Do we really need 1001 shifts for energy calibration?

28 January 1999 – Pippa Wells

- Dominant sources of uncertainty in the present energy calibration
- Energy calibration measurements in 1998
- How do the measurements affect the uncertainty
- Areas of inefficiency/improvements
- The bottom line... how many shifts?

Reminder of the extrapolation method

- NMR probes measure B field very precisely in up to 16 LEP main bend dipoles
- Calibrate NMR's w.r.t. polarisation measurements 40–60 GeV.
  - Linear fit: $E_{\mathrm{pol}} = a + bB_{\mathrm{NMR}}$
  - Control of non-linearity $\Rightarrow$ systematic error
  - Derive energy in physics from NMR B field in physics runs
- Main source of error - compare measured total B field from flux loop with predicted total B field from NMR's: $B_{\mathrm{FL}} = c + dB_{\mathrm{NMR}}$
- "Statistical" error from scatter of NMR predictions
- Further systematic error from variation of NMR calibrations through the year
- Other systematics relatively small... see error table
- Will rely on "magnetic extrapolation" until the spectrometer is proved to work

Error Table for 1997 analysis

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

Where did all the time go?

Energy calibration measurements in 1998

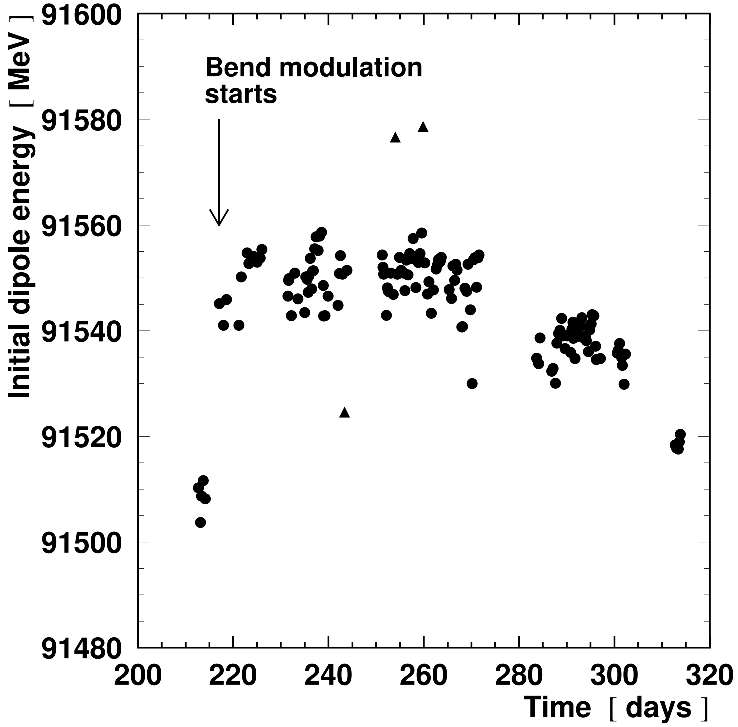
Fill	From	To	MD	Hours	Comment
4665	14-06 06:00	15-06 14:30		8.5	60/60 commiss.
4666	14-06 14:30	15-06 11:00		20.5	60/60
4669	18-06 00:00	18-06 12:00	Y	12.0	102/90 cross cal
4843	15-07 06:00	16-07 08:00	Y	26.0	60/60
5025	12-08 20:00	13-08 12:00		16.0	k-modulation on 60/60
5135-5137	05-09 14:00	06-09 14:00	Y	24.0	60/60
5141	07-09 06:30	08-09 10:00	Y	27.5	60/60
5214	20-09 06:00	21-09 08:00		26.0	60/60
5231-5232	29-09 11:30	30-09 08:00		20.5	102/90 cross cal
5337	18-10 06:30	19-09 09:00	Y	26.5	60/60
5421-5422	02-11 17:00	03-11 12:00		19.0	102/90 Pol at 92 GeV

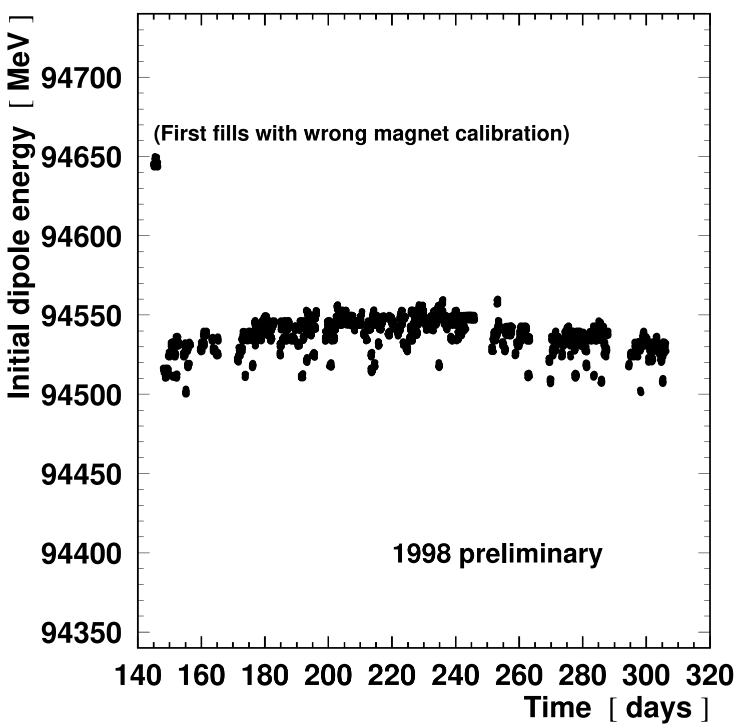
Total: 226.5 hours, 9.5 days

Polarisation Measurements

Date	Fill	41 GeV	45 GeV	50 GeV	55 GeV	61 GeV	Optics
19/08/96	3599			•			90/60
31/10/96	3702		•				90/60
03/11/96	3719		•	•			90/60
17/08/97	4000		•				90/60
06/09/97	4121		•	•			60/60
30/09/97	4237		•	•			60/60
02/10/97	4242	•	•	•	•		60/60
10/10/97	4274		•				90/60
11/10/97	4279	•	•	•	•		60/60
29/10/97	4372	•	•				60/60
14/06/98	4666		•	•	•		60/60
18/06/98	4669		•				102/90
15/07/98	4843		•		•		60/60
06/09/98	5137		•				60/60
07/09/98	5141	•	•	•			60/60
20/09/98	5214	•	•	•	•	•	60/60
29/09/98	5232		•				102/90
18/10/98	5337	•	•	•	•	•	60/60

Initial energy in fill - 1997 vs 1998

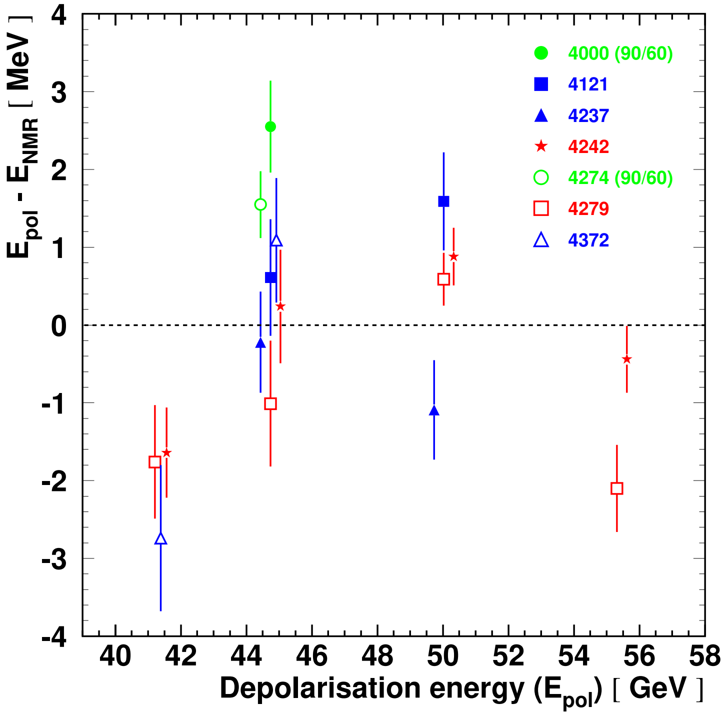


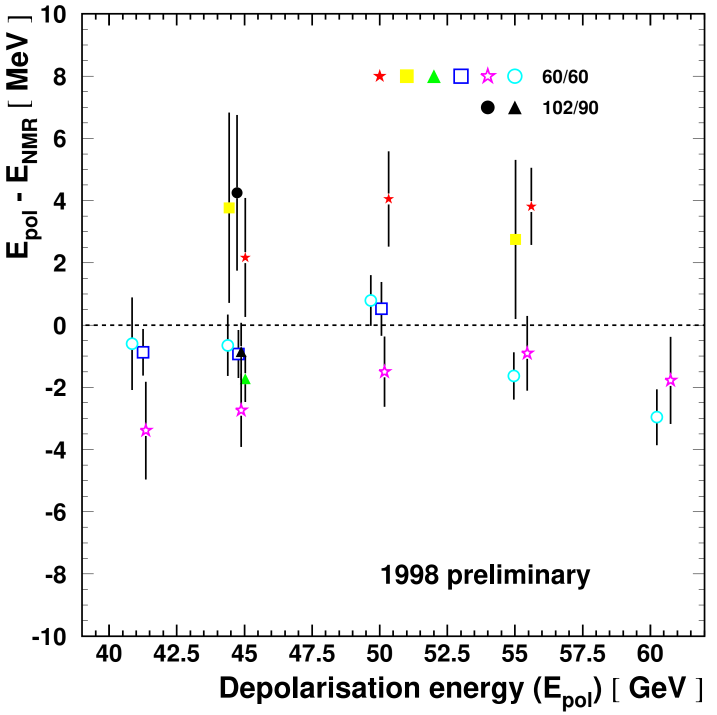


Most anomalies understood

Small scatter $\Rightarrow$ small error

Residuals of polarisation fits 1997 vs 1998

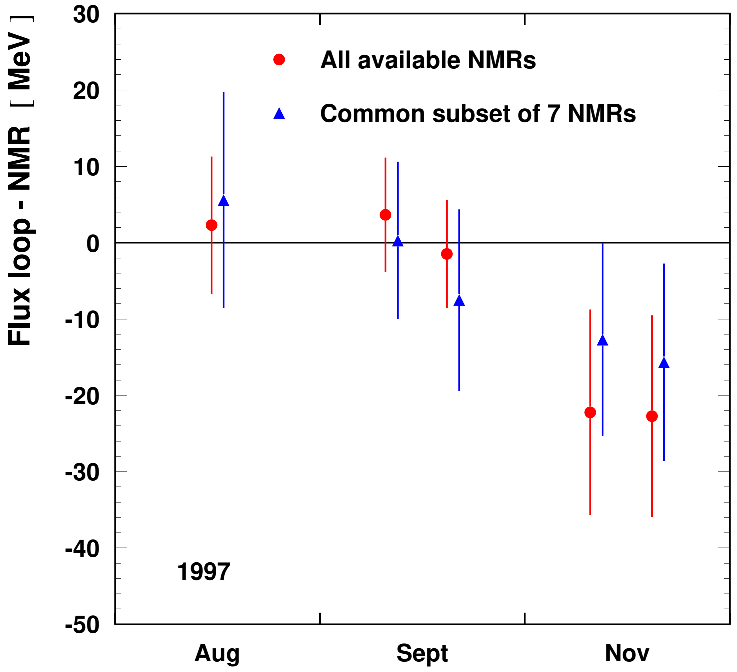


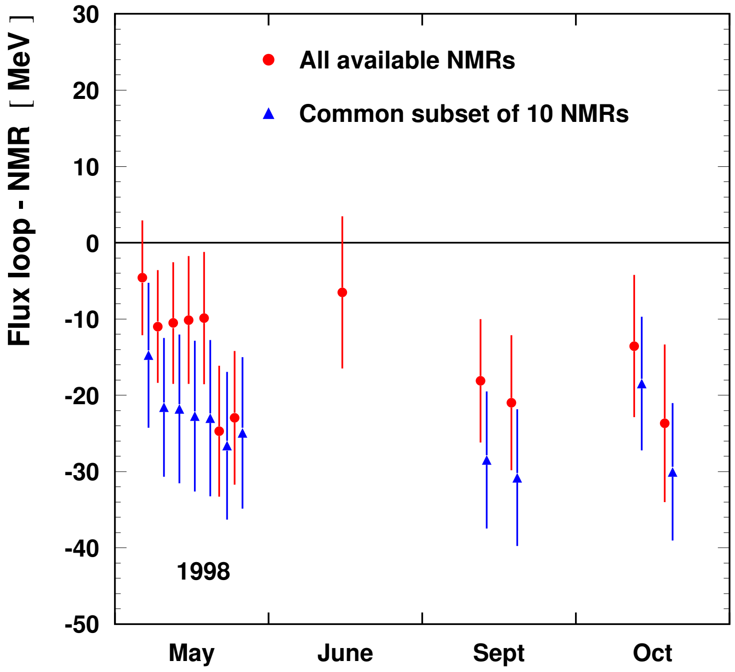


$10 \oplus 5$ MeV error in 1997

Larger fill-to-fill scatter in preliminary 1998 data.

Flux-loop NMR difference 1997 vs 1998

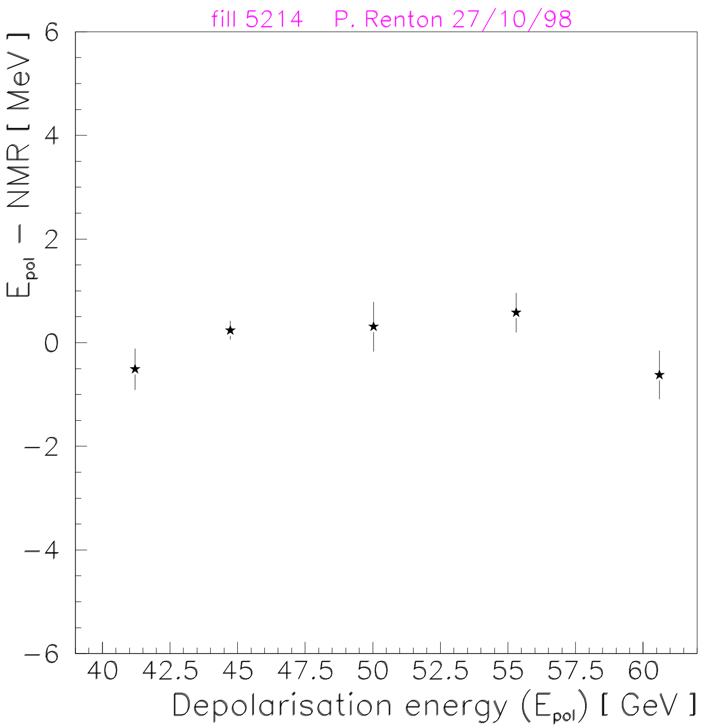




FL-NMR residual at physics energy dominates error

Time variation during the year not understood

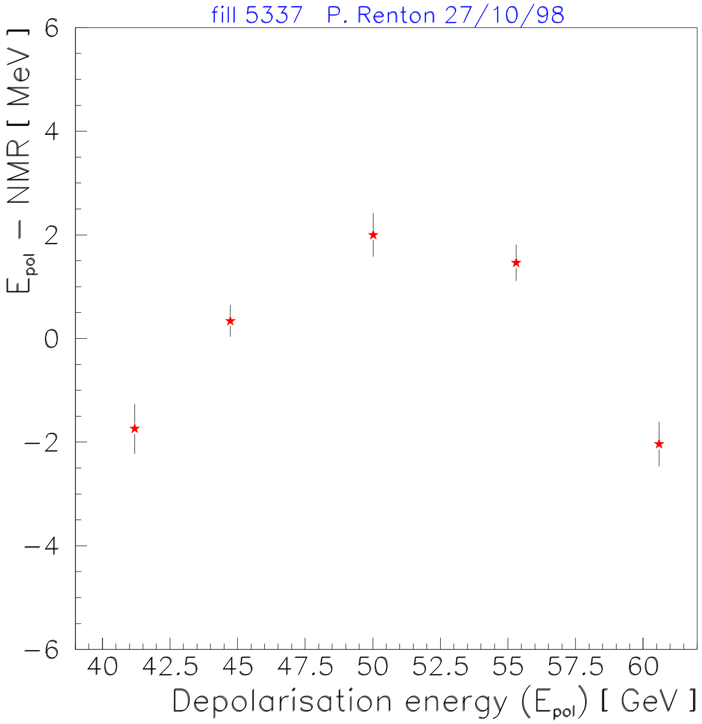
Oscar for best polarisation fill

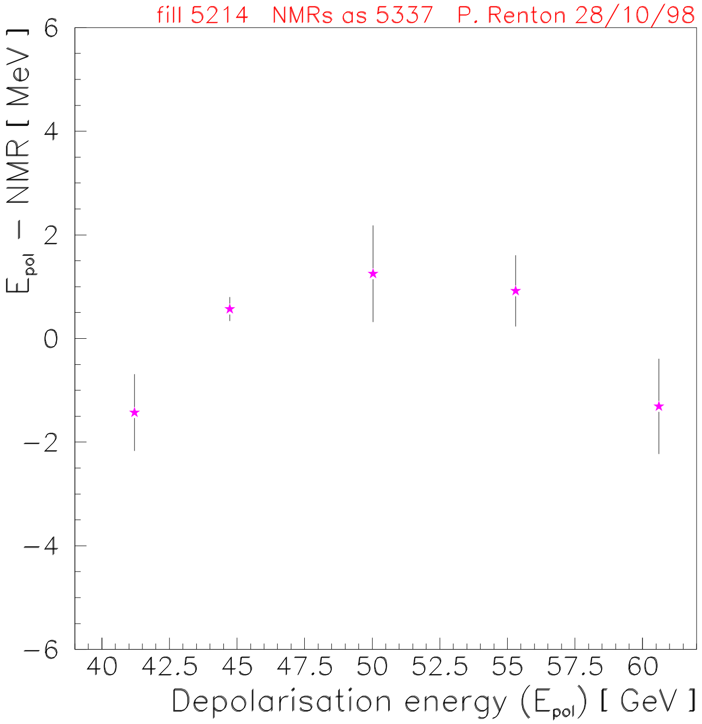


- Residuals from a straight line for five point polarisation fill, all NMR probes working
- Error bars from scatter over NMR's
- Non-linearities less than 1 MeV
- Larger residuals seen in some other fills... why?

Best fill explains banana

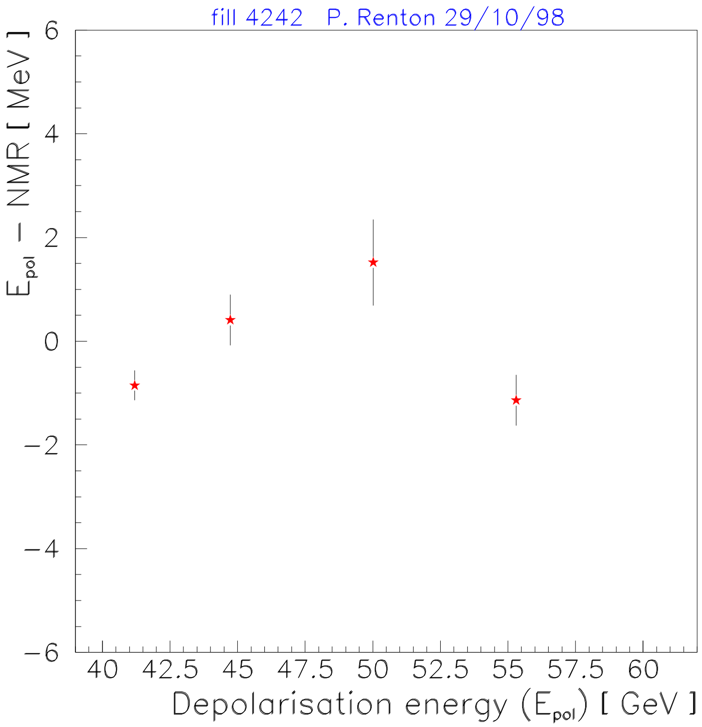
Use subset of NMR's to mimic an other fill

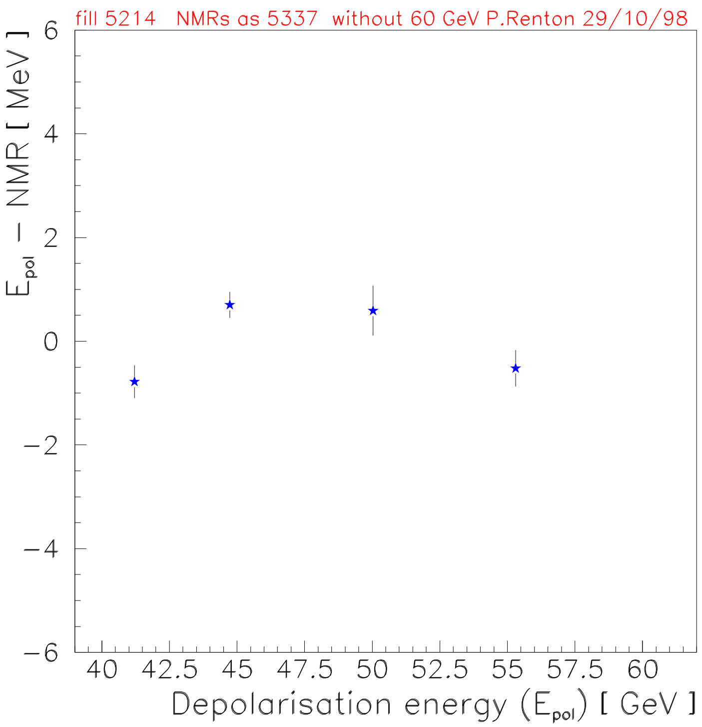




Banana flavour preserved from 1997 to 1998

Use subset of points and NMR's to mimic 1997





W mass errors

Worst case example still shows improvement in error

- W mass statistical error is proportional to $1/\sqrt{\mathcal{L}}$.
- Statistical error of experiments combined, 500pb^{-1}, is 25 MeV
- Assume combined systematic error from experiments is the same size, and also scales with $1/\sqrt{\mathcal{L}}$ $\Rightarrow$ experimental error 35.4 MeV for 500pb^{-1}
- Gross overestimate: 10% of the luminosity is used to improve the energy calibration error from 25 MeV to 10–15 MeV.
- So taking 10% of days for energy calibration increases error from experiments from 35.4 to 37.3 MeV
- Total error: $35.4 \oplus 25 = 43.3$ MeV reduced to $37.3 \oplus 15 = 40.2$ or even $37.3 \oplus 10 = 38.6$ MeV

And in general, do not want energy scale to be one of largest systematics

Extrapolation method statistical error

- Sensitive to span of polarisation points, and maximum polarised energy
- Not particularly reduced by having multipoint polarisation fills.

  Example - assume 2 MeV error per point:

  – 45 plus 55 GeV gives error of 12.8 MeV at 95 GeV

  – 40 plus 60 GeV gives error of 6.5 MeV at 95 GeV

  – 40-45-50-55-60 GeV gives error of 5.8 MeV at 95 GeV
- Just one fill with two energy points would be enough to calibrate if you knew the system was stable and linear
- But energy calibration must be robust $\Rightarrow$ systematic errors from stability, reproducibility and uncertainty in linearity assumption

To control the extrapolation systematic error...

- Essential to have at least three points in a fill to calibrate NMR's (fitting two parameters) to eliminate mistakes at one of polarisation points
- Desirable to have one five point fill to verify understanding of non-linear behaviour
- Essential to have several calibration fills during the year, to check for stability
- Essential to repeat calibration if NMR coils are replaced (radiation damage)
- Essential to cross calibrate physics and polarisation optics (differences depend on imperfections)
- Essential to have regular flux-loop measurements. (Last year, many were done in the shadow of RF maintenance. Automated procedure exists)

Extrapolation method requirements - 1

Rely on extrapolation until spectrometer proven. (Reduce request in 2000)

- At least two pol measurements on PHYSICS optics, 45 GeV, solenoids on
  - Optics dependent effects vary with imperfections
  - Will be in shadow of spectrometer request (see later)
- Four fills with at least three energy points per fill

  60/60 optics, solenoids off, as many NMR's locking as possible
  - Fills spread through the year to check stability
  - Exact energy points depend on how well NMR's are locking
  - Optimal energies for minimising error: 40-50-60 GeV, but 60 GeV is not reliable, so add at least one additional point, 45 or 55 GeV
  - Continue up in energy to 70 GeV and maybe higher (ref. Ralph)
  - Spectrometer also uses these fills as cross check

Continued ...

Extrapolation method requirements - 2

- Need k-modulation data BEFORE trying polarisation at higher energies
  - This is also needed to optimise performance in physics
- Flux loops after each polarisation MD, and in shadow of RF maintenance
- Replace NMR's during year (twice??)
- Look for polarisation above 90 GeV
  - PHYSICS optics, solenoids off. Need polarimeter shielding
- With lower priority, at least one 5 point fill with all NMR's working.
  - This 5 point fill would count as one of the the four multipoint fills
- Long term test of rise at 45 GeV, physics optics
  - Eight hours extension of cross-calib fill

Spectrometer time requests

Aim: measure difference between polarisation and physics energy much more precisely.

Spectrometer requests 4 fills with physics optics

- Polarisation and angle measurement at 45 GeV
- Ramp and make angle measurement at physics energy
- Plus end of fill tests

Total: 4 x 16 hours at the right time of day to avoid trains!!!

Spectrometer does NOT measure continuously in physics. Requires NMR's to transfer energy scale from dedicated spectrometer measurement.

Advantage: spectrometer fixes normalisation at physics energy directly $\Rightarrow$ no additional extrapolation uncertainty.

Total time for energy calibration

On physics optics

- 24 hours - dedicated k-modulation on physics optics
- 4*16 hours - polarisation at 45 GeV and spectrometer measurement
- 1*8 hours - add rise test in one of the above four fills
- 16 hours - polarisation at 90+ GeV. If it works, rediscuss plan!

On 60/60 optics

- 1*16 hours - set up 60/60 optics
- 3*16 hours - three/four-point polarisation (+flux loop)
- 2*24 hours - five-point/higher energy polarisation (+flux loop)
- Could give back one of these if the first four are OK.

Total: 28 shifts, 9.3 days, INCLUDING spectrometer

How to improve efficiency

- Take k-modulation data before trying polarisation above 45 GeV.
- There are many online tools to make polarisation MD more efficient
  - For example, instant display of NMR's
  - Are they locking?
  - Has a train gone by and changed the energy?
- Automatic procedure for flux loop - encourage shift crew to run a flux loop if there is time without beam
- Flexible scheduling - ask operations and experiments to be patient if a measurement is going well.
- Prepare all working points in advance.
  - If polarisation crew are available at short notice, can use any long period with cryo problem because 60/60 optics does not use SC quads

Conclusions

- Essential to have a minimum set of measurements to control energy calibration systematic error for W mass
- Invest time in looking for polarisation at higher energy to reduce statistical error and FL-NMR divergence error
- Need time to establish the spectrometer
- By combining measurements in the most efficient way, even with some contingency, can fit all this into the same number of days as used last year