WBS 1.02: Detector Components

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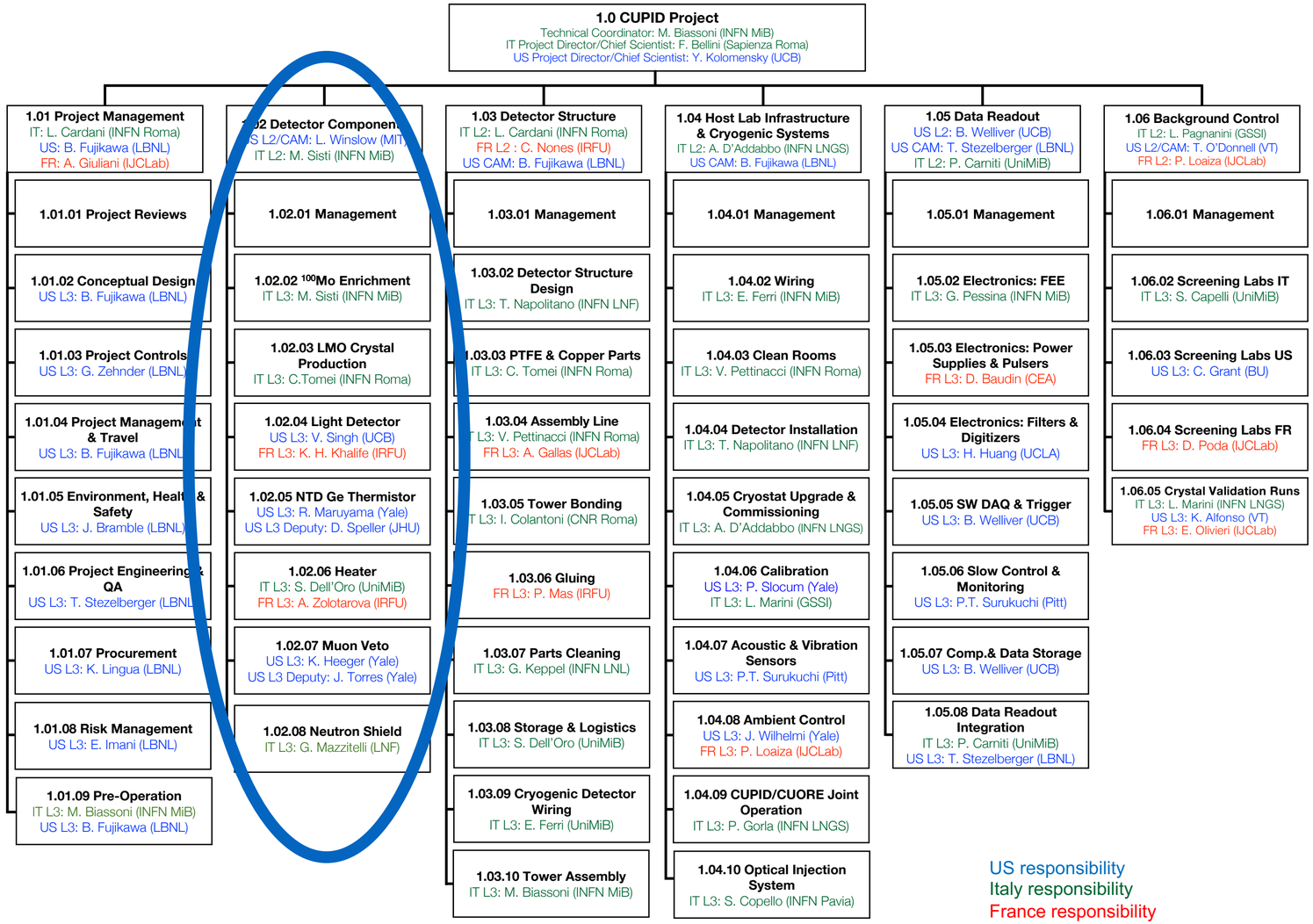
MIT

CUPID LBNL Project Review
December 16-17, 2024

Outline

- Overview
- Requirements
- Technical Readiness of subsystems
- Risks
- Interface with other subsystems
- Cost & Schedule
- Summary

WBS 1.02: Overview



US responsibility
Italy responsibility
France responsibility

L3 first name: primary responsibility
L3 second name: secondary responsibility

1.02 Detector Components
US L2/CAM: L. Winslow (MIT)
IT L2: M. Sisti (INFN MiB)

1.02.01 Management

1.02.02 ^{100}Mo Enrichment
IT L3: M. Sisti (INFN MiB)

1.02.03 LMO Crystal Production
IT L3: C.Tomei (INFN Roma)

1.02.04 Light Detector
US L3: V. Singh (UCB)
FR L3: K. H. Khalife (IRFU)

1.02.05 NTD Ge Thermistor
US L3: R. Maruyama (Yale)
US L3 Deputy: D. Speller (JHU)

1.02.06 Heater
IT L3: S. Dell'Oro (UniMiB)
FR L3: A. Zolotarova (IRFU)

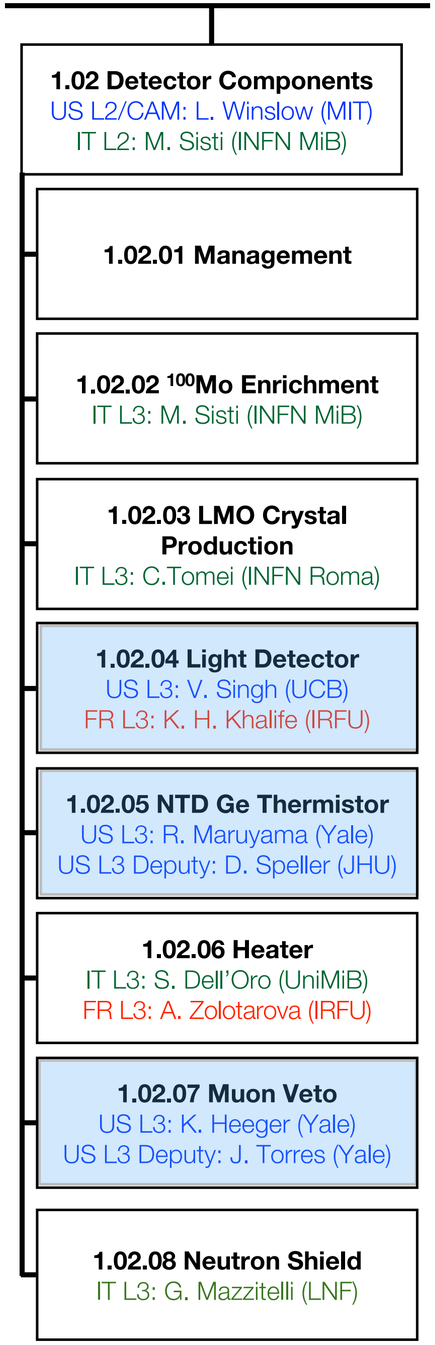
1.02.07 Muon Veto
US L3: K. Heeger (Yale)
US L3 Deputy: J. Torres (Yale)

1.02.08 Neutron Shield
IT L3: G. Mazzitelli (LNF)

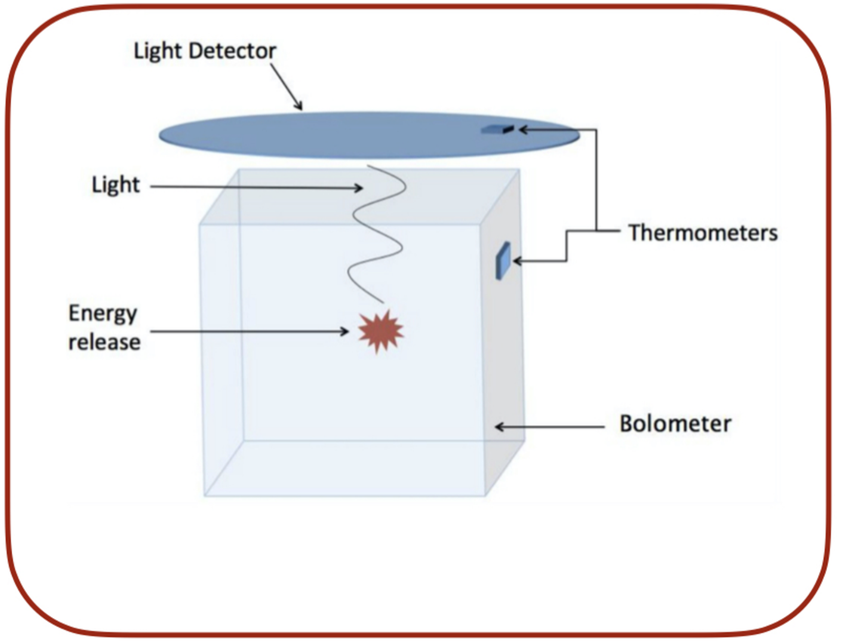
Contain US Project Scope

WBS 1.02: Overview

- The Detector Components are procured or fabricated and then assembled, installed and readout in WBS 1.03,04,05 with 1.06 managing backgrounds.
- Light detectors are the largest US activity in this WBS and are the new technology for CUPID, so will be covered in a devoted talk.



WBS 1.02.05 NTDs: Requirements



- NTDs produced in 1.02.05 are the “Thermometers” for both the Light Detector and main LMO crystal.

  $\eta = dLog(R0) / dLog(T0)$

Requirement	Value	WBS Level	Involved Subsystems	Science Requirement
NTD η LMO	0.5-3.0	3	1.02.05 (NTD)	Energy resolution 5 keV @ Qbb
NTD η Light Detectors	0.5-3.0	3	1.02.05 (NTD)	Energy resolution 5 keV @ Qbb

WBS 1.02.05 NTDs: Technical Specifications

- To meet the requirements for 1.02.05, the design has the following technical specifications.

Technical Specification	Value	Note
NTDs for LMO	2260	
NTDs for Light Detectors	2410	
NTDs for Thermometry	180	
LMO NTD Size	3 mm × 3 mm × 1 mm	
Light Detector NTD Size	3 mm × 1 mm × 1 mm	
LMO Contact Type	Wraparound	
Light Detector Contact Type	Wraparound	
LMO Target fluency	4.13×10^{18} n/cm^2	
Light Detector Target fluency	4.21×10^{18} n/cm^2	

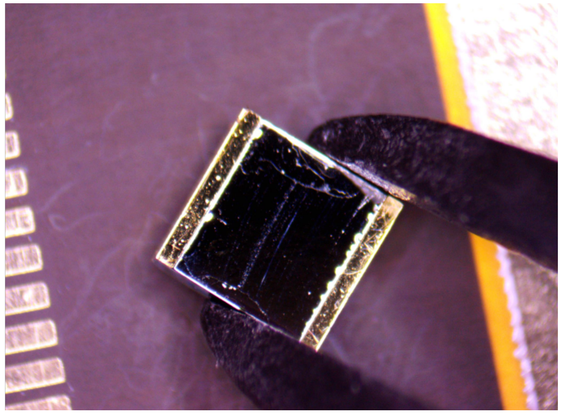
WBS 1.02.05 NTDs: KPPs

- This is the Key Performance Parameter for the NTDs.

Description	Threshold	Objective
WBS 1.02.05 - NTD Thermistors	Delivery to LNGS of required set of NTDs meeting or exceeding technical requirements as demonstrated on a 5% sample of delivered sensors	Delivery to LNGS of required set of NTDs meeting or exceeding technical requirements as demonstrated on a 30% sample of delivered sensors

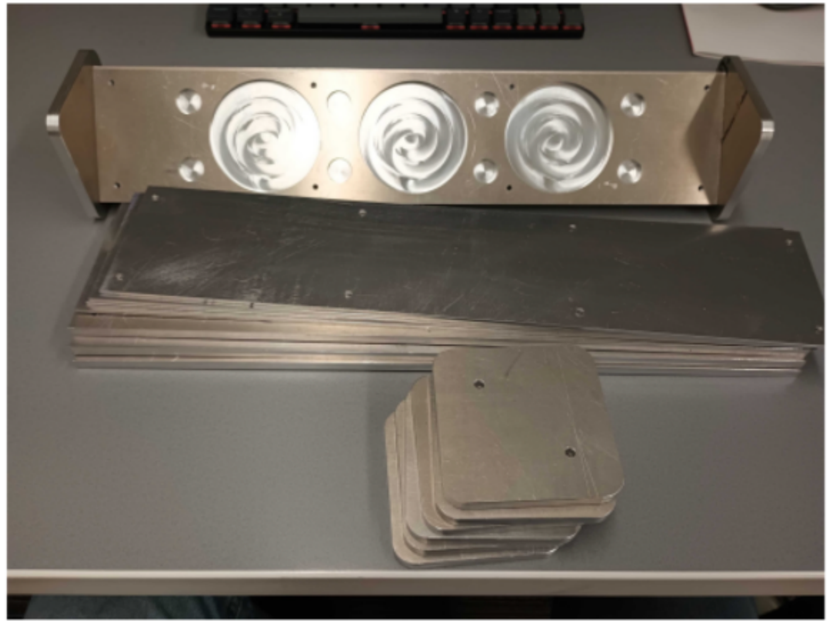
WBS 1.02.05 NTDs: Conceptual Design

- Neutron transmutation doped Germanium thermistors have been used for decades.
- Highly homogeneous p-typed doped semiconductor with resistivity tuned by neutron irradiation.
- The current LMO NTD design is highly mature and is from CUORE, the LD geometry has been optimized in demonstrator scale experiments and dedicated tests.



WBS 1.02.05 NTDs: Required R&D

- The production of the raw material will start as pre-project R&D.
- A “foil” only calibration run is about to start (December 2024). This will be followed by irradiation of germanium which can be fabricated into test devices.
- This burns down the remaining risk for 1.02.05.



WBS 1.02.05 NTDs: Risks

- Risks identified and put into risk registry with mitigation strategies suggested
- Most risks are associated with equipment, facility and people availability.
- Cost, Schedule Contingency are sufficient to cover the risks and uncertainty at this stage of the project

Risk ID	L2	L3	Description	Consequence	Likelihood	Cost Impact	Schedule Impact	Technical Scope	Impact Ranking	Mitigation
302050014	2	5	Fab Availability/ Loss of personnel at LBL	Production of NTDs significantly delayed or will need to be taken up by a new entity; CUORE-style production may become hard to replicate	Likely	Significant (S)	Critical (C)	Critical (C)	Critical (C)	Identify & train additional experts; find and archive documentation on CUORE NTD production
302050012	2	5	E-Beam downtime	Delays in NTD production	Likely	Significant (S)	Critical (C)	Critical (C)	Critical (C)	Regular maintenance; identify replacement if needed; identify possible substitute/shared equipment

WBS 1.02.05 NTDs: Interfaces

- Interface Control Documents started
- Keeps track of various interfaces between subsystems
- L2 manager responsible for top level document and delegate to L3 as appropriate

Interface	Description
Light Detectors (WBS 1.02.04)	Captures the sensors for the light detectors.
Tower Bonding and Gluing (WBS 1.03.05 & WBS 1.03.06)	Captures the gluing and connection of the NTDs to the LMO crystals and the light detectors.
Storage and Logistics (WBS 1.03.08)	Captures the delivery of the NTDs to LNGS
Tower Assembly (WBS 1.03.10)	Captures the delivery of NTDs for cryostat thermometry.
Electronics and FEE (WBS 1.05.02)	Captures FEE needed for NTD test facilities
CCVR Runs (WBS 1.06.05)	Captures NTDs needed for crystal validation runs

WBS 1.02.07 Muon Veto: Requirements

- The muon veto requirements flow down directly by the background budget of the experiment and need to be negligible relative to the other backgrounds.

Requirement	Value	WBS Level	Involved Subsystems	Science Requirement
Muon Veto Efficiency	>94%	1	1.02.07 (Muon Veto)	Background < 1e-4 ckky
Induced CUPID Deadtime	< 1%	3	1.02.07 (Muon Veto), 1.05.05 (DAQ)	Livetime (10 yr)
Muon Veto-to-Bolometer DAQ timing	< 0.1ms	3	1.02.07 (Muon Veto), 1.05.05 (DAQ)	Background < 1e-4 ckky
Aging Stability	> 10 years	3	1.02.07 (Muon Veto)	Livetime (10 yr)

WBS 1.02.07 Muon Veto: Technical Specifications

- To meet the requirements for 1.02.07, the design has the following technical specifications.

Technical Specification	Value	Note
Scintillator Panel Producer and Model	Eljen Technologies Model EJ-200	Model EJ-200
Panel Size	100 cm × 50 cm × 2.5 cm	
Muon Discrimination Efficiency per Module	> 99%	
Number of SiPMs per Module	2	

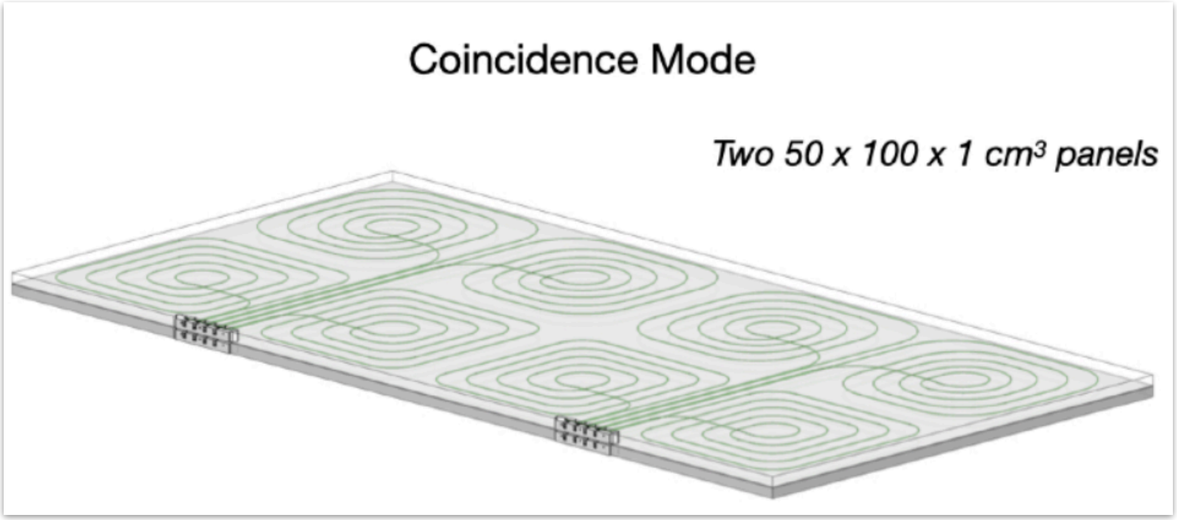
WBS 1.02.07 Muon Veto: KPPs

- This is the Key Performance Parameter for the muon veto.

Description	Threshold	Objective
WBS 1.02.07 - Muon Veto	Delivery to LNGS of Muon Veto System meeting or exceeding technical requirements as demonstrated on a 5% sample of delivered panels.	Delivery to LNGS of Muon Veto System meeting or exceeding technical requirements as demonstrated with a fully deployed system

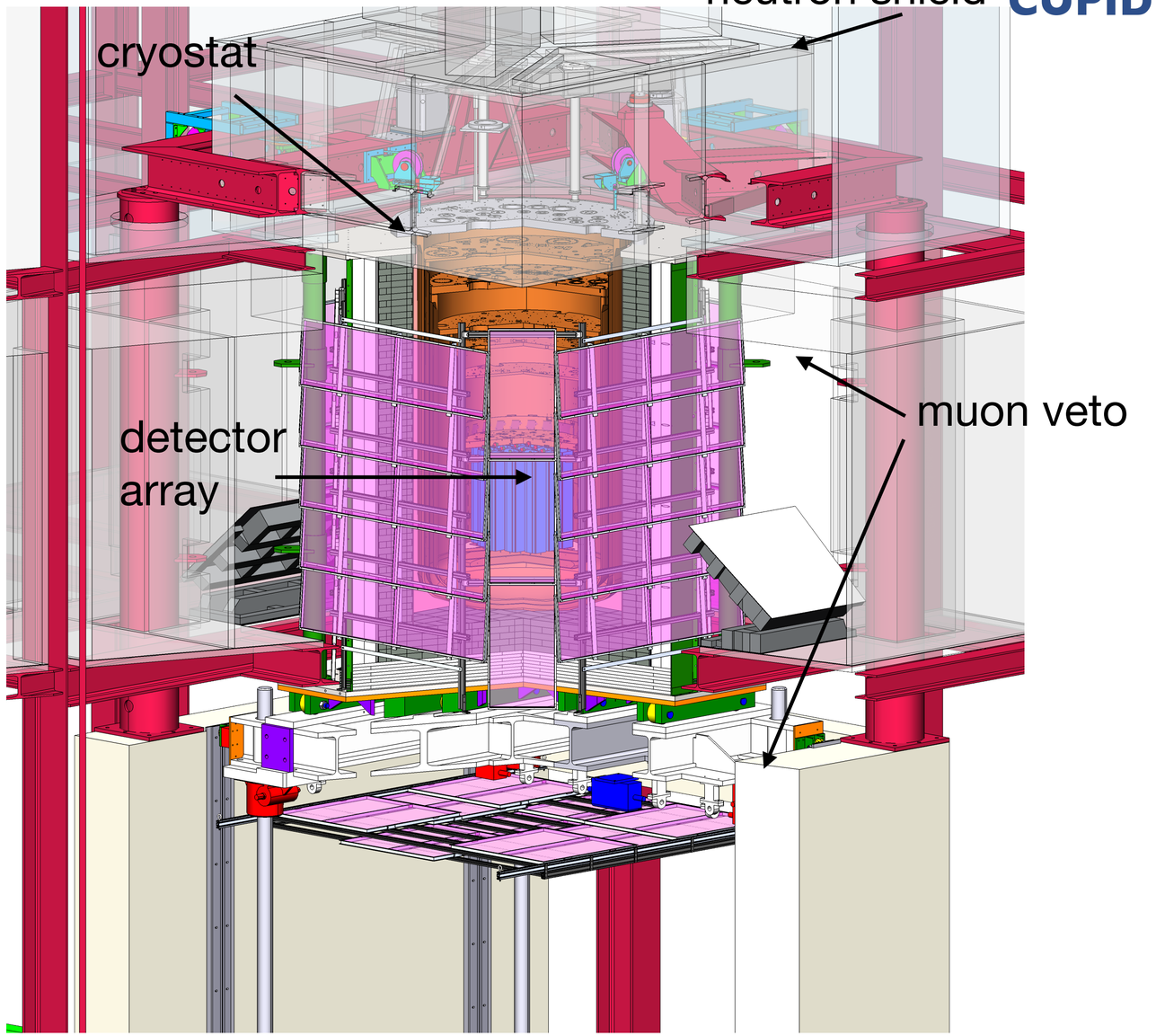
WBS 1.02.07 Muon Veto: Conceptual Design

- The design of the muon veto uses scintillator panel readout via wavelength shifting fibers coupled to SiPMs and off-the-shelf CAEN readout electronics.
- This design of muon veto has been deployed in many experiments and is a mature technology.



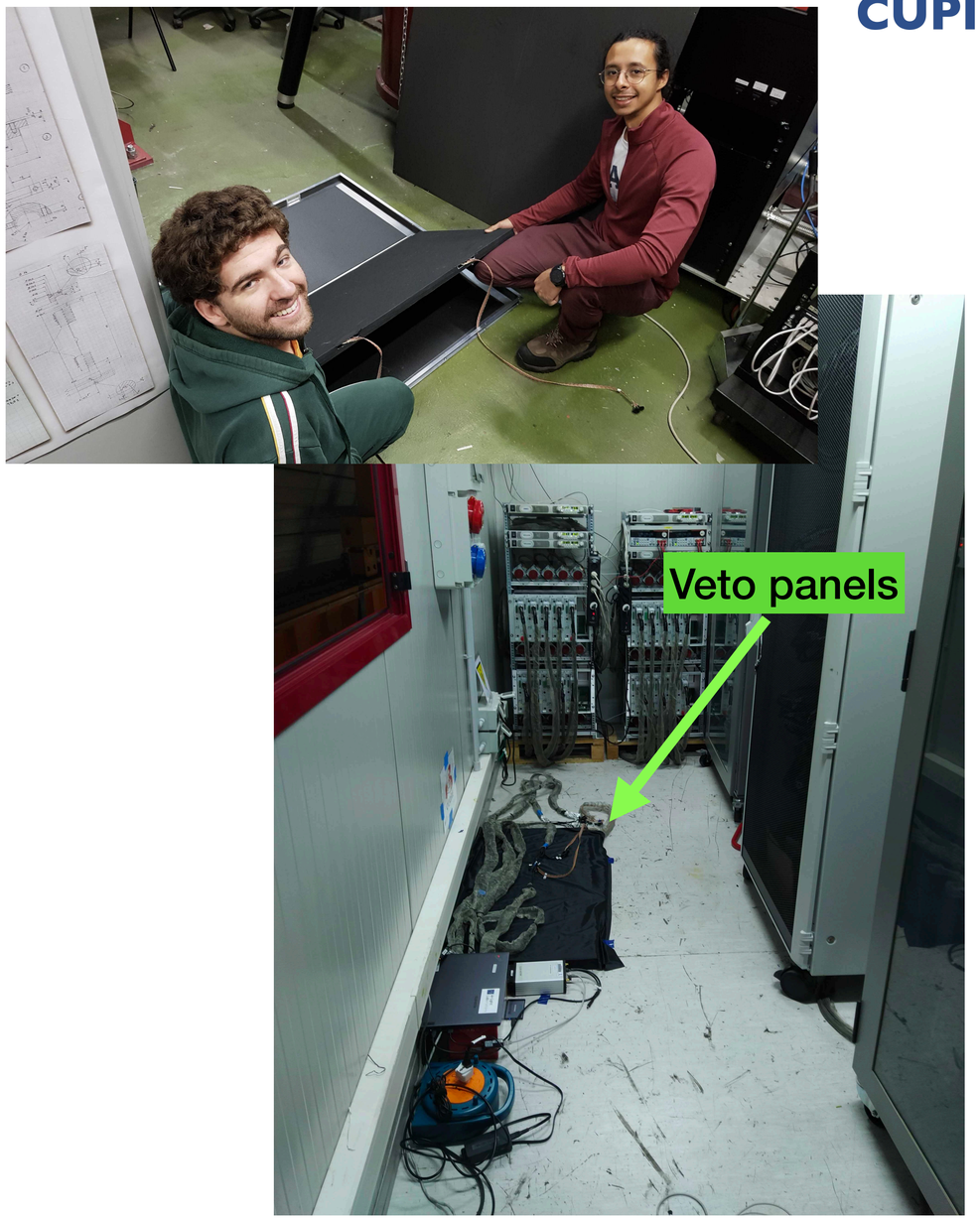
WBS 1.02.07 Muon Veto: Conceptual Design

- The design that meets the minimum muon veto efficiency is a configuration with lateral and bottom panels deployed outside of the cryostat.



WBS 1.02.07 Muon Veto: Required R&D

- The characterization of a panel underground for both robustness of operation and the characterization of the gamma background is ongoing.
- No further R&D is required.



WBS 1.02.07 Muon Veto: Risks

- Risks identified and put into risk registry with mitigation strategies suggested
- Most risks are associated with equipment, facility and people availability.
- Cost, Schedule Contingency are sufficient to cover the risks and uncertainty at this stage of the project

Risk ID	L2	L3	Description	Consequence	Likelihood	Cost Impact	Schedule Impact	Technical Scope	Impact Ranking	Mitigation
102070111	2	7	EM Noise Underground	Muon detection efficiency degraded.	Likely	Marginal (M)	Significant (S)	Marginal (M)	Significant (S)	Operation of test panel and standard noise mitigation strategies.
102070078	2	7	Loss of key expertise	Delays in design, production, and deployment.	Likely	Significant (S)	Marginal (M)		Marginal (M)	Train multiple experts. Ensure documentation of all aspects.

WBS 1.02.07 Muon Veto: Interfaces

- Interface Control Documents started
- Keeps track of various interfaces between subsystems
- L2 manager responsible for top level document and delegate to L3 as appropriate

Interface	Description
Parts Storage (WBS 1.03.08)	Captures need to deliver muon veto to LNGS.
Software DAQ (WBS 1.05.05)	Captures the required interface between the DAQ and the digitizers and other electronics.
Slow Control and Monitoring (WBS 1.05.06)	Capture the monitoring of the muon veto.
Computation and Data Storage (WBS 1.05.07)	Capture the storage of the data and its processing.

WBS 1.02 FY Budget Summary by Country (in $k)

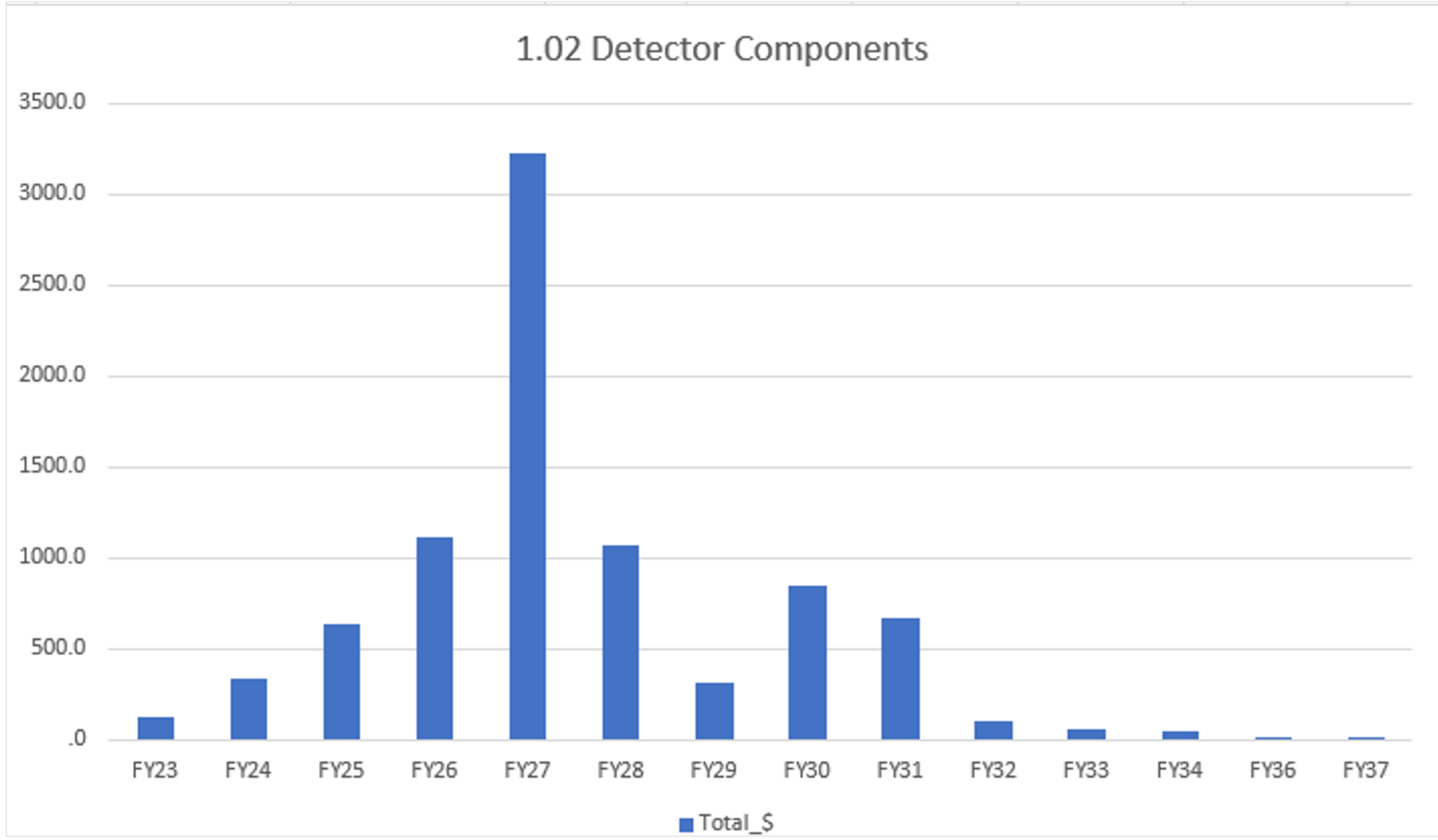
- Fully loaded resources for US costs
- IT and FR only M&S costs shown

Sum of Value	Column Labels														
	Total_$														Total_$ Total
Row Labels	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY36	FY37	
US		125.4	332.7	634.2	1109.0	3223.4	1073.8	316.0	844.5	663.2	101.4	59.0	50.6	16.2	7.7	8557.2
Phase 1		125.4	332.7	634.2	1109.0	3223.4	1073.8	299.5								6798.1
Phase 2								16.5	844.5	663.2	101.4	59.0	50.6	16.2	7.7	1759.2
IT	14.5	89.8	231.7	192.5		3748.2	6985.8	276.4	6241.6	9431.3	6093.9	222.9				33528.5
Phase 1	14.5	89.8	231.7	192.5		3748.2	6985.8	276.4								11538.8
Phase 2									6241.6	9431.3	6093.9	222.9				21989.7
FR			610.0	1057.7	125.7	18.2	118.8	2.0	169.0	5.0						2106.4
Phase 1			610.0	1057.7	125.7	18.2	118.8									1930.4
Phase 2								2.0	169.0	5.0						176.0
Grand Total	14.5	215.2	1174.4	1884.4	1234.7	6989.8	8178.3	594.3	7255.0	10099.6	6195.3	281.9	50.6	16.2	7.7	44192.1

WBS 1.02 US FY Budget Summary (in $k)

- Breakdown by FY in $k
- Costs reasonable for Staged deployment

Sum of Value	Column Labels
Row Labels	Total_$
Grand Total	8557.2



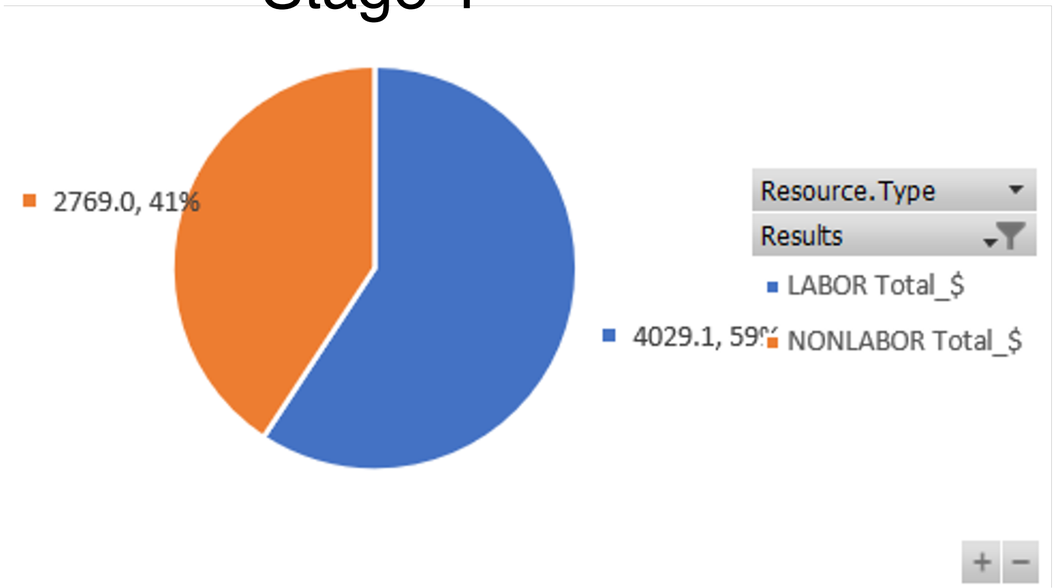
WBS 1.02 US Budget Breakdown (in $k)

- Breakdown by WBS and Stage
- Stage 1 requires muon veto and neutron shield in place.

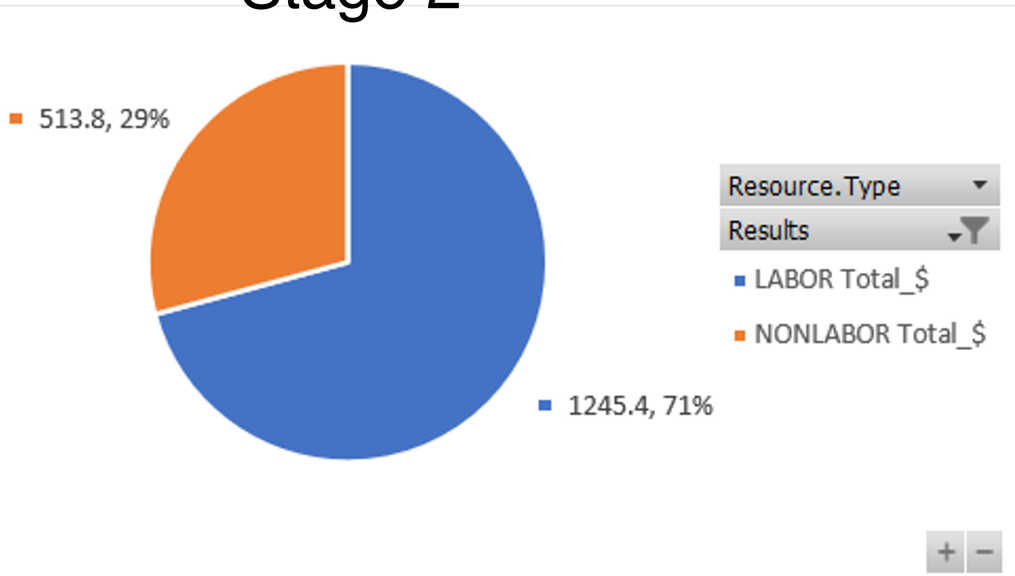
Sum of Value	Column Labels		
Row Labels	HOURS	DOLLARS	Total_$
US	65.5	2491.8	8557.2
Phase 1	53.7	2173.6	6798.1
1.02 Detector Components	53.7	2173.6	6798.1
1.02.01.01 Detector Components Management	1.7	61.4	183.4
1.02.04.01 LD Procurements	.5	1247.6	1602.0
1.02.04.02 SiO Coating and Al Electrode Deposition	2.7	25.5	753.0
1.02.04.03 Gluing	1.2	.0	371.8
1.02.04.04 Light Detector Validation Runs	.6	.0	55.7
1.02.04.05 OPC: LD Procurements	2.1	45.3	307.4
1.02.04.07 Technological transfer	.0	.0	12.6
1.02.05.01 NTD Ge Wafer Irradiation	.8	21.8	171.1
1.02.05.03 Thermistor Production	12.8	70.8	1066.1
1.02.05.04 LD & LMO NTD Testing	2.8	6.4	146.9
1.02.05.05 OPC: NTD Ge Wafer Irradiation	1.1	34.2	54.3
1.02.05.06 OPC: Thermistor R&D	2.7	.0	35.1
1.02.05.07 OPC: Thermistor Production	.5	40.7	195.5
1.02.05.08 OPC: LD & LMO NTD Testing	12.4	15.2	343.7
1.02.07 Muon Veto	11.7	475.4	1316.1
1.02.08 Neutron Shield		129.2	183.4
Phase 2	11.7	318.2	1759.2
1.02 Detector Components	11.7	318.2	1759.2
1.02.01.01 Detector Components Management	1.9	66.8	261.8
1.02.01.02 OPC: Detector Components Management	.2	2.7	23.9
1.02.04.01 LD Procurements	.8	193.3	513.4
1.02.04.02 SiO Coating and Al Electrode Deposition	1.5	43.7	188.8
1.02.04.03 Gluing	.7	.0	125.7
1.02.04.04 Light Detector Validation Runs	.9	.0	93.6
1.02.05.03 Thermistor Production	2.1	.0	330.4
1.02.05.04 LD & LMO NTD Testing	3.7	11.7	221.5
Grand Total	65.5	2491.8	8557.2

WBS 1.02 US Budget by Resource Type (in $k)

Stage 1



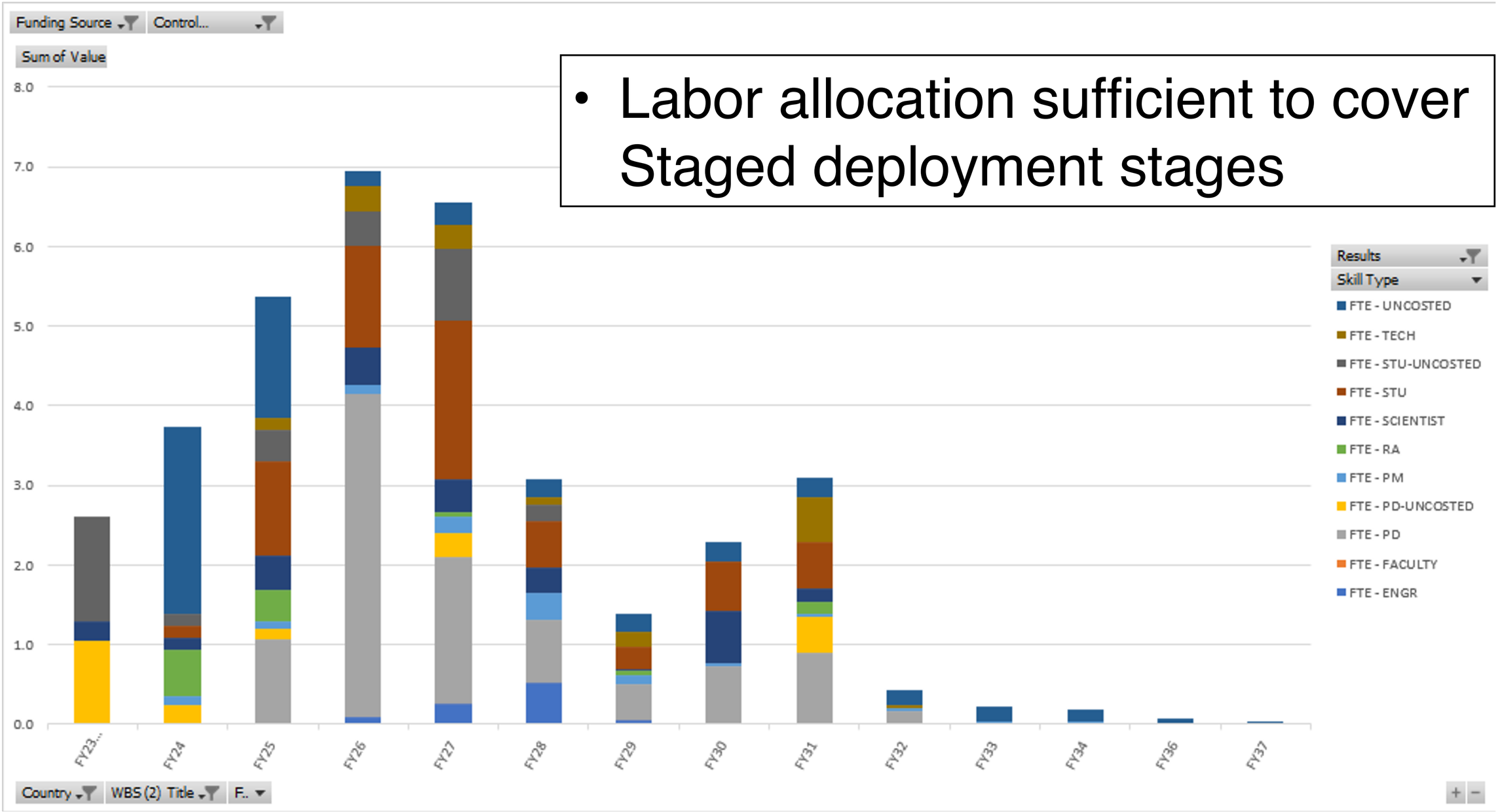
Stage 2



- Costs breakdown by Labor vs Non-labor
- Stage 1 has larger non-labor costs due to muon veto and neutron shield.

WBS 1.02 US FTEs by Skill Type

- Labor allocation sufficient to cover Staged deployment stages



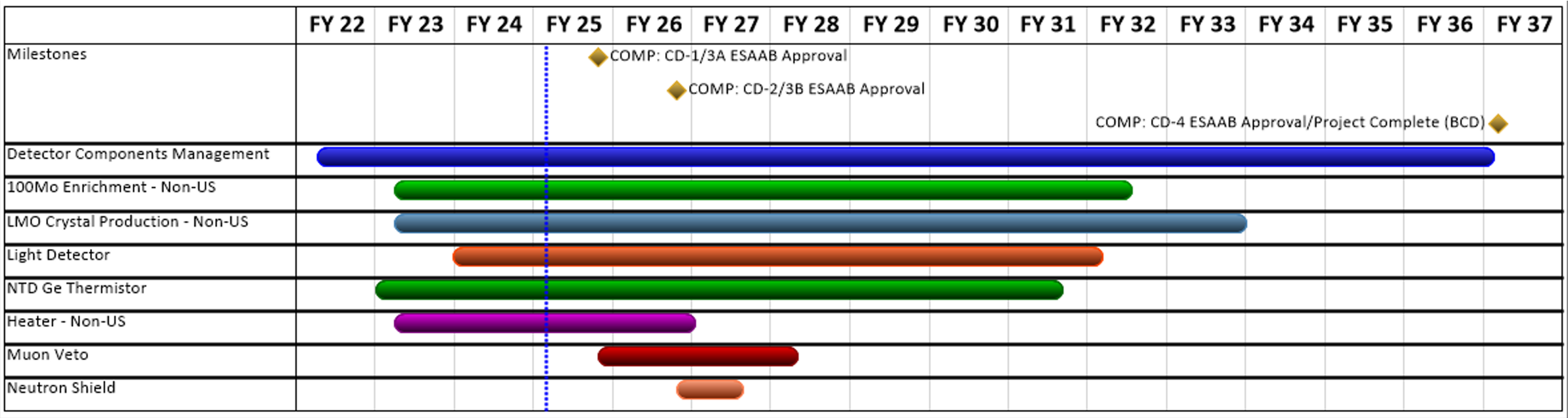
WBS 1.02 US FTEs by Institution

Sum of Value	Column Labels													
Row Labels	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY36	FY37
US	**2.6**	**3.7**	**5.4**	**6.9**	**6.5**	**3.1**	**1.4**	**2.3**	**3.1**	**0.4**	**0.2**	**0.2**	**0.1**	**0.0**
Phase 1	**2.6**	**3.7**	**5.4**	**6.9**	**6.5**	**3.1**	**1.2**							
ANL		0.7	0.5	0.1	0.6	0.8	0.3							
JHU		0.2	1.2	1.4	1.5	0.5	0.2							
LBNL	0.3	0.2	0.5	1.1	0.8	0.6	0.0							
MIT			0.0	0.0	0.0	0.0	0.0							
UCLA							0.3							
UNCOSTED	2.3	2.7	2.1	0.6	1.5	0.4	0.2							
VT			0.2	1.1	1.4	0.4	0.1							
YALE			0.9	2.6	0.8	0.3								
Phase 2							**0.1**	**2.3**	**3.1**	**0.4**	**0.2**	**0.2**	**0.1**	**0.0**
ANL									0.7	0.0				
JHU							0.1	0.5	0.5					
LBNL								1.1	0.5					
MIT								0.0	0.0	0.0	0.0	0.0	0.0	0.0
UCLA									0.3	0.2				
UNCOSTED							0.0	0.2	0.7	0.2	0.2	0.1	0.1	0.0
VT							0.1	0.4	0.4					
Grand Total	**2.6**	**3.7**	**5.4**	**6.9**	**6.5**	**3.1**	**1.4**	**2.3**	**3.1**	**0.4**	**0.2**	**0.2**	**0.1**	**0.0**

- Labor breakdown by US institution

WBS 1.02 Schedule

- Fully loaded schedule accounting for Staged deployment
- US scope not on the critical path.



WBS 1.02: CDR Review Response

- CDR review last year
- Several recommendations by review committee
- Requirements Table
  - A: Requirements table for all levels added.
- Document Interfaces
  - A: ICDs now exist
- More detailed information on production and prototyping.
  - A: This review.
- Light Detector Performance - Next Talk.

WBS 1.02 Detector Components: Summary

- Ready to go
- NTD pre-production underway.
- NTD procedures well understood from CUORE
- Muon veto test panel running underground.
- Muon veto based on mature technology.
- Risks are manageable.
- Light Detectors covered in the next talk.