SuperCDMS SNOLAB

CD2/CD3 Review

Detector Towers Overview

Richard Partridge

January 24-26, 2018

Outline

Scope of Work

WBS Structure and Organization

Requirements and Design Parameters

Technical Overview

Summary of Previous Review Recommendations

Readiness Reviews

Schedule

Cost

Risks and Mitigations

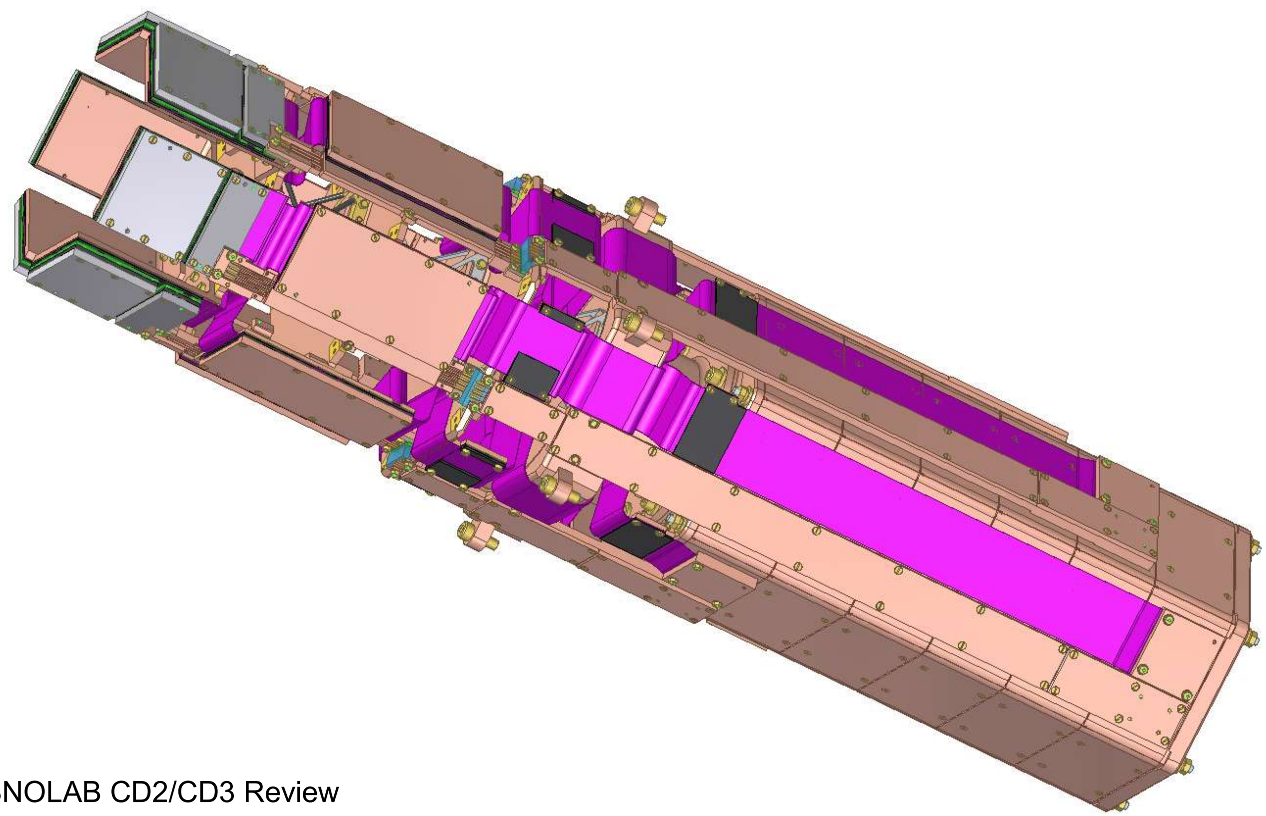
Summary

Detector Towers

Four Detector Towers serve as the payload for the experiment

Each tower provides a modular assembly supporting detectors and associated mechanical and electrical components

Four detector variants: Si HV, Ge HV, Si iZIP, and Ge iZIP

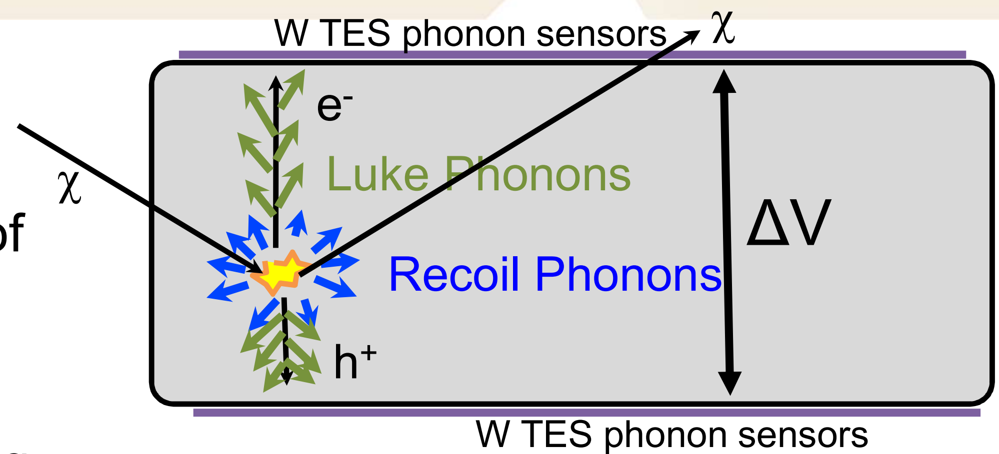


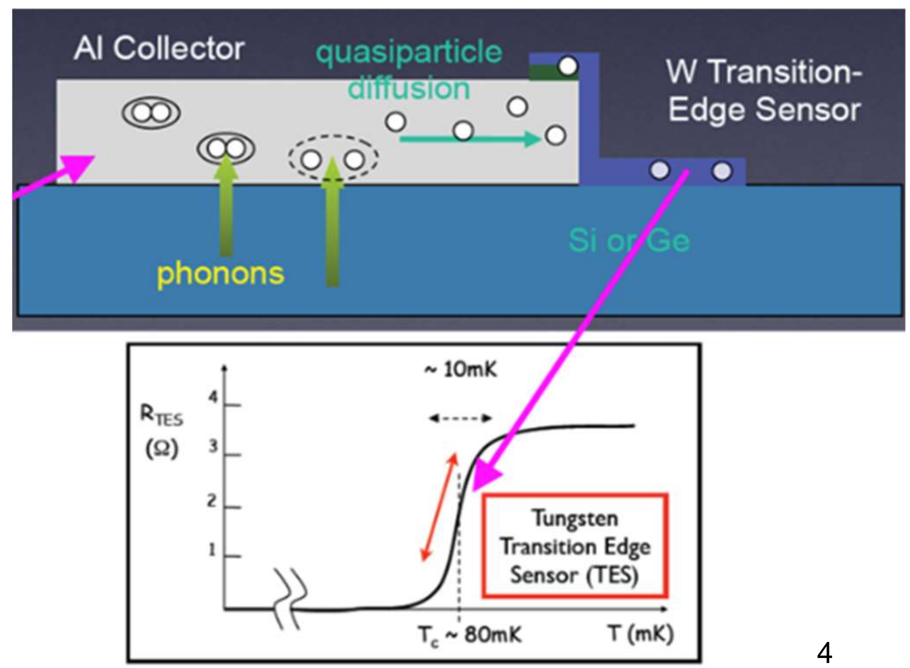
High Voltage Detectors

High Voltage detectors convert ionization into phonon signal

- An e-h pair produces 100 eV of Luke phonons @ ΔV = 100 V
- In addition measure recoil phonons generated by recoiling nucleus
- Excellent phonon resolution (10 eV goal) $\Rightarrow$ very low energy threshold

We measure phonons using Al films connected to W Transition Edge Sensors (TES)

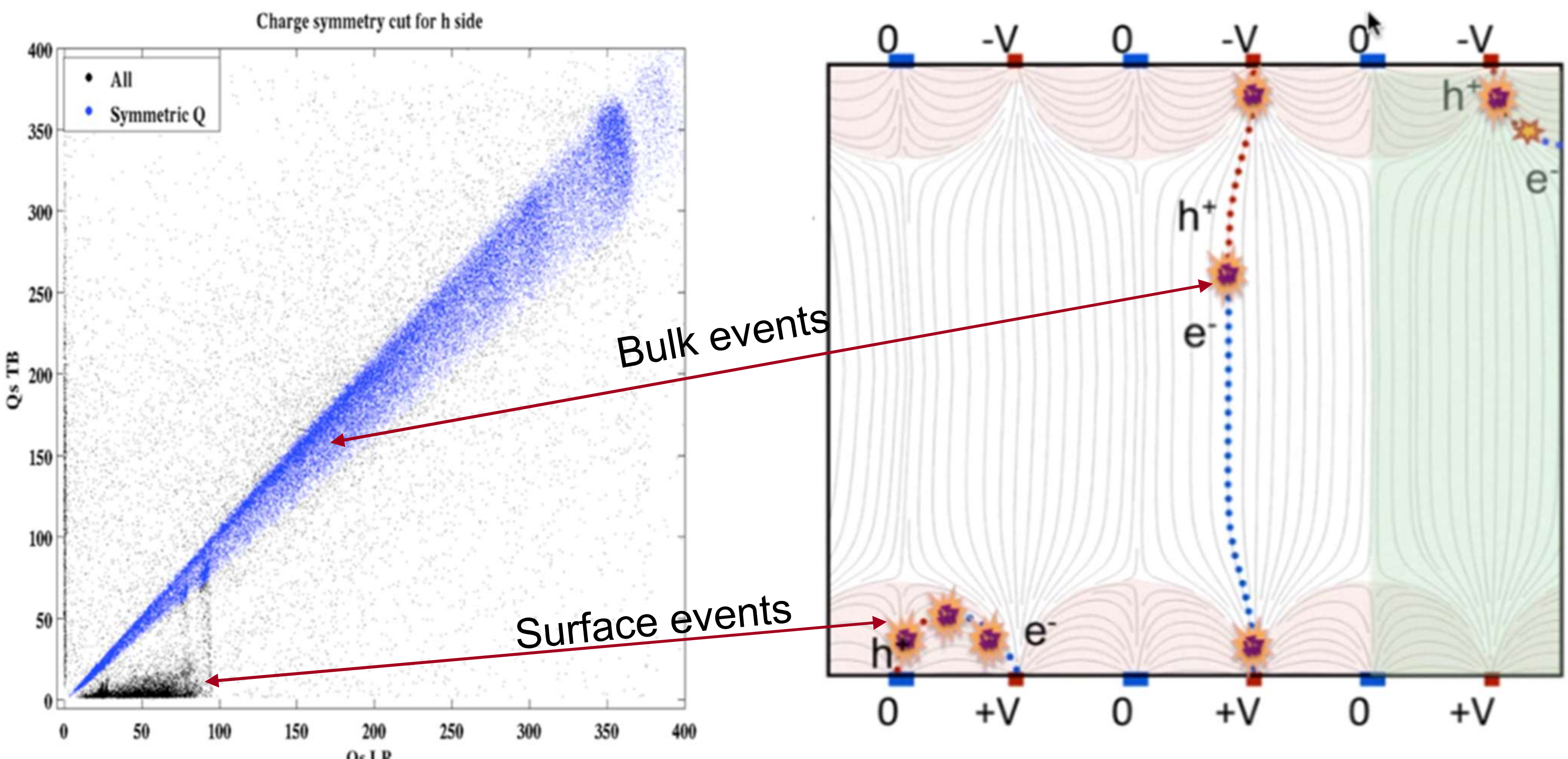




iZIP Detectors

iZIP detectors measure both ionization and phonon signals

- Scalloped electric field rejects surface electrons with high efficiency
- Ionization measurement allows rejection of electron recoil backgrounds



Tower Deliverables

Plan to deploy two preproduction towers (red) and two production towers (green) at SNOLAB

Tower 1 composed of 6 Ge iZIP detectors

- Uses Ge crystals with higher cosmogenic exposure

Tower 2 composed of 4 Ge, 2 Si HV detectors

- First tower using crystals with low cosmogenic exposure

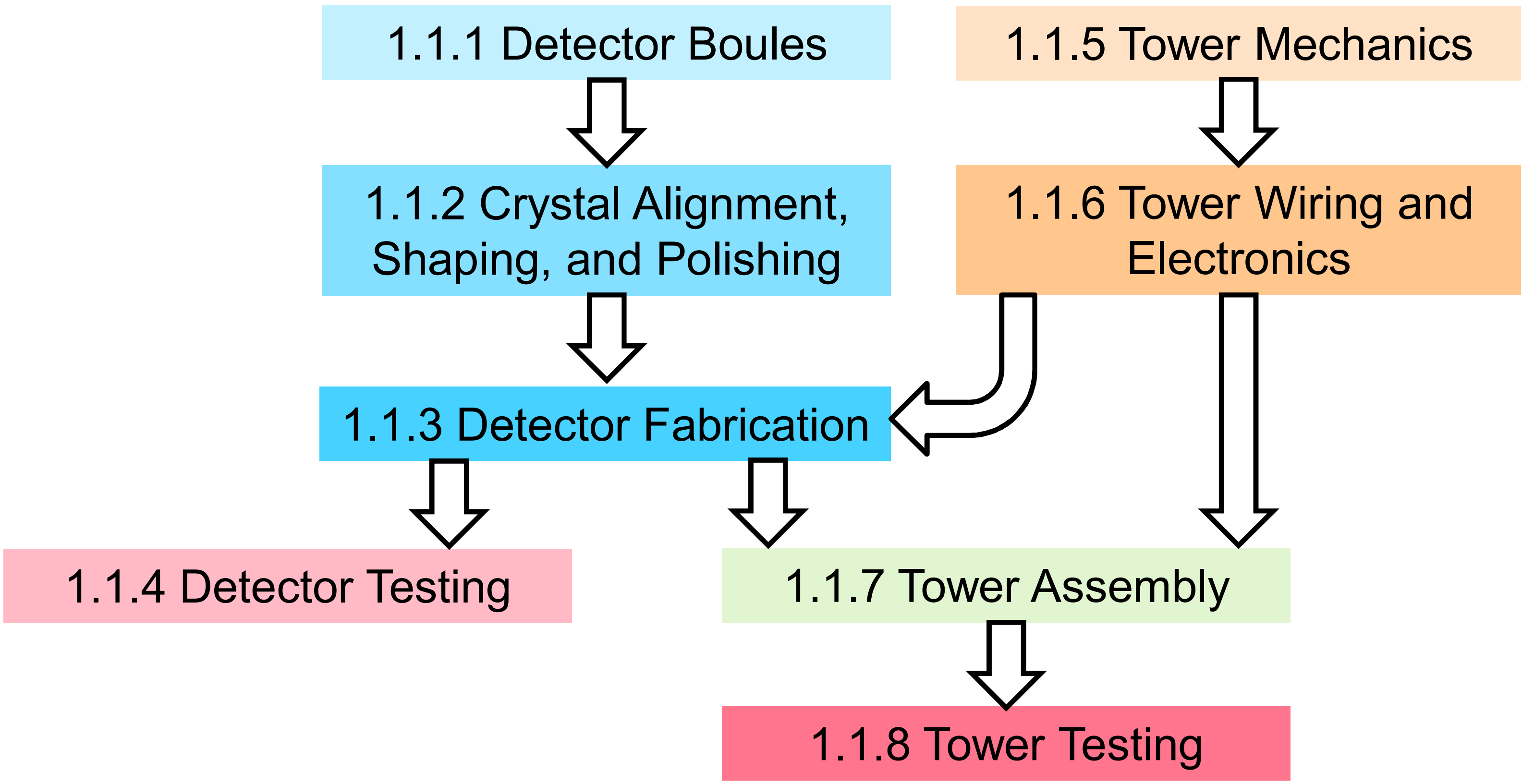
Tower 3 composed of 4 Ge, 2 Si HV detectors

- Second HV tower, fabricated in parallel with Tower 4

Tower 4 composed of 4 Ge, 2 Si iZIP detectors

- Tower 4 iZIPs will assist in understanding Tower 3 backgrounds
- Work underway to quantify additional science reach that can be achieved using analysis techniques that account for backgrounds

Detector Tower WBS



CQ#3

Detector Tower Organization

- 1.1 Detector Towers
R. Partridge
(S. Golwala)
  - WBS 1.1.1 Detector Boules – B. Young
  - WBS 1.1.2 Crystal Polishing – M. Platt
  - WBS 1.1.3 Detector Fab – P. Brink
  - WBS 1.1.4 Detector Testing – M. Fritts
  - WBS 1.1.5 Tower Mechanics – M. Oriunno
  - WBS 1.1.6 Tower Electronics – P. Hansson
  - WBS 1.1.7 Tower Assembly – T. Aramaki
  - WBS 1.1.8 Tower Testing – B. Serfass

Detector Towers is staffed with experienced L3 managers

- Extensive technical expertise in their area of responsibility
- Responsible for delivering their subsystem within baseline budget and schedule

Four breakout talks will cover details of technical design

- Detector Design (including 1.1.4, 1.1.8) – Noah Kurinsky
- Detector Fabrication (including 1.1.1, 1.1.2, 1.1.3) – Paul Brink
- Tower Mechanics (including 1.1.5, 1.1.7) – Marco Oriunno
- Tower Electronics (1.1.6) – Pelle Hansson

Detector Tower effort is staffed with experienced leaders with the experience and expertise needed to deliver the proposed technical scope

Science Goals Flow-down to Technical Requirements

CQ#1

Science Goals
SG-1 Search for dark matter particles with masses below 10 GeV/c^2 using complementary target nuclei (germanium and silicon) and complementary techniques (iZIP and HV) that will provide an understanding of residual backgrounds.
SG-2 Design for the possibility of future upgrades that would further increase the low-mass sensitivity of the experiment to the level where solar neutrinos are detected.

Technical Requirements

	Required	Goal
Number of Detector Towers	4	4
Fraction of fully-operational detectors	80%	100%
HV detectors		
Projected bulk background for Ge (Si)	<100(1100)/keV/kg/year	<50(550)/kev/kg/year
Phonon energy resolution (σ) for Ge (Si)	50 (35) eV_t	10 (7) eV_t
Minimum bias voltage	50 V	100 V
iZIP detectors		
Phonon energy resolution (σ) for Ge (Si)	100 (50) eV_t	50 (25) eV_t
Charge energy resolution (σ) for Ge (Si)	300 (330) eV_{ee}	160 (180) eV_{ee}

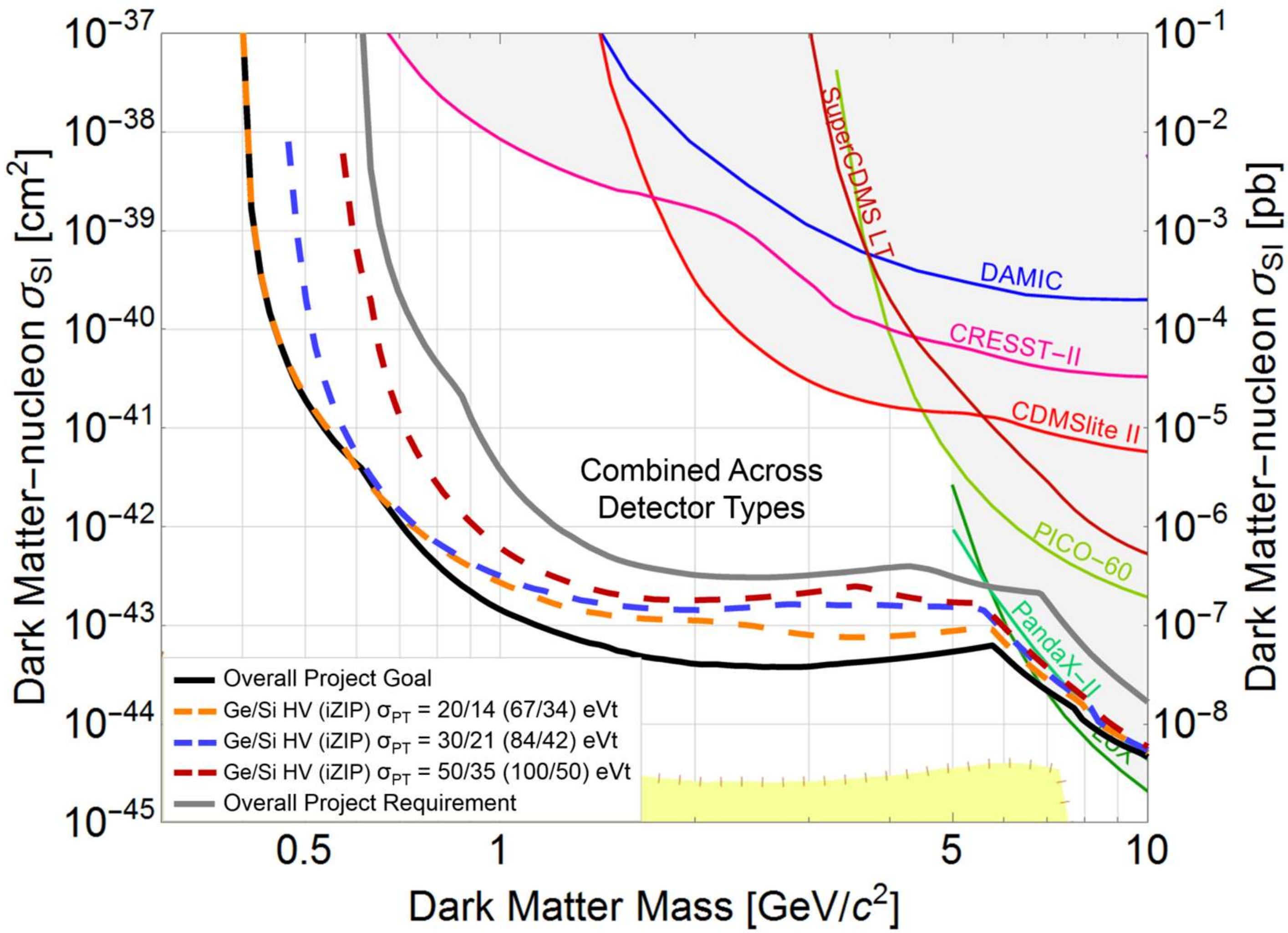
	Required	Goal
SNOBOX Capacity	31 towers	31 towers
Cryogenic operating temperature	30 mK	15 mK
Bandwidth for DAQ/Trigger System	50 MB/s	100 MB/s
Underground clean room Radon levels	< 5 Bq/m^3	< 0.1 Bq/m^3

Flow-down to Detector Tower Design Parameters

Flow-down to Fabrication, Testing, and Material Selection Procedures

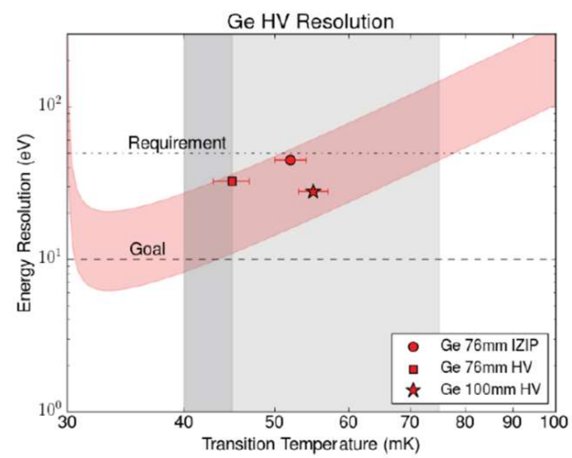
Technical Requirements flow-down to Detector Tower Design Parameters and Fabrication, Testing, and Material Selection procedures

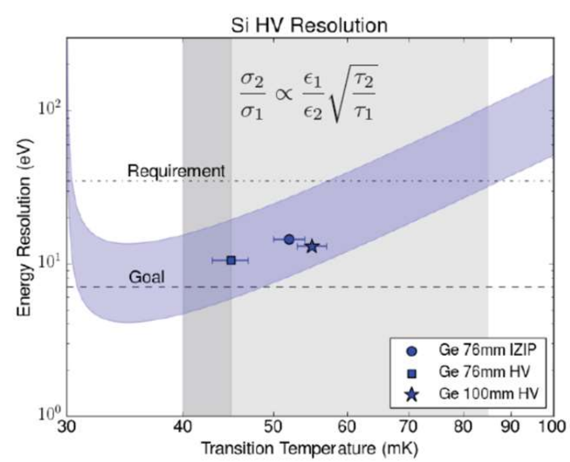
Phonon Energy Resolution Impacts DM Sensitivity



Technical Requirement Flow-down to Design Parameters

Parameter	Design Value CDMS-HV	iZIP
Crystal Temperature	<30 mK	
TES Parameters		
Length	200 μm	155 μm
Normal State Resistance	150 mΩ	
Operating Resistance	50 mΩ	
Loop Inductance	$\ll$ 500 nH	
Shunt Resistance	5 mΩ	
Parasitic Resistance	< 5 mΩ	
$\alpha \left(\frac{R_0}{T_c} \frac{dR}{dT} \Big\|_{I_0} \right)$	$\sim$ 150	
$\|\beta\| \left(\frac{R_0}{I_0} \frac{dR}{dI} \Big\|_{T_c} \right)$	< 0.3	
T_c	40-45 mK	40-60 mK
Risetime (L/R)	2-3 μs	2-4 μs
Falltime (τ_{TES})	30-40 μs	10-40 μs
QET Parameters		
Geometry	"Stadium"	"Linear"
Fin Length	240 μm	80-110 μm
Trap Geometry	"Semicircle"	"Rectangle"
Trap Length	20 μm	5 μm
QET Number	$\sim$1800	$\sim$1400
Energy Efficiency (ϵ_E), Ge	15%	13%
Energy Efficiency (ϵ_E), Si	22%	19%
Aluminum Coverage	35%	4%
Phonon Falltime (τ_{phonon}), Ge	200 μs	1400 μs
Phonon Falltime (τ_{phonon}), Si	40 μs	300 μs
Charge Input Capacitance	N/A	$\leq$300 pF
Charge Channel		100-180 pF
HEMT Input		100 pF
Parasitic		20 pF
Charge Collection Efficiency	N/A	95%





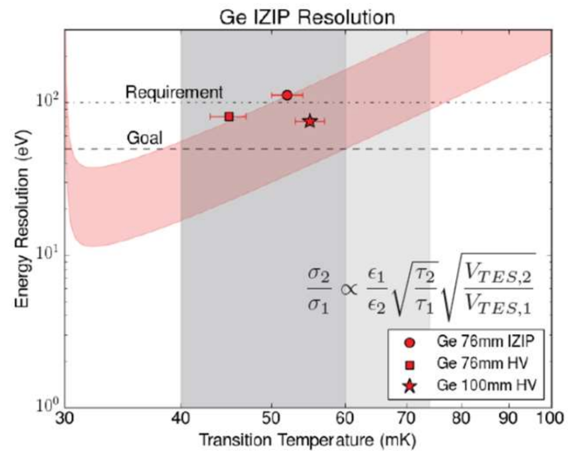
See Detector Design talk by N. Kurinsky for details

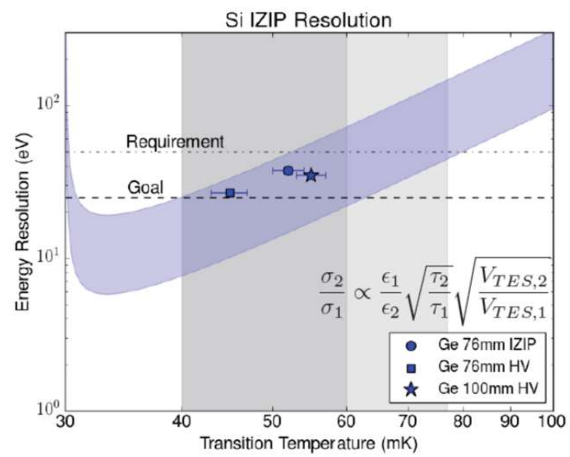
Design parameters achieve HV phonon resolution Technical Requirements

CQ#1

Technical Requirement Flow-down to Design Parameters

Parameter	Design Value CDMS-HV	iZIP
Crystal Temperature	<30 mK	
TES Parameters		
Length	200 μm	155 μm
Normal State Resistance	150 mΩ	
Operating Resistance	50 mΩ	
Loop Inductance	$\ll$ 500 nH	
Shunt Resistance	5 mΩ	
Parasitic Resistance	$<$ 5 mΩ	
$\alpha \left(\frac{R_0}{T_c} \frac{dR}{dT}\Big\|_{I_0} \right)$	$\sim$ 150	
$\|\beta\| \left(\frac{R_0}{I_0} \frac{dR}{dI}\Big\|_{T_c} \right)$	$<$ 0.3	
T_c	40-45 mK	40-60 mK
Risetime (L/R)	2-3 μs	2-4 μs
Falltime (τ_{TES})	30-40 μs	10-40 μs
QET Parameters		
Geometry	"Stadium"	"Linear"
Fin Length	240 μm	80-110 μm
Trap Geometry	"Semicircle"	"Rectangle"
Trap Length	20 μm	5 μm
QET Number	~1800	~1400
Energy Efficiency (ϵ_E), Ge	15%	13%
Energy Efficiency (ϵ_E), Si	22%	19%
Aluminum Coverage	35%	4%
Phonon Falltime (τ_{phonon}), Ge	200 μs	1400 μs
Phonon Falltime (τ_{phonon}), Si	40 μs	300 μs
Charge Input Capacitance	N/A	$\leq$300 pF
Charge Channel		100-180 pF
HEMT Input		100 pF
Parasitic		20 pF
Charge Collection Efficiency	N/A	95%



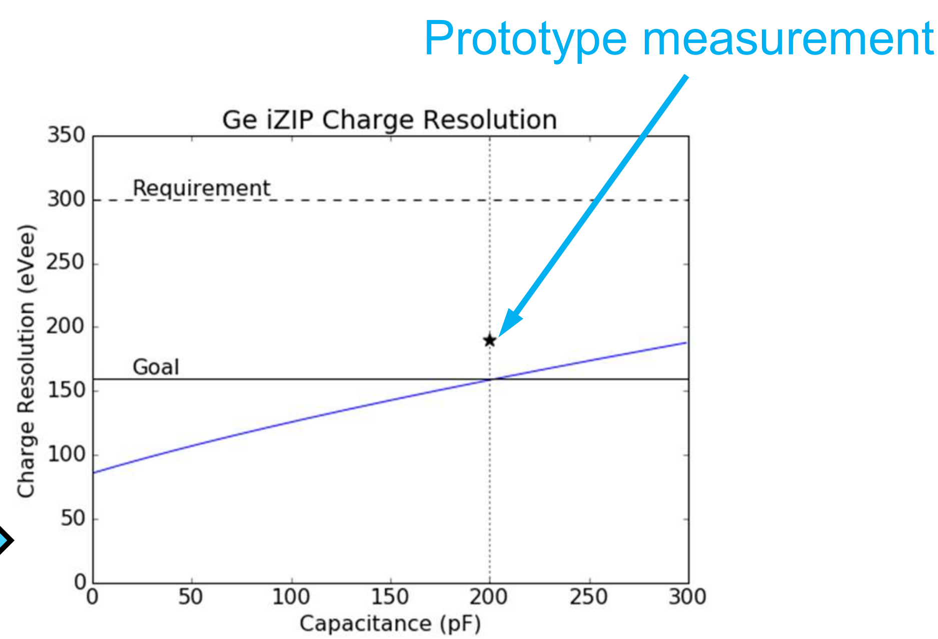


Design parameters achieve iZIP phonon resolution Technical Requirements

CQ#1

Technical Requirement Flow-down to Design Parameters

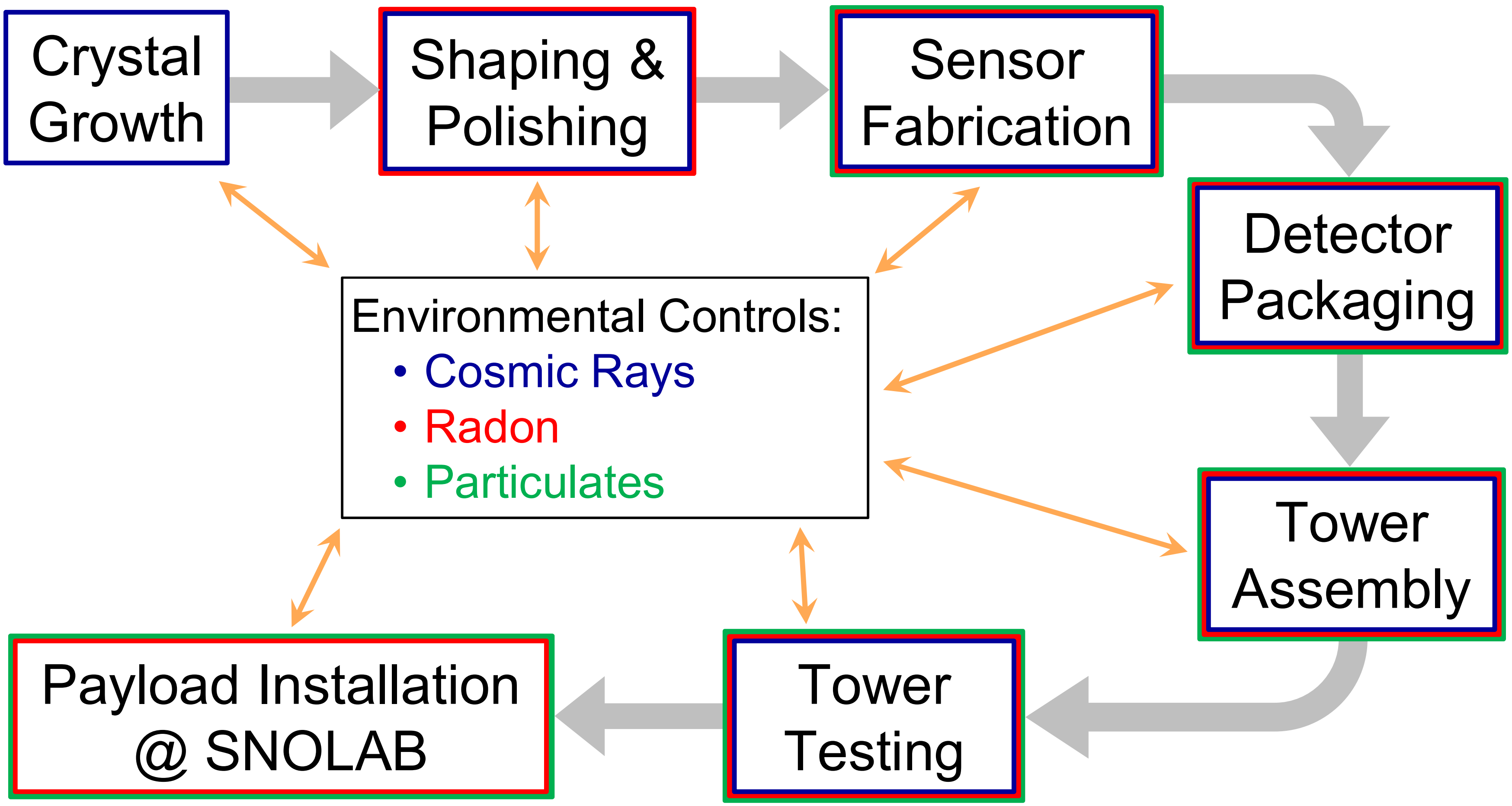
Parameter	Design Value CDMS-HV	iZIP
Crystal Temperature	<30 mK	
TES Parameters		
Length	200 μm	155 μm
Normal State Resistance	150 mΩ	
Operating Resistance	50 mΩ	
Loop Inductance	$\ll$ 500 nH	
Shunt Resistance	5 mΩ	
Parasitic Resistance	< 5 mΩ	
$\alpha \left(\frac{R_0}{T_c} \frac{dR}{dT} \Big\|_{I_0} \right)$	$\sim$ 150	
$\|\beta\| \left(\frac{R_0}{I_0} \frac{dR}{dI} \Big\|_{T_c} \right)$	< 0.3	
T_c	40-45 mK	40-60 mK
Risetime (L/R)	2-3 μs	2-4 μs
Falltime (τ_{TES})	30-40 μs	10-40 μs
QET Parameters		
Geometry	"Stadium"	"Linear"
Fin Length	240 μm	80-110 μm
Trap Geometry	"Semicircle"	"Rectangle"
Trap Length	20 μm	5 μm
QET Number	~1800	~1400
Energy Efficiency (ϵ_E), Ge	15%	13%
Energy Efficiency (ϵ_E), Si	22%	19%
Aluminum Coverage	35%	4%
Phonon Falltime (τ_{phonon}), Ge	200 μs	1400 μs
Phonon Falltime (τ_{phonon}), Si	40 μs	300 μs
Charge Input Capacitance	N/A	$\leq$300 pF
Charge Channel		100-180 pF
HEMT Input		100 pF
Parasitic		20 pF
Charge Collection Efficiency	N/A	95%



Design parameters achieve iZIP charge resolution Technical Requirements

CQ#1

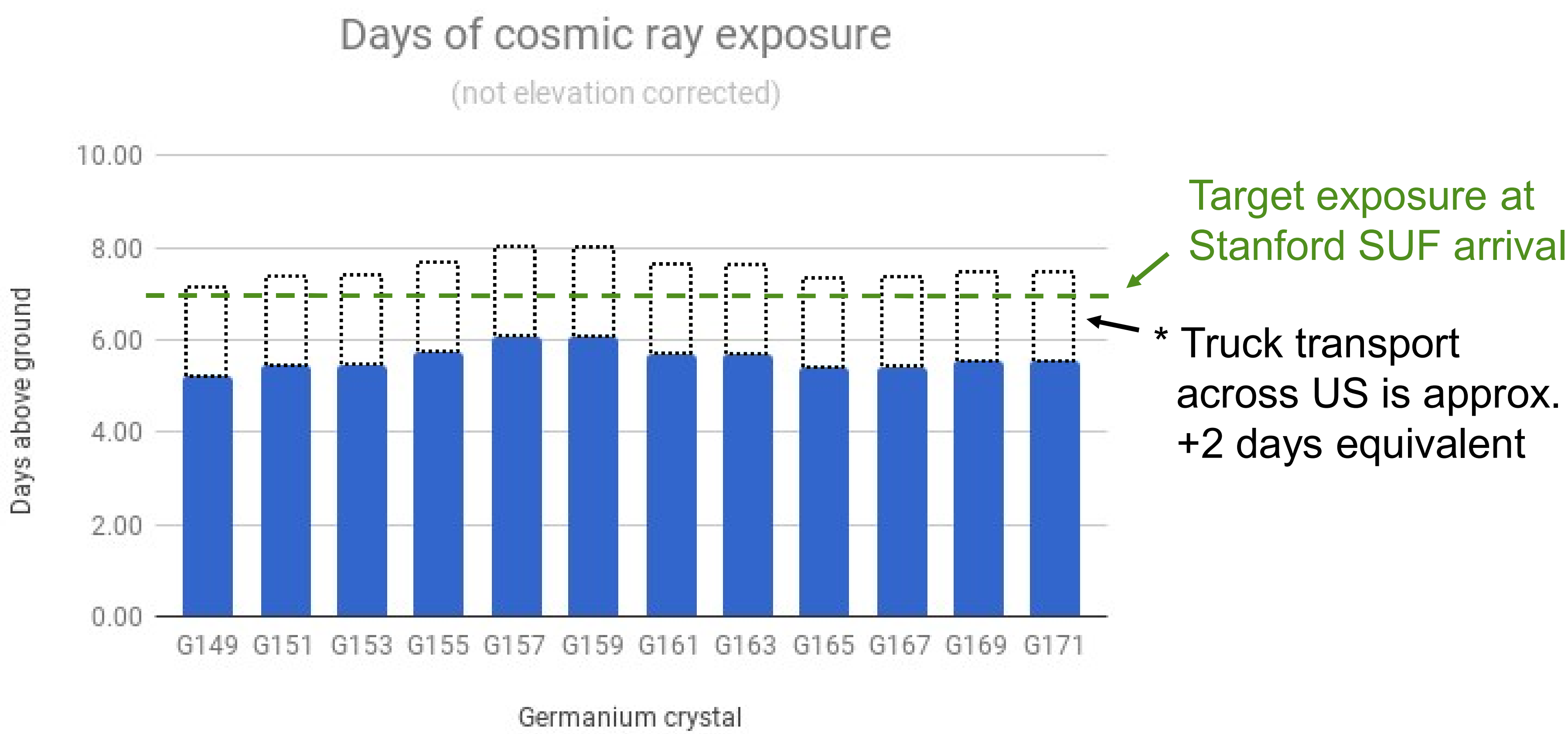
Background Control During Life of a Detector



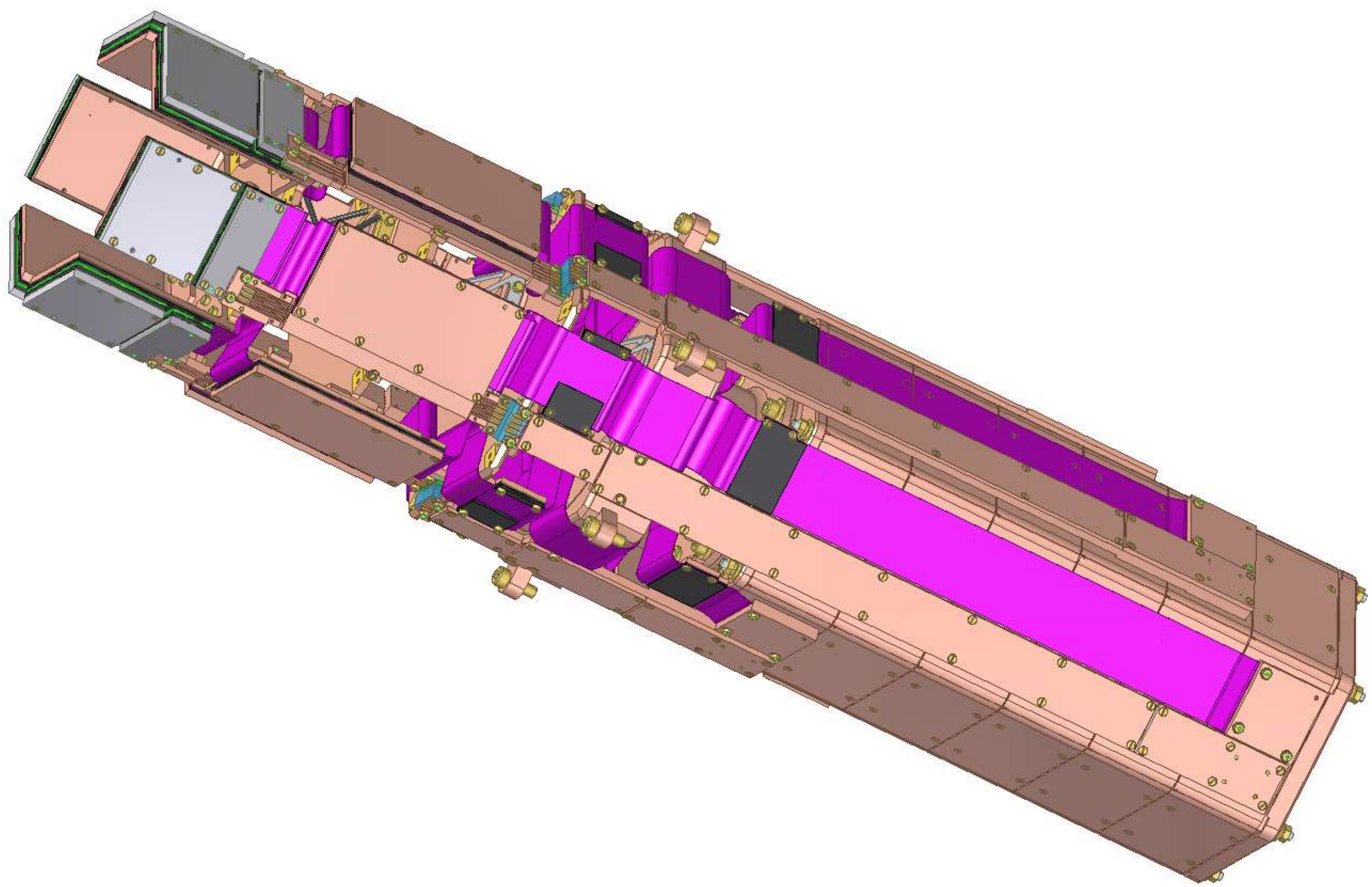
Example: Cosmogenic Exposure Tracking

Tritium produced by cosmic ray interactions is a significant background for Ge HV detectors

- Crystals have been fabricated, shipped to east coast port in shielded cargo container
- On track to meet cosmogenic exposure goal



Detector Tower Technical Overview

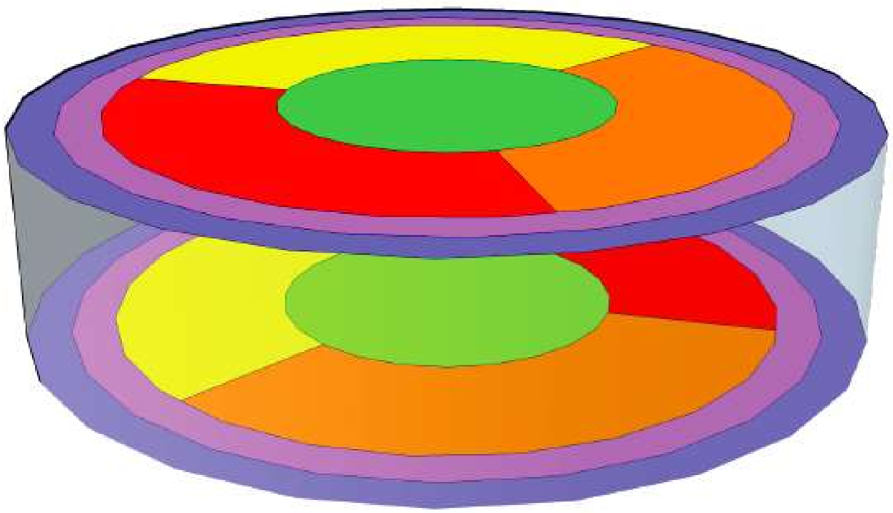


Detector Channel Layouts

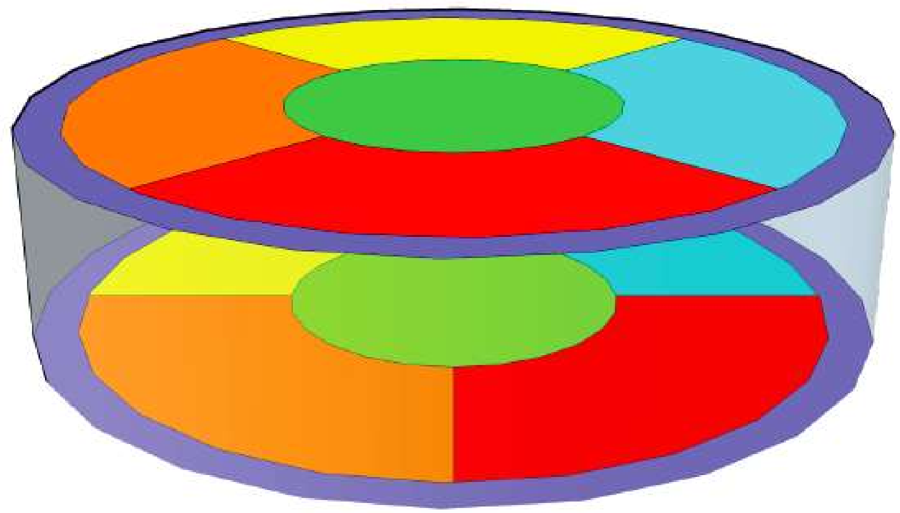
Each detector has 12 phonon channels, with each channel having several thousand TES wired in parallel

iZIP detectors also have 4 ionization channels

- Inner and outer channels on each side define fiducial volume in bulk of crystal



HV Channel Layout

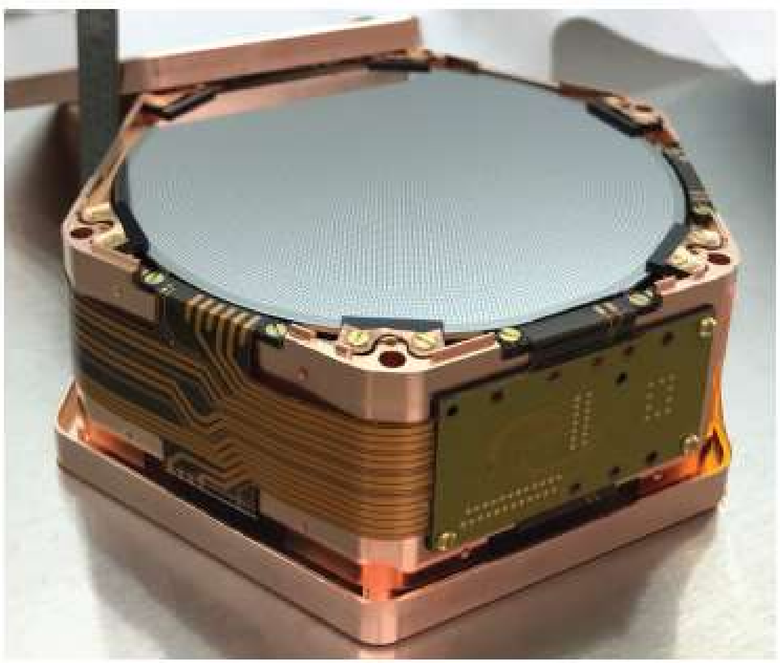


iZIP Channel Layout

Channel layouts optimized for event position identification to help reject surface backgrounds

Detector Fabrication

HV and iZIP detectors fabricated by photolithographic patterning of thin films (Al, W, and pc-Si) deposited on both faces of polished Si / Ge crystals



Ge HV Pathfinder Detector

iZIP Prototype Detector

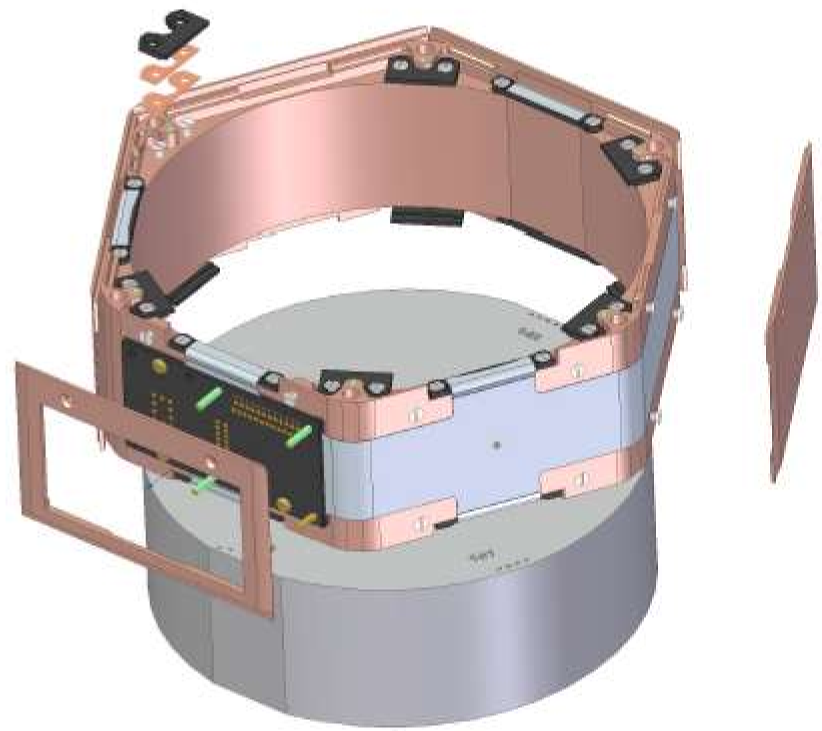
Detectors Mounted in Copper Housing

Cirlex clamps hold detector in place and provide the thermal connection for cooling the detector

Horizontal flex cable wraps around housing to provide the wiring that is fixed to the detector

- Wire bonds connect the detector electrodes to the horizontal flex

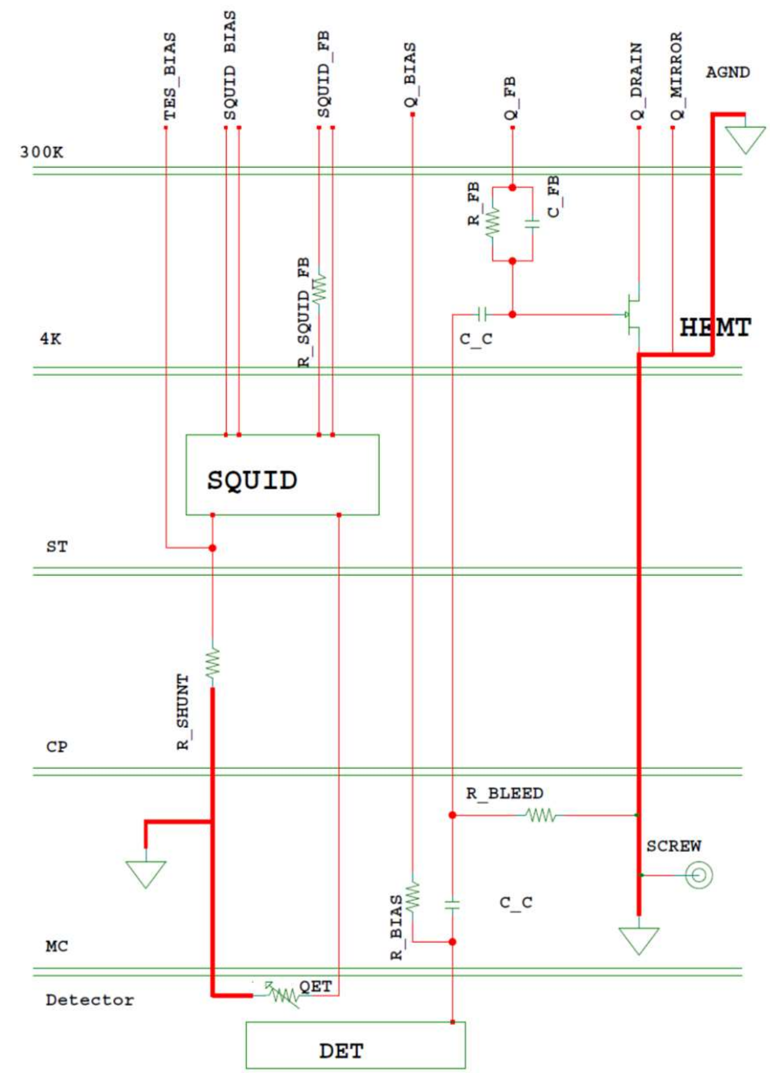
HV and iZIP detectors use identical housings but different horizontal flex cables



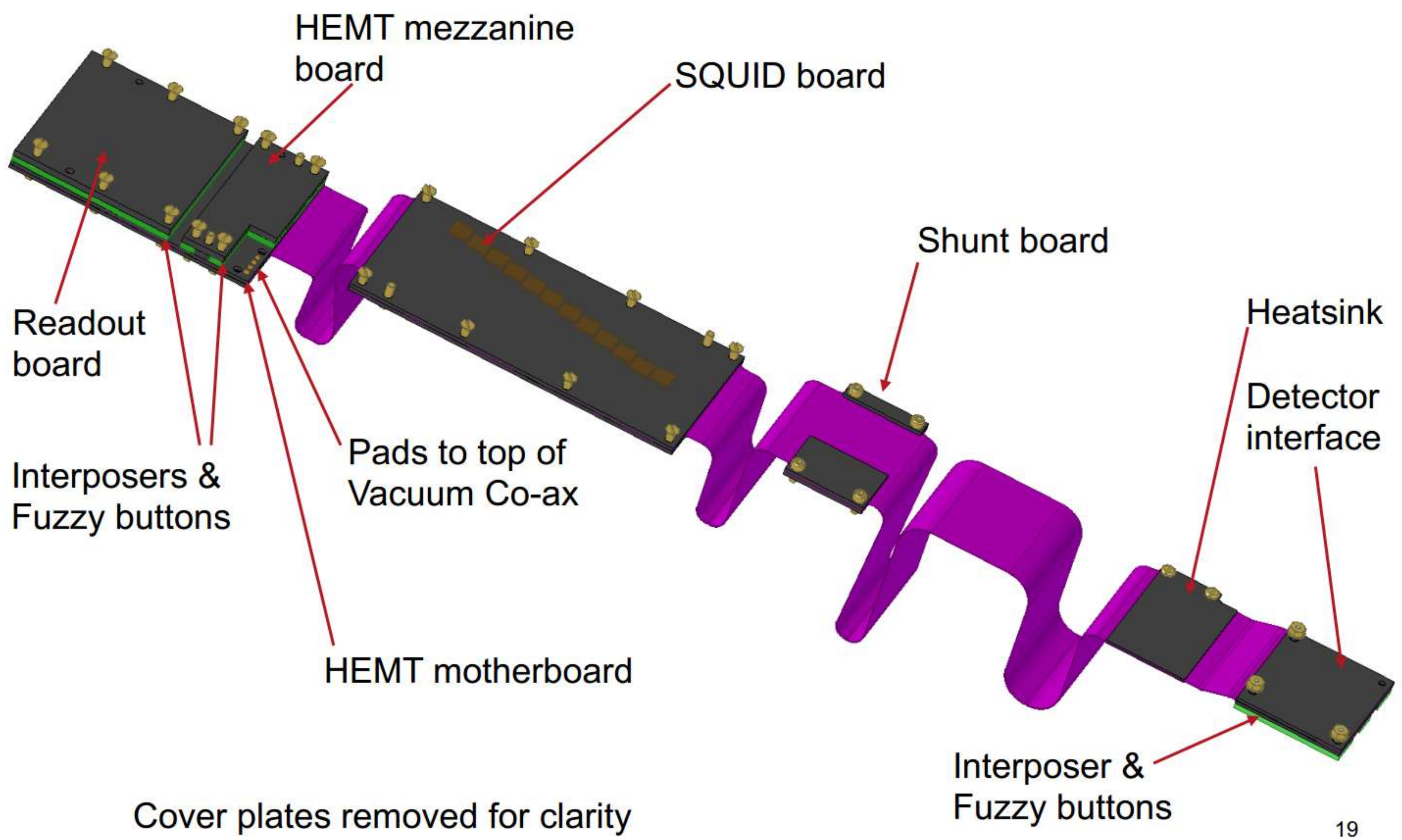
Tower Wiring and Electronics

Tower Wiring and Electronics provides:

- SQUID readout of phonon signals
- HEMT readout of ionization signals
- Wiring must provide:
  - Low parasitic resistance and inductance for SQUID signals
  - Low thermal conductivity
  - Immunity to microphonic pickup of mechanical vibrations



Vertical Flex Cable Implements Cryogenic Electronics



Superconducting Flex Cable Technology

Superconducting vertical flex cable is the backbone for the tower electronics

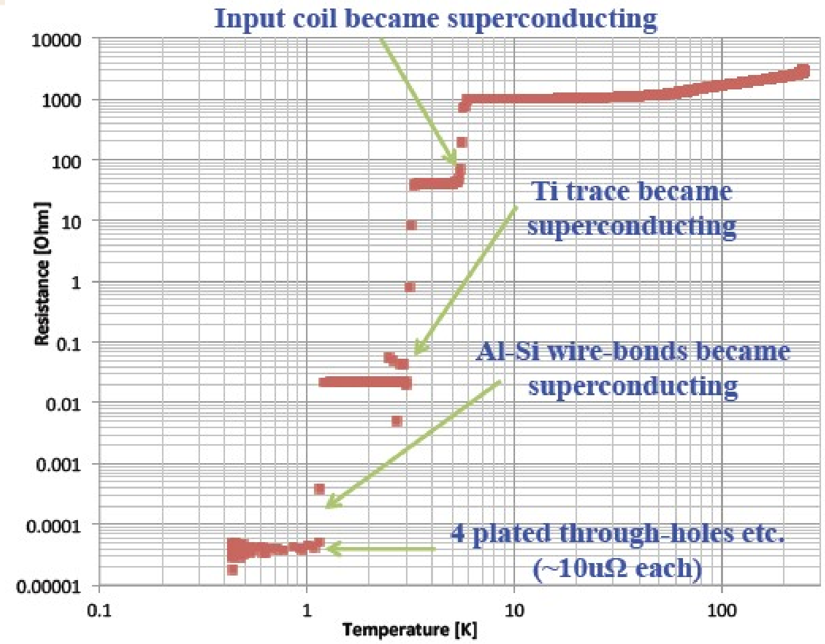
- NbTi foils mounted on a kapton substrate are etched to provide zero-resistance, low thermal conduction wiring
- Cirlex stiffener boards with copper traces are laminated to the flex cable to host the cryogenic front-end electronics
- Connectivity to the NbTi flex cable is made using copper plated through holes that bond to copper plating on the NbTi foil
  - Allows conventional PCB interconnection to NbTi conductors
  - Copper plating is removed on cable sections between the stiffeners to provide thermal isolation

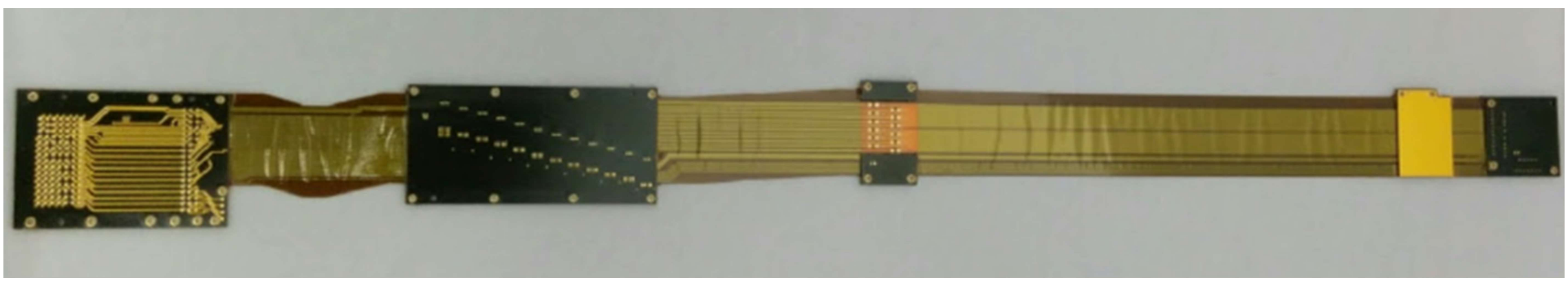
Horizontal flex is made superconducting by tin plating copper traces

Vertical Flex Cable Technology Demonstration

Demonstrated superconducting vertical flex cable technology using Ti 15-3-3-3 foils

- Negligible parasitic resistance
- Preproduction cables with NbTi foils are in fabrication
- Developing fixtures to aid vertical flex cable installation - Ti 15-3-3-3 prototype cables significantly stiffer than earlier Cu prototypes (see talk by M. Oriunno)





Successful demonstration of superconducting vertical flex cable technology

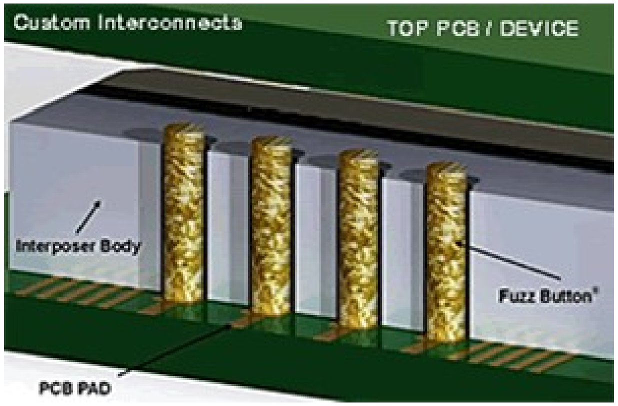
Fuzz Button Interconnections

Traditional connectors do not meet CDMS requirements

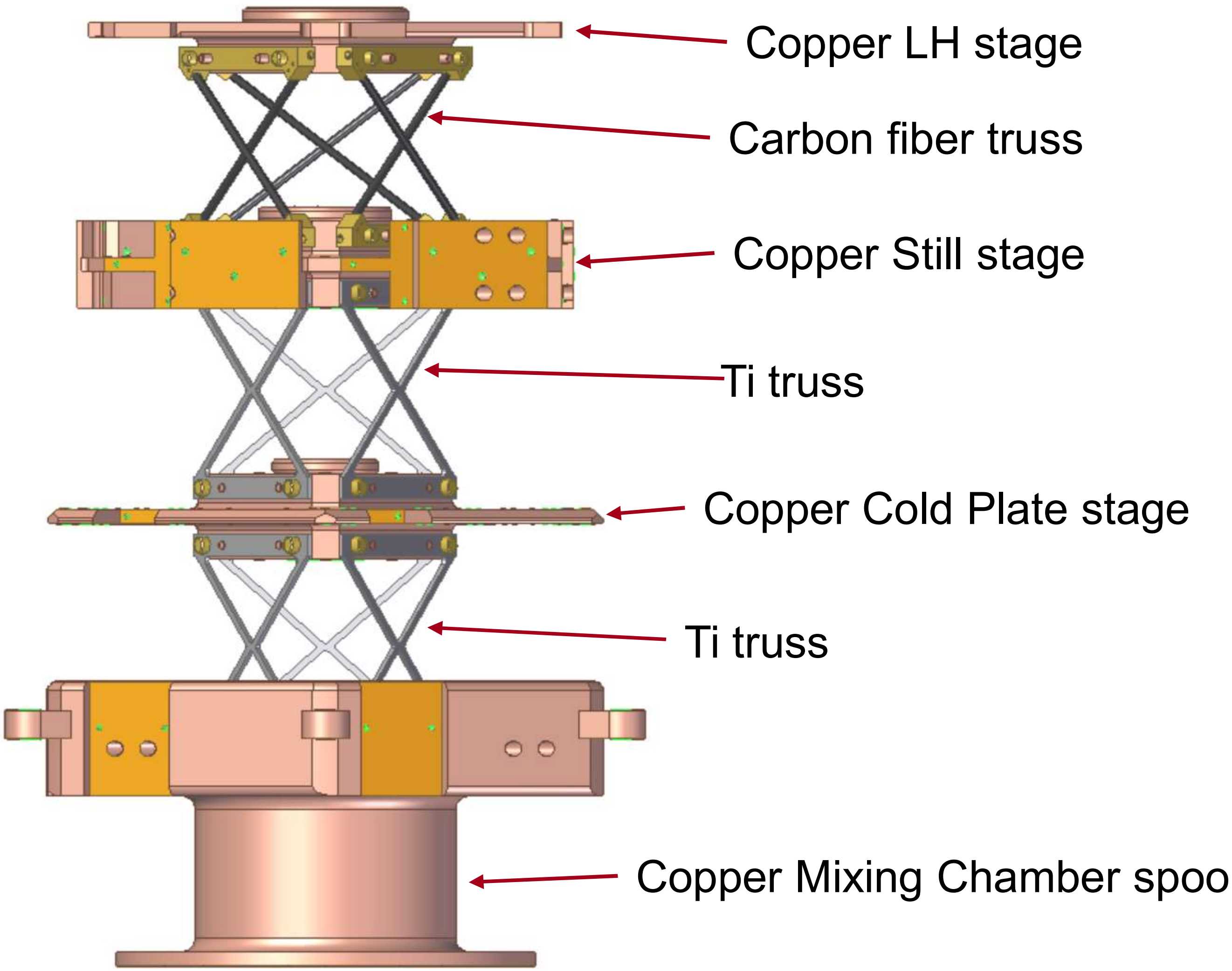
- Connector body and CuBe contacts are too radioactive
- Contact resistance is typically several mOhm

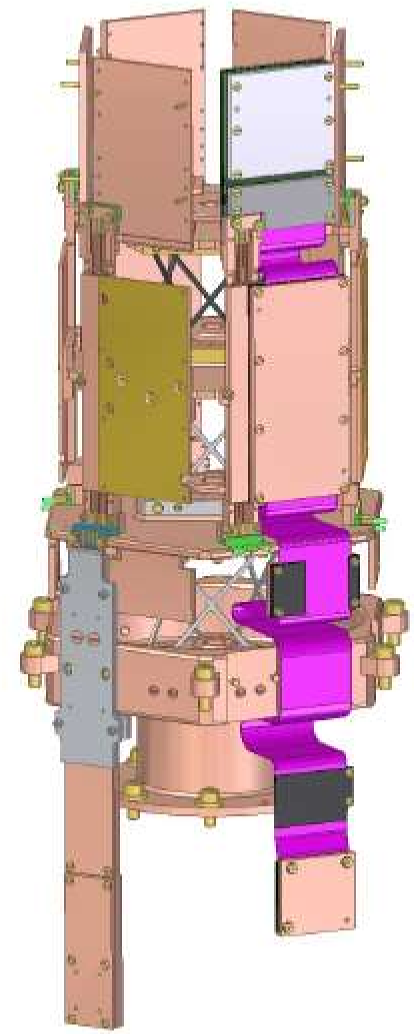
Fuzz button interposers solve both problems

- Custom made using radiopure materials (Mo, cirlex)
- < 1 mOhm contact resistance (Mo is a superconductor)
- Interposer sits between circuits to be connected

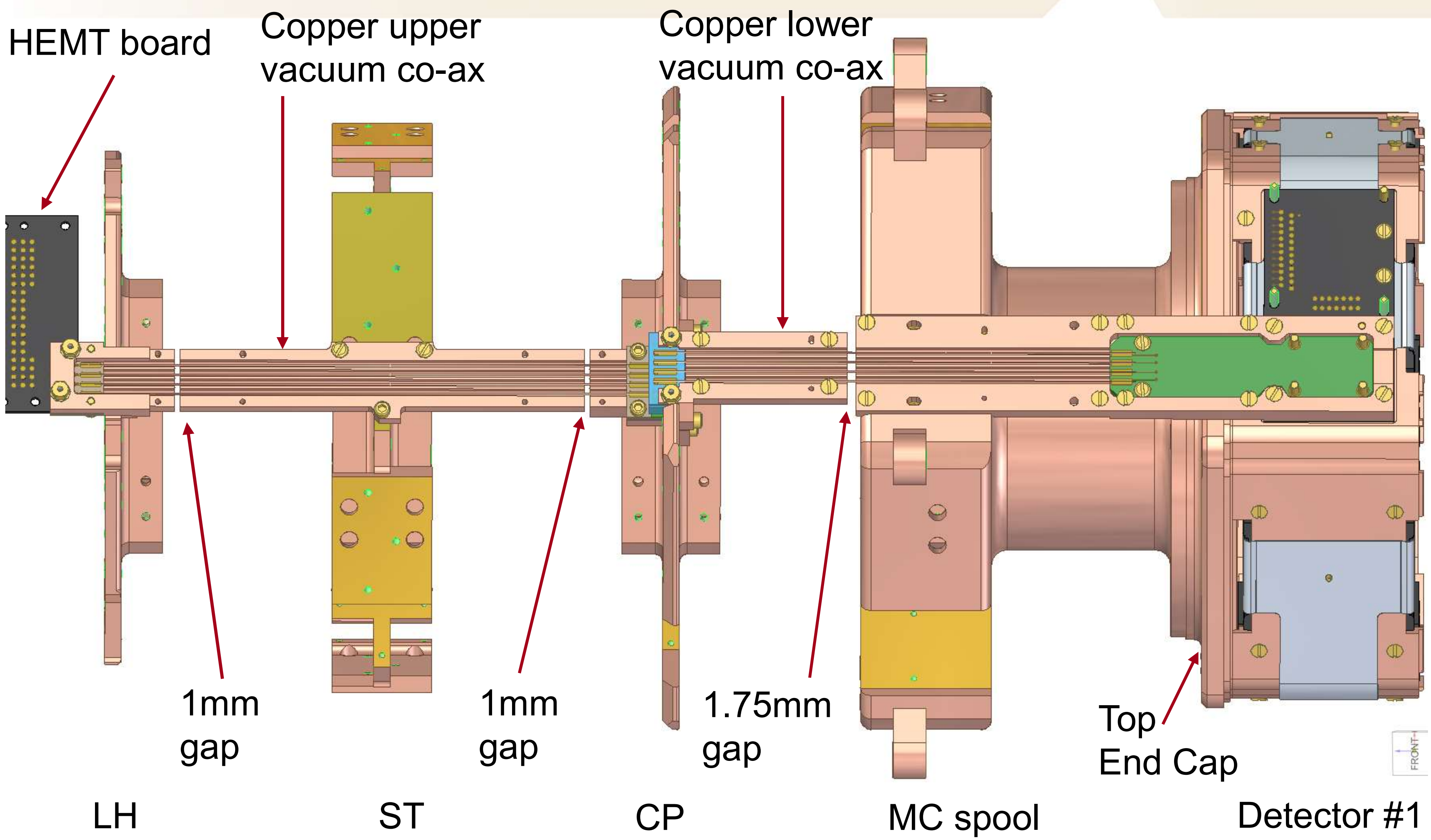


Tower Body Provides Mechanical Support and Heat Sinking for Tower Wiring and Electronics





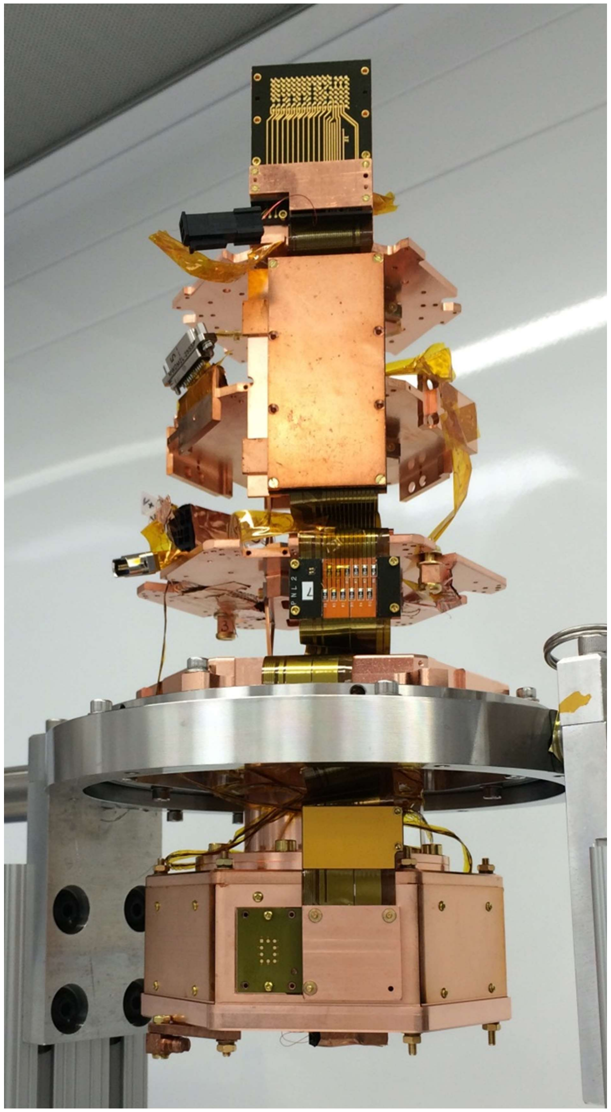
Vacuum Coax Utilizes Tensioned NbTi Wires to Bring iZIP Ionization Electrodes to 4K HEMT Front-End Electronics



Tower Assembly

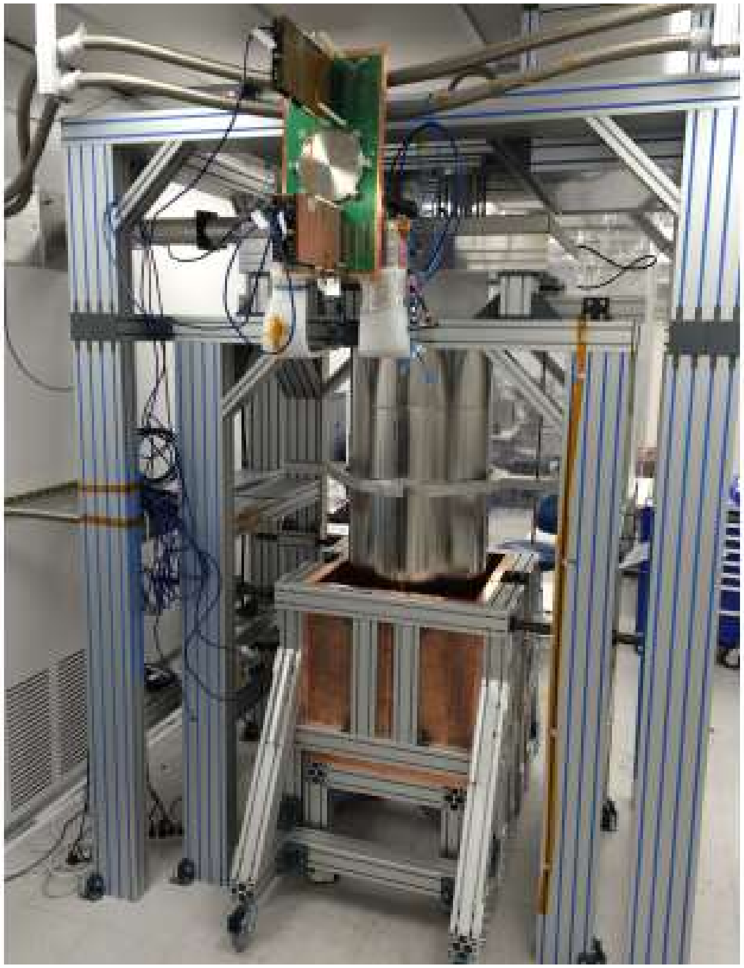
Tower assembly takes place in the SLAC Building 33 clean room

- Integration of detectors, tower mechanics, and tower wiring and electronics
- Soft-wall partition separates CDMS area from rest of clean room to maintain low-background environment
- Tower assembly carried out in Class 10 laminar flow hood in clean room



Ge HV pathfinder detector mounted on preproduction tower mechanics with prototype Ti 15-3-3-3 vertical flex cable

Tower Testing



Surface tower functional testing at SLAC / UCB prior to shipping tower to SNOLAB

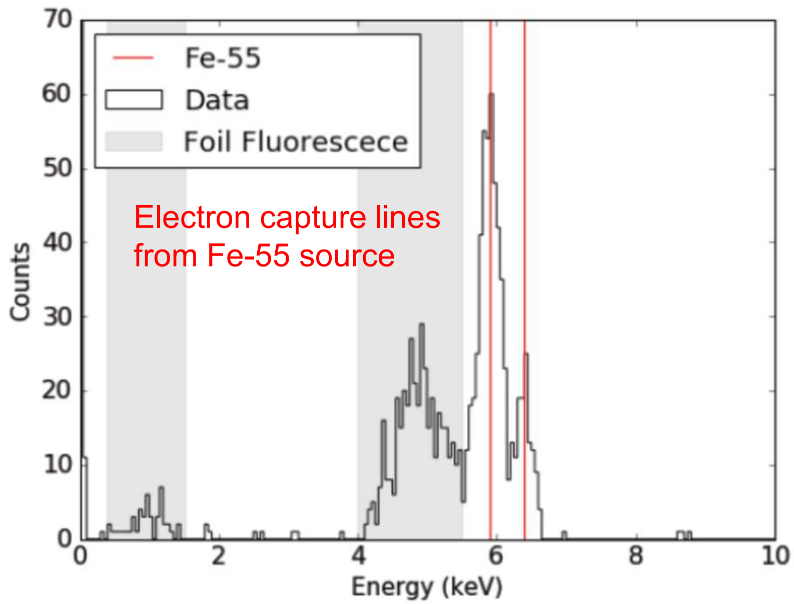
Potential for off-project underground performance testing using the Cryogenic Underground Test facility (CUTE) being developed at SNOLAB by Queens U.

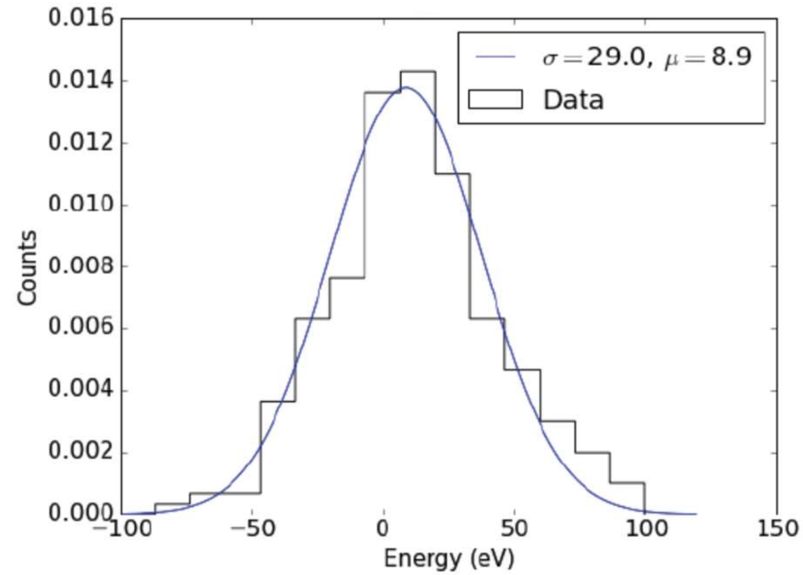
Responses to Past Review Recommendations

2017 Status Review recommended that we conduct an end-to-end surface test of a SuperCDMS-SNOLAB HV detector with prototype cables, frontend readout and DAQ. Show that the detector resolution can meet the design requirement before CD-2/3.

Response to this recommendation:

- End-to-end test of Ge HV pathfinder achieved 29 eV detector resolution, meeting the project design requirement (50 eV) using prototype cables, frontend readout, and DAQ





Past Review Recommendations have been addressed

Readiness Reviews

CQ#5

Completed Readiness Reviews	Date
Ge Batch B and Si Boule Procurement Readiness Review	15 Jan 2017
Ge Batch A Polishing Readiness Review	18 Jan 2017
Preproduction Tower Mechanics Design Review	17 Oct 2016
Preproduction Tower Mechanics Fabrication Readiness Review	17 Mar 2017
SQUID Procurement Readiness Review	11 Nov 2016
Copper Prototype Vertical Flex Design Review	16 Nov 2016
Preproduction Vacuum Coax PCB Fabrication Readiness Review	12 May 2017
Preproduction Fuzz Button Interposer Procurement Readiness Review	12 May 2017
Preproduction Horizontal Flex Cable Fabrication Readiness Review	16 Jun 2016
HEMT Carrier Board Fabrication Readiness Review	30 June 2017
Preproduction Vertical Flex Fabrication Readiness Review	15 Sep 2017
Ge Batch B and Si Boule Shipment Readiness Review	10 Nov 2017

Readiness reviews performed prior to all key fabrication / procurement tasks

Detector Tower Interface Control (ICD) Documents

CQ#5

Interface Control Documents define the interfaces to other L2 subsystems

- Tower / Cryogenics: docdb #1008
- Tower / Infrastructure: docdb #2190
- Tower / Readout Electronics: docdb #1526
- Tower / DAQ: docdb #1271
- Tower / Background Control: docdb #2133

ICDs have been completed for all subsystems that interface with Detector Towers

Risks & Risk Mitigations (Moderate Residual Impact)

SQUID chip availability:

- *Risk*: If the SQUID chips do not provide the performance required then the tower electronics will be delayed and may have performance issues at cold temperatures.
- *Mitigations:*
  1. Early procurement
  2. Work Closely with NIST to solve fabrication process issues

  Note: See Pelle Hansson's breakout talk

Vacuum coax wires lose tension:

- *Risk*: If the wires in the vacuum coax lose tension, then the wires may become shorted to ground and detector performance may be compromised.
- *Mitigations:*
  1. Measure tension of wires when cooled
  2. Fabricate jigs to maintain alignment during tower assembly

  Note: See Marco Oriunno's breakout talk

Risks & Risk Mitigations (Moderate Residual Impact)

CQ#2

Vertical flex cable manufacturing:

- *Risk*: If the vertical flex cable can not be manufactured then an alternate design will need to developed.
- *Mitigations:*
  1. R&D
  2. Fabrication of Ti 15-3-3-3 prototype

  Note: See Pelle Hansson's breakout talk

Phonon energy resolution:

- *Risk*: If the measured phonon energy resolution does not meet the project goal, then the detector performance will be compromised.
- *Mitigations:*
  1. Measure performance with Ge HV pathfinder detector
  2. Evaluate potential detector mask design changes

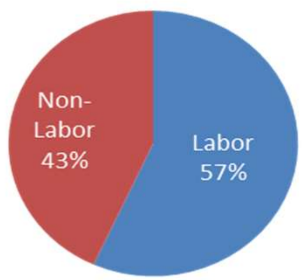
  Note: See Noah Kurinsky's breakout talk

Four moderate risks have been identified and mitigation plans implemented

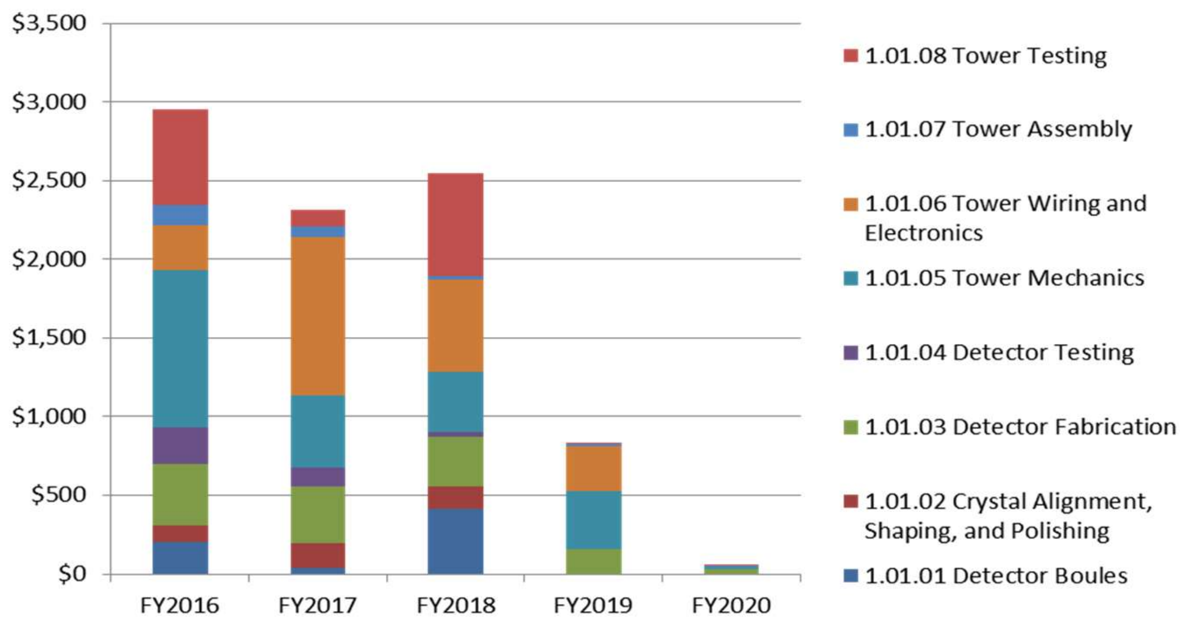
Detector Tower High Level Milestones

Task	Date
Preproduction Tower 1 Fabricated and Tested	Jun 2018
Preproduction Tower 2 Fabricated and Tested	Sept 2018
Tower 3 Fabricated and Tested	Oct 2019
Tower 4 Fabricated and Tested	Nov 2019
Detector Tower Ready for CD-4	Dec 2019

1.01 Detector Towers

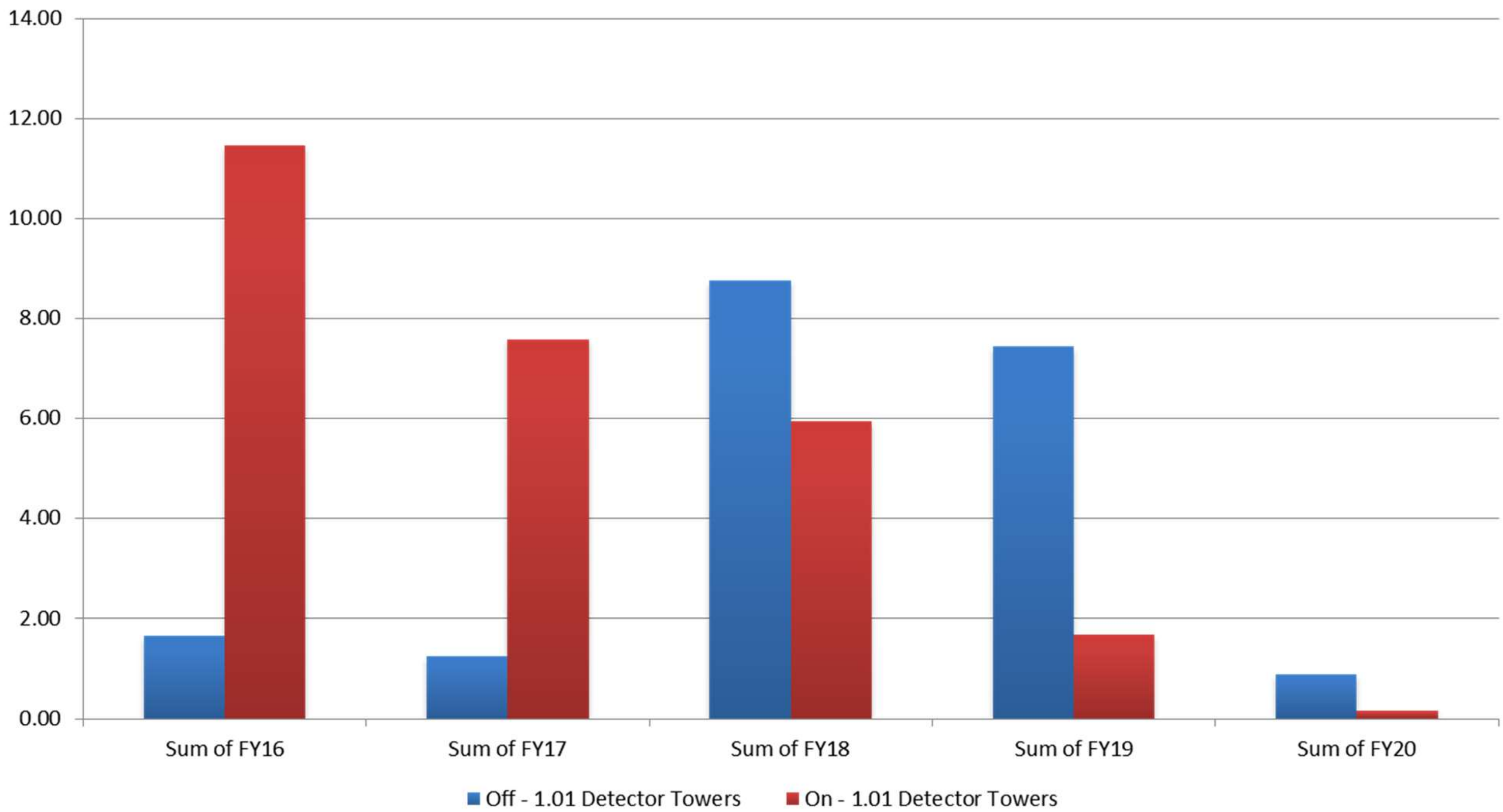


1.01 Detector Towers	
Resource Type	($K)
Labor	$4,935
Non-Labor	$3,760
Total BAC	$8,695



WBS	FY2016	FY2017	FY2018	FY2019	FY2020	Total
1.01.01 Detector Boules	$204	$35	$412	$0	$0	$650
1.01.02 Crystal Alignment, Shaping, and Polishing	$102	$157	$141	$0	$0	$401
1.01.03 Detector Fabrication	$394	$366	$318	$159	$31	$1,267
1.01.04 Detector Testing	$234	$123	$31	$0	$0	$387
1.01.05 Tower Mechanics	$999	$452	$384	$370	$18	$2,222
1.01.06 Tower Wiring and Electronics	$287	$1,013	$586	$287	$0	$2,173
1.01.07 Tower Assembly	$125	$62	$25	$10	$2	$223
1.01.08 Tower Testing	$606	$112	$650	$2	$1	$1,371
Grand Total	$2,951	$2,318	$2,547	$827	$52	$8,695

1.01 Staffing



CQ#6

Detector Tower Major Procurements

L2 Control Account	Activity ID	Activity Name	M&S Dollars	Start	Finish	Procurement Process Status
1.01 Detector Towers	1151.09	Detector housing fabrication	$40,565	22-Jan-19	16-Apr-19	0%
1.01 Detector Towers	1153.1	Tower body fabrication	$31,476	22-Jan-19	29-May-19	0%
1.01 Detector Towers	1154.13	Charge cable and spares fabrication	$34,476	22-Jan-19	29-May-19	0%
1.01 Detector Towers	1162.272	Production tower connectors	$49,575	22-Jan-19	19-Feb-19	0%
1.01 Detector Towers	1162.38	Vertical flex cable fabrication	$72,904	22-Jan-19	30-Apr-19	0%
			$228,996 Procurements start in FY19			
1.01 Detector Towers	1111.02	Ge boule production Lot A	$203,865	12-Jan-16	01-Feb-16	100%
1.01 Detector Towers	1111.06	Ge boule production Lot B – batch 1 (4 crystals)	$120,000	27-Feb-17	31-Oct-17	100%
1.01 Detector Towers	1111.061	Ge bould production Lot B – batch 2 (8 crystals)	$239,000	16-Oct-17	31-Oct-17	100%
1.01 Detector Towers	1111.07	Ge boule storage underground in Belgium	$39,000	27-Feb-17	27-Nov-17	100%
1.01 Detector Towers	1151.06	Preproduction detector housing fabrication	$44,288	1-May-17	22-Sep-17	100%
1.01 Detector Towers	1153.07	Preproduction tower body fabrication	$39,746	1-May-17	30-Nov-17	100%
1.01 Detector Towers	1162.13	Ti prototype vertical flex cable fabrication procurement	$42,818	03-Jan-17	11-Jul-17	100%
1.01 Detector Towers	1162.271	Preproduction tower connectors	$58,984	18-Jul-17	20-Nov-17	100%
1.01 Detector Towers	1162.32	NbTi preproduction vertical flex cable fabrication	$84,713	23-Oct-17	30-Mar-18	100%
1.01 Detector Towers	1164.41	SQUID fabrication procurement	$131,200	23-Mar-17	17-Nov-17	100%
1.01 Detector Towers	1181.03	UCB Dilution Fridge Procurement	$452,192	3-Apr-17	17-Apr-18	100%
1.01 Detector Towers	1182.02	SLAC Dilution Fridge Procurement	$450,142	04-Jan-16	28-Jul-16	100%
			$1,905,948 Procurements placed			

Detector Tower procurement planning is compatible with fabrication in FY 2019. Procurements representing 88% of the major procurement cost have been placed.

Summary

Detector Tower technical design is complete

- Detector Tower design parameters flow down from technical requirements and science goals
- Most Detector Tower components have had at least one round of prototype testing
- Ge HV pathfinder detector test utilizing preproduction tower mechanics and Ti 15-3-3-3 vertical flex demonstrated that we can meet technical requirement for energy resolution
- Details of design and testing efforts will be presented in the technical breakout talks

SNOLAB Tower fabrication is underway

- Fabrication and testing of pre-production towers 1 & 2 will be completed in FY 18
- Fabrication and testing of production towers 3 & 4 planned for FY 19 / early FY 20

Questions?

Optimization Process that Led to Current Detector Mix

Over-riding goals:

- Maximize science opportunities in the search for low-mass DM (m_χ<10 GeV)
- Minimize risk to science program from unexpected performance limitations
- Satisfy NSF funding constraints for Detector Towers

Why have both HV and iZIP detectors?

- HV: best sensitivity below m_χ~5 GeV; iZIP: best sensitivity above m_χ~5 GeV
- Current HV detectors will be background limited, so no benefit to >2 HV towers
- Tower 1 iZIPs significantly increase sensitivity above m_χ~5 GeV
- Tower 4 iZIPs can help constrain HV backgrounds in Tower 3
- Guaranteed science from iZIPs in presence of unexpected HV background

Why have both Si and Ge detectors?

- Si detectors will have the lowest energy threshold, best sensitivity at low mass
  - Sensitivity could be better than shown if Si ionization yield is closer to Lindhard theory (we are using the more conservative DAMIC measurement)
- Multiple target nuclei provide sensitivity to wider range of DM interactions
- Si detectors are less susceptible to charge injection / leakage currents

Is there a cost impact to having four detector types?

- No - fabrication costs are largely independent of detector type
  - Lower cost of Si boules more than compensates for any added complexity

Detector Tower R&D Status

1. HV Detector Technology Demonstration

Activity	Status	Percent Complete	ECD
Completing fabrication and packaging of Ge HV detector prototype	Ge HV detector fabrication completed at TAMU and delivered to SLAC	100%	9/18/2016
	Detector packaged at Stanford/SLAC and delivered to UMN for cryogenic testing	100%	10/29/2016
Ge HV detector prototype testing	Good test results from UMN HV capability has been verified	100%	12/9/2016
Polishing for Si HV detector prototype	Polishing of Si crystal completed	100%	10/31/2016
Fabrication and packaging of Si HV detector prototype	Si HV detector fabrication completed at TAMU and delivered to SLAC	100%	12/1/2016
	Detector packaged at Stanford/SLAC and shipped to UMN for cryogenic testing	100%	12/12/2016
Si HV detector prototype testing	Si Detector is mounted in the fridge at UMN and testing is on going.	100%	3/3/2017

Successfully fabricated and operated Ge and Si HV prototypes with bias voltages up to 100 V

Detector Tower R&D Status

2. Superconducting Vertical Flex Cable Technology Demonstration

Activity	Status	Percent Complete	ECD
Vertical flex cable electrical design	Electrical design and layout by SLAC are complete	100%	11/11/2016
Copper plating and annealing of Ti 15-3-3-3 foils	Plating and annealing of foils at PNNL is complete	100%	12/12/2016
Copper prototype vertical flex cable fabrication	Copper prototype with Sn plated traces is complete	100%	2/3/2017
Copper prototype vertical flex cable test	Cold testing at SLAC to verify superconductivity of Sn plated copper traces is complete	100%	3/3/2017
Ti 15-3-3-3 prototype vertical flex cable fabrication	Ti 15-3-3-3 prototype is complete	100%	7/13/2017
Ti 15-3-3-3 prototype vertical flex cable test	Cold testing at SLAC to verify superconductivity of Ti 15-3-3-3 traces is complete	100%	7/17/2017

Successfully fabricated and tested superconducting vertical flex cable