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CONCEPTS FOR A DØ SILICON TRACKER*

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INTRODUCTION

The purpose of this paper is to present the conceptual basis for a (highly) preliminary design of a Si tracker for DØ. It is intended to represent at least a portion of the reasoning that can help to ensure that the designs which receive detailed simulation later are those which have a good chance of meeting important criteria. Though these concepts have been sharpened by discussion with many DØ colleagues, the DØ collaboration is not necessarily committed to them.

Here we assume that the entire DØ tracker will be replaced in order to handle a nearly 100-fold increase over the luminosity for which it was originally designed. In particular, the TRD will no longer be available. In order to retain an excellent ability to identify electrons, one needs either a new, highly segmented TRD tracker, or the capability for magnetic analysis (permitting an E/p cut). Because the magnet appears likely to be cheaper, to require less R&D, and to greatly benefit the analysis of B decays, we adopt that solution. The cylindrical geometry of the DØ tracking volume is compatible with a solenoidal coil. A superconducting coil producing a central field up to ≈ 1.5 - 2 T would interpose less than 1 X_0 of material before the calorimeter, and appears to be a sensible choice. There is room immediately inside the coil for a high rate outer tracker, the detailed design of which is not central to this discussion.

ROLE OF THE SI TRACKER

If the DØ Si tracker consisted only of a barrel detector extending to small (< 10 cm) radius, as in the CDF SVX, its main function would be the identification of separated vertices, *e.g.* from B decay, in the central rapidity range $|\eta| < 1$. This range is sufficient for identification of $t \to Wb$ decays of a heavy top quark, whose production is central. However, if the DØ Si detector were to include a system of disks extending its coverage to $|\eta| \approx 3$, and if the disk outer radius were large enough ($\approx$ 15 cm) to permit useful momentum analysis of low $p_\perp$ tracks, two advantages for B physics would be gained:

- Acceptance for tagged B decays, assuming that the two B's are uncorrelated, would increase roughly as the square of the η range covered, or by about one order of magnitude.
- Identified muons that penetrate a shield of fixed thickness have a minimum transverse momentum proportional to $\sin\theta$. In the forward direction, decay muons from B's produced at correspondingly smaller $p_\perp$ could be studied, with a further ($\approx \times 10$) increase in muon acceptance.

These advantages are compelling enough that we pursue here the more ambitious alternative.

DIMENSIONS

In a tracker with such a wide η range, most of the Si is in disks spaced along the beam axis over the full tracking length available ($|z| < 135$ cm in DØ.) Therefore the size of the Si system is fixed primarily by the disk outer radius, which must be chosen carefully. In a solenoidal field, at forward angles, this system of disks will provide a roughly uniform resolution dp_T/p_T until η becomes so large that the highest $|z|$ disk is crossed at significantly less than its maximum radius. Beyond that point, dp_T/p_T increases with θ^{-2} if measuring error is most important, and with θ^{-1} if Coulomb scattering is dominant. We define the corner angle θ_c of the disk system using the track that crosses $z = 135$ cm at the maximum disk radius, and we define the useful angular range of the Si disk system by $\theta > 0.8\ \theta_c$. The disk radius R is then set by the useful range that is needed. Of course, enlarging the disks would not degrade the resolution at fixed θ, but the additional expense would be difficult to justify, especially considering that, for $\theta > \theta_c$, additional points on the track become available from the outer tracker.

How should the maximum disk radius R be set? One approach, following the corner-angle argument given above, emphasizes the desired tracking system acceptance. The DØ SAMUS muon system achieves an acceptance, averaged over azimuth, extending to η=3.2. Not accidentally, the DØ electromagnetic calorimeter retains a fine (0.1 × 0.1) segmentation out to the same η. A plot of the rapidity of muons with $p > 4$ GeV/c from decay of J/ψ arising from $B \to J/\psi\ K_S$ is peaked at $\eta \approx 2.1 \pm 0.9$, requiring good momentum measurement out to $\eta \approx 3$. So, for the Si disks, a useful angular range corresponding to $\eta \approx 3.1$ is required, or $\theta = 5.2°$; then $\theta_c = 6.4°$ and $R = 15$ cm.

Another approach considers the momentum resolution that is desired from the Si system alone (e.g. for corner tracks). As noted above, dp_T/p_T depends strongly on R: if $dp_T/p_T = Ap_T \oplus B$, A depends on R^{-2} and B on R^{-1}. For R =15 cm, for the Si alone in a 1.5T solenoidal field without beam constraint, $A = 0.02$ and $B = 0.06$ are achievable. Compared to the performance of *e.g.* the CDF central drift chamber, this level of resolution is unspectacular. Nevertheless it appears to be adequate for reconstruction of final states involving ψ's arising from decay of B's produced at low $p_\perp$, provided that the ψ mass constraint is used. Demonstration[1] of this adequacy requires a detailed simulation that will be described elsewhere. If R were chosen substantially below 15 cm, the Si momentum resolution would no longer be sufficient.

The choice $R = 15$ cm also satisifies a practical constraint. With supports and services, a Si system with this active radius will fit inside the 17.5 cm inner radius of the existing DØ TRD. This will allow early testing of prototype disks in the DØ environment.

SI BARREL

In considering the barrel Si detector for DØ, we have paid close attention to the SVX detector now being readied for CDF's 1991 run. The function of the two detectors is the same: identification of secondary vertices, e.g. from b decay, at central rapidity where tracks are detected in a powerful tracker outside, within a 1.5T solenoidal field. However, it would make no sense for DØ simply to copy the 1991 version of the CDF SVX. First, it is expected[2] that the 1991 CDF SVX must be replaced for later runs, for at least three reasons: readout chip speed, readout chip radiation damage, and drift of (DC coupled) readout chip bias due to radiation-induced strip leakage. Second, we have been encouraged to assume that the luminous region will be reduced in length to 12 cm rms. For vertex tagging in the central region, a four-layer barrel with the same radii as the 1991 CDF SVX, but only half the length, would provide adequate acceptance and tracking capability if its ends are capped by Si disks. Provisionally, we have adopted the SVX barrel dimensions (save for shortening by half) in order to facilitate the possible development of common solutions for runs beyond 1991.

DISK LAYOUT

The number and placement of Si disks can be set by requiring, for example, at least 5 double-sided Si wafers to be hit by tracks with $|\eta| < 3.1$ that are not geometrically accepted by the full outer tracking system. This allows a 2C fit in the bend view from Si information alone. If the track is geometrically accepted by the outer tracking system, only 4 hits are required. For tracks directed toward $+z$, these requirements are imposed for the 80% of primary interactions with $z < 10$ cm. The number of disks needed to satisfy these requirements is minimized at 11 per end provided that their spacing is set by a uniform progression in $ln(z - 10\text{ cm})$. A possible layout is displayed in Fig. 1. The total Si area would be about 2 m^2.

WAFER LAYOUT

For Si wafer layout, the fundamental issues are strip orientation and strip length. First we consider the barrel geometry. For barrel layers in a solenoidal field, the natural strip orientation is axial. Double-sided wafers allow stereo strips at angles ranging from 5 mrad (one SSC conceptual design[3]) to 90°.

Because most of the DØ Si area is in the disks, and disk systems so far are uncommon[4], we have directed most of our initial attention to that geometry. The main choices of strip orientation are radial strips, usually with small-angle stereo, or parallel strips. Radial strips measure p_z, while parallel strips measure p_z multiplied by angular factors. Relative to large stereo angle, small-angle stereo degrades the resolution in the least well measured coordinate and increases the probability for hits to be merged (in three dimensions); but, in the context of particular algorithms[3], it reduces confusion in matching stereo hits. These choices should continue to be studied. We return to the issue of strip orientation near the end of this paper, where the implications for triggering are discussed.

The choice of strip length is often debated. Many of the strip length issues are common to barrel and disk geometries, but there are some differences. Physically the length of (axial) barrel strips is limited only by the length of the barrel, while (radial) disk strips are limited in length to the difference between inner and outer radii. That difference is only 12 cm in the DØ Si disks, much shorter than the present SVX strip length of 25.5 cm.

At the other extreme, Spieler[5] has argued, assuming 20 μW/channel readout power and 70 nsec peaking time, that total power dissipation is minimized for a strip length of 1 cm. This is because the preamp signal to noise ("S/N") decreases inversely with the input capacitance, nearly proportional to strip length. If S/N is to remain fixed as strip length is increased by a factor G, FET channel widths and preamp power per strip must increase by G^2. Then total preamp power scales with G, readout power with $1/G$, and a minimum obtains. A detailed optimization for Tevatron as opposed to SSC conditions has not yet been performed. However, since the optimum strip length is also proportional to the square root of the preamp peaking time, and the crossing time at the Tevatron will be 25× longer than at the SSC, it is doubtful that strips as short as 1 cm could be justified for the Tevatron, even if one were willing to accept the increased complexity that would be implied.

The choice of strip length is also affected by consideration of increased shot noise due to radiation-induced strip leakage. (We assume that the preamps will be AC coupled so that this leakage cannot influence the preamp bias.) This noise is proportional to the square root of the product of strip length and preamp peaking time. Ellison[6] has calculated the radiation damage expected for axial strips at a variety of radii. He considered beam-beam collisions through both the charged fluence and the neutron fluence from DØ calorimeter albedo, but did not include beam-gas collisions and other losses. For a 6 cm strip with a CR-RC shaping time of 200 nsec, exposed to 0.6 fb^{-1} at 3 cm radius, he computed a radiation-induced equivalent noise charge ("ENC") of ≈ 450 electrons, to be added in quadrature to the preamp noise. With an input capacitance of 12 pF, the SVX readout chip in double-sample mode has an ENC of ≈ 1100 electrons, which would make the radiation-induced ENC an 8% effect. If the radius is increased to 5 cm (10 cm) the radiation-induced ENC drops to 320 (250) electrons. Provisionally, we infer that radiation-induced shot noise is an important consideration, but, nevertheless, it is unlikely to force the DØ design toward strips as short as 1 cm, except possibly at the smallest radii.

Pending more detailed optimization of strip length, we have considered a particular layout of Si wafers to provide a framework for visualizing the detector. As in the CDF SVX, each barrel layer is made of 24 "ladders" (12 azimuthal sections × 2 ends). In DØ a ladder is only 12.8 cm long and might be composed of two 6.4 cm wafers, with strips that could be wire-bonded and read out at the end, or (perhaps in the innermost layer) read out individually. Then the barrel would contain 192 wafers and (allowing for stereo readout) at least 600 readout chips of 128 channels each.

A possible layout of wafers on each disk is displayed in Fig. 2. The inner ($3<r<10$ cm) and outer ($10<r<15$ cm) annuli each consist of 12 wafers. Both types of wafer can be cut from 4 inch dia Si crystals. The analog to the barrel "ladder" is a "wedge" consisting of one inner and one adjoining outer wafer. If strips on the inner and outer wafers are wire-bonded together, all readout chips can be located outside a 15 cm radius, reducing material in the active volume and greatly simplifying the cooling. (Again, as an alternative, the wafers could be read out individually.) This disk system would contain 480 double-sided wafers and at least 6336 128-channel readout chips.

ELECTRONICS

The DØ Si tracker is intended to be fully compatible with use of the existing SVX readout chip, with the upgrades in radiation hardness and speed that are already planned[7] and underway for future CDF use. Specifically, if the SVX readout chip risetime is decreased by a factor of four, from 700 to 175 nsec, the S/N is reduced by a factor of two if the preamp power is held fixed. This factor is fully recouped when one takes into account the factor of >2 in S/N gained from the fact that the DØ strips are at most half as long as those in the present SVX. Since in the DØ geometry (as in the SVX) the readout can be confined to small volumes that are easily accessible for cooling, any additional S/N headroom that is needed can be obtained by modestly increasing the channel widths and bias currents. Conversely, the DØ Si tracker could take advantage of any benefits offered by a newly designed chip with characteristics appropriate to moderate strip lengths (5-10 cm) and risetimes (≈ 200 nsec).

TRIGGERING

To conclude this paper, we discuss the implications for triggering of the geometries being considered for the DØ Si strip system. Here "triggering" refers broadly to computations that might be performed at any DØ triggering level (including Level 2) to estimate track momenta (allowing *e.g.* a preliminary E/p cut for electron identification), or to enrich the sample of data with secondary vertices (*e.g.* from B decay). Such computations are distinguished from the full offline analysis by (hopefully) much greater simplicity, dramatically reducing the computing time. The possible level of a Si trigger also depends critically on the speed with which data stored on the readout IC can be made available to a trigger processor – an issue which is not addressed here.

For the disks, two qualitatively different geometries are possible:

- Strips that are parallel to each other. Typically a track would encounter planes of strips having 3 or 4 different directions; for ≥ 2 of these directions, enough planes must be crossed (≥ 4 without a vertex) to get ≥ 1 constraint on a projected track. The strip directions considered make stereo angles with each other in the range $\approx 30°$ - $60°$.

- Strips that are radial. These may coexist with strips that are parallel. The triggering possibilities discussed in this note focus on the radial strips when they are available.

For the barrel, axial strips are a component of most designs. They offer triggering possibilities similar to those of radial strips.

Radial and Axial Strips

Geometry. The coupling between the radial and axial strip geometry and the solenoidal field is intimate. The details of helical trajectories in the solenoidal field are important. To establish notation we set down some elementary relations. Consider a cylindrical coordinate system in which r is the radius $\perp$ to the z axis. Choose $z = 0$ to be at the primary vertex and $\phi = 0$ to be the initial direction of the track under consideration. Take θ to be the initial polar angle of the track, and

$$\rho = \frac{p \sin\theta}{0.3B}$$

to be the (constant) radius of the helix (ρ in m, p in GeV/c, B in T). Then

$$\phi = \frac{z \tan\theta}{2\rho}$$

$$r = 2\rho \sin\phi$$

$$r = 2\rho \sin\frac{z \tan\theta}{2\rho}$$

are the relations between ϕ, z, and r.

Next consider the first derivatives of ϕ *vs.* z and r. The plot of ϕ *vs.* z is a straight line; the slope

$$\frac{d\phi}{dz} = \frac{0.3B}{2p_z}$$

measures the longitudinal momentum with no knowledge of r necessary. The plot of ϕ *vs.* r is an arc sinusoid, which becomes a straight line in the high $p_\perp$ limit. The slope

$$\frac{d\phi}{dr} = (4\rho^2 - r^2)^{-1/2}$$

$$\frac{d\phi}{dr} \approx \frac{0.3B}{2p_\perp}\left(1 + \frac{r^2}{8\rho^2} + \ldots\right)$$

is constant within a small correction. In the worst case of interest to DØ silicon tracking, $r = 0.15$ m and $\rho = 0.5$ GeV/c $/((0.3)(1.5\text{T}) = 1.11$ m, $d\phi/dr$ is corrected by only 0.23% of its value. Thus, for practical purposes, the plot of ϕ *vs.* r is also a straight line, measuring the transverse momentum with no knowledge of z necessary.

Pattern recognition. The fact that tracks emanating from the beam line are straight in ϕ *vs.* z, and essentially straight in ϕ *vs.* r, provides a straightforward basis for recognizing them. Consider pairs of hit ϕ strips on adjacent disks. Each pair defines a line $\phi = \phi_0 + q(z - z_0)$, where $z_0 \approx 0.5$ m is a conveniently defined plane within the collection of disks being considered. If the slope $q = 0.3B/2p_z$ is small enough that p_z is in an interesting range, the pair is allowed to contribute one entry to a scatter plot of ϕ_0 *vs.* q. Clusters in that scatter plot reveal possible tracks. A limited number of hits that contribute to pairs in the region of a cluster are then subjected to fits in ϕ *vs.* z in order to finalize the identification of those hits that are part of the track. In the barrel, pattern recognition can follow the same strategy, with r substituted for z.

Displaced vertex trigger. Now we consider the more general case that the track does not emanate from the beam axis. New coordinates are needed. Imagine extending the particle's helical track so that $-\infty < z < \infty$. Define b as the distance of closest approach between the axis and the (extended) helical track, with b positive (negative) if the beam axis is outside (inside) the helix. Define point A to be the point on the beam axis most closely approaching the helix, and point H to be the point on the helix most closely approaching the beam axis. Then $|b|$ is the distance between H and A. Define the azimuthal coordinate ϕ to have H as its origin. The direction of the helix at that point defines $\phi \equiv 0$. Thus ϕ is very similar to the same coordinate used above. Define a new azimuthal coordinate ϕ' to have A as its origin. Then ϕ' is the azimuth measured by the Si detector system, which is symmetric about the beam axis. At the distance of furthest approach, $\phi \equiv \phi' \equiv \pi/2$. At the distance of closest approach, $\phi' = \pi/2$ for $b > 0$, and $\phi' = -\pi/2$ for $b < 0$.

Next we define the other cylindrical coordinates, r and z. At both points H and A, $z \equiv 0$. Take $r \equiv 0$ at H and $r' \equiv 0$ at A. Then r' is the radius that would be measured by a Si detector system symmetric about the beam axis; since $|r' - r| \leq |b|$, r' and r are nearly the same. It will be convenient to frame the discussion that follows in terms of r, even though it is r' that is measured. This is easily justified for triggering on radial strips in disks, since only very crude knowledge of r is involved. For triggering on axial strips in the barrel, we take advantage of the fact that $r d\phi/dr \approx r/2\rho < 0.068$ for tracks of interest. Then the error in $r\phi$ introduced by the approximation $r' = r$ is less than 6.8% of b, which will not substantially diminish the ability to distinguish $b \neq 0$.

The advantage of the above coordinate choices is that the equations relating ϕ, z, and r are exactly the same as above. It remains only to relate ϕ to ϕ', the measured azimuth:

$$\phi' = \tan^{-1}\frac{\beta + \sin^2\phi}{\sin\phi\cos\phi},$$

where $\beta = b/2\rho$. For b as large as 2 mm, $\beta < 10^{-3}$; $\sin\phi \approx \phi$ to within 4×10^{-4} as before. Then

$$\phi' \approx \tan^{-1}(\phi + \beta/\phi).$$

Note that $\beta/\phi \approx b/r$. With $b < 3$ mm and a first measurement at $r \approx 30$ mm, $b/r < 0.1$. Then, to an accuracy of better than $\approx 1\%$,

$$\phi' - \phi \approx b/r.$$

This last equation is the basis of the displaced vertex trigger. Consider the plot of ϕ' *vs.* r made using hits on axial strips in the barrel. They lie on a nearly straight line defined by

$$\phi' \approx \phi_1 + \frac{0.3B}{2p_\perp}r + \frac{b}{r},$$

where ϕ_1 is a constant. A simple fit yields the transverse momentum $p_\perp$ and the distance of closest approach b.

For the barrel, this result is unremarkable. Each axial strip is located at well-defined values of x and y as well as r and ϕ'. Take the initial direction of the track to be along $\hat{x}$. Then a parabolic fit to y *vs.* x also can be used to find the transverse momentum and distance of closest approach: the analysis can be carried out in Cartesian as well as cylindrical coordinates.

However, the analysis of hits on radial strips in disks must use cylindrical coordinates. Consider the plot of ϕ' *vs.* z made using these hits. They lie on a nearly straight line defined by

$$\phi' \approx \phi_1 + \frac{0.3B}{2p_z}z + \frac{b}{r}.$$

In order to include the last term in the fit, one must estimate r. If the track is thought to have entered disk m at an average radius r_m near 30 mm, and to have exited disk n at an average radius r_n near 150 mm, one can approximate

$$r \approx r_m\frac{z_n - z}{z_n - z_m} + r_n\frac{z - z_m}{z_n - z_m}$$

and proceed to fit p_z and b as in the barrel case. For disk spacings typical of those considered for DØ, the error in r is of order 25%, assuming full efficiency. In the fit it appears mainly as an error in b that is roughly proportional to b. With perfect alignment such an error is probably tolerable: it will not cause tracks with $b = 0$ to appear to have b large enough to trigger.

Effect of beam misalignment on displaced vertex trigger. It is not necessary for b measurement that the barrel Si detector be precisely centered on the beam, provided that its axis is parallel to the beam. For example, if the x and y of the beam are known, an x-y fit to the data readily yields b relative to the known beam position.

However, the effect of beam misalignment on the radial-strip disk trigger is disastrous. Suppose that the beam is misaligned by a distance δ at an azimuthal angle α. Then the analysis of ϕ *vs.* z is expected to result in a false distance of closest approach $b_{false} = -\delta\sin\alpha$. One obtains b by subtracting $b = b_{meas} - b_{false}$. Then the fact that b_{meas} is known only to $\approx$ 25%, due to the need to approximate r, leads to a large error in b if $b_{false} \geq b$. Reliable triggers may be obtained only at particular azimuths where $\alpha \approx 0$ or π.

The requirement that the beam remain centered on the Si disk system to within $\approx 100\mu$ over most of its length seems challenging. Either the beam positions and angles must continually be trimmed (while maintaining luminosity), using a feedback loop based on analysis of Si hits, or the position of the Si detector itself must be adjusted. To maintain the alignment between Si strips and scintillating fibers, the whole tracker would need to be moved. It is difficult enough to maintain the position of the Si detector in a fixed system, much less a moving one.

Disks with Parallel Strips

In fixed target experiments, where the z of the primary interaction can be assumed to be that of the target foil(s), it is possible with planes of parallel strips to measure a projection of the (vector) impact parameter using only a single track in a single view. Other views can give additional triggers without the need (at the trigger stage) to associate tracks found in different views.

When the z of the vertex is not known *a priori*, as in the collider environment, tracks from the event itself must be used to determine it. Because some fraction of tracks in B events do not come from the primary vertex, its location is best determined by statistical methods using a sufficiently large number of tracks that are consistent with a common vertex. Then one may trigger on one or more remaining tracks which are not consistent with that vertex, again using only a single view. The presence of multiple interactions per crossing complicates but might not defeat this strategy. The key issue for impact parameter triggering in the parallel-strip case appears to be the computing time and (for difficult-to-program processors) the algorithmic complexity required to establish a reliable set of primary z vertices.

To discuss the possibility of obtaining a fast estimate of track momentum by using information from parallel strips oriented in a single direction, we need more formulæ. Suppose a set of strips measures the Cartesian coordinate u, which makes an angle γ with the x axis, so that $u = x\cos\gamma + y\sin\gamma$. Then in the solenoidal field

$$u/\rho = \sin\gamma - \sin\left[\gamma - (z/\rho)\tan\theta\right]$$

is the trajectory in u *vs.* z of the measured points. Note that θ, γ, and ρ are constant for any particular track. Make the quadratic fit

$$u = u_0 + mz + kz^2/2.$$

The $z = 0$ intercept u_0 is the projected impact parameter discussed above. In the high momentum limit $r/\rho \ll 1$ ($= 0.135$ in the worst case of interest to DØ) one has

$$p_z \cot\theta \csc\gamma = \frac{0.3B}{k},$$

$$\tan\theta = m\sec\gamma.$$

The quantity measured by the (projected) track curvature, $p_z \cot\theta\csc\gamma$, can be related to something of greater physical interest, *e.g.* p_z or $p_\perp$, only if the track azimuth γ is supplied externally. Likewise, if γ is supplied, θ may be obtained from the (projected) slope m.

Even if γ is known, p_z may not be well enough measured. The curvature k is proportional to $(\tan\theta\sin\gamma)/p_z$. If either θ or γ is too close to 0, a fixed p_z will result in a curvature that is too small to be measured with acceptable precision. Likewise, if γ is too close to $\pm\pi/2$, for a fixed θ the slope m will be too small to be measured with an acceptable fractional error.

Triggering Summary

Axial strips in Si barrel layers furnish a trigger on b, the distance of closest approach of the track to the beam axis. The barrel axis must be parallel to the beam. The hits lie on a line in ϕ *vs.* r that is straight, for practical purposes, except for a term $\approx b/r$ that measures b. The straightness of this line is useful in pattern recognition, and its slope measures $p_\perp$.

Radial strips in Si disks furnish a trigger on b provided that the Si disk system is *centered* on the beam axis over most of its length to an accuracy not much worse than the error in b that is desired. Achieving that degree of alignment would be difficult. The hits lie on a line in ϕ *vs.* z that is straight except for a term $\approx b/r$ that measures b when r is approximated. The straightness of this line is useful in pattern recognition, and its slope measures p_z.

Hits on parallel strips in Si disks that measure a single coordinate lie on curved trajectories. The curvature measures $p_z\cot\theta\csc\gamma$, where θ and γ are the initial polar and azimuthal angles of the track. The slope measures $\tan\theta\cos\gamma$. Provided that other tracks can be used to fix the z_{vertex} of the primary vertex, the intercept with the plane $z = z_{vertex}$ measures the projection of the (vector) impact parameter into that view. Other momentum estimates and projections of the impact parameter can be obtained using parallel strips that measure other views. Disks with parallel strips need not be centered on or parallel to the beam axis.

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FIGURE CAPTIONS

Fig. 1. Layout of the system of barrel layers and disks, with overall dimension 2.7 m × 0.3 m dia. Each polygonal facet represents a Si wafer.

Fig. 2. Layout of double-sided Si wafers on a disk, with inner (outer) radii of 30 (150) mm. Solid and dashed wafers are in different planes enabling slight overlap. As an example, parallel strips are drawn. Rising (falling) hatches show strip directions on the top (bottom) wafer surfaces, making a stereo angle of 30°. The strip pattern has 6-fold symmetry.

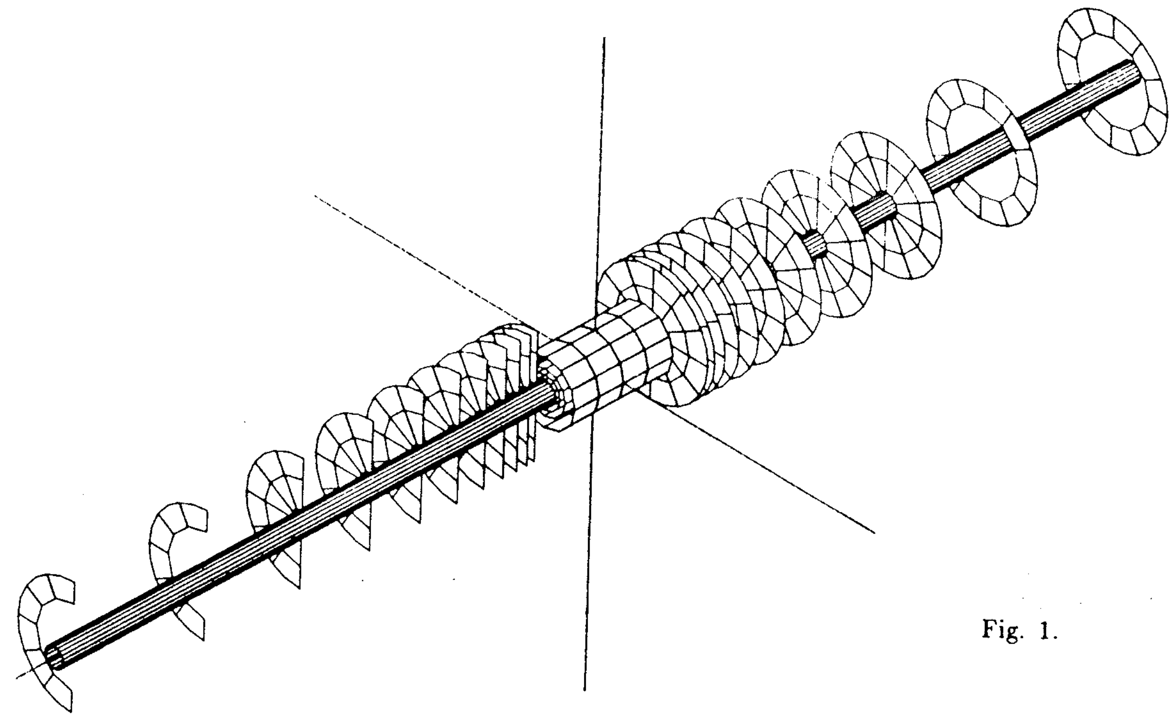

Fig. 1.

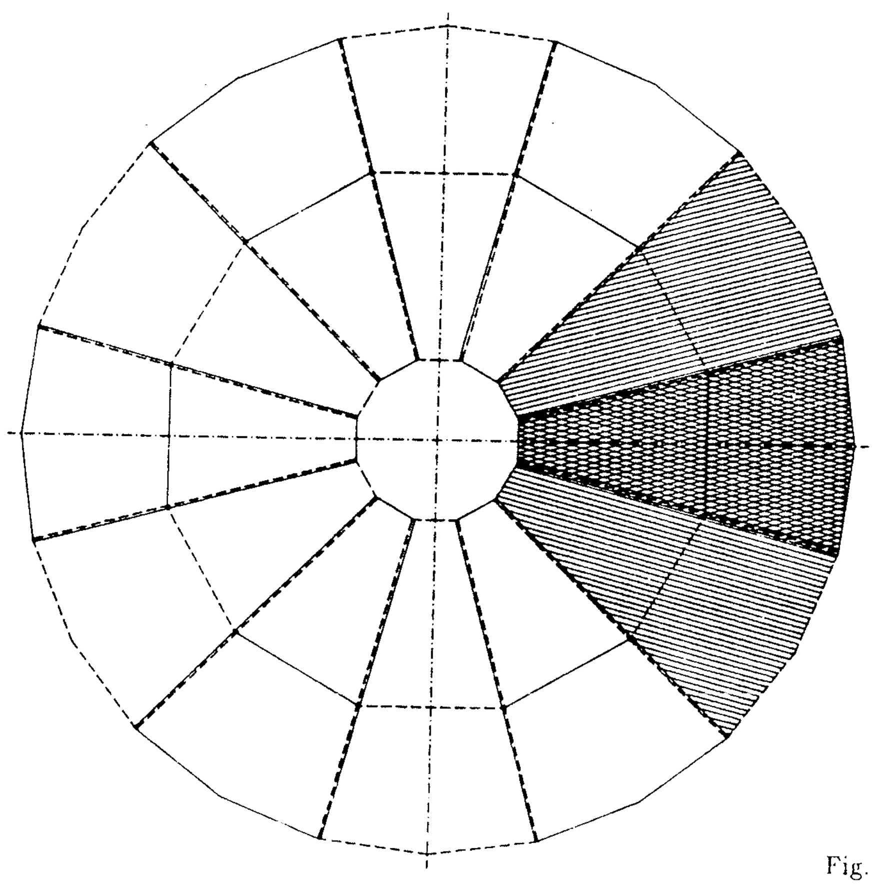

Fig. 2.