Elastic Cross Section for H(e,e'p)

From our 6 kinematics runs (2009, 2033, 2037, 1257, 1243, 1256), our kinematic coverage are from 0.1<Q2<0.6 GeV^2 which translate to 0.3<|q3m|<0.8 GeV/c.

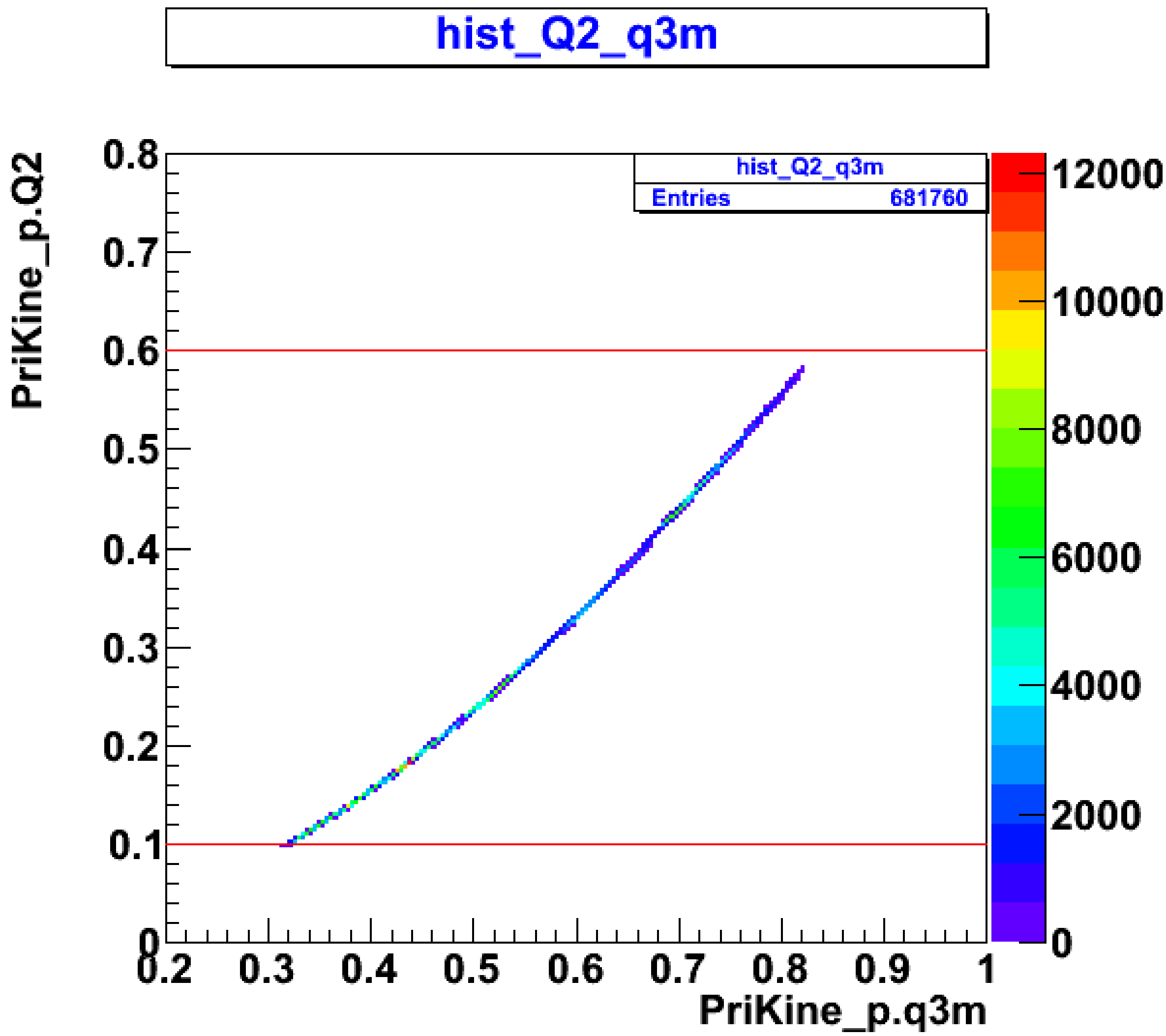

Figure 1. Elastic H(e,e'p) coverage in term of Q^2 and |q3m| with [GeV^2] and [GeV/c] unit respectively.

Each individual run information are as follow.

Run	2009	2033	2037	1257	1243	1256
E_beam [GeV]	1.15976	1.15976	1.15976	2.257	2.257	2.257
Scattering Theta (e') [degree]	17.45	20.5	23.0	14	16.489	19
(e') center momentum [GeV/c]	1.05	1.05	1.05	2.1	2.02	2.02
Main Peak momentum	+4%	+2%	0%			
BigBite.theta [degree]	68	68	68	64.4	64.4	64.4
Q2 [GeV]^2	0.1 to 0.14	0.13 to 0.19	0.17 to 0.23	0.22 to 0.36	0.32 to 0.47	0.42 to 0.58
|q3m|	0.32 to 0.38	0.37 to 0.44	0.42 to 0.49	0.49 to 0.64	0.58 to 0.72	0.68 to 0.82

Table 1: Individual initial data

The Calculated theoretical cross section are follow the following equation:
“Theory cross section”

```
d\sigma    alpha^2                      E'   Ge^2+tau&Gm^2
--------- = -------------------------- *-- {---------------------*cos^2(theta/2) + 2*tau*Gm^2*sin^2(theta/2)}
d\Omega  4*E^2*sin^4(theta/2)   E   (1+tau)
```

with
tau = Q2/(4*Mp^2)
alpha = 1/137
(h_bar*c)^2 = 0.389 GeV^2*mbarn

dipole fit for Ge and Gm:
Ge = 1/(1+Q^2/0.71GeV^2)^2 and
Gm = 2.79*Ge.

Table 2: Cross section Calculation

run		2009	2033	2037	1257	1243	1256
E	GeV	1.1598	1.1598	1.1598	2.26	2.26	2.26
scattered theta	degree	17.45	20.5	23	14	16.5	19
scattered theta	radian	0.3046	0.3578	0.4014	0.2443	0.2880	0.3316
E'	GeV	1.0973	1.0756	1.0560	2.1065	2.0536	1.9955
Q2	GeV^2	0.1171	0.1580	0.1947	0.2824	0.3817	0.4907
Ge	1/(1+Q^2/0.71 GeV^2)^2	0.7368	0.6691	0.6159	0.5118	0.4229	0.3496
Gm	2.79*Ge	2.0557	1.8668	1.7183	1.4279	1.1800	0.9755
tau	Q2/(4*Mp^2)	0.0333	0.0449	0.0553	0.0802	0.1084	0.1394
alpha		0.00730	0.00730	0.00730	0.00730	0.00730	0.00730
sin(theta/2)		0.1517	0.1779	0.1994	0.1219	0.1435	0.1650
cos(theta/2)		0.9884	0.9840	0.9799	0.9925	0.9897	0.9863
alpha^2/(4*E^2*sin^4(theta/2) (GeV^-2)		0.0187	0.0099	0.0063	0.0119	0.0062	0.0035
E'/E		0.9462	0.9274	0.9105	0.9333	0.9099	0.8841
(Ge^2+tau*Gm^2)/(1+tau)*cos^2(theta/2)		0.6463	0.5598	0.4937	0.3880	0.2914	0.2176
2*tau*Gm^2*sin^2(theta/2)		0.0065	0.0099	0.0130	0.0049	0.0062	0.0072
cross section	(GeV^-2)	0.01155	0.00522	0.00289	0.00435	0.00167	0.00070
(h_bar*c)^2	GeV^2* ubarn	389.379	389.379	389.379	389.379	389.379	389.379
cross section	ubarn	4.50E+000	2.03E+000	1.13E+000	1.69E+000	6.50E-001	2.73E-001

Let calculate cross section from experiment say run 2033
With cut as:
DBB.evtypebits&(1<<3) && DBB.edtpl==0 && abs(exL.th)<0.060 && abs(exL.ph)<0.030 && abs(sqrt(PriKine_p.W2)-0.93827)< 0.00449

we have,

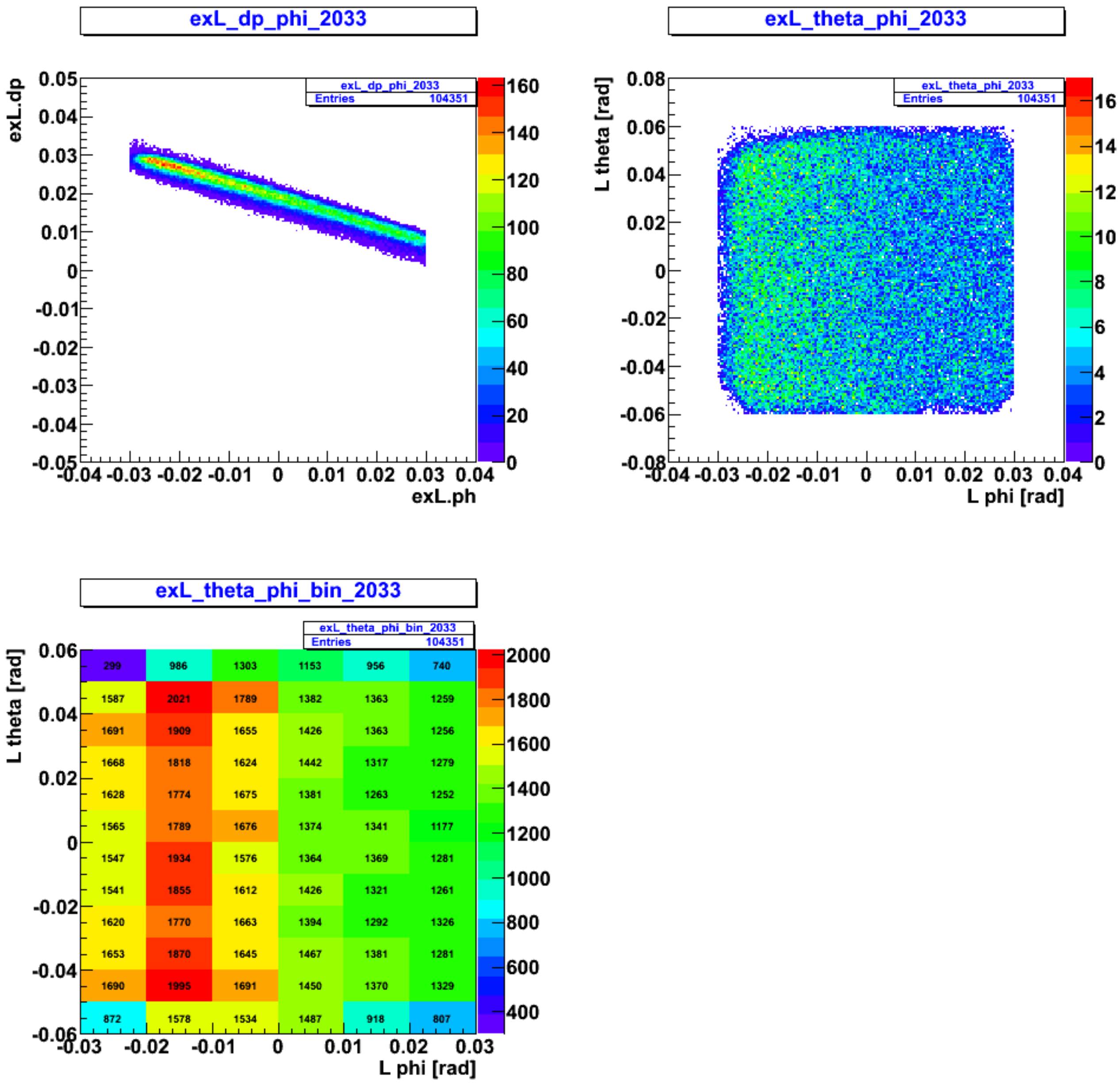

Figure 2. 2.1 dp vs phi, 2.2 theta vs phi and 2.3 theta vs phi binning 10 mrad in both angle.

I make the binning with d_theta = 10 mrad and d_phi = 10 mrad and calculate d_cos(theta_scatter+phi),
I have d\Omega = d_theta* d_cos(theta_scatter+phi)

N_scattered						
x_phi/y_theta	-0.025	-0.015	-0.005	0.005	0.015	0.025
-0.055	872	1578	1534	1487	918	807
-0.045	1690	1995	1691	1450	1370	1329
-0.035	1653	1870	1645	1467	1381	1281
-0.025	1620	1770	1663	1394	1292	1326
-0.015	1541	1855	1612	1426	1321	1261
-0.005	1547	1934	1576	1364	1369	1281
0.005	1565	1789	1676	1374	1341	1177
0.015	1628	1774	1675	1381	1263	1252
0.025	1668	1818	1624	1442	1317	1279
0.035	1691	1909	1655	1426	1363	1256
0.045	1587	2021	1789	1382	1363	1259
0.055	299	986	1303	1153	956	740
d_theta	1.00E-002	1.00E-002	1.00E-002	1.00E-002	1.00E-002	1.00E-002
phi_min	-0.0300	-0.0200	-0.0100	0.0000	0.0100	0.0200
phi_max	-0.0200	-0.0100	0.0000	0.0100	0.0200	0.0300
th_sc	20.5	0.36	deg/rad			
dcos(th_sc+ph	0.00327	0.00336	0.00346	0.00355	0.00364	0.00374
d_Omega	3.27E-005	3.36E-005	3.46E-005	3.55E-005	3.64E-005	3.74E-005

with

Statistical uncertainty from N_scattered			1/sqrt(N_scattered)			
x_phi/y_theta	-0.025	-0.015	-0.005	0.005	0.015	0.025
-0.055	3.4%	2.5%	2.6%	2.6%	3.3%	3.5%
-0.045	2.4%	2.2%	2.4%	2.6%	2.7%	2.7%
-0.035	2.5%	2.3%	2.5%	2.6%	2.7%	2.8%
-0.025	2.5%	2.4%	2.5%	2.7%	2.8%	2.7%
-0.015	2.5%	2.3%	2.5%	2.6%	2.8%	2.8%
-0.005	2.5%	2.3%	2.5%	2.7%	2.7%	2.8%
0.005	2.5%	2.4%	2.4%	2.7%	2.7%	2.9%
0.015	2.5%	2.4%	2.4%	2.7%	2.8%	2.8%
0.025	2.4%	2.3%	2.5%	2.6%	2.8%	2.8%
0.035	2.4%	2.3%	2.5%	2.6%	2.7%	2.8%
0.045	2.5%	2.2%	2.4%	2.7%	2.7%	2.8%
0.055	5.8%	3.2%	2.8%	2.9%	3.2%	3.7%

The prescale for this run is 245 for T3.

T3 prescale rate	487.6	Hz
T3 real rate	119460.9	Hz

Calculation for N_electron and target area number density are from the following numbers:

BCM charges	0.00699	C
N_electron	4.37E+016	electron

barn	1.00E-024	(cm^2/barn)
target density	0.0723	g/cm^3
N_a	6.02E+023	atom/mol
A_z	1	g/mol
thickness	4	cm
target area number density	1.74E+023	atom/cm^2

N_electron*target_area_number_density

7.61E+039	electron*atom/cm^2
7.61E+015	electron*atom/barn

The cross section becomes:

prescale*N_scattered/(d_Omega)/(N_electron*target_area_number_density)						barn
x_phi/y_theta	-0.025	-0.015	-0.005	0.005	0.015	0.025
-0.055	8.59E-007	1.51E-006	1.43E-006	1.35E-006	8.11E-007	6.95E-007
-0.045	1.67E-006	1.91E-006	1.58E-006	1.32E-006	1.21E-006	1.15E-006
-0.035	1.63E-006	1.79E-006	1.53E-006	1.33E-006	1.22E-006	1.10E-006
-0.025	1.60E-006	1.69E-006	1.55E-006	1.26E-006	1.14E-006	1.14E-006
-0.015	1.52E-006	1.78E-006	1.50E-006	1.29E-006	1.17E-006	1.09E-006
-0.005	1.52E-006	1.85E-006	1.47E-006	1.24E-006	1.21E-006	1.10E-006
0.005	1.54E-006	1.71E-006	1.56E-006	1.25E-006	1.19E-006	1.01E-006
0.015	1.60E-006	1.70E-006	1.56E-006	1.25E-006	1.12E-006	1.08E-006
0.025	1.64E-006	1.74E-006	1.51E-006	1.31E-006	1.16E-006	1.10E-006
0.035	1.67E-006	1.83E-006	1.54E-006	1.29E-006	1.20E-006	1.08E-006
0.045	1.56E-006	1.94E-006	1.67E-006	1.25E-006	1.20E-006	1.08E-006
0.055	2.95E-007	9.44E-007	1.21E-006	1.05E-006	8.45E-007	6.38E-007

compare to the theoretical calculation at the center scattering theta 2.03E-6 barn. We do have the same scale (ubarn).

Note that Detector efficiency and the dead time (14.65%) have not yet take into account. Also the radiative tail with background estimate not yet either.

Now if I start to average the sum up of the center cut (d_theta,d_phi) = 2*(10,10) mrad, 4*(10,10) mrad, and (10*10,4*10) mrad in the center of LHRS acceptance which denote in yellow, blue and orange colors.

	yellow	yellow+blue	yellow+blue+orange
cross section (barn)	1.38E-006	1.43E-006	1.45E-006
stat uncertainty	1.29%	0.64%	0.40%
N_scattered	5990	24730	62827
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.61E-006	1.67E-006	1.70E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.79	0.82	0.84

I have the cross section up to statistical uncertainty of 1.29%, 0.64% and 0.4% at 1.61, 1.67, 1.70 mbarn, and ratio to theory is 0.79, 0.82, and 0.84 respectively.

Let get the Vertex cut only at the center +/- 0.01 m.

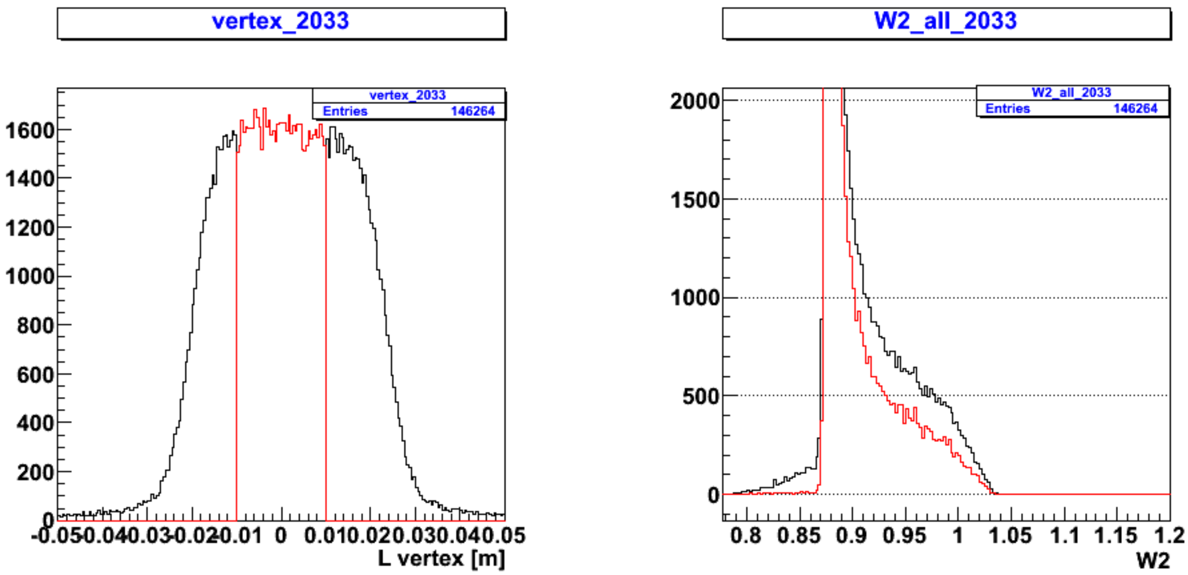

Figure 6.1 vertex cut effects to the W2. The Black lines are when we have cut: T3 & No edtm, |theta| <60 mrad & |phi<30 mrad|.
The red line are the effect of the vertex cut at |L_vertex|<=10 cm. The W2 with vertex cut has scaled by 1.87 (to achieve the same high which will make its easier to compare the background). Clearly the background before W2<=0.87 (GeV^2) reduce to almost none.

Now Let We try the scan on the W2 max cut. This time the maximum cut scan is up to the 1.047 GeV^2.
Now Let See how much the radiative tail we cut off. Note that the single pion production start at W^2 ~ 1.16 GeV^2. Let make the cut at W^2 and see how much we change in number.

The Radiative correction (RC) is applied to the measured cross section as a multiplicative factor. The RC is cut off dependent, i.e. RC = RC(W^2_max). Check Mo and Tsai Rev. Mod. Phys. 41, 205 (1969).

In our setting, the W2 spans from 0.75 to 1.05 (GeV)^2. We do not have the radiative tail up to the pion production at 1.16 GeV^2 within our acceptance.

Let check how much change with the Maximum cut on W2. With minimum cut at (Mp-dp)^2< W^2. Where dp = 4.49 MeV/c.

Vary the maximum cut at (Mp + (2k+1)*dp)^2 where k = {1,2,..}

The cross section evaluate at three cut area. Center box#1 at 20*20 (mrad)^2, box#2 at 40*40 (mrad)^2, and box#3 at 100*40 (mrad)^2.
Using the same method evaluation, we have,

[d\sigma/d\Omega]_RC_corr = RC(W2max)* [d\sigma/d\Omega]_measured

to estimate the RC(W2max) function.

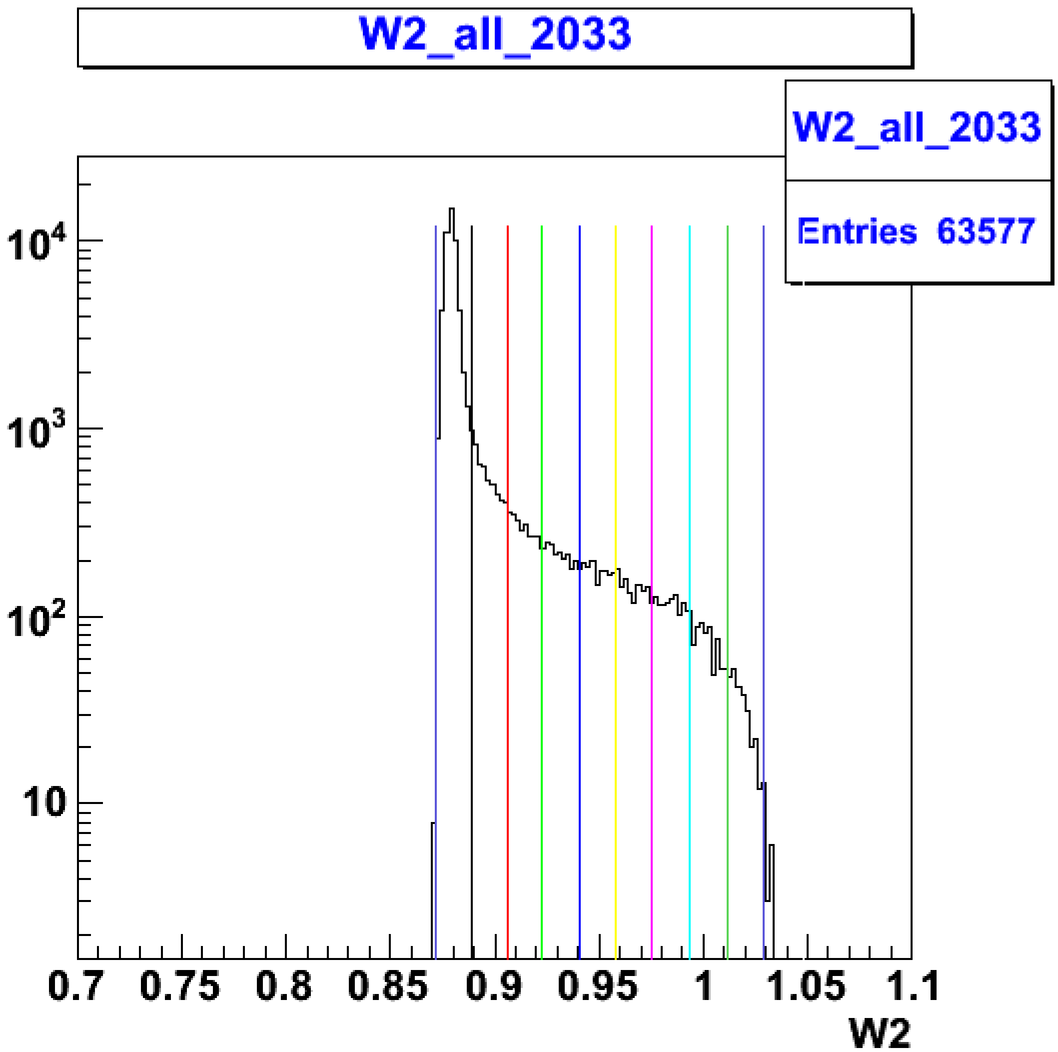

Figure 6.2: W2 after the vertex center cut to half in logarithm scale.

Table B.1

Max Cut W2: 0.88880	Box#1	Box#2	Box#3
stat uncertainty	1.87%	0.93%	0.58%
N_scattered	2869	11571	29551
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.55E-006	1.56E-006	1.60E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.76	0.77	0.79

Table B.2

Max Cut W2: 0.90581	Box#1	Box#2	Box#3
stat uncertainty	1.78%	0.89%	0.56%
N_scattered	3157	12698	32339
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.70E-006	1.71E-006	1.75E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.84	0.84	0.86

Table B.3

Max Cut W2: 0.92298	Box#1	Box#2	Box#3
stat uncertainty	1.74%	0.87%	0.54%
N_scattered	3314	13246	33809
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.78E-006	1.79E-006	1.83E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.88	0.88	0.9

Table B.4

Max Cut W2: 0.94032	Box#1	Box#2	Box#3
stat uncertainty	1.71%	0.86%	0.54%
N_scattered	3425	13678	34933
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.84E-006	1.85E-006	1.89E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.91	0.91	0.93

Table B.5

Max Cut W2: 0.95781	Box#1	Box#2	Box#3
stat uncertainty	1.69%	0.84%	0.53%
N_scattered	3510	14018	35790
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.89E-006	1.89E-006	1.93E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.93	0.93	0.95

Table B.6

Max Cut W2: 0.97547	Box#1	Box#2	Box#3
stat uncertainty	1.67%	0.84%	0.52%
N_scattered	3580	14291	36517
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.93E-006	1.93E-006	1.97E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.95	0.95	0.97

Table B.7

Max Cut W2: 0.99329	Box#1	Box#2	Box#3
stat uncertainty	1.66%	0.83%	0.52%
N_scattered	3636	14520	37076
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.96E-006	1.96E-006	2.00E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.96	0.97	0.99

Table B.8

Max Cut W2: 1.01127	Box#1	Box#2	Box#3
stat uncertainty	1.65%	0.83%	0.52%
N_scattered	3675	14669	37448
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.98E-006	1.98E-006	2.02E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.97	0.98	1

Table B.9

Max Cut W2: 1.02941	Box#1	Box#2	Box#3
stat uncertainty	1.65%	0.82%	0.52%
N_scattered	3681	14718	37561
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.98E-006	1.99E-006	2.03E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.98	0.98	1

Table B.10

Max Cut W2: 1.04772	Box#1	Box#2	Box#3
stat uncertainty	1.65%	0.82%	0.52%
N_scattered	3681	14719	37562
include deadtime	14.56%	14.56%	14.56%
cross section corr (barn)	1.98E-006	1.99E-006	2.03E-006
theory	2.03E-006	2.03E-006	2.03E-006
ratio	0.98	0.98	1

Clearly with Vertex cut we does eliminate most of the background. With integrated of the W2 up to the maximum possible of our acceptance, we have the ratio of experimental to theoretical cross section from 0.76 to 0.98 with the very smallest cut (box # 10) the LHRS center acceptance at +/- 10 mrad in both theta and phi.

Now let consider the elastic cross section in proton detected side of H(e,e'p).

With k = (E,E,0,0) and k' = (E',E'cos(theta),E'sin(theta),0);

$$\frac{E'}{E} = \frac{1}{1+E/M*(1-\cos(theta))}$$

and

$$\tan(theta\_q) = \frac{-E' \sin(theta)}{E-E' \cos(theta)}$$

At L_theta =0 and L_phi = 0, theta_scattered = 20.5 degree with E = 1.1598 GeV,
theta_q = -1.18655 rad = -67.98 degree.
//

With theta+dphi, dphi <<theta

k = (E,E,0,0) and k' = (E',E'cos(theta+dphi),E'sin(theta+dphi),0)

$$\frac{E'}{E} = \frac{1}{1+E/M*(1-\cos(theta+dphi))} = \frac{1}{1+E/M*(1-\cos(theta)+dphi*\sin(theta))}$$

$$\tan(theta\_q) = \frac{-E'\sin(theta)-E'\cos(theta)*dphi}{E-E'\cos(theta)+E'\sin(theta)dphi}$$

with also dth<<theta

k = (E, E, 0, 0) and k' = (E', E'cos(theta+dphi), E'sin(theta+dphi)cos(dth), E'sin(theta+dphi)sin(dth))
with
q = k-k' = (E_q, |q|cos(theta_q), |q|sin(theta_q)cos(phi_q), |q|sin(theta_q)sin(phi_q))

so we have,
|q|cos(theta_q) = E-E'cos(theta+dphi)
|q|sin(theta_q)cos(phi_q) = -E'sin(theta+dphi)cos(dth)
|q|sin(theta_q)sin(phi_q) = -E'sin(theta+dphi)sin(dth)

tan(phi_q) = tan(dth)
|q|sin(theta_q) = -E'sin(theta+dphi)
|q|cos(theta_q) = E-E'cos(theta + dphi)
so
tan(theta_q) = -E'sin(theta+dphi)/(E-E'cos(theta+dphi))

Now let consider the small deviation from both scattered_theta (L_dphi<=10 mrad and L_dth<=20 mrad).

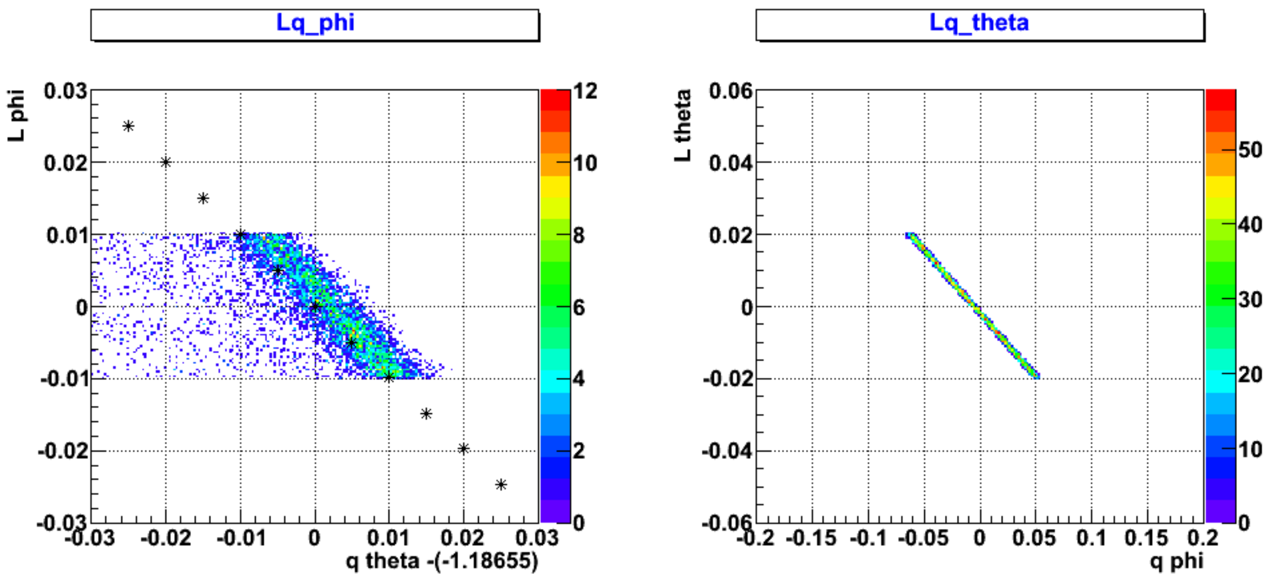

Figure 7.1 showing the correlation between the scattered_electron angles and q_vector angles.
7.1.1: L phi vs theta_q – theta_q_0(-1.18655). The black * represent the calculated theta_q from equation tan(theta_q) = -E'sin(theta+dphi)/(E-E'cos(theta+dphi)).
7.1.2 L theta vs phi_q. From figures we have ~ 2*(phi_q) = -5*(L_theta) which is not the same as what I derive??

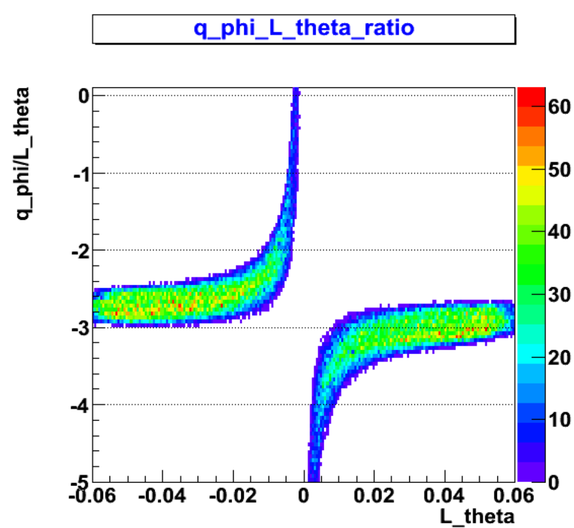

Figure 7.2 The ratio of phi_q to L_theta.

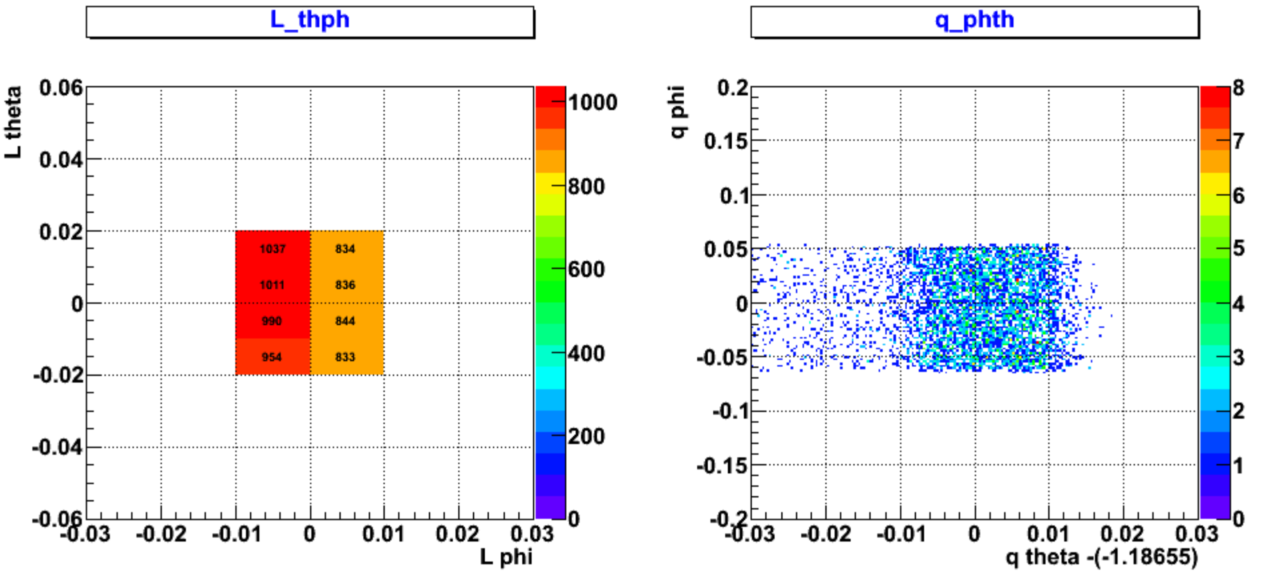

Figure 7.3 box cut in LHRS (theta +/- 20 mrad and phi +/- 10 mrad) in the Left figure, we would have box cut in q_vector (phi_q+/- 50 mrad and theta_q-theta_q_0 +/- 10 mrad).

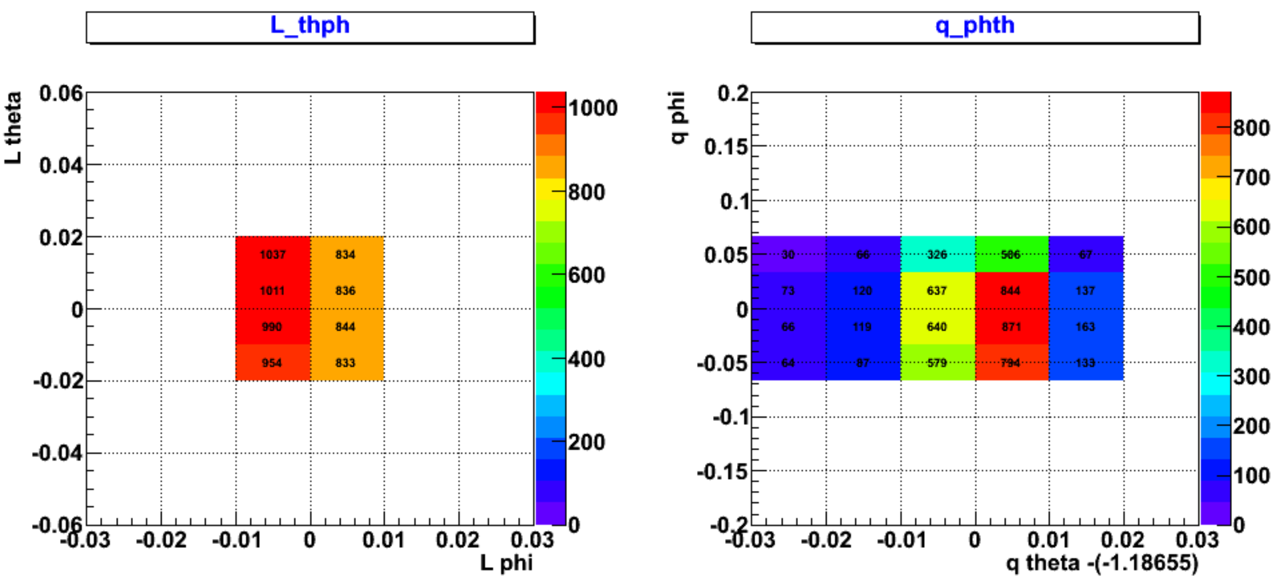

Figure 7.4 box cut in LHRS and translated box figure in q_vector.

Question: What do I do with the data section which show no “correlation” in theta_q (theta_q<-0.01)?
Answers: The radiative tail of W2.

If I directly consider what I see in BigBite, we have,

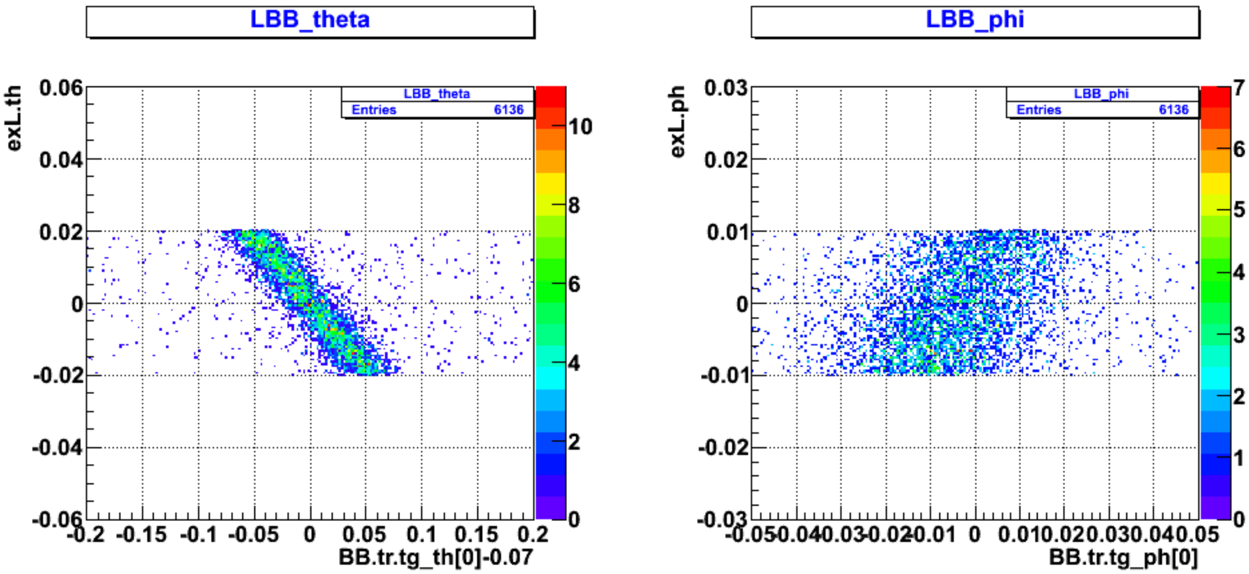

Figure 8.1: correlation between L theta with BB theta (right) and L phi with BB phi (left).

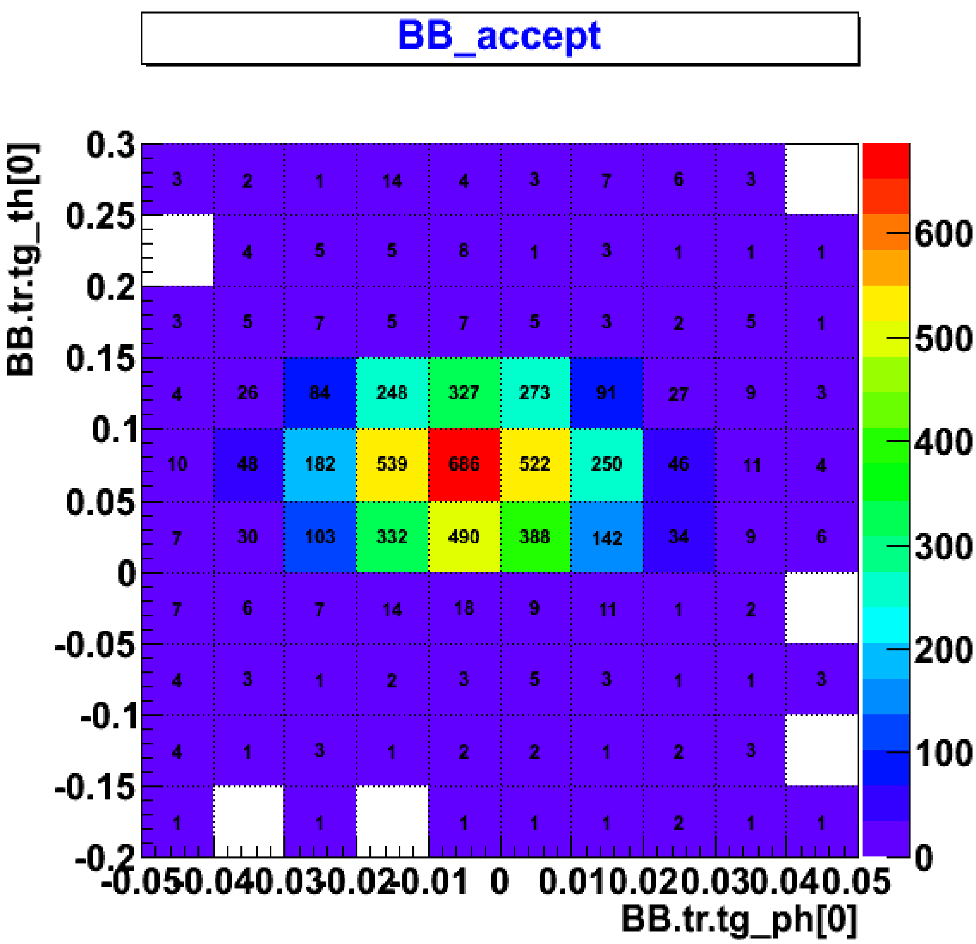

Figure 8.2 BigBite box which correlated to L_theta+/- 20 mrad and L_phi +/- 10 mrad.

Should I try the theoretical calculation base on the d\Omega of scattered electron? Or by the d\Omega of the scattered proton?

Without restriction on LHRS we have all distribution on BB as :

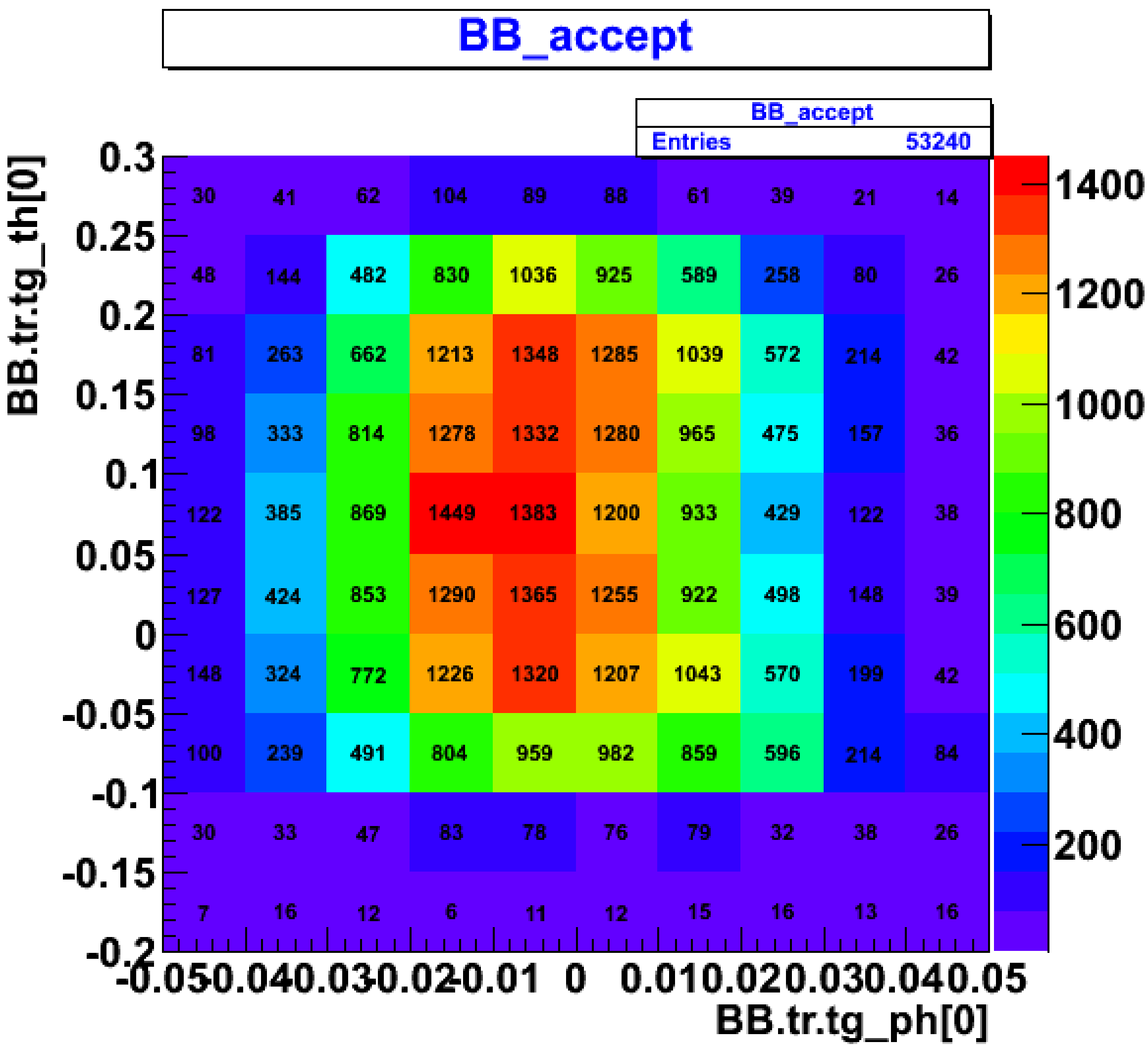

Figure 8.3 BigBite box without any strong correlation in L(theta and phi)

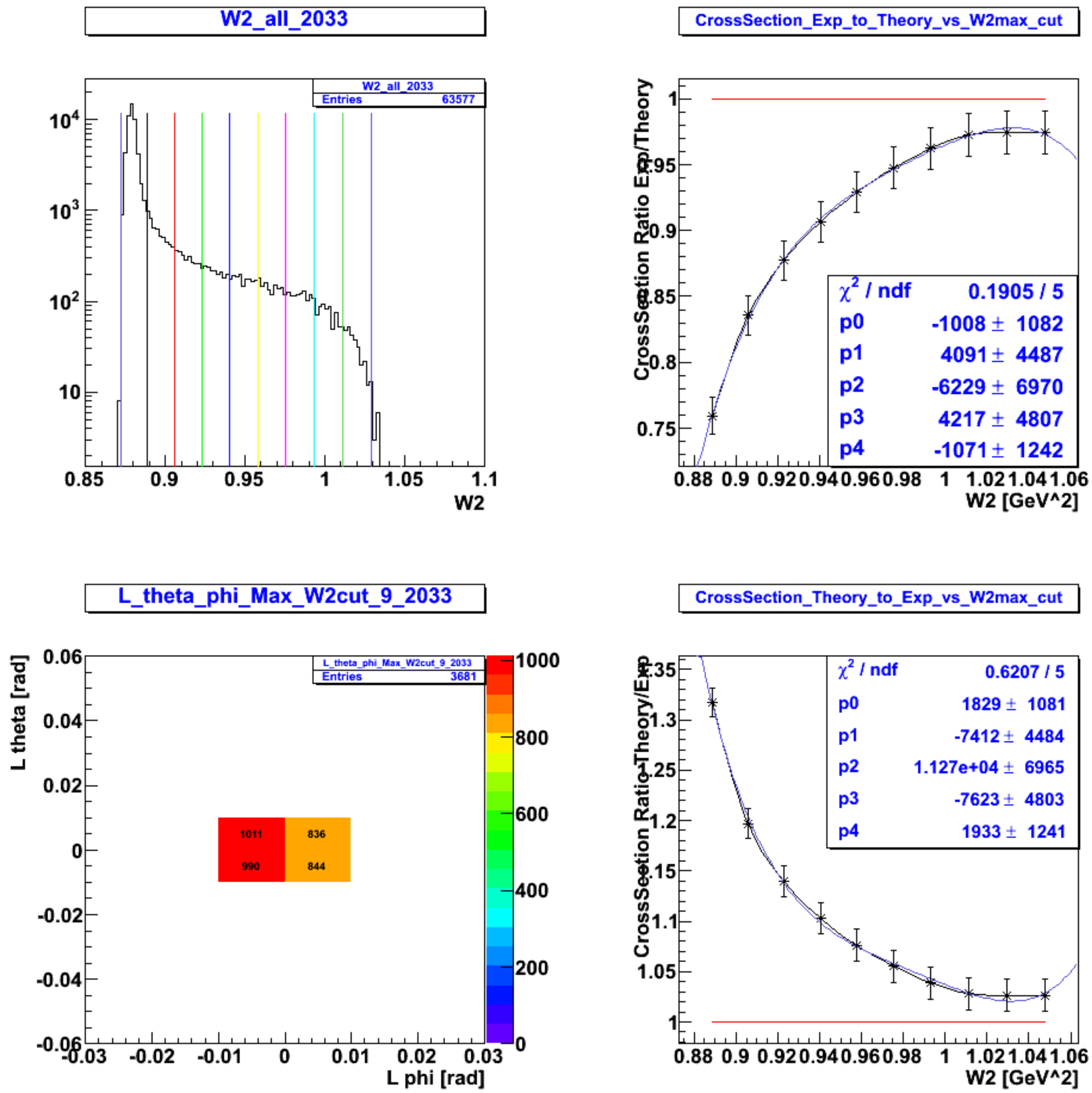

Figure 8.4:

8.4.1: W2 maximum cut scan

8.4.2: The Cross section Ratio Exp/Theory

8.4.3: The acceptance cut on L theta vs phi (20*20 mrad^2)

8.4.4: The invert Cross section Ratio ~ Radiative Corrector (RC) factor where

[Born Cross Section] = RC(W2max) * [Measured Cross Section up to W2max]

Let make a very tight cut on the W2maximum and use the RC factor instead of the integral over all ther radiative tail to ensure the q_theta will be within the BigBite Acceptance area (BB_phi)
The two extreme cases are in fiugre 8.5 and 8.6 where 8.5 has no maximum cut in W2 and 8.6 has tighly cut at **W2max at 0.888 GeV2.**
The tail of the invariant mass extend over -0.16 rad (-9.2 degree) from the center of the q_theta_0 = -1.18655 rad (-67.98 deg). The BigBite acceptance can only take up to maximum of +/- 5 degree with reliable acceptance at smaller degree (+/- 3 degrees).

With the cut at W2max at 0.888 GeV2 (figure 8.6), the radiative tail extended to -0.04 rad (-2.29 degree). **The radiative correction factor RC = 1.3168 at this value of W2 max = 0.888 GeV2 cut.**

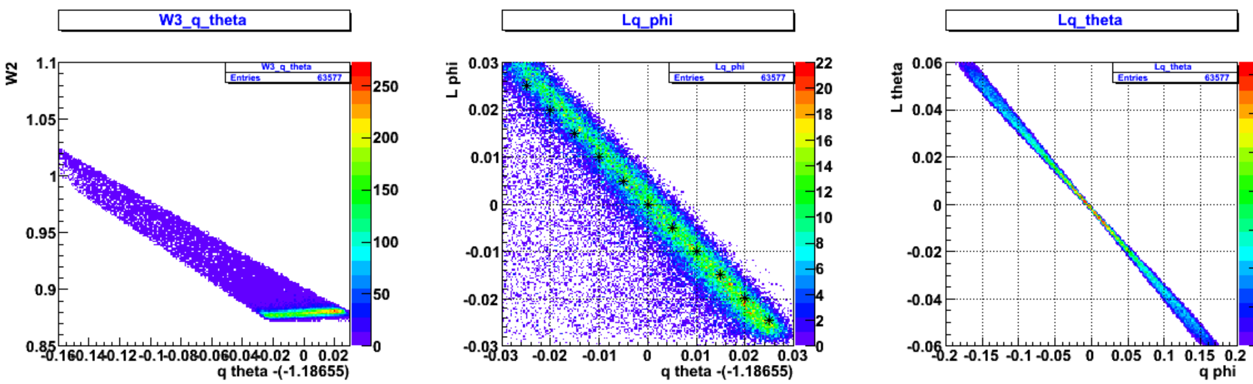

Figure 8.5
8.5.1: theta_q dependent on the radiative tail of invariant mass^2 (W2).
8.5.2: L phi vs theta_q where the radiative tail are the purple scattered.
8.5.3: L theta vs phi_q which has no dependent on W2 radiative tail.

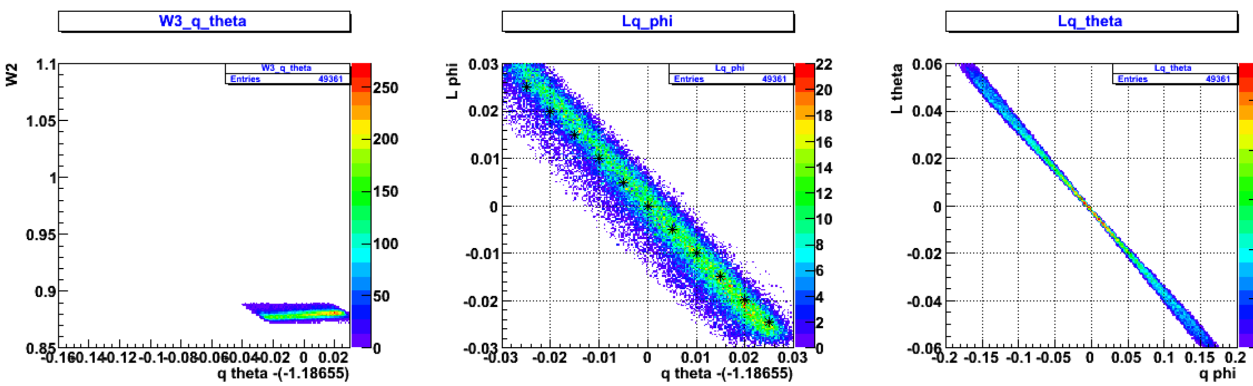

Figure 8.6 with W2max cut at 0.888 GeV2 (first point in 8.4.2)
8.6.1: theta_q dependent on the radiative tail of invariant mass^2 (W2).
8.6.2: L phi vs theta_q where the radiative tail are the purple scattered (see the reduction compare to 8.5.2).
8.6.3: L theta vs phi_q which has no dependent on W2 radiative tail.

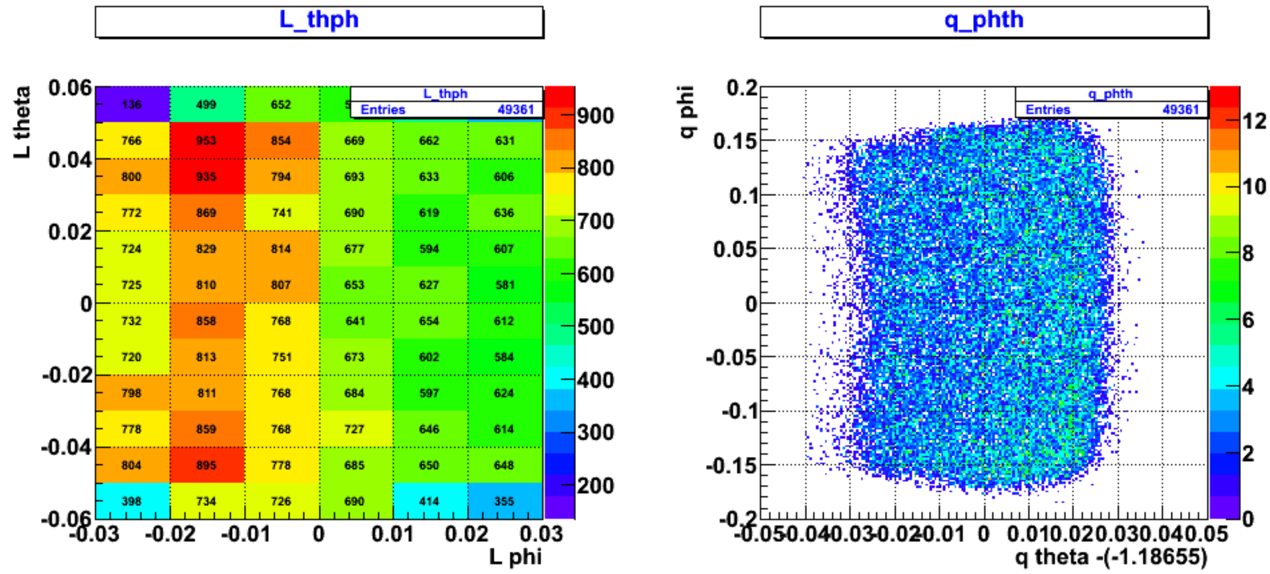

Figure 8.7: The theta and phi in LHRS (left) and in q (right)

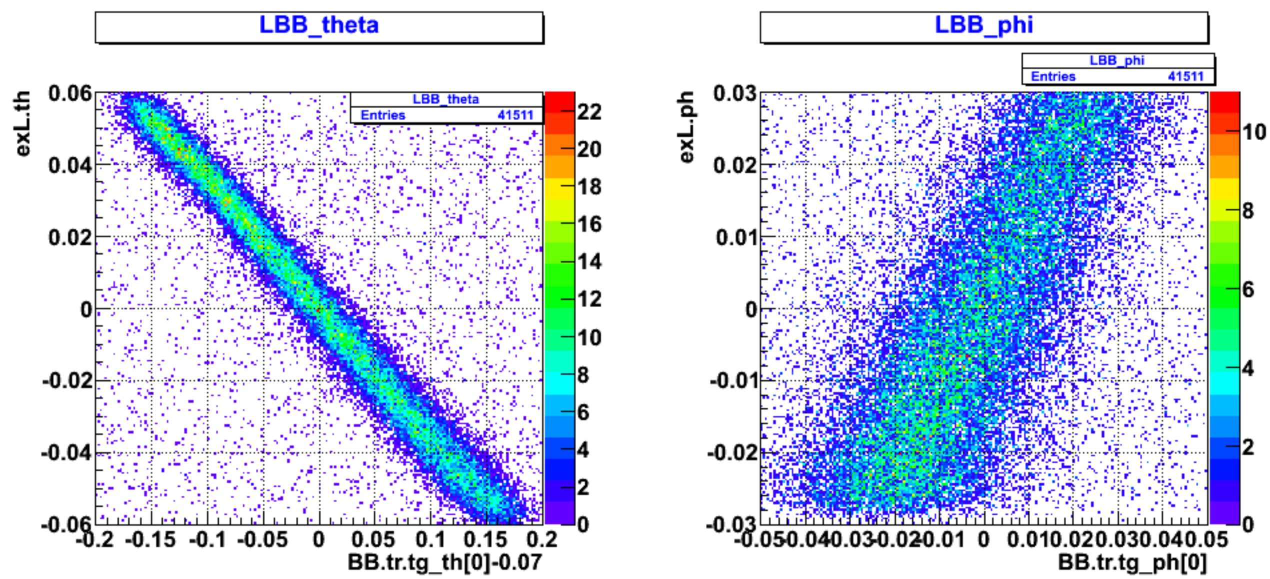

Figure 8.8: The LHRS vs BB theta (left) and the LHRS vs BB phi (right).

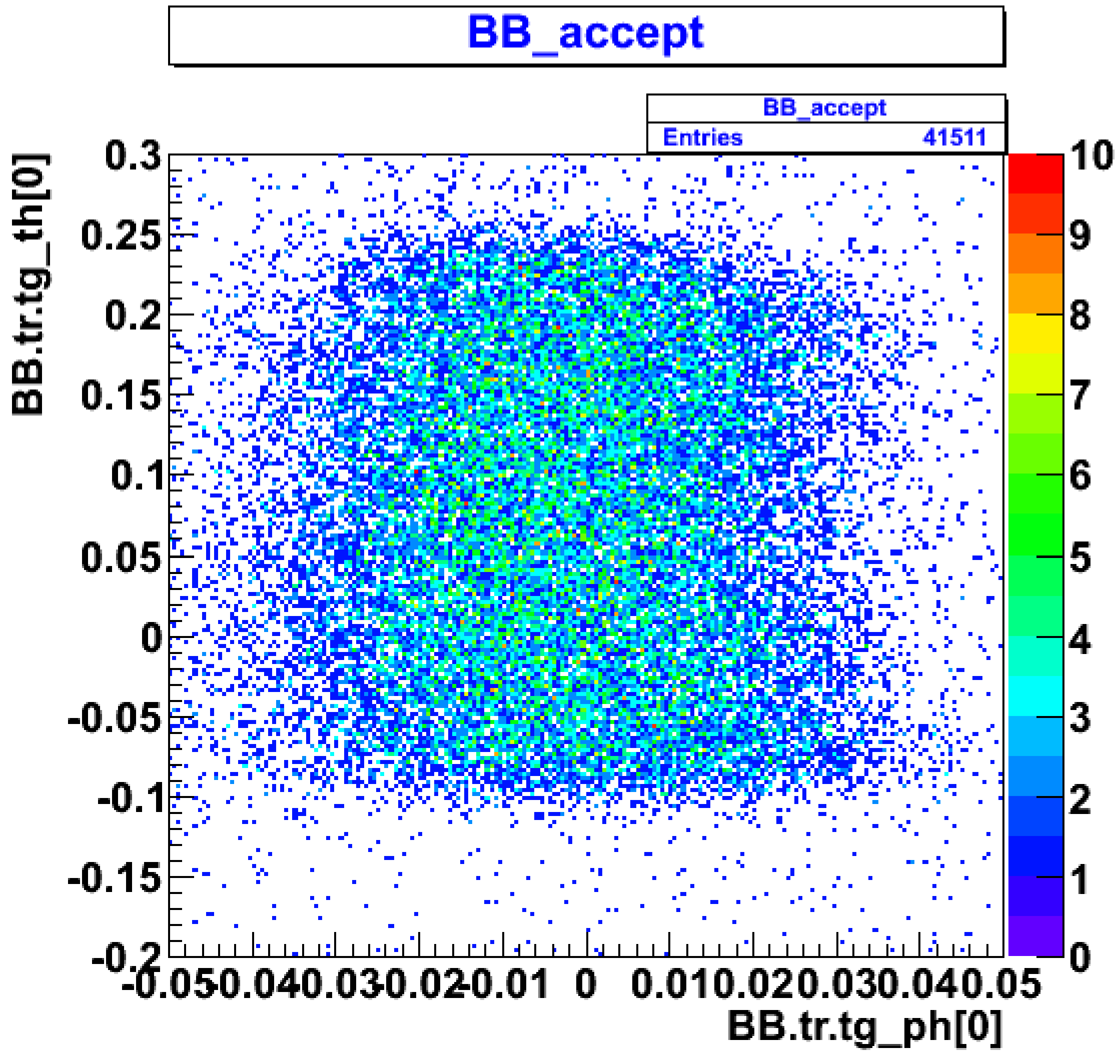

Figure 8.9: Scattered Plot in BB Acceptance for all LHRS acceptance (60,30 mrad)