Beam Instrumentation for the H4 Very Low Energy beamline

1 Introduction

The H4-VLE (Very Low Energy) beamline delivers low energy hadron and electron beams to the ProtoDUNE Single Phase (NP04) prototype. The H4 secondary beam is directed on a thick secondary target made either of Tungsten or Copper, where a tertiary low energy beam is produced. The layout of the tertiary beamline includes quadrupoles for focusing and three bending magnet to select the beam momentum and steer the beam on the NP04 detector. The last bending magnet is also used to choose among the three possible impact positions on the detector.

The H4-VLE instrumentation is being designed with the double purpose of beam monitoring (main interest of the CERN EA and BI groups) and single-particle characterization as requested by the experiment.

Similar considerations and design are valid for the H2-VLE beamline, dedicated to the ProtoDUNE Double Phase (NP02) prototype.

2 Instruments

Beam monitoring, particle tracking, momentum measurement will be done with scintillating fibre (XBPF) detectors. Each detector is composed by 192 square fibres, 1mm side, thus providing position in one direction.

Time of Flight for hadron specie identification at beam momenta up to 2 GeV/c will be provided by XBPF detectors, with the same layout as above, however with a different readout.

Time of Flight for hadron specie identification at higher momenta could be provided by pLAPPD detectors, currently being tested at FermiLab.

Electron discrimination will be performed with a Cerenkov detector. A second Cherenkov could ensure hadron identification at momenta larger than ≈ 3.5 GeV/c for pions. At momenta 5GeV/c Kaon identification via Cerenkov emission becomes feasible, and the electron content of the beam becomes small, therefore hadron identification could be performed with two threshold Cherenkov. Standard CERN Cerenkov counters allow for gas pressures $\leq\approx 3.5$ bar. Higher pressure needs reinforced outer tube. Even higher pressures, > 10 bars, need upgraded gas distribution system.

Beam trigger will be provided by flat scintillator slabs, three of them in coincidence.

XBPF layers and triggering scintillators will be mounted into special supports that can be integrated in the vacuum pipe of the beam line. The supports include gauges for position monitoring and flexibility for position and orientation adjustment. Two devices can be hosted in each support, either two layers of XBPF, or one XBPF layer plus one trigger layer. The pLAPPD detectors should also be hosted in there standard supports, verification of the hardware compatibility is ongoing. In this way, the XBPF ToF and the pLAPPD ToF could be easily interchanged.

3 Layout

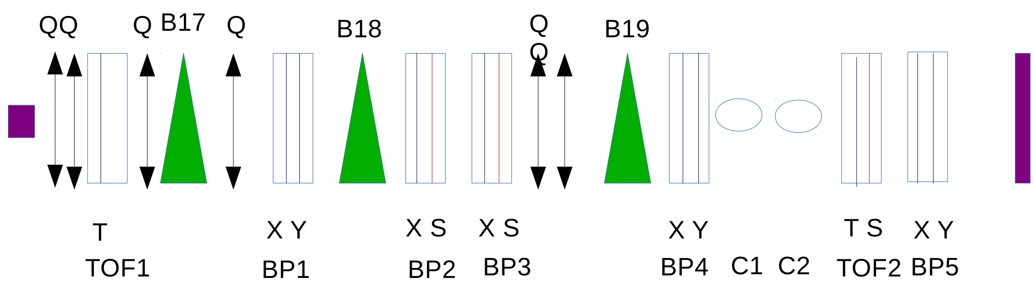

Figure 1: Schematic layout of the H4-VLE beamline. Beam direction is from left to right, from target to cryostat. Black arrows are quadrupoles, green triangles bending magnets. Instrumentation supports are the light blue boxes. X or Y indicate XBPF layers, S stand for trigger scintillators, T or TOF are Time of flight detectors. Ellipses are Cherenkov detectors.

A schematic layout of the beam line with instrumentation is in figure 1. The total length from target end to entrance in the cryostat insulation is 35.6 meters. The distance between the two ToF station will be approximately 28 meters. The first and last X-Y pairs (BP1 and BP5) will be used for beam alignment and monitoring. The two X planes after the B19 bending magnet (BP2 and BP3) will constitute the magnetic spectrometer together with BP1. Finally, the use of two X-Y planes after the last bending (BP4 and BP5) will allow to determine the position and direction of particles at the detector entrance and match them with the tracks in the active volume. BP4 is not foreseen in the beamline for NP02.

All tracking and trigger monitors will be always present in the beamline, for a total of **8 XBPF layers and three trigger planes**. The actual presence/quality of ToF and Cerenkov detectors will depend on the availability of the pLAPPD ToF and on the selected beam momentum. It has to be reminded that the pLAPPD ToF is not suited for the very low energies because of the high material budget and low sensitive area.

3.1 Option 1 : pLAPPD available

- $p \leq 2GeV/c$: XBPF ToF + standard CO_2 Cherenkov for electron discrimination

- $2 < p \leq 5GeV/c$: pLAPPD ToF + standard CO_2 Cherenkov for electron discrimination

- $5 < p \leq 7GeV/c$: pLAPPD ToF + standard CO_2 Cherenkov for electron identification.

Total instrumentation needed: 8 XBPF layers with standard electronics, 2 XBPF layers with ToF electronics, two pLAPPD stations, one standard Cerenkov, and three trigger planes, plus spares.

3.2 Option 2 : pLAPPD not available

- $p \leq 2GeV/c$: XBPF ToF + standard CO_2 Cherenkov for electron discrimination

- $2 < p \leq 3GeV/c$: XBPF ToF + standard CO_2 Cherenkov for electron discrimination. **Kaons cannot be distinguished from protons**

- $3 \leq p \leq 5GeV/c$: standard CO_2 Cherenkov for electrons, high pressure Cherenkov for pions (< 10 bar) **Kaons cannot be distinguished from protons**

- $p > 5GeV/c$: standard CO_2 Cherenkov for pions, high pressure (10-15 bar) CO_2 Cherenkov for kaons. Electron content is small, will not be tagged.

Total instrumentation needed: 8 XBPF layers with standard electronics, 2 XBPF layers with ToF electronics, one standard Cherenkov, one high-pressure Cerenkov with non-standard distribution system, and three trigger planes, plus spares.

4 who does what / status

- XBPF: developed by CERN-BI.
  - Mechanical structure outsourced, first prototypes in production
  - Fibres preparation and mounting: collaboration with CERN EP-DT
  - Readout with SiPM, first version of PCB housing them is being produced by CERN-BI
  - Electronics for position monitors: design of the boards started by CERN-BI
  - Electronics for the ToF detectors: will use special ASIC called STiC developed at Heidelberg University, one board is already at CERN for testing, BI people received training on its use.
  - Test of small prototype ToF system foreseen with cosmics soon.
- Cerenkov counters: CERN-EA
  - Cherenkov heads, mirrors, PMTs, already exists for 4 detectors (NP02 + NP04)
  - Windows and tubes will be manufactured. Might need calculations and tests for safety approval
  - Control systems under re-design within the SPS consolidation effort, first prototype beginning of next year
  - Measurement of the "alpha" parameter, that includes quantum efficiency, light transport efficiency etc, will be done in one of the East Area beam lines.
- pLAPPD: FNAL
  - Production is from Argonne lab, prototypes are now at FNAL

  - Test
  - Readout

- Supports: CERN-EA and CERN-BI
  - Design in advanced stage
  - XBPF and trigger integration studied
  - pLAPPD integration to be studied
  - Integration in the beam line, available space etc almost done, some more studies to be performed for the monitor immediately after the last bend (BP4 in the sketch)

5 Costs/resources

- XBPF: estimated 12kCHF per layer , 10 layers plus one spare = 160kCHF. Need to confirm one person for the development/production, presently on an expiring position (cost of one fellow is about 120kCHF/year, support is for both beamlines).
- Trigger: estimated 4kCHF/detector, total 12kCHF
- Cherenkov: under evaluation.
- pLAPPD: 5k USD per detector, plus 12kUSD for the electronics, for a total of 22 kUSD. A ToF-based trigger board is under development, estimated cost ¡40kUSD.

Part of the costs are covered by existing budget.