B07 – In-depth: ETL Assembly

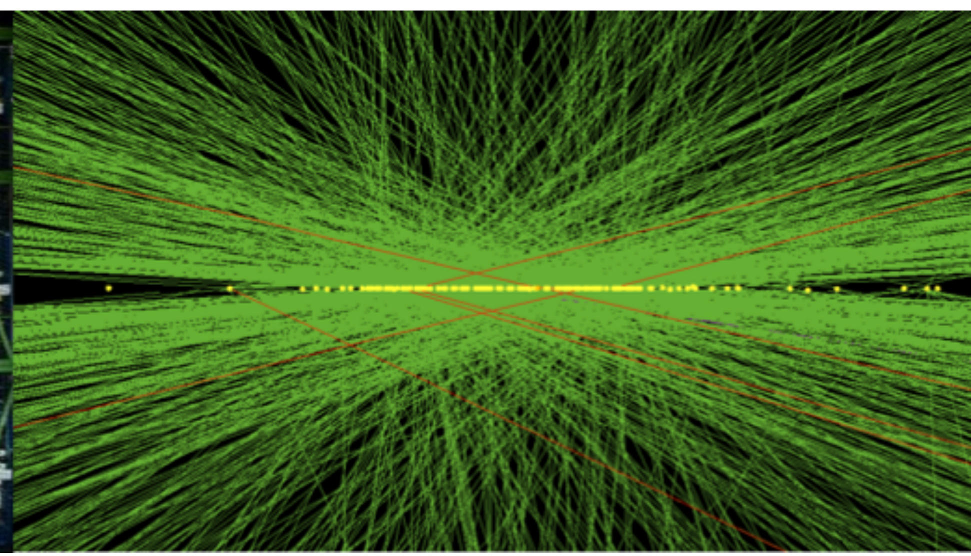
402.8.4.3

Frank Golf

University of Nebraska-Lincoln

HL-LHC CMS CD-1 Review

23 October 2019



Brief Biographical Introduction

- Frank Golf, Assistant Professor at the University of Nebraska-Lincoln.
- Serving as L4 for ETL module assembly in US-MTD.
- Relevant CMS experience:
  - Construction and operation of DAQ for ME-1/1 CSC sub-detector, CSC upgrade test stand coordinator, co-convener of CSC timing task force.
  - Previously served as co-convener of CMS sub-group: searches for supersymmetry, trigger and Monte Carlo.
  - Co-coordinator responsible for analysis data sets and SW tools.
  - Physics interests: searches for new phenomena, top quark physics, Higgs physics.

Outline

- Scope and Deliverables of ETL Assembly (WBS 402.8.4.3)
- Conceptual Design
- Cost and Schedule
- Contributing Institutions
- Resource Optimization
- ES&H
- QA/QC
- Summary

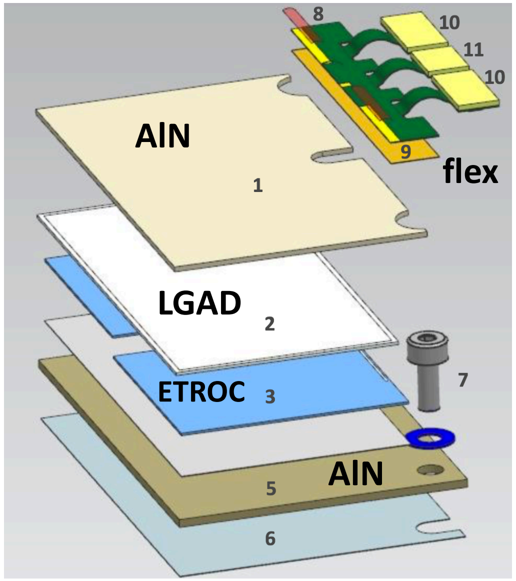
Scope and Deliverables for WBS 402.8.4.3

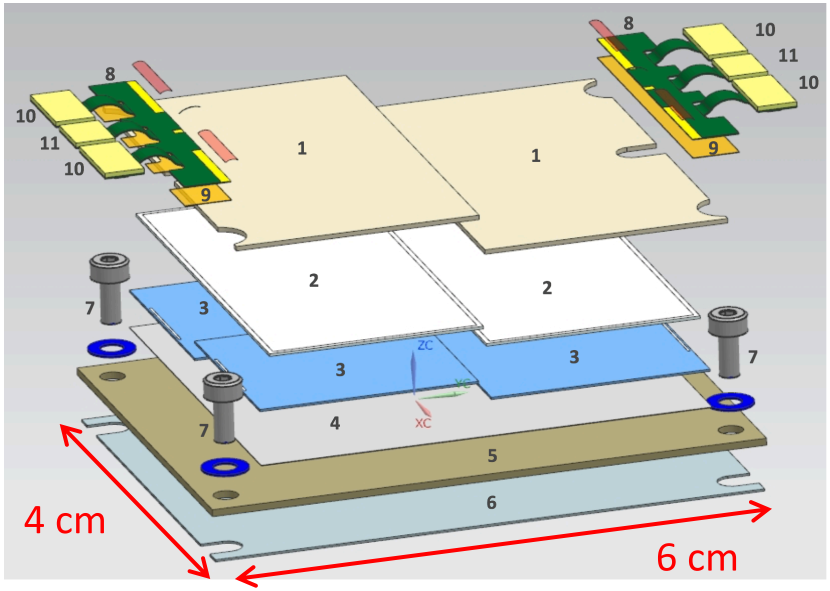
- Scope:
  - Development of the ETL module design.
  - Development of the module assembly procedure.
  - Development of the testing and QA/QC procedures for module sub-components and assembled modules.
  - Assembly of ETL modules.
- Deliverables: The U.S. will deliver to CMS 50% of the total number of modules required for the full 2 disks per endcap design as described in the CDR.
  - U.S. share: 5206 modules = 4408 modules + 798 spares.

Conceptual Design

402.8.4.3: ETL module design

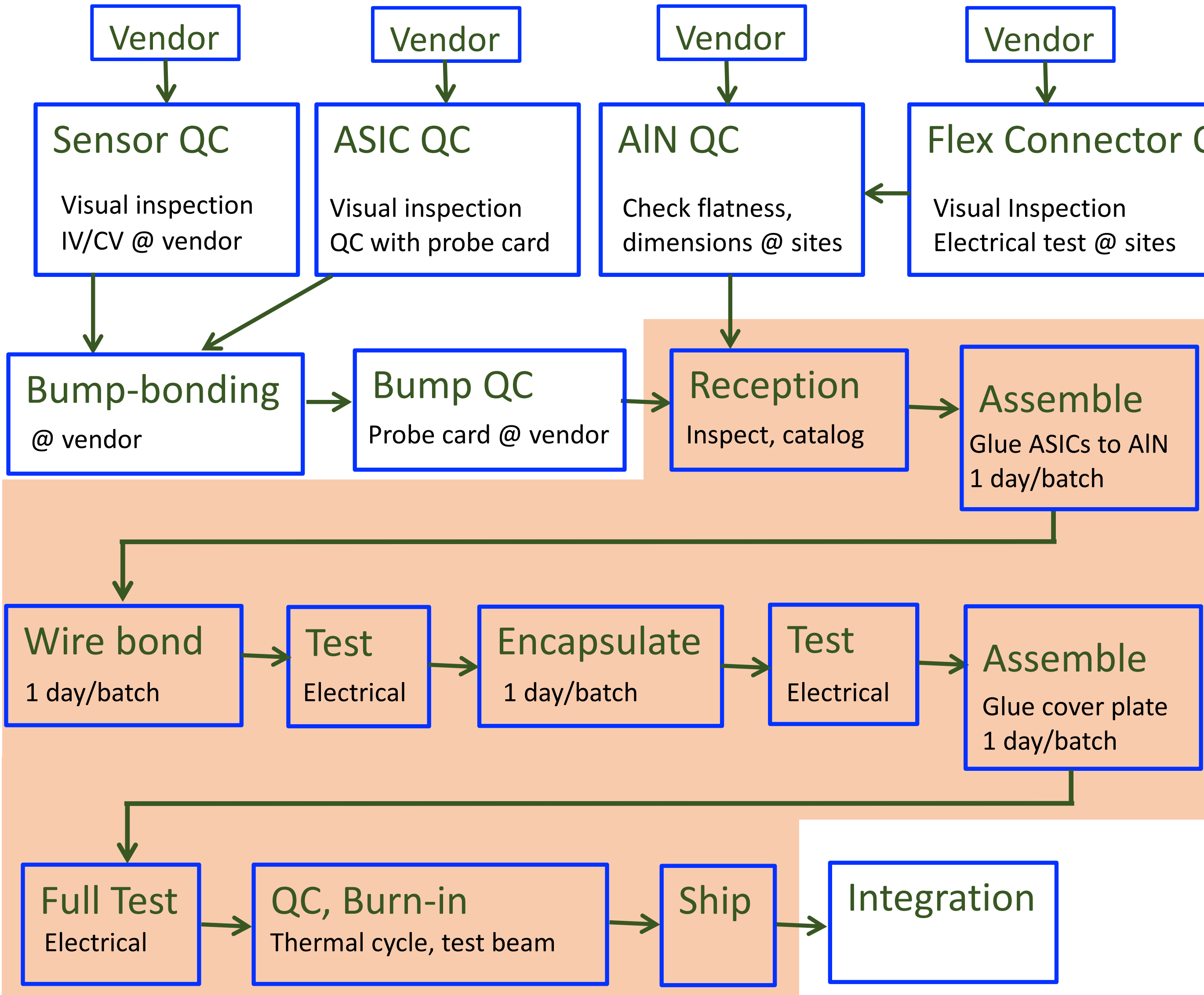
- ETL module design: two-sensor modules and a smaller number of one-sensor modules to cover edges of disks.
  - Mechanical structure protects the LGAD sensor and ETL ASIC and facilitates handling and shipping of modules.
  - Module designed for simple assembly, testing, and installation and to allow for easy replacement of modules.





1: AlN module cover
2: LGAD sensor
3: ETL ASIC
4: Mounting film
5: AlN carrier
6: Mounting film
7: Mounting screw
8: Front-end hybrid
9: Adhesive film
10: Readout connector
11: High voltage connector

402.8.4.3: ETL Module assembly

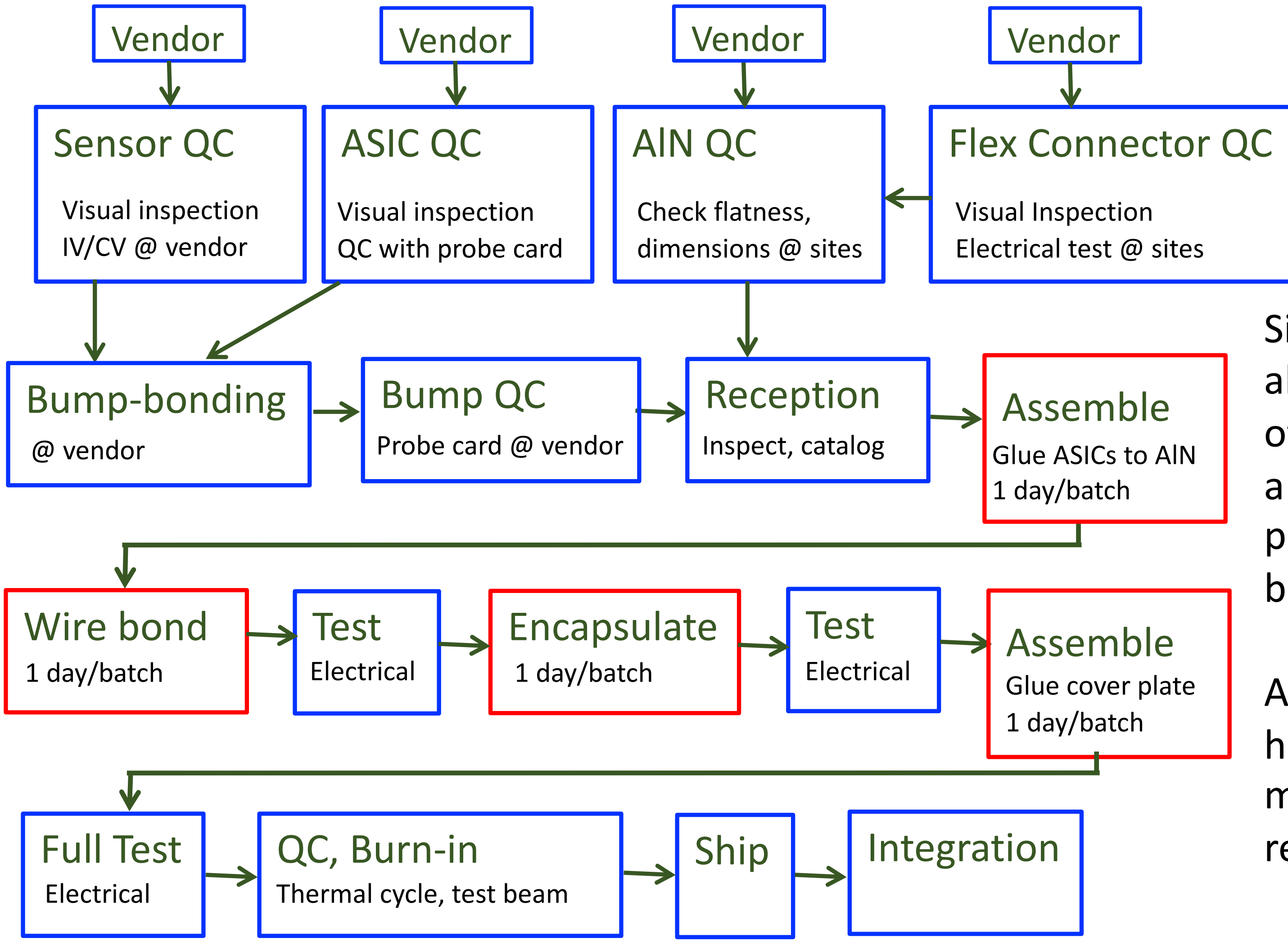


Assembly begins when components arrive at assembly sites.

It ends with modules shipped to CERN.

Primary component QC is performed prior to reception, either by vendor or by another institute.

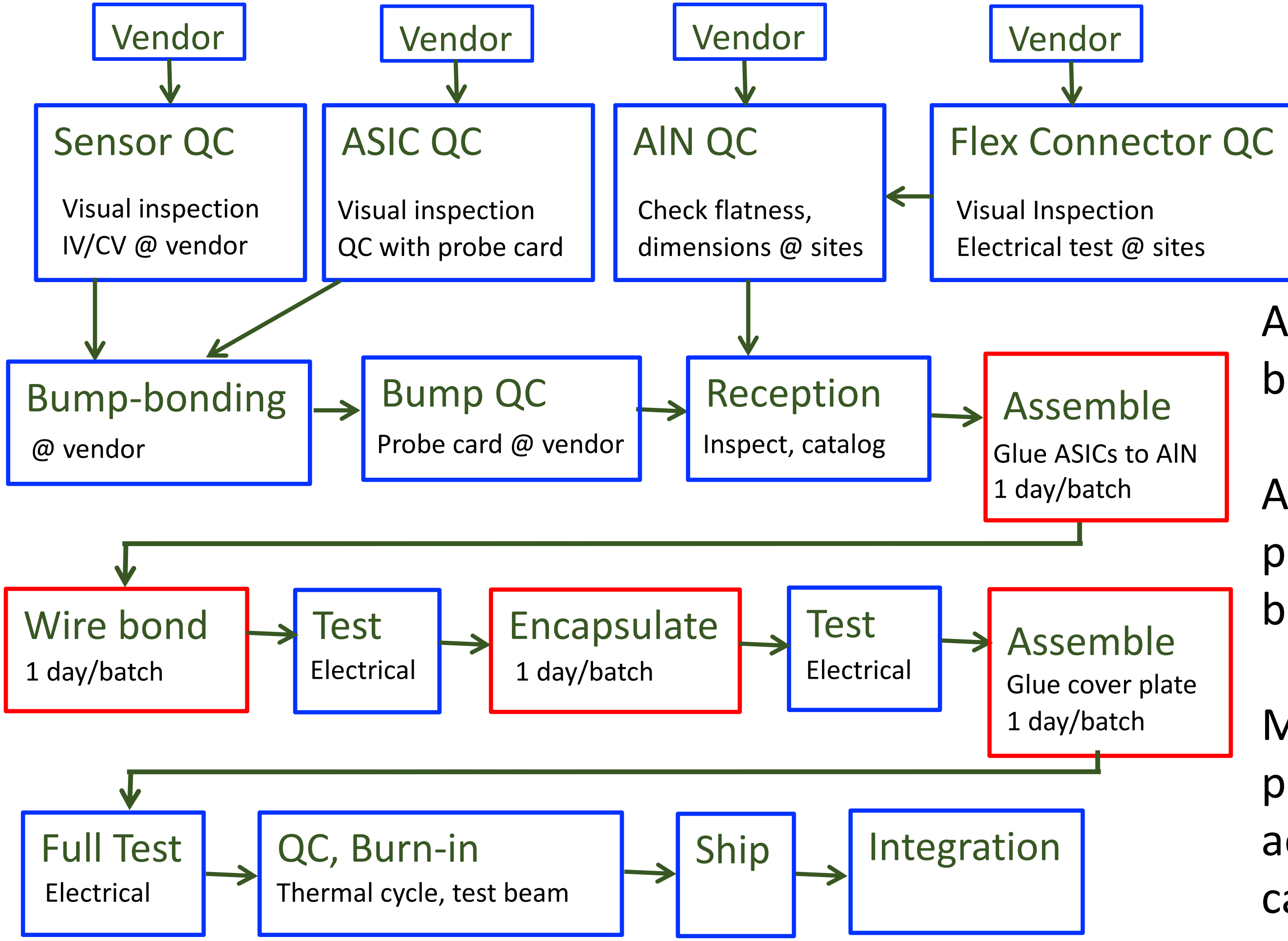
402.8.4.3: ETL Module assembly



Simple module design allows for automation of assembly steps using a robotic gantry and programmable wire bonder.

Automation ensures high yield and QC and minimizes the labor requirements.

402.8.4.3: ETL Module assembly



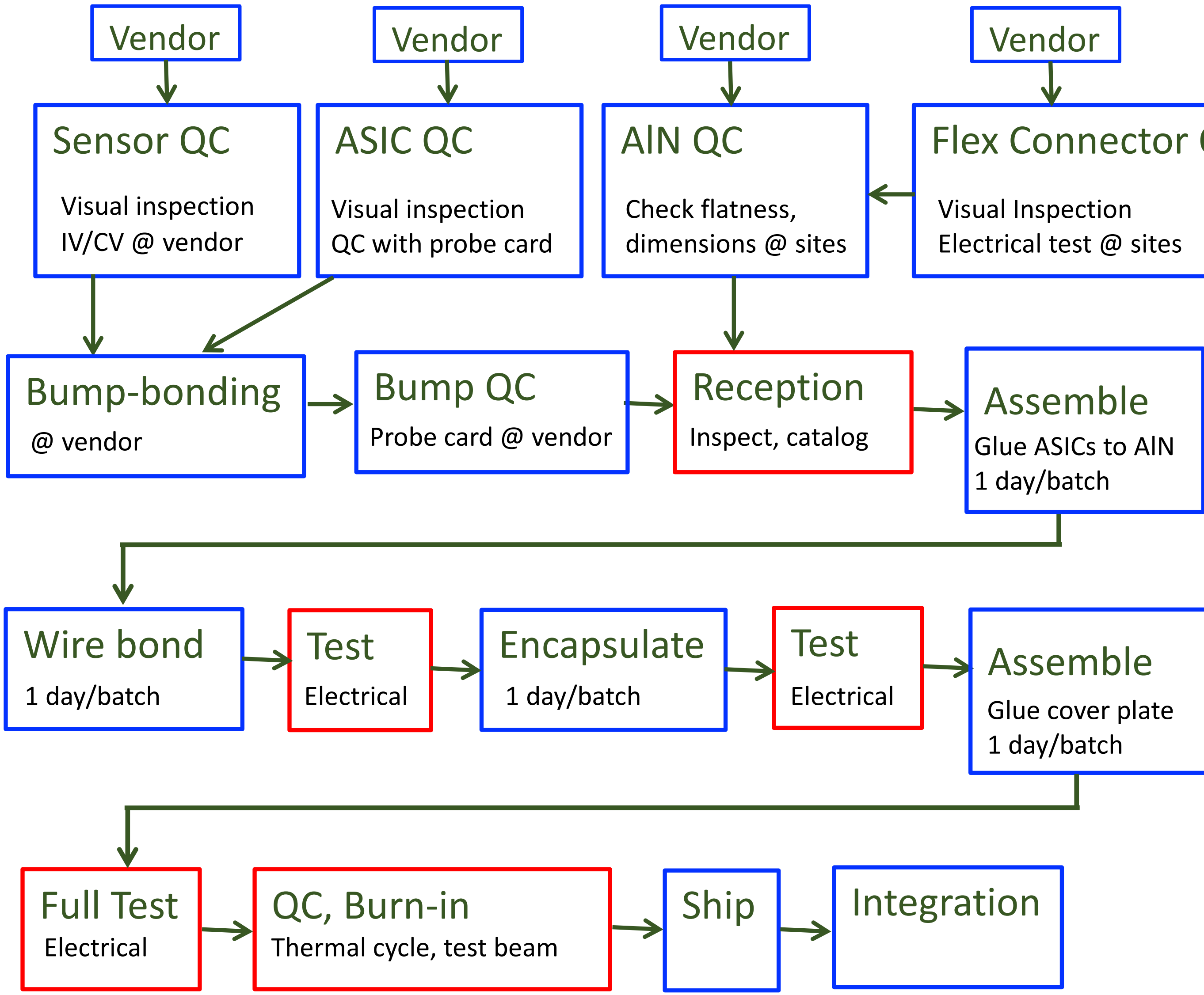
Assemble modules in batches of ~40.

Assemble in a pipelined mode → 2-3 batches per week.

Module and assembly procedure designed to achieve a throughput capacity up to ~100 modules/week/site.

Materials used in assembly such as epoxies, films and encapsulant have been or will be qualified for radiation hardness.

402.8.4.3: ETL Module assembly



Inspection at reception ensures that components meet specifications.

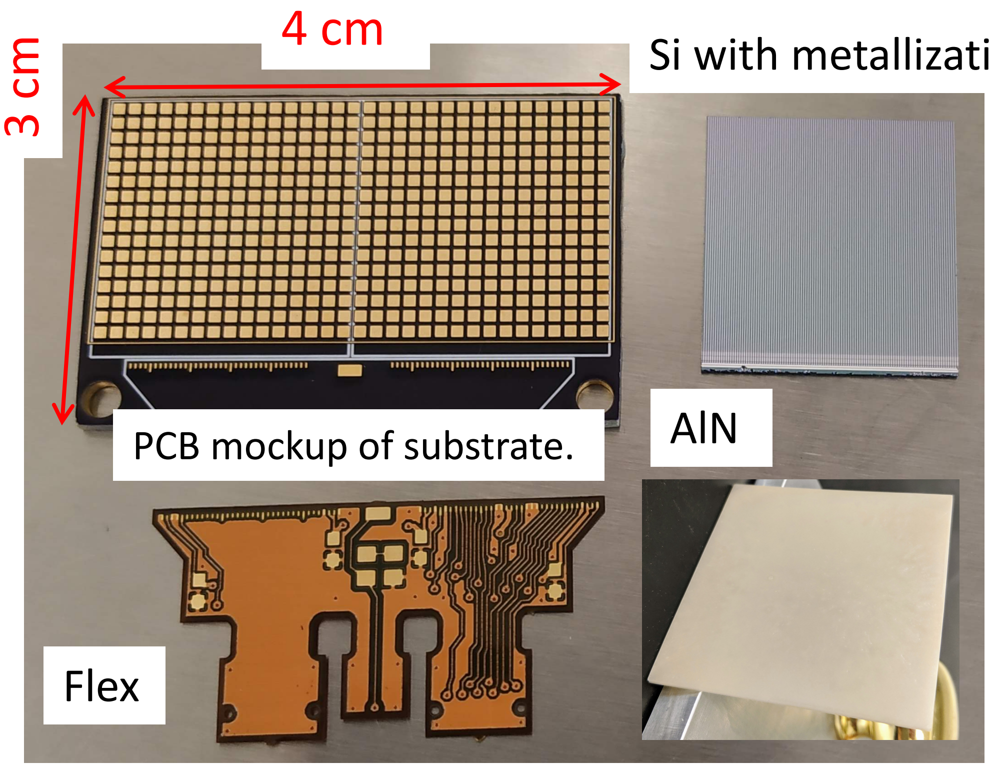
Testing at each stage of assembly ensures good mechanical and electrical connectivity resulting in high yield and QC.

R&D and prototyping

Verify components and module design, and develop assembly & QA/QC procedures with extensive prototyping. Identify vendors and ensure components meet specifications.

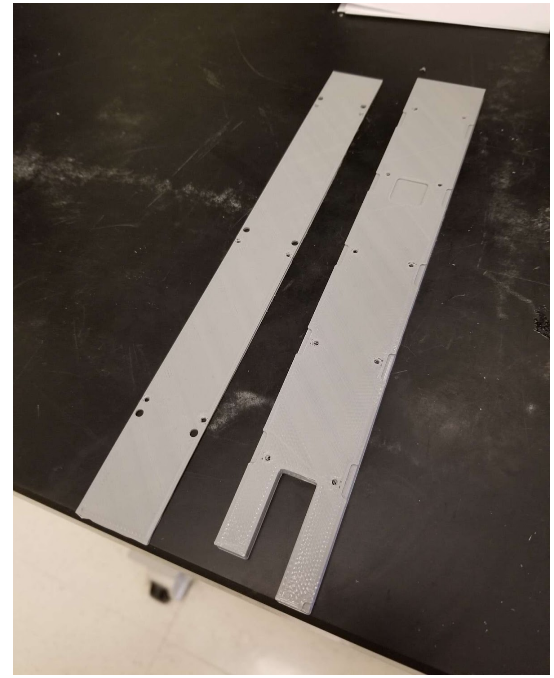
- Validate mechanical and thermal properties of modules, service hybrids, and the integration with the support disk (6/19 – 3/20).
- Validate the bump-bonding procedure (6/19 – 6/20).
- Demonstrate the performance of modules with ETROC1 (10/19 – 11/20).
  - All module functions, test beam, irradiation, system tests.
- Demonstrate the performance of modules with ETROC2 (12/2—4/22).
  - All module functions, test beam, irradiation, system tests.
  - System testing: multiple modules with realistic grounding at high rate.
- Develop and demonstrate the module assembly procedure (10/19-10/21).
  - Assembly sites will demonstrate full throughput capacity.
- Develop the module QC procedures and test stands (4/22-5/23).

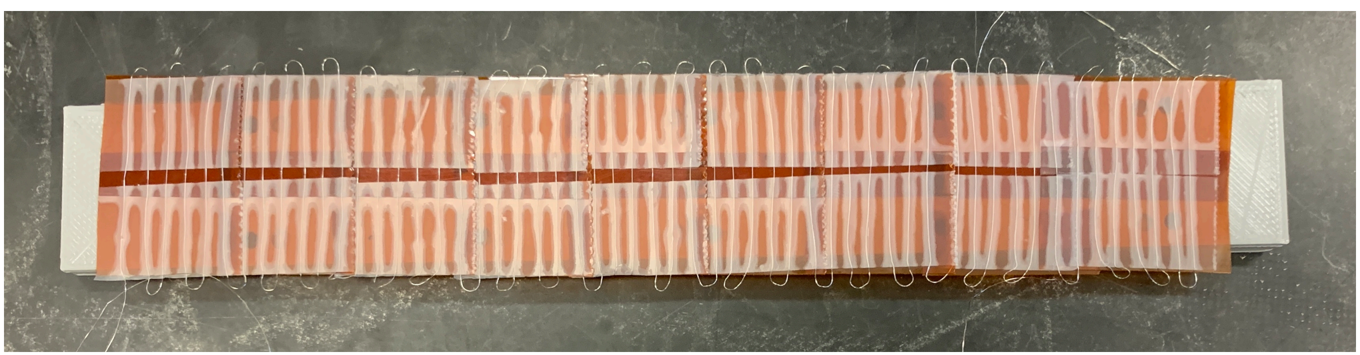
R&D: mechanical mockups



Si with metallization

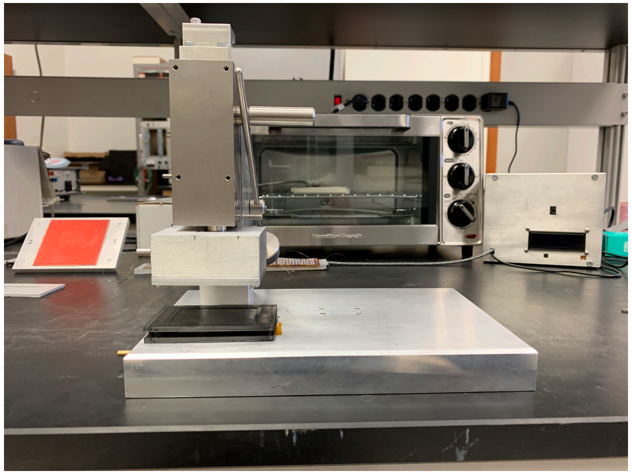
3D printed service hybrid boards.

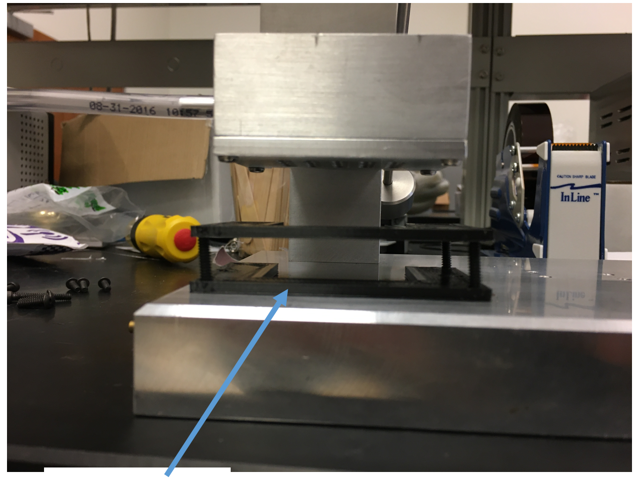




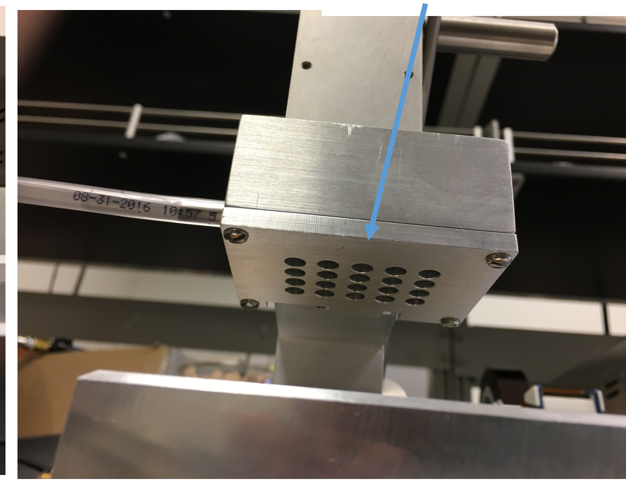
Heating foil.

R&D: placement and gluing jig

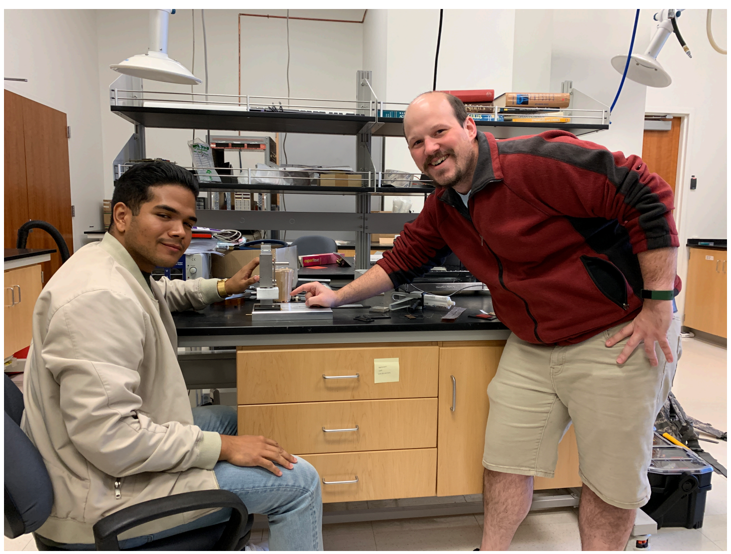




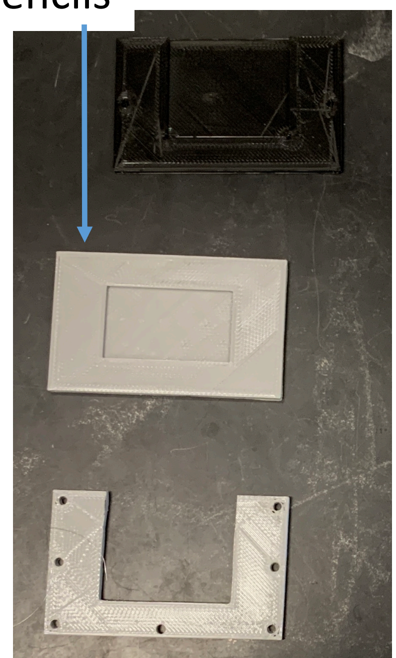
Vacuum head

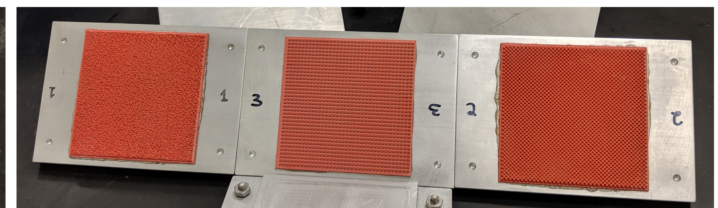


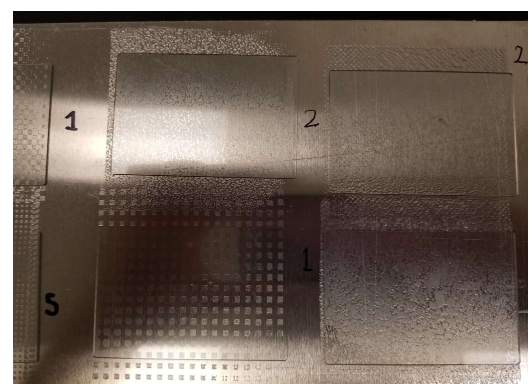
stencils



C. Fangmeier, F. Marcia (UNL)

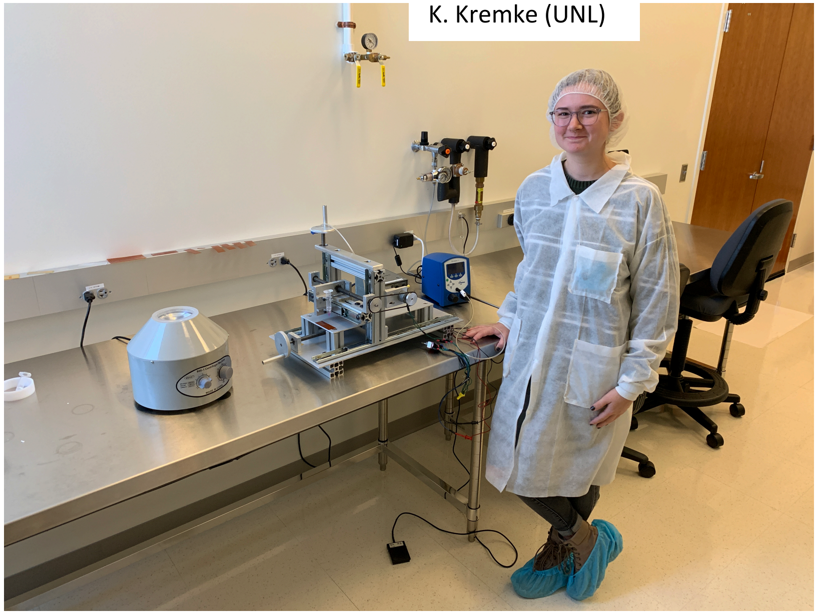


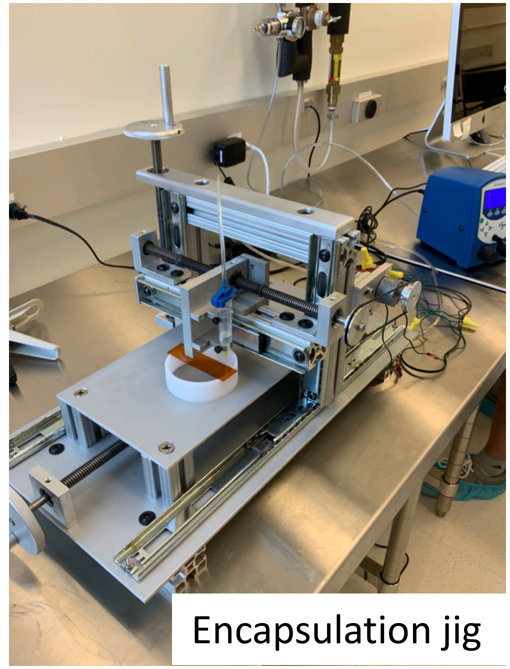




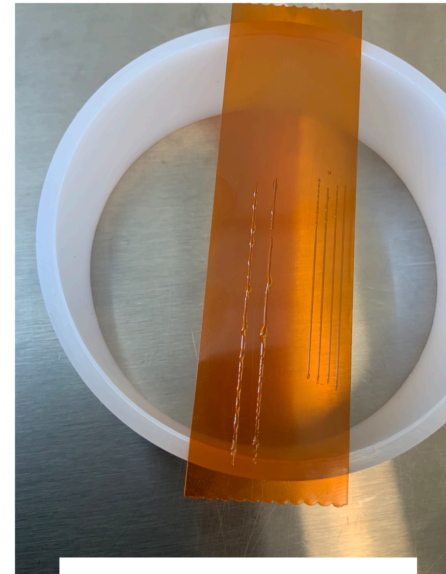
Glue stamps (above) and deposited glue patterns (left).

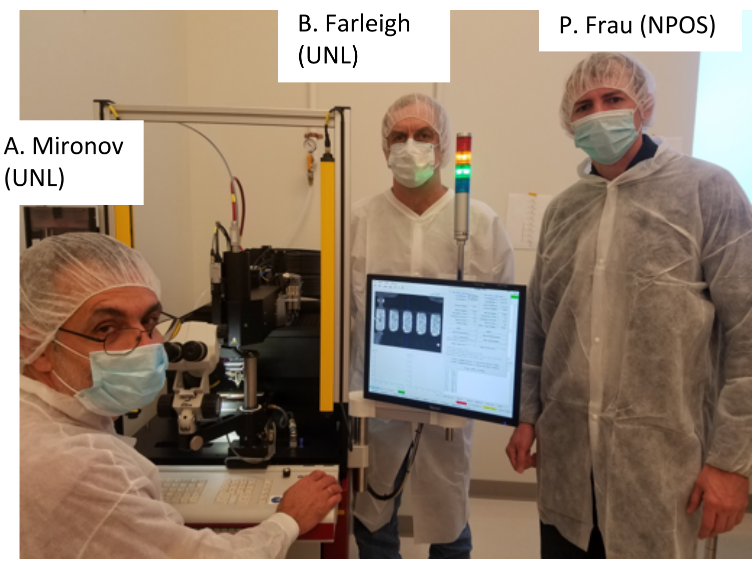
R&D: wire bonding and encapsulation

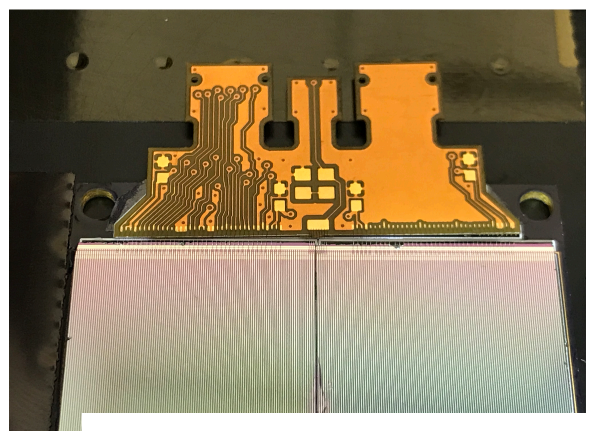


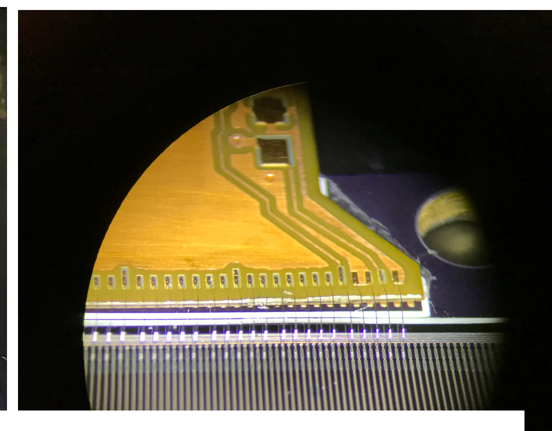

Encapsulation jig

Vacuum head


Encapsulant lines



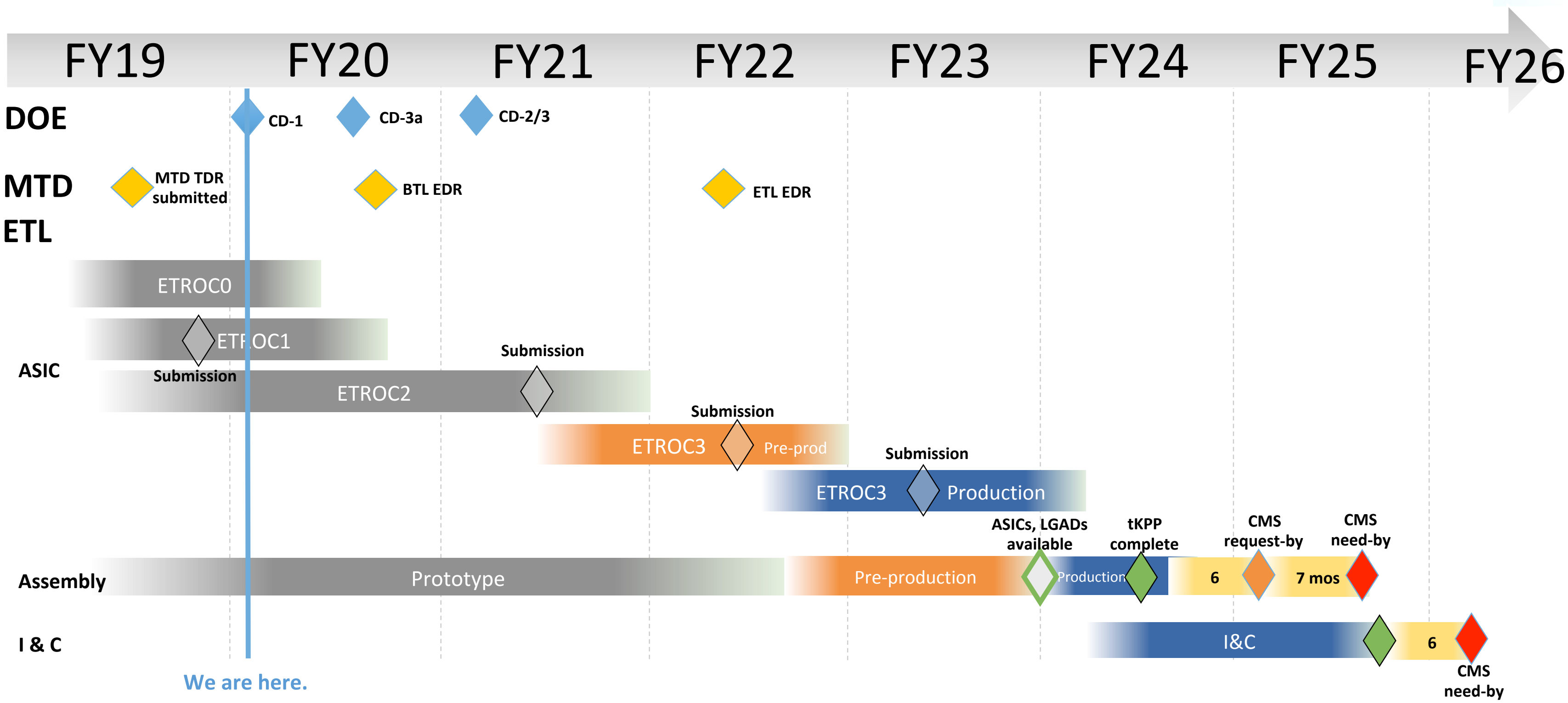



Wire bonds on a mechanical mockup.

Schedule and Cost

Schedule Overview

- Assembly schedule driven by availability of bump-bonded LGAD+ETL ASIC sub-assemblies.
  - Assembly workflow designed for higher throughput, if needed.
- A detailed schedule, resource loaded, is in P6.



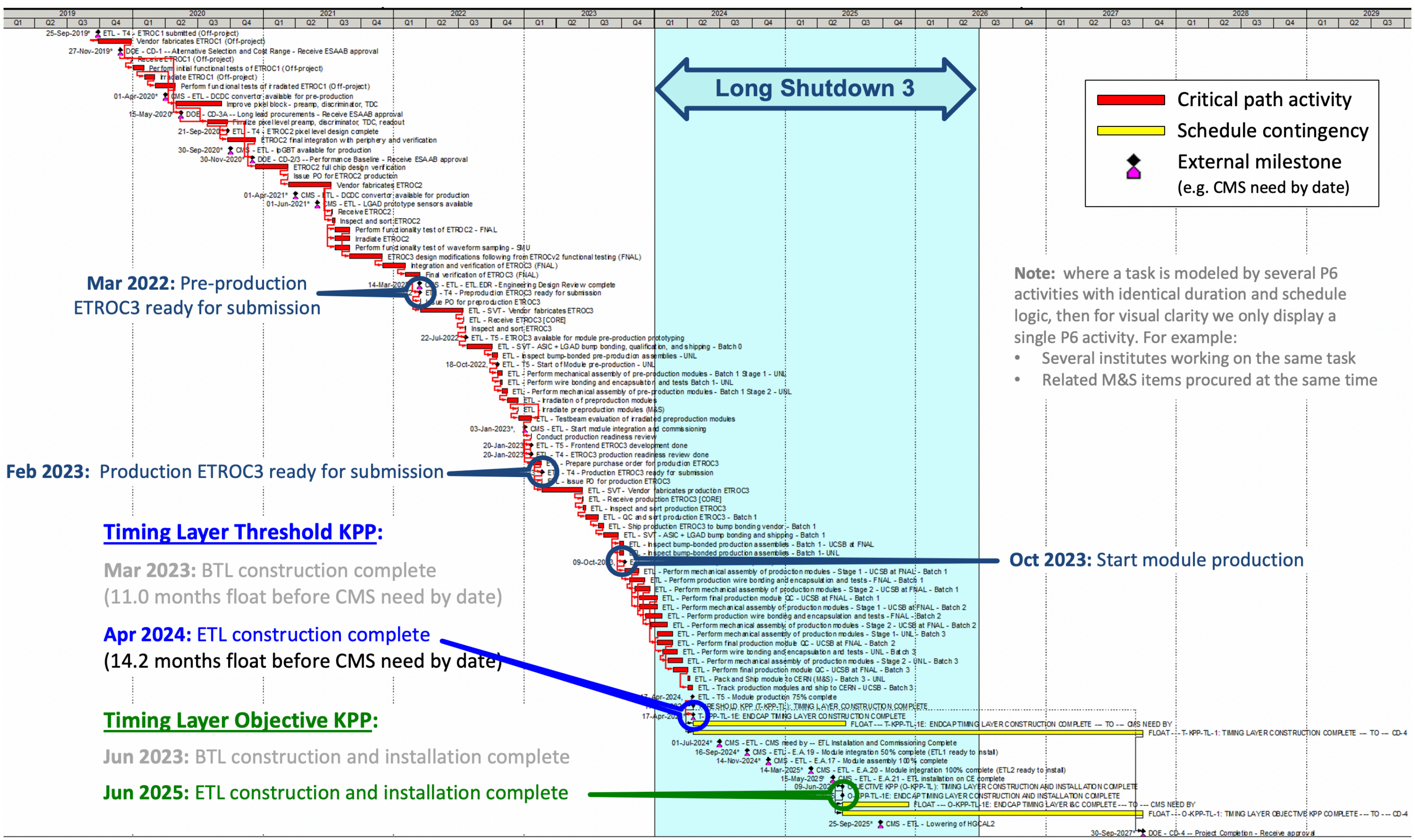
Milestones for 402.8.4.3

- Major milestones for module prototyping, pre-production and production are defined.

Tier	Activity ID	Activity Name	Date
T4	TL1001120	Module mechanical design validated	16 March 2020
T4	TL1001140	Module thermal performance validated	9 June 2020
T4	TL1001480	Module electrical performance validated	20 November 2020
T4	TL1001670	Demonstrated high throughput assembly	1 March 2021
T4	TL1001690	Module production processes validated	18 October 2021
T4	TL10758	Setup module pre-production facilities	18 July 2022
T4	TL8265	Module pre-production complete	1 March 2023
T4	TL1002629	Finalize production module assembly sites	18 May 2023
T4	TL1002639	Start of module production	28 November 2023
T4	TL8586	Module production complete	29 May 2024
T5	TL1000899	Start module assembly R& D	3 June 2019
T5	TL1001269	Start high level module design	1 October 2019
T5	TL8211	Start of module pre-production FNAL	17 October 2022
T5	TL8485	Start of module pre-production UNL	18 October 2022
T5	TL1659	Module pre-production complete FNAL	18 January 2023
T5	TL1658	Module pre-production complete UNL	1 March 2023
T5	TL10768	Module production facility available UNL	2 October 2023
T5	TL8475	Start of module production UNL	2 October 2023
T5	TL10800	Start of module production FNAL	9 October 2023
T5	TL502017	Module production 25% complete FNAL	24 January 2024
T5	TL8435	Module production 25% complete UNL	24 January 2024
T5	TL502018	Module production 50% complete FNAL	6 March 2024
T5	TL8436	Module production 50% complete UNL	13 March 2024
T5	TL502019	Module production 75% complete FNAL	17 April 2024
T5	TL8437	Module production 75% complete UNL	17 April 2024
T5	TL502020	Module production 100% complete FNAL	29 May 2024
T5	TL8438	Module production 100% complete UNL	29 May 2024

Critical Path items for 402.8.4.3

- Critical path driven by module component availability.
  - Assembly requires bump-bonded LGAD+ETL, flex, AlN.



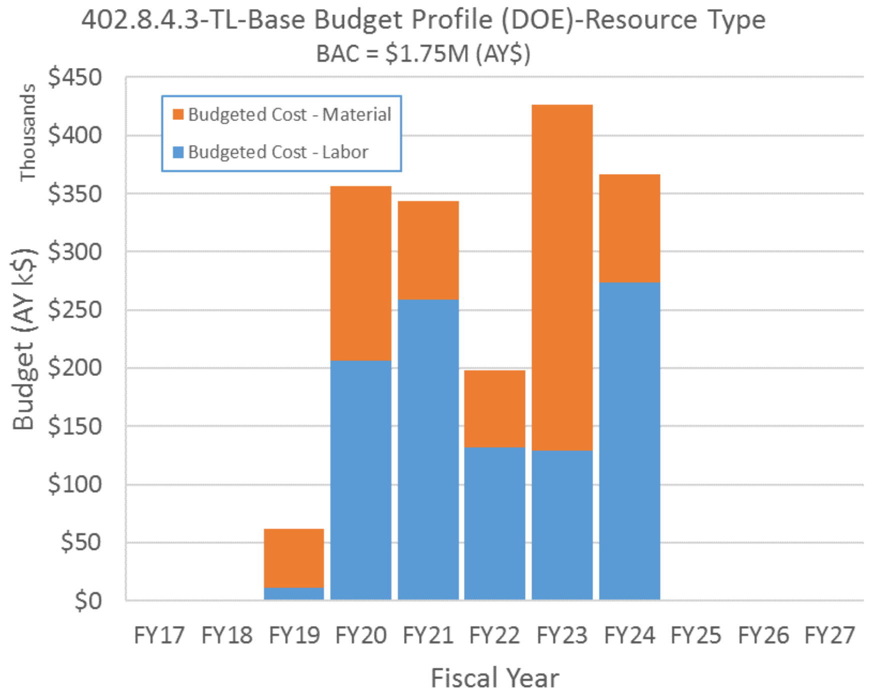
Cost Estimate – ETL assembly process

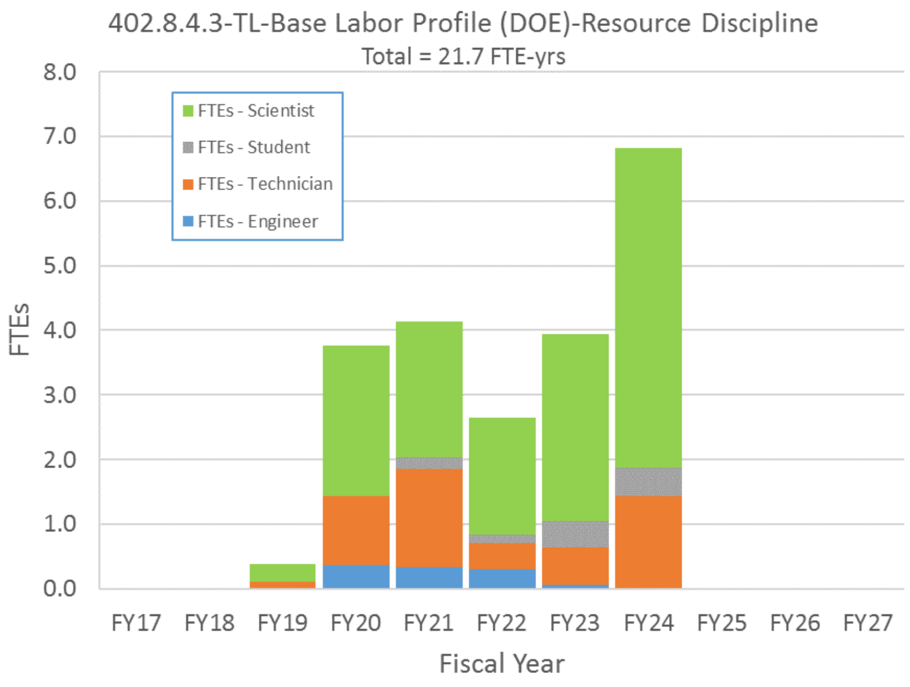
WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
DOE-CD1-402.8 402.8 TL - Timing Layer (at DOE CD1)	6,845,630	156109	88.30	12,718,472	3,230,993	15,949,466
DOE-CD1-402.8.2 TL - Management	1,051,980	26520	15.00	1,245,677	221,782	1,467,459
DOE-CD1-402.8.3 BTL - Barrel Timing Layer	2,832,903	47774	27.02	5,141,304	1,263,514	6,404,817
DOE-CD1-402.8.4 ETL - Endcap Timing Layer	2,960,747	81815	46.28	6,331,492	1,745,697	8,077,190
DOE-CD1-402.8.4.2 ETL - Frontend ASICs	2,110,992	24495	13.85	4,186,640	839,972	5,026,613
DOE-CD1-402.8.4.2.1 ETL - Frontend ASICs General	15,000	0	0.00	16,361	1,322	17,683
DOE-CD1-402.8.4.2.3 ETL - Frontend ASICs v2 development	450,720	12753	7.21	1,402,868	288,248	1,691,116
DOE-CD1-402.8.4.2.4 ETL - Frontend ASICs v3 development	1,645,272	11742	6.64	2,767,411	550,403	3,317,814
DOE-CD1-402.8.4.3 ETL - Assembly	641,455	38348	21.69	1,754,080	787,463	2,541,542
DOE-CD1-402.8.4.3.1 ETL - Assembly R&D and Prototypes	378,180	19836	11.22	1,019,495	486,539	1,506,034
DOE-CD1-402.8.4.3.2 ETL - Module Assembly Pre-production	47,600	5348	3.02	183,694	87,334	271,028
DOE-CD1-402.8.4.3.3 ETL - Module Assembly Production	215,675	13164	7.45	550,891	213,590	764,481
DOE-CD1-402.8.4.5 ETL - Integration and Commissioning	208,300	18972	10.73	390,773	118,262	509,035
DOE-CD1-402.8.4.5.1 ETL - I&C - Assembly Setup	85,000	1448	0.82	118,337	39,579	157,916
DOE-CD1-402.8.4.5.2 ETL - I&C - Assembly	123,300	8976	5.08	166,593	25,762	192,354
DOE-CD1-402.8.4.5.3 ETL - I&C - Cold Testing	0	1820	1.03	11,217	5,609	16,826
DOE-CD1-402.8.4.5.4 ETL - I&C - Mount ETL on EC	0	6728	3.81	94,626	47,313	141,938

- M&S driver is cost to procure components and QC stands.
- Labor driver is the cost of technicians for wire bonding.
- Details in BoE: CMS-doc-13597

Fiscal Year Cost Profile

- M&S & labor profiles, broken down by L4, by fiscal year.
  - We understand our cost profiles and money needs

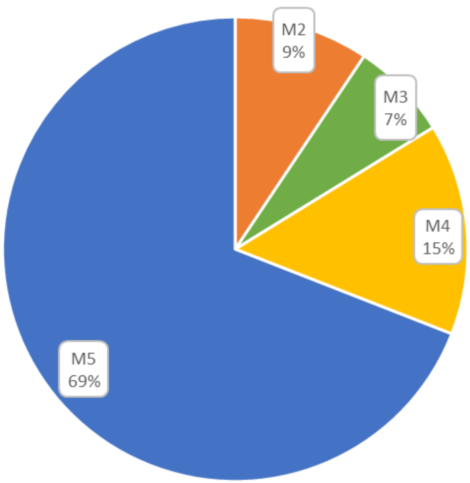




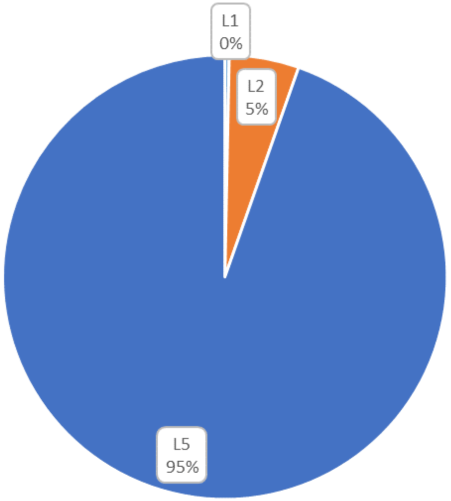
Contingency Breakdown

- Breakdown of M&S and labor contingency codes.
  - We are using the standard OPSS EU method, and the EU is reasonable for this stage of the project

402.8.4.3-TL-Estimate Uncertainty Breakdown-M&S (DOE)
BAC (M&S)=$0.74M (AY$)



402.8.4.3-TL-Estimate Uncertainty Breakdown-Labor (DOE)
BAC (Labor Budget)=$1.01M (AY$)



Risks

- Biggest risk: problem with ETL module assembly facility.
  - e.g. gantry or wire bonder needs servicing, clean room flooding.
  - Smaller risks from availability of components.
  - Potential problems mitigated by having two assembly sites.

RI-ID	Title	Probability	Cost Impact	Schedule Impact	P * Impact (k$)	P * Impact (months)
WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (2)						
WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (14)						
WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (10)						
Risk Rank : 3 (High) (1)						
RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	40 %	500 -- 600 -- 700 k$	4 -- 5 -- 6 months	240	2.0
Risk Rank : 2 (Medium) (5)						
RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	874 -- 930 -- 986 k$	6 -- 7.5 -- 9 months	93	0.8
RT-402-8-55-D	ETL - Schedule delay in submitting ETROC2	30 %	55 -- 110 -- 165 k$	2 -- 4 -- 6 months	33	1.2
RT-402-8-02-D	ETL - ETL module facility unavailable	50 %	20 k$	2 months	10	1.0
RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	28 -- 52 -- 109 k$	2 -- 3 -- 6 months	9	0.6
RO-402-8-01-D	ETL - Use AltiROC	10 %	-720 k$	-8 months	-72	-0.8
Risk Rank : 1 (Low) (4)						
RT-402-8-54-D	ETL - Schedule delay in submitting ETROC3	20 %	27.5 -- 55 -- 82.5 k$	1 -- 2 -- 3 months	11	0.4
RT-402-8-53-D	ETL - Integration facility at CERN runs out of components	25 %	21 k$	3 months	5	0.8
RT-402-8-31-D	ETL - Storage-related degradation of LGADs	10 %	18 k$	3 months	2	0.3
RT-402-8-51-D	ETL - Problem with vendor provision of module components	5 %	0 -- 15 -- 30 k$	1 -- 2 -- 3 months	1	0.1

Contributing Institutions and Resource Optimization

Contributing Institutions

- Assembly sites at UNL and FNAL with BU,KU,UCSB labor.
  - UNL and UCSB have extensive experience assembling pixel and strip tracker modules.
  - BU and KU have a lot of experience with detector electronics.
  - FNAL has extensive experience in many detector systems.

- Wire bonding performed by technicians. The bulk of the remainder of the assembly and testing will be performed by teams of undergraduate and graduate students and postdocs, with support from technicians and engineers.
  - Similar model used previously, e.g. FPIX module assembly.

- Assembly at UNL will use existing clean room, plan to use Lab G space at FNAL.
  - Both sites could expand clean room space, if needed.

Resource Optimization

- Participating institutions have a strong track record building, testing, and commissioning detectors.
  - And have personnel with technical expertise (e.g. engineering, technicians) with the required technologies necessary to execute this project.
- Plan makes maximal use of industrial processes and techniques for module assembly.
  - Automation of major stages of module assembly achieved through the use of technologies such as a robotic gantry and a programmable wire bonder.
  - Assembly will use existing technologies previously acquired for other projects.

Quality Assurance and Quality Control

- QA/QC ensured by training, inspection and testing:
  - assembly sites will demonstrate full throughput capacity with mechanical components followed by a pre-production period,
  - of input components,
  - at each stage of module assembly and before shipping,
  - with documentation of all procedures and tracking of all inputs and outputs at each stage of the assembly process.

- QA/QC plans are in accordance with the QAP for the US CMS HL LHC project: CMS-doc-13093.

Summary of WBS 402.8.4.3

- ETL module assembly is well advanced:
  - Module design and assembly procedure well defined.
  - R&D is ongoing to:
    - validate the module design,
    - develop the module assembly procedure,
    - develop the testing and QA/QC procedures.
- Strong team of contributing institutions with significant prior experience building and testing detectors.
- Cost and schedule are defined and entered in P6.
- We are carrying out a detailed prototyping plan to advance the US to meet its commitment to deliver 50% of required ETL modules.

Backup Slides

ES&H

- A hazard analysis has been performed for this activity and the hazards are listed in the preliminary Hazard Awareness Report (cms-doc-13394). This activity poses no unique hazards not typically encountered in HL LHC upgrade activities.
- Safety is achieved following standard practices appropriate for the lab and institute:
  - Complying with local safety standards.
  - Site Safety officers at Institutes identified in the SOW.
- R&D and some testing will use radiation sources.
  - Tests performed at commonly used radiation and test beam facilities.

Risks

- Biggest risk: problem with ETL module assembly facility.
  - e.g. gantry or wire bonder needs servicing, clean room flooding.
  - Smaller risks from availability of components.
  - Potential problems mitigated by having two assembly sites.

Risk Rank:	2 (Medium) Scores: Probability : 4 (H) ; Cost: 0 (N) Schedule: 1 (L))	Risk Status:	Open
Summary:	This is a general category that includes multiple issues that can lead to a production slowdown or stoppage. If a Module Assembly facility temporarily becomes inoperable due to loss of critical equipment, an act of god or interference from other projects, then the resultant dip in module throughput may jeopardize timely completion of the project.		
Risk Type:	Threat	Owner:	Frank Golf
WBS:	402.8.4 ETL - Endcap Timing Layer	Risk Area:	External Risk / Facilities
Probability (P):	50%	Technical Impact:	0 (N) - negligible technical impact
Cost Impact:	PDF = 1-point - single value Minimum = 10 k$ Most likely = 20 k$ Maximum = 30 k$ Mean = 20.0 k$ P * <Impact> = 10.0 k$	Schedule Impact:	PDF = 1-point - single value Minimum = 1.0 months Most likely = 2.0 months Maximum = 3.0 months Mean = 2 months P * <Impact> = 1 months
Basis of Estimate:	If one center has a major equipment failure or is otherwise unable to meet its throughput expectation the second center can pick up the additional load within the 100% cushion. It is assumed that in max 3 months the equipment would be replaced or facility made becomes available and assembly could then be resumed at the affected site. An expected delay of max 3 months due to a need to transfer components to the second production site and to organize second shift module production.		
Cause or Trigger:		Impacted Activities:	Risk could delay any one of the batches during ETL Assembly
Start date:	1-Jan-2023	End date:	1-Jul-2024
Risk Mitigations:	Having at least two US sites is a risk mitigation, and should one site become temporarily inoperable, components could be redirected to the other site temporarily to mitigate the impact, while the affected production site is being repaired.		
Risk Responses:	Module components can be diverted to the unaffected site to utilize its full throughput, and additional resources added to increase module production throughput at both sites (once the affected one is re-established) to regain time in the schedule.		
More details:			