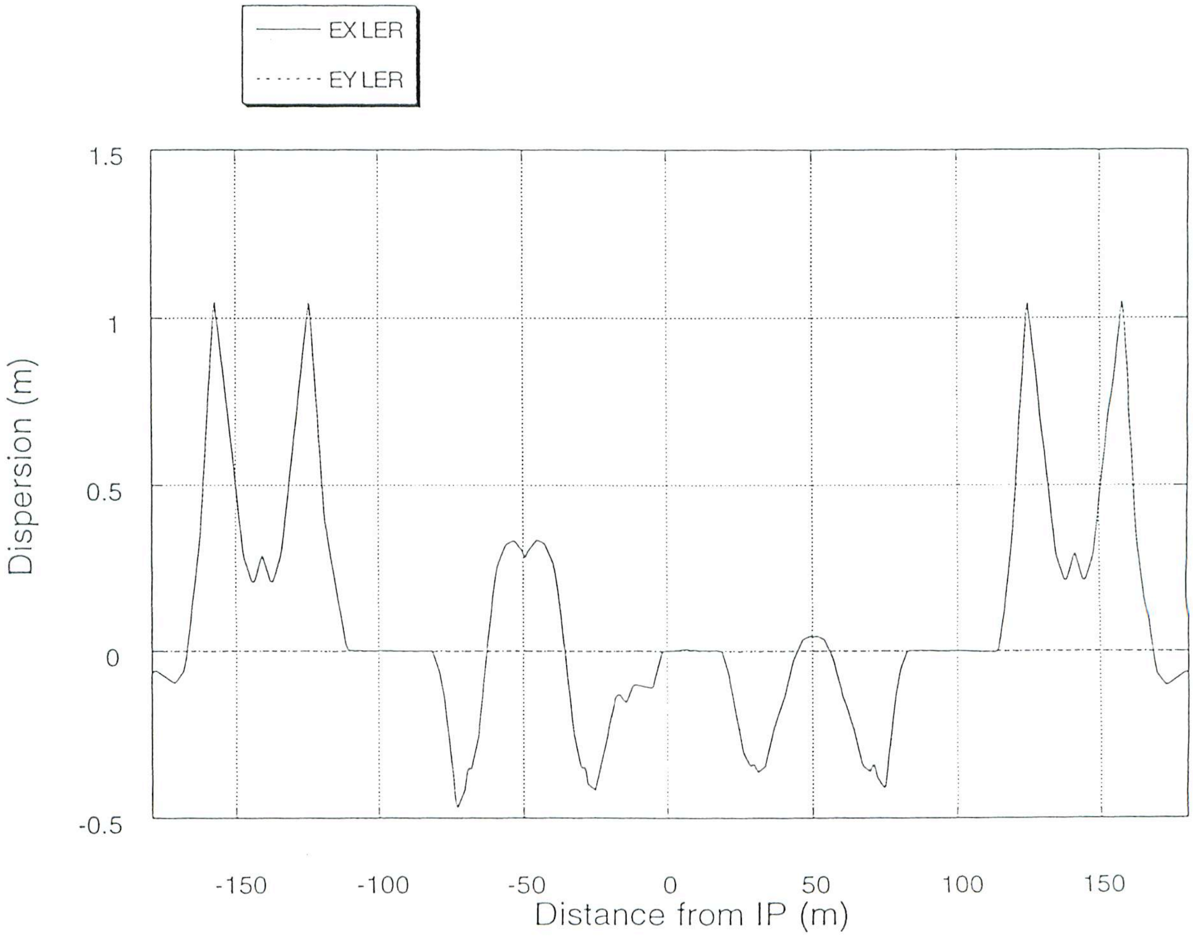


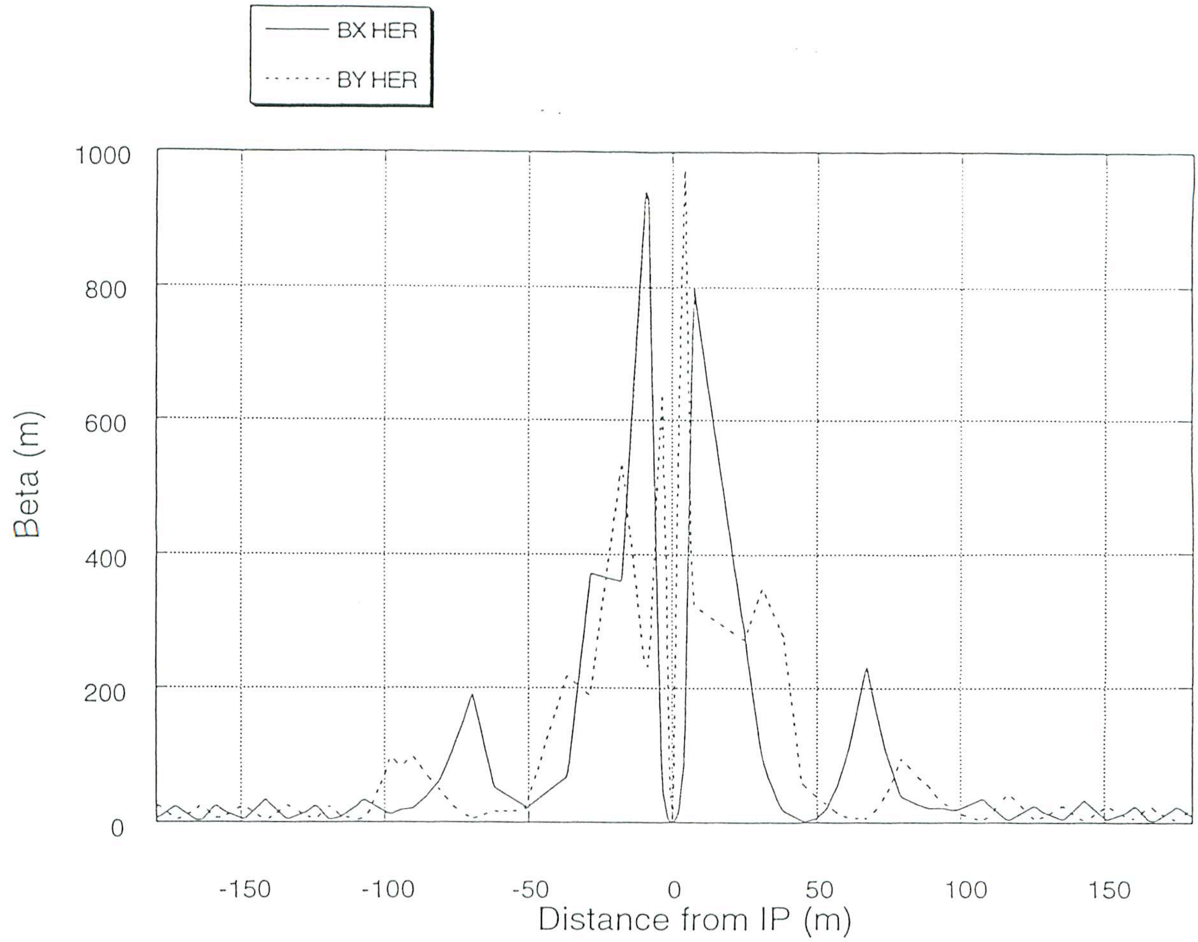


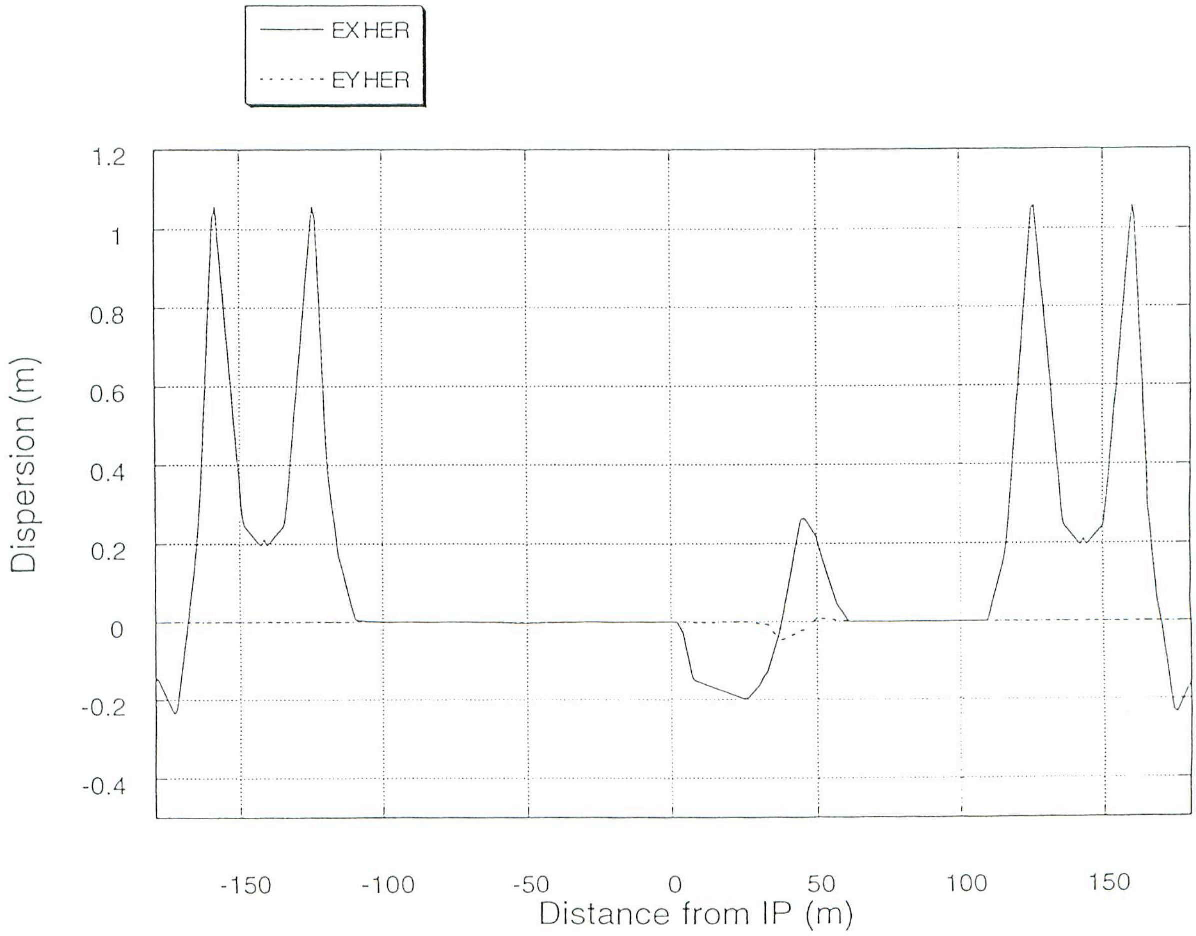
Injection Beam Envelope
(HORIZONTAL)

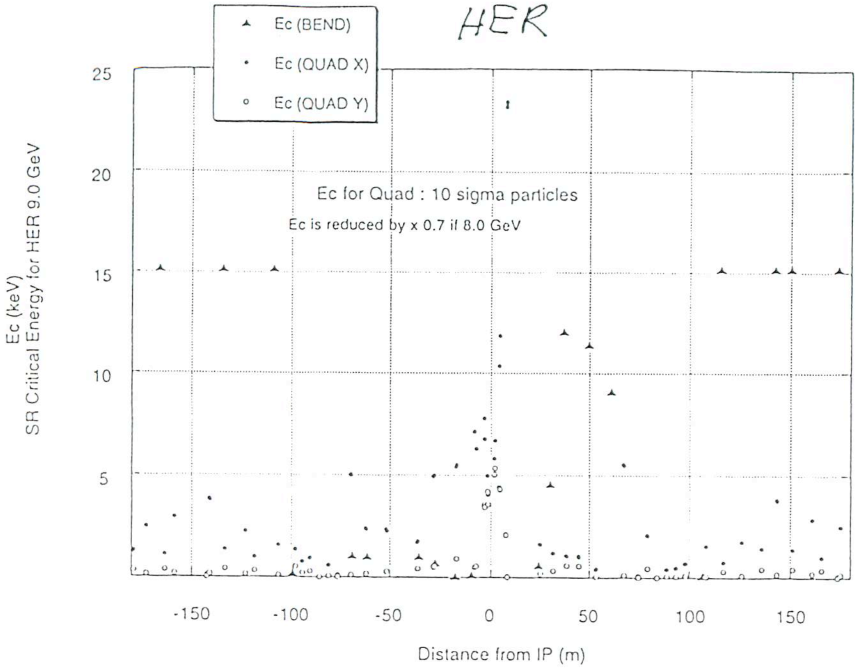


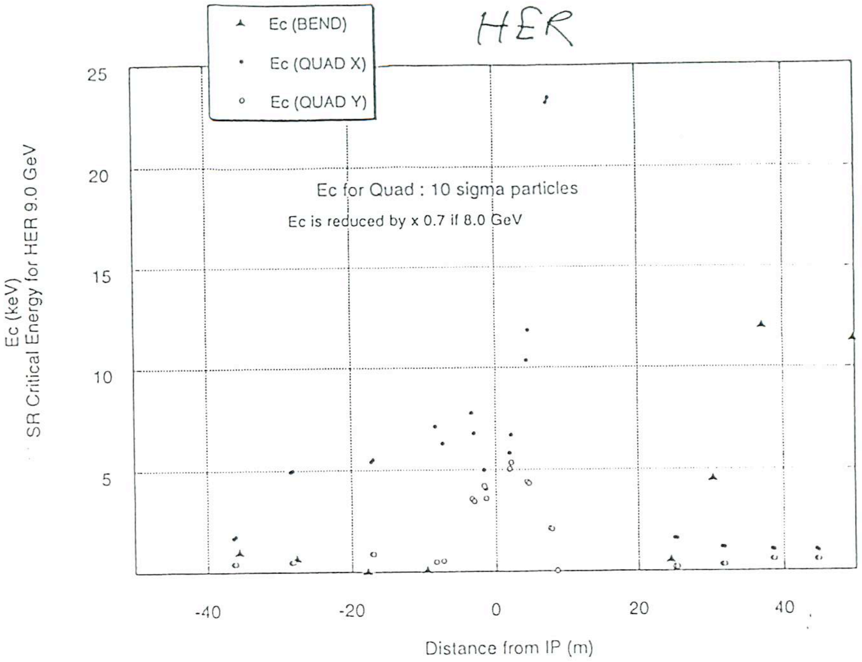

BX LER
BY LER
LER_FQ101/HER_FQ101
Beta (m)
400
300
200
100
0
-150
-100
-50
0
50
100
150
Distance from IP (m)

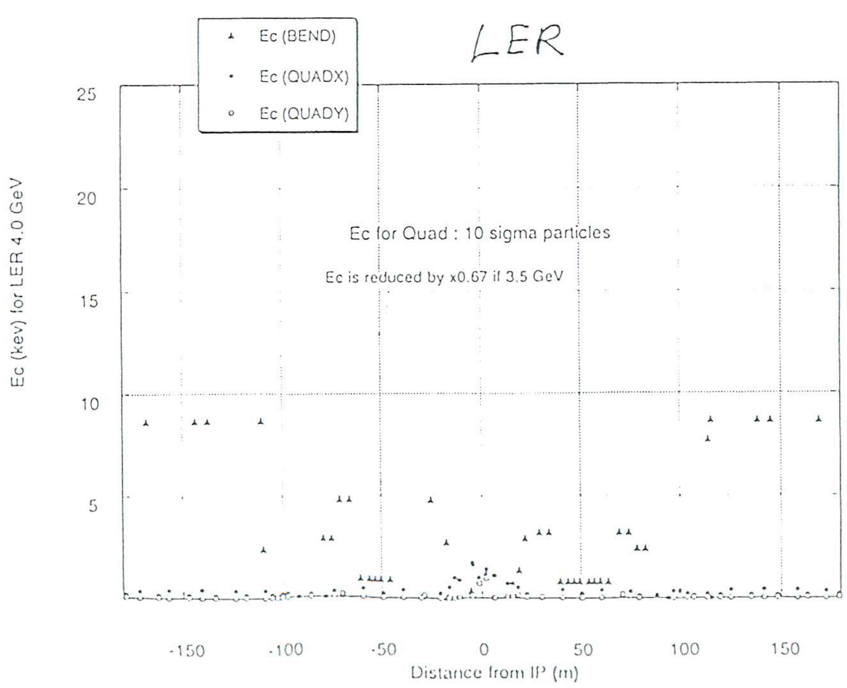

EX LER
EY LER
Dispersion (m)
1.5
1
0.5
0
-0.5
-150
-100
-50
0
50
100
150
Distance from IP (m)

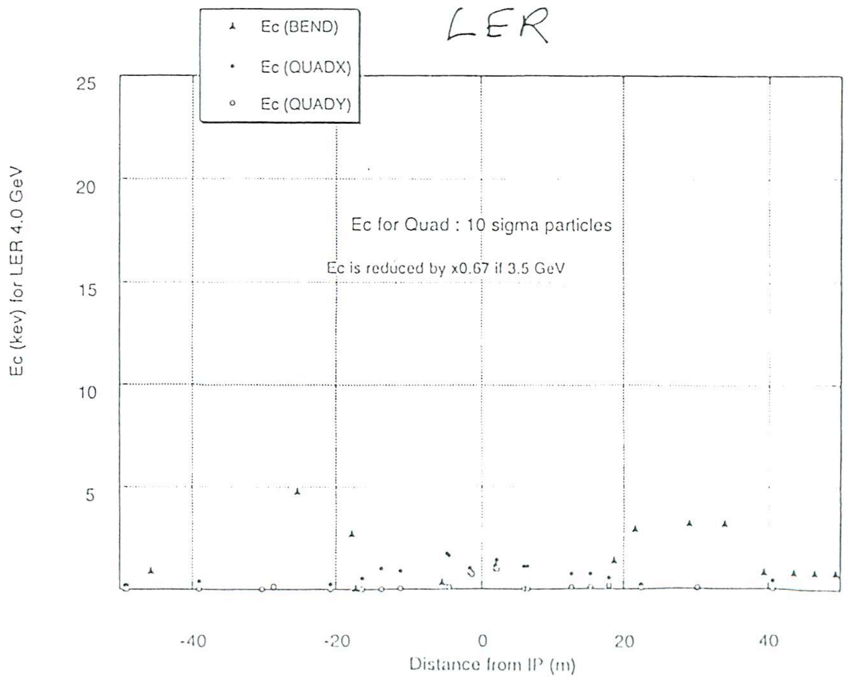

BX HER
BY HER
1000
800
600
400
200
0
Beta (m)
-150
-100
-50
0
50
100
150
Distance from IP (m)


EX HER
EY HER
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Dispersion (m)
-150
-100
-50
0
50
100
150
Distance from IP (m)

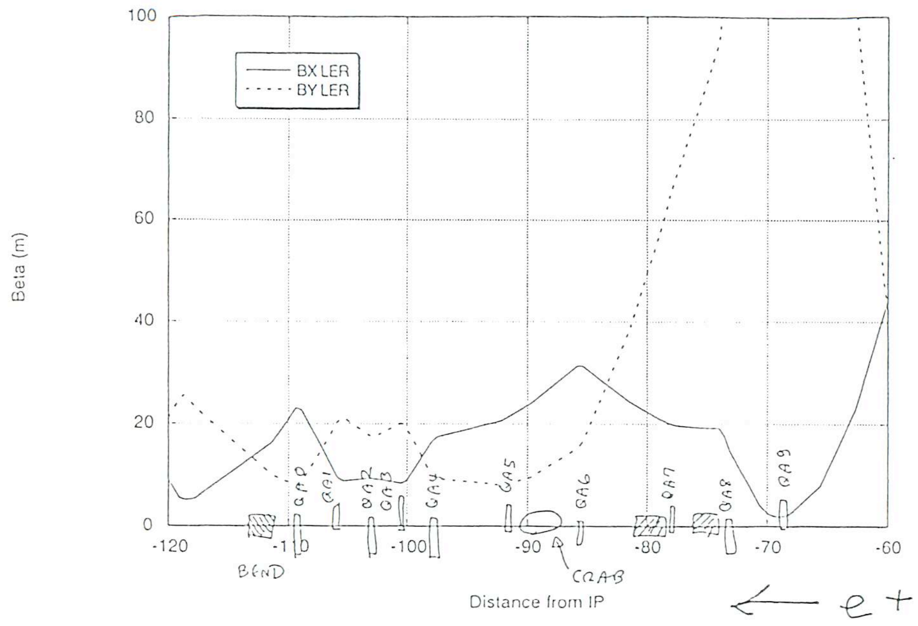

HER
Ec (BEND)
Ec (QUAD X)
Ec (QUAD Y)
Ec for Quad : 10 sigma particles
Ec is reduced by x 0.7 if 8.0 GeV
Ec (keV)
SR Critical Energy for HER 9.0 GeV
25
20
15
10
5
-150
-100
-50
0
50
100
150
Distance from IP (m)


HER
Ec (BEND)
Ec (QUAD X)
Ec (QUAD Y)
Ec for Quad : 10 sigma particles
Ec is reduced by x 0.7 if 8.0 GeV
Ec (keV)
SR Critical Energy for HER 9.0 GeV
25
20
15
10
5
-40
-20
0
20
40
Distance from IP (m)

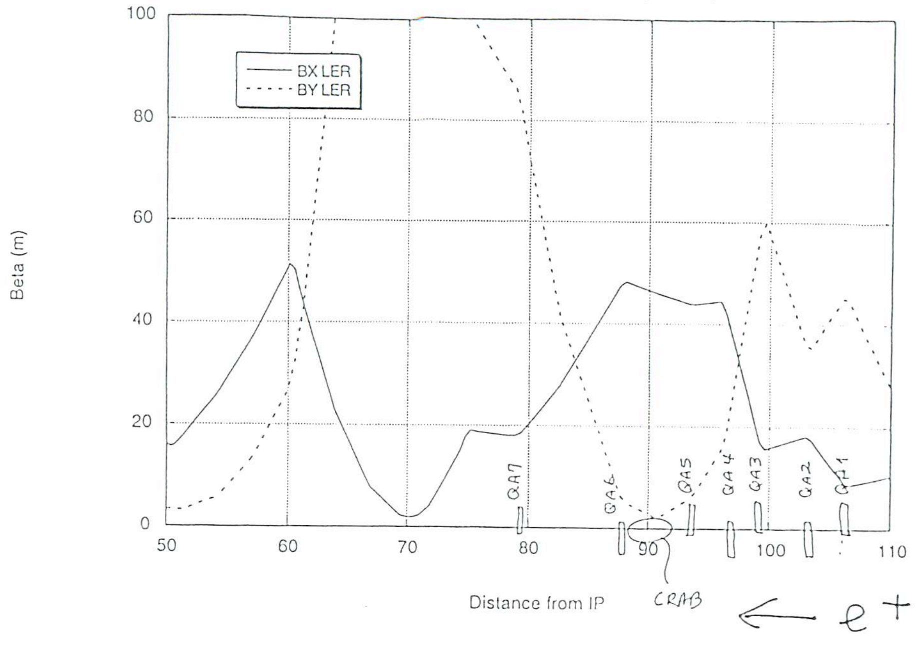

LER
Ec (BEND)
Ec (QUADX)
Ec (QUADY)
Ec for Quad : 10 sigma particles
Ec is reduced by x0.67 if 3.5 GeV
Ec (kev) for LER 4.0 GeV
25
20
15
10
5
-150
-100
-50
0
50
100
150
Distance from IP (m)

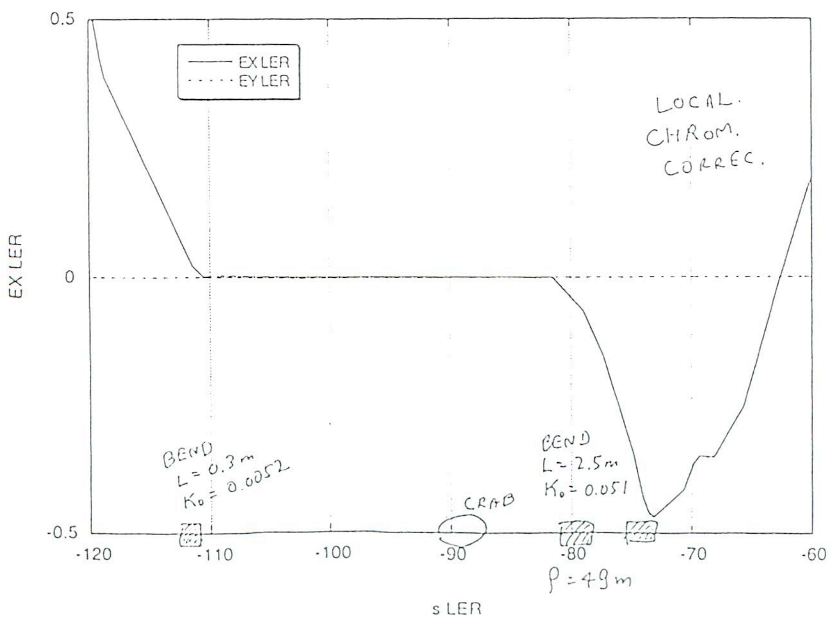

LER
Ec (BEND)
Ec (QUADX)
Ec (QUADY)
Ec for Quad : 10 sigma particles
Ec is reduced by x0.67 if 3.5 GeV
Ec (kev) for LER 4.0 GeV
25
20
15
10
5
-40
-20
0
20
40
Distance from IP (m)

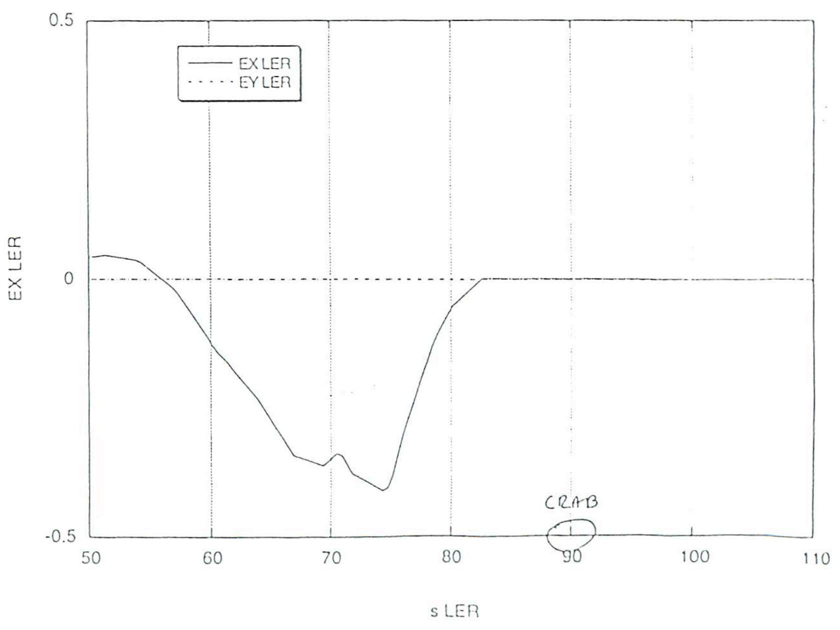
LER: Near the Crab Cavity (Left Side)

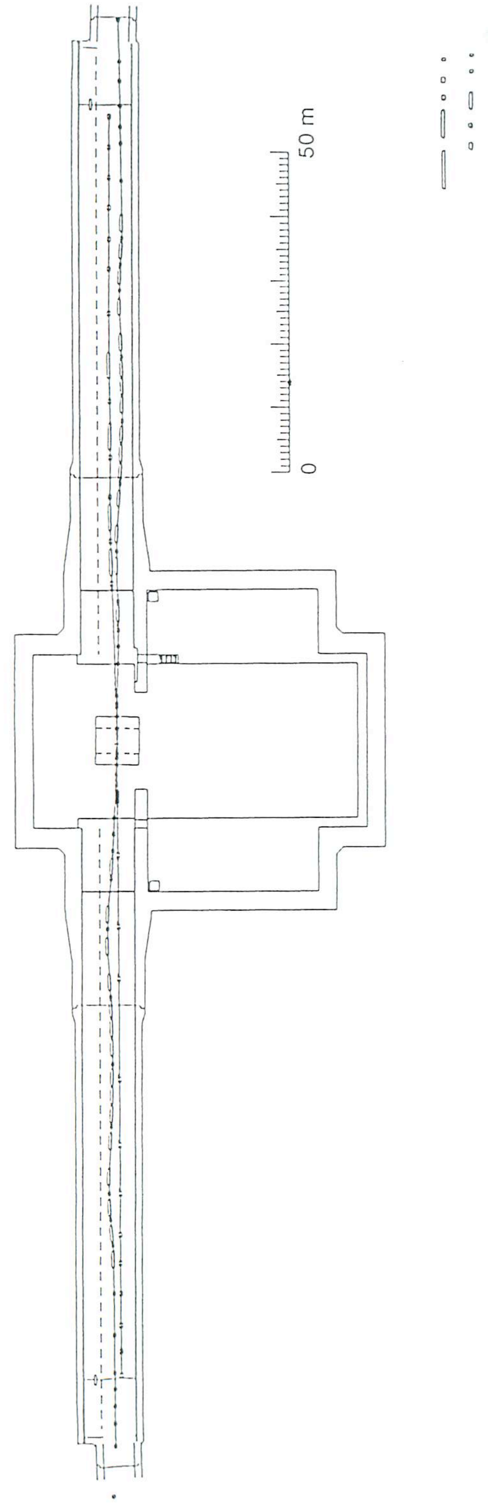


LER: Near the Crab Cavity (Right Side)





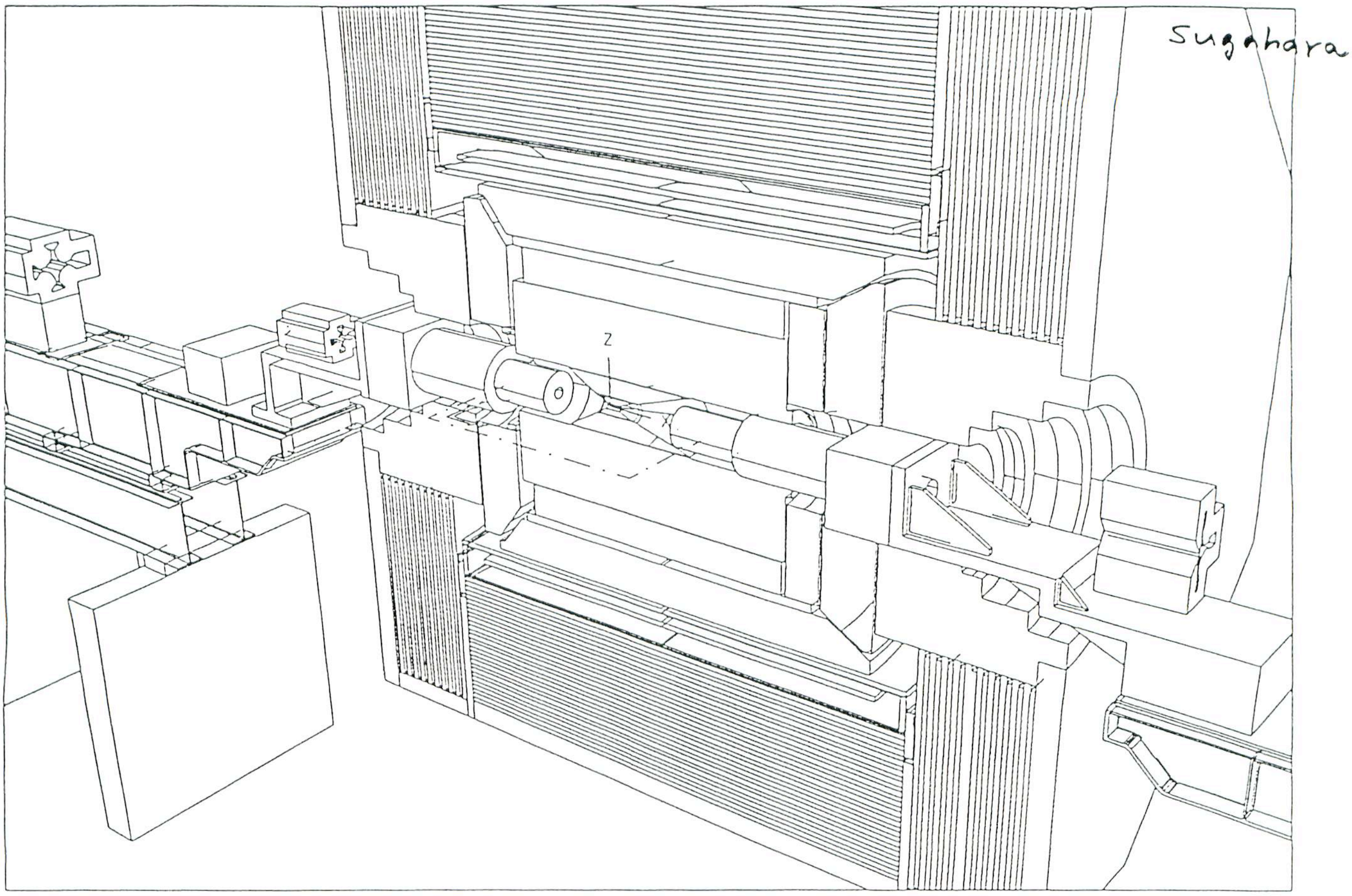




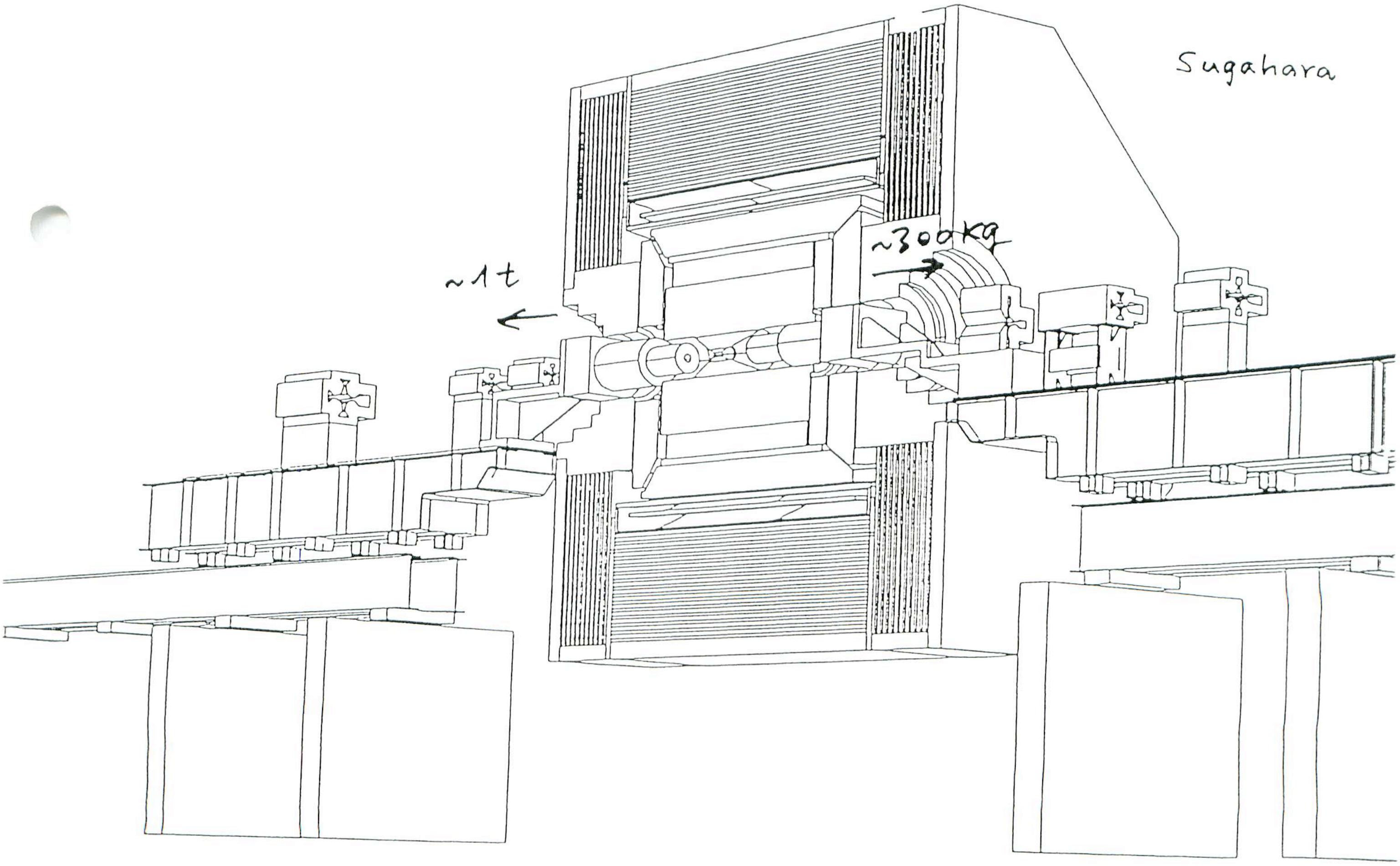
Tsukuba Straight Section

9. Support / Alignment of Accelerator Components near the IP.

- Traditional, cantilever support of QCS.
- Common stage will support SOL-QCS, QC1, QC2P and QC2E of each side. The stage can retract by 4 m in Z.
- No QCS magnet movers. Its position alignment is done by adjusting the support stage jacks.
  Finer adjustments are done by correction coil winding (eqv. a few mm).
- Position monitor device on QCS-cryostat relative to the detector structure. 'Hologauge'
- Look-through windows on the end-plates of the CDC to help alignment work.
- Routing solution exists for the transfer tube (29cmϕ) for QCS-cryostats.
- Some sort of earthquake bracing on QCS cryostats.
- QC1 / QC2 position adjustments by remotely-controlled magnet movers.
- Procedures for initial construction and access maitenance are being worked out.



Sugahara



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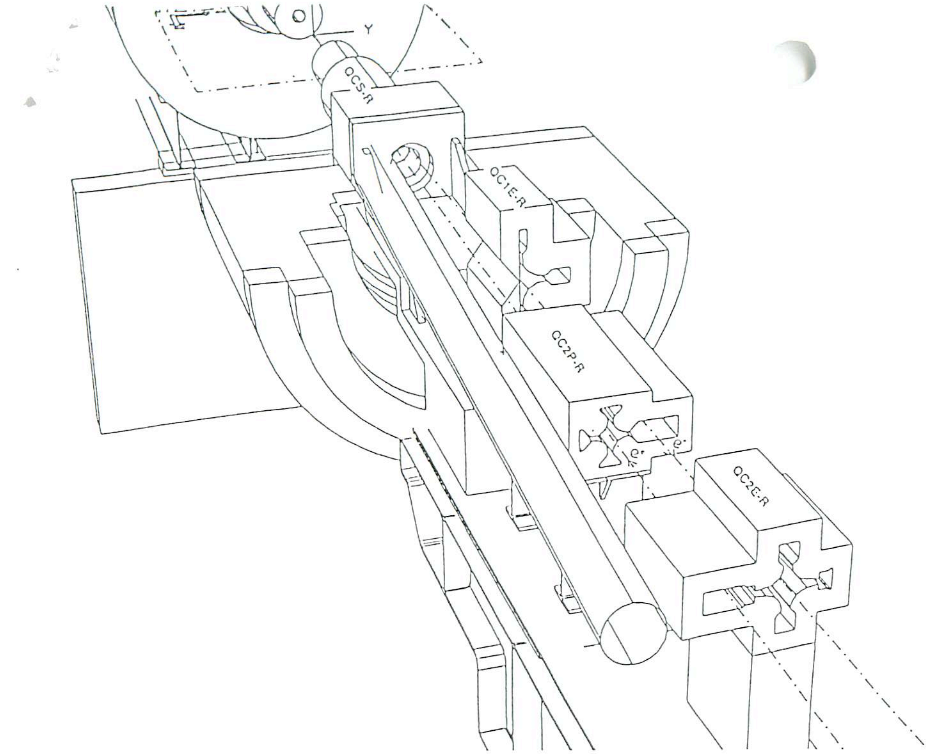

Fig.4 IR R[illegible]-2
1995.02.15 n.S.

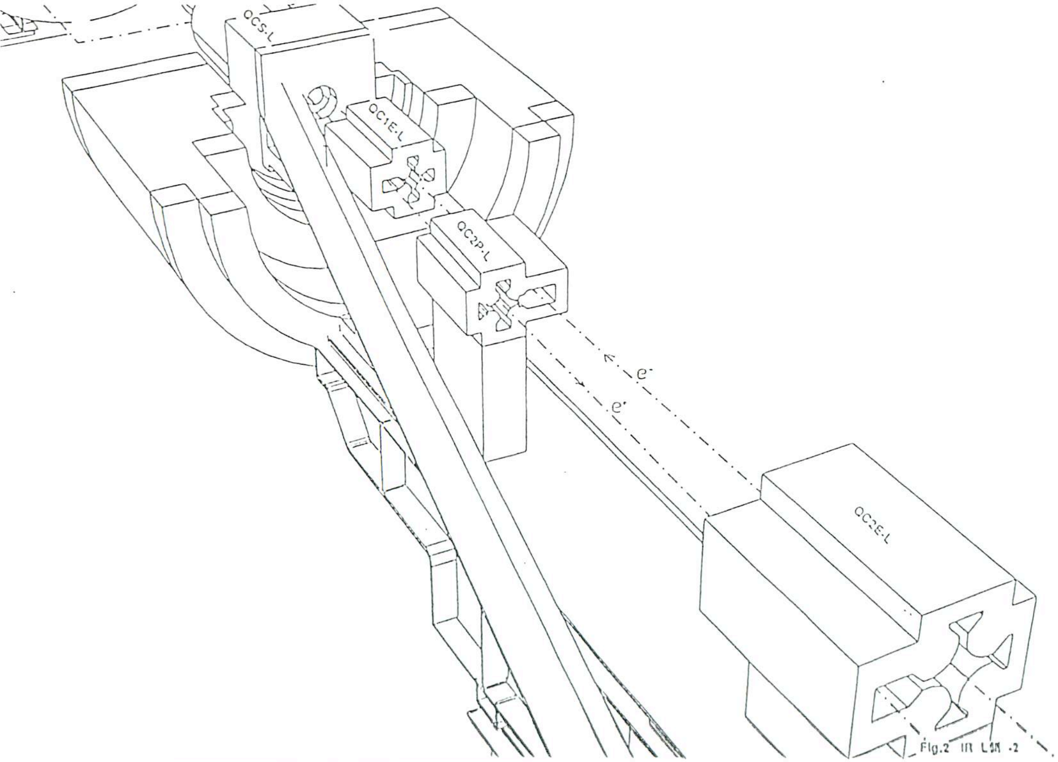

Fig.2 IR L[illegible] -2

10. Task Plan for the Immediate Future

- Finalize the IR straight section optics design
  Evaluate
  - Dynamic aperture. Error sensitivities.
  - SR + beam background near IP and masking
- Realistic vacuum system design
  - Definite aperture specifications needed.
  - Chamber connection and support schemes
  - Impedance and HOM evaluations
- Further system integration
- Beam / noise diagnostics, control, orbit feedback.