Investigation of an optical-fiber based beam loss monitor at the J-PARC extraction neutrino beamline

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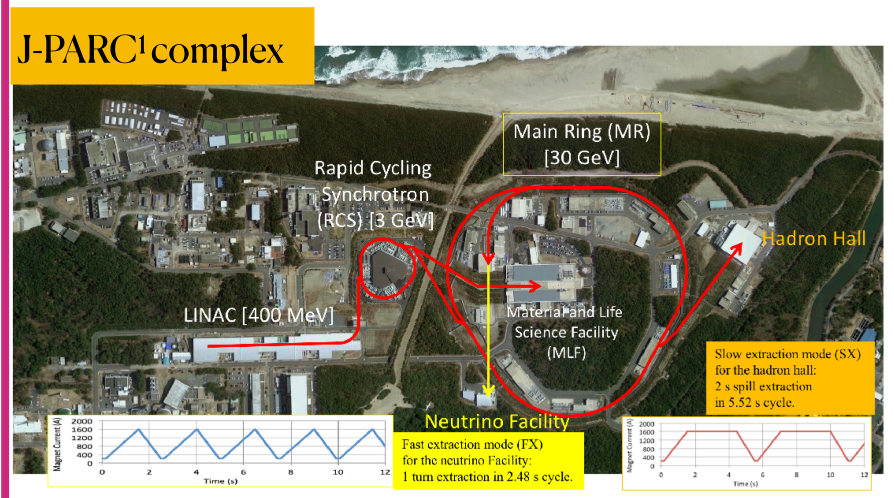
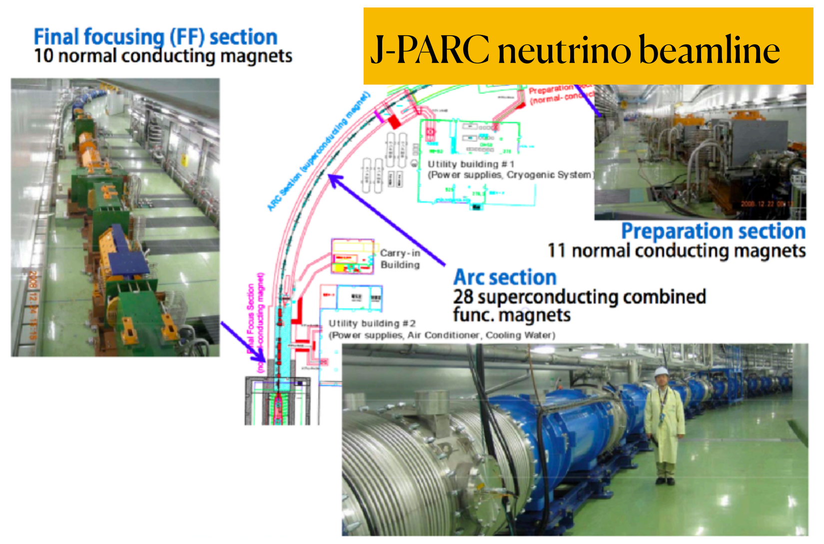
Optical fibers, which at once generate and guide Cherenkov light when charged particles pass through them, are widely used to monitor the beam loss at accelerator facilities. In this report, we investigate this application at the J-PARC extraction neutrino beamline, where a 30GeV proton beam with eight bunches of ~13 ns (1σ) bunch width and 581ns length interval, is extracted from the Main Ring, guided, and hit onto a graphite target to produce a highly intense beam of neutrinos. Three 30m-length 200um-core-diameter optical fibers, which are arranged flexibly to form 60m or 90m length fibers, were installed in the beamline. The beam loss signal was observed with the Muti-Pixel Photon Counters. We will discuss the result and prospects of using optical fibers for monitoring and locating the beam loss source.

J-PARC MW Proton Beam for Neutrino Intensity Frontier

MW beam power, main driver for neutrino intensity frontier, to produce muon (anti-)neutrino beam to long-baseline neutrino experiments





Upgrade[2] J-PARC neutrino beam

Beam power	515 kW (achieved)	750 kW (proposed)	1.3 MW (proposed)
Beam energy	30 GeV	30 GeV	30 GeV
Beam intensity (ppp)	2.65x10^{14}	2.0x10^{14}	3.2x10^{14}
Repetition cycle	2.48 s	1.32 s	1.16 s

To realize MW beam, equipment robustness against high intensity, beam loss tolerability, handling the radioactive waste and precisely and continuously monitoring the beam profile are essential.

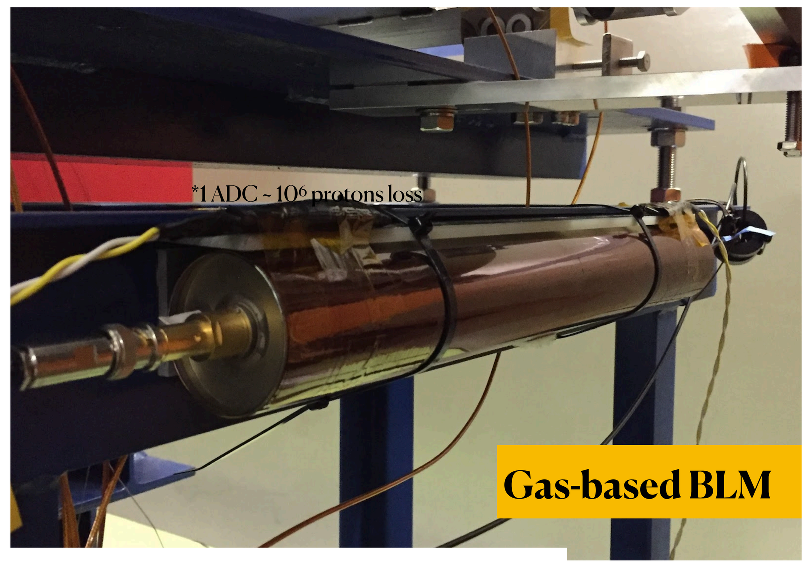
[1] KEK-REPORT-2002-13 [2] arXiv: 1908.05141

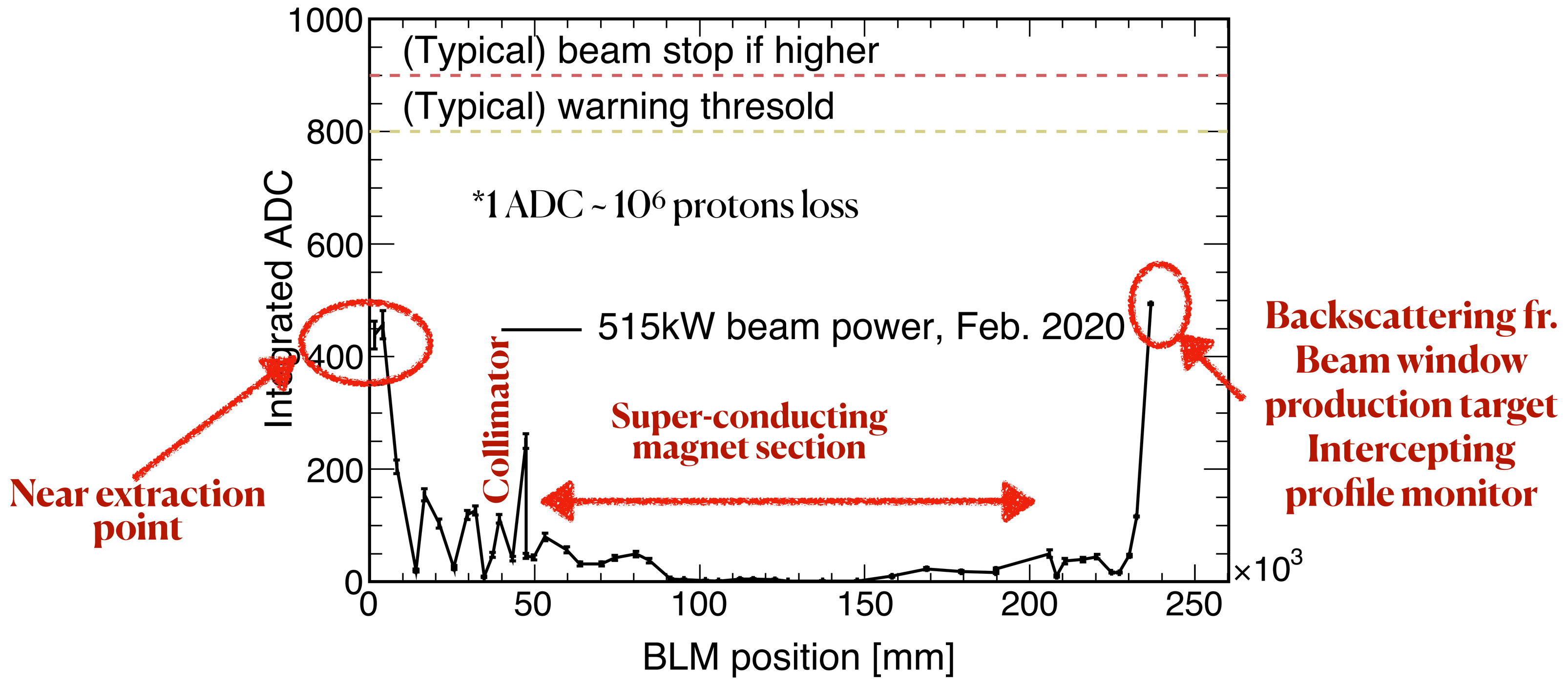
Experience w/ gas-based BLM

- Proportional counter w/ Ar+ CO_2 mixture
- 50 BLMs distributed along ~240m beamline

Experiences

- ☑ Stable
- ☑ Reliable
- ☑ Other assets: *help for beam tuning; estimate the residual dose from integration of signal*



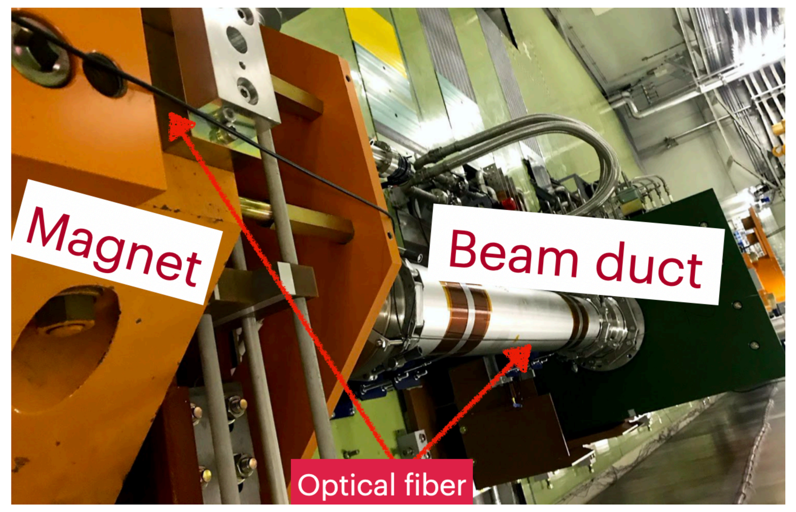


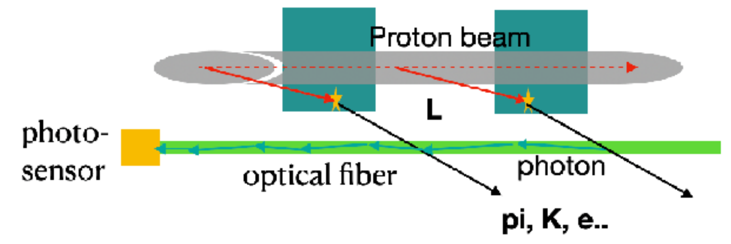
Additional features wanted

- Bunch-by-bunch (in)stability,
- Locate the loss source(s)
- Thermal and fast neutrino?
- Capability for detecting beam halo

Optical-fiber based BLM

Charge particles generate Cherenkov light when passing through the optical fiber, which also plays a role as a light guider to the fast photosensor. Number of observed photons are essentially proportional to the flux of charge particles, i.e beam loss



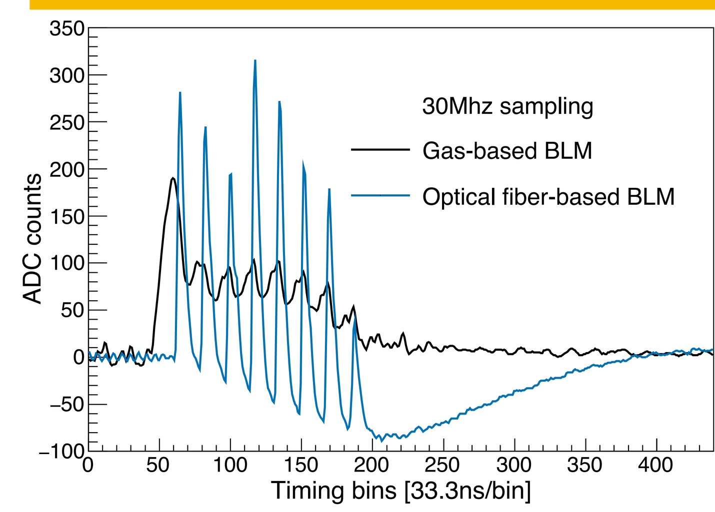


Key features:

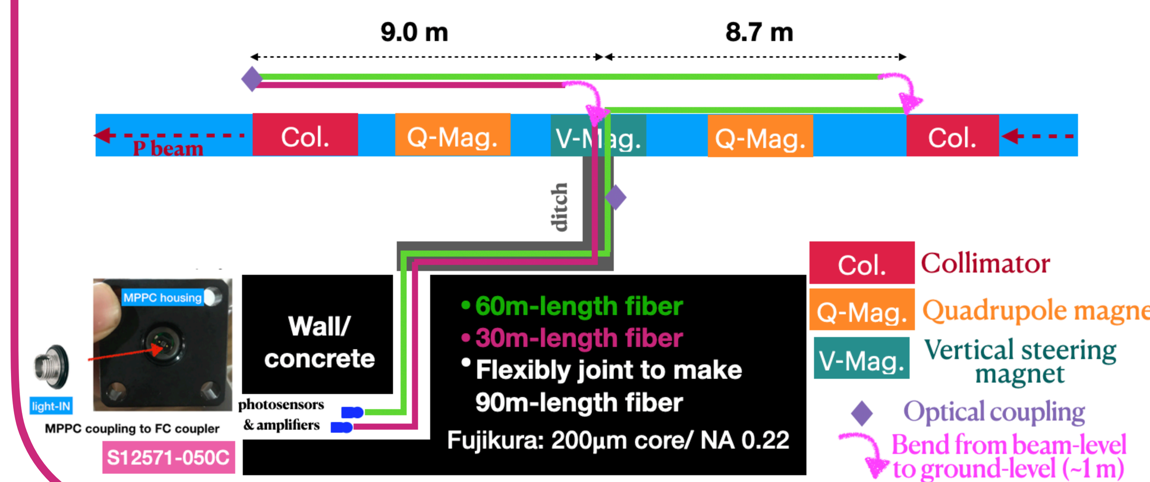
Fast-response, portable, economical

- Proton speed: 3.3ns/m
- Light propagation in fiber: 5ns/m
- Signal separation (maximal): 8.3ns/m
- Bunch width ~ 13ns; signal readout resolution 3ns → well-separated if two signal-induced position separated by ~7m (*assumed background<<signal*)

Gas-based BLM vs. O-BLM: spill structure



Experimental setup for loss location

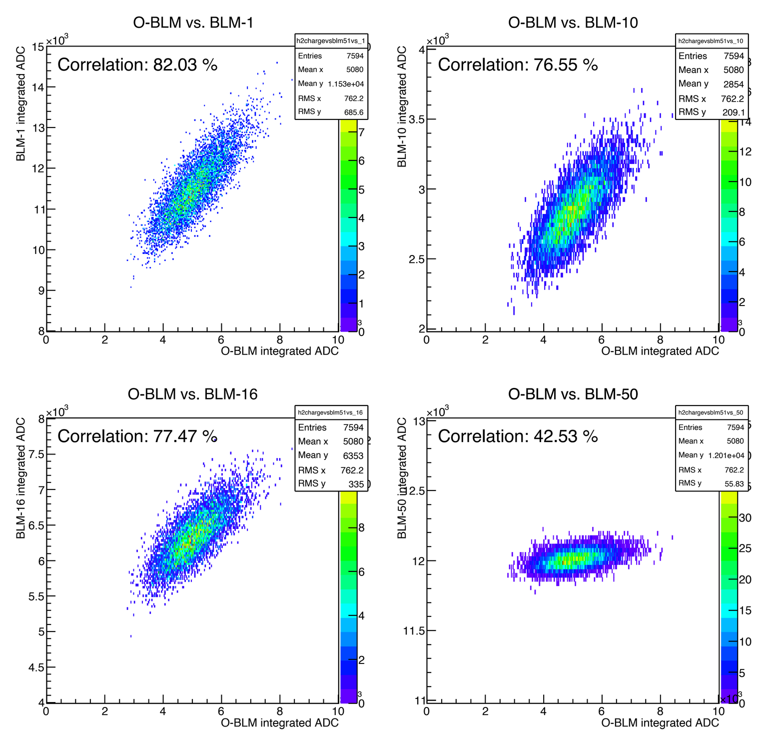


- MPPC is not rad-hard; fiber is guided to sub-tunnel
- Signal is amplified in tunnel before sent ~130m to ground
- Use oscilloscope or 30MHz sampling ADC to read signals

Conventional functionalities

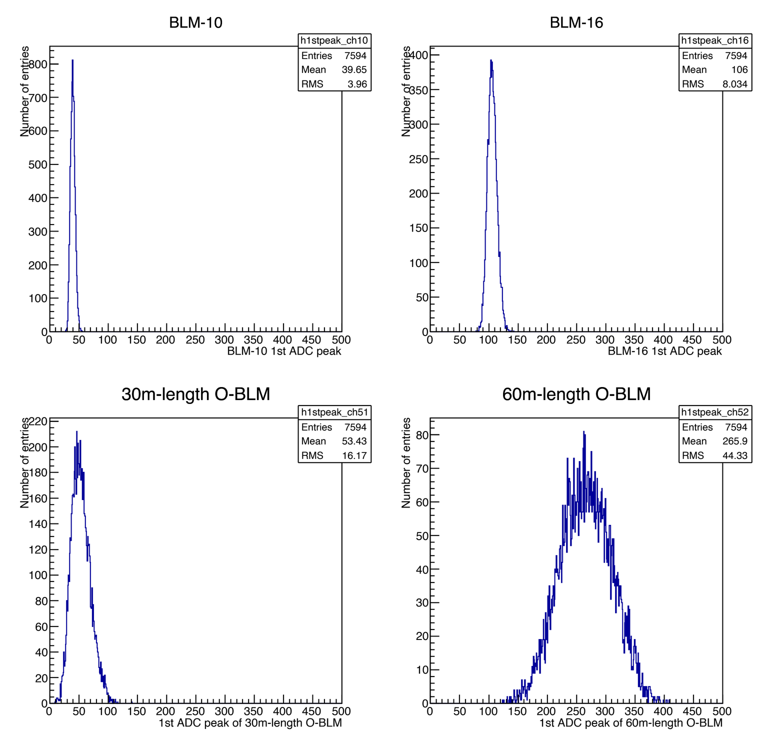
Correlation to gas-BLM

Strong correlation btw O-BLM signals and nearby BLMs but reduced w/ faraway BLM



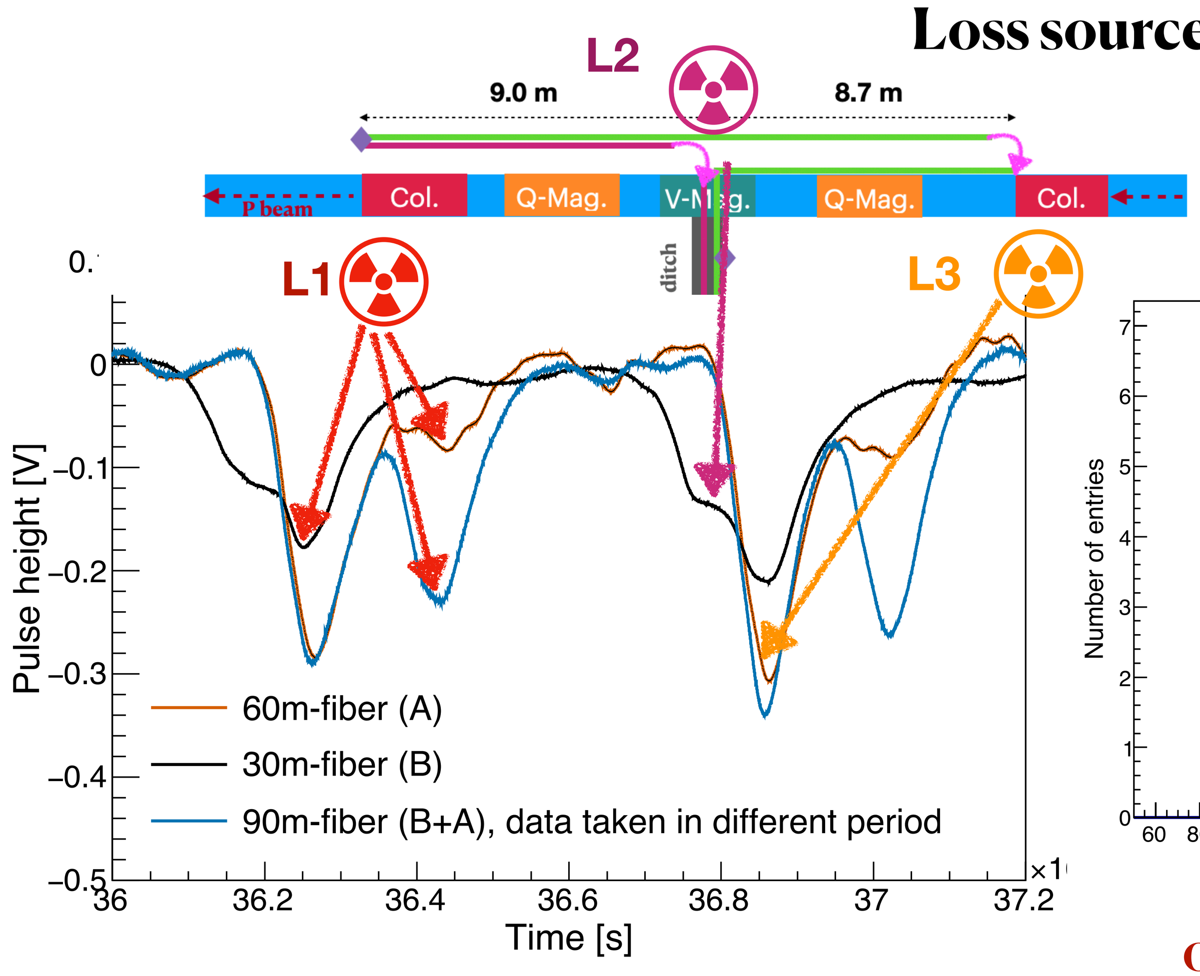
Stability

Stability of the O-BLM amplitude is not as good as that of the BLM →need further investigation



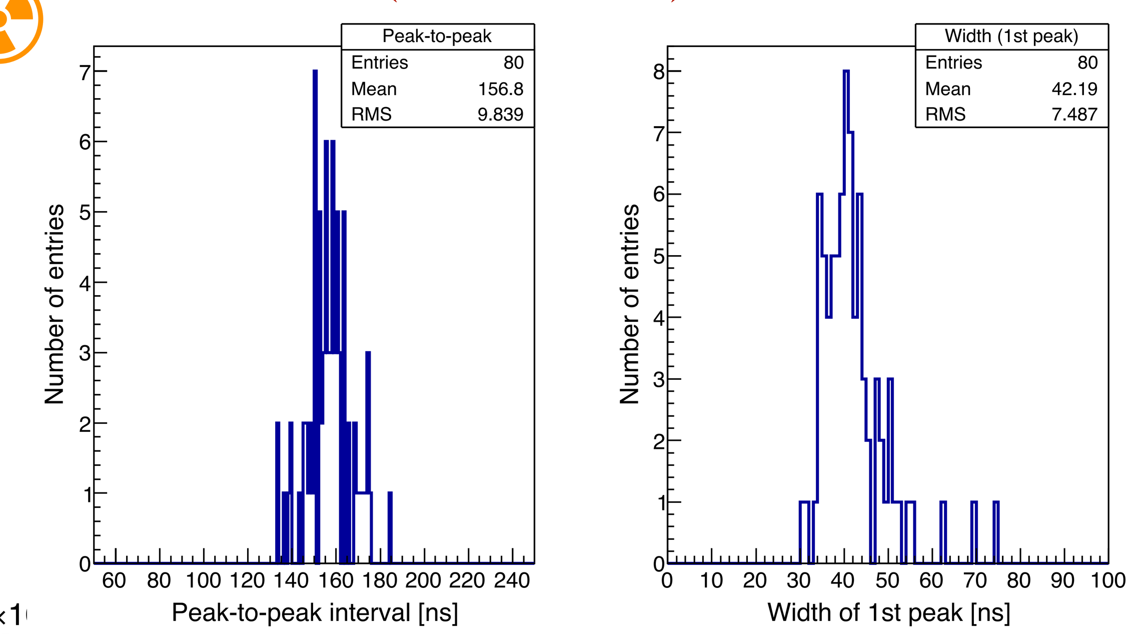
BLM-10 (16) are at the most upstream (downstream) of the 60 m-length O-BLM respectively. BLM-01 (50) are 30 m upstream away and 190 m downstream from the O-BLM respectively . Data taken in ~ 3hours.

Loss source location



Signals from both 30 m- and 60 m-length fibers seem to have a two-peak structure for each bunch. When two fibers are joined to form 90 m-length fiber second peak of the signal is enhanced significantly

The 2nd peak timing information is used to locate L1 loss source and peak-to-peak interval allows us to locate second loss (L2 or L3 or both)



O-BLM signal widths are larger than the proton beam width may indicate that the loss source is not a point source but a fairly long segment of fiber is fired

Summary

- Observed beam loss using the optical fibers with a clear bunch structure, allowing to monitor beam (in)stability in bunch-by-bunch basis
- Signals with different fiber configuration show the capability for loss source identification

Prospects

- Simplify the fiber layout to interpolate the loss source intuitively from the signal waveform
- Investigate other types of photosensor (radiation-hard, fast-response, magnetic-invulnerable and wide-dynamic range)
- Can cover entire beamline with at least 4 fibers of 60-m length and readout with both ends to measure precisely the beam arrival without relying on the beam trigger

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