WBS1.06 Background Control

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Virginia Tech

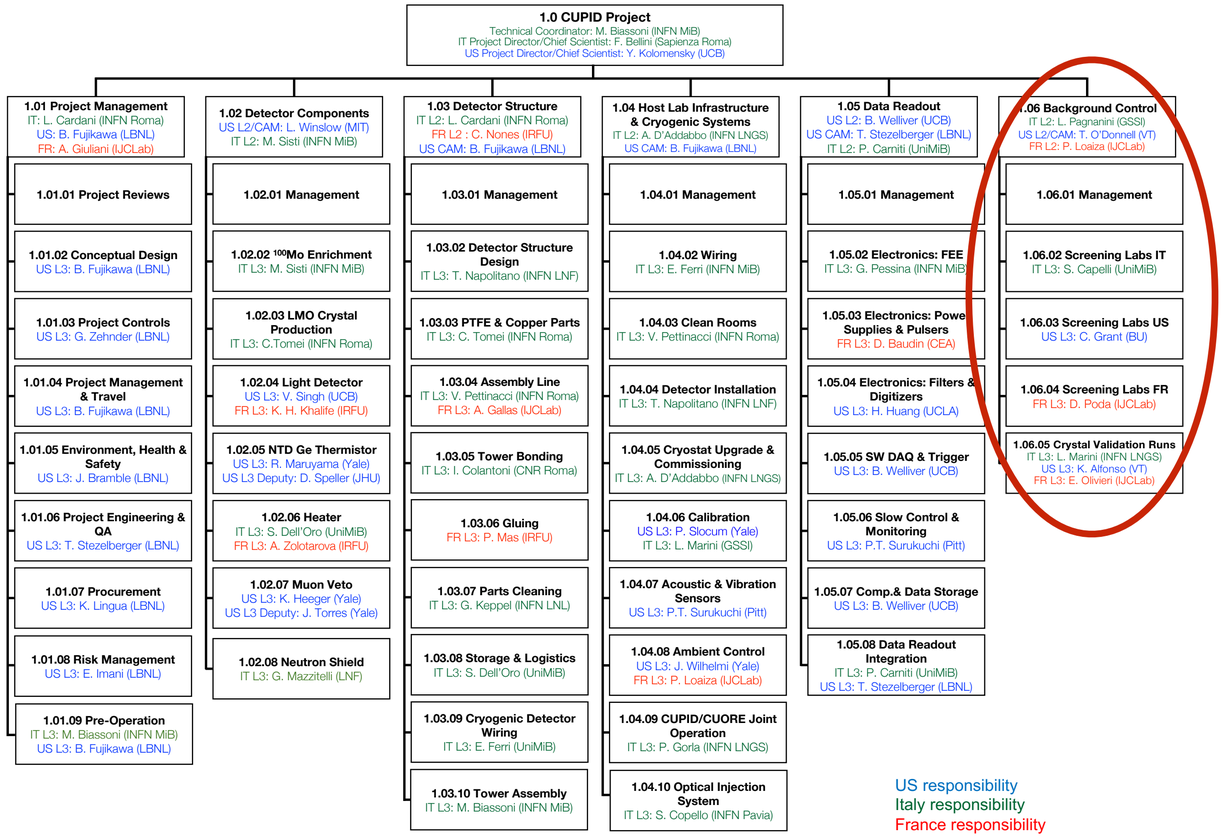
CUPID LBNL Project Review
December 16-17, 2024

VIRGINIA TECH

WBS 1.06: Overview

- Organization
- Requirements
- Scope and Technical Specification
- Risks
- Cost and Schedule
- Interfaces
- Lessons Learned
- Summary

WBS 1.06: Organization



US responsibility
Italy responsibility
France responsibility

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

1.06 Background Control
IT L2: L. Pagnanini (GSSI)
US L2/CAM: T. O'Donnell (VT)
FR L2: P. Loaiza (IJCLab)

1.06.01 Management

1.06.02 Screening Labs IT
IT L3: S. Capelli (UniMiB)

1.06.03 Screening Labs US
US L3: C. Grant (BU)

1.06.04 Screening Labs FR
FR L3: D. Poda (IJCLab)

1.06.05 Crystal Validation Runs
IT L3: L. Marini (INFN LNGS)
US L3: K. Alfonso (VT)
FR L3: E. Olivieri (IJCLab)

Contain US Project Scope

CUPID: L1 Requirements

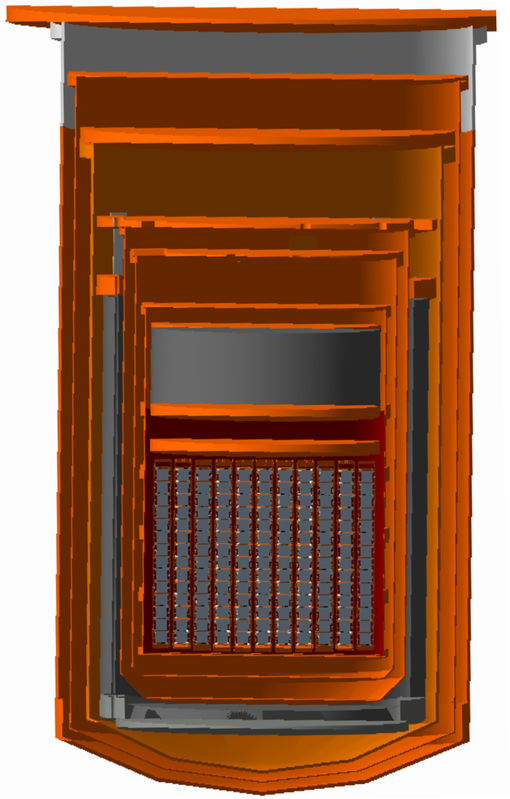
Requirement	Value
Pileup BI	$0.5{\cdot}10^{-4}$ counts/(keV·kg·yr)
Radioactive BI	$0.47{\cdot}10^{-4}$ counts/(keV·kg·yr)
β/γ-α Discrimination Efficiency	99.7%
Light Detector Risetime	0.5 ms
Light Detector S/N after NTL amplification	60
Detector Cooling Time	6 weeks
Minimum Achievable Operating Temperature	10 mK
Light Yield^{+}	0.36 keV/MeV
Combined Signal Selection Efficiency*	86.3%
Fraction of Working LD At Beginning of Operation	0.98
Fraction of Working HD At Beginning of Operation	0.995
Readout Wires Total Capacitance	500 pF
Total Cross-Talk	-65 dB
Hardware/Spare Operation Time	20 yr

- Science driver: background budget of 1×10^{-4} ccky to achieve design sensitivity
- Requirements for WBS1.06 flow down from this

Background budget components

- Total background budget requirement: 1.0×10^{-4} ccky
- There many paths to meet this requirement

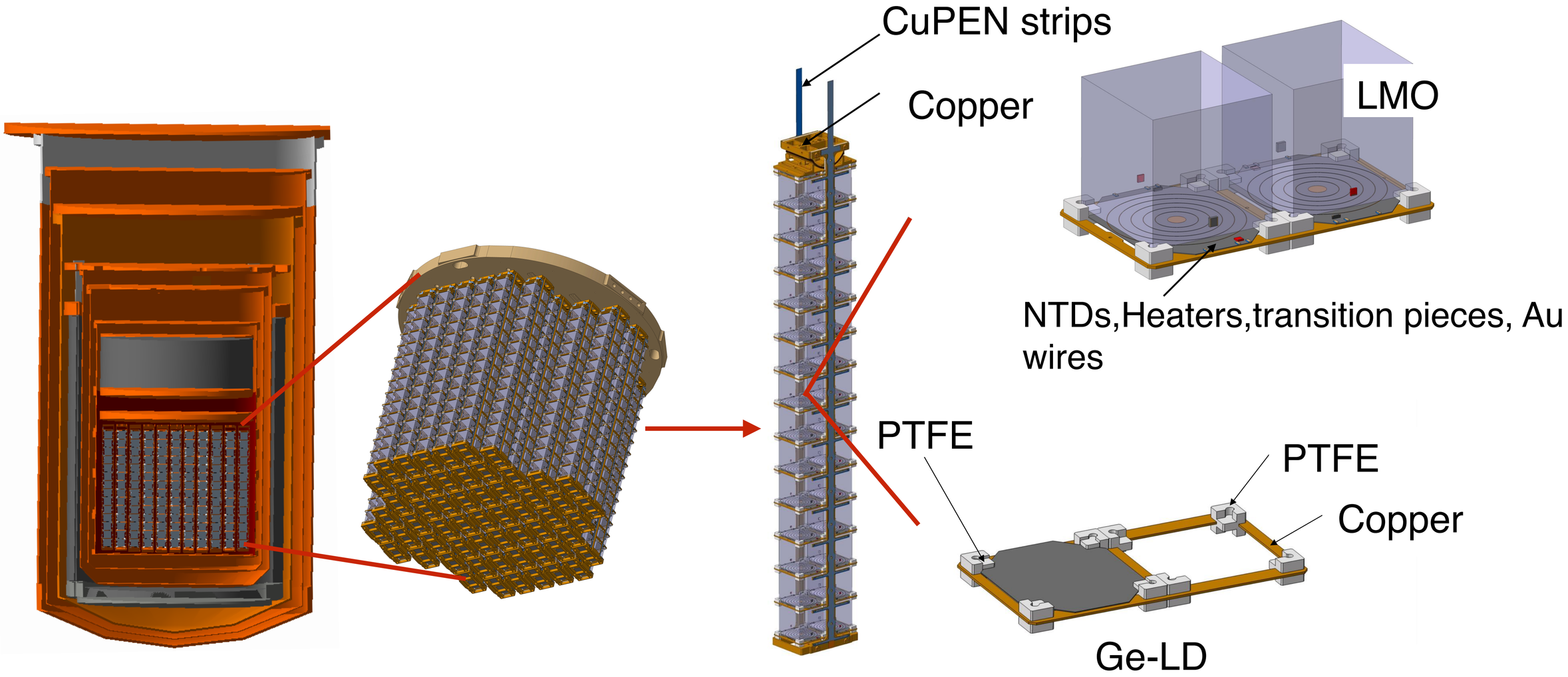
Quick reminder of jargon



Quick reminder of jargon

Cryostat and Shields refers to the cryogenic and shielding infrastructure already in place from CUORE which will remain in CUPID

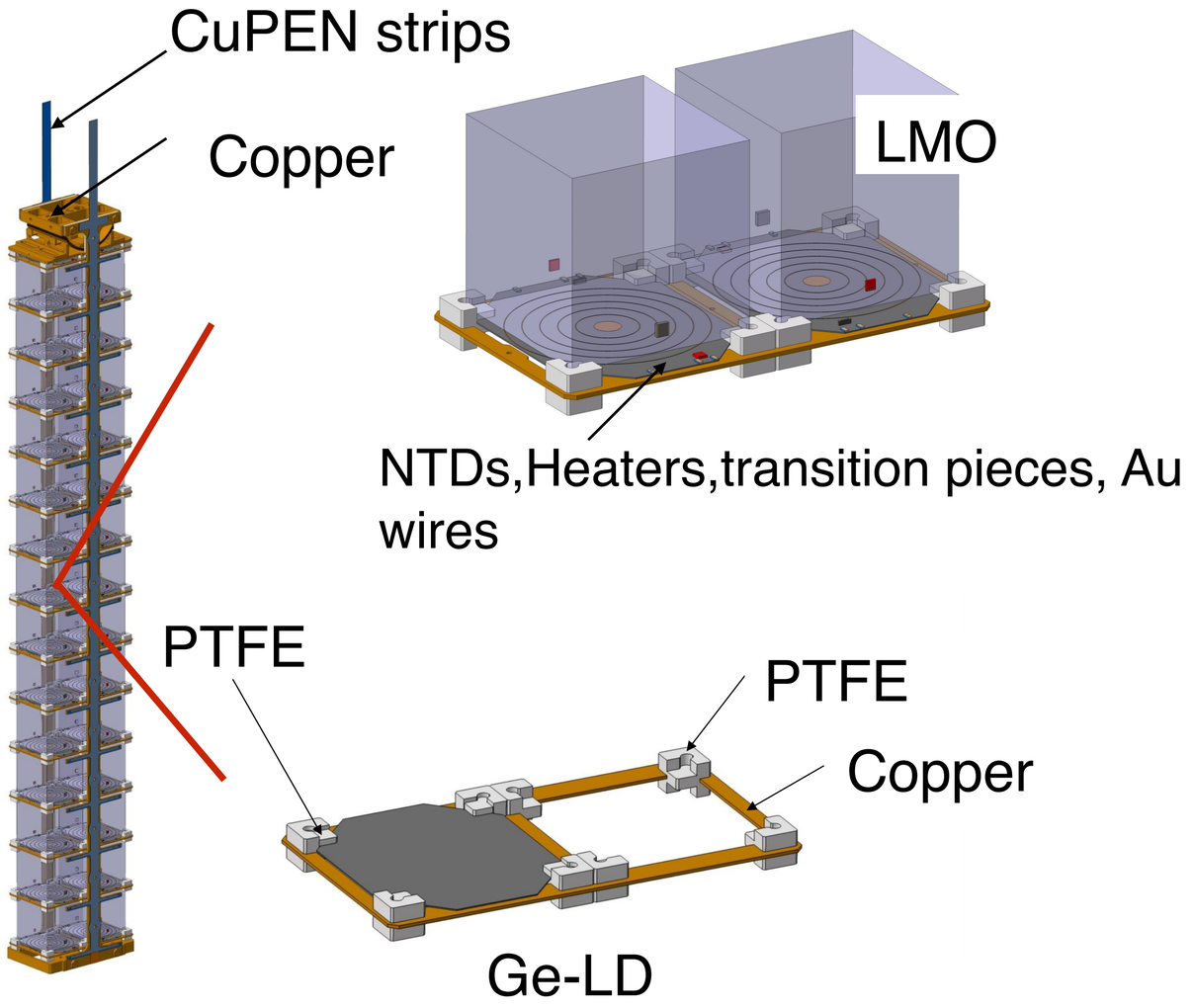
Quick reminder of jargon



Quick reminder of jargon

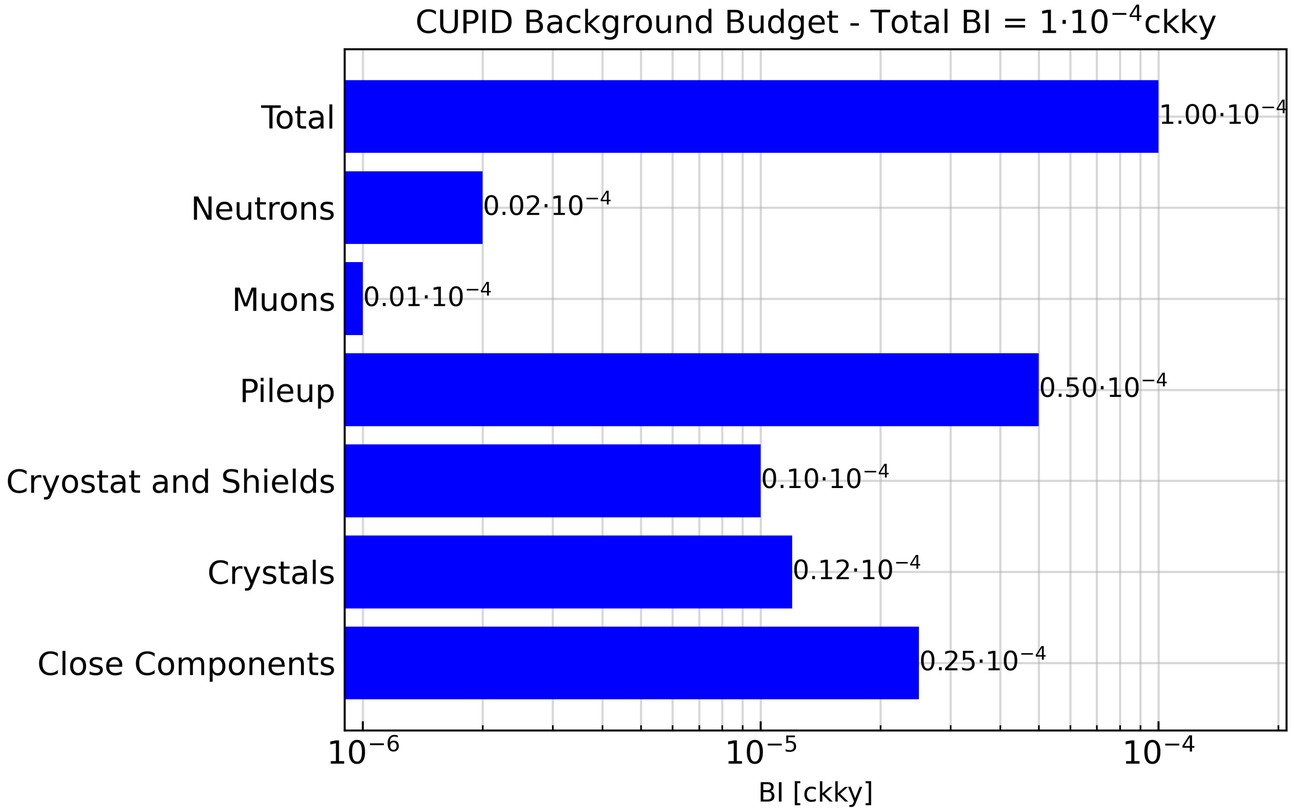
Crystals refers to active/sensitive detector elements, namely LMO crystals and Ge-LDs

Close components refers inactive detector elements near the sensitive elements: Cu frames, PTFE, CuPEN, and small parts such as the NTDs, heaters, transition pieces and Au wire



Background budget components

- Total background budget requirement: 1.0×10^{-4} ccky
- There many possible paths to meet this requirement
- We have adopted this path as it presents low risk to meet requirement



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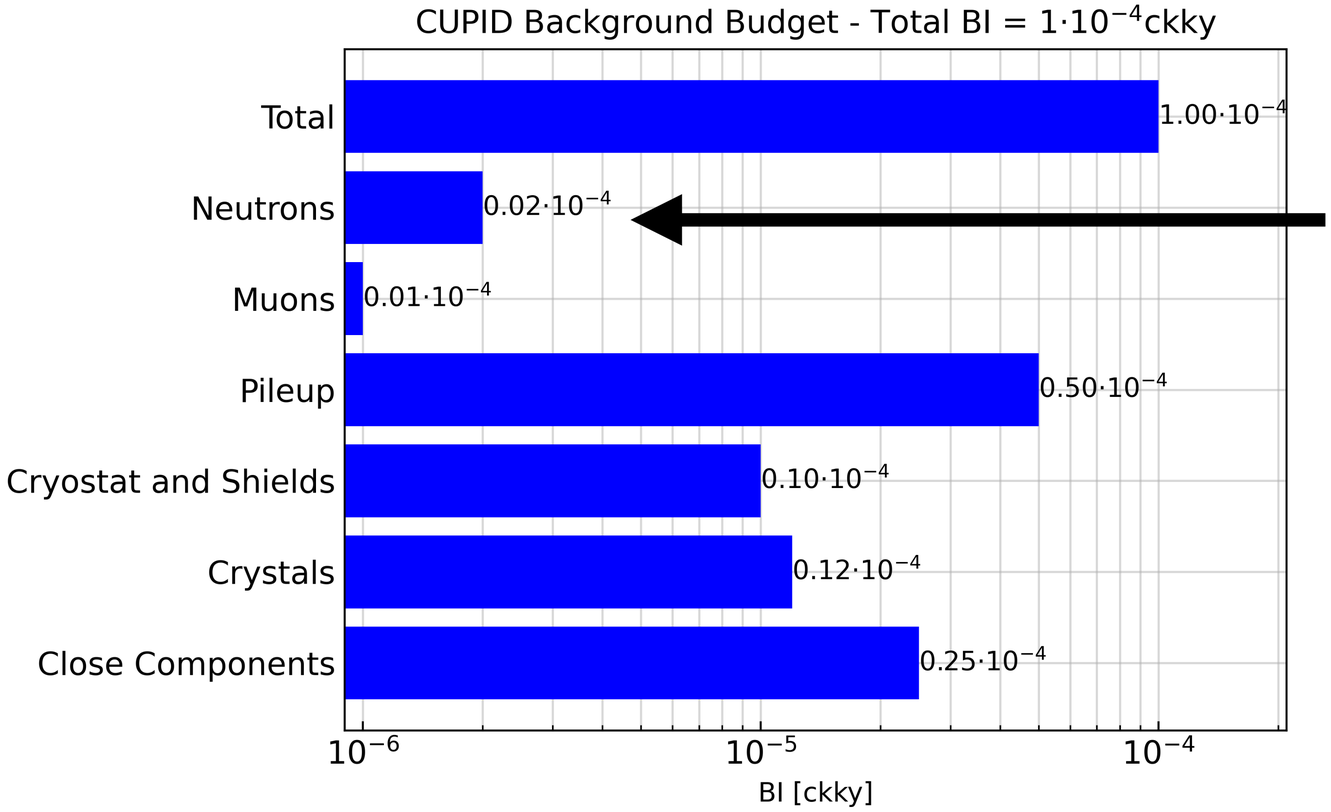

WBS1.02.04 Neutron shield

- Italian scope — design simulations implementing conventional shielding solutions used to set this requirement, thus can be met with low risk

Background budget components

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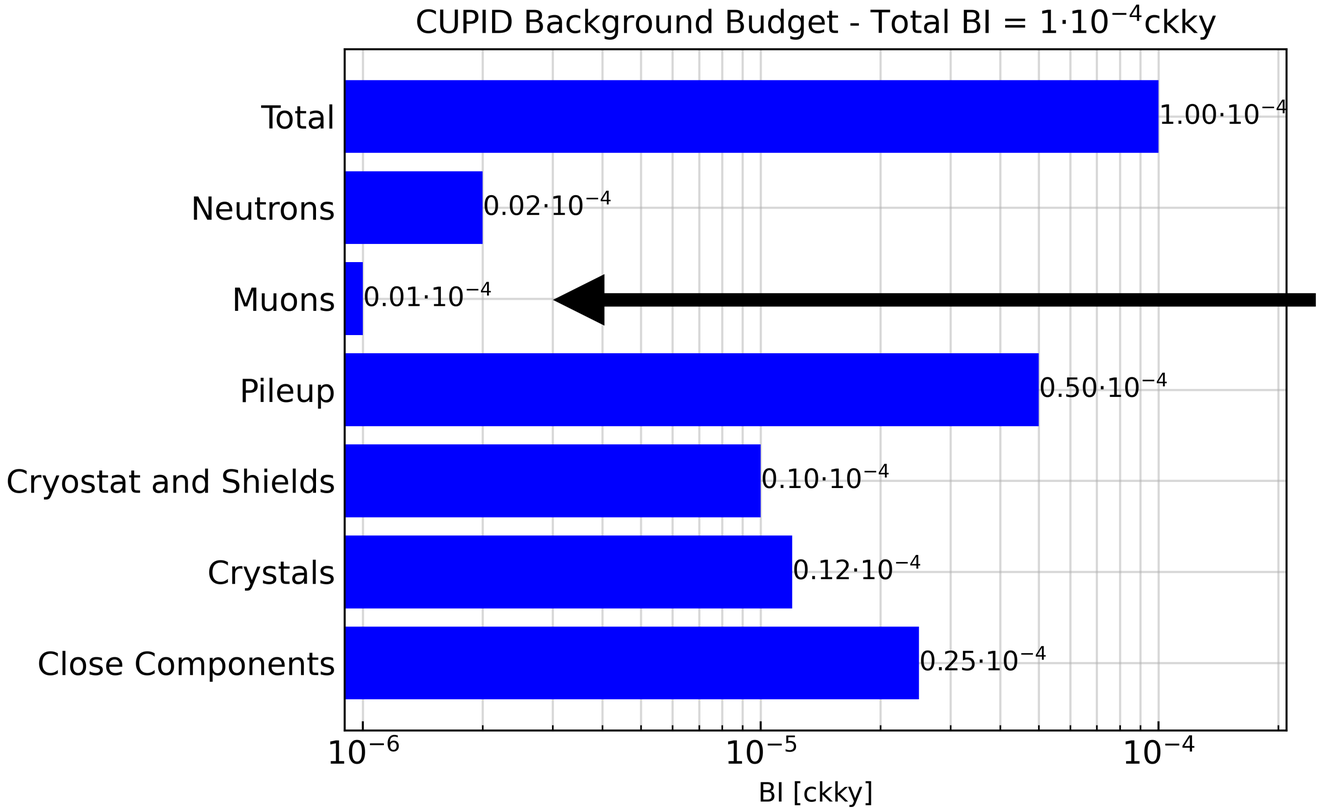

WBS1.02.07 Muon veto

- US scope — this requirement can be met with conventional muon tagging solutions, see dedicated WBS1.02.07 talk

Background budget components

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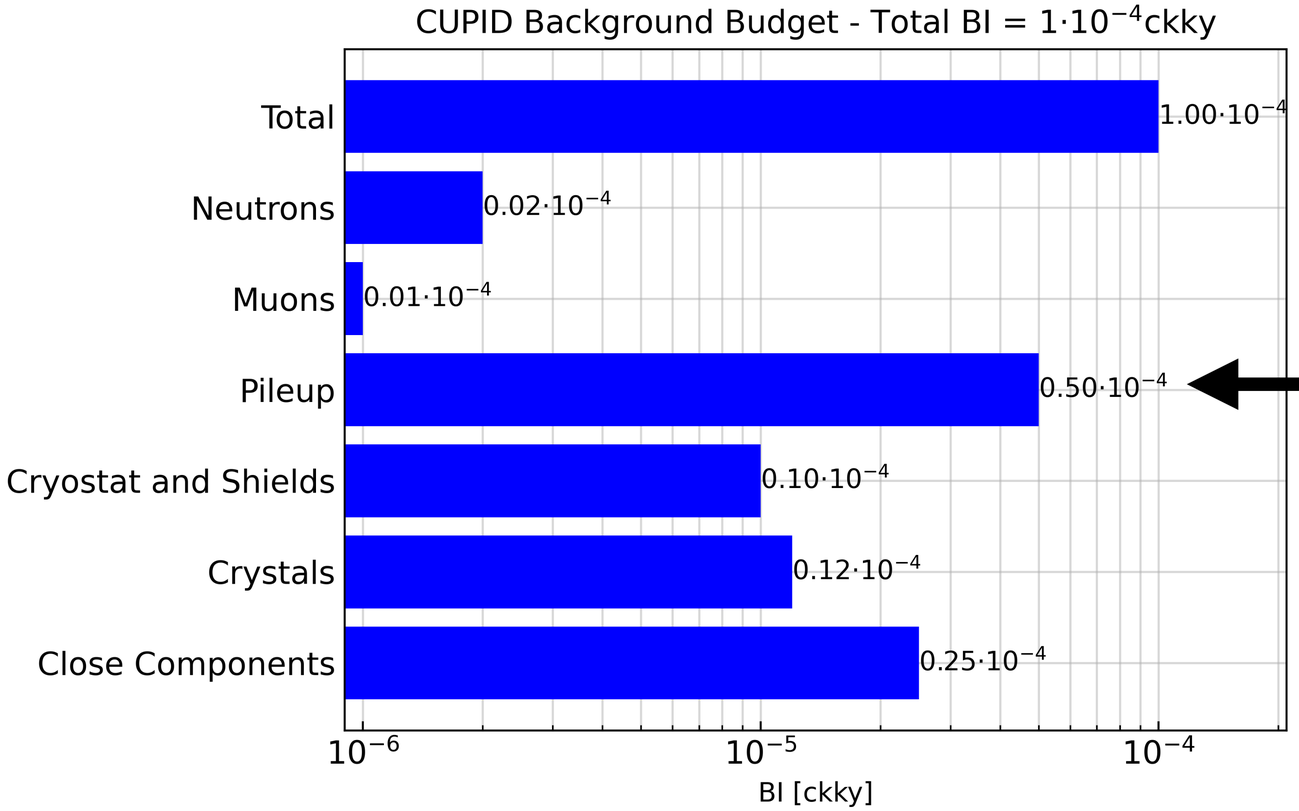

WBS1.02.04 Light detector

- US + Fr scope — projected LD performance can meet this requirement, see dedicated WBS1.02.04 talk

Background budget components

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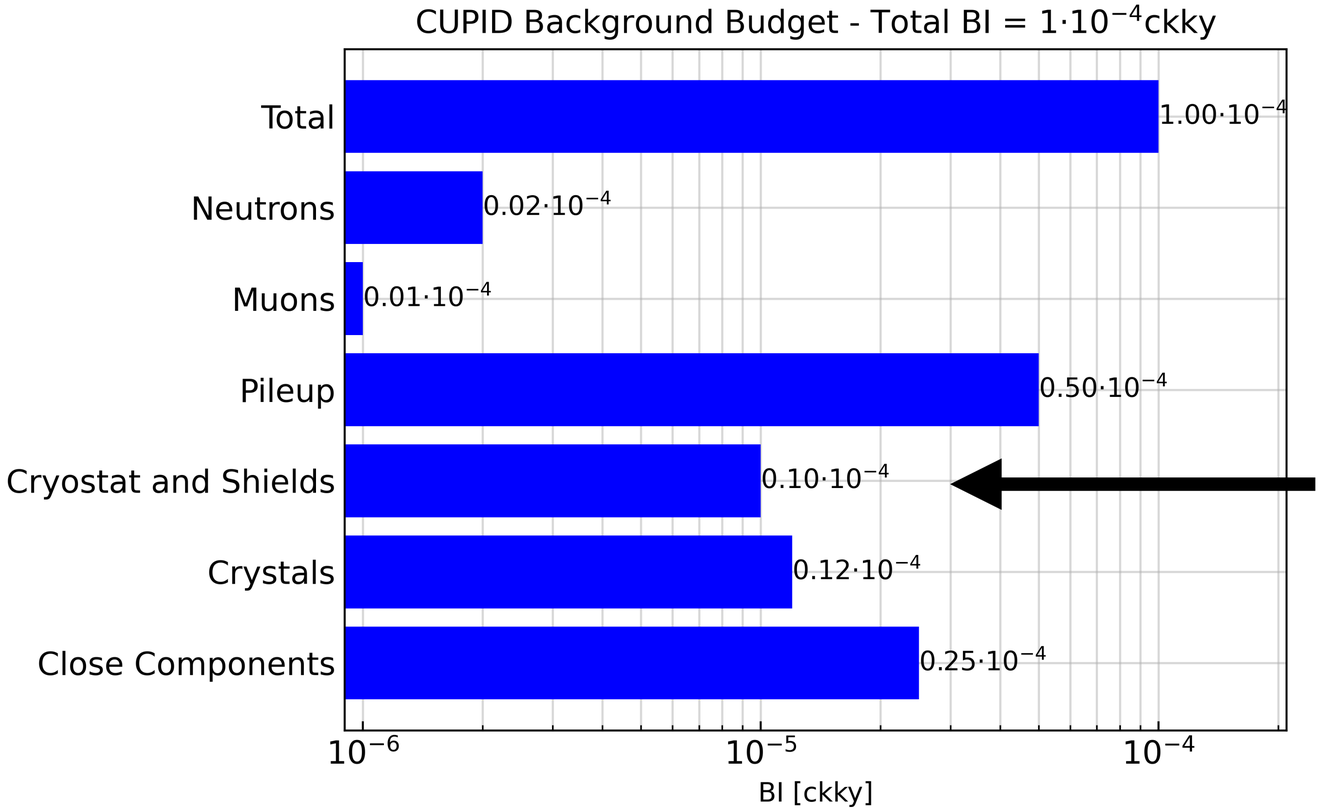

- Reuse the CUORE cryostat and shields
- Background measurement with CUORE used to set requirement.
- No improvements needed to meet this requirement

Background budget components

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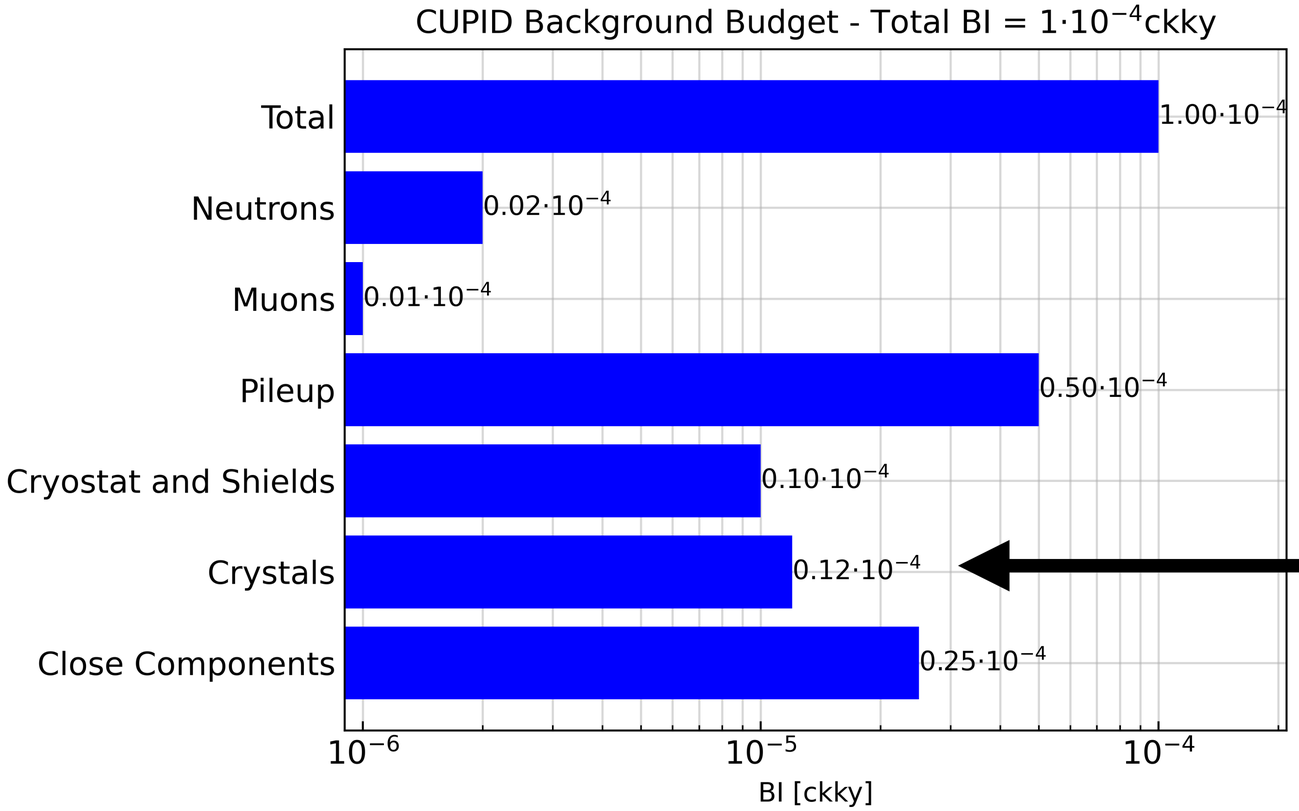

- Radiopurity demonstrated in CUPID-Mo used to set this requirement
- No improvements over demonstrated radiopurity needed to meet this requirement

Background budget components

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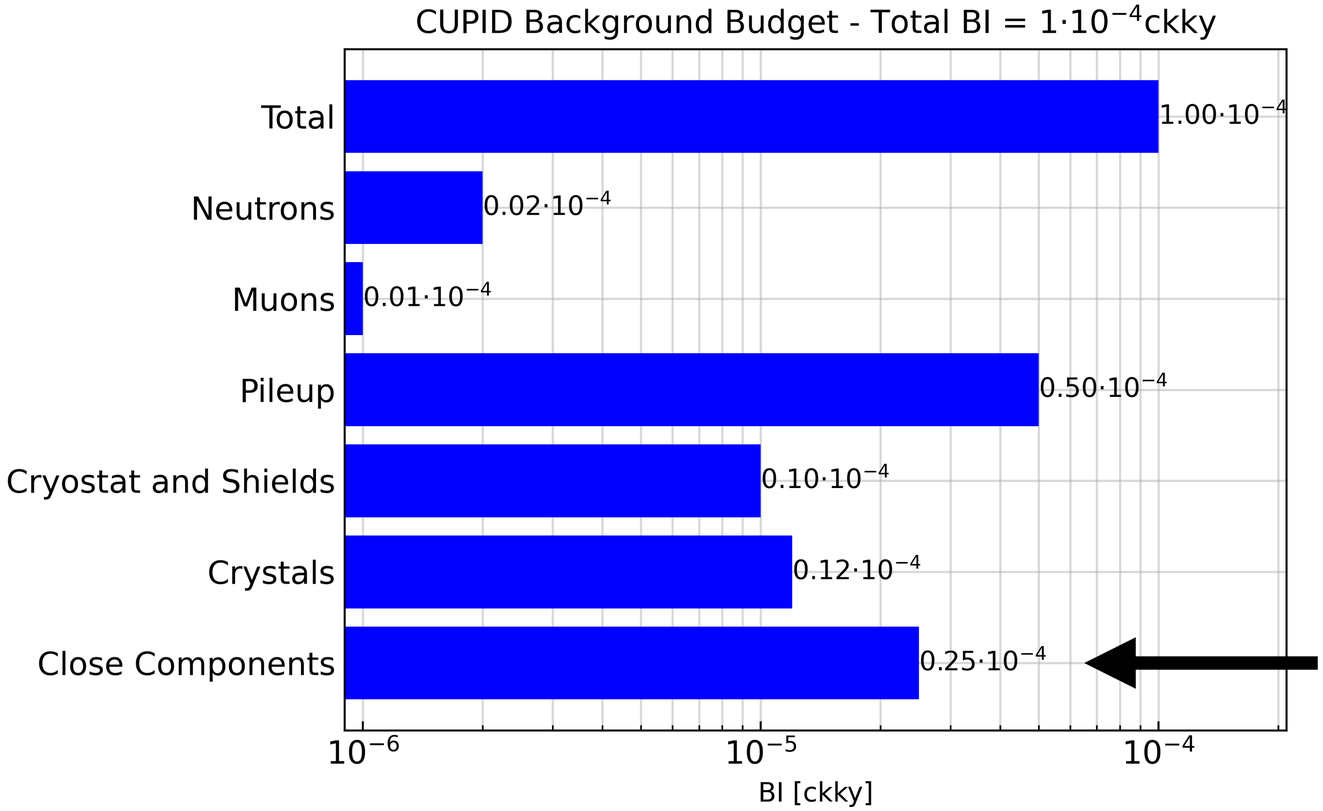

- Remaining space in budget used to set requirement on Close Components
- Meeting this requirement necessitates a factor of 1.6 improvement in surface radio-purity relative to CUORE
- We expect this can be achieved due to simpler design of CUPID close components, allowing contact-less machining and easier cleaning

WBS 1.06: Overall Scope

- Screen detector materials using techniques with appropriate sensitivity (ICPMS, NAA, HPGe and bolometric screening)
- Document results
- Monitor integrity of handling procedures by screening witness samples
- Deliver decision on whether or not material is consistent with radioactive BI requirement

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Contain US Project Scope

WBS 1.06:Low level requirements methodology

- Lower level requirements on sensitivity of screening flow down from the background budget
- The low-level requirements are determined using the CUPID detector simulation which can estimate the radioactive background index corresponding to a given amount of radio-contamination of materials
- In the following we state the low-level requirements in terms of bulk and surface radioactivity levels
- Due to CUPID's alpha discrimination ability, the dominant contributors to the background budget are high Q-value beta+gamma emitters (226Ra and 228Th chains), particularly surface contamination with these emitters
- The surface radio purity requirements also lead to requirements on recontamination for example with radon or dust

WBS 1.06: Inventory of Materials

Material	Mass (kg)	Surface Area (m^2)
LMO Crystals	446.487	19.391
Copper structure	89.650	18.049
Light detectors (Ge)	10.077	7.721
PTFE holders	8.290	4.538
PEN Flex cables	0.879	2.910
Heaters + Transition pieces (Si)	0.056	0.111
NTDs (Ge)	0.104	0.072
Au wire	0.001	0.008

(Detector geometry + simulations + detector response) + background budget set the radiopurity screening requirements for detector materials

WBS 1.06: Requirement on Radioactive BI

Material	Bulk (uBq/kg)	Surface (nBq/cm2)	Planned Assay method
LMO Crystals	0.4 (226Ra) 0.4 (228Th)	2.0 (226Ra) 2.5 (228Th)	Bolometer/ICPMS/NAA
Copper structure	6.6 (226Ra) 17.3 (228Th)	4.8 (226Ra) 5.5 (228Th)	Bolometer/NAA/HPGe
Light detectors (Ge)	20 (226Ra) 10 (228Th)	10 (226Ra) 10 (228Th)	Bolometer/NAA/ICPMS
PTFE holders	100 (226Ra) 32 (228Th)	4.4 (226Ra) 1.5 (228Th)	Bolometer/NAA/HPGe
PEN Flex cables	500 (226Ra) 400 (228Th)	10 (226Ra) 10 (228Th)	NAA/ICPMS/HPGe
Heaters + Si pieces	2000 (226Ra) 600 (228Th)	100 (226Ra) 50 (228Th)	NAA/ICPMS/alpha spect.
NTDs (Ge)	5000 (226Ra) 2000 (228Th)	100 (226Ra) 50 (228Th)	NAA/ICPMS/alpha spect.
Au wire	10000 (226Ra) 4000 (228Th)	100 (226Ra) 50 (228Th)	ICPMS

WBS 1.06: Requirement on Radioactive BI

Material	Bulk (uBq/kg)	Planned Assay Method
$^{100}MoO_3$ powder	2500 (226Ra) 800 (228Th) 100 (40K)	HPGe/ICMPS/NAA
Li_2CO_3	500 (226Ra) 500 (228Th) 15 (40K)	HPGe/ICMPS/NAA

Screening requirements on precursors are more modest as our experience is crystal growth significantly purifies the material

WBS 1.06: Requirement on Radon Recontamination

- Simulations + Background budget set Rn recontamination requirement: 80nBq/cm^2
  - More relaxed than ^{226}Ra and ^{228}Th due to active PID
- Mitigations:
  - Nitrogen-flushed glovebox handling
  - Rn impervious storage
  - Rn-free air when glovebox handling not feasible (installation)
  - Monitoring by deploying and counting witness samples

WBS 1.06: Requirement on dust

- Simulations + Background budget set surface dust requirement: 10ng/cm^2
- Mitigations:
  - Clean room handling
  - Nitrogen-flushed glovebox handling inside cleanroom
  - Monitoring dust by deploying and counting witness surfaces

WBS 1.06.03: Screening Labs US — Scope

- Manages Screening Resources in US other than bolometric screening
  - Screen samples of precursor powders for crystals with HPGe, ICPMS and NAA
  - Screen samples of LMO crystals with ICPMS
  - Screen samples of PTFE(small parts) with ICPMS and NAA
  - Screen samples of light detector and NTD Ge with ICPMS and NAA

WBS 1.06.03: Technical Specifications

- Manages Screening Resources in US other than bolometric screening
  - ICPMS
    - Contract with PNNL, routinely achieves 10^{-15}-10^{-12} g/g sensitivity on U/Th contamination which meets our requirements
  - HPGe Screening
    - Access to low background counting facility at SURF for screening precursors, sensitivities better than 0.1 mBq/kg which meets our requirements
  - NAA
    - Neutron Irradiation at MITR
    - HPGe detectors at BU and VT for counting
    - Sensitivities of 10^{-14}-10^{-12} g/g on U/Th contamination which meets our requirements

WBS 1.06.03: Maturity

- NAA, HPGe and ICPMS are well-established techniques that meet our scope requirements
- L3 Manager has decades of experience with these the techniques

WBS 1.06.05: Crystal Validation Runs — Scope

- Bolometric screening of final detector-quality components operated as mini-array in dilution refrigerator
- This is our most sensitive screening technique. Designed to achieve sensitivity:
  <0.2uBq/kg bulk LMOs
  <2nBq/cm2 surface LMOs
  <2nBq/cm2 surface on LDs
- Runs will be performed in HallC cryostat at LNGS
- US scope is to perform 4 CCVR runs (run 3, 6, 8 and 10)
  - Assemble CCVR array
  - Installation and cooldown of cryostat
  - Data taking and data analysis
  - Warmup and dismounting array

WBS 1.06.05: Technical Specifications

Description	Specification
#LMO crystals	12 (3 floors of 4) randomly selected
#LDs	16 (4 floors of 4) randomly selected
#NTDs / Heaters	28 / 28 randomly selected
#NTL HV channels	16
#Cu frames +PTFE	Enough for 3 LMO floors and 4 LD floors
Cryostat run time	60 days
Cryostat base temperature	10mK
DAQ live time	40 days
Analysis Efficiency	80%
Measured LMO Energy resolution	Be able to measure 5keV FWHM at 2615keV
Measured Light Yield	Be able to measure 0.3keV/MeV

WBS 1.06.05: Maturity

- Crystal validation runs are a well-established technique in the CUPID collaboration.
- Method was used successfully to validate the crystals of CUORE
- HallC cryostat has been used to run CCVR for CUORE and R&D runs for CUPID which meet the technical specifications

WBS 1.06: KPPs

	Threshold	Objective
WBS 1.06	Delivery to LNGS of screening results of samples with required screening technique and sensitivity	Same as Threshold

WBS 1.06: Risks

- L2 and L3 managers maintain this section of the risk registry
- Some examples

Risk Rating	Low	Medium	High

Risk ID	Description	Likelihood	Consequence			
			Cost	Schedule	Technical	Mitigation
106030055	Turnover of key personnel	Very likely	Marginal	Significant	None	Hiring schedule, overlap training, train deputies
106030052	Material fails screening	Unlikely	Marginal	Significant	None	Float between screening and material usage
106030054	Instrument/facility downtime/unavailable	Likely	Marginal	Significant	None	Redundant backup instruments available

WBS 1.06: Cost, Schedule and Interfaces

- Methodology
  - Schedule and logic developed in Primavera P6
  - List of tasks screening tasks developed in consultation with L2s and L3s for each WBS
  - Resources required: time, labor, internal and external facilities, materials, were estimated in consultation with instrument operators and stakeholders using bottoms-up approach
  - Past experience with similar tasks
  - Vendor quotes
  - Dependancies tracked in P6 as predecessors and successors
  - Iterate/scrub regularly

WBS 1.06 FY Budget by Country

Unit: $k

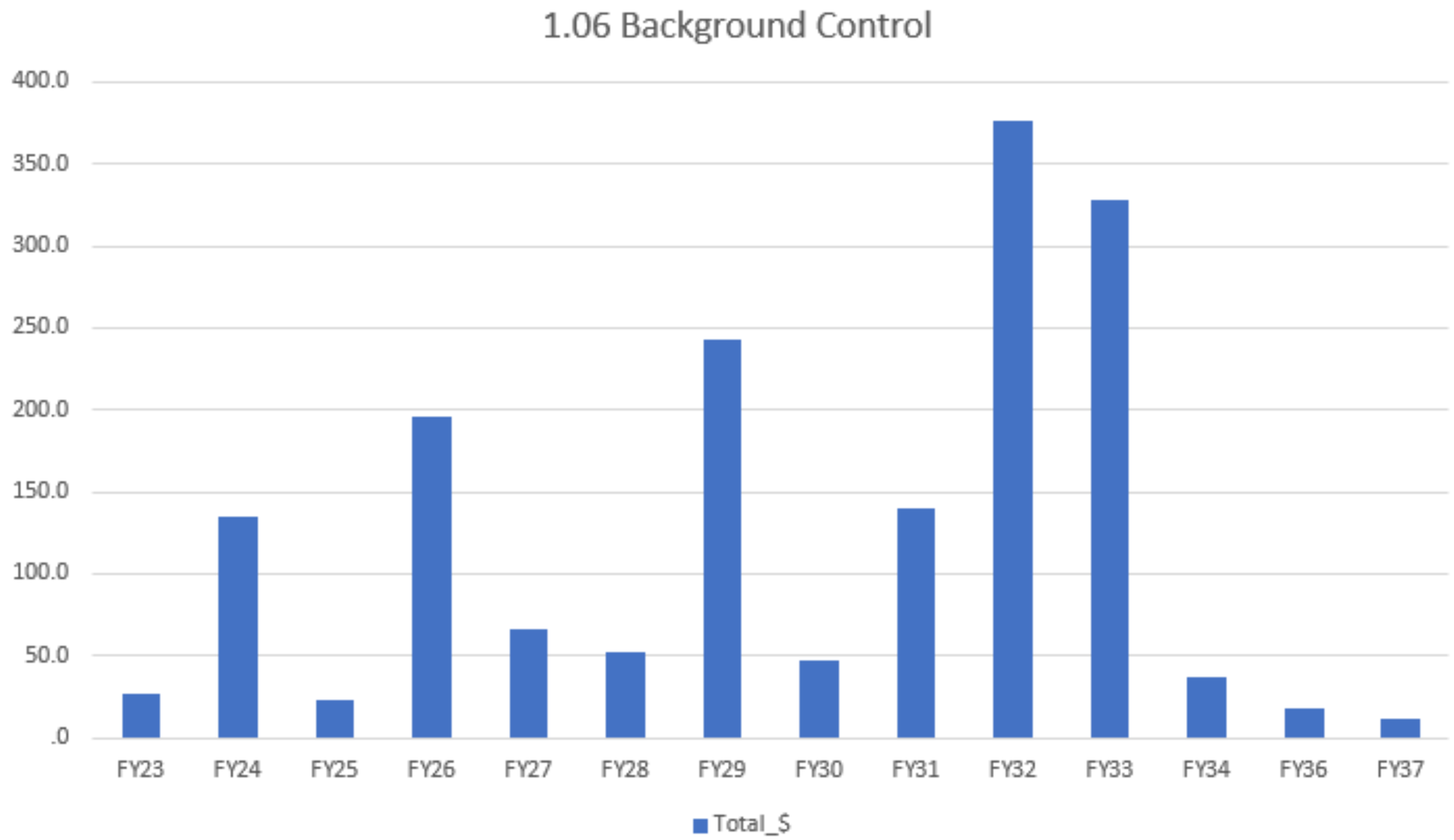
Sum of Value	Column Labels														
	Total_$														Total_$ Total
Row Labels	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY36	FY37	
US		27.2	135.0	22.9	196.2	66.2	51.9	242.7	47.0	139.7	376.7	328.1	36.9	18.0	11.0	1699.5
Phase 1		27.2	135.0	22.9	196.2	66.2	51.9	242.7	14.9	34.0						791.0
Phase 2									32.1	105.7	376.7	328.1	36.9	18.0	11.0	908.5
IT			69.6	63.8	178.2	60.4	280.9	67.2	161.7	151.4	113.4	36.3				1182.8
Phase 1			69.6	63.8	178.2	60.4	280.9	67.2	9.1	36.3						765.3
Phase 2									152.6	115.1	113.4	36.3				417.5
FR	101.1	60.0	14.9													176.0
Phase 1	101.1	60.0	14.9													176.0
Grand Total	101.1	87.2	219.4	86.7	374.4	126.6	332.7	309.9	208.7	291.1	490.2	364.4	36.9	18.0	11.0	3058.2

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

WBS 1.06 US Budget

- Breakdown of US costs by FY in $k

Sum of Value	Column Labels
Row Labels	Total_$
Grand Total	1699.5



1.06 Budget

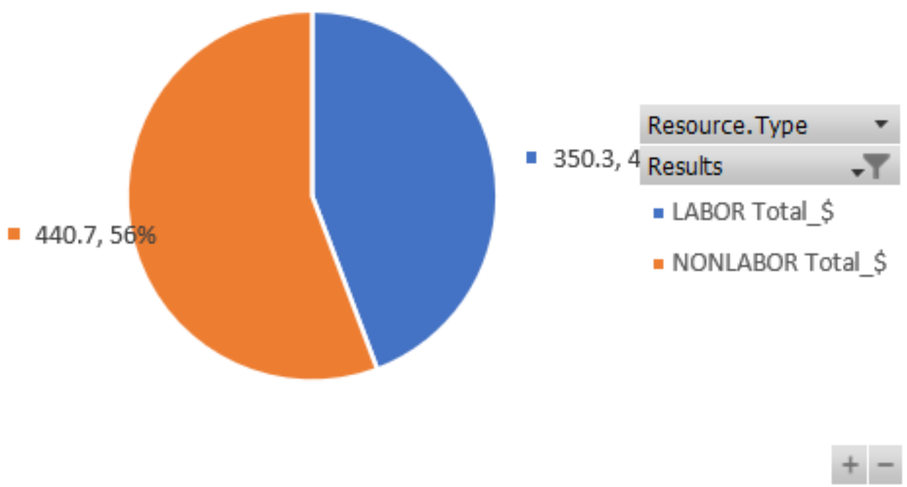
- Budget Breakdown by WBS and stage

Unit: $k

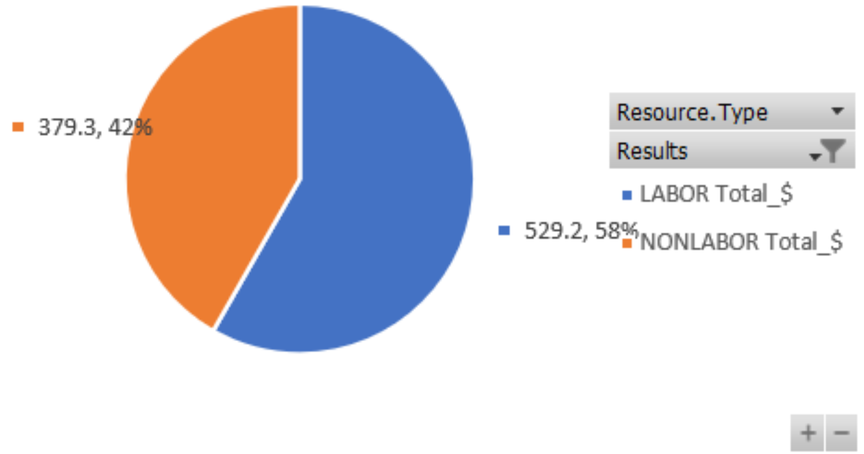
Sum of Value	Column Labels		
Row Labels	HOURS	DOLLARS	Total_$
⊟US	28.1	544.2	1699.5
⊟Phase 1	13.0	355.8	791.0
⊟1.06 Background Control	13.0	355.8	791.0
⊞1.06.01.01 Background Control Management	1.7	53.4	112.0
⊞1.06.01.02 OPC: Background Control Management		5.3	7.1
⊞1.06.03.01 Screening Labs US	1.9	239.9	347.1
⊞1.06.03.02 OPC: Screening Labs US	.3	15.0	18.0
⊞1.06.05.01 Commission US CCVR Lab	1.8	16.0	70.8
⊞1.06.05.02 LMO Crystal Validation Runs	7.3	26.2	236.0
⊟Phase 2	15.1	188.3	908.5
⊟1.06 Background Control	15.1	188.3	908.5
⊞1.06.01.01 Background Control Management	2.0	66.8	182.0
⊞1.06.01.02 OPC: Background Control Management	.2	8.0	29.0
⊞1.06.03.01 Screening Labs US	1.4	14.9	105.8
⊞1.06.05.02 LMO Crystal Validation Runs	11.5	98.7	591.6
Grand Total	28.1	544.2	1699.5

1.06 US Budget by Resource Type (in $k)

Stage 1



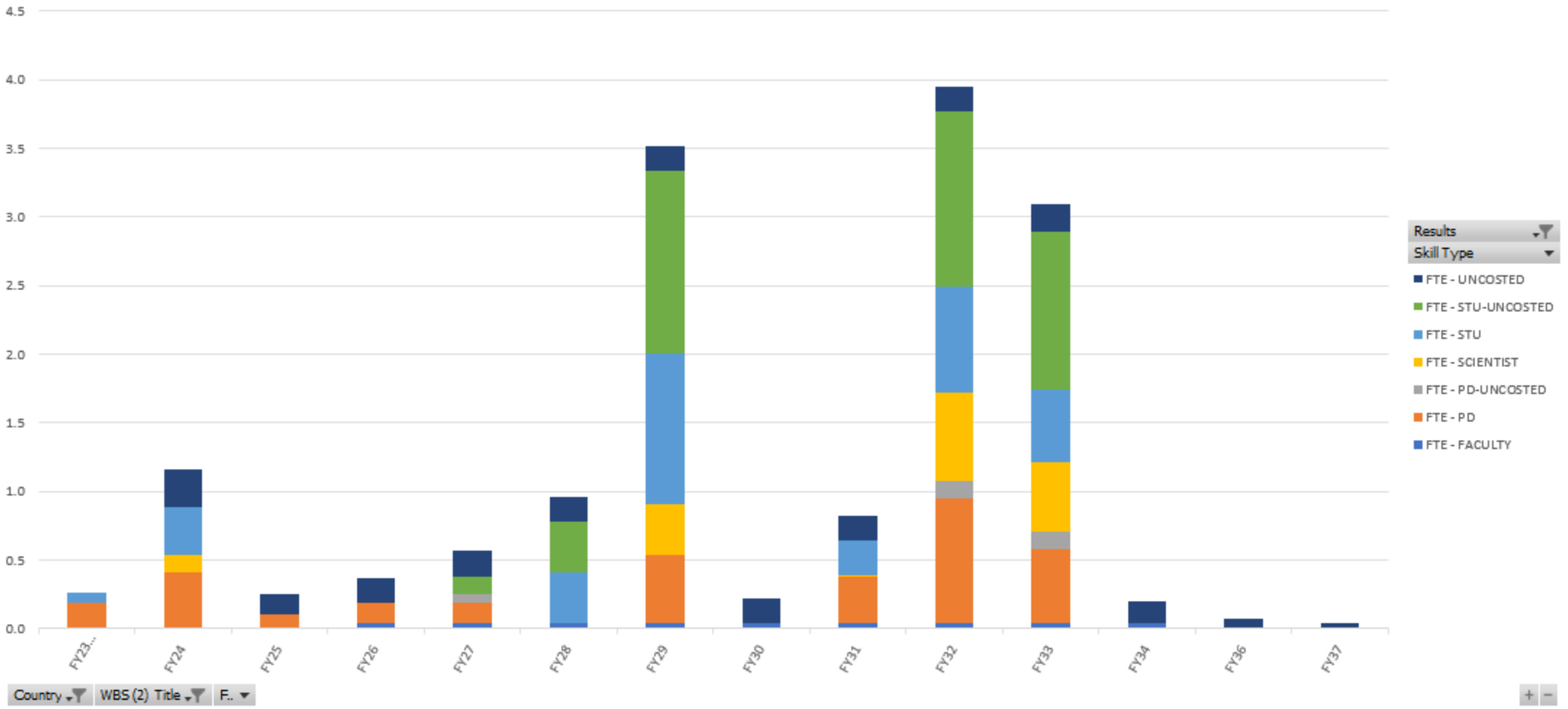
Stage 2



- US costs breakdown by Labor vs Non-labor

WBS 1.06 Personnel requirements

Unit: FTE



- US labor requirements by skill-type vs FY

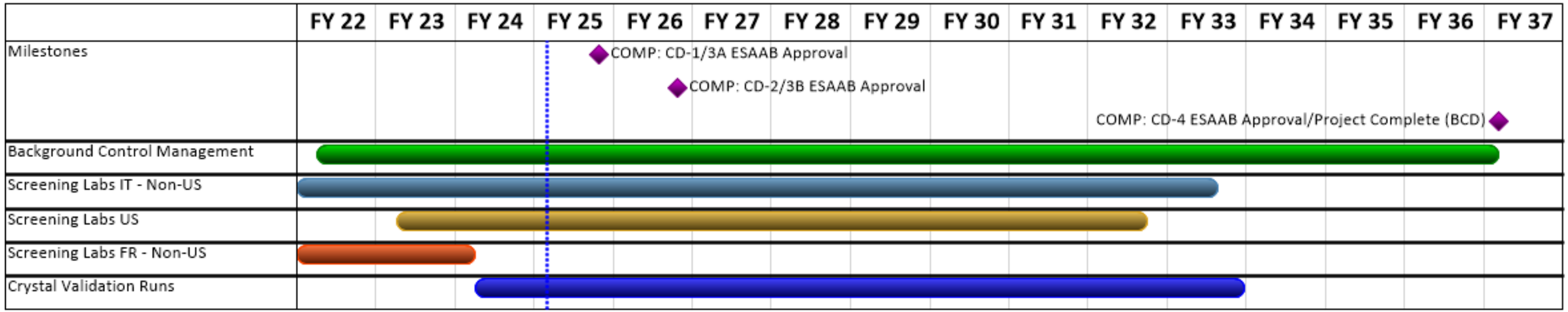
WBS 1.06 Personnel requirements

Sum of Value	Column Labels													
Row Labels	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY36	FY37
US	**0.3**	**1.2**	**0.2**	**0.4**	**0.6**	**1.0**	**3.5**	**0.2**	**0.8**	**3.9**	**3.1**	**0.2**	**0.1**	**0.0**
Phase 1	**0.3**	**1.2**	**0.2**	**0.4**	**0.6**	**1.0**	**3.5**		**0.1**					
BU	0.1	0.1	0.1	0.1	0.1									
NW		0.7				0.4	2.0							
UNCOSTED		0.3	0.1	0.2	0.4	0.5	1.5							
VT	0.2	0.1	0.0	0.0	0.1	0.0	0.0		0.1					
Phase 2								**0.2**	**0.7**	**3.9**	**3.1**	**0.2**	**0.1**	**0.0**
BU									0.2	0.1				
NW									0.1	2.0	1.6			
UNCOSTED								0.2	0.2	1.6	1.5	0.2	0.1	0.0
VT								0.0	0.3	0.2	0.0	0.0	0.0	0.0
Grand Total	**0.3**	**1.2**	**0.2**	**0.4**	**0.6**	**1.0**	**3.5**	**0.2**	**0.8**	**3.9**	**3.1**	**0.2**	**0.1**	**0.0**

- US labor breakdown by skill-type vs institution

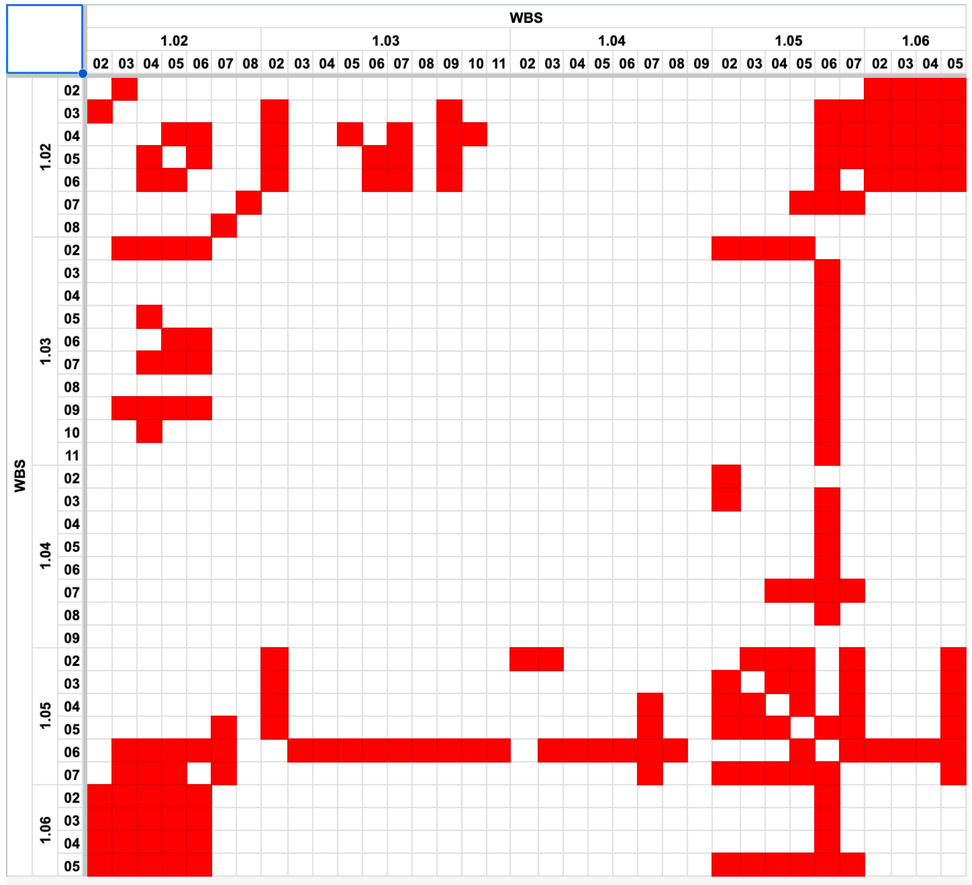
WBS 1.06: Schedule

- Fully loaded schedule from P6 for staged deployment
- Not on critical path except for final CCVR test (crystals needed for final tower)



WBS 1.06: Interfaces

- Dependancies tracked in P6 as predecessors and successors
- L2 and L3 managers control interfaces, draft interface control documents in place



- Interface matrix

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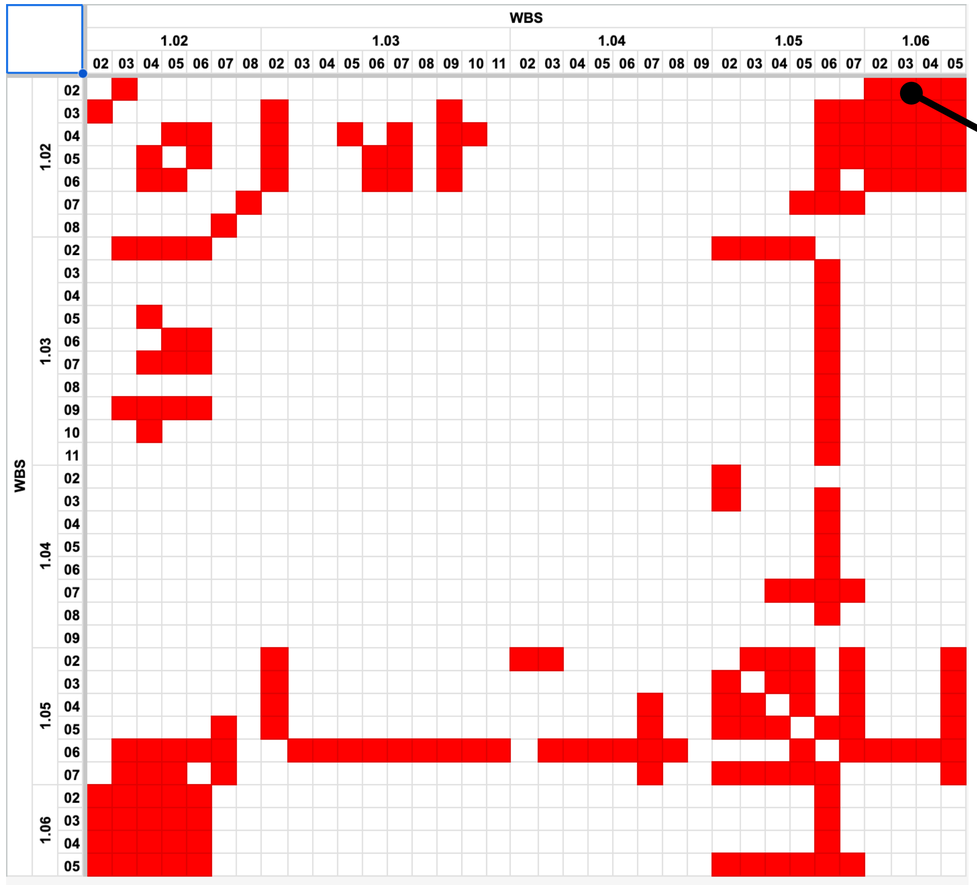

Sample exchange and screening results between WBS1.02.02 and WBS1.06.03

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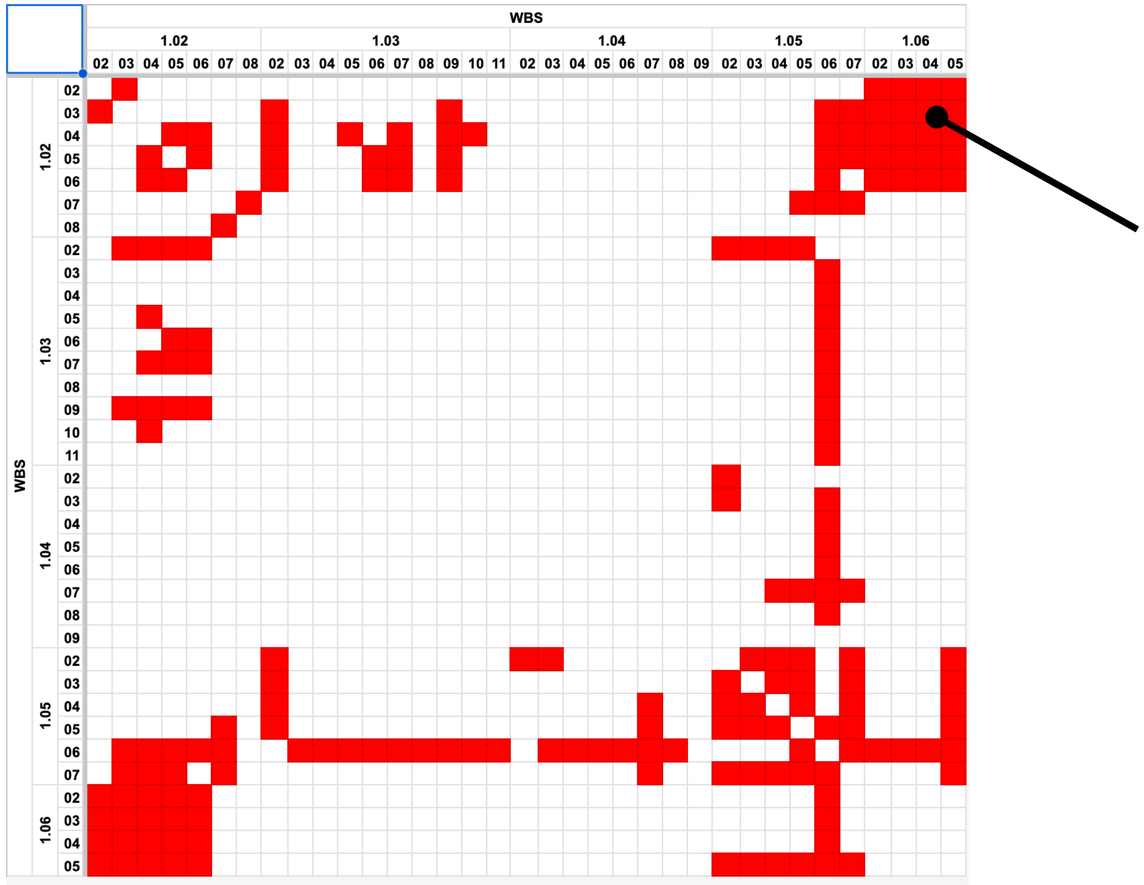

CCVR crystals interface
between WBS1.02.03 and WBS1.06.05

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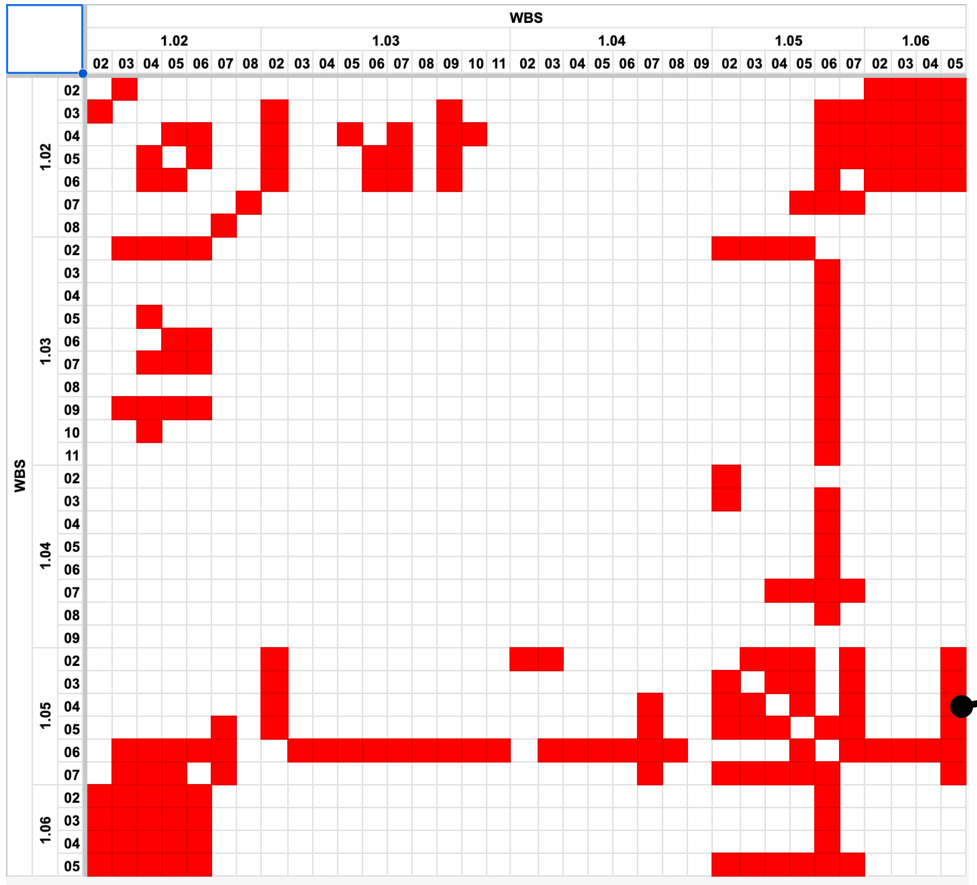
- Dependancies tracked in P6 as predecessors and successors
- L2 and L3 managers control interfaces, draft interface control documents in place



Readout for CCVR interface
between WBS1.05 and WBS1.06.05

WBS 1.06: Lessons learned/Technical Review Response

- Technical review held in July 2023
- Review committee provided three recommendations

> - The Collaboration should make sure to have the risk registry in order for CD-1.

Response: Risk registry is now in place

> - The Collaboration's message on the background index (BI) is not perspicuous. The differentiation between their goal and KPP on BI can be sharpened (e.g., a clear delineation of the achieved level and projected improvements, as well as their tie to the goal (UPP)).

Response: We now state the background budget with a breakdown of requirements by component. We identify levels that have been achieved and levels which assume projected improvements

> - The Collaboration has not established a written agreement with SuperCDMS on the usage of the NEXUS facility. The Collaboration should pursue this agreement to secure the availability and priority of the facility for its CVR.

Response: We no longer plan to use NEXUS

WBS 1.06: Summary

- Scope of WBS 1.06 Background control is to assess radiopurity of detector materials
- CUPID radiopurity requirements come from background budget and mature simulations of detector geometry and response
- Well-established techniques are available, validated by data from the current generation of low-background experiments
- The management team (L2s and L3s) have experience in Background Control
- Risks are manageable

References

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