R&D of 4 Cell Prototype WOM-based Liquid-Scintillator Detector

1st High-D Consortium Meeting
AP2.1

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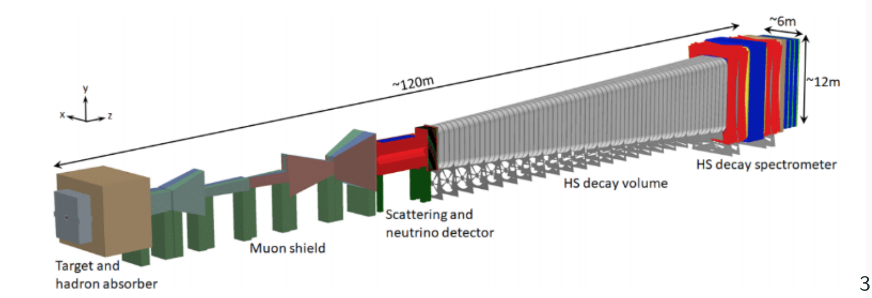
Experimental Motivation

- Aim: build large-scale ($\mathcal{O}(1000)$ m^2) liquid-scintillator (LS) based detector for high dimensional resolution
  - Spatial
  - Time
  - Energy
- LS provides:
  - High hermicity and efficiency
  - Low cost
- Wavelength-shifting optical modules (WOMs) provide:
  - Sufficient light collection with small-area photon-detectors
  - Time resolution
  - Spatial info from LS cell granularity/WOM positioning
  - Directional info from timing/light yield sharing between WOMs
- Potential applications in particle physics
  - Particle identification
  - Background tagging

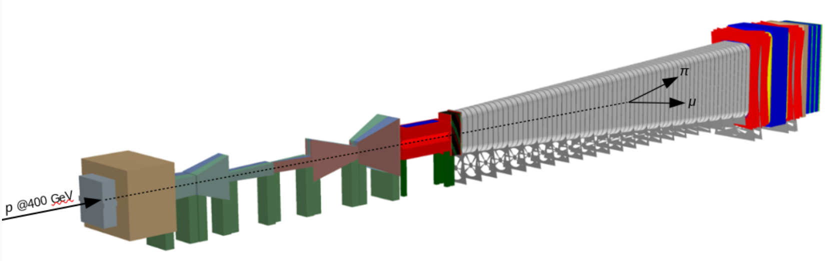
SHiP Experiment

- Proposed experiment at CERN SPS [1]
- 400 GeV protons dumped in high-density target
- Muon shield deflects muons out of beam line
- Scattering and neutrino detector for light dark matter searches
- Hidden sector decay volume: vacuum vessel
- Reconstruction of hidden sector decays in spectrometer



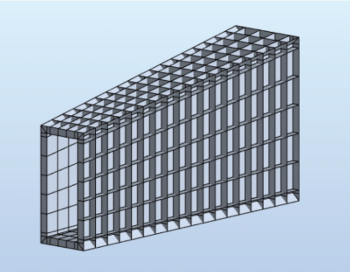
SHiP Background Sources

- Hidden sector particle decay $\rightarrow$ isolated vertex
- Particles originating from outside could mimic signal event
- Aim: detect
  - Deep inelastic scattering of muons/neutrinos in vessel walls
  - Muons entering vessel from outside
- Solution: Surround Background Tagger outside decay vessel based on WOM-LS technology



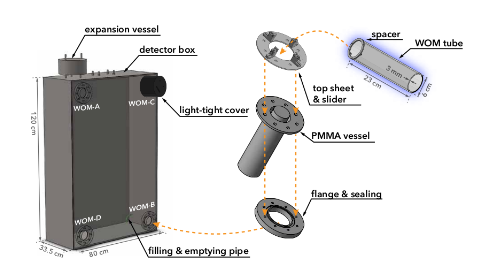
Surround Background Tagger

- 50 m long, upstream: 2×4 m, downstream: 5×10 m
- $\sim$ 2000 individual cells with steel walls
- 30 cm deep, 80 cm wide, height $\sim$ 80-150 cm
- Parallelepiped shaped cells
- Filled with LS, WOMs catch light for readout by silicon photomultipliers (SiPMs)



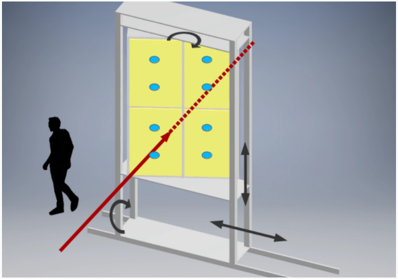
Previous Prototypes

- $50 \times 50 \times 25$ cm cell tested at CERN in 2017 SPS [3]
- $118 \times 78 \times 31$ cm cell tested at CERN/DESY in 2018/19 [2]
- Detector efficiency can be improved with
  - Higher efficiency SiPMs
  - LS purification
  - Increase of absorption probability in WOMs
  - Increase of cell wall reflectivity
  - Better SiPM-WOM coupling



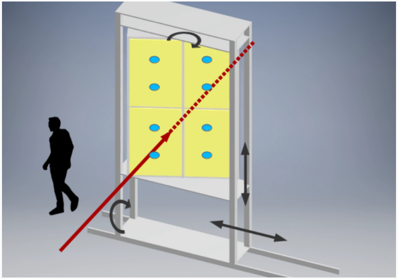
4 Cell Prototype

- Aim: build and test first 4 cell prototype
- 2 WOMs per cell
- $\sim 120 \times 80 \times 30$ cm per cell
- Test beam application to tune:
  - Cell construction
  - Filling/emptying
  - Material compatibility
  - Electronics
  - Monte Carlo simulation
  - Reconstruction capabilities



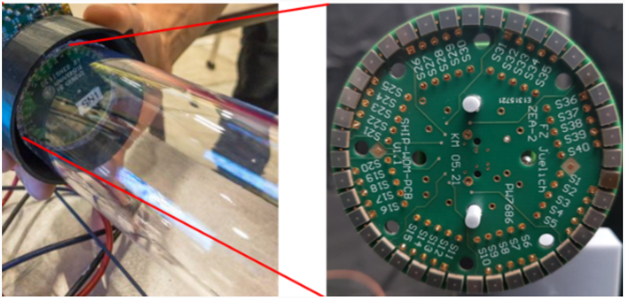
Support Structure

- Must hold cells weighing $\sim$2 tonnes
- Translation and 180° rotation in 2 dimentions (X, Y)
- Want to test trajectories with beam incident on any face of cells with beam angle between 0-90°
- Overflow tank to ensure complete filling and no bubbles in LS



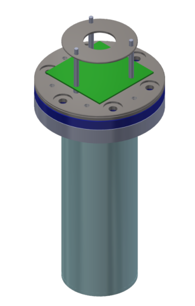
Electronics

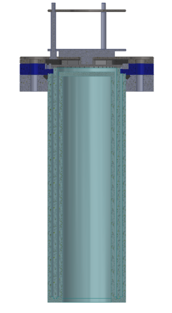
- Array of 40 3×3 mm SiPMs
  - Hamamatsu S1416-3050HS
  - onsemi J-Series 30035
- Readout:
  - Short term: commercial multichannel board (Citiroc/Triroc) plus preamplifier and ADC
  - Long term: custom preamplifier with integrated ADC, feature extraction, transmitter, and HV supply (AP3.5)



WOM Integration

- PMMA housing
  - Ensure air gap for reflection
  - Hold WOM in place
  - Minimal touching to catch maximum amount of light
- Flange
  - Must be light tight
  - Couple SiPM array to WOM
  - Transmit signal from SiPM to board





Ongoing/Future work

- 1 cell in 2022 for DESY test beam (e-) and cosmics (μ)
- 4 cells in 2023/24 for CERN test beam (μ)
- Design aspects in development:
  - Support structure
  - WOM wavelength-shifting coating
  - Cell reflectivity coating
  - WOM mounting
  - Readout electronics

References

[1] C. Ahdida et al.
The SHiP experiment at the proposed CERN SPS Beam Dump Facility.
12 2021.

[2] Jan Zimmermann.
Efficiency studies of a liquid-scintillator detector based on wavelength-shifting optical modules.
Master's thesis, Humboldt-Universitaet zu Berlin, 2020.

[3] M. Ehlert, A. Hollnagel, I. Korol, A. Korzenev, H. Lacker, P. Mermod, J. Schliwinski, L. Shihora, P. Venkova, and M. Wurm.
Proof-of-principle measurements with a liquid-scintillator detector using wavelength-shifting optical modules.
Journal of Instrumentation, 14(03):P03021–P03021, Mar 2019.