Summary of Constraints and Performance

1 Introduction

From our studies at Liverpool, a number of points have become clear and certain arguments crystallised, so that we are now in a position to focus on a relatively small number of solutions and examine their respective merits.

The major constraints and performance related issues are discussed and conclusions drawn.

2 Signal to Noise Constraints

Designs in which a large number ($> 20\%$) of tracks spread their charge over greater than three strips will not work. This effectively eliminates the 8-fold 50μm pitch solution [1]. We must go to a) greater modularity and/or b) larger strip pitches.

3 Readout Chip Constraints

Given that there is a reasonably hard limit of about 128 readout chips, only a limited number of solutions exist in terms of modularity and strip pitch. If the radius of the detector is assumed to be 1.6cm; each plaquette is assumed to have a tilt of 10 degrees; an overlap of 10% is requested for alignment purposes; then the minimum strip pitch allowed can be calculated. The following table shows the result.

Modularity	Circumference (cm)	Width of Plaquette (cm)	Minimum strip pitch	Number Readout Chips
8	12.77	1.597	125 (62)	64 (128)
9	12.51	1.390	109 (55)	72 (144)
10	12.32	1.232	96	80
11	12.17	1.107	86	88
12	12.06	1.005	78	96
13	11.97	0.921	72	104
14	11.90	0.850	66	112
15	11.83	0.789	62	120
16	11.79	0.737	58	128

Numbers in brackets are for **two** readout chips per plaquette

Whatever solution we choose must conform, more or less, to these limits: small variations on these numbers can be obtained by reducing the overlaps or the tilt.

4 Rad-Hard Technology Constraint

The next point we must factor in, is our knowledge (personally at Liverpool or in the global literature) of making rad-hard detectors at given strip pitches. We are not going to have a prototype run, so we must use tried and trusted solutions.

If we require n-in-n technology, we are confident that a design based on a pitch of about 75μm pitch will work, as these detectors have already been prototyped and tested, and have performed well in test-beam studies. An n-in-n design of 50μm pitch would possibly work, but would require a prototyping run with Hamamatsu for which we do not have time.

For the p-in-n technology, working prototypes already exist for a range of strip pitches between 50μm and 80μm.

4.1 p-in-n versus n-in-n

We have looked at the increase in voltage which would be necessary to fully deplete the detectors as they become progressively more damaged due to radiation.

An integrated luminosity of 1fb^{-1} per year was assumed, which corresponds to 1MRad/cm^2 per year which is equivalent to 1.7×10^{13} neutrons per cm^2 or $3. \times 10^{13}$ protons per cm^2. The CV parameterisation, as found in the ATLAS TDR [2] was used. The detector was assumed to run at -10C. Any favourable annealing effects were ignored, while reverse annealing was calculated assuming that the detector was allowed to heat to 20C for one week at the end of each year for maintenance purposes.

Figure 1 shows the predicted evolution of the Voltage for 300μm thick detectors. After 2 years (2fb^{-1}) the detectors would need to be run at 100 volts, while after 3 years (3fb^{-1}) it would be necessary to rise to 150 volts.

A comparison of this prediction with a parameterisation from recent test-beam data [3] gives similar results. A further comparison has been made with the curve in the CMS TDR [4] (reproduced in the Layer00 proposal [5],) which shows very similar behaviour after inversion.

If we are only designing for 2fb^{-1}, p-in-n technology can be used. For luminosities above this value, the voltage must be raised above the 100V which constitutes the maximum specification of the silicon. One therefore risks damaging the silicon. We would probably be safe up to 3fb^{-1} (150 volts) where there is some experience that Hamamatsu detectors can perform reliably at this voltage. Above this value however, we run the risk of a possible catastrophic breakdown, due to bad beam conditions which could cause large local ionisation, leading to very large currents which could destroy the detector.

With a n-in-n technology, this risk could be avoided by running the detectors partially depleted at a lower voltage. Figures 2&3 from the Cambridge group [3] show the efficiency for observing a single strip signal of at least 3:1 (with a noise of 2000 electrons) as a function of voltage, for various n-in-n and p-in-n detectors after irradiation at a fluence of 3×10^{14} protons/cm^2. Running p-in-n detectors at 100 to 150 volts gives poor performance (<50% efficiency) while n-in-n detectors can be run at 150 volts and >90% efficiency.

5 Mechanical Constraints

There may be mechanical constraints on building a very small detector. We need to think how the silicon will be mounted and how the cables will be taken out. Two obvious designs present themselves: firstly, a castellated design with the normals at the centre of the plaquettes and alternate plaquettes at different radii; and secondly, an angled design in which each plaquette in a perfect polygon is tilted though an angle so as to allow space for the dead regions in the silicon and for overlaps. Our feeling at the moment is that an angled design may make fanning out the cables easier. It might also be useful in reducing the effect of the Lorenz angle, but this calculation is still to be done.

6 Occupancy Studies (Summary)

We come now to the impact the design will have on the physics. The myriad of numbers in the previous reports are condensed and the salient points are reproduced in the table below. The results are for $t\bar{t}$ events with one minimum bias event superimposed. In answer to two of Paul's questions: The numbers are similar for $b\bar{b}$ events; Percentages are similar for events with five minimum bias events superimposed.

Modu-larity	Pitch	Tracks spreading over				Strip Sharing	B-Strip Sharing	Track Sharing	B-Track Sharing
		2-strips	3-strips	4-strips	5-strips				
8	50μm	21%	41%	33%	5%	4.2%	?	12 (10%)	2.8 (27%)
12	75μm	48%	51%	1%	0%	5.0%	18%	13(11%)	3.0(28%)
14	50μm	37%	57%	5%	0%	3.7%	13%	10(9%)	2.4(22%)
16	50μm	42%	55%	2%	0%	3.3%	12.7%	9.8(8.4%)	2.3(21%)

Increasing the modularity and decreasing the pitch gives a small but nonetheless significant improvement. Going from 12-fold 75μm to 16-fold 50μm improves the doublely hit B-strips from 18% to 13% and improves the mis-measured b tracks from 3.0 to 2.3. That is an improvement of 0.7 tracks per event or 25% less badly measured b tracks.

7 Impact Parameter Resolution

The most important reason for Layer00 however is in recovering good impact parameter resolution for low momentum tracks. To evaluate the effect of different strip pitches for Layer00, a simulation has been performed. Tracks were followed outwards from the interaction point, scattered randomly on passing through the beam-pipe and the layers of silicon, and measured with the expected resolution in Layer00, SVX2 and ISL. Then the process was reversed, and a full track fit performed including the (correlated) effects of multiple scattering. Finally, the results were parameterised according to the formula $A \oplus B/p_T$. Note, this is a very *poor* parameterisation for the particular geometry we are considering. Therefore, results are also given for the average resolution at 1,2,3 and 4 GeV. These are considerably *worse* than you would expect from the formula.

The inputs to the simulation are as given in Joe's talk [6]: The radius of Layer00 is taken to be 1.6cm and the radius of the inner layer of SVX2 is 2.615cm. The resolution in SVX2 is 12μm and in ISL is 32μm. The Molière scattering formula [7], $\theta_0 = .0136\sqrt{X}_0(1 + .038 \log X_0)$, is used but the log term is neglected.

Pitch	Parameterisation	Resolution at			
		1 GeV	2 GeV	3 GeV	4 GeV
50μm	$8 \oplus 29/P_T$	29μm	20(37)μm	17(45)μm	15(51)μm
75μm	$9 \oplus 36/P_T$	35μm	25(47)μm	21(57)μm	18(62)μm
100μm	$10 \oplus 42/P_T$	40μm	28(52)μm	23(62)μm	20(69)μm
No L00	$10 \oplus 63/P_T$	57μm	37(74)μm	30(90)μm	24(96)μm

The numbers in brackets are the implied values of B in the formula $A \oplus B/p_T$

Reducing the strip pitch clearly affects both the asymptotic term and the multiple scattering term. It is felt that the asymptotic term improvement is somewhat irrelevant, especially as we read in the Layer 00 proposal [5] "The intrinsic asymptotic resolution of 9-10μm will of course not be realized in practice." The multiple scattering term is the important parameter and it improves from 42μm for 100μm pitch to 29μm for 50μm pitch which is significant. Just as importantly, for 2GeV tracks it reduces from 28μm to 20μm.

With the inputs to the simulation detailed above, we were successful in reproducing the numbers in the Layer 00 proposal [5]. These numbers may however be somewhat pessimistic. There are two inputs which could be better than has been assumed: firstly, why is the log term in Molière scattering ignored; secondly, why is the resolution 12μm for a 60μm pitch detector? At LEP a 7μm resolution is obtained for a 50μm pitch, a number which includes alignment effects. In the table below, the effect that altering these inputs has on the impact parameter resolution is examined.

Pitch	Description	Resolution at		
		Infinity	1 GeV	2 GeV
No L00	As in Proposal	10μm	55μm	37μm
No L00	Include log term	10μm	50μm	34μm
No L00	8.5μm precision for SVXII	8μm	50μm	32μm
No L00	8.5μm for SVXII & log term log	8μm	45μm	29μm
100μm L00	""	7μm	28μm	21μm
75μm L00	""	6μm	25μm	19μm
50μm L00	""	6μm	19μm	15μm

From this parameterisation of the scattering and with a more realistic detector resolution, there is perhaps a less compelling reason for going to smaller strip pitches. Nonetheless, a multiple scattering term of $18/p_T$ as derived from the last line of this table, would be truly excellent, approaching the level to which the alignment was successful in Run1.

8 Discussion

These points are now summarised and our conclusions presented.

The facts are (hopefully) objective, but the conclusions are inevitably subjective and open to debate. It is entirely possible to argue the matter in a completely different manner.

In terms of the physics, both occupancies and impact parameter resolutions, it is clear that as the pitch reduces, so too do the occupancies and resolutions. A continuous improvement is seen; there are no hard cut-offs; we see a sliding scale of progressive benefits from increasing the granularity; the improvements are small but significant.

Therefore, it seems reasonable to aim for the smallest strip pitch which is technically feasible and which can confidently be built in the time-scales allowed. The physics gains from the best granularity. One must now factor in what is technically possible.

We have a hard limit for the modularity at 16-fold from the cost of readout chips. Can we therefore take on a 16-fold, 50μm pitch detector ?

The crucial issue here would appear to be the radiation dose. If we are only planning for 2fb^{-1}, then p-in-n sensors are sufficient. If however we wish to plan for higher luminosities, or foresee Layer 00 as providing a clearly defined upgrade path for Run-III, then we would recommend n-in-n sensors. In that case, given the time-scales, 75μ pitch sensors are known to work and we would propose building a 12-fold detector which would provide almost as good physics output.

9 Conclusion

In summary, we see two design options.

- A 16-fold, 50μm pitch detector based on p-in-n technology.
- A 12-fold, 75μm pitch detector based on n-in-n technology.

We would like some feedback on what you think of this proposal, whether you agree with our analyses, and whether you agree with our conclusions. We welcome discussion via email and telephone so that we are in a position to finalise the geometry and the detectors at the November 23rd meeting at FNAL.

Notwithstanding the above, we still have a number of issues which need resolving: castellated versus angled design; how to fan the cables out; cable capacitances; cooling. We shall try to investigate these issues within the constraints of the two designs specified above.

References

[1] 'The third study' on occupancies at http://hep.ph.liv.ac.uk:80/cdf/

[2] The ATLAS TDR.

[3] P.Allport et al., 'ATLAS Irradiation Studies of n-in-n and p-in-n Silicon Microstrip Detectors', *submitted to NIM*

[4] The CMS TDR.

[5] P.Azzi-Bacchetta et al., 'Proposal for a Very Low Mass, Very Small Radius Silicon Layer in the CDFII Upgrade.'

[6] J.Incandela & R.Snider, 'Effect of material on SVXII impact parameter resolution', Transparencies to the Upgrade Meeting Jan 9th, 1998. Available at http://www-cdf.fnal.gov/internal/upgrades/xvsii/Mechanical/Mass/mass.html

[7] Particle Data Group Book.

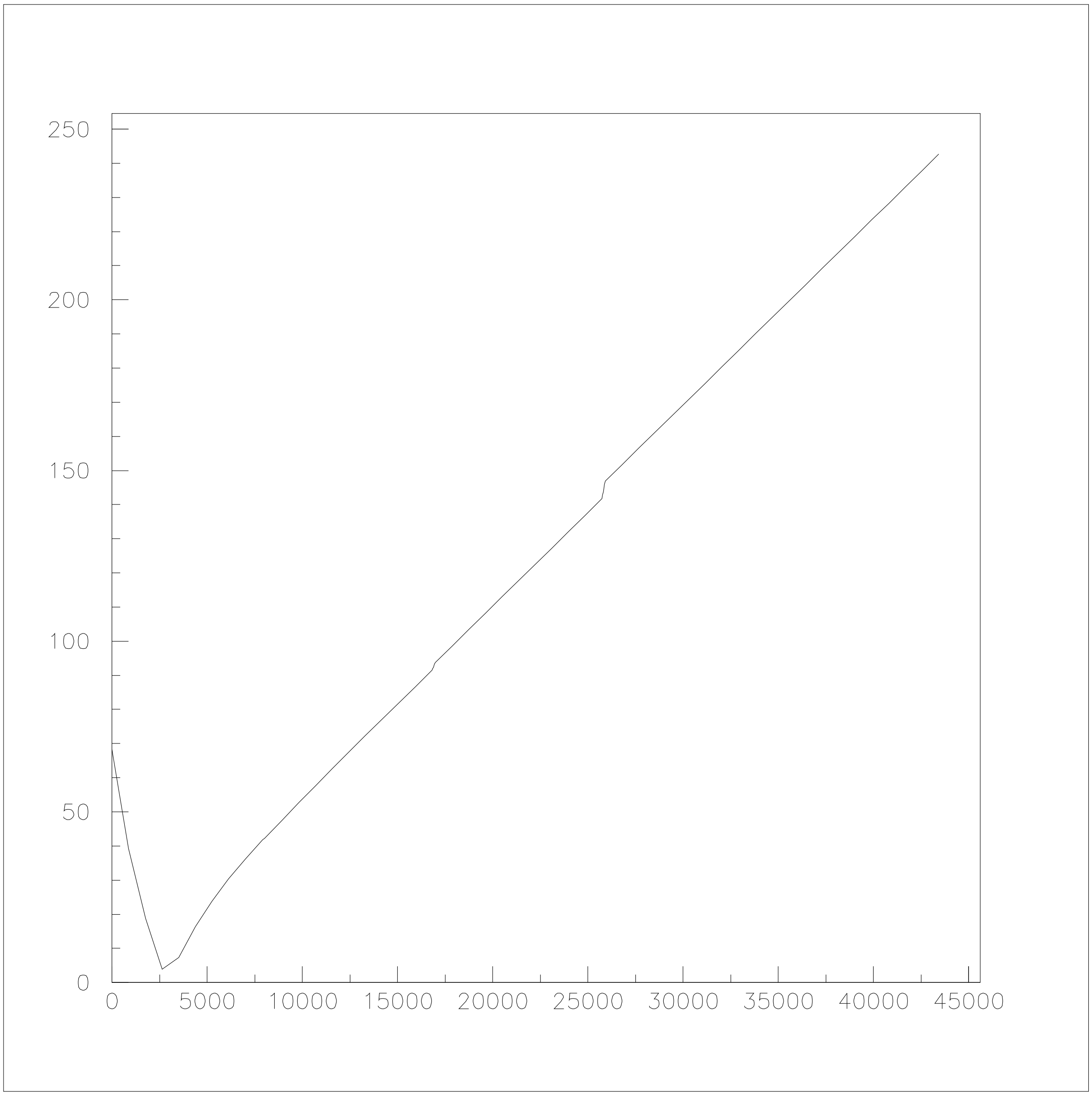

Figure 1: Full Depletion Voltage (vertical axis) as a function of time in hours (horizontal axis.)

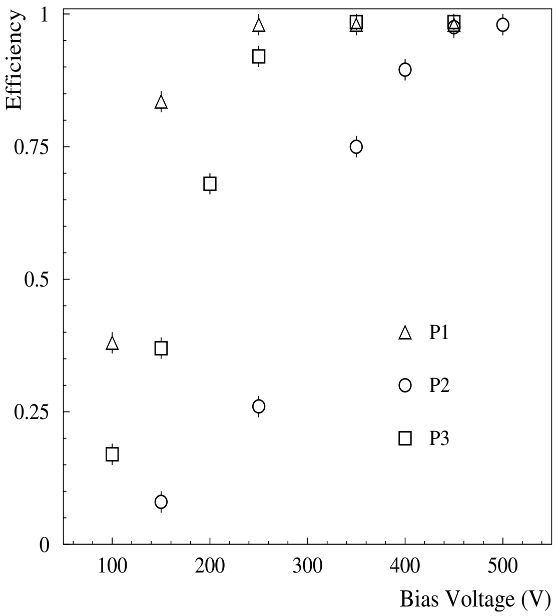

Figure 4: Measured efficiency as a function of bias voltage for the three irradiated p-in-n detectors, P1, P2 and P3.

15

Figure 2: This figure for p-in-n detectors is taken from [3]

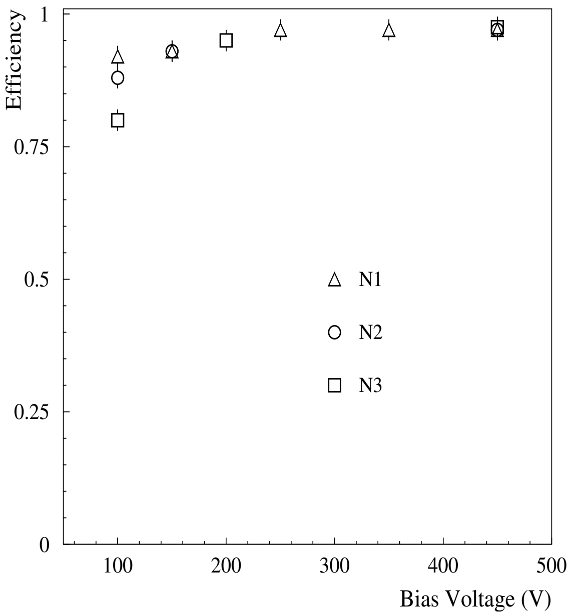

Figure 5: Measured efficiency as a function of bias voltage for the three irradiated n-in-n detectors, N1, N2 and N3.

Figure 3: This figure for n-in-n detectors is taken from [3]

16