SMT Longevity

Eric Kajfasz, Breese Quinn

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1 Introduction

The DØ Silicon Microstrip Tracker (SMT) was designed for use in Run IIa, which has been defined as a Tevatron run consisting of 2 fb^{-1} of integrated luminosity[1]. The SMT as built should withstand ~4 fb^{-1} before succumbing to the debilitating effects of radiation damage. Previous estimates of the SMT operational lifetime will be briefly summarized at the end of this document.

However, there are at least two other issues to consider when evaluating the effective lifetime of the SMT. One consideration is the failure rate of individual silicon devices. Here, we focus on failures of device elements that are inaccessible and thus not repairable (i.e. silicon sensor, high density interconnect, and low mass cable). A device will be referred to as an HDI. The other major issue is HDI noise and the extent to which it can render a device ineffective or even inoperable.

2 HDI Failures

2.1 Disabled HDI history

One way to see a "snapshot" of the general health of the SMT is to look at the percentage of HDI's that have been disabled over time. This is shown in Figure 1 going back to the end of 2001. Separate curves are displayed for barrel ladders, F disk wedges and H disk wedges. Disabled HDI's encompass those that have been certified dead and irreparable as well as more recent trouble devices that have been turned off pending comprehensive attempts at diagnosis and repair.

There are a few interesting features in the Figure1 plot. The first major event is the sharp spike in disabled HDI's around June, 2002. That time corresponds to a Tevatron shutdown period of a few weeks. An increase in disabled HDI's during a shutdown does not imply that activity in and around the detector causes a rash of problems. More common is the effect that during such periods, there is more time available for thorough diagnosis of existing problems. For example, careful analysis of an HDI that has been generally operational could reveal that its data is irreversibly corrupted in a subtle way. The reduction in disabled HDI's at the end of the January, 2003 shutdown is a case where the extra time for debugging resulted in the recovery of several disabled devices. This, of course, can only occur when the fault in a problem device occurs somewhere in the readout chain downstream from the external end of the low mass cable. It should be noted that it is extremely unlikely that the percentage of working HDI's will ever improve beyond the levels attained at the beginning of February, 2003. Virtually all disabled HDI's at that point were confirmed to have faults with inaccessible elements of the devices.

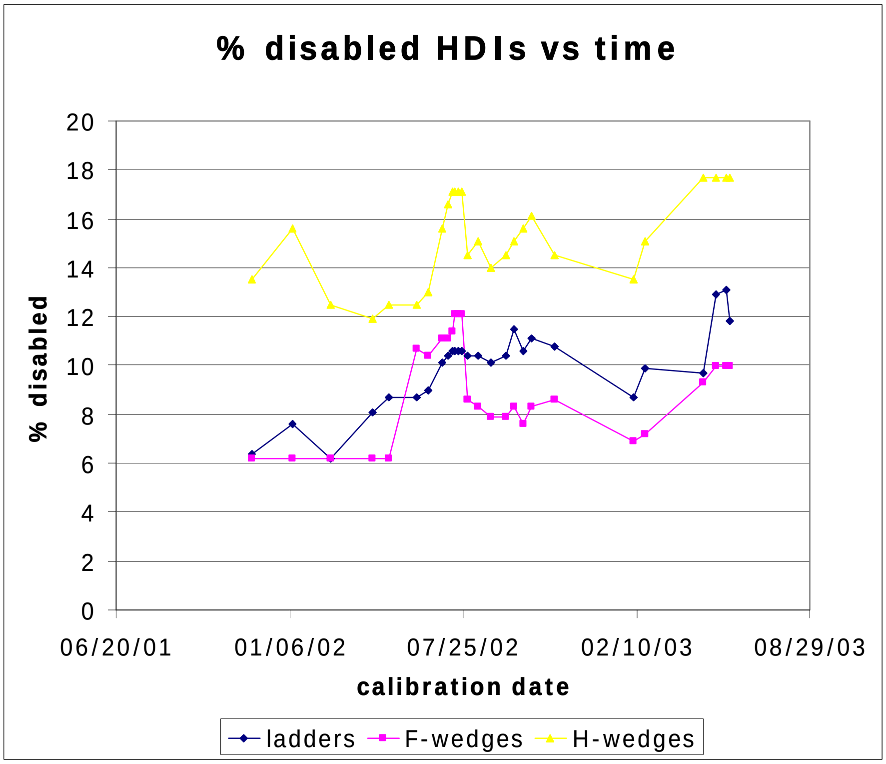

Figure 1. Percentage of disabled ladders, F wedges, and H wedges as a function of time.

Of some concern is the rise in the number of disabled HDI's over the last couple of months. It is particularly unclear how much of this recent rise represents actual failed devices. This is because shifter operation of the SMT has been somewhat altered since the end of the January, 2003 shutdown. Operational guidelines now encourage shifters to quickly disable any HDI giving problems during the run in order to avoid losing delivered luminosity. There has been less downtime which is typically used to determine if some disabled devices are ready to be re-enabled for data taking. In particular, it is expected that some of the ladders responsible for the jump from 10% to 13% disabled will be recovered.

It is quite difficult to attempt an estimate of disabled devices by 2009 based on this information alone. Under different sets of assumptions, Figure 1 could extrapolate to figures anywhere between 13% and 100%. The lower bound of 13% represents the current situation which is perfectly acceptable. This conclusion is supported by the distribution of disabled ladders in the barrels which is shown in Figure 2. There one can see that the pattern of unused HDI's is nearly random. There is a small level of clustering due to specific failure modes such as a problem with a Sequencer card or biasing which can group devices near to each other geographically. Even so, 13% disabled HDI's has not resulted in any loss of fiducial volume and only local reduction of tracking efficiencies on the order of 3%-5%[2]. However, it is probable that just twice the current

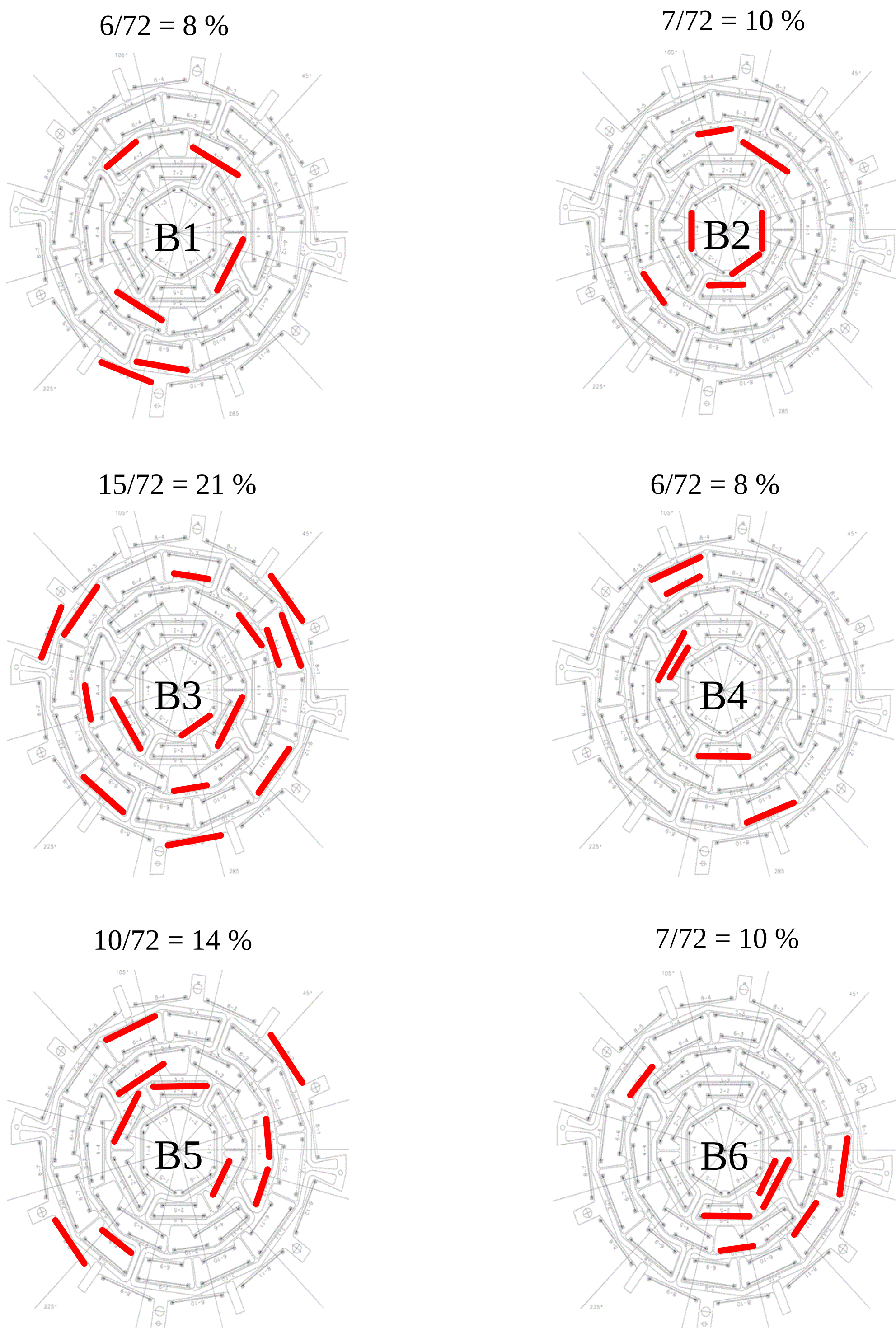

Figure 2. Fraction and location of the disabled ladders on the 6 barrels as of 5/27/03.

level of disabled HDI's could drastically alter that situation, possibly leaving the detector blind to small regions of f -?.

2.2 Characteristics of HDI failure

A slightly different perspective on HDI failure rates is to examine characteristics of the actual failures rather than the disable action used to deal with them. The most important distinction between this approach and that of section 2.1 is that here we consider the histories of only those HDI's that are currently disabled, i.e. we do not consider those HDI's which were disabled but subsequently recovered.

2.2.1 Time profile

A time profile of failed HDI's is given in Figure 3. Each failed HDI is entered in the month of operation in which it first exhibited a failure mode for which it had to be disabled. Some clear points emerge from this profile. The first is that there was 4.6% infant mortality upon completion of SMT installation. The second is that even though many problem devices have been recovered during shutdowns, most of the truly failed devices developed their problems during or near those same shutdowns. However, this observation is somewhat lessened when one considers the reason for the gaps in summer 2001 and fall 2002. Those gaps overlap with periods when the SMT Commissioning database was not functioning. This database is where changes in HDI status are typically recorded and from where the data for the time profile is taken. This means that the bins corresponding to the October, 2001 and January, 2003 shutdowns are somewhat artificially elevated due to the database getting 'caught up.' Several entries there likely belong in months during the database gaps.

If the spike in May, 2001 is infant mortality, then the spike at October, 2001 could be considered in-situ burn-in. Even considering the database gaps, the average rate of failure from June, 2001 through October, 2001 is 4.5 HDI's/month. This is twice the rate from November, 2001 through January, 2003 of 2.1 HDI's/month. The enhancement in March and April, 2003 is at least partly due to the operational changes discussed in section 2.1 and the likelihood that many of those entries are recently disabled HDI's which will be recovered.

If the infant mortality and burn-in periods are excluded, one can hazard a crude extrapolation of failed HDI's. Assuming that the most recent months are biased high, the failure rate of 2.1 HDI's/month would yield 18% disabled by 2006 and 27% disabled by 2009. If the last two months are fully included, the rate is 2.8 HDI's/month and the extrapolation is 20% by 2006 and 32% by 2009. However, these estimates assume that there are no specific limiting expected lifetimes of any device components.

2.2.2 Failure modes

There are several recognized HDI failure modes. Figure 4 details the distribution of the most common ones. It is an inclusive distribution in that there are many double entries for devices that exhibit more than one failure mode. Inability to download the SVXIIe chips is by far the most common cause for the loss of an HDI. Frequently, this is accompanied by very high DVDD current draw, and sometimes it is preceded by the observation of bad readout from the HDI. Damage to the fragile clock cables is often

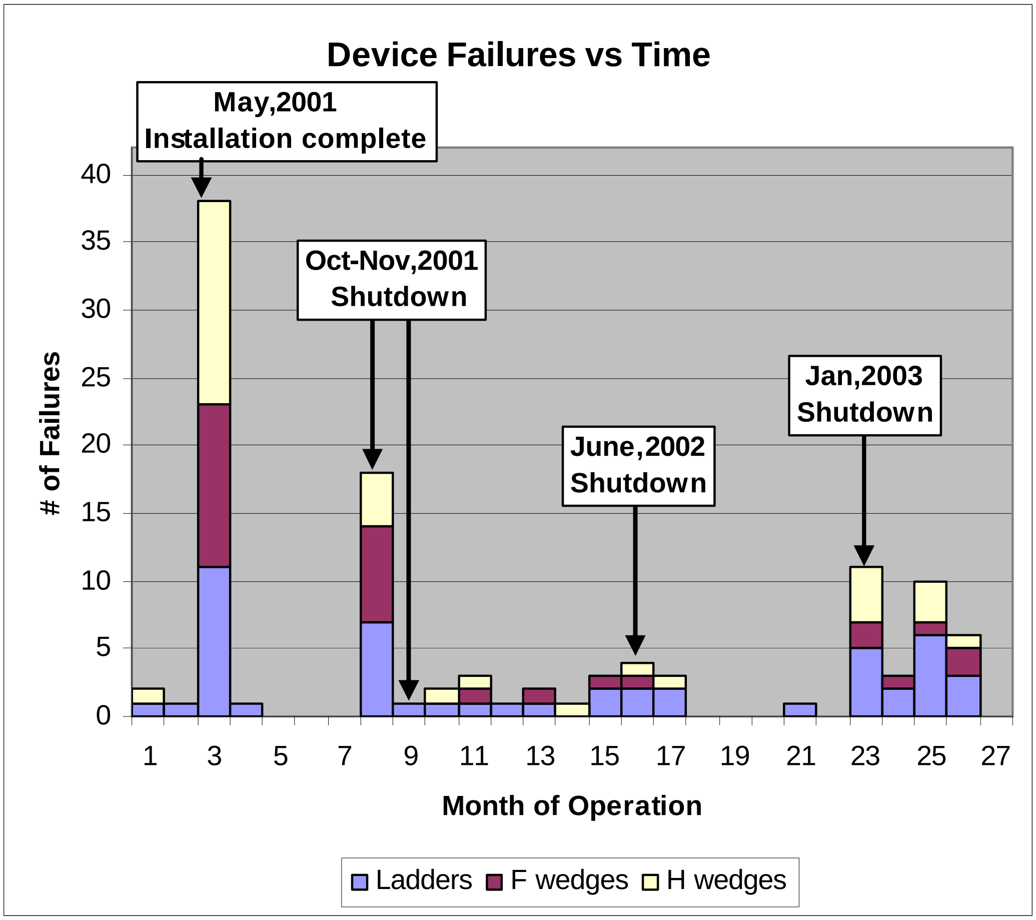

Figure 3. HDI failures as a function of time. Each failed HDI is entered in the month of operation in which it first exhibited a disabling failure mode. Note that this plot does not include devices that were disabled at one time but have since been recovered.

responsible for the loss of download functionality, although in many cases no specific cause for the problem can be identified because diagnosis would require access to the HDI.

Some type of problem with HDI readout is the next most common failure mode. This data corruption can take a variety of forms such as shorts of data lines to ground or missing chips in the readout. Anomalously high low voltage current draws are responsible for several lost HDI's, with the DVDD current more likely to be at fault than either AVDD or AVDD2. Fatal bias voltage problems are rare.

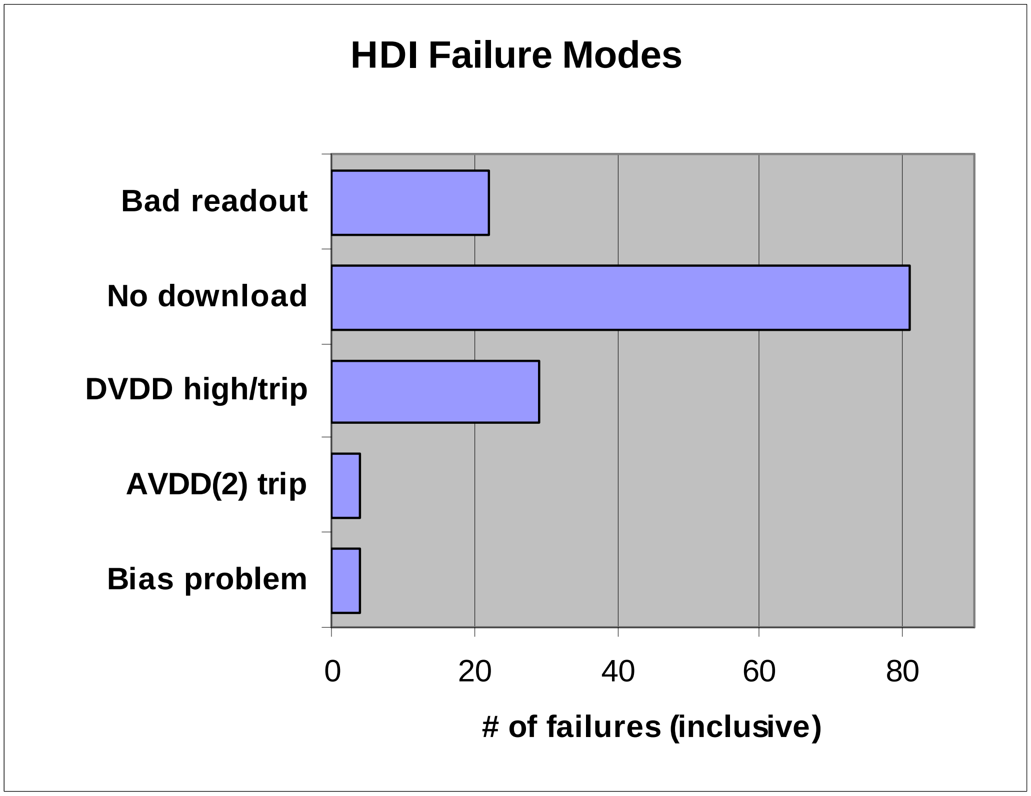

Figure 4. HDI failure modes. The graph is inclusive, i.e. HDI's that exhibited more than one failure mode have multiple entries.

3 HDI noise

The noise present in the SMT is not well understood. Some sources such as the coherent pedestal shifts that are a function of tick number are not particularly relevant to questions of the SMT lifetime. Other noise sources such as the grassy noise exhibited primarily in F wedges are a growing concern for HDI reliability.

3.1 Ladders

The noise situation for the barrels is shown in Figure 5 (north barrels) and Figure 6 (south barrels). In these graphs, the fraction of noisy strips on ladder p- and n-sides is plotted for layers 1+2, 3+4, 5+6, and 7+8 as a function of calibration run number (the runs span about 1.5 years). Noisy strips are defined as those with a noise level higher than 4 ADC counts (typical noise levels are between 1.5 and 2.5 ADC counts). The noisy strip fractions shown are quite low except for Barrel 5, Layer 3+4, n-side, which has about 10% noisy strips. This is due to a single ladder, B5-3-1.

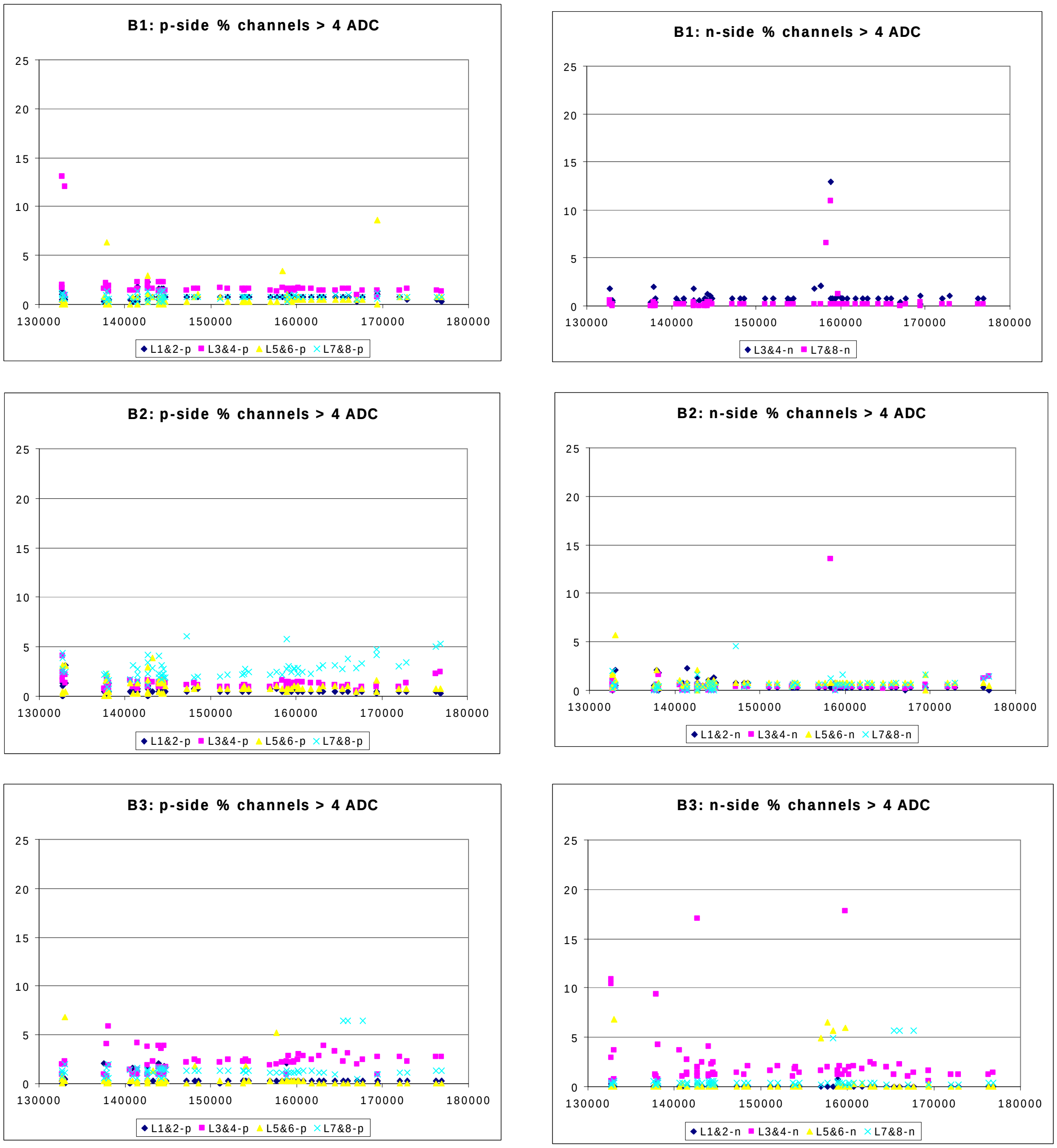

Figure 5. North barrels fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with a noise threshold of 4 ADC counts.

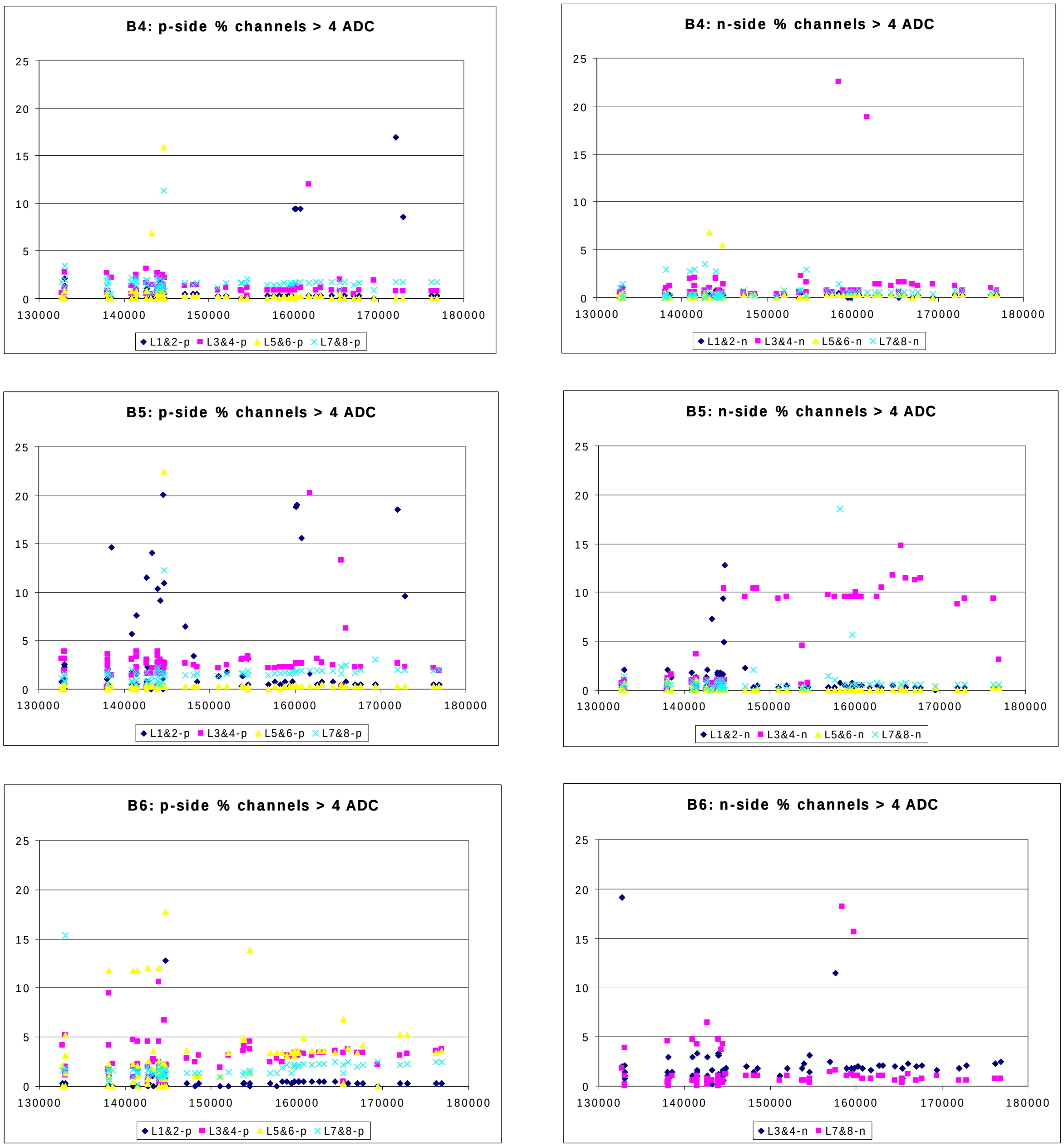

Figure 6. South barrels fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with a noise threshold of 4 ADC counts.

3.2 F wedges

Noise in the F disks is shown in Figure 7 - Figure 9. The fraction of noisy strips on each F wedge p- and n-side is plotted as a function of calibration run number (the runs span about 1.5 years). In Figure 7, noisy strips are defined as those with a noise level higher than 4 ADC counts (typical noise levels are between 1.5 and 2.5 ADC counts). In Figure 8, noisy strips have more than 6 ADC counts and in Figure 9, the noise cut is 10 ADC counts. Two striking features are evident. One is that F disks 3, 5, 8, and 10, which are all made of Eurisys wedges, have very low noise. The other is that all of the other F disks, which are made of Micron wedges, are characterized by high noisy strip fractions that are increasing with time, with F6 in particularly bad shape. This typical grassy noise has already required that some F wedges be disabled to avoid unacceptably high occupancies. If the F wedge grassy noise is not brought under control, the Micron F disks could become unusable within a few years.

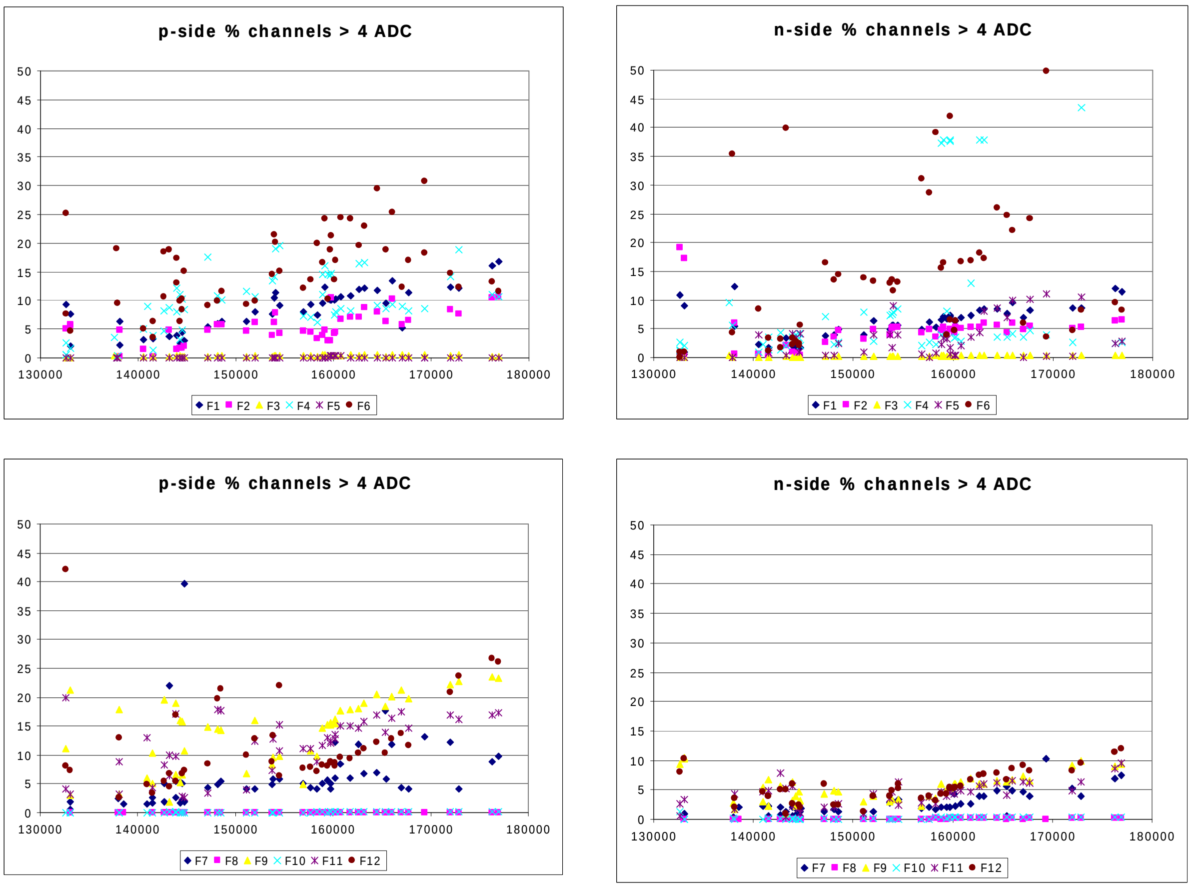

Figure 7. F disks fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with a noise threshold of 4 ADC counts.

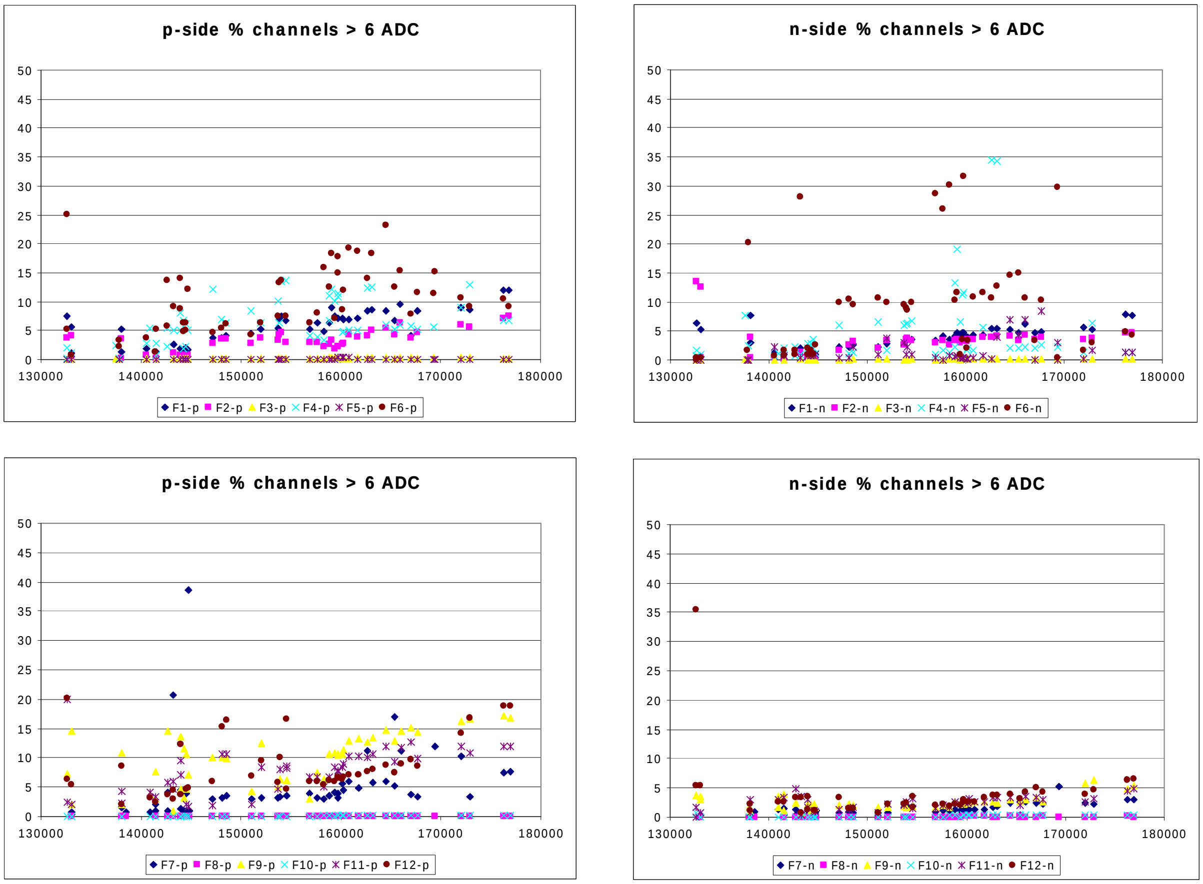

Figure 8. F disks fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with a noise threshold of 6 ADC counts.

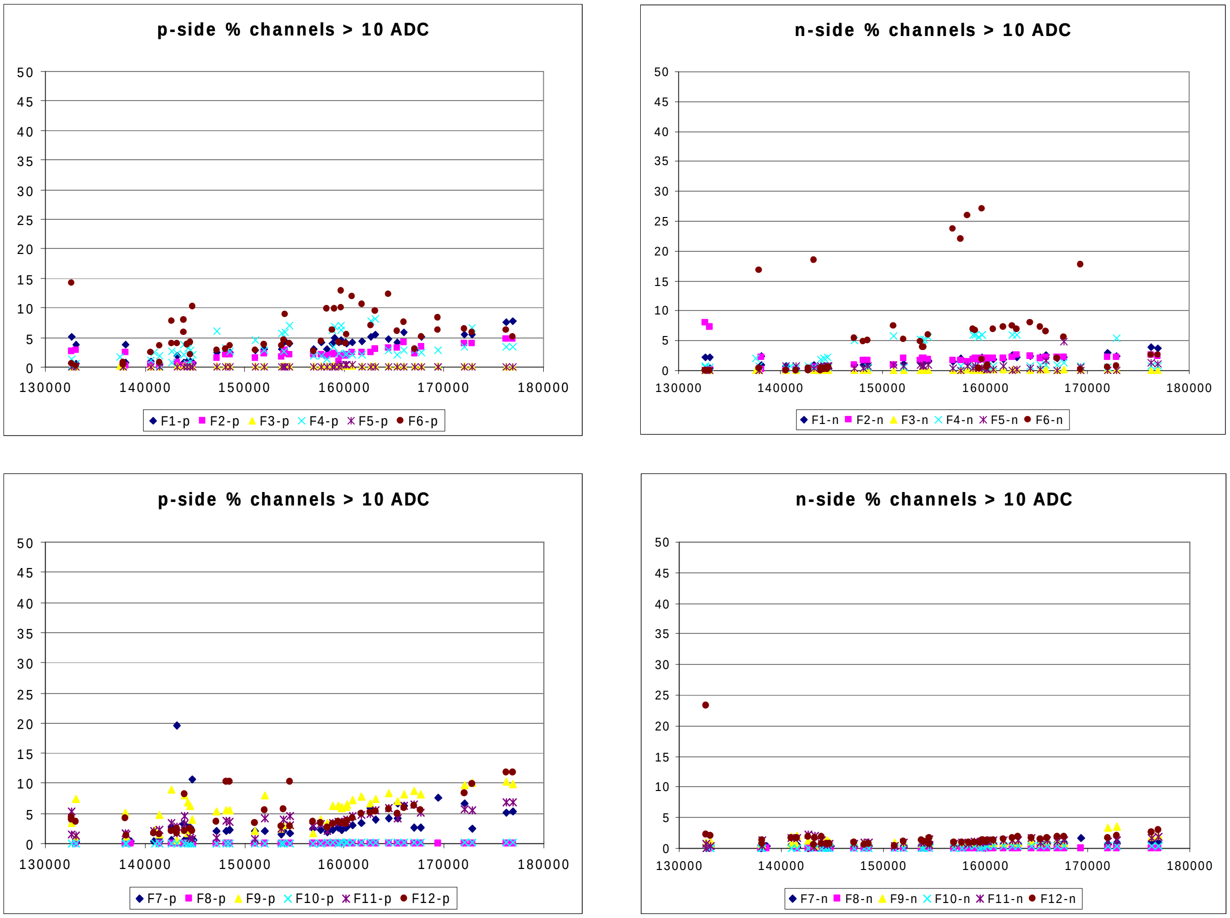

Figure 9. F disks fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with a noise threshold of 10 ADC counts.

3.3 H wedges

The H disk noise is shown in Figure 10. The fraction of noisy strips on each H wedge “p”- and “n”-side is plotted as a function of calibration run number (the runs span about 1.5 years) for noise thresholds of 4, 6, and 10 ADC counts (typical noise levels are between 1.5 and 2.5 ADC counts). It seems that for all H disks there is a significant step function change in the noise environment that occurs at the June, 2002 shutdown. The percentage of noisy strips jumps by a few percent after the shutdown. This increase is not understood. The H disk noise appears fairly stable otherwise.

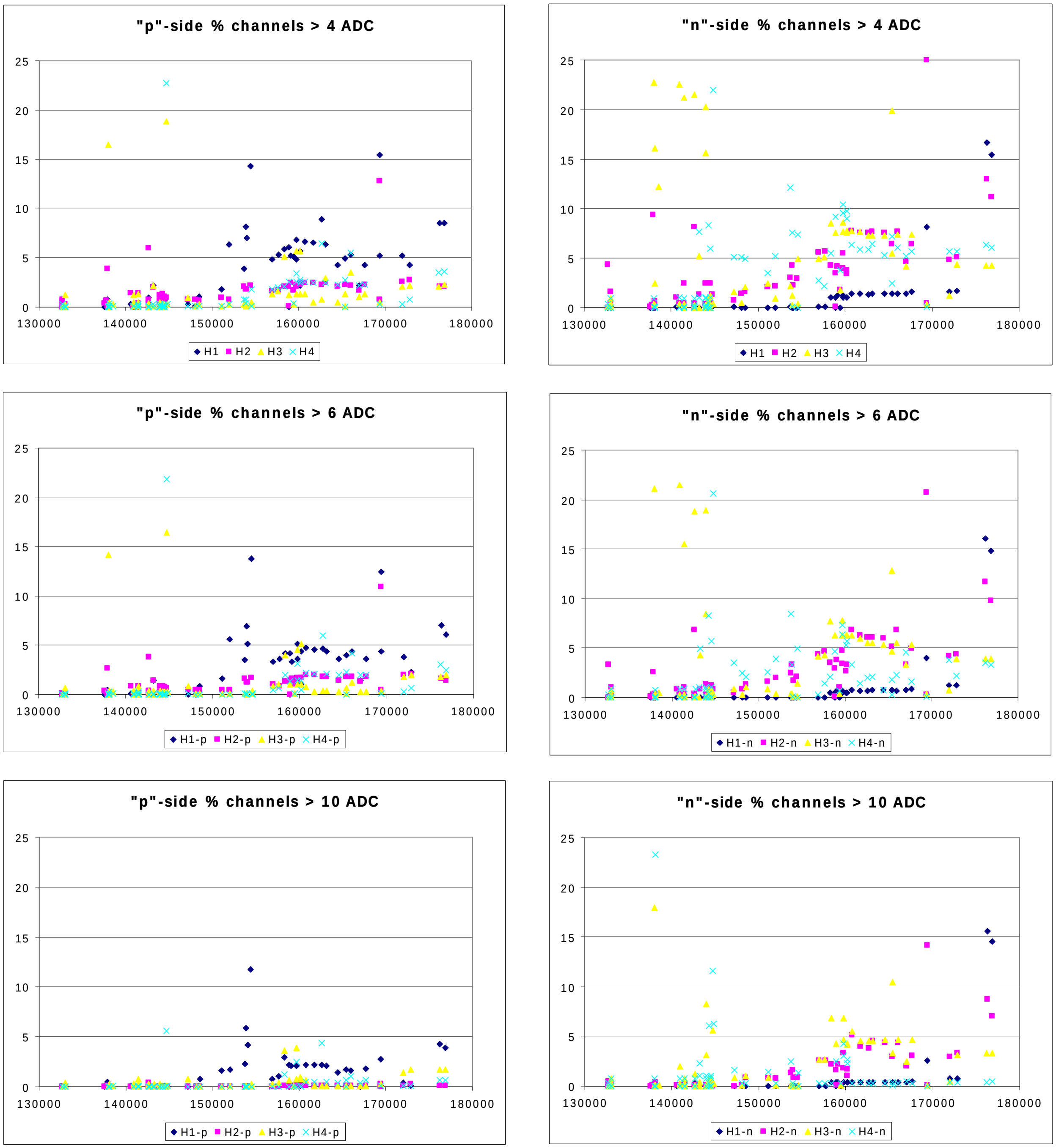

Figure 10. H disks fraction of noisy strips as a function of calibration run number (Run #130,000 = 10/01/2001, Run # 177,000 = 05/15/2003) with noise thresholds of 4, 6, and 10 ADC counts.

4 Radiation Damage

An estimate of the SMT lifetime based on calculations and measurements of radiation damage has been made[3]. The expectation is that the lifetime of the SMT will be limited by micro-discharge breakdown of the junction in the Micron-supplied detectors in the inner four barrels. This will begin to occur at bias values of ~150 volts and all channels will fail at bias values of ~200 volts. In addition, for double-sided detectors, breakdown of the coupling capacitors will start soon after bias voltages exceed 100 volts per side. This coupling capacitor breakdown will dramatically impair the operation of the corresponding HDI's. Significant numbers of channels will be lost at an integrated luminosity of 3.6 fb^{-1} and 100% of the inner layer channels will be dead by 4.9 fb^{-1}. Errors in estimating the micro-discharge formation and dose accumulation lead to uncertainties in these numbers of about 50%.

5 Summary

Based on radiation damage alone, the SMT should remain useful until integrated luminosity reaches ~4 fb^{-1}. However, if the Tevatron takes several years to reach that luminosity, the SMT lifetime may be limited by other factors. The HDI mortality rate is not well understood, but if we extrapolate with the current rate of HDI failures, up to a fifth of the channels could be lost by 2006, and about a third could be dead by 2009. Those figures do not include any specific component lifetimes, and therefore could be underestimates. Noise problems, particularly in the F wedges, could exacerbate the situation by rendering some F disks inoperable on a somewhat shorter time scale. Although there is significant uncertainty in these expectations due to limited understanding of the HDI failure modes and noise sources, it does not appear likely that the SMT will be a viable tracking detector late into this decade.

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[1] DØ Silicon Tracker Technical Design Report, DØ Note 2169 (1994).
[2] Guennadi Borissov, private communication.
[3] Ron Lipton, Comparision Lifetime of the DØ Silicon Tracker, DØ Note 4077 (2003).