Design, Deliverables, Budget, Plan

DUNE Far Detector #2
Photon Detector System Workshop

July 26, 2021
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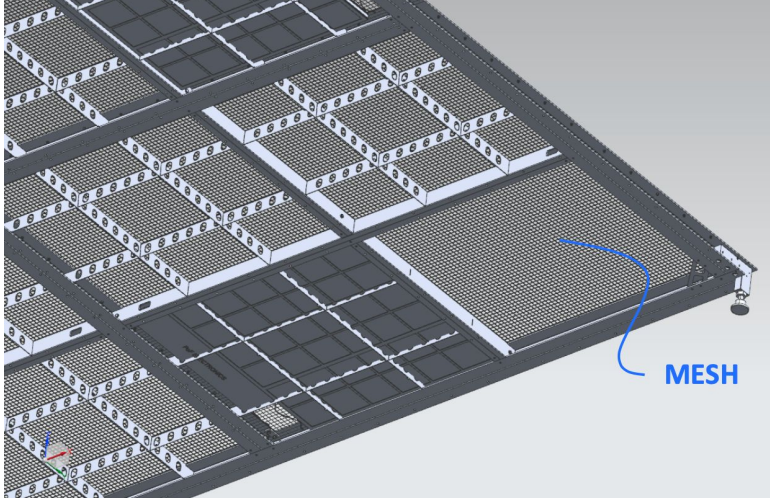
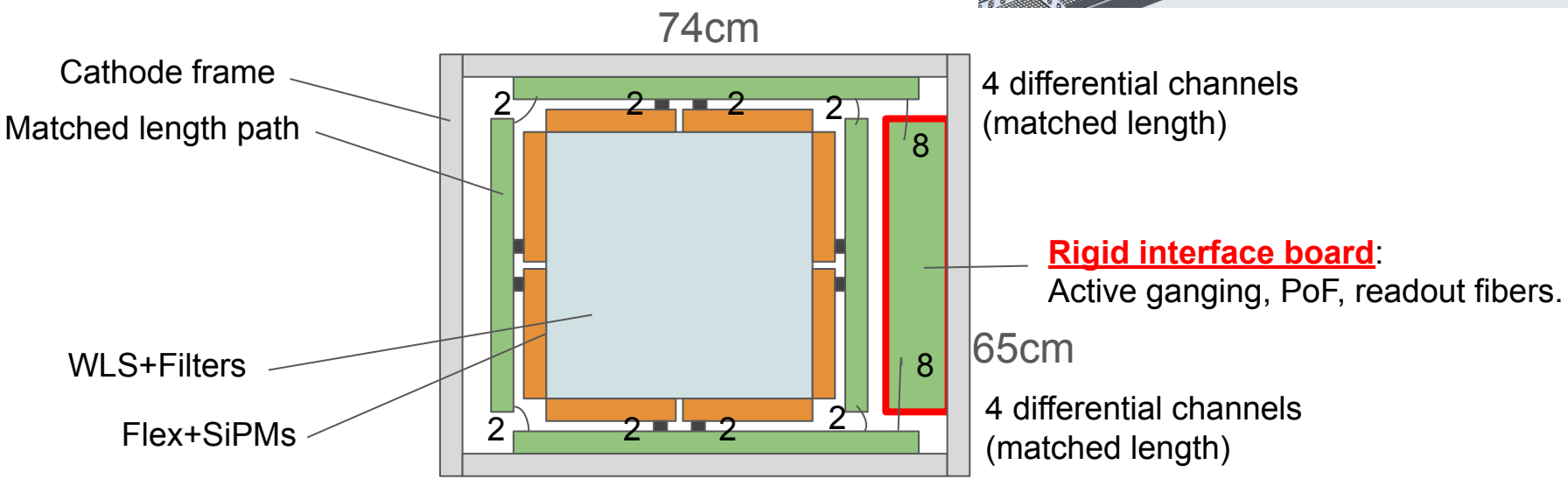
Design & Deliverables

- Two primary components:
  a. Detector
  b. Readout
- FD2 PDS design lends itself well to collaboration rather than competition among collaborators.
- WBS plan includes prototype path, 1/20th scale module-0, and production
- The baseline **production plan** is 320 cathode modules + 320 membrane modules with analog readout in the cold.
- The **prototype path** considers multiple readout flavors.
- Through **module-0 path** considers multiple detector types.

Detector Module Types (1 of 3)

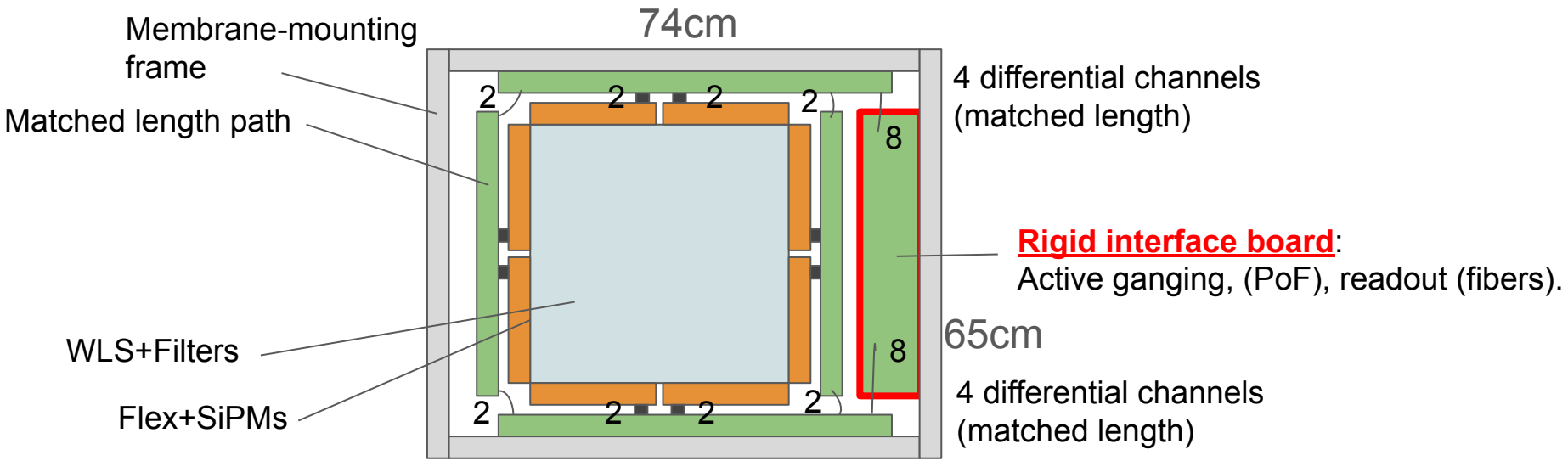
Cathode-mount: 60cm x 60cm WLS plate w/160 SiPMs, 2-channels (80 SiPMs/ch)





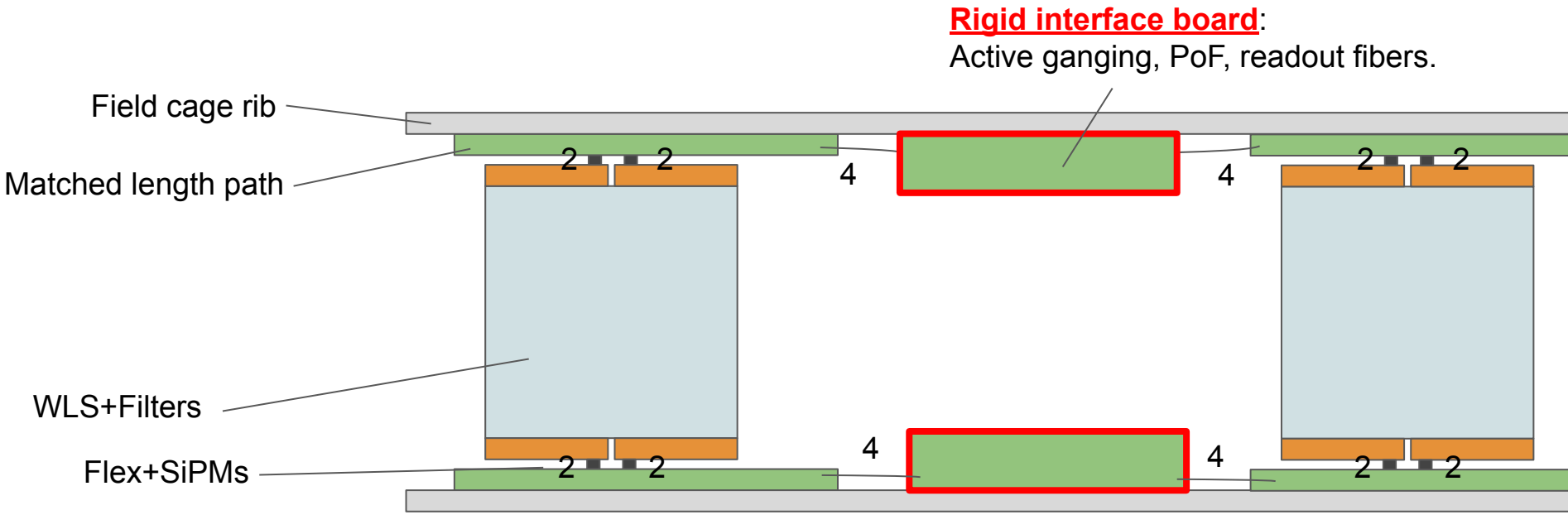
Detector Module Types (2 of 3)

Membrane-mount: 60cm x 60cm WLS plate w/160 SiPMs, 2-channels (80 SiPMs/ch)



Detector Module Types (3 of 3)

Field Cage-mount: 60cm x 60cm WLS plate w/80 SiPMs, 2-channels (40 SiPMs/ch)

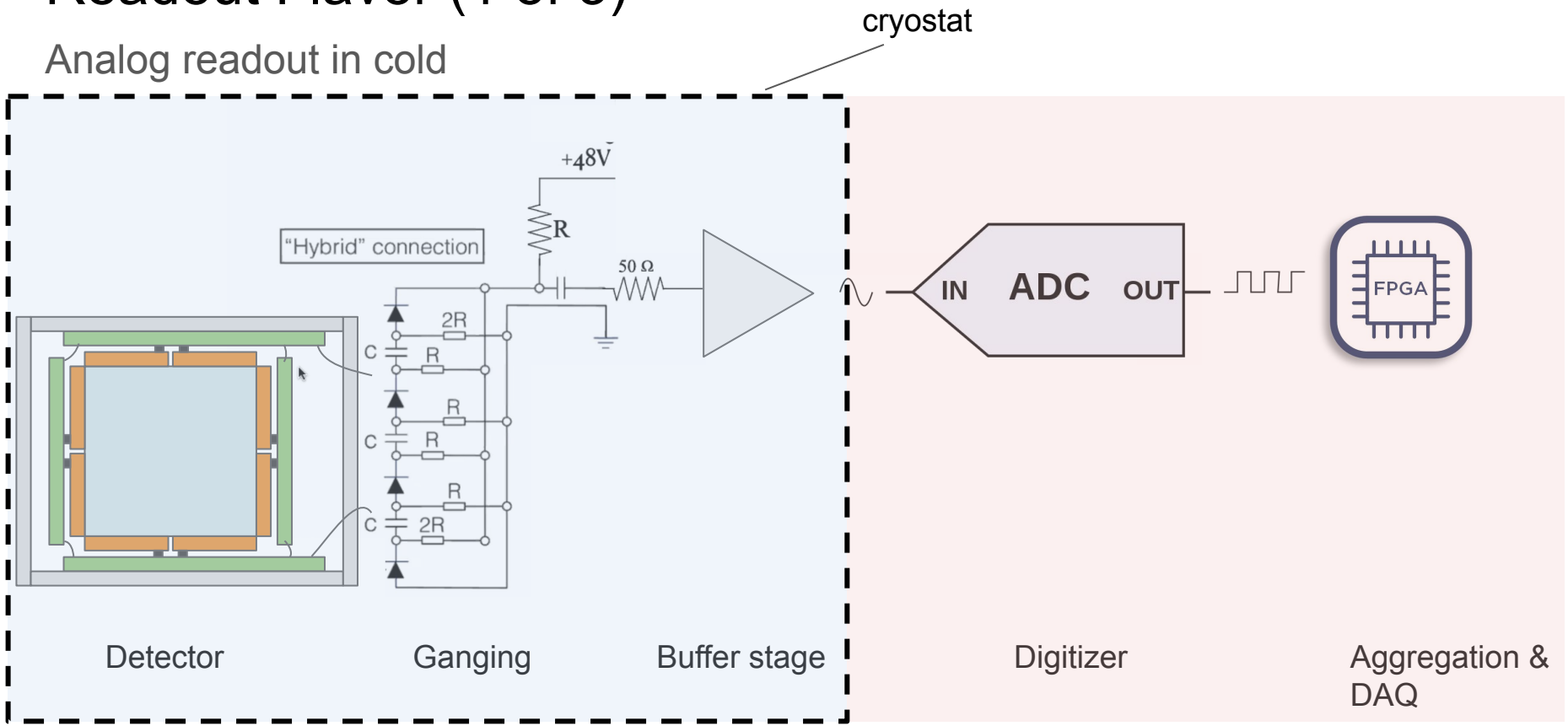


Readout Flavors

- Primary factors:
  a. Signal quality
  b. Long-term cold qualification trade-offs
  c. Topology cost
- Where is the cold/warm boundary?
- Where is the analog/digital boundary?
- Otherwise same components:
  a. Passive/active SiPM ganging
  b. Buffer stage
  c. Digitizer
  d. Aggregation & DAQ interface layer

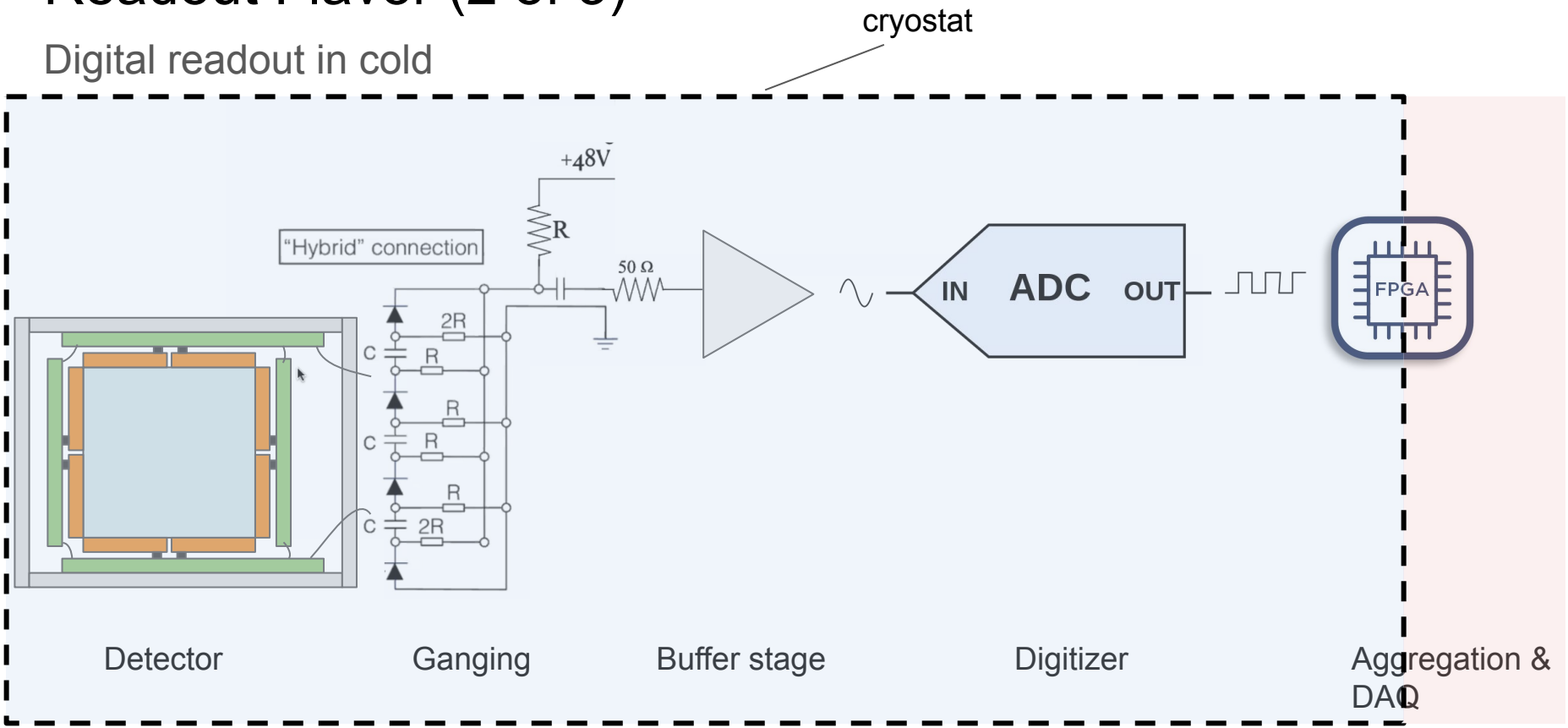
Readout Flavor (1 of 3)

Analog readout in cold



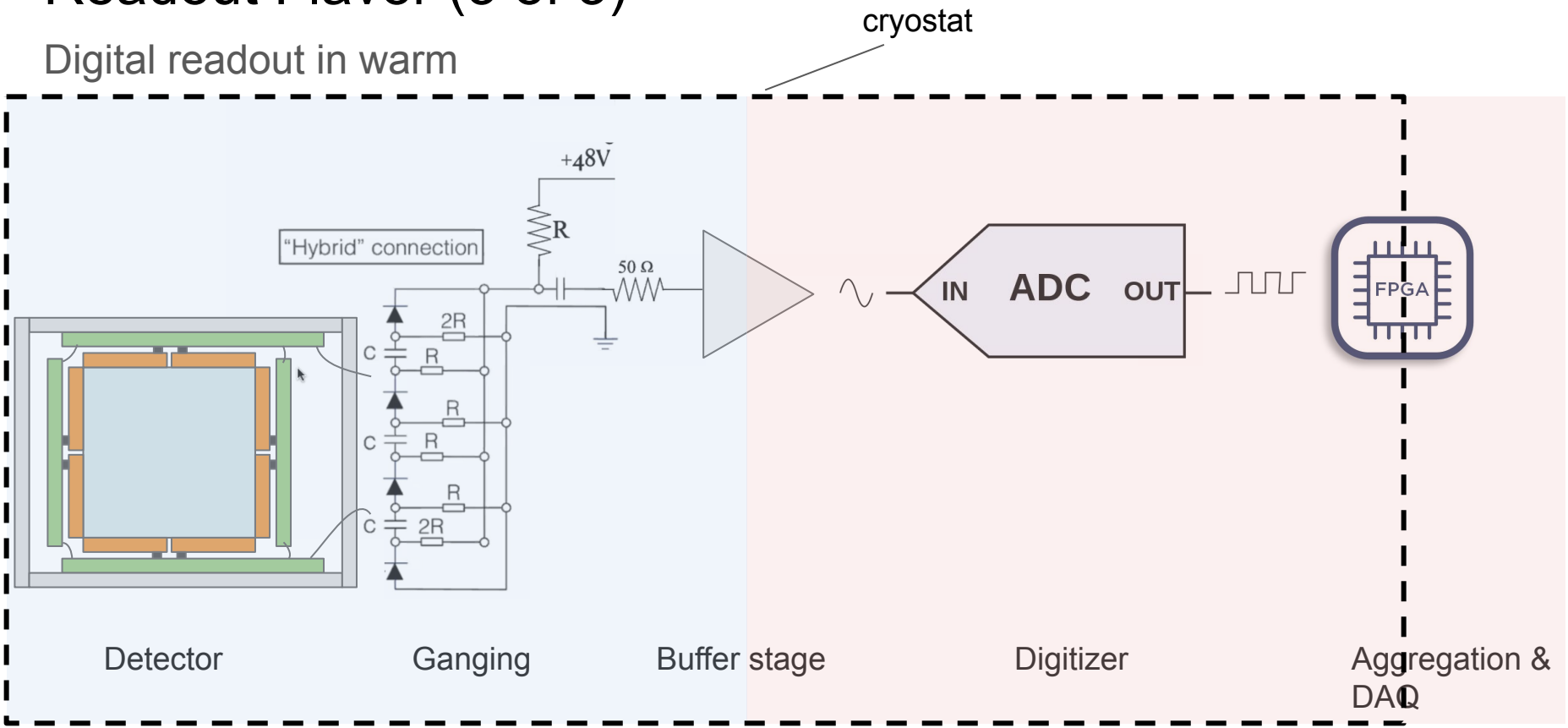
Readout Flavor (2 of 3)

Digital readout in cold



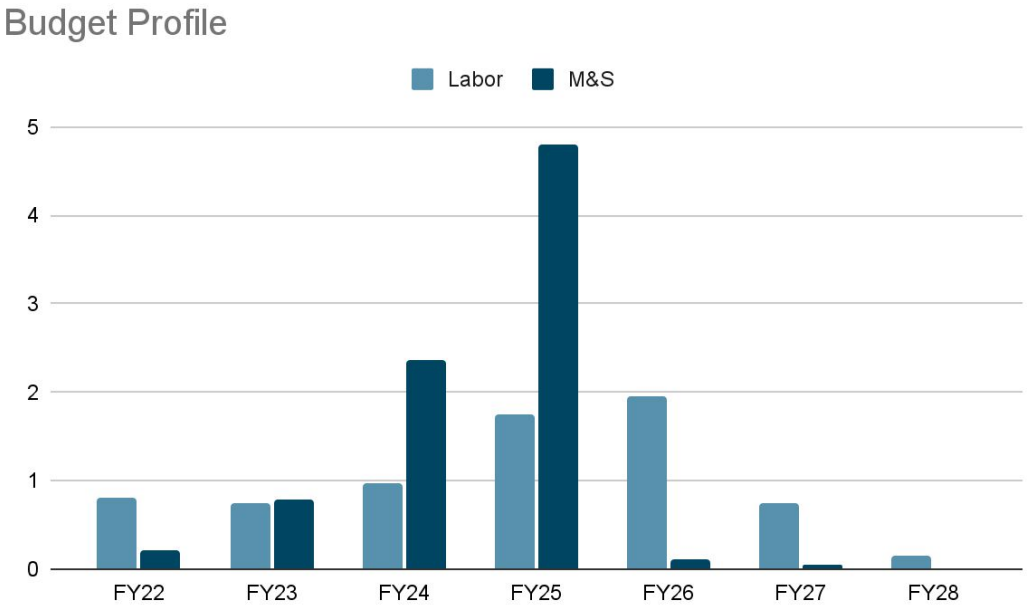
Readout Flavor (3 of 3)

Digital readout in warm



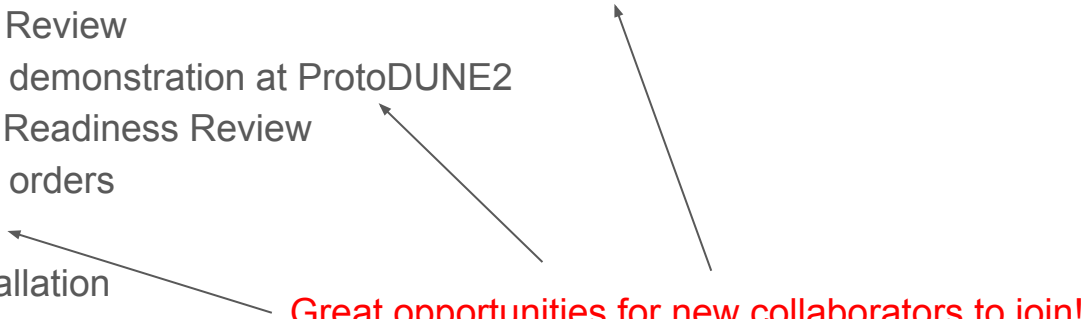
WBS

- We have full P6 schedule through commissioning in 2028
- 1:1 labor hour ratio for University:Lab



Schedule

- October 2021 and January 2022 Cold Box 1 & 2 demonstrations
- Spring 2022 Preliminary Design Review
- Summer and Fall 2022 Long-term qualification studies and Cold Box 3 & 4 demonstrations
- Early 2023 Final Design Review
- Summer 2023 module-0 demonstration at ProtoDUNE2
- End-of-2023 Production Readiness Review
- 2024 Launch production orders
- 2024-2026 Construction
- Fall 2026 Ready for installation
- 2027 Commissioning



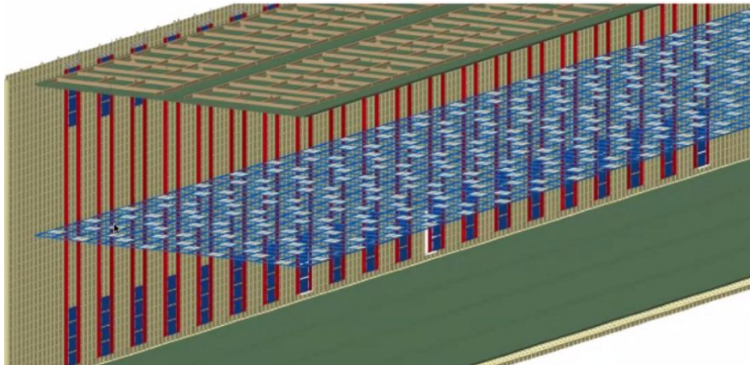
Demonstration Progression

- Cold Box 1
  - Goals: Cathode mounted detector module, power-over-fiber, analog readout
  - Stretch: Cryosub readout
- Cold Box 2
  - Improved Cathode mounted detector module, power-over-fiber, analog and digital/Cryosub readout
  - Membrane mounted detector module, power, readout.
  - DAQ integration
- Cold Box 3
  - Improved Cathode mounted detector module, power-over-fiber, analog and digital/Cryosub readout
  - Improved Membrane mounted detector module, power, readout.
  - “Field-cage” type module mounted on Cathode, with isolated readout
  - Improved DAQ integration
- Cold Box 4
  - Improved Cathode mounted detector module, power-over-fiber, analog and digital/Cryosub readout
  - Improved Membrane mounted detector module, power, readout.
  - Improved “Field-cage” type module mounted on Cathode, with isolated readout
  - Improved DAQ integration
- ProtoDUNE2 module-0
  - 3 module types (Cathode, Field-cage, and Membrane), power-over-fibers, readout, DAQ integration
  - Study Field-Cage occlusion for Membrane module type

Risks

Type	Title	Cathode Point Estimate	40%-Membrane Point Estimate	Probability	Expected Value
Threat	Insufficient Power-over-Fiber efficiency	$ 400,000	$ -	35%	$ 140,000
Threat	Insufficient Data Compression achieved before cold waveform SERDES	$ -	$ -	35%	$ -
Threat	Physics simulation shows additional detector coverage required	$ 1,000,000	$ 1,000,000	35%	$ 700,000
Threat	Detector less efficient than estimated	$ 500,000	$ 50,000	35%	$ 192,500
Opportunity	Commodity prices decrease	$ 80,000	$ 80,000	20%	$ (32,000)
Threat	Commodity prices escalate faster than inflation	$ 80,000	$ 80,000	20%	$ 32,000
Opportunity	Insulation solution allows for warm electronics in cryostat	$ 500,000	$ -	20%	$ (100,000)
Threat	Components fail 30-year cold validation testing	$ 1,000,000	$ 500,000	35%	$ 525,000
Threat	Underestimate in level of effort required for 30-year cold validation	$ 1,000,000	$ 500,000	35%	$ 525,000
Threat	Production mechanical packaging costs exceed estimated cost	$ 80,000	$ -	50%	$ 40,000
Threat	Production assembly support M&S costs exceed estimated cost	$ 80,000	$ -	35%	$ 28,000
Threat	Production installation costs require additional costed technician labor	$ 500,000	$ 250,000	35%	$ 262,500
Threat	Cathode plane HV potential variation requires modifications to power distribution	$ 2,000,000	$ -	35%	$ 700,000
Threat	Photon detector electronics generates noise on the TPC wire readout	$ 100,000	$ 200,000	20%	$ 60,000
Opportunity	Additional collaborating funding agencies identified	$ 2,000,000	$ 2,000,000	35%	$ (1,400,000)
			Cathode Risk Total:		$ 1,673,000

Baseline Estimates



- **Cathode(analog) + 40%-Membrane**
  - $3.5M detector + $2M electronics +
  - $5M labor + $1.5M non-labor = $12.0M
- Membrane only
  - $3.7M detector + $2M electronics + $5M labor + $1.5M non-labor = $12.2M
- Cathode(analog) + 25%-Field Cage(analog)
  - $2.8M detector + $2M electronics + $5M labor + $1.5M non-labor = $11.5M
- Cathode(1/36 digital) + 25%-Field Cage(1/36 digital)
  - $2.8M detector + $1M electronics + $5M labor + $1.5M non-labor = $10.5M

Cathode(analog) + 40%-Membrane(analog)

- Detector:
  - 288 Membrane, 160 SiPMs, 60cm x 60cm, $5.1K * 288 = $1.5M
  - 6.6% detector coverage, 0.044 SiPMs/cm2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 = $2.0M
  - 14.8% coverage, 0.044 SiPMs/cm2
- Cold Electronics + Power-over-Fiber:
  - 1 CE box per 4 PD modules = $0.5M membrane + $0.9M cathode = $1.5M
  - 0.1 kW membrane + 0.2 kW cathode = 0.3 kW
- Warm Electronics:
  - $180K membrane + $60K cathode = $0.25M
- Total:
  - $3.5M detector + $2M electronics + $5M labor + $1.5M non-labor = $12.0M

Note: M&S is no overhead and no spares. Labor is fully-loaded.

Membrane(analog) Only

- Detector:
  - Qty. 720, 160 SiPMs, 60cm x 60cm, $5.1K * 720 = $3.7M
  - 16.6% detector coverage, 0.044 SiPMs/cm2
- Cold Electronics:
  - 1 CE box per 4 PD modules = $1.4M
  - 0.2 kW
- Warm Electronics:
  - $135K digitizer + $285 power supplies = $420K
- Total:
  - $3.7M detector + $2M electronics + $5M labor + $1.5M non-labor = $12.2M

Note: M&S is no overhead and no spares. Labor is fully-loaded.

Cathode(analog) + 25%-Field Cage(analog)

- Detector:
  - 192 Field Cage, 90 SiPMs, 60cm x 60cm, $4K * 192 = $0.78M
  - 3.7% detector coverage, 0.025 SiPMs/cm2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 = $2.0M
  - 14.8% coverage, 0.044 SiPMs/cm2
- Cold Electronics + Power-over-Fiber:
  - 1 CE box per 4 PD modules = $0.5M field-cage + $0.9M cathode = $1.5M
  - 0.1 kW field-cage + 0.2 kW cathode = 0.3 kW
- Warm Electronics:
  - $120K field-cage + $60K cathode = $0.18M
- Total:
  - $2.8M detector + $2M electronics + $5M labor + $1.5M non-labor = $11.5M

Note: M&S is no overhead and no spares. Labor is fully-loaded.

Cathode(digital) + 25%-Field Cage(digital)

- Detector:
  - 192 Field Cage, 90 SiPMs, 60cm x 60cm, $4K * 192 = $0.78M
  - 3.7% detector coverage, 0.025 SiPMs/cm2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 = $2.0M
  - 14.8% coverage, 0.044 SiPMs/cm2
- Cold Electronics + Power-over-Fiber:
  - 1 CE box per 36 PD modules = $0.25M field-cage + $0.4M cathode = $0.65M
  - 0.05 kW field-cage + 0.15 kW cathode = 0.2 kW
- Warm Electronics:
  - $120K field-cage + $60K cathode = $0.18M
- Total:
  - $2.8M detector + $1M electronics + $5M labor + $1.5M non-labor = $10.5M

Note: M&S is no overhead and no spares. Labor is fully-loaded.

Timeline Summary

- There will be key decision points for baseline changes to mitigate risk, meet physics requirements, or reduce topology cost before launching production.
  - October 2021 and January 2022 Cold Box 1 & 2 demonstrations
  - Spring 2022 Preliminary Design Review
  - Summer and Fall 2022 Long-term qualification studies
  - Early 2023 Final Design Review
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