White Rabbit system's overwiew

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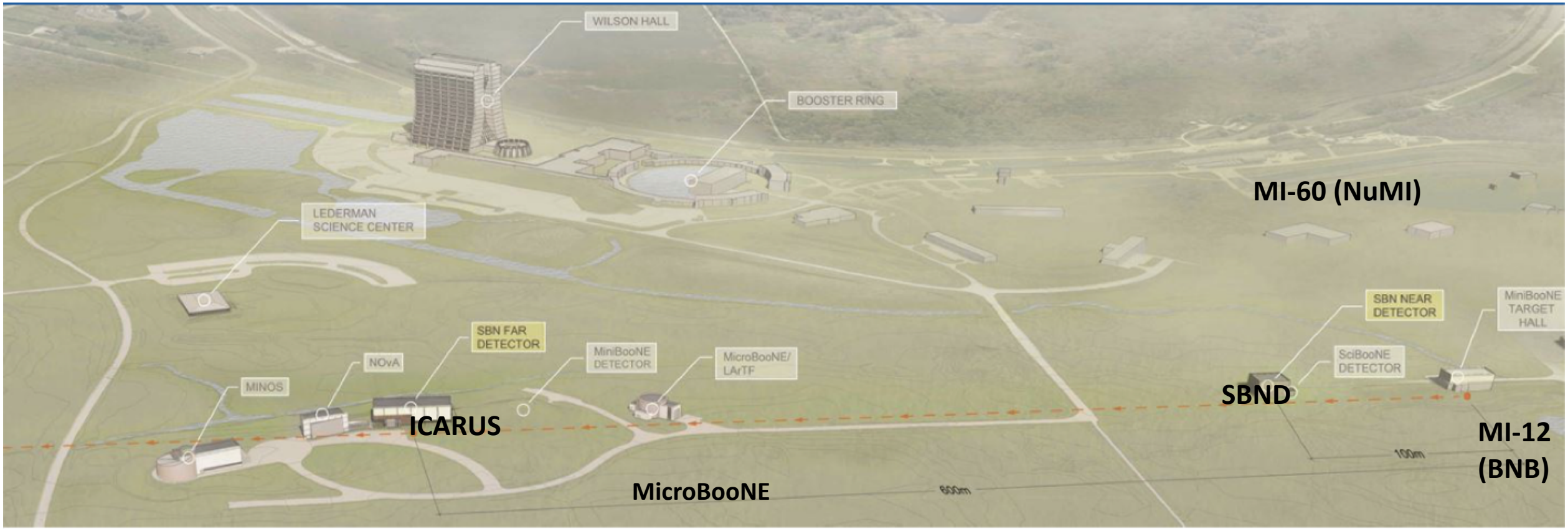
Timing and beam extraction for the SBN program

- An “absolute” GPS timing in the form of a PPS (Pulse Per Second) signal will be provided to all detectors involved in the SBN Program and to the beams extraction locations.
- Timestamps, in the same “absolute” time reference frame, of several signals related to beam extraction will also be made available to all detectors.
- **Distribution of such timestamps will occur through the White Rabbit system,** an Ethernet based network for synchronization of distributed systems with sub-ns accuracy, < 50 ps precision, developed and successfully implemented at CERN and now widely spreading in the world.
- The WR network implementation in the SBN program will be the 1st one in North America.

SBN campus map



NuMI beam signals are generated at MI-60
BNB beam signals are generated at MI-12
An infrastructure of single mode fibers (SM) has ben implemented to distribute beam signals' timestamps between the various location via the WR network

Available beam signals

BNB (MI-12)

- BES (Booster Extraction Synch): protons are about to be extracted
- Gated BES (BES gated with $1F (Booster extraction)): arrives 0.328 ms before protons hit the target
- $1D/$1D early: proton extraction at each Booster cycle, usually 35/22.7 ms before the proton hit the target
- BNB RWM : 2GHz waveform recording of Resistive Wall Monitor (RWM) detectors, which provide the BNB proton beam's structure

NuMI (MI-60)

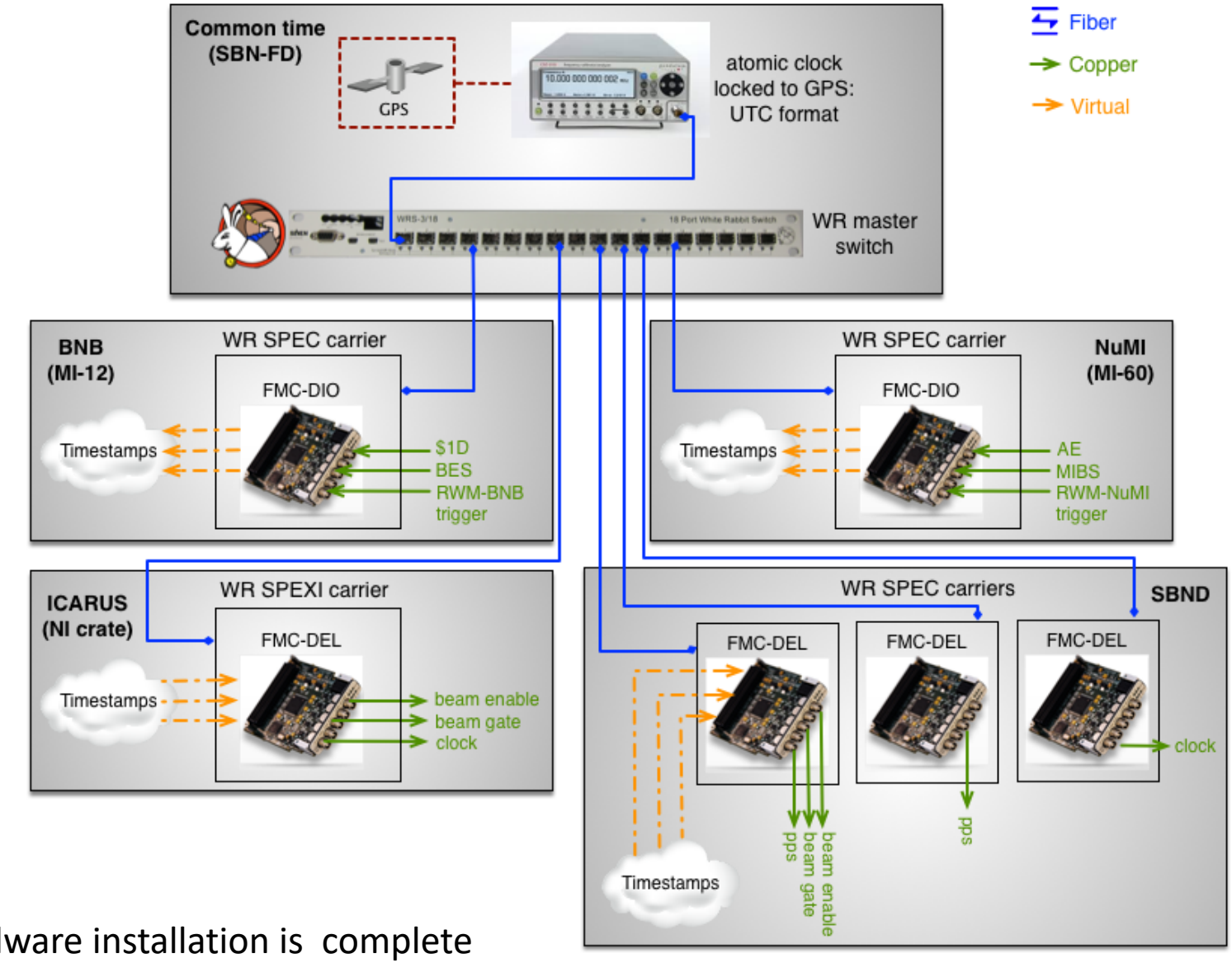
- MIBS $74 (Main Injector Beam Synch): originates at MI-60 and arrives 1.78 ms before protons hit target
- $AE early : 719 ms before protons hit target
- NuMI RWM : 2GHz waveform recording of Resistive Wall Monitor (RWM) detectors, which provide the NuMI proton beam's structure

Off Target: needs to be implemented (just a "NO-beam" signal ?)

NOTE:

- The WR network will distribute ALL the above signals: however only the leading edge of the RWMs will be distributed
- As a backup, we are planning to provide the listed beam signals via Accelerator Division IRM (Intra Rack Monitor) modules, already installed at both experimental buildings, and dedicated Multi Mode (MM) fibers

Architecture of the SBN White Rabbit network at Fermilab



ICARUS

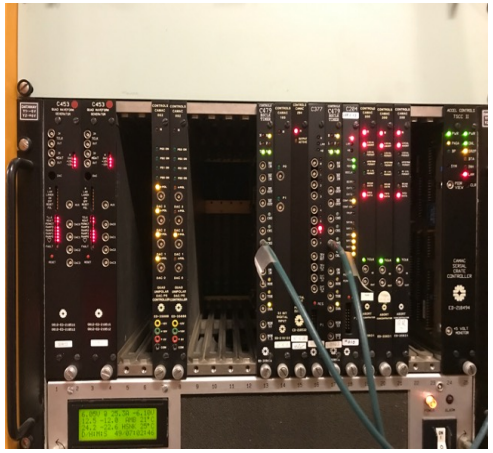
SBND setup still under discussion

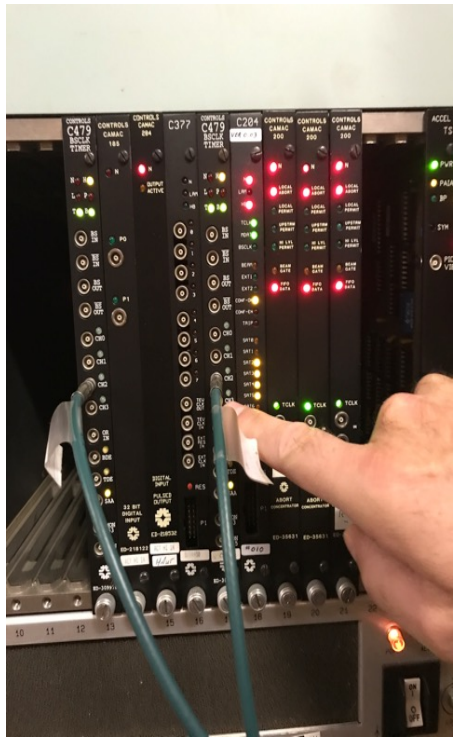
Status of hardware installation is complete

Backup of the entire network will be available with a WR master switch and clock/GPS units at SBND.

WR network installation photos at MI-60, MI-12

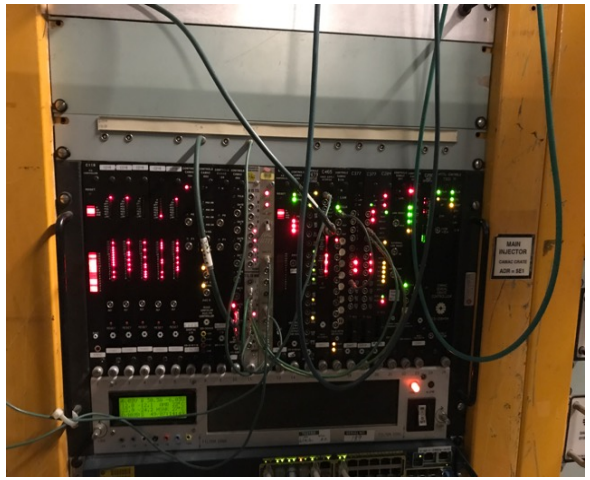
AD (Acceleration Division) crate at MI-60





WR node at MI-60 sending NuMI beam signals ($AE, $MIBS)

AD crate at MI-12



WR node at MI-12 sending BNB beam signals (BES and RWM)

WR network latency measurements

Why? We need to find out if we can send beam signals from MI-60 or MI-12 to experiments locations before the beam arrives !

Using FMC DIO (Digital I/O) cards at MI-60 & MI-12

- Tests performed so far in situ:
  - WR switch at ICARUS-FD + 2 WR nodes (@ ICARUS-FD and MI-12): ~155 μs
  - WR switch at ICARUS-FD + 3 WR nodes (at ICARUS-FD, MI-12, MI-60): ~ 170 μs
  - WR switch at ICARUS-FD + 5 WR nodes (added two nodes at SBND): ~ 170 μs

    Why the same latency with 3 or 5 servers?

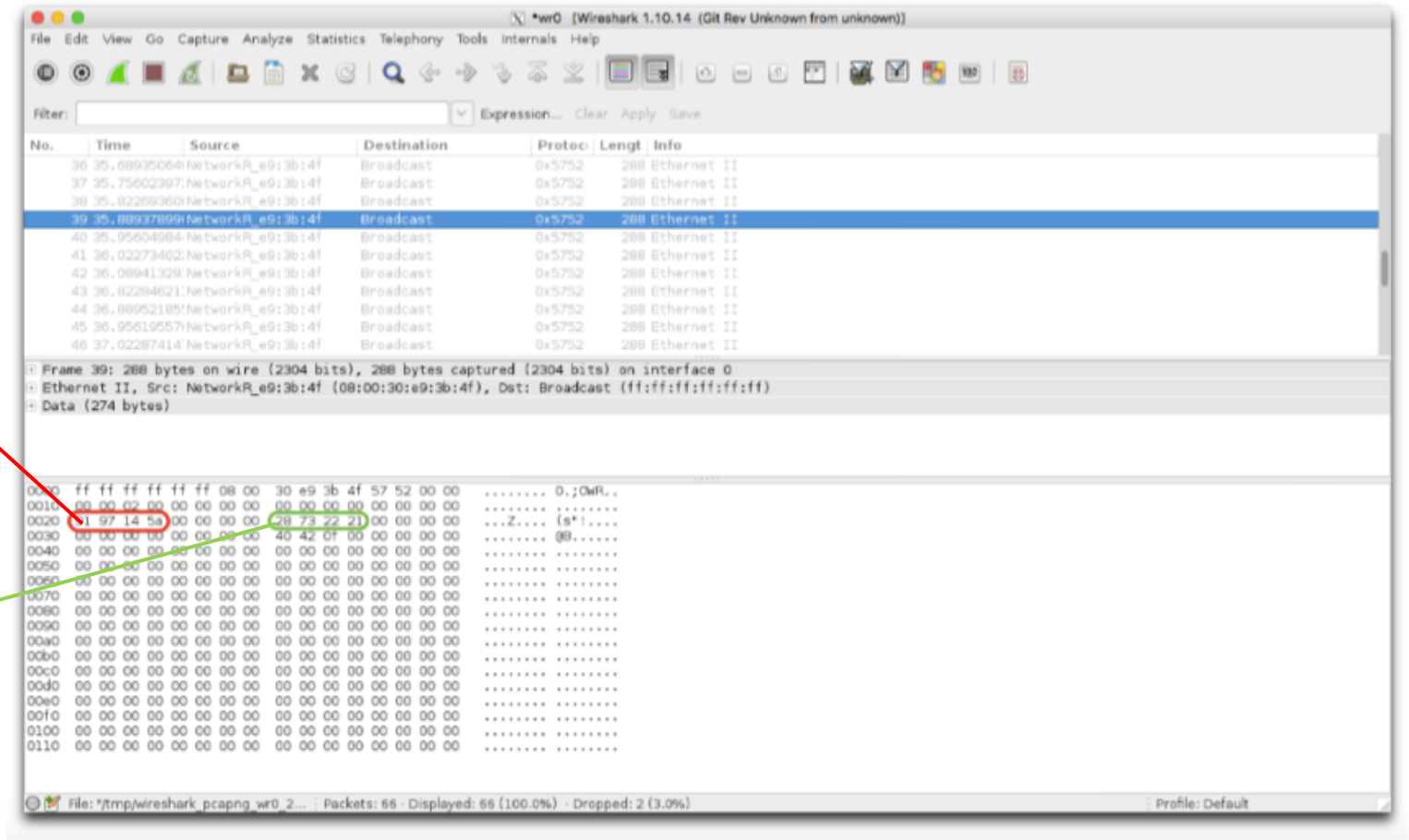
    Probably due to the fact that we are adding a network path that is SHORTER than the longest one we have (MI-60-→FD)so even adding two servers at SBND, the max latency does not change.
- We ran tests with different DIOs on different servers which gave different latency results. We think that the DIO ruler/agent software that broadcasts the packets uses the TCPIP protocol which depends on the operating system of the server. Different servers can lead to different latencies

Next: WR timestamps distribution and decoding tests

- Structure of timestamp packet send via WR-NIC (Network Interface Card) and captured

seconds
5a149791 =
1511298961

nanoseconds are
21227328 =
555905832



- Verified feasibility of sending multiple signals to same remote node, software development needed.

Summary

- All SBN campus WR network infrastructures installed
- Basic WR functionalities demonstrated in situ and at test stand
- Need to test sending and decoding of WR packet with SPEXI card as soon as possible

Future system upgrade:

- Discussing upgrading of software or firmware (or both) to broadcast WR packets with DIO (with latest WR-NIC software) and TDC/FineDelay (via the CERN Mock Turtle package) for better timing resolution (< 8ns)
- WR system’s timestamps information’s recording and monitoring tools (spring 2019)

Backup slides

WR hardware components & most notable functionalities

- **WR Switch (**PTP Gigabit Ethernet based with sub-ns time accuracy and deterministic data transfer, up to 1000 nodes on a 10 Km range)
  - 18 SFP 1GbE ports
  - 1PPS Input &1PPS Output
  - 10 MHz reference clock Input (GPS/Cesium)
  - 10 MHz && 62.5 MHz output reference clock
- **SPEC (Simple PCIE card) or SVEC (Simple VME card)**
  - Installed on a PC or in VME 64x crate
  - Can host any one of the available WR FMC (FPGA Mezzanine Cards) below
  - PTP core runs in FPGA with several drivers to communicate with mezzanine cards and host computers
- **DIO (Digital I/O) mezzanine**
  - 5 channels: Ch0 provides PPS by default, the other 4 channels are independently configurable as either input or output
  - 8ns time resolution
  - broadcasting software (WR-NIC)available to distribute over the network WR packets with timestamps information
- **TDC mezzanine card**
  - 5 input channels
  - 80-100 ps time accuracy: desirable to exploit the RWM signals bunch structure
  - NO broadcast software available: [firmware upgrade under consideration here at Fnal]
  - CERN working in developing Mock Turtle product (firmware/software combo) to address this issue [discussion item]
- **FineDelay mezzanine card**
  - 5 channels: 1 input channel, 4 output channels
  - Provides PPS in Ch0 and 10MHz at any of its 4 outputs
  - NO broadcast software available yet (see TDC comment above)

WR network equipment installed and locations

@MI-60

- WR server (sbnd-daq23) with SPEC/DIO PCIe mezzanine

@MI-12

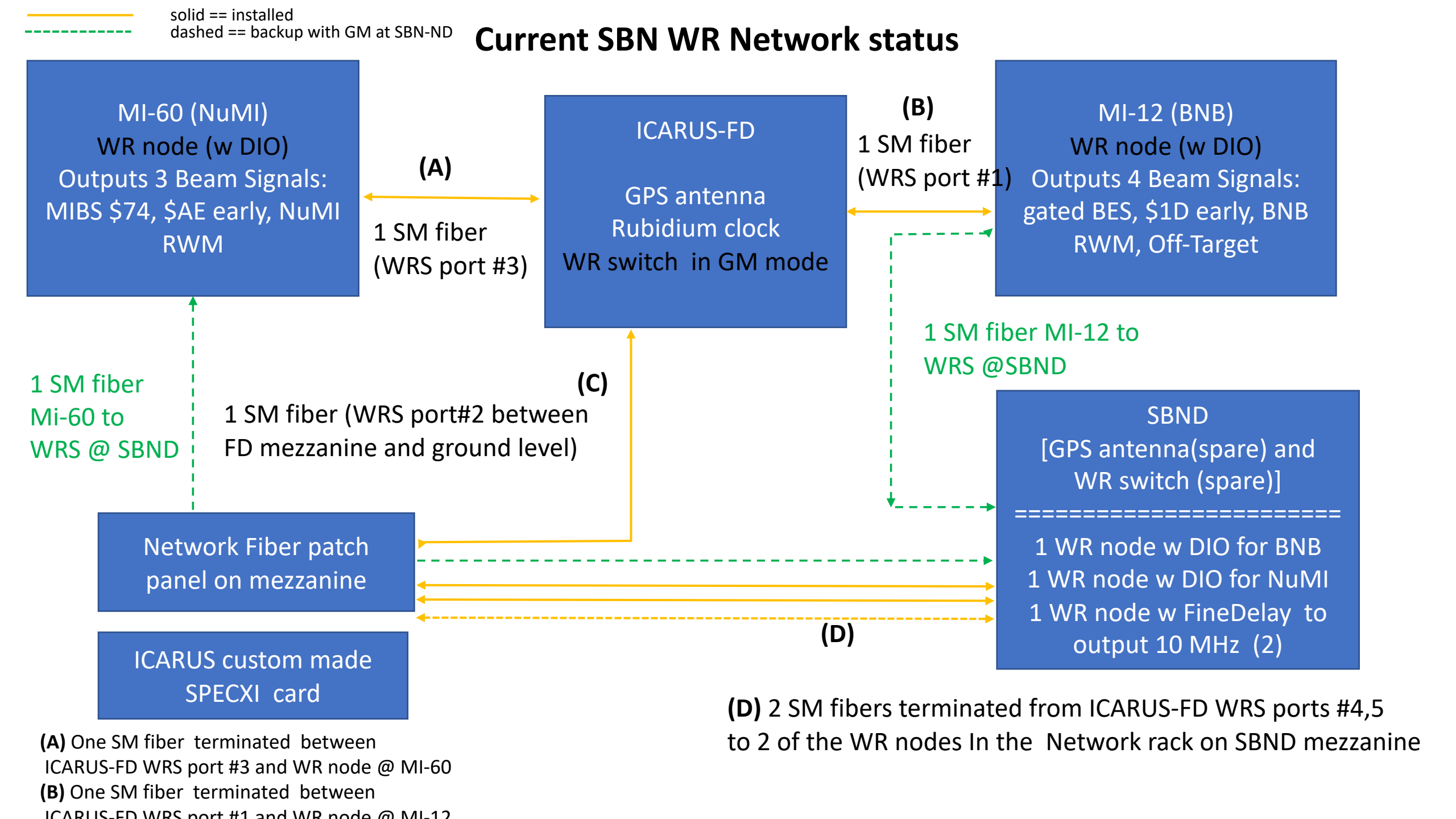
- WR server (sbnd-daq26) with SPEC/DIO PCIe mezzanine

@ICARUS

- WR Switch : GM (Grand Master) mode – connected to GPS and Rubidium Clock
- WR node (icarus-daq02) with SPEC/DIO mezzanine

@SBN-ND

- [back up WR Switch with GPS and Rubidium Clock: hardware available but NOT installed yet]
- 3 WR nodes to be installed soon:
- WR node with SPEC/DIO for distributing PPS/BNB signals
- WR node with SPEC/DIO for distributing PPS/NuMI signals
- WR node with SPEC/FineDelay for distributing 10MHz clock (tested @DAB test stand and in use for Penn Trigger board trigger development)


solid == installed
dashed == backup with GM at SBN-ND
Current SBN WR Network status
MI-60 (NuMI)
WR node (w DIO)
Outputs 3 Beam Signals:
MIBS $74, $AE early, NuMI
RWM
(A)
1 SM fiber
(WRS port #3)
ICARUS-FD
GPS antenna
Rubidium clock
WR switch in GM mode
(B)
1 SM fiber
(WRS port #1)
MI-12 (BNB)
WR node (w DIO)
Outputs 4 Beam Signals:
gated BES, $1D early, BNB
RWM, Off-Target
1 SM fiber MI-12 to
WRS @SBND
1 SM fiber
Mi-60 to
WRS @ SBND
(C)
1 SM fiber (WRS port#2 between
FD mezzanine and ground level)
SBND
[GPS antenna(spare) and
WR switch (spare)]
1 WR node w DIO for BNB
1 WR node w DIO for NuMI
1 WR node w FineDelay to
output 10 MHz (2)
Network Fiber patch
panel on mezzanine
(D)
ICARUS custom made
SPECXI card
(A) One SM fiber terminated between
ICARUS-FD WRS port #3 and WR node @ MI-60
(B) One SM fiber terminated between
ICARUS-FD WRS port #1 and WR node @ MI-12
(D) 2 SM fibers terminated from ICARUS-FD WRS ports #4,5
to 2 of the WR nodes In the Network rack on SBND mezzanine

Optical converter tests

Test A

- There is a limited number of fibers connecting the ICARUS Network switch on the mezzanine floor to the ground floor where the GPS /WR switch now reside
- the high cost of installing new fibers (15 K) could be avoided by simply moving the WRS to the mezzanine" and substituting the copper connection between GPS and WRS with a copper—>fiber—>copper one
- If we need more WR connections, we might have to move the WR switch to the mezzanine hence far away from the GPS and send the PPS to the mezzanine via fiber
- Question: can we do this without degrading the PPS signal?
- We tested this at DAB (next slide)

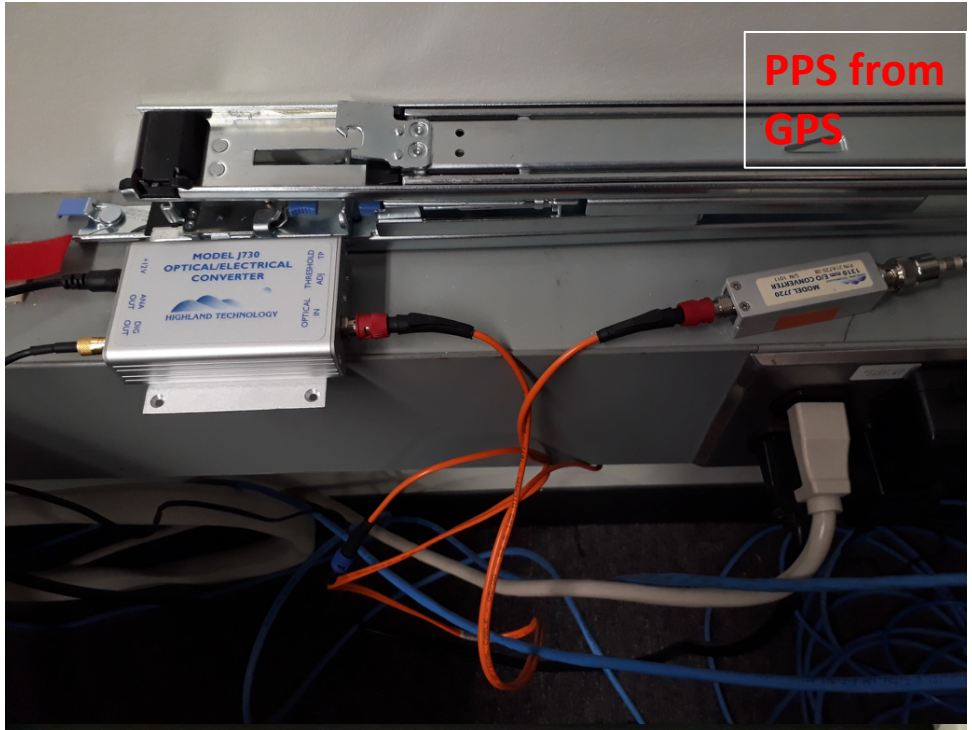
Test B

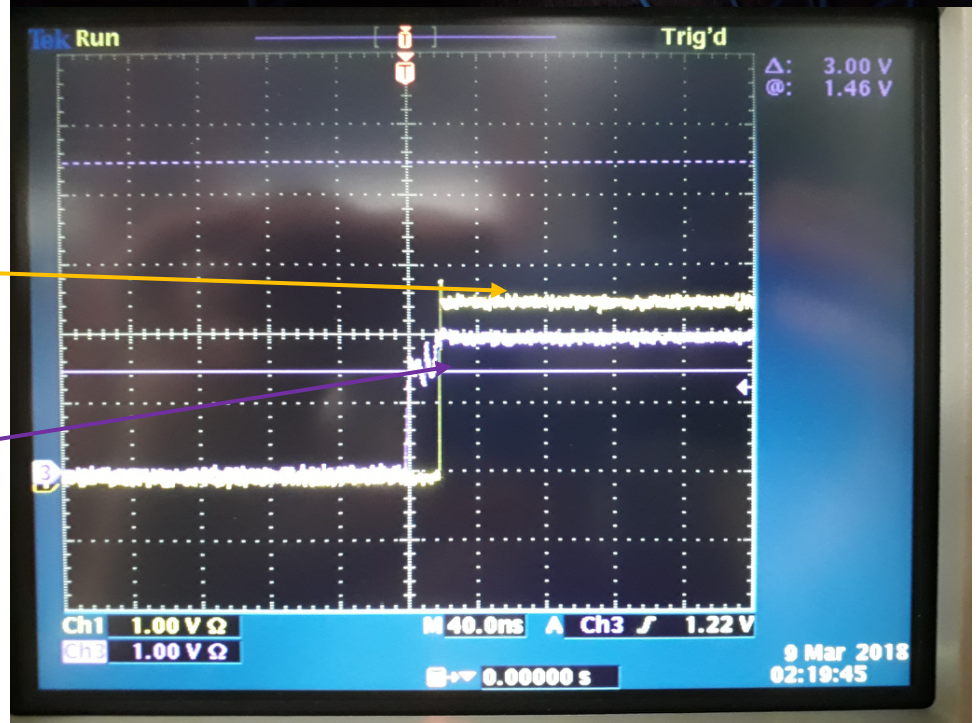
- At SBND, if we use SPEC cards hosted in servers on building ground, we'll have to use CU/FI -> FI/CU converted to transport the signals to the Front End Electronics on detector ground.
- Question: can we do this without degrading the signals?
- This still needs to be done, but we should expect similar results to Test A

PPS signal to WRS via optical fiber

- Split PPS signal from GPS
- Sent one signal to oscilloscope and the other one to a pair of optical converters CU/FI →FI/CU then to oscilloscope
- Top photo shows setup
- Bottom photo the oscilloscope screen : purple signal straight from GPS; yellow after the two converters
- Yellow signal is delayed ~20 nsecs from purple; degradation in quality due to cableing (?)
- We should be able to move the WRS at the ICARUS building from the ground floor to the mezzanine

setup





yellow

purple