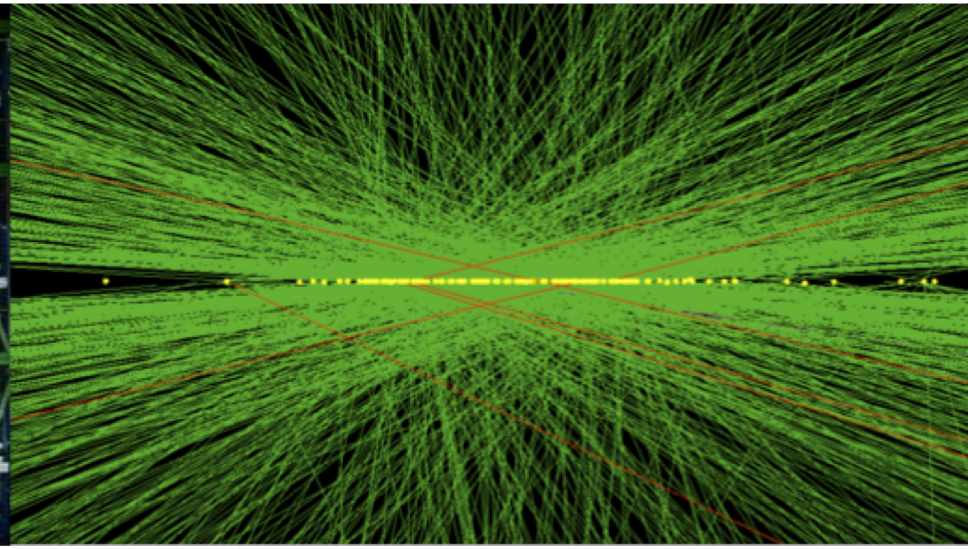
In-depth: ETL Assembly

WBS 402.8.4.3

Frank Golf

HL-LHC CMS Upgrade CD-1 Director's Review

20 March 2019



Brief Biographical Introduction

Charge #5

- 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 for Run 2.
  - 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

Charge #4

- 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 completed modules.
  - Assembly of modules for the Endcap Timing Layer for CMS.

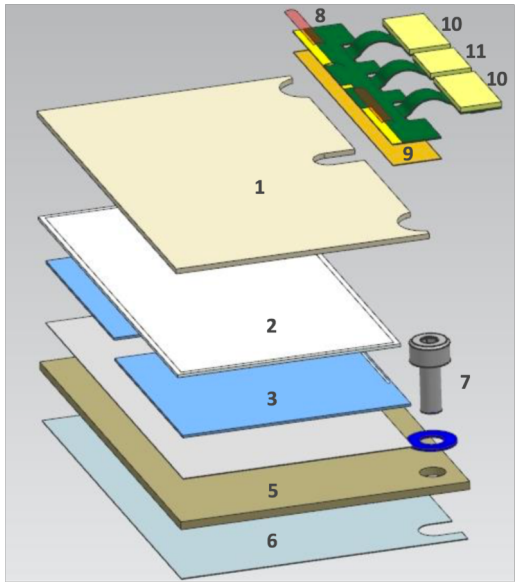
- Deliverables: The U.S. will deliver to CMS a number of modules sufficient to cover both faces of one disk of each endcap of the ETL detector, i.e. 50% of the total number of modules required for the full 2 disks per endcap design as described in the TDR.
  - U.S. share: 5206 modules = 4408 modules + 798 spares.

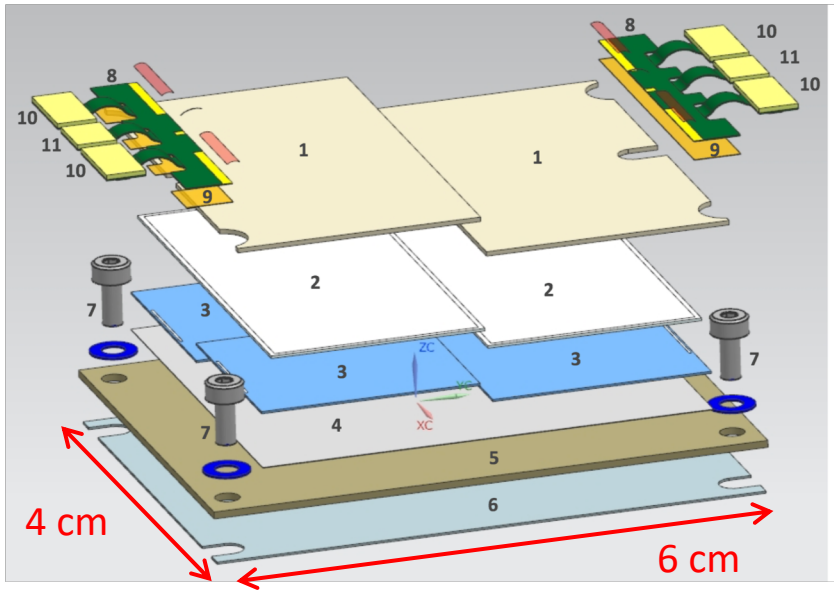
Conceptual Design

402.8.4.3: ETL module design

Charge #1,2

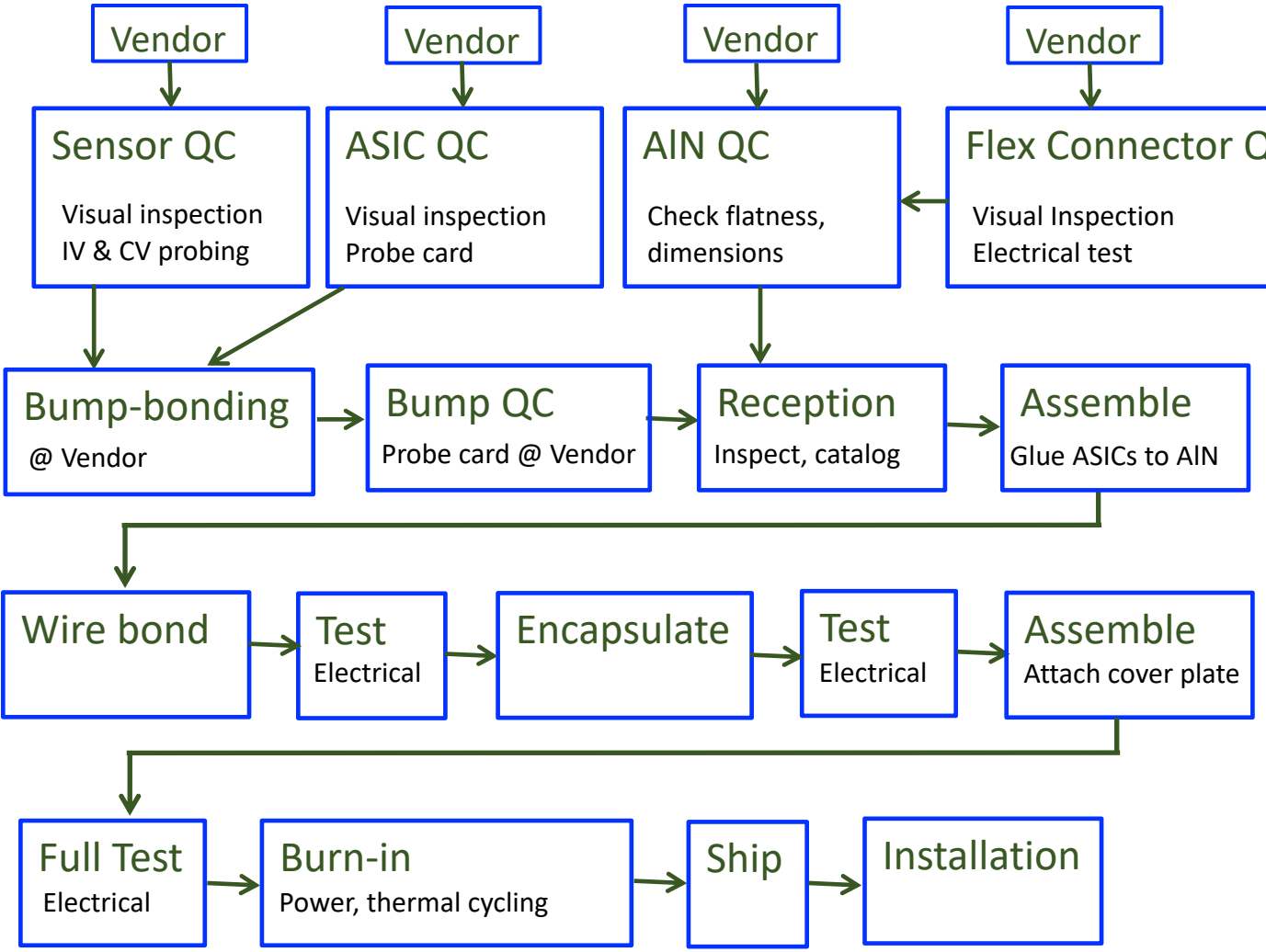
- ETL module design: two-sensor and one-sensor modules.
  - Mechanical structure protects the LGAD sensor and ETL ASIC and facilitates handling and shipping of modules.
  - Module designed for simple assembly, testing, and installation and to allow for easy replacement of modules.





402.8.4.3: ETL Module assembly

Charge #1,2



Assemble modules in batches of 40.***

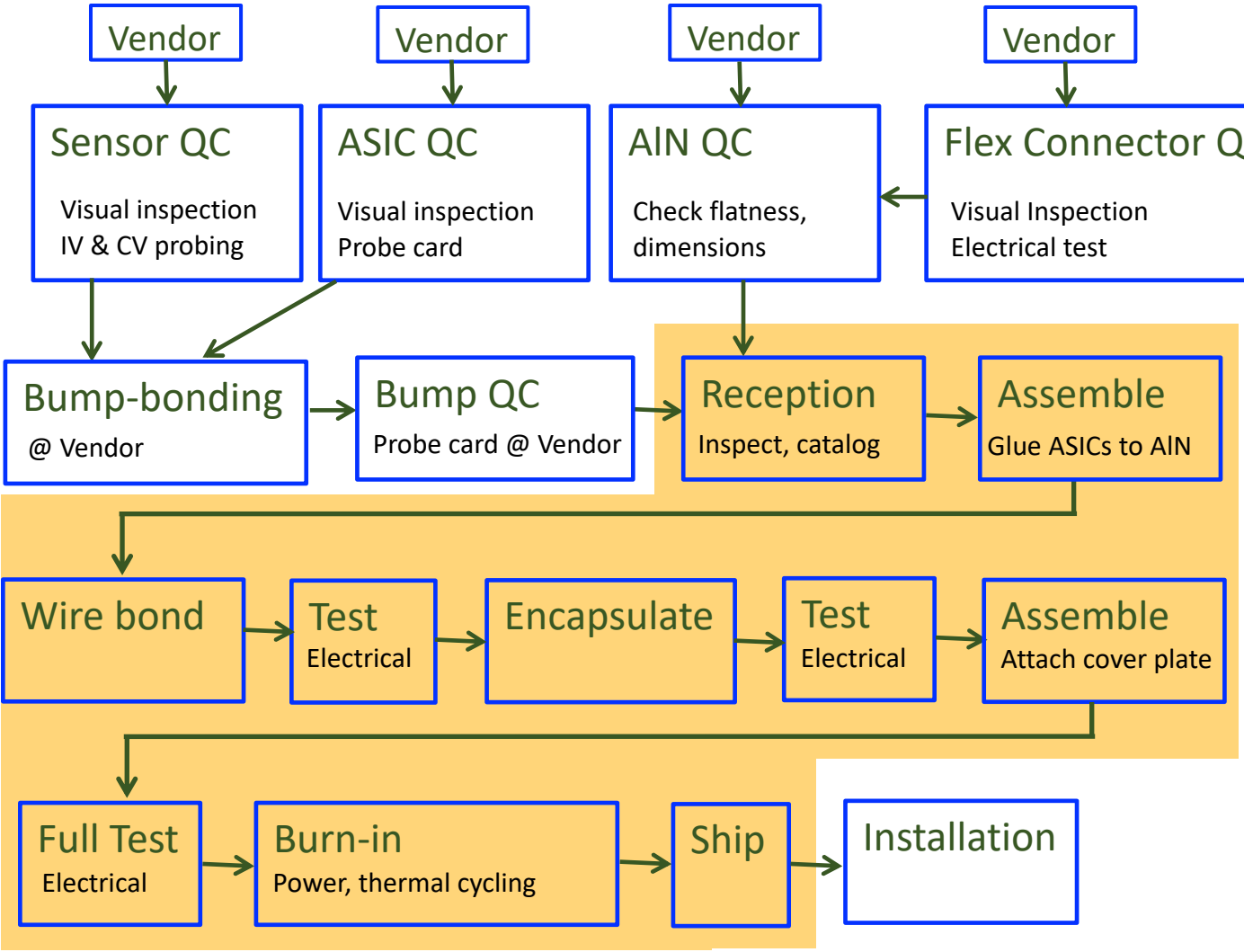
Assemble in a pipelined mode → two batches per week.

Target O(100) modules/week throughput capacity at UNL and FNAL.

***Module design modified after BoE frozen. Change organization of sensors into modules (6 → 2 sensors/module), total number of sensors the same. Change is cost and effort neutral.

402.8.4.3: ETL Module assembly

Charge #1,2



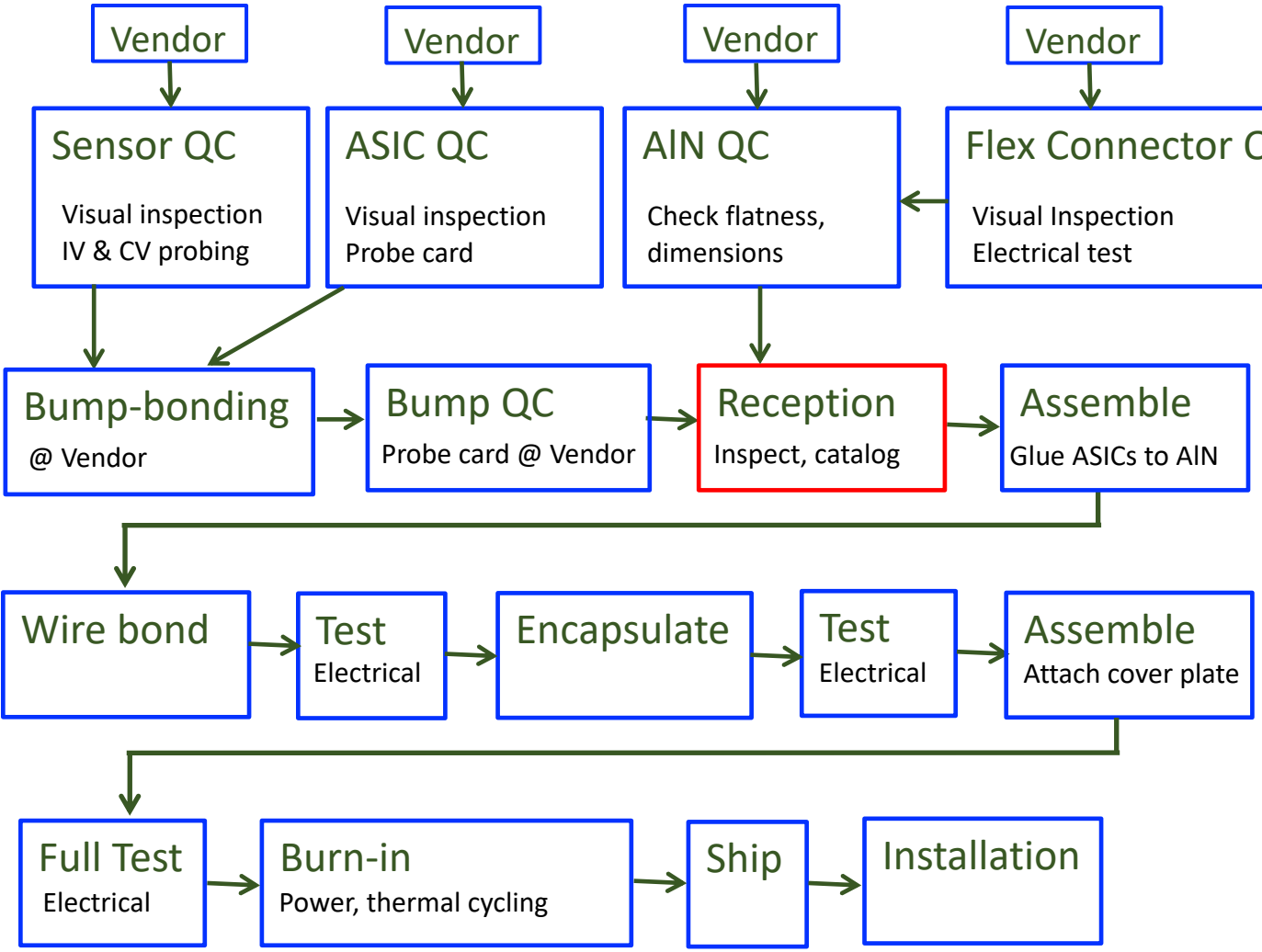
Assembly begins when components arrive at assembly sites.

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

Charge #1,2



Component inspection ensures that mechanical components meet specifications and that wire bond pads are clean to allow for good electrical connections when bonding.

402.8.4.3: ETL Module assembly

Charge #1,2

Vendor

Sensor QC
Visual inspection
IV & CV probing

Vendor

ASIC QC
Visual inspection
Probe card

Vendor

AlN QC
Check flatness, dimensions

Vendor

Flex Connector QC
Visual Inspection
Electrical test

Bump-bonding
@ Vendor

Bump QC
Probe card @ Vendor

Reception
Inspect, catalog

Assemble
Glue ASICs to AlN

Wire bond

Test
Electrical

Encapsulate

Test
Electrical

Assemble
Attach cover plate

Full Test
Electrical

Burn-in
Power, thermal cycling

Ship

Installation

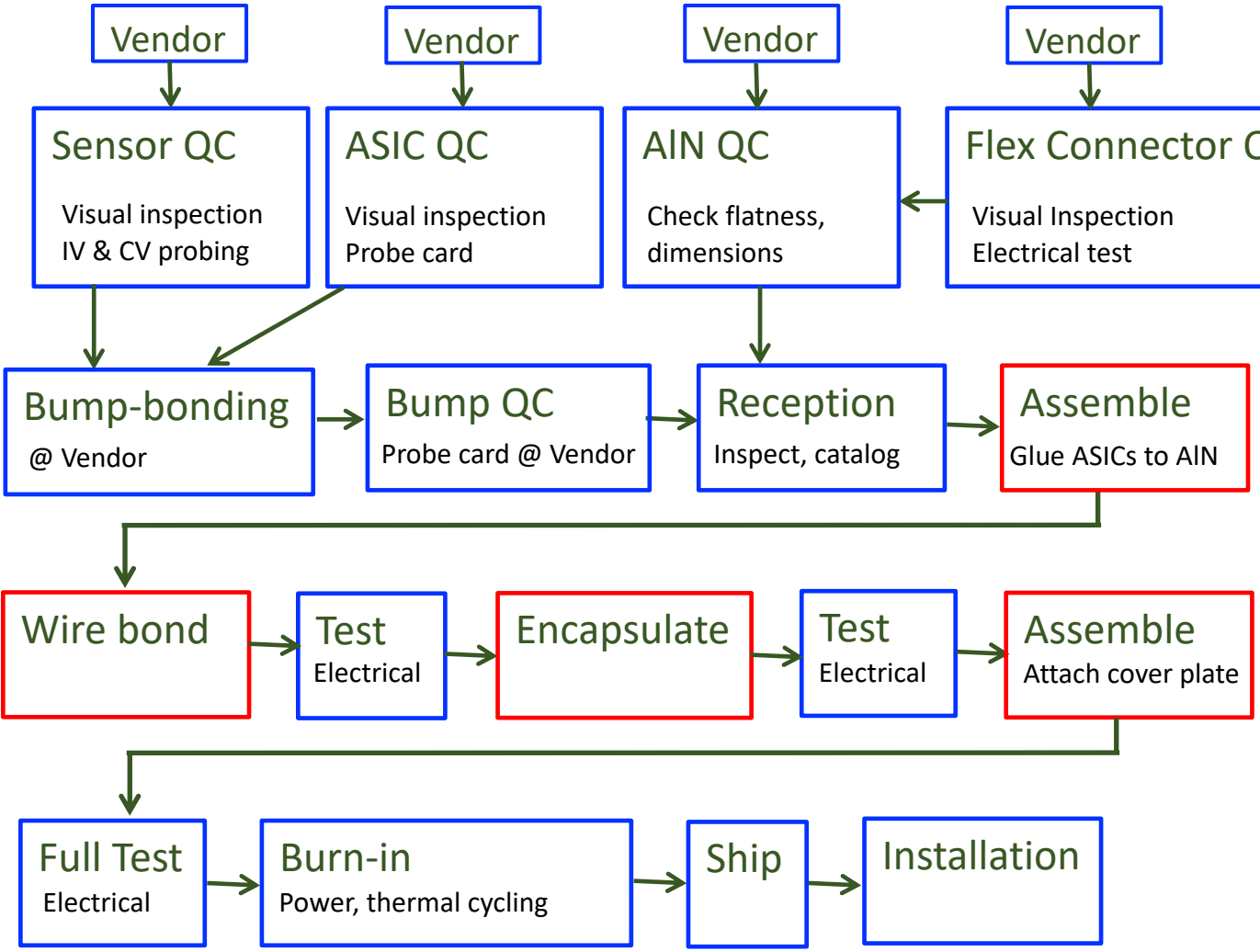
Simple module design allows for automation of assembly steps using a robotic gantry and programmable wire bonder.

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

LGAD
ASIC
AlN
Flex
Connector

402.8.4.3: ETL Module assembly

Charge #1,2



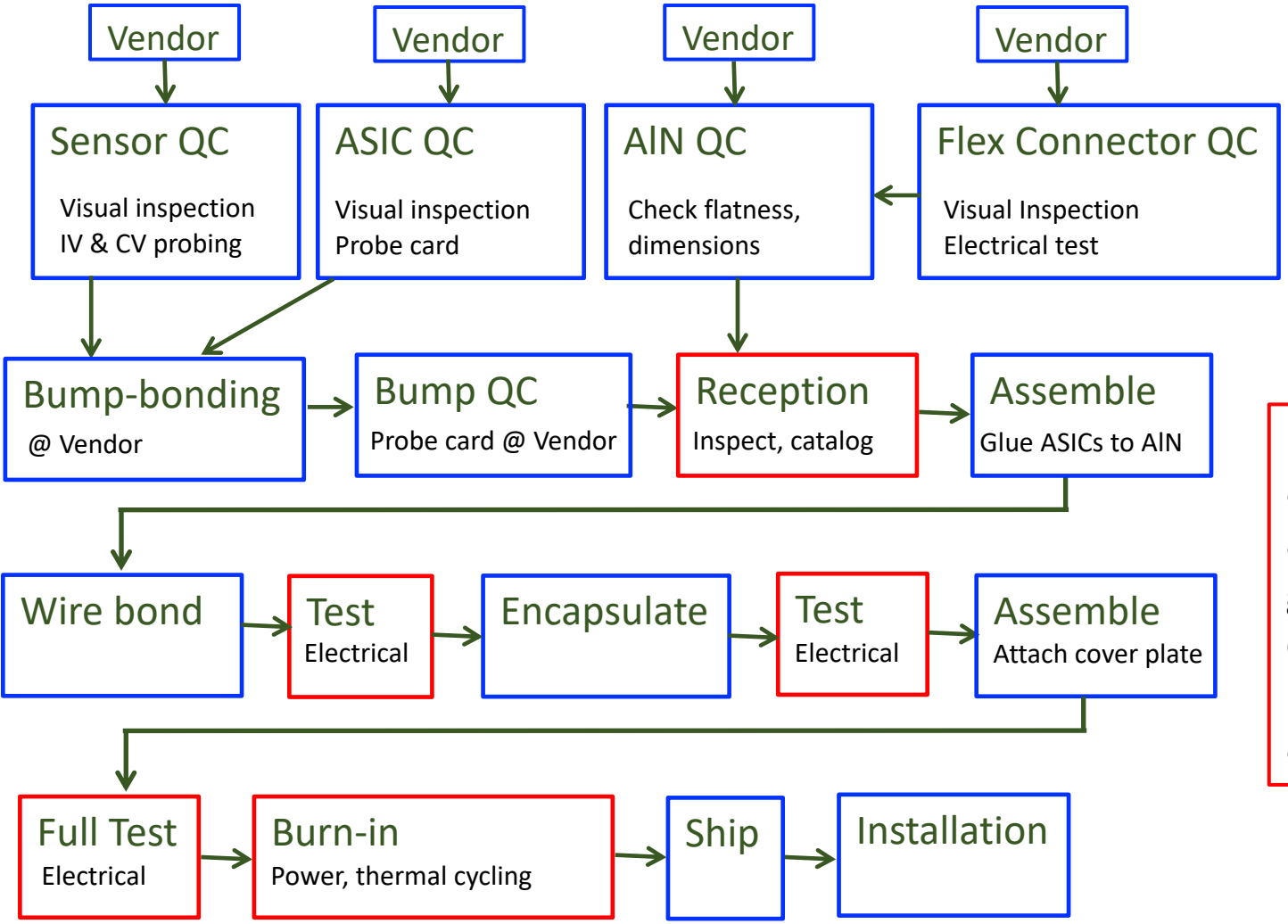
Simple module design allows for automation of assembly steps using a robotic gantry and programmable wire bonder.

Automation ensures high yield and QC and minimizes labor requirements.

Material 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

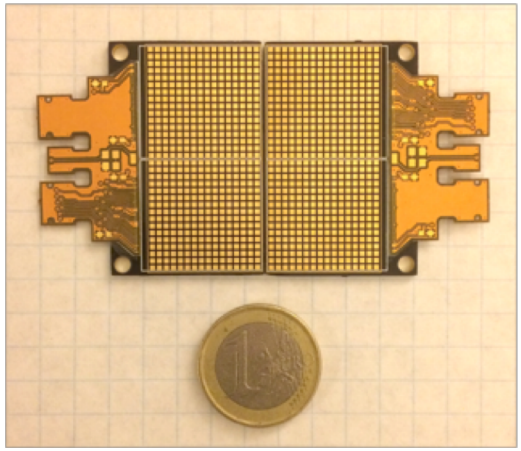
Charge #1,2



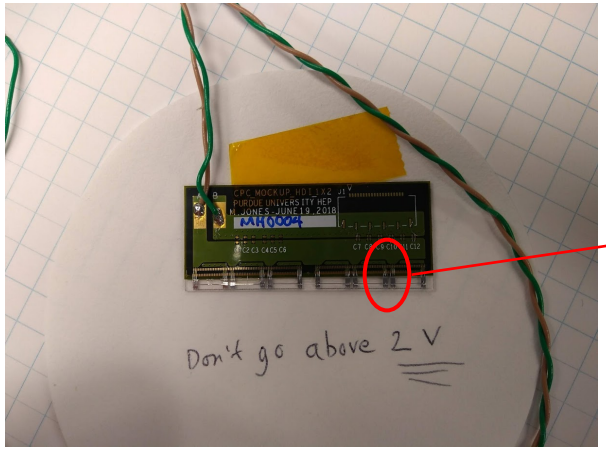
Inspection and testing at each stage of assembly ensures good mechanical and electrical connectivity resulting in high yield and QC.

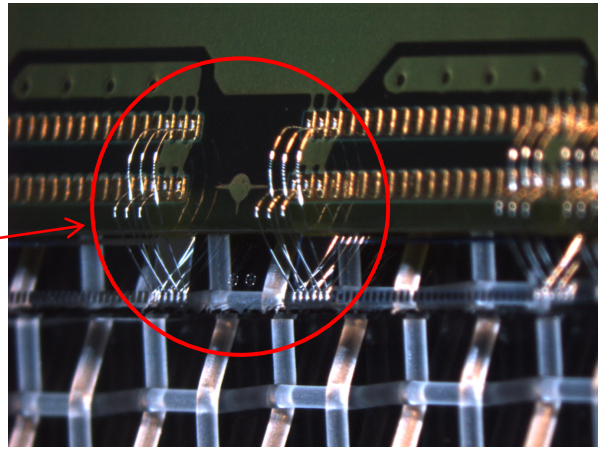
R&D Achieved

- Mechanical mockups of all module components have been constructed and work is now starting to investigate mechanical aspects of module assembly and installation.
- Assembly sites have demonstrated basic wire bonding capabilities, e.g. using simple PCB and glass with Al pads.



Mechanical mockups of module components as a two-sensor module.





Demonstration of wire bonding at UNL – Fall 2018.

R&D towards final module design and assembly procedure

Charge #2, 4

- Construct mechanical mockups of modules (2019-2020).
  - Develop and demonstrate all stages, except electrical testing, of the module assembly procedure.
  - Verify module mechanical and thermal properties investigate potential mechanical issues with module installation.
- Construct electrically functional modules (2020-2022).
  - Develop and demonstrate module testing procedures, building on system testing experience described in talk by A. Apresyan.
  - Verify the full end-to-end module assembly procedure.
    - Demonstrate component handling procedures.
    - Demonstrate ability to reliably make required electrical connections.
  - Radiation test assembled modules.
- Build up team and train people through these activities.

Schedule and Cost

Schedule Overview and Milestones

Charge #3

- Schedule and major milestones are in P6 (CMS-doc-13321):
  - ETL assembly R&D: now – Oct 2019
  - ETL assembly prototyping: Oct 2019 – July 2022
  - ETL assembly pre-production: July 2022 – Nov 2022
  - ETL assembly production: Nov 2022 – Nov 2023
- Consistent with (or earlier than) international schedule and milestones.
- Schedule driven by component availability: bump-bonded LGAD+ETL ASIC sub-assemblies, flex circuits, AlN pieces.
  - Assembly workflow designed for higher throughput, if needed.

Cost Estimate – ETL assembly process

Charge #3

WBS	Direct M&S ($)	Labor (Hours)	FTE	Direct + Indirect + Esc. ($)	Estimate Uncertainty ($)	Total Cost ($)
CD1-v2-DR-402.8 402.8 TL - Timing Layer	6,561,457	161764	91.50	11,364,763	3,026,706	14,391,469
CD1-v2-DR-402.8.2 TL - Management	433,000	26520	15.00	568,714	144,562	713,276
CD1-v2-DR-402.8.3 BTL - Barrel Timing Layer	3,352,236	49800	28.17	5,410,860	1,318,476	6,729,336
CD1-v2-DR-402.8.4 ETL - Endcap Timing Layer	2,776,221	85444	48.33	5,385,188	1,563,669	6,948,857
CD1-v2-DR-402.8.4.1 ETL - LGAD Sensors	0	3872	2.19	0	0	0
CD1-v2-DR-402.8.4.1.1 ETL - LGAD Sensors - R&D and Prototypes	0	2400	1.36	0	0	0
CD1-v2-DR-402.8.4.1.2 ETL - LGAD Sensors - Pre-Production and Production	0	1472	0.83	0	0	0
CD1-v2-DR-402.8.4.2 ETL - Frontend ASICs	1,922,500	22588	12.78	3,874,081	1,039,579	4,913,660
CD1-v2-DR-402.8.4.2.3 ETL - Frontend ASICs v2 development	256,000	14634	8.28	1,474,236	556,360	2,030,596
CD1-v2-DR-402.8.4.2.4 ETL - Frontend ASICs v3 development	1,666,500	7954	4.50	2,399,845	483,219	2,883,064
CD1-v2-DR-402.8.4.3 ETL - Assembly	680,860	30088	17.02	1,145,013	397,283	1,542,296
CD1-v2-DR-402.8.4.3.1 ETL - Assembly R&D and Prototypes	268,660	19164	10.84	488,722	152,824	641,546
CD1-v2-DR-402.8.4.3.2 ETL - Module Assembly Pre-production	62,000	626	0.35	91,721	25,958	117,679
CD1-v2-DR-402.8.4.3.3 ETL - Module Assembly Production	350,200	10298	5.82	564,569	218,501	783,070
CD1-v2-DR-402.8.4.4 ETL - System Testing	79,561	6322	3.58	103,418	38,340	141,759
CD1-v2-DR-402.8.4.4.1 ETL - System Testing - Prototyping	60,448	1898	1.07	79,459	30,061	109,520
CD1-v2-DR-402.8.4.4.2 ETL - System Testing - Preproduction	9,584	1878	1.06	12,004	4,154	16,158
CD1-v2-DR-402.8.4.4.3 ETL - System Testing - Production	9,529	2546	1.44	11,955	4,125	16,080
CD1-v2-DR-402.8.4.5 ETL - Integration and Commissioning	93,300	22574	12.77	262,676	88,467	351,143
CD1-v2-DR-402.8.4.5.1 ETL - I&C - Assembly Setup	0	1768	1.00	0	0	0
CD1-v2-DR-402.8.4.5.2 ETL - I&C - Assembly	93,300	14434	8.16	164,318	39,288	203,606
CD1-v2-DR-402.8.4.5.3 ETL - I&C - Cold Testing	0	1888	1.07	20,355	10,178	30,533
CD1-v2-DR-402.8.4.5.4 ETL - I&C - Mount ETL on EC	0	948	0.54	78,003	39,001	117,004
CD1-v2-DR-402.8.4.5.5 ETL - I&C - Commissioning	0	3536	2.00	0	0	0

- M&S driver is the cost to procure flex connectors from vendor.
- Labor driver is the cost of technicians for wire bonding.

Risks

- Biggest risk: ETL module assembly facility is unavailable.
  - e.g. gantry or wire bonder needs servicing, clean room flooding, etc.
  - Potential problems mitigated by having more than one assembly site.
- Smaller risks from availability of components partially mitigated by operating with higher throughput.

Risk Rank	RI-ID	Title	Probability	Schedule Impact	Cost Impact	P * Impact (k$)
WBS / Ops Lab Activity : 402.8 TL - Timing Layer (general risks) (3)						
WBS / Ops Lab Activity : 402.8.3 BTL - Barrel Timing Layer (15)						
WBS / Ops Lab Activity : 402.8.4 ETL - Endcap Timing Layer (12)						
Risk Type : Opportunity (1)						
2 (Medium)	RO-402-8-01-D	ETL - Use AltiROC	10 %	-8 months	-760 k$	-76
Risk Type : Threat (11)						
3 (High)	RT-402-8-01-D	ETL - Additional FE ASIC prototype cycle is required	50 %	4 -- 5 -- 6 months	500 -- 600 -- 700 k$	300
2 (Medium)	RT-402-8-03-D	ETL - FE ASIC does not meet specs - needs another pre-prod run	10 %	6 -- 7.5 -- 9 months	914 -- 970 -- 1026 k$	97
2 (Medium)	RT-402-8-02-D	ETL - Problems with ETL module assembly facility	50 %	1 months	30 k$	15
2 (Medium)	RT-402-8-10-D	ETL - Sensor quality problem during production	15 %	2 -- 3 -- 6 months	28 -- 52 -- 109 k$	9
1 (Low)	RT-402-8-53-D	ETL - Integration facility at CERN runs out of components	25 %	3 months	21 k$	5
1 (Low)	RT-402-8-48-D	ETL - Delay in delivery of parts from iCMS	20 %	1 months	10 -- 20 -- 30 k$	4
1 (Low)	RT-402-8-31-D	ETL - Storage-related degradation of LGADs	10 %	3 months	18 k$	2
1 (Low)	RT-402-8-52-D	ETL - Module Radiation Tolerance	10 %	1 months	15 k$	2
1 (Low)	RT-402-8-49-D	ETL - Delays or damage in transport of ETL modules to CERN	5 %	1 months	10 k$	1
1 (Low)	RT-402-8-50-D	ETL - Module assembly yield is low	10 %	0 -- 0 -- 1 months	0 -- 5 -- 15 k$	1
1 (Low)	RT-402-8-51-D	ETL - Problem with AlN vendor	5 %	1 -- 2 -- 3 months	0 -- 15 -- 30 k$	1

Contributing Institutions and Resource Optimization

Contributing Institutions

- UNL and FNAL will serve as assembly sites. UCSB will provide additional labor.
  - UNL and UCSB have extensive experience assembling pixel and strip tracker modules and with detector electronics.
  - FNAL has extensive experience in many detector systems.
- Wire bonding performed by technicians. Other stages of assembly and testing will be performed by a team of undergraduate and graduate students and postdocs.
- 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.

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 demonstrate and optimize:
    - preliminary module design,
    - module assembly procedure,
    - and testing and QA/QC procedures.
- Strong team of contributing institutions with significant prior experience building and testing detectors and managing HEP projects.
- Cost and schedule are defined and entered in P6.
- Planning and R&D are advancing for the US to meet its commitment to deliver 50% of required ETL modules.

Extra Material

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.

Resource Optimization

Charge #4

- 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.

Modification to module design

- Recently modified the module design to be based on 2 sensors. It was previously based on 6 sensors.
  - Detailed drawings from engineering favor smaller modules.
  - Even simpler assembly and testing, higher yield.
  - Impact of is minimal:
    - No change in number of sensors, just re-organize their grouping.
    - Change is cost neutral.