Resonance Analysis

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1 Raw Asymmetries

The raw asymmetries are summarized in this section, followed by some details on data quality check while extracting these raw numbers.

1.1 The Numbers

The raw, dithering-corrected and regression-corrected asymmetries for both electrons and pions are summarized in Table 1, for all resonance kinematics. These asymmetries are run-averaged, weighted by the statistic error of each run. All asymmetries are **Unblinded**.

Figure 1 shows the run-wise asymmetry plots, which is a good rough check to see if any particular run is problematic. As one can see, there are no 3-sigma away runs.

		RES 3 (L)	RES 4 (L)	RES 5 (R)	RES 7 (L)	RES 7b (L)
A_{e^-} Narrow	A_{raw}	-55.39 ± 6.77	-63.54 ± 5.91	-54.39 ± 4.47	-104.53 ± 15.26	-68.98 ± 21.25
	A_{dit}	-55.11 ± 6.77	-63.75 ± 5.91	-54.38 ± 4.47	-104.04 ± 15.26	-67.87 ± 21.25
	A_{reg}	-55.21 ± 6.76	-63.60 ± 5.91	-54.62 ± 4.46	-104.30 ± 15.26	-68.59 ± 21.23
A_{e^-} Wide	A_{raw}	-54.85 ± 6.77	-63.63 ± 5.91	-53.98 ± 4.46	-105.04 ± 15.25	-68.97 ± 21.45
	A_{dit}	-54.56 ± 6.77	-63.86 ± 5.91	-53.98 ± 4.46	-104.55 ± 15.25	-67.93 ± 21.46
	A_{reg}	-54.64 ± 6.77	-63.69 ± 5.91	-54.20 ± 4.46	-104.88 ± 15.24	-68.74 ± 21.44
A_{π^-} Narrow	A_{raw}	-45.09 ± 40.10	-69.44 ± 26.45	-16.97 ± 8.54	20.88 ± 47.74	-46.80 ± 64.02
	A_{dit}	-44.19 ± 40.10	-69.83 ± 26.45	-17.12 ± 8.54	21.82 ± 47.74	-46.67 ± 64.03
	A_{reg}	-46.81 ± 40.07	-70.22 ± 26.44	-17.68 ± 8.53	24.06 ± 47.71	-47.61 ± 63.98
A_{π^-} Wide	A_{raw}	-46.51 ± 39.40	-69.03 ± 26.09	-18.10 ± 8.47	29.91 ± 47.61	-50.75 ± 63.88
	A_{dit}	-45.41 ± 39.41	-69.21 ± 26.09	-18.25 ± 8.47	30.87 ± 47.61	-51.01 ± 63.89
	A_{reg}	-48.05 ± 39.38	-70.03 ± 26.07	-18.87 ± 8.46	33.49 ± 47.58	-51.81 ± 63.84

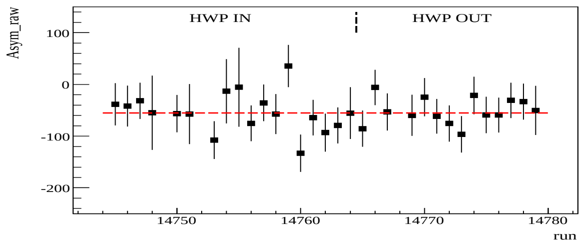
Table 1: Run-averaged asymmetries (raw, dithering, regression) for both electrons and pions

1.2 Data Quality Checks

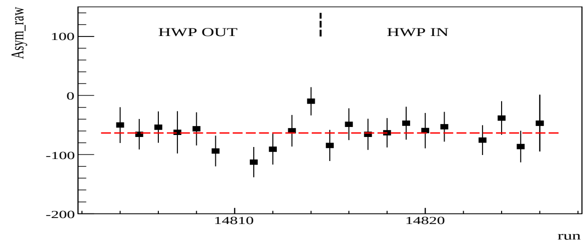
The statistical quality of data is checked using different techniques. Three kinds of the diagnositic plots are shown here as examples.

Check 1: The Yield Plot

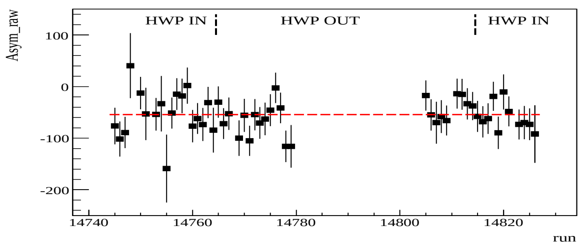
One of the diagnostic plots that is proved in practice to be quite useful is the Yield plot, where the Yield is defined as the event rate normalized to beam current. A lot of non-statistical fluctuations of experimental parameters are reflected on this plot, many of which actually indicates problems/faults of the experiment, such as:



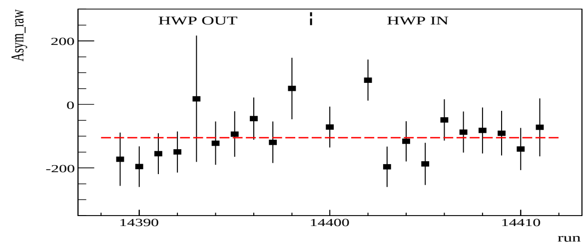
(a) RES 3



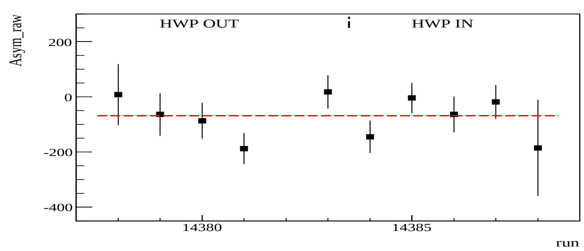
(b) RES 4



(c) RES 5



(d) RES 7



(e) RES 7b

Figure 1: Asymmetry v.s. run number. Asymmetries plotted are already sign corrected

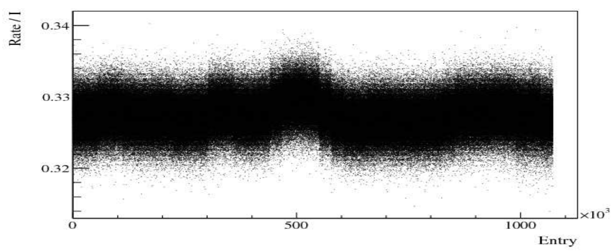
- Magnets malfunction, e.g. when the magnet trips, the yield becomes significantly lower. One might miss magnet trips sometimes if they are not well documented in halog, but the yield plot helps to spot them.

- PID changes. PID efficiency may vary due to all kinds of reasons, such as the baseline drift of the fan-in/out modules, or wrong threshold settings of the discriminators at the beginning of kinematics change. PID changes always show up in the yield plot, however, it is usually less an issue as we correct this effect using PID analysis.

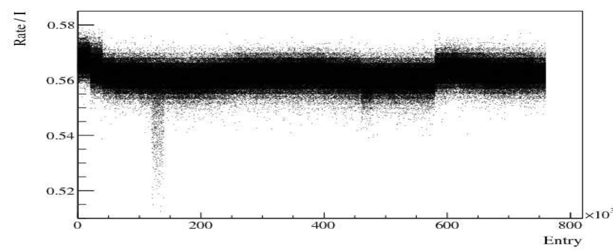
- DAQ changes. Some DAQ changes would significantly change the event rates, and the yield plot would always remind us of them if sometimes overlooked.

- DAQ malfunction. One example is that close to the end of DIS 2, the anding modules for groups 5 and 6 on the left arm behaved abnormally, loosing counts from time to time.

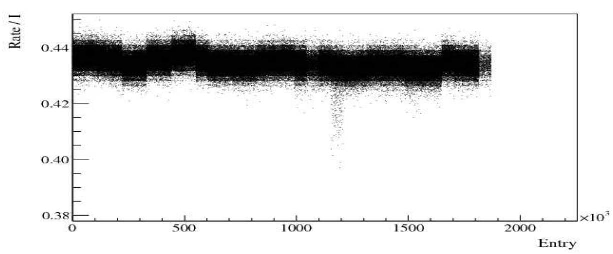
- Sometimes runs at the beginning or ending of one kinematics can be mistaken as belonging to adjecent kinematics. Such mistakes can be easily seen on the yield plot



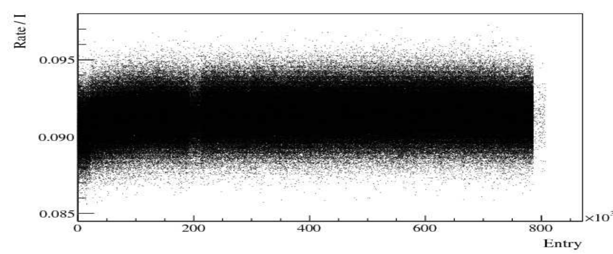
(a) RES 3



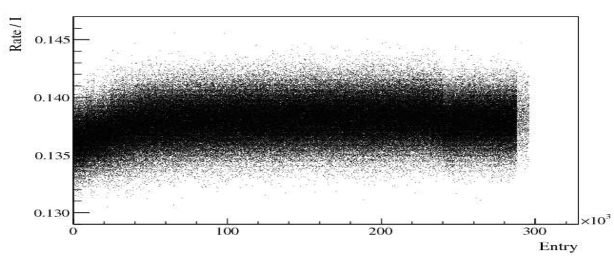
(b) RES 4



(c) RES 5



(d) RES 7



(e) RES 7b

Figure 2: Yield plots

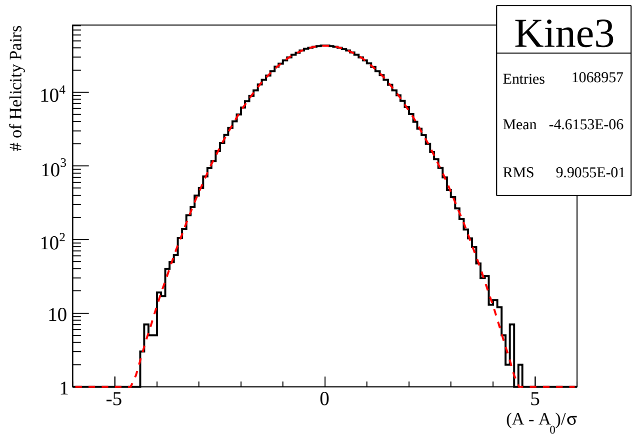
When the experiment is running smoothly, the yield is very stable. It is also insensitive to beam current fluctuation, except for small changes due to deadtime, on the level a percent at most. Figure 2 shows the yield plots for resonance kinematics.

Check 2: The (pair-wise) Pull Plot

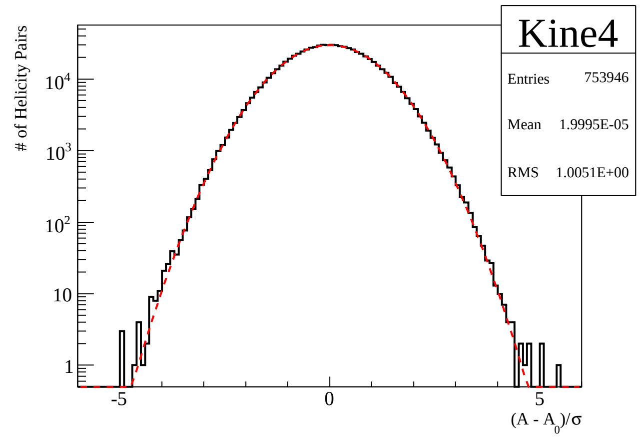
Pull plots are always good diagnose on statistical quality checks. For the resonance anslysis, the run-wise pull plot won't tell us much because of the limited number of runs. Instead, we look at the more useful pair-wise pull plot, with the "pull" defined as $(A_i - <A>)/\delta A_i$ for each helicity pair. If the data is purely statistical, the pull plot will resemble a strict standard normal distribution. Figure 3 shows the pull plots of resonance kinematics, with the gaussian fits plotted in red lines.

Check 3: Dithering Events Included v.s. Excluded

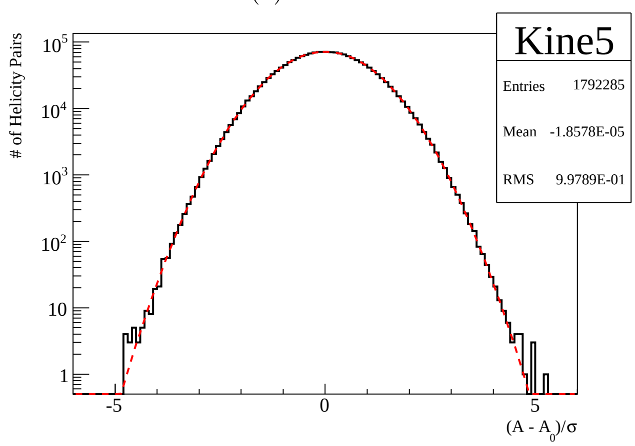
Another thing worth checking is the asymmetry's sensitivity to beam movement. It can already be seen from Section 1.1 that the correction due to beam movement is small. However, it doesn't



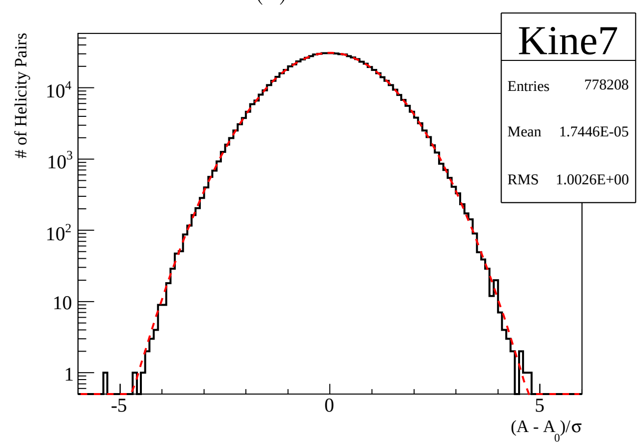
(a) RES 3



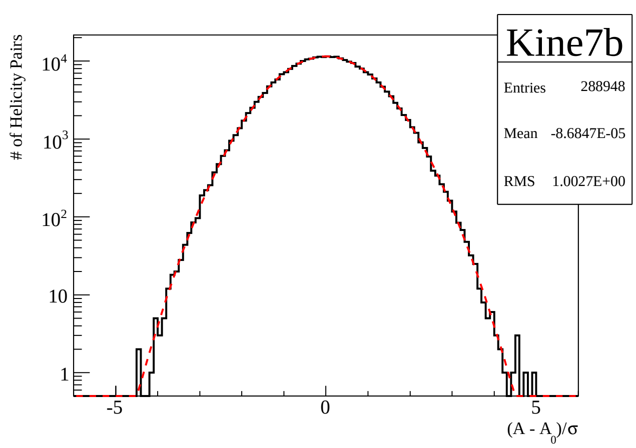
(b) RES 4



(c) RES 5



(d) RES 7



(e) RES 7b

Figure 3: Pair-wise pull plots

harm to check it from another perspective, by comparing the asymmetry results from analyzes including and excluding the dithering events. Table 2 shows such comaprison for the narrow path electron trigger, and confirms again that the beam movement doesn't induce significant systematics.

Dithering In/Ex	$A_{e^-}Narrow$	RES 3 (L)	RES 4 (L)	RES 5 (R)	RES 7 (L)	RES 7b (L)
Included	A_{raw}	-55.39 ± 6.77	-63.54 ± 5.91	-54.39 ± 4.47	-104.53 ± 15.26	-68.98 ± 21.25
	A_{dit}	-55.11 ± 6.77	-63.75 ± 5.91	-54.38 ± 4.47	-104.04 ± 15.26	-67.87 ± 21.25
	A_{reg}	-55.21 ± 6.76	-63.60 ± 5.91	-54.62 ± 4.46	-104.30 ± 15.26	-68.59 ± 21.23
Excluded	A_{raw}	-57.11 ± 7.13	-61.11 ± 6.22	-53.41 ± 4.70	-107.60 ± 16.29	-76.04 ± 22.18
	A_{dit}	-56.84 ± 7.13	-61.22 ± 6.22	-53.41 ± 4.70	-107.26 ± 16.29	-75.16 ± 22.18
	A_{reg}	-56.92 ± 7.12	-61.09 ± 6.21	-53.63 ± 4.70	-107.54 ± 16.28	-75.80 ± 22.16

Table 2: Comparison of the electron narrow asymmmetries between analyzes including and excluding dithering events.

2 Beam Modulation

		RES 3	RES 4	RES 5	RES 7	RES 7b
Beam Movements(um)						
BPM4ax		0.012 ± 0.014	0.046 ± 0.015	0.025 ± 0.010	-0.106 ± 0.021	-0.037 ± 0.033
BPM4ay		0.014 ± 0.013	0.018 ± 0.015	0.014 ± 0.010	0.016 ± 0.023	-0.029 ± 0.039
BPM4bx		0.014 ± 0.018	0.070 ± 0.019	0.036 ± 0.013	-0.109 ± 0.022	-0.047 ± 0.035
BPM4by		0.011 ± 0.014	0.015 ± 0.015	0.011 ± 0.010	0.013 ± 0.024	-0.029 ± 0.041
BPM12x		0.012 ± 0.020	0.068 ± 0.022	0.032 ± 0.015	0.012 ± 0.014	0.008 ± 0.021
Dithering Corrections(ppm)						
Narrow	BPM4ax	-0.175	0.313	-0.013	-1.004	-3.708
	BPM4ay	0.230	0.096	0.047	0.328	0.400
	BPM4bx	0.369	-0.568	0.020	1.398	4.754
	BPM4by	-0.139	-0.132	-0.038	-0.235	-0.265
	BPM12x	-0.010	0.045	-0.005	0.002	-0.035
	A_{cor} *total*	0.275	-0.246	0.011	0.489	1.146
Wide	BPM4ax	-0.178	0.320	0.000	-1.192	-3.631
	BPM4ay	0.224	0.107	0.046	0.328	0.317
	BPM4bx	0.375	-0.582	-0.005	1.596	4.603
	BPM4by	-0.133	-0.143	-0.037	-0.250	-0.183
	BPM12x	-0.011	0.045	-0.005	0.003	-0.036
	A_{cor} *total*	0.277	-0.253	-0.001	0.485	1.070

3 Kinematics

Comparisons between Data and HAMC on reconstruction of kinematics variables (Q^2 and W^2) are shown in Figure 4 to 8, together with the basic target variables. Mean values are summarized in Table 3. A couple of things noticed here are:

		RES 3	RES 4	RES 5	RES 7	RES 7b
Q^2	DATA	0.950	0.831	0.757	1.472	1.278
	HAMC	0.956	0.832	0.745	1.456	1.268
W^2	DATA	1.595	2.530	3.450	3.923	4.122
	HAMC	1.600	2.528	3.443	3.925	4.109

Table 3: Kinematics

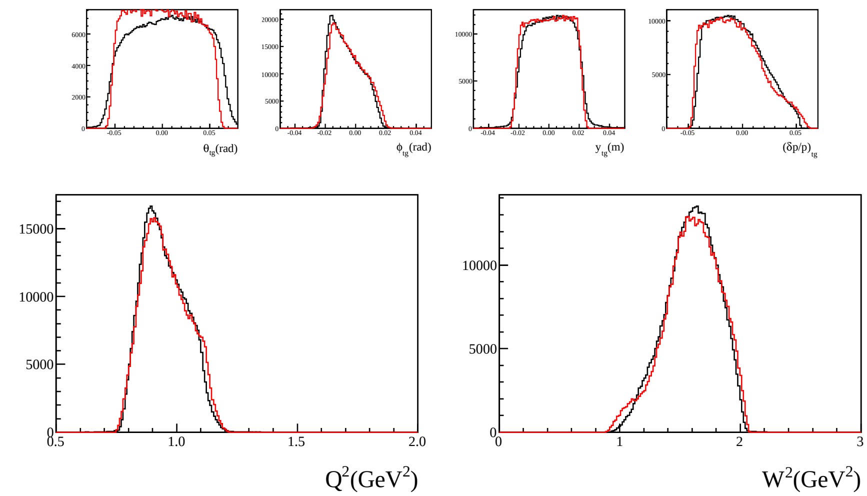


Figure 4: Resonance 3

- I start to doubt that I'm not using the correct databases for replaying data. (Maybe Kai can generate the data rootfiles to make sure they are right). The out-plane angle (θ) for RES 3 & 4 (without collimator) seems shifted, and the outgoing energy (E') for RES 7 shows a strange shape.
- Better agreement on the mean values of Q^2 and W^2 doesn't necessarily mean better tuned simulation. Sometimes it could just be coincidence, as the agreement on target variables might appear worse.

4 Corrections

4.1 Beam Polarization

The beam polarization correction for resonance kinematics are quite simple because of their shorter running time. Actually, it is not even necessary to perform a run-by-run correction. All resonances are within the period when Compton is functional, therefore, the average value from Compton measurement is used. For each resonance, there is only one Moller measurement, the result of

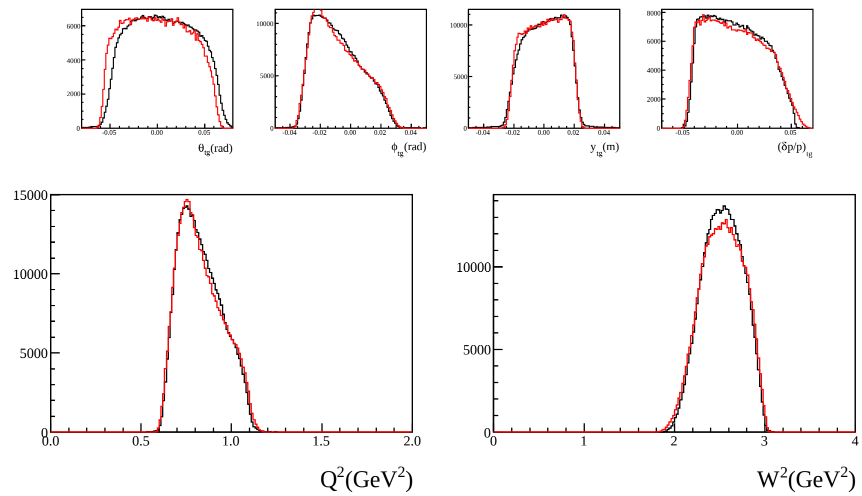


Figure 5: Resonance 4

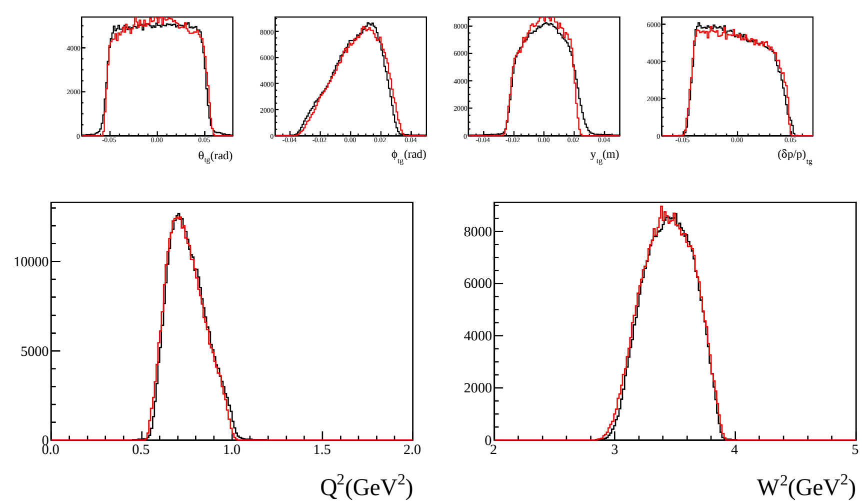


Figure 6: Resonance 5

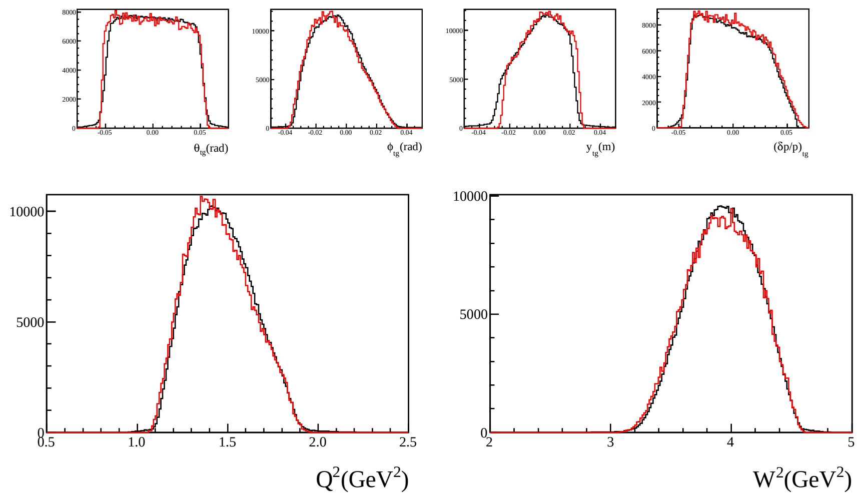


Figure 7: Resonance 7

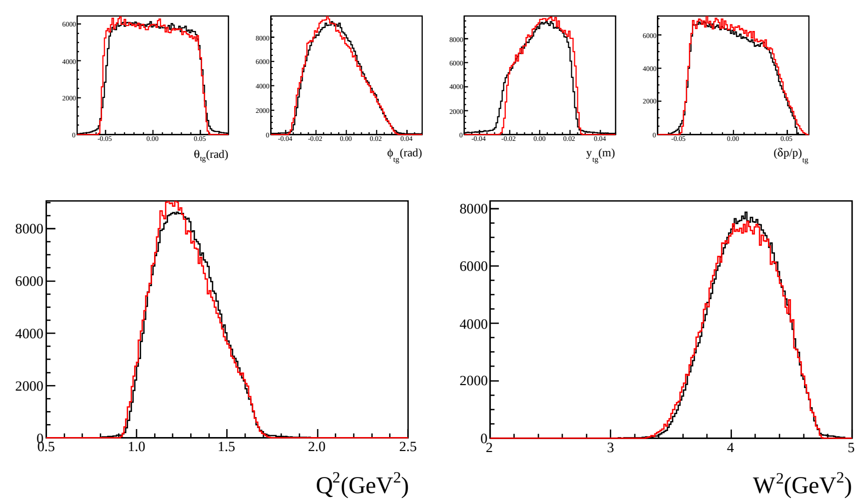


Figure 8: Resonance 7b

which is then used throughout the kinematics. A simple combination of Compton and Moller results is sufficient for resonance polarization analysis.

	RES 3	RES 4	RES 5	RES 7	RES 7b
Compton	$89.45\% \pm 1.71\%$				
Moller	$90.40\% \pm 1.54\%$			$89.88\% \pm 1.80\%$	
Combined	$89.97\% \pm 1.14\%$			$89.65\% \pm 1.24\%$	

Table 4: Beam polarization correction

4.2 Deadtime Correction

Deadtime of resonances are simulated using HATS, as shown in Figure 9. In practice, the deadtime is corrected run by run. For each run, its deadtime correction factor is calculated using beam current information from data and linear fit slope from Figure 9. The global correction from the run-by-run analysis is summarized in Table 5.

		RES 3	RES 4	RES 5	RES 7	RES 7b
Deadtime	Narrow	1.45%	2.19%	1.96%	0.75%	
@100uA	Wide	1.66%	2.56%	2.27%	0.82%	
Deadtime	Narrow	1.48%	2.47%	2.09%	0.76%	
run by run	Wide	1.70%	2.89%	2.42%	0.83%	

Table 5: Deadtime from run-by-run based correction. Still missing the error estimation.

4.3 EM Radiative Correction

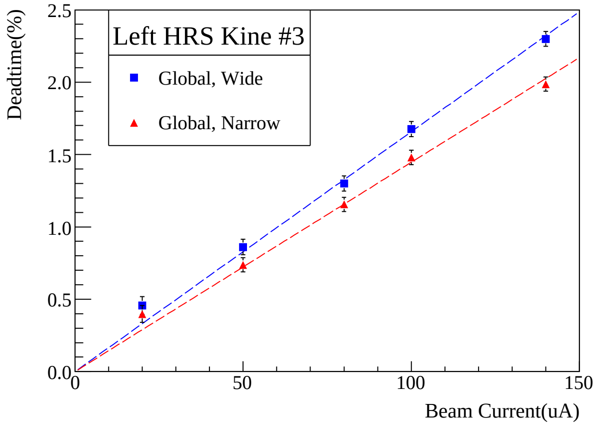
As usual, the radiative correction factor is calculated using:

$$f_{rad} = \frac{A(< Q^2 >, < W >)}{< A(Q^2_{vx}, W_{vx}) >} \tag{1}$$

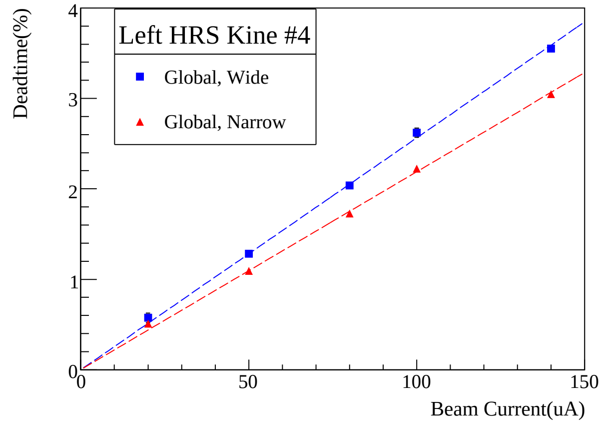
where the point value $A(< Q^2 >, < W >)$ is evaluated using the most populated model. Different models are already described in detail elsewhere. The preliminary results are summarized in table 6.

5 Futher Analysis with Group Triggers

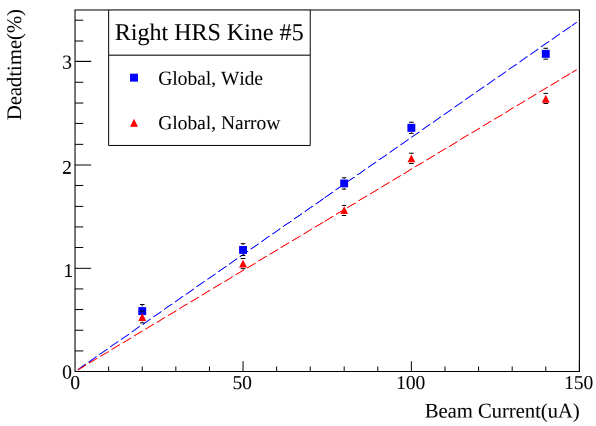
Remember we have group triggers? Although the statistics become lower when divided into groups, we do gain more information(??) by looking at individual groups than just the global trigger. This may be useful for resonances when combined with the fact that group triggers are relatively well seperated from each other in W, as shown in Figure 10 for example.



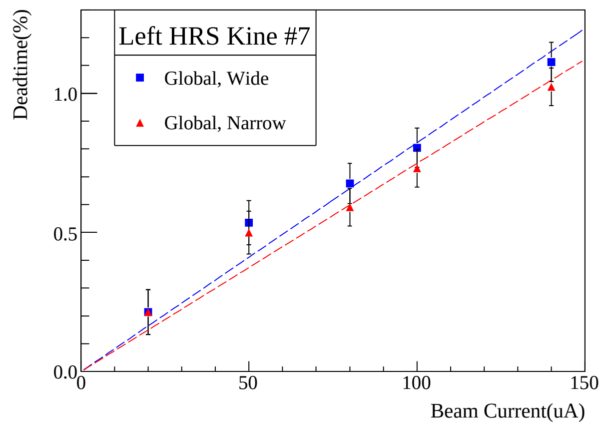
(a) RES 3



(b) RES 4



(c) RES 5



(d) RES 7

(e) RES 7b

Figure 9: Deadtime v.s. Beam Current from HATS.

		Elas.	Q.E.	Table	DIS	Toy	$< A(Q^2, W) >$	$A(< Q^2 >, < W >)$	f_{rad}
Using Table Lee & Tao									
RES 3	%	0.15	13.10	86.15	0	0.60	-82.17	$-93.39(Table)$	1.137
	A	78.94	-45.85	-88.20	0	-49.38			
RES 4	%	0.03	1.29	5.10	0	93.58	-65.46	$-65.47(Toy)$	1.00017
	A	56.92	-26.74	-77.85	0	-65.36			
RES 5	%	0.02	1.65	1.64	0	96.69	-59.05	$-58.64(Toy)$	0.9930
	A	42.01	-17.38	-54.44	0	-59.87			
RES 7	%	0.04	0.82	0.81	34.01	64.33	-116.74	$-117.48(Toy)$	1.0063
	A	84.35	-45.38	-102.29	-107.86	-122.63			
RES 7b	%	0.04	1.15	0.69	55.09	43.04	-101.43	$-103.87(DIS)$	1.0241
	A	70.60	-35.34	-92.24	-97.24	-108.84			
Using Table Misha									
		Elas.	Q.E.	Table	DIS	Toy	$< A(Q^2, W) >$	$A(< Q^2 >, < W >)$	f_{rad}
RES 3	%	0.15	13.16	86.70	0	0	-82.23	$-88.97(Table)$	1.082
	A	78.94	-45.87	-88.02	0	0			
RES 4	%	0.03	1.58	94.09	0	4.31	-68.28	$-71.07(Table)$	1.0408
	A	56.92	-28.48	-69.43	0	-58.67			
RES 5	%	0.02	1.70	92.05	0	6.23	-62.02	$-62.51(Table)$	1.0079
	A	42.01	-17.57	-62.59	0	-66.20			
RES 7	%	0.04	0.83	59.89	34.01	5.24	-120.38	$-123.71(Table)$	1.0276
	A	84.35	-45.42	-128.23	-107.86	-125.15			
RES 7b	%	0.04	1.15	34.44	55.09	9.29	-103.60	$-103.87(DIS)$	1.0027
	A	70.60	-35.35	-117.53	-97.24	-98.75			

Table 6: Radiative Corrections

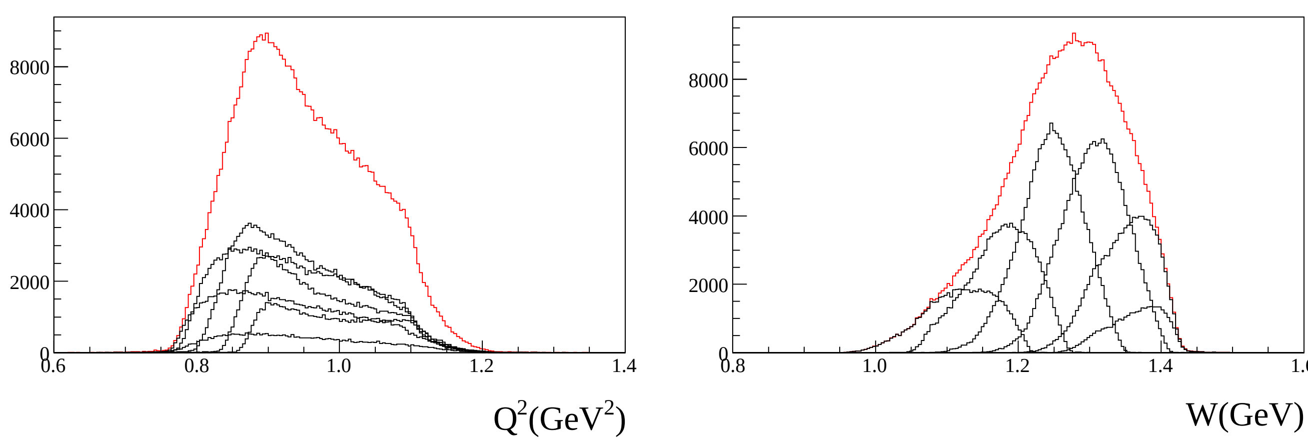


Figure 10: Seperation in Q^2 and W for group triggers. RES 3 is used here as an example. Red line is the global trigger and black lines represent the group triggers

The group asymmetries are summarized in Table 7 and 8. And Figure 11 plots the (Q^2-scaled) asymmetry's dependence on W. Maybe people can fit their theory to this plot? However, limited by statistics, I'm not sure how conclusive statements can be made.

RES 3						
Group	1	2	3	4	5	6
Q^2	0.992	0.966	0.948	0.940	0.931	0.940
W	1.119	1.175	1.245	1.305	1.350	1.364
A_{raw}	-30.84	-57.65	-54.01	-46.12	-60.24	-95.49
ΔA	18.31	14.34	11.51	11.33	14.41	23.85
RES 4						
Group	1	2	3	4	5	6
Q^2	0.856	0.849	0.834	0.820	0.808	0.819
W	1.503	1.533	1.583	1.629	1.662	1.672
A_{raw}	-60.67	-55.15	-77.16	-65.46	-65.92	-61.73
ΔA	13.24	11.18	10.55	10.57	12.95	20.71
RES 7						
Group	1	2	3	4	5	6
Q^2	1.531	1.533	1.473	1.442	1.427	1.378
W	1.901	1.922	1.978	2.020	2.049	2.071
A_{raw}	-103.29	-91.13	-82.82	-117.19	-142.95	87.30
ΔA	32.87	32.21	27.24	27.00	37.52	96.85

Table 7: Group Asymmetries for RES 3, 4 and 7. All are raw asymmetries from narrow path

RES 5								
Group	1	2	3	4	5	6	7	8
Q^2	0.731	0.719	0.730	0.744	0.761	0.777	0.796	0.799
W	1.928	1.923	1.905	1.880	1.851	1.820	1.790	1.771
A_{raw}	-58.62	-38.74	-56.02	-56.74	-56.67	-57.15	-52.57	-35.99
ΔA	26.82	13.05	9.95	9.57	9.58	9.97	11.13	24.24

Table 8: Group Asymmetries for RES 5. All are raw asymmetries from narrow path

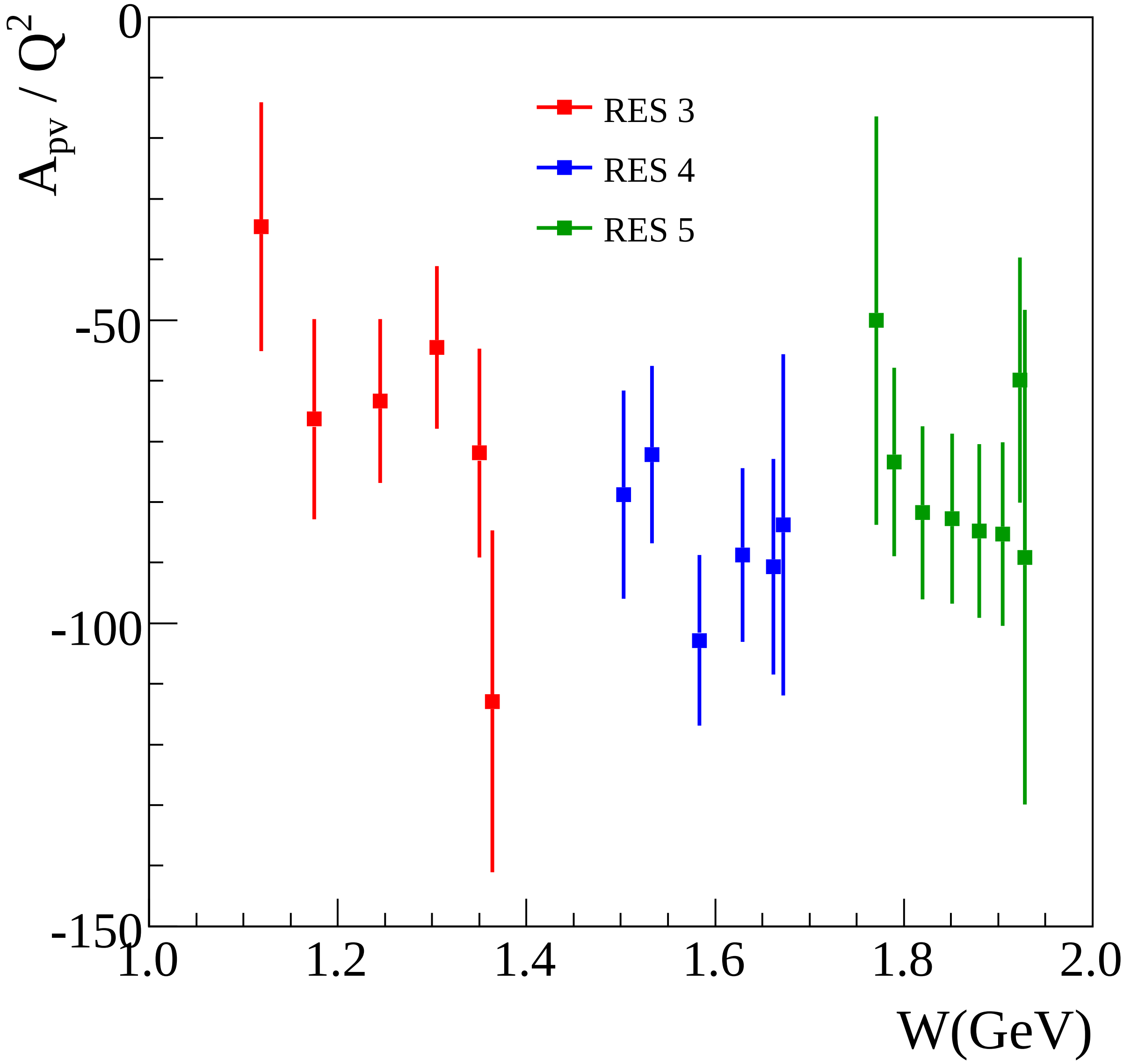


Figure 11: Group asymmetry scaled by Q^2 plotted v.s. W. Asymmetries are already corrected for beam polarization. RES 7 is not included because it has different beam energy and also far away from resonance.