Minutes of the 173rd Energy Calibration Meeting held on 19 February 1999

The discussion of errors in these minutes has been supplemented by subsequent e-mail exchanges. In summary, the preliminary uncertainty in the beam energy for the 1998 data is 20 MeV. The correlation matrix relating the uncertainties for the four samples with centre-of-mass energy of about 161, 172, 183 and 189 GeV is:

$$\begin{pmatrix} 1.00 & 1.00 & 0.91 & 0.75 \\ 1.00 & 1.00 & 0.82 & 0.67 \\ 0.91 & 0.82 & 1.00 & 0.75 \\ 0.75 & 0.67 & 0.75 & 1.00 \end{pmatrix}$$

A short LEP Energy Group internal note will be prepared to show the data quality of the 1998 data in comparison with 1997, and including the table of errors and this correlation matrix. Details of the error break down are also given in these minutes.

1 Cross-check of dipole energies

Anke Muller showed a cross check of the initial dipole energies, with and without NMR4 (which is number 8 in her numbering system). These are calculated using a different normalisation procedure to Guy Wilkinson, but show good agreement as before.

Anke also showed a plot giving the fraction of time the probes were working correctly at 45 GeV and physics energies. The least efficient are in the string in octant 5.

2 Status of energy files

Guy Wilkinson announced that the "technical" energy files have been updated since the last meeting. Missing fills and parts of fills have been included, and where possible, missing NMR data has been recovered from private logging. The RF model was also updated, to include the best estimate of the voltage scale. This caused a shift in the average centre of mass energies by 2 MeV w.r.t. the technical files.

There is still a problem with fill 5373, during which the switch from summer to winter time occured. The logging information for this fill shows no apparent problems, but is 1 hour shorter than it should be. however, the fill was extremely stable, and this has a tiny effect on the overall energies.

3 Error analysis

The first estimate of the error breakdown for 1998 is given in the table below. The systematic checks leading to any new evaluations are discussed in the following sections.

Source	Error [MeV] 1997	1998	Correlation
Extrapolation from NMR–polarisation:			
NMR rms/$\sqrt{N}$ at physics energy	10	8	100%
Different E_{pol} fills	5	4	0%
Flux-loop test of extrapolation:			
NMR flux-loop difference at physics energy	20	15	75%
Field not measured by flux loop	5	5	100%
Polarisation systematic	1	1	100%
e^+e^- energy difference	2	2	100%
Optics difference	4	6	50%
Corrector effects	3	4	50%
Tide	1	1	100%
Initial dipole energy	2	1	0%
Dipole rise modelling	1	1	100%
IP specific corrections ($\delta E_{\mathrm{CM}}/2$):			
RF model	4	4	100%
Dispersion	2	2	100%
Total	25	20	

3.1 Scatter in predicted physics energy over NMR's

The rms scatter of the average initial energy per NMR in physics runs for the 1998 data is 33 MeV, compared to 41 MeV in 1997. This implies a slightly reduced uncertainty of 8 MeV.

3.2 Different Epol fills

NMR4 has been seen to have a strange behaviour, leading to a larger scatter of residuals in polarisation fills. If this NMR is omitted, the scatter and error bars are reduced, and the energy shifts by 3.3 MeV.

Using different groups of polarisation fills also causes shifts in the mean energy. The largest come from splitting the data into July and earlier, and September and later. NMR4 was exchanged between these two, so the difference is largely a reflection of the NMR4 strange behaviour. The shifts are $+4$ and -2.3 MeV w.r.t. the default fit to all fills. An error of 4 MeV is therefore assigned, and this is almost entirely driven by the unexplained strange behaviour of NMR4 in 1998.

Using coefficients calculated by Peter Renton in an independent analysis gives consistent results to 1.5 MeV.

3.3 Flux-loop/NMR difference at physics energy

Peter Renton sent the results of his study of the flux-loop data. He has updated his fits to use the region corresponding to polarisation measurements in 1998 (40-60 GeV) and to look at the bias at 94.5 GeV beam energy. His quality cuts are somewhat looser than those used by Guy Wilkinson, so more probes are available for each flux loop measurement.

For fills where Guy and Pete use the same NMR's, the same values for the bias are found.

The typical bias during the year is -15 MeV using all available NMR's, 20 MeV using only the common subset of NMR's. There is no strong trend through the year. (This is more convincing with when Pete's extra fills are included. Guy's more stringently selected subset show some hint of a trend.) Using the common subset of NMR's, the maximum difference in bias during the year is also around 15 MeV.

Pippa Wells used Guy's fits probe-by-probe to calculate the average bias per probe, and then the average bias over the probes. This reduces the sensitivity to probes failing during the year. The average bias calculated in this way is -11 MeV. The error on this mean from the rms over the probes is 7.8 MeV. Combining this in quadrature with the typical scatter over flux-loops for one probe, which is 6.4 MeV, gives a total error of 10 MeV. The bias calculated in this way is therefore only about 1 sigma from zero, and was considered as lower bound on any reasonable error estimate.

Peter also provided plots of the bias probe-by-probe, but the average calculated by finding the average value per probe first has not yet been made.

The flux loop "banana" has a peak to peak amplitude of less than 1 MeV, and is not very banana shaped.

From these studies and arguments, and error from the flux-loop bias test of 15 MeV was proposed for the 1998 data.

3.4 Optics difference

The residuals for the two 102/90 points are $+4$ and -1 MeV if NMR4 is included, but shift to $+5$ and -3 MeV excluding NMR4.

NMR4 is used for the central values, suggesting an average optics difference of 1.5 MeV, with an rms of 3 MeV. However, the data without NMR4 have an average shift of 1 MeV, and an rms of 4 MeV.

The optics difference scales with beam energy, so an uncertainty of 6 MeV has been assigned, based on the rms with NMR4 included.

3.5 Corrector effects

The average shift from horizontal orbit correctors was 7.9 MeV, evaluated by removing the correction. Following the same prescription as for 1997, the uncertainty is half of the effect, i.e. 4 MeV.

3.6 Initial dipole energy

The rms is 8 MeV for 440 fills, leading to an uncertainty of less than 1 MeV. Following tradition, an entry remains in the table with the negligible 1 MeV contribution (as was already done for polarisation uncertainty, for example).

3.7 Dipole rise modelling

The average energy in phyiscs changes by -0.8 MeV if the dipole rise term is ignored. The corresponding systematic uncertainty is therefore expected to be much less than 1 MeV, and following the convention of other such negligible uncertainties, we retain an entry of 1 MeV in the error table.

3.8 Error matrix for different years

Peter Renton proposed that an error matrix for the different years should be provided. The correlations for the 1996 and 1997 data were defined in the recent paper, but he is of the opinion that providing a matrix is more clear.

Reminder of previous prescription:

- 1996 161 and 172 GeV points can be assumed to be fully correlated.
- The 25 MeV uncertainty for 1997 can be assumed to be correlated with the 1996 points.

Pippa Wells has added to the error table above a proposal for the correlations for each error source between 1997 and 1998, from which an overall correlation coefficient can be calculated. Reasoning:

- The average initial dipole energy per NMR shows a strong correlation between 1997 and 1998. This is understood to mean that the scatter reflects the intrinsic properties of the magnets in the positions measured by the NMR's, and is therefore preserved when the probes are exchanged.
- Different E_{pol} fills is dominated by one strange fill in 1997, and NMR4 in 1998 – different effects, so uncorrelated
- Flux loop uncertainty, 15 MeV is in common, so this gives a correlation coefficient of 0.75.
- Field outside the flux loop is the same in both years.
- Polarisation and e^+e^- energy difference is same in both years.
- Optics dependence has some systematics in common, but the actual value is thought to depend on imperfections, so choose a somewhat arbitrary 50%.

- Similar argument for correctors - the systematics are in common, but the actual values depend on the golden orbit from year to year.
- Initial dipole energy - independent scatter each year, but it's so small that who cares how it's correlated?
- Dipole rise - presumably a correlated systematic effect.
- RF and dispersion effects, susceptible to the same systematic uncertainties each year.

For the 1996 data points (161 and 172 GeV), then assume that the total errors from 1997 and 1998 are fully correlated with these points. This approximation is presumably good enough, given the lower statistics at the lower energy points. Using the detailed error breakdown from the table for 1997 and 1998, and applying the approximation for the correlations with 1996 data gives:

Year	Centre-of-mass energy	Error in Ebeam
1996	161 GeV	27 MeV
1996	172 GeV	30 MeV
1997	183 GeV	25 MeV
1998	189 GeV	20 MeV

The covariance matrix for Ebeam (calculated to slightly higher precision than the above total errors) is:

$$\begin{pmatrix} 729. & 810. & 606. & 410. \\ 810. & 900. & 606. & 410. \\ 606. & 606. & 606. & 375. \\ 410. & 410. & 375. & 410. \end{pmatrix}$$

and the correlation matrix is:

$$\begin{pmatrix} 1.00 & 1.00 & 0.91 & 0.75 \\ 1.00 & 1.00 & 0.82 & 0.67 \\ 0.91 & 0.82 & 1.00 & 0.75 \\ 0.75 & 0.67 & 0.75 & 1.00 \end{pmatrix}$$

4 AOB

The referee for the 1997 energy paper said the paper was nice, and that the result is robust since a conservative assumption has been taken in evaluating the systematic error on the extrapolation...

There are a few comments, asking for small text changes to improve the clarity. The most significant refers to section 5.4 (horizontal correctors), which is "difficult to understand". Pippa Wells will implement the trivial text changes, and ask for help with the difficult ones.

5 Next meeting

The next meeting will be arranged after feedback on the proposed errors has been evaluated.

Pippa Wells, 19 February 1999. Updated 25 February.