Tile Module Assembly for the CMS High Granularity Calorimeter at Fermilab

New Perspectives 2023

Ryan S. Kim

Florida State University

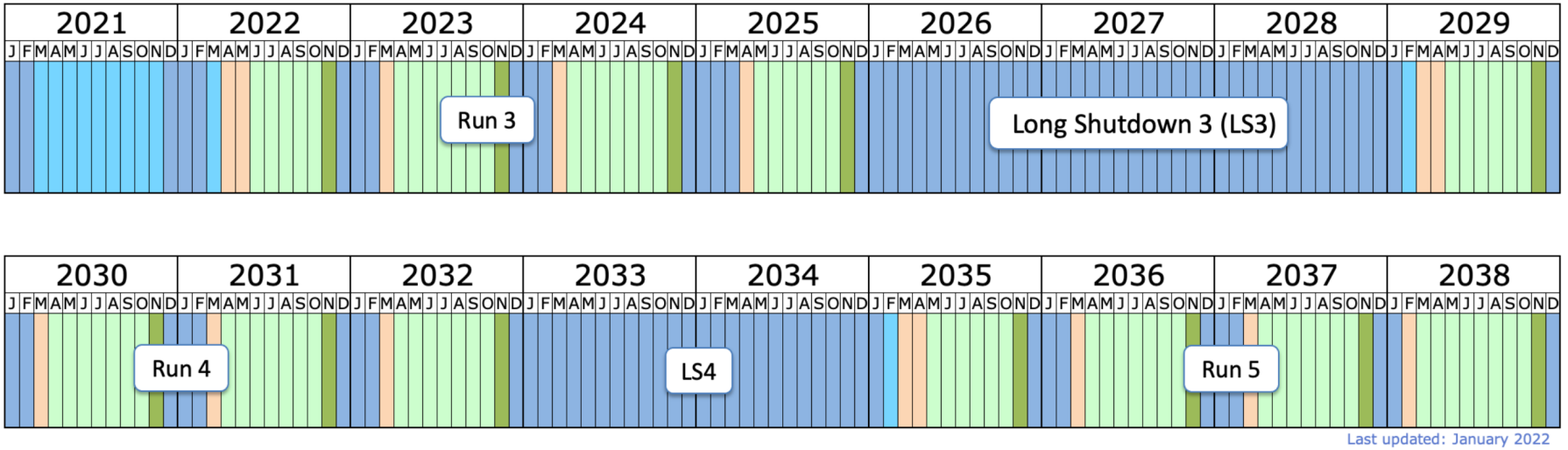
On behalf of the CMS Collaboration

June 27, 2023

DOE Report Number: FERMILAB-SLIDES-23-149-CMS

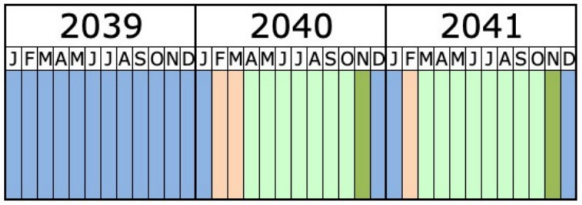
Long Term LHC Schedule

Not shown: Run 1 & 2 (2009 – 2018): ~170 fb^{-1}

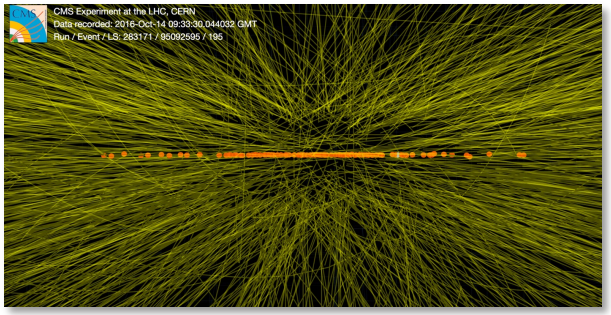


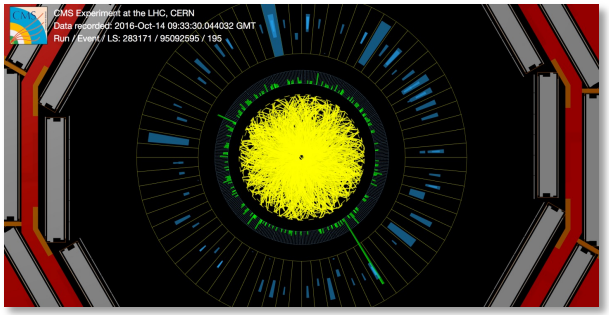
Run 4 & 5: High Luminosity LHC

Total Expected ~3000 fb^{-1}

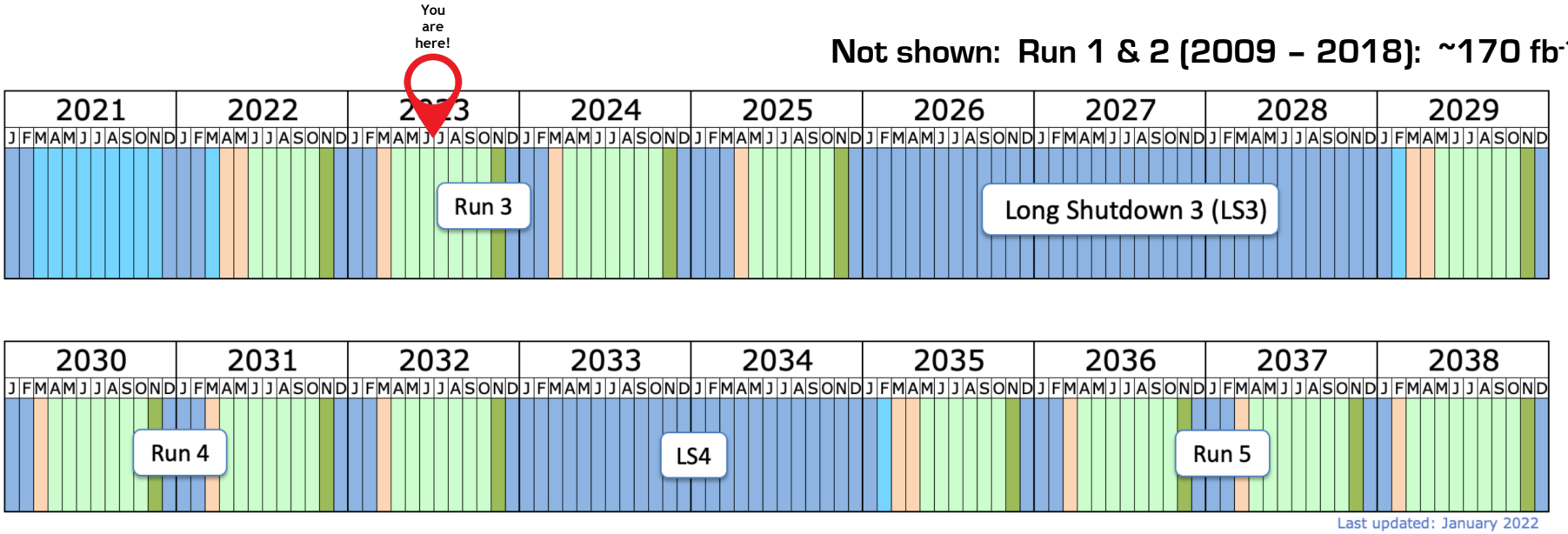


Pile up of 140-200! Detectors with higher radiation tolerance, finer spatial granularity, and better timing precision are needed





Long Term LHC Schedule



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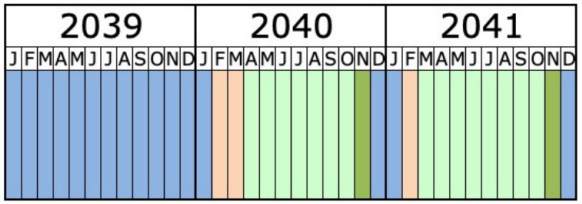

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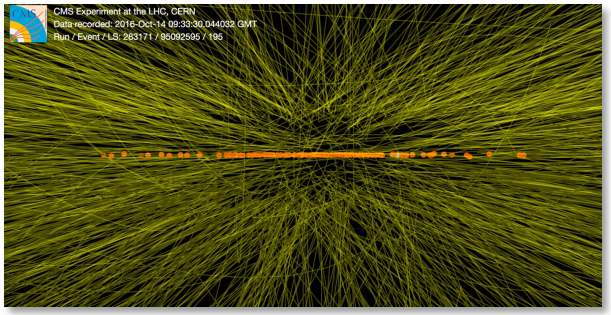
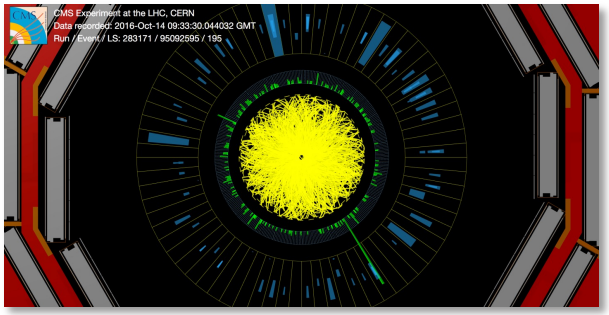
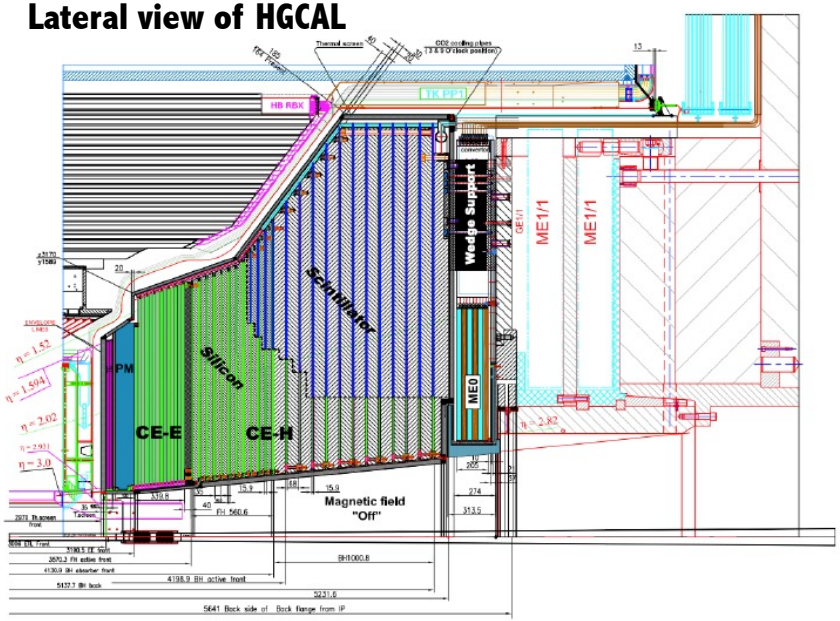




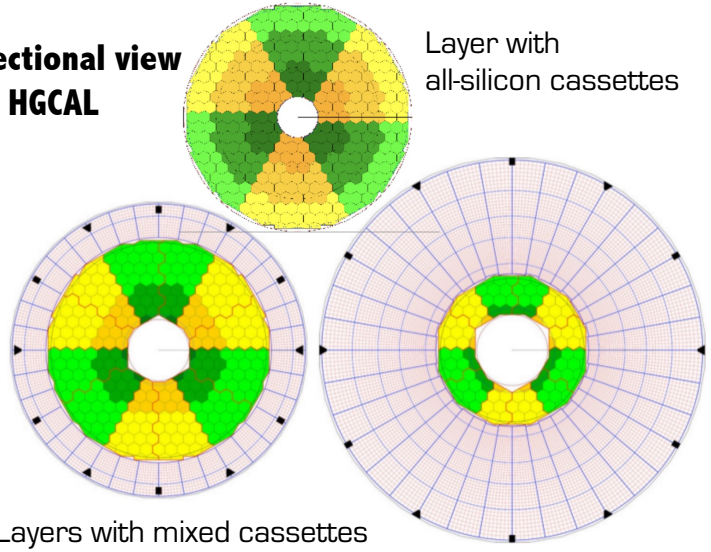
CMS High Granularity Calorimeter

- High Granularity Calorimeter (HGCAL) is a new endcap calorimeter meeting these criteria, replacing the current endcaps in CMS before HL-LHC
- State-of-the-art detector technologies:
  - Radiation-hard silicon sensors closer to the interaction point
  - Plastic scintillator tiles in the back in lower radiation regions, using "SiPM-on-Tile" technology
- Layers consist of "cassettes" that either contain all silicon modules or have a mix of silicon modules and tile modules
- 5D calorimetry: energy measurement, fine spatial granularity (silicon cells 0.5 – 1.1 cm^2, tiles 4 – 30 cm^2), precise timing (~30 ps for particle showers)

Lateral view of HGCAL



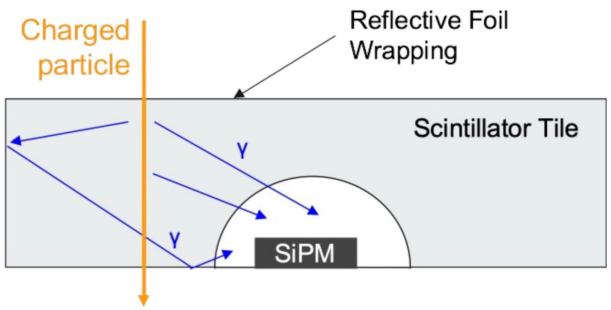
Cross-sectional view of HGCAL



Layer with all-silicon cassettes

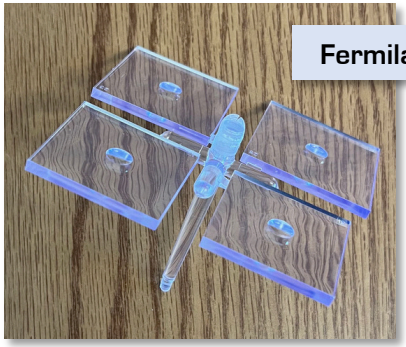
Layers with mixed cassettes

SiPM-on-Tile



SiPM-on-Tile technology

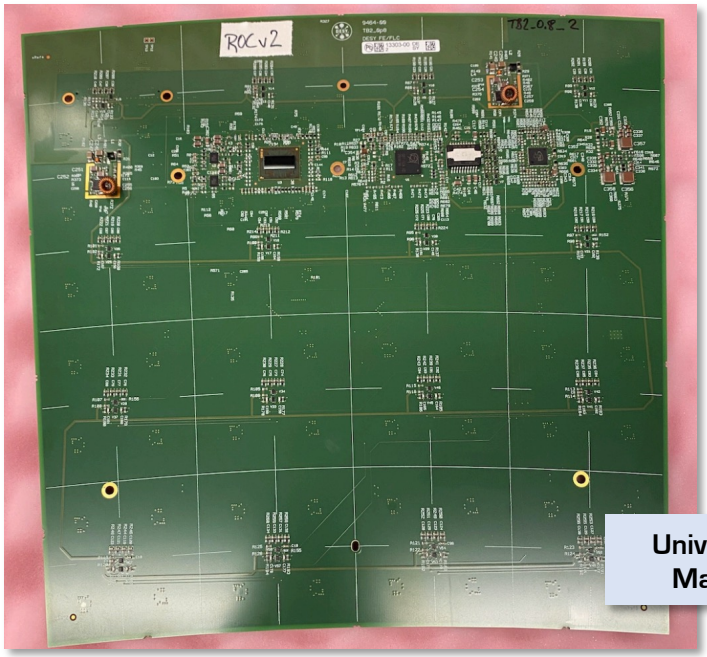
Bare tiles



Fermilab

Wrapped tiles

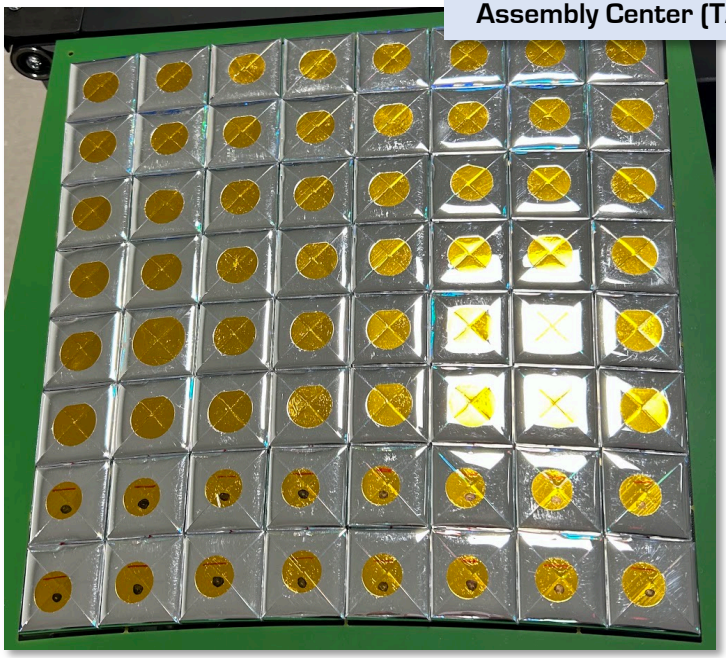
Northern Illinois University



University of Maryland

Tileboard with electronics

Fermilab Tile Module Assembly Center (TAC)



Wrapped tiles assembled on tileboard ≡ "tile module"

Fermilab Tile Module Assembly Center

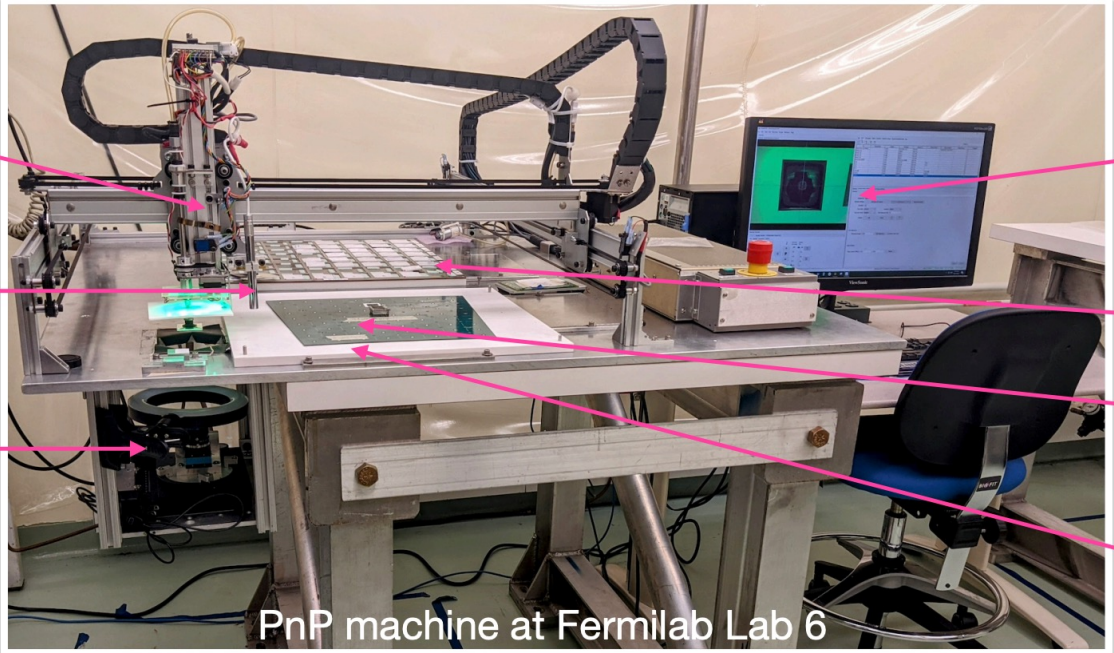
Assembly of ~2000 tile modules to be carried out by pick-and-place (PnP) machines

Fermilab TAC tasks leading up to production:

- Construction & maintenance of PnP machine hardware
- Development & maintenance of PnP machine software
- Development of assembly procedures
- Development of quality assurance plans
- Development of quality control (QC) plans for completed tile modules including thermal cycling and electric QC

Main collaborators:

- **Harry Cheung**
- **Jim Freeman**
- **Don Lincoln**
- **Daniel Guerrero**
- **John Burch**
- **Christian Wimber**



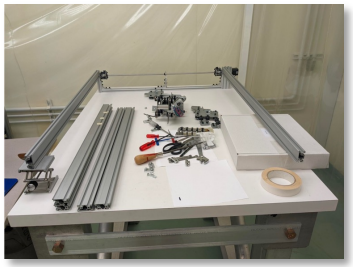
PnP machine at Fermilab Lab 6

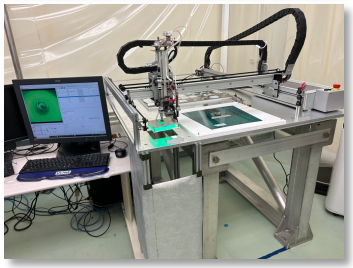
PnP Machine Hardware & Software

Hardware

Construction of two additional PnP machines in progress

- Two machines will be at Fermilab *for production*
- One machine will be at NIU *for wrapped tile QC*

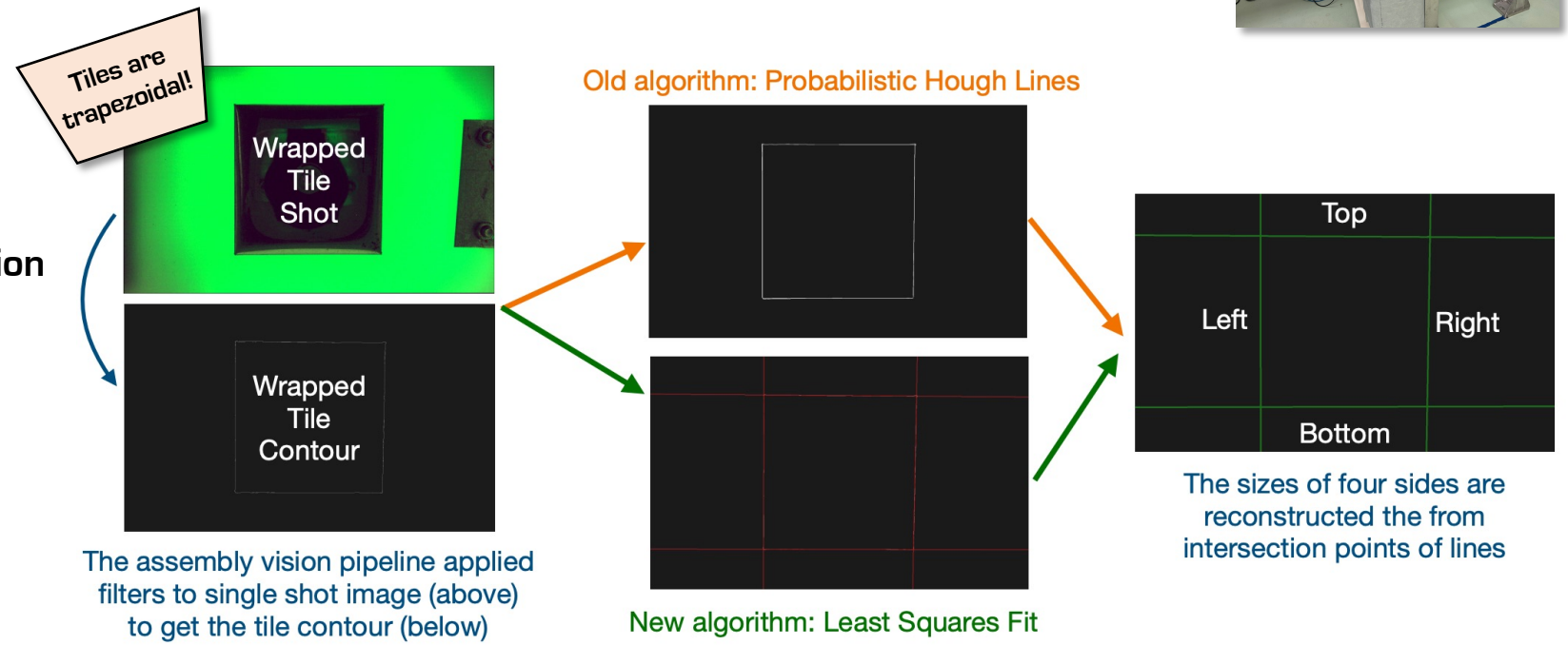




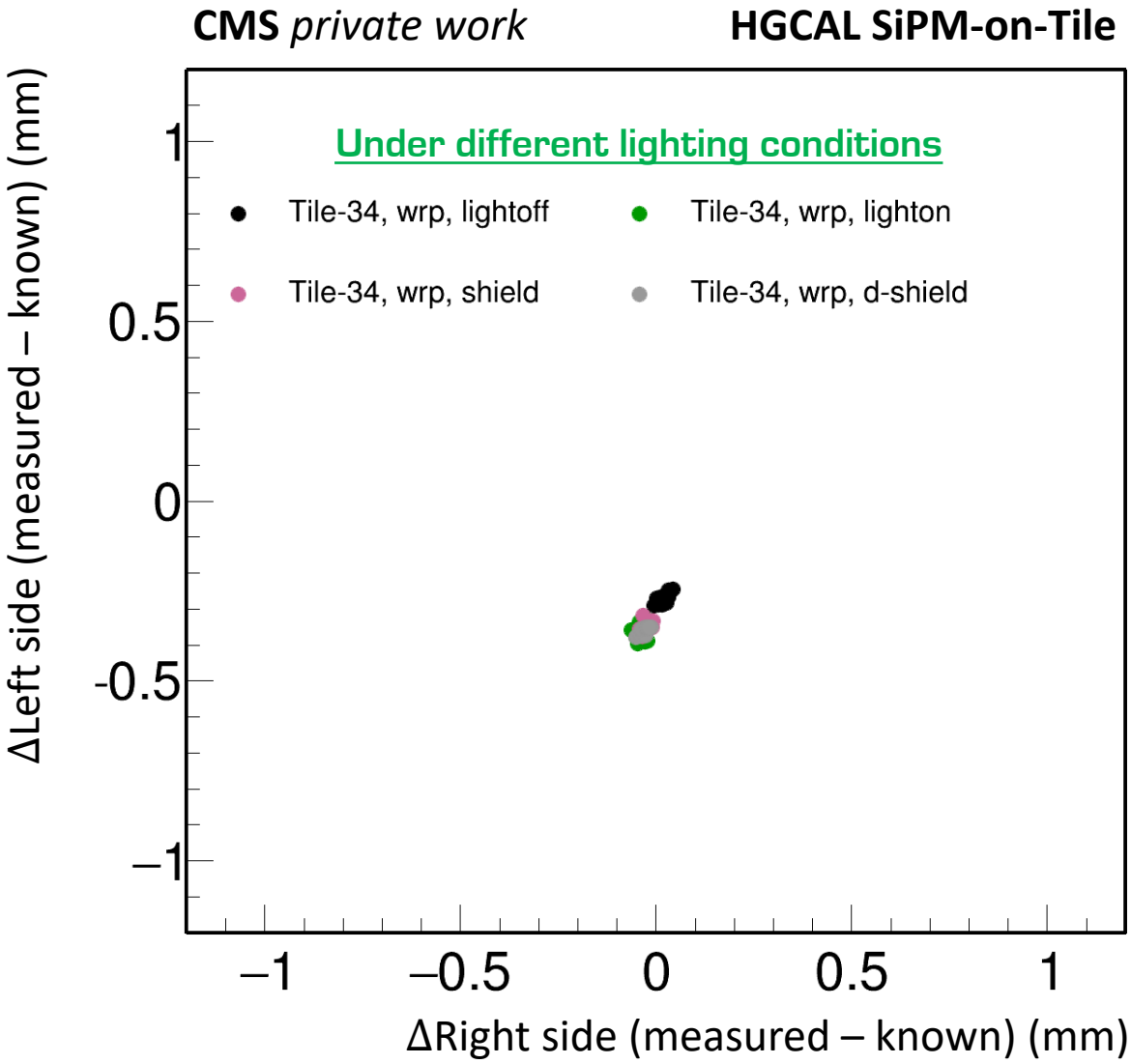
Software

- Operated by open-source program called openpnp
- Our forked repository has branches for testing & optimizing
- We take contours from tile images and apply *least-squares fit*

Machine Vision on Tile



PnP Machine Vision Performance



Our machine vision is very stable and reproducible!

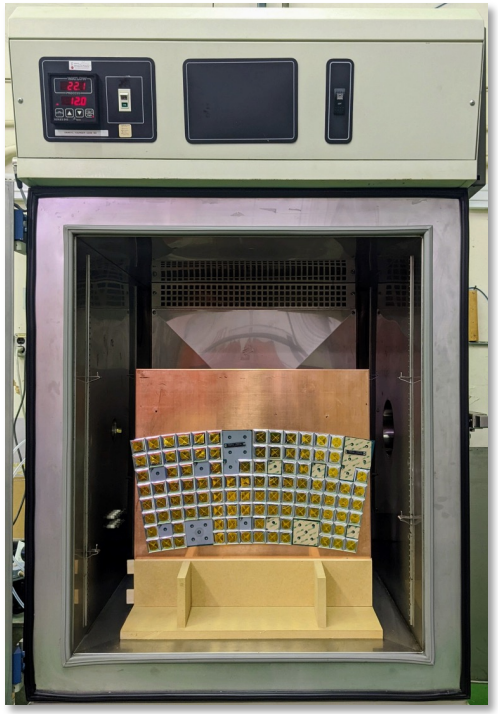
Plans for Quality Control

Visual inspection and robustness

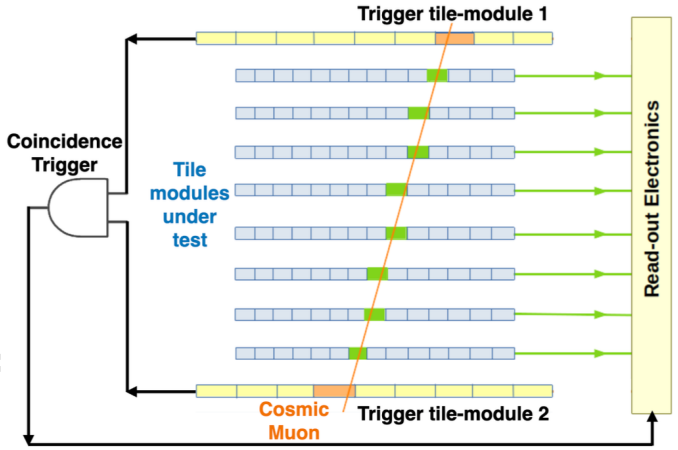
- Verify labeling and numbering
- Thermal cycling: room temperature to -40C
- Perform handling tests before and after thermal cycling

Electrical validation

- Verify registers and pedestals
- Verify charge injection functionality
- Verify SiPM response to LED light
- Cosmic ray runs of 24-48 hours using multi-module test stand at room temperature



Thermal cycling trial in the oven



Schematic sketch for multi-module cosmic ray test stand

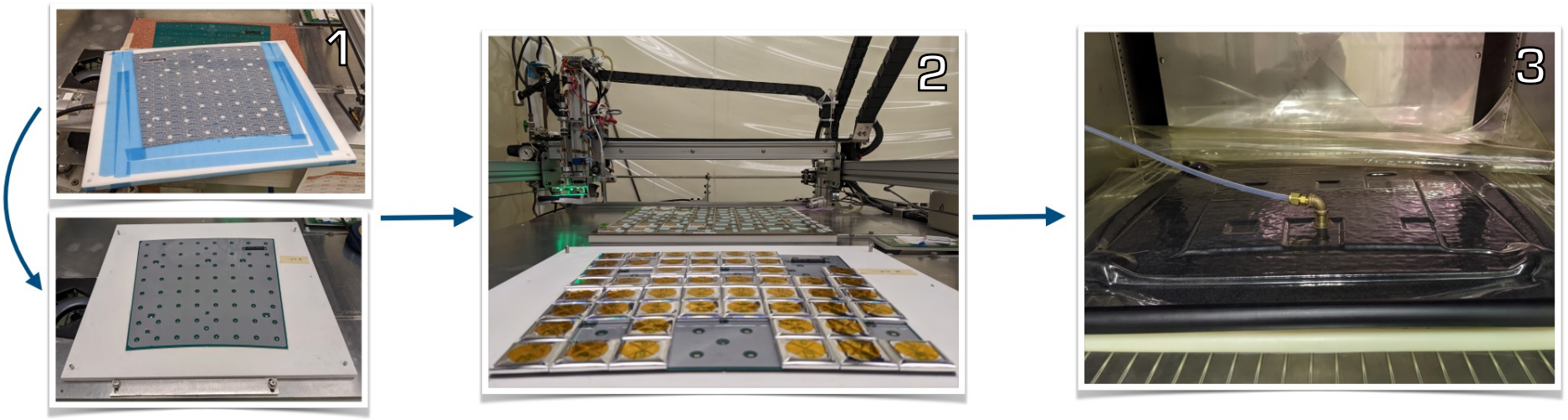
Summary & Outlook

- The HGCAL is a complicated and ambitious detector using state-of-the-art technologies, promising high performance for the HL-LHC era with 5D calorimetry of particle energy measurement, fine spatial granularity, and precise timing
- Fermilab has leading roles in building this detector, including in tile module assembly
- The pick-and-place machine hardware and machine vision software that will be used for assembly, as well as post-assembly QC plans, are being developed & optimized
- Production is expected to begin in 2024!

Thank you!

Additional Material

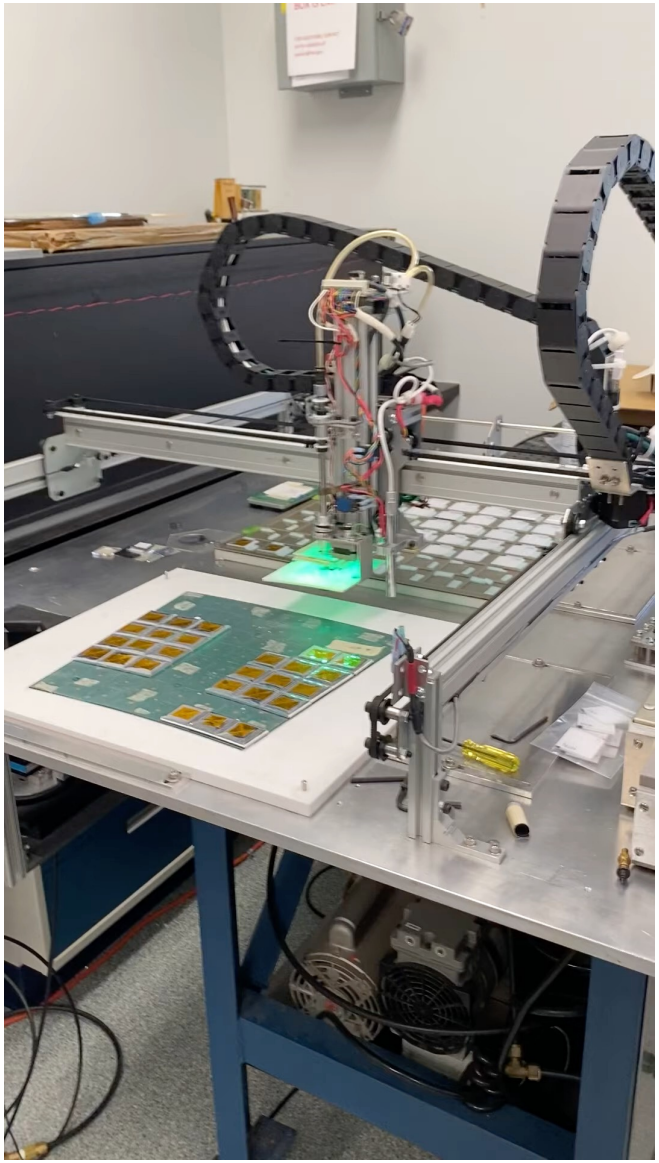
Tile Module Assembly Procedure



1) Adhesive material is placed on tileboard using a vacuum jig
2) Pick-and-place machine places tiles on the tileboard
- Tiles are taken from tile tray
- Correct size & orientation are verified using the vision system
- Tiles are placed on the tileboard with an accuracy of ~50 μm in its assigned location

3) The tile module is transferred to a vacuum bag and cured in an oven for bonding strength of the adhesive material
4) Completed tile modules are then protected by cover plates

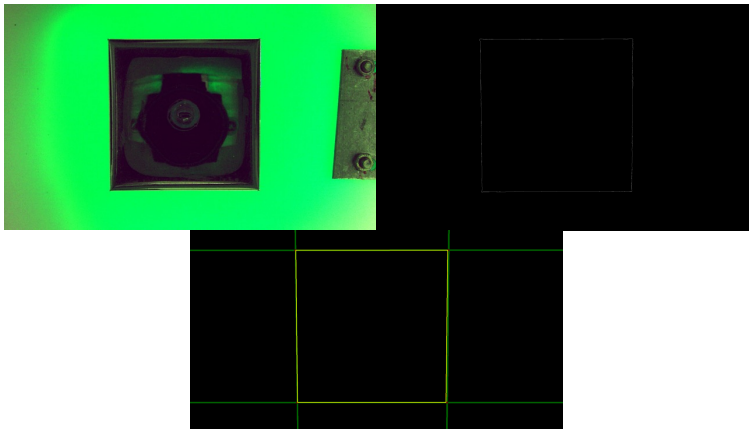
(Old) Video of PnP Machine in Operation



Pick-and-Place Machine Software

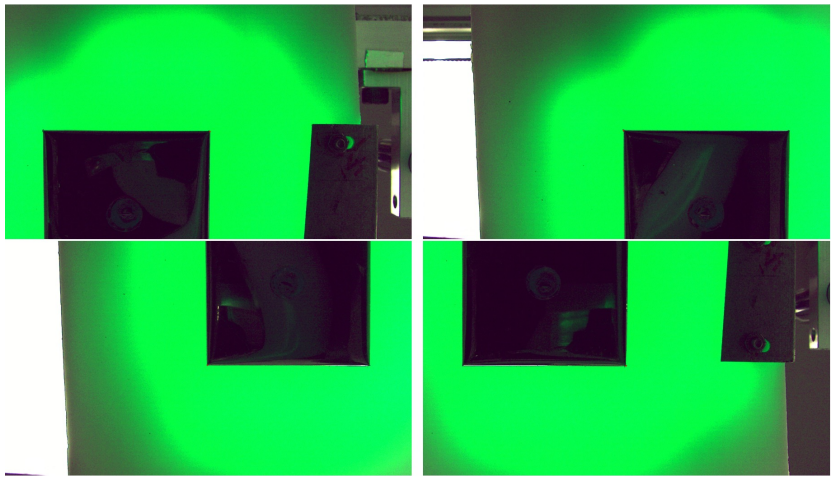
- Our forked repository is based on OpenPnP software — branches for testing & optimizing
- We take contours from tile images and apply *least-squares fit*
- Single-shot quick in-situ tile dimension & orientation check
- Multi-shot takes shot of each corner, better precision expected but slower

Single-shot machine vision on tile



Reconstructed trapezoid

Multi-shot machine vision on tile



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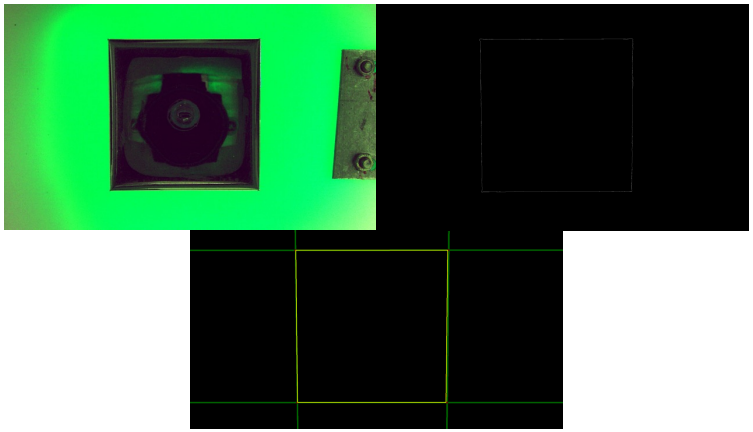

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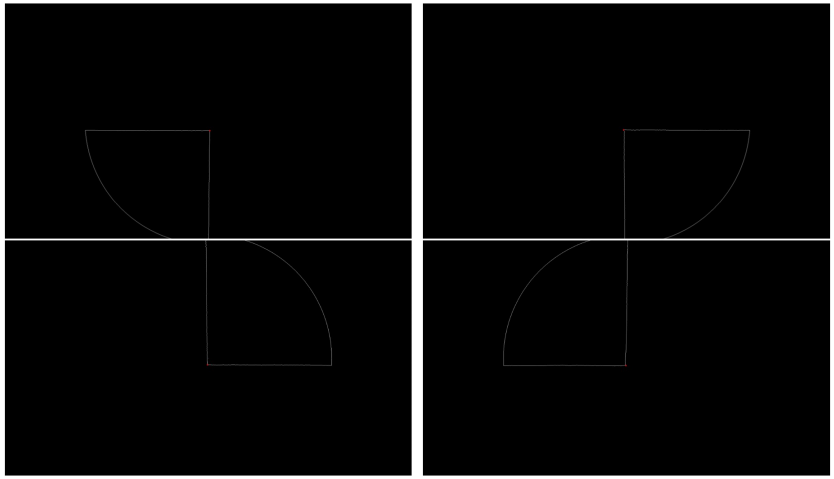

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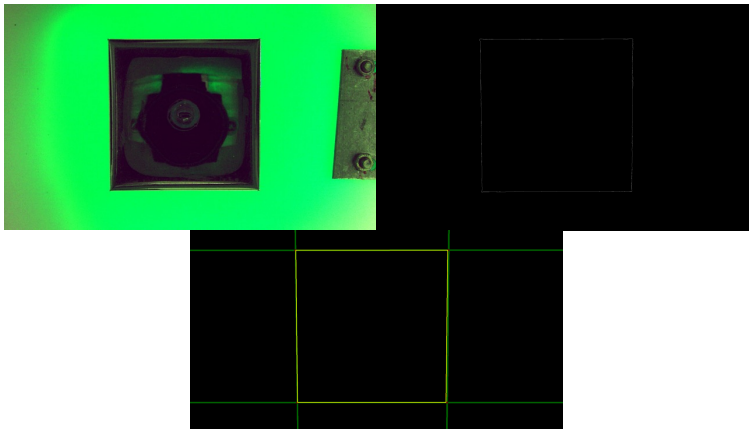

Reconstructed trapezoid

Multi-shot applying least-squares fit (y-axis flipped and not to scale)