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# The beam lines design for the CERN neutrino platform in the CERN north area and an outlook on their expected performance

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**Abstract.** In the framework of the CERN Neutrino Platform project, extensions to the existing SPS North Area secondary beam lines “H2” and “H4”, able to provide low-energy charged particles in the momentum range from 0.4 to 12 GeV/c, have been designed. The parameters of these “very low energy” beam lines, the expected beam composition as seen by the experiments as well as an outlook on their expected performance are summarized in this paper. Results from Monte-Carlo simulations, important for the optimization of the future instrumentation of the beam lines (serving both the purpose of beam tuning and the experiments’ needs for particle identification and momentum measurements), are also presented.

## 1. Introduction

The CERN’s North Area Experimental Halls are multi-purpose facilities designed to deliver primary ion and attenuated proton beams, as well as a wide spectrum of secondary and tertiary particle beams of varying and flexible composition (hadrons and leptons) to fixed-target experiments. In the framework of the CERN Neutrino Platform project (CENF), the EHN1 experimental hall is extended to house two large-size detector prototypes for future neutrino experiments, designated ‘ProtoDUNE-Dual Phase’ (NP-02) and ‘ProtoDUNE - Single Phase’ (NP-04), served by extensions of the H2 and H4 beam lines, respectively. The required beam parameters for these experiments are summarized in Table 1, while the layout of the extension can be seen in Figure 1.

The existing H2 and H4 beam lines were designed to transport high-energy particles in the order of several hundreds of GeV. The magnet’s power supplies are therefore out of their stability region when operating at very low currents. In addition, the overall length of the existing secondary beamlines exceeds by far the decay length of pions and kaons at the low momenta required by the experiments. Therefore, a new design of a ‘third generation particle’ beam line had to be devised towards the extension of the experimental hall in order to produce the required low-energy beams requested by the experiments.



**Table 1.** The main design beam parameters as described in the experimental proposals, for ProtoDUNE –SP (NP-04) [1] and ProtoDUNE – DP (NP-02) [2].

Parameter	ProtoDUNE – DP	ProtoDUNE - SP
Particle Type	$\pi^+$ , $\mu^+$ , $e^+$ , K, p	
Momentum	< 12 GeV/c	< 7 GeV/c
$\Delta p/p$	< 5 %	
Beam Size Rms	~ 10 cm at the entrance of the cryostats	
Max Rate	< 100 Hz	< 100 Hz



**Figure 1.** Layout of the extension of the EHN1 building. The two new detector prototypes (ProtoDUNE-NP02 and protoDUNE-NP-04), along with the extensions of the H2 and H4 beam lines is depicted.

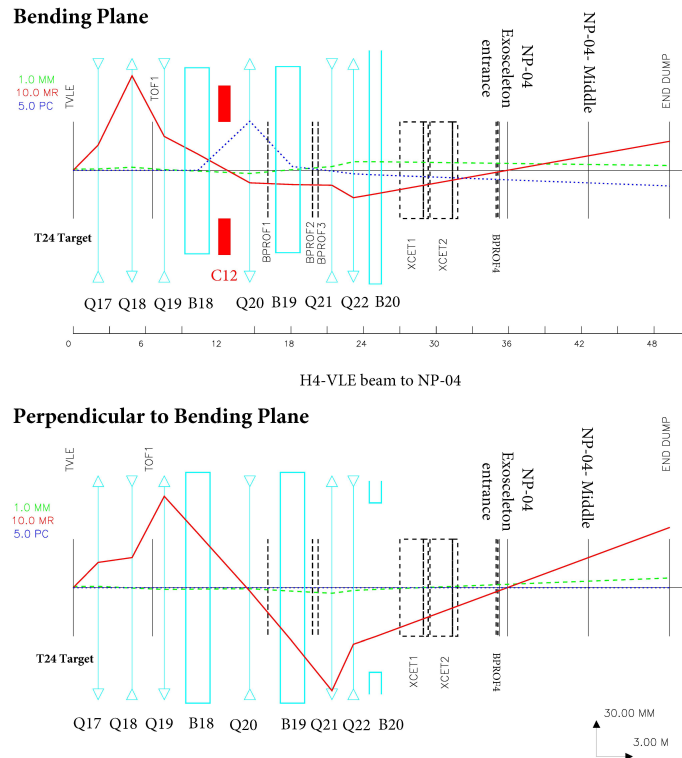
## 2. Beam line design & performance

### 2.1. Layout & Optics

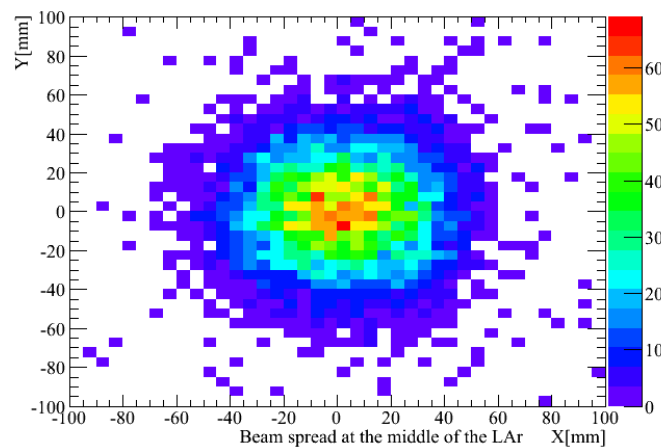
In order to overcome the aforementioned challenges, a two stage production, momentum selection and transport beam line has been designed and incorporated in the current infrastructure: a secondary beam produced at the primary and existing beryllium target ('T2') of North Area, with medium intensity of approximately 106 particles/spill and a chosen momentum of 80 GeV/c is being transported to a 'secondary target', where the lower momenta particles are produced via hadronic and electromagnetic interactions. After this target, a magnetic spectrometer four (two for H4-VLE) large-aperture dipoles and a momentum selection station with a field-lens quadrupole and a two-jaw collimator selects the desired momenta. The beam is focused on the experiment by a quadrupole doublet. Since the beam impact point on both cryostats had to be displaced horizontally and vertically from the trajectory of the upstream secondary beam line, the bending and quadrupole magnets, as well as the beam instrumentation had to be tilted by 34.30 (56.75 for H4) degrees with respect to the floor. The beam optics visualisation for H2-VLE, calculated with TRANSPORT [3] can be seen in Figure 2.

Both beam lines have been optimized for a maximum angular acceptance from the production target equal to 10 mrad. The beam envelope is then focused between the four (two for H4-VLE) bends and the momentum analysis stage is performed with a collimator having the jaws parallel to the beam bending plane. The field-lens positioned between the bending magnets, recombines the momentum before the final focusing at the experiment with the last quadrupole doublet. The spot size at the

position of the experiment has been calculated with G4BeamLine [4] for H2-VLE [5] and is shown in Figure 3. The spot-size in H4-VLE is of similar dimensions.



**Figure 2.** Optics diagram for the H2-VLE beam line. The red line corresponds to the sine-like ray, the blue dotted line represents the dispersive ray and the green line the magnification term.



**Figure 3.** Spot size of the beam in the centre of NP-02 detector.

## 2.2. Beam composition

The beam can be operated in a “hadron” or “electron” mode. In the hadron mode, the composition of the beam calculated with G4BeamLine is shown in Table 2, for the H2 beam line. For the momenta up to 3 GeV/c a W target was used, since it absorbs more electrons and increases the relative amount of hadrons in this very low momentum regime, while for momenta > 3 GeV/c a Cu target is used. In

the “electron” mode, a Pb target of a few radiation lengths will be used, and the resulting electron beam will have a purity of about 99.95 %.

**Table 2.** Beam composition for the hadron beams, including all the beam line material and magnetic elements. Below and equal to 3 GeV the W-target was used.

Momentum [GeV/c]	e+	K+	mu+	p	pi+
0.4	97.61%	0.00%	0.00%	0.48%	1.91%
1	74.20%	0.00%	0.00%	14.94%	10.86%
2	45.83%	0.67%	0.96%	20.04%	32.50%
3	25.16%	1.56%	1.56%	17.56%	54.17%
3	68.29%	0.64%	0.42%	7.72%	22.94%
4	53.72%	1.46%	0.65%	7.56%	36.61%
5	42.38%	2.47%	0.83%	9.18%	45.14%
6	31.42%	3.83%	0.73%	10.10%	53.92%
7	24.70%	4.08%	0.85%	9.92%	60.46%
8	19.36%	5.11%	0.97%	11.33%	63.24%
9	15.12%	5.67%	0.82%	11.10%	67.29%
10	12.36%	6.02%	0.71%	12.25%	68.66%
11	10.46%	6.95%	0.82%	13.57%	68.20%
12	8.90%	6.89%	0.66%	14.26%	69.30%

### 2.3. Momentum resolution

The beam line is equipped with a momentum selection and recombination station. The effect of the C12 collimator is defined by the optics and verified with G4BeamLine. It is demonstrated in [5] that for a small slit-size the momentum spread can be reduced down to ~2% at an expense of the rate.

## 3. Instrumentation

The VLE beam line will be equipped with several types of beam instrumentation devices with the aim at fulfilling different requirements, serving both the purpose of beam tuning and particle identification for the experiments.

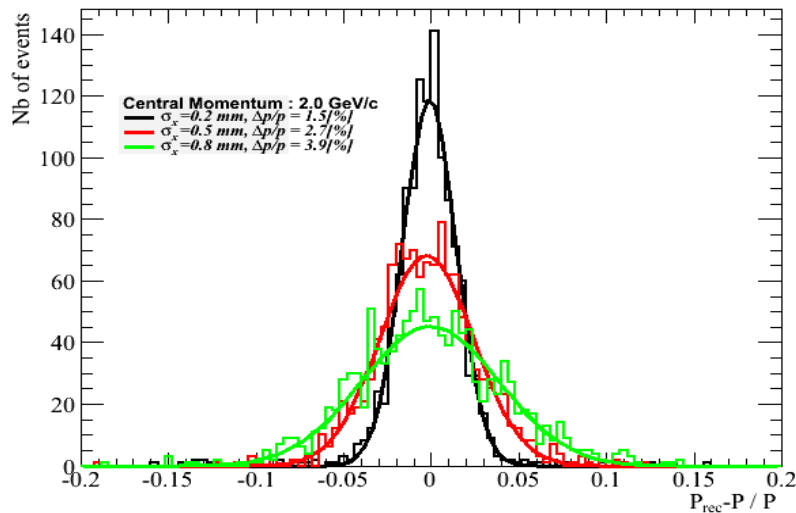
### 3.1. Beam profile monitors

A principal requirement of the instrumentation is to provide beam profile measurements at various locations along the beam line. Towards this purpose, special beam profile monitors are being developed by CERN’s Beam Instrumentation (BE/BI) group [6]. Each detector consists of one or two layers of thin scintillating fibers of square shape and 1 mm width, covering a large active area of 200 x 200 mm<sup>2</sup>, therefore measuring the horizontal and vertical position of the beam particles, providing at the same time certain timing information. Two profile monitors will be installed in both extension beam lines, to serve as profile monitors. Three more per beam line are installed in a spectrometer configuration, as described in the next section. Thin scintillating tiles will also be used in order to provide trigger to the experiment.

### 3.2. Momentum measurement

To achieve a better momentum definition without reducing the count rate, the three beam profile monitors described in the previous section, placed around the fourth (second) bending magnet of the line are used as a spectrometer. The technique has been used in the past with success [7], and the here applied implementation is described in detail in [5]. The performance of the spectrometer, was validated with high statistics Monte-Carlo. The use of Euclidean geometry, allows the computation of

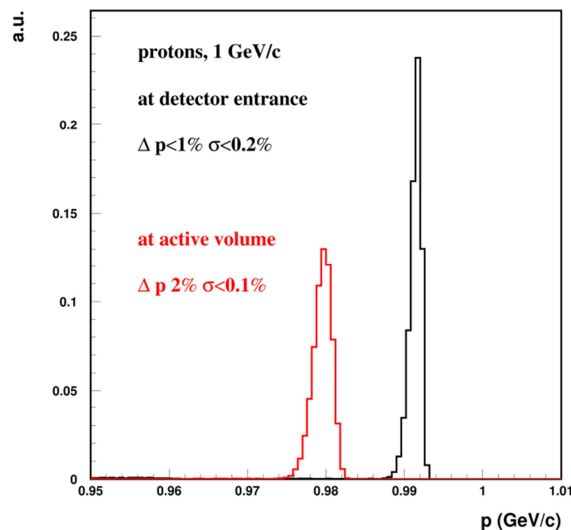
the particle position in the three spectrometers, which allows the  $\Delta p/p$  calculation. For the 2 GeV/c beam configuration, the reconstructed momentum resolution can be as low as 1.5%, as shown in Figure 4.



**Figure 4.** Reconstructed momentum spread for a beam of 2 GeV, taking into account the material on the beam line

### 3.3. Effect of instrumentation material

When choosing the solution for the beam instrumentation, care has been taken in limiting the material budget that the particles will transverse until they reach the detectors. The impact of beam instrumentation and detector beam windows has been cross-checked with a detailed FLUKA [9, 10] simulation. As an example, Figure 5 shows the proton spectra at the end of the beam line and at the entrance of the NP04 active volume, for a monochromatic 1 GeV/c proton beam.



**Figure 5.** Momentum distribution of protons at the end of the beam line and at the entrance in the NP04 active volume, for a monochromatic 1 GeV/c proton beam. Note the highly zoomed momentum range. The area under the peaks differ by 7% only.

The momentum degradation is limited, below 2%, with a negligible spread. The beam intensity with respect to a theoretical “no material” configuration is reduced by 15% only in the beam line and an additional 7% at the detector window.

#### 4. Summary and next steps

The beam line design and an outlook on their expected performance has been reported in this paper. Additionally, a PID system for both beam lines is being currently studied, using a combination of two threshold Cherenkov counters (XCET). R134a is considered [10] as radiating gas in combination with CO<sub>2</sub>, possibly combined with a Time-of-Flight system based on scintillating fibers.

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