1 Cuts

1.1 Spill Level

There has to be one and only one entry in the Spill, and BeamDAQ tables for the spill. There has to be one and only one entry in the Beam table for the S:G2SEM value for the spill. There has to be one and only one entry in the Scaler table for end of spill for each of the values TSgo, AcceptedMatrix1, and AfterInhMatrix1. There has to be one and only one entry in the Target table for the value TARGPOS_CONTROL. There has to be a beginning of spill entry in the Scaler table for the value acceptedMatrix1, to ensure that recording began before the spill started.

Document 1307-v7 on the docdb has an analysis of the following data quality spill cuts.

Table	Value	Roadsets	Good range
Spill	dataQuality	all	0
Spill	targetPos	all	1 to 7
Target	TARGPOS_CONTROL	all	Spill table targetPos
Scaler	TSgo	57, 59	1,000 to 8,000 inclusive
Scaler	TSgo	61	1,000 to 12,000 inclusive
Scaler	TSgo	62, 67, 70	100 to 6,000 inclusive
Scaler	acceptedMatrix1	57, 59	1,000 to 8,000 inclusive
Scaler	acceptedMatrix1	61	1,000 to 12,000 inclusive
Scaler	acceptedMatrix1	62, 67, 70	100 to 6,000 inclusive
Scaler	afterInhMatrix1	57, 59	1,000 to 30,000 inclusive
Scaler	afterInhMatrix1	61	1,000 to 100,000 inclusive
Scaler	afterInhMatrix1	62, 67, 70	100 to 10,000 inclusive
Scaler	acceptedMatrix1/afterInhMatrix1	57, 59	0.2 to 0.9 inclusive
Scaler	acceptedMatrix1/afterInhMatrix1	61	0 to 0.9 inclusive
Scaler	acceptedMatrix1/afterInhMatrix1	62, 67, 70	0.2 to 1.05 inclusive
Beam	S:G2SEM	all	2e12 to 1e13 inclusive
BeamDAQ	QIESum	all	4e10 to 1e12 inclusive
BeamDAQ	trigger_sum_no_inhibit	all	4e9 to 1e11 inclusive
BeamDAQ	inhibit_block_sum	57, 59, 61	4e9 to 1e11 inclusive
BeamDAQ	inhibit_block_sum	62, 67, 70	4e9 to 2e12 inclusive
BeamDAQ	dutyfactor53MHz	57, 59, 61	15 to 60 inclusive
BeamDAQ	dutyfactor53MHz	62, 67, 70	10 to 60 inclusive

There are also some bad spill ranges that I avoid.

First spillID	Last spillID	Reason
371870	376533	trigger timing shift
378366	379333	trigger timing shift
394287	409540	Run 3 commissioning period
394287	414555	Deuterium flask filled with LH2
416207	424180	Manual target control
482574	484924	Magnet flipped compared to rest of roadset 62
526201	526364	Bad QIE inhibit timing
581369	582460	KMag off
675814	684041	Gas flow problems in station 1
684663	689443	D3p has wrong in time window

1.2 Event Level

There has to be one and only one entry in the Event, kEvent, and QIE tables for the event. Other quality cuts are in the table below.

Table	Value	Good range
kTrack	numHits	> 14
kTrack	roadID	not 0
kTrack	z0	-400 to 200 exclusive
kTrack	chisq/(numHits - 5)	< 5
kTrack	pz1 (Where numHits != 18)	> 18
kDimuon	dx	-2 to 2 exclusive
kDimuon	dy	-2 to 2 exclusive
kDimuon	dz	-300 to 200 exclusive
kDimuon	dpx	-3 to 3 exclusive
kDimuon	dpy	-3 to 3 exclusive
kDimuon	dpz	30 to 120 exclusive
kDimuon	xB	0 to 1 exclusive
kDimuon	xT	0 to 1 exclusive
kDimuon	xF	-1 to 1 exclusive
kDimuon	trackSeparation	-250 to 250 exclusive
kDimuon	chisq_dimuon	< 15
kDimuon	px1	> 0
kDimuon	px2	< 0
kEvent	status	0
QIE, BeamDAQ	RF+08 through RF-08	< Inh_thres
QIE	RF+16 through RF-16	> 0
QIE	triggerCount	>= 0

Additionally, there is a target cut. chisq_dump - chisq_target of both kTracks > 10, and kDimuon dz between -60 and -300 exclusive. Additionally there is a mass cut of > 4.2 GeV.

2 Raw Yield

Roadset 57	
target	yield
LD2	3225
LH2	2848
Empty	74

Roadset 57				
x Min	x Max	hydrogen	deuterium	empty
0.08	0.14	446	494	11
0.14	0.16	466	549	12
0.16	0.18	502	536	8
0.18	0.21	534	599	13
0.21	0.25	431	488	10
0.25	0.31	307	360	12
0.31	0.53	162	199	8

Roadset 57							
x Min	x Max	H2 $\langle x_T \rangle$	H2 $\langle x_B \rangle$	H2 $\langle mass \rangle$	D2 $\langle x_T \rangle$	D2 $\langle x_B \rangle$	D2 $\langle mass \rangle$
0.08	0.14	0.1266	0.7163	4.408	0.1263	0.7181	4.406
0.14	0.16	0.1503	0.6384	4.545	0.15	0.6355	4.523
0.16	0.18	0.1704	0.5986	4.685	0.1698	0.6035	4.698
0.18	0.21	0.1947	0.5739	4.902	0.1938	0.5745	4.91
0.21	0.25	0.2281	0.5703	5.287	0.2273	0.5682	5.287
0.25	0.31	0.2755	0.557	5.728	0.2758	0.5504	5.725
0.31	0.53	0.3525	0.5404	6.399	0.3627	0.5385	6.492

Roadset 62	
target	yield
LD2	4610
LH2	4518
Empty	203

Roadset 62				
x Min	x Max	hydrogen	deuterium	empty
0.08	0.14	692	713	29
0.14	0.16	709	697	36
0.16	0.18	752	760	35
0.18	0.21	893	882	45
0.21	0.25	723	713	29
0.25	0.31	574	471	14
0.31	0.53	267	282	15

Roadset 62							
x Min	x Max	H2 $\langle x_T \rangle$	H2 $\langle x_B \rangle$	H2 $\langle mass \rangle$	D2 $\langle x_T \rangle$	D2 $\langle x_B \rangle$	D2 $\langle mass \rangle$
0.08	0.14	0.126	0.7207	4.404	0.1264	0.7244	4.417
0.14	0.16	0.1502	0.635	4.525	0.1503	0.6392	4.55
0.16	0.18	0.1697	0.6002	4.671	0.1696	0.6029	4.688
0.18	0.21	0.1935	0.5857	4.931	0.1936	0.5734	4.896
0.21	0.25	0.227	0.5694	5.273	0.2273	0.5658	5.275
0.25	0.31	0.2751	0.5538	5.731	0.2758	0.5638	5.788
0.31	0.53	0.3613	0.5326	6.436	0.3592	0.5427	6.489

Roadset 67	
target	yield
LD2	15853
LH2	14601
Empty	633

Roadset 67				
x Min	x Max	hydrogen	deuterium	empty
0.08	0.14	2108	2381	97
0.14	0.16	2391	2502	104
0.16	0.18	2403	2632	112
0.18	0.21	2842	3142	106
0.21	0.25	2268	2401	107
0.25	0.31	1660	1829	65
0.31	0.53	929	966	42

Roadset 67							
x Min	x Max	H2 $\langle x_T \rangle$	H2 $\langle x_B \rangle$	H2 $\langle mass \rangle$	D2 $\langle x_T \rangle$	D2 $\langle x_B \rangle$	D2 $\langle mass \rangle$
0.08	0.14	0.1263	0.7205	4.405	0.1262	0.7226	4.414
0.14	0.16	0.1504	0.637	4.533	0.1502	0.6401	4.548
0.16	0.18	0.1698	0.6007	4.681	0.1699	0.6029	4.696
0.18	0.21	0.1942	0.5817	4.925	0.1939	0.5784	4.921
0.21	0.25	0.2274	0.5657	5.257	0.2285	0.566	5.29
0.25	0.31	0.2753	0.5516	5.711	0.275	0.5557	5.744
0.31	0.53	0.361	0.5356	6.443	0.3572	0.5369	6.429

3 Live Protons

To get these numbers I sum over liveG2SEM in the Spill table where targetPos is the appropriate value. LH2 is 1, LD2 is 3, empty is 2.

Roadset 57	
target	protons
LH2	4.0258e+16
LD2	2.0242e+16
Empty	4.47319e+15

Roadset 62	
target	protons
LH2	5.43056e+16
LD2	2.44426e+16
Empty	1.12935e+16

Roadset 67	
target	protons
LH2	1.61684e+17
LD2	7.72245e+16
Empty	3.67375e+16

4 Rate Dependence Correction

There are two rate dependence corrections, the kTracker efficiency correction and the empty target correction. Both corrections use fits that are a function of chamber intensity. Chamber intensity is an estimate of the intensity seen by our wire chambers, and is a weighted average over the RF values in the QIE table.

For more on chamber intensity, you can refer to docdb 1572.

4.0.1 kTracker Efficiency

The kTracker efficiency can be calculated with two sets of data. The first set, the clean set, is simply GMC Drell-Yan data. The second set, the messy set, is the same GMC events with the hits from NIM3 events from data added to the Hit table. Both sets are then kTracked. To calculated a kTracker efficiency one divides the total GMC weight of good kDimuons in the messy sample by the total GMC weight of good kDimuons in the clean sample. If this data is binned by intensity (of the NIM3 event), a rate dependence of the kTracker efficiency can be seen. I used the Wilson score interval to calculate the mean and uncertainty:

$mean = \frac{n}{n+1} * (p + 1/2n)$

$uncertainty = \frac{n}{n+1} * \sqrt{\frac{p*(1-p)}{n} + \frac{1}{4n^2}}$

This had to be modified for the weights W_i, so instead of the standard definitions of p and n I used:

$p = \frac{\Sigma^{messy} W_i}{\Sigma^{clean} W_i}$

$n = \frac{(\Sigma^{clean} W_i)^2}{\Sigma^{clean}(W_i^2)}$

I fit the efficiency of each x_T bin, each target, and each roadset as a function of chamber intensity, with a bin width of 5,000 from 0 to 100,000 intensity. Based on Evan's recommendation the same fits are used for roadsets 57 and 62, but a separate fit is used for 67. After trying several fit forms I found that exponential decay works the best. For the cross section ratio analysis I assign each kDimuon an efficiency value based on these fits. The weight for each kDimuon is 1/efficiency.

To find the affect of the uncertainty of the hydrogen fits on the cross section ratio, I calculate the cross section ratio three times, once with the exponent at its normal value, and once each with the exponent changed by $\pm 1\sigma$. The difference between the base cross section ratio and the $+\sigma$ cross section ratio is the upper uncertainty associated with the hydrogen efficiency correction, and similar for the lower uncertainty. Similarly for deuterium, except the $+\sigma$ difference is associated with the lower uncertainty and vice versa. I consider these uncertainties statistical as they improve with more data.

For more on these studies, you can refer to docdb 1573.

target	x Min	x Max	roadset	exponent	uncertainty
1	0.08	0.14	57, 62	-1.42605e-05	7.61862e-07
3	0.08	0.14	57, 62	-1.1993e-05	1.00418e-06
1	0.14	0.16	57, 62	-1.32104e-05	8.78562e-07
3	0.14	0.16	57, 62	-1.31595e-05	1.22247e-06
1	0.16	0.18	57, 62	-1.43421e-05	8.97883e-07
3	0.16	0.18	57, 62	-1.72028e-05	1.31634e-06
1	0.18	0.21	57, 62	-1.26886e-05	7.06168e-07
3	0.18	0.21	57, 62	-1.5151e-05	1.09742e-06
1	0.21	0.25	57, 62	-1.49492e-05	6.72384e-07
3	0.21	0.25	57, 62	-1.72127e-05	1.09776e-06
1	0.25	0.31	57, 62	-1.64611e-05	6.17661e-07
3	0.25	0.31	57, 62	-1.99773e-05	9.95294e-07
1	0.31	0.53	57, 62	-2.1024e-05	5.78876e-07
3	0.31	0.53	57, 62	-2.2415e-05	9.1281e-07
1	0.08	0.14	67	-1.2091e-05	4.82085e-07
3	0.08	0.14	67	-1.4007e-05	5.46091e-07
1	0.14	0.16	67	-1.35785e-05	5.90799e-07
3	0.14	0.16	67	-1.53868e-05	6.77346e-07
1	0.16	0.18	67	-1.35148e-05	5.86474e-07
3	0.16	0.18	67	-1.50155e-05	6.09509e-07
1	0.18	0.21	67	-1.40672e-05	5.12602e-07
3	0.18	0.21	67	-1.65732e-05	5.65149e-07
1	0.21	0.25	67	-1.69593e-05	4.93993e-07
3	0.21	0.25	67	-1.75879e-05	5.02167e-07
1	0.25	0.31	67	-1.78703e-05	4.21461e-07
3	0.25	0.31	67	-2.05073e-05	4.83502e-07
1	0.31	0.53	67	-2.12488e-05	3.9209e-07
3	0.31	0.53	67	-2.40273e-05	4.52406e-07

4.1 Empty Target Correction

The empty target data has a strong rate dependence, with many more kDimuons per proton being found at higher intensities. To properly analyze this data we should first correct it for kTracker efficiency. Unfortunately, there are currently no GMC with empty flask NIM3 embedded data sets to extract the kTracker efficiency. One can assume that the difference between the targets is a function of how much of the beam interacts with the target. Using A_T as the exponential decay constant for a target, and X_T as the fraction of the beam that interacts with the target, we can linearly extrapolate to come up with a formula for A_E. First we figure out X_T where NIL is nuclear interaction length:

$X = interactionFraction = 1 - e^{-length*density/NIL}$

$$A_E = A_{LH2} - X_{LH2} * \frac{A_{LD2} - A_{LH2}}{X_{LD2} - X_{LH2}}$$

Once we correct the empty target data for kTracker efficiency it can be fit to find a function, C(I), that would be the chance of a target dimuon actually being from outside the target (dump, upstream, from the flask edges). However, this function needs a normalization factor, B. If we sum B*C(I) over all target dimuons it should be equal to the number of dimuons from the empty target, once differences in live protons are accounted for. Also we should correct both sides for kTracker efficiency, K(I, T). B is different for each target. The T and E superscripts on the Σ indicate whether the sum is over target or empty flask dimuons. P_T and P_E are the live proton sums for the target and empty flask, respectively.

$$\Sigma^T \frac{B * C(I)}{P_T * K(I,T)} = \Sigma^E \frac{1}{P_E * K(I,E)}$$

We can then easily solve for B.

$$B = \frac{P_T}{P_E} * \frac{\Sigma^E \frac{1}{K(I,E)}}{\Sigma^T \frac{C(I)}{K(I,T)}}$$

The weight for the empty target correction is (1 - B*C(I)). The combined weight is

$$\frac{1 - B * C(I)}{K(I,T)}$$

I made a linear fit to the empty flask data from roadsets 57, 62, and 67, as a function of chamber intensity. I did not use the data from the none target. The function I fit was $p0(1 + p1 * I)$. The reasoning behind this is that the magnitude doesn't matter, as that will change when B is calculated. So p0 and its uncertainty can be ignored, and we only need to know p1 and its uncertainty. When I did the fit my results were:

$$p1 = 6.966e - 5 \pm 1.477e - 5$$

To find the uncertainty resulting from this fit I run the cross section ratio calculation three times, once with p1 at its normal value, and once each with this value changed by $\pm 1\sigma$. The difference in the results was less than 0.1% of the cross section ratio. To find the uncertainty in B I treated everything except the number of empty dimuons as constant, as the statistics for the empty target are so much smaller.

$$\delta_B = \frac{P_{Target}}{P_{Empty}} * \frac{1}{\Sigma^T \frac{C(I)}{K(I,Target)}} * \sqrt{\Sigma^E \frac{1}{K(I,Empty)^2}}$$

To find the affect of the uncertainty in B on the cross section ratio, I calculate the cross section ratio three times, once with B at its normal value, and once each with B changed by $\pm$ 1 σ. The difference between the base cross section ratio and the $+\sigma$ cross section ratio is the upper uncertainty associated with the empty target correction, and similar for the lower uncertainty. This uncertainty is statistical.

4.2 Remaining Rate Dependence

If one plots a graph of the rate dependence of the LH2 or LD2 target, after these factors have been taken into account, then there are clearly sources of rate dependence unaccounted for. However, if one plots a graph of the ratio of LD2 and LH2, both for trigger intensity and chamber intensity, then the graphs are a horizontal line within the uncertainties of a linear fit, with acceptable χ^2. A systematic error should be estimated from this and added to the uncertainties.

4.3 Results

Below are the total yields in each bin for each target, once before any rate corrections, once after the efficiency correction, and once after both the efficiency and empty target corrections.

Roadset 57				
x Min	x Max	LH2 initial	LH2 efficiency corrected	LH2 empty corrected
0.08	0.14	446	660.5	496.4
0.14	0.16	466	658.8	500.5
0.16	0.18	502	724.1	552.5
0.18	0.21	534	743.3	565.6
0.21	0.25	431	637.2	483.6
0.25	0.31	307	472.7	358
0.31	0.53	162	278	210

Roadset 57				
x Min	x Max	LD2 initial	LD2 efficiency corrected	LD2 empty corrected
0.08	0.14	494	671.2	598.7
0.14	0.16	549	765.7	683.2
0.16	0.18	536	808.3	723.5
0.18	0.21	599	841.4	756.8
0.21	0.25	488	758.1	674.7
0.25	0.31	360	579	518
0.31	0.53	199	347.3	309.2

Roadset 62				
x Min	x Max	LH2 initial	LH2 efficiency corrected	LH2 empty corrected
0.08	0.14	692	1026	807.1
0.14	0.16	709	1009	798.3
0.16	0.18	752	1111	875.6
0.18	0.21	893	1254	992
0.21	0.25	723	1078	852
0.25	0.31	574	890.8	703.3
0.31	0.53	267	468.8	368.5

Roadset 62				
x Min	x Max	LD2 initial	LD2 efficiency corrected	LD2 empty corrected
0.08	0.14	713	983.3	889.4
0.14	0.16	697	981.5	889.3
0.16	0.18	760	1183	1071
0.18	0.21	882	1299	1177
0.21	0.25	713	1095	993
0.25	0.31	471	810.9	730.8
0.31	0.53	282	497.5	450.3

Roadset 67				
x Min	x Max	LH2 initial	LH2 efficiency corrected	LH2 empty corrected
0.08	0.14	2108	2975	2433
0.14	0.16	2391	3504	2868
0.16	0.18	2403	3490	2865
0.18	0.21	2842	4195	3441
0.21	0.25	2268	3617	2966
0.25	0.31	1660	2743	2241
0.31	0.53	929	1696	1381

Roadset 67				
x Min	x Max	LD2 initial	LD2 efficiency corrected	LD2 empty corrected
0.08	0.14	2381	3509	3239
0.14	0.16	2502	3845	3546
0.16	0.18	2632	3955	3653
0.18	0.21	3142	4913	4538
0.21	0.25	2401	3845	3552
0.25	0.31	1829	3198	2950
0.31	0.53	966	1794	1658

5 $\sigma_{pd}/2\sigma_{pp}$

5.1 Uncorrected Cross Section

To find the cross section of a target requires some knowledge of the target properties. The lengths of the targets are 20 inches $\pm$ 2.5 mm. The nuclear interaction lengths(NIL) and atomic masses were taken from the particle data group, 2014.

target	length(cm)	density (g/cm^3)	NIL (g/cm^2)	atomic mass (g/mol)
LH2	50.8 $\pm$ 0.25	0.0708	52.0	1.00794
LD2	50.8 $\pm$ 0.25	0.1634	71.8	2.01410

Some other quantities are calculated from these basic quantities:

$interactionFraction = 1 - e^{-length*density/NIL}$

$atomsPerArea = interactionFraction * NIL/atomicMass$

After this, the cross section for a target without applying acceptance corrections, the empty flask correction, or the target contamination correction is calculated as:

$\sigma = \frac{W}{protons*atomsPerArea}$

where W is the sum of the weights for all dimuons reconstructed from that target. Without the acceptance correction this should only be used for calculating cross section ratios, where that correction almost completely cancels out.

5.2 Target Contamination Correction

I am working under the assumption that the heavier nuclear molecules are caught in the cold trap and do not make it into the target. I also assume that the Helium exists in a gaseous state at the top of the target and does not interact with the proton beam. I correct the nuclear interaction length and atomic mass of the target based on the target contamination. Since only the atoms matter here, I calculate these based on molar fractions of hydrogen atoms and deuterium atoms. For runs before run 11653 I treat the hydrogen contamination in the deuterium target as 0.08 $\pm$ 0.04. For runs 11653 and after the deuterium is pure to several decimal places. Using A as atomic mass, λ as the nuclear interaction length (in g/cm^2), and F_x as the fraction of x in the target:

$A = A_H * F_H + A_D * F_D$

$\frac{1}{\lambda} = \frac{F_H}{\lambda_H} + \frac{F_D}{\lambda_D}$

$\lambda = \frac{\lambda_H * \lambda_D}{F_H * \lambda_D + F_D * \lambda_H}$

We also have to correct for the fact that some dimuons on the LD2 target come from Hydrogen atoms. Using T_x as the target cross section, p as the proton-proton cross section, n as the proton-neutron cross section, $LH2$ and $LD2$ as the cross sections between a proton and the pure material, a and c as the number of protons per atom in LH2 and LD2 targets (1 and 1), and b and d as the number of neutrons per atom in the LH2 and LD2 targets, respectively (which are the fractions of deuterium atoms in those targets):

$T_H = a * p + b * n$

$T_D = c * p + d * n$

$LH2 = p = \frac{b * T_D - d * T_H}{b * c - a * d}$

$n = \frac{a * T_D - c * T_H}{a * d - b * c}$

$LD2 = p + n$

The amount of contamination in our target (for most of our data) has an uncertainty. To calculate the uncertainty in the cross section ratio as a result of this I calculate the cross section three times, once with the contamination at the base value and once each with the contamination raised or lowered by the uncertainty. The contamination uncertainties are asymmetric. These uncertainties are systematic, and are the only systematic uncertainty on the cross section ratio considered so far.

5.3 Final Calculation

I use $Q_T = \frac{W_T}{P_T}$ and $G_T = atomsPerArea_T$. The cross sections are:

$\sigma_{pp} = \frac{b * \frac{Q_D}{G_D} - d * \frac{Q_H}{G_H}}{b * c - a * d}$

$\sigma_{pd} = \sigma_{pp} + \frac{a * \frac{Q_D}{G_D} - c * \frac{Q_H}{G_H}}{a * d - b * c}$

Treating the hydrogen target as pure and replacing a and c with one results in:

$\sigma_{pp} = \frac{Q_H}{G_H}$

$\sigma_{pd} = \sigma_{pp} + \frac{Q_D}{d{*}G_D} - \frac{Q_H}{d{*}G_H}$

$\frac{\sigma_{pd}}{2\sigma_{pp}} = 1 + \frac{G_H{*}Q_D}{d{*}G_D{*}Q_H} - \frac{1}{d}$

There are two parts to the statistical uncertainty, the uncertainty on the deuterium weight, and the uncertainty on the hydrogen weight.

$\delta_1 = \delta_{LD2} * \frac{G_H}{d{*}G_D{*}Q_H{*}P_D}$

$\delta_2 = \delta_{LH2} * \frac{-d{*}G_D{*}G_H{*}Q_D}{P_H{*}(d{*}G_D{*}Q_H)^2}$

These two uncertainties, the efficiency uncertainties, and the empty target uncertainties are added in quadrature to find the statistical uncertainties on the cross section ratio. The systematic uncertainty is currently just from the target contamination. In the tables, stat+ is the upper statistical uncertainty and stat- is the lower. sys± are the systematic uncertainties.

For merging the results together from multiple roadsets, $\sigma_{pd}/2\sigma_{pp}$ and the systematic errors were treated as weighted averages with weights of $1/\sigma^2$, where σ is the average of the upper and lower statistical uncertainty. The new statistical uncertainties were

$\sigma_{\pm} = 1/\sqrt{\Sigma\sigma_{\pm}^2}$

5.4 Cross Section Ratio Results

Roadset 57							
x Min	x Max	$\langle x_T \rangle$	$\sigma_{pd}/2\sigma_{pp}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1264	1.117	0.08707	0.08582	0.02321	0.02167
0.14	0.16	0.1502	1.27	0.09843	0.09685	0.02871	0.02681
0.16	0.18	0.1701	1.216	0.09425	0.09269	0.02679	0.02501
0.18	0.21	0.1943	1.244	0.08884	0.08748	0.02777	0.02594
0.21	0.25	0.2277	1.299	0.1023	0.1009	0.02975	0.02778
0.25	0.31	0.2756	1.348	0.1194	0.1183	0.03154	0.02945
0.31	0.53	0.3576	1.373	0.1616	0.1608	0.03243	0.03029

Roadset 62							
x Min	x Max	$\langle x_T \rangle$	$\sigma_{pd}/2\sigma_{pp}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1262	1.141	0.07357	0.07291	0.02316	0.02167
0.14	0.16	0.1502	1.154	0.07785	0.0769	0.0236	0.02209
0.16	0.18	0.1697	1.271	0.08583	0.08453	0.02767	0.02591
0.18	0.21	0.1935	1.232	0.07302	0.07218	0.02631	0.02463
0.21	0.25	0.2271	1.209	0.07723	0.07647	0.02552	0.02389
0.25	0.31	0.2755	1.073	0.07862	0.07808	0.02082	0.01949
0.31	0.53	0.3603	1.27	0.1209	0.1205	0.02762	0.02586

Roadset 67							
x Min	x Max	$\langle x_T \rangle$	$\sigma_{pd}/2\sigma_{pp}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1262	1.275	0.04634	0.0461	0.015	0.01447
0.14	0.16	0.1503	1.183	0.04534	0.04496	0.01327	0.0128
0.16	0.18	0.1698	1.22	0.04475	0.04444	0.01397	0.01348
0.18	0.21	0.194	1.263	0.0422	0.04193	0.01478	0.01425
0.21	0.25	0.2279	1.145	0.04072	0.04054	0.01256	0.01212
0.25	0.31	0.2751	1.261	0.04959	0.04943	0.01473	0.01421
0.31	0.53	0.3591	1.147	0.05876	0.05867	0.01262	0.01217

Combined Results							
x Min	x Max	$\langle x_T \rangle$	$\sigma_{pd}/2\sigma_{pp}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1263	1.217	0.03548	0.03575	0.0174	0.01833
0.14	0.16	0.1503	1.188	0.03603	0.0364	0.01676	0.01766
0.16	0.18	0.1698	1.229	0.03621	0.03657	0.01749	0.01842
0.18	0.21	0.1939	1.254	0.03349	0.03379	0.01818	0.01915
0.21	0.25	0.2278	1.174	0.03375	0.03398	0.01614	0.01699
0.25	0.31	0.2753	1.223	0.03938	0.03957	0.01723	0.01813
0.31	0.53	0.3592	1.19	0.05012	0.05023	0.01629	0.01713

6 $\bar{d}/\bar{u}$ from $\sigma_{pd}/2\sigma_{pp}$

6.0.1 Method

Once the ratio (R_d) of LD2/LH2 cross sections is obtained from data, it is time to calculate $\bar{d}/\bar{u}$. First, an initial estimate of $\bar{d}/\bar{u}$ is set. For each dimuon in the yield of LH2 and LD2, an estimate of the cross section ratio for that dimuon's mass, x_B, and x_T is calculated with the initial value of $\bar{d}/\bar{u}$. The mean value of all of the predictions is taken as the prediction of the cross section ratio (R_p). The difference $R_d - R_p$ is added to the estimate of $\bar{d}/\bar{u}$. This procedure is then repeated 50 times so the estimate of $\bar{d}/\bar{u}$ converges and $R_d - R_p = 0$. In all calculations all quark distributions, the $\bar{d} + \bar{u}$ distribution, and the $\bar{d}/\bar{u}$ distribution outside the analysis range is taken from a PDF set. $\bar{d}/\bar{u}$ inside the analysis range for both beam and target quarks is taken from the current estimate.

The cross section prediction for a single dimuon is leading order only in the current results. NLO calculations are forthcoming but take some time to complete. The NLO calculations use some old Fortran code from the CTEQ collaboration. The LO calculation is shown below:

$$\sigma_{H2} = 4u(x_B)\bar{u}(x_T) + d(x_B)\bar{d}(x_T) + 4\bar{u}(x_B)u(x_T) + \bar{d}(x_B)d(x_T) + 8c(x_B)c(x_T) + 2s(x_B)s(x_T)$$

$$\sigma_{D2} = \sigma_{H2} + 4u(x_B)\bar{d}(x_T) + d(x_B)\bar{u}(x_T) + 4\bar{u}(x_B)d(x_T) + \bar{d}(x_B)u(x_T) + 8c(x_B)c(x_T) + 2s(x_B)s(x_T)$$

$$R_p(1 \text{ dimuon}) = \frac{\sigma_{D2}}{\sigma_{H2}}$$

Note that due to the terms with anti-quarks from the beam, R_d in one bin can have a small effect on other bins.

Once $\bar{d}/\bar{u}$ is calculated, the uncertainties are calculated. This requires running the extraction part of the program 2n times more, where n is the number of bins. For the first n times, one bin of R_d is adjusted upwards by an amount equal to its error bars, while all other bins of R_d stay the same. The last n times are similar, except the bin of R_d is adjusted downwards. The results of each of the 2n extractions are compared to the original extraction of $\bar{d}/\bar{u}$, and the differences are taken as uncertainties. Terms for changing the same bin of R_d are averaged together, to get n uncertainties. The resulting terms are then added in quadrature to get the error bars.

To propagate the systematic uncertainty in the cross section ratio, I use:

$$\delta_{\bar{d}/\bar{u},systematic} = \frac{\delta_{\bar{d}/\bar{u},statistical}\delta_{R,systematic}}{\delta_{R,statistical}}$$

The uncertainties in the PDF set are also taken as a systematic uncertainty. LHAPDF, the program I use to access the PDFs, contains a function that will return the uncertainty in any function of parton distribution functions you submit. Using R as σ_{pd}/σ_{pp} and the average x_b and Q values in each bin I submitted the function

$$\frac{4u(x_b,Q)*R-4u(x_b,Q)-d(x_b,Q)}{4u(x_b,Q)+d(x_b,Q)-d(x_b,Q)*R}$$

as an approximation of $\bar{d}/\bar{u}$. I derived this from

$$R = \frac{1+\frac{d(x_b)}{4u(x_b)}}{1+\frac{d(x_b)}{4u(x_b)}\frac{\bar{d}(x_t)}{\bar{u}(x_t)}}\left(1+\frac{\bar{d}(x_t)}{\bar{u}(x_t)}\right)$$

This is a crude estimation of the uncertainty from the PDFs but this uncertainty is small. I add the pdf uncertainty and the propagated systematic uncertainty to get the total systematic uncertainty. Note that I do not add these in quadrature as the propagated uncertainty is from the contamination uncertainty which is very not Gaussian.

For merging the results together from multiple roadsets, $\bar{d}/\bar{u}$ and the systematic errors were treated as weighted averages with weights of $1/\sigma^2$, where σ is the average of the upper and lower statistical uncertainty. The new statistical uncertainties were

$\sigma_{\pm} = 1/\sqrt{\Sigma\sigma_{\pm}^2}$

6.1 Results

Roadset 57							
x Min	x Max	$\langle x_T \rangle$	$\bar{d}/\bar{u}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1264	1.274	0.2096	0.2015	0.07095	0.06593
0.14	0.16	0.1502	1.671	0.2563	0.2439	0.103	0.0958
0.16	0.18	0.1701	1.55	0.2474	0.2349	0.0887	0.08178
0.18	0.21	0.1943	1.643	0.2434	0.2309	0.09541	0.08778
0.21	0.25	0.2277	1.822	0.2994	0.2815	0.1124	0.1028
0.25	0.31	0.2756	2.057	0.3995	0.3683	0.1363	0.1225
0.31	0.53	0.3576	2.447	0.6489	0.5833	0.1671	0.1468

Roadset 62							
x Min	x Max	$\langle x_T \rangle$	$\bar{d}/\bar{u}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1262	1.333	0.1797	0.1742	0.07578	0.07101
0.14	0.16	0.1502	1.379	0.1943	0.187	0.07303	0.06786
0.16	0.18	0.1697	1.693	0.2298	0.2191	0.09871	0.09178
0.18	0.21	0.1935	1.613	0.1984	0.1902	0.09009	0.08352
0.21	0.25	0.2271	1.579	0.217	0.2071	0.08753	0.08054
0.25	0.31	0.2755	1.243	0.2199	0.209	0.06286	0.05678
0.31	0.53	0.3603	2.071	0.452	0.4181	0.1266	0.113

Roadset 67							
x Min	x Max	$\langle x_T \rangle$	$\bar{d}/\bar{u}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1262	1.667	0.1173	0.1151	0.08166	0.0798
0.14	0.16	0.1503	1.451	0.1136	0.111	0.05075	0.04909
0.16	0.18	0.1698	1.562	0.1168	0.1141	0.05538	0.0535
0.18	0.21	0.194	1.698	0.1157	0.1129	0.06246	0.06033
0.21	0.25	0.2279	1.407	0.1107	0.1081	0.04421	0.04235
0.25	0.31	0.2751	1.806	0.1571	0.1519	0.06756	0.06457
0.31	0.53	0.3591	1.646	0.1995	0.1923	0.05355	0.05059

Merged Results							
x Min	x Max	$\langle x_T \rangle$	$\bar{d}/\bar{u}$	stat+	stat-	sys+	sys-
0.08	0.14	0.1263	1.513	0.08669	0.08896	0.0751	0.07825
0.14	0.16	0.1503	1.464	0.08887	0.0916	0.05938	0.06255
0.16	0.18	0.1698	1.584	0.09293	0.09599	0.06462	0.06817
0.18	0.21	0.1939	1.672	0.08951	0.09247	0.06946	0.07337
0.21	0.25	0.2278	1.482	0.09073	0.09369	0.05567	0.05927
0.25	0.31	0.2753	1.657	0.1166	0.1218	0.06775	0.07273
0.31	0.53	0.3592	1.774	0.1673	0.1757	0.06775	0.0737