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Addendum to ATS Note CERN-ACC-NOTE-2016-0052

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Abstract

The authors would like to publish this addendum to their note [1] in order to present specific results for H4-VLE beam line, and the corresponding experiment, designated "NP-04".

1. H4 Beam Layout

A CATIA drawing of the H4-VLE extension pointing to the 11×11 m^2 Single Phase ProtoDUNE (NP-04) experiment is shown in Fig.1.

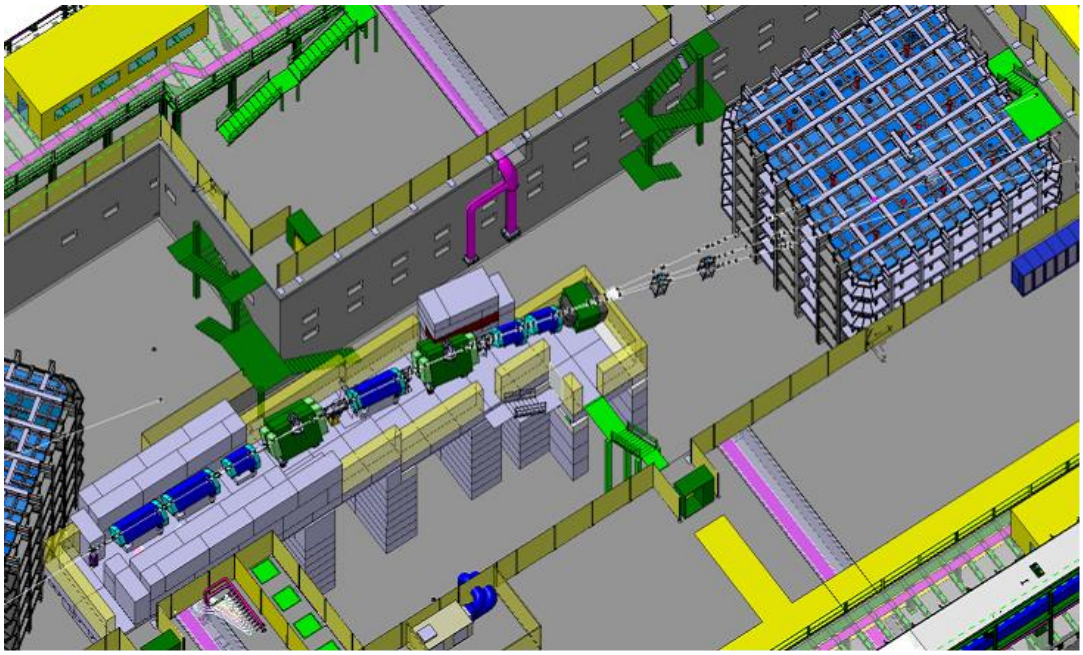

Figure 1: CATIA drawing of the H4-VLE beam line extension. The overall beam line length from the secondary target at the bottom left of the figure to the experiment, is 39.644 m. The NP-04 cryostat is depicted on the top right of the figure. (Courtesy V. Clerc)

Similarly with the H2-VLE in the H4-VLE extension, downstream the secondary target, is located an initial quadrupole acceptance triplet, followed by a momentum selection and recombination station with two bends. Between the two bends the momentum collimator and the field-lens quadrupole are located. Finally, a set of focusing quadrupoles shapes the beam on the

experiment providing a spot size of approximately 12×12 cm^2 at the entrance of the cryostat. The conceptual layout of the beam line along with the assumed instrumentation is shown in Figure 2.

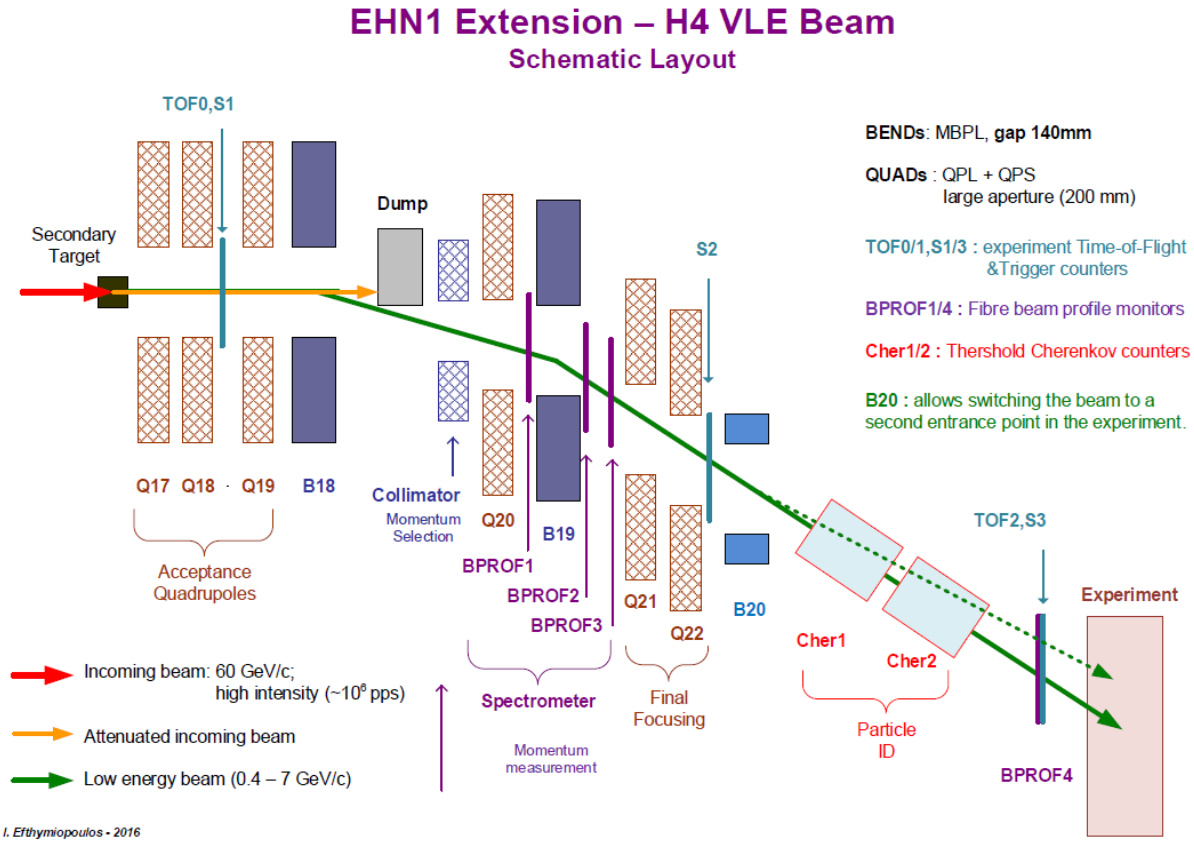

Figure 2: Schematic layout of H2-VLE beam line. Between the elements, several instrumentation devices are depicted.

The maximum momentum spread accepted by the beam line is ±5%. In order to maximize the acceptance and reduce the overall length of the beamline, the two bending magnets are tilted by ~60 degrees with respect to the floor, while an extra horizontal bend allows for the horizontal scanning of the beam. The optics drawing of the beam line depicting the beam envelope is shown in Figure 3. Figure 4 shows the spot size of the beam at the focal point at the entrance of the NP-04 detector. More details on the beam design can be found in reference [3].

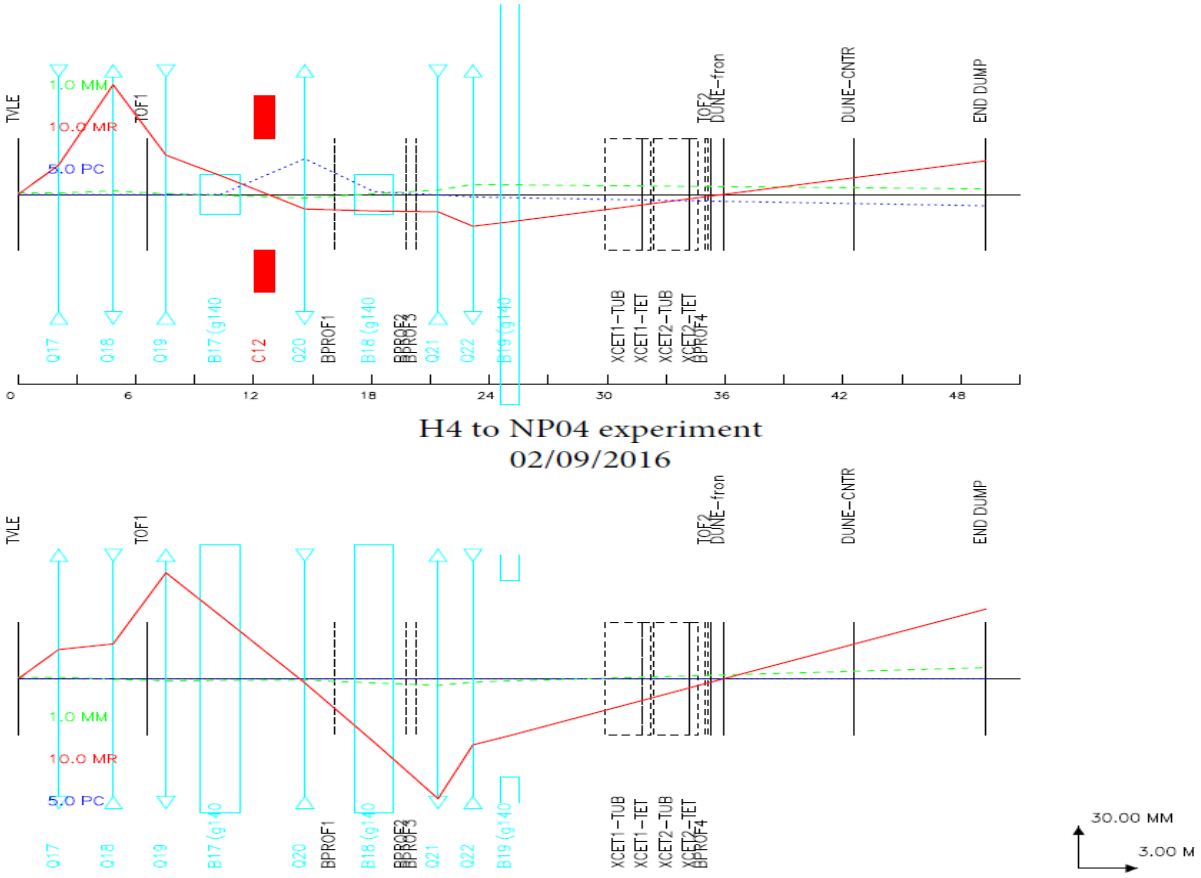

Figure 3: Optics drawing of the H4-VLE beam line. The red line indicates the envelope of particles emitted at 10 mrad from the secondary target origin, the blue the contribution to the beam size from the momentum dispersion, and the green that of the target source of 1mm.

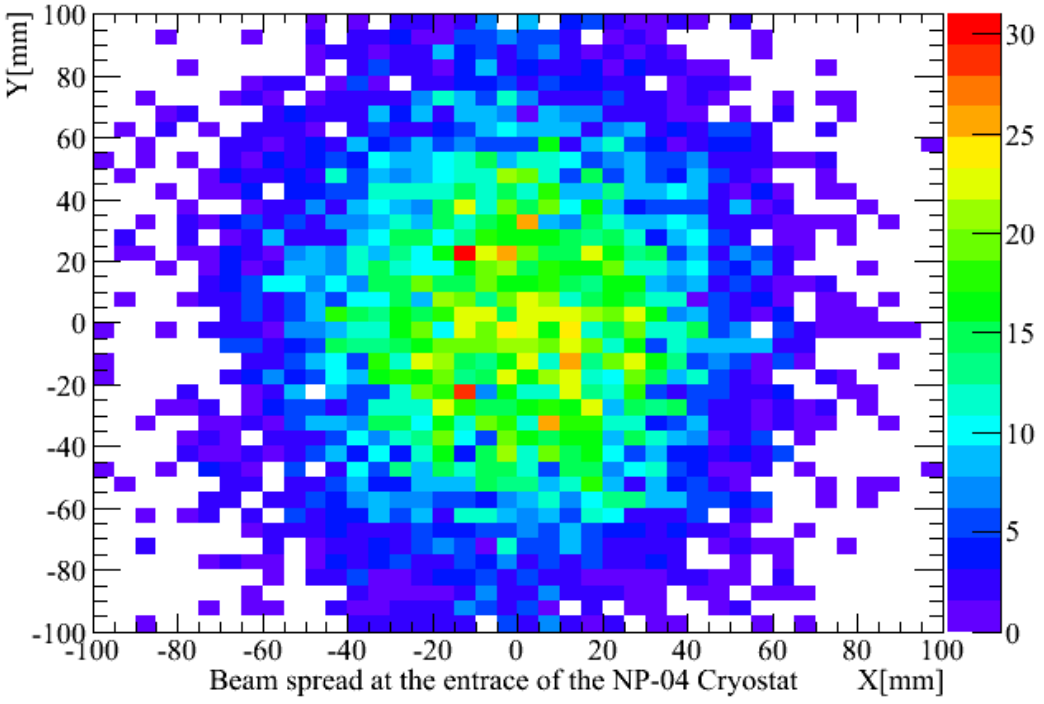

Figure 4: Beam spot size at the entrance of the NP04 detector, where the beam is focused; case for the 7 GeV/c beam.

2. Beam composition and trigger rates

2.1 Triggered Beam Composition

Following the same technique applied in H2, we run a high-statistics (6 million events) simulation requesting that particles satisfy the minimal trigger conditions of the experiment, namely that they cross all the beam detectors. Table 3 shows the expected beam composition. Negative (positive) particle contribution in the positive (negative) beams is negligible. All H4-VLE beams emerge from a positive secondary beam impinging on the tertiary VLE target.

Momentum [GeV/c]	e+-	K+-	mu+-	p+-	pi+-
-7	27.43%	3.39%	0.97%	1.28%	66.92%
-6	33.46%	2.85%	1.16%	1.27%	61.26%
-5	43.21%	1.93%	1.28%	1.07%	52.52%
-4	54.55%	1.10%	1.37%	0.63%	42.34%
-3	28.38%	1.14%	2.28%	1.41%	66.78%
-2	48.89%	0.26%	1.83%	0.39%	48.63%
-1	81.68%	0.16%	1.09%	0.16%	16.93%
-0.4	98.27%	0.00%	0.43%	0.00%	1.30%
0.4	99.07%	0.00%	0.00%	0.46%	0.46%
1	69.26%	0.00%	1.56%	15.30%	13.88%
2	34.94%	0.64%	2.46%	22.93%	39.04%
3	19.93%	2.75%	1.81%	18.93%	56.59%
4	47.07%	1.58%	1.28%	8.75%	41.33%
5	37.04%	2.84%	1.28%	9.35%	49.50%
6	28.07%	3.98%	1.32%	10.42%	56.21%
7	20.59%	5.15%	0.98%	10.65%	62.64%

Table 1: Beam composition for the hadron beams, including all the material in the beam line. Below and at 3 GeV the W-target was used.

2.2 Trigger Rate

Momentum [GeV/c]	anti-p	e-	e+	K-	K+	mu-	mu+	p	pi-	pi+	Total (all particles)
-7	2.64	56.74	0.00	7.01	0.00	2.01	0.00	0.00	138.40	0.00	206.81
-6	2.36	62.05	0.00	5.28	0.00	2.15	0.00	0.00	113.61	0.00	185.45
-5	1.77	71.70	0.00	3.19	0.00	2.12	0.00	0.00	87.15	0.00	165.94
-4	1.08	92.64	0.00	1.88	0.00	2.33	0.00	0.00	71.91	0.00	169.83
-3	0.56	11.22	0.00	0.45	0.00	0.90	0.00	0.00	26.39	0.00	39.51
-2	0.10	13.02	0.00	0.07	0.00	0.49	0.00	0.00	12.95	0.00	26.63
-1	0.03	18.26	0.00	0.03	0.00	0.24	0.00	0.00	3.78	0.00	22.36
-0.4	0.00	7.88	0.00	0.00	0.00	0.03	0.00	0.00	0.10	0.00	8.02
0.4	0.00	0.00	7.43	0.00	0.00	0.00	0.00	0.03	0.00	0.03	7.50
1	0.00	0.00	18.54	0.00	0.00	0.00	0.42	4.10	0.00	3.72	26.77
2	0.00	0.00	13.33	0.00	0.24	0.00	0.94	8.75	0.00	14.90	38.16
3	0.00	0.00	11.08	0.00	1.53	0.00	1.01	10.52	0.00	31.46	55.59
4	0.00	0.00	92.29	0.00	3.09	0.00	2.50	17.15	0.00	81.04	196.08
5	0.00	0.00	74.31	0.00	5.69	0.00	2.57	18.75	0.00	99.31	200.63
6	0.00	0.00	63.61	0.00	9.03	0.00	2.99	23.61	0.00	127.40	226.63
7	0.00	0.00	51.81	0.00	12.95	0.00	2.47	26.81	0.00	157.64	251.67

Table 2: Trigger rate in Hz as seen by the experiment for the standard operation foreseen with 10^6 primary particles on the T2 target. Below and at 3 GeV the W-target was used.

3. Beam Instrumentation

3.1 Momentum measurement

H4-VLE is equipped with a momentum selection station (including the momentum collimator) and a spectrometer around the second bend magnet for the momentum reconstruction particle-by-particle. Figure 5 shows the Δp/p variation as a function of the collimator slit. Figures 6 and 7 show the reconstructed momentum using the spectrometer. Figure 8 depicts the deterioration of particle momenta reaching the active volume of the detector due to the instrumentation material in the line.

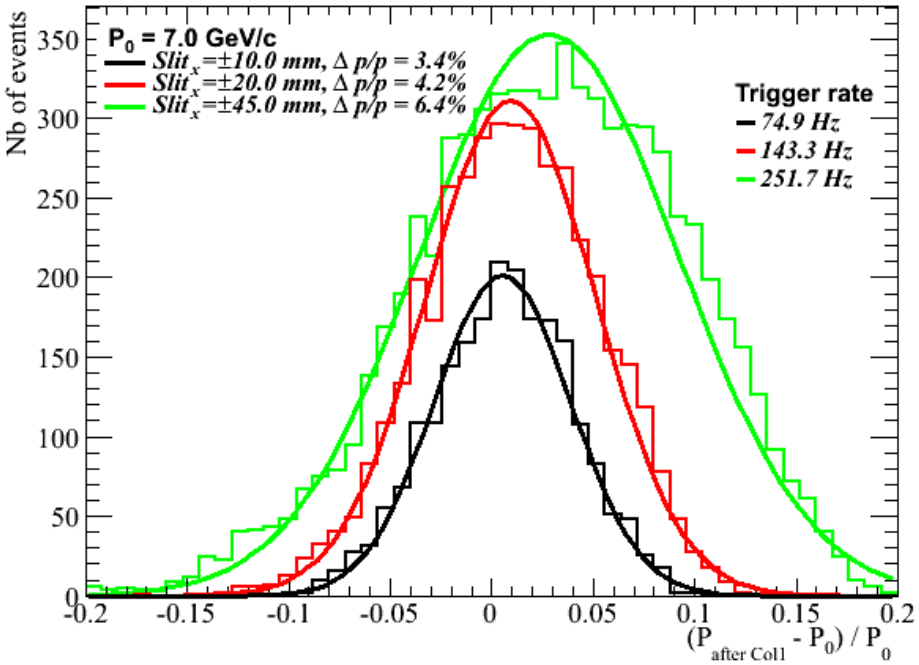

Figure 5: The beam momentum byte (Δp/p) for few settings of the collimator slit (GEANT4 simulation)

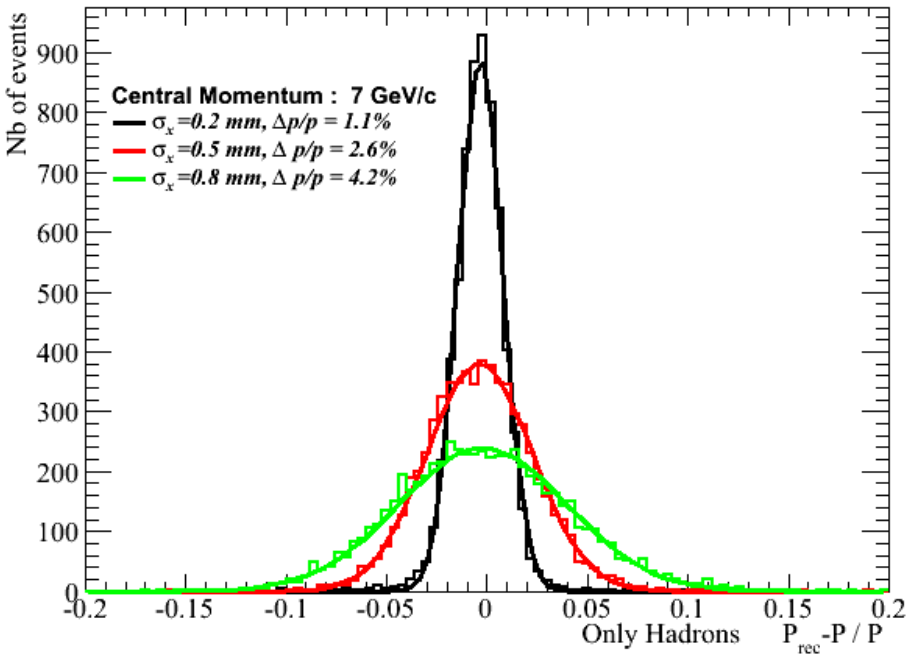

Figure 6: Reconstructed momentum byte for a beam of 7 GeV, taking into account the material on the beam line (GEANT4 simulation)

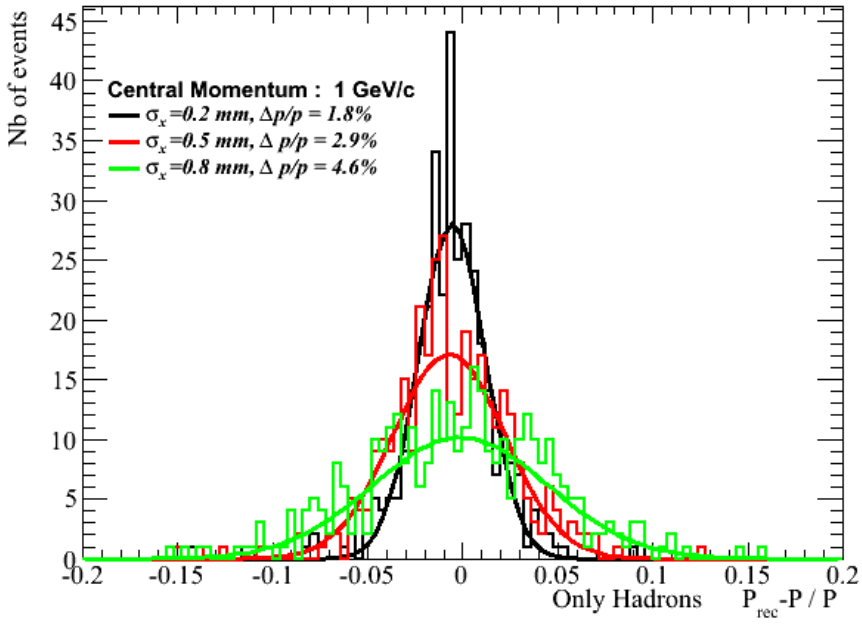

Figure 7: Reconstructed momentum byte for a beam of 1 GeV, taking into account the material on the beam line.

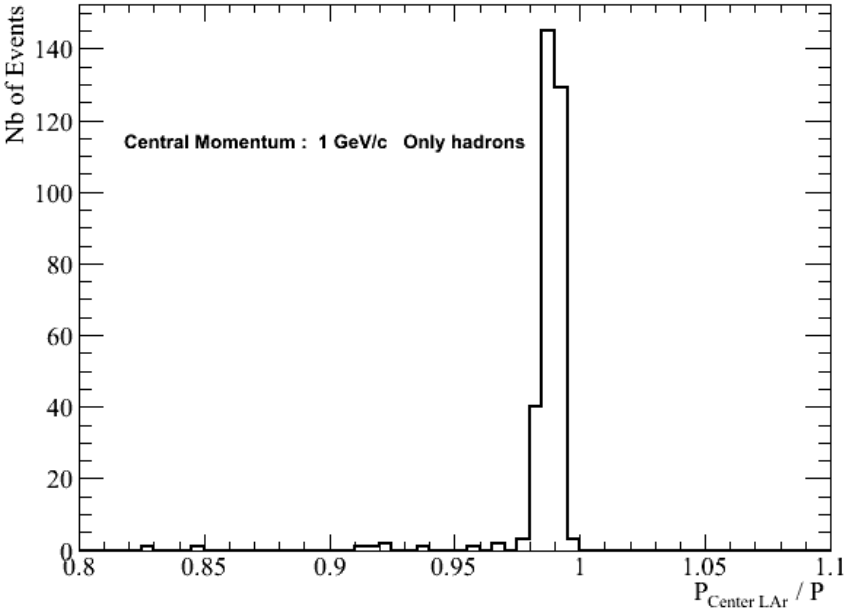

Figure 8: Ratio of the hadrons' momentum in the middle of the detector divided by its initial one. The deterioration of particles' momenta is due to the material present in the line, for the case of 1 GeV/c. The material assumed as present in the line is described in [1].

Acknowledgements

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4. References

[1] N. Charitonidis, Y. Karyotakis, I. Efthymiopoulos, “Beam performance and instrumentation studies for the ProtoDUNE-DP experiment of CENF”, CERN-ACC-NOTE-2016-0052

[2] ProtoDUNE – proposal, CERN-SPSC-2015-020; SPSC-P-351

[3] N. Charitonidis & I. Efthymiopoulos, “The Very Low (0.2 – 12 GeV) Tertiary Beam Line Design for the CENF project”, to be published.