DUNE FD-2 PDS Baseline WBS Sketch

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Membrane Only

- Detector:
  - Qty. 720, 160 SiPMs, 60cm x 60cm, $5.1K * 720 **= $3.7M**
  - 16.6% detector coverage, 0.044 SiPMs/cm^2
- Cold Electronics:
  - 1 CE box per 4 tiles **= $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) + 40%-Membrane

- Detector:
  - 288 Membrane, 160 SiPMs, 60cm x 60cm, $5.1K * 288 **= $1.5M**
  - 6.6% detector coverage, 0.044 SiPMs/cm^2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 **= $2.0M**
  - 14.8% coverage, 0.044 SiPMs/cm^2
- Cold Electronics + PoF:
  - 1 CE box per 4 tiles **= $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.

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/cm^2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 **= $2.0M**
  - 14.8% coverage, 0.044 SiPMs/cm^2
- Cold Electronics + PoF:
  - 1 CE box per 4 tiles **= $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/cm^2
  - 320 Cathode, 160 SiPMs, 60cm x 60cm, $6.2K * 320 **= $2.0M**
  - 14.8% coverage, 0.044 SiPMs/cm^2
- Cold Electronics + PoF:
  - 1 CE box per 36 tiles **= $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.

One Week Ago Slides

Approach to M&S Estimates

- Steps:
  1. Considered detector tile types
  2. Considered cold electronics + power supply topologies
  3. Tallied up warm electronics implications

- Note: no overhead and no spares considered on M&S
- We think component prices are +/- 20%

Outline

- Approach to M&S estimates
- Approach to labor estimates
- Baseline proposal
- Risk assessment
- 2021 R&D strategy

Approach to M&S - Detector

- **Five** Detector tiles considered:
  1. "**high-efficiency Cathode**" tile
     - Qty. 320, 360 SiPMs, 3 x 20cm x 60cm, $10.8K * 320 **= $3.5M**
     - 14.8% coverage, 0.1 SiPMs/cm^2, relative efficiency-factor=1
  2. "**economic Cathode**" tile
     - Qty. 320, 160 SiPMs, 60cm x 60cm, $6.2K * 320 **= $2.0M**
     - 14.8% coverage, 0.044 SiPMs/cm^2, relative efficiency-factor=0.9
  3. "**economic Field Cage**" tile
     - Qty. 768, 90 SiPMs, 60cm x 60cm, $4K * 768 **= $3.1M**
     - 14.6% detector coverage, 0.025 SiPMs/cm^2
  4. "**horizontal-drift Membrane**" tile
     - Qty. 6000, 48 SiPMs, 40cm x 10cm, $1.2K * 6000 **= $7.1M**
     - 15.4% detector coverage, 0.12 SiPMs/cm^2
  5. "**economic Membrane**" tile
     - Qty. 800, 160 SiPMs, 60cm x 60cm, $6.2K * 800 **= $5.0M**
     - 18.5% detector coverage, 0.044 SiPMs/cm^2

Approach to M&S – Cold Electronics + POF

- **Four** parameterized approaches considered:
  1. "**redundant digital**" approach
     - 1 CE box per tile, $3.0M C. + $7.2M FC. **= $10.2M**
     - 1.9 kW C. + 4.5 kW FC. = **6.4 kW**
  2. "**economic digital**" approach
     - 1 CE box per 4 tiles, $1.1M C. + $2.6M FC. **= $3.7M**
     - 1.1 kW C. + 2.6 kW FC. = **3.7 kW**
  3. "**economic analog**" approach
     - 1 CE box per 4 tiles, $0.9M C. + $2.1M FC. **= $2.9M**
     - 0.2 kW C. + 0.4 kW FC. = **0.6 kW**
  4. "**horizontal-drift-style Membrane**" approach
     - 1 CE box per 4 tiles **= $1.4M**
     - **0.2 kW**

Note – Reduced Field Cage

- **Note:** Field Cage M&S can be reduced by eliminating tiles (1/2, 1/4 considered). We have assumed 768 tiles over 8 rows (4 above & below cathode).
  - If we assume 2 rows above & below…
    - 384 tiles
    - Cold electronics + POF M&S = $1.0M FC.
    - 0.22 kW FC.
  - If we assume 1 row above & below…
    - 192 tiles
    - Cold electronics + POF M&S = $0.52M FC.
    - 0.11 kW FC.

Note – Cold Electronics + POF

- **Note:** digital cold electronics cost (and thus power) can always be reduced in exchange for lower sampling/bit rate **and** longer analog signal runs. We have assumed 14-bits @ 80Msps and 1m runs.
  - If we assume <4m analog runs & ½ digitizer data-rate…
    - 1 CE box per 20 tiles, 16 FPGAs
    - $0.5M C. + $1.2M FC. = **$1.7M**
    - 0.3 kW C. + 0.6 kW FC. = **0.9 kW**

  - If we assume <6m analog runs & ¼ digitizer data-rate…
    - 1 CE box per 36 tiles, 9 FPGAs
    - $0.4M C. + $0.9M FC. = **$1.3M**
    - 0.15 kW C. + 0.36 kW FC. = **0.5 kW**

Approach to M&S – Warm Electronics

- Assume $5K board for each 12 CE boxes and $25K crate for each 12 boards:
  1. "**redundant digital**" approach
     - $210K C. + $470K FC. **= $700K**
  2. "**economic digital**" approach
     - $60K C. + $130K FC. **= $200K**
  3. "**economic analog**" approach
     - $60K C. + $130K FC. **= $200K**
  4. "**horizontal-drift-style Membrane**" approach
     - $135K digitizer + $285 power supplies **= $420K**

Approach to M&S – Totals

- Added horizontal-drift style calibration/monitoring system:
  1. "**redundant digital**" approach
     - $7.0M C. + $11.0M FC. **= $18.0M**
  2. "**economic digital**" approach
     - $3.5M C. + $6.0M FC. **= $9.5M**
  3. "**economic analog**" approach
     - $3.3M C. + $5.6M FC. **= $9.0M**
  4. "**horizontal-drift-style Membrane**" approach
     - $5.0M detector + $2.0M electronics **= $7.0M**
- **Note:** numbers are no overhead and no spares

Approach to Labor Estimates

- Phases from FY22 to FY28
  - Based on fully-loaded FY21 labor rates, no escalation
  - FY22/23: "**prototype**" long-term cold validation and QA/QC
  - FY23: 1/20th "**pilot**" module-0 @ ProtoDUNE 2
  - FY24-28: "**production**"
    - Production hours scaled by number of tiles
    - 2:1 labor hour ratio for University:Lab
    - No assumed international collaborators (rather in threat/opportunities)

1. "**redundant digital**" approach
   - 55k + 30K hours ➔ $3.2M Pr&Pi&C. + $2.1M FC. **= $5.3M**
2. "**economic digital**" approach
   - 55k + 30K hours ➔ $3.2M Pr&Pi&C. + $2.1M FC. **= $5.3M**
3. "**economic analog**" approach
   - 55k + 30K hours ➔ $3.2M Pr&Pi&C. + $2.1M FC. **= $5.3M**
4. "**horizontal-drift-style Membrane**" approach
   - 80K hours **= $5.0M**

FY22-28 WBS Estimates

1. “**redundant digital**” approach
   - $3.2M C. labor + $9.1M C. non-labor **= $12.3M**
   - $5.3M C.&FC. labor + $20.4M C.&FC. non-labor **= $25.7M**
2. “**economic digital**” approach
   - $3.2M C. labor + $5.6M C. non-labor **= $8.9M**
   - $5.3M C.&FC. labor + $11.9M C.&FC. non-labor **= $17.2M**
3. “**economic analog**” approach
   - $3.2M C. labor + $5.4M C. non-labor **= $8.7M**
   - $5.3M C.&FC. labor + $11.4M C.&FC. non-labor **= $16.7M**
4. “**horizontal-drift-style Membrane**” approach
   - $4.9M labor + $8.2M non-labor **= $13.1M**

FY22-28 WBS Baseline Proposal

1. "**redundant digital**" approach
   - $3.2M C. labor + $9.1M C. non-labor **= $12.3M**
   - $5.3M C.&FC. labor + $20.4M C.&FC. non-labor **= $25.7M**
2. "**economic digital**" approach
   - $3.2M C. labor + $5.6M C. non-labor **= $8.9M**
   - $5.3M C.&FC. labor + $11.9M C.&FC. non-labor **= $17.2M**
3. "**economic analog**" approach
   - $3.2M C. labor + $5.4M C. non-labor **= $8.7M**
   - $5.3M C.&FC. labor + $11.4M C.&FC. non-labor **= $16.7M**
4. "**horizontal-drift-style Membrane**" approach
   - $4.9M labor + $8.2M non-labor **= $13.1M**

FY22-28 WBS Risks

Type	Title	Cathode Point Estimate	FC Point Estimate	Probability
Threat	Insufficient Power-over-Fiber efficiency	$413,404	$992,171	35%
Threat	Insufficient Data Compression achieved before cold waveform SERDES	$1,309,404	$3,142,571	35%
Threat	Physics simulation shows additional detector coverage required	$1,506,033	$3,614,480	35%
Opportunity	Commodity prices decrease	$85,851	$206,042	20%
Threat	Commodity prices escalate faster than inflation	$85,851	$206,042	20%
Opportunity	Insulation solution allows for warm electronics in cryostat	$1,309,404	$3,142,571	20%
Threat	Components fail 30-year cold validation testing	$1,000,000	$500,000	20%
Threat	Production mechanical packaging costs exceed estimated cost	$80,000	$192,000	50%
Threat	Production assembly support M&S costs exceed estimated cost	$80,000	$192,000	35%
Threat	Production installation costs require additional costed technician labor	$565,611	$1,357,466	35%
Threat	Photon detector electronics generates noise on the TPC wire readout	$500,000	$500,000	20%
Opportunity	Additional collaborating funding agencies identified	$2,000,000	$2,000,000	35%

FY22-28 WBS Risk Assessment

1. "**redundant digital**" approach relative risk 100%
   - Cathode-only risk expected value = **$2.4M**
   - Cathode & Field Cage risk expected value = **$7.5M**
2. "**economic digital**" approach relative risk 100%
   - Cathode-only risk expected value = **$1.3M**
   - Cathode & Field Cage risk expected value = **$4.3M**
3. "**economic analog**" approach relative risk 80%
   - Cathode-only risk expected value = **$1.2M**
   - Cathode & Field Cage risk expected value = **$3.0M**
4. "**horizontal-drift-style Membrane**" approach relative risk 70%
   - Membrane-only risk expected value = **$3.0M**

2021 R&D

2021 R&D Strategy

- Target **two** prototype detector tiles for CERN cold box test:
  - Each 160 SiPMs 60x60cm^2; one SiPM vendor for each
- Target **three** prototype cold-electronics approaches:
  1. "**Cold analog**" approach
     - 80 SiPMs passive-ganging => 1 and/or 2 active-ganged analog waveforms
  2. "**Cold digital**" approach
     - 80 SiPMs passive-ganging => 2 active-ganged digitized waveforms
     - 14-bits @ 80Msps
  3. "**Insulated digital**" approach
     - 80 SiPMs passive-ganging => 2 active-ganged digitized waveforms
     - 280K thermostat. 14-bits @ 80Msps

2021 R&D Component Strategy

- Team of experts launched on each component:
  - xARAPUCA
  - Passive Gang
  - Active Gang
  - Digital Tx
  - Power Solutions
  - Analog Tx
  - SERDES / FPGA
  - ADC
  - Control Rx
  - Sync Distribution

- Short-term cold tests and prototype integration steps planned
- Leaving for FY22…
  - Packaging optimization
  - Power consumption optimization
  - Long-term (30-year) cold studies

2021 R&D Milestone Timeline

Activity			FY21								FY22			
Subsystem or Task	Activity	Notes	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Project Management														
===>	Minor Milestone:	Select Control Rx Phase 1 candidate(s). Target 1 candidate.			X									
===>	Minor Milestone:	Select Control Rx Phase 2 candidate(s). Target 1 candidate.				X								
===>	Minor Milestone:	Select Control Rx Phase 3 candidate(s). Target 1 candidate.					X							
===>	Milestone:	Select Control Rx Prototype final candidate.					X							
===>	Minor Milestone:	Select Sync Distribution Phase 1 candidate(s). Target 1 candidate.				X								
===>	Minor Milestone:	Select Sync Distribution Phase 2 candidate(s). Target 1 candidate.					X							
===>	Minor Milestone:	Select Sync Distribution Phase 3 candidate(s). Target 1 candidate.						X						
===>	Milestone:	Select Sync Distribution Prototype final candidate.						X						
===>	Minor Milestone:	Select Analog/Digital Waveform Optical Tx Phase 1 candidate(s). Target 1 candidate.		X										
===>	Minor Milestone:	Select Analog/Digital Waveform Optical Tx Phase 2 candidate(s). Target 1 candidate.			X									
===>	Minor Milestone:	Select Analog/Digital Waveform Optical Tx Phase 3 candidate(s). Target 1 candidate.				X								
===>	Minor Milestone:	Select SERDES Phase 1 candidate(s). Target 1 candidate.		X										
===>	Minor Milestone:	Select SERDES Phase 2 candidate(s). Target 1 candidate.			X									
===>	Minor Milestone:	Select SERDES Phase 3 candidate(s). Target 1 candidate.				X								
===>	Minor Milestone:	Select ADC Phase 1 candidate(s). Target 1 candidate.		X										
===>	Minor Milestone:	Select ADC Phase 2 candidate(s). Target 1 candidate.			X									
===>	Minor Milestone:	Select ADC Phase 3 candidate(s). Target 1 candidate.				X								
===>	Major Milestone:	Pair-wise integration of most promising phase 1 candidate components and Power-over-fiber.				X								
===>	Milestone:	Analog Front-end integration Prototype in cold validated.					X							
===>	Milestone:	SERDES Tx integration Prototype in cold validated.					X							
===>	Milestone:	SERDES Rx integration Prototype in cold validated.					X							
===>	Major Milestone:	Downselect ADC/SERDES/digital Tx or analog Tx Prototype final candidate.					X							
===>	Major Milestone:	ADC+SERDES+Optical Rx/Tx integration Prototype **OR** Analog Optical Tx integration Prototype in cold validated.						X						
===>	Milestone:	1-channel waveform readout integration Prototype in cold validated.						X						
===>	Major Milestone:	Full modules waveform readout integration Prototype in cold validated.							X					
===>	Major Milestone:	Two synchronized integration Prototype modules in cold validated.							X					
===>	Milestone:	Two synchronized integration Prototype modules in cold <10KV plane validated. Or documented as not needed.							X					
===>	Major Milestone:	Two Prototype v1 modules installed at CERN Cold Box Test Part-A.								X				
===>	Major Milestone:	Two Prototype v2 modules installed at CERN Cold Box Test Part-B.										X		
===>	Major Milestone:	Synchronized waveform readout of two Prototype modes in CERN Cold Box Test.										X		

2021 R&D WBS

- Estimate through CERN Cold Box Test (i.e. FY21-22)
  - Labor = $850K
  - Non-labor = $190K
  - Total = $1M
- 1:1 labor hour ratio for University:Lab
- Starting BCR process this week with Janet