

# ProtoDUNE Cold Cable

Matthew Worcester (BNL)

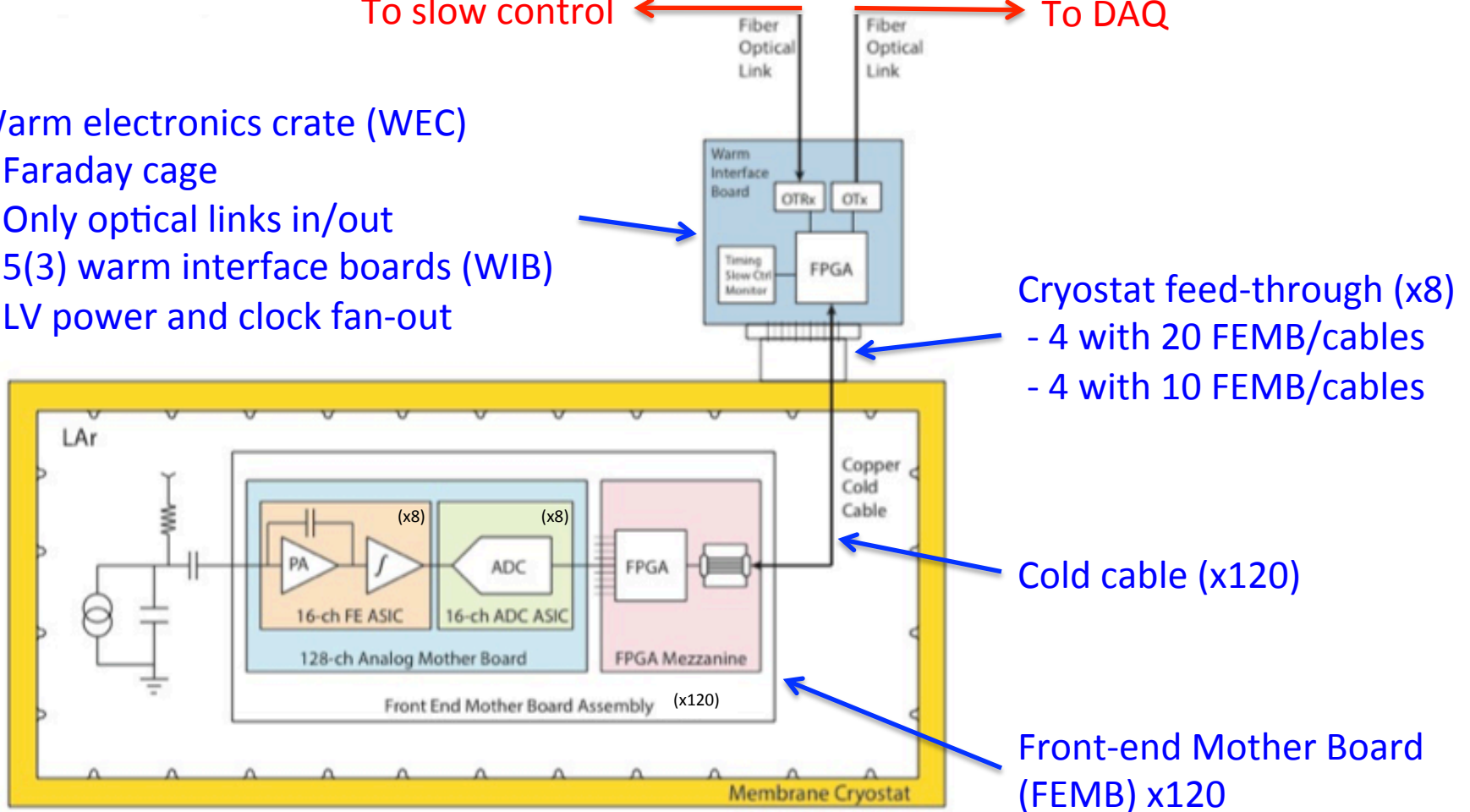
WIB Discussion

April 21, 2016

# TPC Electronics

- Warm electronics crate (WEC)
- Faraday cage
  - Only optical links in/out
  - 5(3) warm interface boards (WIB)
  - LV power and clock fan-out

To slow control ← Fiber Optical Link → To DAQ

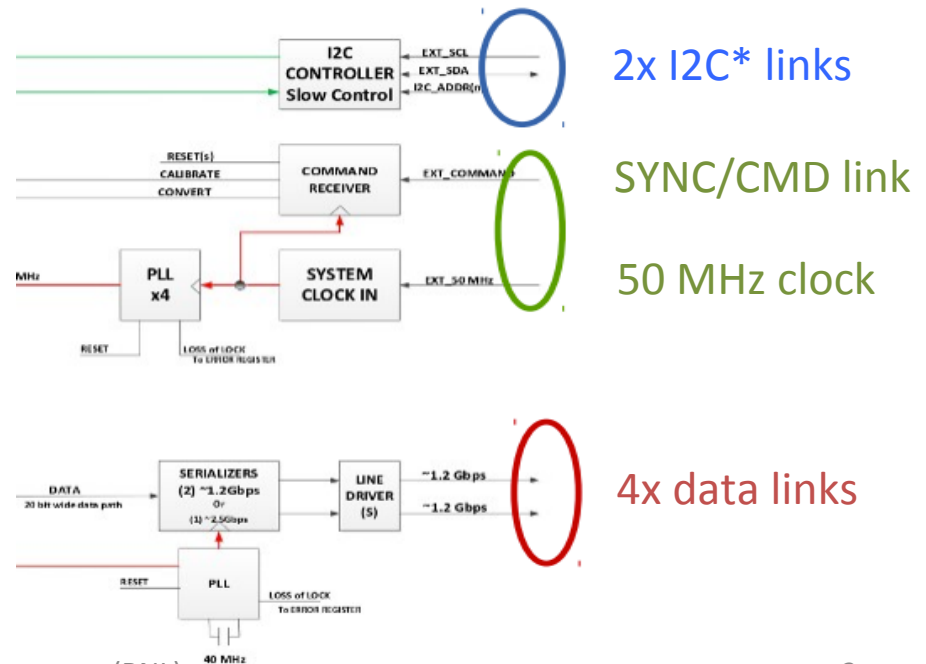


# Cold Cable

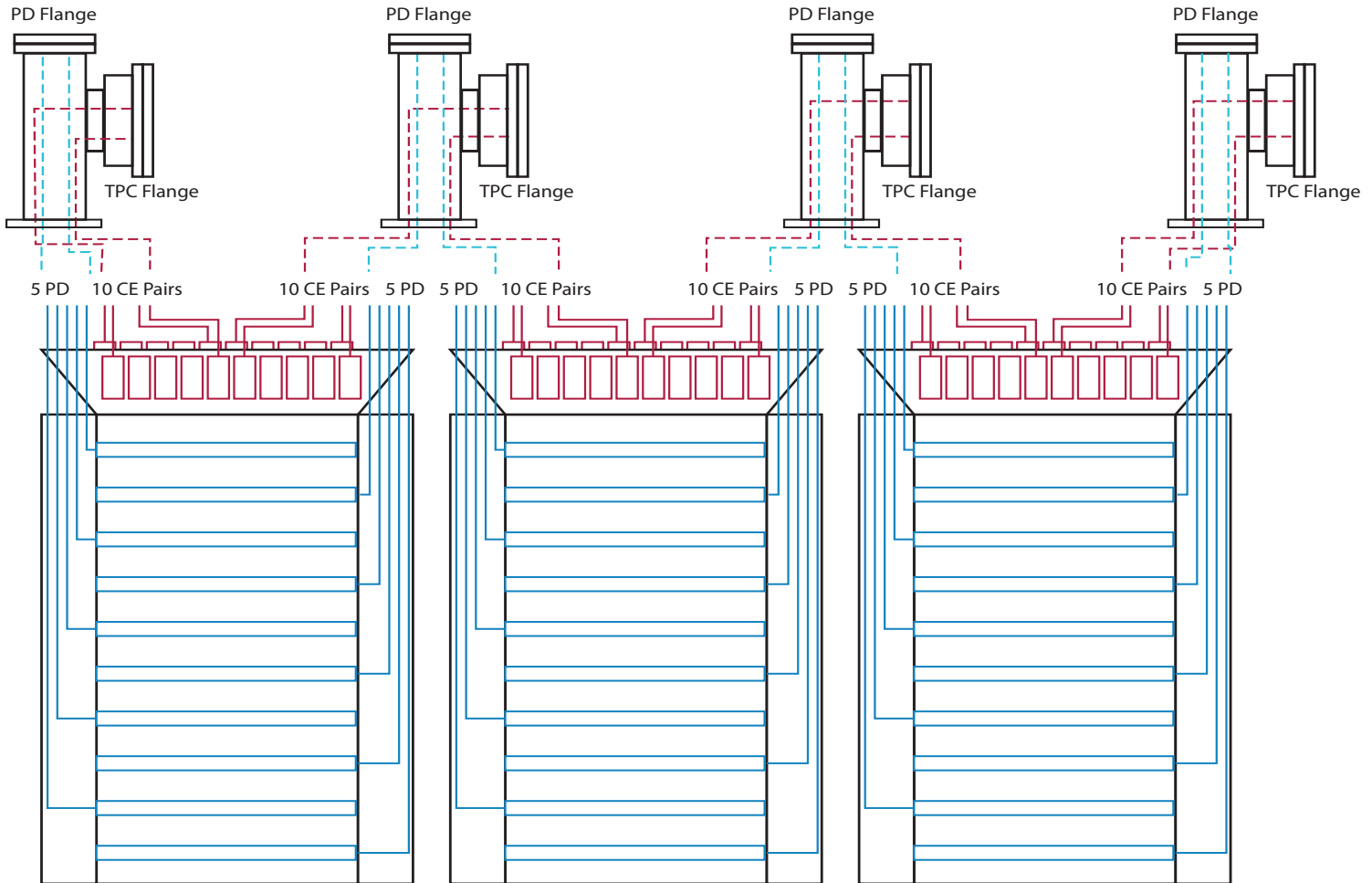
- High-speed data:  $480 \text{ bits} \times 2 \text{ MHz} \times 1.25 \text{ (8b/10b encoding)} = 1.2 \text{ Gbps}$ 
  - Per 32 channels: 4 per FEMB



- 12 links required per FPGA
  - Four 1.2 Gbps data links
  - Two differential I2C\* links
  - One differential 50 MHz clock
  - One differential SYNC/CMD link
  - 4 JTAG signals (single-ended) for FPGA programming
- Not including LV power
- COLDATA mezzanine requires 9 differential links



# Cable Routing Scheme



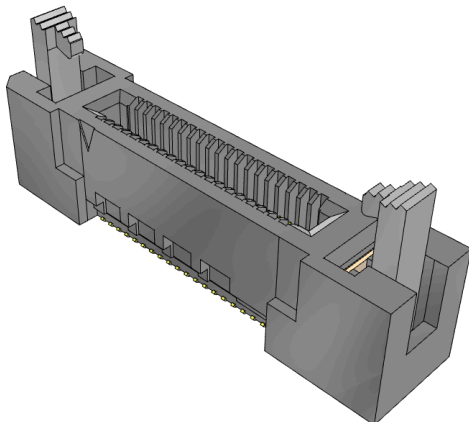
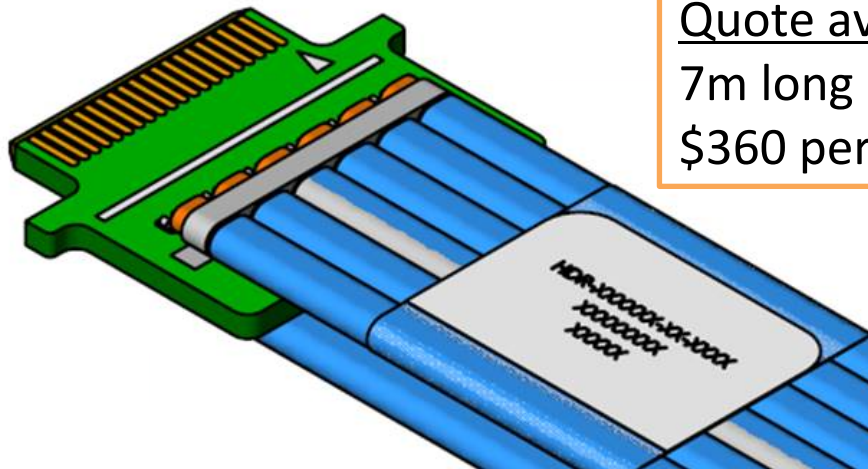
Longest cable = 6.4m including contingency, same as DUNE upper APAs

# Samtec 12-Pair Cable Bundles

Samtec 26-gauge twin-axial cable will carry all 12 links

- Samtec will custom assemble with Samtec HSEC8 connector
- All cable bundles in ProtoDUNE will be short (< 7 meters)

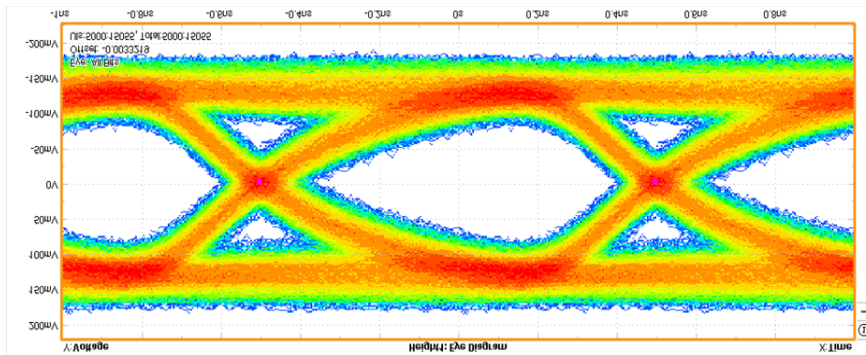
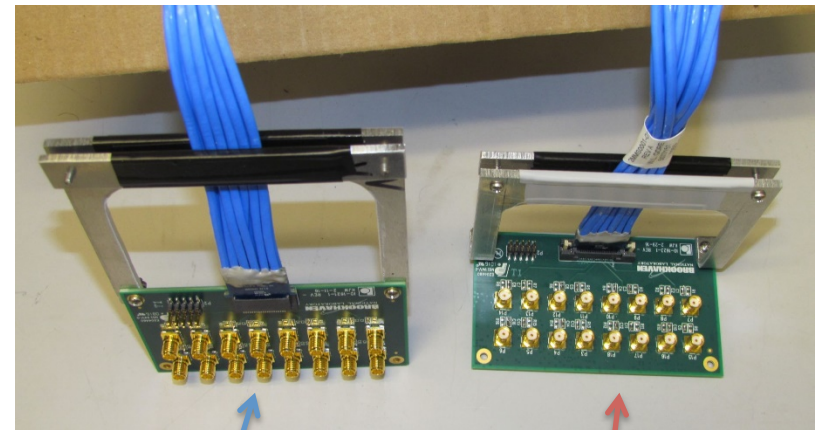
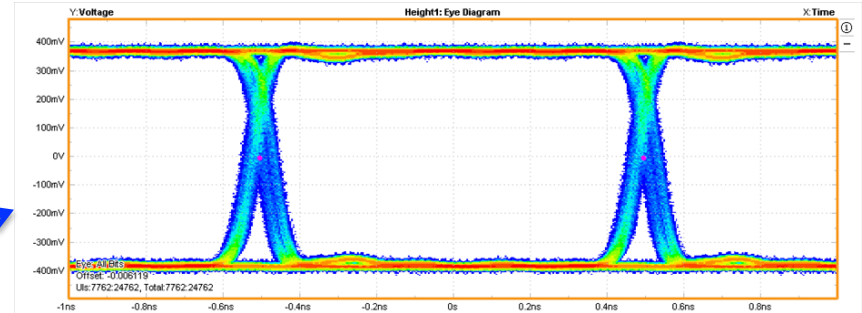
Quote available from Samtec  
7m long cable bundle  
\$360 per bundle (>100)



- Drawings not final, but lead time now estimated to be 8 weeks
- HSEC8-DV latch to attach and hold bundle

# Recent Test Results

- Samtec 26-gauge cable tested at 25m (DUNE long cable) with active equalizer at warm end for signal recovery
  - Produced eye diagram
  - Passed BER test up to  $10^{13}$  bits
- Samtec connectors tested in LiN with 25m of warm Gore 24-gauge cable
  - Produced eye diagram (below)
  - Passed BER test up to  $10^{12}$  bits



# Samtec Twinax Cable



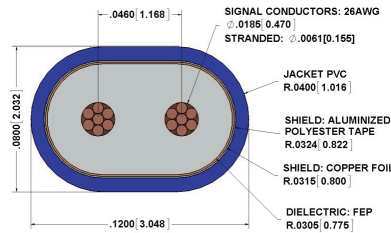
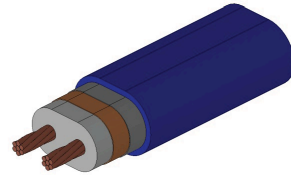
100 Ohm, 26 AWG Twinax Cable  
Data Sheet

## PERFORMANCE DATA

**Capacitance:** 13 pF/ft (nominal)  
**Skew:** 10 ps/m within pairs  
**Propagation Delay:** 1.46 ns/foot  
**Flex Cycles:** 4,000 cycles, single\*  
**Current Rating:** Single Conductor = 4.7 Amps\*\*  
 Two Conductors = 3.4 Amps\*\*

**Shield DCR:** 63Ω/1000ft  
**CC DCR:** 39Ω/1000ft  
**Min. Bend Radius:** .125"  
**Availability:** Single, tape bonded  
**Temperature Rating:** -25°C to 105°C, UL VW-1 Tested \*\*\*  
**DWV Working Voltage:** 575 V\*\*\*\*  
**Performance Rating:**

IL	.25m	1m
-3dB	>20GHz	11.4GHz
-7dB	>20GHz	>20GHz



A 3M Company

- 30 AWG THV insulated twinax cable is available
  - Cold test at BNL to check integrity of cable insulation OK at LN2 temperature
  - Sample of cable is undergoing purity test at Fermilab MTS, results due by the end of April
- 26 AWG THV insulated twinax cable sample will be available by the end of April
  - To verify electrical test results, compared to PVC insulated twinax cable already tested at BNL
- Fabrication of 12-pair cable assembly will start after purity test at Fermilab and electrical test at BNL

**Dyneon™**  
**Fluorothermoplastics**

THV 500G

### Product Features

- Excellent flexibility
- Processing profile allows co-processing with olefinic plastics and hydrocarbon elastomers
- Excellent chemical- and permeation-resistance
- Low flammability
- Bondable to itself and other substrates (for multi-layer constructions)

### Typical Properties (Data not for specification purposes)

Form	Pellets	
Melting Point	165°C (330°F)	ASTM D4591
Melt Flow Index	10 (265°C/5 kg)	ASTM D1238
Specific Gravity	1.98 g/cm <sup>3</sup>	ASTM D792
Tensile at Break	28 MPa (4,060 psi)	ASTM D638 (film)
Elongation at Break	500%	ASTM D638
Flexural Modulus	210 MPa (30,000 psi)	ASTM D790
Limiting Oxygen Index	>75	ASTM D2863
Packaging	25 kg (55lb) bag 590 kg (1,300 lb) tote	

### Introduction

THV 500G is a flexible, transparent fluoroplastic composed of tetrafluoroethylene, hexafluoropropylene, and vinylidene fluoride in the form of pellets. It provides a balance of low temperature processing, low flammability, thermal stability, and melt processability. It can be used to prepare

### Safety/Toxicology

This is a fluoroplastic material so normal precautions observed with fluoroplastics should be followed. Before processing these products, consult the Material Safety Data Sheet and labels. Follow all directions and handling precautions. General handling/processing

# Remaining Schedule

- Prototypes of 7 meter long Samtec bundle with connector available by summer 2016
  - Cable validation tests at BNL
  - Noise and integration tests at FNAL, CERN, BNL
- Prototype FEMB mezzanine and flange boards available by summer 2016
  - Will be tested with cable in cold electronics integration teststand at BNL
- If Samtec cables fail prototyping tests, fallback is 3M mini-SAS cable
  - Mini-SAS will be tested concurrently for SBND
- Final order of Samtec bundles for protoDUNE by end of 2016
  - 120 + 20 spares
  - 8 weeks of lead time: bundles available for validation by March 2017

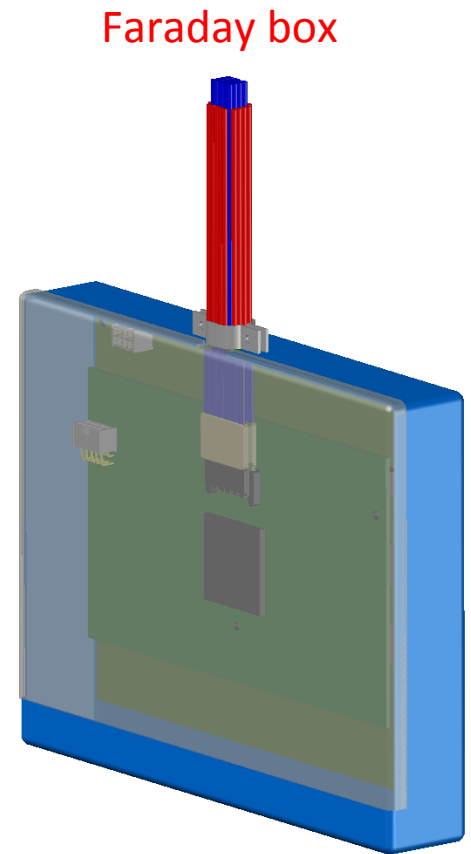
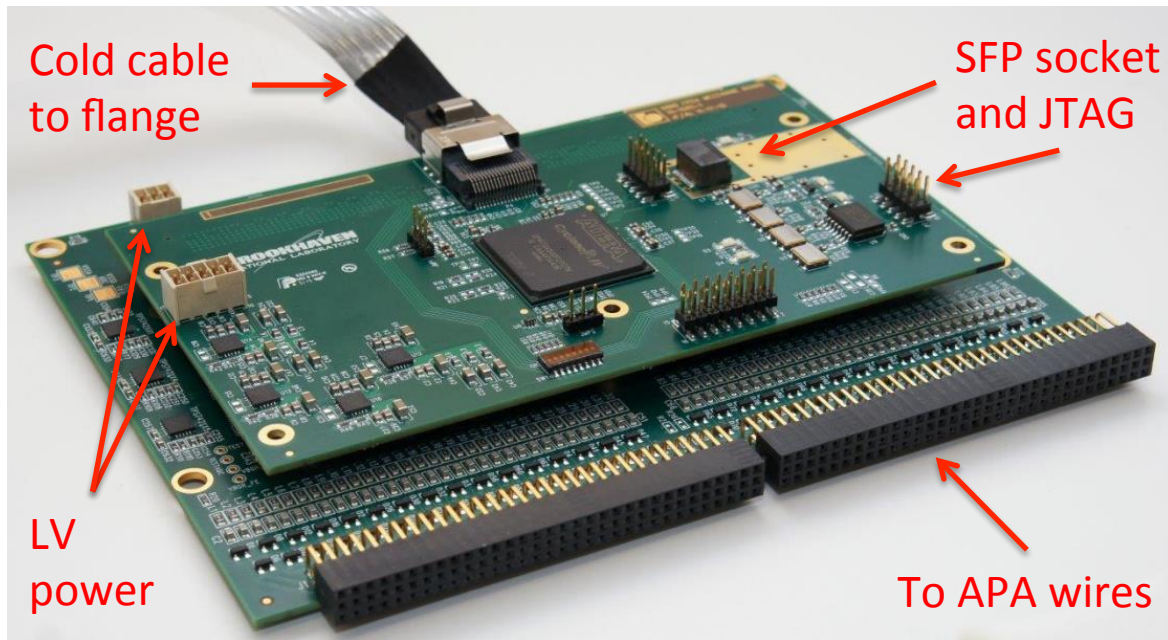


# Conclusion

- Samtec 26 AWG cable bundles will be used in ProtoDUNE
  - Candidate for all cable lengths in DUNE far detector
  - All bundles will be short ( $< 7$  meter)
  - 8 week lead time works in accelerated ProtoDUNE schedule
- Cable testing, FEMB and flange designs ongoing at BNL

# Backup Slides

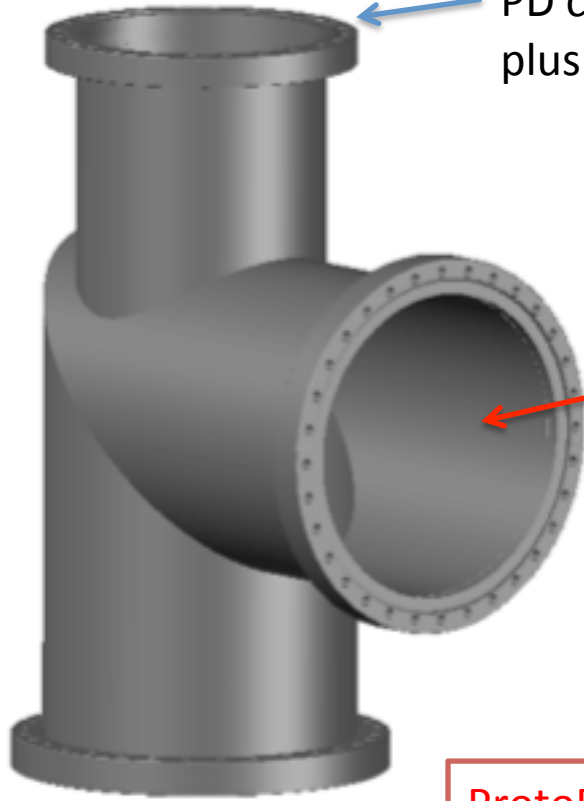
# FEMB



- 128 channels of digitized TPC wire readout
  - 8 FE ASICs/8 ADC ASICs on the analog motherboard
  - Controlled by 2 COLDATA/1 FPGA on the mezzanine
- 12 bit ADCs digitizing at 2 MHz
- Mounted in modular Faraday box with built-in cable strain relief

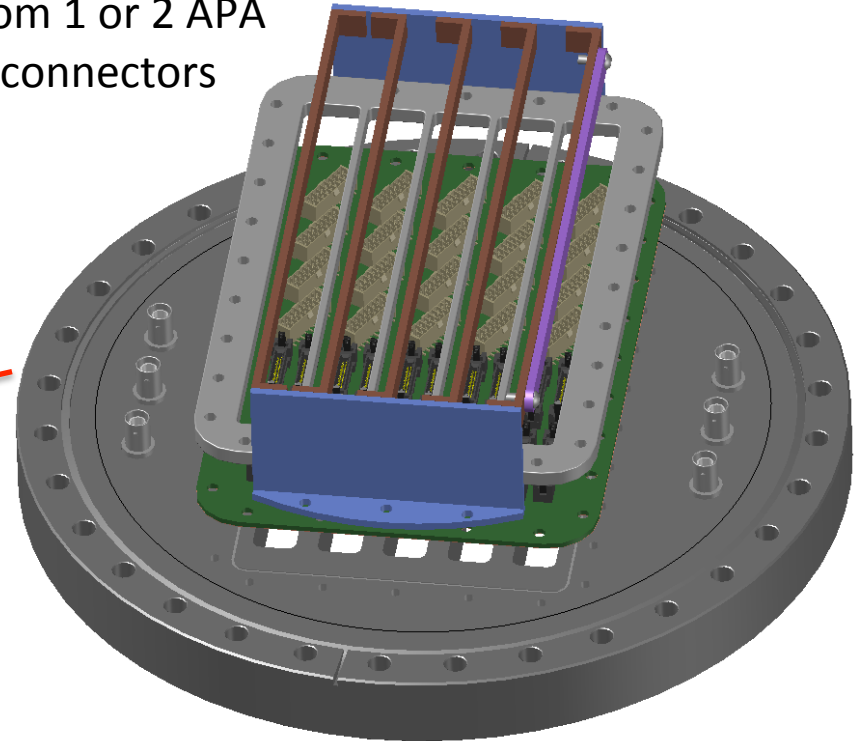
# Cryostat Flange and Feed-through

10" CF flange for the PD cables from 1 or 2 APA plus 4 DB15 connectors



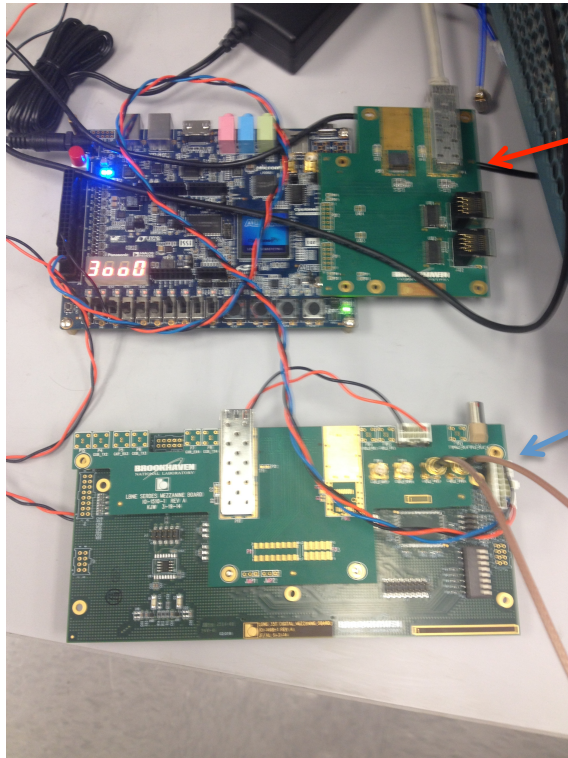
10" pipe, 12" CF flange for the cryostat nozzle

ProtoDUNE = 8 of each



12" CF flange for the CE cables from 1 or 2 APA plus wire bias connectors

# Cold Cable Test Setup at BNL



Cyclone V evaluation board

- generates a random bit pattern
- sends pattern to 35ton FPGA

35ton FPGA mezzanine

- sends bits over LVDS cable pair to scope
- sets pre-emphasis "kick" to drive data



Tektronix oscilloscope

- locks onto bit pattern and generates eye diagram
- eye diagram necessary to validate cable but not guarantee of 0 bit error rate



# DUNE Cable Length Estimate

## Condition #1

This will apply to all of the upper APA. 3 rows of 25 or 75 total.

743 (distance from fin to inner ceiling)+  
900 (insulation thickness)+ 1148 (warm  
structure thickness)+ 2320 (width of APA)  
= 5111 mm + 25% = 6400 mm **6m**

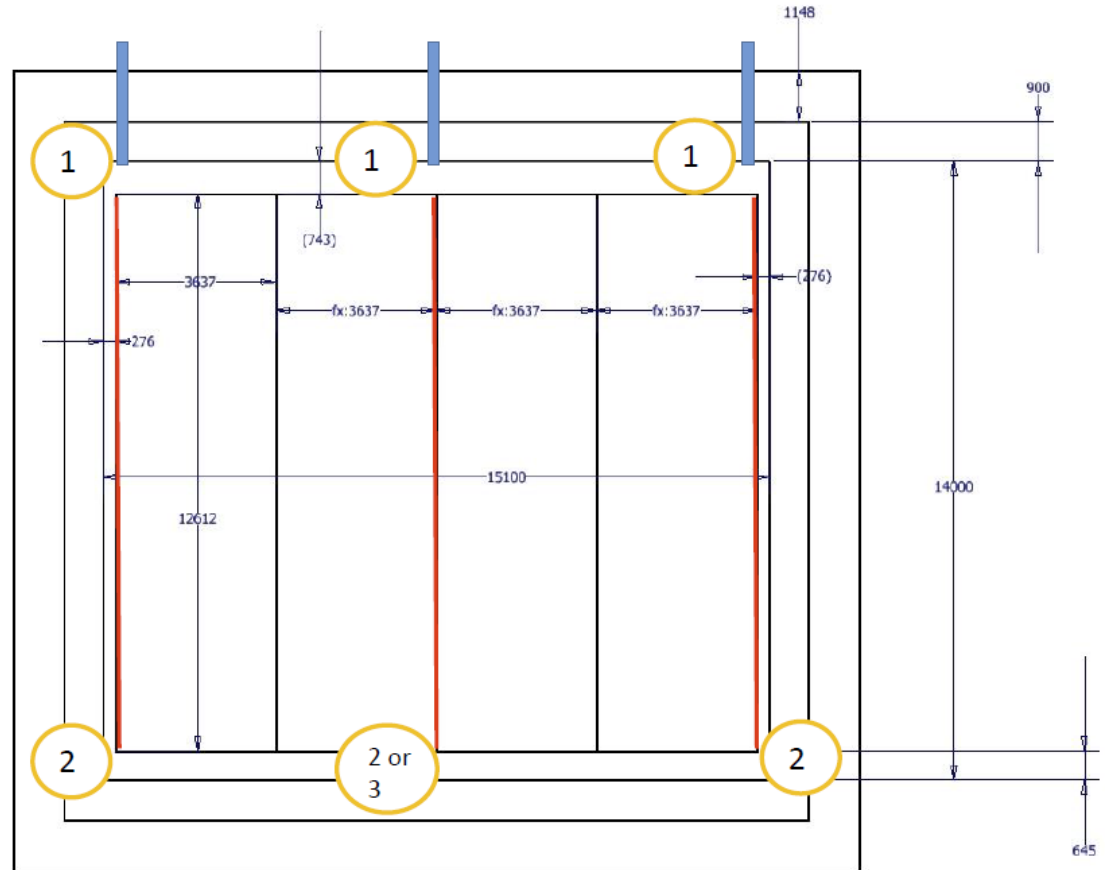
## Condition #2

This will apply to the bottom APA on the  
two outer rows. 2 row of 25 or 50 total.  
Same as #1, 5111 + 12612 (height of two  
APAs) = 17723 + 25 % = 22150 mm **18m**

## Condition #3

If we cannot route the lower APA cables  
through the structural tubes of the upper  
APA the cables will need to go the  
cryostat floor, route over to the walls and  
then up to the feed thrus. This will apply  
to the final 25 APAs.

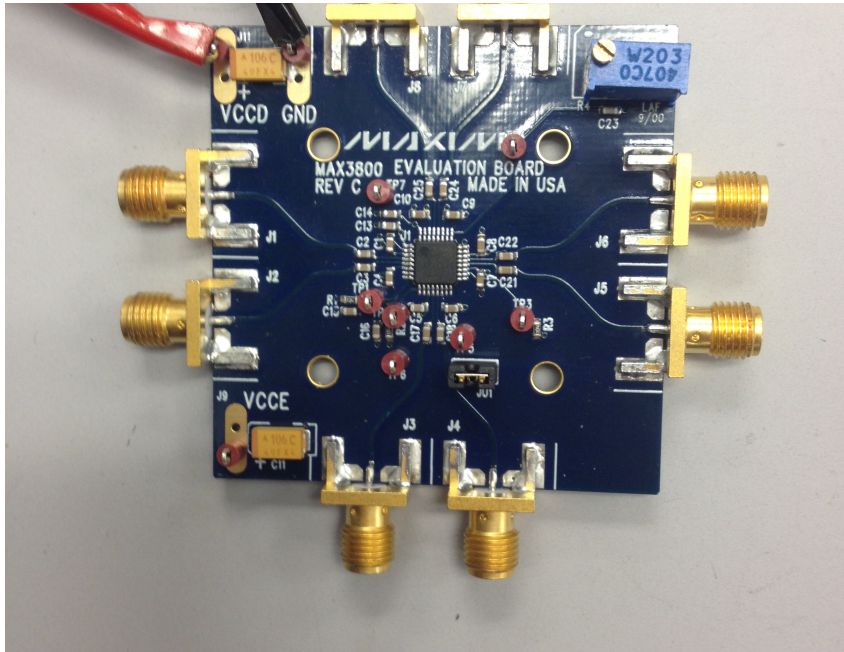
Same as #2, 17723 + 3637 (distance  
between CPA and APA) + 3637  
= 24997 + 25 % = 31250 mm



**25m**

Readout of this length at room temperature is biggest challenge

# Samtec Cable Testing



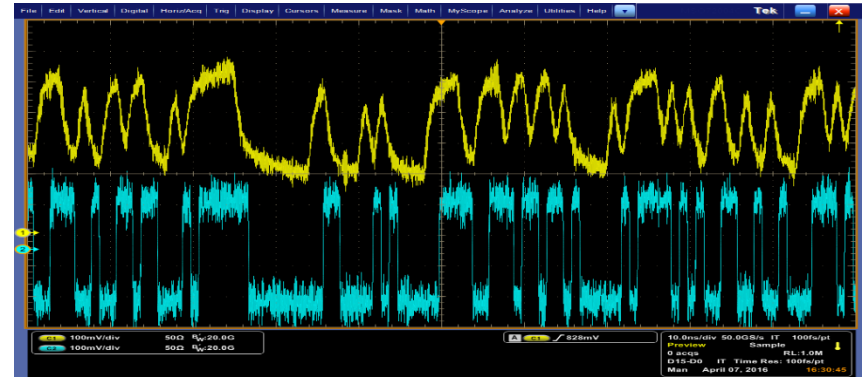
26-gauge Samtec is an option for DUNE far detector long cable.

- Use commercial active equalizer to recover signals at warm end of long cable
  - MAX3800 from Maxim Integrated
  - Equalizers will be implemented on WIB with a bypass option
- Samtec HSEC8 connector tested in cryo
  - With Gore bundle
  - Passed eye diagram and bit error rate (BER) tests

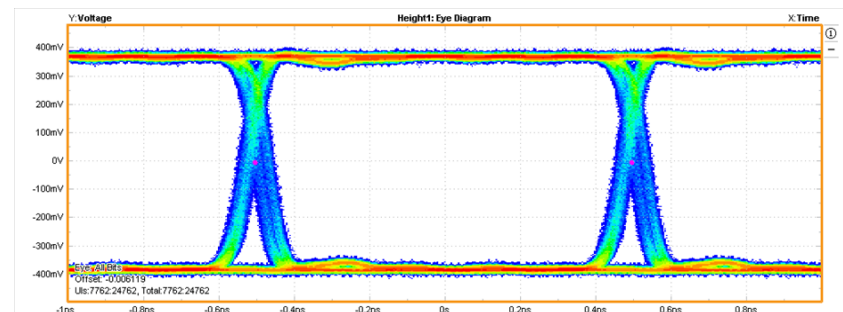
# Cold Cable

## Active Signal Equalization

- One way to enhance cable performance is to use an equalization IC on the output end of the cable. Shown is a screen shot comparison of the two sides of the twin-axial signal from a 25 meter, 26 gauge cable (Omnibit) manufactured by Hitachi.
- In the figure one conductor is equalized and one conductor is not. The equalizer used is a Max3800.
- The 2<sup>nd</sup> figure shows an eye diagram of a 25 meter, 26 gauge, Samtec twin-axial cable after equalization.
- It should be noted that an eye diagram produced with equalization is probably not a sufficient test of the cable signal integrity. A Bit Error Rate Test (BER) must be performed also.
- Both the Samtec and Hitachi Omnibit cables passed a BER test up to  $10^{13}$  bits.



Comparison of signals through a cable with and without equalization.



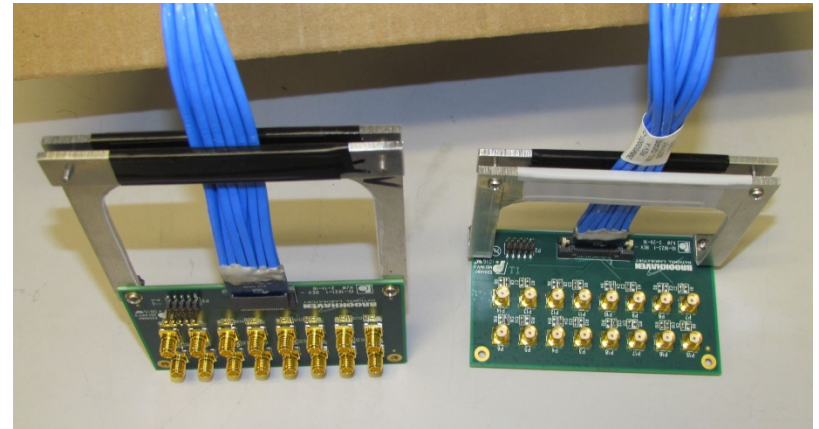
Eye diagram of a 25 meter, 26 gauge cable from Samtec after equalization



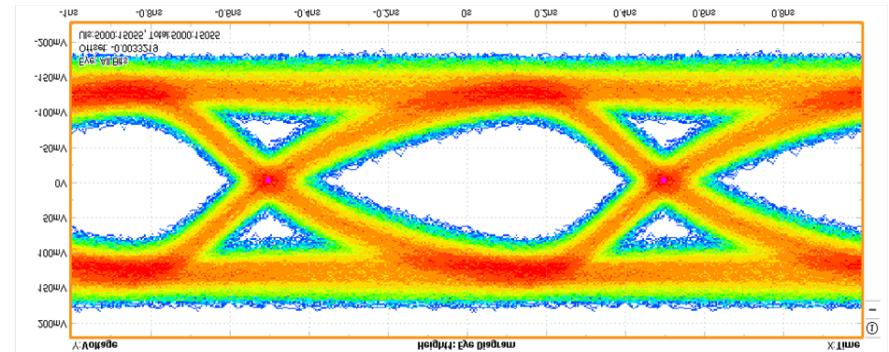
# Cold Cable

## Gore Prototype Cable Tests

- The Gore proto-type cable has the following characteristics
  - 1) 12 twin-axial, 24 gauge pairs
  - 2) 25 meters long
  - 3) PC boards designed to insert into a Samtec HSEC8-120 connector
- Shown are the 2 terminations along with the breakout boards (one with a vertical connector and the other with a right angle connector) along with strain relief used for testing. Eight of the twin-axial pairs are terminated with SMA connectors for testing.
- To test the cable termination, each breakout board was separately immersed in LN and a BER test made up to  $10^{12}$  bits. All 8 twin-ax pairs for each board passed.
- All 8 twin-axial pairs were also tested at room temperature. All passed and shown is a typical eye diagram from one of the pairs. The total variance in eye height and jitter from pair to pair is approximately 10% for eye height and 20% for total jitter .



Terminations and strain relief for cable breakout



Typical Eye diagram for Gore proto-cable at RT.  
Eye height = 131 mV, Total Jitter = 427 ps

# Cable Option Summary

	Gore	Samtec	3M mini-SAS
Validated length	25m	25m (w/equalizer)	7m
Gauge	24	26	30
Type	Twin-axial	Twin-axial	Twin-axial/single
Connector	Samtec HSEC8	Samtec HSEC8	Molex
FEMB revision	Next	Next	Current (SBND)
Decision for first prototypes	End of April 2016	End of April 2016	End of April 2016
Decision for final components	September 2016 (cable lead time)	September 2016 (FEMB design)	September 2016 (FEMB design)
Cost (/bundle)	\$2,175	\$360	\$72
Lead time	5 months	8 weeks	10 weeks
Status	Sample at BNL	Sample fabrication in May 2016	Sample at BNL (r/o SBND FEMB)