Changes to the DPMJET and FLUKA packages

Sonam Mahajan (Panjab University, Chandigarh), Rajendran Raja (Fermilab) and Holger Meyer (Wichita State University)

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Abstract

Changes to the DPMJET and FLUKA packages are described. These changes include the generation of new beam profiles, beam momentum and spreads in momentum and are applied to Liquid Hydrogen and Empty-Cryogenic target and all thin targets i.e. Beryllium, Bismuth, Carbon 2% interaction length and Uranium including Empty target at all the energies.

1 Beam profile generation for LH_2 target using DPM-JET

1.1 Description of the problem

It is observed that the beam for Liquid Hydrogen target is wider for the Monte Carlo as compared to the data. Figure 1 shows the 2-dimensional histograms of beam x and y for LH_2 +58 GeV data and Monte Carlo. The MC beam profile is generated at the STDHEP level i.e generation level. For Liquid Hydogen target, DPMJET is used as an event generator while for all the other MIPP targets, FLUKA is used for the event generation. The beam transverse position distributions for the MC and the data were shown [1] and it was decided that we should regenerate the MC beam profiles using the data beam profiles as input to make their shapes similar.

1.2 Previous and new method for beam profile generation

All the codes in DPMJET package are FORTRAN based. A number of routines have been written. The beam generation has been done in the routine 'beam_gen.F'. In the previous method of beam generation, a Gaussian distribution of width (σ) 1 cm was generated. The part of the routine which does this is as follows:

```
CALL RANNOR(R1,R2)
DVX = SIG_X*R1
DVY = SIG_Y*R2
VX = DVX + TARG_X
VY = DVY + TARG_Y
```

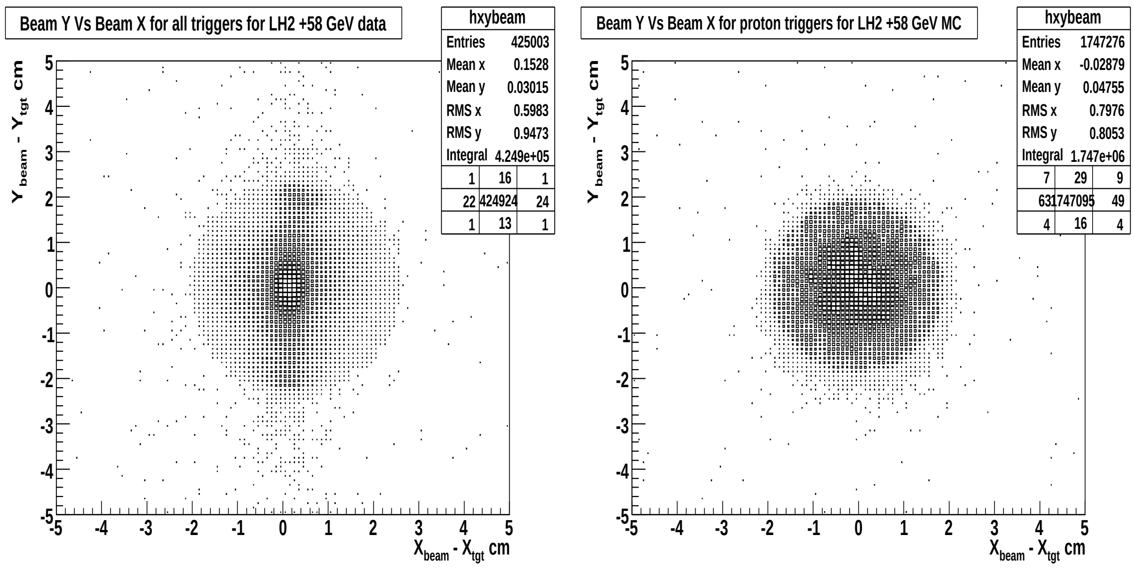


Figure 1: Left- Beam y vs beam x distribution for LH_2 +58 GeV data. Right- Beam y vs beam x distribution for LH_2 +58 GeV MC.

The value of SIG_X and SIG_Y was 1. In the new method of beam profile generation, a 2-dimensional histogram of beam x and y from the data is used. Beam x and y are the positions of the beam particles (calculated by projecting the BC3 track segment onto the target center) relative to the target center. The target center is not exactly at (0,0), so this offset is subtracted from the data beam positions before using them as input. The data beam x and y positions are stored in a .txt file and are read to fill a 2D histogram. This histogtram is saved in HBOOK format. This HBOOK is then called in 'beam_gen.F' routine and random numbers are generated using the 2D histogram from the data.

The beam profiles for proton, pion and kaon triggers were studied separately for LH_2 target data at +58 and -58 GeV. It was decided that a single histogram would be used to generate the beam profiles for different triggers and the beam profiles for positive and negative beams would be generated separately [2]. The variation of beam profiles with run numbers was also studied [3]. It was observed that beam profiles are wider for the run range 13XXX as compared to the run range 16XXX for LH_2 +58 GeV data. This is because these two sets of data were taken in different time-periods and run conditions were also different. The momentum for one set was +58 GeV/c and for the other set was +59 GeV/c.

The LH_2 and Empty-Cryogenic target data is available at 16 beam momenta which are +19, +19.8, +20, -19, -19.8, -20, +58, +59, -58, -59, +84, +85, +86, -84, -85 and -86 GeV/c. The comparison of beam x and y profiles for data sets at different momenta is shown in Figures 2, 3 and 4. Since the beam profiles vary for different data sets, we have decided to generate different beam profiles for each data set. So, there are 16 different input data histograms. These histograms

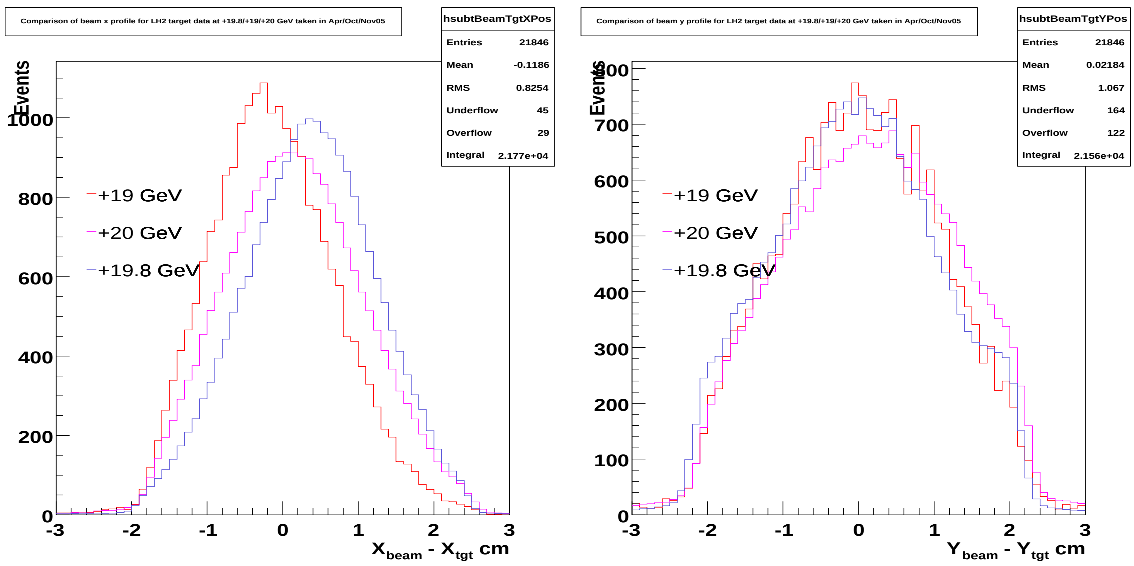


Figure 2: Left- Comparison of beam x profiles for LH_2 target data at +19, +19.8 and +20 GeV. Right- Comparison of beam y profiles for LH_2 target data at +19, +19.8 and +20 GeV.

are stored in 16 directories with different names in the same HBOOK. The histogram ID of all the 16 histograms is the same which is 115. Depending on which beam momentum particle is incident, the corresponding directory is opened and the input data histogram is read. The new part of the routine is as follows:

```
IF(FIRST)THEN
CALL HROPEN(41,‘MIPP’,‘beamgen.hbook’,‘ ’,1024,ISTAT)
CALL HCDIR(DIR,‘ ’)
CALL HRIN(0,999999,0)
CALL HCDIR(‘\’,‘ ’)
CALL HBOOK2(215,‘ ’,100,-5.0,5.0,100,-5.0,5.0,0.0)
ENDIF
CALL HRNDM2(115,R1,R2)
DVX = R1
DVY = R2
CALL HF2(215,DVX,DVY,1.0)
VX = DVX + TARG_X
VY = DVY + TARG_Y
```

115 is the histo-id of the input 2D histogram i.e. beam y vs beam x from the data. Now the random numbers are generated according to the entries of the input histogram to generate the correlation between beam x and y similar to the data. The newly generated MC beam profile is

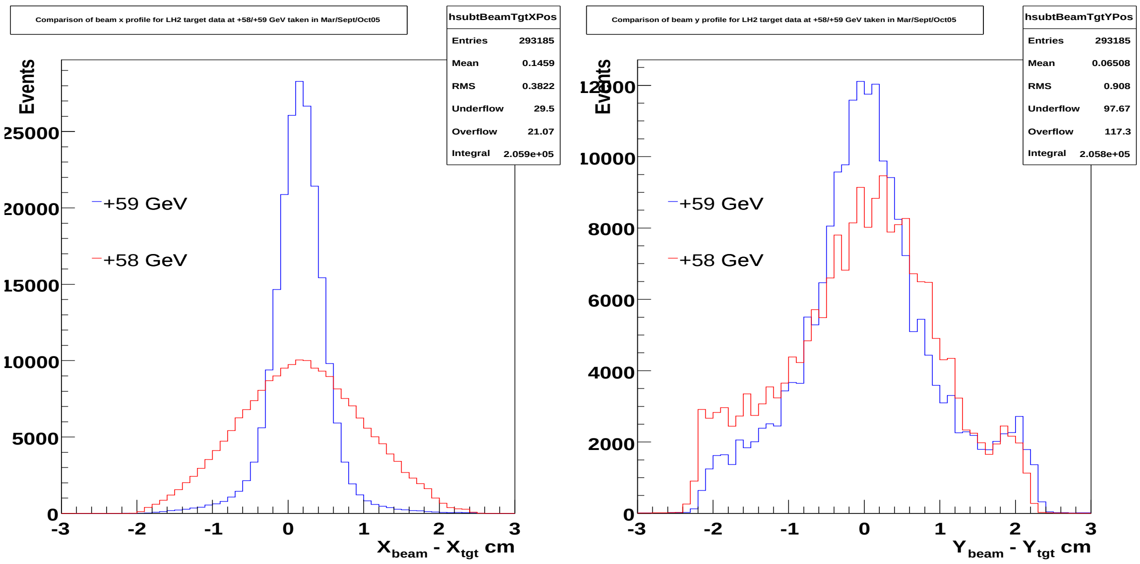


Figure 3: Left- Comparison of beam x profiles for LH_2 target data at +58 and +59 GeV. Right- Comparison of beam y profiles for LH_2 target data at +58 and +59 GeV.

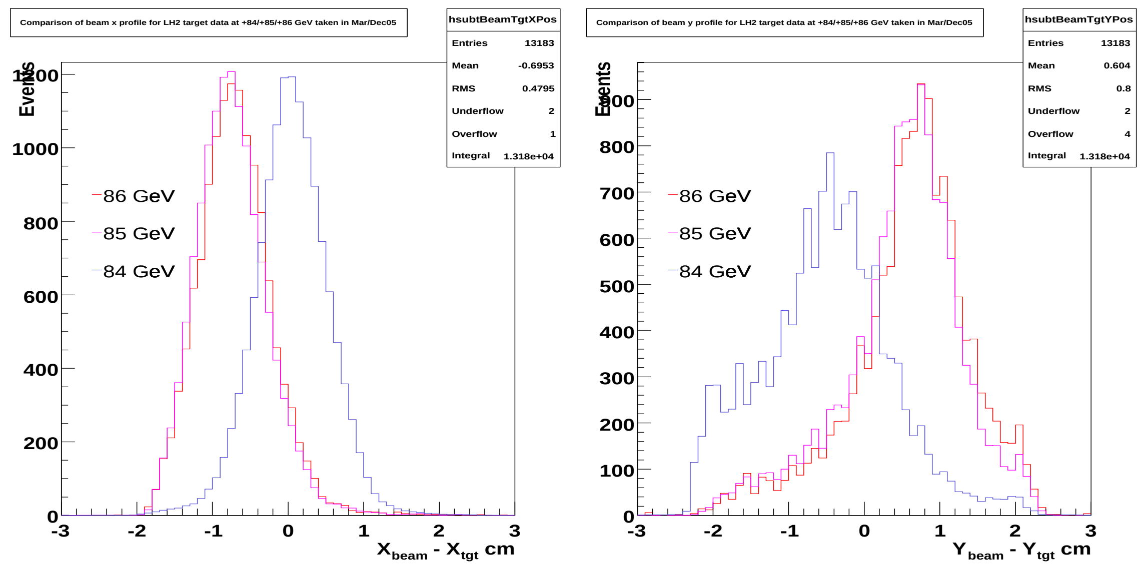


Figure 4: Left- Comparison of beam x profiles for LH_2 target data at +84, +85 and +86 GeV. Right- Comparison of beam y profiles for LH_2 target data at +84, +85 and +86 GeV.

Runnummin	Runnummax	Momentum (GeV/c)	Mean X	FWHM X	Mean Y	FWHM Y
13984	14046	+19.8	0.6	-2.0	0.5	-2.2
14083	14300	+58	0.3	-1.8	0.1	-2.0
14301	14374	-58	0.3	-1.8	0.3	-2.0
15258	16090	120	0.05	-0.5	0.5	-0.6
16098	16108	+59	0.7	-1.0	1.2	-1.6
17087	17278	+59	0.1	-1.0	0.4	-1.6
17369	17502	-60	-0.2	-1.0	0.3	-2.0

Table 1: Table of mean positions (cm) and FWHM's (cm) of beam in x and y direction used in FLUKA input cards for various run ranges for thin targets (including Empty target).

stored as the histo-id 215. A cut is applied on the generated beam positions in this routine that they should be inside the target volume. After this cut, the beam positions lie between -2 to 2 cm. Before applying this cut, the range is -5 to 5 cm as the input data beam positions lie between -5 to 5 cm.

The x and y projections for LH_2 +58 GeV data and the generated projections for LH_2 +58 GeV MC before cut are shown in Figure 5. The generated x and y projections for LH_2 +58 MC after cut are shown in Figure 6. A comparison of generated x and y projections before and after cut is shown in Figure 7.

2 Beam Profile generation for thin targets using FLUKA

For thin targets, FLUKA has been used as a generator. For generating the MC beam profile shapes similar to the data, the beam positions and widths in x and y direction are calculated by studying the beam x and y distributions for the data. These positions and widths are then put in the FLUKA input cards. The target offset is subtracted before using these data positions as input. The FLUKA input cards 'BEAM' and 'BEAMPOS' are defined on page numbers 69 and 75 respectively in the FLUKA manual [4]. We have divided the data sets on basis of run time-period and momentum. According to that, we have 7 data sets with different run ranges. The beam profiles for all thin targets in different run time-periods are shown in Figures 8, 9, 10 and 11. In a particular time-period, the data beam profiles for different targets are almost similar and an average beam position and width in x and y are calculated. The widths in x and y are multiplied by 2.3548 to get the FWHM's. The mean positions and FWHM's of the beam in x and y direction for all the run ranges at different momenta are shown in table 1.

The comparison of generated (MCTRUE) beam x and y profiles using the data positions and widths in x and y as input with beam x and y profiles for MCRECO and data for Be target at +58 GeV (run number=14103) is shown in Figure 12.

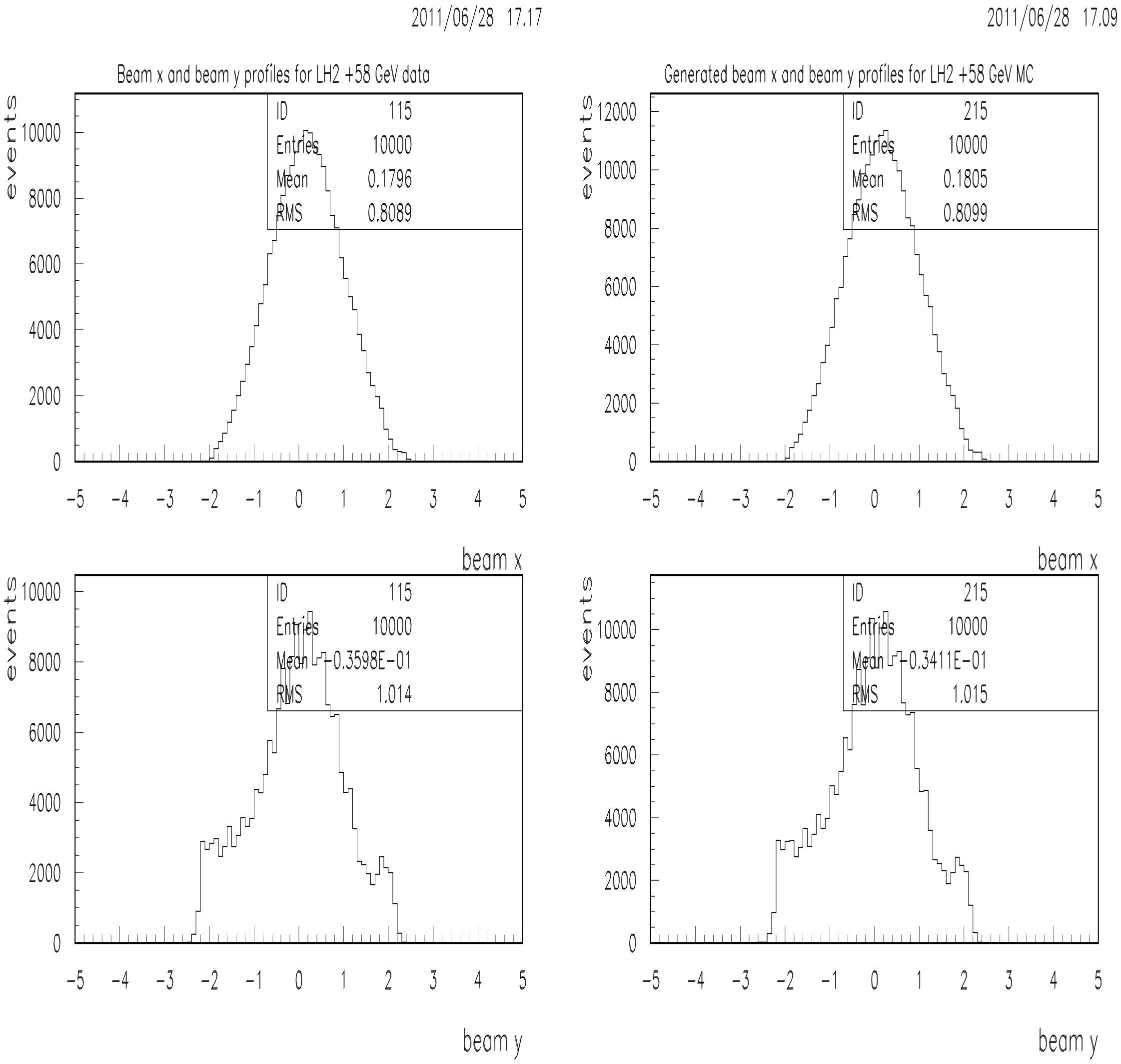


Figure 5: Left- Beam x and y projections for LH_2 +58 GeV data. Right- Generated beam x and y projections for LH_2 +58 GeV MC before cut.

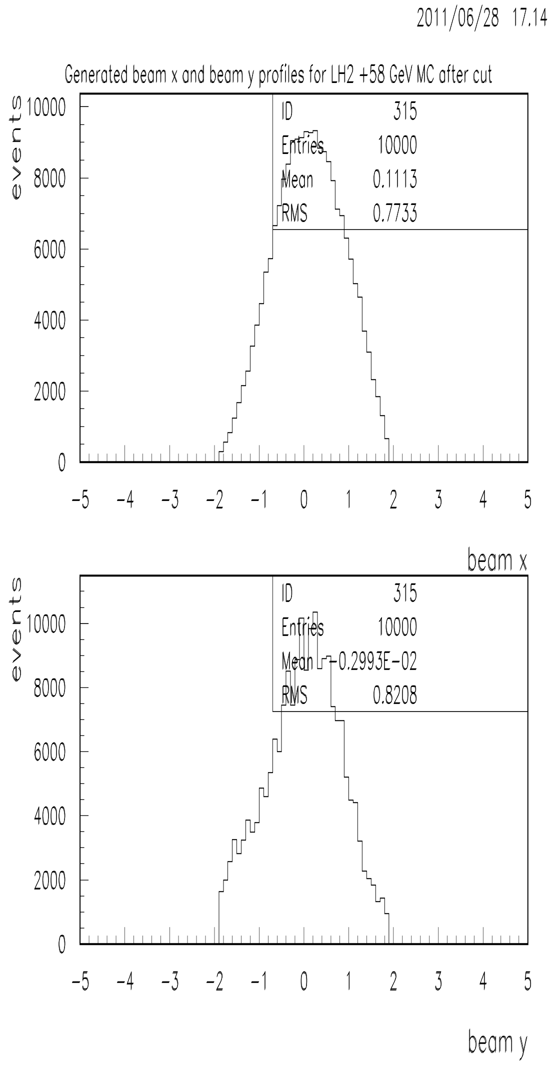


Figure 6: Generated beam x and y projections for LH_2 +58 GeV MC after cut.

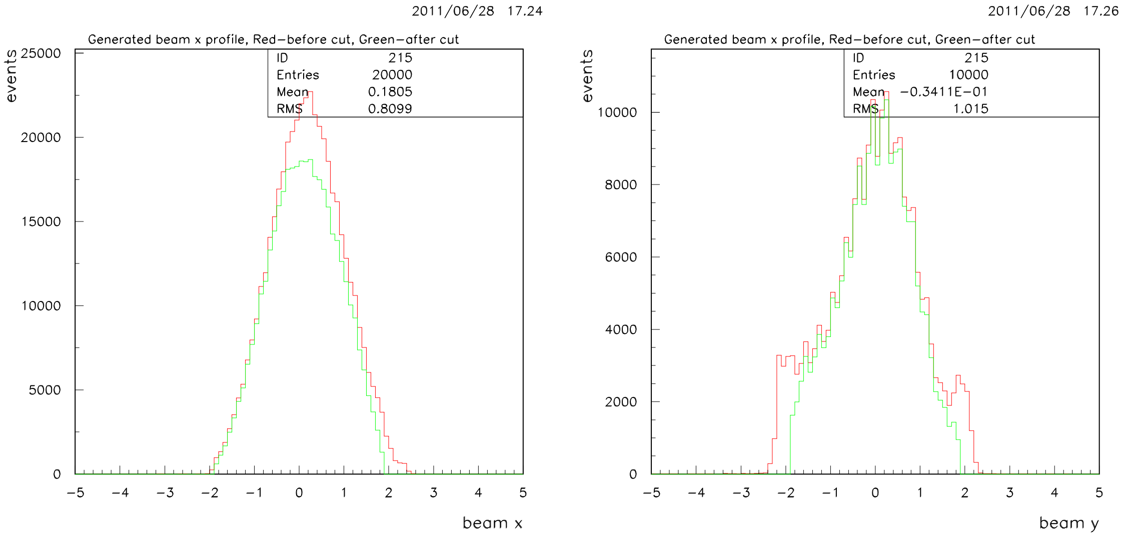


Figure 7: Left- Comparison of generated beam x projections before and after cut for LH_2 +58 GeV MC. Right- Comparison of generated beam y projections before and after cut for LH_2 +58 GeV MC.

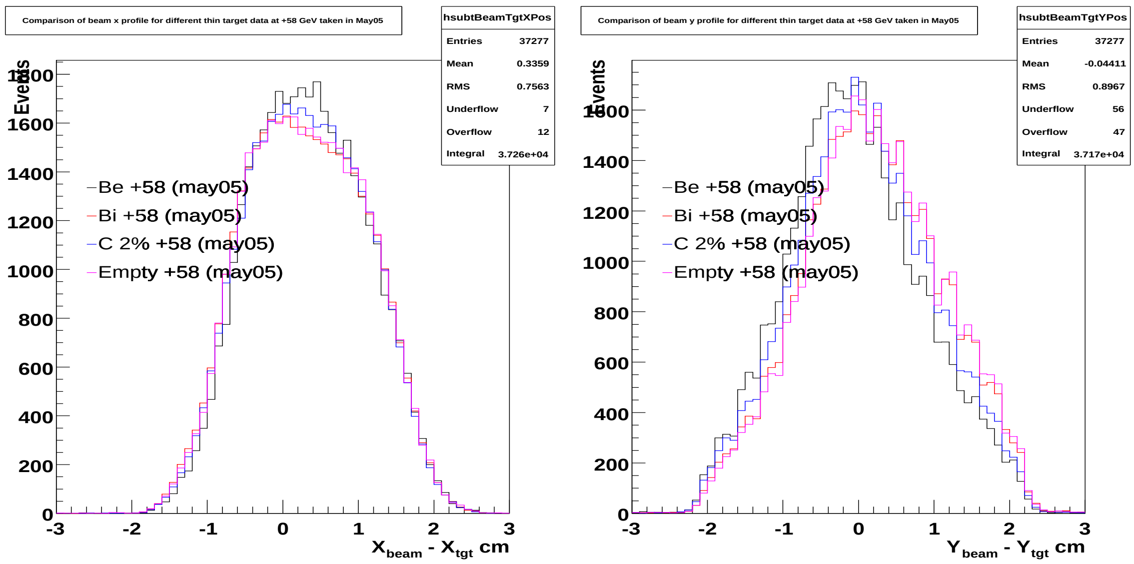


Figure 8: Left- Comparison of beam x profiles for all thin target data at +58 GeV. Right- Comparison of beam y profiles for all thin target data at +58 GeV.

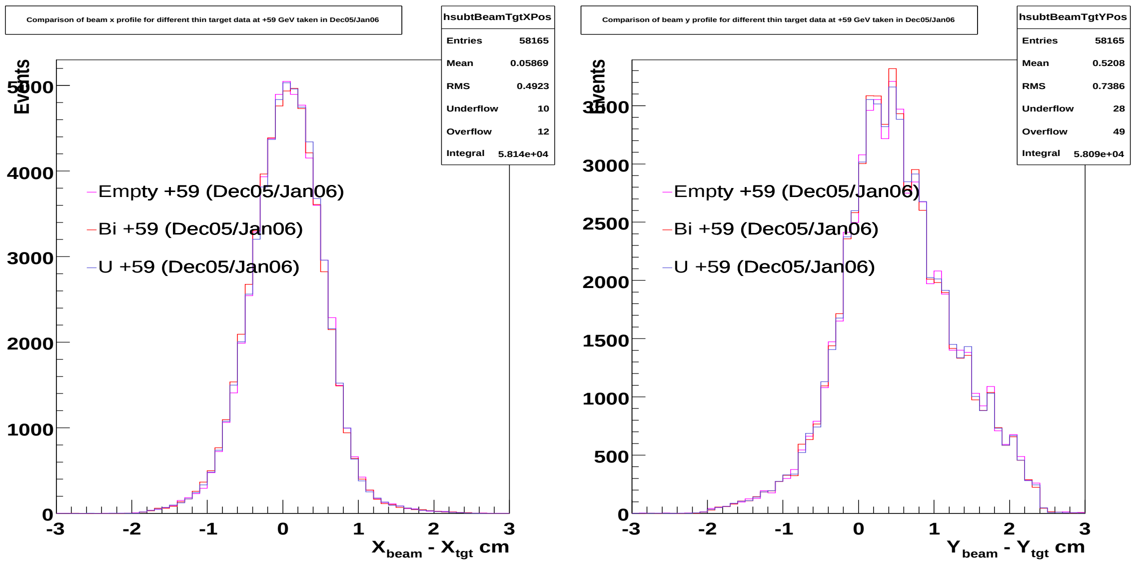


Figure 9: Left- Comparison of beam x profiles for all thin target data at +59 GeV. Right- Comparison of beam y profiles for all thin target data at +59 GeV.

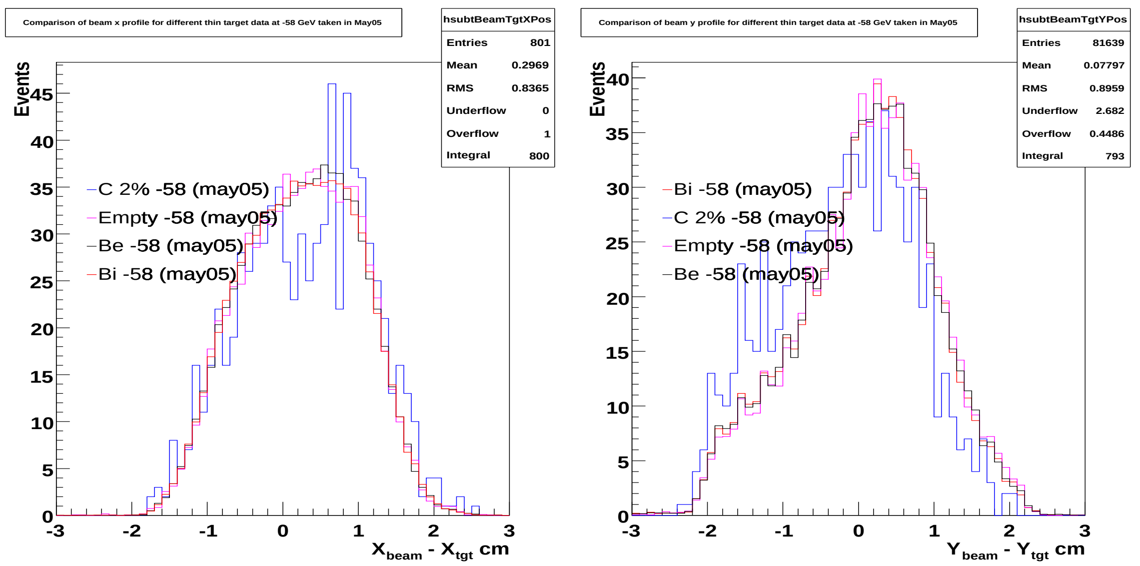


Figure 10: Left- Comparison of beam x profiles for all thin target data at -58 GeV. Right- Comparison of beam y profiles for all thin target data at -58 GeV.

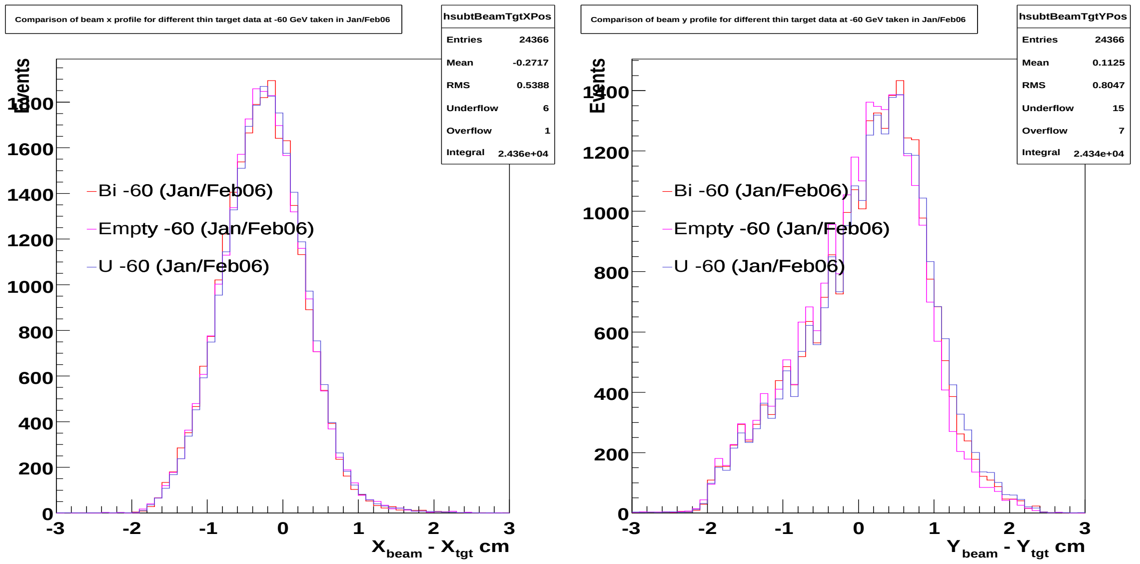


Figure 11: Left- Comparison of beam x profiles for all thin target data at -60 GeV. Right- Comparison of beam y profiles for all thin target data at -60 GeV.

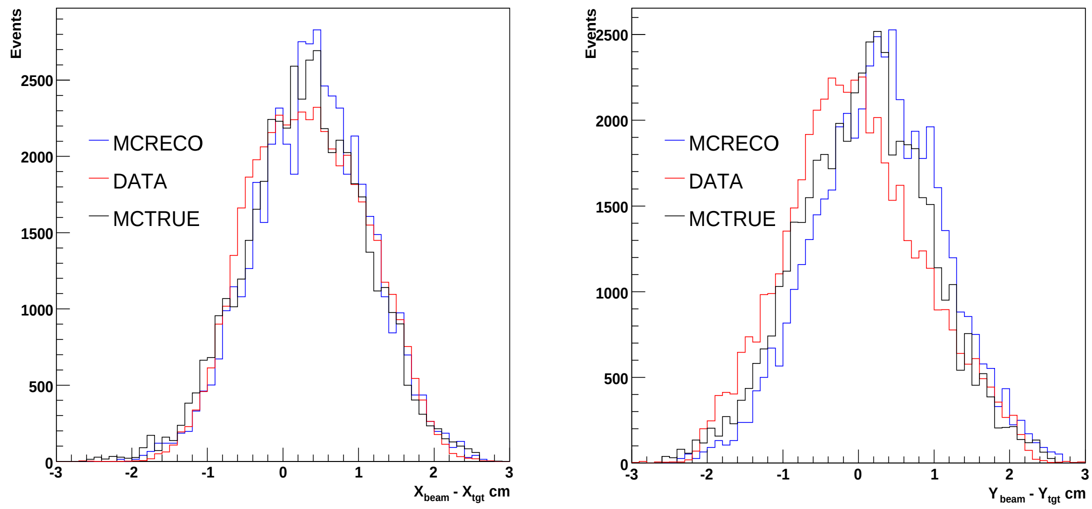


Figure 12: Left- Comparison of generated (MCTRUE) beam x profile with beam x profiles for MCRECO and data for Be target at +58 GeV. Right- Comparison of generated (MCTRUE) beam y profile with beam y profiles for MCRECO and data for Be target at +58 GeV.

Data set	Mean momentum (GeV/c)	$\sigma_{measured}$	$\sigma_{resolution}$	σ_{bite}	% resolution=($\frac{dP}{P}$)100
Thin target +19.8	19.76	0.706	0.478	0.520	2.63 %
Thin target +58	56.44	2.101	1.899	0.899	1.59 %
Thin target +59	56.88	2.6	1.921	1.75	3.08 %
Thin target +59	57.82	1.981	1.968	0.226	0.39 %
Thin target -58	57.44	2.255	1.949	1.134	1.97 %
Thin target -60	57.61	2.066	1.957	0.662	1.15 %

Table 2: Table of values of mean momentum, $\sigma_{measured}$, $\sigma_{resolution}$, σ_{bite} and % resolution for thin target (including Empty target) data sets at different momenta. For +59 GeV, we have two data sets for thin targets. One was taken in September, 2005 (run range: 16098-16108) and the other in December, 2005/January, 2006 (run range: 17087-17278).

3 Generation of new beam momentum and spreads in momentum in MC for thin targets using FLUKA

- Calculation of bite in momentum

The total momentum distribution of straight-through tracks for the data is drawn and a Gaussian function is fitted. The mean momentum and width (σ) of the momentum distribution are obtained from the fit. These numbers are calculated for all the run ranges for thin targets. The straight-through tracks are selected by using some cuts in the data. These cuts are as follows:

- Selection of only single beam tracks
- Vertex should have the incoming beam track – beam track index shouldn't be -ve
- No. of tracks in a vertex should be 1
- The difference of sum of p_T's of the outgoing tracks and incoming beam track p_T should be less than 100 MeV

The width of the momentum distribution gives $\sigma_{measured}$.

$$\sigma^2_{measured} = \sigma^2_{resolution} + \sigma^2_{bite}$$

$\sigma_{resolution}$ is the error in the measurement of the momentum and is obtained using the utility 'mipp_dp' in the routine 'DSTUtil.cxx' for a particular momentum. σ_{bite} is the spread in the momentum. Therefore,

$$\sigma_{bite} = \sqrt{\sigma^2_{measured} - \sigma^2_{resolution}}.$$

The mean momentum, $\sigma_{measured}$, $\sigma_{resolution}$, σ_{bite} and % resolution for various thin target data sets are shown in table 2. The σ_{bite} is multiplied by 2.3548 to get the FWHM of the momentum spread and put in the 'BEAM' card.

A Gaussian fit to the total momentum distribution of beam tracks (MCTRUE) using momentum spread from the data as input for thin target data set at +58 GeV (run number=14103) is shown in Figure 13. The distribution is centered at 58.02 GeV/c with a bite (σ) of $\sim$ 0.84

Data set	New MC beam momentum (GeV/c)
Thin target +19.8	19.91
Thin target +58	56.89
Thin target +59	57.38
Thin target +59	58.26
Thin target -58	57.72
Thin target -60	58.03

Table 3: Table of values of new MC momentum for thin target (including Empty target) data sets at different momenta. For +59 GeV, we have two data sets for thin targets. One was taken in September, 2005 (run range: 16098-16108) and the other in December, 2005/January, 2006 (run range: 17087-17278).

Data set	Mean momentum (GeV/c)	$\sigma_{measured}$	$\sigma_{resolution}$	σ_{bite}	% resolution=$(\frac{dP}{P})100$
LH_2 +19	18.44	1.084	0.441	0.990	5.37 %
LH_2 +19.8	19.51	0.635	0.471	0.426	2.18 %
LH_2 +20	18.56	1.133	0.444	1.042	5.61 %
LH_2 +58	56.35	2.28	1.895	1.268	2.25 %
LH_2 +59	56.85	2.062	1.919	0.754	1.33 %
LH_2 +84	81.96	4.758	3.356	3.373	4.12 %
LH_2 +85	81.87	3.551	3.350	1.178	1.44 %
LH_2 +86	82.12	3.377	3.366	0.272	0.33 %
LH_2 -19	18.56	0.956	0.444	0.847	4.56 %
LH_2 -19.8	19.78	0.811	0.479	0.654	3.31 %
LH_2 -20	18.77	1.171	0.450	1.081	5.76 %
LH_2 -58	56.6	2.511	1.907	1.634	2.89 %
LH_2 -59	56.58	2.247	1.906	1.19	2.1 %
LH_2 -84	82.66	3.7	3.402	1.455	1.76 %
LH_2 -85	82.86	3.836	3.415	1.747	2.11 %
LH_2 -86	82.66	3.678	3.402	1.398	1.69 %

Table 4: Table of values of mean momentum, $\sigma_{measured}$, $\sigma_{resolution}$, σ_{bite} and % resolution for LH_2 target (including Empty-Cryogenic target) data sets at different momenta.

Data set	New MC beam momentum (GeV/c)
LH_2 +19	18.61
LH_2 +19.8	19.67
LH_2 +20	18.72
LH_2 +58	56.78
LH_2 +59	57.27
LH_2 +84	82.56
LH_2 +85	82.49
LH_2 +86	82.74
LH_2 -19	18.74
LH_2 -19.8	19.92
LH_2 -20	18.91
LH_2 -58	56.92
LH_2 -59	56.93
LH_2 -84	83.2
LH_2 -85	83.4
LH_2 -86	83.17

Table 5: Table of values of new MC momentum for LH_2 target (including Empty-Cryogenic target) data sets at different momenta.

which is close to the momentum bite (σ) from the data i.e. 0.899. The Gaussian fits to the total momentum distributions of straight-through tracks for the MCRECO and data for this data set are shown in Figure 14. The widths (σ's) of the two distributions are comparable. Both the momentum bite and resolution contribute to the width of the MCRECO momentum distribution similar to the data. The comparison of total momentum distribution of straight-through tracks for MCRECO and data is shown in Figure 15. The average momentum for the data is quite low (56.43 GeV/c) as compared to that for the MCRECO (57.64 GeV/c). Momentum corrections are needed. For this, we have correction functions 'CorrMomData' and 'MCPtotCorr' in routine 'DSTUtil.cxx' which correct for total momentum of the data and MC tracks respectively. Even after correction, data momentum remains low (56.89 GeV/c) as compared to MCRECO momentum (58.06 GeV/c). So, now we have decided to generate the MC momentum using the corrected (true) momenta from the data. The total momentum for straight-through tracks for the data is corrected using the scale factor from 120 GeV data which is the ratio of corrected and uncorrected momentum [5]. This corrected data momentum is now used to generate the MC momentum. The corrected momenta are calculated for all the thin target data sets and are shown in table 3. The uncorrected and corrected momentum distributions of straight-through tracks for thin target data set at +58 GeV are shown in Figure 16.

A Gaussian fit to the total momentum distribution of beam tracks (MCTRUE) using new beam momentum and spread in momentum from the data as input for thin target data set at +58 GeV (run number=14103) is shown in Figure 17. The distribution is centered at 56.85 GeV/c

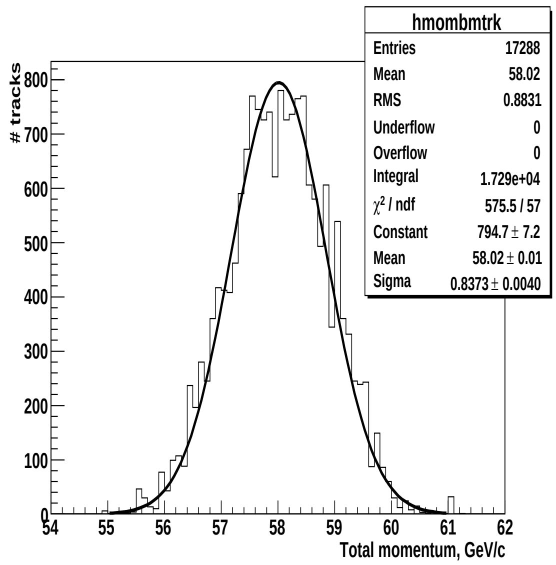
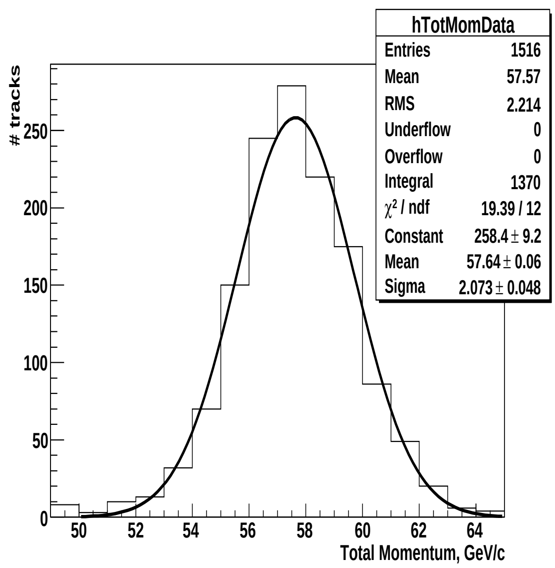


Figure 13: A Gaussian fit to the total momentum distribution of beam tracks (MCTRUE) for thin target data set +58 GeV (run number=14103) using new momentum spread from the data.



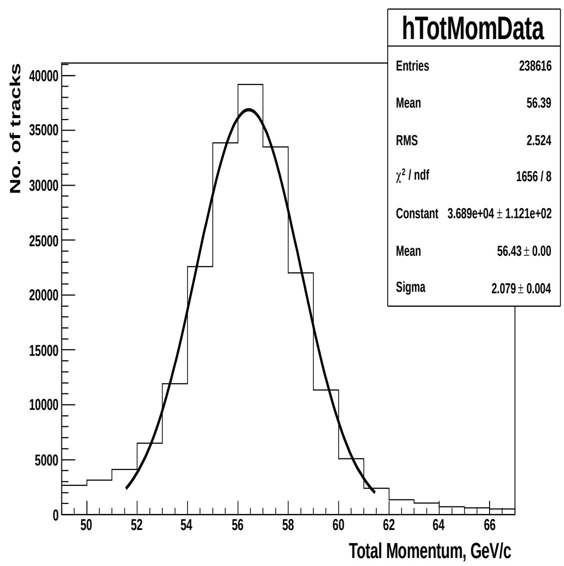


Figure 14: Left- A Gaussian fit to the MC reconstructed total momentum distribution of straight-through tracks for thin target data set at +58 GeV (run number=14103) . Right- A Gaussian fit to total momentum distribution of straight-through tracks for thin target data set at +58 GeV.

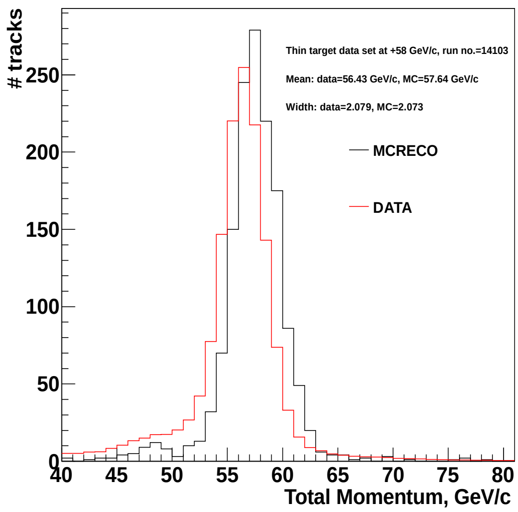


Figure 15: Comparison of total momentum distribution of straight-through tracks for MCRECO and data for thin target data set at +58 GeV.

with a bite (σ) of $\sim$ 0.85. These numbers are close to input beam momentum of 56.89 GeV/c and momentum bite (σ) of 0.899 from the data. A Gaussian fit to the MC reconstructed total momentum distribution of straight-through tracks for this data set is shown in Figure 17. The MCRECO momentum is corrected using the MC correction function 'MCPtotCorr' to get the true momentum. For the correction, a profile of reconstructed vs true momentum is made and a straight line of the form 'a+bx' is fitted. The parameters of the fit i.e a and b are 0.04851 and 0.9917 respectively. The reconstructed momentum becomes a function of true momentum i.e f(T) = R where R is the reconstructed momentum and T is the true momentum. We have to find the zeroes of the function g(T) = f(T) - R i.e. for a particular reconstructed momentum, what is the corresponding true momentum. For this, we use the Newton-Raphson method. The initial guess to the Newton-Raphson method is 56.89 GeV/c which is same as MCTRUE momentum. Figure 18 shows the fitted profile and momentum distribution after correction. The corrected MCRECO momentum is same as the true input momentum. Figure 19 shows the comparison of total momentum distribution of straight-through tracks for the corrected MCRECO and data. There is no shift in the means of the MCRECO and data momentum distributions now.

4 Generation of new beam momentum and spreads in momentum in MC for LH_2 target using DPMJET

For each of the 16 data sets, momentum bite is calculated in the same way as for the thin targets. These numbers are shown in table 4. The corrected momenta are calculated for all the data sets using the scale factor from 120 GeV data and are now used to generate the MC momenta similar

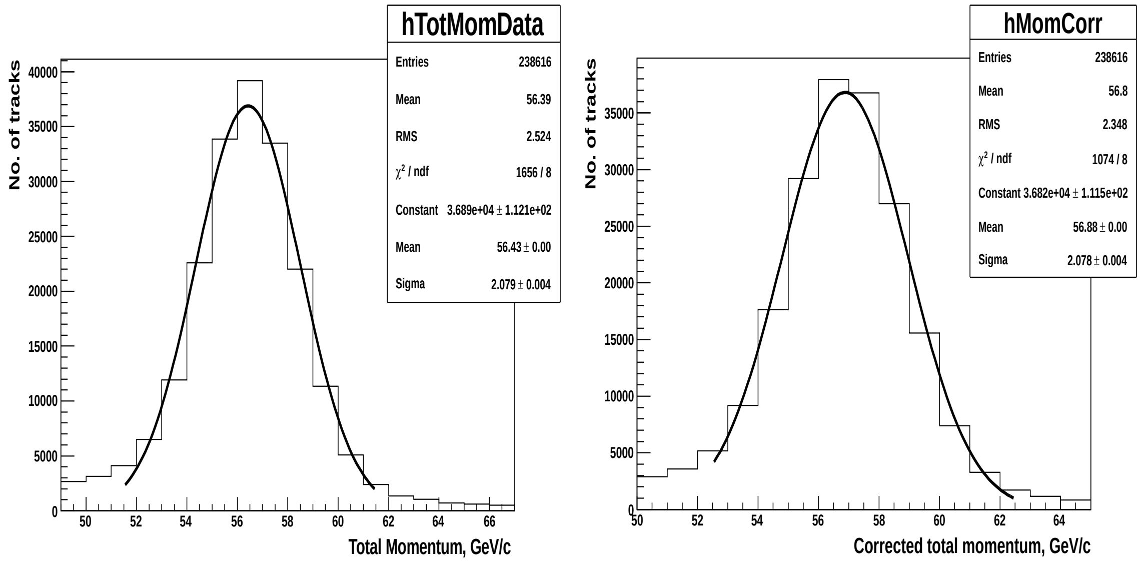


Figure 16: Left- A Gaussian fit to the uncorrected total momentum distribution of straight-through tracks for thin target data set at +58 GeV. Right- A Gaussian fit to the corrected total momentum distribution of straight-through tracks for thin target data set at +58 GeV using scale factor from 120 GeV data.

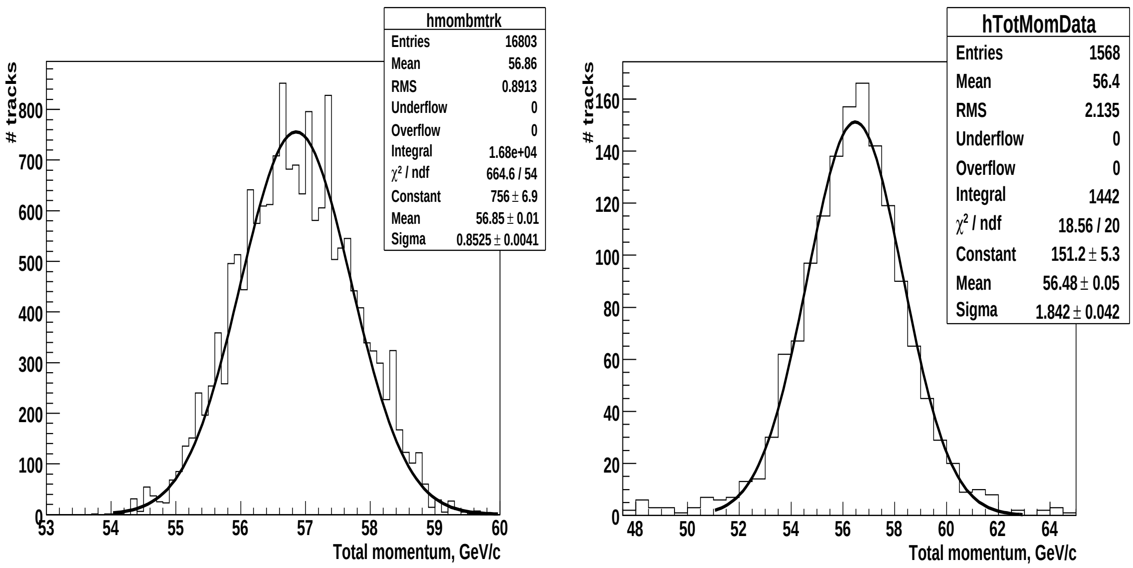


Figure 17: Left- A Gaussian fit to the total momentum distribution of beam tracks (MCTRUE) for thin target data set at +58 GeV (run number=14103) using new beam momentum and spread in momentum from the data. Right- A Gaussian fit to the MC reconstructed total momentum distribution of straight-through tracks for thin target data set at +58 GeV (run number=14103) using new beam momentum.

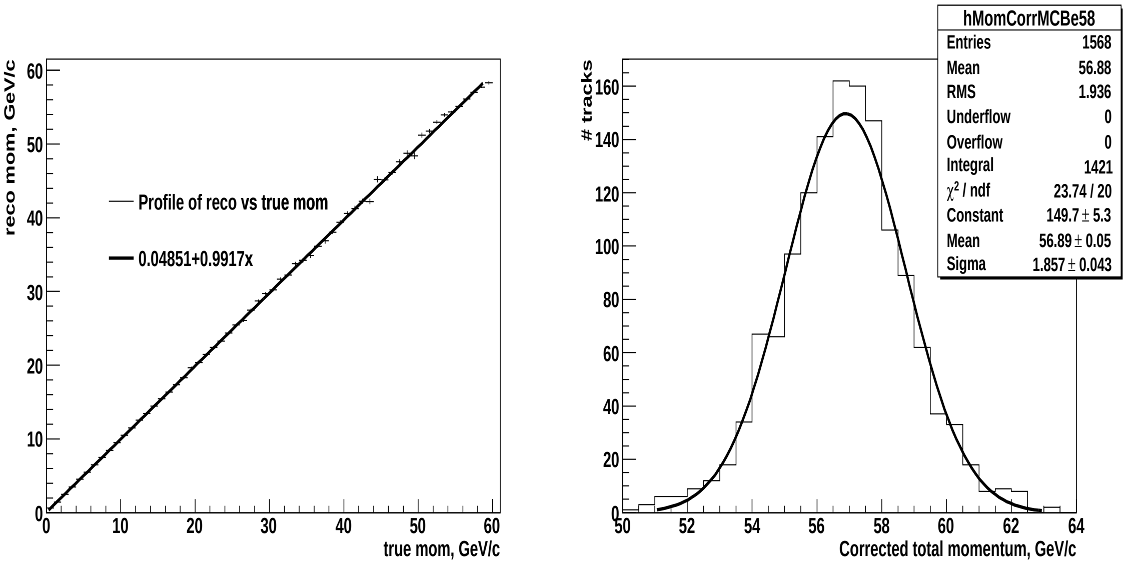


Figure 18: Left- A straight line fit to the profile of reconstructed vs true momentum for thin target data set at +58 GeV (run number=14103). Right- A Gaussian fit to the corrected MC reconstructed total momentum distribution of straight-through tracks for thin target data set at +58 GeV (run number=14103) using MC correction function 'MCPtotCorr'.

to thin targets. These new MC momenta are shown in table 5. One dimensional momentum histogram is generated using the new MC momentum as the mean momentum and bite as the width (σ) for each set of data. E.g. for +58 GeV/c data set, this histogram is centered at +56.78 GeV/c and has a width (σ) of 1.3. This histogram is put in the same directory of the input HBOOK in which 2D histogram of beam x and y from the data is stored. This is done for all the data sets i.e 16 momentum histograms are generated. The histo-id of all the 16 momentum histograms is the same which is 125.

In 'beam_gen.F' routine, the momentum histogram is then called from the input HBOOK and random numbers are generated according to the entries of the histogram. The part of the routine which does this is as follows:

```
R4=HRNDM1(125)
NEWMOM=R4
PBEAM_LAB_R(1) = DX*NEWMOM
PBEAM_LAB_R(2) = DY*NEWMOM
PBEAM_LAB_R(3) = DZ*NEWMOM !new beam in lab (mom with bite)
DPBMR=DSQRT(PBEAM_LAB_R(1)**2+PBEAM_LAB_R(2)**2+PBEAM_LAB_R(3)**2)
PBEAM_LAB_R(4) = DSQRT(PBEAM_LAB(5)**2+DPBMR**2)
PBEAM_LAB_R(5) = PBEAM_LAB(5)
```

DX, DY and DZ are the direction cosines of the beam (beam is projected backwards up to

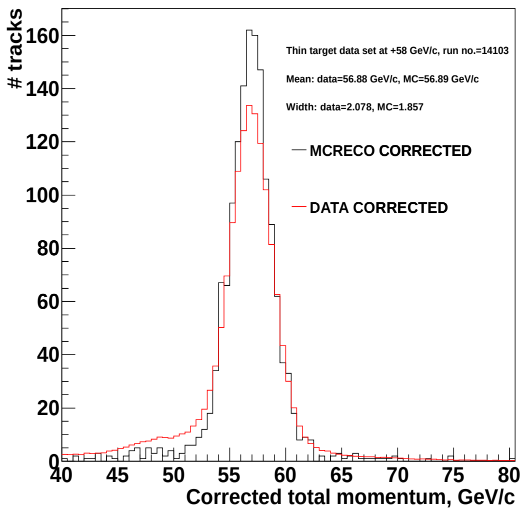


Figure 19: Comparison of total momentum distribution of straight-through tracks for corrected MCRECO and data for thin target data set at +58 GeV.

scintillator counter TBD) and these are multiplied by the total momentum (NEWMOM) including the bite from the input histogram to get the new components of momentum. DPBMR is the new total momentum with the bite. The energy PBEAM_LAB_R(4) is also calculated again and given as $\sqrt{mass^2 + momentum^2}$.

The outgoing longitudinal momentum is scaled by the total momentum including the bite from the input histogram. The outgoing momentum vector is rotated such that the new beam direction is kept. The routine ROT_TO_NEW_BEAM does this rotation. After rotation, the outgoing momentum vector is same as the rotated beam momentum vector. The outgoing energy is also calculated using the new scaled momentum after rotation. The part of the routine which does this is as follows:

PART(3) = PART(3)*(NEWMOM/DPBM) (DPBM is the true momentum)

CALL ROT_TO_NEW_BEAM(PBEAM_LAB,PBEAM_LAB_R,PART,PARTN,JJ)

MOMTOTROT = DSQRT(PARTN(1)**2+PARTN(2)**2+PARTN(3)**2)

PARTN(4) = DSQRT(MOMTOTROT**2+PART(5)**2)

5 Acknowledgements

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References

[1] Beam transverse position distributions for the MC and the data were shown in weekly MIPP meeting. See document MIPP-doc-1080-v1.

[2] Beam profiles for different triggers for LH_2 target data at beam energies of +58 and -58 GeV were shown in weekly MIPP meeting. See document MIPP-doc-1092-v1.

[3] Beam x and y profiles for different run numbers were shown in weekly MIPP meeting. See document MIPP-doc-1098-v1.

[4] Alfredo Ferrari, Paola R. Sala, Alberto Fassò, Johannes Ranft, "Fluka: a multi-particle transport code (Program version 2008)", available at http://www.fluka.org/content/manuals/FM.pdf.

[5] The uncorrected and corrected momentum distributions for thin target data sets at +58 and +59 GeV/c using scale factor from the data were shown in weekly MIPP meeting. See MIPP-doc-1117-v1.