# HARP Collaboration

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*http://cern.ch/dydak/AN.t0corr.pdf*

# Correction for the t0 constants of the forward RPCs

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**Abstract**

It is argued that the 'neutral' $t0$ calibration is appropriate for the forward RPCs while it is beset with too large systematic uncertainties for the barrel RPCs. The toy Monte Carlo calculation of the correction is described that moves the '50% point' on the rising slope of the time distribution of 'neutral' hits in the forward RPCs to the theoretical point that would be measured in an infinitely small pad located at the pad's centre and that serves for the absolute normalization of time-of-flight.

# 1 Introduction

This note discusses the absolute normalization of time-of-flight in the forward RPCs by way of 'neutral' hits which are interpreted as photons from $\pi^0$ decays in the target centre.

In practice, one does not measure 'the time-of-flight of a photon' but a time-of-flight distribution of many photons. Considering

- the finite time resolution of the measurement of photon time-of-flight,
- the large pad size (in comparison with the length of 5 cm that corresponds to the RPC time resolution);
- the subdivision of a pad into eight strips with different transit times,
- the asymmetric electronics readout on one side of the pad only,
- the (in principle) non-uniform impact distribution of photons across the pad,
- and (in principle) the contamination by hits of other origin than from the primary interaction in the RPCs of photons from $\pi^0$ decay,

it is a non-trivial issue to relate information obtained from the time-of-flight distribution of 'neutral' hits to the wanted information: **the time of a direct photon from $\pi^0$ decay in the target centre which hits exactly the geometrical pad centre.**

The photon is *a priori* the preferred candidate for the absolute calibration of time-of-flight since its velocity is free of uncertainties from particle mass and momentum resolution.

We chose the '50% point' on the rising slope of the time distribution of neutral hits as reference point because it can be measured both easily and precisely. The correction from the time of the '50% point' to the wanted time of a photon in the pad centre is calculated in a toy Monte Carlo which will be discussed below. This toy Monte Carlo simulates the electronics response of the RPCs and takes their geometrical layout and their pulse propagation properties into account. It produces for each pad

- the time interval between the '50% point' and the nominal point; and,
- the time interval between 20 and 80% at the rising slope of the time distribution (this is a number that can be measured and permits some crosscheck on the toy Monte Carlo calculation).

# 2 Why the 'neutral' calibration is appropriate only for the forward RPCs

In the forward RPCs, 'neutral' hits are conjectured to arise almost exclusively from photons from the decay of $\pi^0$'s produced in the primary interaction in the target (this conjecture stems from the observed RPC charge which is consistent with two charged particles from $e^+e^-$ pair creation rather than with a single charged particle from Compton scattering, see Section 4). In the barrel RPCs, a relatively larger admixture of low-energy photons ($\approx 1$ MeV) is expected that originate from de-excitation after nuclear break-up in the primary interaction. While above $\approx 10$ MeV pair creation is dominant, Compton scattering cannot be ignored for photons below 10 MeV.

The knock-on electron from Compton scattering cannot go into the backward direction, its maximum scattering angle is 90°. The $e^+e^-$ pair is also emitted in the forward direction, with a probability of order 1% only for emission of one of the particles at an angle larger than 90°.

Effects from secondary electrons and positrons require at 90° polar angle (e.g. padring 3) backscattering at almost 180°, while in the forward region (e.g. padrings 7 and 8) smaller backscattering angles will contribute. Yet the dominant effect is expected to arise from the magnetic field especially inside the copper coil which will bend electrons and positrons back into the RPCs. The importance of the bending means also that outer barrel chambers are expected to be relatively more affected than inner barrel chambers.

While one can think of a detailed simulation of all these processes, the question arises what systematic precision can be achieved.

Considering that for the simulation good knowledge of the following is needed:

- the spatial and energy distributions of photons from $\pi^0$ decays,
- the admixture of low-energy photons from de-excitation after nuclear break-up,
- the amount and geometrical location of material that gives rise to Compton effect and pair creation, and to energy loss of secondary electrons and positrons,
- and the magnetic field inside of the coils of the solenoid;

considering further that the conversion of photons in the RPCs occurs with some 10% probability while the conversion of the photon in the coil immediately behind the RPCs occurs with 100% probability, it was concluded that the systematic error of the 'neutral' $t0$ calibration in the barrel is too large. Therefore, the 'neutral' $t0$ calibration of the barrel RPCs was abandoned in favour of a 'charged' $t0$ calibration.

Thus we lost the attractive feature of independent momentum calibration by way of time-of-flight that was determined independently of the momentum.

(However, some momentum calibration can be maintained from the comparison of time-of-flight of positive and negative tracks, provided a model is employed that translates a momentum bias of positive tracks to the one of negative tracks [2].)

The arguments against a 'neutral' $t0$ calibration for the barrel RPCs do not apply for the forward RPCs. There,

- the relative admixture of low-energy photons is reduced,

- the Forward Trigger Plane (FTP) behind the forward RPCs represents only 1 cm (2 planes, each 5 mm thick) of scintillator material for photon conversion, and therefore converts photons with a probability of the same order as the RPCs themselves,
- the FTP is located at $z = 2240$ mm, 12 cm farther downstream than the plane of vertical RPCs at 2102.4 and 2110.1 mm, respectively,
- and there is only a small magnetic (stray) field.

Mainly because of the absence of a strong bending field and the large distance between RPCs and the FTP (which is equivalent to 800 ps when adding forward and backward flight times) backscattering from converted photons is not of concern.

Considering further that the momentum reconstruction of very forward tracks is difficult because of the few TPC clusters involved, the 'neutral' $t0$ calibration appears preferable over the 'charged' calibration.

# 3 Simulation details

The toy Monte Carlo simulates the time distribution of signals in 101 equally spaced points along the 106 mm long active length of each strip (we stress that time distributions are simulated, not signal shapes!). The time distribution at each point is taken as Gaussian with a nominal resolution of 180 ps, convoluted with the sum of two exponentials,

$$f(t) = \exp\left(-t/\tau_1\right) + \kappa \cdot \exp\left(-t/\tau_2\right) .$$

The standard values of the input parameters are $\tau_1 = 0.01$ ns, $\tau_2 = 0.1$ ns, and $\kappa = 0.1$, values suggested by the data which show typically a small asymmetry toward larger time-of-flight.

The nominal time resolution of 180 ps is motivated by the fact that one prime contributor is the resolution of beam particle timing which is known to be 106 ps. The other prime contributor is the intrinsic RPC resolution which is 140 ps. Added quadratically together with minor bits and pieces such as inadequacies of the timeslewing correction, 180 ps seems a reasonable choice for the time resolution.

The pulse travels from the point of origin to the preamplifier (whose position on one side of the strip depends on the RPC under consideration) with a charge-dependent effective velocity. This velocity (expressed in ns/100 mm) if taken from data and parametrized as

$$v = 5.157 \times 10^{-2} + Q \cdot 3.667 \times 10^{-5} .$$

For Q = 2000 ADC counts, the velocity is 0.125 ns/10 mm.

(The use of the effective velocity takes into account the charge-dependent interplay between the timing and amplitudes of the direct and the reflected signals.)

The toy Monte Carlo comprises the non-uniformities in the amount of converting material (RPCs located more downstream 'feel' the non-uniform material distribution in the RPCs located closely upstream).

The non-uniformities concern essentially four regions: the $\approx$ 15 mm wide 'overlap' regions at both ends of a strip (weighted up by a factor of two), and two $\approx$ 13 mm wide regions where $\approx$ 10 mm thick structural aluminum is located (weighted up by a factor of three).

The time distributions from each of the 101 test points are averaged to the strip's average time distribution.

'Neutral' hits that exceed a polar angle of 17°, are weighted down by a factor of 10 bevor they enter the averaging; this measure is motivated by the shielding of neutral hits by the copper of the coil and the iron of the flux return of the solenoid.

The time distributions of the eight strips of a pad are averaged. Thereby, a flat distribution of photons across the strips of a pad is assumed which appears a good approximation for the forward RPCs.

Finally, the 50% point and the time interval between 20 and 80% on the rising slope of the averaged time distribution of a pad are determined.

# 4 Results

Figure 1 shows the calculated $t0$ correction constants and the time interval from 20 to 80% (lower panel) for the forward RPCs, as a function of the channel number. The somewhat irregular pattern stems from the peculiar geometrical arrangement of the forward chambers, their peculiar orientation of the preamplifiers, and from the shielding of large regions by the coil and the iron of the flux return of the solenoid.

The calculated $t0$ correction constants are estimated to be correct within $\pm$30 ps. This assessment stems from the variation of the average $t0$ correction constant with the change of input parameters as shown in Table 1.

**It turns out that the most sensitive input parameter is the time resolution whose nominal value was 180 ps in the simulation. A change of the time resolution adds linearly to the $t0$ correction constants.**

**We also note that the time interval from 20 to 80% is sensitive essentially only to the time resolution. Therefore, in case of a discrepancy between data and the above MC simulation of this time interval, the $t0$ correction constants should get the discrepancy simply added.**

Figure 2 shows the simulated distribution of ADC charges (in ADC counts) in a single RPC gap (which is an exponentially falling spectrum whose average, multiplied by four, corresponds to the average pulseheight of a charged track traversing all four gaps of the RPC), and the simulated ADC charge of photons in a four-gap RPC. Agreement of the latter with the observed charge spectrum of 'neutral' hits requires that twice the charge of a single charged hit is deposited per gap, which corroborates the conjecture that the dominant process that gives rise to 'neutral' hits, is photon conversion into $e^+e^-$ pairs.

The channel number of the forward RPCs takes into account the geometrical configuration:

Table 1: Change of the average $t0$ correction constant and of the average time interval from 20 to 80% with a change of input parameters.

| | $t0$ corr. const. [ns] | time int. 20 to 80% [ns] |
|---|---|---|
| Standard set | 0.169 | 0.219 |
| time resolution 0.210 ns | 0.199 (+0.030) | 0.252 (+0.033) |
| time resolution 0.150 ns | 0.139 (−0.030) | 0.186 (−0.033) |
| transit time +50 ps | 0.171 (+0.002) | 0.222 (+0.003) |
| transit time −50 ps | 0.167 (−0.002) | 0.218 (−0.001) |
| +20 ps in strips 1,2,7 and 8 | 0.160 (−0.009) | 0.220 (+0.001) |
| −20 ps in strips 1,2,7 and 8 | 0.178 (+0.008) | 0.219 (+0.000) |
| $\tau_1 = 0.03$ ns, $\tau_2 = 0.3$ ns | 0.150 (−0.019) | 0.225 (+0.006) |
| $\tau_1 = 0.003$ ns, $\tau_2 = 0.03$ ns | 0.188 (+0.019) | 0.214 (−0.005) |
| $\kappa = 0.2$ | 0.158 (−0.011) | 0.222 (+0.003) |
| $\kappa = 0.05$ | 0.178 (+0.009) | 0.217 (−0.002) |
| 1.5 × photon charge | 0.170 (+0.001) | 0.221 (+0.002) |
| 1/1.5 × photon charge | 0.168 (−0.001) | 0.219 (+0.000) |

- one upstream 'plane' (plane no. 1) of $2 \times 4 = 8$ horizontal chambers, and one downstream 'plane' (plane no. 2) of $2 \times 4 = 8$ vertical chambers;
- looking downstream, the horizontal plane is subdivided into a lower 'plank' (plank no. 1) and into an upper 'plank' (plank no. 2) of four chambers each; analogously, the vertical plane is subdivided into a left 'plank' (plank no. 1) and into a right 'plank' (plank no. 2) of four chambers each;
- each chamber is subdivided into 8 pads; looking downstream, the pad numbering runs from bottom to top, and from left to right;
- the position of the preamplifiers is specified in Table 1 of Ref. [1].

The channel no. of the forward RPCs is calculated according to

$$\text{channel no.}=64\times(\text{plane no.-1})+32\times(\text{plank no.-1}) +8\times(\text{chamber no.-1})+\text{pad no.} \;,$$

where pad 1 is the leftmost and pad 8 the rightmost in the plane 1 of horizontal chambers, and where pad 1 is the downmost and pad 8 the upmost in the plane 2 of vertical chambers.

The numerical results are given in the Appendix. The numbers are reproduced from the file available at *http://cern.ch/dydak/RPCFntcorr.mod.dat*).

# 5 Application

The purpose of the such determined $t0$ corrections is to ADD them to the 50% points determined from the data, with a view to arriving at the time-of-flight of a photon according to

$$t_{50\%} + t_{\rm corr} - tz0 - t0 = t^{\rm TOF}_{\rm photon} ,$$

where $t^{\rm TOF}_{\rm photon}$ refers to the time-of-flight of a photon from the target centre to the respective pad centre, $tz0$ is the time of arrival of the beam particle at the target, $t0$ is the pad-specific fixation of the origin of the time coordinate, and $t_{\rm corr}$ the pad-specific correction whose determination for the forward RPCs is the subject of this paper.

# References


[1] I. Boyko, G. Chelkov, F. Dydak, A. Elagin, M. Gostkin, V. Koreshev, Yu. Nefedov, K. Nikolaev, J. Wotschack and A. Zhemchugov, RPCs: the choreography of precise timing, HARP Memo 05-103 (9 March 2005), *http://cern.ch/dydak/timeslewing.pdf*

[2] We are grateful to I. Boyko who made this point.

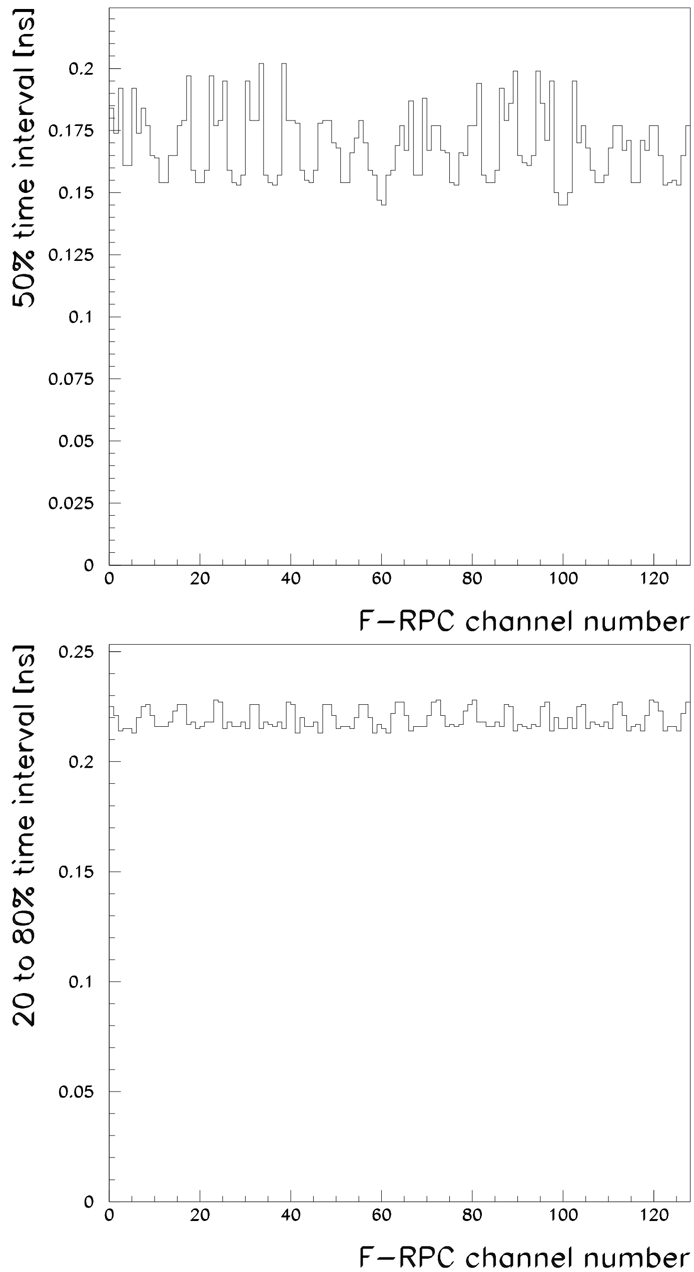


Figure 1: $t0$ correction constants (upper panel) and time intervals from 20 to 80% (lower panel) for the forward RPCs, as a function of the forward RPC channel number.

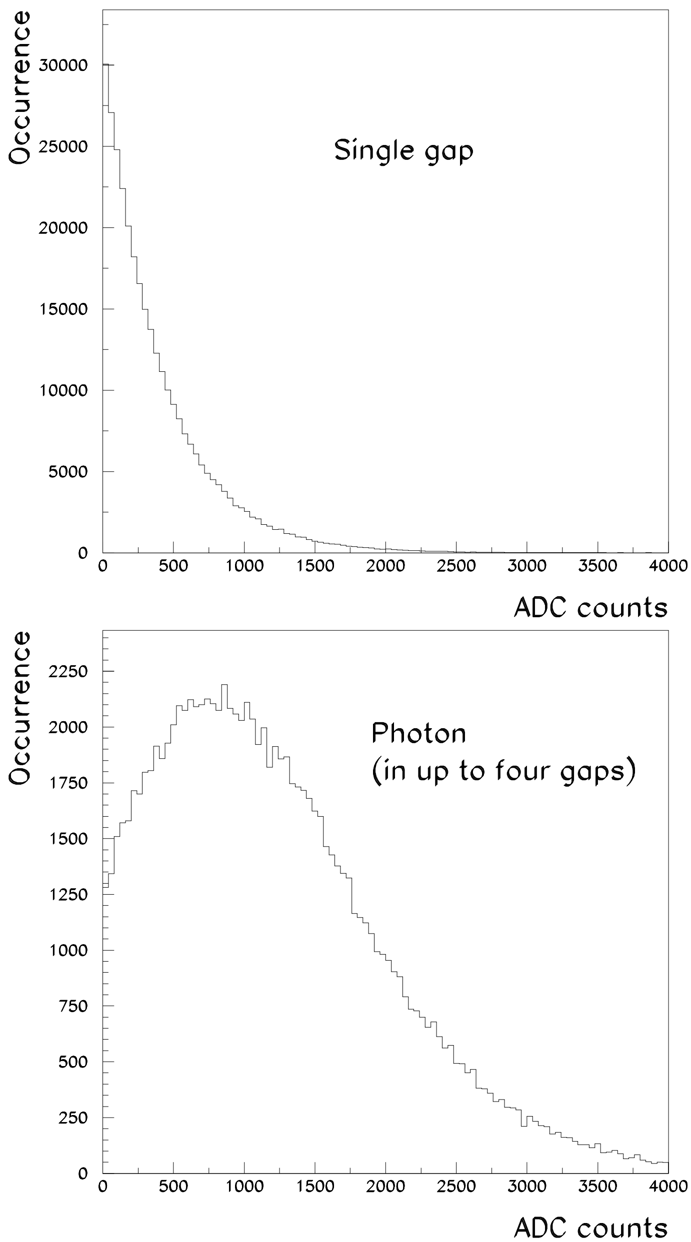


Figure 2: Distribution of ADC charges (in ADC counts) in a single RPC gap (upper panel), and for photons in a four-gap RPC (lower panel).

APPENDIX:
Pad-specific time-of-flight corrections for the forward RPCs
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horizontal [1] or vertical [2]
lower horizontal/left vertical [1] or upper horizontal/right vertical [2
chamber number [1 to 4] bottom -> up or left -> right
pad number [1 to 8] left -> right or bottom -> up
x, y, z coordinates [mm] of pad centre
TOF [ns] of photon from origin to pad centre
time distance of t(0.5) [ns]
t(0.8) minus t(0.2) [ns]
channel number [1 to 128]
Wotschack's chamber number

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 1. | 1. | 1. | 840.00 | -531.00 | 2085.70 | 7.706 | 0.184 | 0.225 | 1. | 16-O |
| 1. | 1. | 1. | 2. | 600.00 | -531.00 | 2085.70 | 7.453 | 0.174 | 0.221 | 2. | 16-O |
| 1. | 1. | 1. | 3. | 360.00 | -531.00 | 2085.70 | 7.279 | 0.192 | 0.214 | 3. | 16-O |
| 1. | 1. | 1. | 4. | 120.00 | -531.00 | 2085.70 | 7.190 | 0.161 | 0.215 | 4. | 16-O |
| 1. | 1. | 1. | 5. | -120.00 | -531.00 | 2085.70 | 7.190 | 0.161 | 0.215 | 5. | 16-O |
| 1. | 1. | 1. | 6. | -360.00 | -531.00 | 2085.70 | 7.279 | 0.192 | 0.213 | 6. | 16-O |
| 1. | 1. | 1. | 7. | -600.00 | -531.00 | 2085.70 | 7.453 | 0.174 | 0.220 | 7. | 16-O |
| 1. | 1. | 1. | 8. | -840.00 | -531.00 | 2085.70 | 7.706 | 0.184 | 0.225 | 8. | 16-O |
| 1. | 1. | 2. | 1. | 840.00 | -441.00 | 2068.90 | 7.592 | 0.177 | 0.226 | 9. | 16-I |
| 1. | 1. | 2. | 2. | 600.00 | -441.00 | 2068.90 | 7.334 | 0.165 | 0.221 | 10. | 16-I |
| 1. | 1. | 2. | 3. | 360.00 | -441.00 | 2068.90 | 7.158 | 0.164 | 0.216 | 11. | 16-I |
| 1. | 1. | 2. | 4. | 120.00 | -441.00 | 2068.90 | 7.067 | 0.154 | 0.216 | 12. | 16-I |
| 1. | 1. | 2. | 5. | -120.00 | -441.00 | 2068.90 | 7.067 | 0.154 | 0.216 | 13. | 16-I |
| 1. | 1. | 2. | 6. | -360.00 | -441.00 | 2068.90 | 7.158 | 0.165 | 0.218 | 14. | 16-I |
| 1. | 1. | 2. | 7. | -600.00 | -441.00 | 2068.90 | 7.334 | 0.165 | 0.223 | 15. | 16-I |
| 1. | 1. | 2. | 8. | -840.00 | -441.00 | 2068.90 | 7.592 | 0.177 | 0.226 | 16. | 16-I |
| 1. | 1. | 3. | 1. | 840.00 | -351.00 | 2085.70 | 7.591 | 0.179 | 0.226 | 17. | 17-O |
| 1. | 1. | 3. | 2. | 600.00 | -351.00 | 2085.70 | 7.333 | 0.197 | 0.217 | 18. | 17-O |
| 1. | 1. | 3. | 3. | 360.00 | -351.00 | 2085.70 | 7.156 | 0.159 | 0.218 | 19. | 17-O |
| 1. | 1. | 3. | 4. | 120.00 | -351.00 | 2085.70 | 7.066 | 0.154 | 0.215 | 20. | 17-O |
| 1. | 1. | 3. | 5. | -120.00 | -351.00 | 2085.70 | 7.066 | 0.154 | 0.216 | 21. | 17-O |
| 1. | 1. | 3. | 6. | -360.00 | -351.00 | 2085.70 | 7.156 | 0.159 | 0.218 | 22. | 17-O |
| 1. | 1. | 3. | 7. | -600.00 | -351.00 | 2085.70 | 7.333 | 0.197 | 0.218 | 23. | 17-O |
| 1. | 1. | 3. | 8. | -840.00 | -351.00 | 2085.70 | 7.591 | 0.177 | 0.228 | 24. | 17-O |
| 1. | 1. | 4. | 1. | 840.00 | -261.00 | 2068.90 | 7.499 | 0.179 | 0.227 | 25. | 17-I |
| 1. | 1. | 4. | 2. | 600.00 | -261.00 | 2068.90 | 7.238 | 0.195 | 0.215 | 26. | 17-I |
| 1. | 1. | 4. | 3. | 360.00 | -261.00 | 2068.90 | 7.059 | 0.159 | 0.218 | 27. | 17-I |
| 1. | 1. | 4. | 4. | 120.00 | -261.00 | 2068.90 | 6.967 | 0.154 | 0.216 | 28. | 17-I |
| 1. | 1. | 4. | 5. | -120.00 | -261.00 | 2068.90 | 6.967 | 0.153 | 0.216 | 29. | 17-I |
| 1. | 1. | 4. | 6. | -360.00 | -261.00 | 2068.90 | 7.059 | 0.157 | 0.218 | 30. | 17-I |
| 1. | 1. | 4. | 7. | -600.00 | -261.00 | 2068.90 | 7.238 | 0.195 | 0.215 | 31. | 17-I |
| 1. | 1. | 4. | 8. | -840.00 | -261.00 | 2068.90 | 7.499 | 0.179 | 0.226 | 32. | 17-I |
| 1. | 2. | 1. | 1. | 840.00 | 261.00 | 2068.90 | 7.499 | 0.179 | 0.226 | 33. | 18-I |
| 1. | 2. | 1. | 2. | 600.00 | 261.00 | 2068.90 | 7.238 | 0.202 | 0.215 | 34. | 18-I |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | 2. | 1. | 3. | 360.00 | 261.00 | 2068.90 | 7.059 | 0.157 | 0.218 | 35. | 18-I |
| 1. | 2. | 1. | 4. | 120.00 | 261.00 | 2068.90 | 6.967 | 0.154 | 0.217 | 36. | 18-I |
| 1. | 2. | 1. | 5. | -120.00 | 261.00 | 2068.90 | 6.967 | 0.153 | 0.216 | 37. | 18-I |
| 1. | 2. | 1. | 6. | -360.00 | 261.00 | 2068.90 | 7.059 | 0.157 | 0.218 | 38. | 18-I |
| 1. | 2. | 1. | 7. | -600.00 | 261.00 | 2068.90 | 7.238 | 0.202 | 0.215 | 39. | 18-I |
| 1. | 2. | 1. | 8. | -840.00 | 261.00 | 2068.90 | 7.499 | 0.179 | 0.227 | 40. | 18-I |
| 1. | 2. | 2. | 1. | 840.00 | 351.00 | 2085.70 | 7.591 | 0.179 | 0.226 | 41. | 18-O |
| 1. | 2. | 2. | 2. | 600.00 | 351.00 | 2085.70 | 7.333 | 0.178 | 0.213 | 42. | 18-O |
| 1. | 2. | 2. | 3. | 360.00 | 351.00 | 2085.70 | 7.156 | 0.159 | 0.220 | 43. | 18-O |
| 1. | 2. | 2. | 4. | 120.00 | 351.00 | 2085.70 | 7.066 | 0.155 | 0.216 | 44. | 18-O |
| 1. | 2. | 2. | 5. | -120.00 | 351.00 | 2085.70 | 7.066 | 0.154 | 0.216 | 45. | 18-O |
| 1. | 2. | 2. | 6. | -360.00 | 351.00 | 2085.70 | 7.156 | 0.159 | 0.218 | 46. | 18-O |
| 1. | 2. | 2. | 7. | -600.00 | 351.00 | 2085.70 | 7.333 | 0.178 | 0.213 | 47. | 18-O |
| 1. | 2. | 2. | 8. | -840.00 | 351.00 | 2085.70 | 7.591 | 0.179 | 0.226 | 48. | 18-O |
| 1. | 2. | 3. | 1. | 840.00 | 441.00 | 2068.90 | 7.592 | 0.179 | 0.226 | 49. | 19-I |
| 1. | 2. | 3. | 2. | 600.00 | 441.00 | 2068.90 | 7.334 | 0.170 | 0.221 | 50. | 19-I |
| 1. | 2. | 3. | 3. | 360.00 | 441.00 | 2068.90 | 7.158 | 0.168 | 0.215 | 51. | 19-I |
| 1. | 2. | 3. | 4. | 120.00 | 441.00 | 2068.90 | 7.067 | 0.154 | 0.216 | 52. | 19-I |
| 1. | 2. | 3. | 5. | -120.00 | 441.00 | 2068.90 | 7.067 | 0.154 | 0.216 | 53. | 19-I |
| 1. | 2. | 3. | 6. | -360.00 | 441.00 | 2068.90 | 7.158 | 0.166 | 0.215 | 54. | 19-I |
| 1. | 2. | 3. | 7. | -600.00 | 441.00 | 2068.90 | 7.334 | 0.172 | 0.220 | 55. | 19-I |
| 1. | 2. | 3. | 8. | -840.00 | 441.00 | 2068.90 | 7.592 | 0.179 | 0.226 | 56. | 19-I |
| 1. | 2. | 4. | 1. | 840.00 | 531.00 | 2085.70 | 7.706 | 0.170 | 0.226 | 57. | 19-O |
| 1. | 2. | 4. | 2. | 600.00 | 531.00 | 2085.70 | 7.453 | 0.159 | 0.220 | 58. | 19-O |
| 1. | 2. | 4. | 3. | 360.00 | 531.00 | 2085.70 | 7.279 | 0.157 | 0.213 | 59. | 19-O |
| 1. | 2. | 4. | 4. | 120.00 | 531.00 | 2085.70 | 7.190 | 0.147 | 0.217 | 60. | 19-O |
| 1. | 2. | 4. | 5. | -120.00 | 531.00 | 2085.70 | 7.190 | 0.145 | 0.215 | 61. | 19-O |
| 1. | 2. | 4. | 6. | -360.00 | 531.00 | 2085.70 | 7.279 | 0.157 | 0.213 | 62. | 19-O |
| 1. | 2. | 4. | 7. | -600.00 | 531.00 | 2085.70 | 7.453 | 0.159 | 0.222 | 63. | 19-O |
| 1. | 2. | 4. | 8. | -840.00 | 531.00 | 2085.70 | 7.706 | 0.169 | 0.227 | 64. | 19-O |
| 2. | 1. | 1. | 1. | 571.00 | -840.00 | 2102.40 | 7.788 | 0.177 | 0.227 | 65. | 20-I |
| 2. | 1. | 1. | 2. | 571.00 | -600.00 | 2102.40 | 7.537 | 0.167 | 0.221 | 66. | 20-I |
| 2. | 1. | 1. | 3. | 571.00 | -360.00 | 2102.40 | 7.365 | 0.187 | 0.214 | 67. | 20-I |
| 2. | 1. | 1. | 4. | 571.00 | -120.00 | 2102.40 | 7.278 | 0.157 | 0.216 | 68. | 20-I |
| 2. | 1. | 1. | 5. | 571.00 | 120.00 | 2102.40 | 7.278 | 0.157 | 0.216 | 69. | 20-I |
| 2. | 1. | 1. | 6. | 571.00 | 360.00 | 2102.40 | 7.365 | 0.188 | 0.216 | 70. | 20-I |
| 2. | 1. | 1. | 7. | 571.00 | 600.00 | 2102.40 | 7.537 | 0.167 | 0.221 | 71. | 20-I |
| 2. | 1. | 1. | 8. | 571.00 | 840.00 | 2102.40 | 7.788 | 0.177 | 0.227 | 72. | 20-I |
| 2. | 1. | 2. | 1. | 481.00 | -840.00 | 2119.10 | 7.771 | 0.177 | 0.228 | 73. | 20-O |
| 2. | 1. | 2. | 2. | 481.00 | -600.00 | 2119.10 | 7.520 | 0.167 | 0.221 | 74. | 20-O |
| 2. | 1. | 2. | 3. | 481.00 | -360.00 | 2119.10 | 7.347 | 0.166 | 0.216 | 75. | 20-O |
| 2. | 1. | 2. | 4. | 481.00 | -120.00 | 2119.10 | 7.259 | 0.154 | 0.217 | 76. | 20-O |
| 2. | 1. | 2. | 5. | 481.00 | 120.00 | 2119.10 | 7.259 | 0.153 | 0.216 | 77. | 20-O |
| 2. | 1. | 2. | 6. | 481.00 | 360.00 | 2119.10 | 7.347 | 0.166 | 0.217 | 78. | 20-O |
| 2. | 1. | 2. | 7. | 481.00 | 600.00 | 2119.10 | 7.520 | 0.165 | 0.223 | 79. | 20-O |
| 2. | 1. | 2. | 8. | 481.00 | 840.00 | 2119.10 | 7.771 | 0.177 | 0.226 | 80. | 20-O |
| 2. | 1. | 3. | 1. | 391.00 | -840.00 | 2102.40 | 7.664 | 0.177 | 0.228 | 81. | 21-I |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | 1. | 3. | 2. | 391.00 | -600.00 | 2102.40 | 7.409 | 0.194 | 0.218 | 82. | 21-I |
| 2. | 1. | 3. | 3. | 391.00 | -360.00 | 2102.40 | 7.233 | 0.157 | 0.218 | 83. | 21-I |
| 2. | 1. | 3. | 4. | 391.00 | -120.00 | 2102.40 | 7.144 | 0.154 | 0.216 | 84. | 21-I |
| 2. | 1. | 3. | 5. | 391.00 | 120.00 | 2102.40 | 7.144 | 0.154 | 0.216 | 85. | 21-I |
| 2. | 1. | 3. | 6. | 391.00 | 360.00 | 2102.40 | 7.233 | 0.159 | 0.218 | 86. | 21-I |
| 2. | 1. | 3. | 7. | 391.00 | 600.00 | 2102.40 | 7.409 | 0.192 | 0.216 | 87. | 21-I |
| 2. | 1. | 3. | 8. | 391.00 | 840.00 | 2102.40 | 7.664 | 0.179 | 0.226 | 88. | 21-I |
| 2. | 1. | 4. | 1. | 301.00 | -840.00 | 2119.10 | 7.670 | 0.186 | 0.225 | 89. | 21-O |
| 2. | 1. | 4. | 2. | 301.00 | -600.00 | 2119.10 | 7.415 | 0.199 | 0.214 | 90. | 21-O |
| 2. | 1. | 4. | 3. | 301.00 | -360.00 | 2119.10 | 7.240 | 0.165 | 0.217 | 91. | 21-O |
| 2. | 1. | 4. | 4. | 301.00 | -120.00 | 2119.10 | 7.151 | 0.162 | 0.216 | 92. | 21-O |
| 2. | 1. | 4. | 5. | 301.00 | 120.00 | 2119.10 | 7.151 | 0.161 | 0.215 | 93. | 21-O |
| 2. | 1. | 4. | 6. | 301.00 | 360.00 | 2119.10 | 7.240 | 0.165 | 0.217 | 94. | 21-O |
| 2. | 1. | 4. | 7. | 301.00 | 600.00 | 2119.10 | 7.415 | 0.199 | 0.216 | 95. | 21-O |
| 2. | 1. | 4. | 8. | 301.00 | 840.00 | 2119.10 | 7.670 | 0.186 | 0.225 | 96. | 21-O |
| 2. | 2. | 1. | 1. | -301.00 | -840.00 | 2119.10 | 7.670 | 0.171 | 0.227 | 97. | 22-O |
| 2. | 2. | 1. | 2. | -301.00 | -600.00 | 2119.10 | 7.415 | 0.195 | 0.214 | 98. | 22-O |
| 2. | 2. | 1. | 3. | -301.00 | -360.00 | 2119.10 | 7.240 | 0.150 | 0.220 | 99. | 22-O |
| 2. | 2. | 1. | 4. | -301.00 | -120.00 | 2119.10 | 7.151 | 0.145 | 0.215 | 100. | 22-O |
| 2. | 2. | 1. | 5. | -301.00 | 120.00 | 2119.10 | 7.151 | 0.145 | 0.215 | 101. | 22-O |
| 2. | 2. | 1. | 6. | -301.00 | 360.00 | 2119.10 | 7.240 | 0.150 | 0.220 | 102. | 22-O |
| 2. | 2. | 1. | 7. | -301.00 | 600.00 | 2119.10 | 7.415 | 0.195 | 0.215 | 103. | 22-O |
| 2. | 2. | 1. | 8. | -301.00 | 840.00 | 2119.10 | 7.670 | 0.170 | 0.225 | 104. | 22-O |
| 2. | 2. | 2. | 1. | -391.00 | -840.00 | 2102.40 | 7.664 | 0.177 | 0.226 | 105. | 22-I |
| 2. | 2. | 2. | 2. | -391.00 | -600.00 | 2102.40 | 7.409 | 0.168 | 0.215 | 106. | 22-I |
| 2. | 2. | 2. | 3. | -391.00 | -360.00 | 2102.40 | 7.233 | 0.159 | 0.218 | 107. | 22-I |
| 2. | 2. | 2. | 4. | -391.00 | -120.00 | 2102.40 | 7.144 | 0.154 | 0.217 | 108. | 22-I |
| 2. | 2. | 2. | 5. | -391.00 | 120.00 | 2102.40 | 7.144 | 0.154 | 0.216 | 109. | 22-I |
| 2. | 2. | 2. | 6. | -391.00 | 360.00 | 2102.40 | 7.233 | 0.157 | 0.218 | 110. | 22-I |
| 2. | 2. | 2. | 7. | -391.00 | 600.00 | 2102.40 | 7.409 | 0.168 | 0.215 | 111. | 22-I |
| 2. | 2. | 2. | 8. | -391.00 | 840.00 | 2102.40 | 7.664 | 0.177 | 0.226 | 112. | 22-I |
| 2. | 2. | 3. | 1. | -481.00 | -840.00 | 2119.10 | 7.771 | 0.177 | 0.227 | 113. | 23-O |
| 2. | 2. | 3. | 2. | -481.00 | -600.00 | 2119.10 | 7.520 | 0.167 | 0.221 | 114. | 23-O |
| 2. | 2. | 3. | 3. | -481.00 | -360.00 | 2119.10 | 7.347 | 0.171 | 0.214 | 115. | 23-O |
| 2. | 2. | 3. | 4. | -481.00 | -120.00 | 2119.10 | 7.259 | 0.154 | 0.216 | 116. | 23-O |
| 2. | 2. | 3. | 5. | -481.00 | 120.00 | 2119.10 | 7.259 | 0.154 | 0.217 | 117. | 23-O |
| 2. | 2. | 3. | 6. | -481.00 | 360.00 | 2119.10 | 7.347 | 0.171 | 0.214 | 118. | 23-O |
| 2. | 2. | 3. | 7. | -481.00 | 600.00 | 2119.10 | 7.520 | 0.167 | 0.221 | 119. | 23-O |
| 2. | 2. | 3. | 8. | -481.00 | 840.00 | 2119.10 | 7.771 | 0.177 | 0.228 | 120. | 23-O |
| 2. | 2. | 4. | 1. | -571.00 | -840.00 | 2102.40 | 7.788 | 0.177 | 0.227 | 121. | 23-I |
| 2. | 2. | 4. | 2. | -571.00 | -600.00 | 2102.40 | 7.537 | 0.165 | 0.223 | 122. | 23-I |
| 2. | 2. | 4. | 3. | -571.00 | -360.00 | 2102.40 | 7.365 | 0.153 | 0.214 | 123. | 23-I |
| 2. | 2. | 4. | 4. | -571.00 | -120.00 | 2102.40 | 7.278 | 0.154 | 0.216 | 124. | 23-I |
| 2. | 2. | 4. | 5. | -571.00 | 120.00 | 2102.40 | 7.278 | 0.155 | 0.216 | 125. | 23-I |
| 2. | 2. | 4. | 6. | -571.00 | 360.00 | 2102.40 | 7.365 | 0.153 | 0.214 | 126. | 23-I |
| 2. | 2. | 4. | 7. | -571.00 | 600.00 | 2102.40 | 7.537 | 0.165 | 0.222 | 127. | 23-I |
| 2. | 2. | 4. | 8. | -571.00 | 840.00 | 2102.40 | 7.788 | 0.177 | 0.227 | 128. | 23-I |