SLAC-PUB-4317
April 1987
(E)

PROSPECTS FOR COLLIDER VERTEX DETECTORS*

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1. Introduction

This talk discusses the technologies available for vertex detection and the restrictions imposed by event topologies and multiple coulomb scattering. It will be shown that ultimate performance limits for collider detectors are set by how close active detection starts relative to the interaction region. This in turn is determined by the machine characteristics and the care taken to provide collimation and shielding to minimize radiation backgrounds.

Invited talk at the International Conference on Advances in
Experimental Methods for Colliding Beam Physics
Stanford, California, March 9-13, 1987

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* This work was supported in part by the Department of Energy under contract number DE-AC03-76SF00515.

2. Limitations

Table 1 lists currently proposed detectors and their expected performance. The proportional gas detectors have measurement resolutions which do not significantly limit ultimate performance. As shown below their track pair resolutions do become significantly limiting at distances within 4 cm of the vertex. Silicon based detectors are not limited either by intrinsic resolutions or by track pair resolutions and almost certainly should be used for active detectors closer than 4 cm to the vertex. Layered CCD detectors should true 3D reconstruction and, while expensive, would provide the ultimate in track and track-pair resolution. Expected maximum allowable radiation tolerances are roughly comparable for all detector types although the fine segmentation of the Charpak–Sauli multidrift tubes may provide some advantage.

"True" vertex detection has been observed in fixed target experiments detecting charm decays. Figure 1 shows a typical charm–decay event. The topology is simple, the momenta are high and there is no limitation set on how close detection can start relative to the IR point. Unfortunately none of these statements apply to vertex detection in a collider environment. Figure 2 shows a typical $B^0\bar{B}^0$ event configuration that might be observed in a collider environment. To optimally extract physics, the charged leptons, kaons and hadrons from the B–decay vertices should be unambiguously identified. The large numbers of tracks usually associated with such events will cause combinatorial ambiguities in vertex assignments.

Illustrative results for Monte Carlo predicted momenta distributions,[1] are shown below. Figure 3(a) shows the momenta distributions for $Z^0 \rightarrow c\bar{c}$. Figure 3(b) shows the progressively softer momenta spectra expected for $Z^0 \rightarrow b\bar{b}$ and $Z^0 \rightarrow t\bar{t}$. The momenta associated with these topologies are low. The multiple scattering induced errors on the impact parameter determinations relative to the primary vertices (the measure used to associate tracks with vertices) are correspondingly high. These comparatively low track momenta will result in substantial mutiple scattering degradation of the angular precision and this if combined with comparatively long extrapolations from the active detectors to the interaction point will cause errors in impact parameter determinations relative to the IP.

The radiation lengths of materials in the detector and between the active elements and IP (beam–pipe) even with careful design cannot be indefinitely reduced. Typical radiation lengths of multiple scattering material incorporated in a vertex chamber design (the MAC vertex chamber with beam pipe at 3.5 cm from the IP) are listed in Table 2 . This table shows the difficulties of reducing amounts of multiple scattering materials associated with a vertex detector substantially below 0.5% radiation lengths.

Figure 4 shows the theoretically predicted impact parameter distribution in the absence of measurement errors expected for charged decay particles from Z_0 decays. Decay lengths follow exponential distributions and thus peaking at zero decay distances. This results in a substantial fraction of decay tracks with impact-parameters smaller than 20 μm. Figure 5 shows the estimated precision in impact parameter determinations attainable with a high precision CCD detector 1 cm from the vertex (possible at SLC) and that attainable with identical relative configuration and equally good state of the art resolution for a detector ~8 cm. from the vertex (as proposed for current LEP detector). Even at large momenta the LEP detector errors are set by the multiple scattering in the material before the detector. The errors are large and only a very small fraction of events would have unambiguously determined vertices. The results of calculations[2] on the fraction of unambiguously reconstructed vertices that would be observed for $W \rightarrow t\bar{b}$ in UA1 with a vertex detector starting at a radius of 2 cm from the IP are given in Table 3 .

Reference to Table 1 shows that current proportional gas technologies meet resolution and track pair resolution requirements down to 4 cm. Silicon technologies meet requirements below 4 cms. We conclude from the Monte Carlo event simulations that multiple scattering makes unambiguous vertex characterization of colliding beam events difficult even for detectors starting at a radius of 1 cm from the IP. Bettering the resolution of detectors above present state of the art will not appreciably improve verticizing. Only moving the active detectors closer to the IP and/or minimizing radiation lengths of material in front of the detector can lead to improvements in verticizing. Viewed from this perspective performance of detectors will be limited by the ability to integrate them into the parent machine.

3. Experience with close–in detection.

Soon after commissioning, the MAC detector at PEP was run for a short period with a 2" ID stainless steel beam–pipe substituting for the regular 7" ID aluminum beam pipe. The background tracking chamber hits associated with individual events were still, surprizingly, small. The limitation on performance of the central tracking chamber came from the average radiation induced DC current causing Malter breakdowns. The radiation backgrounds resulted from:

1. Beam electrons that lost substantial energy by bremsstrahlung in the approaches to the IP and were then overfocussed, by the quads close–in to the IP, into the vacuum chamber at the IP.
2. Synchrotron radiation from the arc bends hitting the material at the IP.
3. Synchrotron radiation from the quads close in to the IP.

The most serious source of background is the quad synchrotron background. This background comes from the synchrotron radiation at large angles from particles in the beam halo. The population of beam halo particles is fed by coulomb gas scattering occuring over the circumference of the machine and by beam–beam interaction. Early in the machine fill or under unstable operating conditions very large halo occupation can be created. This occupation may typically be many orders of magnitude larger than calculated with the assumption of a gaussian beam distribution.

Based on this experience a masking configuration was designed for the MAC detector to allow close–in operation. For a circular machine all collimators must be located outside the beam stay clear region not to interfere with machine operation. A configuration meeting this requirement was designed such that the vacuum chamber walls close to the IP were shielded from synchrotron radiation from beam particles within 5 sigma of the beam. Calculations indicated that population of halo particles outside this radius would be sufficiently small to not interfere with chamber operation. Figure 6(a) shows the original MAC masking configuration and Fig. 6(b) shows the final MAC configuration with the addition of small diameter shadowing collimators 60 cm from the IP. The added collimators were in turn shielded by thick heavimet shielding to mask out the products from the electromagnetic showering of overfocussed electrons. A titanium liner was added within the beam pipe to absorb backscattered photons from L–fluorescence within the tantalum collimators. Entirely satisfactory running for the MAC vertex chamber[3] resulted with this configuration with the beryllium beam pipe at 3.5 cm from the IP.[3]

From our experience we have estimated how close detectors might be placed to the IPs at SLC and LEP. The critical energy of synchrotron radiation goes as E^2B and is effectively peaked at several hundred keV not at the tens of keV for PEP quad synchrotron radiation. This is substantially harder and correspondingly substantially more difficult to shield than at PEP. For LEP we calculate that direct radiation from beam halo particles will result in large backgrounds and should not be permitted to strike the vacuum chamber at the IP. This criteria correspond to ensuring that radiation from particles out to beam stay clear misses the vacuum chamber at the IP and is equivalent to requiring that particles out to $\sim$ 10 sigma (not the 5 sigma criterion used in the MAC design at PEP) should not produce synchrotron radiation directly impinging on the close–in collimators. If the beam–pipe is placed within this radiation cone, we would expect high ambient background levels sufficient to cause chamber deterioration.[4] SLC, of course is a single pass machine and collimators can be at any radius without interfering with machine operations. To calculate backgrounds, we assume for initial operation that it will be possible to clip the beam to 6 sigma far from the IP (SLC1) and that later the beam can be clipped down to a 3 sigma level (SLC2).

Based on these assumptions we have estimated from the projected emittances and final focus quad configurations the closest distance that detectors can be placed relative to the IP.

Table 4 gives the results, listed are assumed emittances and apertures. We would project that LEP detectors will eventually operate within 4 to 5 cms from the IP and at SLC detectors should ultimately operate to within 1 cm of the beam–line. At 1 cm, while still difficult, true verticizing should become possible.

Hadron collider limits are set by initial injection conditions where the beam pipe is required to be outside beam stay–clear. For the present colliders this corresponds to a minimum radius of 2.5 to 4 cm.

4. Conclusions

Vertex chambers are extemely useful for improving overall tracking performance, unambiguously permitting identification of conventional strange decays and tagging and determining lifetimes on a statistical basis. However their performance is ultimately limited by the radiation lengths of material contained in the beam pipe and support structures and by the shielding environment of the machine. The main variable that can be controlled by the experimentalist is the shielding environment of the machine and this determines how close active detectors can be placed relative to the IP. Even with the most meticulous attention to details of the machine detector interface, it would appear improbable that at LEP and the Tevatron that detectors can be placed closer in radius than 4 cm to the IP. Only at SLC does it appear possible to provide active detection down to a radius of 1 cm from the IP. Thus true verticizing, even with the use of CCD technology will probably only be achievable at SLC.

REFERENCES

1. C.J.S. Damerell, RAL–86-077, July 1986, Lectures at St. Croix.
2. UA1 upgrade proposal, 1983.
3. SLAC–PUB–4311, 1987, submitted to NIM.
4. Masking schemes can be designed so that radiation reflected from primary collimators does not directly hit the vacuum chamber but must make a second reflection to hit the vacuum chamber. Such schemes substantially reduce the radiation levels. However detailed considerations generally find that while the primary collimators can be placed substantially closer to the IP the secondary collimators out of the line of direct radiation must be placed further out. The net gains in placement resulting from more complex masking schemes are usually small or non existent.

TABLE CAPTIONS

1. Some currently proposed vertex detectors and their expected resolutions, track pair resolutions and maximum permissible radiation dosages.
2. Radiation lengths of material used in the MAC vertex chamber at PEP. Appended for comparison is the value for silicon strips.
3. Fraction of reconstructed vertices that would be observed for $W \to t\bar{b}$ in UA1 with a vertex detector starting at a radius of 2 cm from the IP.
4. Emittances at the Z^0 and estimated closest distances for placement of vertex chambers listed for various accelerators.

Table 1

Vertex Chamber Parameters For Various Detectors

Proportional Gas Detectors			
Detector	Resolution Microns	Separation Microns	Lifetime 10^{19} eV/gm
OPAL	25	2000	1
L3 GAS	30	600	1
MARK II	30	600	1
MULTIDRIFT	30	600	5
Silicon Detectors			
MSD 50 μm pitch	5-15	50	> 0.6
CCD 20x20 μm	6	20x20	0.6

Table 2

Multiple Scattering Load

for the MAC Vertex Chamber

	% RL
Titanium Liner	.21
3.5 cm Be Pipe	.32
VC Be Support	.22
6 Straw Layer	.76
Silicon 200 μm Thick	.2

Table 3

UA1 Calculated Probabilities of Reconstructing at least N Decay Vertices from $W \rightarrow t\bar{b}$ in a Vertex Chamber 2.5 cm from IP (90% Confidence Level)

$N = 0$	17%
$N \geq 1$	83%
$N \geq 2$	46%
$N \geq 3$	14%
$N = 4$	02%

Table 4

Accelerator Parameters and Minimum Vertex Chamber Radii

	x,y Emittances NRadian-M	Minimum Approach Distances in x and y (cm)
PEP	120 by 40	2.4 by 3.0
LEP	60 by 20	4.8 by 3.6
SLC1	0.3 by 0.3	2.5 by 1.6
SLC2	0.3 by 0.3	1.0 by .60

At hadron colliders, the minimum approach is set to 2-4 cm by beam-stay clear requirements.

FIGURE CAPTIONS

1. Typical charm decay event in a fixed target experiment.
2. Typical B_s $\bar{B}_s$ event configuration with two leptonic decays.
3. (a) shows the momenta distributions for $Z^0 \rightarrow c\bar{c}$. (b) shows the progressively softer momenta spectra expected for $Z^0 \rightarrow b\bar{b}$ and $Z^0 \rightarrow t\bar{t}$. The average momenta of charged Z^0 decay tracks for charm, beauty and top events are 8.3, 3.3 and 1.6 GeV/c respectively.
4. The impact parameter distribution in the absence of measurement errors expected for charged decay particles from Z_0 decays.
5. The precision in impact parameter determinations for a CCD detector 1 cm from the vertex at SLC and for the identical resolution and relative configuration of a LEP detector (~8 cm. from the vertex).
6. (a) shows the original MAC masking configuration and (b) shows the final MAC configuration with added small diameter shielded collimators 60 cm from the IP. Q1, Q2, and Q3 are quads and C1, C2, C3, C4, and C5 are shielding collimators.

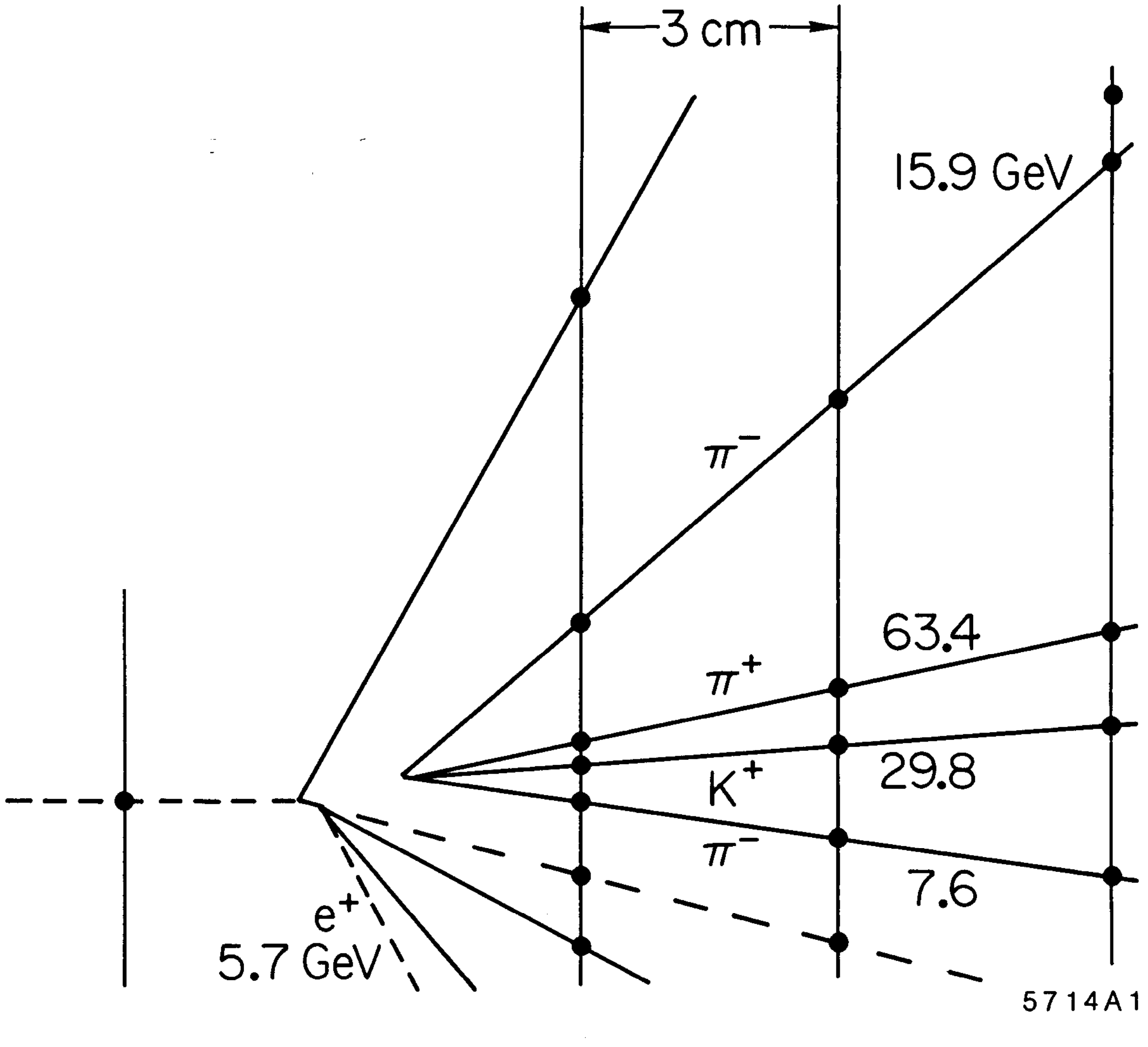

Fig. 1

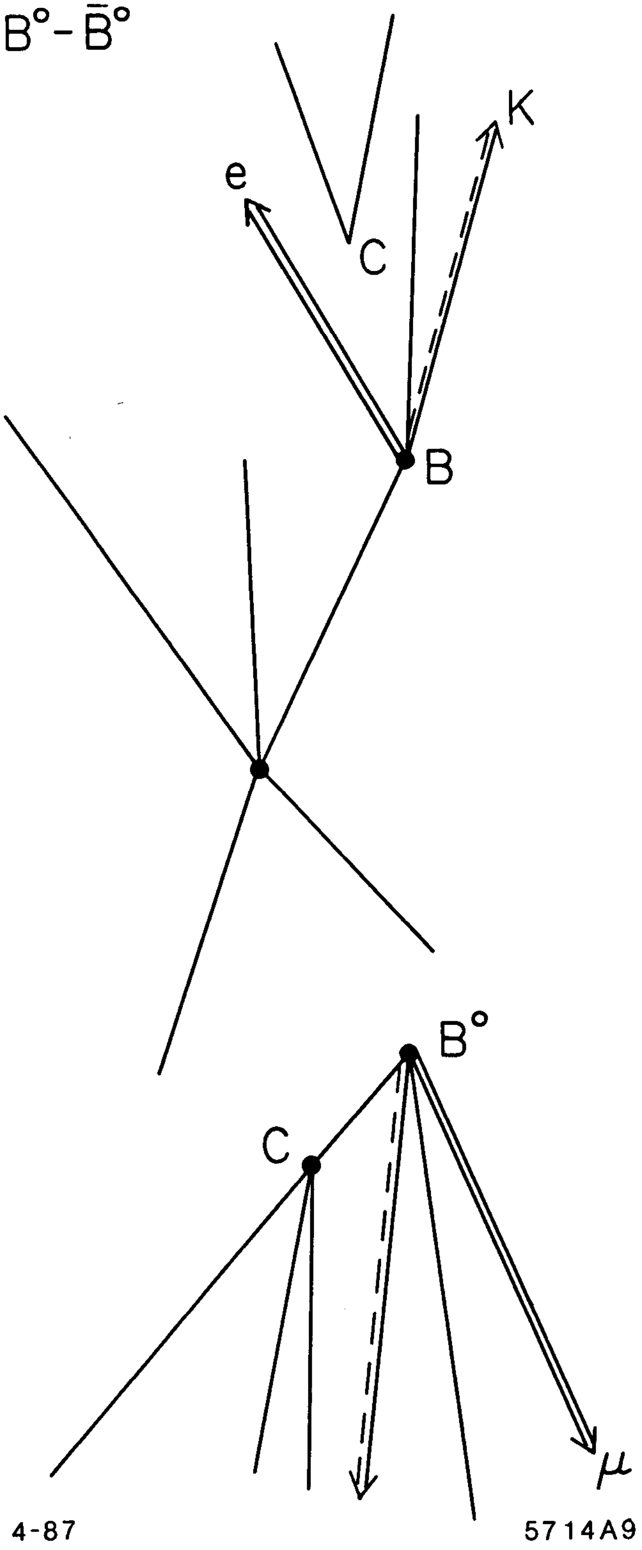

Fig. 2

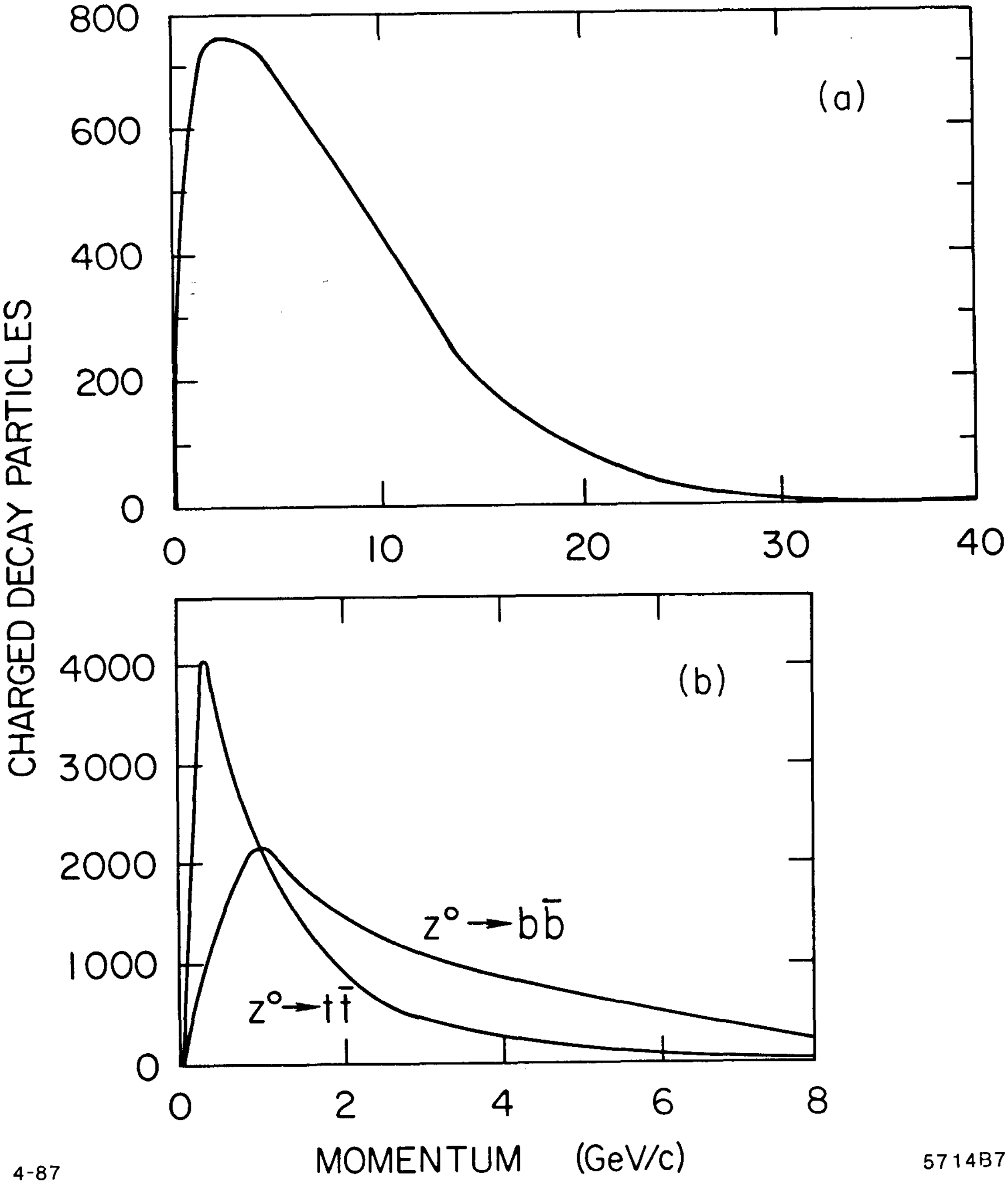

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Fig. 3

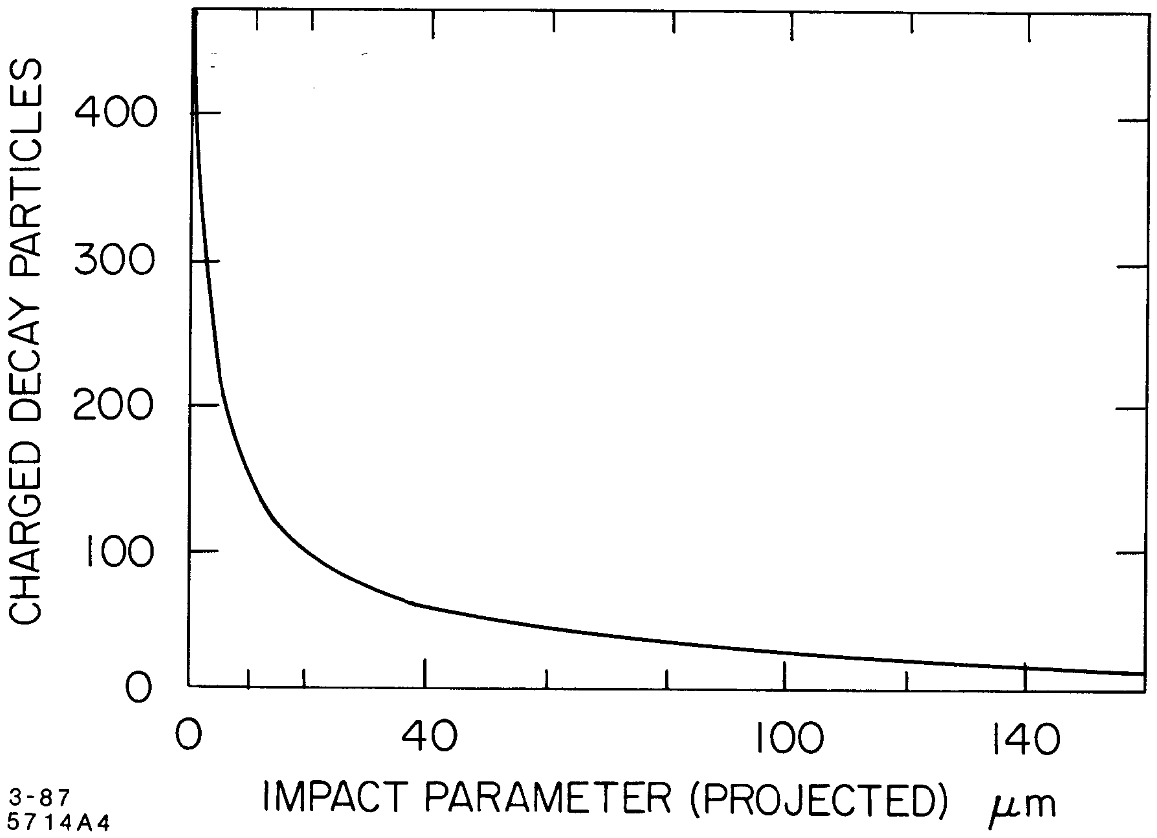
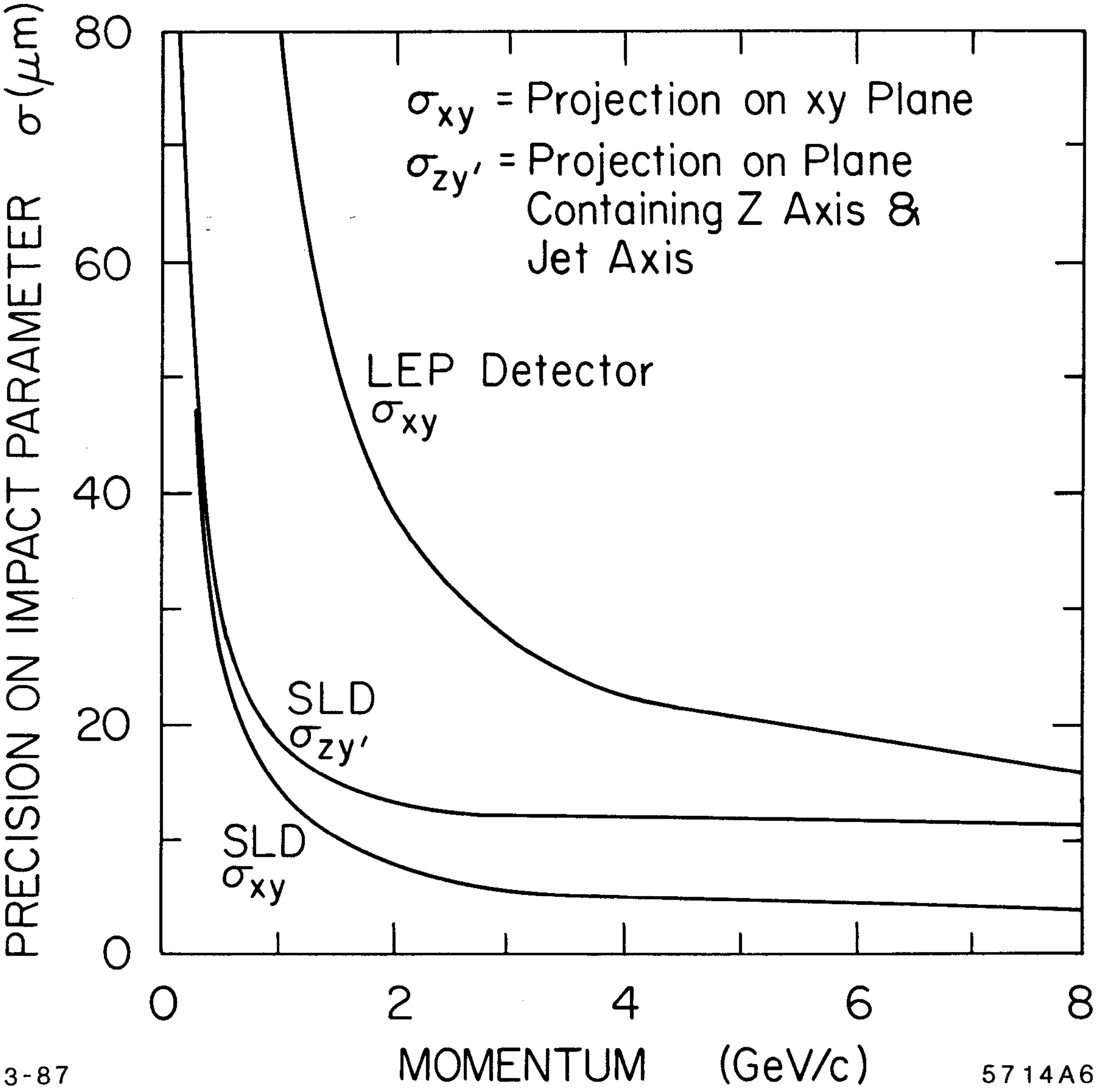

CHARGED DECAY PARTICLES
400
300
200
100
0
0
40
100
140
IMPACT PARAMETER (PROJECTED) μm
3-87
5714A4

Fig. 4



σ_{xy} = Projection on xy Plane
$\sigma_{zy'}$ = Projection on Plane Containing Z Axis & Jet Axis
LEP Detector σ_{xy}
SLD $\sigma_{zy'}$
SLD σ_{xy}
PRECISION ON IMPACT PARAMETER σ (μm)
0
20
40
60
80
0
2
4
6
8
MOMENTUM (GeV/c)
3-87
5714A6

Fig. 5

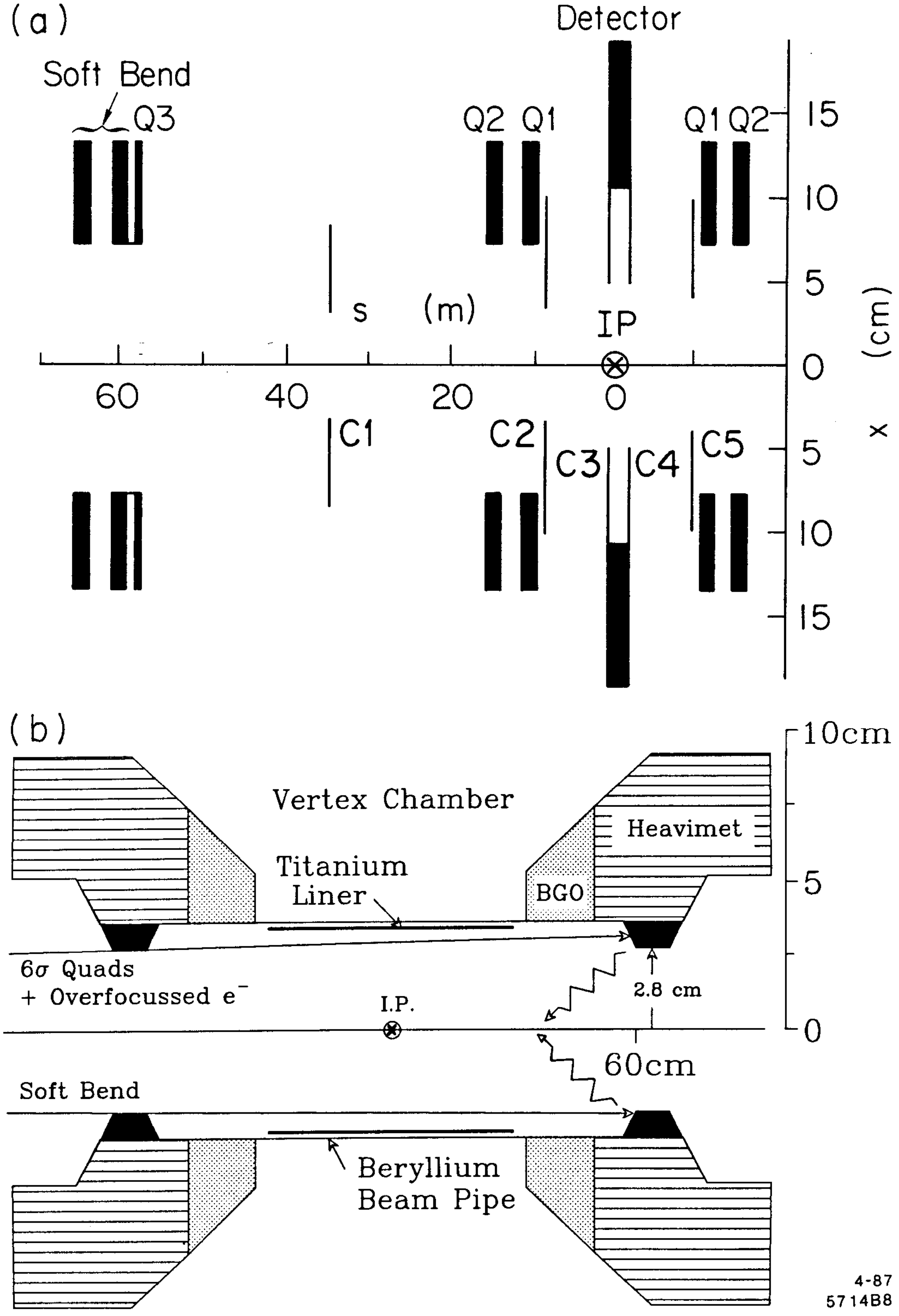

(a)
Detector
Soft Bend
Q3
Q2 Q1
Q1 Q2
15
10
5
s (m)
IP
0
(cm)
60
40
20
0
x
C1
C2
C3
C4
C5
5
10
15
(b)
10cm
Vertex Chamber
Heavimet
Titanium
Liner
BGO
5
6σ Quads
+ Overfocussed e⁻
2.8 cm
I.P.
0
60cm
Soft Bend
Beryllium
Beam Pipe
4-87
5714B8

Fig. 6