D0 Note 4329 - A crosscheck of the Run II Luminosity Monitor Efficiency

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1 Introduction

This note describes a cross check of the luminosity monitor efficiency estimate done by Tamsin Edwards[4]. The luminosity monitor efficiency is found to be $87.6 \pm 0.7 \pm 1.7\%$. The efficiency calculation is broken down into subcomponents and all are consistent with Tamsin's independent analysis.

1.1 Method

The technique used here is to use the energy deposition in the endcap calorimeters as a tag of measurable energy in the luminosity monitors. The analysis is complicated by the existence of single diffractive events, which should not and do not fire the luminosity counters on both sides. These events must be removed from the sample before an efficiency can be estimated. We use events with no luminosity monitor signal on either side and no vertex as an estimate of the energy distribution in the north and south calorimeters when no interaction occurred. This same 'noise' distribution of energy should occur on one side in single diffractive events with no backwards particles and can be used as a tag for such events. The total energy distribution for events in which the luminosity counters did fire is fit to a polynomial + the noise distribution and the noise(single diffractive contribution) is substracted out. The remaining events should represent real non-diffractive events in which both luminosity monitors should have fired. Any failure to fire in the non-diffractive sample is considered to be an inefficiency of the luminosity counters.

2 Detector

The RunII a luminosity detector and electronics are described in references [1],[4].

3 Data Sample

The data sample used was a set of QCD root-tuples created by Pawel Demine from zero bias skims of runs 151892 to 176308.

The LumByTick method [3] was used to check for lum quality, 9,866 events in the sample were rejected because they did not have good luminosity information, leaving 1.64M events.

3.1 Cuts and Data Classification

Events were classified based on the AND/OR bits from the luminosity system and on the presence or absence of a vertex. The events were considered to have a vertex if at least one vertex had 3 or more tracks.

The bits were

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North - 0,1
South - 0,1
FASTZ - 0,Z,P,A (nothing, FASTZ, ProtonHalo, AntiProton Halo)
VTX   - 0,1
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Events with Halo bits were excluded from the analysis as they are handled separately in draft D0 note 4292 [5].

Calorimeter energy behind the luminosity monitors was summed and plotted for each end of the detector, cells with energy below some threshold (100 or

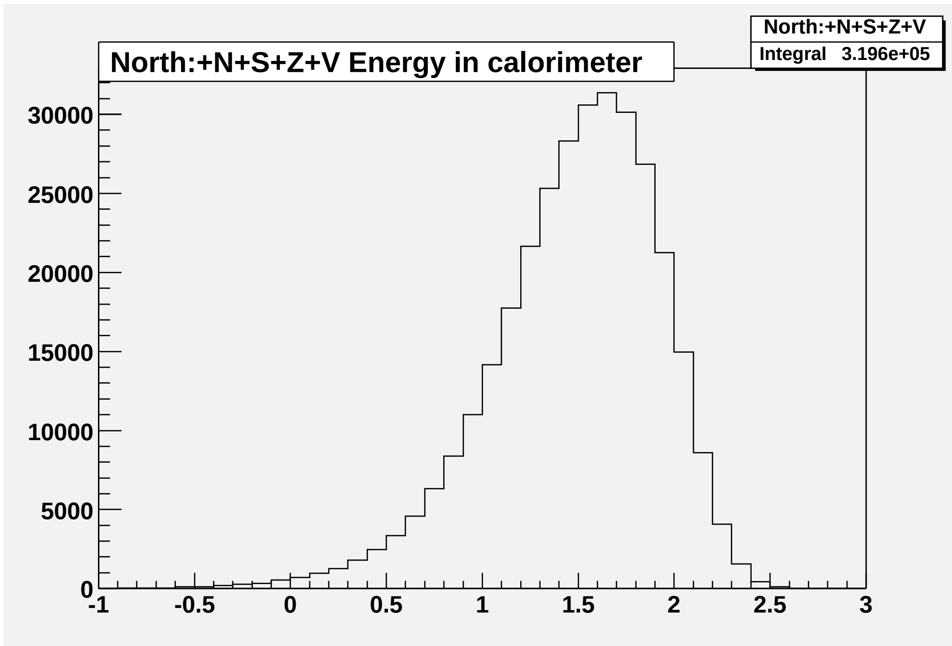

Figure 1: Energy sum for cells with energy > 100 GeV from in which N+S+FASTZ fired and there is a vertex, these are mostly hard scatters. a) shows data with a 100 MeV cut per cell .

200 MeV) were not included in the sum. Most of the results shown are for the 100 MeV cut.

The Log of the energy was plotted for each of the 32 possible combinations of AND/OR bits and vertex information.

Several examples are shown in Figures 1,3,4

$$1 \leq \quad \text{ilayer} \leq 7 \qquad (1)$$

$$28 \leq \quad |\text{ieta}| \leq 35 \qquad (2)$$

$$100, 200 MeV \leq \quad E(cell) \qquad (3)$$

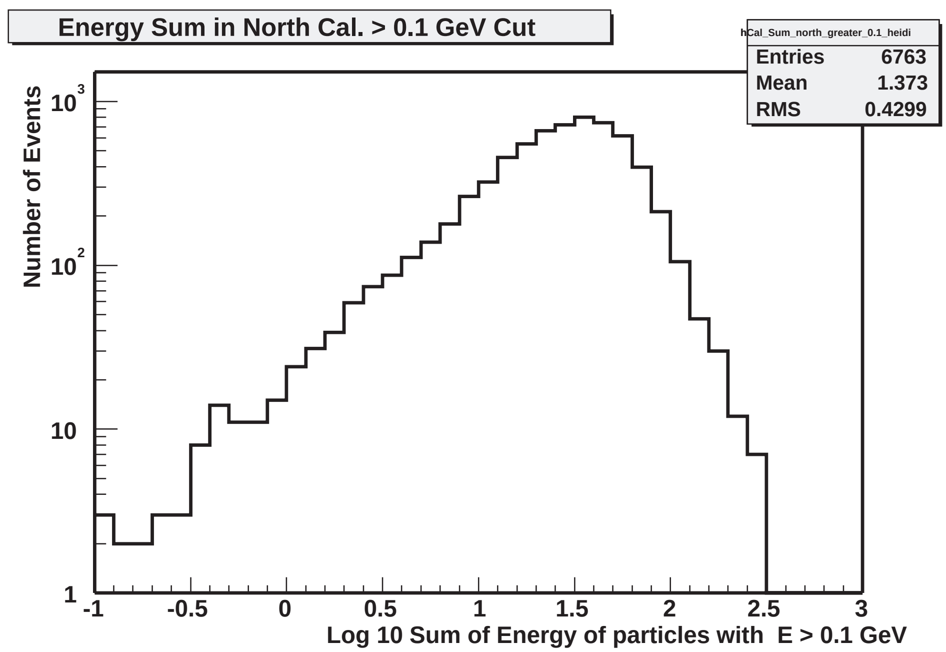

Figure 2: Energy sum for cells with energy $>$ 100 GeV from Pythia stable particles.

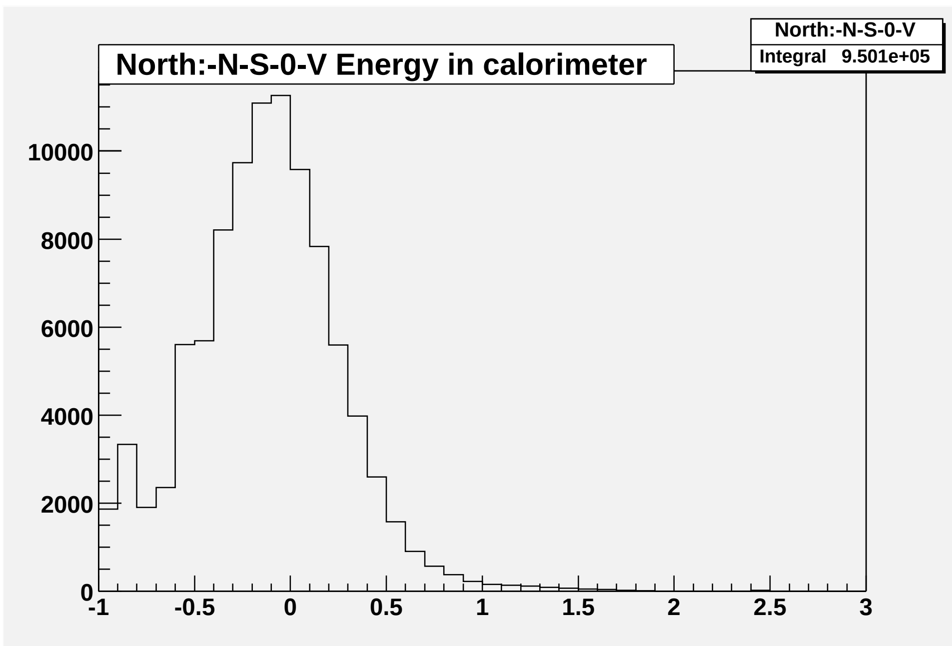

Figure 3: Events in which none of N+S+FASTZ fired and there was no vertex, these are mostly events in which no interaction occurred.

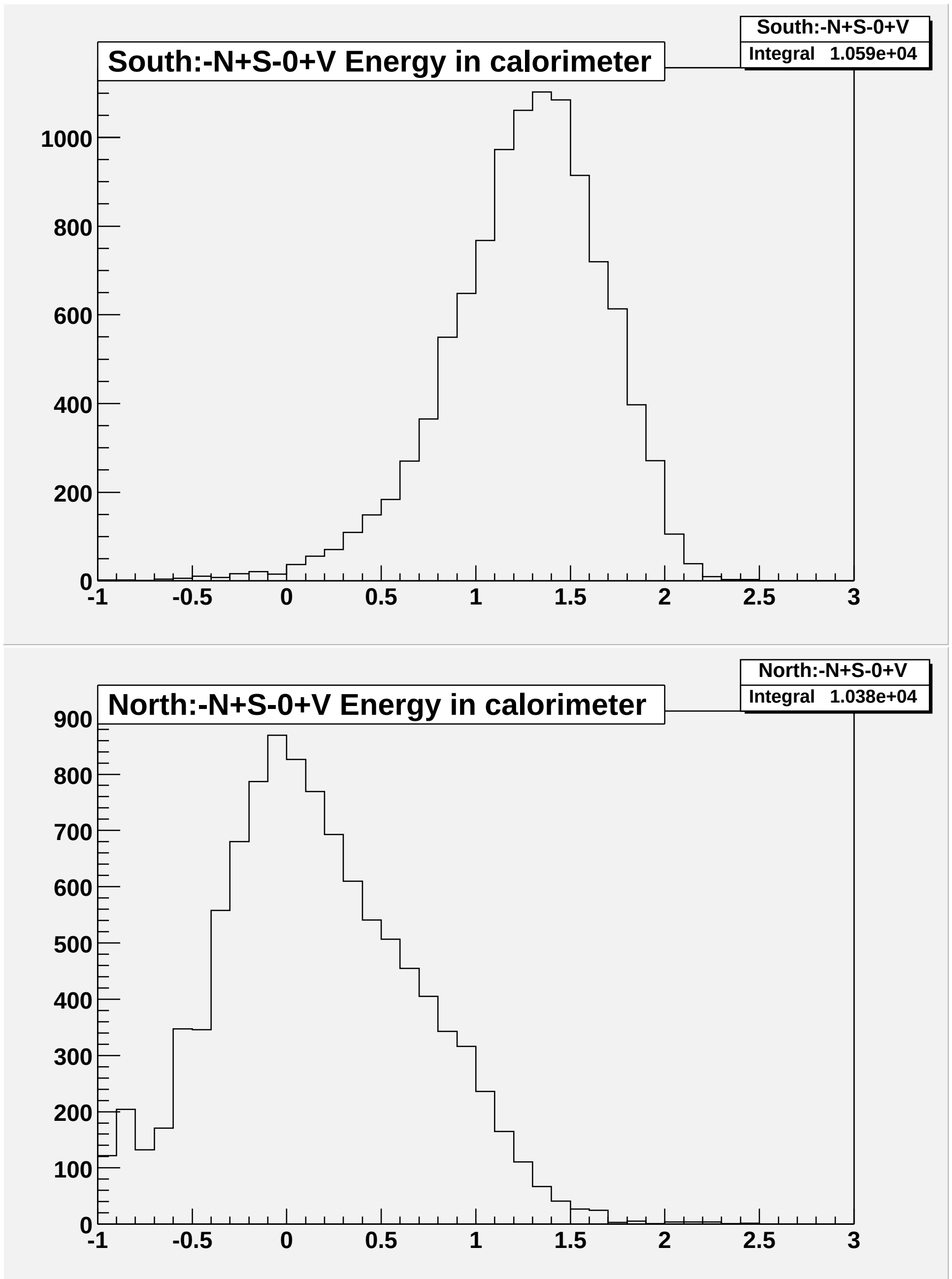

Figure 4: Events in which S fired but N did not and there is a vertex, these are mostly single diffractive interactions or hard scattering events in which N was inefficient. Both plots are for a 100 MeV threshold. The upper plot shows the energy on the south side, where the luminosity counters indicate that an interaction took place. This should look similar to the signal sample. The lower plot shows the North side, where the luminosity monitor shows no hits.

4 Method

We would like to find the efficiency of the luminosity counters for hard scatters. Because single diffractive events which produce no particles in the luminosity detector acceptance produce the same signal in the AND/OR terms as an inefficient luminosity counter (hit on only one side), we need to remove the true single diffractive events which are not in the acceptance from the sample, leaving a hard scatttering sample, before determining the efficiency. This is done by using the zero bias sample (-N-S-0-V) (Figure 3) as a noise reference sample for the calorimeter signal expected in single diffrative events. All energy spectra are fit to the noise sample plus an exponential function which appears as a straight line or quadratic on a log y plot.

$$f(\log_{10} E) = \alpha_0 \text{noise}(\log_{10} E) + \exp(\beta_0 + \beta_1 \log_{10} E + \beta_2 (\log_{10} E)^2) \qquad (4)$$

The exponential is assumed to be the extrapolation of the signal under the noise peak and is not subtracted off.

The number of hard scatters in each sample is then estimated as:

$$N_{hard} = \sum_i N_i - \sum_i \alpha_0 \text{noise}_i \qquad (5)$$

The fits are done with two fit functions, one plain exponential and the other including a gaussian component. The fit range is $-1.0 \leq \log_{10} E \leq 0.5$

For the rest of this discussion, we will use the 100 MeV cutoff data, 200 MeV data will be used to estimate the error due to the method.

5 Results

If we define the efficiency of the North counter as the fraction of background subtracted nonhalo events in which N fired. Here there is no assumption about the presence or absence or absence of a vertex.

$$\epsilon_N = \frac{(N \cdot S \cdot Z) + (N \cdot S \cdot 0)}{(N \cdot S \cdot Z) + (N \cdot S \cdot 0) + (\overline{N} \cdot S \cdot Z) + (\overline{N} \cdot S \cdot 0)} \qquad (6)$$

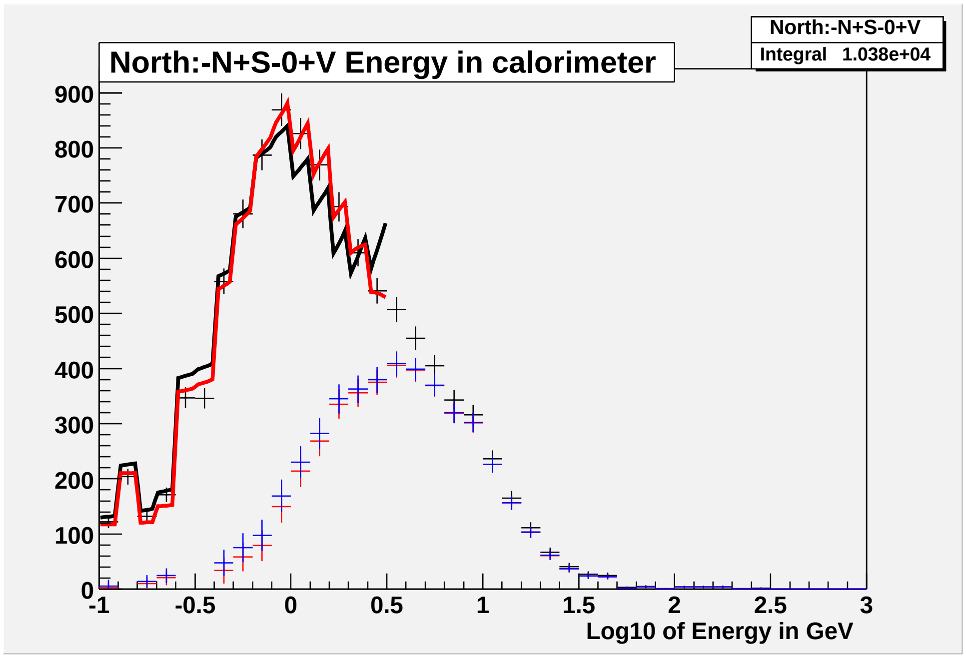

Figure 5: An example of the subtraction for the sample in which S fired and there was a vertex but N did not fire, this sample is a mixture of N inefficiency and single diffraction. The plot shows the energy on the north side with curves from the two fits, the red fit has one additional parameter, the χ^2's are respectively 7(red) and 76(black). The red points shows the subtracted 'signal' distribution using the 4-parameter fit and the blue show the subtracted 'signal' distribution using the 3-parameter fit.

Counter Efficiency	4-parameter	3-parameter
North	$96.8 \pm 0.4\%$	97.3 ± 0.4 %
South	93.5 ± 0.4 %	94.0 ± 0.4 %
N·S	$90.5 \pm 0.6\%$	$91.5 \pm 0.6\%$

Table 1: Efficiencies for the North and South counters excluding halo events

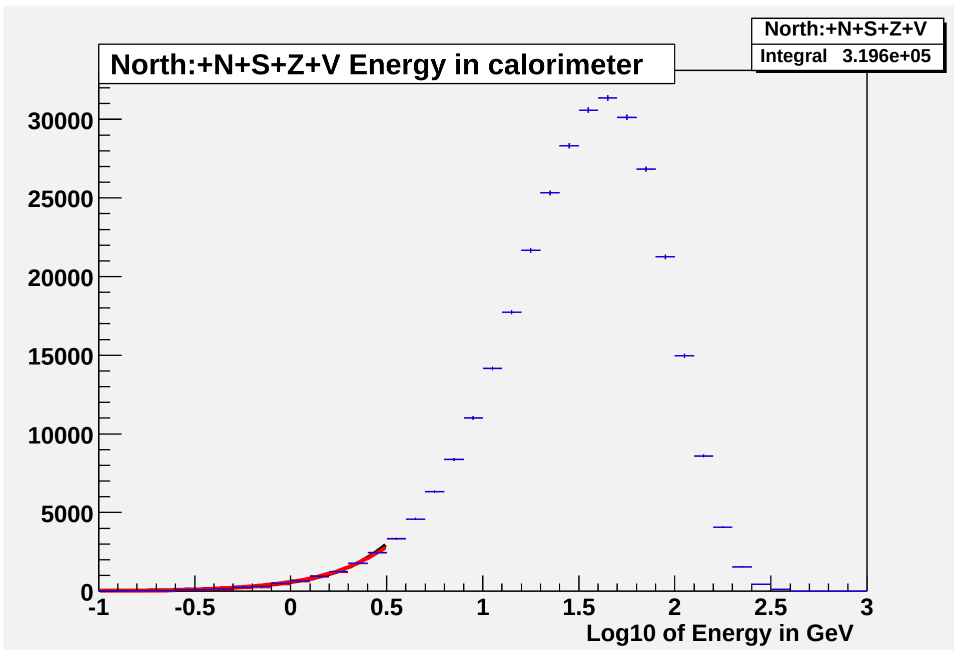

Figure 6: Data in which all counters fired properly and a vertex was found The black points are the raw data with curves from the two fits, which have χ^2 of 14 (red) and 45 (black) respectively. The red points are the estimated signal if the background estimated from the 4-parameter method is used. The blue points are the estimated signal if the background estimated from the 3-parameter method is used.

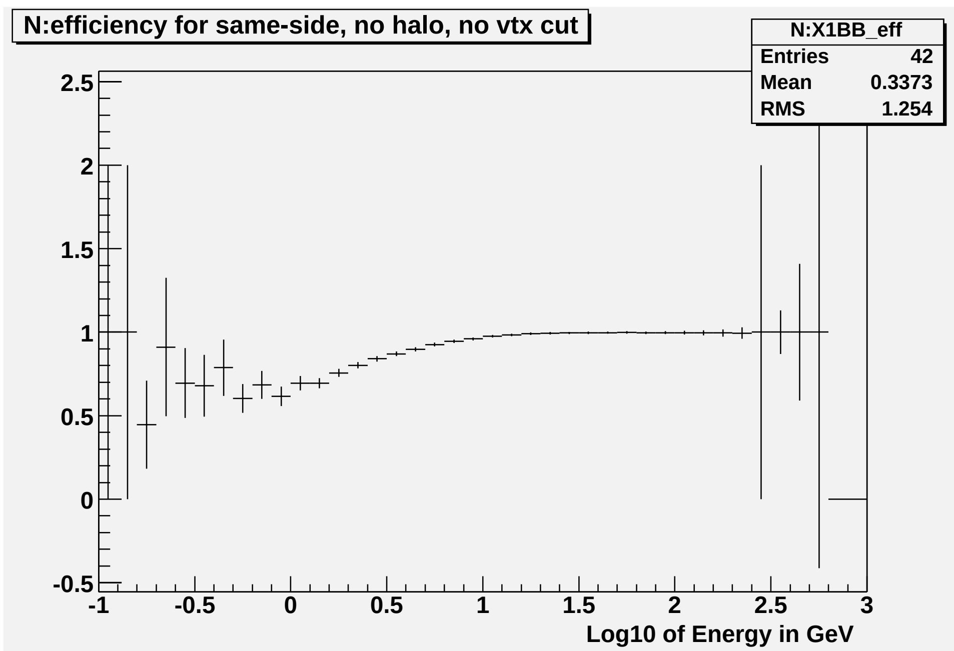

Figure 7: North counter efficiency derived from the previous two plots.

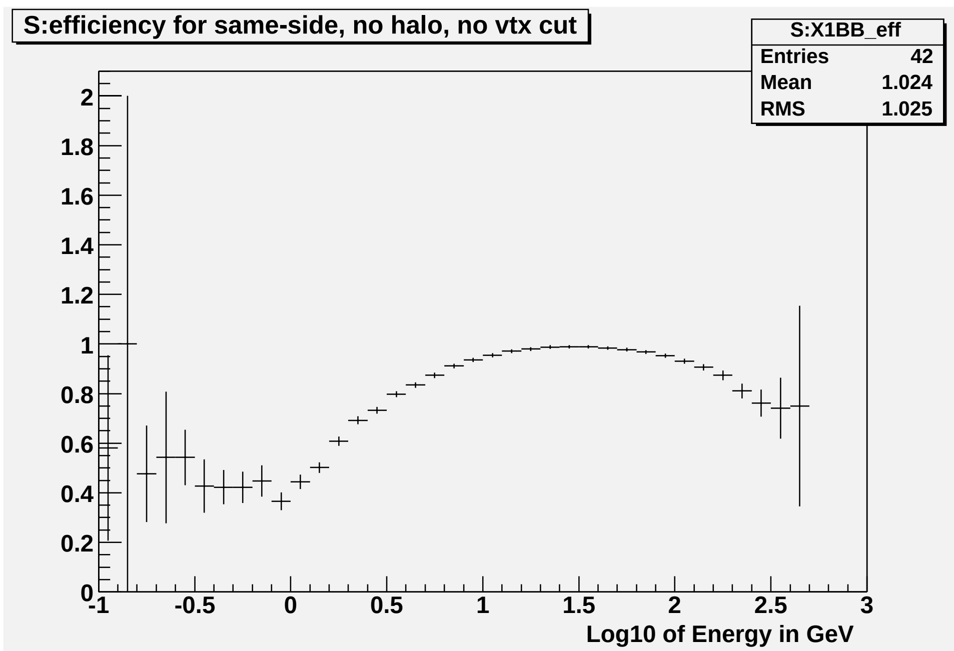

Figure 8: South counter efficiency.

Counter Efficiency	4-parameter	3-parameter
North	$97.0 \pm 0.4\%$	$97.4 \pm 0.4\%$
South	$93.6 \pm 0.4\%$	$94.0 \pm 0.4\%$
N·S	$90.8 \pm 0.6\%$	$91.5 \pm 0.6\%$

Table 2: Efficiencies for the North and South counters using all events

Electronics Efficiency	4-parameter	3-parameter
North	$99.7 \pm 0.4\%$	$99.7 \pm 0.4\%$
South	$98.3 \pm 0.4\%$	$98.3 \pm 0.4\%$

Table 3: Electronics Efficiency - the statistical errors are almost 100% correlated with the counter statistical errors.

5.1 Counter efficiencies including halo events

In principle the N and S counter efficiencies should not depend strongly on whether or not halo is included in in the samples. (There should be some dependence as the efficiency is summed over the energy distributions of events and halo events have different energy distributions.)

If halo events are included in the N + S efficiencies (no 0/P/A/Z information is used) the efficiencies are essentially unchanged, as illustrated in table 2.

Conclusion: The inclusion of the halo events thus does not affect the individual N/S efficiencies.

5.2 Electronic inefficiency

These inefficiencies include both the intrinsic inefficiency of the N and S counters and the inefficiency of the electronics which leads to the AND/OR terms after the FASTZ signals have been split off. This electronics efficiency of the N and S signals has no effect on the FASTZ inefficiency and needs to be corrected for. We can determine this efficiency by looking at events where FASTZ fired and one of N or S did not.

$$\epsilon_{elec}(N) \simeq \frac{(N \cdot S \cdot Z)}{(N \cdot S \cdot Z) + (\overline{N} \cdot S \cdot Z)} \tag{7}$$

Correlation correction	4-parameter
Uncorrelated $\epsilon_N \times \epsilon_S$	$90.5 \pm 0.7\%$
After correlations	$89.6 \pm 0.7 \pm 1.0\%$

Table 4: Effect of North South energy correlations on joint efficiency from Monte Carlo Simulation.

If halo events are included, the electronics efficiencies are S = 97.8% and N = 99.7%.

This correction will be applied separately at the end.

5.3 Joint efficiency for N·S to fire

If one assumes no correlation between N and S and just takes the product of the efficiencies, one gets

$96.8 \times 93.5 = 90.5$ % for the 4 parameter joint efficiency of N·S.

However the energies on the two sides could be correlated and the efficiencies are strong functions of energy. An efficiency which takes this into account can be formed by taking an inelastic Monte Carlo sample and weighting the events by the efficiency for finding a vertex and the N and S efficiencies as a function of the measured calorimeter energy for each side. The true N+S efficiency is then

$$\epsilon_(N \cdot S) = \frac{\sum_{ij} \epsilon_N(i)\epsilon_S(j)\mathcal{N}_{ij}}{\sum_{ij} \mathcal{N}_{ij}} \tag{8}$$

where i, j index the energy binds. This calculation yields a joint N S efficiency of 89.6%. The effect of the correlation is present but small (-0.9%) as most events are in the highly efficient region. We take a 1% systematic error for this as the Pythia MC simulation is not perfect. The result is summarized in table 4.

6 Efficiency of FastZ electronics

Once N+S have fired, we need to know the efficiency for the fast Z electronics.

The ratio

$$\epsilon_{FASTZ} = \frac{(N \cdot S \cdot Z)}{(N \cdot S \cdot Z) + (N \cdot S \cdot 0)} \tag{9}$$

yields $\epsilon_{FASTZ} = 98.2\%$ for 4 parameters and 98.3% for 3 parameters.

6.0.1 Including halo events

$$\epsilon_{FASTZ} = \frac{(N \cdot S \cdot Z)}{(N \cdot S \cdot Z) + (N \cdot S \cdot \overline{FASTZ})} \tag{10}$$

yields $\epsilon_{FASTZ} = 92.4\%$ for 4 parameters and 92.5% for 3 parameters.

Thus 6% of all events are being classified as halo.

7 Error estimate

The previous sections stated the values for the 4-parameter fit. If the 3-parameter fit is used, the electronics efficiency does not change but the joint N+S efficiency before electronics correction is 91.5 instead of 90.5%.

If the fit range is reduced to $-0.5 < \log_{10} E < 0.5$, the North efficiency is 0.970 , the South efficiency is 0.936%, the electronics efficiencies are unchanged and the joint N+S efficiency before electronics correction is $90.4 \pm 2.8\%$.

There are all consistent with the 90.5% from the default four parameter fit.

8 Current bottom line

The raw N·S efficiency after correction for correlations is somewhere around $89.6 \pm 0.7 \pm 1.0\%$.

The N/S bit electronics inefficiency is 2% and needs to be ADDED to the N·S efficiency.

The FASTZ inefficiency once N·S have fired is 98.2%

tag	Total	4par	3par	err-4	err-3	chi -4	chi -3
North:-N-S-0-V	983412.0	0.0	0.0	1431.9	1431.9	0.0	0.0
North:-N-S-0+V	1676.0	706.9	506.6	172.4	77.4	4.4	19.0
North:-N-S+Z-V	3.0	3.0	3.0	1.7	1.7	–	–
North:-N-S+Z+V	21.0	21.0	21.0	4.6	4.6	–	–
North:-N-S+P-V	24.0	24.0	24.0	4.9	4.9	–	–
North:-N-S+P+V	19.0	19.0	19.0	4.4	4.4	–	–
North:-N-S+A-V	1.0	1.0	1.0	1.0	1.0	–	–
North:-N-S+A+V	–	–	–	–	–	–	–
North:-N+S-0-V	60055.0	9632.8	7097.8	1352.9	523.6	12.6	39.2
North:-N+S-0+V	10594.0	4411.3	4574.0	310.9	225.1	7.1	46.7
North:-N+S+Z-V	388.0	360.3	358.6	24.4	23.3	1.5	2.8
North:-N+S+Z+V	818.0	815.5	818.0	38.0	82.0	18.8	18.8
North:-N+S+P-V	107.0	74.5	79.9	14.8	17.1	4.1	5.3
North:-N+S+P+V	90.0	90.0	90.0	9.5	9.5	–	–
North:-N+S+A-V	5.0	5.0	5.0	2.2	2.2	–	–
North:-N+S+A+V	0.0	0.0	0.0	0.0	0.0	0.0	0.0
North:+N-S-0-V	49412.0	40488.8	40933.6	453.0	354.1	18.1	111.2
North:+N-S-0+V	12715.0	12579.3	12715.0	115.7	132.8	31.7	45.9
North:+N-S+Z-V	1992.0	1120.0	1091.3	82.3	71.8	20.6	24.2
North:+N-S+Z+V	6664.0	6664.0	6664.0	82.3	81.6	3.6	3.4
North:+N-S+P-V	2027.0	1734.0	1824.8	75.4	76.9	10.7	25.7
North:+N-S+P+V	747.0	736.2	747.0	28.2	48.6	8.0	8.7
North:+N-S+A-V	64.0	64.0	64.0	8.0	8.0	–	–
North:+N-S+A+V	11.0	11.0	11.0	3.3	3.3	–	–
North:+N+S-0-V	5294.0	4486.1	4064.1	223.6	120.1	11.2	43.6
North:+N+S-0+V	3779.0	3675.8	3659.8	72.5	67.1	17.2	23.2
North:+N+S+Z-V	150963.0	136586.0	135562.0	638.5	508.7	22.1	24.3
North:+N+S+Z+V	319683.0	318614.0	319300.0	603.2	591.2	13.9	44.7
North:+N+S+P-V	27410.0	21094.3	20924.7	349.1	295.3	18.8	567.9
North:+N+S+P+V	6170.0	6006.1	6043.9	85.2	90.6	6.0	21.6
North:+N+S+A-V	1878.0	1671.2	1687.6	59.0	57.3	6.5	15.6
North:+N+S+A+V	590.0	571.7	573.1	24.9	27.9	2.9	5.4

Table 5: Table containing the values/fits for the 32 possible bit combinations. Combinations with less than 100 events were not fitted.

tag	Total	4par	3par	err-4	err-3	chi-4	chi-3
South:-N-S-0-V	983412.0	0.0	0.0	1428.8	991.7	0.0	0.0
South:-N-S-0+V	1676.0	859.3	802.9	125.1	79.0	10.4	23.6
South:-N-S+Z-V	3.0	3.0	3.0	1.7	1.7	–	–
South:-N-S+Z+V	21.0	21.0	21.0	4.6	4.6	–	–
South:-N-S+P-V	24.0	24.0	24.0	4.9	4.9	–	–
South:-N-S+P+V	19.0	19.0	19.0	4.4	4.4	–	–
South:-N-S+A-V	1.0	1.0	1.0	1.0	1.0	–	–
South:-N-S+A+V	0.0	0.0	0.0	0.0	0.0	–	–
South:-N+S-0-V	60055.0	54382.0	55193.0	378.2	353.0	15.1	75.4
South:-N+S-0+V	10594.0	10580.4	10557.7	123.9	110.9	14.6	14.3
South:-N+S+Z-V	388.0	357.2	362.0	22.0	26.6	17.3	18.0
South:-N+S+Z+V	818.0	813.9	813.6	28.8	28.8	0.9	0.9
South:-N+S+P-V	107.0	101.1	101.1	11.3	11.4	2.1	2.3
South:-N+S+P+V	90.0	90.0	90.0	9.5	9.5	–	–
South:-N+S+A-V	5.0	5.0	5.0	2.2	2.2	–	–
South:-N+S+A+V	0.0	0.0	0.0	0.0	0.0	–	–
South:+N-S-0-V	49412.0	15577.4	13759.0	1230.8	476.9	25.7	105.1
South:+N-S-0+V	12715.0	8482.1	7894.1	312.6	207.3	21.6	123.4
South:+N-S+Z-V	1992.0	1284.4	1199.4	91.8	66.5	23.1	33.2
South:+N-S+Z+V	6664.0	6654.4	6654.9	81.7	81.7	2.6	3.2
South:+N-S+P-V	2027.0	2019.7	2027.0	50.6	75.0	4.1	4.2
South:+N-S+P+V	747.0	0.0	0.0	66.7	70.0	–	–
South:+N-S+A-V	64.0	64.0	64.0	8.0	8.0	–	–
South:+N-S+A+V	11.0	11.0	11.0	3.3	3.3	–	–
South:+N+S-0-V	5294.0	4725.6	4783.9	88.9	97.8	20.1	25.4
South:+N+S-0+V	3779.0	3750.2	3747.9	67.0	65.1	11.3	10.9
South:+N+S+Z-V	150963.0	134869.0	135814.0	416.4	440.8	22.2	74.6
South:+N+S+Z+V	319683.0	318727.0	319415.0	584.6	584.3	6.1	33.9
South:+N+S+P-V	27410.0	26512.2	26769.4	187.1	196.7	9.9	54.1
South:+N+S+P+V	6170.0	6170.0	6170.0	79.5	79.5	8.1	8.2
South:+N+S+A-V	1878.0	1744.5	1534.0	139.5	80.9	5.6	22.2
South:+N+S+A+V	590.0	590.0	583.6	37.0	28.7	6.9	5.9

Table 6: Table containing the values/fits for the 32 possible bit combinations. Combinations with less than 100 events were not fitted.

The Losses due to halo are $2.4 \pm 1.0\%$.

The net efficiency if you roughly combine these is $89.6 \times (1.02) \times (0.982) \times (1/1.024) = 87.6\%$ with a statistical error of 0.7% from the individual efficiencies and errors of order 1.0% each from varying the fit assumptions and from the Energy correlations.

This yields an efficiency estimate of

$$87.6 \pm 0.7(\mathrm{stat}) \pm 1.7(\mathrm{syst}) \tag{11}$$

8.1 Comparison to Tamsin Edward's estimates

Tamsin Edwards has done an independent analysis which yields the same results.[4] This analysis was done for an earlier data (pre April 24, 2003) sample than Tamsin's reference sample but appears to yield similar results.

Tamsin Edward's single counter efficiencies are equivalent to the ones quoted here after they have been corrected for the electronics inefficiencies. This analysis yields

$$\epsilon_N = 96.8\% \tag{12}$$

$$\epsilon_S = 93.5\%. \tag{13}$$

Compare to the first column in Tamsins Table 9 which has $\epsilon_N 96.7 - 97.1\%$ and $\epsilon_S = 93.3 - 93.8\%$.

The Monte Carlo method yields a correlated efficiency correction of $0.9 \pm 1.0\%$. Tamsin's study in section 4.2 finds that this number is small with unknown error and assume 0.0 correlation correction.

Tamsin Edward's timing efficiency is the FASTZ efficiency quoted above with additional losses due to halo overlaps. If done in her way, this analysis would estimate

$$\epsilon_{FASTZ} = 98.2 \times (1 - 0.024) = 95.8\% \tag{14}$$

for this quantity. Compare to 95.9% in the paragraph after Table 12 in Tamsin's memo.

The bottom line estimated here is 87.6% while Tamsin's is 88.5%. The full difference is the correlation estimate.

References

[1] M. Begel *et al.*, D0 notes 3970,3972, 3973.

[2] J. Bantly, J. Krane, D. Owen, R. Partridge and L. Paterno, "D0 luminosity monitor constant for the 1994-1996 tevatron run," FERMILAB-TM-1995 http://www.slac.stanford.edu/spires/find/hep/www?r=fermilab-tm-1995

[3] http://www-d0.fnal.gov/phys_id/luminosity/data_access/lm_access/doc

[4] D0 Note XXXX : D0 Luminosity in Run II: FASTZ Efficiency - Tamsin Edwards

[5] D0 Note 4292: Effect of Halo Events on the Measured Minimum Bias Rates for Luminosity, Schellman, Casey, Edwards and Partridge