Monte Carlo Study of Triple Gauge-boson Couplings at LHC

Hadron Collider Physics

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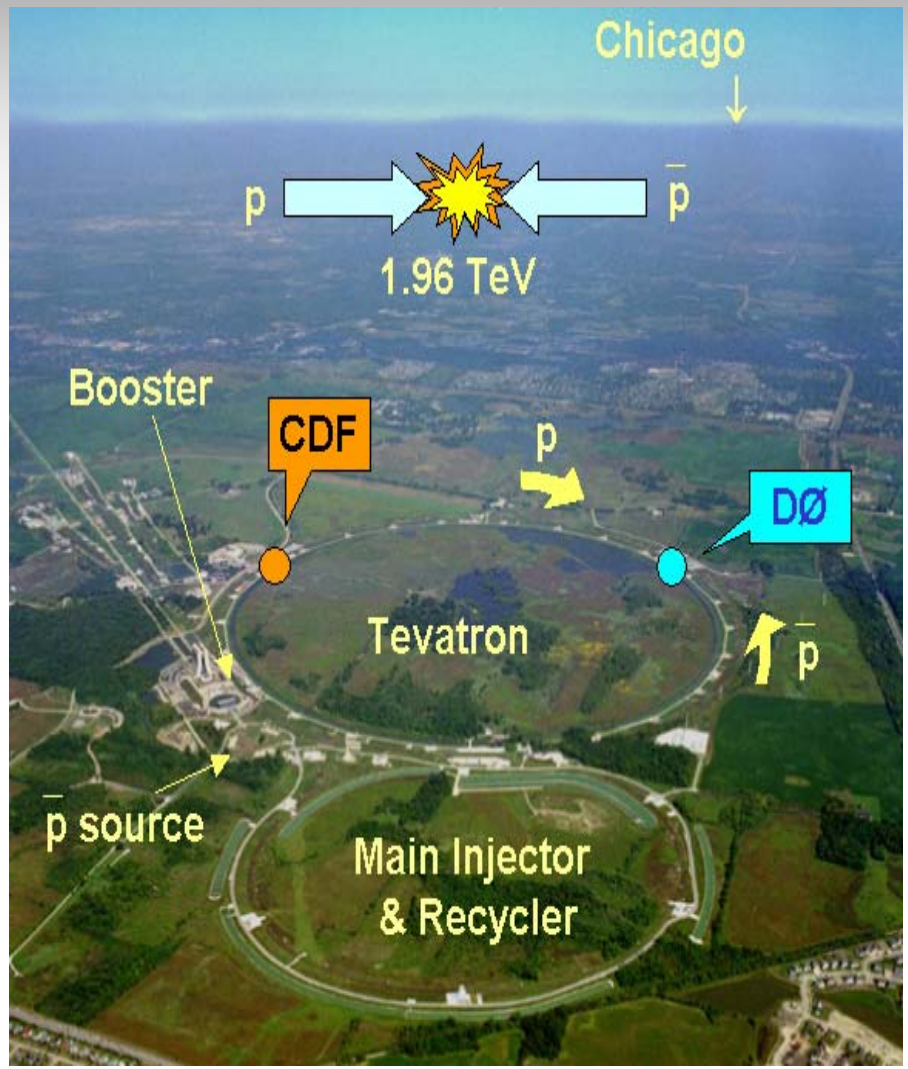
MOTIVATIONS

- Have to prove the Standard Model, non-Abelian SU(2)xU(1) gauge theory of electroweak interaction

- The deviations will hint to new physics not described in the SM

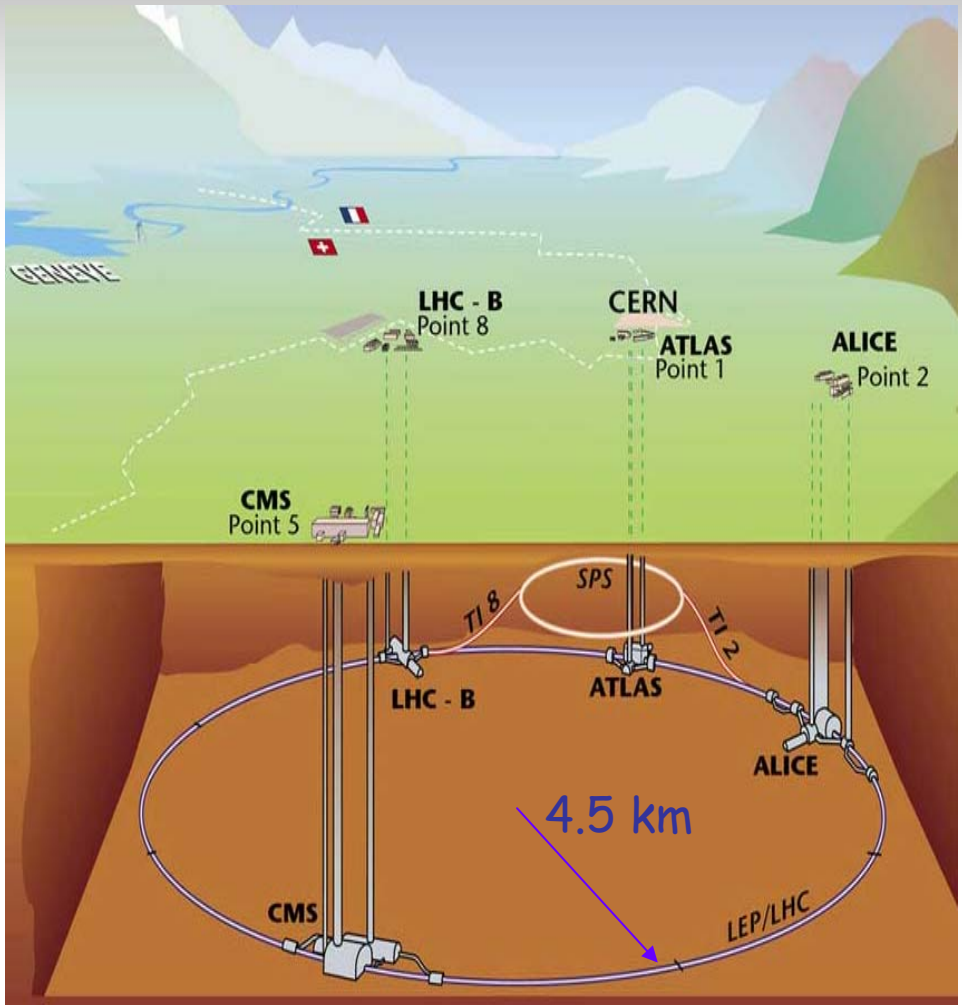
Introduction



- In the last few years, the Large Electron Positron (LEP) and Tevatron have provided accurate tests of the non-Abelian gauge theory SU(2)xU(1) of electroweak interactions of the Standard Model (SM), probing the existence of self-interactions among electroweak gauge bosons (W, Z, γ)
- The experimental collaborations have performed several measurements of charged and neutral triple gauge-boson couplings (TGCs)

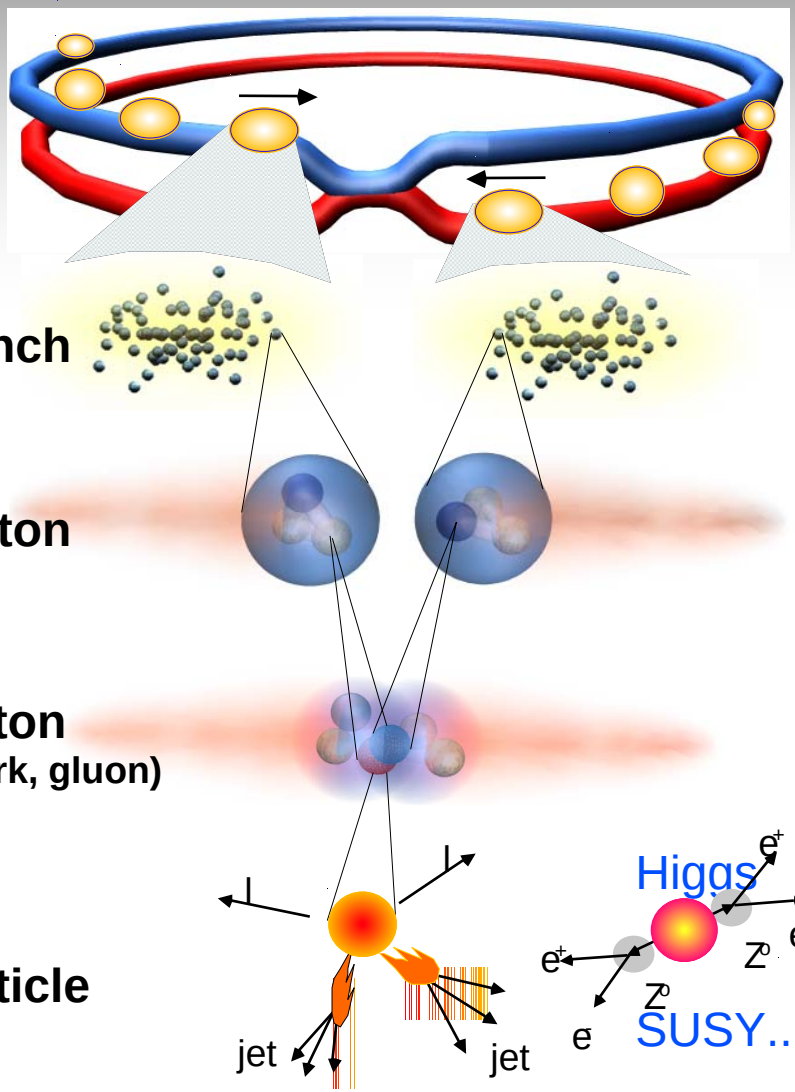
The Large Hadron Collider

(The world's Largest Particle Accelerator)



- In the near future, the Large Hadron Collider (LHC) will measure precisely the reaction products of the vector bosons produced in P-P collision at centre-of-mass energy of 14 TeV.
- The LHC will be the main source of vector gauge bosons and good place to study their properties.

Collisions at the LHC



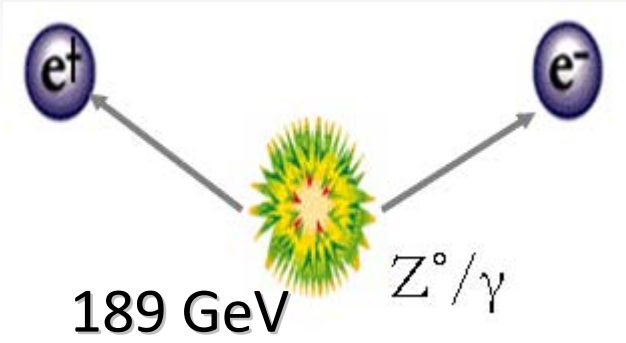
- 2804 bunches/beam
- 10^{11} protons/bunch
- 10^{9} pp collisions/s
- 7 TeV + 7 TeV
- separation: 7.5 m (25 ns)
- 40 MHz crossing rate
- $N = L \times \sigma(pp) = 10^{9}$
- Mostly low pt events (soft) events
- Interesting high pt events are rare
- New physics rate ~ 0.00001 Hz
- event selection:
  1 in 10,000,000,000,000

Triple Gauge –boson Couplings (TGCs)

- In the SM, gauge-bosons interact not only with matter particles, but also with one another
- These interactions manifest themselves as couplings between three (or more) gauge-bosons, such as $WW\gamma$ or WWZ coupling, referred as triple gauge-boson couplings (TGC's)
- Existence of these couplings has been beautifully verified at LEP and Tevatron
- The results so far are consistent with SM predictions
- The starting point for TGC is the non-Abelian structure of SM
- The couplings of $WW\gamma$, WWZ vertices reflect the full gauge group structure of SM

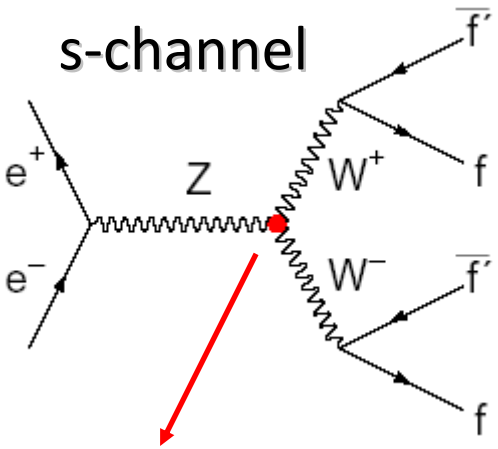
TGCs at LEP

- W-pair production in e^+e^- annihilation involves the triple gauge-boson vertices $WW\gamma$ or WWZ which are present in the SM

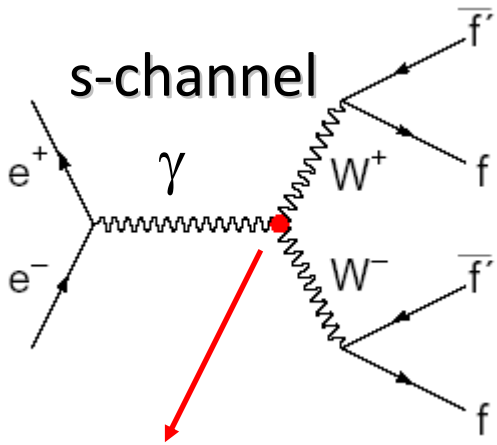


189 GeV

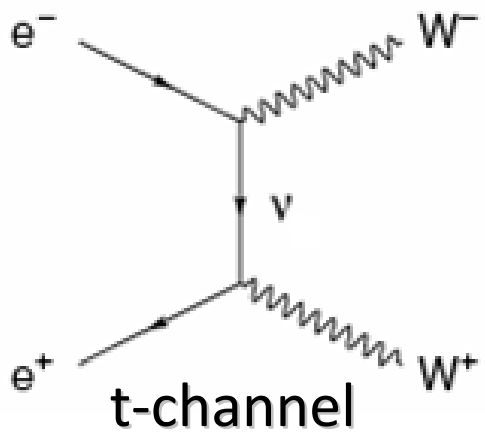
Tree Level Feynman diagrams of triple gauge coupling



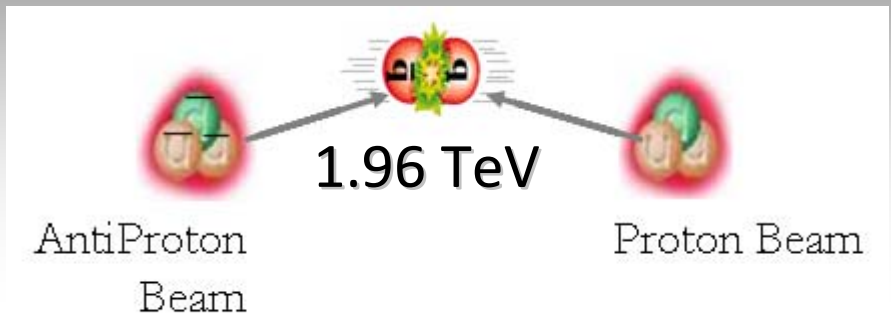
Gauge Couplings !



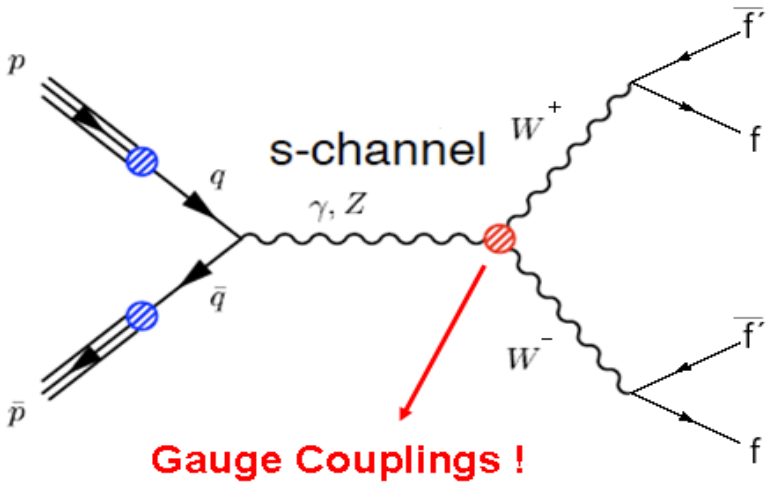
Gauge Couplings !

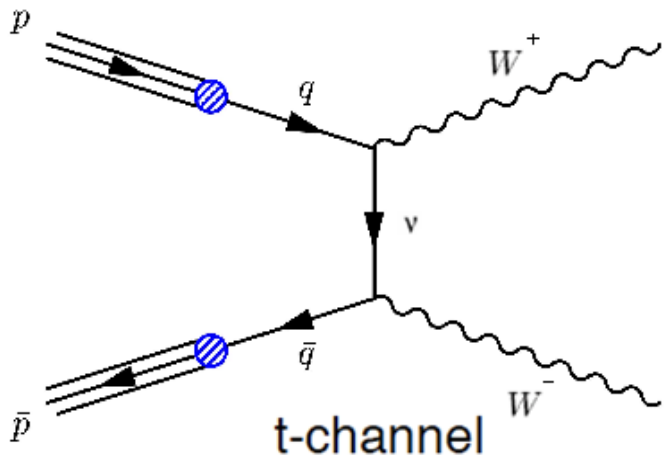


TGCs at Tevatron

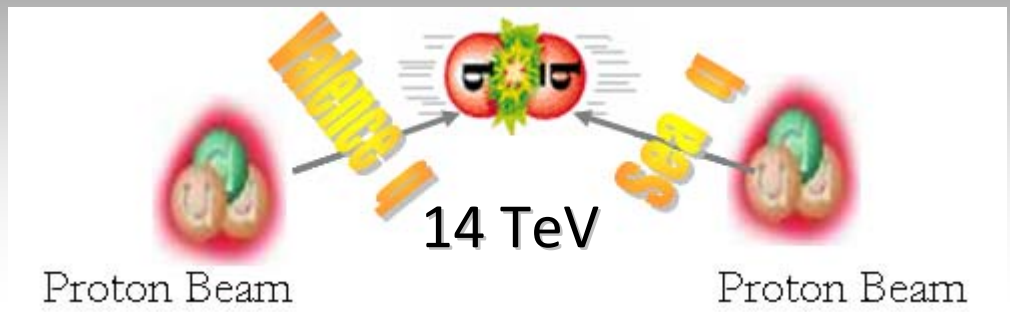


Tree Level Feynman diagrams of triple gauge coupling

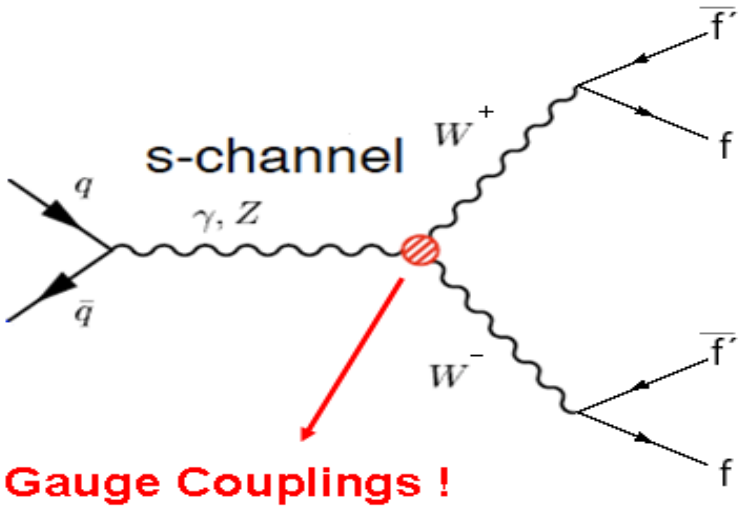


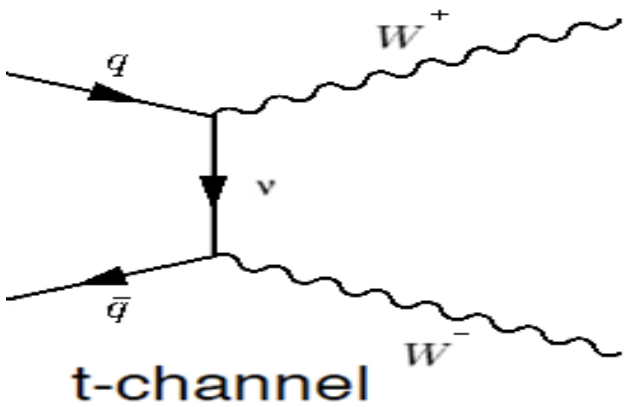


TGCs at LHC



Tree Level Feynman diagrams of triple gauge coupling

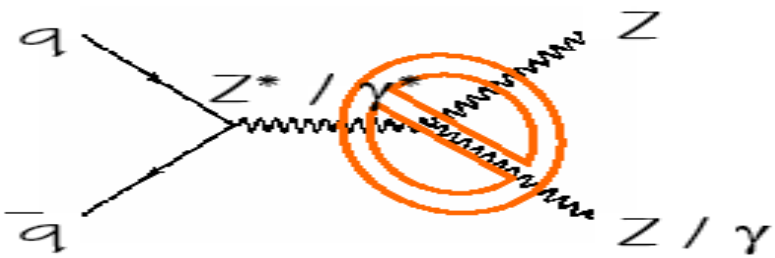




s, t are the Mandelstam variables

Charged & Neutral TGCs

- Charged TGCs allowed in the SM
- Only s channel has three boson vertex, which manifest the gauge boson coupling
- WWZ and WWγ
- ZZZ, ZZγ, Zγγ and γγγ vertices are not allowed in the Standard Model, because neither the Z nor the γ carries charge which is the quantum number to which the gauge-bosons couple
- Vertices containing an odd number of W-bosons (WZZ, WZγ, Wγγ and WWW) are excluded by charge conservation



TGCs: W^+W^- Analysis

- Decaying Branching Ratios of W^+W^- by pure hadronically, semileptonically, pure leptonically are given as follows

$W^+W^- \rightarrow qqqq$ (~45%)

$W^+W^- \rightarrow \tau\nu qq$ (~15%)

$W^+W^- \rightarrow \mu\nu qq$ (~15%)

$W^+W^- \rightarrow e\nu qq$ (~15%)

$W^+W^- \rightarrow e\nu\mu\nu$ (~4%)

- I am working on charged Triple Gauge-boson Couplings (TGC);

$$q\bar{q} \rightarrow Z^{*0} \rightarrow W^+W^-$$

where a virtual Z is produced at intermediate level

- I am studying the pure hadronically decay of W^+W^- ($q\bar{q}'q\bar{q}'$)

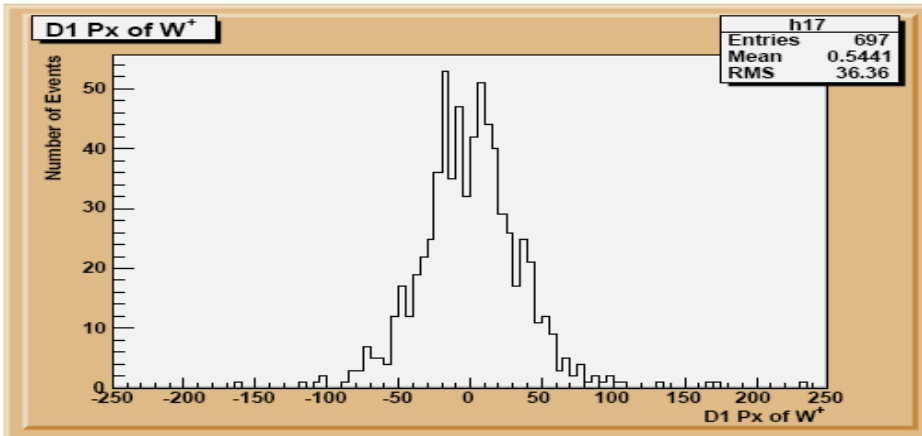
How to Find the Momentum (P) & Energy (E) Distributions

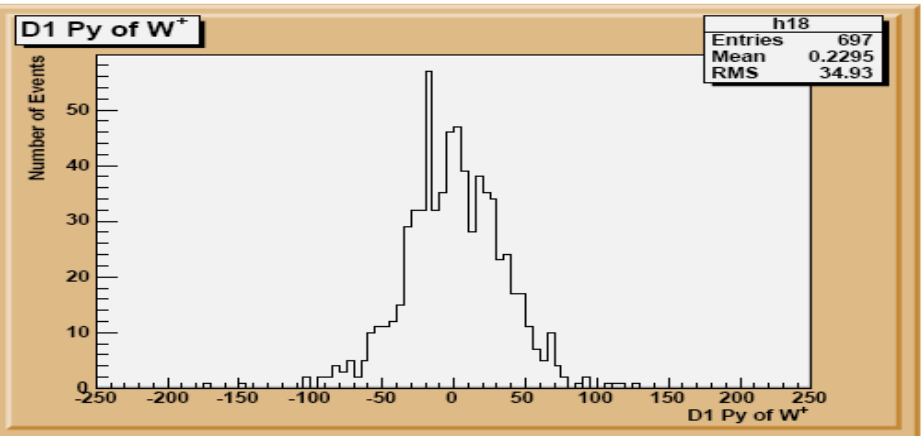
PYTHIA Event Listing (complete event)

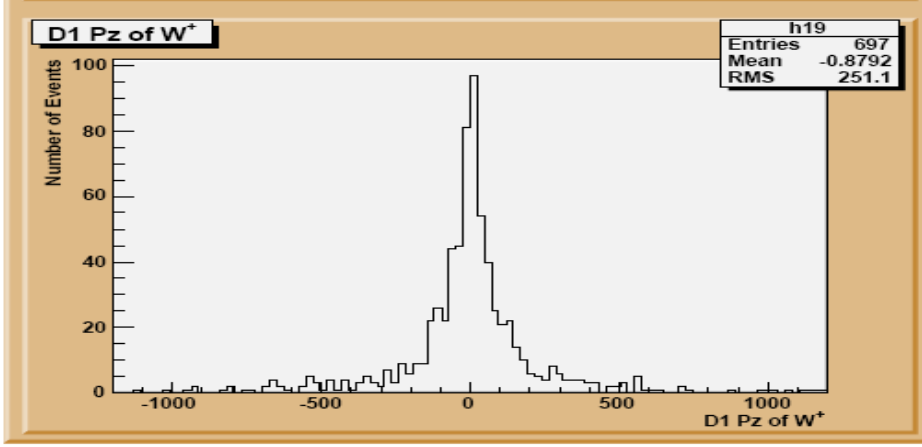
no	id	name	status	mothers		daughters		colours		p_x	p_y	p_z	e	m
0	90	(system)	-11	0	0	1	2	0	0	0.000	0.000	0.000	14000.000	14000.000
1	2212	(p+)	-12	0	0	279	0	0	0	0.000	0.000	7000.000	7000.000	0.938
2	2212	(p+)	-12	0	0	280	0	0	0	0.000	0.000	-7000.000	7000.000	0.938
3	-2	(ubar)	-21	7	7	5	6	0	101	0.000	0.000	54.594	54.594	0.000
4	2	(u)	-21	8	0	5	6	102	0	0.000	0.000	-1042.471	1042.471	0.000
5	-6	(tbar)	-22	3	4	9	9	0	101	-73.897	-53.244	-174.768	261.166	171.372
6	6	(t)	-22	3	4	10	10	102	0	73.897	53.244	-813.108	835.899	171.131
7	-2	(ubar)	-42	12	0	3	3	0	101	0.000	0.000	54.594	54.594	0.000
8	2	(u)	-41	13	13	11	4	104	0	-0.000	-0.000	-1191.549	1191.549	0.000
9	-6	(tbar)	-44	5	5	14	14	0	101	-71.565	-51.768	-210.234	285.251	171.372
10	6	(t)	-44	6	6	15	15	102	0	82.715	58.828	-926.573	947.695	171.131
11	21	(g)	-43	8	0	16	16	104	102	-11.150	-7.060	-0.149	13.198	0.000
25	21	(g)	-51	23	0	37	37	106	105	19.037	28.329	38.331	51.325	0.000
26	21	(g)	-51	23	0	39	39	101	106	6.832	-19.532	2.861	20.889	0.000
27	-6	(tbar)	-52	20	20	34	34	0	101	-88.187	-52.597	-231.302	305.635	171.372
44	21	(g)	-31	48	0	46	47	114	113	0.000	0.000	0.707	0.707	0.000
45	1	(d)	-31	49	49	46	47	113	0	0.000	0.000	-255.118	255.118	0.000
46	21	(g)	-33	44	45	50	50	114	115	2.524	5.061	-11.187	12.535	0.000
47	1	(d)	-33	44	45	51	51	115	0	-2.524	-5.061	-243.224	243.290	0.330
378	2	(u)	-63	1	0	492	492	113	0	-0.319	-0.512	1340.638	1340.638	0.330
379	2101	(ud_0)	-63	1	0	492	492	0	113	-0.427	-1.024	3266.905	3266.906	0.579
380	2	(u)	-63	1	0	493	493	108	0	-0.720	-1.118	56.936	56.952	0.330
381	-3	(sbar)	-63	1	0	519	519	0	117	-0.382	-0.112	1364.384	1364.384	0.500
486	-11	e+	23	441	0	0	0	0	0	7.949	-14.875	-217.791	218.443	0.001
487	12	nu_e	23	441	0	0	0	0	0	70.533	75.395	-668.054	675.985	0.000
502	1	(d)	-71	342	342	505	508	115	0	-3.404	-4.046	-233.825	233.885	0.330
503	21	(g)	-71	367	367	505	508	181	115	-0.384	-0.368	-9.293	9.309	0.000
504	-2	(ubar)	-71	370	370	505	508	0	181	-3.167	-0.517	-68.782	68.858	0.330
505	311	(K0)	-83	502	504	789	789	0	0	-2.046	-0.406	-58.420	58.460	0.498
506	331	(eta')	-83	502	504	941	942	0	0	-1.070	-2.000	-93.597	93.629	0.958
507	-323	(K*-)	-83	502	504	790	791	0	0	-2.736	-2.575	-132.287	132.344	0.943
508	111	(pi0)	-84	502	504	943	944	0	0	-1.102	0.050	-27.596	27.618	0.135
789	130	K_L0	91	505	505	0	0	0	0	-2.046	-0.406	-58.420	58.460	0.498
790	-311	(Kbar0)	-91	507	0	932	932	0	0	-0.900	-1.003	-55.248	55.267	0.498
791	-211	pi-	91	507	0	0	0	0	0	-1.836	-1.571	-77.039	77.077	0.140
792	-211	pi-	91	516	0	0	0	0	0	0.117	-0.161	-1.617	1.635	0.140
793	111	(pi0)	-91	516	0	1069	1070	0	0	-0.431	-0.098	-0.498	0.680	0.135
794	2212	p+	91	537	0	0	0	0	0	-1.175	0.093	-0.721	1.670	0.938
795	211	pi+	91	537	0	0	0	0	0	-0.414	0.352	-0.340	0.657	0.140
1316	22	gamma	91	1313	0	0	0	0	0	-1.574	0.014	-0.839	1.783	0.000
1317	22	gamma	91	1313	0	0	0	0	0	-0.887	0.068	-0.569	1.056	0.000
			Charge sum:	2.000				Momentum sum:		-0.000	0.000	-0.000	14000.000	14000.000

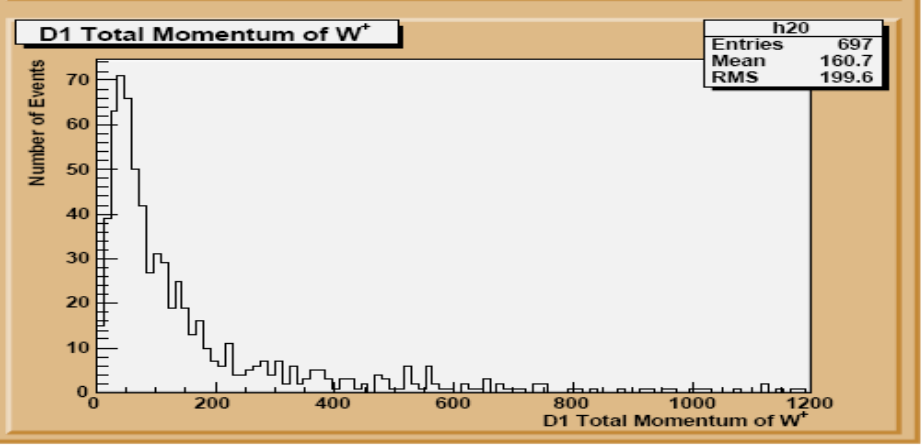
End PYTHIA Event Listing

P Distribution of 1st Daughter (D_1) of W^+









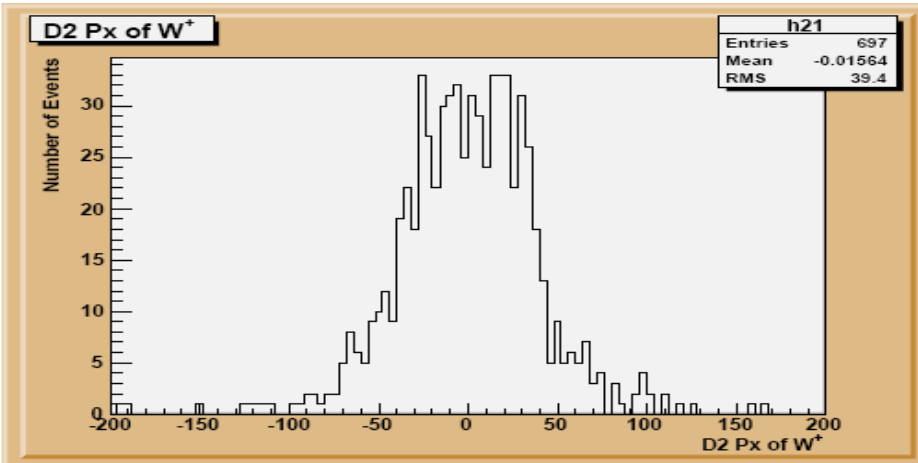
$$\vec{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k}$$

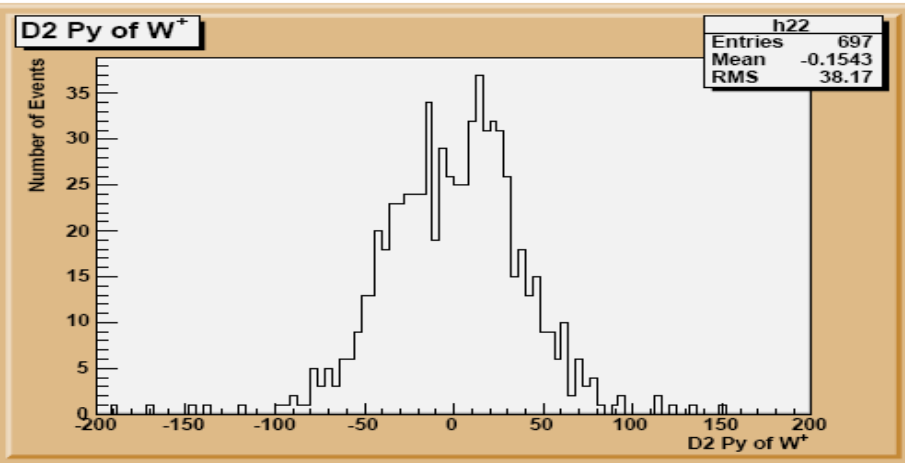
$$\vec{A} \cdot \vec{A} = |A|^2 = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

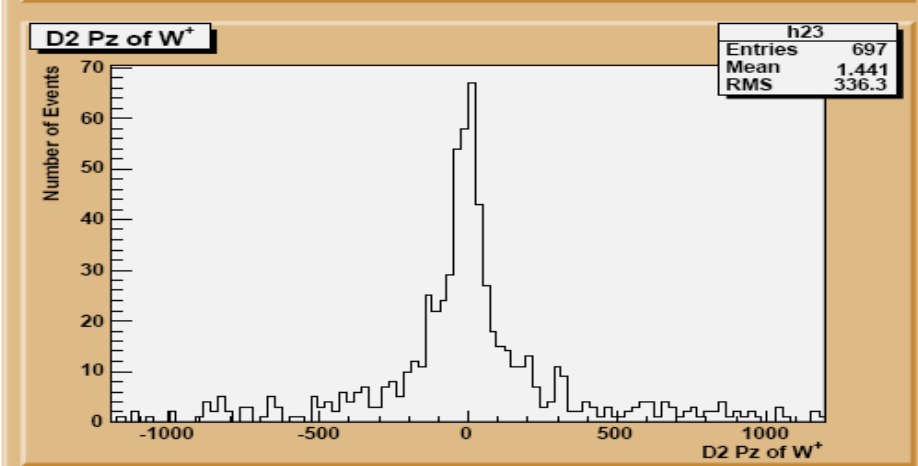
$$p_{W^+D_1} = \sqrt{p^2_{W^+D_1x} + p^2_{W^+D_1y} + p^2_{W^+D_1z}}$$

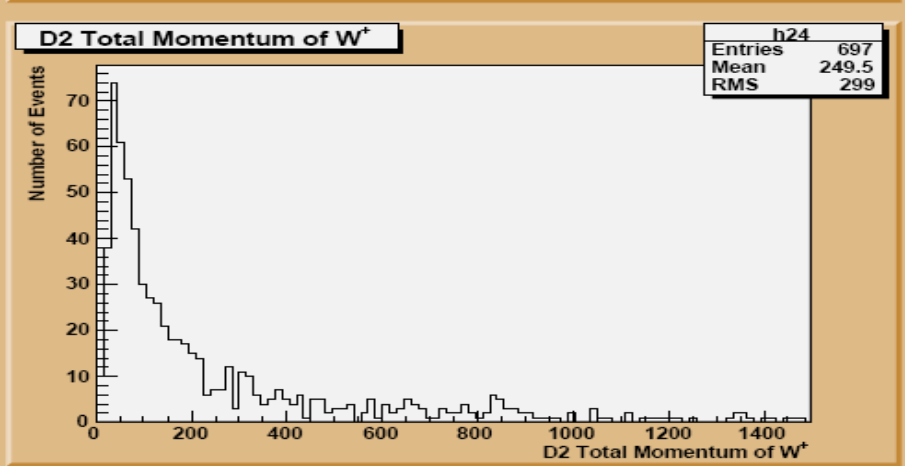
Total P (GeV) of D_1 (W^+)

P Distribution of 2nd Daughter (D_2) of W^+





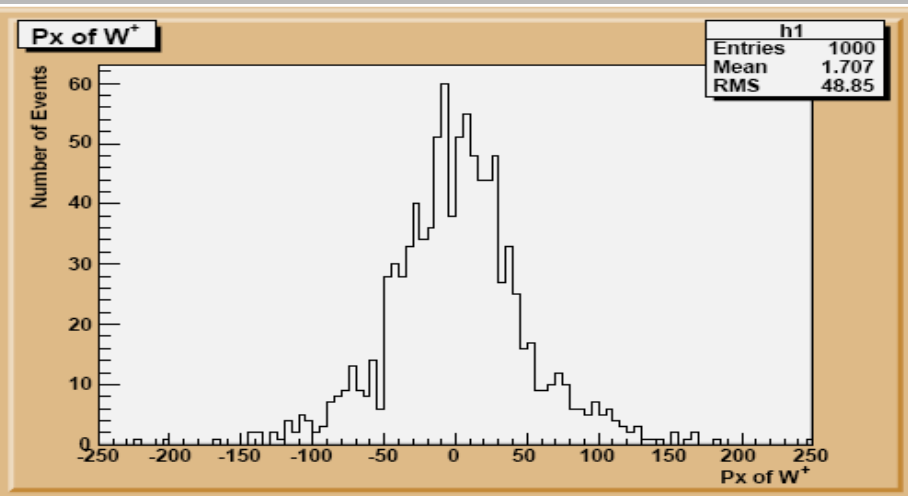


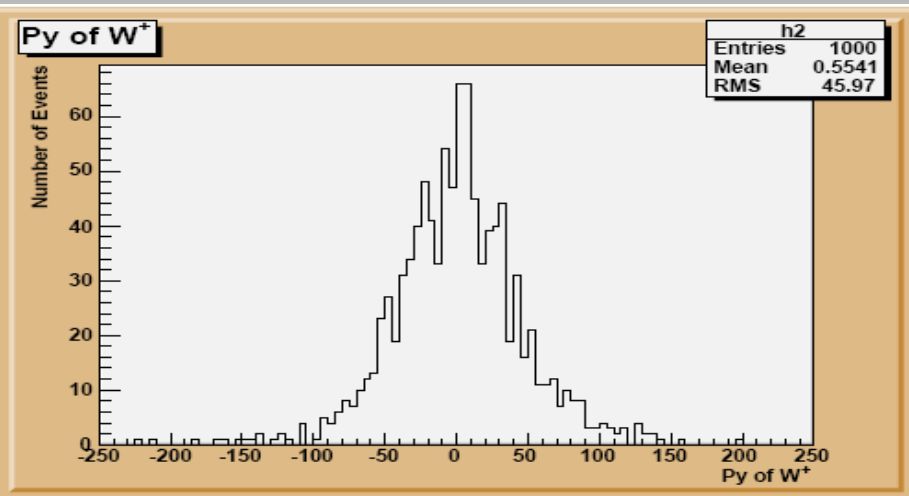


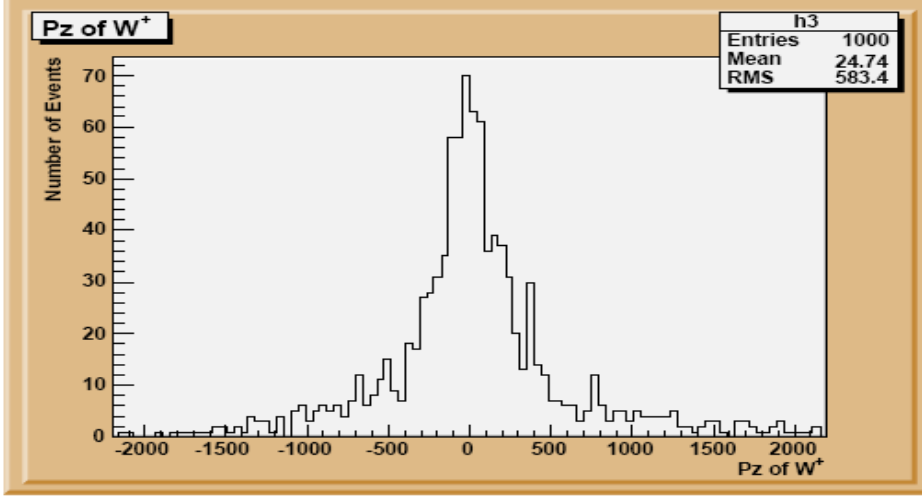
Total P (GeV) of D_2 (W^+)

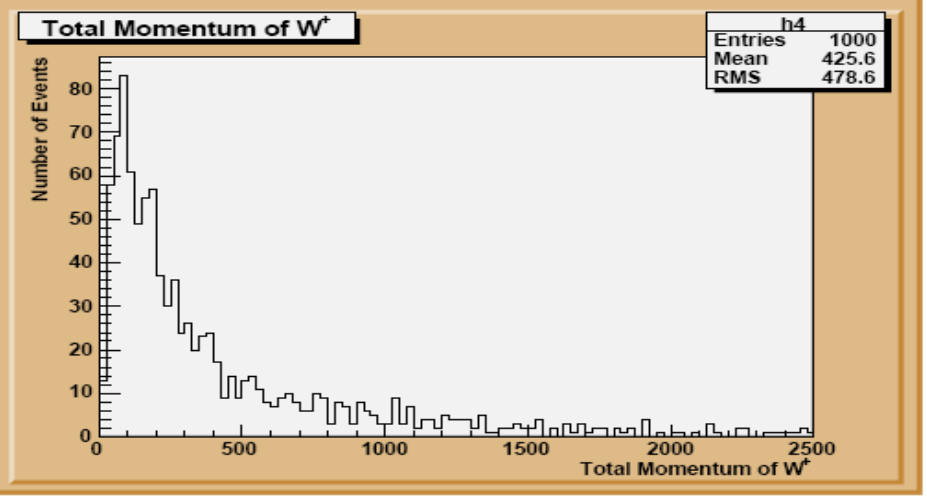
$$p_{W^+D_2} = \sqrt{p^2_{W^+D_2x} + p^2_{W^+D_2y} + p^2_{W^+D_2z}}$$

P Distribution of W^+



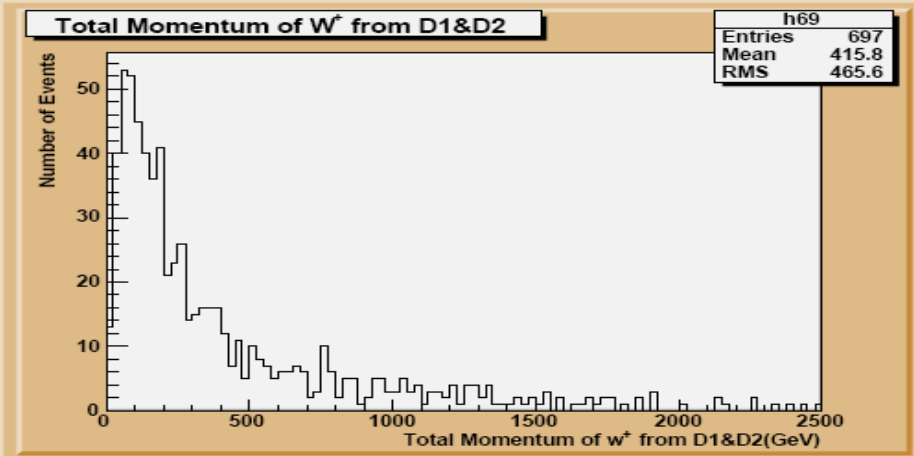


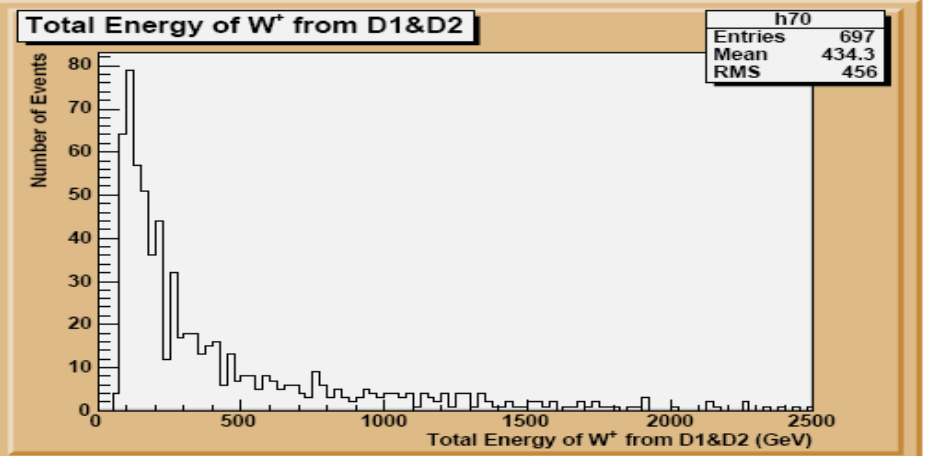


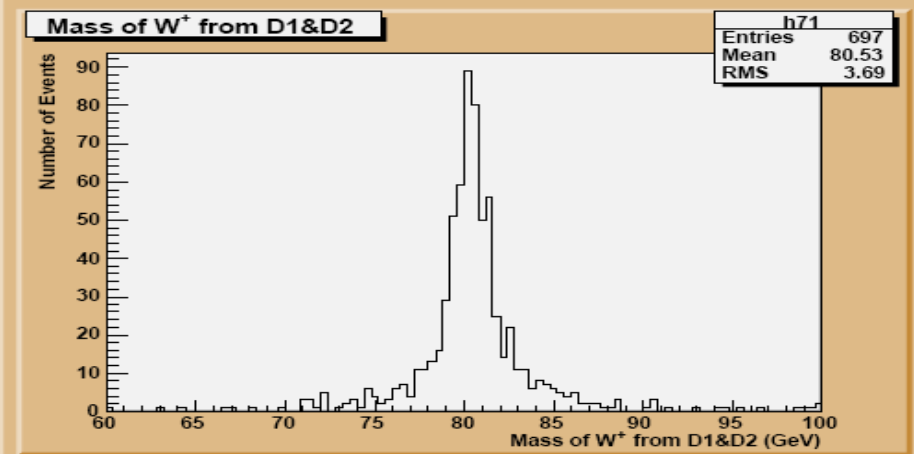


Total P (GeV) of W^+ $p_{W^+} = \sqrt{p_{W^+x}^2 + p_{W^+y}^2 + p_{W^+z}^2}$

P, E & Mass (M) of W^+ from D1D2







$$E_{W^+} = E_{D1W^+} + E_{D2W^+}$$

Relativistic energy-momentum equation

$$E^2 = (mc^2)^2 + (pc)^2$$

$$c = 1 \quad E^2 = m^2 + p^2$$

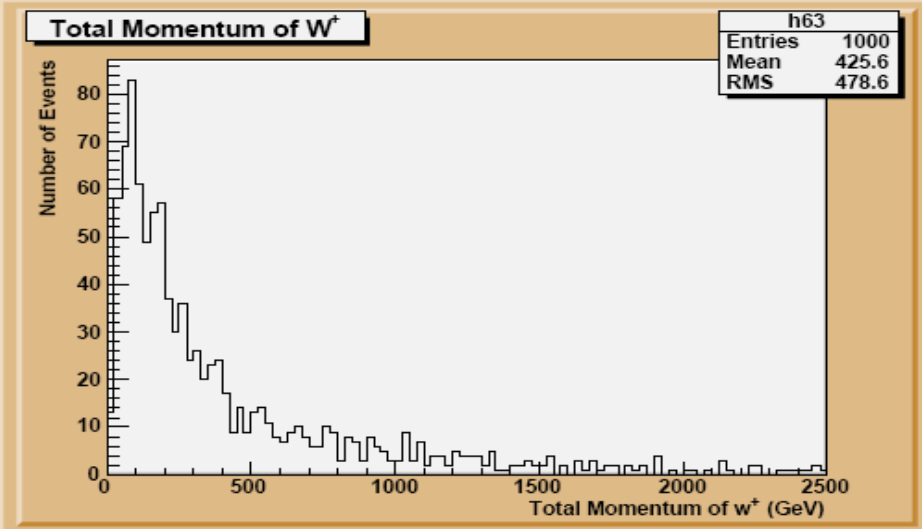
Invariant Mass

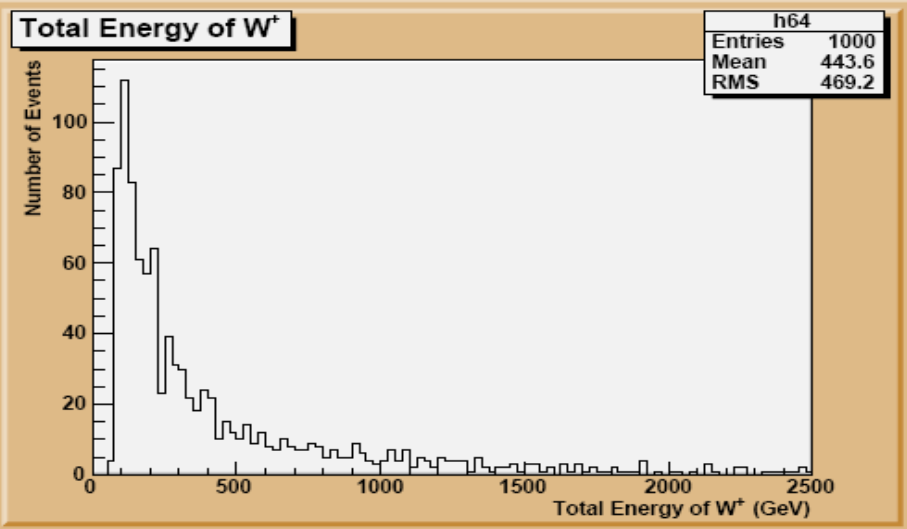
$$m^2 = E^2 - p^2 \qquad m_{W^+} = \sqrt{E_{W^+}{}^2 - p_{W^+}{}^2}$$

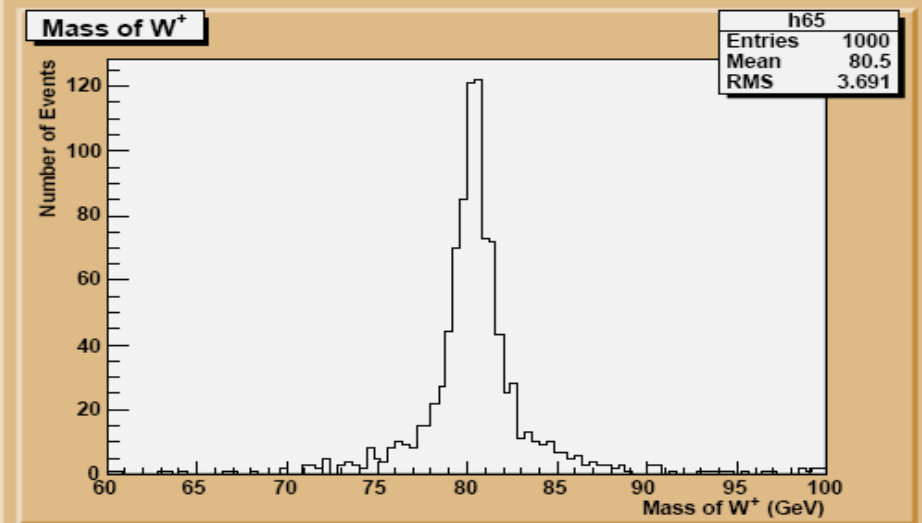
$$p_{W^+} = \sqrt{\left(p_{W^+D_1x} + p_{W^+D_2x}\right)^2 + \left(p_{W^+D_1y} + p_{W^+D_2y}\right)^2 + \left(p_{W^+D_1z} + p_{W^+D_2z}\right)^2}$$

Total P (GeV) of W^+ from D1 & D2

P, E & M (GeV) of W+







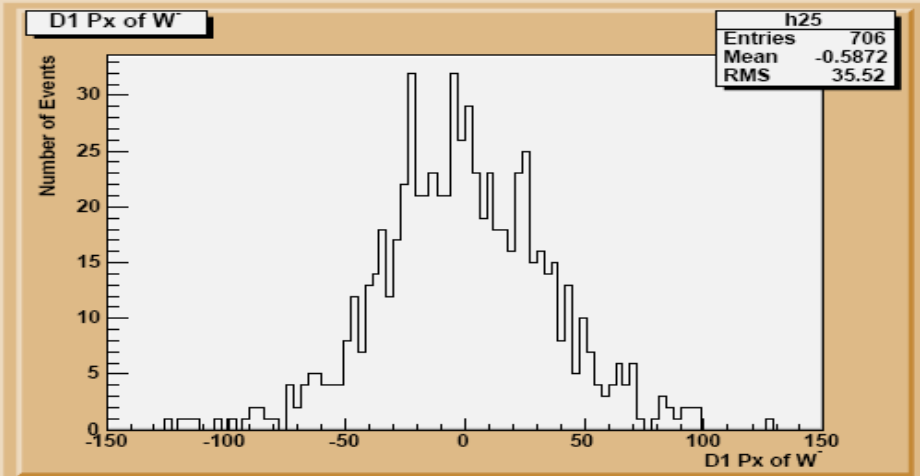
$$p_{W^+} = \sqrt{p_{W^+x}^2 + p_{W^+y}^2 + p_{W^+z}^2}$$

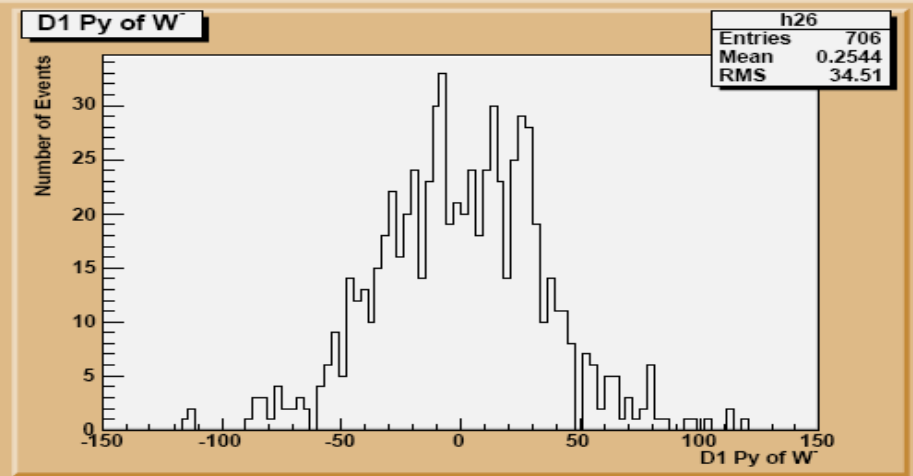
Relativistic energy-momentum equation

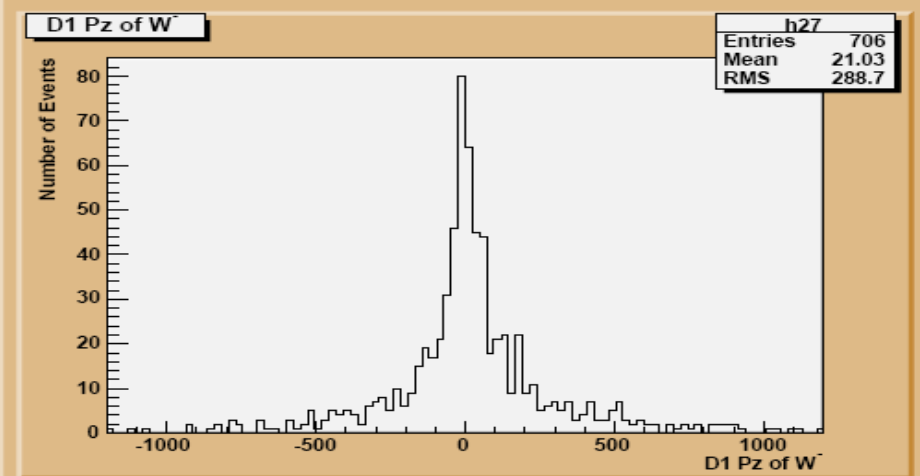
$$E^2 = (mc^2)^2 + (pc)^2$$

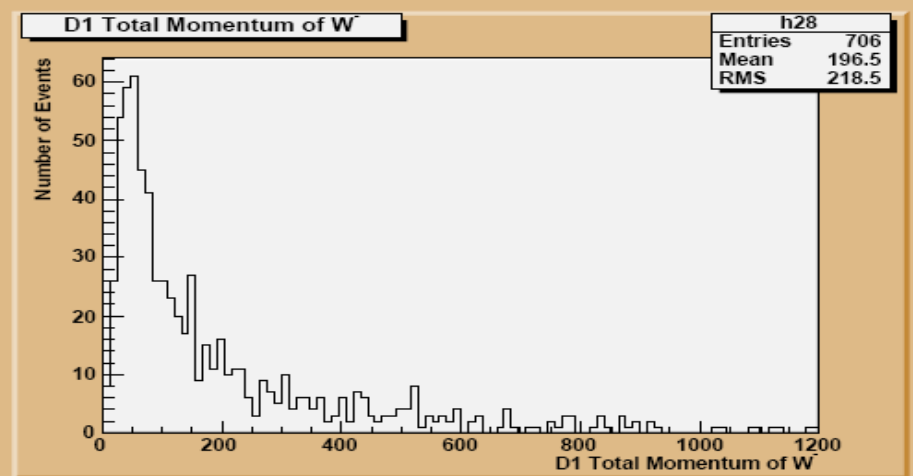
$$m_{W^+} = \sqrt{E_{W^+}{}^2 - p_{W^+}{}^2}$$

P Distribution of D_1 of W^-



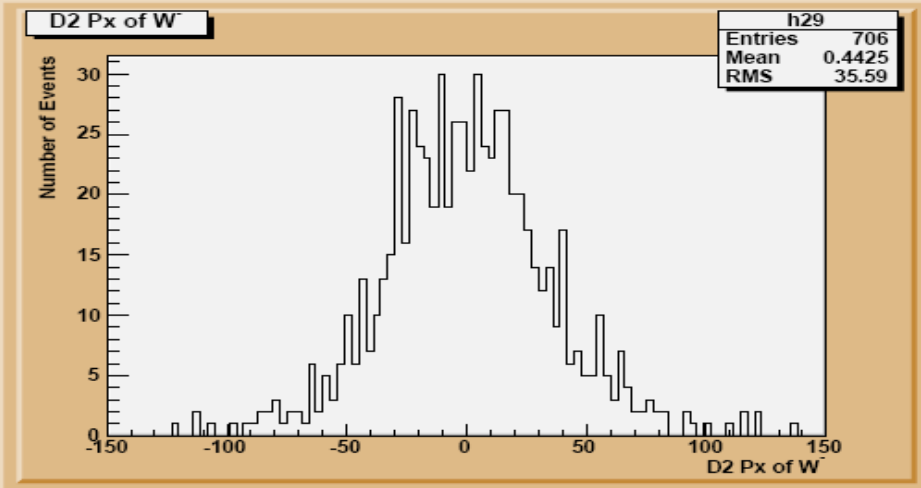


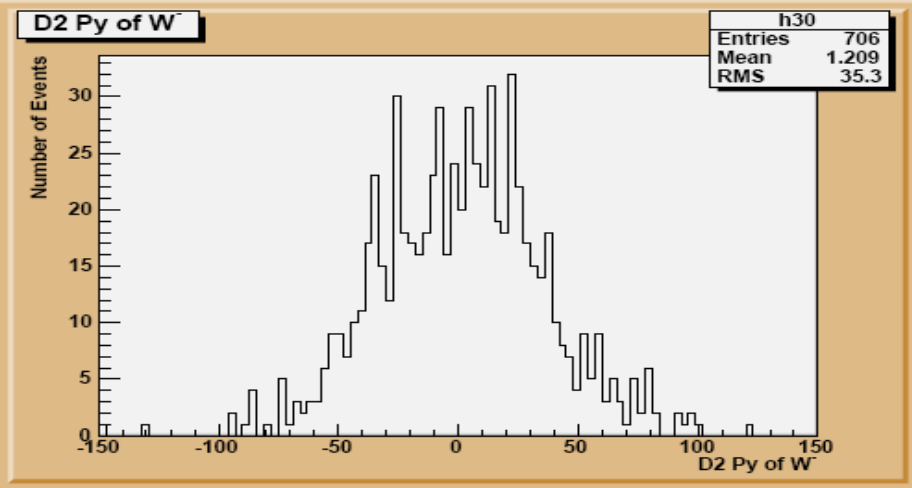


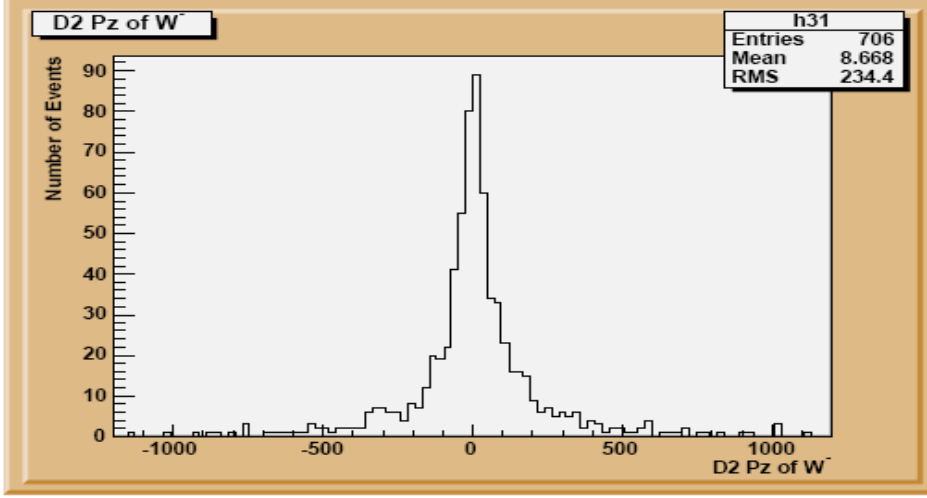


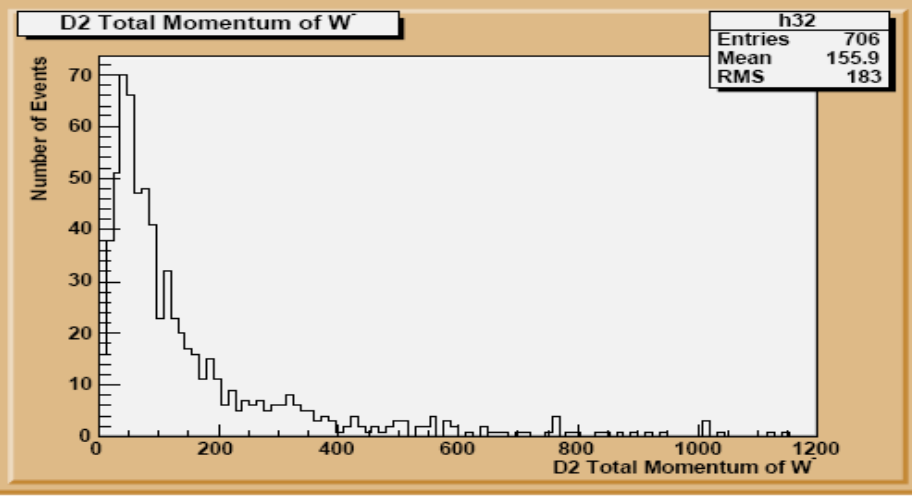
Total P (GeV) of D_1 (W^-) $p_{W^-D_1} = \sqrt{p^2_{W^-D_1 x} + p^2_{W^-D_1 y} + p^2_{W^-D_1 z}}$

P Distribution of D_2 of W^-



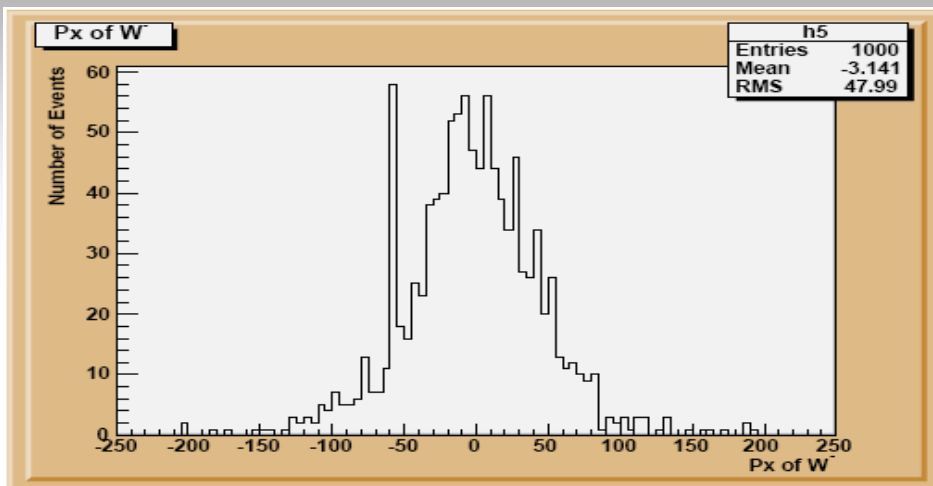


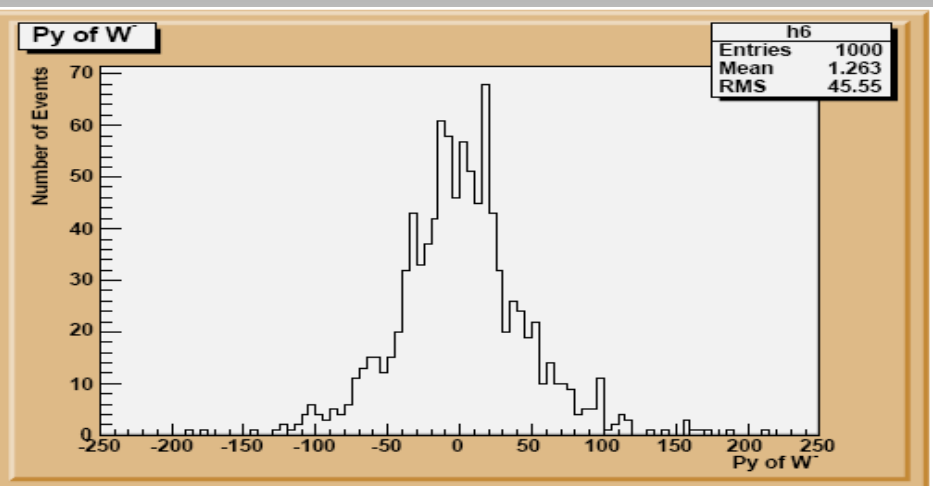


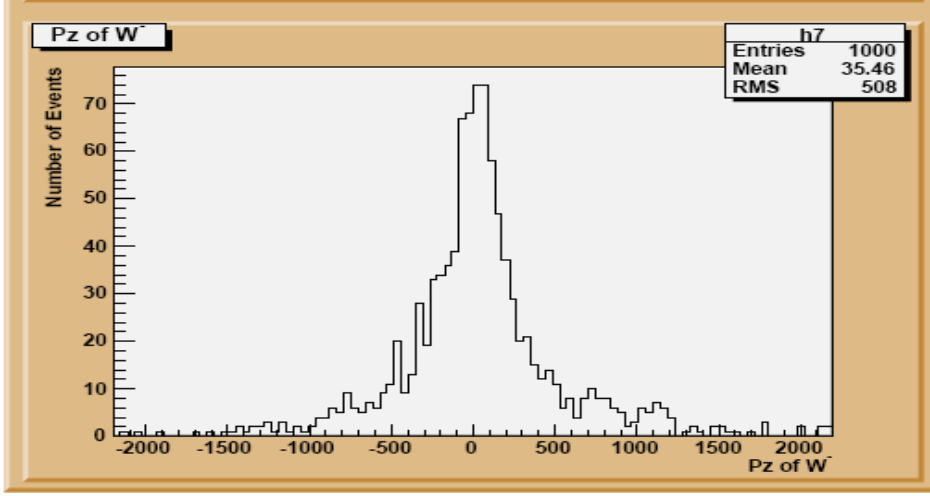


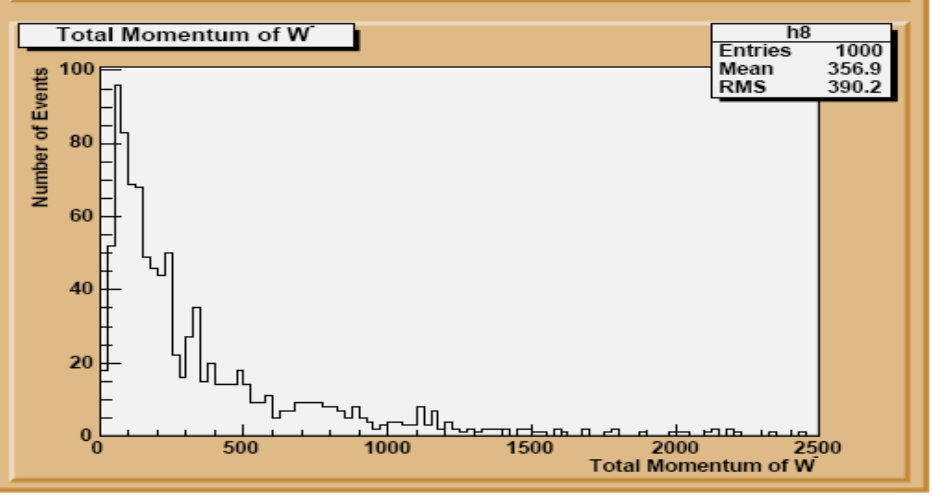
Total P (GeV) of D_2 (W^-) $p_{W^- D_2} = \sqrt{p^2_{W^- D_2 x} + p^2_{W^- D_2 y} + p^2_{W^- D_2 z}}$

P Distribution W-



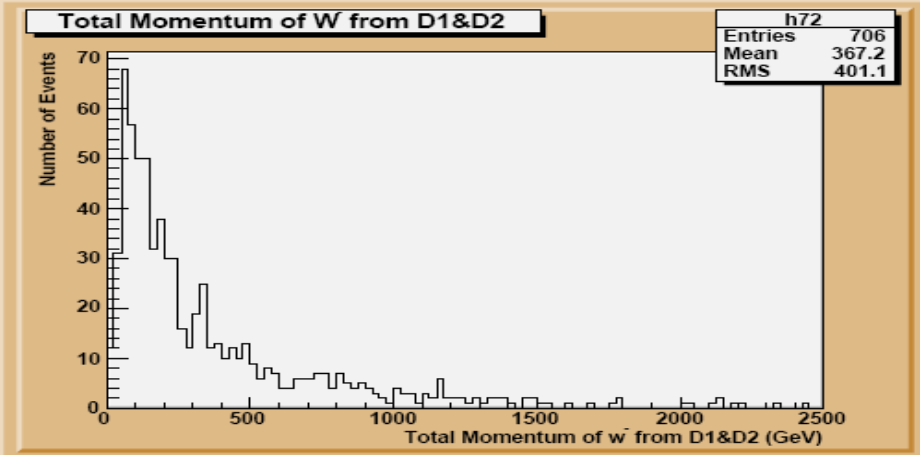


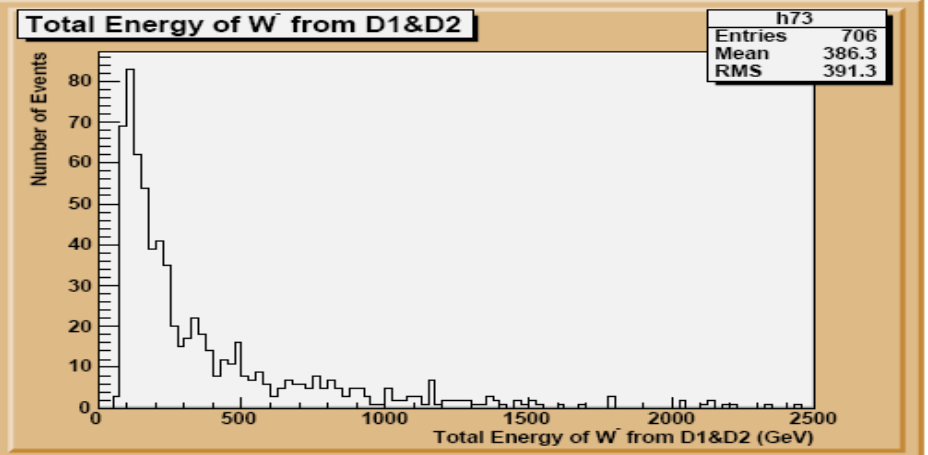


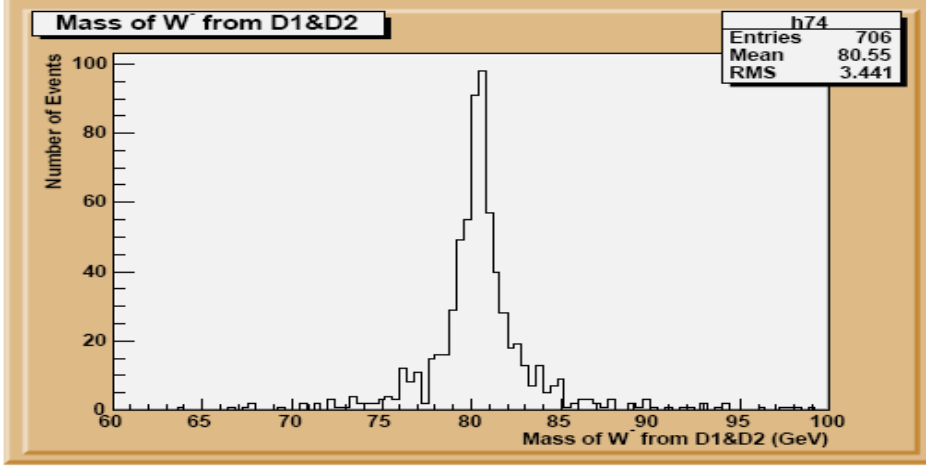


$$p_{W^-} = \sqrt{p_{W^-x}^2 + p_{W^-y}^2 + p_{W^-z}^2}$$ **Total P (GeV) of W-**

P, E & M (GeV) of W- from D1D2







$$E_{W^-} = E_{D1W^-} + E_{D2W^-}$$

Relativistic energy-momentum equation

$$E^2 = (mc^2)^2 + (pc)^2$$

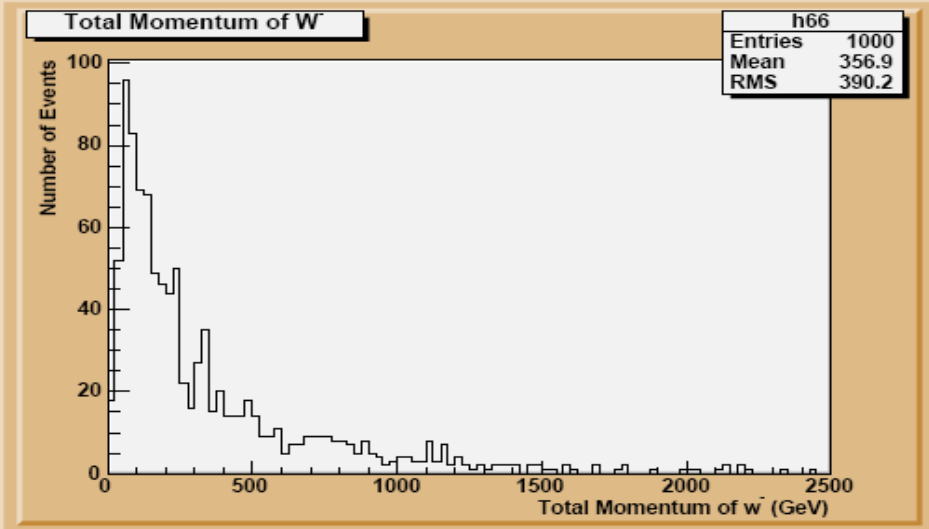
$$m^2 = E^2 - p^2$$

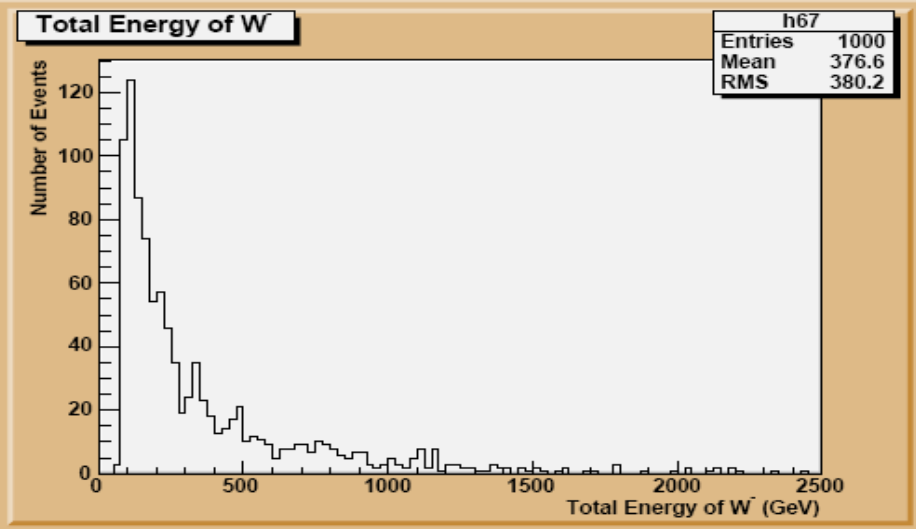
$$m_{W^-} = \sqrt{E_{W^-}{}^2 - p_{W^-}{}^2}$$

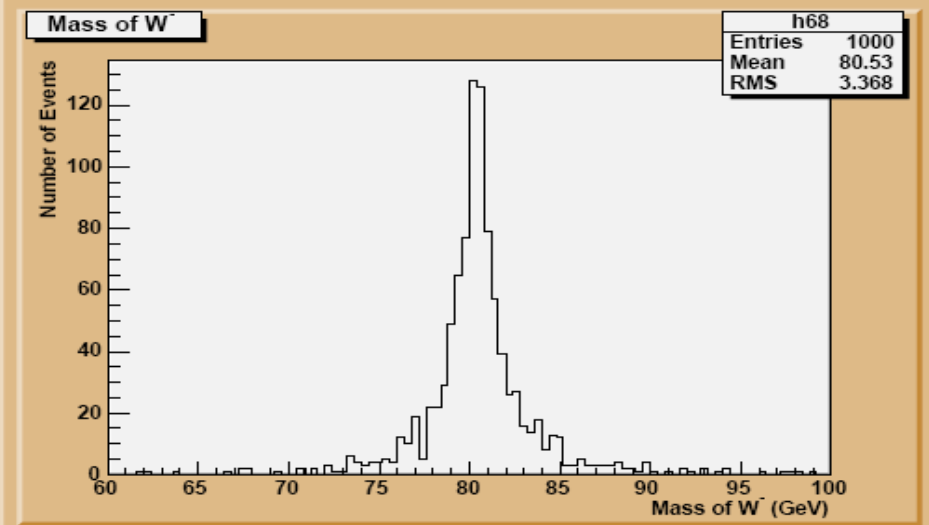
$$p_{W^-} = \sqrt{\left(p_{W^-D_1x} + p_{W^-D_2x}\right)^2 + \left(p_{W^-D_1y} + p_{W^-D_2y}\right)^2 + \left(p_{W^-D_1z} + p_{W^-D_2z}\right)^2}$$

Total P (GeV) of W- from D1 & D2

P, E & M (GeV) of W-







$$p_{W^-} = \sqrt{p^2_{W^-x} + p^2_{W^-y} + p^2_{W^-z}}$$

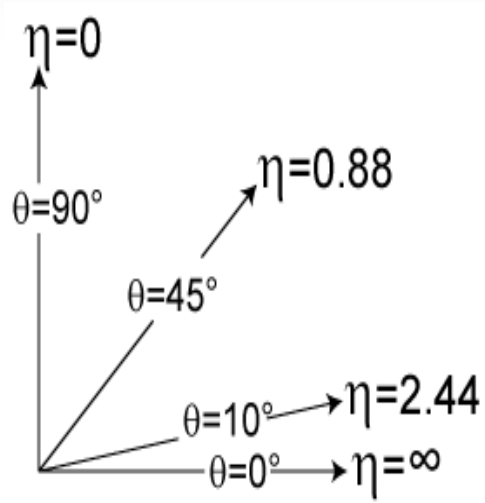
$$m_{W^-} = \sqrt{E_{W^-}{}^2 - p_{W^-}{}^2}$$

How to Find Pseudorapidity (η), Transverse Momentum (P_T) , Transverse Energy (E_T)

- Pseudorapidity, η, is a commonly used spatial coordinate describing the angle of a particle relative to the beam axis. It is defined as

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right],$$

where θ is the angle between the particle momentum $\vec{p}$ and the beam axis

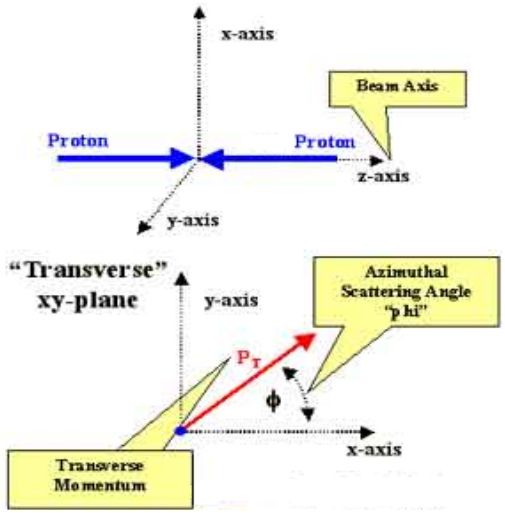


- Transverse Momentum

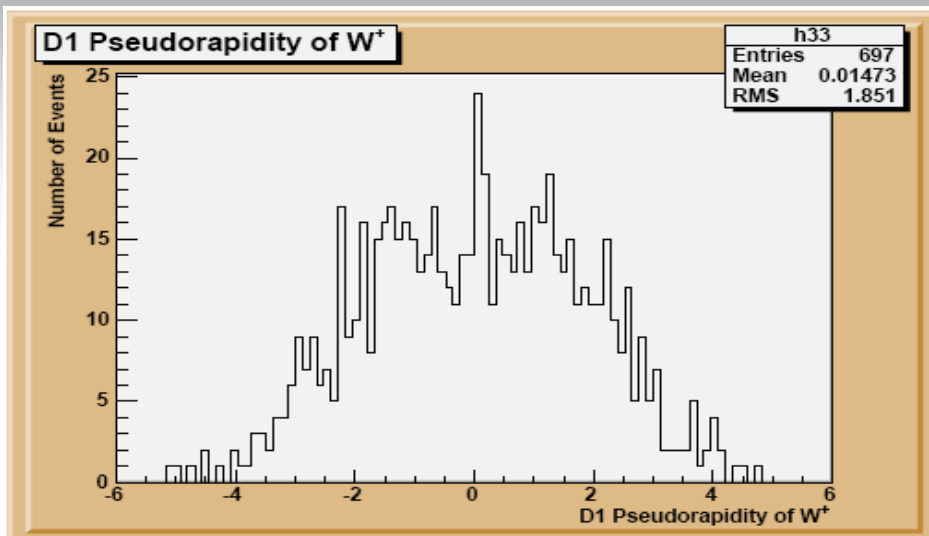
$$p_T = \sqrt{p_x^2 + p_y^2}$$

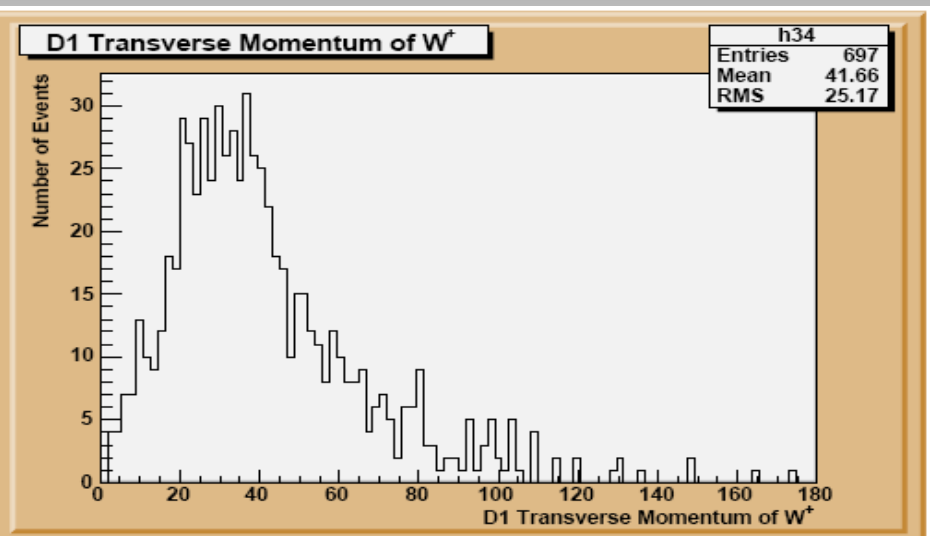
- Transverse Energy

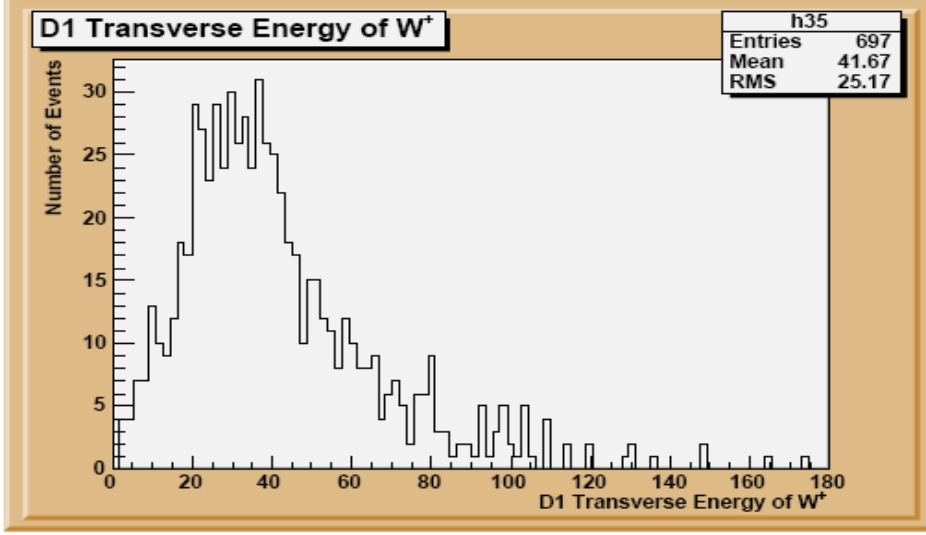
$$E_T = \sqrt{E_x^2 + E_y^2}$$

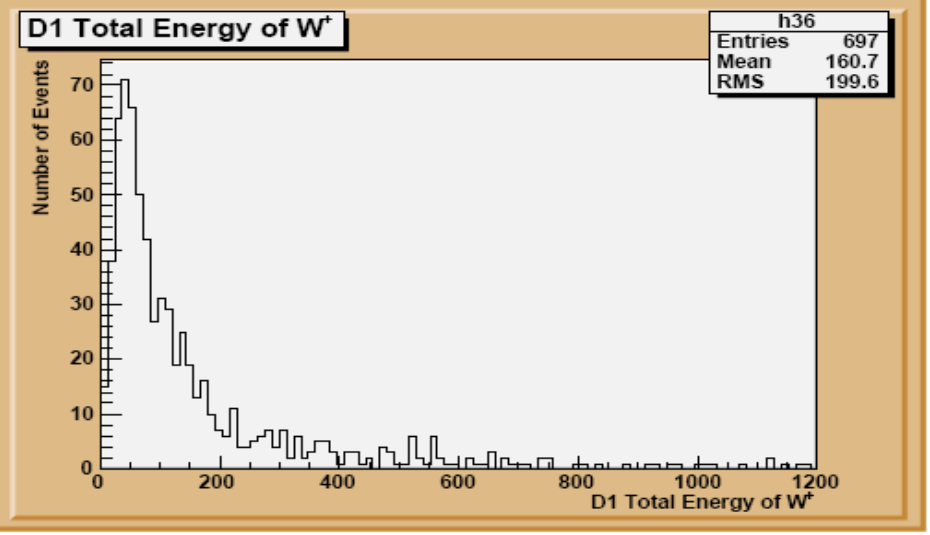


η, P_T, E_T & E (GeV) of D_1 (W^+)

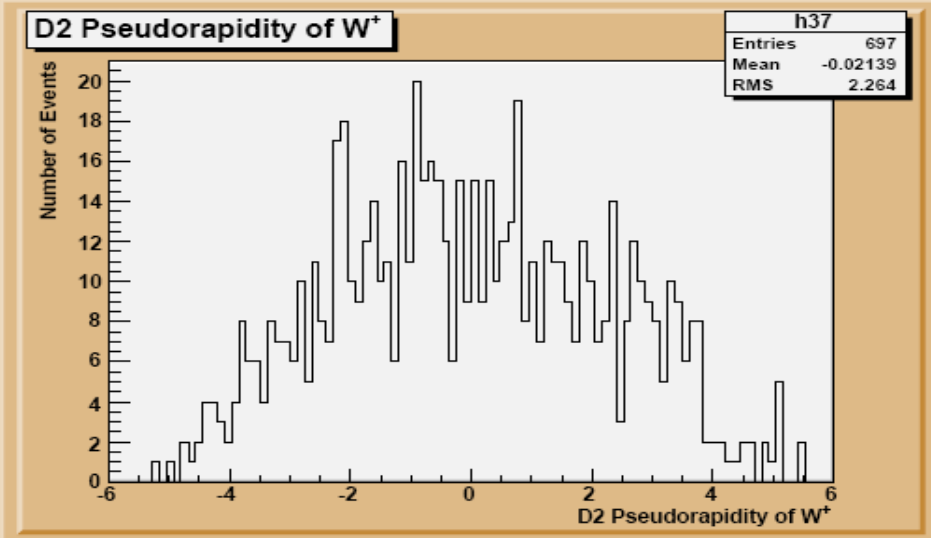


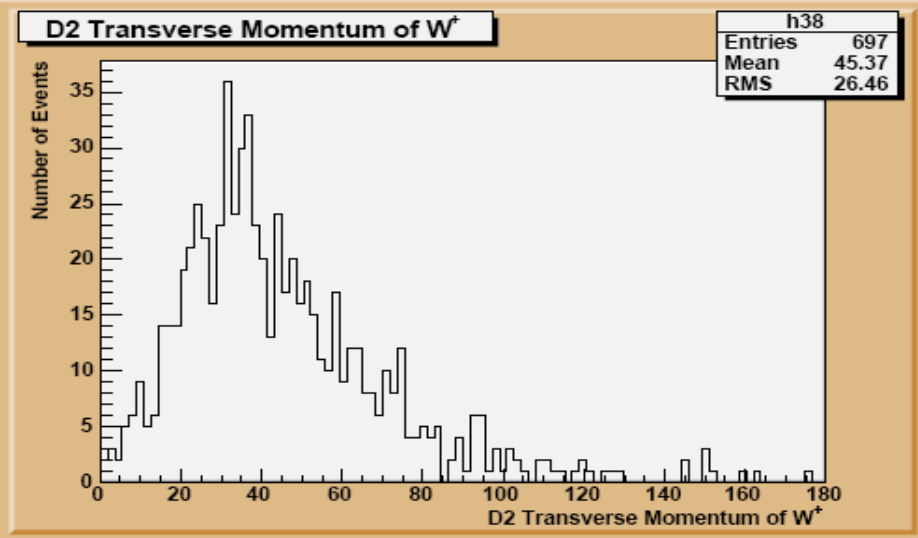


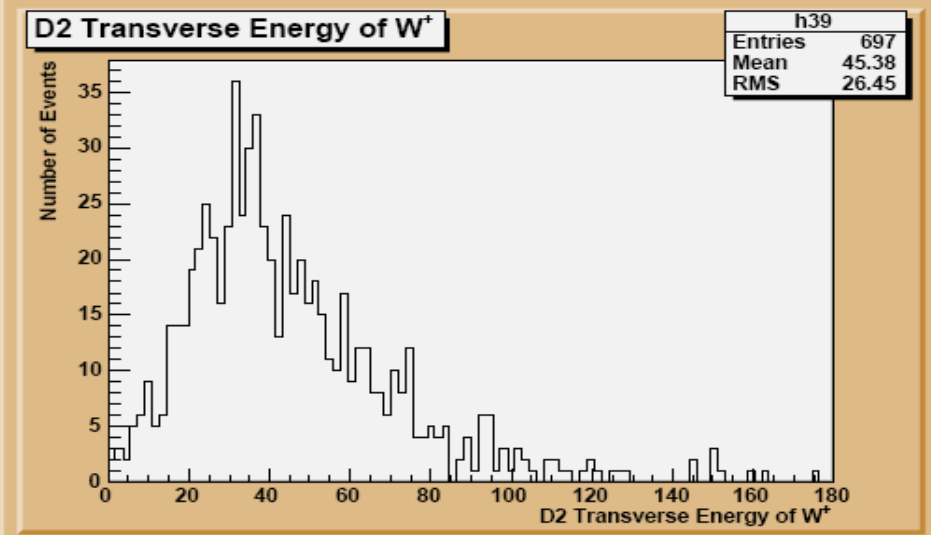


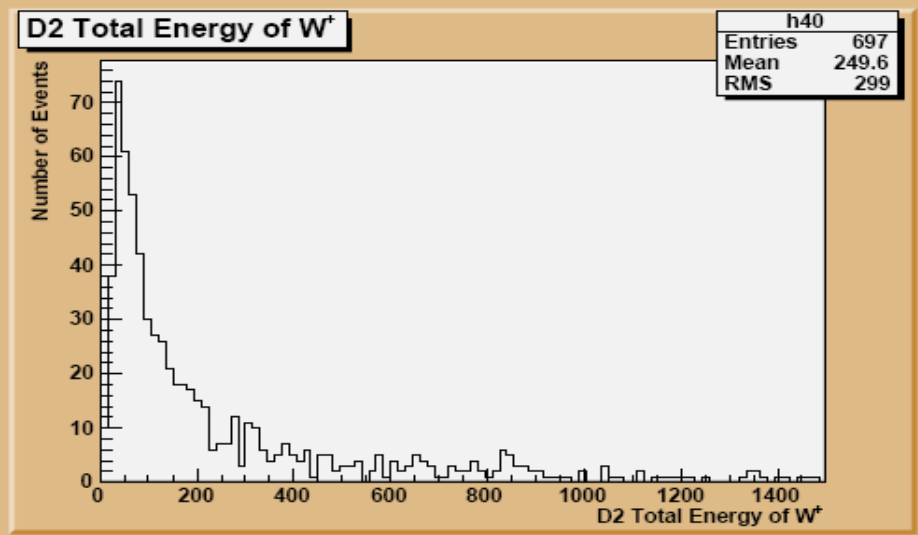


η, P_T, E_T, Total E (GeV) of D_2 (W^+)

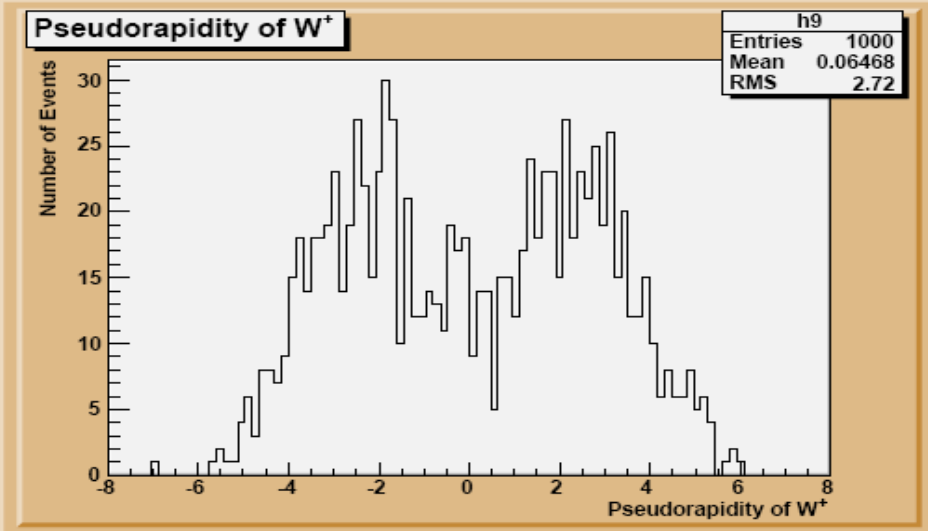


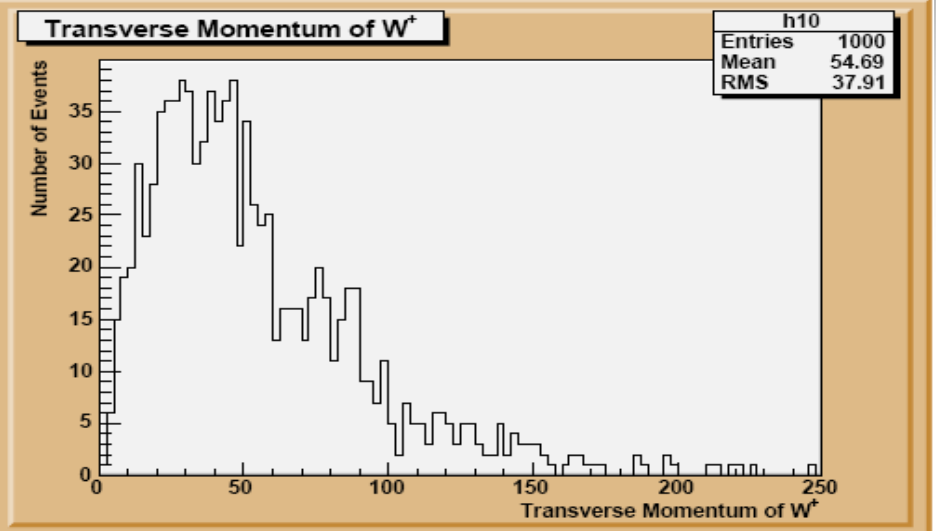


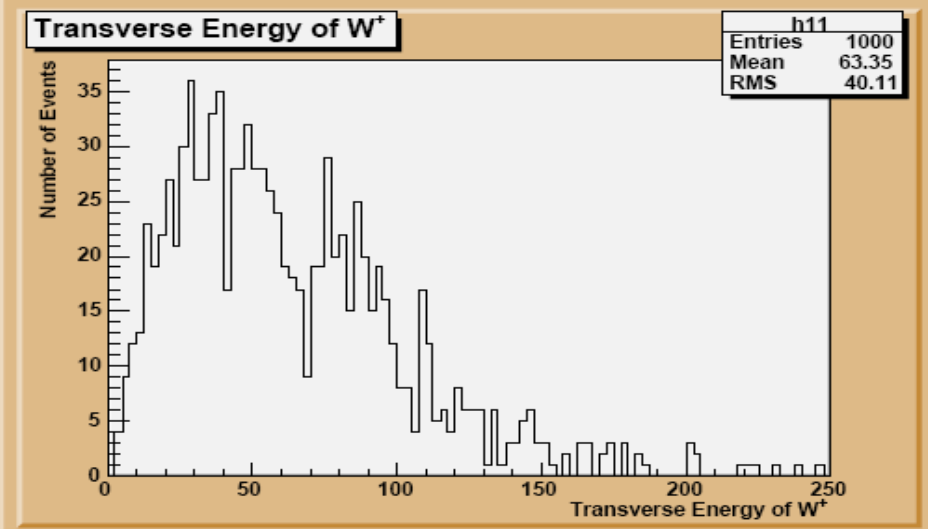


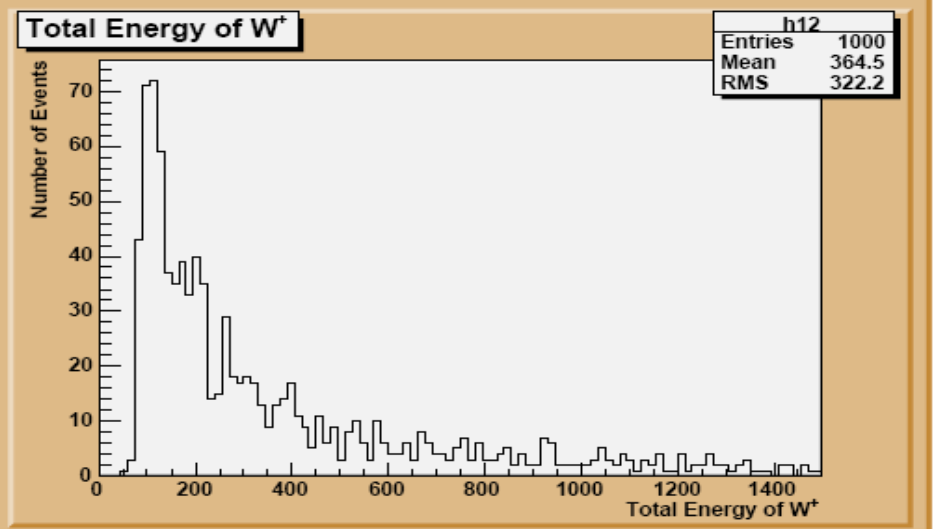


η, P_T, E_T, Total E (GeV) of W^+

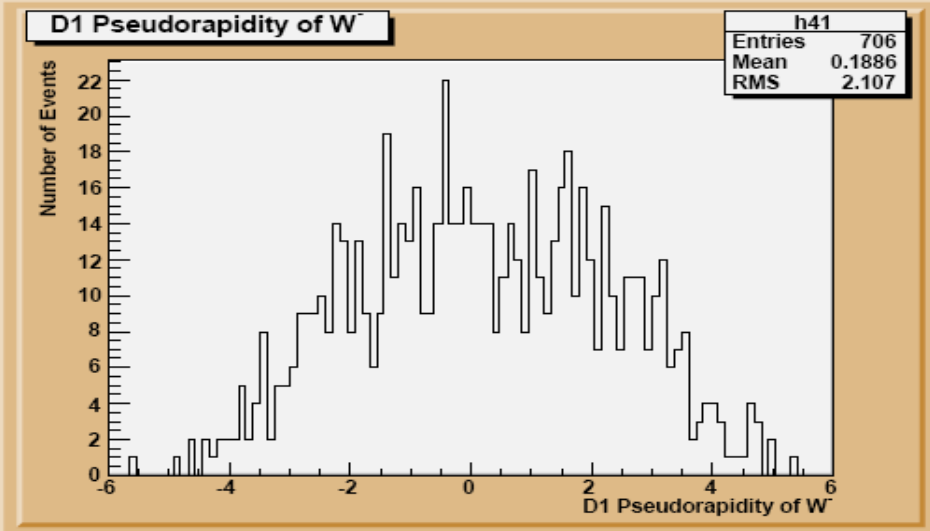


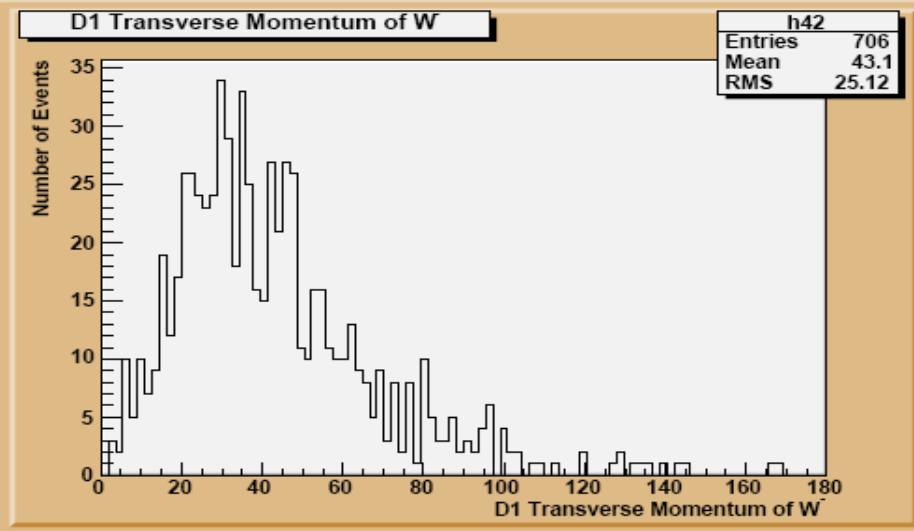


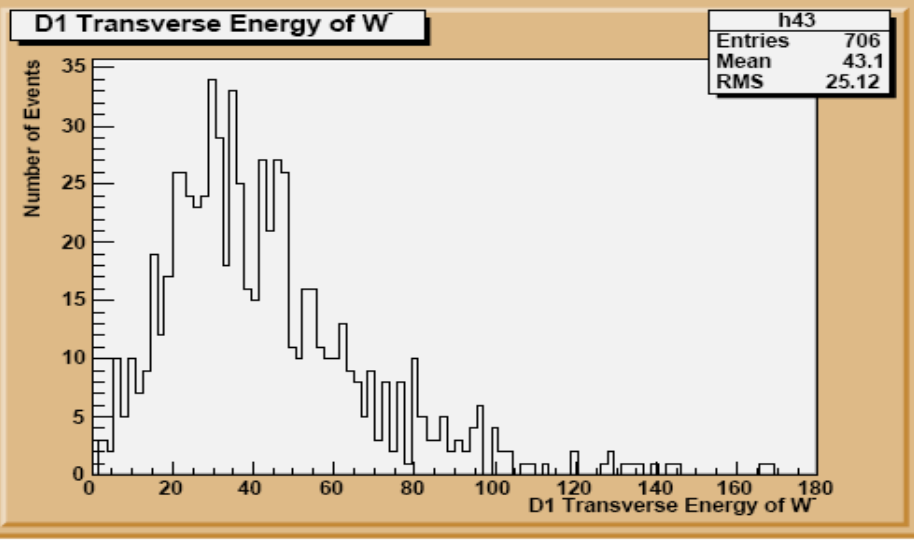


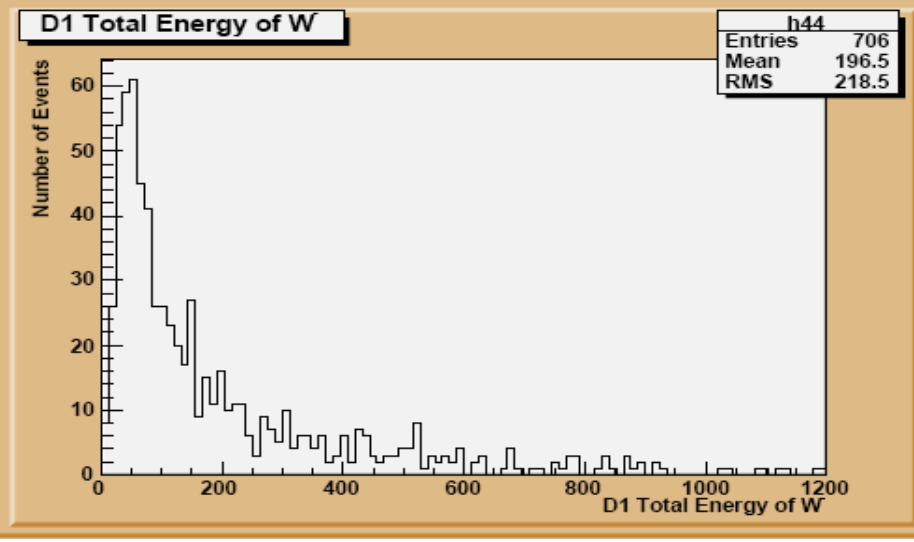


η, P_T, E_T, Total E (GeV) of D_1 (W^-)

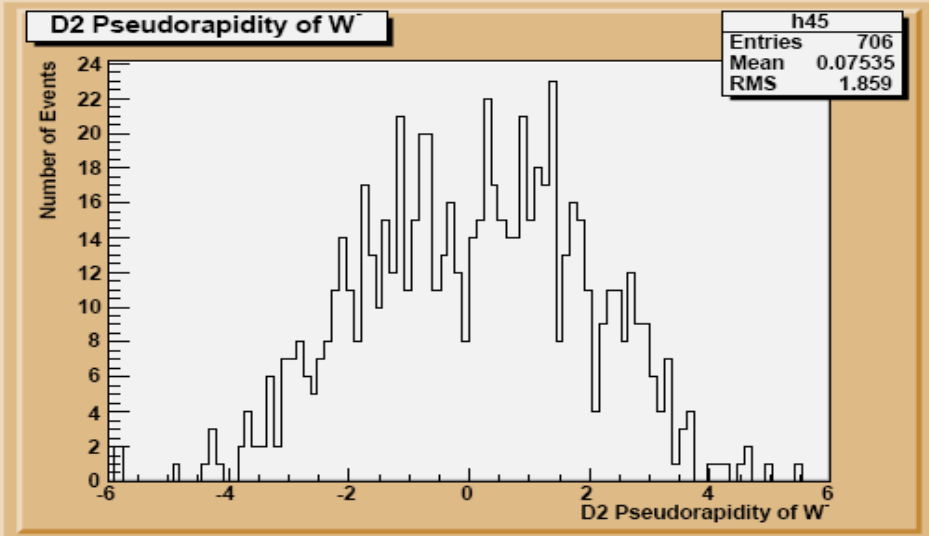


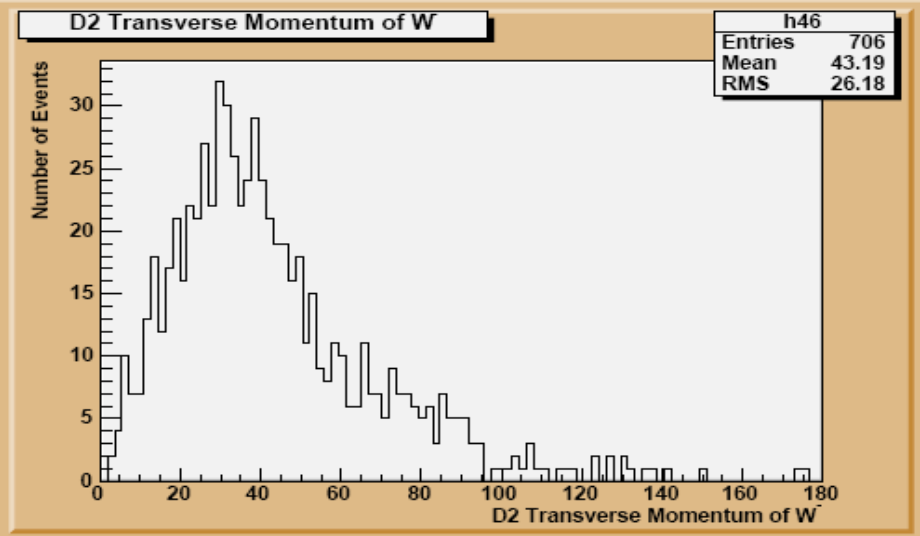


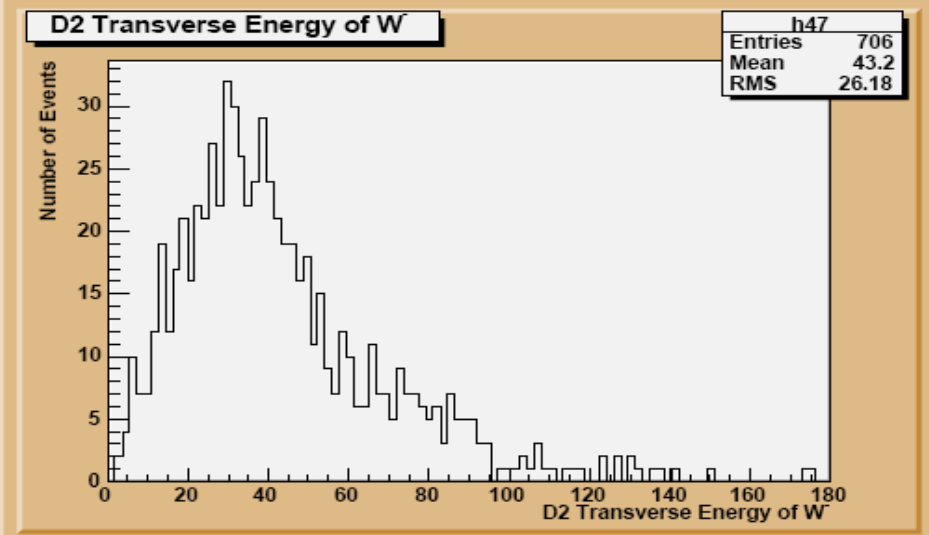


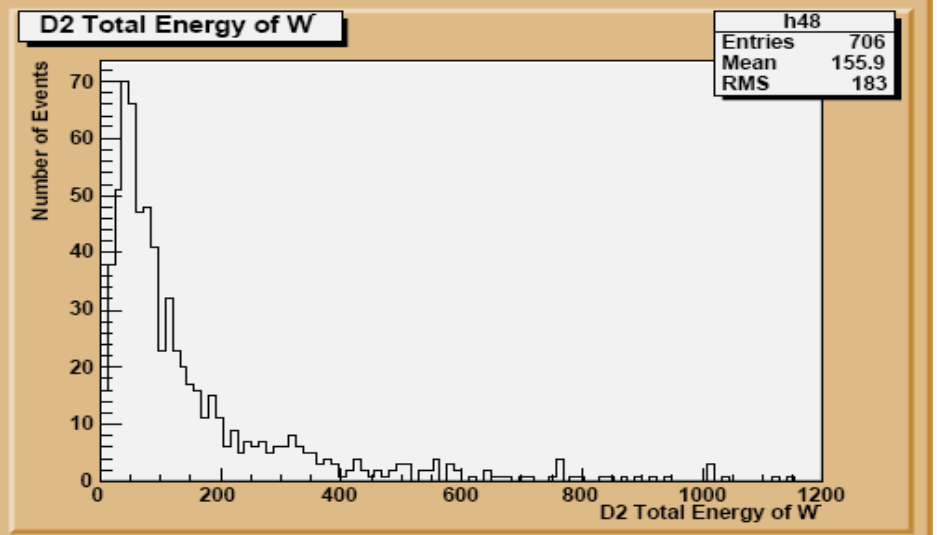


η, P_T, E_T, Total E (GeV) of D_2 (W^-)

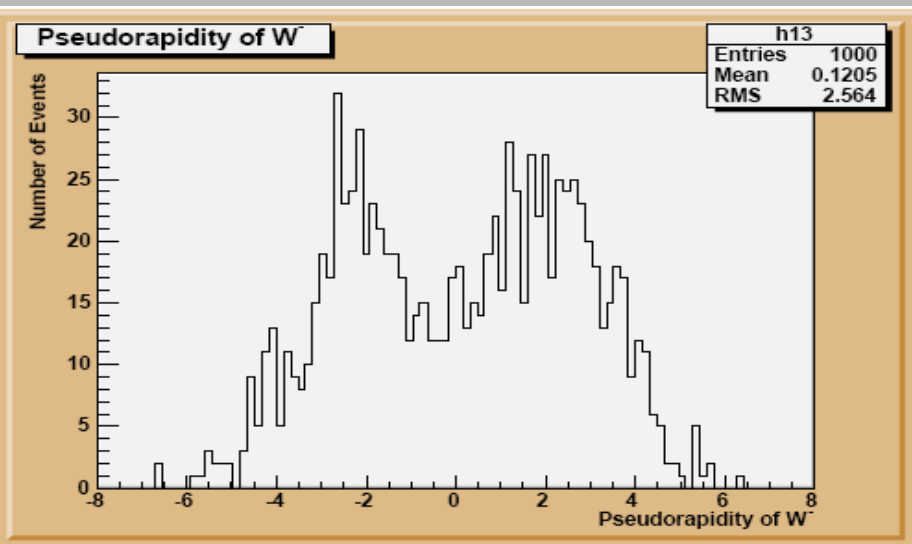


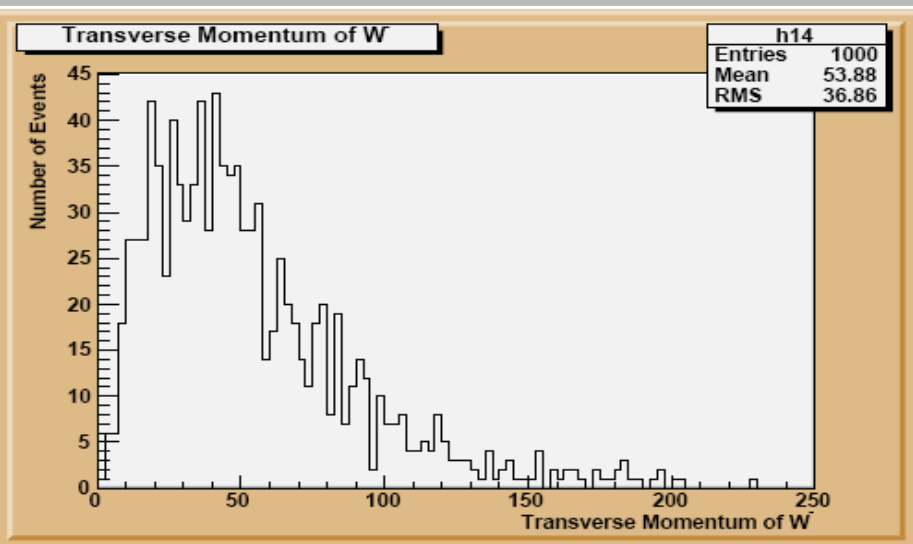


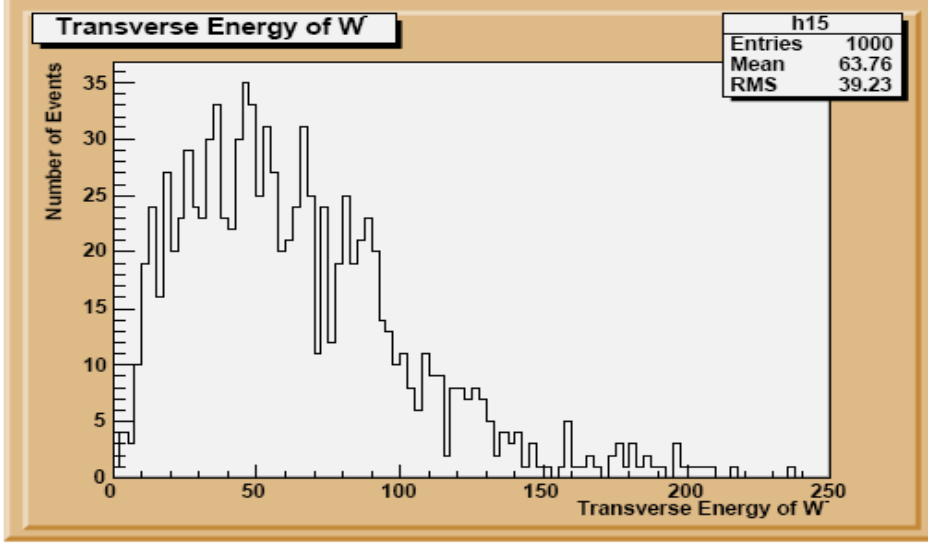


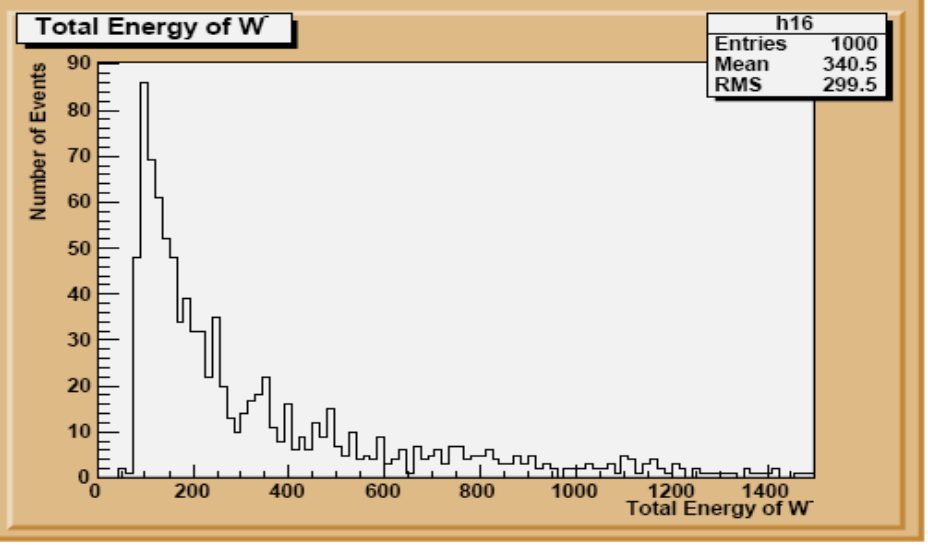


η, P_T, E_T, Total E (GeV) of W-

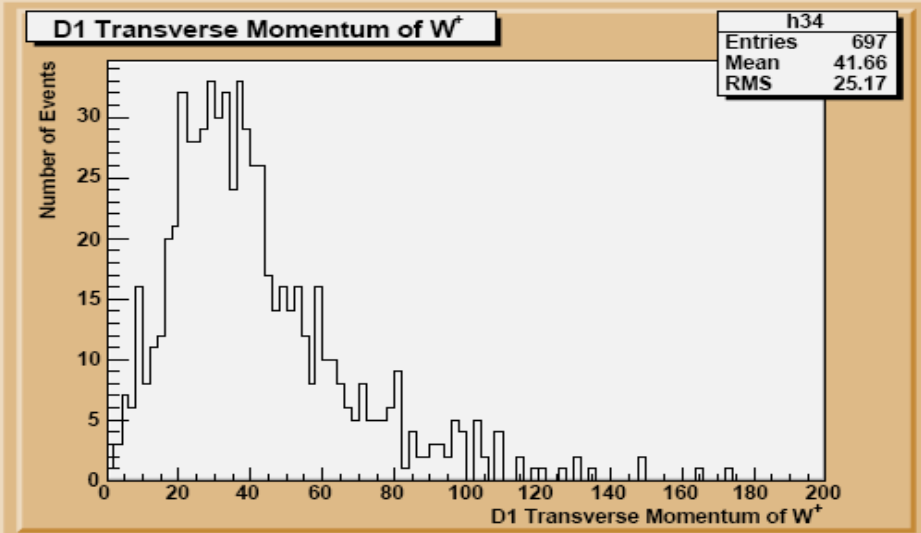


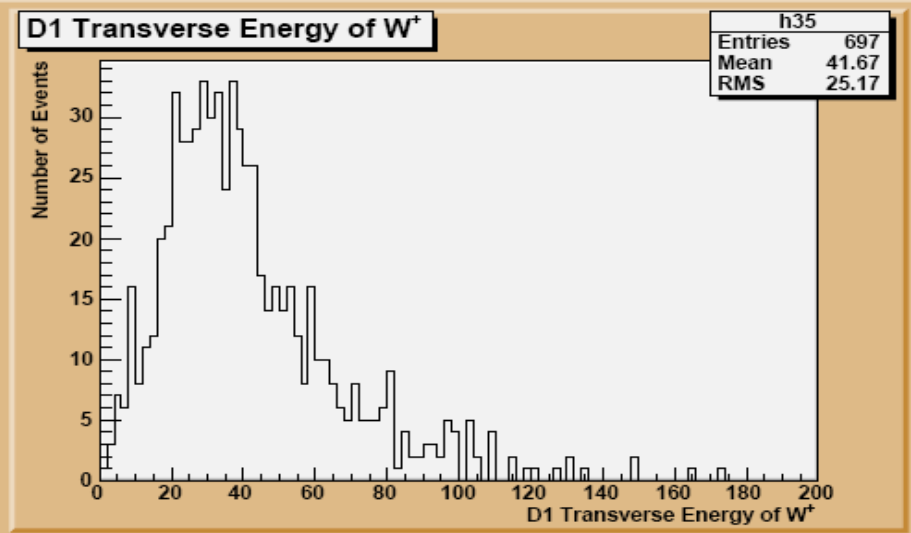


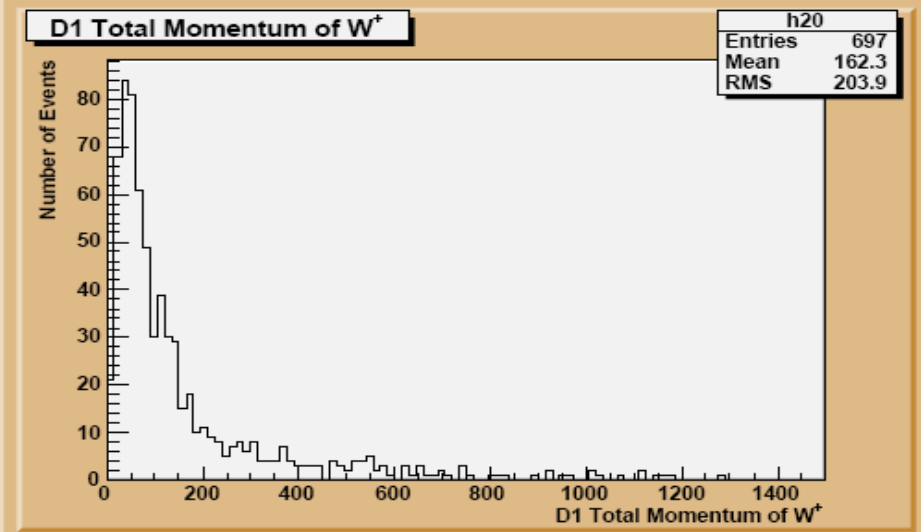


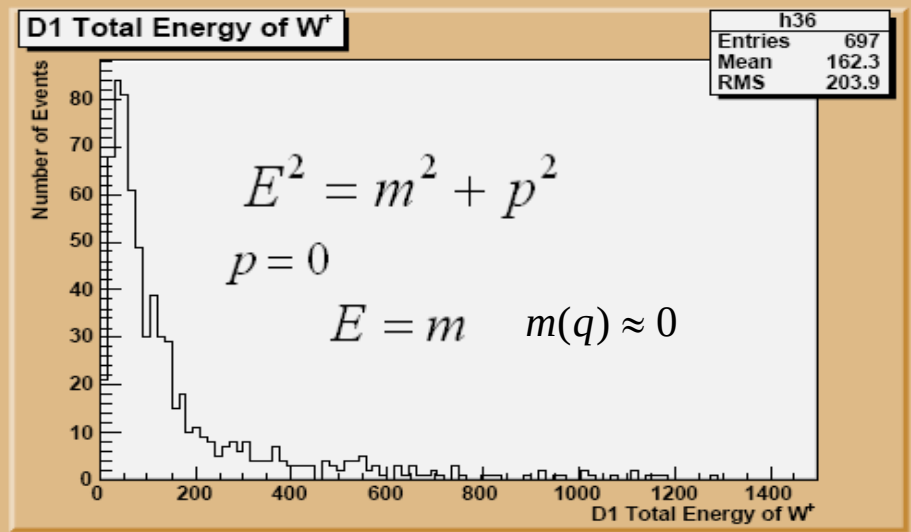


P_T, E_T, E & P (GeV) of D_1 (W^+)







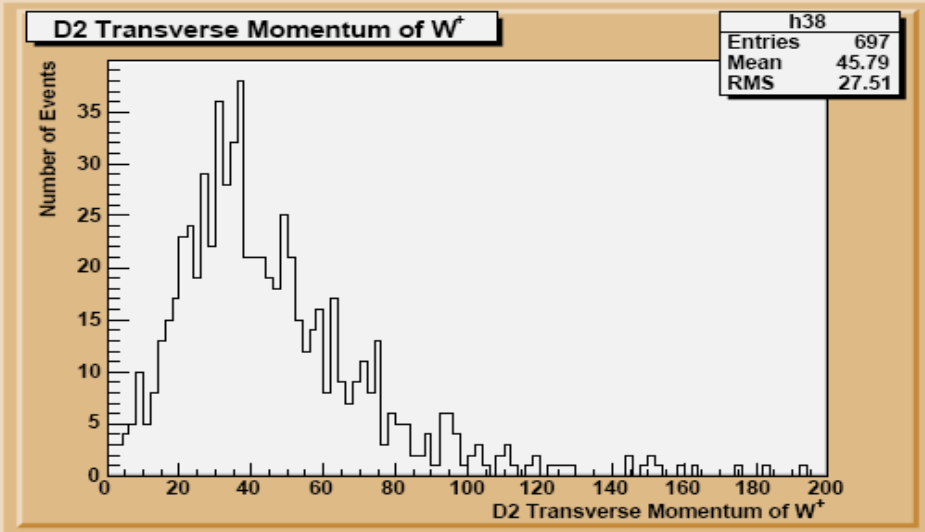


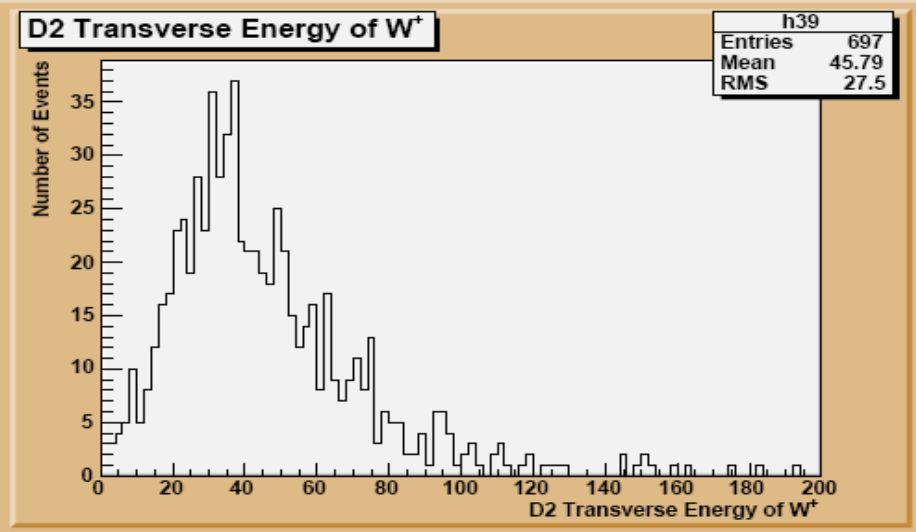
$$E^2 = m^2 + p^2$$

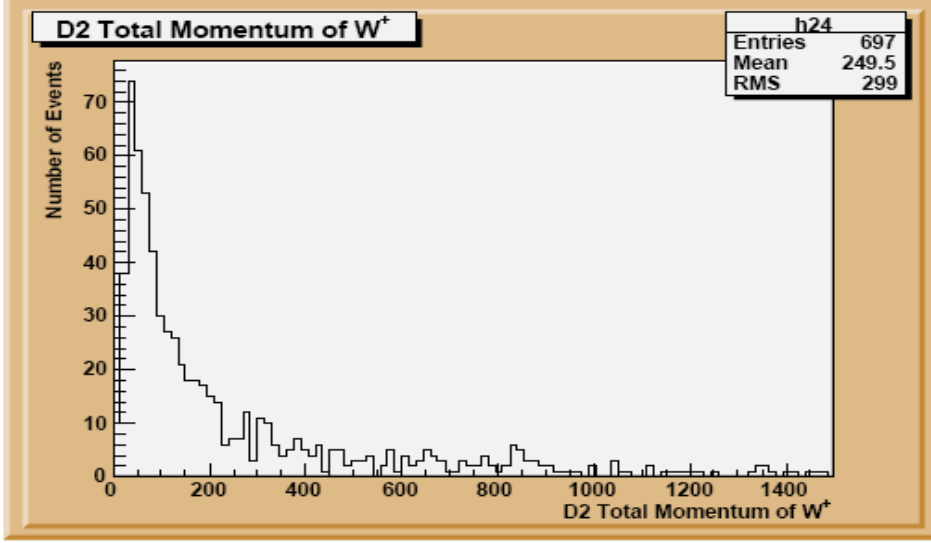
$$p = 0$$

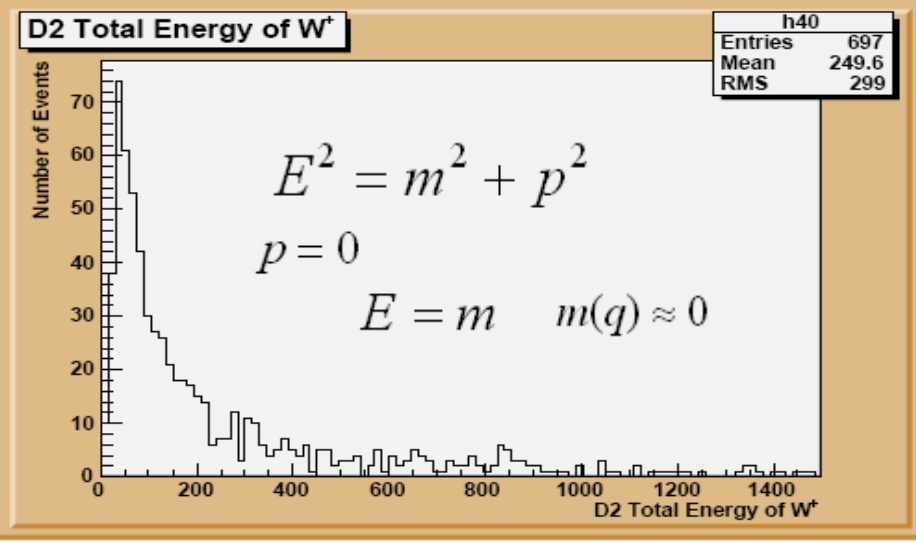
$$E = m \qquad m(q) \approx 0$$

P_T, E_T, E & P (GeV) of D_2 (W^+)







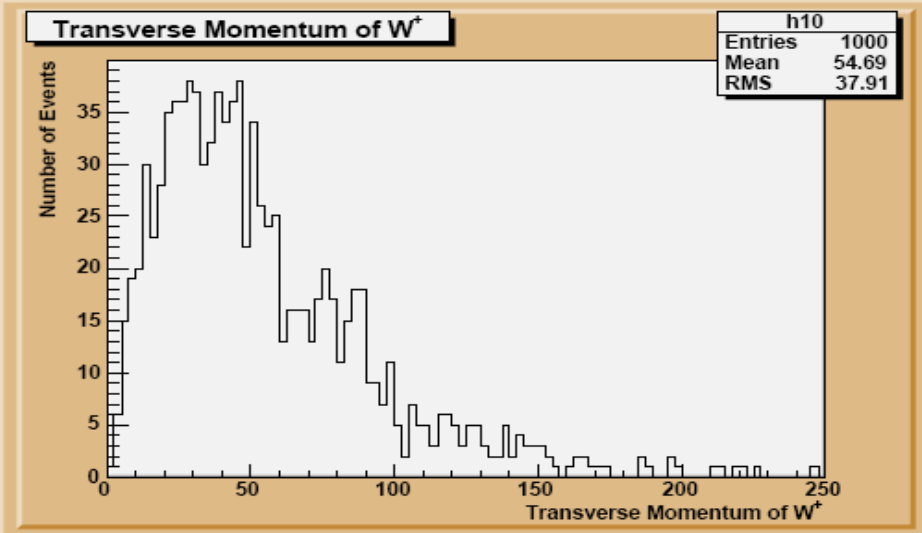


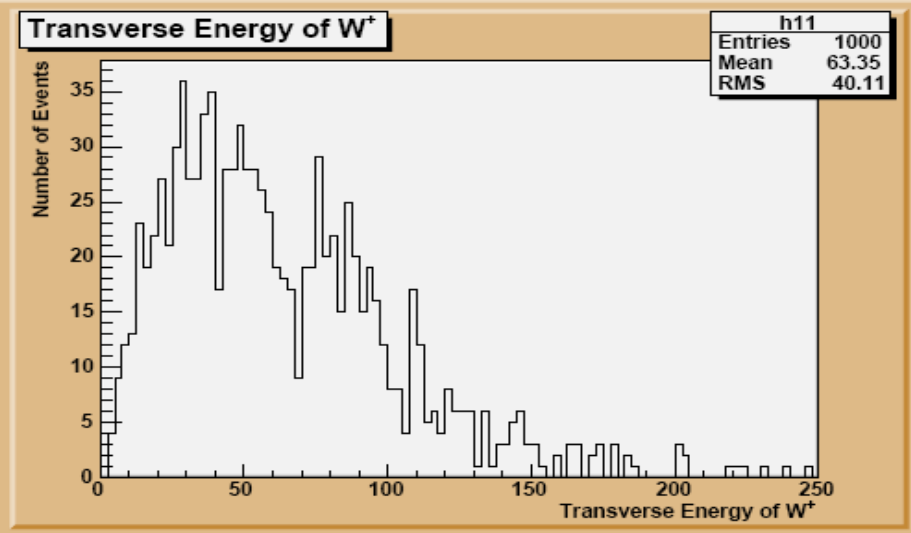
$$E^2 = m^2 + p^2$$

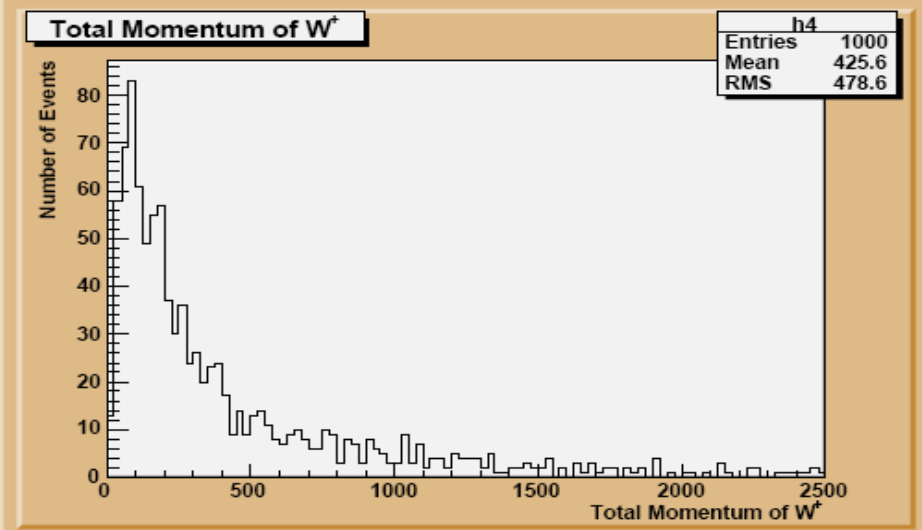
$$p = 0$$

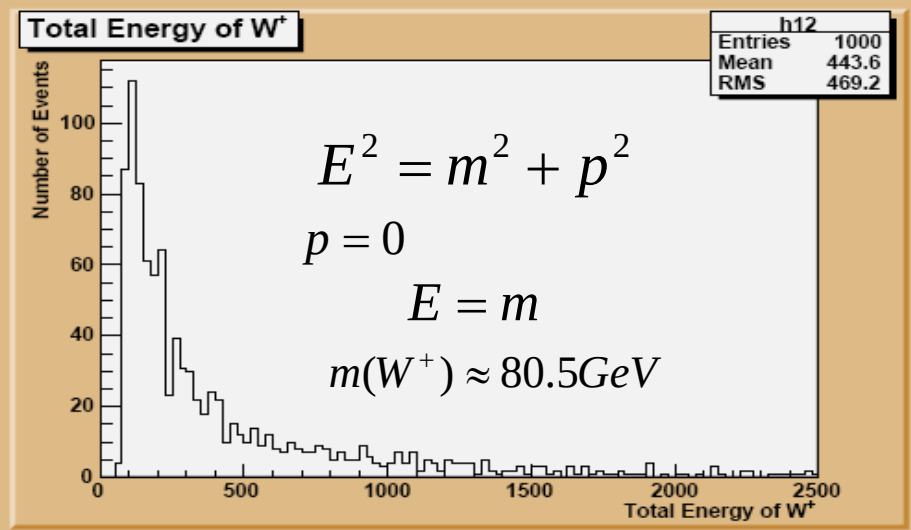
$$E = m \qquad m(q) \approx 0$$

P_T, E_T, E & P (GeV) of W^+









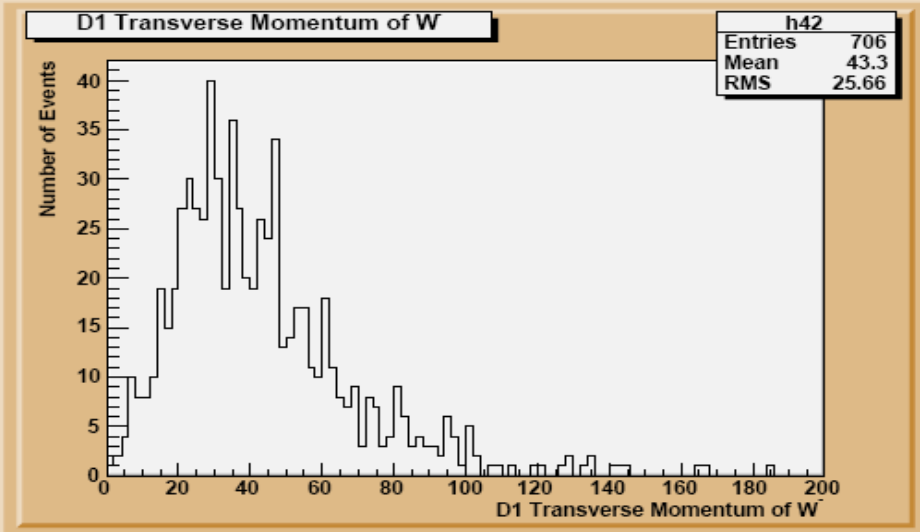
$$E^2 = m^2 + p^2$$

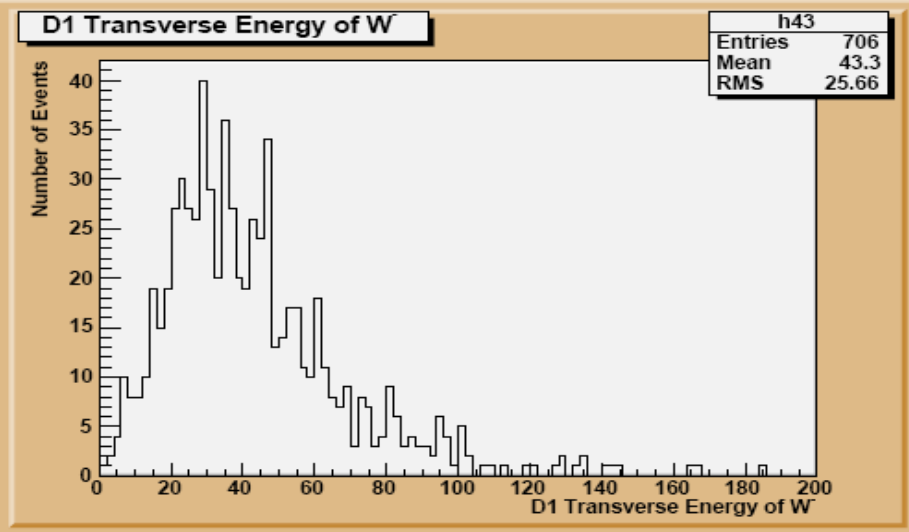
$$p = 0$$

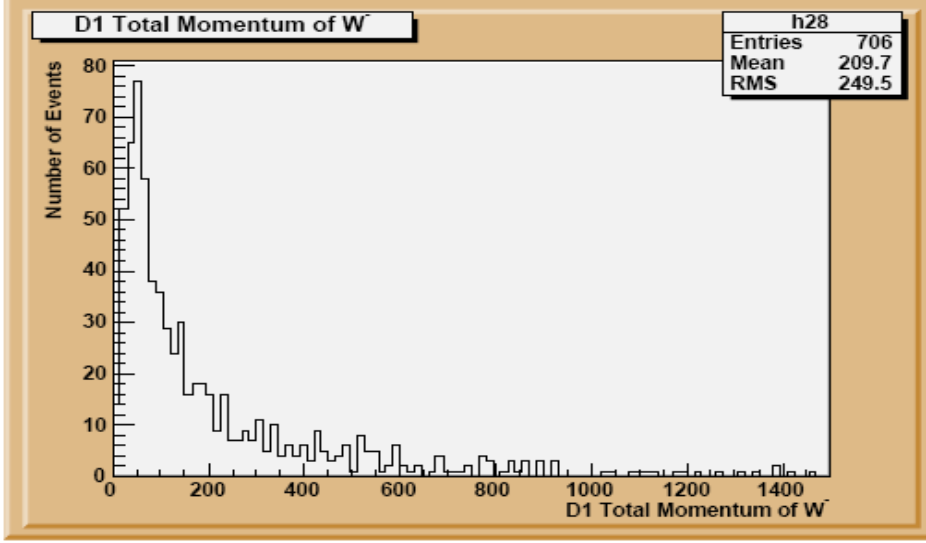
$$E = m$$

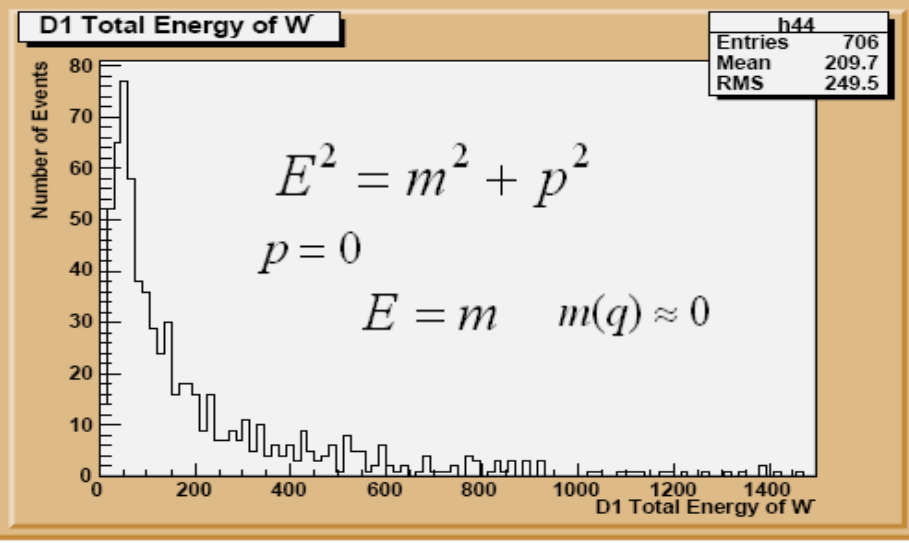
$$m(W^+) \approx 80.5 GeV$$

P_T, E_T, E & P (GeV) of D_1 (W^-)







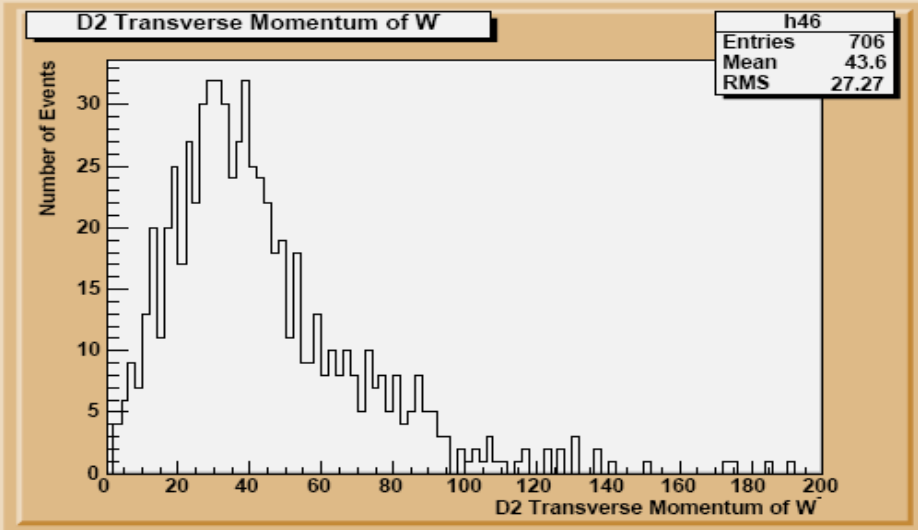


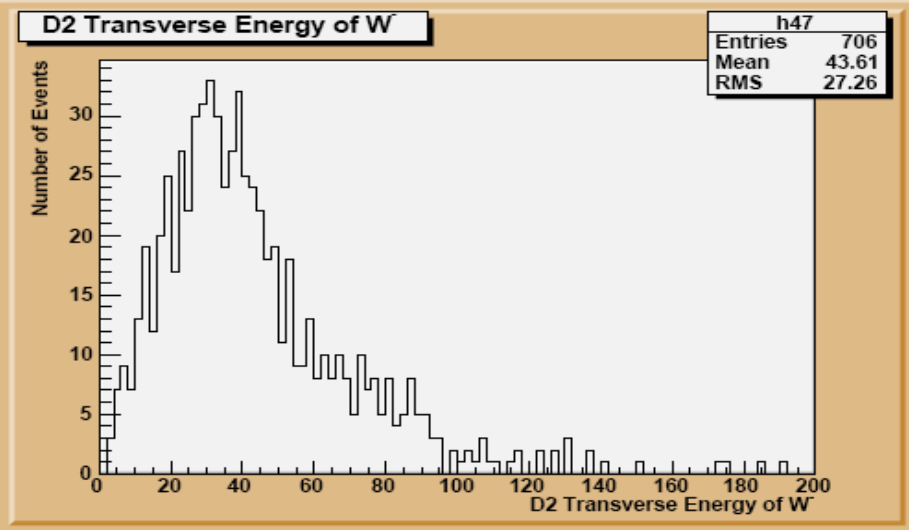
$$E^2 = m^2 + p^2$$

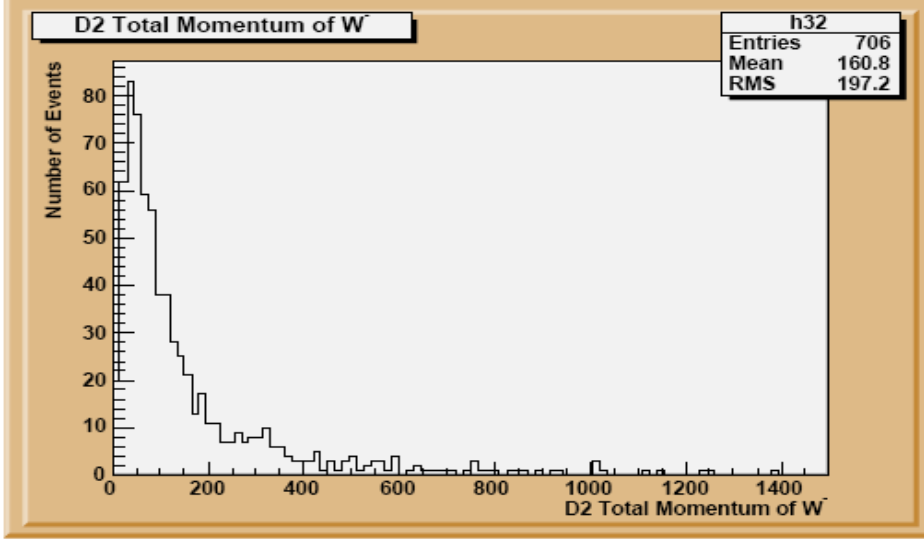
$$p = 0$$

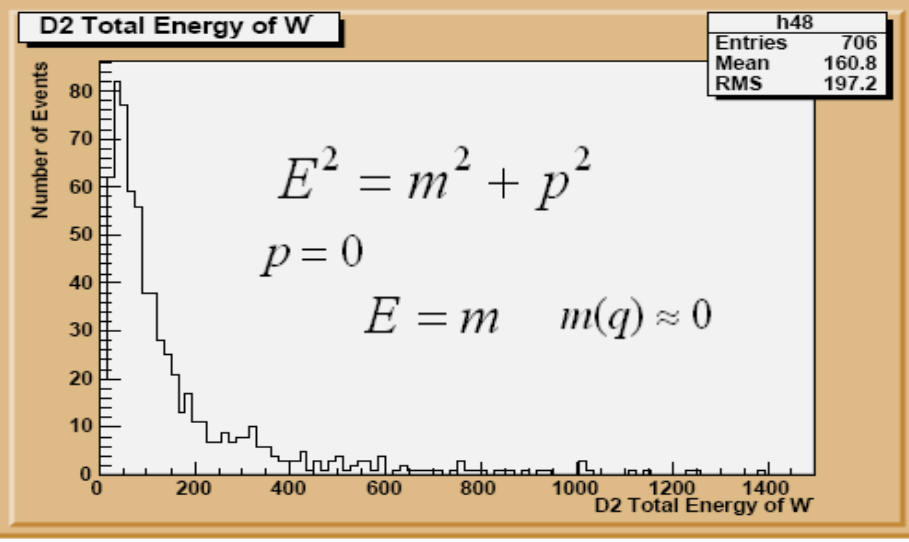
$$E = m \qquad m(q) \approx 0$$

P_T, E_T, E & P (GeV) of D_2 (W^-)

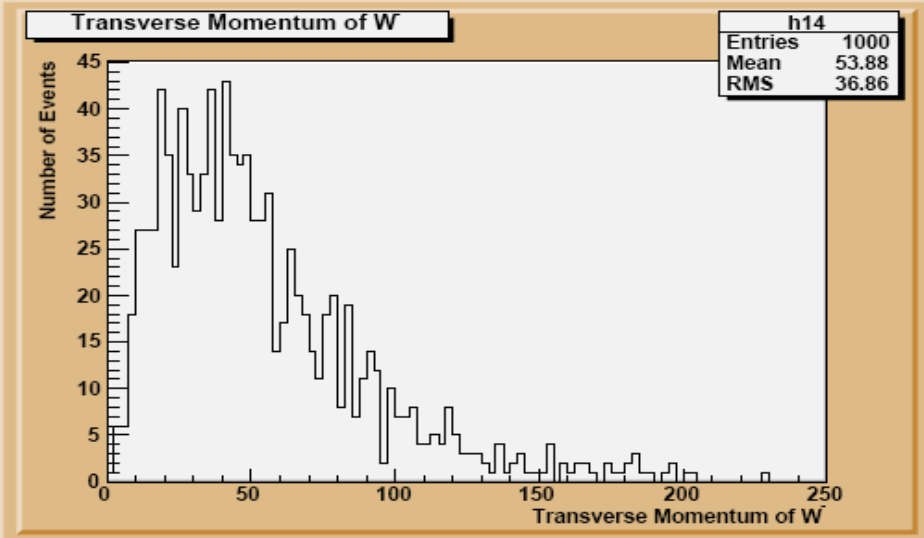


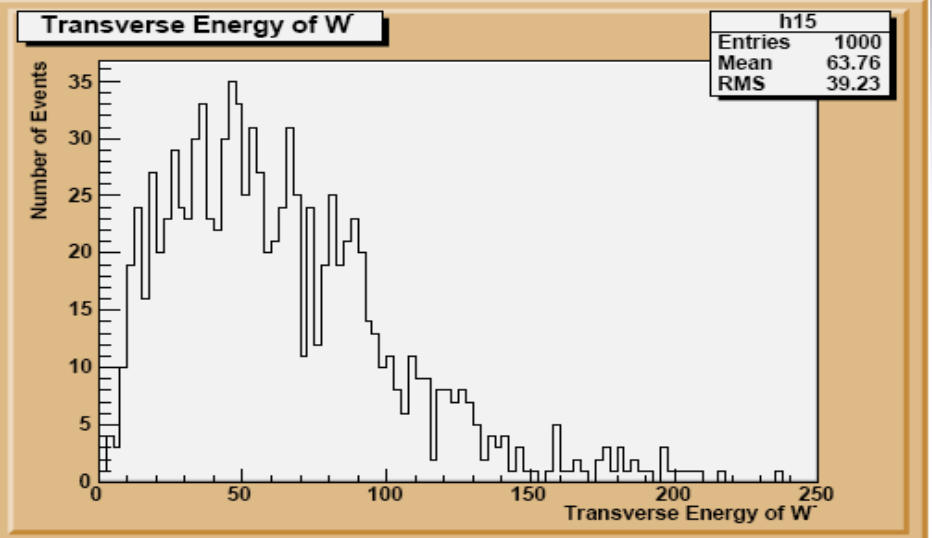


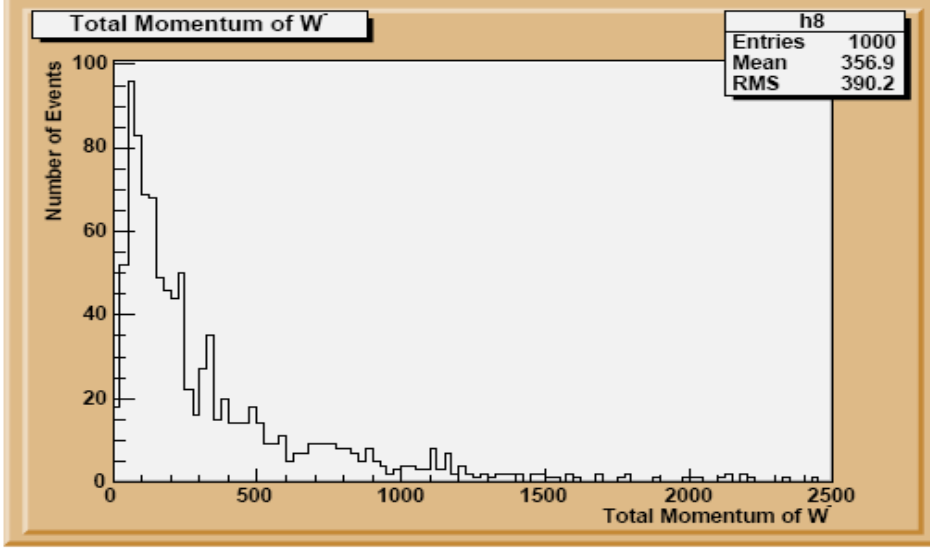


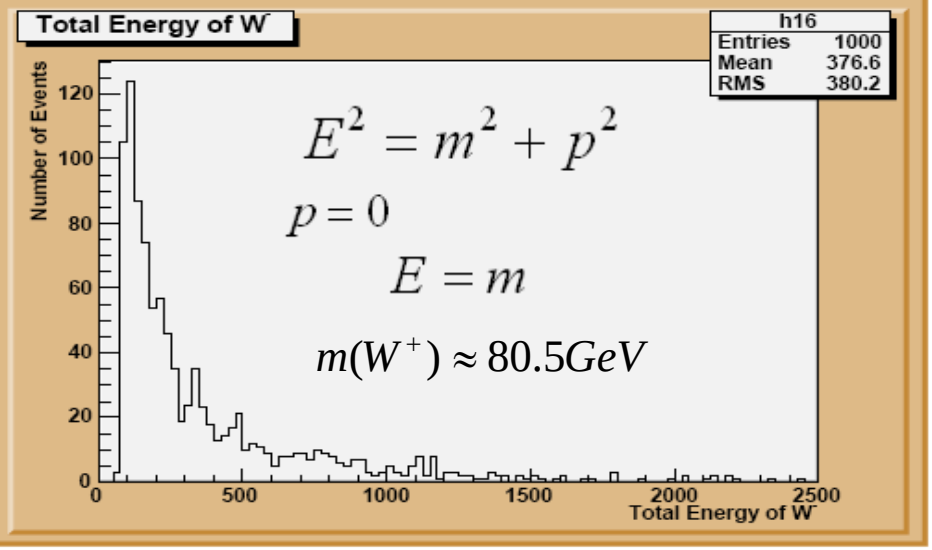


P_T, E_T, E & P (GeV) of W^-









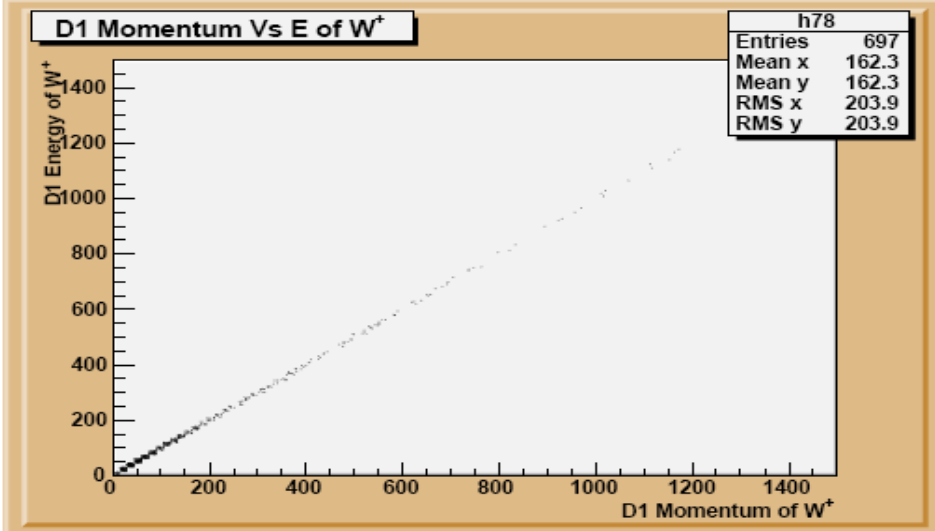
$$E^2 = m^2 + p^2$$

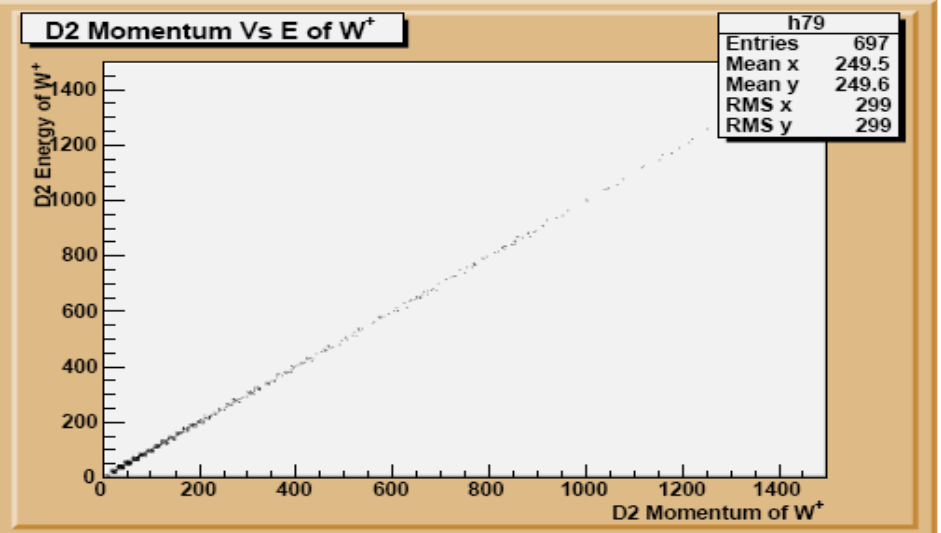
$$p = 0$$

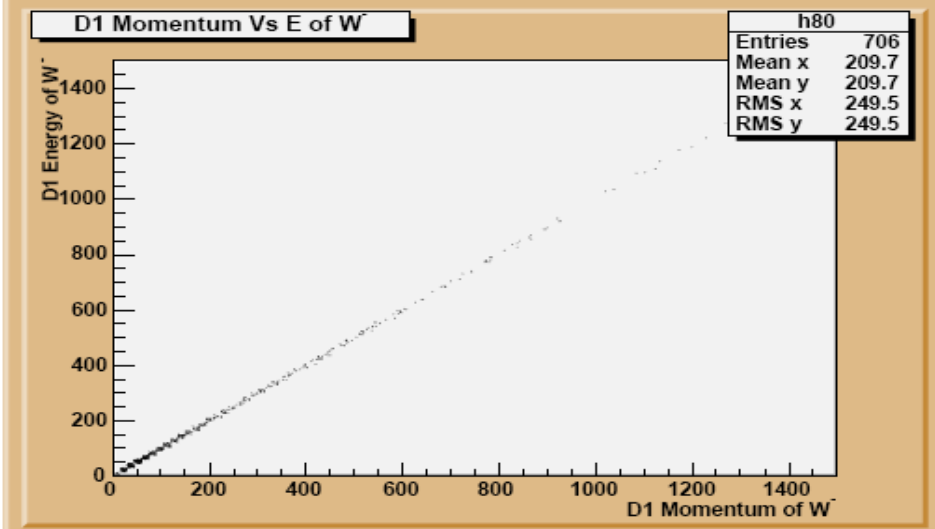
$$E = m$$

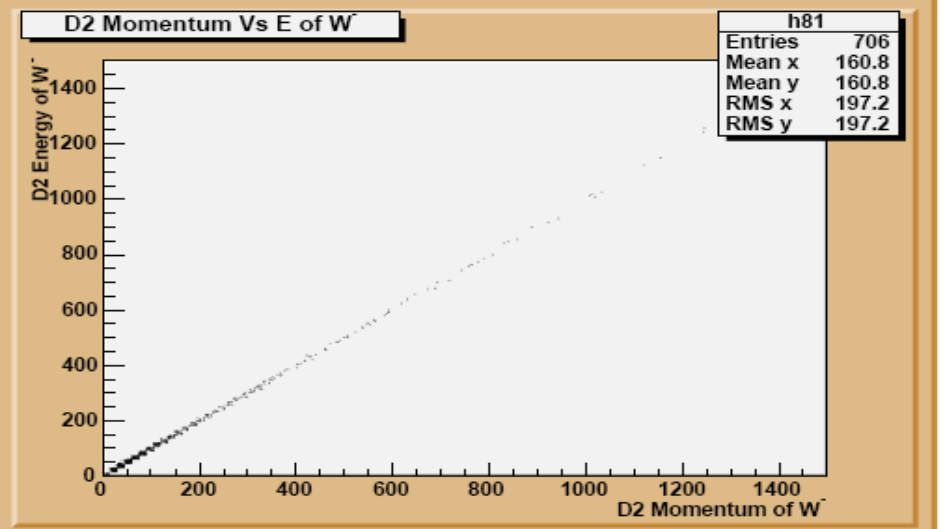
$$m(W^+) \approx 80.5 GeV$$

E Vs P (GeV) of D_1D_2 W^+W^-

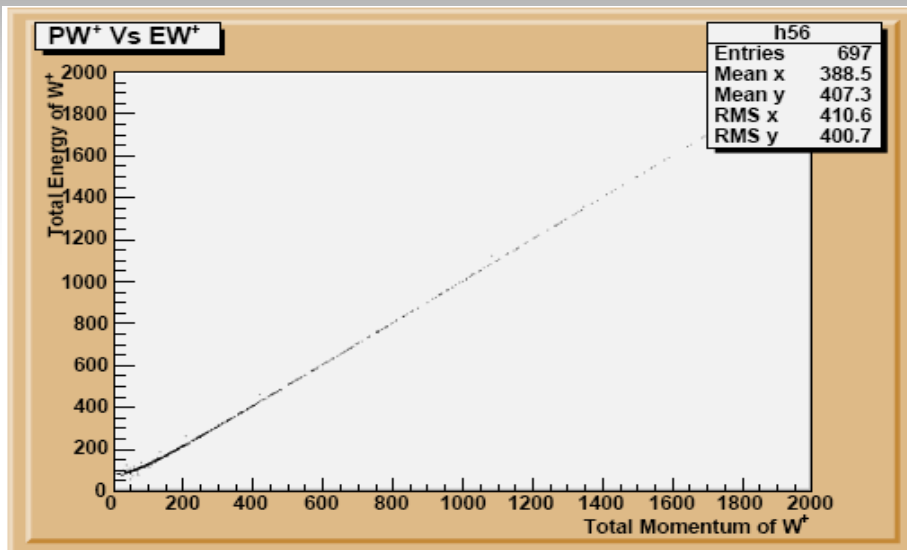


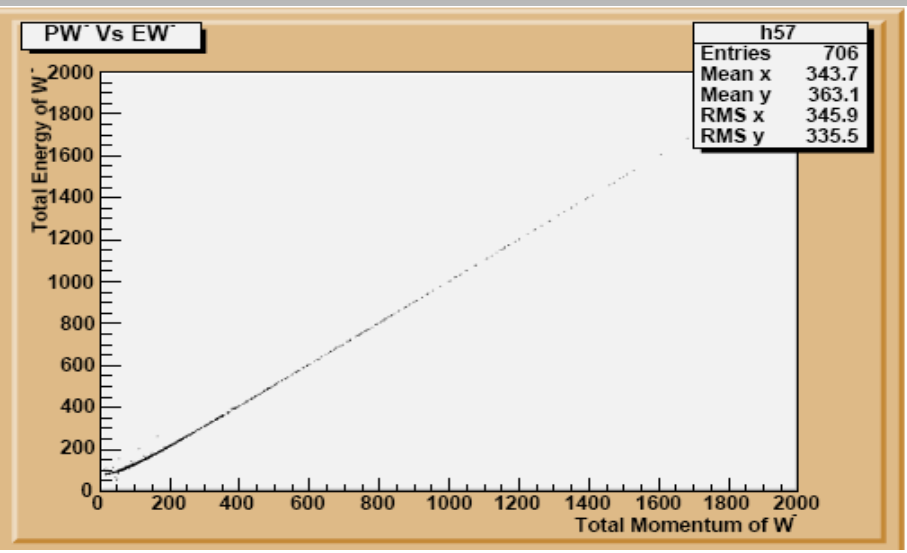


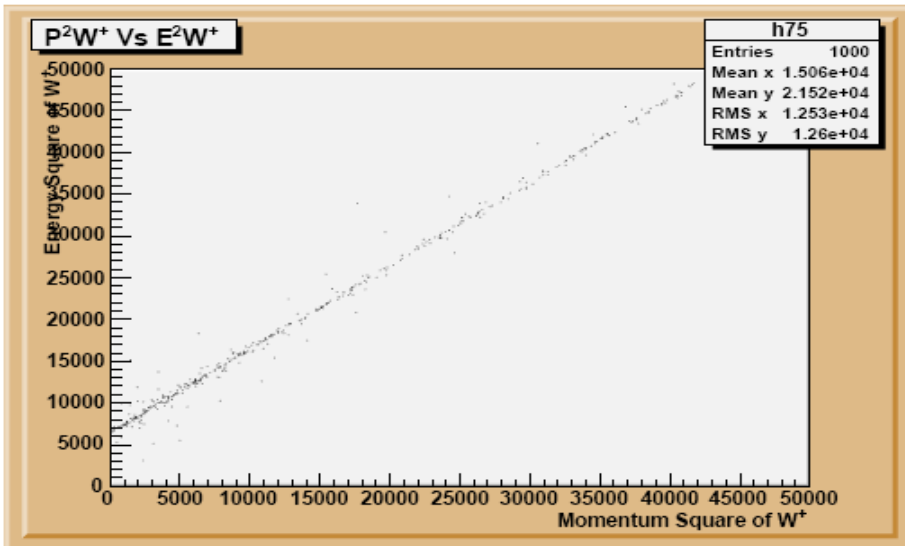


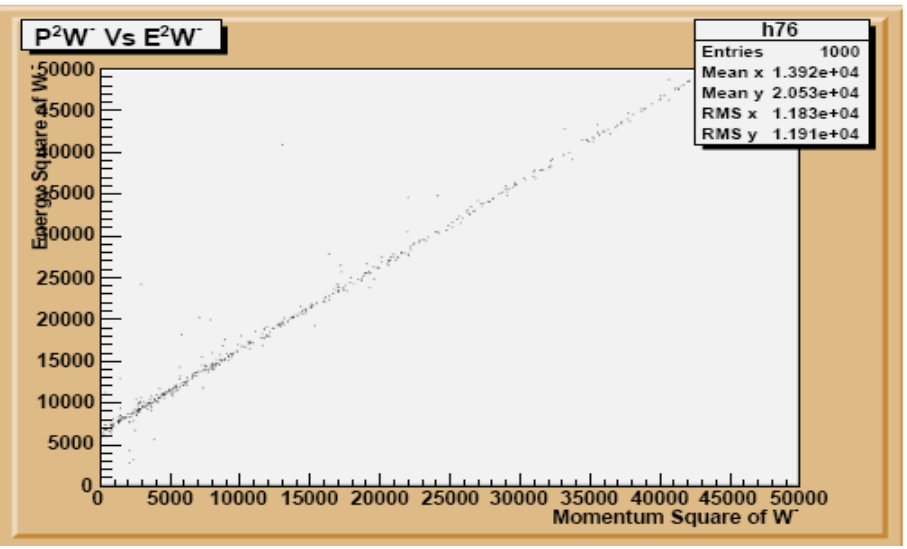


E Vs P, E^2 Vs P^2 of W^+,W^-

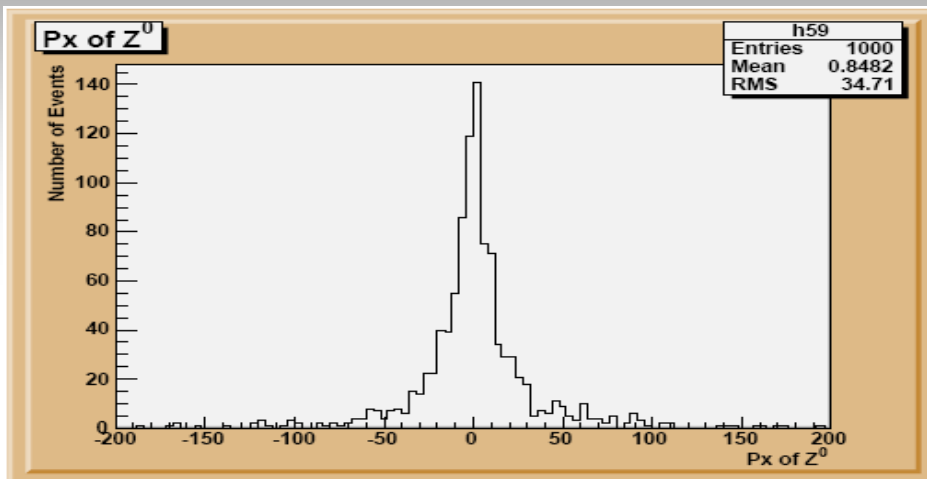


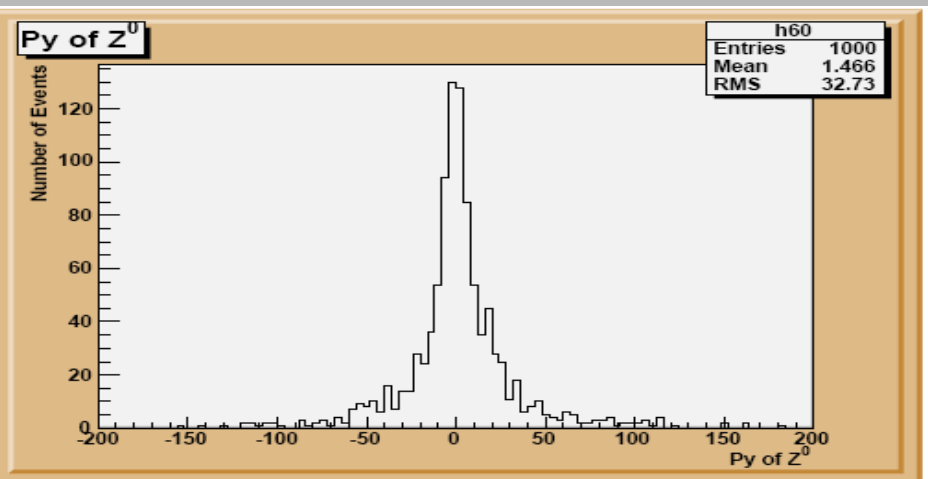


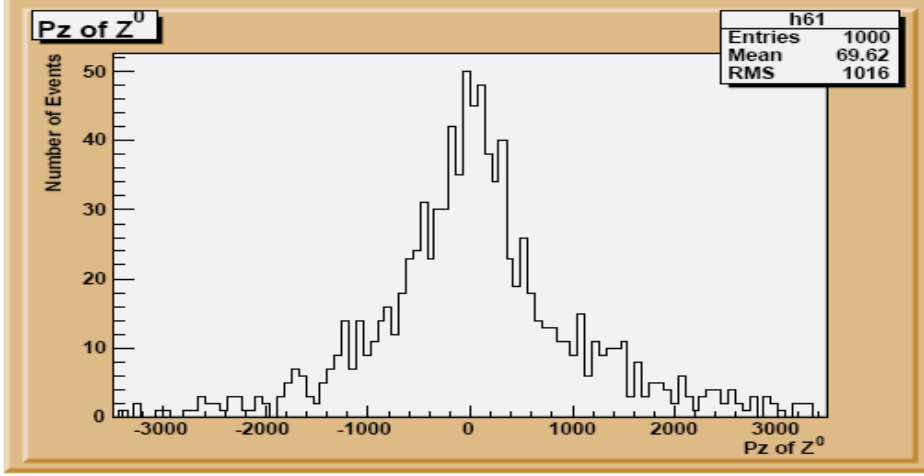


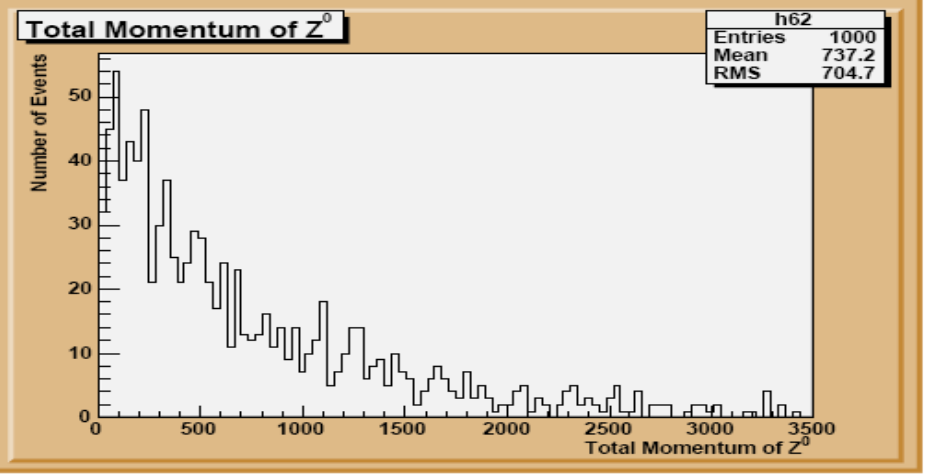


P Distribution Z°





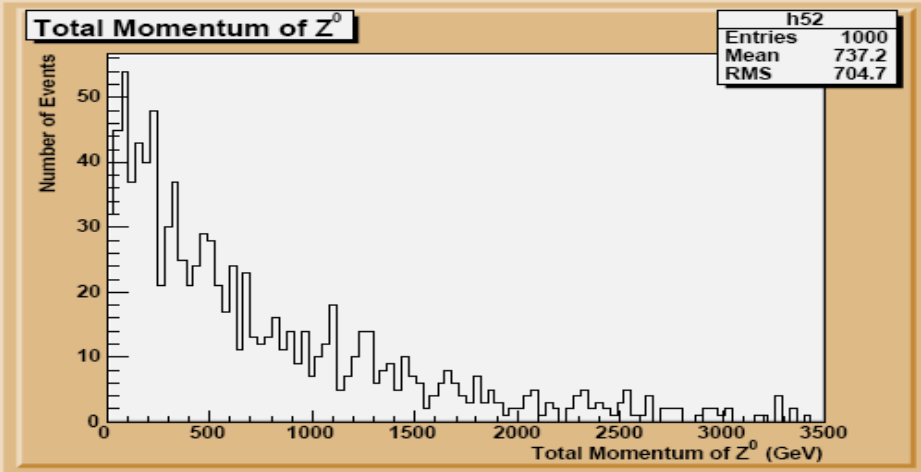


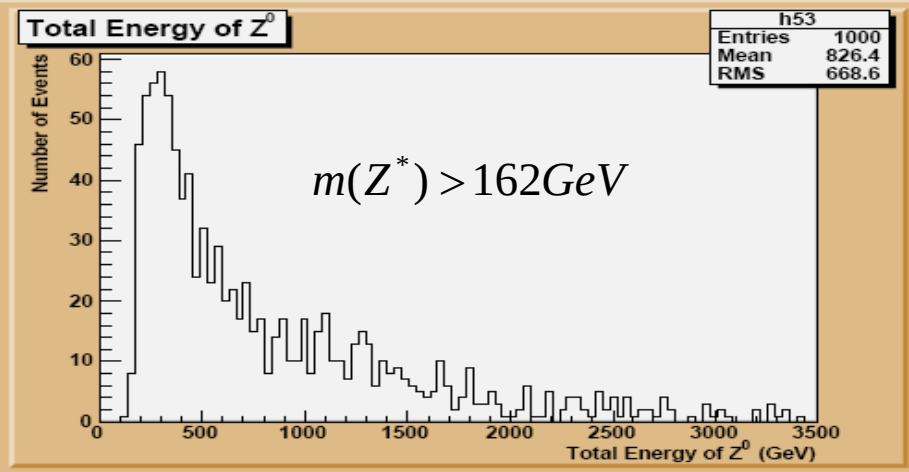


Total P (GeV) of Z^0 from W^+ & W^-

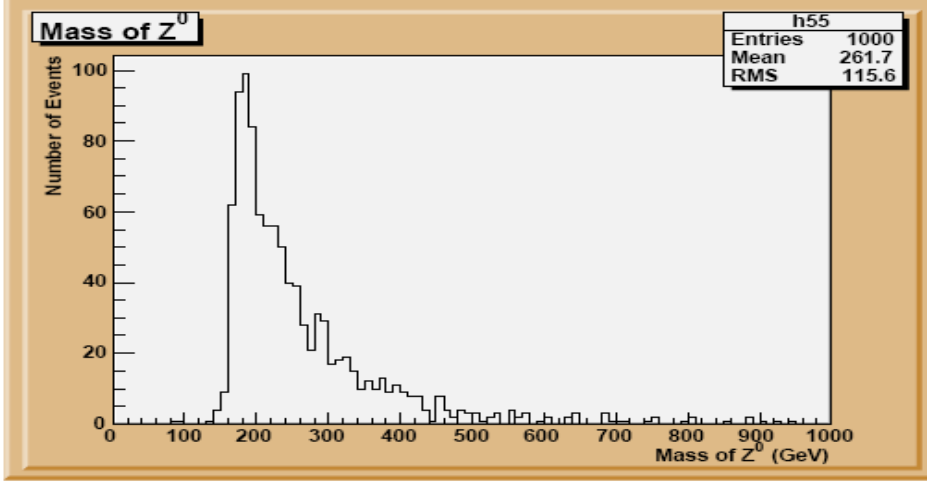
$$p_{Z^0} = \sqrt{\left(p_{W^+x} + p_{W^-x}\right)^2 + \left(p_{W^+y} + p_{W^-y}\right)^2 + \left(p_{W^+z} + p_{W^-z}\right)^2}$$

P, E & M (GeV) of Z^0





$$m(Z^*) > 162GeV$$



$$E_Z = E_{W^+} + E_{W^-}$$

$$p_{Z^0} = \sqrt{\left(p_{W^+x} + p_{W^-x}\right)^2 + \left(p_{W^+y} + p_{W^-y}\right)^2 + \left(p_{W^+z} + p_{W^-z}\right)^2}$$

CONCLUSIONS

- Calculated the different parameters like η, P, E, P_T, E_T, Opening Angle etc. of decaying products of both W^+W^-
- Then, using the four momenta, I reproduced the invariant mass (80.5 GeV) of W^+W^-
- Calculated the above parameters also for both W^+W^-
- Then, using the four momenta, I reproduced the invariant mass > 161 GeV
- Experimentally, there is no such a predicted particle whose mass is > 161 GeV
- So it proves that it's a virtual particle (γ^* , Z^*)
- The Monte Carlo results proved that the interaction between gauge bosons (known as Triple gauge-boson Couplings) exist.

OUTLOOK

- Converting my analysis code in latest version of CMS Software, which is CMSSW_3_1_4.
- First complete Generator Level analysis.
- Then detector simulation and reconstruction will be added in the analysis code.
- CMS official data sets are available at Tier-2 center of CERN computing Grid, which will be used for my analysis.

THANKS