

Updated Charged Pion Production Results

publication in preparation

The MINERvA Collaboration

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1 p_μ

1.1 Cross Section

p_μ (GeV/c)	$d\sigma/dp_\mu$	stat(%)	sys(%)	tot(%)
1.0 - 2.0	7.81	8	23	24
2.0 - 2.5	9.75	6	18	19
2.5 - 3.0	9.37	5	16	17
3.0 - 3.5	6.99	5	15	16
3.5 - 4.0	3.71	7	17	18
4.0 - 5.0	1.82	7	15	17
5.0 - 7.0	0.91	7	16	17
7.0 - 10.0	0.21	10	36	37

Flux averaged differential cross section in muon momentum p_μ , $d\sigma/dp_\mu$ ($10^{-40}\text{cm}^2/\text{GeV}/c/\text{nucleon}$), for $1\pi^+$ production with statistical (stat), systematic (syst), and total (tot) uncertainties.

1.2 Systematics Summary

p_μ (GeV/c)	I	II	III	IV	V	Total
1.0 - 2.0	14.1 (9.1)	15.7 (5.6)	4.4 (0.5)	7.5 (0.3)	2.1 (0.4)	22.9 (10.7)
2.0 - 2.5	10.8 (1.9)	11.3 (1.3)	4.8 (0.6)	7.5 (0.2)	1.8 (0.7)	18.1 (2.5)
2.5 - 3.0	10.4 (2.6)	8.4 (1.6)	4.6 (0.8)	7.5 (0.3)	1.7 (0.8)	16.1 (3.3)
3.0 - 3.5	10.6 (6.3)	6.2 (3.8)	3.1 (1.4)	7.4 (0.1)	1.5 (1.2)	14.8 (7.6)
3.5 - 4.0	13.1 (10.3)	5.7 (4.3)	3.6 (0.9)	7.4 (0.2)	1.8 (1.2)	16.6 (11.2)
4.0 - 5.0	10.7 (7.8)	5.7 (4.5)	4.2 (1.3)	7.4 (0.9)	3.0 (0.5)	15.1 (9.1)
5.0 - 7.0	11.6 (7.7)	6.1 (4.3)	4.1 (1.8)	7.4 (0.8)	3.8 (1.5)	16.1 (9.2)
7.0 - 10.0	22.4 (14.8)	6.5 (10.8)	12.5 (9.2)	7.4 (0.9)	22.6 (20.1)	35.6 (28.7)

Fractional systematic uncertainties (in percent) on $d\sigma/dp_\mu$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

1.3 Correlation Matrix

Bins (GeV/c)	1.0 - 2.0	2.0 - 2.5	2.5 - 3.0	3.0 - 3.5	3.5 - 4.0	4.0 - 5.0	5.0 - 7.0	7.0 - 10.0
1.0 - 2.0	1.0000	0.8233	0.7412	0.5550	0.3877	0.4677	0.4925	0.3903
2.0 - 2.5	0.8233	1.0000	0.8801	0.7732	0.6375	0.6793	0.6961	0.5098
2.5 - 3.0	0.7412	0.8801	1.0000	0.8381	0.7294	0.7515	0.7552	0.5502
3.0 - 3.5	0.5550	0.7732	0.8381	1.0000	0.8273	0.8055	0.8035	0.5050
3.5 - 4.0	0.3877	0.6375	0.7294	0.8273	1.0000	0.8034	0.7914	0.4740
4.0 - 5.0	0.4677	0.6793	0.7515	0.8055	0.8034	1.0000	0.8139	0.5420
5.0 - 7.0	0.4925	0.6961	0.7552	0.8035	0.7914	0.8139	1.0000	0.5913
7.0 - 10.0	0.3903	0.5098	0.5502	0.5050	0.4740	0.5420	0.5913	1.0000
1.0 - 2.0	1.0000	0.1642	-0.3171	-0.6067	-0.6386	-0.5757	-0.5576	-0.1863
2.0 - 2.5	0.1642	1.0000	-0.0198	-0.1519	-0.1949	-0.2179	-0.2172	-0.1160
2.5 - 3.0	-0.3171	-0.0198	1.0000	0.3218	0.2849	0.2237	0.1654	-0.0123
3.0 - 3.5	-0.6067	-0.1519	0.3218	1.0000	0.6435	0.5465	0.4989	-0.0361
3.5 - 4.0	-0.6386	-0.1949	0.2849	0.6435	1.0000	0.6175	0.5751	0.0417
4.0 - 5.0	-0.5757	-0.2179	0.2237	0.5465	0.6175	1.0000	0.5879	0.1085
5.0 - 7.0	-0.5576	-0.2172	0.1654	0.4989	0.5751	0.5879	1.0000	0.2036
7.0 - 10.0	-0.1863	-0.1160	-0.0123	-0.0361	0.0417	0.1085	0.2036	1.0000

Full correlation matrix followed by shape correlation matrix for bins of $d\sigma/dp_\mu$.

2 θ_μ

2.1 Cross Section

θ_μ (deg)	$d\sigma/d\theta_\mu$	stat(%)	sys(%)	tot(%)
0 - 2	0.36	10	12	15
2 - 4	0.83	6	12	14
4 - 6	1.19	6	13	14
6 - 8	1.37	6	13	15
8 - 10	1.57	6	14	15
10 - 12	1.31	7	16	17
12 - 16	0.90	7	19	20
16 - 20	0.88	10	25	27
20 - 25	0.47	21	54	58

Flux averaged differential cross section in muon angle θ_μ , $d\sigma/d\theta_\mu$ ($10^{-40}\text{cm}^2/\text{deg}/\text{nucleon}$) for $1\pi^+$ production with statistical (stat), systematic (syst), and total (tot) uncertainties.

2.2 Systematics Summary

θ_μ (deg)	I	II	III	IV	V	Total
0 - 2	8.1 (4.6)	1.1 (2.2)	3.5 (5.2)	7.5 (0.6)	2.2 (7.1)	11.8 (10.2)
2 - 4	8.7 (3.8)	1.9 (2.5)	3.3 (4.4)	7.5 (1.0)	2.3 (6.9)	12.3 (9.4)
4 - 6	9.0 (3.1)	1.8 (2.2)	3.7 (3.5)	7.5 (0.8)	1.9 (7.3)	12.5 (9.0)
6 - 8	10.0 (2.1)	1.9 (2.2)	3.8 (2.4)	7.5 (0.8)	2.5 (6.8)	13.4 (7.8)
8 - 10	10.4 (1.9)	1.8 (1.9)	4.4 (2.4)	7.5 (0.5)	2.6 (6.7)	13.9 (7.6)
10 - 12	12.1 (2.6)	2.0 (1.5)	5.3 (1.6)	7.5 (0.4)	3.2 (6.0)	15.7 (6.9)
12 - 16	15.0 (5.4)	2.9 (1.7)	6.4 (2.2)	7.6 (0.8)	6.2 (3.1)	19.2 (6.8)
16 - 20	18.1 (8.7)	4.3 (3.3)	7.6 (4.1)	7.7 (0.7)	12.0 (3.1)	24.7 (10.6)
20 - 25	14.7 (20.1)	14.7 (12.2)	13.4 (9.9)	8.9 (3.2)	47.2 (38.3)	54.0 (46.2)

Fractional systematic uncertainties (in percent) on $d\sigma/d\theta_\mu$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

2.3 Correlation Matrix

Bins (deg)	0 - 2	2 - 4	4 - 6	6 - 8	8 - 10	10 - 12	12 - 16	16 - 20	20 - 25
0 - 2	1.0000	0.6702	0.6781	0.6674	0.6651	0.6235	0.5703	0.4969	0.1554
2 - 4	0.6702	1.0000	0.7992	0.7951	0.7785	0.7447	0.7025	0.5929	0.1836
4 - 6	0.6781	0.7992	1.0000	0.8294	0.8203	0.7917	0.7531	0.6406	0.1718
6 - 8	0.6674	0.7951	0.8294	1.0000	0.8369	0.8226	0.7997	0.7014	0.2123
8 - 10	0.6651	0.7785	0.8203	0.8369	1.0000	0.8372	0.8105	0.7234	0.2047
10 - 12	0.6235	0.7447	0.7917	0.8226	0.8372	1.0000	0.8349	0.7561	0.2243
12 - 16	0.5703	0.7025	0.7531	0.7997	0.8105	0.8349	1.0000	0.8226	0.3195
16 - 20	0.4969	0.5929	0.6406	0.7014	0.7234	0.7561	0.8226	1.0000	0.4216
20 - 25	0.1554	0.1836	0.1718	0.2123	0.2047	0.2243	0.3195	0.4216	1.0000
0 - 2	1.0000	0.5795	0.5779	0.5239	0.5003	0.3314	-0.0214	-0.3192	-0.4289
2 - 4	0.5795	1.0000	0.6867	0.6363	0.5841	0.4145	0.0470	-0.3709	-0.5348
4 - 6	0.5779	0.6867	1.0000	0.6694	0.6310	0.4724	0.1087	-0.3374	-0.6043
6 - 8	0.5239	0.6363	0.6694	1.0000	0.6099	0.4889	0.1670	-0.2641	-0.6272
8 - 10	0.5003	0.5841	0.6310	0.6099	1.0000	0.5216	0.2038	-0.1944	-0.6536
10 - 12	0.3314	0.4145	0.4724	0.4889	0.5216	1.0000	0.3185	-0.0281	-0.6212
12 - 16	-0.0214	0.0470	0.1087	0.1670	0.2038	0.3185	1.0000	0.2504	-0.4432
16 - 20	-0.3192	-0.3709	-0.3374	-0.2641	-0.1944	-0.0281	0.2504	1.0000	-0.0346
20 - 25	-0.4289	-0.5348	-0.6043	-0.6272	-0.6536	-0.6212	-0.4432	-0.0346	1.0000

Correlation matrix followed by shape correlation matrix for bins of $d\sigma/d\theta_\mu$.

3 θ_π

3.1 Cross Section

θ_π (deg)	$d\sigma/d\theta_\pi$	stat(%)	sys(%)	tot(%)
0 - 15	0.12	8	22	23
15 - 22	0.23	8	19	21
22 - 29	0.28	7	19	20
29 - 36	0.38	6	19	20
36 - 43	0.36	6	19	20
43 - 50	0.30	7	19	20
50 - 57	0.23	8	19	21
57 - 72	0.22	8	18	20
72 - 108	0.17	6	18	19
108 - 130	0.10	10	18	21
130 - 140	0.08	9	17	19
140 - 150	0.06	10	17	19
150 - 165	0.04	13	16	21
165 - 180	0.02	19	17	26

Flux averaged differential cross section in muon angle θ_π , $d\sigma/d\theta_\pi$ (10^{-40} cm²/deg/nucleon) for $1\pi^+$ production with statistical (stat), systematic (syst), and total (tot) uncertainties.

3.2 Systematics Summary

θ_π (deg)	I	II	III	IV	V	Total
0 - 15	11.4 (2.1)	12.8 (2.7)	9.4 (4.6)	7.7 (0.2)	4.8 (1.3)	21.6 (5.9)
15 - 22	10.1 (2.6)	12.5 (2.3)	5.9 (1.8)	7.8 (0.7)	3.8 (0.3)	19.2 (3.9)
22 - 29	10.3 (1.8)	12.6 (2.5)	4.6 (2.4)	7.9 (0.7)	3.3 (1.5)	18.9 (4.2)
29 - 36	10.9 (1.3)	12.1 (2.0)	4.9 (1.8)	7.7 (0.2)	3.3 (1.6)	19.0 (3.4)
36 - 43	11.4 (2.1)	12.0 (1.9)	5.2 (1.7)	7.7 (0.1)	3.3 (0.8)	19.3 (3.4)
43 - 50	12.0 (2.2)	11.6 (1.8)	4.7 (1.7)	7.7 (0.3)	3.2 (0.9)	19.3 (3.4)
50 - 57	11.6 (2.3)	12.0 (1.9)	4.3 (1.7)	7.6 (0.5)	4.8 (1.5)	19.5 (3.8)
57 - 72	11.3 (1.3)	10.7 (0.8)	3.2 (3.5)	7.7 (0.5)	3.9 (0.6)	18.1 (3.9)
72 - 108	11.0 (1.1)	8.4 (1.8)	6.7 (2.6)	7.7 (0.2)	4.5 (0.7)	17.7 (3.5)
108 - 130	11.6 (3.1)	6.2 (4.0)	9.0 (5.1)	7.6 (0.4)	4.6 (0.7)	18.3 (7.3)
130 - 140	10.1 (2.8)	6.6 (3.7)	8.0 (5.4)	7.7 (0.2)	4.4 (1.1)	17.0 (7.2)
140 - 150	9.6 (3.2)	7.1 (3.2)	7.3 (4.8)	7.7 (0.7)	4.4 (0.6)	16.5 (6.7)
150 - 165	10.0 (3.1)	5.6 (4.6)	6.7 (5.6)	7.9 (1.4)	5.5 (1.7)	16.4 (8.2)
165 - 180	11.6 (2.8)	4.0 (6.4)	5.9 (8.8)	7.6 (1.3)	7.2 (3.7)	17.2 (11.9)

Fractional systematic uncertainties (in percent) on $d\sigma/d\theta_\pi$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

3.3 Correlation Matrix

Bins (deg)	0 - 15	15 - 22	22 - 29	29 - 36	36 - 43	43 - 50	50 - 57	57 - 72	72 - 108	108 - 130	130 - 140	140 - 150	150 - 165	165 - 180
0 - 15	1.0000	0.8411	0.8344	0.8561	0.8561	0.8437	0.8104	0.7787	0.8562	0.7050	0.7002	0.6942	0.5834	0.4134
15 - 22	0.8411	1.0000	0.8468	0.8617	0.8606	0.8438	0.8254	0.7975	0.8330	0.6916	0.6979	0.6959	0.6005	0.4242
22 - 29	0.8344	0.8468	1.0000	0.8735	0.8608	0.8527	0.8377	0.8141	0.8475	0.6781	0.6873	0.6856	0.5911	0.4354
29 - 36	0.8561	0.8617	0.8735	1.0000	0.8897	0.8810	0.8574	0.8376	0.8573	0.7041	0.7238	0.7180	0.6152	0.4589
36 - 43	0.8561	0.8606	0.8608	0.8897	1.0000	0.8924	0.8637	0.8317	0.8607	0.7207	0.7273	0.7261	0.6309	0.4594
43 - 50	0.8437	0.8438	0.8527	0.8810	0.8924	1.0000	0.8564	0.8264	0.8589	0.7070	0.7171	0.7169	0.6203	0.4633
50 - 57	0.8104	0.8254	0.8377	0.8574	0.8637	0.8564	1.0000	0.8160	0.8358	0.7020	0.7147	0.7176	0.6325	0.4621
57 - 72	0.7787	0.7975	0.8141	0.8376	0.8317	0.8264	0.8160	1.0000	0.8095	0.7047	0.7304	0.7186	0.6330	0.5031
72 - 108	0.8562	0.8330	0.8475	0.8573	0.8607	0.8589	0.8358	0.8095	1.0000	0.7619	0.7509	0.7447	0.6452	0.4745
108 - 130	0.7050	0.6916	0.6781	0.7041	0.7207	0.7070	0.7020	0.7047	0.7047	1.0000	0.7444	0.7208	0.6442	0.4579
130 - 140	0.7002	0.6979	0.6873	0.7238	0.7273	0.7171	0.7147	0.7304	0.7509	0.7444	1.0000	0.7534	0.6670	0.4832
140 - 150	0.6942	0.6959	0.6856	0.7180	0.7261	0.7169	0.7176	0.7186	0.7447	0.7208	0.7534	1.0000	0.6555	0.4646
150 - 165	0.5834	0.6005	0.5911	0.6152	0.6309	0.6203	0.6325	0.6330	0.6452	0.6442	0.6670	0.6555	1.0000	0.4535
165 - 180	0.4134	0.4242	0.4354	0.4589	0.4594	0.4633	0.4621	0.5031	0.4745	0.4579	0.4832	0.4646	0.4535	1.0000
0 - 15	1.0000	0.1354	0.0517	0.0744	0.0749	0.0398	-0.0402	-0.1437	0.0246	-0.1014	-0.1758	-0.1729	-0.2075	-0.1953
15 - 22	0.1354	1.0000	0.1271	0.1103	0.0946	0.0315	0.0284	-0.0353	-0.0906	-0.1318	-0.1414	-0.1208	-0.1098	-0.1260
22 - 29	0.0517	0.1271	1.0000	0.1420	0.0449	0.0407	0.0565	0.0178	-0.0405	-0.2110	-0.2069	-0.1831	-0.1541	-0.1015
29 - 36	0.0744	0.1103	0.1420	1.0000	0.1160	0.1053	0.0622	0.0401	-0.1384	-0.2093	-0.1596	-0.1514	-0.1535	-0.0861
36 - 43	0.0749	0.0946	0.0449	0.1160	1.0000	0.1810	0.0954	-0.0129	-0.1380	-0.1503	-0.1665	-0.1366	-0.1135	-0.1024
43 - 50	0.0398	0.0315	0.0407	0.1053	0.1810	1.0000	0.0944	0.0027	-0.0817	-0.1692	-0.1678	-0.1353	-0.1212	-0.0702
50 - 57	-0.0402	0.0284	0.0565	0.0622	0.0954	0.0944	1.0000	0.0405	0.0100	-0.1010	-0.1094	-0.0992	-0.0607	-0.0412
57 - 72	-0.1437	-0.0353	0.0178	0.0401	-0.0129	0.0027	0.0405	1.0000	-0.1240	-0.0187	0.0545	0.0374	0.0490	0.1203
72 - 108	0.0246	-0.0906	-0.0405	-0.0405	-0.1384	-0.1380	-0.0817	-0.1010	1.0000	0.0718	0.0009	0.0073	-0.0021	-0.0014
108 - 130	-0.1014	-0.1318	-0.2110	-0.2093	-0.1503	-0.1692	-0.1094	-0.0187	0.0718	1.0000	0.2879	0.2371	0.2143	0.1062
130 - 140	-0.1758	-0.1414	-0.2069	-0.1596	-0.1665	-0.1678	-0.0992	0.0545	0.0009	0.2879	1.0000	0.3333	0.2787	0.1714
140 - 150	-0.1729	-0.1208	-0.1831	-0.1514	-0.1366	-0.1353	-0.0607	0.0374	0.0073	0.2371	0.3333	1.0000	0.2632	0.1452
150 - 165	-0.2075	-0.1098	-0.1541	-0.1535	-0.1135	-0.1212	-0.0279	0.0490	-0.0021	0.2143	0.2787	0.2632	1.0000	0.1924
165 - 180	-0.1953	-0.1260	-0.1015	-0.0861	-0.1024	-0.0702	-0.0412	0.1203	-0.0014	0.1062	0.1714	0.1452	0.1924	1.0000

Correlation matrix followed by shape correlation matrix for bins of $d\sigma/d\theta_\pi$.

4 T_π

4.1 Cross Section

T_π (MeV)	$d\sigma/dT_\pi$	stat(%)	sys(%)	tot(%)
35 - 55	0.12	14	21	26
55 - 75	0.13	7	20	21
75 - 100	0.12	6	17	18
100 - 125	0.09	6	16	17
125 - 150	0.08	6	17	18
150 - 200	0.07	5	16	17
200 - 350	0.04	5	22	22

Flux averaged differential cross section in T_π , $d\sigma/dT_\pi$ ($10^{-40}\text{cm}^2/\text{MeV}/\text{nucleon}$) for $1\pi^+$ production with statistical (stat), systematic (syst), and total (tot) uncertainties.

4.2 Systematics Summary

T_π (MeV)	I	II	III	IV	V	Total
35 - 55	15.0 (9.7)	9.5 (2.3)	6.8 (2.9)	7.7 (0.5)	5.4 (1.9)	21.2 (10.5)
55 - 75	11.7 (5.1)	9.6 (3.1)	8.5 (4.6)	7.7 (0.3)	4.8 (1.4)	19.6 (7.6)
75 - 100	10.0 (5.3)	9.2 (2.3)	6.6 (3.8)	7.7 (0.4)	3.9 (0.7)	17.4 (7.0)
100 - 125	11.3 (3.3)	6.8 (1.7)	5.0 (1.8)	7.8 (0.5)	3.1 (0.7)	16.4 (4.2)
125 - 150	12.7 (3.3)	6.6 (1.5)	5.3 (1.9)	7.7 (0.2)	3.3 (0.2)	17.4 (4.1)
150 - 200	11.1 (3.3)	6.9 (2.0)	5.3 (2.8)	7.7 (0.2)	2.8 (1.8)	16.3 (5.1)
200 - 350	16.6 (7.4)	8.2 (1.4)	7.8 (4.1)	7.7 (0.2)	3.0 (1.3)	21.7 (8.6)

Fractional systematic uncertainties (in percent) on $d\sigma/dT_\pi$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

4.3 Full Correlation Matrix

Bins (MeV)	35 - 55	55 - 75	75 - 100	100 - 125	125 - 150	150 - 200	200 - 350
35 - 55	1.0000	0.7178	0.6969	0.6691	0.6598	0.5719	0.5313
55 - 75	0.7178	1.0000	0.8679	0.8090	0.7962	0.6995	0.6617
75 - 100	0.6969	0.8679	1.0000	0.8266	0.8137	0.7249	0.6626
100 - 125	0.6691	0.8090	0.8266	1.0000	0.8823	0.8166	0.7830
125 - 150	0.6598	0.7962	0.8137	0.8823	1.0000	0.8295	0.8024
150 - 200	0.5719	0.6995	0.7249	0.8166	0.8295	1.0000	0.8985
200 - 350	0.5313	0.6617	0.6626	0.7830	0.8024	0.8985	1.0000
35 - 55	1.0000	0.2812	0.1992	0.0244	-0.0165	-0.2894	-0.3614
55 - 75	0.2812	1.0000	0.4578	0.0762	0.0012	-0.4101	-0.5079
75 - 100	0.1992	0.4578	1.0000	0.1801	0.0794	-0.2635	-0.5860
100 - 125	0.0244	0.0762	0.1801	1.0000	0.2653	-0.0376	-0.2881
125 - 150	-0.0165	0.0012	0.0794	0.2653	1.0000	-0.0198	-0.1724
150 - 200	-0.2894	-0.4101	-0.2635	-0.0376	-0.0198	1.0000	0.3278
200 - 350	-0.3614	-0.5079	-0.5860	-0.2881	-0.1724	0.3278	1.0000

Correlation matrix followed by shape correlation matrix for bins of $d\sigma/dT_\pi$.

5 E_ν

5.1 Cross Section

E_ν (GeV)	$\sigma(E_\nu)$	stat(%)	sys(%)	tot(%)
1.5 - 2.0	21.60	29	39	49
2.0 - 3.0	27.93	5	20	20
3.0 - 3.5	30.02	5	18	19
3.5 - 4.0	30.45	5	17	18
4.0 - 5.0	27.43	5	19	20
5.0 - 6.0	30.09	9	16	19
6.0 - 8.0	33.30	7	18	19
8.0 - 10.0	29.00	11	19	22

Total cross section in neutrino energy E_ν , $\sigma(E_\nu)$ ($10^{-40}\text{cm}^2/\text{nucleon}$) for $1\pi^+$ production with statistical (stat), systematic (sys), and total (tot) uncertainties.

5.2 Systematics Summary

E_ν (GeV)	I	II	III	IV	V	Total
1.5 - 2.0	32.9 (31.6)	17.3 (7.7)	7.9 (3.9)	8.2 (3.4)	2.9 (0.7)	39.0 (32.9)
2.0 - 3.0	11.5 (4.8)	13.3 (3.8)	4.7 (0.6)	7.6 (3.5)	1.4 (1.5)	19.8 (7.2)
3.0 - 3.5	10.3 (3.6)	11.4 (2.0)	5.4 (1.2)	7.1 (2.7)	1.7 (1.2)	17.9 (5.2)
3.5 - 4.0	10.8 (5.8)	10.1 (1.0)	3.6 (1.3)	7.8 (3.3)	1.7 (1.4)	17.2 (7.0)
4.0 - 5.0	12.0 (7.6)	9.1 (1.3)	3.4 (1.4)	10.8 (6.5)	1.8 (1.3)	18.9 (10.3)
5.0 - 6.0	10.1 (4.5)	6.9 (3.2)	4.3 (1.0)	9.4 (3.2)	3.5 (0.5)	16.4 (6.5)
6.0 - 8.0	11.7 (4.8)	6.5 (3.7)	4.7 (1.9)	9.4 (3.8)	4.4 (1.6)	17.5 (7.6)
8.0 - 10.0	13.0 (5.7)	6.6 (4.3)	4.7 (1.6)	9.5 (4.6)	6.1 (3.1)	19.0 (9.2)

Fractional systematic uncertainties (in percent) on $\sigma(E_\nu)$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

5.3 Full Correlation Matrix

Bins (GeV)	1.5 - 2.0	2.0 - 3.0	3.0 - 3.5	3.5 - 4.0	4.0 - 5.0	5.0 - 6.0	6.0 - 8.0	8.0 - 10.0
1.5 - 2.0	1.0000	0.5408	0.4099	0.2066	0.1154	0.2021	0.2040	0.1936
2.0 - 3.0	0.5408	1.0000	0.9010	0.7637	0.6321	0.6400	0.6705	0.5944
3.0 - 3.5	0.4099	0.9010	1.0000	0.8451	0.7414	0.7061	0.7173	0.6315
3.5 - 4.0	0.2066	0.7637	0.8451	1.0000	0.8775	0.7643	0.7365	0.6491
4.0 - 5.0	0.1154	0.6321	0.7414	0.8775	1.0000	0.7774	0.7091	0.6295
5.0 - 6.0	0.2021	0.6400	0.7061	0.7643	0.7774	1.0000	0.7719	0.7003
6.0 - 8.0	0.2040	0.6705	0.7173	0.7365	0.7091	0.7719	1.0000	0.7850
8.0 - 10.0	0.1936	0.5944	0.6315	0.6491	0.6295	0.7003	0.7850	1.0000
1.5 - 2.0	1.0000	0.3641	-0.0117	-0.4470	-0.4870	-0.3375	-0.3640	-0.2571
2.0 - 3.0	0.3641	1.0000	0.4063	-0.1682	-0.4323	-0.4366	-0.3924	-0.3419
3.0 - 3.5	-0.0117	0.4063	1.0000	0.2158	-0.0166	-0.1959	-0.2319	-0.2538
3.5 - 4.0	-0.4470	-0.1682	0.2158	1.0000	0.5982	0.1954	0.0352	-0.0450
4.0 - 5.0	-0.4870	-0.4323	-0.0166	0.5982	1.0000	0.3469	0.1000	0.0328
5.0 - 6.0	-0.3375	-0.4366	-0.1959	0.1954	0.3469	1.0000	0.2917	0.2118
6.0 - 8.0	-0.3640	-0.3924	-0.2319	0.0352	0.1000	0.2917	1.0000	0.4184
8.0 - 10.0	-0.2571	-0.3419	-0.2538	-0.0450	0.0328	0.2118	0.4184	1.0000

Correlation matrix followed by shape correlation matrix for bins of $\sigma(E_\nu)$.

6 Q^2

6.1 Cross Section

Q^2 (GeV^2)	$d\sigma/dQ^2$	stat(%)	sys(%)	tot(%)
0.00 - 0.10	36.40	4	11	12
0.10 - 0.25	35.04	4	13	14
0.25 - 0.40	24.58	6	15	16
0.40 - 0.60	19.46	6	17	18
0.60 - 0.85	14.18	8	21	22
0.85 - 1.15	8.63	10	26	28
1.15 - 1.55	5.33	13	40	42
1.55 - 2.00	4.06	17	45	48

Flux averaged differential cross section in muon angle Q^2 , $d\sigma/dQ^2$ ($10^{-40}\text{cm}^2/\text{GeV}^2/\text{nucleon}$) for $1\pi^+$ production with statistical (stat), systematic (syst), and total (tot) uncertainties.

6.2 Systematics Summary

Q^2 (GeV^2)	I	II	III	IV	V	Total
0.00 - 0.10	7.7 (8.5)	1.3 (3.3)	3.4 (5.0)	7.5 (1.2)	0.8 (6.2)	11.4 (12.2)
0.10 - 0.25	9.7 (4.9)	1.3 (3.6)	3.6 (3.2)	7.6 (0.9)	1.5 (5.6)	13.0 (8.9)
0.25 - 0.40	11.5 (3.3)	2.1 (4.0)	5.2 (3.2)	7.7 (0.6)	1.8 (5.5)	15.0 (8.3)
0.40 - 0.60	13.5 (1.8)	2.8 (3.2)	4.8 (2.4)	7.9 (0.5)	2.6 (4.4)	16.8 (6.2)
0.60 - 0.85	15.5 (4.3)	5.5 (4.3)	7.8 (4.9)	8.4 (1.6)	6.1 (1.2)	21.0 (8.1)
0.85 - 1.15	17.4 (6.1)	8.6 (4.9)	9.6 (4.5)	8.6 (1.8)	12.2 (5.3)	26.3 (10.6)
1.15 - 1.55	19.4 (9.8)	17.3 (13.8)	15.8 (10.9)	8.4 (2.2)	24.9 (18.0)	40.2 (27.1)
1.55 - 2.00	23.4 (13.9)	18.6 (15.1)	15.6 (11.1)	8.8 (4.4)	29.1 (22.2)	45.4 (32.5)

Fractional systematic uncertainties (in percent) on $d\sigma/dQ^2$. Parentheses indicate shape error.

Breakdown of systematic uncertainty: detector response (I), neutrino cross section model (II), nuclear effects including FSI (III), flux (IV), and other sources (V).

6.3 Full Correlation Matrix

Bins (GeV^2)	0.00 - 0.10	0.10 - 0.25	0.25 - 0.40	0.40 - 0.60	0.60 - 0.85	0.85 - 1.15	1.15 - 1.55	1.55 - 2.00
0.00 - 0.10	1.0000	0.8275	0.7630	0.6961	0.5447	0.4778	0.3362	0.2956
0.10 - 0.25	0.8275	1.0000	0.8599	0.8423	0.7335	0.6439	0.4510	0.4148
0.25 - 0.40	0.7630	0.8599	1.0000	0.8491	0.7391	0.6670	0.4614	0.4189
0.40 - 0.60	0.6961	0.8423	0.8491	1.0000	0.8223	0.7542	0.5453	0.5174
0.60 - 0.85	0.5447	0.7335	0.7391	0.8223	1.0000	0.8211	0.6012	0.5751
0.85 - 1.15	0.4778	0.6439	0.6670	0.7542	0.8211	1.0000	0.7798	0.7491
1.15 - 1.55	0.3362	0.4510	0.4614	0.5453	0.6012	0.7798	1.0000	0.8764
1.55 - 2.00	0.2956	0.4148	0.4189	0.5174	0.5751	0.7491	0.8764	1.0000
0.00 - 0.10	1.0000	0.7972	0.6115	0.3401	-0.2175	-0.6300	-0.6538	-0.6569
0.10 - 0.25	0.7972	1.0000	0.6650	0.4646	-0.0636	-0.5931	-0.7319	-0.7215
0.25 - 0.40	0.6115	0.6650	1.0000	0.4977	-0.0031	-0.4587	-0.6706	-0.6740
0.40 - 0.60	0.3401	0.4646	0.4977	1.0000	0.1931	-0.2695	-0.5774	-0.5464
0.60 - 0.85	-0.2175	-0.0636	-0.0031	0.1931	1.0000	0.2360	-0.1827	-0.1600
0.85 - 1.15	-0.6300	-0.5931	-0.4587	-0.2695	0.2360	1.0000	0.4455	0.4297
1.15 - 1.55	-0.6538	-0.7319	-0.6706	-0.5774	-0.1827	0.4455	1.0000	0.7724
1.55 - 2.00	-0.6569	-0.7215	-0.6740	-0.5464	-0.1600	0.4297	0.7724	1.0000

Correlation matrix followed by shape correlation matrix for bins of $d\sigma/dQ^2$.