SHiP-LNF: 2017 Status Report

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1 Status of the SHiP project

The SHiP project is moving ahead along the lines defined in 2016, with the main goal of preparing documents to be used as input of the next European Strategy for Particle Physics (ESPP). The main novelties with respect to 2016 are:

1. **The Beam Dump Facility (BDF) project**, that includes the SHiP beam line, the target, experimental hall and related infrastructure is now a CERN project under the responsibility of Mike Lamont as part of the Physics Beyond Collider (PBC) activity [1]. A funding profile has been defined in the MTP 2018-2022 for a total amount of about 9 MCHF for pursuing the necessary R&D for the beam line. The money allocated for the BDF has been increased by about a factor of two with respect to what was allocated in the previous MTP (2017-2021).

2. **The SHiP project is officially included in the BSM WG of the PBC activity**, together with many other projects dedicated to the search for hidden particles below the EW scale proposed at the SPS (NA64, NA62 in dump mode, LDMX) and at the LHC interaction points (MATHUSLA and FASER at ATLAS, Codex-B at LHCb). G. Lanfranchi is one of the five experimental conveners of the BSM WG (with K. Kirsh, K. Jungmann, G. Ruoso and A. Rozanov). The PBC will provide documents to the European Strategy group by the end of 2018.

3. **The SHiP collaboration is preparing a Comprehensive Design Study (CDS)** to serve as input for the ESPP. This document will contain the improvements in the detector design and the results of the R&D achieved since the presentation of the Technical Proposal [2] in 2015. A major step towards the completion of the CDS has been identified to be the measurement of the muon flux, which is a crucial input for the design of the large active SHiP magnetic shield (see *Publications list, n.1*). Another important input for the CDS is the measurement of the $c\bar{c}$ cross-section in a thick target, to be used as normalization in the search for heavy neutral leptons. Two documents detailing the strategy for these two measurements (see *Publications list, n.2 and n.3*) along with a request of four weeks of beam time at the H4 line in the North Area in 2018 have been submitted in 2017 to the SPSC. The SPSC has given positive response and recently approved the beam time request [3].

4. **The SHiP collaboration in 2017 has actively pursued a lively R&D activity** of several technologies in order to have a more precise estimate of the performance of different subdetectors and related costs. In 2017 a large amount of beam time slots has been allocated by the SPSC for SHiP-related test beams:

   - 3 weeks at the H2 area of the SPS: combined test beam for Calorimeter, Straw tubes and Surrounding Background Tagger;
   - 2 weeks at the H8 area of the SPS: μRWELLS test beam for the Target Tracker;
   - 2 weeks at the T9 area of the PS: test beam of emulsions;

- 2 weeks at the T10 area of the PS: combined test beam for Muon System and Timing Detector.

The LNF group has actively contributed to the test beam activities as described below.

2 Activities of the LNF group

In 2017 the Frascati group continued to work along the directions presented in the 2016 activity report, namely:

1. R&D of the muon system and related electronics;
2. R&D of a high-spatial resolution tracker based on GEM/μ-RWELL technology for the tau neutrino detector;

For each item we report here below a short description of the 2017 activity.

2.2 R&D of muon system and related electronics

Groups involved: INFN-Bologna, INFN-Cagliari, INFN-LNF, INR, MEPhY;
G. Lanfranchi co-project Leader (with Yuri Kudenko, INR)

The Muon System is described in Section 4.11 of the SHiP Technical Proposal [2] and comprises four stations of active layers interleaved by three muon filters 6 m wide and 12 m high. The baseline technology chosen for the active layers is extruded plastic scintillator strips with wavelength shifter fibers (WLS) and SiPM readout.

The results obtained in the 2015 test beam have been published on 2017 on JINST (see *Publications list, n.4*). The 2015 test beam showed that the baseline solution for the SHiP muon system which consists of 3 m long, 5 cm wide scintillating bars with WLS fibers and SiPM readout cannot reach time resolutions better than 700-800 ps, as it is fully dominated by the time fluctuation of the scintillating process inside the fibers themselves.

In order to improve the time resolution while keeping high efficiency, a new technology based on scintillating tiles with direct SiPM readout has been investigated in 2017. This technology, would have also the advantage to provide directly the x, y position, without relying on crossings or complicated time corrections to estimate the impinging point of a particle. Results obtained in the context of the PANDA experiment showed that small tiles made of EJ200 or EJ228 scintillator with $3 \times 3 \times 0.5$ cm^3 dimensions and read out at one side by 3×3 mm^2 SiPMs of different manufacturers, can reach $\sim$100 ps time resolution.

First prototypes with this technology have been built at LNF and Bologna: two tiles (tile A: $7 \times 7 \times 0.6$ cm^3 and tile B: $7 \times 24 \times 1$ cm^3) have been designed, built, equipped and then tested during a 2-weeks long test beam performed at the T10 area of the CERN PS in the period 18-31 October 2017 (see Fig. 1).

An excellent time resolution of $\sigma_t \sim 200$ ps, well beyond expectations, has been measured for the small tile, with no dependence on the particle impinging point. For the larger tile, the results are more involved, as we observed a dependence of the time resolution with the position of the impinging point of the beam on the tile. An extended R&D has been already planned for 2018 to overcome this limitation and two more weeks of test beam at the T10 area of the CERN PS in October 2017 have been recently granted by the SPSC in the January meeting [3]. The 2018 test beam will be also used to extensively test different solutions for the front-end electronics that are currently under study within the muon group and for which the INFN-Gruppo1 has allocated about 20 kEuro in 2018.

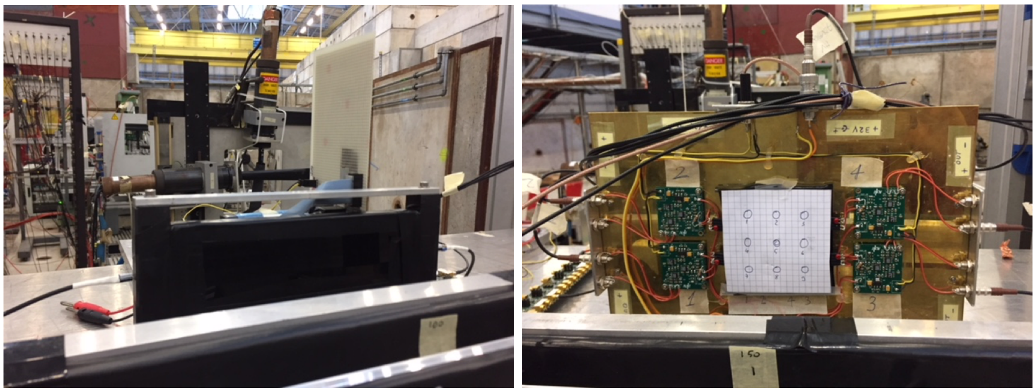

Figure 1: The two tiles built, instrumented and tested at the T10 area of CERN PS in October 2017.

2.3 R&D of the target tracker for the tau neutrino detector

Groups involved: INFN-Napoli, INFN-Bari, INFN - Gran Sasso, LNF(IT), INFN-Rome, Nagoya University (Japan) , Nihon University (Japan), Aichi University (Japan), Kobe University (Japan), Toho University (Japan), MSU (Russia), Lebedev Institute (Russia), NRC KI (Russia), Gwangju (Korea), **LNF for the GEM/μ-RWELLS option.**

The target tracker is described in Section 4.2.2 of the Technical Proposal [2]. It provides the time stamp to the events reconstructed in the emulsion bricks and predicts the target unit where the neutrino interaction occurred. The neutrino emulsion target is made of 11 walls, each interleaved with a Target Tracker (TT) plane of a transverse size of about (2×1) m^2, with the longest side being horizontal. The physics performance, to be obtained in a magnetic field with a strength between 1.0 and 1.5 Tesla, are: 100 μm spatial resolution on both coordinates (also considering the coupling with the emulsions) and high efficiency ($> 99\%$) for angles up to 1 rad.

A first test beam was performed in 2015 to test the behavious of triple-GEM detector coupled with emulsions. The results were discussed in the *SHiP Activity Report* in 2016 and recorded in a JINST paper published in 2017 (see *Publications list, n.5*).

However, given the request of large area detectors, the solution proposed in 2017 for the TT by the LNF group is based on a new Micro-Pattern Gaseous Detector: the μ-RWELL [5]. This detector is composed of two parts: the cathode glued on a frame, defining the gas convertion gap, and the amplification stage embedded in a PCB. A GEM-like foil coated on one side with Diamond-Like Carbon provides the channels for the electronic avalanche. The resistive layer quenches the discharge amplitude, avoiding that a large current is induced on the properly segmented readout and then to the FEE.

The requirements on the track reconstruction must be fulfilled for a large range of angles of the impinging particles: $45^\circ - 90^\circ$ with respect to the detector plane. While for tracks orthogonal, or close, to the readout plane the Charge Centroid (CC) method provides the best space resolution value, this gets worse as the angle decreases. A new method has been proposed by ATLAS-

Micromegas group to improve the space resolution in this latter case: the μ-TPC mode [6]. The name suggests the application of the TPC algorithm to reconstruct the tracks inside a small gas gap. Each strip cluster is actually projected inside the drift gap exploiting the information about the drift velocity of electrons in the gas mixture. These projections allow to localize part of the primary ionization clusters, to fit their position and then to obtain a track segment.

In October 2017 a test beam has been held at H8C-SPS CERN North Area: two μ-RWELL detectors have been installed on a rotating table, so that the angle of the track was well defined for different runs. Due to the dependence of the drift velocity on the electric field, the space resolution has been studied also for different drift fields. Figure 2 shows the space resolution obtained by a weighted average of the values provided by both methods (CC and $\mu-$TPC) as a function of the track angle for different drift fields. A space resolution well below 100μm can be obtained with a proper optimization of the drift field for a large range of angles.

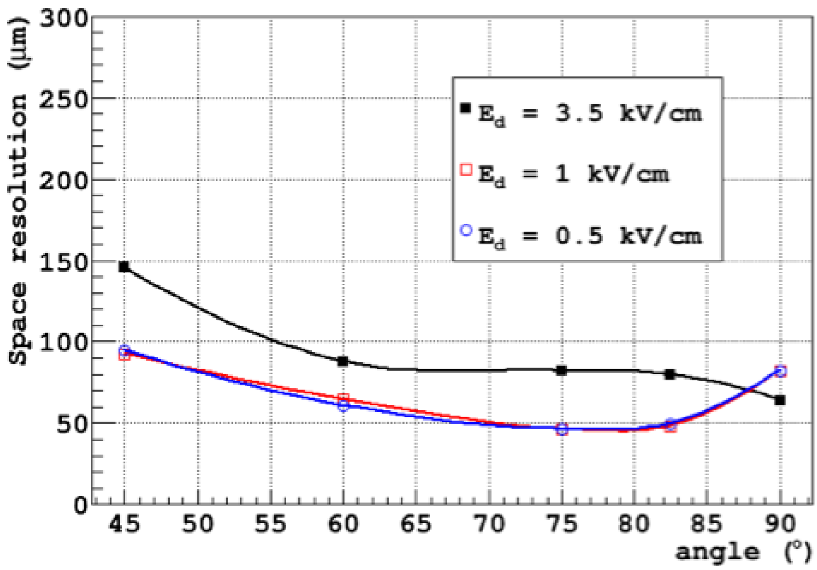

Figure 2: Space resolution as a function of the track impinging angle with respect to the readout plane.

3 Talks and Publications

Talks:

1. *Beyond SM physics: experimental context*, G. Lanfranchi, *Physics Beyond Colliders workshop*, plenary talk, CERN, March 2017.

2. *Search for Hidden Sector Particles with the SHiP experiment*, G. Lanfranchi, invited Seminar at Weizmann Institute, Tel Aviv, May 2017.

3. *SHiP Physics Reach*, G. Lanfranchi, invited Seminar, LPNHE - Universite Pierre et Marie Curie, Paris, October 2017.

4. *Search for New Physics at the Intensity Frontier*, G. Lanfranchi, invited Colloquium at Weizmann Institute, Tel Aviv, November 2017.

Publications:

1. SHiP collaboration (A. Akmete *et al.*), *The active muon shield in the SHiP experiment*, *JINST* **12** (2017) no.05, P05011. e-Print: arXiv:1703.03612.

2. SHiP collaboration (A. Akmete (*et al.*), *Muon-flux measurements for SHiP at H4* , CERN-SPSC-2017-020 ; SPSC-EOI-016.

3. SHiP collaboration (A. Akmete *et al.*), *Measurement of associated charm production induced by 400 GeV/c protons*, CERN-SPSC-2017-033 ; SPSC-EOI-017.

4. W. Baldini, A. Blondel, A. Calcaterra, R. Jacobsson, A. Khotjantsev, Y. Kudenko, V. Kurochka, G. Lanfranchi, A. Mefodiev, O. Mineev, A. Montanari, N. Tosi, A. Saputi, E.Noah Messomo, *Measurement of parameters of scintillating bars with wavelength-shifting fibres and silicon photomultiplier readout for the SHiP Muon Detector. JINST* **12** (2017) no.03, P03005, e-Print: arXiv:1612.01125

5. A. Alexandrov, G. Bencivenni, M. Bertani, A. Buonaura, C. Capoccia, G. Cibinetto, A. Calcaterra, G. De Lellis, E. De Lucia, A. Di Crescenzo, D. Domenici, R. Farinelli, G. Felici, N. Kitagawa, M. Komatsu, G. Morello, K. Morishima, M. Poli Lener, and V. Tioukov, *JINST* **12** (2017) no.09, P09001, e-Print: arXiv:1705.06635 [physics.ins-det].

6. A. Paoloni, A. Longhin, A. Mengucci, F. Pupilli, M. Ventura, *Gas mixture studies for streamer operated Resistive Plate Chambers*, *JINST* **11** (2016) no.06, C06001.

7. A. Paoloni for the SHiP Collaboration, *The SHiP experiment*, *Nuovo Cimento* **C40** (2017) no.1, 54

References

1. See *http:pbc.web.cern.ch.*

2. M. Anelli *et al.* (SHiP collaboration), *Technical Proposal: A facility to Search for Hidden Particles (SHiP) at the CERN SPS*, CERN-SPSC-2015-016, SPSC-P-350,arXiv:1504.04956 [physics.ins-det].

3. See *http://sps-schedule.web.cern.ch/sps-schedule/.*

4. S. Alekhin *et al.*, *A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case*, CERN-SPSC-2015-017, arXiv:1504.04855 [hep-ph].

5. G. Bencivenni, R. De Oliveira, G. Morello, M. Poli Lener, *The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD JINST* **10** no.02 P02008 (2015), arXiv:1411.2466.

6. T. Alexopoulos *et al.*, *Development of large size Micromegas detector for the upgrade of the ATLAS muon system*, *Nucl. Instrum. Meth.* **A617** (2010) 161.