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SDC
SOLENOIDAL DETECTOR NOTES

SIMPLIFIED CENTRAL Si TRACKER FOR SDC

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Simplified Central Si Tracker for SDC

1. Summary. This note reports an effort to improve the conceptual design of the SDC central Si tracker by

- Raising the S/N and/or lowering the power dissipation by reducing the maximum strip length from 18 to 8 cm, with each Si detector independently read out.
- Eliminating fragile "Si bridge" multi-detector subassemblies while retaining the advantages of "cooling rings" at every readout IC.
- Using a modular, open, uniform, and rugged structure in order to simplify assembly, alignment, repair, and transport of the finished device.

In the new conceptual design considered, these objectives are achieved without sacrificing the present levels of performance, material thinness, and likely cost. Specifically, numbers of cooling rings, support rings, foam cylinders, and readout IC's are up, respectively, by $\times 1.08$, $\times 1.31$, $\times 1.33$, and $\times 1.28$; the Si area, number of 4 inch diameter Si wafers, and number of wire bonds are down, respectively, by $\times 1.33$, $\times 1.08$, and $\times 1.81$.

2. Scope. This report addresses the central ($r < 0.5$ m, $|z| < 0.5$ m) region of the SDC Si detector, in the LoI comprising ten barrel layers capped by ten disks on either end. It is assumed that any alternative central Si tracker would occupy essentially the same volume. Only rough concepts are discussed; no new engineering effort is reported. Other issues important particularly for vertex measurement, such as the radius of the first detector and the measurability of both components of the impact parameter, also are not addressed in this report.

3. LoI design. Details of the "long-strip" LoI design "*A*" are taken from Ref. 1. A side view is shown in Fig. 1. Ten barrel Si layers meet ten Si disks at θ=45° and again at 135°. At the same azimuth, up to (12) 6×3.2 cm^2 Si detectors from two adjacent layers are glued into "Si bridges" up to 36 cm long. The bridges are read

out and supported only on the ends. Ends that are read out are supported by hollow cooling rings from which heat is removed by evaporation from within; other ends are fixed by support rings. The rings are held by foam cylinders, attaching at the ends to space-frame elements that are not shown.

A few rough numbers characterizing this design appear in Table 1. To facilitate comparison with other layouts, simplifying assumptions are made there even though a more exact design has been worked out.[1] Calculated Si areas approximate barrel layers as perfect cylinders, and disks as perfect annuli. In the barrel, the number of detectors around the azimuth is approximated as the cylindrical circumference divided by the detector width (3.2 cm), rounded up to the nearest even integer. In the disks, detectors are 3.2 cm wide at the radius where they are read out; the number of azimuthal elements is rounded up to the nearest integer. At all readout IC's the strip pitch is 50μ.

With these approximations, there are 19.29 m^2 of double-sided Si, supported by 24 cooling rings and 26 support rings. The central tracker contains 10356 double-sided detectors, which may be fabricated from 5178 four inch diameter Si wafers. The detectors are read out by 44820 128-channel readout IC's, and are connected to the IC's and to each other by 1.33×10^7 wire bonds.

Unusual aspects of this layout include the self-supporting Si structures with a span up to 36 cm, and the wide range of Si strip lengths (4.5 to 18 cm, with an average of $\approx$13.5 cm). After assembly onto their respective foam cylinders, half of the detectors (on the layers furthest from the cylinders) are readily visible for survey etc. Clearance for cables, services etc. along the 45° crack between barrel and endcap layers is tight.

4. New design. A side view of the new design "*B*" is shown in Fig. 2. Its main differences from design *A* are

- Eight layers with unit geometric efficiency, in place of ten with $\approx$95% efficiency.[1] In both cases the minimum number of geometrically accepted hits is eight.
- Individually read out 8×3.84 cm^2 Si detectors, in place of 6×3.2 cm^2 detectors that are wire bonded together. The minimum S/N is raised $\times2$, or the power dissipation is cut $\times2.8$.
- Barrel-endcap interfaces with a 2 cm clear path near 45° and 135°. The interfaces are staggered over $\Delta z = 4$ cm, small compared to the 16 cm full length of the

luminous region.

- Foam support cylinders that are integral with the cooling and support rings. After assembly onto their rings and cylinders, all Si detectors are easily visible for survey and accessible for repair.

Features of design A that are *retained* include

- Busing and evaporative cooling of each readout IC by means of an immediately adjacent cooling ring. No detector carrier or distributed cabling scheme is required.
- Si detector fabrication from 4 inch diameter wafers. In design A, the two-detector pattern has a diagonal of 8.85 cm; in design B, the detector diagonal is 8.87 cm.
- Support of Si detector subassemblies by (cooling or support) rings at the ends. In design A the subassembly is a Si bridge; in design B it is a single detector.
- Mechanically independent barrel subassemblies organized around foam cylinders that are supported by space-frame elements (space frames are not shown in Figs. 1 and 2).
- Disk subassemblies, also supported by space-frame elements, that are mechanically independent of the barrel.

We return below to a more detailed comparison of the designs.

Table 2 displays the numbers characterizing design B, with the same assumptions as in Table 1. Below the grand totals are summarized for both Tables:

Quantity	Design A	Design B	B/A
Si area (m^2) (cylinders + disks)	19.29	14.47	1/1.33
No. of cooling rings	24	26	1.08
No. of support rings	26	34	1.31
No. of foam cylinders	3	4	1.33
No. of Si detectors	10356	4780	1/2.17
No. of 4 inch diameter Si wafers	5178	4780	1/1.08
No. of 128-channel readout IC's	44820	57360	1.28
No. of wire bonds (Si-Si + Si-IC)	1.33×10^7	0.73×10^7	1/1.81

5. Detailed comparisons. First we discuss the four main aspects of design B in the order used above. We conclude with some observations on cost and material.

- Eight layers with unit geometric efficiency.

When multiple Si detectors are bonded together for readout by a single IC, geometric inefficiencies arise. The bonded detectors usually lie in the same plane. If so, dead regions at the ends of detectors (guard ring, voltage distribution) cannot be overlapped by live regions. Reading out stereo strips may require introducing triangular regions at the sides of the detector which are not covered both by axial and stereo strips. For fixed stereo angle these triangular areas are proportional to the square of the strip length. The geometrical inefficiency per layer in design A is estimated[1] to be 5%. If these inefficiencies are uncorrelated, in 10 layers there would be a 1.2% probability of obtaining fewer than 8 hits, regarded[1] as the minimum for robust pattern recognition.

When Si detectors are individually read out as in design B, in principle dead areas in one detector can overlap live areas in adjacent detectors, yielding a geometrical efficiency approaching unity. Then, in design B, 8 layers should suffice.

It may be argued that it is better, in design A, to get typically 9 or 10 hits, as opposed to 8 in design B. That can depend on the pattern recognition algorithm. "Vector" algorithms which pair hits on adjacent layers depend heavily on high efficiency. For example, of the 9 adjacent pairs that can be formed from 10 layers, as few as 5 pairs remain if hits on 2 layers are missing. The same 8 hits on 8 layers yield 7 pairs.

The layers forming pairs in design A are separated by 3 cm, while those in B are 4 cm apart. Pattern recognition in design B will consider more false pairs, but will benefit from improved angular resolution per pair and for the shorter (8 *vs.* 13.5 cm) average strip length. Consequent moderate differences in pattern recognition capability are possible and should be modeled.

The momentum resolutions of the two designs should be little different, since $\Delta r \equiv r_{max} - r_{min}$ is nearly the same: $\Delta r_A = \Delta z_A = 27$ cm; $\Delta r_B = \Delta z_B = 28$ cm. The vertex resolution of design B should be slightly better, since the minimum barrel radius is reduced from 18 to 16 cm, and the minimum disk radius from 15 to 14 cm. This slight contraction is in accord with recent progress[2] in understanding charged and neutral fluences and their effect on Si type reversal, and with the substantial reduction in radiation-induced shot noise expected when the detector is operated at 0°C.

- Individually read out 8×3.84 cm^2 Si detectors.

With a reduction in maximum strip length from 18 to 8 cm, the maximum source capacitance drops by a factor of $\approx$2. If preamp power is fixed, this improves the minimum S/N by nearly the same factor. Alternatively, if the S/N is fixed, the preamp power (per preamp) is reduced by a factor of $\approx$4.

Spieler[3] has calculated the dependence on strip length of *total* power for the Si front end electronics. If the total power is minimized for 6.2 cm strip length (readout power of 500 μW/channel, bipolar input transistor), reducing the strip length from 18 to 8 cm cuts the total front end power by a factor of 1.6. This assumes that the number of preamps scales inversely with the strip length. To compare designs A and B, we must correct for the actual number of preamps, which is larger in design B by $\times1.28$, not $\times18/8 = 2.25$. Then, for fixed S/N, the *total* power consumed by Si front end electronics would be smaller in design B by $1.6\times2.25/1.28 = 2.8$. This is an important factor. For example, a table of weight estimates has been presented[4] in which 46% of the total weight of the Si tracker is devoted to power busing.

Another issue is the effort required to align and fasten the Si subassemblies (bridges or individual detectors) on their rings. It may be argued that aligning and fastening the longer Si bridges in design A is easier, since (once the bridges are fabricated) fewer subassemblies need be installed. Comparison of designs A and B in this respect is complicated by the fact that the bridges are 3-dimensional objects with more alignment degrees of freedom than the $\approx$2-dimensional Si detectors. Also, in design A the Si bridges are captured by their pair of cooling or support rings; it is at least challenging to visualize installing the second through n^{th} bridges once the rings have been fixed by installation of the first.

A more straightforward comparison of assembly and alignment effort can be made if in design A it is imagined that one bridge of up to 12 detectors in two layers is replaced by two bridges of up to 6 detectors, each in only one layer. Necessary stiffness could be provided by "Si rails", as has recently been proposed.[5] Then, in design A, the total number of (half) bridges to be attached to the barrel is 2214 (Table 1). In design B, 3056 detectors are attached to the barrel (Table 2). This is not a much larger number. Considering that the individual detectors are smaller and more rugged than

the Si bridges, we estimate that aligning and fastening the detectors to the rings is comparably difficult in each design.

As a final note, the Si detectors for design A have at least 12 different geometries, while in design B there can be as few as 5 geometries. Design A also involves at least 12 different geometries in which the Si detectors are glued into bridges.

- Staggered barrel-endcap interfaces.

In design A the barrel-disk interface is at θ=45°, chosen to minimize material crossed by the tracks. In order to allow as many tracks as possible to be analyzed entirely either in the barrel or in the disks, the transition is not staggered. No clear path for cables, services, or supports is immediately evident (Fig. 1).

In design B the barrel-disk interface is still near 45°, but it is staggered over $\Delta z = 4$ cm. This is chosen to permit good geometrical acceptance through the transition region while maintaining a 2 cm clear path for cables, services and supports. Also, all the Si detectors can be exactly 8 cm long.

To what extent does the staggered interface of design B compromise the goals of design A? The main issue is whether the transition from barrel to disk is sufficiently abrupt. Consider a track emanating from the axis at $z = -4.7$ cm (4.7 cm is the median $|z|$). In design A (B) it fails to cross all barrel layers for $\theta < 42.16°(44.55°)$, while it fails to cross all disk layers for $\theta > 38.86°(39.73°)$. Then the widths of the angular regions within which neither the barrel nor the disks are fully traversed are $\Delta\theta_A = 3.30°$; $\Delta\theta_B = 4.82°$. In design A the transition *is* somewhat more abrupt, but in this respect the difference between the two designs is hardly fundamental.

- Foam cylinders integral with cooling and support rings.

In design A, four barrel layers are attached to each foam cylinder (the attachments are not shown in Fig. 1). After a barrel subsystem consisting of one cylinder and its four layers is assembled, half of the layers (the innermost and outermost) are easily visible for optical survey, and half are not.

In design B, at the expense of adding one cylinder, only two layers are attached to each cylinder, so that both are easily visible for survey after final assembly onto the cylinder. If a detector fails, it can be replaced without disturbing any other detector. The aspect ratio of the cylinders (length = diameter) is such that it is feasible to work inside as well as outside.

Design B allows integration of the cooling and support rings with the foam cylinders. We expect this to lead to many advantages. The rings stiffen the cylinder against out-of-round distortion. It would be natural for the coolant manifolding, power busing, and signal distribution also to be made integral with the support cylinder. Precise control of signal paths can lead to substantial cancellation of unwanted electromagnetic radiation, which (due to long Si strip antennæ and light construction) is easy to pick up and difficult to shield.

After the entire barrel is fully assembled, design B provides for $\approx$4 cm annular access paths that are adjacent to every detector layer. These material free regions are useful for diagnostic, survey, and calibration work. In design A the access is much more limited.

- Cost.

According to M.G.D. Gilchriese's 12/90 cost presentation to the SSCL, Si detectors produced at the rate of two per 4 inch diameter Si wafer cost \$650 apiece (averaged for 80% double-sided and 20% single-sided). 64-channel readout chips cost \$17.83 each. Detector/readout assemblies cost a total of \$476K, of which about 2/3 applies to the central Si tracker.

At that level of analysis, the cost differences between designs A and B are negligible compared to the total of $\approx$\$30M. Design B saves \$517K on Si detectors but spends \$447K extra on readout chips. If the cost of detector/readout assemblies is proportional to the number of wire bonds, design B may save an additional \$175K.

More subjectively, we believe that the Si detector system costs are far less well understood now than the costing exercises may have implied. The reason is technical risk. In a Si system for high energy physics, many of the SDC features are unprecedented: maintaining 5-10μ alignment in an extremely light structure of 5 m $\times$ 1 m diameter scale; using Si structures ("bridges") as self-supporting structural elements; simultaneously amplifying primary signals and reading out data in a structure too light for effective electromagnetic shielding; reading out and bonding to both sides of AC-coupled detectors along the same edge; combining 16 nsec time-stamping resolution with the high source capacitance of 18 cm strips; planning to fill the detector volume with highly flammable cooling gas amid widespread safety hysteria in DOE. It is not demonstrated now that the SDC Si system could be built for any price.

Reducing the technical risk to an acceptable level requires not only vigorous and incisive R&D, but also the discipline to eliminate from the design any unproven aspects that are not absolutely necessary to meet performance objectives. Design B moves in that direction by eliminating

- Si bridges, and/or detector carriers with distributed cabling and cooling;
- Increased noise and/or power dissipation associated with reading out 18 cm strips;
- Detectors that are not readily visible and accessible after assembly onto barrel cylinders.

The first item is particularly important. By substituting single detectors for bridges as the delivered product, a larger number of Si detector vendors will be able to qualify. Localized points of stress on the Si can be avoided, simplifying handling, assembly, and shipping. By eliminating the carriers, the option of confining the flammable gas to the interior of the cooling rings can be preserved. This greatly reduces the flammable inventory in the immediate vicinity of the detector, affecting its Risk Class and the associated regulations for its construction.

- Material.

According to Ref. 4, detector wafers account for 19.5 kg of weight, of which about 2/3 apply to the central detector considered here. Barrel rings amount to 3.3 kg, and barrel support shells add 4.2 kg. Cabling adds 74 kg, mostly for power busing (this figure assumes 40 kW of power, while it is now hoped that 10 kW will suffice).

Based on these figures, design B saves 3.2 kg of Si while adding 0.8 kg of ring and 1.4 kg of support shell material. These differences are negligible compared to the overall weight of 172 kg (40 kW), or ≈117 kg (10 kW).

However, reducing the power dissipated by a factor of 2.8, as would be possible in design B, cuts the material devoted to power busing by ≈48 kg (40 kW), or ≈12 kg (10 kW). These are significant reductions.

6. References.

[1] J. Hylen *et al.*, Santa Cruz Institute for Particle Physics preprint no. SCIPP 90/24 (September 1990); W. Miller, private communications.

[2] H. Sadrozinski, presented at Dallas SDC meeting (January 1991).

[3] H. Spieler, presented at Fort Worth (October 1990).

[4] W. Miller, presented at Santa Cruz (December 1990).

[5] W. Miller, private communication (January 1991).

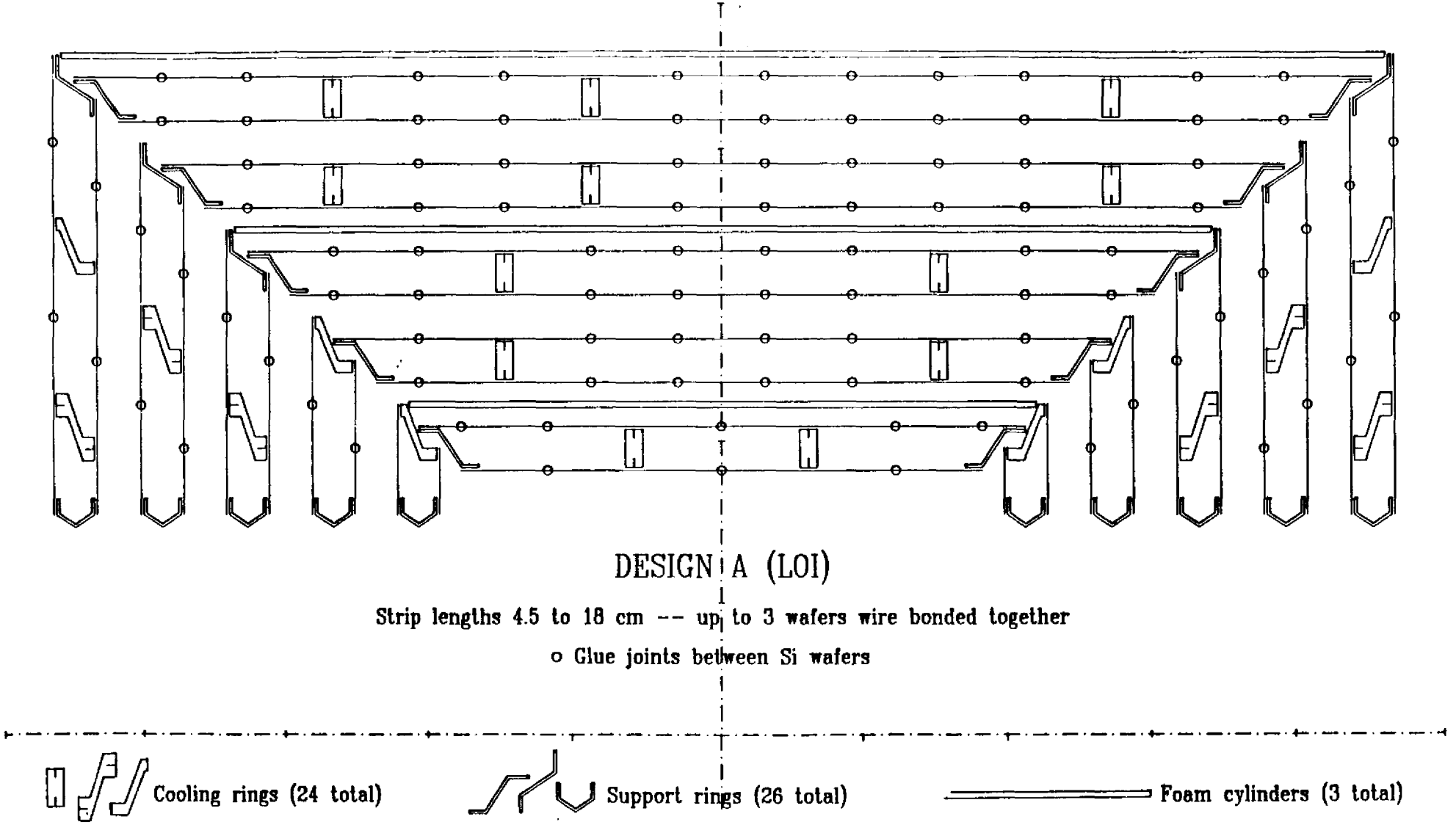
DESIGN A (LOI)
Strip lengths 4.5 to 18 cm -- up to 3 wafers wire bonded together
o Glue joints between Si wafers
Cooling rings (24 total)
Support rings (26 total)
Foam cylinders (3 total)

Fig. 1

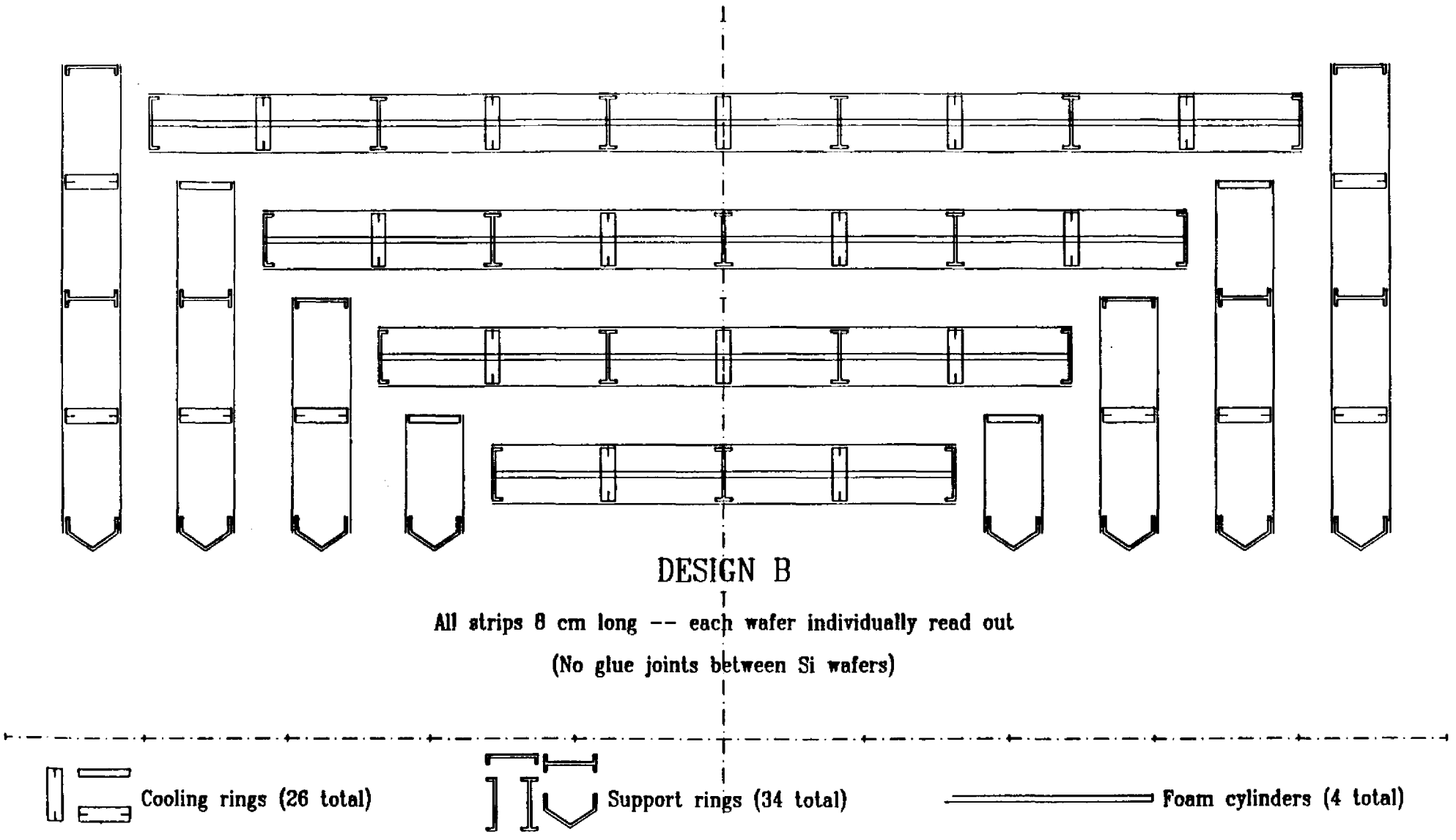
DESIGN B
All strips 8 cm long -- each wafer individually read out
(No glue joints between Si wafers)
Cooling rings (26 total)
Support rings (34 total)
Foam cylinders (4 total)

Fig. 2

Table 1

DESIGN A (LOI) FOR CENTRAL SI TRACKER

BARREL LAYER	1	2	3	4	5	6	7	8	9	10	Total
Radius (cm)	18	21	24	27	30	33	36	39	42	45	
Length (cm)	36	42	48	54	60	66	72	78	84	90	
Cylindrical area (m^2)	0.41	0.55	0.72	0.92	1.13	1.37	1.63	1.91	2.22	2.54	13.40
# cooling ring halves	2	2	2	2	2	2	3	3	3	3	24
# support ring halves	2	2	2	2	2	2	2	2	2	2	20
Detector length X width	6	X	3.2	cm							
# half bridges-same phi	3	3	3	3	3	3	4	4	4	4	
# detectors at same phi	6	8	9	9	11	11	13	13	15	15	
# detectors at same z	35.3	41.2	47.1	53.0	58.9	64.8	70.7	76.6	82.5	88.4	
above row rounded up	36	42	48	54	60	66	72	78	84	90	
# half bridges	108	126	144	162	180	198	288	312	336	360	2214
# detectors	216	336	432	486	660	726	936	1014	1260	1350	7416
# IC's (128 ch)/detector	10	(5 per side X 2 sides)									
# IC's at same phi	3	3	4	4	4	4	5	5	5	5	
# IC's (128 ch)	1080	1260	1920	2160	2400	2640	3600	3900	4200	4500	27660
# kilo wire bonds	276	430	552	622	844	930	1198	1298	1612	1728	9492

DISK NUMBER	1	2	3	4	5	6	7	8	9	10	Total
z (cm)	19.5	22.5	25.5	28.5	31.5	34.5	37.5	40.5	43.5	46.5	
Inner radius (cm)	15	15	15	15	15	15	15	15	15	15	
Outer radius (cm)	19.5	22.5	25.5	28.5	31.5	34.5	37.5	40.5	43.5	46.5	
Plane area (m^2)	0.05	0.09	0.13	0.18	0.24	0.30	0.37	0.44	0.52	0.61	2.[illegible]
# cooling ring halves	1	1	1	1	1	1	1	1	2	2	12
# support ring halves	1	1	1	1	2	2	2	2	2	2	16
Radius of IC's:											
inner readout ring	19.5	22.5	25.5	28.5	19.5	22.5	25.5	28.5	19.5	22.5	
middle readout ring	0	0	0	0	19.5	22.5	25.5	28.5	19.5	22.5	
outer readout ring	0	0	0	0	0	0	0	0	31.5	34.5	
Detector width at IC's	3.2	cm									
# detectors at same phi:											
inner readout ring	1	1	2	2	1	1	2	2	1	1	
middle readout ring	0	0	0	0	2	2	2	2	2	2	
outer readout ring	0	0	0	0	0	0	0	0	2	2	
# detectors at same r:											
inner readout ring	38	44	50	56	38	44	50	56	38	44	
middle readout ring	0	0	0	0	38	44	50	56	38	44	
outer readout ring	0	0	0	0	0	0	0	0	62	68	
# detectors	38	44	100	112	114	132	200	224	238	268	1470
# IC's (128 ch)	380	440	500	560	760	880	1000	1120	1380	1560	8580
# kilo wire bonds	48	56	128	144	146	168	256	286	304	344	1882

GRAND TOTALS FOR CENTRAL SI ($r < 0.5$ m, $|z| < 0.5$ m)

Cyl.+plane area (m^2)	19.29
# cooling rings	24
# support rings	26
# detectors	10356
# 4" dia Si wafers	5178
# IC's (128X)	44820
# kilo wire bonds	13256

Table 2

DESIGN B FOR CENTRAL SI TRACKER

BARREL LAYER	1	2	3	4	5	6	7	8	Total
Radius (cm)	16	20	24	28	32	36	40	44	
Length (cm)	32	32	48	48	64	64	80	80	
Cylindrical area (m^2)	0.32	0.40	0.72	0.84	1.29	1.45	2.01	2.21	9.25
# cooling ring halves	2	2	3	3	4	4	5	5	28
# support ring halves	3	3	4	4	5	5	6	6	36
Detector length X width	8	X	3.84	cm					
# detectors at same phi	4	4	6	6	8	8	10	10	
# detectors at same z	26.2	32.7	39.3	45.8	52.4	58.9	65.4	72.0	
above row rounded up	28	34	40	46	54	60	66	72	
# detectors	112	136	240	276	432	480	660	720	3056
# IC's (128 ch)/detector	12	(6 per side X 2 sides)							
# IC's at same phi	4	4	6	6	8	8	10	10	
# IC's (128 ch)	1344	1632	2880	3312	5184	5760	7920	8640	36672
# kilo wire bonds	172	208	368	424	664	738	1014	1106	4694

DISK NUMBER	1	2	3	4	5	6	7	8	Total
z (cm)	18	22	26	30	34	38	42	46	
Inner radius (cm)	14	14	14	14	14	14	14	14	
Outer radius (cm)	22	22	30	30	38	38	46	46	
Plane area (m^2)	0.09	0.09	0.22	0.22	0.39	0.39	0.60	0.60	2.61
# cooling ring halves	1	1	1	1	2	2	2	2	12
# support ring halves	1	1	2	2	2	2	3	3	16
Radius of IC's:									
inner readout ring	22	22	22	22	22	22	22	22	
2nd readout ring	0	0	22	22	22	22	22	22	
3rd readout ring	0	0	0	0	38	38	38	38	
outer readout ring	0	0	0	0	0	0	38	38	
Detector width at IC's	3.84	cm							
# detectors at same phi is 1 for each readout ring.									
# detectors at same r:									
inner readout ring	35	35	35	35	35	35	35	35	
2nd readout ring	0	0	35	35	35	35	35	35	
3rd readout ring	0	0	0	0	62	62	62	62	
outer readout ring	0	0	0	0	0	0	62	62	
# detectors	35	35	70	70	132	132	194	194	862
# IC's (128 ch)	420	420	840	840	1584	1584	2328	2328	10344
# kilo wire bonds	54	54	108	108	202	202	298	298	1324

GRAND TOTALS FOR CENTRAL SI ($r < 0.5$ m, $|z| < 0.5$ m)

Cyl.+plane area (m^2)	14.47
# cooling rings	26
# support rings	34
# detectors	4780
# 4" dia Si wafers	4780
# IC's (128X)	57360
# kilo wire bonds	7342