Kinematics Redesign for E97-111

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This document describes how the kinematics for E97-111 were adapted to the final set of beam energies as depicted on the CEBAF accelerator schedule. Those energies are:

- 3.944 GeV (replaces 4.045 GeV in proposal)
- 3.164 GeV (replaces 3.245 GeV in proposal)
- 2.384 GeV (replaces 2.445 GeV in proposal)

1 Counting Rates

Counting rates were computed from AEEXB simulations. The 10 cm tuna can cell was assumed, with a density of 0.1377 g/cm^3. The Wiringa spectral function was used, and compensations were made neither for final state interactions nor radiative tail losses. We might expect the combined effect of these two phenomena to be about 35% (reduction in computed rates). We might also reasonably allow a 30% reduction due to an inadequacy of the acceptance simulation. The angular acceptance is assumed to be independent of momentum and vertex position (although there are separate cuts on angular acceptance and collimator location). Thus we can expect the true rates in the experiment (under the assumption that the impulse approximation holds) to be about half those predicted here.

Some of the plots below are generated for a some limited range of vector momentum transfer q. The rationale is that we will likely wish to make cuts on the data, especially in the CQΩ settings, to match the electron kinematics for the various regions in p_m. Without cuts, there is a bias in q as p_m varies which changes not only the electron kinematics but as well the relationship between p_m and θ_{pq}. As was discussed in the proposal, it is not clear that the q cut is the optimum one, but it does at least provide a mechanism for accounting for this expectation in the rate calculations.

Each of these cuts corresponds to roughly 1/4 of the full acceptance *range* in q. By range I mean that no attempt was made to equalize the counting rate in each bin, the range of q values observed in the simulation was simply cut into four equal chunks. Figure 1 illustrates the situation. Rates from the fourth cut (the highest values of q) are not displayed below; these rates will be the absolute lowest due to both the large values of q as well as a reduced detection volume.

2 CQΩ-I Kinematics

These kinematics are designed to have constant relative energy between the knocked-out proton and the recoiling $A-1$ system (here a triton). The old idea behind this is that the same optical potential is relevant for the entire angular distribution, and in this sense "FSI effect is constant". The variable which is exploited to generate different recoil momenta, is a change of the proton angle relative to $|\vec{q}|$.

The relative energy was chosen to be 250 MeV, which is close to the "dip" region in the proton-nucleus total cross section (or the peak in the mean free path of the proton in nuclear matter as a function of kinetic energy). The following equation relates this relative energy $E_{\rm rel}$, the magnitude of the three-momentum transfer $q \equiv |\vec{q}|$, and the lab energy transfer ω:

$$q^2 = (\omega/c)^2 + 2\omega m_A + m_A^2 c^2 - \frac{1}{c^2}\left(m_{A-1}c^2 + m_p c^2 + E_{\rm rel}\right)^2 .$$

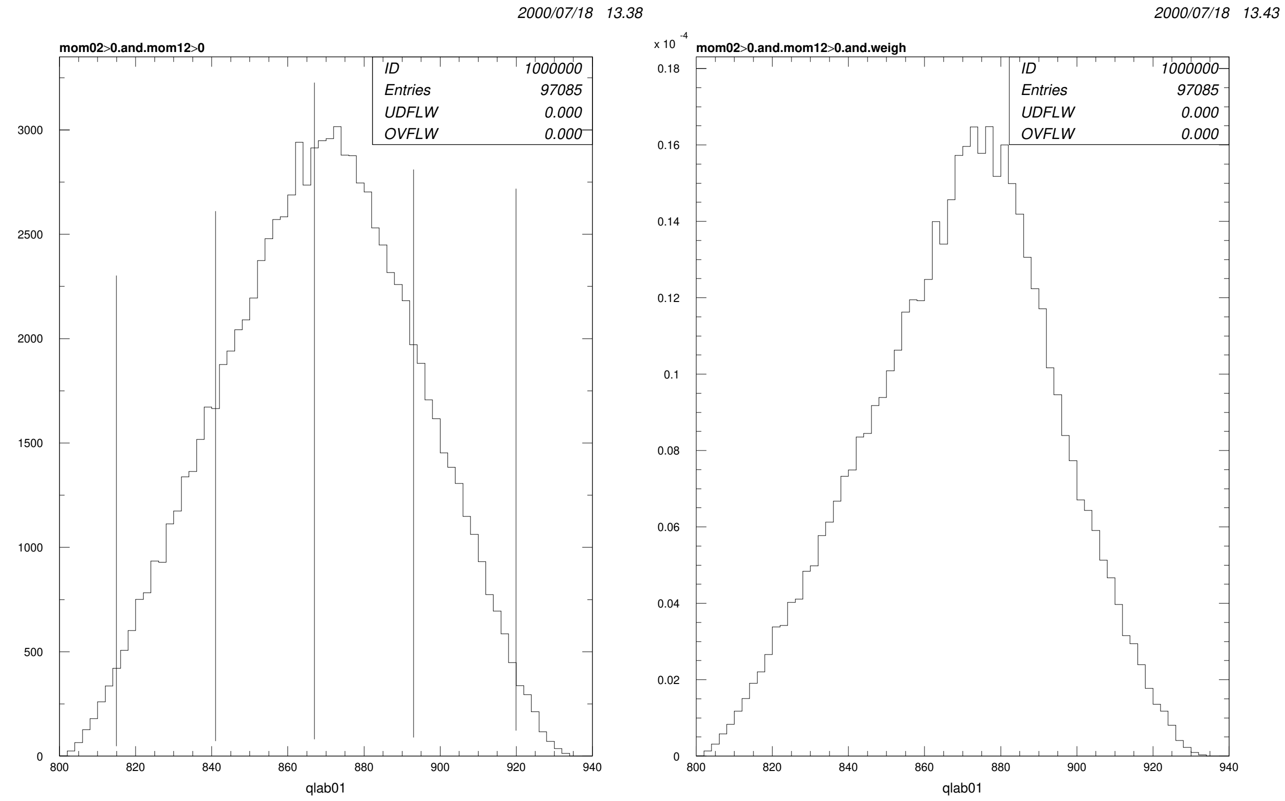

Figure 1: The range of q values accepted for the "D" setting of the PY-I program. The left hand plot shows the detection volume for the various values of q. The associated cuts are 26.25 MeV/c bites starting at 815 MeV/c, *i.e.* the first cut is $815 < q < 841.25$ MeV/c and so on. The locations of the cut borders are depicted on this plot. The right hand plot shows the same except that now a cross-section weighting has been applied. Thus this plot is the same as a counting rate except for a scale factor.

CQΩ Kinematics I			
$E_0 = 3944$ MeV	$\theta_e = 14.11$ deg	$\omega = 393$ MeV	$\lvert\vec{q}\rvert = 1000$ MeV$/c$
$Q^2 = 0.846\ (\mathrm{GeV}/c)^2$		$y = -85.6$ MeV$/c$	
θ_p (deg)	p_p (MeV$/c$)	p_m (MeV$/c$)	θ_{pq} (deg)
61.24	914.3 (907.1)	88.2	1.25
74.09	899.9 (907.1)	253.5	14.1
84.09	873.1 (862.5)	410.2	24.1
89.99	851.8 (862.5)	500.2	30.0

Table 1: Kinematical settings for the first CQΩ segement of the experiment. For the proton momenta, the values in parentheses are the actual spectrometer momentum settings. The other values are the ones which correspond to protons which occupy the center of all acceptances in the electron arm, as well as the center of the spatial acceptance of the hadron arm. The p_m values quoted correspond to this same central value.

ω was chosen at 393 MeV, mainly searching for a value which roughly reproduced the scattering angle printed in the proposal. This value for ω, coupled with the value of $E_{\mathrm{rel}} = 250$ MeV, yields 1000 MeV$/c$ for q. Coupling this with the beam energy of 3944 MeV, and the relation for scattering angle in terms of q and ω,

$$\cos\theta = \frac{E_0^2 + (E_0 - \omega)^2 - q^2}{2E_0\,(E_0 - \omega)},$$

the scattering angle is 14.11 deg.

I tried to optimize the four proton-spectrometer bites using the following criteria: firstly I wanted one of the settings (pref. the third one) to be more or less centered on the "dip" location. Secondly I wanted the overlap to be as good as it could be over the range 0–600 MeV$/c$ given four settings.

The final set of kinematics at which I arrived is shown in table 1. The acceptances and expected counting rates for the settings in missing momentum p_m are shown in figure 2.

In the table column for proton momentum, the value in parenthesis was used for the count-rate simulation — neigboring pairs of settings were close enough that it was of little use to change the spectrometer setting.

3 CQΩ-II Kinematics

The same principles apply here as for the first CQΩ setting. Firstly the relative tp kinetic energy is held fixed at 250 MeV. One can see with a little effort that in this type of kinematics, as we increase the three-momentum transfer two things will happen:

- the longitudinal recoil momentum y must increase (become more negative). This must happen since even though we transfer a large momentum, the proton comes out with the same relative momentum with respect to the triton. Thus the proton's initial momentum must have been large and directed against $\vec{q}$, more so as q increases.
- the energy transfer must increase, but not so fast (since E_{rel} is fixed) so that Q^2 will increase.

We don't want the minimum recoil momentum for this setting to be more than about 400 MeV$/c$ lest we miss the minimum. So a compromise setting for ω is 517 MeV. This yields, together with the first equation, a three-momentum transfer of 1427 MeV$/c$. Coupling this with the scheduled beam energy gives a scattering angle of 20.85 degrees. The full set of kinematic settings is tabulated in table 2.

Figure 3 shows the results of the simulations for the selected kinematics for this setting. The plots have the same meaning as in the previous section. Note that the overlap here was much stronger between settings. Given our scant beamtime allotment, we have chosen to drop one point here to give us more time at other settings.

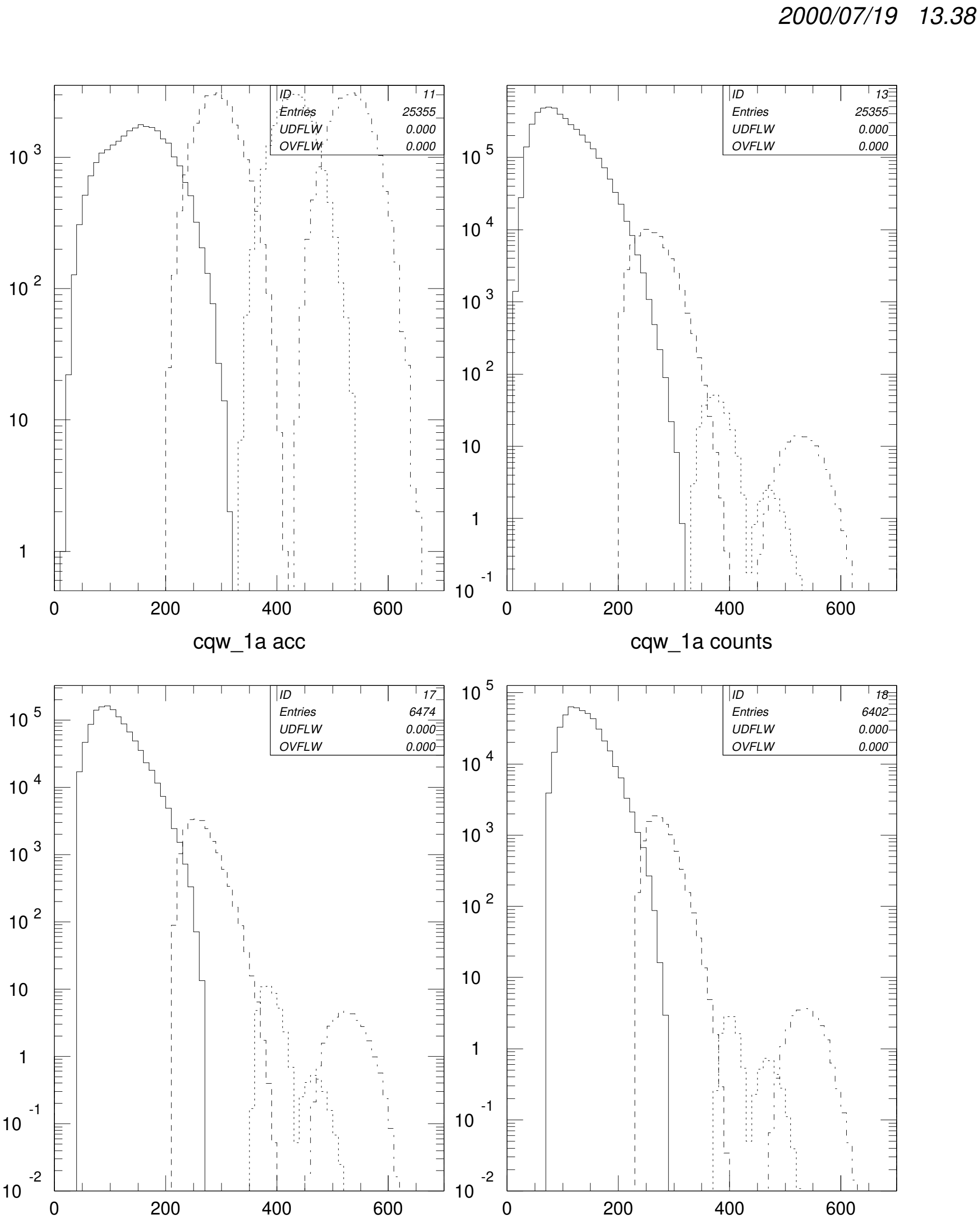

Figure 2: Simulation results for CQΩ-I kinematics. The upper left panel shows the "acceptance" in p_m, *i.e.*, not weighted by the cross section. These curves include a cut on the magnitude of the vector momentum transfer, $965 < q < 1010$ MeV/c. This is about one-fourth of the full acceptance in q. The upper right panel shows the number of counts expected in each of the spectrometer settings, in units of counts per 100 μA-hr. In this plot no cuts have been applied. The bottom panes show similar counts plots, except that here cuts in q have been applied. The cuts used for the lower-left pane are the same as those used for the upper left pane; the lower right pane shows an adjacent bin in q, $1010 < q < 1055$ MeV/c.

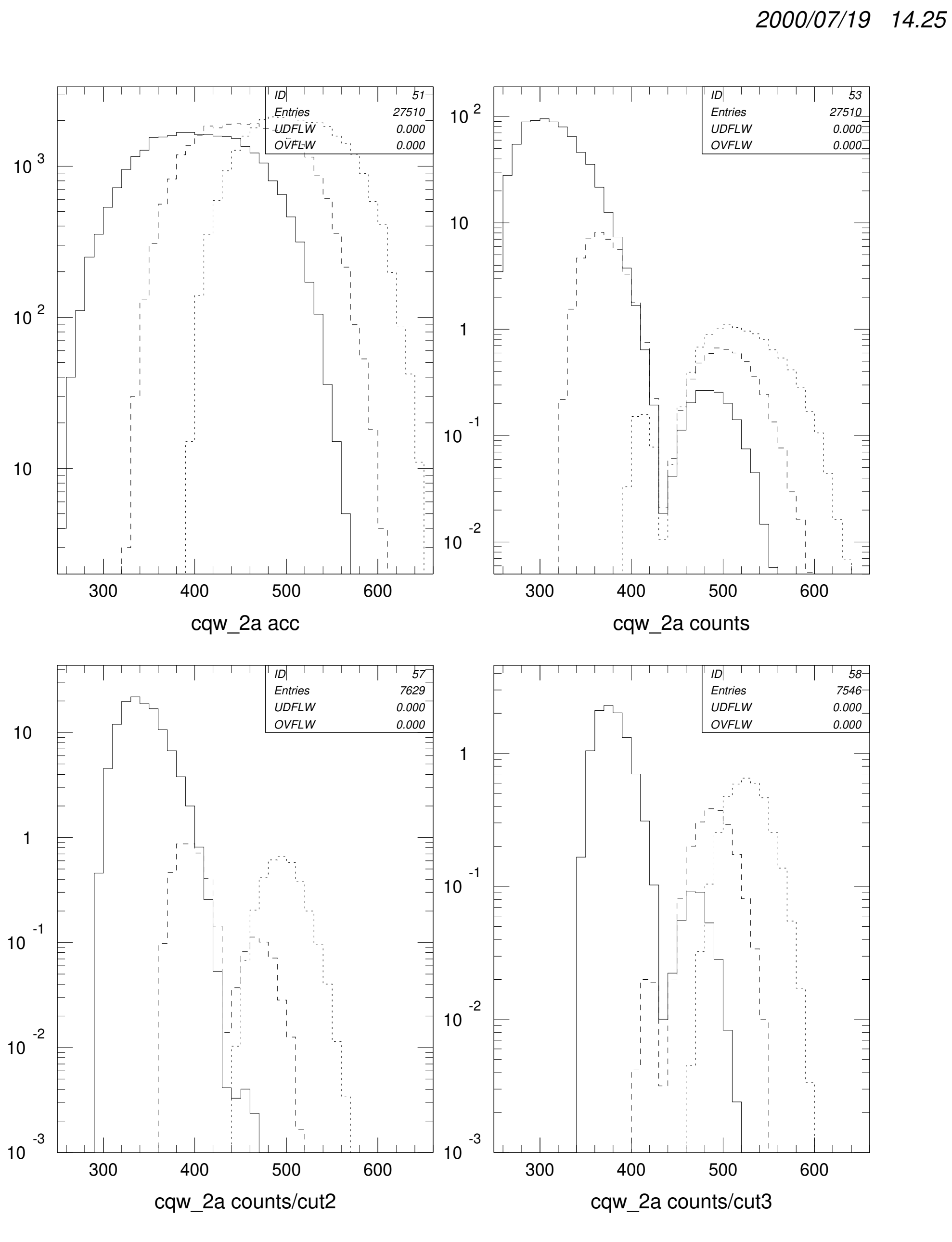

Figure 3: Missing momentum acceptances and counting rates for the second CQΩ program. The plots follow the same conventions as in Fig. 2. The cuts in q have been shifted to match the q acceptance of the electron spectrometer. As before, they each correspond to about $1/4$ of the full acceptance in q.

CQΩ Kinematics II			
$E_0 = 3944$ MeV	$\theta_e = 20.85$ deg	$\omega = 517$ MeV	$\lvert\vec{q}\rvert = 1427$ MeV/c
$Q^2 = 1.77$ (GeV/c)^2		$y = -373.9$ MeV/c	
θ_p (deg)	p_p (MeV/c)	p_m (MeV/c)	θ_{pq} (deg)
59.96	1053.2 (1040.9)	375.1	1.25
68.31	1041.4 (1040.9)	436.5	9.6
72.56	1028.7 (1040.9)	494.2	13.85

Table 2: Complete list of settings for the second CQΩ part of the experiment. For the proton momenta, the values in parentheses are the actual spectrometer momentum settings. The other values are the ones which correspond to protons which occupy the center of all acceptances in the electron arm, as well as the center of the spatial acceptance of the hadron arm. The p_m values quoted correspond to this same central value.

Plus y Kinematics I						
Beam Energy 2384 MeV				$\theta_e = 16.88$ deg		
p_e	ω	$\lvert\vec{q}\rvert$	p_m	θ_p (deg)	p_p	Q^2 (GeV/c)^2
2105	279	714.3	29.4	58.83	743.8	0.432
2020	364	739.9	129.9	52.44	869.9	0.415
1911	473	785.0	229.7	44.98	1014.8	0.393
1765	619	863.6	329.9	36.40	1193.5	0.363
1559	825	1000.4	430.0	26.90	1430.5	0.320
1354	1030	1157.2	499.9	19.86	1657.1	0.278

Table 3: PY-I Kinematics. All energies in MeV and momenta in MeV/c unless otherwise noted.

4 PY-I Kinematics

The idea is to make all points as parallel as possible here. The match with the CQΩ kinematics is through the value of the three-momentum transfer q. This match is optimized at 430 MeV recoil momentum, close to the value at which it should become zero in PWIA.

In order to match the missing momentum and obtain parallel kinematics, choosing the value of q will mean that the value of ω is constrained, and given that the beam energy is fixed then the scattering angle is also constrained. The givens are again $p_m = 430$ MeV/c, $q = 1000$ MeV/c, and $E_0 = 2384$ MeV. This fixes the scattering angle at 16.88 deg. The rest of the points are arrived at by choosing values of ω which result in 100 MeV/c steps in p_m over the range $30 \leq p_m \leq 430$ MeV/c with an additional point at 500 MeV/c.

A few points at low p_m have been added to the proposed measurements per Kees' suggestion.

5 PY-II Kinematics

The idea here is to make similar measurements as for PY-I; the exception is that we try to double Q^2. In order to do so we first increase the beam energy to 3164 MeV. Then we change the scattering angle and the energy loss so that we arrive at 430 MeV/c in parallel kinematics with Q^2 double what it was in PY-I at 430 MeV/c. The rest of the points are again filled in so as to make nice steps in the p_m coverage.

6 Additional Points

Since the data come in quickly we can consider taking a few additional runs at lower p_m. This is of special interest since there has been some buzz lately about Q^2 dependence of spectroscopic factors (see the article by Lapikas,

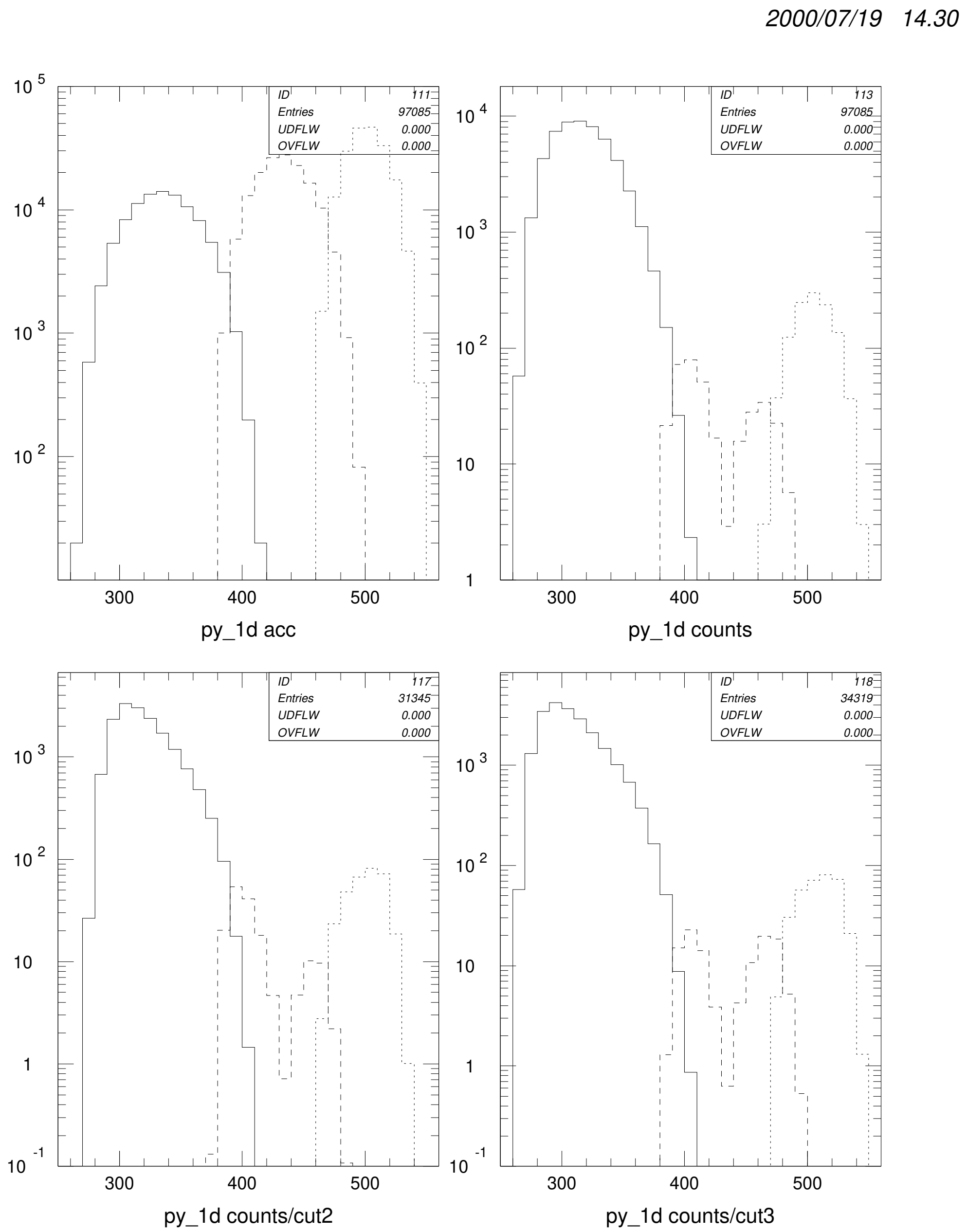

Figure 4: Missing momentum acceptances and counting rates for the first PY (plus-y) program. The plots follow the same conventions as in Fig. 2. The cuts in q have been shifted to match the q acceptance of the electron spectrometer. As before, they each correspond to about $1/4$ of the full acceptance in q. Here we show only the "D", "E", and "F" settings which correspond to those proposed.

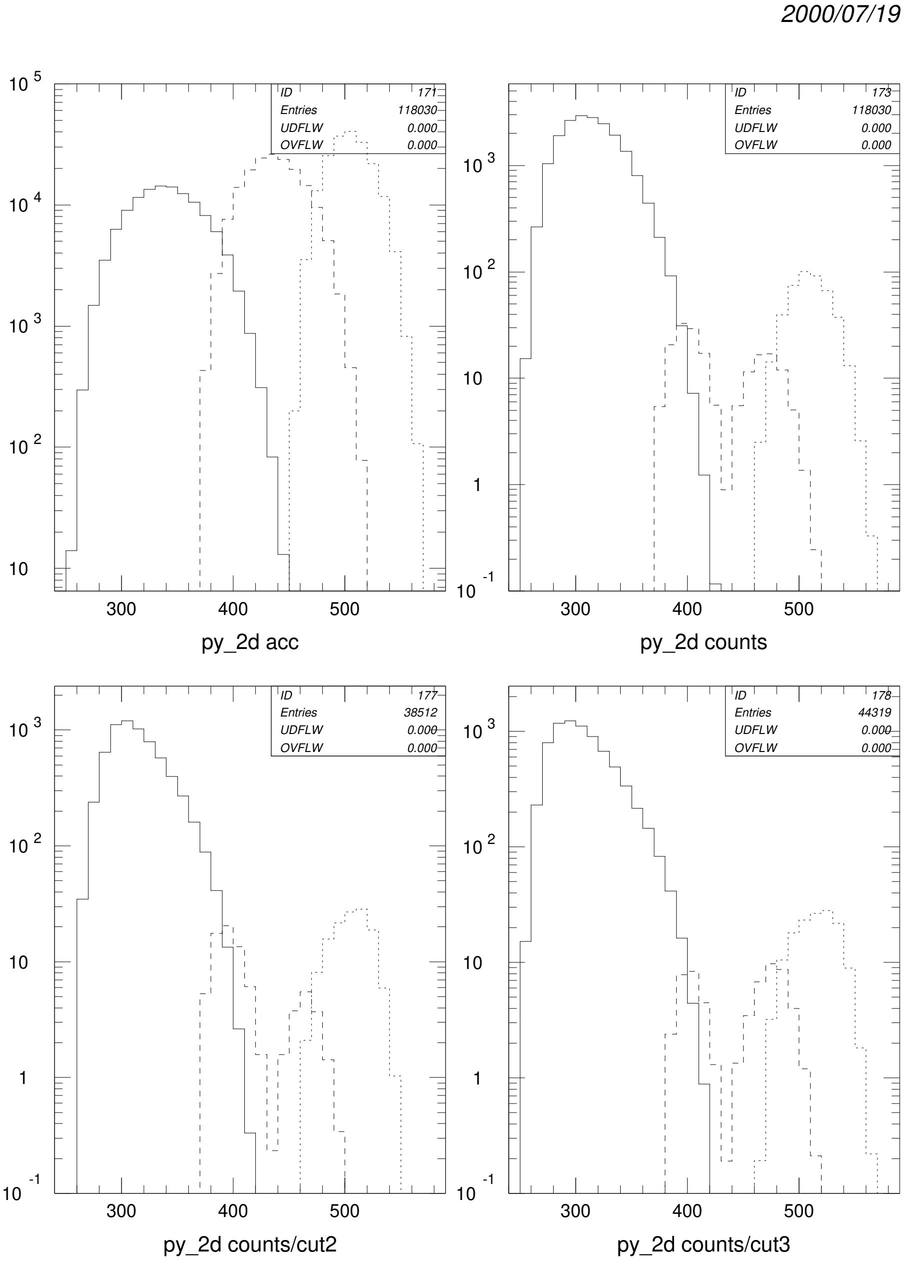

Figure 5: Missing momentum acceptances and counting rates for the second PY (plus-y) program. The plots follow the same conventions as in Fig. 2. The cuts in q have been shifted to match the q acceptance of the electron spectrometer. As before, they each correspond to about $1/4$ of the full acceptance in q. Here we show only the "D", "E", and "F" settings which correspond to those proposed.

Plus y Kinematics II						
Beam Energy 3164 MeV				$\theta_e = 18.62$ deg		
p_e	ω	$\lvert\vec{q}\rvert$	p_m	θ_p (deg)	p_p	Q^2 $(\mathrm{GeV}/c)^2$
2633	531	1074.3	30.3	51.50	1104.6	0.872
2517	647	1119.1	130.3	45.90	1249.3	0.834
2372	792	1188.7	230.2	39.58	1418.9	0.786
2185	979	1297.0	330.0	32.54	1627.0	0.724
1931	1233	1469.7	430.0	24.80	1899.7	0.640
1689	1475	1653.8	500.0	19.03	2153.8	0.559

Table 4: PY-II Kinematics. All energies in MeV and momenta in MeV$/c$ unless otherwise noted.

Strikman *et al.*)

The points I'm referring to are the first three on both the PY-I and PY-II programs.

Low-p_m data are already a part of the CQΩ-I program, and we can't take low-p_m data in the CQΩ-II program due to the large y value.

7 Expected Results

In fig. 8 I show the final result. The following assumptions go into the calcuation:

- the simulations above were used as a starting point
- the hours requested in the proposal were used, scaled up by a factor 1.6 which is what we did in the beam-time request to compensate for expected lower beam current and target density
- result scaled down by a factor of 0.5 to account for acceptance, FSI, and radiative tail effects
- a beam current of 70 μA was assumed.

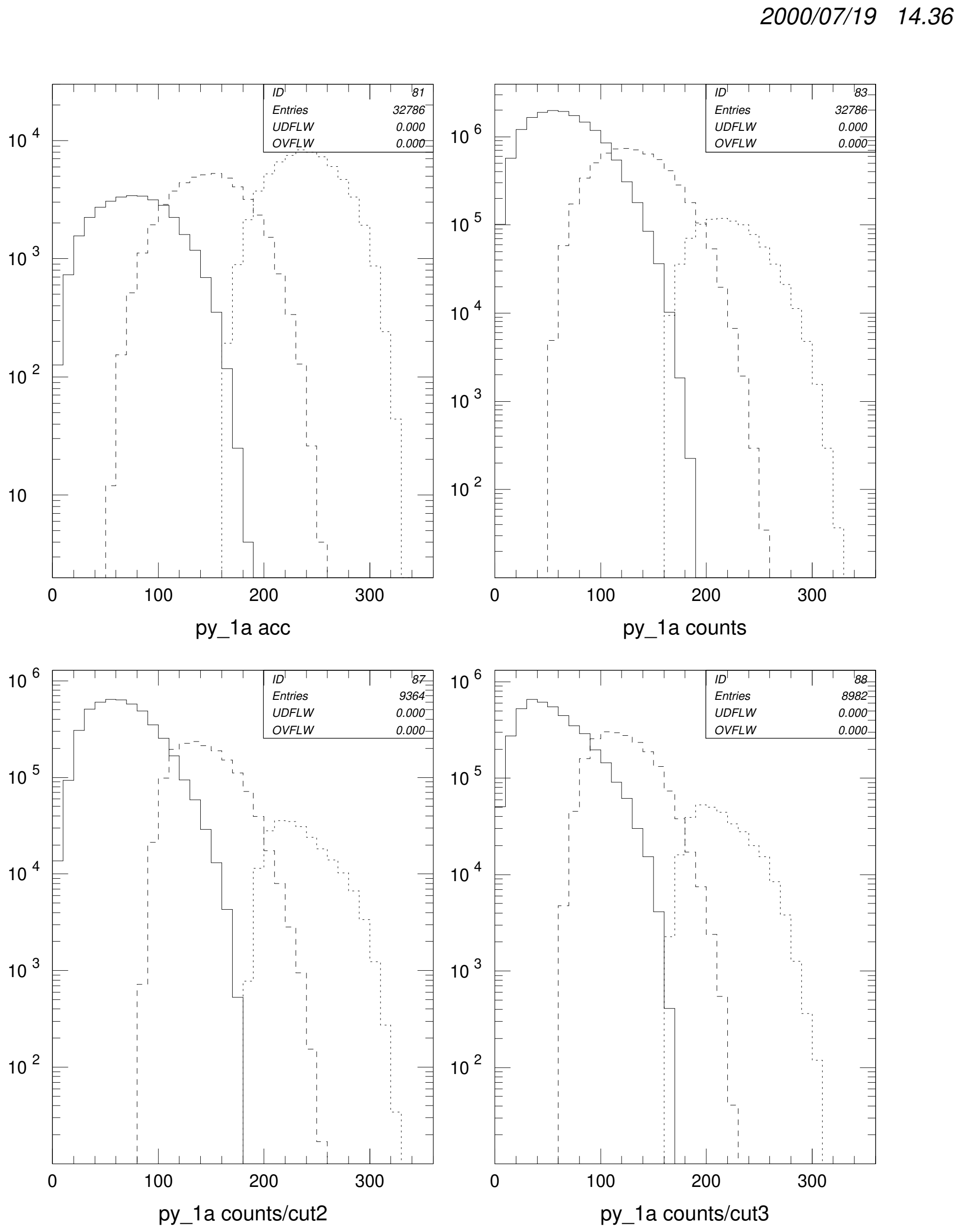

Figure 6: Missing momentum acceptances and counting rates for the first PY (plus-y) program. The plots follow the same conventions as in Fig. 2. The cuts in q have been shifted to match the q acceptance of the electron spectrometer. As before, they each correspond to about $1/4$ of the full acceptance in q. Here we show only the "A", "B", and "C" "extra" settings.

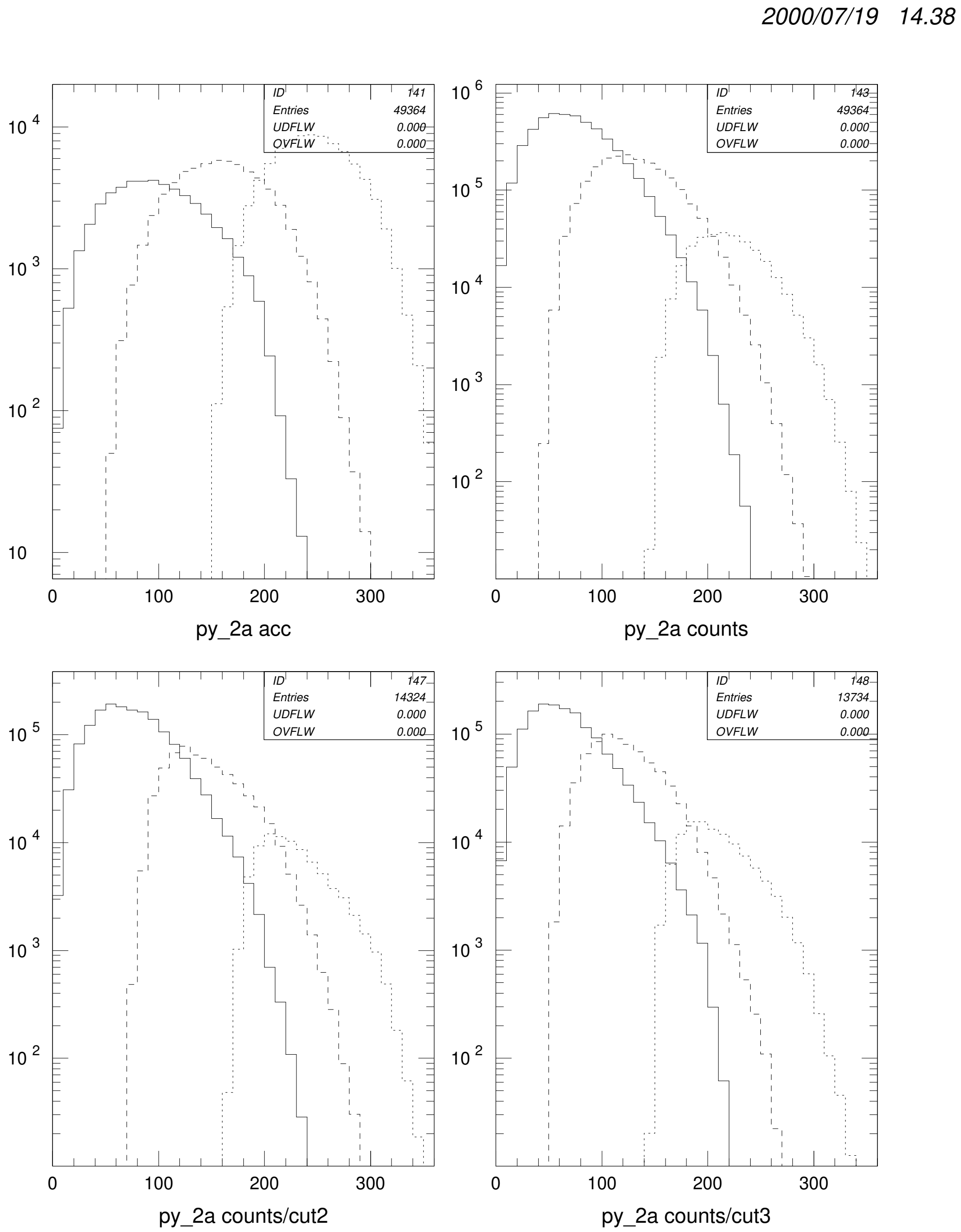

Figure 7: Missing momentum acceptances and counting rates for the second PY (plus-y) program. The plots follow the same conventions as in Fig. 2. The cuts in q have been shifted to match the q acceptance of the electron spectrometer. As before, they each correspond to about $1/4$ of the full acceptance in q. Here we show only the "A", "B", and "C" "extra" settings.

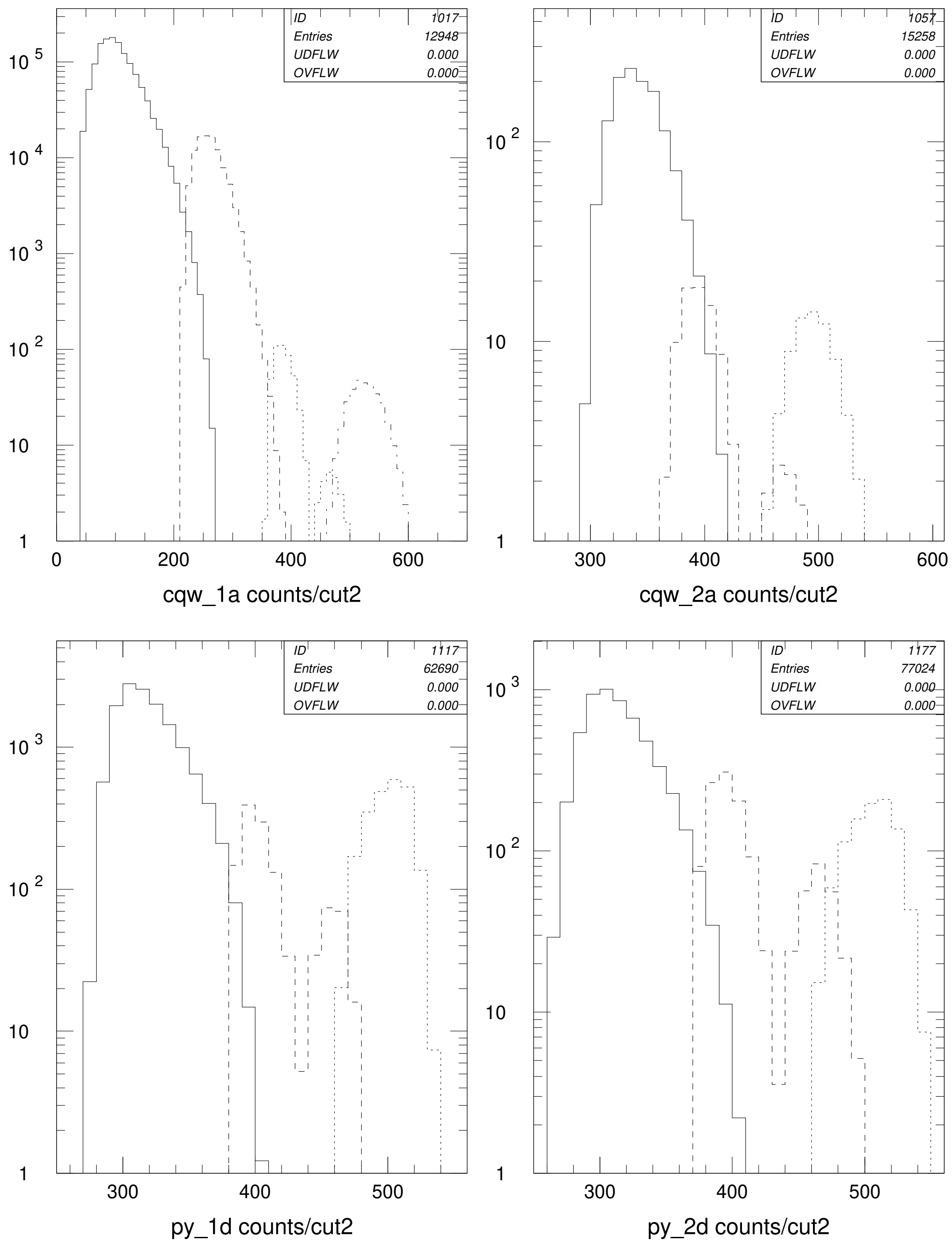

Figure 8: Number of counts for all the proposed settings. See text.